First proton-lead results from ALICE

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on behalf of the ALICE collaboration

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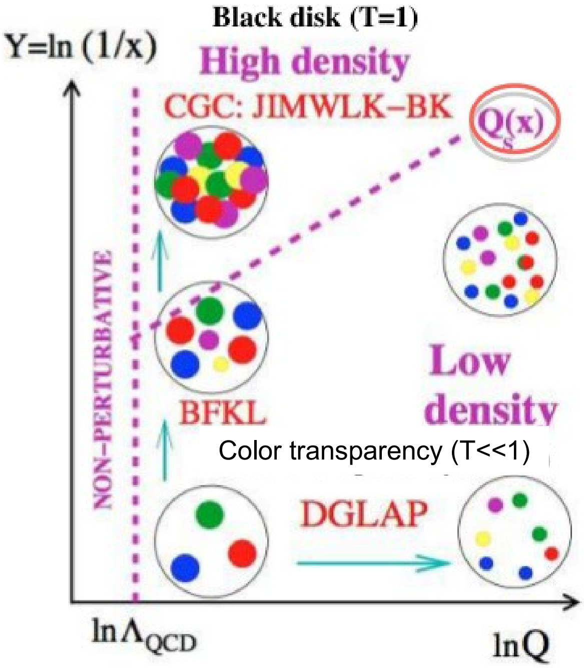
Motivation

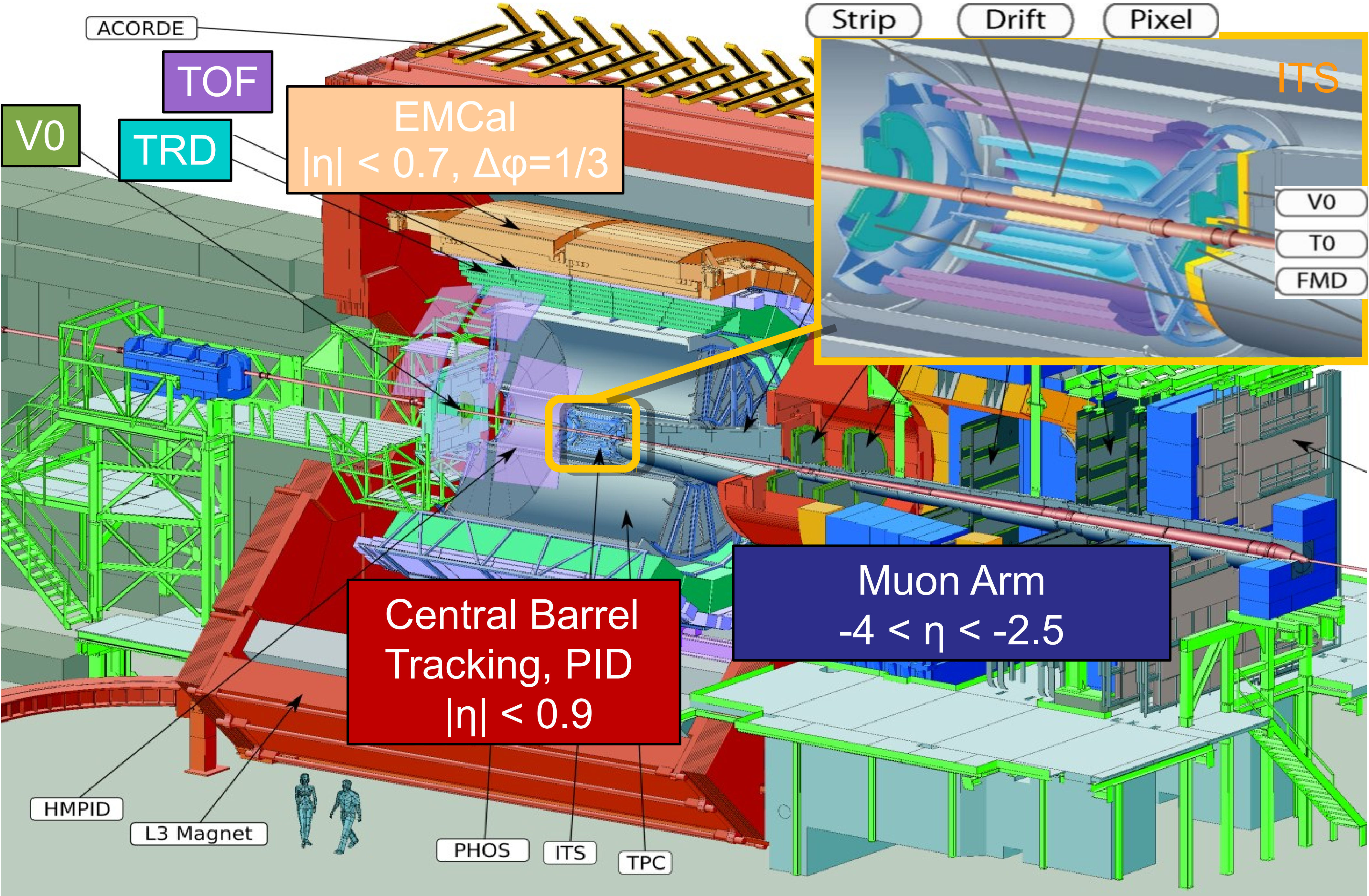
- Study high-density QCD in saturation region
  - Saturation scale (Q_s) enhanced in nucleus ($Q^2_s \sim A^{1/3\lambda}$)
  - In perturbative regime at the LHC: $Q^2_s \sim 2\text{-}3$ GeV^2
  - Qualitatively expect $x \sim 10^{-4}$ at $\eta=0$ (vs 0.01 at RHIC)
- Study pA as a benchmark for AA
  - Disentangle initial from final state effects
  - Characterize nuclear PDFs at small-x
- Expect surprises
  - pA contains elements of both: pp and AA
- Other physics opportunities
  - Diffraction
  - Photo-nuclear excitation



PRL 91 (2003) 072302

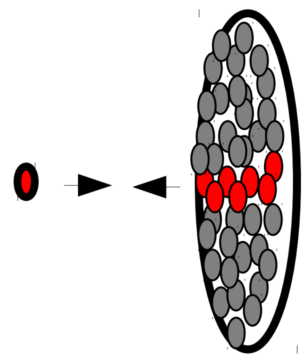
Motivations summarized in JPG 39 (2012) 015010

The ALICE detector

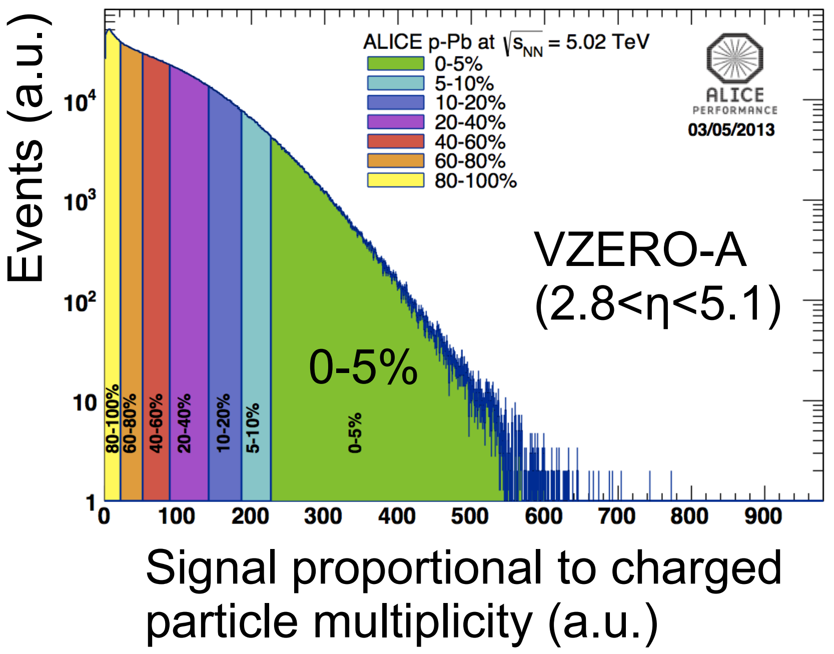


Event multiplicity classes

- Correlation between collision geometry and multiplicity not as strong as in AA
- System also exhibits features of biased pp (NN) collisions in the multiplicity tails
- Complicates precise extraction of Glauber related quantities
  - Use minbias instead ($\sigma_{pA} = A\,\sigma_{pp}$)
- Define event classes by slicing various multiplicity related distributions
  - Every experiment uses its own selection and usually provides (corrected) multiplicity at mid-rapidity
    - Forward multiplicity/energy on Pb side
  - Event class definition may matter for particular measurements
  - Systematics using different selections

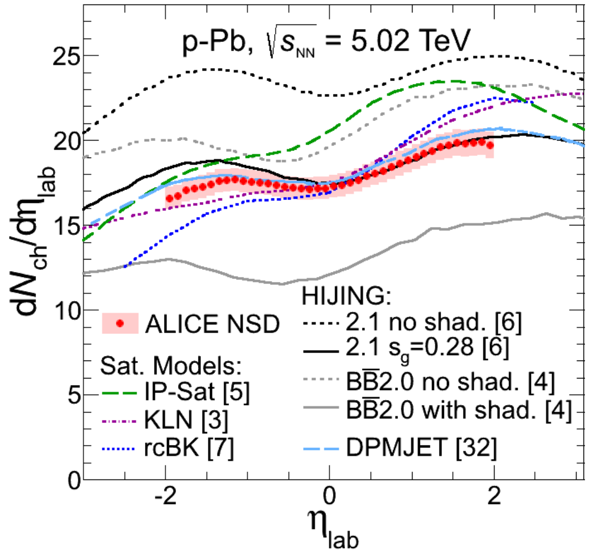


$N_{part}=8$ ($N_{coll}=N_{part}-1$)



ALICE pPb results

ALICE, PRL 110 (2013) 032301



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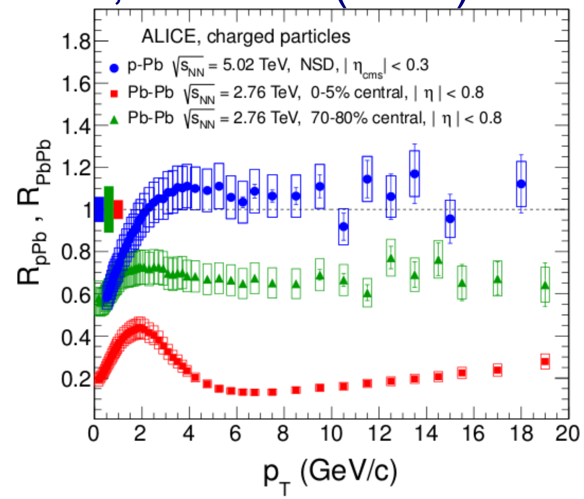
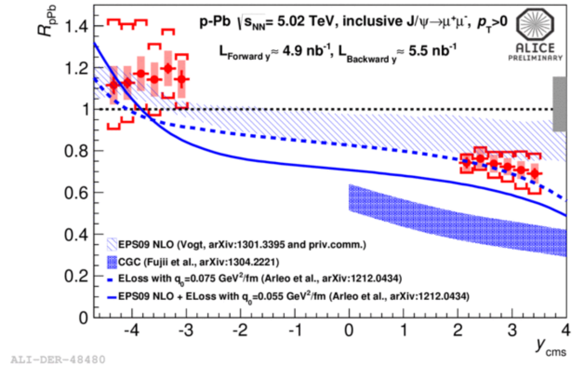


ALICE preliminary



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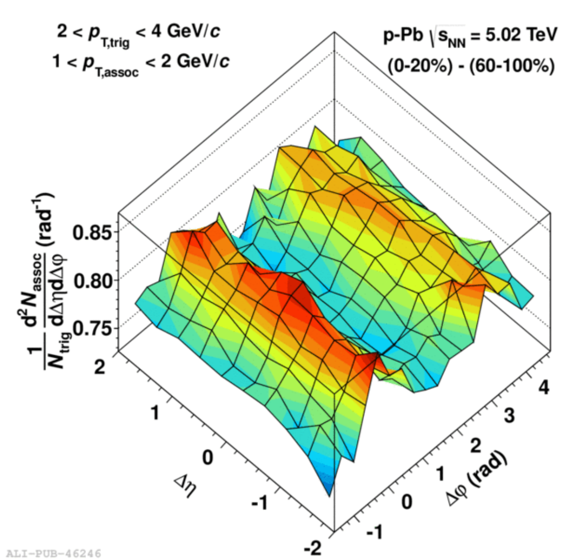
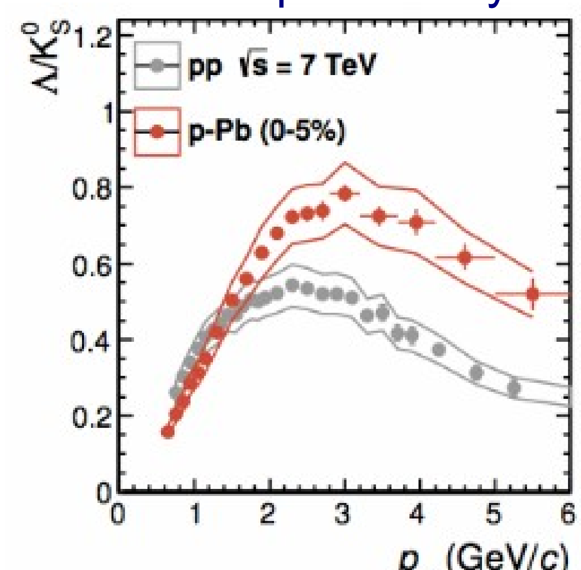


