Results from pPb collisions at the LHC

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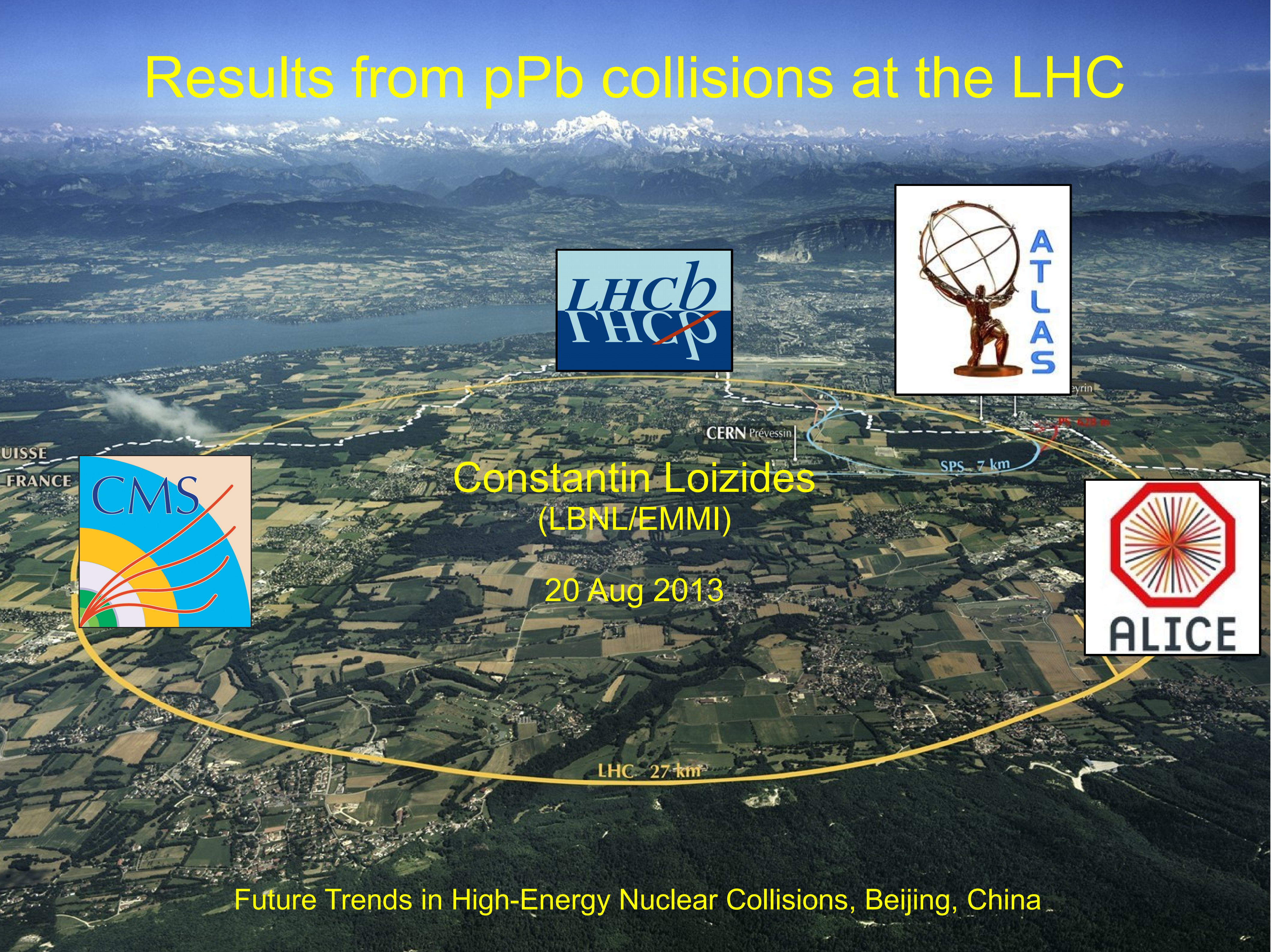
(LBNL/EMMI)

20 Aug 2013



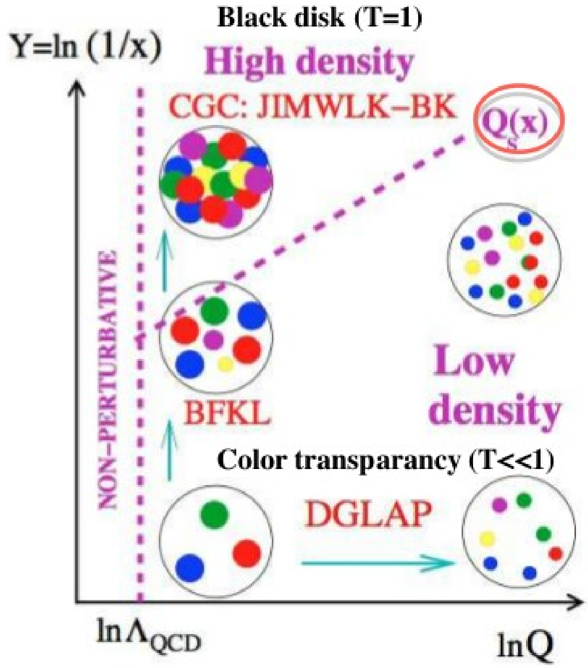
Future Trends in High-Energy Nuclear Collisions, Beijing, China

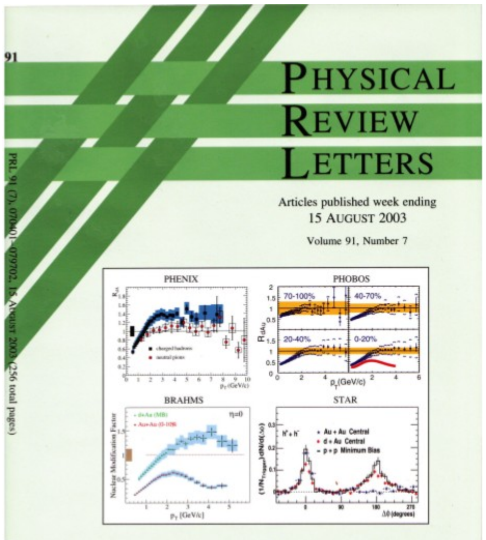
Published and preliminary pPb results

1. ALICE, PRL 110 (2013) 032301, Pseudorapidity density of charged particles
2. ALICE, PRL 110 (2013) 082302, Transverse momentum and R_{pPb} of charged particles
3. CMS, PLB 718 (2012) 795, Near-side ridge
4. ALICE, PLB 719 (2013) 29, Double ridge (v_2 and v_3)
5. ATLAS, PRL 110 (2013) 182302, Double ridge (v_2 and v_3)
6. ATLAS, arXiv:1303.2084, Two and four-particle correlations
7. CMS, PLB 724 (2013) 213, Two and four-particle correlations compared to PbPb
8. LHCb-CONF-2012-034, Inelastic pPb cross section
9. CMS-PAS-HIN-13-001, Dijet production versus forward energy
10. ALICE preliminary, Inclusive J/ψ production
11. LHCb-CONF-2013-008, Prompt and non-prompt J/ψ production
12. ALICE, arXiv:1307.1094, Average transverse momentum compared to pp and PbPb
13. ALICE, arXiv:1307.3237, Double ridge (v2) for pion, kaon, protons
14. CMS, arXiv:1307.3442, Identified hadron (pion, kaon, proton) spectra
15. ALICE, arXiv:1307.6796, Identified hadron (pion, kaon, proton, lambda) spectra
16. ALICE, preliminary, Inclusive charged jets
17. ALICE, preliminary, Inclusive Upsilon (1S) production
18. ALICE, preliminary, D-meson production
19. ALICE, preliminary, HFE production
20. ALICE, preliminary, Centrality in pPb (Q_{pPb})
21. ALICE, preliminary, UPC in pPb (not discussed in this presentation)

Motivation for pPb at the LHC

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



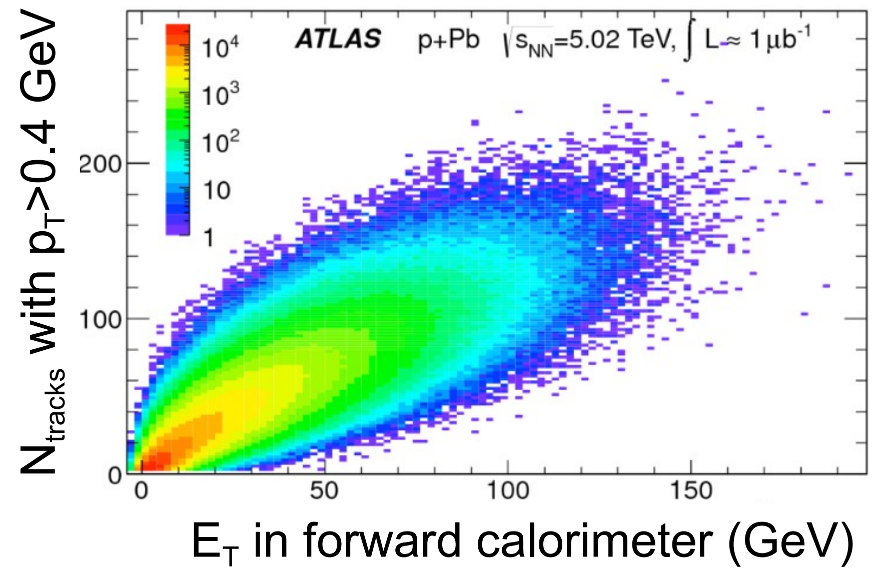


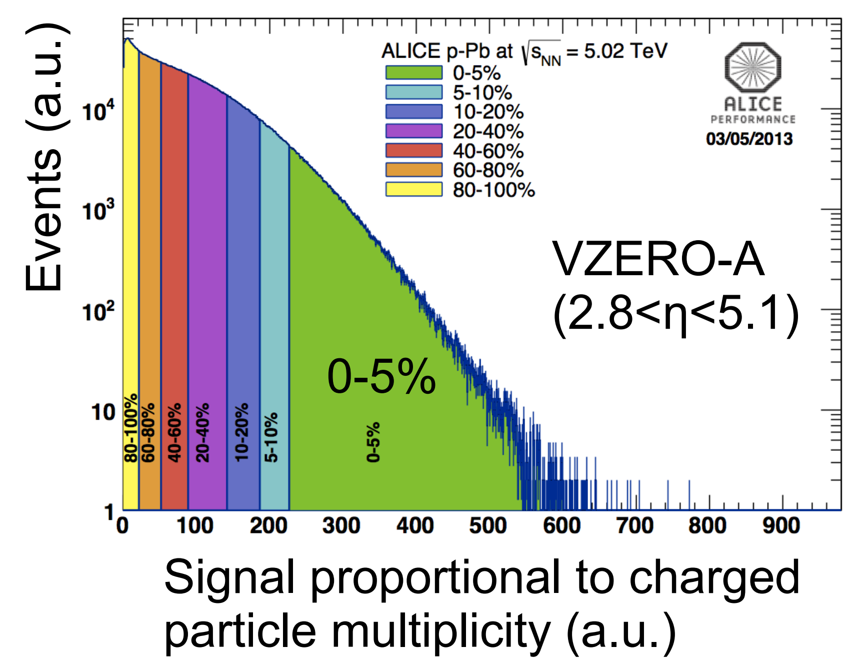
PRL 91 (2003) 072302

Motivations summarized in JPG 39 (2012) 015010

Event multiplicity classes in pPb

- Relation of multiplicity to centrality via Glauber model not straight-forward
  - 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
  - N_{coll} from Glauber not the only relevant scaling variable (see later)
  - Use minimum-bias collisions instead ($N_{coll} = A\ \sigma_{pp}/\sigma_{pA}$)
- Define event classes by slicing various multiplicity related distributions
  - Every experiment uses its own selection and usually provides (corrected) multiplicity at mid-rapidity
  - Event class definition may matter for particular measurements
  - Systematics from different selections

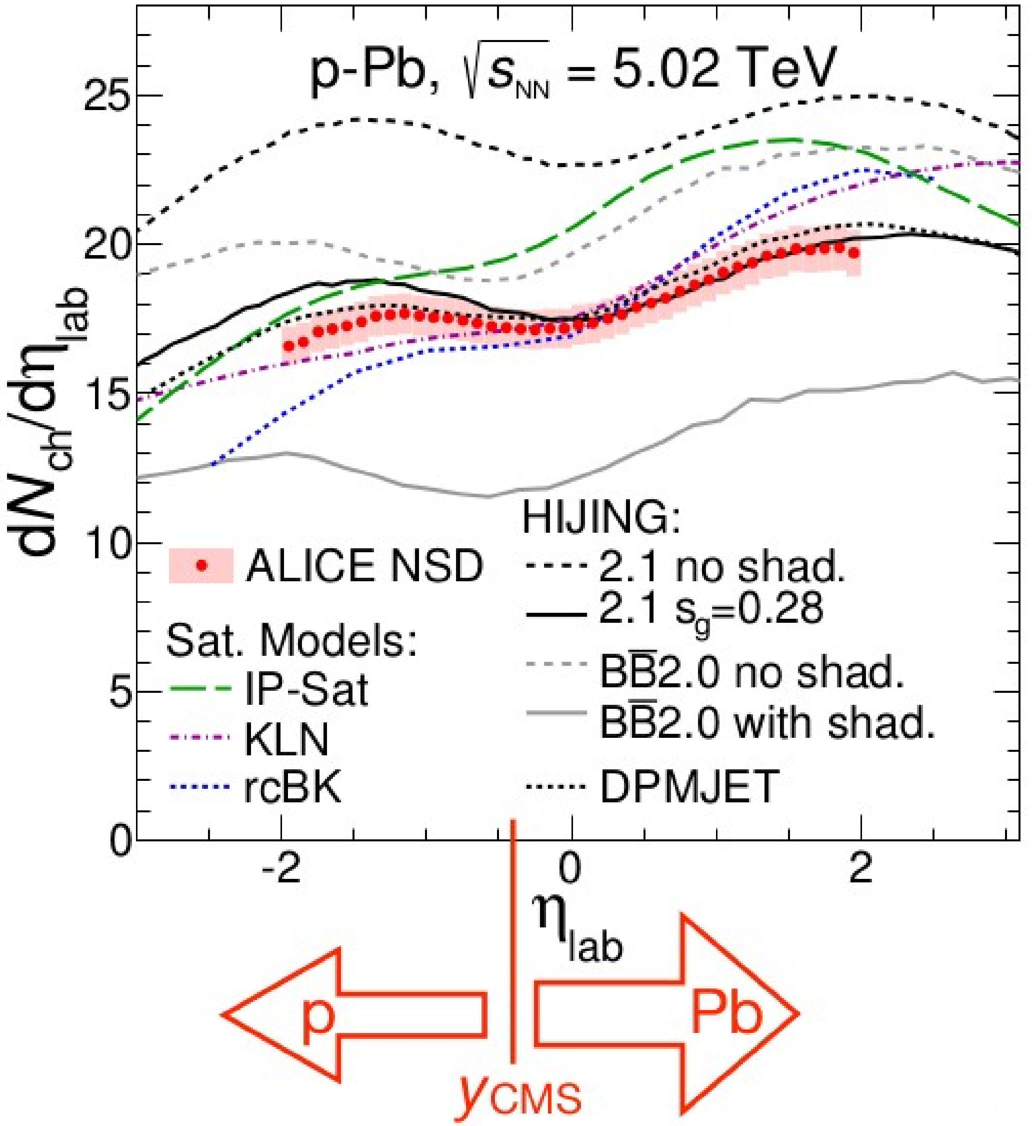




Charged particle pseudorapidity density

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 (direction of proton)
- 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

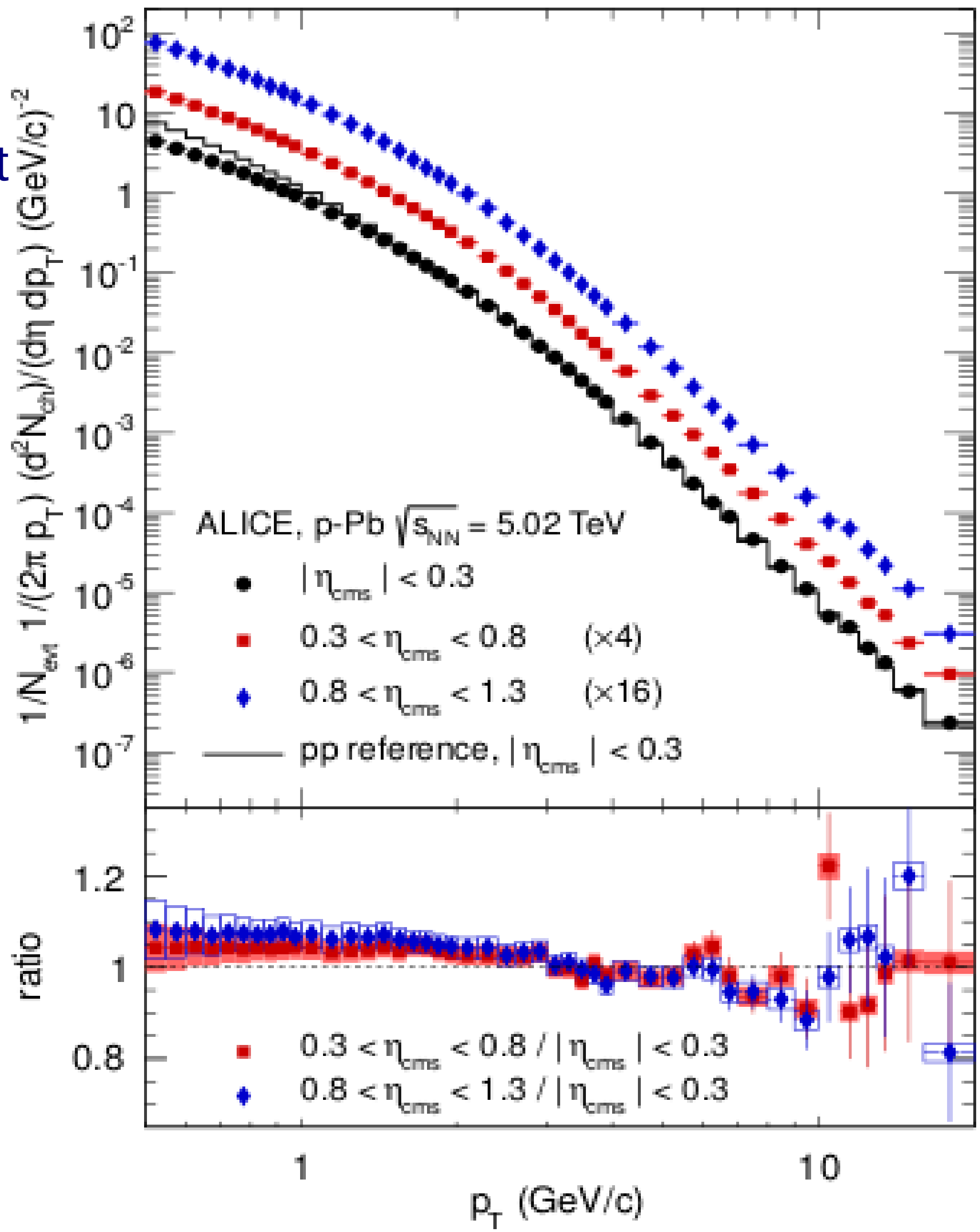


NB: HIJING calculations are expected to increase by ~4% from INEL to NSD

Charged particle p_T in bins of η

- Primary charged tracks (3 η bins)
  - Reconstructed in ITS+TPC (|η|<0.8)
  - Assume $\eta_{cms} = \eta_{lab} - y_{cms}$, 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 (ALICE, arxiv:1307.1093)
    - Systematic uncertainty: 8%
    - Normalization uncertainty: 3.6%
  - $\langle T_{pPb} \rangle = 0.0983 \pm 0.0035\ mb^{-1}$ from Glauber model

ALICE, PRL 110 (2013) 082302

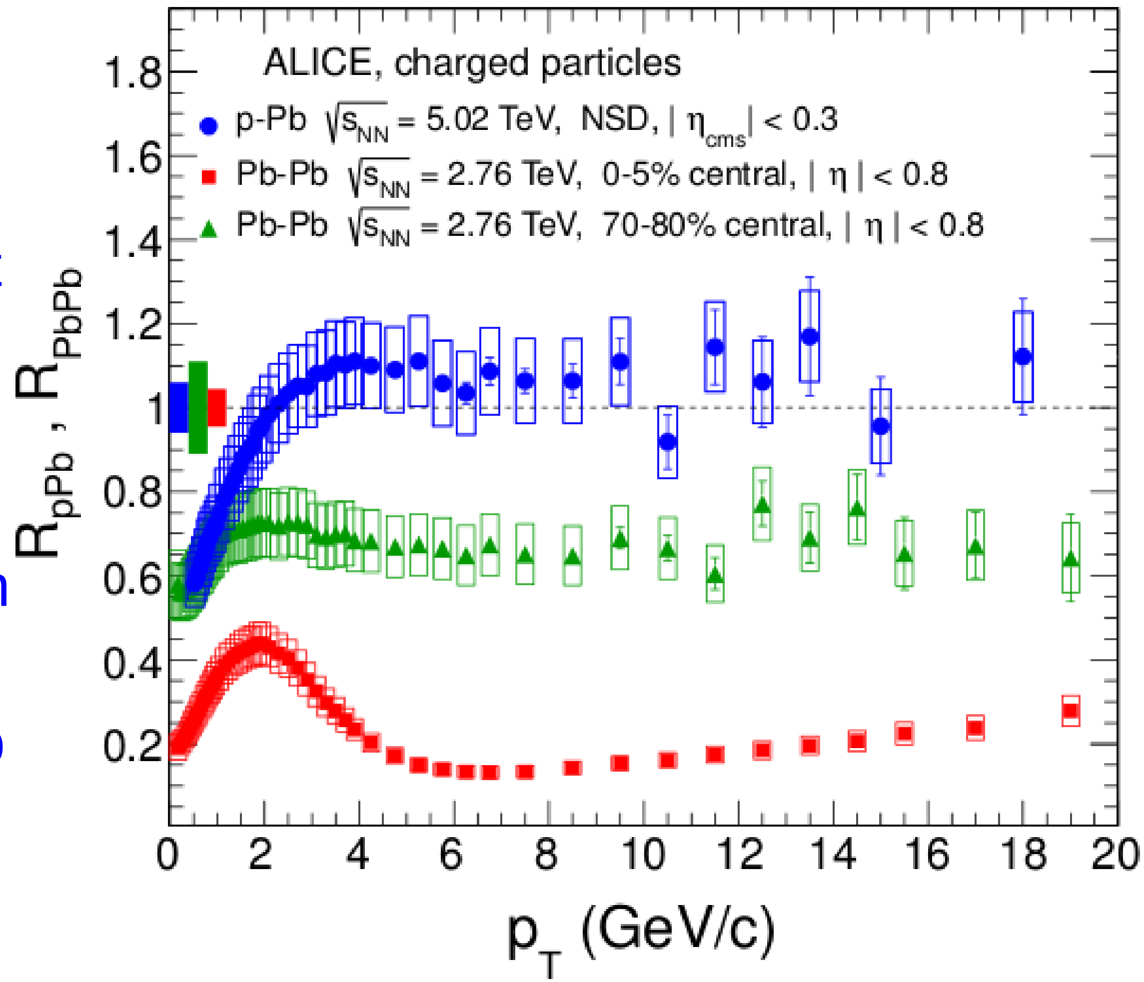


Nuclear modification for charged particles

$$R_{AB} = \frac{dN_{AB}/dp_T}{\langle N_{coll}\rangle dN_{pp}/dp_T}$$

- 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

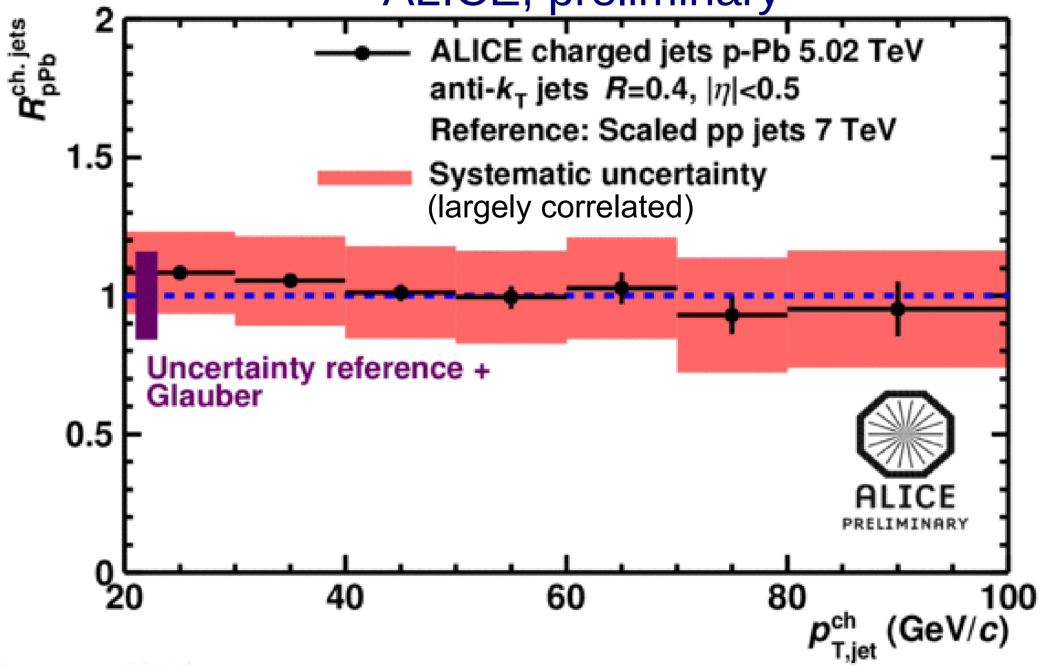
ALICE, PRL 110 (2013) 082302

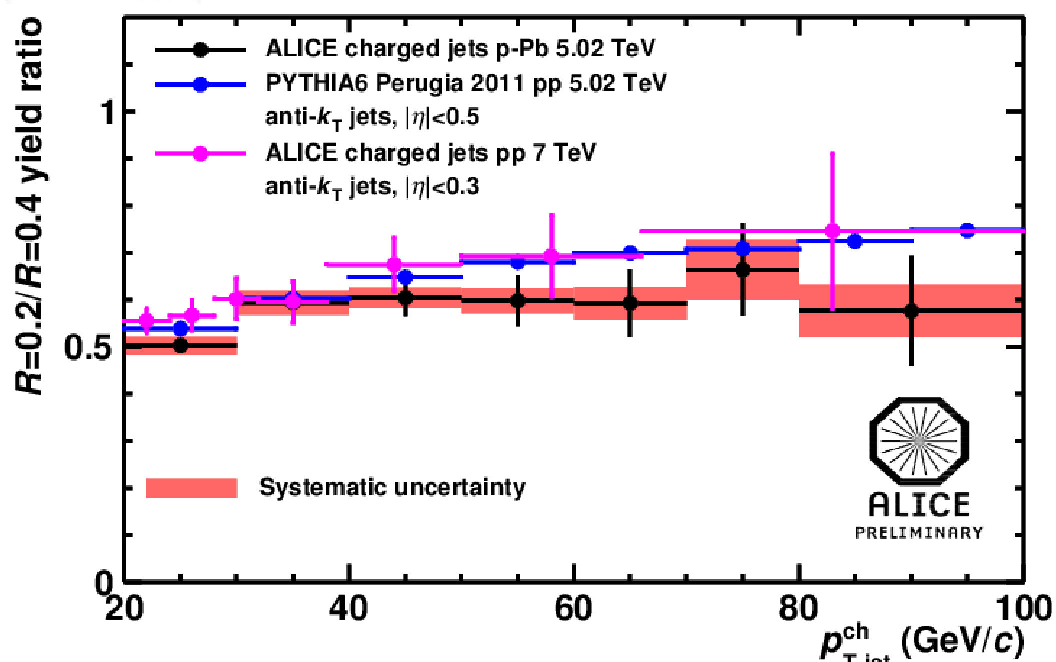


Nuclear modification for charged jets

- Charged jet spectrum in minimum bias pPb with anti-k_T for R=0.2 and 0.4 in $|\eta_{lab}|<0.5$
  - Subtraction of UE with jet area/median approach (CMS, JHEP 08 (2012) 130)
  - Unfolding of background fluctuations and detector response using SVD
- Reference spectrum for pp using 7 TeV data and scaled with PYTHIA6 (Perugia 2011)
- No sign of nuclear modification
  - Nuclear modification factor consistent with unity within large uncertainties
  - Jet structure ratio consistent with that in pp

ALICE, preliminary

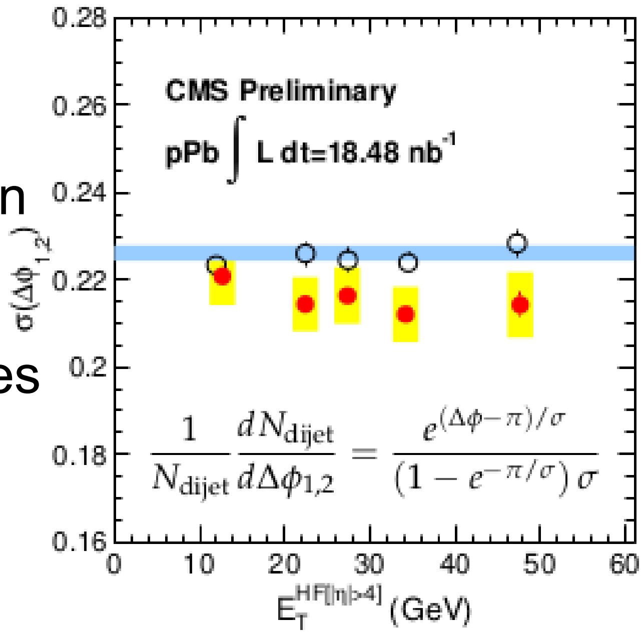


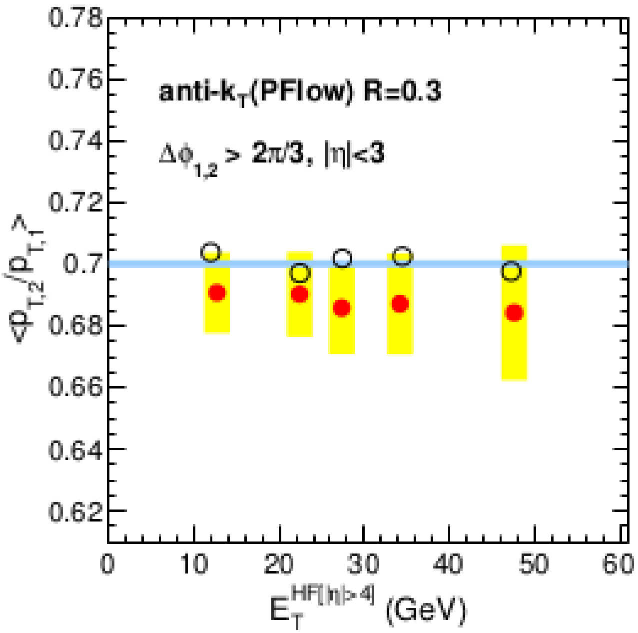


Measurements of dijet properties

CMS-PAS-HIN-13-001

$\Delta\varphi$ distribution the same for all forward energy classes





P_{T1}>120 GeV/c
P_{T2}>30 GeV/c
R=0.3
$|\eta_{lab}|$<3

p_T imbalance the same for all forward energy classes

Large imbalance measured in AA is final state effect

Measurements of dijet properties

CMS-PAS-HIN-13-001

Δφ distribution the same for all forward energy classes

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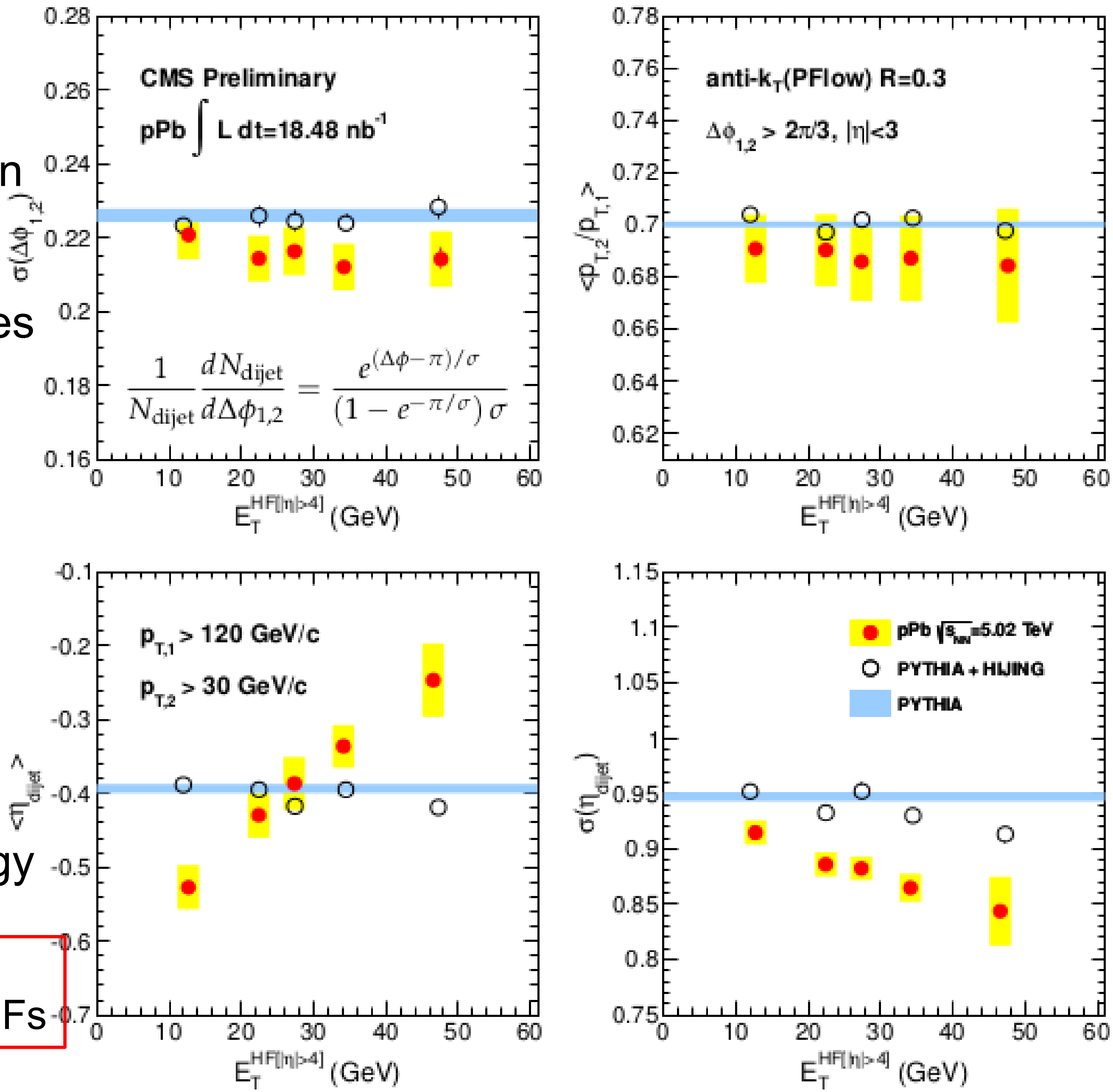


p_T imbalance the same for all forward energy classes

Large imbalance measured in AA is final state effect

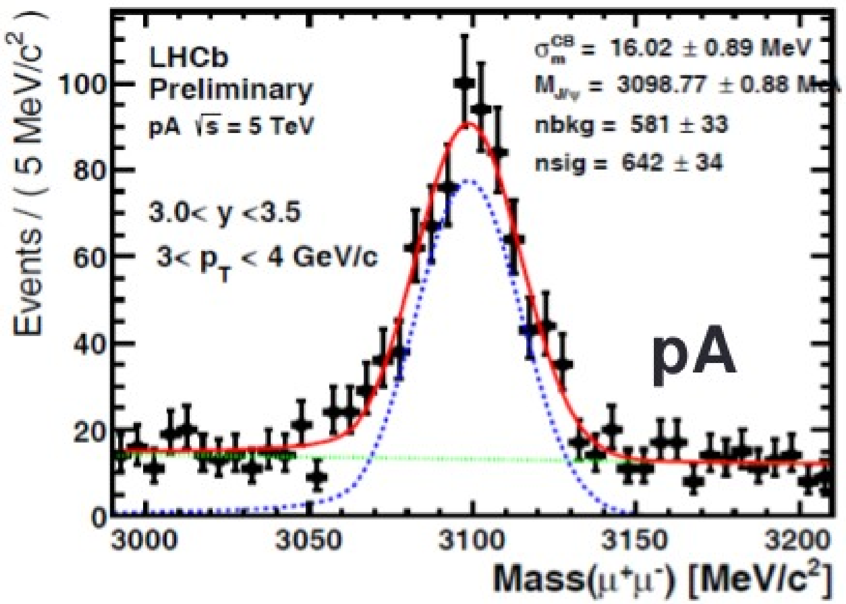
Dijet η shifts forward for increasing forward energy

