Photoproduction at collider energies: from RHIC and HERA to the LHC

ECT* – Workshop, Trento, January 15 - 19, 2007

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ABSTRACT

We present the mini-proceedings of the workshop on "Photoproduction at collider en-

ergies: from RHIC and HERA to the LHC" held at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*, Trento) from January 15 to 19, 2007. The workshop gathered both theorists and experimentalists to discuss the current status of investigations of high-energy photon-induced processes at different colliders (HERA, RHIC, and Tevatron) as well as preparations for extension of these studies at the LHC. The main physics topics covered were: (i) small-x QCD in photoproduction studies with protons and in electromagnetic (aka. ultraperipheral) nucleus-nucleus collisions, (ii) hard diffraction physics at hadron colliders, and (iii) photon-photon collisions at very high energies: electroweak and beyond the Standard Model processes. These mini-proceedings consist of an introduction and short summaries of the talks presented at the meeting.

Introduction

Photon-induced collisions at high-energy are a fruitful tool to investigate strong and electromagnetic interactions. On the one hand, photon-hadron processes at the HERA *ep* collider have provided precise information on QCD – parton structure and evolution at low-x, partonic structure of the photon, measurement of the strong coupling constant, factorization breaking in diffractive processes, etc. – via measurements of inclusive hard photoproduction (heavy-flavour, (di)jets, prompt photons ...) and exclusive diffractive vector meson production. On the other hand, ultra-relativistic proton and heavy-ion beams accelerated at BNL-RHIC ($\sqrt{s_{NN}}$ = 200 GeV), FNAL-Tevatron ($\sqrt{s}$ = 1.96 TeV) and CERN-LHC ($\sqrt{s_{NN}}$ = 5.5 – 14 TeV) energies generate strong electromagnetic fields which are equivalent to a flux of quasi-real photons with maximum energies in the range $E_\gamma^{max} \approx 3 - 2000$ GeV. At the LHC, these photons offer the opportunity to study γp, γA and $\gamma\gamma$ processes at energies one order of magnitude larger than at previous colliders, probing parton distributions at still lower x values, and also opening interesting windows to electroweak and beyond the Standard Model physics.

At heavy-ion colliders, the electromagnetic field due to the coherent action of the $Z \approx 80$ proton charges (for lead or gold nuclei) results in photon beams fluxes $Z^2 \approx 7000$ times larger than those of corresponding electron or proton beams at the same energies. Photonuclear production of ρ and J/ψ, as well as e^+e^- pair production in two-photon collisions have been studied in "ultraperipheral collisions" (UPCs) of gold nuclei at RHIC. Studies of the small-x QCD regime accessible in γA processes with UPCs at LHC are of critical importance for the interpretation of heavy ion data, and provide a clean tool for the study of non-linear QCD effects in the nuclear wave-function. In addition, coherent $\gamma\gamma$ processes in UPCs at the LHC allow one to study QED in a very strong field regime ($Z\alpha_{\rm em} \approx 0.6$) as well to measure the couplings of the γ, Z and $W^{\pm}$ gauge bosons among themselves.

After 6 years of rich physics operation at HERA-II and RHIC, and less than one year before the start of LHC, it seemed a timely moment to have a workshop, gathering both theorists and experimentalists, to discuss the current status of investigations of photon-induced processes in *ep* at HERA and UPC ion-ion collisions at RHIC, and preparations for extension of these studies in PbPb and pp at LHC. A meeting was organized at the ECT* (Trento) from January 15–19, 2007, with partial financial support from the center. The meeting had 35 participants whose names and institutes are listed below. There were 30 presentations of various lengths. Ample time was left for discussions after each talk. The talks and discussions were organized around the following main topics:

- Overview theoretical and experimental talks on photoproduction at RHIC, HERA, Tevatron and prospects for LHC.
- Inclusive and exclusive photoproduction at HERA: dijets, heavy-quarks, prompt photons, and vector mesons.
- Vector-meson and hard- photoproduction in UPC ion-ion at RHIC and LHC, with emphasis on the high gluon density regime at small-x in the nucleus.
- Photoproduction in $pp, p\bar{p}$ collisions at Tevatron and LHC: QCD (quarkonia, jets, top), electroweak (W, Higgs) and beyond the SM processes.
- Two-photon processes: studies of QED in strong field regime in UPCs, $\gamma\gamma \to l^+ l^-$ as a luminometer at the LHC, triple and quartic gauge $WW\gamma(\gamma)$ couplings.

The programme, list of participants and a one-page summary of each talk including a few relevant references follow. We felt that this was more appropriate a format than full-fledged proceedings. Most results are or will soon be published and available on the archives. This approach leads to speedy publication and avoids too much duplication. Most of the talks can also be downloaded from the workshop website:

`http://cern.ch/david.denterria/photoprod_ect07/`

We thank the ECT* management and secretariat, in particular Serena Degli Avancini and Cristina Costa, for the excellent organization of the workshop and all participants for their valuable contributions. We believe that this was only the first workshop of this kind and look forward to similar meetings in the future.

GERHARD BAUR, DAVID D'ENTERRIA, SPENCER KLEIN,
JOAKIM NYSTRAND, and MARK STRIKMAN

Programme

Monday, 15 January 2007

09:30 *Open problems of small x physics and UPC of heavy-ions* (1h00')	L. Frankfurt
11:00 *On the non-perturbative foundations of the dipole picture* (1h00')	O. Nachtmann
14:00 *Probing small x dynamics in hard VM production phenomena* (50')	M. Strikman
14:50 *Overview of photoproduction in CDF* (50')	A. Hamilton

Tuesday 16 January 2007

09:30 *Hard photoproduction at HERA: theory* (50')	M. Klasen
10:40 *Hard photoproduction at HERA: experiment* (50')	S. Levonian
11:30 *Review talk on parton shower algorithms* (1h00')	Z. Nagy
14:00 *Electromagnetic nucleus-nucleus collisions: from RHIC to LHC* (50')	R. Vogt
14:50 *Exclusive ρ^0 photoproduction in UPC with STAR* (40')	Y. Gorbunov
15:30 *J/ψ and dilepton pairs in electromagnetic AuAu at 200 GeV* (40')	D. Silvermyr
16:10 *Exclusive diffraction at Tevatron and prospects for the LHC* (40')	A. Hamilton

Wednesday 17 January 2007

09:30 *Diffractive and Photonic Reactions in QCD* (50')	S. J. Brodsky
10:40 *Diffraction results at HERA* (30')	A. Valkarova
11:10 *Onium photoprod. and models of diffractive exclusive production* (50')	H. Kowalski
12:00 *Hard photoproduction in ZEUS at HERA* (30')	A. Savin
14:00 *Hard diffraction in DIS and pA* (50')	V. Guzey
14:50 *Single W boson photo-production in pp and pA collisions* (30')	U. Dreyer
15:20 *Anomalous gauge couplings in e^+e^- and $\gamma\gamma$ scatt. at high energy* (40')	O. Nachtmann

Thursday 18 January 2007

09:30 *MC models for γp and γA interactions* (50')	R. Engel
10:40 *Low-x QCD via electromagnetic PbPb colls. at 5.5 TeV in CMS* (40')	D. d'Enterria, A. Hees
12:00 *Trigger capabilities of the ALICE TOF for UPCs* (30')	E. Scapparone
14:00 *Strong electromagnetic fields in UPCs: multiphoton processes* (40')	G. Baur
14:40 *A low multiplicity trigger for peripheral collisions in ALICE* (30')	R. Schicker
15:10 *NA60 experimental capabilities for ultraperipheral collisions* (25')	C. Lourenco
15:40 *Dimuon production in ultra-peripheral In-In collisions in NA60* (30')	P. Ramalhete

Friday 19 January 2007

09:30 *UPC lepton pair production to all orders in $Z\alpha$* (50')	A. Baltz
10:40 *High energy photon interactions at the LHC* (50')	K. Piotrzkowski
11:30 *Anomalous single top photoproduction at the LHC* (30')	K. Piotrzk. J. de Favereau
14:00 *Photoproduction and low-x* (50')	M. Machado
14:50 *Coulomb corrections in l^+l^- production in UPCs* (30')	M. Yilmaz
15:20 *Photon-photon and photon-nucleus collisions in ALICE at LHC* (30')	J. Nystrand

List of Participants

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Challenges of small x hard QCD

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Challenges, puzzles of small x QCD as well as promising methods to resolve them are explained. Firstly we outline basic theoretical results obtained by methods of pQCD including lack of significant ambiguity in the pQCD calculations in the kinematics of LHC and their success in the explanation of existing experimental data obtained at FNAL and HERA. Theoretical and experimental restrictions on the region of applicability of existing pQCD methods and necessity of new QCD regime of strong interaction with small coupling constant are discussed (for the review see [1]). We show that probability conservation and related complete absorption at high energies prevent unrestricted increase with energy of amplitudes of hard processes at fixed impact parameter. Using pQCD calculation of cross section for the scattering of small dipole off a hadron target we demonstrate existence of boundary for the applicability of methods of pQCD. We demonstrate that problems with probability conservation become important for the gluon distribution within a nucleon in the end of kinematics of HERA and more clearly in the kinematics of leading jets at RHIC and in a wider kinematical region at LHC. Rapid onset of new regime is the combination of large value of gluon distribution within a nucleon- $xG_N(x,Q^2)$ at low scale which is due to spontaneously broken chiral symmetry and fast increase with energy of pQCD amplitudes. Thus there is urging practical problem to investigate possible impact of this regime on the LHC physics including new particle production. Account of complete absorption gives us powerful and legitimate method of calculation of amplitudes of hard processes in a region of sufficiently small x. We explain that structure functions of a hadron target will rapidly increase with energy forever: $F_2(x,Q^2) = cQ^2\mu^2 ln^3(x_o/x)$ [2].

