HEAVY QUARKONIUM PRODUCTION IN PB-PB COLLISIONS AT ATLAS

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On behalf of the ATLAS Collaboration
Heavy Quarkonium 2011, GSI, Darmstadt, Oct 4-7th, 2011

Heavy Ions at the LHC

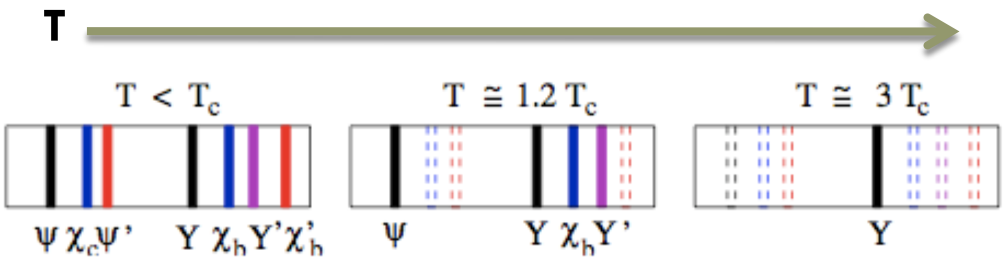
- First lead-lead data from the LHC collected on tape in 2010,
  - Excellent performance of the LHC machine,
  - Excellent performance of the detectors,
- Huge energy jump from RHIC
  - factor of 14 in the center-of-mass energy!

	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-muon production: J/ψ and Z
  - Results on W production.

Di-lepton studies

- 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,

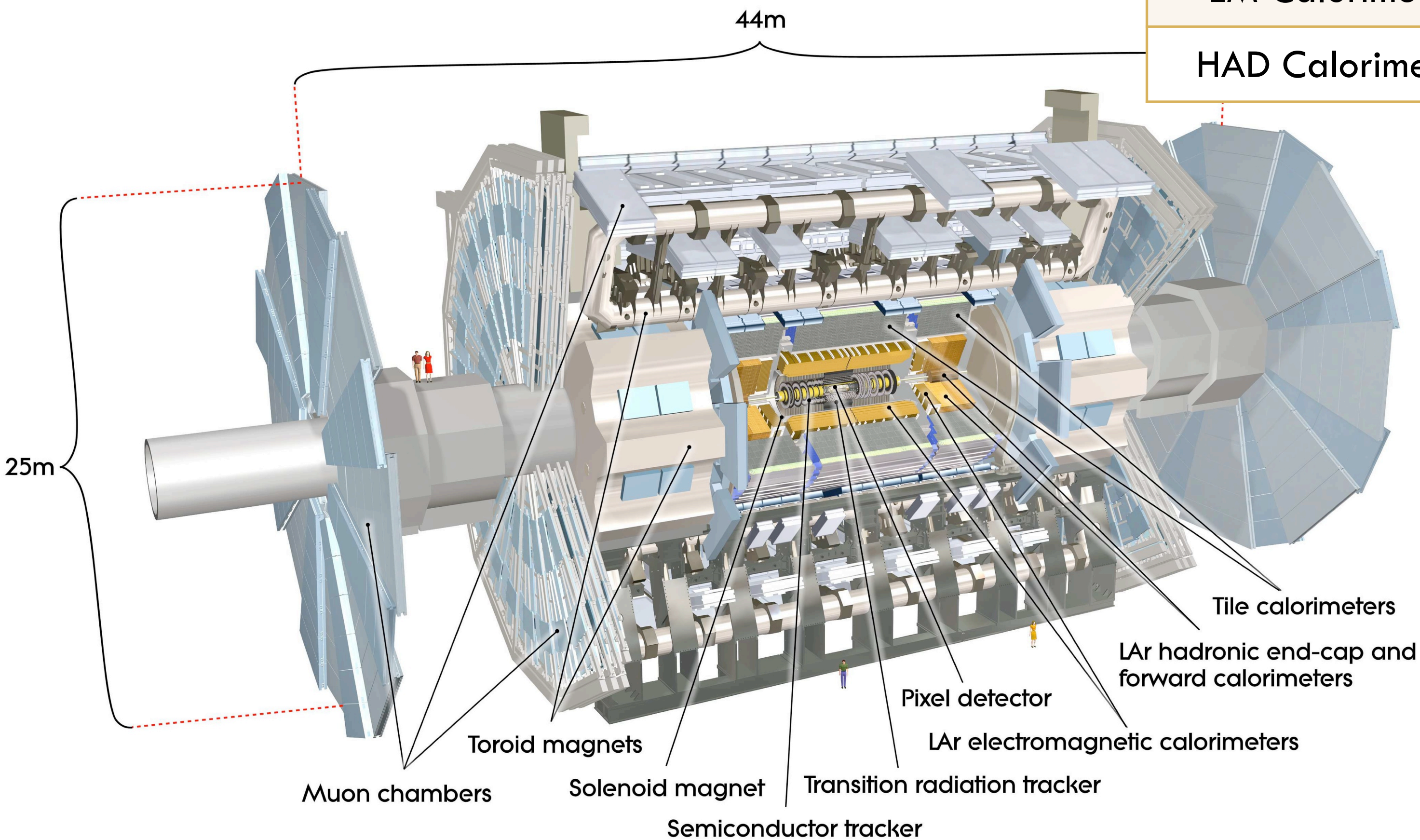


  - J/ψ suppression has already been seen at SPS and RHIC but details are poorly understood, interplay of cold and hot effects,
  - J/ψ enhancement by regeneration of J/ψ from the (large) number of uncorrelated cc pairs could also be tested at the LHC,
- Weak bosons have not been observed in Au-Au collisions at RHIC,
  - Test of nuclear PDFs,
  - Standard candle for other processes,
- This opens perspectives for the LHC experiments.

ATLAS Detector

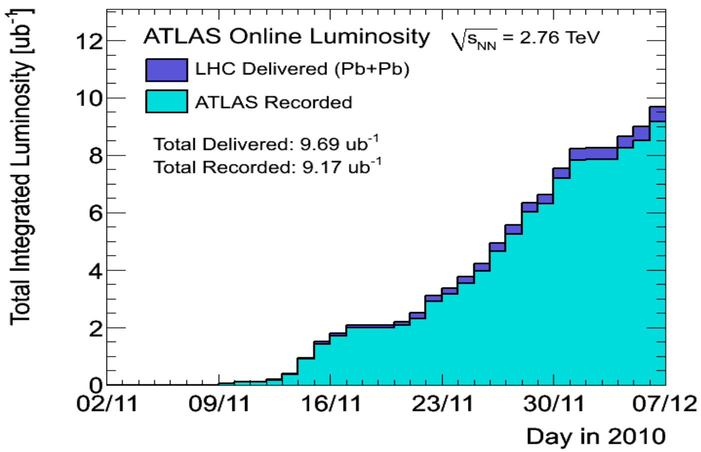
Three main components: Inner tracker, electromagnetic (EM) and hadronic (HAD) calorimeters, and muon system

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 Run in 2010



- First heavy ion run at $\sqrt{s_{NN}} = 2.76 TeV$
  - Nov 4th-Dec 6th, 2010,
  - ATLAS recorded 9.2 μb^{-1} of PbPb data,
    - With 1 μb^{-1} magnetic field-off data,
  - Data recording efficiency > 95%,
  - Fraction of data passing data-quality criteria > 99% .
- Prospects for 2011
  - 40-80 μb^{-1} data at 2.76 TeV.

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

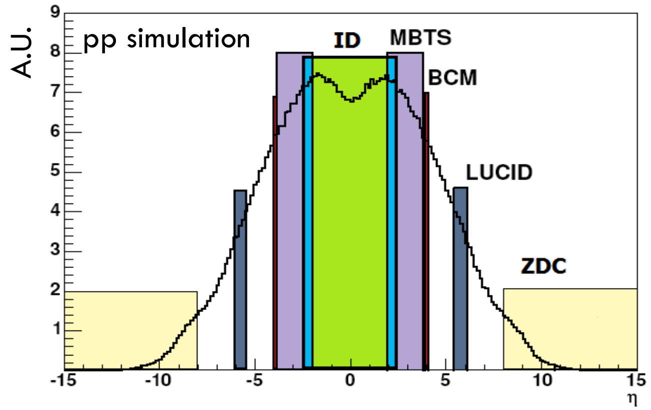
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV between November 8th and 17th (in %).