Change may constrain nPDFs

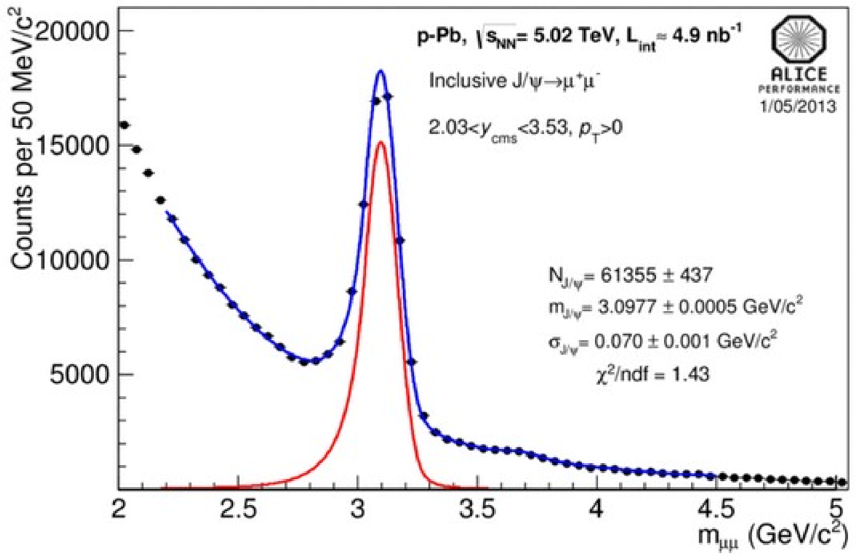
Dijet η width decreases for increasing forward energy

J/ψ production

LHCb-CONF-2013-008



ALICE, preliminary



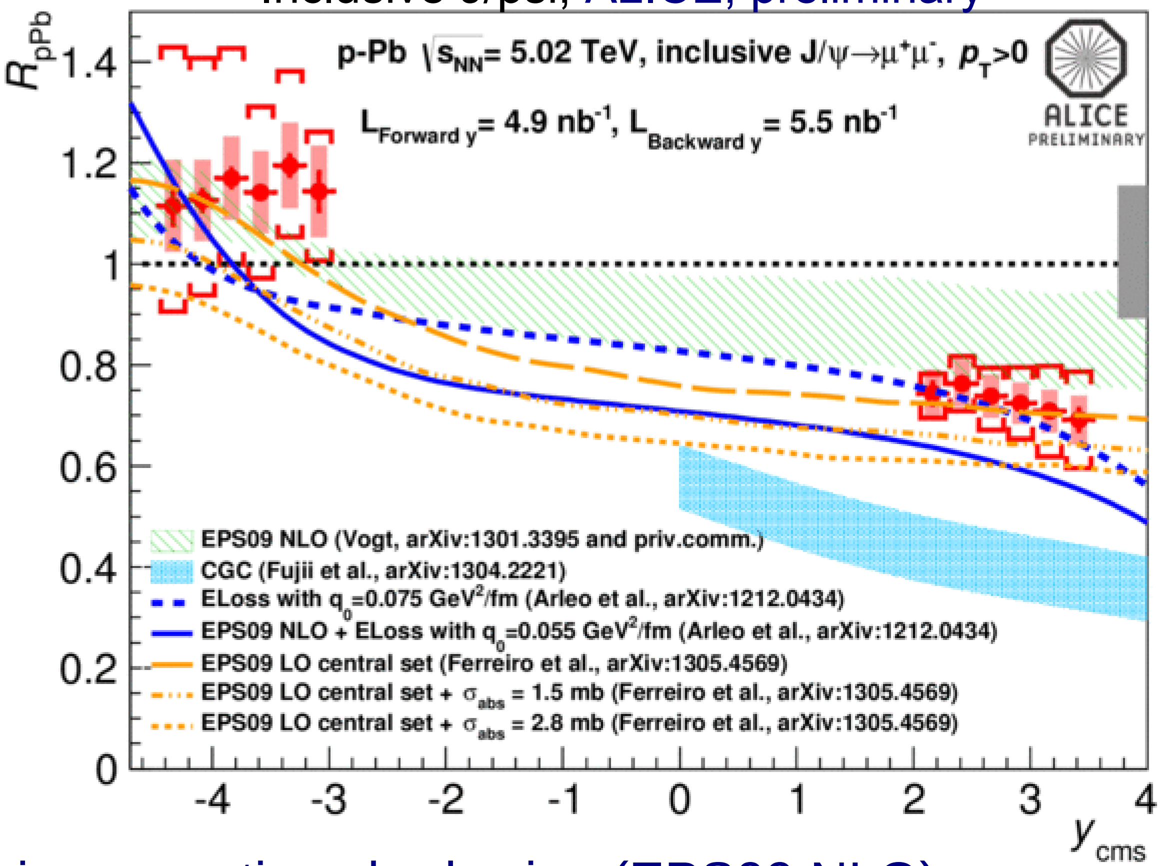
- Extraction of prompt J/psi and J/psi from b decays using simultaneous fit of mass and pseudo-proper time
- Obtain (total) cross sections
  - Forward: 1.5<y<4.0 (0.75/nb)
  - Backward: -5.0<y<-2.5 (0.3/nb)
  - p_T<14 GeV/c

- Extraction of inclusive J/psi using Crystal Ball as signal and exponential plus polynomial as background
- Obtain invariant yields
  - Forward: 2.03<y<3.53 (~4.9/nb)
  - Backward: -4.46<y<-2.96 (~5.5/nb)
  - p_T<15 GeV/c

Nuclear modification for inclusive J/ψ

- Uncertainty on R_{pPb} dominated by uncertainty of pp reference (constructed by interpolating existing data)
  - R_{pPb} decreases with forward y
  - Within large uncertainties, no apparent y dependence in backward region

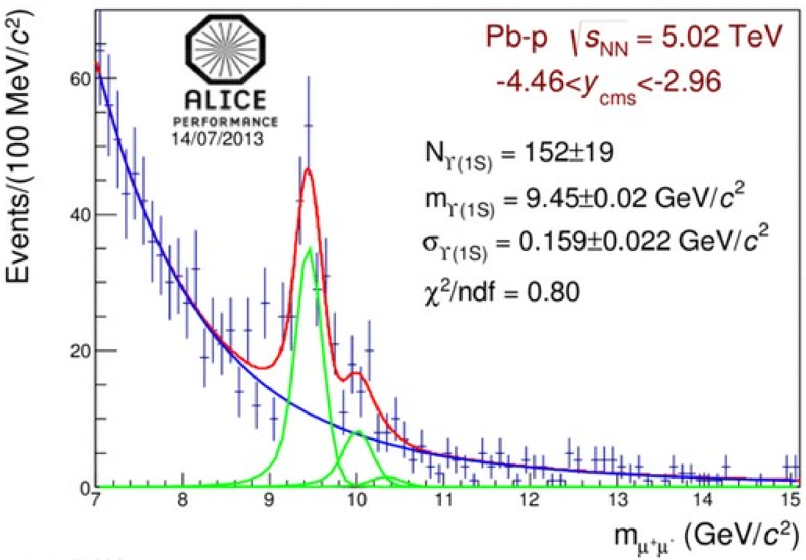
Inclusive J/psi, ALICE, preliminary

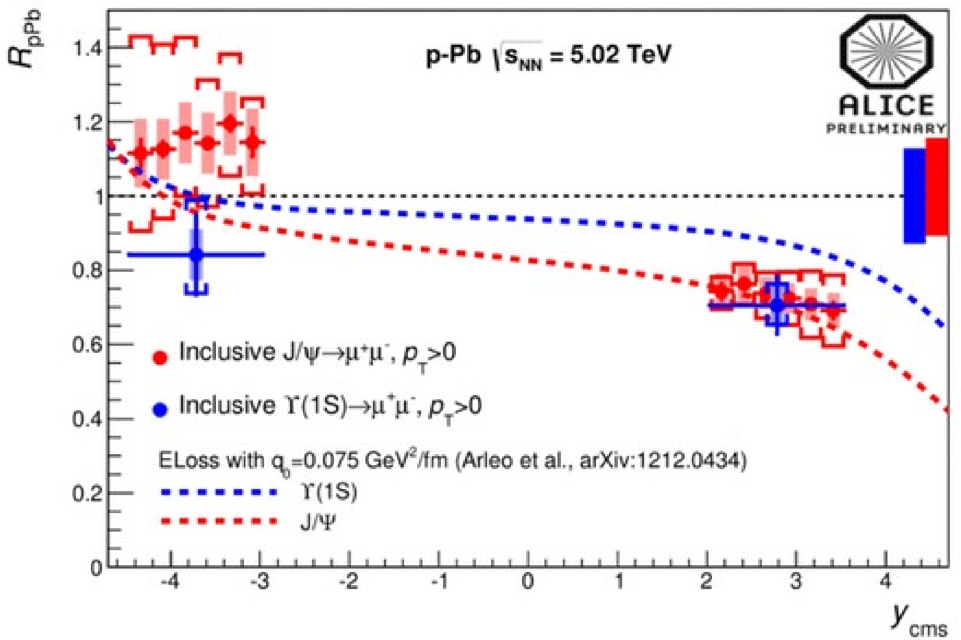


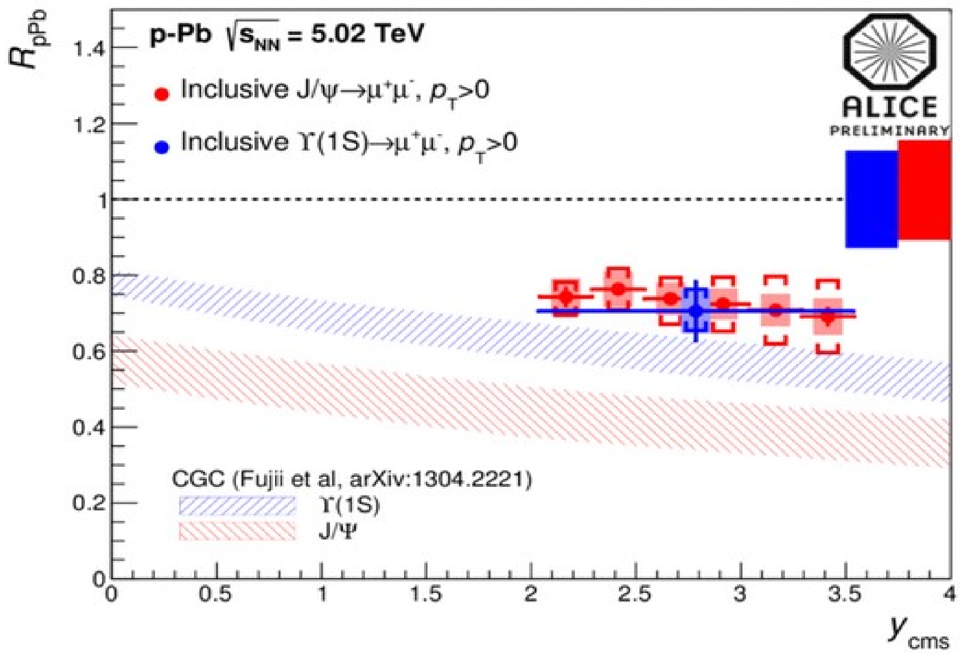
- Comparison with models
  - Good agreement with models incorporating shadowing (EPS09 NLO) and/or a contribution of coherent parton energy loss
  - CGC model (Fujii et al.) disfavored by the data
  - Rapidity dependence in backward region may provide additional constraints
- Preliminary LHCb results about 30% lower (see backup)
  - Differences being discussed between experiments

Nuclear modification for Υ(1S)

ALICE, preliminary

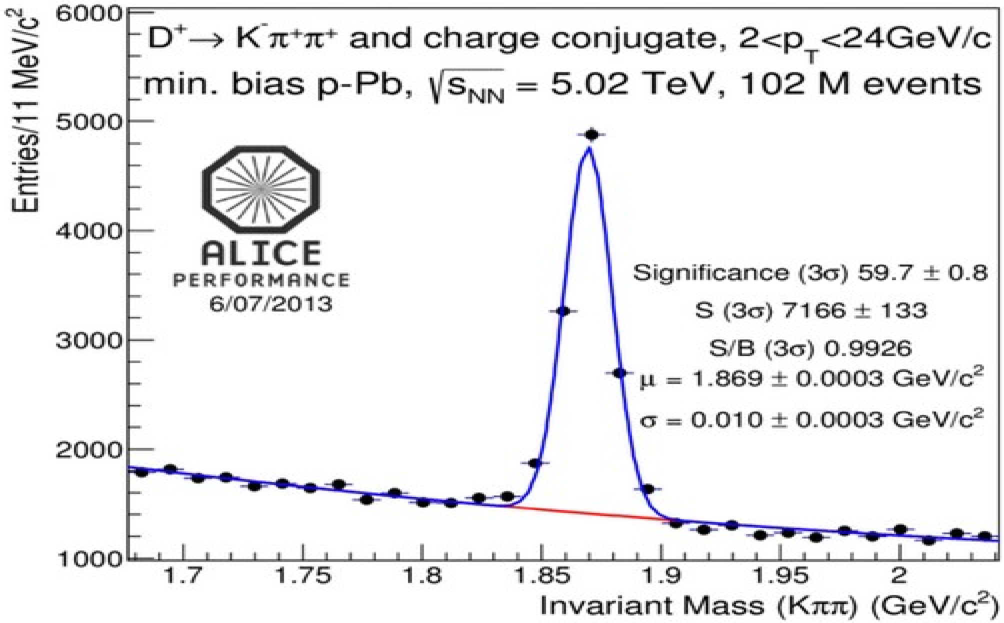




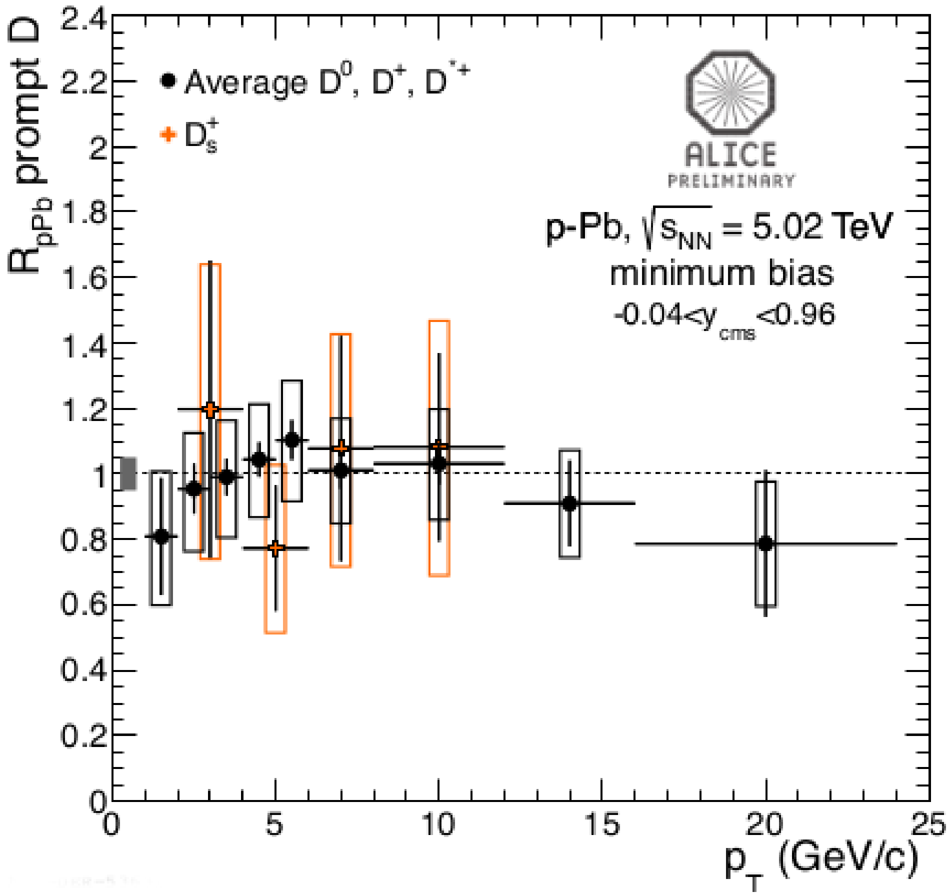


- Extract yield using 3 extended CB fits with 5 parameters (3 amplitudes, mean and width for Υ(1S), tails from MC)
- Reference constructed by interpolating existing pp data
- Comparison with models
  - “Somewhat orthogonal” to what is concluded from J/ψ
  - Combined dataset provides strong constraints to models

Nuclear modification of D-mesons



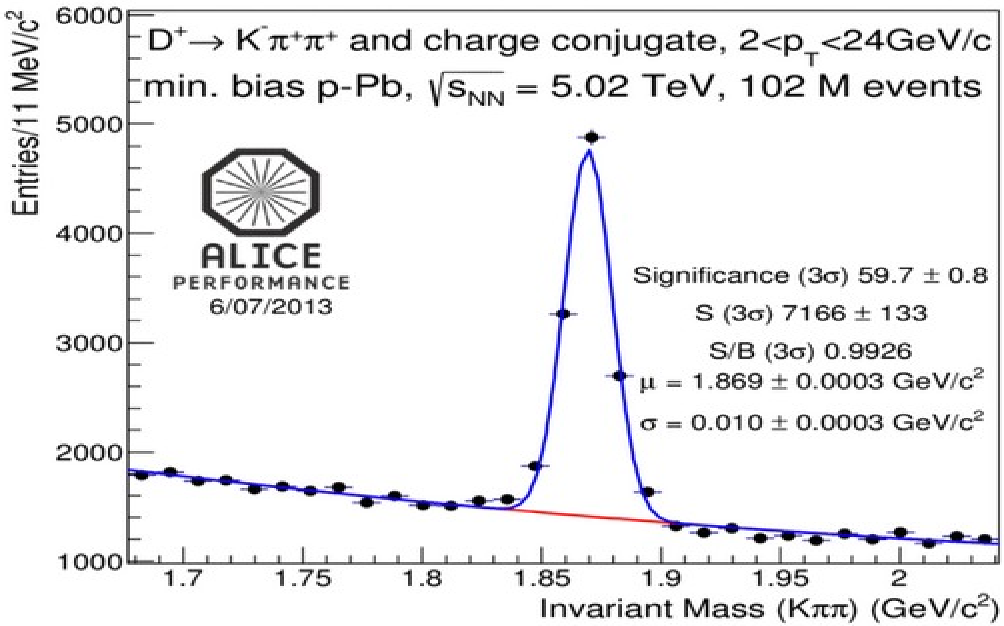
ALICE, preliminary



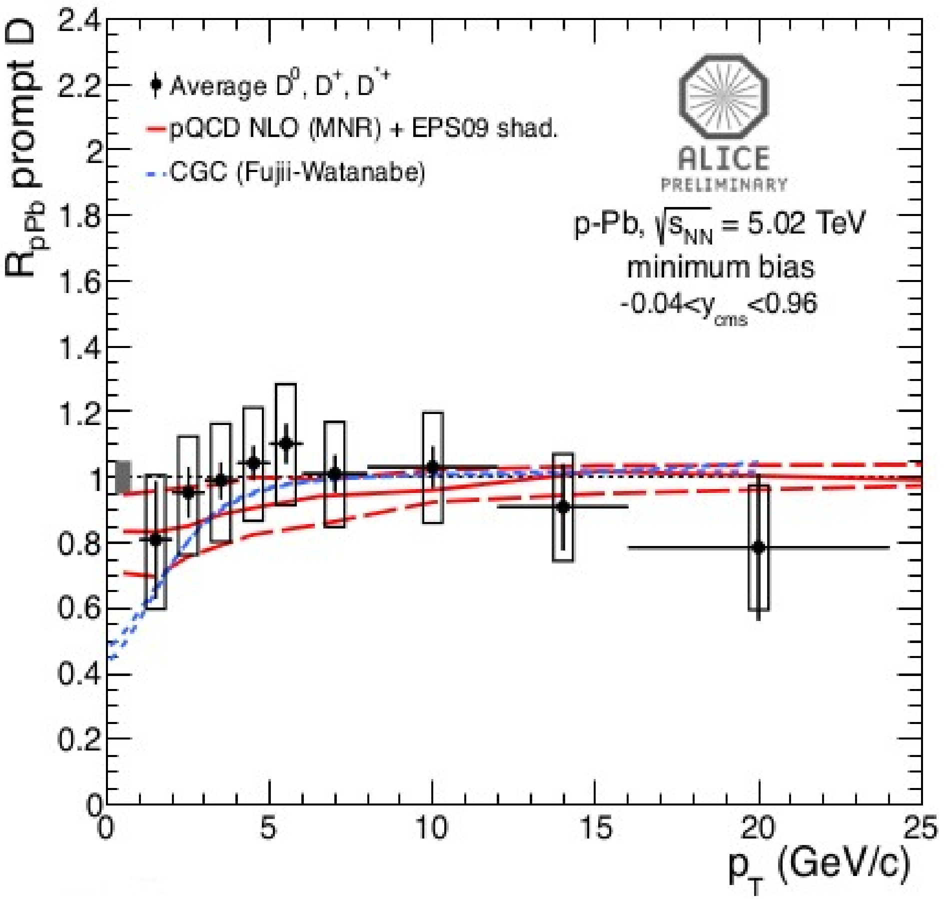
- Reconstruction using decay topology (displaced vertex, PID)
- Extraction of yield using Gaussian + Exponential fit
- Fraction of feed-down Ds subtracted using FONLL and assumption that "prompt ≈ non-prompt R_{pPb}"
- Reference constructed using data at 7 TeV scaled by FONLL

- R_{pPb} for D-mesons consistent and unity within uncertainty

Nuclear modification of D-mesons



ALICE, preliminary



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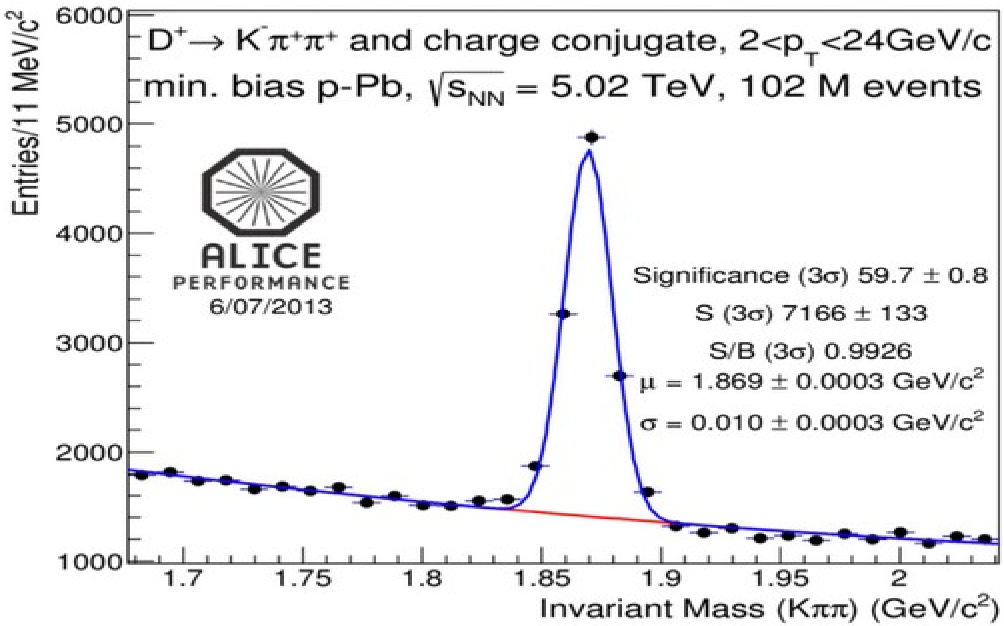
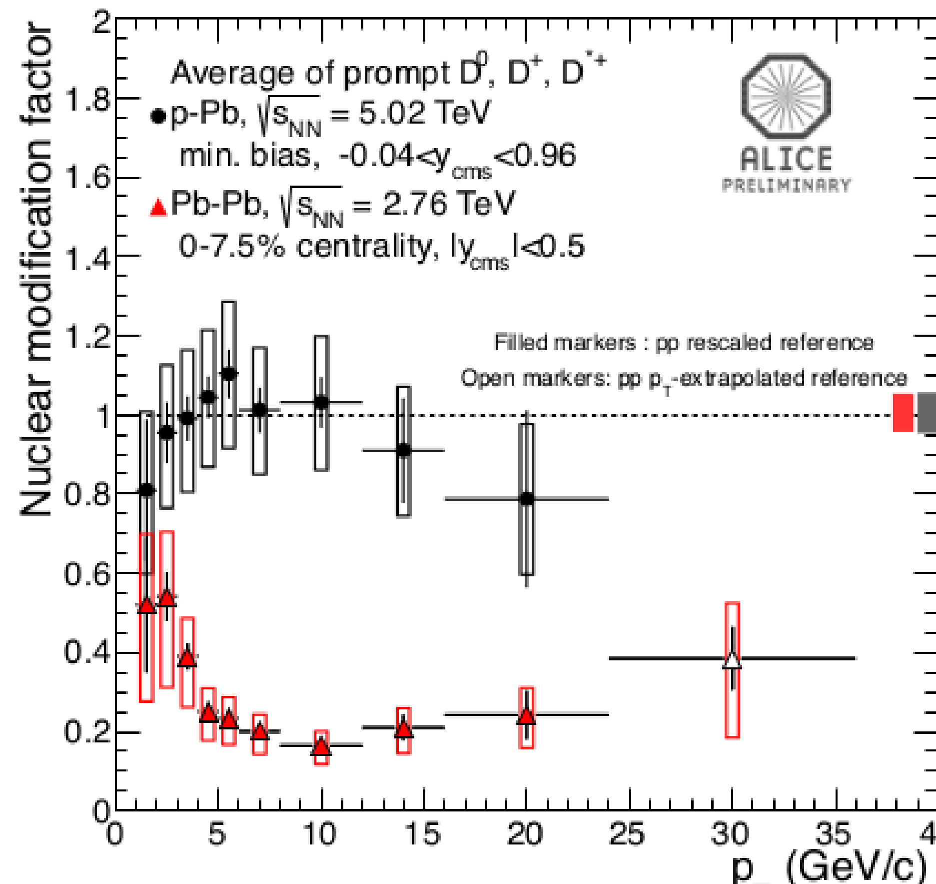
- R_{pPb} for D-mesons consistent and unity (within large) uncertainty
- CGC and shadowing calculations describe the data

Nuclear modification of D-mesons



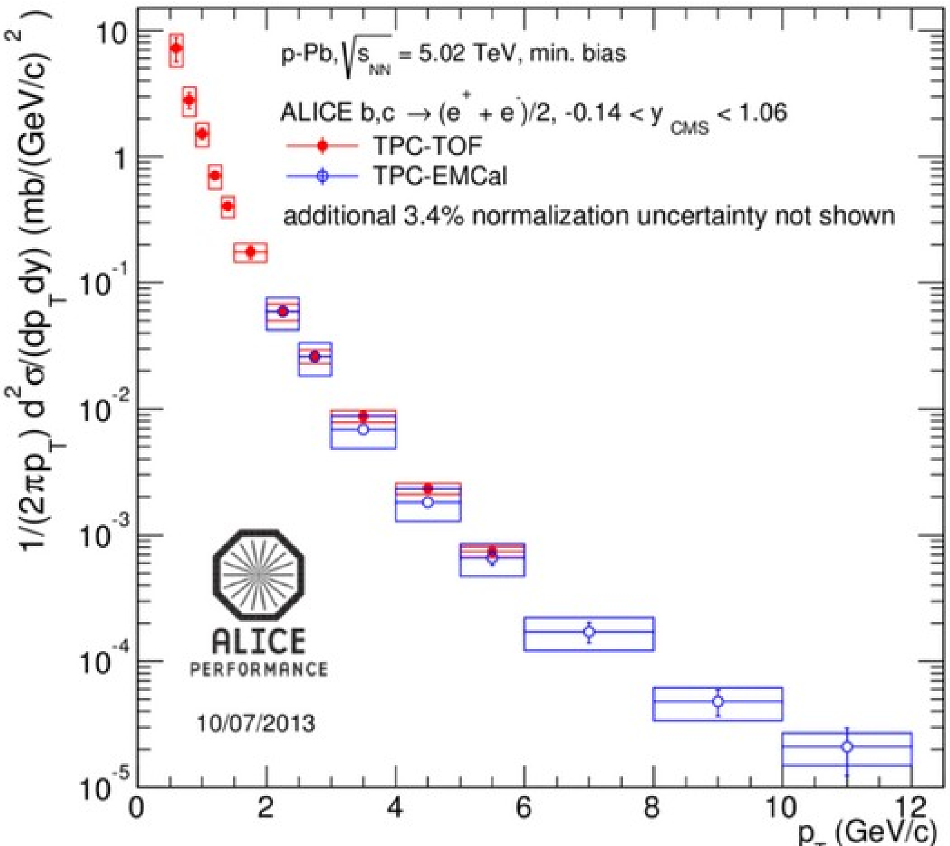
ALICE, preliminary



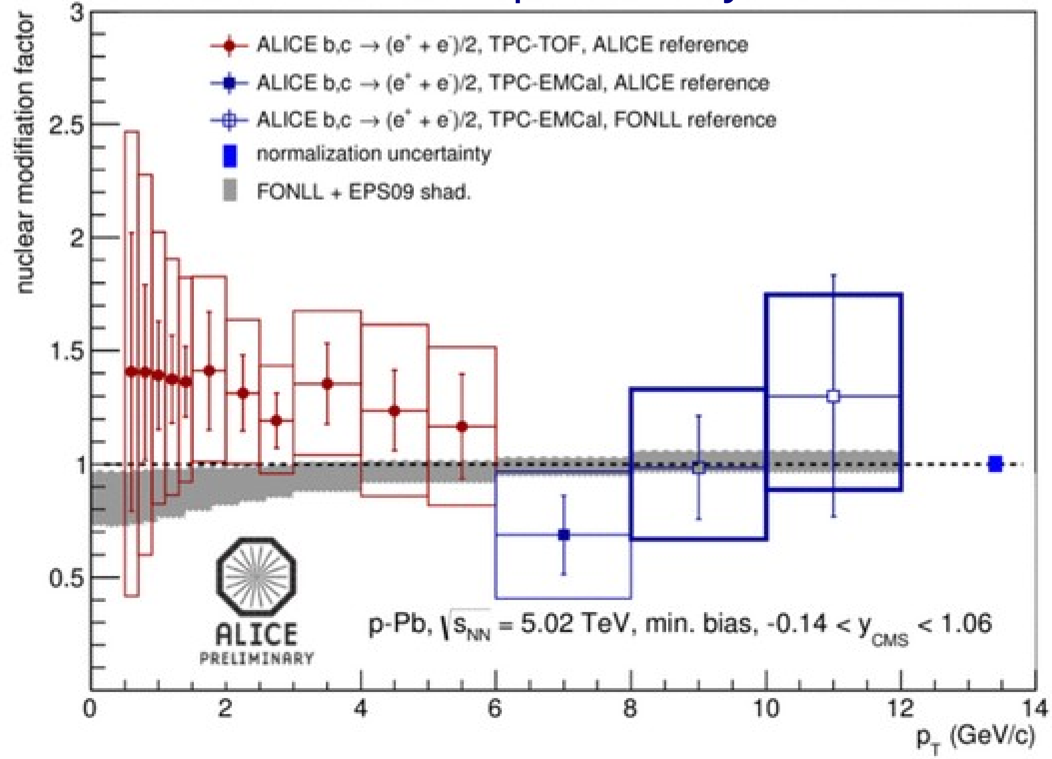
- Reconstruction using decay topology (displaced vertex, PID)
- Extraction of yield using Gaussian + Exponential fit
- Fraction of feed-down Ds subtracted using FONLL and assumption that “prompt ≈ non-prompt R_{pPb}”
- Reference constructed using data at 7 TeV scaled by FONLL

- R_{pPb} for D-mesons consistent and unity (within large) uncertainty
- CGC and shadowing calculations describe the data
- Final state suppression in PbPb

