Longitudinal Asymmetry and its Measurable Effects in Pb-Pb Collisions at 2.76 TeV

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Plan of the Talk

Introduction

Experimental and Data Details

Analysis and Systematic Errors

Results

Comparison with Simulations

Conclusions

Introduction

- In most collisions of identical nuclei
  - Unequal number of participants => Collision asymmetric
    - Longitudinal asymmetry
  - Consider p-A collisions
    - No symmetry about the N-N CM frame

      (ALICE Collaboration: PRL 110, 032301 (2013))
- Asymmetry in collisions may affect all measurements affected by Fluctuations, Number of participants, Symmetry about N-N CM frame (Rapidity distributions !)
- A and B nucleons from each nucleus => a shift in rapidity of participant zone $y_0 = \frac{1}{2} \ln (A/B) = \frac{1}{2} \ln (1+\alpha_{part})/(1-\alpha_{part})$

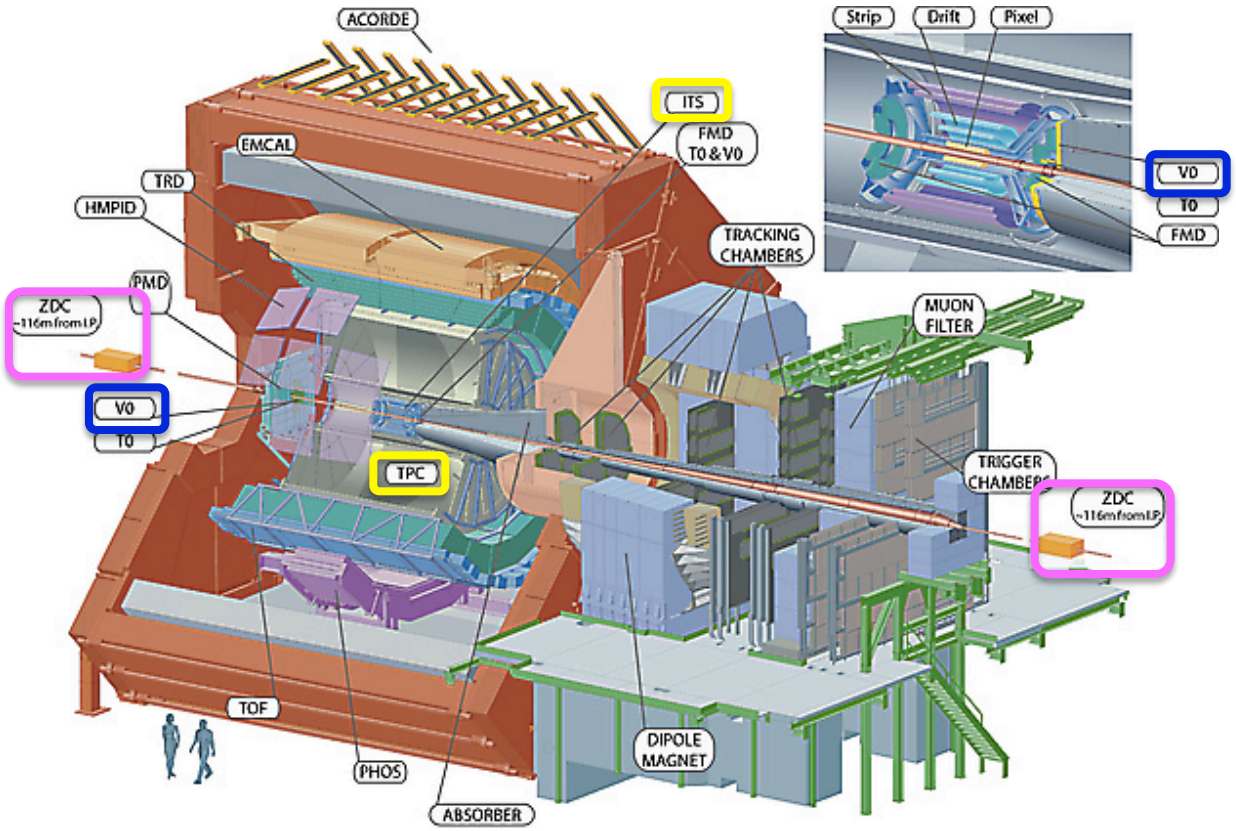
  For a typical case

  (at ~6.5 fm impact parameter for Pb-Pb, using Glauber MC)

  A = 126, B = 114 and $\alpha_{part} = 0.05$ and $y_0 = 0.05$

  $\alpha_{part} = (A-B)/(A+B)$

EXPERIMENTAL AND DATA DETAILS



Pb-Pb Collision
$\sqrt{s_{NN}}$ = 2.76 TeV

~3M Mininum bias events in 0-40%

Centrality using
- V0A and V0C (V0M Centrality)
- Track Multiplicity (Track Centrality)

- ZDC, ITS, TPC, V0, Centrality Triggers

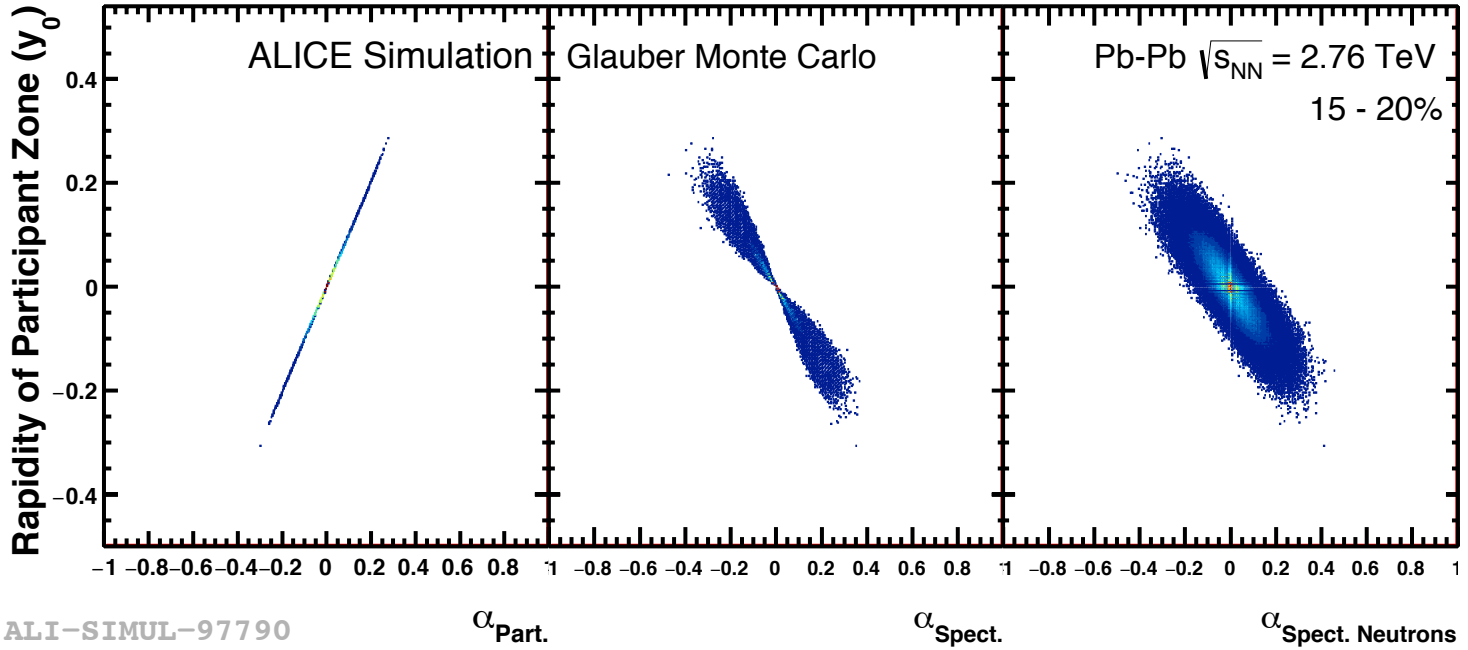
  Acceptance, tracks / hits, quality, normalisations (scaling in ZNA and ZNC), Mention quality checks for different runs

