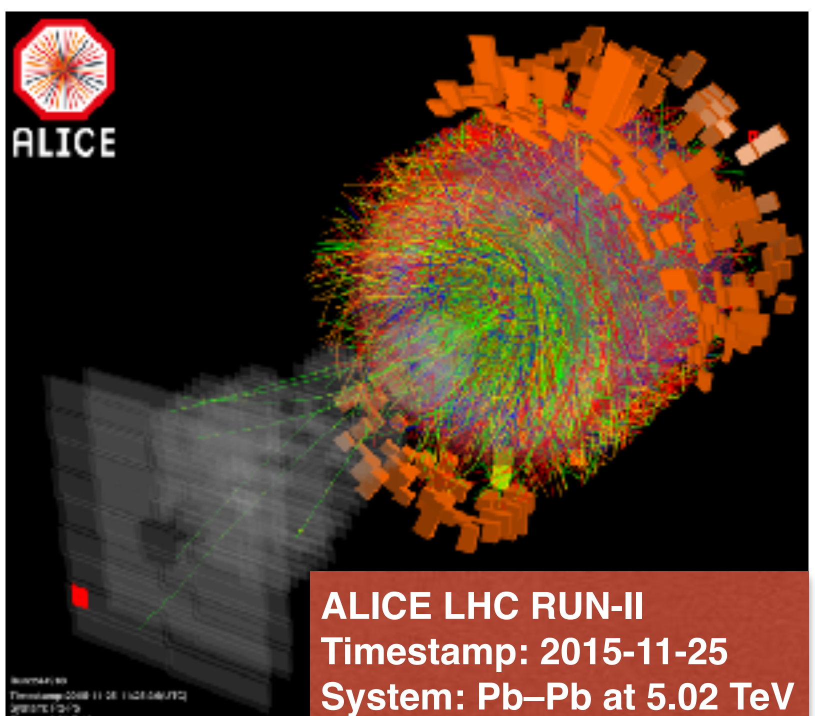
ALICE Highlights of Recent Results

With personal bias

Xiaoming Zhang (Central China Normal University)



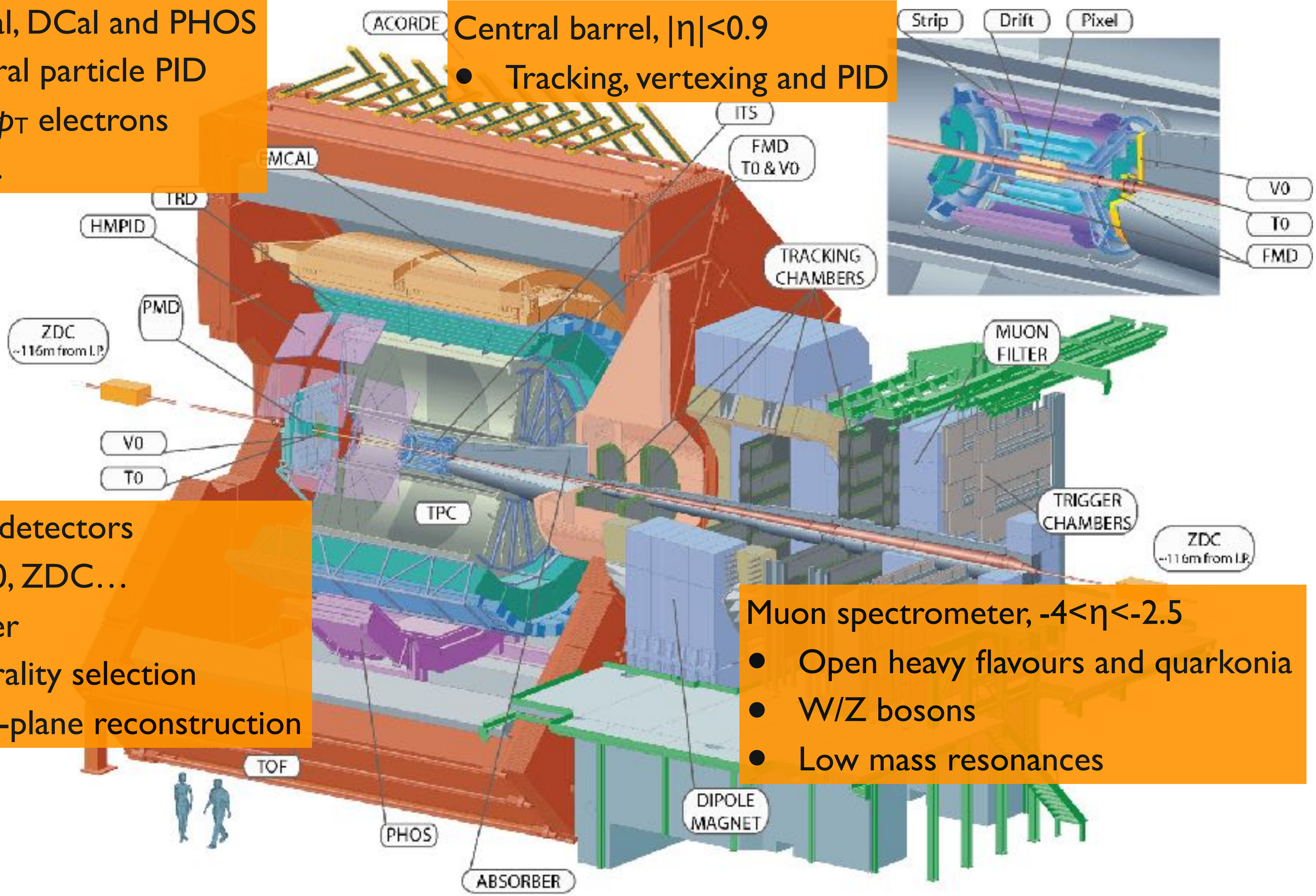
- ALICE experiment at the LHC
- Bulk properties
- Hard probes

10th France China Particle Physics Laboratory Workshop
Tsinghua University, Beijing, China, March 27 - 30 2017

The ALICE Experiment

EM calorimeters, $|\eta|<0.7$
- EMCal, DCal and PHOS
- Neutral particle PID
- High-p_T electrons
- Jets…

Central barrel, $|\eta|<0.9$
- Tracking, vertexing and PID



Forward detectors
- V0, T0, ZDC…
- Trigger
- Centrality selection
- Event-plane reconstruction

Muon spectrometer, $-4<\eta<-2.5$
- Open heavy flavours and quarkonia
- W/Z bosons
- Low mass resonances

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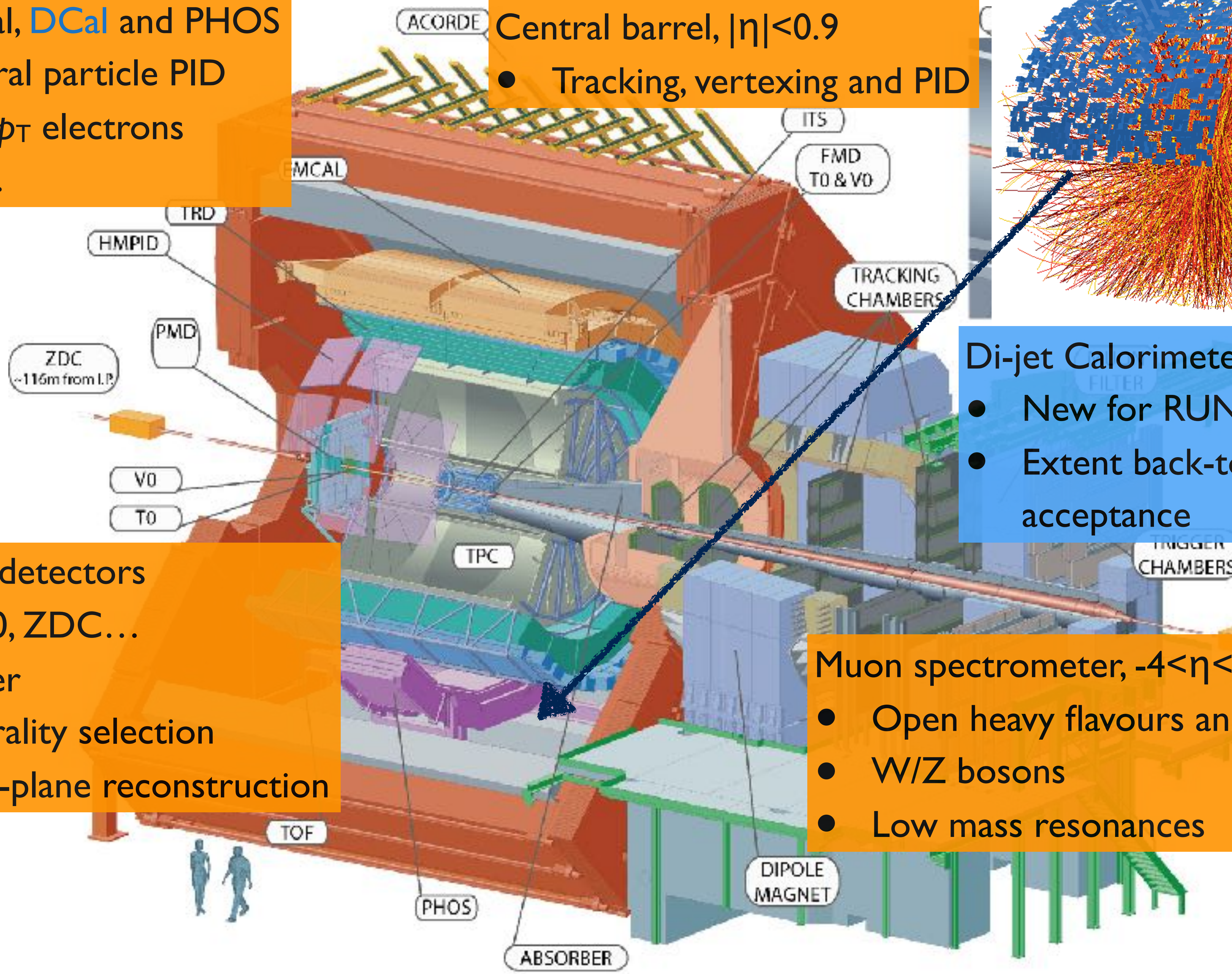

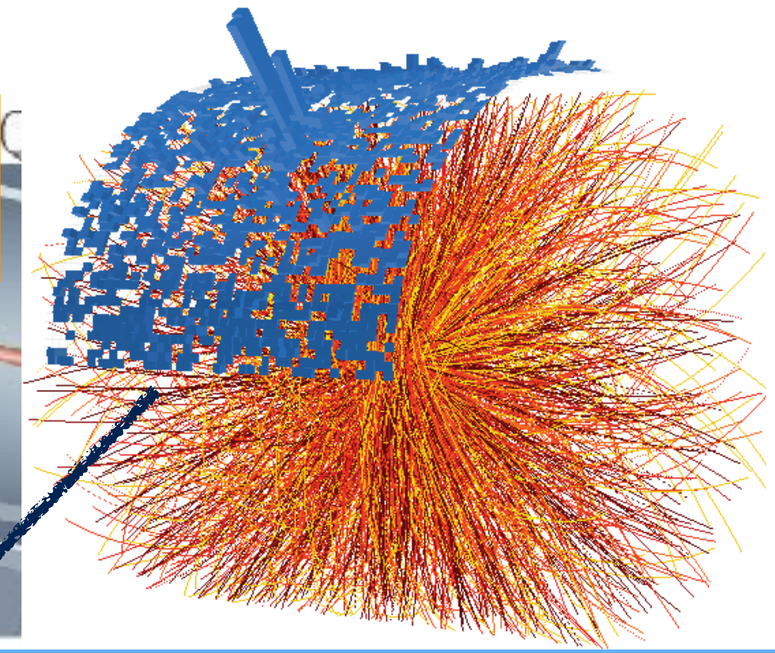

Di-jet Calorimeter (DCal)
- New for RUN-II
- Extent back-to-back di-jet acceptance

Forward detectors
- V0, T0, ZDC…
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Muon spectrometer, -4<η<-2.5
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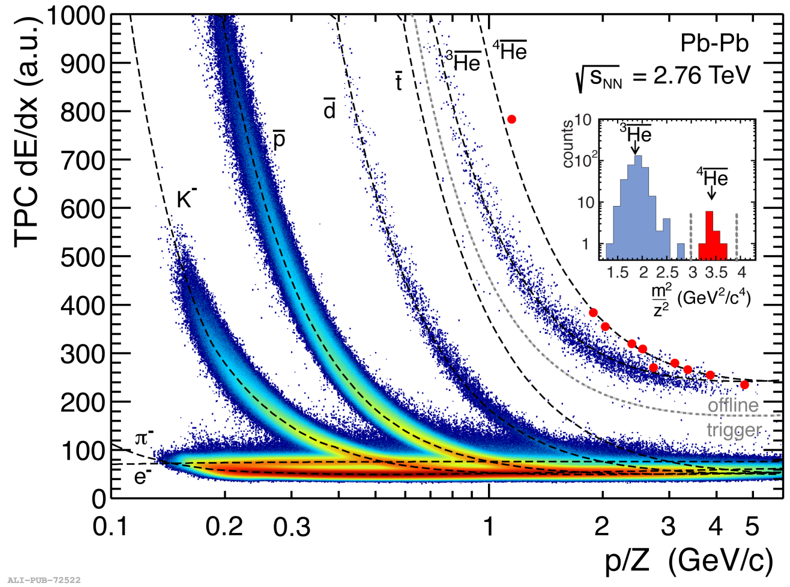
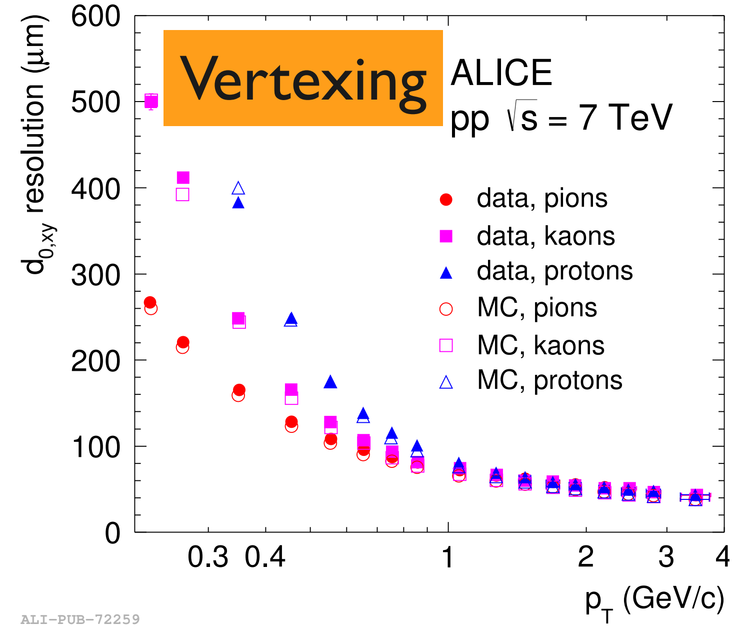
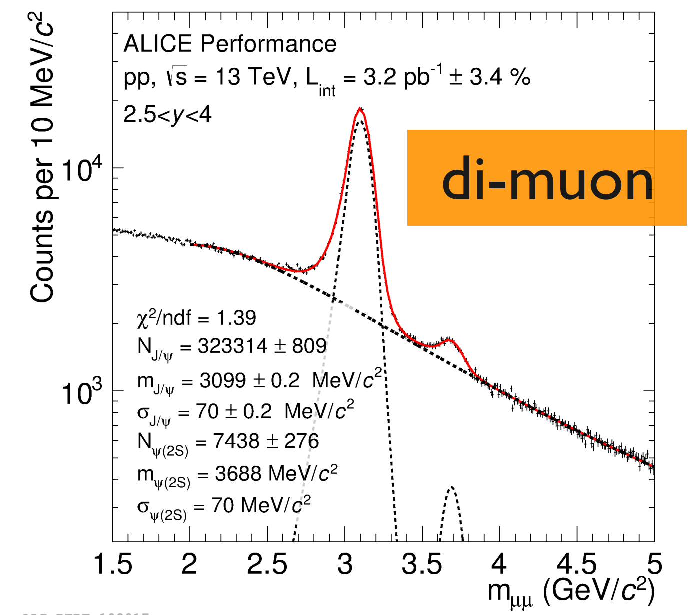
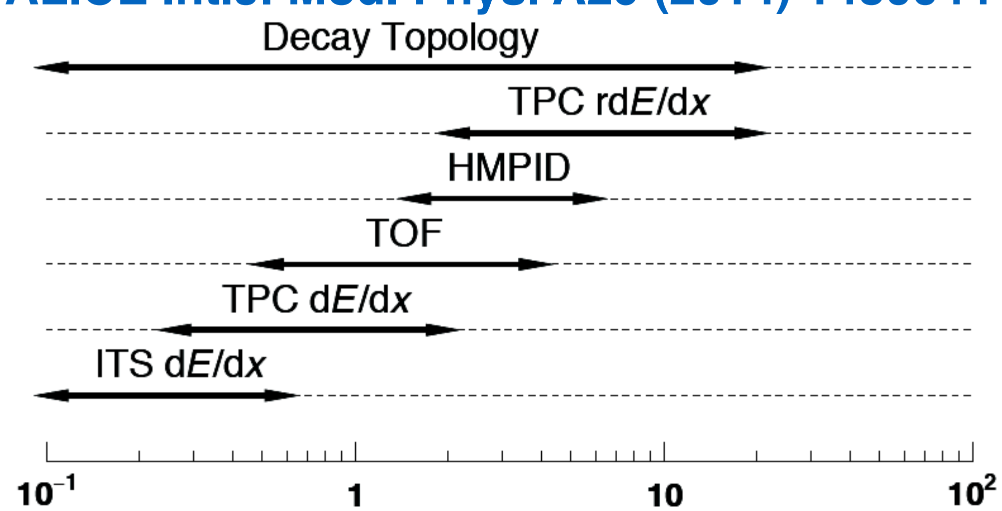
ALICE Performance

