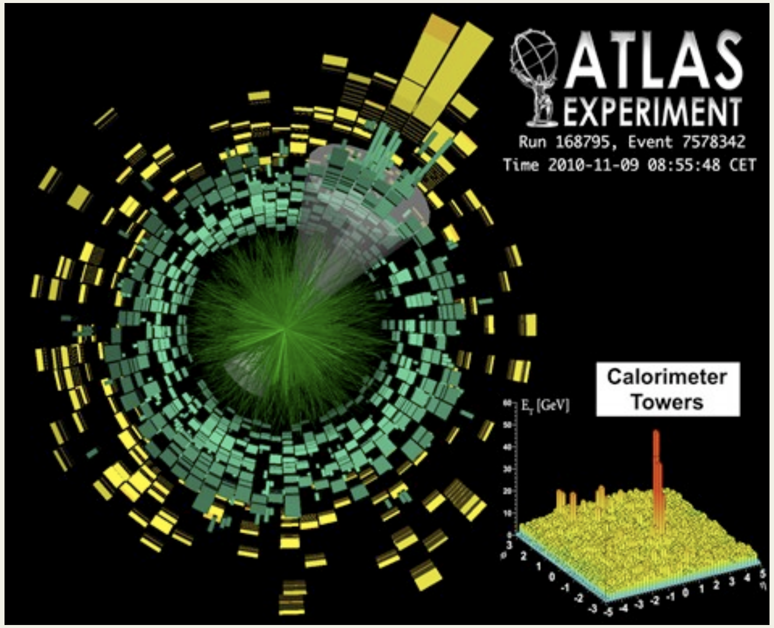

Heavy Ion Physics with the ATLAS Detector

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On behalf of the ATLAS Collaboration

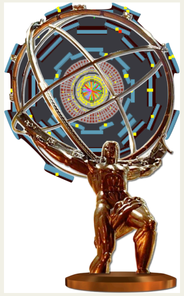
Epiphany, Kraków, Jan 10-12th, 2011

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: a factor 14!

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

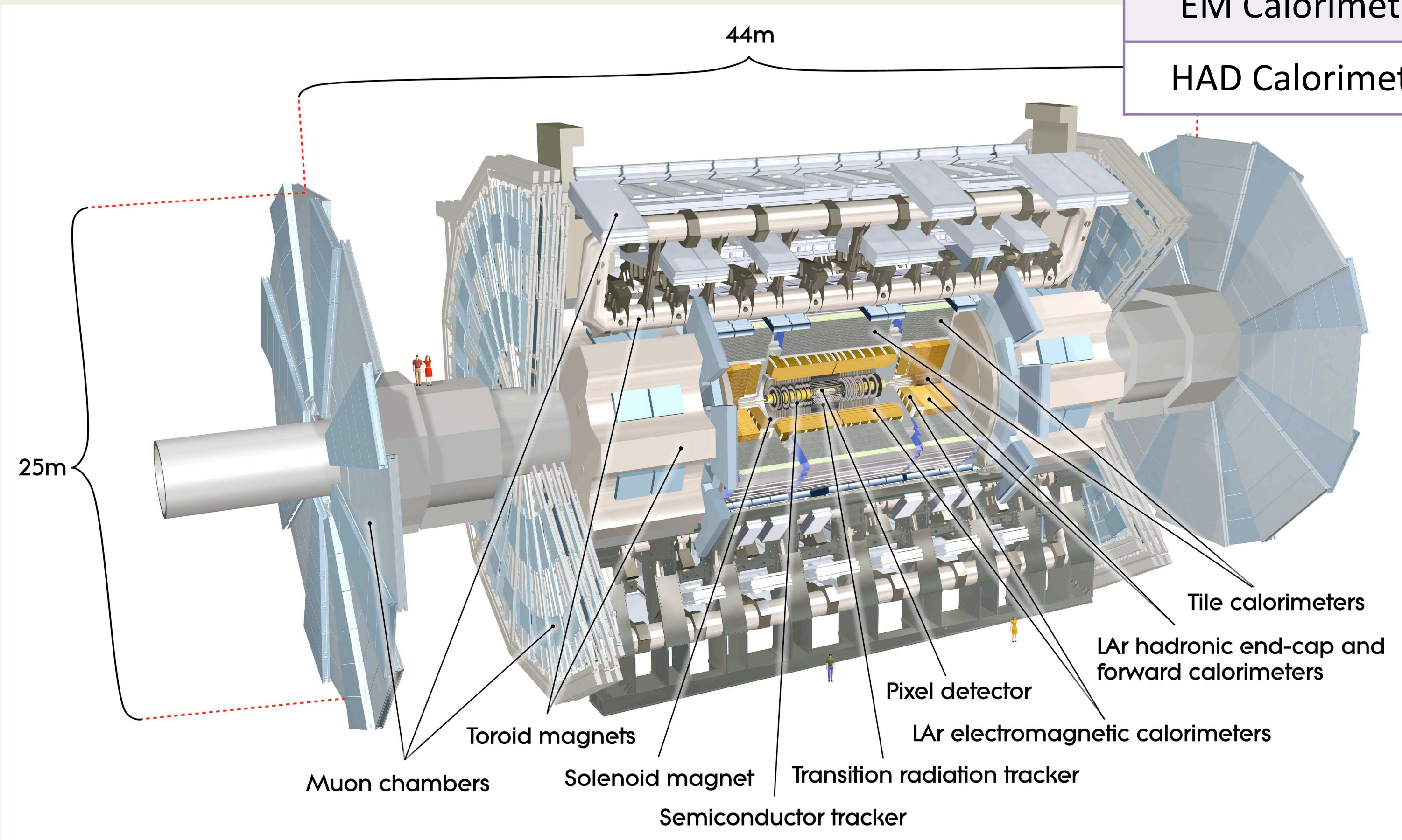
- Highest temperatures ever achieved in the laboratory,
- Access to new probes and processes,
- In this talk two topics are discussed:
  - Observation of a di-jet asymmetry in E_T,
  - Di-muon production: J/ψ and Z.



ATLAS Detector

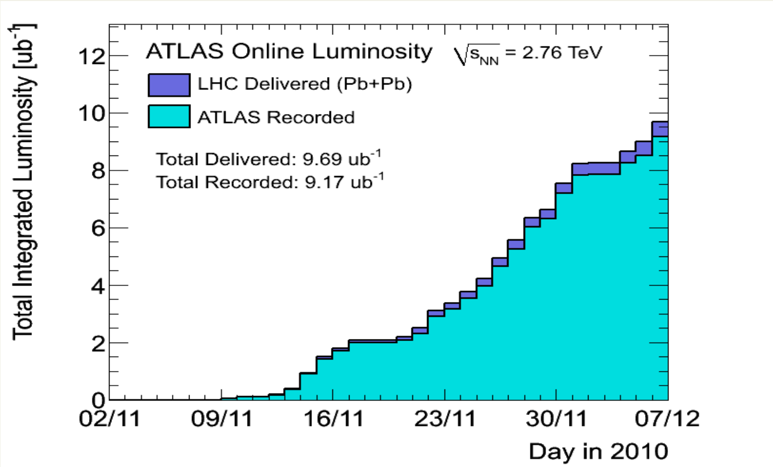
Measurements	η coverage
Inner Tracker	(-2.5, 2.5)
Muon Spectrometer	(-2.7, 2.7)
EM Calorimeter	(-3.2, 3.2)
HAD Calorimeter	(-4.9, 4.9)

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



Full azimuthal acceptance

Heavy Ion Run in 2010



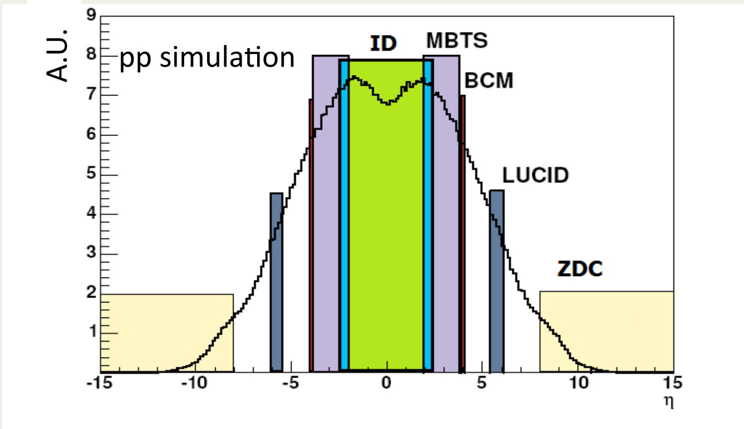
- First heavy ion run at $\sqrt{s_{NN}} = 2.76 TeV$
  - Nov 4th-Dec 6th, 2010,
  - ATLAS recorded 9.17 μb^{-1} of PbPb data,
  - Data recording efficiency > 95%
  - Fraction of data passing data-quality criteria > 99%

