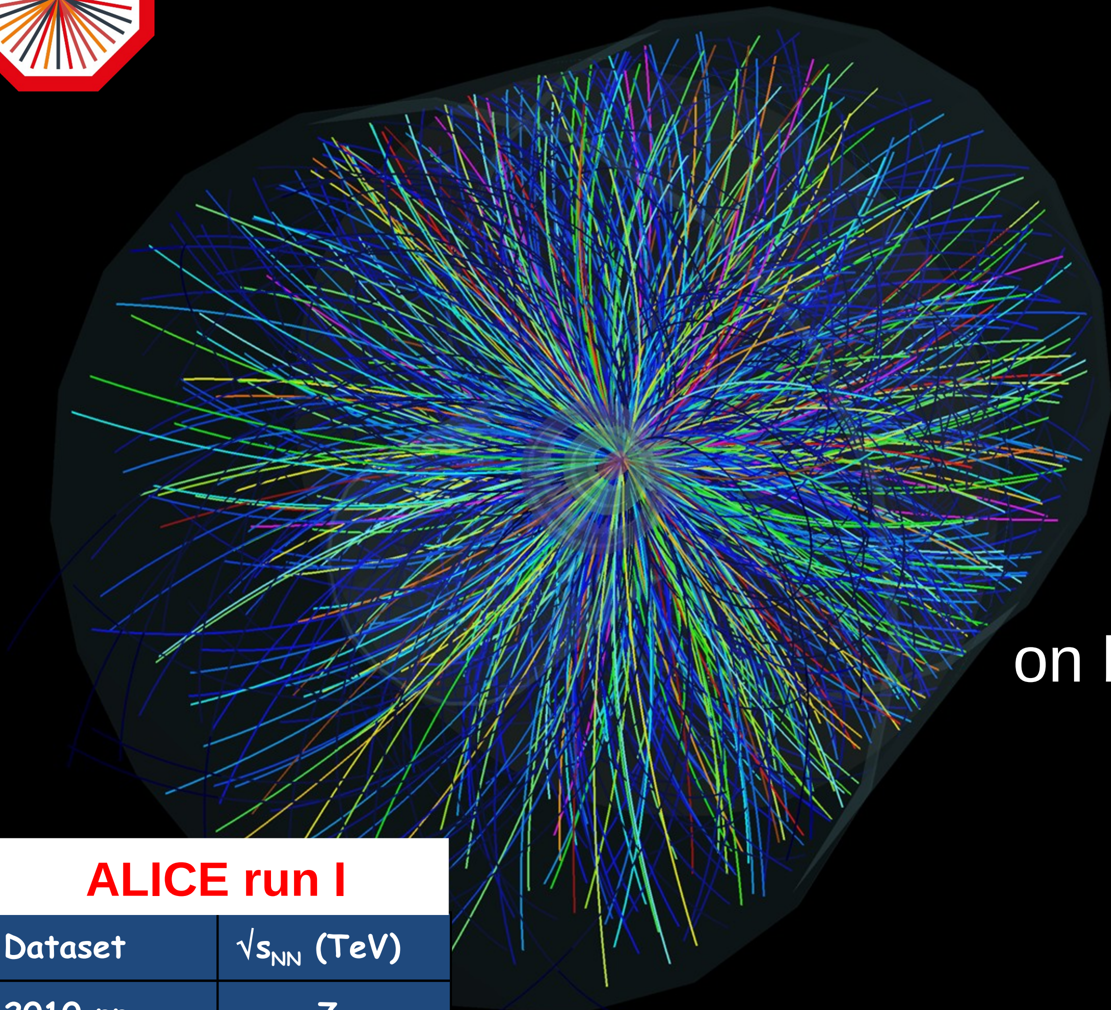


ALICE highlights

(Dec 3, 2014)

C.Loizides (LBNL)
on behalf of the ALICE collaboration

ALICE run I

Dataset	$\sqrt{s_{NN}}$ (TeV)
2010 pp	7
2011 pp	2.76
2010 Pb-Pb	2.76
2011 Pb-Pb	2.76
2013 p-Pb	5.02

Focus on results since the last IS conference
(not shown in other ALICE talks)

- Collectivity in pPb
- Multi-pion studies
- Centrality in pPb

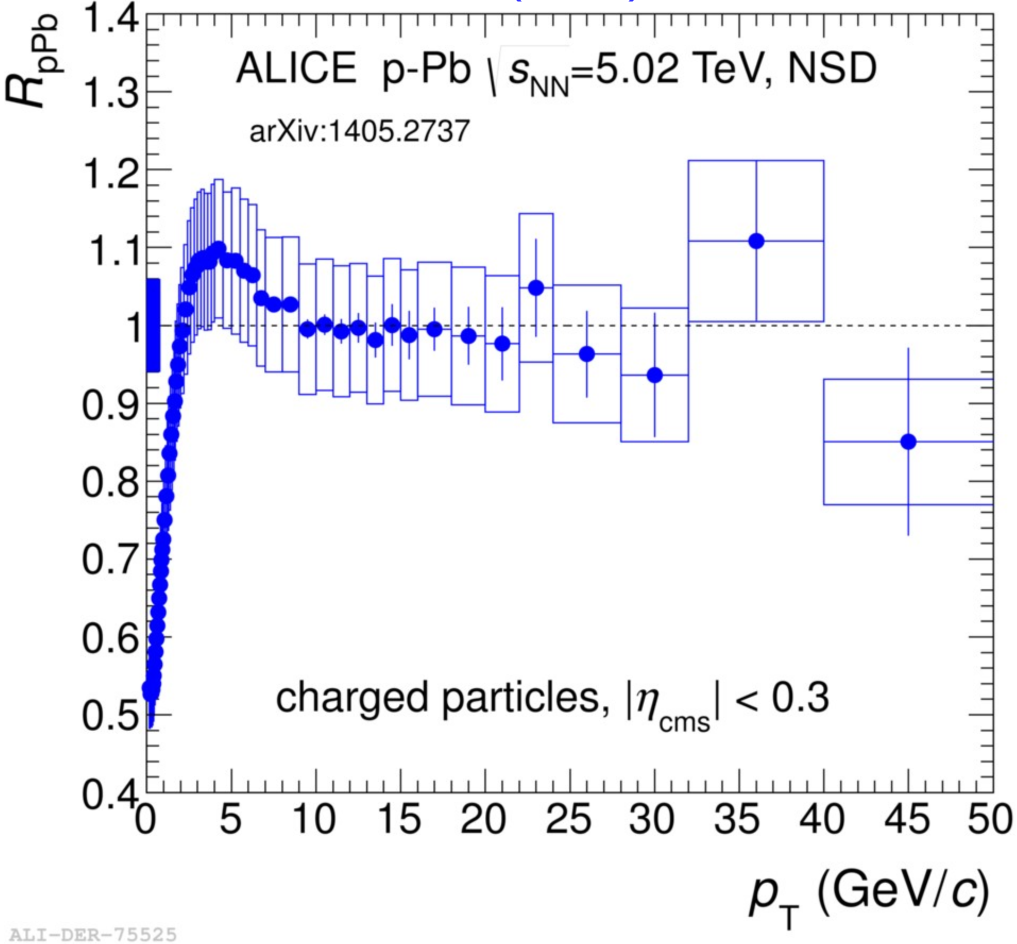
The 2nd International Conference on the Initial Stages in High-Energy Nuclear Collisions

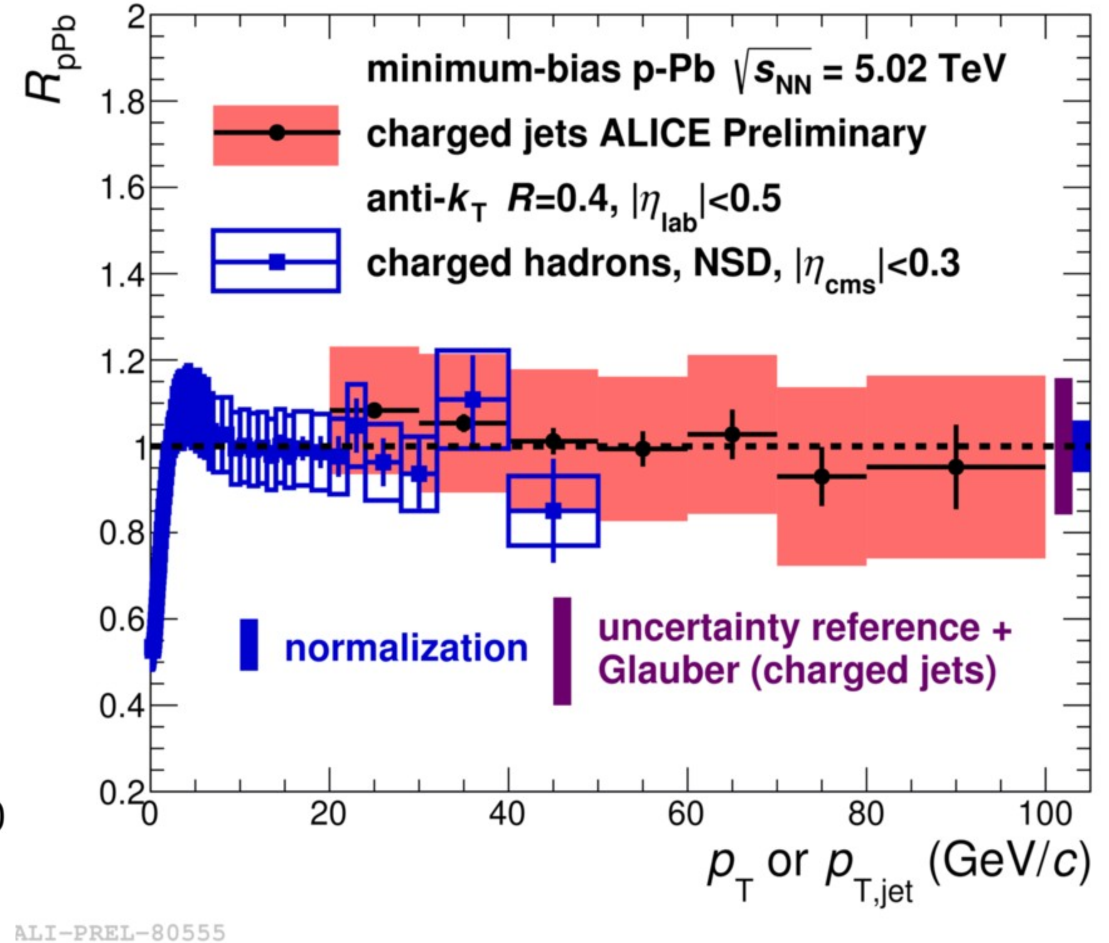
Nuclear modification factor

(M.Connors)

$$R_{\mathrm{pPb}} = \frac{\mathrm{d}N_{pPb}/\mathrm{d}p_{\mathrm{T}}}{N_{\mathrm{coll}}\,\mathrm{d}N_{pp}/\mathrm{d}p_{\mathrm{T}}}$$

EPJC 74 (2014) 3054



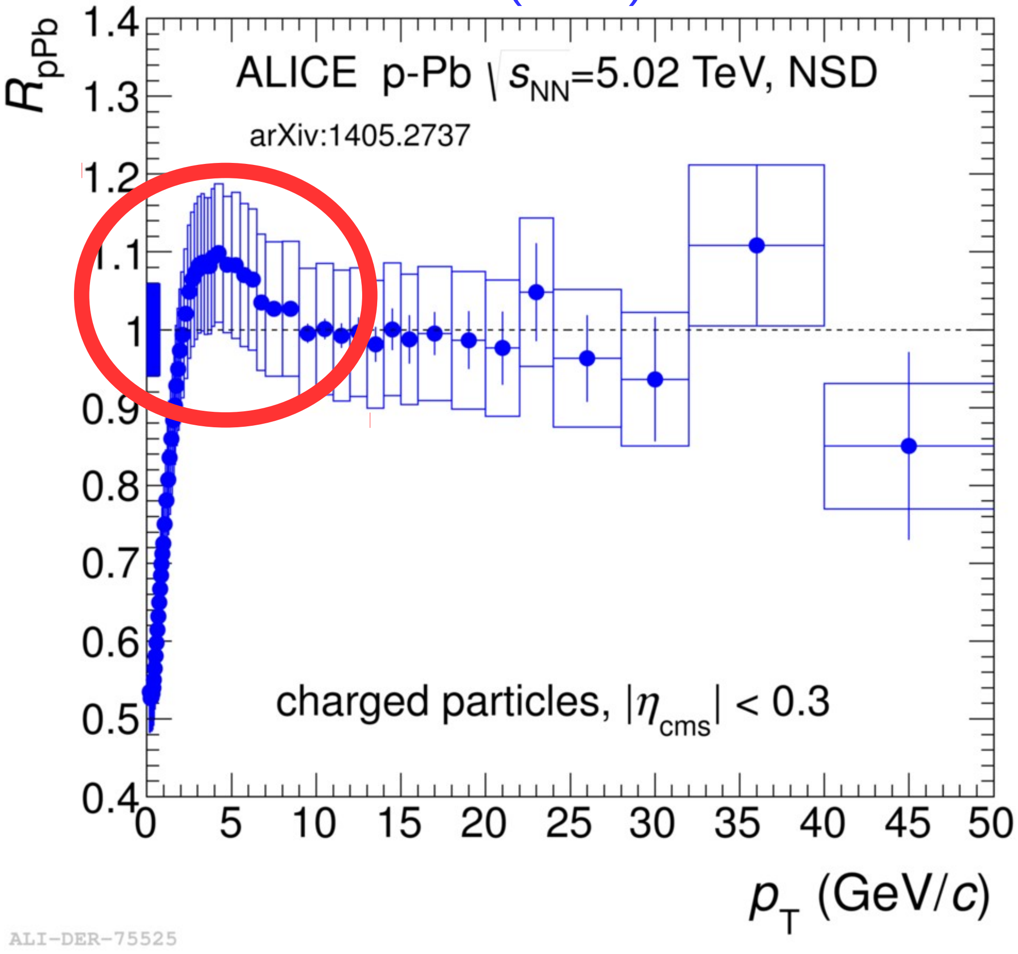


No modification at high p_T

Nuclear modification factor

$$R_{\mathrm{pPb}} = \frac{\mathrm{d}N_{pPb}/\mathrm{d}p_{\mathrm{T}}}{N_{\mathrm{coll}}\,\mathrm{d}N_{pp}/\mathrm{d}p_{\mathrm{T}}}$$

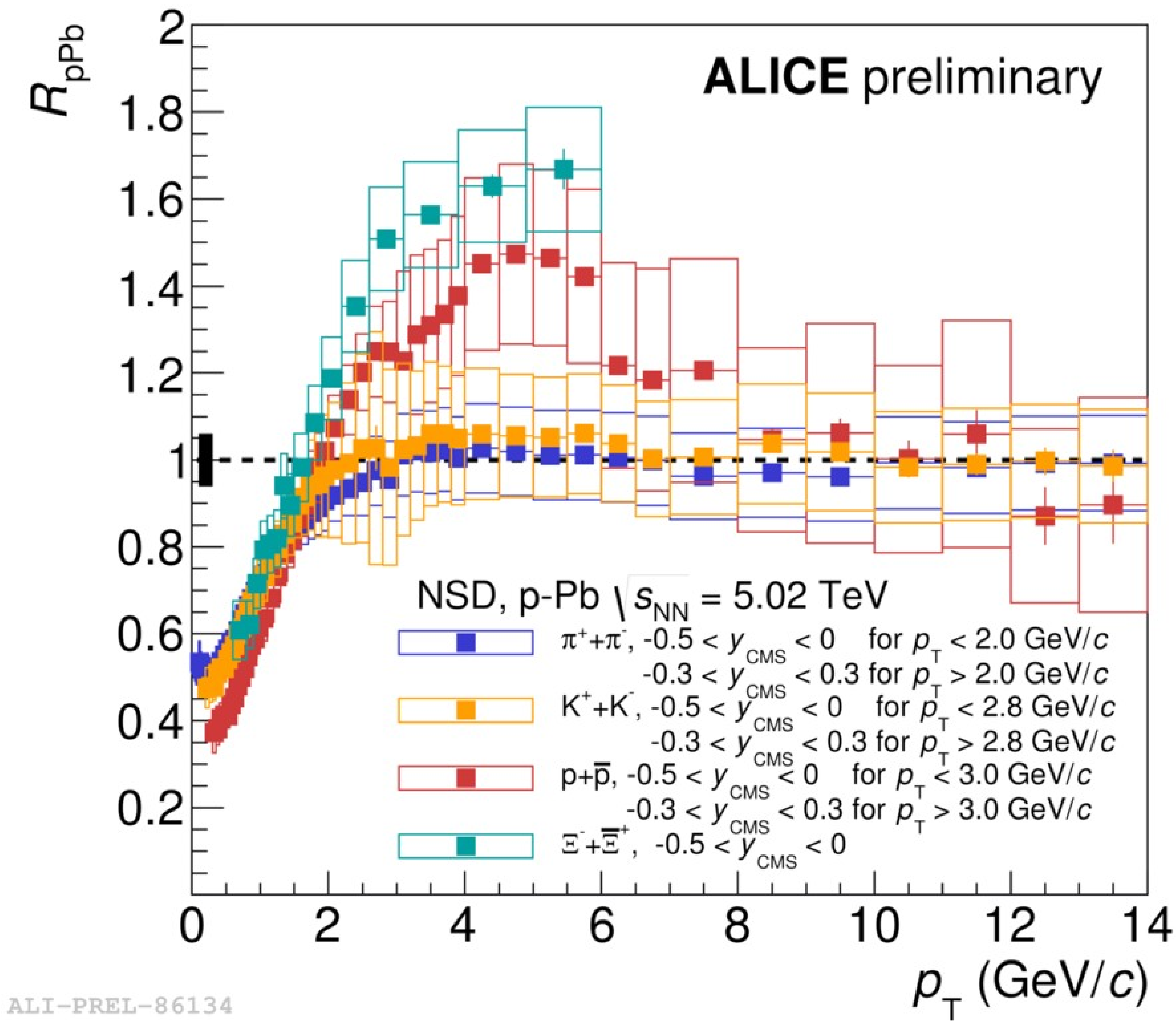
EPJC 74 (2014) 3054



- "Cronin" enhancement
  - First observed by Cronin in PRD 11 (1975) 3105
- Traditional explanation
  - Multiple soft scatterings in IS prior to hard scatter (arXiv:hep-ph/0212148)

Enhancement at intermediate p_T

Nuclear modification factor

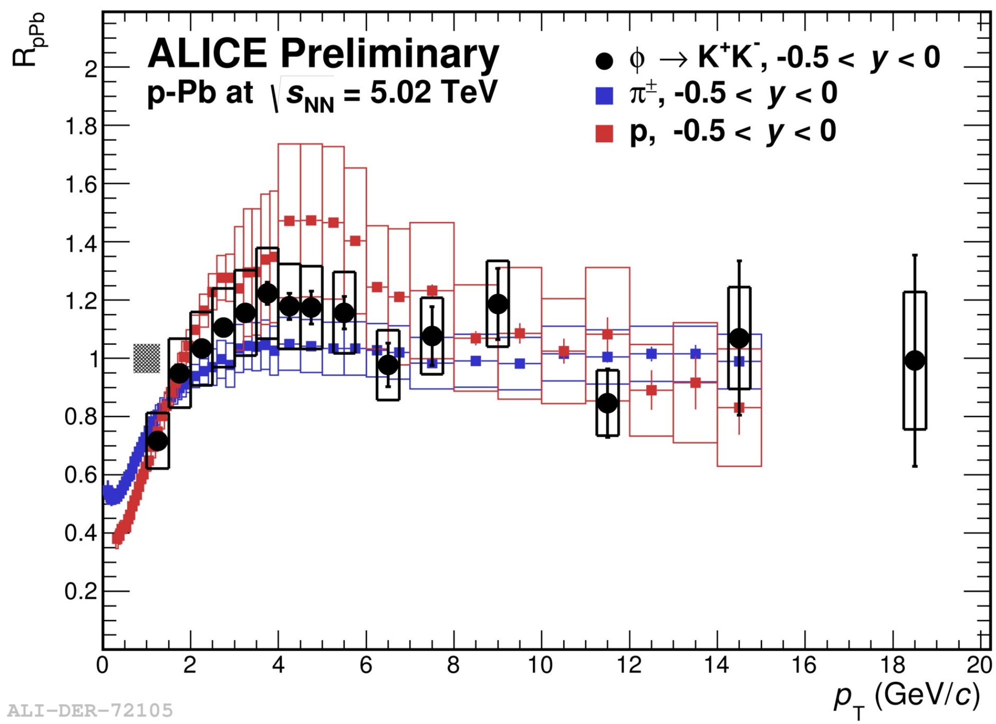


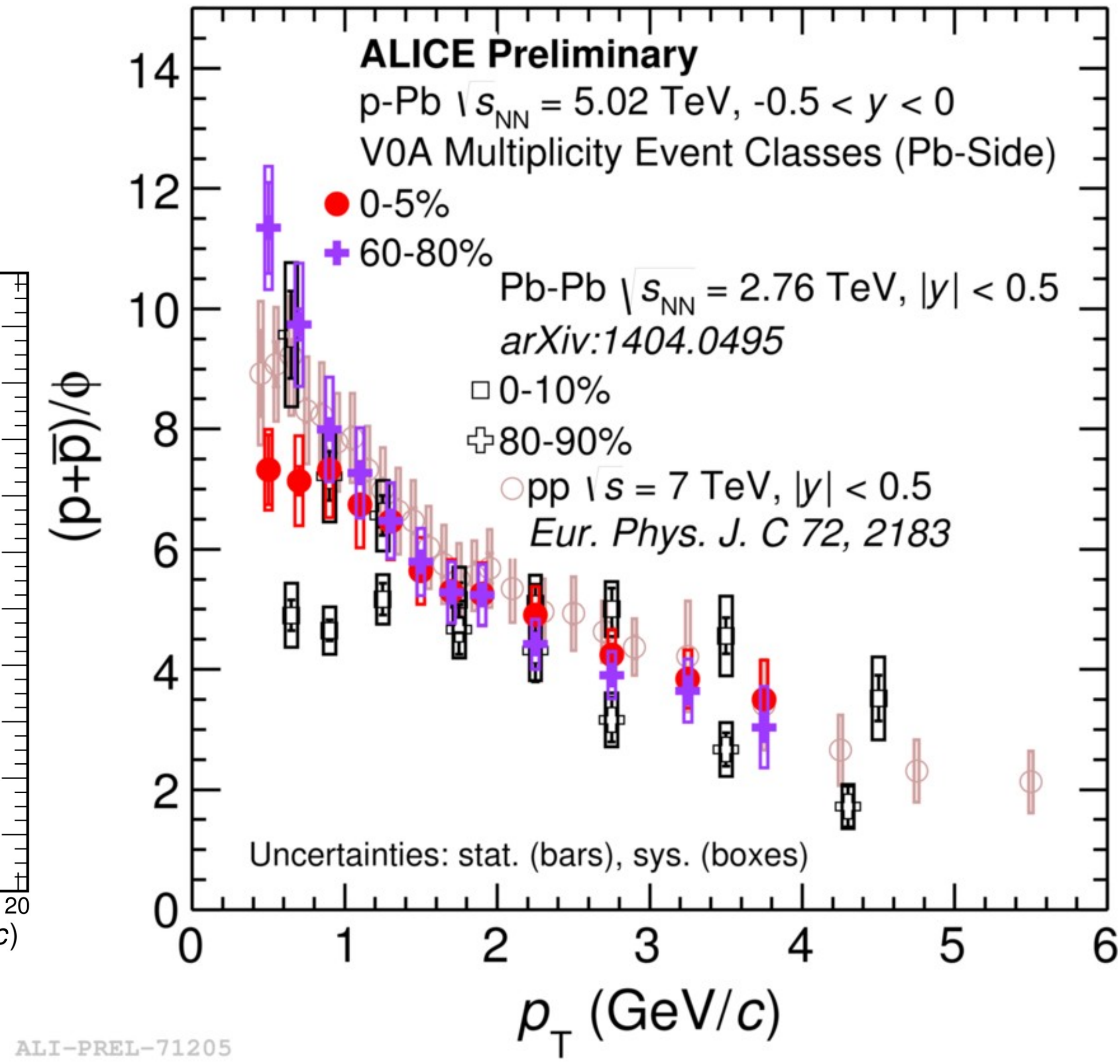
At intermediate p_T (Cronin region):

- Indication of mass ordering
  - No enhancement for pions and kaons
  - Pronounced peak for protons
  - Even stronger for cascades

Particle species dependence points to relevance of final state effects

The Φ meson

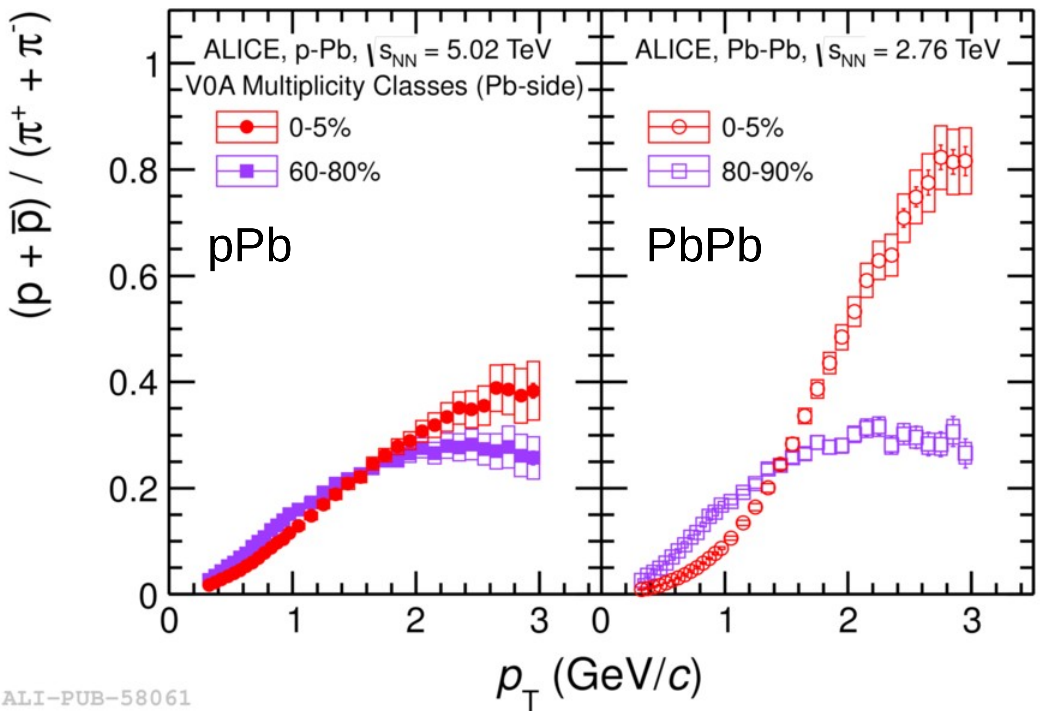




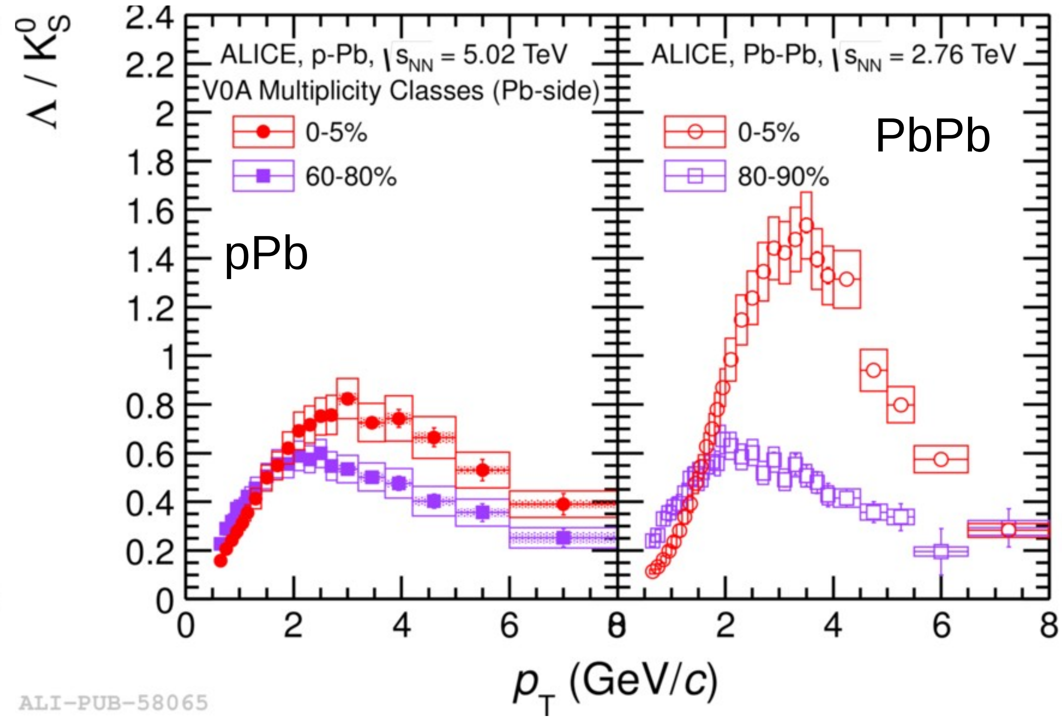
The Φ does not have the same Cronin enhancement as the proton, and also its shape in pPb does not change significantly with multiplicity

Baryon-over-meson enhancement

Proton over pion ratio



Λ over K^0_S ratio



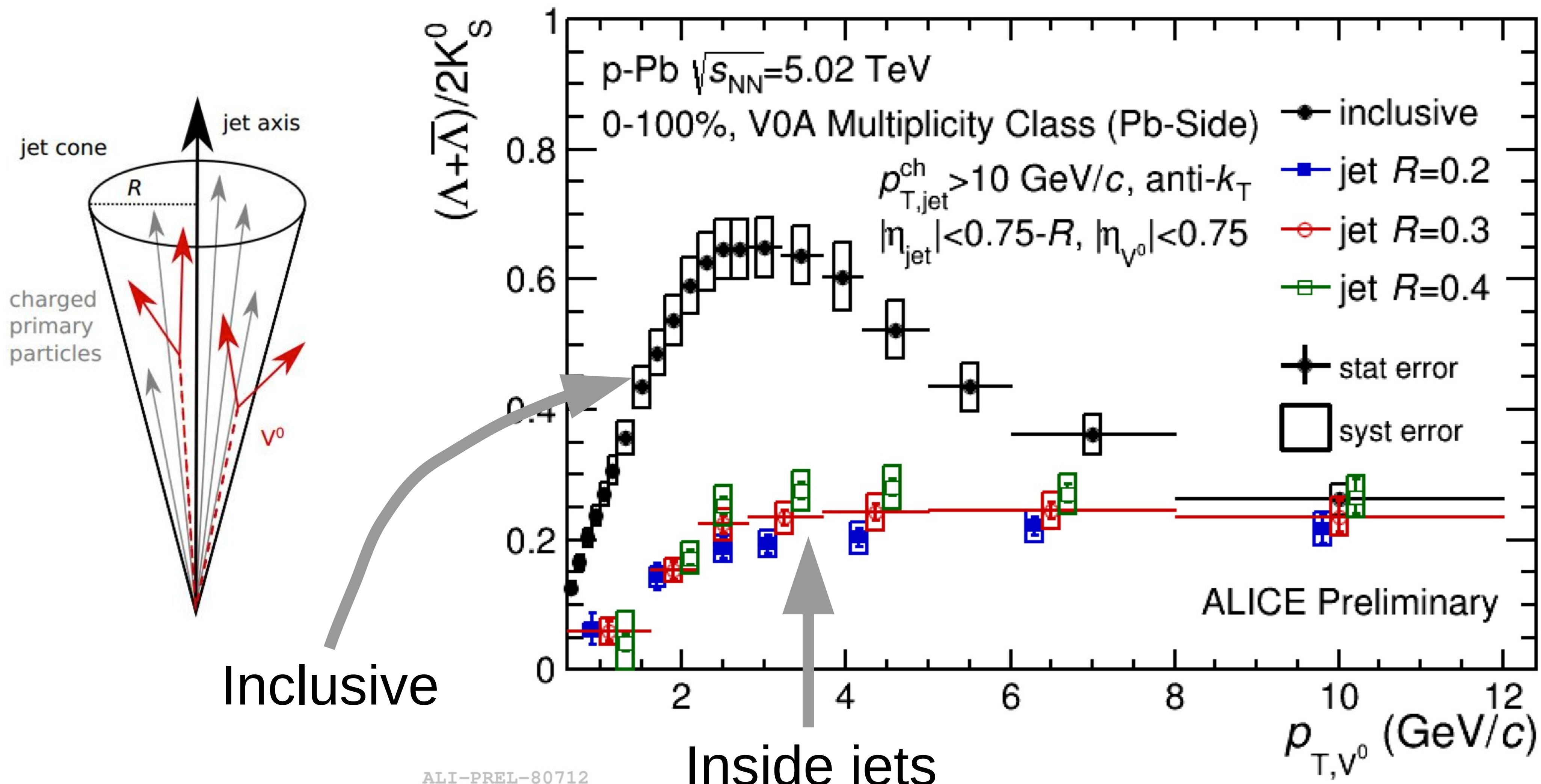
Significant multiplicity dependence of proton over pion and Λ over K^0_S ratio:
reminiscent of observations in PbPb
(usually attributed to radial flow or recombination)