At infinite energies c and μ (universal tail of impact parameter distribution within hadron target) are the same for hadrons and nuclei. Factor Q^2 demonstrates complete violation of Bjorken scaling,of two dimensional conformal invariance. Total cross section of nucleon photodisintegration should increase faster with energy than cross sections of hadronic collisions $\sigma(\gamma N \to X) = c\ln^3(s/s_o)$. HT effects form significant part of cross section. Golden plate experiment will discover that cross section of HT process: $\gamma A \to 2\,jet + A$ should constitute nearly 50% of the total cross section [2]. We explain variety of phenomena which follow from regime of complete absorption. One of key theoretical tools is the account of the causality - the S.Mandelstam cancellation of the eikonal diagrams recently generalized to pQCD. Similar cancellations follow from energy-momentum conservation [3]. Critical prediction of QCD is increase with energy of the scale of processes having large cross section. One of new effects signaling onset of new QCD regime is energy losses of energetic partons produced in hadron-hadron and in hadron-nucleus collisions. Recent STAR data on leading parton production in dA collisions found :suppression of leading jet, presence of recoil jet and negative correlation with centrality trigger. All these features are well consistent with significant (around 10%) energy losses for leading partons [4]. In the kinematics of LHC significantly more evidences for new QCD regime is expected and considered in the talk.

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On the dipole picture in photon induced reactions

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The idea that a high energy photon-hadron reaction can be related to a hadron-hadron reaction goes back to the 1960s. In the modern view the photon is supposed to fluctuate into a colour dipole quark-antiquark state long before the interaction. This color dipole interacts then with the hadron. We give a general nonperturbative treatment of photon-induced hadronic reactions based on the functional integral. The quark skeleton diagrams which are leading at high energies are identified. These diagrams are then separated into parts describing the photon splitting into $q\bar{q}$ and the $q\bar{q}$ scattering. Renormalisation is done using Schwinger-Dyson equations. This leads to the introduction of a rescattering term. The assumptions needed to go from there to the usual colour dipole picture of photon induced reactions are spelled out in detail. It is shown that the usual colour dipole picture for deep inelastic electron-proton scattering leads to rigorous inequalities for ratios of structure functions. We find an upper bound for $R = F_L/F_T$ and upper and lower bounds for the ratios of structure functions F_2 at the same $\gamma^* p$ c.m. energy W but different Q^2. The comparison with the data from HERA suggests that the range of validity of the colour-dipole model may be more restricted than commonly thought.

The results described in the talk are based on work done by C. Ewerz and O. Nachtmann, see hep-ph/0404254, 0604087, 0611076.

Probing small x dynamics in hard vector meson production

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Study of production of exclusive and semiexclusive production of J/ψ and Υ production at LHC will allow to study elastic and inelastic interactions of small dipoles protons and nuclei in the a kinematic range 30 GeV $\geq W_{\gamma N} \geq$ 1 TeV with . The coherent channel provides an effective method to probe the leading twist hard QCD regimes of color transparency and perturbative color opacity as well as the onset of black disk regime (BDR) in the soft and hard QCD interactions [1]-[3]. Study of UPC pA collisions will allow to study both exclusive onium production off protons and nuclei at much larger energy interval than for AA collisions [4].

The use of the neutron tagging will allow to select photon interactions at higher energies away from zero rapidity and will test dynamics of inelastic interactions of small dipoles [5]. We demonstrate that study of large t vector meson photoproduction with rapidity gaps in ultraperipheral proton-ion and ion-ion collisions at LHC would allow to investigate the energy dependence of cross section of elastic scattering of a small dipole off the parton over a wide range of energies $10^3 < s_{dipole-parton} < 10^6$ GeV^2 where this cross section is expected to change by a factor ≥ 20. The accessible energy range exceeds the one reached at HERA by a factor of 10 both in γp and in γA scattering. In addition, study of A-dependence of this process will allow to determine the t range where interaction of small dipoles gives the dominant contribution and to investigate effects of absorption for the propagation of ultrarelativistic small $q\bar{q}$ dipoles through the nuclear media and probe in a novel way onset of the BDR [6].

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Overview of Photoproduction at CDF

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The Collider Detector at Fermilab (CDF) [1] has performed a search for exclusive photoproduction of lepton pairs in $p\bar{p}$ collision data at $\sqrt{s} = 1.96$ TeV. We report an observation of exclusive $\gamma\gamma \to e^+e^-$, and a status report on the search for exclusive $\mu^+\mu^-$ pairs. In an exclusive dilepton process there are no particles produced other than the lepton pair and the incident hadrons do not dissociate. Exclusive events have been proposed as a search channel for new physics at the Large Hadron Collider (LHC) [2]. The primary advantage for exclusive $\gamma\gamma$ processes in the search for new physics at the LHC is that the measurement of the outgoing protons' momenta can provide an additional method to calculate the invariant mass of the particles produced by the $\gamma\gamma$ system [3]. Also, since the cross sections are generally known with an accuracy better than 1%, exclusive dilepton processes are interesting candidates for improving the typical 5% uncertainty on the luminosity measurement at hadron colliders [4].

The observation of exclusive $\gamma\gamma \to e^+e^-$ selects candidate events [5] from a data sample with $\mathcal{L} = 532 \pm 32$ pb^{-1} by requiring an e^+e^- pair ($E_T > 5$ GeV and $|\eta| < 2.0$) with no other particles detected in CDF ($|\eta| < 7.4$). The proton and antiproton lose a small fraction of their momentum in these collisions and escape along the beam direction without being detected. The events are simulated using the LPAIR Monte Carlo generator [6]. The selection efficiency for the candidate events is determined to be (1.6 ± 0.2)%. The efficiency is dominated by the requirement that there be no other particles observed in the detector because bunch crossings with an exclusive event as well as another $p\bar{p}$ interaction will be vetoed by this selection criteria. A total of 16 candidate events pass the selection criteria. Four backgrounds are considered: jets that pass electron requirements (jet fakes), cosmic rays that interact in the detector, non-exclusive events, and $\gamma\gamma \to e^+e^-$ events with proton dissociation. The jet fake background is estimated to be very small, $0.0^{+0.1}_{-0.0}$ events, and the cosmic background is found to be negligible. By fitting the inclusive e^+e^- portion of the data sample as a function of the number of clusters in the calorimeter, the non-exclusive background is estimated to be 0.3 ± 0.1 events. The number of dissociation events in the 16 event signal sample is estimated to be 1.6 ± 0.3 using both the GRAPE-DILEPTON and LPAIR MC programs. Therefore, the sum of all background sources is $N_{\text{bkgd}} = 1.9 \pm 0.3$ events.

The cross section for exclusive $p\bar{p} \to p + e^+e^- + \bar{p}$ is measured to be $1.6^{+0.5}_{-0.3}(\text{stat}) \pm 0.3(\text{syst})$ pb. This agrees with the theoretical cross section 1.71 ± 0.01 pb predicted by LPAIR. The kinematics of the events also agree with the predictions of LPAIR. The probability of observing 16 events when 1.9 ± 0.3 background events are expected is 1.3×10^{-9}, equivalent to a 5.5σ effect. The search for exclusive $p\bar{p} \to p + \mu^+\mu^- + \bar{p}$ has selected candidate events by requiring a $\mu^+\mu^-$ pair with $2.7 < M_{\mu^+\mu^-} < 4.0$ and no additional particles observed in the detector. Most of the candidate events have invariant masses consistent with the J/ψ or ψ' resonances. This indicates that there could be significant contributions from γ-Pomeron exchange. The analysis is still on-going, with results expected soon.

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Hard photoproduction at HERA: theory

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We review the present theoretical understanding of photons and hard photoproduction processes at HERA, discussing the production of jets, light and heavy hadrons, quarkonia, and prompt photons. Virtual and polarized polarized photons are also briefly discussed. The most important leading and next-to-leading order quantum chromodynamics results are presented in analytic form, and a variety of numerical predictions is compared to recent data [1].

