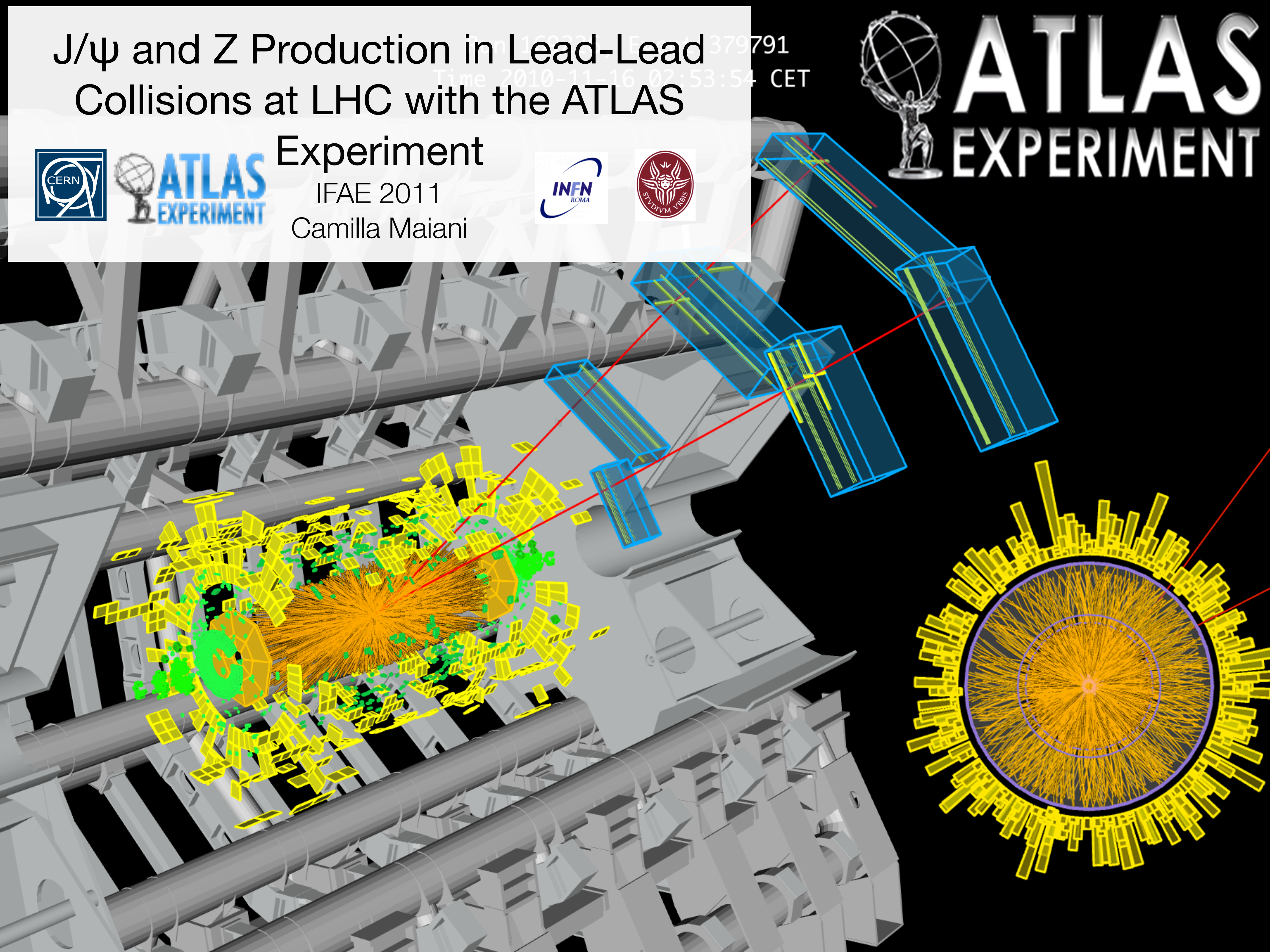
J/ψ and Z Production in Lead-Lead Collisions at LHC with the ATLAS Experiment

IFAE 2011

Camilla Maiani



Introduction

- In 2010 intense ATLAS heavy ions programme:
  - ATLAS Dijet Asymmetry publication[1]
  - J/ψ suppression and Z observation in Pb-Pb collisions publication[2]
- J/ψ suppression measurement overview:
  - Yield extraction
  - Efficiency assessment
  - J/ψ suppression results
  - Cross-check: first observation of Z bosons in heavy ions collisions

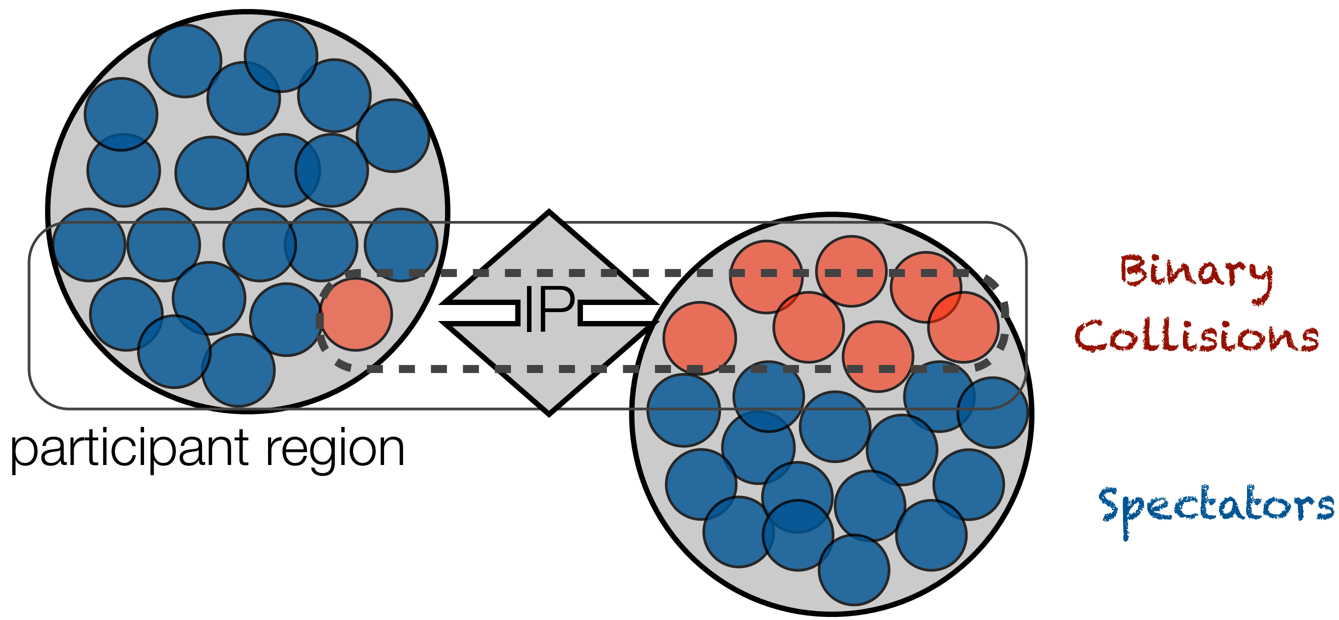
Physics Motivation

- Why the quarkonia suppression is so interesting?
  - Suppression could be a consequence of quark-gluon plasma production[3]
  - Suppressed quarkonium yield → direct experimental sensitivity to medium temperature [4]
- Suppression of J/ψ events already observed in past experiments:
  - NA50 at CERN SPS in Pb-Pb at $\sqrt{s_{NN}}$ = 17.3 GeV [5]
  - PHENIX at RHIC in Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV [6]

→ $\sqrt{s_{NN}} \sim T^4$

- Is it useful to study it at LHC? ...yes!
  - Suppression mechanism not fully understood, additional effects might be there [7]
  - Proposal for J/ψ enhancement at high energies from charm quark recombination [8]
  - First Z measurement is possible: no suppression expected there[9]

Our Starting Point in Pb-Pb Collisions



- In each ion collision we have N_{coll} binary collisions between N_{part} particles

  → Any yield measurement must be normalized on N_{coll}

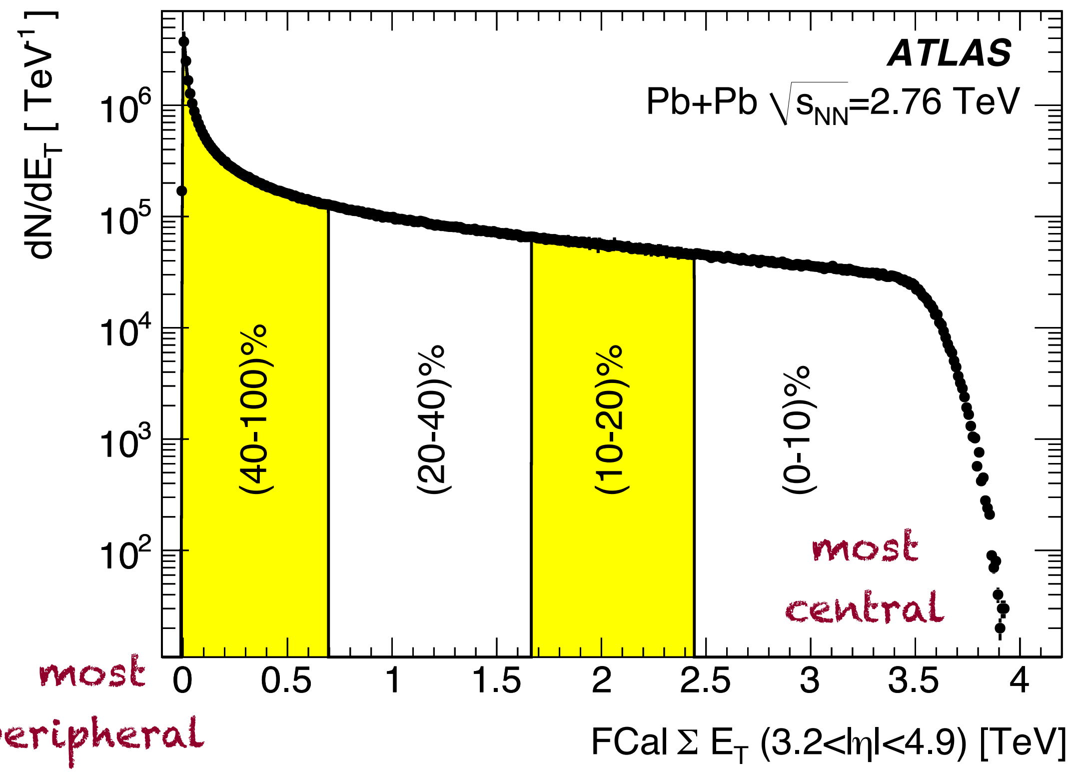
- N_{coll} depends on the **Impact Parameter** (IP) between the two nucleons

  → how can we measure IP in data?

N_{coll} Estimate: Centrality Definition

we cannot measure the IP directly! But..