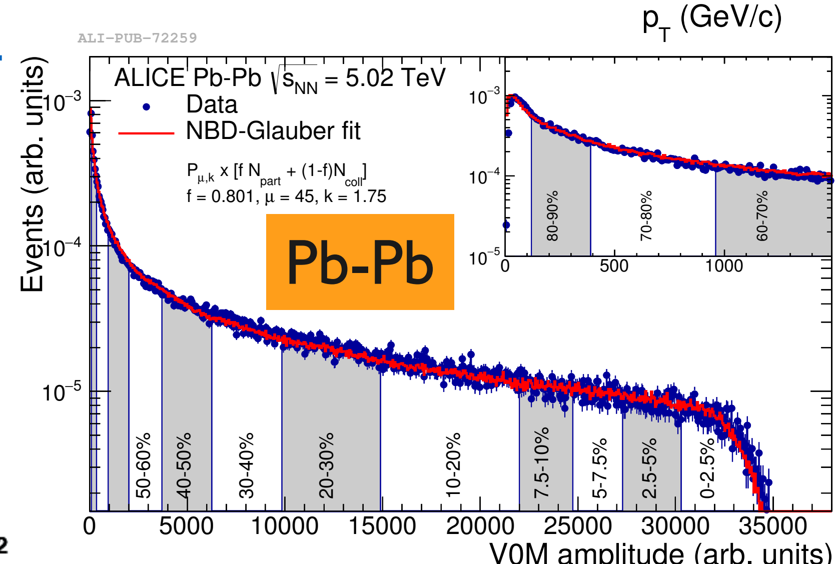






ALICE Int.J. Mod. Phys. A29 (2014) 1430044





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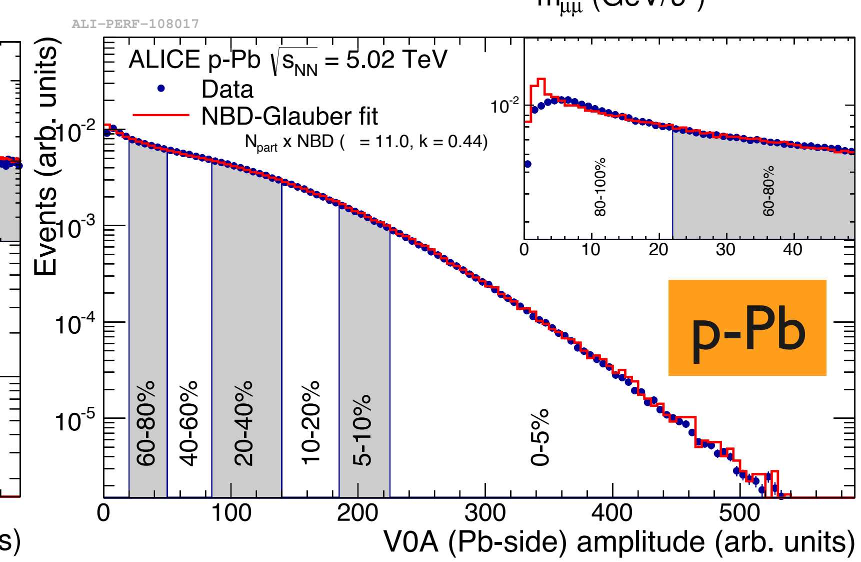
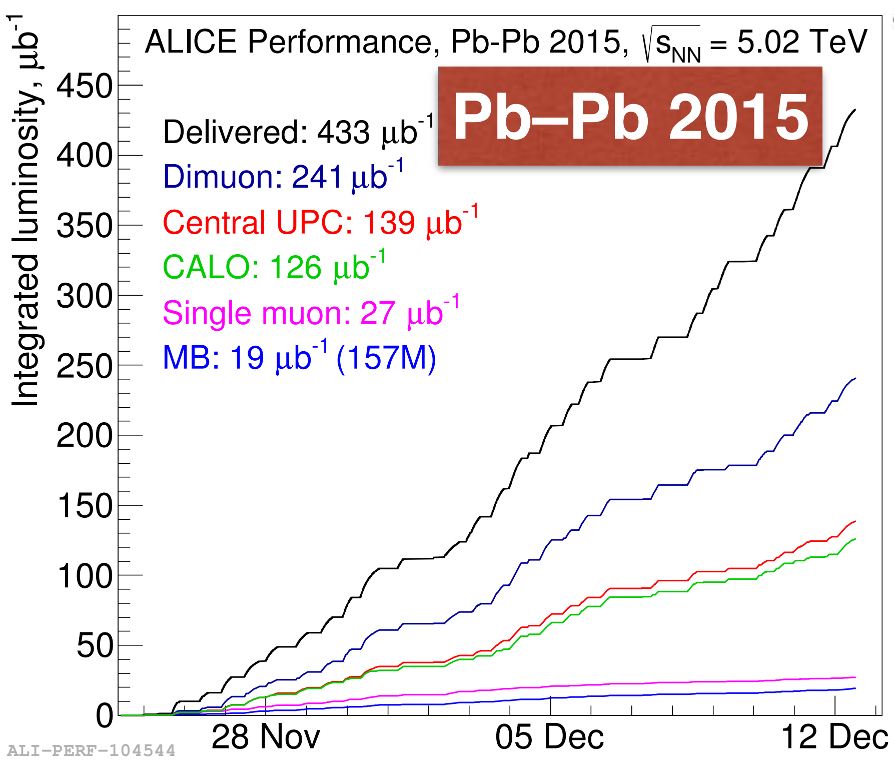


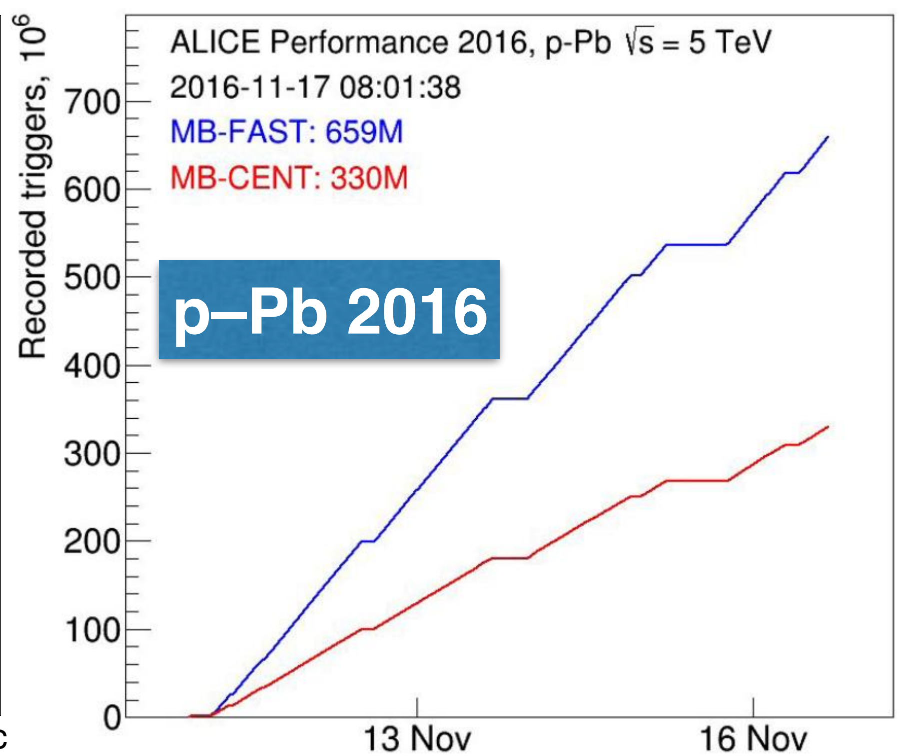
ALICE Phys. Rev. C91 (2015) 064905

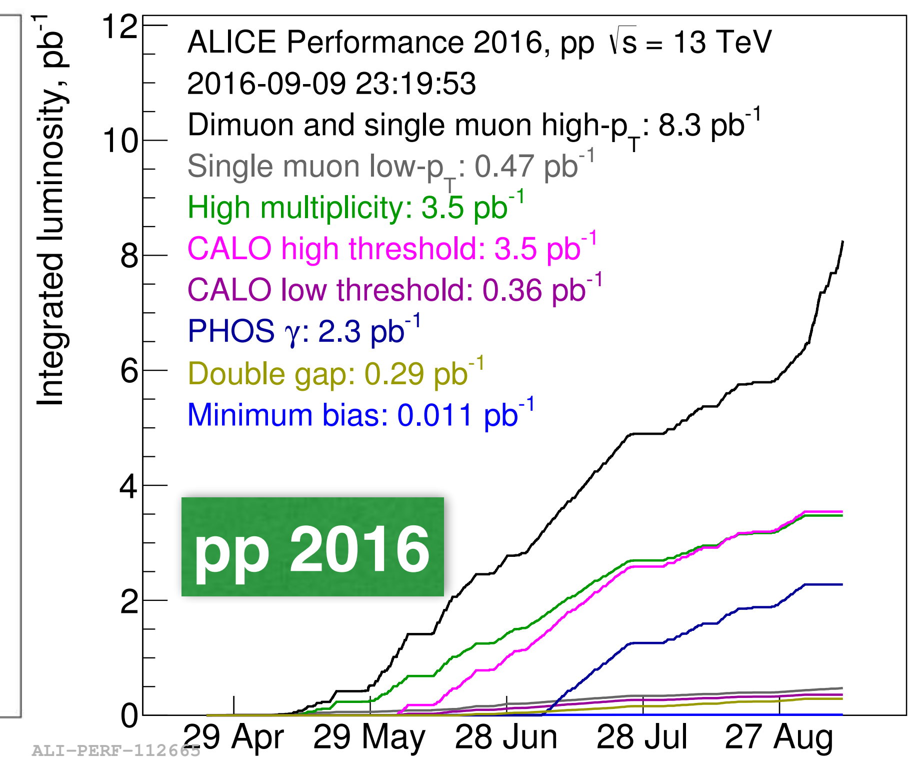
- Efficient low-p_T tracking — down to 150 MeV/*c*
- Excellent particle identification — anti-^{3}He observed directly, hadron, lepton and photon identification up to high momenta
- Excellent vertexing capabilities (heavy flavours, V^0, cascades, conversions)
- Forward muon spectrometer: J/ψ and Υ reconstruction down to p_T = 0
- Precise event characterization (for both Pb-Pb collisions and small systems)

Data Collection in LHC RUN-II

Collision System	Pb–Pb	p–Pb	pp
Year	2015 / 2018	2016	2015 - 2018
Energy (TeV)	5.02	5.02 / 8	5.02 / 13







- Pb–Pb: properties of the QCD medium
- p–Pb: Cold nuclear matter effects
- pp: reference for p–Pb and Pb–Pb, onset of collectivity?

