QCD@Work - International Workshop on QCD Theory and Experiment
25-28 June 2018 Matera, Italy

ALICE recent results

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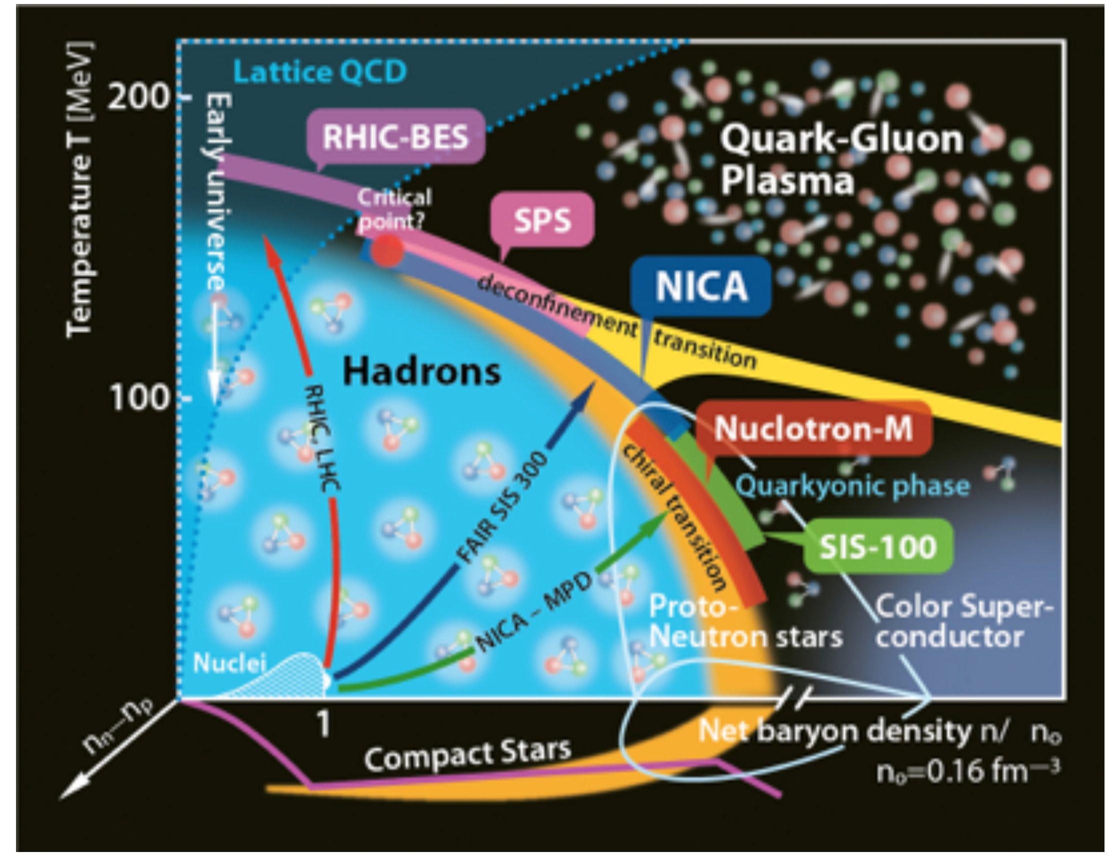
Courtesy of the Author: Michele Volpicella, Bari

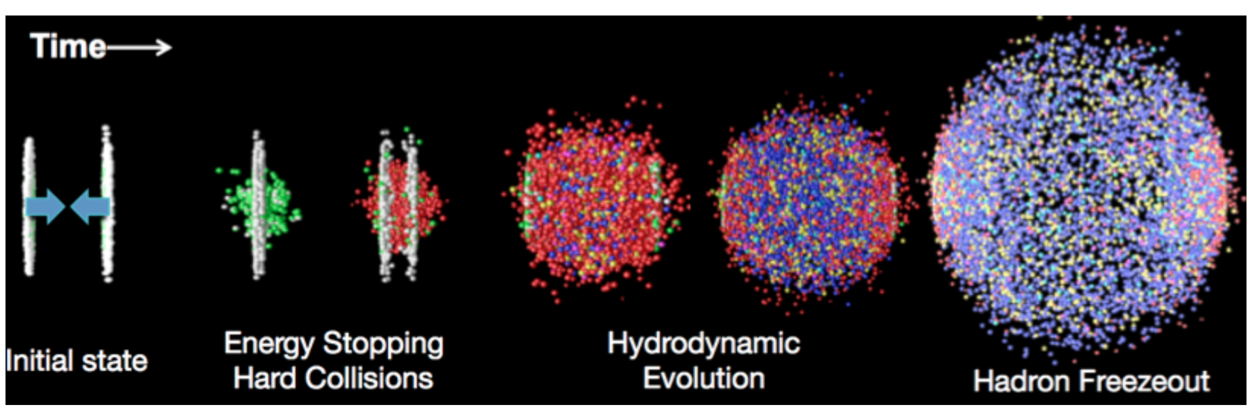
Quark Gluon Plasma in Heavy-Ion collisions

- QCD predicts a phase transition from hadron gas to a **strongly interacting, deconfined medium** (QGP).

- High energy heavy-ion collisions allow to compress a large energy in a small volume and produce a “fireball” of hot matter

- Evidence of QGP already at CERN-SPS and BNL-RHIC experiments.

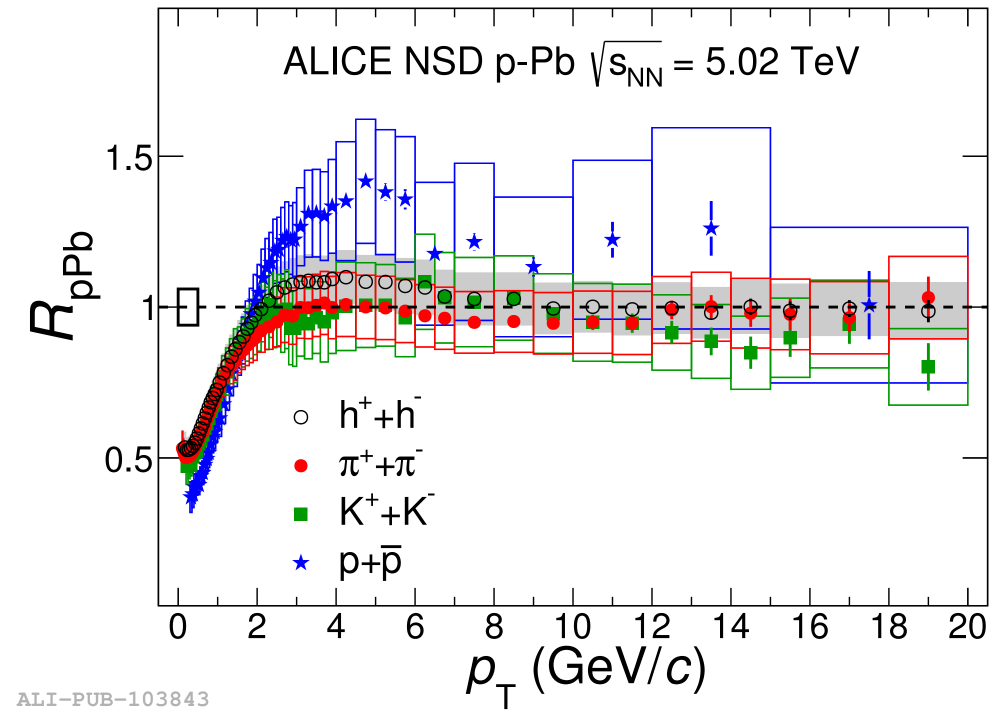




- At the LHC, precise characterization of QGP parameters:
  - degrees of freedom,
  - transport properties,
  - diffusion coefficients,
  - ...

Cold-nuclear matter effects and reference

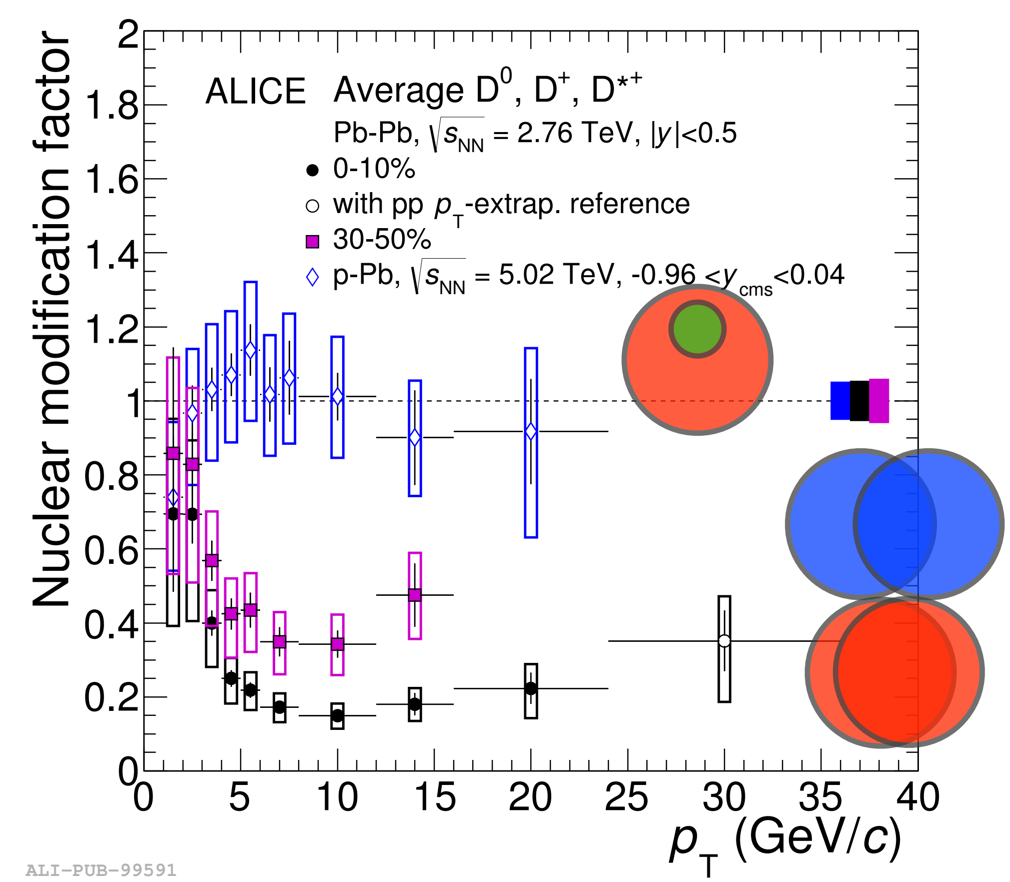
- p-A collisions used to study cold nuclear matter effects where no QGP is formed:
  - Shadowing
  - Saturation
  - Color Glass Condensate



- pp collisions used as reference system, compared with A-A collisions:
  - Nuclear modification factor (R_{AA})

$$R_{AA}(p_T) = \frac{1}{< N_{coll} >} \times \frac{d^2N_{AA}/dp_T d\eta}{d^2N_{pp}/dp_T d\eta}$$

- $R_{AA} = 1 \rightarrow$ A-A collisions "just" a superimposition of many pp collisions



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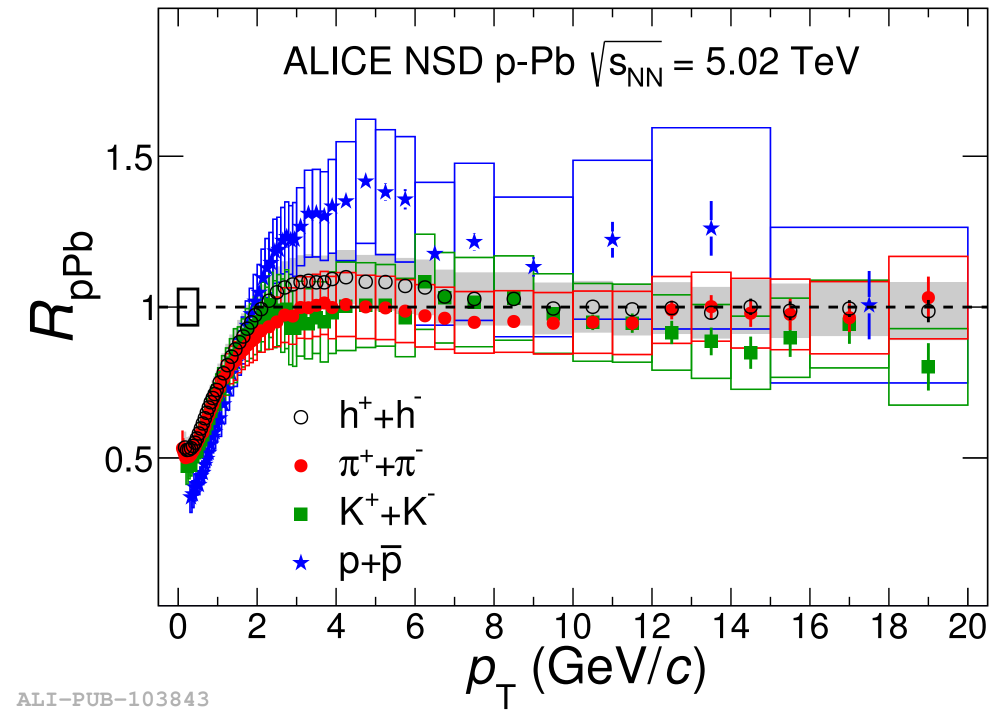

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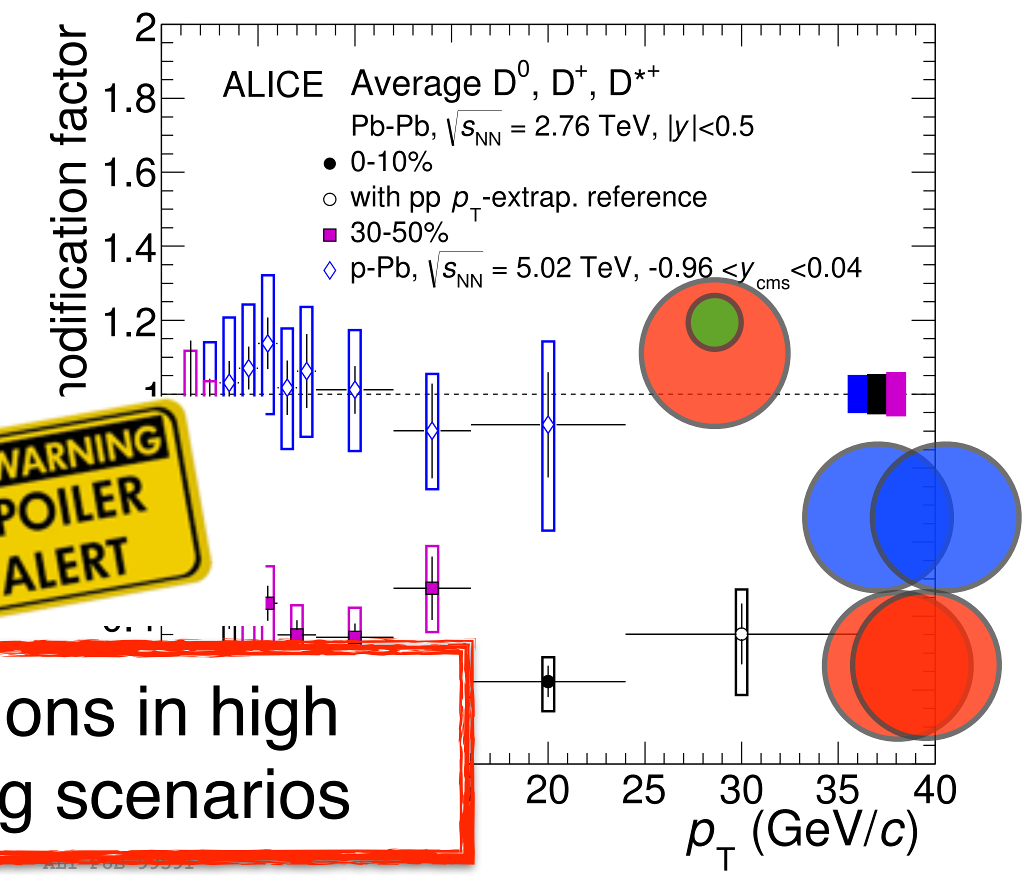
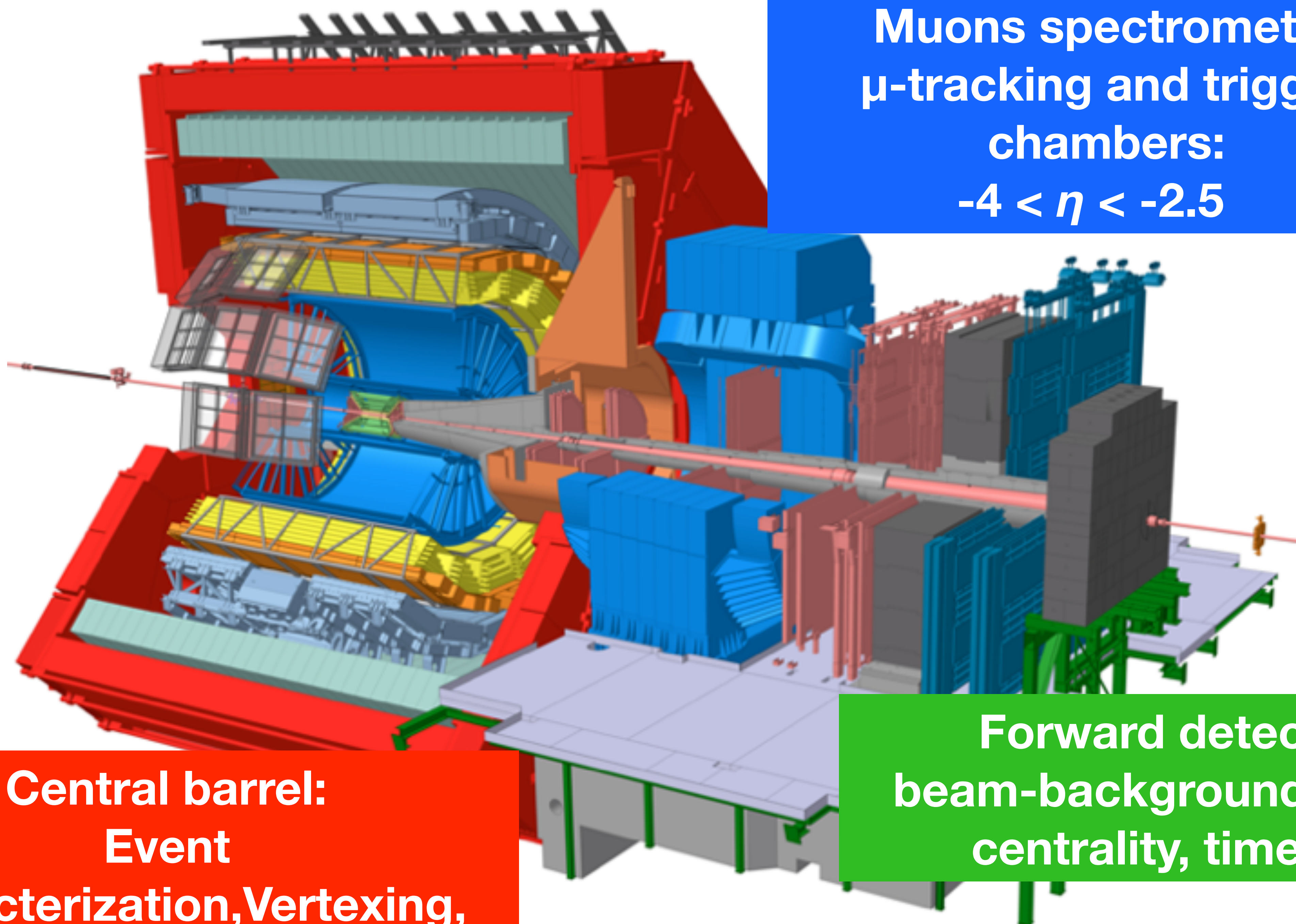


But observation of long-range azimuthal correlations in high multiplicity p-Pb collisions opened new interesting scenarios

A Large Ion Collider Experiment (ALICE)



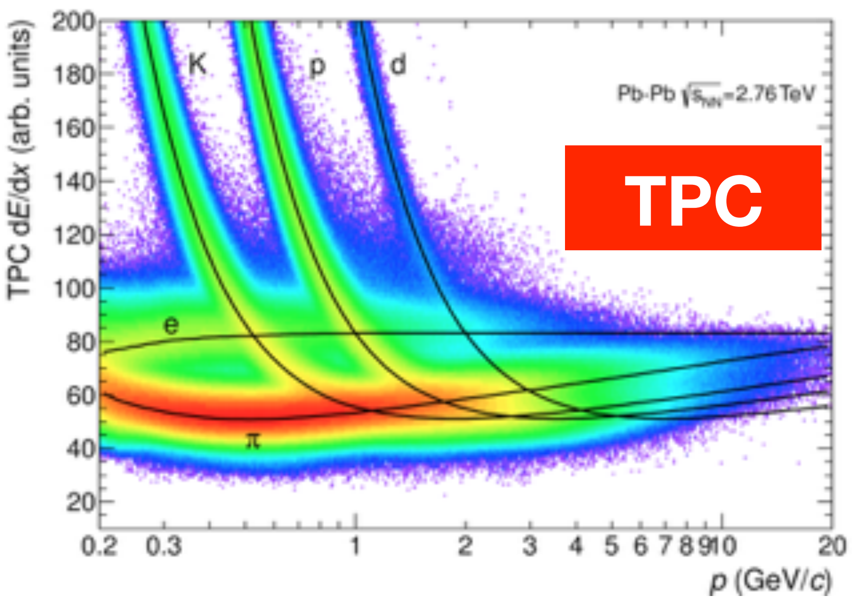
Muons spectrometer μ-tracking and trigger chambers:
$-4 < \eta < -2.5$

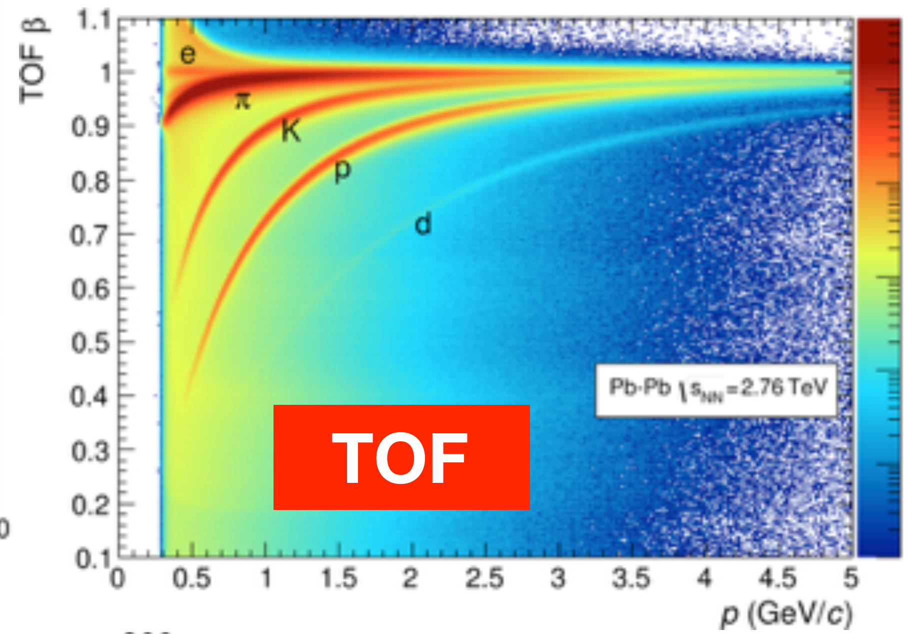
Central barrel:
Event characterization,Vertexing, Tracking, PID.
$|\eta| < 0.9$

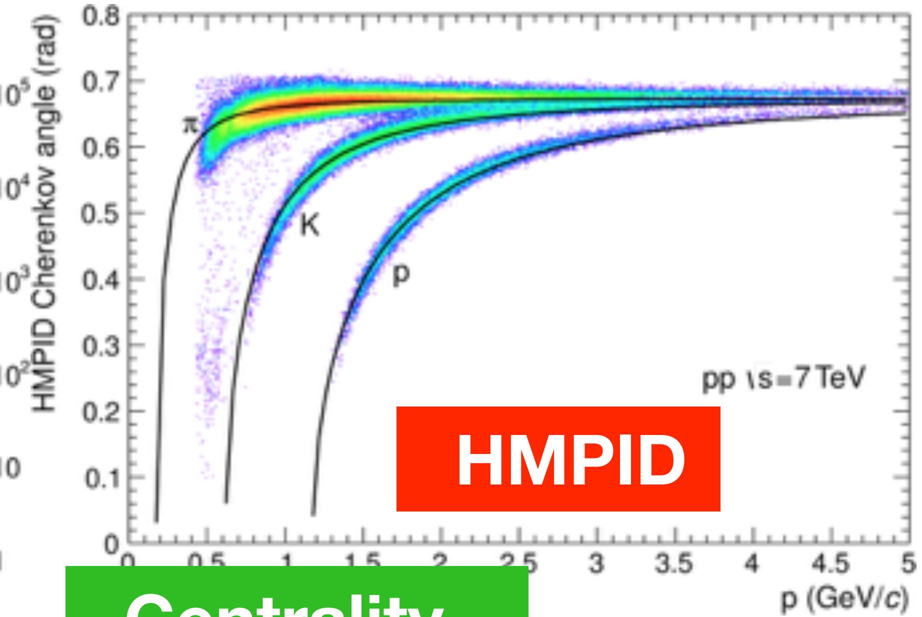
Forward detectors:
beam-background, trigger, centrality, time zero

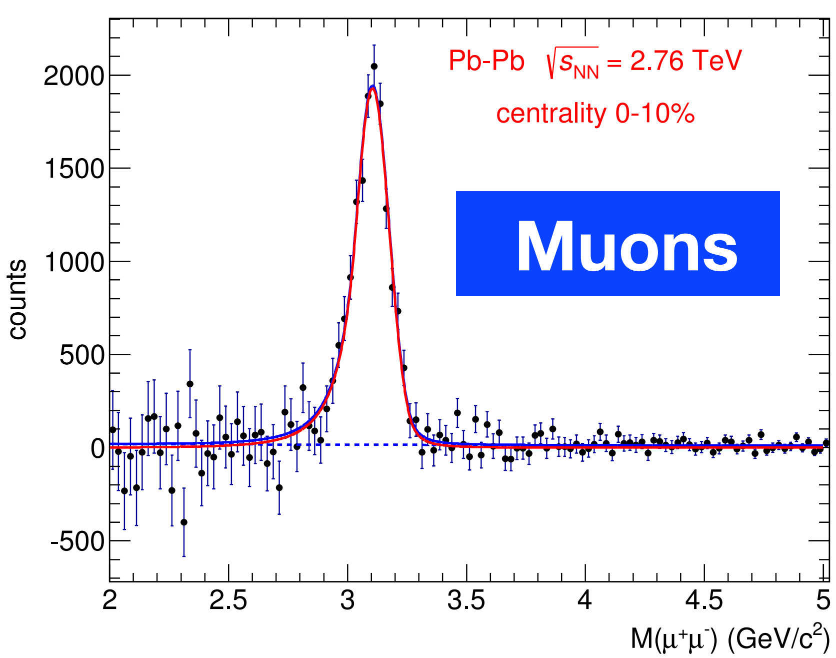
JINST, 3 (2008), S08002
Phys Rev Lett, 106 (2011), 032301
Int. J. Mod. Phys. A 29 (2014) 1430044

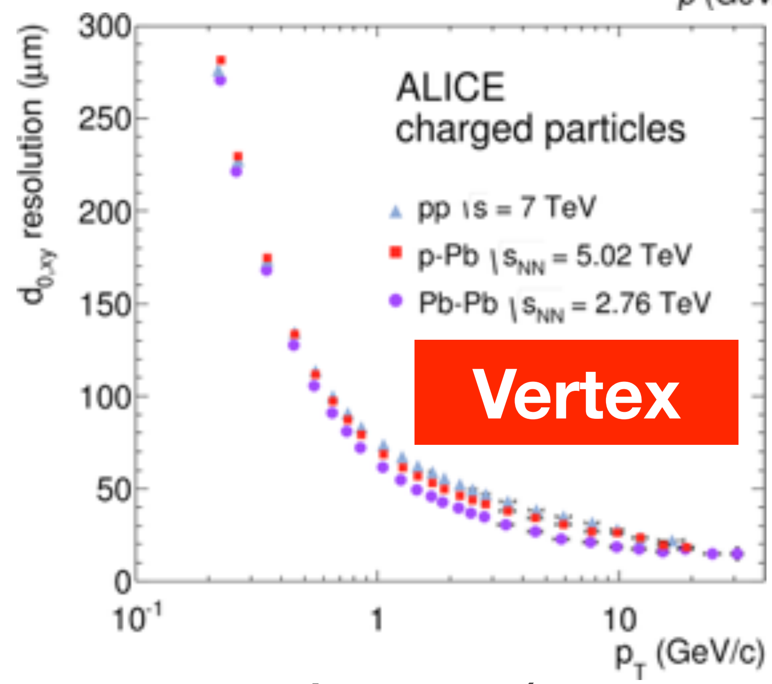
A Large Ion Collider Experiment (ALICE)

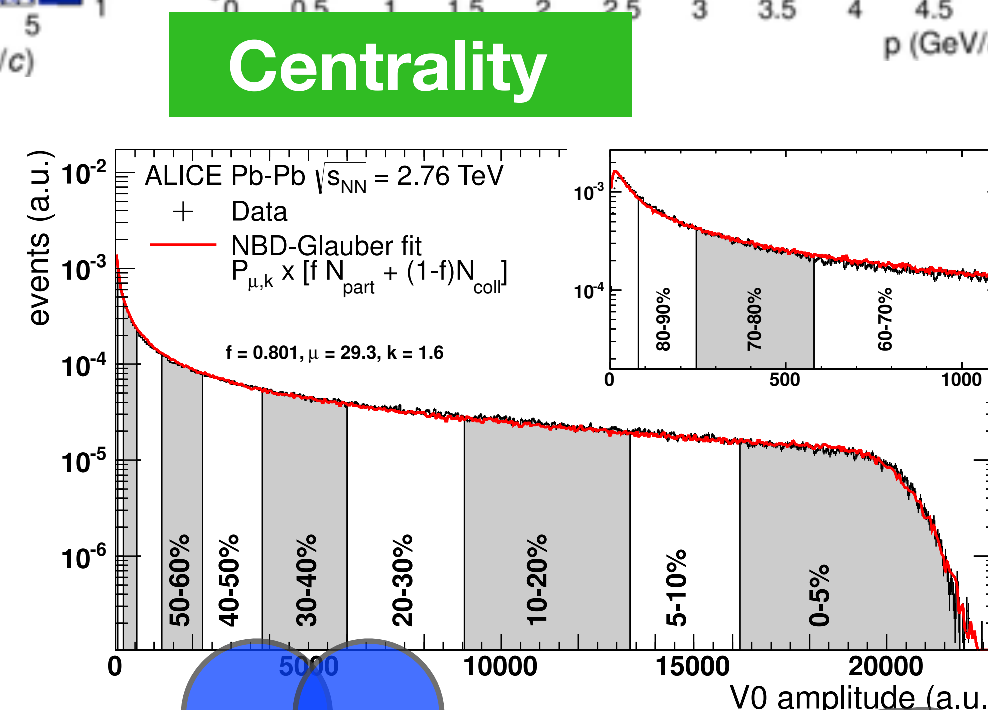










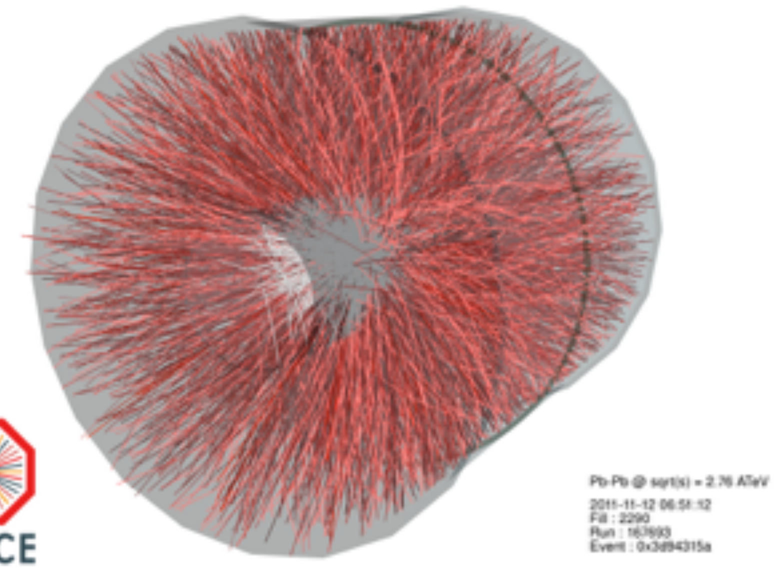


- Efficient tracking down to very low p_T (p_T > 150 MeV)
- Many techniques for particle identification (⟨dE/dx⟩, TOF, Cherenkov, TRD)
- Excellent vertexing capabilities

Int. J. Mod. Phys. A 29 (2014) 1430044

ALICE Data samples

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010-2011	2.76	~75 μb^{-1}
	2015	5.02	~250 μb^{-1}
	by end of 2018	*5.02*	*~1 nb^{-1}*
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013	5.02	~15 nb^{-1}
	2016	5.02, 8.16	~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013	0.9, 2.76, 7, 8	~200 μb^{-1}, ~100 nb^{-1}, ~1.5 pb^{-1}, ~2.5 pb^{-1}
	2015,2017	5.02	~1.3 pb^{-1}
	2015-2017	13	~25 pb^{-1}



- LHC Run2 data analysis in full swing
- Significant increase in integral luminosity in pp, p-Pb and Pb-Pb collisions → more precise measurements also for rare probes.
- Pb-Pb run at the end of 2018 with expected L_{int} ~1nb^{-1}

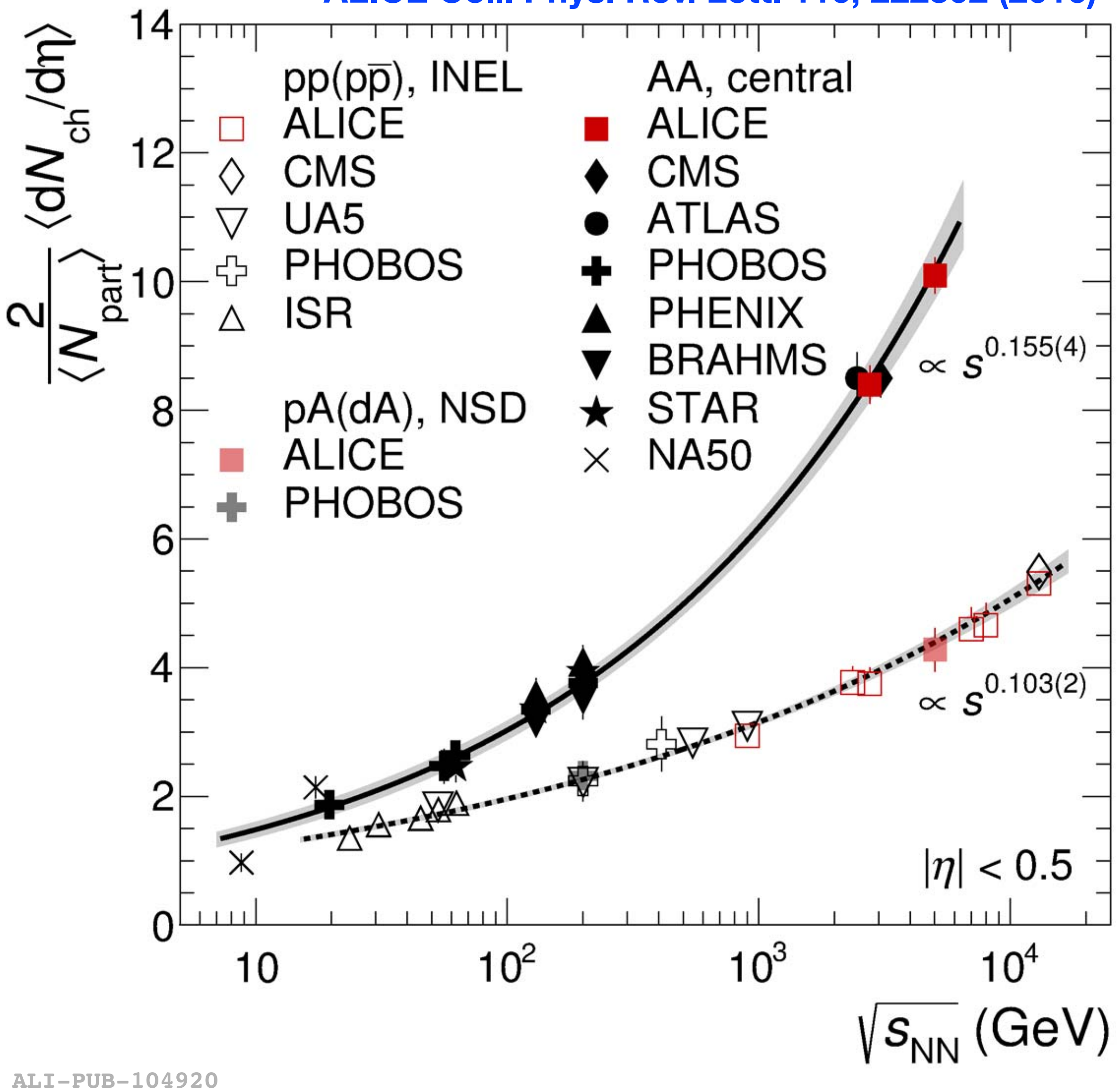
Soft probes

- Study of particle productions at very low-p_T
  - produced at QGP freeze-out.
  - address global properties of the medium, anisotropies and fluctuations.