We address in particular the extraction of the strong coupling constant from photon structure functions [2] and inclusive jet measurements, the infrared safety and computing time of jet definitions [3], the sensitivity of dijet cross sections on the parton densities in the photon, diffractive dijet photoproduction and the question of factorization breaking [4], the treatment of the heavy-quark mass in different variable flavor number schemes [5], the relevance of the color-octet mechanism to quarkonium production [6]. We emphasize in particular the interplay of direct and resolved photon components in real and slightly virtual photon collisions.

For dijet photoproduction in diffractive events [4] and events with a leading neutron [7], we show that at next-to-leading order the predicted cross sections overshoot the data and that absorptive corrections are necessary. We propose a scale-independent factorization scheme of suppressing not only the resolved, but also the direct initial-state contributions [8], and apply it to the transition region of virtual and real photons [9]. Within the Durham two-channel eikonal model [10], a reasonable description of H1 and ZEUS data with recent H1 diffractive parton densities (for diffraction) or GRV pion densities (for leading neutrons) can be achieved.

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Hard photoproduction at HERA: experiment

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The largest cross sections in ep collisions at HERA are due to quasi-real photons of low virtuality, $Q^2 \approx 0$, interacting with protons. These photoproduction processes provide rich possibilities to improve our understanding of the details of strong interactions at high energies by comparing experimental data with perturbative QCD calculations, which are presently available up to $\mathcal{O}(\alpha_s^2)$.

In this review a brief summary is given on jet production [1-9], prompt photons [10-12] and heavy quark final state [13-17] studies at HERA-1 by H1 and ZEUS collaborations. The data are sensitive both to proton and photon structure in previously unexploited kinematical range, as well as to the dynamics of hard scattering at partonic level. For inclusive jets and dijet photoproduction NLO calculations provide fair description. It is not yet the case for heavy quarks and multijet final states where clear indications are seen for sizable higher order corrections, lacking in the theoretical calculations. The same conclusion comes also from the fact, that for most of the measurements theoretical uncertainties dominate over experimental errors.

Scaled E_T distributions [1] demonstrate that inclusive jet spectra in γp interactions are harder than those in $p\bar{p}$ collisions. This can be attributed both to the direct photoproduction and anomalous component of the photon structure. α_s extracted from scaling violation in jet photoproduction [2] with competitive precision agrees with world average value.Dijets were used to provide unique information on gluonic content of the photon down to $x_\gamma = 0.05$ [3] as well as to constrain gluon in the proton at large x_p [6],[7],[18]. Angular distributions of dijets one of which containing D^* is indicative of large fraction of intrinsic charm in the photon (in LO framework) [14].

Results on the prompt photon and charm production show the sensitivity to the details of parton evolution. NLO calculations [19] using k_T-factorisation scheme and unintegrated parton density functions provide best description of γ+jet cross sections. Cascade [20] Monte Carlo program based upon CCFM evolution describes inclusive D^* cross sections better than Monte Carlo programs based on DGLAP and collinear factorisation scheme. Beauty photoproduction at HERA [15-17], albeit statistically limited, provides additional valuable tests of pQCD. Present NLO calculations tend to somewhat underestimate b cross section in low p_t range. Many of those results will be further improved by using new HERA-2 data, which amount to 3-fold luminosity of HERA-1 run and were taken with upgraded detector capabilities. In order to make best use of those data, we expect corresponding progress from theory side.

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Review talk on parton shower algorithms

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In this talk I gave a short overview on the structure of the parton shower algorithms and the current development of the field. I compared the HERWIG [1], PYTHIA [2] and ARIADNE [3] models and I reviewed the matching problems.

The largest contribution in high energy collisions comes from the hadronic event. The origin of the large hadronic contributions is the strong interaction, QCD. According to the perturbation theory we are able to calculate the hard part (short distance physics part) of the cross section and deal with only few partons in the final state instead of branch of hadrons. But in the detector we can see lots of hadrons. The hadronization happens at low energy and we are not able to calculate the hadronization effect from the QCD but we can set up a suitable model for it. We can calculate the high energy part and we have model for the low energy part, so we need a *bridge* between these two parts. The bridge is the parton shower. Can we calculate high multiplicity cross section in the perturbative framework? We cannot do it exactly but approximately it is possible.

The parton shower is based on the factorization property of the QCD matrix elements in the soft and collinear regions. In principle this would be a *well defined approximation* but in the parton shower algorithm we have further approximations top on the soft-collinear approximation: i) strong approximation in the phase space; ii) neglecting of the subleading color contribution ($1/N_c^2$ expansion); iii) even the leading color correlations are approximated according to the angular ordering; iv) spin correlations are also neglected.

These approximations allow us to have an algorithm that can produced unweighted hadronic events (as we can see in the detector) but we have to keep in mind that the parton shower is not the *nature*, it cannot be considered a QCD prediction. But we can improve them. One of the way is to add exact QCD matrix element. The CKKW [4] algorithm deals with exact tree level matrix elements while the MC@NLO [5] algorithm matches the shower calculations and the fix order NLO computations.

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Determining the Nuclear Gluon Distribution in UPCs

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In this talk, we discuss photoproduction of hard processes, accessible at RHIC and the LHC. The high photon-nucleon center of mass energy, $\sqrt{s_{\gamma N}}$, and the large luminosities result in high rates for $Q\overline{Q}$ (charm and bottom) [1]-[2] and jet+jet [2] final states. In particular, at the LHC, the high energies and large rapidity coverage make the nuclear gluon distribution accessible in the interesting low x and perturbative Q^2 regime. In AA collisions, both ions serve as photon emitters and the effective photoproduction process is γA. The photon flux from a nucleus is enhanced by a factor of Z^2 relative to the proton. Thus in pA interactions, the γA luminosity, where the photon comes from the proton, is negligible relative to the γp luminosity where the the photon comes from the nucleus.

We consider both direct photoproduction, where a photon from the virtual photon field surrounding the nucleus interacts with a parton in the opposite nucleus, and resolved production, where the virtual photon fluctuates into states with multiple gluons and $q\overline{q}$ pairs, opening more channels but increasing the average x probed. The nuclear gluon distribution is more cleanly probed in direct photoproduction. The possible effects of nuclear modifications of the parton densities on the γA interactions, most important at low x and moderate Q^2 [1]. We compared two parameterizations of nuclear shadowing which differ strongly for gluons, EKS98 [3] and FGS [4], to show the range of the measurable effect. It is precisely this modification that these LHC measurements can study. The average x values for the nucleon parton momentum fraction are shown as a function of heavy quark p_T (integrated over rapidity) and rapidity (p_T integrated) and jet p_T (rapidity integrated). We have also shown the $b\overline{b}$ and jet rates as a histogram in x and p_T in the ATLAS acceptance [2].

Heavy flavor production is especially useful since, in direct photoproduction, the only contribution is from $\gamma g \to Q\overline{Q}$. Of course heavy flavor measurements are rather difficult and jet measurements may be simpler. Jet production proceeds dominantly by $\gamma g \to q\overline{q}$ at low p_T but includes a contribution from the QCD Compton process, $\gamma q(\overline{q}) \to gq(\overline{q})$ which, although small at moderate p_T, increases with p_T. The heavy flavor results are shown as a function of quark p_T and rapidity as well as $Q\overline{Q}$ pair mass. The jet results are shown as a function of jet p_T. Final state pion, kaon and proton p_T distributions are also shown – if jets are not directly measurable, these leading hadrons may be. The results show that the rates are sufficiently high for these processes to provide clean measurements of the nuclear gluon distribution for γA in AA and the proton parton distribution γp in pA interactions.

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Photoproduction results in Ultra Peripheral Relativistic Heavy Ion Collisions with STAR

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We present a measurement of the coherent ρ^0 and direct $\pi^+\pi^-$ pair photo-production in ultra peripheral relativistic heavy ion collisions at $\sqrt{s_{NN}}$=200 GeV. At impact parameters larger then twice the nuclear radius, the nuclei do not physically collide, but interact via long-range electromagnetic fields. The process $AuAu \rightarrow Au^*Au^*\rho^0$ with accompanying mutual nuclear excitations is observed. We report on ρ^0 production cross section with coherent and incoherent coupling accompanied by mutual nuclear break-up and on direct $\pi^+\pi^-$ production. The cross section has been studied as a function of p_T, y_{rho^0} and $M_{\pi\pi}$. The measured production cross section is compared to the theoretical models [1]-[3] and found to be in agreement with [1]. ρ^0 helicity matrix elements have been measured and are consistent with S-channel helicity conservation.and in agreement with γp experiment [7].