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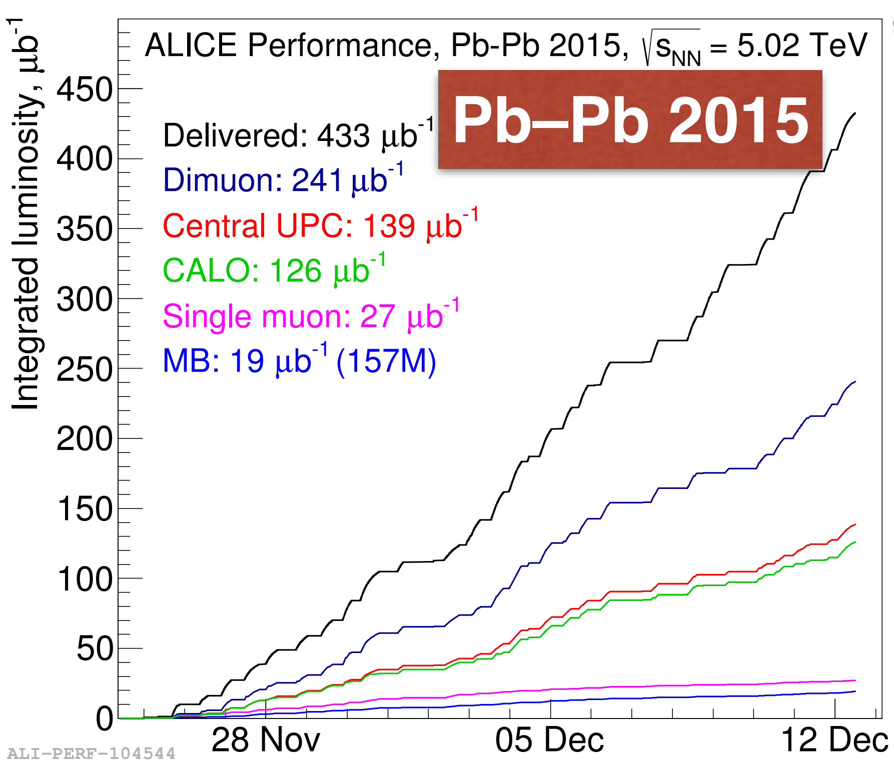
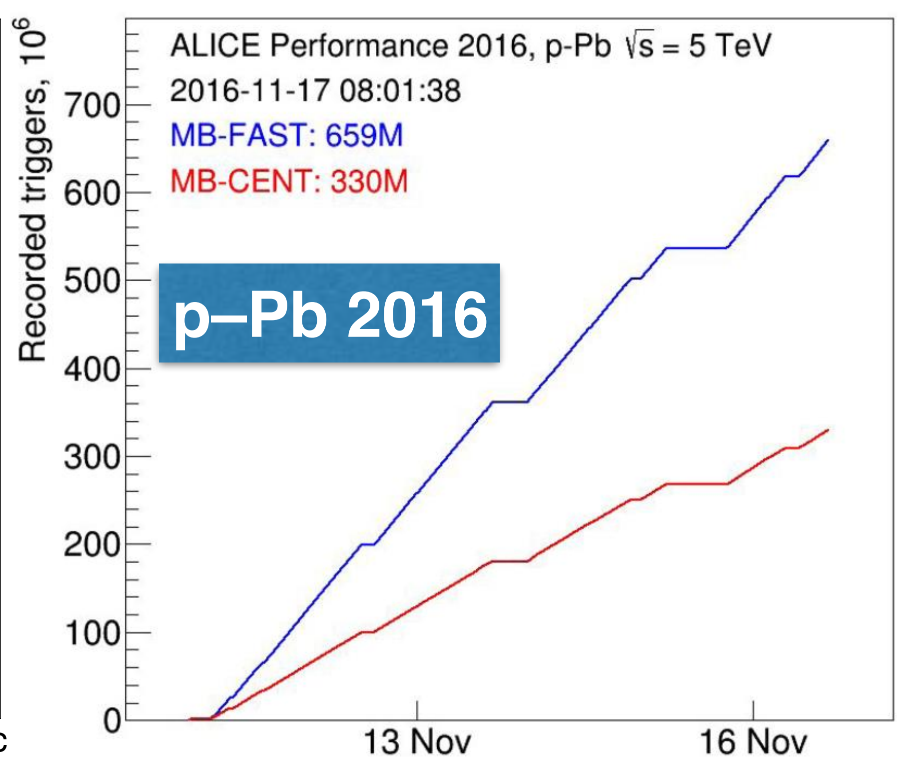
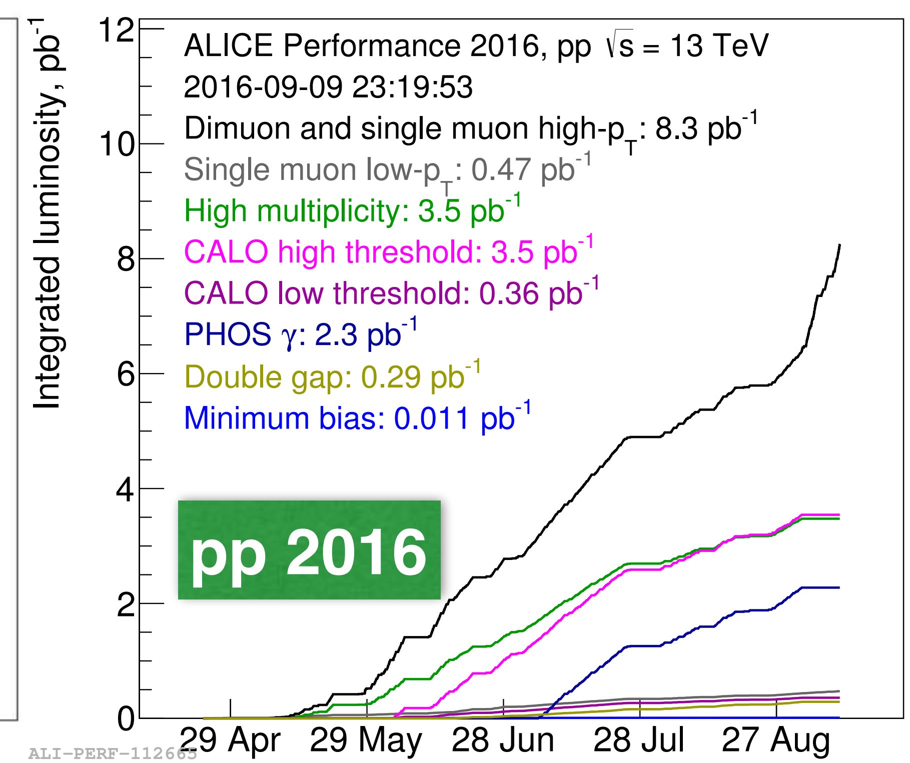




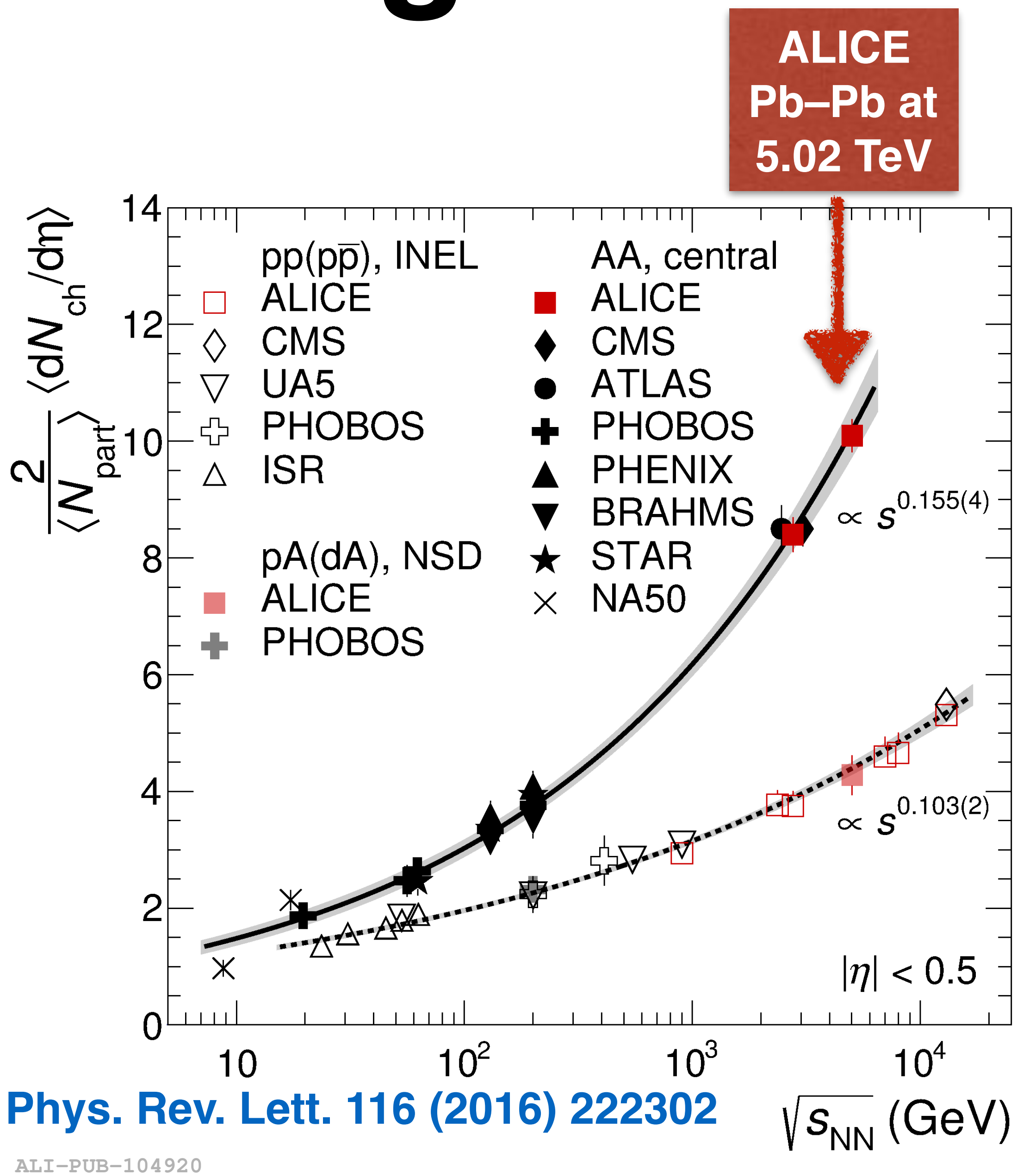


- Pb–Pb: properties of the QCD medium

LHC RUN-II: various triggers for physics diversity, higher collision energy and data taking luminosity than RUN-I

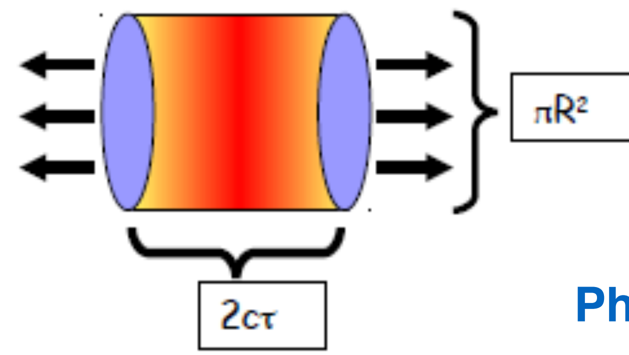
- pp: reference for p–Pb and Pb–Pb, onset of collectivity?

Charged-Particle Multiplicity



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

Bjorken estimate:



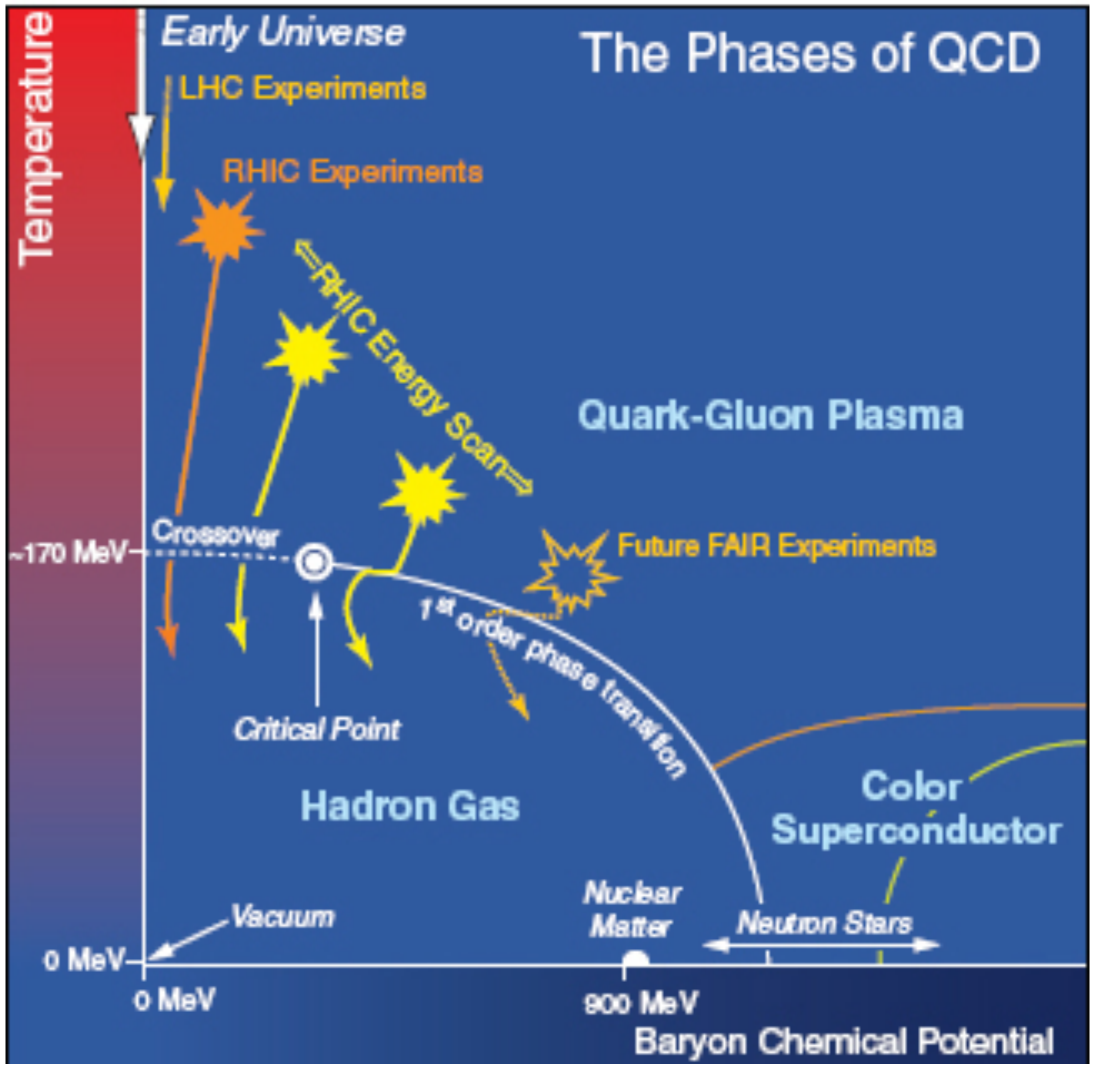
Phys. Rev. D27 (1983) 140

$$\langle \varepsilon \rangle (\tau) = \frac{1}{\tau \pi R^2} \frac{dE_T}{dy} \longleftrightarrow dN/d\eta$$

- Central Pb–Pb collisions at 5.02 TeV
  - d*N*/dη ~ 2000
  - Energy density ε ~18 GeV/fm³ above deconfinement transition (~1 GeV/fm³)

- ALICE: Pb–Pb at 5.02 TeV — highest energy so far
  - For 0–5% most central collisions, confirms trend from lower energies
- <dN_{ch}/dη> vs. <N_{part}>: ~20% increase going from 2.76 to 5.02 TeV
  - Provides further constraints for models

Net-Baryon Moments



$$\kappa_1(x) = <x>$$

$$\kappa_2(x) = <x^2> - <x>^2$$

$$\kappa_2(\mathrm{Skellam}) = \kappa_1(\mathrm{p}) + \kappa_1(\overline{\mathrm{p}})$$

- Net-Baryon fluctuations: expressed as (ratio of) cumulants which can be compared with lQCD predictions — particularly interesting for studies of QCD phase diagram

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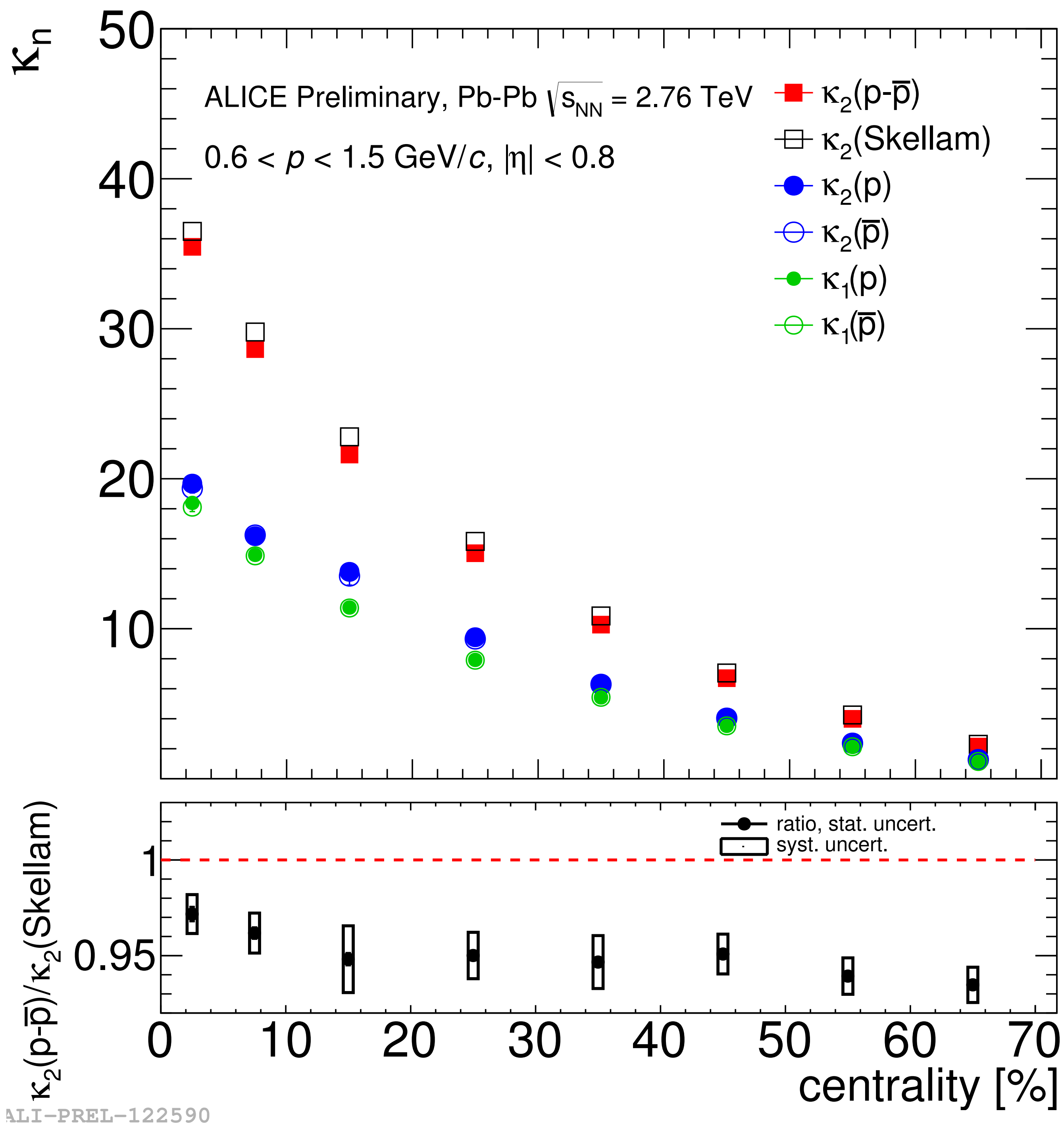