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

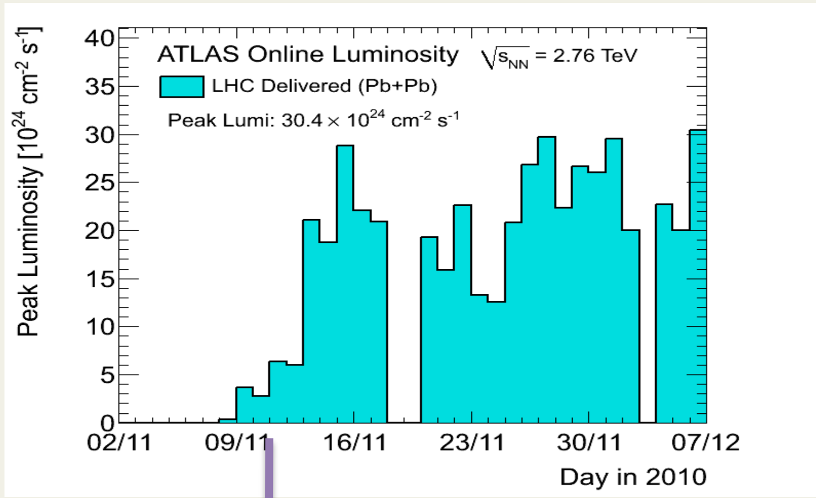
Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV between November 8th and 17th (in %).

Data Triggering

Triggering strategy:
record to tape a minimum bias sample,
trigger efficiency 100% for n_{tracks}>20.



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



Only LVL1 trigger

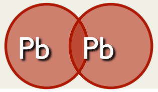
Above $5x10^{24}cm^{-2}s^{-1}$ High Level Trigger (HLT) applied to filter out beam backgrounds and improve event selection. No selection based on physics objects like jets, muons, etc .

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

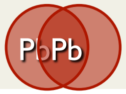
Minimum bias, centrality

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

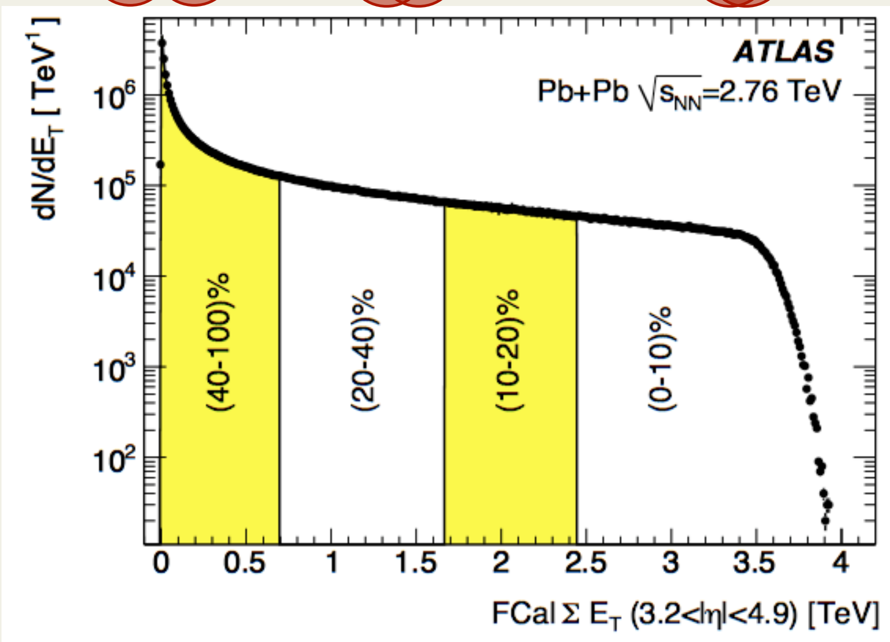
Peripheral collisions

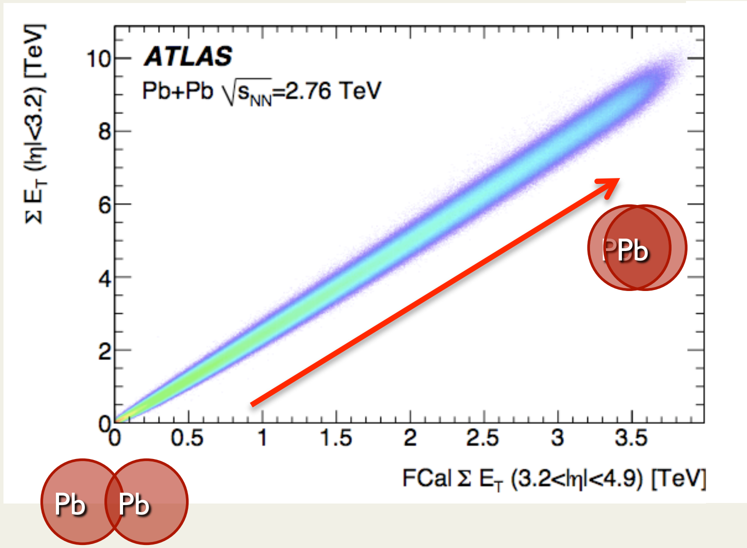


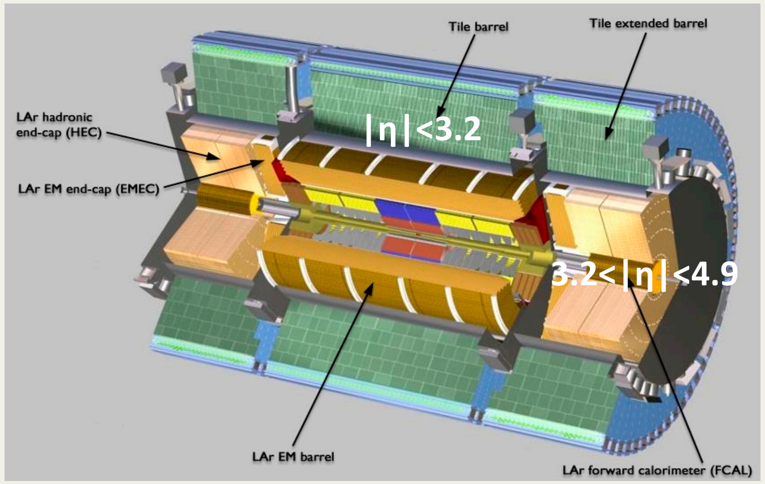
Mid-central collisions



Central collisions



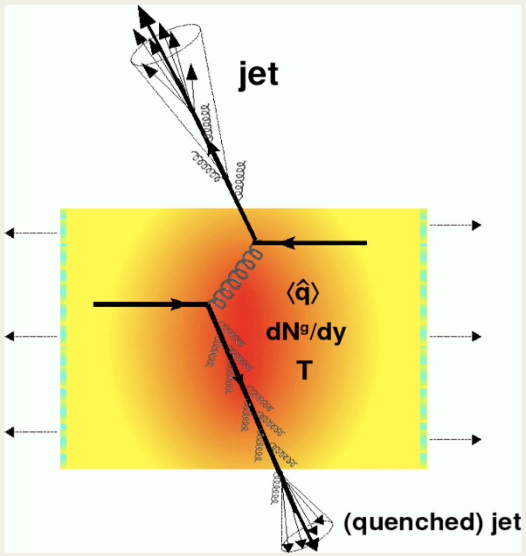


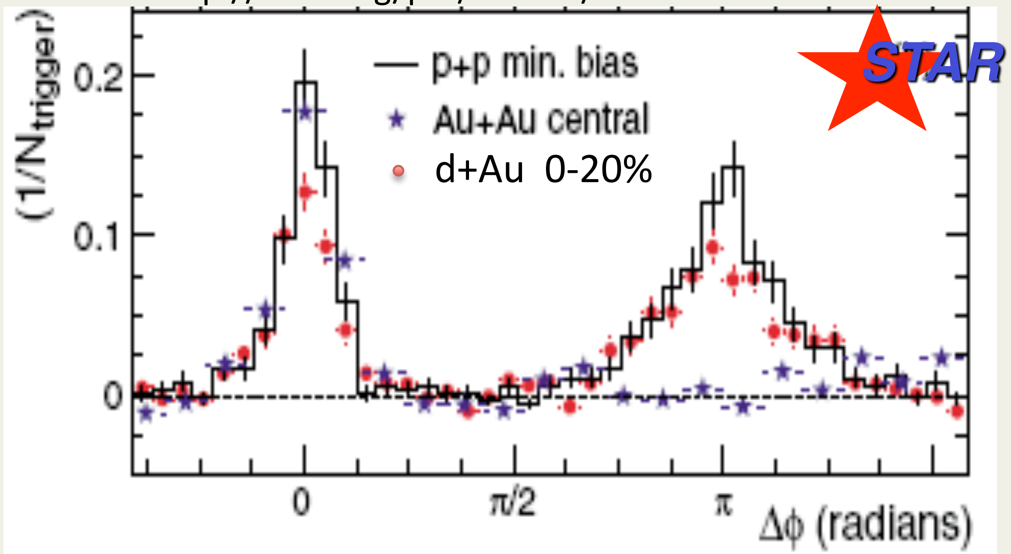


Jet quenching

Key question: How do parton showers in hot, dense medium differ from those in vacuum?

