ALICE physics

with focus on activities from the Dutch groups

Marco van Leeuwen,
Nikhef, Utrecht University and CERN

NuPECC meeting, 16-17 March,
Amsterdam

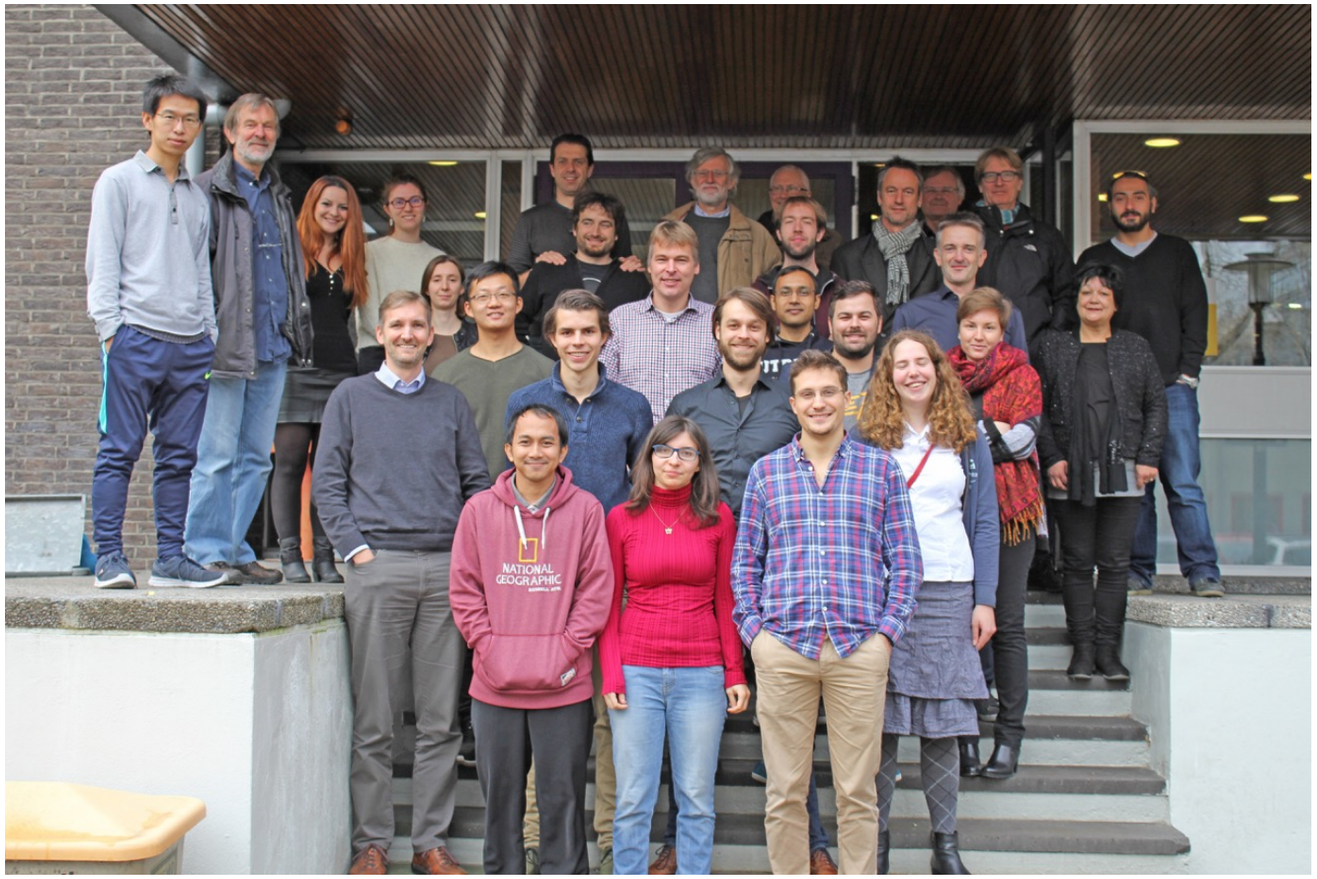
Universiteit Utrecht

Nikhef

ALICE

Meet the group

- Composition
  - 7 staff
  - 6 postdocs
  - 12 PhD students
- Analysis/physics involvement:
  - Flow, collective effects
  - Photons
  - Heavy flavour
  - High-p_T and jets
- Detector involvement:
  - Silicon Strip Detector (current ITS)
  - ITS upgrade
  - FOCAL: Si-W EMCal development
- Large impact on physics publications
  - Organisational roles in ALICE: PWG convener(s), PAG coordinators, Editorial board, Conference Committee membership, Physics Coordinator



Quick word on funding

- Four main sources of funding:
  - Permanent staff funded by Nikhef, Utrecht University
  - NwO ‘program funding’: research postdocs+PhD students (a few positions)
  - NwO ‘Big’: investment funding for detector construction and computing; common with other LHC experiments
  - Personal grants (NwO/ERC): other PhD students + postdocs (majority)

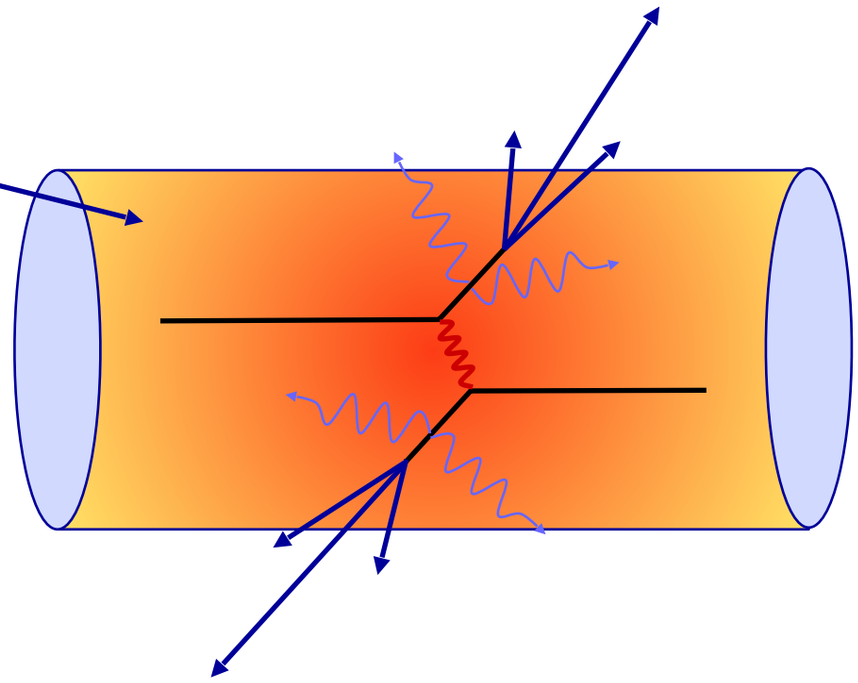
Heavy ion collisions

Heavy-ion collisions produce
'quasi-thermal' QCD matter

Dominated by soft partons
p ~ T ~ 100-300 MeV

'Bulk observables'

Study hadrons produced by the QGP
Typically p_T < 1-2 GeV



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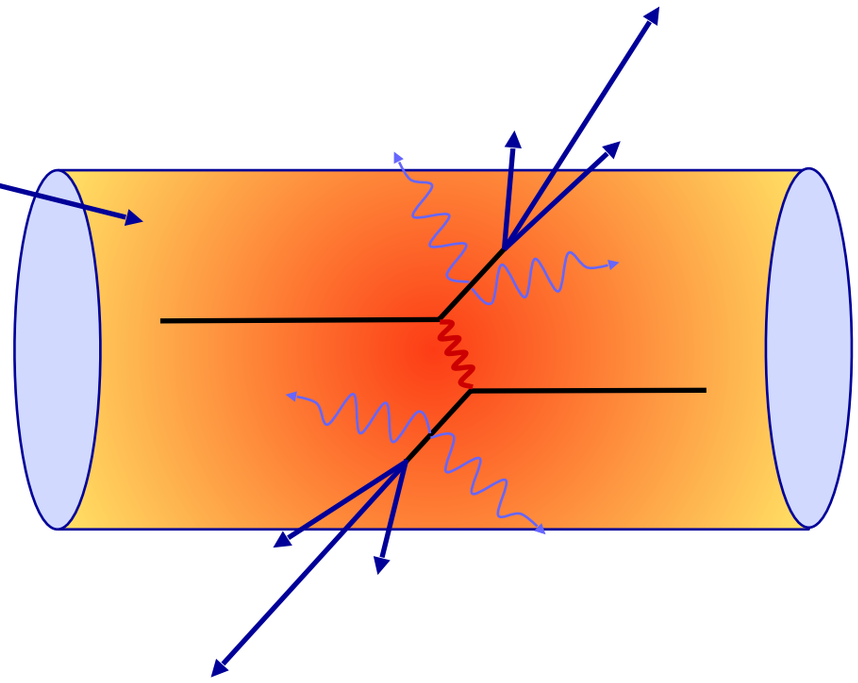

'Hard probes'

Hard-scatterings produce 'quasi-free' partons
⇒ Probe medium through energy loss
p_T > 5 GeV

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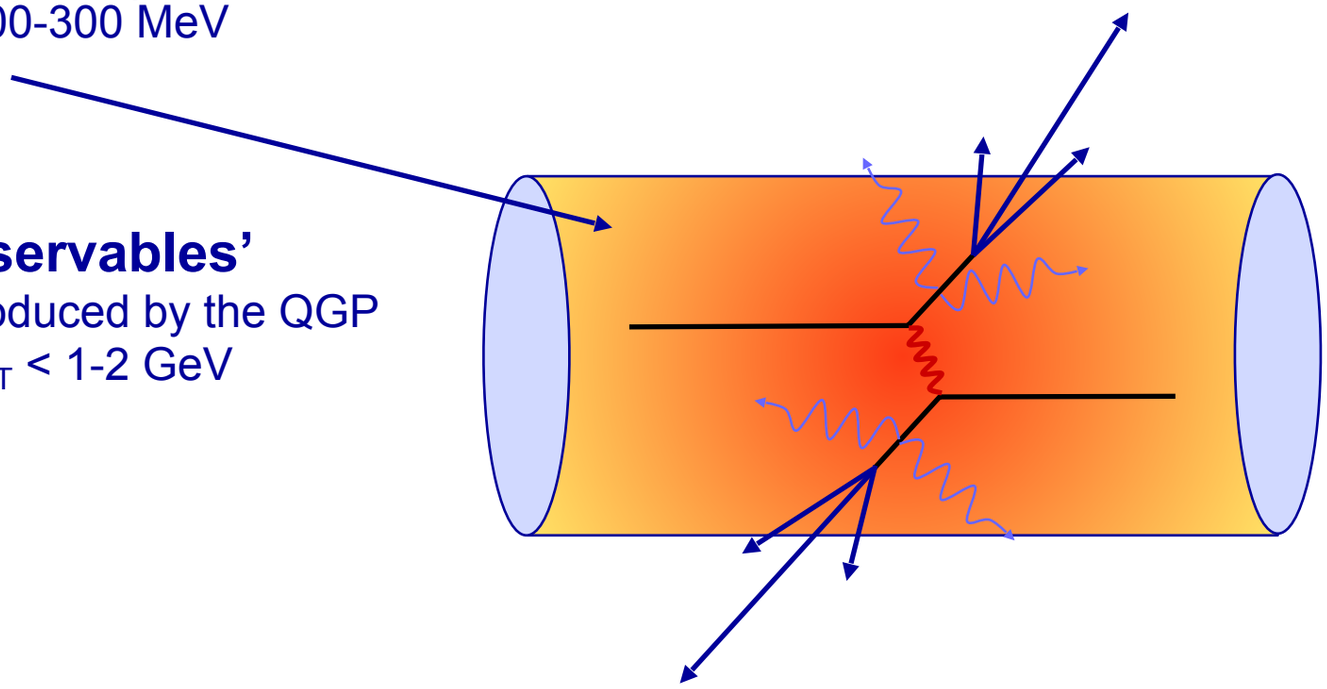

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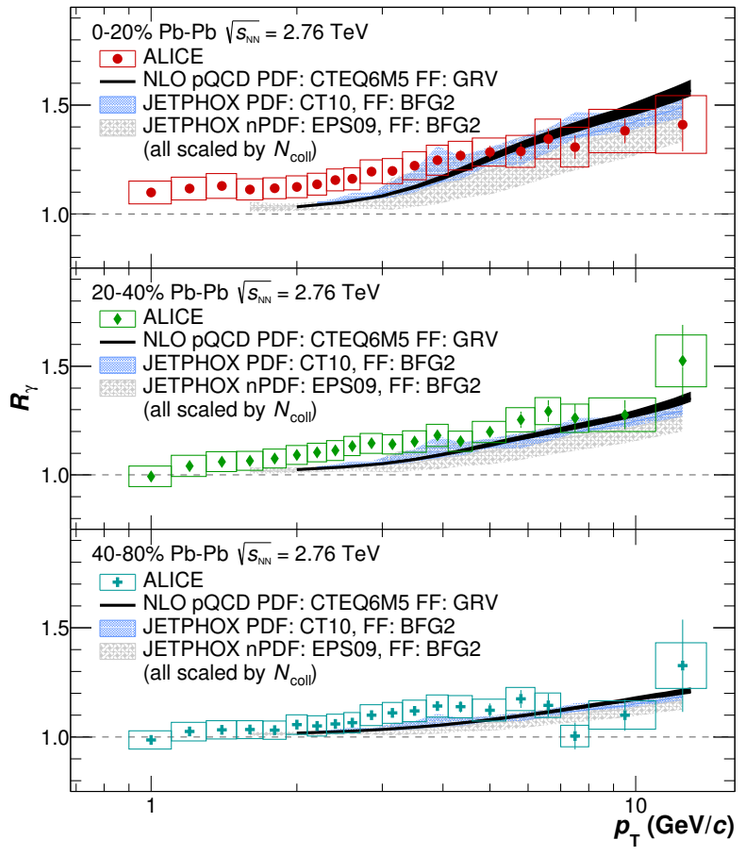
Two basic approaches to learn about the QGP
1) Bulk observables
2) Hard probes

Direct photons

Direct/decay photon double ratio



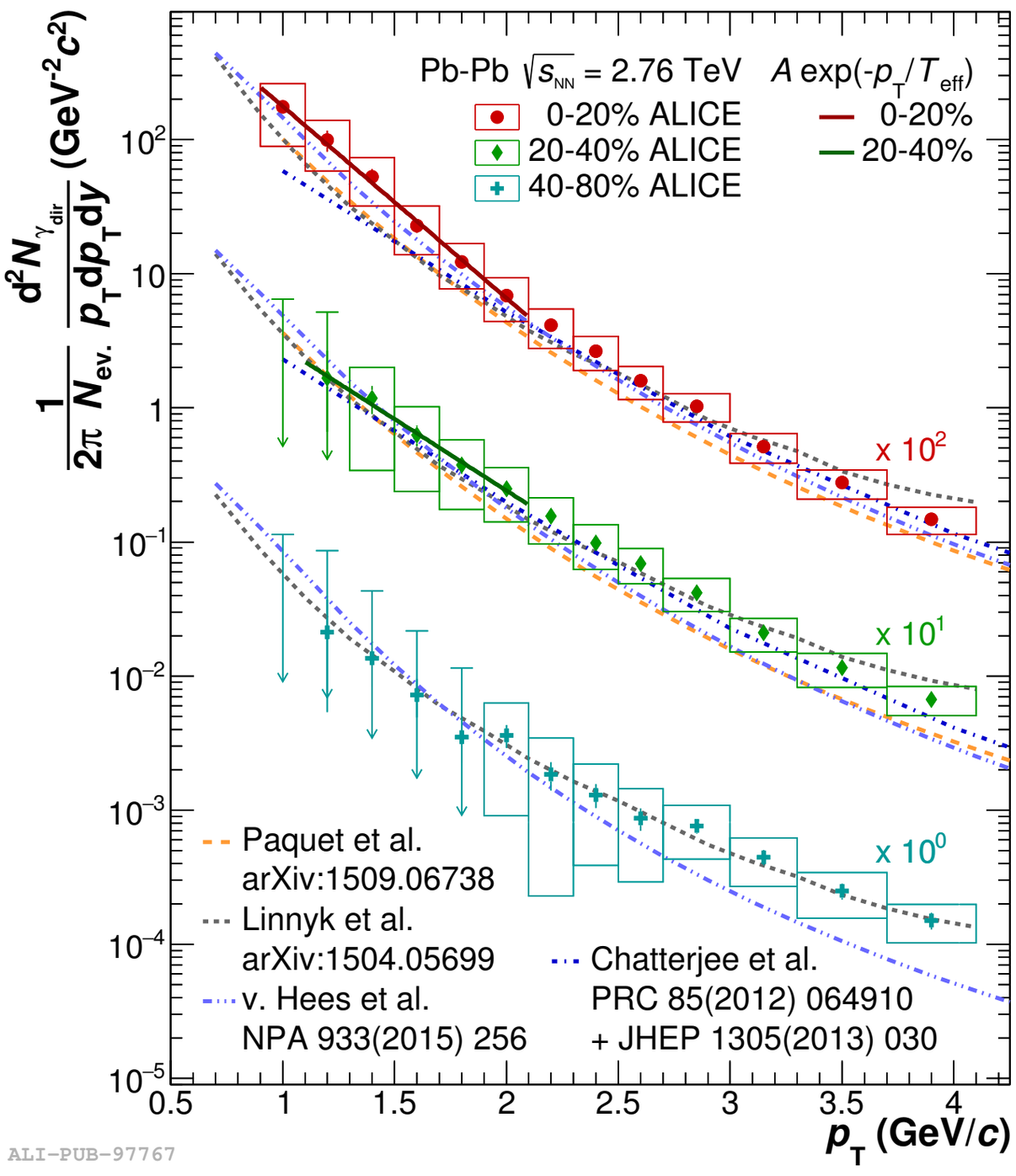
Main expected sources:

- High p_T: hard scattering; quark-gluon Compton process
- Low p_T: thermal radiation