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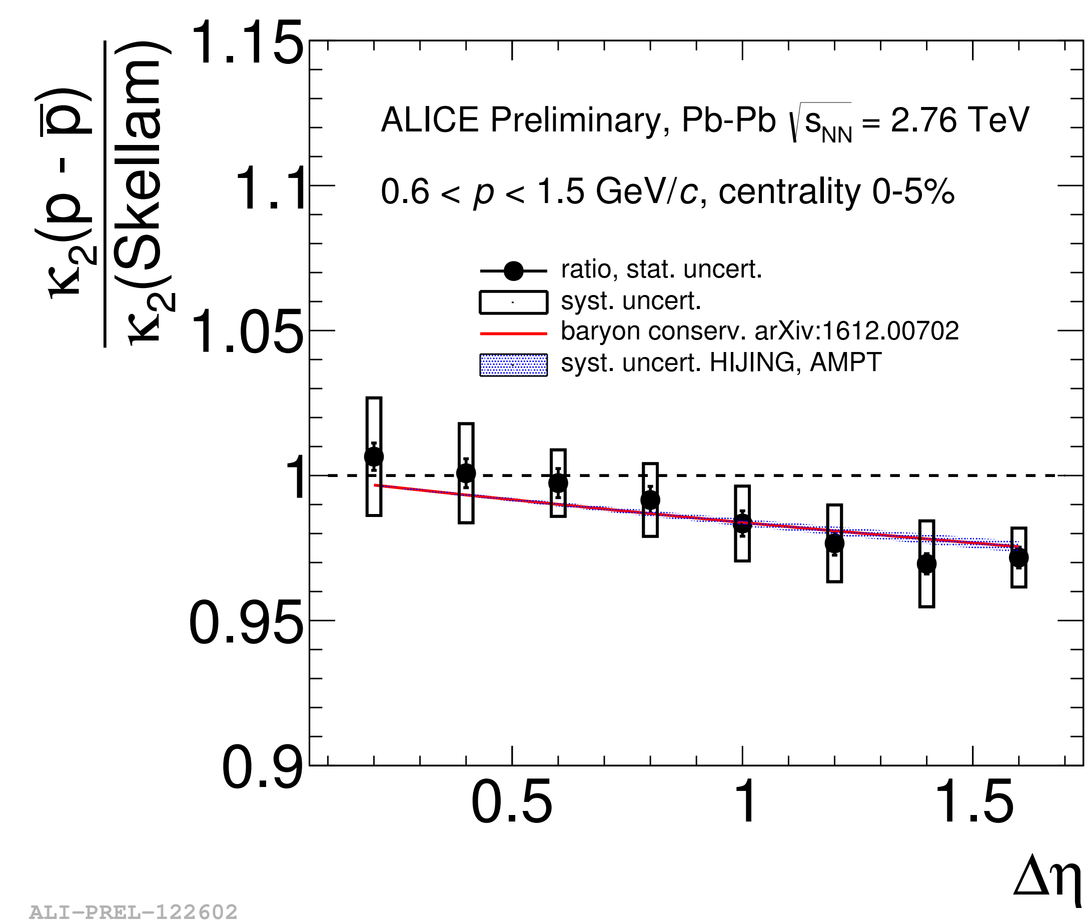
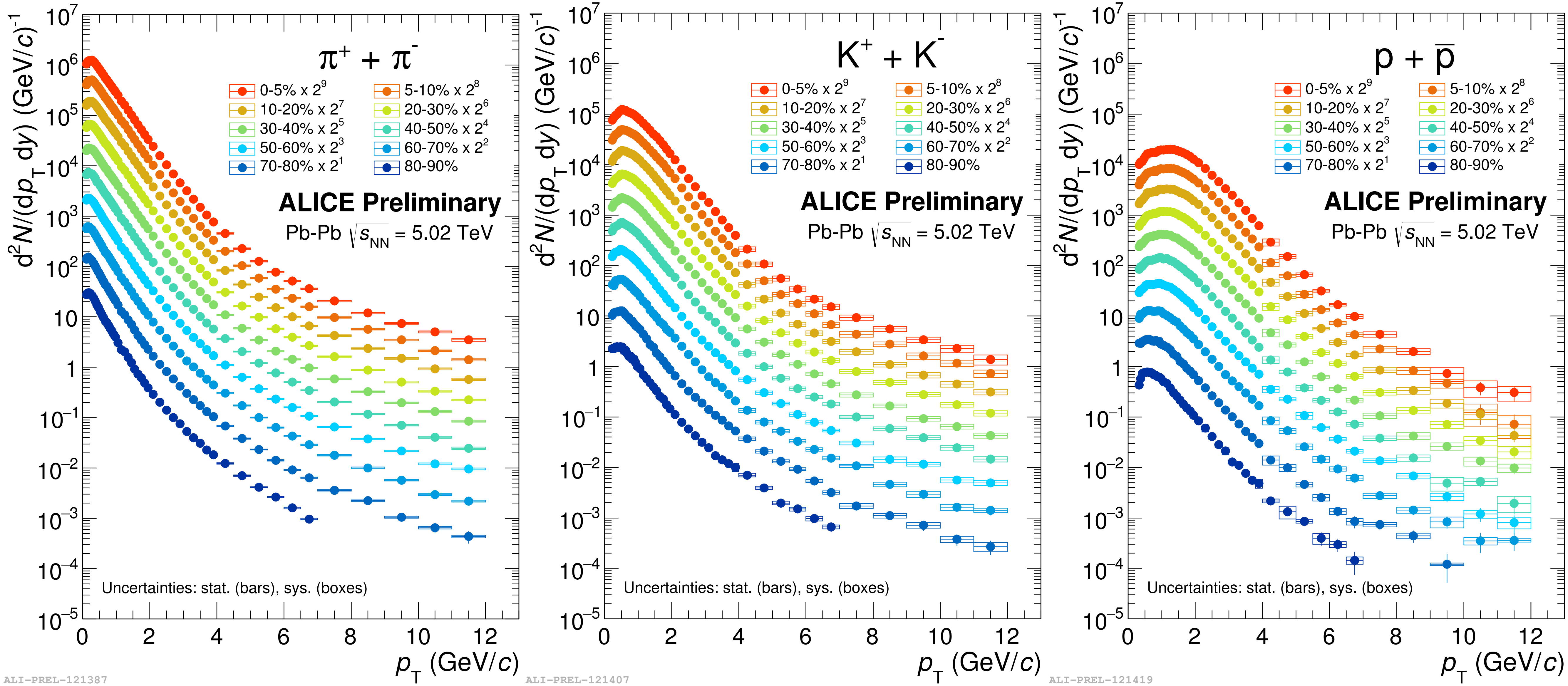


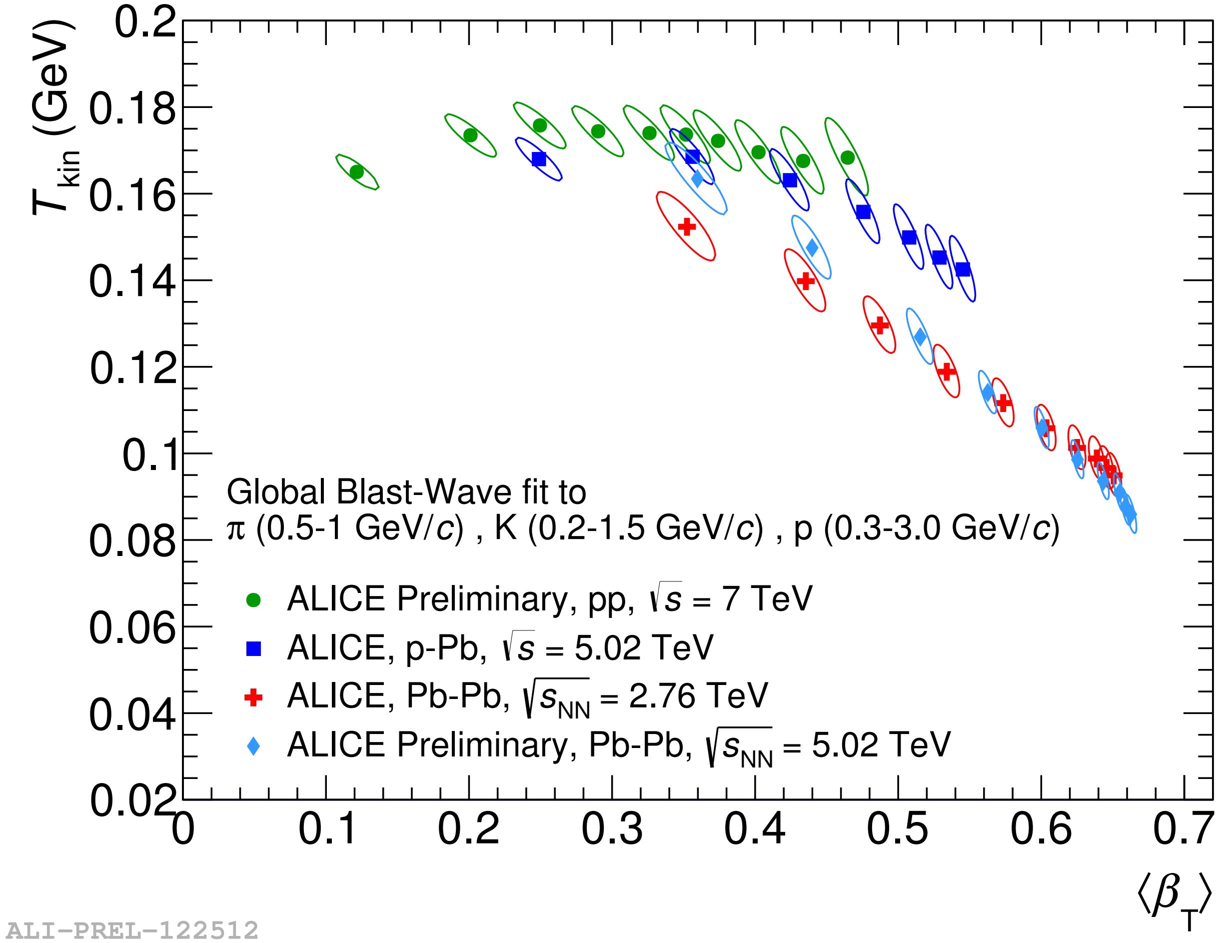
- Net-Baryon fluctuations: expressed as (ratio of) cumulants which can be compared with lQCD predictions — particularly interesting for studies of QCD phase diagram
- First measurement at LHC energies — critical reference for RHIC program

Identified Particle Production



- Particle identification with different techniques: ITS, TPC, TOF and HMPID
  - Topological identification of Kaons from kinks
- Mass dependent hardening of particle spectra with increasing centrality

Bulk Profiles



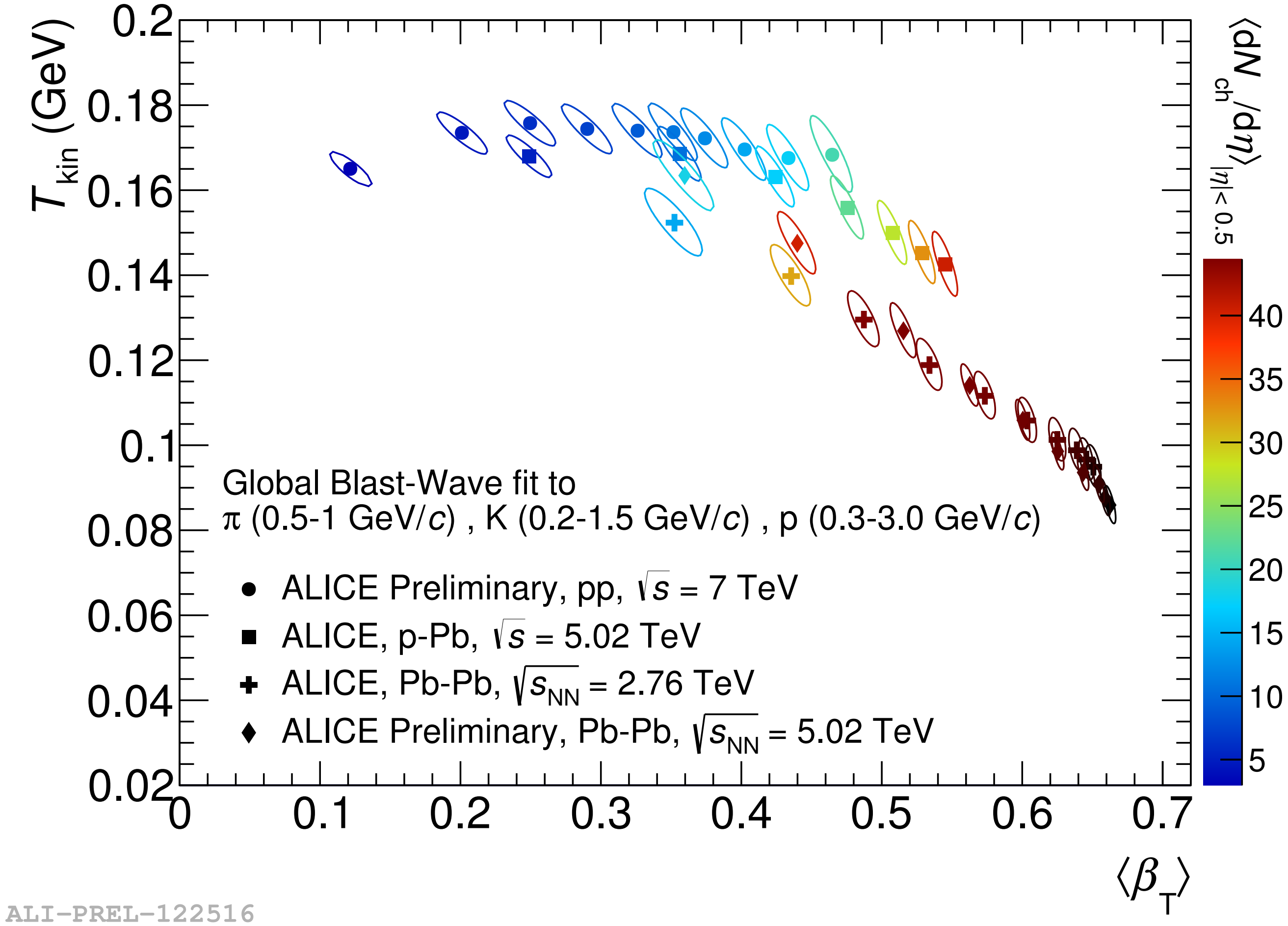
- Simultaneously fit the K, π and proton spectra with Boltzmann-Gibbs Blast-Wave model
- Simplified hydrodynamics model with three parameters
  - $\langle\beta_T\rangle$ — mean radial expansion velocity
  - T_{kin} — kinetic freeze-out temperature
  - n — velocity profile

In Pb–Pb collisions at 5.02 TeV

- Fit quantity similar to that at 2.76 TeV
- Blast-Wave parameters follow the trend obtained at lower energy
- For the most central collisions