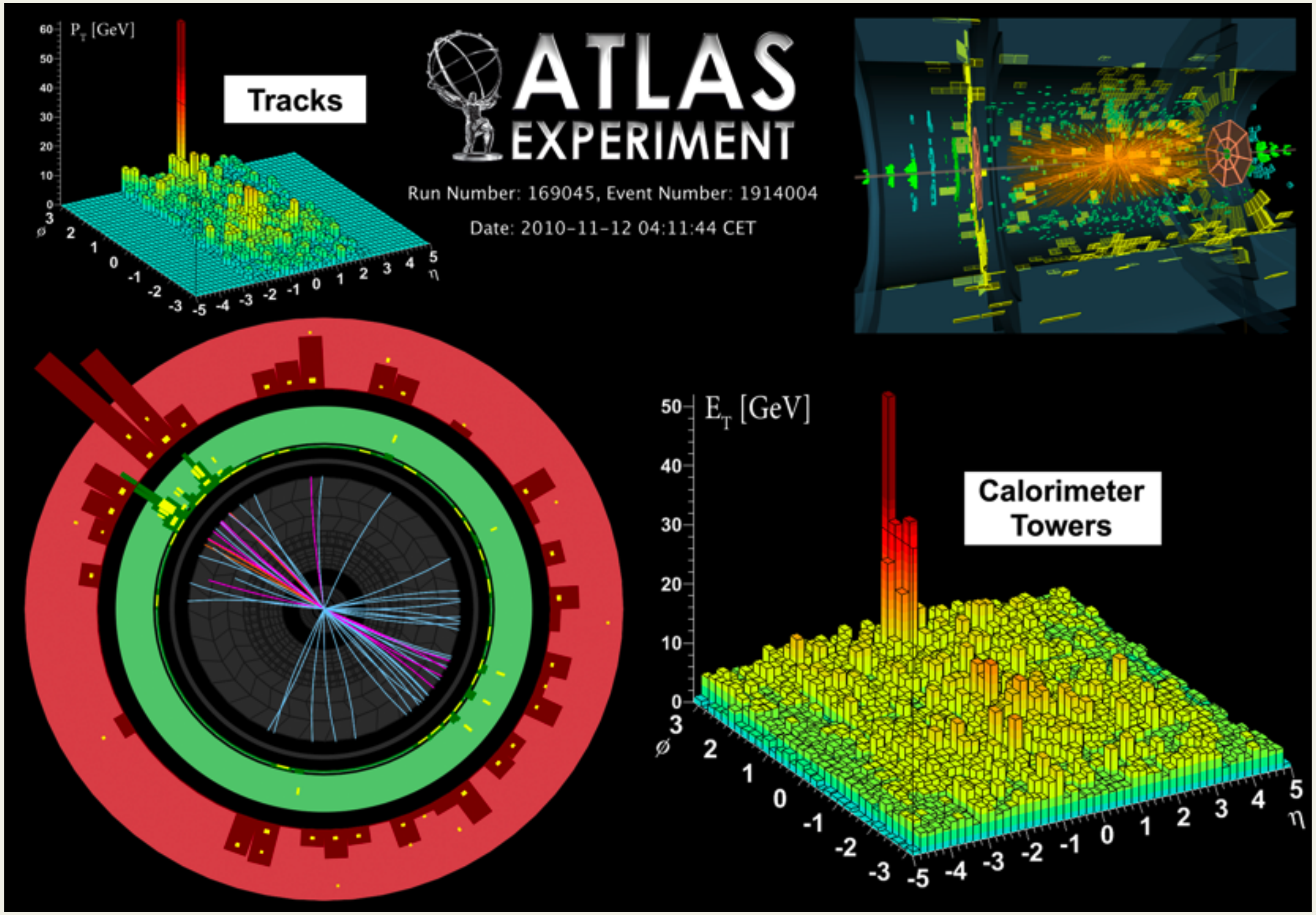
http://arXiv.org/pdf/nucl-ex/0306024v3





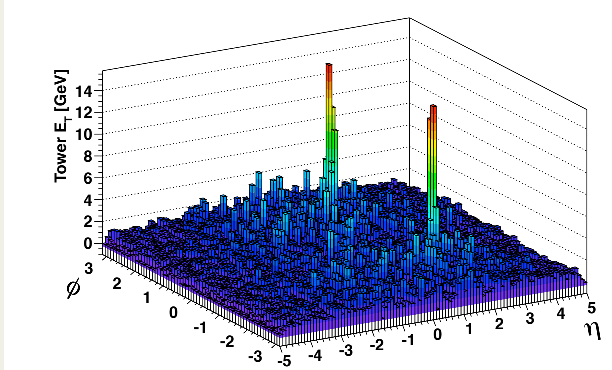
- Strong quenching effects were observed in single particle spectra and particle correlations at $\sqrt{s_{NN}}$=200 GeV at RHIC (indirect observation),
- Direct jet reconstruction possible at RHIC but very difficult (jet energies comparable to the underlying event energy),
- NLO QCD calculations predict abundant rates of jets above 100 GeV at the LHC,
  - This opens perspectives for the LHC experiments.

Asymmetric jets

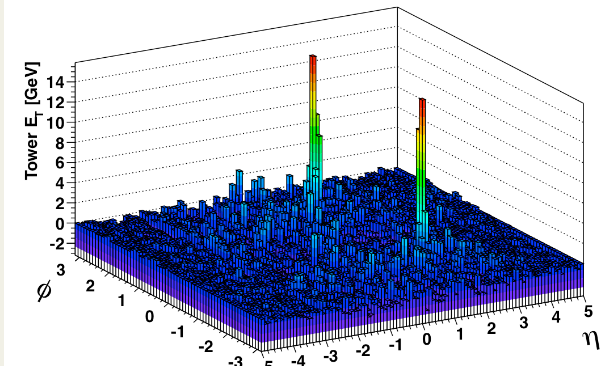


Centrality dependent di-jet asymmetry

- Use R = 0.4 anti-k_T jets
  - calibrated using energy density cell weighting,
  - underlying event (UE) estimated and subtracted for each longitudinal layer and for 100 slices of $\Delta\eta = 0.1$,
- Select events with leading jet, $E_{T,1} > 100$ GeV, $|\eta| < 2.8$
  - 1693 events after cuts in 1.7 μb^{-1}
- Sub-leading: highest E_T jet in opposite hemisphere, $\Delta\phi = |\phi_1 - \phi_2| > \pi/2$ with $E_{T,2} > 25$ GeV, $|\eta| < 2.8$
  - 5% of selected have no sub-leading jet
- Introduce new variable to quantify di-jet imbalance
  - Not used before in jet quenching literature:
    - **Asymmetry:** $$A_j = \frac{E_{T,1} - E_{T,2}}{E_{T,1} + E_{T,2}}$$
- Measurement of an azimuthal angle separation, $\Delta\phi$.