We are also sensitive to the interference between two production modes: the first nucleus emits a photon and scatters from the second or vice versa. We observe that ρ^0 production at low p_T is suppressed, as expected if ρ^0 production at the two ions interfere destructively. The measured level of interference is 93 $\pm$ 6(stat.) $\pm$ 8(syst.) $\pm$ 15(theory)% of that expected [4]. STAR has also studied ρ^0 production in dAu collisions. Both coherent (deuteron stays intact) and incoherent (deuteron dissociates) interactions have been observed. The p_T^2 spectra matches those observed at eA at HERA [6]. The $AuAu \rightarrow \pi^+\pi^-\pi^+\pi^-$ state (ρ^{0*} 1450) produced via excited states is observed and peaked at low $p_T < 100$ MeV/c and the 4-pion mass spectra is peaked around 1.5 GeV/c^2. Finally, lepton pairs production (e^+e^-) accompanied by mutual Coulomb dissociation have been observed. The kinematic distribution match those predicted by the lowest order QED [5].

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Photoproduction of J/ψ and high mass e^+e^- in Ultra-Peripheral Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV

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High energy ultra-peripheral collisions (UPC) of heavy-ions generate strong electromagnetic fields which open the possibility to study $\gamma\gamma$ and γ-nucleus processes in a kinematic regime so far unexplored. In this talk, we discuss photoproduction of J/ψ and high mass e^+e^- in Ultra-Peripheral Au+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV, tagged with forward neutron emission from the $Au^\star$ dissociation. The electromagnetic field of any relativistic charged particle can be described as a flux of "equivalent" photons, originally due to Fermi [1], and given by the Weizsäcker-Williams [2] or Equivalent Photon Approximation (EPA) formula. The validity of the application of the EPA formula for heavy-ions is limited to the case where *all* the protons of the nucleus interact electromagnetically in a coherent way. In that case, the wavelength of the resulting photon is larger than the size of the nucleus, given by its radius R_A. This "coherence" condition limits the maximum virtuality of the produced photon to very low values [3]. The two topics discussed in this talk are the coherent photoproduction of:

I. J/ψ, the heaviest vector meson effectively accessible in γA collisions at RHIC, via: $A+A\ (\rightarrow \gamma+A) \rightarrow A^\star + A^{(\star)} + J/\psi$.

II. High mass di-electron continuum in $\gamma\gamma$ collisions: $A+A\ (\rightarrow \gamma+\gamma) \rightarrow A^\star + A^{(\star)} + e^+ + e^-$.

For the first process (I), the cross-section for heavy vector meson ($J/\psi, \Upsilon$) photoproduction is found to depend (i) *quadratically* on the gluon density $G_A(x,Q^2)$ [4] as well as on (ii) the probability of rescattering or absorption of the $Q\overline{Q}$ pair as it traverses the nucleus. The study of quarkonia production in γA collisions at RHIC or LHC energies is, thus, considered a good probe of (i) the gluon distribution function $G_A(x,Q^2)$ in nuclei, and (ii) vector-meson dynamics in nuclear matter.

The PHENIX data taking during Run4 (2004) included a special UPC trigger requiring a charged particle veto rapidity gap (empty $|y| \in [3,4]$ region), at least one single particle (cluster) seen in the mid-rapidity calorimeter with an energy of at least 800 MeV, and that the zero-degree calorimeters should see at least one neutron emitted at very forward rapidities. Roughly 40% of the UPCs leading to J/ψ production, fulfill this latter requirement due to Coulomb excitation of at least one of the two nuclei. After event selection, offline analysis cuts (incl. electron ID), and like-sign combinatorial background subtraction, a few tens of di-electron pairs remain in the data sample. These pairs can then be further divided up into coherent and incoherent J/ψ candidates, and continuum dielectron pairs, via their invariant mass (M_{inv}) and transverse momentum (p_T) distributions. The preliminary PHENIX results [5] on these topics are presented, illustrating that the trigger and analysis scheme is functional. The current analysis is however clearly statistically limited, but with future higher luminosity runs (expected in 2007-08) more significant measurements should be possible.

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Exclusive Diffraction at CDF

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Diffractive pp collisions are mediated by the exchange of a colorless object with the quantum numbers of the vacuum, the Pomeron, which allows the protons to stay intact while still producing some central system X, $pp \to p+X+p$. If X is completely determined, then the interaction is called an *exclusive diffractive* collision. Exclusive diffractive processes heavily favour final states with the quantum number of the vacuum, $J^{PC}=0^{++}$. Exclusive diffraction could play a significant role in the observation (and precision measurement) of the Standard Model (SM) Higgs boson and other beyond the SM processes at the LHC - if suitable proton tagging detectors are installed [1]. The advantages of exclusive processes rely on two things: 1) M_X can be determined by the momentum of the outgoing protons, 2) X is heavily favoured to have $J^{PC}=0^{++}$. The detectors necessary for proton tagging at ATLAS and CMS are being developed by the FP420 Collaboration [2] One of the challenges in the development of the exclusive experimental program at LHC, is the lack of confirmation of the theoretical models for exclusive diffraction. Two theoretical models have been proposed and developed to the point where they can be experimentally tested; the Durham model [3] implemented in the ExHuME MC [4] and the Saclay model [5] implemented in the DPEMC MC [6].
The Collider Detector at Fermilab (CDF) [7] is attempting to distinguish these models using $p\bar{p}$ collisions at $\sqrt{s}=1.96$ TeV. CDF has looked at three exclusive diffractive production processes; $\gamma\gamma$ (through a quark loop), dijet, and $\chi_c \to J\psi+\gamma$. In the $\gamma\gamma$ channel three candidate events have been observed, but the background estimates are not yet complete. The ExHuME MC predicts 1^{+3}_{-1} events expected in the data sample examined in the $\gamma\gamma$ analysis. Because the definition of an *exclusive jet* is experimentally ambiguous, the dijet channel examines a variable called the *dijet mass fraction*, $R_{jj} \equiv \frac{M_{jj}}{M_X}$, where M_{jj} is the mass of the dijet system and M_X is the mass reconstructed using all the observed particles in the detector. The dijet channel has extracted an exclusive dijet signal in the high R_{jj} region of an inclusive diffractive dijet sample. The signal favors the ExHuME MC predictions over the DPEMC predictions. By using the fraction of heavy flavor jets in the inclusive diffractive dijet sample, the $J^{PC}=0^{++}$ selection of exclusive events has also been observed.

In the χ_c channel, candidate events have been selected, but detailed analysis of acceptance, efficiency, and backgrounds are not yet complete. Backgrounds from γ-Pomeron interactions to $J\psi$ are expected. In conclusion, the CDF Collaboration is actively searching for exclusive diffractive processes to distinguish proposed theoretical models. The results in the dijet channel favour the Durham model of exclusive production over the Saclay model.

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Photonic and Diffractive Processes in QCD

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The prospect of proton-proton and ion-ion collisions at the LHC collider has led to a new focus on diffractive collisions where one or both of the projectiles remain intact. In this talk I emphasize a number of novel physics features of photon-photon and photon-Pomeron collisions which are accessible in diffractive and ultra-peripheral reactions.

1. The equivalent photon distribution [1] of a nucleus in light-cone fraction x and $k_\perp$ is most easily derived using frame-independent light-front methods. Nuclear coherence is maintained for $x < (M_A R_A)^{-1}$, leading to a remarkably large kinematic range for particle production from photon-photon and photon-Pomeron interactions up to hundreds of GeV for heavy ion collisions at the LHC. Coulomb corrections as expressed by the Schwinger-Sommerfeld interaction [2] with large nuclear charge give large distortions of the trajectories of the charged particles, particularly when relative velocities are small. The Coulomb corrections also produce interesting charge asymmetries in ultra-peripheral lepton-pair production [3]. Hadron production in diffractive interactions can involve both photon and multi-gluon/Pomeron exchange, giving amplitudes with different charge conjugation which can interfere and thus also produce charge asymmetries.

2. The elastic Coulomb scattering of heavy ions is modified by quantum corrections associated with vacuum polarization and light-by-light scattering, giving $\mathcal{O}(\alpha)$ corrections to the effective Lippmann-Schwinger kernel when $Z\alpha = \mathcal{O}(1)$.

3. Diffractive deep inelastic scattering $\ell p \to \ell p + X$ arises in QCD at leading twist from the final-state interactions of the struck quark [4]. This in turn leads to nuclear shadowing and corrections to the observed structure functions of hadrons and nuclei at leading twist which are not in the wavefunction of the target hadron computed in isolation [5]. Such final-state interactions also give single-spin asymmetries in single-inclusive DIS which measure the orbital angular momentum of quarks and gluons in the target hadron [6]-[7]. In the case of the Drell-Yan reaction, one gets analogous leading-twist effects from initial-state interactions, but with a sign reversal of the single-spin asymmetry [8]-[9]. When one allows for both the quark and antiquark to interact in the initial state, one gets a leading-twist contribution to the $\cos 2\phi$ distribution of the lepton pair which violates the Lam-Tung relation of PQCD [10]-[11]. An important lesson is that one must include - even at leading twist - the interactions of the active quarks with the spectator quarks due to the “dangling gluons” associated with the Wilson line. The same effects arise from other Feynman diagrams in the case of light-cone gauge [4].

