HARD PROBES IN PB-PB COLLISIONS AT ATLAS

Iwona Grabowska-Bold (AGH UST, Kraków)
On behalf of ATLAS Collaboration

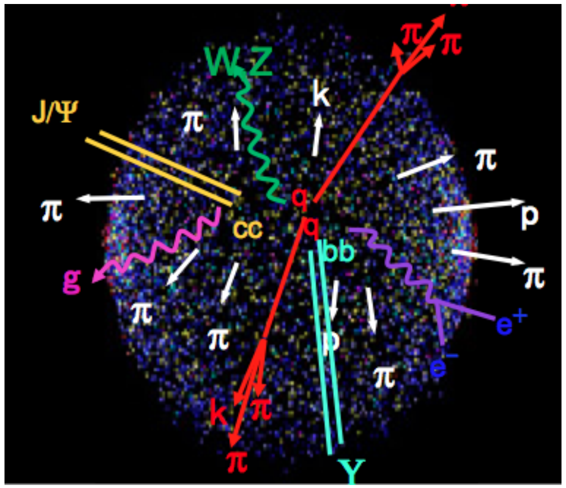
XLVII Rencontres de Moriond, QCD and High Energy Interactions
March 10-17th, 2012

Heavy Ions at the LHC

- Two runs in 2010-11 with lead-lead data from the LHC collected on tape,
  - Excellent performance of the LHC machine,
  - Excellent performance of the detectors,
- Huge energy jump from RHIC
  - factor of 14 in the center-of-mass energy!

	SPS		RHIC		LHC
	PbPb	→	AuAu	→	PbPb
$\sqrt{s_{NN}}$	17.3 GeV		200 GeV		2760 GeV

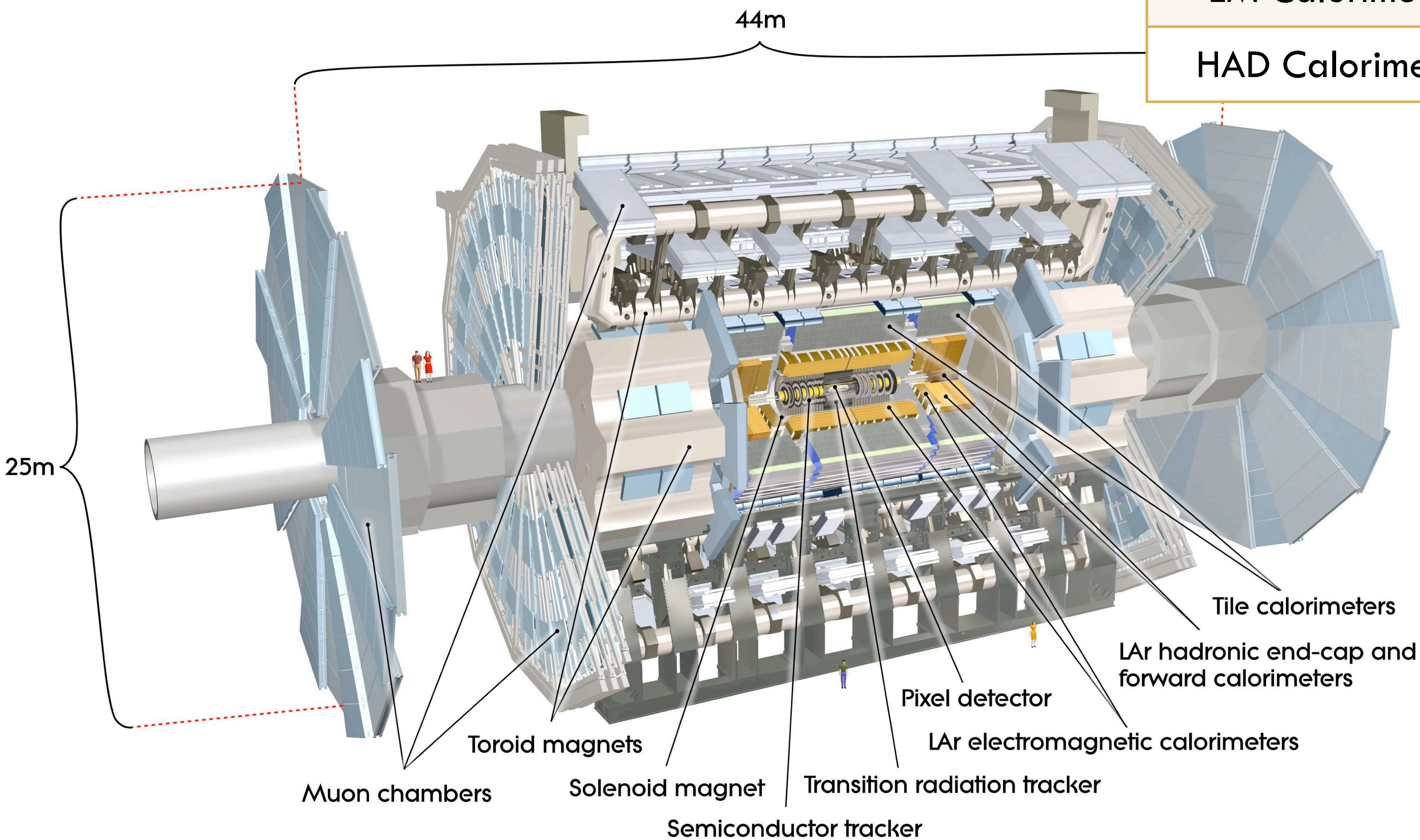
- Highest temperatures ever achieved in the laboratory,
- Access to new probes and processes,
- In this talk we discuss:
  - Di-jets and inclusive jets
  - Charged-particle spectra
  - Di-muon production: J/ψ and Z
  - W production.



ATLAS Detector

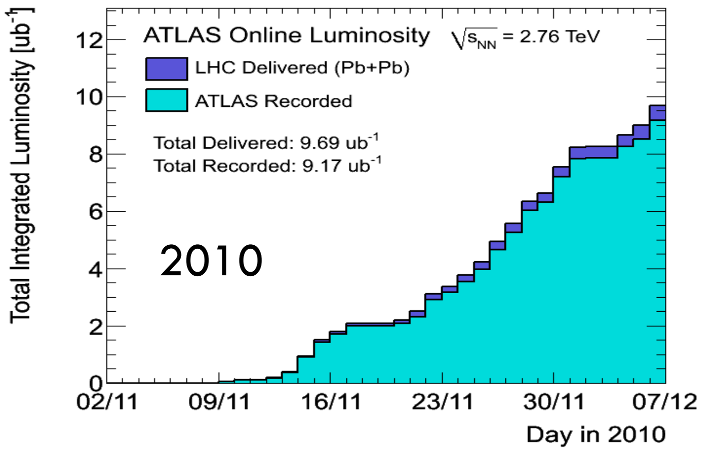
Three main components: Inner tracker, electromagnetic (EM) and hadronic (HAD) calorimeters, and muon system

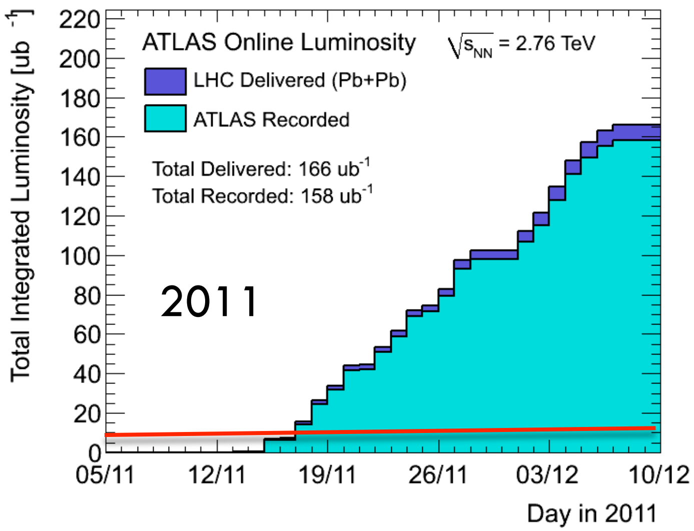
Measurements	η coverage
Inner Tracker	(-2.5, 2.5)
Muon Spectrometer	(-2.7, 2.7)
EM Calorimeter	(-3.2, 3.2)
HAD Calorimeter	(-4.9, 4.9)



Full azimuthal acceptance

Heavy-Ion Runs in 2010-11





Heavy-ion runs at $\sqrt{s_{NN}} = 2.76 TeV$

- Nov 4th-Dec 6th, 2010 and Nov 12th-Dec 7th, 2011
- In 2010 ATLAS recorded 9.2 μb^{-1} of PbPb data,
  - With 1 μb^{-1} magnetic field-off data,
  - Minimum bias triggers only,
  - Physics results based on this data set will be shown,
- In 2011 ATLAS recorded 158 μb^{-1} of PbPb data,
  - Various High Level Triggers used,
- Data recording efficiency > 95%,
- Fraction of data passing data-quality criteria > 99% .

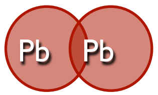
Inner Tracking Detectors			Calorimeters				Muon Detectors			
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.7	100	100	99.2	100	100	100	100	99.6	100	100

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV between November 8th and 17th (in %).