Before UE subtraction



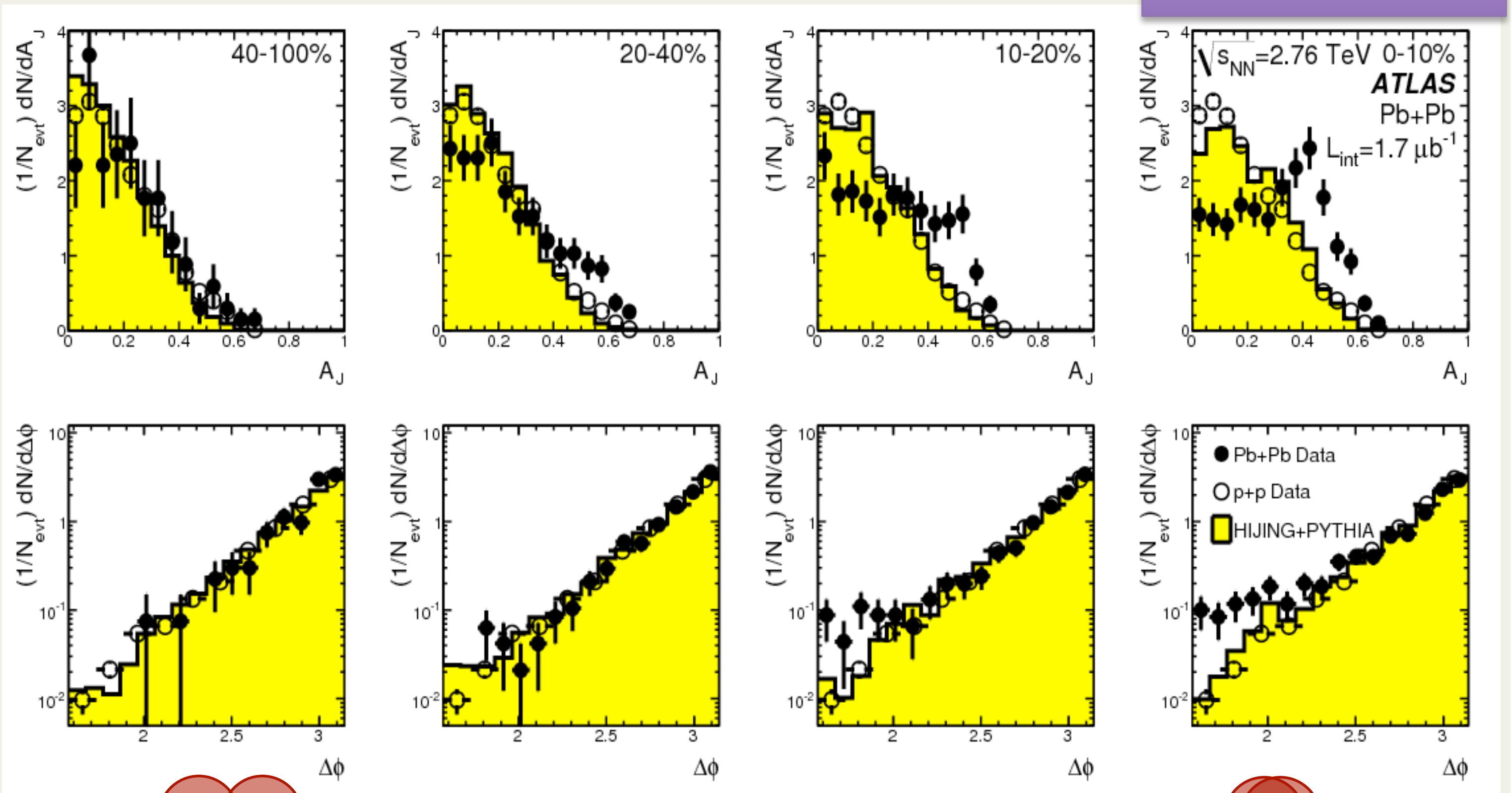
After UE subtraction

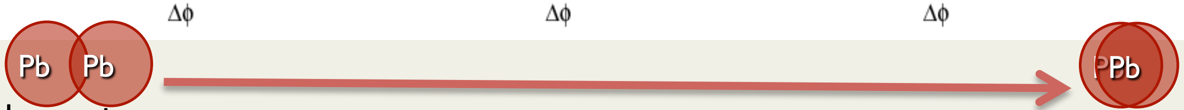
Di-jet energy asymmetry

First ATLAS HI paper: arXiv:1011.6182, Phys. Rev. Lett. 105, 252303

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

$$\Delta\phi = |\phi_1 - \phi_2|$$

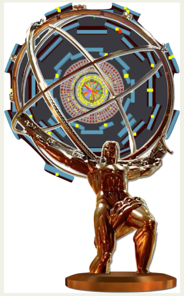


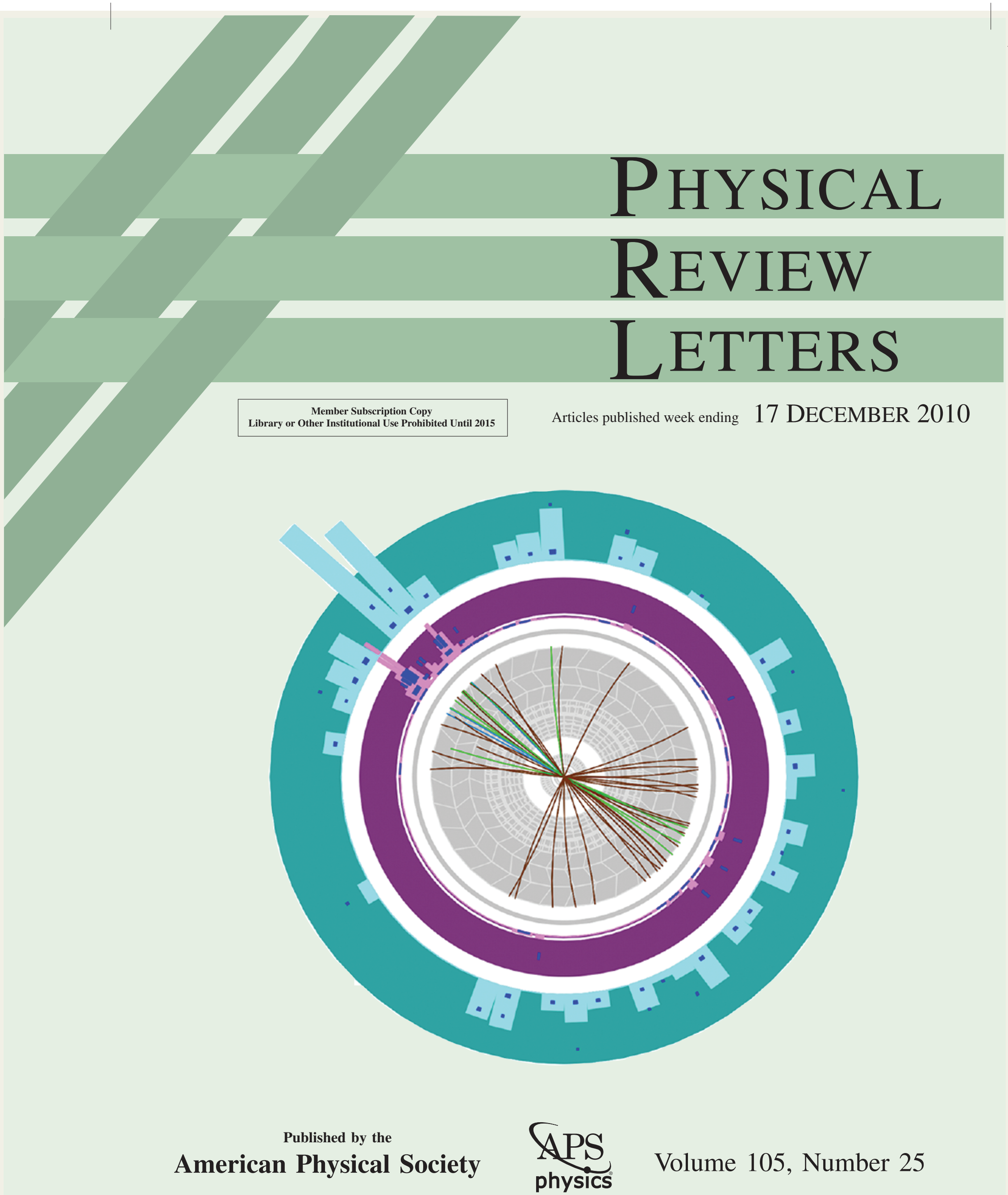


Peripheral events

Central events

A_j broadens with centrality, the mean shifts to higher values, a new peak visible at higher centralities.
The Δϕ distribution predominantly is still back to back at higher centrality values.