➡ Largest the radial flow ever observed in heavy-ion collisions

Bulk Profiles



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  - <β_T> — mean radial expansion velocity
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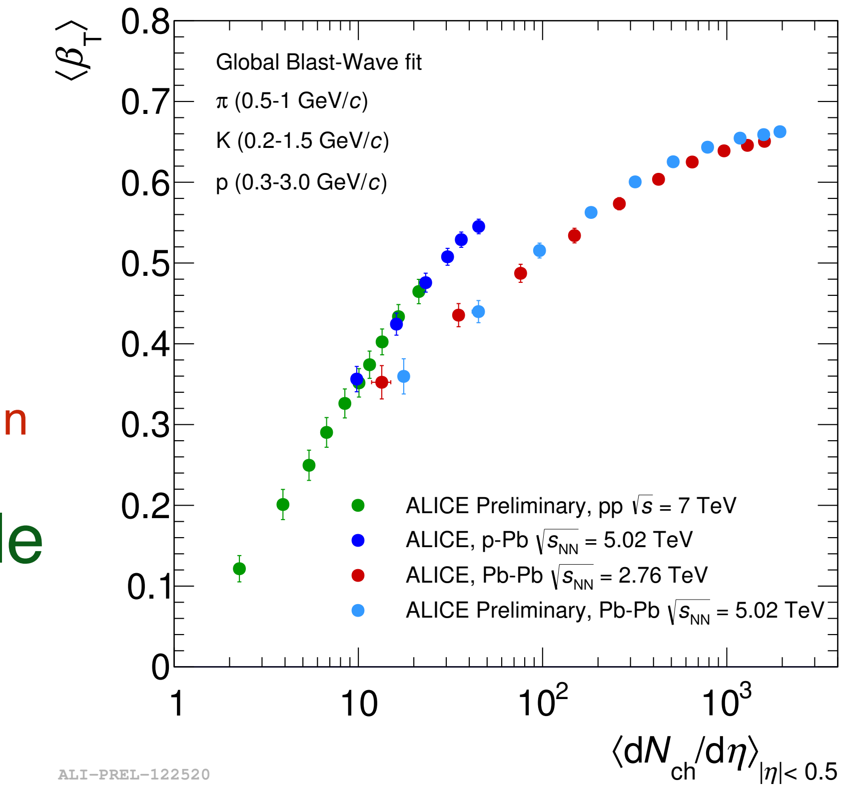
Blast-Wave parameters in small systems (pp and p–Pb)

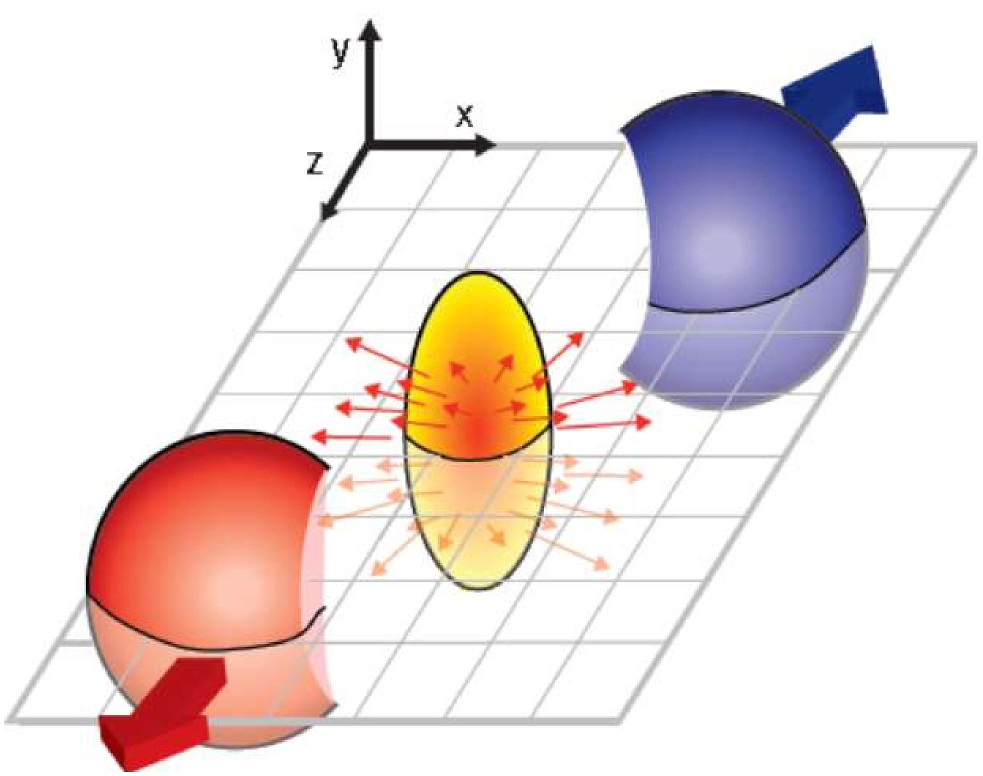
- Similar features as observed in Pb–Pb collisions
  - With increasing multiplicity — larger <β_T>, smaller T_{kin}
- Higher <β_T> for smaller collision systems at comparable multiplicity
- Does not exclude hydro-like collective behavior

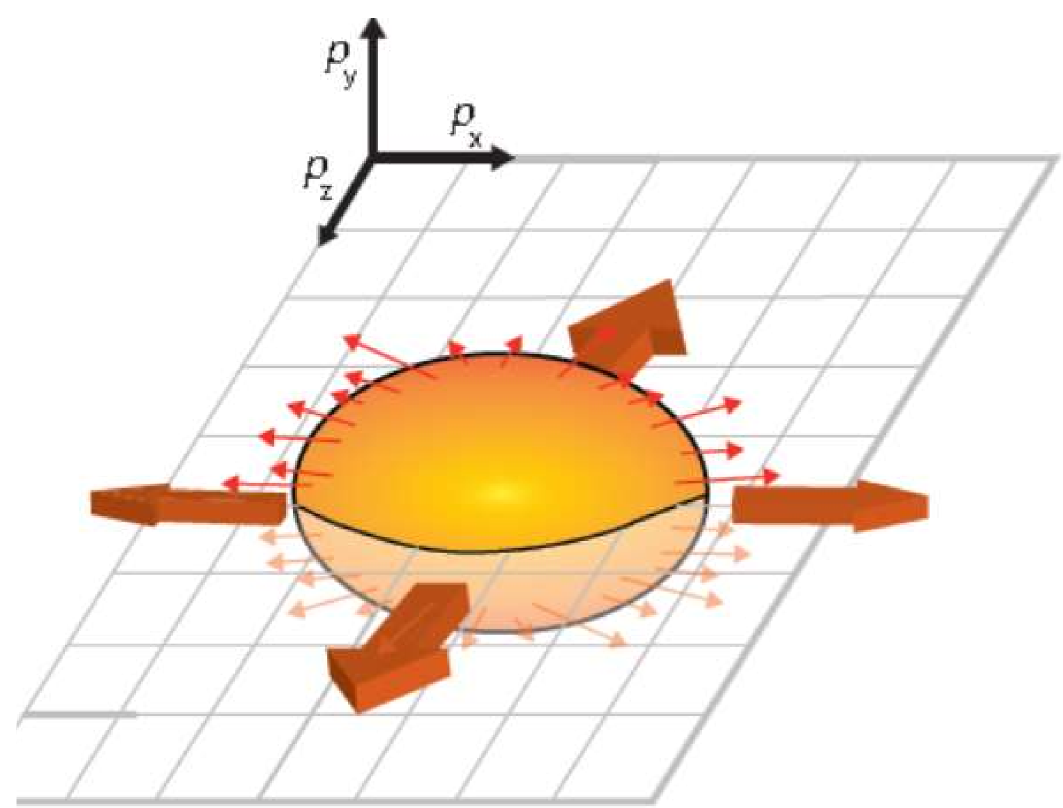


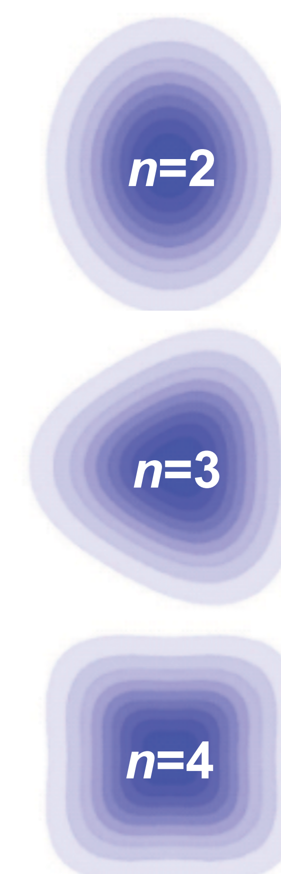
Azimuthal Anisotropy

- Quantify anisotropy: Fourier decomposition of particle azimuthal distribution relative to the reaction plane (Ψ_{RP}) — coefficients v_2, v_3, v_4… v_n
- Elliptic flow (v_2): spatial anisotropy — pressure gradients lead to momentum anisotropy — hydrodynamics
- Higher order flow: bring additional constraints on the initial conditions, η/s, EoS, freeze-out conditions…

$$v_n = \langle \cos n(\varphi - \Psi_{\mathrm{RP}}) \rangle$$







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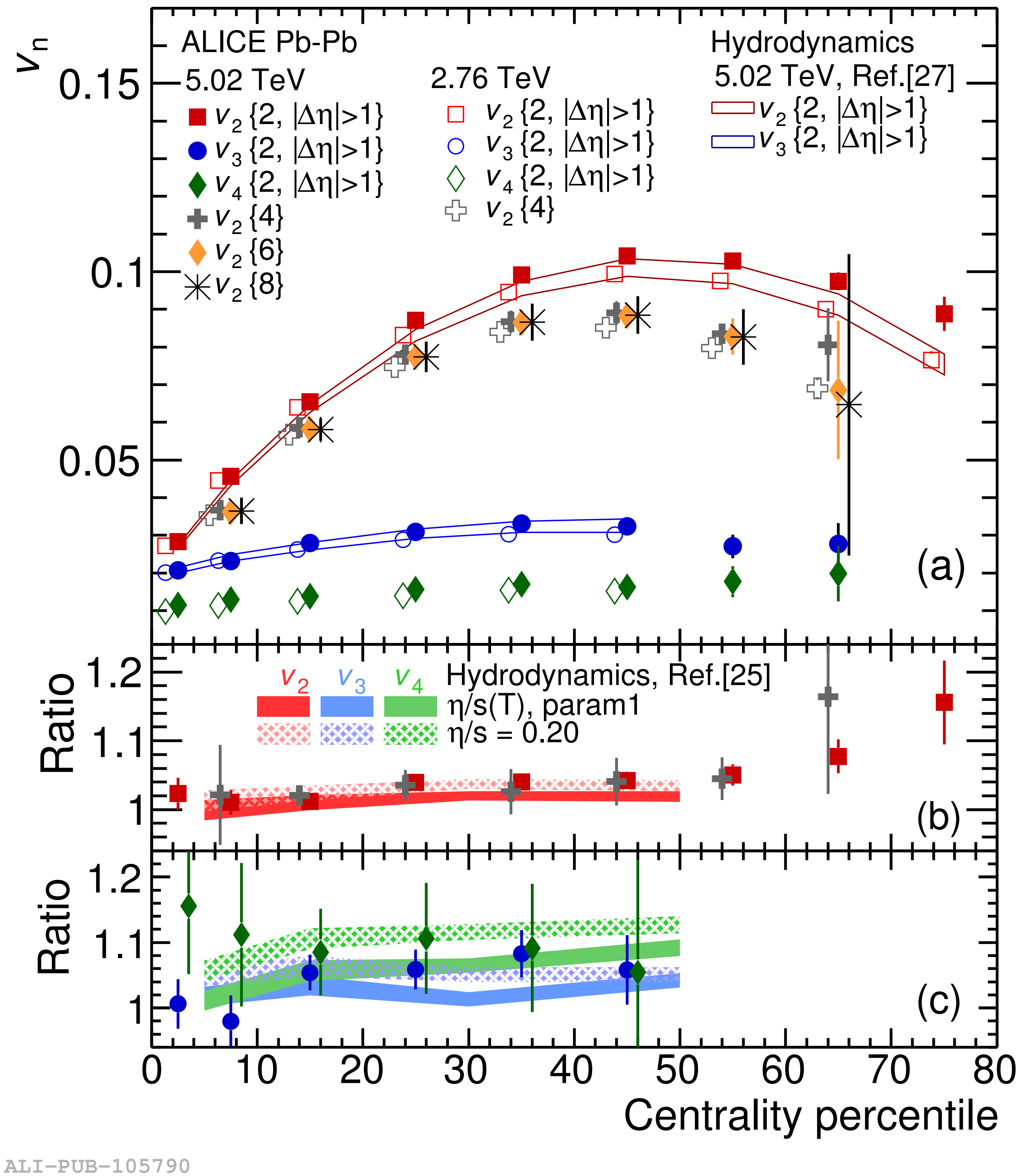
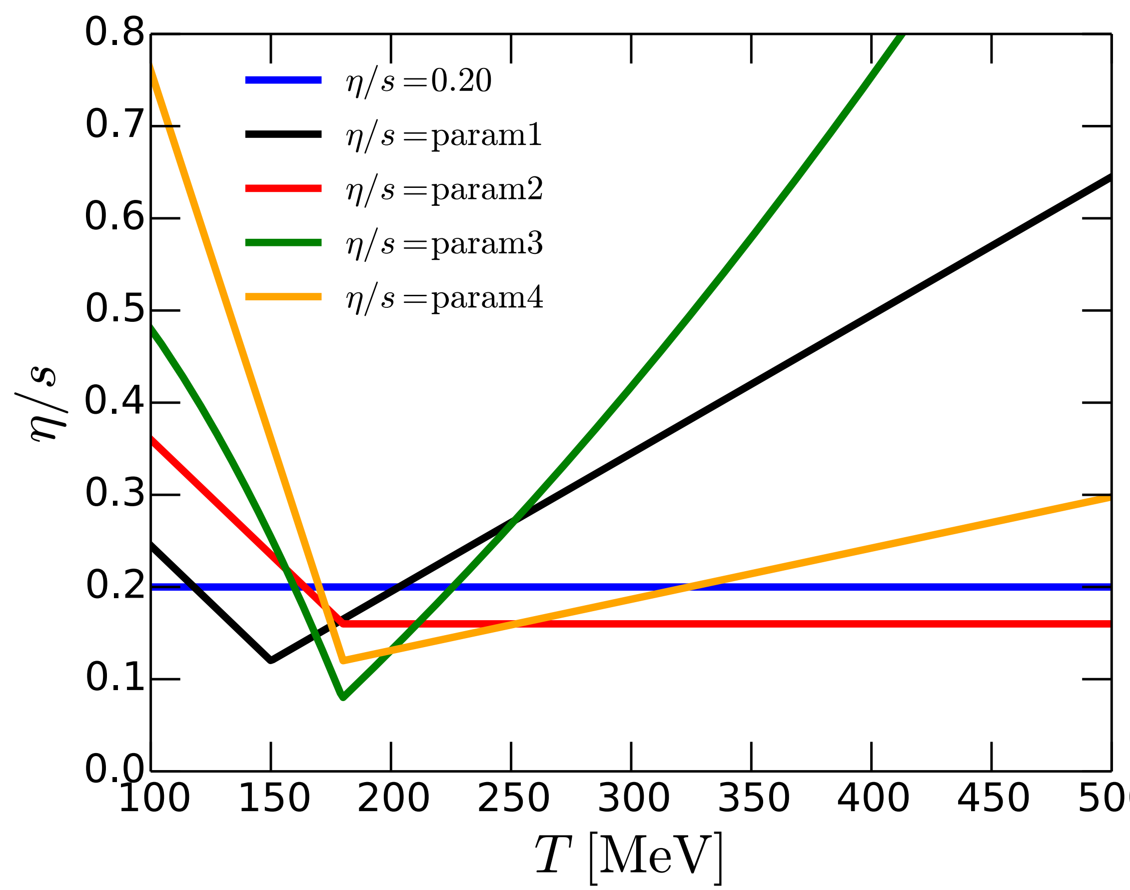
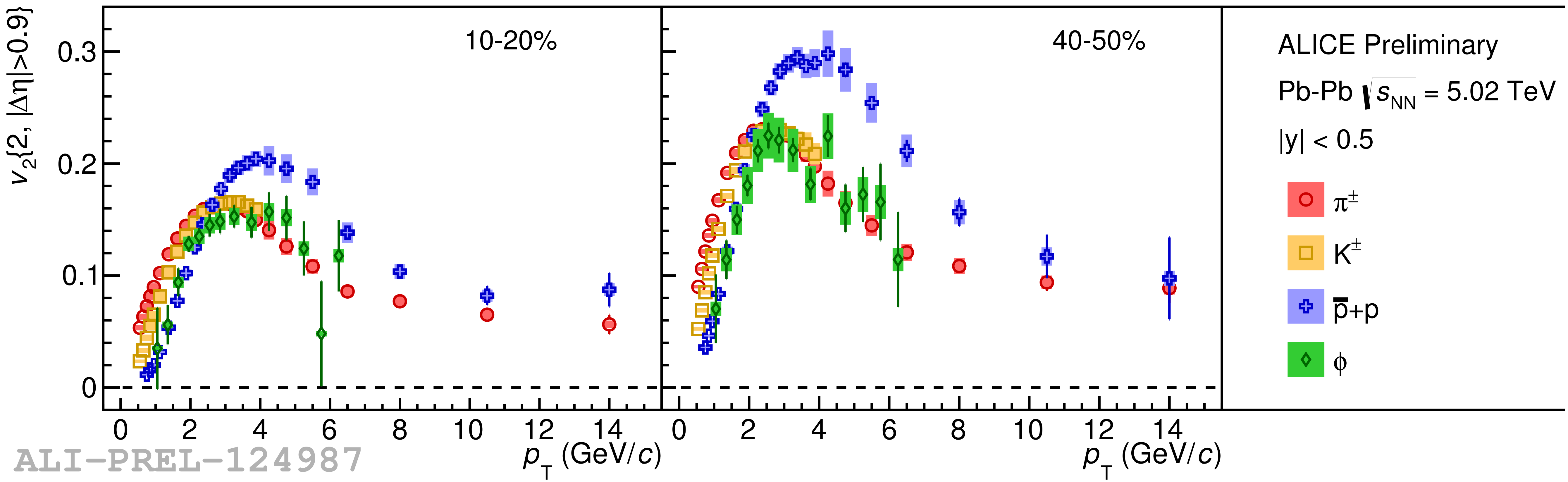