Nuclear modification for HFE



ALICE, preliminary

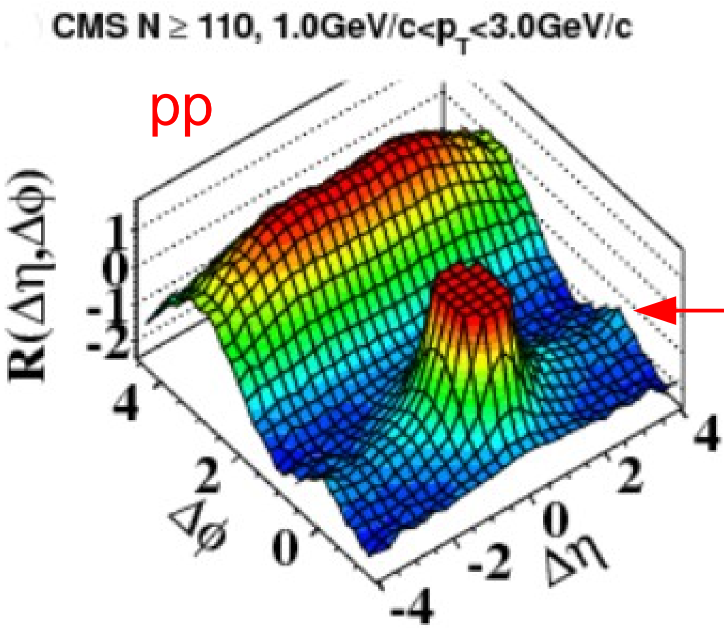


- Measurement with TPC+TOF and TPC+EMCAL
- Subtraction of background obtained either with cocktail simulation or tagged electrons from photon conversions

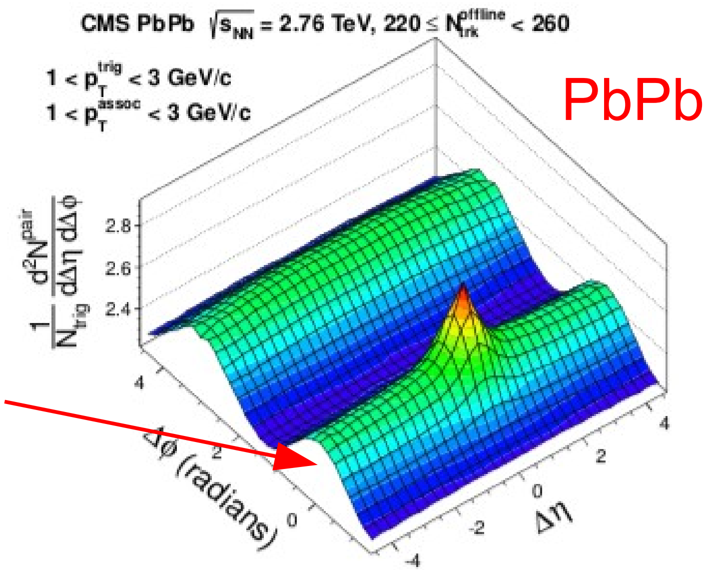
- Reference obtained using 7 TeV data scaled by FONLL
- R_{pPb} consistent with unity within large uncertainty (perhaps some “cronin enhancement”)
- Calculations describe data

Two-particle angular correlations

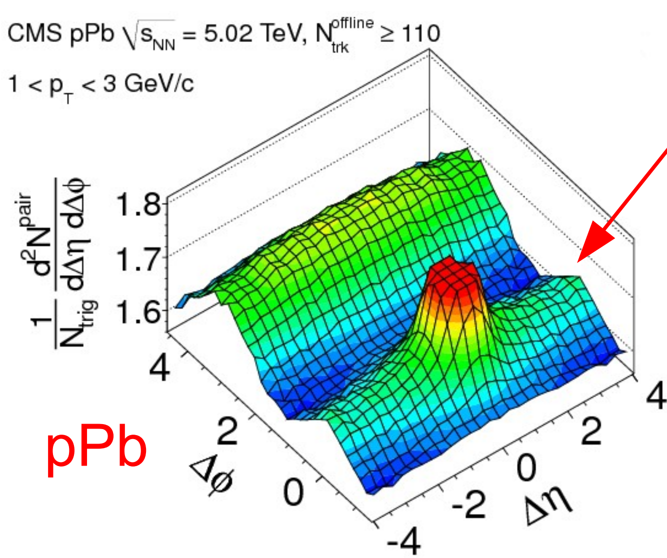
Near-side ridges apparent in high multiplicity events at LHC energies



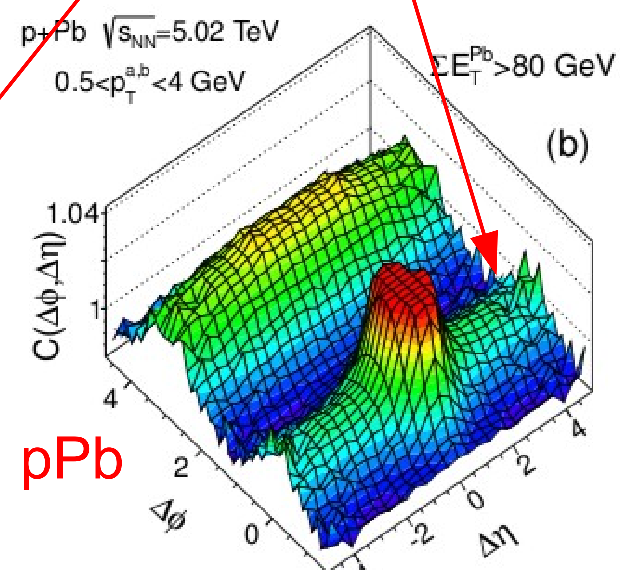
CMS, JHEP 1009 (2010) 91



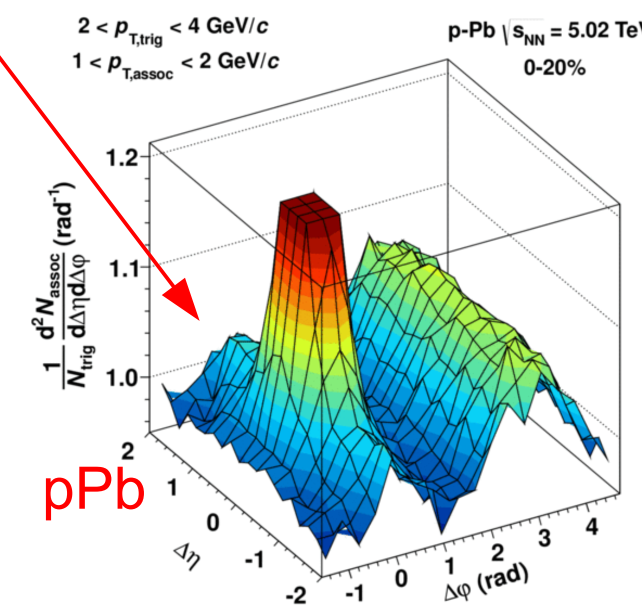
CMS, PLB 724 (2013) 213



CMS, PLB 718 (2012) 795

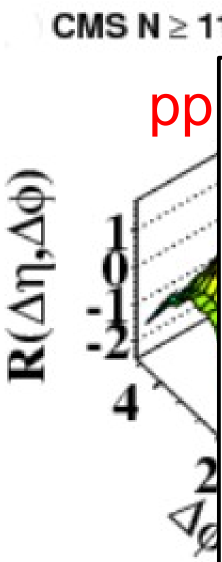


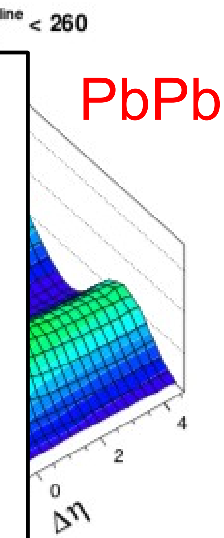
ATLAS, PRL 110 (2013) 182302



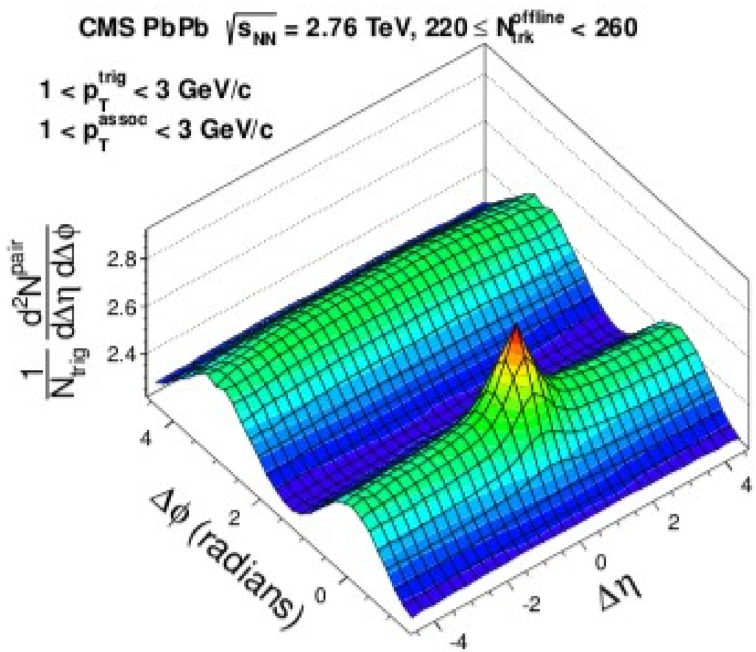
ALICE, PLB 719 (2013) 29

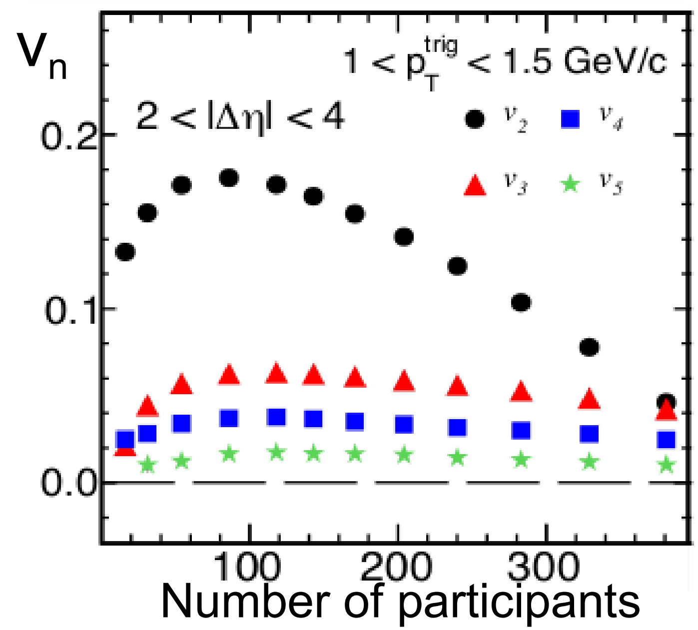
Two-particle angular correlations

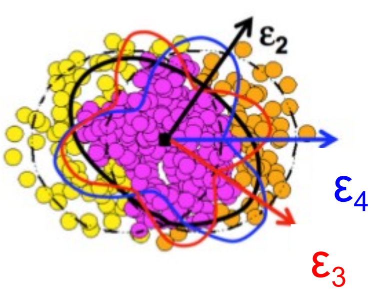




CMS, EPJC 72 (2012) 10052



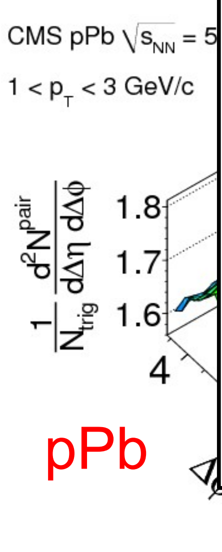


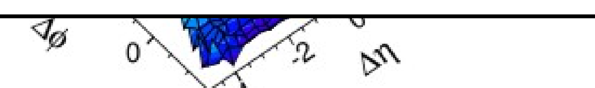


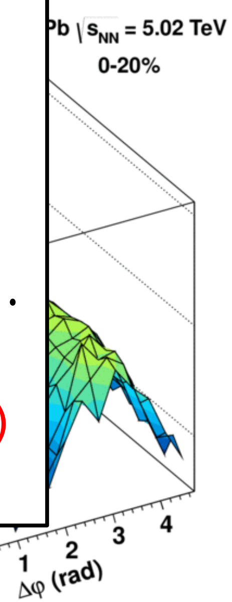
$$\frac{dN}{d\varphi} \sim 1 + 2v_2\cos[2(\varphi-\psi_2)] + 2v_3\cos[3(\varphi-\psi_3)] + 2v_4\cos[4(\varphi-\psi_4)] + 2v_5\cos[5(\varphi-\psi_5)] + \dots$$

In PbPb, long-range correlations can be explained by flow harmonics (v_n)

CMS, ... (2013) 213



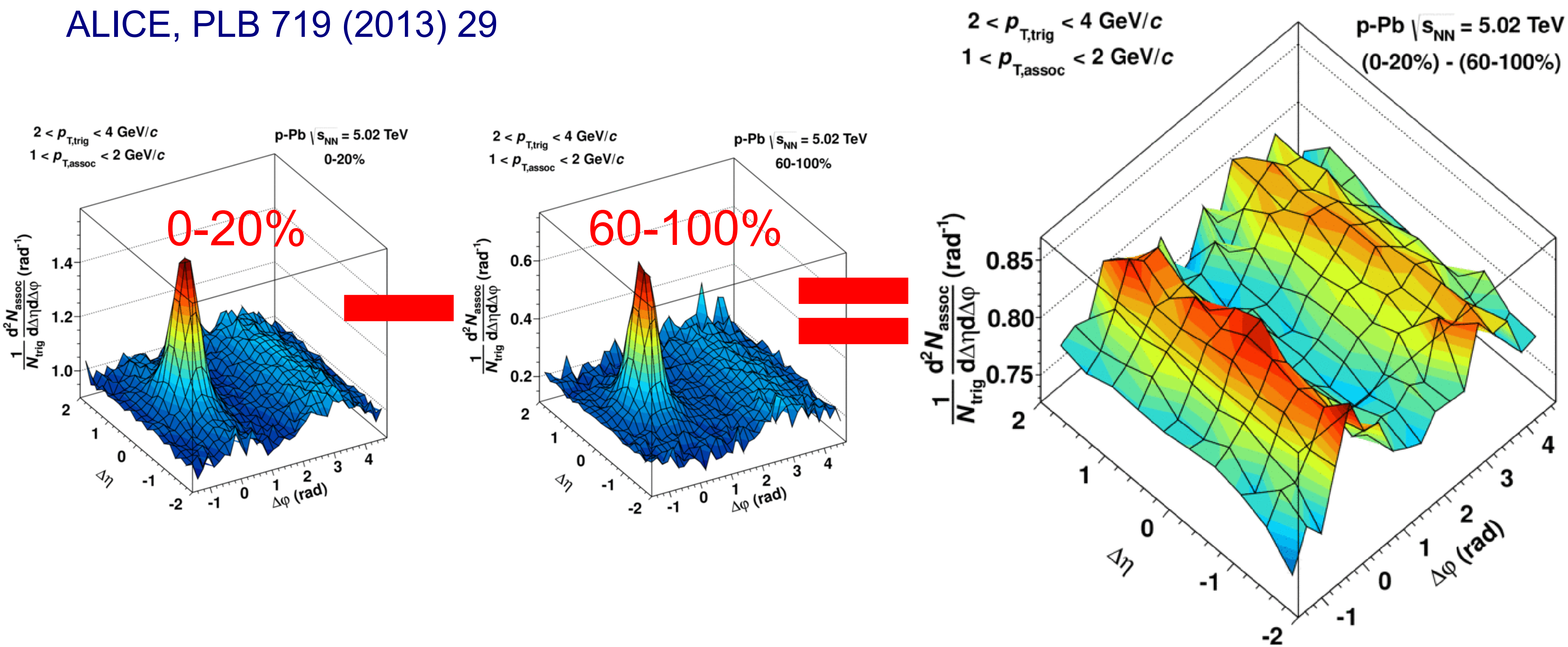




CMS, PLB 718 (2012) 795 | ATLAS, PRL 110 (2013) 182302 | ALICE, PLB 719 (2013) 29

Extraction of double ridge structure

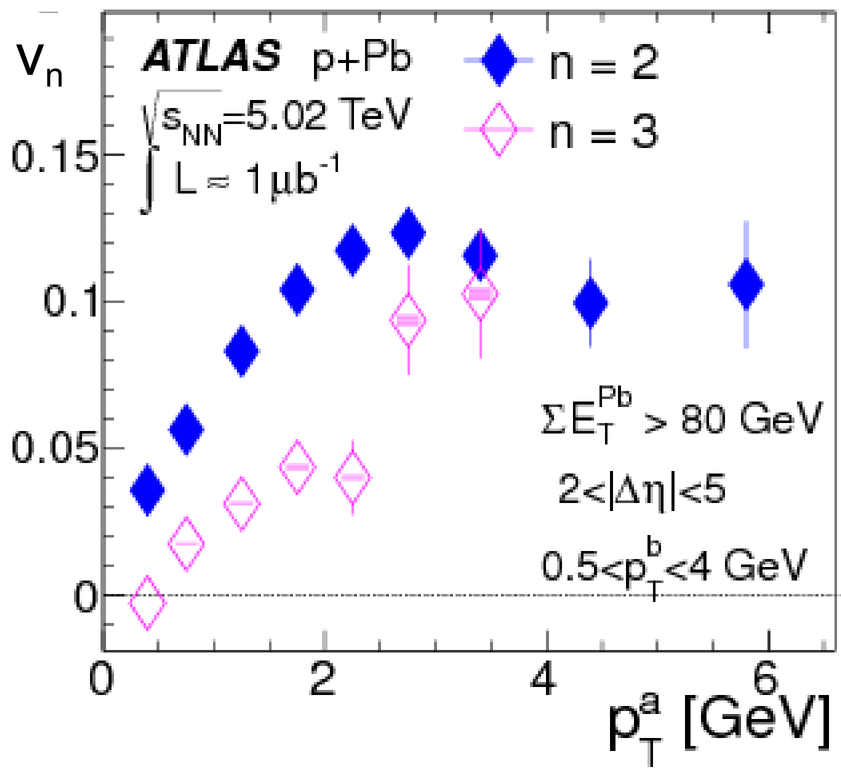
ALICE, PLB 719 (2013) 29



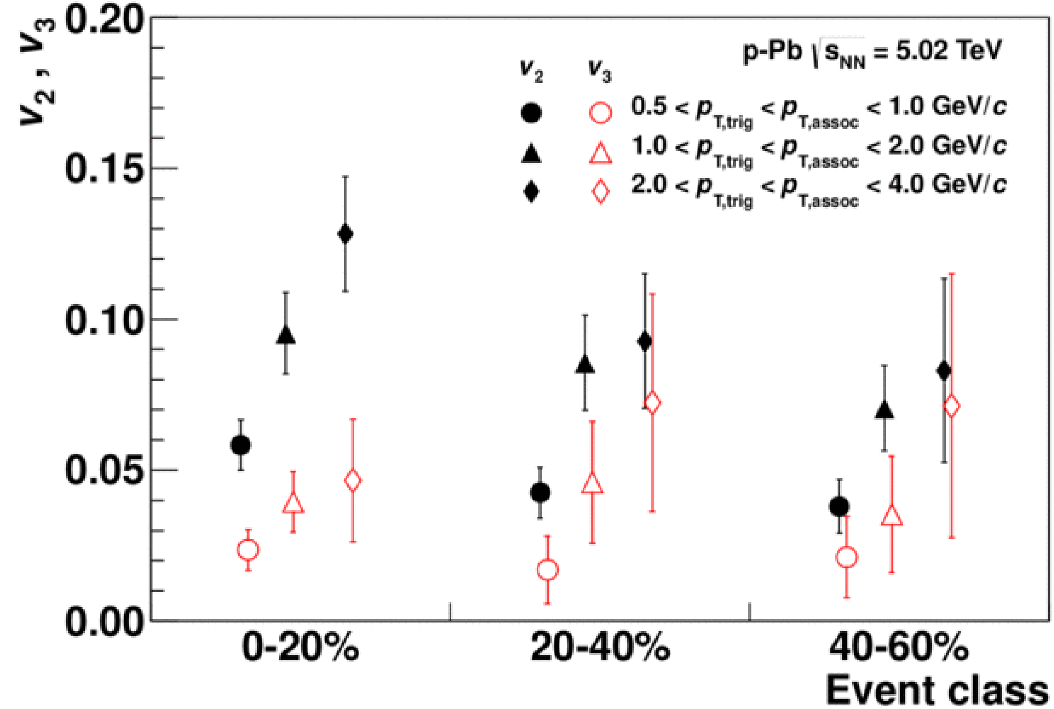
- Extract double ridge structure using a standard technique in AA collisions, namely by subtracting the jet-like correlations
  - It is assumed that the 60-100% class is free of non-jet like correlations
  - The near-side ridge is accompanied by an almost identical ridge structure on the away-side
  - Similar analysis strategy by ATLAS (PRL 110 (2013) 182302)

Ridge v_2 and v_3

ATLAS, PRL 110 (2013) 182302



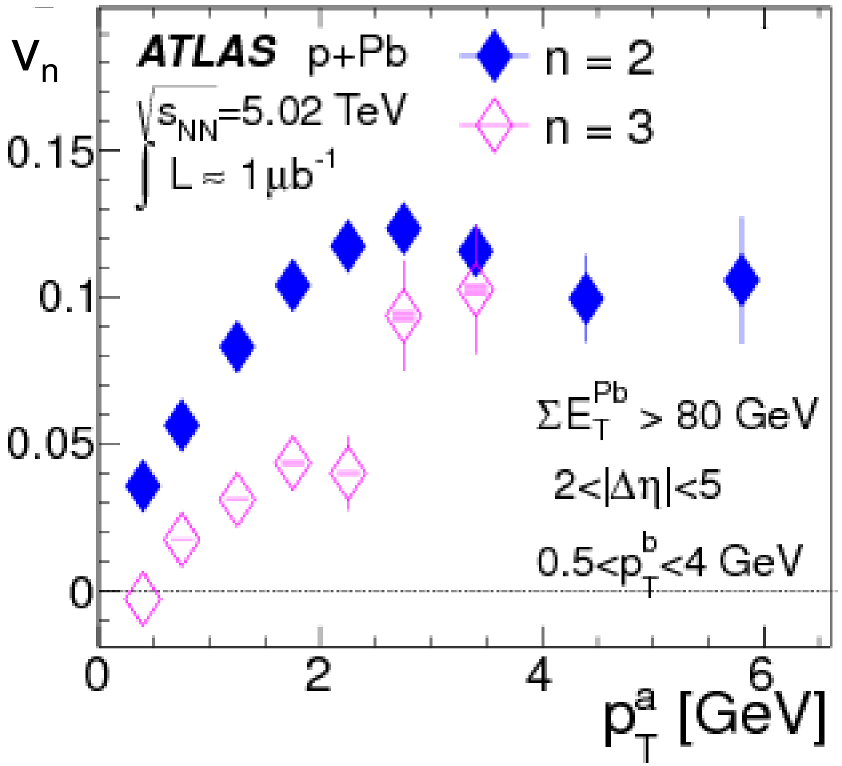
ALICE, PLB 719 (2013) 29



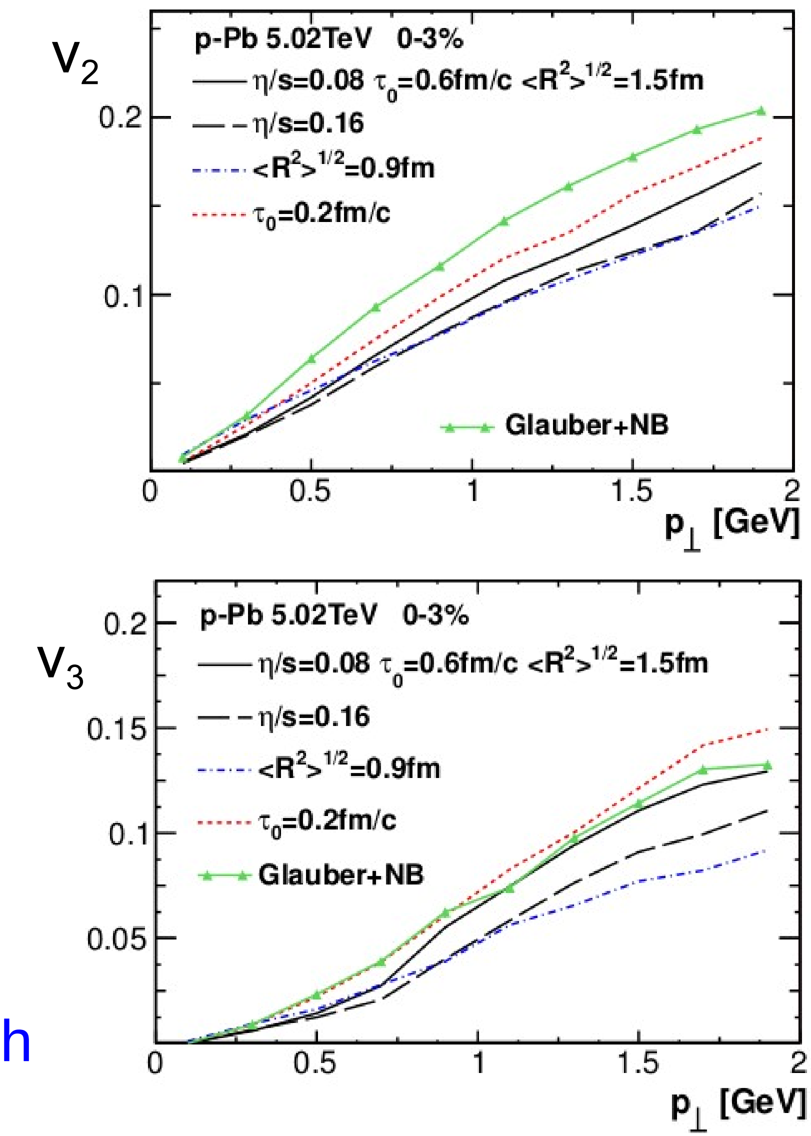
- Sizable values for v_2 and even v_3 reached for high-multiplicity events

Ridge v_2 and v_3 and hydrodynamics

ATLAS, PRL 110 (2013) 182302



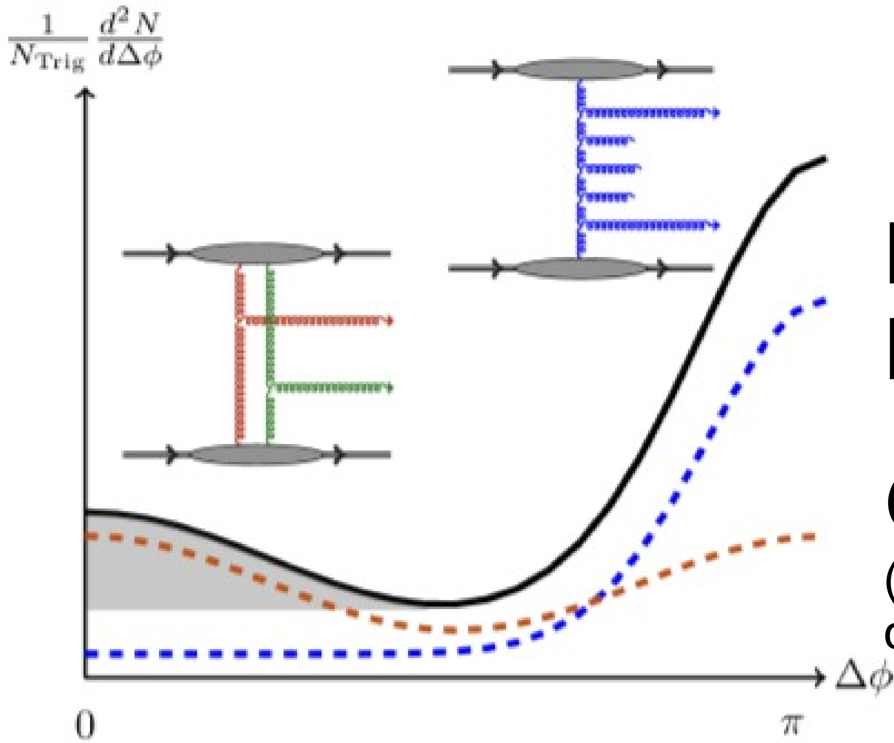
Bozek and Broniowski, PRC 88 (2013) 014903



- Sizable values for v_2 and even v_3 reached for high-multiplicity events
- Results qualitatively consistent with viscous hydrodynamic calculations with initial state fluctuations from Glauber
  - Caveat: Calculations in pPb less robust wrt changes of assumptions than in AA

Ridge modulation v_2 and v_3 and CGC

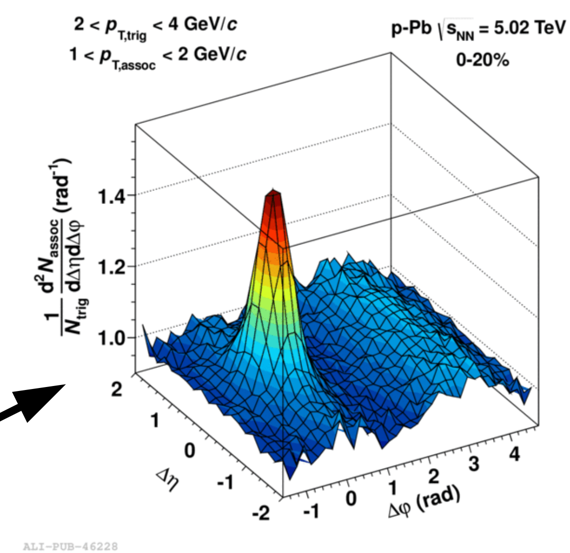
- Two symmetric ridges predicted by CGC glasma graphs found to describe the ridge yields and shape
- However, a large v_3 component would be a challenge for the model

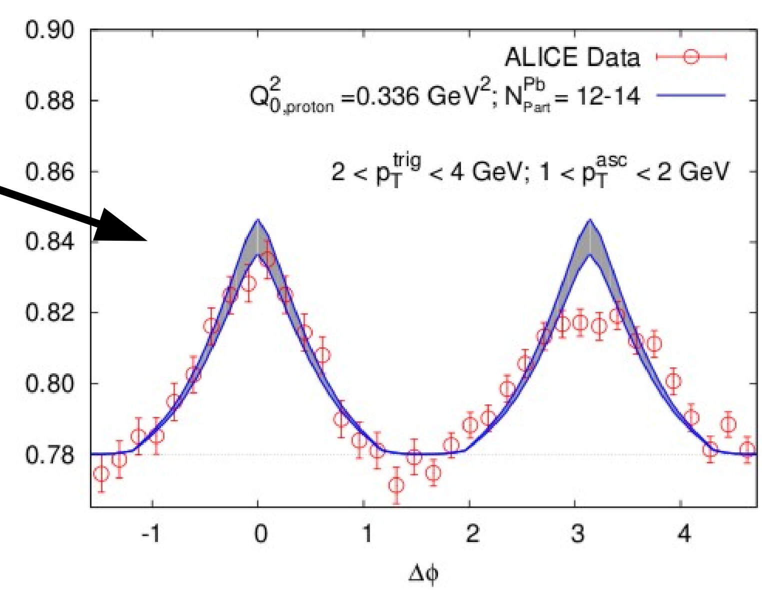


Dusling and Venugopalan, PRD 87 (2013) 094034

BFKL-Minijets

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





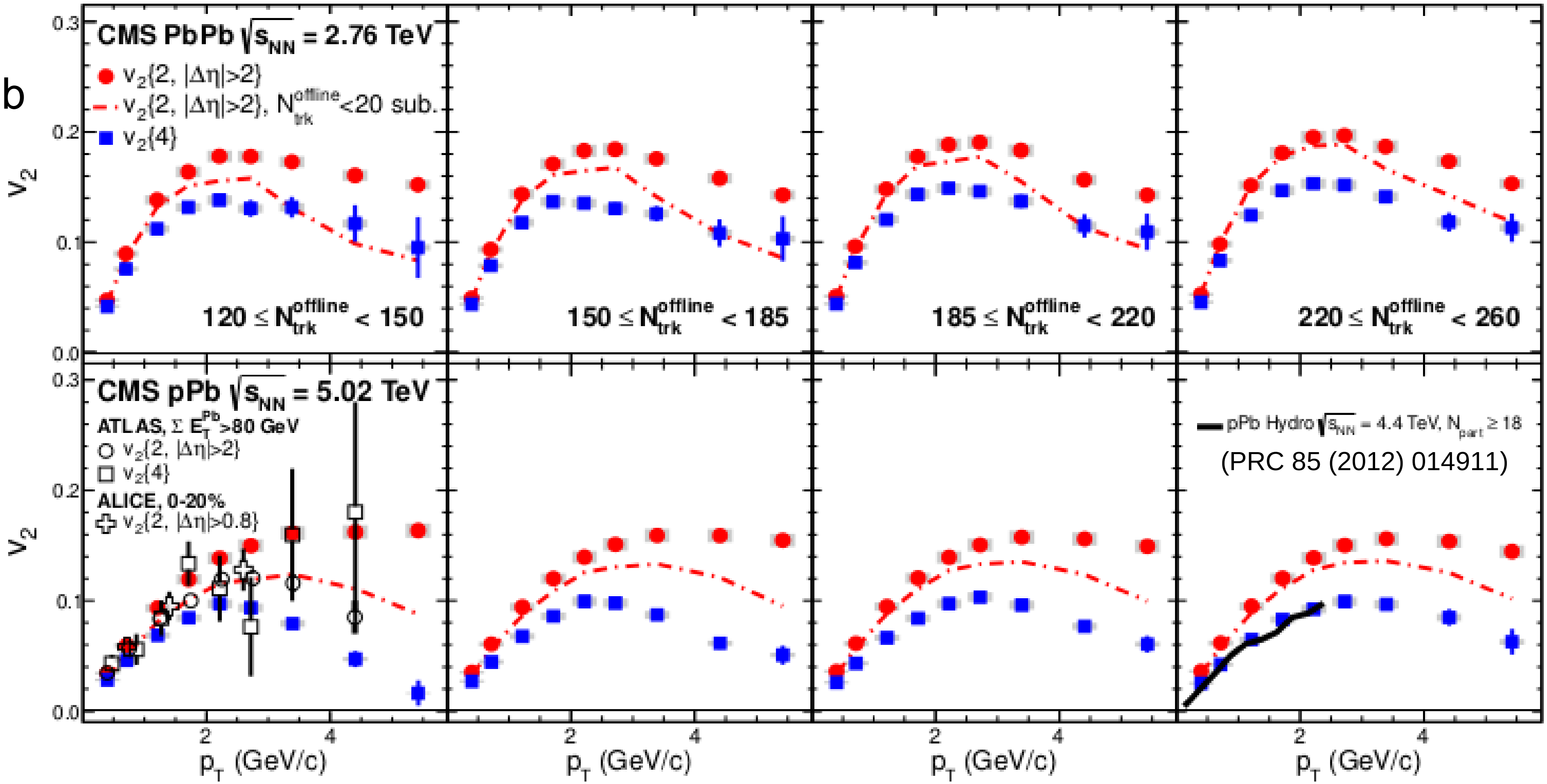
v_2 in pPb and PbPb

CMS, PLB 724 (2013) 213

Multiplicity →

PbPb

pPb

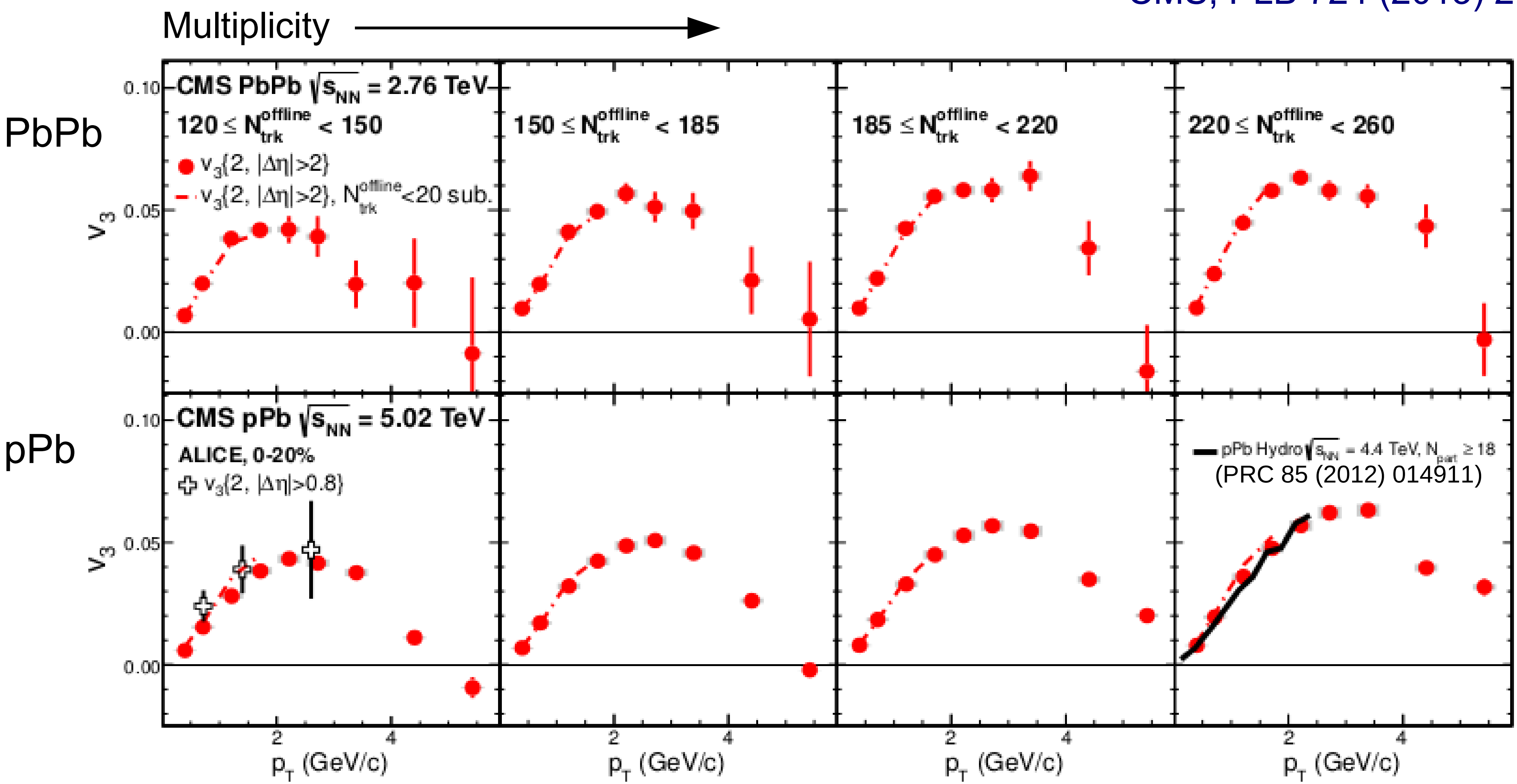


Similar shape of v_2 in pPb and PbPb but with smaller magnitude.