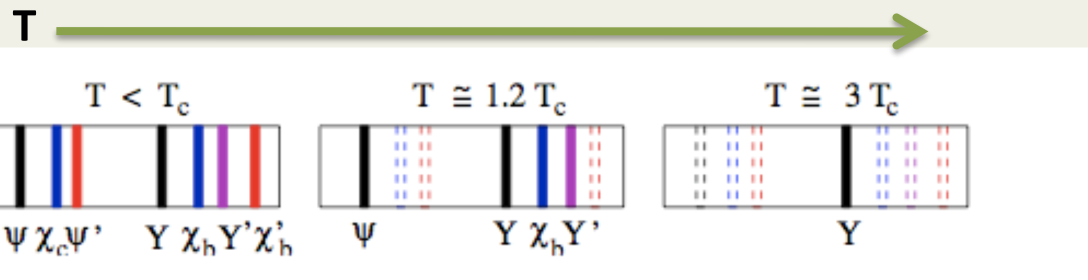




The di-jet asymmetry results published in December 2010 in PRL with the ATLAS event display on the cover.

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,

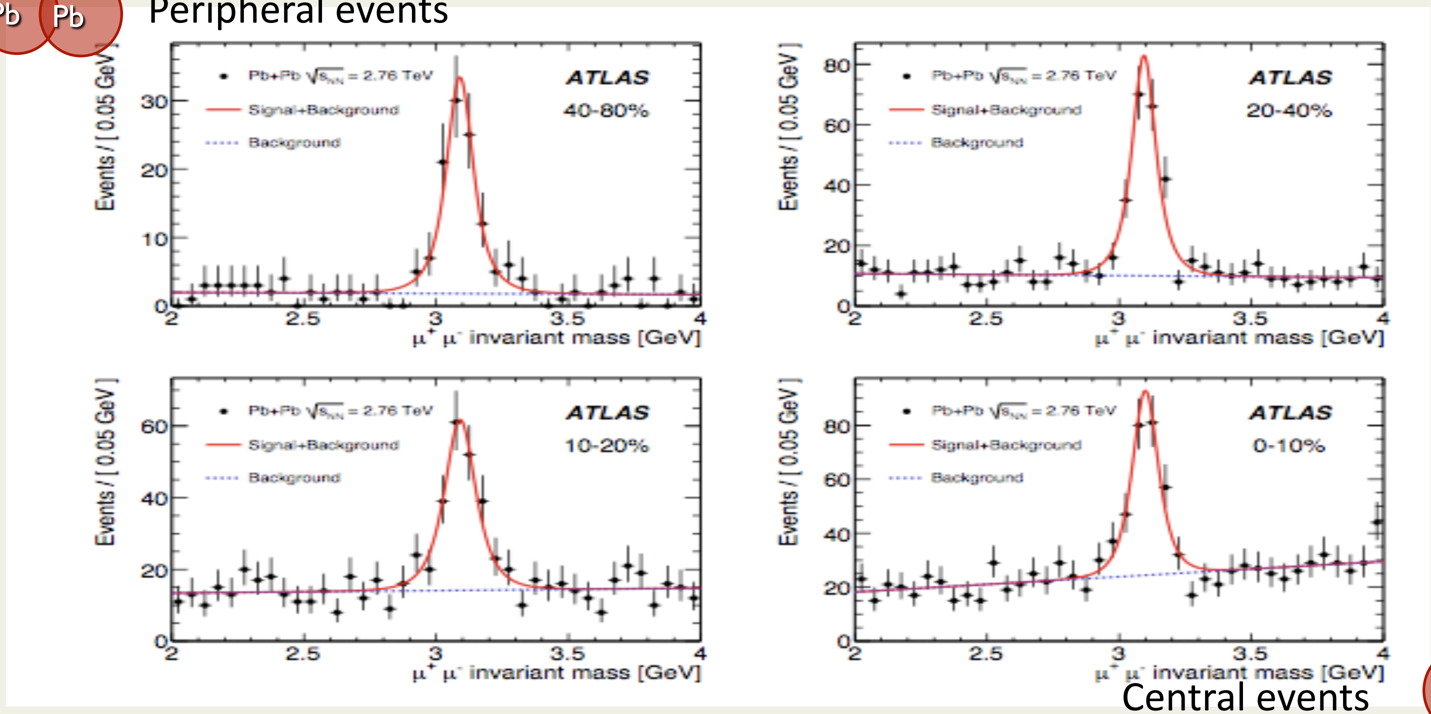


  - J/ψ suppression has already been seen at SPS and RHIC but details are poorly understood, interplay of cold and hot effects,
  - J/ψ enhancement by regeneration of J/ψ from the (large) number of uncorrelated cc pairs could also be tested at the LHC,
- Weak bosons have not been observed in Au-Au collisions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

J/ψ production in ATLAS

Analysis selection:
- Integrated luminosity analyzed: 6.7 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.

Pb Pb Peripheral events



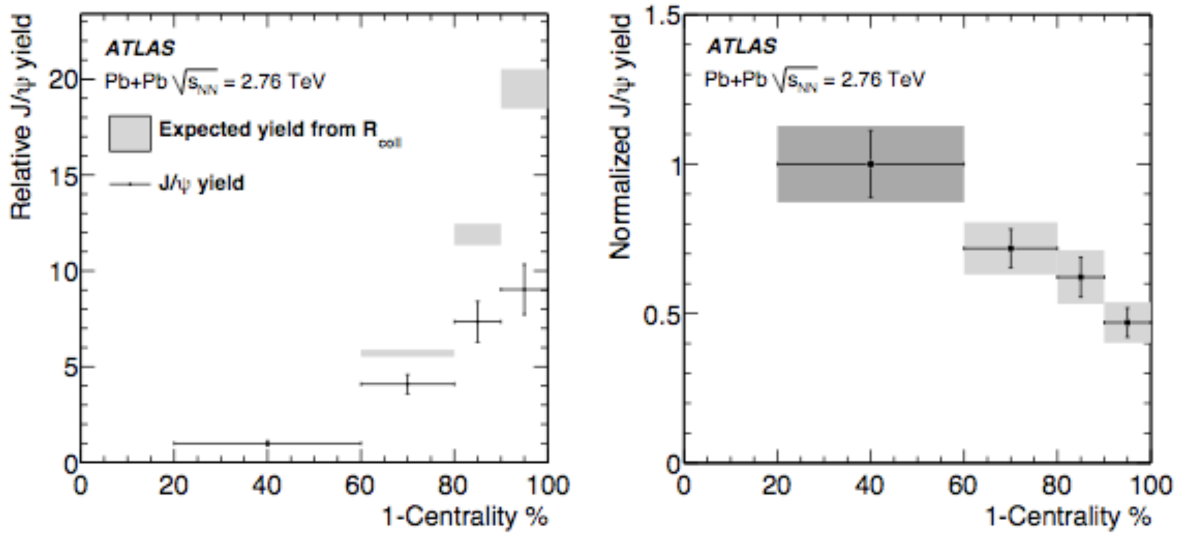
Central events PPb

J/ψ yields in each centrality bin are obtained using a sideband technique.
Fits are used as a cross check.