Relation of Asymmetries with Rapidity-Shift

Asymmetry in participants, α_{part} , related to y_0

Asymmetry in spectators, α_{spec}, related to y_0

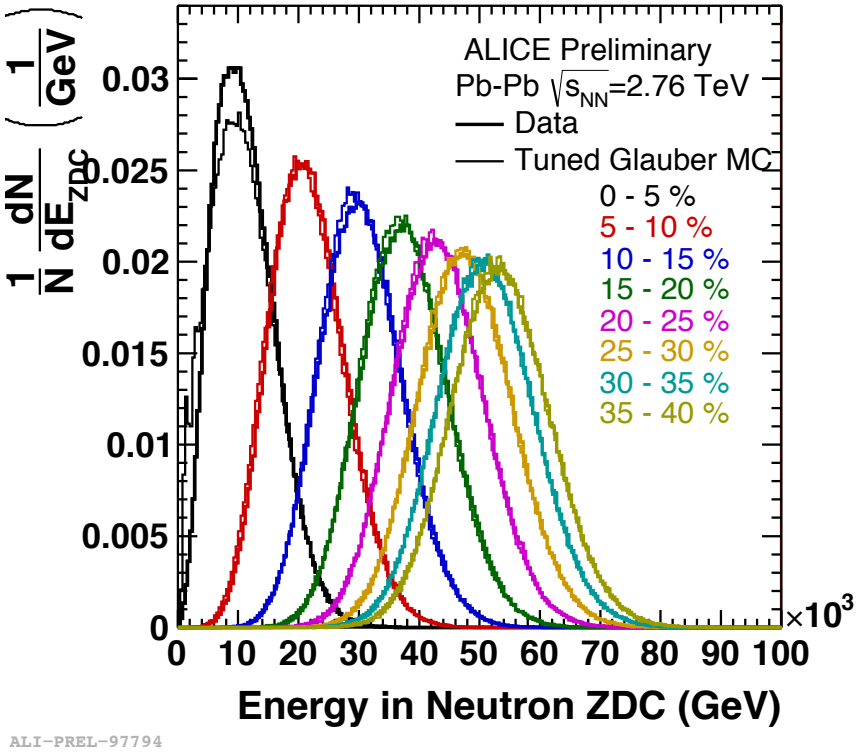
Asymmetry in neutron spectators, $\alpha_{spect\text{-}neutrons}$, related to y_0



Estimate asymmetry by measuring energy in neutron ZDCs

Distribution of Energy in ZDC from : Experiment and Tuned Glauber MC (TGMC)

Neutron spectators from Glauber MC + ZDC Resolution + tuning loss of neutrons due to fragment formation reproduces the ZDC energy distribution.



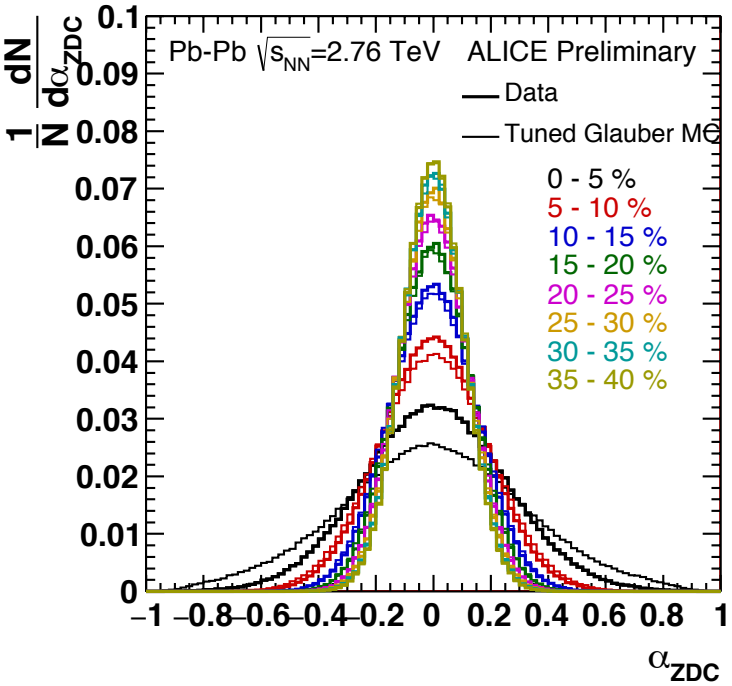
(PHOBOS) Glauber MC: Alver, Baker, Loizides, Steinberg arXiv: 0805.4411

Distribution of Asymmetry α_{ZDC}: Experiment and Tuned Glauber MC

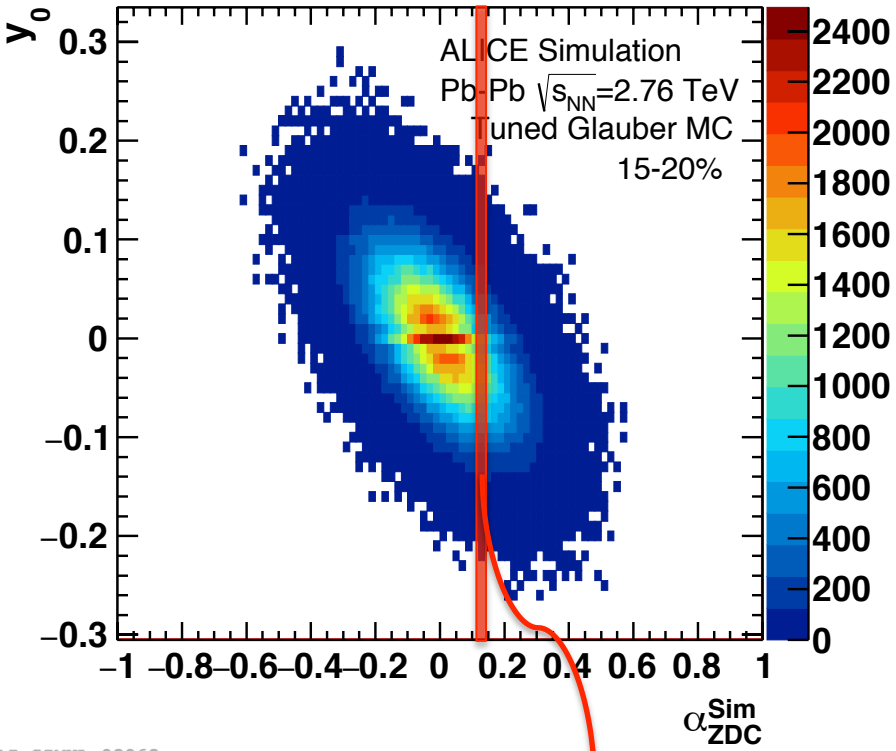
Obtain asymmetry $\alpha_{ZDC} = (ZDC_1 - ZDC_2) / (ZDC_1 + ZDC_2)$