Excess at low p_T in central collisions indicates thermal photon production

T_{init} ~ 200-400 MeV

Direct photon spectra

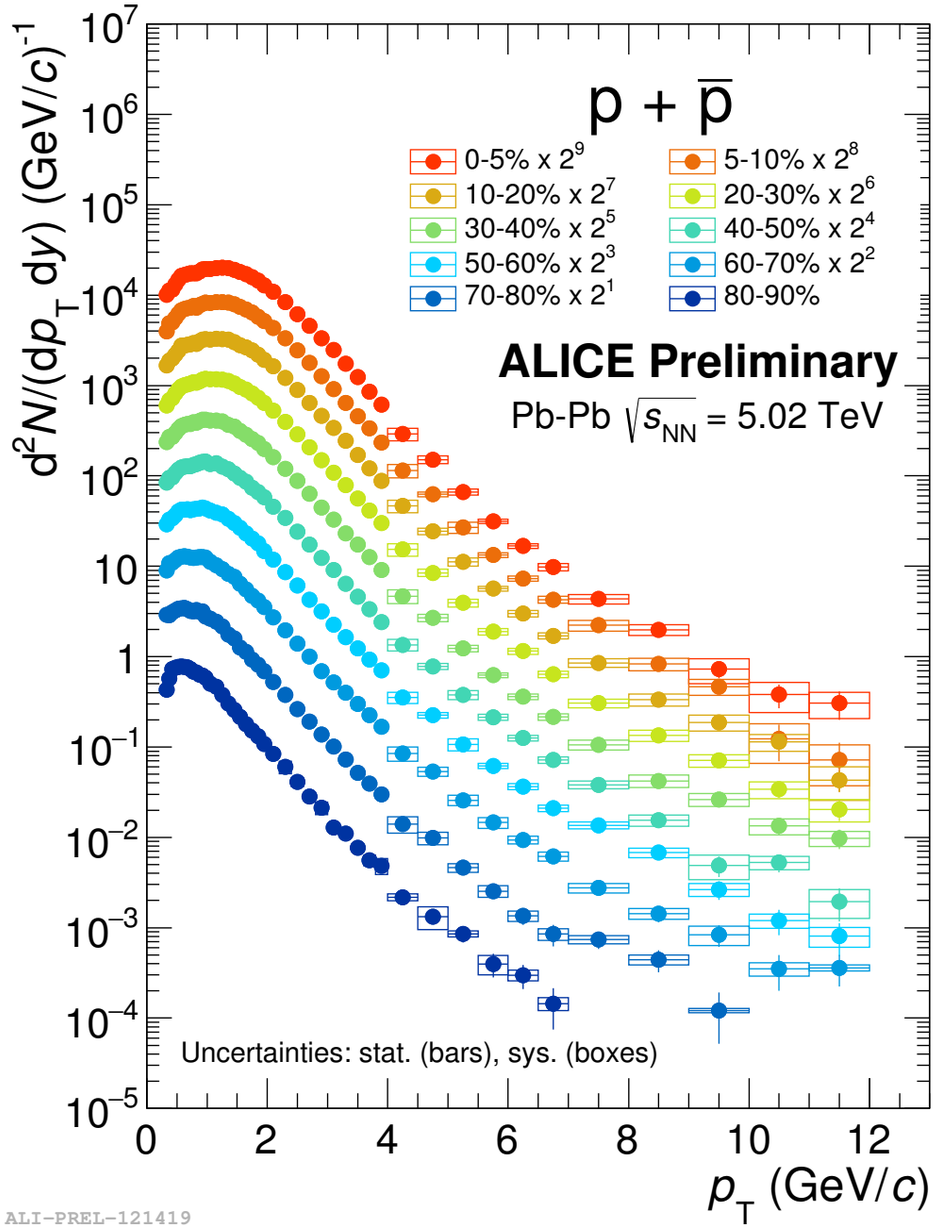


ALI-PUB-97767

arXiv:1509.07324

Identified particle spectra and radial flow

Proton momentum distribution



Large range in p_T
using 4 different detector systems

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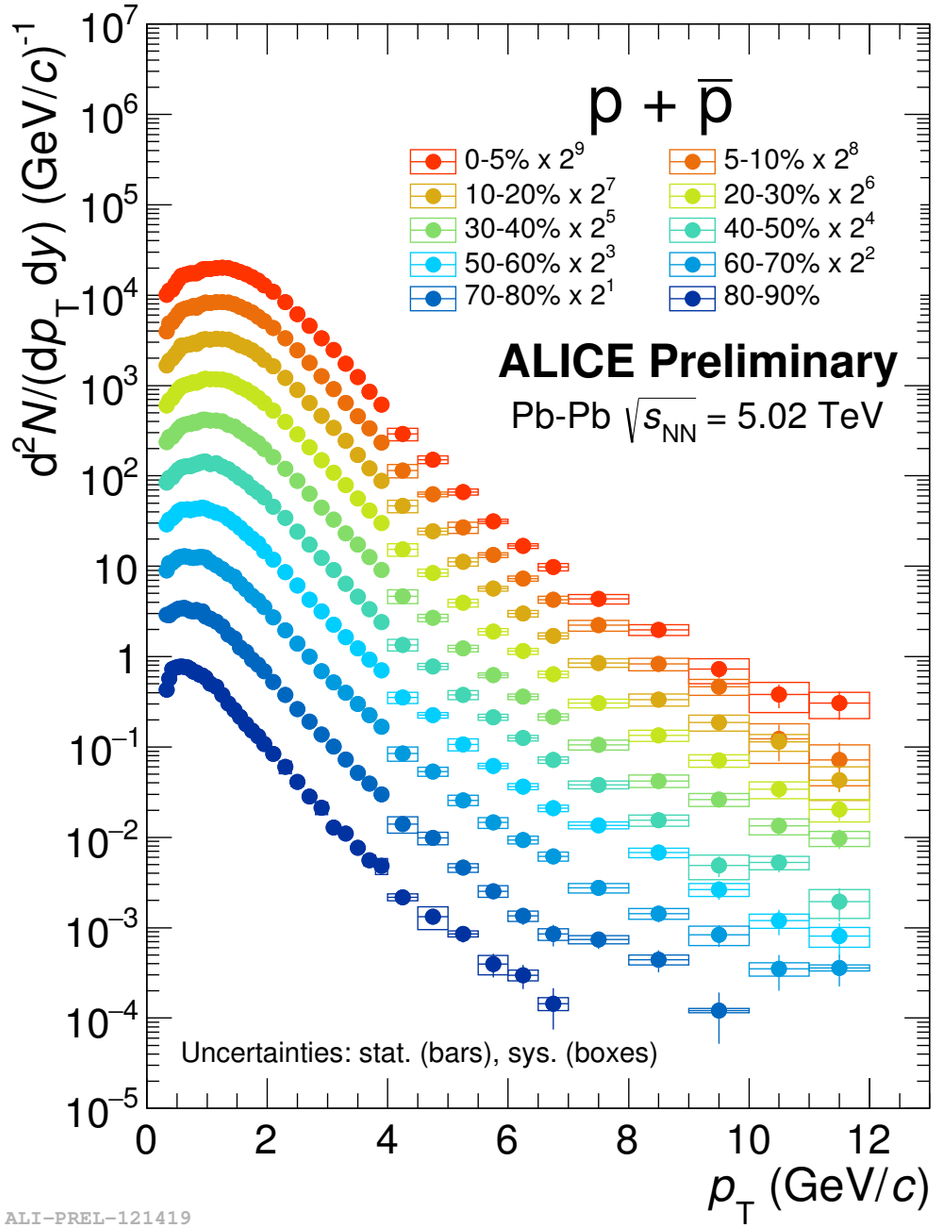
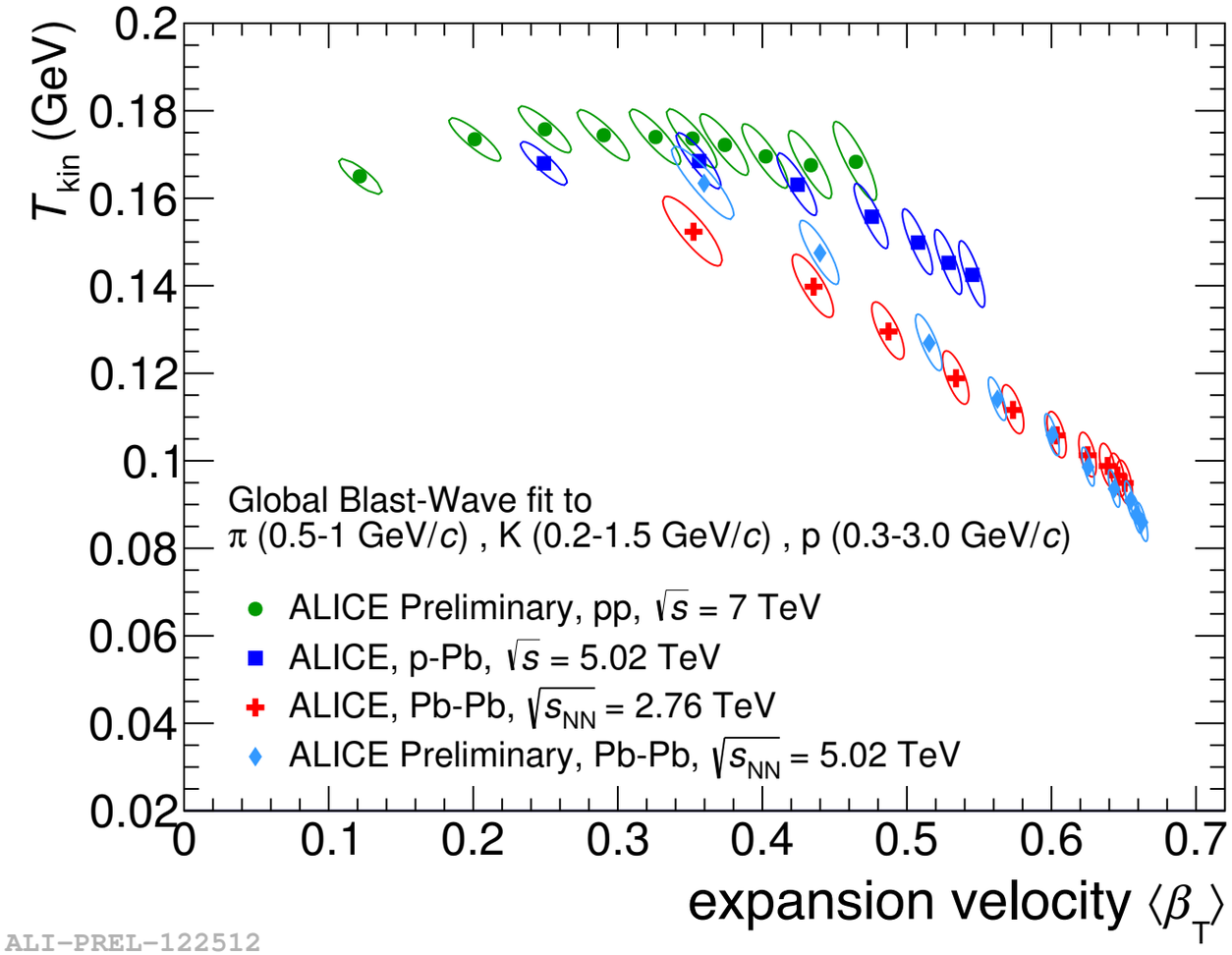


ALI-PREL-121419

Radial expansion model: blast wave



ALI-PREL-122512

Large range in p_T
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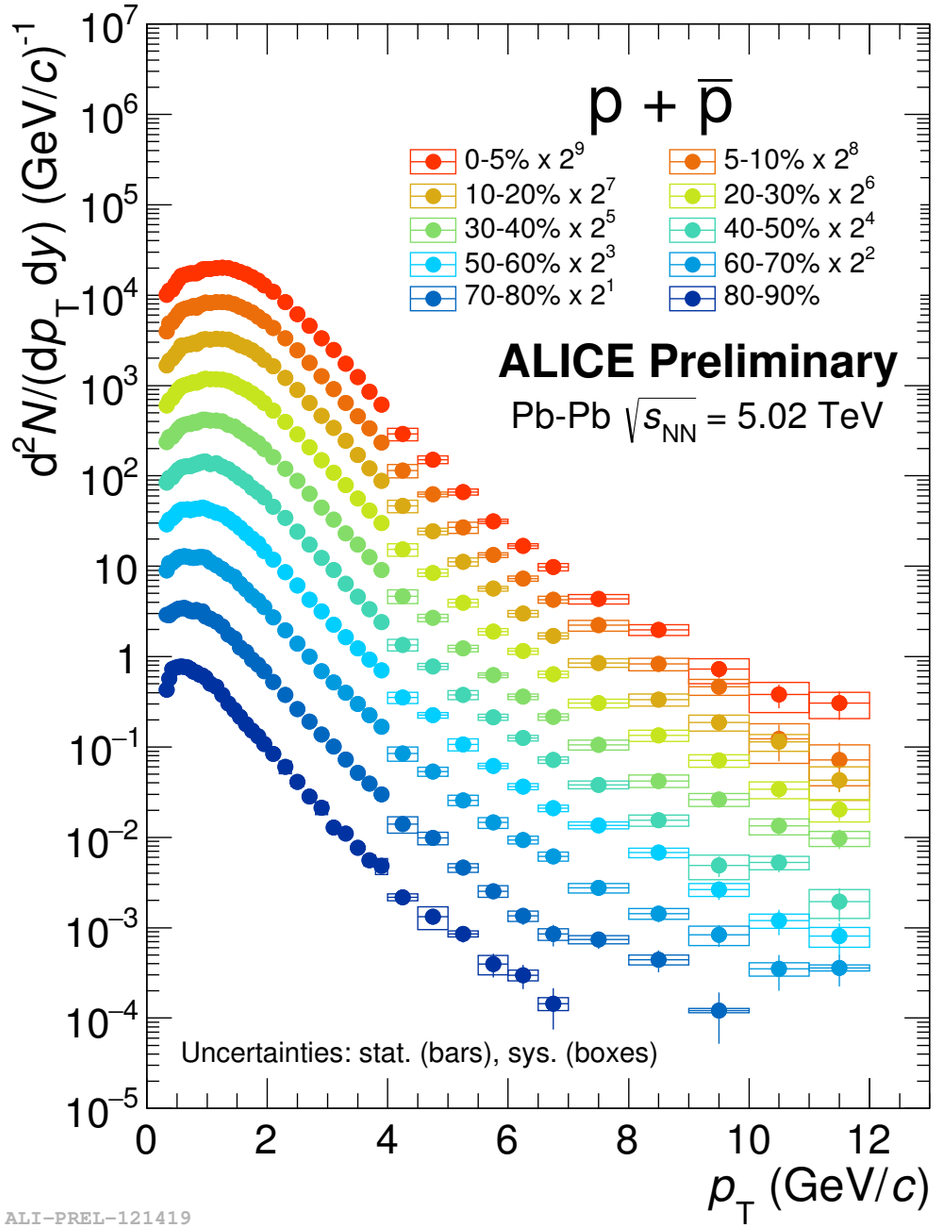

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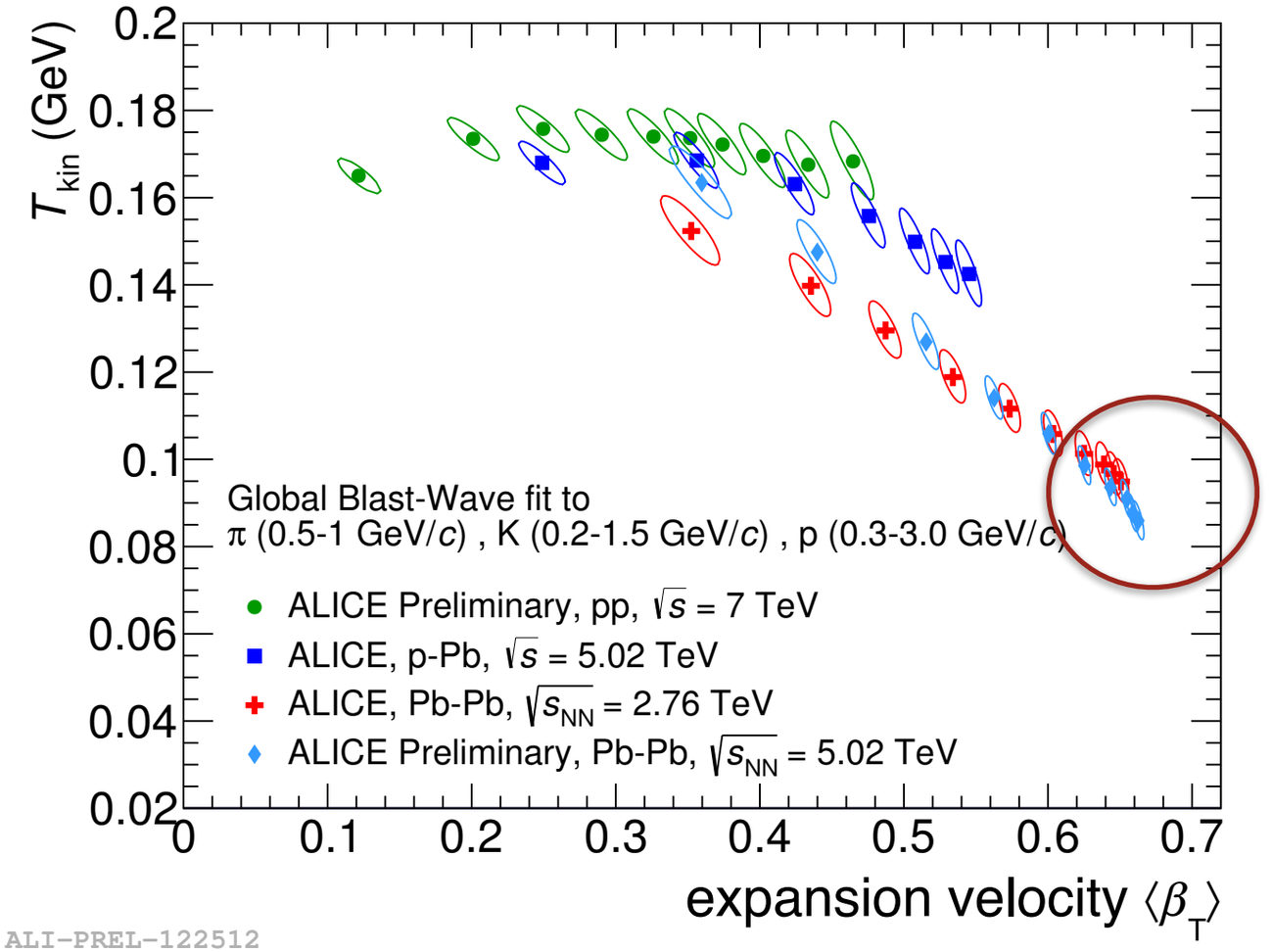
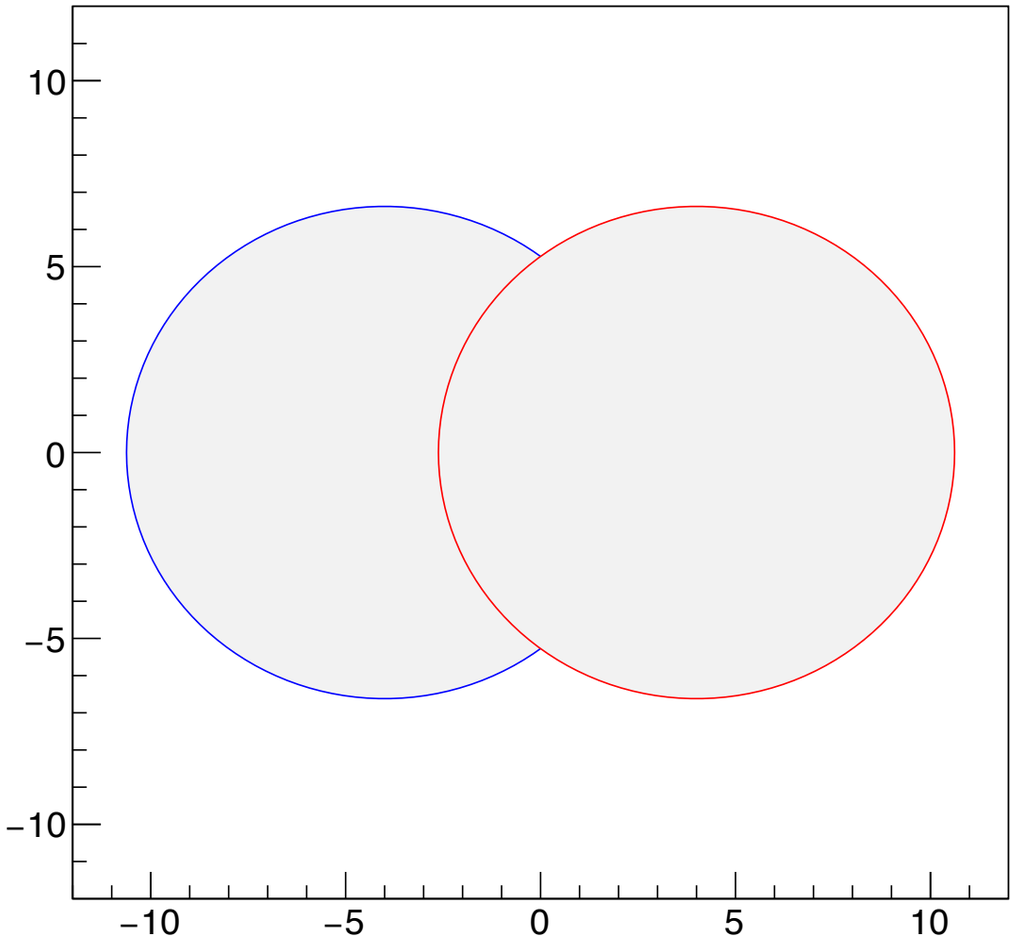


ALI-PREL-122512

Largest expansion velocities
observed in the laboratory achieved
in Run 2 ($\sqrt{s_{NN}}$ = 5.02 TeV)
0.66 times the speed of light!

Azimuthal anisotropy: initial and final states

MC event: location of nucleons



Characterise shape by angular moments:

$$\varepsilon_n = \frac{\sum r^2(\cos^2 n\varphi + \sin^2 n\varphi)}{\sum r^2}$$

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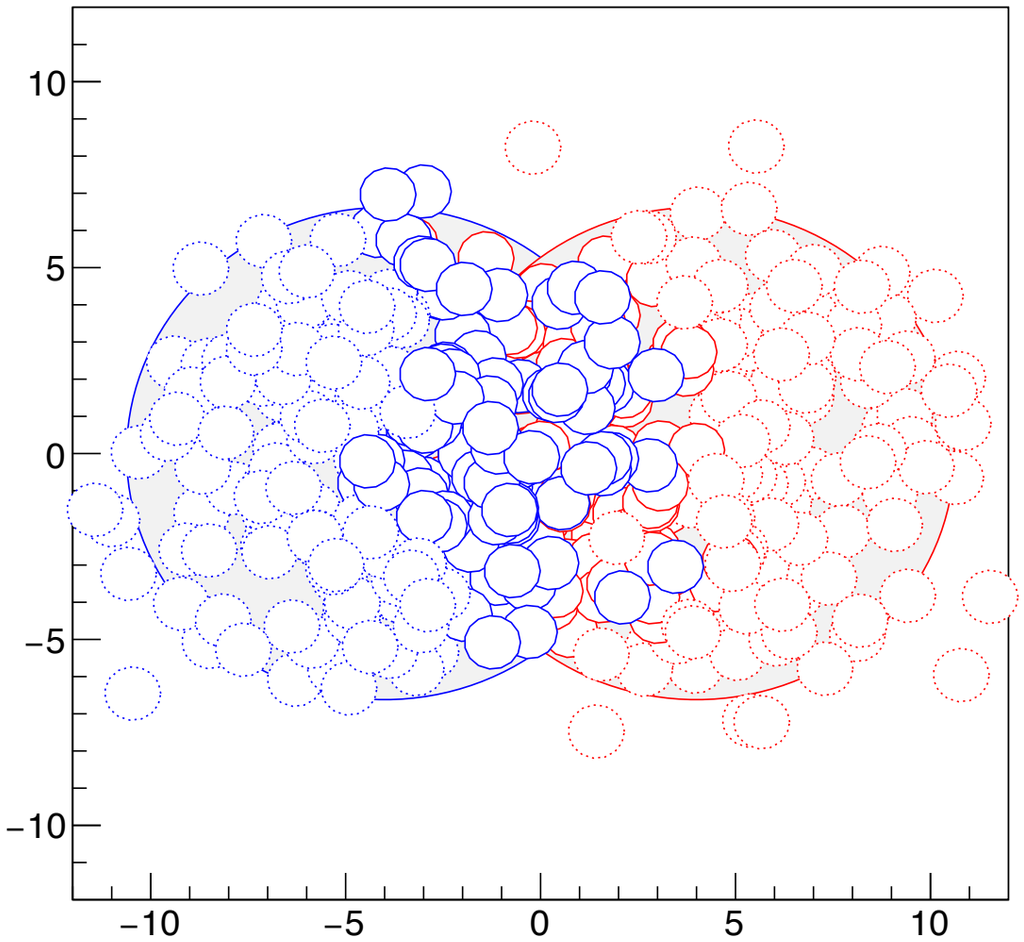