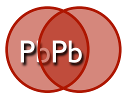
Centrality

Characterize centrality by percentiles of the total cross-section using forward calorimeter (FCal) ΣE_T $(3.2 < |\eta| < 4.9)$

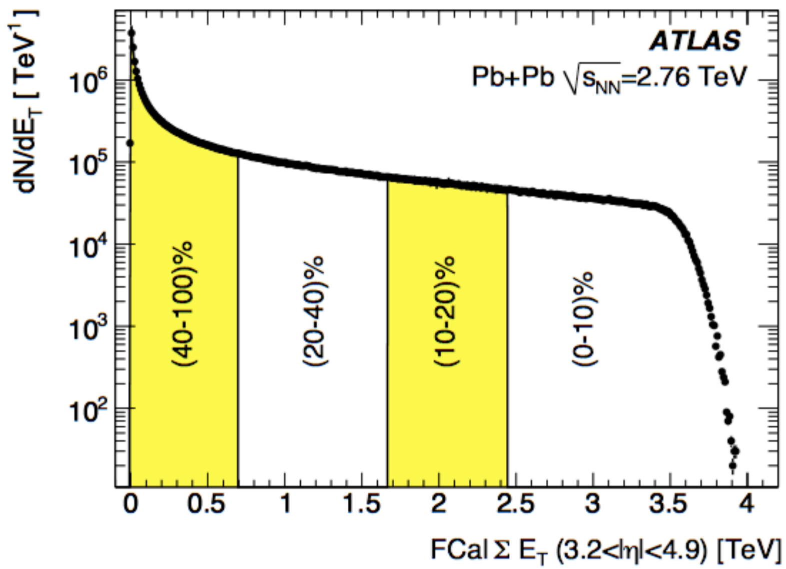
Peripheral collisions

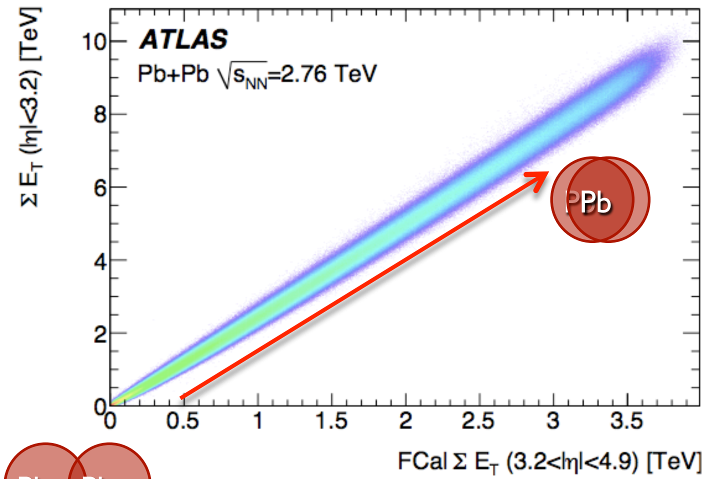


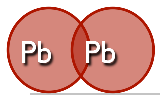
Mid-central collisions

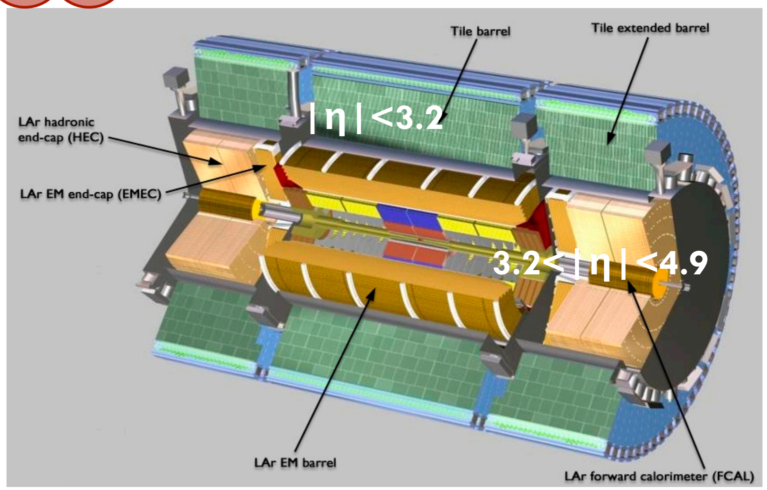


Central collisions

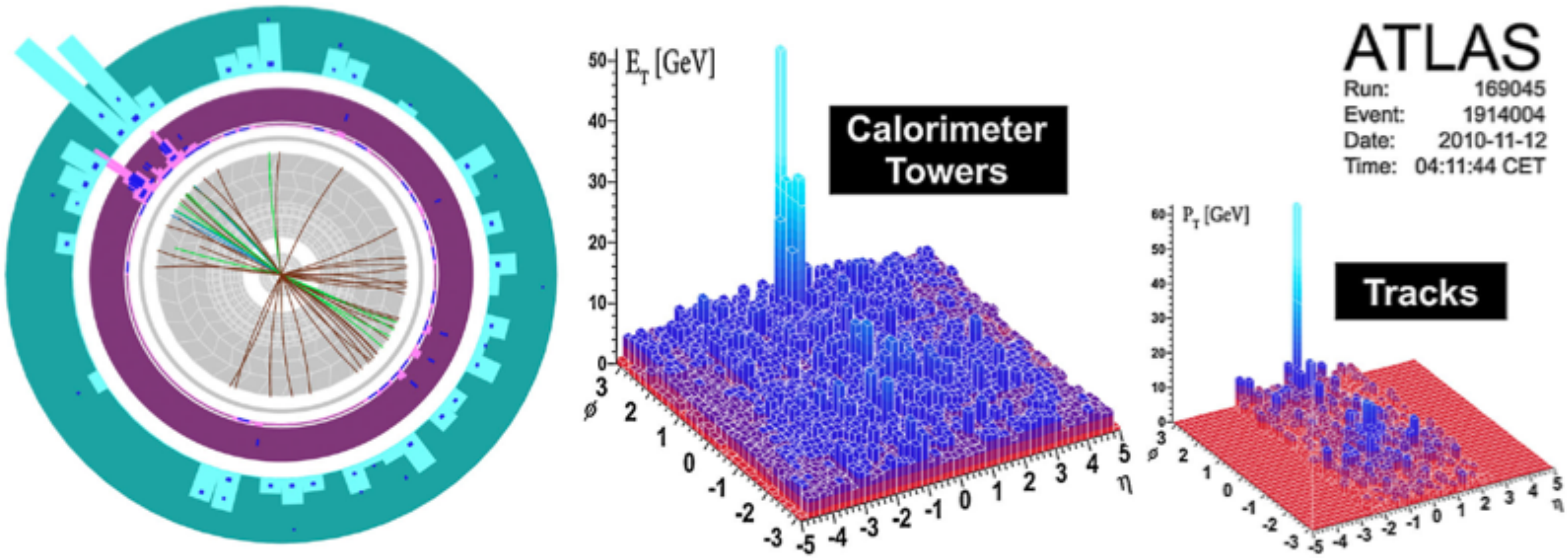








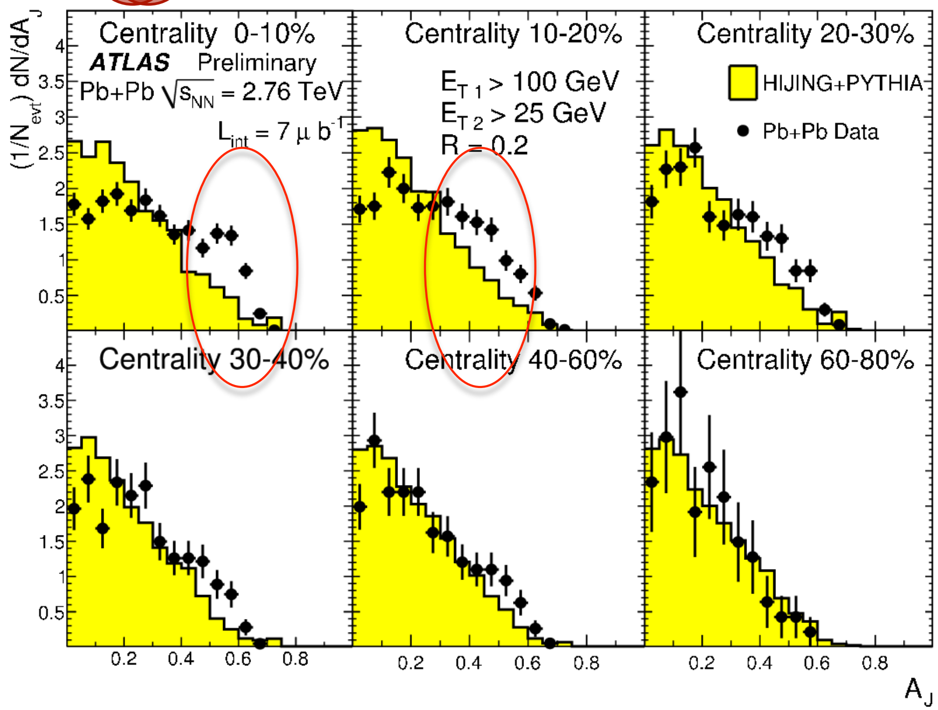
Jets in ATLAS



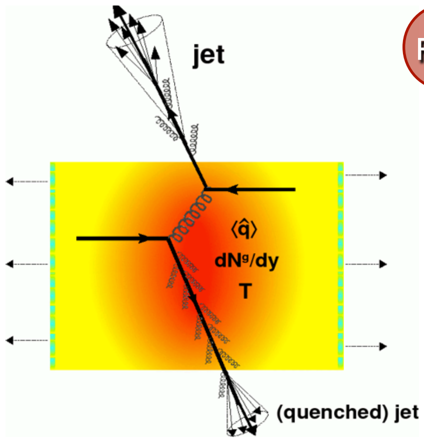
Di-jet asymmetry

First ATLAS result based on 2010 data:
Phys. Rev. Lett. 105, 252303

- Anti-k_T jet reconstruction with two jet sizes 0.2 and 0.4,
  - calibrated using energy density cell weighting,
  - underlying event (UE) estimated and subtracted for each longitudinal layer and for 100 slices of $\Delta\eta = 0.1$,
- Di-jet asymmetry A_j measured for back-to-back jets,
- A_j broadens with centrality, the mean shifts to higher values and excess of events with large asymmetries at higher centralities for both jet sizes (0.2 and 0.4),
- The $\Delta\phi$ distribution predominantly is still back-to-back at higher centrality values,
- Caveat: A_j is less sensitive to events where each jet in a di-jet pair loses a comparable amount of energy.



