Results on isolated photon, photon+jet and diphoton production in ATLAS (p-p, Pb-Pb collisions)

Photon 2015, BINP, Novosibirsk

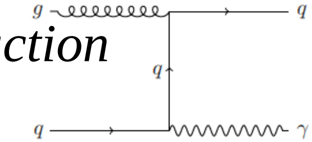
Marc Escalier, LAL

Isolated photons : a rich probe with various goals

Photons in pp environment

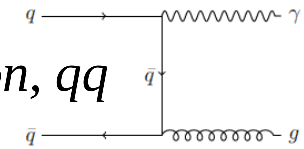
-sensitive to gluon content

Compton production (dominant)

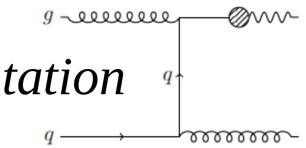


- test of perturbative QCD

annihilation, qq



fragmentation



-final state in search for resonance

γj

γ+MET

γγ+MET

γγ : XD

$H \rightarrow \gamma\gamma$

-generic gauss shape signal

-non-thermal Quantum Black Holes (QBH)

-excited quark ($q^* \rightarrow q\gamma$)

-LED (ADD), G+γ

-dark matter (WIMP χ), qqχχ + γ

-squarks + γ

$q \rightarrow q + \tilde{\chi}_1^0$

-GMSB : NLSP : case of lightest neutralino $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$

LSP : gravitino $\tilde{G} \rightarrow G\gamma$

-UED: production pair KK of quarks/gluons

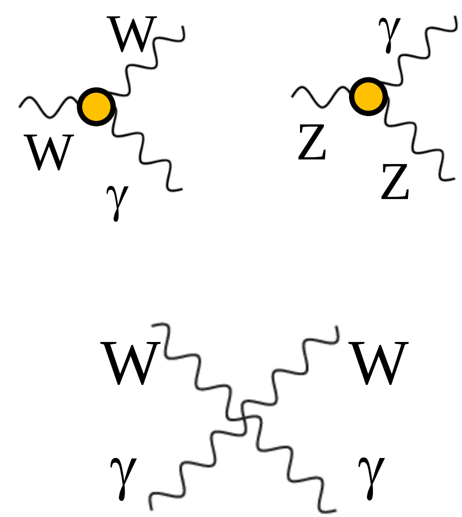
decay cascade until lightest KK particle :

KK photon $\gamma^* \rightarrow \gamma + G$

-RD : KK $G^* \rightarrow \gamma\gamma$

(dedicated talk by **Yohei Yamaguchi)**

-probe aTGC & aQGC



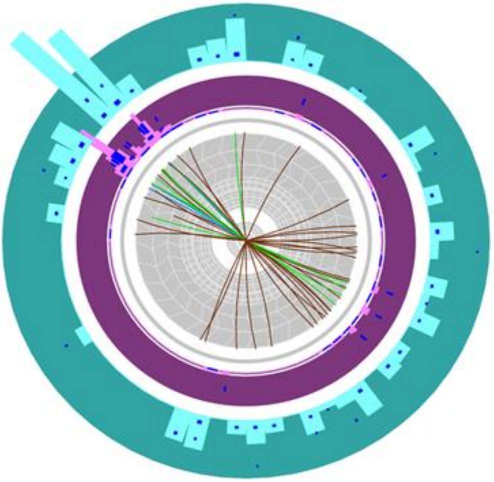
Photons in Pb Pb environment

photon…

- colorless : transparent to evolution of matter :

  → probe very initial state of collision
- sensitive to nuclear modifications (nPDFs)
- helps understanding jet quenching (di-jet asym) in hot/dense medium :

  proper energy calibration of initial (before quenching) jets



example of jet quenching, ATLAS : Phys. Rev. Lett. 105, 252303 (2010)

Struggling against background

Main background for photons object : photons from hadronic jets :
mostly light neutral mesons : π^0, η
'fake photons'

Main background for : -prompt photon production γj : jj
-$\gamma\gamma$ production : γj, jj

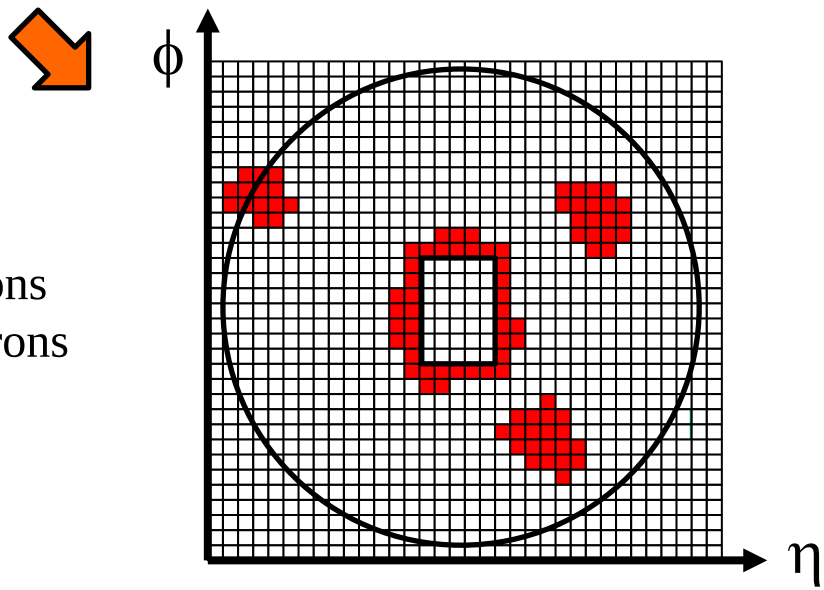
Struggling against fake photons, fakes leptons :