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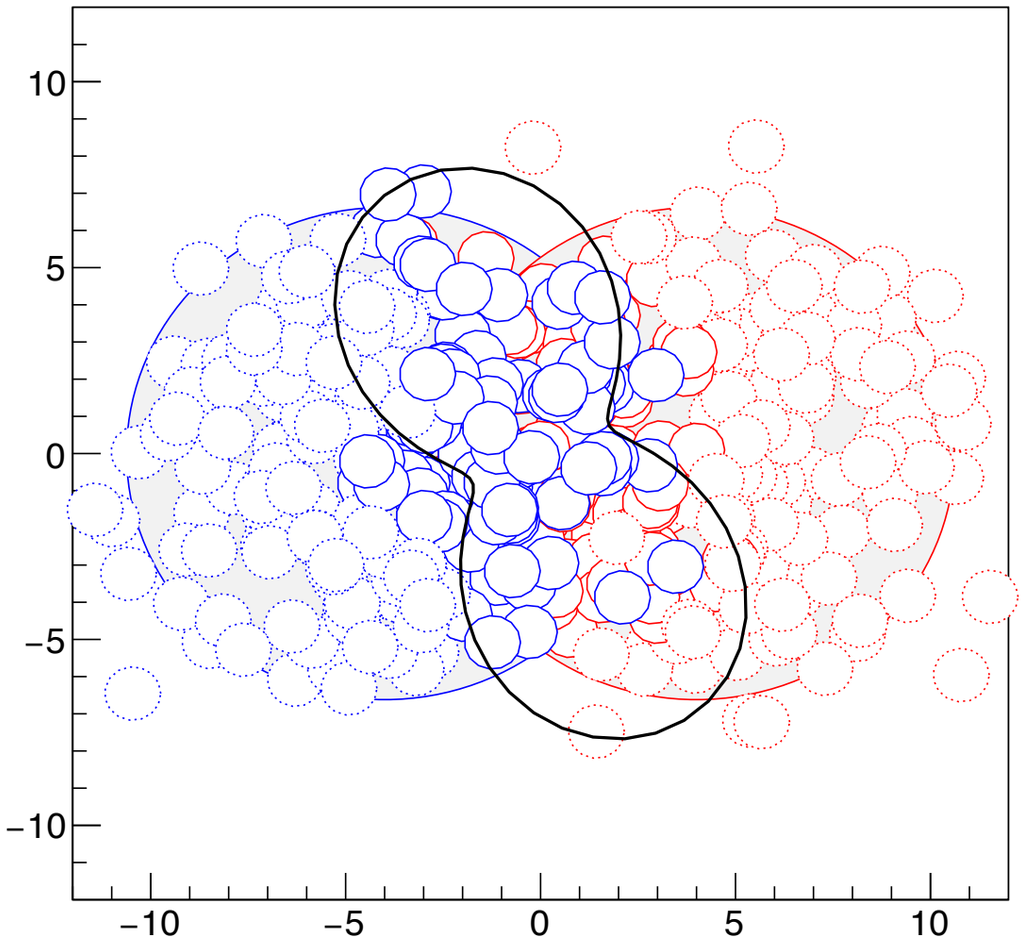

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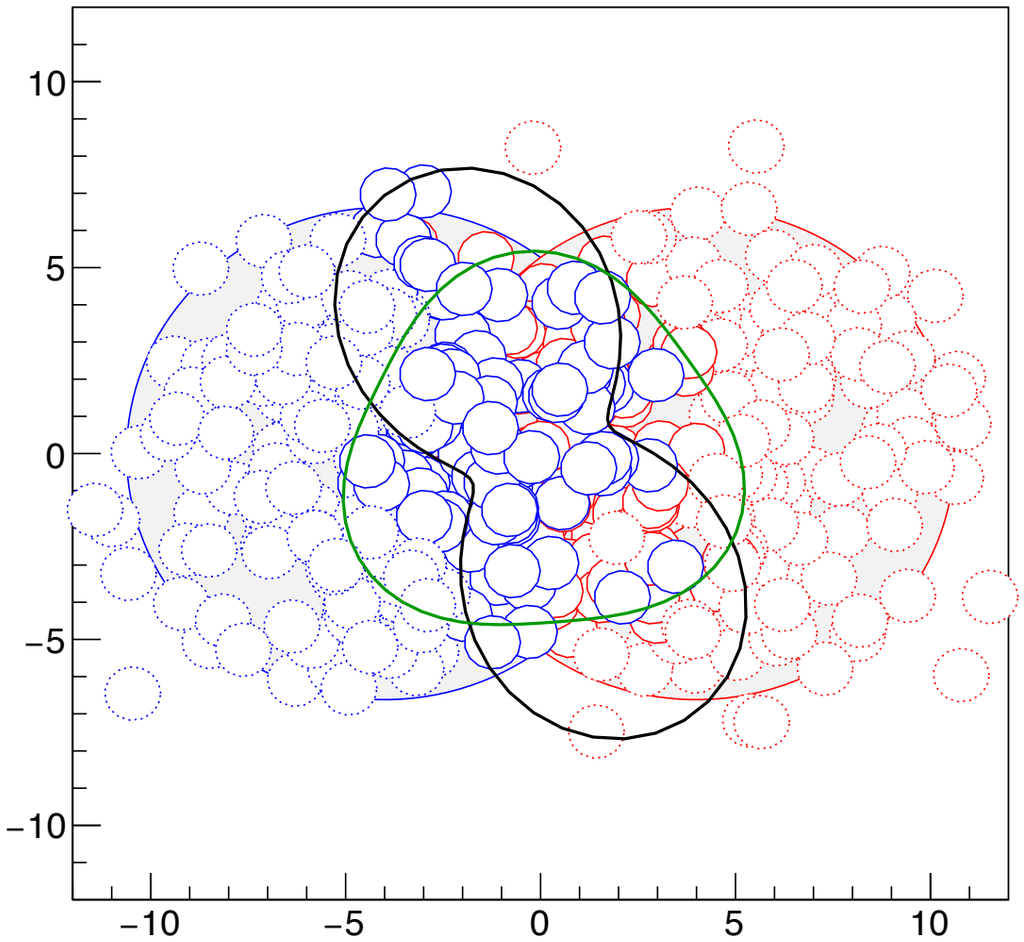

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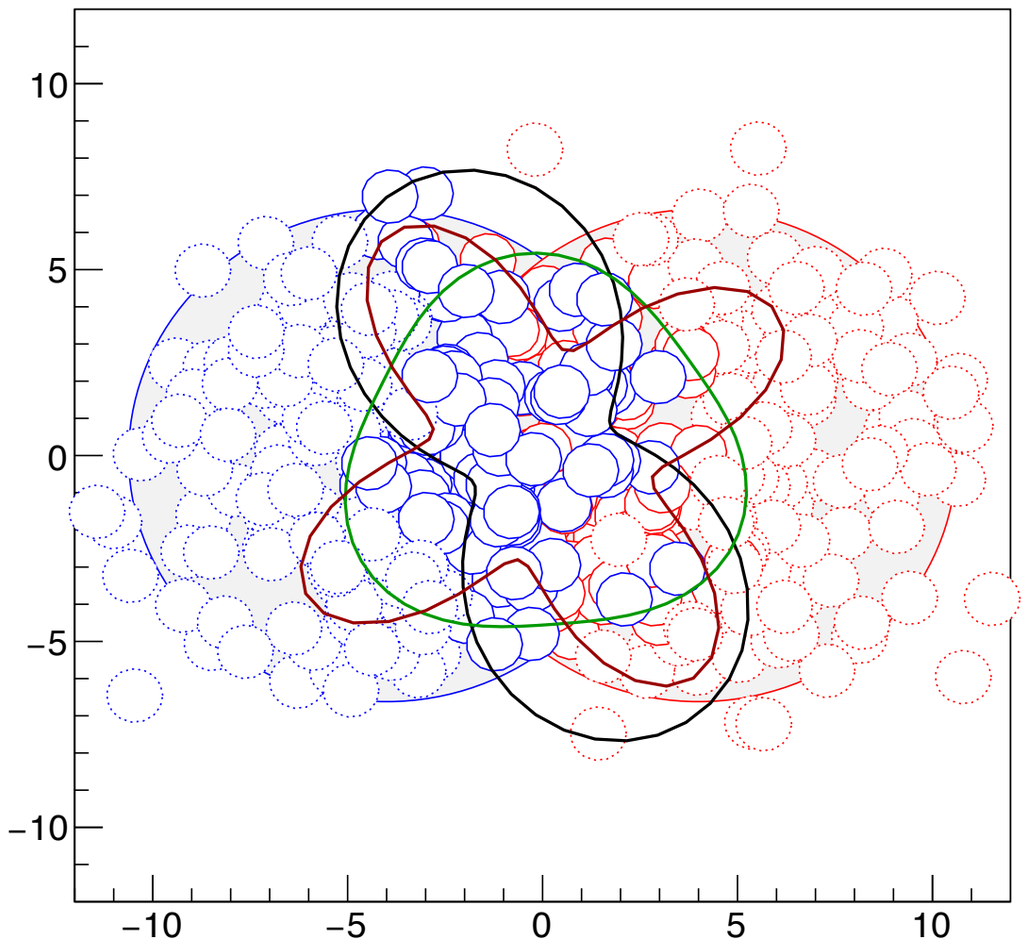

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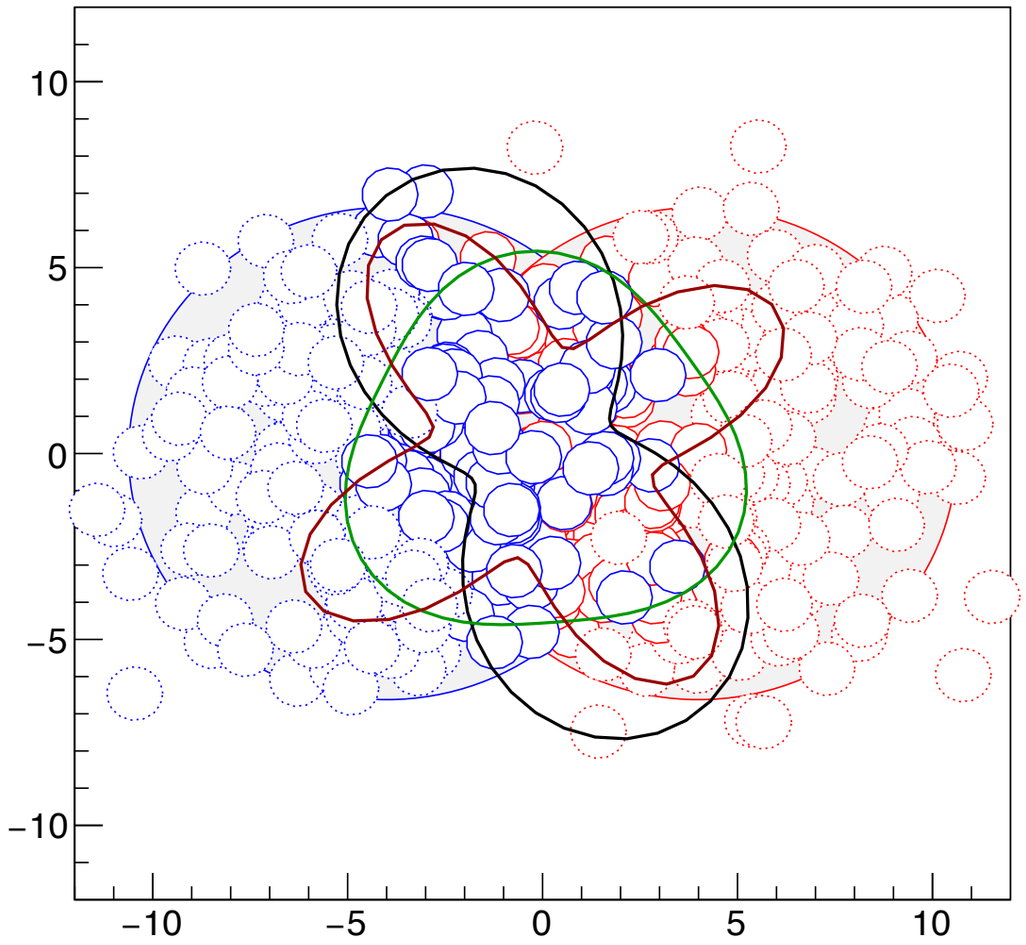
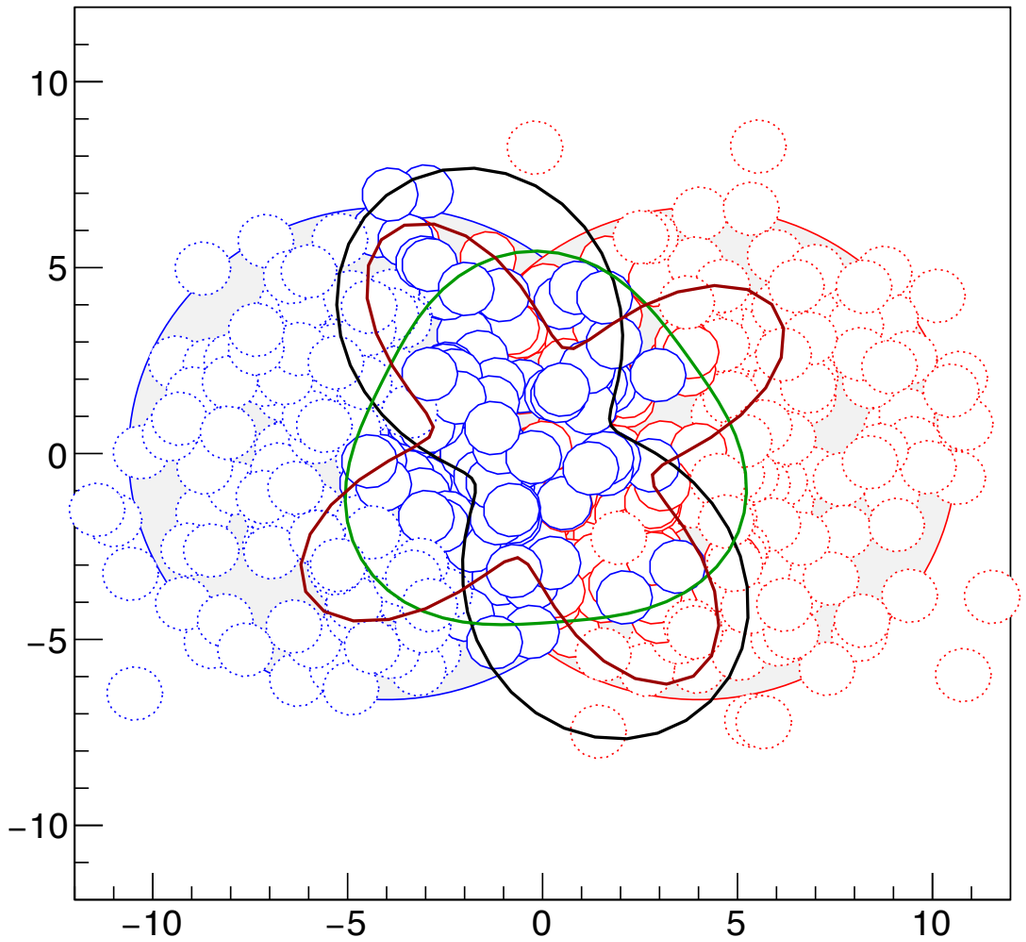


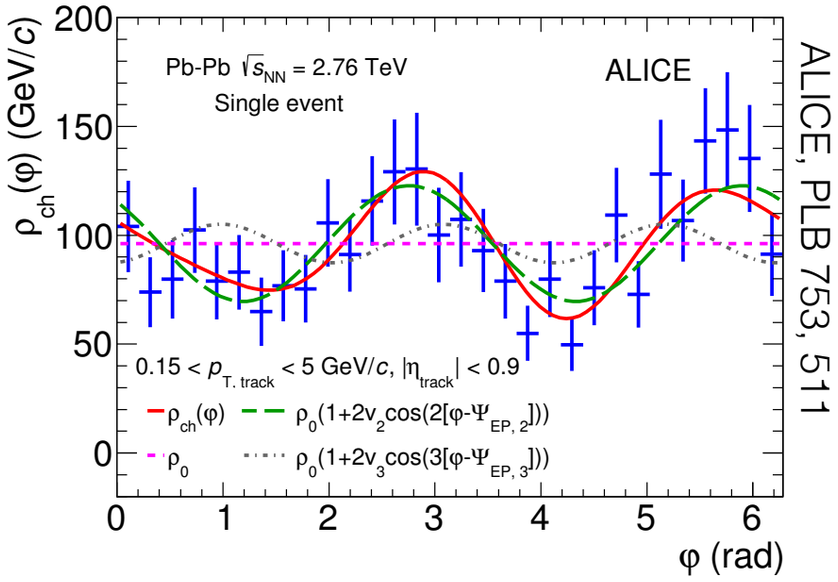
Initial state spatial anisotropies ε_n are transferred into final state momentum anisotropies v_n by pressure gradients, flow of the Quark Gluon Plasma

Azimuthal anisotropy: initial and final states

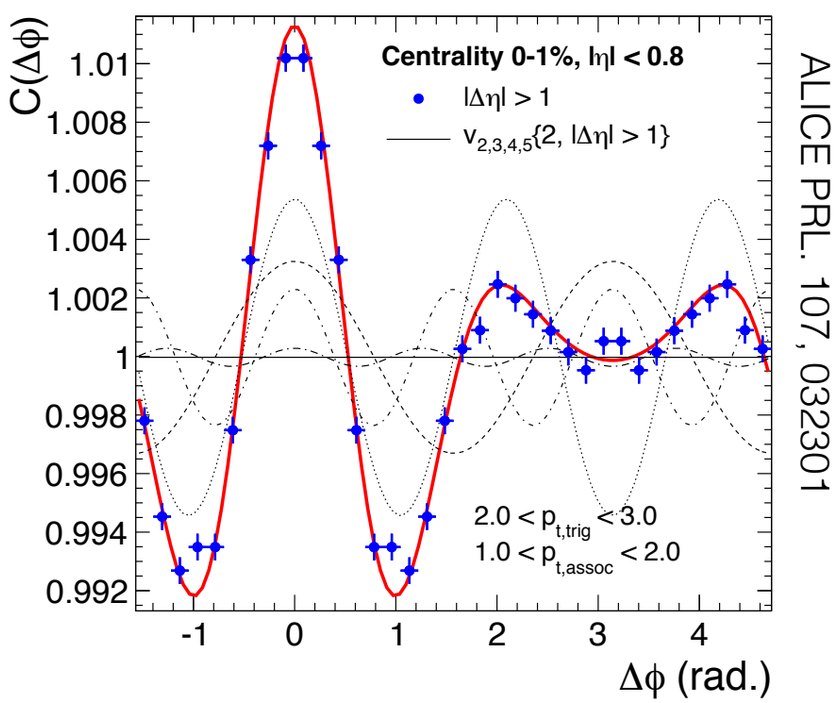
MC event: location of nucleons



Azimuthal distribution single event

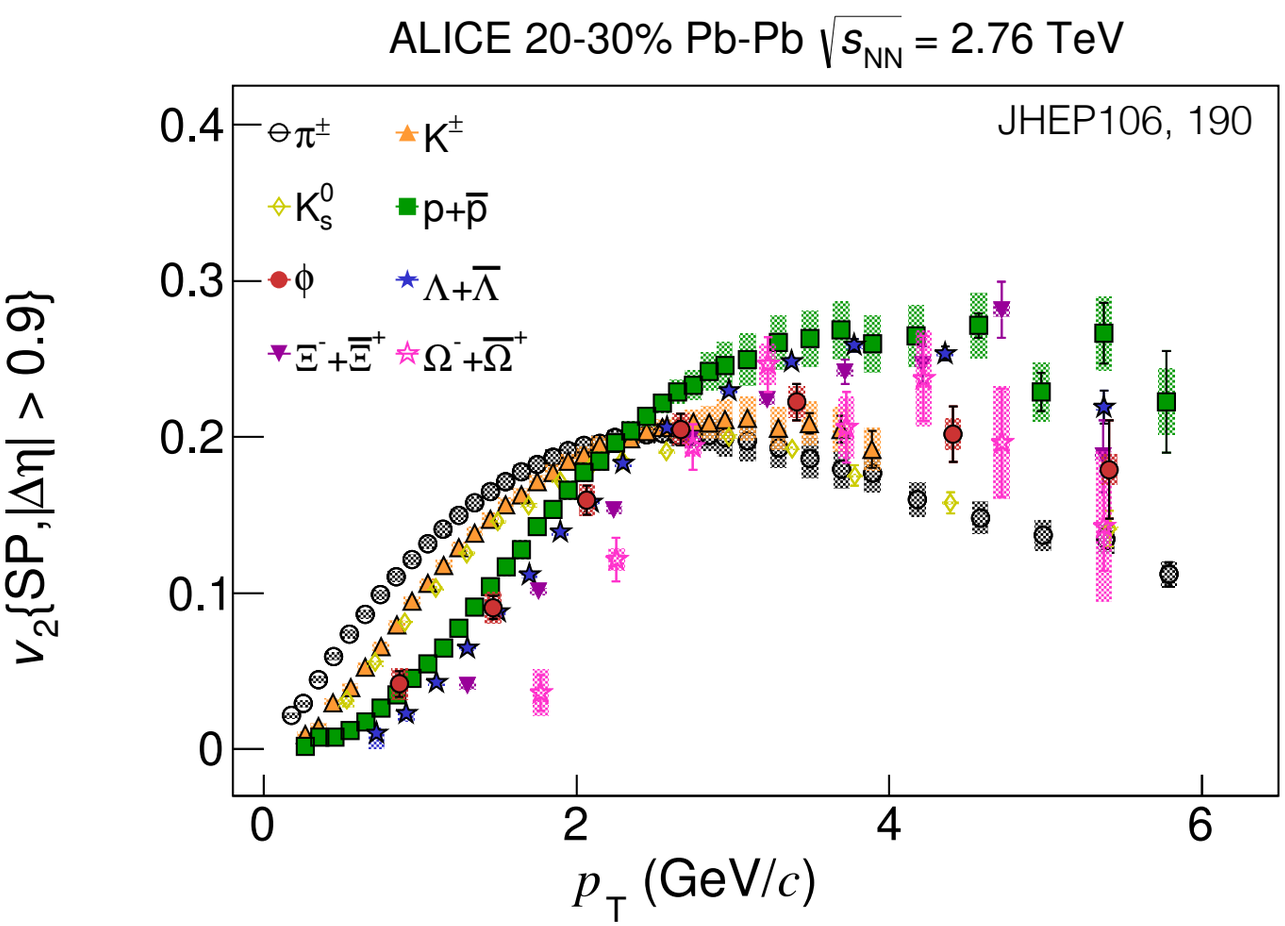


Sum over many events



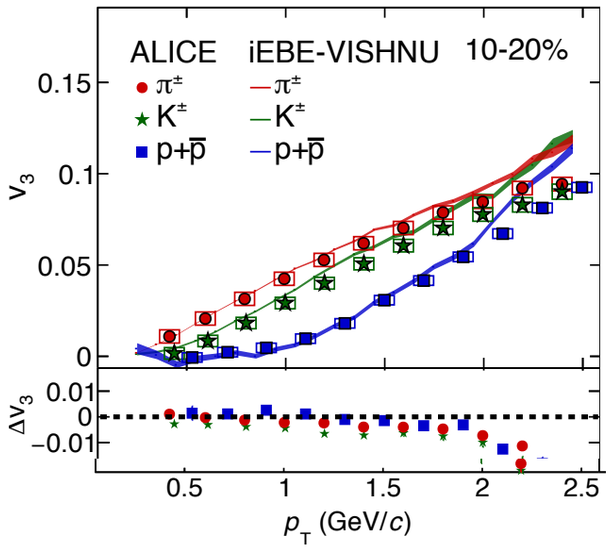
Initial state spatial anisotropies ε_n are transferred into final state momentum anisotropies v_n by pressure gradients, flow of the Quark Gluon Plasma