As in PbPb, v2{4} in pPb non-zero, and not equal to v2{2}.

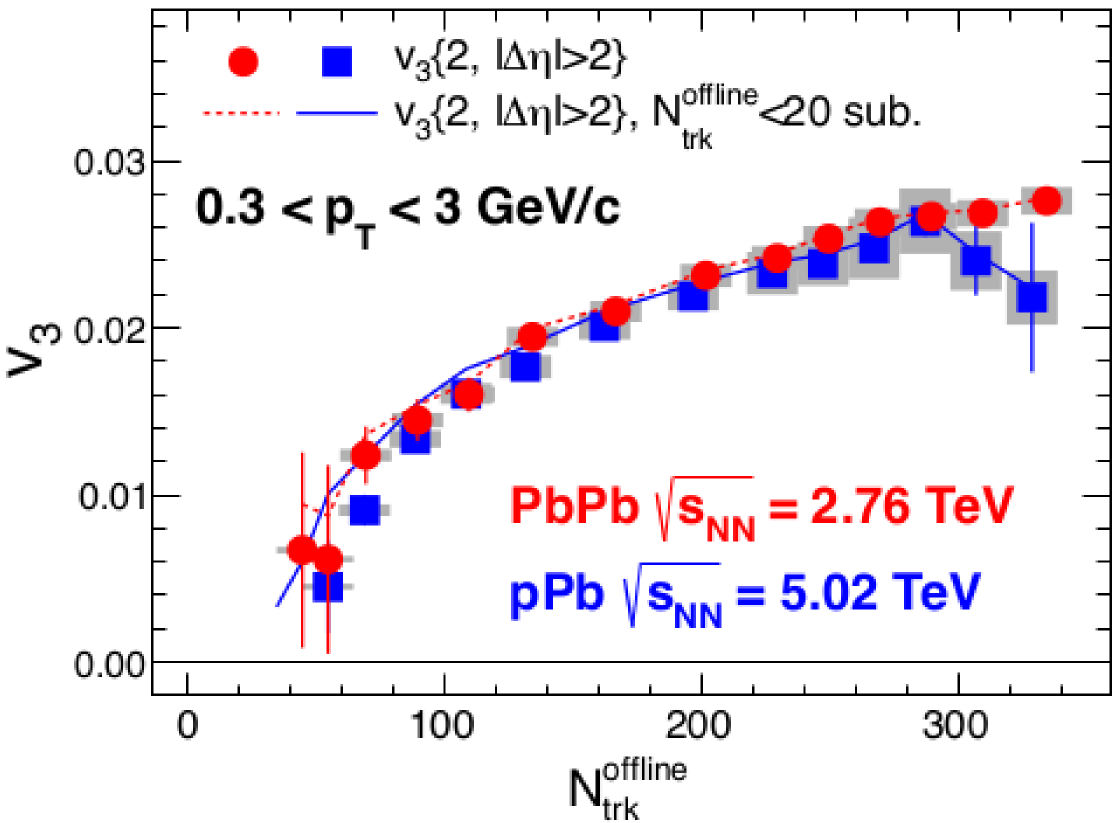
v_3 in pPb and PbPb

CMS, PLB 724 (2013) 213

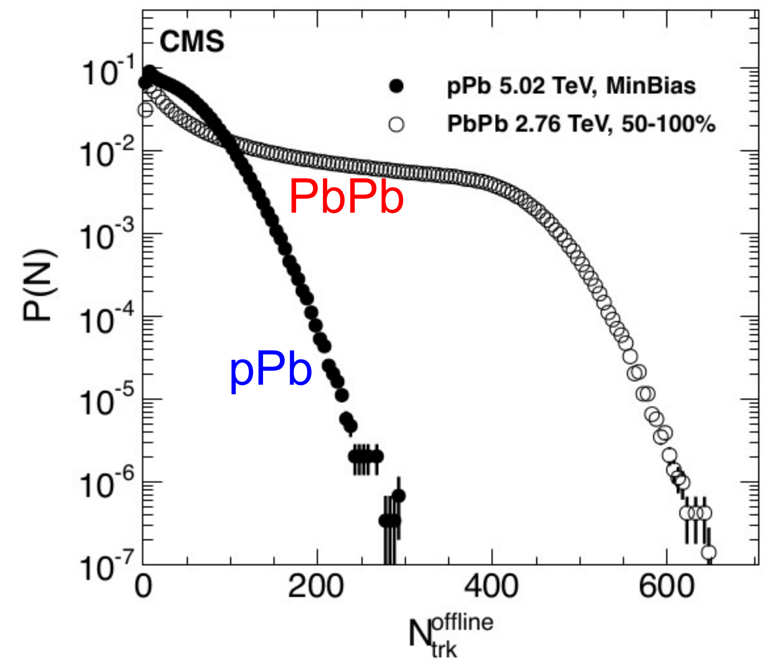


Similar shape and magnitude of v_3 in pPb and PbPb.
As for v_2 hydro predictions describe high-multiplicity data.

v_3 in PbPb and pPb



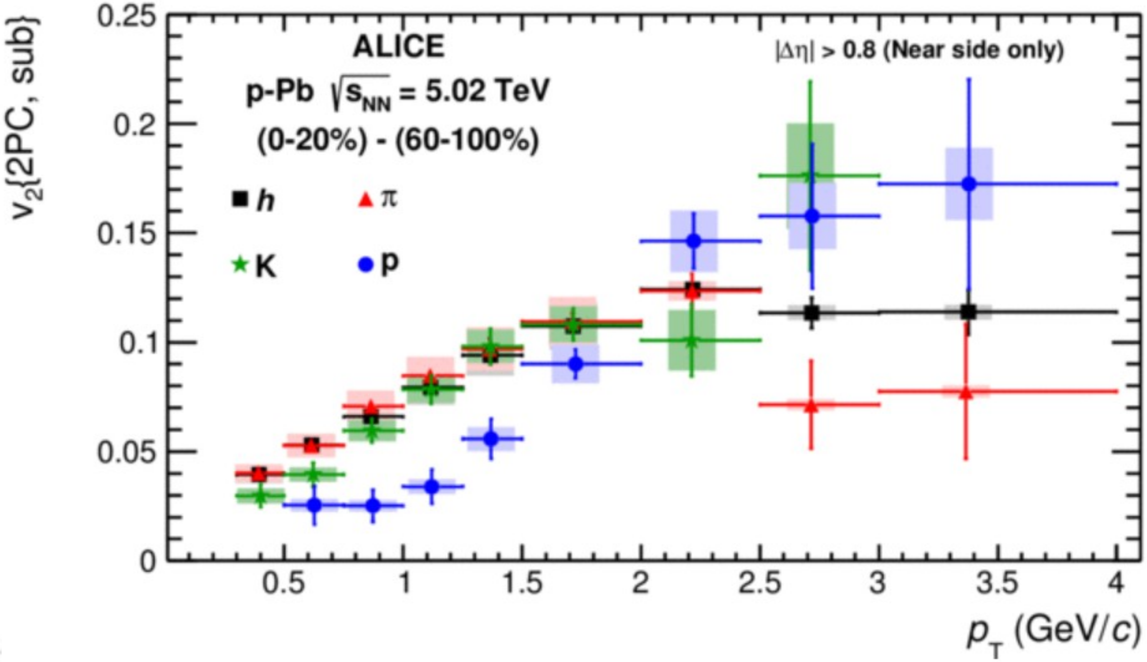
CMS, PLB 724 (2013) 213

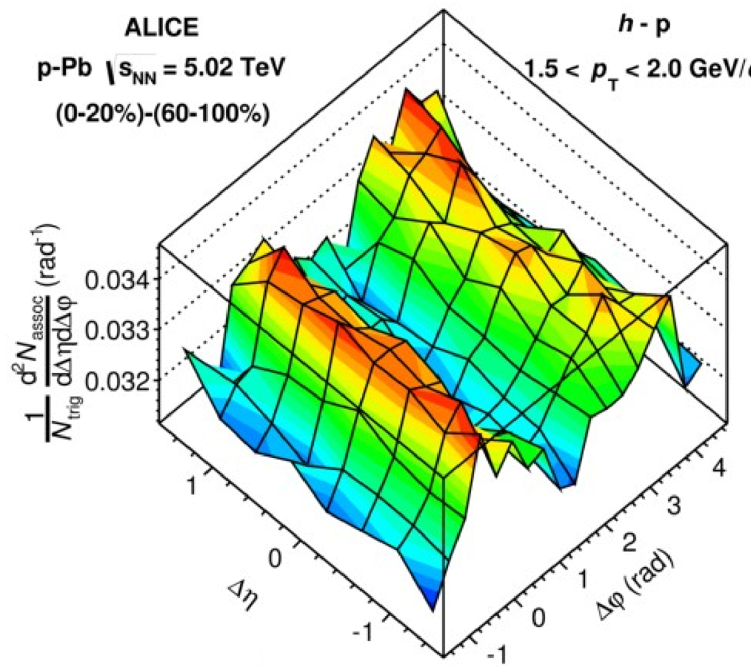


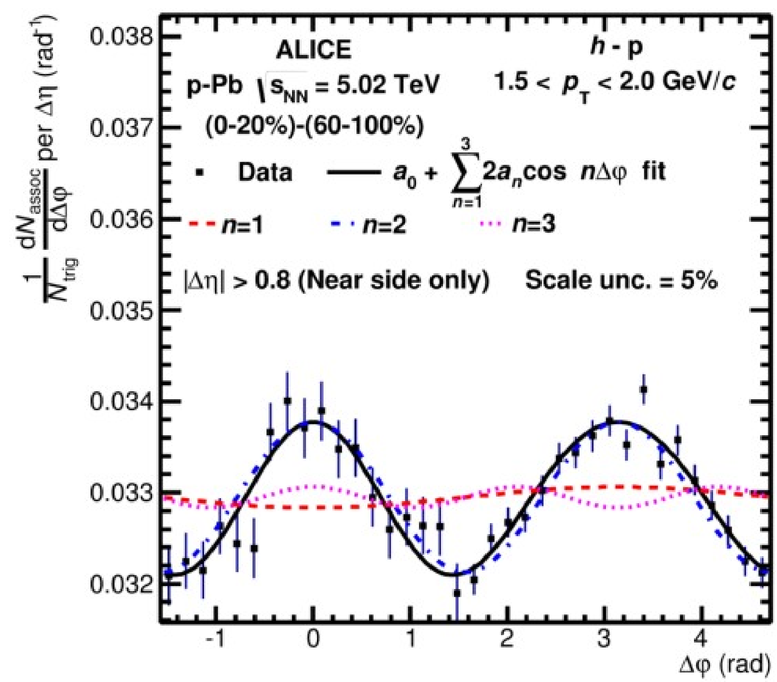
- Same v_3 in pPb as in PbPb
- Turn on at around M=50 tracks (~minbias pPb)
- Established picture in PbPb
  - Fluctuations of initial state are transformed into final state through interactions
- Same physics mechanism despite different underlying dynamics (+ system size)?
- Maybe we select on events in which the proton wave function fluctuated to large values (fat proton, Mueller, arXiv:1307.5911v2)

Identified particle v_2

ALICE, arXiv:1307.3237



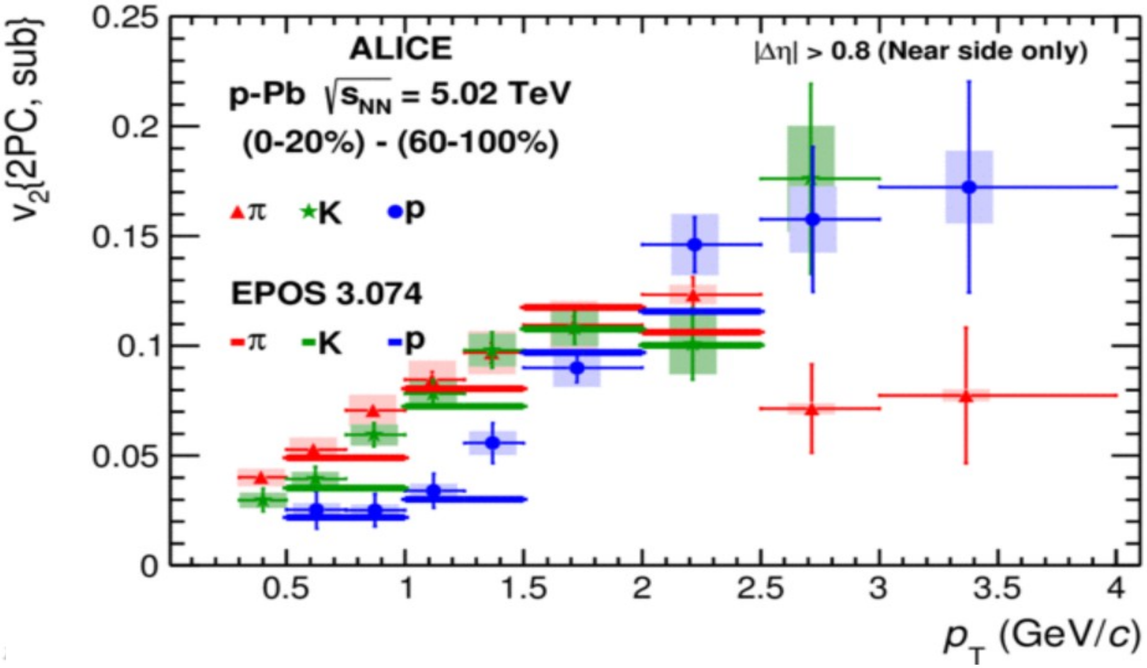


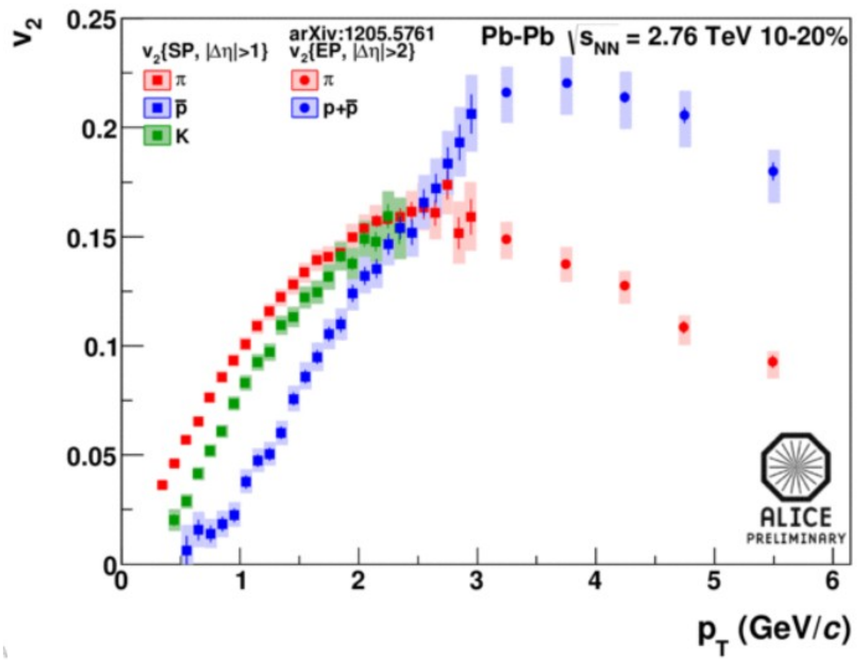


- Per-trigger yield with π, K, or p as associated particles rel. to trigger particles (h)
- Subtract low- (60-100%) from high-multiplicity (0-20%) and Fourier decompose
- Unidentified particle v_2 extended (and consistent with previous low-statistics measurement)

Identified particle v_2

ALICE, arXiv:1307.3237





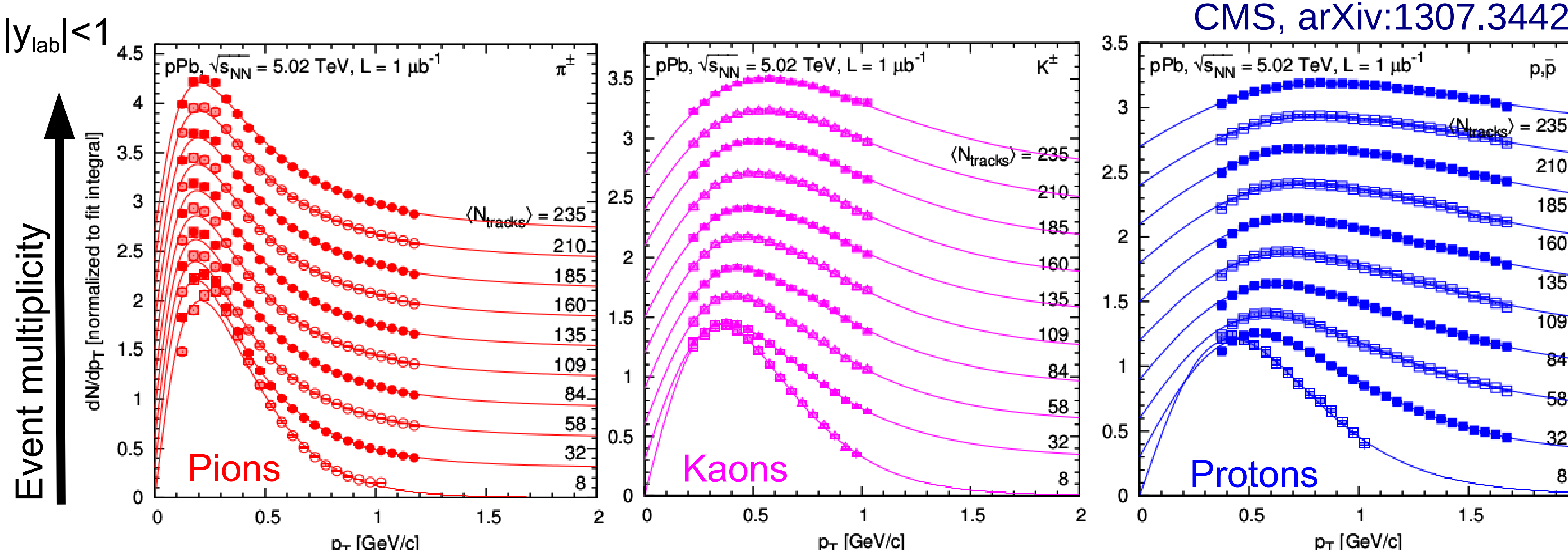
- Per-trigger yield with π, K, or p as associated particles rel. to trigger particles (h)
- Subtract low- (60-100%) from high-multiplicity (0-20%) and Fourier decompose
- Unidentified particle v_2 extended (and consistent with previous low-statistics measurement)
- Characteristic mass splitting observed as known from PbPb
- Crossing of proton and pion in the same p_T region (2-3 GeV/c)
- Models including a hydrodynamic expansion describe the data

Werner et al., arXiv:1307.4379

Bozek et al., arXiv:1307.5060

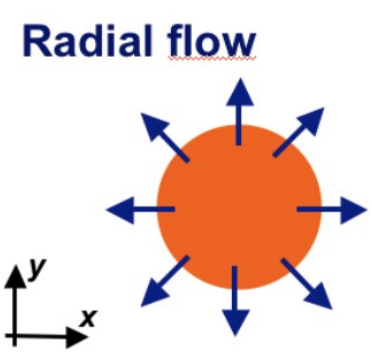
Identified particle p_T spectra

CMS, arXiv:1307.3442



$\pi^{\pm}$	0.1 – 1.2 GeV/*c*
$K^{\pm}$	0.2 – 1.05 GeV/*c*
$p(\bar{p})$	0.4 – 1.7 GeV/*c*

- Spectra measured in bins of multiplicity
  - For kaons and more for protons shape changes with increasing multiplicity



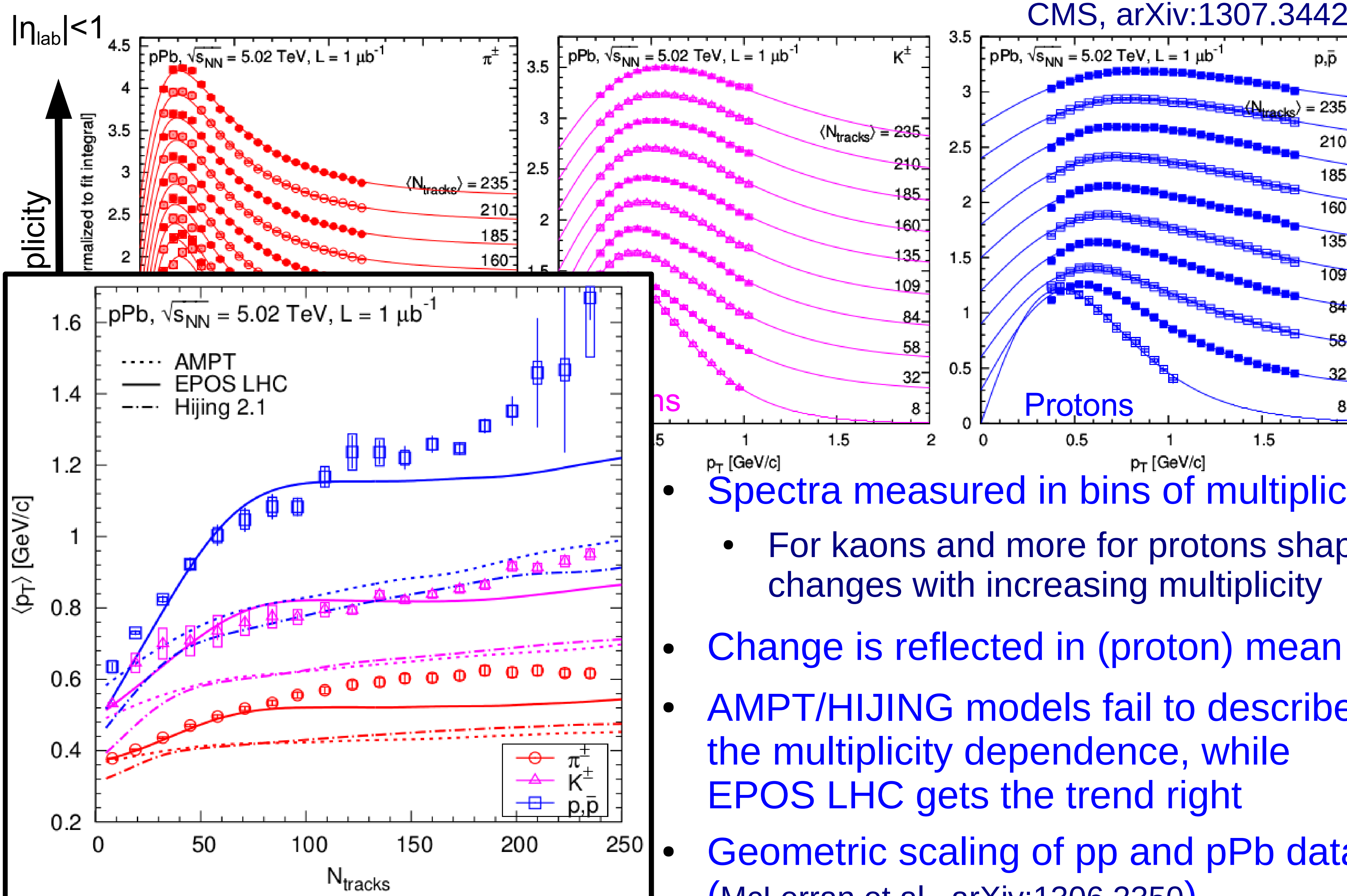
$$p_T^{flow} = p_T + m\beta_T^{flow}\gamma_T^{flow}$$

Radial flow expected to reflect in spectra, in particular in p/π ratio

Shuryak and Zahed, arXiv:1301.4470

Identified particle p_T spectra

CMS, arXiv:1307.3442

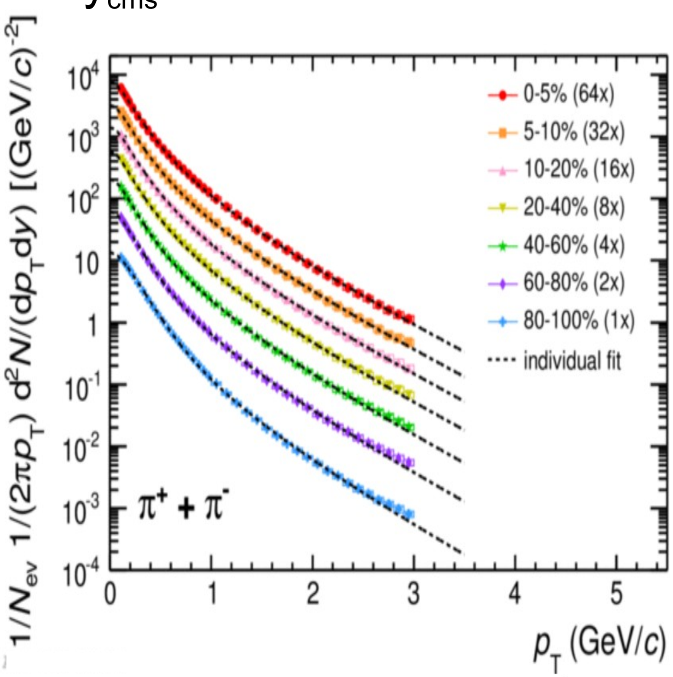


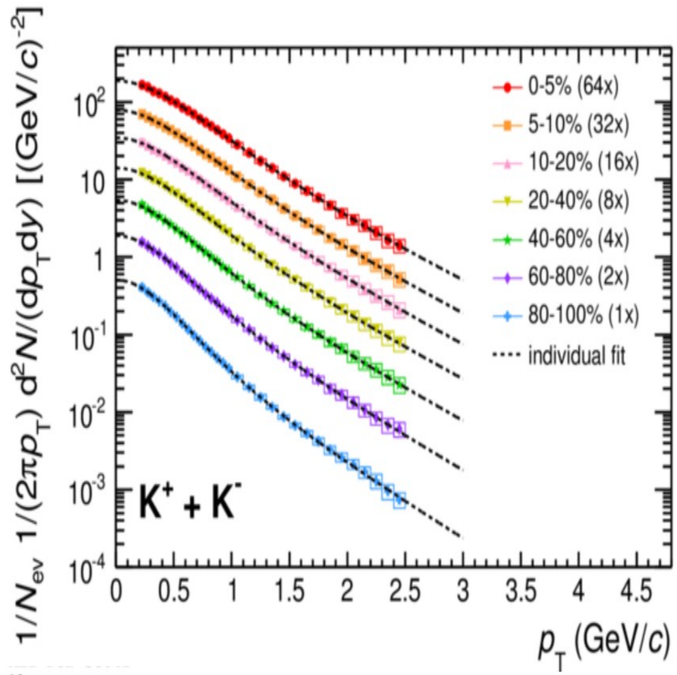
- Spectra measured in bins of multiplicity
  - For kaons and more for protons shape changes with increasing multiplicity
- Change is reflected in (proton) mean p_T
- AMPT/HIJING models fail to describe the multiplicity dependence, while EPOS LHC gets the trend right
- Geometric scaling of pp and pPb data? (McLerran et al., arXiv:1306.2350)

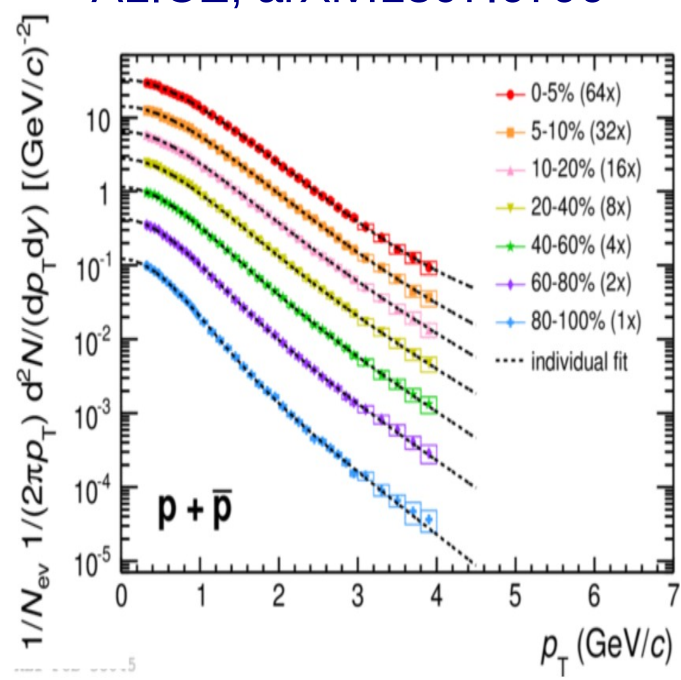
Identified particle p_T spectra

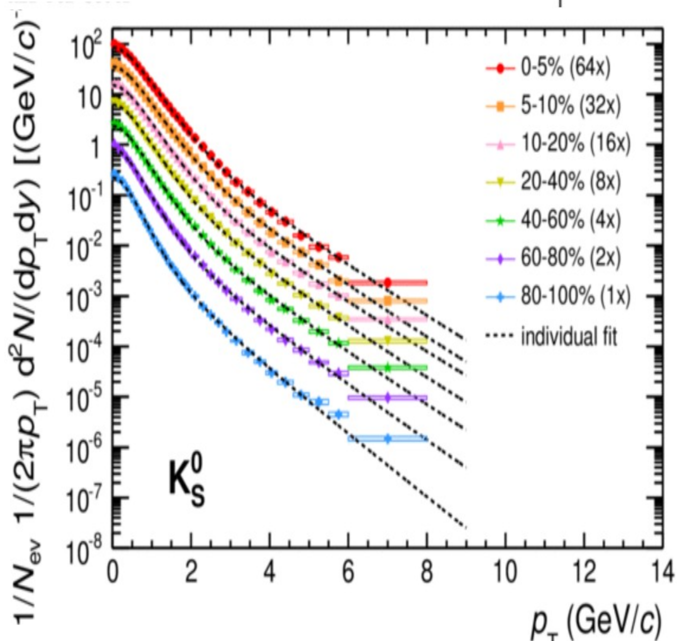
$0<y_{cms}<0.5$

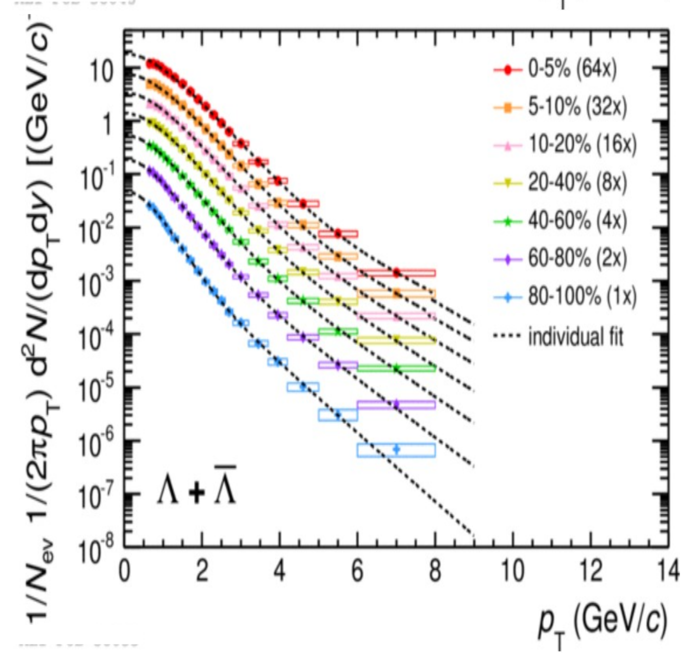
ALICE, arXiv:1307.6796











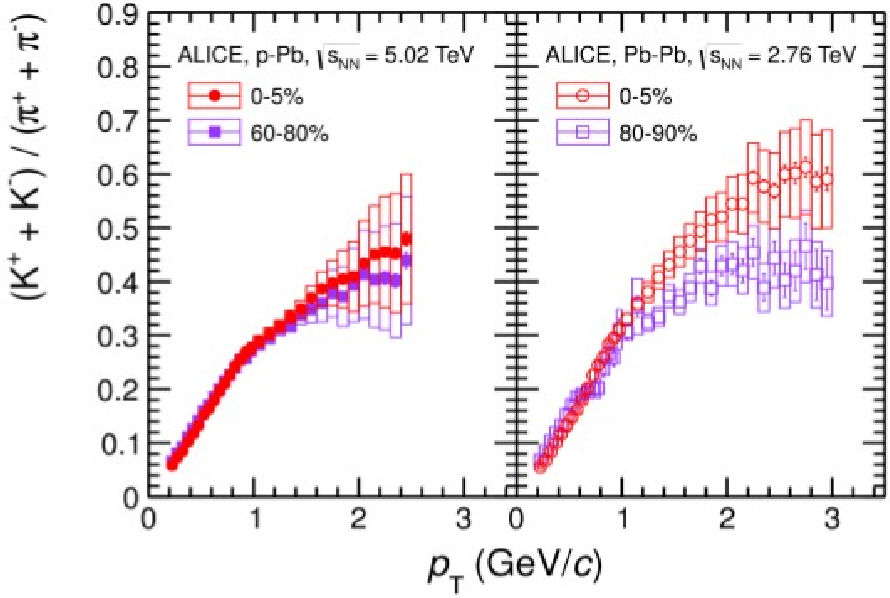
p_T spectra in several V0A multiplicity classes