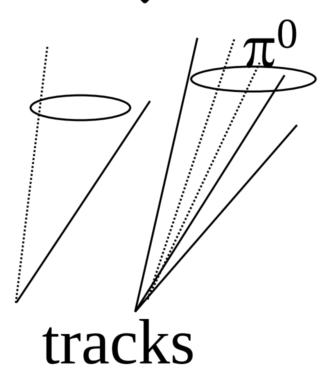
-shower-shape identification

-calorimeter isolation

-track isolation

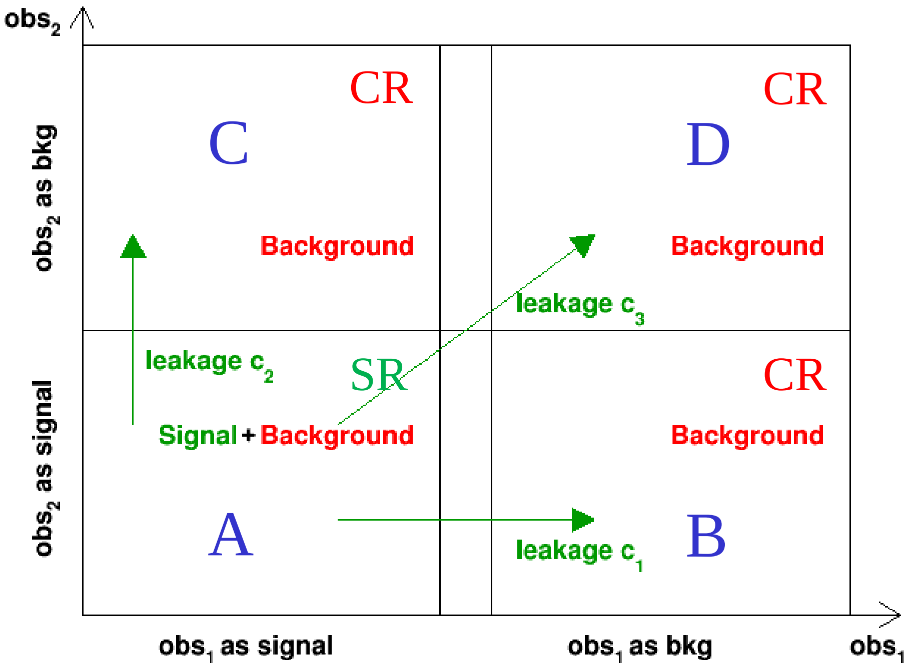
-photons
-electrons





Measuring bkg (X+j) wrt signal (X+γ)

1 Split phase space w/ two observables
-Signal Region (SR) : 'A' : contains signal+bkg
-Control Regions (CR's) : 'B', 'C', 'D' : dominated by bkg



Applicable to various processes :

Signal	vs	bkg	obs_1	obs_2
γj		jj	photon isol	; quality
γγ		γj, jj	photon isol	; quality
W(lν)γ		W(lν)j	photon isol	; quality
W(lν)γ		γj	lepton isol	; MET

2 Bkg in SR : deduced from CR's

ABCD method : $N_{bkg}^{A} = N^{B} \times \frac{N^{C}}{N^{D}}$

(purity : $N_{sig}^{A} / N_{obs}^{A}$)

3 consider signal leakage (c_i=O(5 %))

$$N_{bkg}^{A} = (N_B - c_1 N_{sig}^{A}) \frac{(N_C - c_2 N_{sig}^{A})}{(N_D - c_3 N_{sig}^{A})}$$

4 phase space properties C, D may slightly differ from A, B

→introduce : correction factor

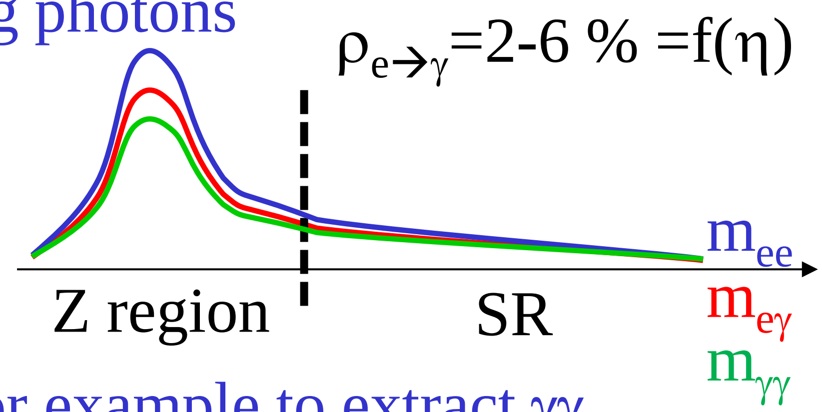
$$R = \frac{N_{bkg}^{A} \times N_{bkg}^{D}}{N_{bkg}^{B} \times N_{bkg}^{C}}$$

Measuring bkg (X+j) wrt signal (X+γ)

Some other methods to discriminate signal vs bkg, and evaluate bkg

- Calorimeter isolation template, in 2D
- Drell-Yan and sources w/ electrons faking photons

computes $\rho_{e\rightarrow\gamma}$ fake rate from $Z\rightarrow ee$ resonance
exploits ratio of $N_{e\gamma}$; N_{ee} from data
eg : evaluation of $N^{DY}_{\gamma\gamma}$ (SR) :
applies $\rho_{e\rightarrow\gamma}$ on N_{ee} in SR

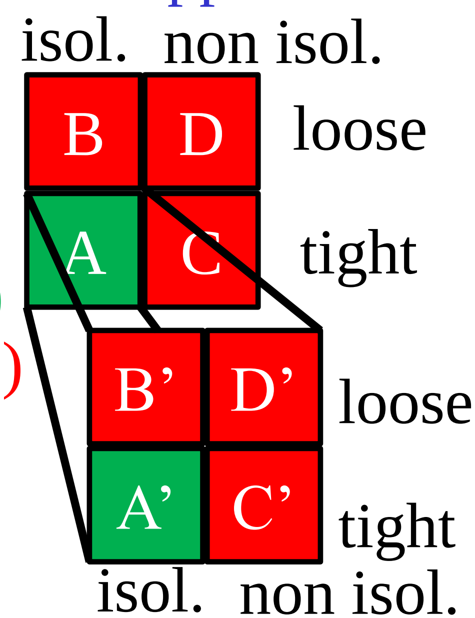


- ABCD method could be applied twice, for example to extract $\gamma\gamma$

leading γ candidate (highest p_T)

signal region : O(γ)
control region : O(j)

sub-leading γ



connection of each region with bkg processes : $\gamma\gamma$, γj, jj

$p\,p \rightarrow \gamma X$

$\sqrt{s}$=7 TeV ; L=4.6 fb^{-1}

- Selection

$100 \leq E_T^{\gamma} \leq 1000$ GeV, barrel : $|\eta|_{\gamma} < 1.37$; end-cap : $1.52 \leq |\eta|_{\gamma} < 2.37$

- Bkg estimation

-jets faking photons (dominant)

ABCD : calo isolation threshold : 7 GeV

-electrons faking photons (<0.5 %) estimated from Z region

- Integrated cross-section

barrel $\sigma(\gamma + X) = 236 \pm 2\ (\mathrm{stat})^{+13}_{-9}(\mathrm{syst}) \pm 4\ (\mathrm{lumi})\ \mathrm{pb}$

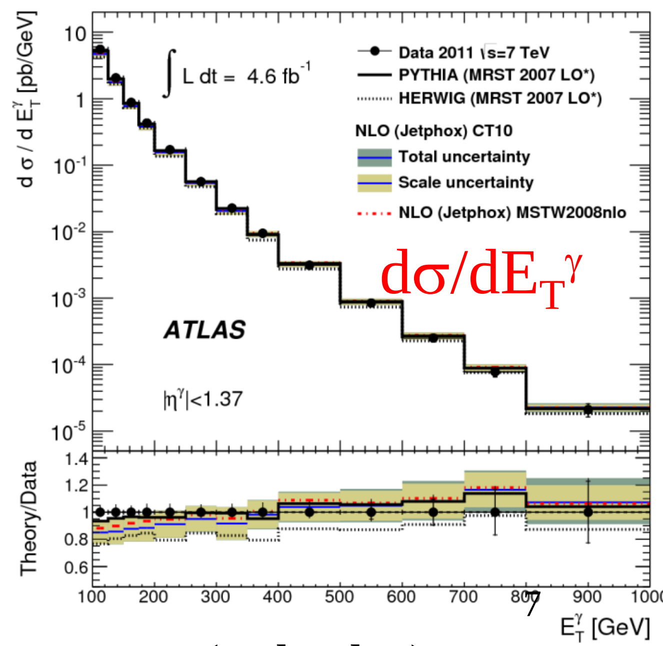
σ_{th}=203 ± 25 (th) pb (NLO : jetphox, CT10)

end-cap $\sigma(\gamma + X) = 123 \pm 1\ (\mathrm{stat})^{+9}_{-7}(\mathrm{syst}) \pm 2\ (\mathrm{lumi})\ \mathrm{pb},$

