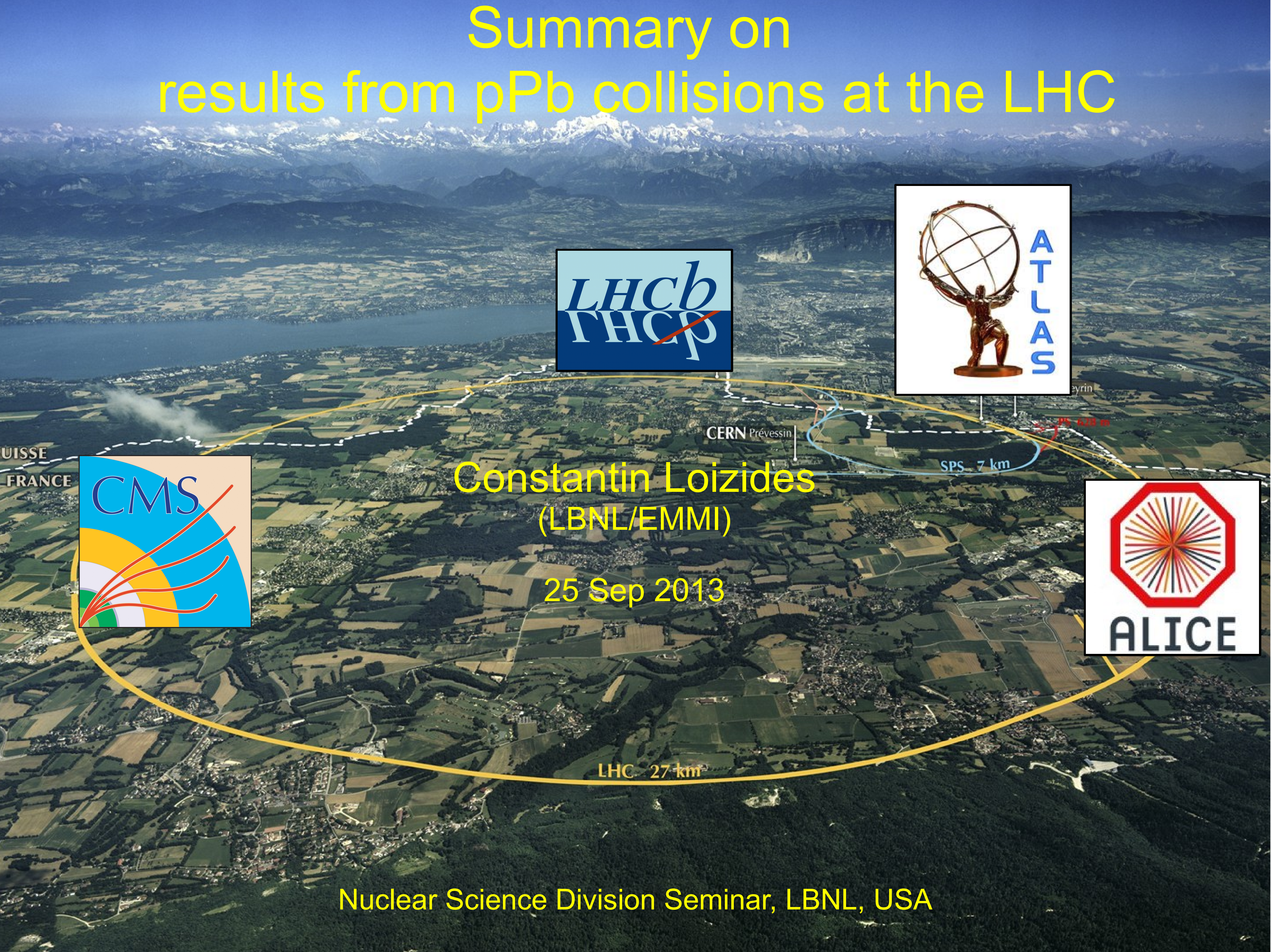
Summary on results from pPb collisions at the LHC



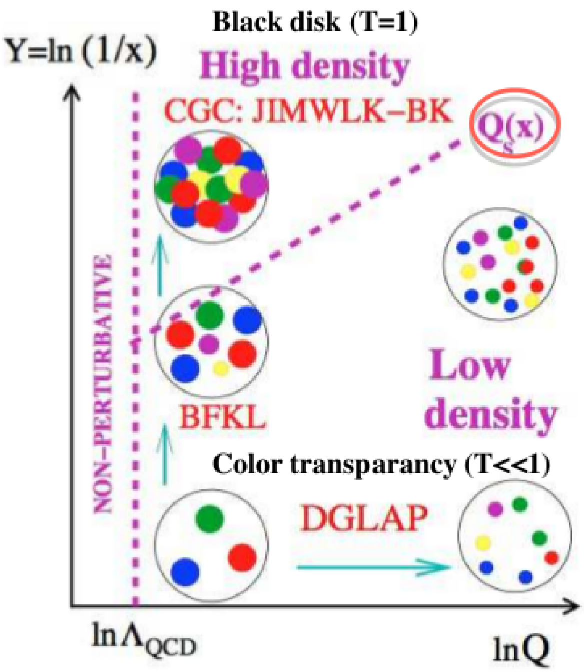
Constantin Loizides
(LBNL/EMMI)

25 Sep 2013

Nuclear Science Division Seminar, LBNL, USA

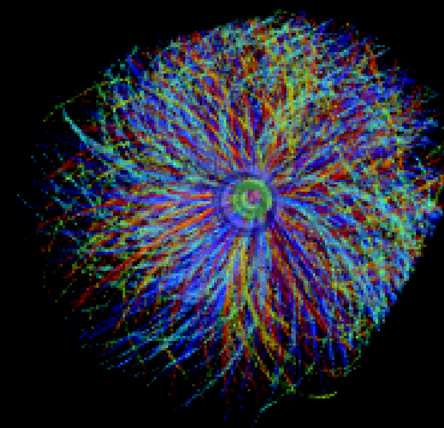
Motivation for pPb at the LHC

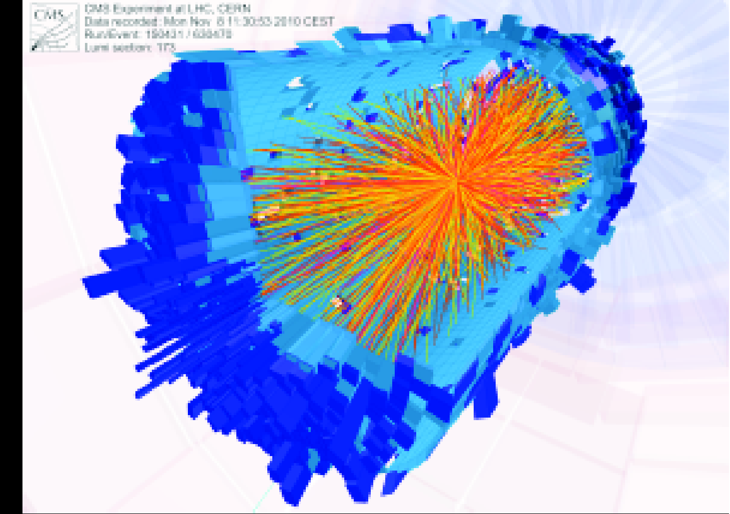
- Study high-density QCD in saturation region
  - Saturation scale (Q_s) enhanced in nucleus ($\sim A^{1/3\lambda}$)
  - In perturbative regime at the LHC: $Q_s^2 \sim$2-3 GeV/c
  - Qualitatively expect x~10^{-4} at η=0 (vs 0.01 at RHIC)
- Study pA to benchmark AA
  - Measure properties of hard processes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

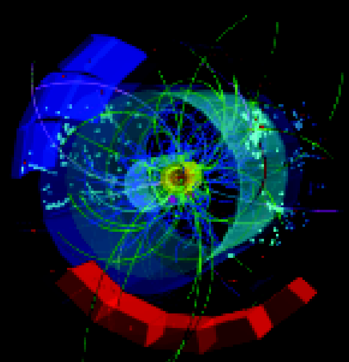


PRL 91 (2003) 072302

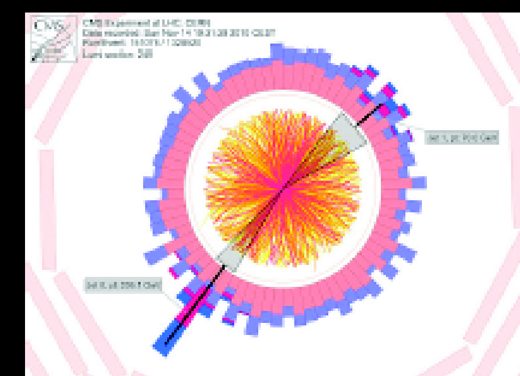
Motivations summarized in JPG 39 (2012) 015010

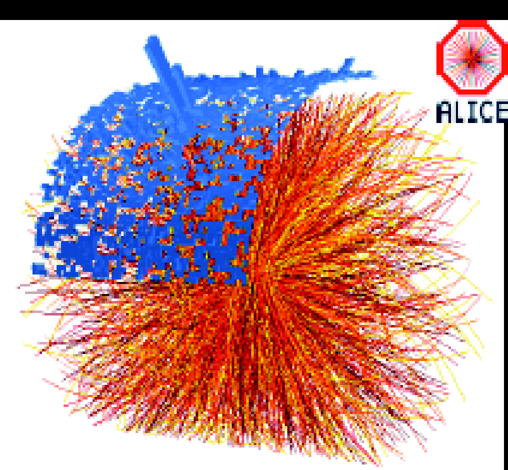


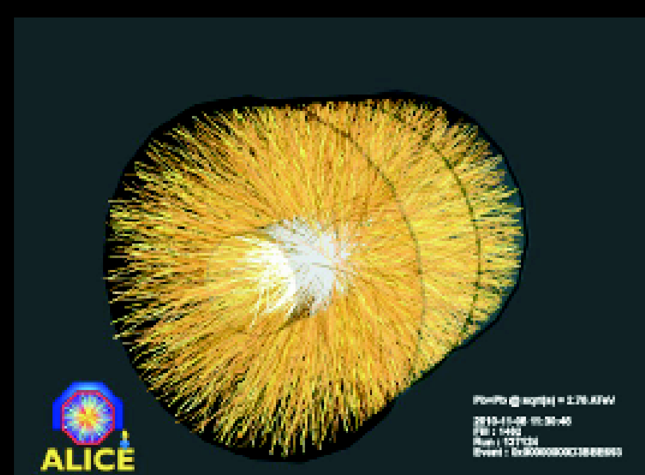


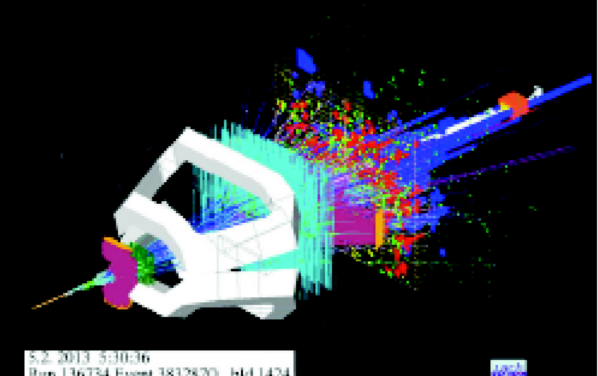


Results from PbPb collisions at the LHC









Heavy-ion reaction model and observables

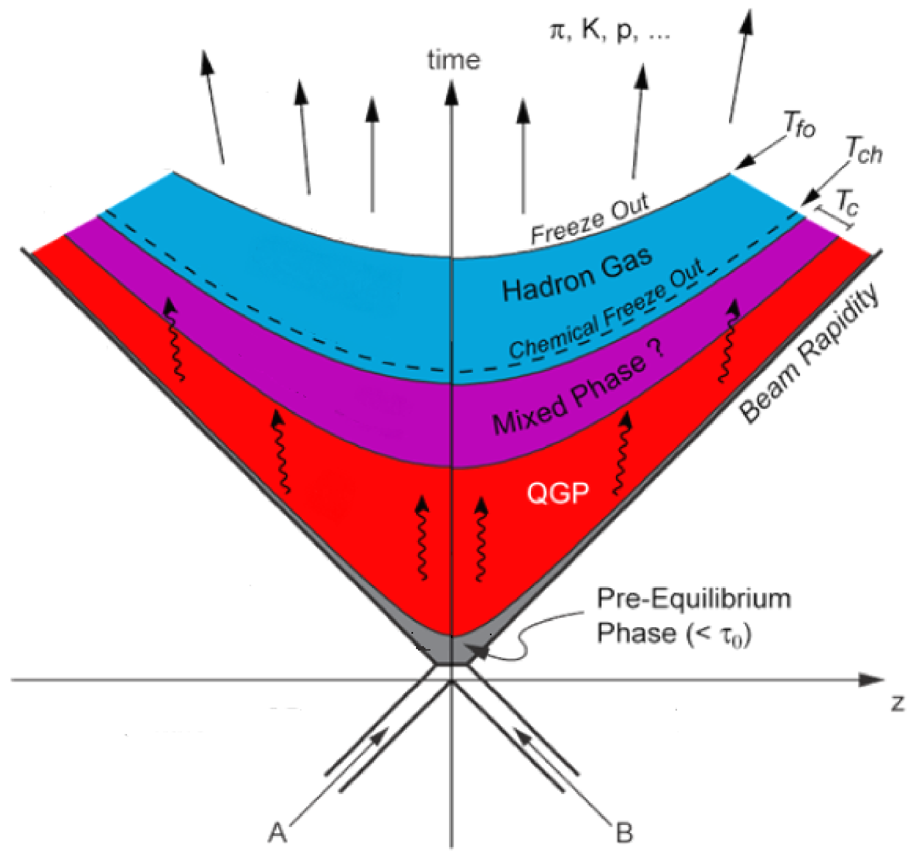
(Some) Concepts

Hadron cascade/
Statistical models

Hydrodynamics/
(Parton cascade)

GLASMA

CGC/Glauber



(Some) Observables

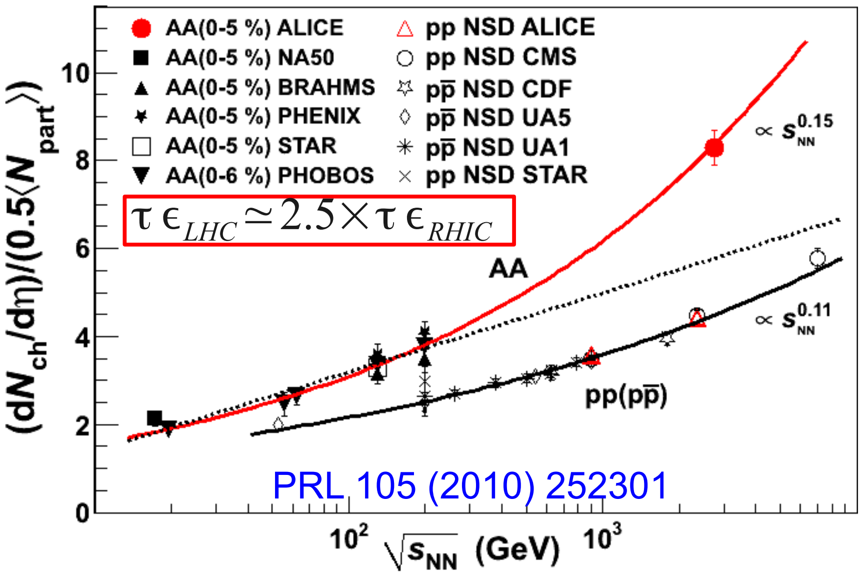
Yields,
Spectra,
HBT

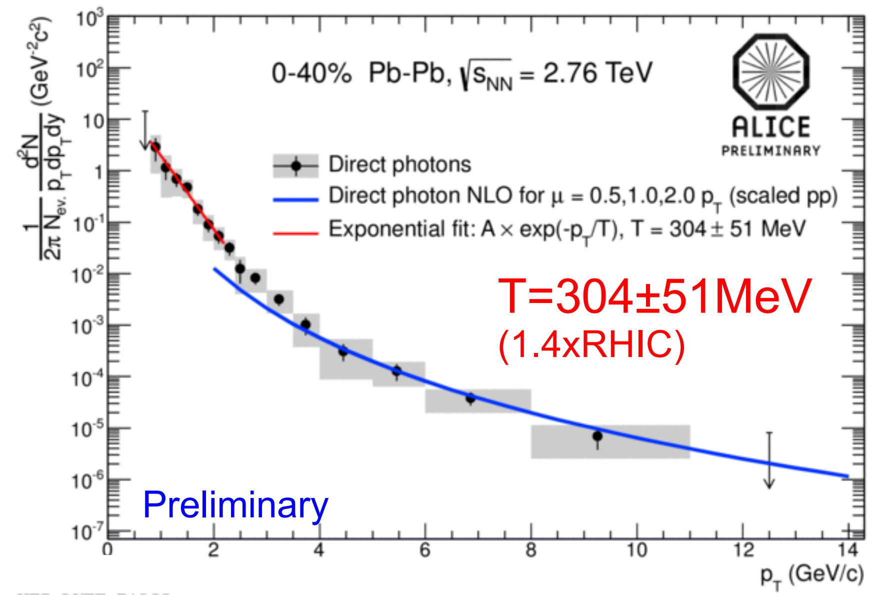
v_2, v_3, etc.

Hard probes
(jets, heavy flavor)

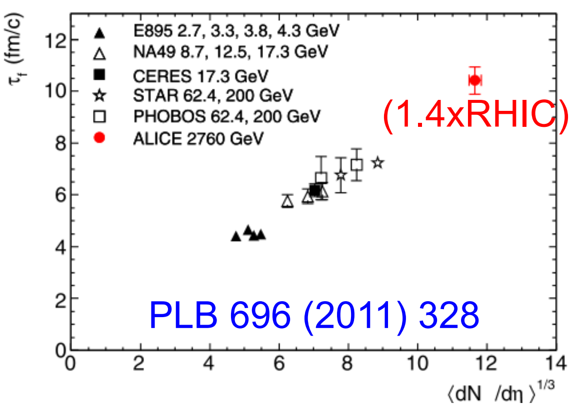
Experimental approach is to study various observables
with different sensitivity to the different stages of the collision

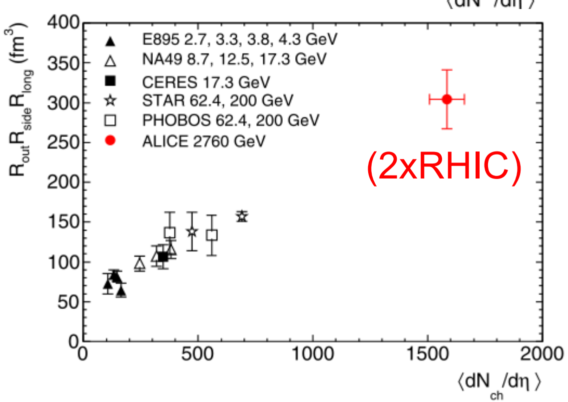
Global properties of central PbPb collisions

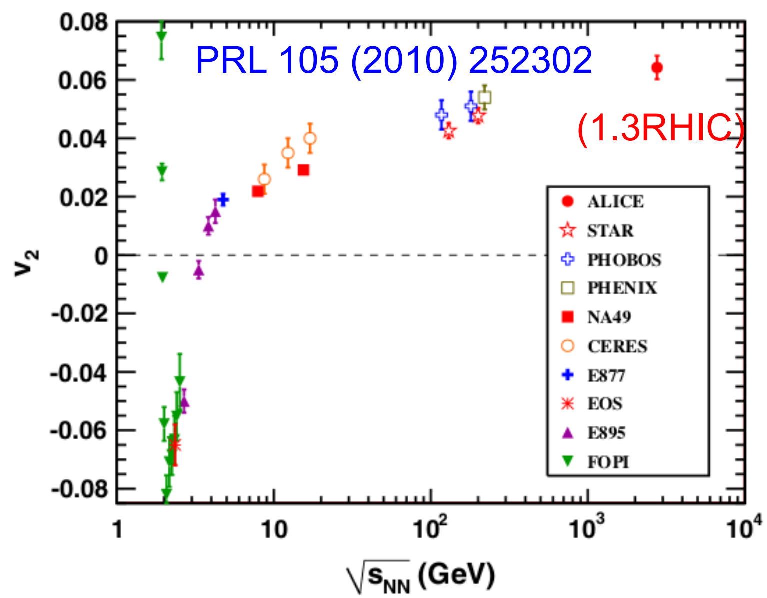


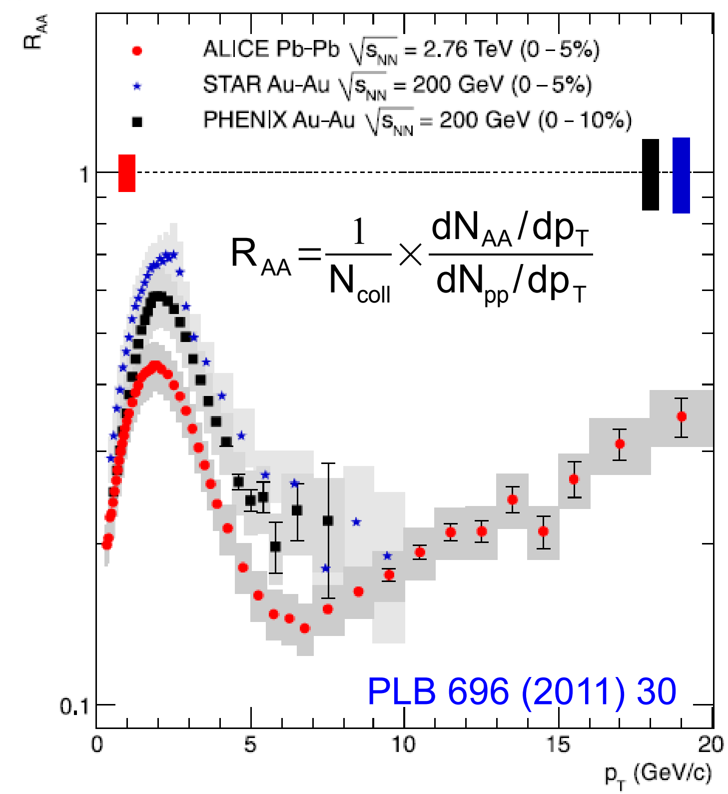


Denser, larger, hotter and strongly coupled





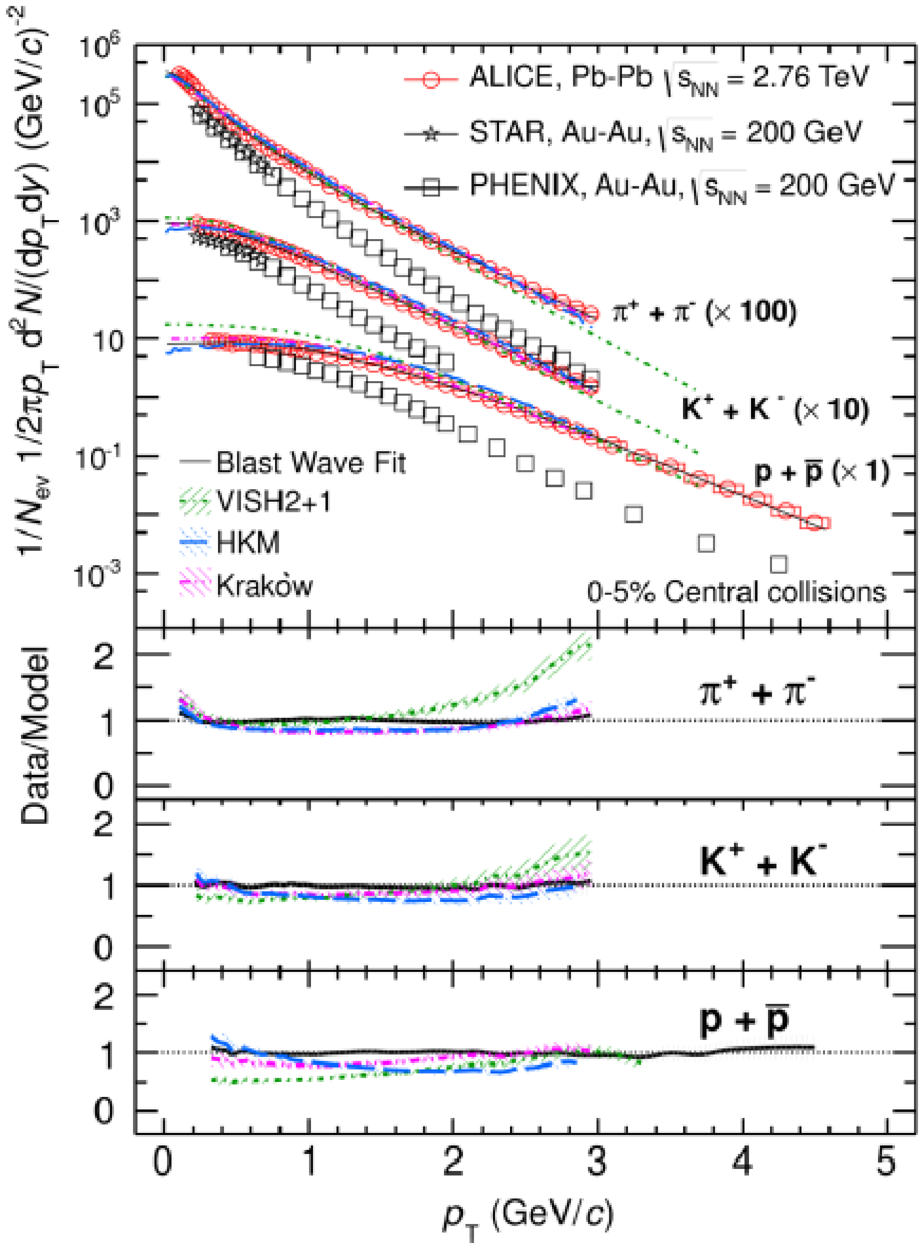


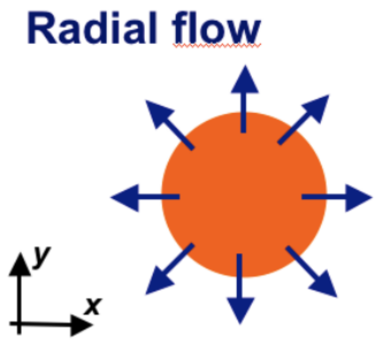


Radial flow and kinetic freeze-out

- Different shape for particles with different masses indicate radial flow
- Hydro calculations can describe the data
- Blast-wave fits assuming a boosted thermal source with a common temperature and radial velocity

PRL 109 (2012) 252301





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

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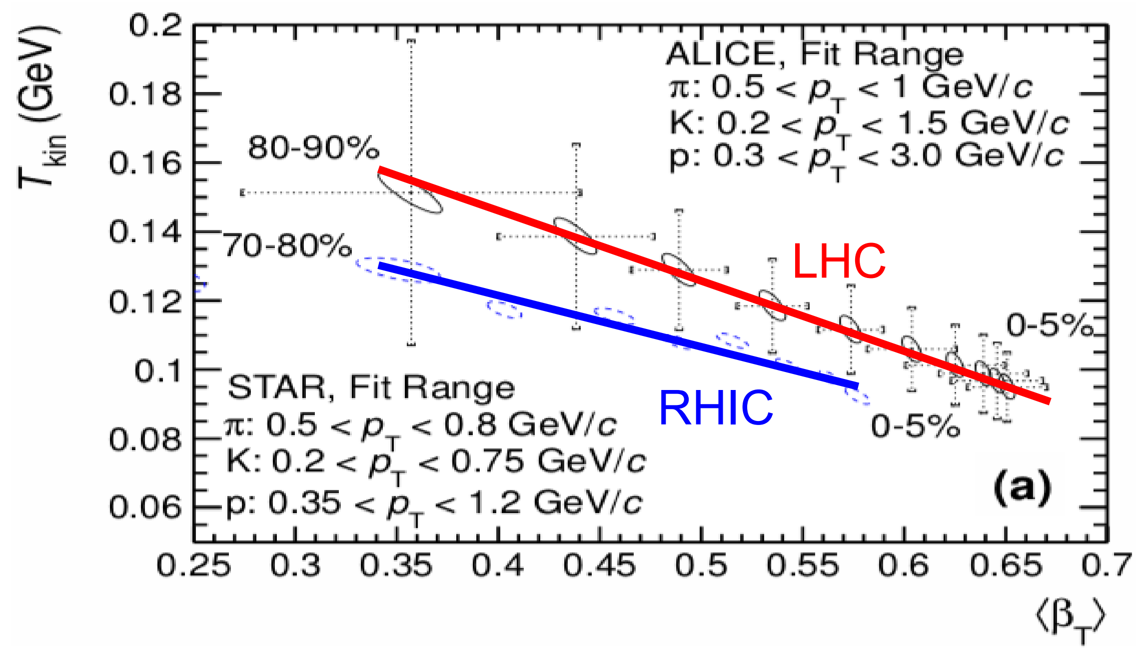
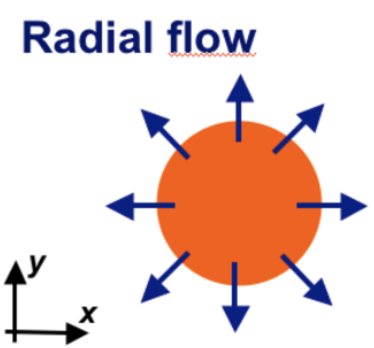
PRL 109 (2012) 252301



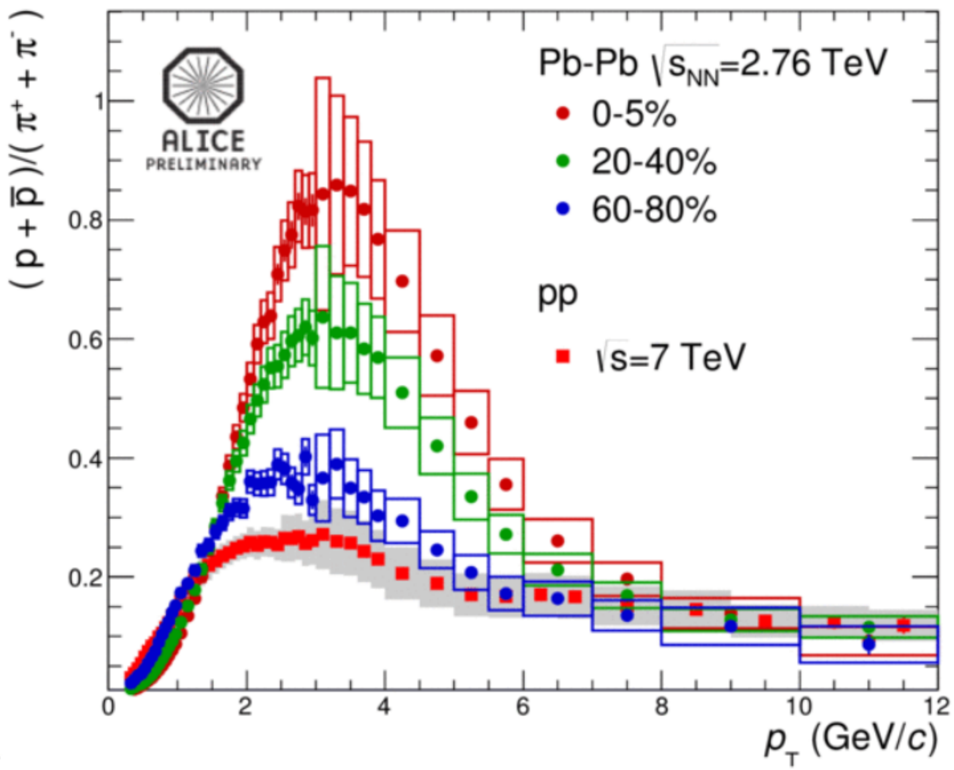
- Strong radial flow up to $\beta_{LHC,central}$ = 0.65c
  - $\beta_{LHC,central}$ = 1.1 $\beta_{RHIC,central}$
- Similar kinetic freeze-out T_{kin}

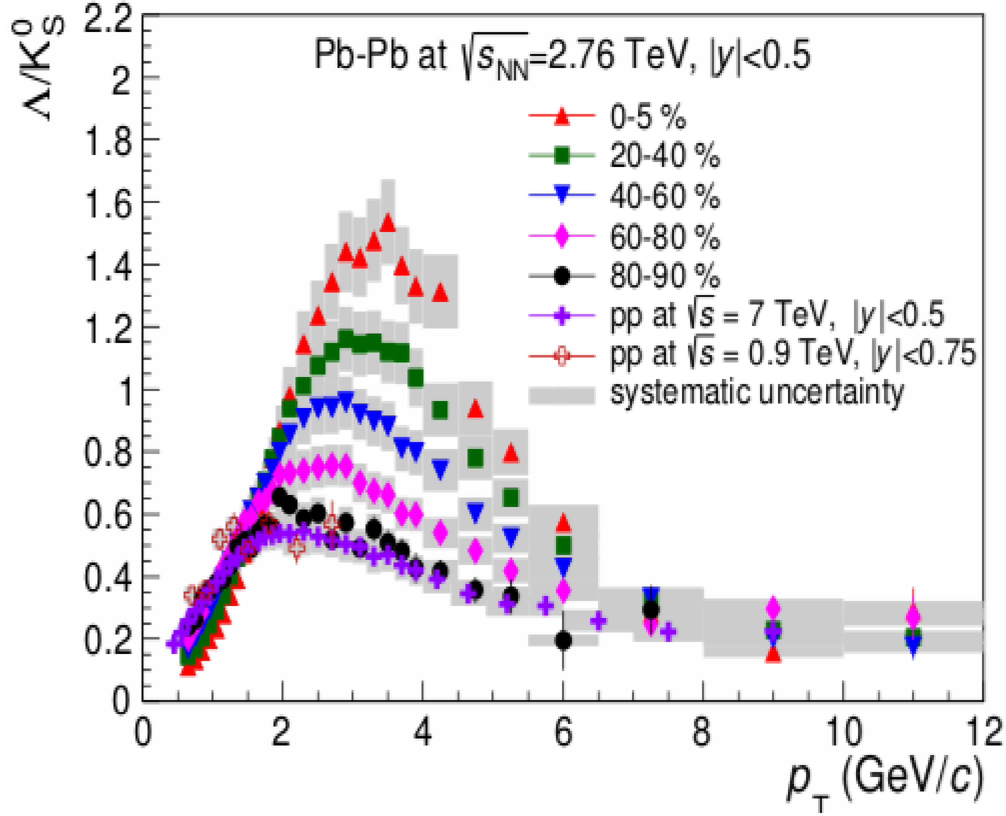


$$p_T^{flow} = p_T + m\beta_T^{flow}\gamma_T^{flow}$$

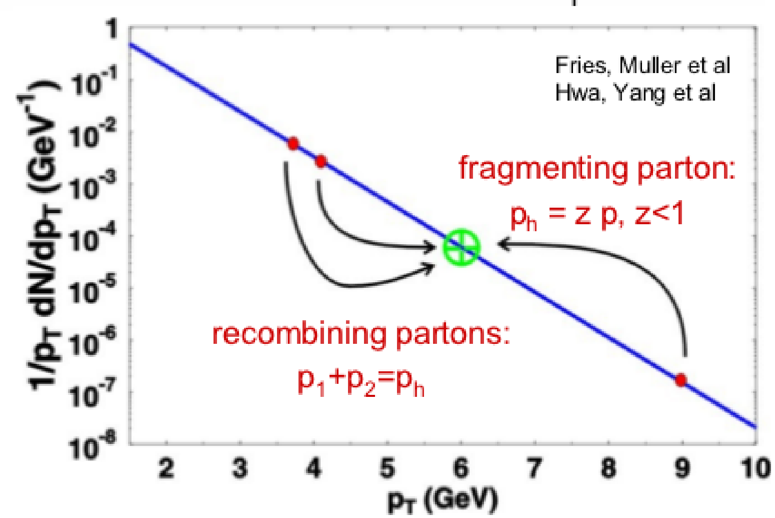
Particle ratios versus p_T

arXiv:1307.5530

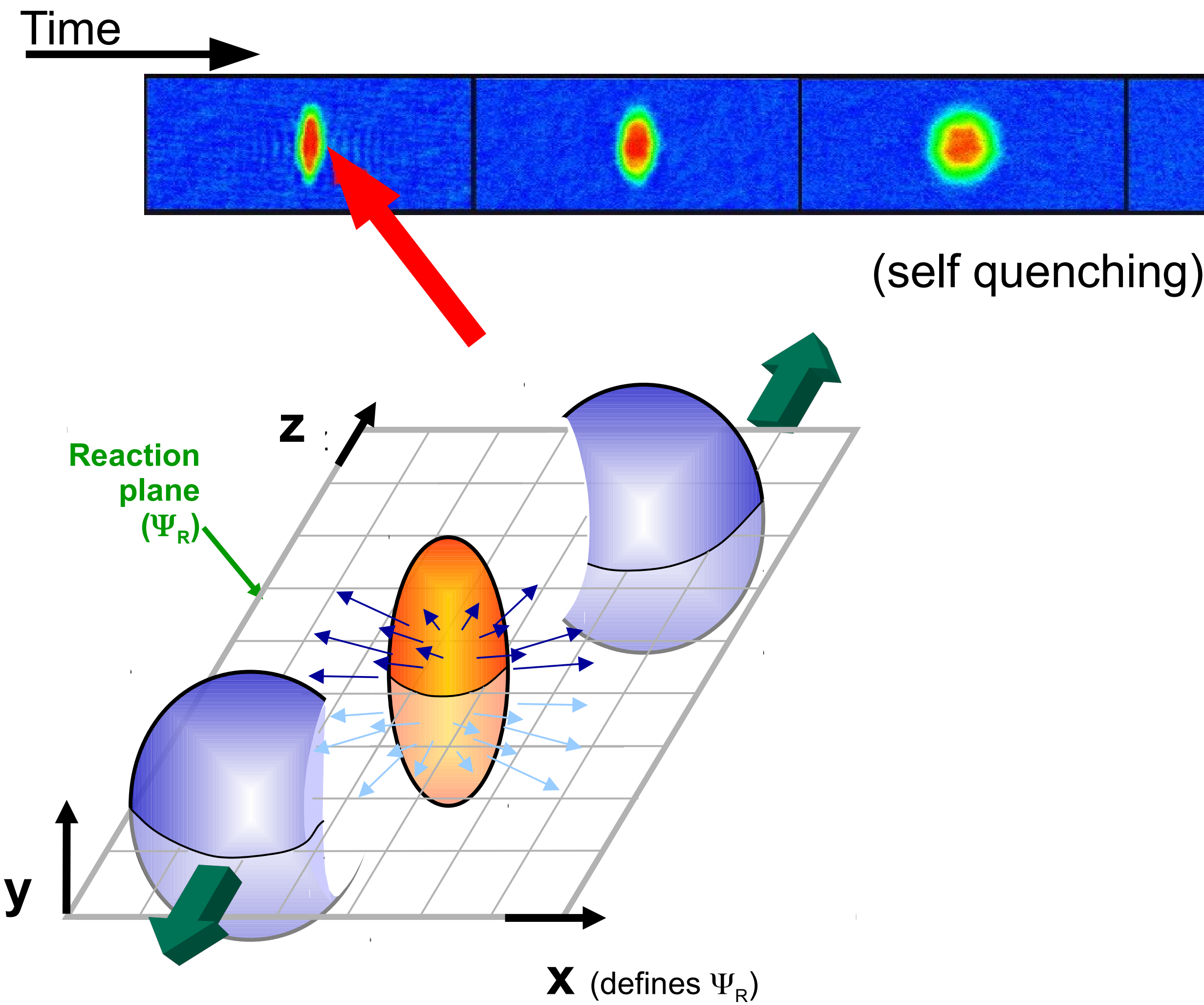


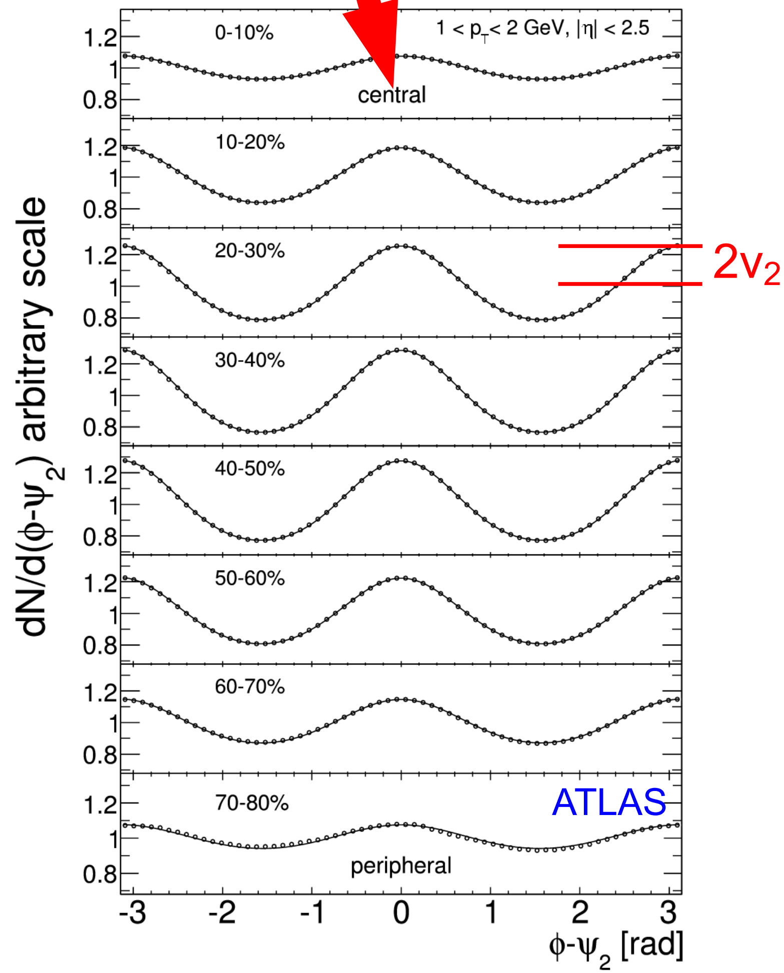


- Enhancement at low and intermediate p_T
  - Typically attributed to radial flow and recombination
- No visible modification at high p_T