$$A_j = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$

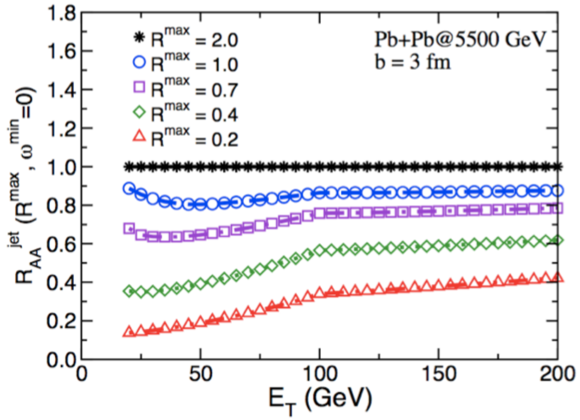


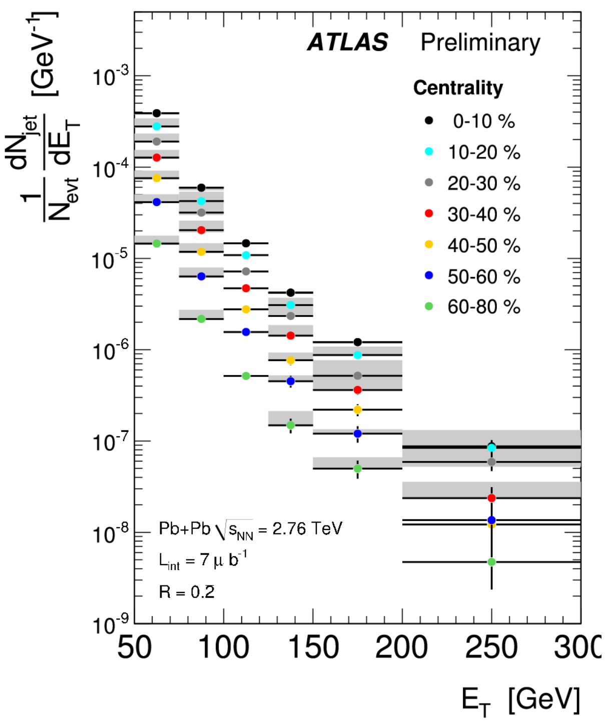
R_{cp} for jets

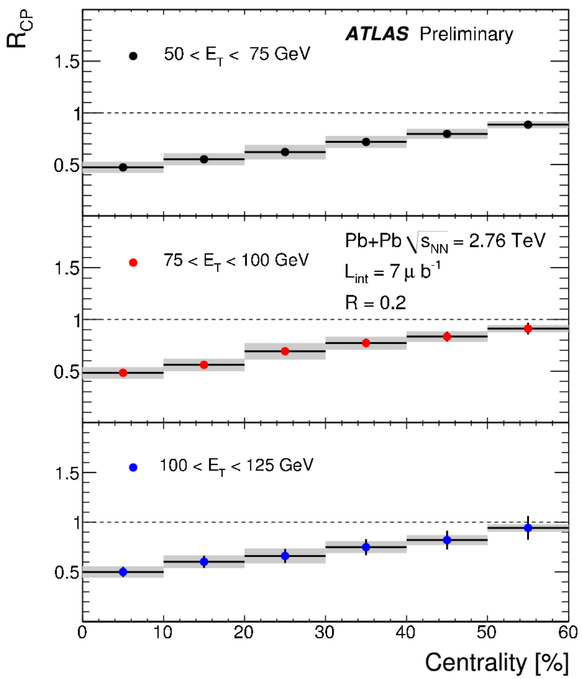
More in: ATLAS-CONF-2011-075

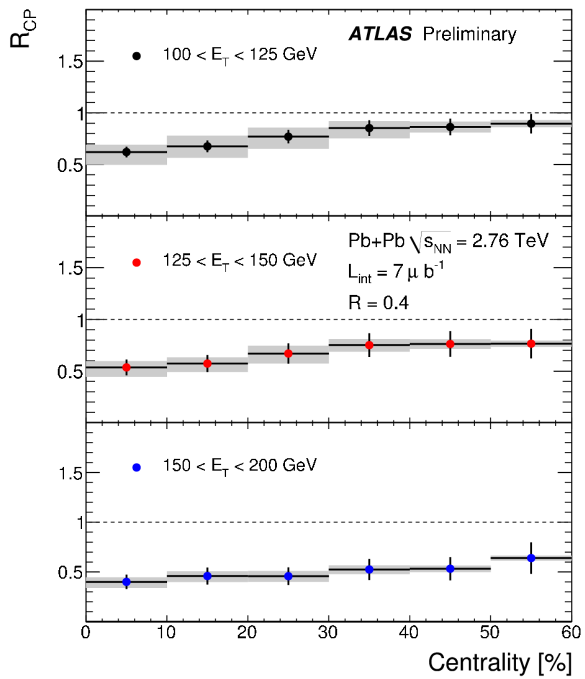
- Observable which is sensitive to the "inclusive" jet quenching in the spectrum of single jets,
- Prediction of the impact of medium-induced radiative energy loss on the jet yield due to the radiation falling outside the reconstructed jet cone,
- ATLAS data inconsistent with this expectation
  - R_{cp} similar for two jet sizes 0.2 and 0.4.

Prediction by Vitev, Zhang, Wicks





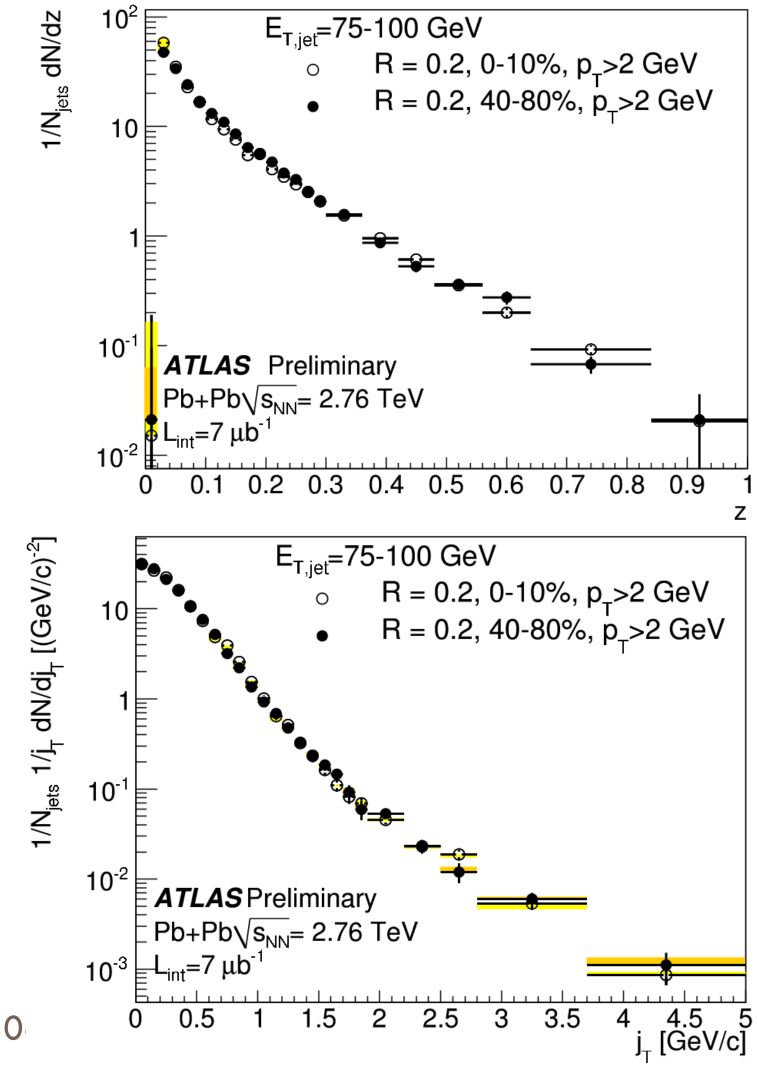




Jet fragmentation

More in: ATLAS-CONF-2011-075

- Another observable sensitive to the "inclusive" jet quenching is the charged fragmentation spectrum:
  - Longitudinal: $z = \frac{p_T^{part}}{E_T^{jet}} \cos \Delta R$
  - Transverse: $j_T = p_T^{part} \sin \Delta R$
- Radiative quenching is expected to re-distribute the energy among the final-state hadrons and suppress those with a large jet momentum fraction,
- ATLAS observes no substantial change between central and peripheral jets despite the large change in the yield.