Anisotropic flow results



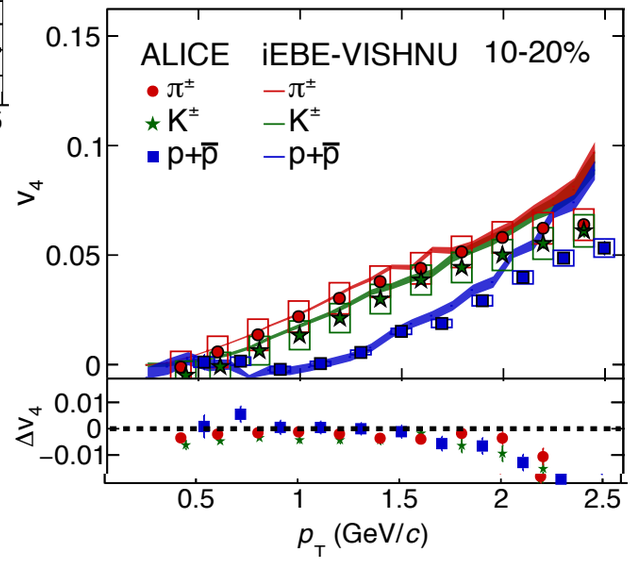
I-PUB-82677

v_3



arXiv:1606.06057

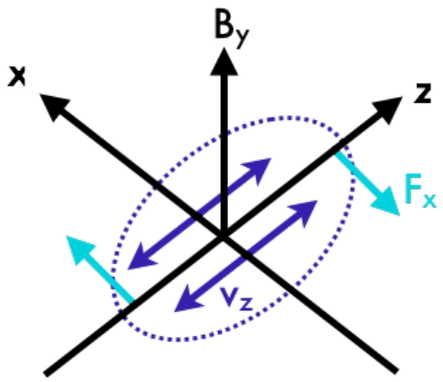
v_4



Mass-dependence of v_2 measures flow velocity

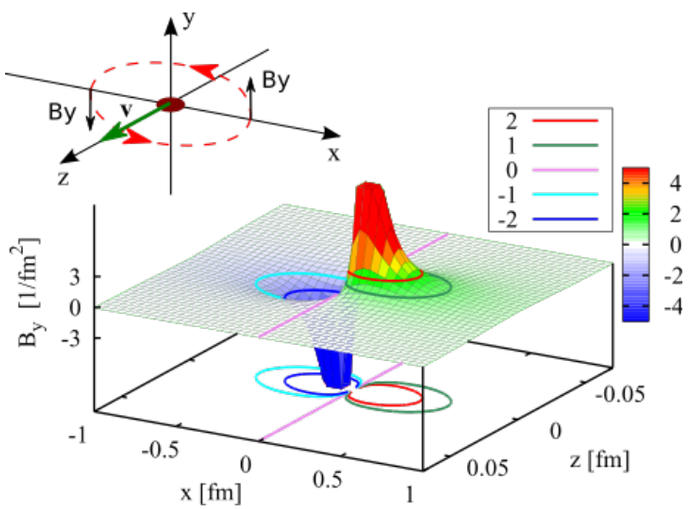
Tests hydrodynamical description, freeze-out models

Charge dependence of directed flow

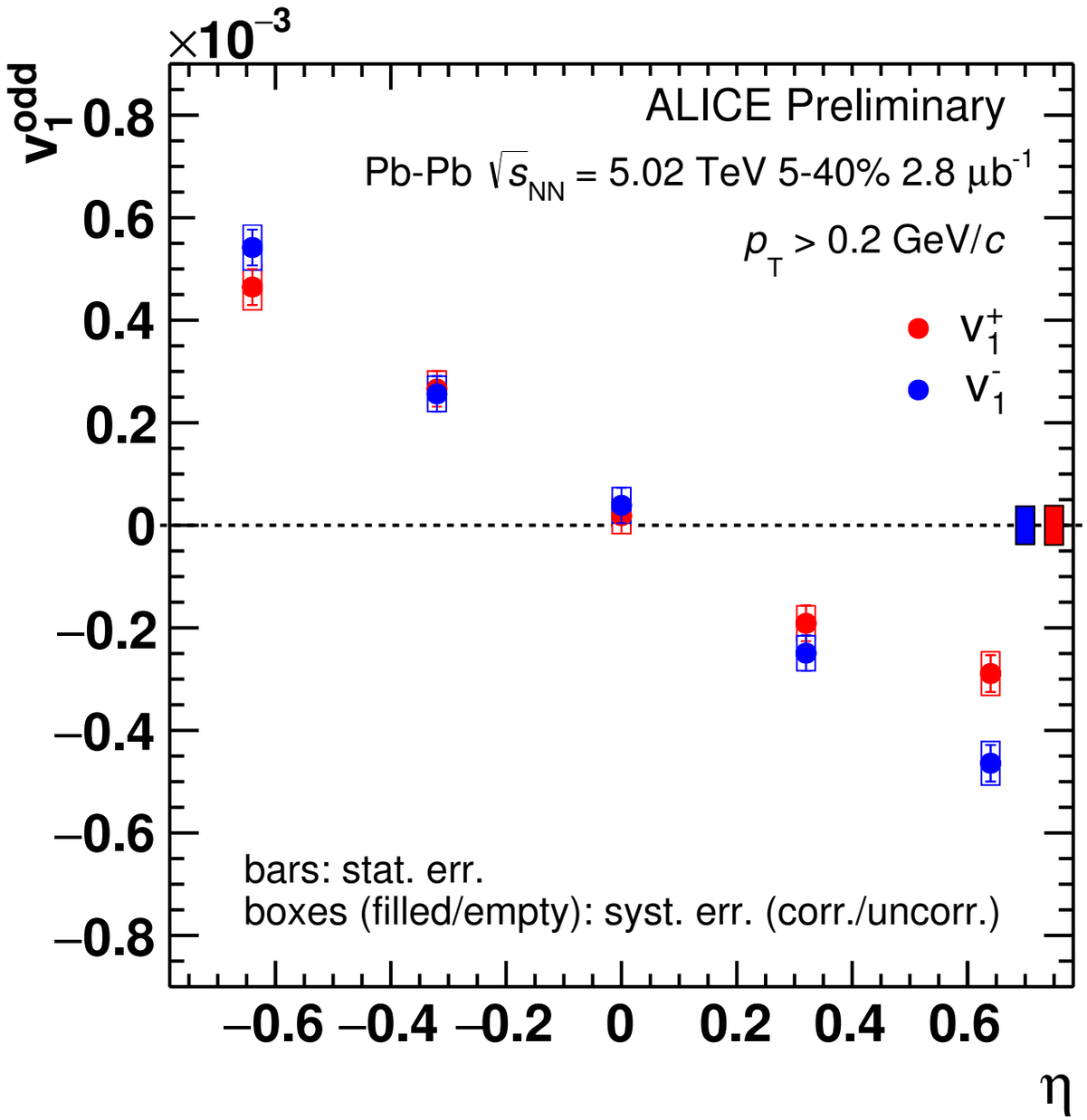


$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$$

Fast moving spectator matter generates large magnetic field



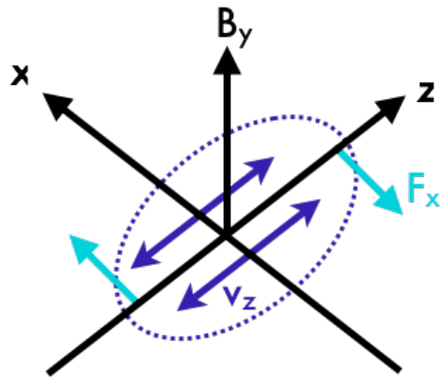
V. Voronyuk et al, arXiv:1103.4239



ALI-PREL-129681

Charge dependence of v_1 measures the magnetic field (Lorentz and Hall effect)

Charge dependence of directed flow



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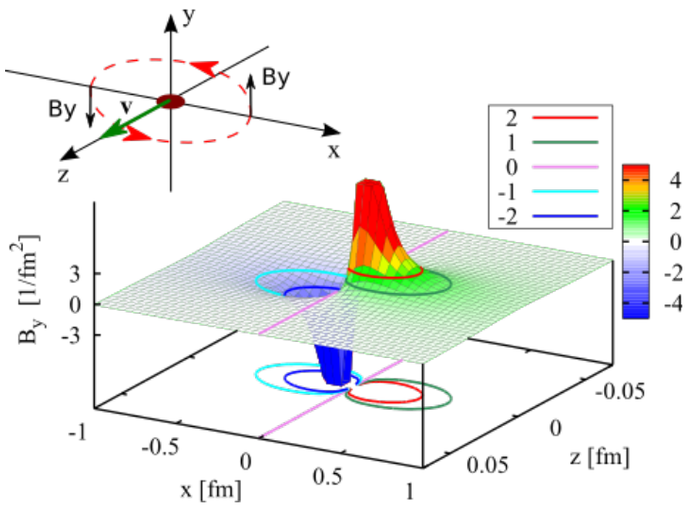

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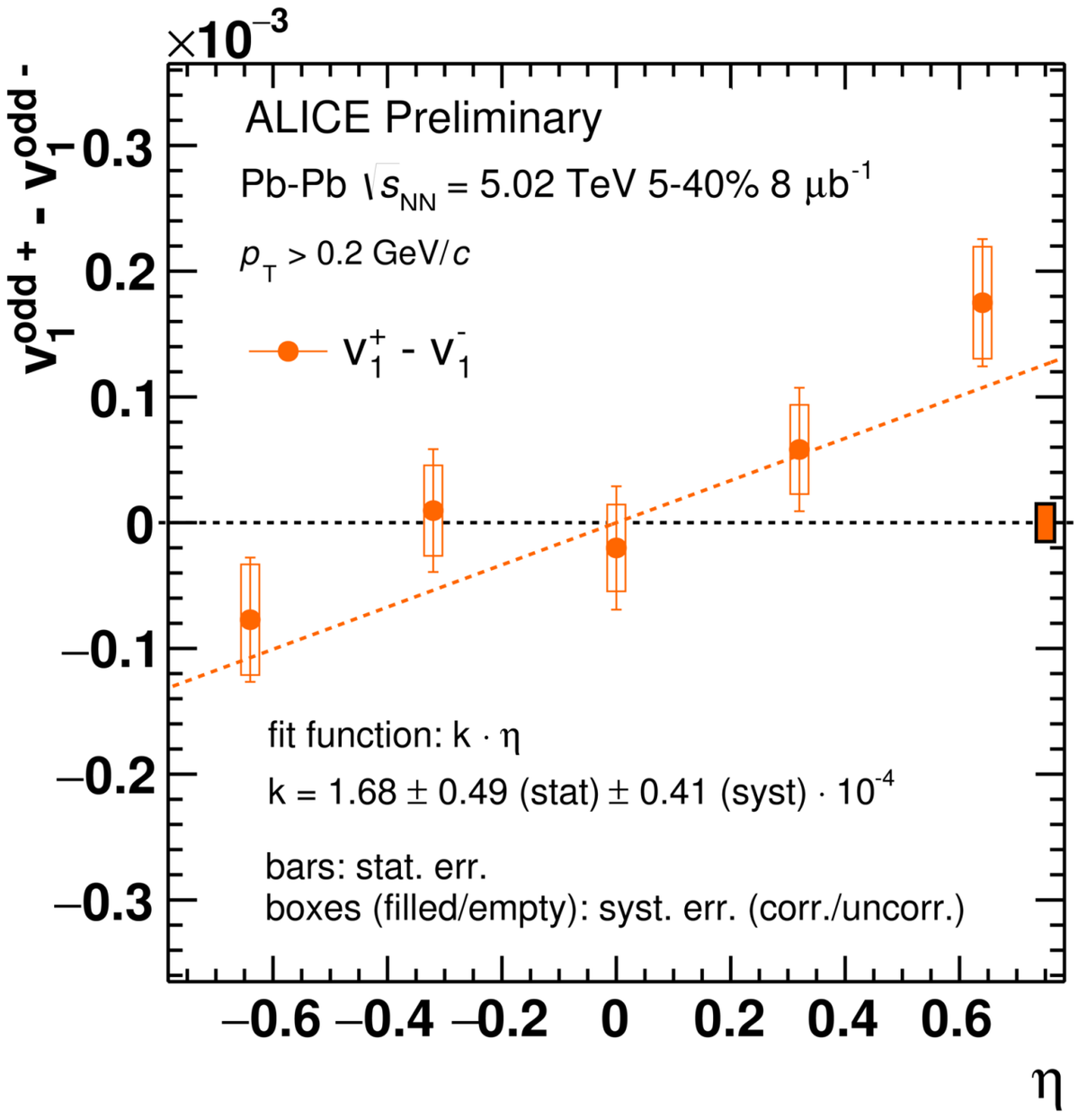

ALI-PREL-129689

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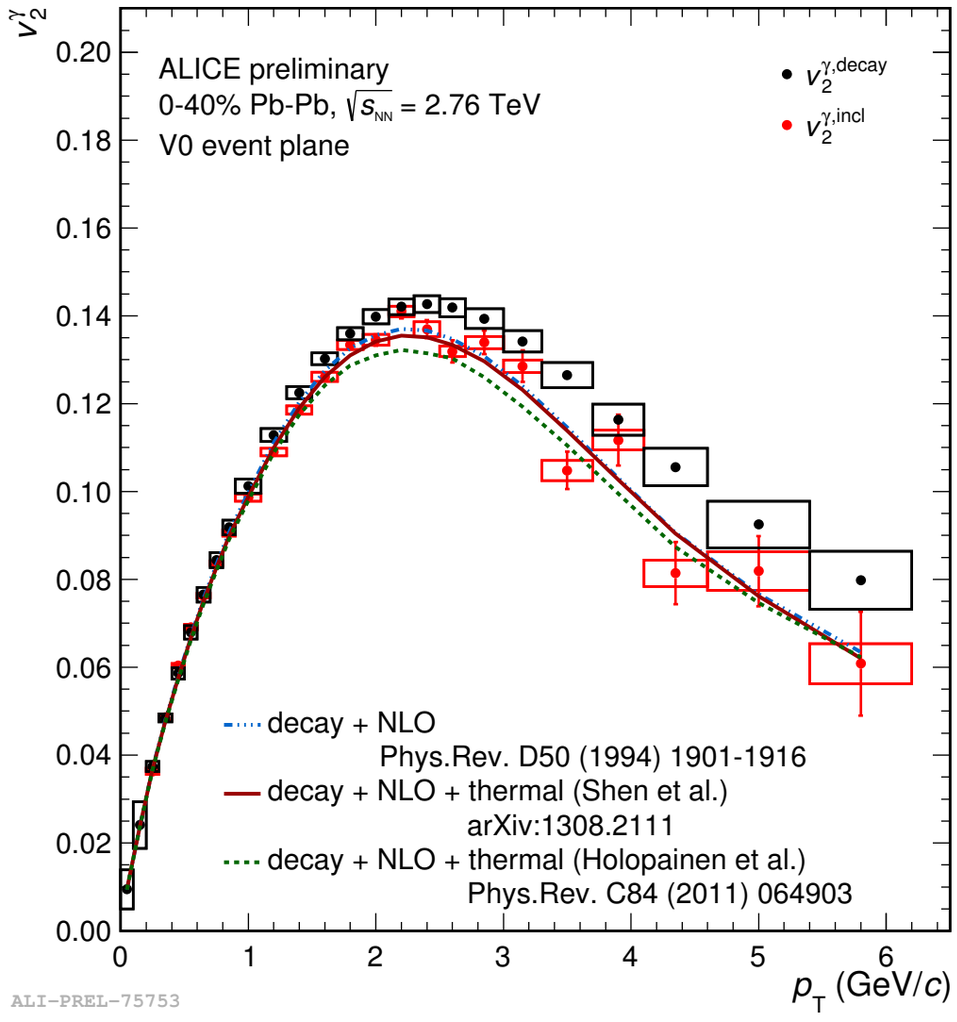
Direct photon v_2

Inclusive and decay photon v_2



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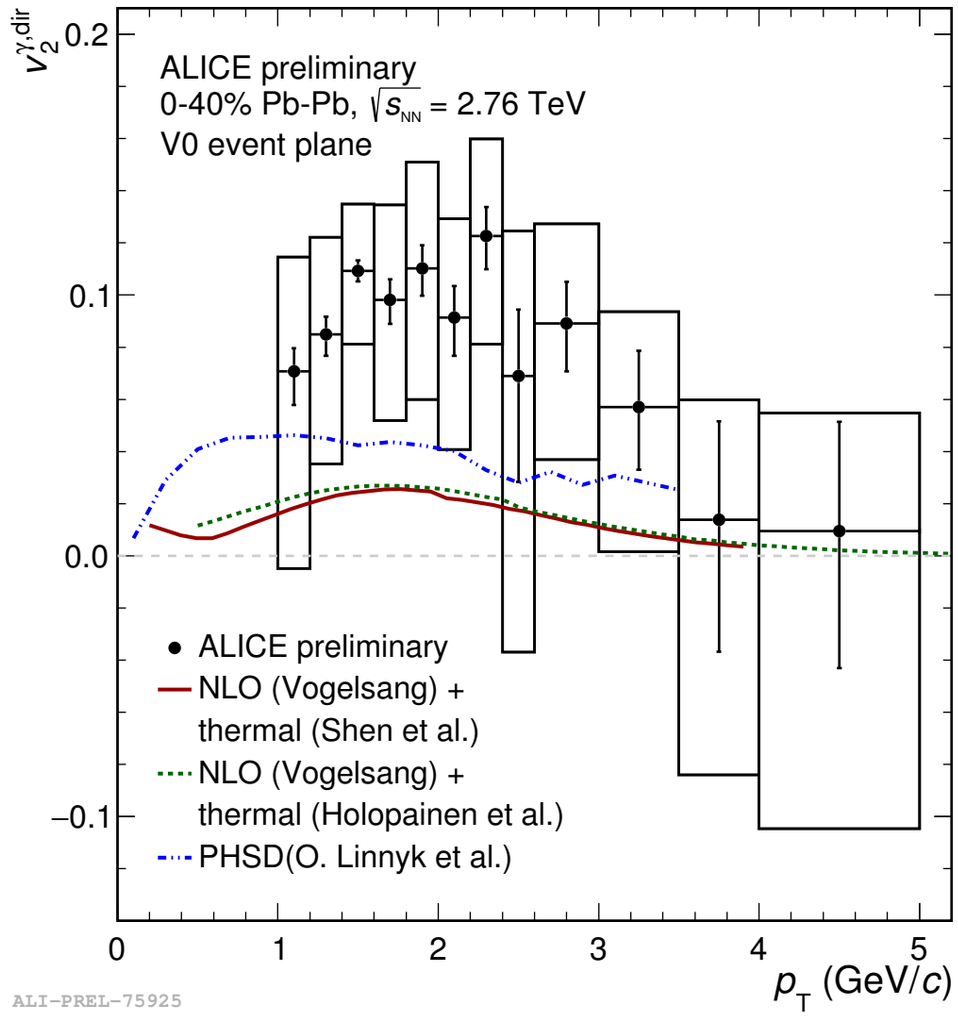

Thermal direct photons produced early in collision — sensitive to time evolution of QGP

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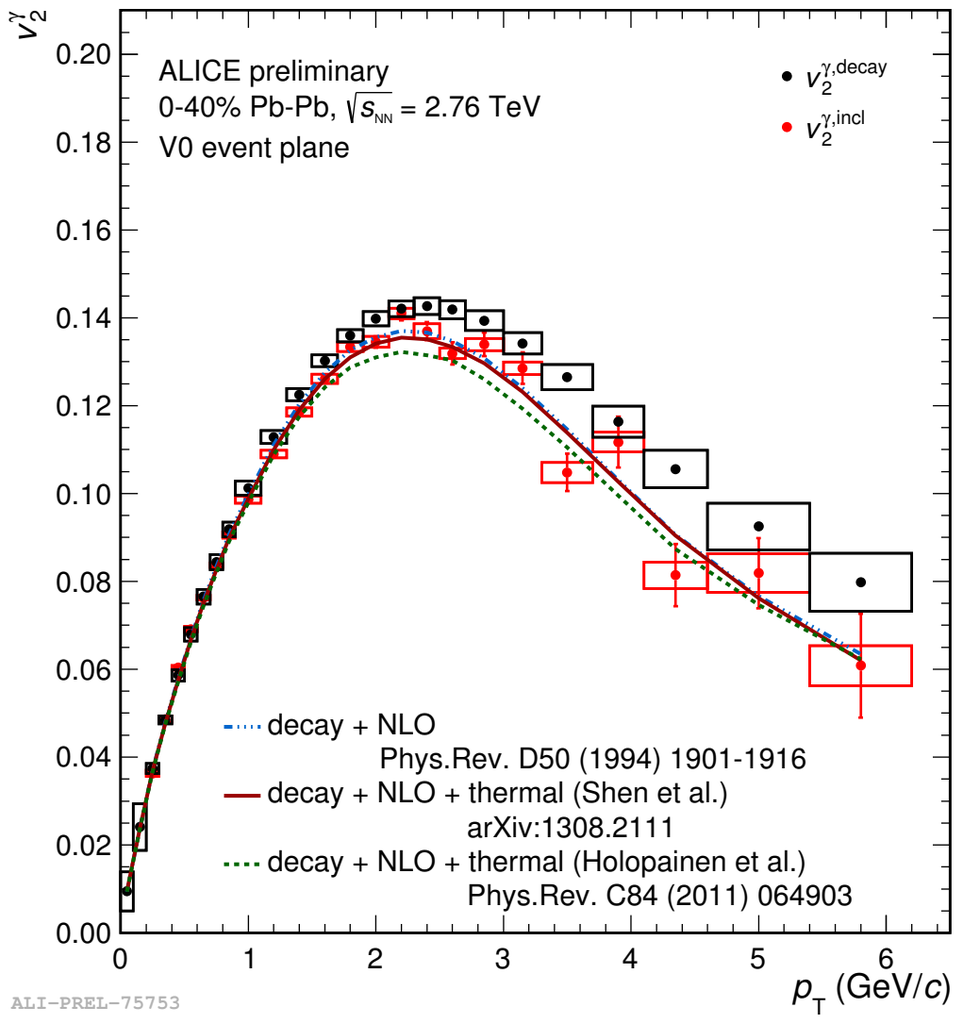