PLB 728 (2014) 25-38

Baryon-over-meson enhancement in/out jets

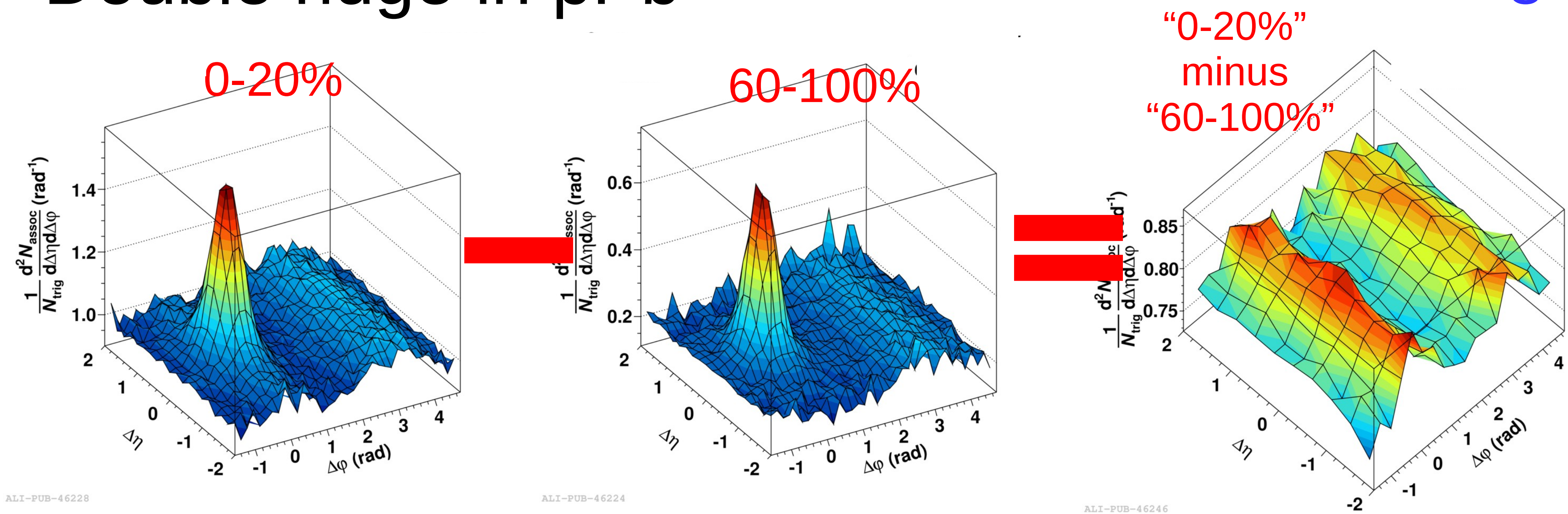
(X. Zhang)

Λ over K_S^0 ratio inclusive vs inside jets

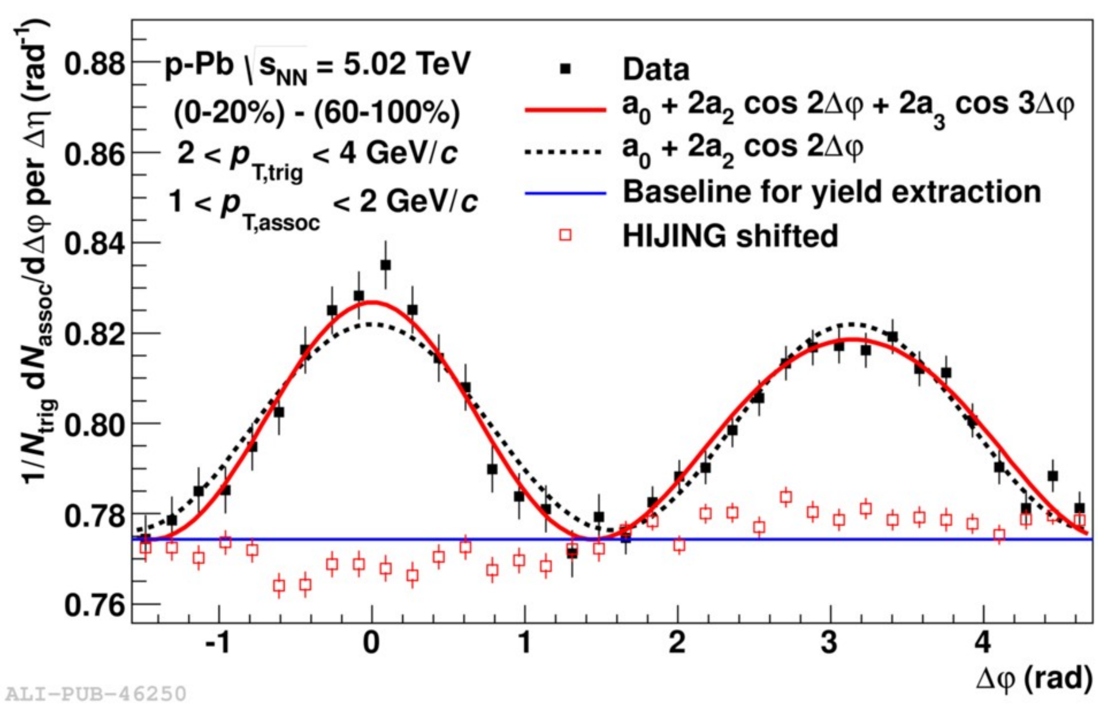


The enhancement is not coming from jets

Double ridge in pPb

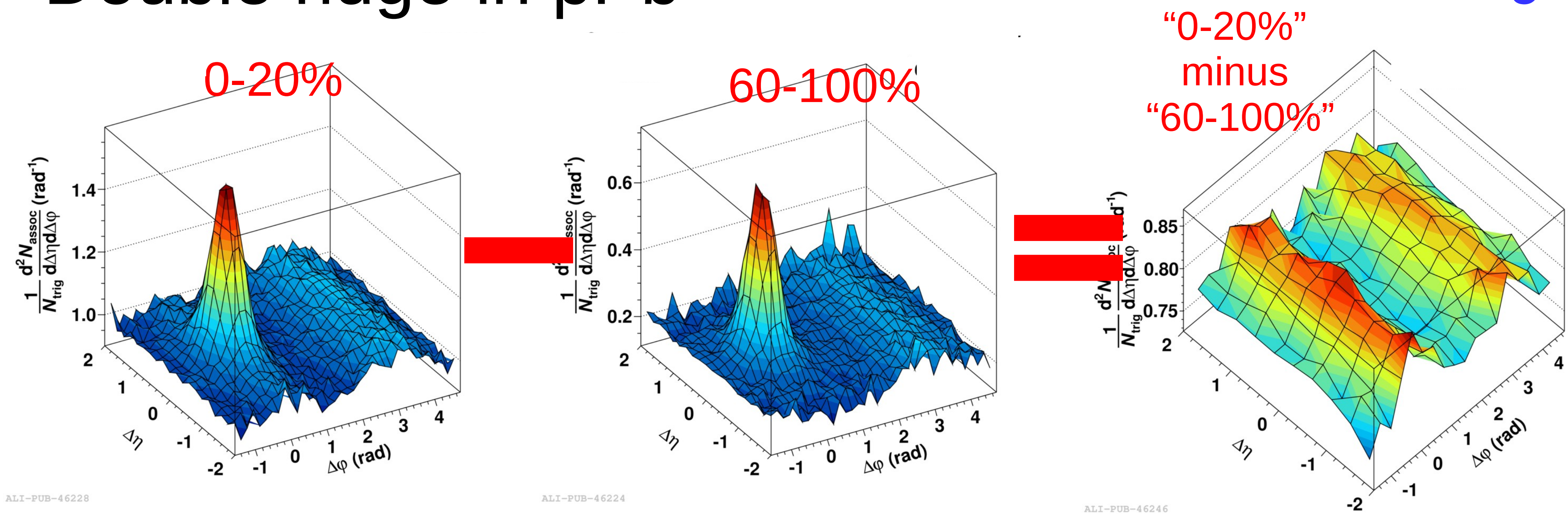


- Reveal double ridge by subtracting per-trigger yield of low from high multiplicity events
- Results looks so much like flow in AA

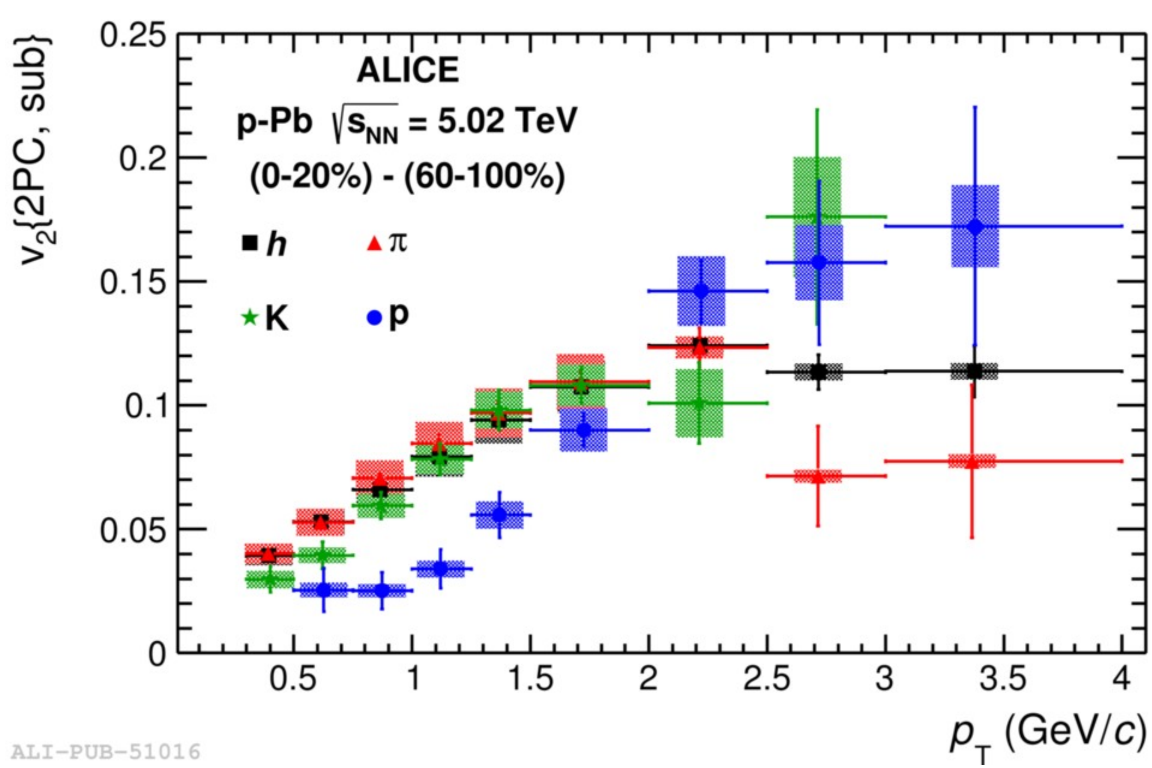


PLB 719 (2013) 29

Double ridge in pPb



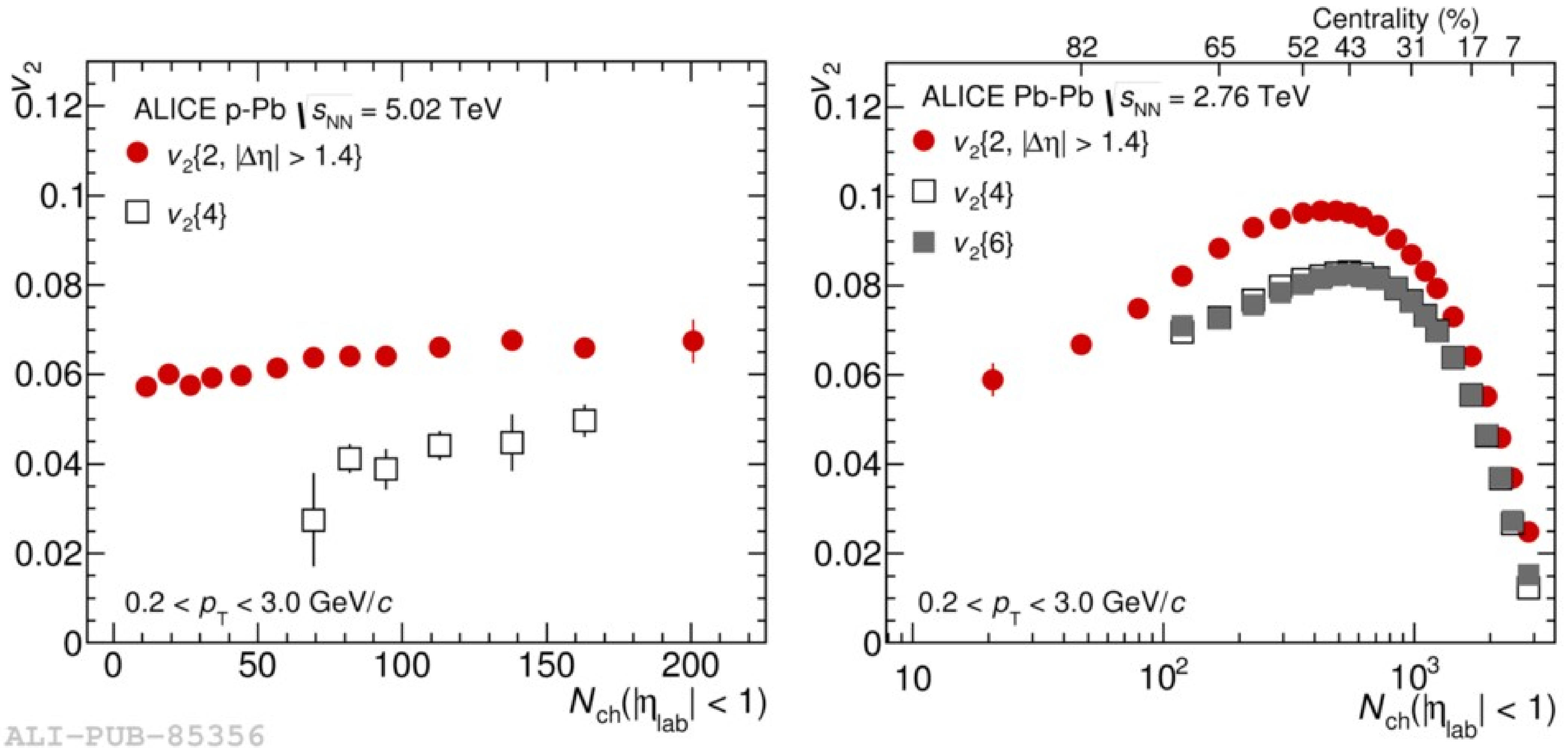
- Reveal double ridge by subtracting per-trigger yield of low from high multiplicity events
- Results looks so much like flow in AA
- Mass ordering and crossing



PLB 726 (2013) 164

Genuine four-particle correlations

(A.Timmins)

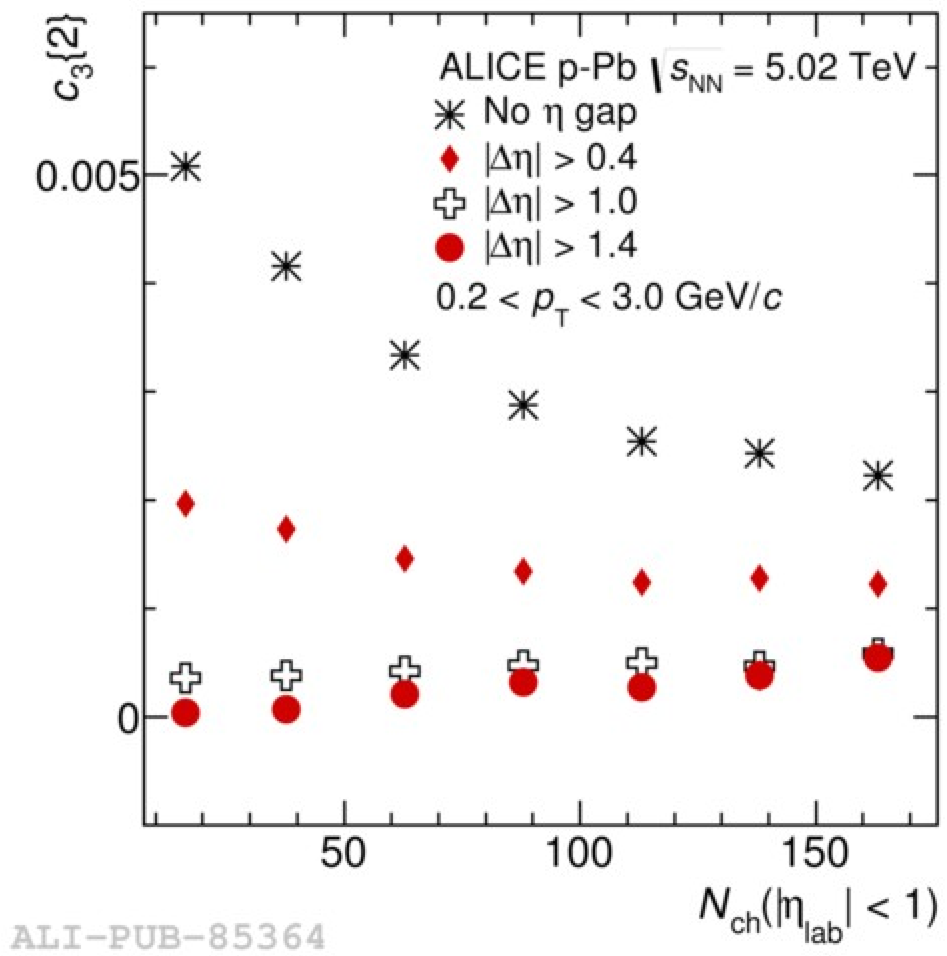


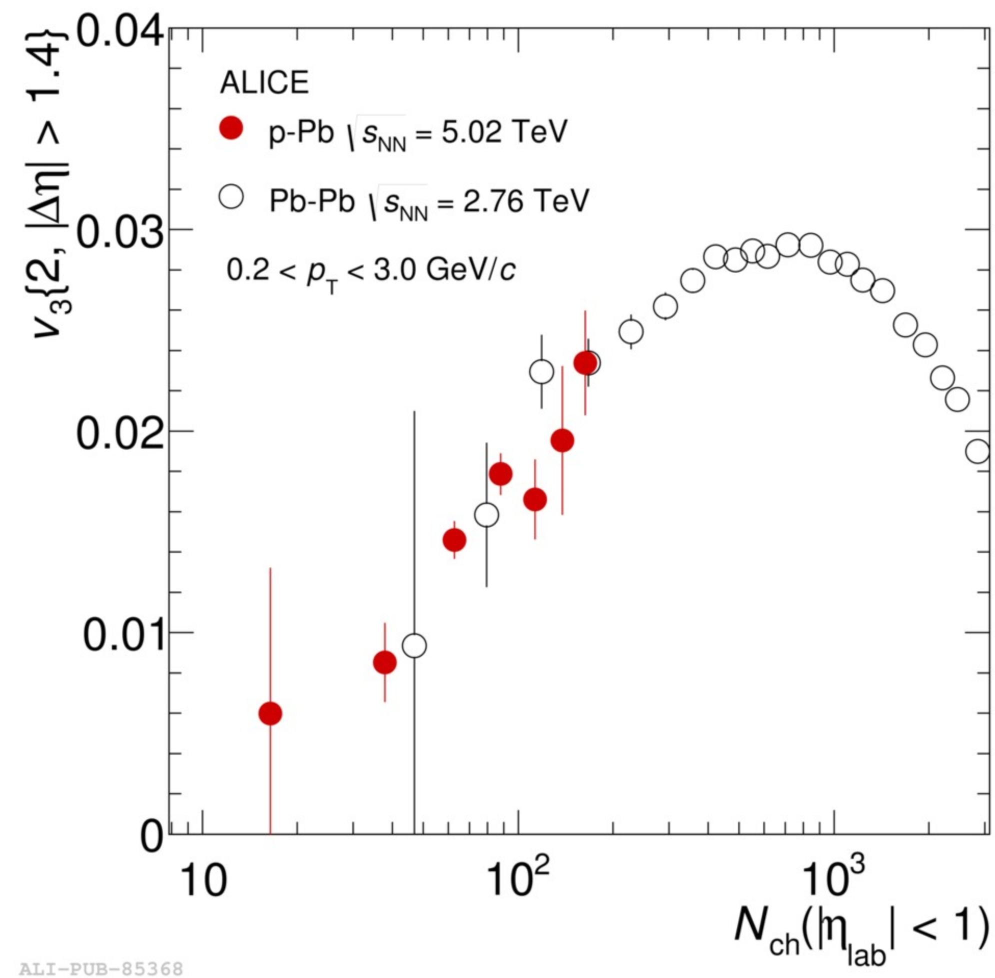
Genuine four-particle correlations, $v_2\{4\}>0$, in pPb

PRC 90 (2014) 054901

3rd harmonics from two particle correlations

(A.Timmins)





Third harmonics $v_3\{2\}$ non-zero in pPb,

and for large $\Delta\eta$ gap similar to PbPb

PRC 90 (2014) 054901

Femtoscopy using 3-pion cumulants

- Enhance Bose-Einstein (QS) signal
- Suppress 2-pion (non-femto) background
- Measure 3-pion correlations

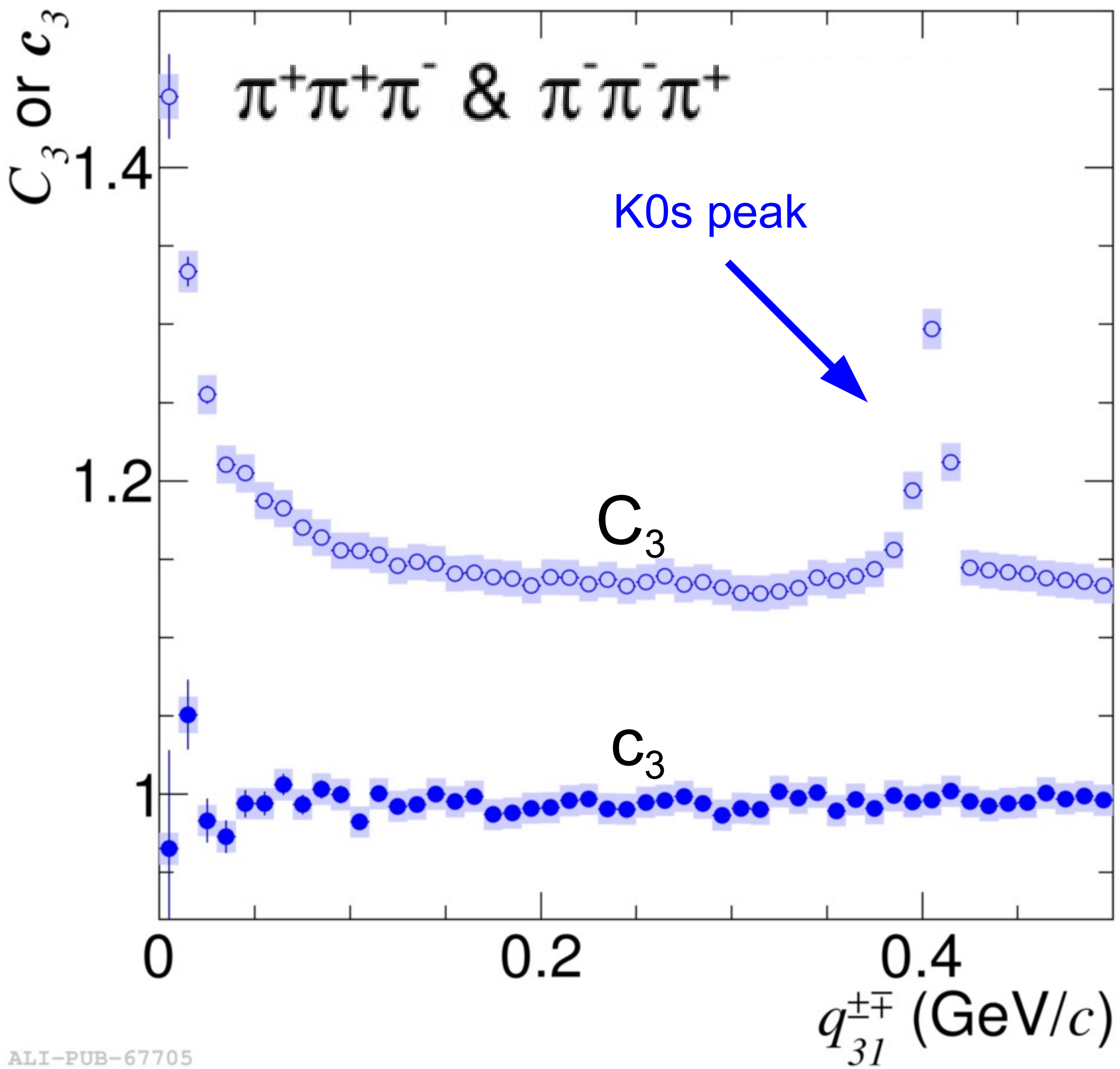
$$C_3(p_1, p_2, p_3) = \frac{N_3(p_1, p_2, p_3)}{N_1(p_1)N_1(p_2)N_1(p_3)}$$

- Subtract all 2-pion QS correlations to arrive at 3-pion cumulant c_3
- Express correlation C_3 and cumulant c_3
  - vs momentum transfer

$$Q_3 = \sqrt{q^2_{inv,12} + q^2_{inv,13} + q^2_{inv,23}}$$

  - for avg. triplet momentum

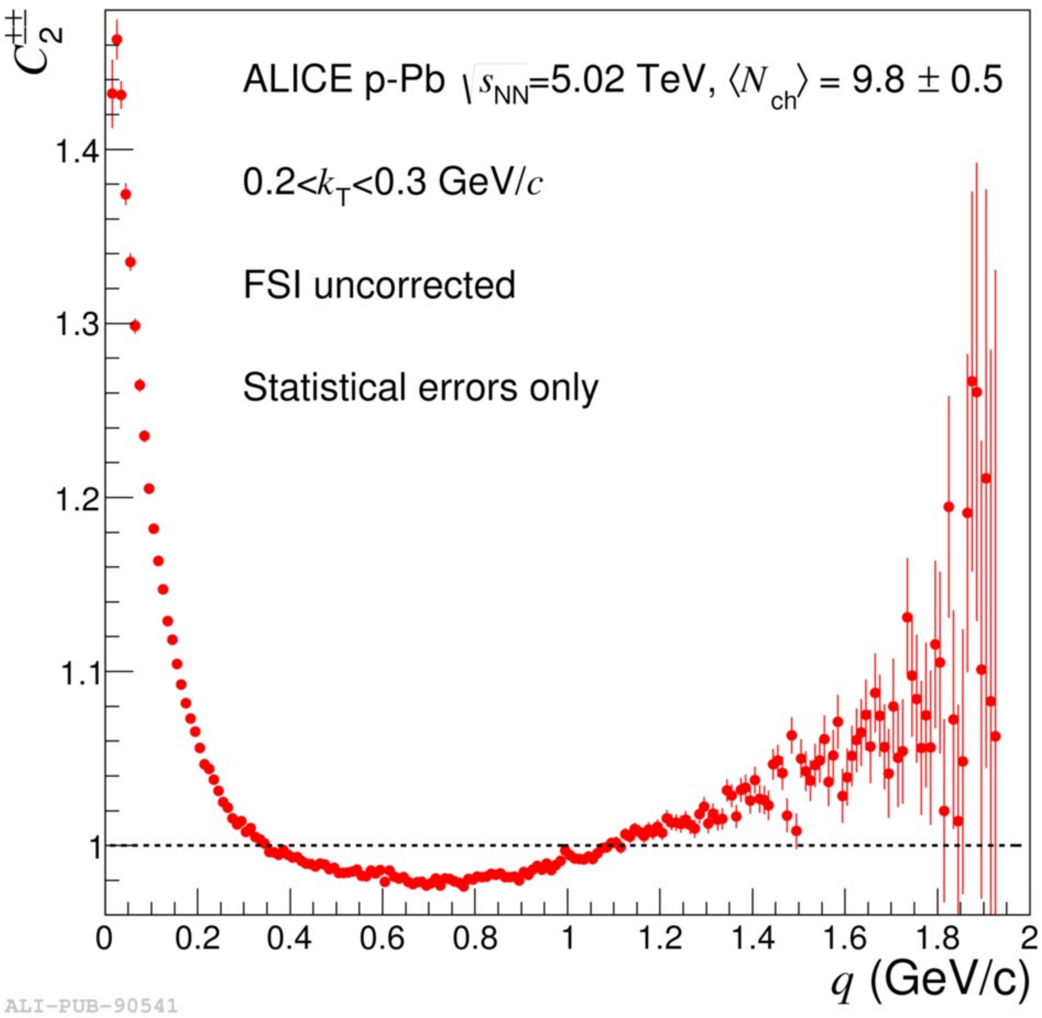
$$K_{t,3} = \frac{|\mathbf{p}_{T,1} + \mathbf{p}_{T,2} + \mathbf{p}_{T,3}|}{3}$$