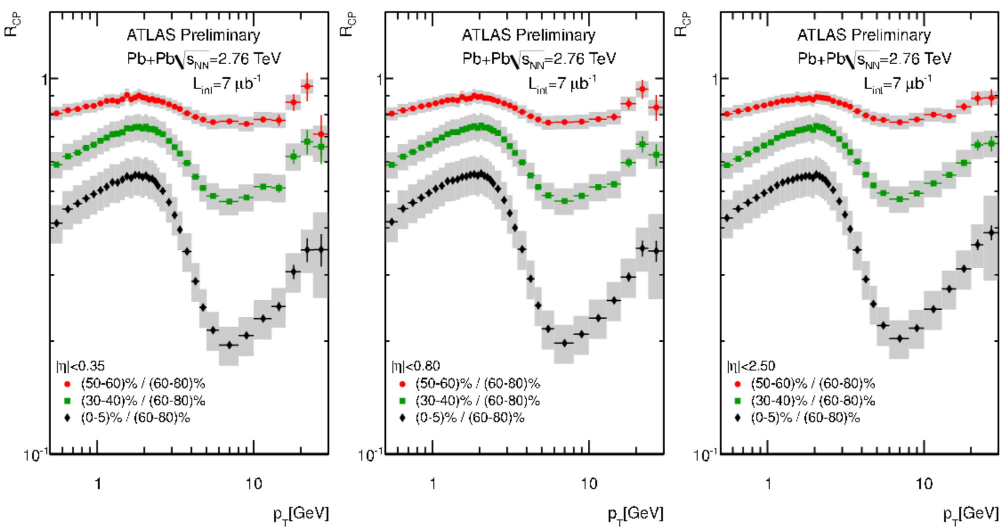


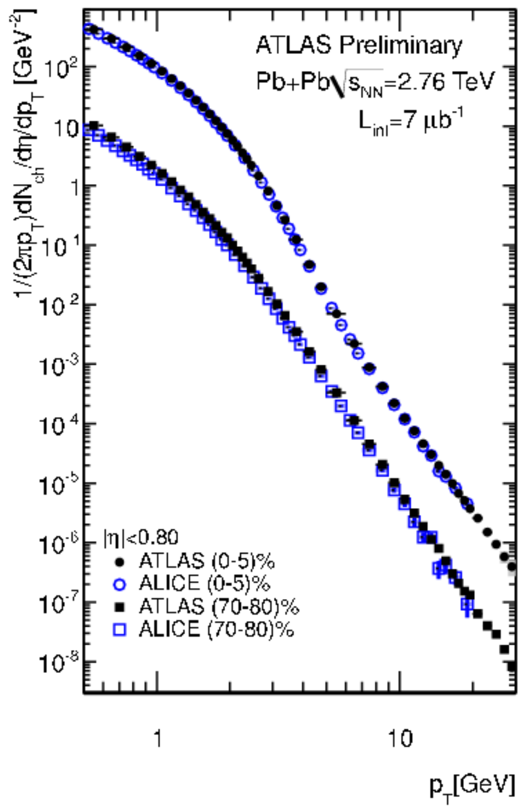
More in: ATLAS-CONF-2011-079

Charged particle spectra

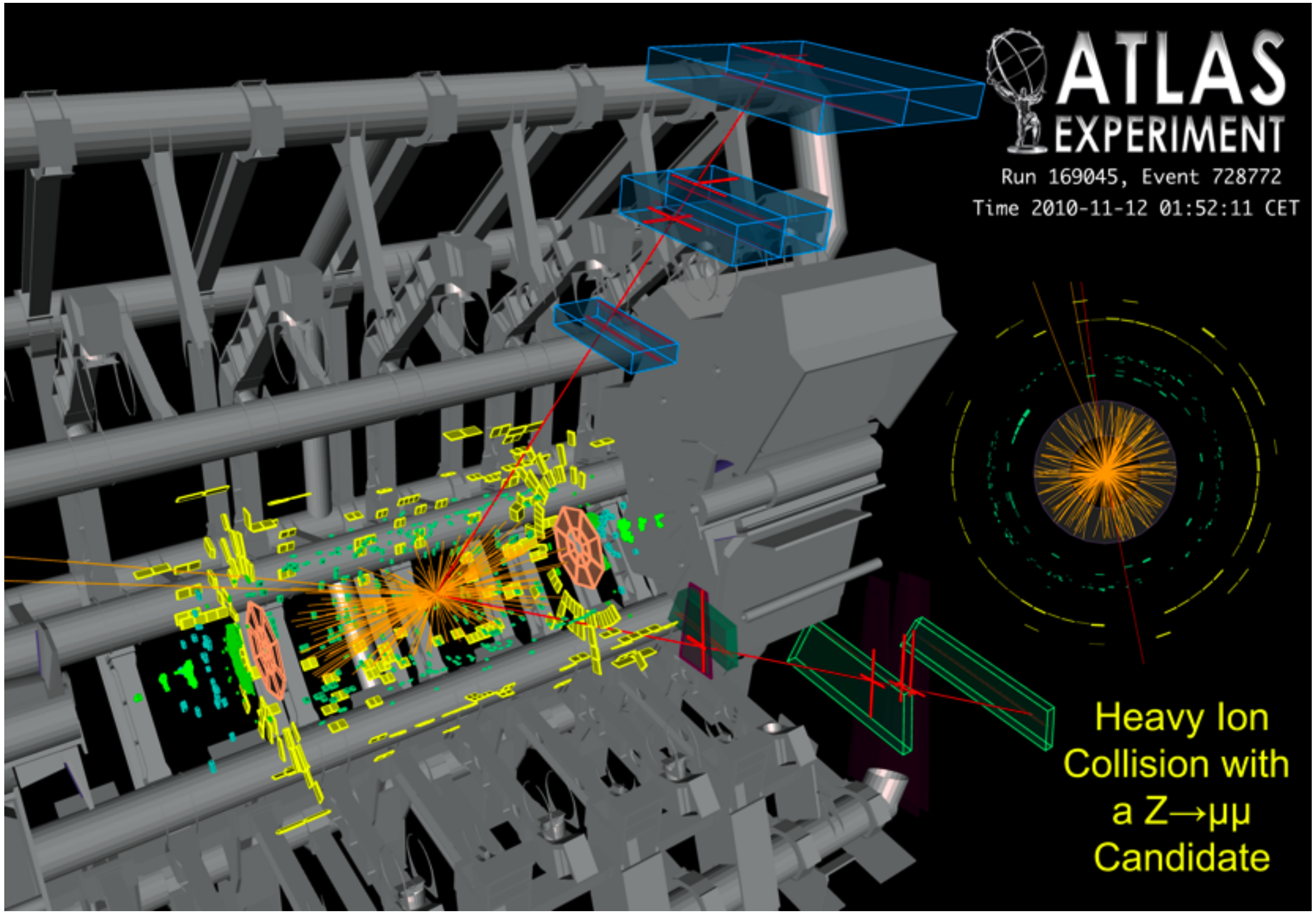
- Global look at hard probes via inclusive spectra at large p_T,
- Tracks reconstructed in Pixel+SCT in $|\eta|<2.5$,
- ATLAS measurement agrees with ALICE result for $|\eta|<0.8$,
- Medium modification explored via R_{cp},
  - Minima around 7 GeV then rise, no η dependence

$$R_{CP} = \frac{N^C_{coll}}{N^P_{coll}} \frac{N^P_{evt}}{N^C_{evt}} \frac{d^2N^C/d\eta dp_T}{d^2N^P/d\eta dp_T}$$





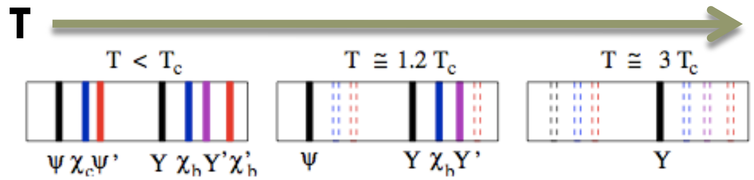
J/ψ, Z and W in ATLAS



J/ψ production

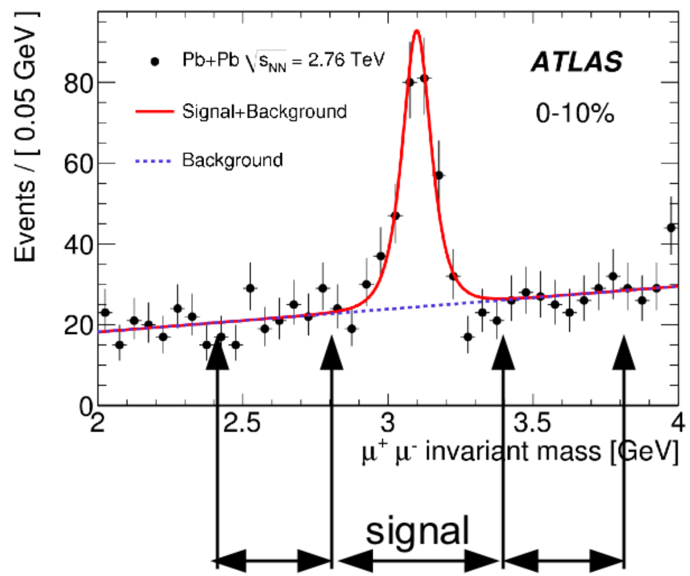
Quarkonia dissociation due to color screening is considered as a promising signature of quark-gluon plasma (QGP) formation

- Various quarkonia states are expected to "melt" at different temperatures,
- This was seen by SPS and RHIC experiments



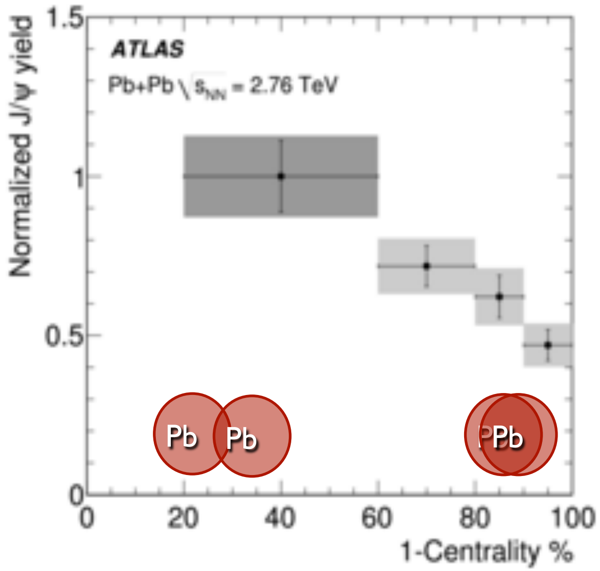
Analysis selection:

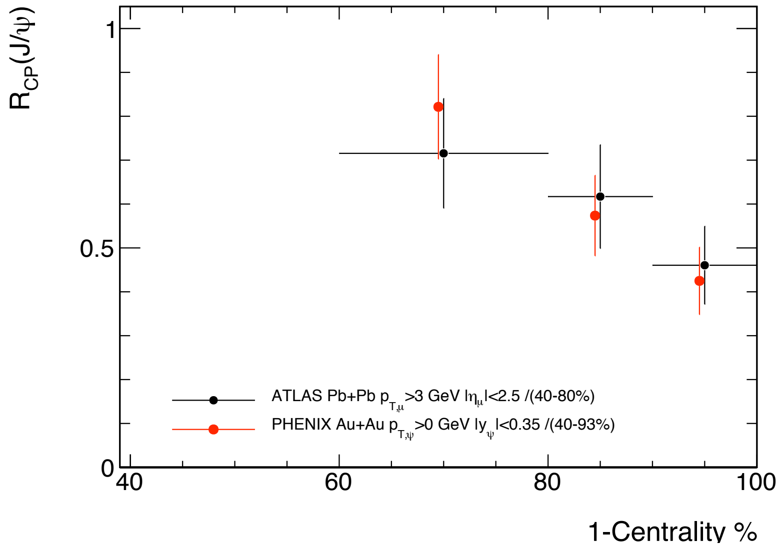
- Integrated luminosity analyzed: 7 μb^{-1},
- $J/\psi \rightarrow \mu^{+}\mu^{-}$ channel explored,
- Primary vertex required in the minimum bias-triggered data sample,
- Muons combined in the Inner Tracker and Muon Spectrometer with $p_T > 3$ GeV and $|\eta| < 2.5$,
- This results in 80% of J/ψ with $p_T > 6.5$ GeV,
- No distinction between prompt and non-prompt components of J/ψ.



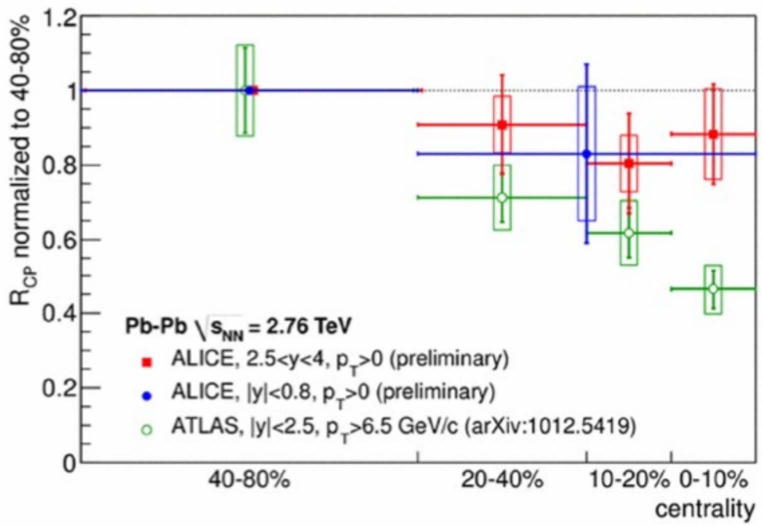
Phys. Lett. B697 (2011) 294

R_{cp}: J/ψ suppression



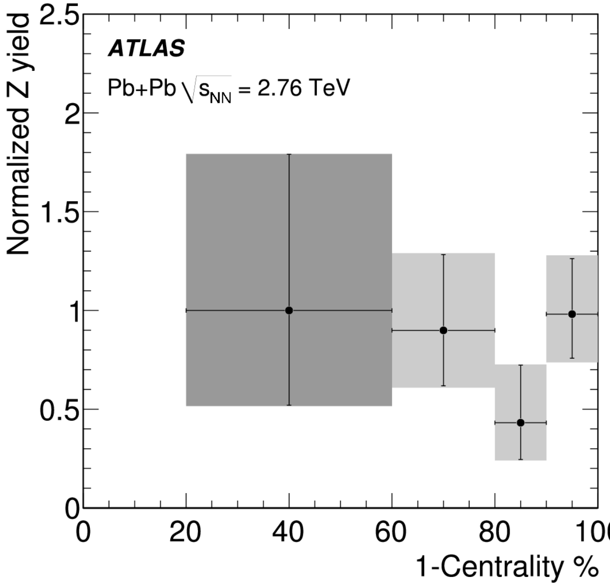


- J/ψ yield is normalized to the 80-40% peripheral bin,
- ATLAS observes a centrality-dependent suppression of the J/ψ yield,
- Consistent with the PHENIX result over p_T despite different momentum ranges,
- ALICE shows the weaker suppression than ATLAS but at much larger $|\eta|$ and lower p_T.