For each simulated event we know y_0 and α_{ZDC}.

Similar distributions of asymmetry for data and Tuned Glauber MC (TGMC).

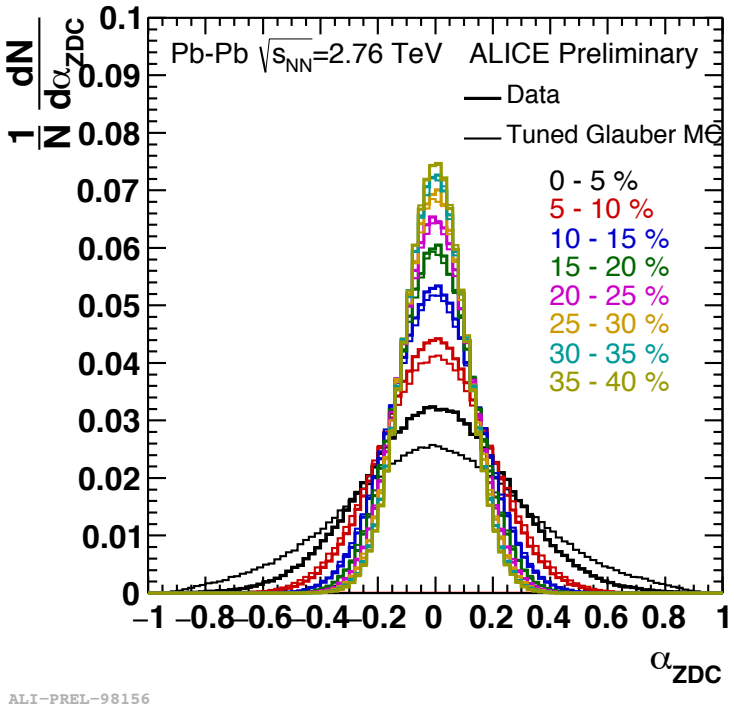


Response Matrix

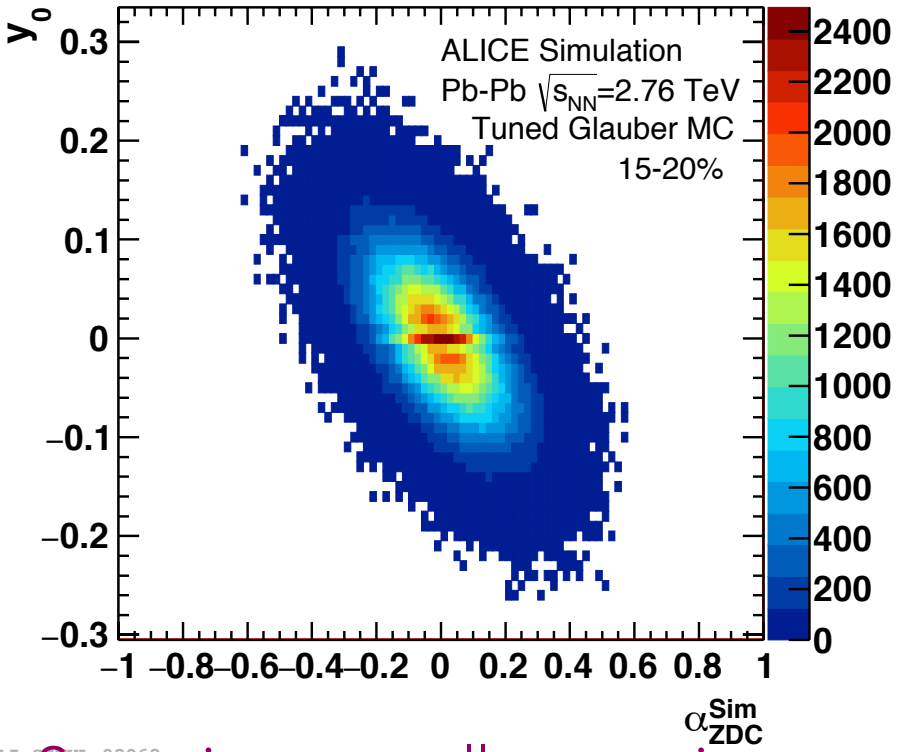


$$f(y_0, \alpha^{DATA}_{ZDC}) = f(y_0, \alpha^{SIM}_{ZDC}) \frac{N^{DATA}_{events}}{N^{SIM}_{events}}$$

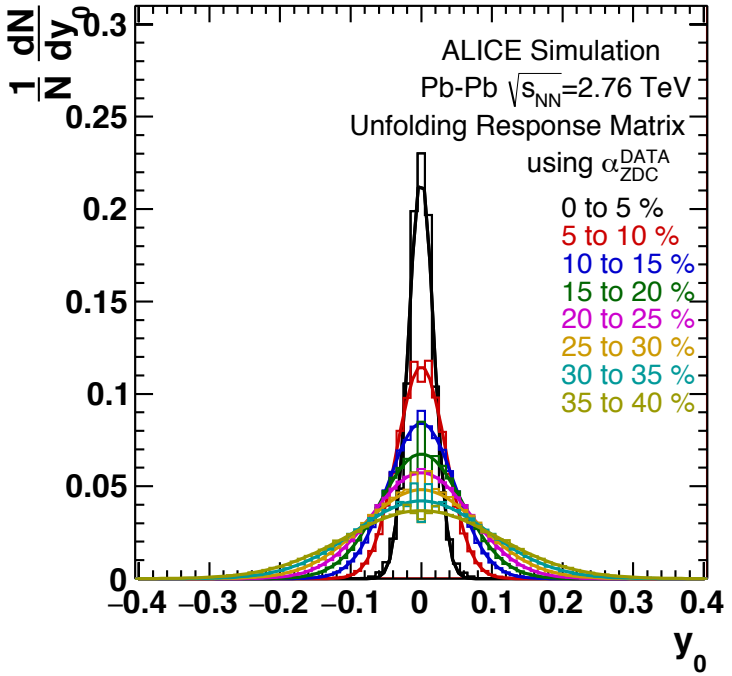
For each centrality class, there exists a distribution in y_0 for events with a given α_{ZDC}