4. Diffractive dijet production, such as $\pi A \to \mathrm{JetJet} + A$ as measured in the E791 experiment at Fermilab [12] not only tests QCD color transparency [13], a fundamental property of color gauge theory, but they also measure the frame-independent light-front wavefunction of the projectile [14] . Such measurements can be used to determine the proton LFWF by measuring $ep \to e\mathrm{JetJetJet}$ at HERA or diffractive tri-jet production $pA \to \mathrm{JetJetJet} + A$ in proton-ion collisions. The hadronic input, the nonperturbative LFWFs of hadrons can be predicted using AdS/CFT [15] . Diffractive dA reactions can also provide a new test of “hidden color” in the deuteron wavefunction [16]. Hard exclusive processes, such as $\gamma\gamma \to H\bar{H}$ at large s and $-t$, and diffractive photoproduction $\gamma p \to V^0 p$ are also sensitive to the shape of the hadron light-front wavefunction or distribution amplitude of the produced mesons [17].

5. The existence of intrinsic charm and bottom Fock states [18] in the proton $|uudQ\bar{Q}>$ with probability $1/M_Q^2$ [19] leads to doubly diffractive processes such as $pp \to \Upsilon + p + p$ and $pp \to H + p + p$ [20], where a heavy quarkonium state such as an Υ or the neutral Higgs couples to both members of the intrinsic

heavy quark pair and thus can attain a longitudinal momentum fraction x_F as large as 0.8. The fact that the intrinsic heavy quark Fock states have a large color-octet dipole moment, such as $|(uud)_{8C}(c\bar{c})_{8C} >$ requires that the gluon exchange producing the color-singlet quarkonium occurs at the nuclear surface, thus explaining the remarkable $A^{2/3}$ behavior of $pA \to J/\psi X$ cross section observed at high x_F [21]. Double intrinsic charm Fock states [22] lead to double J/ψ production as observed by NA3 [23] and the doubly charmed baryons observed by SELEX [24] at large x_F.

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Diffraction at HERA[2]

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Factorization in diffraction:
The QCD properties of diffraction can be studied at HERA via diffractive positron proton interactions of type $e^+p \to e^+XY$. There hadronic diffractive system x is separated by large rapidity gap (due to colour singlet exchange) from the system Y which consists of a proton or a low mass system.The QCD collinear factorization implies that diffractive processes in deep inelastic scattering (DDIS) can be understood as a convolution of the process dependent perturbatively calculable matrix elements with universal diffractive parton density functions (DPDF), which gather the nonperturbative components of diffractive process [1]. These are determined from NLO QCD fits to measurements of inclusive diffractive DIS cross sections within the factorizable Pomeron model and using DGLAP evolution equations [2]. If QCD factorization is fulfilled, NLO QCD calculation based on these DPDFs should be able to predict the production rates of exclusive diffractive processes like dijet and open charm production. It has been found that in the regime of DIS the predictions of QCD are in good agreement with the experimental results [3]-[6]. In the regime of photoproduction the cross section for dijet production was however found to be suppressed by factor about 1.6 in comparison with NLO QCD predictions thus indicating QCD factorization breaking in photoproduction [7]-[8]. On the contrary there is not observed the evidence for such a suppression (within large theoretical and experimental errors) in open charm photoproduction [5]-[9].

Vector meson production:
¿From the measurement of the W dependence of the exclusive ρ^0 photoproduction the Pomeron trajectory $\alpha_P(t)$ has been extracted. The value α' was found to be smaller than the value 0.25 GeV^2 [10]. The cross section for elastic J/ψ in photoproduction was measured [11]. Within models, the data show a high sensitivity to the gluon density of the proton in the low x and low Q^2 region. The diffractive photoproduction of ρ^0 [12] and J/ψ [13]-[14] with large momentum squared at the proton vertex, $|t|$, has been investigated. The data of diffractive photoproduction of ρ^0 indicate a violation of s-channel helicity conservation[12], on the contrary J/ψ production data were found to be compatible with helicity conservation [14]. Data were compared to the predictions of QCD perturbative models.

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Onium photoproduction and models of diffractive exclusive production

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One of the most important discovery of HERA was the observation of abundant diffractive reactions, in which the proton remained intact and lost only a small fraction of its momentum. The fraction of diffractive processes is well above 10% at $Q^2 = 10$ GeV^2 and decreases only logarithmically with increasing Q^2. The abundance of diffractive reactions indicates that they are the shadow of inclusive DIS processes. At low x, the leading order QCD description of DIS (in the momentum space) is equivalent to the scattering of small dipoles (defined in the configuration space) and the optical theorem relates directly inclusive and diffractive scattering.

For small dipoles, with a size r, the dipole cross section is proportional to the gluon density and r^2,

$$\sigma^{\gamma^* p}(r^2) \propto r^2 \alpha_S xg(x, Q^2) \quad (1)$$

The inclusive DIS cross section is proportional to the dipole cross section whereas the diffractive ones are proportional to its square.

In the dipole picture the physical cross section is obtained by averaging the dipole cross section with probabilities to find a dipole of size r given by the wave functions. For the inclusive DIS process only the photon wave function is needed and it is known from QED. The only unknown quantity is the gluon density, and it is then extracted from fits to data. For vector meson production, the vector meson wavefunction is also needed, and there exist good approximations.
The dipole models provide a simultaneous description of F_2 and inclusive and exclusive diffractive measurements at HERA of astonishing quality [1]-[3]. The cross section for exclusive J/Ψ, ϕ, ρ photo- and electro-production and DVCS process and the ratio of the cross sections for longitudinally and transversely polarized vector mesons are very well described as a function of Q^2, W^2 and the squared momentum transfer, t. One of the results of this type of analysis is a clear indication of saturation effects in the core of the proton [2].

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Photoproduction of Jets with ZEUS at HERA

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In photoproduction, a quasireal photon, emitted by the incoming positron, interacts with a parton from the proton. Photoproduction may be categorised at leading order (LO) as being either direct, if the photon interacts as a pointlike particle, or resolved, if it fluctuates into a partonic system, and subsequently transfers only a fraction of its momentum to the hard interaction. In resolved photoproduction more than one pair of partons from the incoming hadrons may interact, e.g. multiparton interactions (MPIs) may take place. The secondary scatters generate additional hadronic energy flow in the event, the topology of which is poorly understood theoretically.

Differential cross sections for three and four-jet photoproduction events in a wide region of jet-system invariant mass $M_{3(4)j}$ demonstrate, that the resolved part of the cross sections at low values of $M_{3(4)j}$ can be only described by the models by adding the MPI process to the standard MC simulation. Therefore this region is of particular interest for studying of the MPI regime at HERA. The pQCD calculations, existing currently only at order of $O(\alpha, \alpha_S^2)$ describe the data at high values of M_{3j}, but do it much poorly in the low M_{3j} region.

The production of events with two high transverse energy jets in the final state separated by a large rapidity interval provides an ideal environment to study the interplay between soft (nonperturbative) and hard (perturbative) QCD. The dominant mechanism for the production of jets with high transverse energy in hadronic collisions is a hard interaction between partons in the incoming hadrons via a quark or gluon propagator. The exchange of color quantum numbers generally gives rise to jets in the final state that are color connected to each other and to the remnants of the incoming hadrons. This leads to energy flow populating the pseudorapidity region both between the jets and the hadronic remnants, and between the jets themselves. The fraction of events with little or no hadronic activity between the jets is expected to be exponentially suppressed as the rapidity interval between the jets increases. A nonexponentially suppressed fraction of such events would therefore be a signature of the exchange of a colorsinglet object. The high transverse energy of the jets provides a perturbative hard scale at each end of the colorsinglet exchange, so that the cross section should be calculable in perturbative QCD.

Dijet photoproduction has been measured for configurations in which the two jets with highest transverse energy are separated by a large rapidity gap. The fraction of events with very little transverse energy between the jets is inconsistent with the predictions of standard photoproduction MC models. The same models with the inclusion of a colorsinglet exchange sample at the level of 2-3% are able to describe the data, including the gapfraction dependency on different kinematic variables.

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Hard diffraction in DIS and pA

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In this talk, we reviewed several coherent diffractive processes with nuclear targets. They included soft hadron-nucleus diffraction, hard inclusive diffraction in Deep Inelastic Scattering (DIS) on nuclear targets and hard diffraction in proton-nucleus scattering. We discussed the leading twist theory of nuclear shadowing [2]-[5] and presented predictions for usual and diffractive nuclear parton distribution functions [6].

We presented a novel method for the calculation of hard coherent proton-nucleus diffraction [7] using the leading twist theory of nuclear shadowing. We discussed the novel dramatic prediction that soft multiple interactions lead to very large factorization breaking in hard coherent pA diffraction. We compared hard and e.m. mechanisms of hard coherent diffractive production of two jets in pA scattering. We observed that: (i) For heavy nuclei (Pb-208) at the LHC, hard diffraction is suppressed compared to the e.m. mechanism; (ii) for lighter nuclei (Ca-40), hard diffraction is compatible to the e.m. mechanism for the production of quark and gluon jets; hard diffraction is suppressed compared to the e.m. mechanism for heavy-quark-jets.