Z production

Phys. Lett. B697 (2011) 294

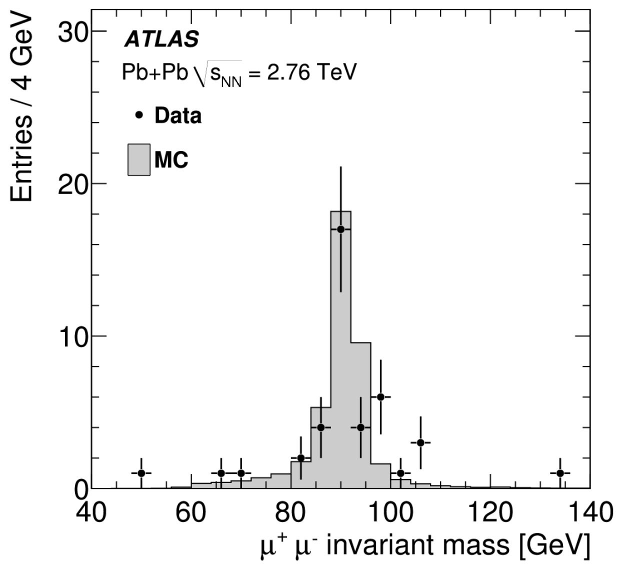


Analysis selection:
- Integrated luminosity analyzed: 7 μb^{-1},
- $Z \rightarrow \mu^+\mu^-$ channel explored,
- Primary vertex required in the minimum bias-triggered data sample,
- Muons combined in the Inner Tracker and Muon Spectrometer with p_T>20 GeV and $|\eta|$<2.5.

✓ First published observation of the Z boson peak in PbPb collisions at the LHC,

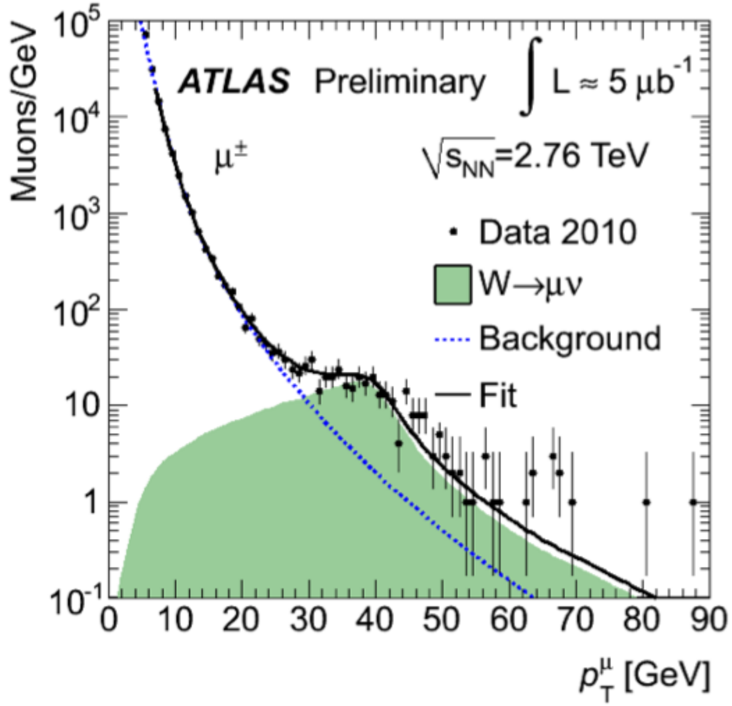
✓ 38 candidates are selected in the mass window of 66 to 116 GeV,

✓ No conclusion can be inferred about the Z yield scaling with a number of binary collisions because of limited statistics.



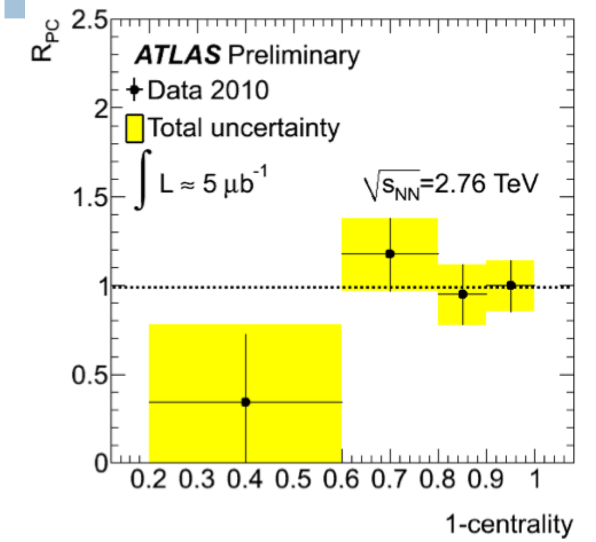
W production

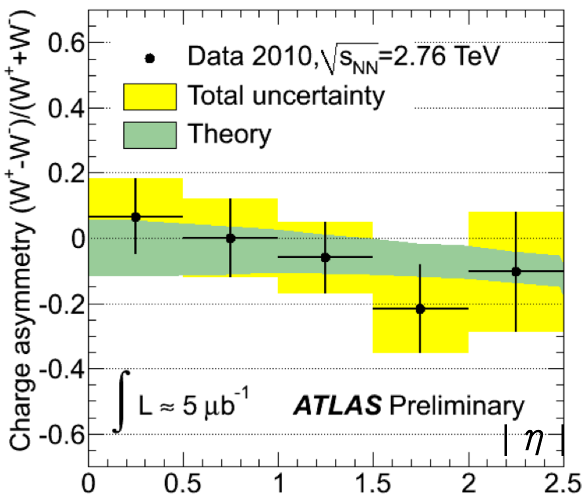
- Theory predicts an order of magnitude more W than Z produced at 2.76 TeV,
- Measurement of $W \rightarrow \mu\ \nu$ requires missing energy term to be reconstructed, which is unreliable in a Pb+Pb environment,
- Therefore, we try to rely only on a p_T distribution of muons
  - Muons from W are on average more energetic than muons from QCD processes,
  - At high p_T two dominating sources of single muons are *b*-quark decays and W decays,
  - Veto di-muons with $m_{\mu\ \mu}$>66 GeV (Z/DY candidates),
  - Find the best estimate of number of W by fitting signal and background to data
    - Template method.



Divide Pb+Pb dataset in subsets of charge, pseudorapidity (η) and centrality and fit each subset independently.

W yields and charge asymmetry





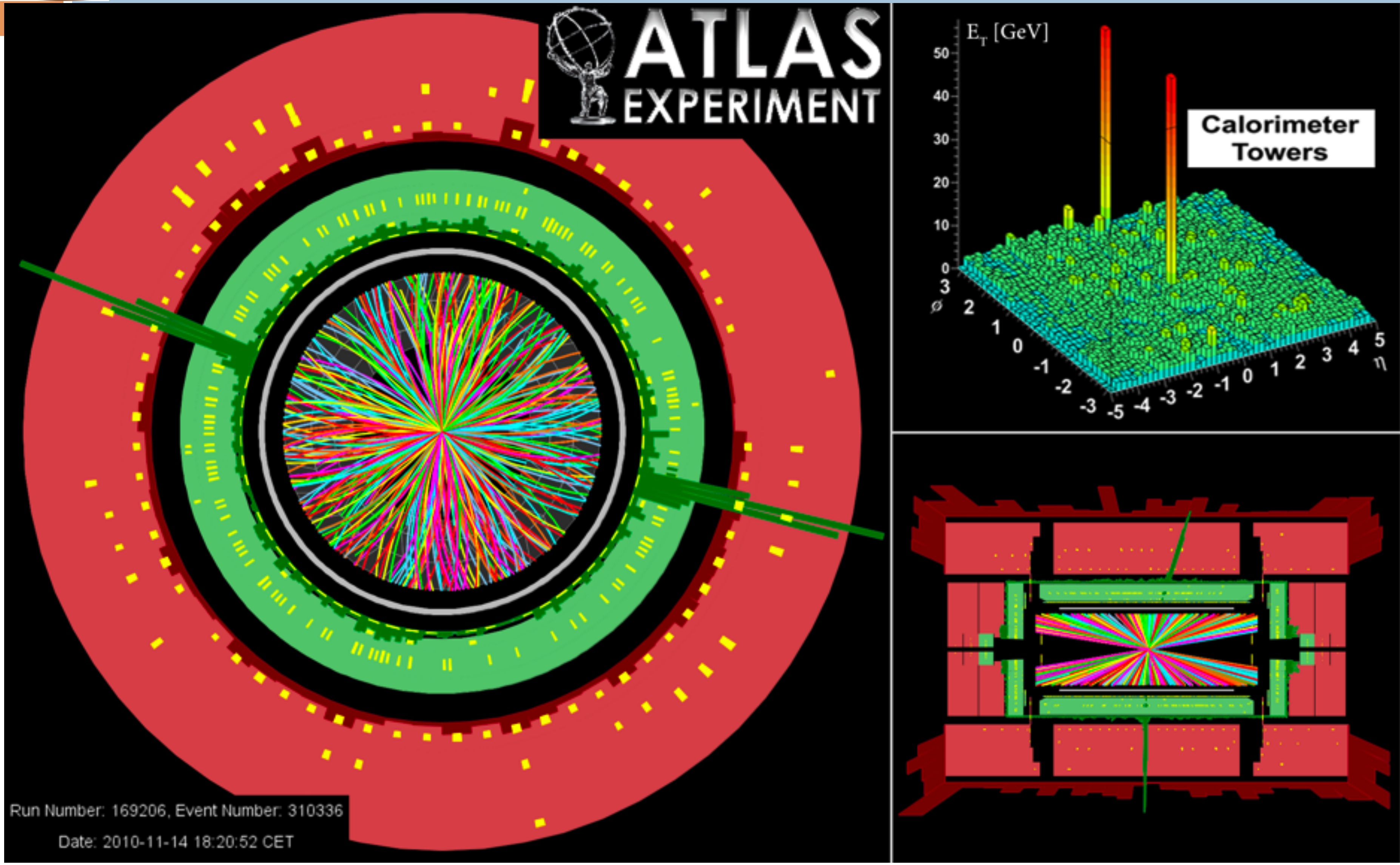
- No suppression hypothesis (flat line) is fitted to the data with χ^2/dof =5.72/3 (p=0.13).
  - **Result is consistent with no suppression of W bosons,**
  - Statistical uncertainty dominates, systematics come from a number of binary collisions and template fits,
- Ratio ***$R_{W/Z}$* = 10.5±2.3** for 5 μb^{-1}
  - Good agreement with Standard Model prediction!
- Precision test of W charge asymmetry provides information on PDFs,
  - Nuclear effects may give modifications to PDFs,
  - Statistical uncertainty is still limiting but with higher accumulated statistics a detailed measurement of the charge asymmetry as a function of centrality will be feasible.