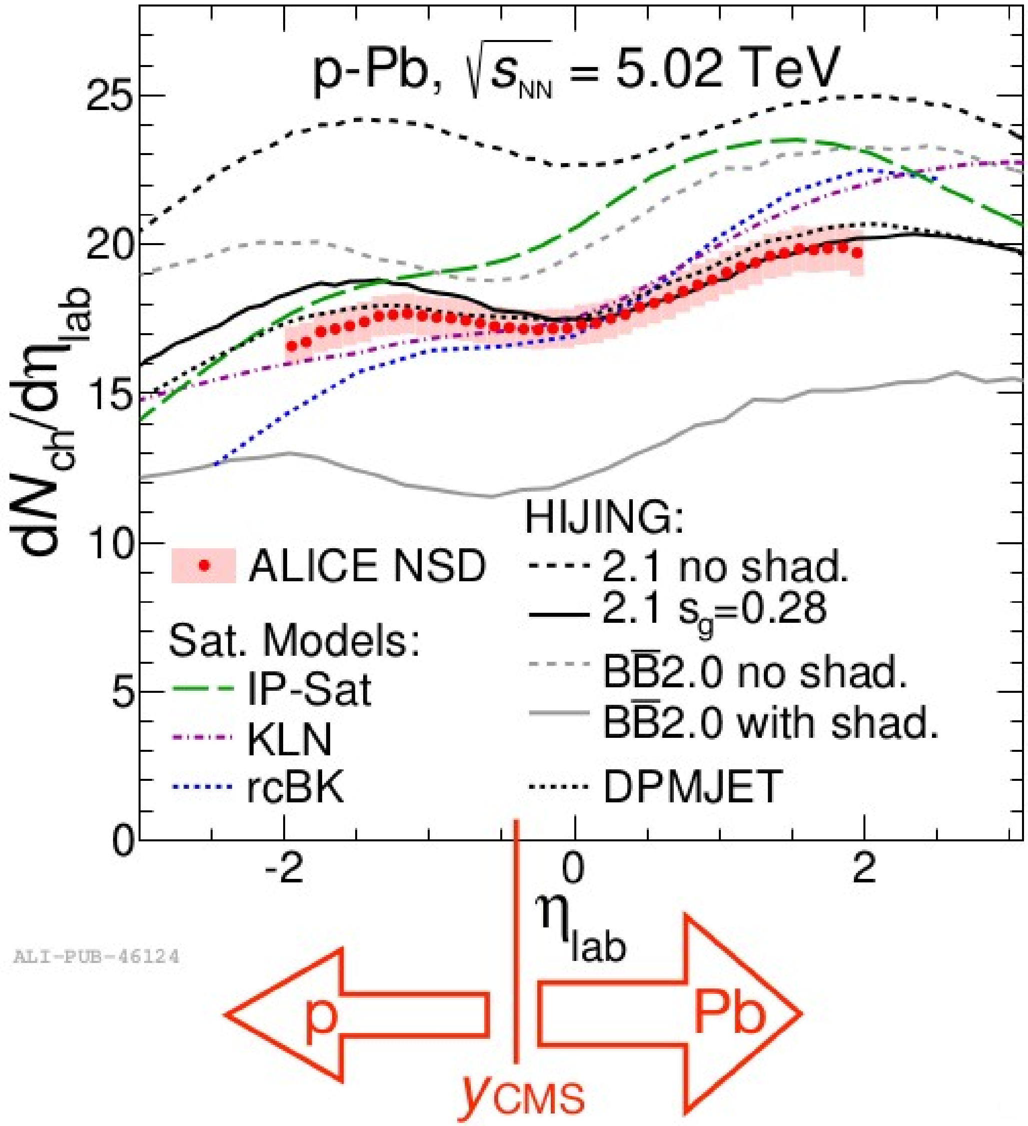
ALICE preliminary



Charged particle pseudorapidity density

ALICE, PRL 110 (2013) 032301

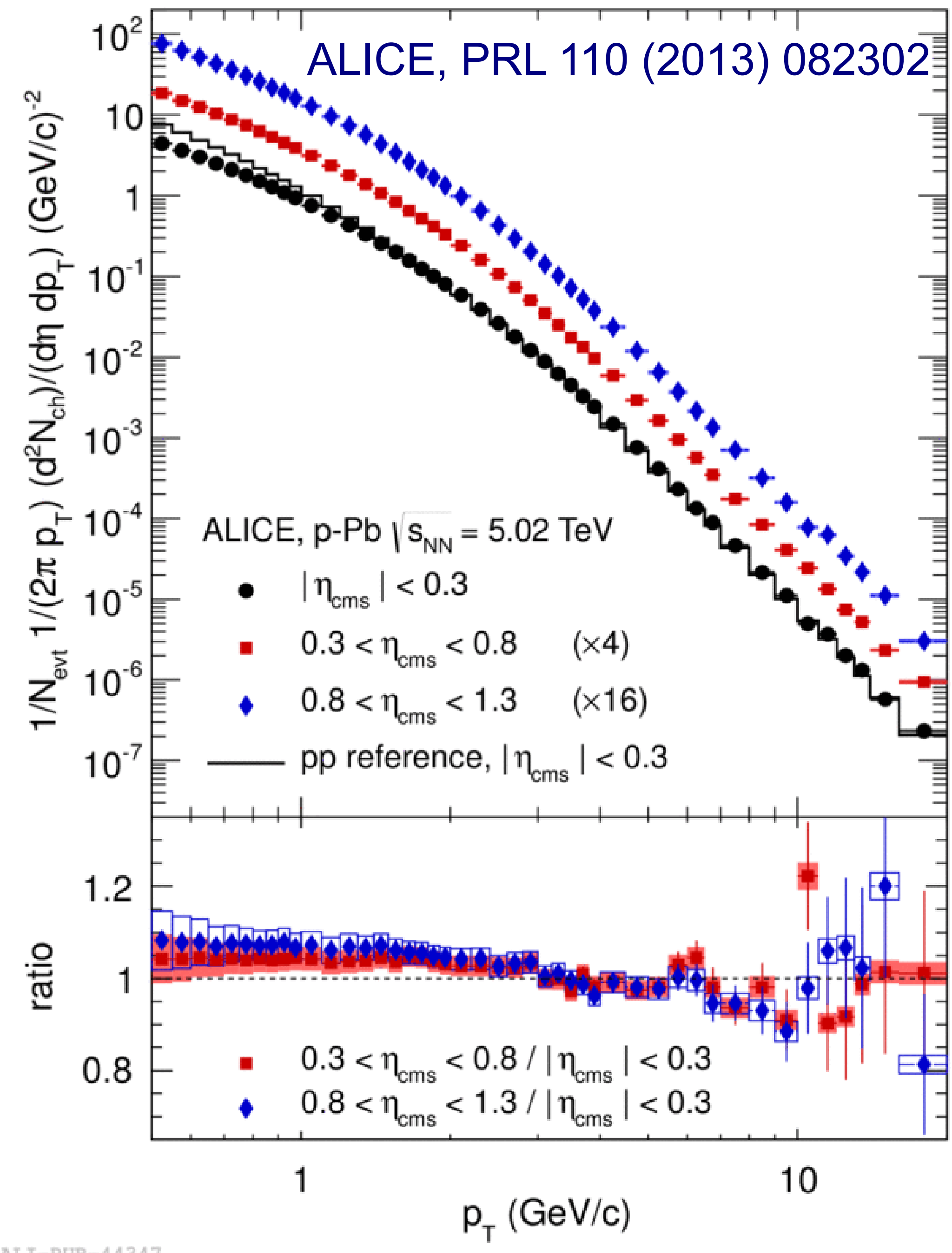
- Tracklet based analysis
  - Dominant systematic uncertainty from NSD normalization of 3.1%
- Reach of SPD extended to |η|<2 by extending the z-vertex range
- Results in ALICE laboratory system
  - y_{cms} = - 0.465
- Comparison with models
  - Most models within 20%
  - Saturation models have too steep rise between p and Pb region
  - See for further comparisons Albacete et al., arXiv:1301.3395



NB: HIJING calculations are expected to increase by ~4% from INEL to NSD

Charged particle spectra in bins of η

- Primary charged tracks (3 η bins)
  - Reconstructed in ITS+TPC (|η|<0.8)
  - Use $\eta_{cms} = \eta_{lab} - y_{cms}$, then correct
  - Systematic uncertainty: 5.2-7.1%
  - NSD normalization: 3.1 %
- Hint for slightly softer spectrum at higher η (Pb side)?
- Reference constructed from pp (INEL) data at 2.76 and 7 TeV
  - Interpolation below 5 GeV/c, and above scaled by factor obtained from NLO calculation
    - Systematic uncertainty: 8%
    - Normalization uncertainty: 3.6%
  - $\langle T_{pPb} \rangle = 0.0983 \pm 0.0035\ \mathrm{mb}^{-1}$ from Glauber model



Nuclear modification factor pPb vs PbPb

$$R_{AB} = \frac{\mathrm{d}N_{AB}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}} \rangle \mathrm{d}N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- R_{pPb} (at mid-rapidity) consistent with unity for p_T > 2 GeV/c
- High-p_T charged particles exhibit binary scaling
- Unlike in PbPb, no suppression at high p_T is observed
- Suppression at high p_T in PbPb is not an initial state effect

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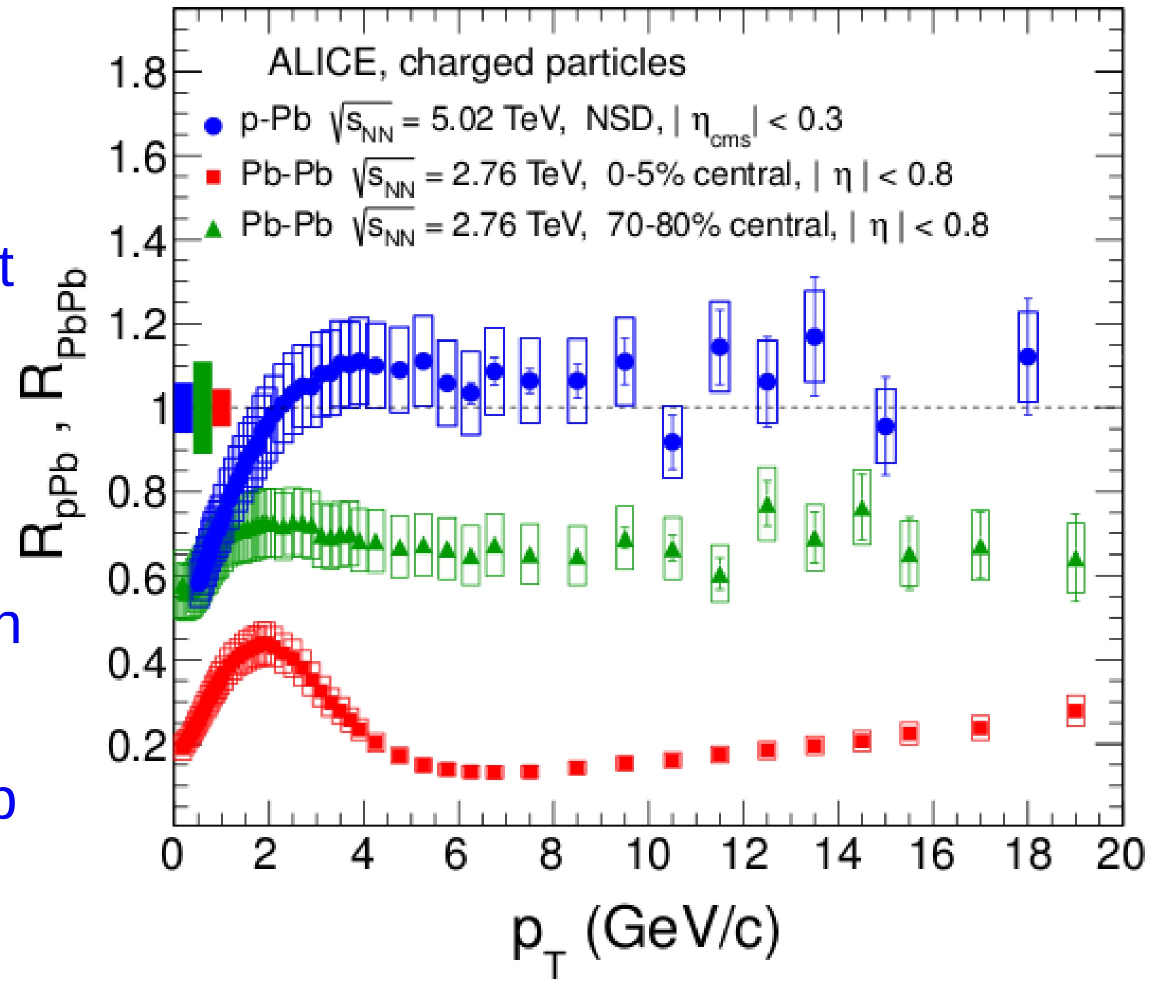
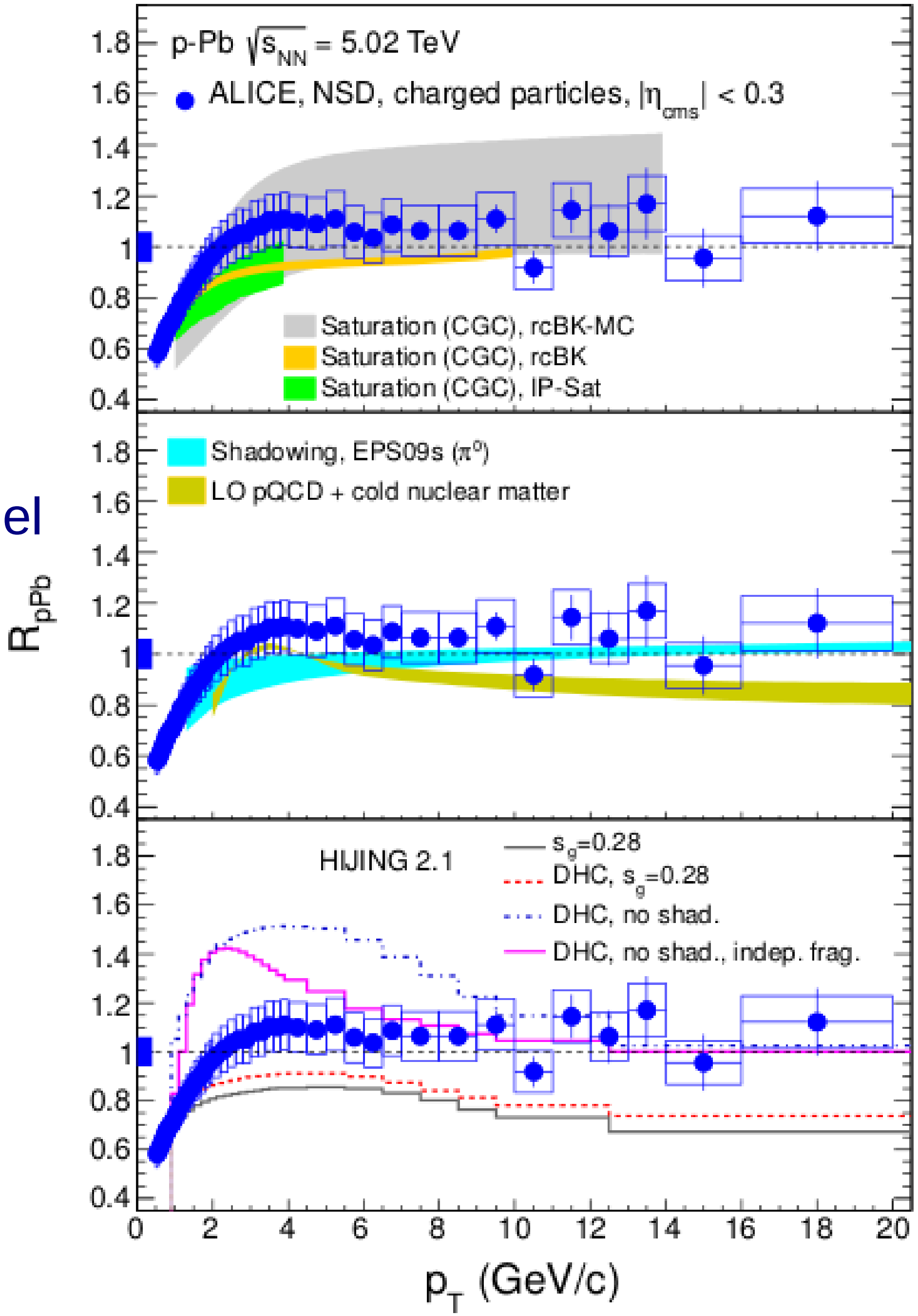


Nuclear modification factor vs models

- Saturation (CGC) models:
  - Consistent with the data
  - Large uncertainties
- pQCD models with shadowing
  - Consistent with data
  - Tension at high p_T for LO+CNM model
- HIJING 2.1
  - With shadowing only matches at very low p_T (see also dN/dη)
  - No shadowing better at high p_T
- Spectrum itself interesting
  - Neither HIJING nor DPMJET do describe the pPb p_T spectrum itself

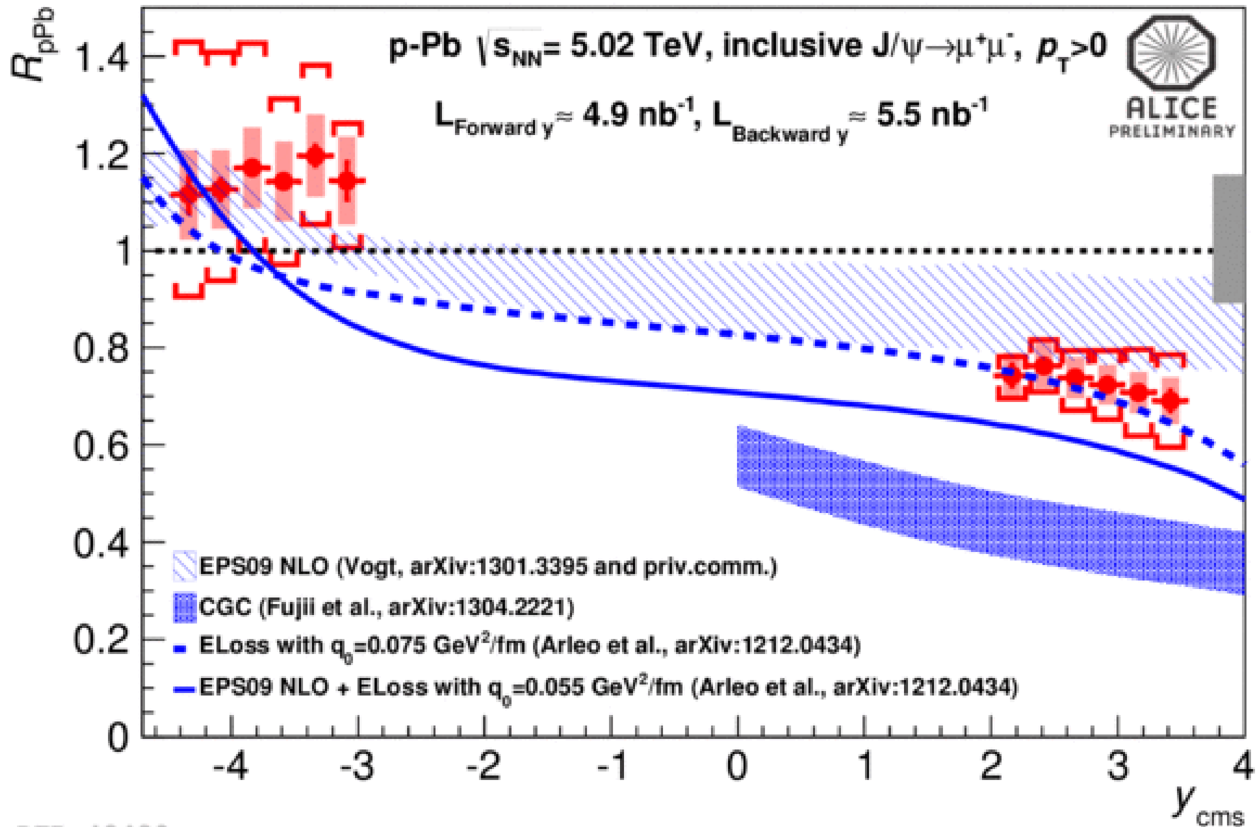
NB: HJING calculations are expected to increase by ~4% from INEL to NSD



J/ψ nuclear modification factor vs models

- R_{pPb} decreases towards forward y
- Uncertainty dominated by uncertainty of pp reference
- No apparent rapidity dependence in backward region