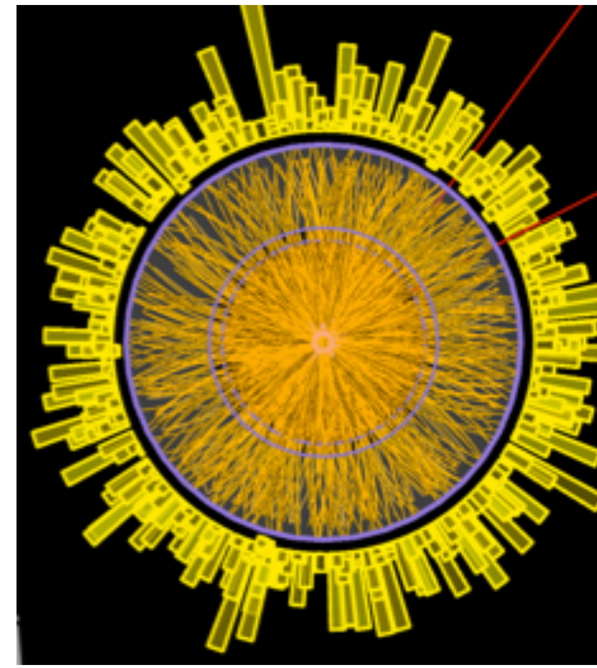
- Multiplicity increases monotonically as IP decreases
- Using transverse energy deposited in the forward calorimeters (3.2 < |η| < 4.9) we define centrality:
  - Central event: small IP
  - Peripheral event: big IP



nothing to do with detector pseudo-rapidity!

Data And Monte Carlo Samples

- LHC provided Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, ATLAS collected ~8 μb^{-1} of integrated luminosity:
  - Analyzed ~ 6.7 μb^{-1}
- Tracking in heavy ions environment → high occupancy, especially for central events
  - Dedicated tracking reconstruction: tight cuts on track quality
  - Only use muons with both inner detector track and muon spectrometer track (Combined Muons)
  - $p_T^{\mu} > 3$ GeV



Event display for highly central event

~ 613 J/ψ Candidates

Aim of the Measurement

most peripheral centrality bin

normalized mean number of binary collisions

$R_{coll} = N_{coll,c} / N_{coll,40-80}$

centrality bin

$$R_c = \frac{N_c^{corr}(J/\Psi \to \mu^+\mu^-)}{N_{40-80\%}^{corr}(J/\Psi \to \mu^+\mu^-) \cdot R_{coll}}$$

$N_c^{corr} = N_c^{meas} / (\varepsilon(J/\psi)_c \times W_c)$

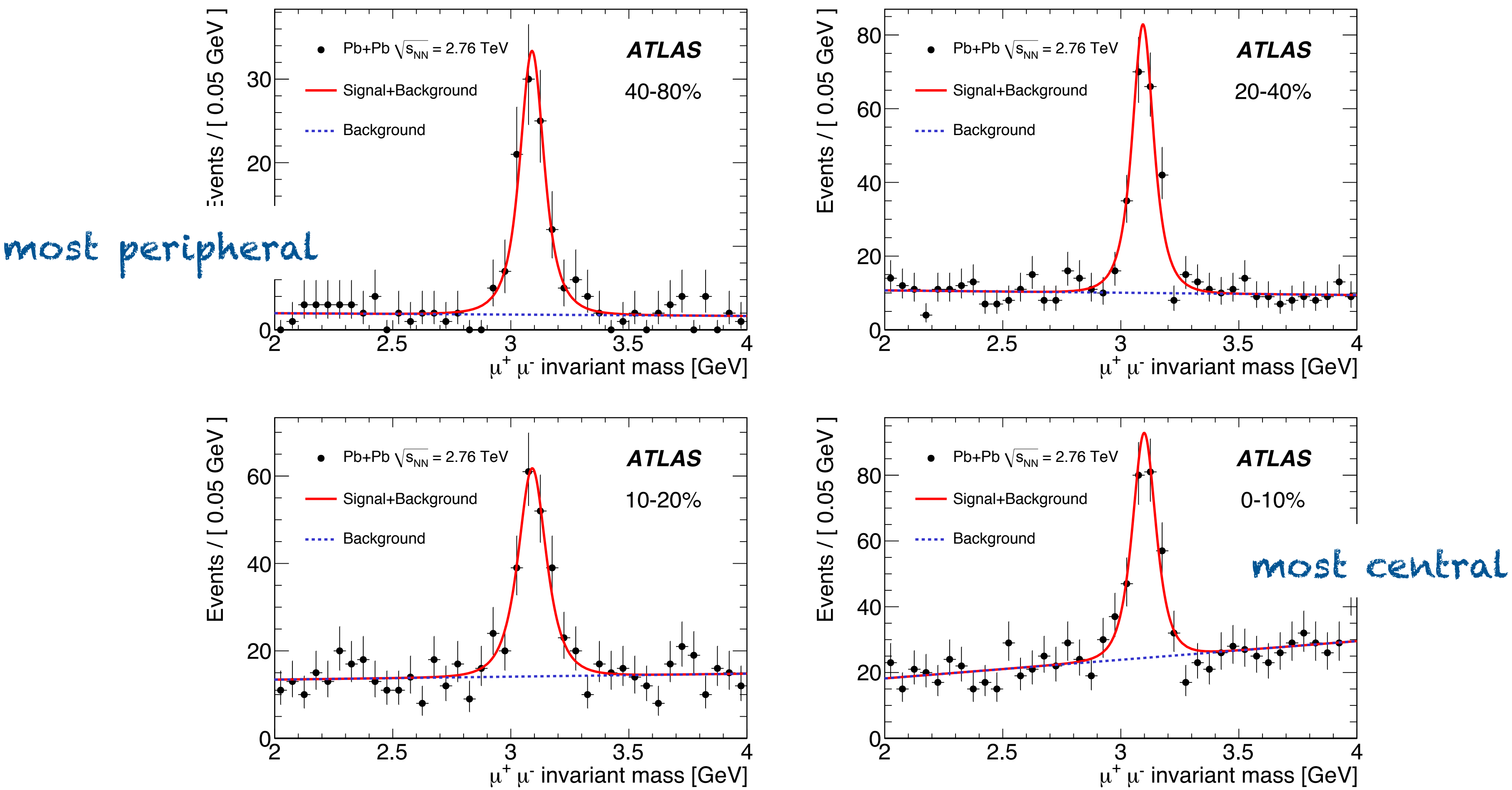
reconstruction efficiency

centrality bin width

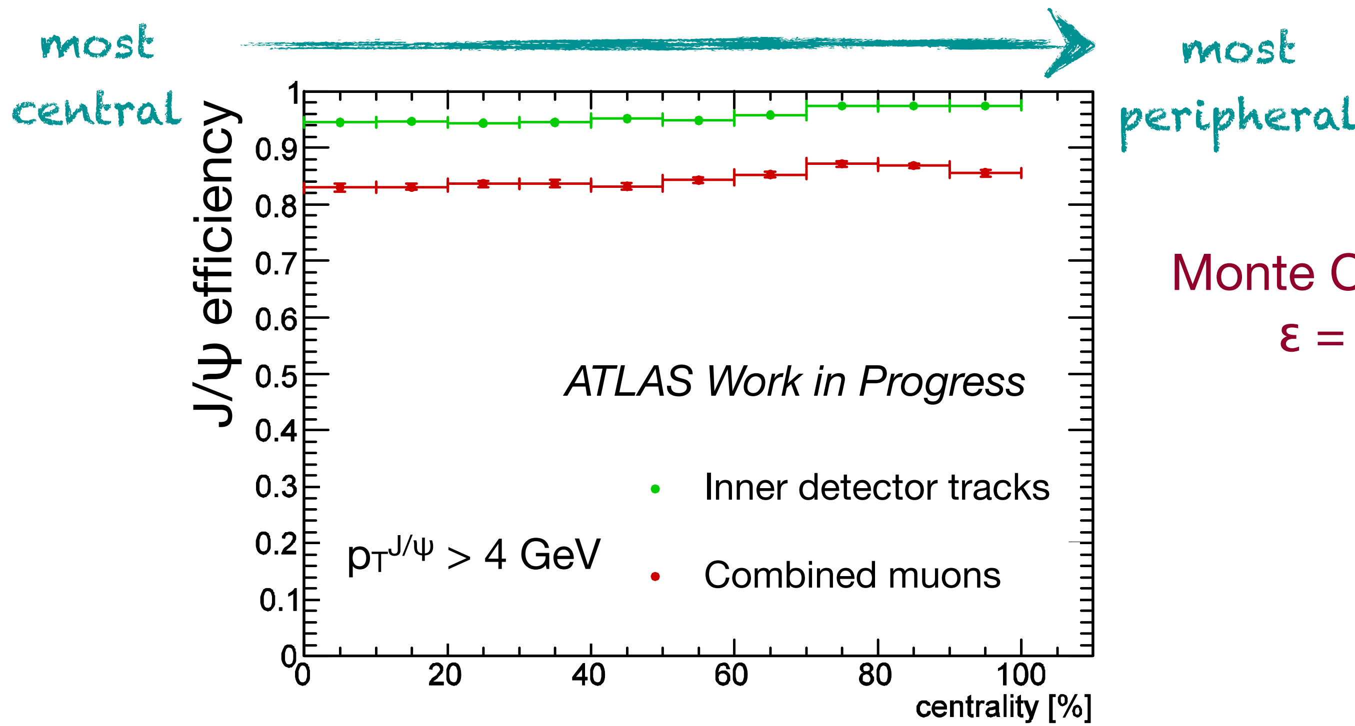
- No attempt to compare with p-p results
- Normalization on most peripheral bin

First Ingredient: J/ψ Yield Extraction

- Two methods
  - Sideband subtraction method
  - Unbinned maximum likelihood fit with per-event error



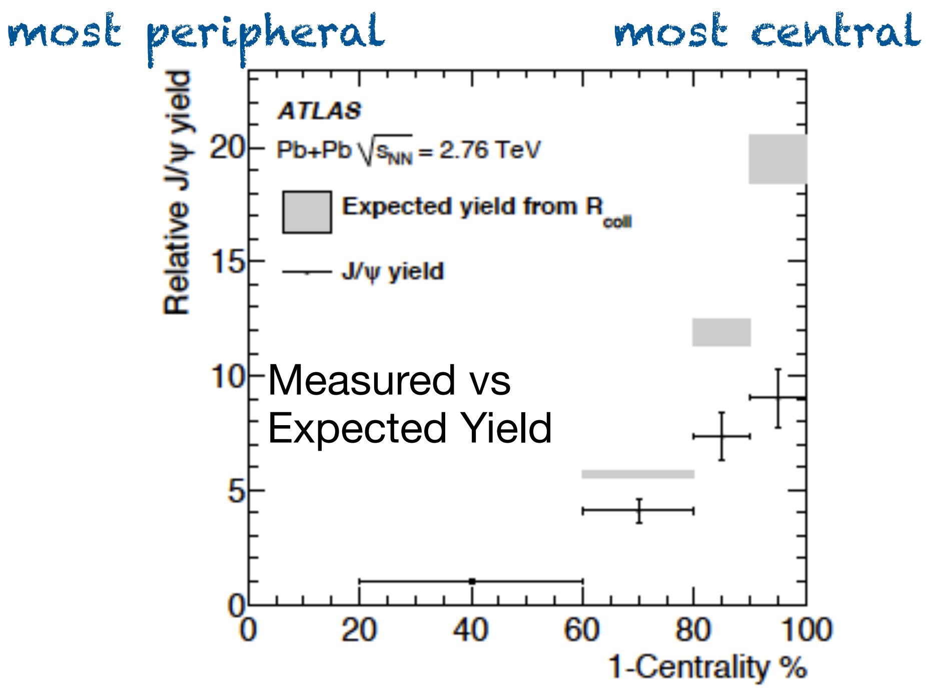
Monte Carlo Efficiency Dependence on Centrality