σ_{th}=105 ± 15 (th) pb (NLO : jetphox, CT10)

Good agreement w/ NLO QCD calculation

- Differential cross-section

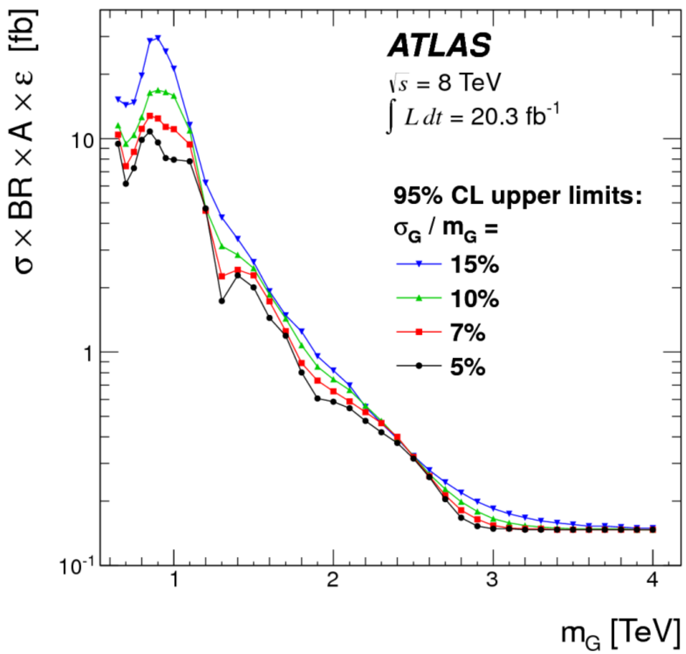


(+ $d\sigma/d\eta^{\gamma}$)

resonances w/ γ+j

- 95 % CL limits

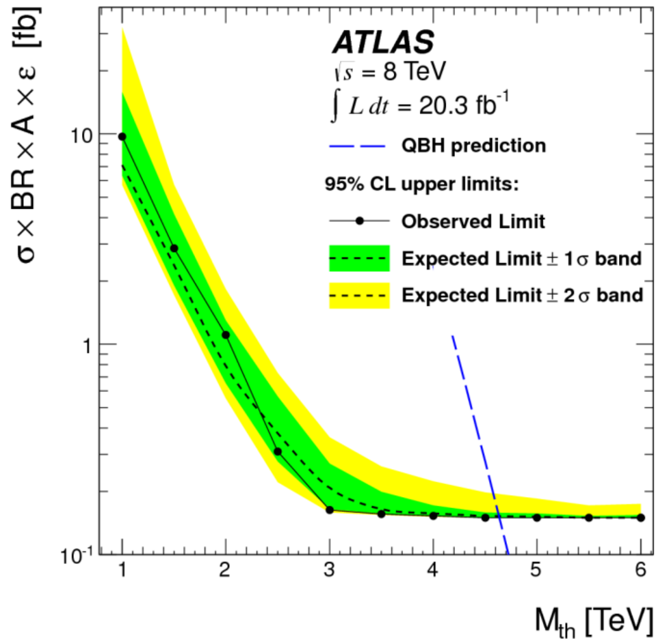
-generic gauss shape signal



excluded 4 TeV
resonance w/ σ_{eff}=0.1 fb

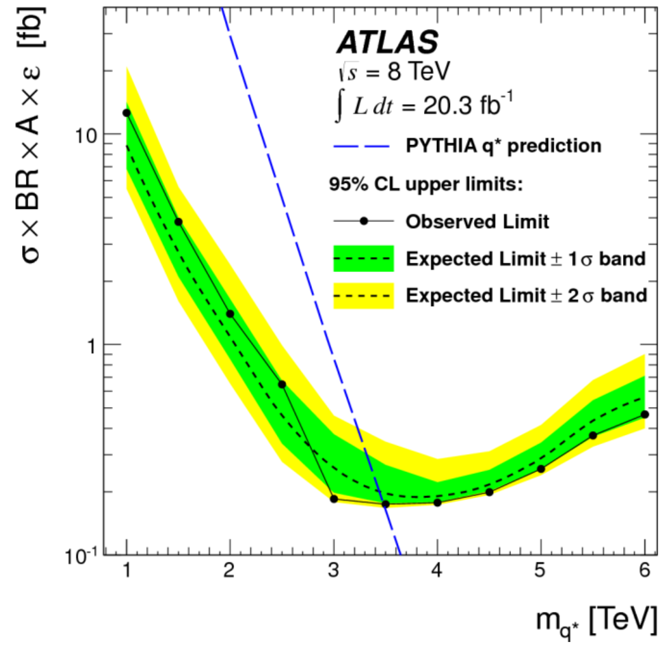
(σ_{eff}=σ x BR x A x ε)