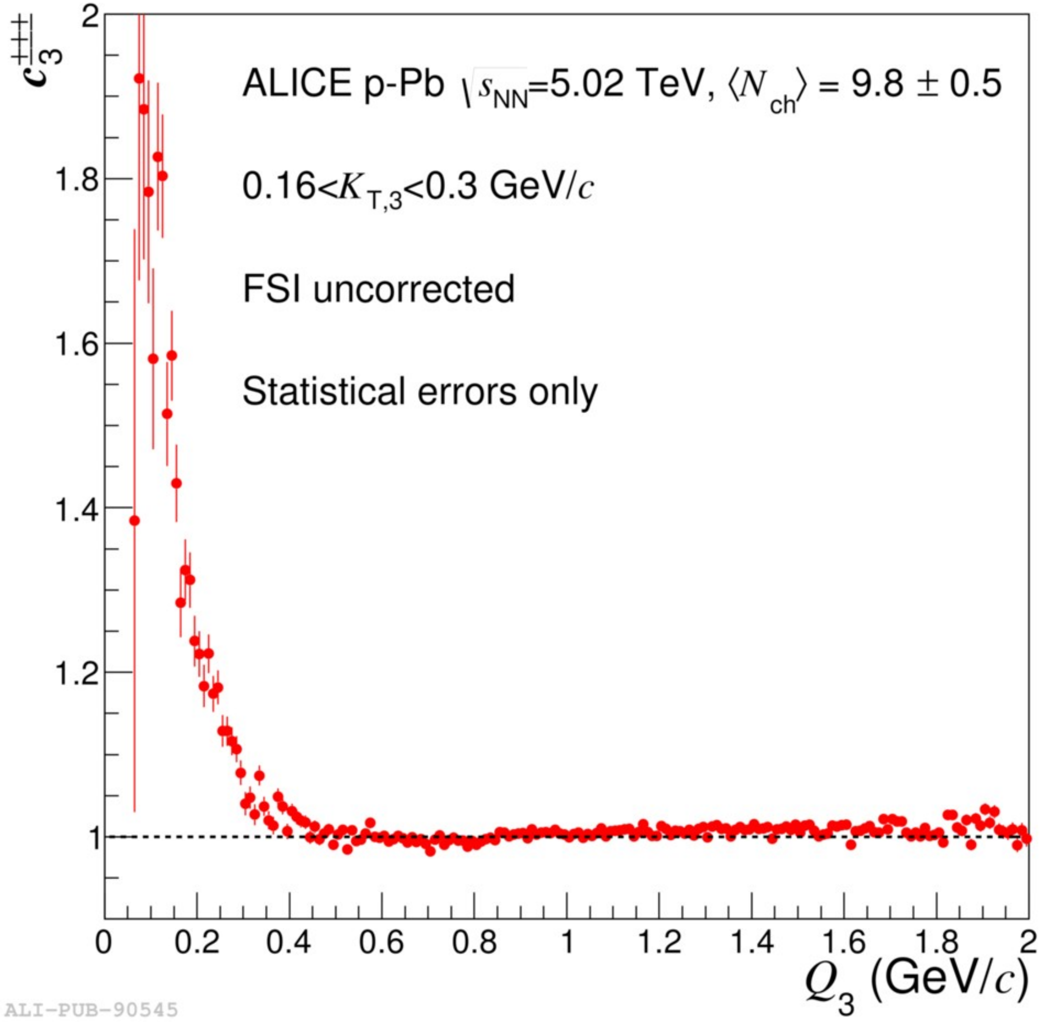


3-pion cumulant performance for mixed-charge case projected onto 2-pion momentum space

PLB 739 (2014) 139

Comparison 2-pion vs 3-pion correlations

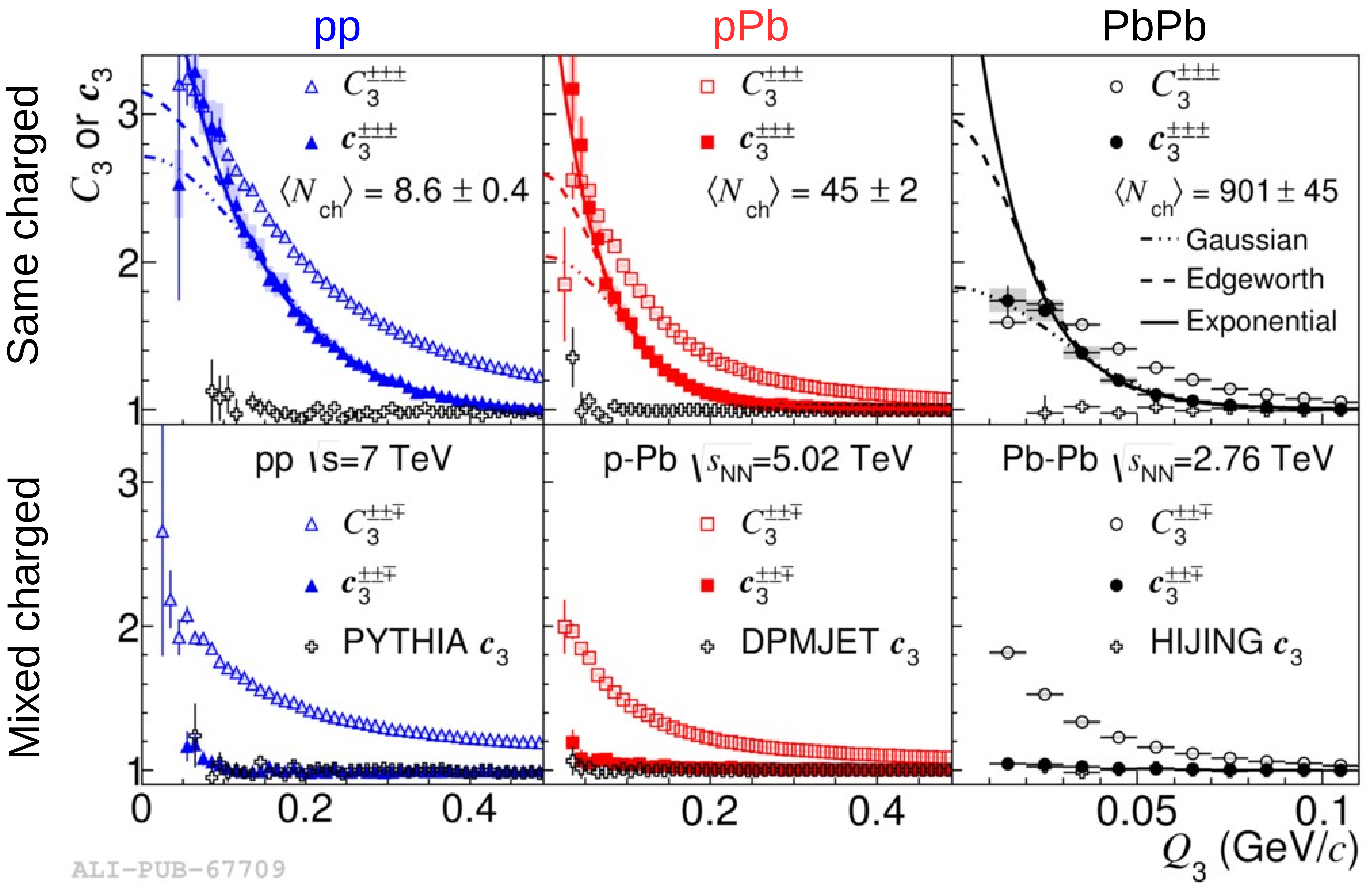




The baseline for the 3-pion cumulants is
much more flat than for 2-pion correlations

PLB 739 (2014) 139

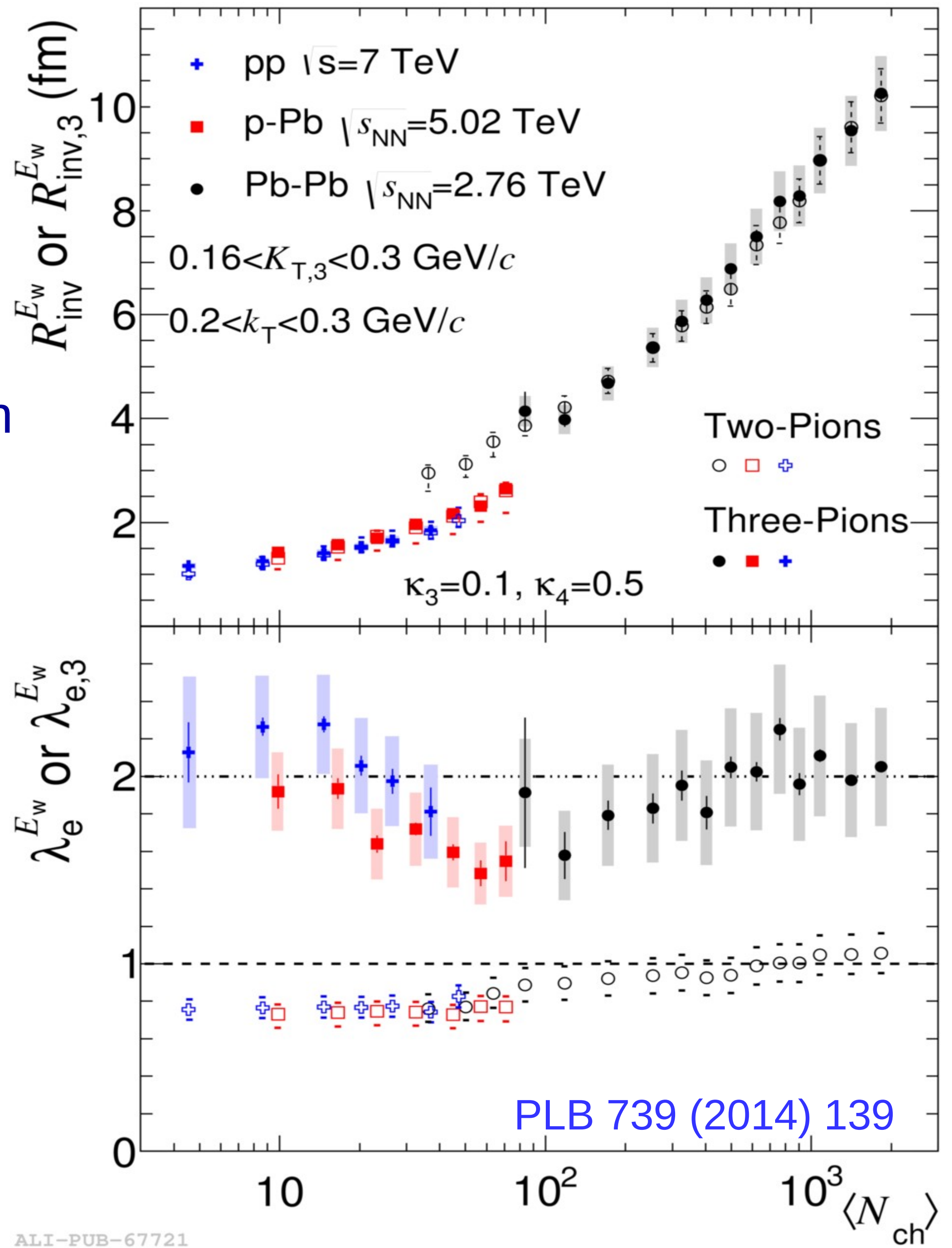
3-pion correlation functions



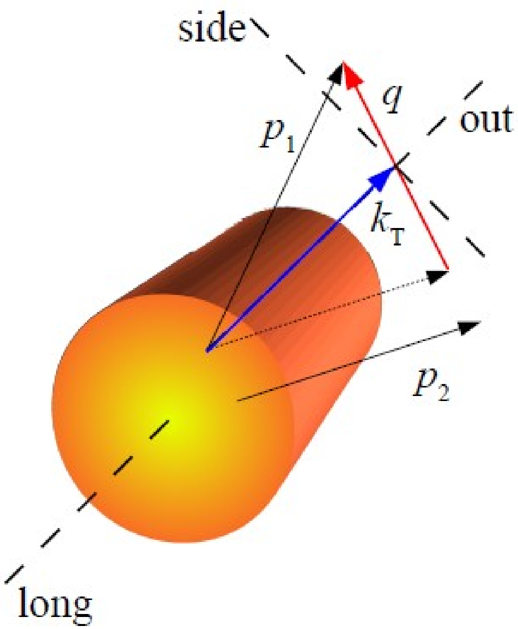
PLB 739 (2014) 139

Radii and intercepts for Edgeworth fit

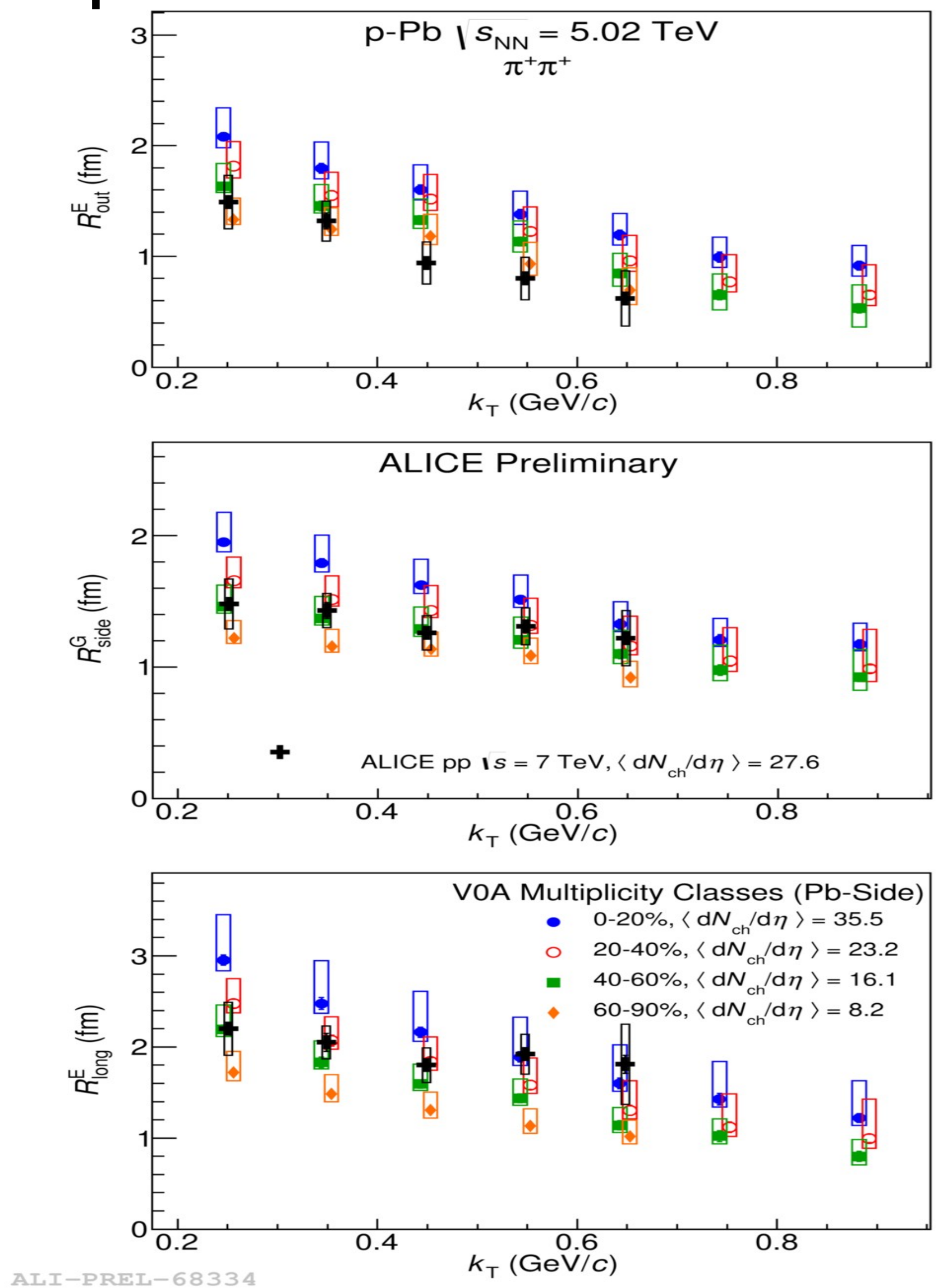
- Extraction or radii vs Nch
  - pp similar to pPb
  - pPb smaller than PbPb
  - Different (lin.) trends with $Nch^{1/3}$
  - Independent of parameterization
    - Difference can be seen directly by looking at the c_3 functions
- Intercepts close to chaotic limits
- Possible interpretation
  - Not much room for hydro-dynamic expansion in pPb, beyond what may be in pp at the same Nch
  - Yang-Mills evolution in IP-GLASMA reproduces difference



k_T dependence of radii in pPb

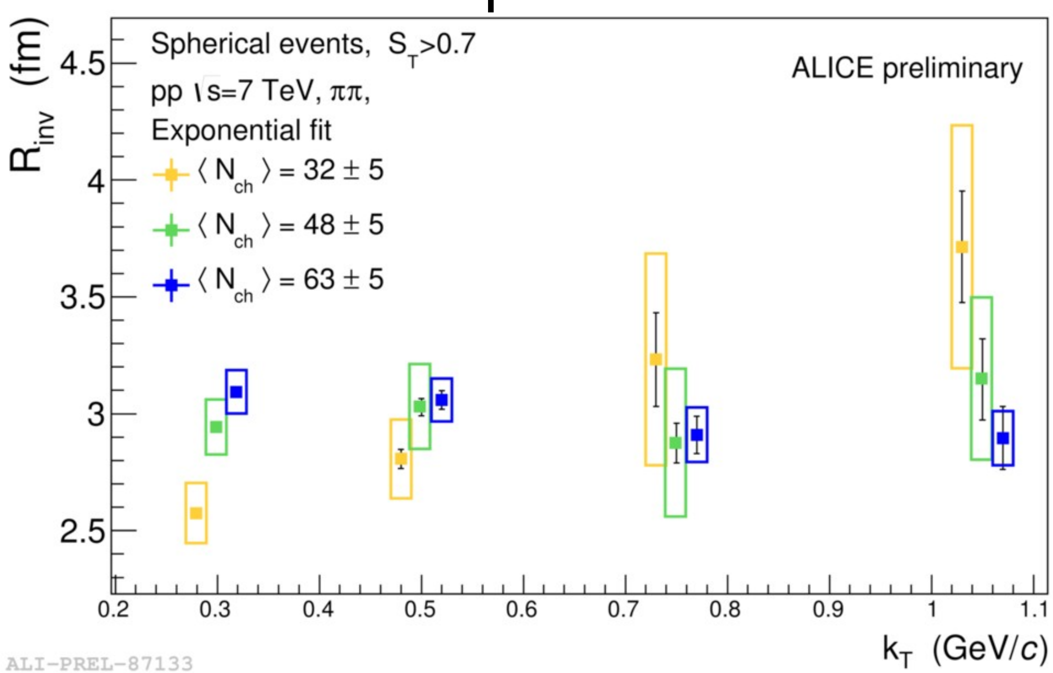


- 3d radii in LCMS from two-particle correlations
  - Needs understanding of background using MC
- Radii decrease w increasing k_T as in AA (and in hydro)
  - Similar high multiplicity pp

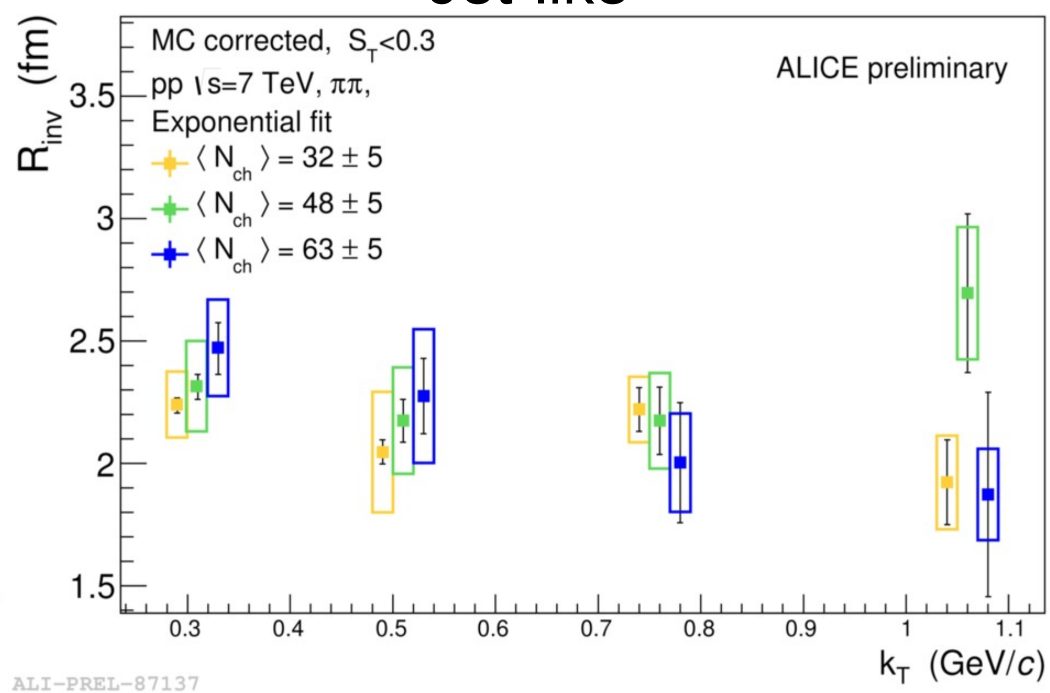


Radii for spherical and jet-like pp events

Spherical



Jet-like



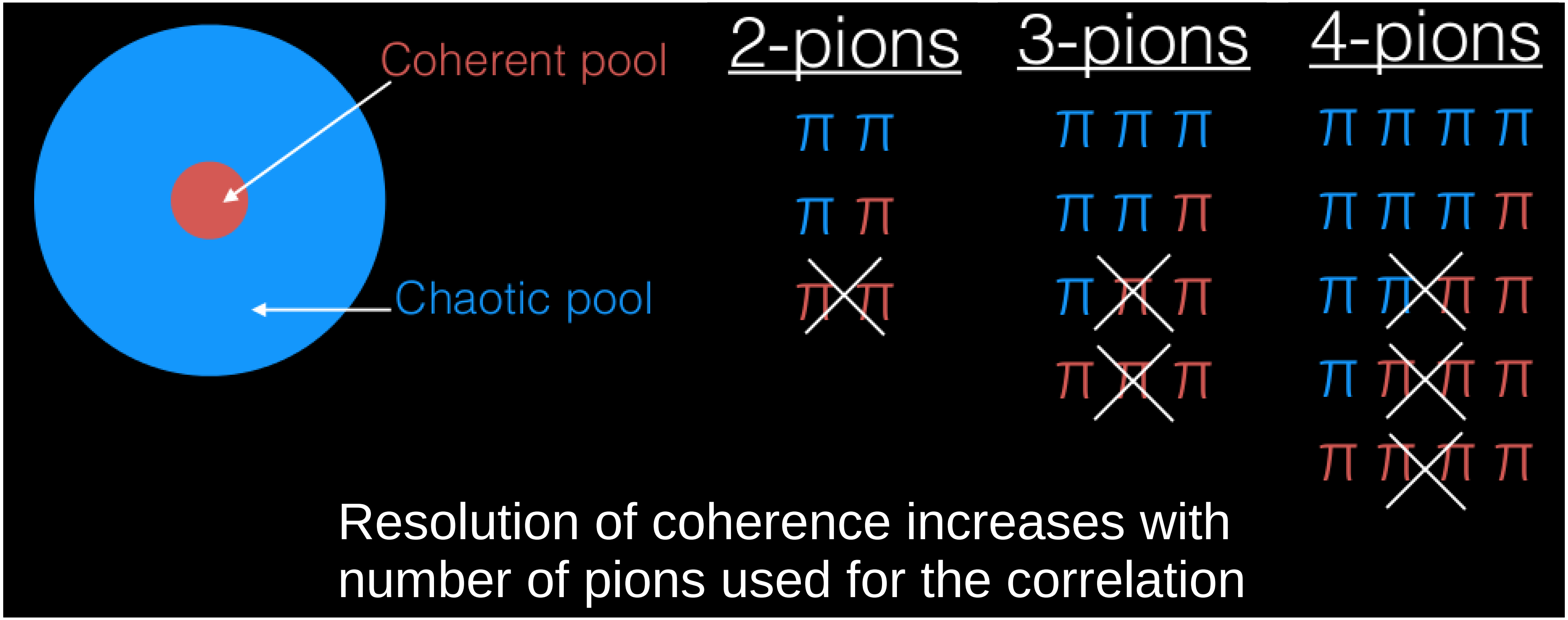
Spherical and jet-like events each show little dependence with k_T

Classify events based on Sphericity

$$S^L_{xy} = \frac{1}{\sum_i p_{T\,i}} \sum_i \frac{1}{p_{T\,i}} \begin{pmatrix} p^2_{x\,i} & p_{x\,i}\, p_{y\,i} \\ p_{y\,i}\, p_{x\,i} & p^2_{y\,i} \end{pmatrix}$$

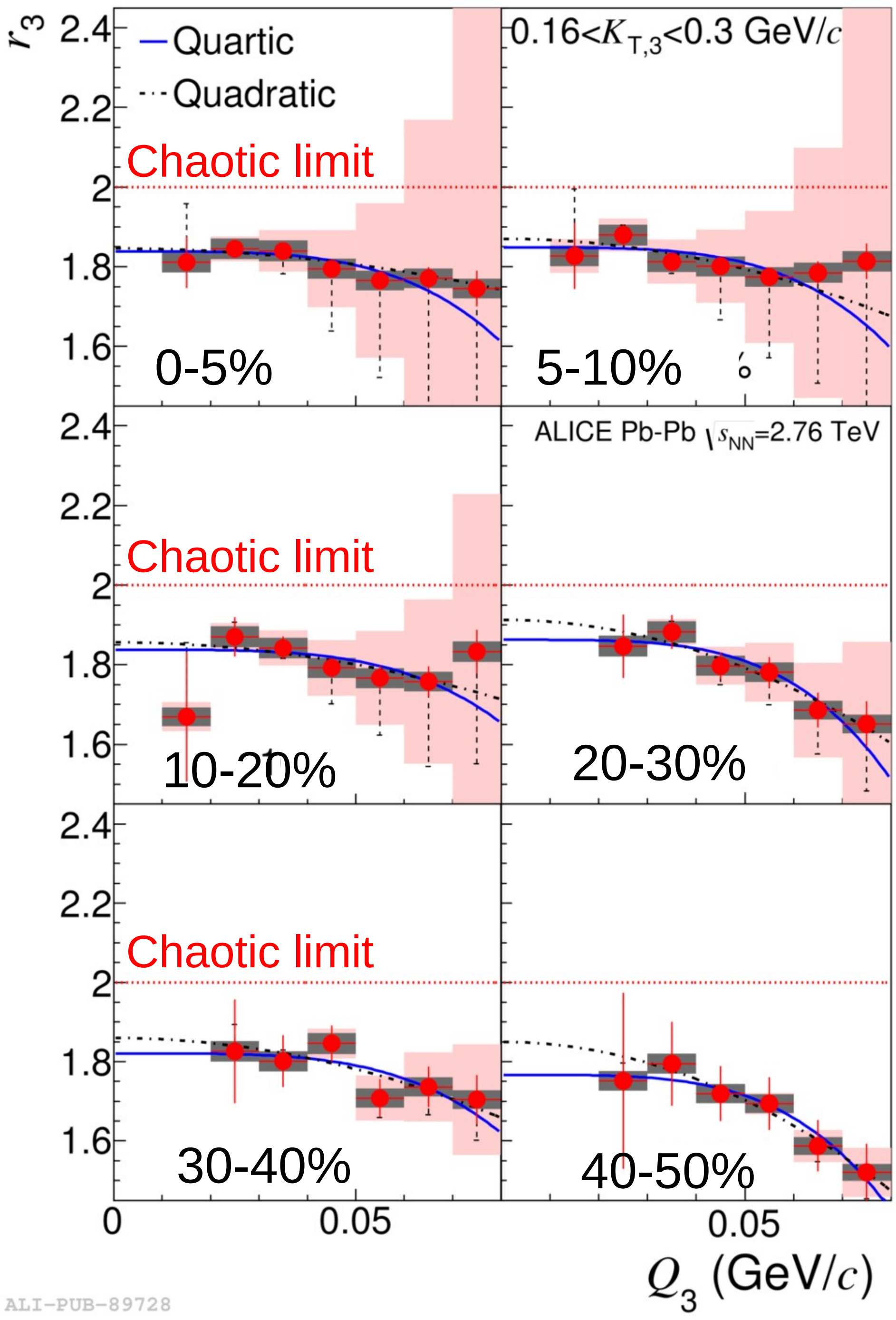
$$S_T = \frac{2\lambda_2}{\lambda_1 + \lambda_2} \Rightarrow S_T = \begin{cases} \approx 0 & \text{Jet-like} \\ \approx 1 & \text{Spherical} \end{cases}$$

Quantum coherence in PbPb



- Pion condensates or Disoriented Chiral Condensates may create a coherent pool of pions
- For coherence to survive in the final state, the chaotic pool must not fully interact with the coherent pool
- Observation of coherence would imply disjunct sources

3-pion to 2-pion ratio r_3 in PbPb



- Measure ratio of 3-pion over 2-pion QS correlations

$$r_3(Q_3) = \frac{c_3(Q_3) - 1}{\sqrt{(C_2^{QS}(Q_{12})-1)(C_2^{QS}(Q_{13})-1)(C_2^{QS}(Q_{23})-1)}}$$

- Extract I = $r_3(Q_3 \to 0)$
  - For chaotic particle production, expect I=2
- Measure r_3 about 1.5σ below chaotic limit (from two types of fits) at low triplet momentum
  - At high k_{T3}, we measure I≈2
- Possible interpretation:
  - At least 23% ± 8% of low momentum pions are emitted coherently

PRC 89 (2014) 024911

New approach: Built C_4^{QS}

(D.Gangadharan)

Weiner et al.
Int.J.Mod.Phys.A.
26 4577 (1993)

T. Csorgo.
Heavy Ion Phys.
151 (2002)

$$
\begin{aligned}
C_2^{QS}-1 &= (1-G^2)T_{12}^2 \\
C_3^{QS}-1 &= (1-G)^2(T_{12}^2+T_{13}^2+T_{23}^2) \\
&+ (6G(1-G)^2+2(1-G)^3)T_{12}T_{13}T_{23} \\
C_4^{QS}-1 &= (1-G^2)(T_{12}^2+T_{13}^2+T_{14}^2+T_{23}^2+T_{24}^2+T_{34}^2) \\
&+ (4G(1-G)^3+(1-G)^4(T_{12}^2T_{34}^2+T_{13}^2T_{24}^2+T_{14}^2T_{23}^2) \\
&+ (6G(1-G)^2+2(1-G)^3)(T_{12}T_{13}T_{23}+T_{12}T_{14}T_{24}+T_{13}T_{14}T_{34}+T_{23}T_{24}T_{34}) \\
&+ (8G(1-G)^3+2(1-G)^4)(T_{12}T_{13}T_{24}T_{34}+T_{12}T_{14}T_{23}T_{34}+T_{13}T_{14}T_{23}T_{24})
\end{aligned}
$$

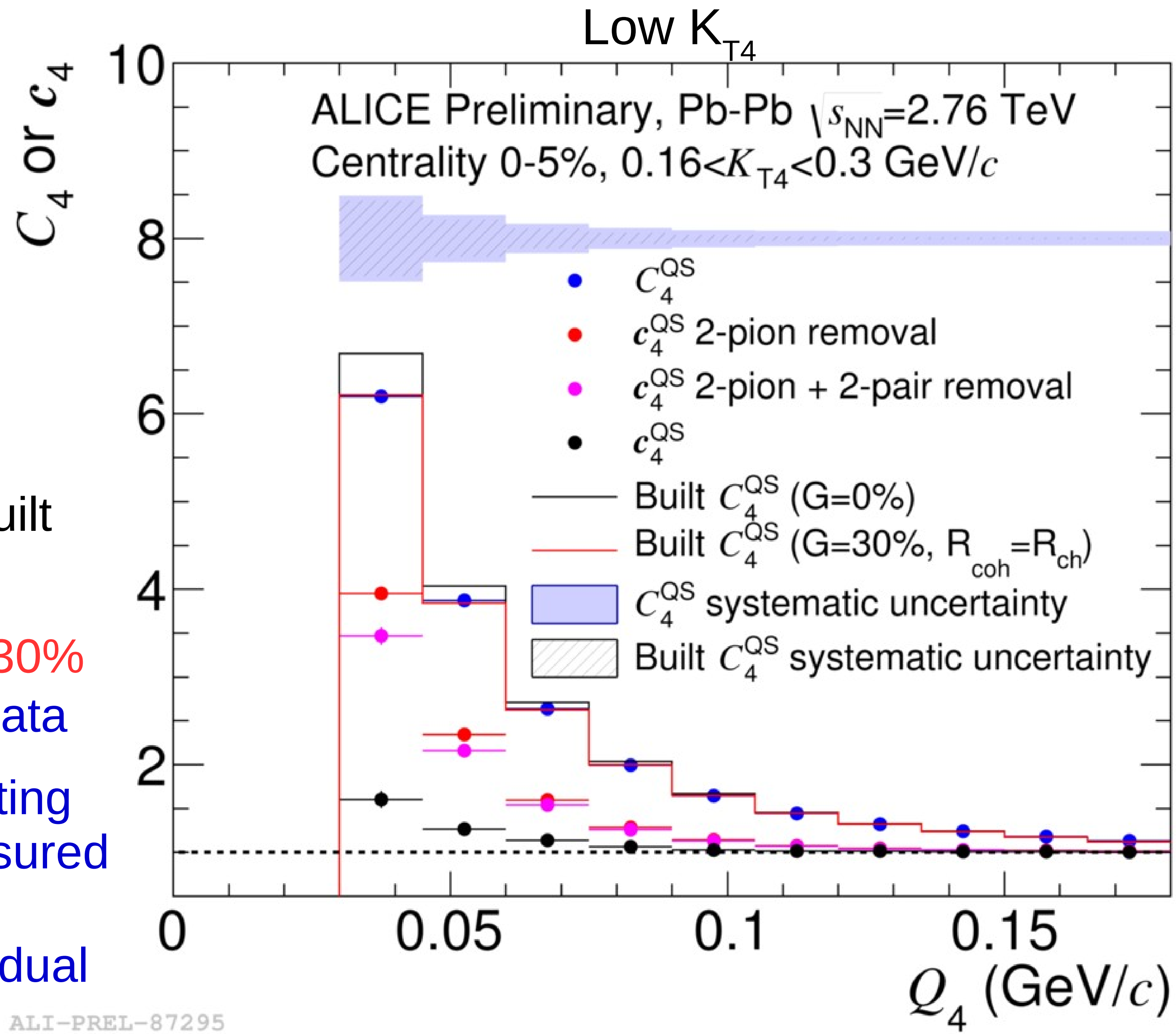
(equations, written without permutations, are valid for coherent radius = chaotic radius)

- C_2 is statistically very precisely measurable
- For fully chaotic emission, the pair exchange amplitude (T_{ij}) is given by $T_{ij}^2 = C_2^{\mathrm{QS}} - 1$
- For fully chaotic emission and neglecting multi-pion phases for 3- and 4-pion exchanges, C_4^{QS} is fully built from each of the 6 T_{ij}

4-pion correlations: −−−−

Systematics at top:
Blue band for C_4^{QS},
Shaded for Built C_4^{QS},
c_4^{QS} are the same
scaled by c_4^{QS} /C_4^{QS}.