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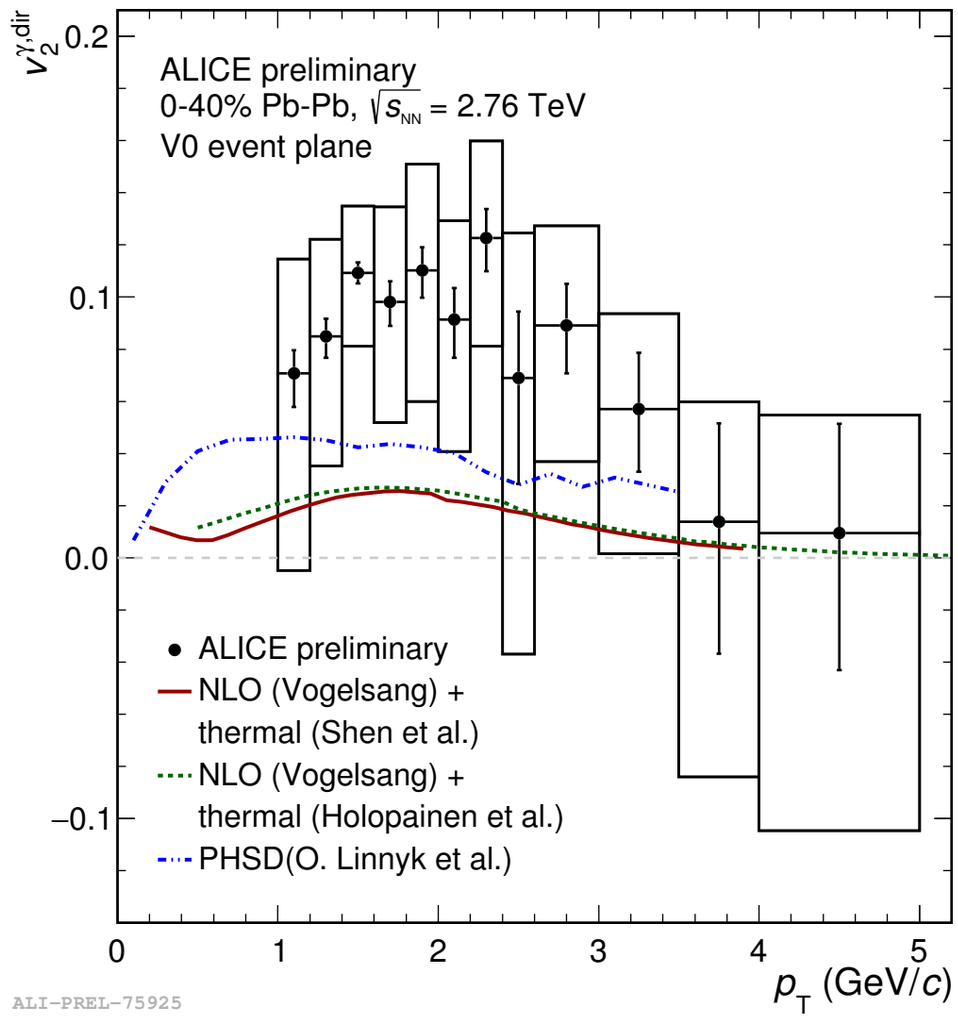

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Direct photon v_2 larger than expected — yield and v_2 are related:
early emission: large yield, small v_2
late emission: small yield, large v_2

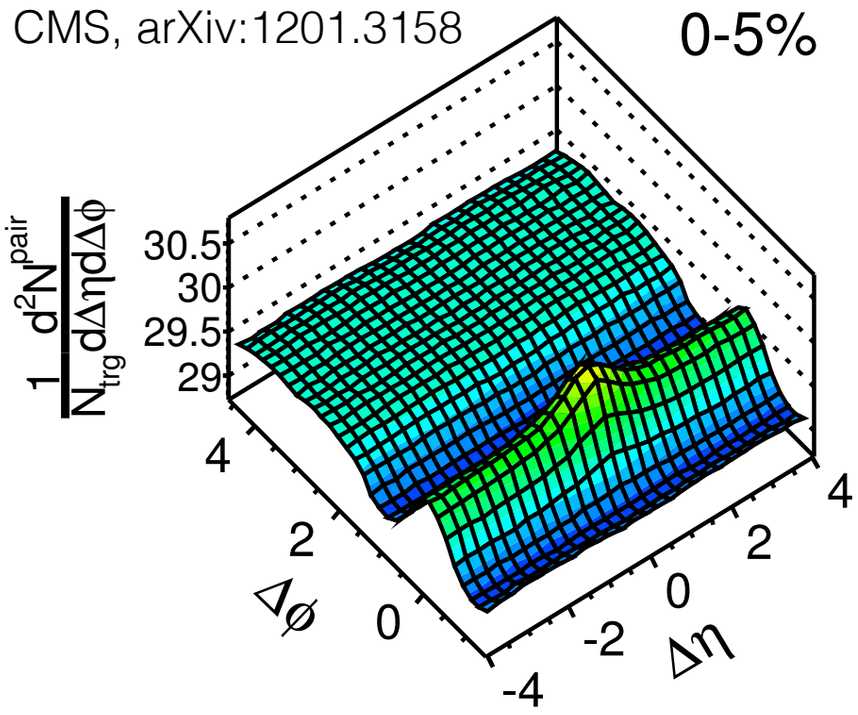
Heavy-ion-like effects in (pp and) p-Pb collisions

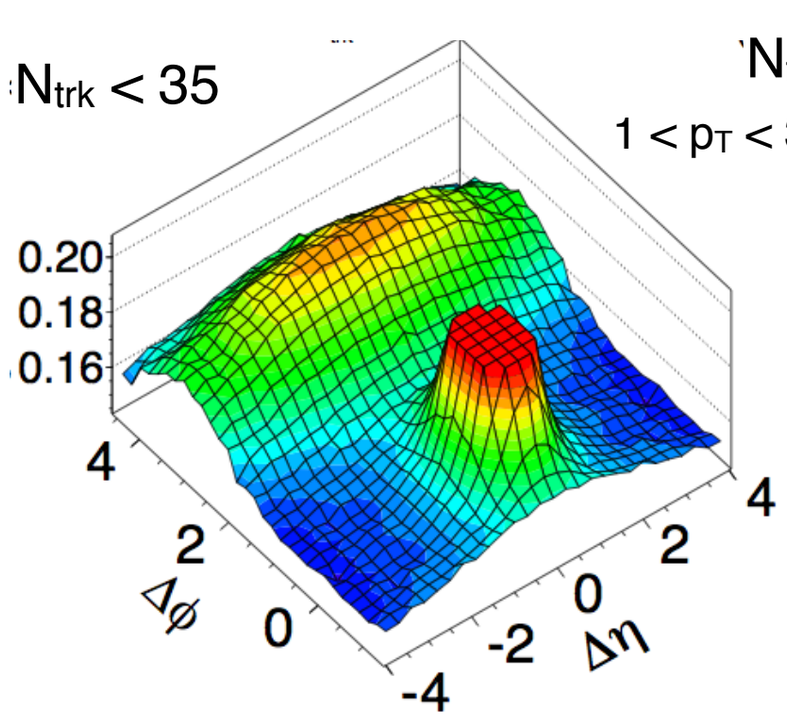
Two-particle correlations in pp and Pb+Pb

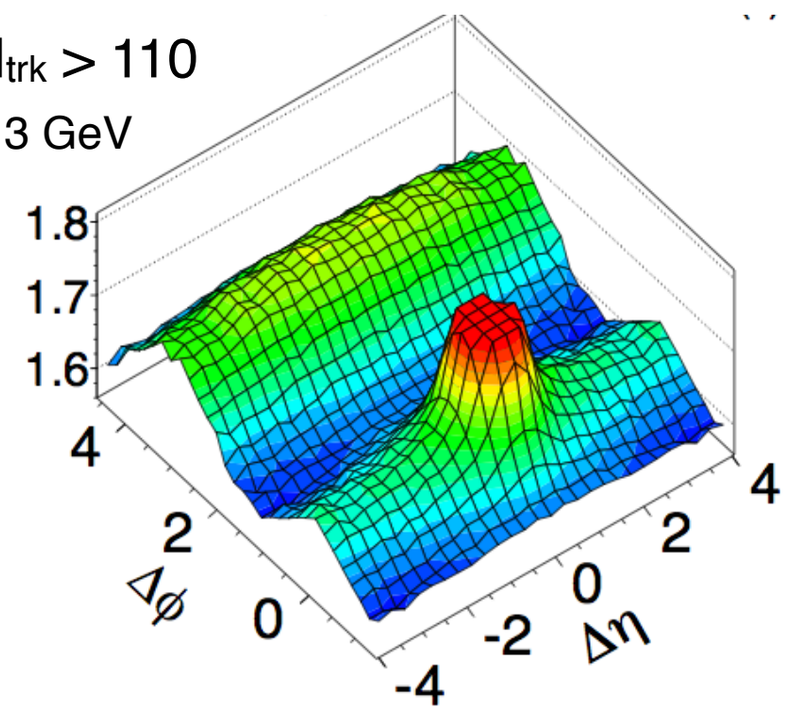
Central Pb+Pb

p+p low multiplicity

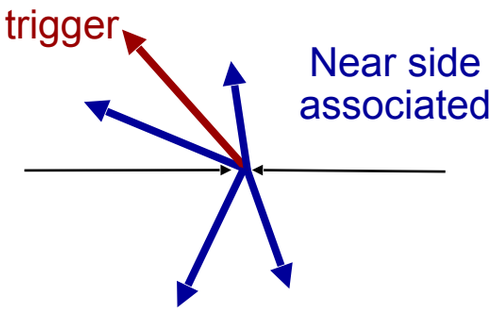
p+p high multiplicity







CMS, PLB 718, 795



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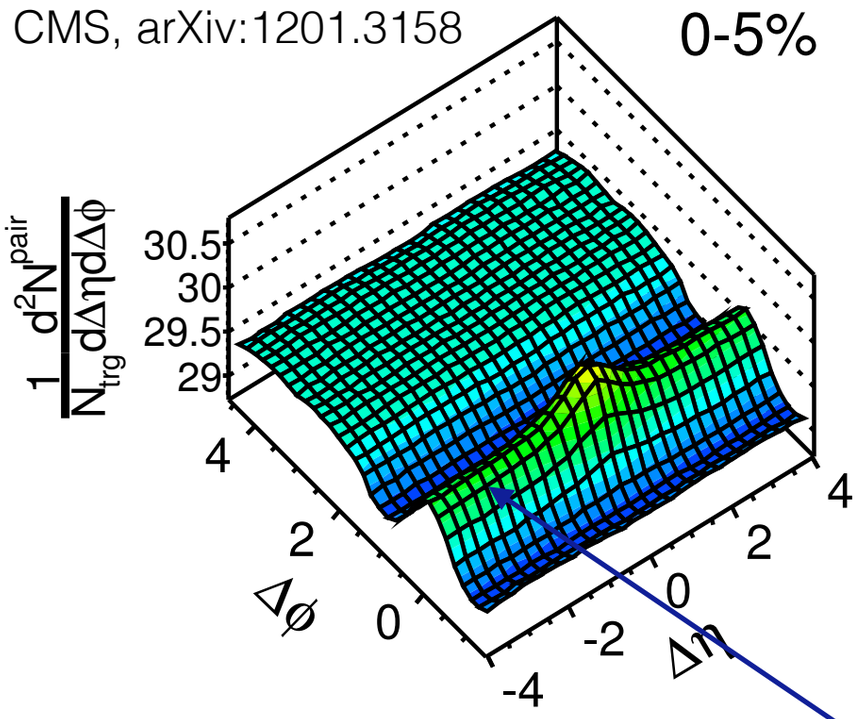

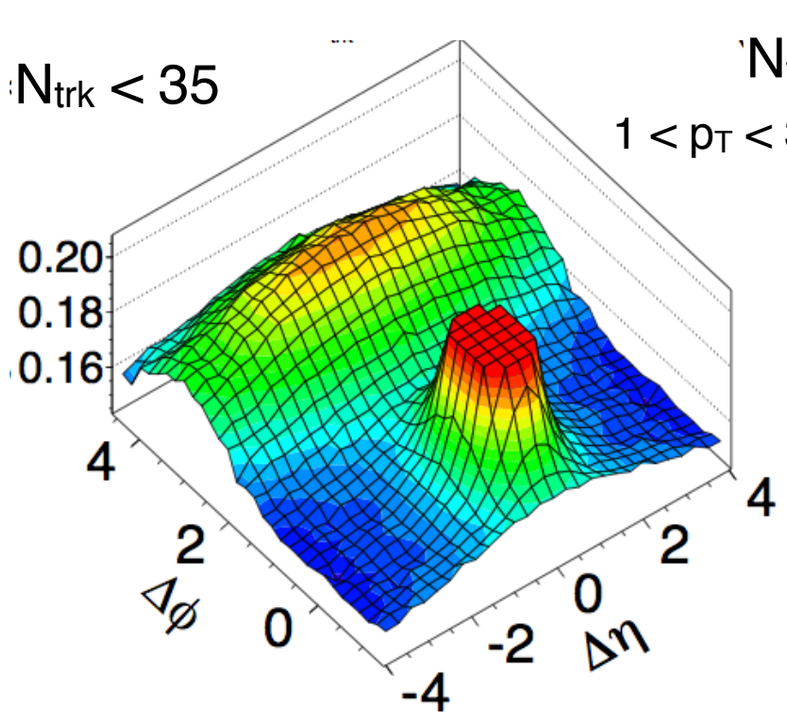

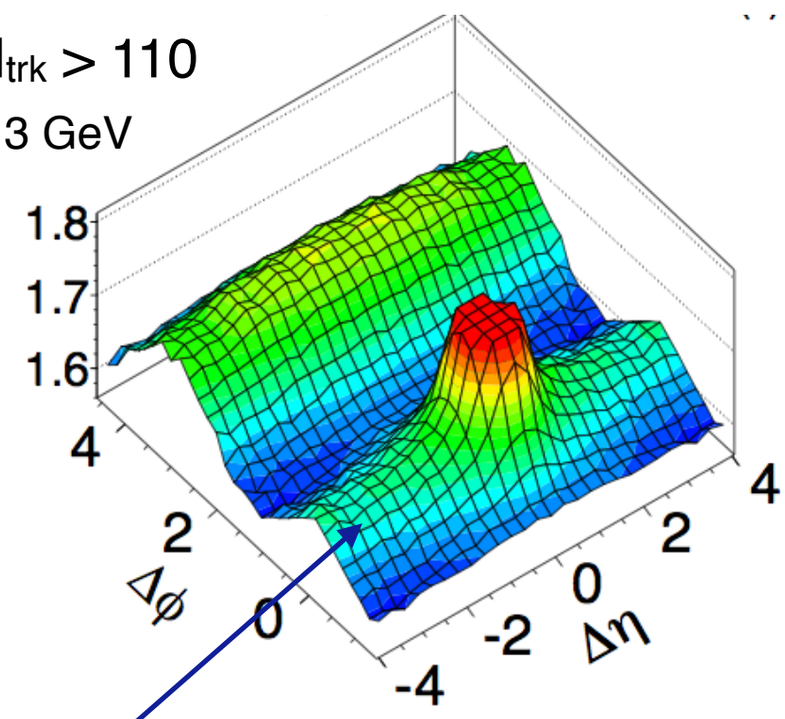

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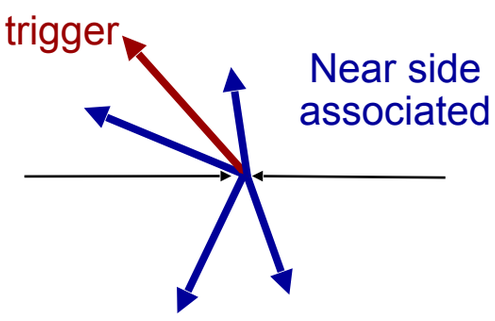

Near-side long range correlation: indicates early time origin

Two-particle correlations in pp and Pb+Pb

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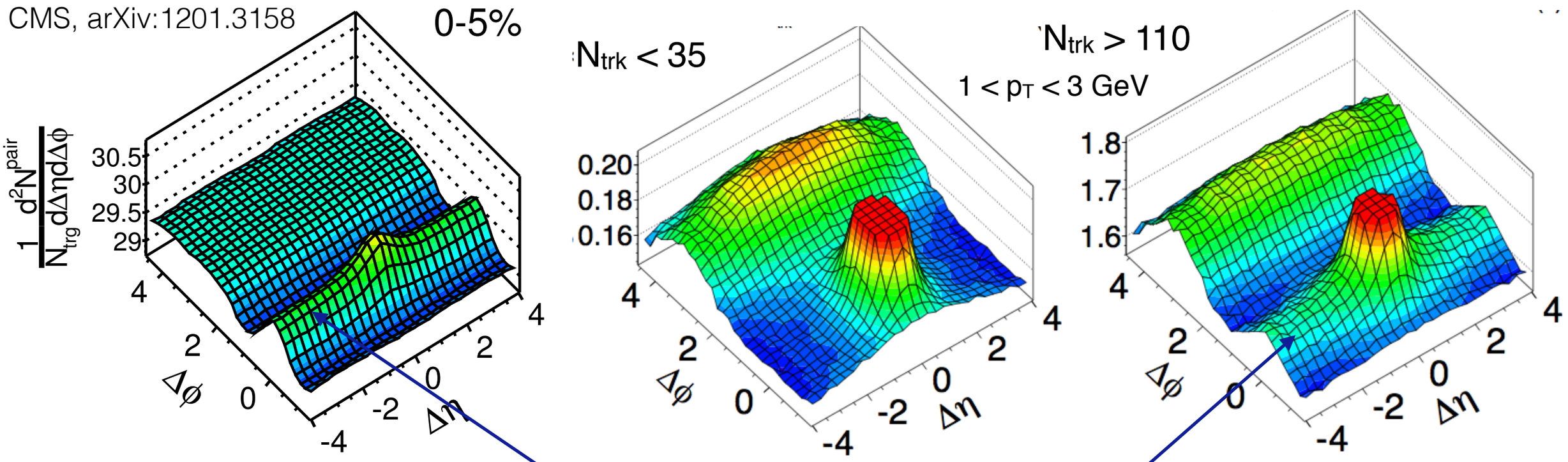
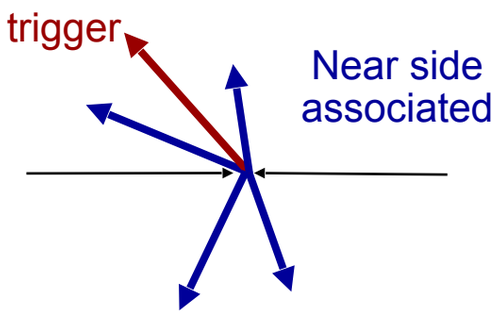


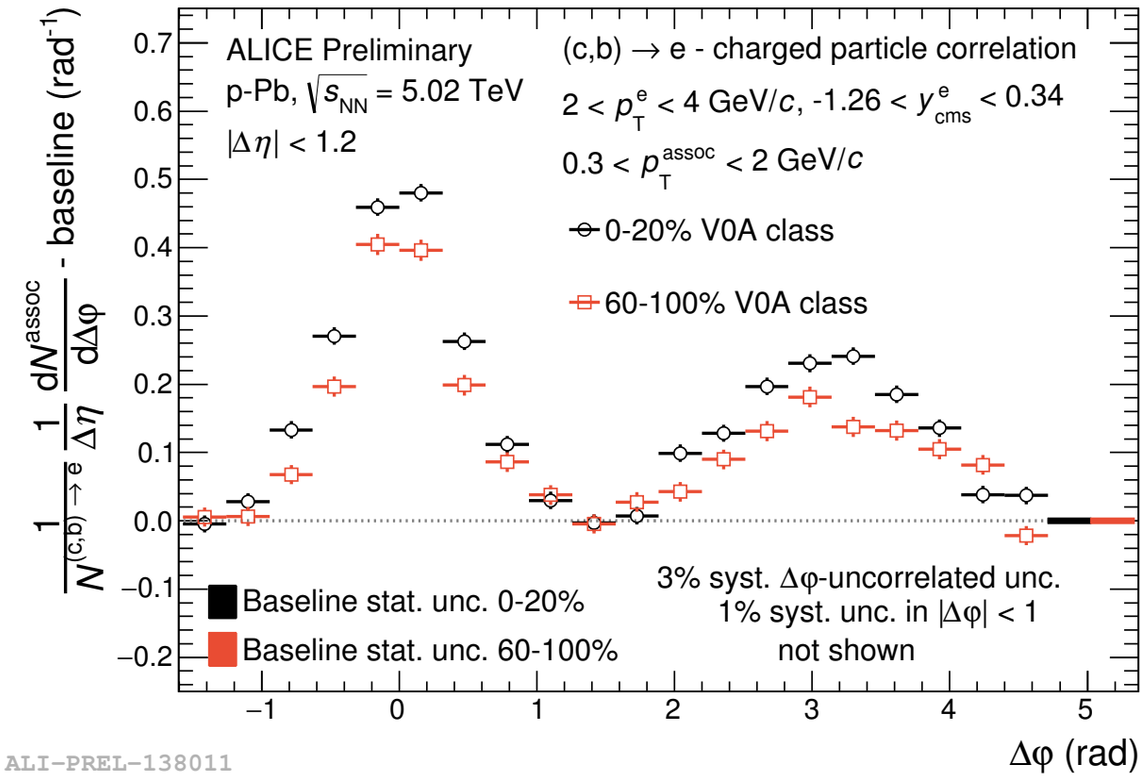


Near-side long range correlation: indicates early time origin

Seen in high-multiplicity pp and p+Pb events

Collective effects for charm in p-Pb?