ATLAS paper:
arXiv:1012.5419,
Submitted to Phys Lett. B

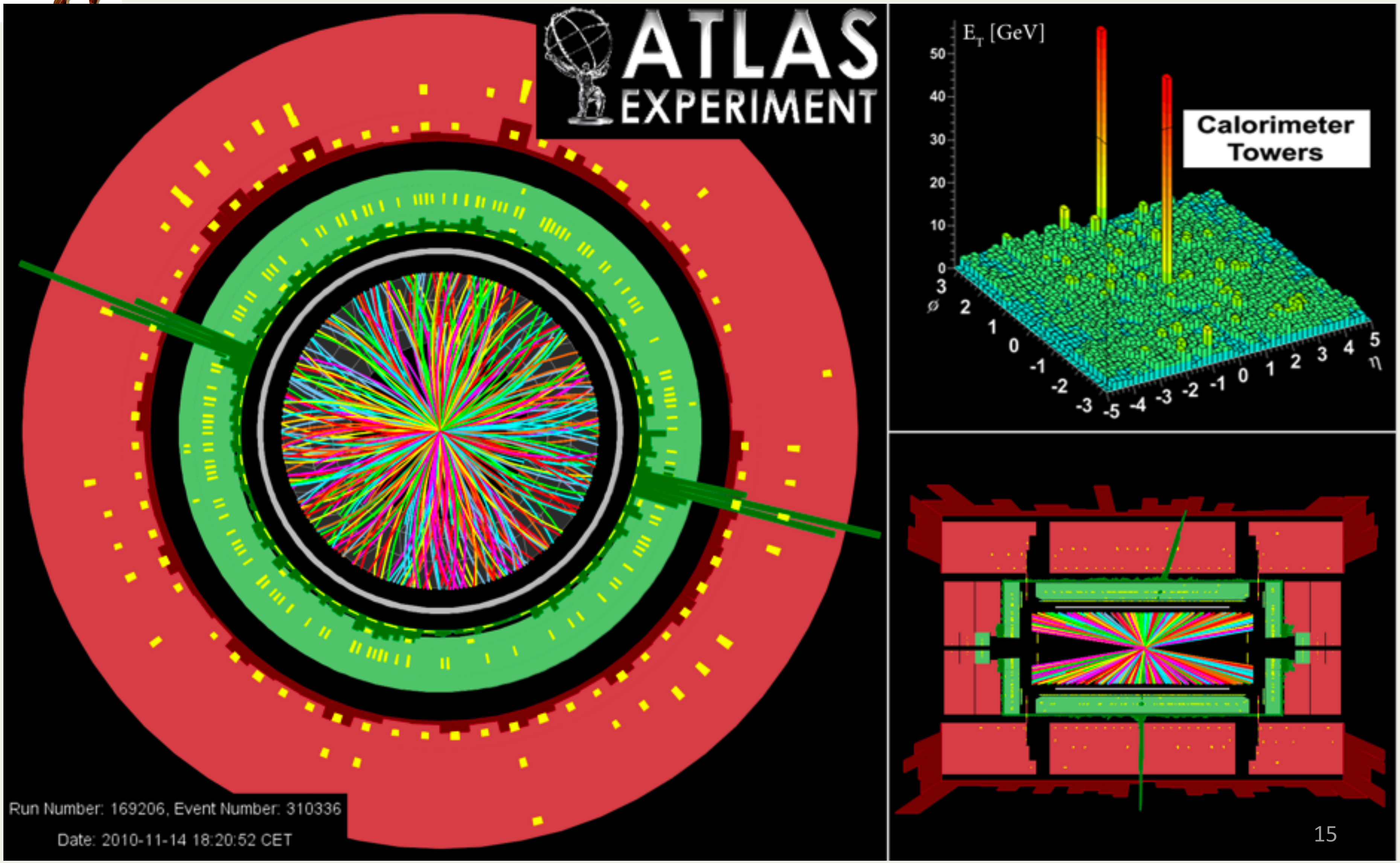
J/ψ suppression

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

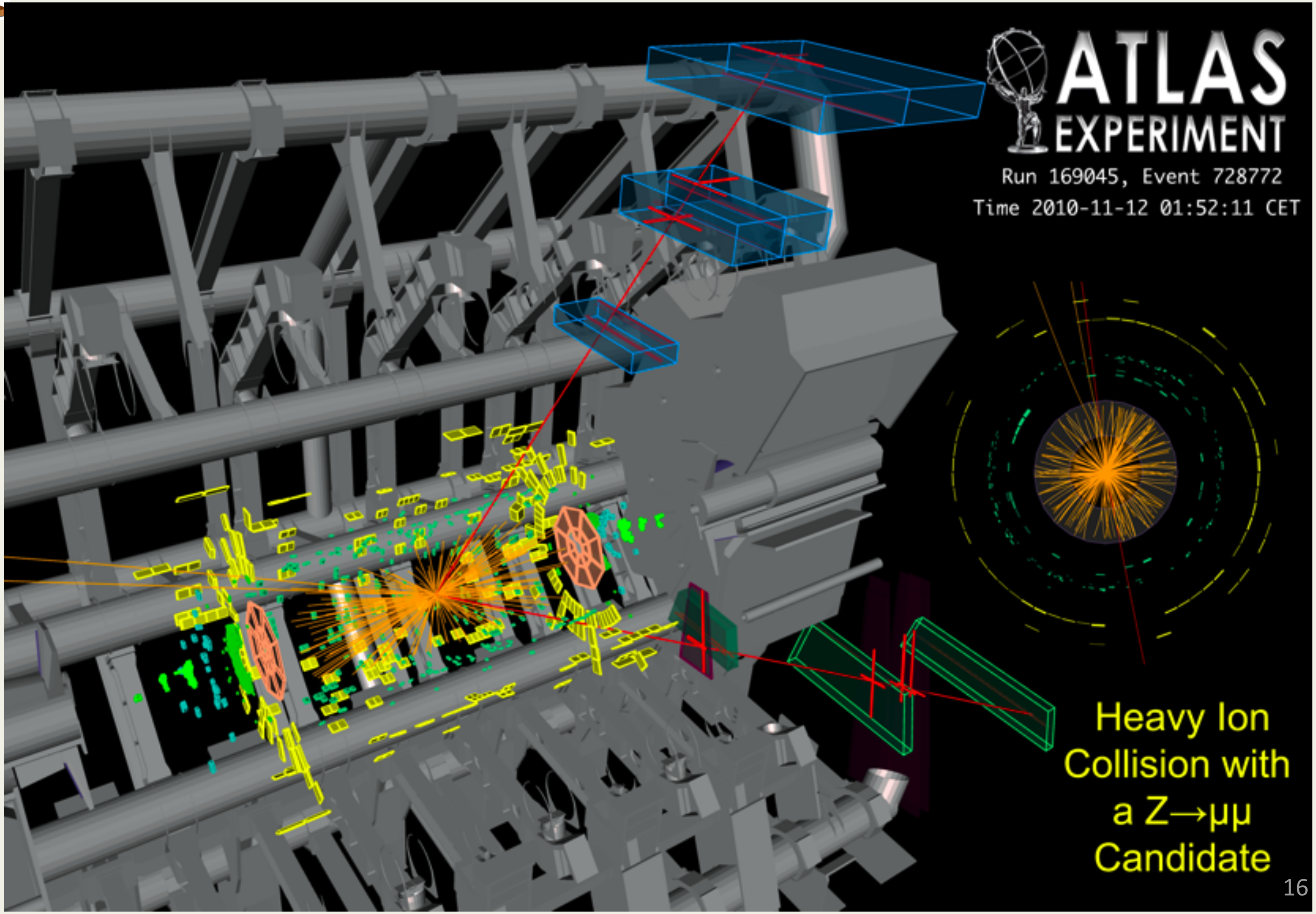


✓ Relative J/ψ yield normalized to the yield in the most peripheral bin 40-80%,
✓ Normalized J/ψ yield with a number of binary nucleon-nucleon collisions significantly decreases from peripheral to central collisions,
✓ Centrality dependence is found to be qualitatively similar to trends observed at previous, lower energy experiments.

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

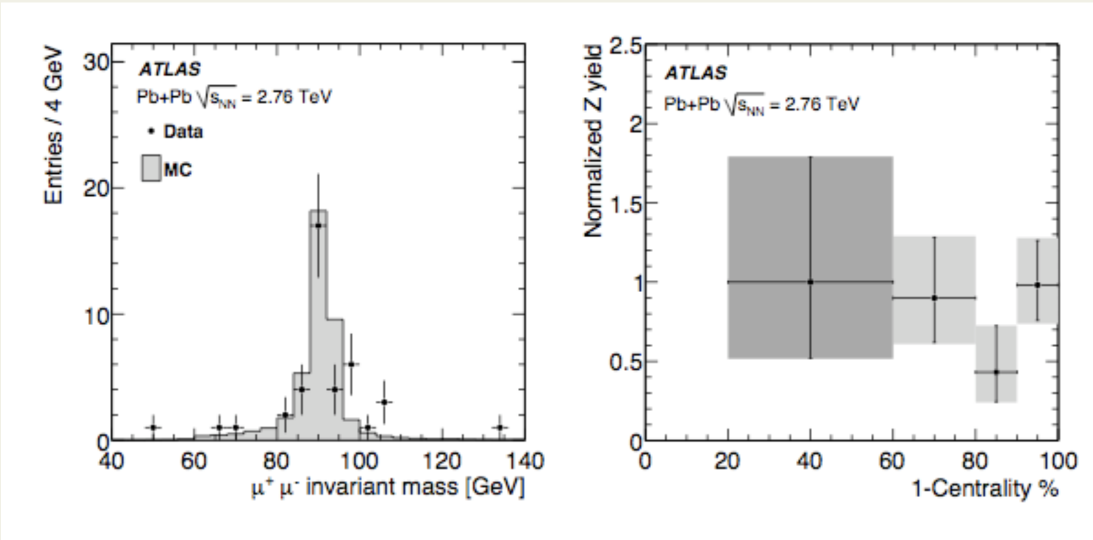


$Z \rightarrow \mu^+\mu^-$ candidate



Z production

Analysis selection similar to J/ψ:
- Integrated luminosity analyzed: 6.7 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 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.