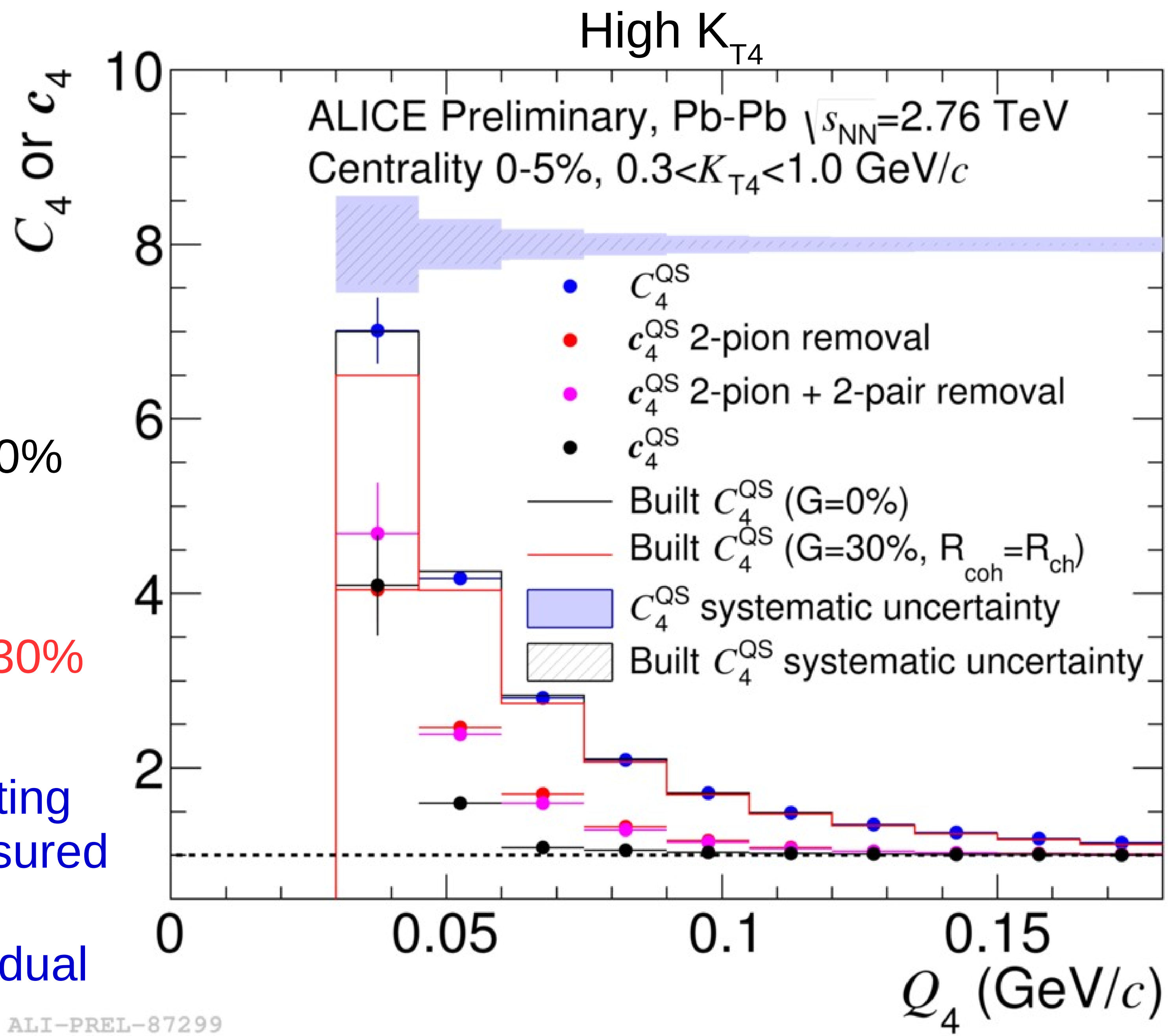
- Measured C_4^{QS} is suppressed wrt Built C_4^{QS} with G=0%
- Built C_4^{QS} with G=30% better describes data
- Systematics affecting difference of measured and built C_4 are dominated by residual −−−+ correlation



4-pion correlations: −−−−

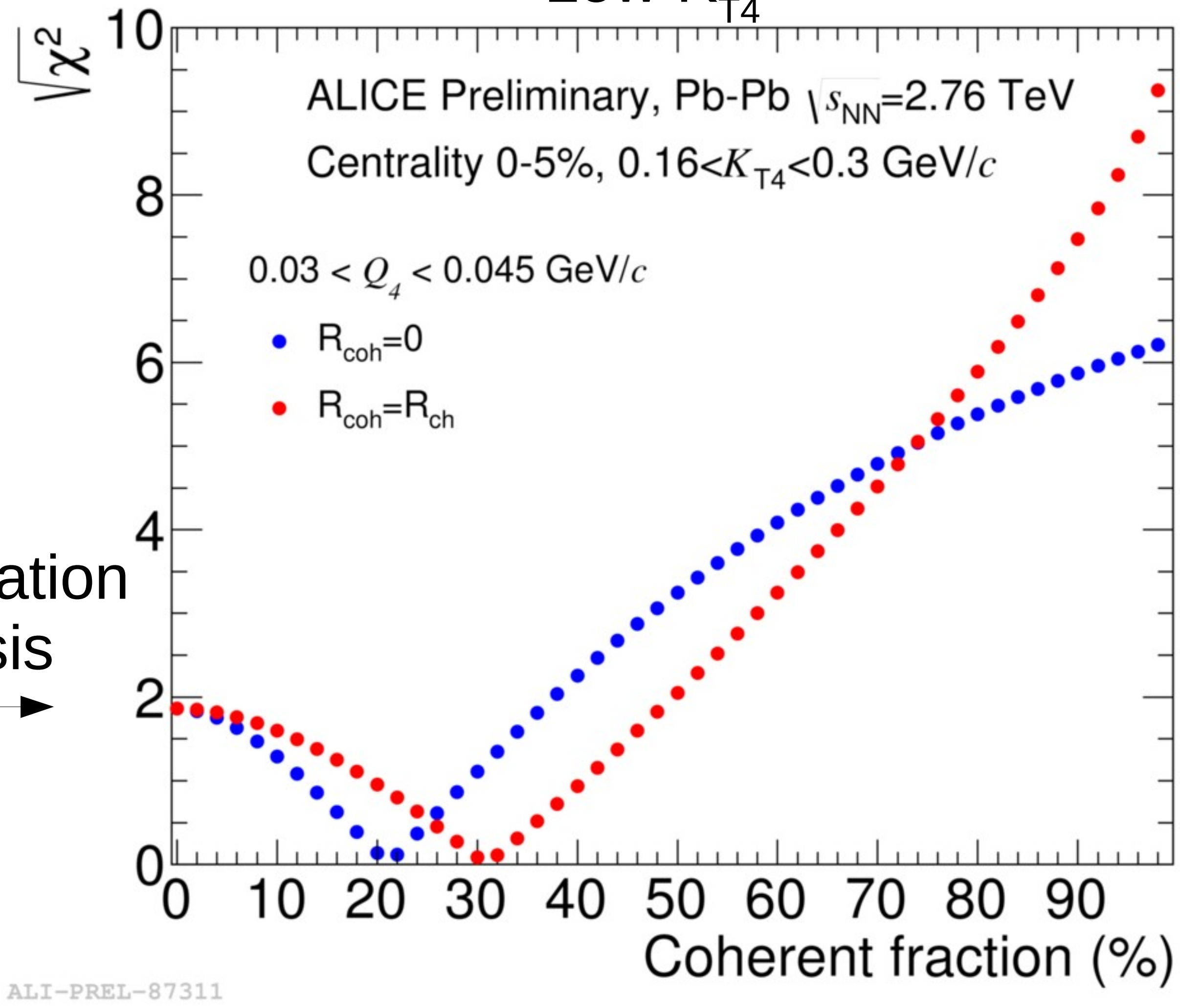
Systematics at top:
Blue band for C_4^{QS},
Shaded for Built C_4^{QS},
c_4^{QS} are the same
scaled by c_4^{QS} /C_4^{QS}.

- Built C_4^{QS} with G=0% agrees better with Measured C_4^{QS}
- Built C_4^{QS} with G=30% is worse
- Systematics affecting difference of measured and built C_4 are dominated by residual −−−+ correlation



Quantifying the coherent fraction

Low K_{T4}

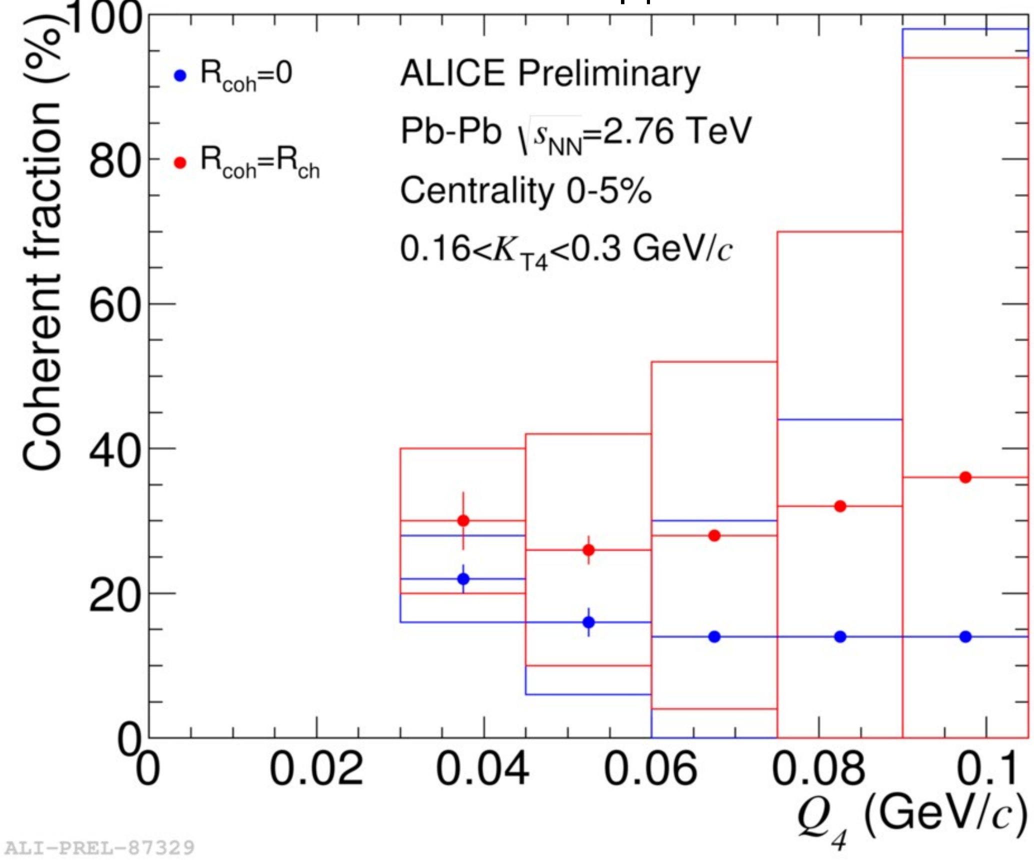


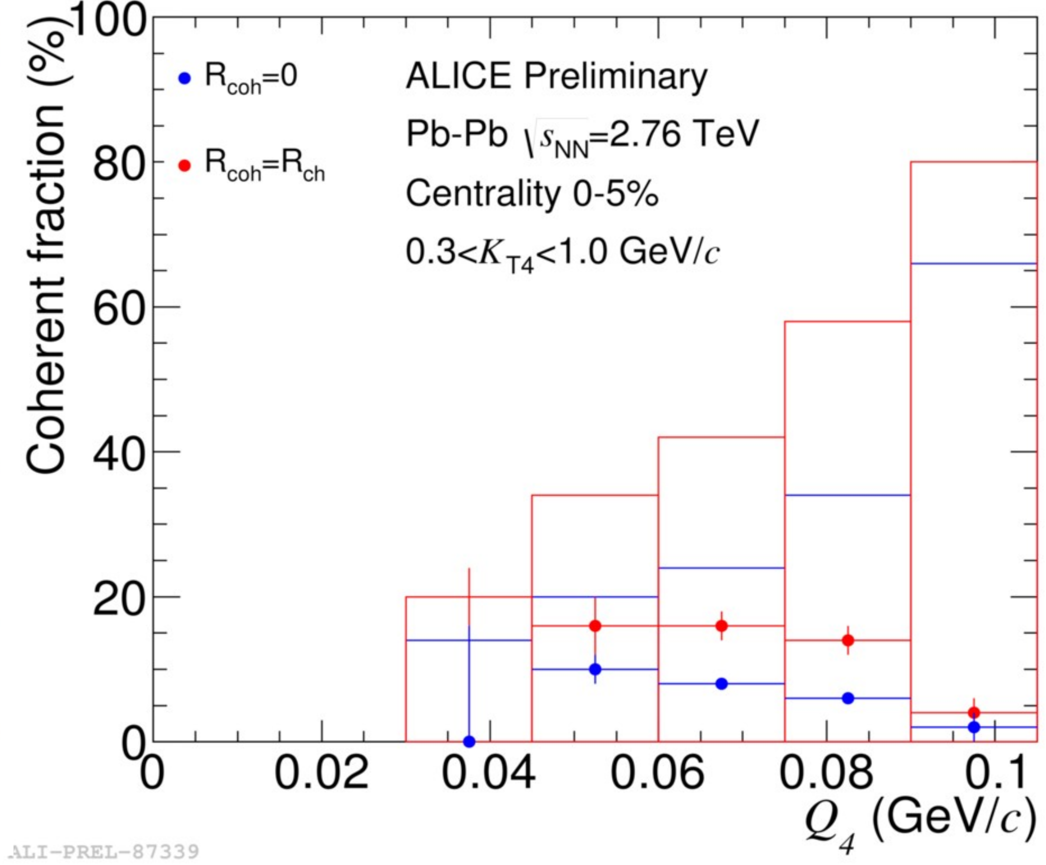
2σ (stat+sys) deviation from null hypothesis

Estimates of G done bin-by-bin in Q_4 with two assumptions on R_{coh}

Minima vs Q_4

Low K_{T4} High K_{T4}



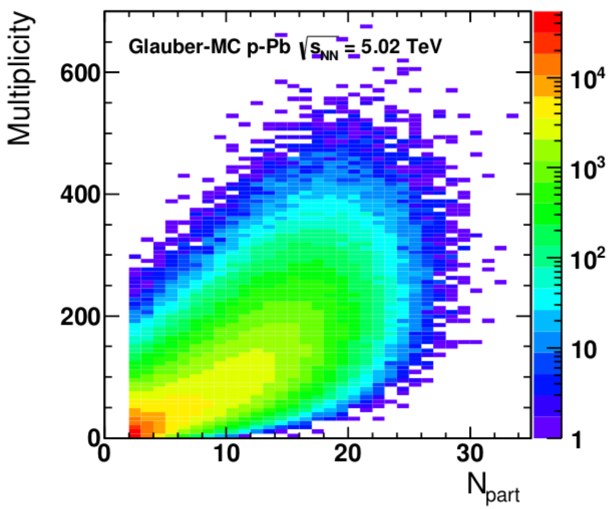


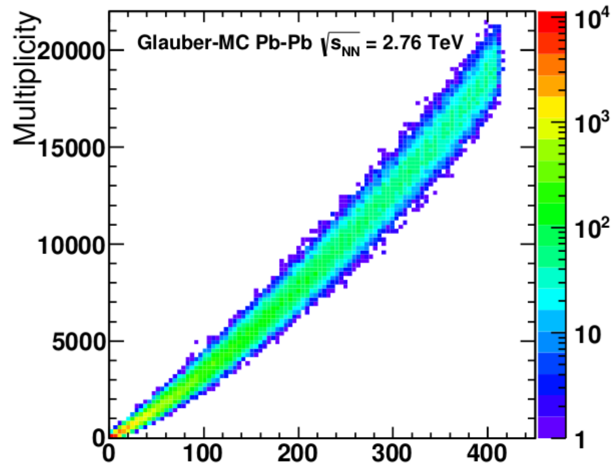
Coherent fraction is fairly stable with Q_4

Systematics are dominated by residual −−−+ correlation

Centrality from multiplicity in pPb

(A.Morsch)

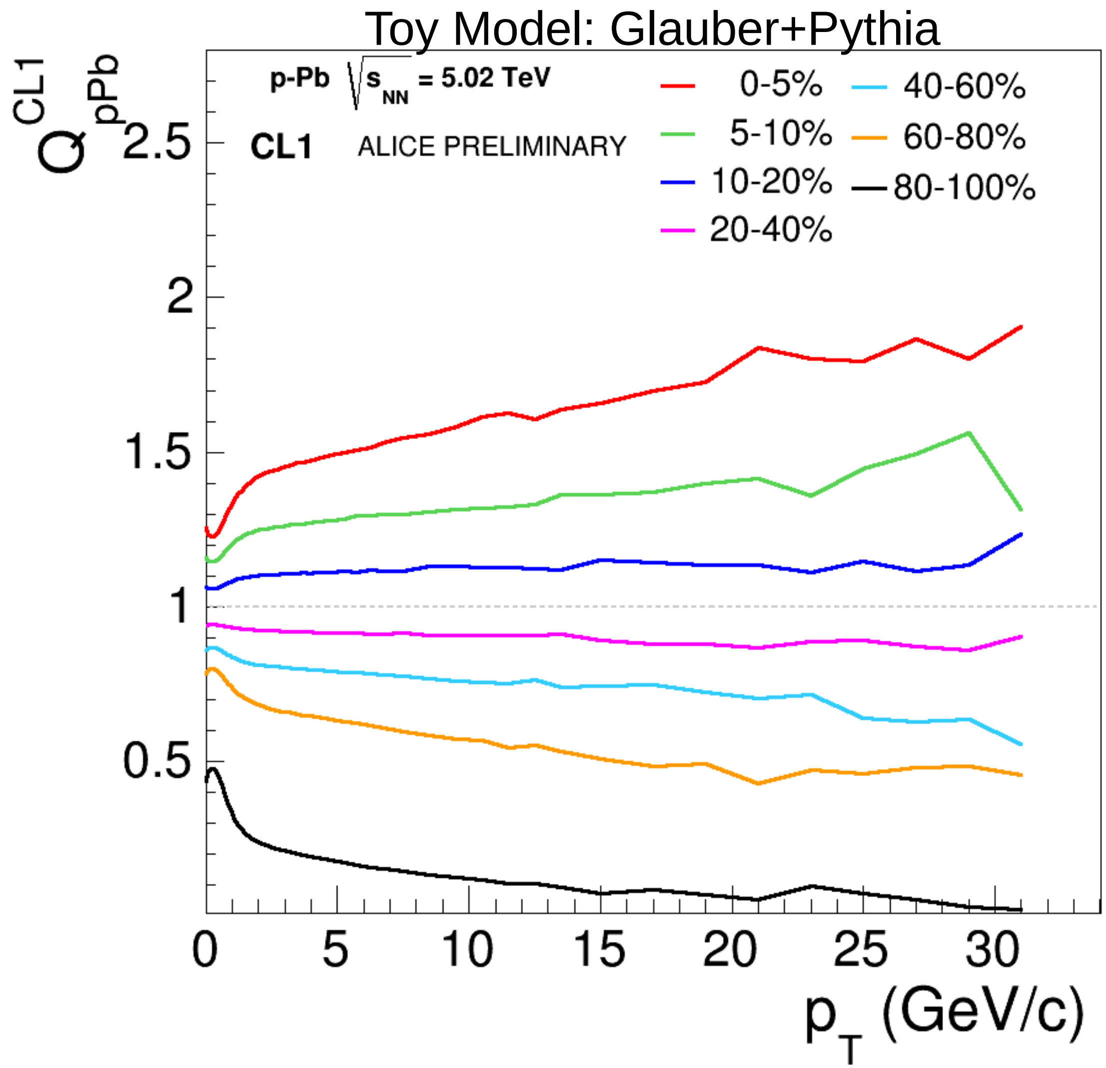




- Small dynamic range
- Several biases are present
  - Multiplicity bias
  - Jet veto bias
  - Geometrical bias
- Include (and indicate) bias in the definition

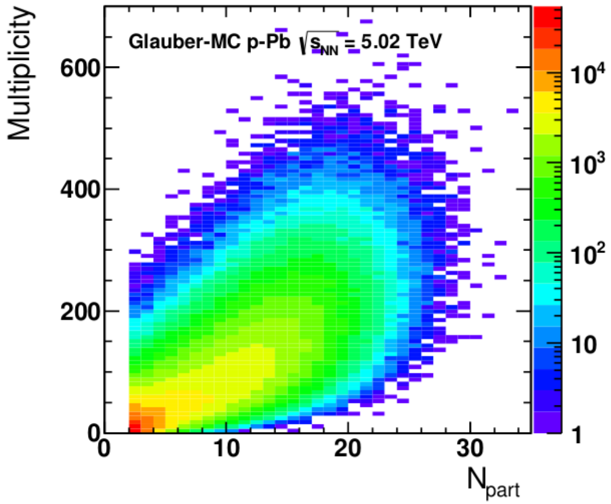
$$Q_{pPb,\,cent} = \langle N^{Glauber}_{cent} \rangle \frac{\langle dN^{pPb}/dp_T \rangle_{cent}}{dN^{pp}/dp_T}$$

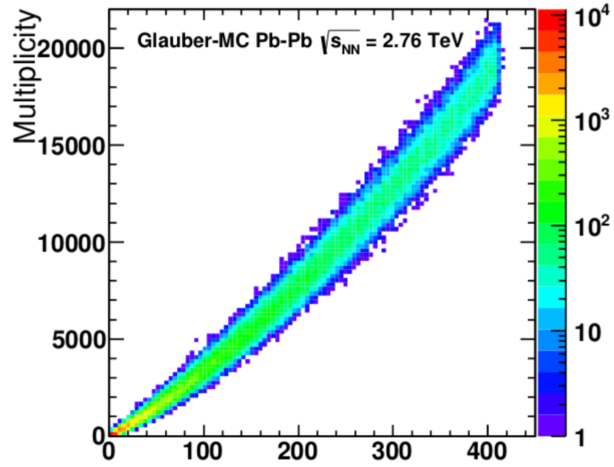
- Note Q_{pPb} is not 1 in absence of nuclear effects



Centrality from multiplicity in pPb

(A.Morsch)





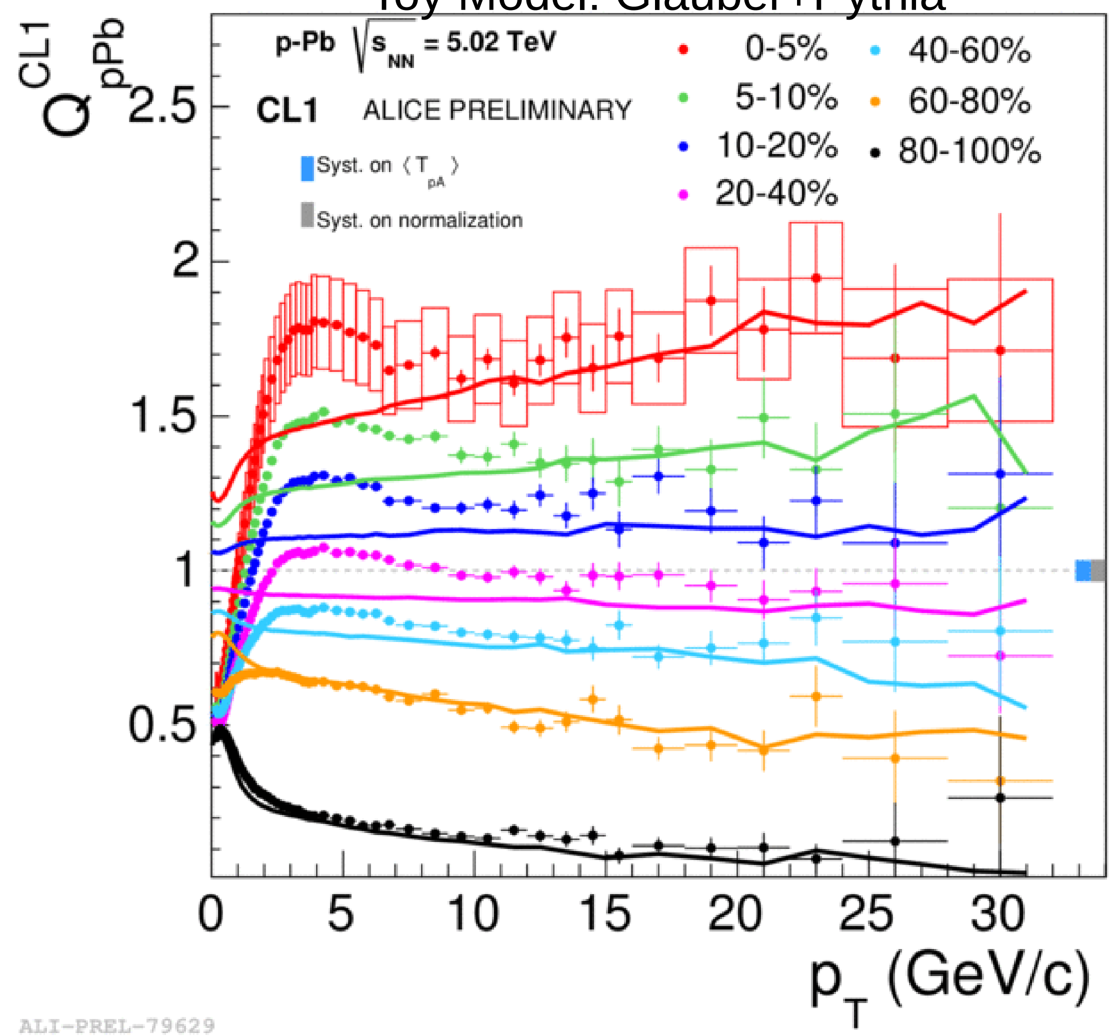
Using hits
at mid-rapidty (CL1)

Toy Model: Glauber+Pythia

- Small dynamic range
- Several biases are present
  - Multiplicity bias
  - Jet veto bias
  - Geometrical bias
- Include (and indicate) bias in the definition

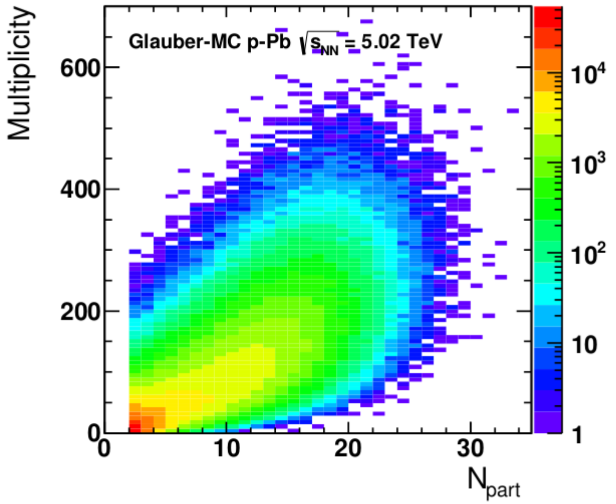
$$Q_{pPb,cent} = \langle N_{cent}^{Glauber} \rangle \frac{\langle dN^{pPb}/dp_T \rangle_{cent}}{dN^{pp}/dp_T}$$

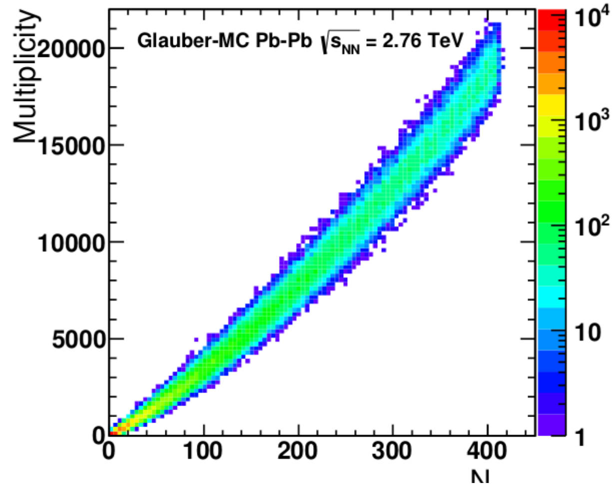
- Note Q_{pPb} is not 1 in absence of nuclear effects



Centrality from multiplicity in pPb

(A.Morsch)