$\pi^{\pm}$	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*

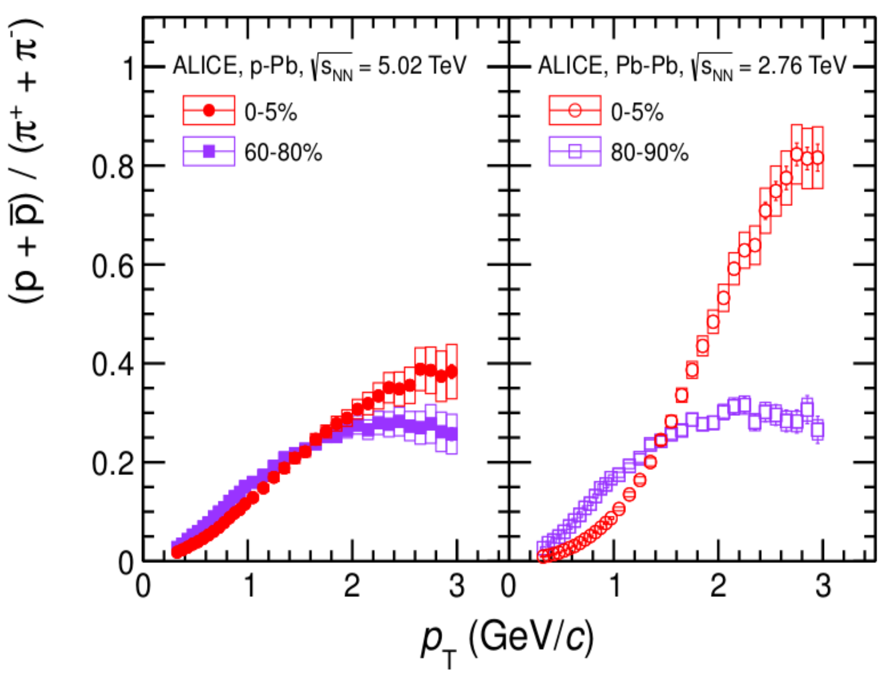
Particle ratios versus p_T

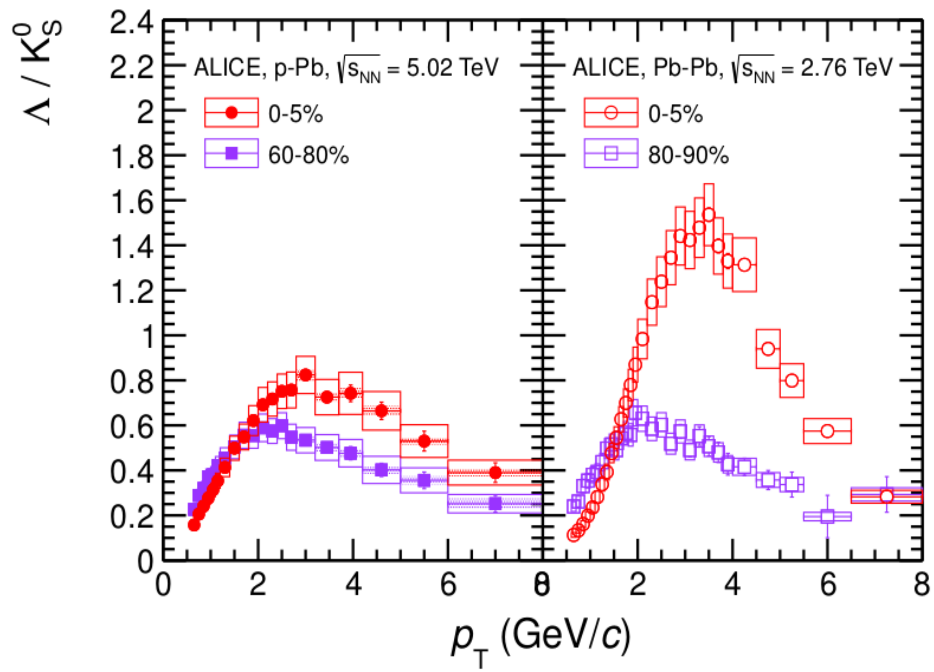
$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796



- Particle ratios in pPb show similar trends than those in PbPb
- The strength of the effects is similar to those in peripheral PbPb collisions
- Increase of p/π and Λ/K in PbPb usually explained by radial flow and/or parton recombination



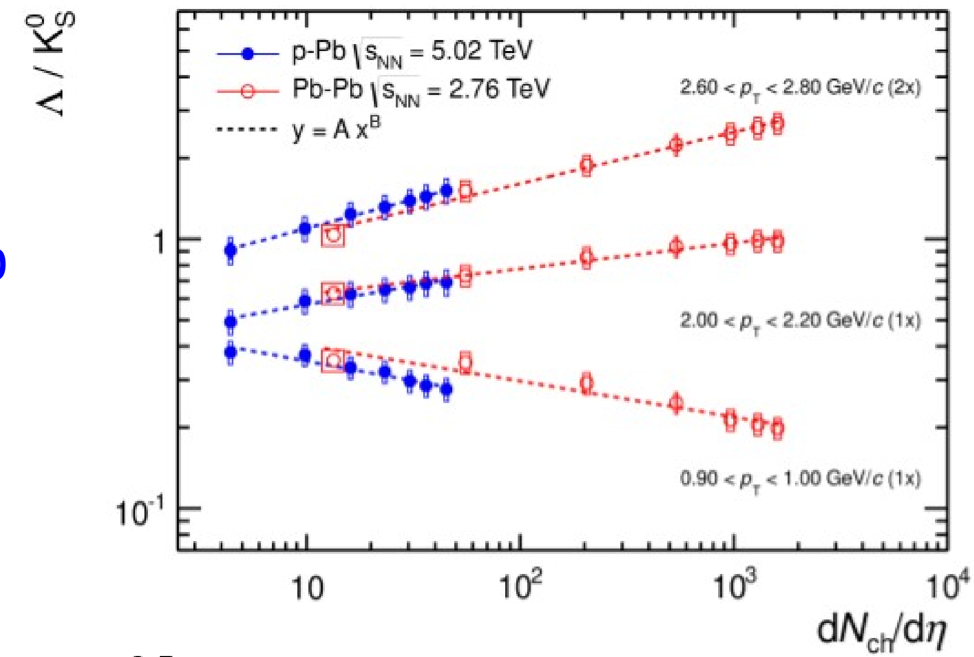


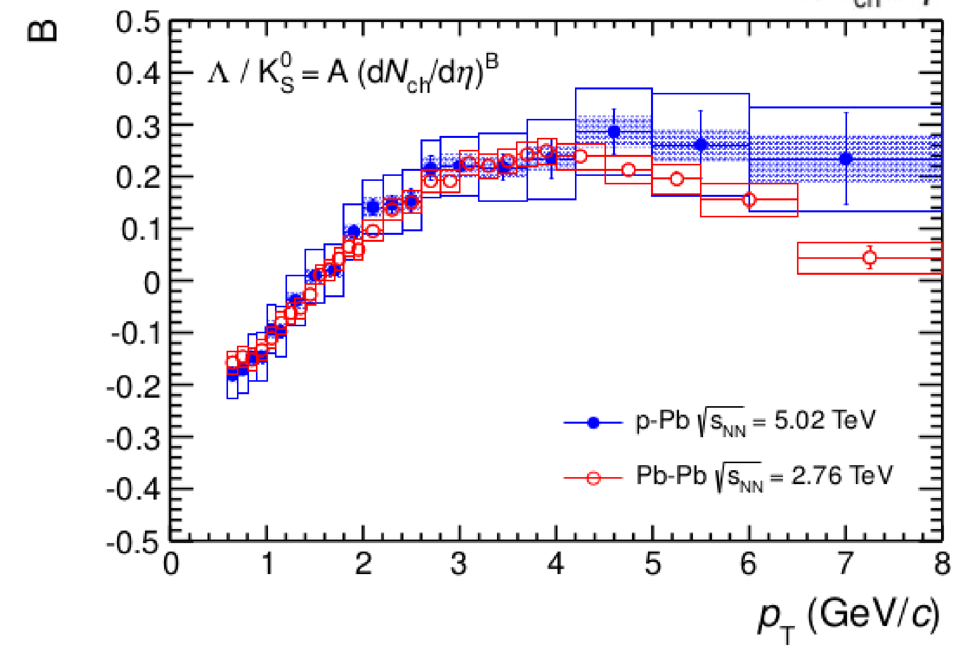
Multiplicity scaling of ratios

$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796

- Fit ratio vs dN/dη in p_T bins with power-law ($A\,x^B$ with x=dN/dη)
- Same increase of ratio for similar increase of dN/dη in pPb and PbPb
- Same power-law scaling exponent (B) in pPb and PbPb
  - Underlying mechanism?
- Similar scaling found for p/π

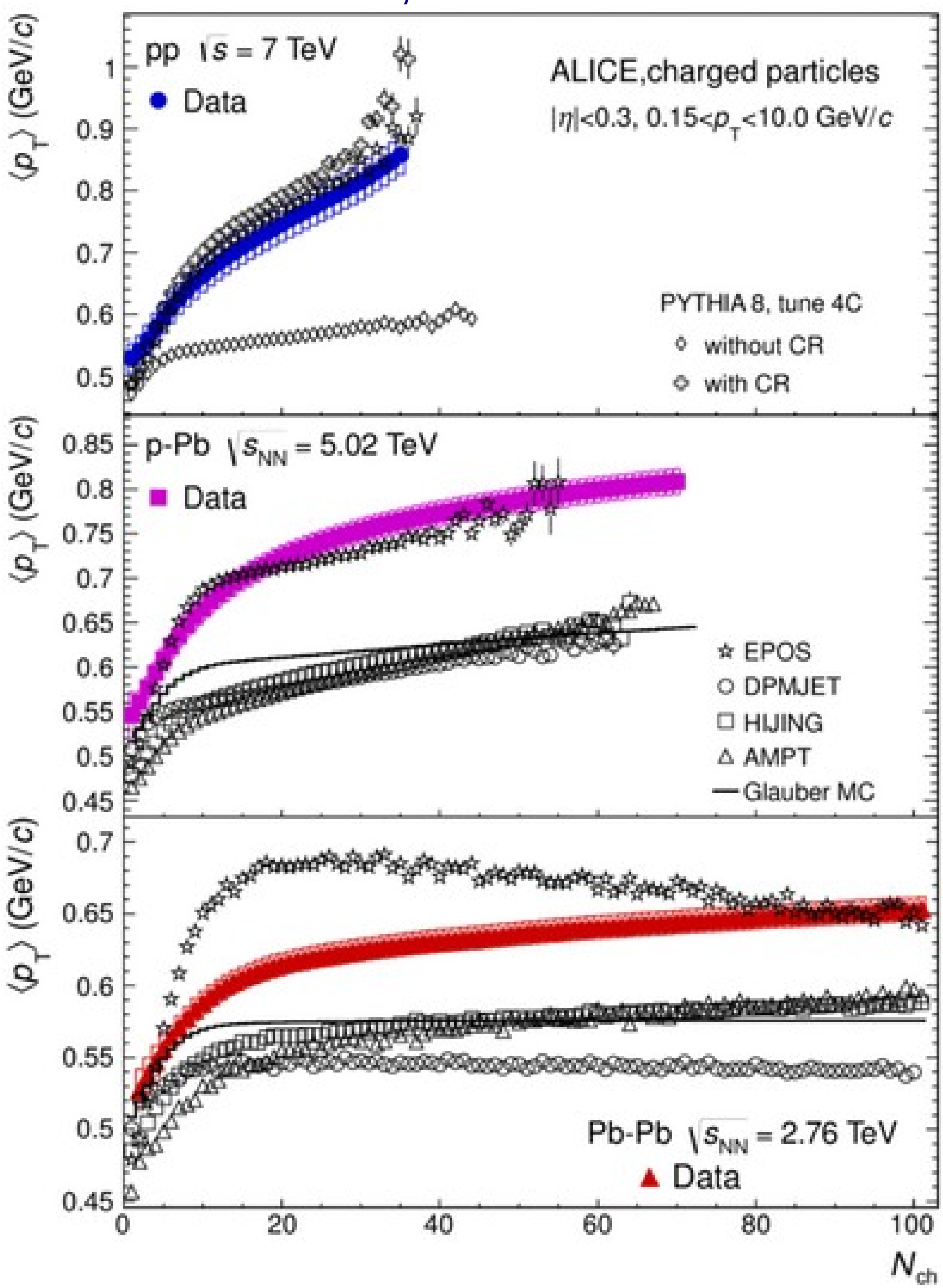




Similar scaling also holds for pp
(see backup)

Average p_T versus N_{ch}

ALICE, arXiv:1307.1094



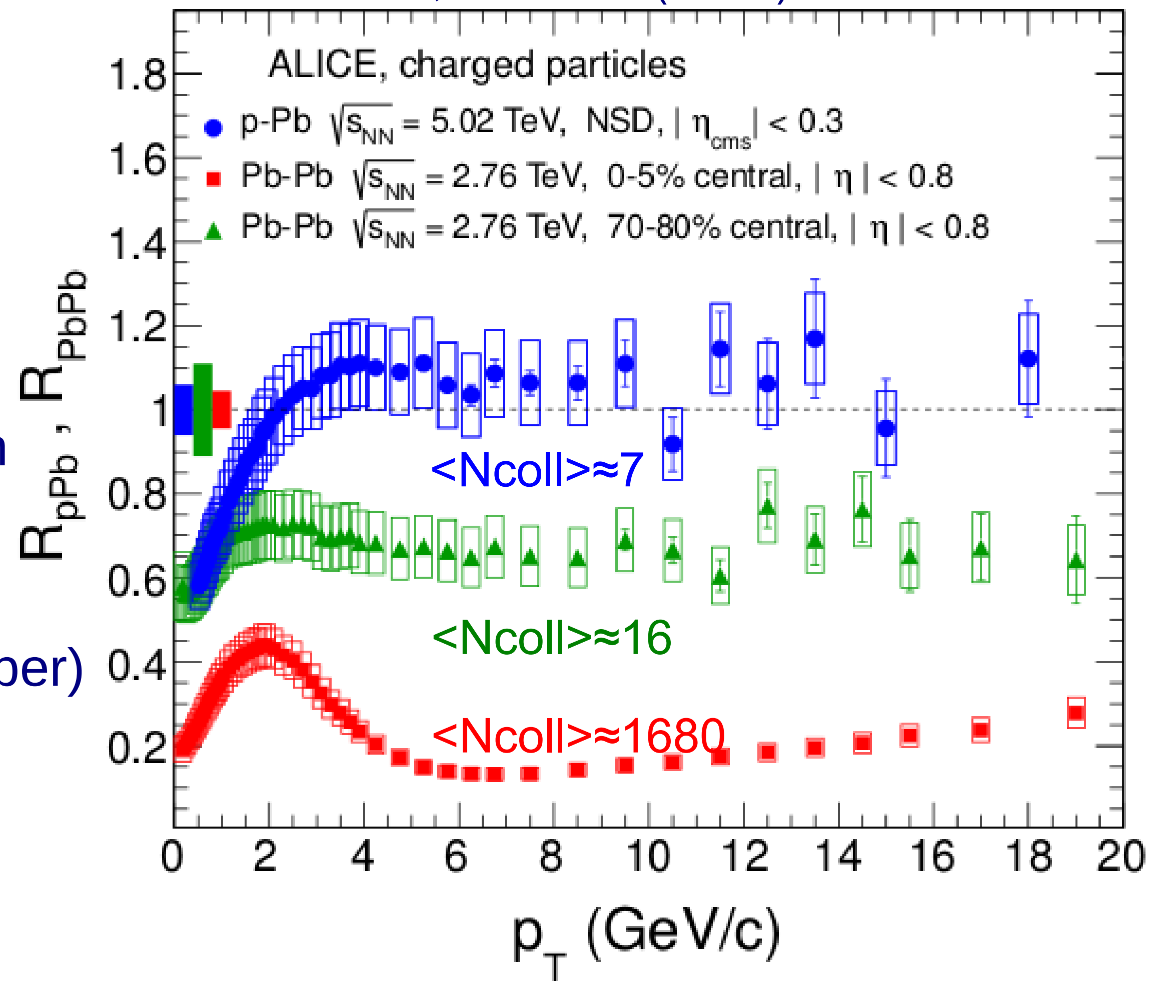
- pp
  - Within PYTHIA model increase in mean p_T can be modeled with Color Reconnections between strings
  - Can be interpreted as collective effect (e.g. Velasquez et al., arXiv:1303.6326v1)
- pPb
  - Increase follows pp up to N_{ch}~14 (90% of pp cross section, pp already biased)
  - Glauber MC (as other models based on incoherent superposition) fails
  - Like in pp: Do we need a (microscopic) concept of interacting strings?
  - EPOS LHC which includes a hydro evolution describes the data (also pp)
- PbPb
  - As expected, incoherent superposition can not describe data

Centrality dependent nuclear modification

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

- $\langle N_{coll}\rangle = A\ \sigma_{pp}/\sigma_{pA} \approx 7$ with
  - σ_{pp} = 70 mb from interpolation of existing data
  - σ_{pA} = 2090 ± 120 mb from LHCb-CONF-2012-034 (or Glauber)
- Note: $\langle N_{coll}\rangle \approx 15$ is reached in "0-5% central" pPb collisions

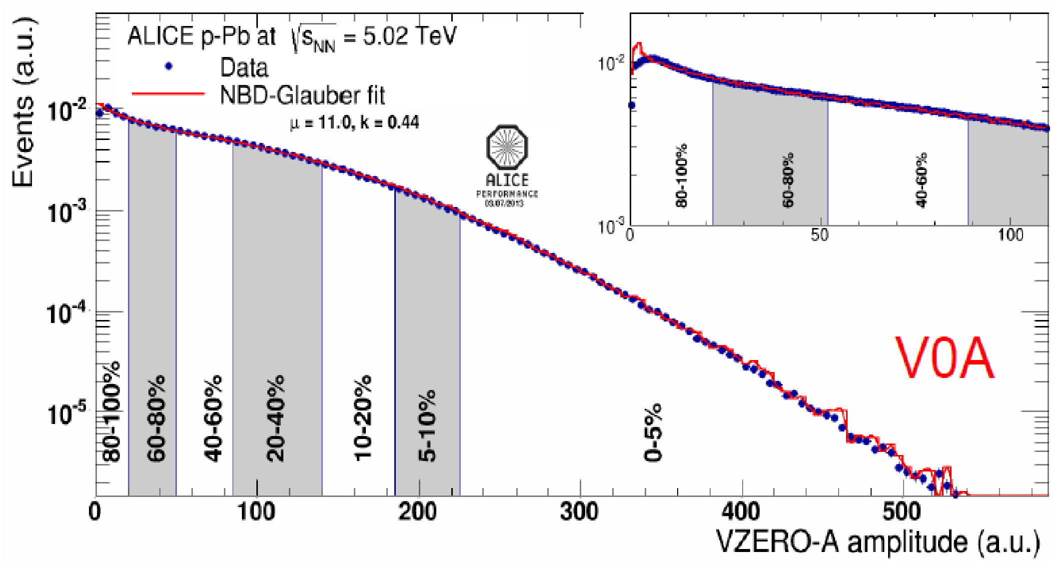
ALICE, PRL 110 (2013) 082302



How to make measurement centrality dependent?

$$R_{\mathrm{pA}}^{\mathrm{cent}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{pA}}^{\mathrm{cent}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} = \frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}}^{\mathrm{cent}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

N_{coll} from Glauber in multiplicity classes



ALICE, preliminary

Centrality	<N_{coll}> CL1	<N_{coll}> V0M	<N_{coll}> V0A	Max Diff.	*Impact Parameter* Slicing
0 - 5%	15.4	15.8	14.8	6.8%	14.4
5 - 10%	13.5	13.7	13.1	4.5%	13.8
10 - 20%	12.0	12.1	11.7	3.4%	12.7
20 - 40%	9.3	9.4	9.4	1.1%	10.2
40 - 60%	6.0	6.1	6.5	6.6%	6.3
60 - 80%	3.46	3.33	3.85	16%	3.1
80 -100%	1.86	1.67	1.94	16%	1.44

- Glauber fit to multiplicity distribution (V0A) with Negative Binomial ansatz coupled to Glauber MC
  - Obtain $P(N_{part})$ in centrality slices
  - Same approach as in ALICE, arXiv:1301.4361
- Obtain <N_{coll}> (= <N_{part}> -1) from Glauber
  - Similar for different estimators (CL1, V0M, V0A)
  - Similar to MC closure (done with HIJING) and systematic uncertainty from variation of Glauber parameters

Glauber MC Parameters

$$\rho(r) = \rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

R = 6.62 ± 0.06 fm

a = 0.546 ± 0.01fm

Minimum NN distance: 0.4±0.4 fm

pN Cross-section

σ_{pN} = 70 ± 5 mb

Proton radius

R_p = 0.6 ± 0.2 fm

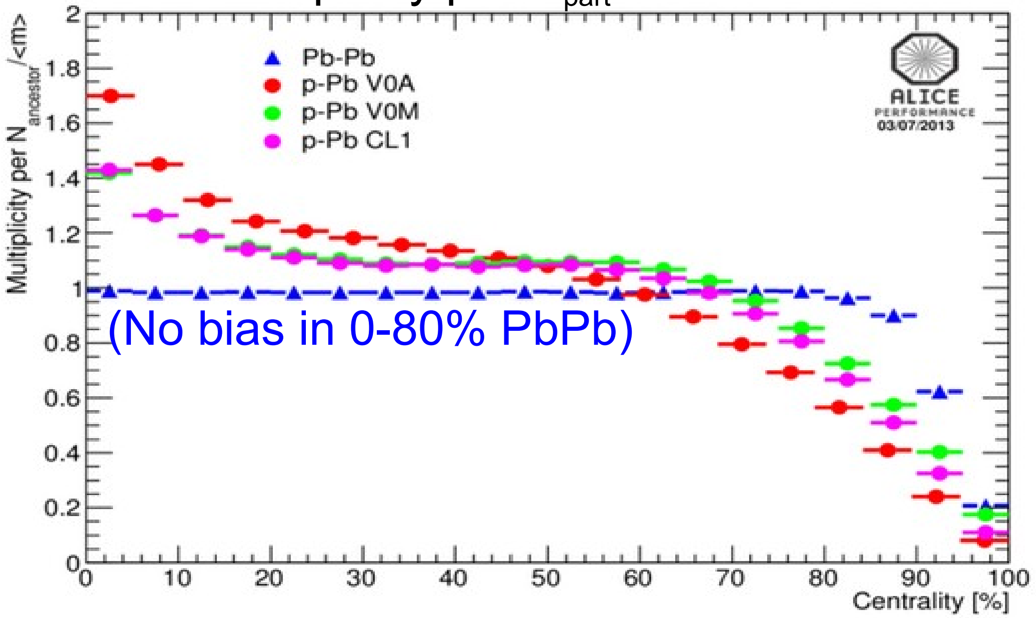
ALICE, preliminary

- But, $\langle N_{coll} \rangle$ from Glauber is not the right scaling variable
- Multiplicity per N_{part} strongly biased in pPb
  - Models including MPI (e.g. like HIJING) intrinsically include a fluctuating number sources for particle production
- For a given centrality hard processes qualitatively scale with

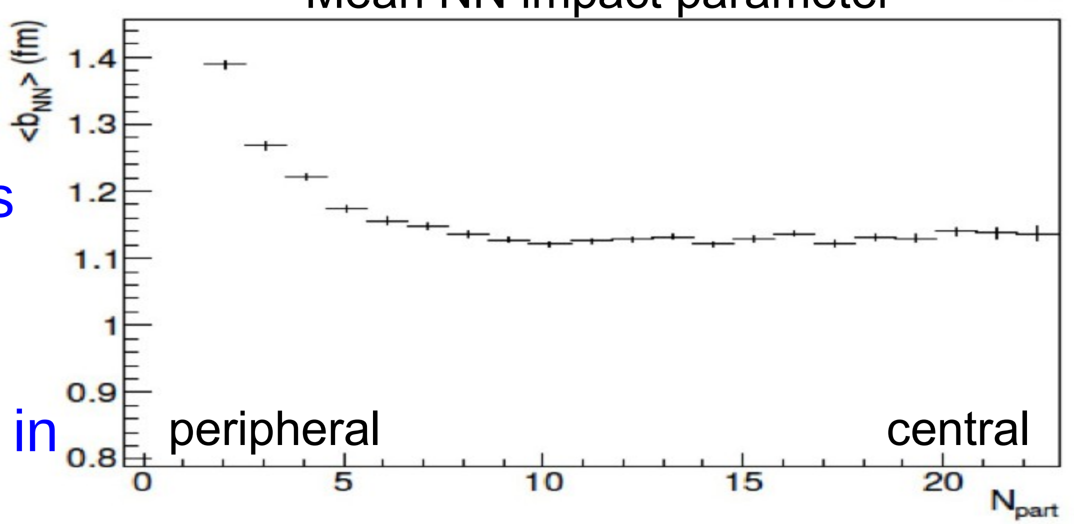
$$\langle N_{coll,cent}^{Glauber} \rangle \langle n_{hard} \rangle_{cent} / \langle n_{hard} \rangle_{pp}$$

- Mean NN impact parameter increases in peripheral collisions
  - Expect softer than average collisions?
- Also, veto for high-p_T processes in low multiplicity classes

Multiplicity per N_{part} / Mean NBD

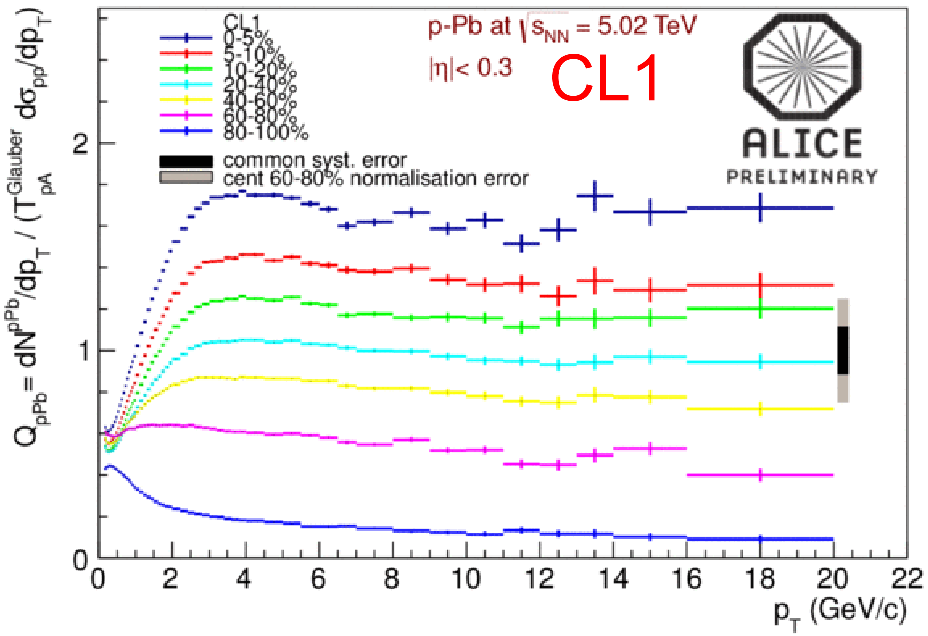


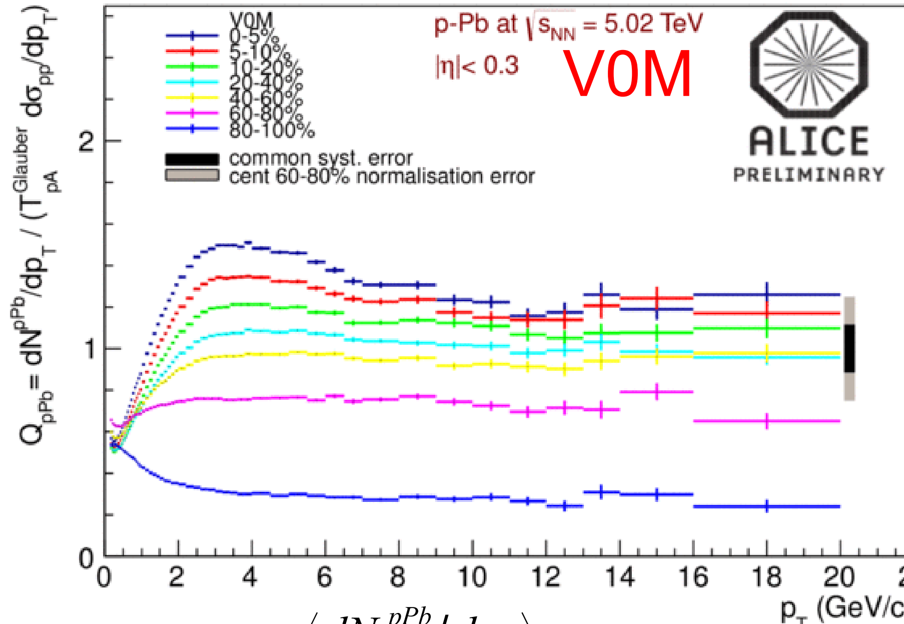
Mean NN impact parameter

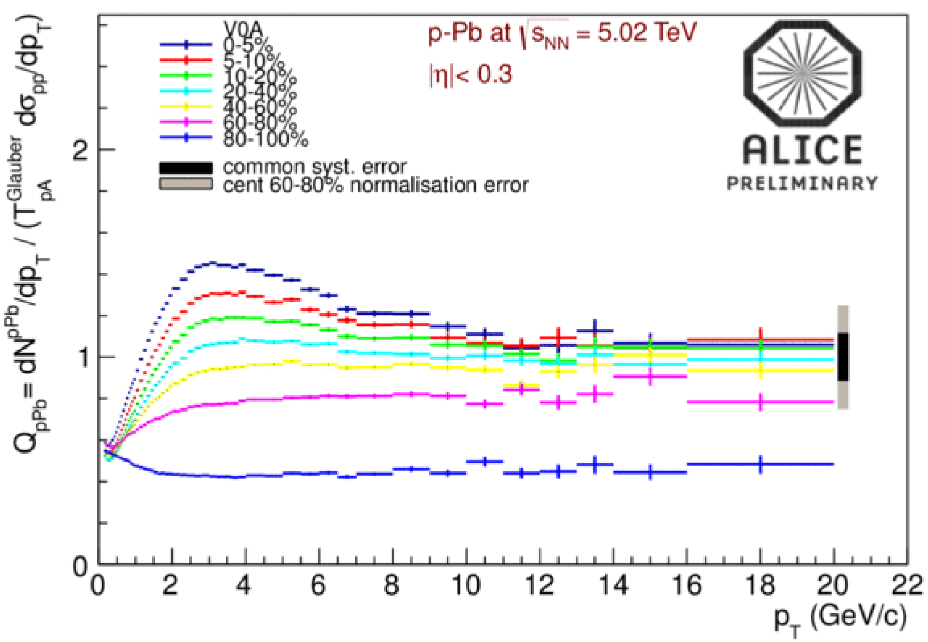


Q_{pPb} (not R_{pPb})