Summary

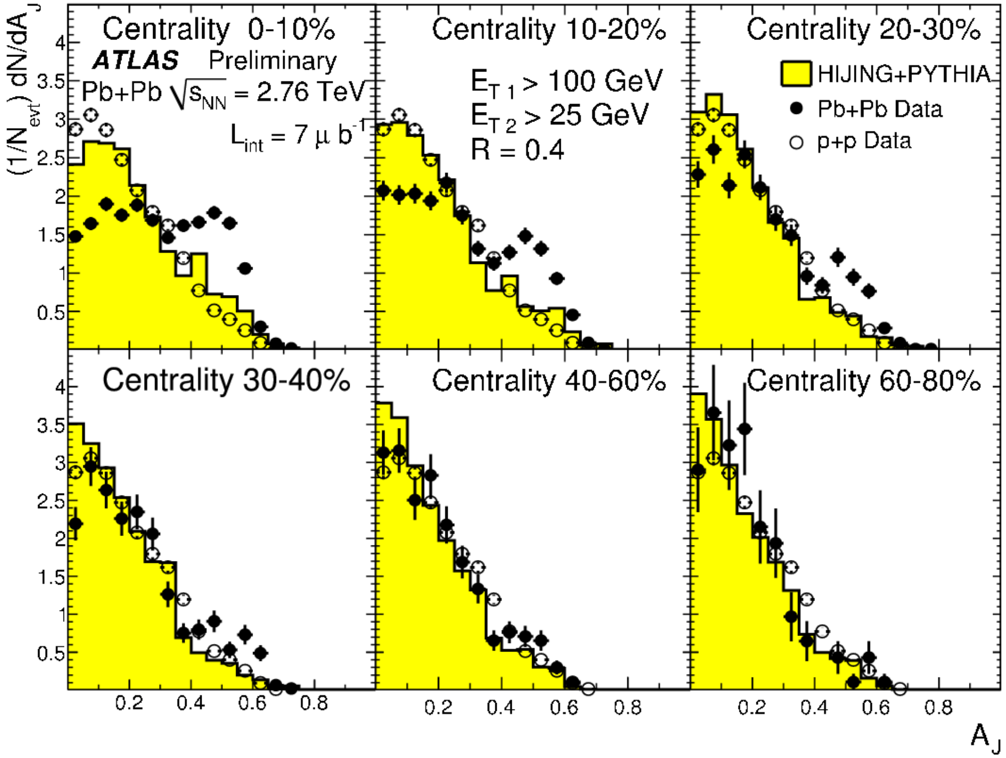
- ATLAS has released results on a variety of hard probes produced in heavy-ion collisions at sqrt(s_{NN})=2.76 TeV
  - Di-jets, inclusive jets, charged hadrons with high p_T, J/psi, weak bosons,
  - Measurements based on statistics from 2010 data,
  - We have O(15) times more statistics from 2011 data,
- First confirmation of jet quenching reported in Dec 2010 and confirmed in more advanced studies
  - Various jet sizes, di-jet asymmetry, R_{cp} and fragmentation functions,
- Observation of suppression of J/ψ in deconfined matter which is consistent with results from earlier lower-energy experiments,
  - But details are not yet understood,
- Observation of no suppression for W/Z bosons – their yields follow a binary scaling with centrality.

Back-up slides

$Z \rightarrow e^+e^-$ candidate

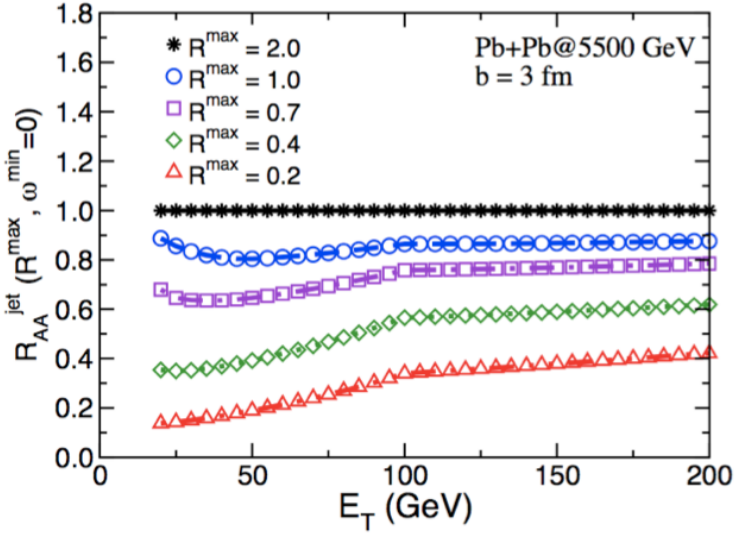


Dijet asymmetry for 0.4 jets



Prediction for inclusive jets

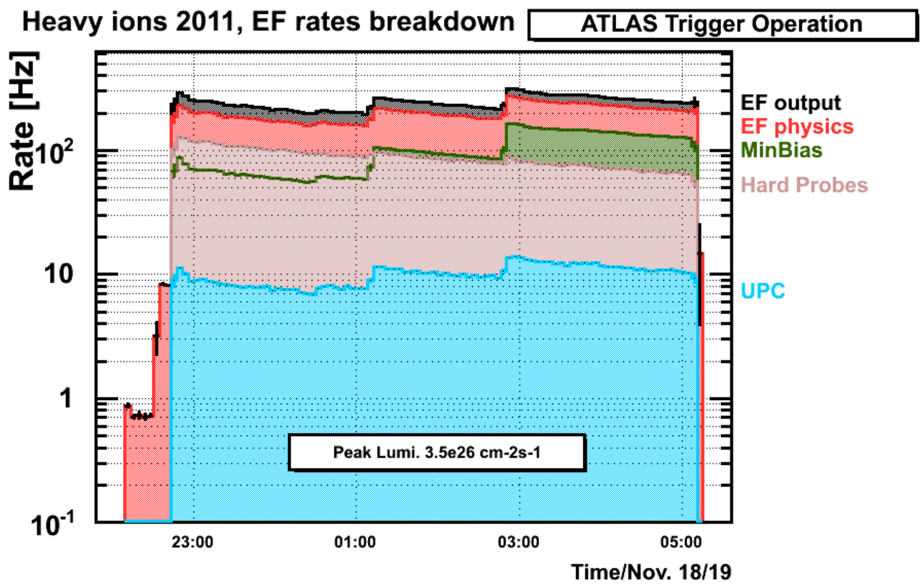
Prediction by Vitev, Zhang, Wicks



Impact of medium-induced radiative energy loss on the jet yield due to the radiation falling outside the angular coverage of the jet measurement

Trigger Strategy in 2010-11

- In 2010: Peak luminosity $3x10^{25}cm^{-2}s^{-1}$ which gives 350 Hz of min bias rate at L1
  - Record all min bias events to tape,
- In 2011: Peak luminosity $5.1x10^{26}cm^{-2}s^{-1}$ which gives 6 kHz of min bias rate at L1,
  - High Level Trigger (HLT) essential to bring an output rate down to 200 Hz,
  - Two approaches used:
    - Full scan reconstruction at HLT on all minimum bias events triggered by L1 (jets, muons),
    - Region-Of-Interest (RoI)-based reconstruction seeded of the lowest-p_T threshold at L1 (muons, photons, electrons),
  - In addition to min bias data high-p_T jets, muons, electrons, photons and UPC were enhanced

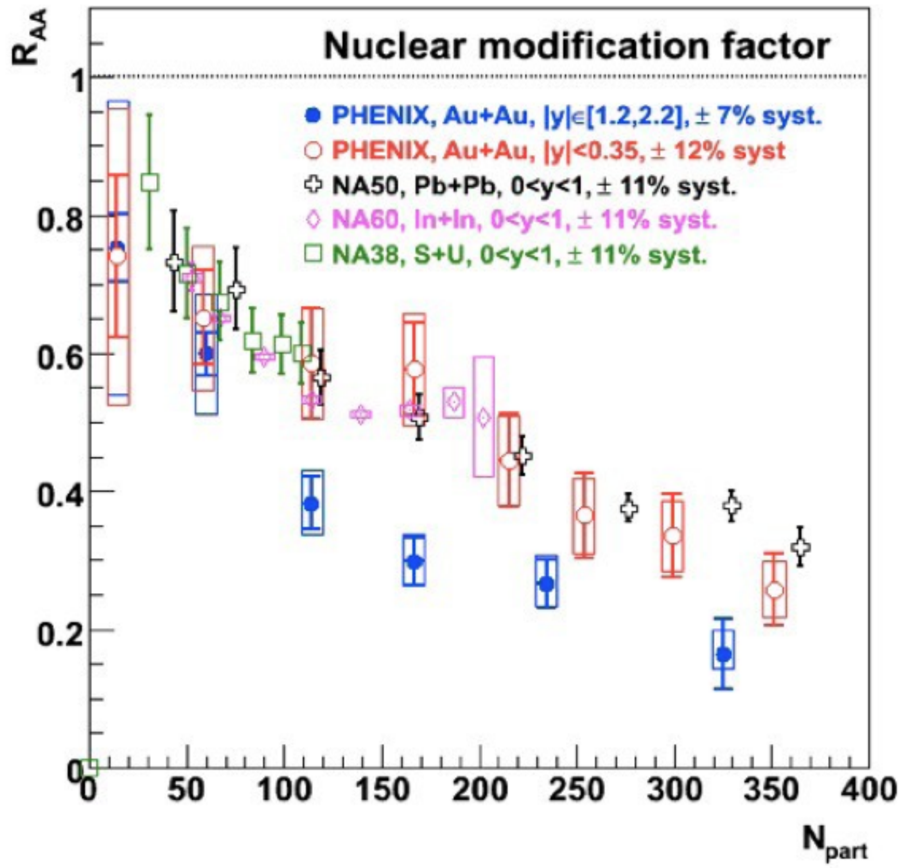


Signature	Trigger
Jets	single jet p_T> 20 GeV
Muons	single muon p_T>4 GeV di-muon p_T>2 GeV
Egamma	single egamma p_T>14 GeV di-egamma p_T>5 GeV
UPC	low track multiplicity cut