Response Matrix



Widths increasing with decreasing centrality
Ranges from ~ 0.02 to 0.11



Summing over all α_{ZDC} gives

$$f(y_0) = \sum_{\alpha^{DATA}_{ZDC}} f(y_0, \alpha^{SIM}_{ZDC}) \frac{N^{DATA}_{events}}{N^{SIM}_{events}}$$

Effect on Pseudorapidity Distributions

Particle production is symmetric about CM in N-N collisions

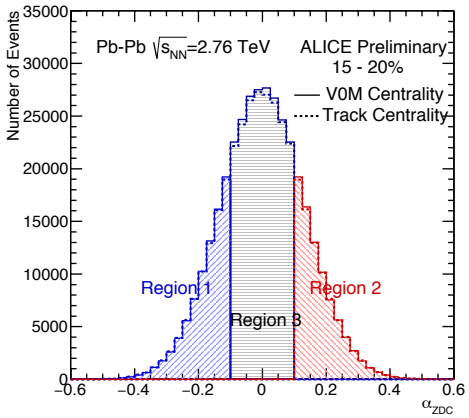
- There is a shift of CM rapidity in asymmetric collisions
- We assume that particle production is symmetric about the shifted rapidity.
- Look at ratios of rapidity distributions

$$\frac{(dN/dy)_2}{(dN/dy)_1} = \frac{Nexp(-\frac{(y-y_0)^2}{2\sigma_y^2})}{Nexp(-\frac{y^2}{2\sigma_y^2})} \quad \Rightarrow \quad \frac{(dN/dy)_2}{(dN/dy)_1} \approx 1 + \frac{yy_0}{\sigma_y^2} \approx 1 + c_1 y$$

In the experiment

- Select symmetric and asymmetric events
- Measure their pseudorapidity distributions
- The ratio $(dN_{ch}/d\eta)_2 / (dN_{ch}/d\eta)_1 \approx 1 + c_1\eta$
- We observe from simulations, and from HIJING,
  - $y_0 \approx c_1 \sigma_\eta^2$!

Ratio of $dN_{ch}/d\eta$ --- (Asymmetric/Symmetric)



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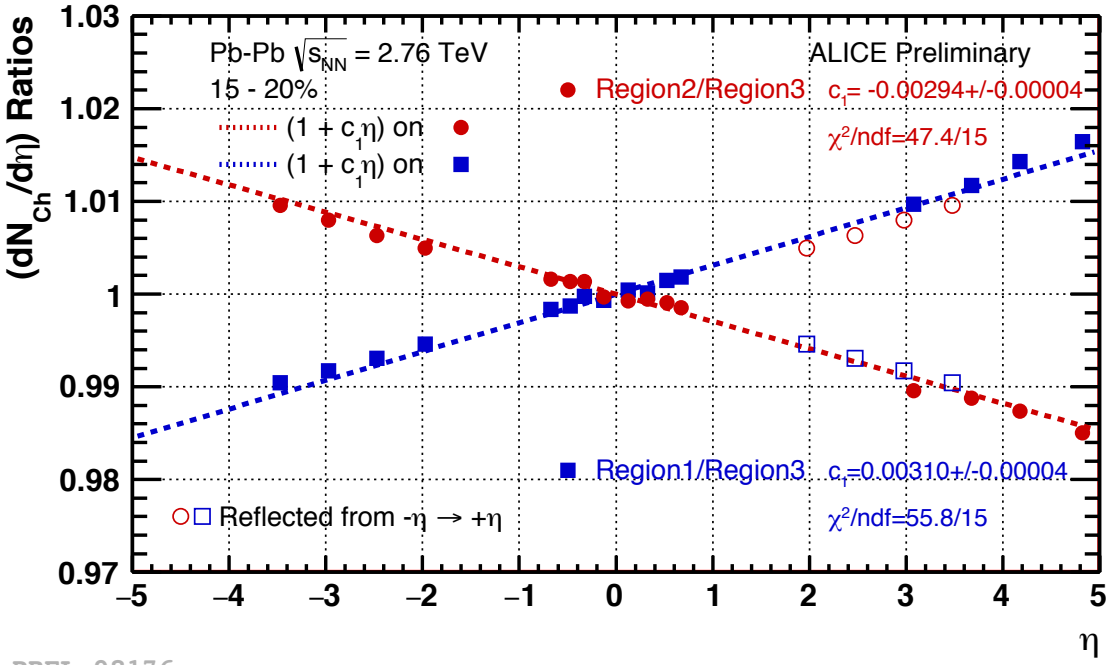
- Classify events on the basis of asymmetry in ZDC
- Obtain ratios of $dN_{ch}/d\eta$ distributions of events corresponding to different (a)symmetries.
- Fit a function linear in η to the ratio of $dN_{ch}/d\eta$

- 3.7 < η < -1.7 V0C
2.8 < η < 5.1 V0A
-0.8 < η < 0.8 TPC + ITS



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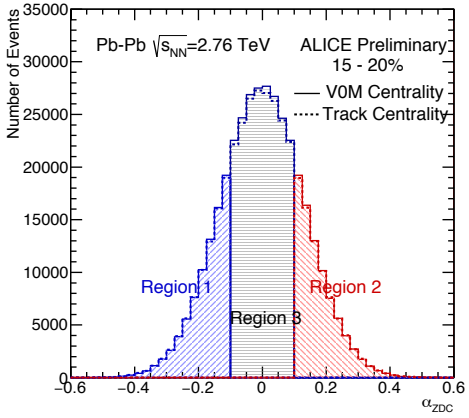
Ratio of $dN_{ch}/d\eta$ --- (Asymmetric/Symmetric)