ALICE, preliminary



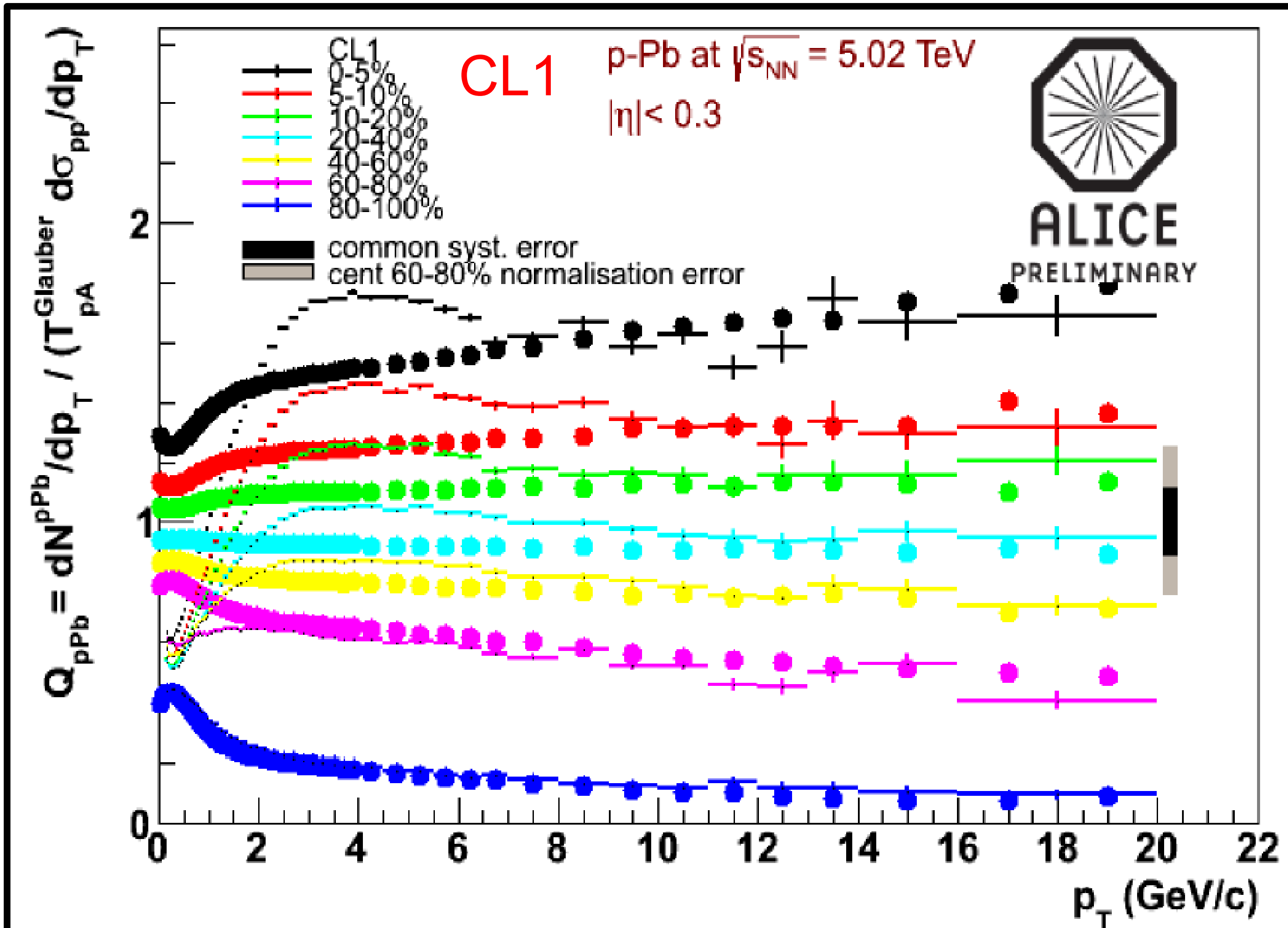


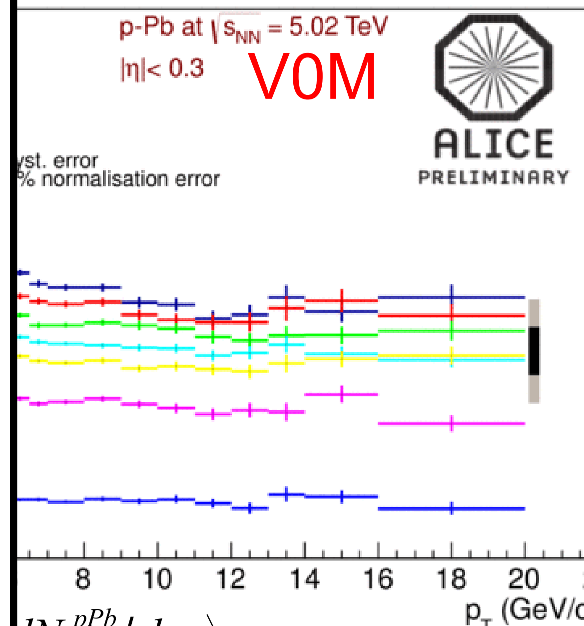


- $Q_{pPb,cent} = \langle N_{cent}^{Glauber} \rangle \dfrac{\langle dN^{pPb}/dp_T \rangle_{cent}}{dN^{pp}/dp_T}$
- Not a R_{pPb} measurement as not equals to 1 in absence of nuclear effects!!!
- Spread reduces: CL1 → V0M → V0A
- Jet veto present in CL1, but not in V0A

Q_{pPb} (not R_{pPb})

ALICE, preliminary



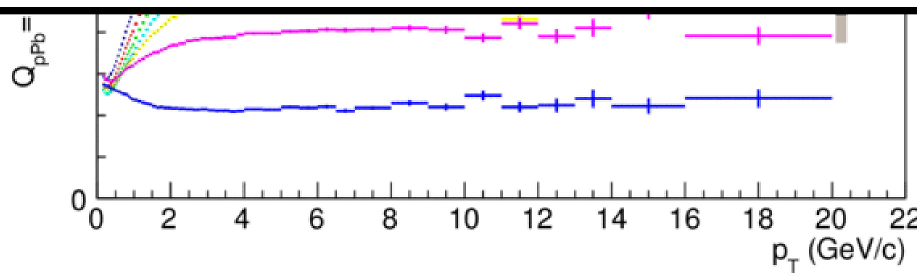


$\frac{dN^{pPb}/dp_T\rangle_{cent}}{dN^{pp}/dp_T}$

surement as not equals
of nuclear effects!!!

s: CL1 → V0M → V0A

t in CL1, but not in V0A



- Bias (at high p_T) described by incoherent superposition of pp
- ZNA (spectator) based classes may provide least biased selection

Summary

1. ALICE, PRL 110 (2013) 032301, I
2. ALICE, PRL 110 (2013) 082302, T
3. CMS, PLB 718 (2012) 795, Near-
4. ALICE, PLB 719 (2013) 29, Doub
5. ATLAS, PRL 110 (2013) 182302,
6. ATLAS, arXiv:1303.2084, Two an
7. CMS, PLB 724 (2013) 213, Two a
8. LHCb-CONF-2012-034, Inelastic
9. CMS-PAS-HIN-13-001, Dijet prod
10. ALICE preliminary, Inclusive J/ψ p
11. LHCb-CONF-2013-008, Prompt a
12. ALICE, arXiv:1307.1094, Average
13. ALICE, arXiv:1307.3237, Double r
14. CMS, arXiv:1307.3442, Identified
15. ALICE, arXiv:1307.6796, Identifie
16. ALICE, preliminary, Inclusive char
17. ALICE, preliminary, Inclusive Ups
18. ALICE, preliminary, D-meson proc
19. ALICE, preliminary, HFE producti
20. ALICE, preliminary, Centrality in p
21. ALICE, preliminary, UPC in pPb (

- Minbias measurements on various probes in pPb (h, jets, J/Ψ, Y, Ds and Bs) show that suppression in PbPb at LHC is essentially only from final state
  - Initial state models, in particular those based on shadowing, typically successful
- Due to fluctuations, centrality determined in |η|<5 includes a bias on the hardness of the collision that needs to be accounted for in models
- Two-particle correlation and PID results prompt debate of initial and final state effects in pPb and PbPb (+in high mult. pp)
  - Observables exhibit features thought to be characteristic for AA
  - Very exciting moment in our field

Thanks to the LHC for superb pPb operations and to the experiments for their beautiful results

Extra

LHC pPb runs at 5.02 TeV

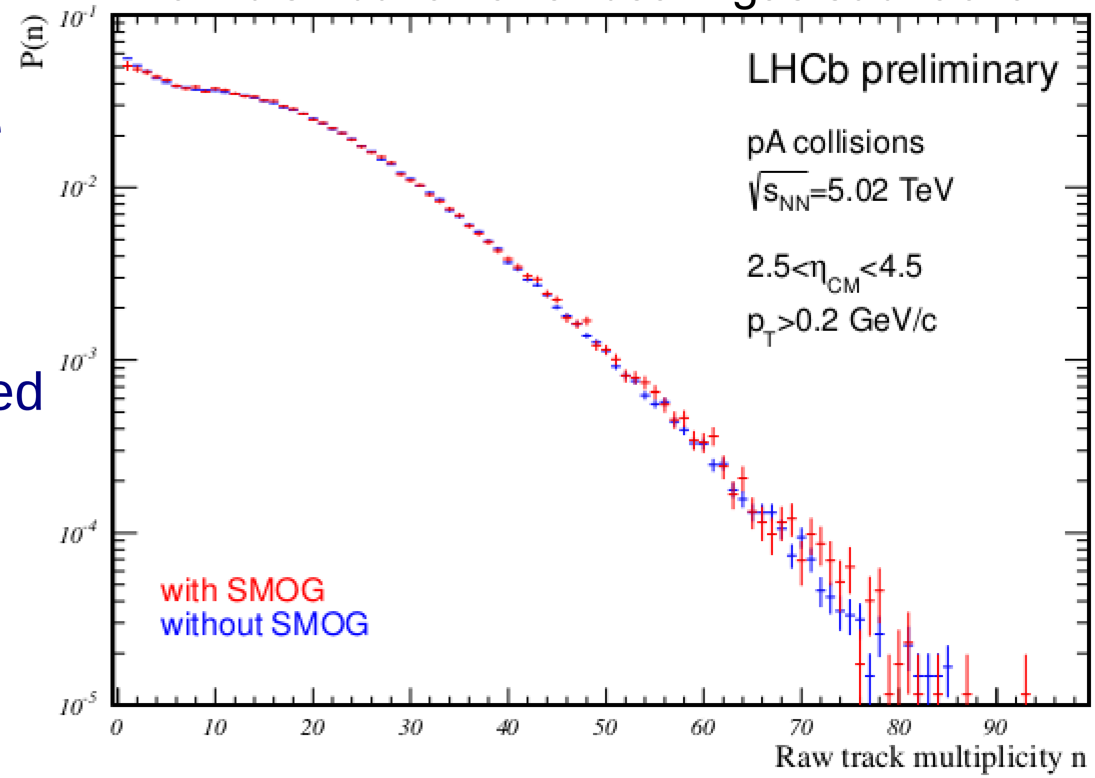
- LHC operated with
  - 4 TeV proton beam and 1.57 TeV / nucleon Pb beam
    - Center of mass energy 5.02 TeV per nucleon pair
    - Center of mass per nucleon pair rapidity shift dY = 0.465 in direction of proton
- 2012 pilot run (4 hours of data taking)
  - About 1/μb per experiment with very low pileup
- 2013 long run (3 weeks of data taking)
  - Delivered about 30/nb to ATLAS, CMS and ALICE
    - ALICE recorded also about 50/μb with $\mu<0.003$ (for the rest $\mu<0.05$)
    - About 2/nb for LHCb (new to heavy-ion operation)
  - Beam reversal (relevant for ALICE and LHCb) for about half of statistics
  - Van der Meer scans in both beam configuations
- No pp reference data available at 5.02 TeV
  - Use scaled results pp collisions at 2.76, 7 and 8 TeV and/or models

Inelastic pPb cross section

- Count collisions which produce at least one track in $2.5<\eta<4.5$ (proton side) with $p_T>0.2$ GeV/c
  - In HIJING/DPMJET only 1-2% events without a charged particle
- Analysis steps
  - Beam gas subtraction
  - Pileup below permille level ignored
  - Trigger efficiency 100% ±1%
  - Correction for finite single track finding efficiency: 98% ± 2%
  - Convert using integrated luminosity measured with SMOG
  - Systematic uncertainty dominated by 5.2% error on luminosity

LHCb, CERN-LHCb-CONF-2012-034

Raw distribution after beam-gas subtraction



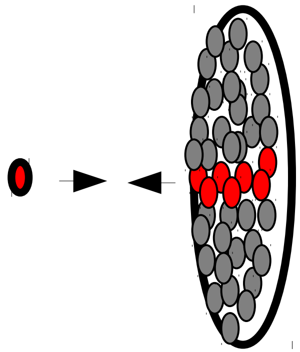
$$\sigma_{inel}(2.5 < \eta_{cm} < 4.5,\ p_T > 0.2\,\mathrm{GeV}/c) = 2.09 \pm 0.12\,\mathrm{b}$$

(consistent with HIJING, DPMJET and Glauber with σ_{NN}=70mb)

NSD pPb normalization

ALICE, PRL 110 (2013) 032301

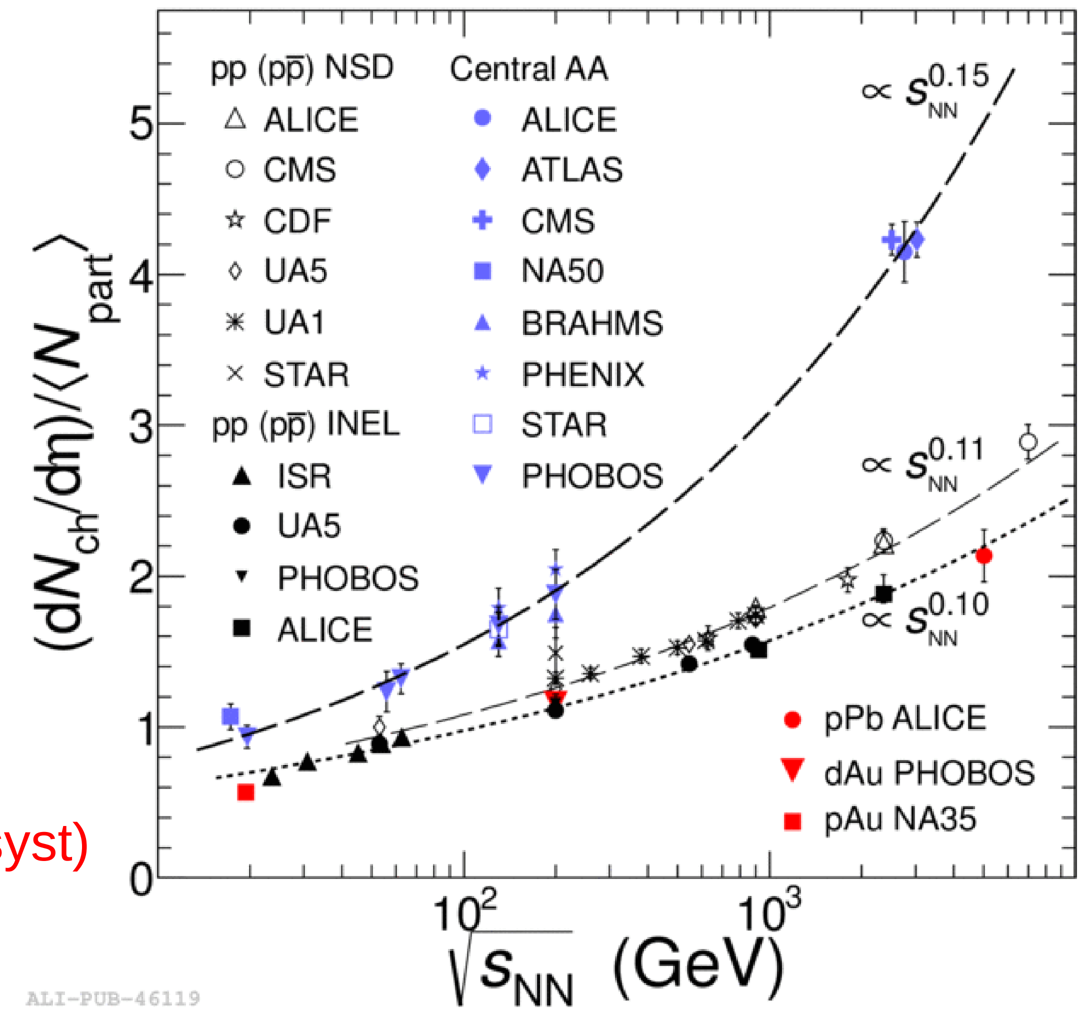
- Event selection
  - VZERO-A (2.8<η<5.1) and VZERO-C (-3.7<η<-1.7) incl. time cuts
  - Systematic variation using ZDC on nucleus side (ZNA)
- Resulting event sample
  - Non single-diffractive (NSD)
    - At least one binary N+N interaction is NSD (Glauber picture)
    - Inspired from DPMJET, which includes 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)



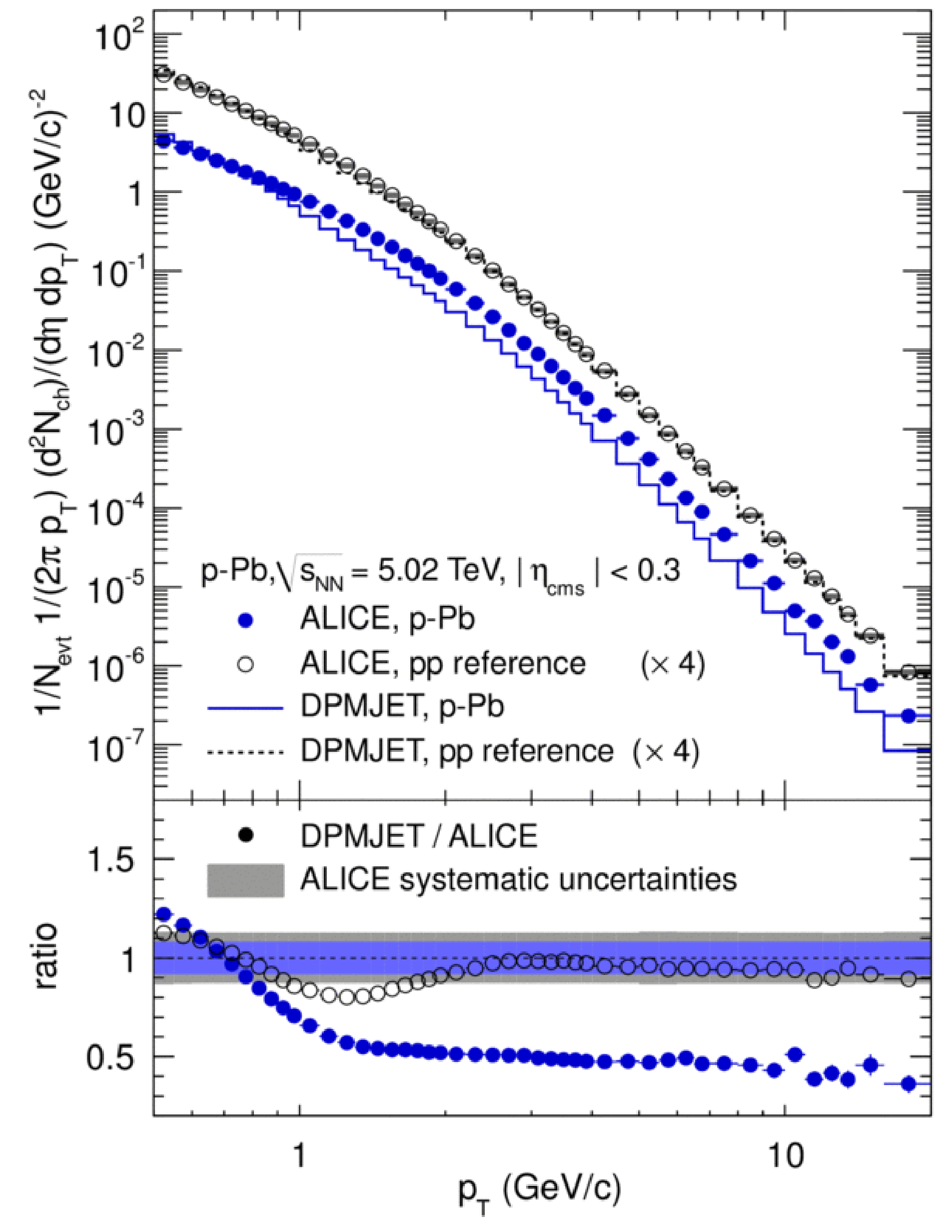
Pseudorapidity density at midrapidity

- Measurement (tracklet based)
  - $dN/d\eta = 16.81 \pm 0.71$ (syst)
  - Converted into centre-of-mass system using HIJING
  - Dominant uncertainty from NSD normalization of 3.1%
- Glauber model for pPb
  - With $\sigma_{INEL} = 70 \pm 5$ mb
  - $\langle N_{part} \rangle = 7.9 \pm 0.6$ (syst)
- Participant scaled value
  - $(dN/d\eta)/\langle N_{part} \rangle = 2.14 \pm 0.17$ (syst)
  - About 15% below NSD pp
  - Similar to pp INEL
- Inelastic pPb would be 4% lower (estimate from models)

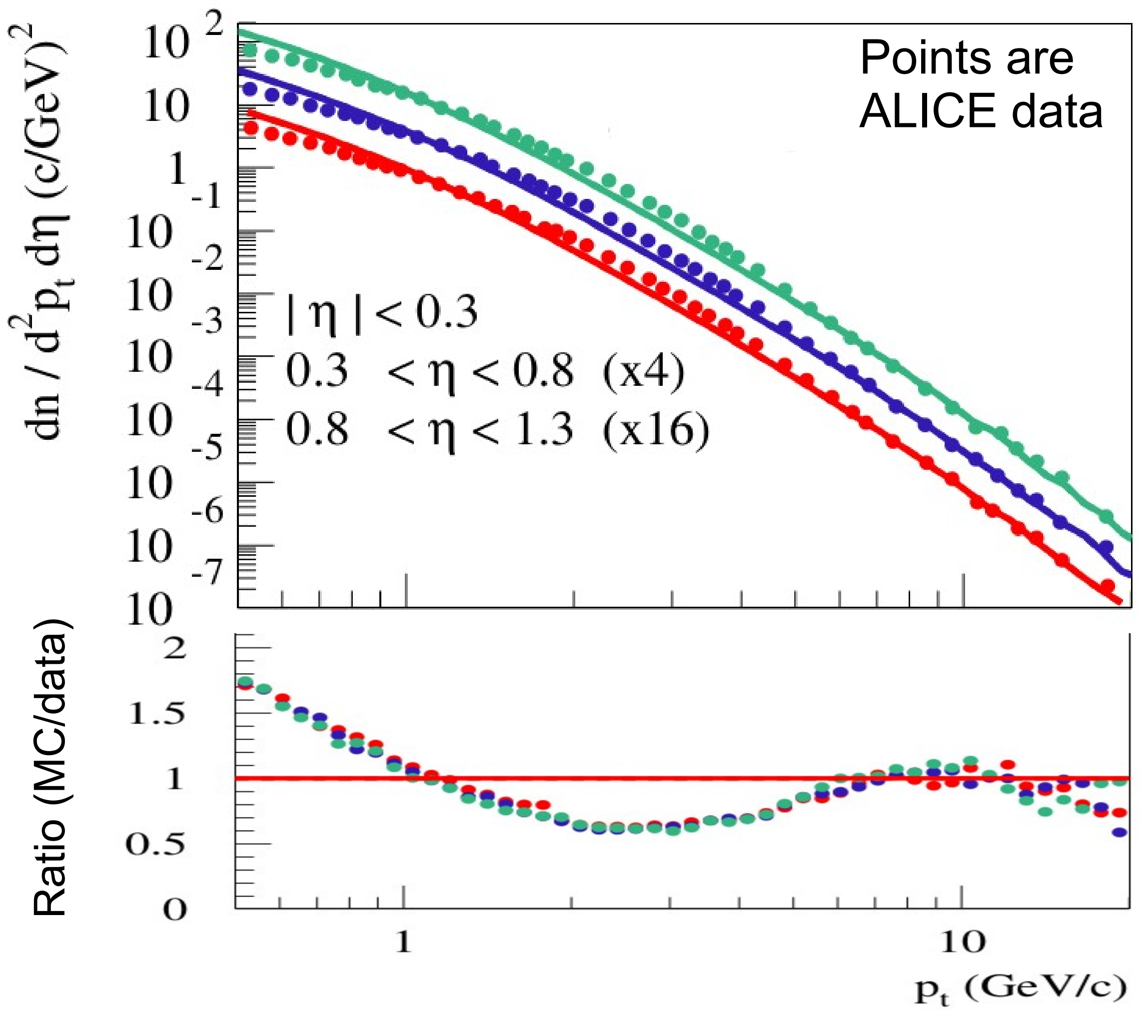
ALICE, PRL 110 (2013) 032301



Charged particle p_T vs models

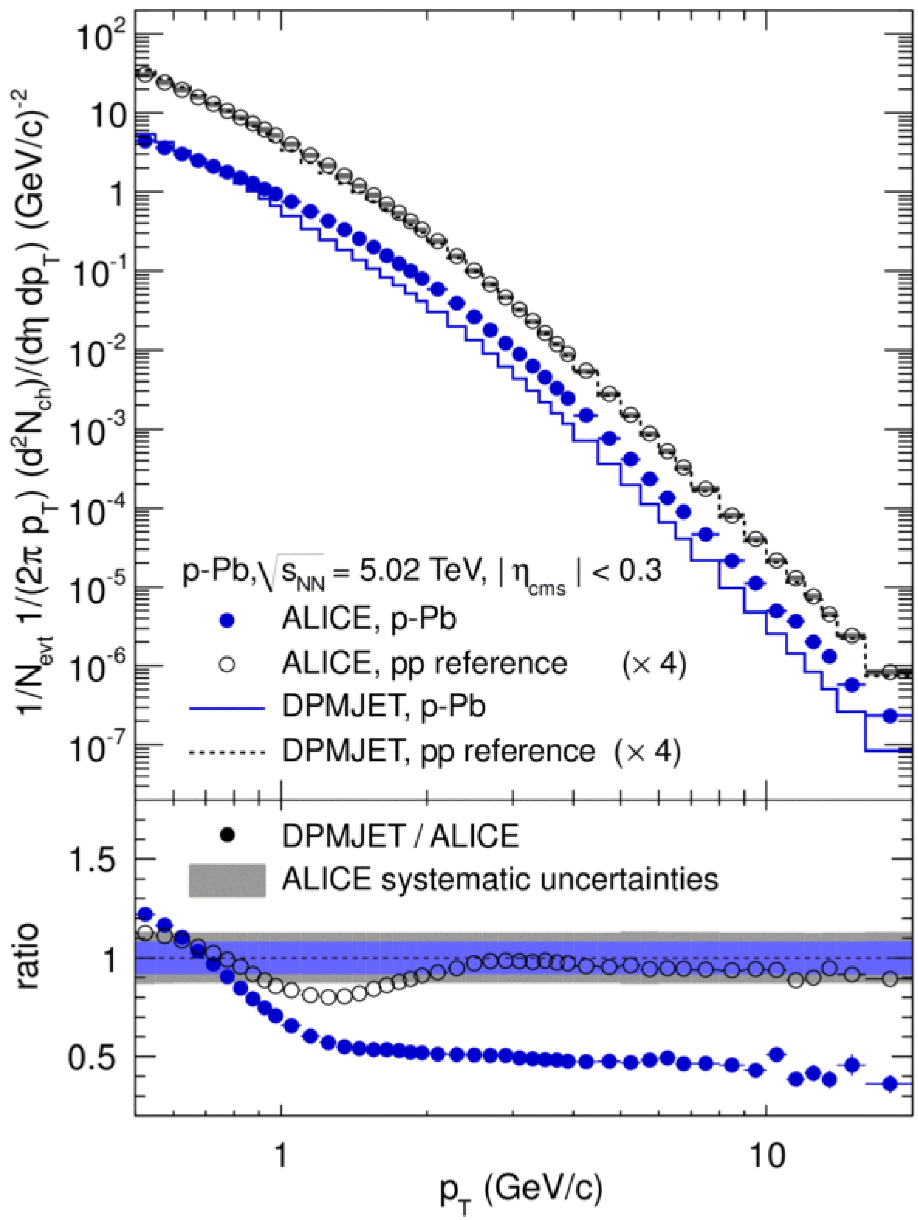


Werner et al., EPOS3 (preliminary)

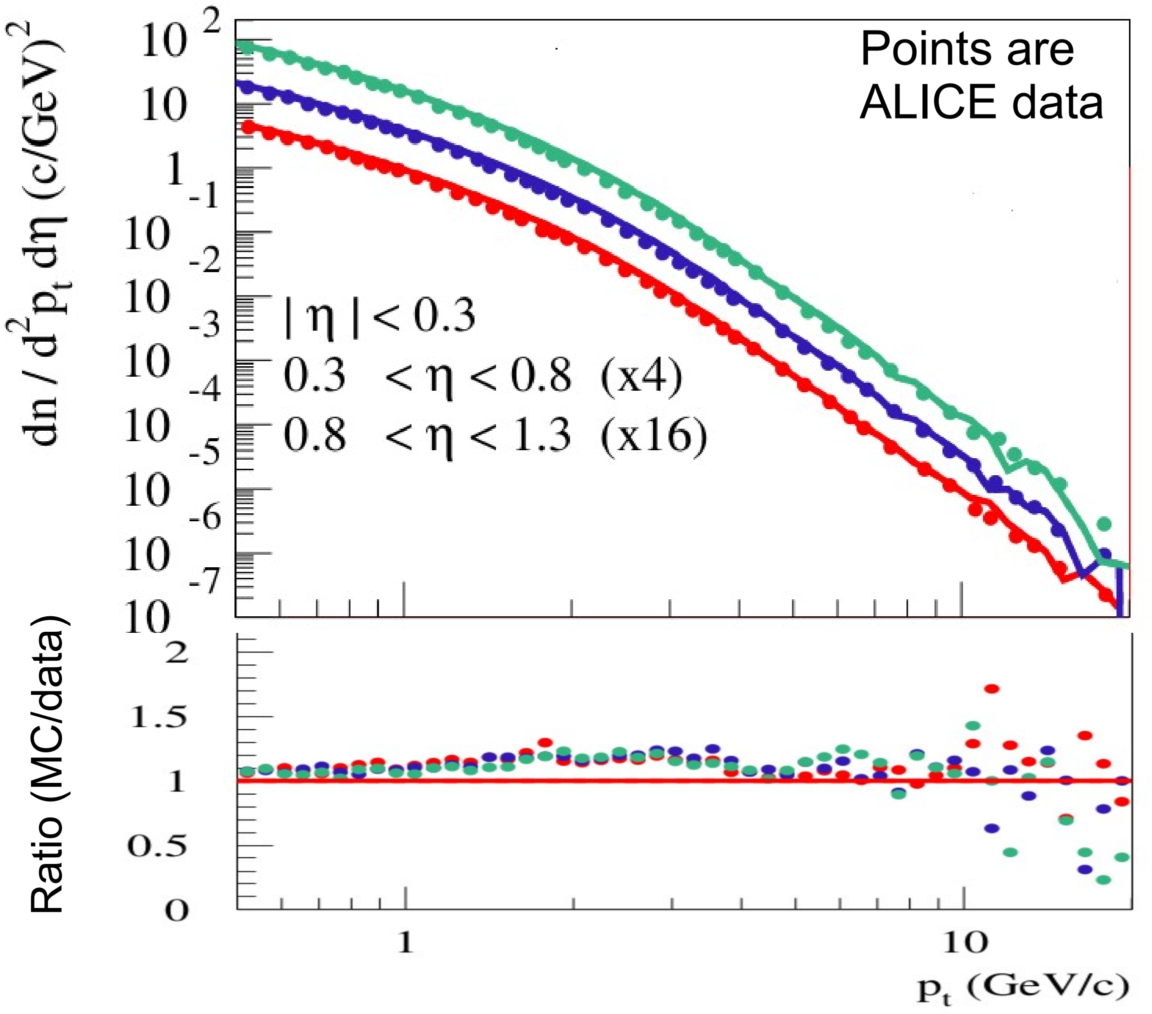


Spectra are not straight forward to describe.

Charged particle p_T vs models



Werner et al., EPOS3 (preliminary)



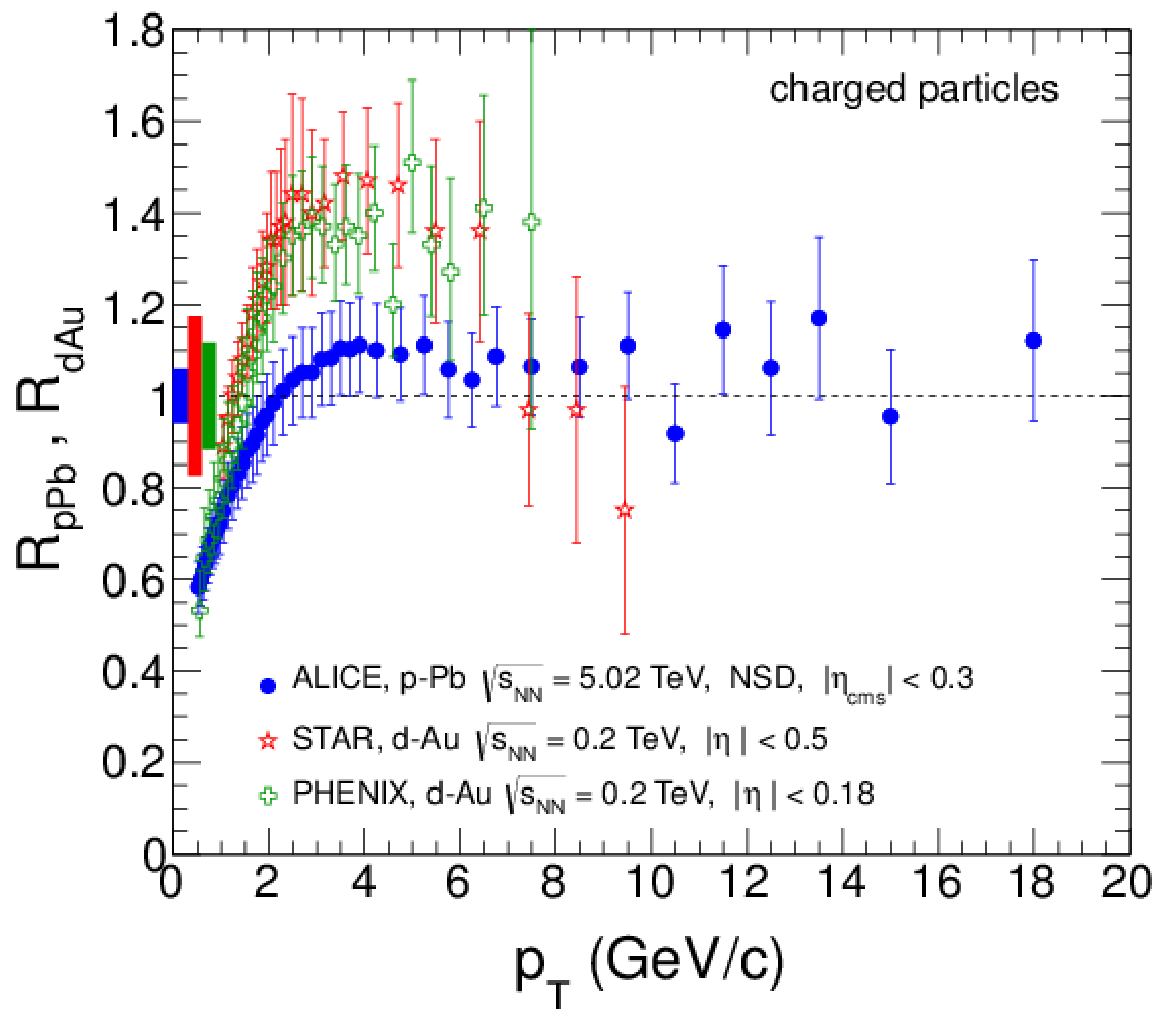
Spectra are not straight forward to describe.
Today we know that it is possible e.g.
by including a hydrodynamical evolution.