Initial and final state anisotropy



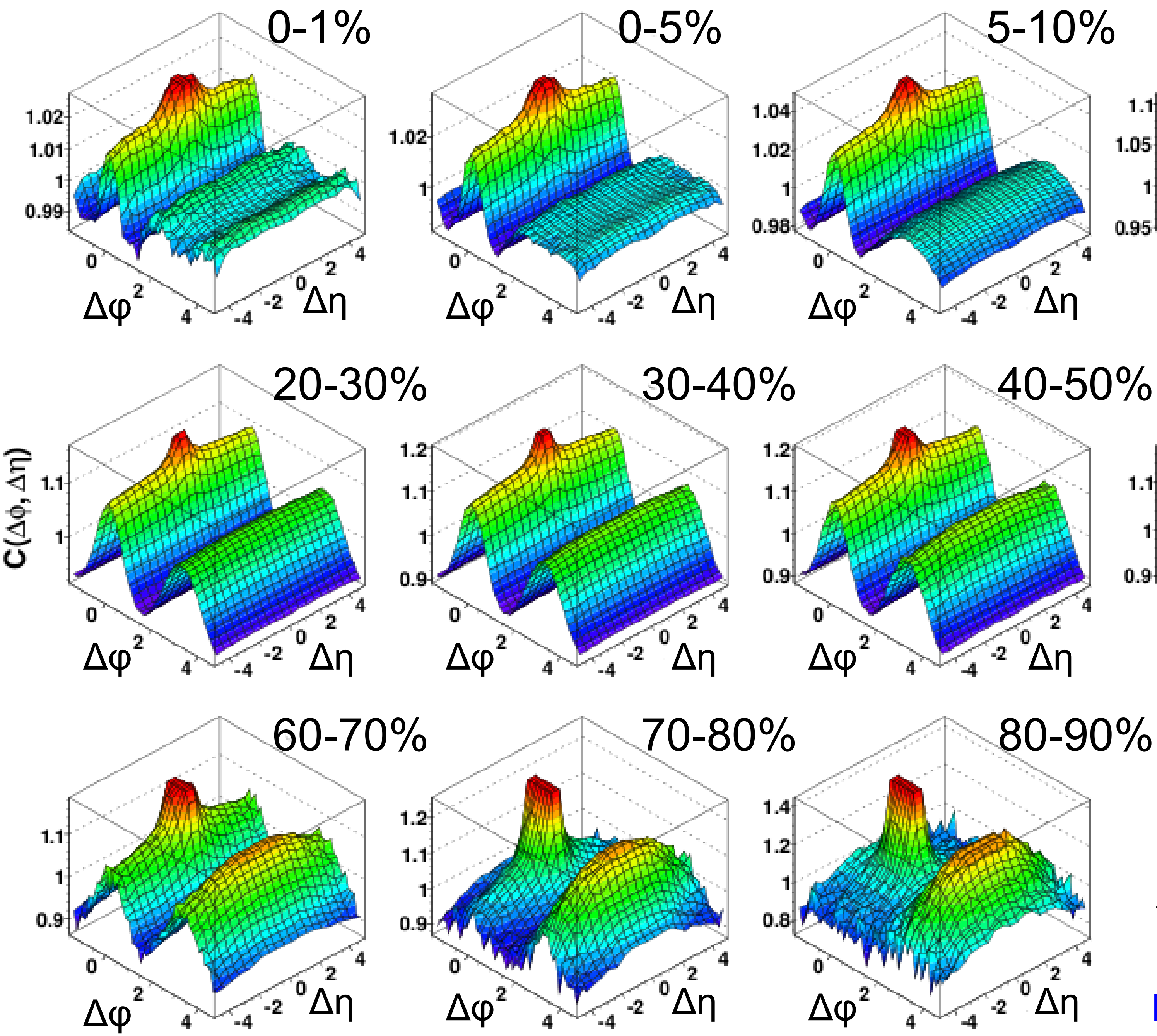


Initial spatial anisotropy: eccentricity ε

Interactions present early

Momentum space anisotropy: elliptic flow $v_2 = \langle \cos(2\varphi - 2\Psi_R) \rangle$

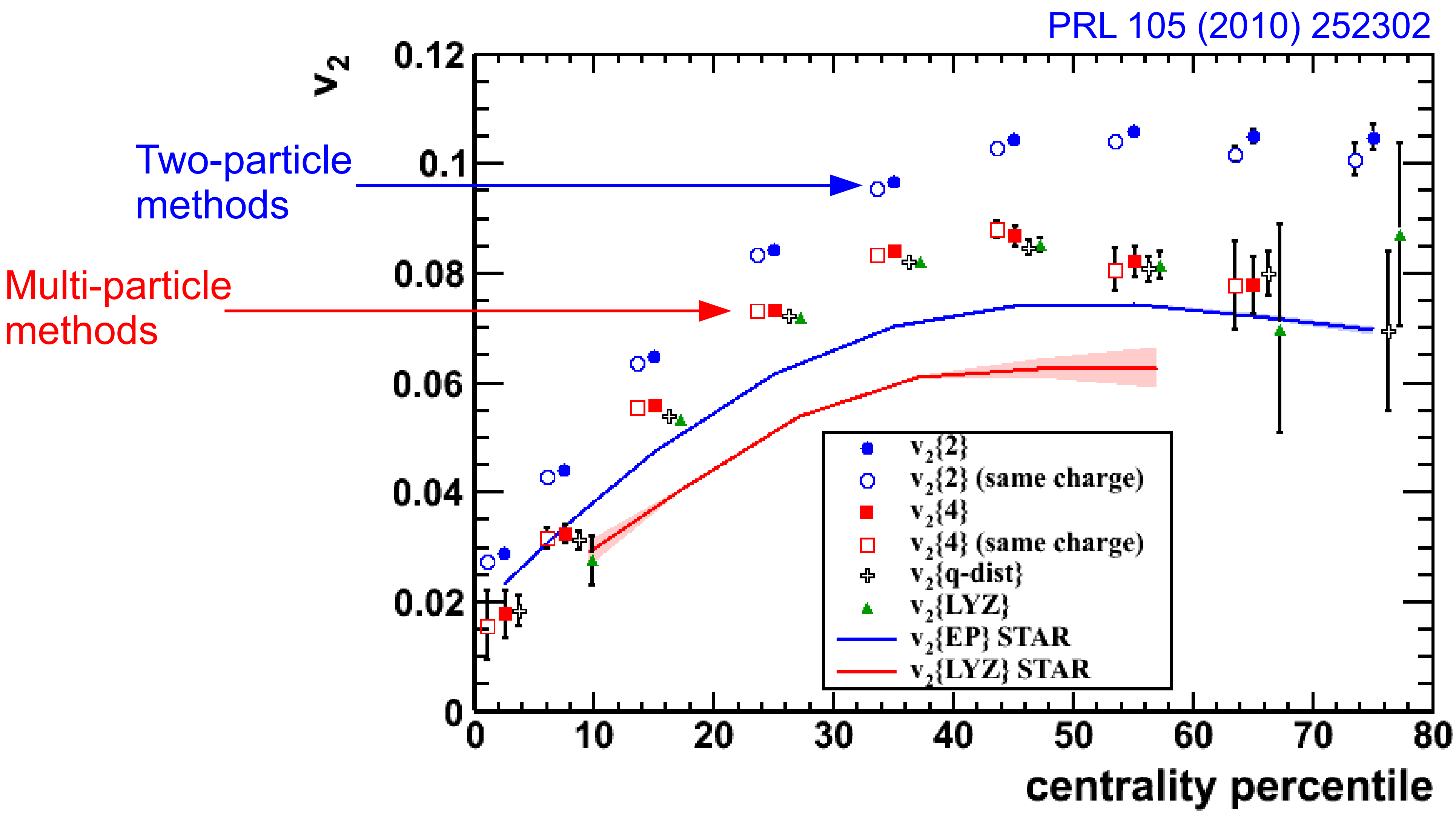
Two-particle angular correlations



ATLAS
$2 < p_T^{trig}, p_T^{assoc} < 3$ GeV/c

PRC 86 (2012) 014907

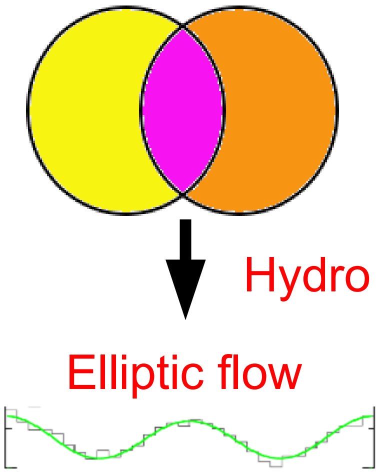
Integrated elliptic flow using various methods 30



Integrated v_2: ~30% larger than at RHIC
(due to the increase of <p_T>)

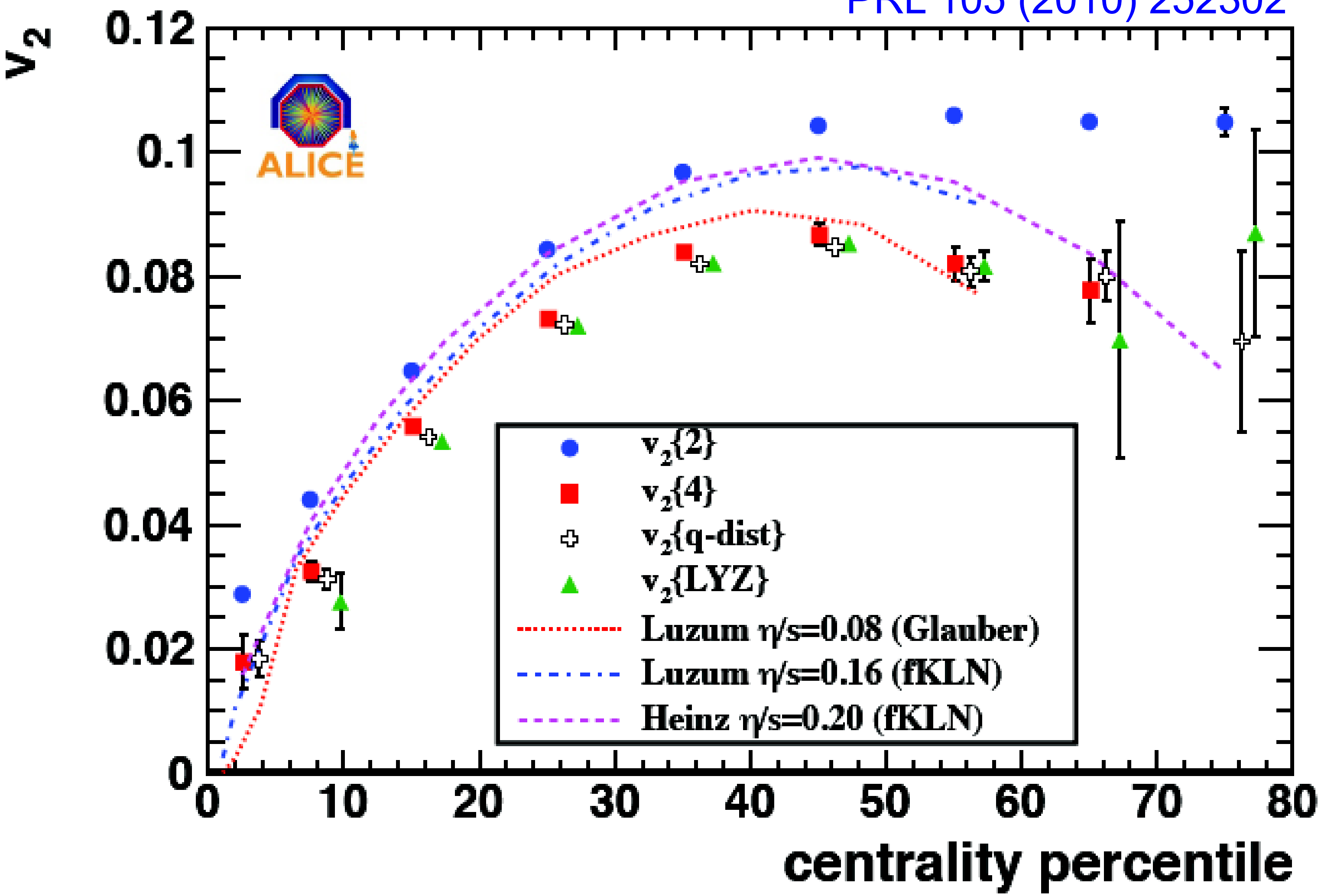
$$v_2 = \langle \cos[2(\phi - \Psi_{RP})] \rangle$$

Integrated elliptic flow and hydro



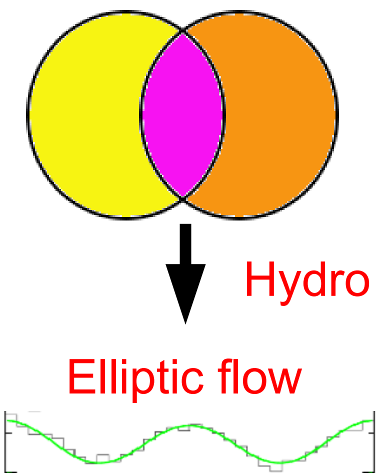
Calculation:
M.Luzum,
arXiv:1011.5173

PRL 105 (2010) 252302



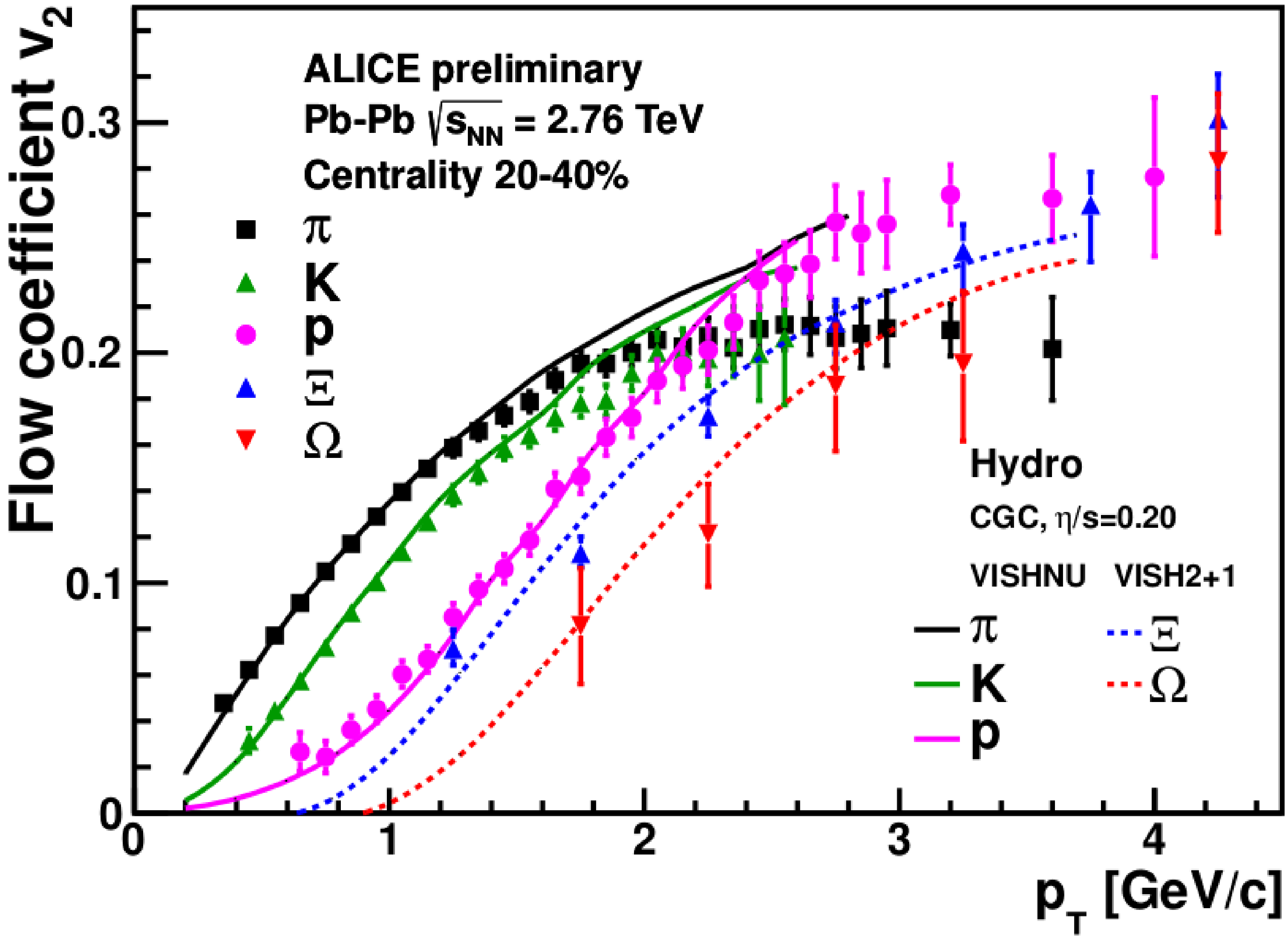
Measured v_2 well within the range of viscous hydro predictions

Identified particle elliptic flow versus p_T



Calculation:
M.Luzum,
arXiv:1011.5173

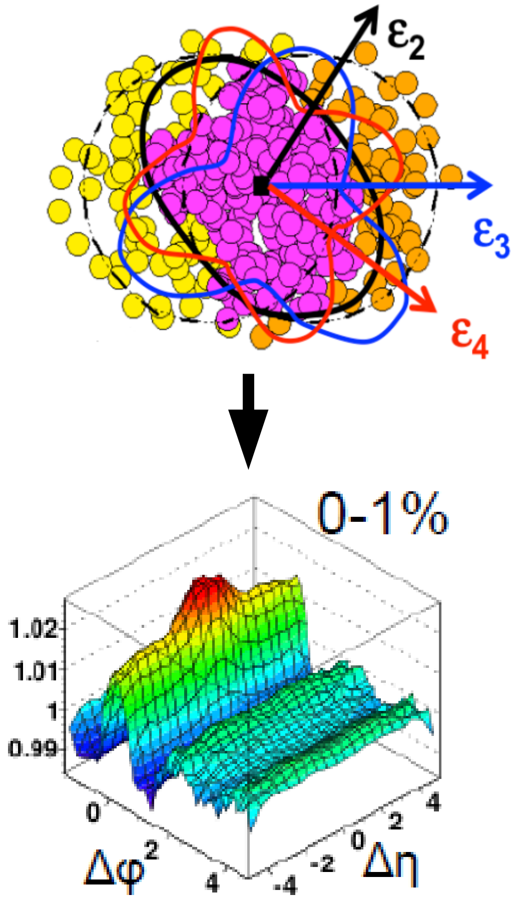
arXiv:1202.3233



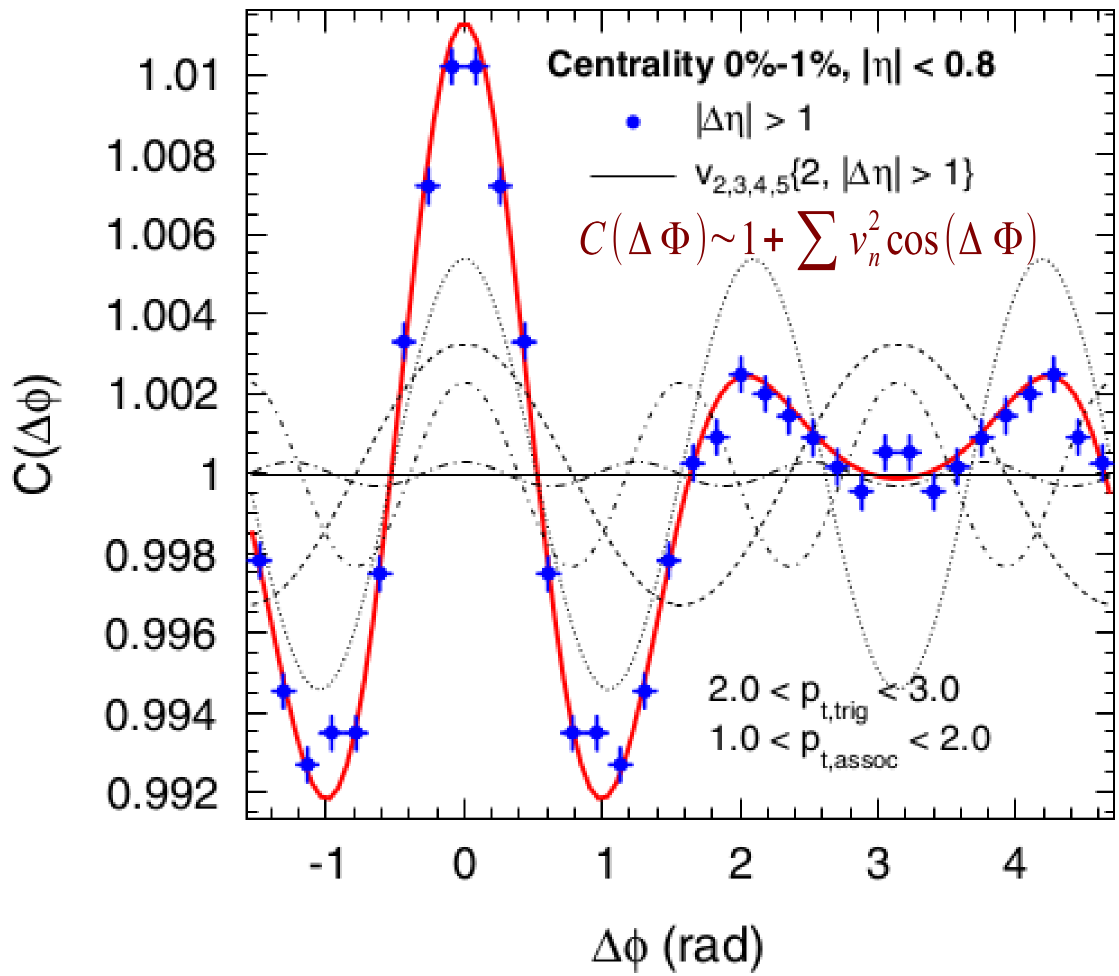
Observed mass ordering in v_2 due to radial flow can be described by hydrodynamical models

Initial state fluctuations and flow ridges

Alver+Roland, 2010



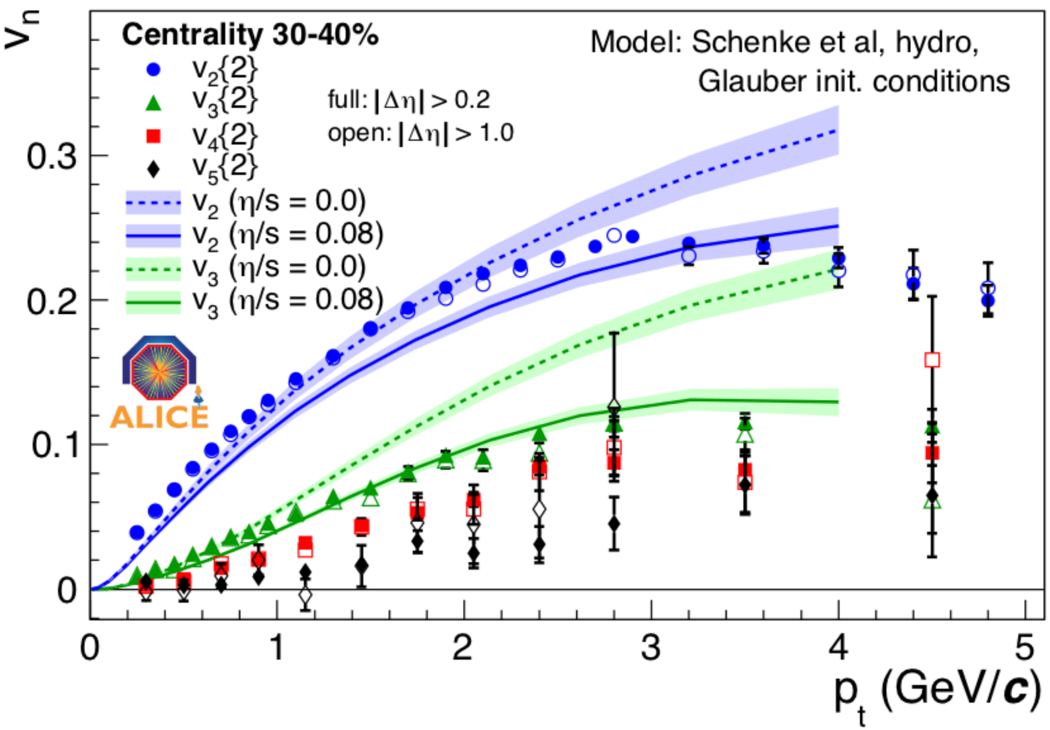
ALICE, PRL 107 (2011) 032301

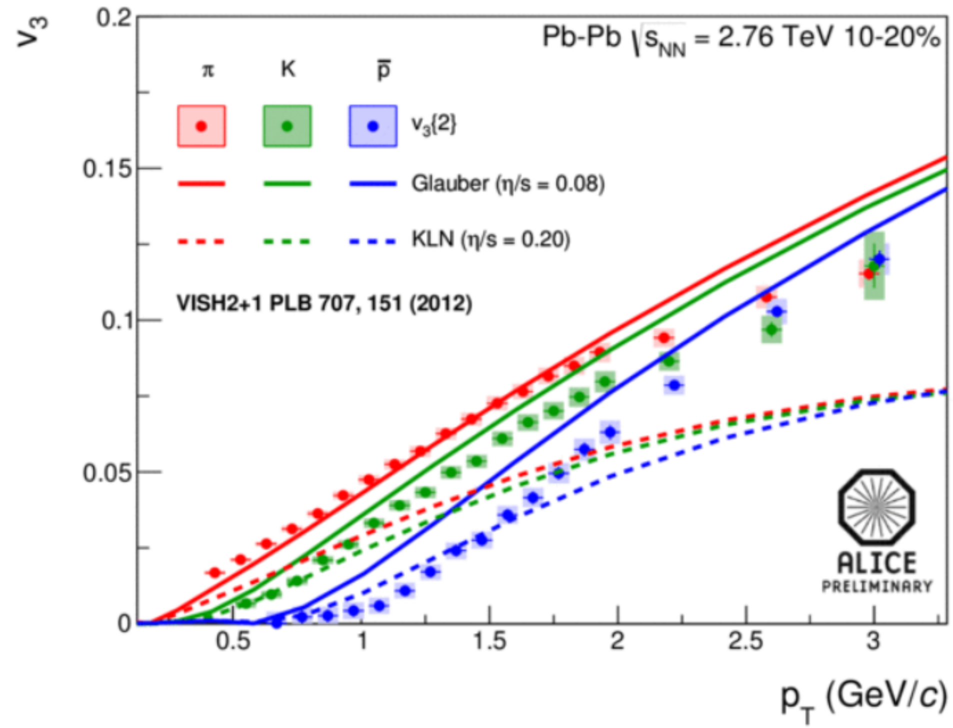


Structures seen in two particle correlations are naturally explained by measured flow harmonics assuming fluctuating initial conditions.

Second and higher harmonic flow

PRL 107 (2011) 032301



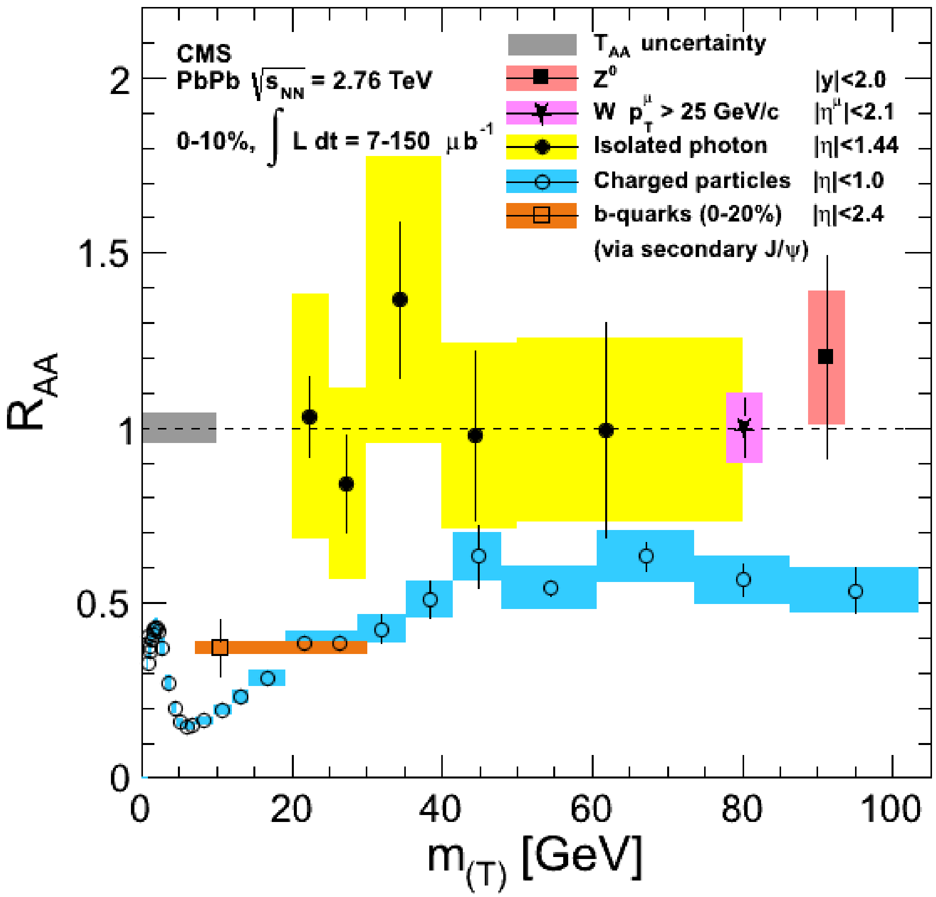


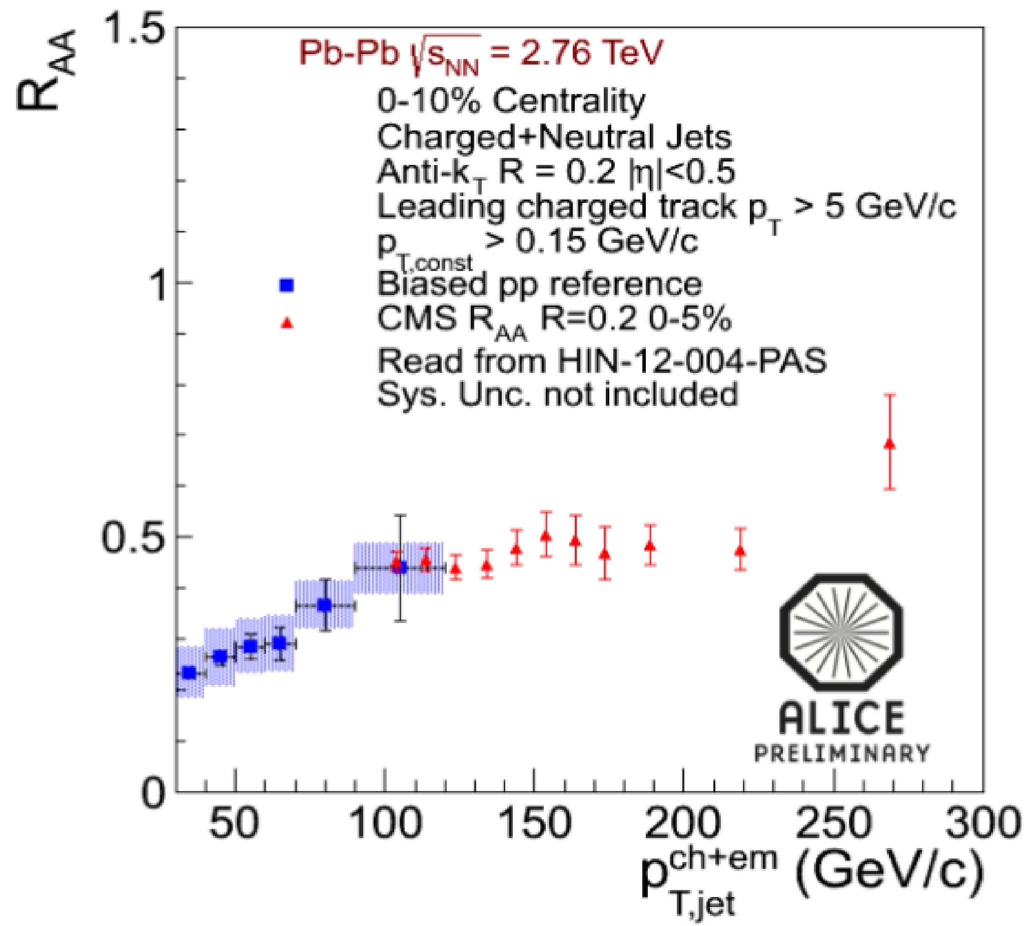
- Significant triangular (and higher harmonic) flow observed
  - Centrality dependence as expected if arising from fluctuations (not shown)
- Measured harmonics provide strong constraints to viscous hydrodynamical calculations

- Similar mass splitting for v_3
- Can be described by hydro (+ hadronic afterburners)
- Provides additional constraints on η/s

Nuclear modification factor

$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$



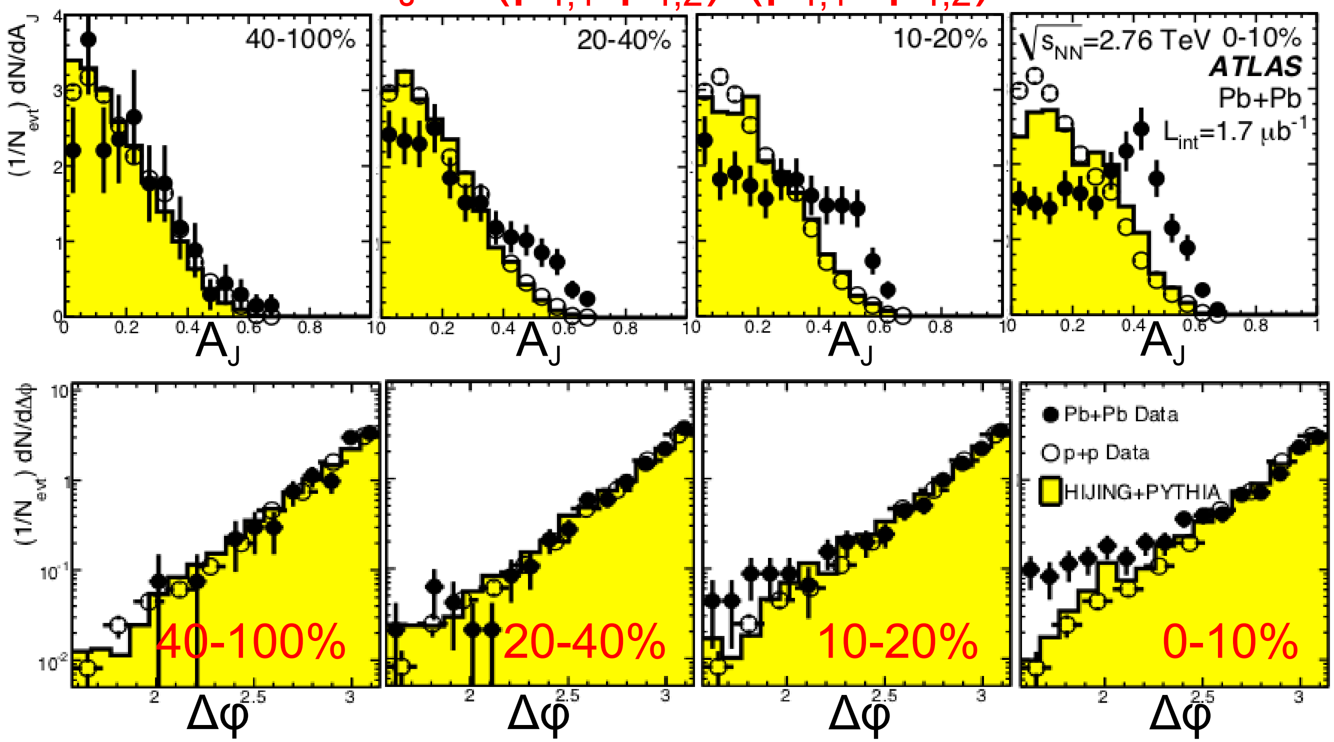


- Control probes (isolated γ, Z, W) scale, ie. $R_{AA} \sim 1$
- Charged particles strongly suppressed, ie. $R_{AA} \sim 0.5$ at high p_T

- Even jets are strongly suppressed
- Above 100 GeV/c, suppression similar to that of charged hadrons, ie. $R_{AA} \sim 0.5$ for high E_T

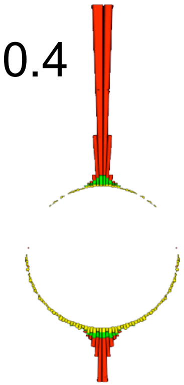
Dijet suppression aka momentum imbalance

$A_J = (p_{T,1}-p_{T,2})/(p_{T,1}+p_{T,2})$



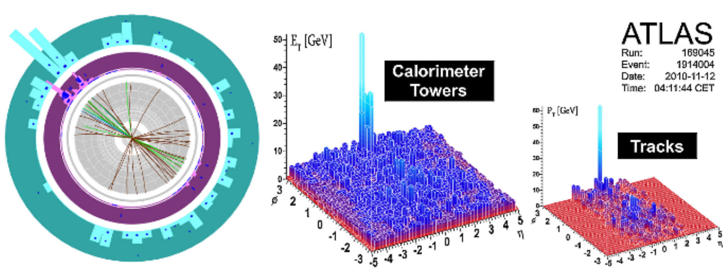
$p_{T,1}$>100 GeV/c

R=0.4

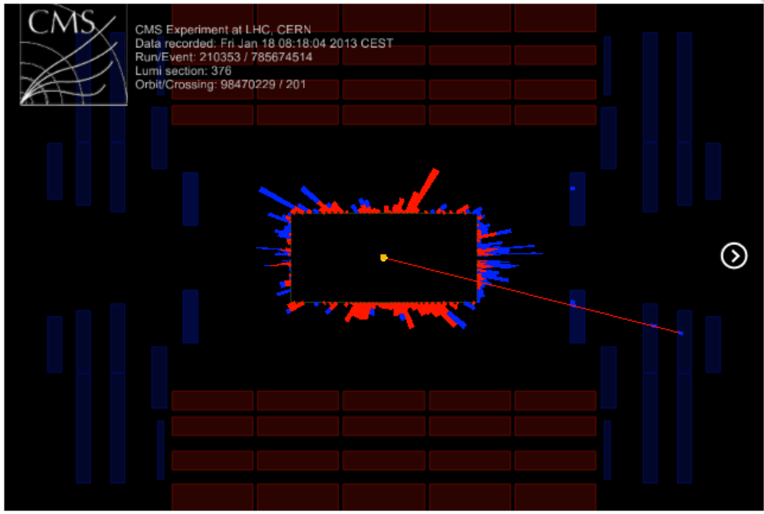


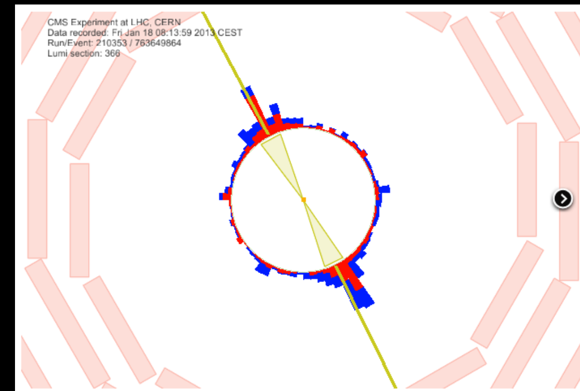
$p_{T,2}$>25 GeV/c

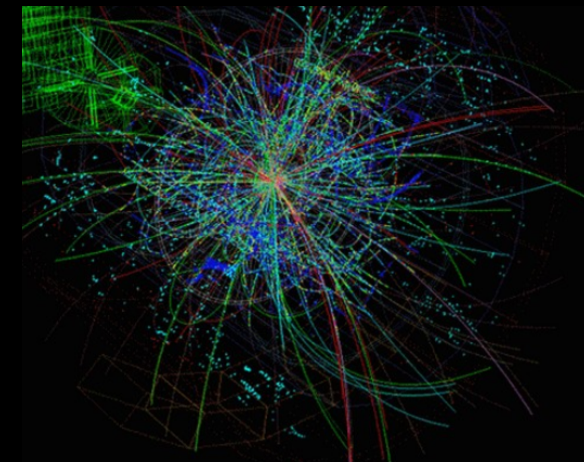
Larger momentum imbalance wrt to MC reference.
Difference increases with increasing centrality.
But no (very little) increasing azimuthal decorrelation.