This suggests the following experimental strategies: (i) The use of heavy nuclei would allow to cleanly study the γp interaction; (ii) The use of lighter nuclei would allow to study factorization breaking in nuclear diffractive PDFs; (iii) In the same kinematics, a comparison of diffractive dijet production to heavy-quark-jet production would probe nuclear diffractive gluon PDF.

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W boson photoproduction in pp and pA collisions at LHC

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The couplings of gauge bosons among themselves belong to one of the least tested sectors of the electroweak theory. A process well-suited to testing the gauge boson self-interaction is the photoproduction of single W bosons from a nucleon. In particular, this process is sensitive to the $WW\gamma$ coupling. In the framework of the equivalent photon approximation [1]-[5] either one of the protons in p-p collisions or the ion in p-A collisions at LHC is replaced by a spectrum of equivalent photons. Thus, the production rate of single W bosons in ultraperipheral collisions can be determined either from the convolution of the equivalent photon spectrum with the exclusive process $\gamma + p \to W^+ + n$ or the corresponding inclusive process. While the cross section for the inclusive process is expected to be larger, the exclusive process has the advantage of a neutron in forward direction with approximately the energy of the initial proton.

First, we calculate the cross section for real photoproduction of single W bosons and cross-check our results with those of Fearing *et al.* [6]-[7], who have calculated this cross section with a smaller W boson mass in mind. Next, we extend the calculations of Fearing *et al.* by including a weak magnetic form factor and the correct W boson mass, and convolve the photoproduction cross sections with the equivalent photon spectra of ions and protons [4]-[8] in order to obtain results for p-p and p-A collisions.

We show how the choice of the weak timelike form factors affects the sensitivity of the total cross section to the anomalous magnetic moment of the W boson. Furthermore, we give an estimate of the total cross sections for p-p ($\sim 10^{-39} cm^2$) and Pb-p ($\sim 10^{-36} cm^2$) collisions. However, the feasibility of measuring this process is still an open question. For p-p collisions yet another possibility exists. For large momentum transfers Q^2 of the photon, the proton should be regarded as a collection of partons which in turn can be approximated by an equivalent stream of photons [9]-[11]. Convolving the photoproduction cross sections with the deep inelastic equivalent photon spectrum over the appropriate range of momentum transfers, we obtain rates in a similar range as for the elastic case. Whether the dominant diagrams are the same as for real photoproduction is still to be checked.

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Anomalous gauge boson couplings in $e^-e^+ \to W^-W^+$ and $\gamma\gamma \to W^-W^+$ at an ILC

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One important physics topic which will be studied at a e^+e^- linear collider, the ILC, with c.m. energies 0.5 to 1.0 TeV concerns the couplings of the gauge bosons γ, Z and $W^\pm$ among themselves. In the Standard Model (SM) these couplings are fixed by the requirement of renormalisability. Any deviation from the SM couplings would, therefore, signal new physics. We describe the accuracies achievable for anomalous couplings in various proposed modes of operation of the ILC. The reactions $e^-e^+ \to W^-W^+, \gamma\gamma \to W^-W^+$ and Z decays at Giga Z are considered. From the theoretical side we follow first a form factor approach. It is known that 28 real parameters describe the general γWW and ZWW vertices. All of these parameters can be measured in $e^-e^+ \to W^-W^+$ at an ILC if also transversely polarised e^- and e^+ beams are available. A particularly interesting option for the ILC is a $\gamma\gamma$ collider. To compare the sensitivities reachable for anomalous gauge boson couplings in e^-e^+ and $\gamma\gamma$ collisions we use an effective Lagrangian approach. It turns out that in such an approach also Z decay observables become sensitive to anomalous gauge couplings. From presently available electroweak precision measurements we deduce a correlation between the value for the Higgs mass and a certain anomalous coupling. Already small values for the latter allow Higgs masses up to 500 GeV. At an ILC the various reactions, $e^-e^+ \to W^-W^+, \gamma\gamma \to W^-W^+$ and Z decays give complementary information on the gauge-boson couplings. The indirect reach for new physics in these reactions will be up to around 10 TeV.

The results presented in the talk are based on work done by M. Diehl, F. Nagel, M. Pospischil, A. Utermann and O. Nachtmann, see Z. Phys. **C62**, 397 (1994) and Eur. Phys. J. **C1**, 177 (1998), **C27**, 375 (2003), **C32**, 17 (2003), **C40**, 497 (2005), **C42**, 139 (2005), **C45**, 679 (2006), and **C46**, 93 (2006).

Simulation of Photoproduction on Nuclei and Astroparticle Physics Connection

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The interaction of photons with nuclei is an important process in astroparticle physics. It takes place in the source regions where cosmic rays are accelerated, leads to energy losses and secondary particle production during propagation, and determines the muon content of em. showers in the Earth's atmosphere. On the other hand, photoproduction interactions provide an interesting means of investigating QCD processes in accelerator experiments and also represent background reactions for the investigation of rare processes.

In the presentation, the connection between astroparticle physics and high energy physics is illustrated using the particularly striking example of ultra-high energy cosmic rays [1]-[2]. The need for detailed simulation of photoproduction interactions in the energy range from particle production threshold to the highest observed energies is emphasized [3].

In the second part of the presentation, currently available minimum bias Monte Carlo codes for simulation of photoproduction are reviewed, focussing on SOPHIA [4], FLUKA [5], RELDIS [6], and DPMJET III [7]. Physics concepts applied for describing particle production at different energies are introduced and their implementation in simulation packages is discussed. Comparisons with measurements are used to demonstrate the applicability of different programs. Finally the limitations and the considerable uncertainties of simulating multiparticle production simulations at very high energy are stressed.

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Low-x QCD via electromagnetic PbPb collisions at 5.5 TeV in CMS

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Photoproduction of heavy vector-mesons in electromagnetic interactions (aka. Ultra-Peripheral Collisions, UPCs) of heavy-ions at very high energies provides direct information on the parton distribution function (PDF) in the nucleus at low values of Bjorken-x [1]. The capabilities for the measurement of Υ produced in ultraperipheral PbPb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV in the Compact Muon Solenoid (CMS) experiment at LHC [2] are studied in the e^+e^- and $\mu^+\mu^-$ decay channels [3].

The measurement discussed here makes use of the CMS tracker, ECAL and muon chambers ($|\eta| < 2.5$, full ϕ) for muon and electron reconstruction, and the Zero Degree Calorimeters (ZDC) [4] for tagging the ultra-peripheral PbPb events accompanied by forward neutron emission. The STARLIGHT event generator [5] is used as input Monte Carlo for the double differential cross-sections of (i) the Υ photoproduction signal, and (ii) the most significant source of physical background: coherent production of high-mass lepton pairs in $\gamma\gamma \to l^+ l^-$ processes. The mass, p_T and rapidity spectra of the $\Upsilon \to e^+e^-$, $\mu^+\mu^-$ obtained after background subtraction with a full simulation and reconstruction analysis are presented. The excellent bottomonia mass resolution of the CMS muon chambers ($\sigma_\Upsilon \approx 90$ MeV/c^2) will allow one to measure separately the different vector states ($\Upsilon, \Upsilon', \Upsilon''$). The dedicated L1 and high-level triggers proposed for the UPC measurement are also discussed. The final expected rates ($\sim$400 Υ's) for a nominal PbPb run with integrated luminosity of 0.5 nb^{-1} will make possible a differential study of the rapidity dependence of Υ photo-production. Such a measurement is expected to constrain the underlying gluon PDF in the Pb nucleus in a kinematic regime ($x \approx 10^{-3}$, $Q^2 \approx 40$ GeV^2) unexplored so far [6].