ALICE Phy. Rev. Lett. 116 (2016) 132302

- p_T-integrated values indicate an increase with collision-energy attributed to the increase in $\langle p_T \rangle$
- Good agreement with hydrodynamical calculations
  - Measurements support a low value for η/*s* ratio ~0.2



Elliptic Flow of Identified Particles



- Improvements over RUN-I: kinematic range is extended

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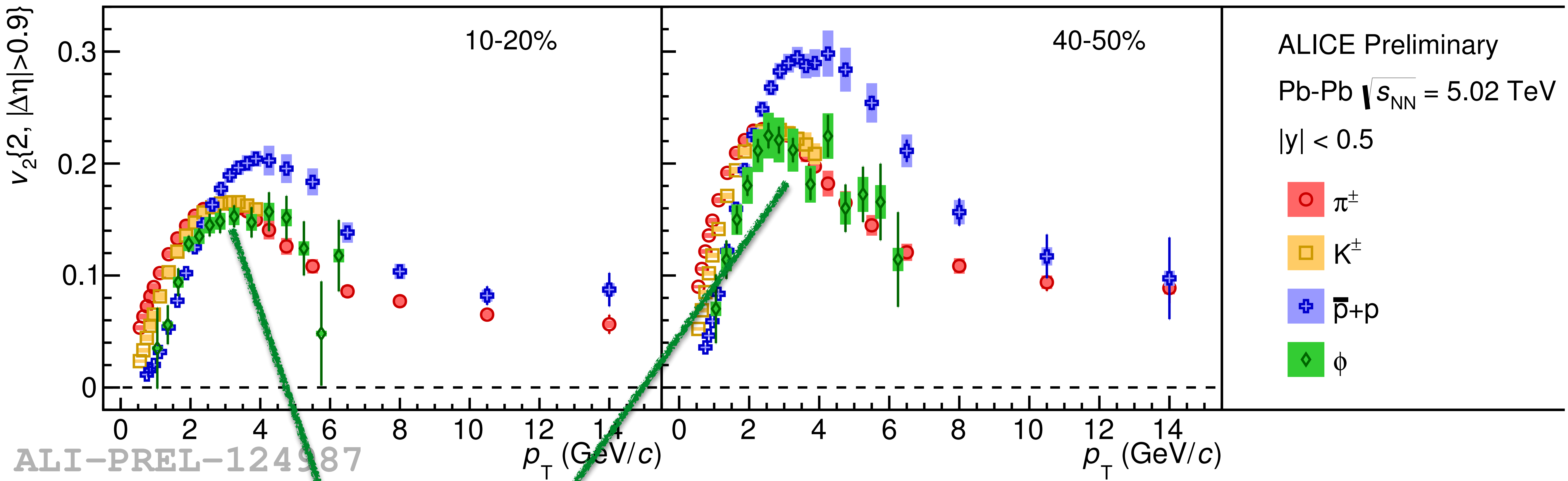

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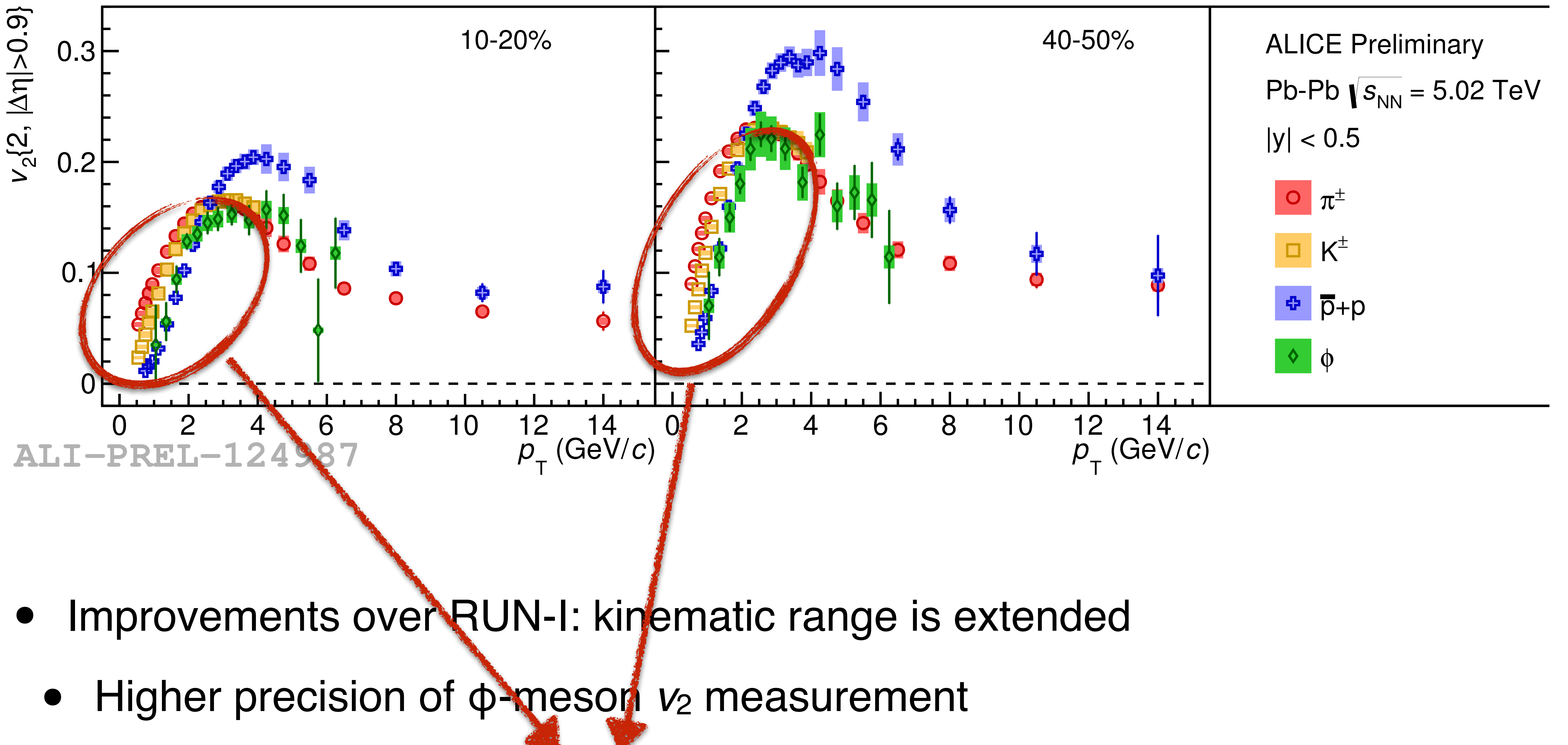

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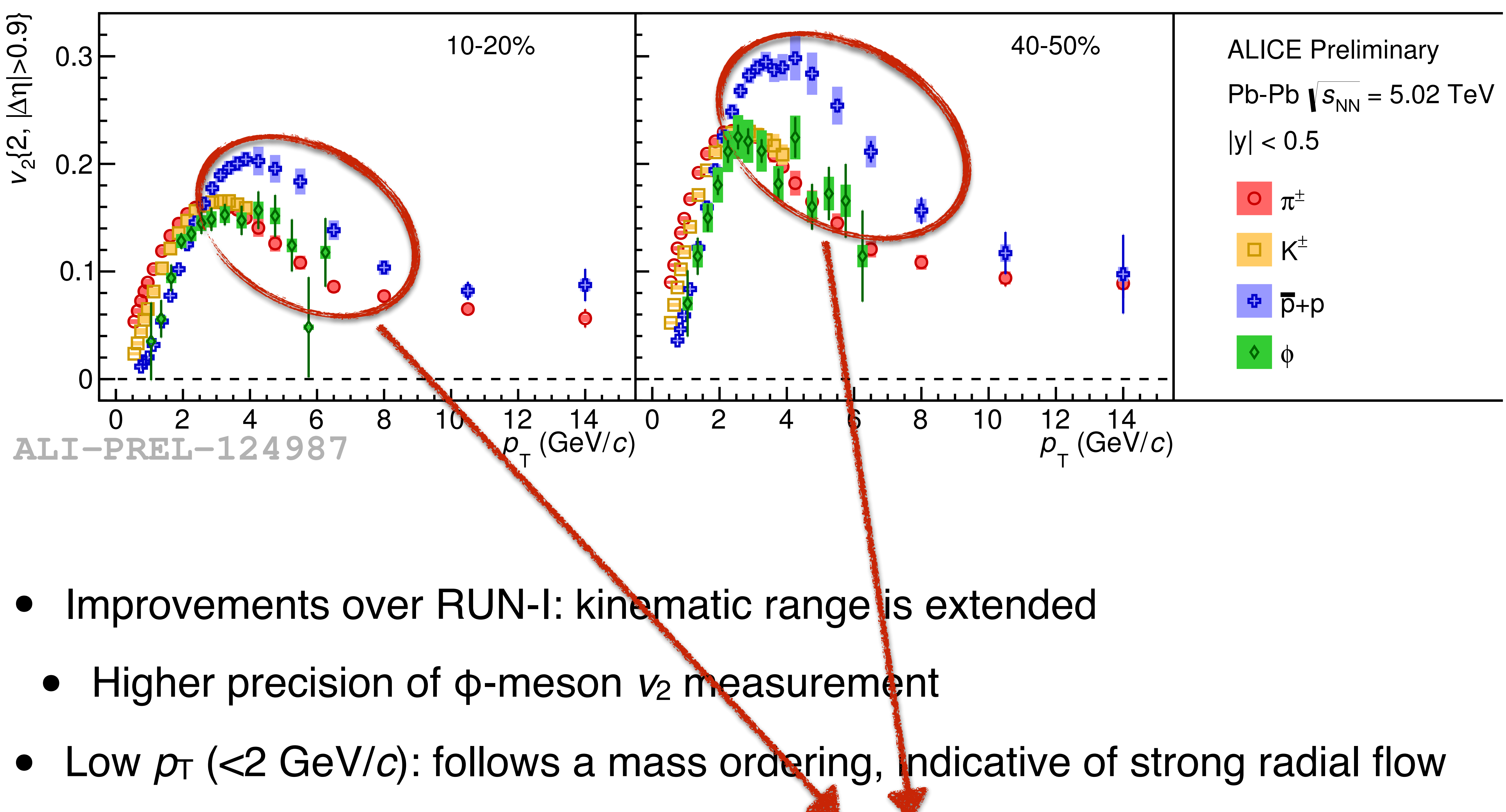

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- Intermediate p_T ($3<p_T<8$ GeV/c): type dependence

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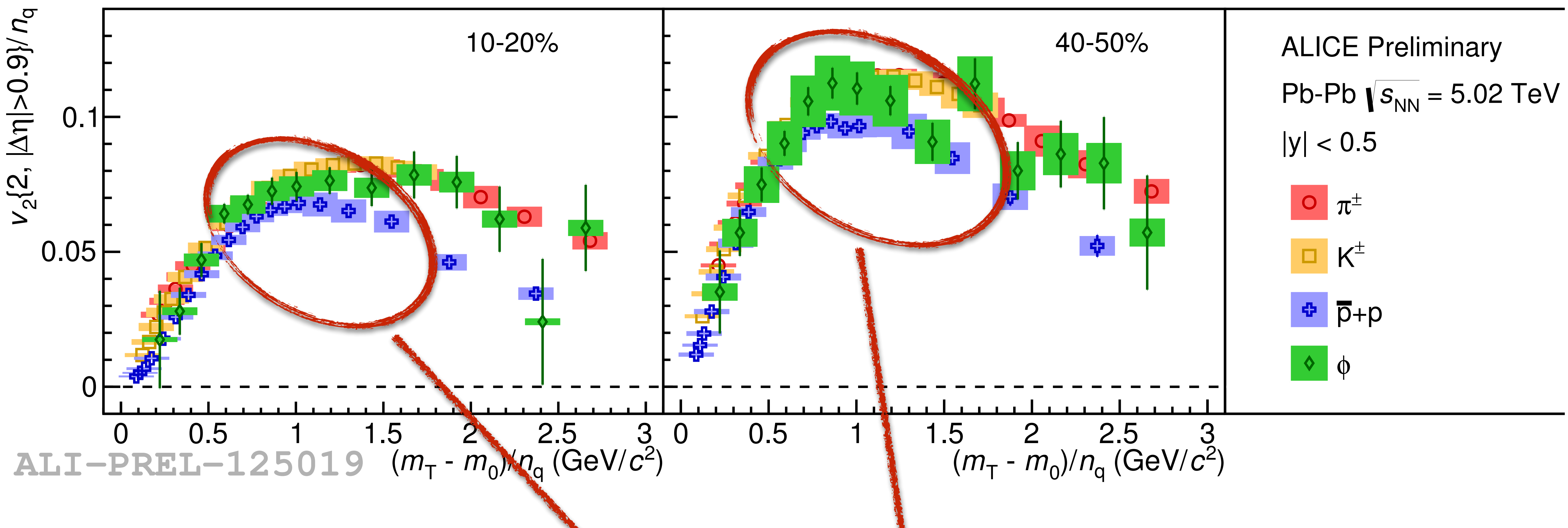