-QBH



excluded up to 4.6 TeV

-excited quark q^*



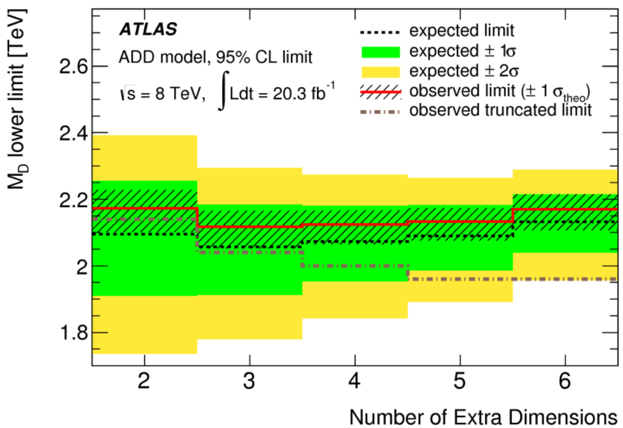
excluded up to 3.5 TeV

γ+MET : BSM
$\sqrt{s}$=8 TeV ; L=20.3 fb^{-1}

- 95 % CL limits

σ_{fid} (γ+MET)=5.3 fb

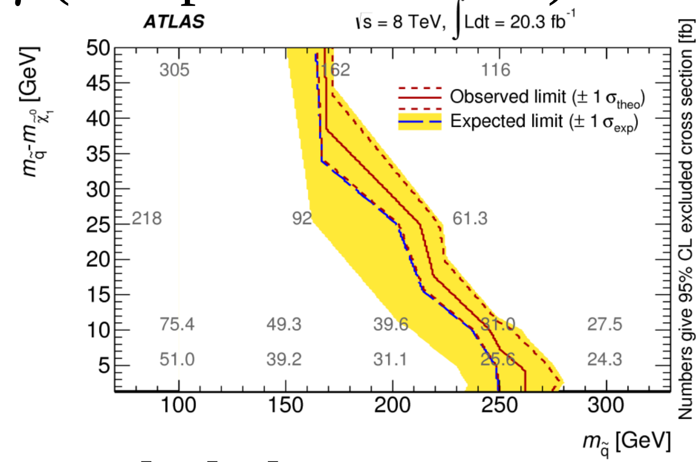
-LED : G+γ



exclude m_D=2.17 TeV

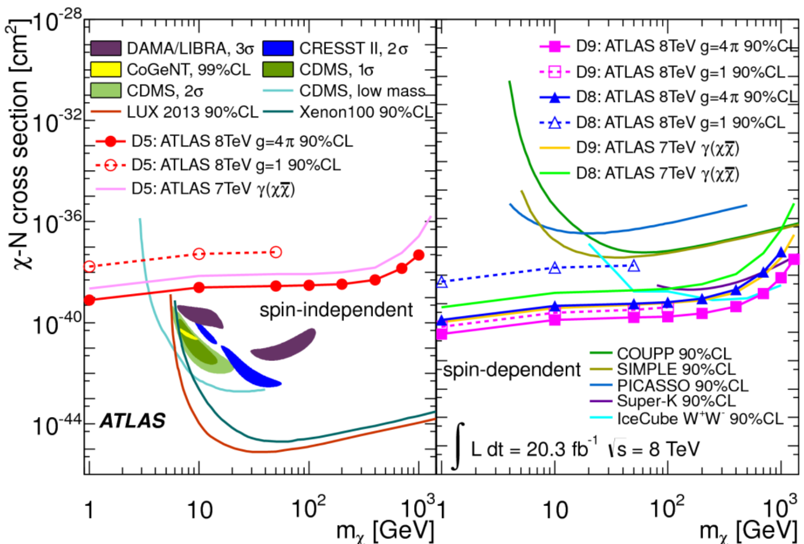
-squarks + γ (compressed model)

$\tilde{q} \rightarrow q+\chi_1^0$



excluded up to 250 GeV

-Dark matter



EFT operators for WIMP :
D5 (V), D8 (A), D9 (T)

pp$\rightarrow \tilde{q}\tilde{q}^*\gamma$+X
extends results to m_χ<10 GeV

$p\,p \rightarrow \gamma\gamma$

$\sqrt{s}$=7 TeV ; L=4.9 fb^{-1}

- Selection

$E_{T\gamma}^{L,\,S}$>25 GeV ; 22 GeV

$|\eta|_{\gamma}$<1.37 ; 1.52≤$|\eta|_{\gamma}$<2.37

- Bkg estimation :

-2D template likelihood fit : calorimeter isolation

-2 ABCD sidebands

- Integrated cross-section (σ_{integ})

Measured : $=44.0^{+3.2}_{-4.2}$ pb

Predicted : 44^{+6}_{-5} pb

2γNNLO : NNLO QCD direct part γγ, no fragmentation

(some lower order tested also)

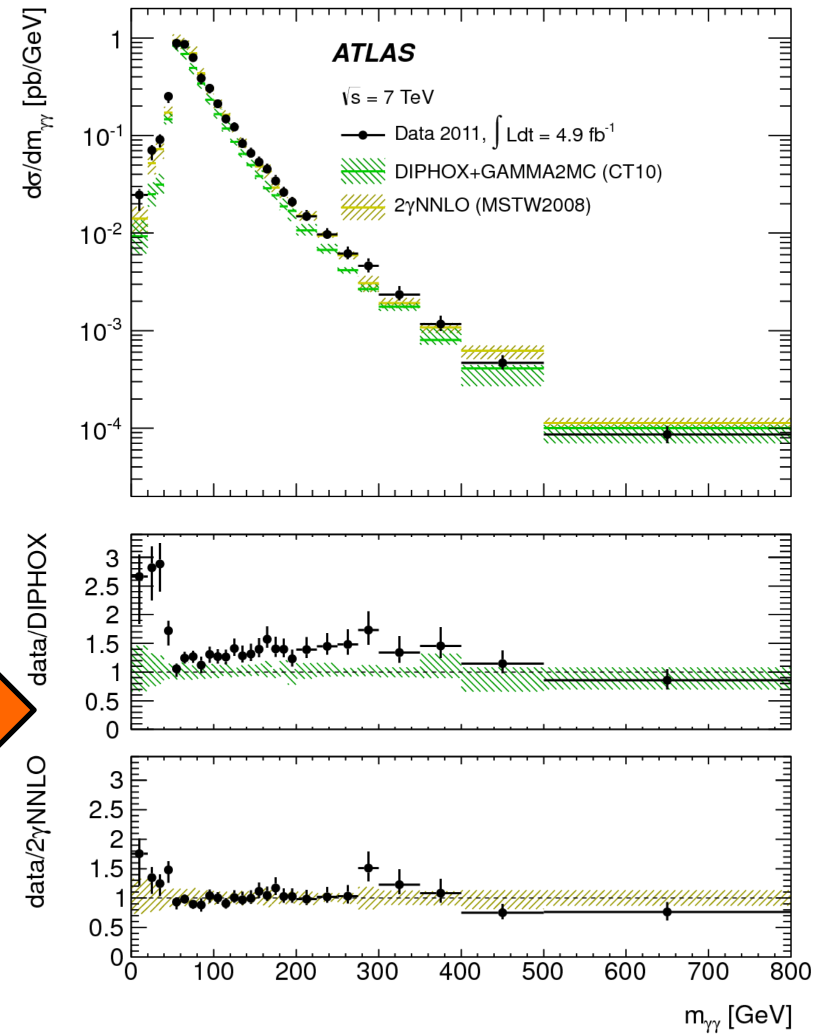
- Differential cross-section

$m_{\gamma\gamma}$: resonance search

$p_{T\gamma\gamma}$: probe HO QCD pertub. effects, fragm.