Particle multiplicity density

- High energy density (ε > 0.5-1 GeV/fm^3) necessary condition for deconfinement
- ε connected to the dN/dy via Bjorken estimate **Bjorken, PRD 27 (1983) 140**
  - rapid evolution of the system: τ ~ 1 fm/c upper limit for "thermalisation"

ALICE Coll. Phys. Rev. Lett. 116, 222302 (2016)



$$\langle\epsilon\rangle(\tau) = \frac{\langle m_{\mathrm{T}}\rangle}{\tau\pi R^2}\frac{\mathrm{d}N_{ch}}{\mathrm{d}\eta}$$

AGS (Au-Au): $\sqrt{s_{\mathrm{NN}}}$ = 5 GeV ⇒ ε~1.5 GeV/fm^3

SPS (Pb-Pb): $\sqrt{s_{\mathrm{NN}}}$ = 17 GeV ⇒ ε~2.9 GeV/fm^3

RHIC(Au-Au): $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV ⇒ ε~5.4 GeV/fm^3

LHC (Pb-Pb): $\sqrt{s_{\mathrm{NN}}}$ = 5020 GeV ⇒ ε~18 GeV/fm^3

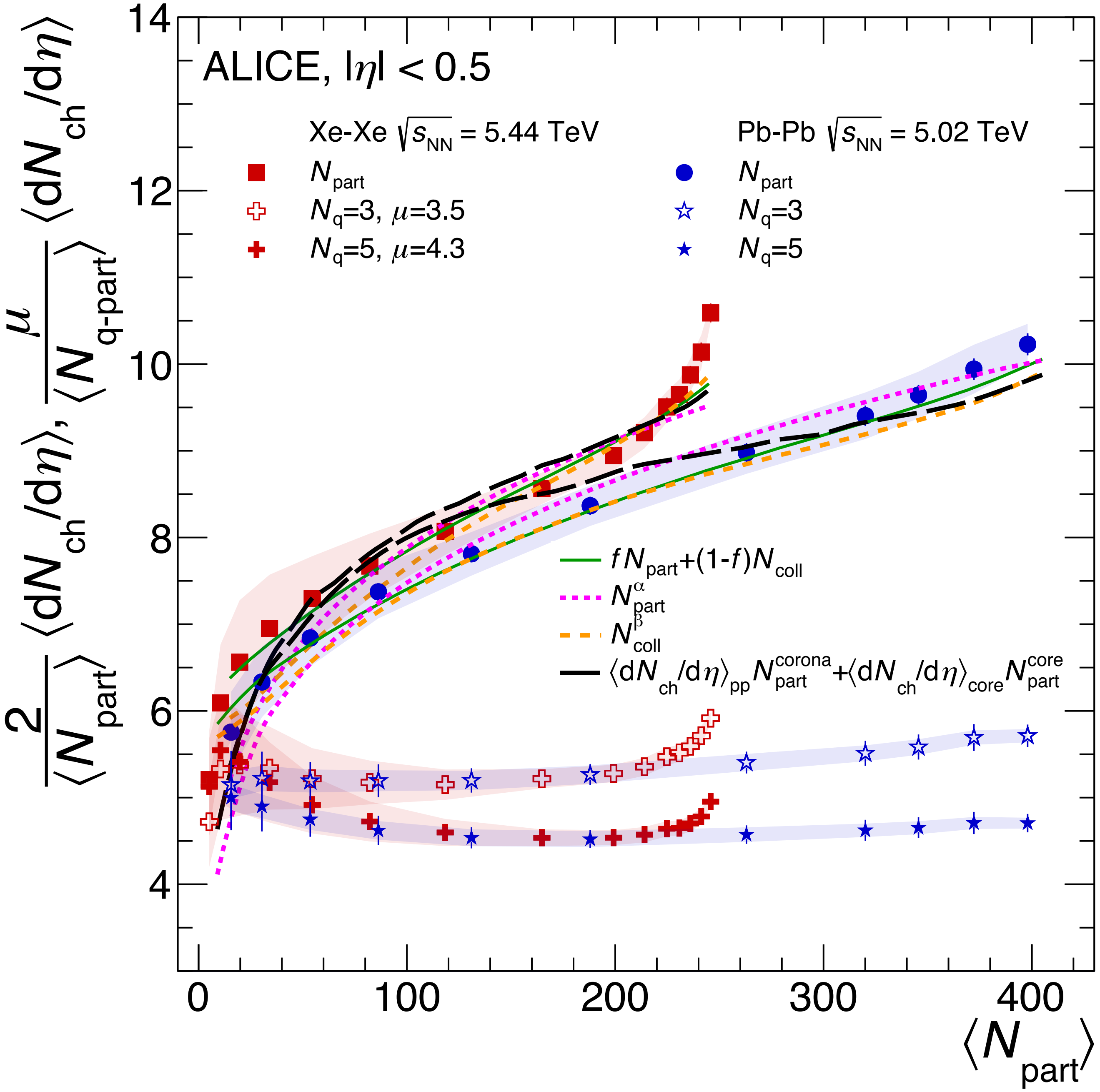
Particle multiplicity vs N_{part}

- ⟨dN/dη⟩ scaling with N_{part} violated
  - already known in **Pb-Pb collisions**
  - confirmed with **Xe-Xe data**

- but well described by combination of N_{part} and N_{coll} , participant quark scaling $N_{q\text{-}part}$ and theoretical model

- Central Xe-Xe collisions produce more particles than mid-central Pb-Pb collisions at the same N_{part}
- Multiplicity fluctuations ?

ALICE Coll. arXiv:1805.04432

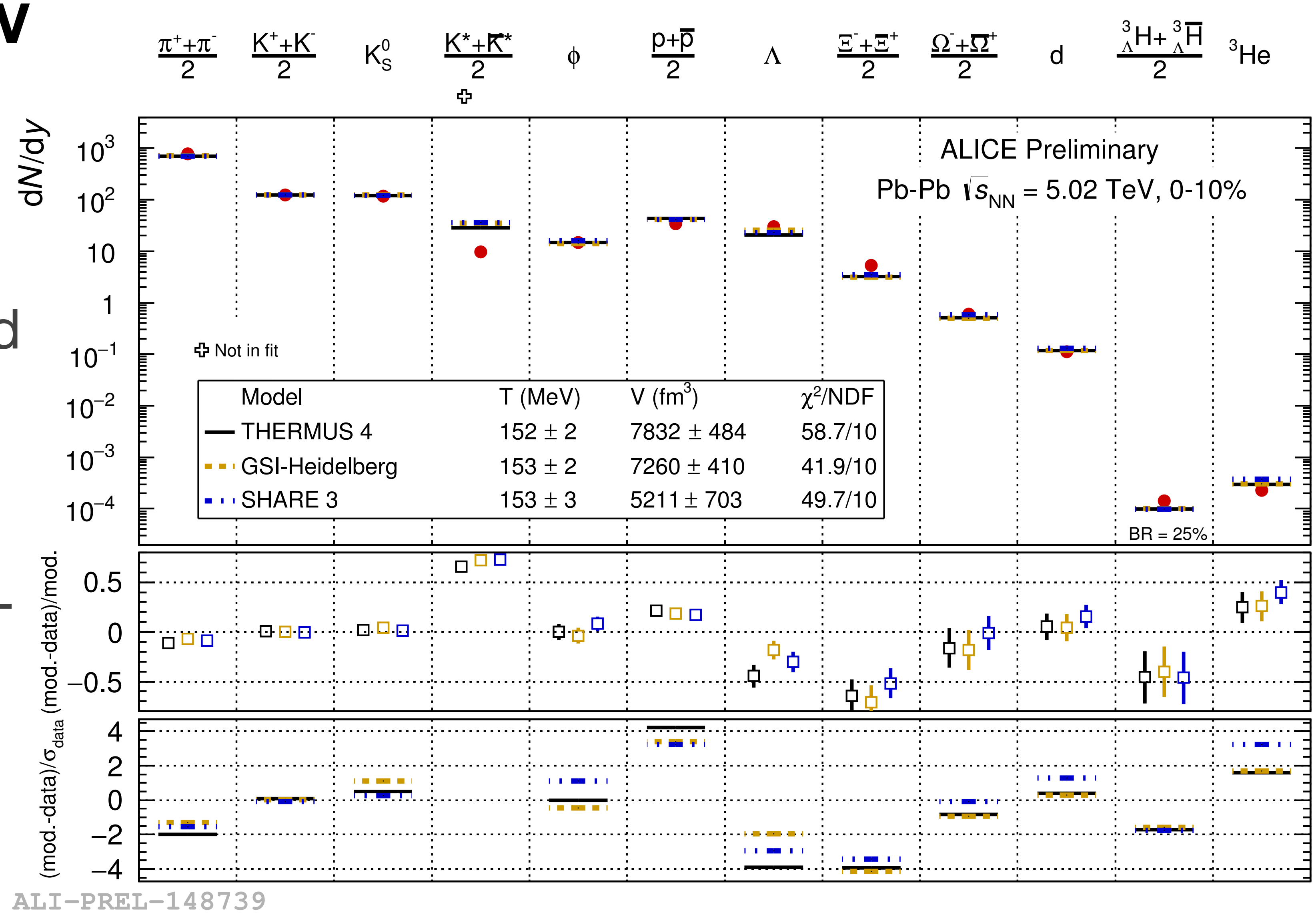


Particle Ratios

- Yields of light flavor hadrons fixed at chemical freeze-out
  - qualitatively described by **equilibrium thermal/statistical models over 7 orders of magnitude**
  - related to temperature (T_{ch}), net-baryonic content

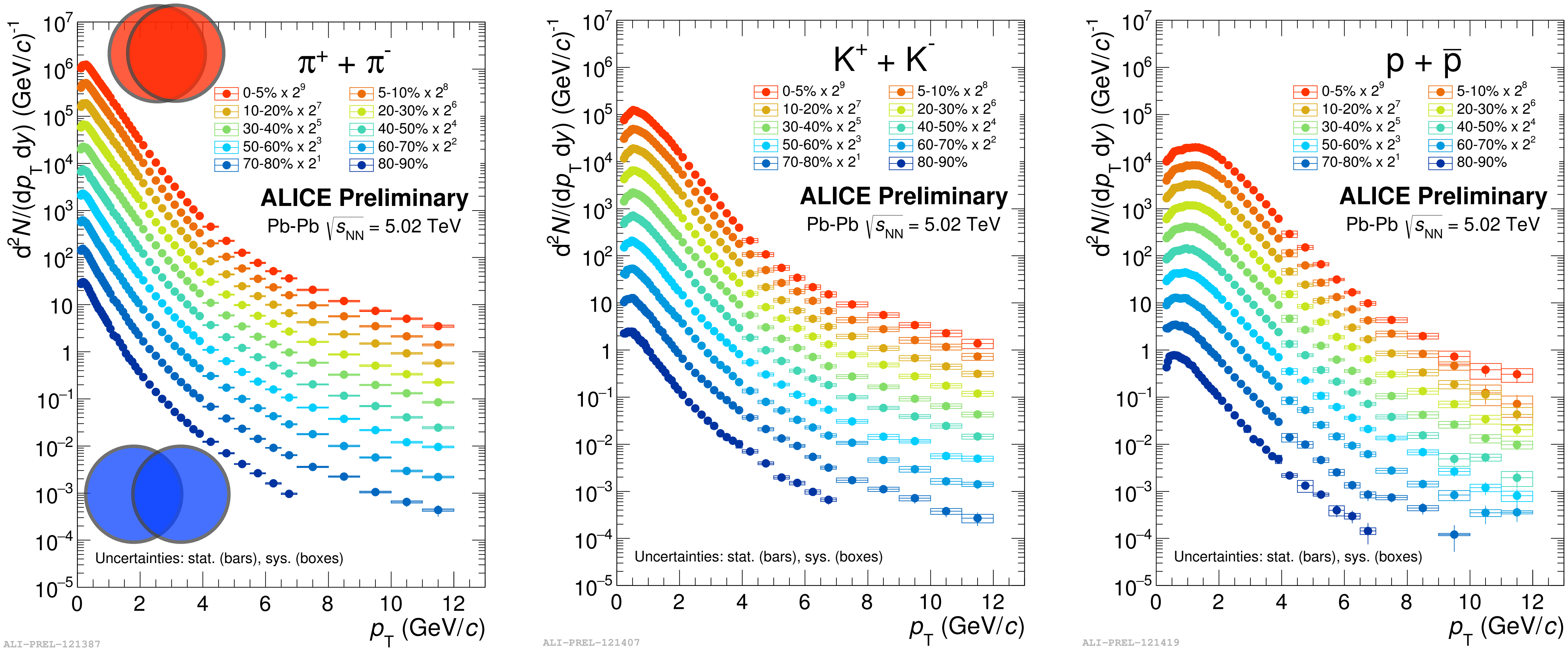
Lower χ^2 for T_{ch} ~ 153 MeV

- Small tensions protons yield
  - Re-scattering in hadronic phase
  - Non-equilibrium effects
  - Flavour dependent freeze-out



Radial Flow

- Pressure gradient in the transverse plane leads to a **collective radial expansion** → “explosive source”
  - transverse mass scaling associated to “thermal source” broken
  - mass dependent hardening of p_T spectrum



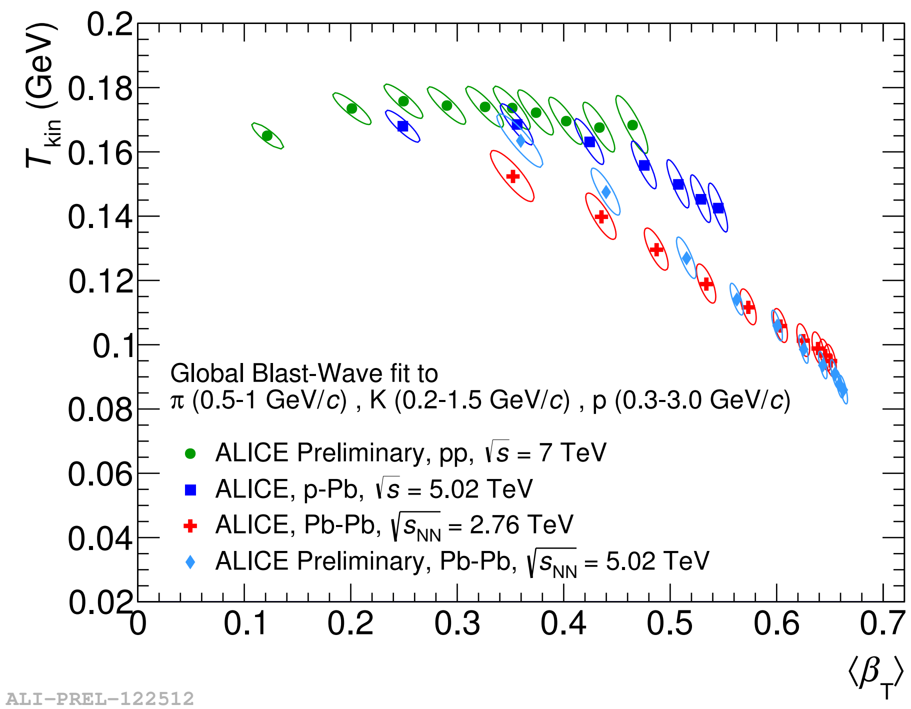
- Observations compatible with radial flow effects

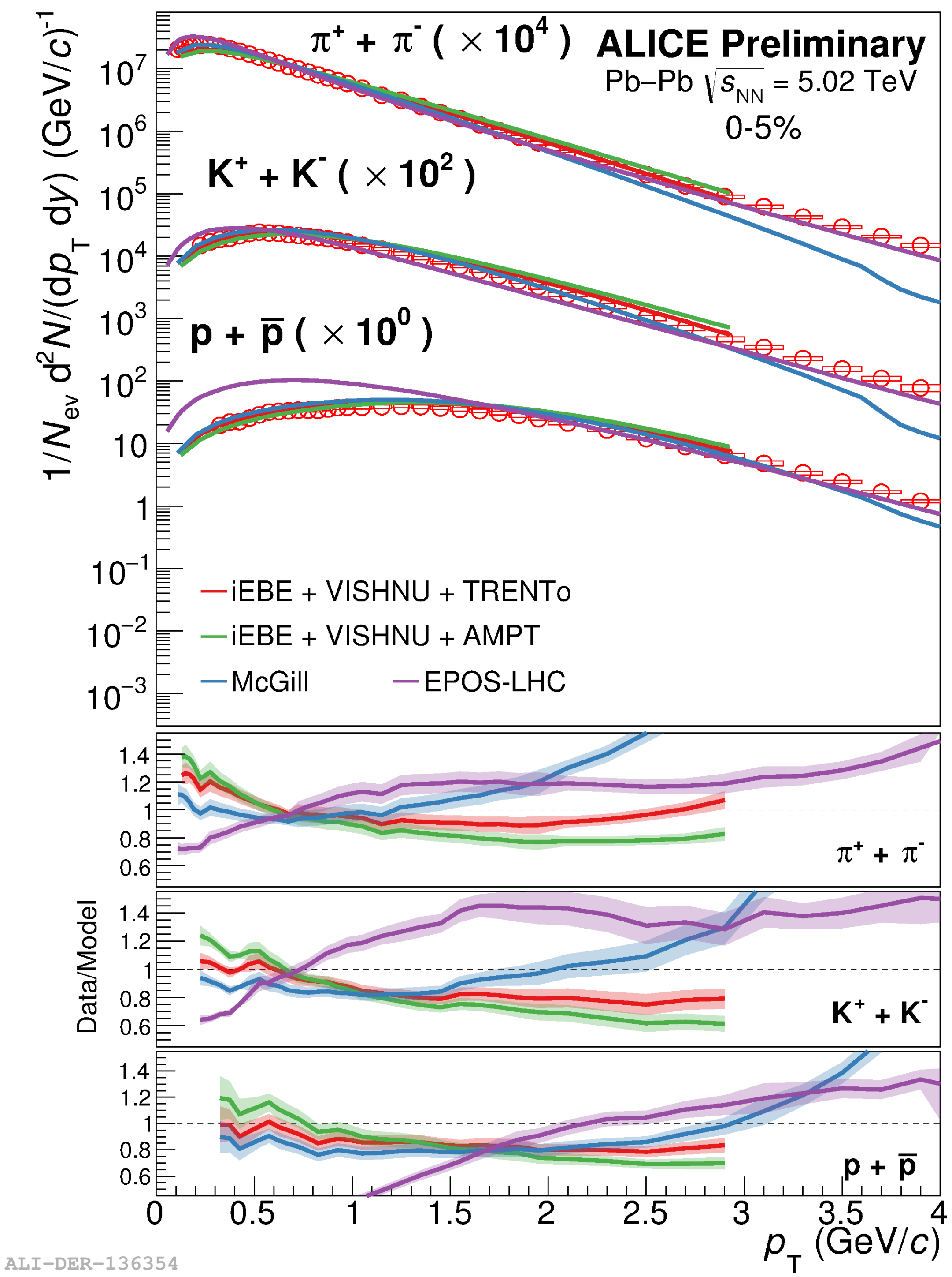
Radial Flow

- Freeze out surface can be modeled with:
  - Kinetic freeze out temperature (T_{kin})
  - Radial flow velocity $\langle \beta_T \rangle$

- Hydrodynamical models work quite well to reproduce the data.

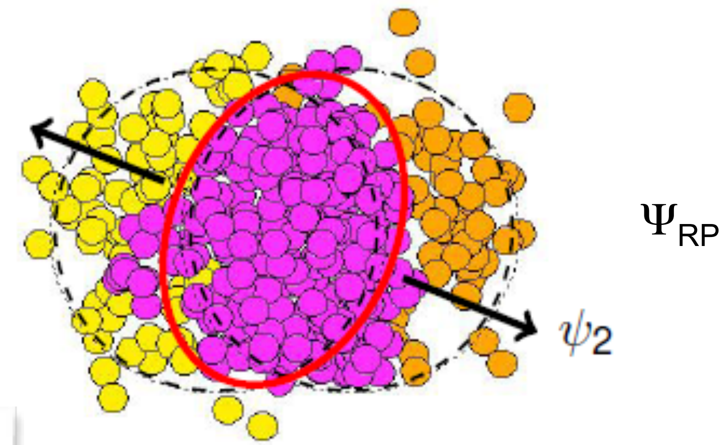
- Blast Wave fit to p_T particle spectra
  - $\boldsymbol{T_{kin}}$ **~ 90 MeV**
  - $\boldsymbol{\langle \beta_T \rangle}$ **~ 0.65**





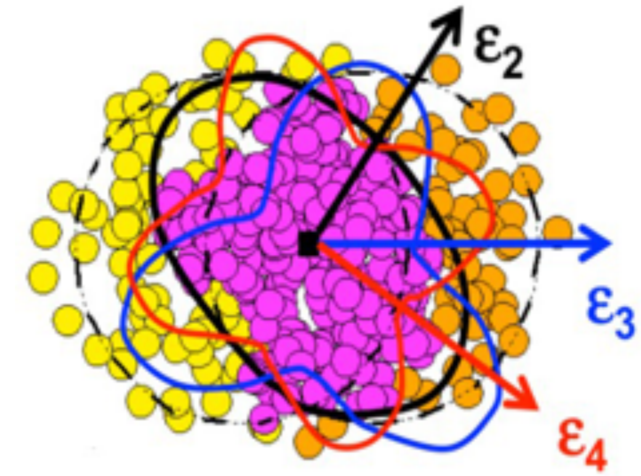
Elliptic flow

- Initial spatial anisotropy generates pressure gradients that induce particle momentum anisotropy
- Fourier expansion of particle production vs azimuthal angle.



$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2(p_T)\cos[2(\varphi - \Psi_2)] + ...)$$

Elliptic flow



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- Higher order harmonics induced by fluctuations of the collision geometry (v_2, v_3, v_4, …)

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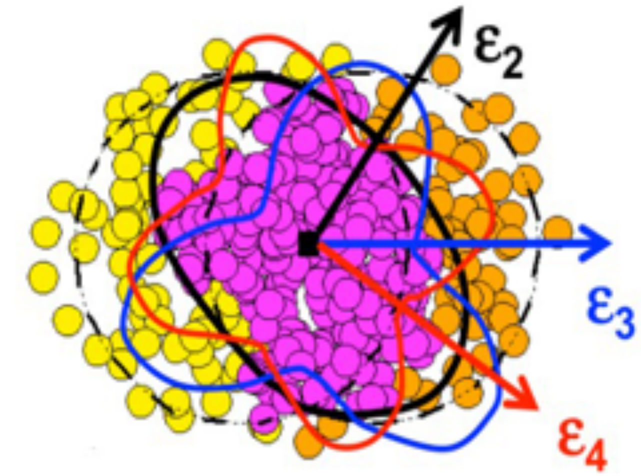
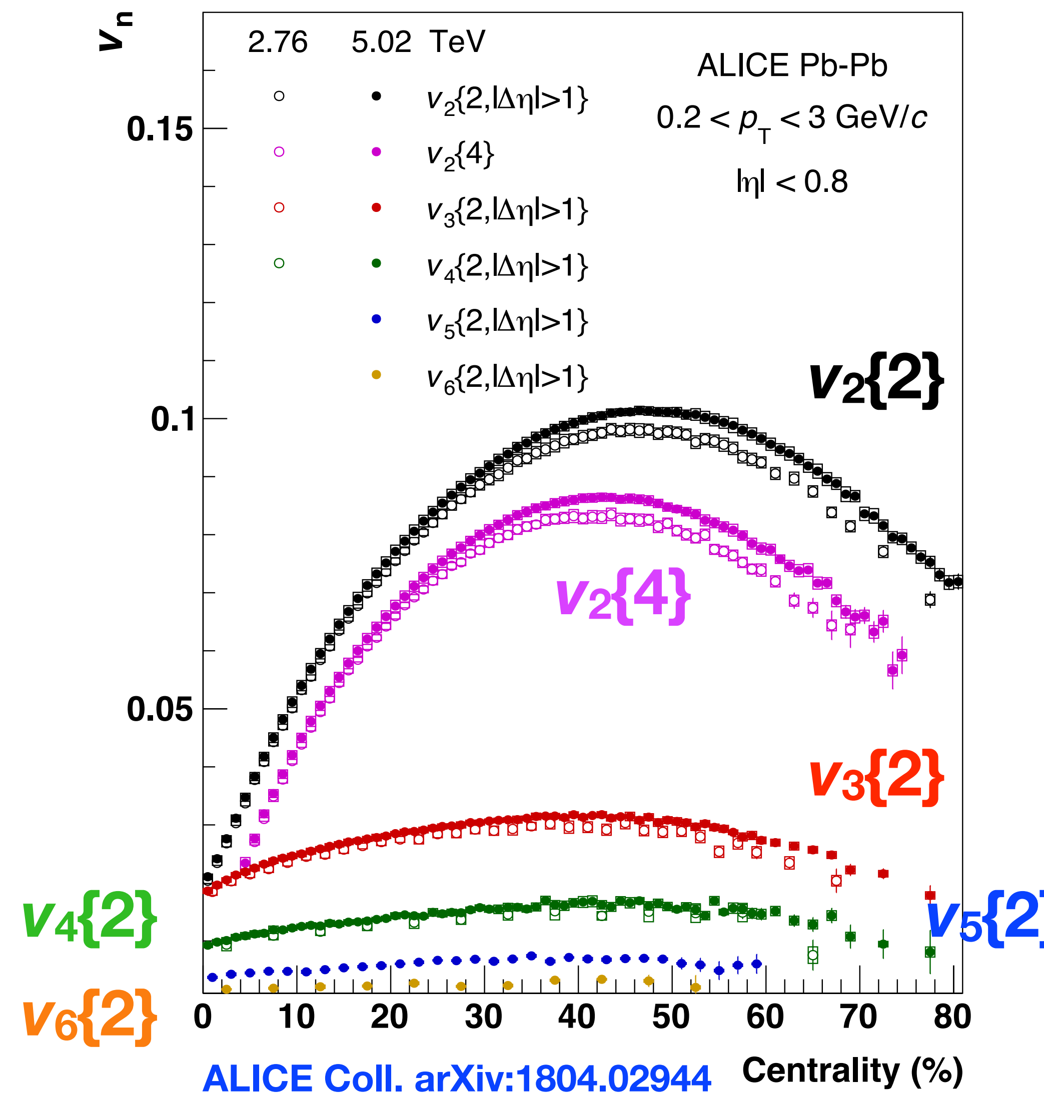


- Not only large v_2 but also large value of higher harmonics
- In central events initial state fluctuations dominate the "total flow" contribution
- Peripheral events dominated by v_2



ALICE Coll. arXiv:1804.02944

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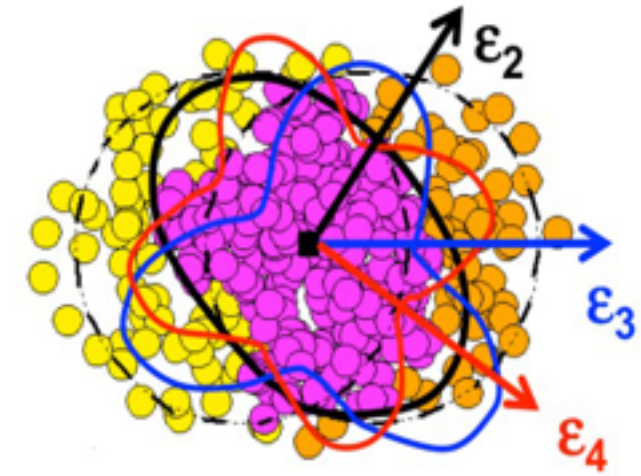
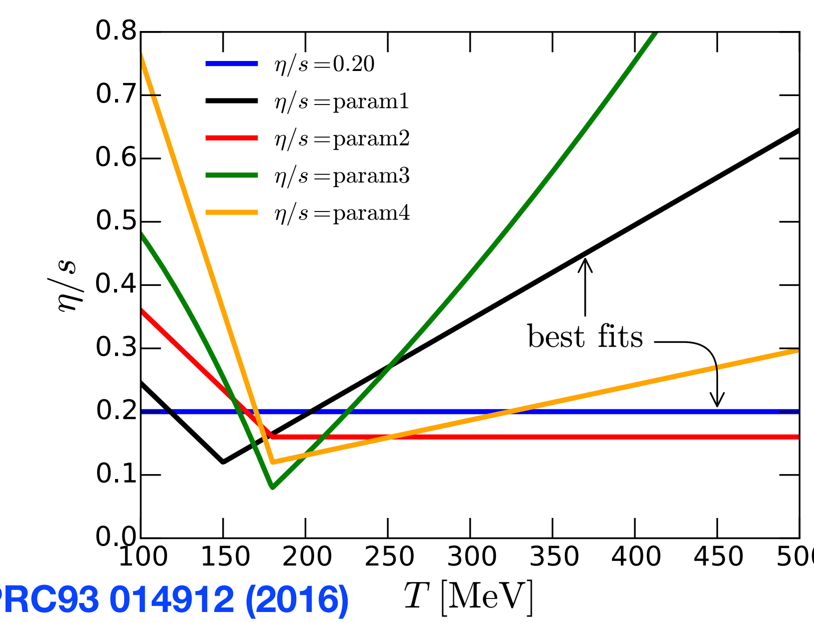
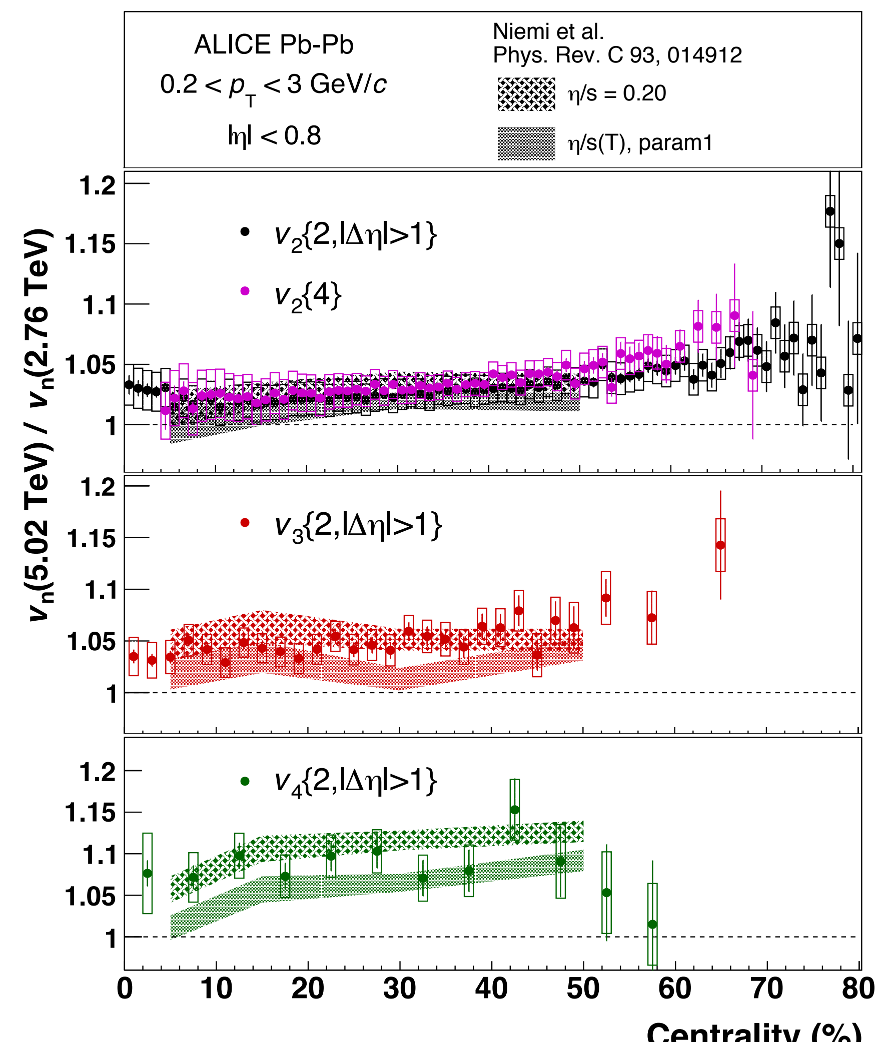


- ~ 5% between $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV
- Precision of the data start to constraint different trend for ***η/s(T)***
- ***η/s(T)* =0.2** favored by the data



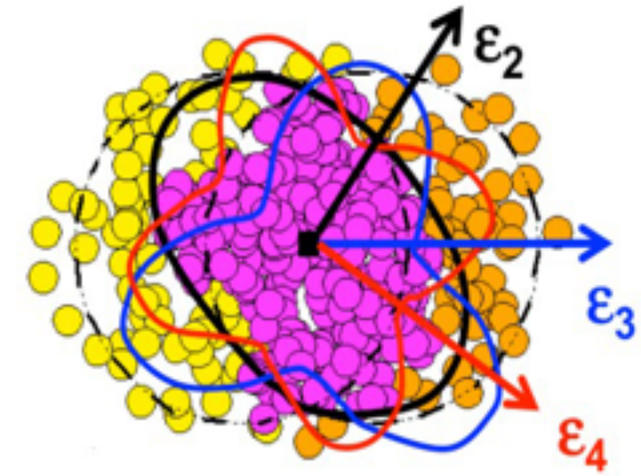
H.Niemi et al. PRC93 014912 (2016)