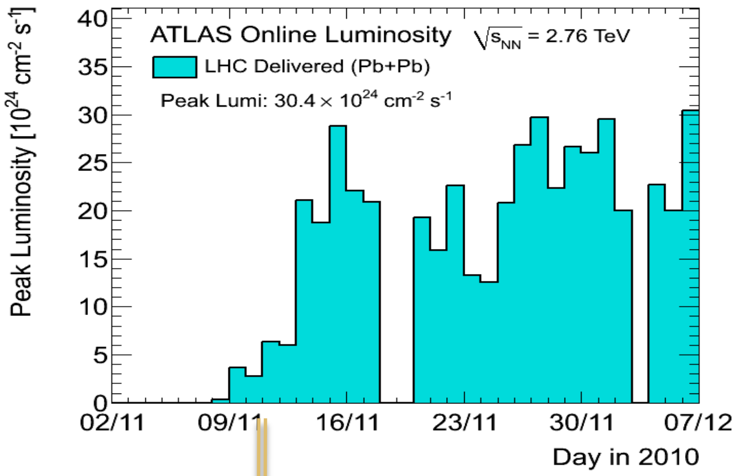
Data Triggering

Triggering strategy:

record to tape a minimum bias sample,

trigger efficiency 100% for $n_{tracks}>20$.





Only LVL1 trigger

Above $5x10^{24}cm^{-2}s^{-1}$ High Level Trigger (HLT) applied to filter out beam backgrounds and improve event selection. No selection based on physics objects like jets, muons, etc .

Main minimum bias triggers:

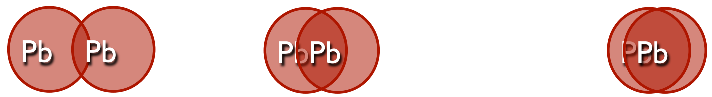
- Minimum Bias Trigger Scintillators (MBTS),
- Zero Degree Calorimeter (ZDC),
- Hits counting in the Inner Tracker (ID),
- The LUCID integrating Cherenkov detector

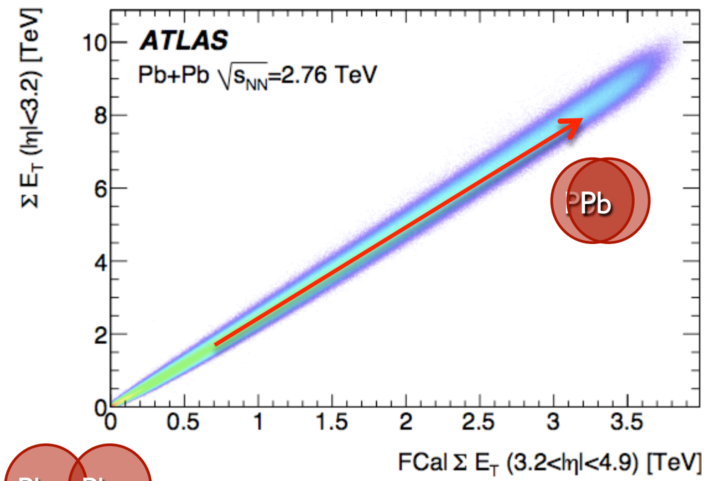
<u>Recording rates:</u> ~500 Hz in the peak

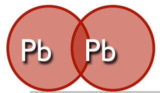
Centrality

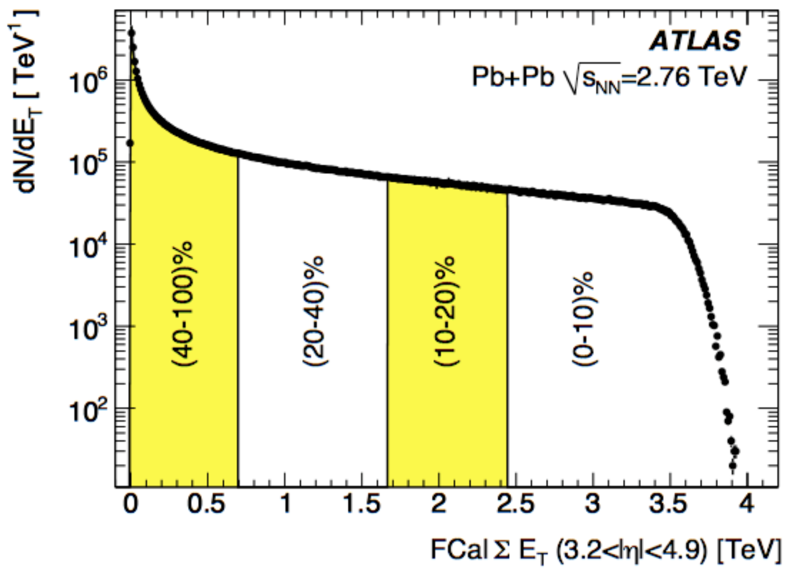
Characterize centrality by percentiles of the total cross-section using forward calorimeter (FCal) ΣE_T $(3.2 < |\eta| < 4.9)$

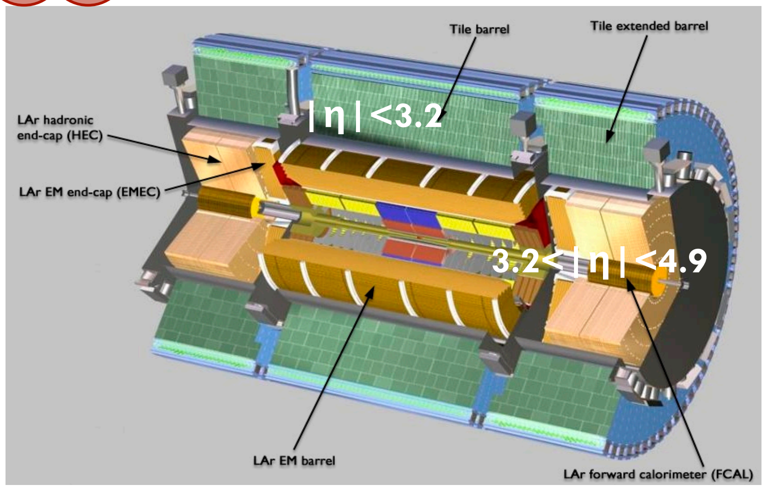
Peripheral collisions | Mid-central collisions | Central collisions