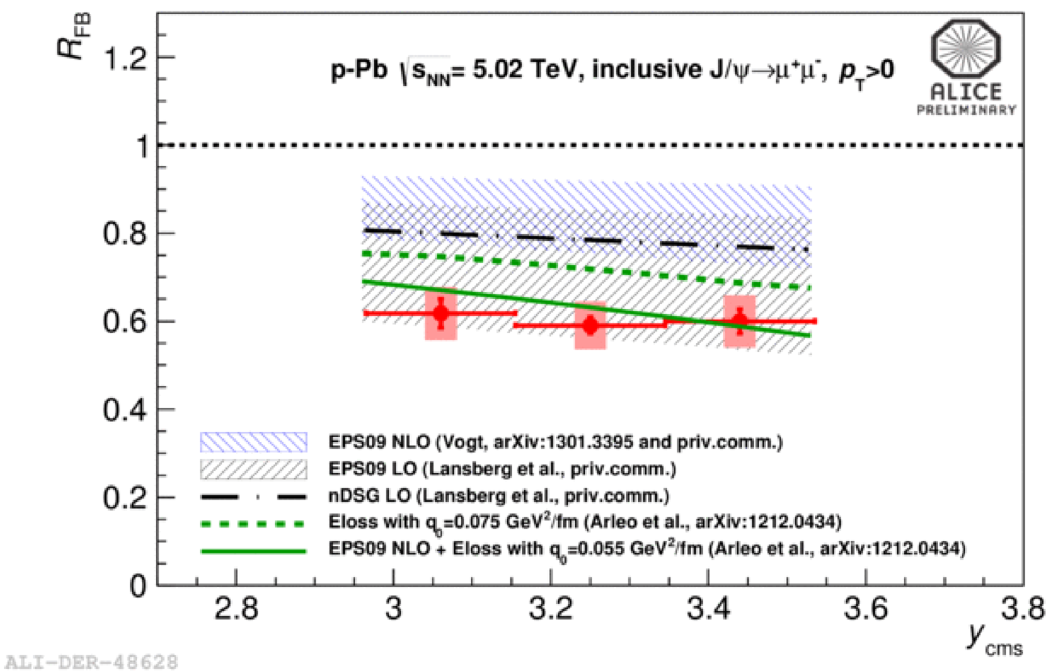
Inclusive J/psi, ALICE preliminary

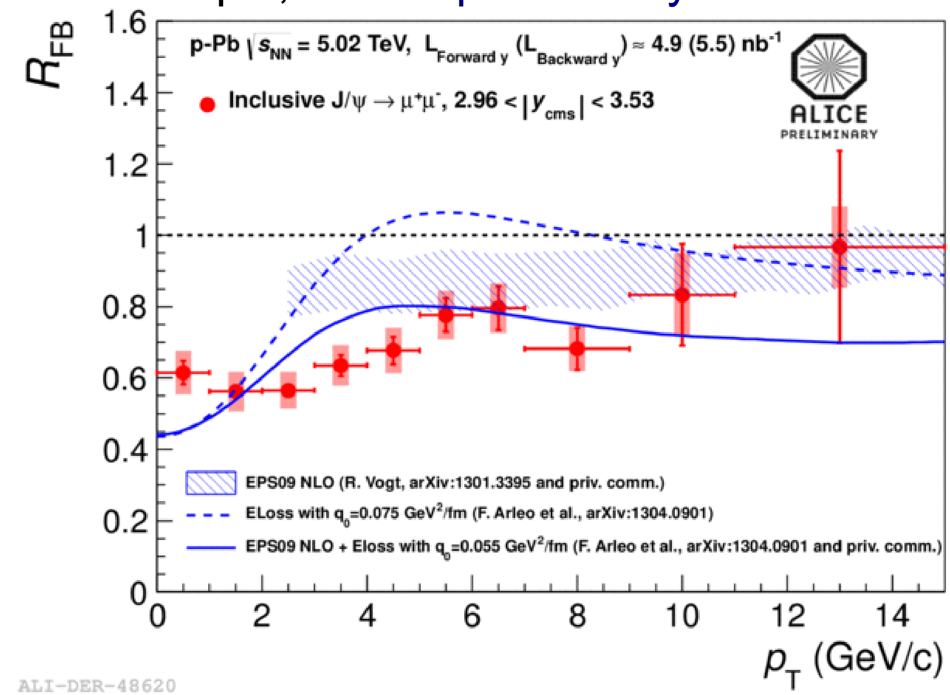


- Comparison with models
  - Good agreement with models incorporating shadowing (EPS09 NLO) and/or a contribution of coherent parton energy loss
  - CGC model (Fujii et al.) disfavored by the data
  - Rapidity dependence in backward region may provide additional constraints

J/ψ forward-backward asymmetry

Inclusive J/psi, ALICE preliminary



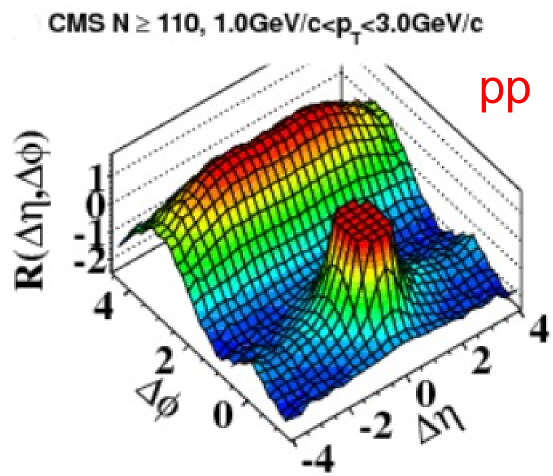


- Forward-to-backward ratio in common |y| ranges
  - Free of uncertainty from pp reference
- Models incorporating shadowing and energy loss consistent with data
  - p_T dependence provides additional constraints for models

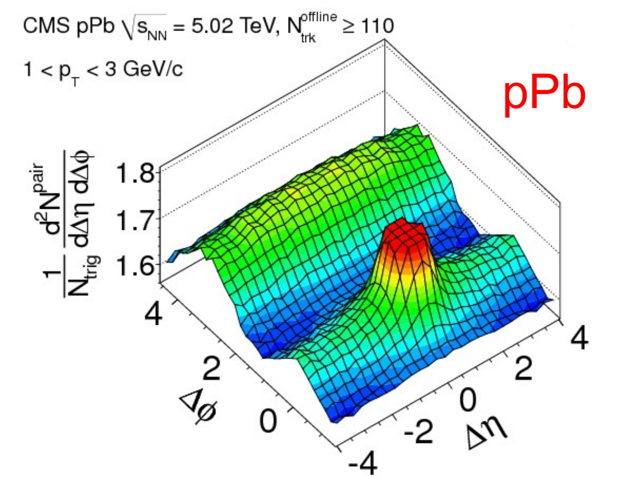
Di-Hadron Correlations (DHC)

- CMS: pp, pPb at LHC
  - Long-range near-side correlations (ridge) appear at high-multiplicity
    - Collective effects in pp and pPb?
    - CGC initial state effects?

CMS, JHEP 1009 (2010) 91

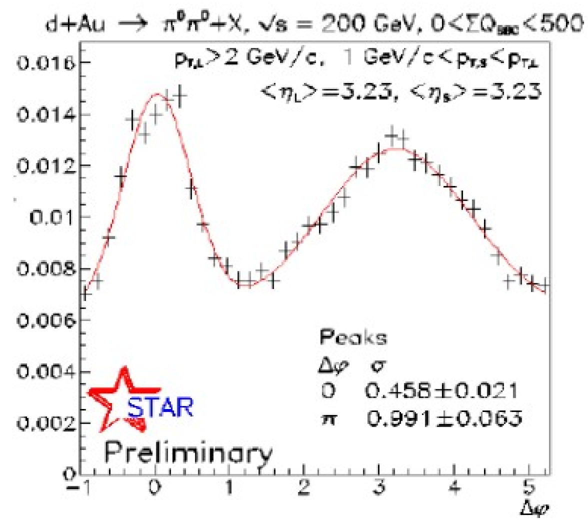


CMS, PLB 718 (2012) 795

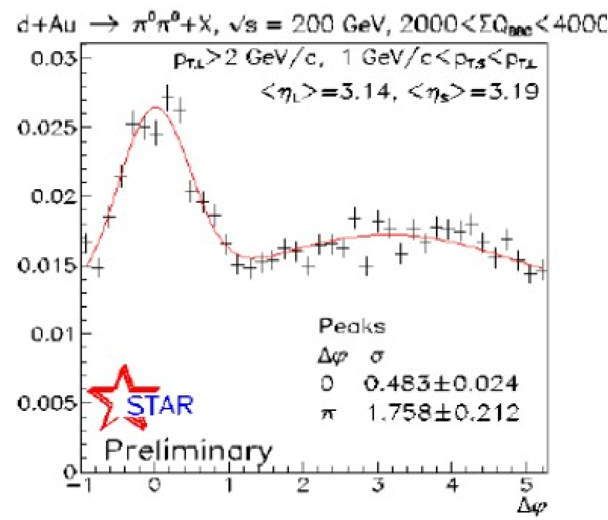


- STAR: dAu at RHIC
  - Back-to-back (jet-like) correlations in forward π^0 correlations disappear in high-multiplicity events
    - Compatible with CGC predictions
- LHC mid- and RHIC forward-η probe a similar x regime

STAR, arXiv:1005.2378



Peripheral



Central

DHC: Extraction of double ridge structure

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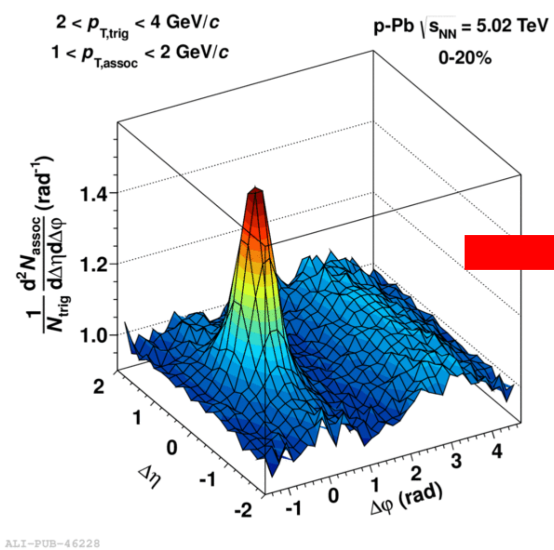
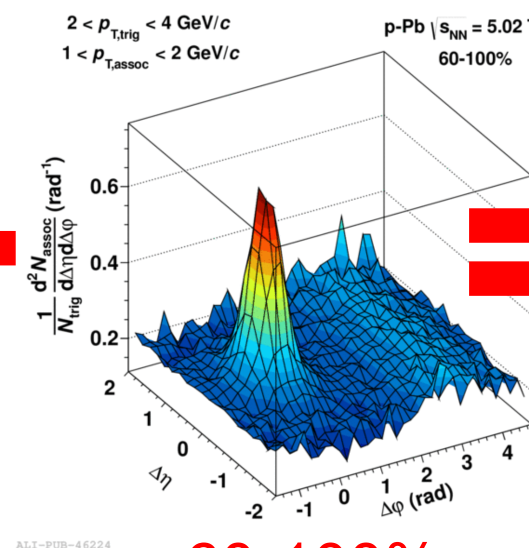
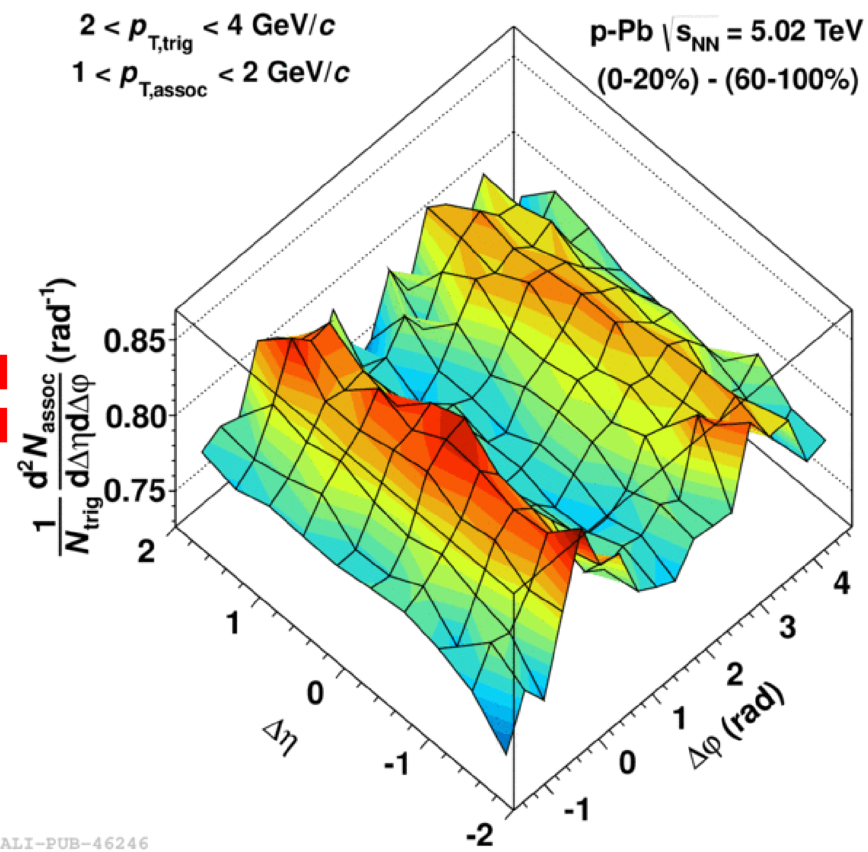


0-20%



60-100%



- Extract double ridge structure using a standard technique in AA collisions, namely by subtracting the jet-like correlations
  - It has been verified that the 60-100% class is similar to pp
  - The near-side ridge is accompanied by an almost identical ridge structure on the away-side

DHC: Ridge yields

- Integrate two ridges above baseline on the
  - Near side ($|\Delta\varphi|<\pi/2$)
  - Away side ($\pi/2<|\Delta\varphi|<3\pi/2$)

- Near and away-side ridge yields
  - Change significantly
  - Agree for all p_T and multiplicity ranges
  - Increase with trigger p_T and multiplicity
  - Widths are approximately the same (not shown)

- The correlation between near- and away-side yields suggests a common underlying origin

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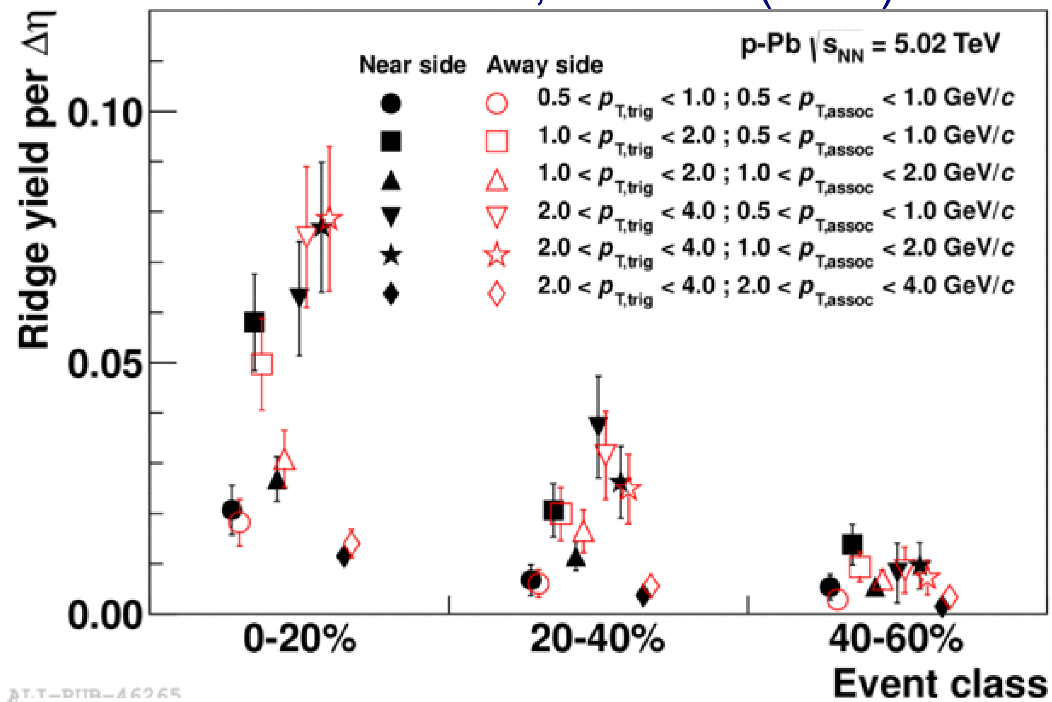

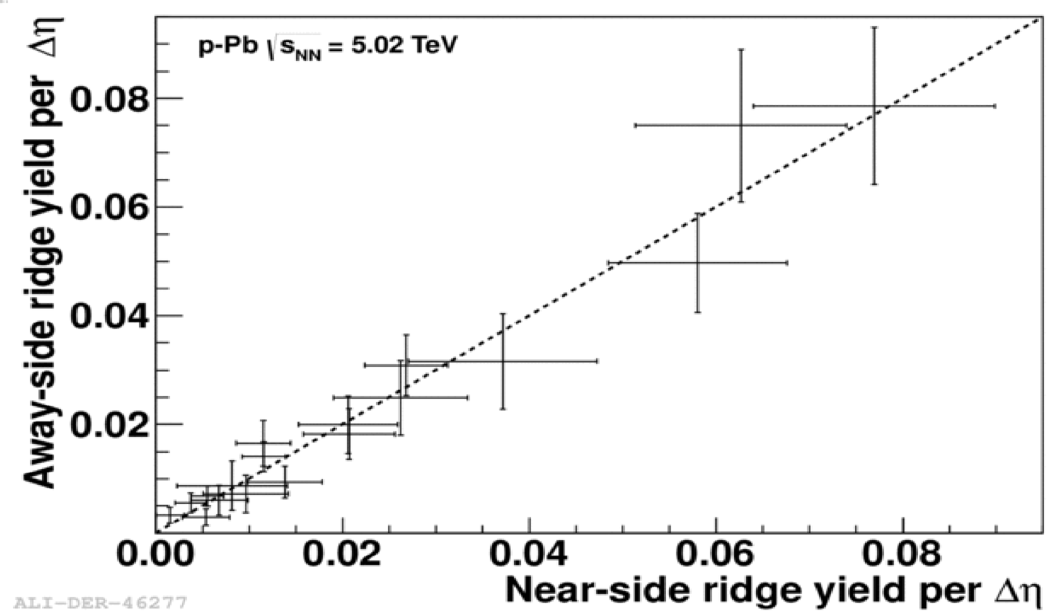

DHC: Ridge v_2 and v_3 and Hydro

- Obtain $v_n = \sqrt{(a_n/b)}$ from $a_0+2a_2\cos(2\Delta\varphi)+2a_3\cos(3\Delta\varphi)$ fit where b is baseline in higher multiplicity class
  - v_2 increases strongly with p_T and mildly with multiplicity
  - v_3 increases with p_T within large uncertainties
  - The p_T dependences are in qualitative agreement with hydrodynamical predictions