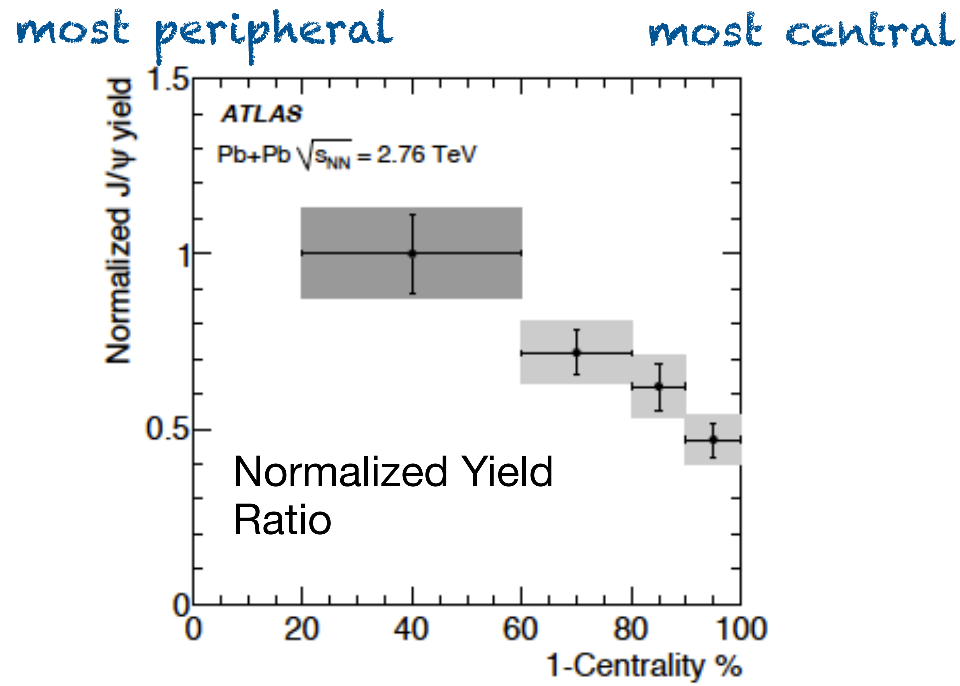


Monte Carlo efficiency:
$\varepsilon = N^{reco}/N^{truth}$

- Small centrality dependence for combined muons
  - ~3-4% drop from Inner Detector tracks reconstruction
  - As expected: no occupancy issue in muon chambers
- Efficiency used to correct raw yield
- Systematic associated to Data - Monte Carlo discrepancies on track reconstruction performance

First Observation of J/ψ Suppression at LHC!



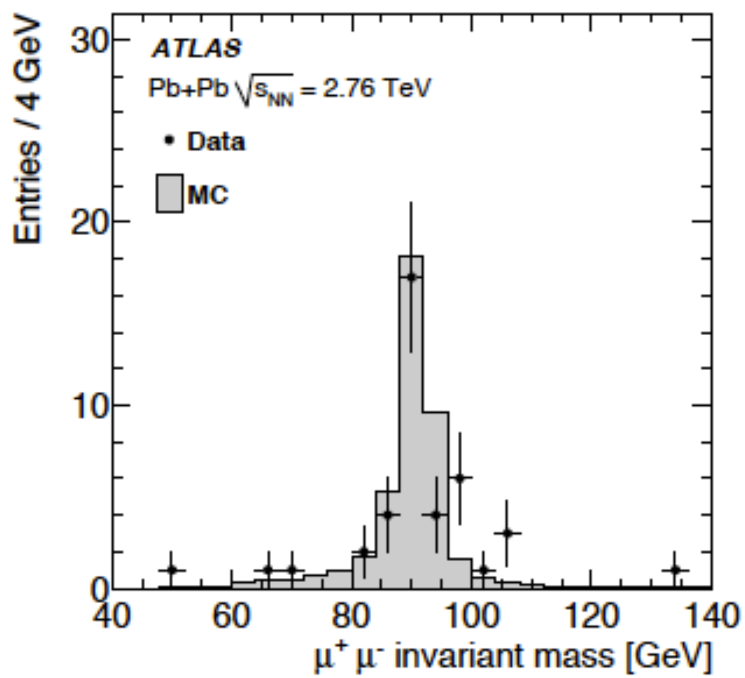


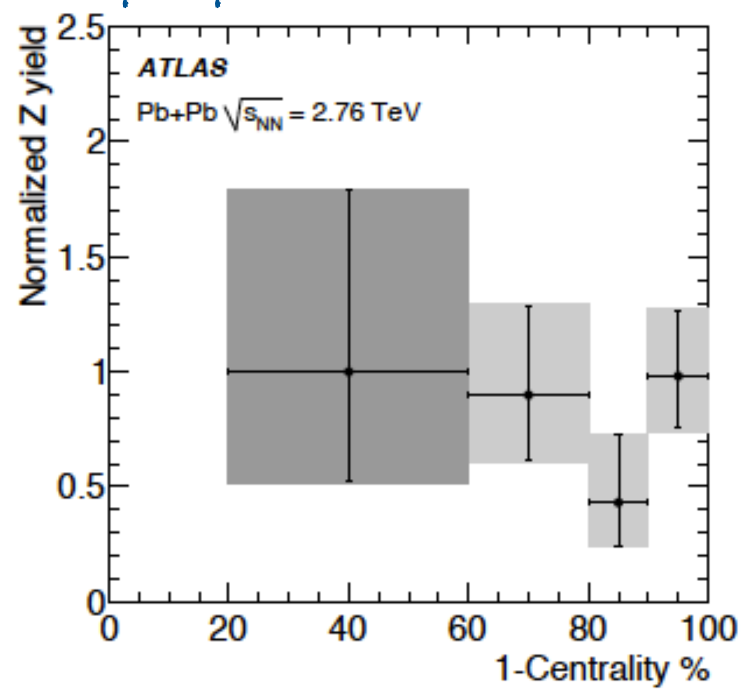
- Data points (right plot) **not consistent with their average**: $P(\chi^2, NDoF = 3) = 0.11\%$
  → Significant decrease of the ratio is observed as a function of centrality
- Qualitatively **same effect** as the one seen by NA50 and PHENIX at different temperatures
- Main systematics: J/ψ reconstruction efficiency ~2.3-6.8%, signal extraction ~5.2-6.8%, R_{coll} estimate ~3.2-5.3%

First Observation of Z Boson in Pb-Pb Collisions at LHC!

38 Z Candidates found

most peripheral most central





- Z Boson reconstructed in heavy ions Pb-Pb collisions
- Normalized yield doesn't show a trend: not enough statistics but still useful as a cross-check
- Systematic on the measurement conservatively the same as for J/ψ

Conclusions and Plans

- Very good understanding of muon and tracking systems and reconstruction achieved at ATLAS in the first year of data taking allowed:
  - First observation of J/ψ suppression in Pb-Pb collisions at LHC[1]
  - First Z peak reconstruction in Pb-Pb collisions at LHC[1]
- Future Plans:
  - More Pb-Pb statistics will be available by the end of the year
  - Run with p-p collisions at 2.76 TeV in 2011
  - Provide a differential measurement in p_T and y of the J/ψ

Bibliography

[1] the ATLAS Collaboration, G. Aad *et al.*, "Observation of a Centrality-Dependent Dijet Asymmetry in Lead-Lead Collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ATLAS Detector at the LHC", arXiv:1011.6182v2, accepted for publication at Phys. Rev. Lett.
[2] the ATLAS Collaboration, G. Aad *et al.*, "Measurement of the Centrality Dependence of J/ψ Yields and Observation of Z Production in Lead-Lead Collisions with the ATLAS Detector at the LHC", arXiv:1012.5419v1, accepted for publication at Phys. Lett. B
[3] T. Matsui and H. Satz, Phys. Lett. B178 (1986) 416
[4] A. Mocsy and P. Petreczky, Phys. Rev. Lett. 99 (2007) 211602
[5] NA50 Collaboration, B. Alessandro *et al.*, Eur. Phys. J. C39 (2005) 335-345
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[8] R. L. Thews and M. L. Mangano, Phys. Rev. C73 (2006) 014904
[9] R. Vogt, Phys. Rev. C64 (2001) 044901

Backup Slides

Overall view of the LHC experiments.

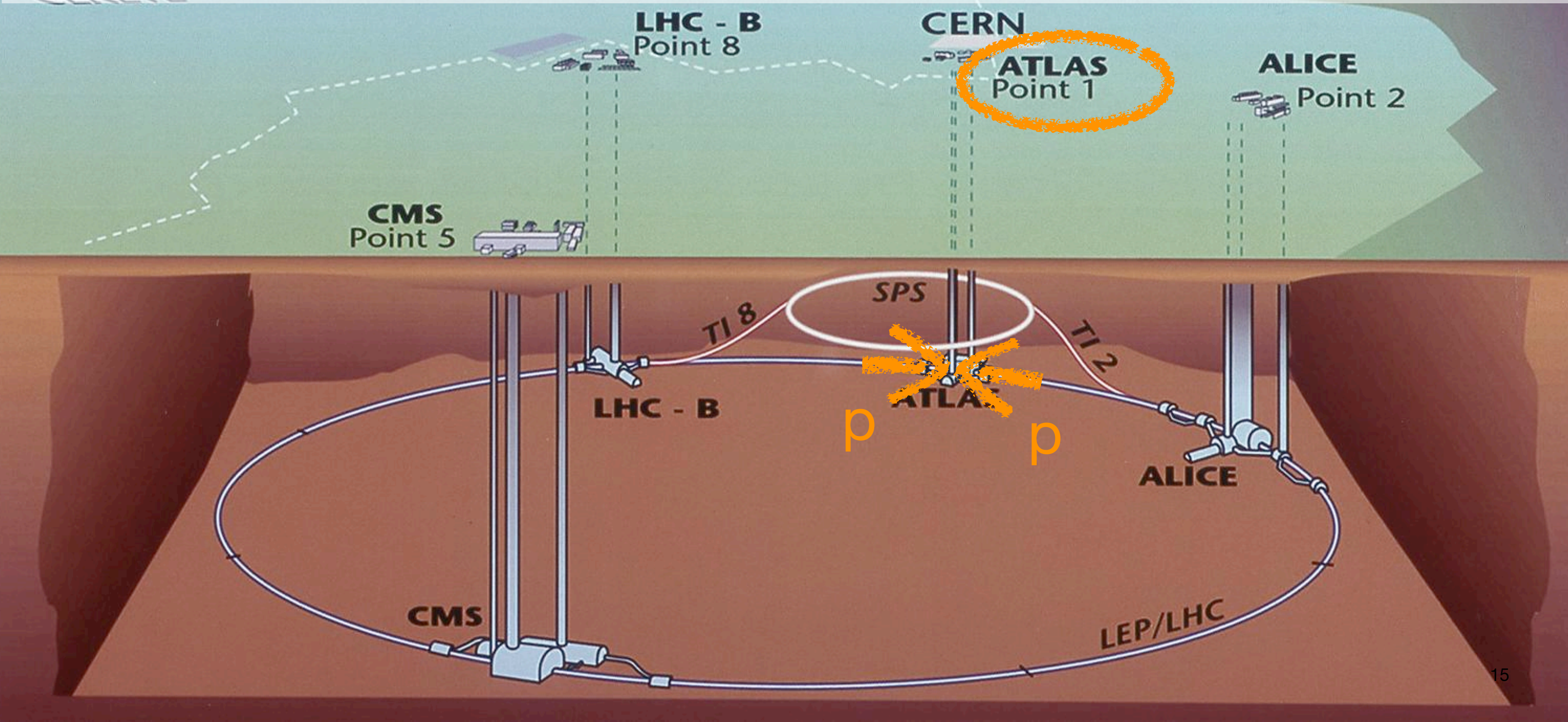
- proton-proton collider
- 27 Km of circumference
- Four experiments at the four interaction points

2010 p-p collisions:

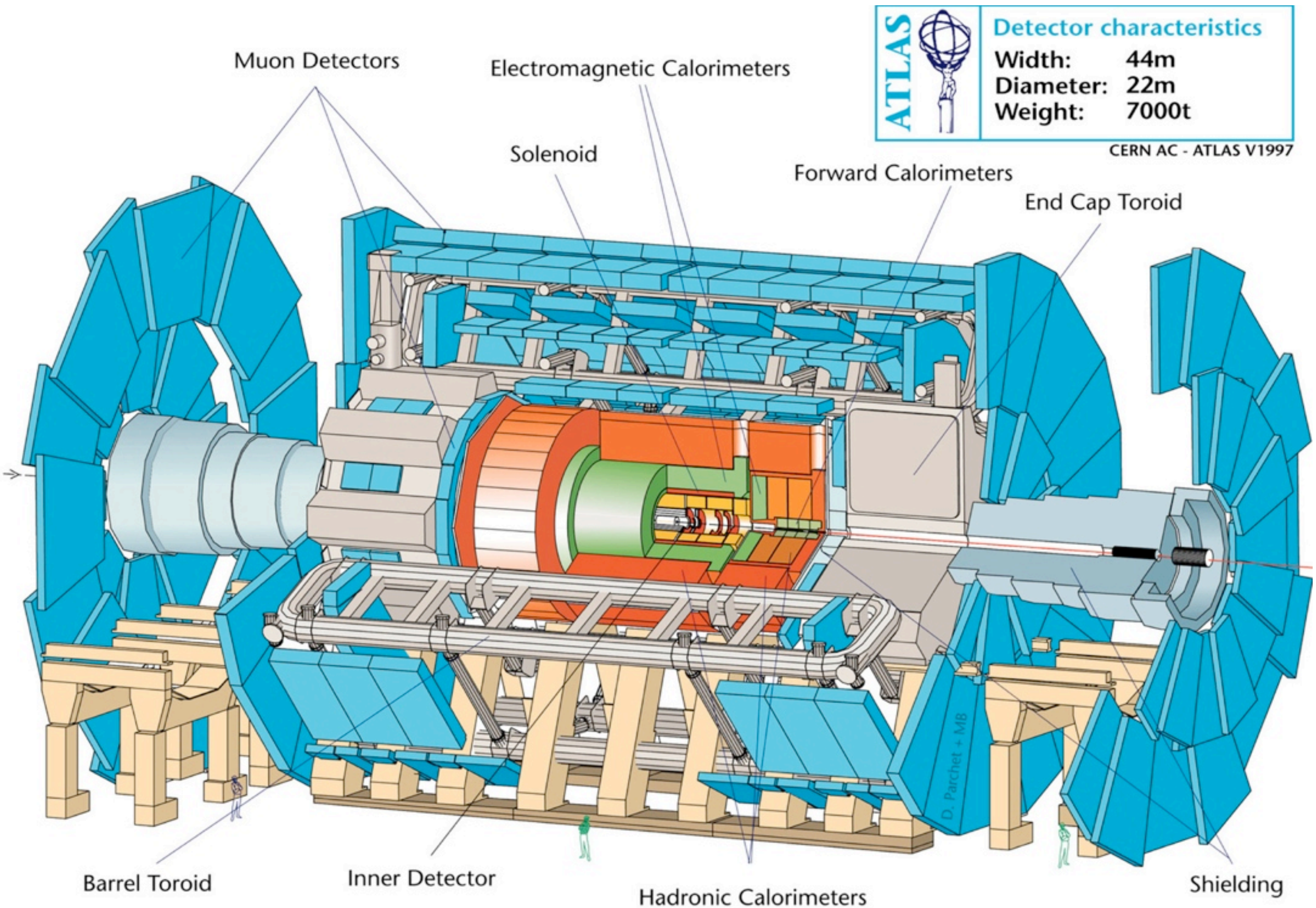
- Center-of-mass energy: $\sqrt{s}$ = 7 TeV
- highest instantaneous luminosity reached: L = 2 10^{32} $cm^{-2}s^{-1}$
- 41 pb^{-1} of p-p data collected in 2010 by ATLAS

2010 Pb-Pb collisions:

- Center-of-mass energy: $\sqrt{s}$ = 2.76 TeV per nucleon
- 8 μb^{-1} of Pb-Pb data collected in 2010 by ATLAS



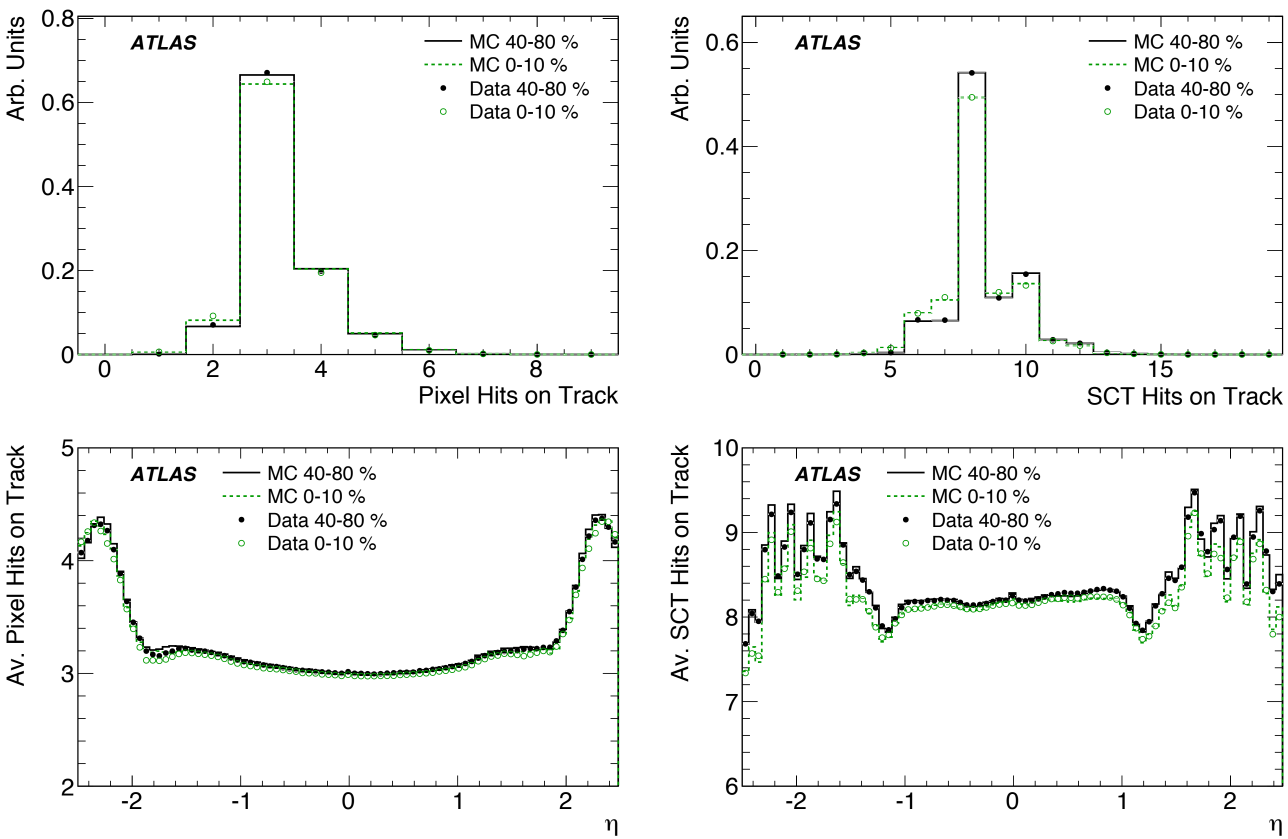
The ATLAS Experiment at LHC



Is Monte Carlo Simulation Reliable?

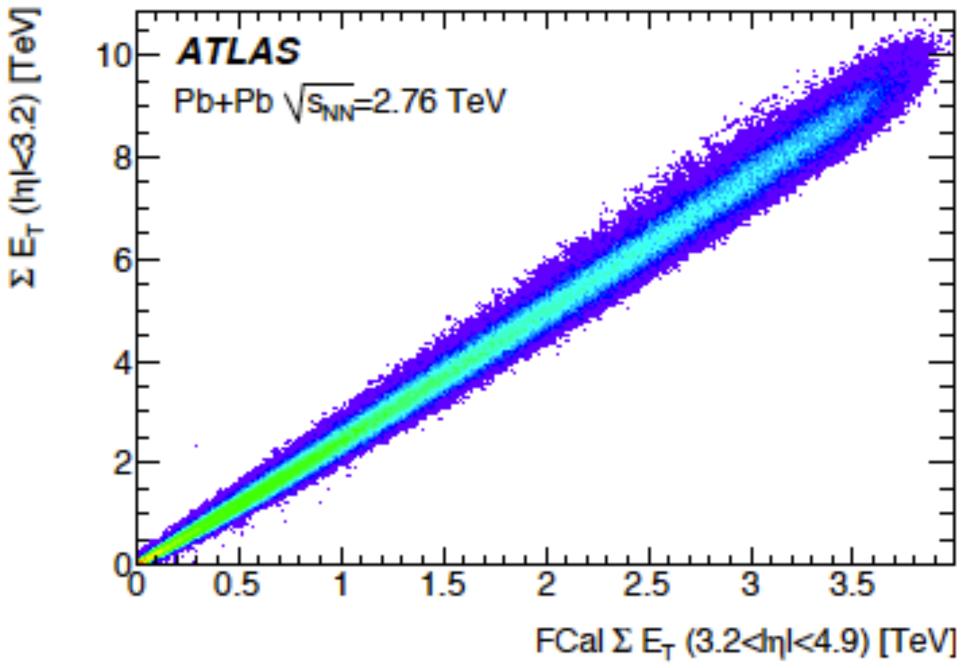
- Comparing (muon) track activity in MC and data
- Comparing (muon) tracks basic properties in MC and data vs centrality
- Associating a systematic uncertainty