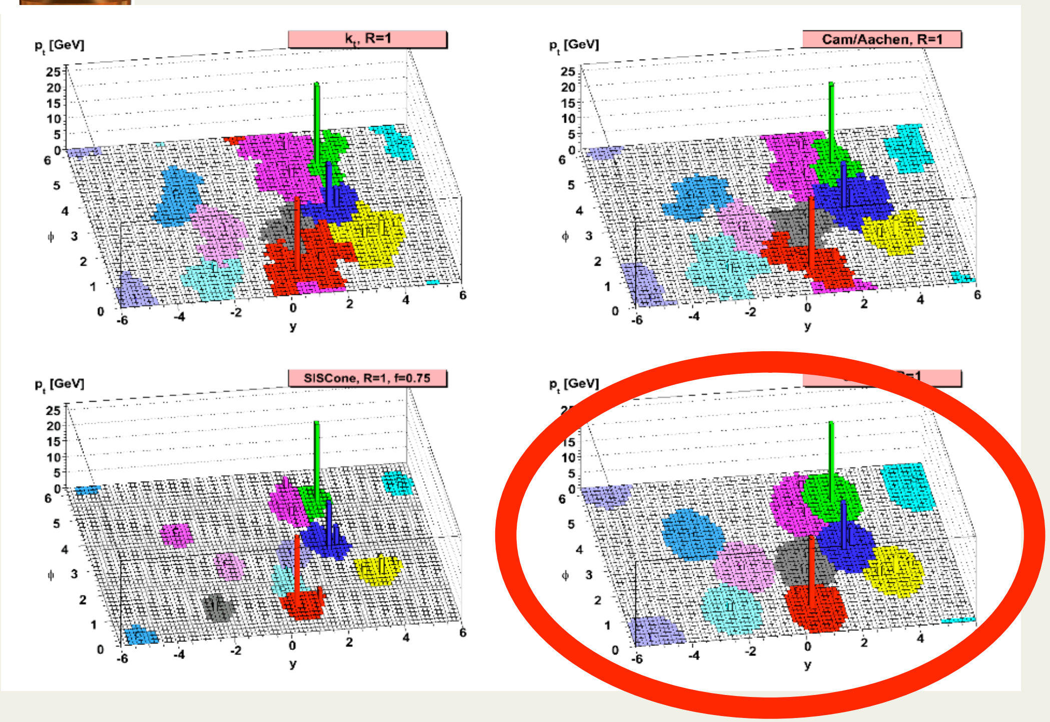
Summary

- ATLAS recorded first lead-lead data in Nov-Dec 2010,
  - LHC machine was performing excellently,
  - Integrated luminosity about 5 times higher than expected,
  - Many millions of minimum bias events on tape to analyze,
- First physics results are coming out
  - On di-jet asymmetry in E_T: arXiv:1011.6182, Phys. Rev. Lett. 105, 252303,
    - The analysis continues to understand the asymmetry phenomenon in more detail, and look at the properties of single jets as well,
  - On J/Ψ suppression, Z observation: arXiv:1012.5419, submitted to Phys Lett. B,
  - They show first evidence of a new era in heavy ion physics.

Back-up slides

Jet reconstruction (1)

Cacciari, M., Salam, G. P. and Soyez, G., *The anti-kt jet clustering algorithm*, Journal of High Energy Physics, 2008, 063



Use anti-k_t clustering algorithm

cone-like but
infrared and collinear safe

- Perform anti-k_T reconstruction prior to any background subtraction
  - R = 0.4 for main analysis
  - R = 0.2, 0.6 for cross-check (+ physics)
- Input: $\Delta\eta$ x $\Delta\phi$ = 0.1 x 0.1 towers

Jet reconstruction (2)

– Take maximum advantage of ATLAS segmentation

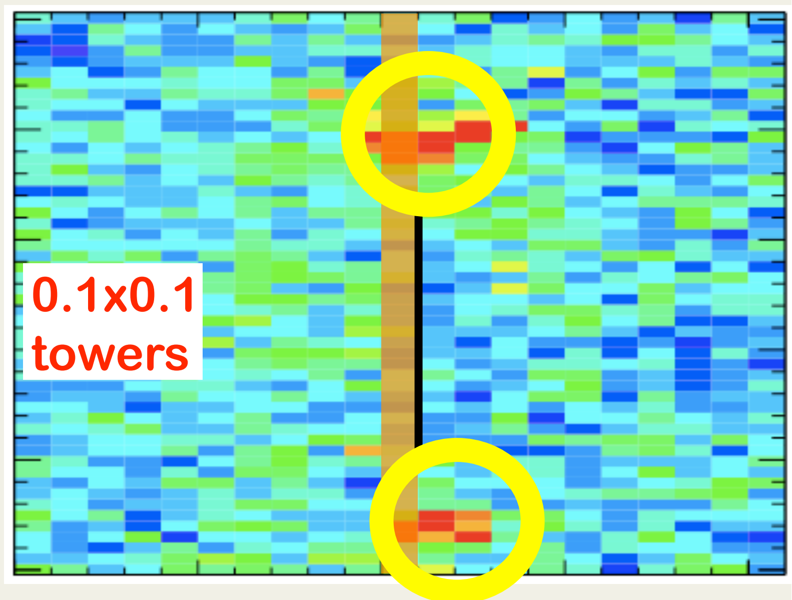
- Underlying event estimated and subtracted for each longitudinal layer and for 100 slices of $\Delta\eta = 0.1$
  - $E_{T\,sub}^{cell} = E_T^{cell} - \rho^{layer}(\eta) \times A^{cell}$
- ρ is energy density estimated event-by-event
  - From average over $0 < \phi < 2\pi$

– Avoid biasing ρ due to jets

- Using anti-k_T jets:
  - Exclude cells from ρ if

$$D = E_{T\,max}^{tower} / \langle E_T^{tower} \rangle > 5$$

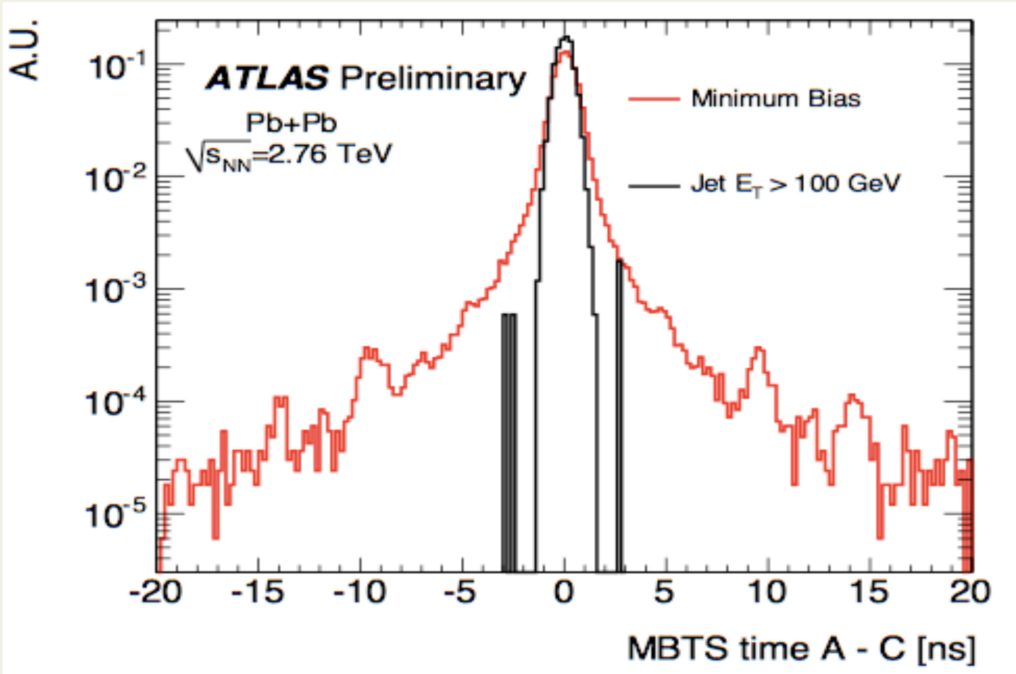
- Cross check
  - Sliding Window algorithm