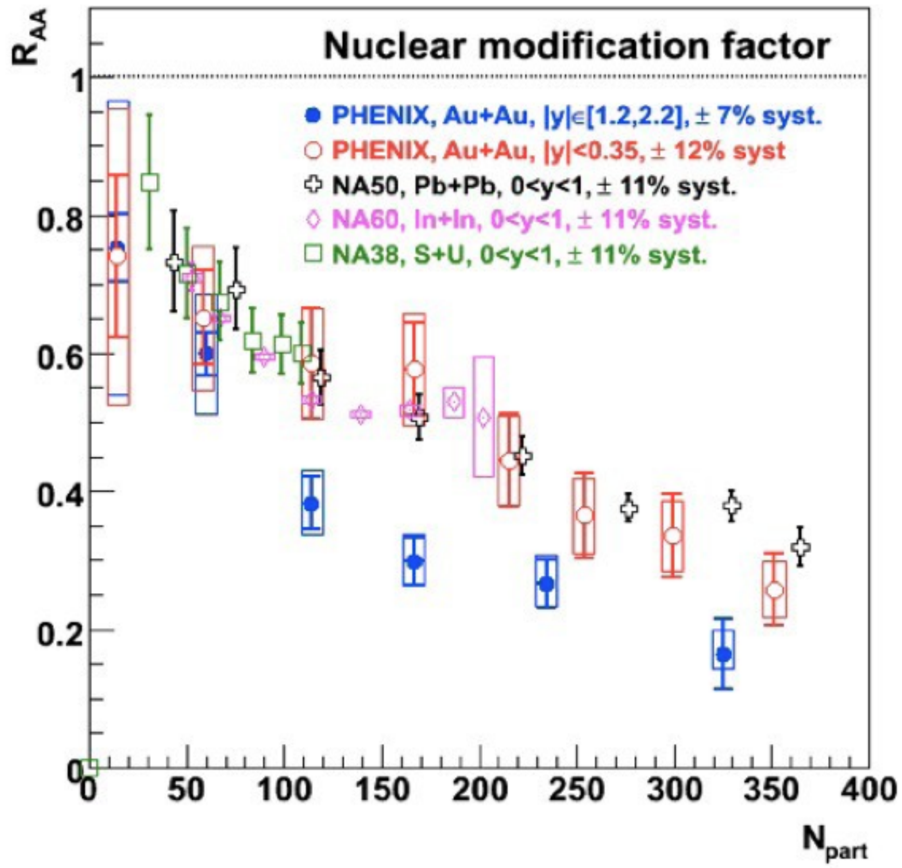






Earlier J/ψ measurements

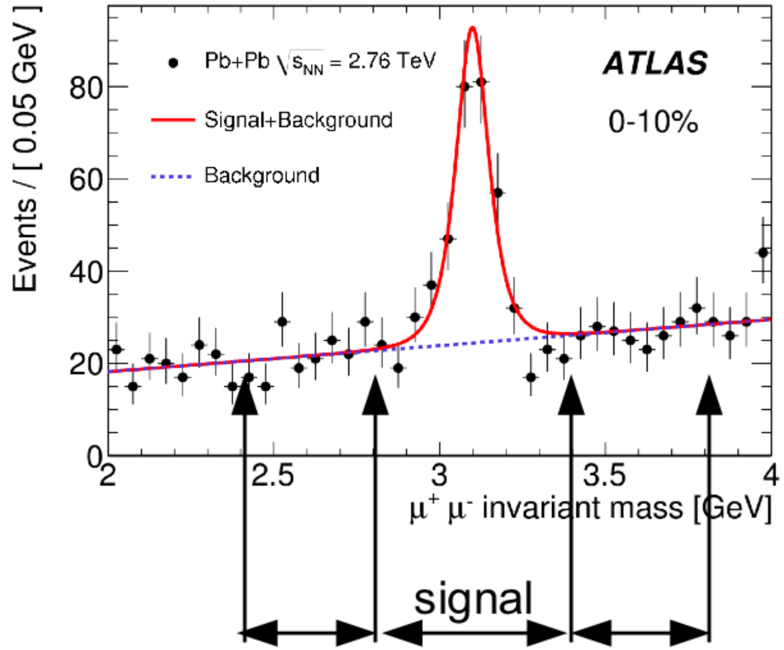
- J/ψ suppression in HI collisions as a function of centrality already observed in past experiments
- Various experiments roughly consistent with each other
- Possible dependence on rapidity and also transverse momentum.



J/ψ event selection

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,
- 80-100% centrality bin excluded from the analysis due to larger systematic uncertainty in determining a number of binary collisions.



J/ψ yields in each centrality bin are obtained using a sideband technique:

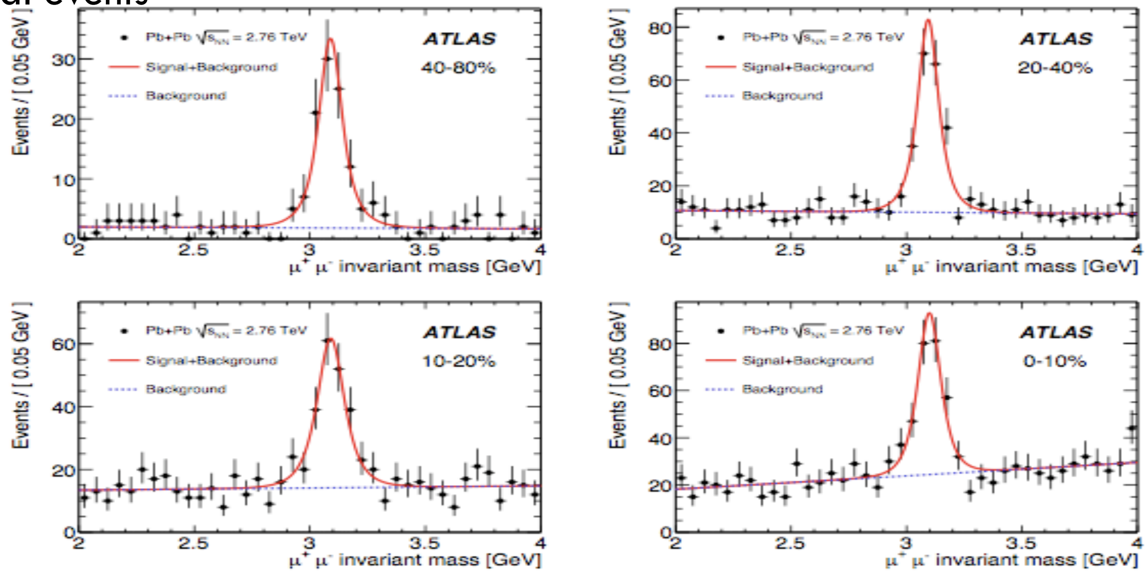
→ Signal mass window: $2.95 < m_{\mu\mu} < 3.25$ GeV,

→ Sideband mass window: $2.4 < m_{\mu\mu} < 2.8$ GeV and $3.4 < m_{\mu\mu} < 3.8$ GeV,

- Cross-check yields using a maximum likelihood fit with the mass resolution left as free parameter,
- Two different background models used: first and second order polynomial

J/ψ yields

Pb Pb Peripheral events



Central events Pb

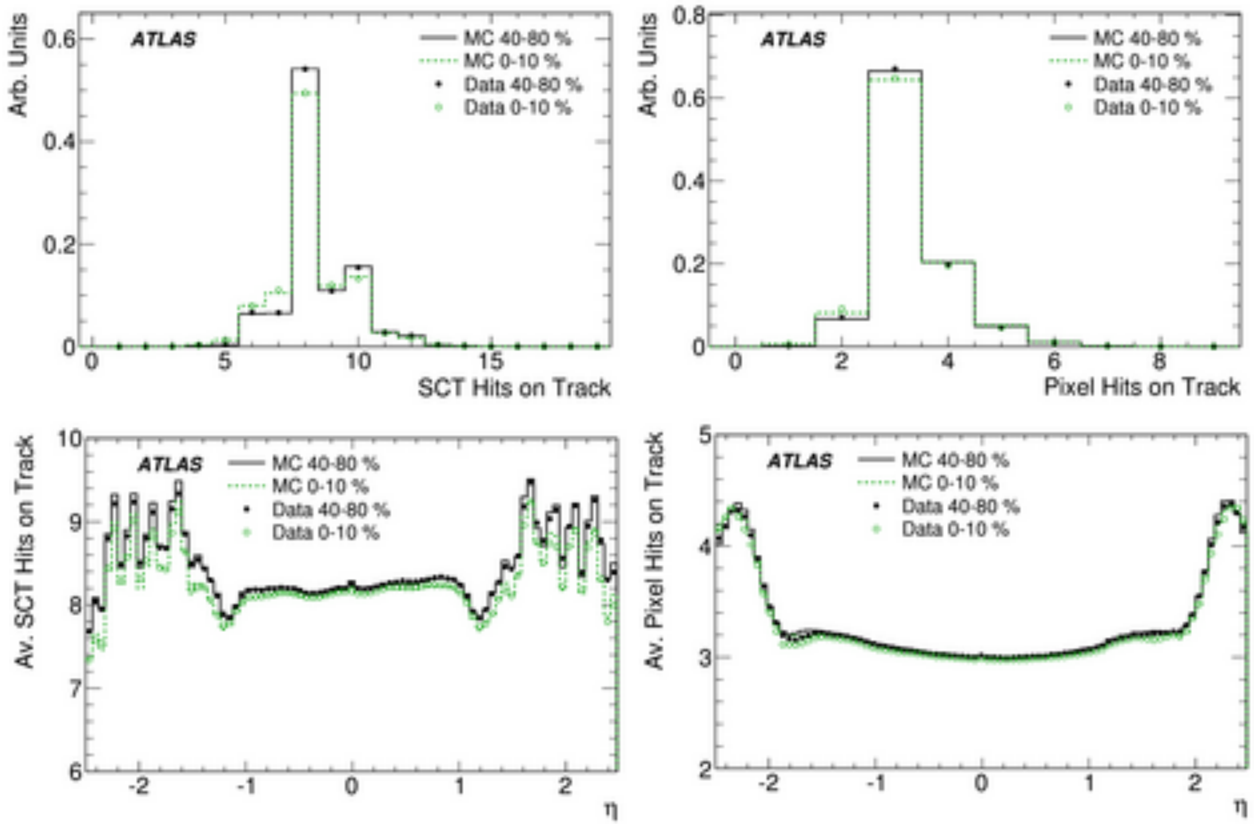
Centrality	$N^{meas}(J/\psi)$
0-10%	190±20
10-20%	152±16
20-40%	180±16
40-80%	91±10