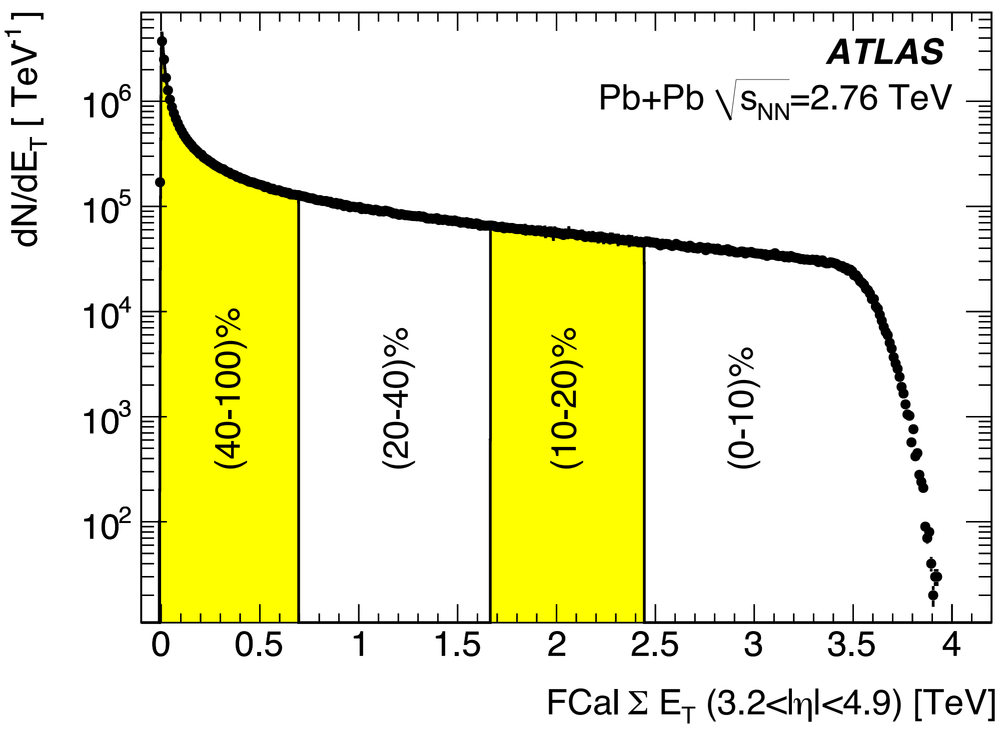
Muon tracks properties
$p_T > 0.5$ GeV



very good agreement is found

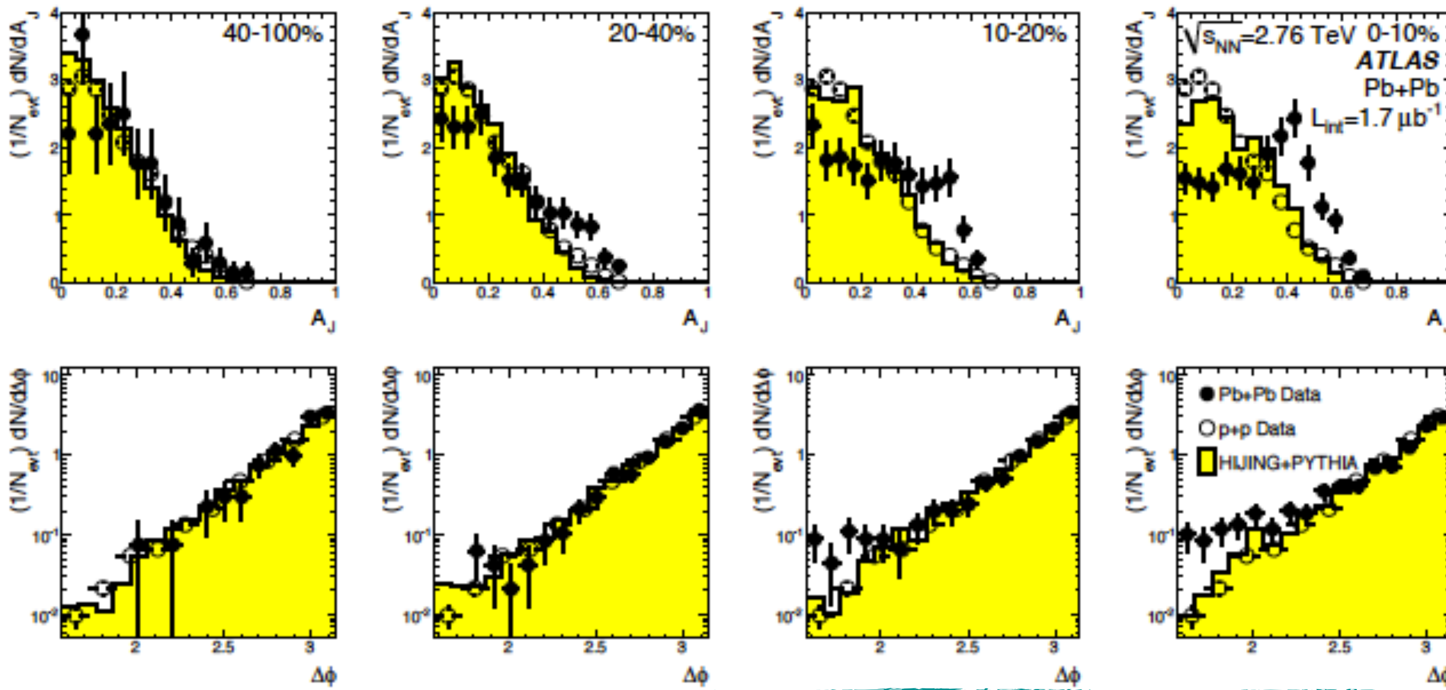
Centrality Definition





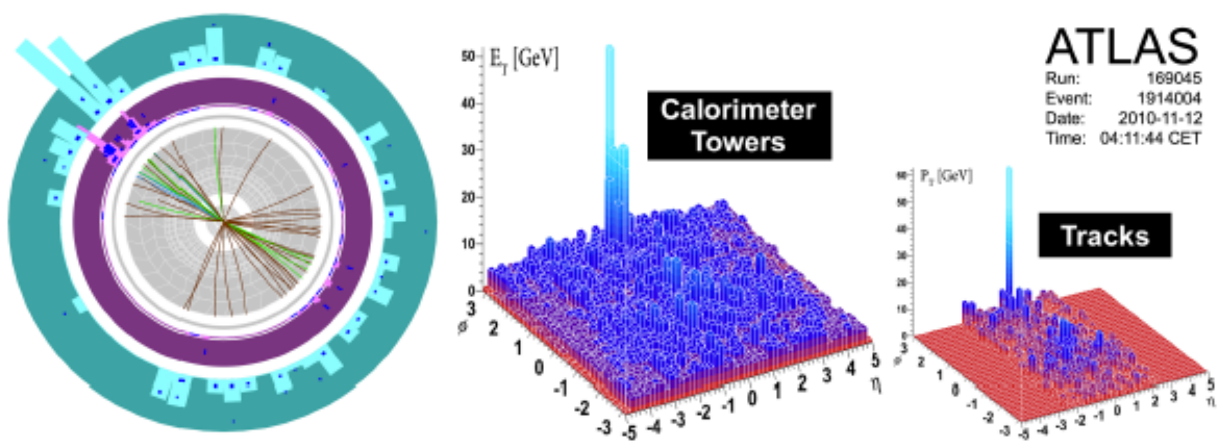
Central vs Forward Calorimeter

Centrality Dependent Dijet Asymmetry

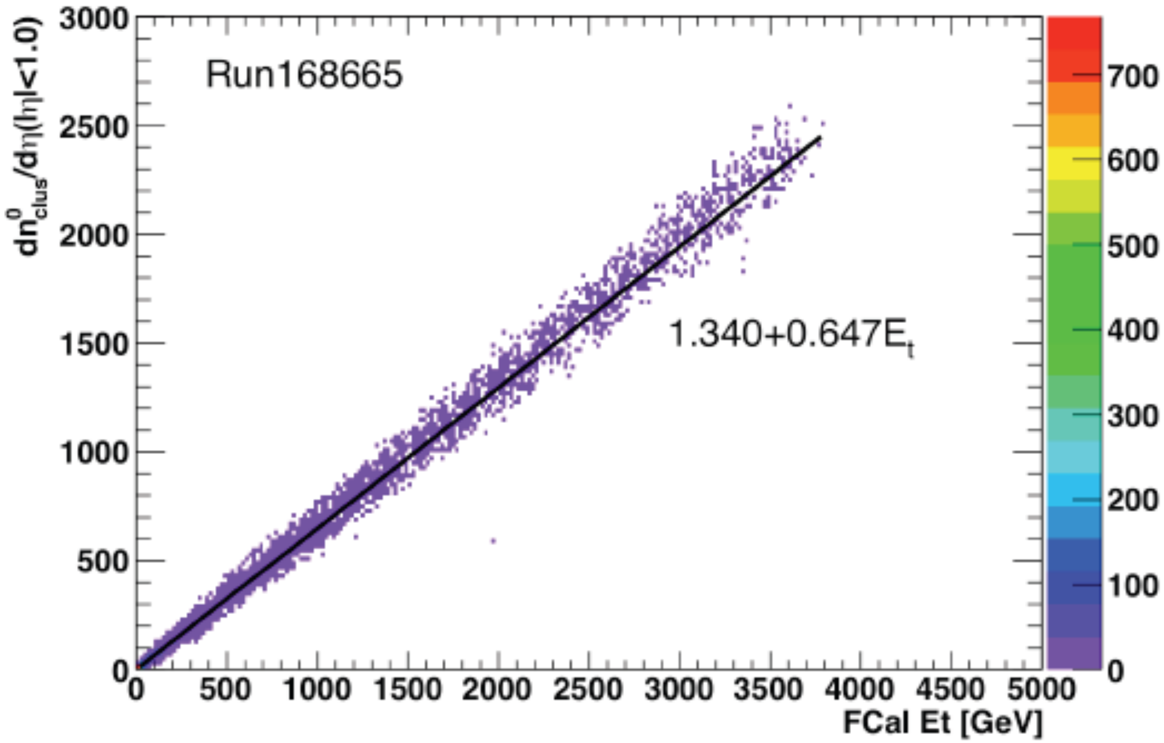


most peripheral → most central

Highly asymmetric event

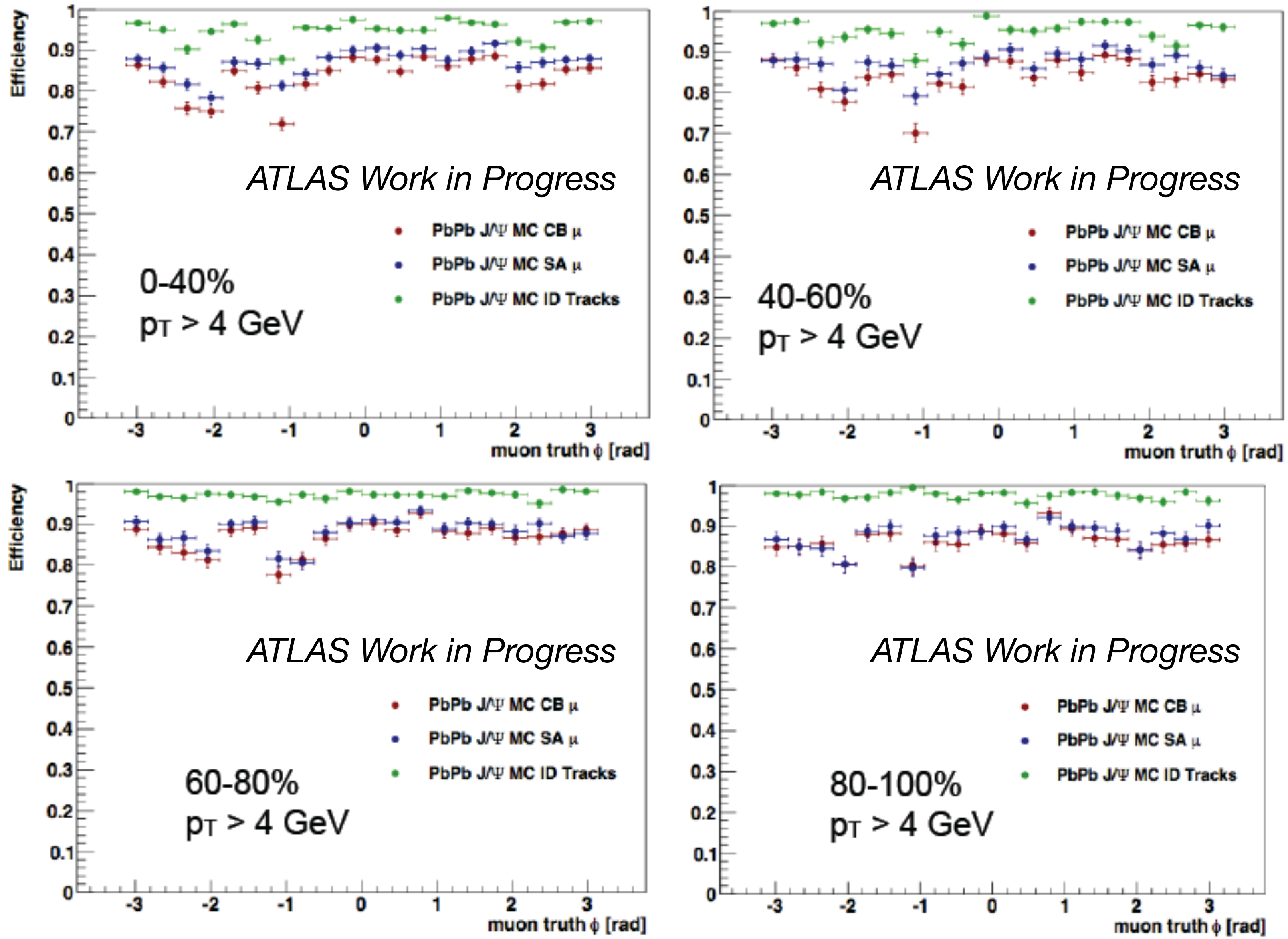


Centrality In Tracking Efficiency Studies

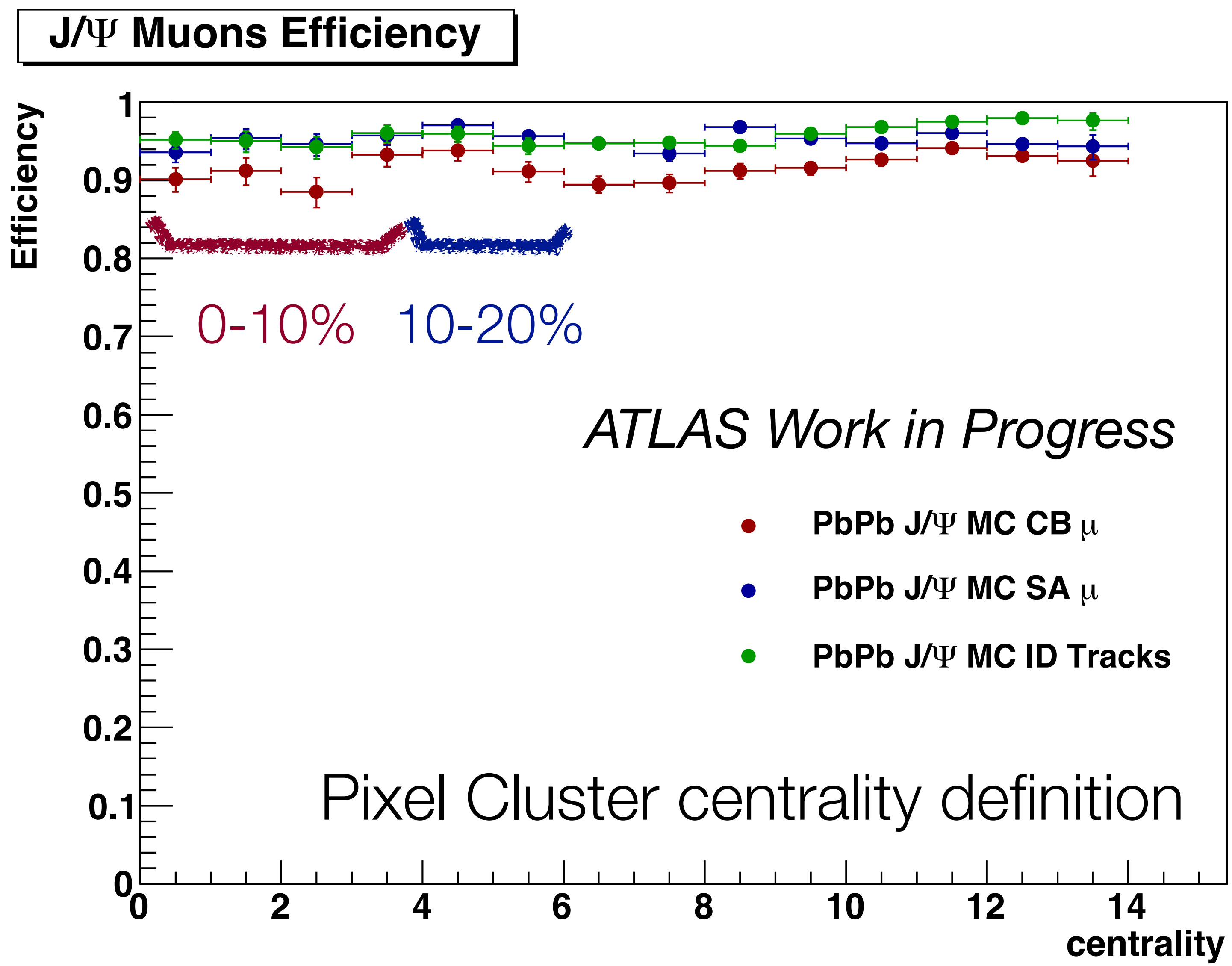