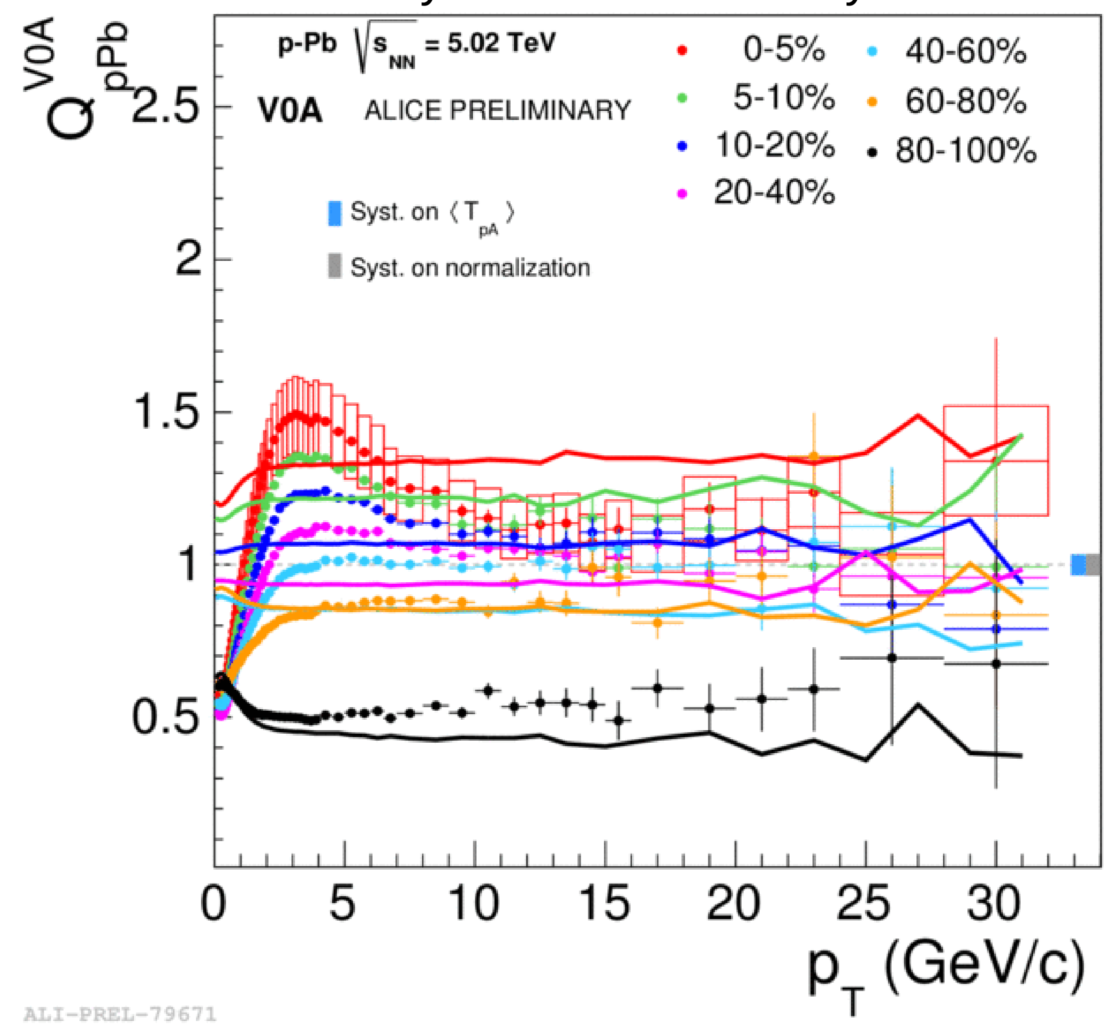
Using V0A amplitudes at forward rapidity

Toy Model: Glauber+Pythia

- Small dynamic range
- Several biases are present
  - Multiplicity bias
  - Jet veto bias
  - Geometrical bias
- Include (and indicate) bias in the definition

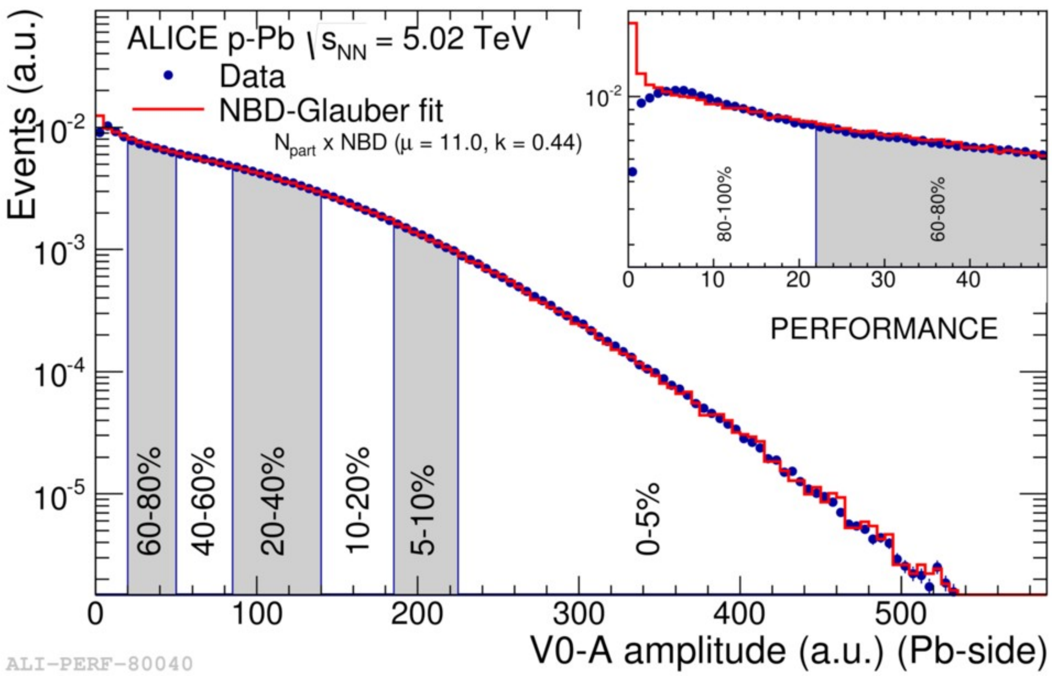
$$Q_{pPb,\,cent} = \langle N_{cent}^{Glauber} \rangle \frac{\langle dN^{pPb}/dp_T \rangle_{cent}}{dN^{pp}/dp_T}$$

- Note Q_{pPb} is not 1 in absence of nuclear effects

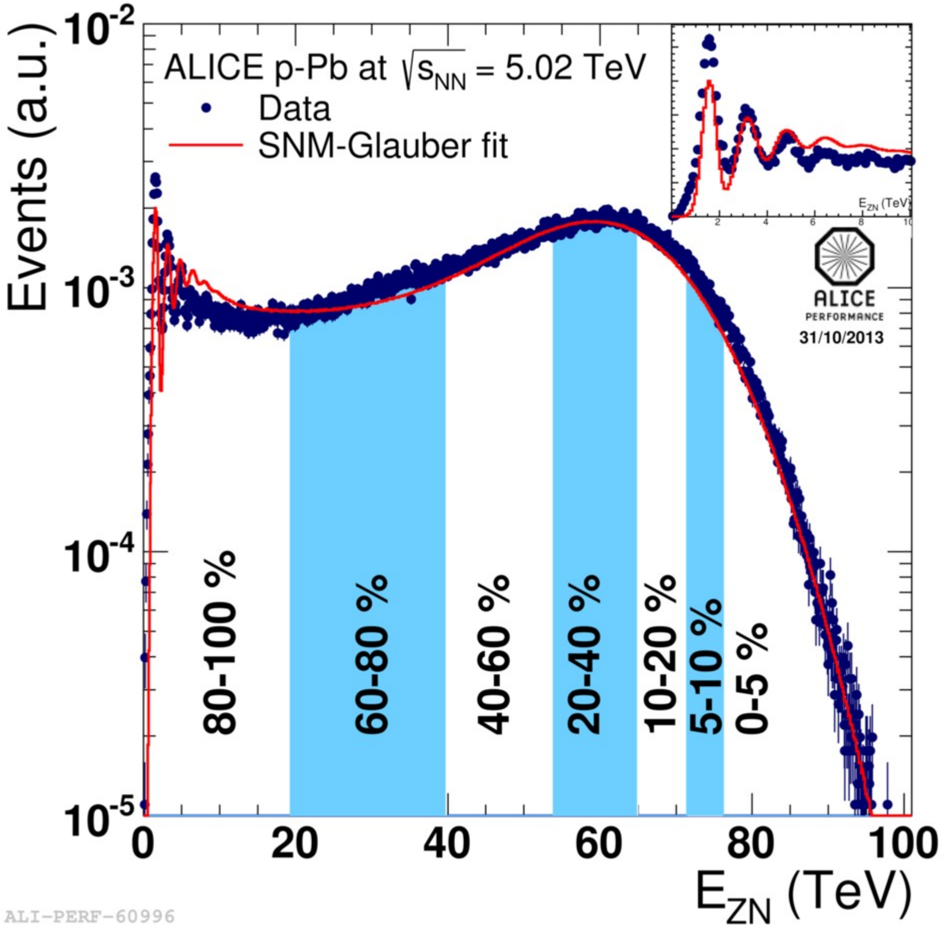


Forward neutron energy vs multiplicity

NBD method

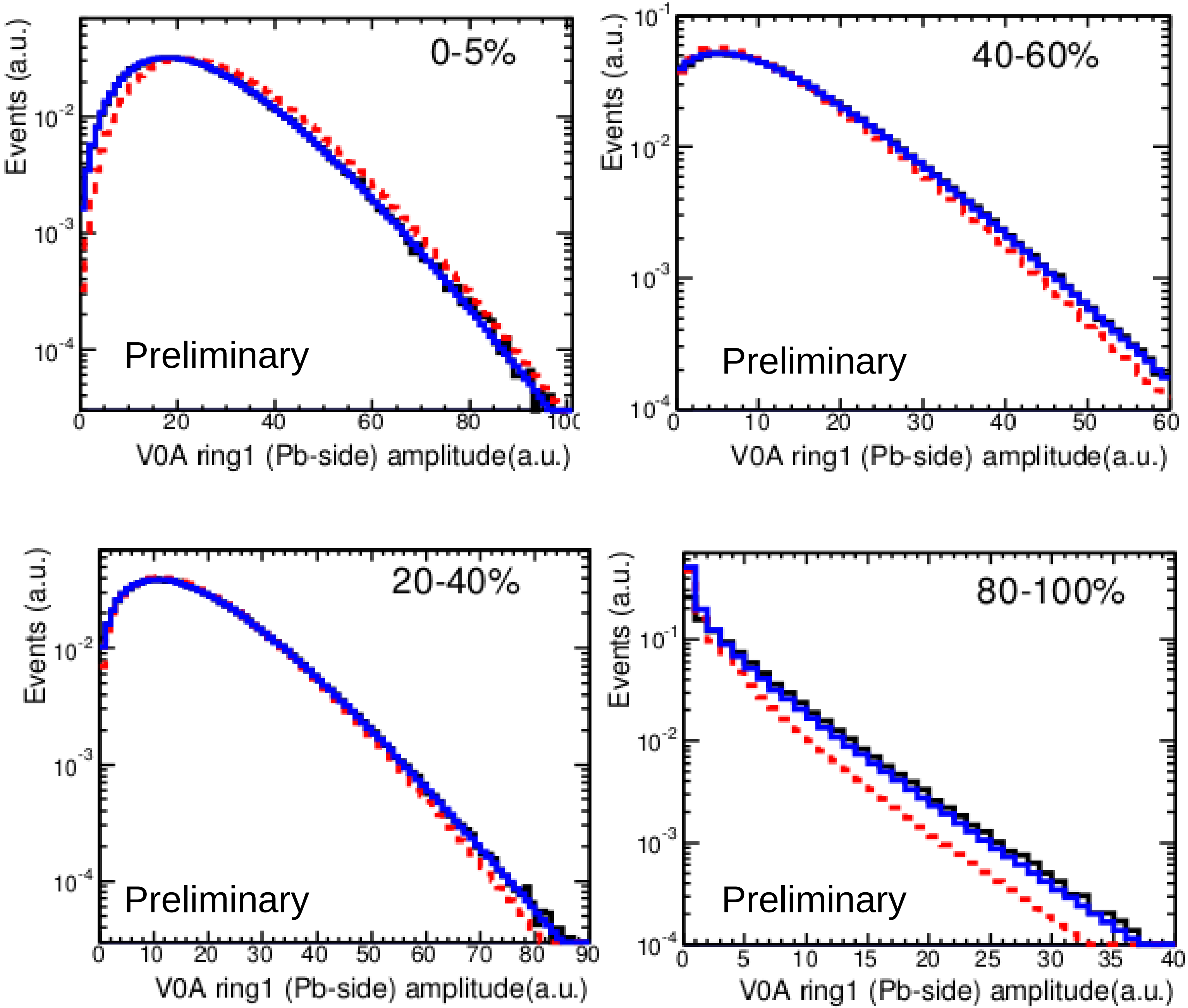


SNM method



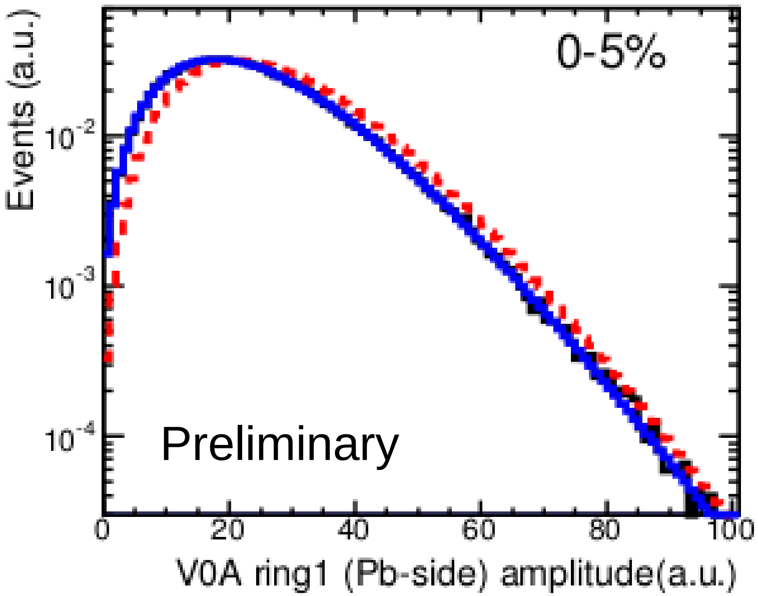
Correlation between forward neutron energy and multiplicity?

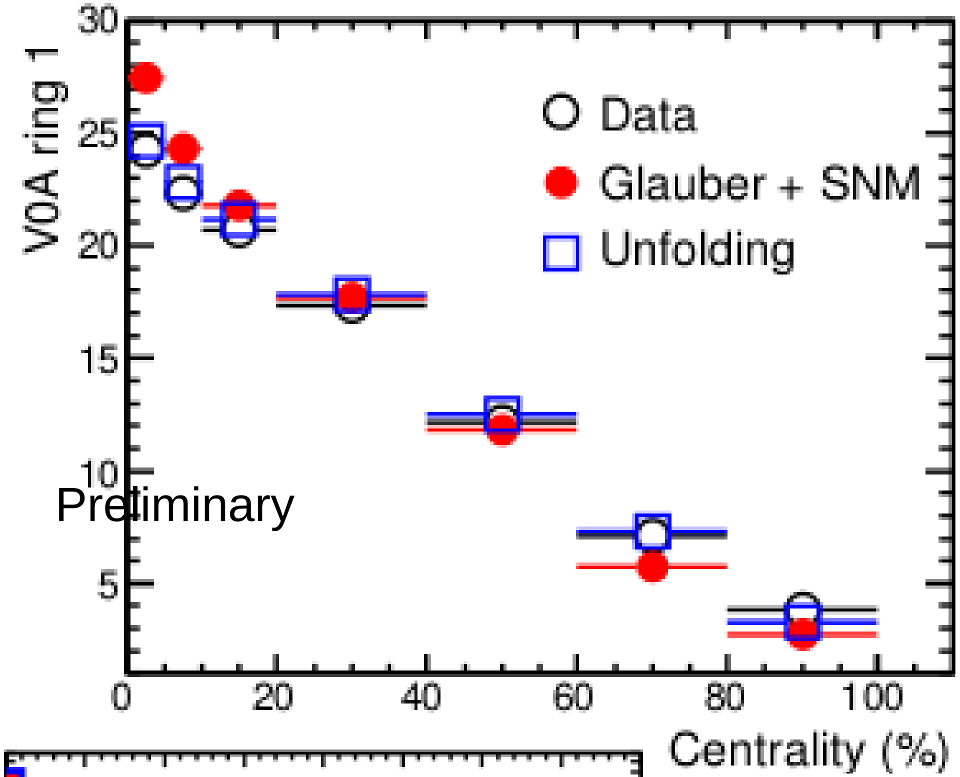
Correlation of V0A and ZNA

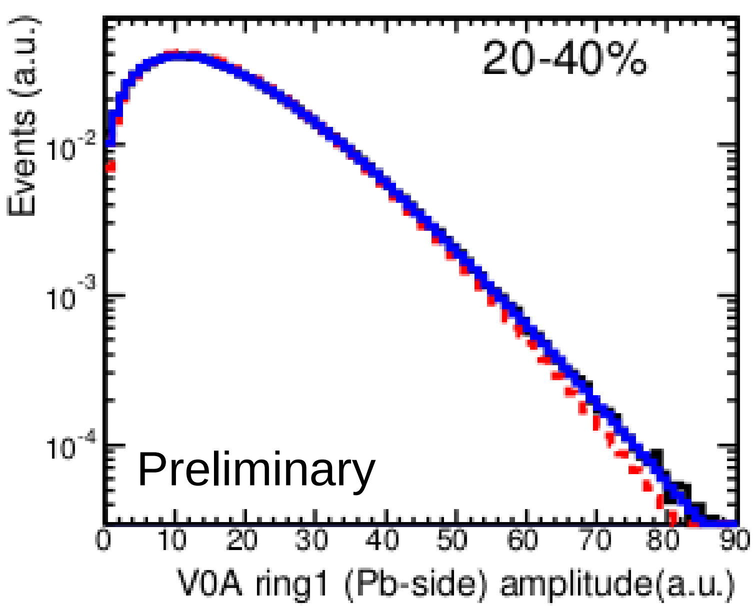


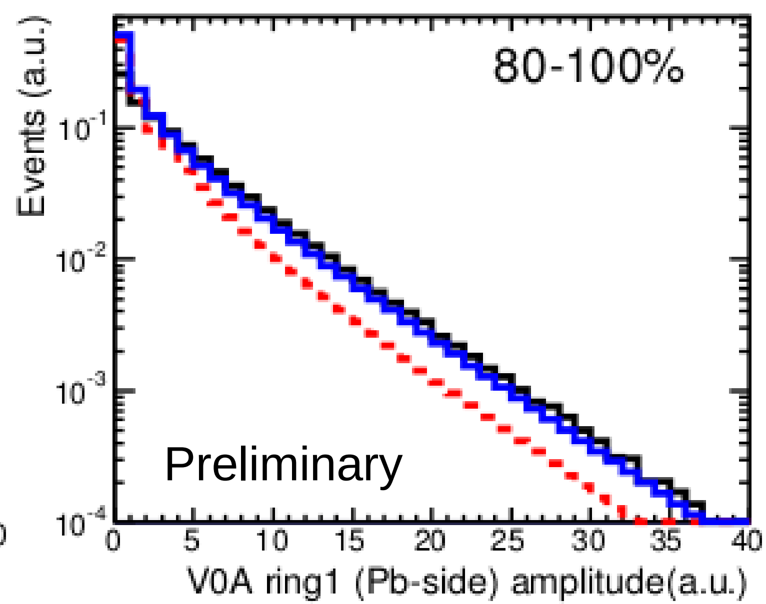
V0A in ZNA slices
Convolution of P(ZNA) x NBD(V0A)
Unfolded

Correlation of V0A and ZNA









V0A in ZNA slices
Convolution of
P(ZNA) x NBD(V0A)
Unfolded

ZN slicing +scaling of data (Hybrid Method)

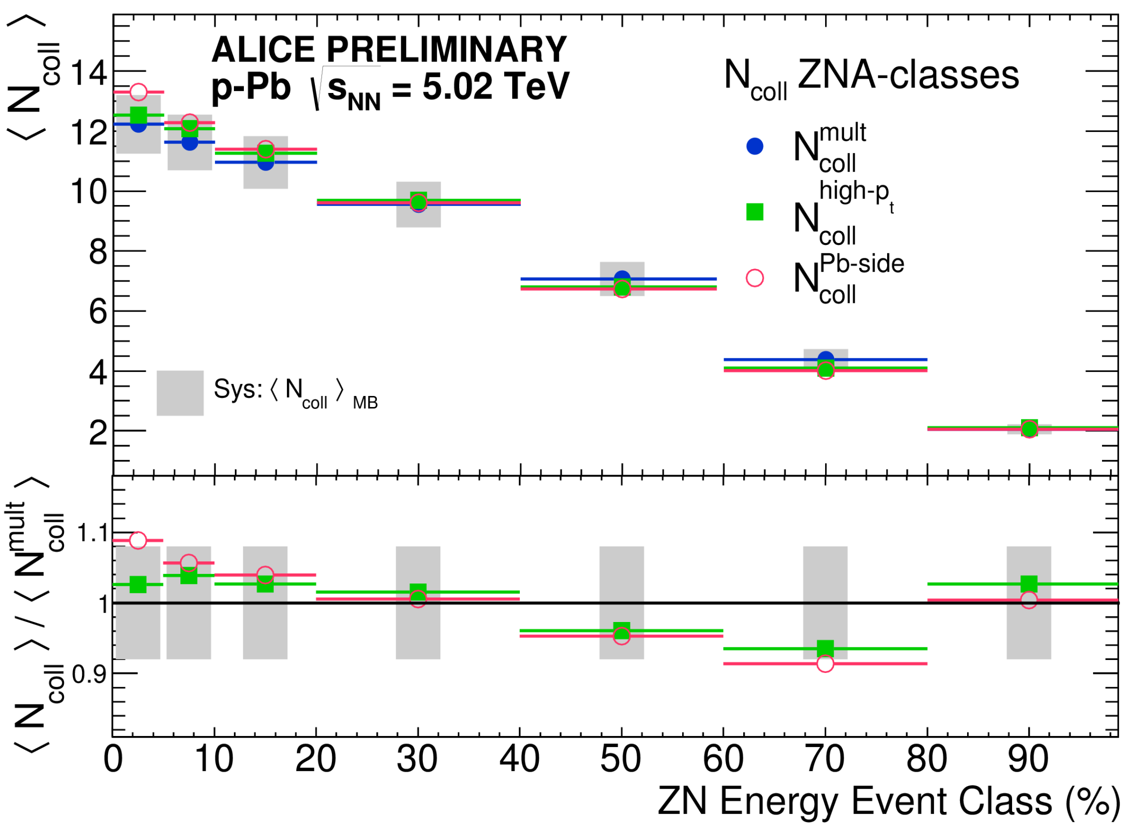
1) Assume: ZN insensitive to dynamical biases → slice events in ZN
2) Assume scaling
   a) Mid-rap dN/dη scales with N_{part}
   b) Pb-side dN/dη scales with N_{part}^{target} (= N_{coll} in pA)
   c) Yield at high-p_T scales with N_{coll}

$$\langle N_{\rm part}\rangle_i^{\rm mult} = \langle N_{\rm part}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$

$$\langle N_{\rm coll}\rangle_i^{\rm mult} = \langle N_{\rm part}\rangle_i^{\rm mult} - 1$$

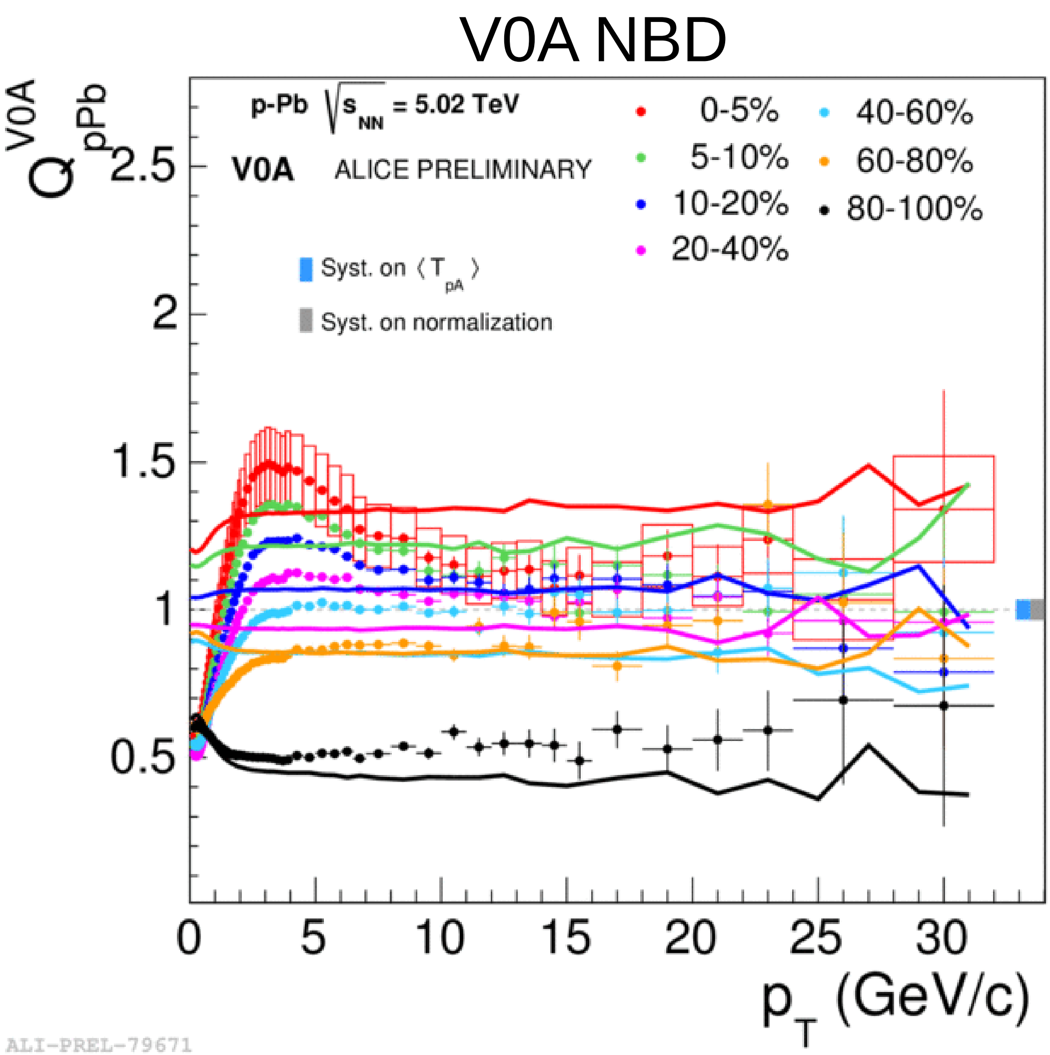
$$\langle N_{\rm coll}\rangle_i^{\rm Pb-side} = \langle N_{\rm coll}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$

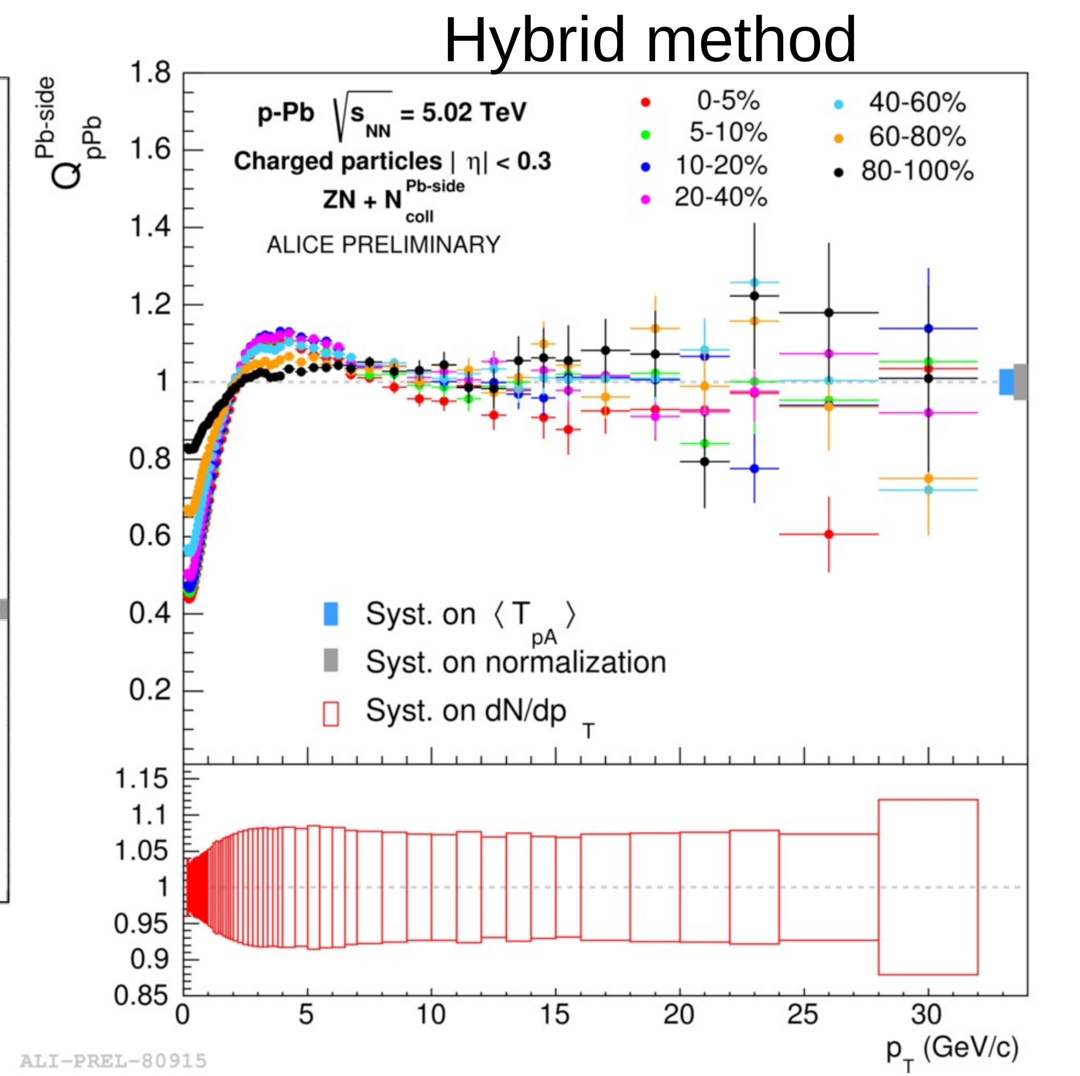
$$\langle N_{\rm coll}\rangle_i^{\rm high-p_T} = \langle N_{\rm coll}\rangle_{MB} \cdot \frac{\langle S\rangle_i}{\langle S\rangle_{MB}}$$



- All values within at most 10% → consistency of assumptions
- This does not yet prove the validity of any (or all) of these assumptions

Charged particle QpPb



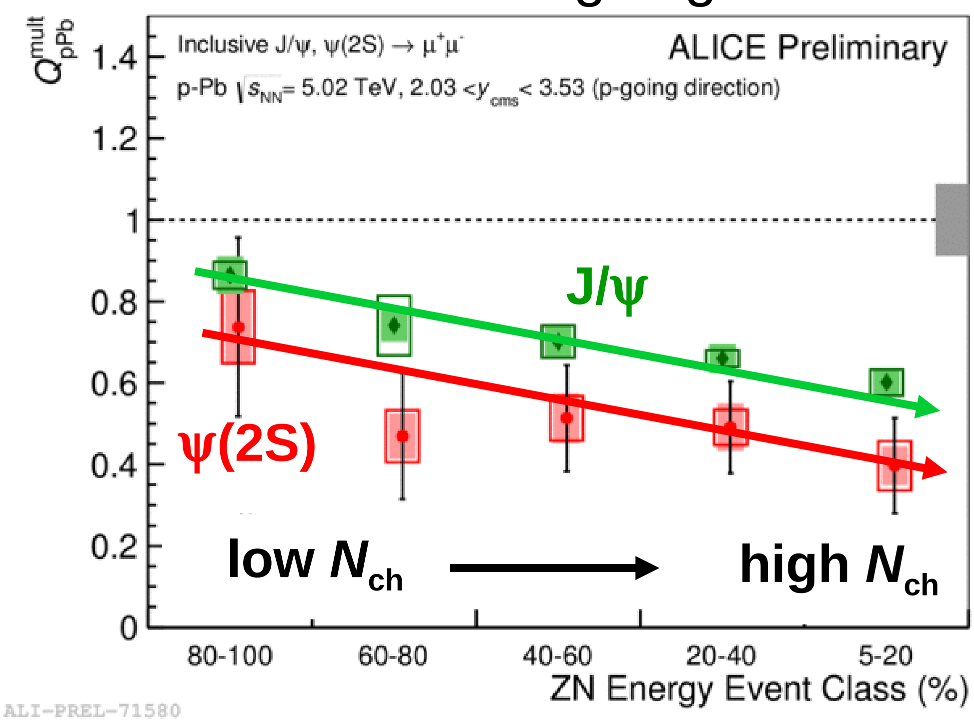


Hybrid method:

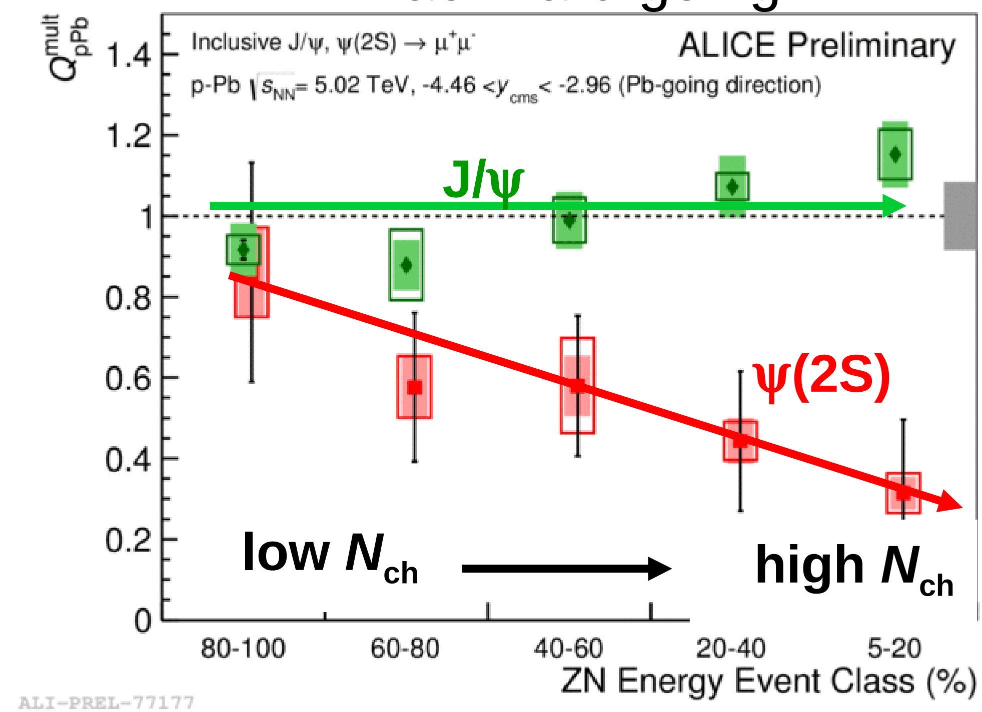
- Charged particle Q_{pPb} consistent with unity at high p_T
- Cronin peak develops with multiplicity

J/Ψ and Ψ(2S) suppression

Forward going

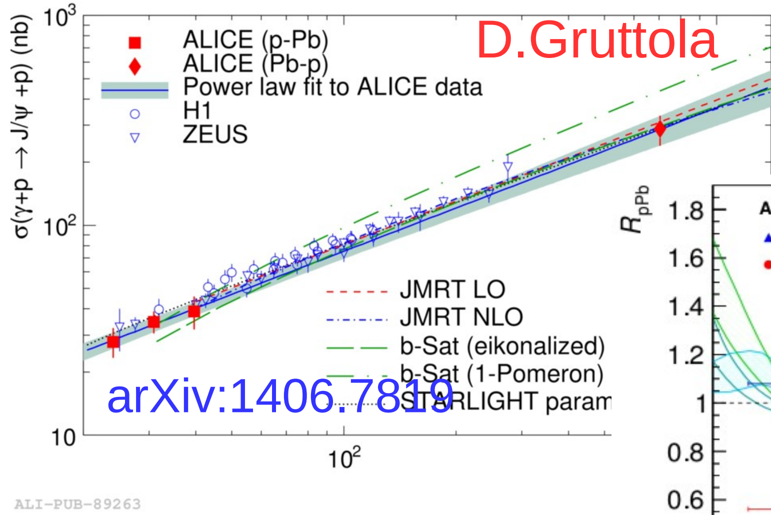


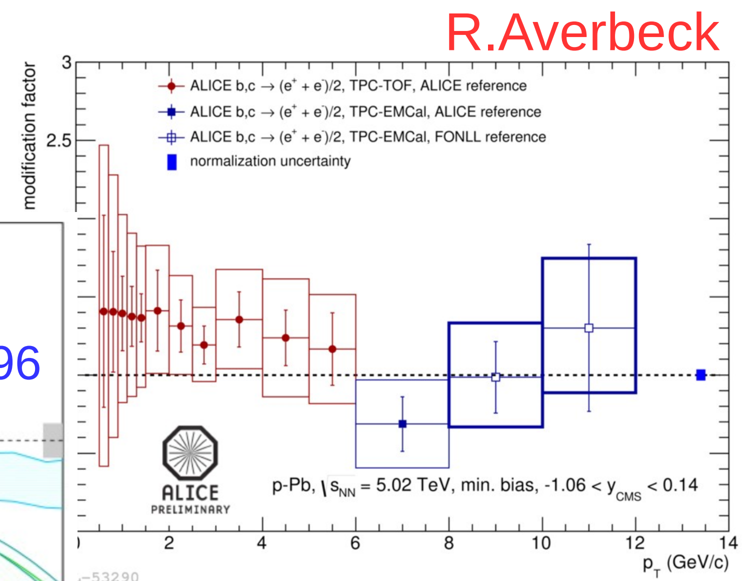
Backward going

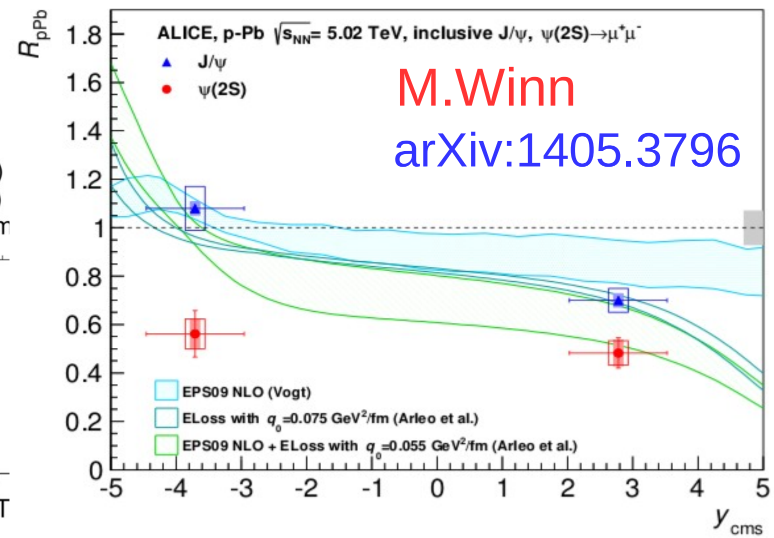


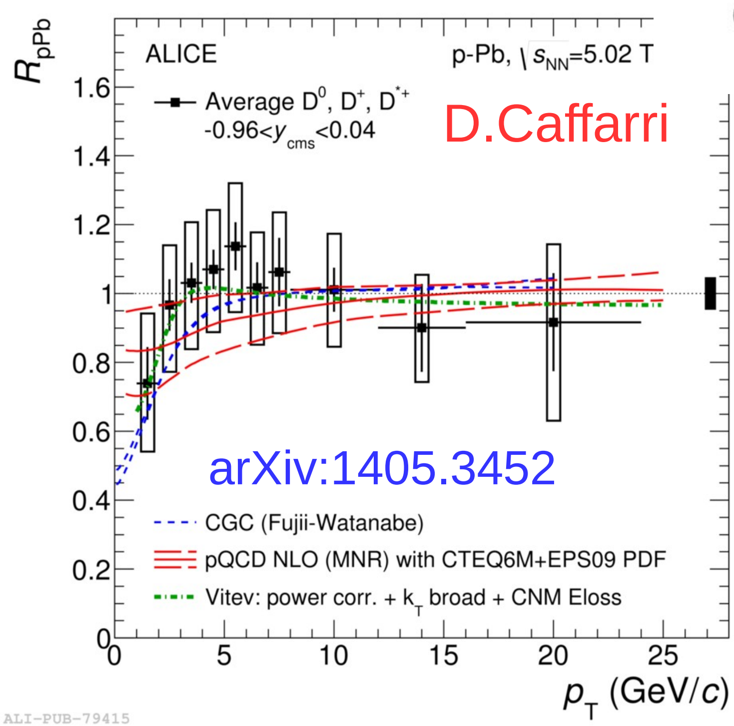
- J/ψ → μμ: Multiplicity dependent suppression in p-going direction, and no suppression in Pb-going direction
  - Consistent with shadowing
- ψ(2S) → μμ: Multiplicity dependent suppression in both directions
  - Needs additional effect (Final state?)

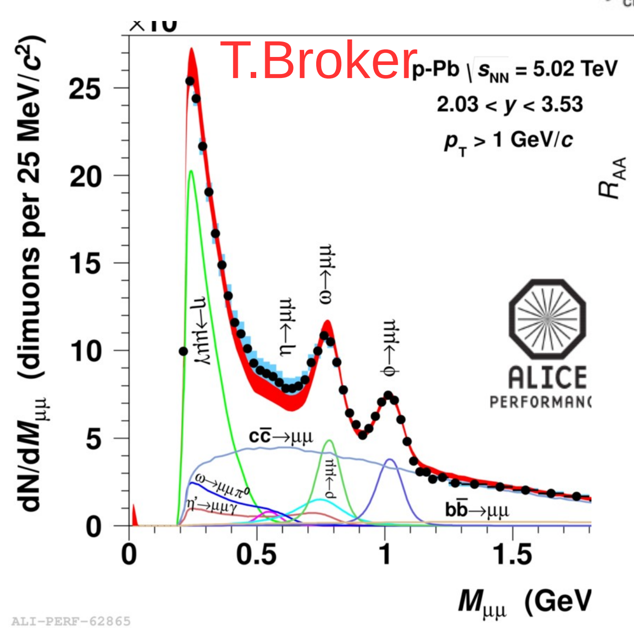
Highlights included in other ALICE talks

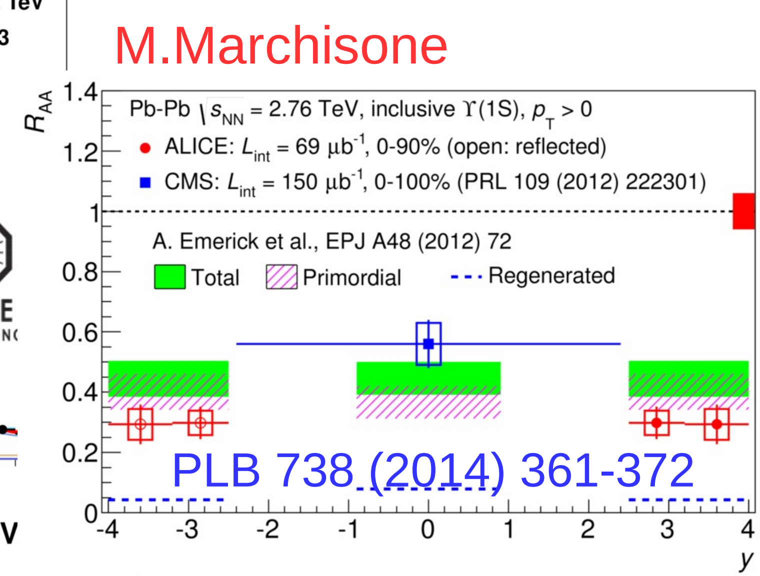




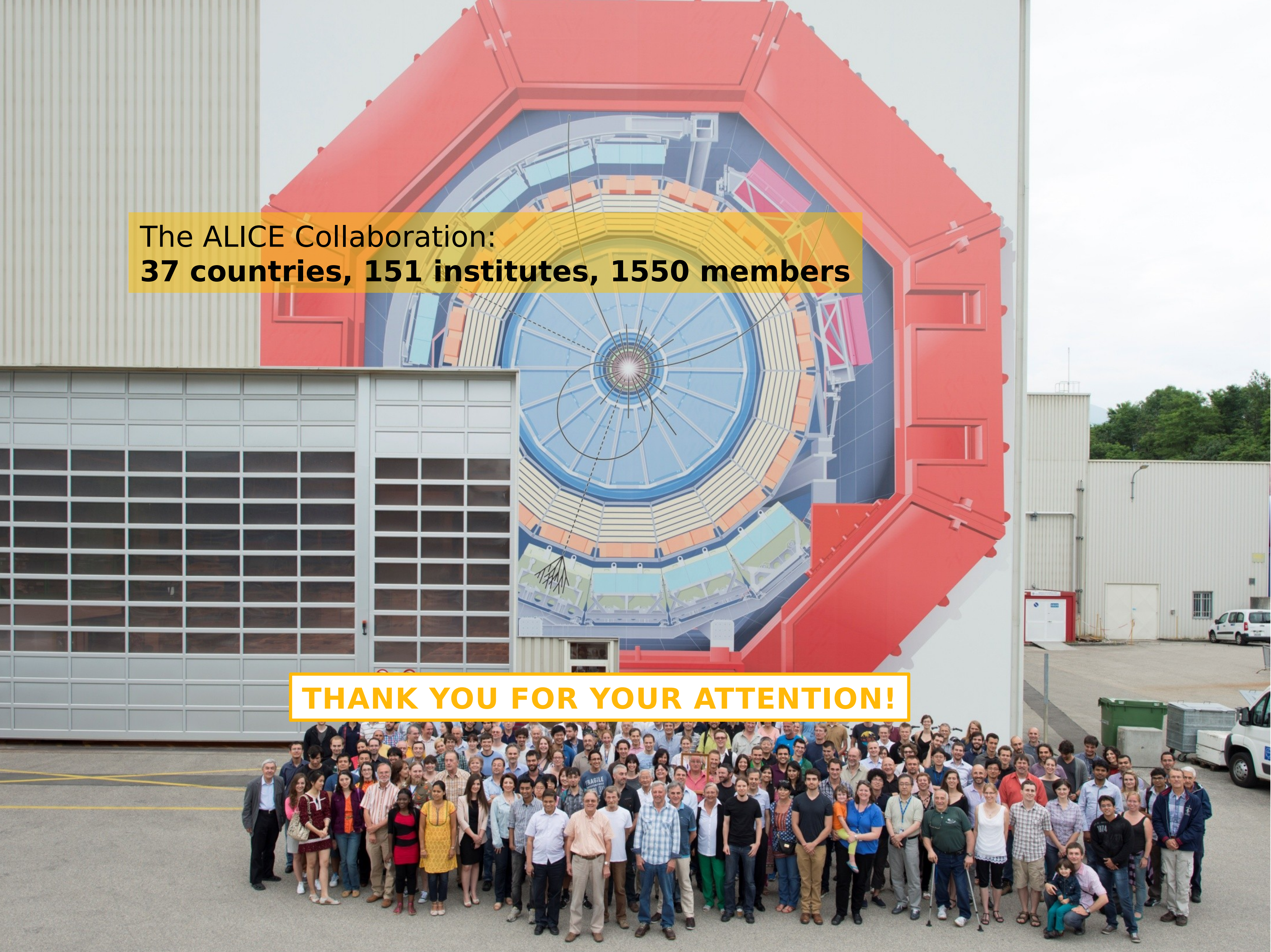








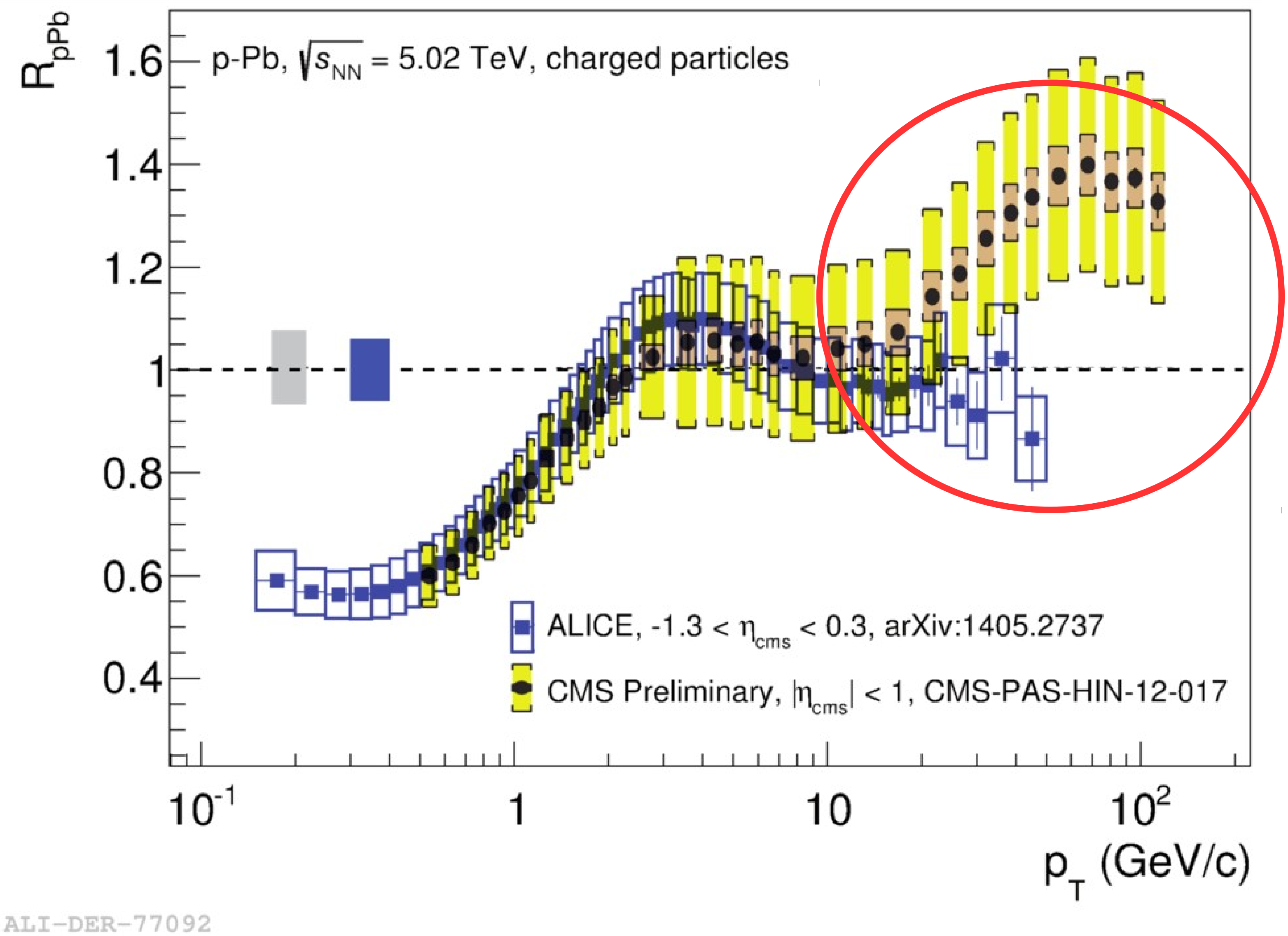
The ALICE Collaboration:
37 countries, 151 institutes, 1550 members



THANK YOU FOR YOUR ATTENTION!

Extra

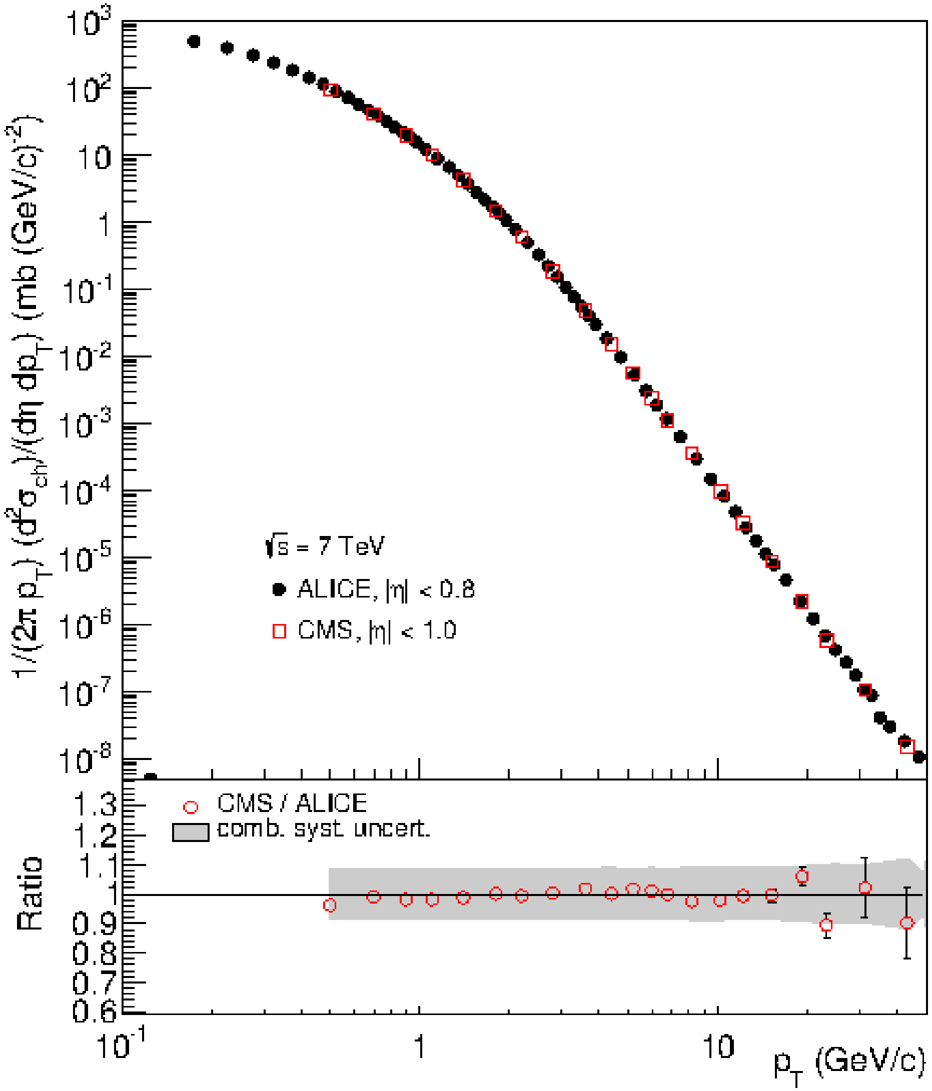
Nuclear modification factor: CMS vs ALICE



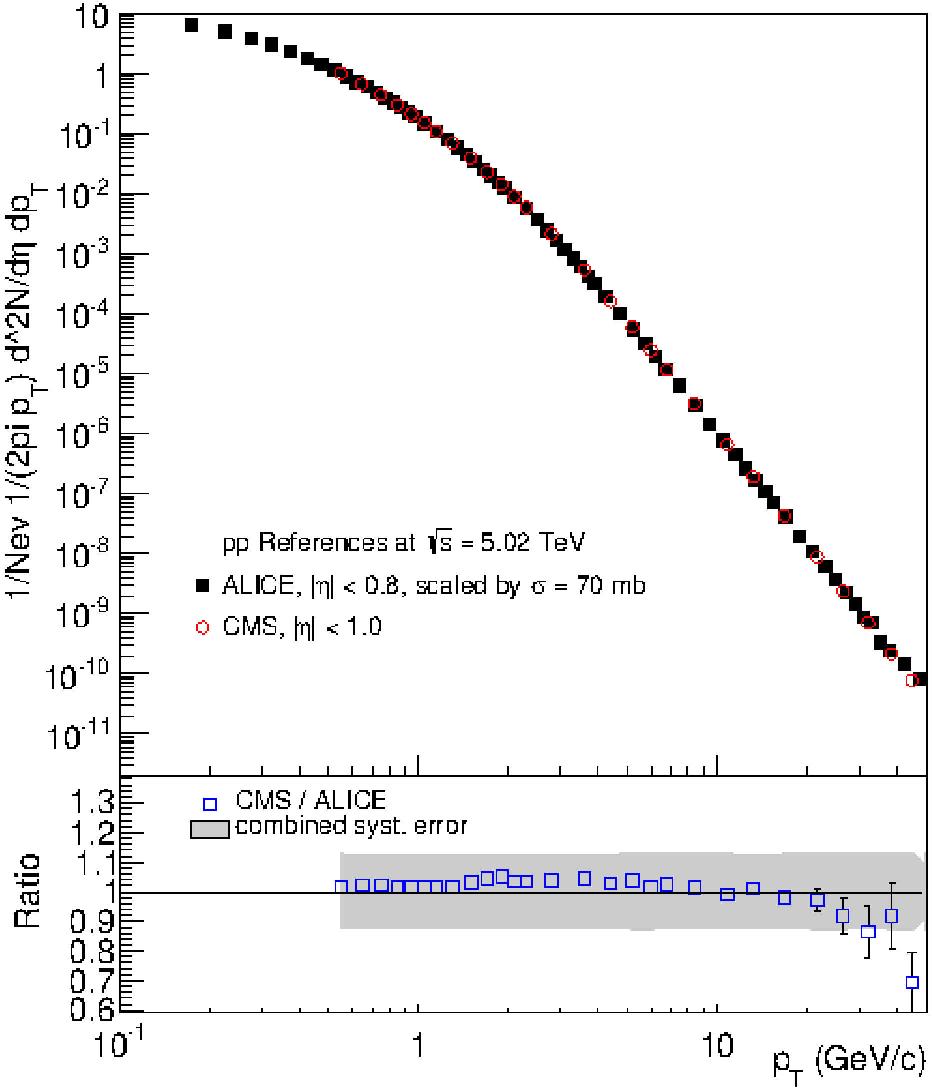
About 2/3 of the discrepancy arise from the (interpolated) pp references

Comparison pp spectra: ALICE vs CMS

7 TeV

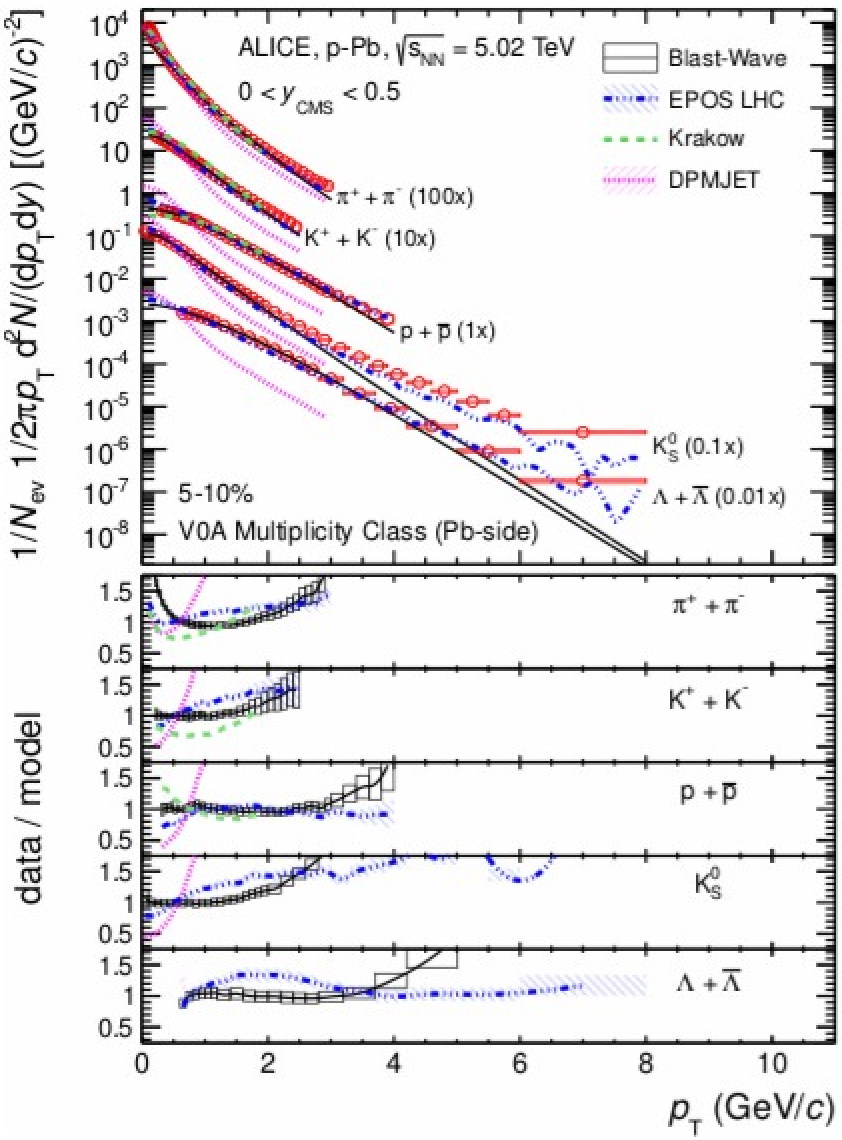


5 TeV (interp.)

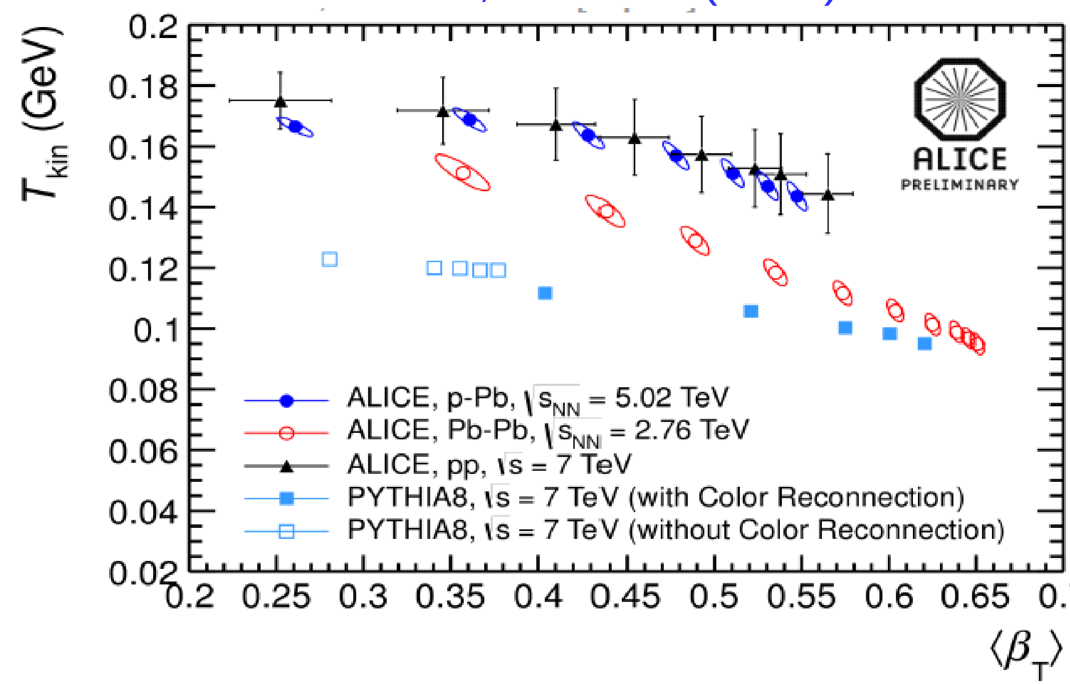


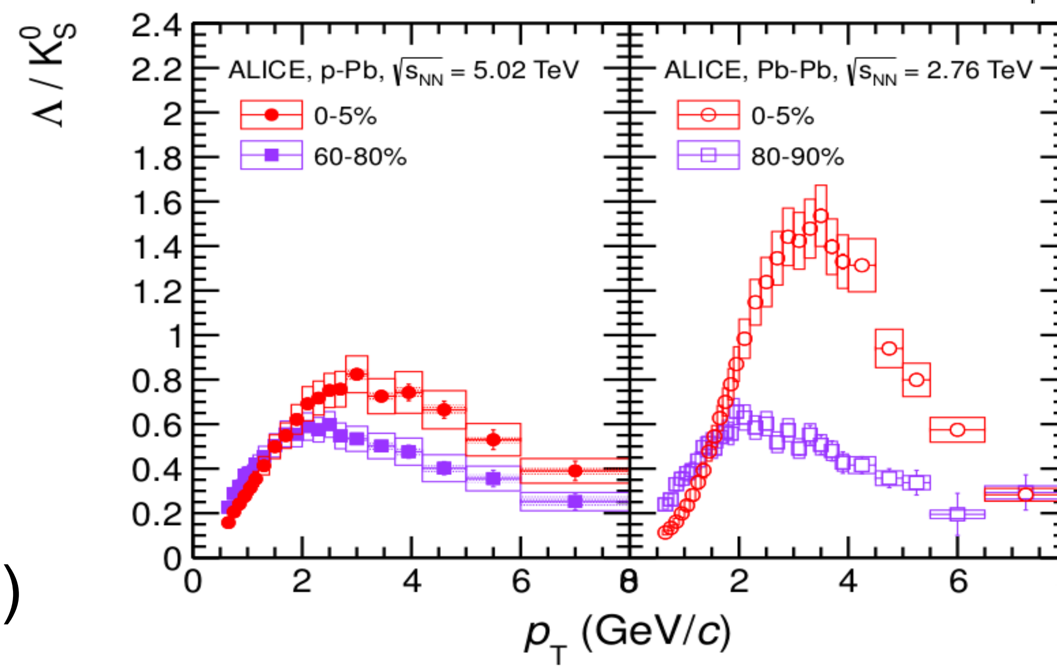
Needs a measurement of the pp reference during run 2