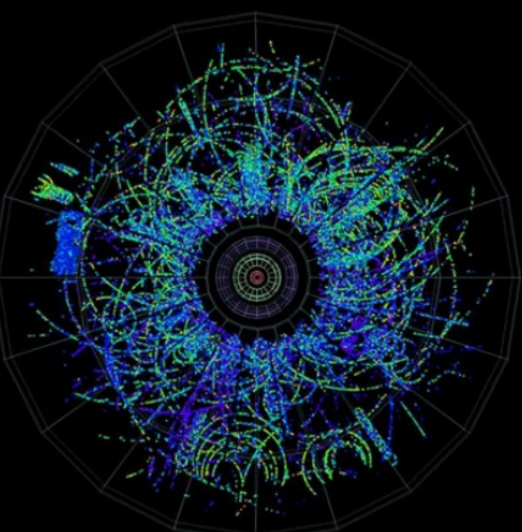


ATLAS, PRL 105 (2010) 252303
CMS, PRC 84 (2011) 024906

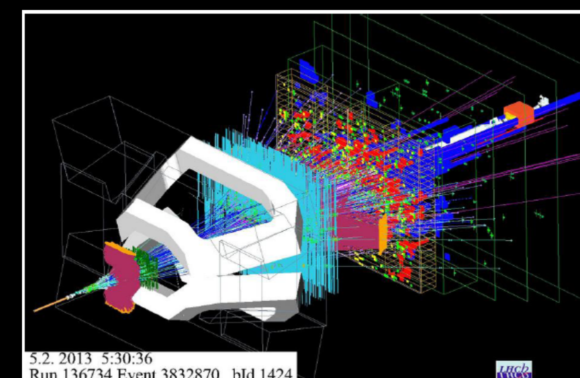


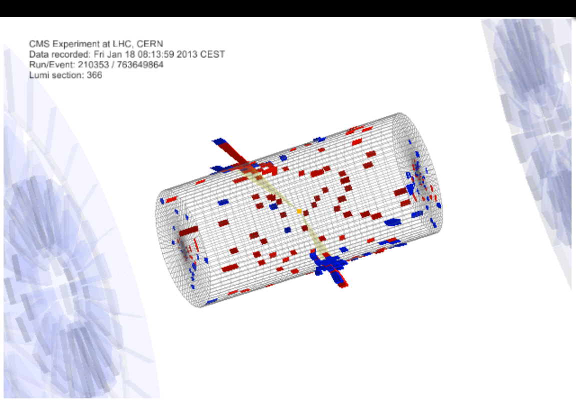


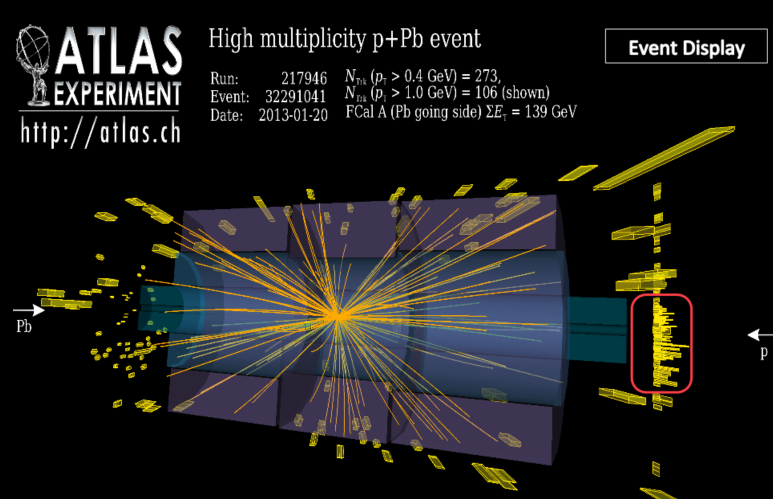


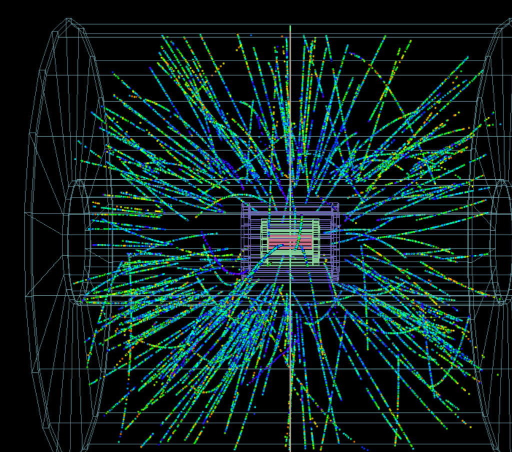


Results from pPb collisions at the LHC









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, PLB 725 (2013) 60, 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, arXiv:1308.6726, Inclusive J/ψ production
11. LHCb, arXiv:1308.6729, 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 (v_2) 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
22. CMS-HIN-13-003, Υ(1S), Υ(2S) and Υ(3S) compared to pp and PbPb
23. ATLAS-CONF-2013-096, Centrality dependence of dN/dη

Selected pPb results

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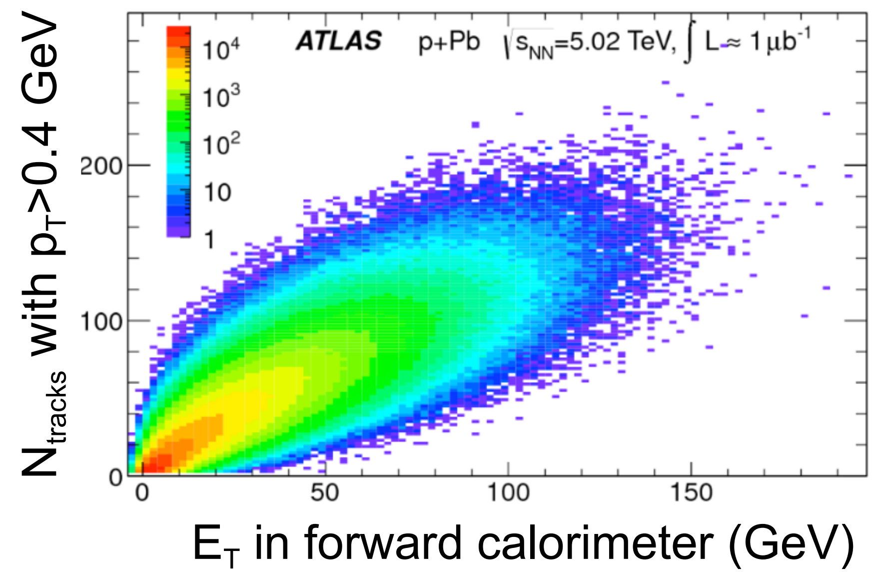
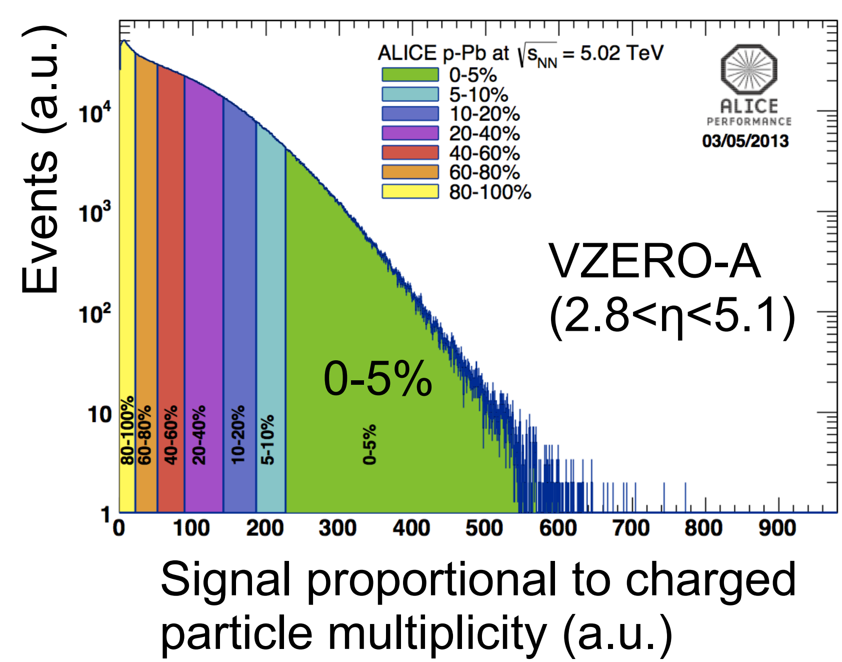
Color code:
Spectra,
v_2, v_3, etc.
Hard probes

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 exhibits features of biased pp (NN) collisions in the multiplicity tails
  - Results in bias so that N_{coll} from Glauber is the the only scaling variable
  - 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

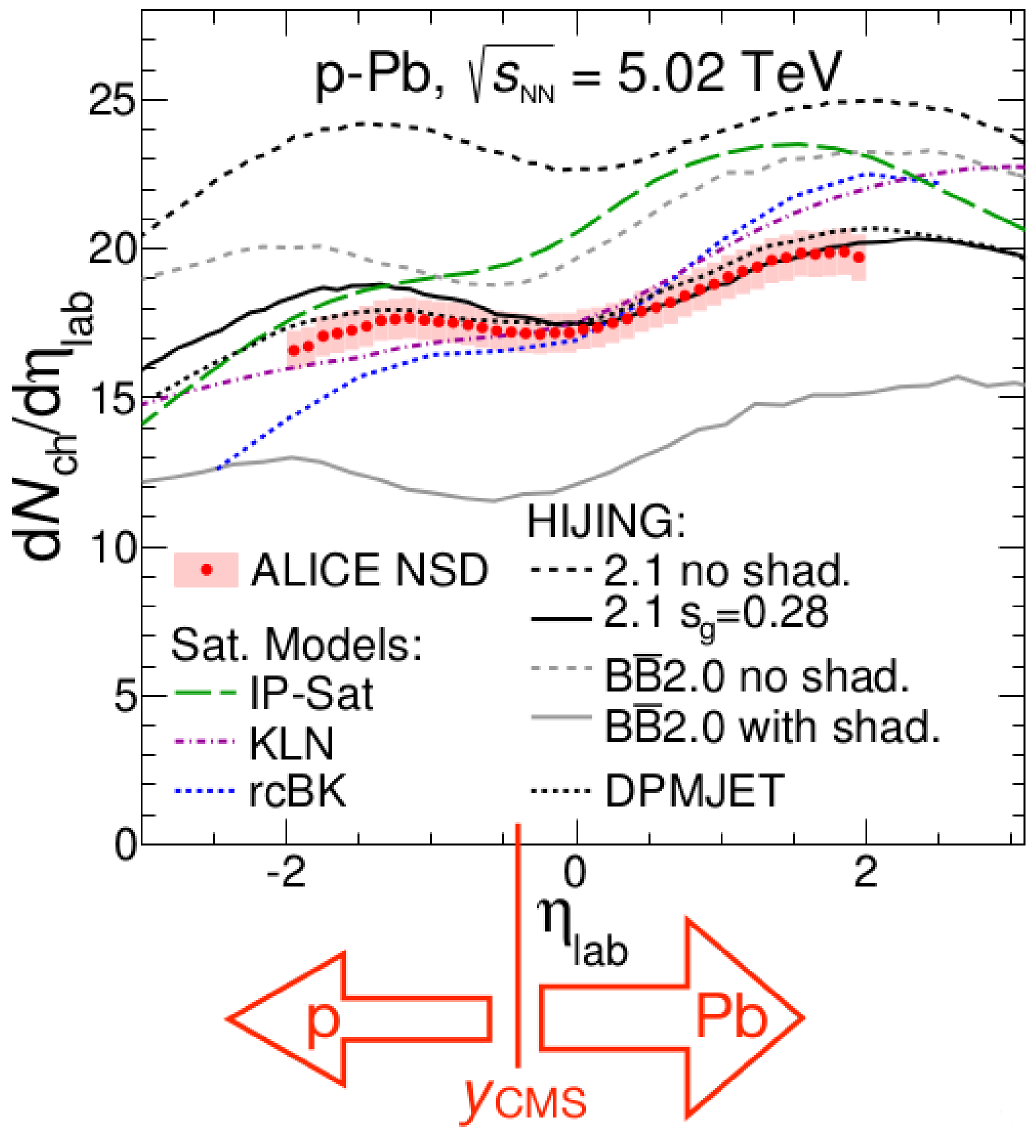




Charged particle pseudorapidity density

ALICE, PRL 110 (2013) 032301

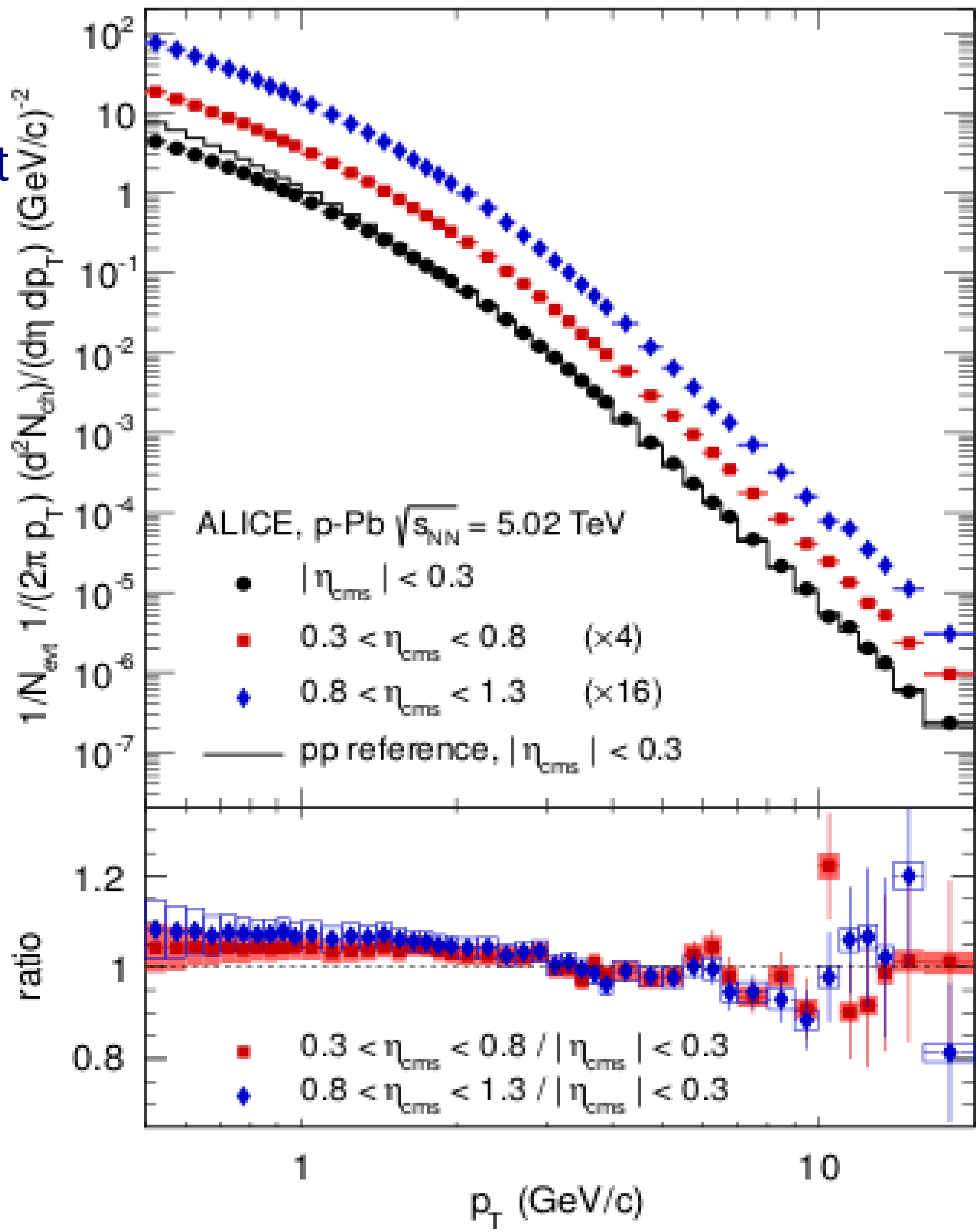
- Tracklet based analysis
  - Dominant systematic uncertainty from NSD normalization of 3.1%
- Reach of SPD extended to |η|<2 by extending the z-vertex range
- Results in ALICE laboratory system
  - y_{cms} = - 0.465 (direction of proton)
- Comparison with models
  - Most models within 20%
  - Saturation 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

- Primary charged tracks (3 η bins)
  - Reconstructed in ITS+TPC ($|\eta|<0.8$)
  - 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

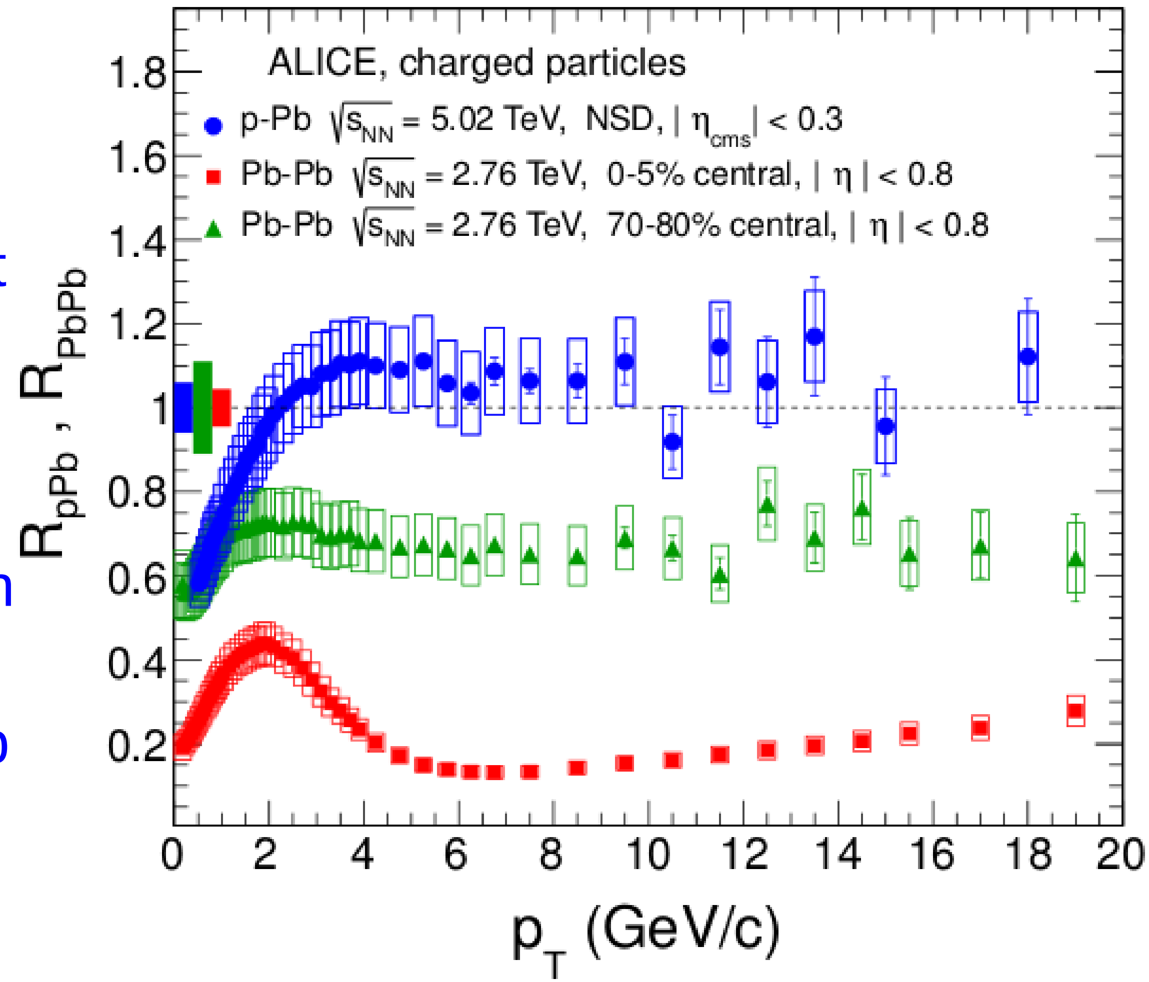


Nuclear modification for charged particles

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

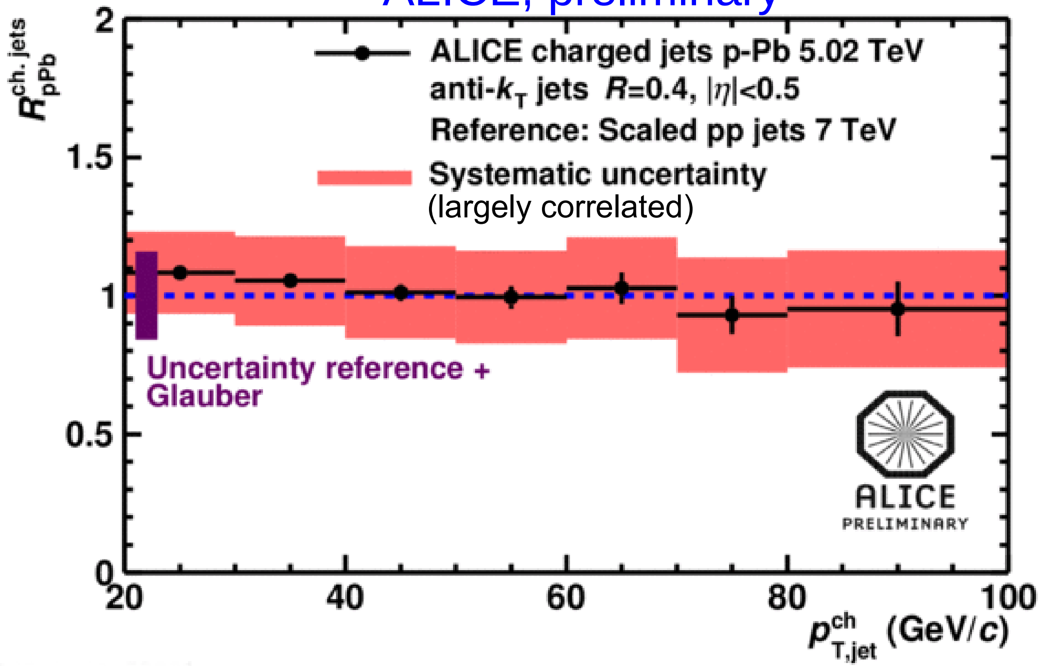
- R_{pPb} (at mid-rapidity) consistent with unity for p_T > 2 GeV/c
- High-p_T charged particles exhibit binary scaling
- Unlike in PbPb, no suppression at high p_T is observed
- Suppression at high p_T in PbPb is not an initial state effect

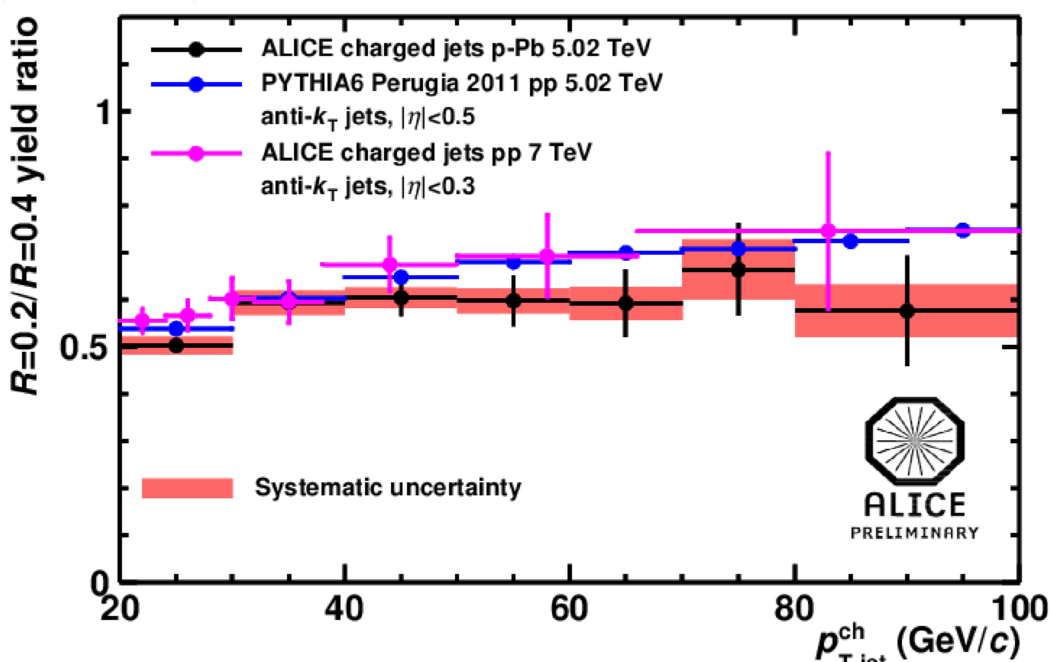
ALICE, PRL 110 (2013) 082302



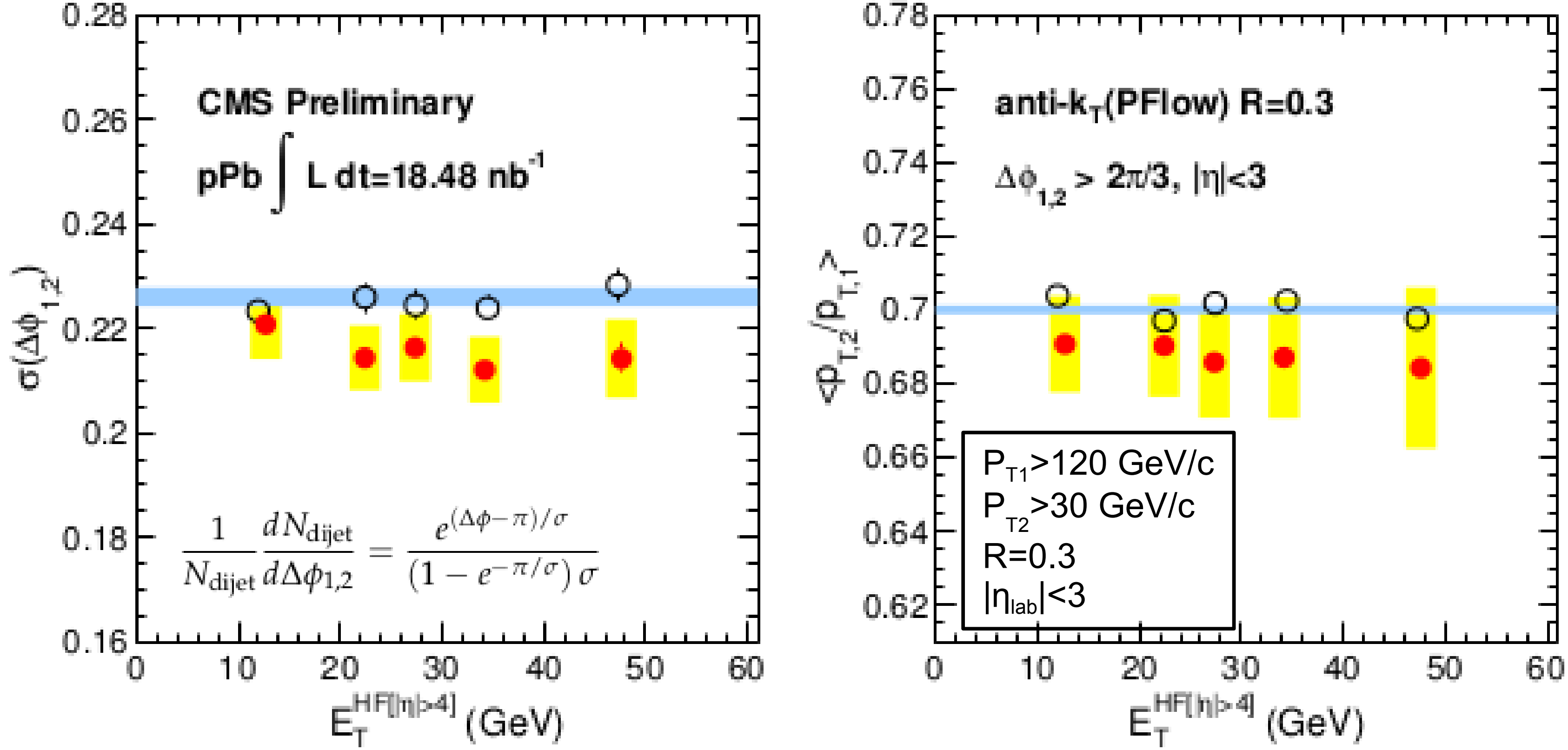
- Charged jet spectrum in minimum bias pPb with anti-k_T for R=0.2 and 0.4 in $|\eta_{lab}|<0.5$
  - Subtraction of UE with jet area/median approach (CMS, JHEP 08 (2012) 130)
  - Unfolding of background fluctuations and detector response using SVD
- Reference spectrum for pp using 7 TeV data and scaled 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





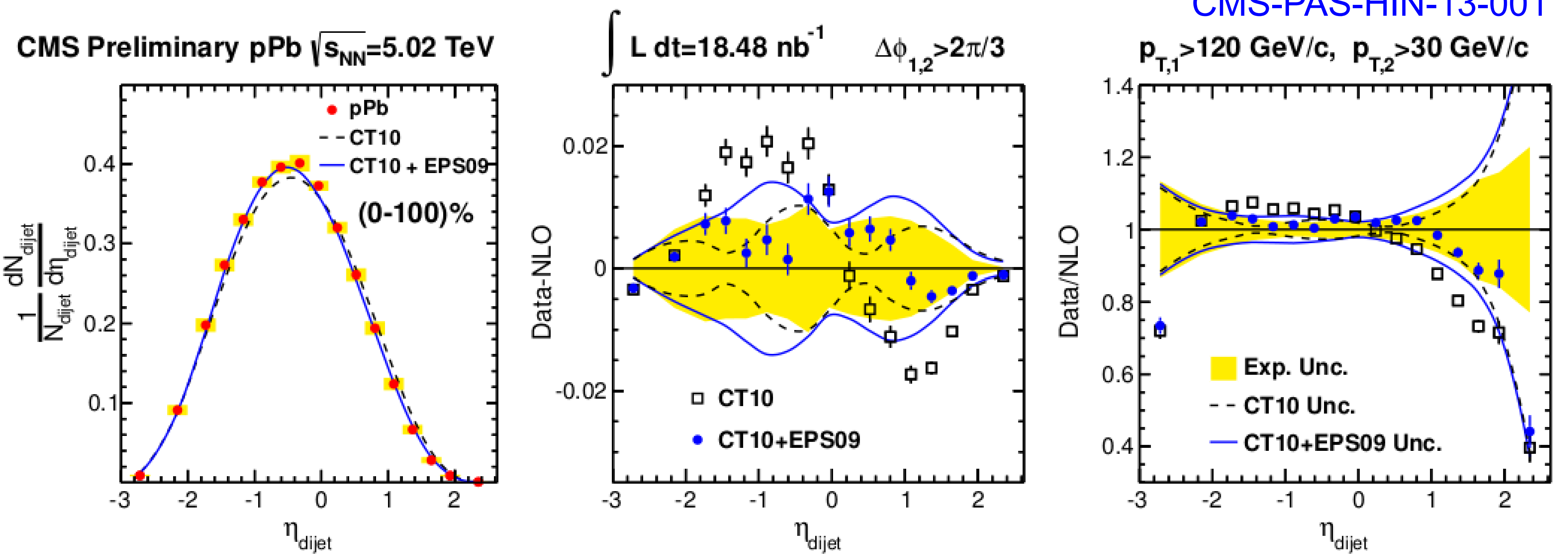
CMS-PAS-HIN-13-001

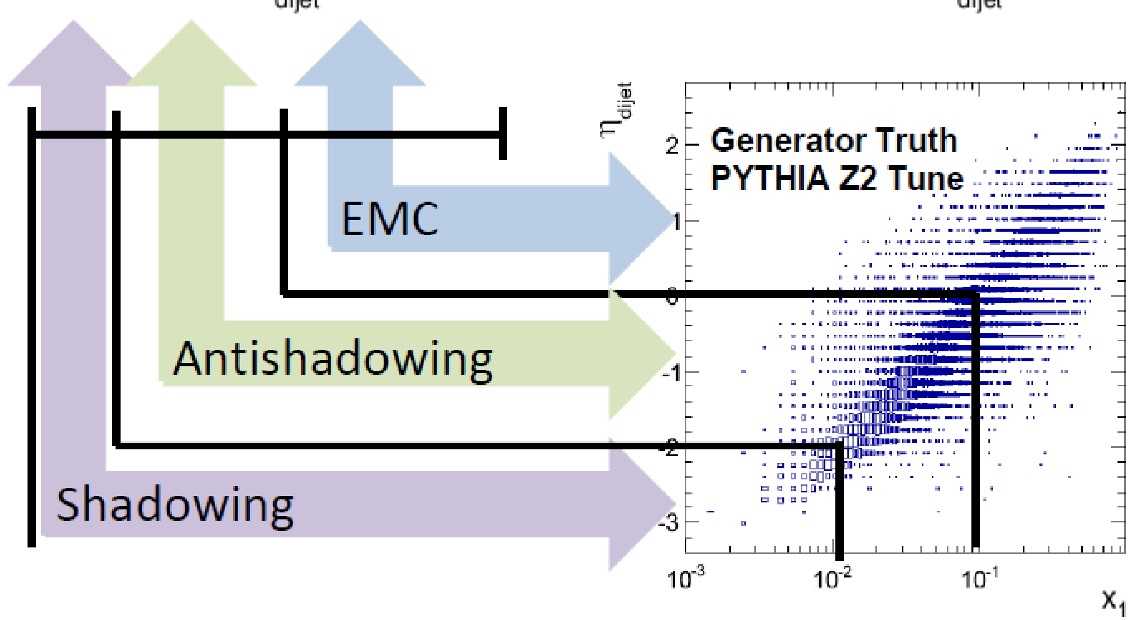


No significant modification in the momentum ratio of subleading over leading jet (e.g. induced by jet quenching) is observed. Large imbalance measured in AA is final state effect.

Dijet properties: η_{dijet} distribution

CMS-PAS-HIN-13-001

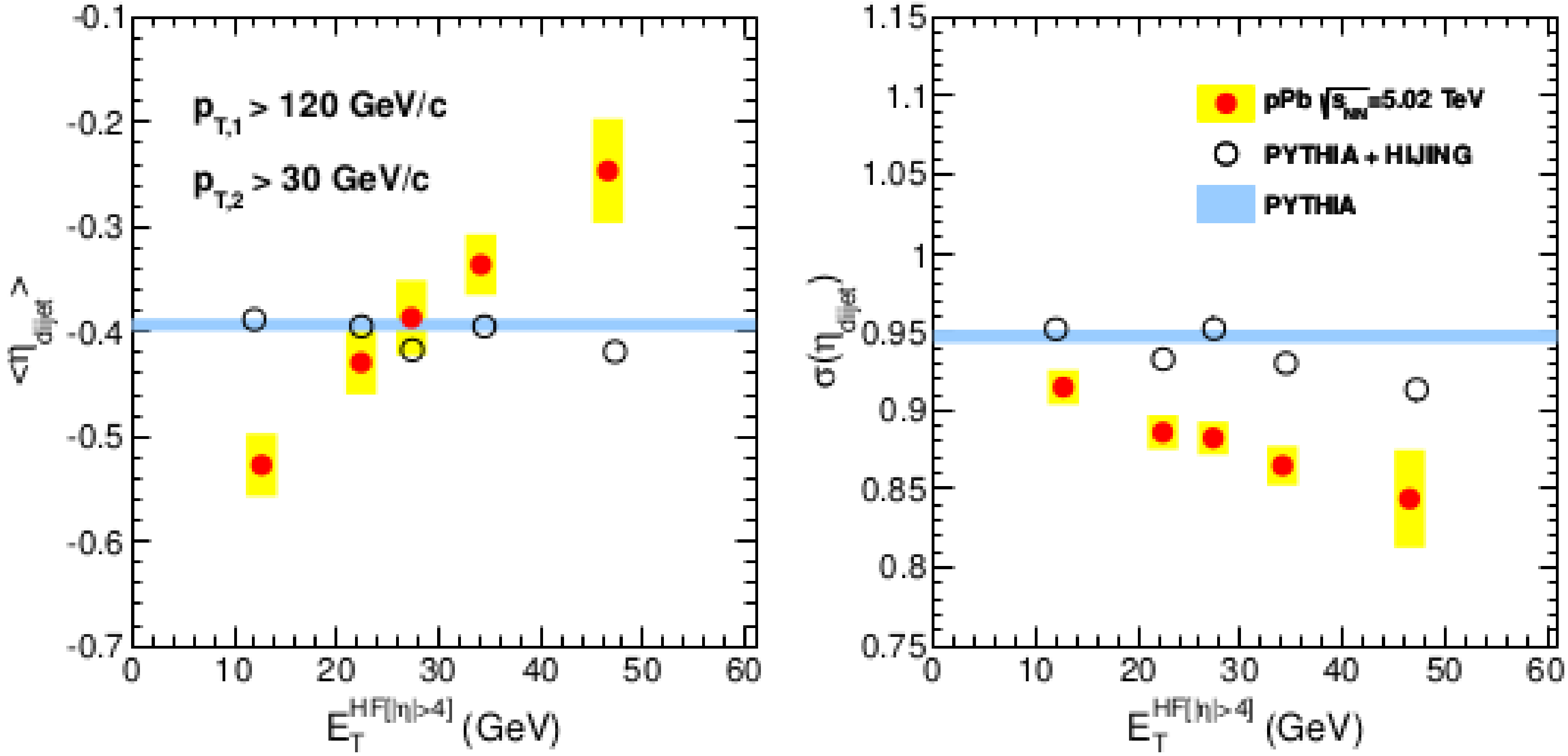




- Data provide sensitivity to nuclear PDFs
- Good agreement with EPS09
- Data slightly more modified in Anti-shadowing and EMC region

Dijet properties: η_{dijet} distribution

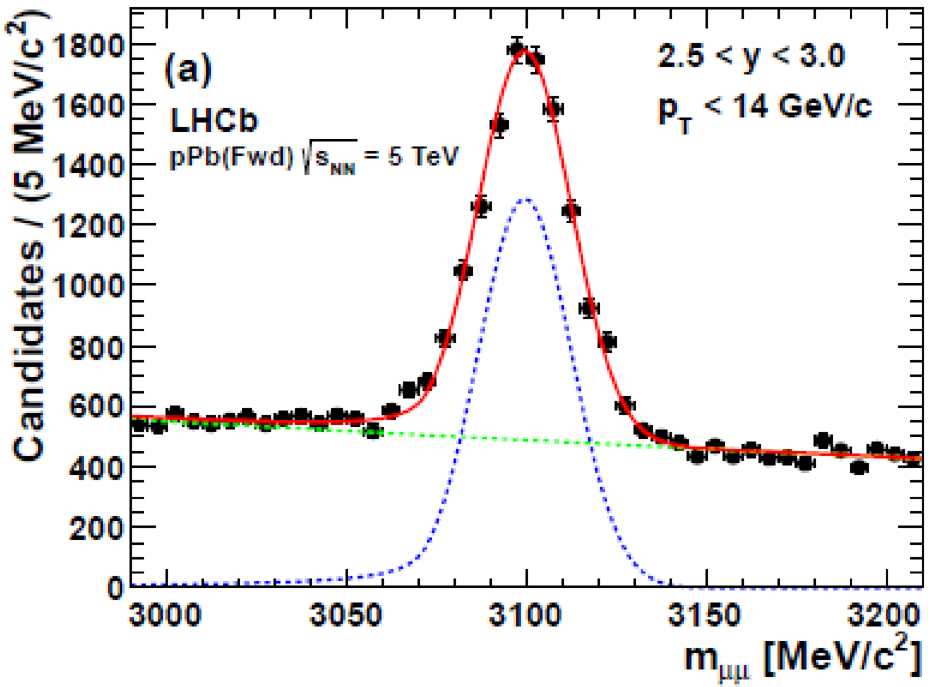
CMS-PAS-HIN-13-001



Dijet η shifts forward (and width decreases) for increasing forward energy. Change much stronger than expected from nuclear PDFs.