- For the tracking the relevant quantity is the occupancy vs centrality
- For tracking efficiency studies only we use an occupancy based definition of centrality: number of pixel clusters in the barrel
- We see here that this definition is equivalent to the standard one defined from the ΣE_T^{FCAL}

Efficiencies in Centrality Bins

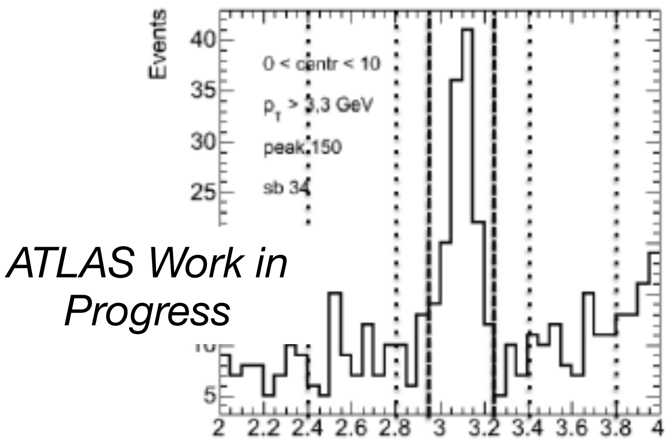


Efficiencies With Finer Centrality Binning

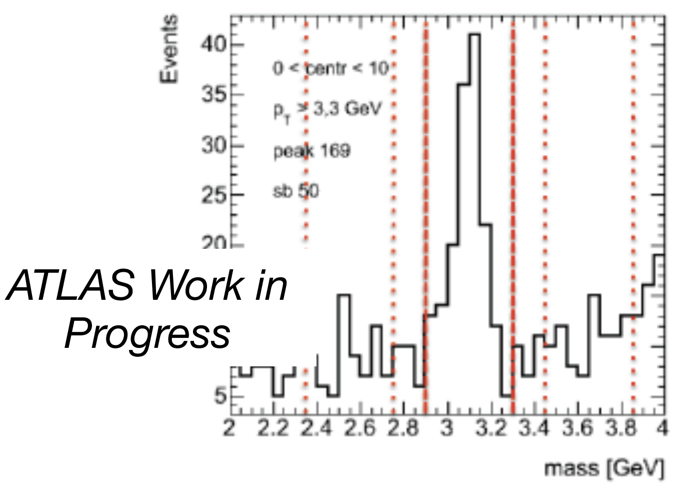


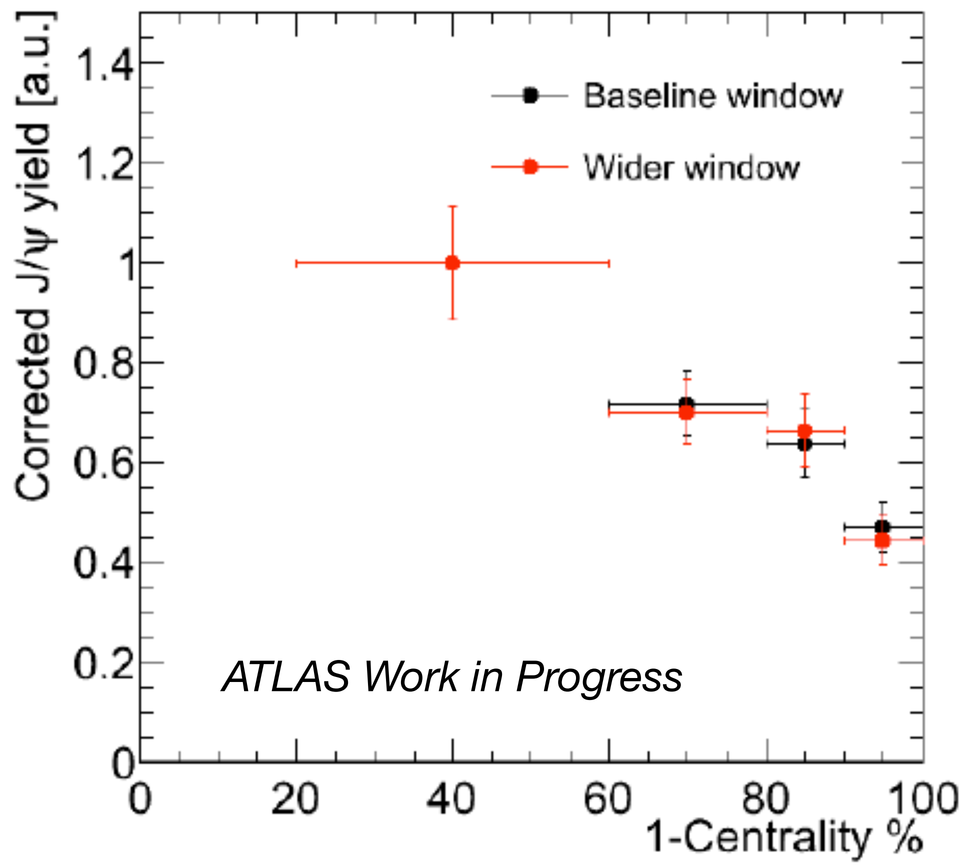
Systematic Check on Sideband Subtraction