Central events Pb

Peripheral events Pb Pb

Observed signal events after background subtraction and before further corrections

MC control plots

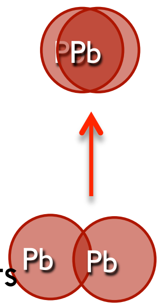


- → MC samples with superimposed J/ψ events from pp at sqrt(s)=2.76TeV from PYTHIA onto PbPb events from HIJING,
- → MC used for reconstruction efficiency determination,
- → For comparisons tracks selected with p_T>500 MeV,
- → Two centrality bins explored: 0-10% and 40-80%,
- ✓ MC describes data very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

Systematic uncertainties

- 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.

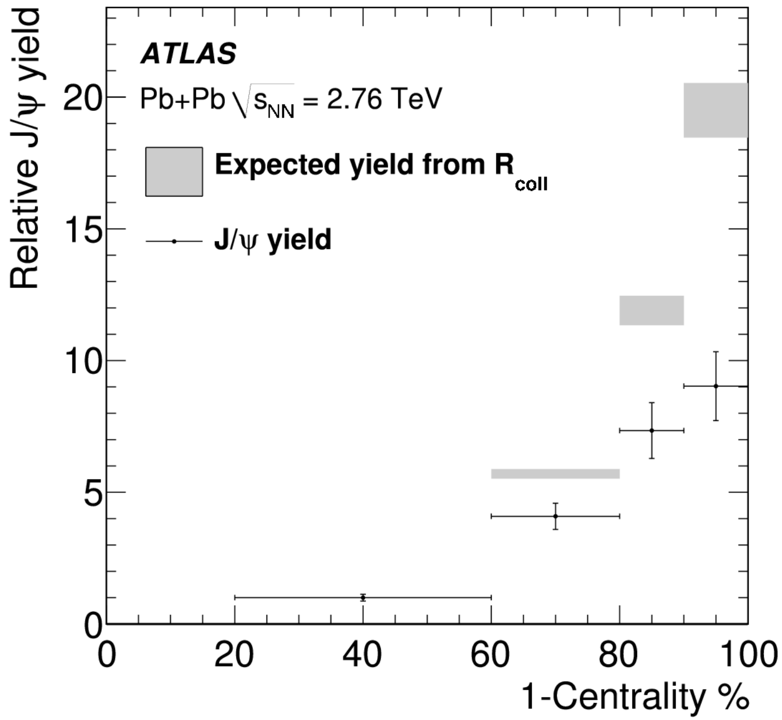
Central events

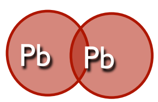


Peripheral events

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

Relative J/ψ yields





Peripheral

Central

Hypothesis: linear scaling of a number of J/ψ with a number of binary nucleon-nucleon collisions

- Relative J/ψ yield in "i-th" bin=$N_i^{corr}/N_{40\text{-}80\%}^{corr}$, where N_i^{corr} is a corrected yield of J/ψ mesons,
  - Yields include $B \rightarrow J/\psi$ as well as prompt J/ψ production.
- Compare with $R_{coll}^i = N_{coll}^i / N_{coll}^{40\text{-}80\%}$, where N_{coll}^i is a mean number of binary collisions in "i-th" bin from the Glauber model,
- A clear difference as a function of centrality between both numbers, indicating a deviation from the expectation based on QCD factorization.

R_{cp}: J/ψ suppression

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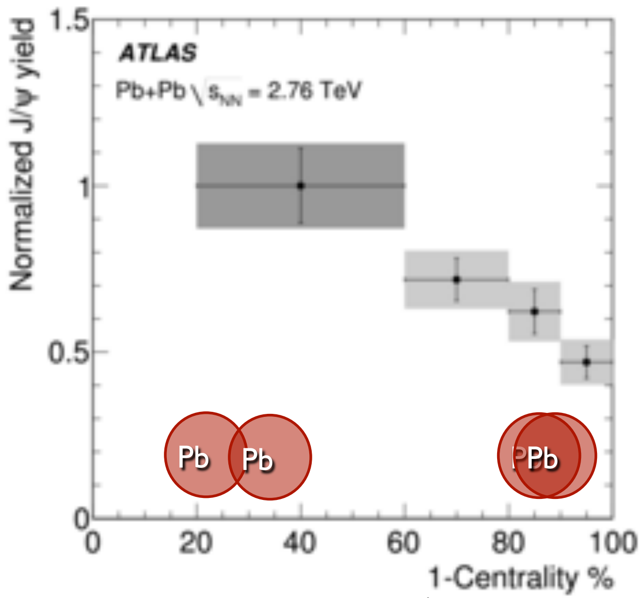

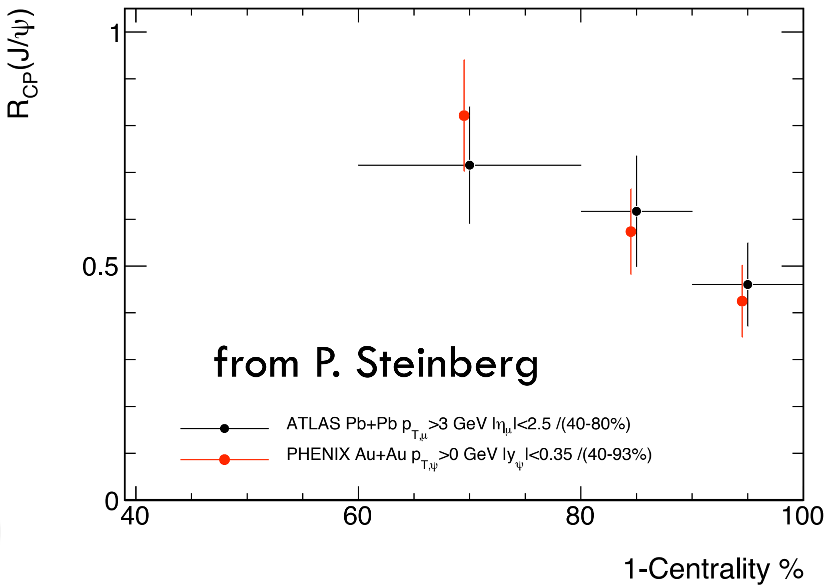

- J/ψ yield normalized to R_{coll}^{i} and divided by the peripheral yield,
  - Vertical error bars: statistical uncertainty, shaded regions: statistical and systematic uncertainties,
- We observe a centrality dependent suppression of the J/ψ yield,
  - Probability of no suppression: $p(\chi^2, ndof) = 0.11\%$. (including systematics in χ^2),
- Similar result when integrating PHENIX result over p_T despite different momentum ranges.