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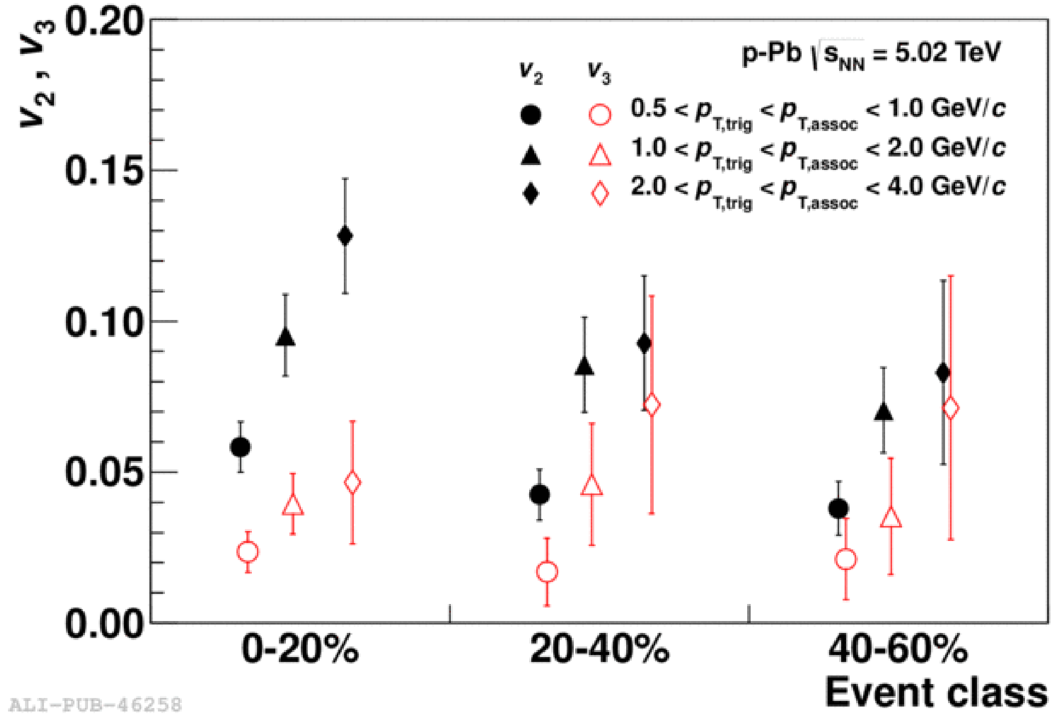
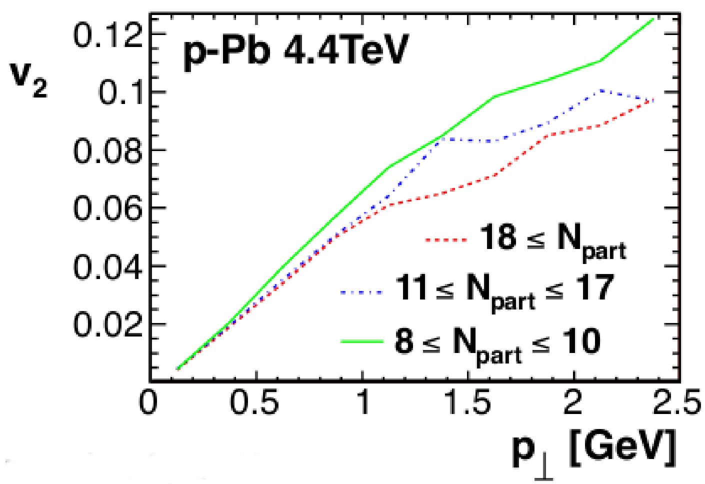
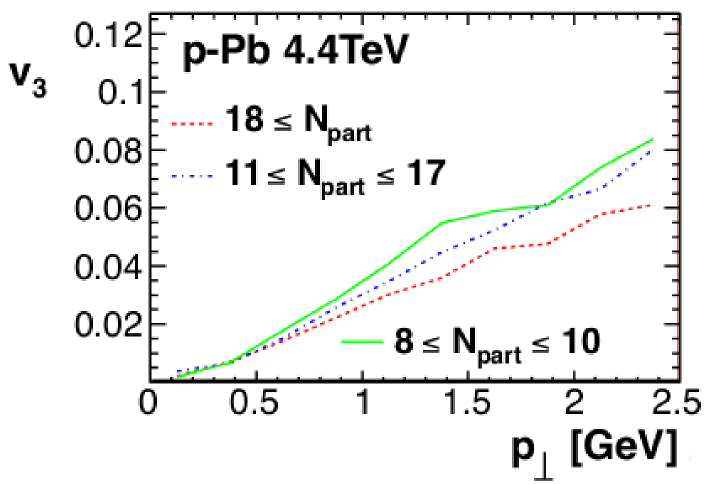


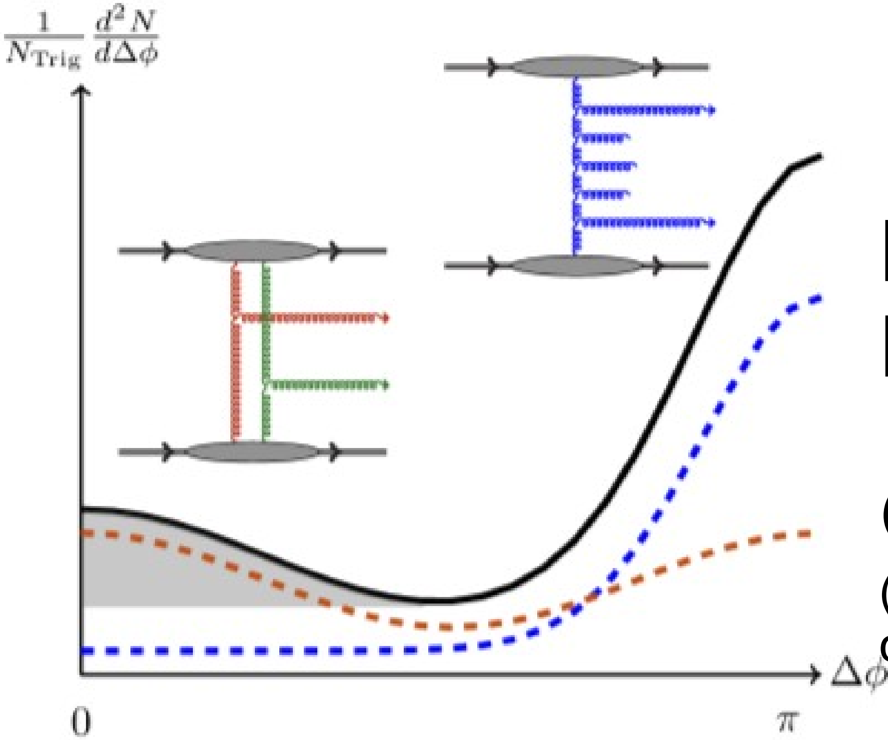
Bozek, PRC 85 (2012) 014911





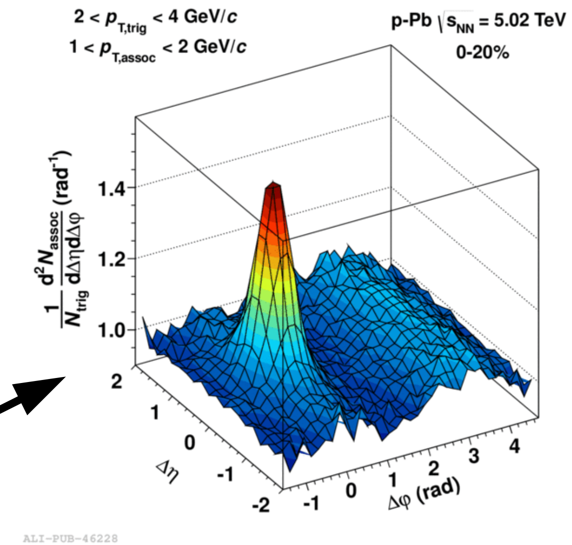
DHC: Ridge v_2 and v_3 and CGC

- Two symmetric ridges predicted by CGC glasma graphs found to describe the ridge yields and shape

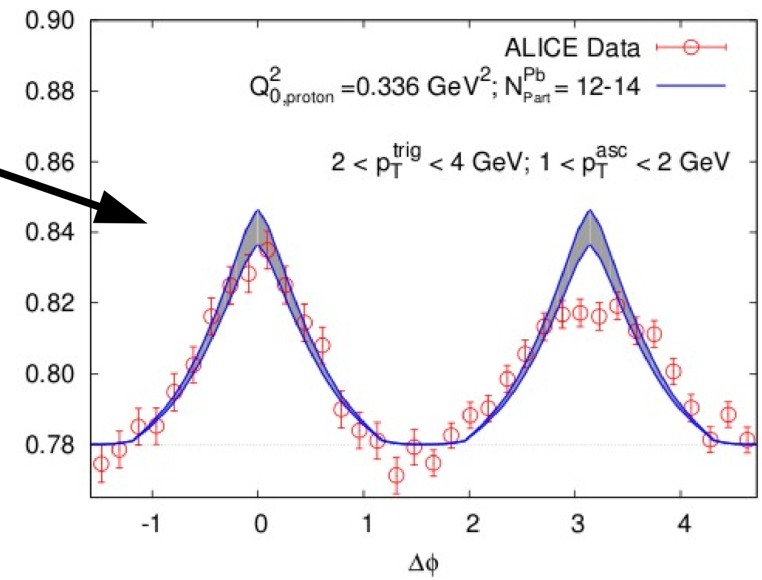


Dusling and Venugopalan, arXiv:1302.7018

BFKL-Minijets



Glasma
(enhanced by α_s^{-8} for $k_T < Q_s$)



- However, a large v_3 component may be a challenge for the model

Identified particle p_T spectra

$0<\eta<0.5$

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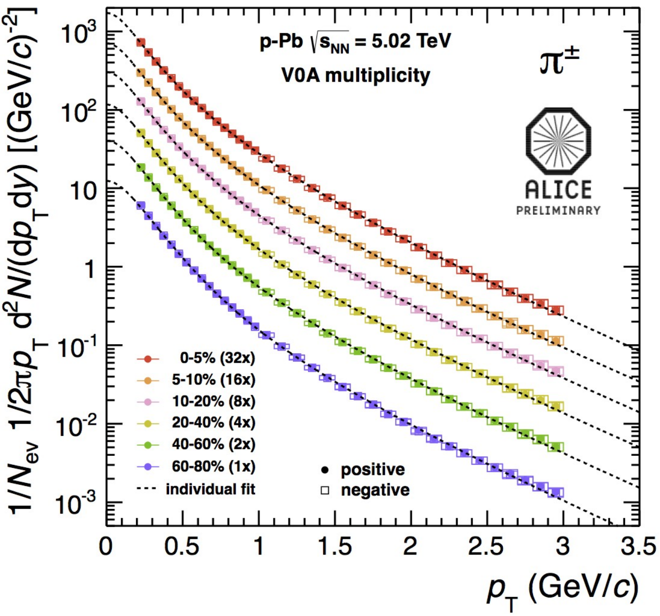
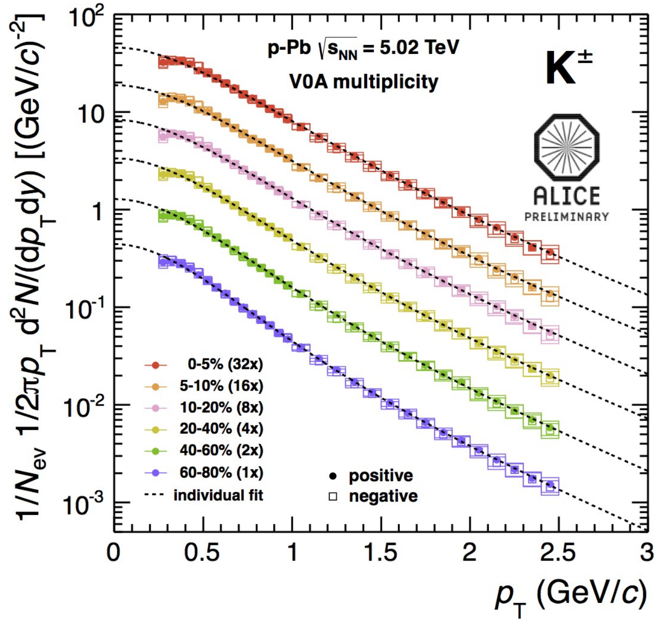
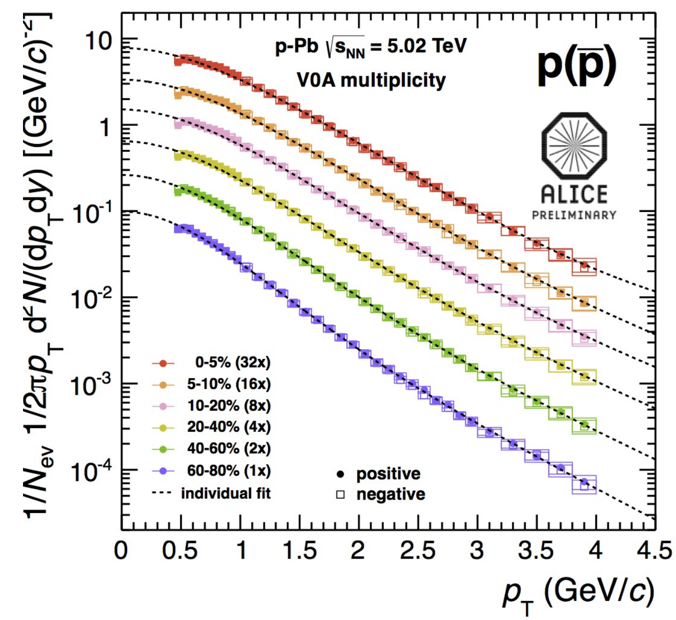
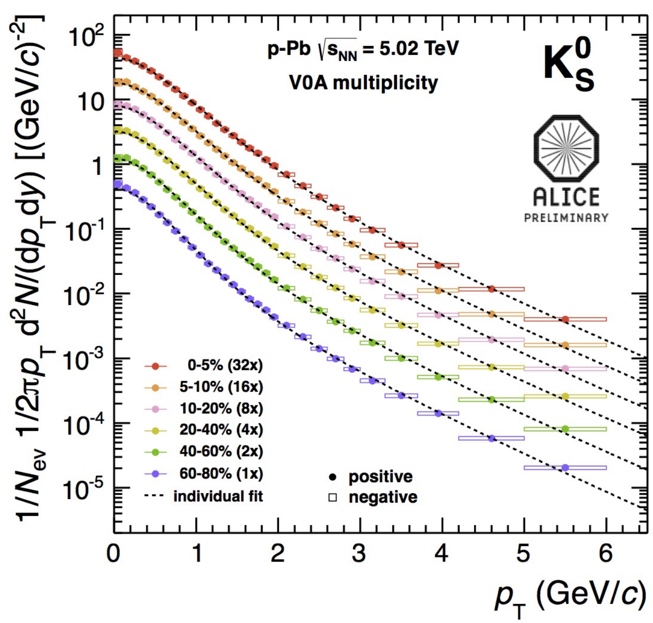


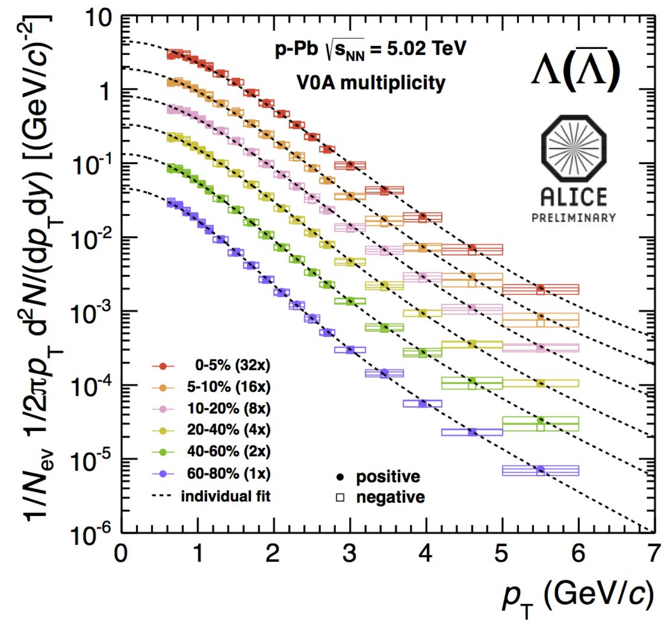




p_T spectra in several VZERO-A multiplicity classes

$\pi^{\pm}$	0.2 – 3.0 GeV/c
$K^{\pm}$	0.25 – 2.5 GeV/c
$p(\bar{p})$	0.45 – 4.0 GeV/c
K^0_S	0 – 6.0 GeV/c
$\Lambda(\bar{\Lambda})$	0.6 – 6.0 GeV/c