Identified particle spectra



ALICE, PLB 278 (2014) 25





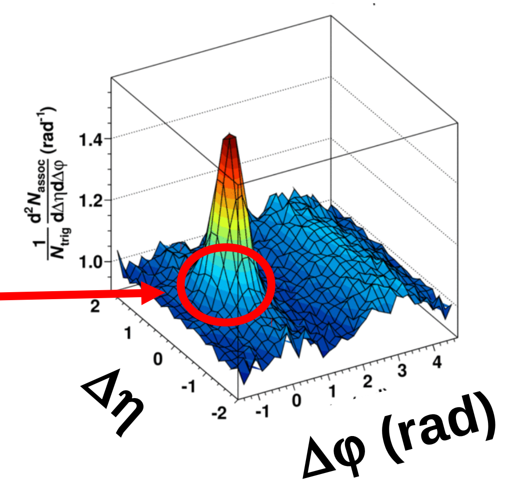
Spectra consistent with radial flow picture (also in pp)

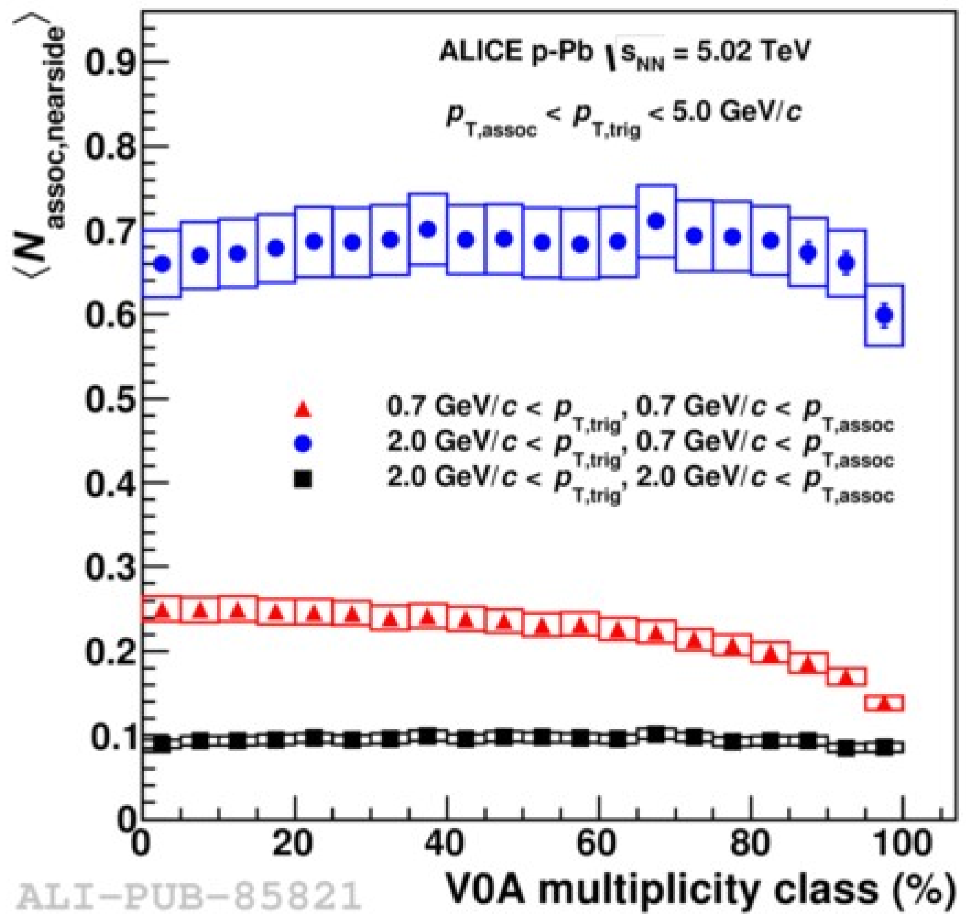
And the jet at low p_T?

- Ridge and jet yield seem additive in 2PC
- Subtract ridge to obtain jet yields
- Resulting jet yields are constant over >60% of the pPb cross section
  - No modification even at low p_T
- Consistent with picture of minijets in pPb from independent super-positions of NN collisions with incoherent fragmentation

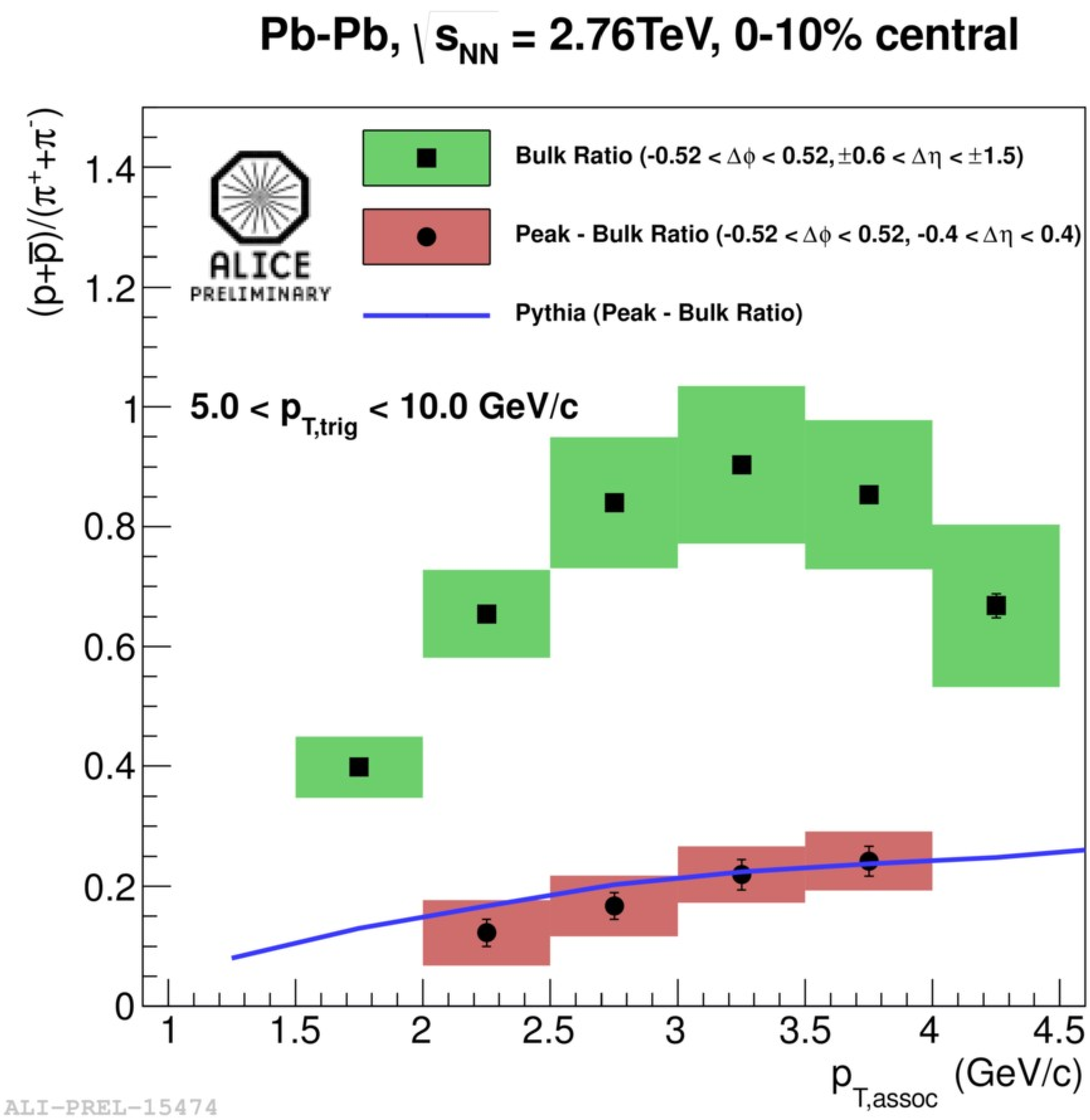
arXiv:1406.5463

What happens to jet at low p_T?





Proton-over-pion ratio: Jet vs bulk region



3-pion correlation formalism

$$
\begin{aligned}
N_3(p_1,p_2,p_3) &= f_1 N_1(p_1)N_1(p_2)N_1(p_3) \\
&+ f_2\left[N_2(p_1,p_2)N_1(p_3) + N_2(p_3,p_1)N_1(p_2) + N_2(p_2,p_3)N_1(p_1)\right] \\
&+ f_3 K_3(q_{\mathrm{inv},12}, q_{\mathrm{inv},31}, q_{\mathrm{inv},23}) N_3^{QS}(p_1,p_2,p_3), \\
\mathbf{c}_3(p_1,p_2,p_3) &= 1 + [2N_1(p_1)N_1(p_2)N_1(p_3) \\
&- N_2^{QS}(p_1,p_2)N_1(p_3) - N_2^{QS}(p_3,p_1)N_1(p_2) - N_2^{QS}(p_2,p_3)N_1(p_1) \\
&+ N_3^{QS}(p_1,p_2,p_3)]/N_1(p_1)N_1(p_2)N_1(p_3).
\end{aligned}
$$

$$
r_3(p_1,p_2,p_3) = \frac{\mathbf{c}_3(p_1,p_2,p_3) - 1}{\sqrt{(C_2^{QS}(p_1,p_2)-1)(C_2^{QS}(p_3,p_1)-1)(C_2^{QS}(p_2,p_3)-1)}}
$$

In Core/Halo picture, given λ, the probability of choosing N particles from the core is $\lambda^{N/2}$

$f_1 = (1-\lambda^{1/2})3 + 3(1-\lambda^{1/2})2\lambda^{1/2} - 3(1-\lambda^{1/2})(1-\lambda)$

$f_2 = (1-\lambda^{1/2})$

$f_3 = \lambda^{3/2}$

Comparison of c_3 at similar Nch

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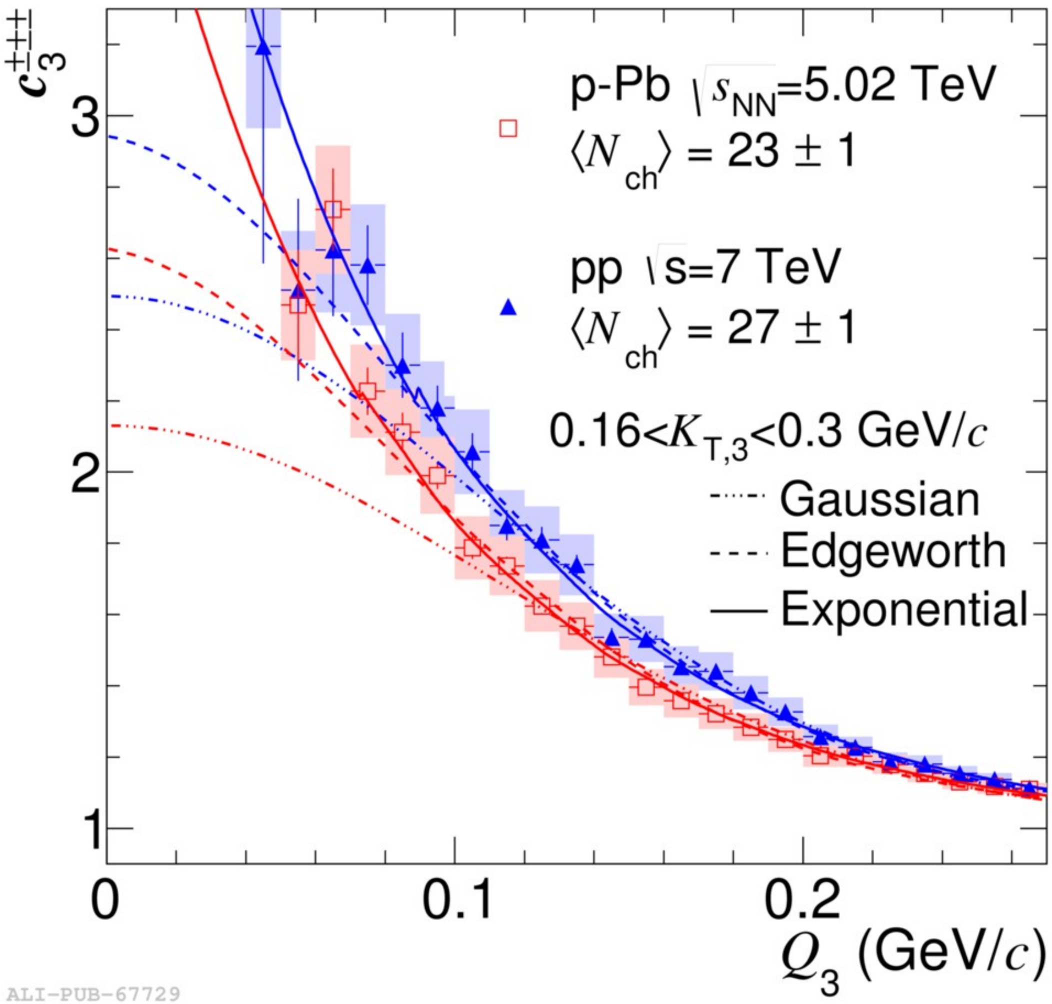

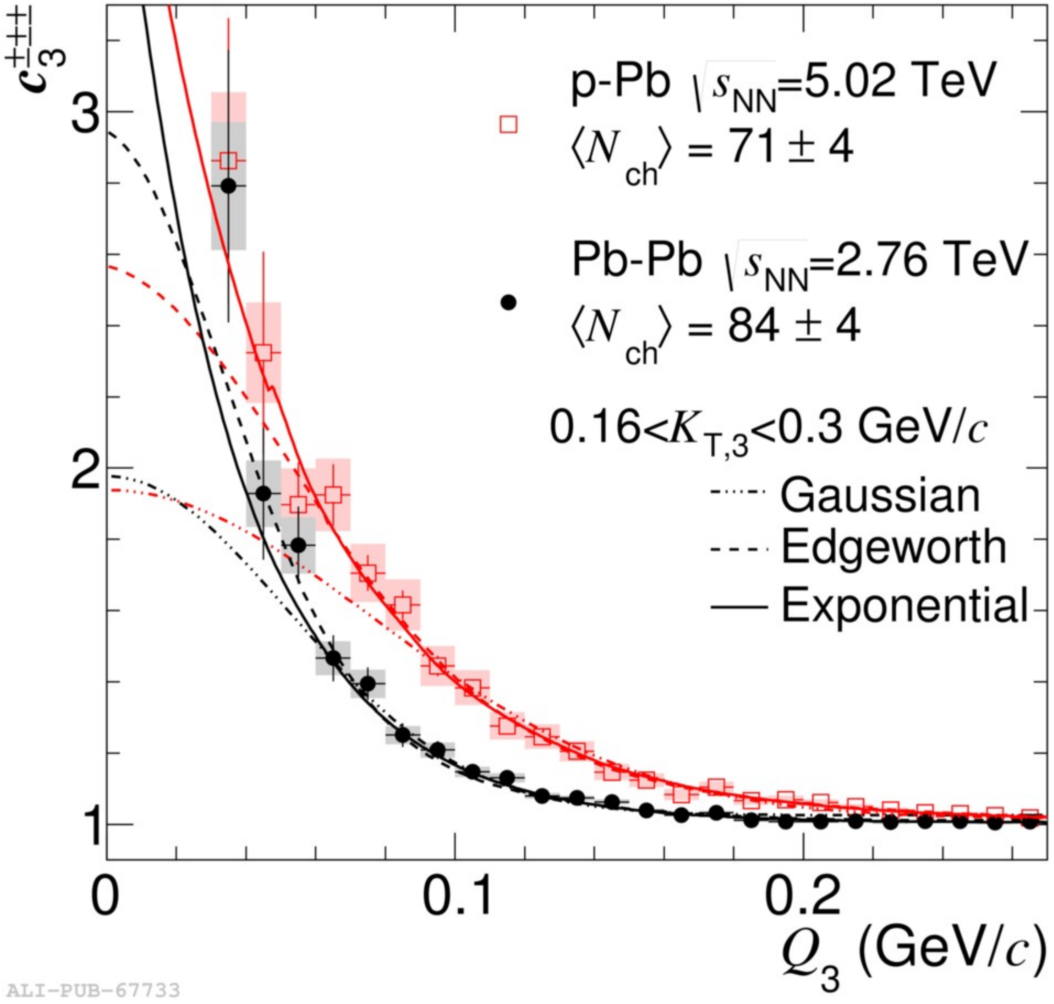

Similar for pp and pPb

Different for PbPb and pPb

3-pion Gaussian and Exponential fit results

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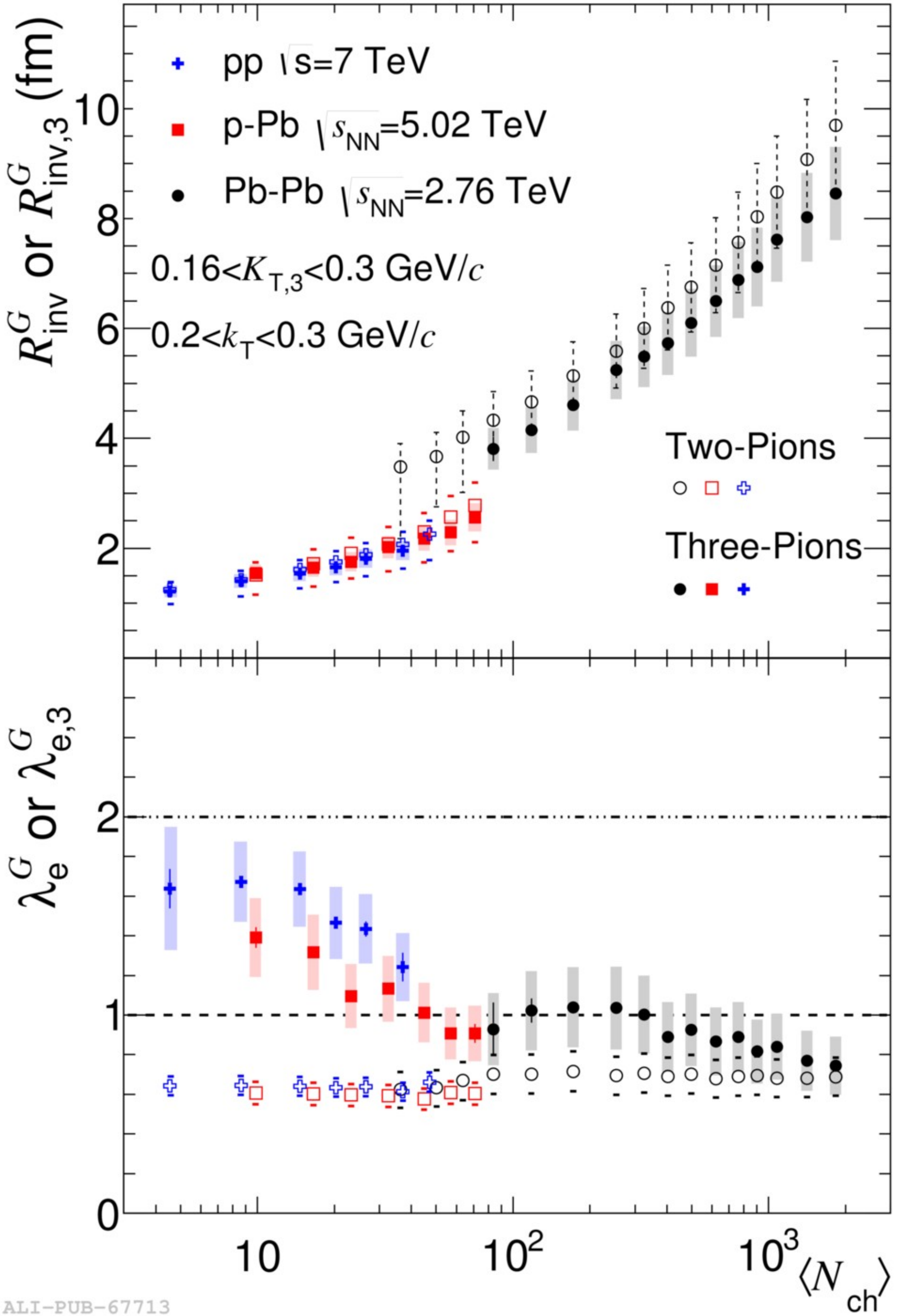
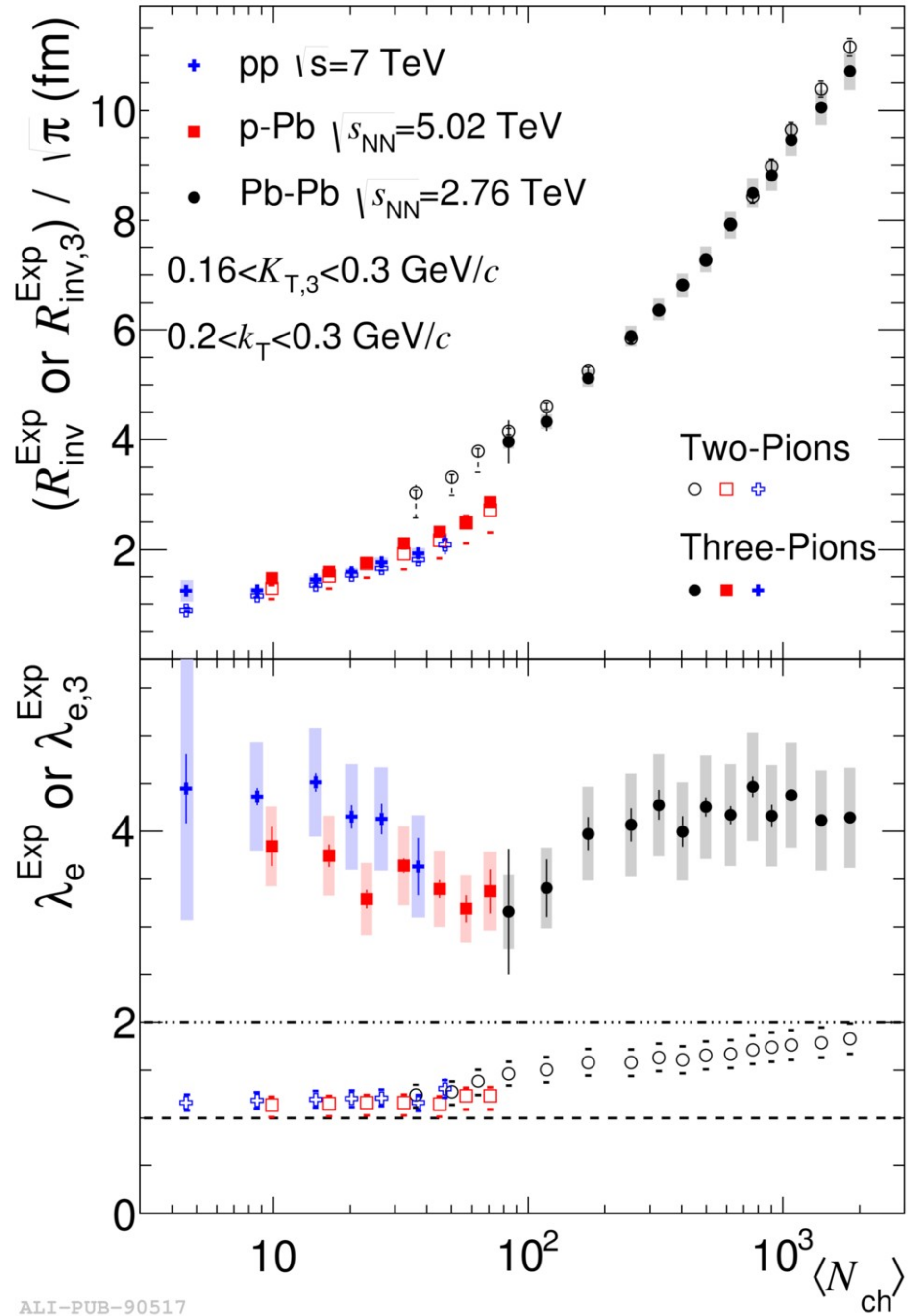
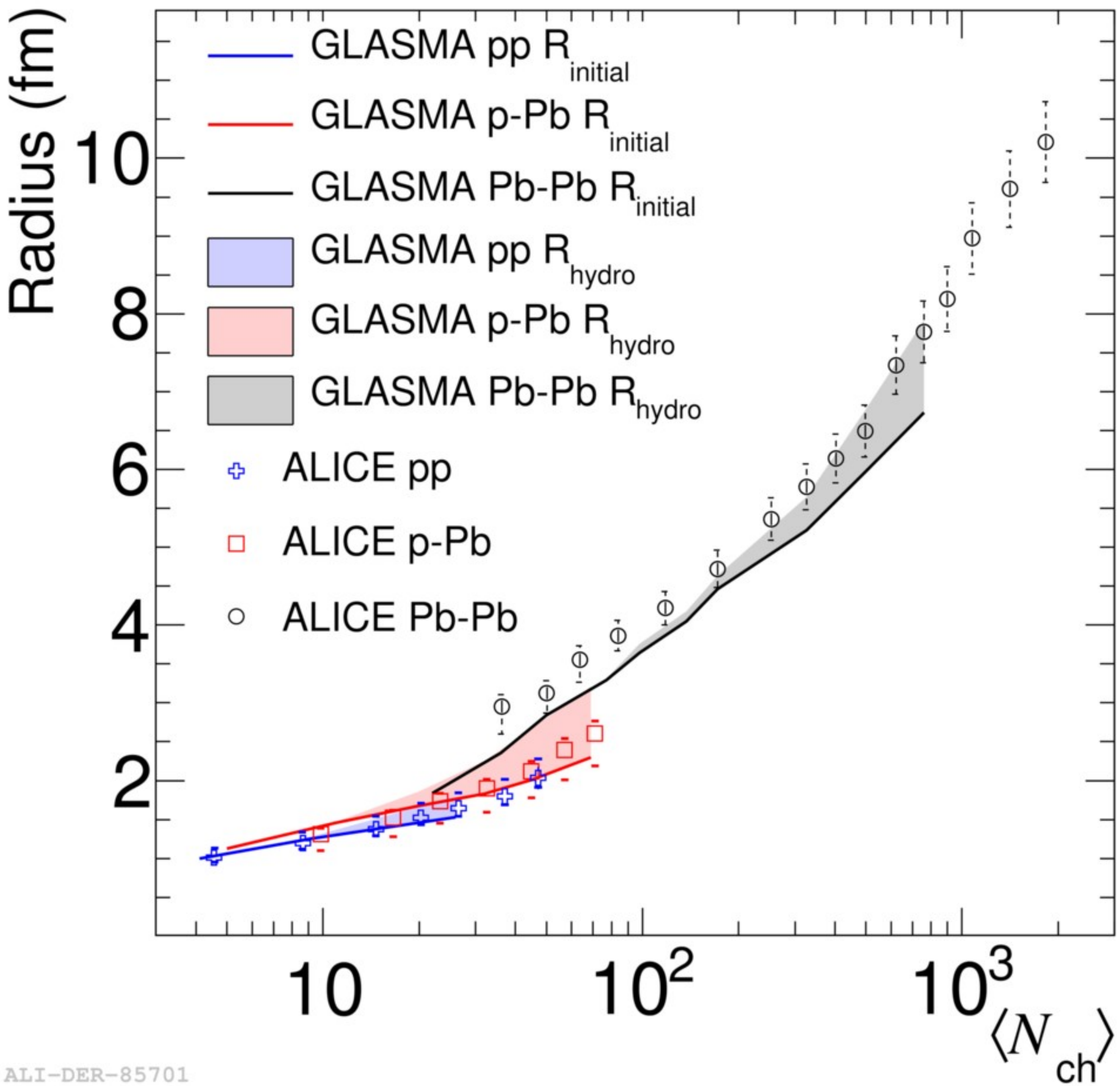




Gaussian radii comparison with IP-GLASMA

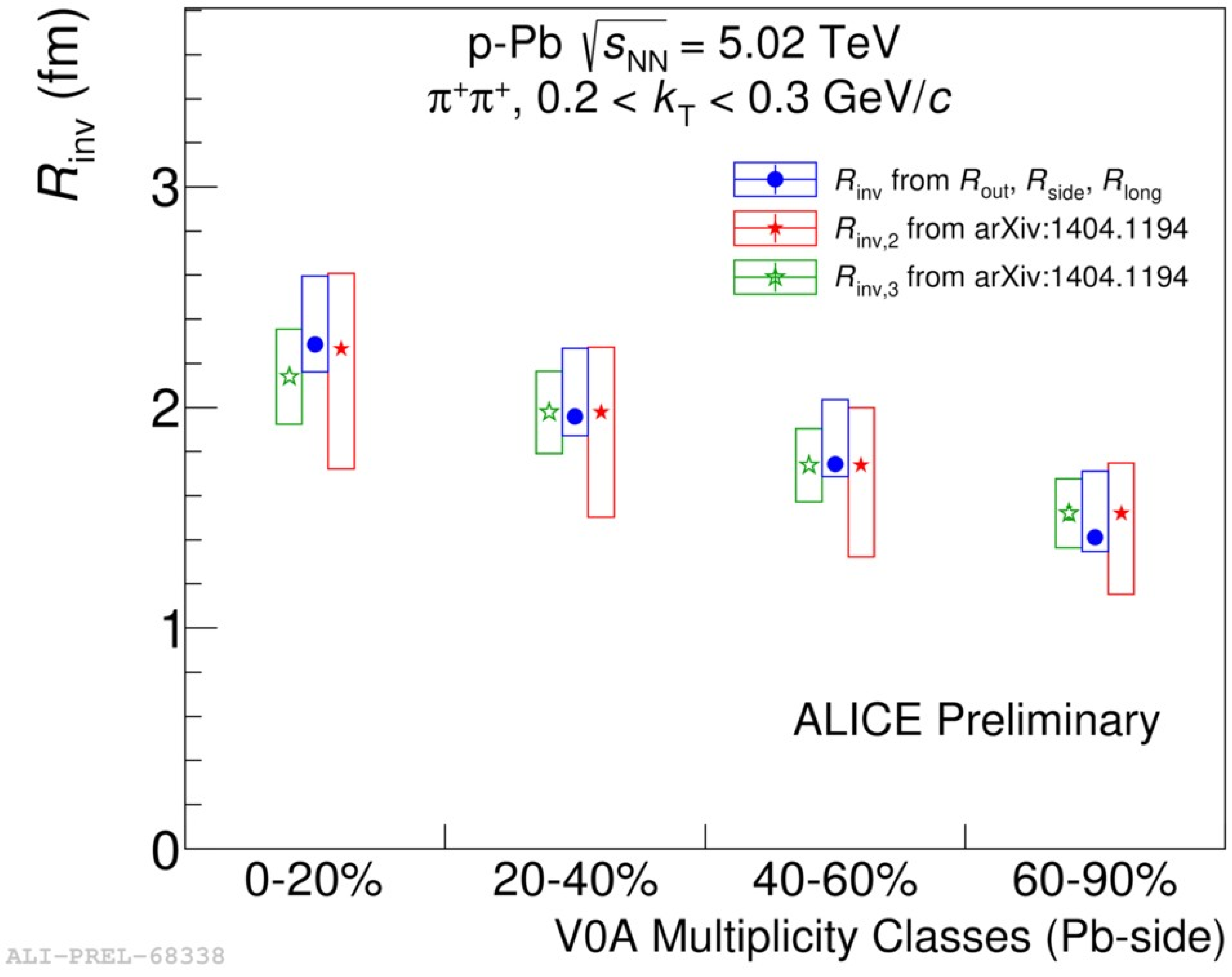
- Similarity of radii in pp and pPb can be reproduced by IP-GLASMA initial conditions alone
- The radii in pPb can also described by adding a hydro-dynamic phase