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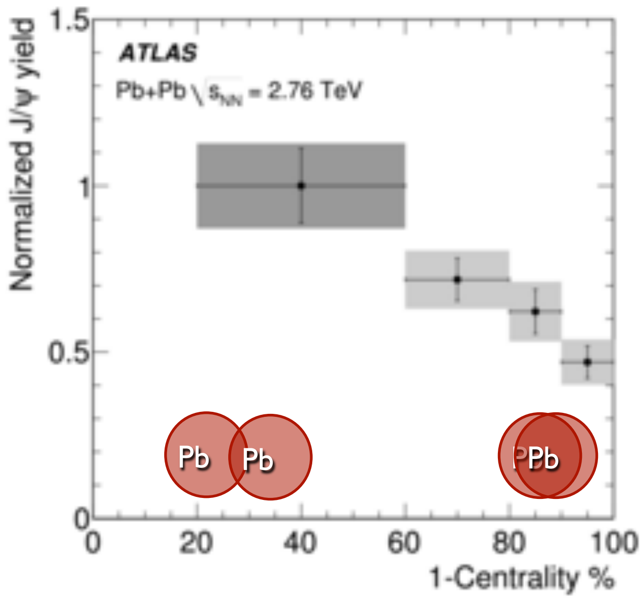
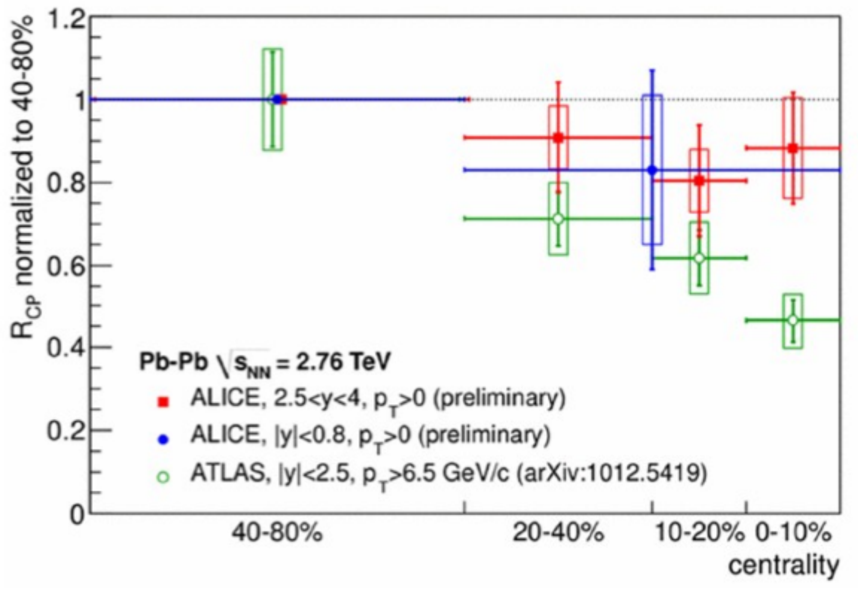
R_{cp}: J/ψ suppression

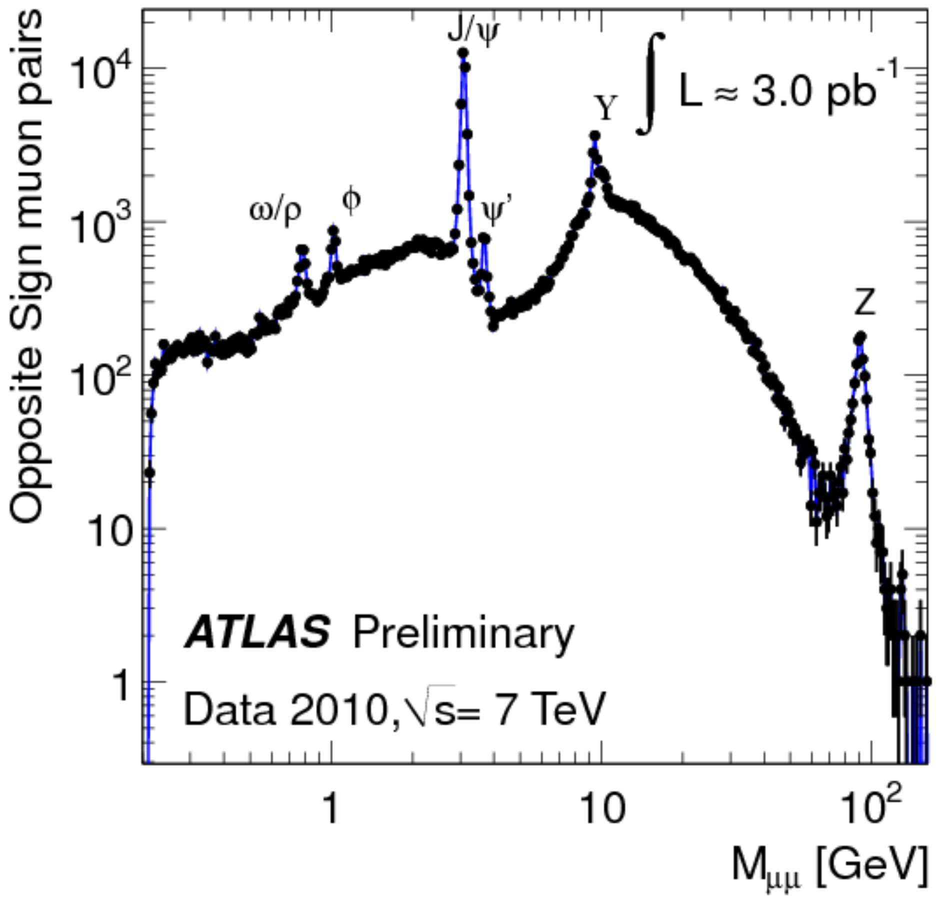




- J/ψ yield normalized to R_{coll}^{i} and divided by the peripheral yield,
  - Vertical error bars: statistical uncertainty, shaded regions: statistical and systematic uncertainties,
- We observe a centrality dependent suppression of the J/ψ yield,
  - Probability of no suppression: $p(\chi^2, ndof) = 0.11\%$. (including systematics in χ^2),
- ALICE shows weaker suppression than ATLAS but at much larger $|\eta|$ and lower p_T.