Dotted lines are individual (BW) fits for low-p_T extraplation

Average p_T vs $dN_{ch}/d\eta$ in pPb

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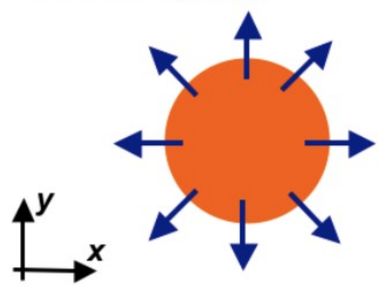
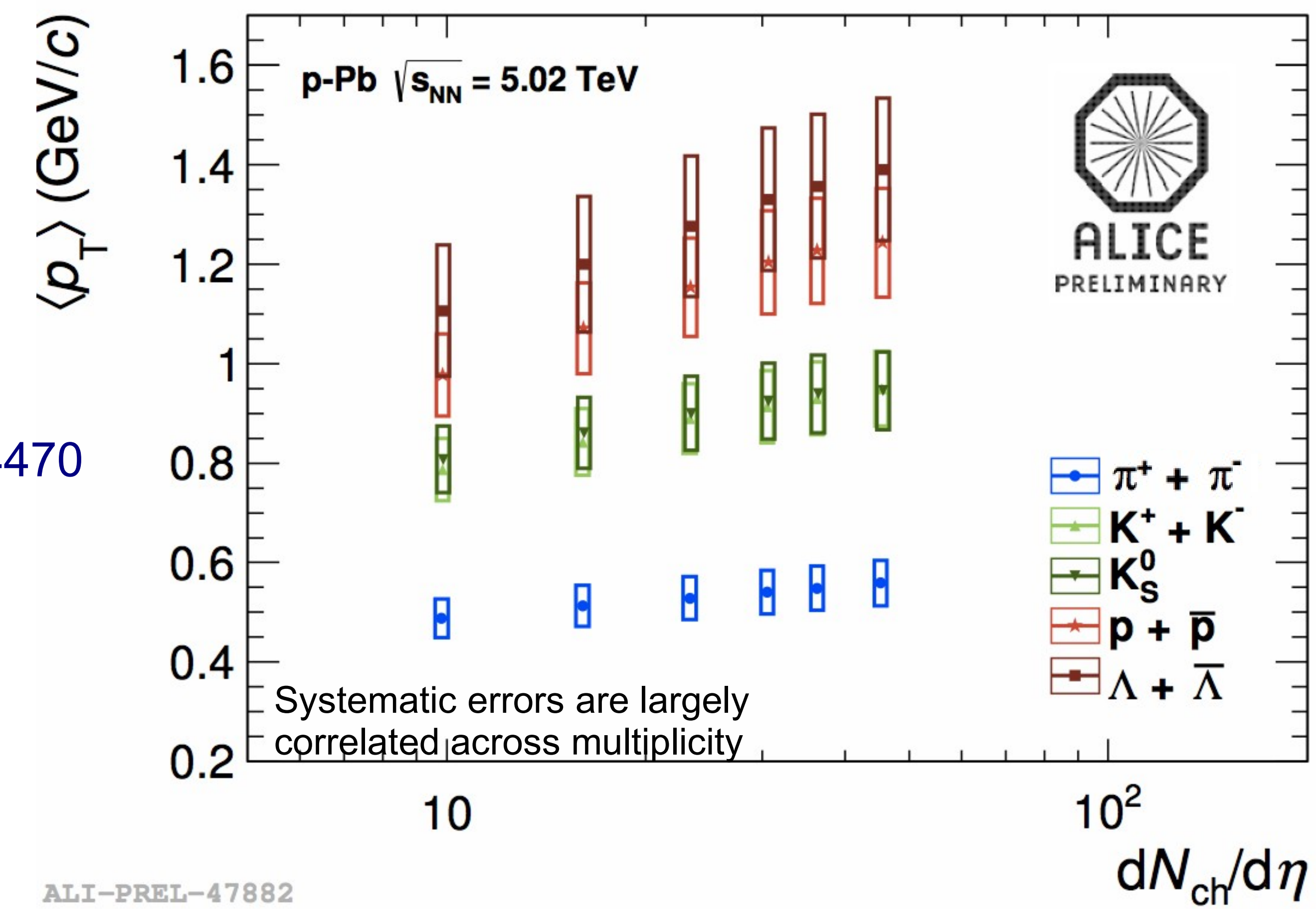
Radial flow



$$p_T^{flow} = p_T + m\beta_T^{flow}\gamma_T^{flow}$$

Shuryak and Zahed, arXiv:1301.4470



- Average p_T increases with multiplicity in all V0A multiplicity classes
- Mass ordering: Larger mass also larger average p_T
- Generators implementing incoherent superposition of nucleon collisions do not describe the data (not shown)

Proton-to-pion ratio

Systematic errors are largely correlated across multiplicity

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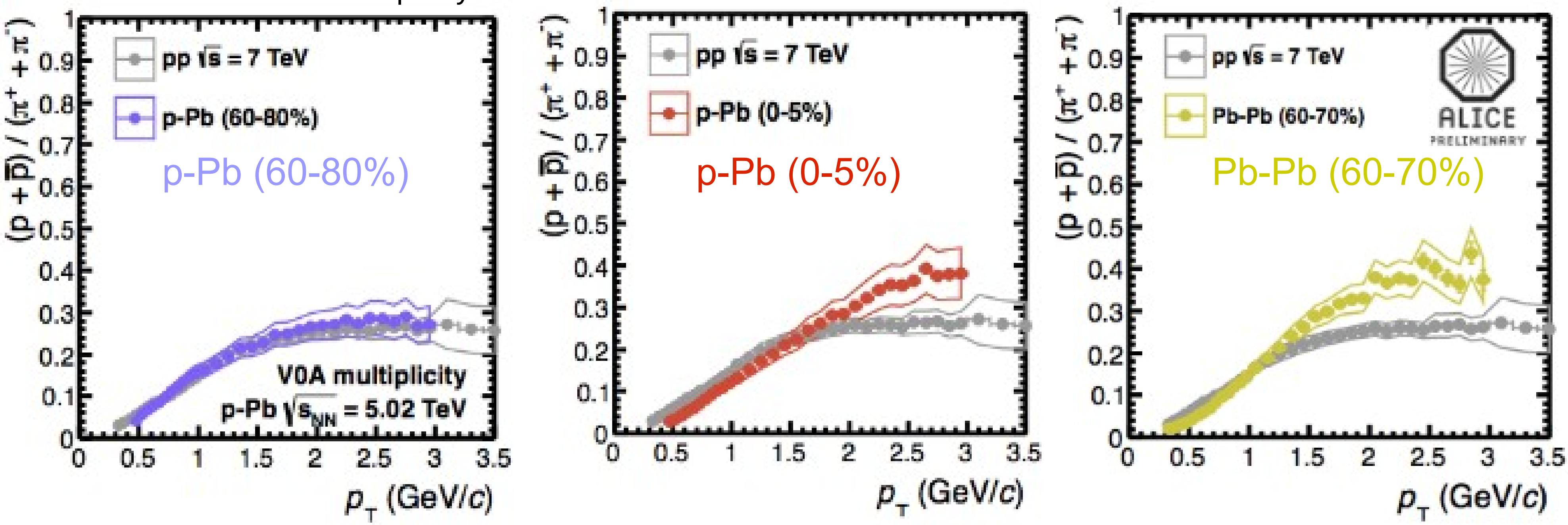

- Ratio in 0-5% shows similar p_T dependence as observed in peripheral PbPb
  - Significant increase at intermediate p_T with increasing V0A multiplicity
  - Corresponding significant depletion in the low-p_T region
- Dependence in PbPb usually explained by radial flow
  - Dependence in pPb qualitatively as expected by eg. Shuryak and Zahed, arXiv:1301.4470

Λ/K^0_s ratio versus p_T

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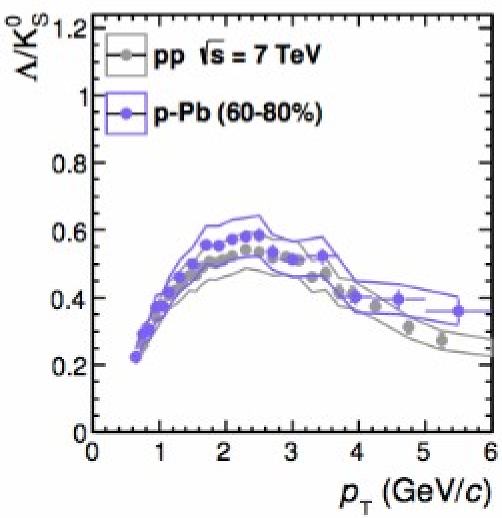
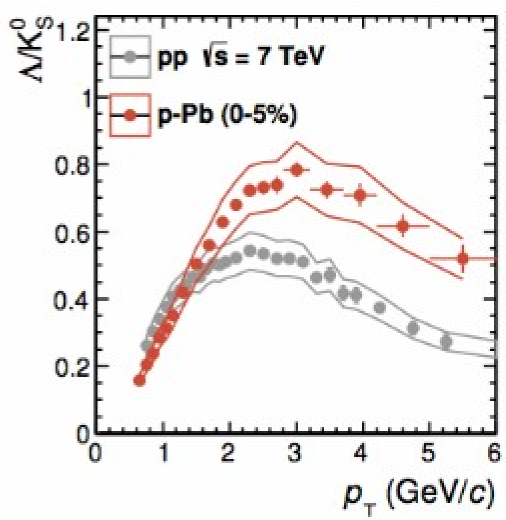
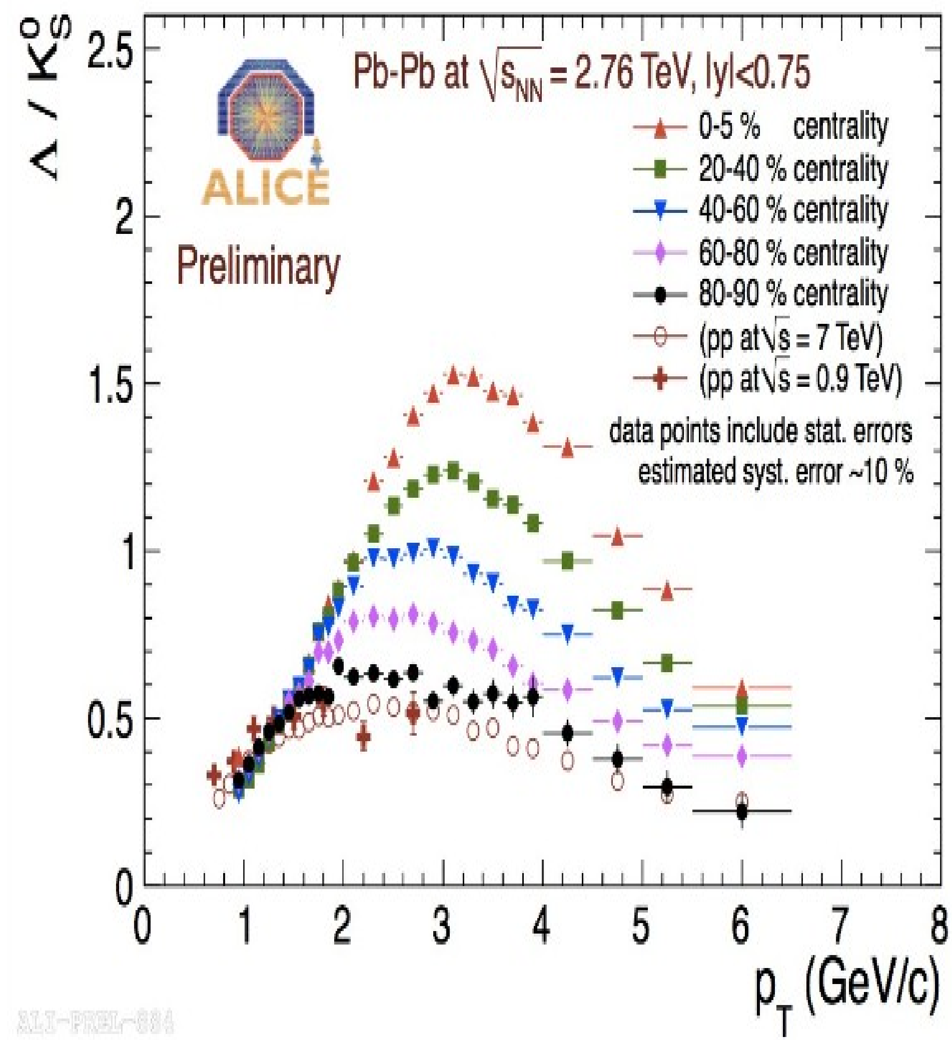
- Clear evolution of Λ/K^0_s ratio with increasing V0A multiplicity
- Also this is reminiscent of a similar trend observed in AA
- In AA this is generally explained by collective flow and parton recombination

Systematic errors are largely correlated across multiplicity







Summary & Outlook

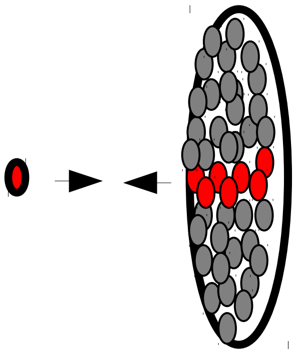
- Measurements of unidentified dN/dη and dN/dp_T spectra
  - Various models describe data, but no single model describes all aspects
- Measurements of J/ψ spectra
  - Data can be described by model including shadowing plus energy loss
- Correlation analyses in pA started fundamental debate of initial and final state effects in high-multiplicity events
  - We may see aspects of both
- PID spectra at high multiplicity show trends also observed in peripheral PbPb and qualitatively consistent with radial flow
  - Similar trends also expected for high multiplicity pp events (Analysis of 7 TeV pp data ongoing)
- Further pPb measurements expected soon
  - Identified particle v2
  - HBT radii

Extra

NSD pPb normalization

ALICE, PRL 110 (2013) 032301

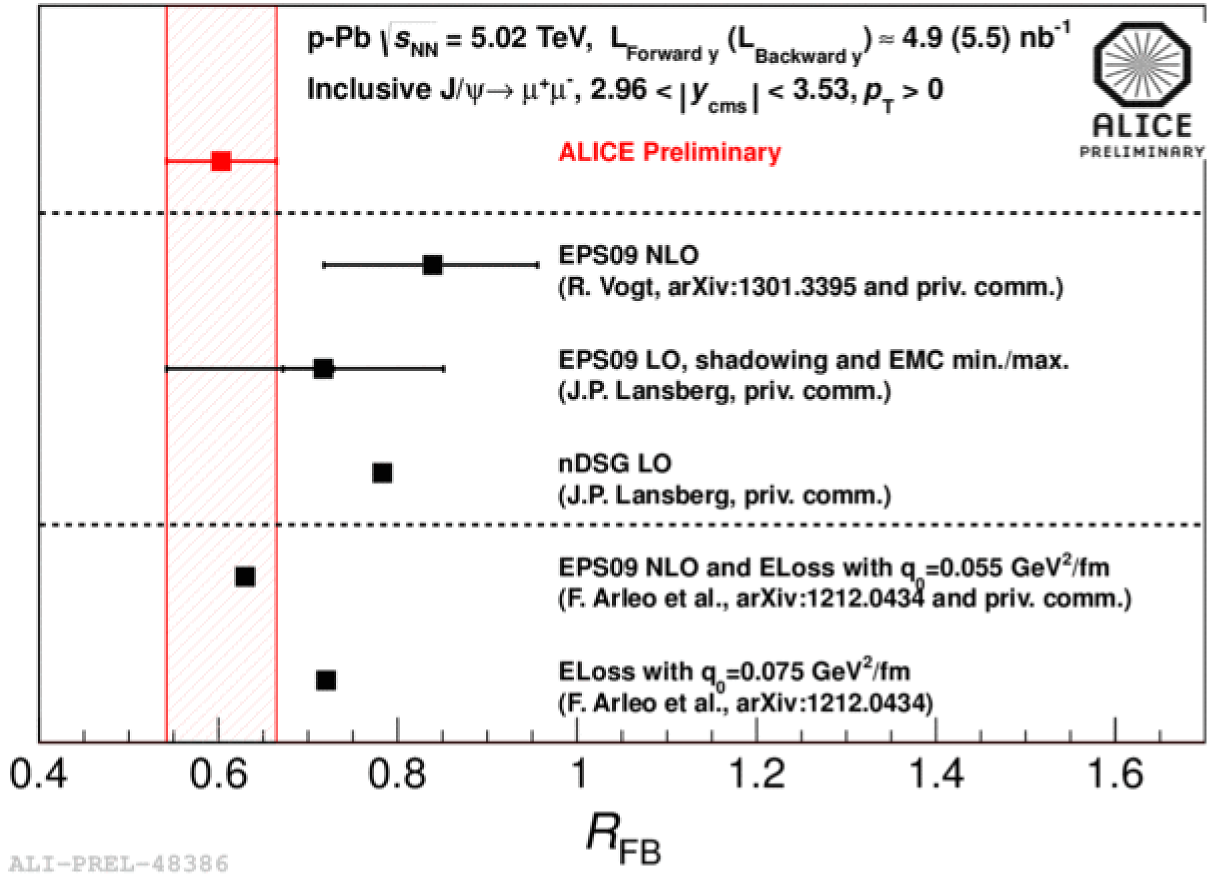
- Event selection
  - VZERO-A (2.8<η<5.1) and VZERO-C (-3.7<η<-1.7) incl. time cuts
  - Systematic variation using ZDC on nucleus side (ZNA)
- Resulting event sample
  - Non single-diffractive (NSD)
    - At least one binary N+N interaction is NSD (Glauber picture)
    - Inspired from DPMJET, which includes incoherent SD of the projectile with target nucleons that are mainly concentrated on the surface of the nucleus
    - SD about 4% from HIJING, DPMJET or standalone Glauber
  - Negligible contamination from SD and EM processes



- Validated with a cocktail of generators
  - DPMJET for NSD (2b)
  - PHOJET + Glauber for incoherent SD part (0.1b)
    - SD/INEL = 0.2 in pp at 7 TeV (arXiv:1208.4968)
  - EM with STARLIGHT (0.1-0.2b)