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Trigger capabilities of ALICE TOF for Ultra-Peripheral Collisions

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The ALICE TOF detector is a natural candidate to address UPC selection. The fast response of the MRPC, the large area covered at $|\eta| < 1$ and the high segmentation make the TOF well suited for triggering at L0 level in the central region. Each Front End card (FEA) reads 24 MRPC pads and makes their OR. Such OR is daisy chained with the OR of the closer FEA. The resulting signal (hereafter TOF-OR), made by the ORs of 48 pads, (i.e. $\simeq 500\ cm^2$) is sent to the first TOF trigger layer, a VME board called Local Trigger Module (LTM). Each of the 72 TOF VME crates contains a LTM module, sending 24 bits in parallel to the Cosmic and Topology Trigger Module (CTTM), located 60 m far away, close to the ALICE CTP. The CTTM is expected to take the L0 trigger decision and to send it to the CTP. UPC can produce lepton pairs in $\gamma\gamma$ interactions, and vector mesons and jets in photoproduction events. When triggering on the exclusive production of vector mesons, the most important parameter to face is the fake trigger rate (FTR), due to combinatorial background. Such events show up as few tracks in an otherwise empty detector. The key ingredient when computing the FTR, is the MRPC noise, whose measurement gives 0.5 Hz/cm^2. Such noise is mainly due to ionizing particles in the chamber. A guess on the noise that the TOF will experience when running in ALICE is not straightforward: as a safety margin we will use for the prediction reported below a MRPC noise of 2.5 Hz/cm^2. The FTR, when selecting a number of fired $N_{TOF-OR} \geq 5$ is $\simeq 1$ Hz, while the FTR for $N_{TOF-OR} = 2$ is 200 kHz. Such high rate, unmanageable also at L0 level, can be further reduced by using the vector meson decay topology. We simulated the J/$\Psi \to l^+l^-$ and the $\rho \to \pi\pi$ decay, using the STARLIGHT Monte Carlo. The particles produced in the decay were traced in a empty cylinder in a B=0.5 T magnetic field. We found an efficiency for containing both the decay products of $\varepsilon^{J/\Psi}_{cont}$=16.7% and $\varepsilon^{\rho}_{cont}$=8.3% respectively. A full simulation is in progress. Taking advantage of the produced particle topology in the J/Ψ decay, by selecting only the TOF-OR pairs in a $150^o \leq \Delta\phi \leq 170^o$ window the FTR can be reduced by a factor 18. For the pions from ρ decay by selecting only the TOF-OR pairs in a $70^o \leq \Delta\phi \leq 110^o$ window, the FTR can be reduced by a factor 9, while keeping 60% of the signal. A further FTR reduction can be obtained for both vector mesons decay considering that in Pb-Pb interaction, despite a bunch crossing length of 125 ns, the TTC will distribute a 40 MHz clock. Since the OR signal has a 20 ns length, we can align this signal so that the positive edge of the TTC clock is well inside it. By enabling the latching only in the edge effectively corresponding to the bunch crossing, we can reduce the noise by a factor of 5. In the combinatorial background, for $N_{TOF-OR} = 2$, this corresponds to a factor 25, giving:

$\mathrm{FTR}_{L0} < 200$ kHz/18/25 = 440 Hz for $J/\Psi \to l^+l^-$ and $\mathrm{FTR}_{L0} < 200$ kHz/9/25 = 880 Hz for $\rho \to \pi\pi$.

Such FTR at L0 level has to be compared with the genuine J/ψ and ρ rates:

$\mathrm{Rate}_{J/\Psi} = L \cdot \sigma \cdot \varepsilon^{J/\Psi}_{cont} \cdot \Gamma$=0.32 Hz and $\mathrm{Rate}_{\rho} = L \cdot \sigma \cdot \varepsilon^{\rho}_{cont} \cdot \varepsilon_{\Phi}$=130 Hz.

The FTR_{L0} rates can be reduced requiring a coincidence with L0 triggers from other central detectors.

Strong electromagnetic fields in heavy ion collisions: multiphoton processes

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The characteristic properties of ultraperipheral relativistic heavy ion collisions are discussed. Very strong fields occur for a very short time. This means that the corresponding equivalent photon spectrum extends to energies which exceed present photon energies available at other facilities [1]-[2]. Also, due to the high charge of the ions ($Z = 79$ at RHIC and $Z = 82$ at the forthcoming LHC) multiphoton processes occur in a single collision, see e.g. [3].

One of the main interests is in coherent vector meson photoproduction , which was observed at RHIC and is relevant for low-x QCD studies [4]. The transverse momentum distribution depends on an interference effect. The photon producing the vector meson can come from either ion [5]. The transverse momentum distribution is determined by the transverse momentum distribution of the photon and on the production process on the target, this is studied in semiclassical and Glauber models in [6].

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A low multiplicity trigger for peripheral collisions in ALICE

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The ALICE experiment at the LHC is presently being built as a general purpose heavy ion detector. ALICE consists of a central barrel covering a pseudorapidity range $-0.9 < \eta < 0.9$ and a forward muon spectrometer covering a range $2.5 < \eta < 4.0$. Additional detectors are used for event characterization and for trigger purposes.
The physics programme of ALICE focuses on the study of strongly interacting matter at high energies with a multitude of experimental observables. Such a programme necessitates data taking in nucleus-nucleus as well as in nucleon-nucleon collisions. The total nucleon-nucleon cross section at LHC energies is expected to be about 100 mb with a substantial contribution of 30 mb due to diffractive events. The subclass of central exclusive production is characterized by particle production at midrapidity and by the existence of a rapidity gap on either side. The kinematics of central exclusive production is matched to the acceptance of the ALICE detector, hence measurements of some channels of diffractive central exclusive production become feasible.
In my talk I will present a trigger scheme for diffractive central exclusive events. I will describe how such a scheme can be realized within the existing ALICE detector systems. I discuss some physics channels which become accessible with such a trigger and present some rate estimates.

NA60 experimental capabilities for ultra-peripheral InIn collisions

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In this presentation we introduce the NA60 experiment, in terms of concept, detectors and performance, placing emphasis on issues of relevance for the tagging of Ultra-Peripheral Collisions, which is necessarily done in rather different ways in a fixed-target collision geometry with respect to the presently more common collider experiments. We also mention some specific features affecting the NA60 case, such as beam and interaction pile-up, detector resolutions, etc. In summary, it seems likely that the available NA60 In-In data can provide useful information on dimuon production in Ultra-Peripheral Collisions.

Dimuon production in Ultra-Peripheral In-In Collisions in NA60

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This presentation reports the status of the ongoing analysis to identify Ultra-Peripheral Collisions in the Indium-Indium data collected by NA60 in 2003. A first iteration of the Event Selection procedure is described in detail, with emphasis on aspects that affect the NA60 data differently from what happens in collider experiments, such as beam and interaction pile-up. We conclude that the use of several complementary NA60 detectors should provide a dimuon event sample where Ultra-Peripheral In-In Collisions have a very significant contribution.

UPC lepton pair production to all orders in $Z\alpha$

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Calculations of lepton pair production based on solution of the heavy ion δ function potential Dirac equation are reviewed. For the bound-electron positron problem the full solution of the problem is in perturbation theory form, but with an eikonalized interaction in the transverse direction. This exact semiclassical solution produced a reduction of a little less than 10% from perturbation theory in the predicted cross section for Au + Au at RHIC. One can identify this reduction as an additional Coulomb correction from the moving ion not receiving the electron to bound-electron positron pair production [1].

A two center light cone calculation of continuum pairs was made by solving the semi-classical Dirac equation for colliding δ function potentials [2]-[4]. Several authors have argued that a correct regularization of integrals leading this exact Dirac equation amplitude should lead to Coulomb corrections [5]-[6]. A physically motivated cutoff of the transverse potential effected this correct regularization and leads to an "exact" cross section expression with Coulomb corrections [7]. A full numerical evaluation of the "exact" total cross section for e^+e^- production with gold or lead ions shows reductions from perturbation theory of 28% (SPS), 17% (RHIC), and 11%(LHC), and no final momentum region was found in which there was no reduction or an insignificant reduction of the exact cross section [8]. Reductions in the exact total probability of e^+e^- production from perturbation theory were seen at all impact parameters [9]. Suggested possibilities for observing Coulomb corrections at LHC were made: (1) forward e^+e^- pairs, (2) $\mu^+\mu^-$ pairs, and (3)deviations from Z^4 scaling.

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High energy photon interactions at the LHC

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First collisions of 7 TeV protons at the CERN Large Hadron Collider are expected in 2008, when studies of interactions of proton constituents, quarks and gluons, at unprecedented energies will begin. However, protons are charged particles, and a significant fraction of pp collisions will involve high-energy interactions of photons exchanged by one, or both incoming protons. Most of the time such protons will stay intact and will be scattered at very small angles, and thanks to significant proton energy losses, tagging the high-energy photon-photon and photon-proton interactions by dedicated forward detectors becomes possible [1]. Hence, by adding such detectors to the ATLAS and CMS experiments one can extend their physics reach and effectively convert the LHC into a high-energy photon-photon or a photon-proton collider. The same tagging technique can be used to select diffractive interactions at high luminosity [2].

The rate of the photon–induced electroweak processes is significant. Apart from the low-mass muon pairs, the highest cross-section of about 40 pb is obtained for the single W boson photo- production. One should note that a large cross-section of about 1 pb is expected for large photon-proton cms energies, $W_0 > 1$ TeV, so interesting studies will become possible already at initial low luminosity. It is therefore not surprising that the cross-section for the associated WH photoproduction is significant, above 20 fb for the SM light Higgs boson, and WH photoproduction constitutes more than 2% of the total inclusive WH production at the LHC! Contrary to the pp case, the top pair photoproduction of 1.5 pb is not so overwhelming, and the top background will be much less severe, allowing for a complementary measurement of the WH production provided sufficient luminosity.