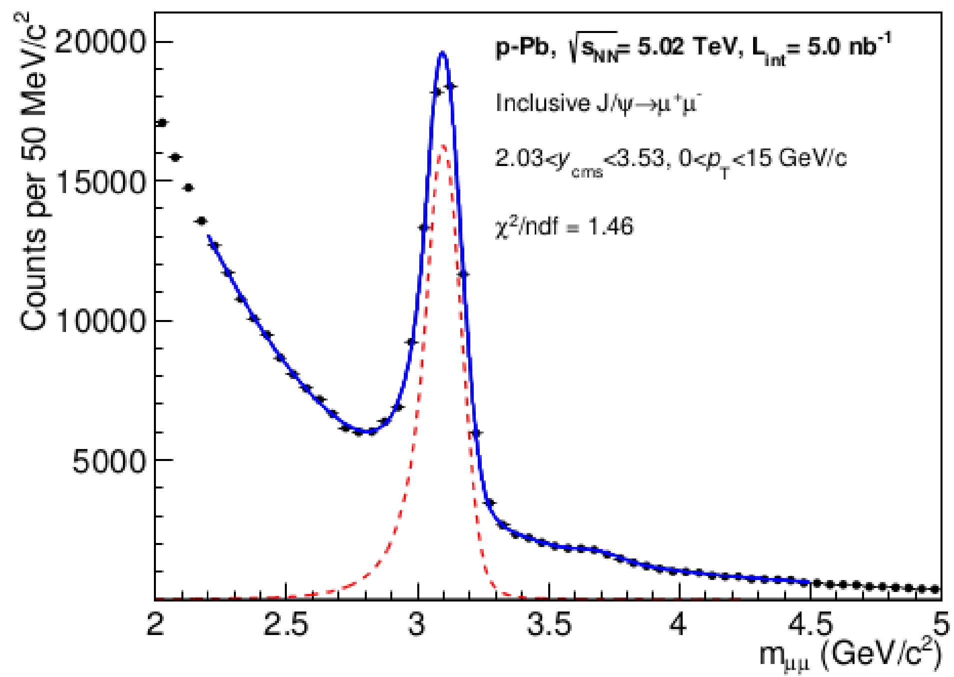
J/ψ production

LHCb, arXiv:1308.6729



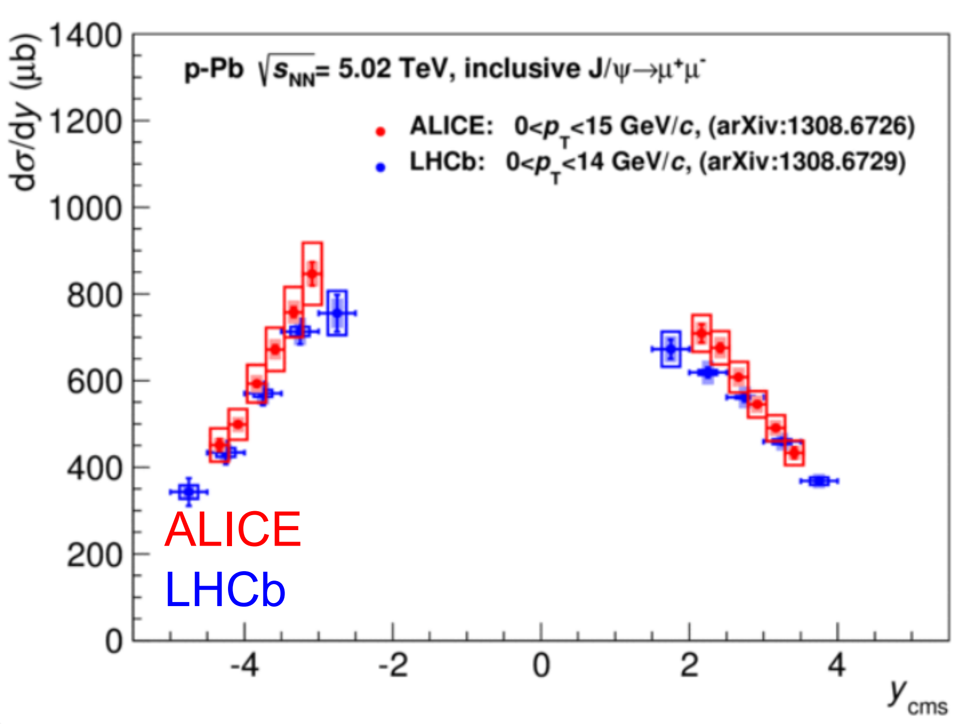
- Extraction of prompt J/psi and J/psi from b decays using simul-taneous fits of mass (CB+Exp) and pseudo-proper time
- Report cross sections
  - Forward: 1.5<y<4.0 (1.1/nb)
  - Backward: -5.0<y<-2.5 (0.5/nb)
  - p_T<14 GeV/c

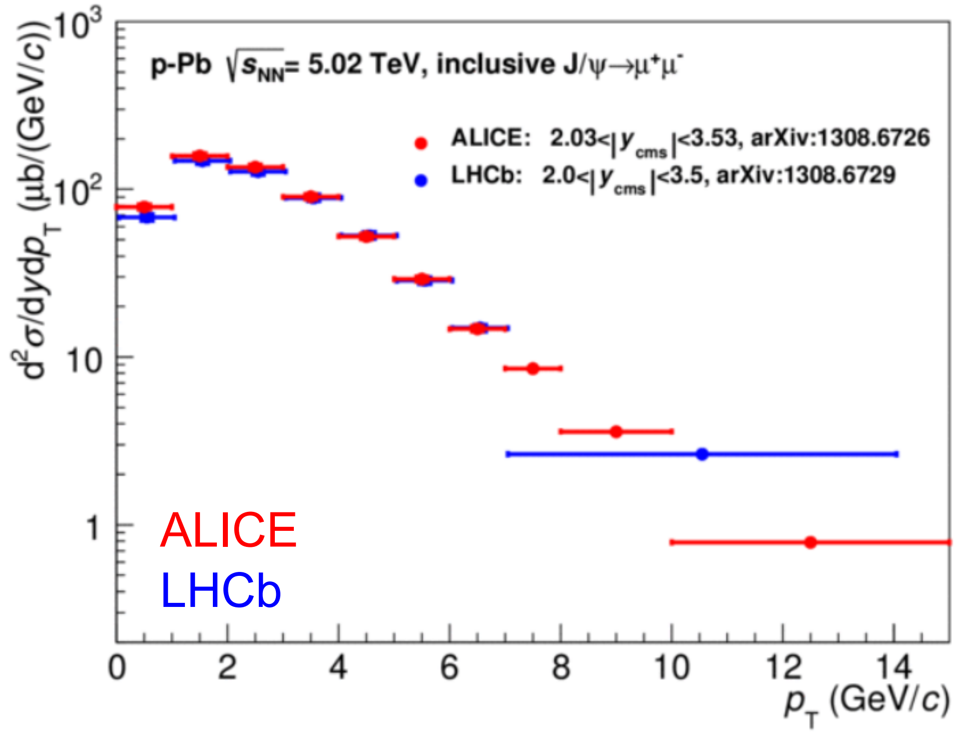
ALICE, arXiv:1308.6726



- Extraction of inclusive J/psi using Crystal Ball for signal and exponential plus polynomial for background
- Report cross sections
  - Forward: 2.03<y<3.53 (5.0/nb)
  - Backward: -4.46<y<-2.96 (5.8/nb)
  - p_T<15 GeV/c

Comparison: Inclusive J/ψ production

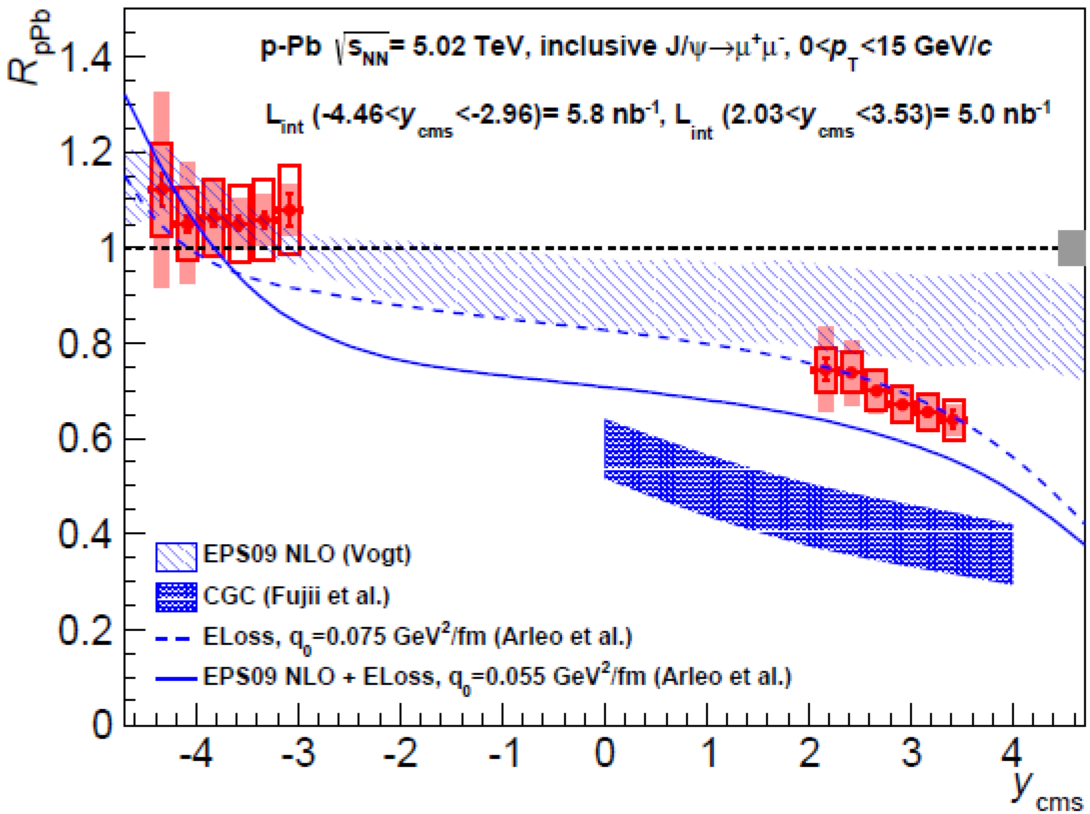




- Good agreement between LHCb and ALICE (for inclusive J/Ψ)
- In both cases, pp references interpolated from available pp measurements at different center-of-mass energies
- More infomation will be provided soon in a common note between LHCb and ALICE

Nuclear modification for inclusive J/ψ

Inclusive J/ψ, ALICE, arXiv:1308.6726

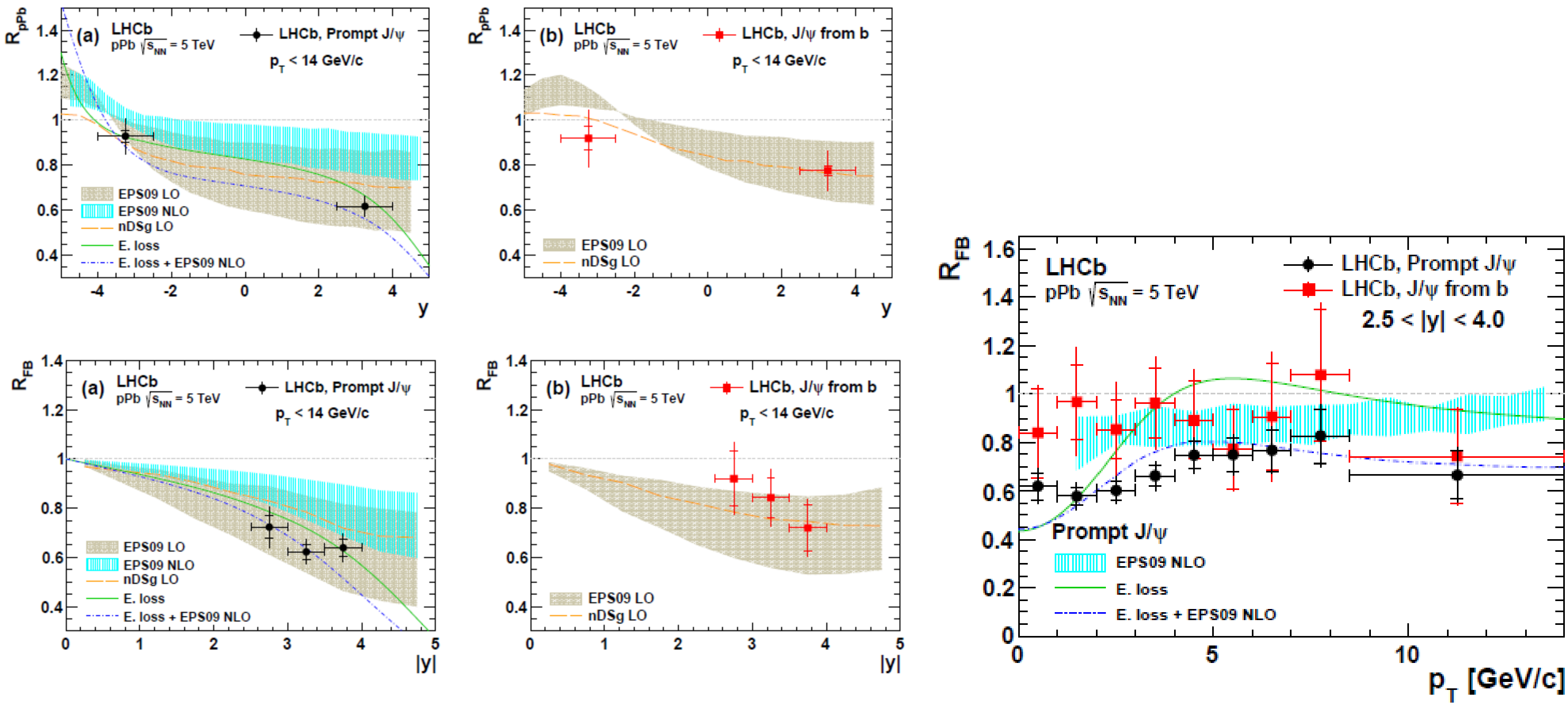


- Uncertainty on R_{pPb} dominated by uncertainty of pp reference (constructed by interpolating existing data)
  - R_{pPb} decreases with forward y
  - Within large uncertainties, no apparent y dependence in backward region

- 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

Prompt J/ψ versus J/ψ from B

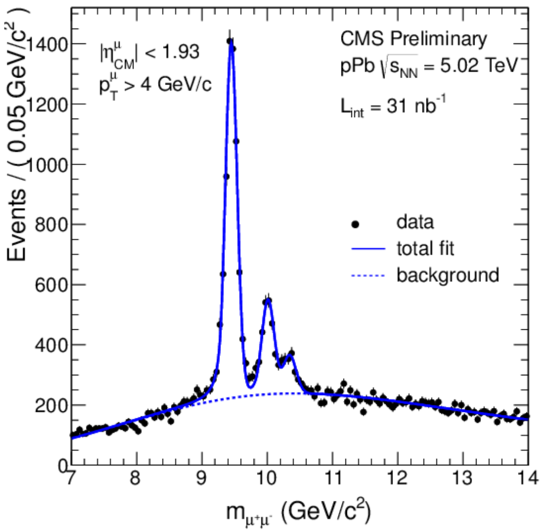
LHCb, arXiv:1308.6729

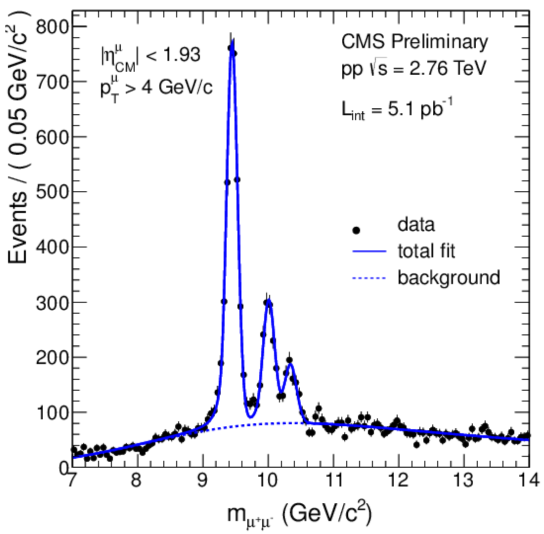


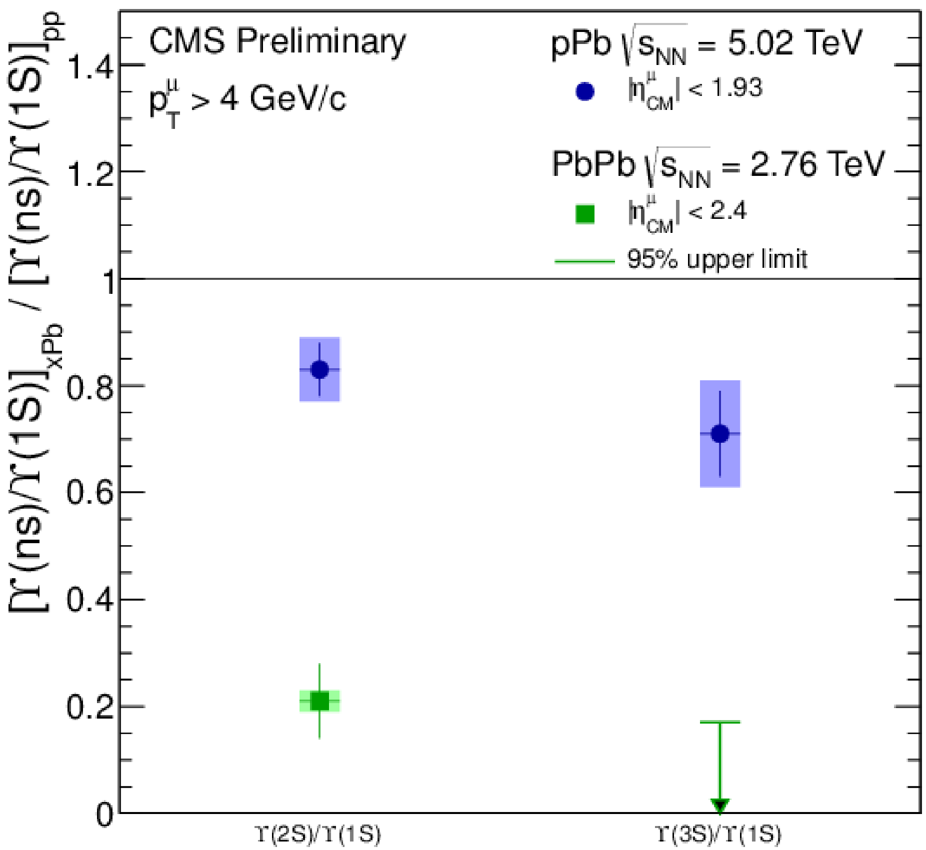
- First R_{pPb} (R_{FB}) measurement separating prompt J/ψ and J/ψ from B
- Results indicate that cold nuclear matter effects are smaller for J/ψ from B, ie smaller for B-hadrons, than for prompt J/ψ

Υ(1S), Υ(2S) and Υ(3S) production

CMS-HIN-13-003



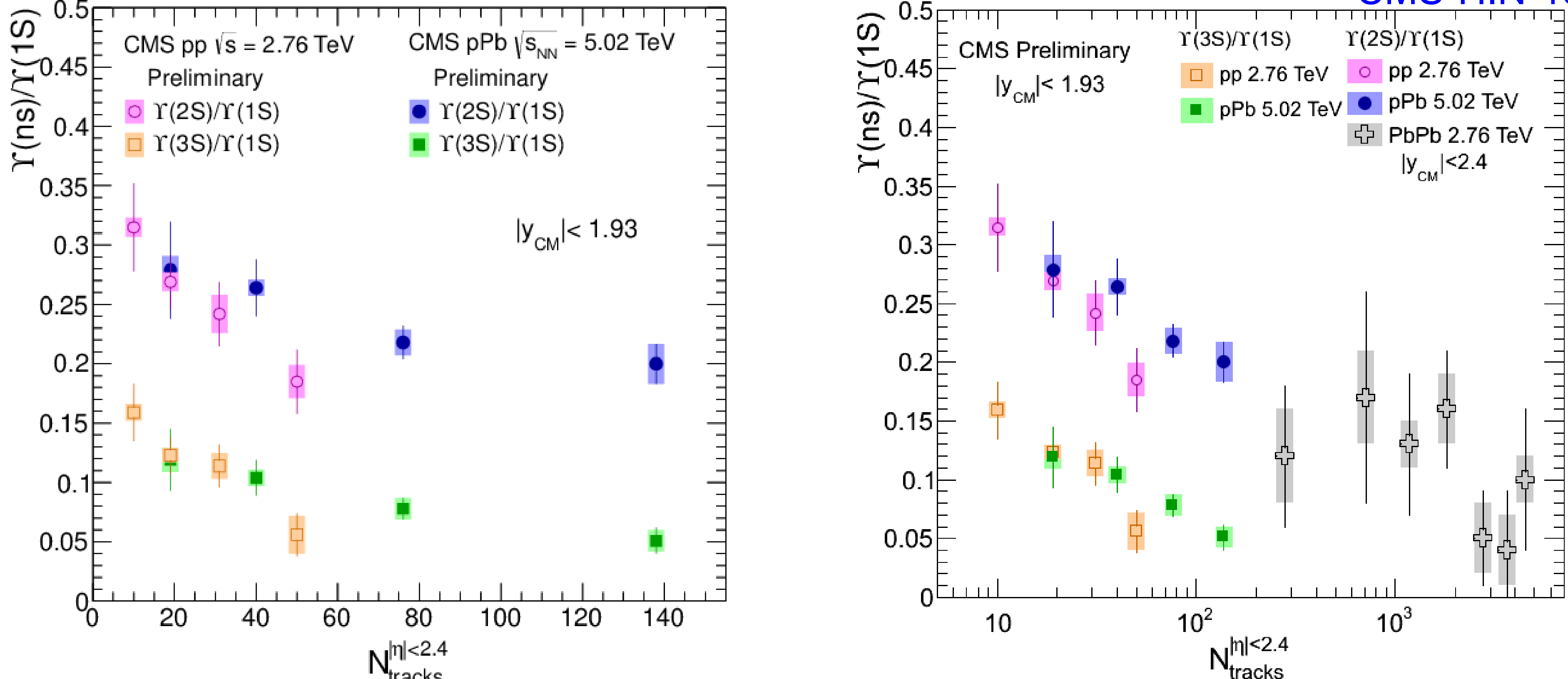




- Consistent signal extraction in pp, pPb and PbPb (not shown)
- Double ratio shows
  - Excited states relative to ground state in pPb suppressed when compared to pp
  - Magnitude of suppression much larger in PbPb
  - Suggests additional (or stronger) final state effects in PbPb
    - Needs model to extrapolate from pPb to PbPb

Y(2S)/Y(1S) and Y(3S)/Y(1S)

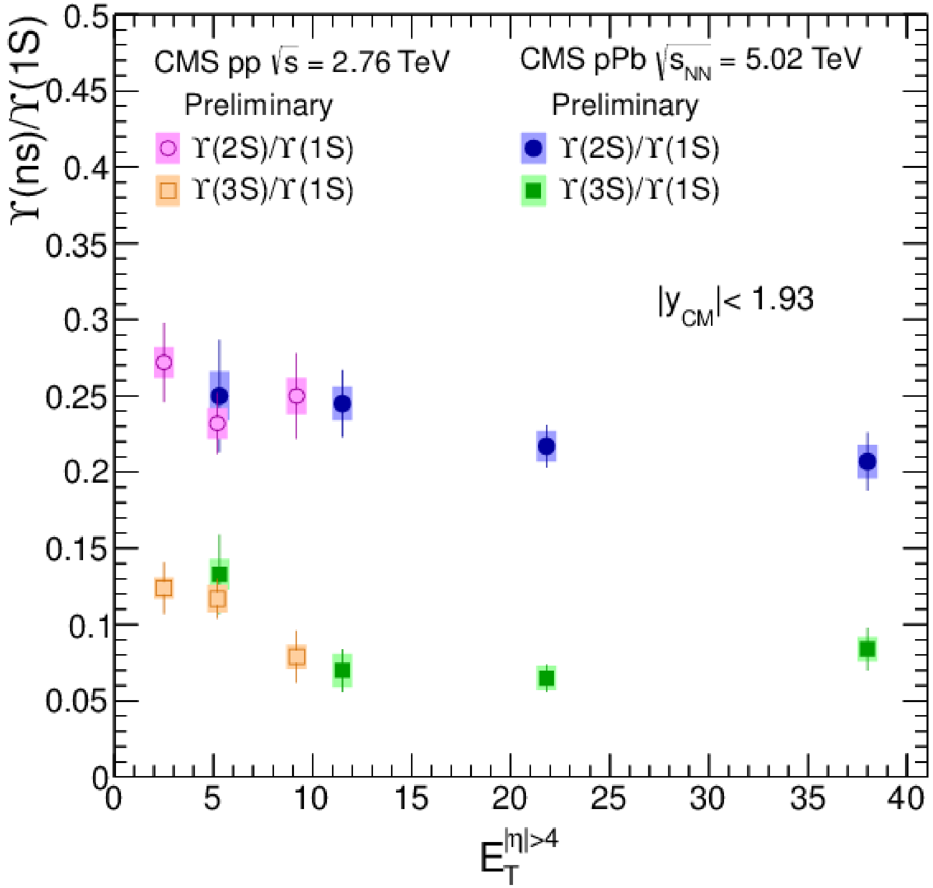
CMS-HIN-13-003

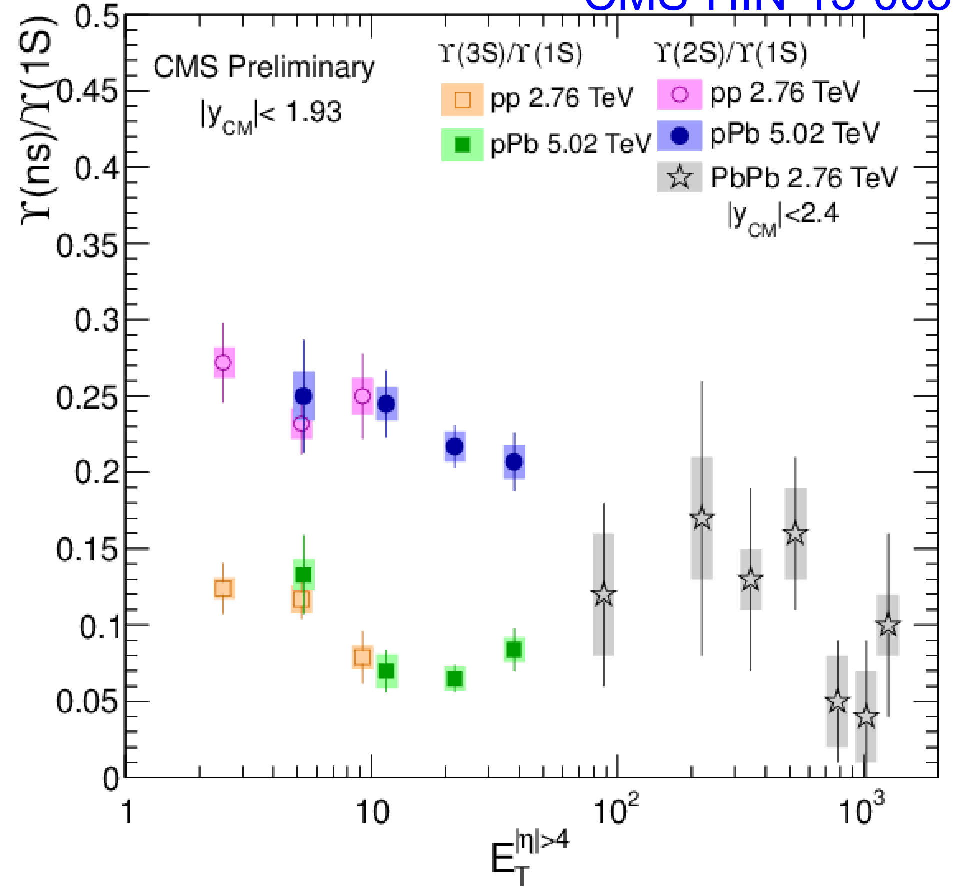


- Ratios significantly decrease with increasing multiplicity
  - This effect is weaker when slicing using the forward calorimeters
  - Not much can be concluded about PbPb with the current dataset
- Origin can be a combination of two effects
  - In high multiplicity events, the activity around the Y breaks the exited states
  - Events with Y(1S) have on average ~2 more tracks compared to Y(2S) and Y(3S), ie may be relevant for the low multiplicity bin

Υ(2S)/Υ(1S) and Υ(3S)/Υ(1S)

CMS-HIN-13-003

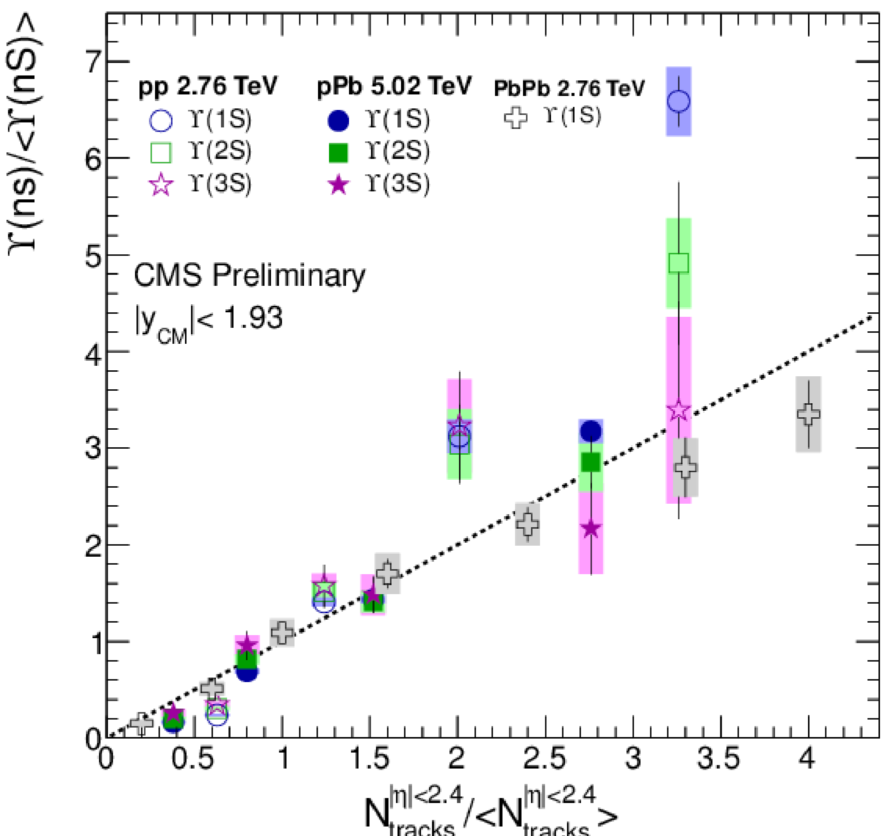


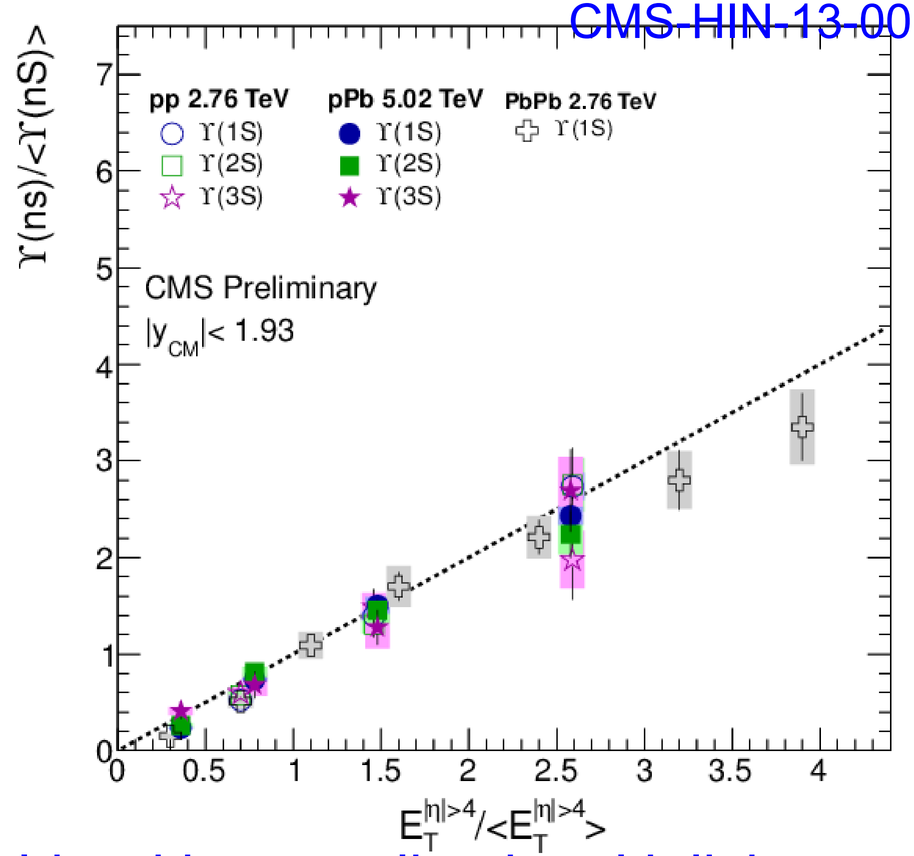


- Ratios do not as significantly depend on the energy in the forward calorimeters as when slicing with the number of tracks in acceptance

Self-normalized ratios: Y(sN)/<Y(sN)>

CMS-HIN-13-003

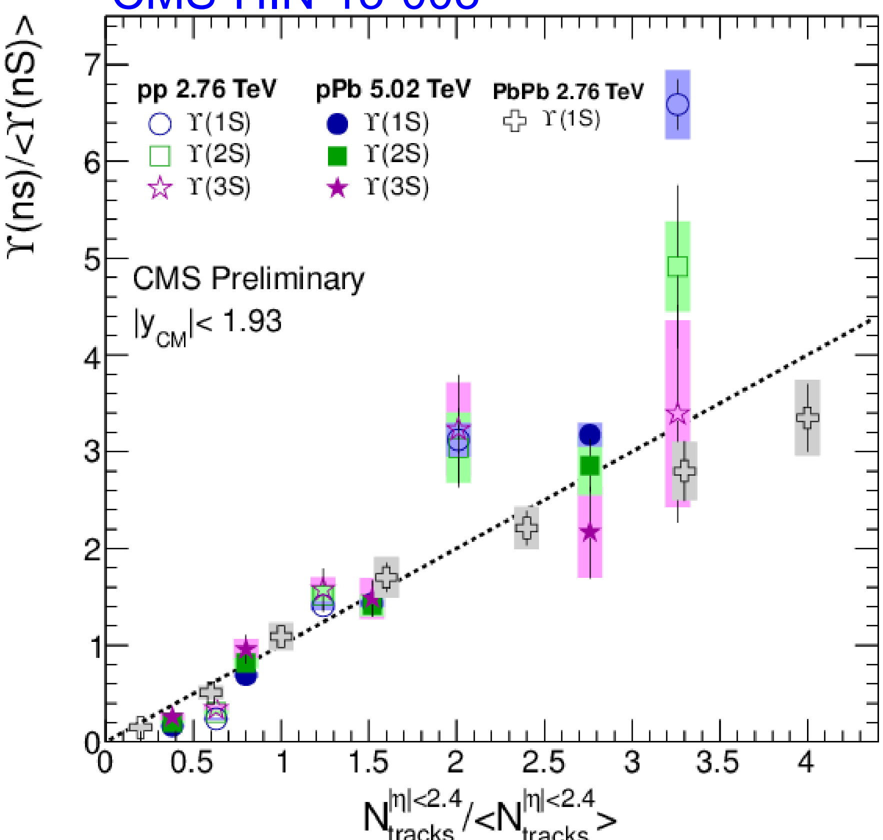




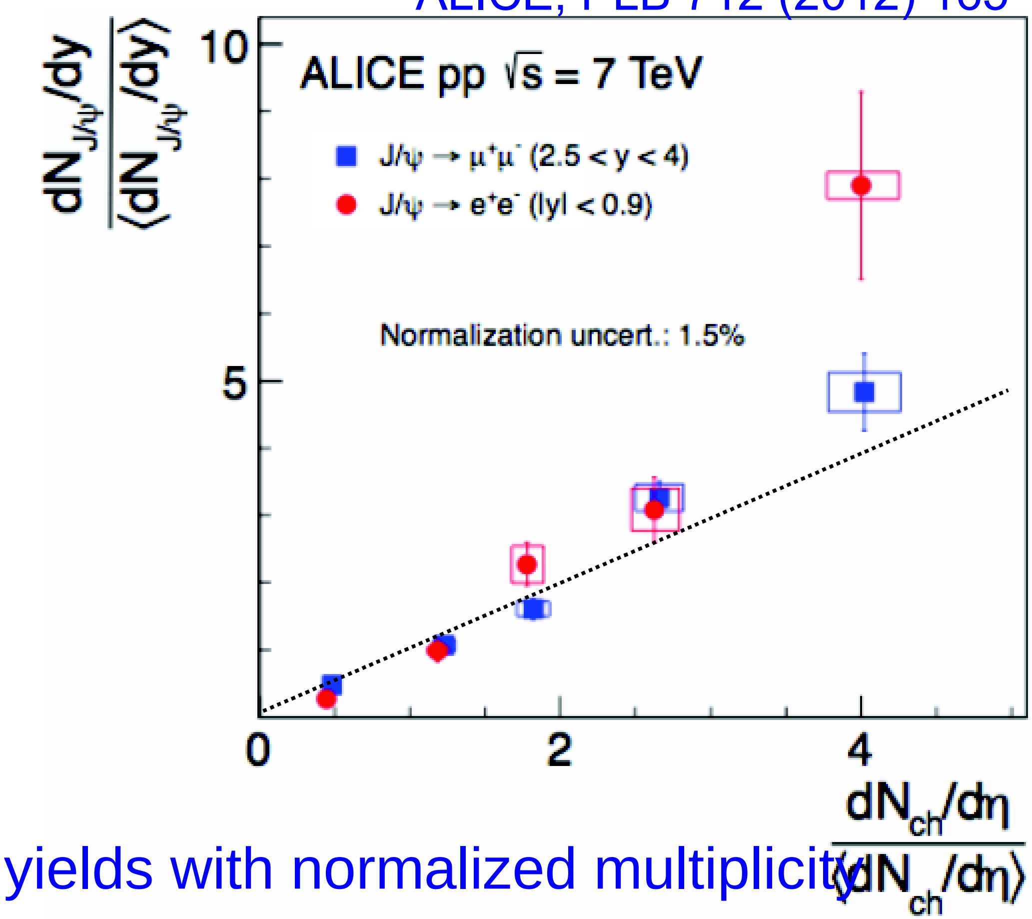
- Almost linear scaling of normalized yields with normalized multiplicity
  - Slope is very close to 1 for forward energy despite very different mean energy values of ~4 (pp), 15 (pPb) and 760 GeV (PbPb)
  - In pp, perhaps a unexpected deviation for highest pp points?
    (Needs more statistics to check)

Self-normalized ratios: Y(sN)/<Y(sN)>

CMS-HIN-13-003



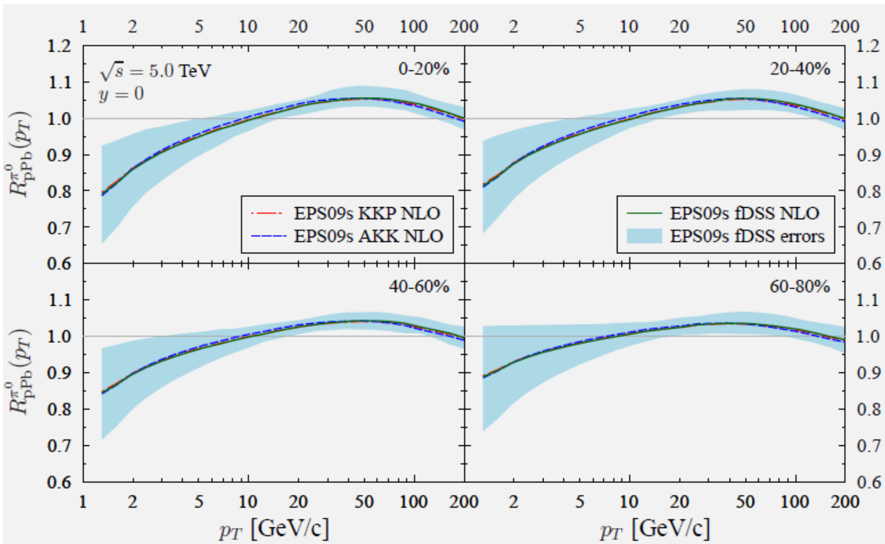
ALICE, PLB 712 (2012) 165



- Almost linear scaling of normalized yields with normalized multiplicity
  - Slope is very close to 1 for forward energy despite very different mean energy values of ~4 (pp), 15 (pPb) and 760 GeV (PbPb)
  - In pp, perhaps a unexpected deviation for highest pp points? (Needs more statistics to check)
- Similar trends seen for J/ψ (and D-mesons) in pp at 7 TeV
- Similar to dijets, strong correlation between hard scattering and UE

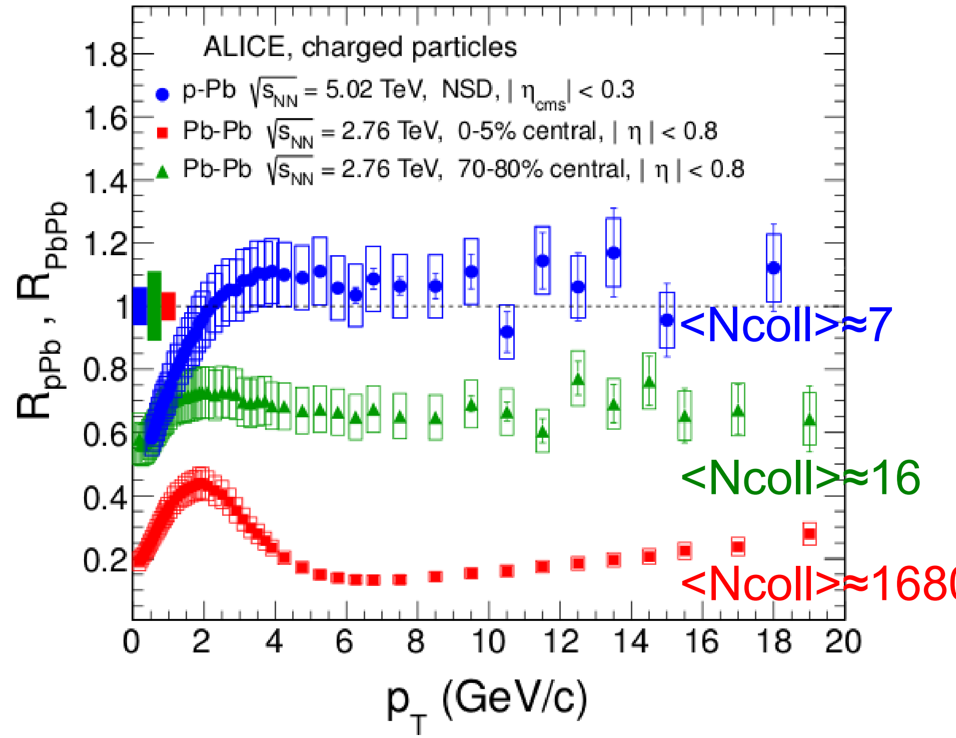
Centrality in pPb

Centrality dependent nPDFs



I.Helenius, K.Eskola, H.Honkanen and C.Salgado, HP2012

ALICE, PRL 110 (2013) 082302



How to make measurement centrality dependent?