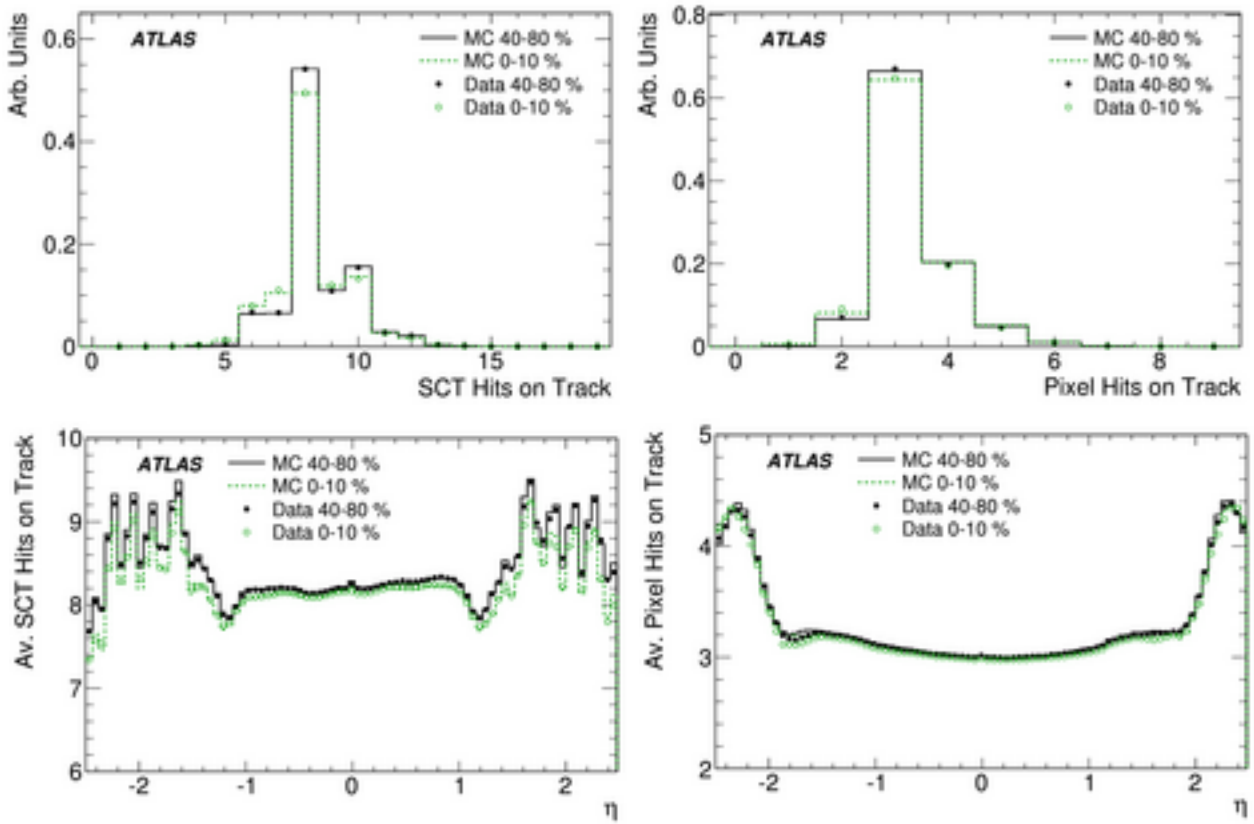
Stream	Events Taken	Reco CPU/evt [s]
Min Bias	60M	70
Hard Probes	54M	140
UPC	6.6M	30

Earlier J/ψ measurements

- J/ψ suppression in HI collisions as a function of centrality already observed in past experiments
- Various experiments roughly consistent with each other
- Possible dependence on rapidity and also transverse momentum.



MC control plots

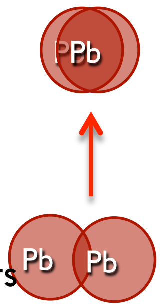


- → MC samples with superimposed J/ψ events from pp at sqrt(s)=2.76TeV from PYTHIA onto PbPb events from HIJING,
- → MC used for reconstruction efficiency determination,
- → For comparisons tracks selected with p_T>500 MeV,
- → Two centrality bins explored: 0-10% and 40-80%,
- ✓ MC describes data very well
  - ✓ Also centrality dependence reproduced.

Systematic uncertainties for J/ψ

- Reconstruction efficiency
  - Variation of the reconstruction efficiency with centrality due to the larger occupancy in the Inner Tracker,
  - Stringent track quality requirements are made w.r.t. the pp ones,
- Extraction of a number of signal events
  - Use un-binned maximum likelihood fit with mass resolution as a free parameter,
  - Explore two different background parameterizations with a first or second order polynomial.

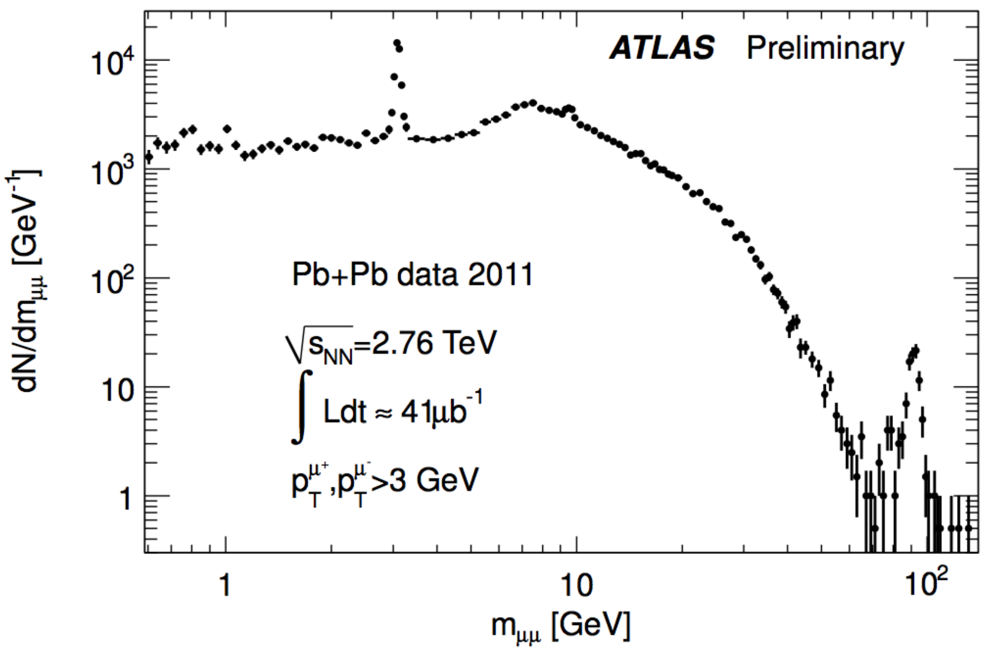
Central events



Peripheral events

Centrality	Reco. eff. [%]	Sig. extr. [%]	Total syst. [%]
0-10%	6.8	5.2	8.6
10-20%	5.3	6.5	8.4
20-40%	3.3	6.8	7.5
40-80%	2.3	5.6	6.1

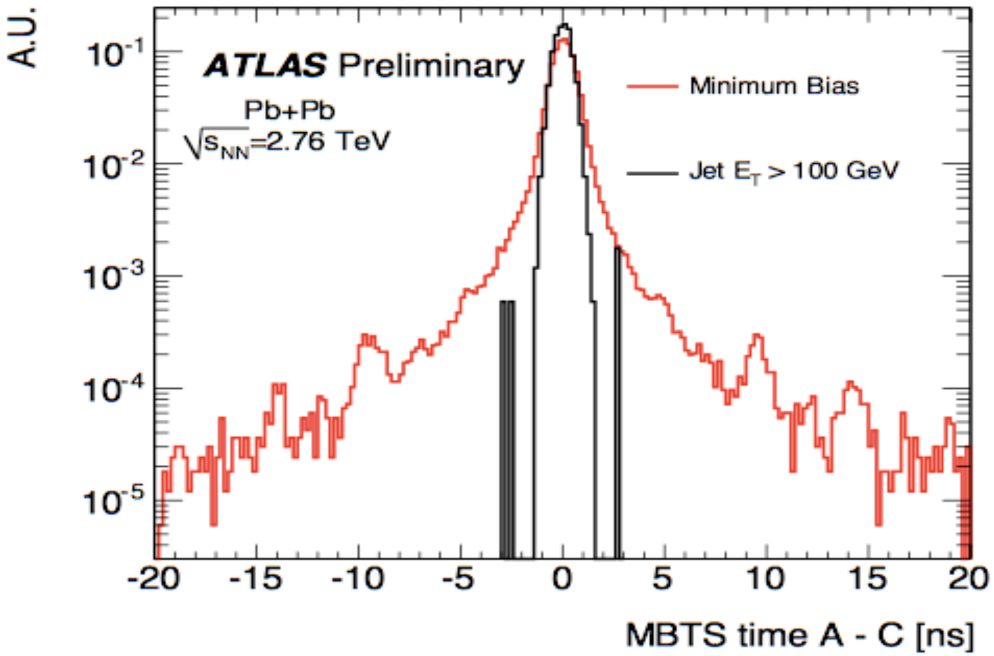
More results to come soon



- ATLAS published results on $J/\psi \rightarrow \mu\mu$ studies in PbPb collisions so far,
- Aim for using pp data at sqrt(s) =2.76TeV for normalization,
- In 2011 we increased our statistics by a factor of 15,
  - Access to prompt and non-prompt components of J/ψ,
  - Access to other resonances,
- Further PbPb results will be reported soon.

HLT Selection

- At HLT only a simple selection on a time difference between two MBTS sides is applied
  - No requirement on physics objects as jets, electrons, muons, etc.