Cronin effect at RHIC and LHC

ALICE, PRL 110 (2013) 082302
STAR, PRL 91 (2003) 072304
PHENIX, PRL 91 (2003) 072030

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

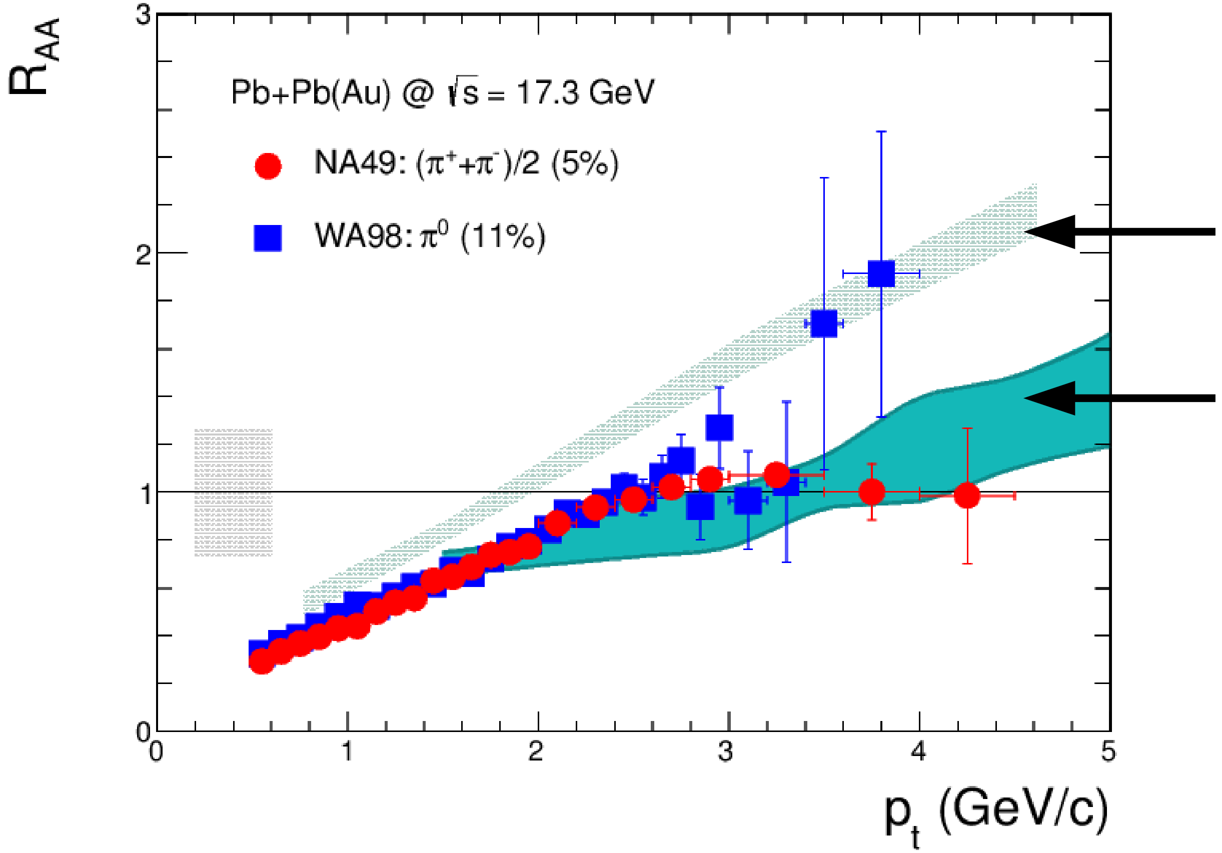
- $R_{AB} > 1$ at intermediate p_T observed in dAu collisions at RHIC typically attributed to Cronin effect
- No enhancement seen in pPb at the LHC
- No Cronin effect?



Cronin effect at SPS

- Reminder from SPS energies: RAB ≈ 1 does not necessarily imply absence of effects

NA49, NPA 783 (2007) 65
WA98, PRL 89 (2002) 252301



Calculation taking into account:

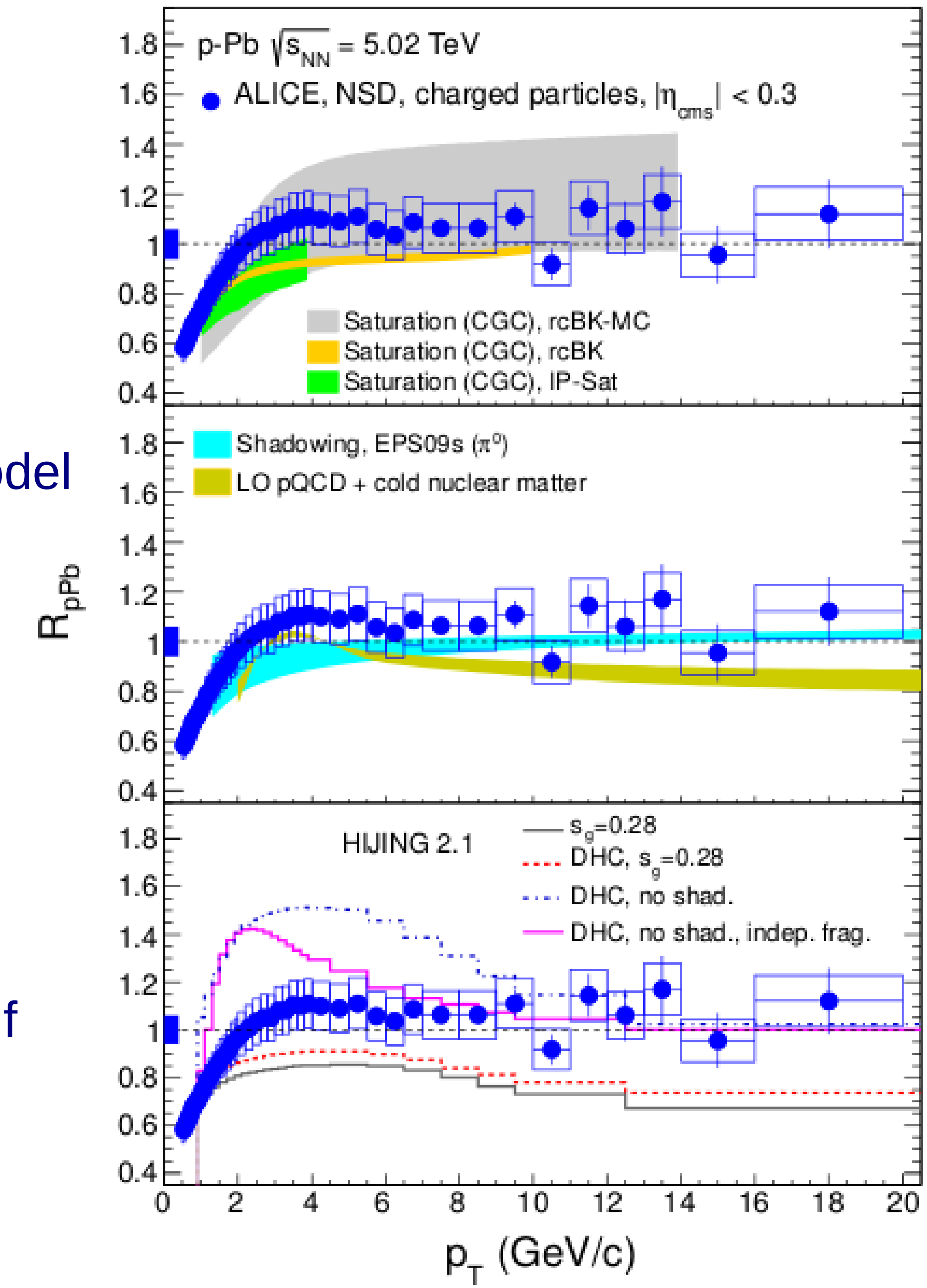
Cronin effect + shadowing

Cronin effect, shadowing plus partonic energy loss

- Model comparisons are required to understand R_{pPb} at the LHC

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 low p_T (see also dN/dη)
  - No shadowing better at high p_T
- Spectrum itself interesting
  - Neither HIJING nor DPMJET do describe the p-Pb p_T spectrum itself

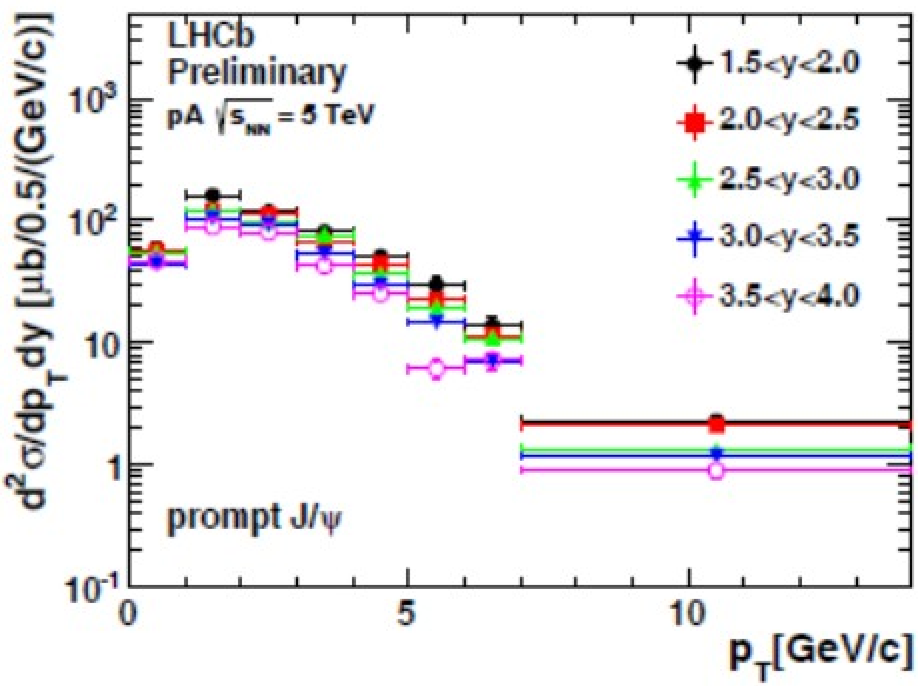


NB: HJING calculations are expected to increase by ~4% from INEL to NSD

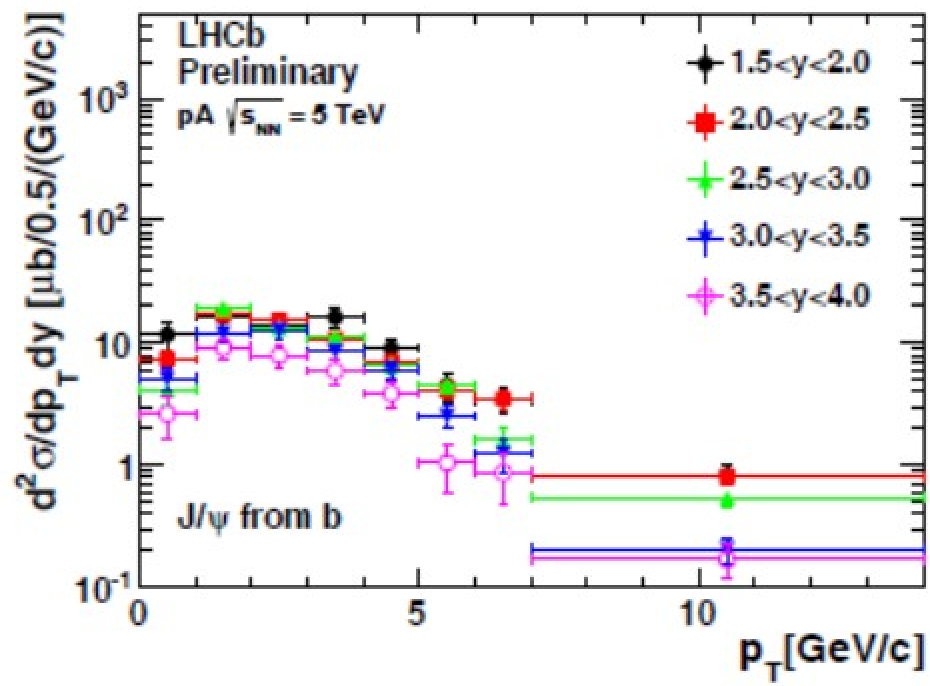
J/ψ double differential cross section

LHCb-CONF-2013-008

Prompt J/ψ



J/ψ from b



Total cross-sections:

Forward: $p_T < 14\ \mathrm{GeV/c}\,, \mathbf{1.5 < y < 4.0}$

$$\sigma_{pA}(prompt\ J/\psi\ ) = \mathbf{1028.2 \pm 13.6\ (stat.) \pm 88.6(syst.)\ \mu b}$$

$$\sigma_{pA}(\ J/\psi\ from\ b\ ) = \mathbf{150.1 \pm 4.2\ (stat.) \pm 12.6(syst.)\ \mu b}$$

Backward: $p_T < 14\ \mathrm{GeV/c}\,, \mathbf{-5 < y < -2.5}$

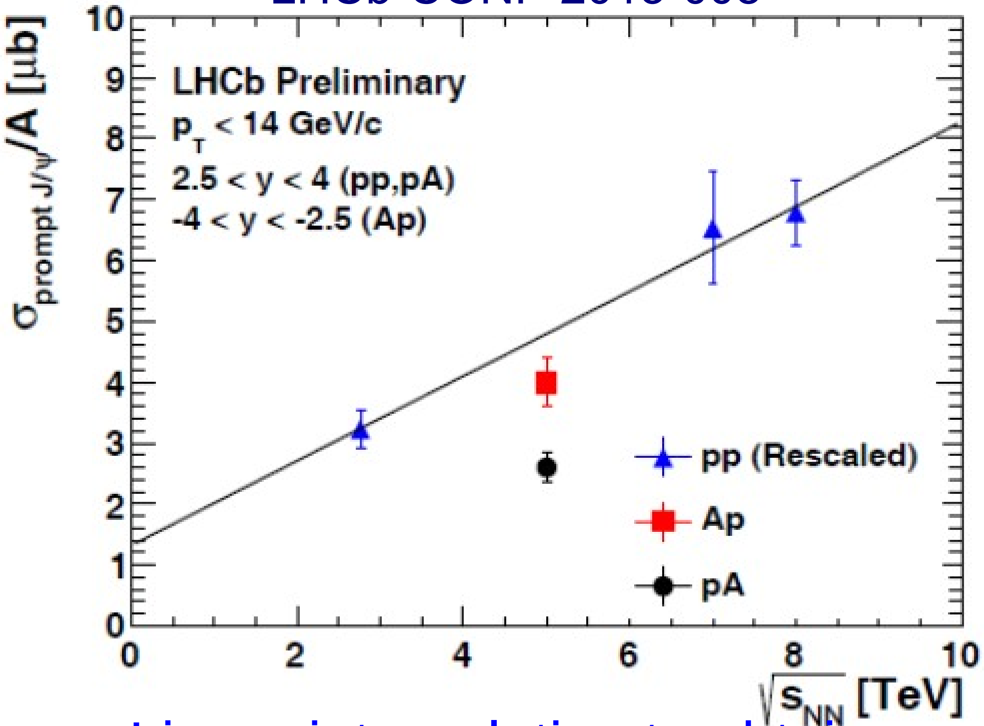
$$\sigma_{Ap}(prompt\ J/\psi\ ) = \mathbf{1141.9 \pm 49.8\ (stat.) \pm 98.4(syst.)\ \mu b}$$

$$\sigma_{Ap}(\ J/\psi\ from\ b) = \mathbf{119.7 \pm 8.3\ (stat.) \pm 10.0(syst.)\ \mu b}$$

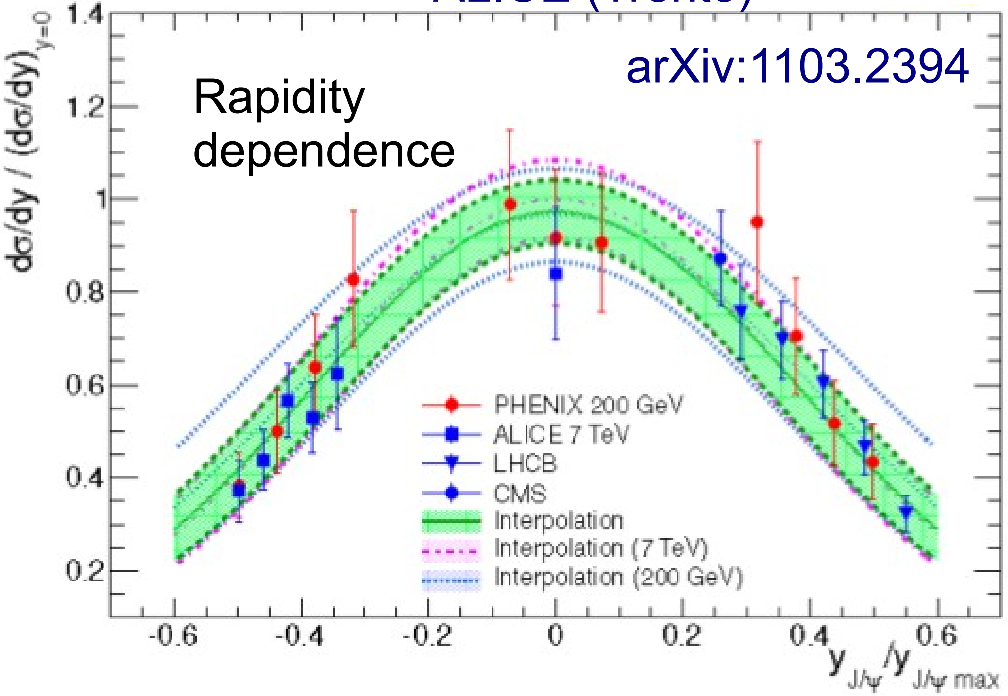
Systematic uncertainties dominated by luminosity, fit model and data-mc consistency

J/ψ interpolated pp reference

LHCb-CONF-2013-008



ALICE (Trento)



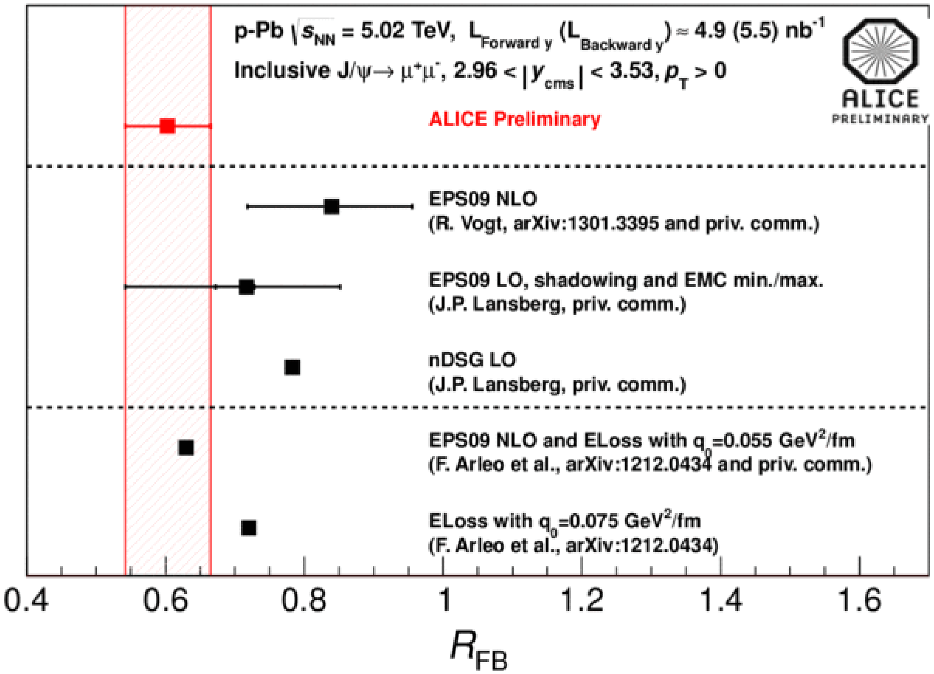
- Linear interpolation to obtain prompt J/psi cross section in pp at 5.02 TeV
- Clear suppression in pPb, while moderate in Pbp

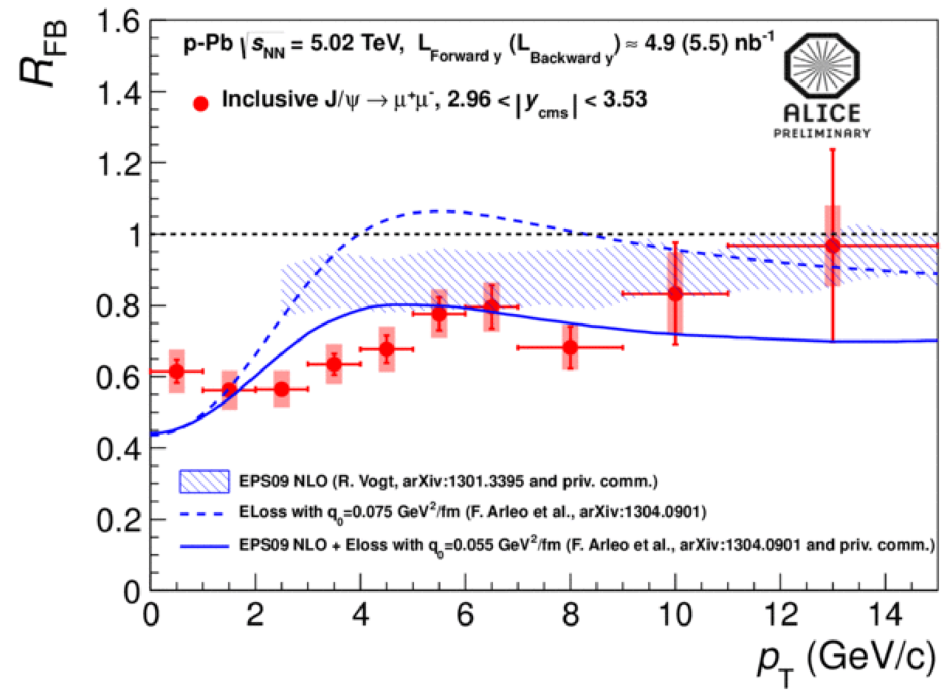
LHCb and ALICE interpolations are consistent within large uncertainties. Need pp reference run at 5.02 TeV!

- Interpolation between RHIC, CDF and LHC data based on phenomenological shape for the inclusive J/psi cross section
  - $d\sigma/dy = 3.85 \pm 0.68\ \mu b^{-1}$ (2.03<y<3.53)
  - $d\sigma/dy = 2.65 \pm 0.66\ \mu b^{-1}$ (-4.46<y<-2.96)
- Consistent with FONLL and CEM

Forward-backward asymmetry

Inclusive J/psi, ALICE, preliminary

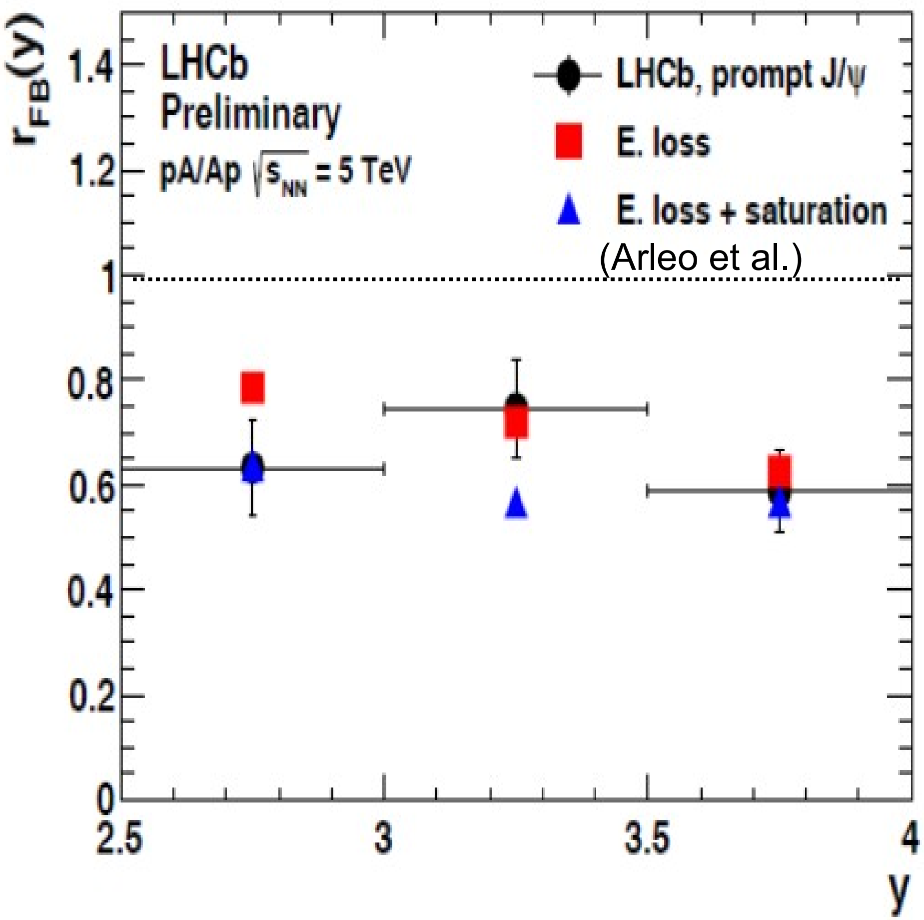




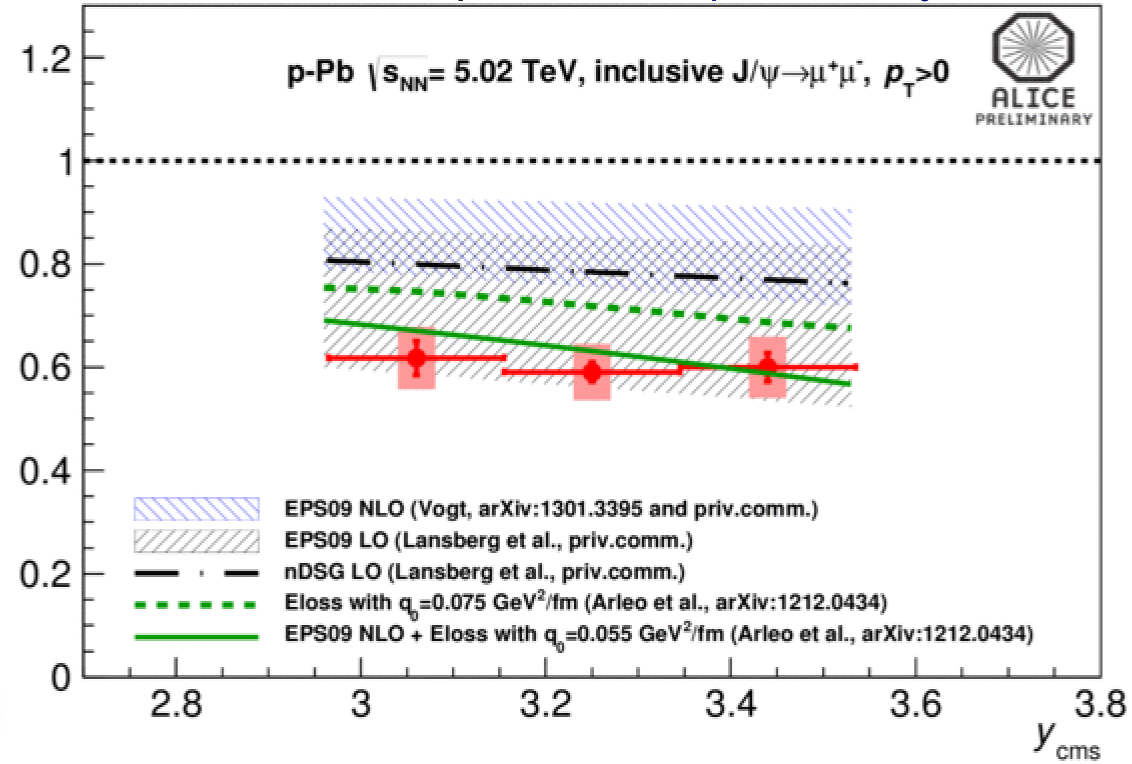
- Forward-to-backward ratio in the range 2.96<|y|<3.53
  - R_{FB} = 0.60 ± 0.01 (stat) ± 0.06 (syst)
  - Free of uncertainty from pp reference
- Pure shadowing models seem to overestimate the ratio
- p_T dependence provides additional constraints

Forward-backward asymmetry

Prompt J/psi, LHCb-CONF-2013-008



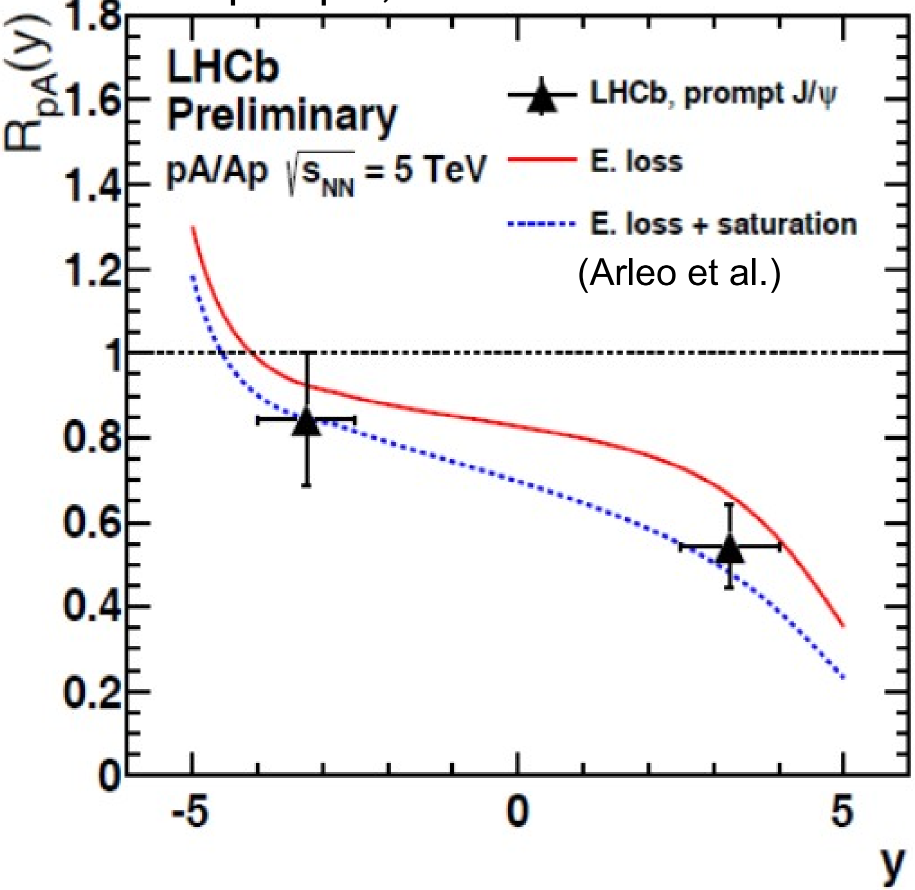
Inclusive J/psi, ALICE, preliminary



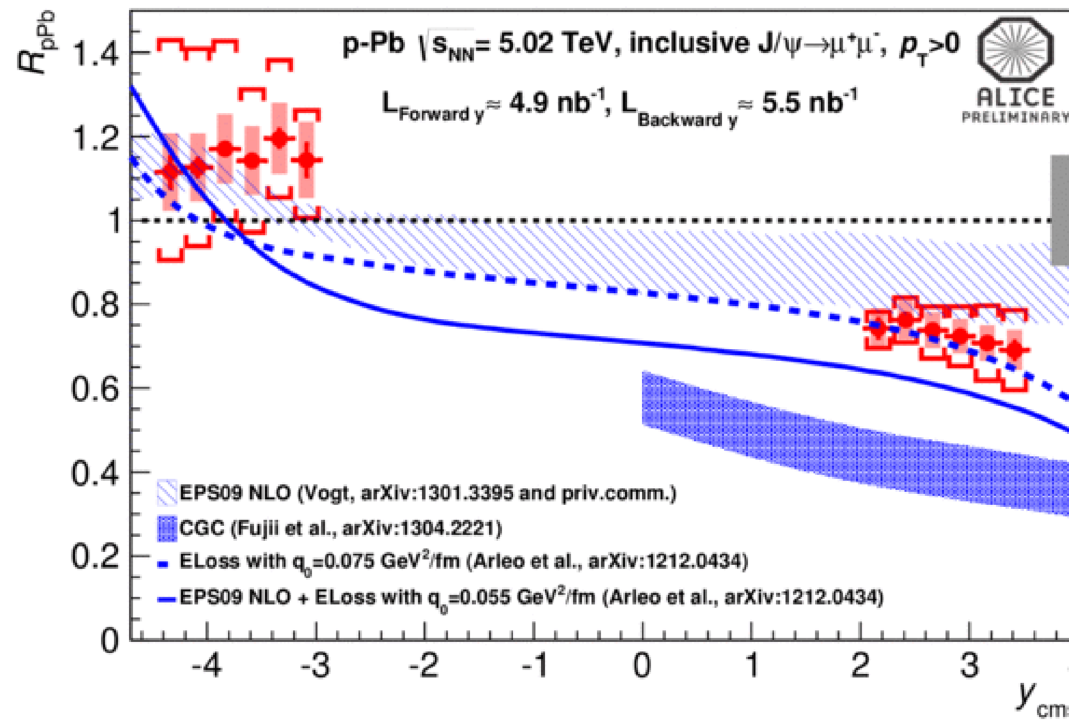
- Forward-to-backward ratio in common |y| ranges
  - Free of uncertainty from pp reference
  - Good agreement between prompt and inclusive measurement
- Models incorporating shadowing and energy loss consistent with data