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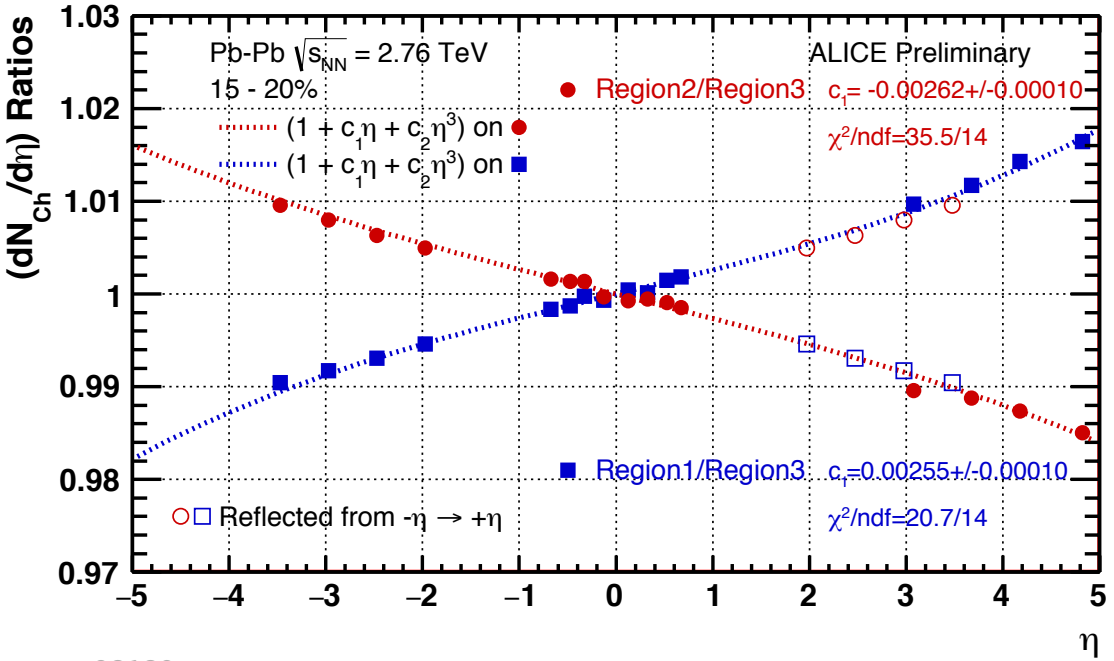
- Classify events on the basis of asymmetry in ZDC
- Obtain ratios of $dN_{ch}/d\eta$ distributions of events corresponding to different (a)symmetries.
- Fit a function linear in η to the ratio of $dN_{ch}/d\eta$
  - Add a term cubic in η

$-3.7 < \eta < -1.7$ V0C

$2.8 < \eta < 5.1$ V0A

$-0.8 < \eta < 0.8$ TPC + ITS



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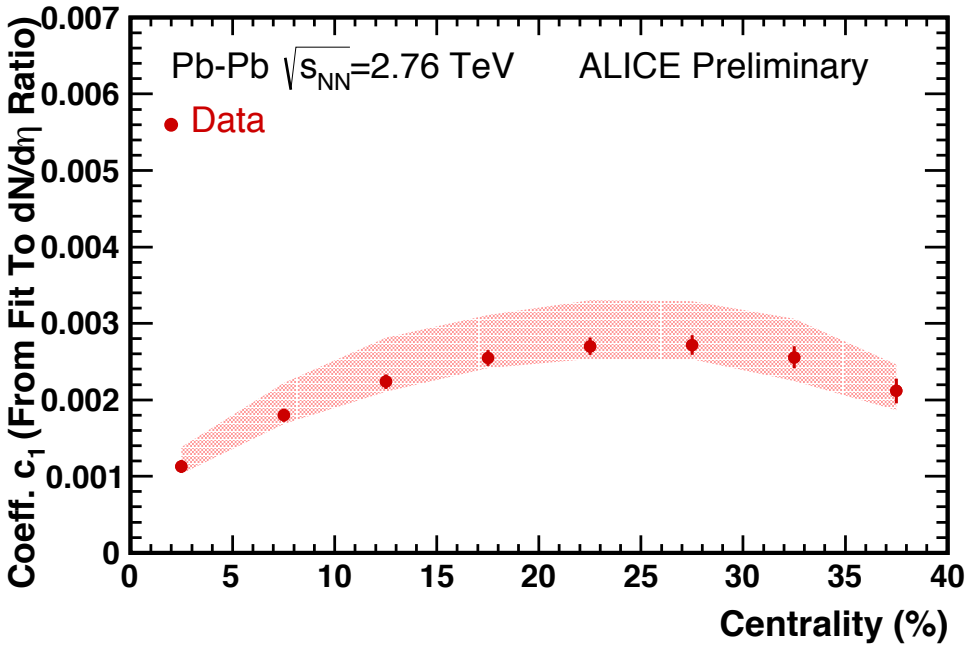
Coefficient c_1 of Term Linear in η

$$f(\eta) = 1 + c_1\eta + c_2\eta^3$$



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Significance of c_1 ?

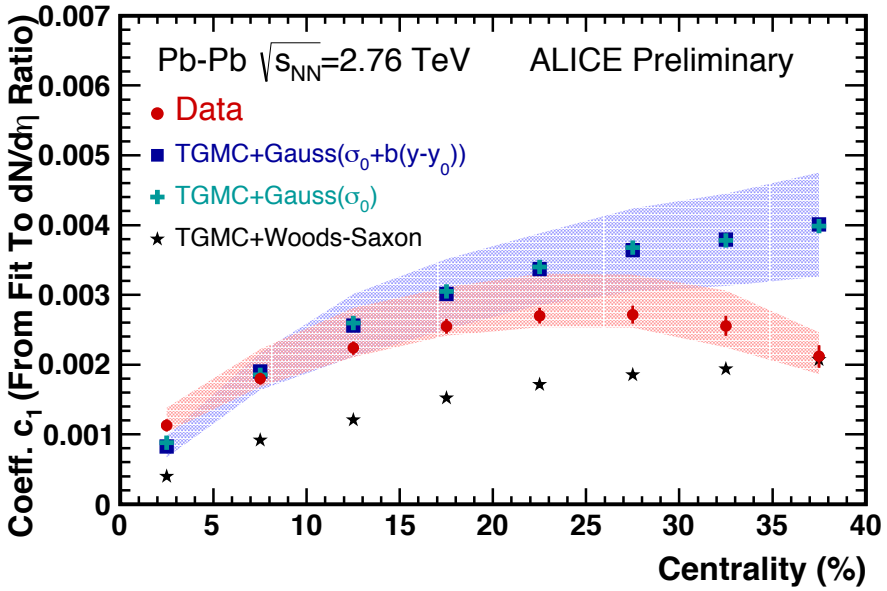
Systematic errors due to change in centrality criteria, vertex cuts, difference in region 1 and region 2 and difference in linear and cubic function fit

Recall: $y_0 \approx c_1 \sigma_\eta^2$ (~within 5%)

c_1 for Different Rapidity Distributions

For symmetric and asymmetric events

- Assume certain rapidity distribution
- Use rapidity-shift y_0 from tuned Glauber MC (TGMC)
- Obtain η distributions (realistic p_T distributions and particle ratios)