– NO jet removal on basis of D, or any other quantity

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

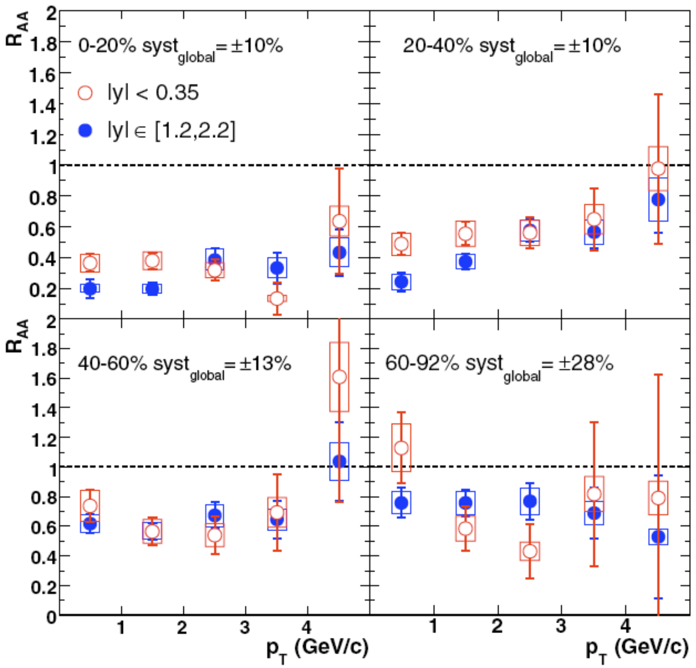


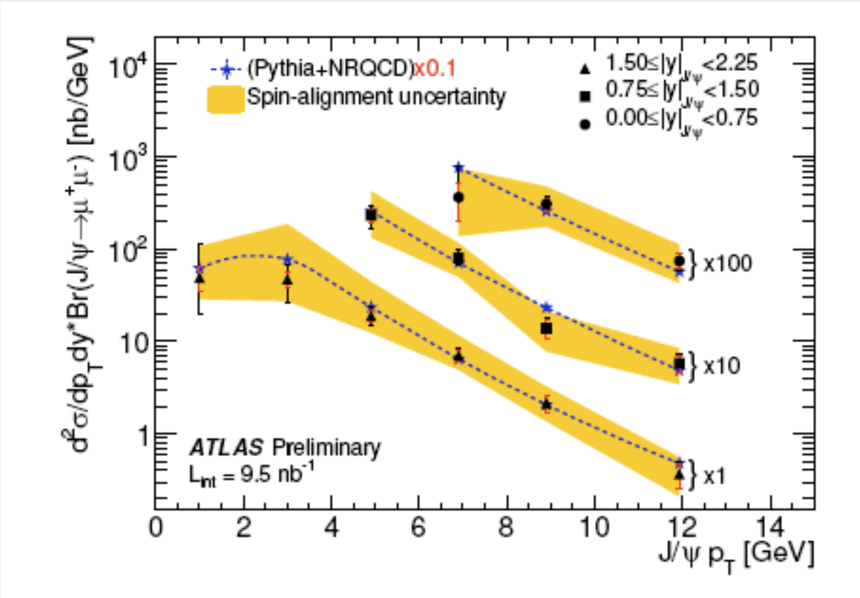
FIG. 3 (color online). J/ψ R_{AA} versus p_T for several centrality bins in Au + Au collisions. Mid (forward) rapidity data are shown with open (solid) circles. See text for description of the errors and Ref. [21] for data tables.

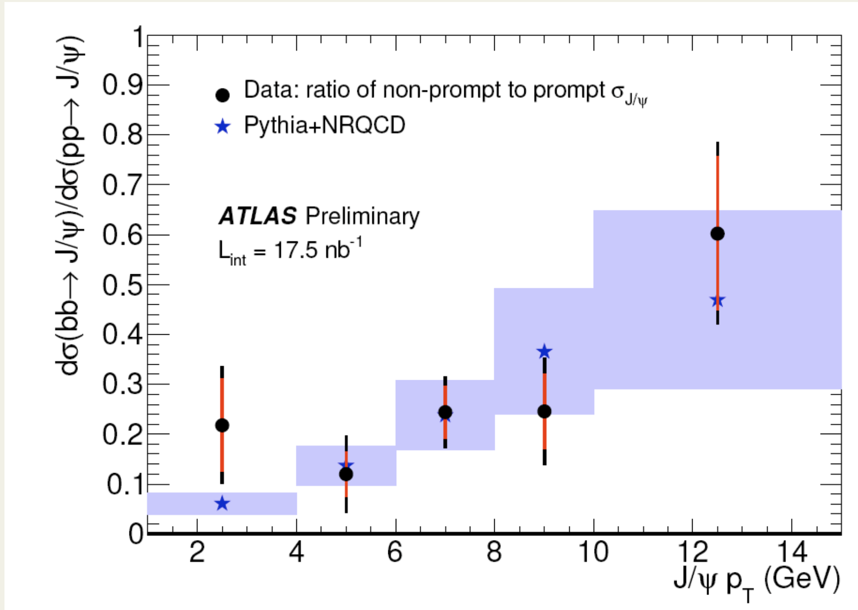
- J/ψ suppression in HI collisions as a function of centrality already observed in past experiments
- PHENIX measurement in Au-Au collisions @ $\sqrt{S_{NN}}$=200 GeV

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

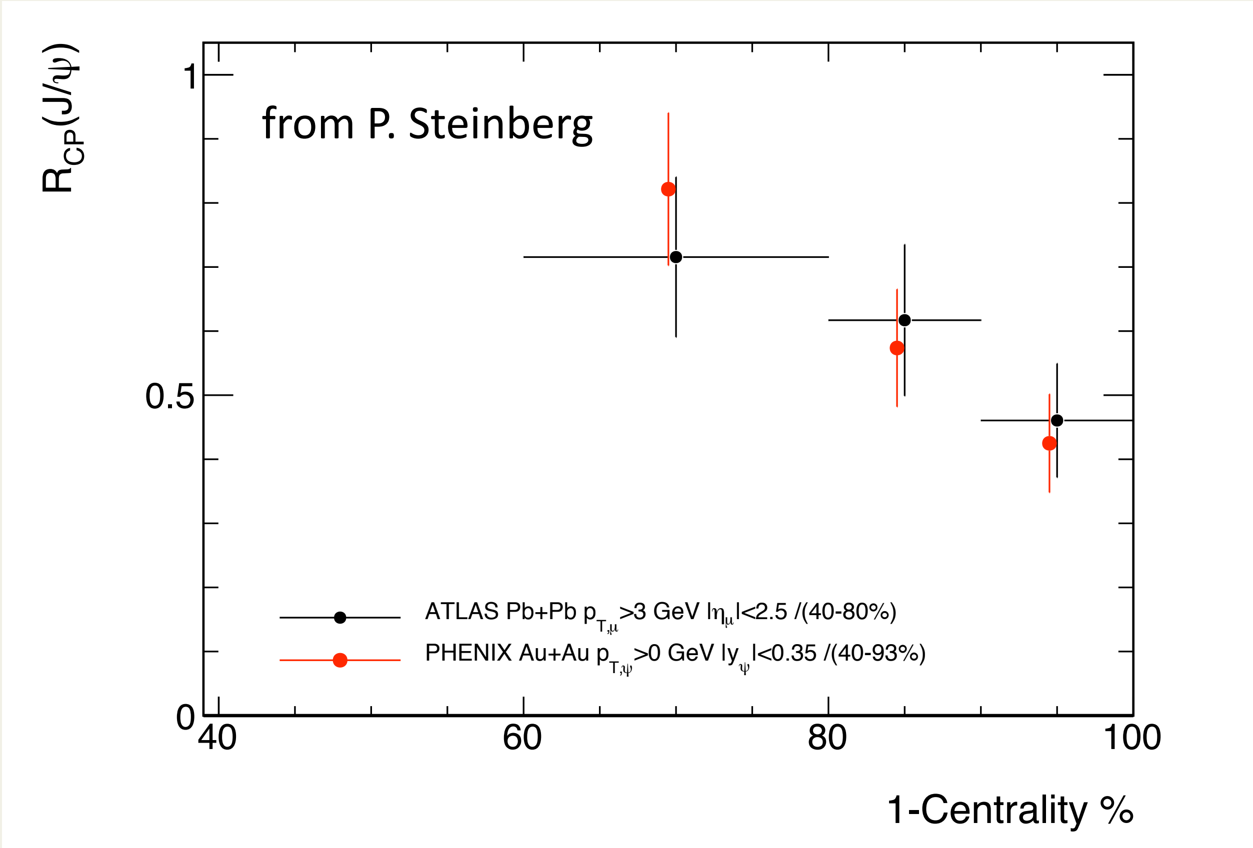
J/ψ in pp in ATLAS

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





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)