baseline window
signal = [2.95,3.25] GeV
side-band = [2.4,2.8] and [3.4,3.8] GeV

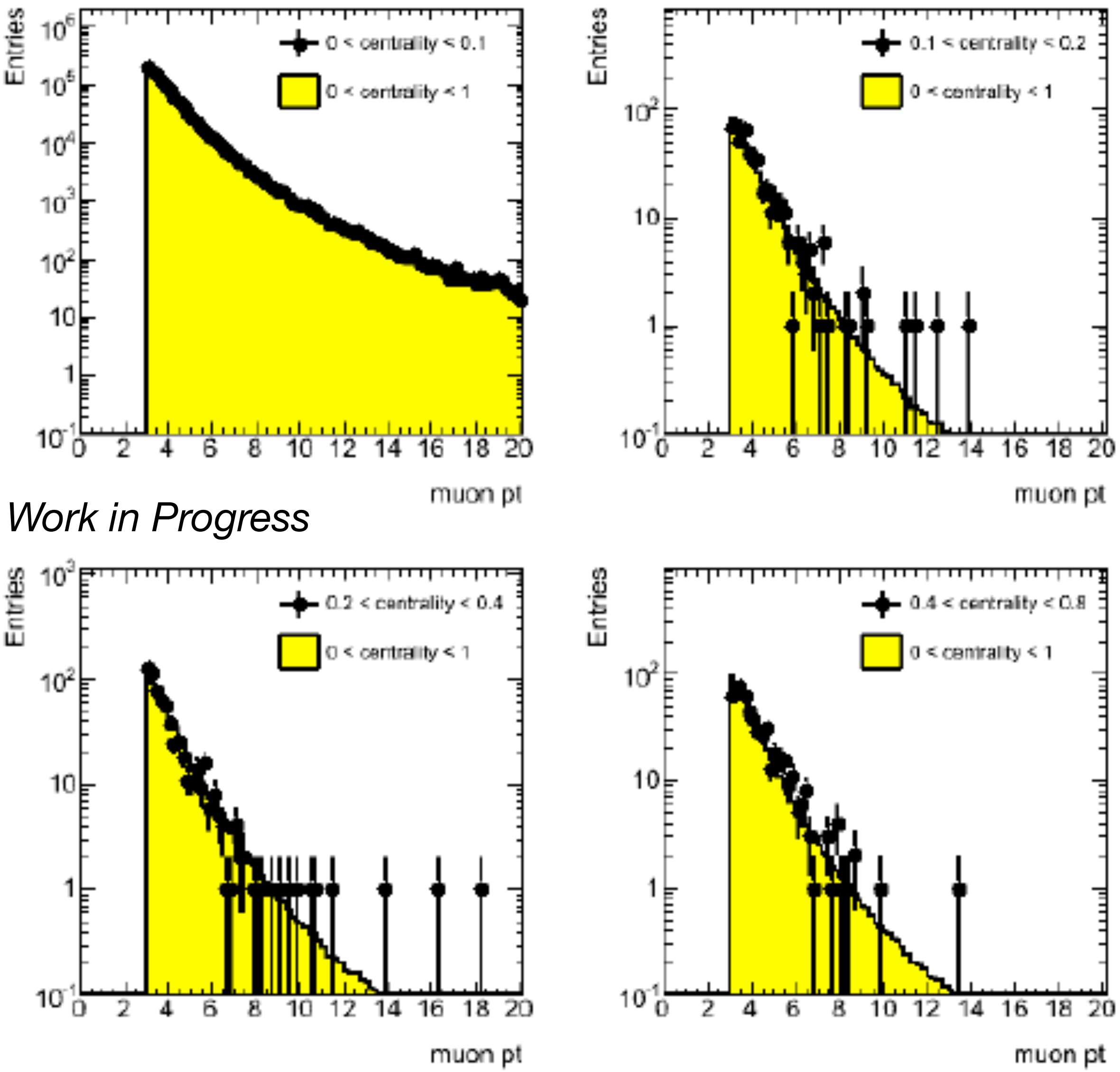


wider window
signal = [2.9,3.3] GeV
side-band = [2.35,2.75] and [3.45,3.85] GeV





Single Muons p_T Spectra vs Centrality



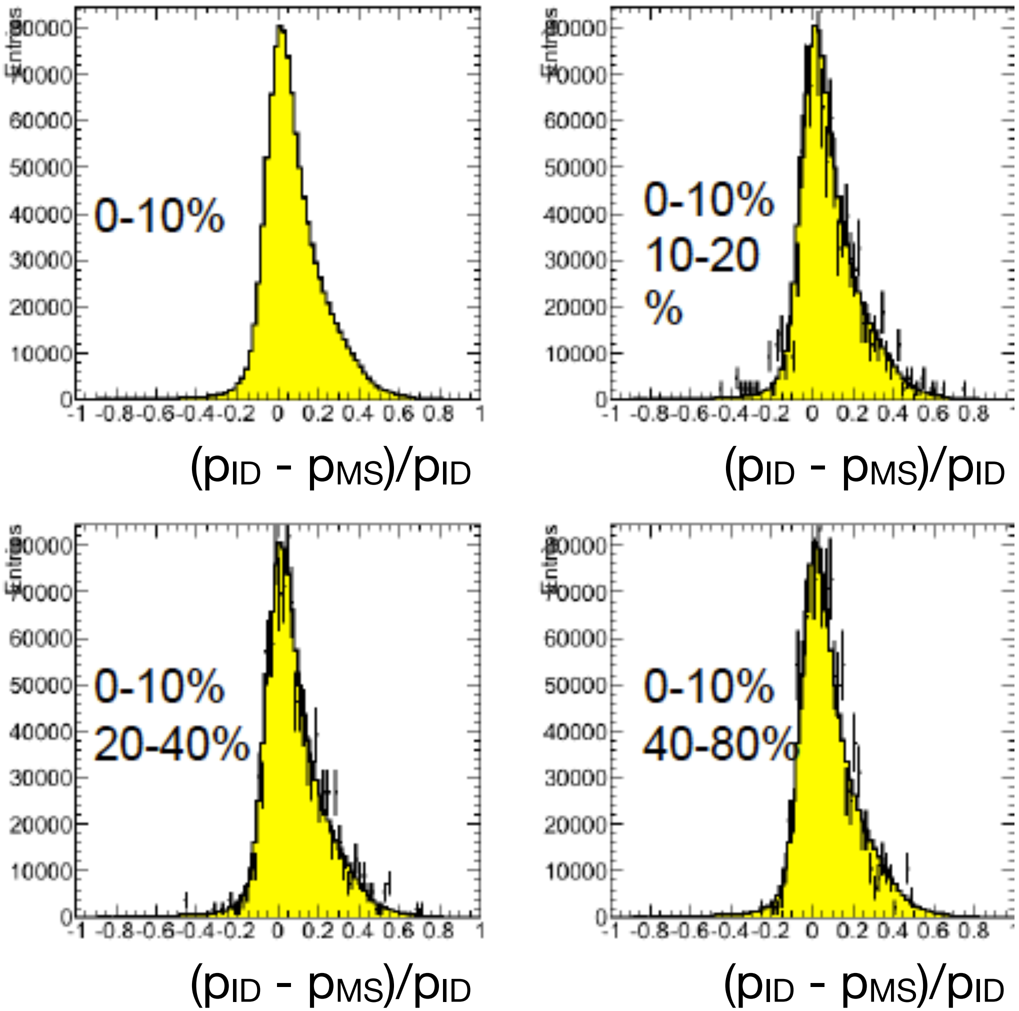
ATLAS Work in Progress

data in 0-10% centrality bin compared with data in the other three centrality bins

Very good agreement, small variation of the muon p_T spectrum vs centrality

Check ID Track - Muon Spectrometer Track Comb. vs Centrality

ATLAS Work in Progress



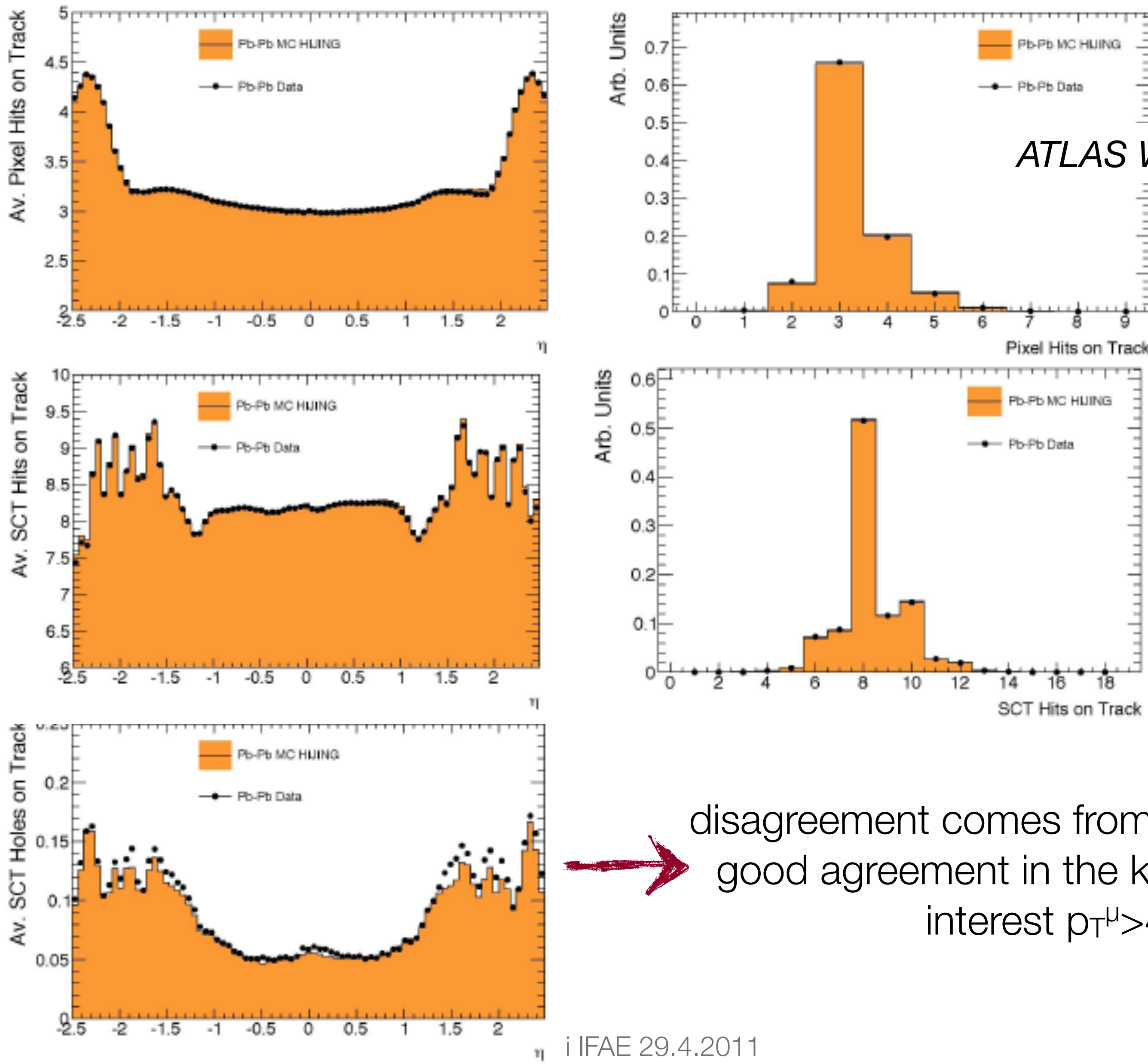
Data in 0-10% centrality bin compared with data in the other three bins

↓

Very good agreement, small variation of the matching efficiency expected

Is Monte Carlo Simulation Reliable?

Tracks properties
$p_T > 0.5$ GeV

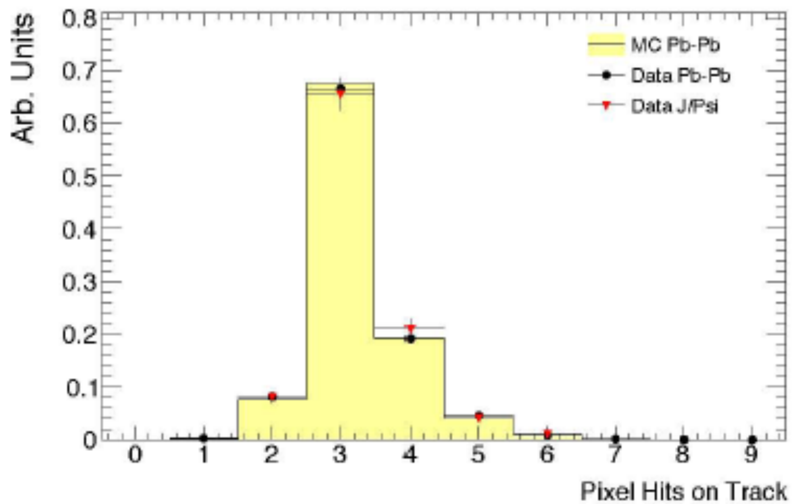


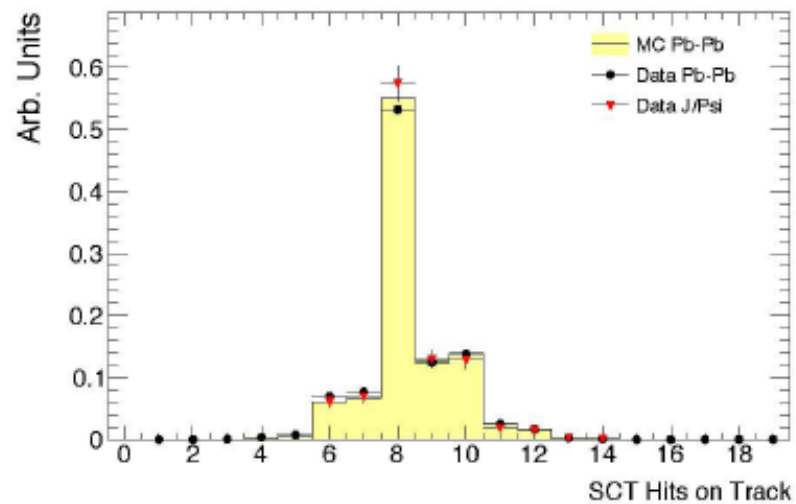
disagreement comes from very low p_T tracks, good agreement in the kinematic region of interest $p_T^{\mu}>4$ GeV

Is Monte Carlo Simulation Reliable?