$\Delta\phi_{\gamma\gamma}$, : probe specific regions of phase space

$\cos\theta^{*}_{\gamma\gamma}(\gamma)$: probe spin of diphotons resonance



excellent agreement data/prediction

$\gamma\gamma$: XD

- Randall-Sundrum model

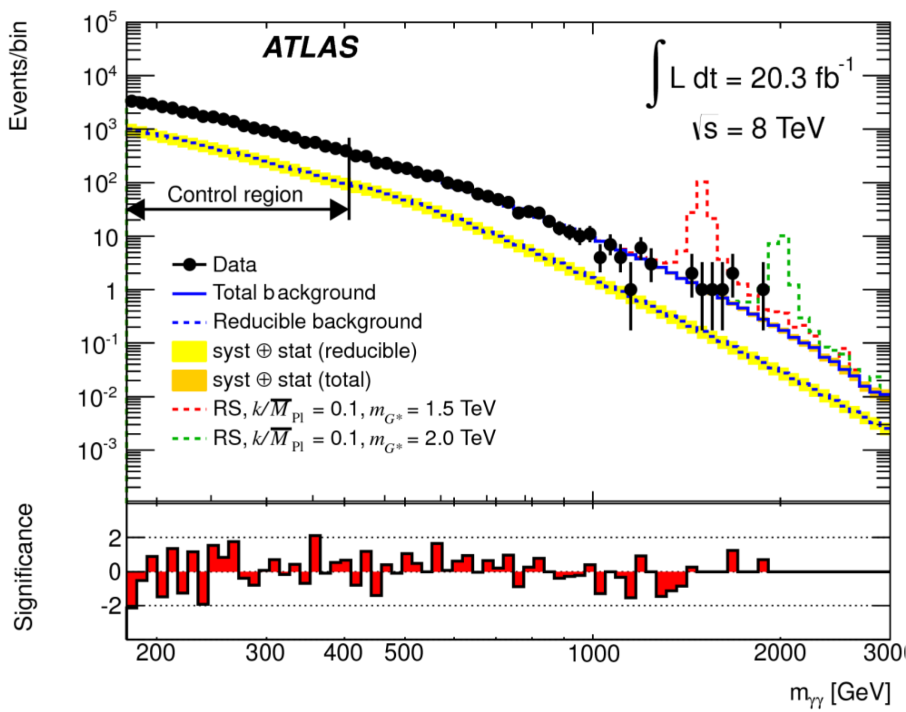
Compactification of XD→KK graviton excitation G^*

Phenomenology=f(m_{G^*} ; dimensionless coupling to SM : for $k/\overline{M}_{Pl}$=0.1

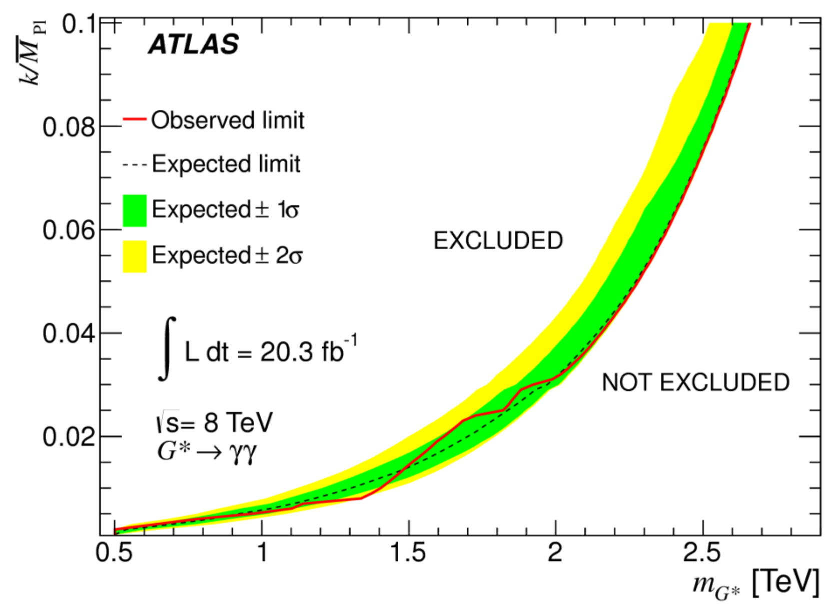
($\overline{M}_{Pl}=M_{Pl}/\sqrt{(8\pi)}$)

- Selection

photons : E_T>50 GeV, isolated (calo isol<8 GeV)



- 95 % CL limits



lightest graviton m_G>2.66 TeV for $k/\overline{M}_{Pl}$=0.1

$\gamma\gamma$ + MET

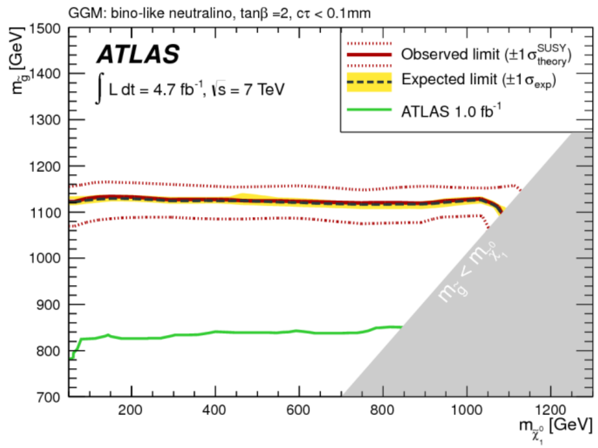
$\sqrt{s}$=7 TeV ; L=4.8 fb^{-1}

- Selection

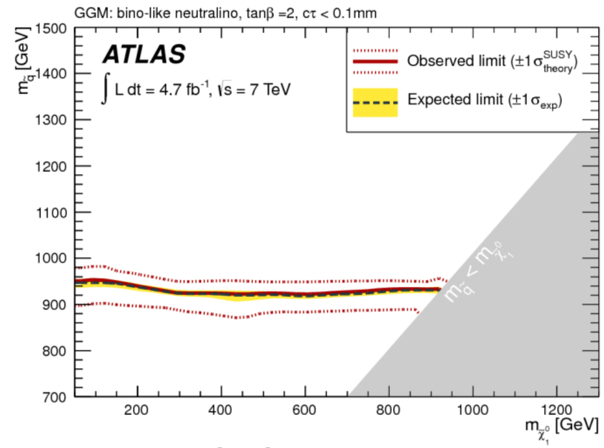
≥2 photons, p_T>50 GeV

- 95 % CL limits

-GMSB

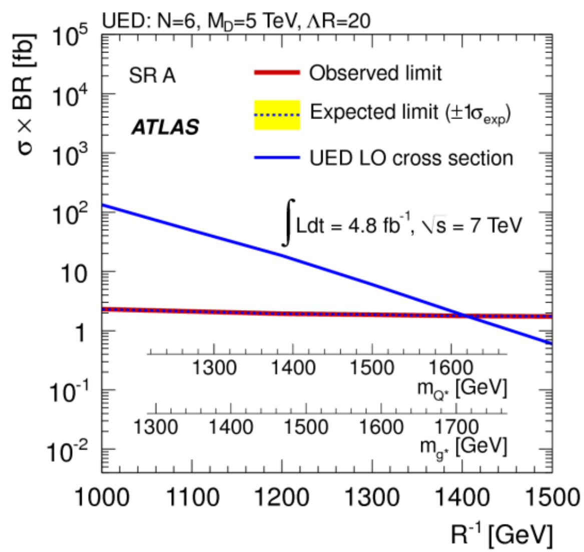


$m_{\tilde{g}}$>1.07 TeV



$m_{\tilde{q}}$>0.87 TeV

-UED 1-D : 1/R>1.40 TeV



(W/Z)γ $\sqrt{s}$=7 TeV

$\sqrt{s}$=7 TeV ; L=4.6 fb^{-1}

- final states : W(lν)γ, Z(ll)γ, Z(νν)γ
- Data driven estimation of bkg
- Fiducial cross-section