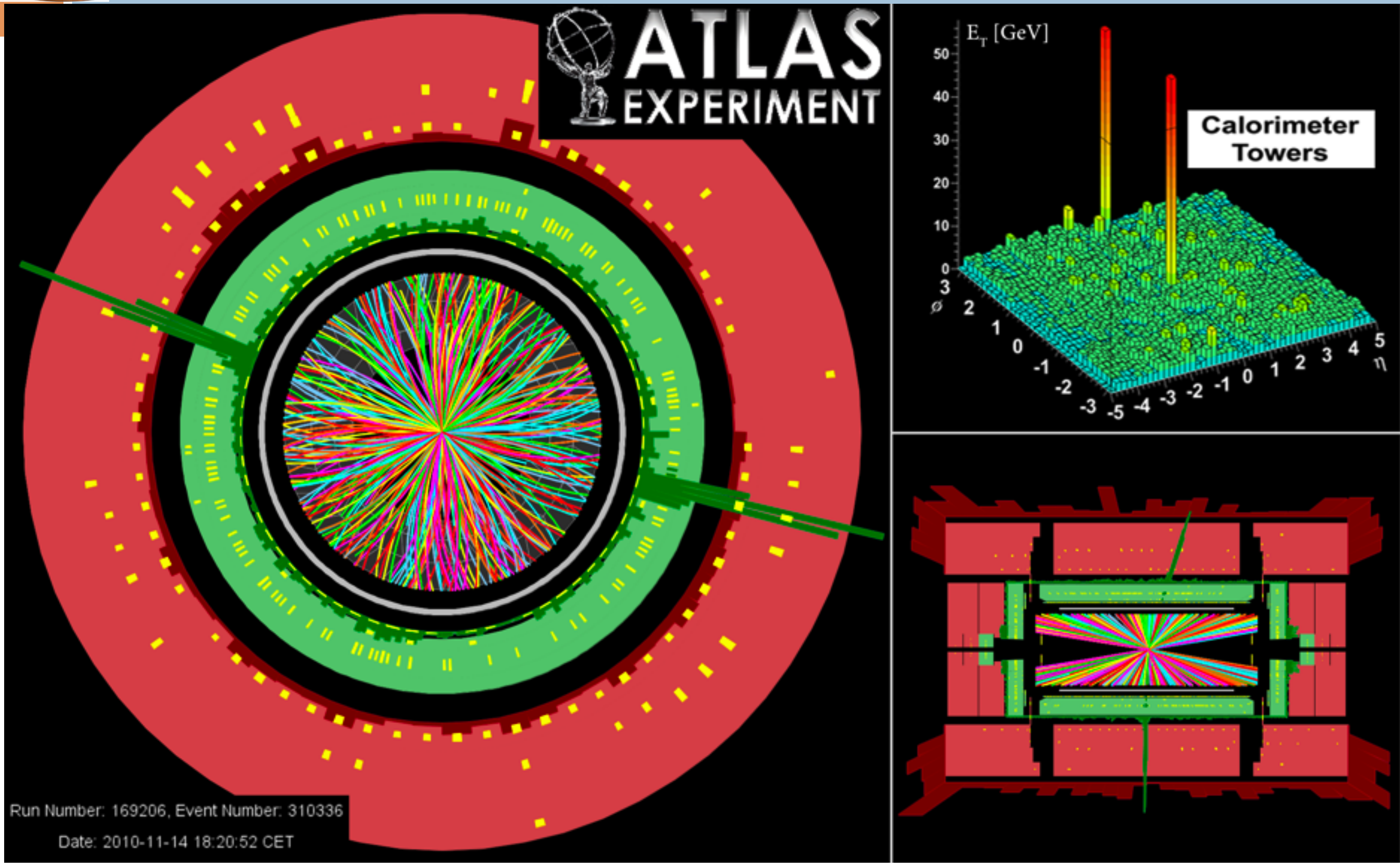
More results to come soon

pp data

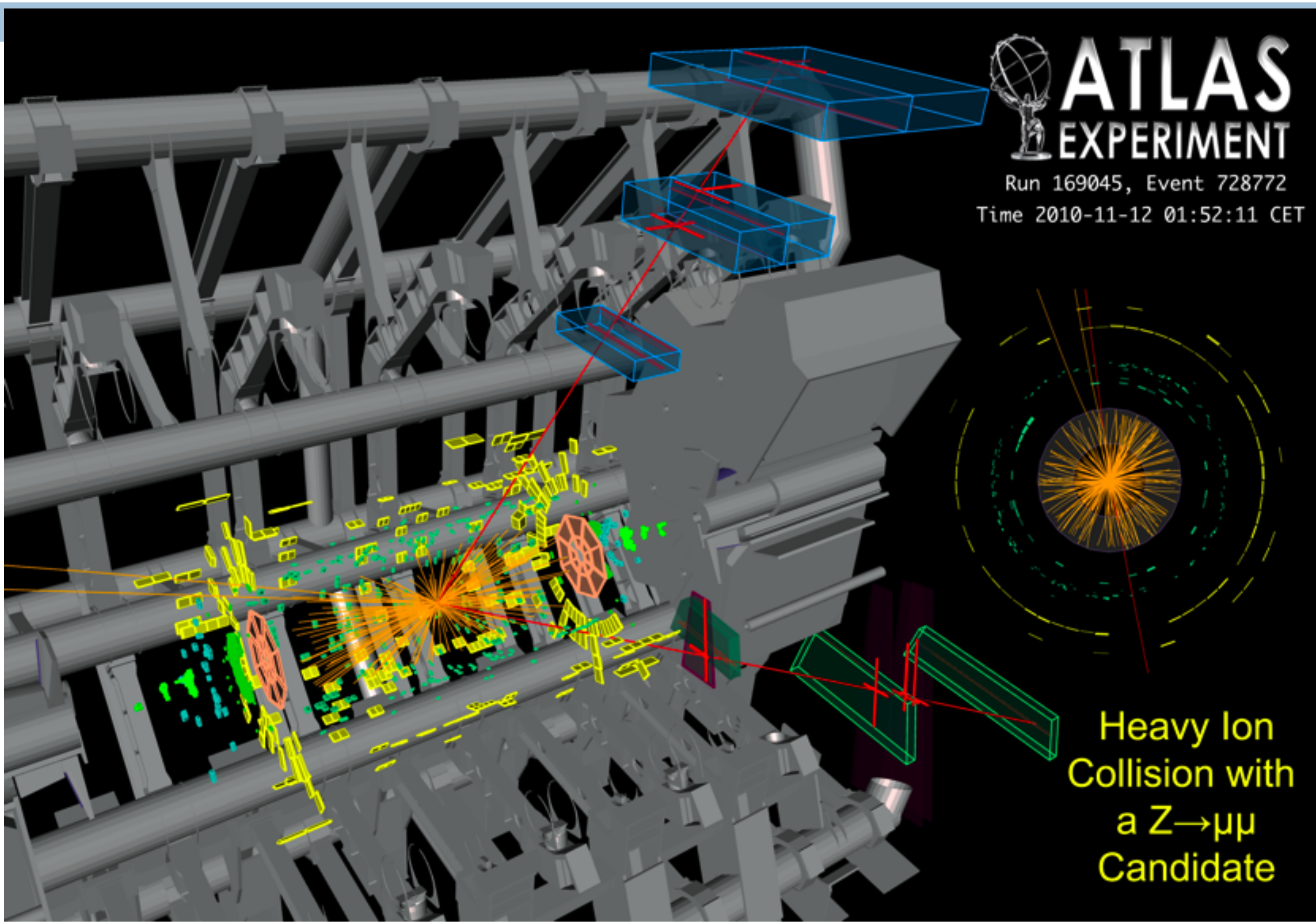


- ATLAS published results on $J/\psi \rightarrow \mu\ \mu$ studies in PbPb collisions so far,
- It is fully capable to perform also other measurements similarly as in pp collisions,
  - See a talk by M. Biglietti on Tuesday,
- Further PbPb results will be reported soon.

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



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



Z production

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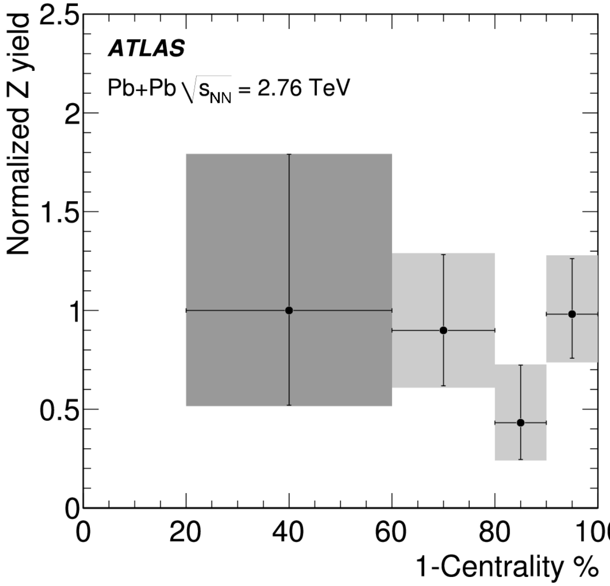
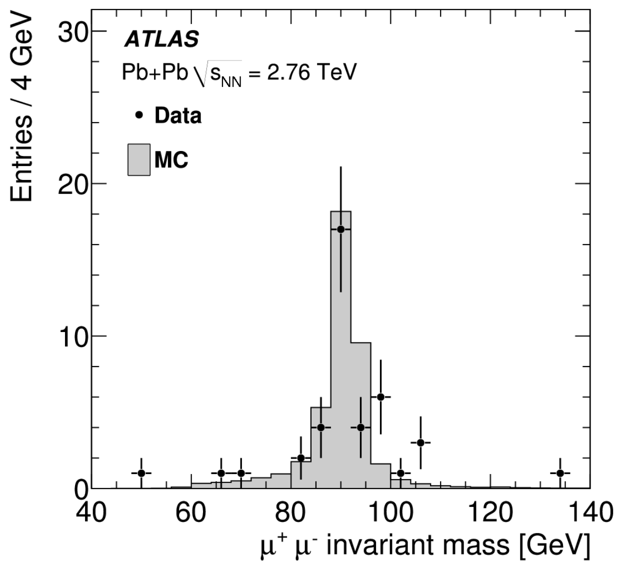


Analysis selection similar to J/ψ:
- Integrated luminosity analyzed: 7 μ b^{-1},
- Z→$\mu^+\mu^-$ channel explored,
- Primary vertex required in the minimum bias-triggered data sample,
- Muons combined in the Inner Tracker and Muon Spectrometer with p_T>20 GeV and | η | <2.5.