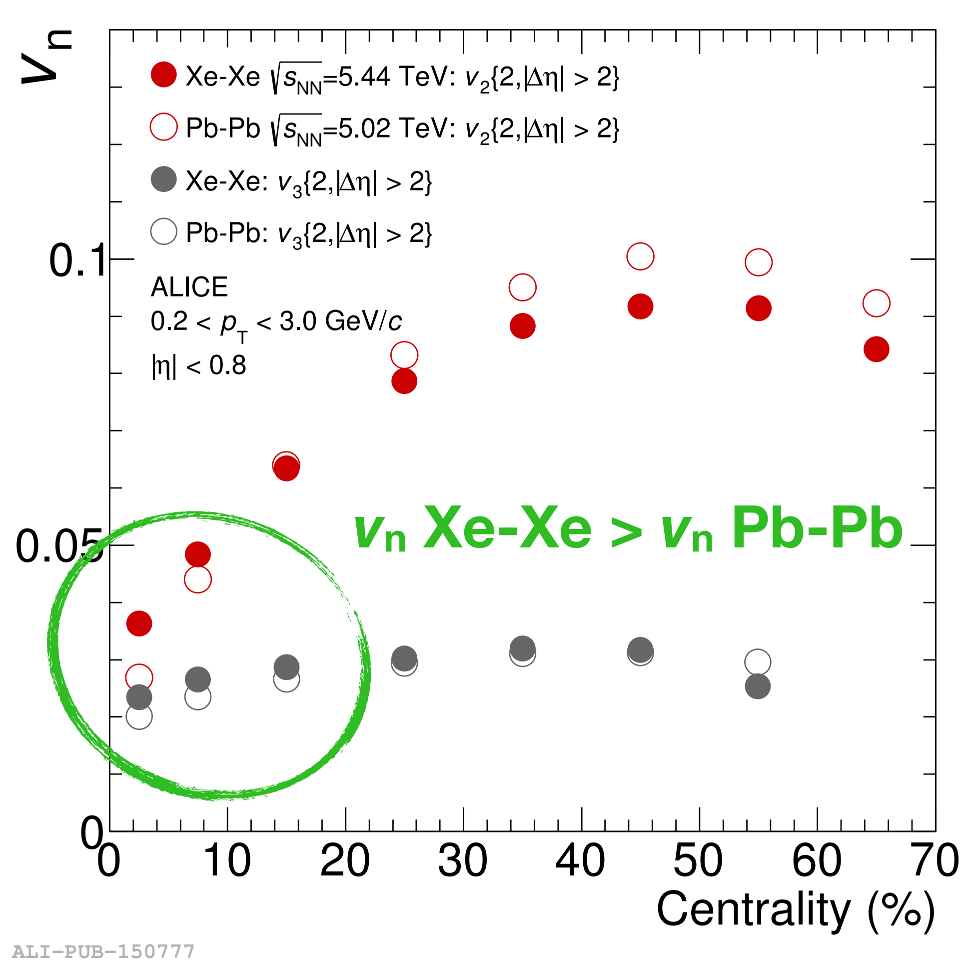
ALICE Coll. arXiv:1804.02944

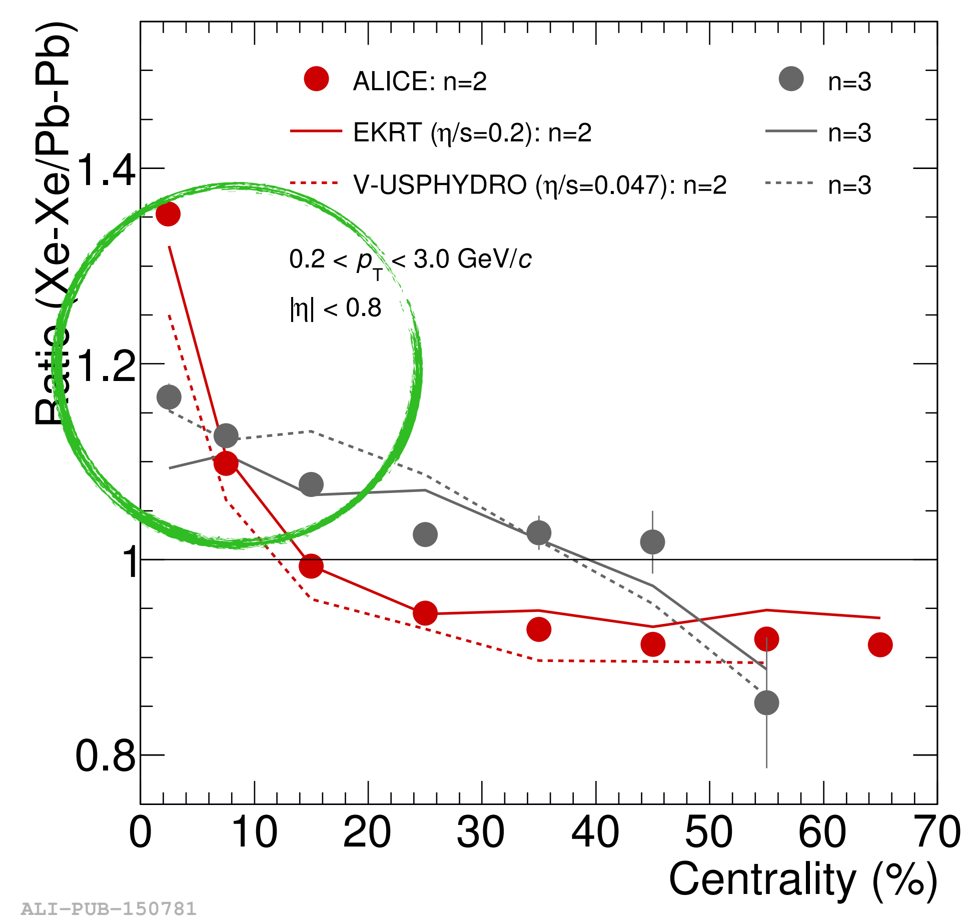
Elliptic flow in Xe-Xe

- Similar values of v_2 and v_3 in Xe-Xe collisions as in Pb-Pb ones
  - Larger asymmetries in **central Xe-Xe** collisions



ALICE Coll. arXiv:1805.01832





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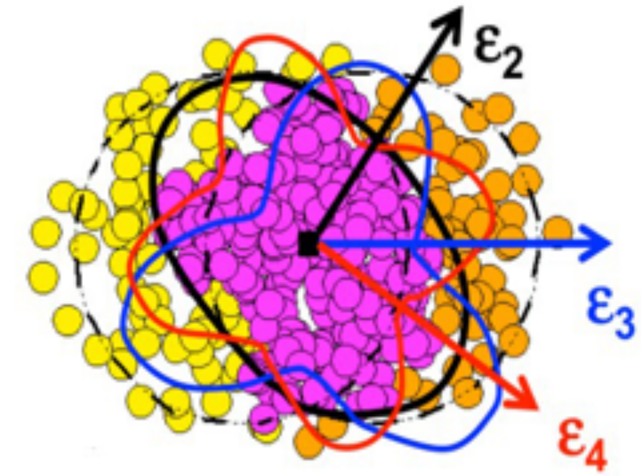
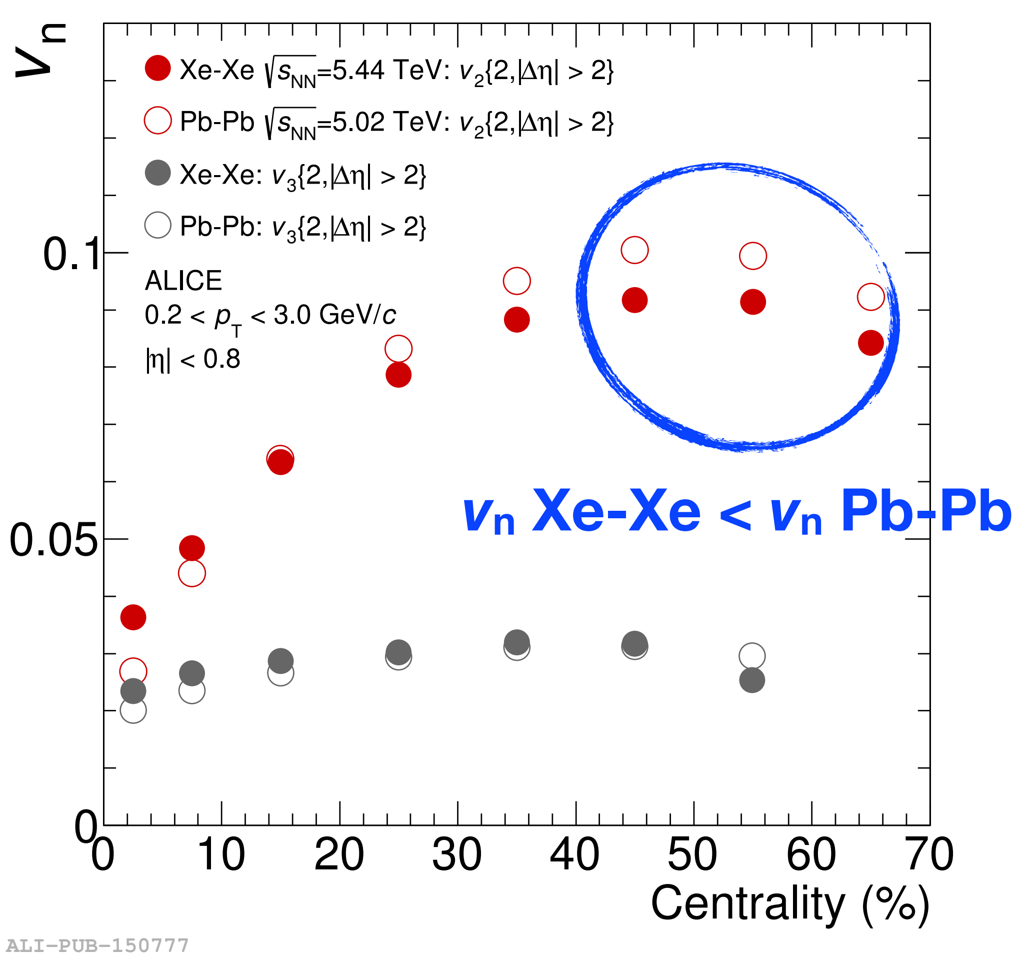
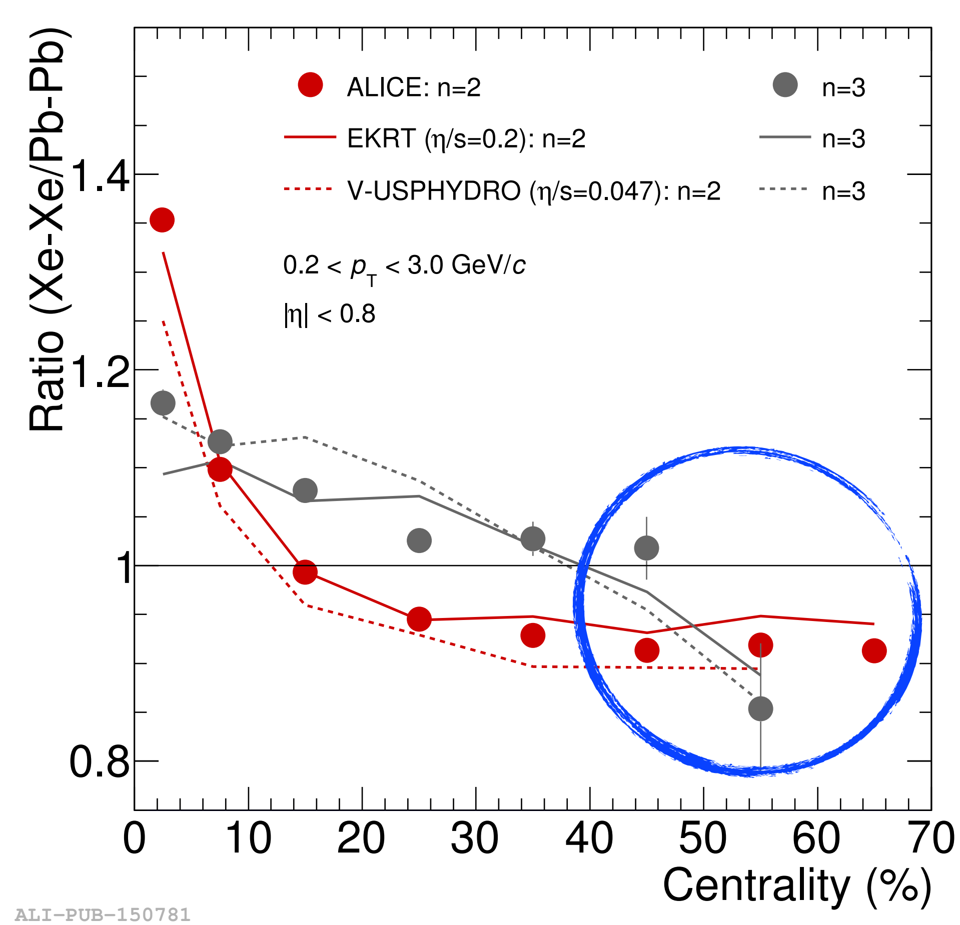


- Similar values of v_2 and v_3 in Xe-Xe collisions as in Pb-Pb ones
  - Larger asymmetries in **central Xe-Xe** collisions
  - Larger asymmetries in **peripheral Pb-Pb** data
  - Comparison with models reproduced when considering deformation of ^{129}Xe

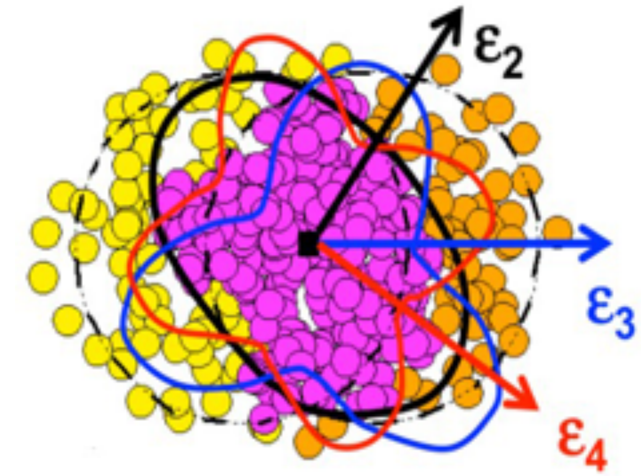
ALICE Coll. arXiv:1805.01832

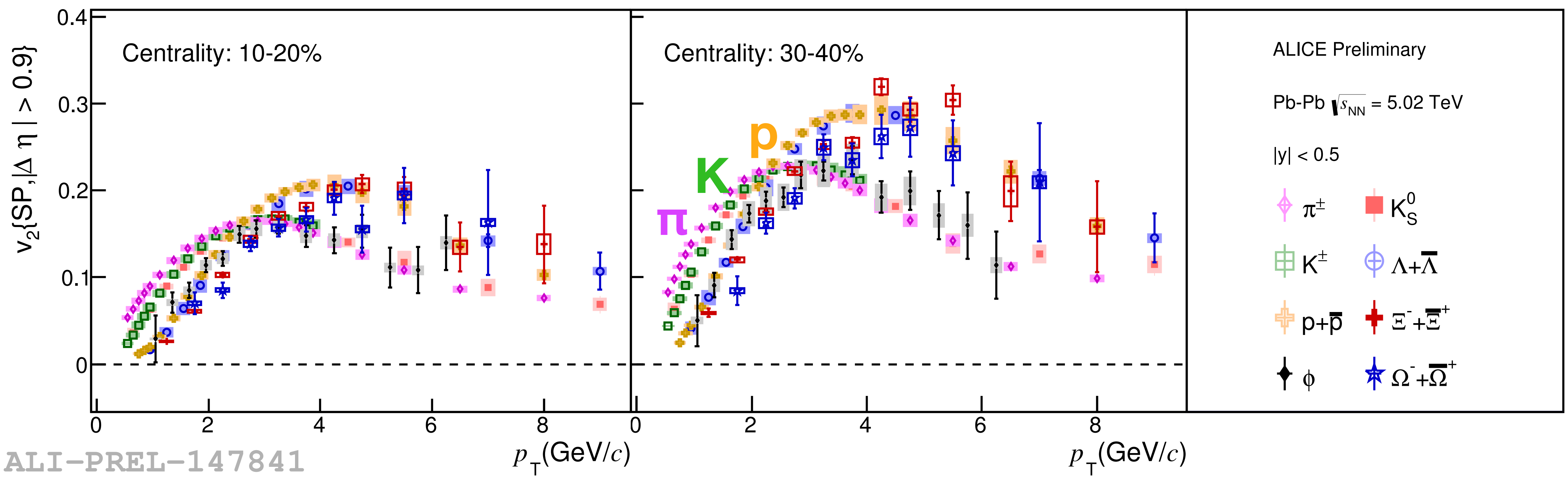




Elliptic flow

- Mass ordering for p_T < 2 GeV/c interpreted as an interplay of radial and elliptic flow
- Good agreement with hydrodynamical calculations





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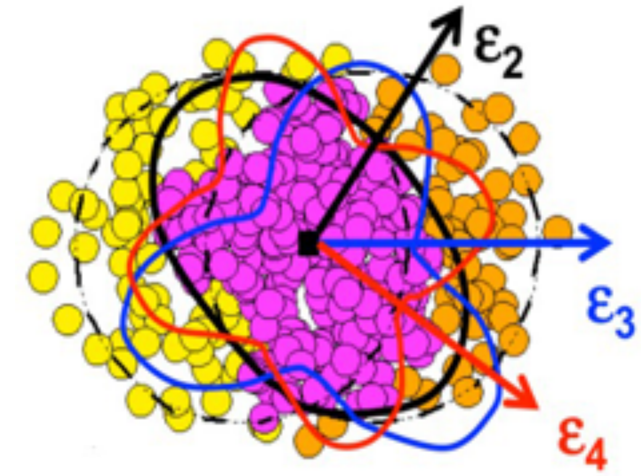
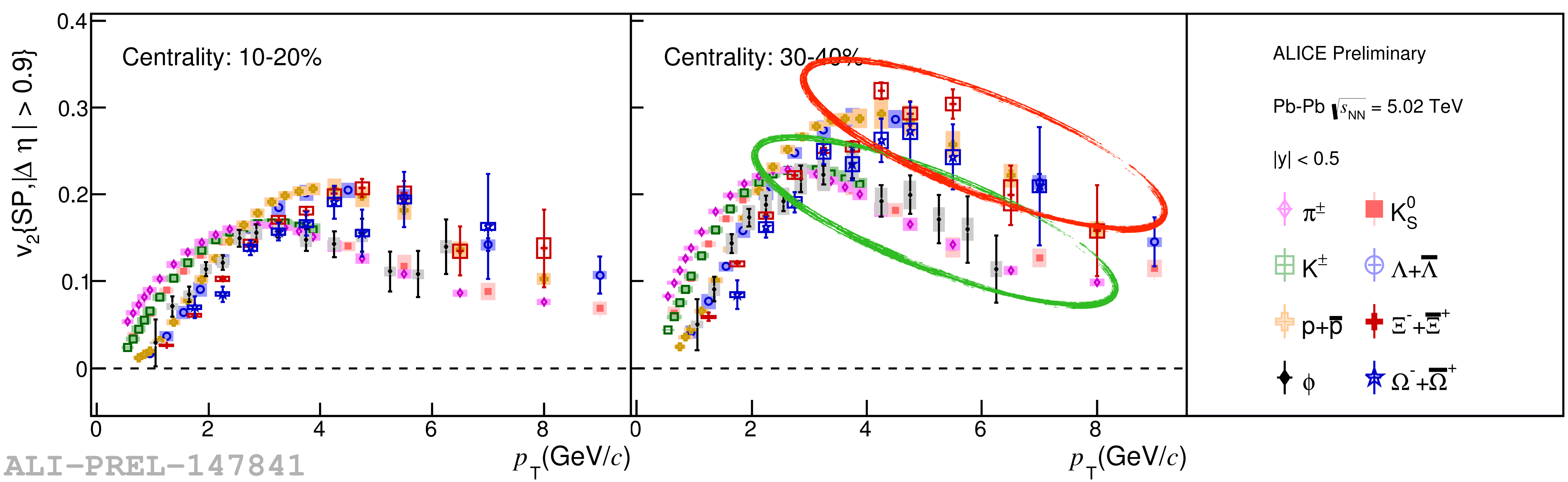
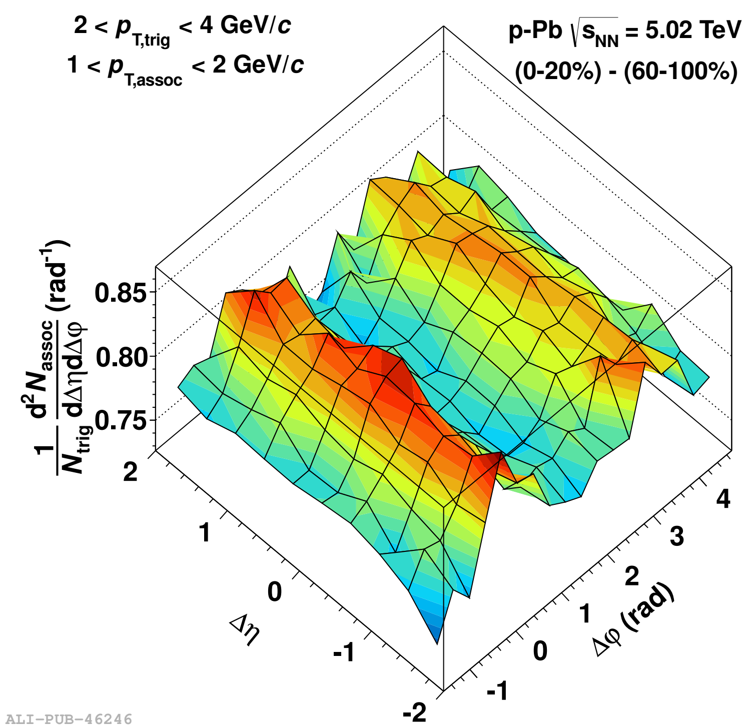


- Mass ordering for p_T < 2 GeV/c interpreted as an interplay of radial and elliptic flow
- Good agreement with hydrodynamical calculations
- Interesting different behavior for **mesons** and **baryons** at intermediate p_T
  - hadronization via recombination?



Small Systems (pp, p-Pb collisions)

- First observation of double ridge structure in p-Pb collisions in 2012
- Usually associated to v_2 development
  - Collective effects in p-Pb?

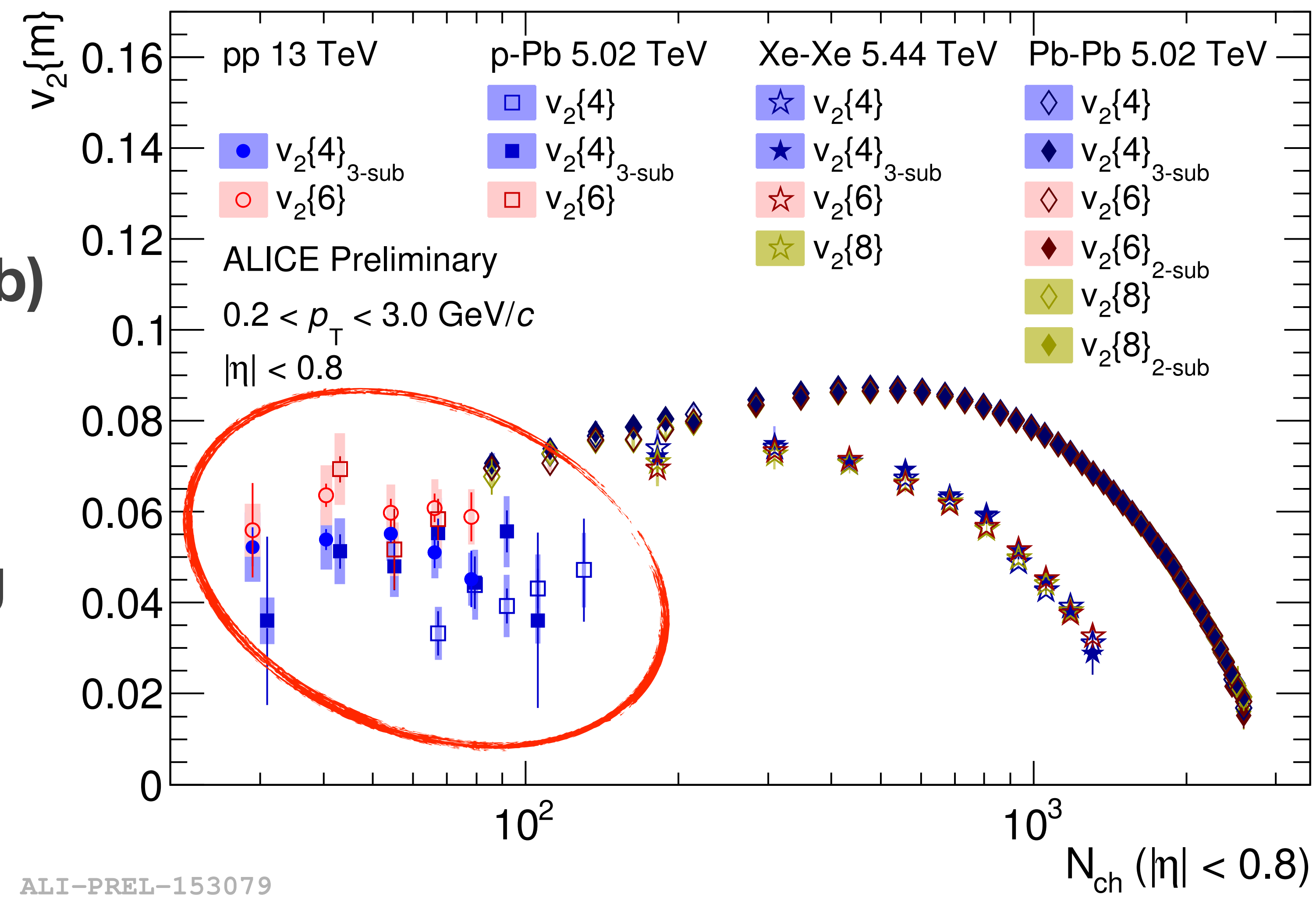


ALICE Coll. Phys. Lett. B 719 (2013) 29-41

Elliptic flow vs particle multiplicity

- Detailed measurements of v_2 using m-particle cumulants technique vs particle multiplicity for different systems.
- This method allows the suppression of non-flow contributions (jets, resonances, …)
  - Important in pp and p-Pb collisions

- **$v_2 > 0$ observed also for smallest systems (pp, p-Pb)**
- Indication of collective effects in high-multiplicity collisions ?
- Other QCD effects entering in the observable definition (proton fluctuations) ?

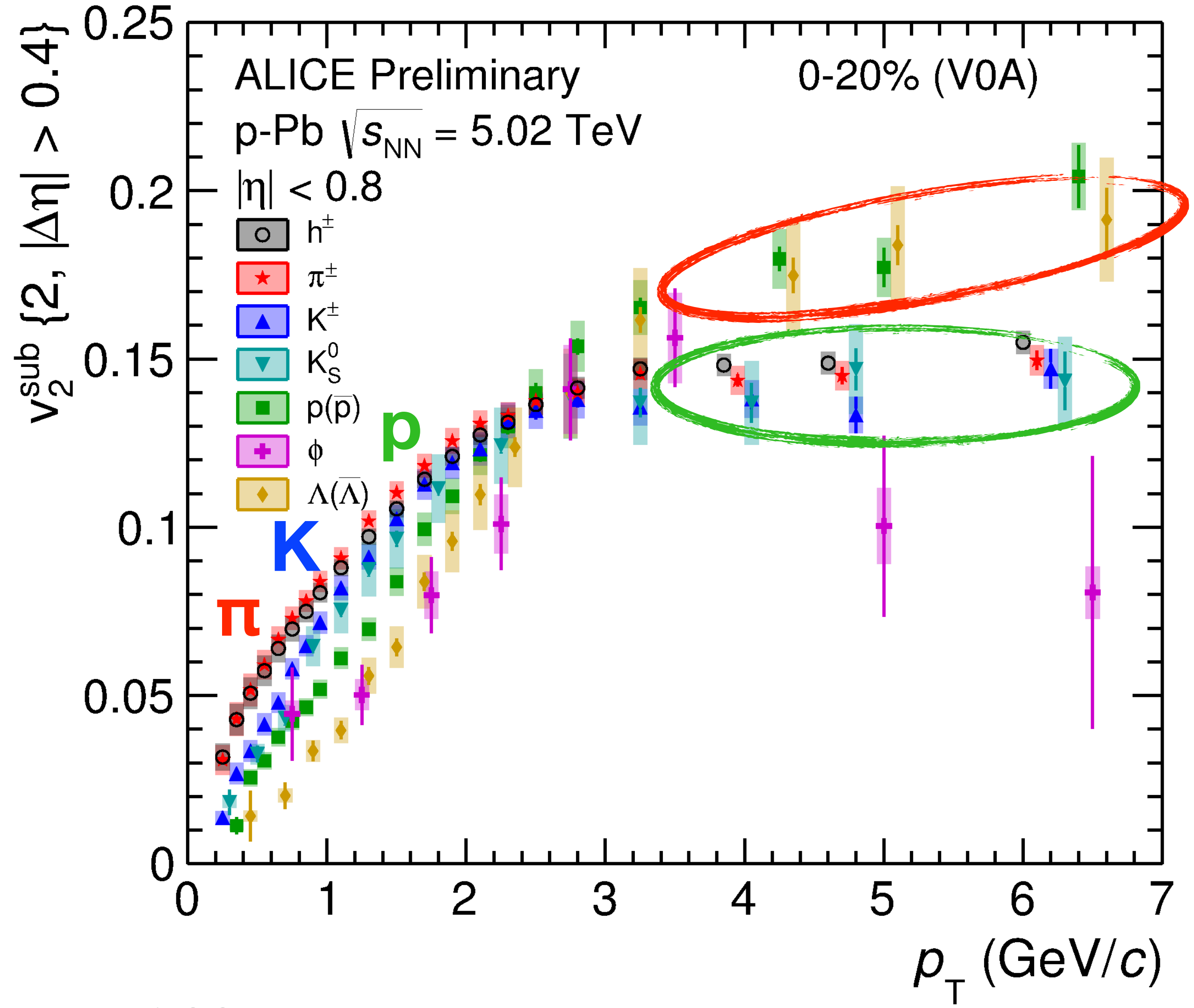


Elliptic flow of ID-particles in p-Pb

- New results on identified particles of v_2^{sub} show a clear mass ordering in p-Pb collisions

- Consistent with hydrodynamic expansion but also with other effects:
  - Initial stages effect (PYTHIA + Lund string)
  - Parton escape (AMPT)
  - Hadronic re-scattering (UrQMD)

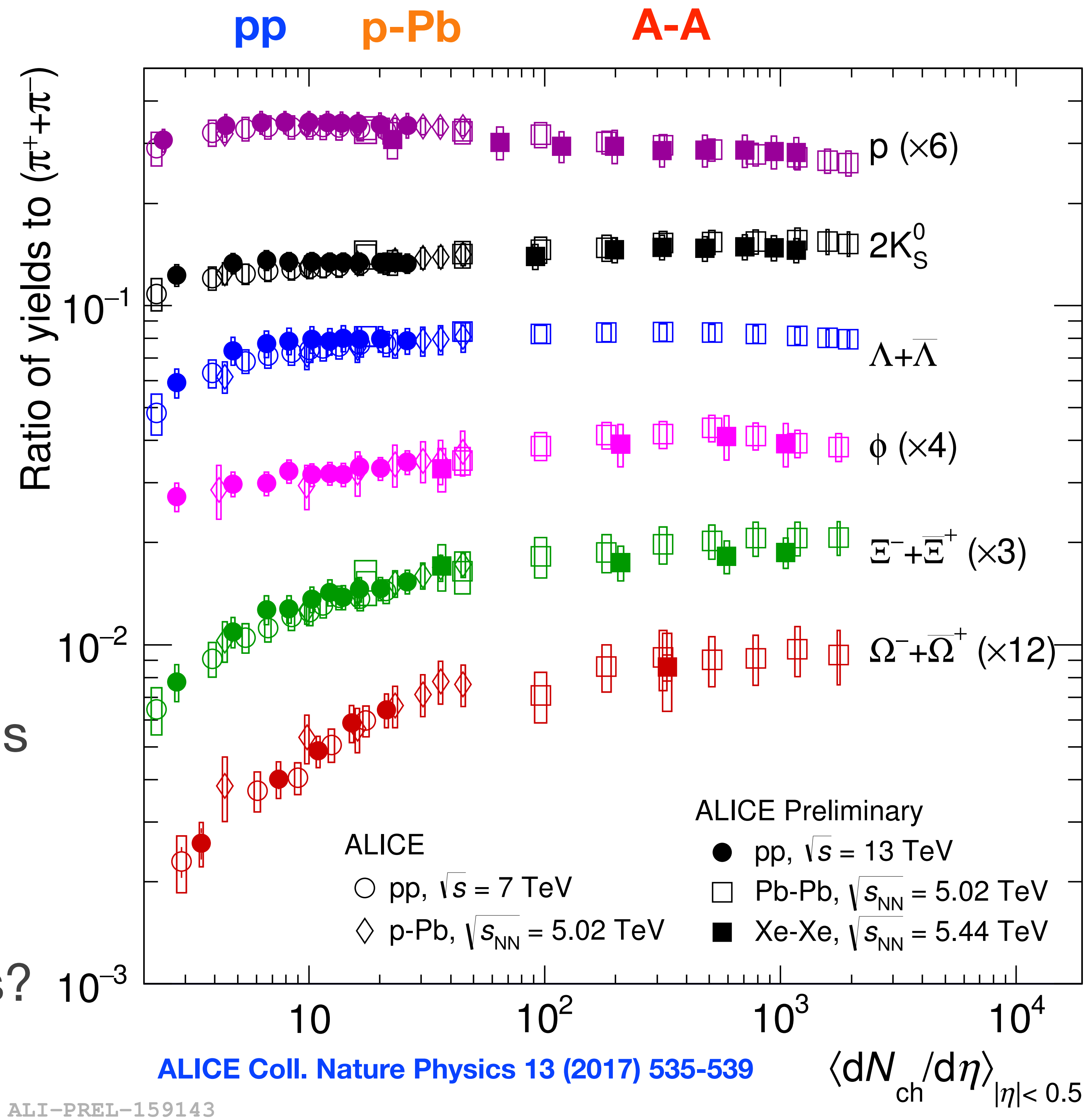
- Also the **mesons**/**baryons** grouping observed as in Pb-Pb collisions



ALI-PREL-156487

Strangeness production vs particle multiplicity

- Smooth evolution of particle production from small to large system vs charged multiplicity
- Increase strangeness production with increasing multiplicity until saturation (grand-canonical plateau) is reached
- Also confirmed for pp collisions at $\sqrt{s}$ = 13 TeV and Xe-Xe ones
- Common origin for all systems?



ALICE Coll. Nature Physics 13 (2017) 535-539

Hard probes

- Hard probes
  - produced in the early stage of the collisions,
  - they can “observe” the full evolution of the QGP and interact with it.