Forward-backward asymmetry

Inclusive J/psi, ALICE preliminary

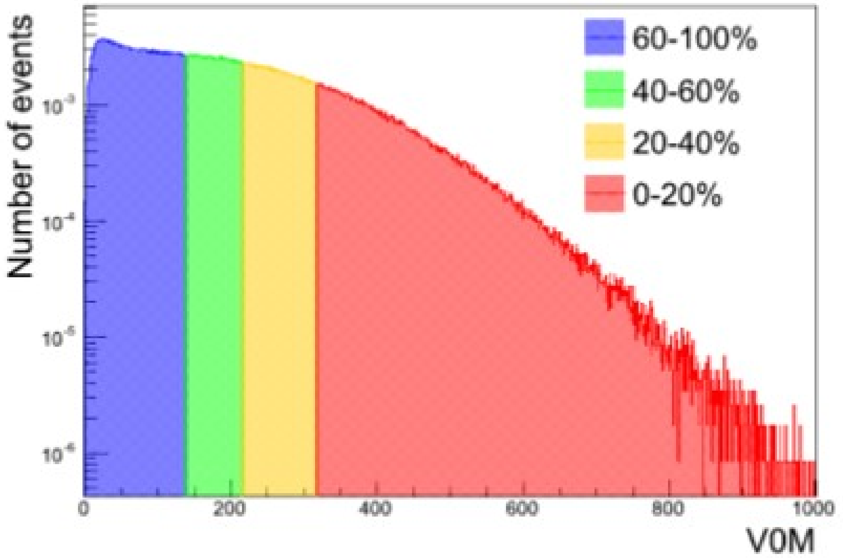


- Forward-to-backward ratio in the range 2.96<|y|<3.53
  - R_{FB} = 0.60 ± 0.01 (stat) ± 0.06 (syst)
  - Free of uncertainty from pp reference
- Pure saturation models seem to overestimate the ratio

DHC: Multiplicity classes

ALICE, PLB 719 (2013) 29

- Correlation between geometry and multiplicity in pA is not as strong as in AA
  - System also shows features of biased pp (NN) collisions in the low and high multiplicity tails
- Define multiplicity classes
  - Use charge in VZERO to avoid correlation with tracks in barrel
  - V0M: sum of amplitudes from
    - VZERO-A (2.8<η<5.1)
    - VZERO-C (-3.7<η<-1.7)
- Systematic checks using
  - SPD (|η|<1.4)
  - ZNA (beam neutron on Pb side)

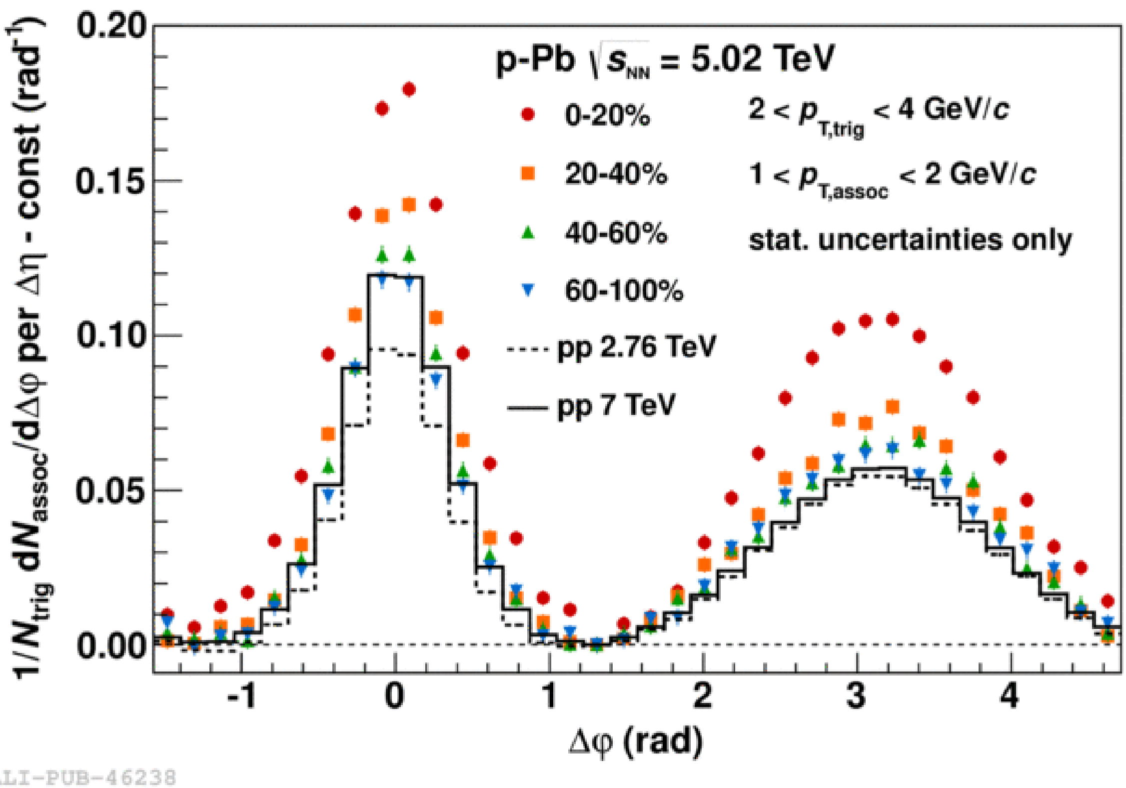


Event class	V0M range (a.u.)	$\langle dN_{ch}/d\eta \rangle \|_{\|\eta\|<0.5}$ $p_T > 0$ GeV/c	$\langle N_{trk} \rangle \|_{\|\eta\|<1.2}$ $p_T > 0.5$ GeV/c
60–100%	< 138	6.6 ± 0.2	6.4 ± 0.2
40–60%	138–216	16.2 ± 0.4	16.9 ± 0.6
20–40%	216–318	23.7 ± 0.5	26.1 ± 0.9
0–20%	> 318	34.9 ± 0.5	42.5 ± 1.5

DHC: Multiplicity dependence

ALICE, PLB 719 (2013) 29

- Compare associated yield in pPb multiplicity classes and pp
  - Project to Δφ over |Δη|<1.8
  - Subtract baseline at Δφ~1.3
- Low multiplicity pPb is similar to pp (at 7 TeV)
- Yield rises on near and away side with increasing multiplicity
- In contrast with away-side suppression observed in dAu at RHIC at forward η (similar x)



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- Associated yield per trigger particle (with $p_T^{trig} > p_T^{assoc}$)

$$\frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{assoc}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi} = \frac{S(\Delta\eta, \Delta\varphi)}{B(\Delta\eta, \Delta\varphi)}$$

- Signal (same event) pair yield

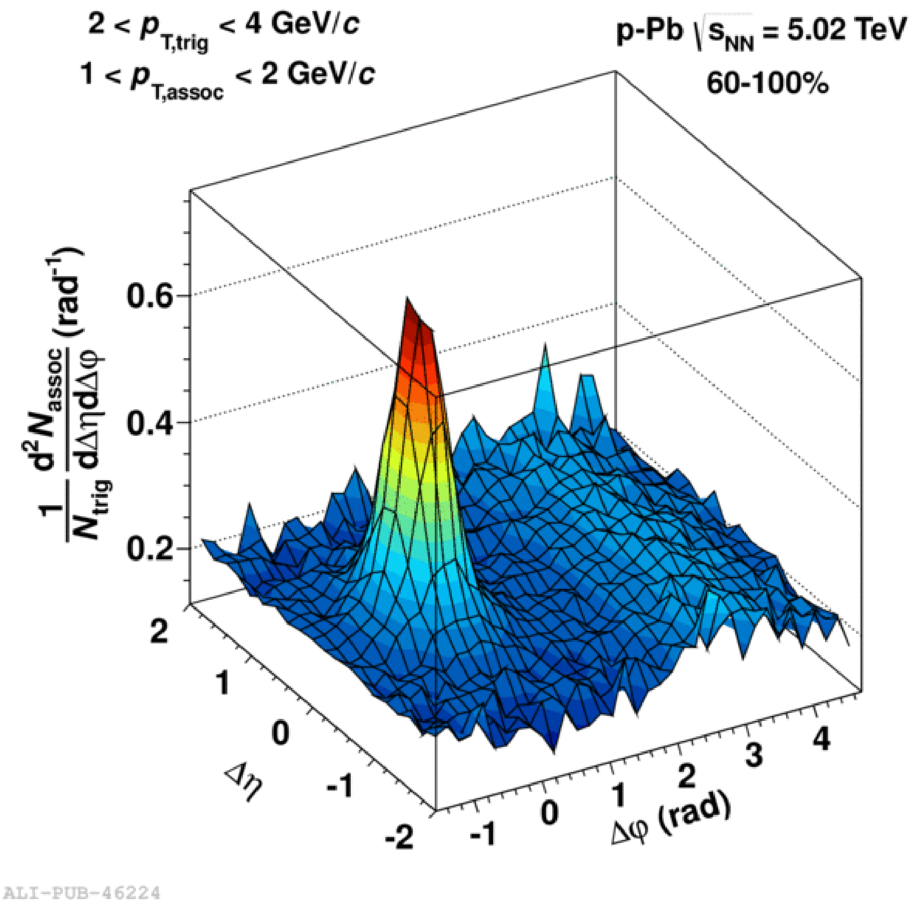
$$S(\Delta\eta, \Delta\varphi) = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{same}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi}$$

  - Definition as ratio of sums is multiplicity independent

$$\frac{N_{pair}}{N_{trig}} = \frac{\sum_{i=1}^{N_{evt}} \sum_{j=1}^{N_{source}^{i}} \frac{1}{2} n_{ij}(n_{ij}-1)}{\sum_{i=1}^{N_{evt}} \sum_{j=1}^{N_{source}^{i}} n_{ij}} = \frac{N_{evt} \langle N_{source} \rangle \frac{1}{2} \langle n(n-1) \rangle}{N_{evt} \langle N_{source} \rangle \langle n \rangle} = \frac{1}{2} \frac{\langle n(n-1) \rangle}{\langle n \rangle}$$

- Background (mixed event) pair yield

$$B(\Delta\eta, \Delta\varphi) = \frac{1}{B(0,0)} \frac{\mathrm{d}^2 N_{\mathrm{mixed}}}{\mathrm{d}\Delta\eta\, \mathrm{d}\Delta\varphi}$$



DHC: Two ridges

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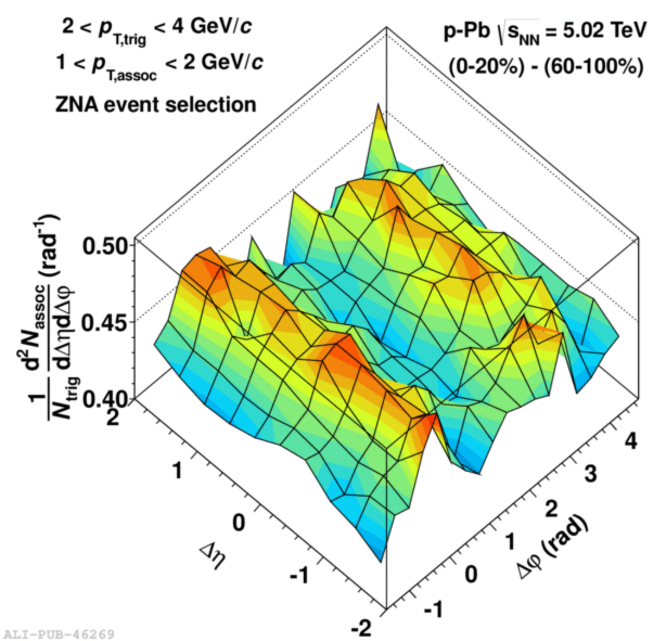
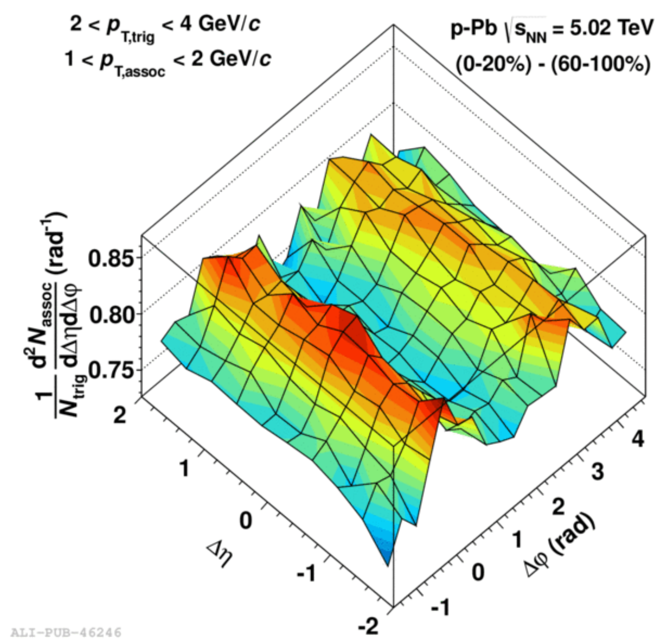
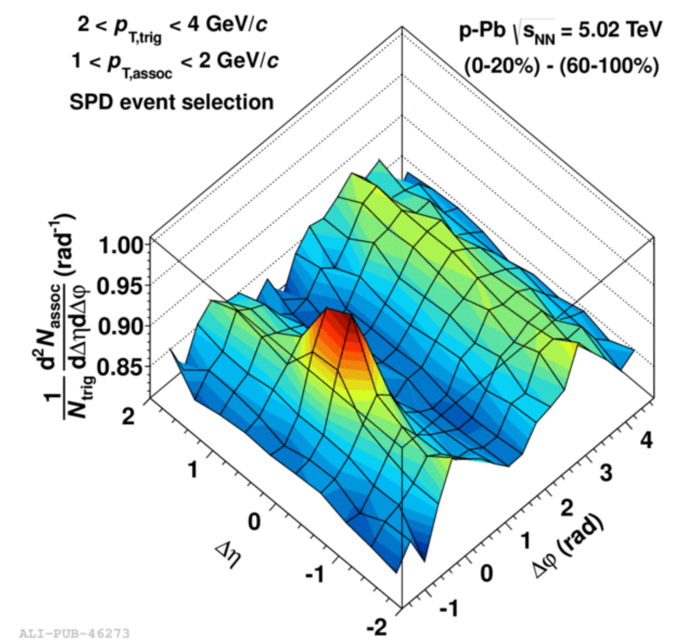
- A residual jet peak at (0,0) remains even after subtraction of 60-100% from the 0-20% multiplicity class
- Compare effects using different event class definition



ZNA



VZERO

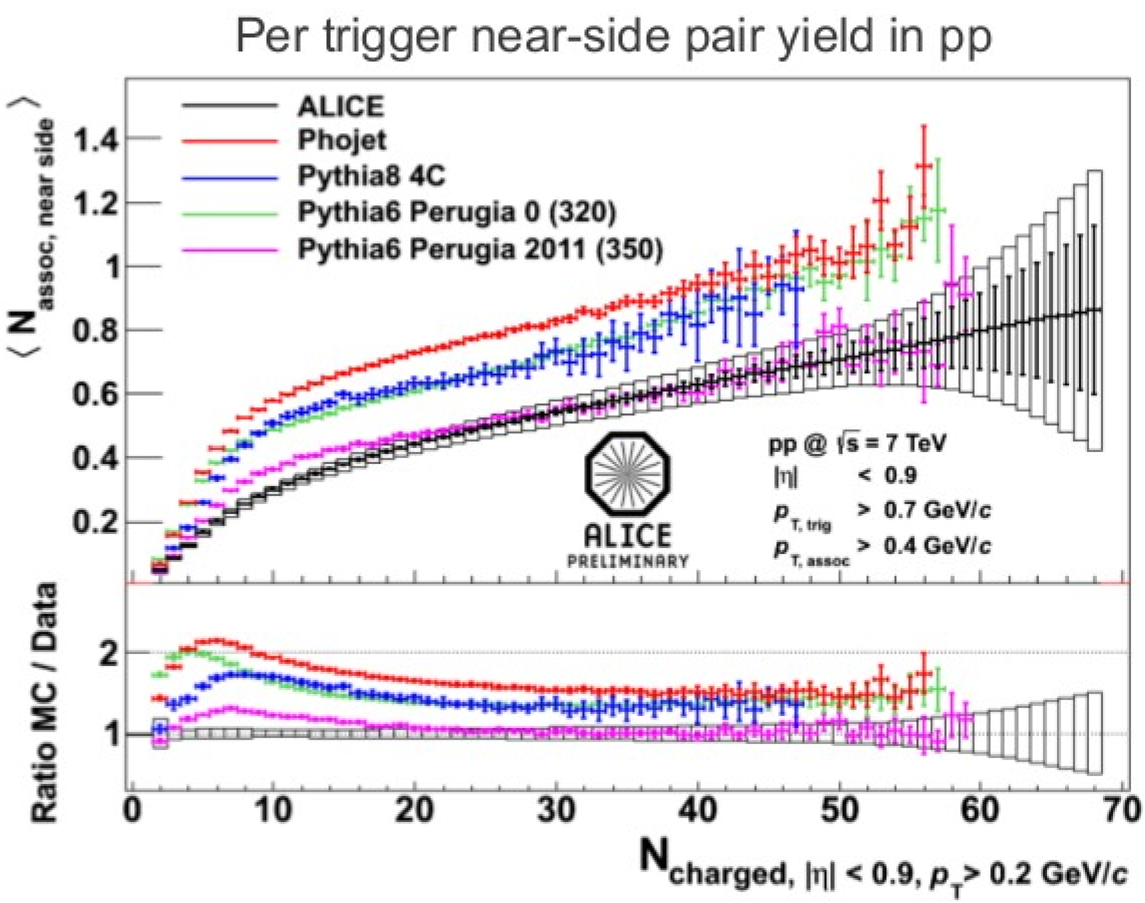


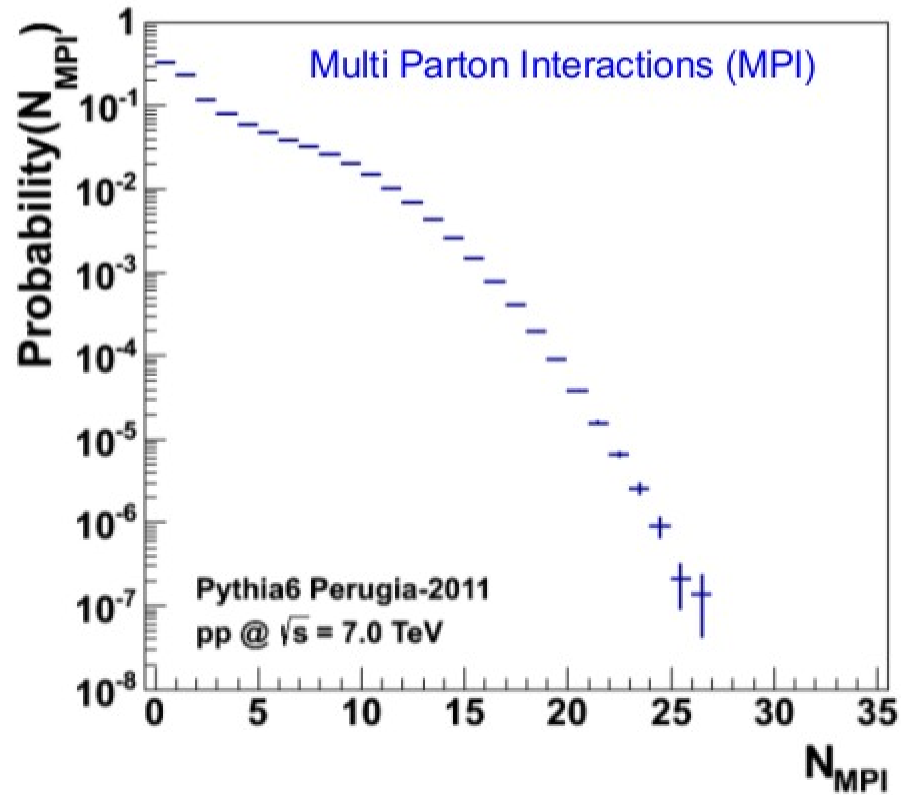
SPD

auto-correlation →

← η separation

DHC: Selection bias on fragmentation (pp)