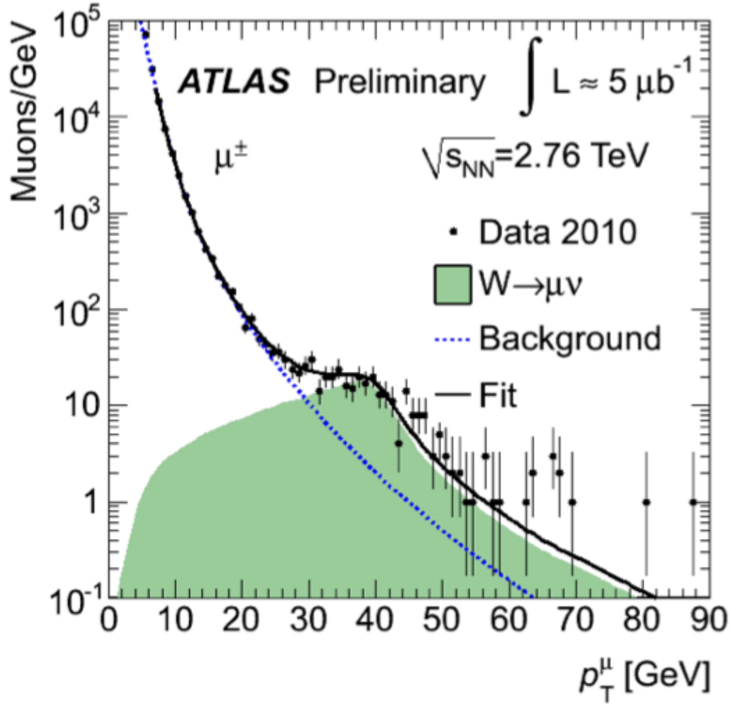
✓ First published observation of the Z boson peak in PbPb collisions at the LHC,

✓ 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.

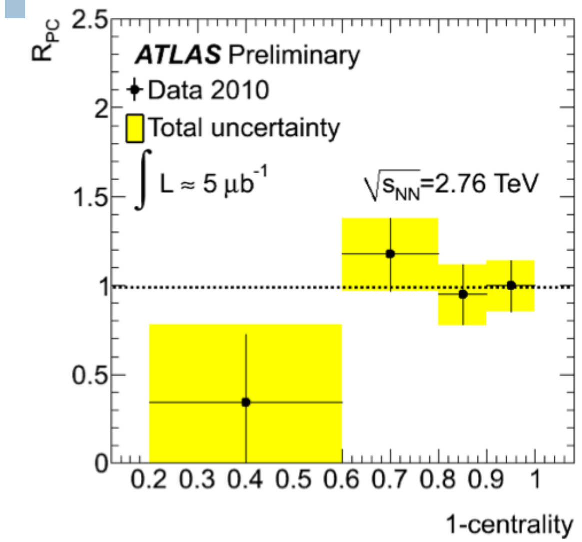
W production

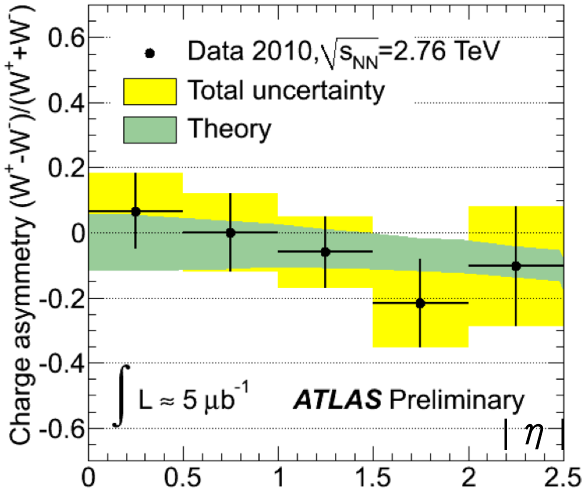
- Theory predicts an order of magnitude more W than Z produced at 2.76 TeV,
- Measurement of $W \rightarrow \mu\ \nu$ requires missing energy term to be reconstructed, which is unreliable in a Pb+Pb environment,
- Therefore, we try to rely only on a p_T distribution of muons
  - Muons from W are on average 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.

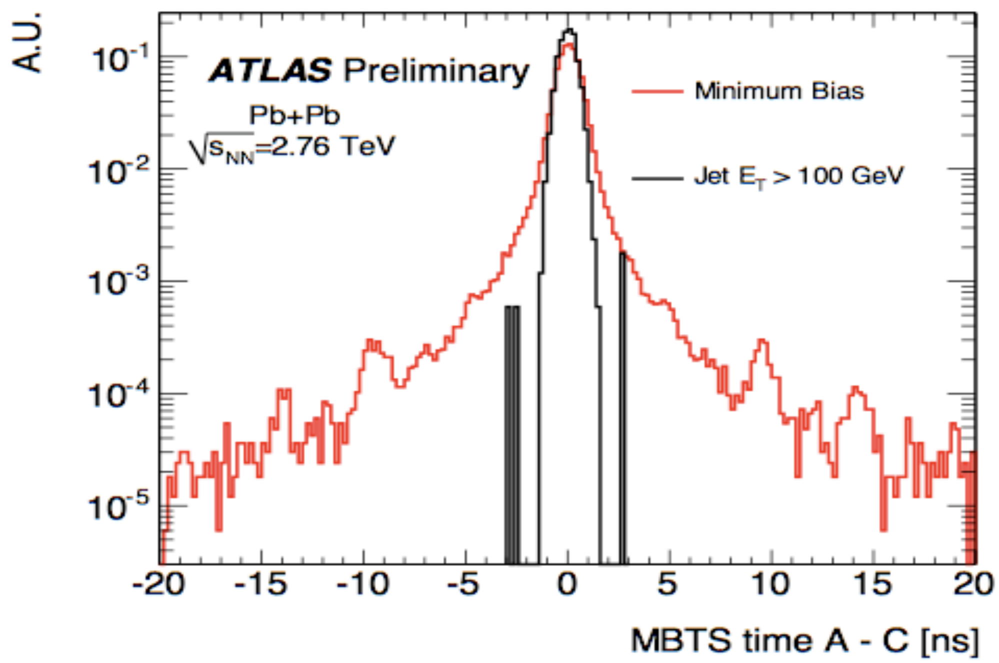
Summary

- First measurements of J/ψ, Z and W production in muon channels in Pb+Pb collisions at $\mathrm{sqrt}(s_{NN})$=2.76 TeV in ATLAS were presented,
- Observation of suppression of J/ψ in deconfined matter confirms results from earlier lower energy experiments,
- Observation of no suppression for W bosons confirms that they are produced at the initial phase of the collisions and that neither the W nor the muon interact with the medium,
- Ratio of W/Z production in Pb+Pb collisions as well as the $W+/W-$ ratio agree with the Standard Model predictions,
- $W \rightarrow \mu$ charge asymmetry versus pseudorapidity was presented
  - Limited statistics, but we expect that higher integrated luminosity will allow us to explore the nuclear modifications to the PDF,
- Future Plans
  - 5-10 times more Pb-Pb statistics should be available by the end of 2011,
  - Use runs with p-p collisions at 2.76 TeV for direct comparisons.