Gaussian with constant width

'Gaussian'-like form with width

$$\sigma_y = \sigma_0 + b(y - y_0)$$

Woods-Saxon distribution

$$f(y) = \frac{1}{1 + \exp\left(\frac{(|y - y_0|) - P}{t}\right)}$$

P = 4.424 and

t = 1.132

Each distribution ~ reproduces experimental width of η distribution

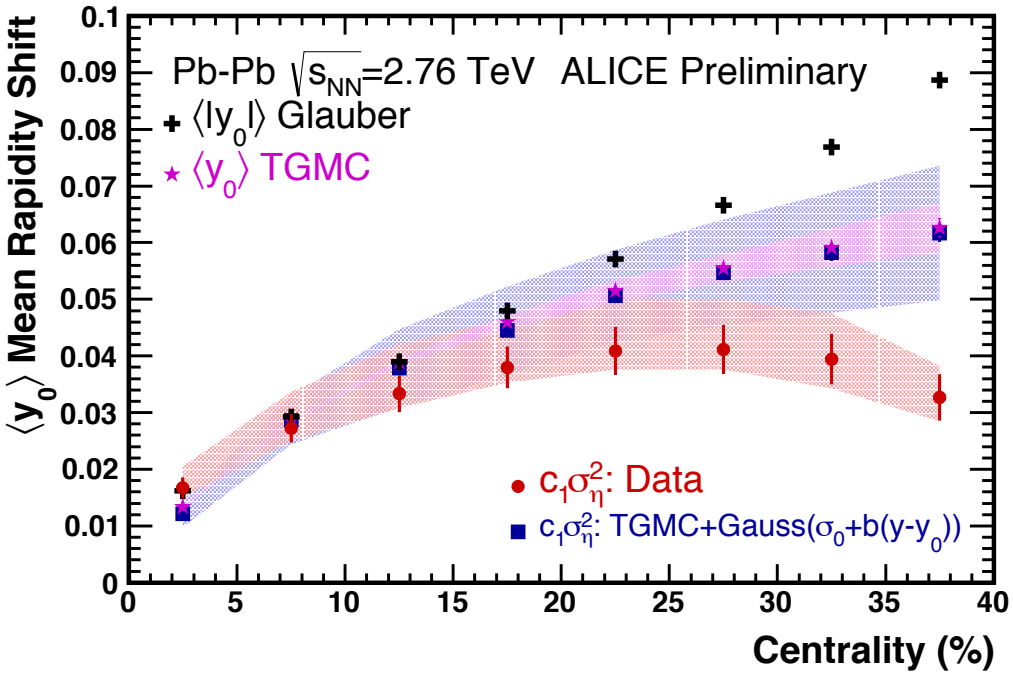
Estimates of $\langle y_0 \rangle$

For a Gaussian Rapidity Distribution

$$y_0 \approx c_1 \sigma_\eta^2$$

y_0 determined from

- Glauber MC
- Tuned Glauber MC
- Ratio of $dN_{ch}/d\eta$ (sim)
- Ratio of $dN_{ch}/d\eta$ (data)



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Summary and Outlook

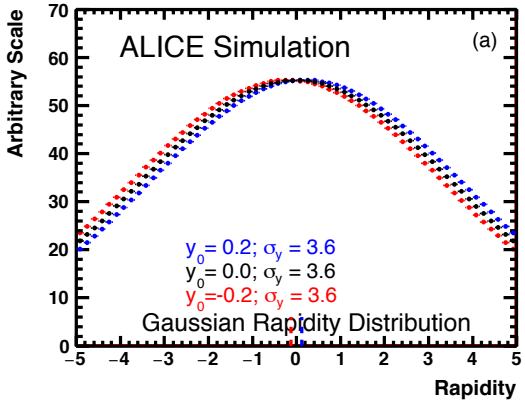
- Longitudinal asymmetry
  - Shifts rapidity of participant zone by y_0
    - Asymmetry measured using ZDCs
    - Model-dependent estimate of y_0 using asymmetry
    - Width of y_0 distributions more for less central collisions
  - Causes changes in rapidity distributions
    - Manifest in the ratio of $dN_{ch}/d\eta$ distributions
    - Ratios affected by shape of rapidity distribution
      - Gaussian, wider-than-Gaussian, Wood Saxon
  - Measurement of ratio estimates rapidity shifts
- Use asymmetry as a classifier and study its effects on
  - Rapidity distributions (present work), source size, flow and its fluctuations, forward-backward correlations, various global observables
- First results on estimates of rapidity-shifts from data
- First results of effects on $dN/d\eta$ distributions

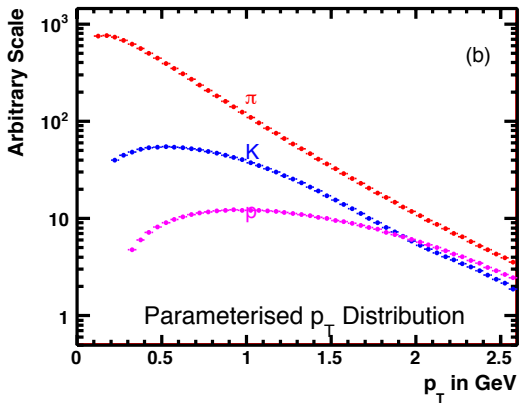
BACKUP SLIDES

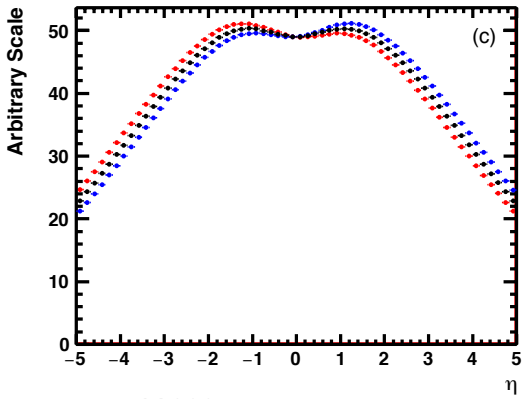
Effect of Shift on η-Distributions

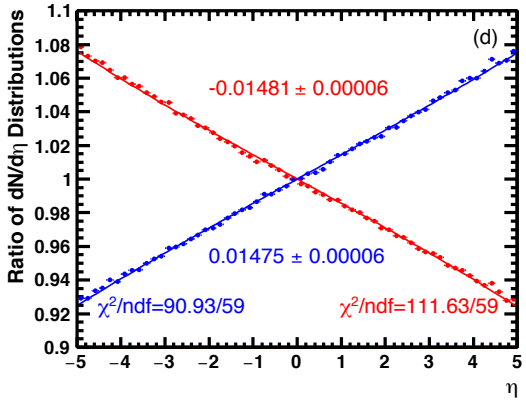
Assume $f(y) \propto e^{\frac{-(y-y_o)^2}{2\sigma_y^2}}$, peaked at 0 and 0.2

Realistic p_T distribution and charged particle composition









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If ratio fitted to

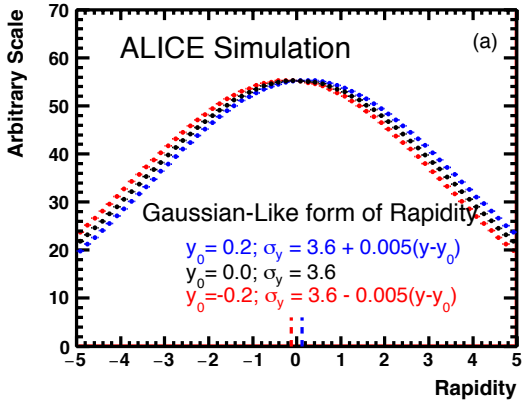
Ratio = 1 + $c_1\eta$;