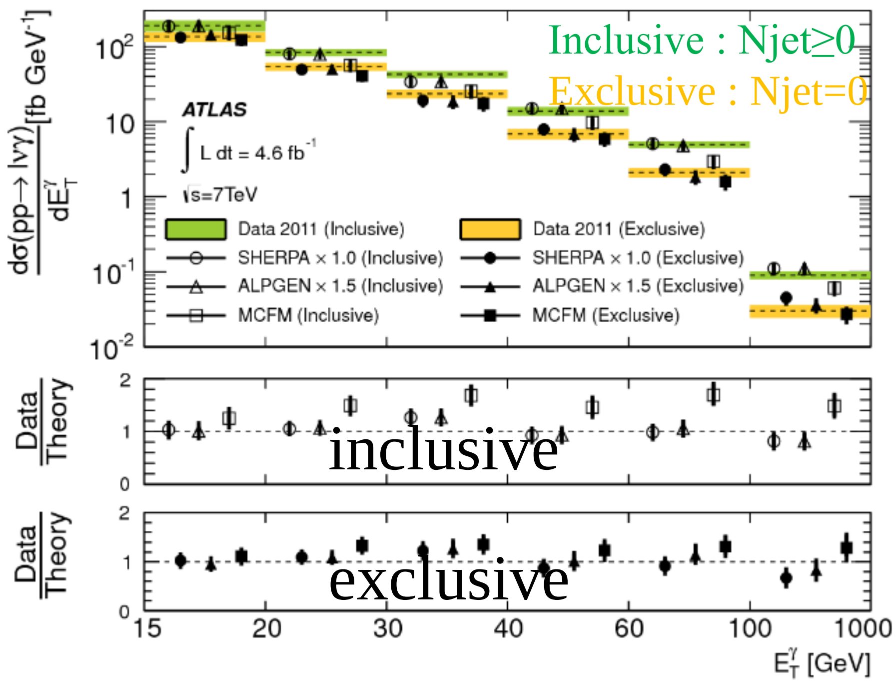
	$\sigma^{ext-fid}$[pb] Measurement	$\sigma^{ext-fid}$[pb] MCFM Prediction
	$N_{jet} \geq 0$	
$e\nu\gamma$	2.74 ± 0.05 (stat) ± 0.32 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$\mu\nu\gamma$	2.80 ± 0.05 (stat) ± 0.37 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$\ell\nu\gamma$	2.77 ± 0.03 (stat) ± 0.33 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$e^+e^-\gamma$	1.30 ± 0.03 (stat) ± 0.13 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\mu^+\mu^-\gamma$	1.32 ± 0.03 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\ell^+\ell^-\gamma$	1.31 ± 0.02 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\nu\bar{\nu}\gamma$	0.133 ± 0.013 (stat) ± 0.020 (syst) ± 0.005 (lumi)	0.156 ± 0.012
	$N_{jet} = 0$	
$e\nu\gamma$	1.77 ± 0.04 (stat) ± 0.24 (syst) ± 0.08 (lumi)	1.39 ± 0.13
$\mu\nu\gamma$	1.74 ± 0.04 (stat) ± 0.22 (syst) ± 0.08 (lumi)	1.39 ± 0.13
$\ell\nu\gamma$	1.76 ± 0.03 (stat) ± 0.21 (syst) ± 0.08 (lumi)	1.39 ± 0.13
$e^+e^-\gamma$	1.07 ± 0.03 (stat) ± 0.12 (syst) ± 0.04 (lumi)	1.06 ± 0.05
$\mu^+\mu^-\gamma$	1.04 ± 0.03 (stat) ± 0.10 (syst) ± 0.04 (lumi)	1.06 ± 0.05
$\ell^+\ell^-\gamma$	1.05 ± 0.02 (stat) ± 0.10 (syst) ± 0.04 (lumi)	1.06 ± 0.05
$\nu\bar{\nu}\gamma$	0.116 ± 0.010 (stat) ± 0.013 (syst) ± 0.004 (lumi)	0.115 ± 0.009

Measurement : ≈2 σ higher wrt NLO

→NNLO solves agreement

(arXiv:1504.01330)

eg : W(lν)γ f=(E_T^γ)



- Differential cross-sections

Few disagreement for W(lν)γ at high E_T^γ

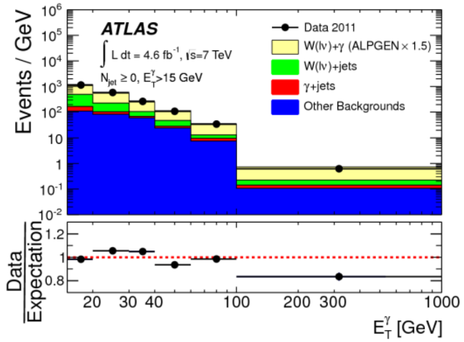
NNLO solves disagreement

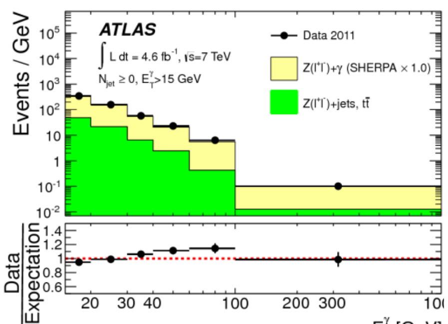
$(W/Z)\gamma$ $\sqrt{s}$=7 TeV

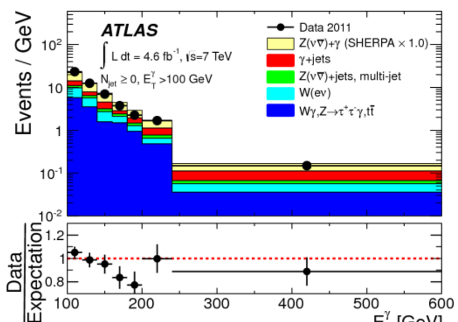
$\sqrt{s}$=7 TeV ; L=4.6 fb^{-1}

anomalous TGC enhance Vγ production w/ high E_T photon (E_T^{γ}>100 GeV)

- Limits on aTGC parameters (CP-conserving Lagrangian considered)