Back-up slides

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

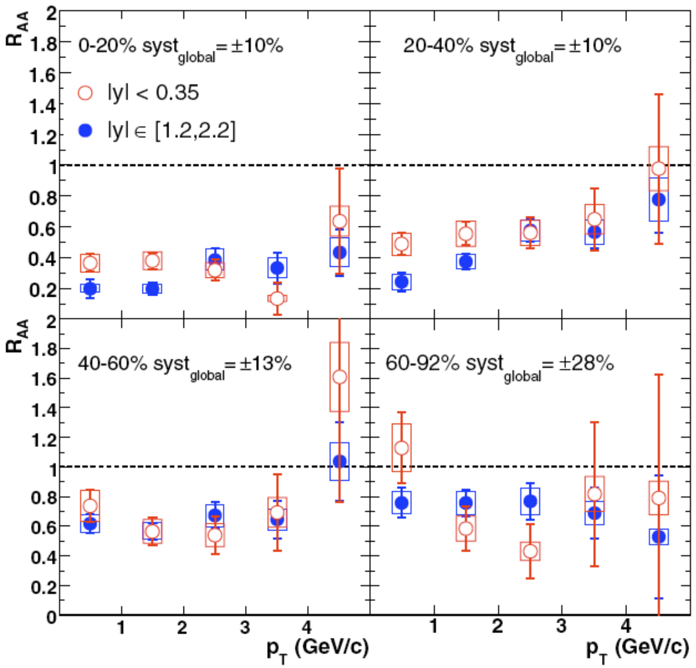


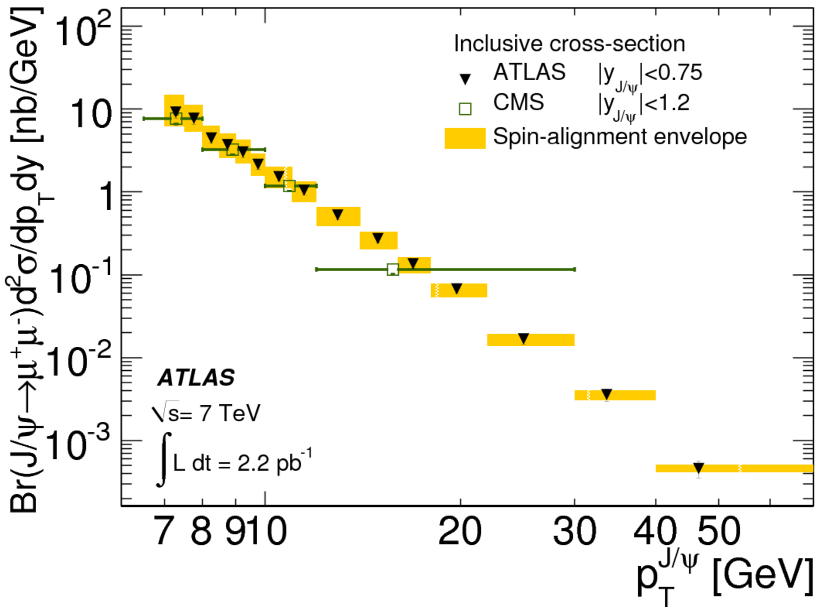
FIG. 3 (color online). J/ψ R_{AA} versus p_T for several centrality bins in Au + Au collisions. Mid (forward) rapidity data are shown with open (solid) circles. See text for description of the errors and Ref. [21] for data tables.

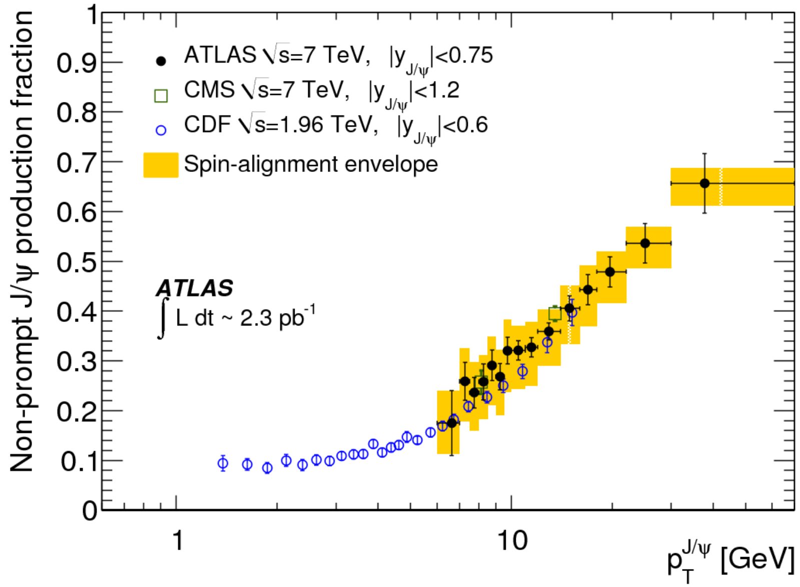
- J/ψ suppression in HI collisions as a function of centrality already observed in past experiments
- PHENIX measurement in Au-Au collisions @ $\sqrt{S_{NN}}$=200 GeV

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

J/ψ in pp in ATLAS

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





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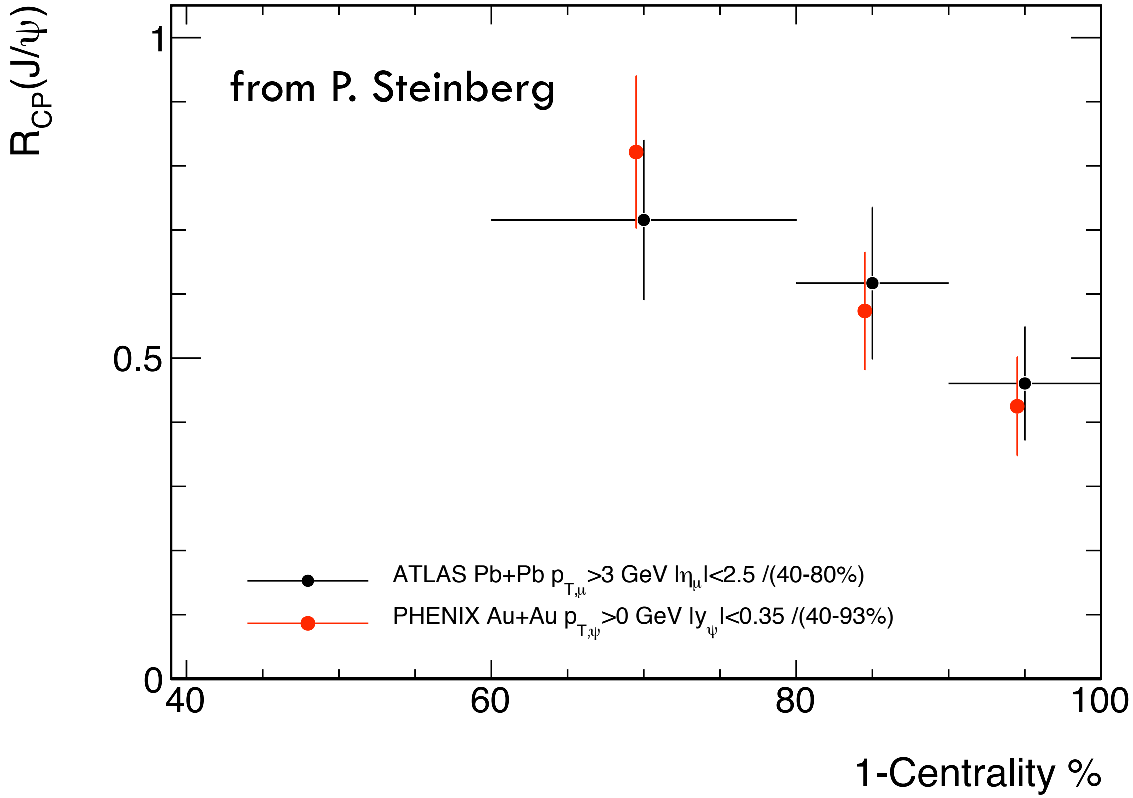
J/ψ suppression
Comparison with other measurements



$$R_{cp} = \frac{N_{cent}/Width_{cent}}{N_{peri}/Width_{peri}} R_{coll} \frac{1}{\varepsilon_{relative}}$$

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)