Heavy flavour-electron-hadron correlations



ALI-PREL-138011

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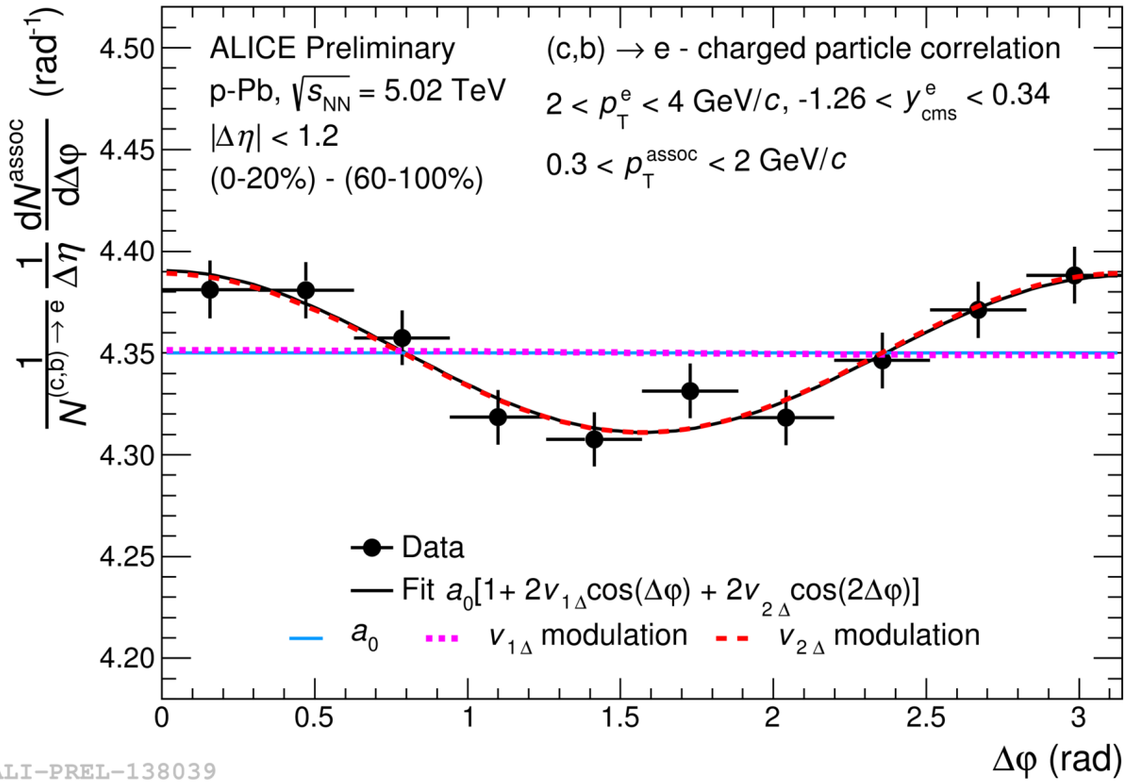

ALI-PREL-138039

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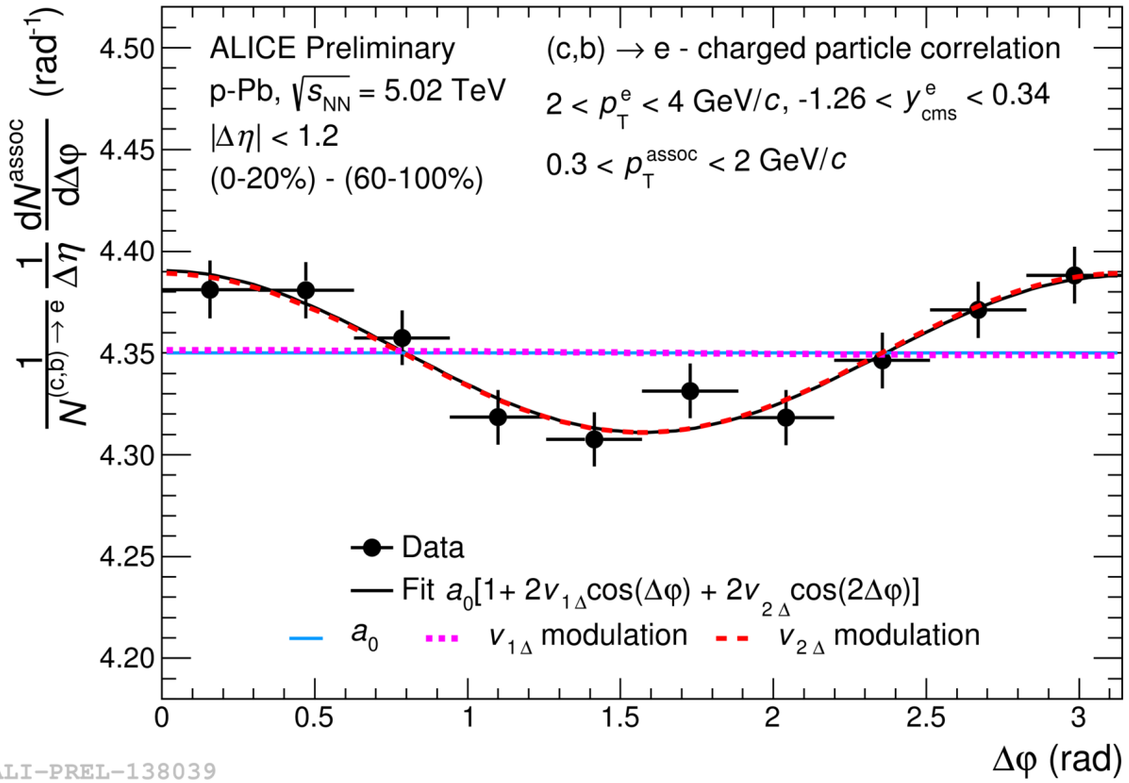
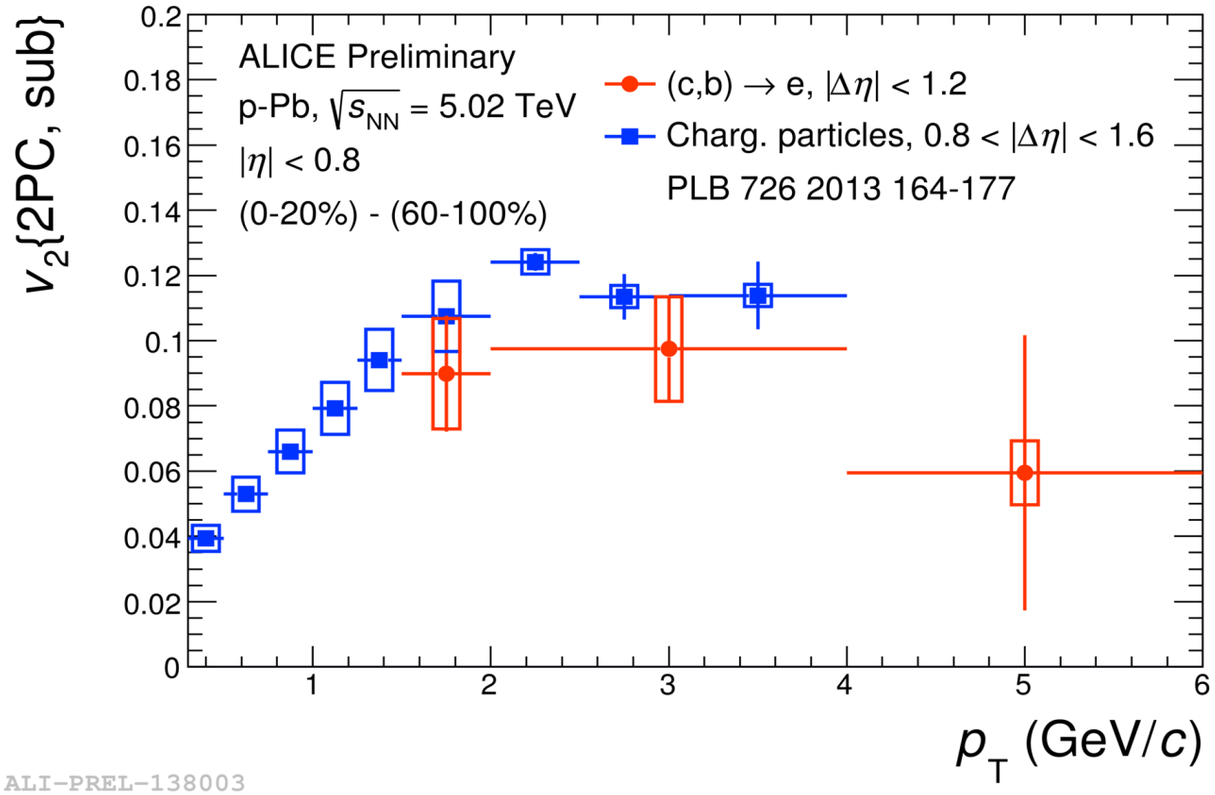


ALI-PREL-138039

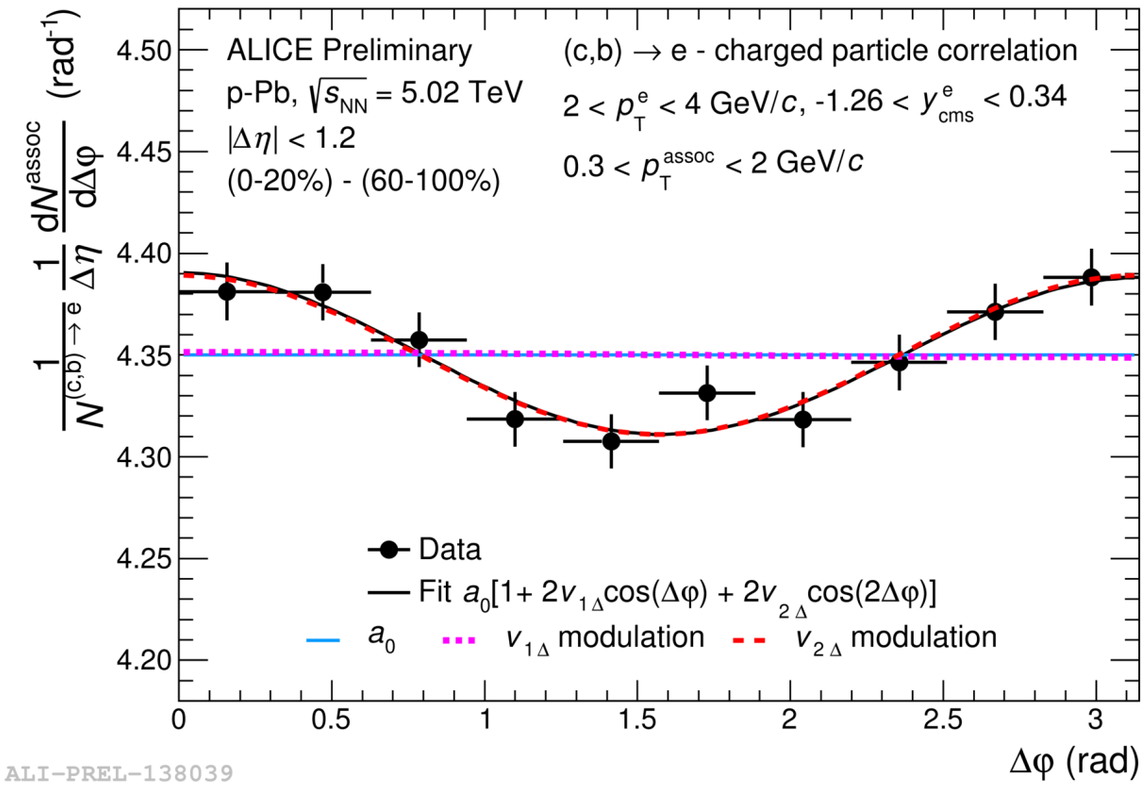
v_2 from 2-particle correlations



ALI-PREL-138003

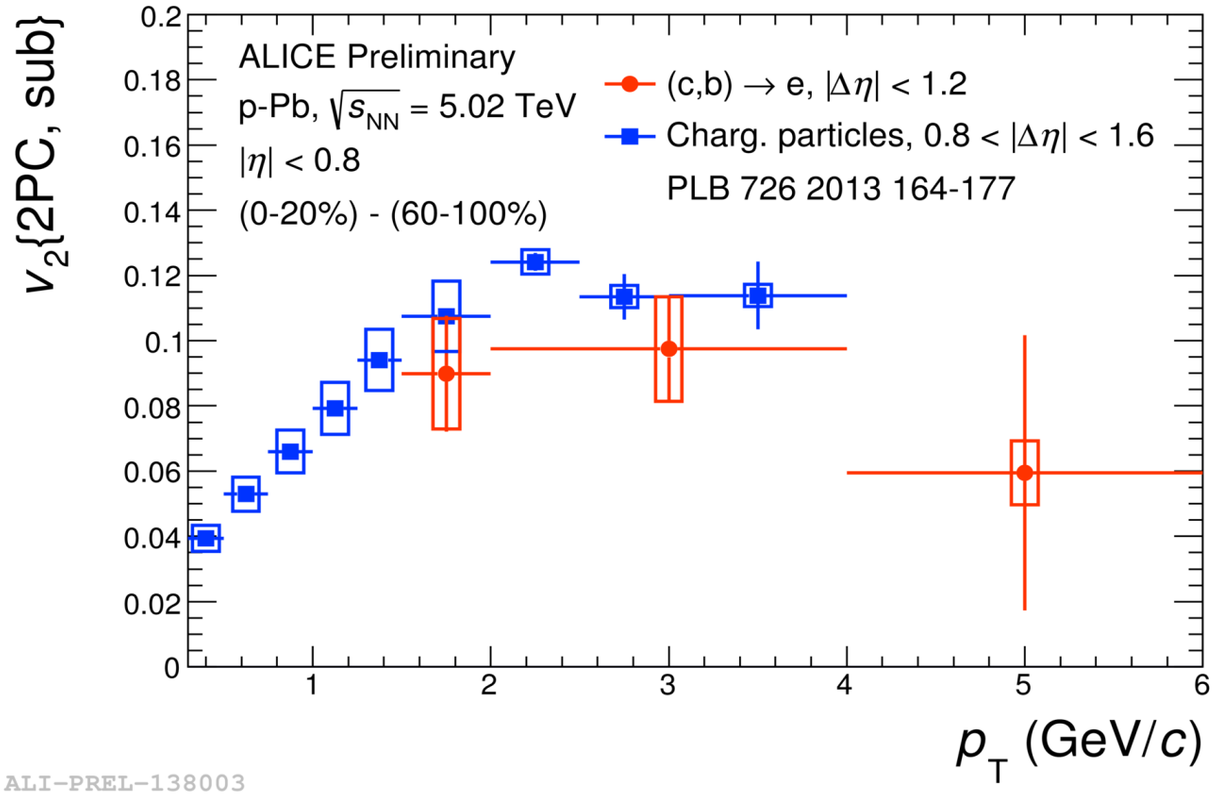
Collective effects for charm in p-Pb?

Heavy flavour-electron-hadron correlations



ALI-PREL-138039

v_2 from 2-particle correlations



ALI-PREL-138003

- azimuthal modulation for HF electrons in p-Pb collisions
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  - and Pb-Pb
- Similar effect also seen for J/ψ

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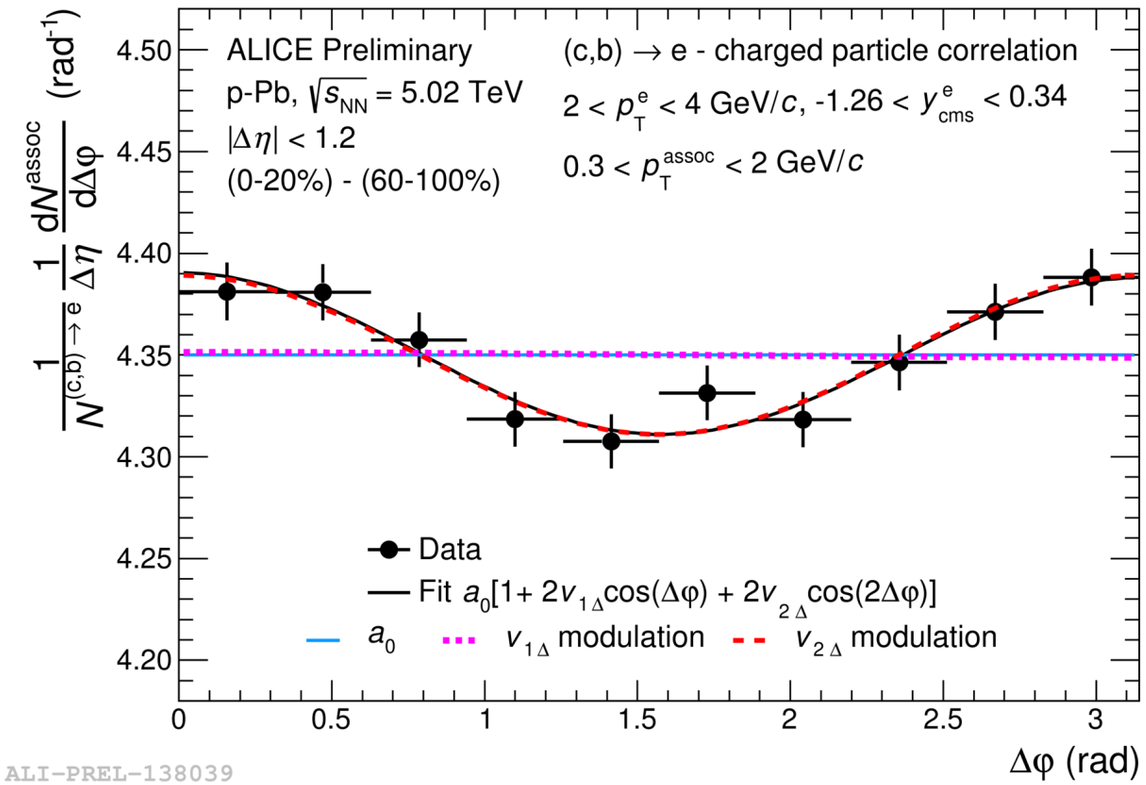

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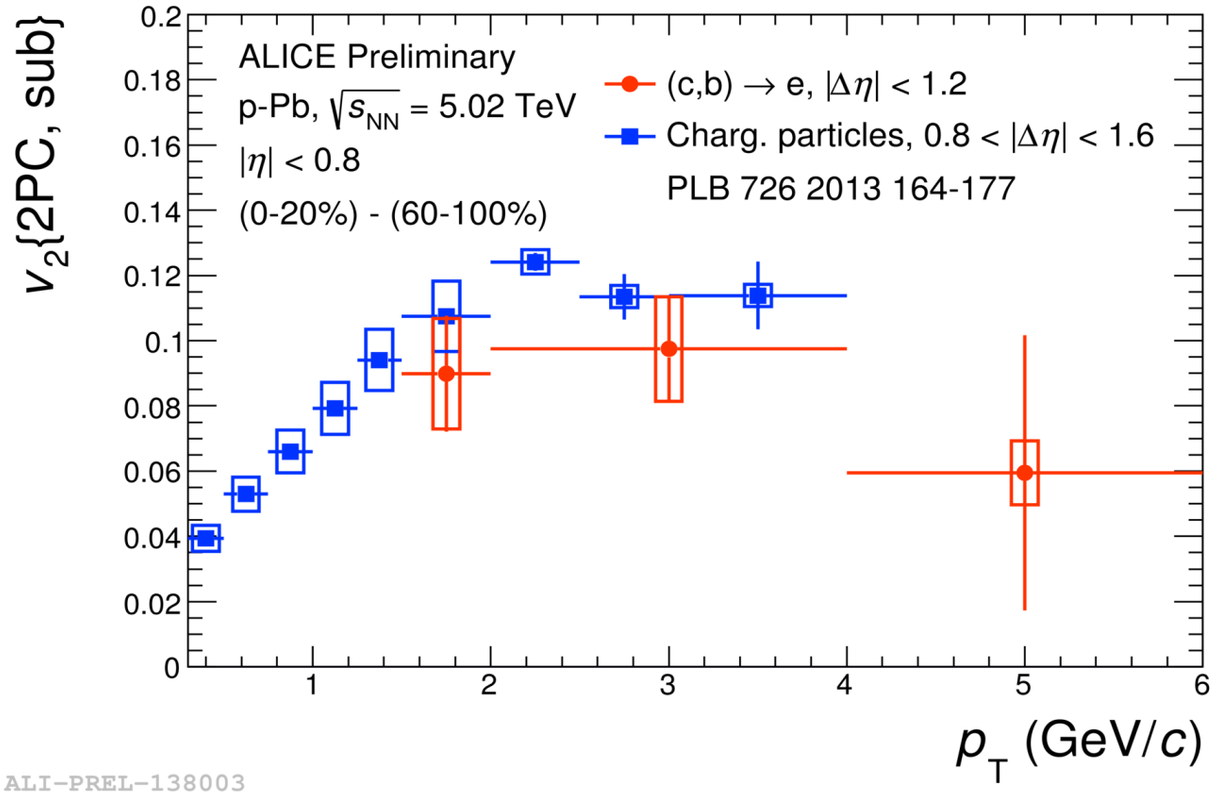