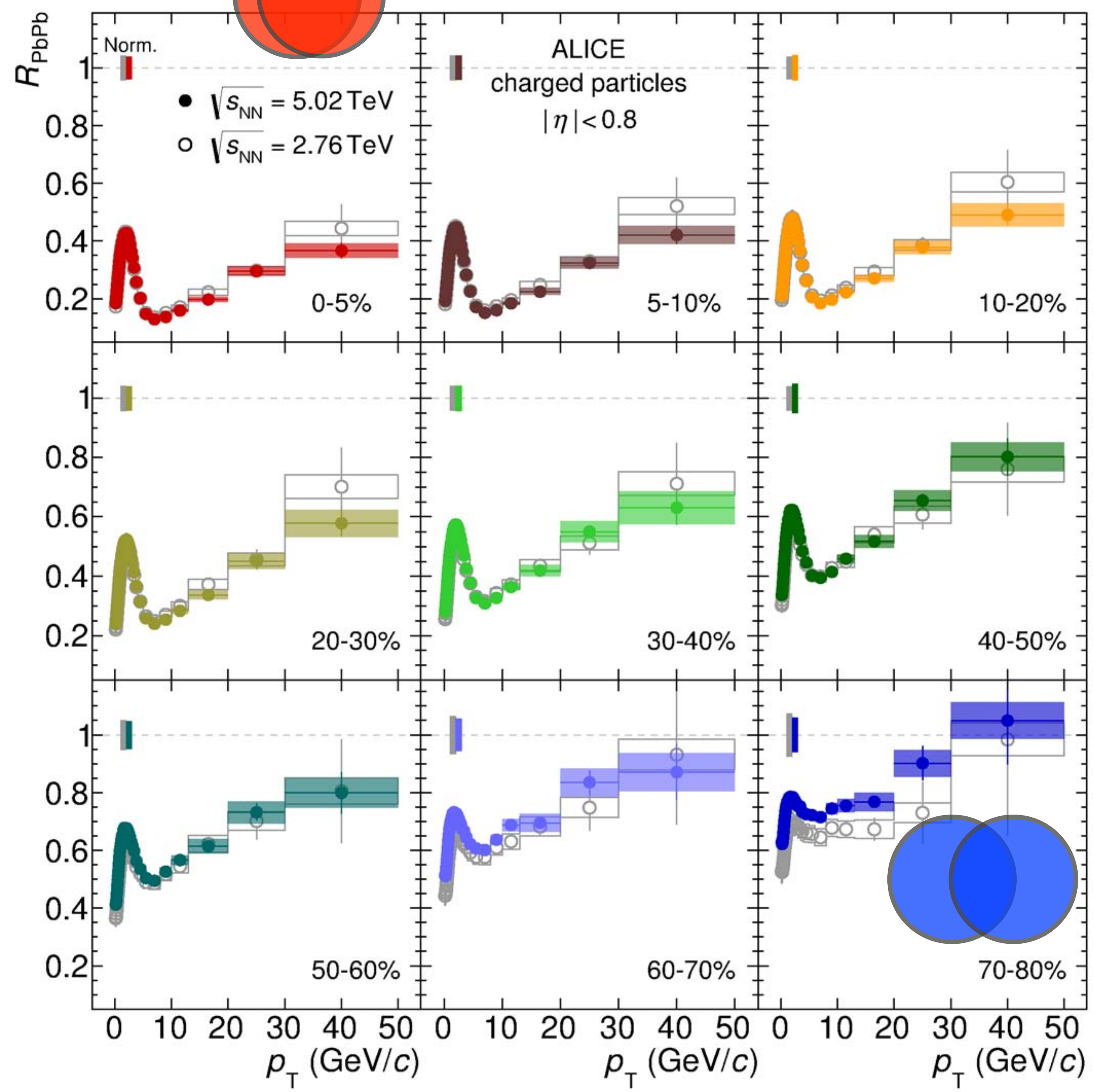
- Originate from hard processes, large momentum transfer $q^2 \rightarrow$ production computed using pQCD.

In-medium energy loss

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{< N_{coll} >} \times \frac{d^2N_{AA}/dp_T d\eta}{d^2N_{pp}/dp_T d\eta}$$

- Nuclear modification factors for charged hadrons:
  - $R_{AA} < 1$ for more central collisions
  - ~ factor 5 suppression at between $5 < p_T < 10$ GeV/c
  - ~ factor 3 suppression at 40 GeV/c
  - suppression decreases (larger R_{AA}) for more peripheral events

ALICE Coll. arXiv:1802.09145



- Models that include radiative energy loss of partons interacting with the medium are in good agreement with the data.

In-medium energy loss in Xe-Xe

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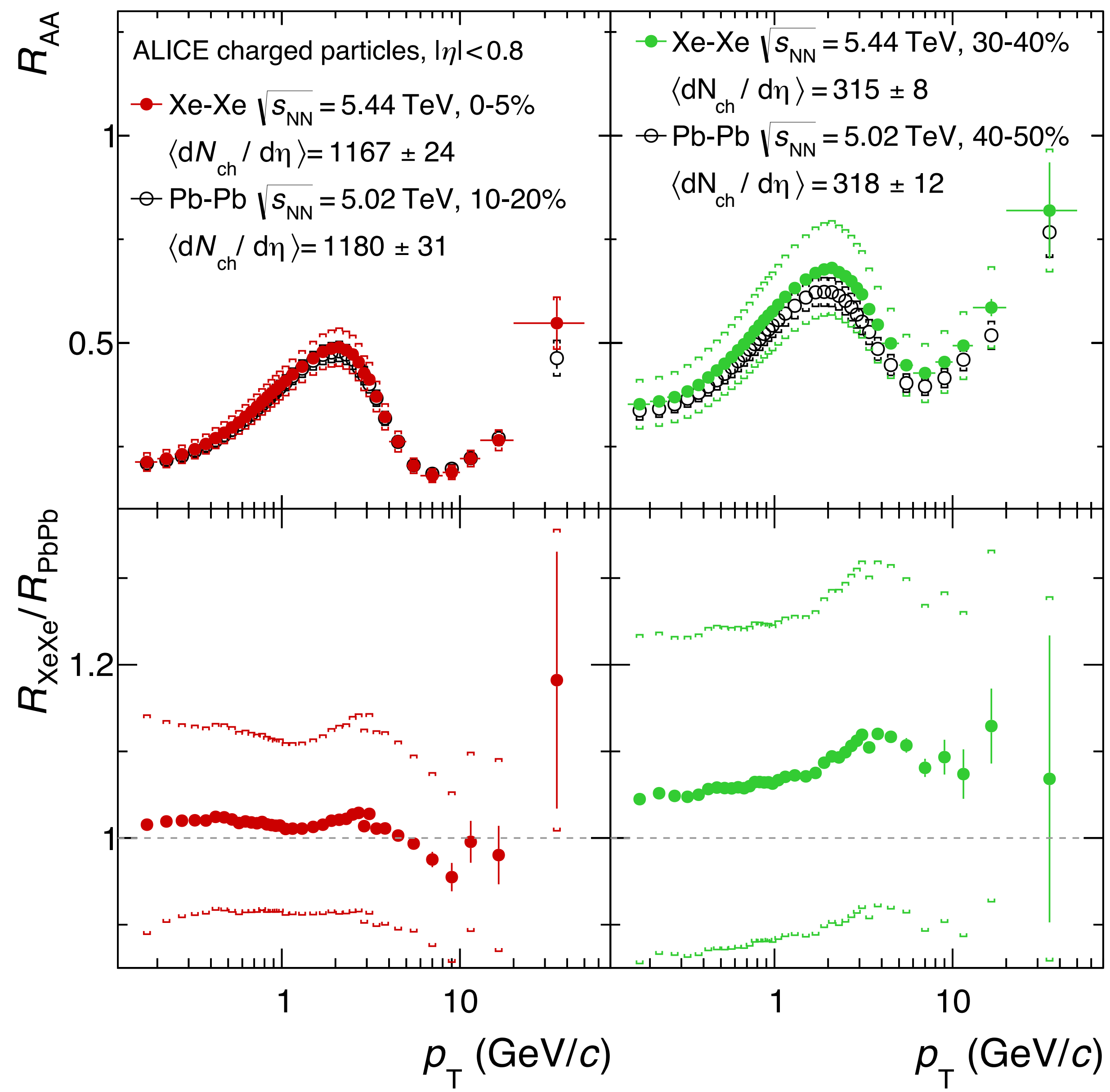
- R_{AA} in central Xe-Xe collisions is similar to R_{AA} in Pb-Pb collisions at similar multiplicity

ALICE Coll. arXiv:1805.04399



*studies of flavor dependent energy loss in talk of Fabio Colamaria this afternoon

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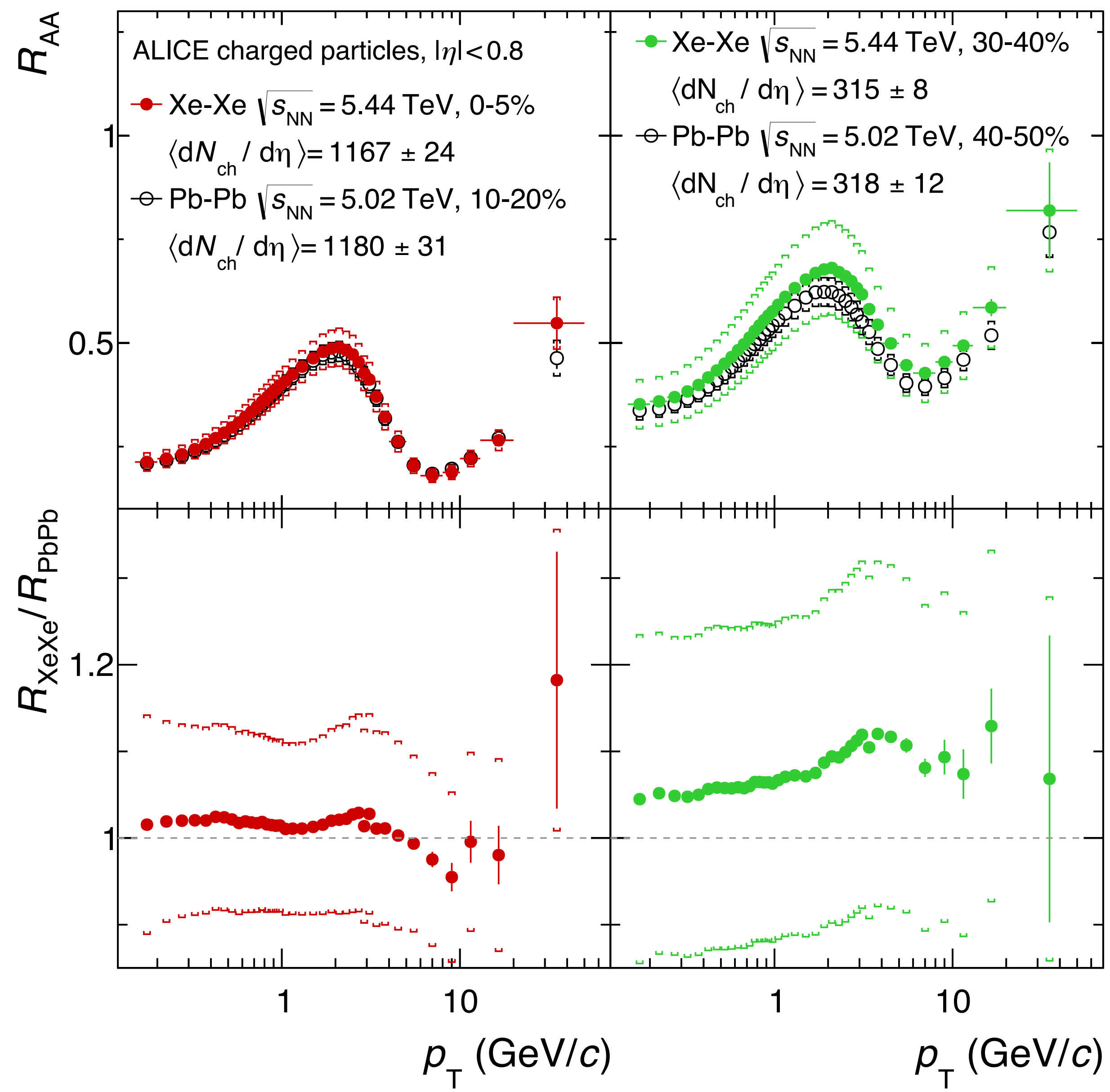
- R_{AA} deviates for peripheral collisions
  - different geometry at same multiplicity

ALICE Coll. arXiv:1805.04399



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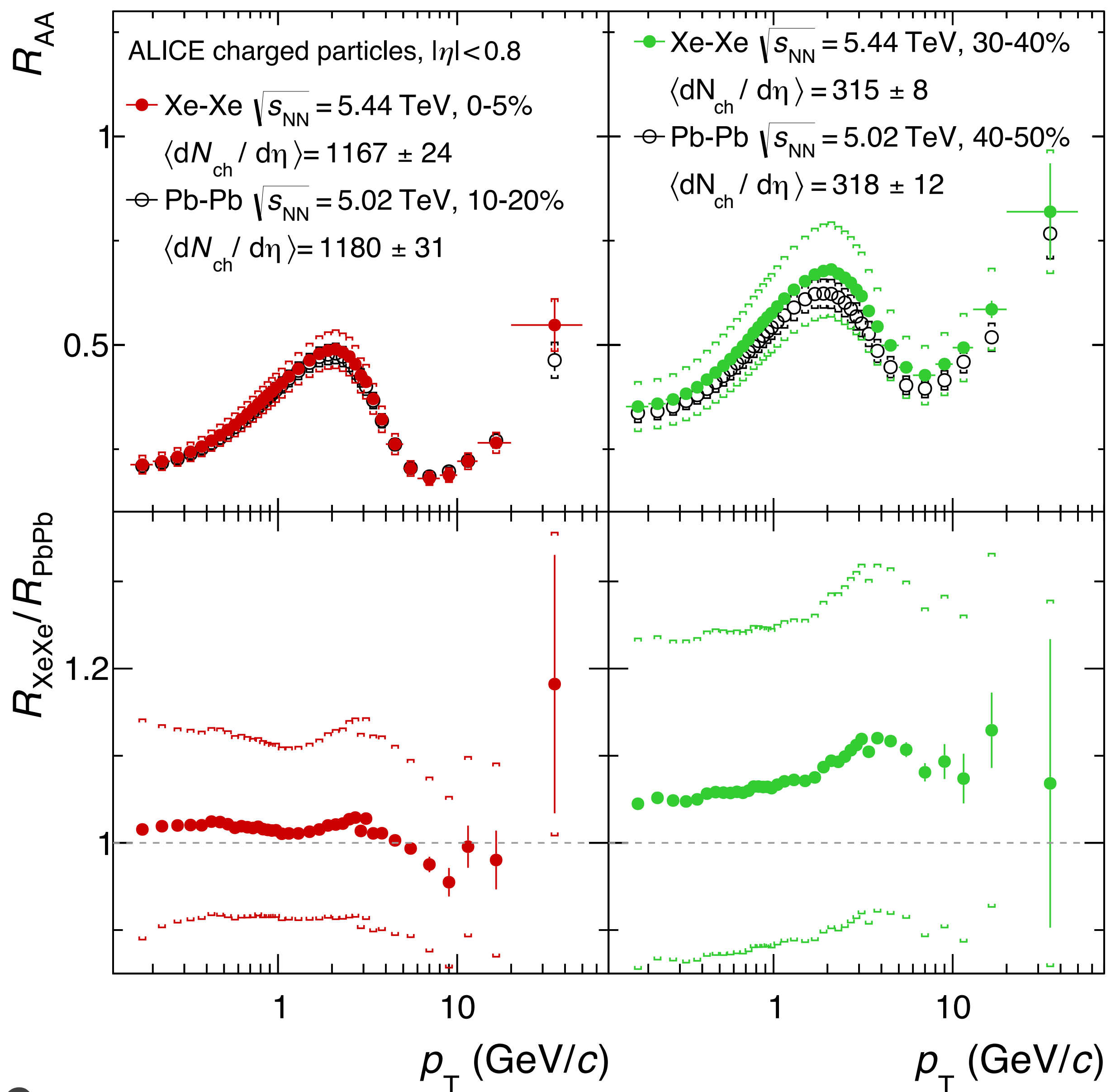
$$R_{\rm AA}(p_{\rm T}) = \frac{1}{< N_{coll} >} \times \frac{d^2N_{AA}/dp_T d\eta}{d^2N_{pp}/dp_T d\eta}$$

- R_{AA} in central Xe-Xe collisions is similar to R_{AA} in Pb-Pb collisions at similar multiplicity
- R_{AA} deviates for peripheral collisions
  - different geometry at same multiplicity
- Non-trivial interplay of collision geometry and path length dependence of the energy loss

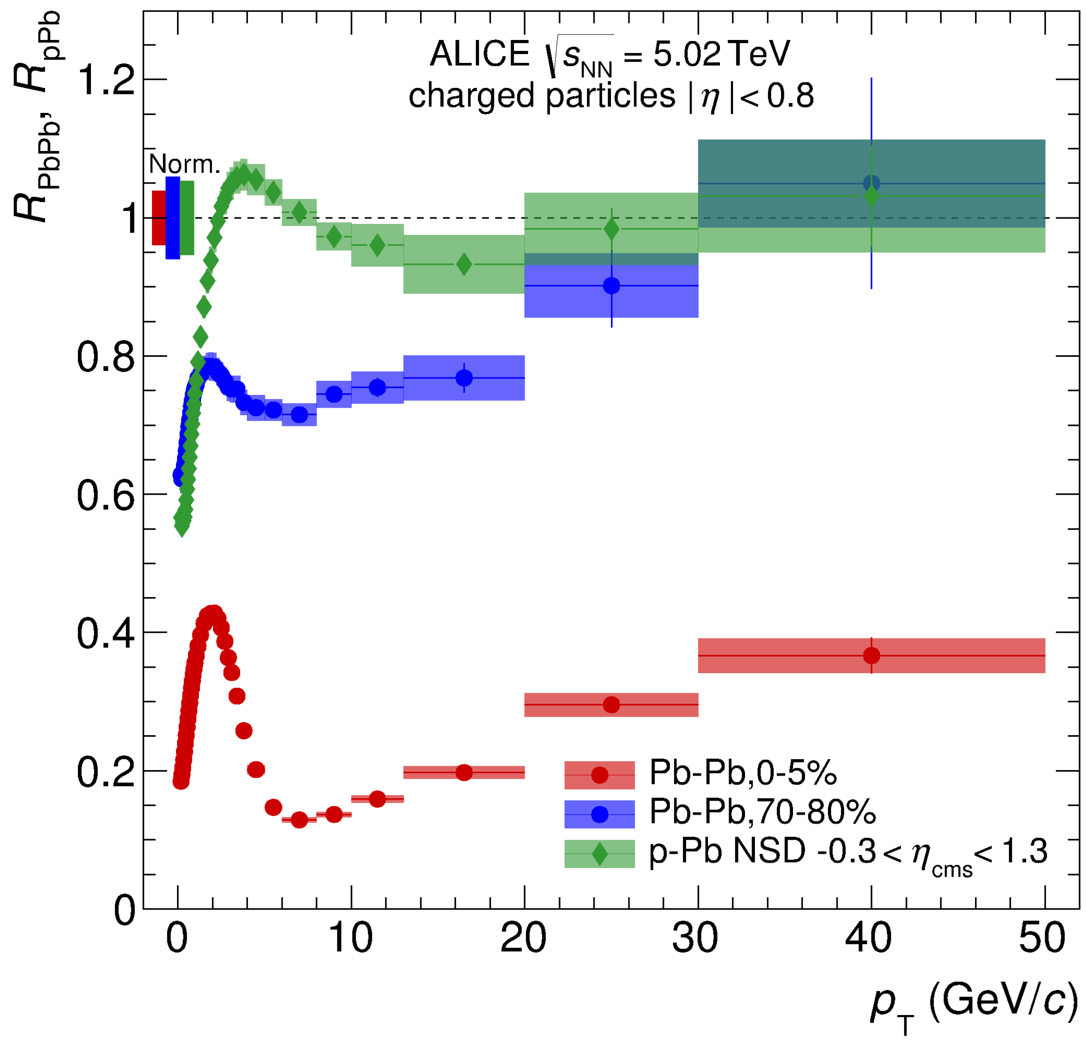
ALICE Coll. arXiv:1805.04399



*studies of flavor dependent energy loss in talk of Fabio Colamaria this afternoon

What about energy loss in small systems?

ALICE Coll. arXiv:1802.09145



- R_{pPb} =1 ⇒ no evidence of energy loss

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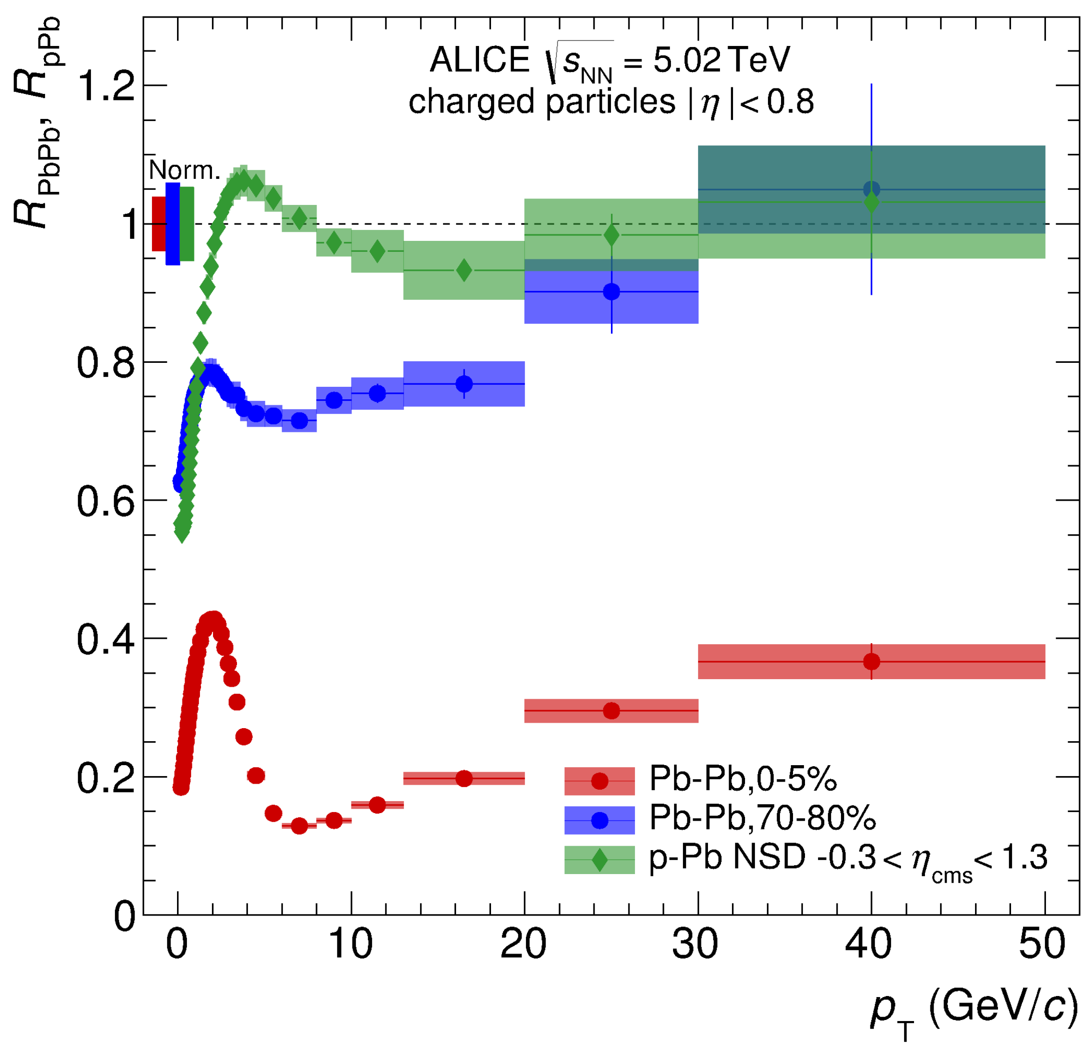
ALICE Coll. arXiv:1802.09145



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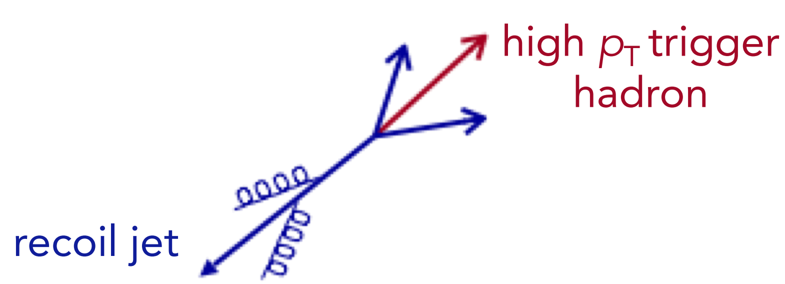
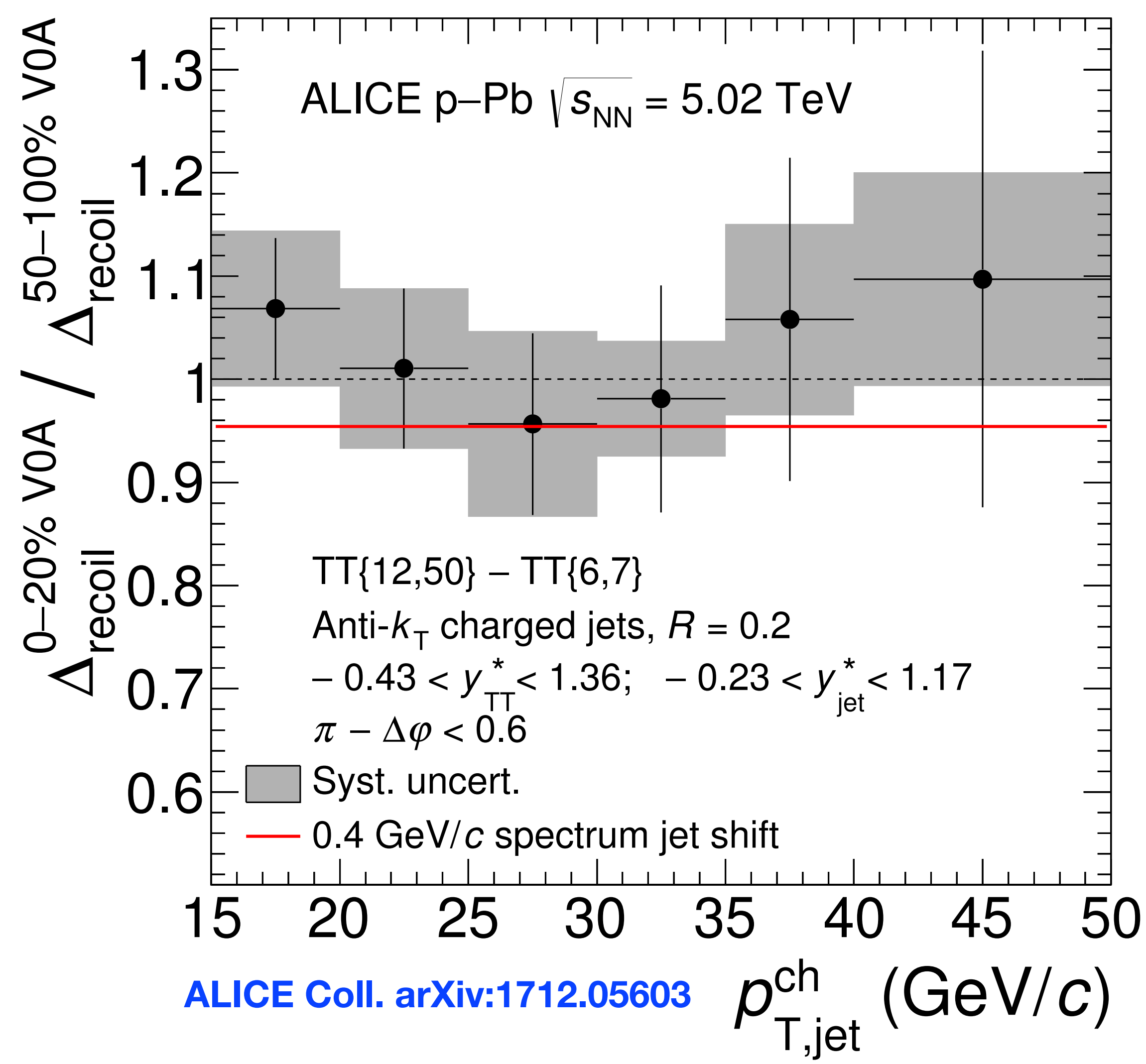


- hadron-recoil jet coincidence measurements
- semi-inclusive recoil jet distribution for different p-Pb multiplicity classes

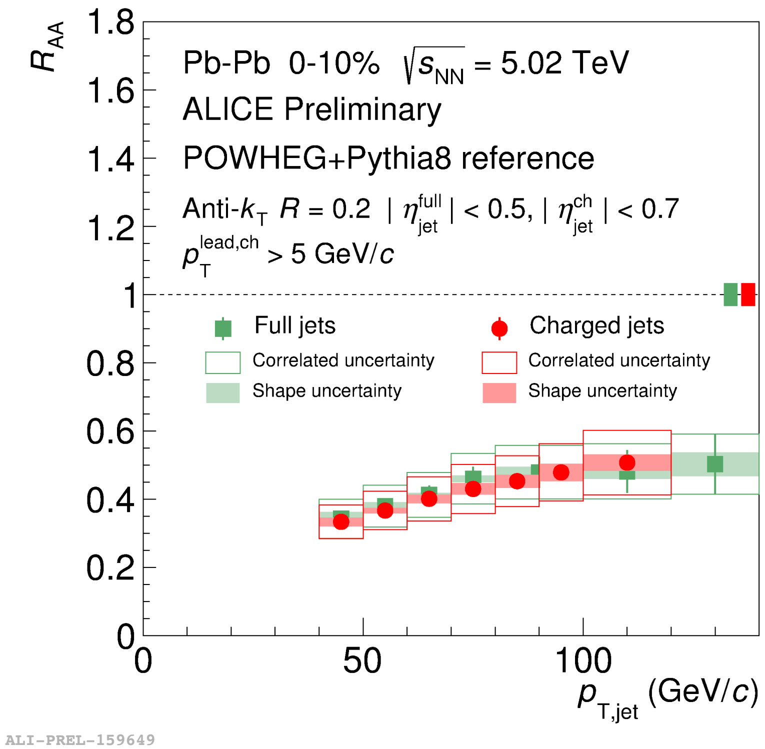


ALICE Coll. arXiv:1712.05603

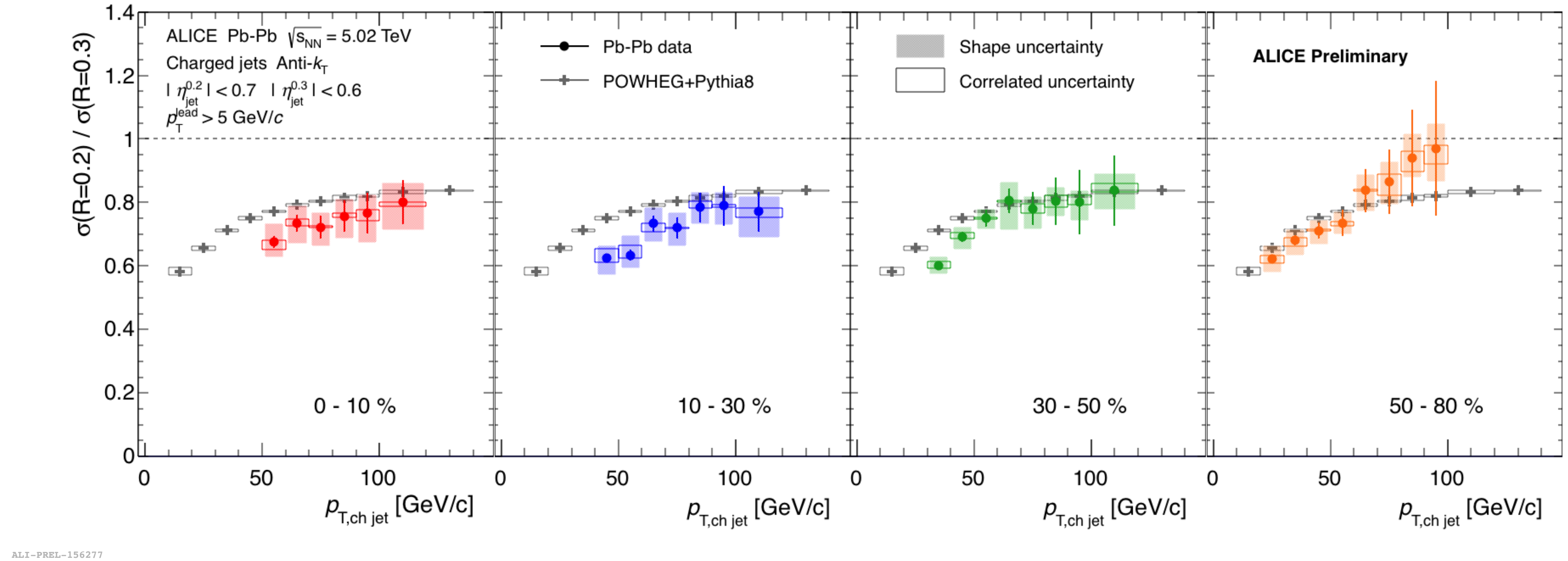
- No significance modifications (ΔE<0.4 GeV)

In-medium energy loss with jets

- Inclusive jet spectra for both charged and full jets for R=0.2, R=0.3
- **Energy expected to be radiated outside of the jet cone** (R_{AA} < 1).