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

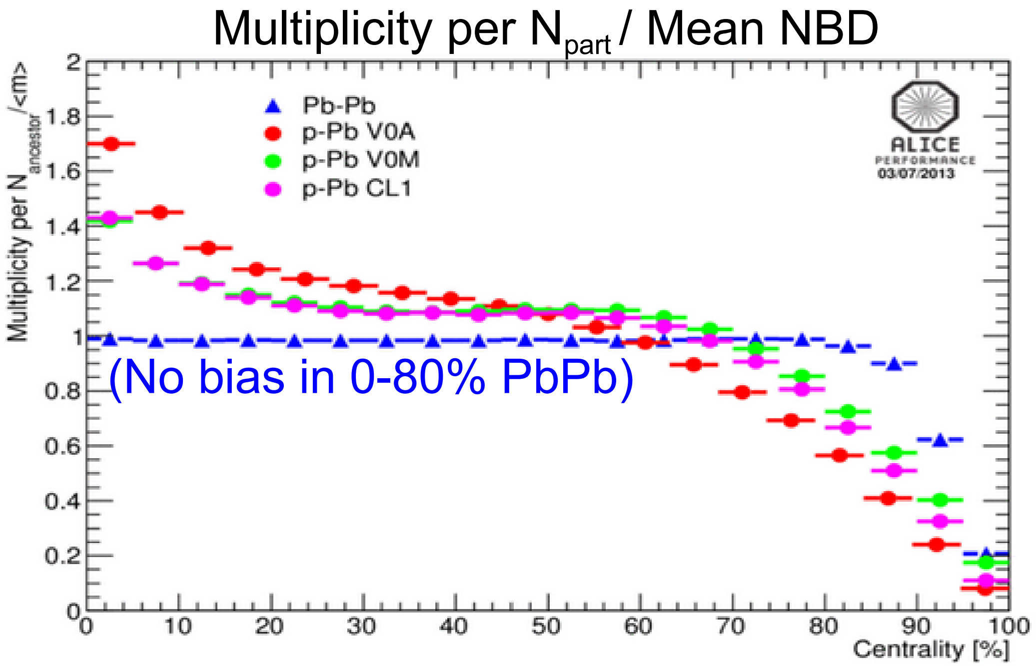
- How many collisions: <Ncoll>
- What is the bias induced by multiplicity fluctuations?

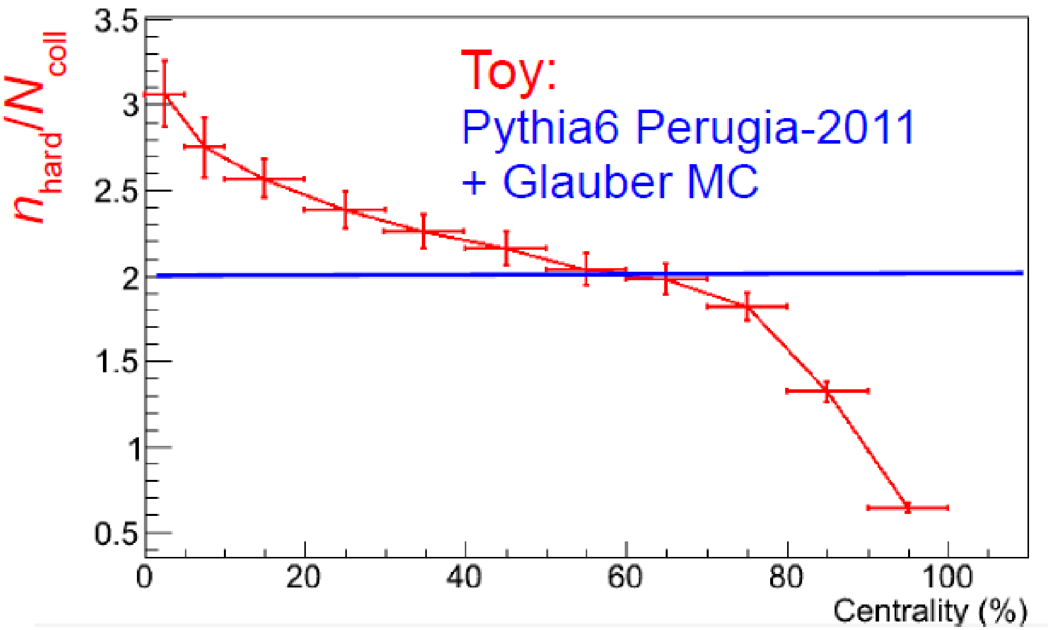
Reminder:
RpA should be 1 in absence of nuclear effects

Biases affecting centrality measurement

- Multiplicity fluctuations induce sizeable bias on Mult/Npart
  - Results in bias on the number of particle sources (hard scatterings)
- Additional for peripheral collisions
  - Mean impact parameter in NN collisions increases
  - Jet veto by cutting into the NN cross section
- Different centrality estimators
  - CL1: Strong bias since in tracking region
  - V0M: Reduced bias since outside tracking region
  - V0A: Reduced bias since dominated by Pb fragmentation
  - ZNA: Smallest bias by slow neutron emission

ALICE, preliminary

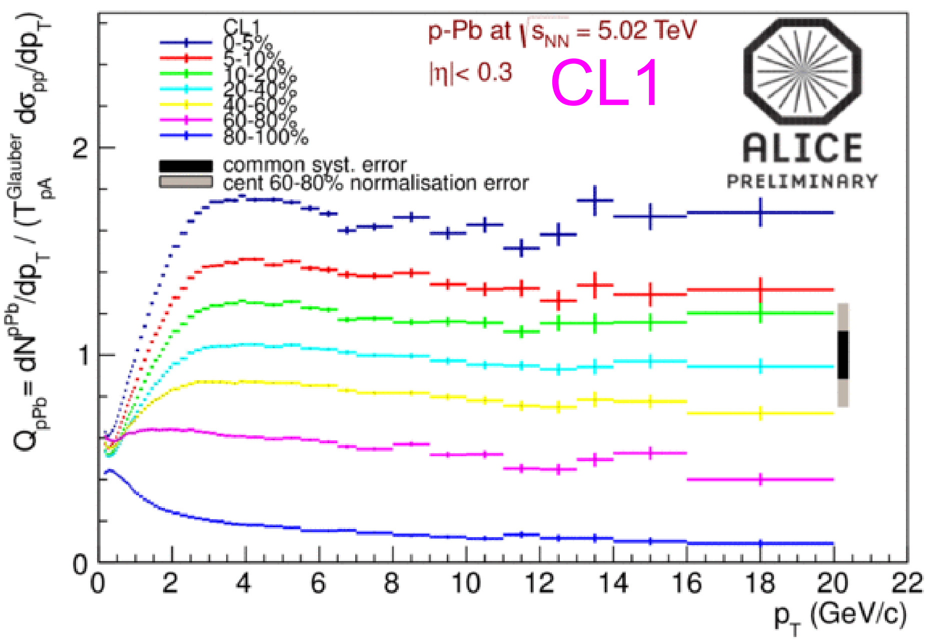


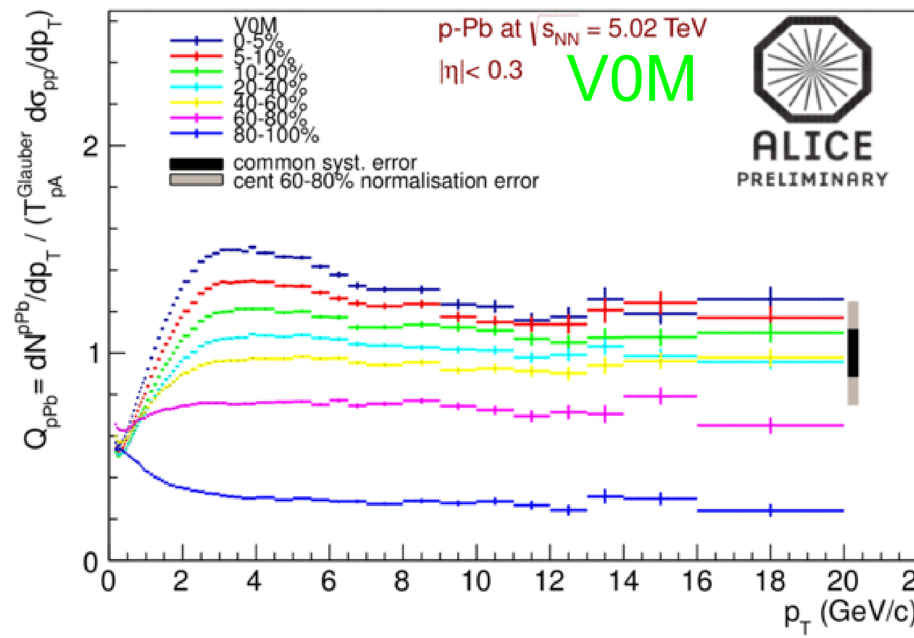


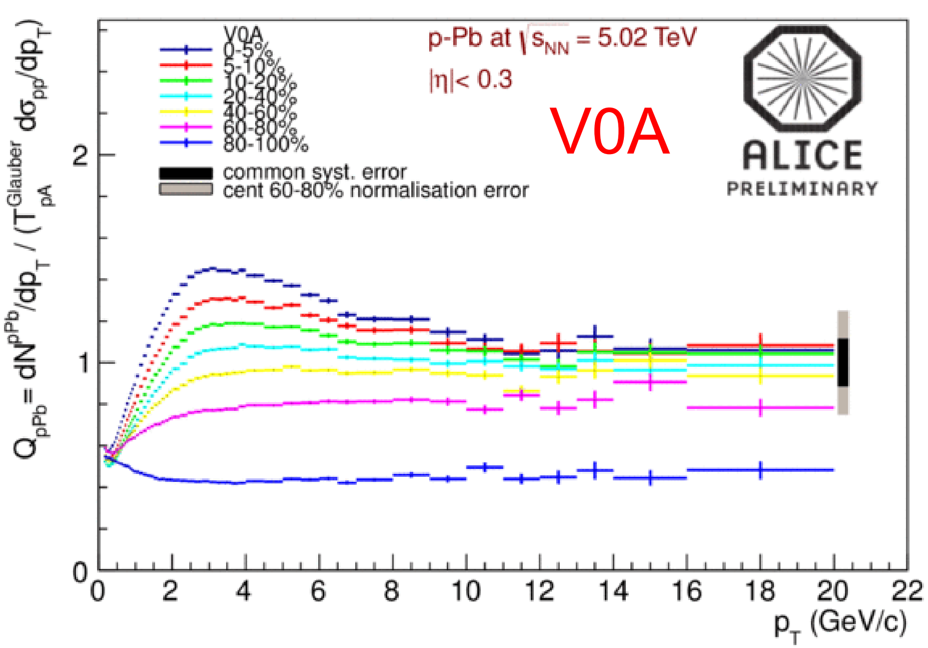
Q_{pPb} (not R_{pPb})

$$Q_{pPb,cent} = \langle N_{cent}^{Glauber} \rangle \frac{\langle dN^{pPb}/dp_T \rangle_{cent}}{dN^{pp}/dp_T}$$

ALICE, preliminary



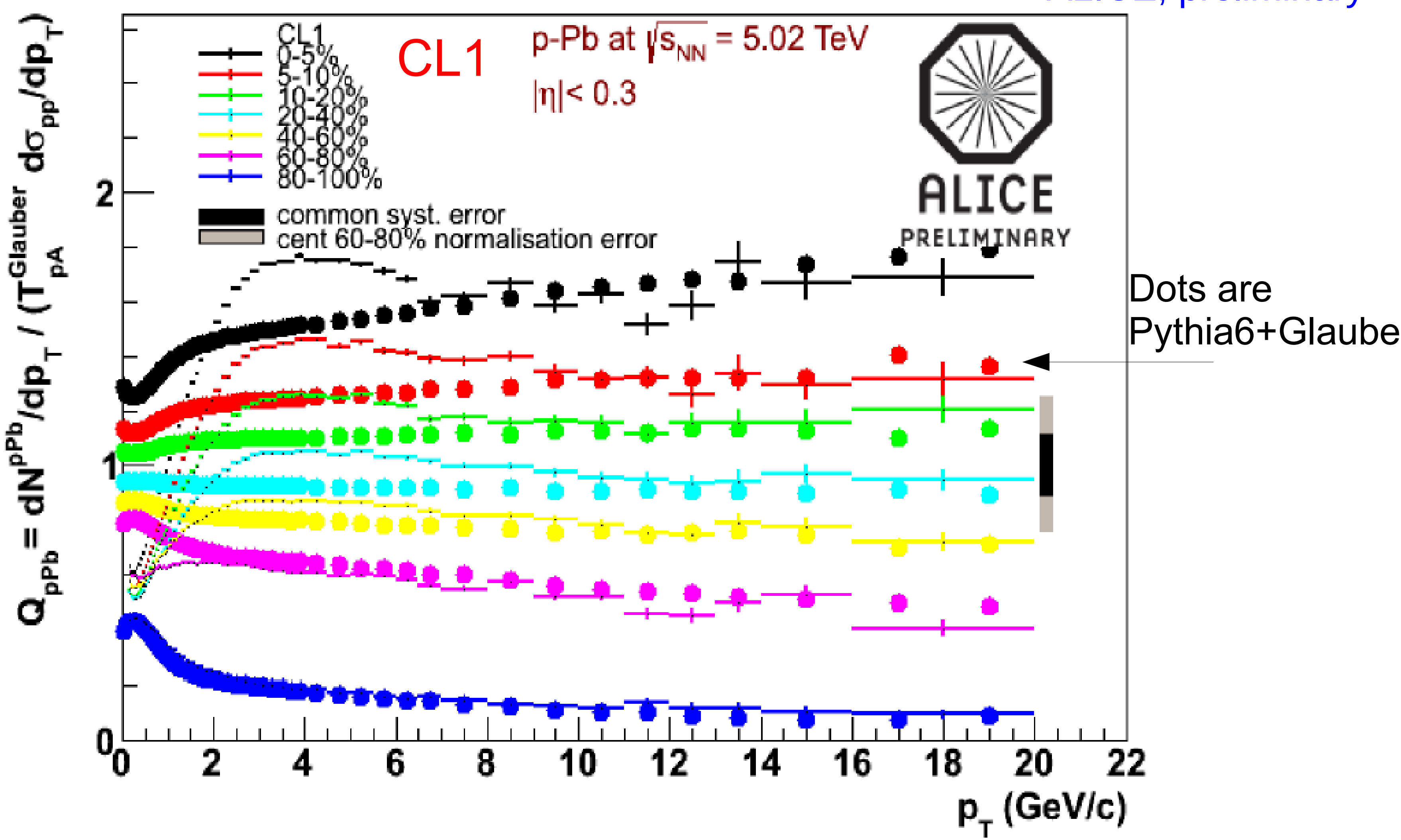




- Not a R_{pPb} measurement as not equals to 1 in absence of nuclear effects!!!
- Spread reduces: CL1 → V0M → V0A
- Jet veto present in 80-100% CL1, but not any longer in V0A

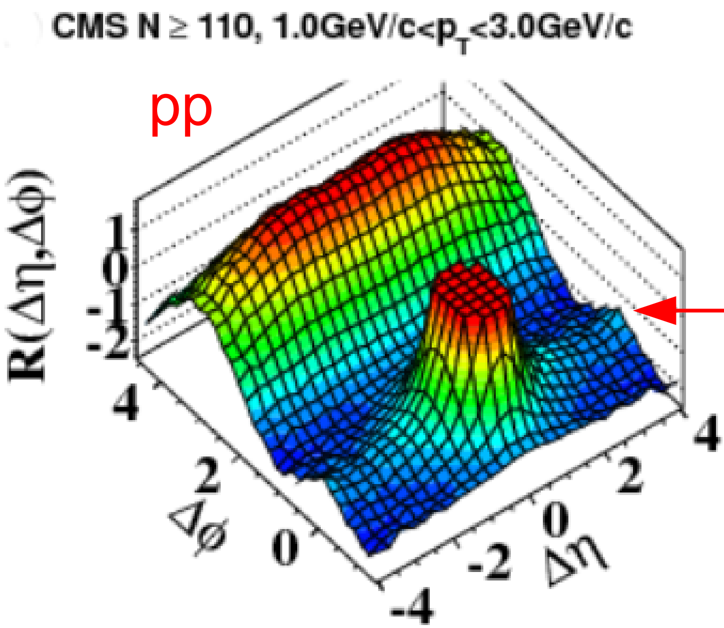
Q_{pPb} (not R_{pPb}) versus Pythia6+Glauber

ALICE, preliminary



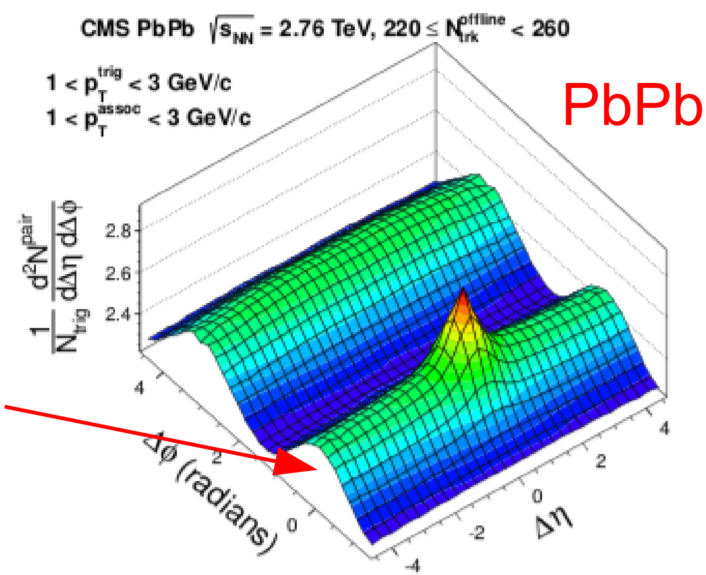
Model incorporating sources of particle production incoherently (Pythia6+Glauber) treated as data (ie mimicking centrality with CL1) describes Q_{pPb} at high p_T and the jet veto bias in 80-100 (and 60-80)

Two-particle angular correlations

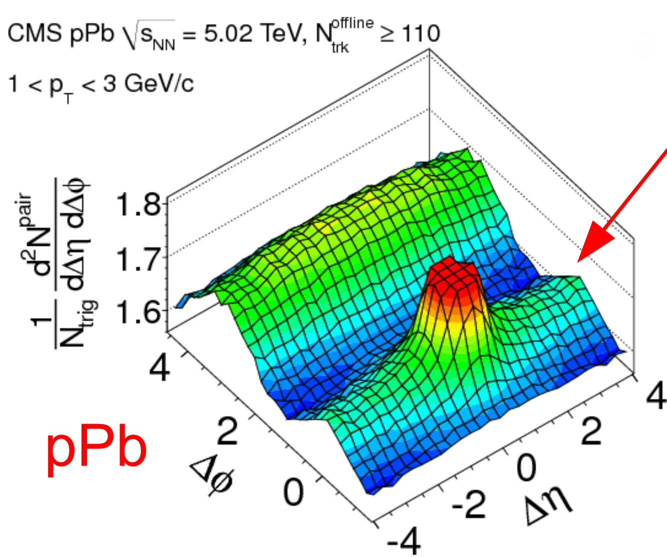


CMS, JHEP 1009 (2010) 91

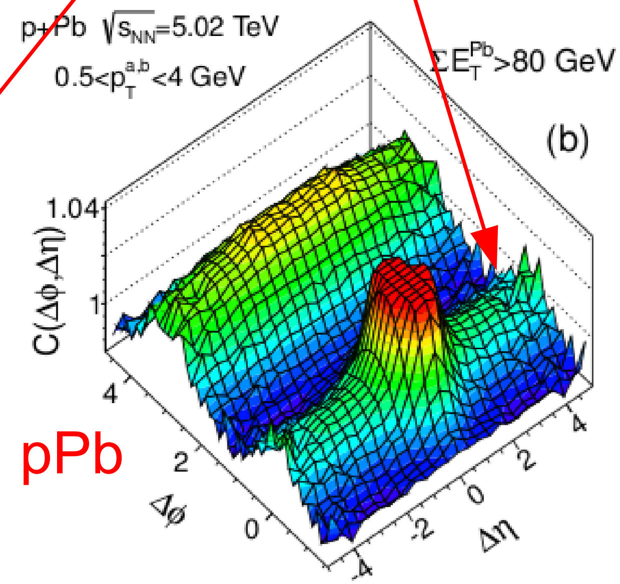
Near-side ridges apparent in high multiplicity events at LHC energies



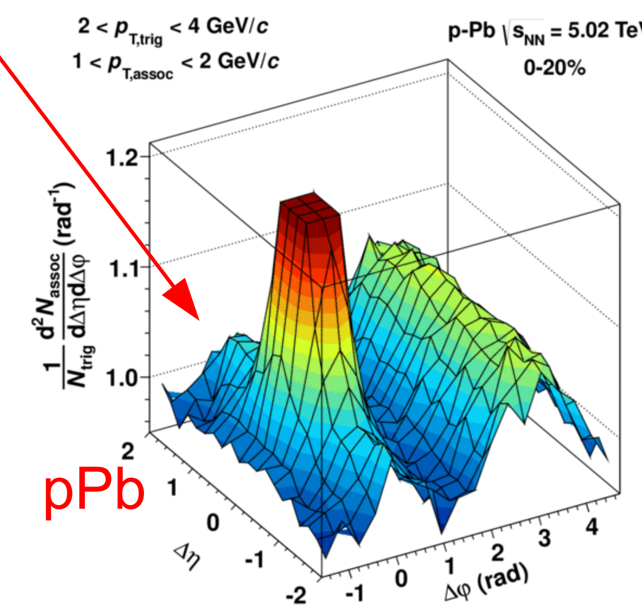
CMS, PLB 724 (2013) 213



CMS, PLB 718 (2012) 795



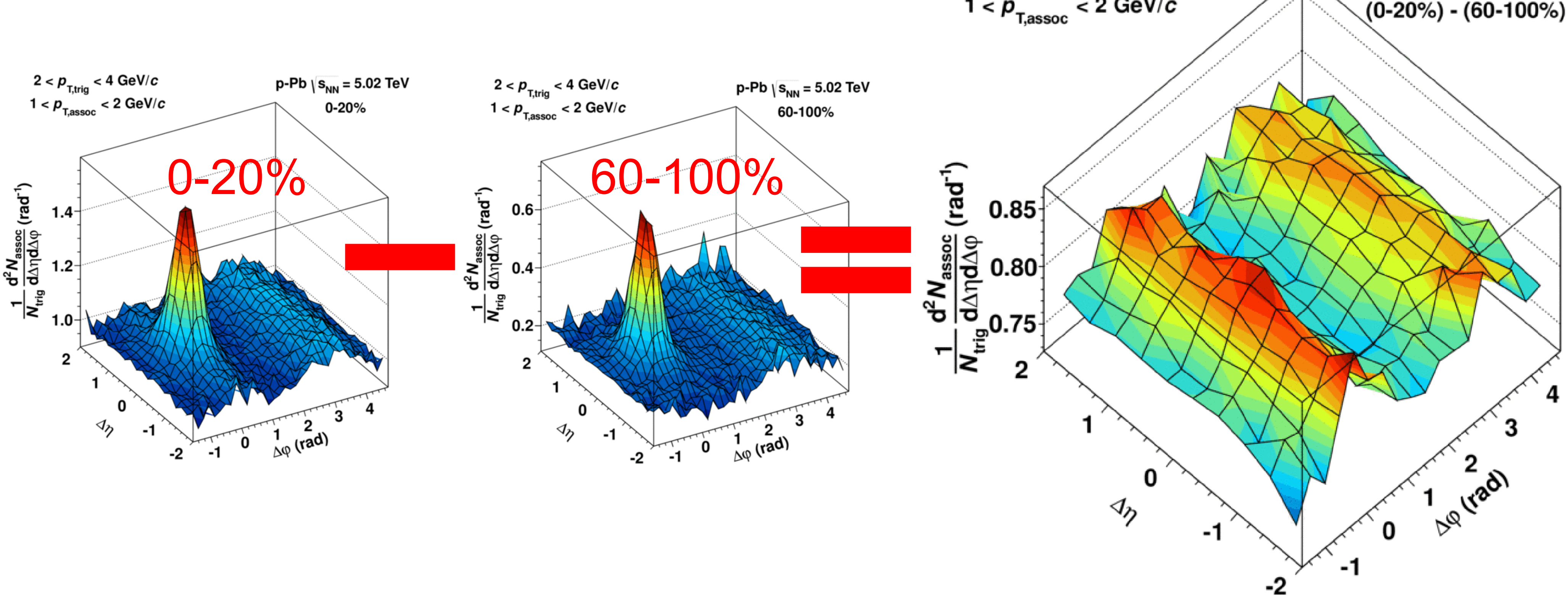
ATLAS, PRL 110 (2013) 182302



ALICE, PLB 719 (2013) 29

Extraction of double ridge structure

ALICE, PLB 719 (2013) 29

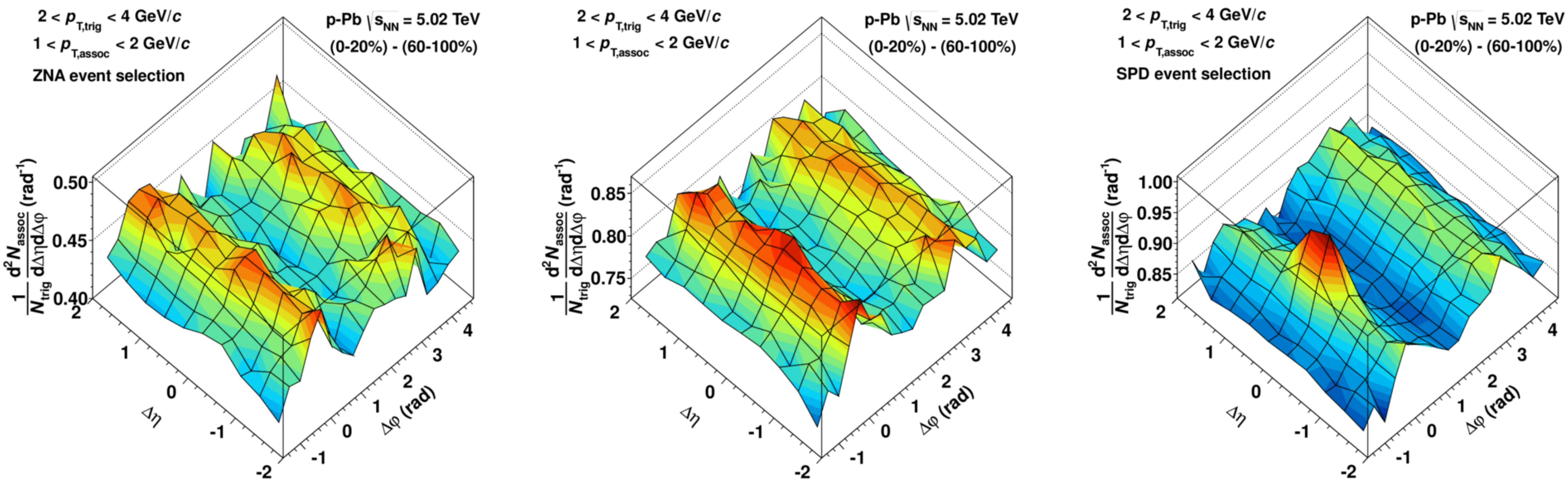


- Extract double ridge structure using a standard technique in AA collisions, namely by subtracting the jet-like correlations
  - It is assumed that the 60-100% class is free of non-jet like correlations
  - The near-side ridge is accompanied by an almost identical ridge structure on the away-side
 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

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

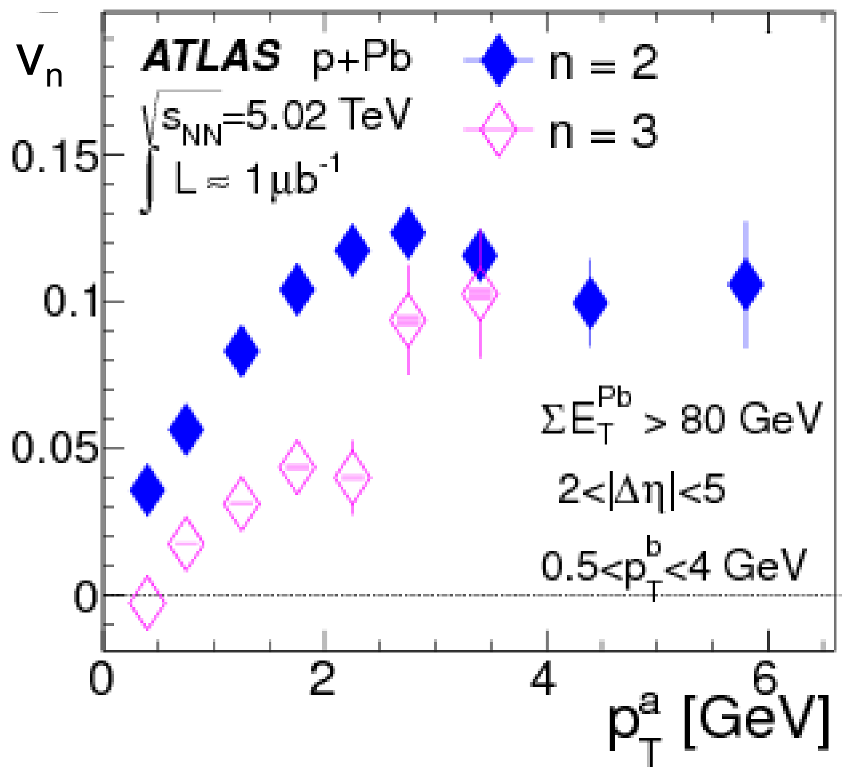


ZNA VZERO SPD

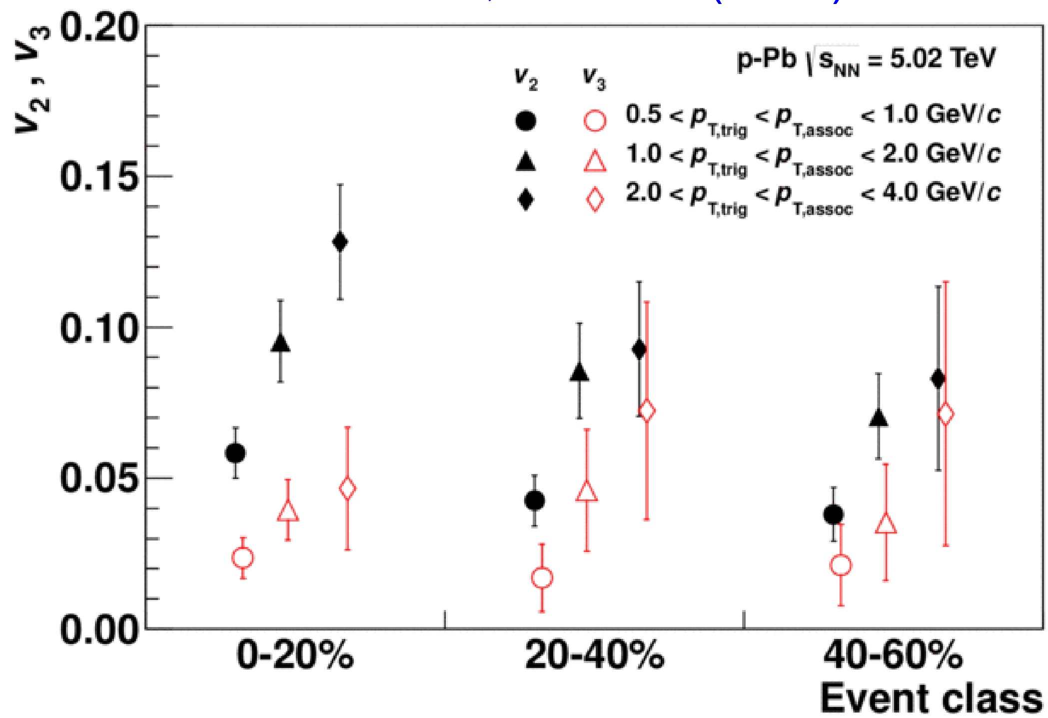
η separation

Ridge v_2 and v_3

ATLAS, PRL 110 (2013) 182302

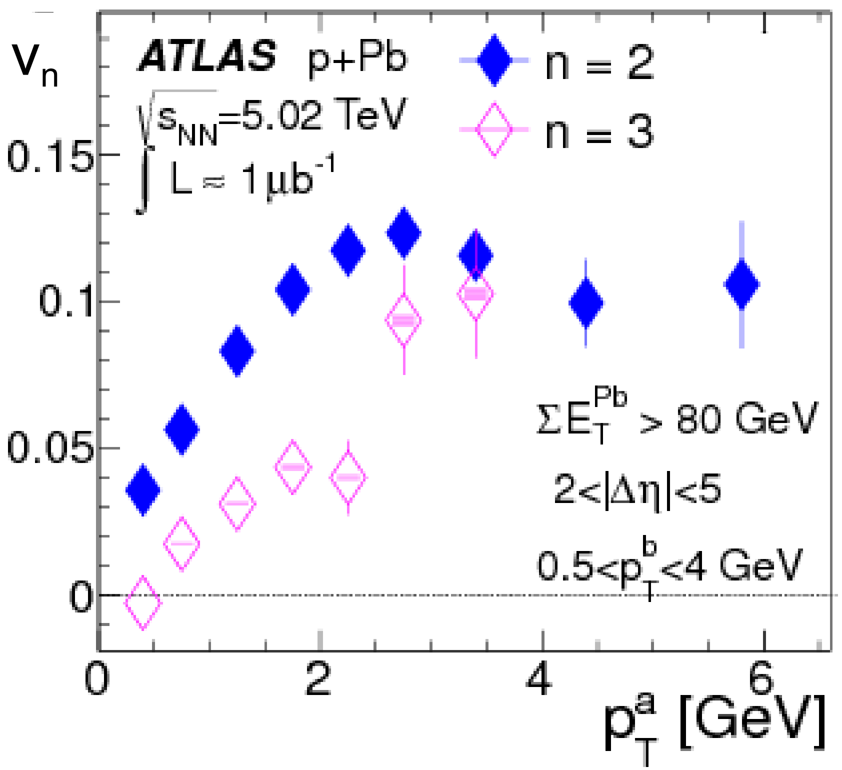


ALICE, PLB 719 (2013) 29

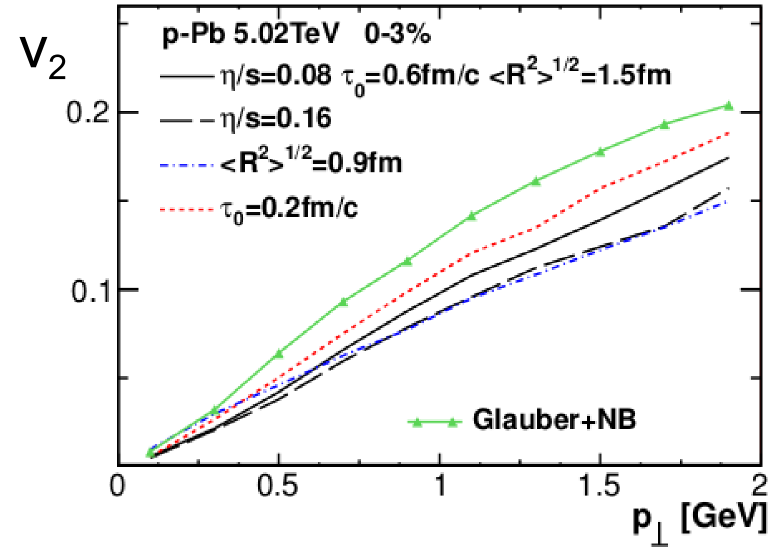


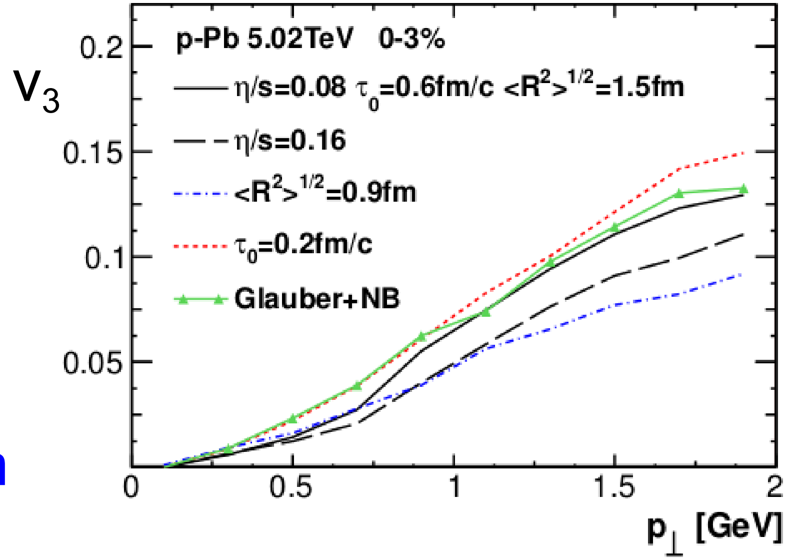
- Sizable values for v_2 and even v_3 reached for high-multiplicity events