Schenke & Venugopalan, PRL 113 (2014) 102301

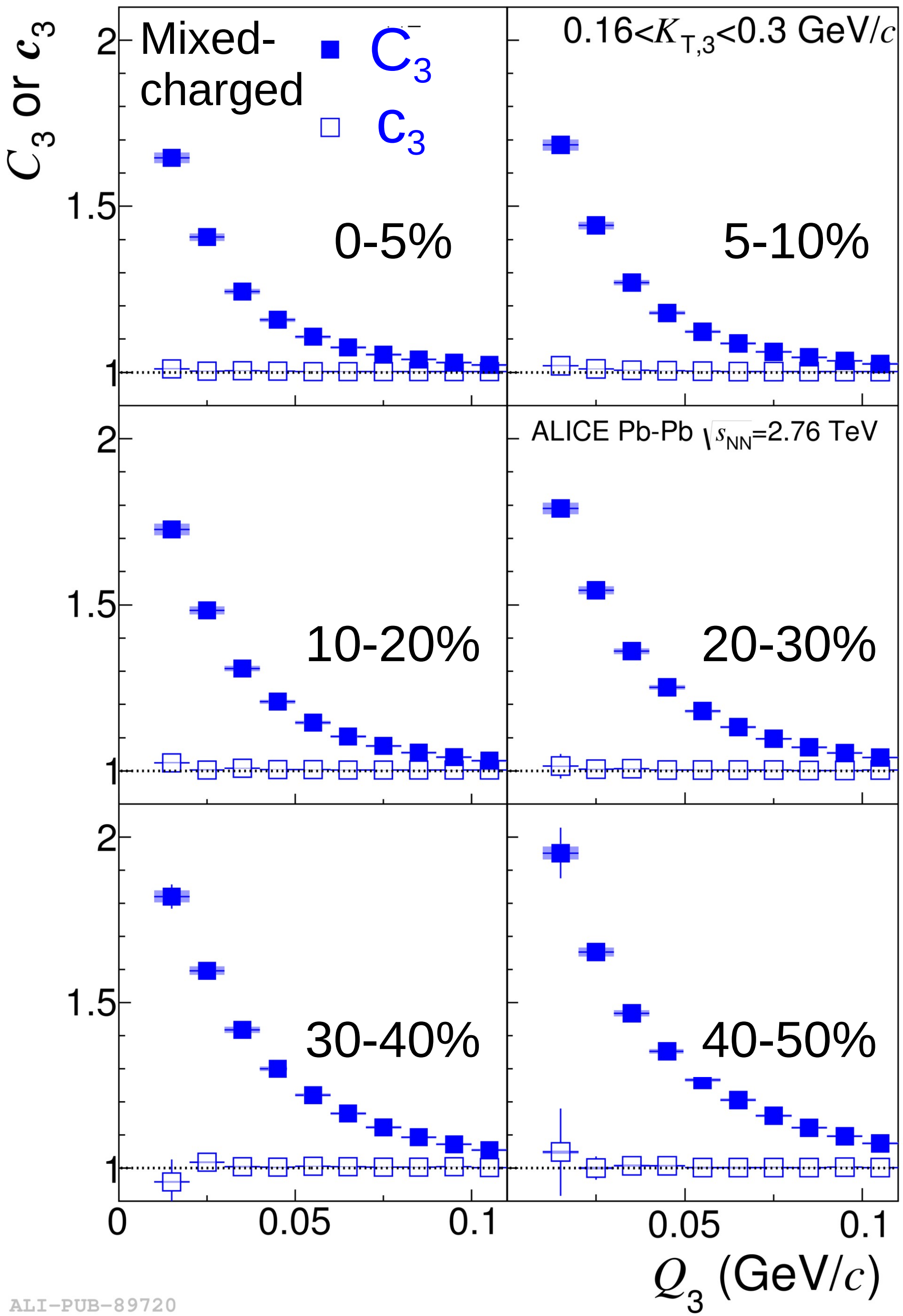


GLASMA result is first scaled with 1.15 such that calculations math the pp ALICE data.
The calculation has an uncertainty due to the infra-red cutoff (m=0.1 GeV).

Comparison 3d versus 1d radii



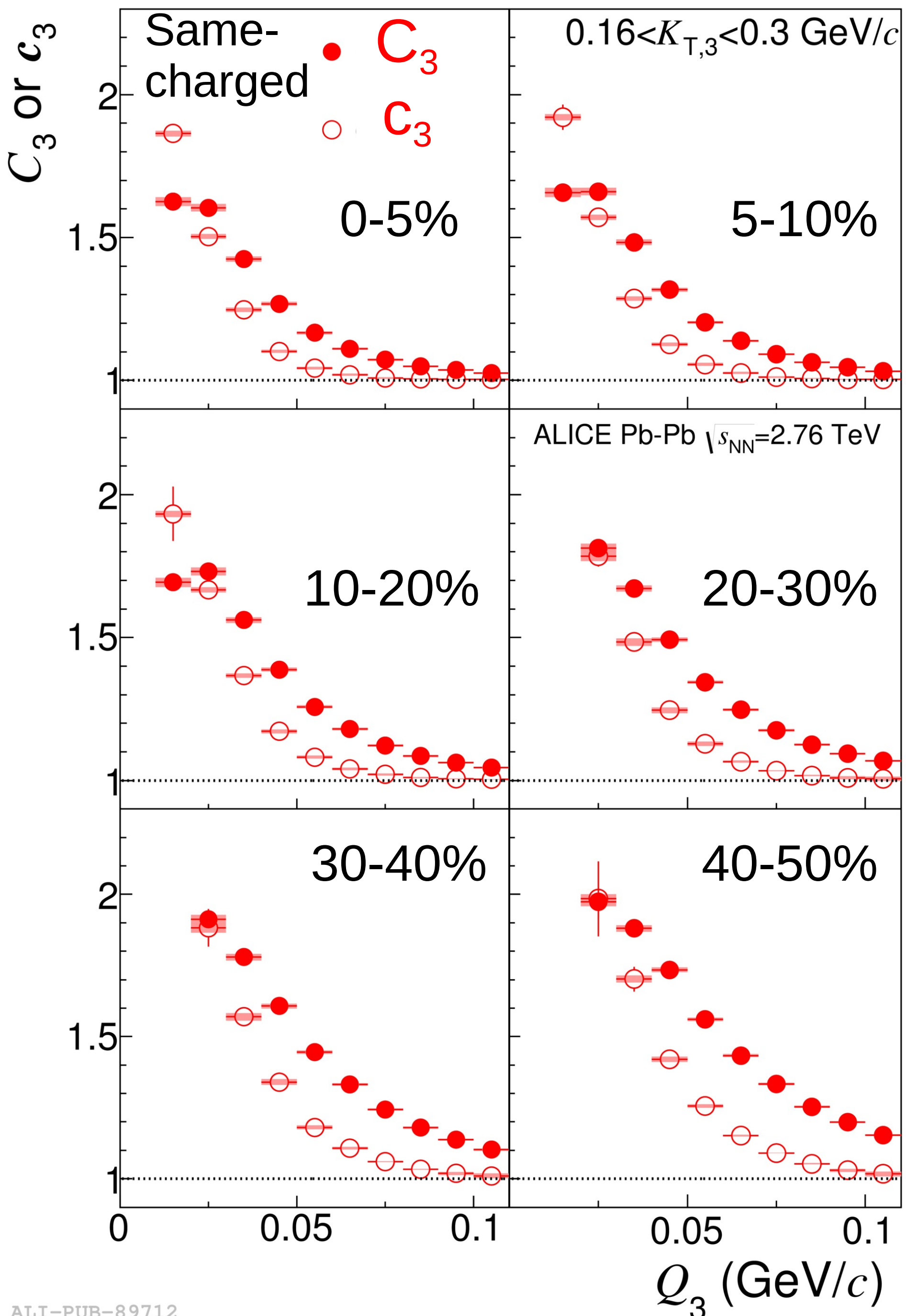
3-pion mixed-charged correlations



- At low Q_3, two- and three-particle correlations (C_3) dominated by final state interactions (FSI)
  - Mainly Coulomb interactions
  - Obtain corrections from Therminator
- Use mixed charged correlation to benchmark performance of FSI corrections
- Mixed-charged cumulant (c_3) consistent with unity
  - Mixed charged case well understood
  - FSI (Coulomb) corrections work well
    - Small residuals from unity treated as systematic uncertainty for same charge cumulant

PRC 89 (2014) 024911

3-pion same-charged correlations



- After FSI corrections large same-charged cumulant (c_3)
- Genuine 3-pion Bose-Einstein correlations

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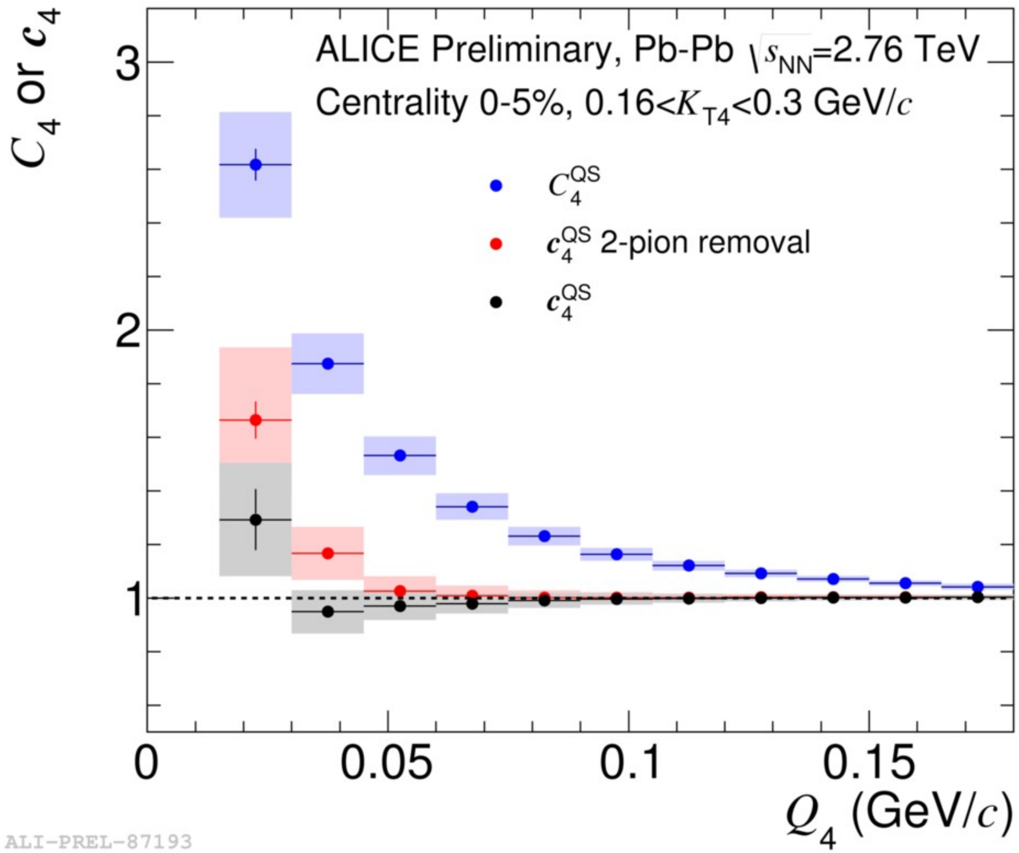
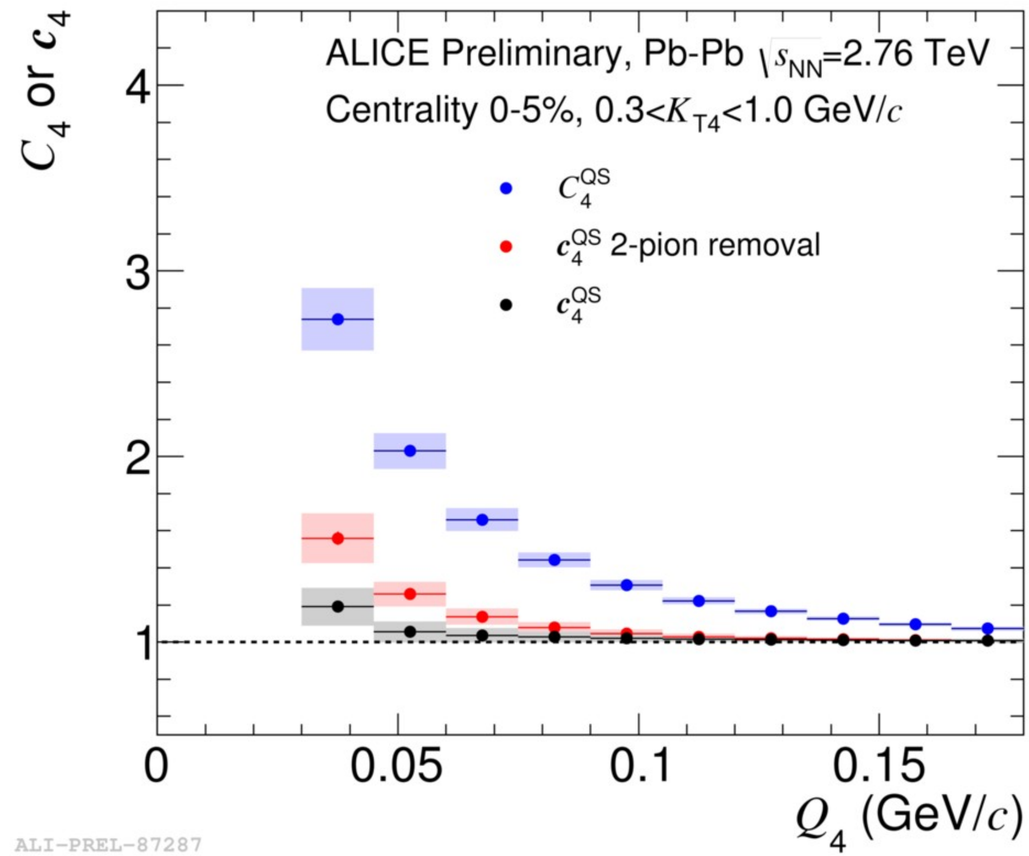
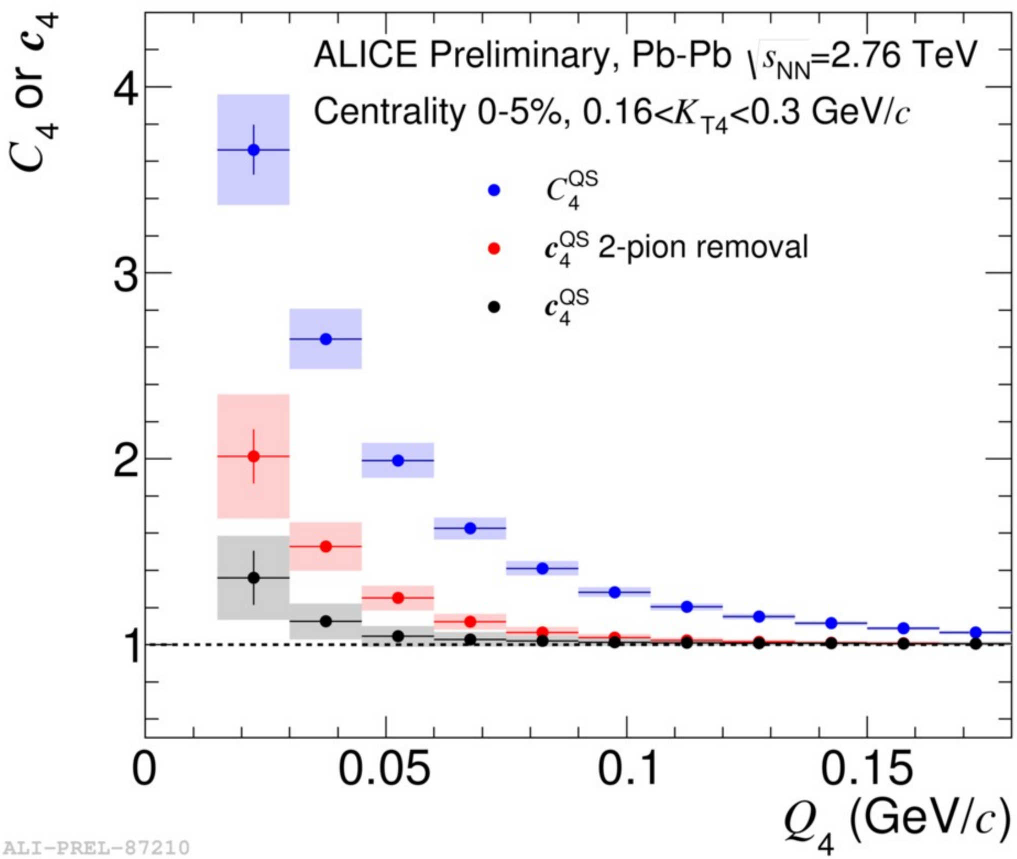
4-pion correlations: −−++

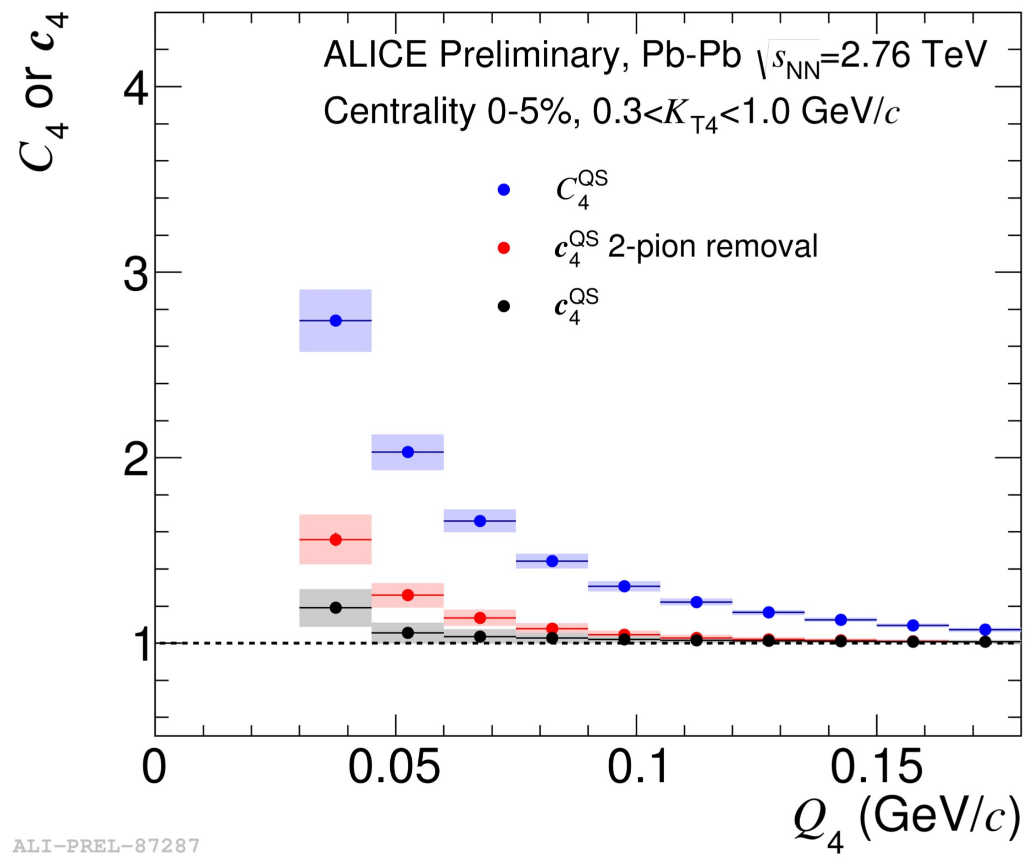




Correlation (−−++) well understood. Cumulant (black) near unity.
Systematics dominated by f_c^2 uncertainty ($0.65<f_c^2<0.75$).

4-pion correlations: −−−+



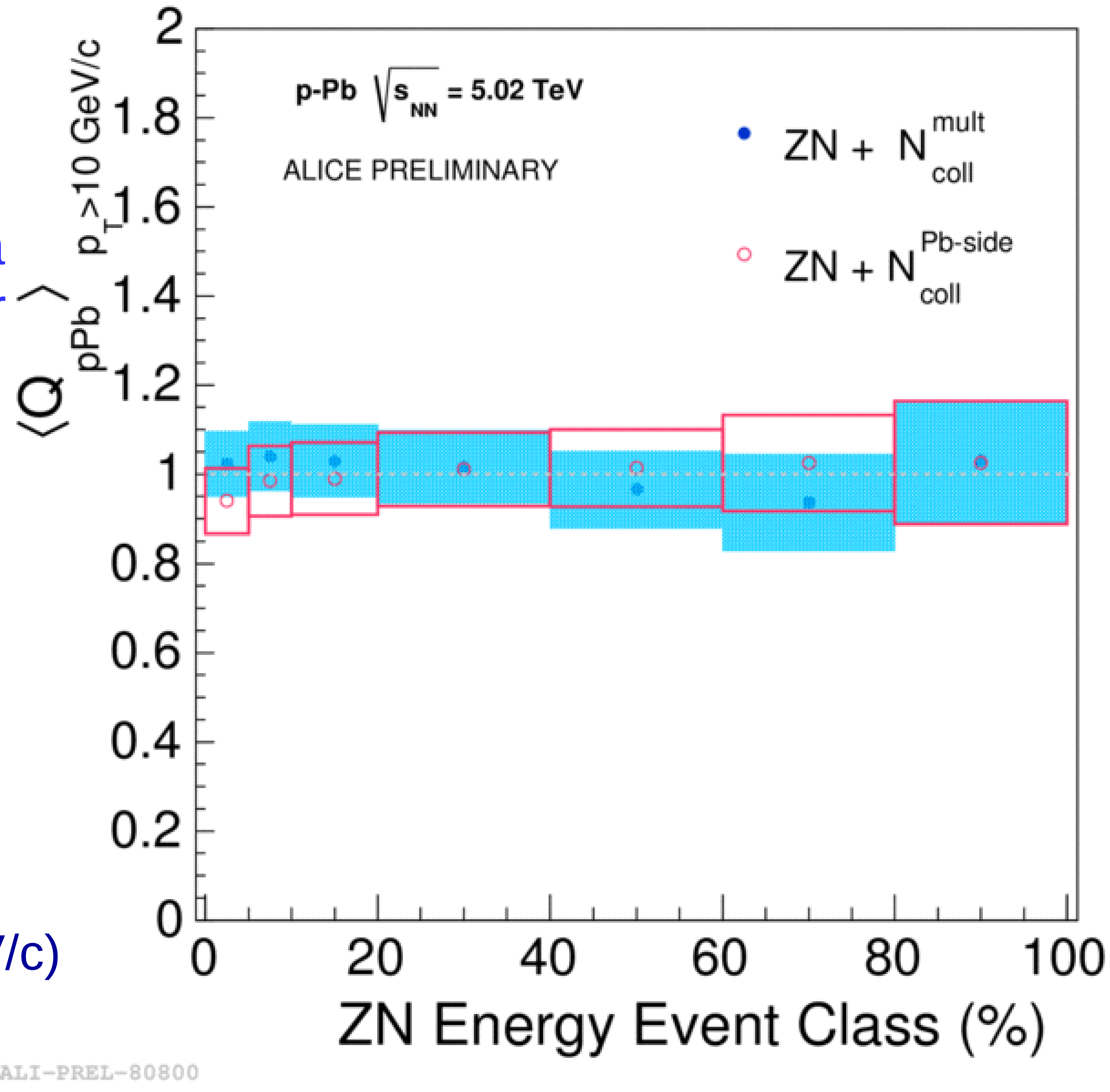


Correlation understood at the ~5% level.
Cumulant (black) shows a residue.
Residue used as a systematic for same-charge channel.
Systematics dominated by f_c^2 uncertainty ($0.65<f_c^2<0.75$).

Alternative approach using neutrons

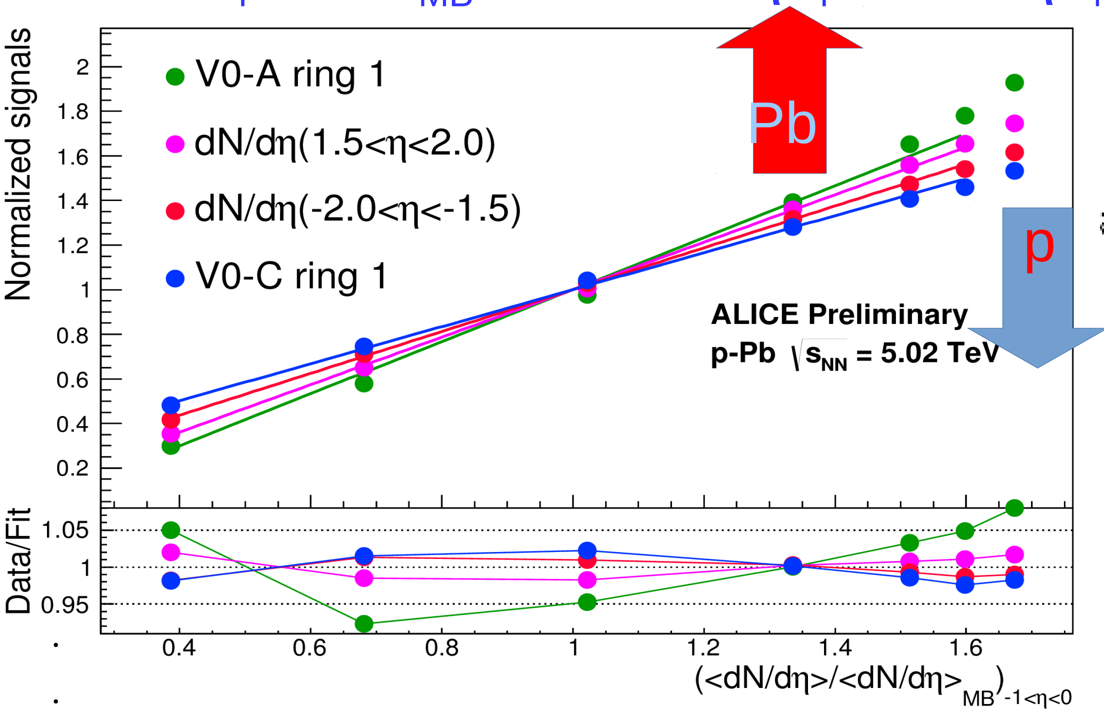
Preliminary

- Use forward neutrons to bin event classes
  - Not expected to lead to selection bias
  - But smaller dynamic range
- Obtain scale factor from data using only minbias values for Glauber $\langle N_i \rangle = \langle N_i \rangle \langle S_i \rangle / \langle S \rangle$
- Assume
  - <Npart>: mid-rapidity signal
  - <Npart>-1: forward signal
  - <Ncoll>: high-p_T yield
- Methods lead to consistent results
  - Q_{pPb} flat at high p_T (>10 GeV/c)
  - <Ncoll> within 10%

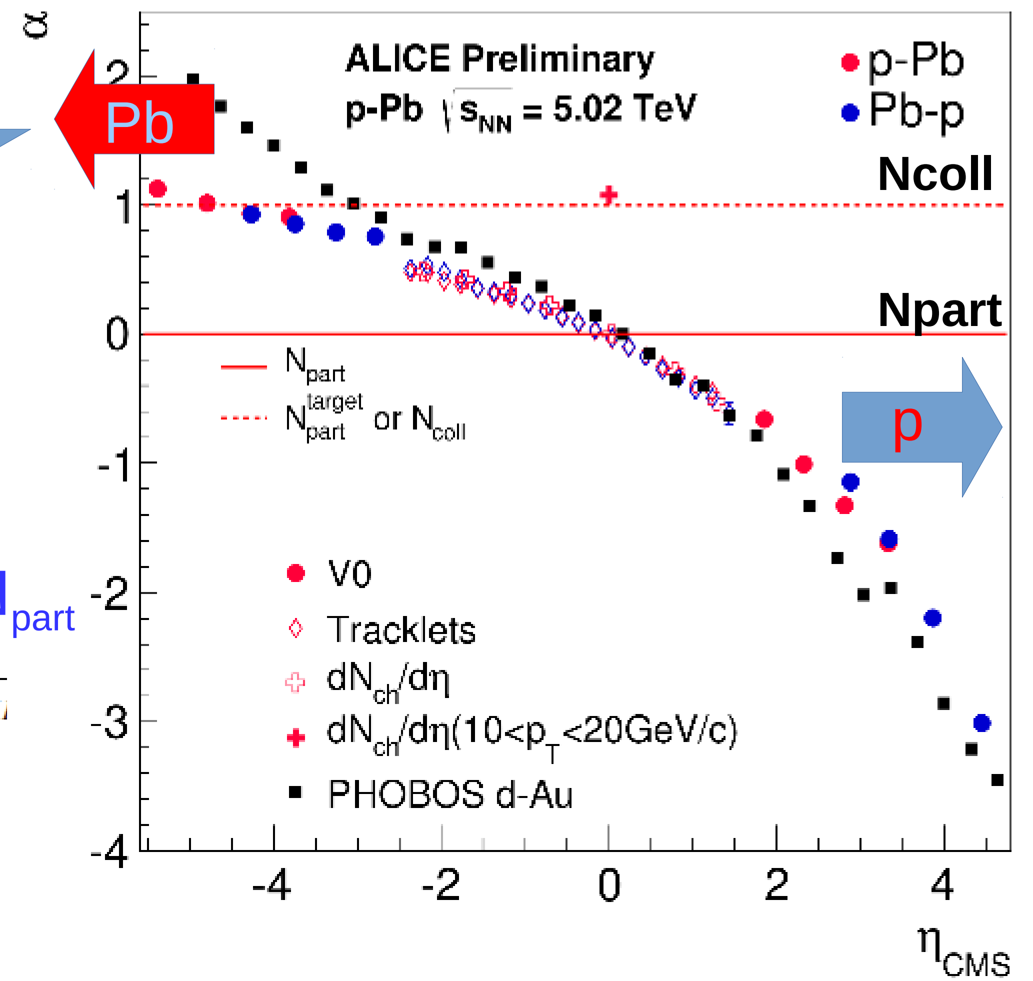


Scaling of particle production

- $\langle S\rangle_i$ / $\langle S\rangle_{MB}$ vs $\langle dN/d\eta\rangle_i/\langle dN/d\eta\rangle_{MB}(-1<\eta_{lab}<0)$



- PHOBOS d-Au: η → 1.6*η (beam rap)
- Similar dependence except A-going dir.



- Fit: assuming dN/dη scales with N_{part}

$$\frac{\langle S\rangle_i}{\langle S\rangle_{MB}} = \frac{\langle N_{part}\rangle_{MB}}{(\langle N_{part}\rangle_{MB}-\alpha)}\cdot\left(\frac{\langle dN/d\eta\rangle_i}{\langle dN/d\eta\rangle_{MB}}\right)_{-1<\eta<0} - \frac{\alpha}{(\langle N_{part}\rangle_{M}}$$

$\alpha = 0$ – perfect N_{part} scaling

$\alpha = 1$ – perfect N_{coll} (or N_{part}^{target}) scaling

α has clear meaning (N_{part} vs N_{coll} scaling)

correlation between causally disconnected observables (eg: slow neutrons - multiplicity)

→ **connection to geometry.**