Charged coupling ($\Delta\kappa_\gamma=\kappa_\gamma-1$) — WW$\gamma$

Neutral coupling — ZZγ

		Measured	Expected
processes		$pp \to \ell\nu\gamma$	
Charged coupling	Λ	∞	∞
	$\Delta\kappa_\gamma$	$(-0.41, 0.46)$	$(-0.38, 0.43)$
	λ_γ	$(-0.065, 0.061)$	$(-0.060, 0.056)$
	Λ	6 TeV	6 TeV
	$\Delta\kappa_\gamma$	$(-0.41, 0.47)$	$(-0.38, 0.43)$
	λ_γ	$(-0.068, 0.063)$	$(-0.063, 0.059)$
processes		$pp \to \nu\nu\gamma$ and $pp \to \ell^+\ell^-\gamma$	
Neutral coupling	Λ	∞	∞
	h_3^γ	$(-0.015, 0.016)$	$(-0.017, 0.018)$
	h_3^Z	$(-0.013, 0.014)$	$(-0.015, 0.016)$
	h_4^γ	$(-0.000094, 0.000092)$	$(-0.00010, 0.00010)$
	h_4^Z	$(-0.000087, 0.000087)$	$(-0.000097, 0.000097)$
	Λ	3 TeV	3 TeV
	h_3^γ	$(-0.023, 0.024)$	$(-0.027, 0.028)$
	h_3^Z	$(-0.018, 0.020)$	$(-0.022, 0.024)$
	h_4^γ	$(-0.00037, 0.00036)$	$(-0.00043, 0.00042)$
	h_4^Z	$(-0.00031, 0.00031)$	$(-0.00037, 0.00036)$

- No evidence for BSM physics

see also talk by Ulrike Schnoor

- Search for narrow resonances (example : Technicolor) : spin-1 mesons

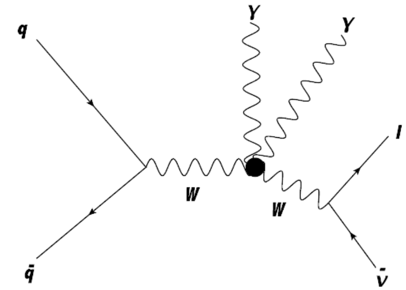
'techni-mesons' : decaying to Wγ, Zγ, using $\sqrt{s}$=8 TeV ; L=20.3 fb^{-1}

$a_T \to W\gamma$: exclude [275 ; 960] GeV $\omega_T \to Z\gamma$: exclude [200 ; 700] U [750 ; 890] GeV

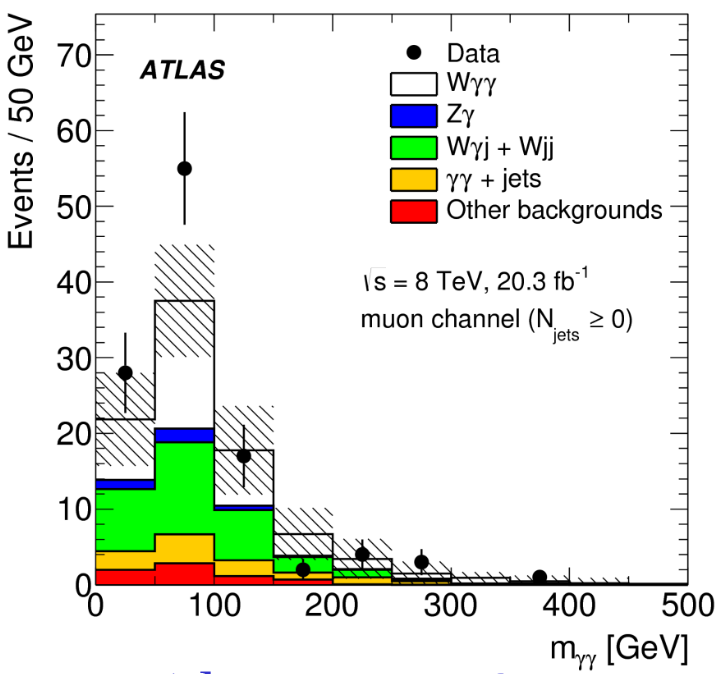
Wγγ evidence, limits aQGC $\sqrt{s}$=8 TeV ; L=20.3 fb^{-1}

- inclusive selection ($N_{jet} \geq 0$)
- Bkg : data-driven estimation

Dominant bkg : jets faking photon or lepton



- Likelihood fit



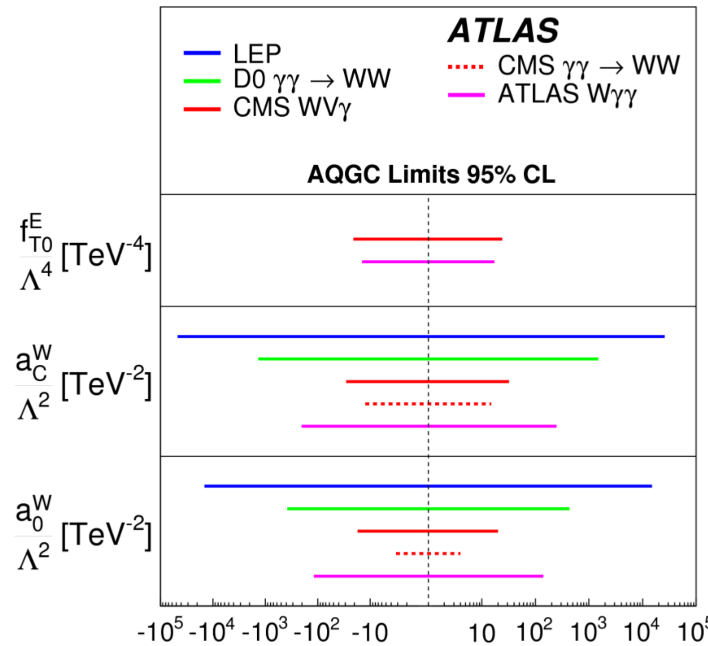
Wγγ evidence ; $p_0 > 3\ \sigma$

measurement : 2 σ higher than NLO

(similar to Wγ : NNLO would help)

σ=f(aQGC parameters)

- aQGC limits {N_{jet}=0 ; $m_{\gamma\gamma}$>300 GeV}



Λ : scale NP

f : coupling operator

better or similar to LEP and D0

Pb Pb

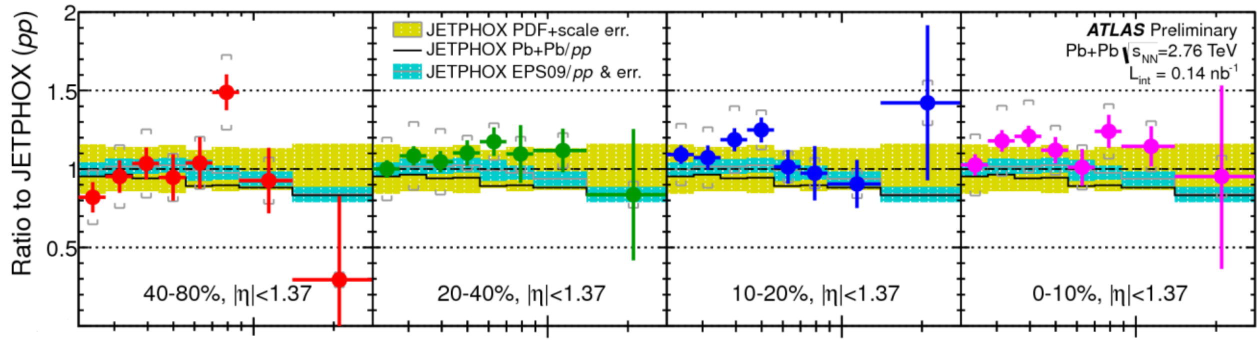
$\sqrt{s}$=2.76 TeV, L=0.14 nb^{-1}

- Estimation of signal ; bkg : 2-ABCD method
- Shower shape tight quality in Pb-Pb environment : small changes wrt pp's
- Isolation : energy deposit around cluster R=0.3