ATLAS, PRL 110 (2013) 182302



Bozek and Broniowski, PRC 88 (2013) 014903

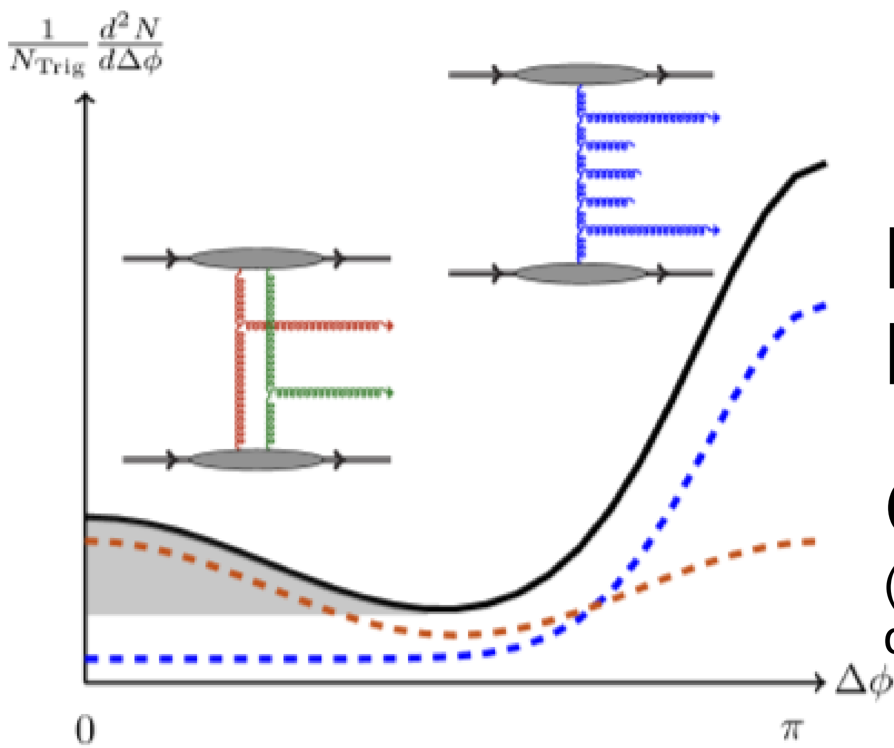




- Sizable values for v_2 and even v_3 reached for high-multiplicity events
- Results qualitatively consistent with viscous hydrodynamic calculations with initial state fluctuations from Glauber
  - Caveat: Calculations in pPb less robust wrt changes of assumptions than in AA

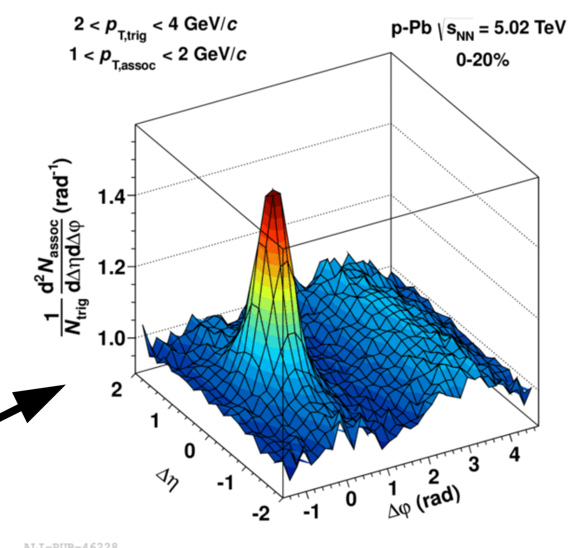
Ridge modulation v_2 and v_3 and CGC

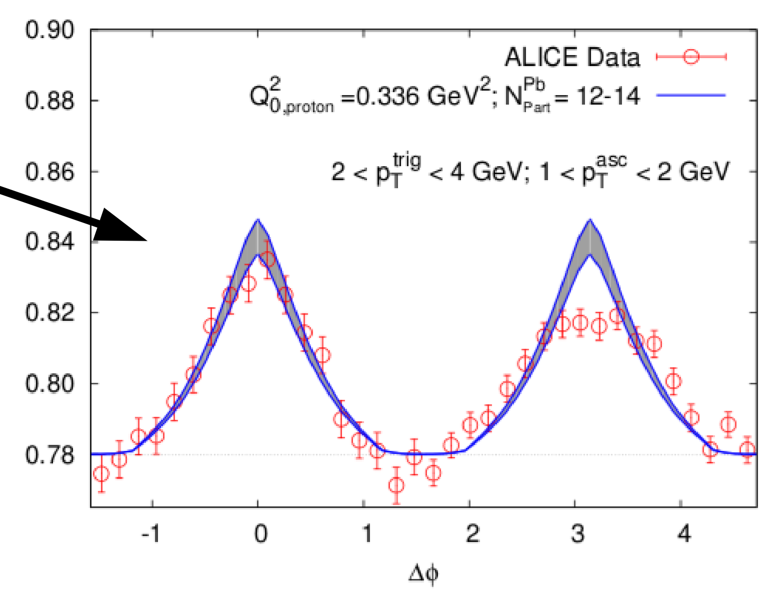
- Two symmetric ridges predicted by CGC glasma graphs found to describe the ridge yields and shape
- However, a large v_3 component would be a challenge for the model



BFKL-Minijets

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

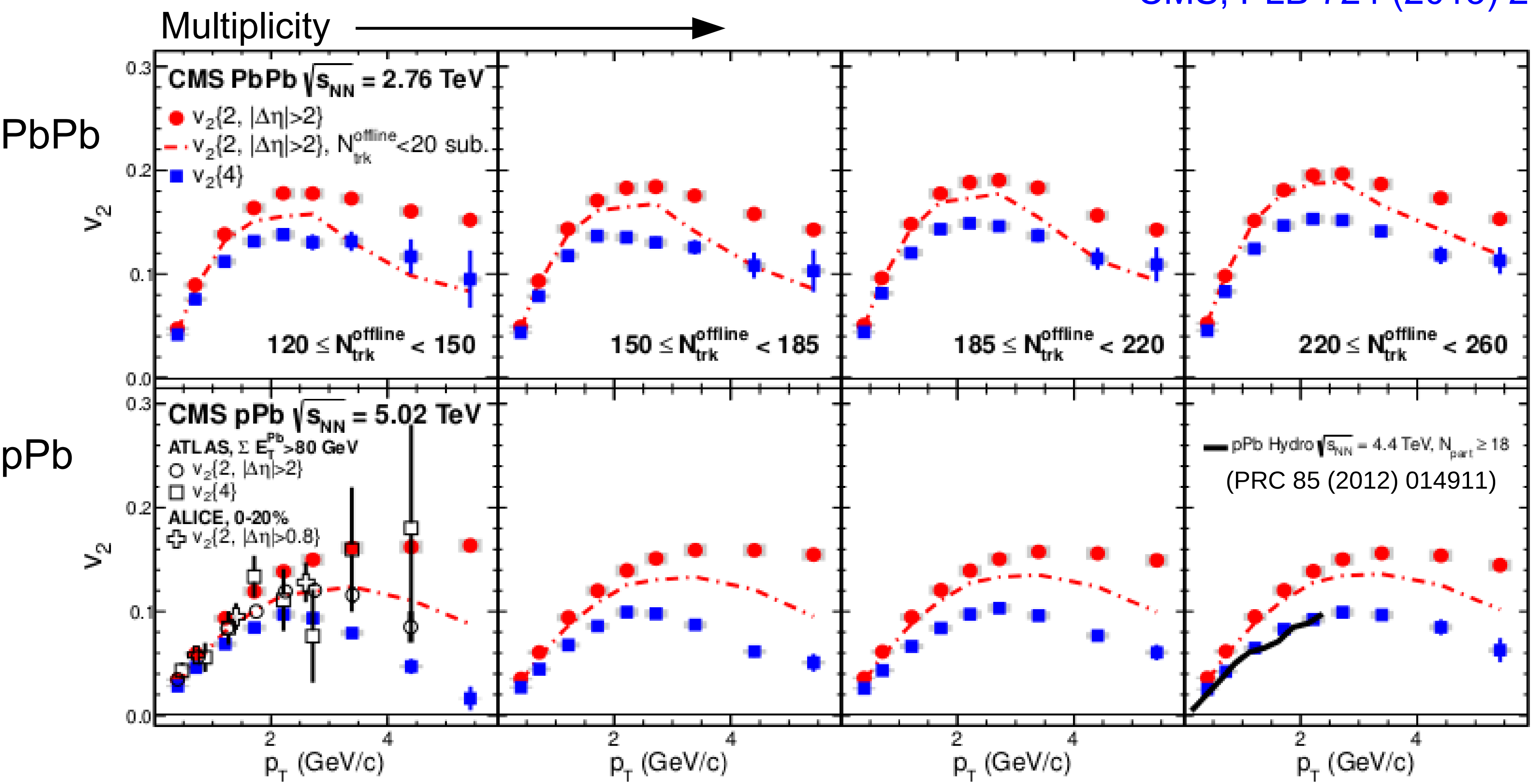




Dusling and Venugopalan, PRD 87 (2013) 094034

v_2 in pPb and PbPb

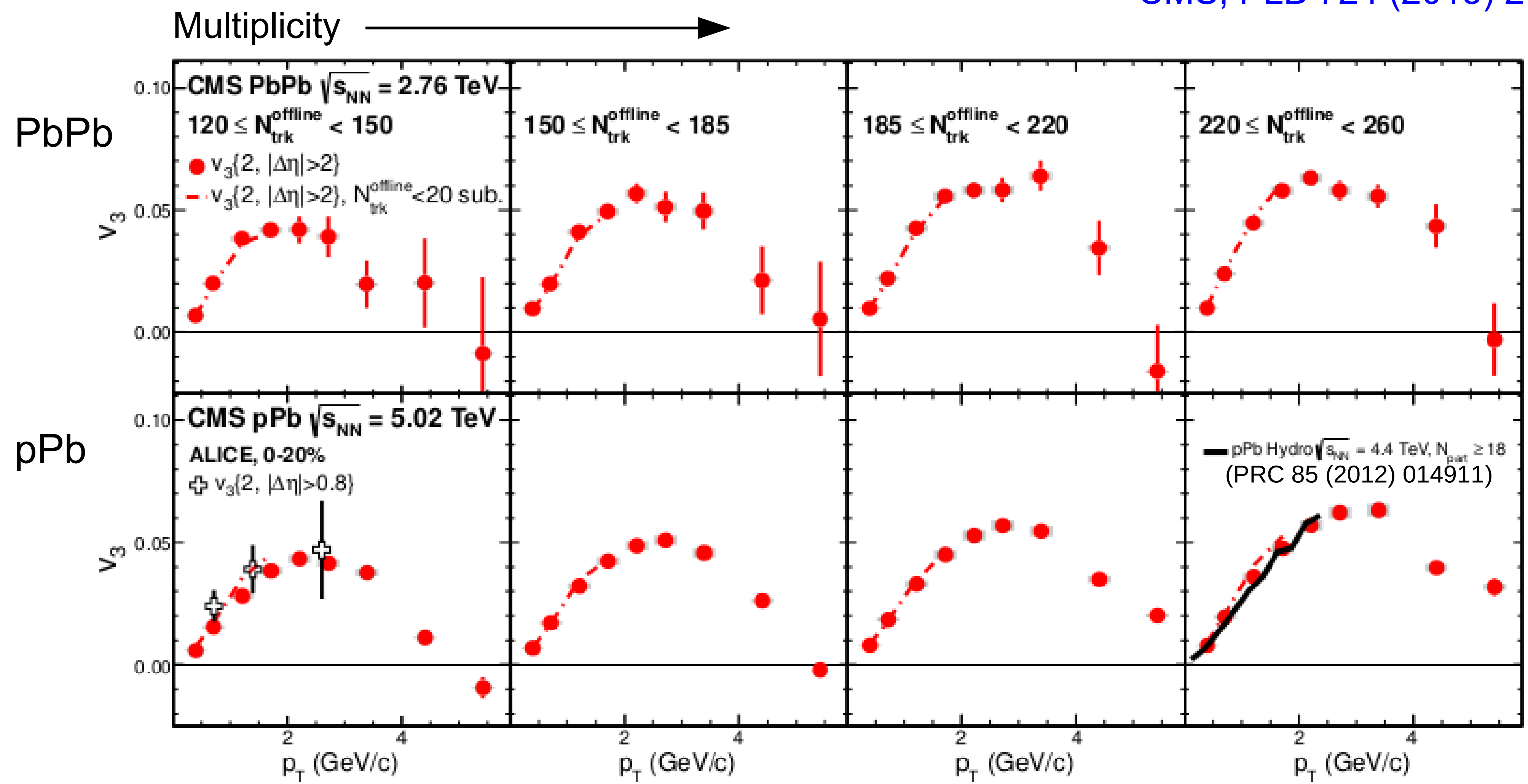
CMS, PLB 724 (2013) 213



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}.

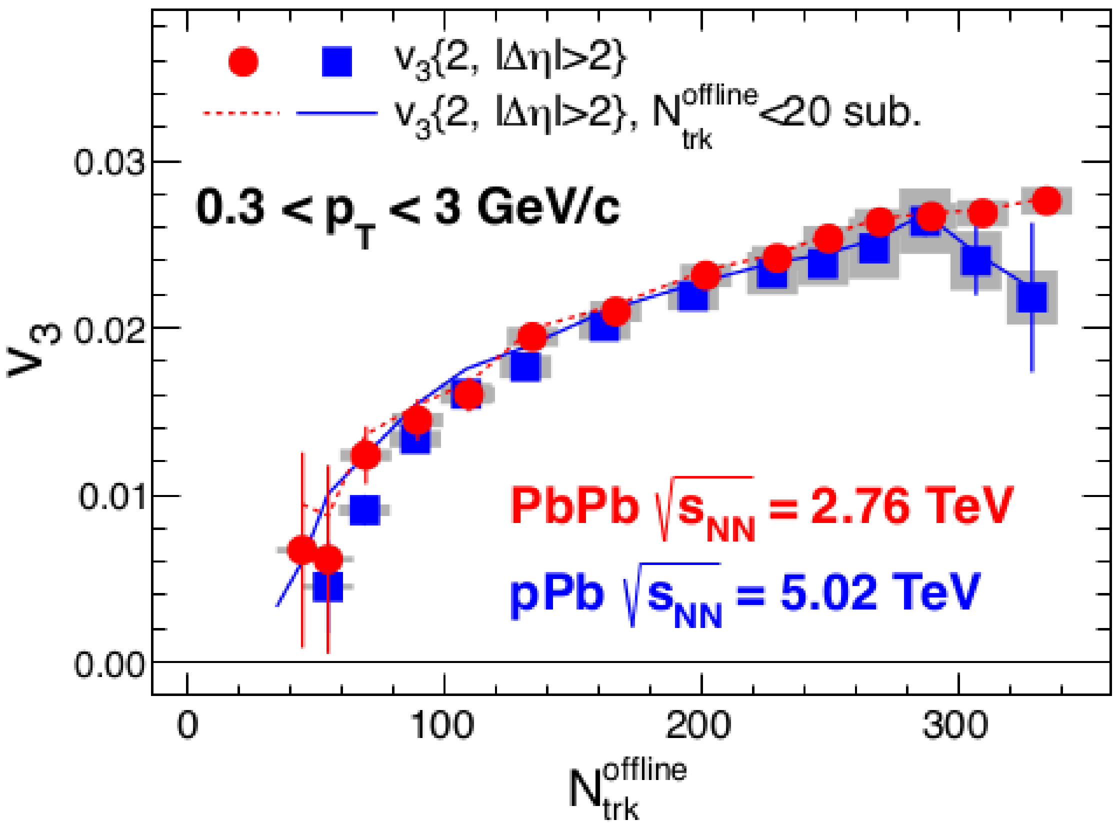
v_3 in pPb and PbPb

CMS, PLB 724 (2013) 213

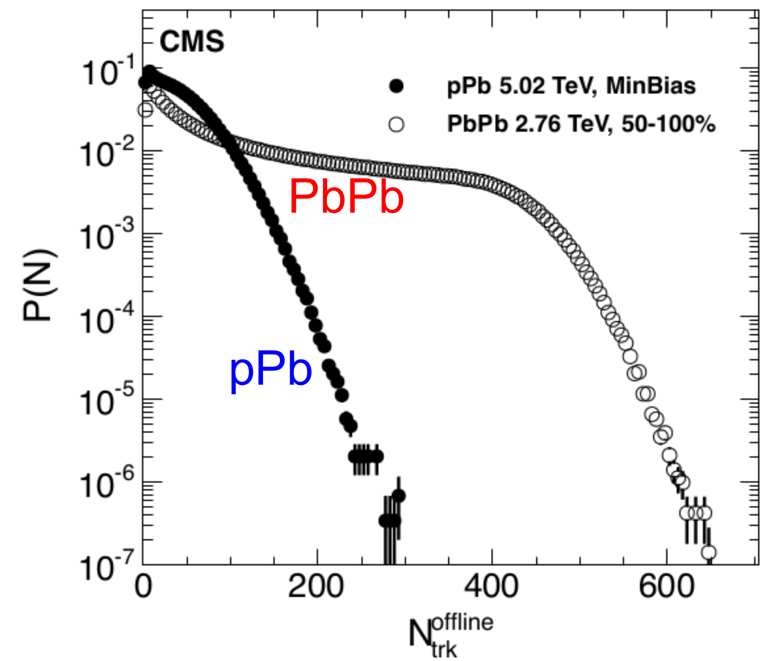


Similar shape and magnitude of v_3 in pPb and PbPb.
As for v_2 hydro predictions describe high-multiplicity data.

v_3 in PbPb and pPb



CMS, PLB 724 (2013) 213

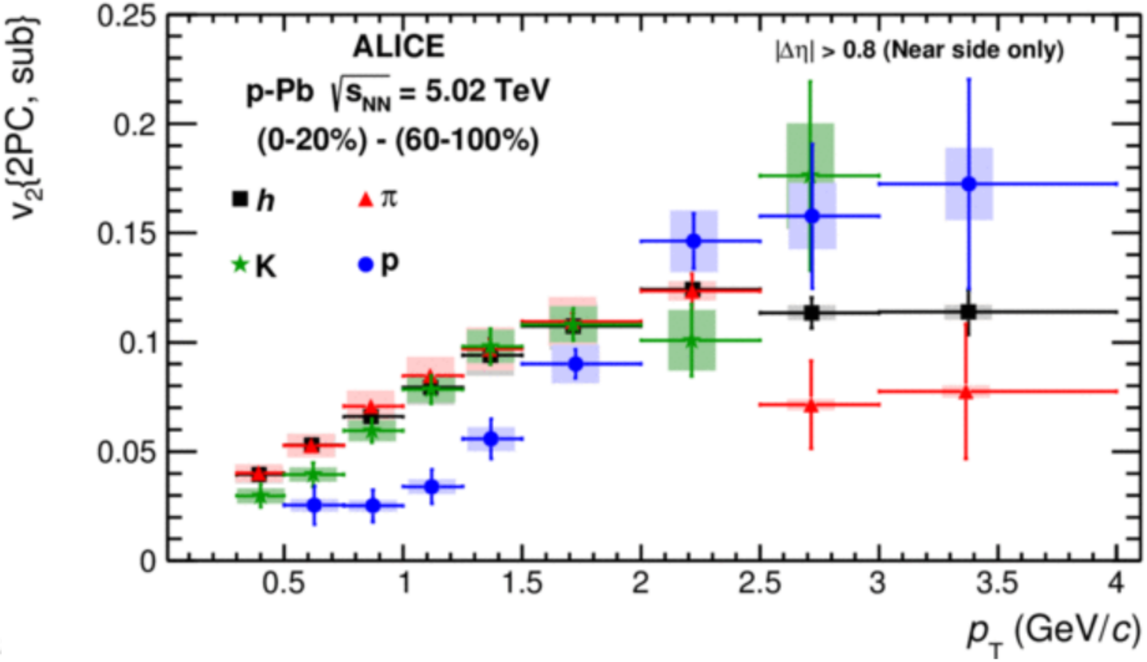


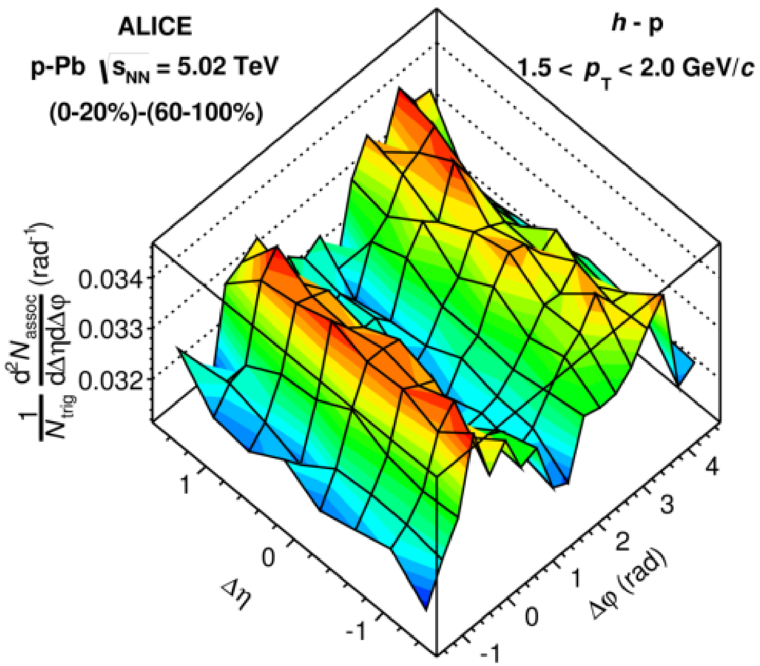
- Same v_3 in pPb as in PbPb
- Turn on at around M=50 tracks (~minbias pPb)
- Established picture in PbPb
    - Fluctuations of initial state are transformed into final state through interactions

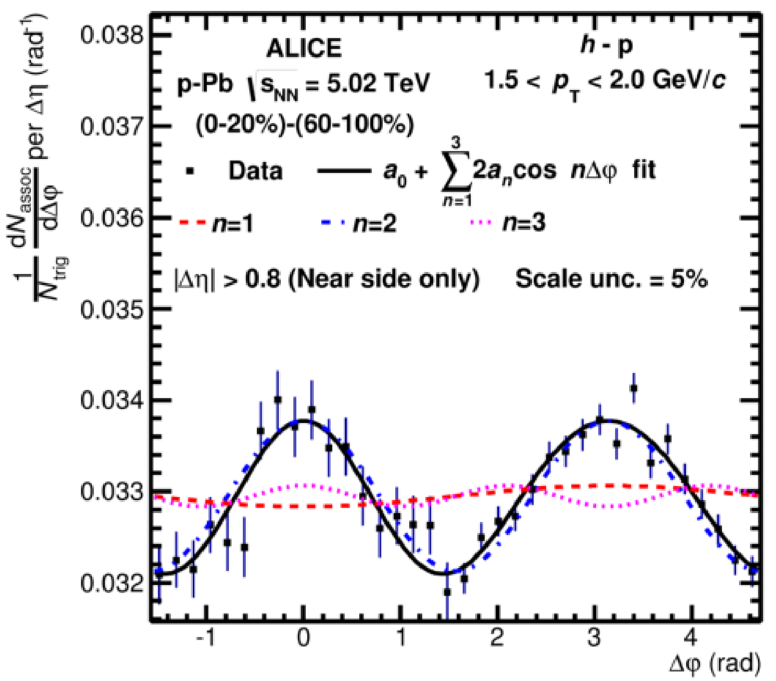
- Same physics mechanism despite different underlying dynamics (+ system size)?
- Maybe we select on events in which the proton wave function fluctuated to large values (fat proton, Mueller, arXiv:1307.5911v2)

Identified particle v_2

ALICE, arXiv:1307.3237



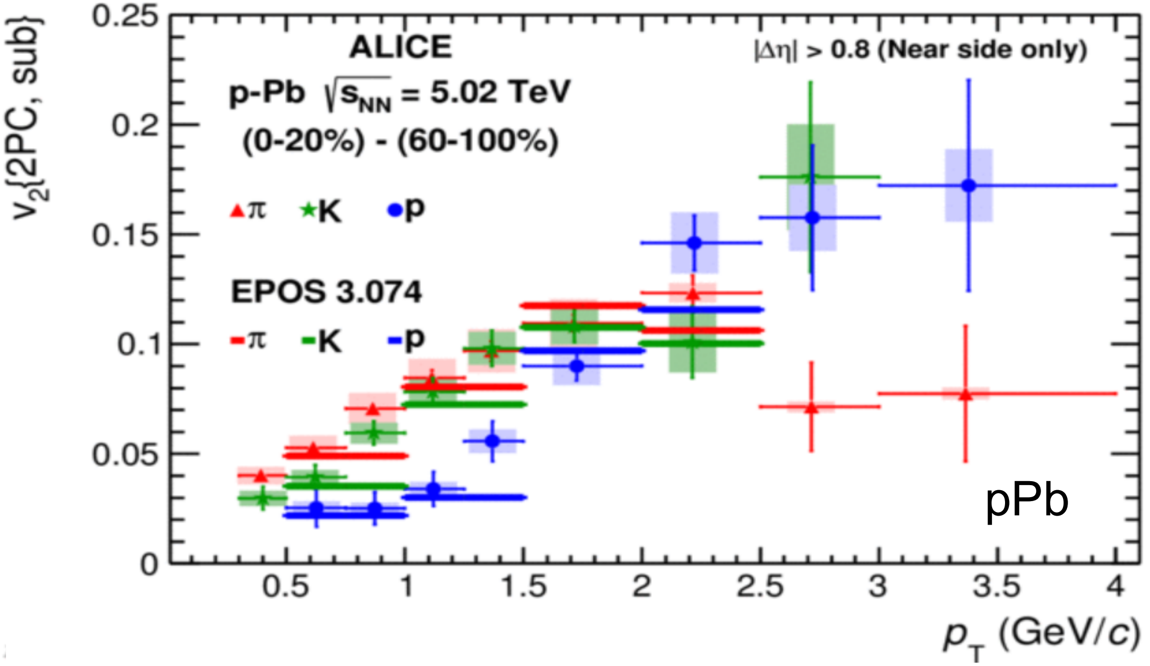


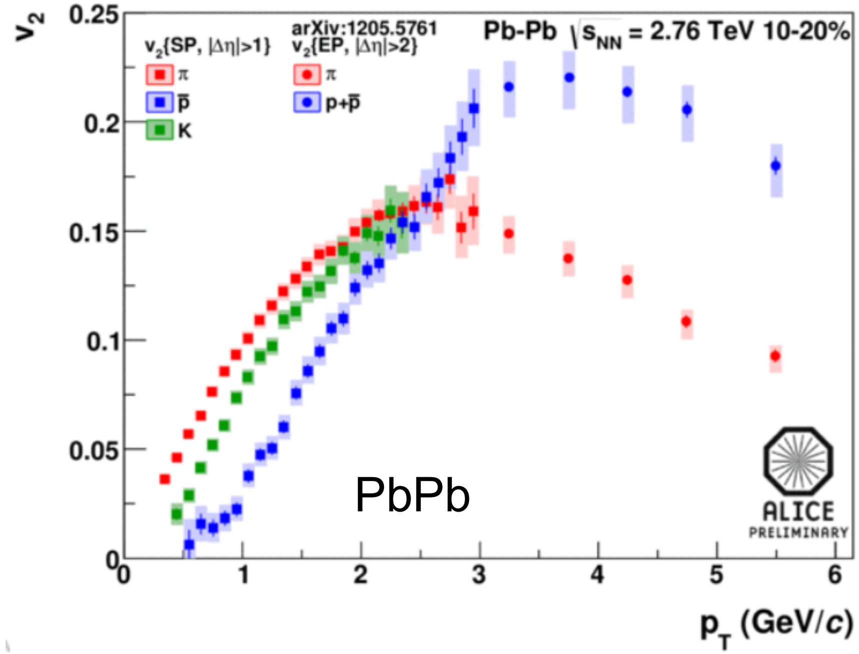


- Per-trigger yield with π, K, or p as associated particles rel. to trigger particles (h)
- Subtract low- (60-100%) from high-multiplicity (0-20%) and Fourier decompose
- Unidentified particle v_2 extended (and consistent with previous low-statistics measurement)

Identified particle v_2 and hydrodynamics

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)

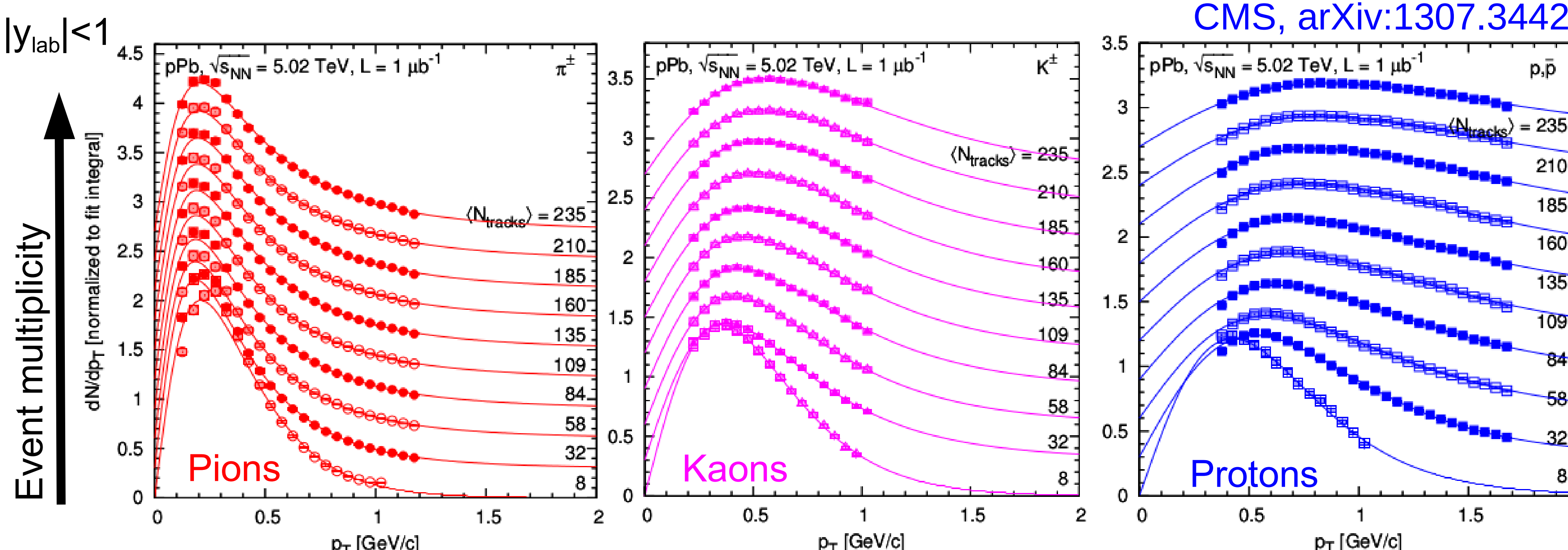
- Characteristic mass splitting observed as known from PbPb
- Crossing of proton and pion in the same p_T region (2-3 GeV/c)
- Models including a hydrodynamic expansion describe the data

  Werner et al., arXiv:1307.4379

  Bozek et al., arXiv:1307.5060

Identified particle p_T spectra

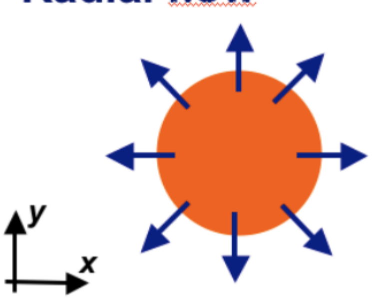
CMS, arXiv:1307.3442



$\pi^{\pm}$	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

Radial flow



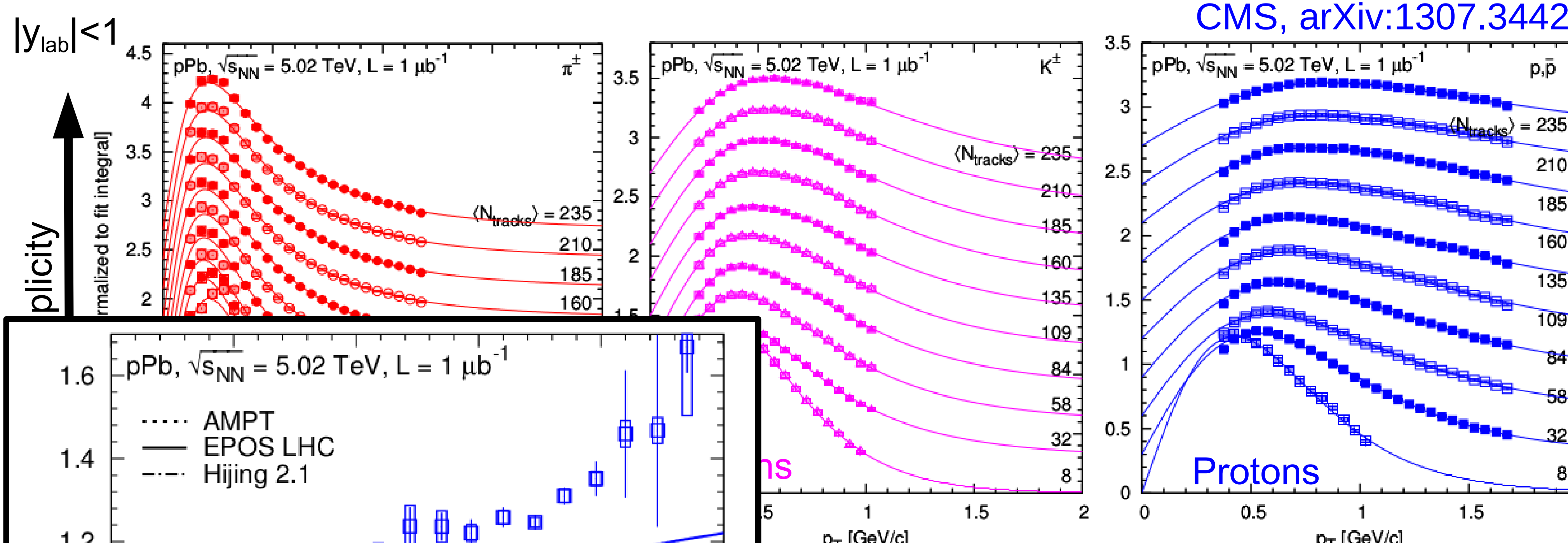
$$p_T^{flow} = p_T + m \beta_T^{flow} \gamma_T^{flow}$$

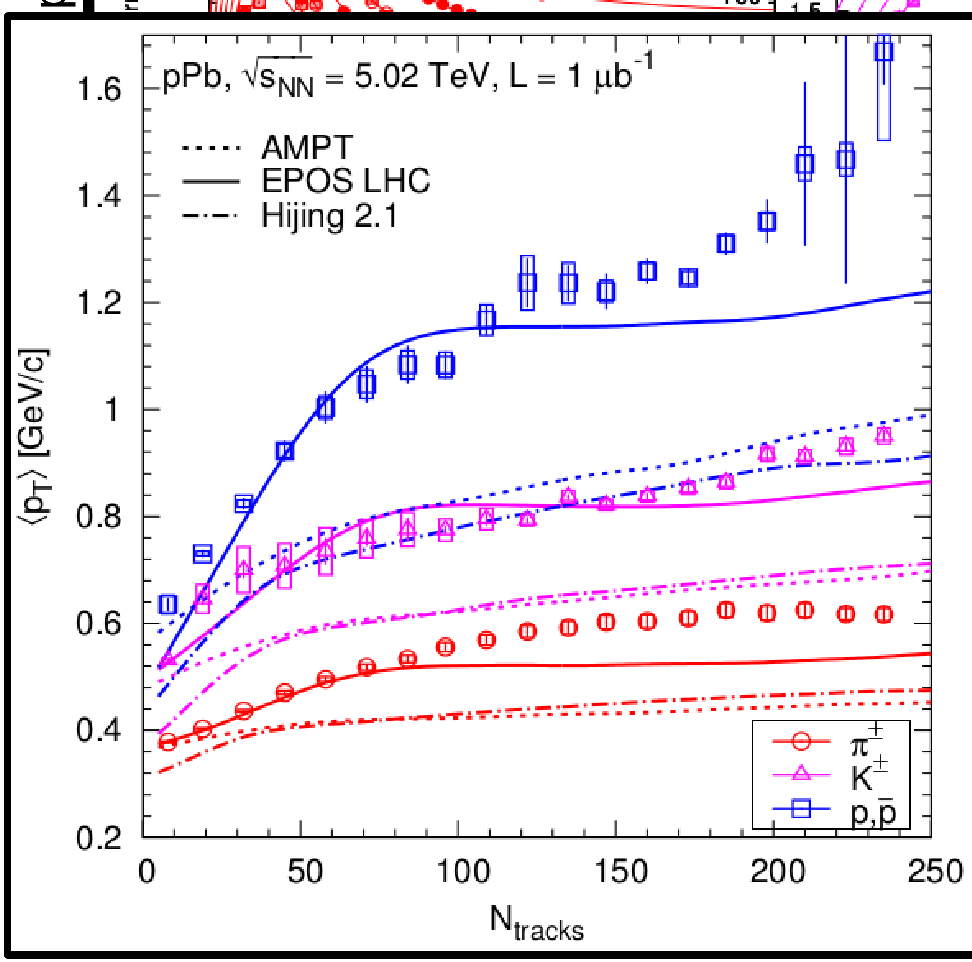
Radial flow expected to reflect in spectra, in particular in p/π ratio

Shuryak and Zahed, arXiv:1301.4470

Identified particle p_T spectra

CMS, arXiv:1307.3442



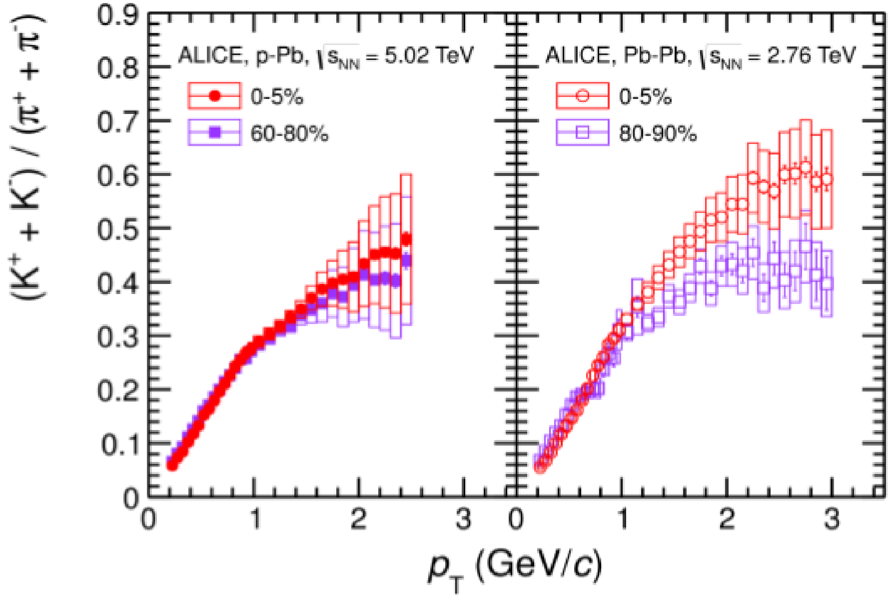


- Spectra measured in bins of multiplicity
  - For kaons and more for protons shape changes with increasing multiplicity
- Change is reflected in (proton) mean p_T
- AMPT/HIJING models fail to describe the multiplicity dependence, while EPOS LHC gets the trend right
- Geometric scaling of pp and pPb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