- Ratios of charged and full jet cross sections R=0.2/R=0.3 are measured
- **No significant difference with respect to jet fragmentation in vacuum** (POWEG + PYTHIA8 reference)

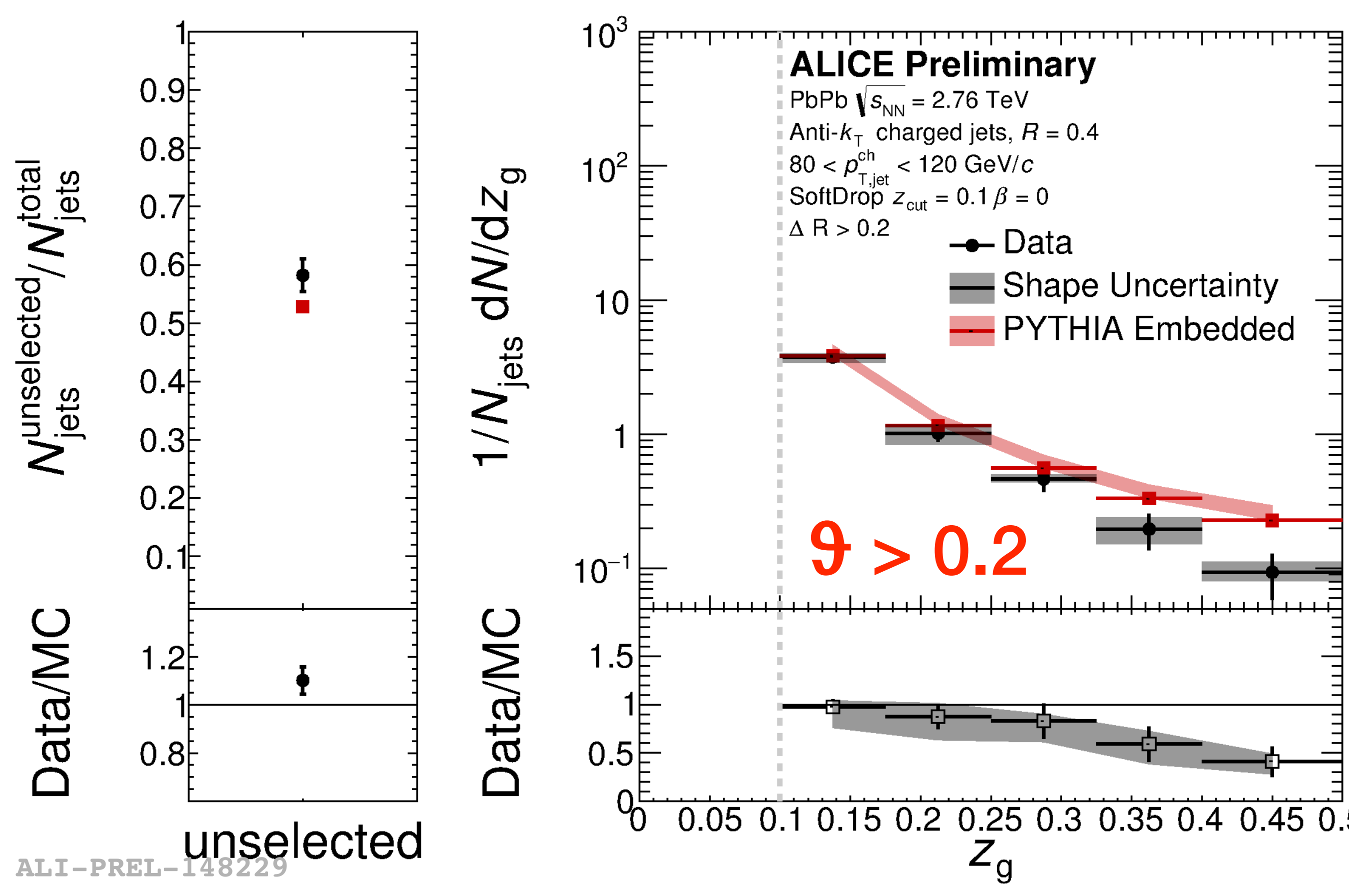


Jet substructures

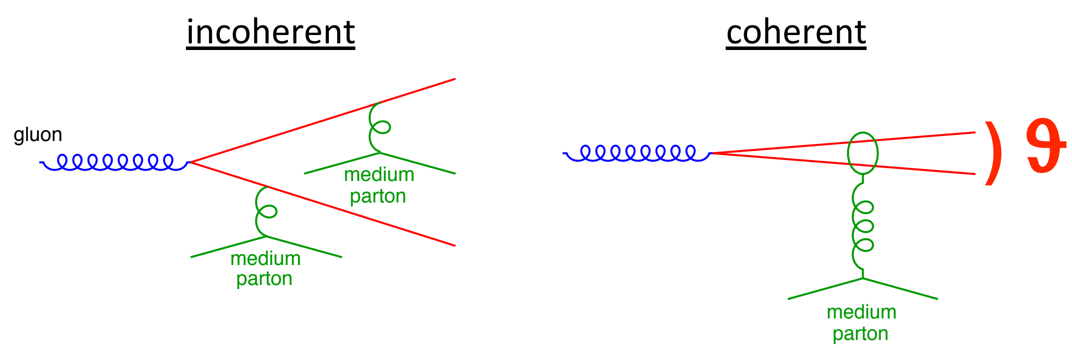
- New detailed studies of in-medium energy loss via jet substructure
- Reconstruction the history of the shower using jet de-clustering algorithm
- Imbalance of the momentum of the two hardest subjet

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}},$$

Charged jets, R = 0.4, 80 < p_T < 120 GeV/c



- Sensitive to coherent/incoherent energy loss

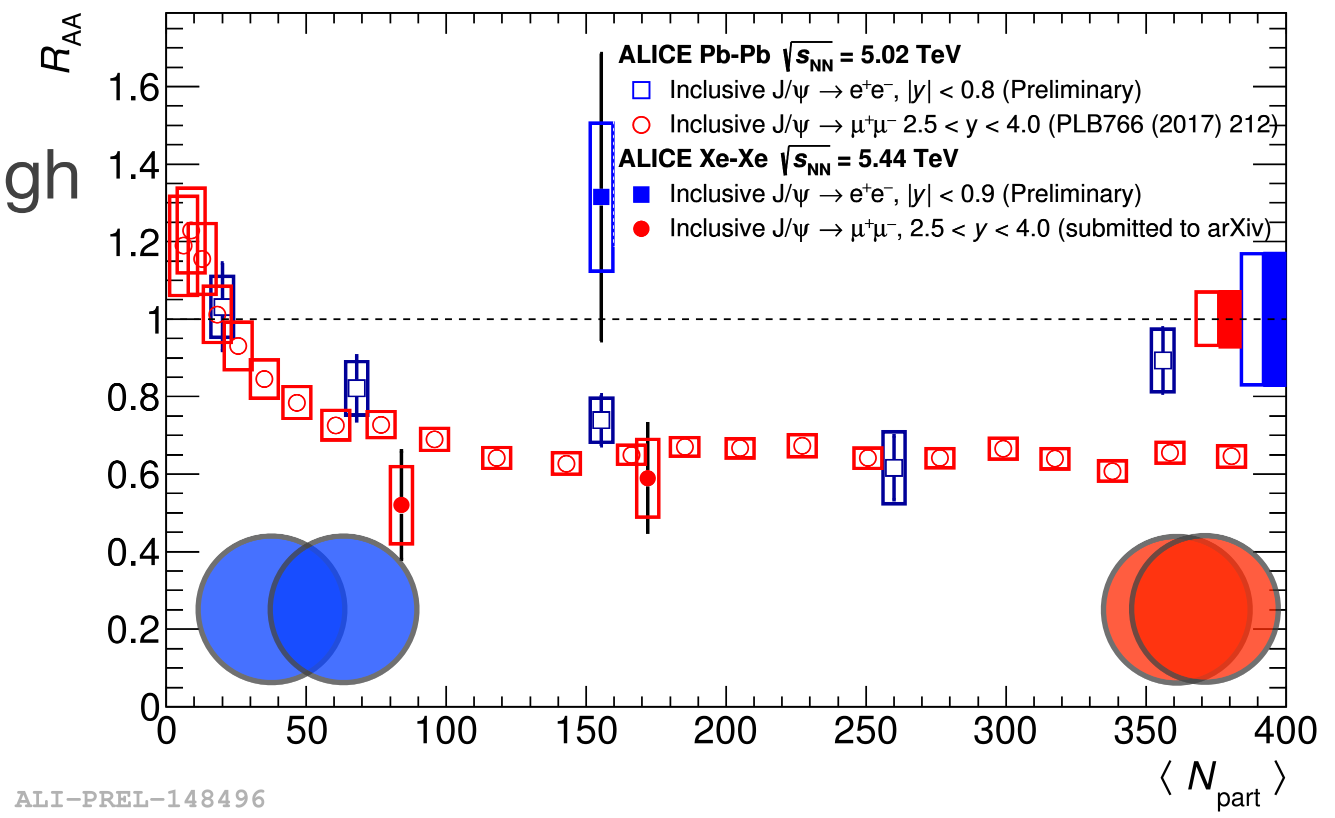


- Suppression of symmetric splitting at large ΔR
- Incoherent energy loss scenario at large ΔR ?

Charmonia in A-A

- J/ψ suppression proposed as QGP signature by Matsui and Satz in 1986.
- Interaction potential in the QGP colored screened beyond λ_D (analogous to the e.m. Debye screening).

- For J/ψ with $p_T > 0$ suppression is:
  - Constant vs centrality
  - Similar for Xe-Xe and Pb-Pb, though large uncertainties



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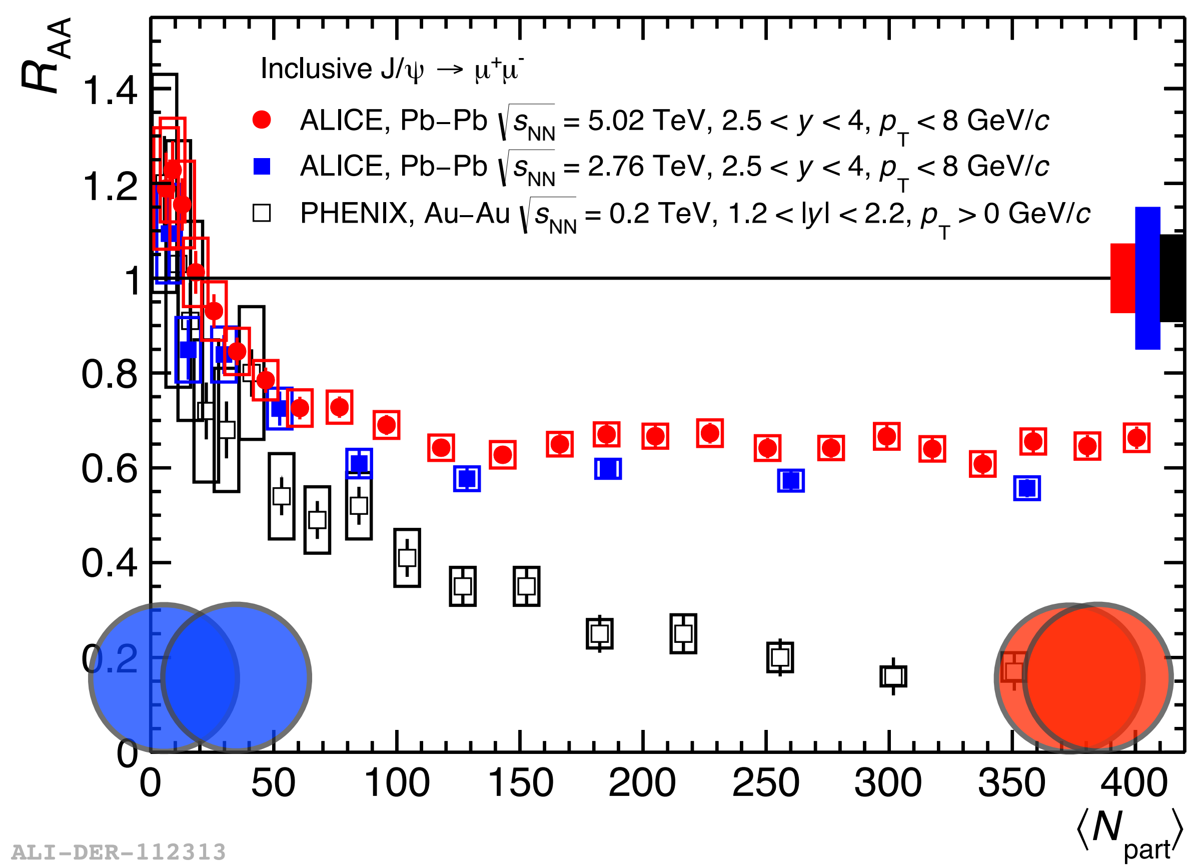
  - Smaller than what observed at RHIC
    - indication of J/ψ production via recombination of charm quarks!

ALICE Coll. Phys. Lett. B 766 (2017) 212-224



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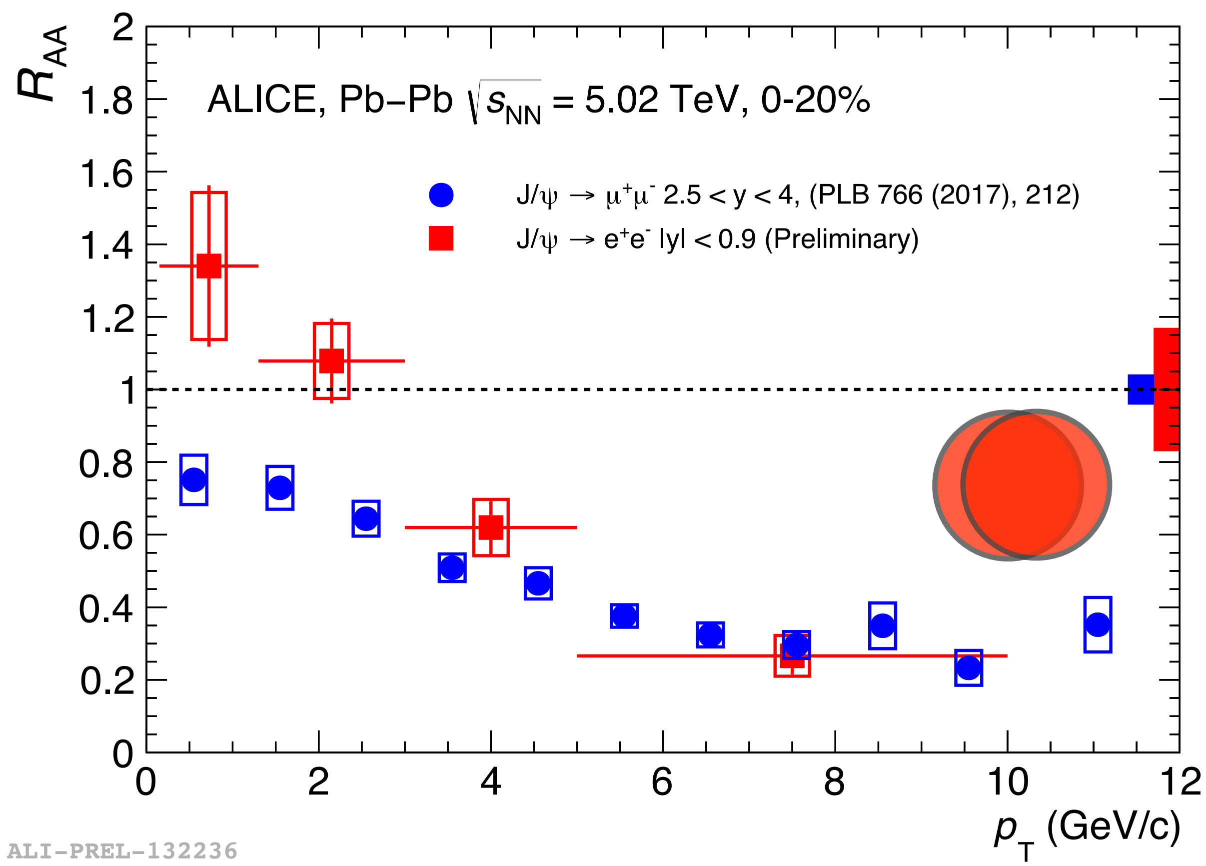
  - suppression of a factor ~4 at $p_T > 5$ GeV/c

ALICE Coll. Phys. Lett. B 766 (2017) 212-224



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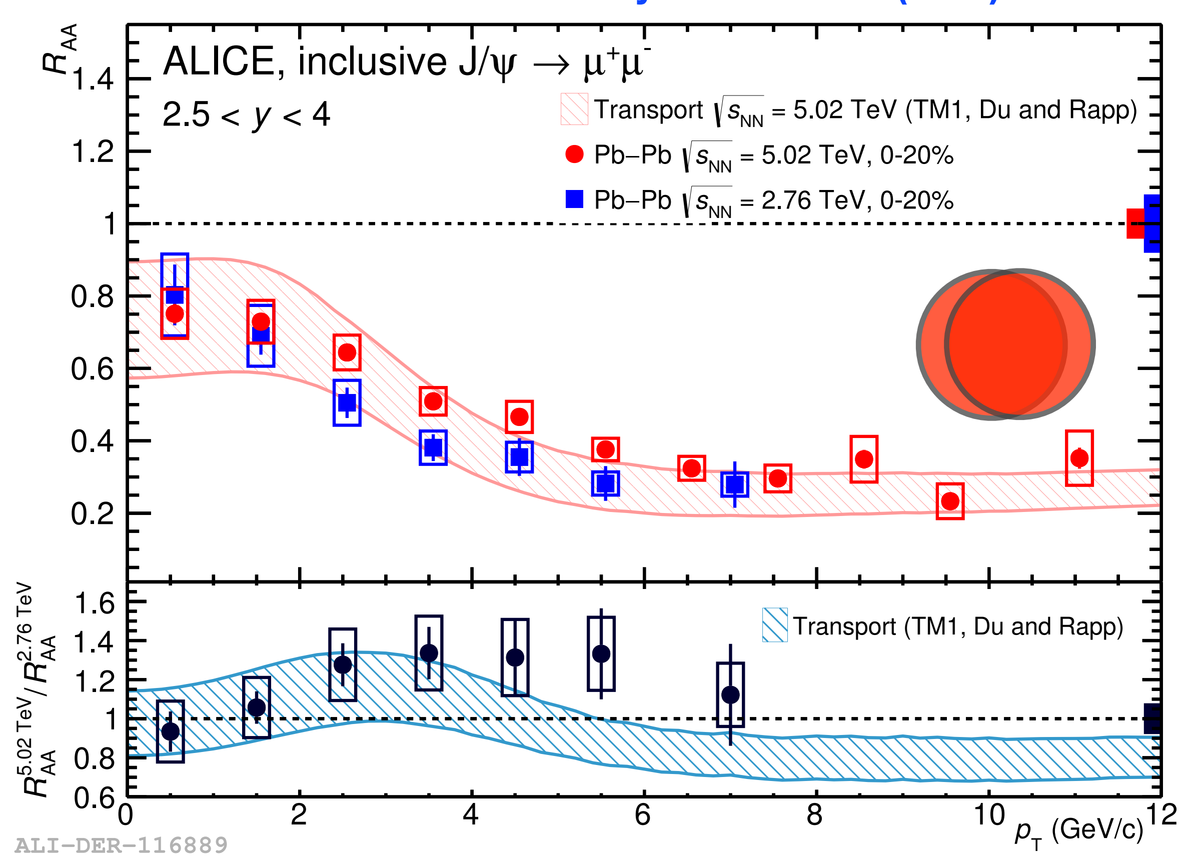
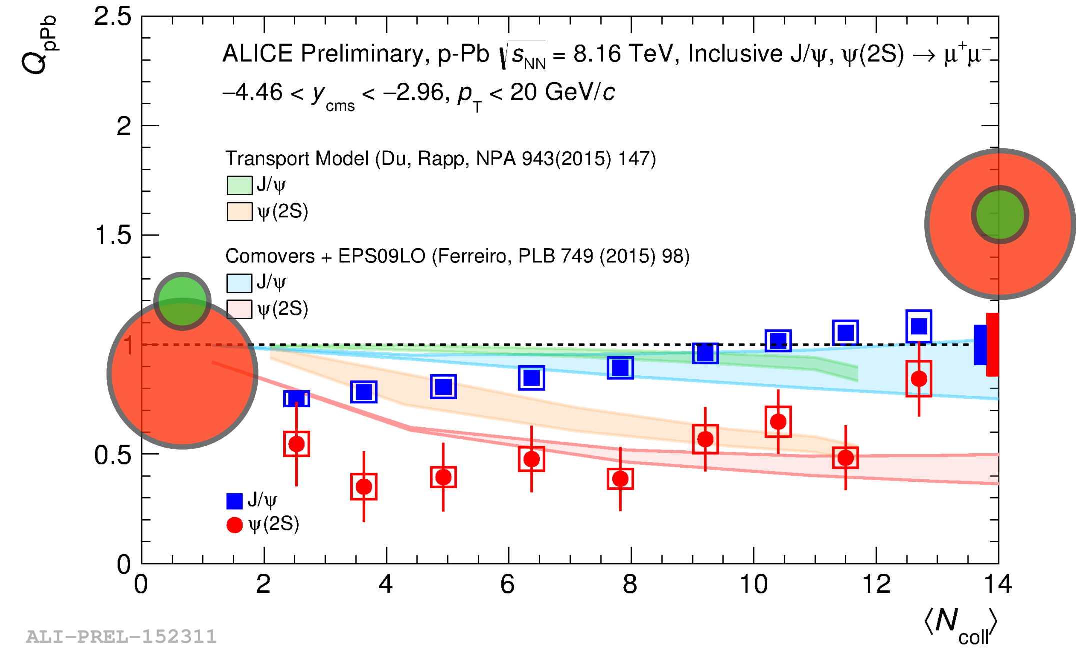


- Transport models that includes recombination of J/ψ at low-p_T reproduced the data

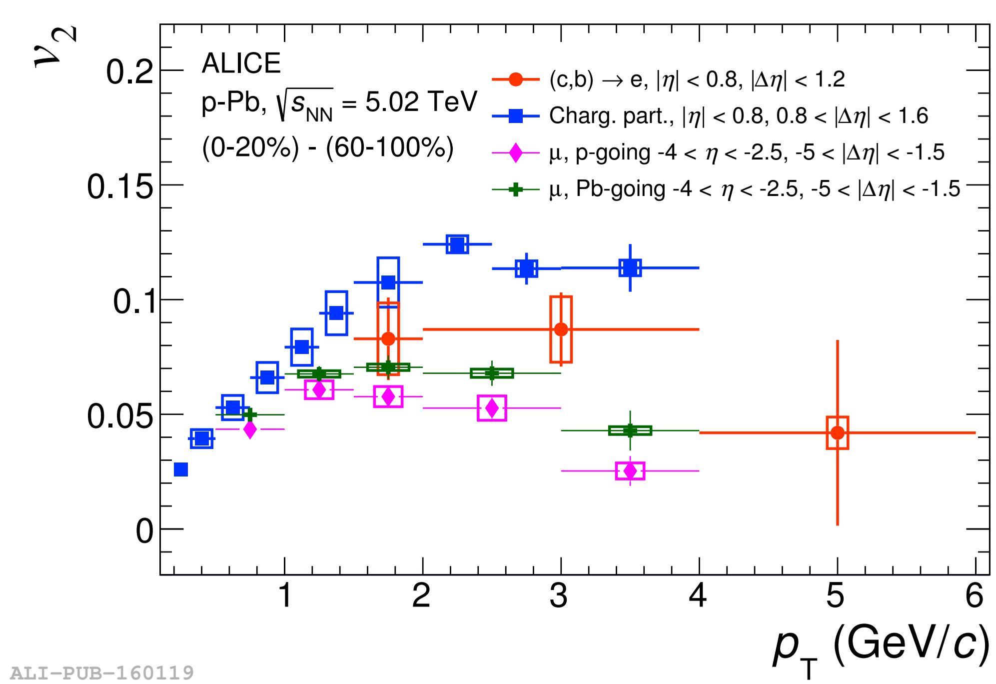
What about charm in small systems?

- No indications of in-medium energy loss in small systems
  - but two charm-related effects that might require final state effects



- **ψ(2S) more suppressed** in p-Pb than **J/ψ** in the backward rapidity region
  - Final state effects are needed to explain this difference

ALICE Coll. arXiv:1805.04367



- e,μ from heavy flavor decays show ***v*₂ > 0** in high-multiplicity p-Pb collisions
  - Initial state effects? Final ones? Collectivity ("hydro-like")?

Conclusions

- **Soft probes used to study the global properties of the Quark Gluon Plasma**
- **Precise measurements allow to**
  - **discriminate** among different **models**
  - put **stronger constraint** on the QGP parameters

$\varepsilon \sim 18$ GeV/fm^3
$T_{ch} \sim 155$ MeV
$T_{kin} \sim 90$ MeV, $\langle \beta_T \rangle \sim 0.65$
$\eta/s \sim 0.2$

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  - No evidence of energy loss with hard probes ($\Delta E < 0.4$ GeV)
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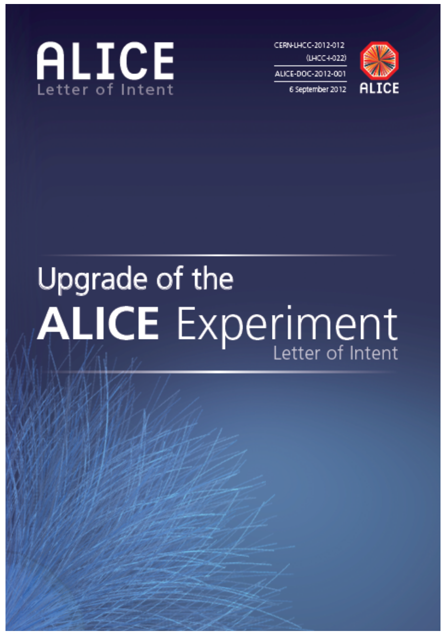
- **Energy loss studies with rare and calculable probes** to understand the details of the **microscopic mechanisms** of this phenomena
  - Entering the precision and differential measurements era

ALICE Upgrade

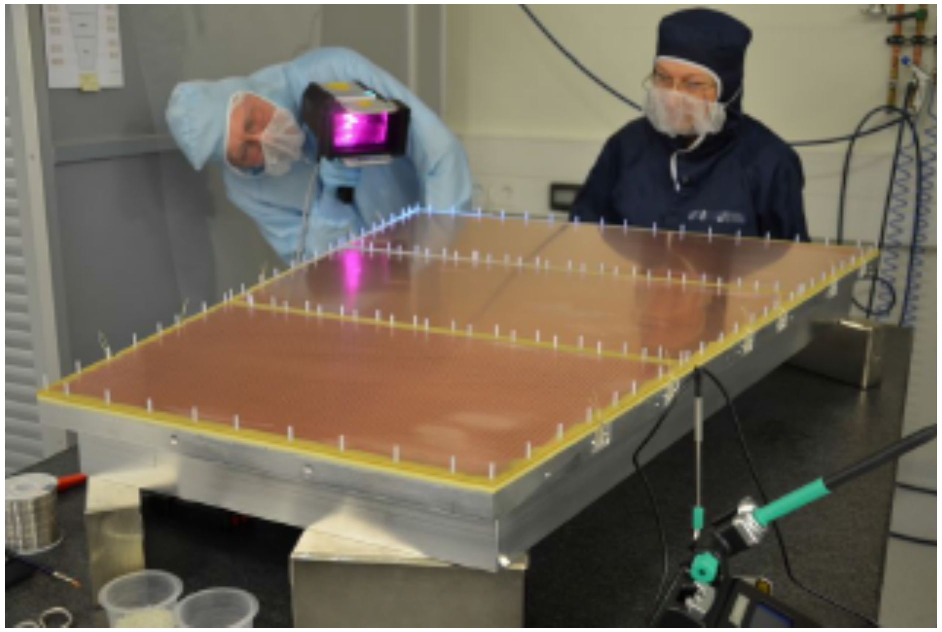
- **Major upgrade** of the ALICE detector during LS2
  - **New Inner Tracking System** based on MAPS
  - **New TPC read-out based** on GEM chambers
  - **Continuous read-out of 50 kHz** in Pb-Pb collisions

- **Experiments requested** total statistics Run3 + Run4
  - $\boldsymbol{L_{\mathrm{int}} \sim 10\ \mathrm{nb}^{-1}\ (+\ 3\ \mathrm{nb}^{-1}\ \mathrm{at}\ B=0.2\ \mathrm{T})}$



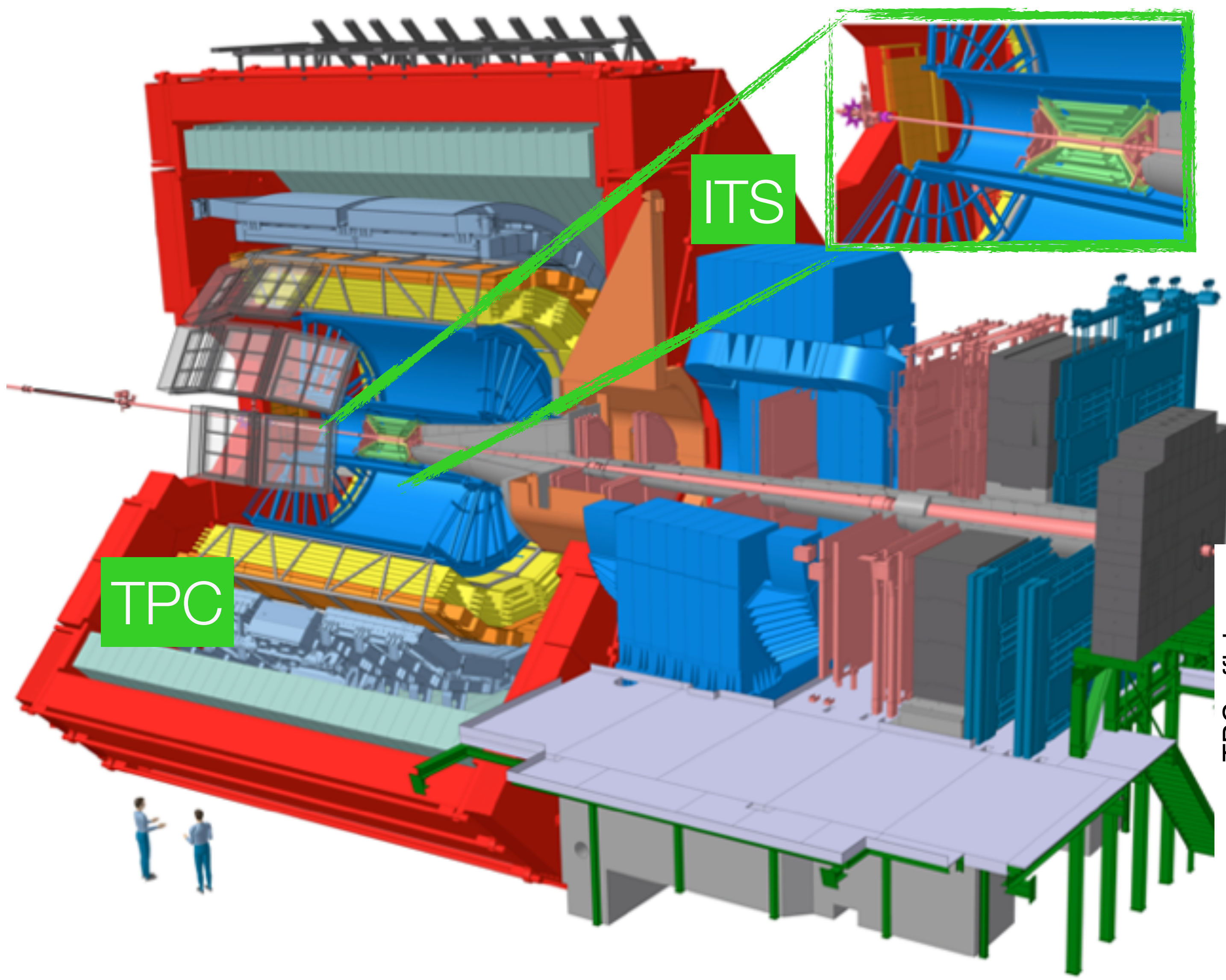
ITS first half layers completed

GEM production completed two weeks ago



Back up slides

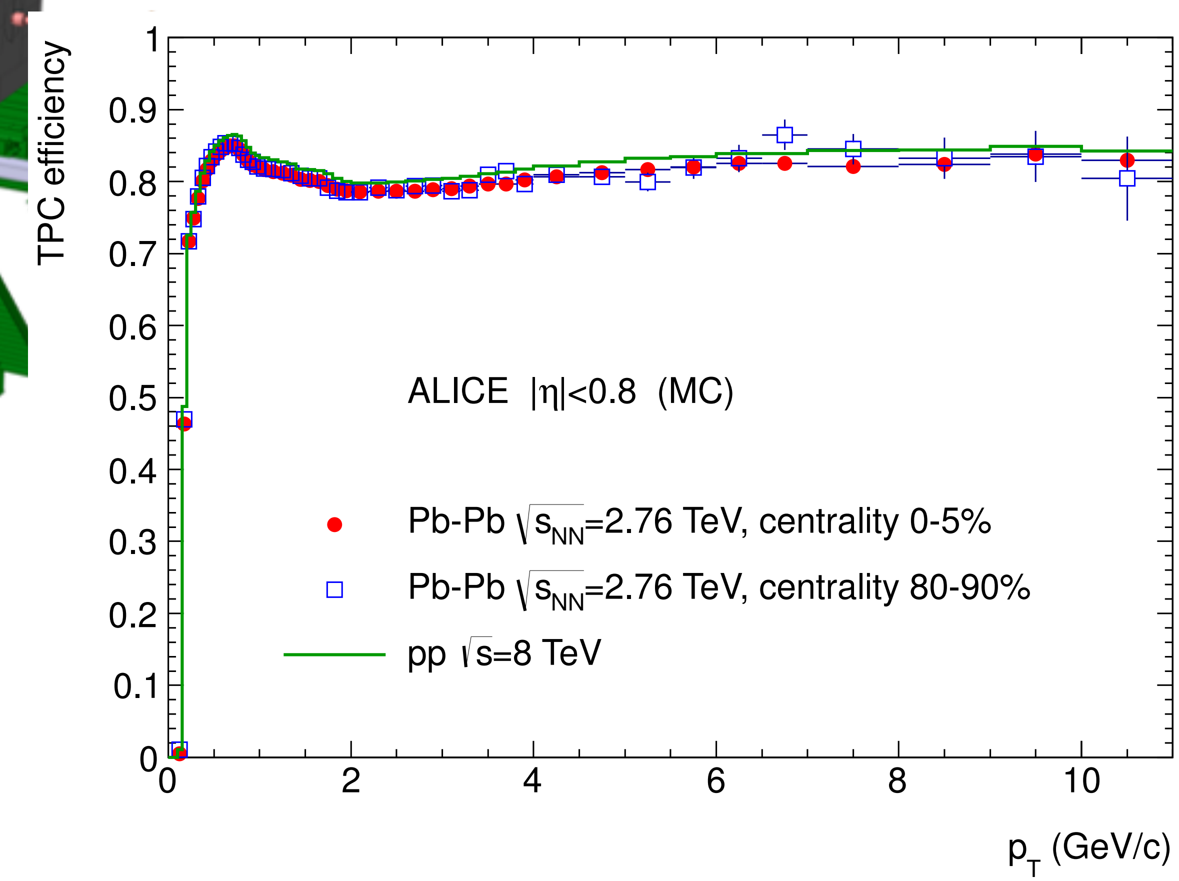
A Large Ion Collider Experiment (ALICE)



Tracking devices:

ITS: Inner Tracking System (silicon)
TPC: Time Projection Chamber

$|\eta| < 0.9$, $0 < \varphi < 2\pi$
Track $p_T > 150$ MeV/c



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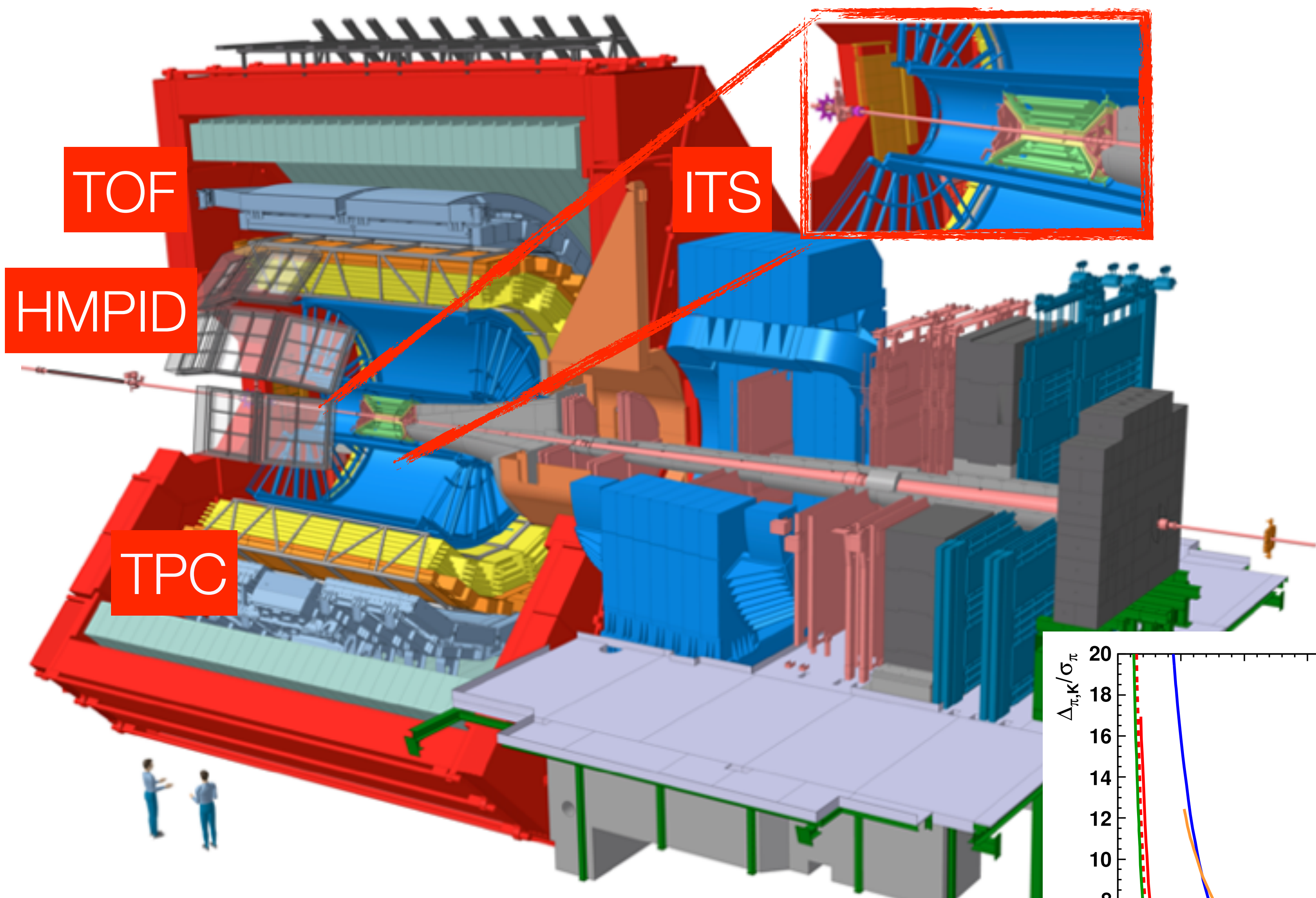
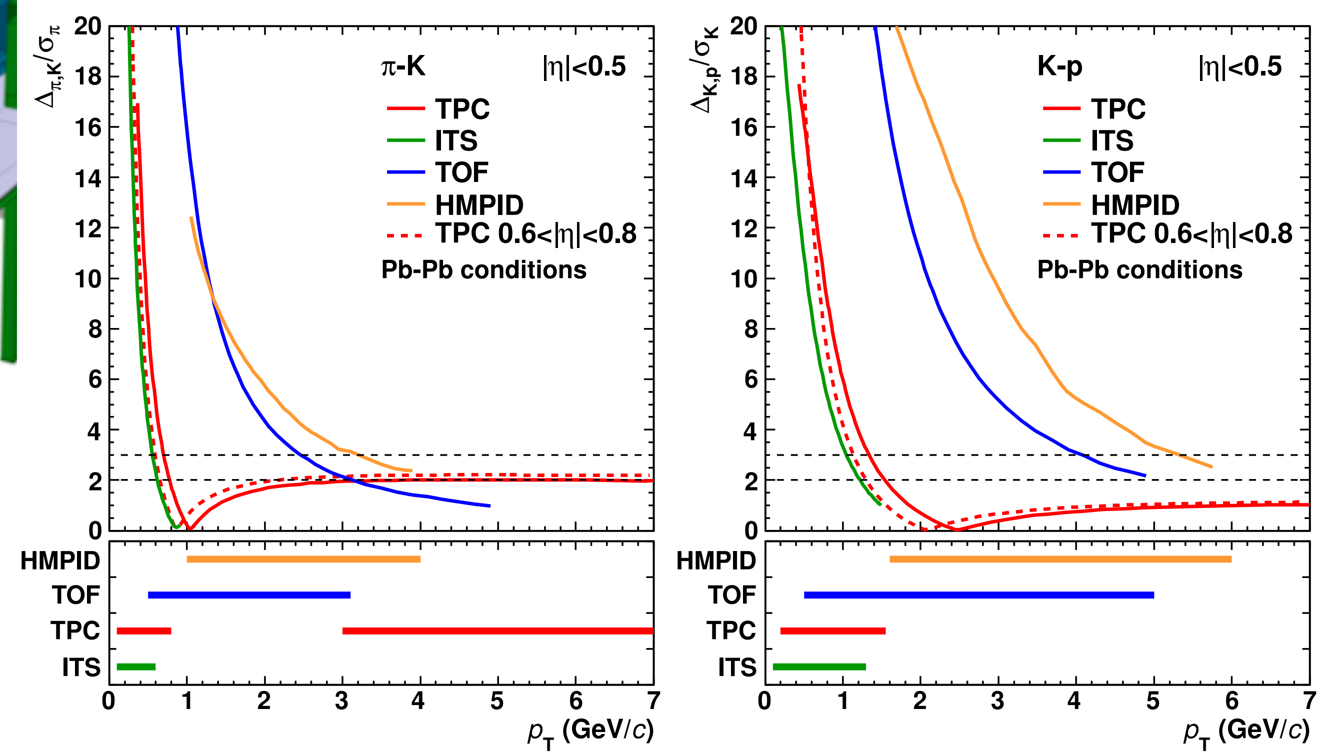