- By selecting on multiplicity, jet fragmentation is biased towards higher number of fragmenting products
- Competition between higher number of MPI and fragmentation

DHC: Symmetric ridge

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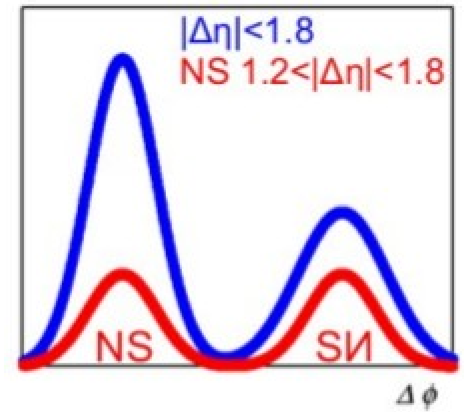
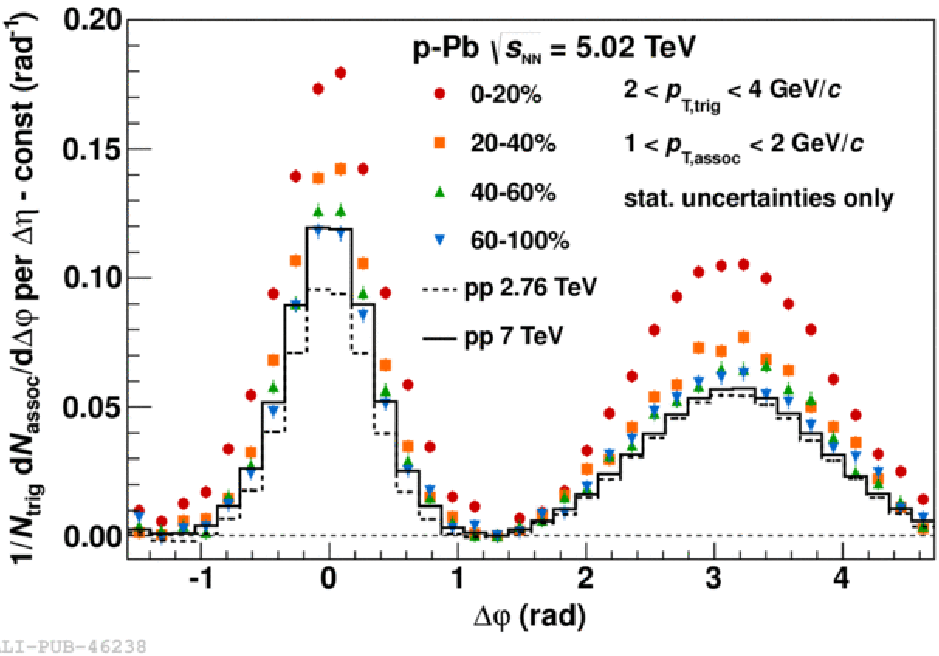
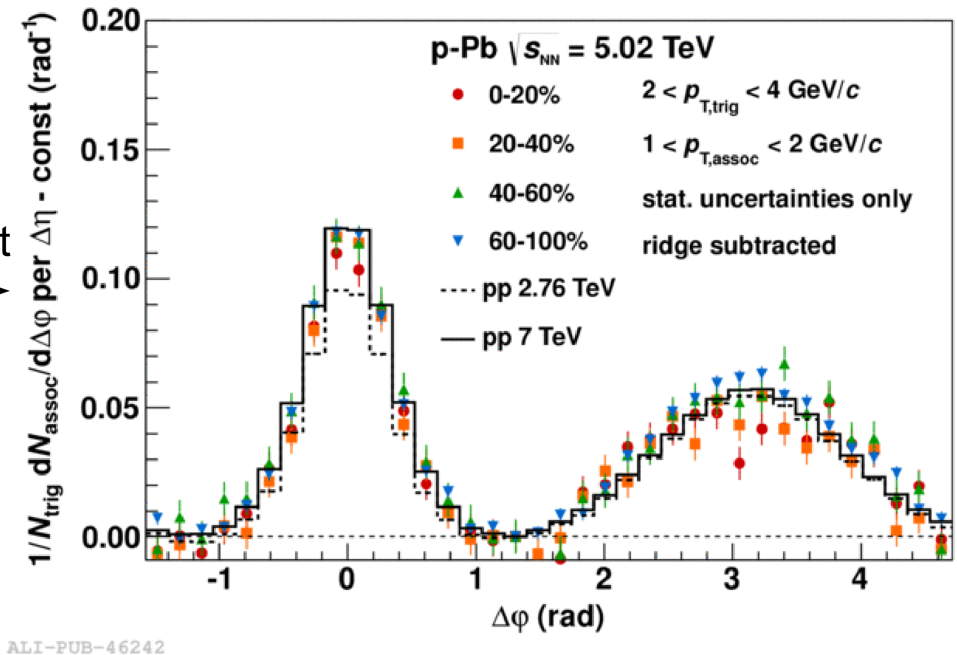
- What would the assumption of a symmetric ridge give?
  - Determine the near-side ridge in 1.2 < |Δη| < 1.8
  - Mirror to away-side and subtract





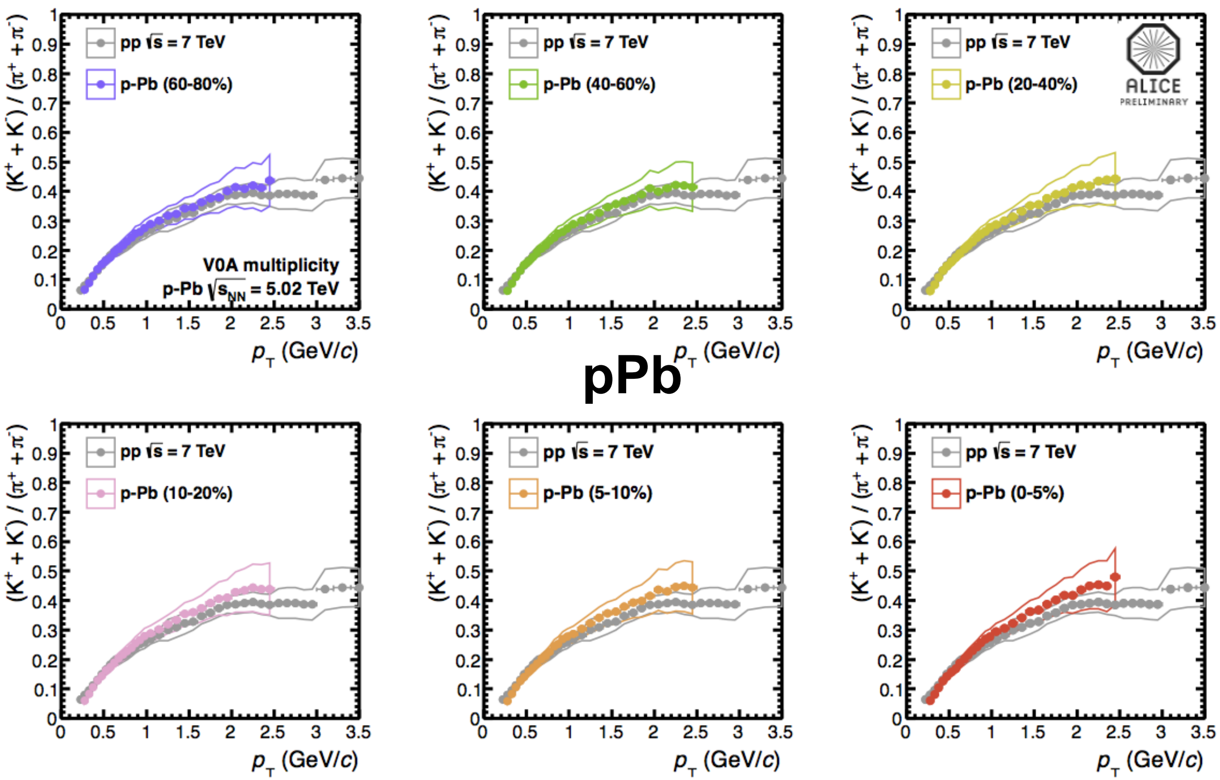
Subtract



- No significant other multiplicity dependent structures left over

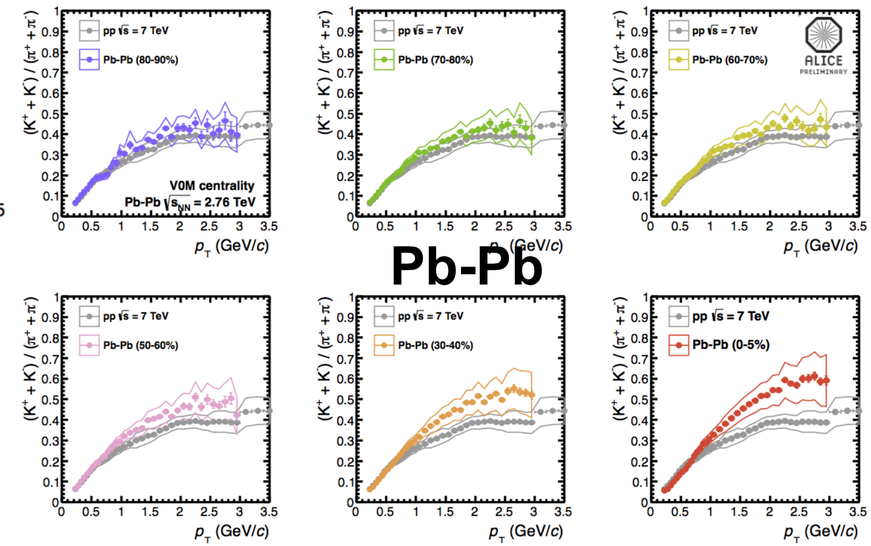
K/π ratio versus p_T

ALICE preliminary



pPb

ALICE, arxiv:1303.0737



Pb-Pb

Systematic errors are largely correlated across multiplicity

- weak evolution with multiplicity in p-Pb

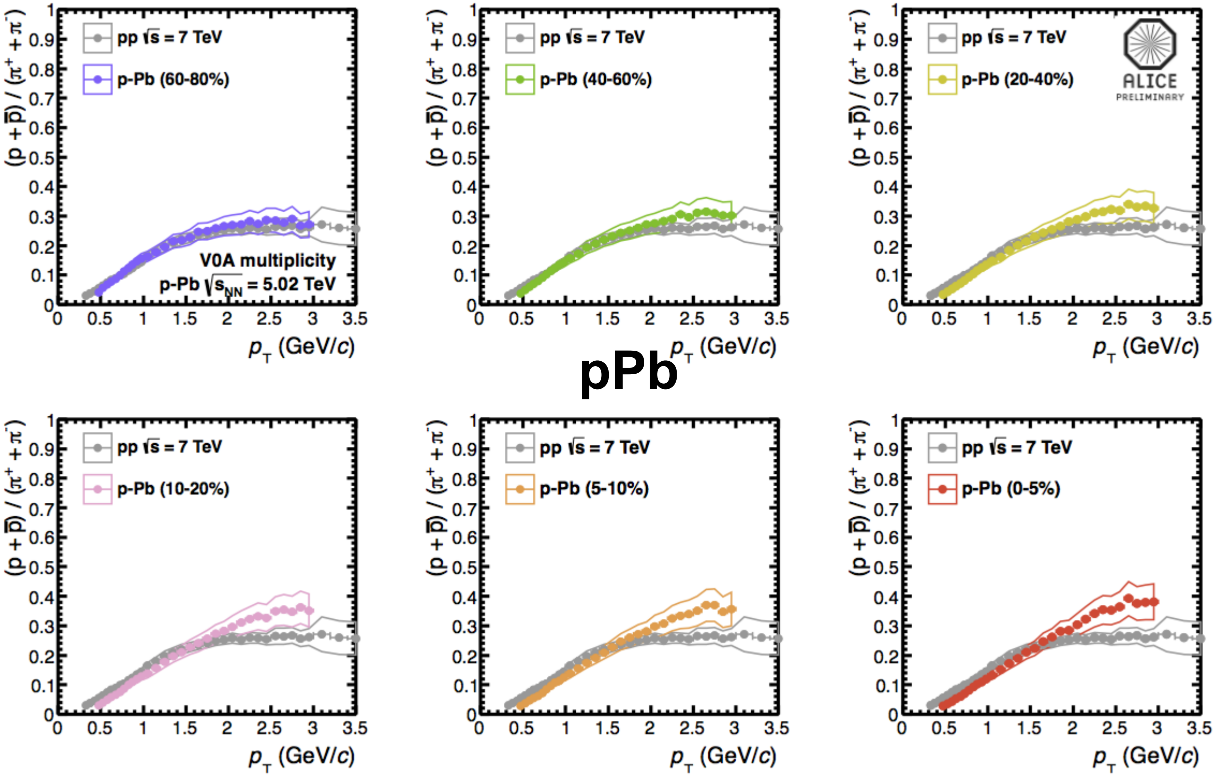
→ small increase at intermediate p_T with increasing V0A multiplicity

→ corresponding small depletion in the low-p_T region

- hints at similar behavior as observed in Pb-Pb collisions

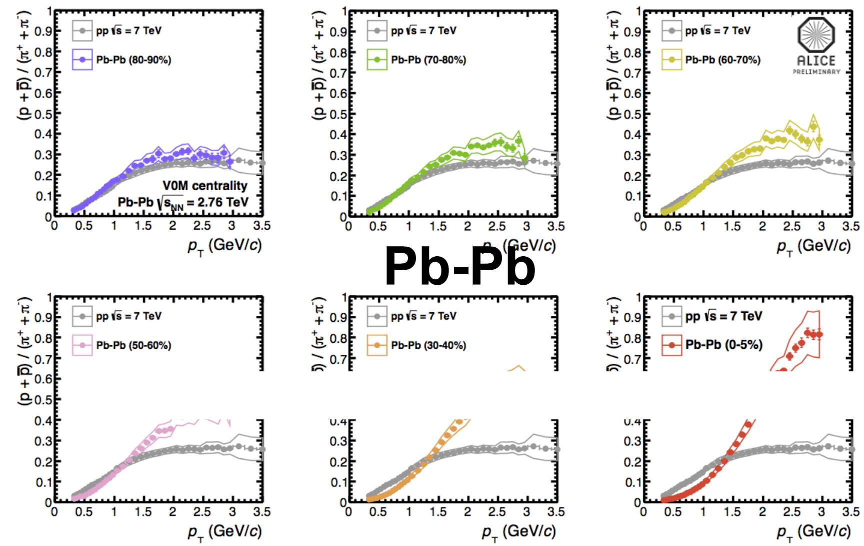
p/π ratio versus p_T

ALICE preliminary



pPb

ALICE, arxiv:1303.0737



Pb-Pb

Systematic errors are largely correlated across multiplicity

- shows similar behavior as observed in Pb-Pb collisions

→ significant increase at intermediate p_T with increasing V0A multiplicity

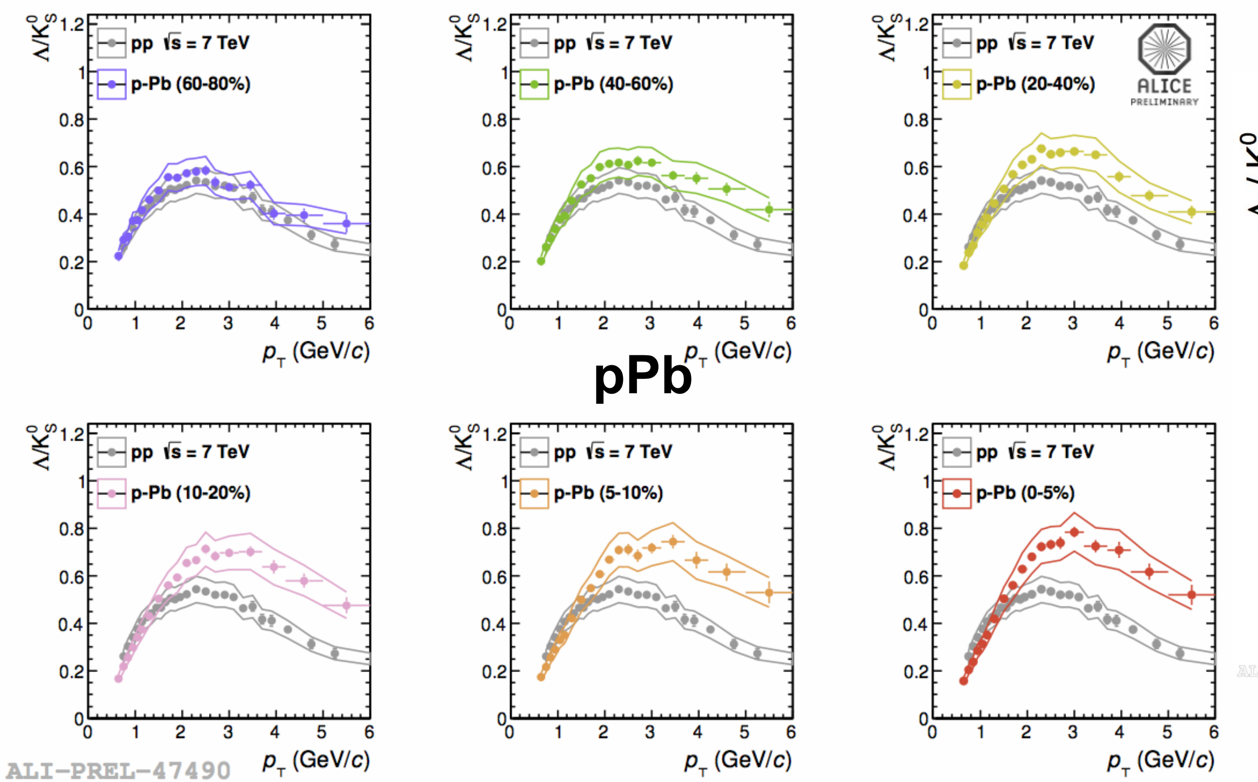
→ corresponding significant depletion in the low-p_T region