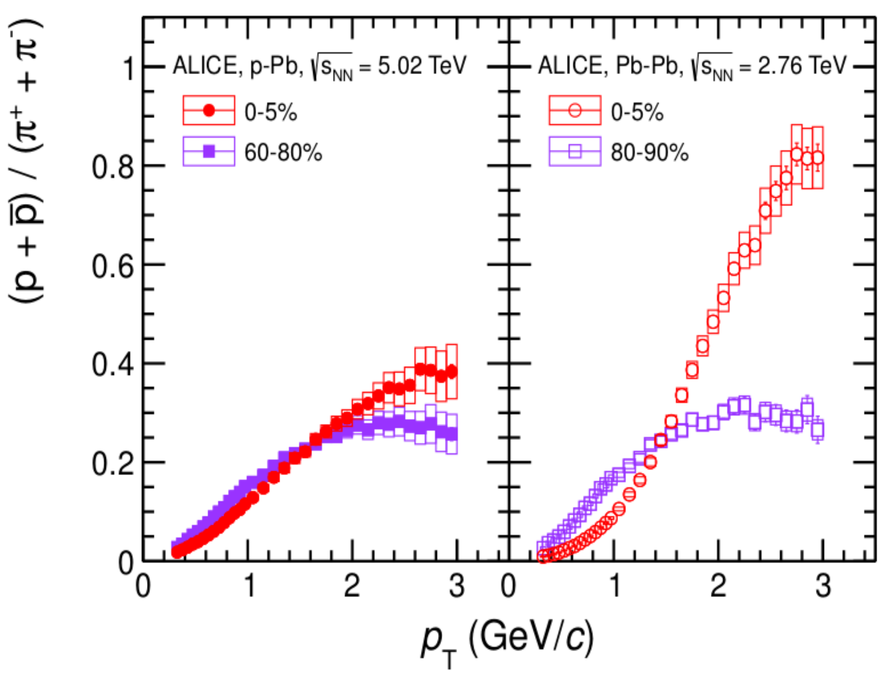
Particle ratios versus p_T

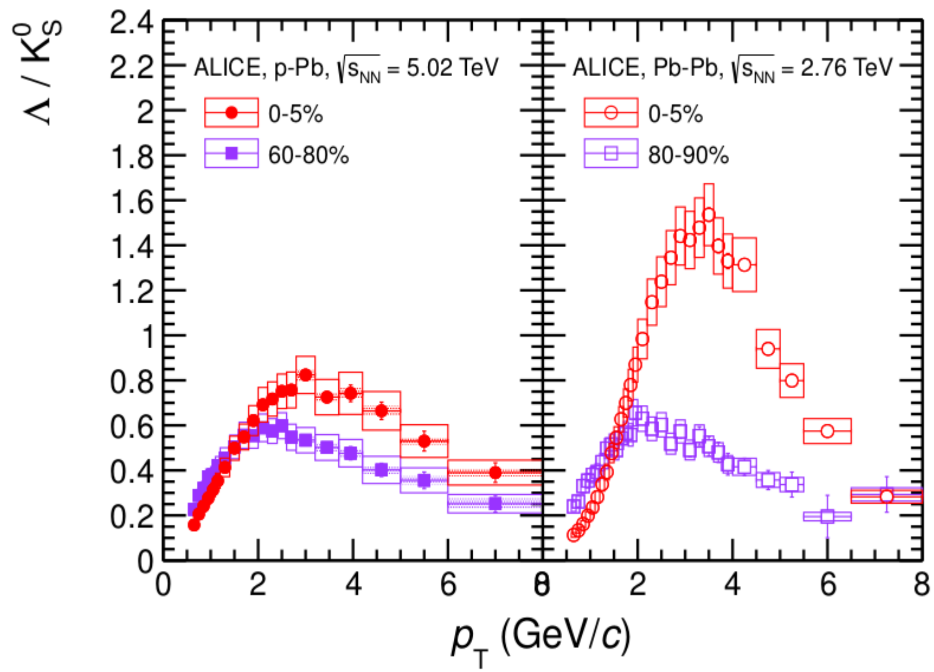
$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796



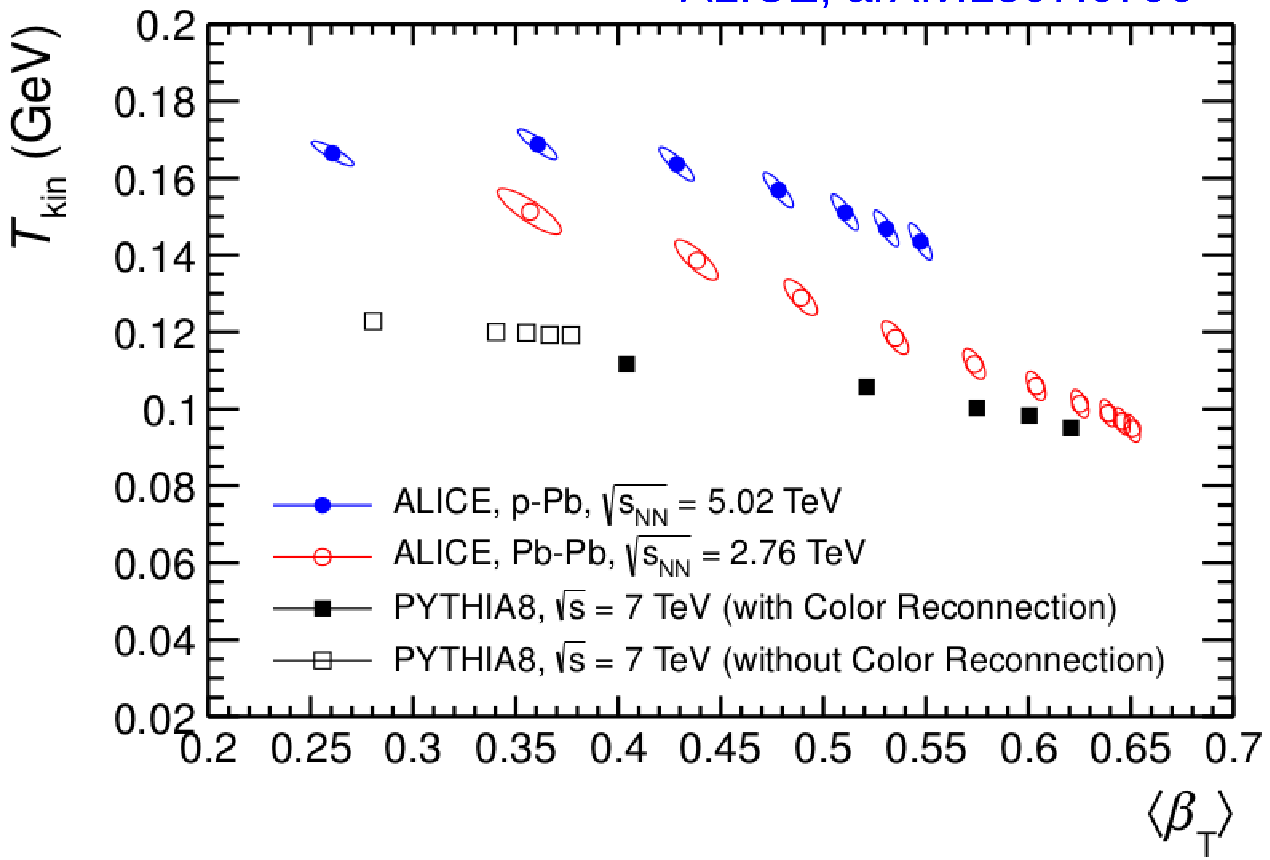
- Particle ratios in pPb show similar trends than those in PbPb
- The strength of the effects is similar to those in peripheral PbPb collisions
- Increase of p/π and Λ/K in PbPb usually explained by radial flow and/or parton recombination





- 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)

Blast-Wave analysis (including pp)

- 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
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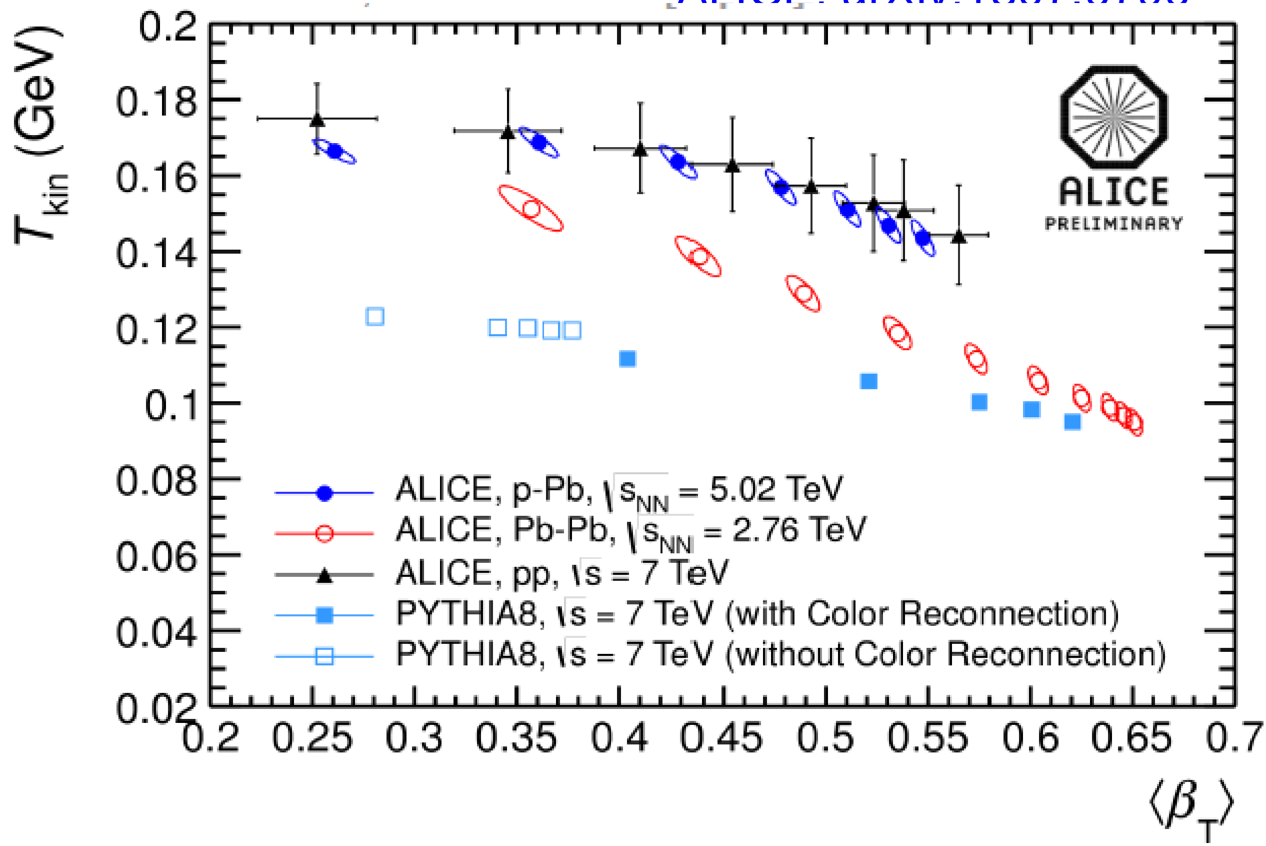
ALICE, arXiv:1307.6796



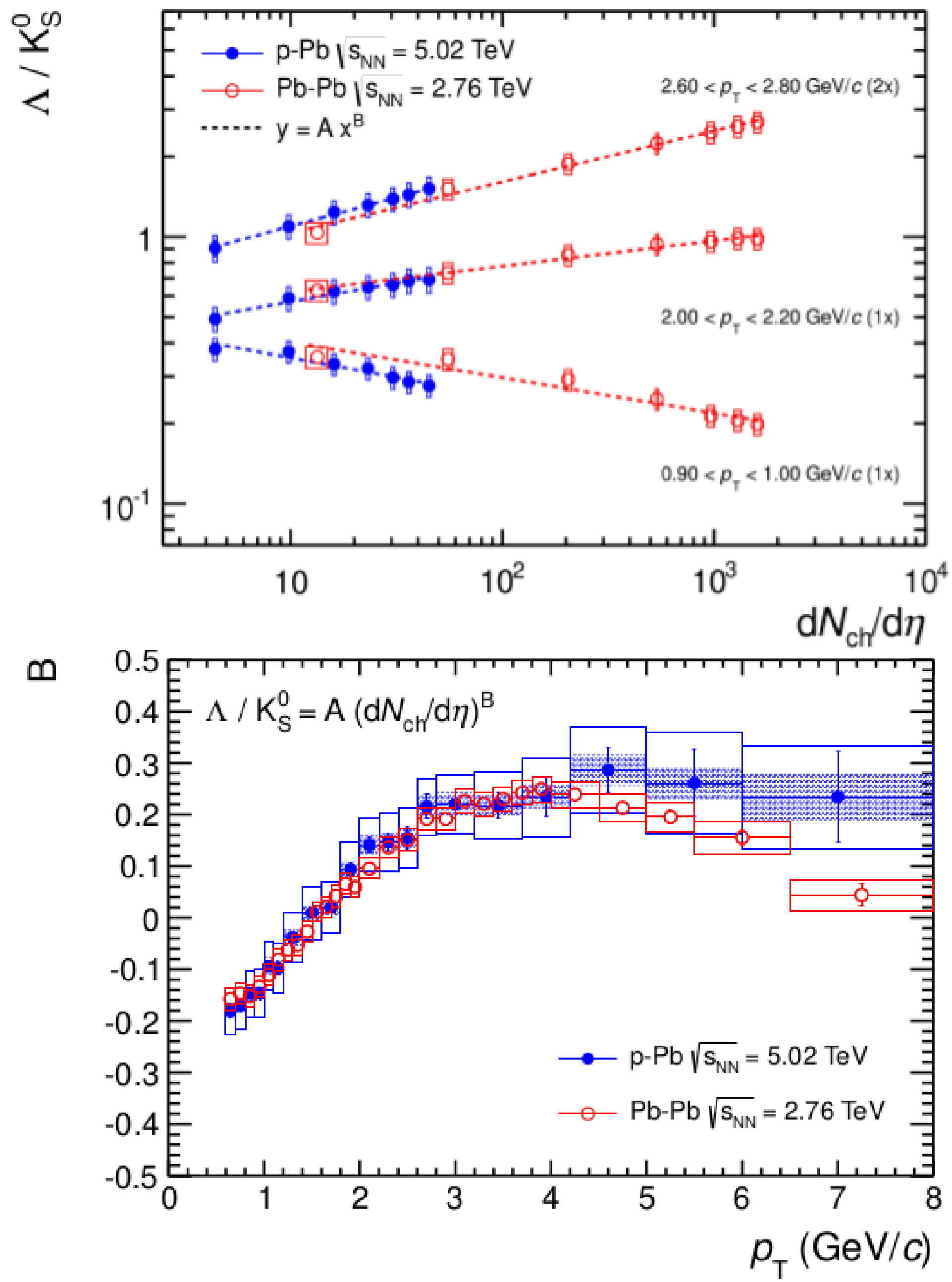
Blast-Wave results from PYTHIA with color reconnection shows qualitatively similar results (but does not include collective flow)

Multiplicity scaling of ratios

$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796

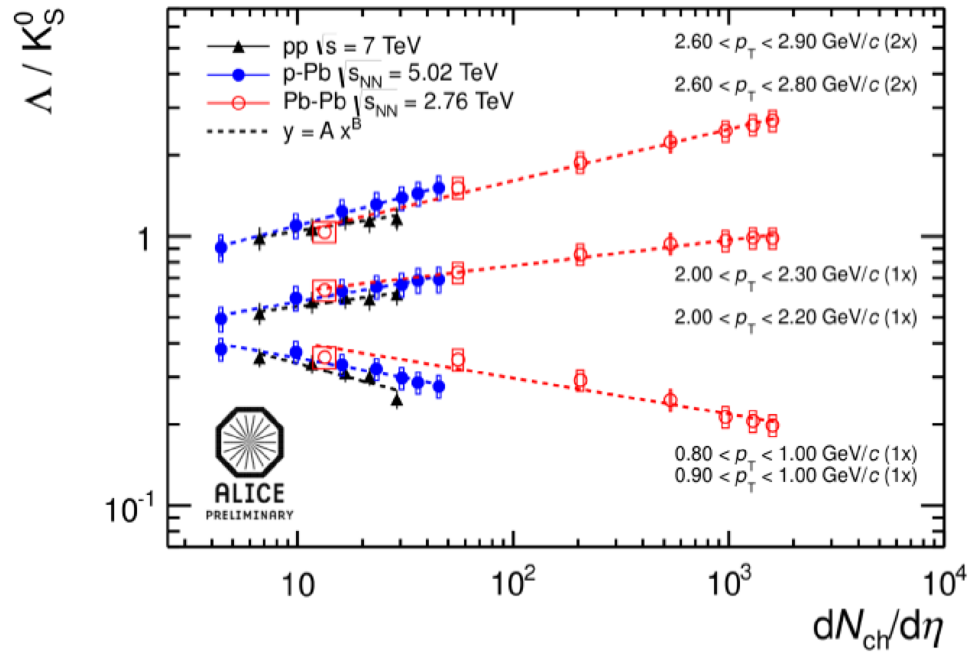
- Fit ratio vs dN/dη in p_T bins with power-law (A x^B with x=dN/dη)
- Same increase of ratio for similar increase of dN/dη in pPb and PbPb
- Same power-law scaling exponent (B) in pPb and PbPb
  - Underlying mechanism?
- Similar scaling found for p/π

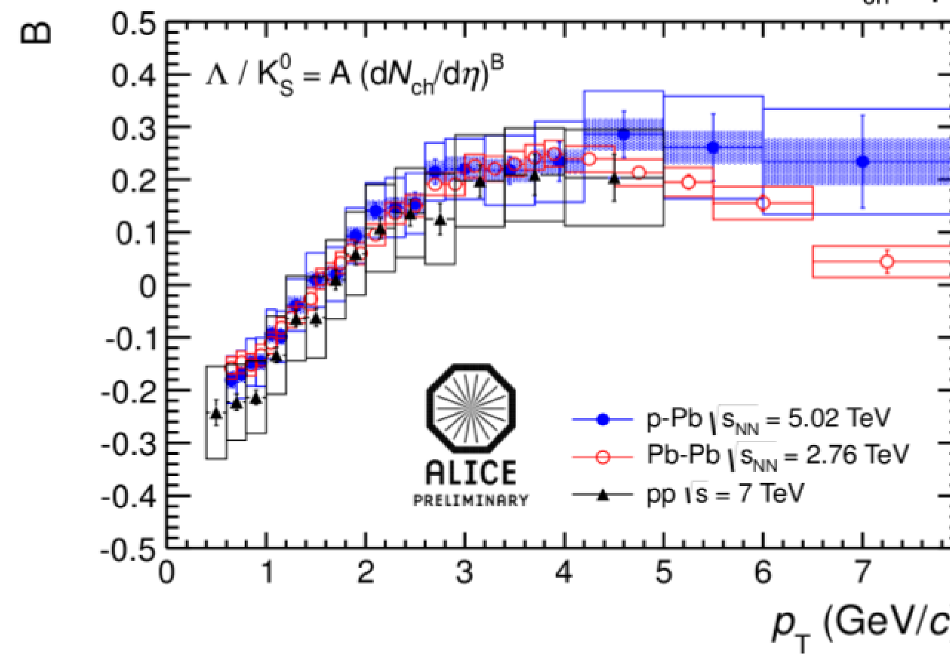


$0<y_{cms}<0.5$

ALICE, arXiv:1307.6796

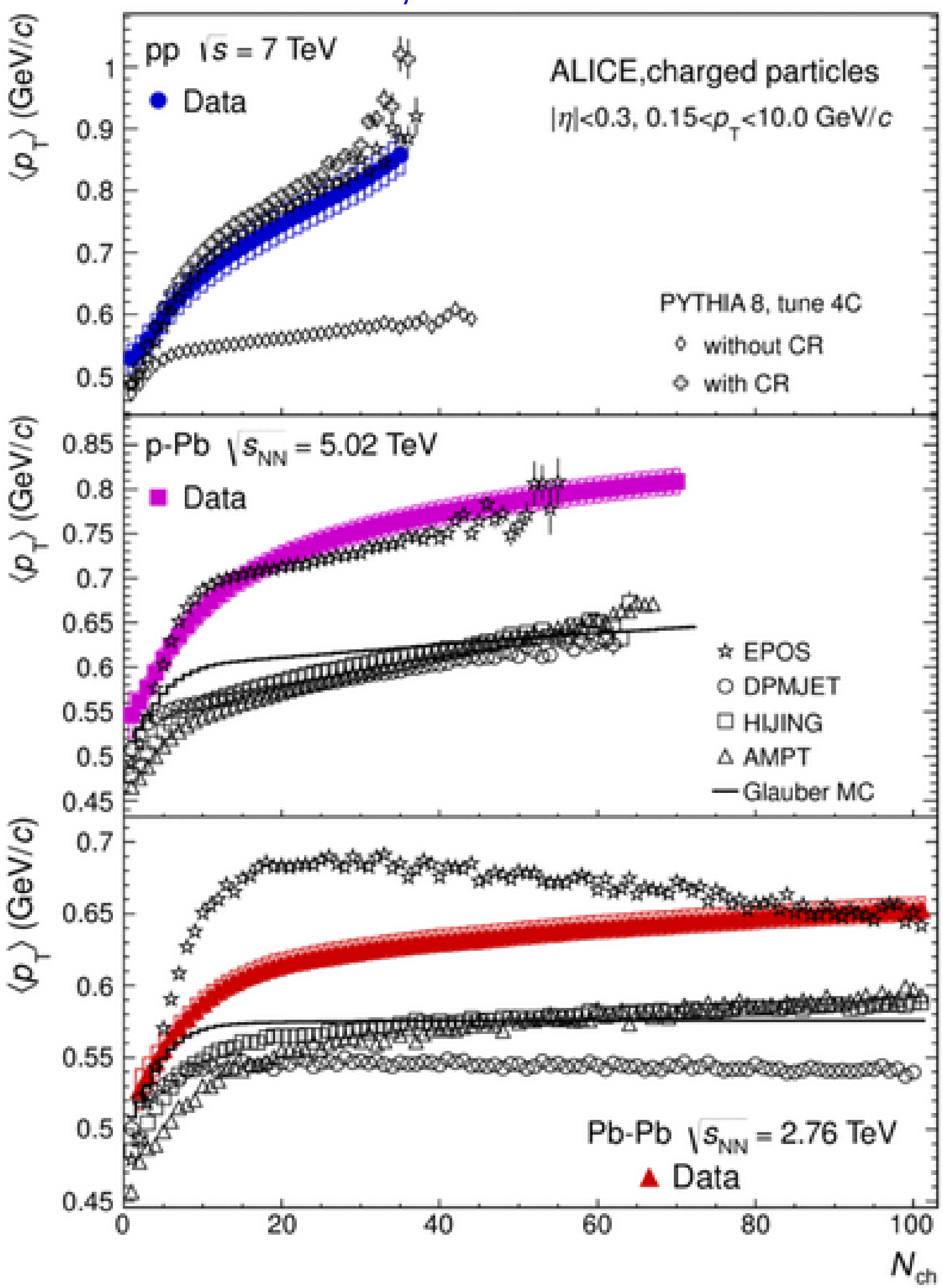
- Fit ratio vs dN/dη in p_T bins with power-law (A x^B with x=dN/dη)
- Same increase of ratio for similar increase of dN/dη in pPb and PbPb
- Same power-law scaling exponent (B) in pPb and PbPb
  - Underlying mechanism?
- Similar scaling found for p/π
- Similar scaling also holds for pp (ALICE, preliminary)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



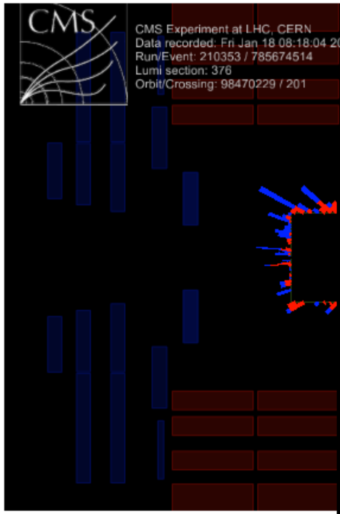


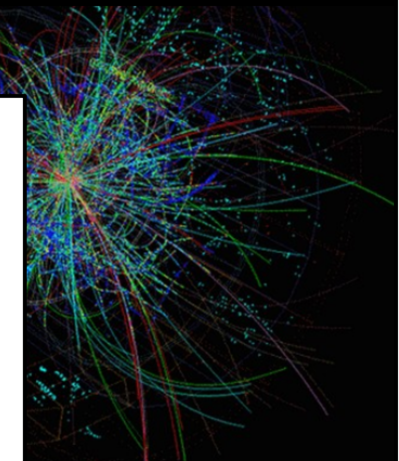
Average p_T versus N_{ch}

ALICE, arXiv:1307.1094

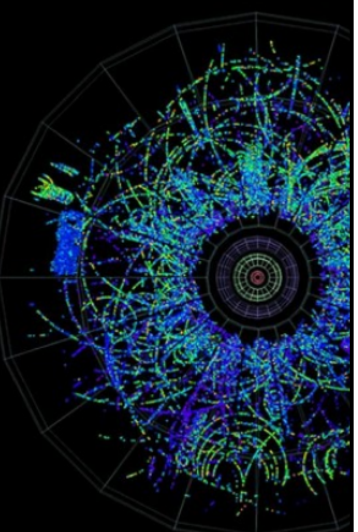


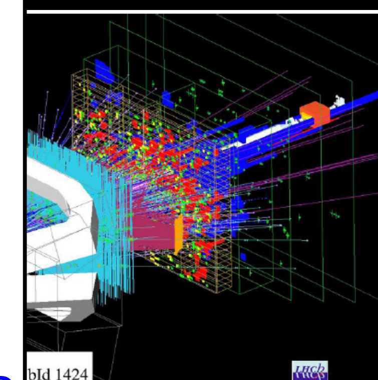
- pp
  - Within PYTHIA model increase in mean p_T can be modeled with Color Reconnections between strings
  - Can be interpreted as collective effect (e.g. Velasquez et al., arXiv:1303.6326v1)
- pPb
  - Increase follows pp up to N_{ch}~14 (90% of pp cross section, pp already biased)
  - Glauber MC (as 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

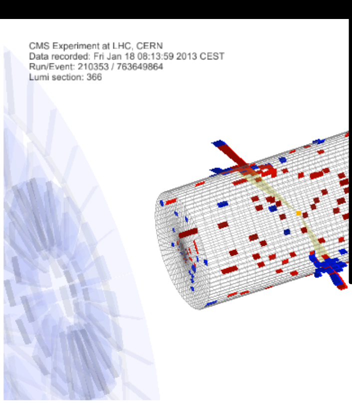


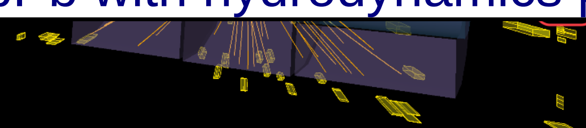


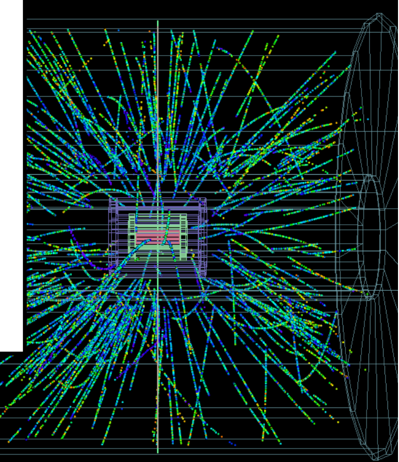
- Minbias measurements on various probes in pPb (h, jets, J/Ψ, Y, Ds and Bs) indicate that effects in (central) PbPb are different or stronger
  - Models, in particular those based on shadowing, can typically describe the data
- Strong correlations between the hard scattering and the underlying event
- Due to fluctuations, centrality determined in $|\eta|<5$ includes a bias on the hardness of the collision
  - Bias must be taken into account in model comparisons
- Two-particle correlation and PID results challenge the role of initial and final state effects in pp, pPb PbPb
  - Observables exhibit features thought to be characteristic for AA
  - Is a unified description of bulk correlations in pp, pPb and PbPb with hydrodynamics physical?











LHC pPb runs at 5.02 TeV

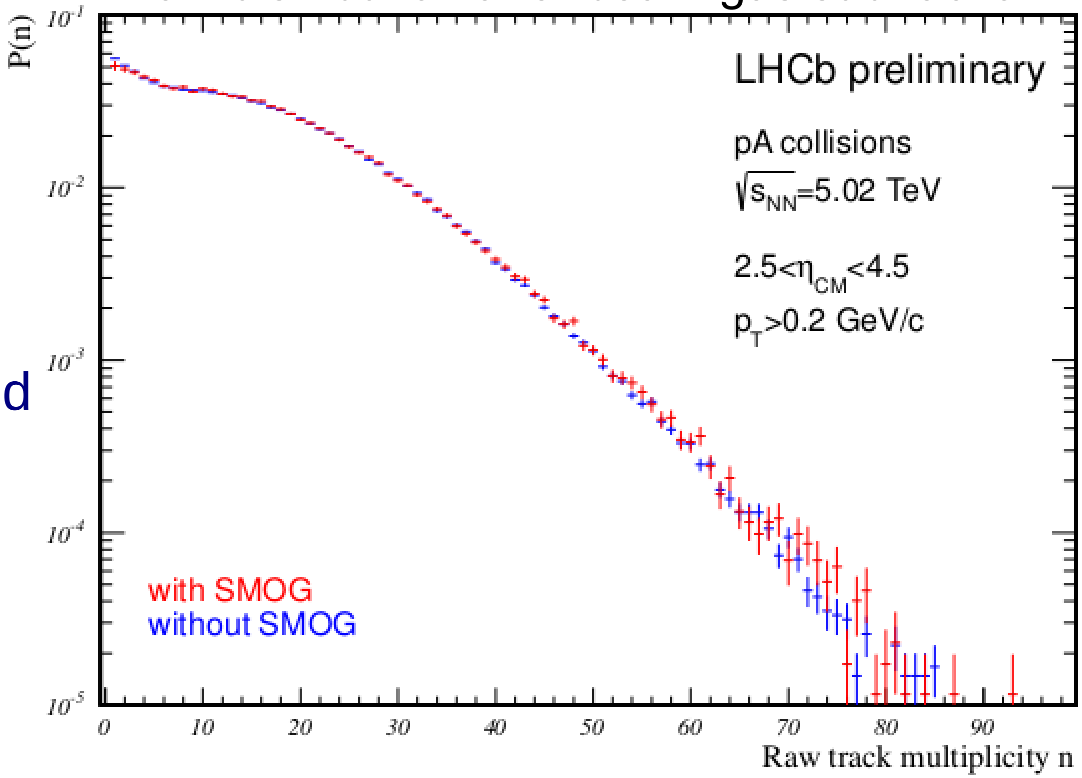
- LHC operated with
  - 4 TeV proton beam and 1.57 TeV / nucleon Pb beam
    - Center of mass energy 5.02 TeV per nucleon pair
    - Center of mass per nucleon pair rapidity shift dY = 0.465 in direction of proton
- 2012 pilot run (4 hours of data taking)
  - About 1/μb per experiment with very low pileup
- 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



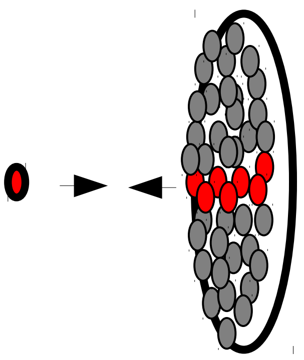
$$\sigma_{inel}(2.5 < \eta_{cm} < 4.5,\ p_T > 0.2\,\mathrm{GeV}/c) = 2.09 \pm 0.12\,\mathrm{b}$$

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

NSD pPb normalization

ALICE, PRL 110 (2013) 032301

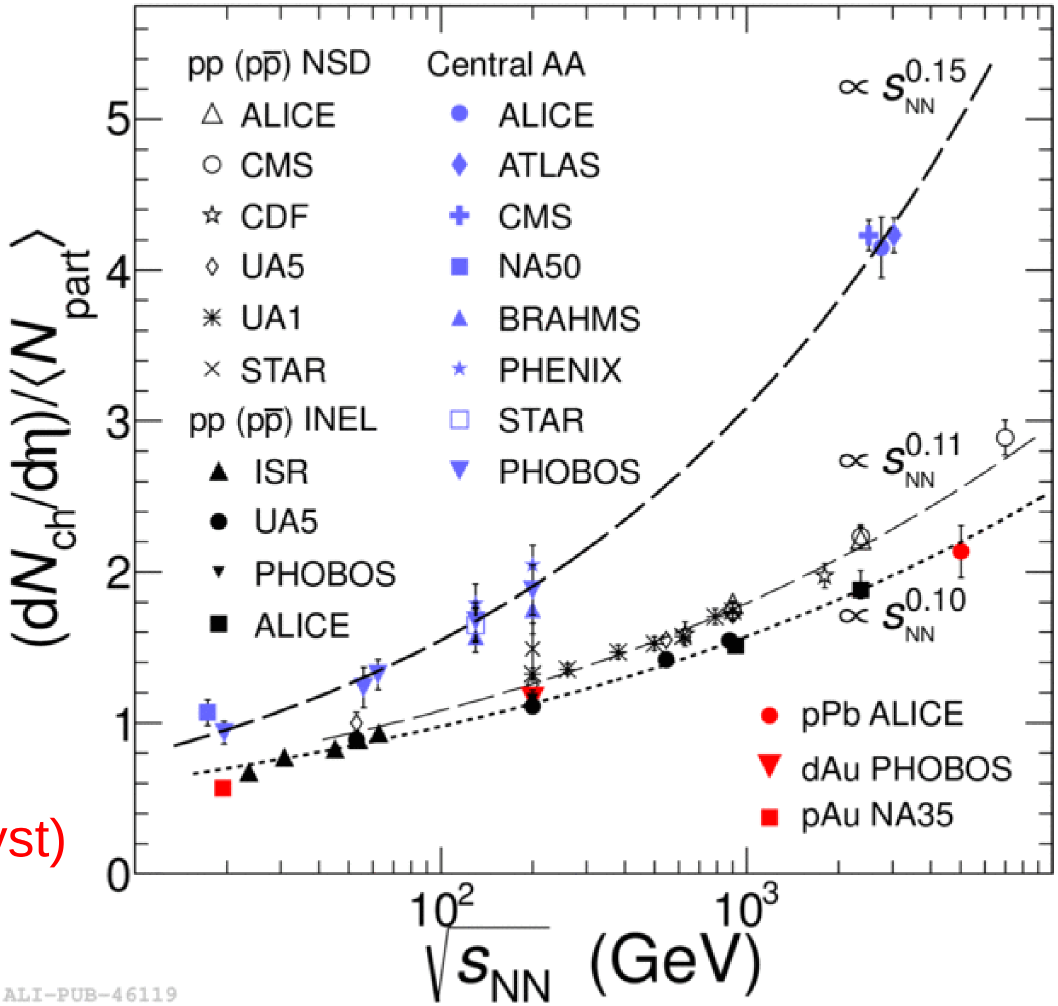
- Event selection
  - VZERO-A (2.8<η<5.1) and VZERO-C (-3.7<η<-1.7) incl. time cuts
  - Systematic variation using ZDC on nucleus side (ZNA)



- 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)

- Measurement (tracklet based)
  - dN/dη = 16.81 ± 0.71 (syst)
  - Converted into centre-of-mass system using HIJING
  - Dominant uncertainty from NSD normalization of 3.1%
- Glauber model for pPb
  - With σ_{INEL}= 70 ± 5 mb
  - <Npart> = 7.9 ± 0.6 (syst)
- Participant scaled value
  - (dN/dη)/<Npart> = 2.14 ± 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

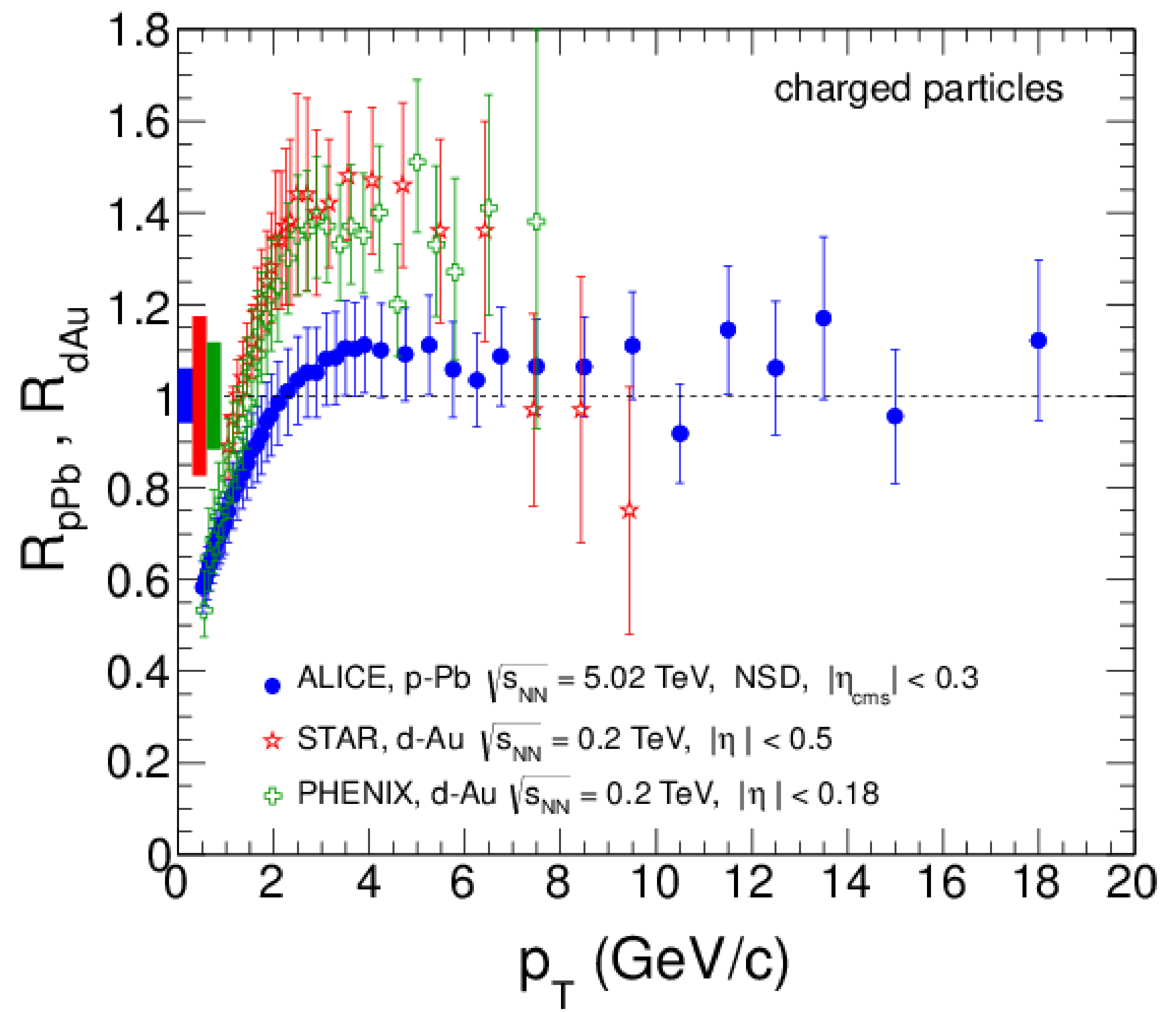


Cronin effect at RHIC and LHC

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

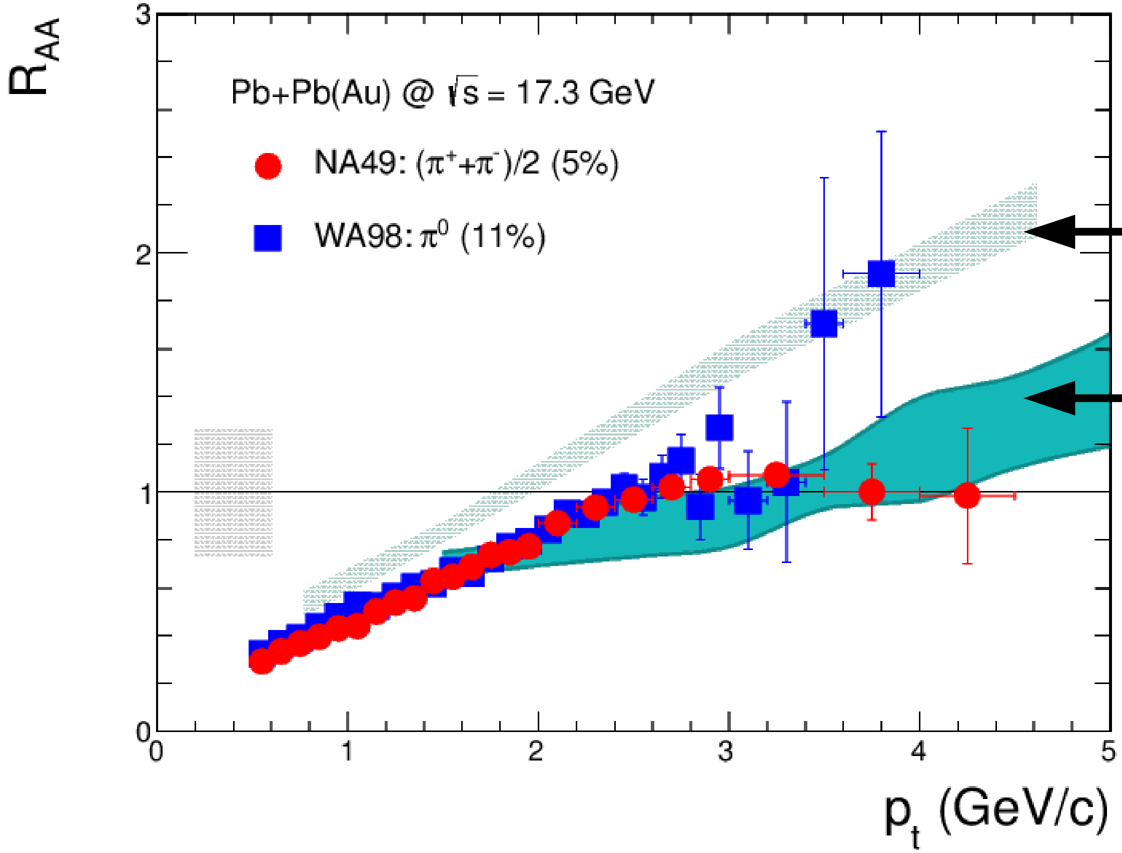
- $R_{AB} > 1$ at intermediate p_T observed in dAu collisions at RHIC typically attributed to Cronin effect
- No enhancement seen in pPb at the LHC
- No Cronin effect?