Hadron PID using:
ITS - TPC
via specific ⟨dE/dx⟩ in the detectors

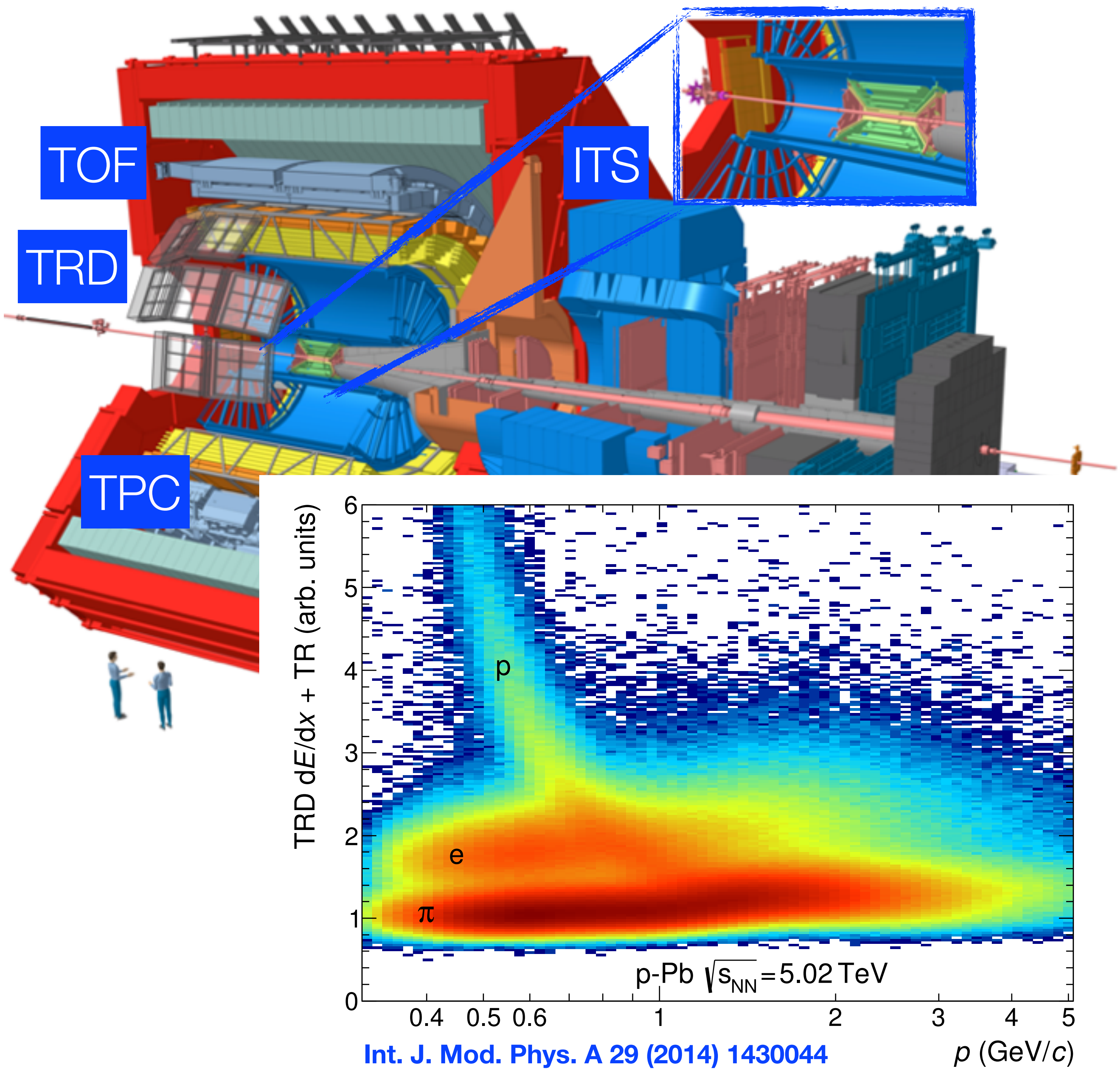
TOF based on Multi-Gap Resistive Plate chambers

High-Momentum PID Cherenkov radiation detector



Int. J. Mod. Phys. A 29 (2014) 1430044

A Large Ion Collider Experiment (ALICE)



Electron PID using:

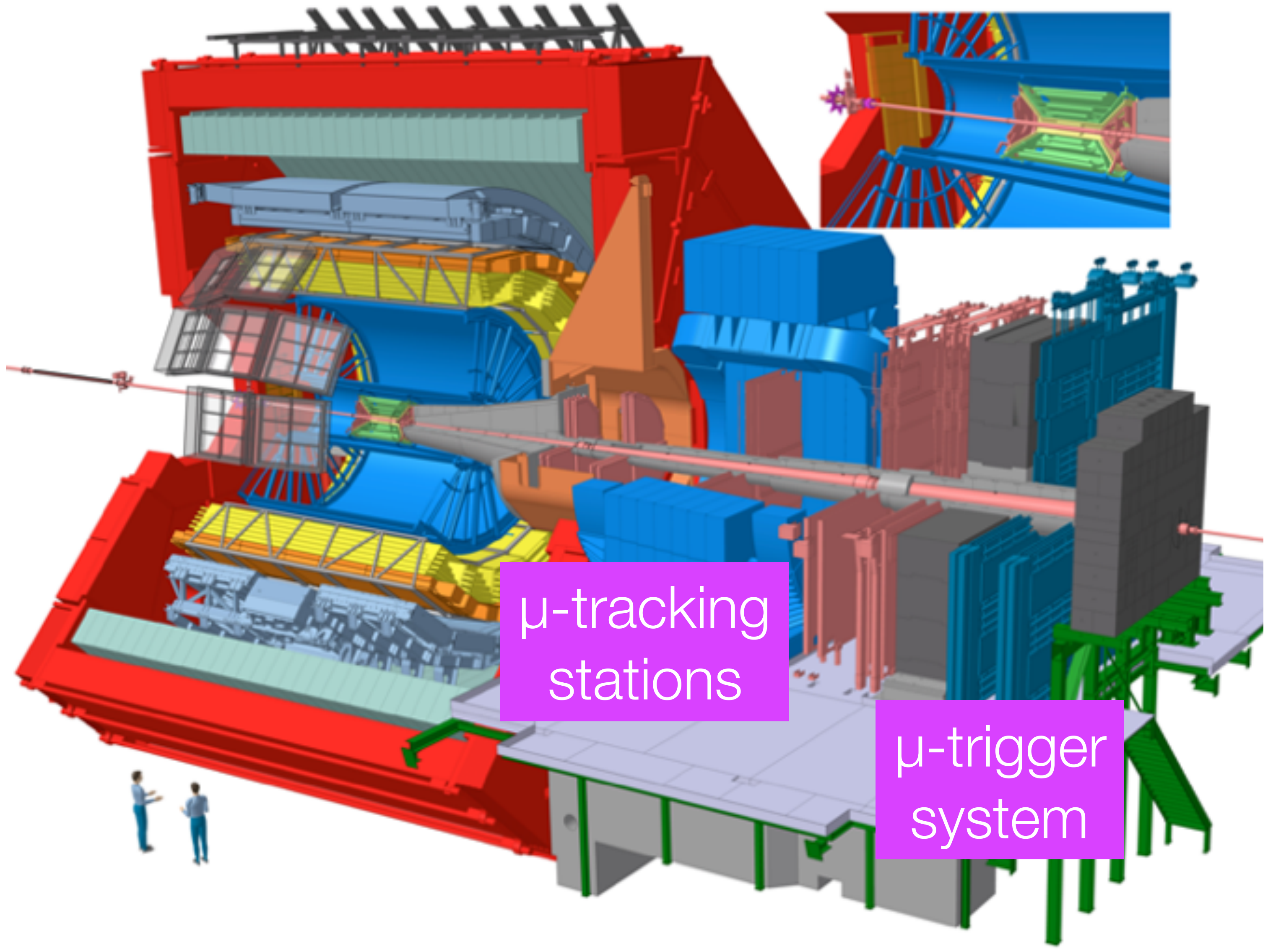
ITS - TPC
via specific ⟨dE/dx⟩ in the detectors

TOF based on Multi-Gap Resistive Plate chambers

Transition Radiation Detector (TRD)

ElectroMagnetic Calorimeter (EMCal)

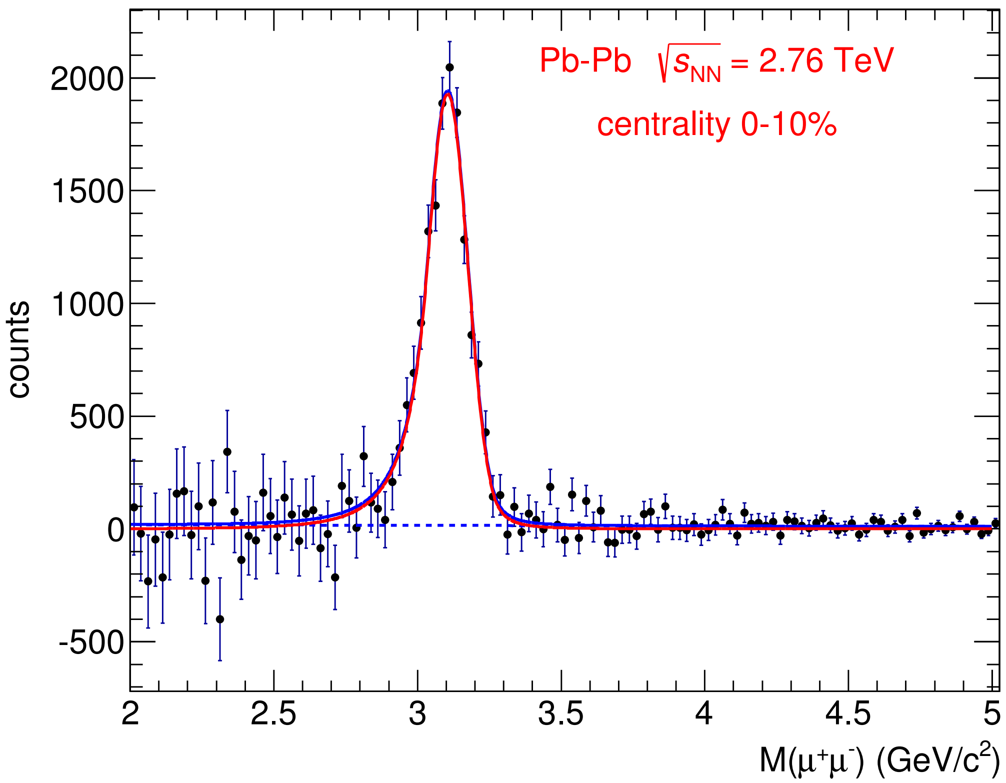
A Large Ion Collider Experiment (ALICE)



Muon spectrometer:
$-4 < \eta < -2.5$

Track $p_T > 1.0$ GeV/c

μ-ID via tracks matched with the trigger system.



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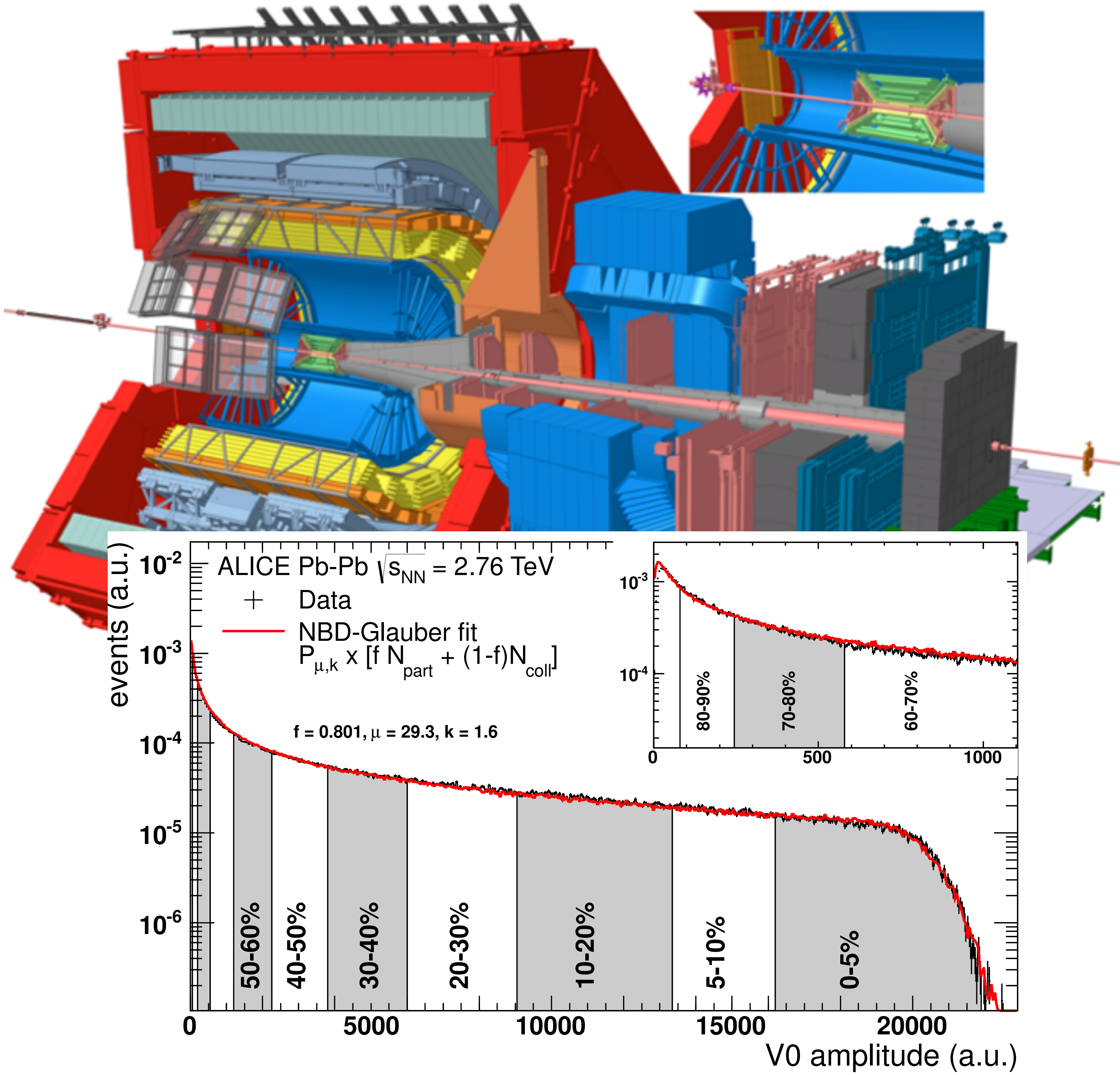


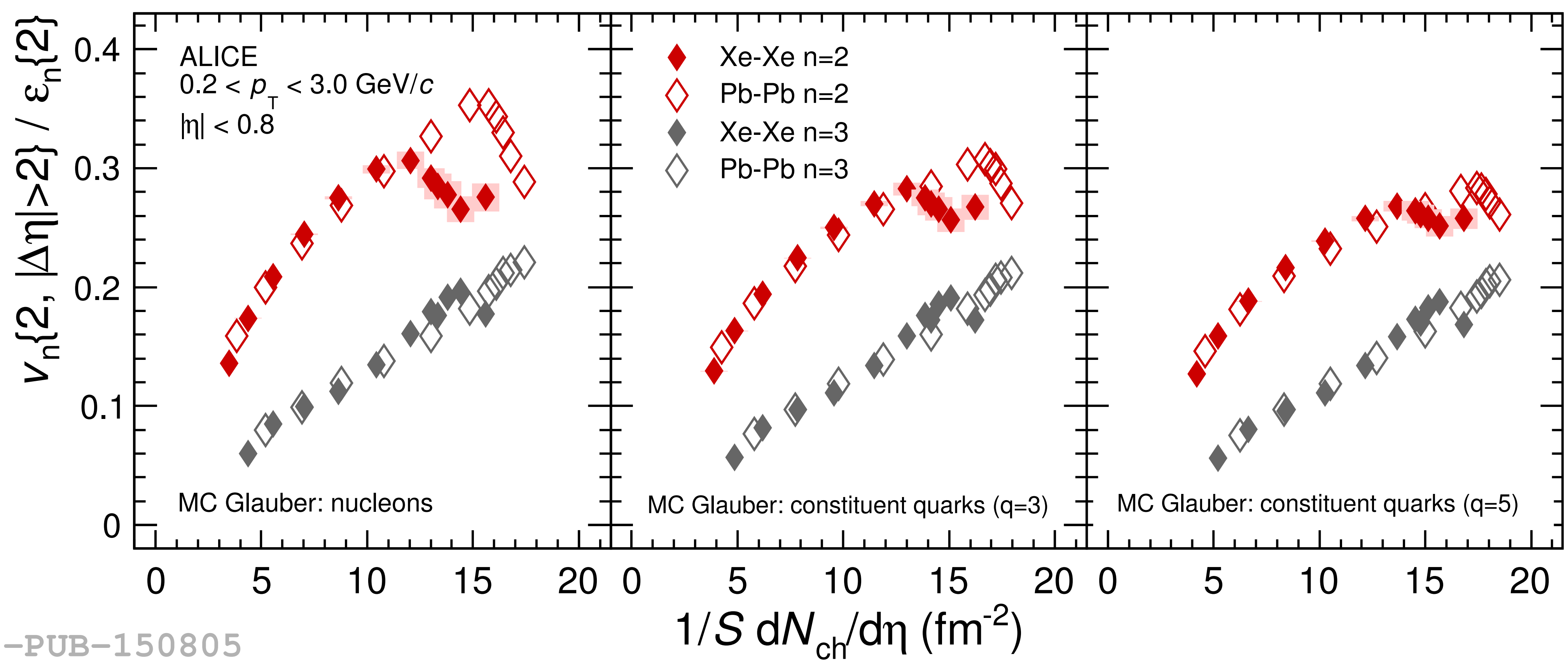
Forward detectors:

- **V0 detector**
  $2.8 < \eta < 5.1$
  $-3.7 < \eta < -1.7$
  trigger
  beam-background reduction, centrality, event plane determination.

- **T0 detector**
  $4.6 < \eta < 4.9$
  $-3.3 < \eta < -3.0$
  luminosity
  collision time-zero

- **Zero Degree Calorimeter**
  ~ 112.m from IP
  beam-background reduction
  centrality determination

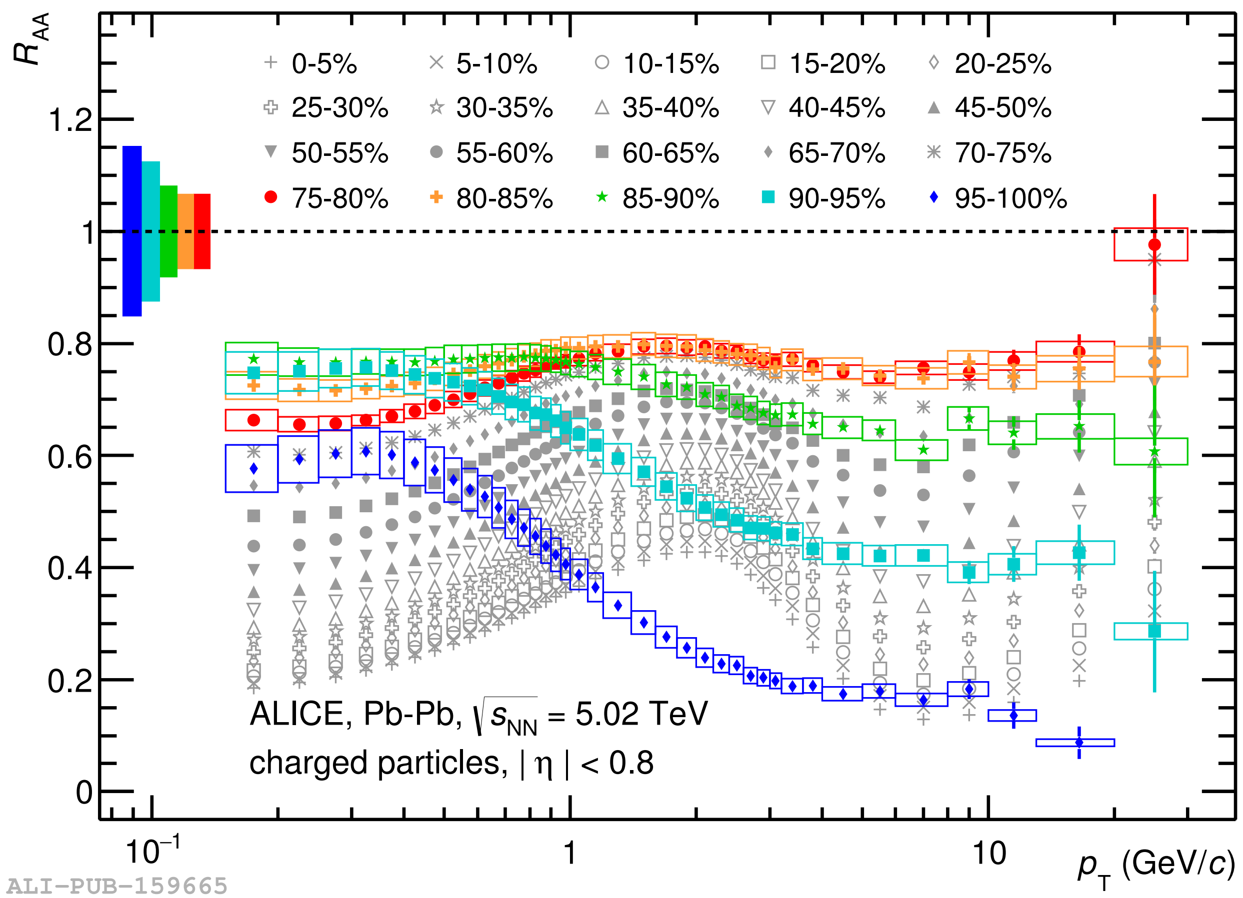
Elliptic flow in Xe-Xe and Pb-Pb

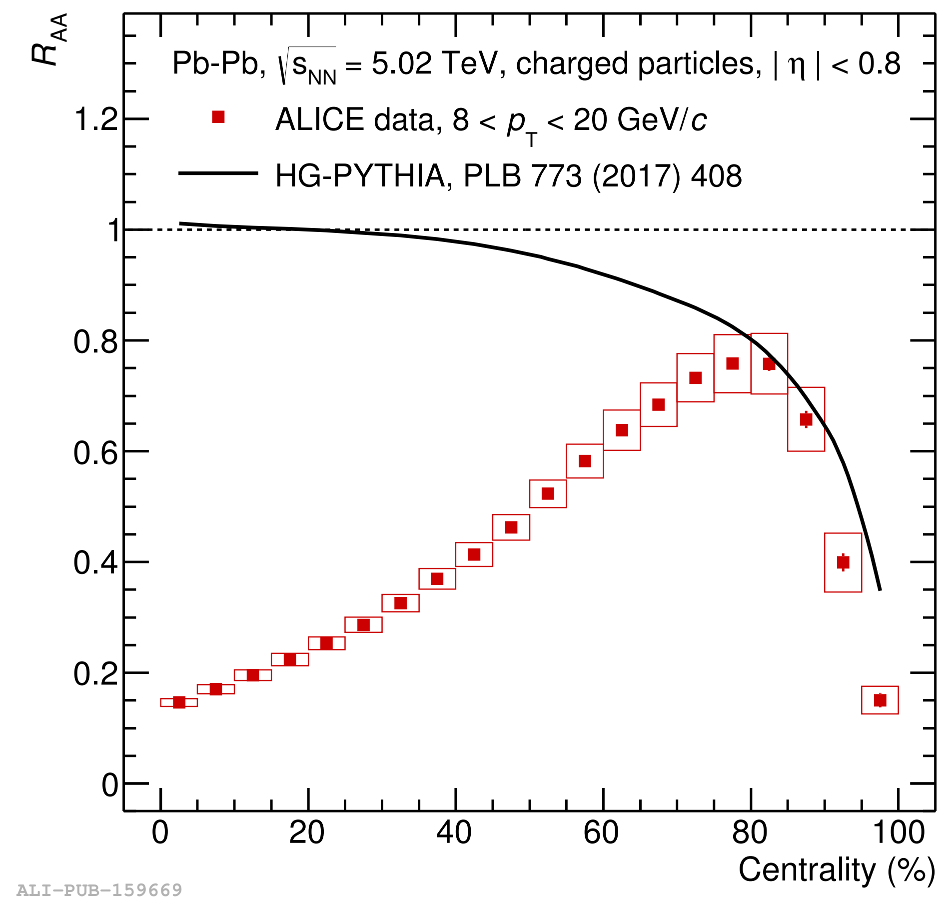


- Scaling with transverse density and eccentricity (hydro) is restored for initial conditions modeled with constituent quark Glauber including Xe deformation.

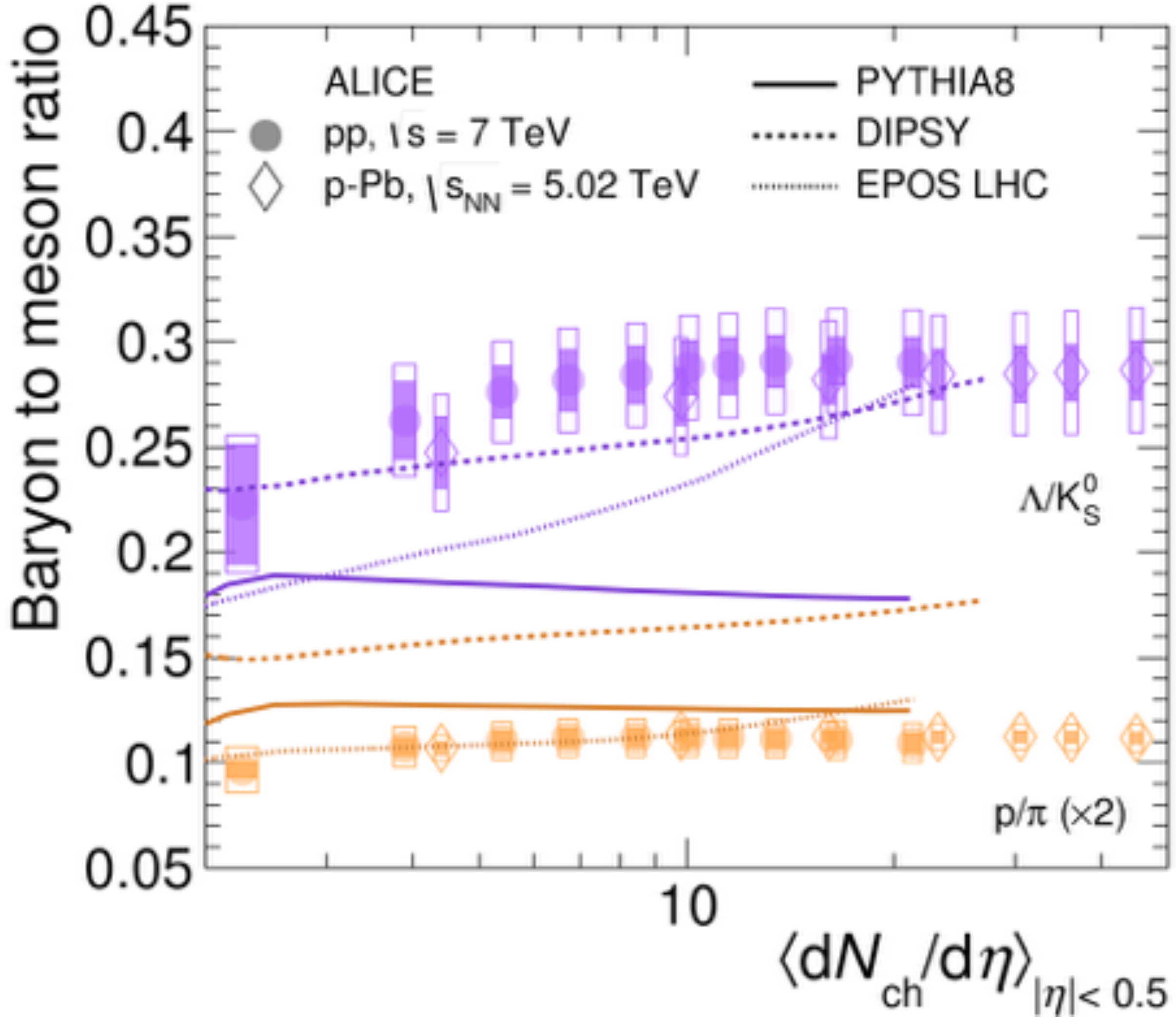
R_{AA} in very peripheral collisions

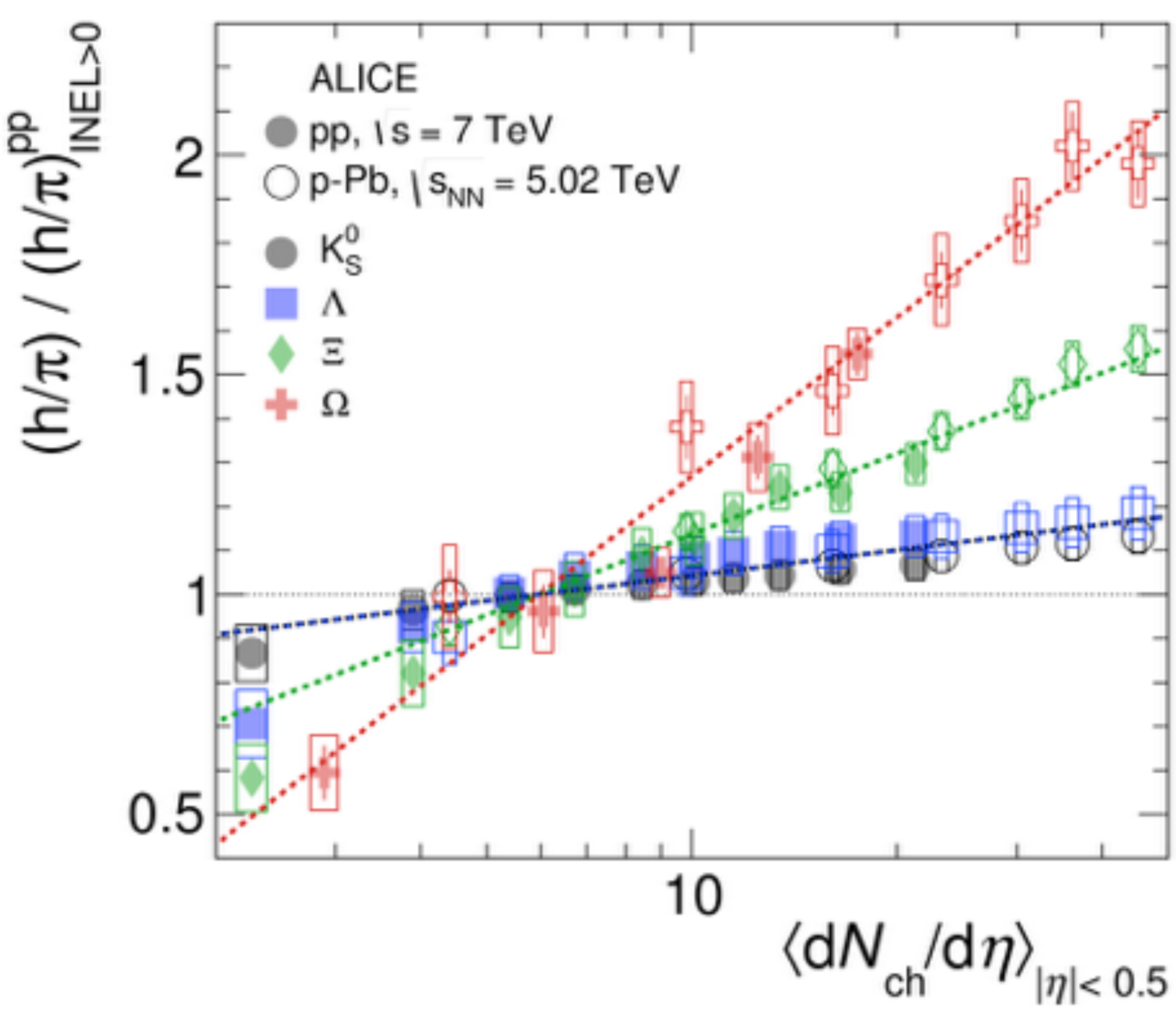
- R_{AA} measured in very fine centrality bins up to very peripheral collisions
- Significant change of behavior beyond 80% centrality
- Explained by bias in event selection and collision geometry and in agreement with PYTHIA MC (no energy loss)