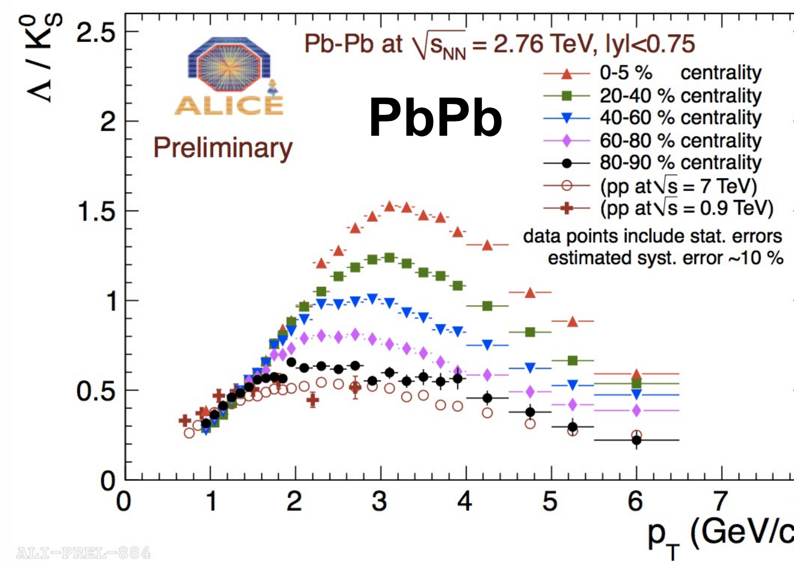
→ stronger enhancement than K/π

- Pb-Pb generally understood in terms of collective flow and/or recombination

Λ/K^0_s ratio versus p_T

ALICE preliminary





Systematic errors are largely correlated across multiplicity

- <u>clear evolution with multiplicity</u> in pPb

→ significant increase at intermediate p_T with increasing V0A multiplicity

→ corresponding significant depletion in the low-p_T region

- also this is <u>reminiscent of nucleus-nucleus phenomenology</u>...

...generally understood in terms of collective flow and/or recombination

Spectra shape analysis: pPb

π/K/p spectral-shape analysis:

- performed with hydro-motivated Blast-Wave model

Schnedermann, PRC 48, 2462 (1993)

aims at characterizing spectral shapes in V0A multiplicity classes with a small set of parameters

- simultaneous fit of all particles with 3 parameters

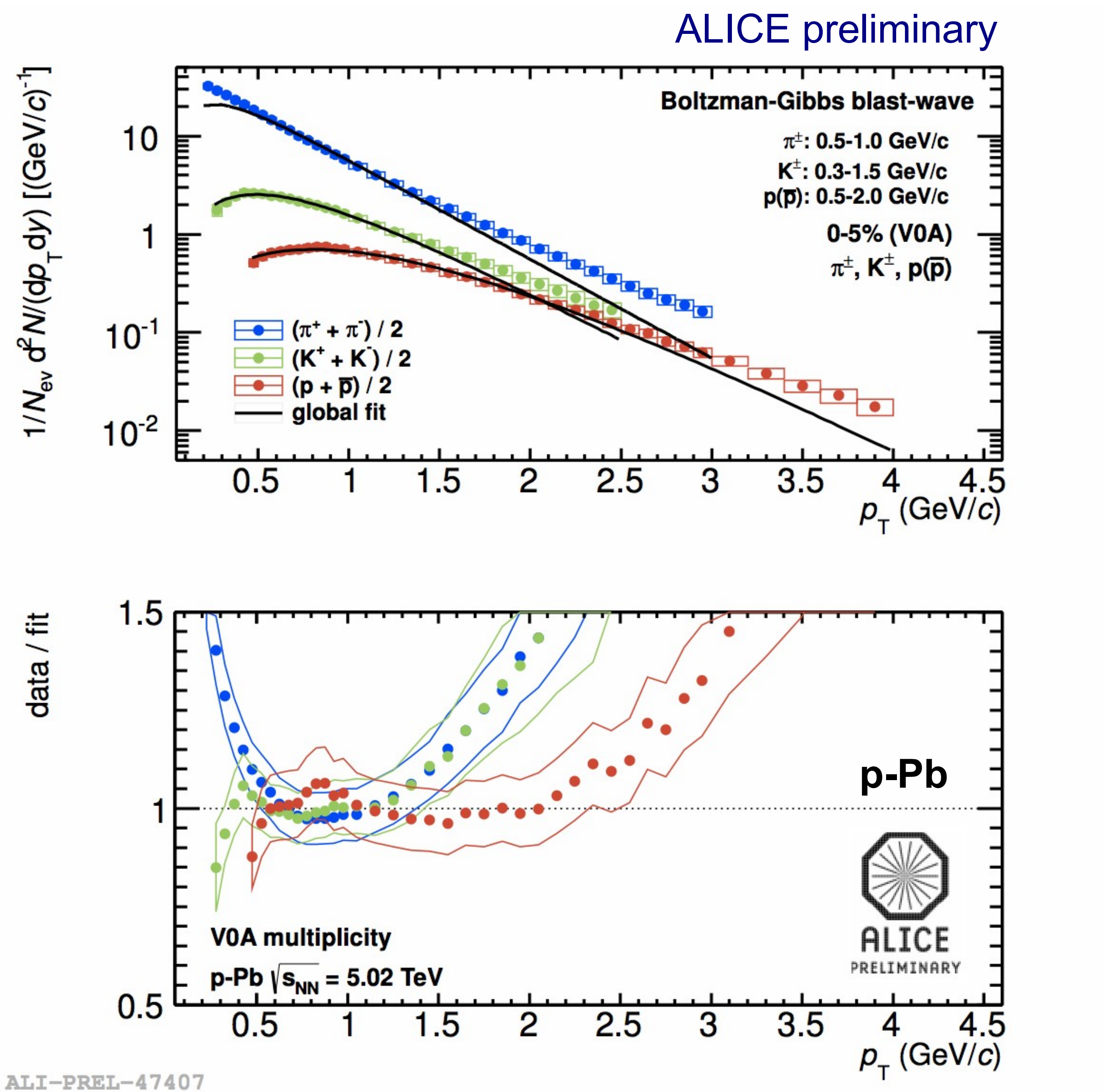
$\langle\beta_T\rangle$ radial flow
T_{fo} freeze-out temperature
n velocity profile

- global fit performed in the following p_T ranges:

π 0.5 – 1.0 GeV/*c*
K 0.3 – 1.5 GeV/*c*
p 0.5 – 2.0 GeV/*c*

- Blast-Wave fits reasonable, though not very good

worse than central Pb-Pb
better than pp minimum bias



Global Blast-Wave fit parameters

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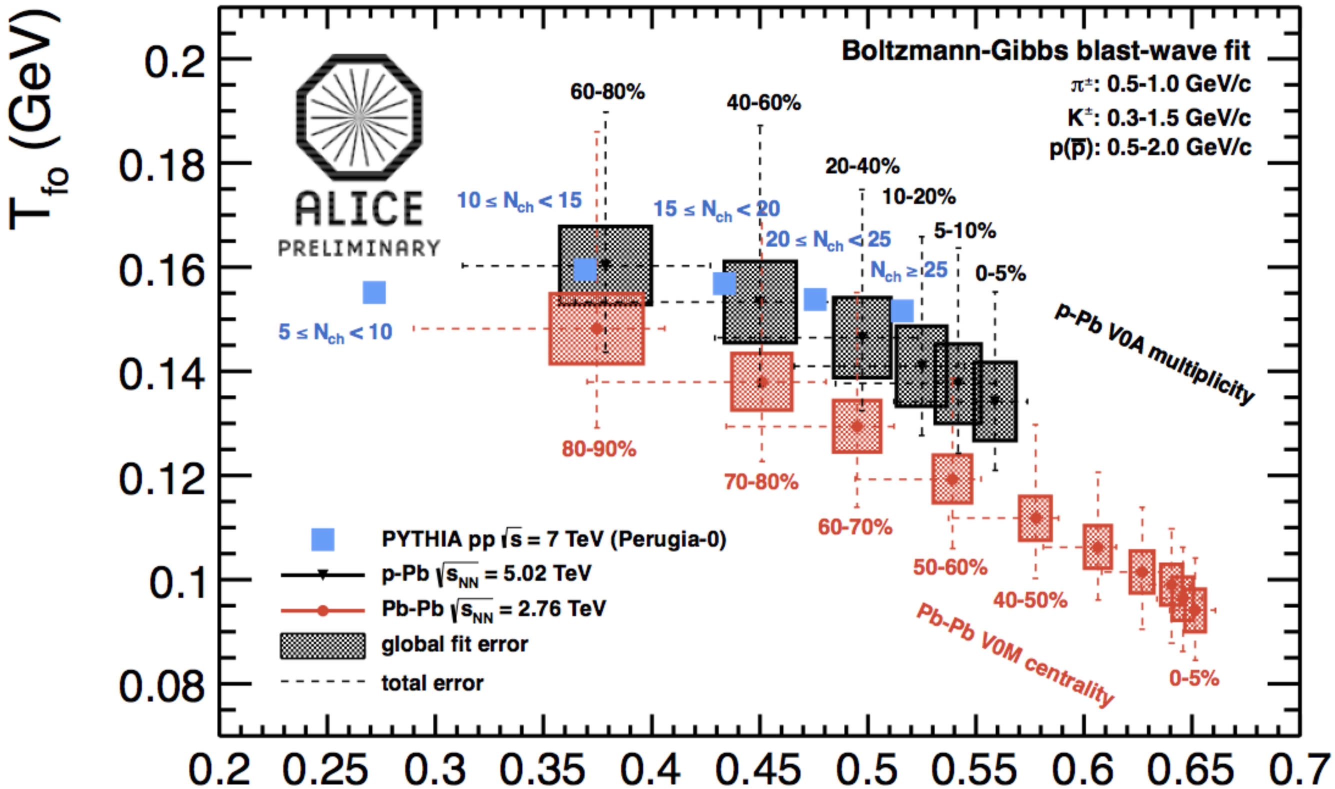
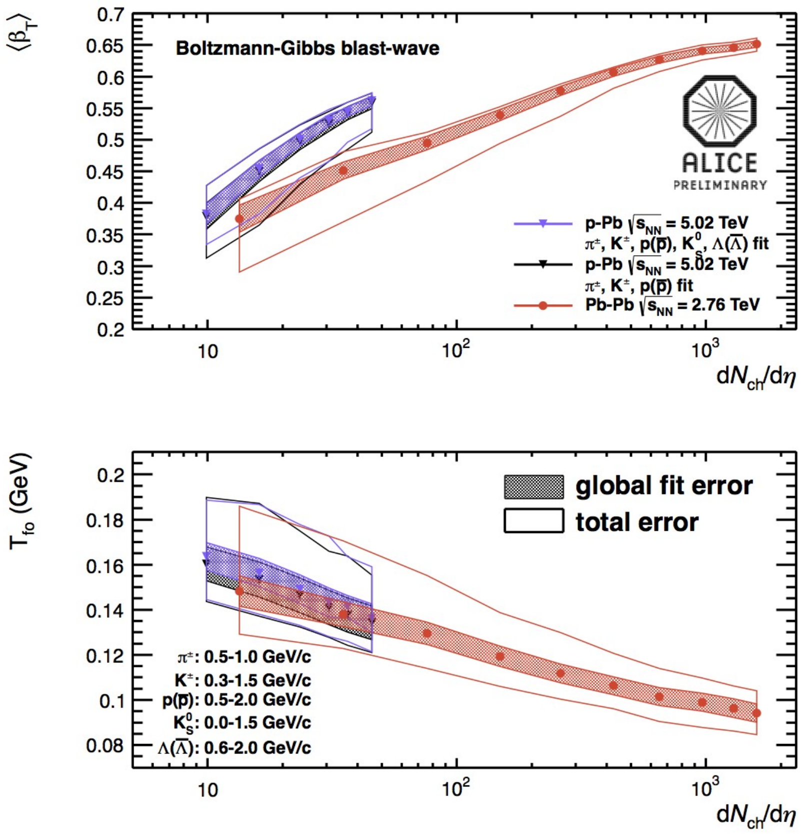
ALICE preliminary

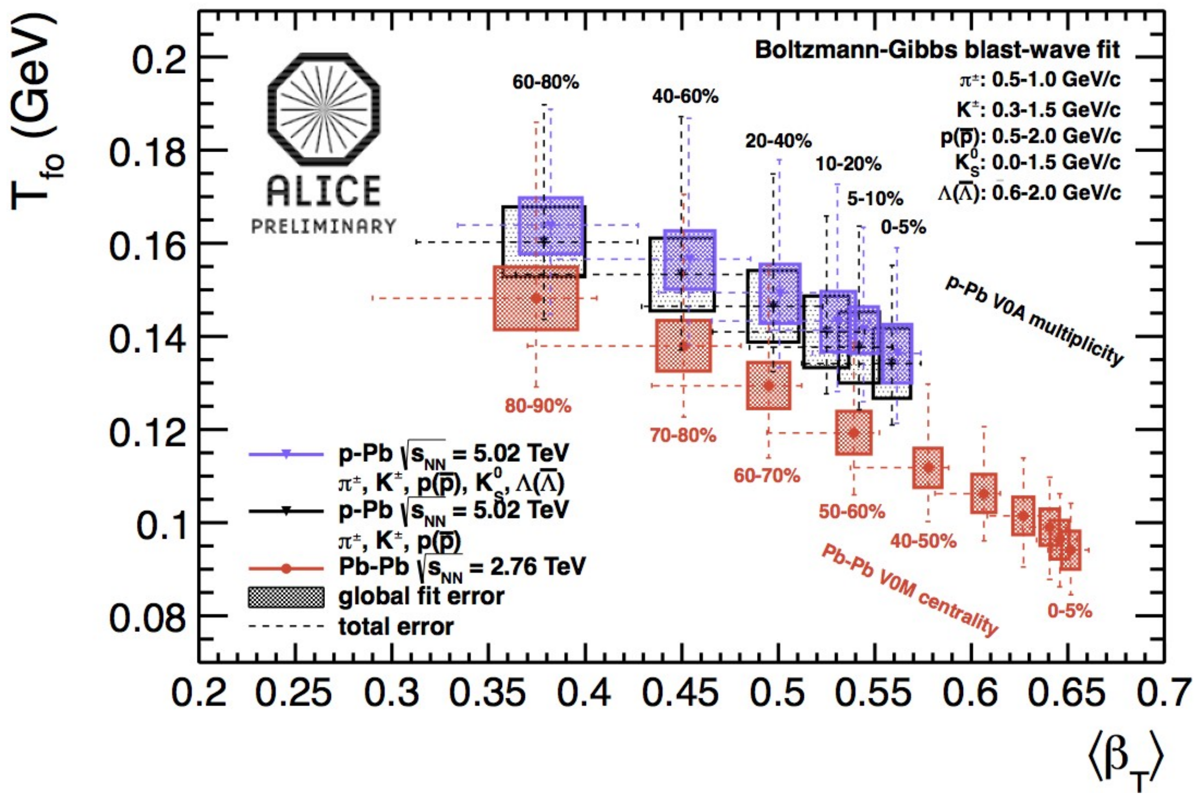


- Blast-wave spectra analysis consistent with radial flow present in pPb as in PbPb
- Not fully conclusive as also exhibited by PYTHIA (with color reconnections)
  - Caveat: MC sliced in track slices
  - 7 TeV pp data being worked on

Global Blast-Wave fit parameters



ALICE preliminary



- p-Pb presents similar features as observed in Pb-Pb

→ parameters evolve with increasing multiplicity: larger $\langle\beta_T\rangle$, smaller T_{fo}

→ T_{fo} is similar to Pb-Pb for similar multiplicity, $\langle\beta_T\rangle$ is larger in p-Pb

- same results when including also Λ and K^0_S in the p-Pb global fit