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



- 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:

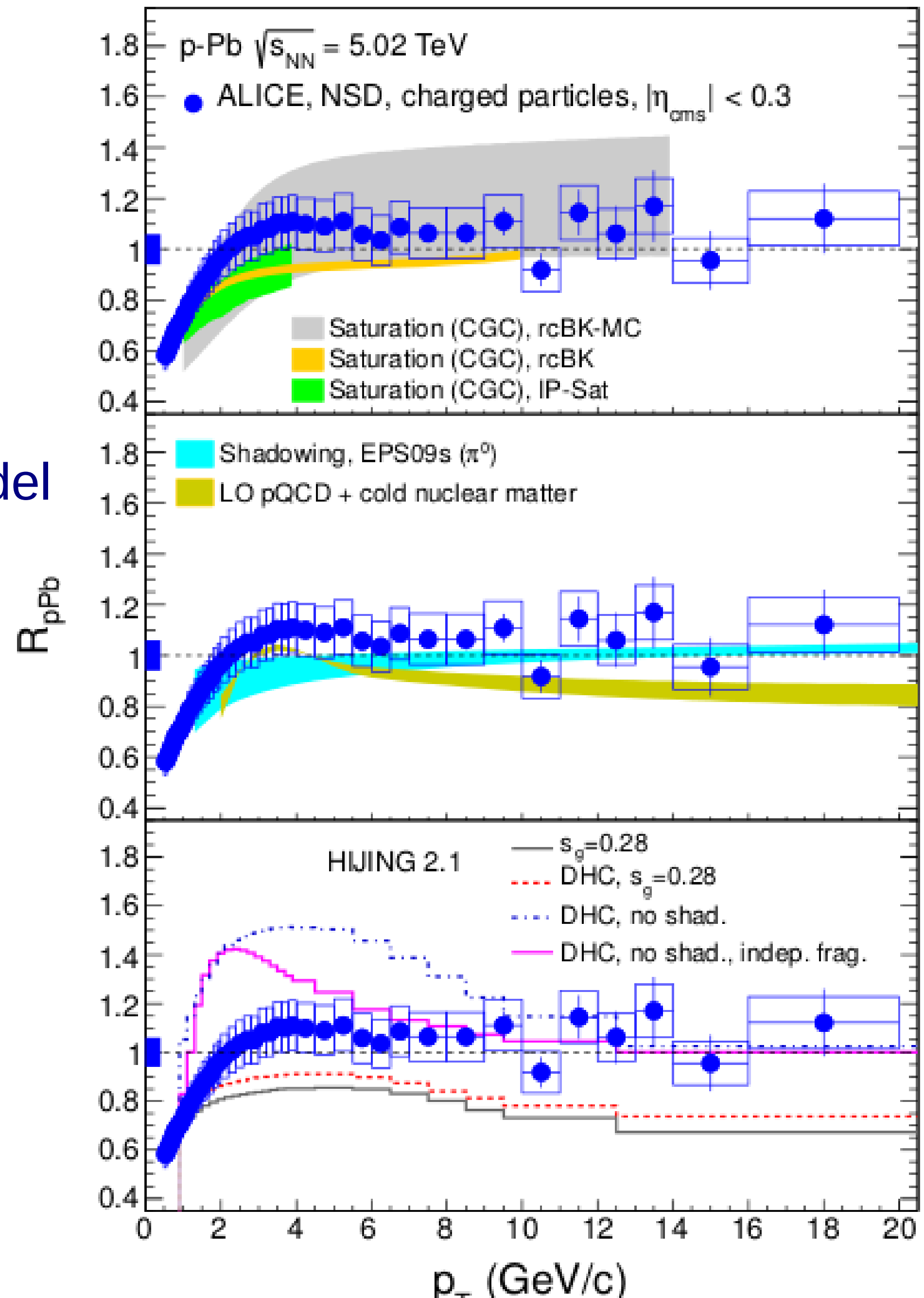
Cronin effect + shadowing

Cronin effect, shadowing plus partonic energy loss

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

Nuclear modification factor vs models

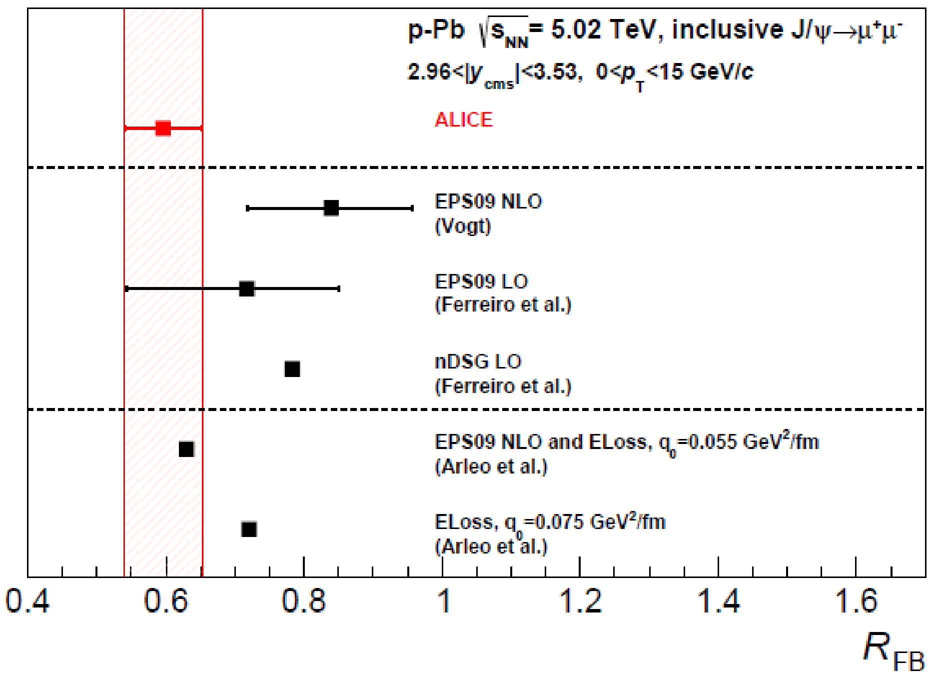
- Saturation (CGC) models:
  - Consistent with the data
  - Large uncertainties
- pQCD models with shadowing
  - Consistent with data
  - Tension at high p_T for LO+CNM model
- HIJING 2.1
  - With shadowing only matches at low p_T (see also dN/dη)
  - No shadowing better at high p_T
- Spectrum itself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

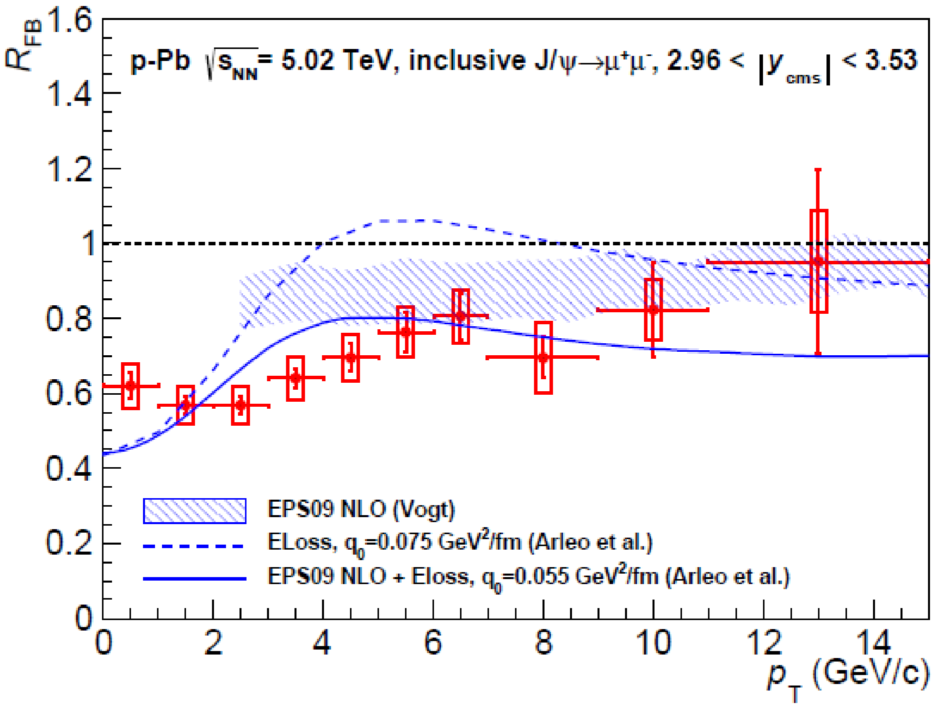


NB: HJING calculations are expected to increase by ~4% from INEL to NSD

J/ψ forward-backward asymmetry

Inclusive J/ψ, ALICE, arXiv:1308.6726

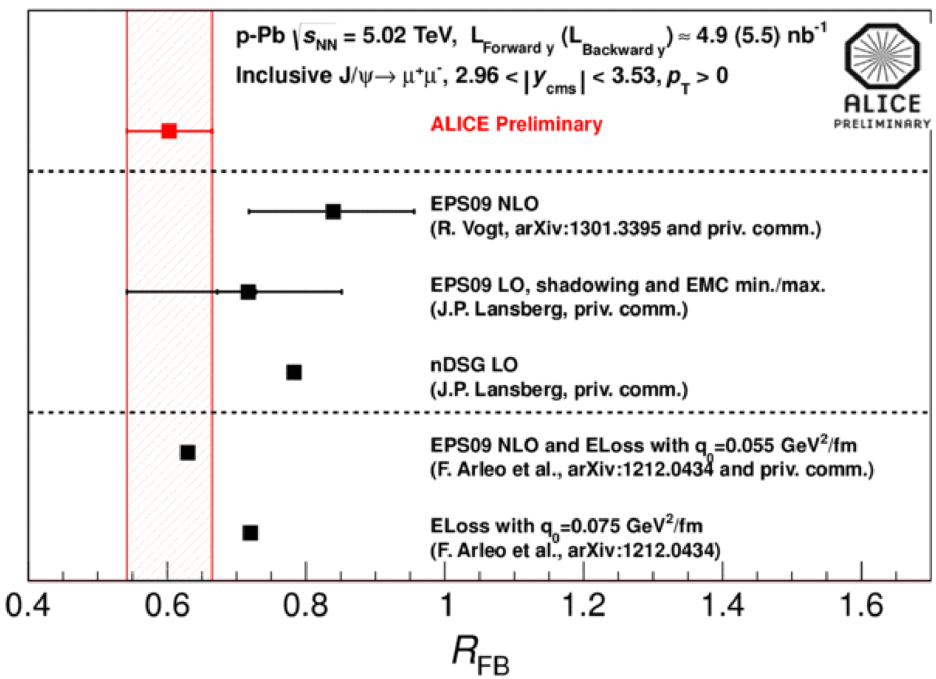


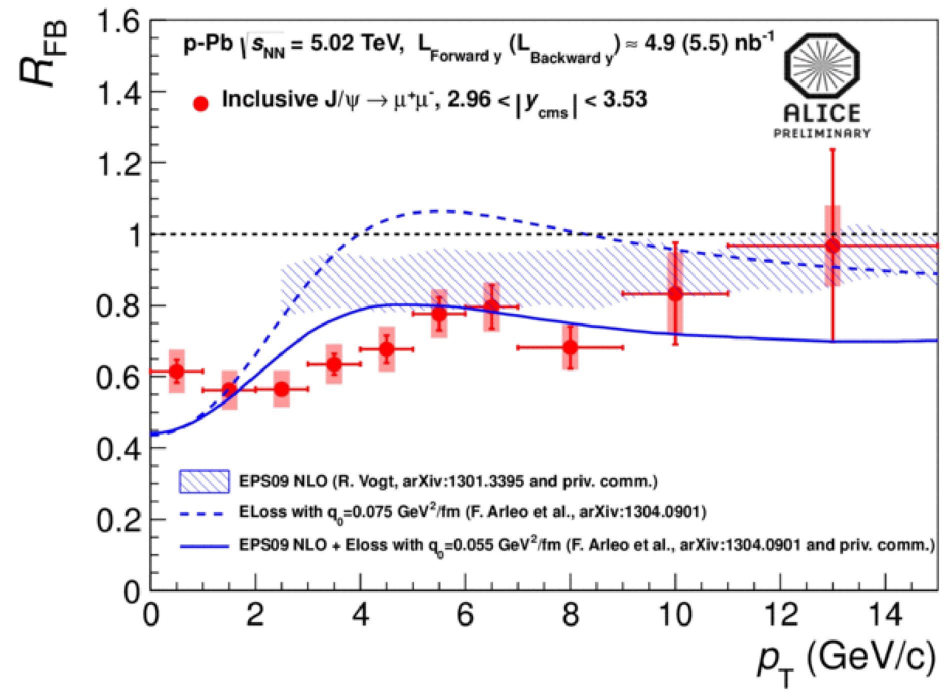


- Forward-to-backward ratio in the range 2.96<|y|<3.53
  - R_{FB} = 0.60 ± 0.01 (stat) ± 0.06 (syst)
  - Free of uncertainty from pp reference
- Pure shadowing models seem to overestimate the ratio
- p_T dependence provides additional constraints

Forward-backward asymmetry

Inclusive J/psi, ALICE, preliminary





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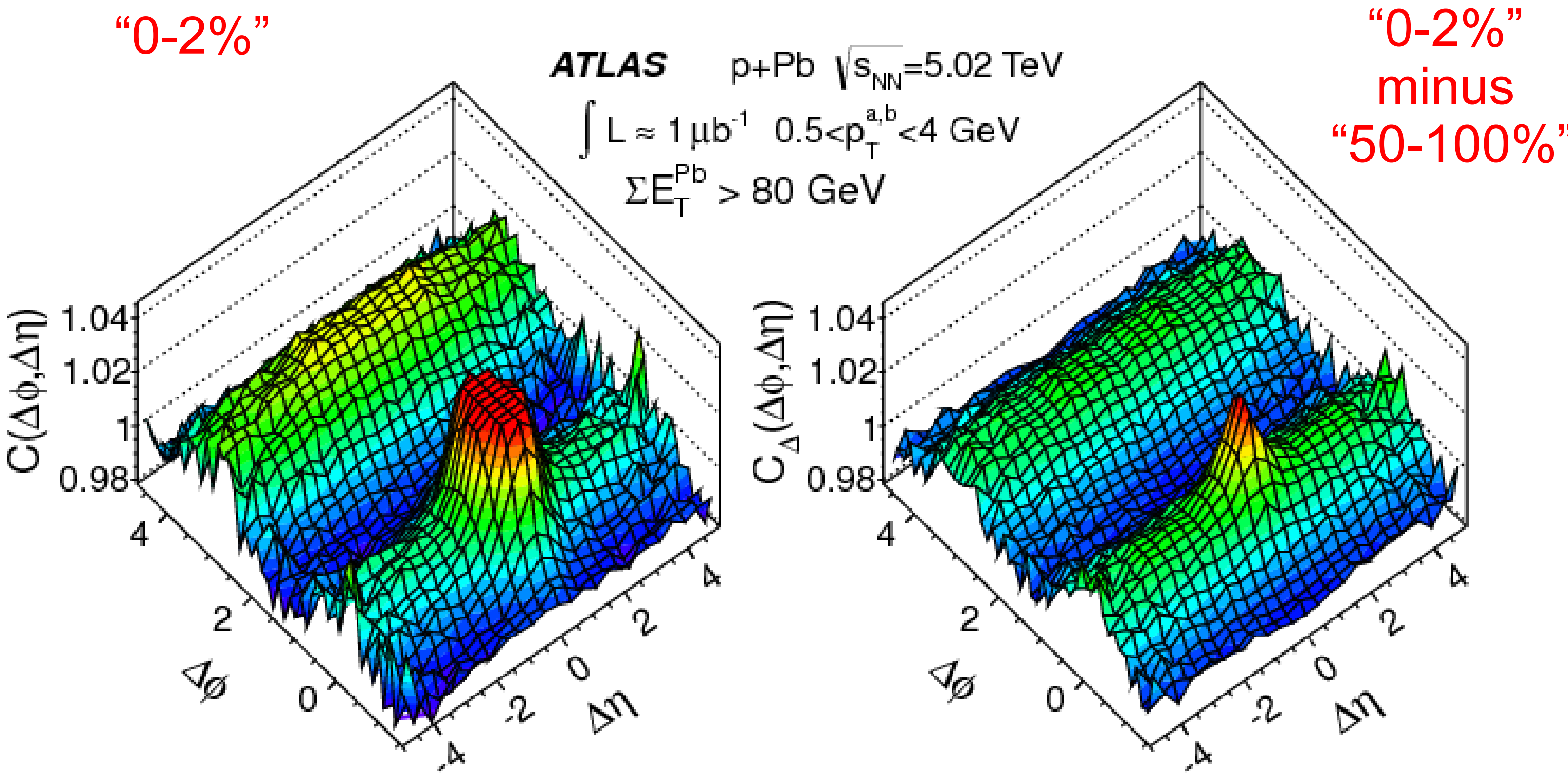
- Pure shadowing models seem to overestimate the ratio
- p_T dependence provides additional constraints

Extraction of double ridge structure

ATLAS, PRL 110 (2013) 182302

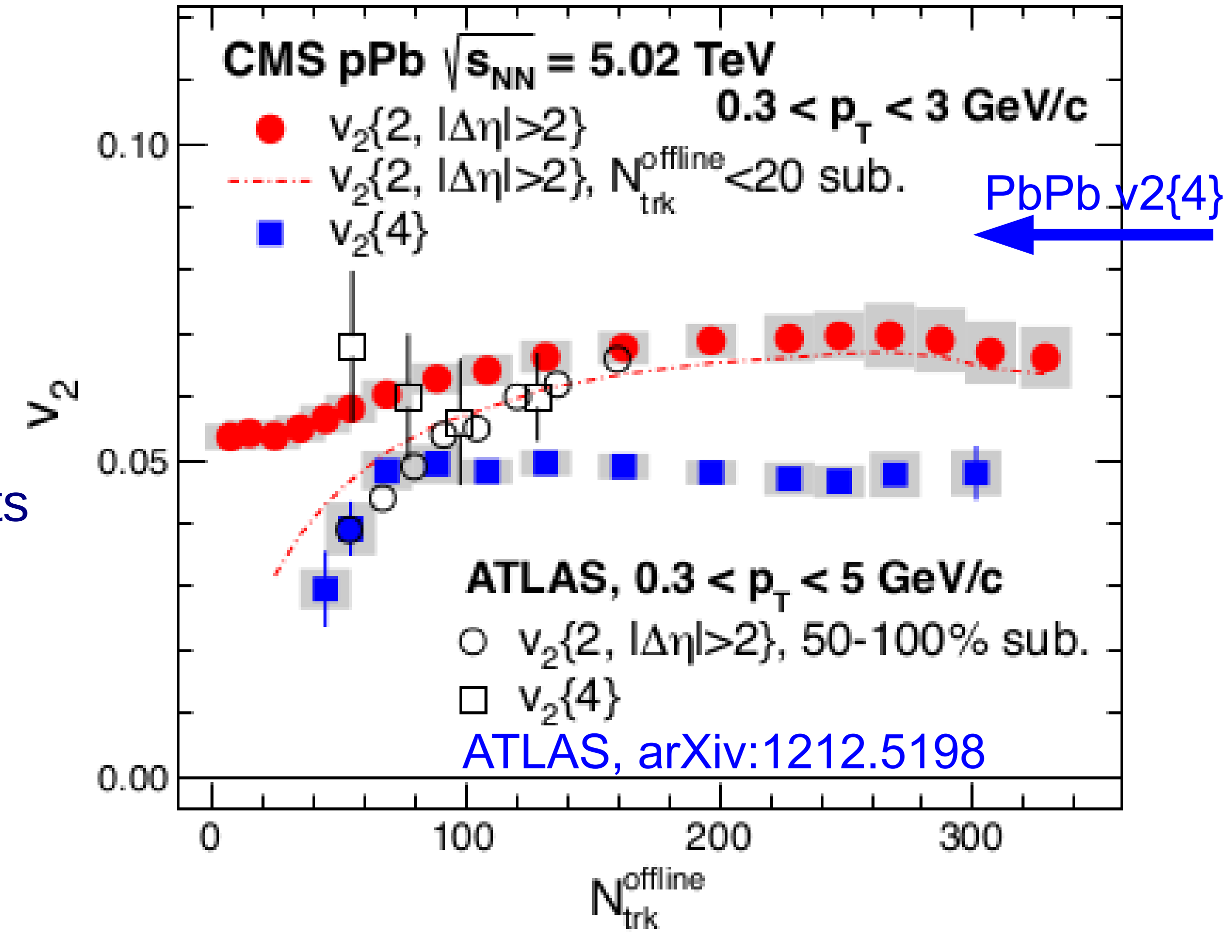
- Similar two ridge structures also observed by ATLAS
  - Event multiplicity classes defined by sum of transverse energy (3.1<η<4.9) on the Pb nucleus side
  - Here, the jet peak at (0,0) remains even after subtraction of 50-100% from the 0-2% multiplicity class



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

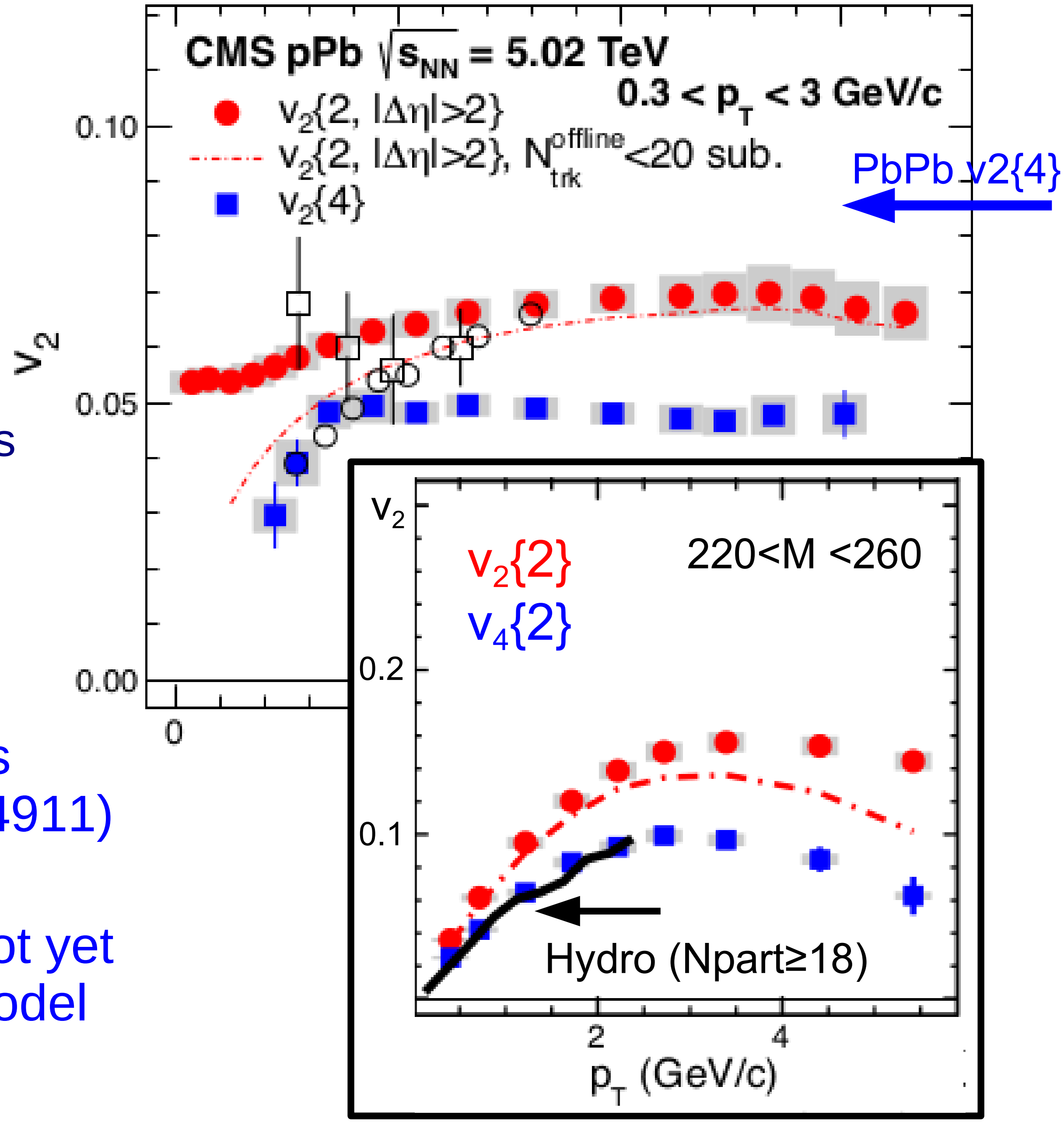
- Using four particle angular correlations subtracting those from two particles
- Genuine four particle correlations present in pPb
  - Turn-on at around M=50 offline tracks
  - Difference to ATLAS points at low M probably due to multiplicity fluctuations
  - Magnitude smaller than in PbPb

CMS, PLB 724 (2013) 213

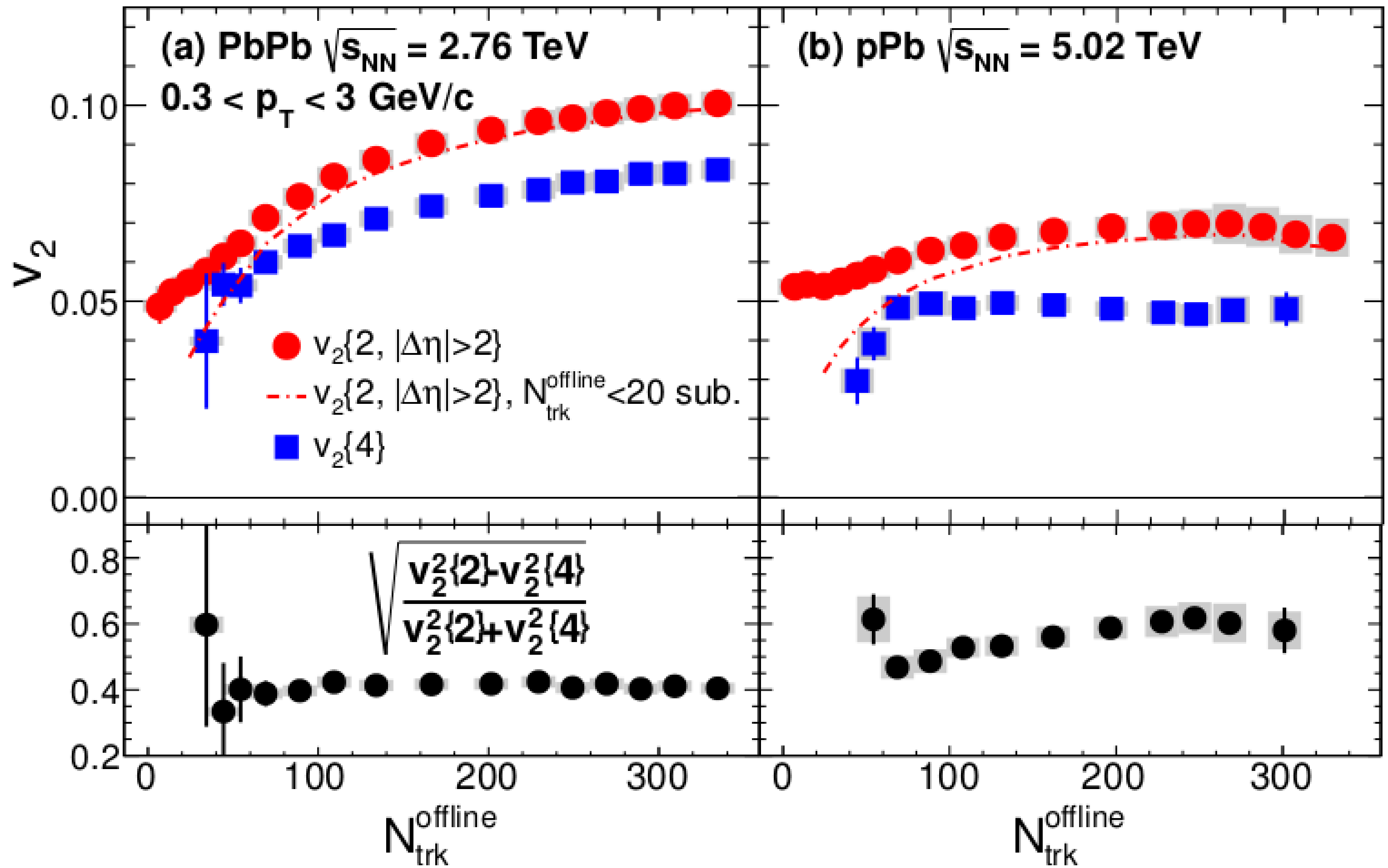


CMS, PLB 724 (2013) 213

- 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



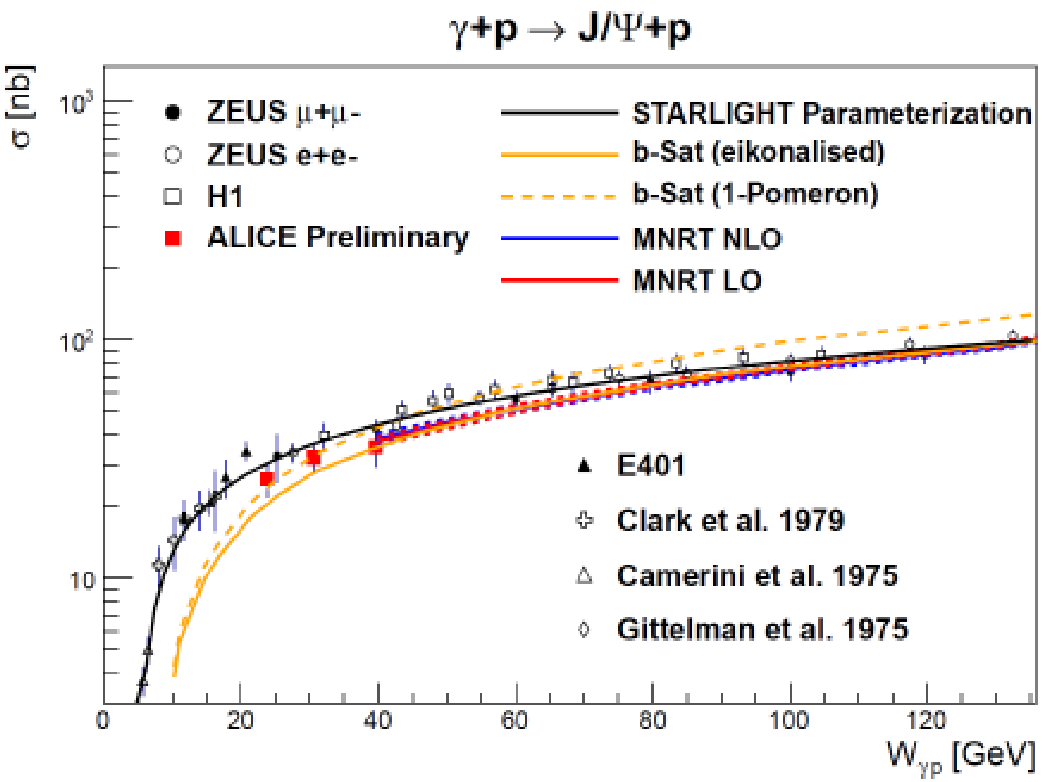
CMS, PLB 724 (2013) 213

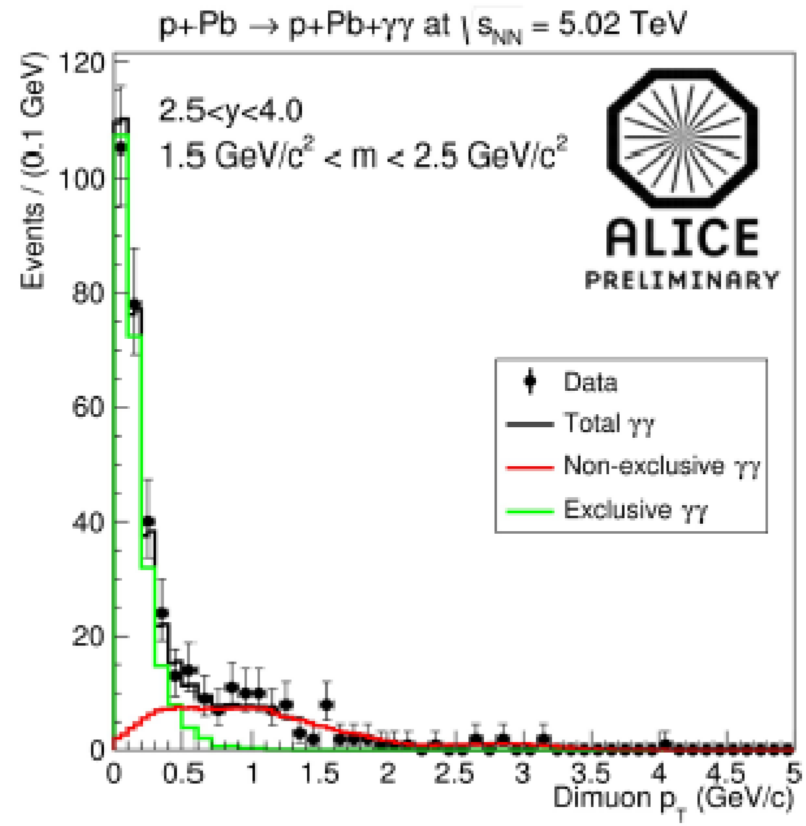


v_2 in pPb is smaller than in PbPb

UPC in pPb

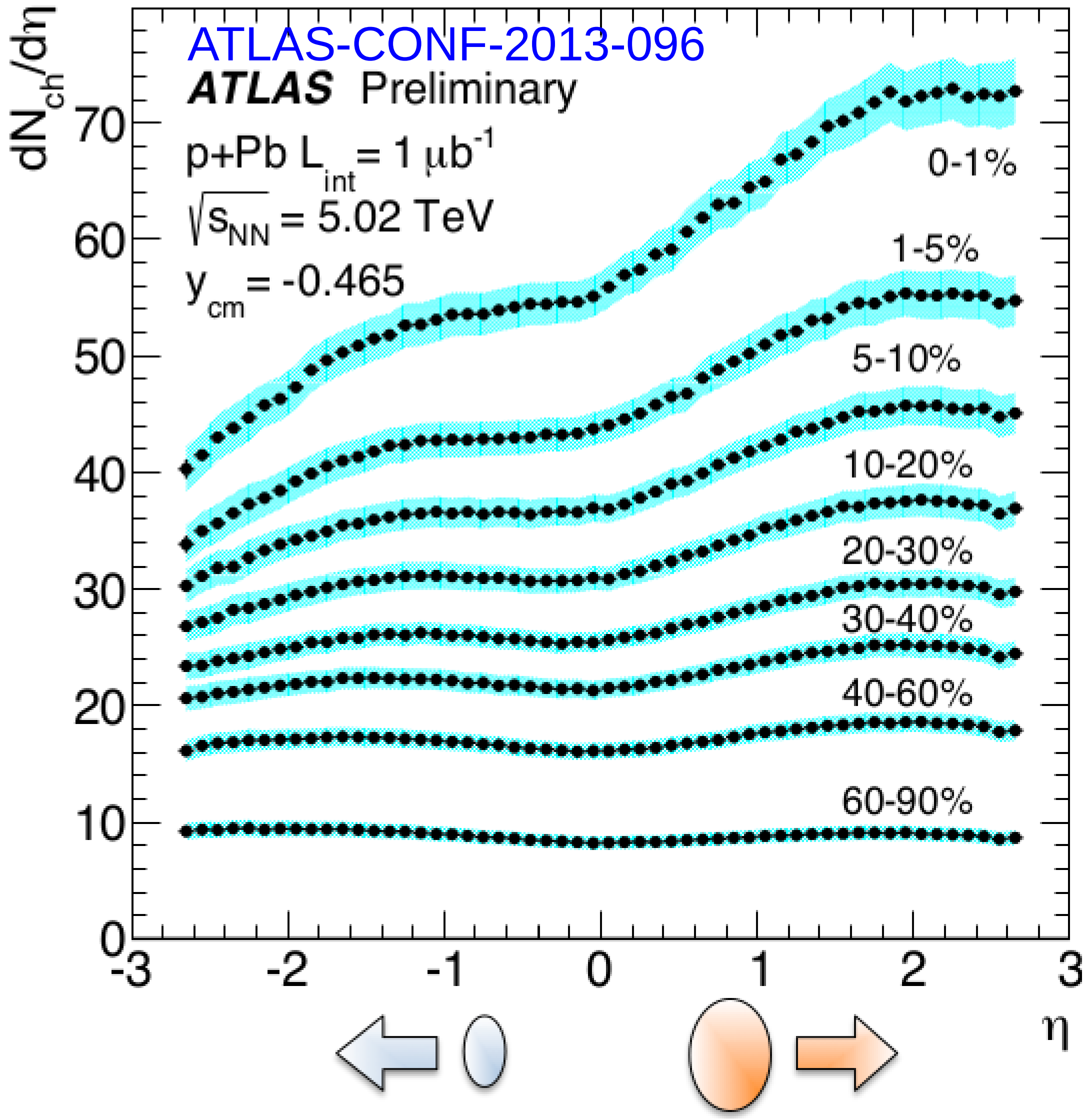
ALICE, preliminary

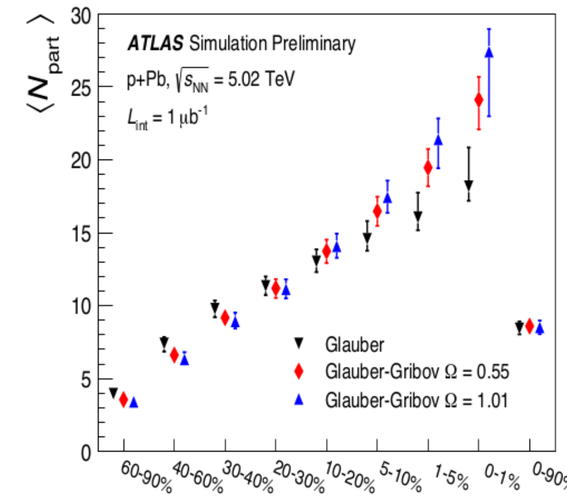


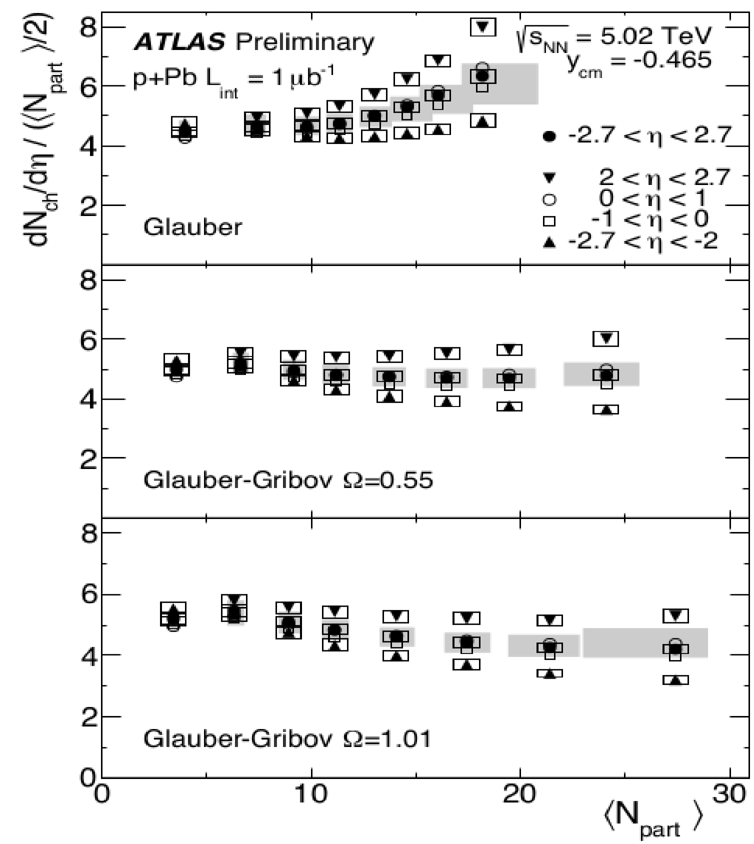


- ALICE covers lowest energies measured at HERA (and can go higher in Pbp
- First γγ measurement in pPb (consistent with STARLIGHT prediction)

Centrality dependent dN/dη







dN/dη extracted in slices of forward activity.
Relation via Npart w/wo fluctuations makes interpretation model dependent.