  Isolated : < 6 GeV   Non Isolated : >8 GeV
- Purity : 50 % (low p_T) - 90 % (high p_T)

Total uncertainties : 10-38 %

- yields γ+X



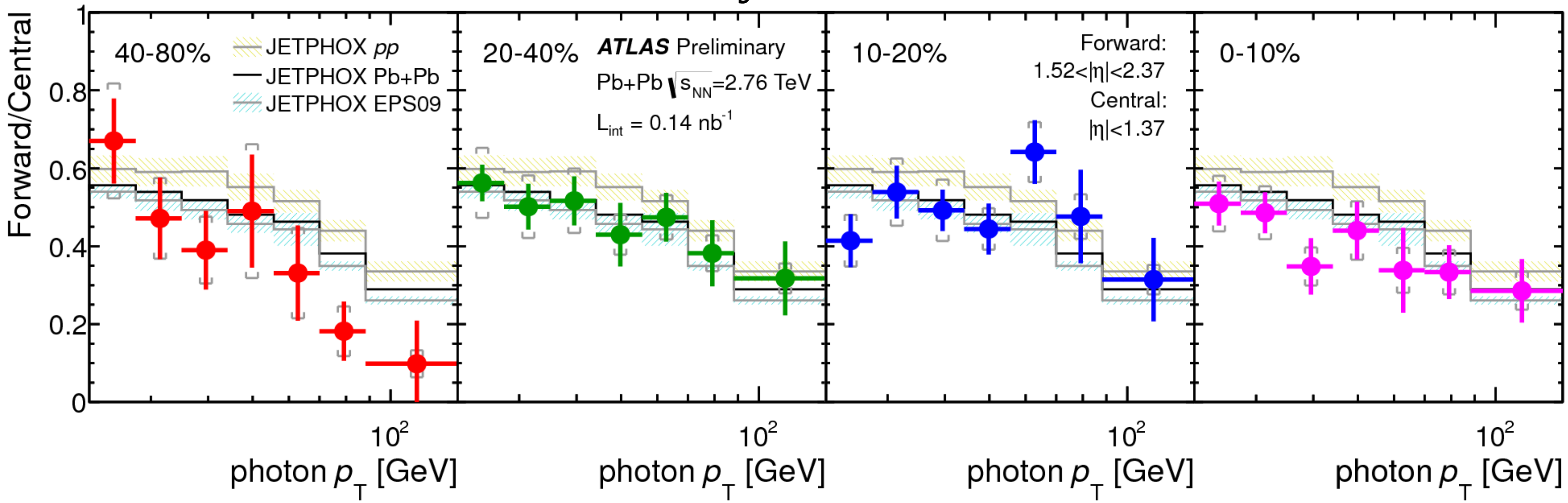
compared w/ Jetphox
w/ various Pdfs :
pp ; Pb Pb, nPDF EPS09
('isospin')   (nuclear modifications to proton)

f(centrality)   (done also for end-cap)

Results

$\sqrt{s}$=2.76 TeV, L=0.14 nb^{-1}

- ratio Fwd/Central : reduces systematics effects



data unable to distinguish btw scenarios ; slight preference for isospin effects

Conclusion

p p

- Single photon
  - Measured int., diff. cross-section
  - Good agreement w/ prediction
  - prospective on parton density functions
- Diphotons
  - Measured int., diff. cross-section
  - Good agreement w/ prediction
- $(W/Z)\gamma$
  - Measured int., diff. cross-section
  - Good agreement w/ prediction
  - Limits on anomalous TGC
  - search narrow resonances
  - no evidence for BSM physics
- $W\gamma\gamma$
  - Evidence for this process
  - Good agreement w/ prediction
  - Limits on aQGC in high $m_{\gamma\gamma}$

measured σ : some tensions w/ NLO computation

NNLO helps

Pb Pb : photon production

f(Centrality, pseudo-rapidity, pT)

Good agreement w/ prediction

Appendix

References

p p

- γ+X : production

$\sqrt{s}$=7 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-16/
Phys. Rev. D 89, 052004 (2014)
http://arxiv.org/abs/1311.1440

- γ+X : constraint proton pdf w/ γ+X production

$\sqrt{s}$=7 TeV

http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2013-018/
ATL-PHYS-PUB-2013-018

- γ+j : resonances (generic gauss signal, QBH, q^*)

$\sqrt{s}$=7 TeV

http://arxiv.org/abs/1112.3580
PRL 108, 211802 (2012)
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2011-04/

$\sqrt{s}$=8 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2012-22/
Phys. Lett. B 728C (2014) 562-578
http://arxiv.org/abs/1309.3230

- γ+MET : LED, squarks, DM

$\sqrt{s}$=7 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2014-06/
Phys. Rev. Lett 110, 011802 (2013)
http://arxiv.org/abs/1209.4625

$\sqrt{s}$=8 TeV

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2014-06/
Phys. Rev. D 91, 012008 (2015)
http://arxiv.org/abs/1411.1559

References

p p

- $\gamma\gamma$: production

  $\sqrt{s}$=7 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-05/

  JHEP01(2013)086 http://arxiv.org/abs/1211.1913

- $\gamma\gamma$: XD

  $\sqrt{s}$=7 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2012-06/

  new J. Phys. 15 (2013) 043007 http://arxiv.org/abs/1210.8389

  $\sqrt{s}$=8 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2012-19/

  submitted to Phys. Rev. D http://arxiv.org/abs/1504.05511

- $\gamma\gamma$ +MET

  $\sqrt{s}$=7 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2011-24/

  Phys. Lett. B 718 (2012) 411-430 http://arxiv.org/abs/1209.0753

- $W\gamma$, $Z\gamma$ production, anomalous TGC, narrow resonances

  $\sqrt{s}$=7 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2012-07/

  Phys. Rev. D 87, 112003 (2013) http://arxiv.org/abs/1302.1283

  $\sqrt{s}$=8 TeV

  narrow resonances

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-09/

  PLB 738 (2014) 428-447 http://arxiv.org/abs/1407.8150

- $W\gamma\gamma$ production

  $\sqrt{s}$=8 TeV

  https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-05/

  sub. to PRL http://arxiv.org/abs/1503.03243

  th. explanations : http://feynrules.irmp.ucl.ac.be/wiki/AnomalousGaugeCoupling

References

- Pb Pb

γ+X production

2011 data

First results :
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-051/
Jet-photon correlations :
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-121/
Last results :
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2014-026/