Muons from J/ψ properties

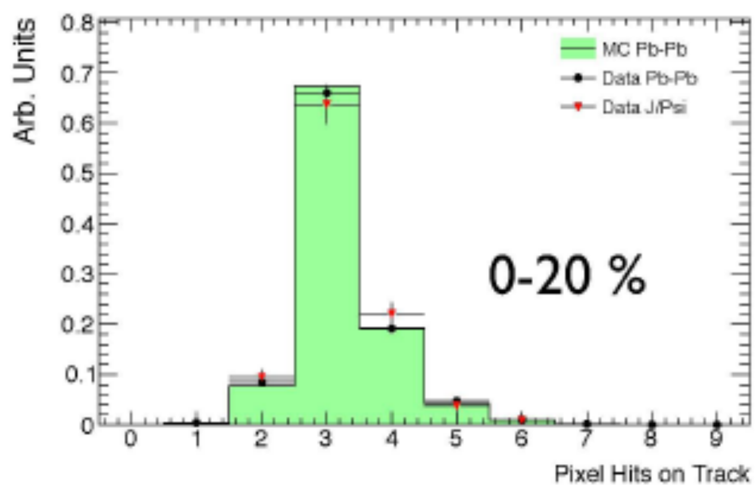
ATLAS Work in Progress

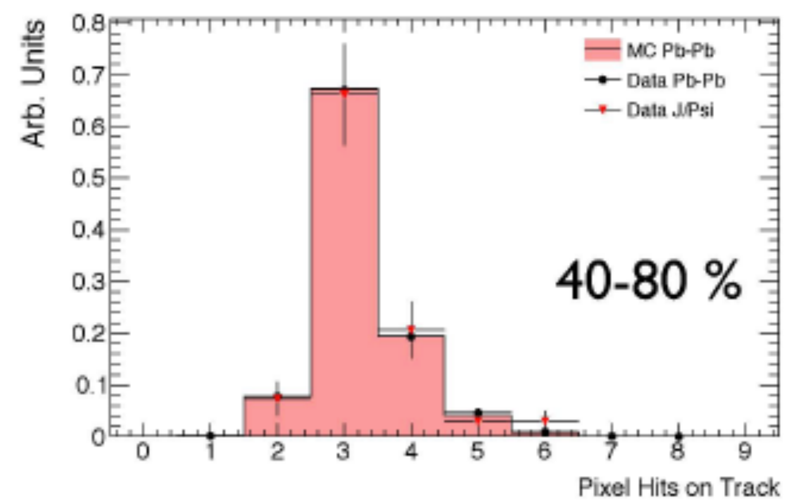




Muons from J/ψ in centrality bins

ATLAS Work in Progress





J/ψ in Heavy Ions: Systematic Studies

J/ψ reconstruction efficiency: ~2.3-6.8%

- Data-Monte Carlo comparison of distributions of hits used to derive systematic uncertainties on track reconstruction
- Monte Carlo statistical uncertainty
- Cross-checks: comparing match between inner detector track and muon spectrometer track, loosening track quality selection

Signal extraction: ~5.2-6.8%

- Mass resolution dependence on centrality
  - Invariant mass fit with free scale factor
- Background modeling
  - Invariant mass fit with 1st and 2nd order chebychev polynomial

R_{coll} estimate: ~3.2-5.3%

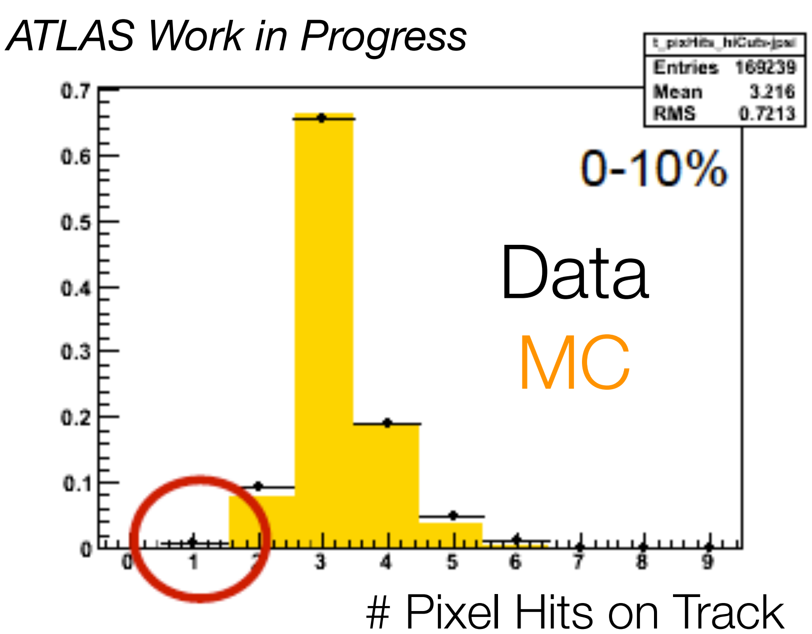
- Variation of the Galuber MC input parameters
- Systematic on trigger and event selection efficiency

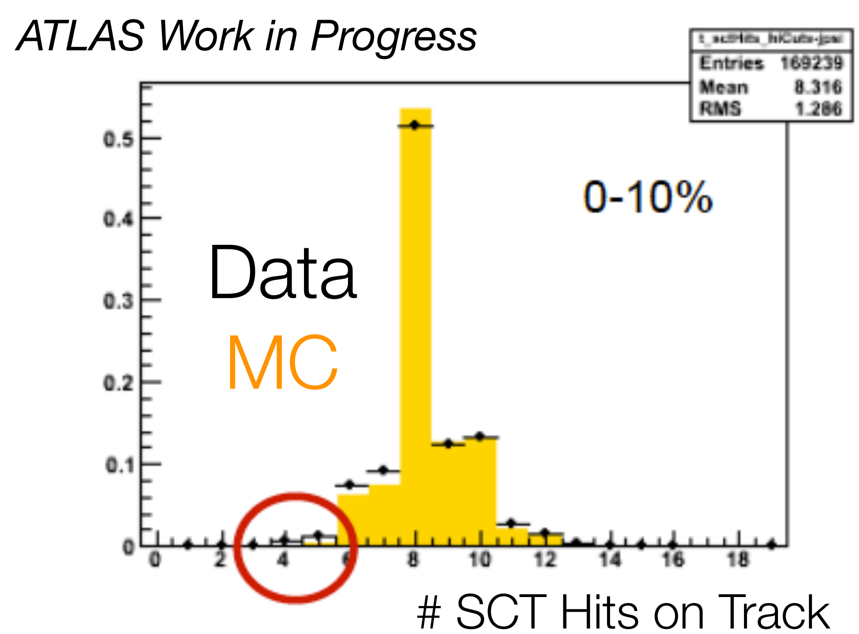
Tracking Reconstruction Systematic

We require:

- 9 silicon hits (reconstruction)
- nPixel >= 1 Pixel hit
- nSCT >= 6 SCT hits

→ data-MC discrepancies used to estimate systematics





Final Numbers and Systematics

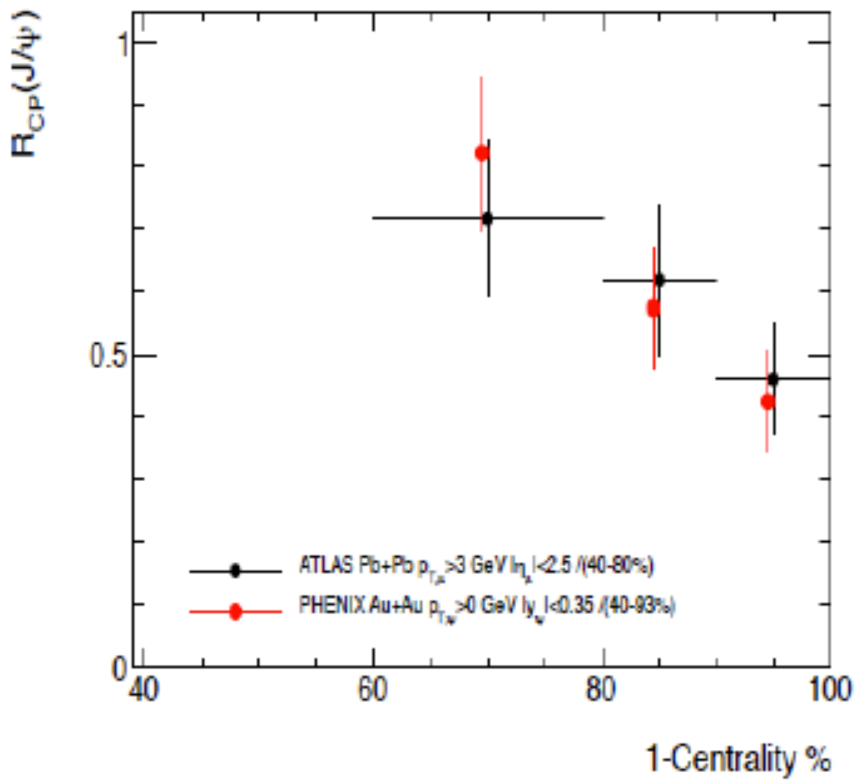
Centrality	$N^{\mathrm{meas}}(J/\psi)$	$\epsilon(J/\psi)_c/\epsilon(J/\psi)_{40-80}$	Systematic Uncertainty		
			Reco. eff.	Sig. extr.	Total
0-10%	190 ± 20	0.93 ± 0.01	6.8 %	5.2 %	8.6 %
10-20%	152 ± 16	0.91 ± 0.02	5.3 %	6.5 %	8.4 %
20-40%	180 ± 16	0.97 ± 0.01	3.3 %	6.8 %	7.5 %
40-80%	91 ± 10	1	2.3 %	5.6 %	6.1 %

Centrality	N(Z)	$\epsilon(Z)_c/\epsilon(Z)_{40-80}$
0-10%	19	0.99 ± 0.01
10-20%	5	0.97 ± 0.01
20-40%	10	0.98 ± 0.01
40-80%	4	1

Centrality	R_{coll}	Uncertainty
0-10%	19.5	5.3 %
10-20%	11.9	4.7 %
20-40%	5.7	3.2 %
40-80%	1.0	–

Comparison with RHIC Data

PAS & J. Jia - replotted from public data



Attempt to replot PHENIX data vs Centrality [P.Steinberg, J.Jia] suggest suppression is energy-independent

- Different p_T ranges:
  - PHENIX: > 0 GeV
  - ATLAS: >~ 6.5 GeV
- Different rapidity ranges:
  - PHENIX: $|y_{J/\psi}| < 0.35$
  - ATLAS: $|\eta_\mu| < 2.5$
- Different b fractions:
  - PHENIX: few percents
  - ATLAS: ~25%

Z in Pb-Pb Collisions