ALI-PREL-138003

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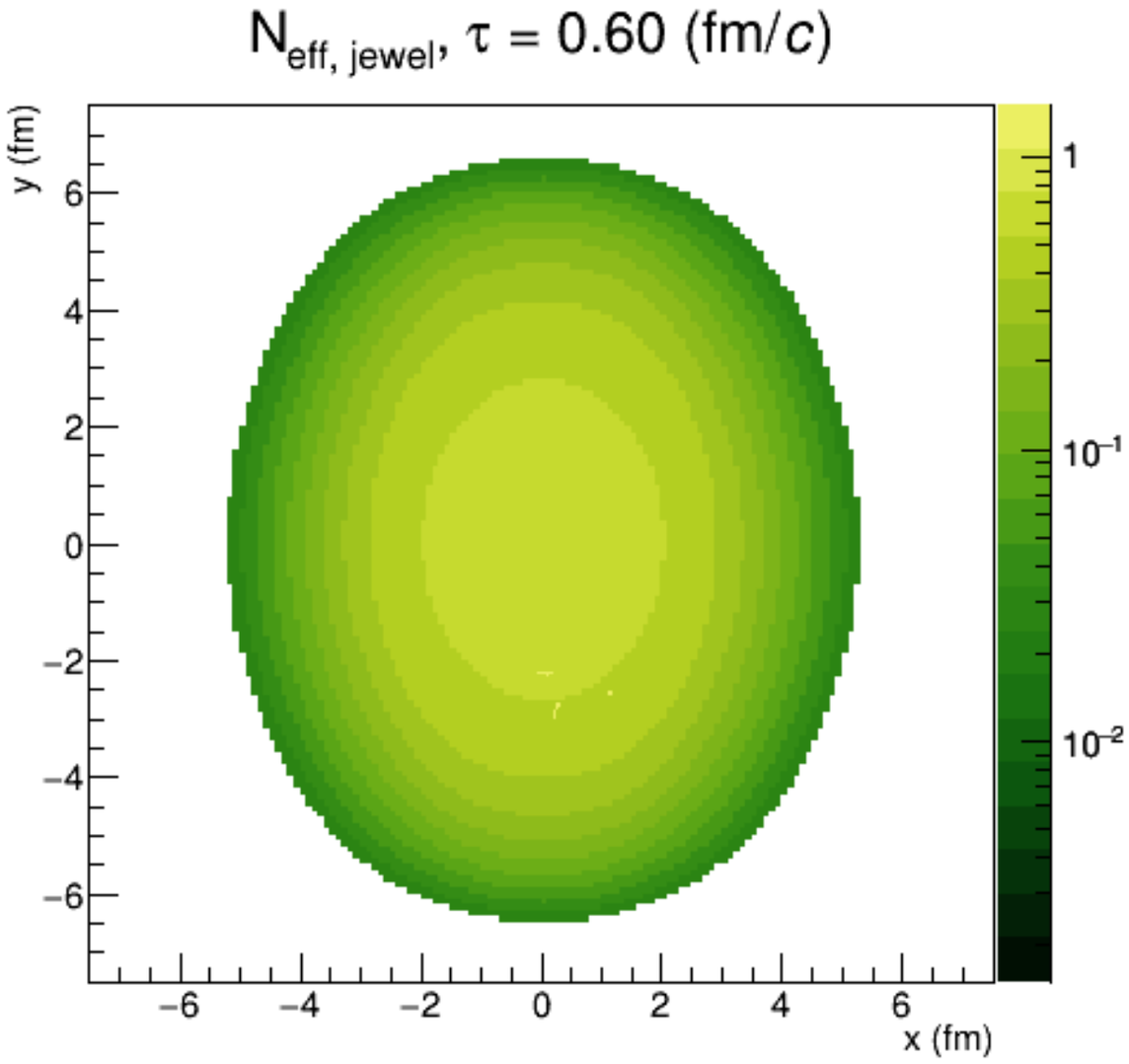
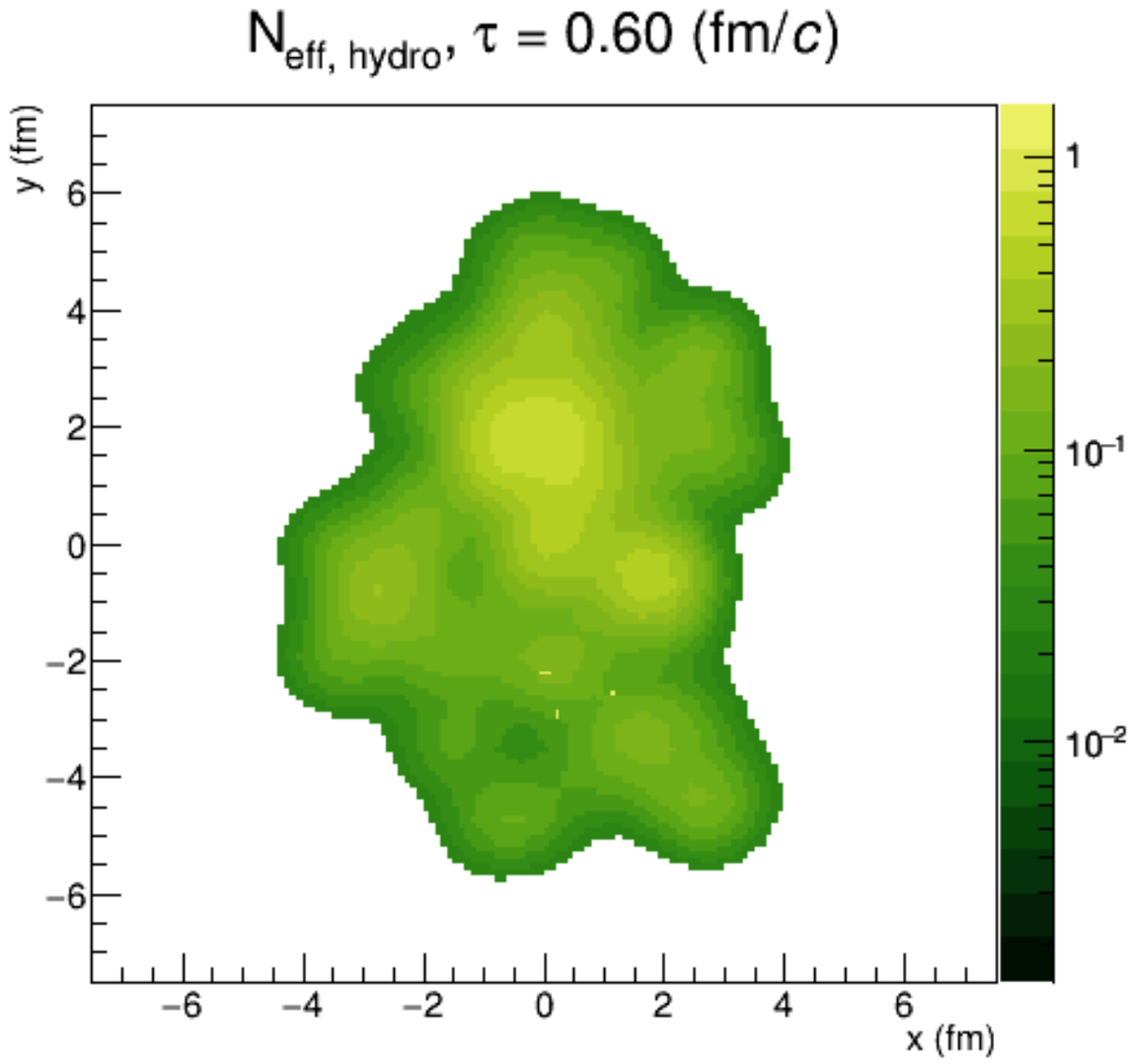
How does this arise in small systems? Final state interactions? Initial state effect?

Higher p_T: probes of the QGP

R Bertens, JEWEL simulation





Hard probes

Hard-scatterings produce quasi-free partons

$\Rightarrow$ Probe medium through energy loss

Expected to be dominant for $p_T > 5$ GeV or so

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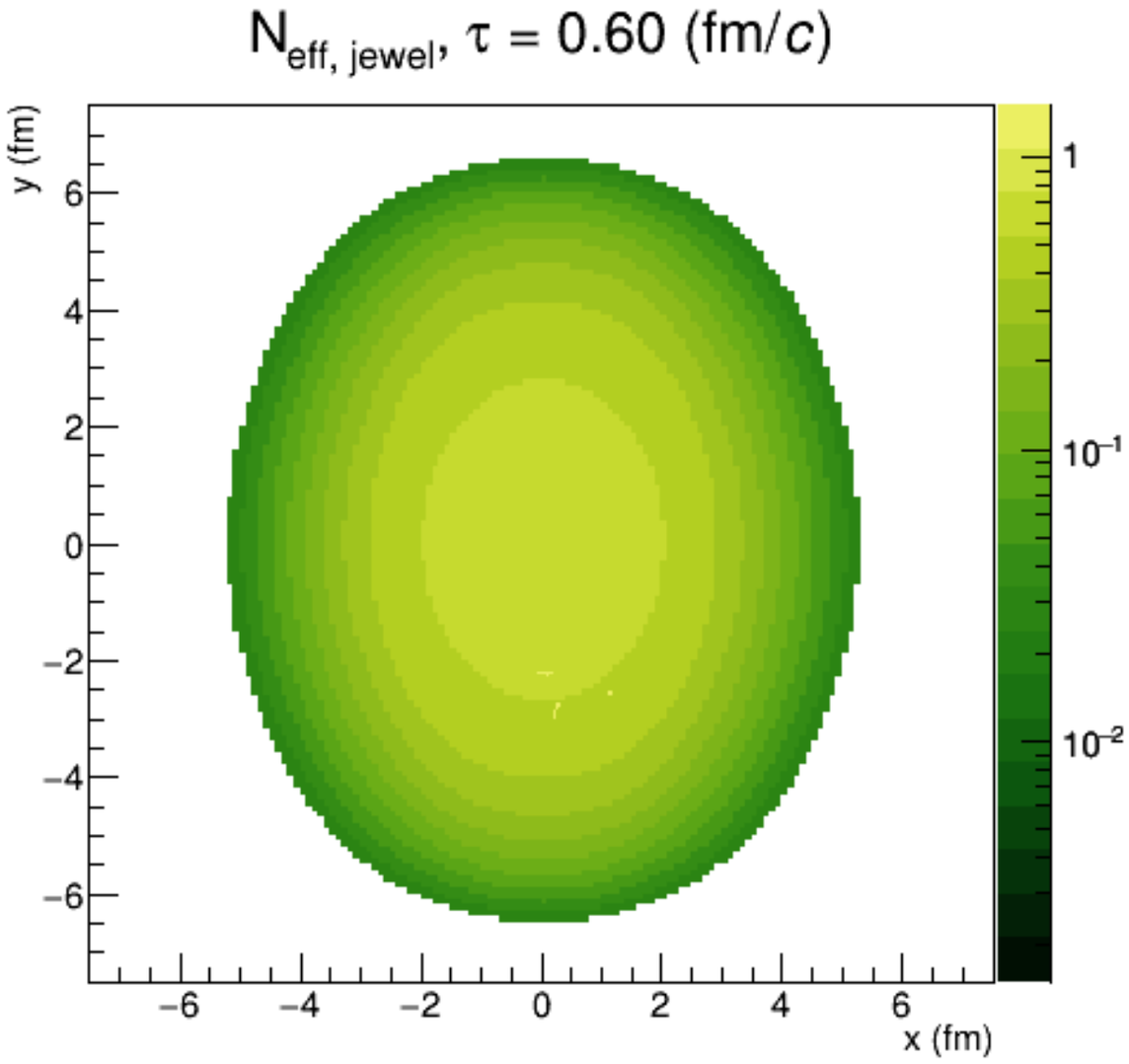

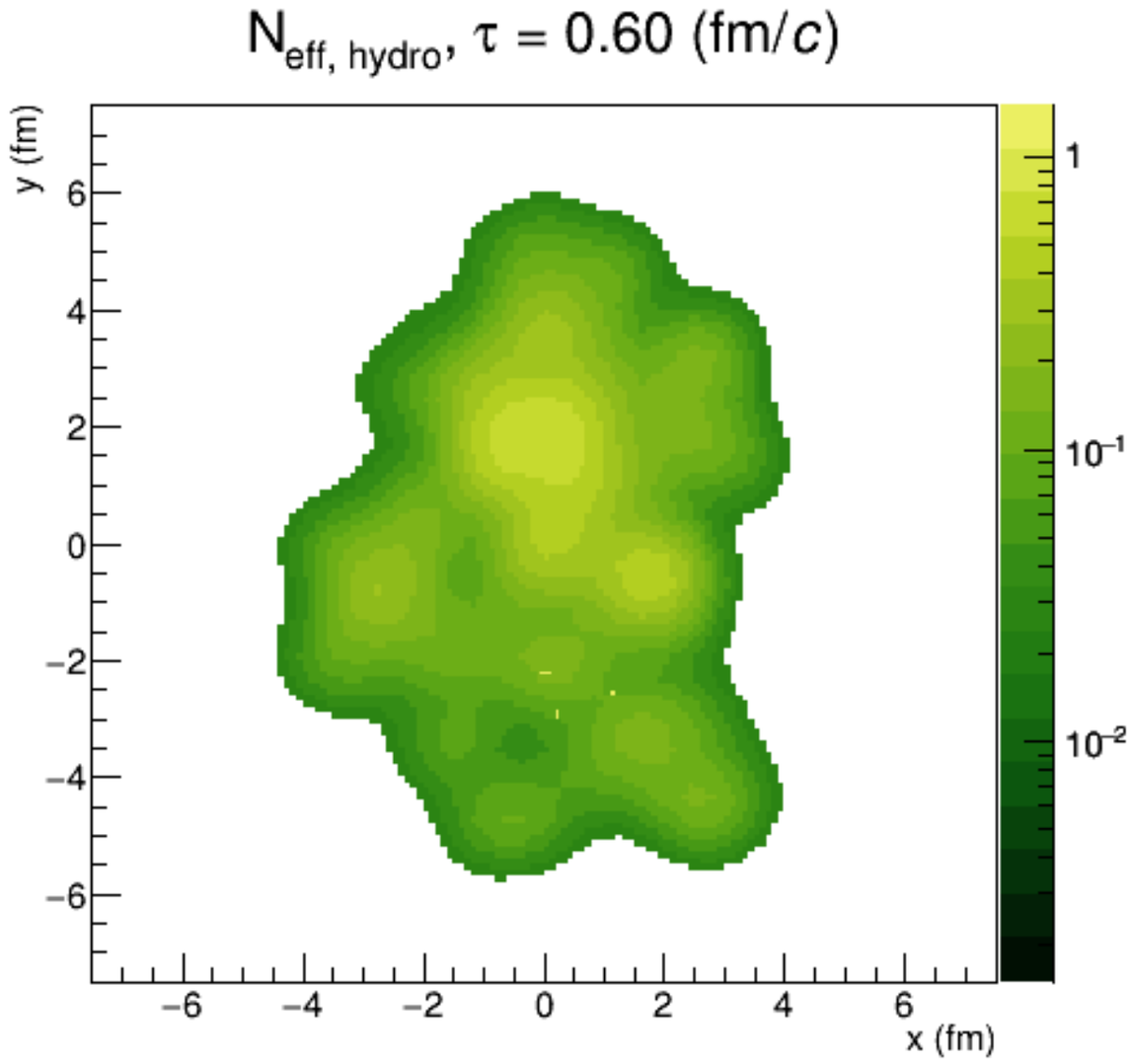

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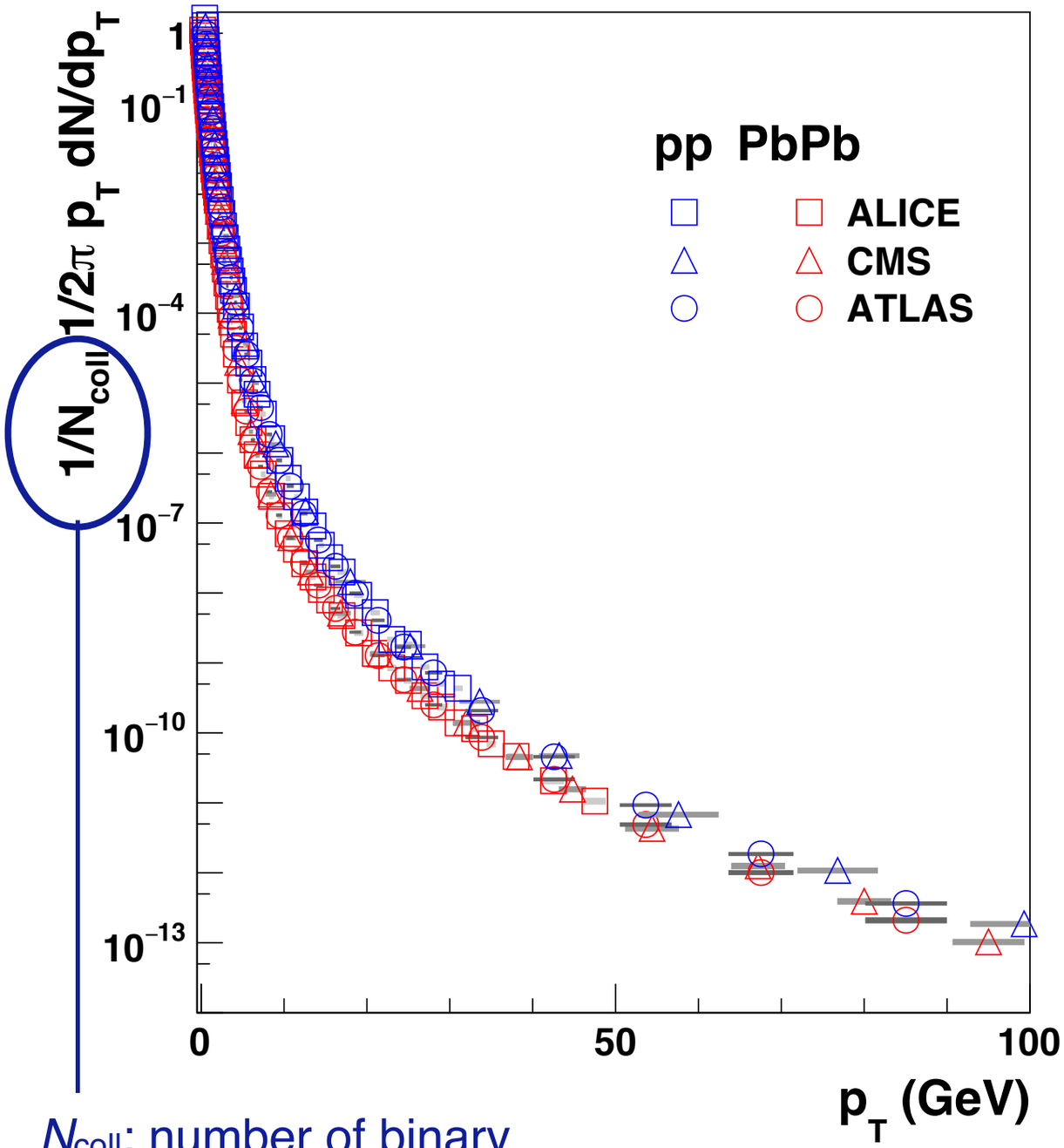
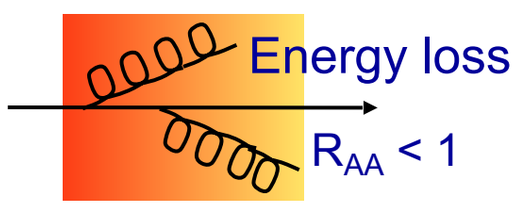
Nuclear modification: Pb+Pb

ALICE, PLB720, 52
CMS, EPJC, 72, 1945
ATLAS, arXiv:1504.04337

Charged particle p_T spectra



N_{coll}: number of binary nucleon-nucleon collisions



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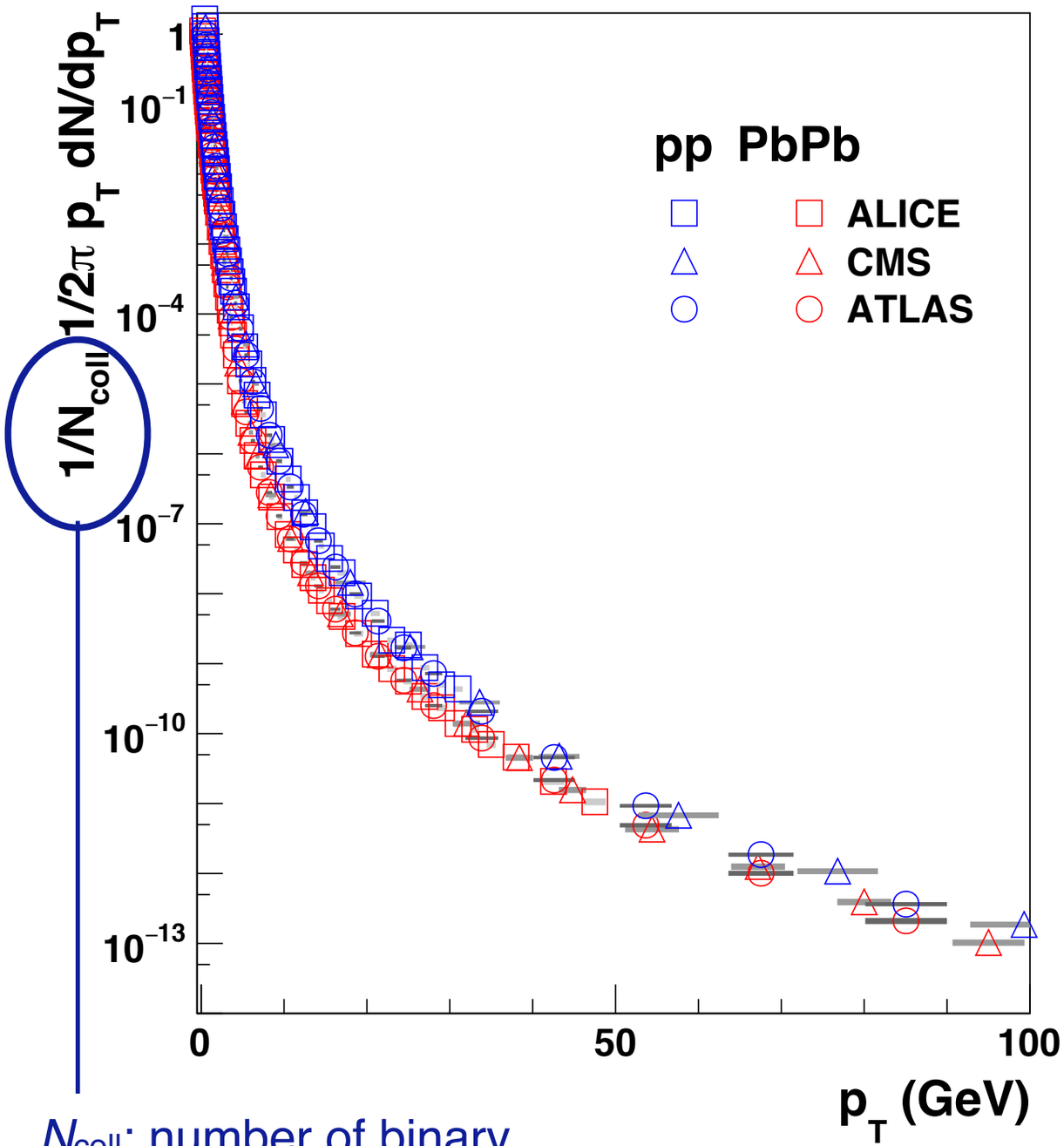