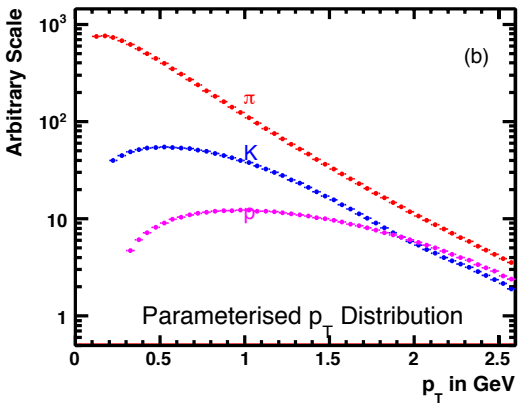
Slope c_1 related to the rapidity shift

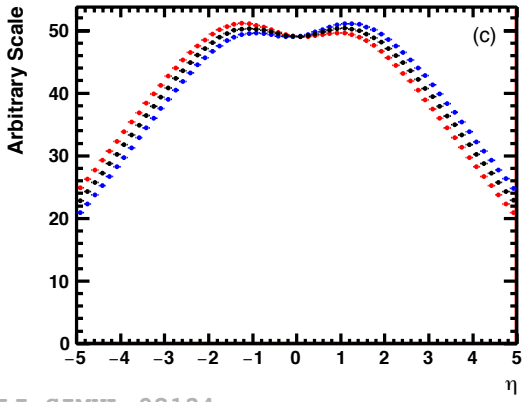
$y_0 = N\, c_1 \sigma_\eta^2$

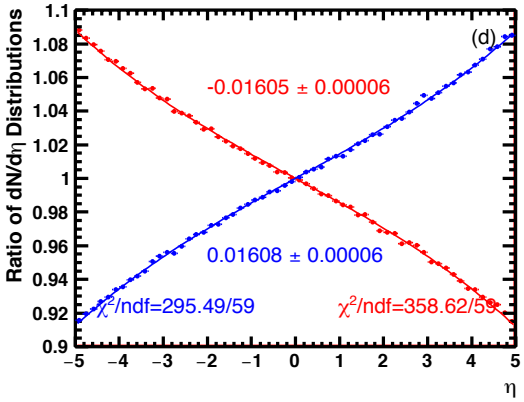
N = 1.00 ± ~5%, depending upon p_T and particle (π-K-p) composition

Effect of Shifted Rapidity Distribution, Wider on One Side ($\sigma = \sigma_0 + b\,(y-y_0)$)









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If ratio fitted to

$R = 1 + c_1\eta + c_2\eta^3$

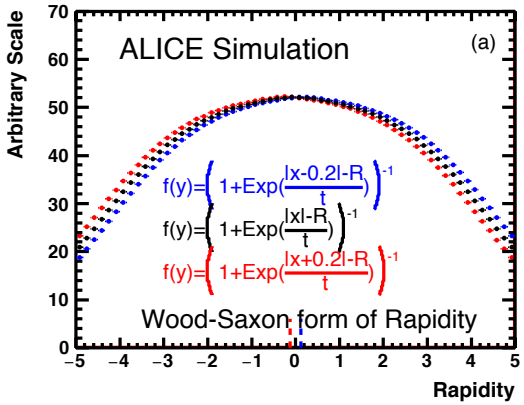
Coefficient c_1 related to the rapidity shift as

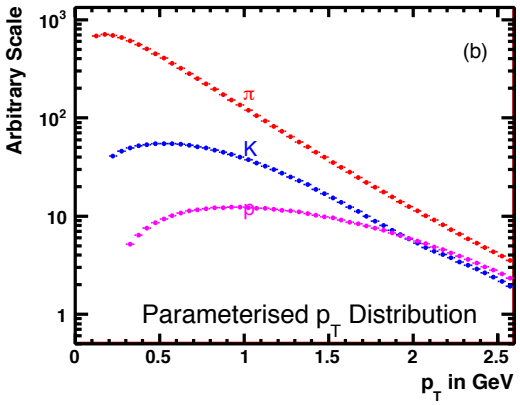
$y_0 = N\, c_1\, \sigma_\eta^2$

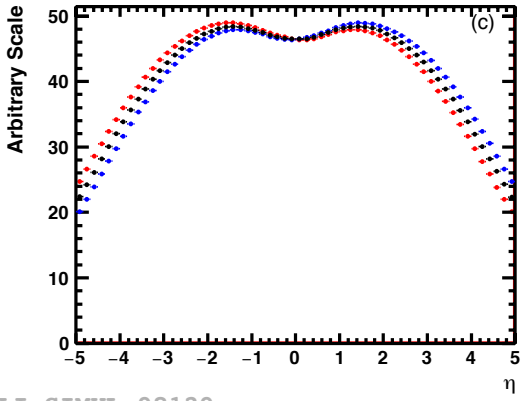
N = 1.00± ~5%,

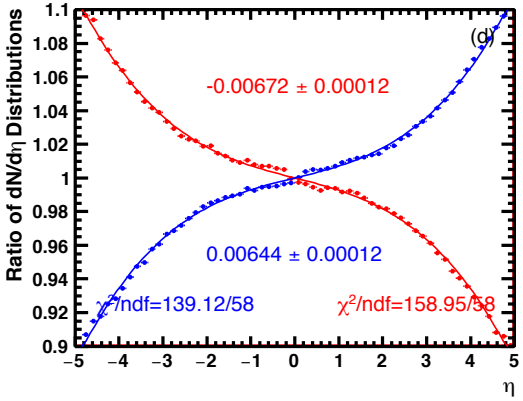
c_2 = 0 for b=0.0

Effect of Woods-Saxon Rapidity Distribution









Yields large cubic term

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Systematic Errors on c_1 in Data

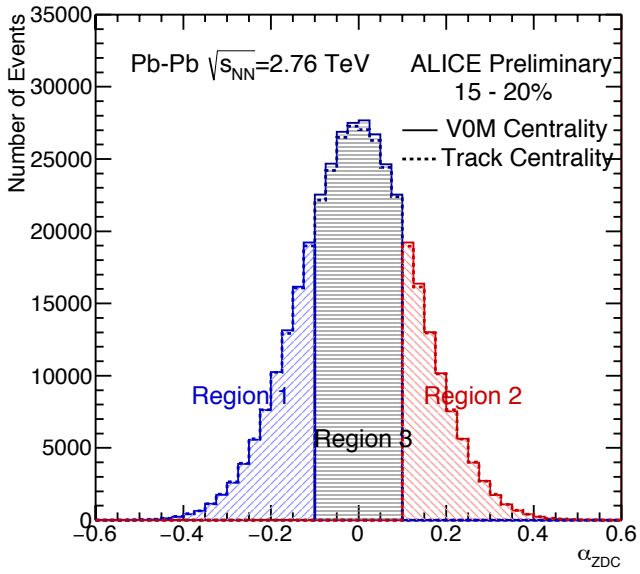
Source of Error	Estimated range of error (in %age) for all centrality intervals
Change in centrality criteria (Trk / V0M)	1 - 7
Cut on vertex position $\|V_z\| < 3$ cm	1 - 4
Difference in c_1 for region 1 and region 2	1 - 11
Total (added in quadrature)*	5 - 12
Additional error on positive side due to difference in c_1 in fits to linear and cubic function	11 - 25
Total (added in quadrature) for positive side	15 - 26