Finally, the two-photon W^+W^- exclusive production has the total cross-section of more than 100 fb, and a very clear signature. Its cross-section is still about 10 fb for $W_0 > 1$ TeV showing sensitivity to physics beyond the SM. On the other hand, the two-photon dimuon production will be an excellent calibration process, with very well known cross-section from QED, and an extremely clear signature of the exclusive, back-to-back dimuons in the central detectors.

These initial studies of photon induced high-energy interactions at the LHC show very interesting prospects. One should stress that apart from the spectacular exclusive muon pairs, all the other considered final states contain at least one W boson. It means that even using the nominal LHC triggers one will be efficiently selecting also photon events. However, for the final selection, and in particular for the suppression of huge inclusive pp backgrounds, tagging photon events by forward proton detectors is mandatory. In addition, it will improve the reconstruction of events by using the measured momenta of the forward-scattered protons. This will lead to very clean samples, in particular for the exclusive two-photon production for example, for the fully leptonic decays of W pairs the final state will consist of two forward protons, two very high pT central leptons of opposite sign, large missing energy and nothing else. Selection of such events should be therefore possible even at the nominal LHC luminosity.

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Anomalous single top photoproduction at the LHC

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FCNC processes are expected in many extensions of the Standard Model. Measurements at HERA show that anomalous couplings $\kappa_{\gamma qt}$ can be strongly constrained by studying the single top photoproduction. Of course, in the Standard Model the single top cross-section is strongly suppressed, as it is zero at the tree level. The recent limits from the ZEUS and H1 collaborations [1] significantly reduce the allowed range for anomalous couplings, in particular for $\kappa_{\gamma ut}$. Rate of the photon-induced electroweak processes is significant at the LHC [2], and the energy reach is about 10 times higher than at HERA. Apart from the low-mass muon pairs, the highest cross-section of about 40 pb is expected for the single W boson photoproduction, which is still at about 1 pb for photon-parton cms energies above 1 TeV. In case of the direct photoproduction the W boson is accompanied by at least one jet, making such W+jets events the major background in searches for the anomalous single top photoproduction at the LHC, in case when the Wj invariant mass is close to the top mass and jet is misidentified as a b-quark jet. It should be noted that the NLO calculations has been done for the HERA kinematics [3], showing complete dominance of the direct photoproduction for the W boson transverse momenta of about 20 GeV, and above.

Initial studies of such measurements at the LHC have been made using the adopted for photon interactions MADGRAPH package [4], interfaced to PYTHIA for the final state hadronization, and PGS - a generic, fast MC program to simulate detector and experimental effects [5]. Leptonic decays of the W boson, from the top quark decay, were assumed and b-jet tagging was requested. The signal selection was done by requesting an electron or muon at large transverse momenta, significant missing energy, the reconstructed invariant mass of the Wj system compatible with the top mass, and by a cut on the direction of the b-jet in the c.m. frame of the Wj system. Photoproduction was identified or by lack of significant energy flow into one of very forward calorimeters, or by requesting a hit in one of the roman pot proton detectors. Very preliminary results suggest that even at very low, initial LHC luminosity the present limits on $\kappa_{\gamma ut}$ and $\kappa_{\gamma ct}$ could be significantly improved. In the near future, the analysis will include full detector simulation and more complete background considerations.

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Photoproduction and low-x

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In this talk, we discuss photoproduction of heavy quarks (charm and bottom) and vector mesons (ρ, ϕ, ω and J/Ψ), which are directly accessible at DESY-HERA and in coherent processes at RHIC and the LHC. In the latter case, the high center of mass energy and the large luminosities produces high event rates. The huge LHC energy will allow probing gluon distribution in nucleon and nuclei towards very low-x. In this region, saturation effects to the gluon distribution are expected to be increasing large. In order to compute the cross section we use the successful color dipole approach, which gives a good description of current accelerator data on photoproduction. The dipole formalism is suitable for the implementation of saturation effects, which are introduced in the modeling of the dipole-target cross section. In addition, we take into account the nuclear shadowing effects. They are computed within the Glauber-Gribov formalism for inelastic shadowing.

First, we consider the charm and bottom photoproduction, $\sigma(\gamma p \to Q\bar{Q}X)$, for DESY-HERA energy [1]. It is shown that the saturation models underestimate the experimental data at high energies and they provide a lower bound for the cross section. The total diffractive contribution is also calculated. In sequence, we compute the photonuclear cross section, $\sigma(\gamma A \to Q\bar{Q}X)$, for different nuclei and show that the strength of nuclear effects is still low for heavy quarks [2]. Those cross section are input in coherent reactions in pp, pA and AA collisions. In that case, the production cross section is obtained by the convolution of the photon flux in the ion (or proton) with the corresponding cross section for photoproduction. The rates are high and the experimental signal is feasible. For details on calculations and results, see Refs. [3]-[5]. In a second investigation, we consider the ρ and J/Ψ photoproduction, $\sigma(\gamma p \to V_M X)$, which is compared with DESY-HERA data [6]. Then, we make prediction for the photonuclear cross section, $\sigma(\gamma A \to V_M X)$, for different nuclei and energies to be accessible at LHC. The color dipole approach gives a unified framework to compute cross sections for both light and heavy mesons. Once again, the rates are large and the typical topology of the final states makes the signal clear [5]-[7]. In both cases, the total inclusive cross section is shown to be smaller than the usual collinear perturbative QCD calculations.

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Coulomb Corrections in the Lepton-Pair Production in Ultrarelativistic Nuclear Collisions

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The strong electromagnetic field of heavy ions can produce different kind of two-photon reactions at relativistic heavy ion colliders. Recently the STAR collaboration has presented [1] results on electron-positron pair productions on ultra-relativistic peripheral collisions. The authors compare the experimental data with QED and equivalent photon approximation (EPA).

We have calculated the electron-positron pair production cross section by using second-order Feynman diagrams. We have employed Monte Carlo methods and solved it exactly. We have generalized this calculation for all energies and charges of the heavy ions. This gives us a semi-analytic cross section and impact parameter dependence of cross-section expressions. Monte Carlo calculation gives an equation for the impact parameter dependence cross section valid for all impact parameters. In these impact parameter regions, the electromagnetic field is very high and a detailed study of this region is important for nonperturbative effects. We then compare our results with Born methods that include Coulomb corrections. The method loses applicability at impact parameters less than the Compton wavelength of the electron, which is the region of greatest interest for the study of nonperturbative effects. We present our results and argue that the Coulomb correction terms are not exact and these terms need to be improved. On the other hand, the authors of Ref. [2] made a small-momentum approximation and obtained an analytic expression. Although most of the integration comes from the small-momentum range, the lowest order in transverse momentum is not adequate to obtain accurate Coulomb corrections and higher orders should be also included. This was first noticed by Baltz [3], and in this work we were also convinced that the small-momentum approximation alone is not adequate to obtain correct Coulomb corrections.

Recent publications about peripheral relativistic heavy ion collisions [4]-[6] show that the impact parameter dependence cross sections of lepton-pair production are very important and detailed knowledge of impact parameter dependence cross sections particularly for small impact parameters can help to understand many physical events in STAR experiments.

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Photon-Photon and Photon-Nucleus Collisions in ALICE at the LHC

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ALICE is a general purpose heavy-ion experiment at the Large Hadron Collider (LHC) at CERN. Its primary aim is to study central nucleus-nucleus collisions (Pb+Pb) in order to investigate the properties of highly excited nuclear matter and the quark-gluon plasma [1]. This talk deals with electromagnetic (photon-induced) interactions in ultra-peripheral collisions in which there is no overlap between the colliding ions [2]. These events will have a very different topology compared with the central, hadronic interactions. They will therefore require different trigger and analysis techniques but will also broaden the physics potential of ALICE.

ALICE is designed to handle charged particle multiplicities up to $dn_{ch}/d\eta = 8000$, far above what is expected for ultra-peripheral collisions. Reconstructing the ultra-peripheral events should thus not be a problem. The major challenge will instead be triggering without a prohibitively high background rate. The Time-of-Flight and Si-pixel detectors can provide a low-multiplicity trigger at mid-rapidity. The foreseen ultra-peripheral trigger will combine the information from these detectors with a requirement of no signal in the V0 and T0 detectors. These are scintillator (V0) and Cherenkov counters (T0) located at forward rapidities on both sides of the collisions point with full azimuthal coverage for pseudo-rapidities $\approx 2 \leq |\eta| \leq 5$.

The expected rates for several interesting ultra-peripheral interactions within the ALICE acceptance are high. For coherent production of the heavy vector mesons J/Ψ and Υ, rates of 150,000 and 600, respectively, in the e^+e^- decay channel can be expected within one ALICE year (corresponding to 10^6 s). The rates for photoproduction of heavy-quarks and jets will also be high, and the yield from these processes within the ALICE acceptance should be significant.

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