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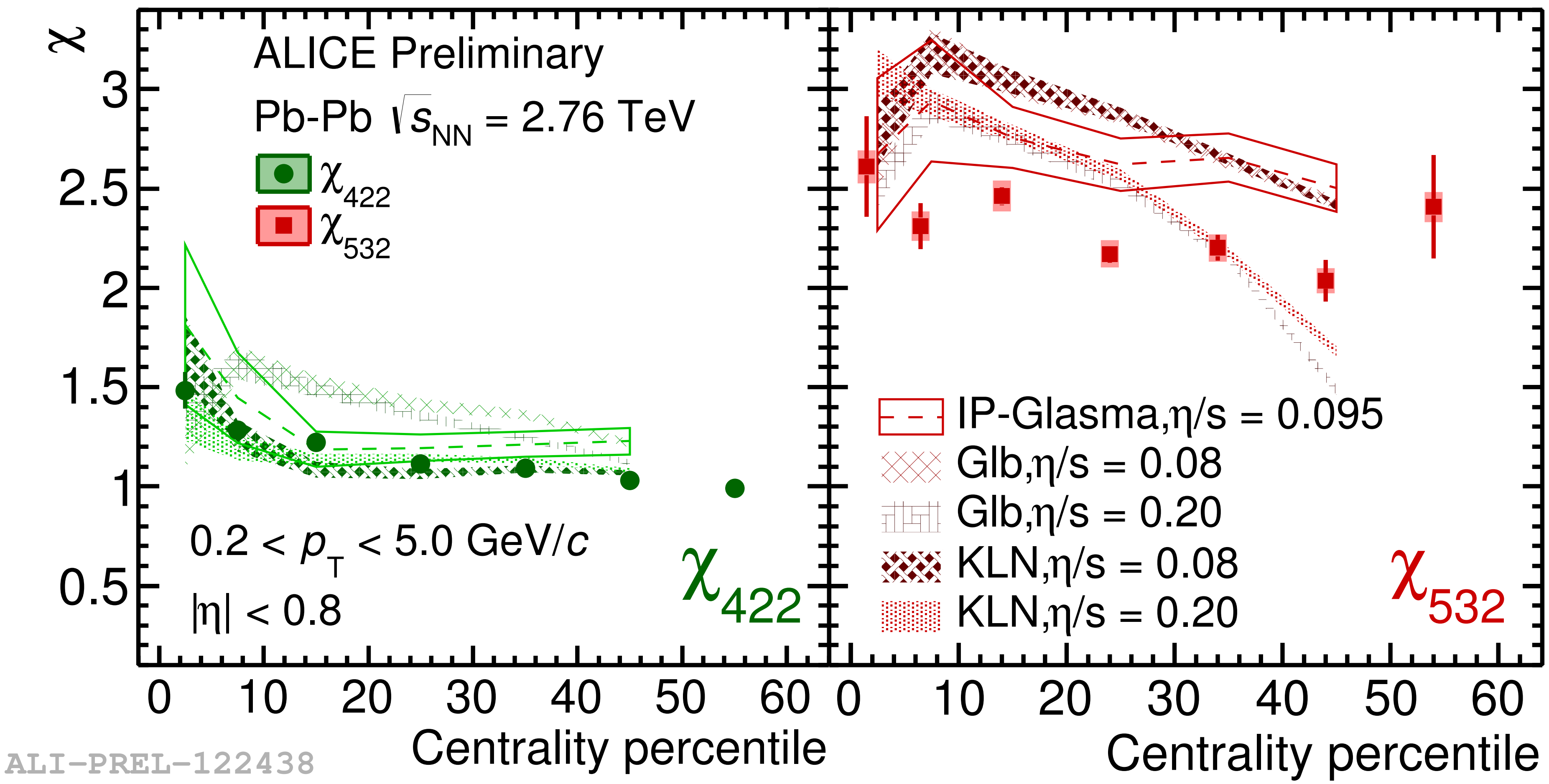
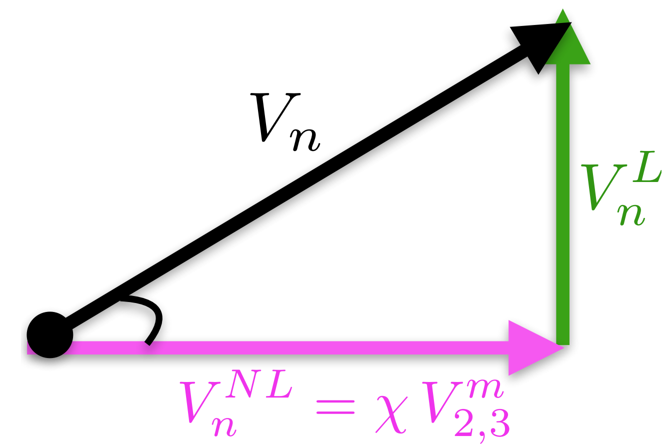
- Intermediate p_T ($3<p_T<8$ GeV/c): type dependence — kE_T/n_q scaling

Flow Harmonic Correlations



$$V_n = V_n^{\mathrm{L}} + V_n^{\mathrm{NL}}$$



$$V_4 = V_4^L + \chi_{422} v_2^2$$

$$V_5 = V_5^L + \chi_{532} v_3 v_2$$

- High harmonic flow is modeled as the sum of linear and non-linear terms
  - Linear response: expected to correspond to the same order eccentricity
  - Non-linear response: corresponds to lower order initial eccentricities
- χ442 — insensitive to η/s but sensitive to initial conditions
- χ532 — weak sensitive to initial conditions, vary significantly with η/s

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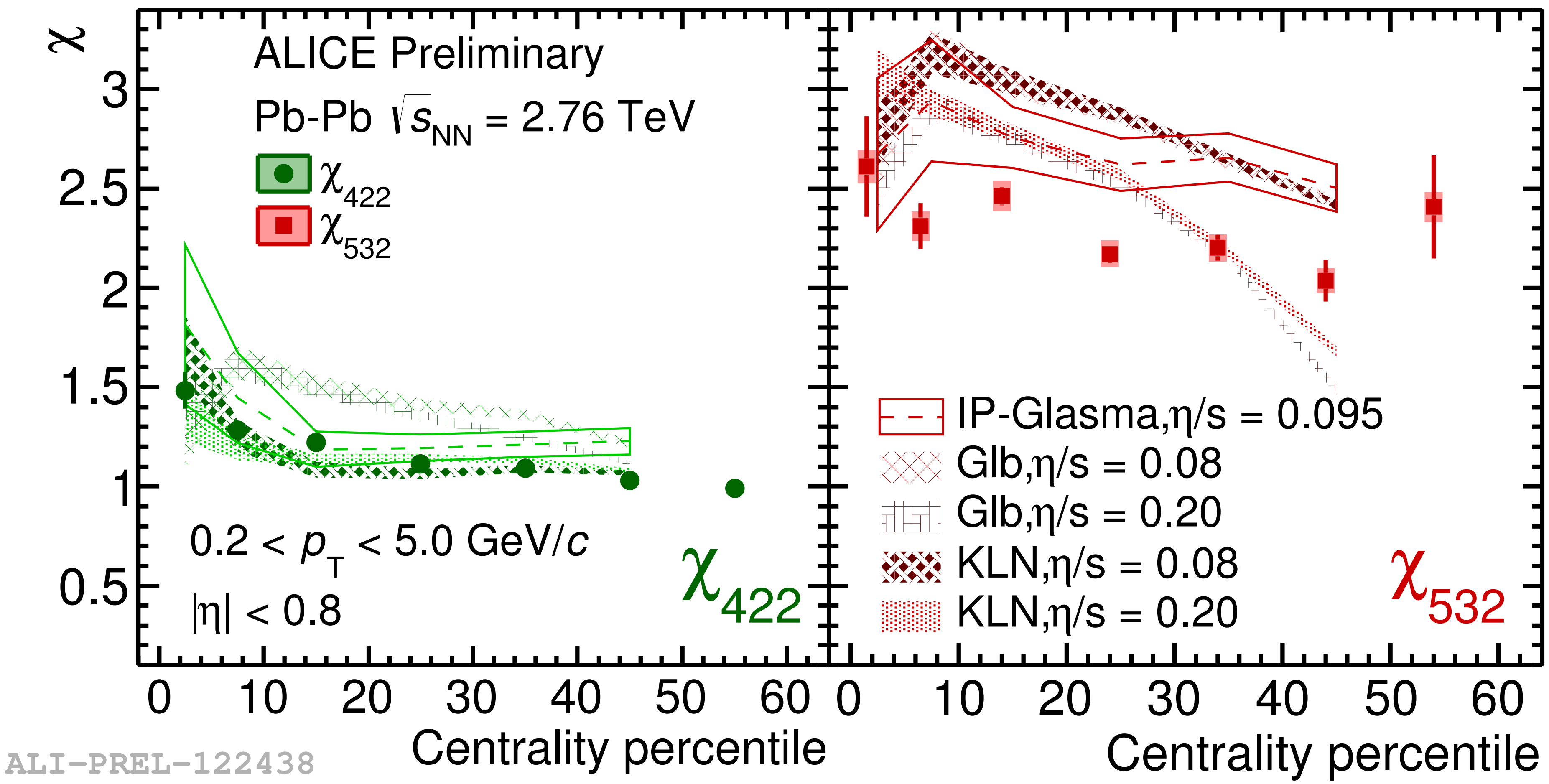

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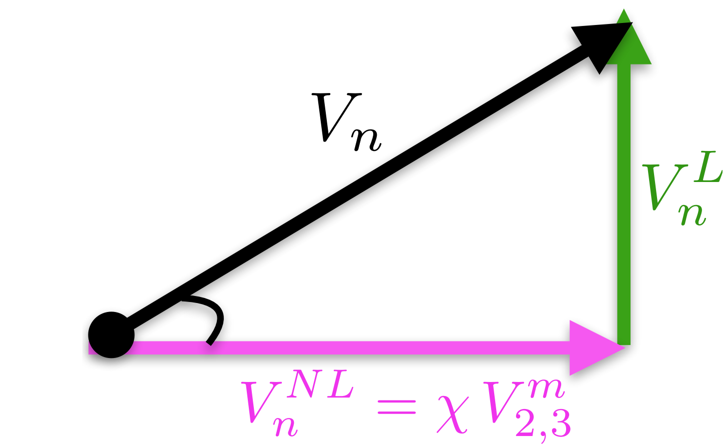

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- High harmonic flow is modeled as the sum of linear and non-linear terms
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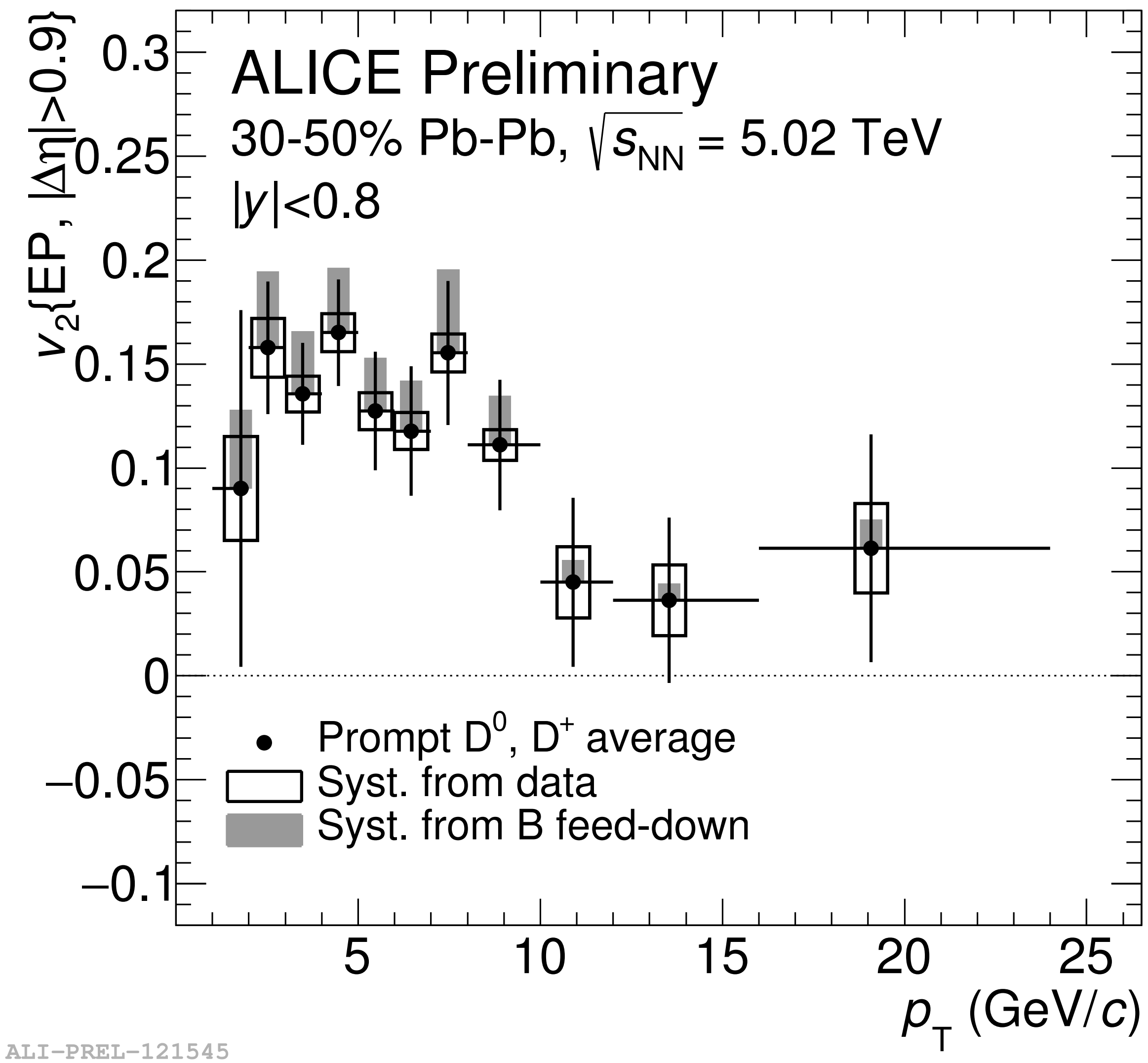
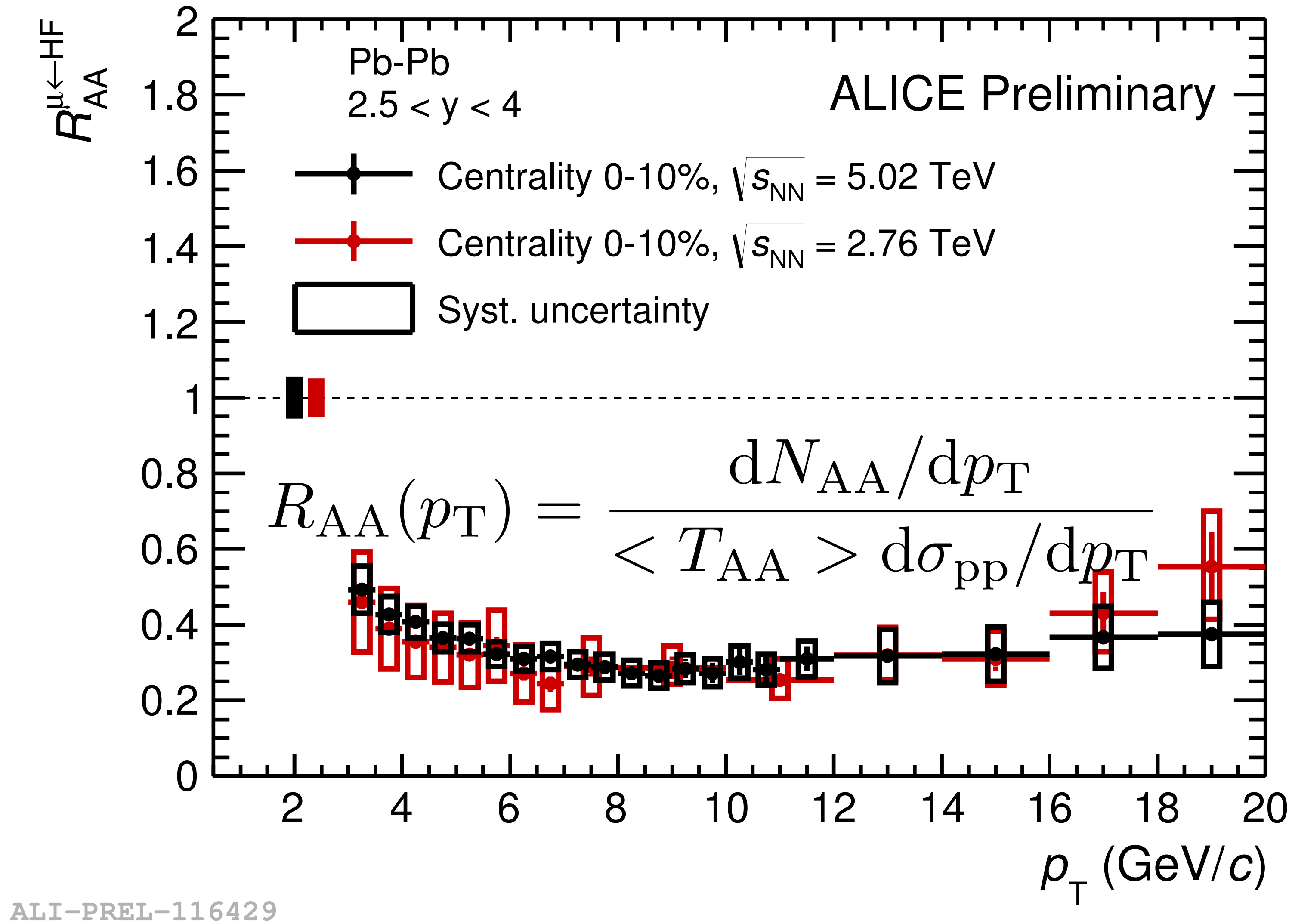
Provided new and stronger constraints on understanding hydro properties of the QGP medium