Prompt vs inclusive J/ψ R_{pPb}

Prompt J/psi, LHCb-CONF-2013-008



Inclusive J/psi, ALICE, preliminary

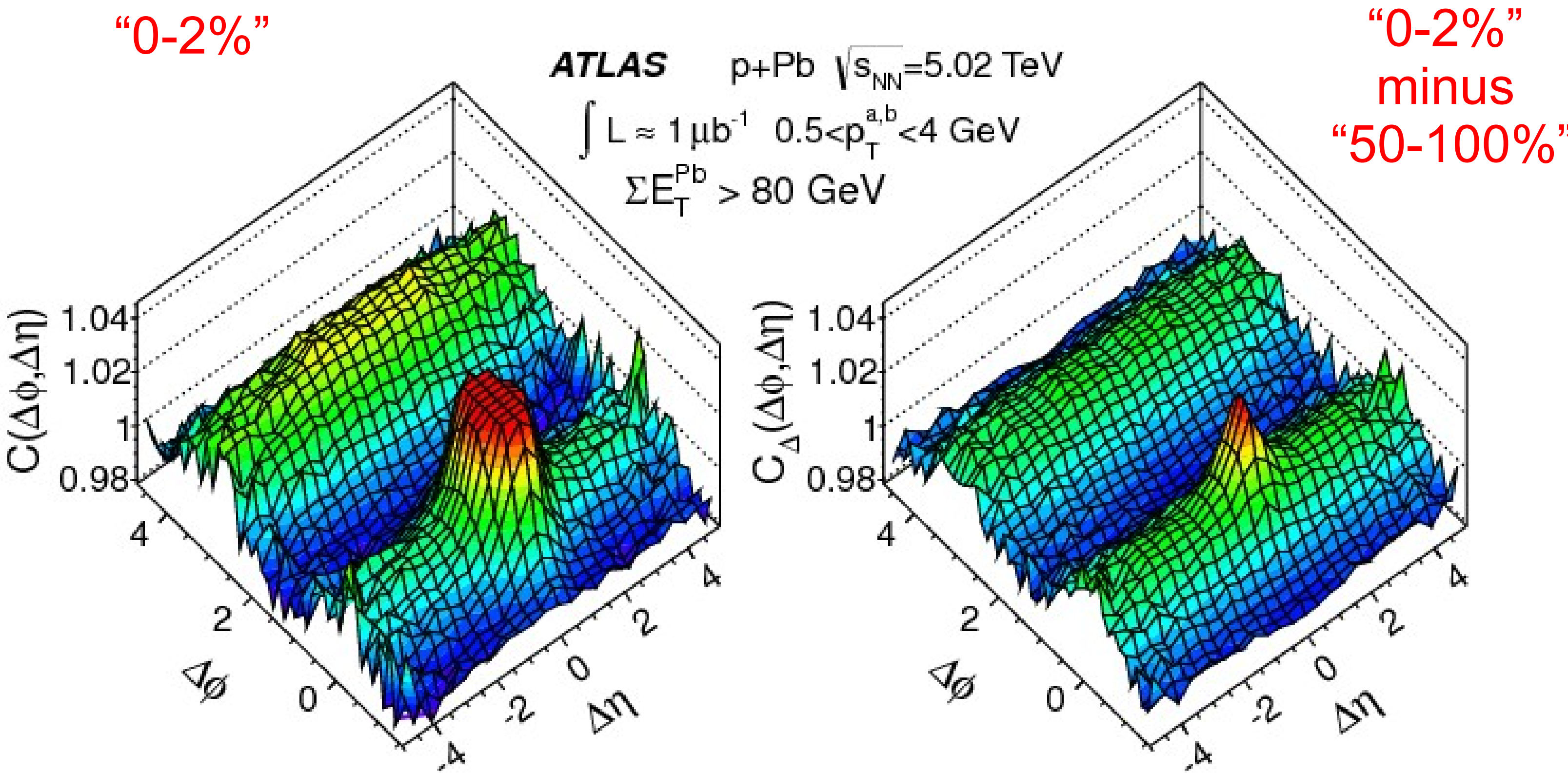


- Comparison between prompt and inclusive measurement
  - Central values for LHCb about 30% lower
    - Both measurements on-the-edge of being compatible within uncertainties
    - Understanding the difference is ongoing
  - Similar conclusions wrt the comparison with models

Extraction of double ridge structure

ATLAS, PRL 110 (2013) 182302

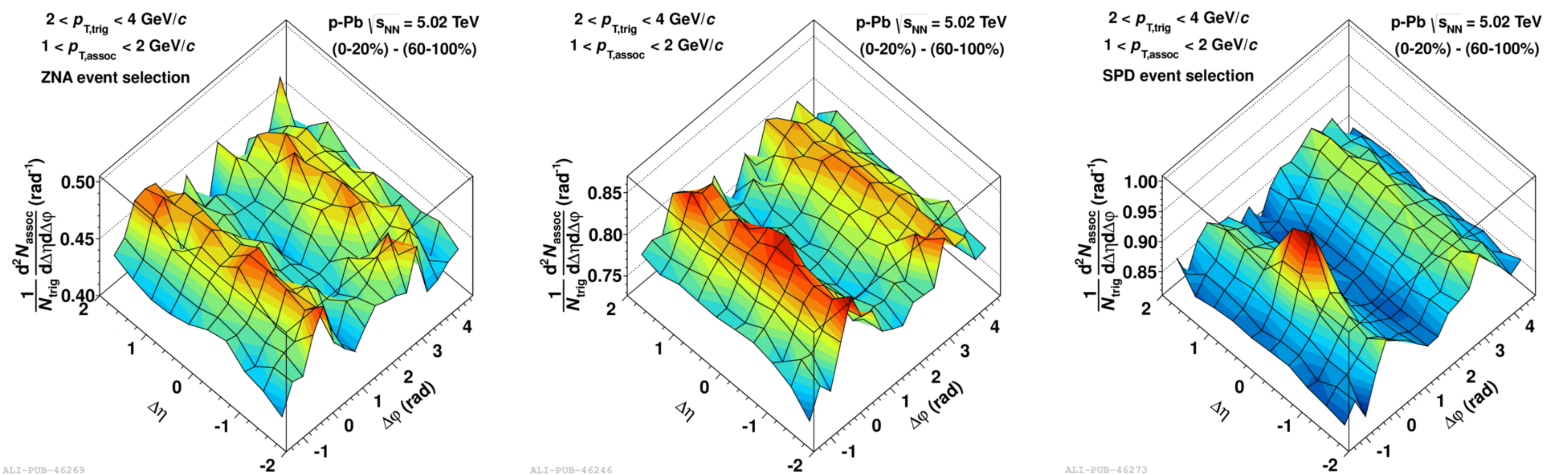
- Similar two ridge structures also observed by ATLAS
  - Event multiplicity classes defined by sum of transverse energy (3.1<η<4.9) on the Pb nucleus side
  - Here, the jet peak at (0,0) remains even after subtraction of 50-100% from the 0-2% multiplicity class



Dependence on event selection

ALICE, PLB 719 (2013) 29

- 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



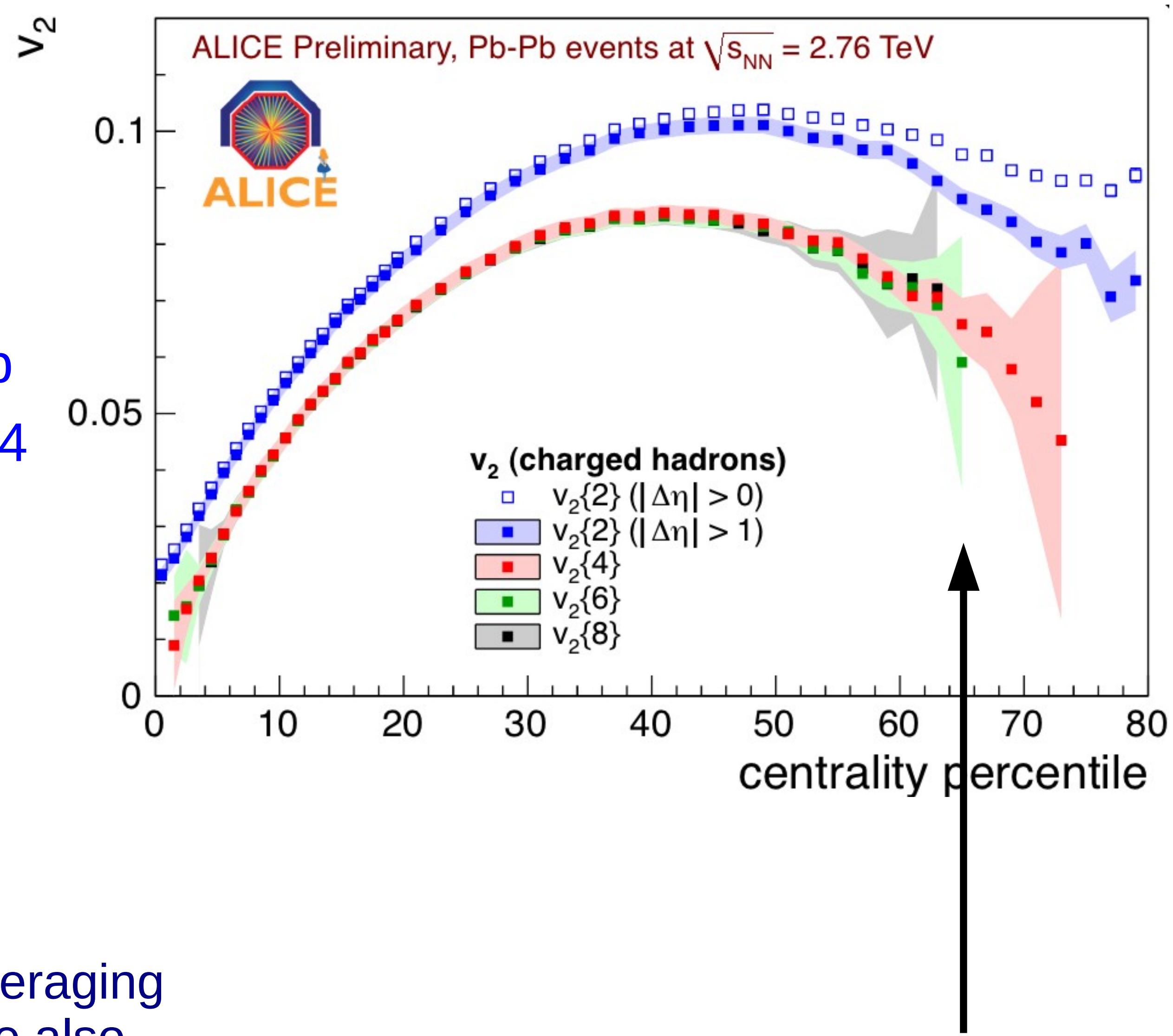
ZNA VZERO SPD

auto-correlation →

← η separation

Multi-particle correlations in PbPb: $v_2\{4\}$

- Cumulants to extract genuine k-particle correlations excluding those from k-1 particles
- Higher order cumulants successfully used in PbPb
- Definitions for k=2 and k=4
  - $$v_2\{2\}^2 = \langle v_2 \rangle^2 + \sigma_{v_2}^2 + \delta_2$$
    $$v_2 \gg 1/\sqrt{M}$$
  - $$v_2\{4\}^2 = \langle v_2 \rangle^2 - \sigma_{v_2}^2$$
    $$v_2 \gg 1/M^{3/4}$$
    - eg. M=100, v_2>>0.03
  - Care is needed when averaging over M, as cumulants are also sensitive to multiplicity fluctuations

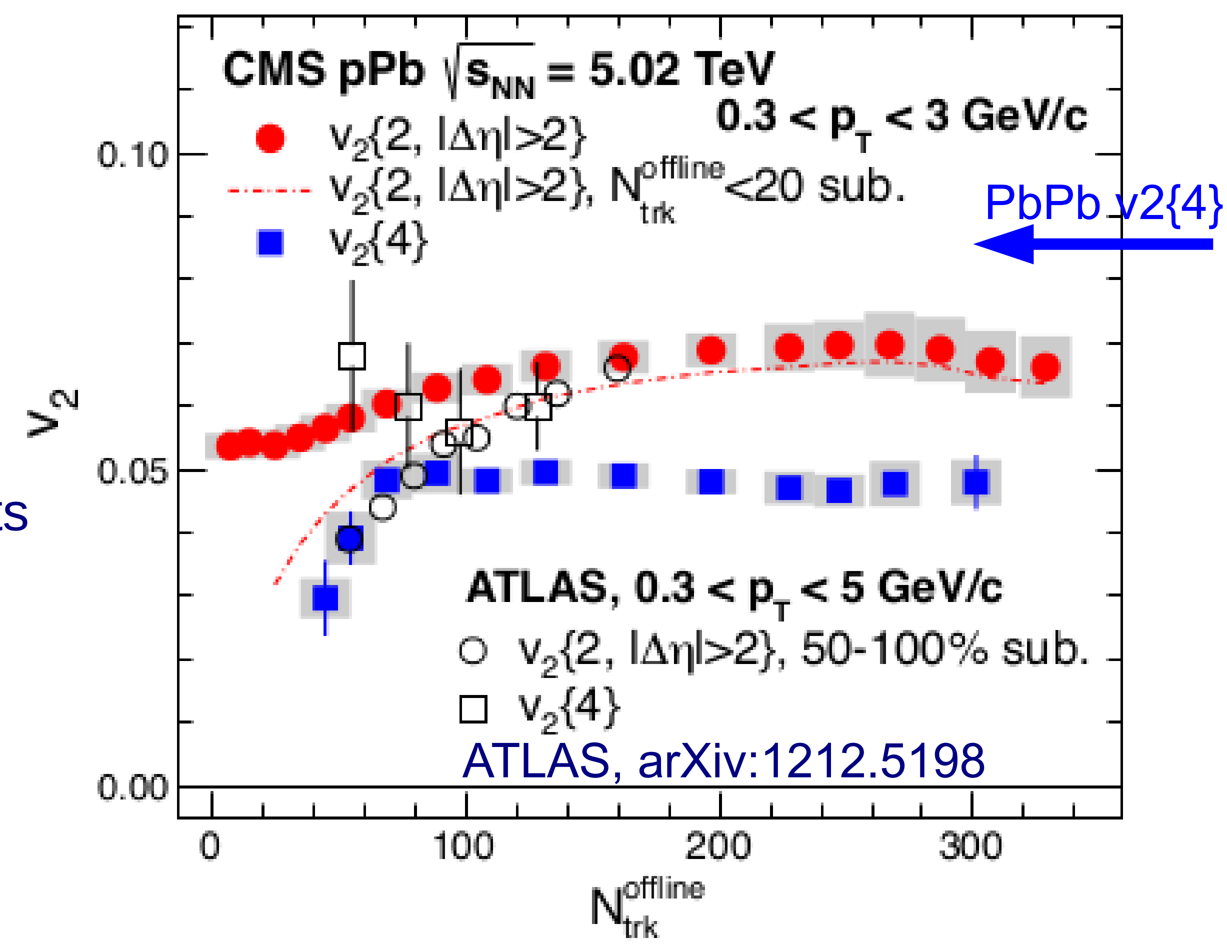


M=<N_{ch}>≈100 in |η|<1

Multi-particle correlations in pPb: $v_2\{4\}$

- Using four particle angular correlations subtracting those from two particles
- Genuine four particle correlations present in pPb
  - Turn-on at around M=50 offline tracks
  - Difference to ATLAS points at low M probably due to multiplicity fluctuations
  - Magnitude smaller than in PbPb

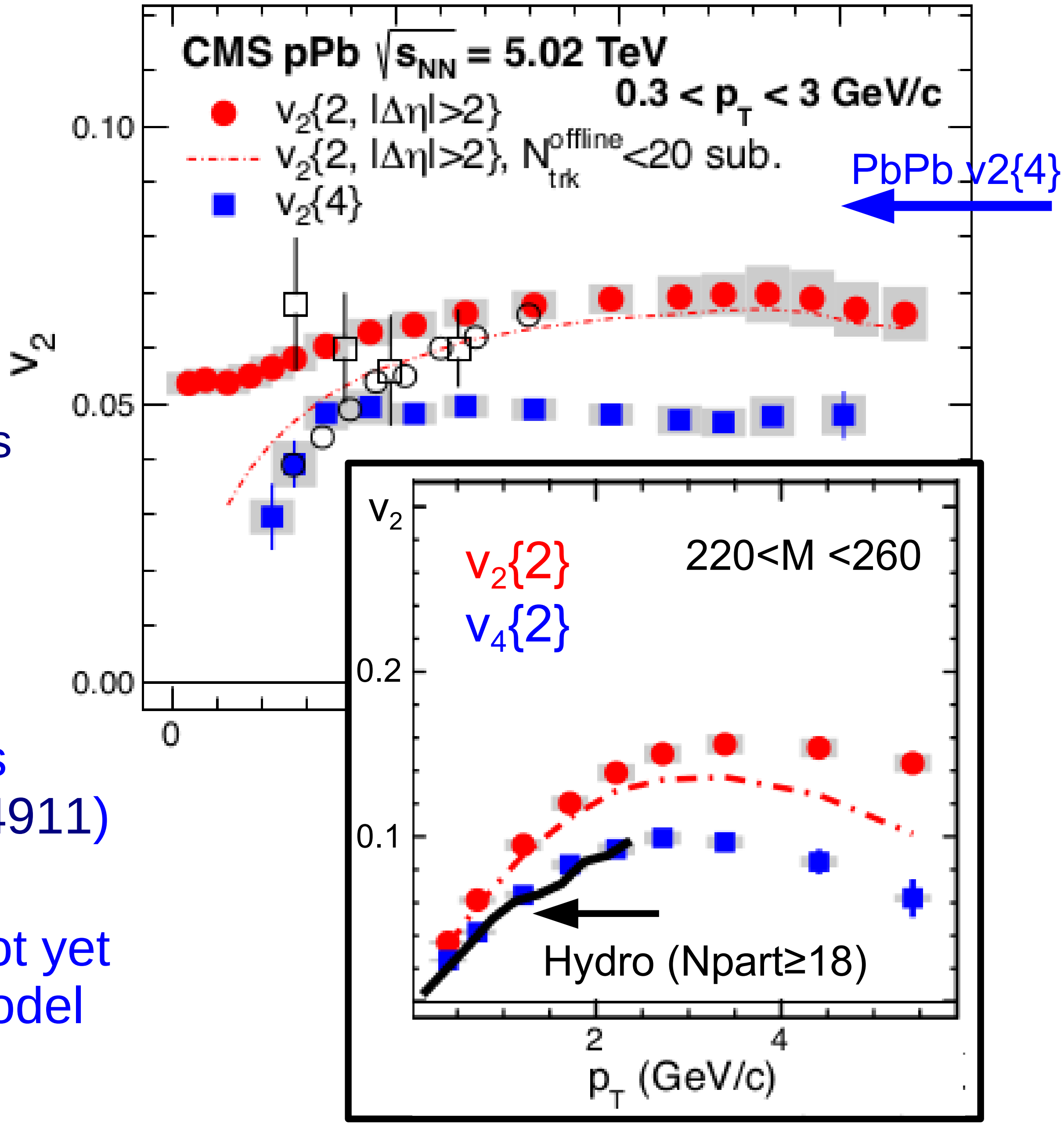
CMS, PLB 724 (2013) 213



Multi-particle correlations in pPb: $v_2\{4\}$

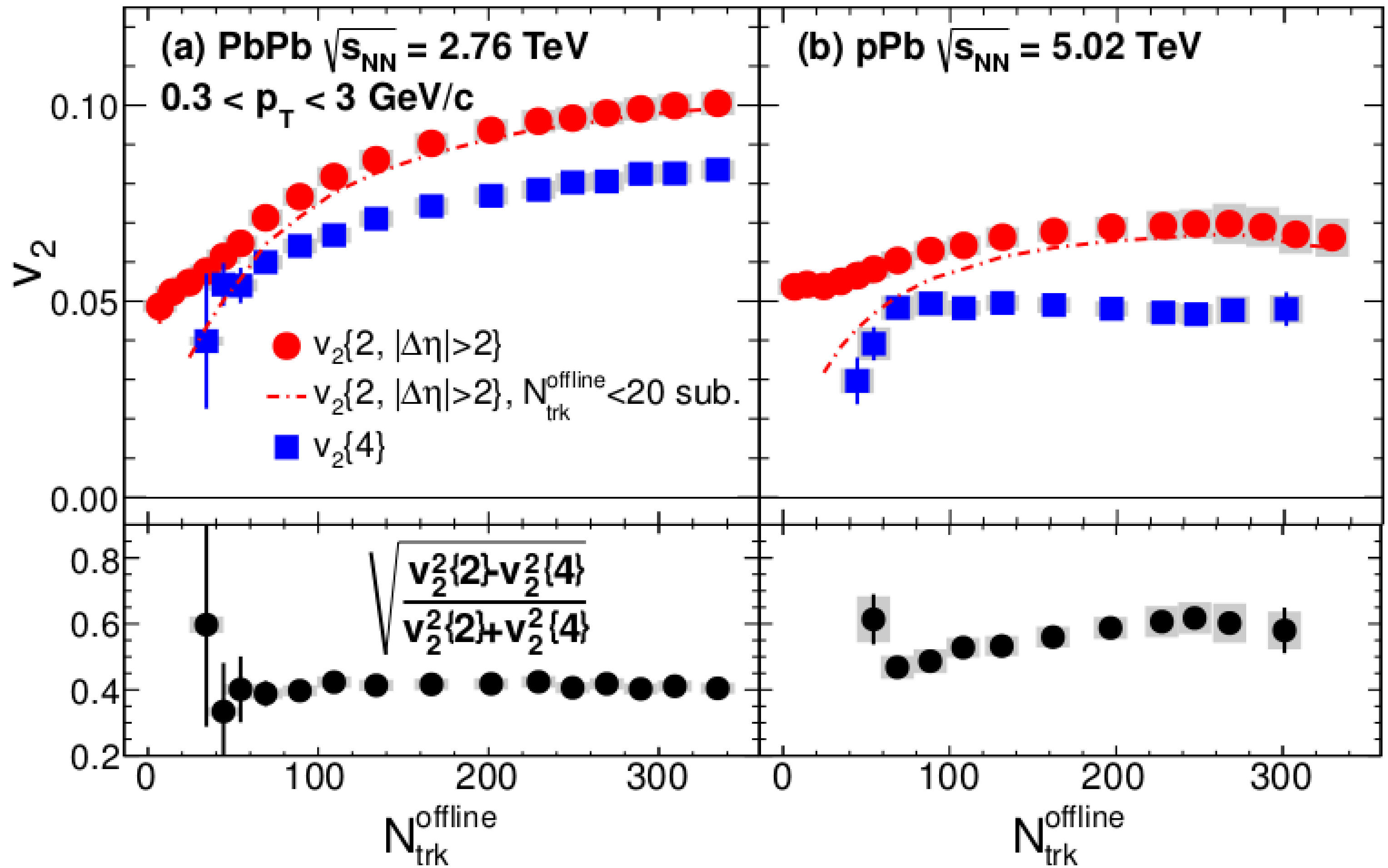
CMS, PLB 724 (2013) 213

- Using four particle angular correlations subtracting those from two particles
- Genuine four particle correlations present in pPb
  - Turn-on at around M=50 offline tracks
  - Difference to ATLAS points at low M probably due to multiplicity fluctuations
  - Magnitude smaller than in PbPb
- Hydrodynamical predictions (Bozek, PRC 85 (2012) 014911) consistent with pPb data
- Higher order correlations not yet included in CGC glasma model



Integrated v_2 in PbPb and pPb

CMS, PLB 724 (2013) 213



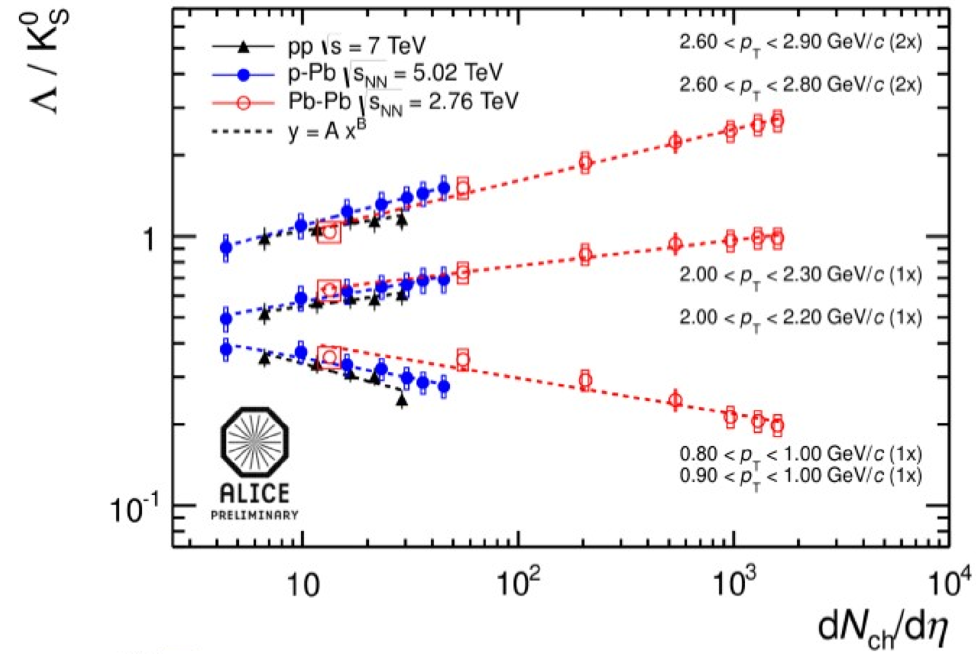
v_2 in pPb is smaller than in PbPb

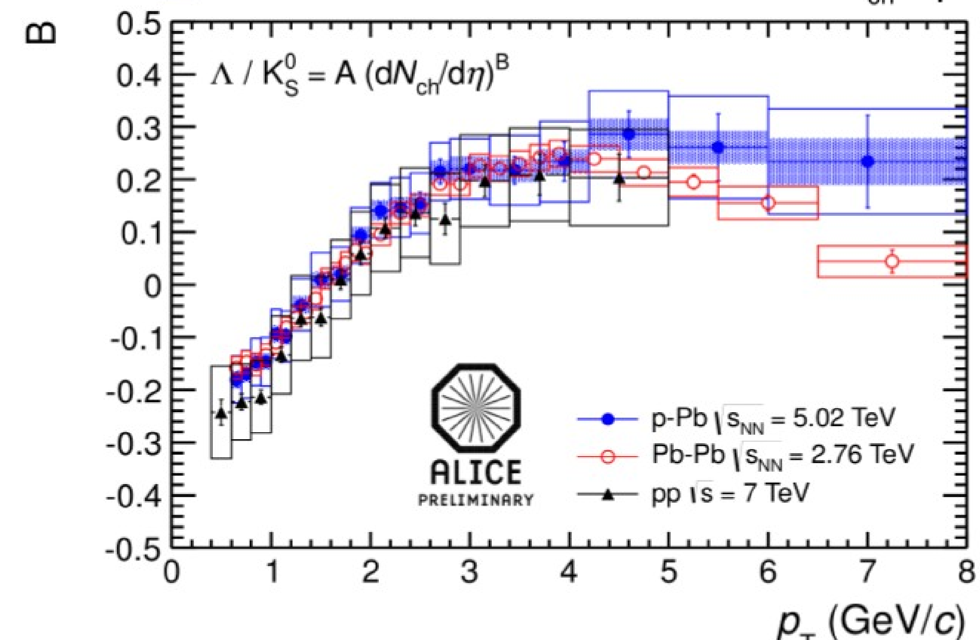
Multiplicity scaling of ratios

$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796

- Fit ratio vs dN/dη in p_T bins with power-law ($A\,x^B$ with x=dN/dη)
- Same increase of ratio for similar increase of dN/dη in pPb and PbPb
- Same power-law scaling exponent (B) in pPb and PbPb
  - Underlying mechanism?
- Similar scaling found for p/π
- Similar scaling also holds for pp (ALICE, preliminary)
  - Caveat: Selection bias

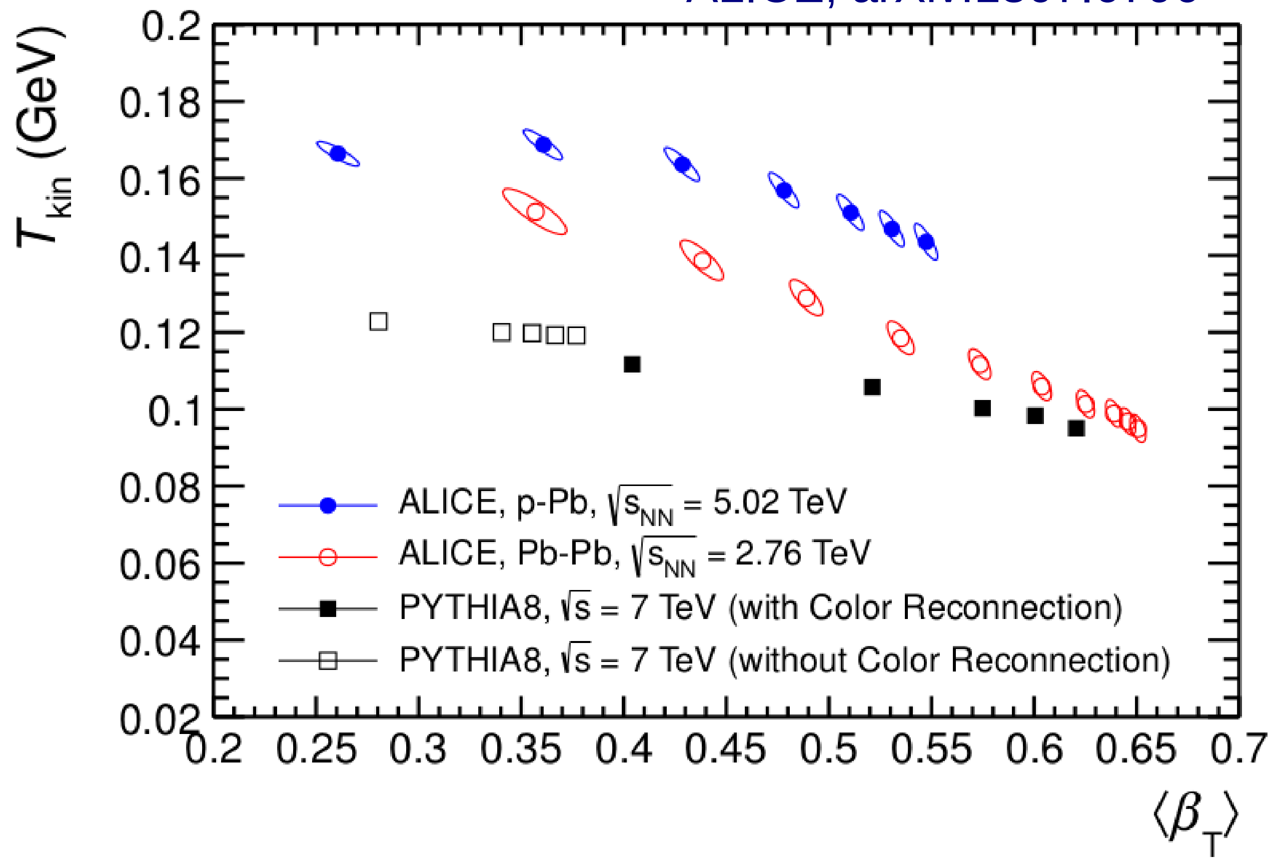




Blast-Wave analysis

- Global Blast-Wave fit with 3 parameters
- Ranges
  - π : 0.5-1.0 GeV/c
  - K: 0.2-1.5 GeV/c
  - p: 0.3-3.0 GeV/c
  - K^0_S: 0.0-1.5 GeV/c
  - Λ: 0.6-3.0 GeV/c
- For the same multiplicity:
  - Similar freeze-out temperature
  - Stronger radial flow

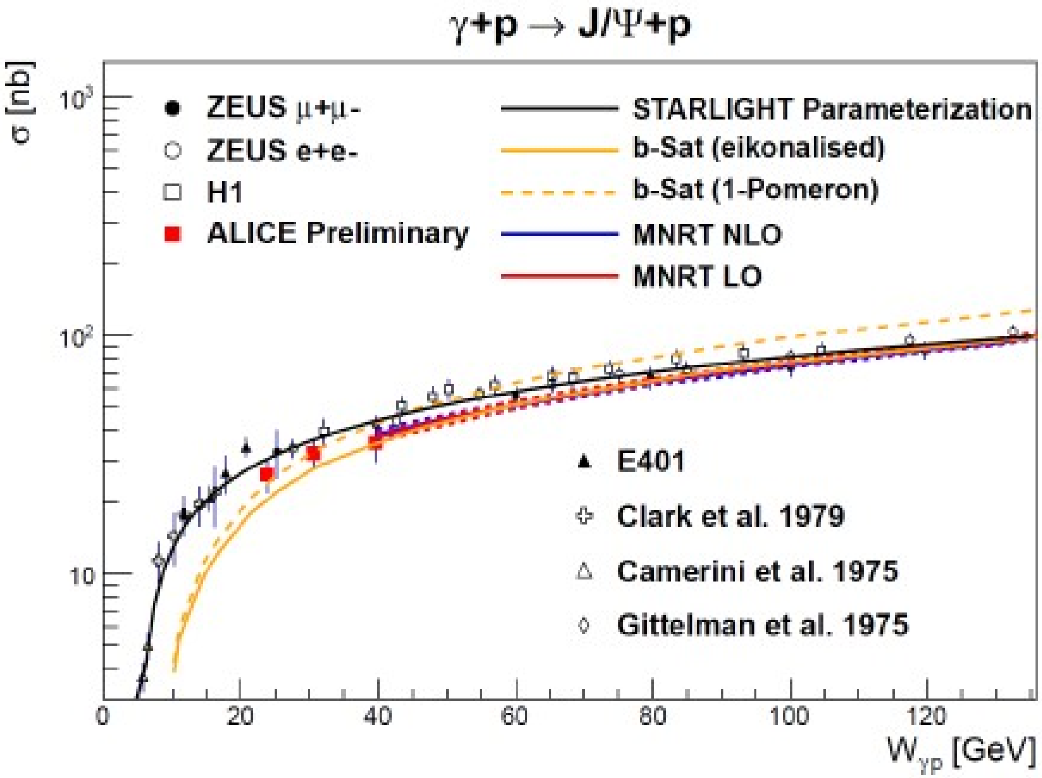
ALICE, arXiv:1307.6796

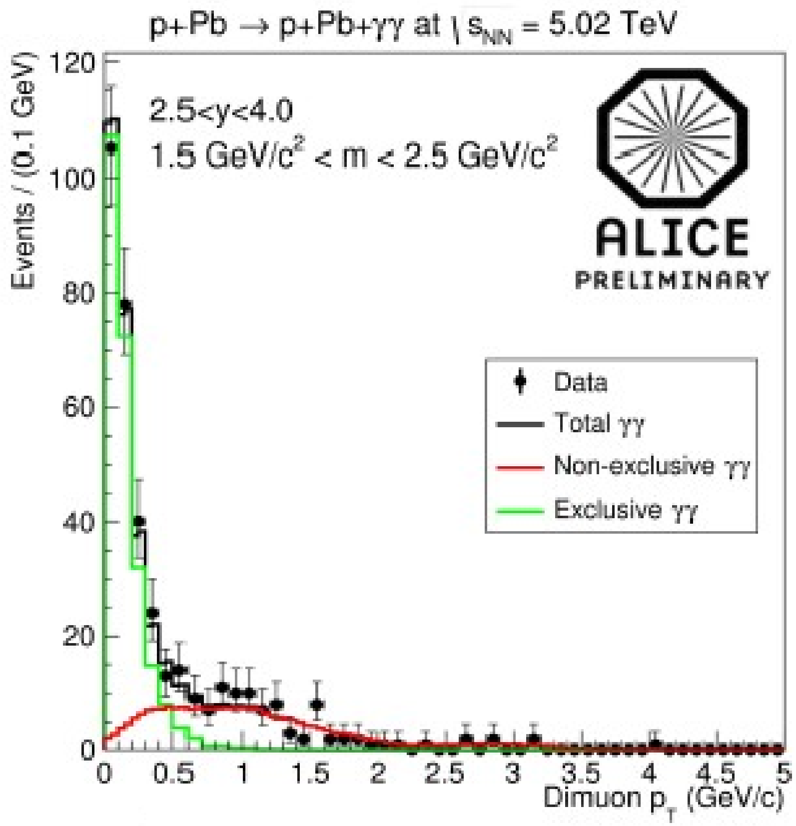


Blast-Wave results from PYTHIA with color reconnection shows qualitatively similar results (but does not include collective flow)

UPC in pPb

ALICE, preliminary





- ALICE covers lowest energies measured at HERA (and can go higher in Pbp
- First γγ measurement in pPb (consistent with STARLIGHT prediction)