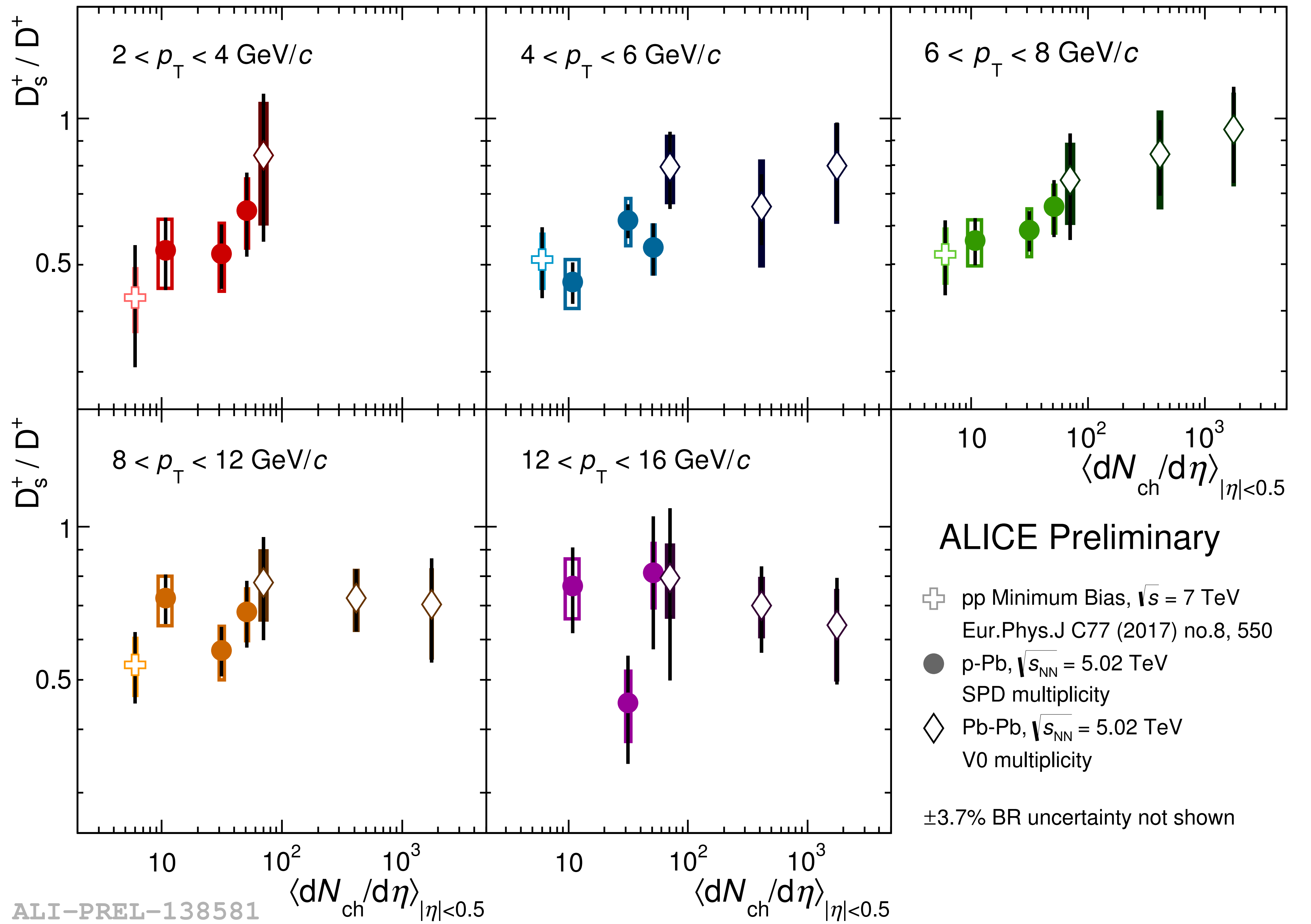


Strangeness production vs particle multiplicity





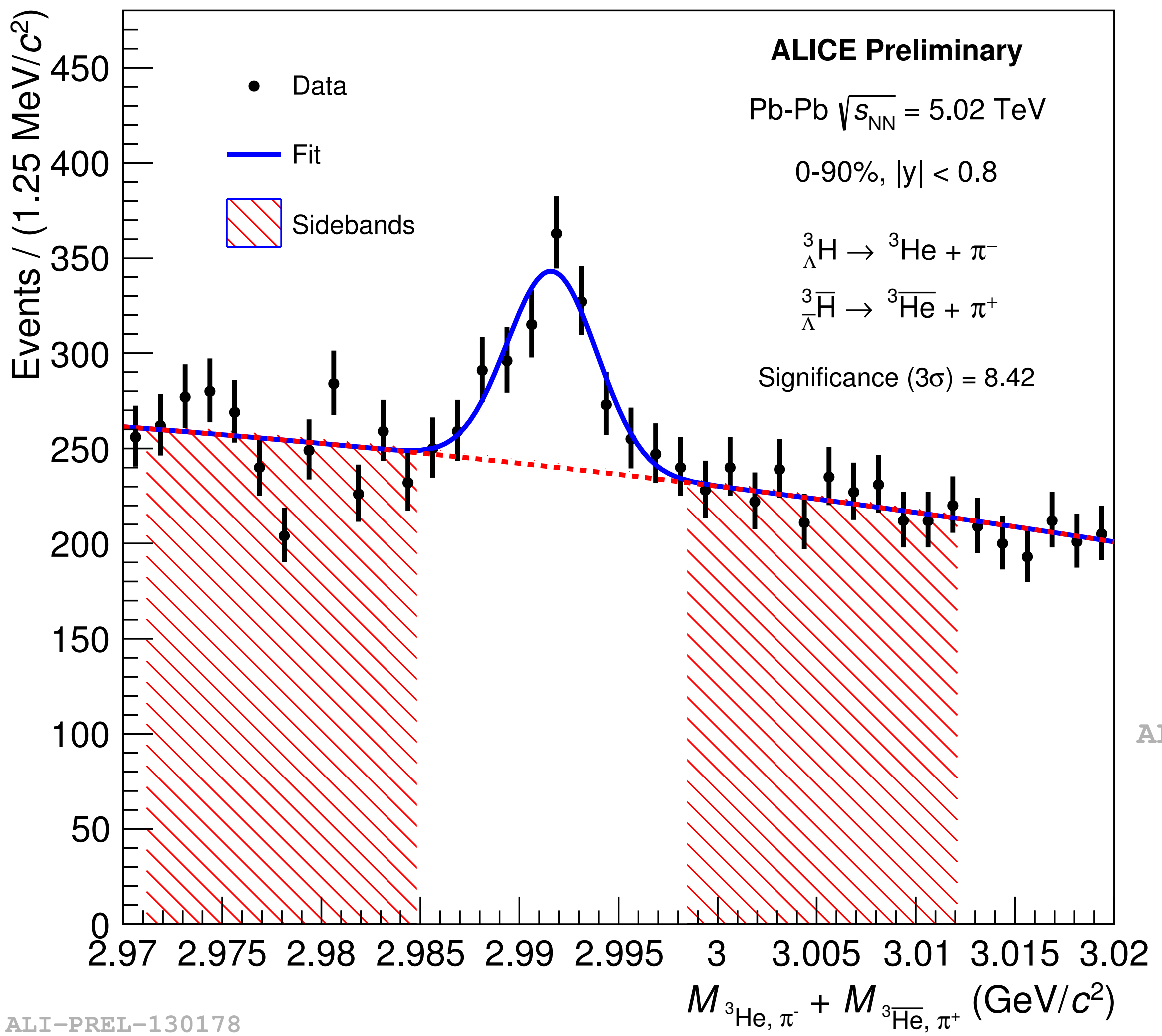
Charm production vs particle multiplicity

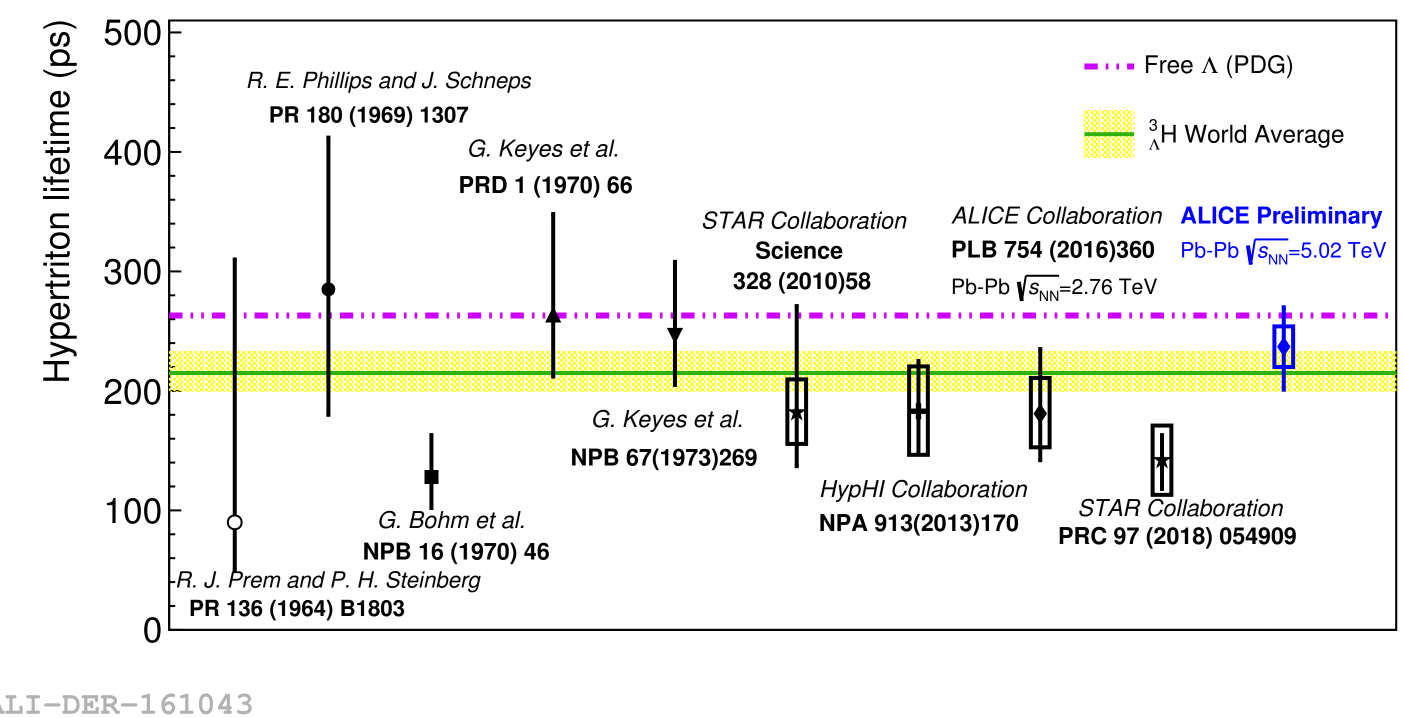


Nuclei production

- Measurement of the hypertriton life time
- pnΛ bound state

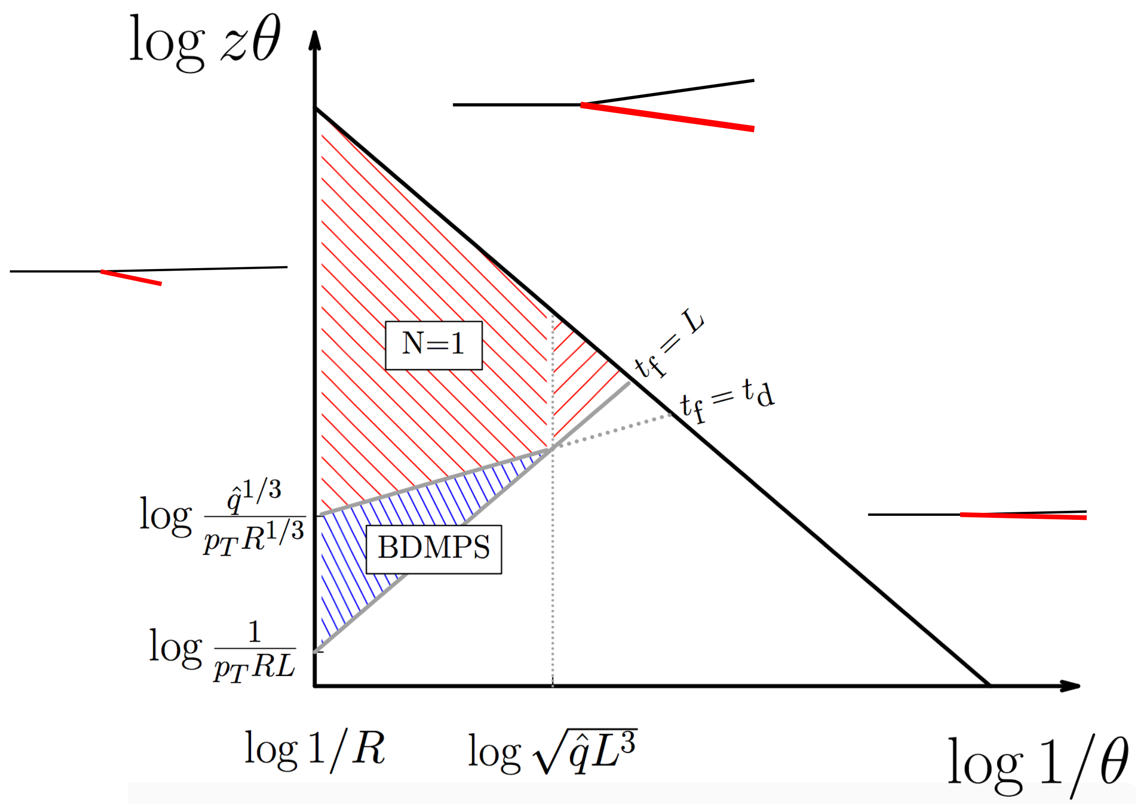
$$ {}^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\,\mathrm{He} + \pi^{-} $$





Splitting in the medium

- Map of the splitting in the medium studied via the Lund diagram
- Iterative de-clustering unwinds the jet structure and stores splitting information
- Cambridge/Achen algorithm is used to de-cluster the jets, preserving the angular ordering



Tywoniuk et al. 5th Heavy Ion Jet Workshop/CERN TH institute

A. J. Larkoski, S. Marzani, G. Soyez, J. Thaler JHEP 05 (2014) 146

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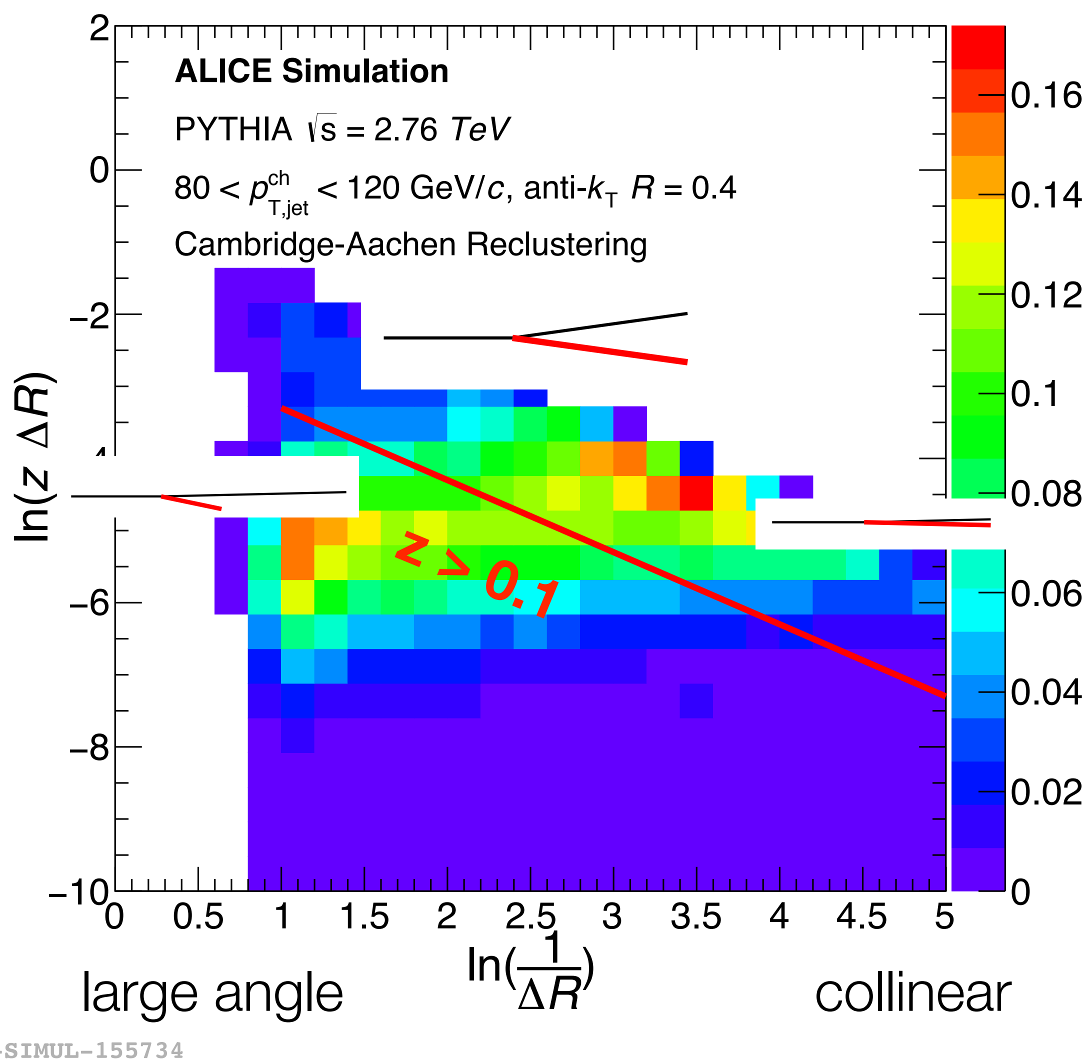
- Iterative de-clustering unwinds the jet structure and stores splitting information
- Cambridge/Achen algorithm is used to de-cluster the jets, preserving the angular ordering
- Focus on different region of the Lund diagram phase-space imposing different grooming conditions

$$z > z_{cut}\theta^{\beta}$$

Soft Drop[2] /mMDT Grooming[3]

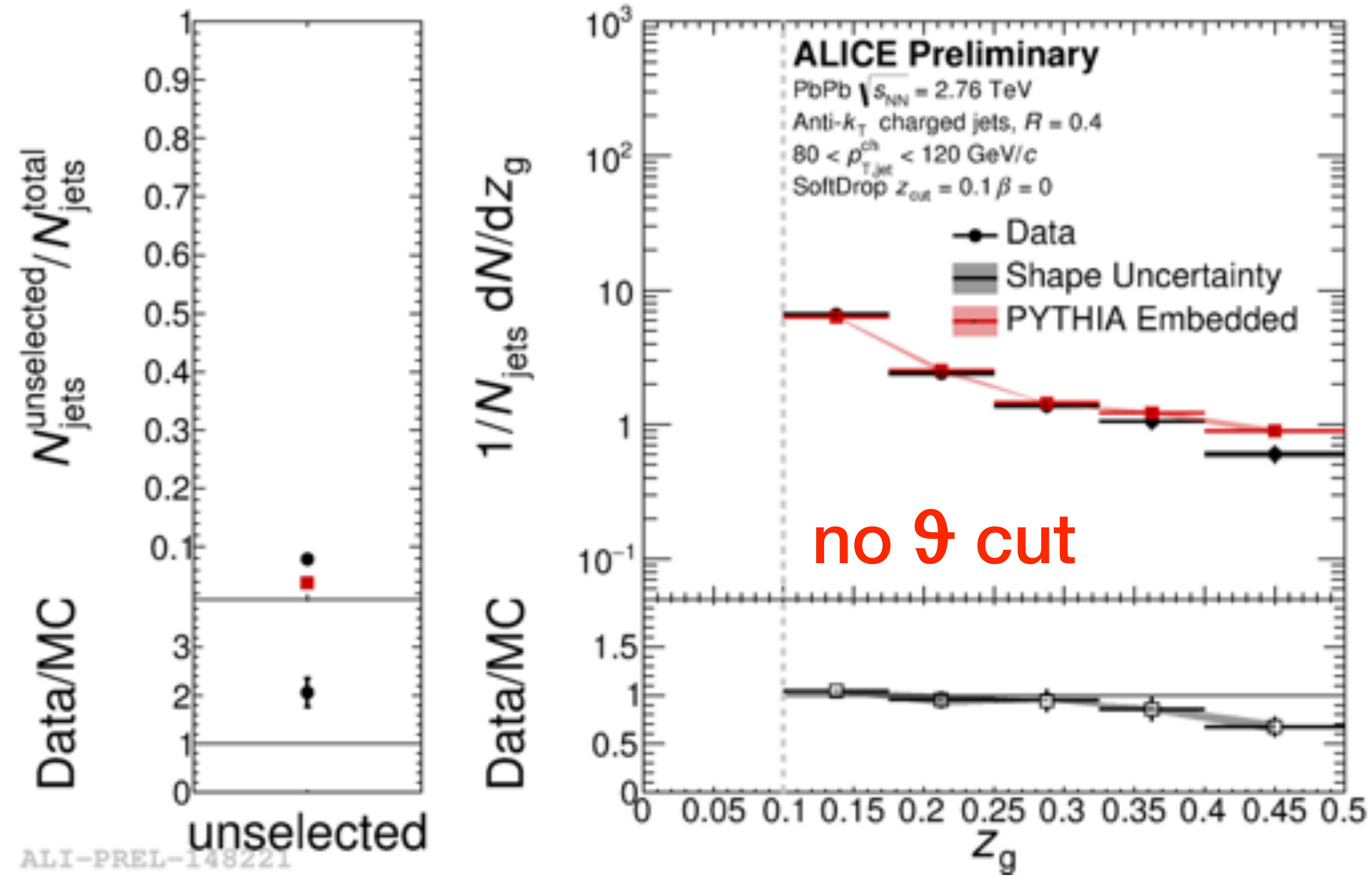


[1] G. Salam gitlab.cern.ch/gsalam/2017-lund-from-MC
[2] M. Dasgupta et al. JHEP 1309 (2013) 029
[3] A. Larkoski et al. JHEP 1405 (2014) 146

z_g, n_{SD} measurements in Pb-Pb collisions

- Difference in the z_g distribution observed when considering less collimated subjets

Charged jets, R = 0.4, 80 < p_T < 120 GeV/c



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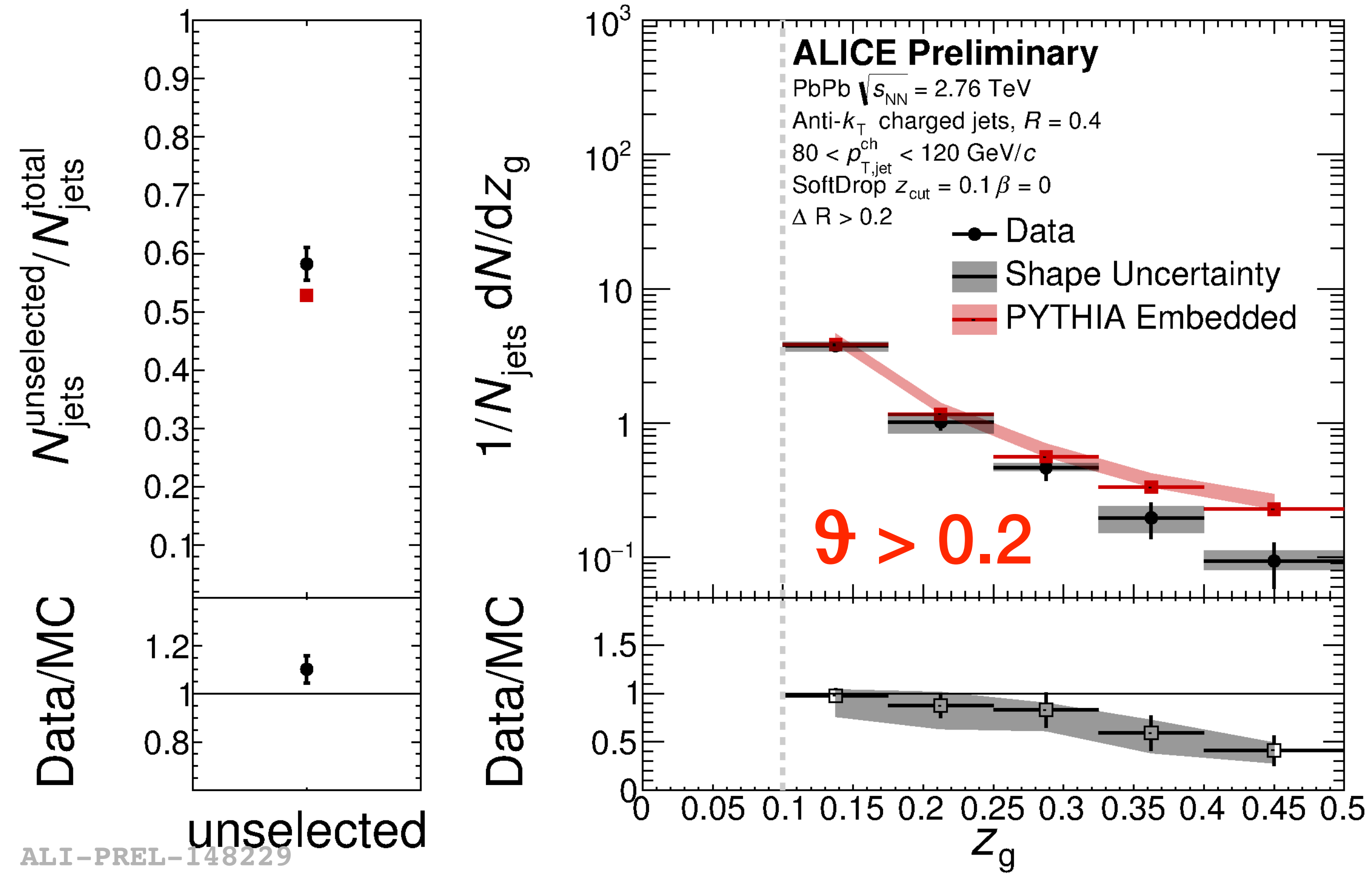

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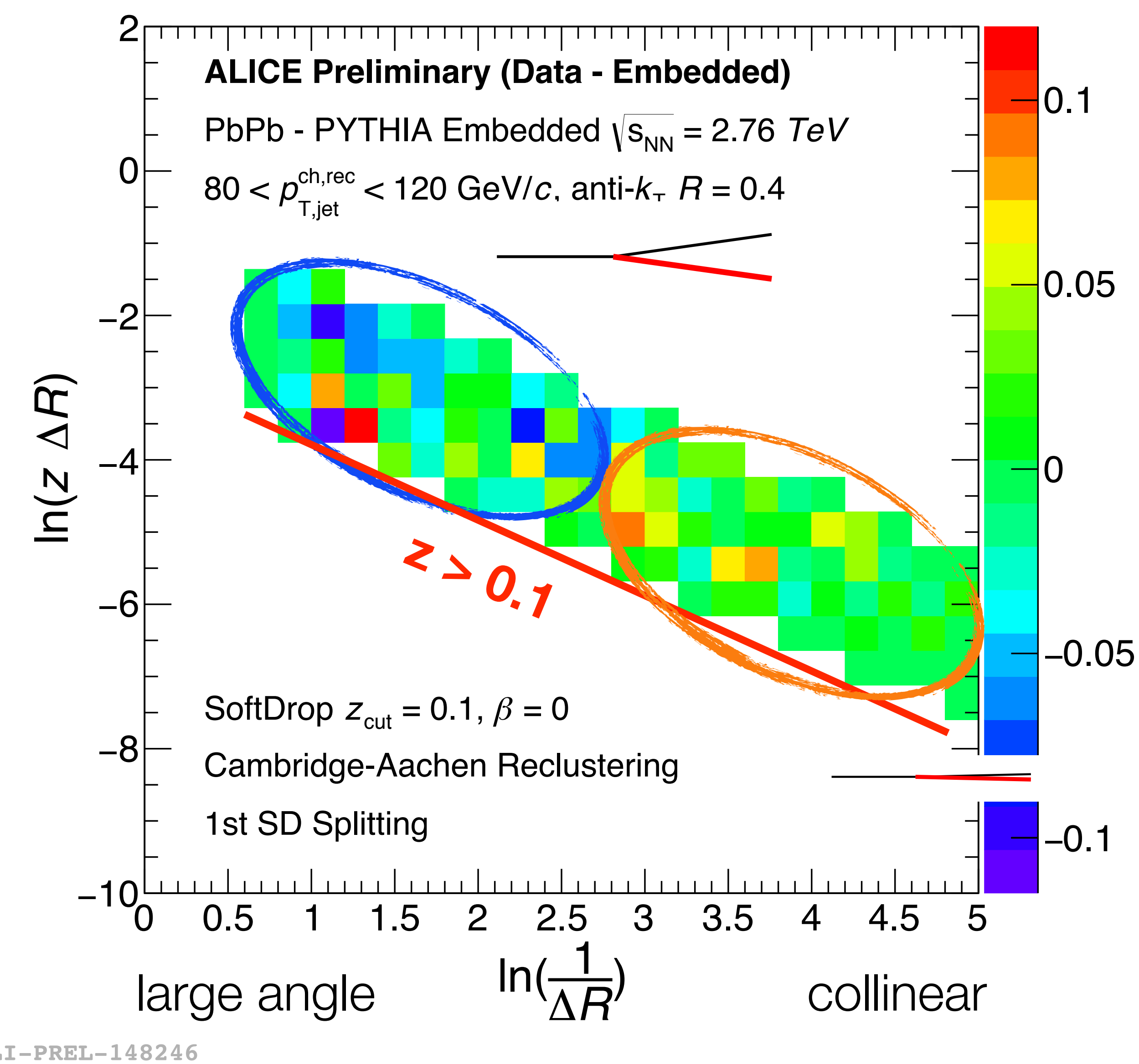

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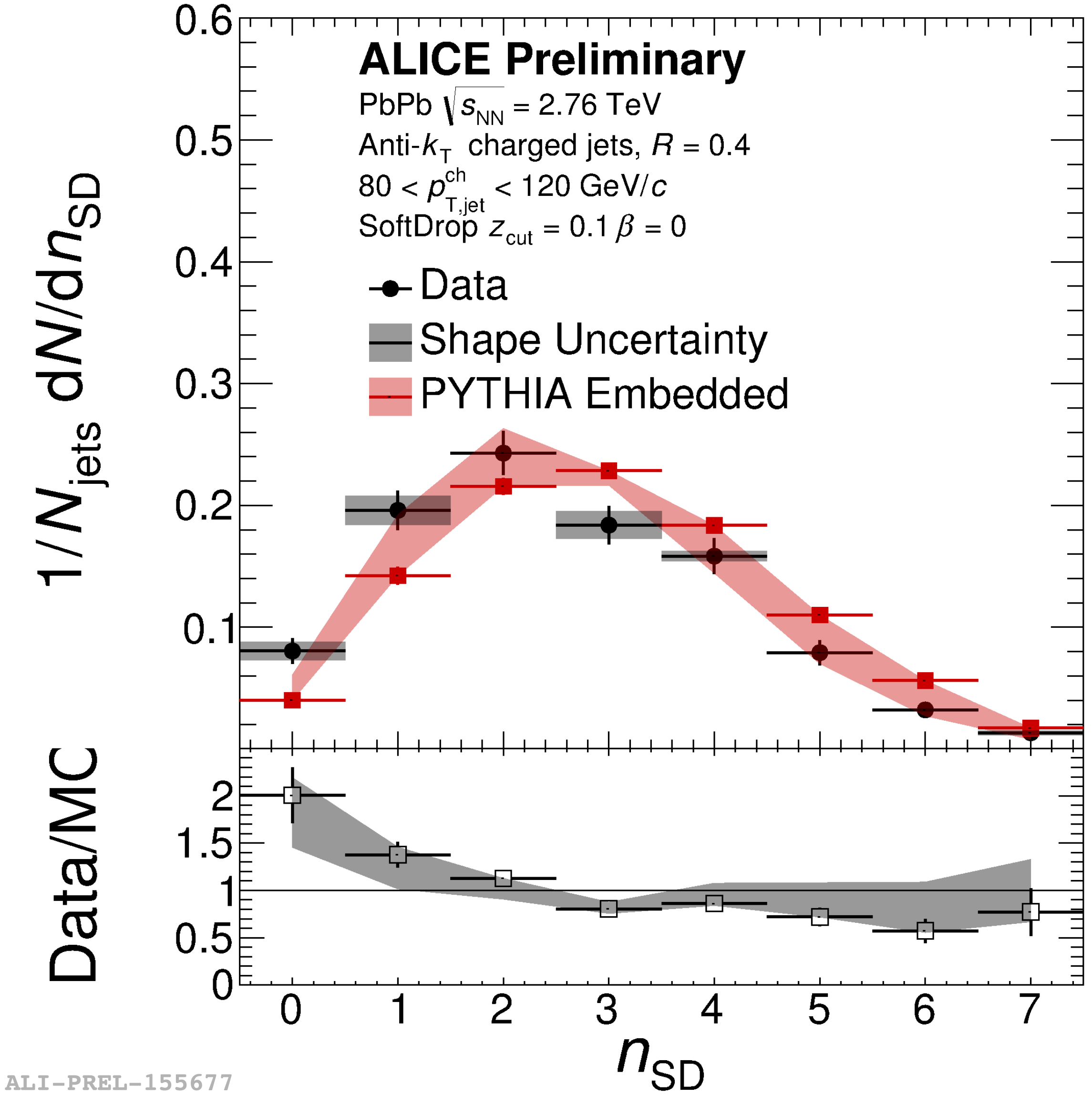
    in Pb-Pb data wrt PYTHIA simulations

- No enhancement in the n_{SD} is present
  - but larger number of jets that don't satisfy the Soft Drop condition in Pb-Pb



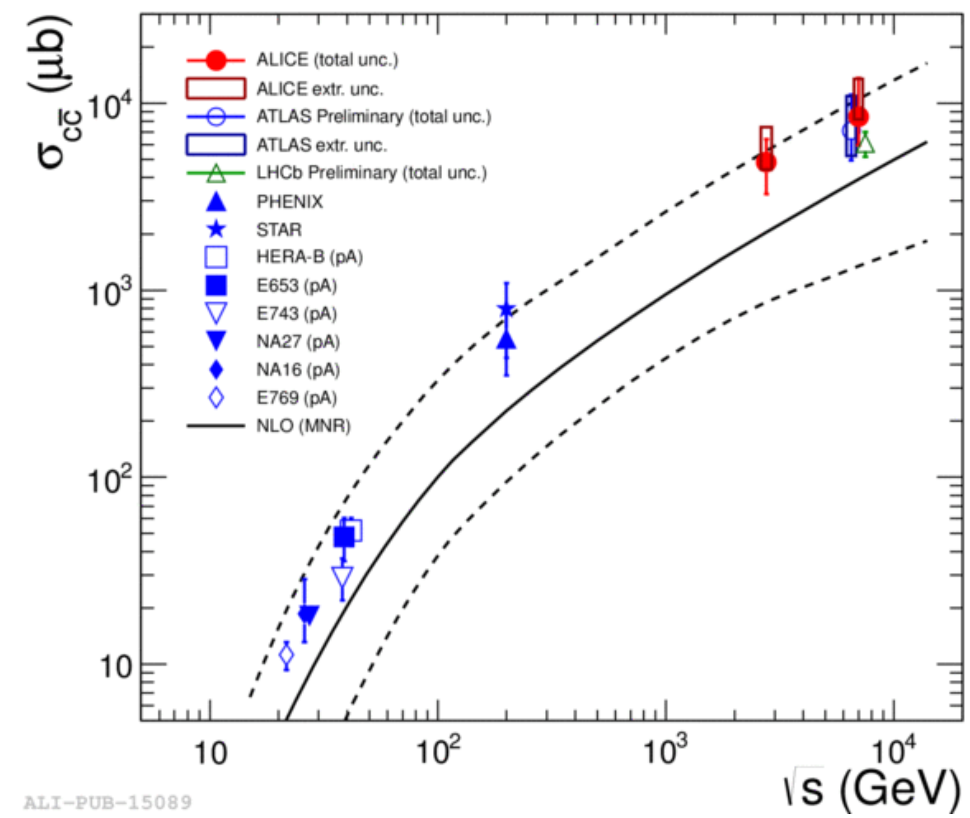
What about regeneration

- Uncorrelated c quarks from the medium could bind at the hadronization of the system and form charmonium.