J/ψ suppression

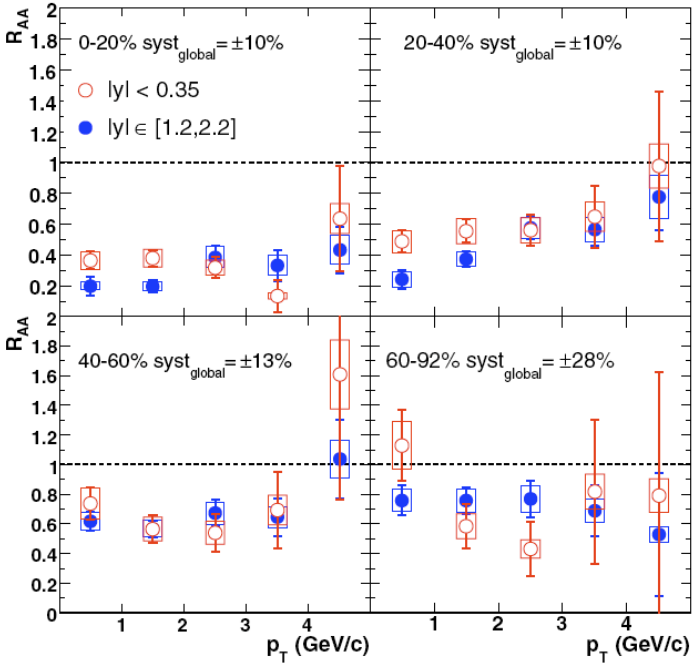


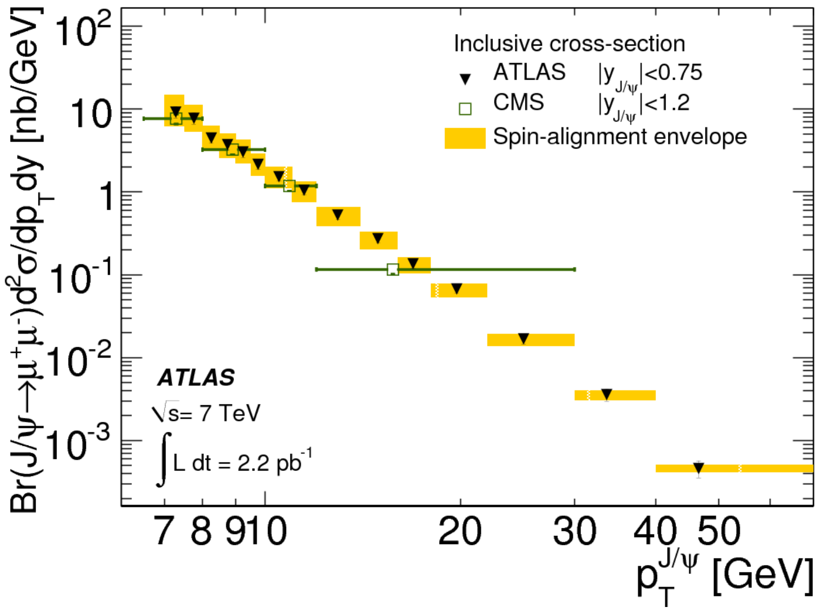
FIG. 3 (color online). J/ψ R_{AA} versus p_T for several centrality bins in Au + Au collisions. Mid (forward) rapidity data are shown with open (solid) circles. See text for description of the errors and Ref. [21] for data tables.

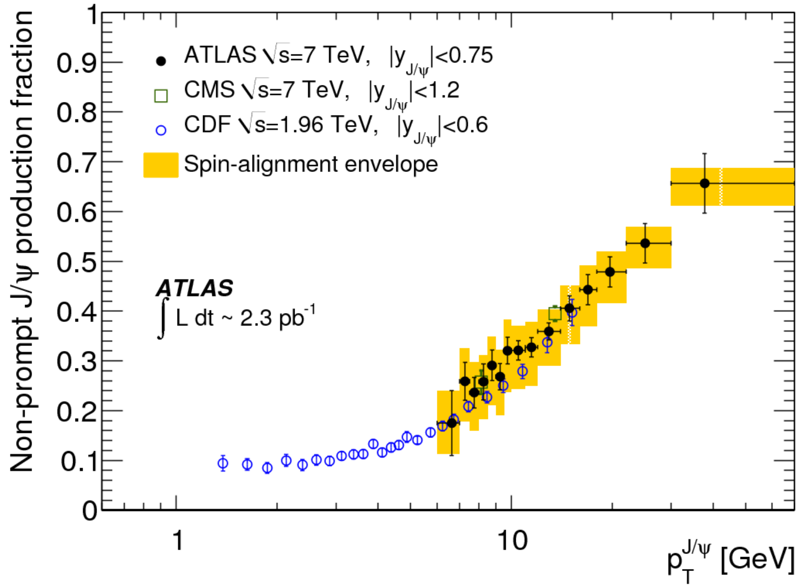
- J/ψ suppression in HI collisions as a function of centrality already observed in past experiments
- PHENIX measurement in Au-Au collisions @ $\sqrt{S_{NN}}$=200 GeV

$$R_{AA} = \frac{d^2N^{AA}_{J/\psi}/dp_T dy}{N_{\rm coll} d^2N^{pp}_{J/\psi}/dp_T dy},$$

J/ψ in pp in ATLAS

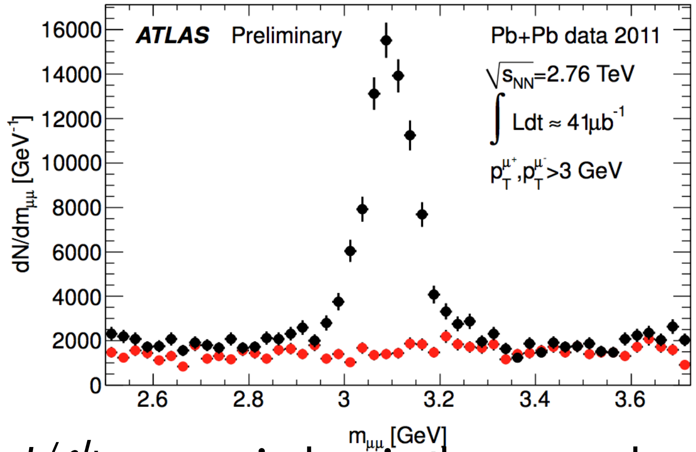
- Cross-section and non-prompt / prompt yields measured by ATLAS



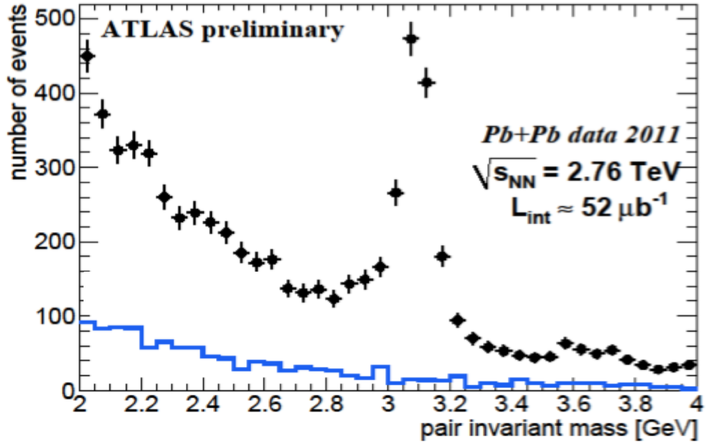


Nuclear Physics B 850 (2011), 387

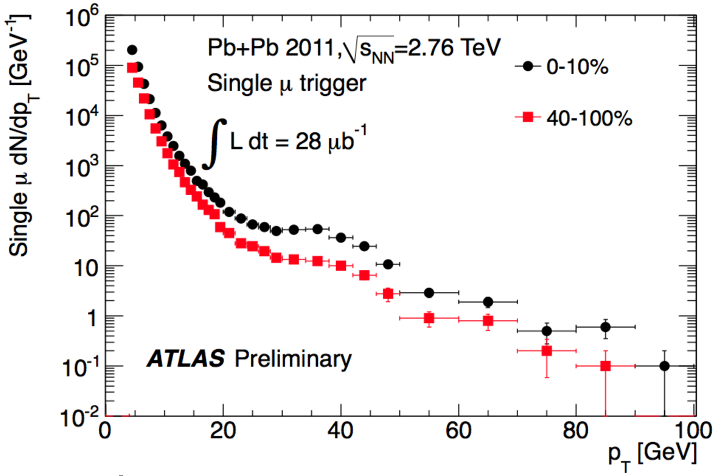
Muons in 2011data



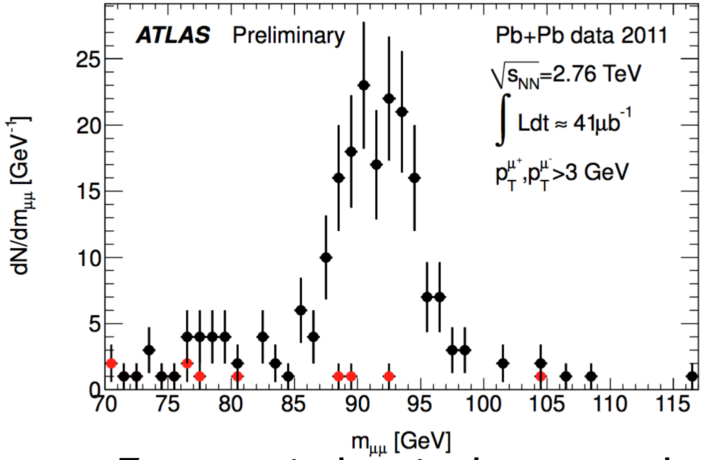
J/ψ mass window in the muon channel



J/ψ mass window in the muon channel in UPC



Inclusive muon spectrum



Z mass window in the muon channel

Glauber fits for ATLAS

- **We are using FCal energy sum, as before**
- **Use standard Glauber MC (http://arXiv.org/abs/arXiv:0805.4411)**
  - R=6.62 fm, a=0.546 fm (skin depth)
- **Assume both participants and collisions contribute**
  - "Two component model", controlled by parameter "x"

$$\Sigma E_{T,FCal} = E_{T,pp} \left((1-x)\frac{N_{part}}{2} + xN_{coll} \right)$$

  - x=0.13±0.01(stat)±0.05(syst) found to describe RHIC data
- **Incorporate FCal energy resolution and noise**
  - Let detector noise be a free parameter (sum of cells)
  - Resolution assumed to be 100%/√(E(GeV))
- **Input data distribution is FCal Et from mbSpTrk selection**
  - Cuts requiring good vertex (>1 track), MBTS (DeltaT<3ns), ZDC (AND)