*Also included is an additional contribution of 3% (maximum) due to differences in distributions of vertex position and centrality for symmetric and asymmetric events

Systematic Errors on c_1 in Simulation

Source of Error	Estimated range of error (in %age) for all centrality intervals
Uncertainty in mean $< y_0 >$	1 - 9
Uncertainty in width σ_0 of rapidity distribution	13 - 17
Different forms of p_T distributions	1 - 6
Difference in c_1 for region 1 and region 2	0 - 4
Total (added in quadrature)	14 - 19

Symmetric and Asymmetric Events: Use α_{ZDC}



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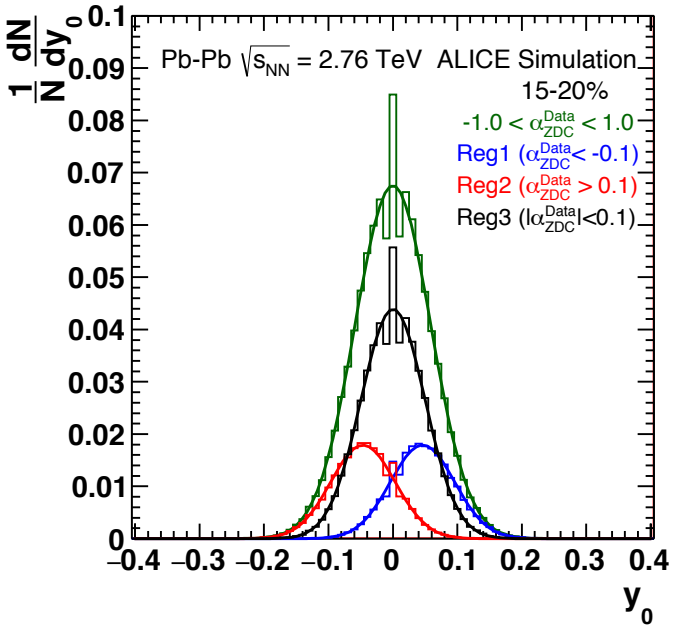
y_0- distribution of events selected using α_{ZDC} ➔

Mean values $\langle y_0 \rangle$ ➘



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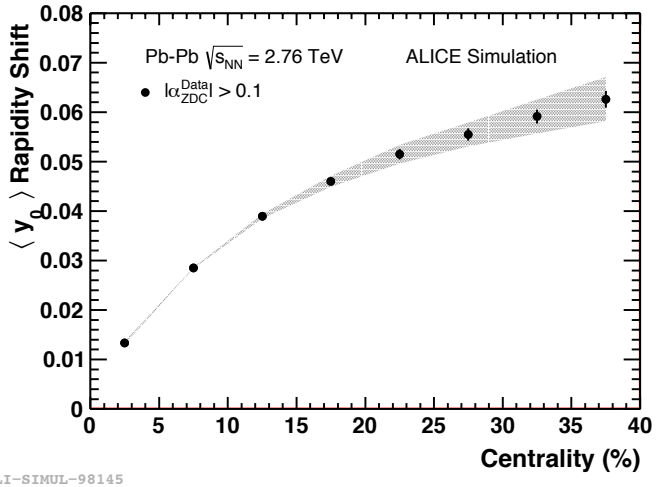

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Systematic errors correspond to different tuning parameters for the ZDC energy distribution

Estimating y_0 from $dN_{ch}/d\eta$ using HIJING +Geant Events

Recall:

Considered two event samples
- With $\langle y_0 \rangle \neq 0$ and $\langle y_0 \rangle = 0$
- Obtain the ratio of $dN_{ch}/d\eta$
- Slope related to y_0

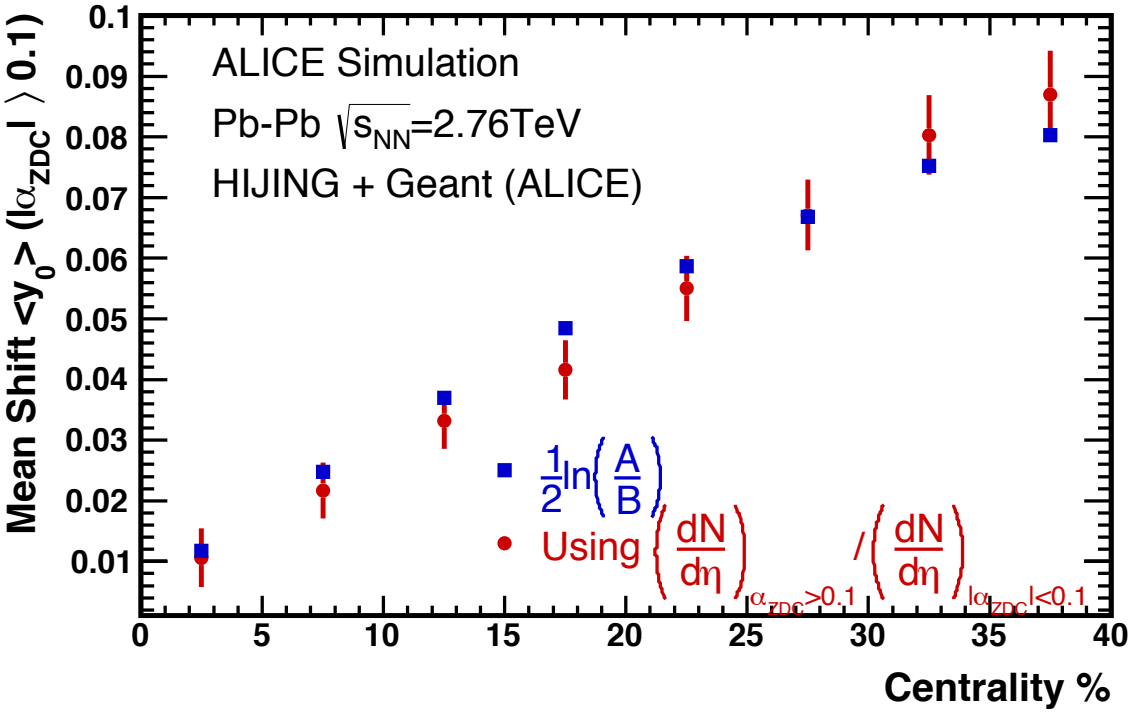
We obtained a distribution of y_0 for any event sample

In Glauber MC we know (true) y_0
In data, we know c_1
In HIJING, we know both

Asymmetry distribution
- Divide into region 1, 2 and 3
- y_0 distribution for each

Fit ratio of $dN_{ch}/d\eta$ to cubic function and obtain
- $y_0 = N\, c_1\, \sigma_\eta^2$

Known y_0 from HIJING and $y_0 = N\, c_1 \sigma_\eta^2$



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Widths σ_η taken from ALICE Data and vary from 3.85 to 3.93

y_0 values comparable to values in data and also as per TGMC