- χ442 — insensitive to η/s but sensitive to initial conditions
- χ532 — weak sensitive to initial conditions, vary significantly with η/s

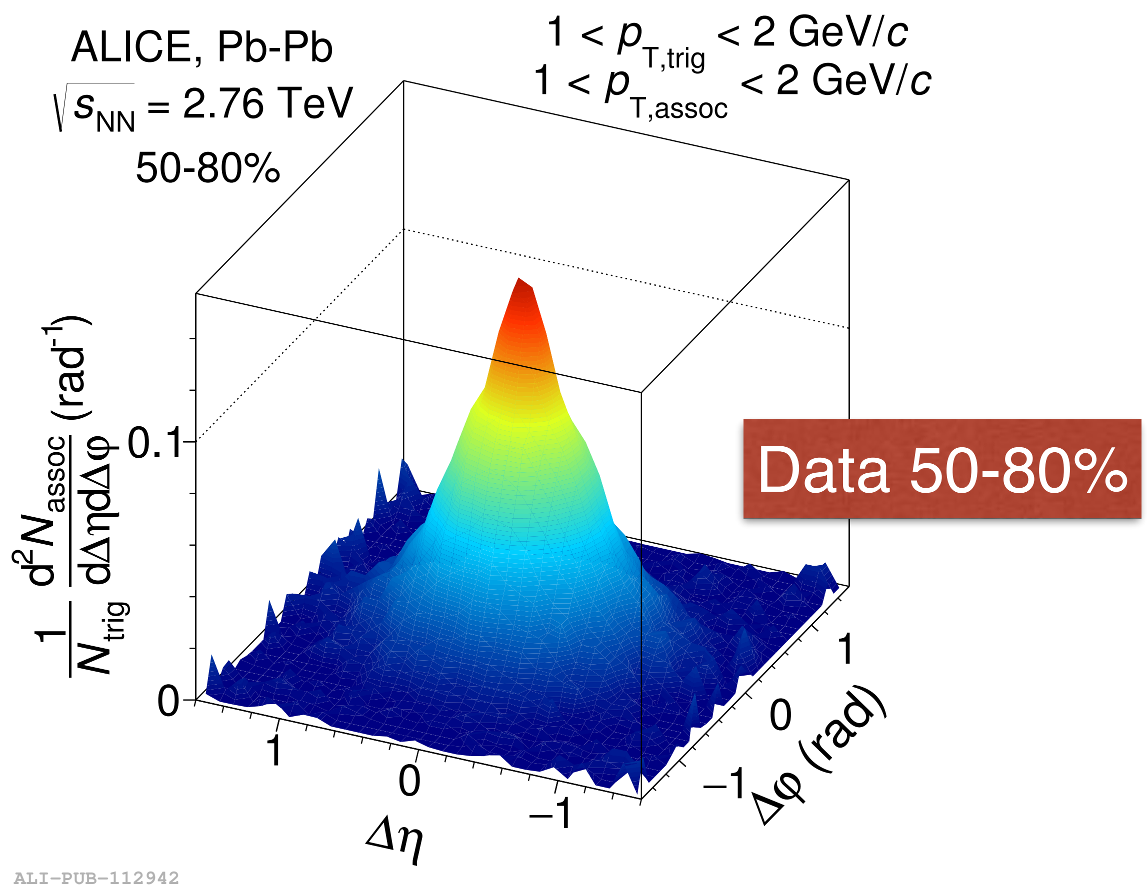
Heavy Flavours

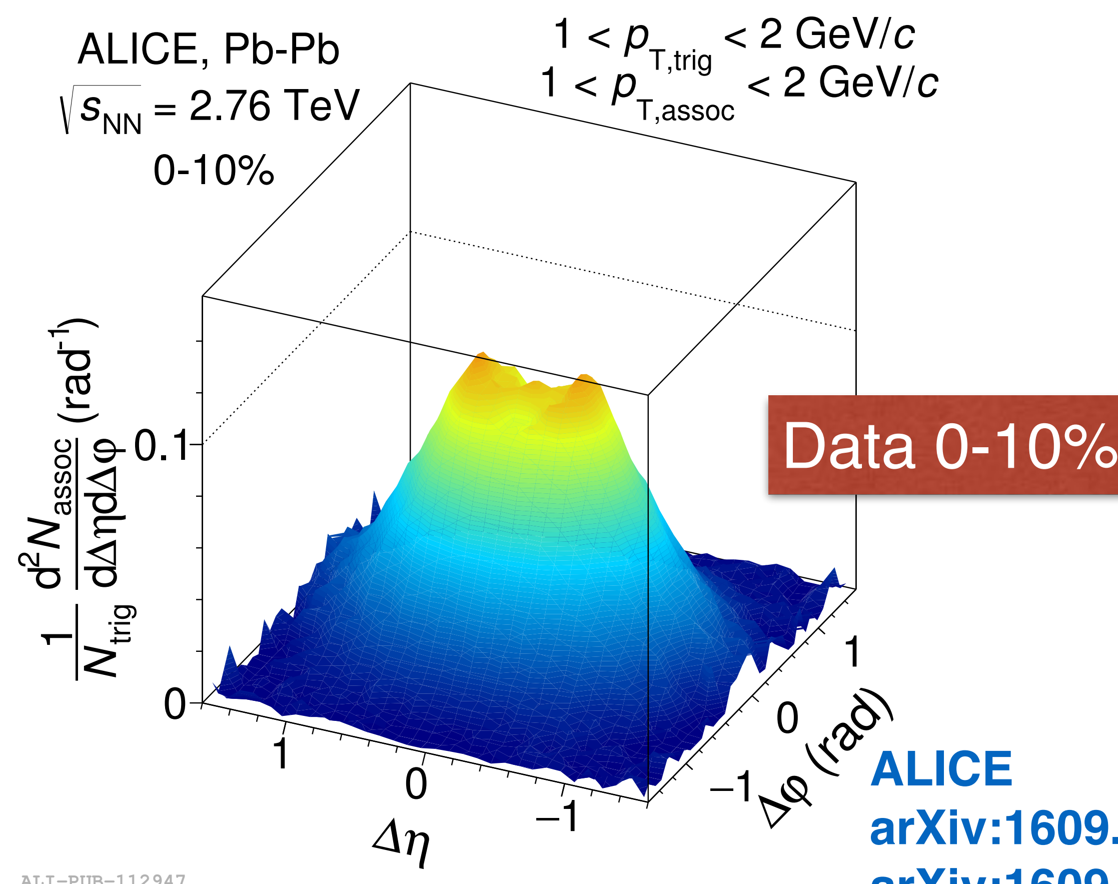




- Confirmed again non-zero v_2 of open heavy flavour in semi-central collisions
- R_{AA} of muon from heavy-flavour decays at forward rapidity — little energy dependence
- Higher precision measurements of R_{AA} and v_2 of open heavy flavours in RUN-II — needed for strong model constraints

Near-side Jet Peak Broadening





ALICE
arXiv:1609.06643
arXiv:1609.06667

- Moderate broadening in Δϕ, while much larger broadening in Δη
  - Hint of strong interaction of jets with the medium

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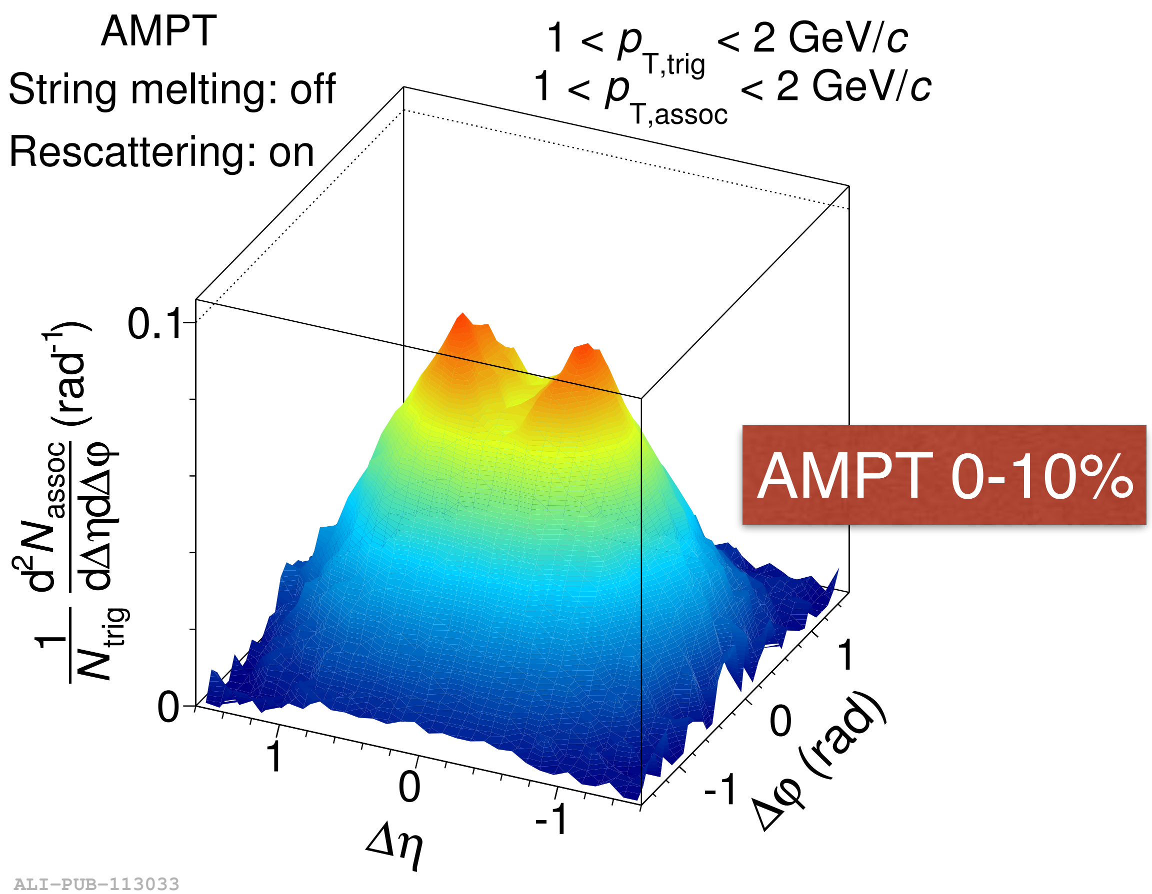

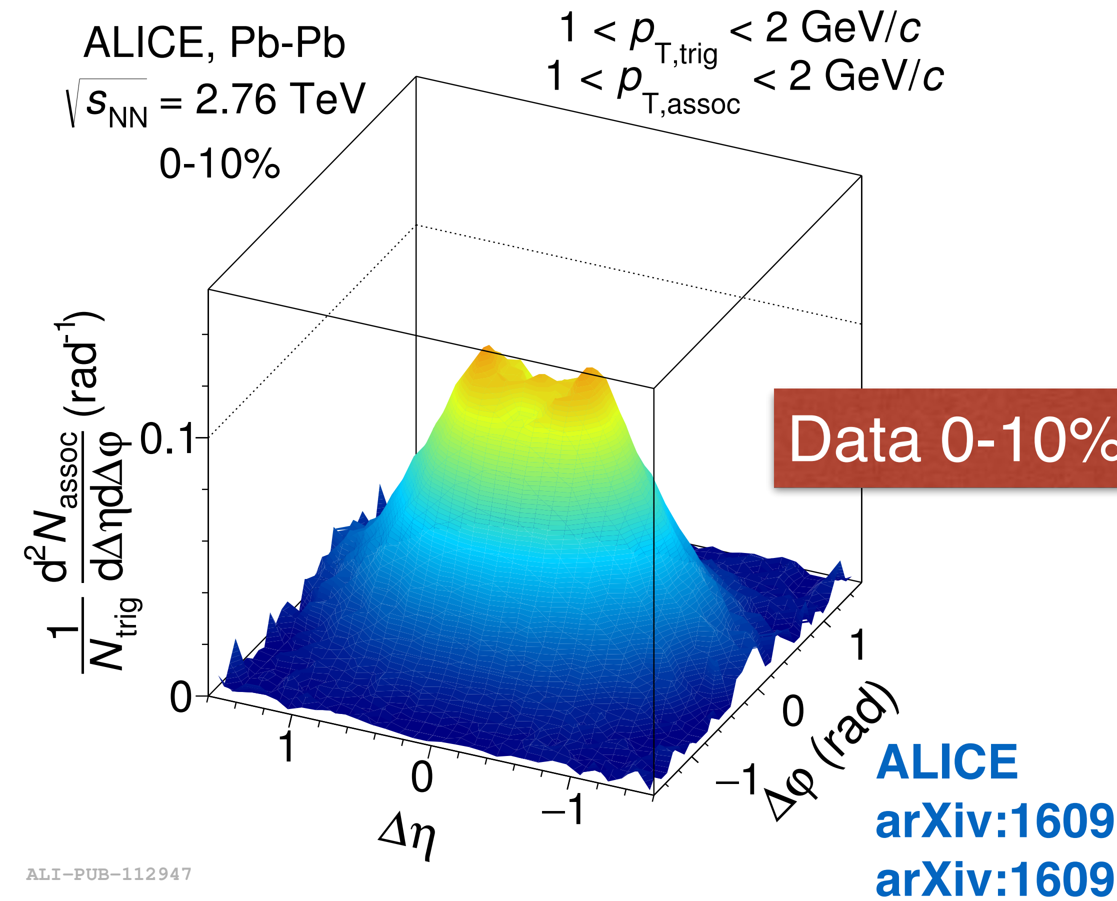

ALICE
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- Moderate broadening in $\Delta\phi$, while much larger broadening in $\Delta\eta$
  - Hint of strong interaction of jets with the medium
- AMPT without melting but with hadronic scattering describes data better than other options — describes both peak broadening and depletion in data
  - Depletion and broadening result from interplay of jets and collective medium, driving factor for depletion and broadening is radial flow

Conclusion

- ALICE LHC RUN-II: 5~10 x data taking rate than RUN-I
- Net-baryon fluctuations: critical reference for study of QCD phase diagram
- Identified particle production
  - The largest radial flow ever observed in heavy-ion collisions
  - Can not exclude hydro correlations at high multiplicity in small systems
- Anisotropic flow: support a low value for η/s (~0.2)
- Flow harmonic correlations: new constraint on understand hydro properties of the QCD medium
- Heavy flavour production: higher precision measurements , strong constraint on the R_{AA} and v_2 puzzle observed in RUN-I
- Jet peak depletion and broadening — interplay of jets and collective medium