- At RHIC and LHC, large number of charm pairs produced in central collisions

$$N_{c\bar{c}} = \frac{\sigma^{pp}_{c\bar{c}}}{\sigma^{pp}_{inel}} \cdot N_{coll} \sim \frac{\sigma^{pp}_{c\bar{c}}}{65\ \mathrm{mb}} \cdot 1600$$

	SPS 20 GeV	RHIC 200 GeV	LHC 2.76 TeV
Ncc/ event	~0.1	~10	~100



JHEP1207 (2012) 191

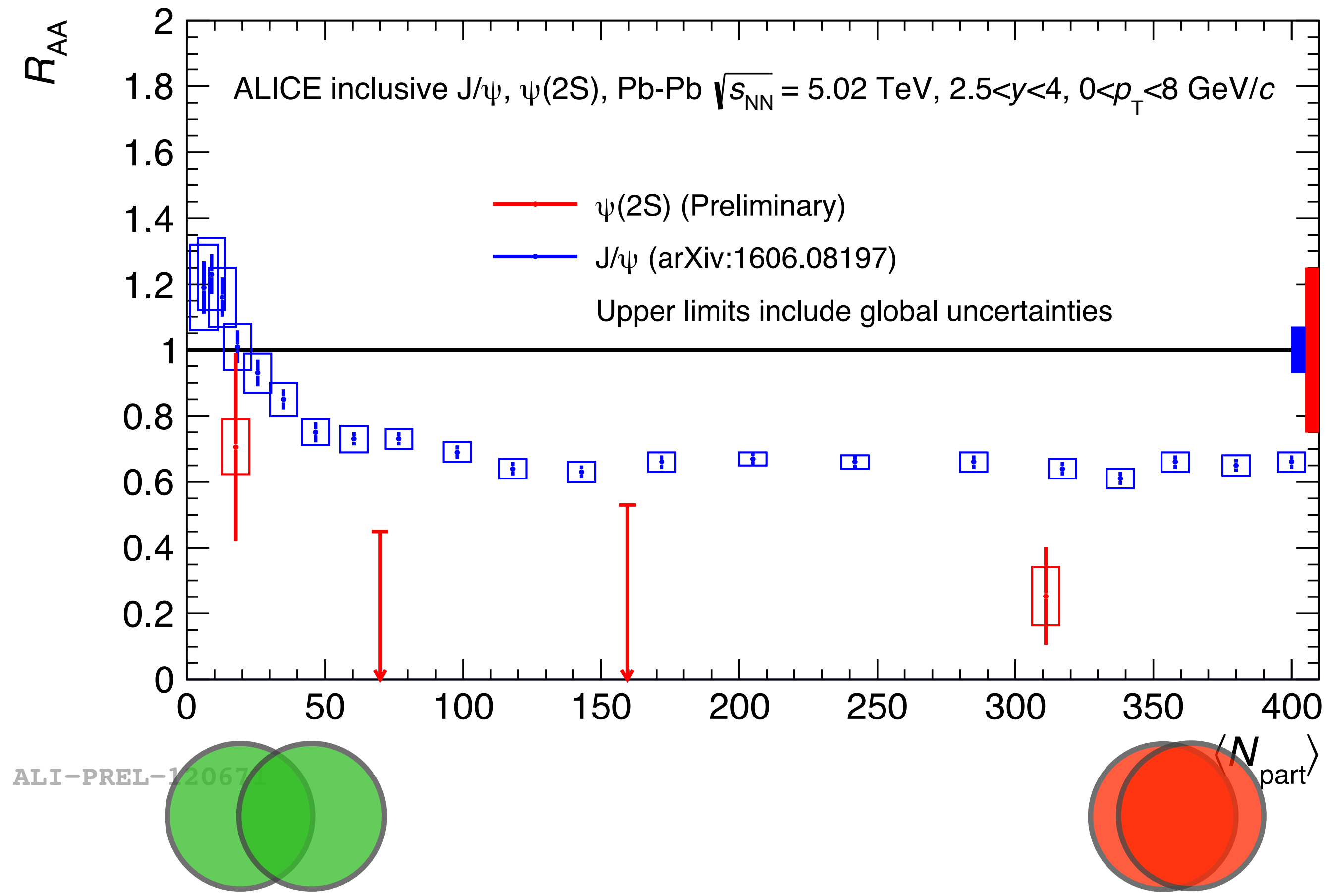
P. Braun-Muzinger and J. Stachel, Phys. Lett. B490(2000) 196
R. Thews et al, Phys.ReV.C63:054905(2001)

- Do we have indication that charm quarks take part in the evolution of the system? Thermalization?

...but not only J/ψ

- **ψ(2S)** is even more suppressed than **J/ψ** for semi central and central collisions.
- more statistic is needed to draw quantitative conclusion

Phys. Lett. B 766 (2017) 212-224



...but not only J/ψ

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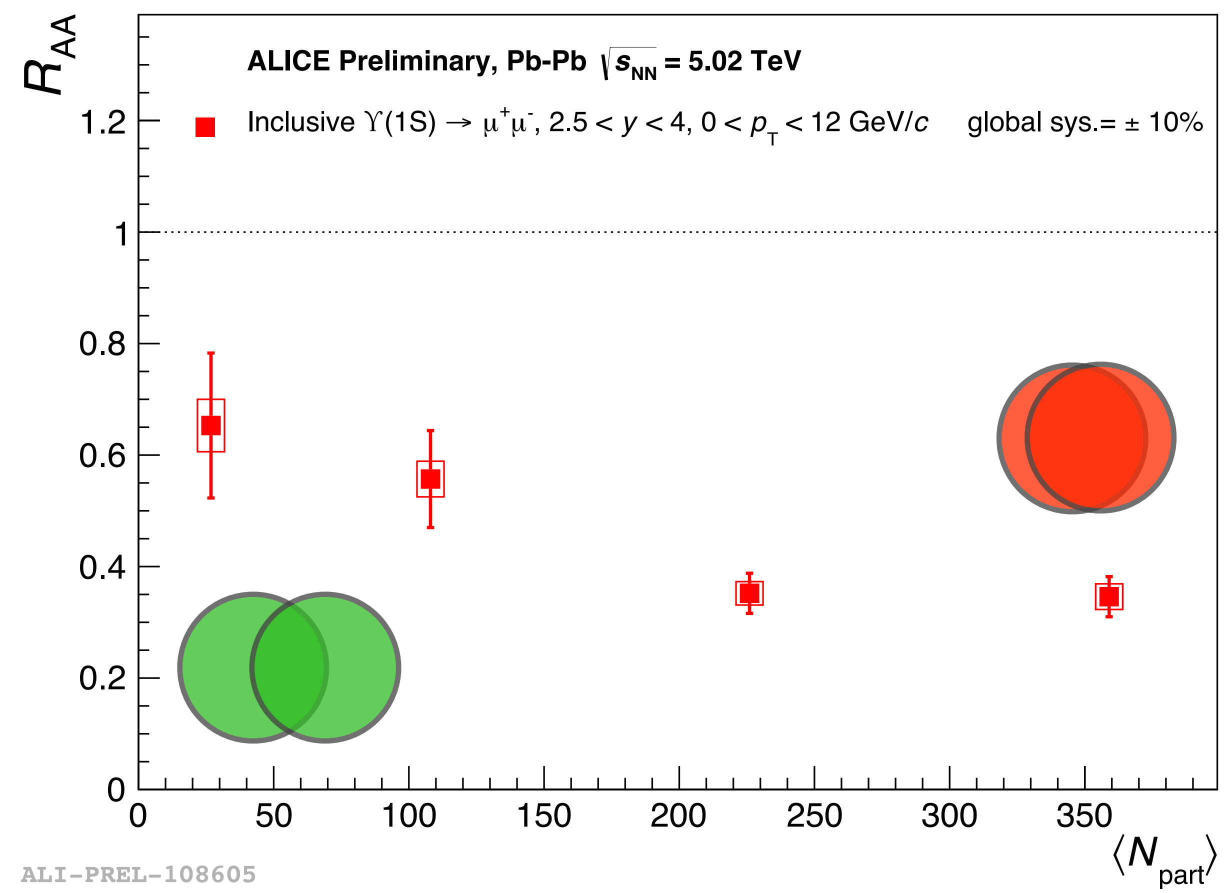
- Strong suppression of the **Υ(1S)** state. More statistic is needed to draw a quantitative conclusion



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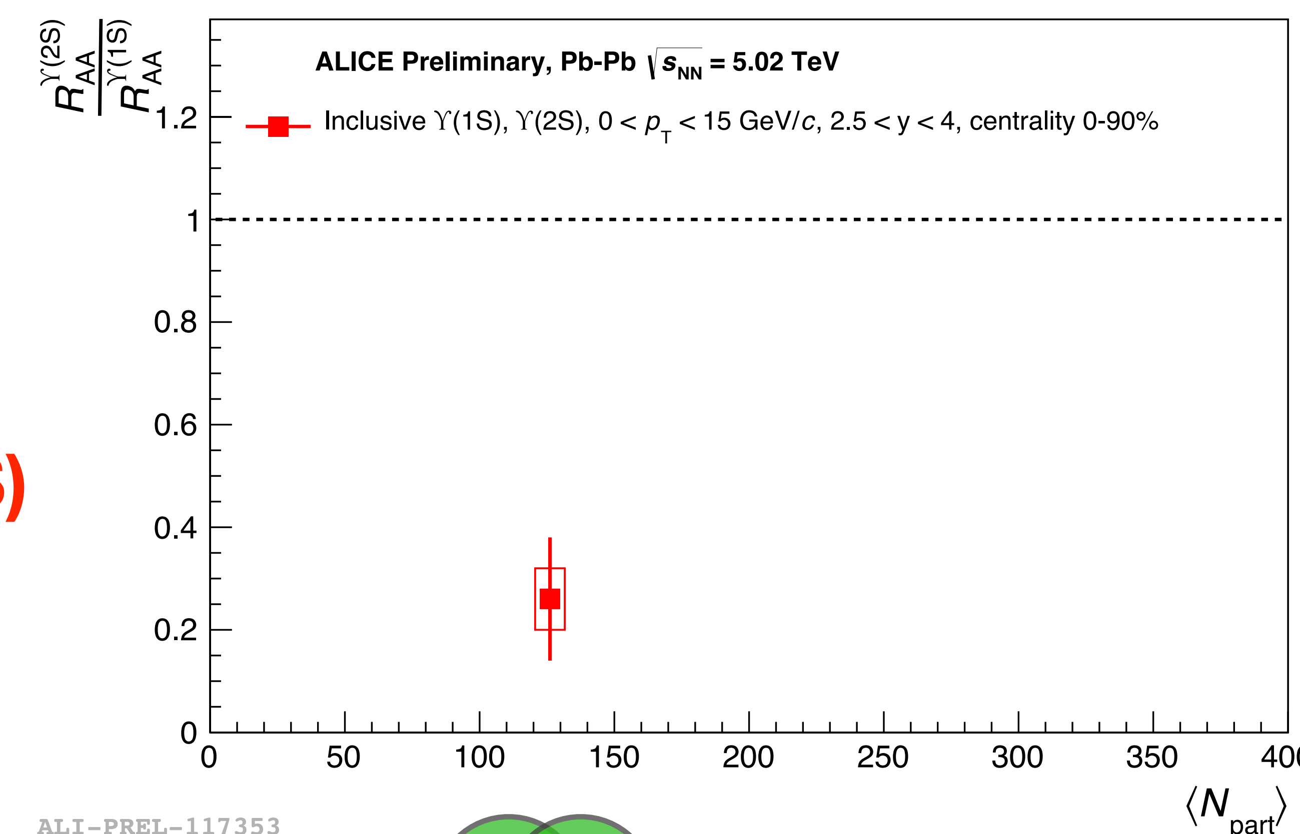
- Strong suppression of the **ϒ(1S)** state. More statistic is needed to draw a quantitative conclusion

- Stronger suppression of the **ϒ(2S)** state than the **ϒ(1S)**
- also here more statistics is needed to improve the results



Does charm also flow?

- Azimuthal anisotropy of particle production related to collective expansion of the medium.
- Can charm quark interact so much and become part of the medium?
- Study of flow of hadrons with charm:
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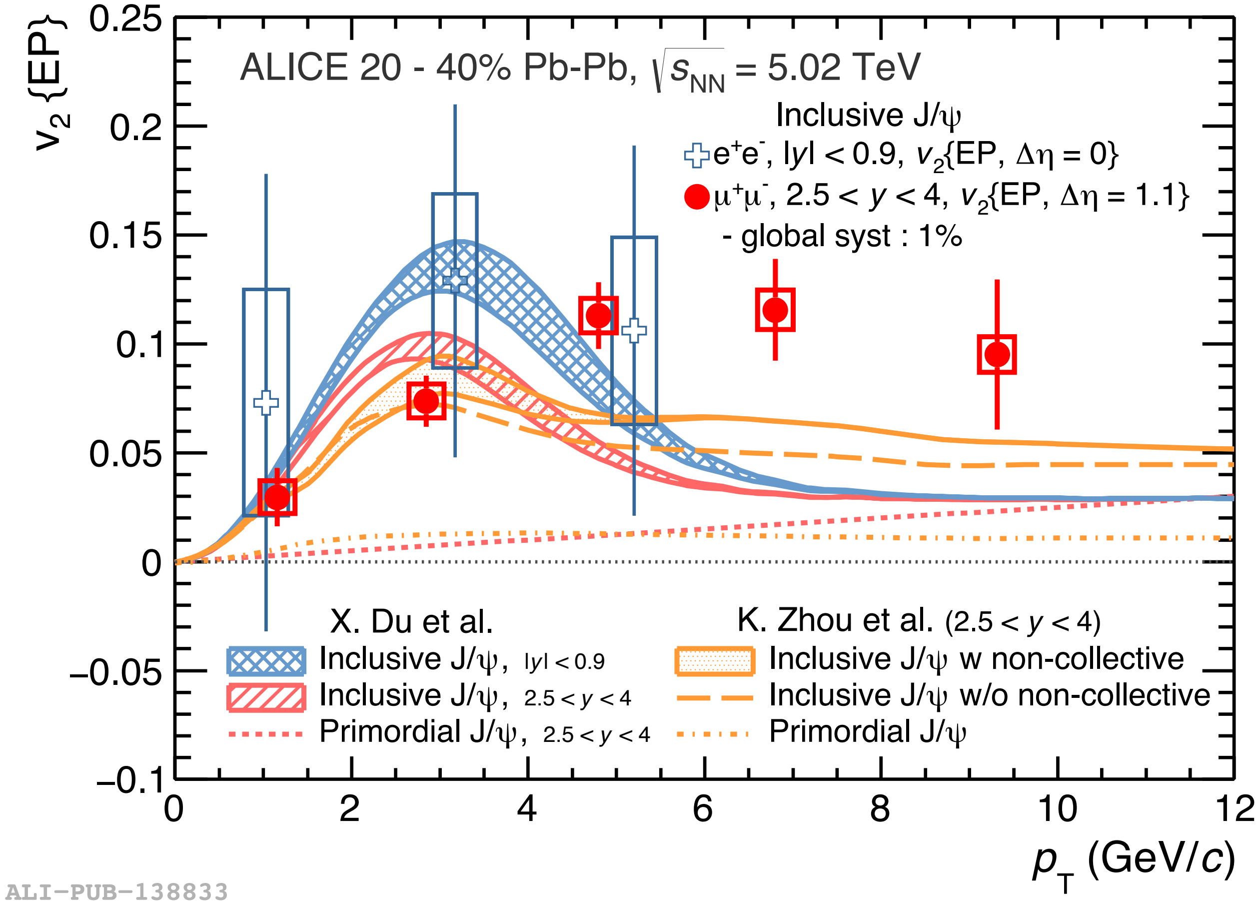

Submitted to PRL, arXiv:170905260

- J/ψ $v_2 > 0$ for intermediate p_T
- Models that include thermalization of charm quarks and J/ψ regeneration can describe the data
- Primordial J/ψ v_2 is expected to be very small

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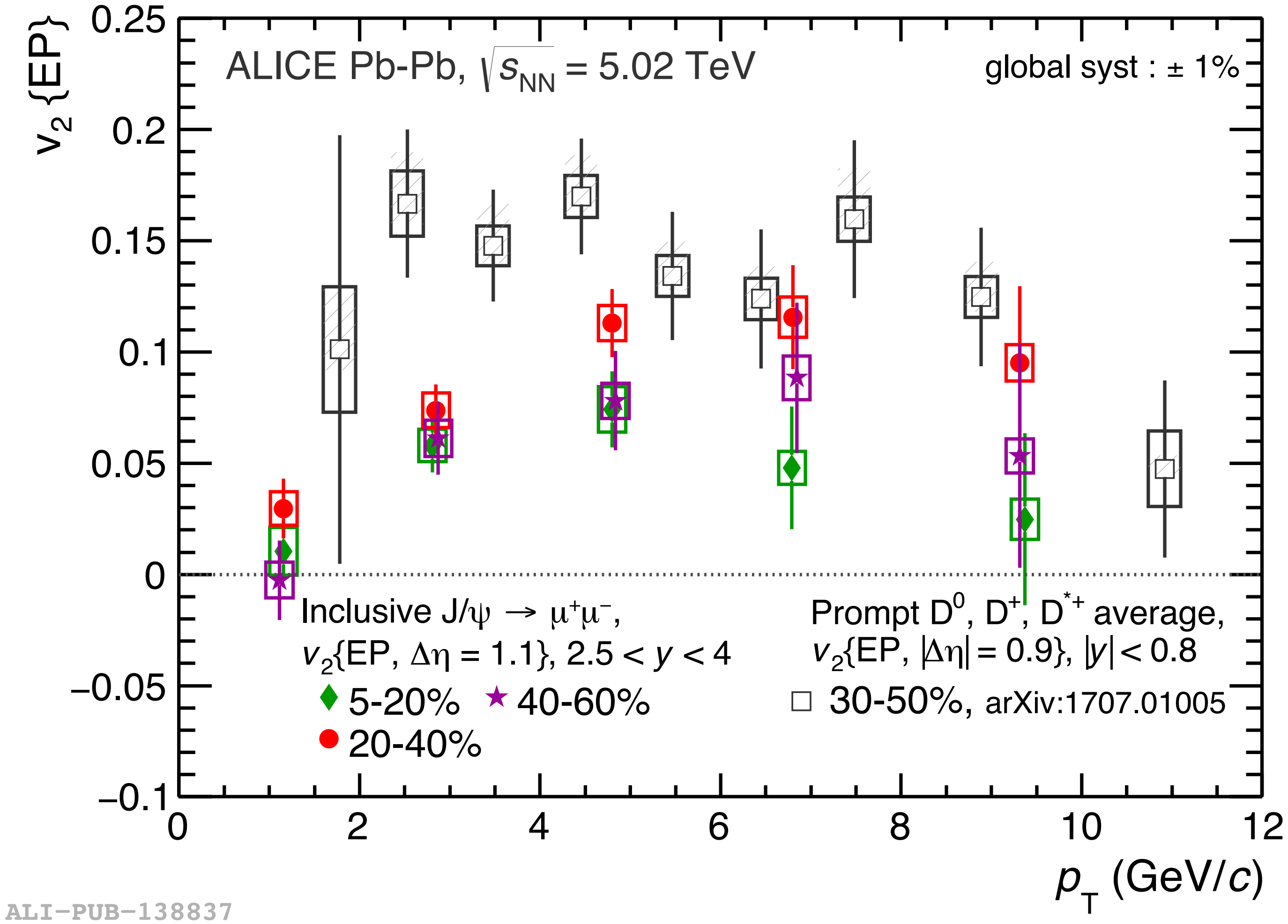
  - D mesons

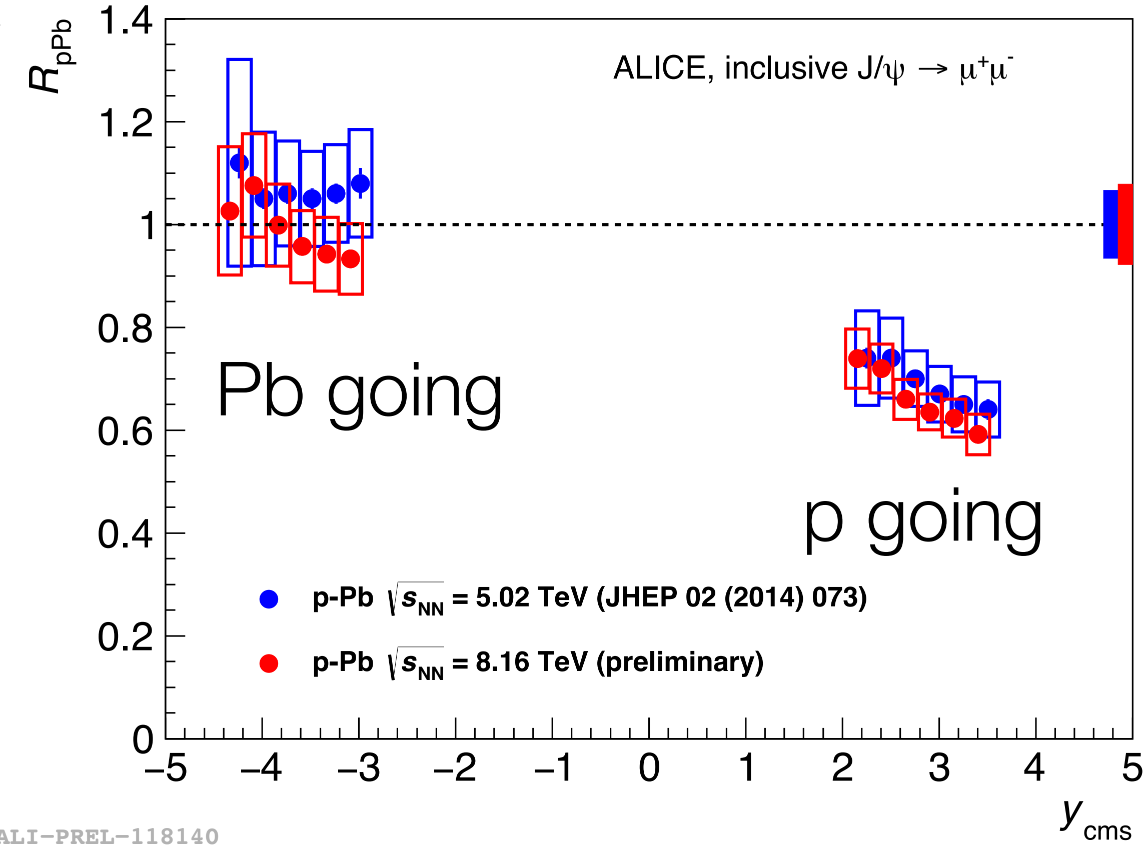


Submitted to PRL, arXiv:170905260

- D mesons $v_2 > 0$ for intermediate p_T
- Another confirmation that charm is slowed down in the medium.
- Recombination of charm and light quarks might generate an higher v_2 than for J/ψ

J/ψ in p-Pb collisions

- J/ψ production is more affected by cold nuclear matter effects than open heavy flavor
- at forward rapidity the J/ψ production is suppressed by about 20%
- not visible difference between $\sqrt{s_{NN}}$ = 5.02 and 8.16 TeV



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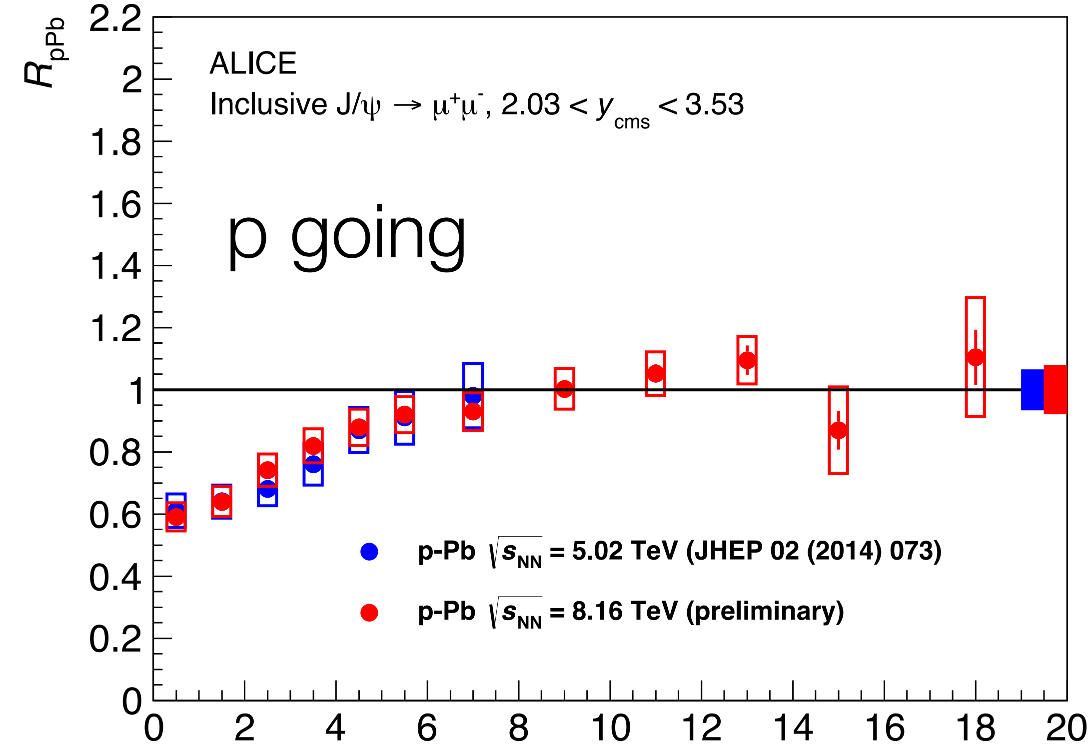

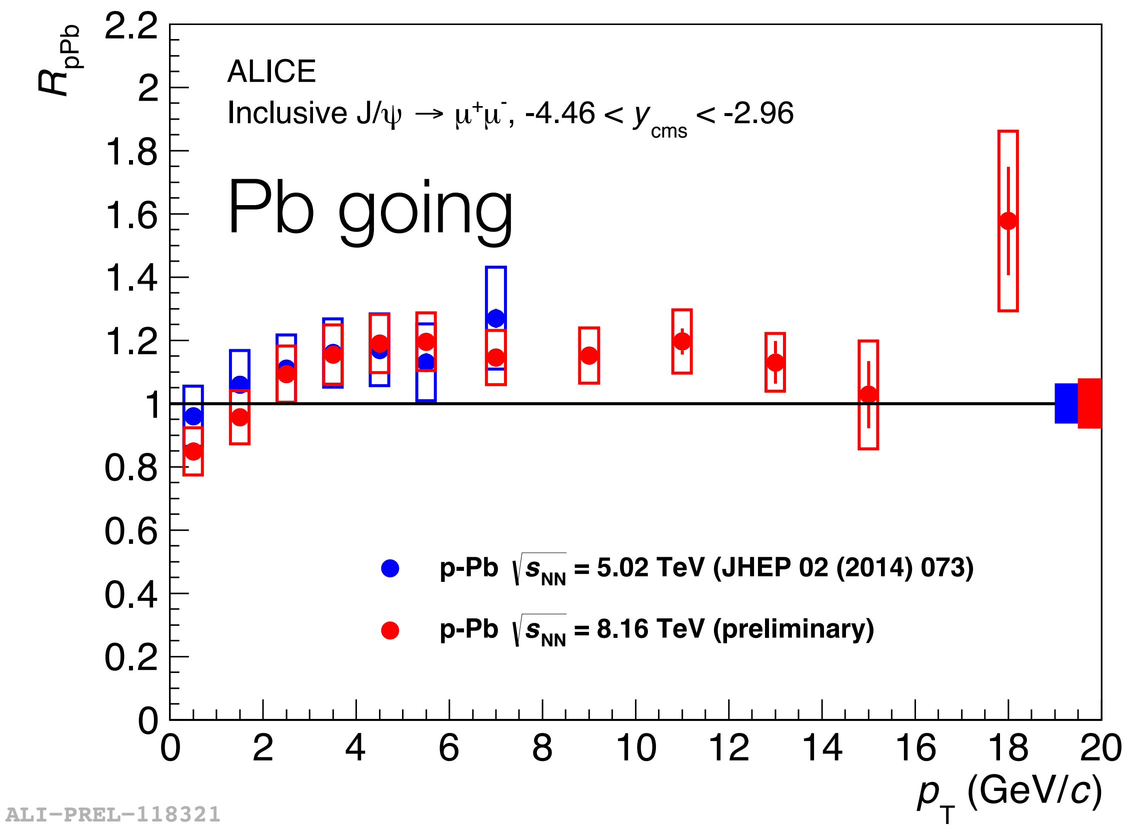

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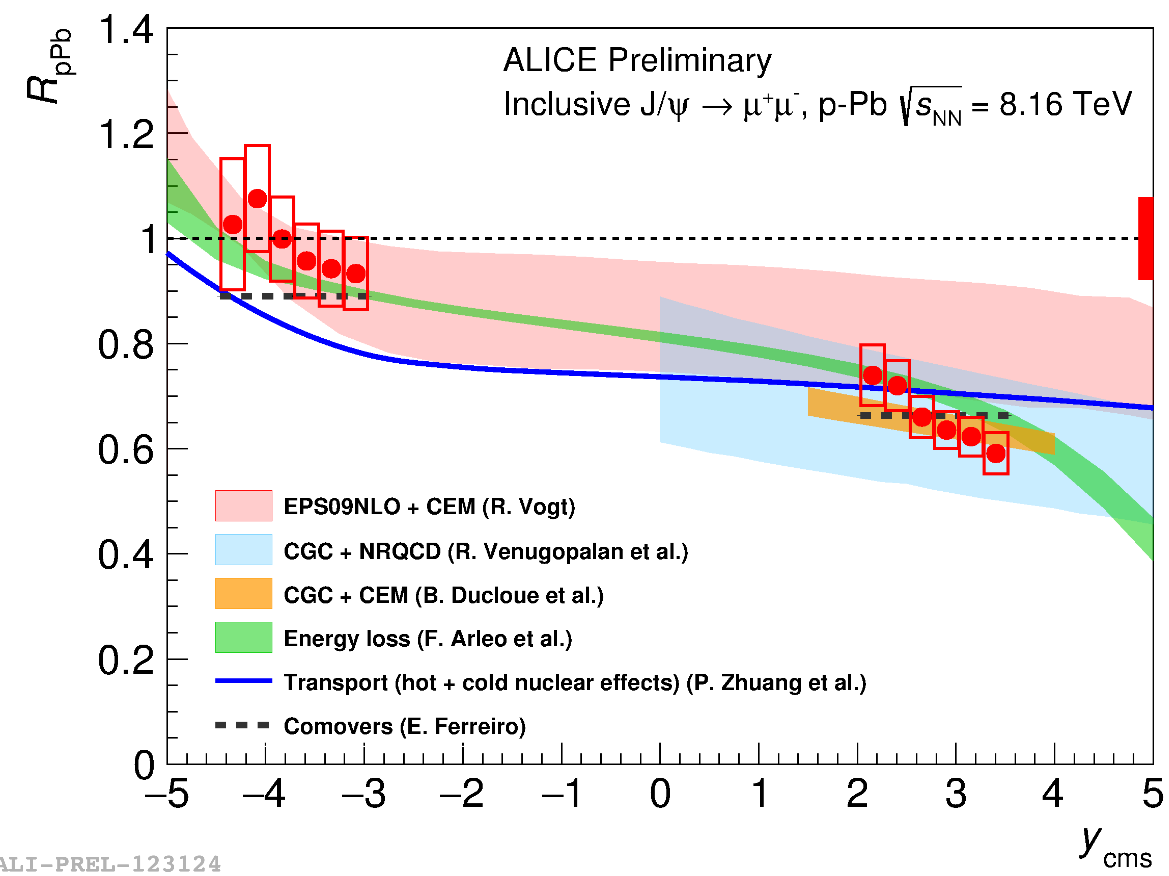
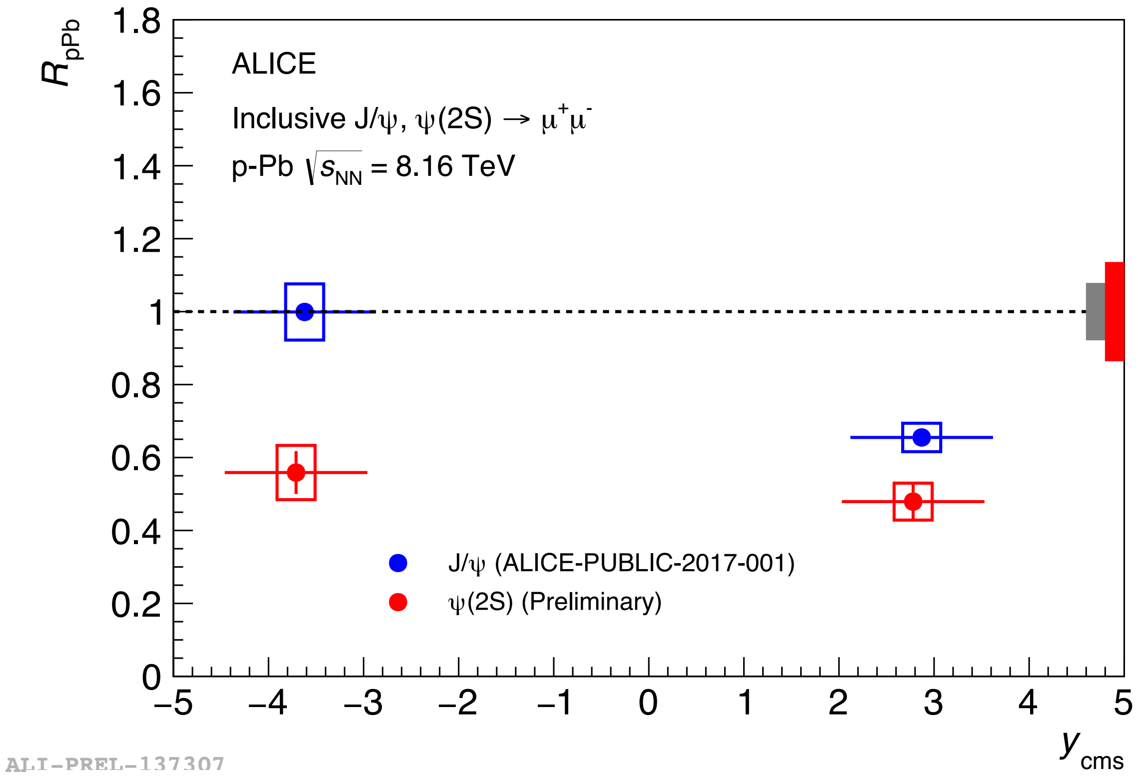


- J/ψ results compatible with models that include initial cold nuclear matter effects

Quarkonia in p-Pb collisions

- ψ(2S) state even more suppressed than J/ψ. In particular in the Pb-going direction.
- only initial state cold nuclear matter effects are not enough to explain the suppression at backward rapidity.



- ϒ(1S) seems to be affected in the same way by cold nuclear matter effects at both forward and backward rapidity