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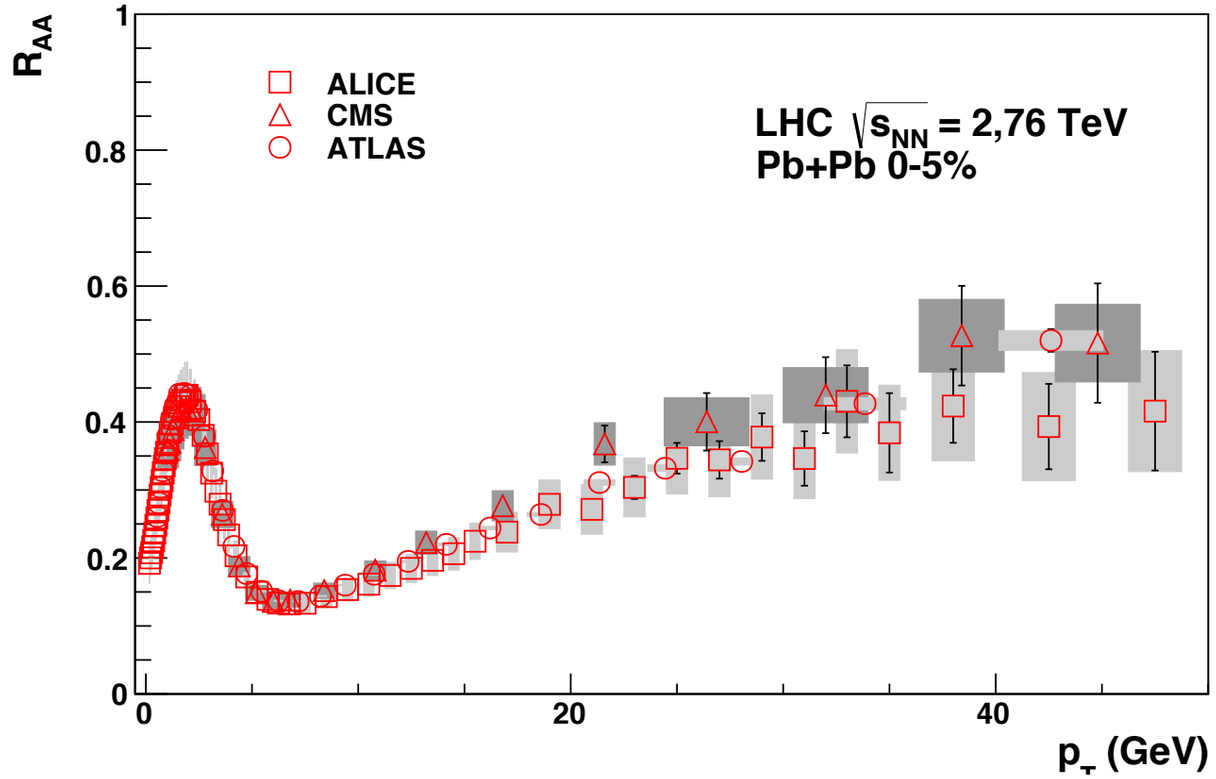
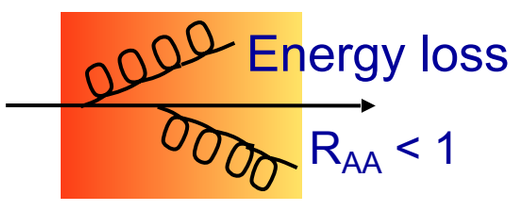


$$R_{AA} = \frac{dN/dp_T\big|_{A+A}}{N_{coll}\ dN/dp_T\big|_{p+p}}$$



Pb+Pb: clear suppression ($R_{AA} < 1$): parton energy loss

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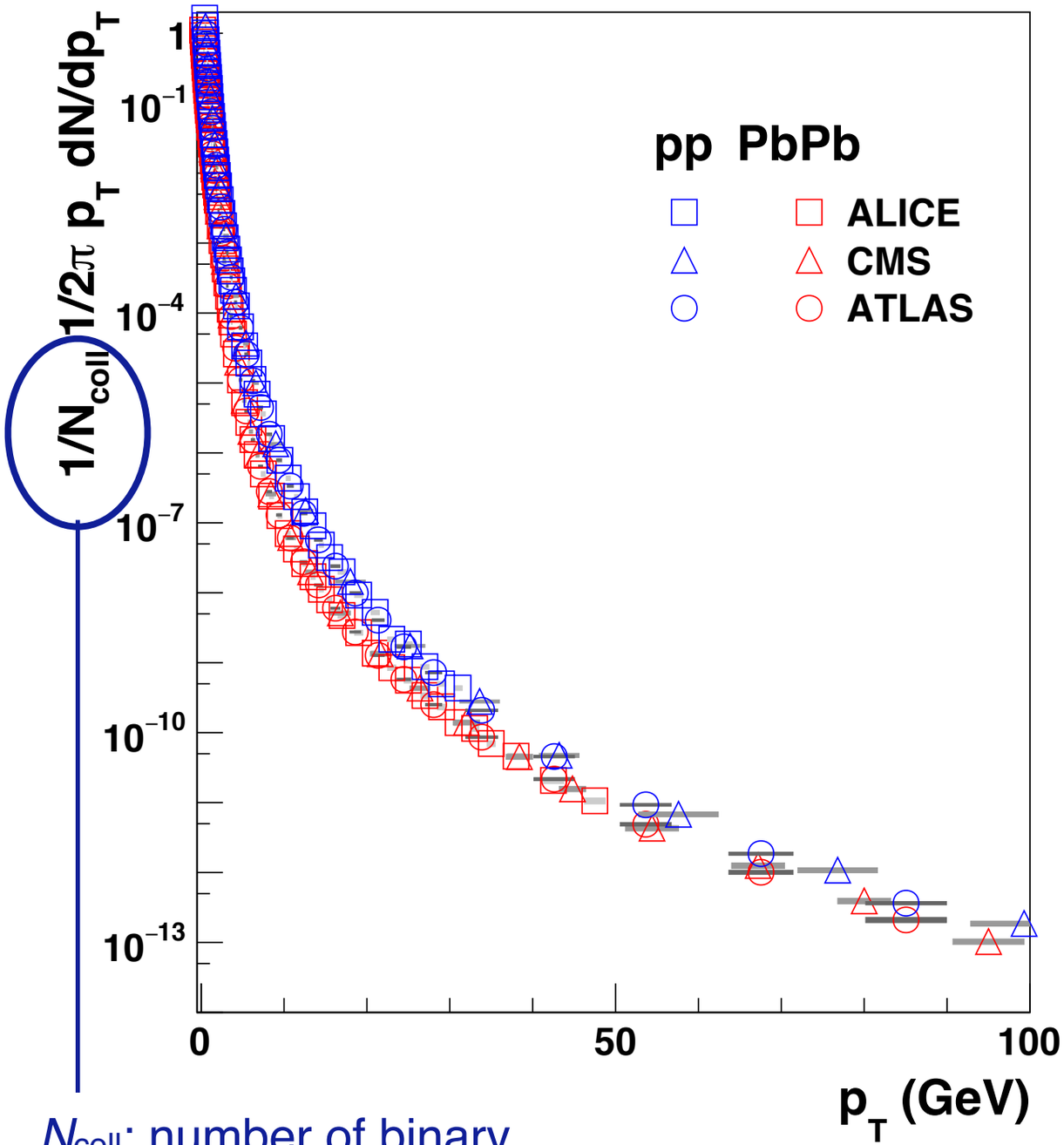

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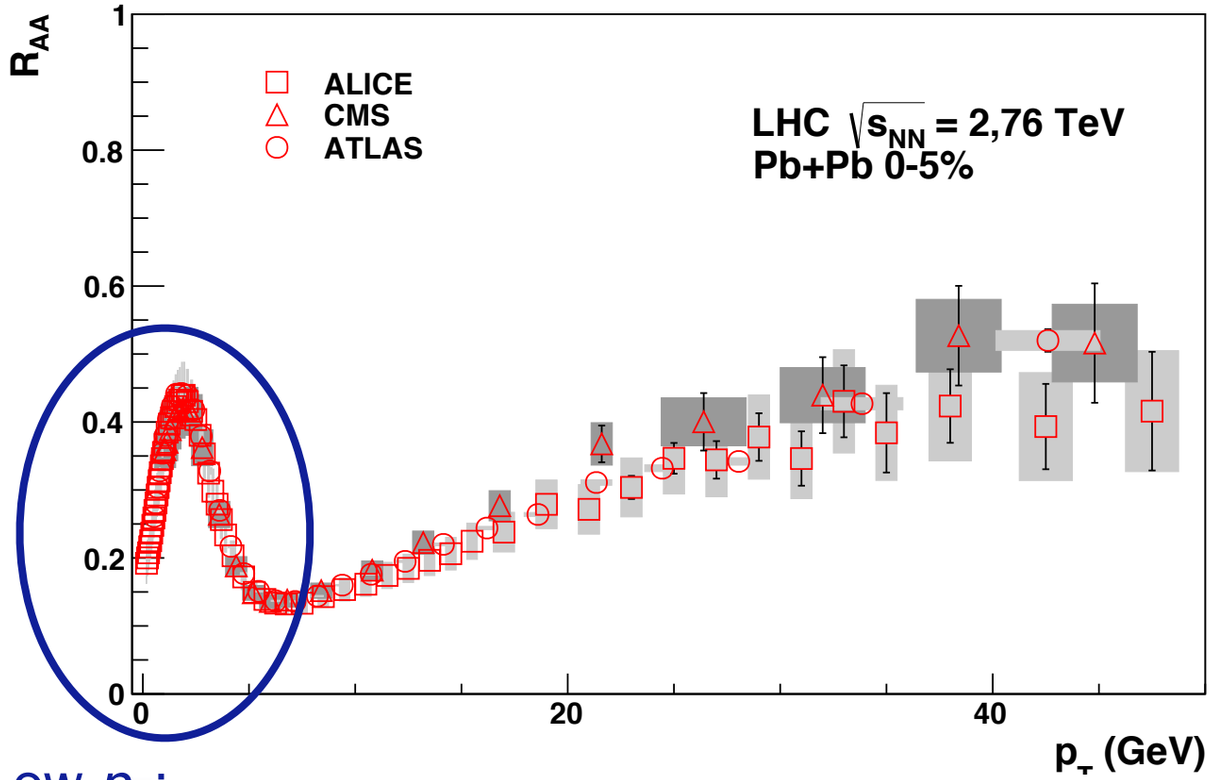

Low p_T:
soft production,
N_{part} scaling

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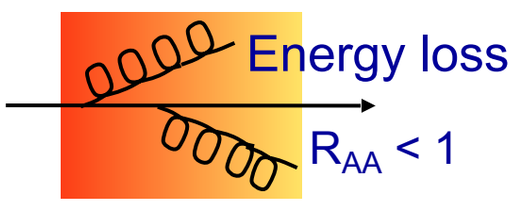

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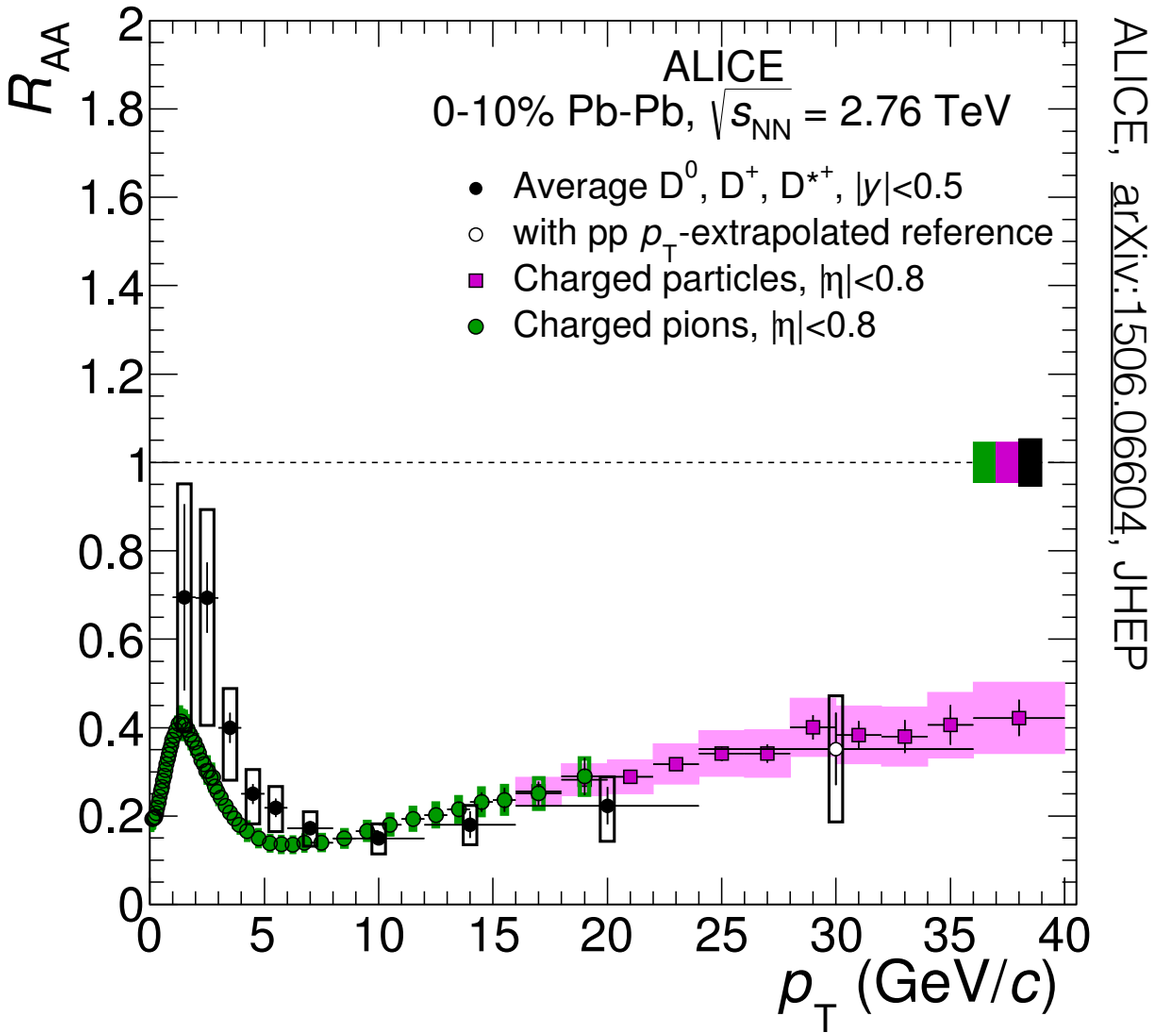
Nuclear modification for light and heavy flavor

charged particles, $\pi^{\pm}$ and D mesons



Light and heavy flavor have similar R_{AA}
despite dead-cone effect, quark/gluon difference

Current understanding: interplay of
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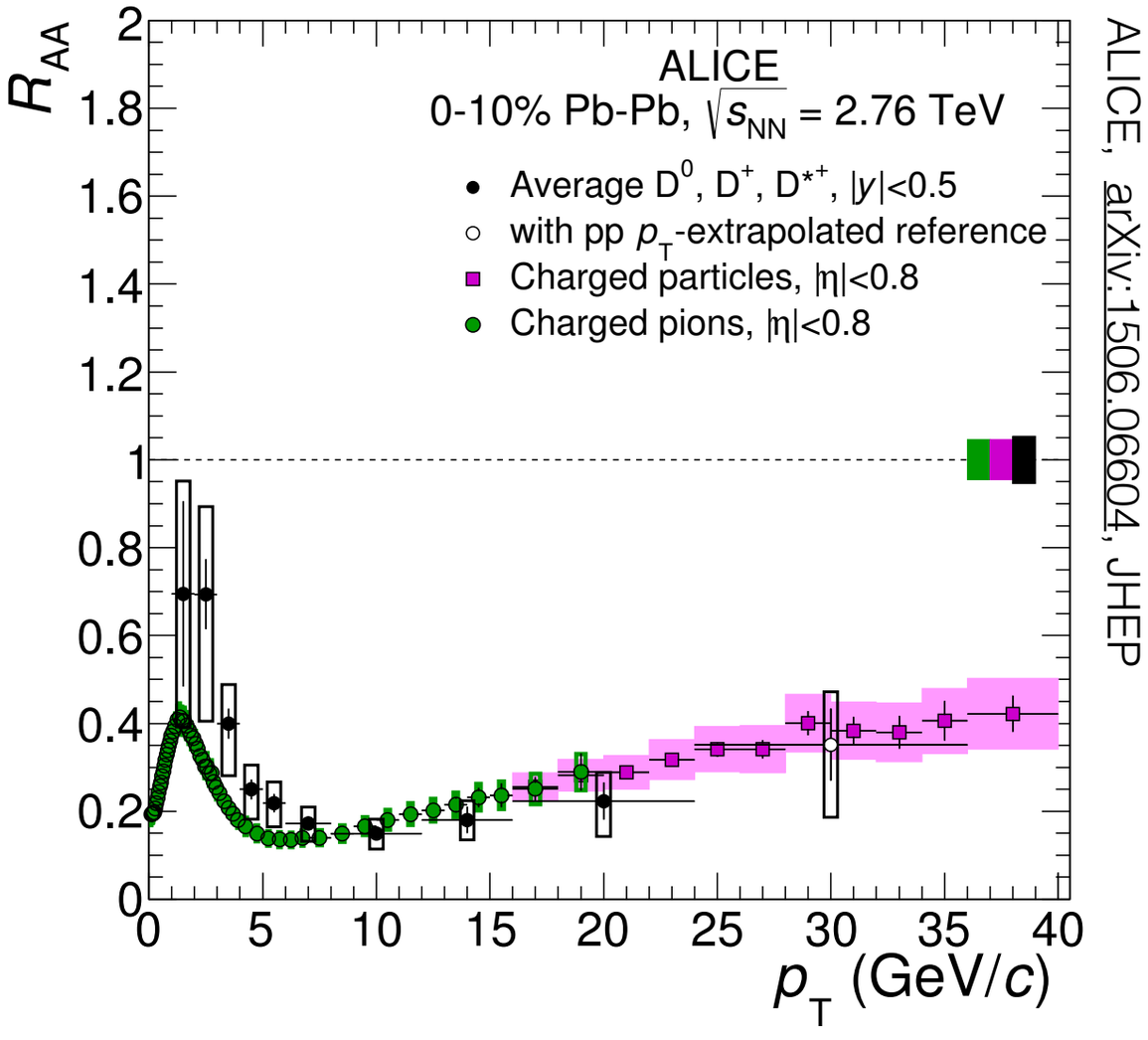

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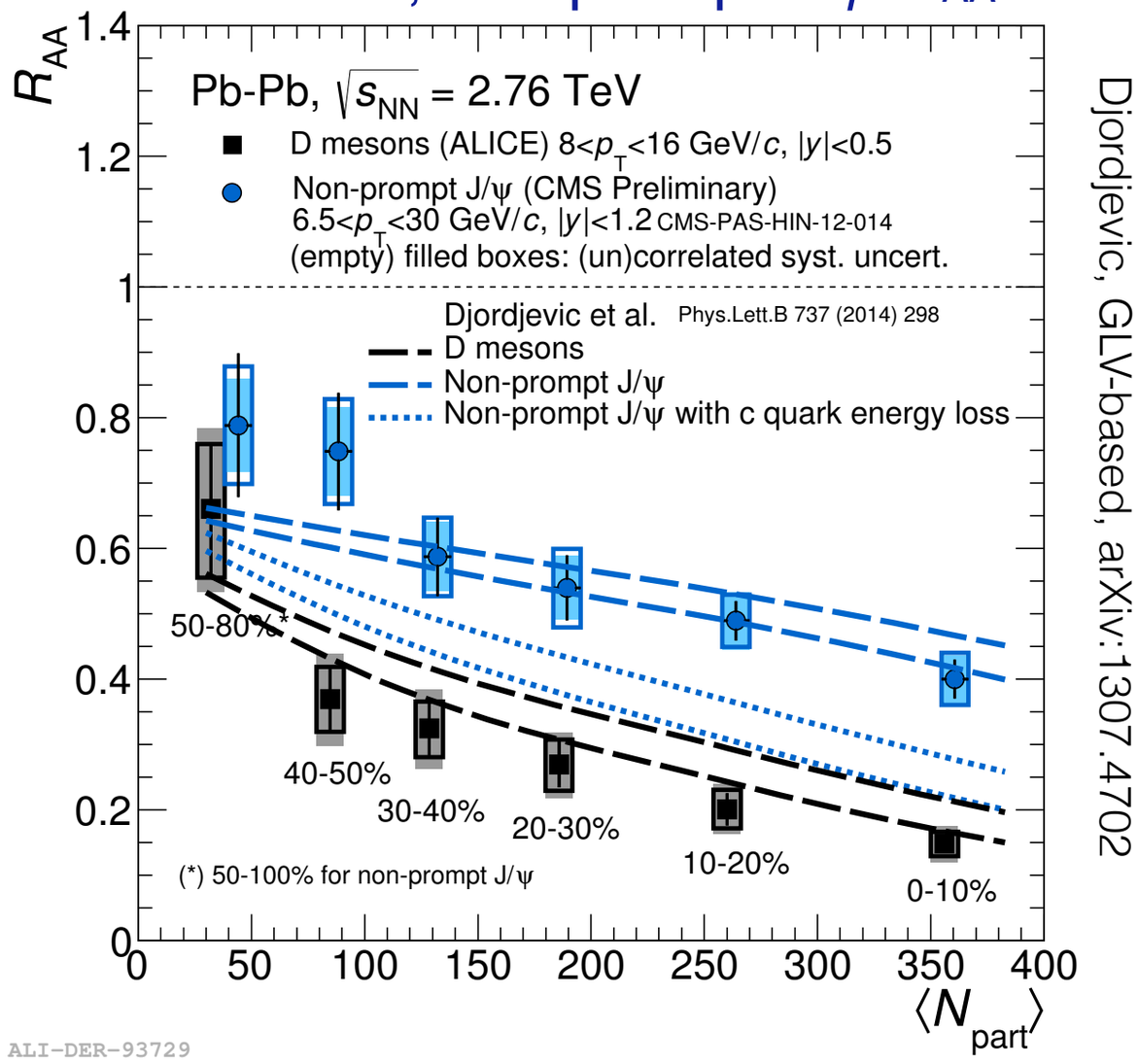

ALI-DER-93729

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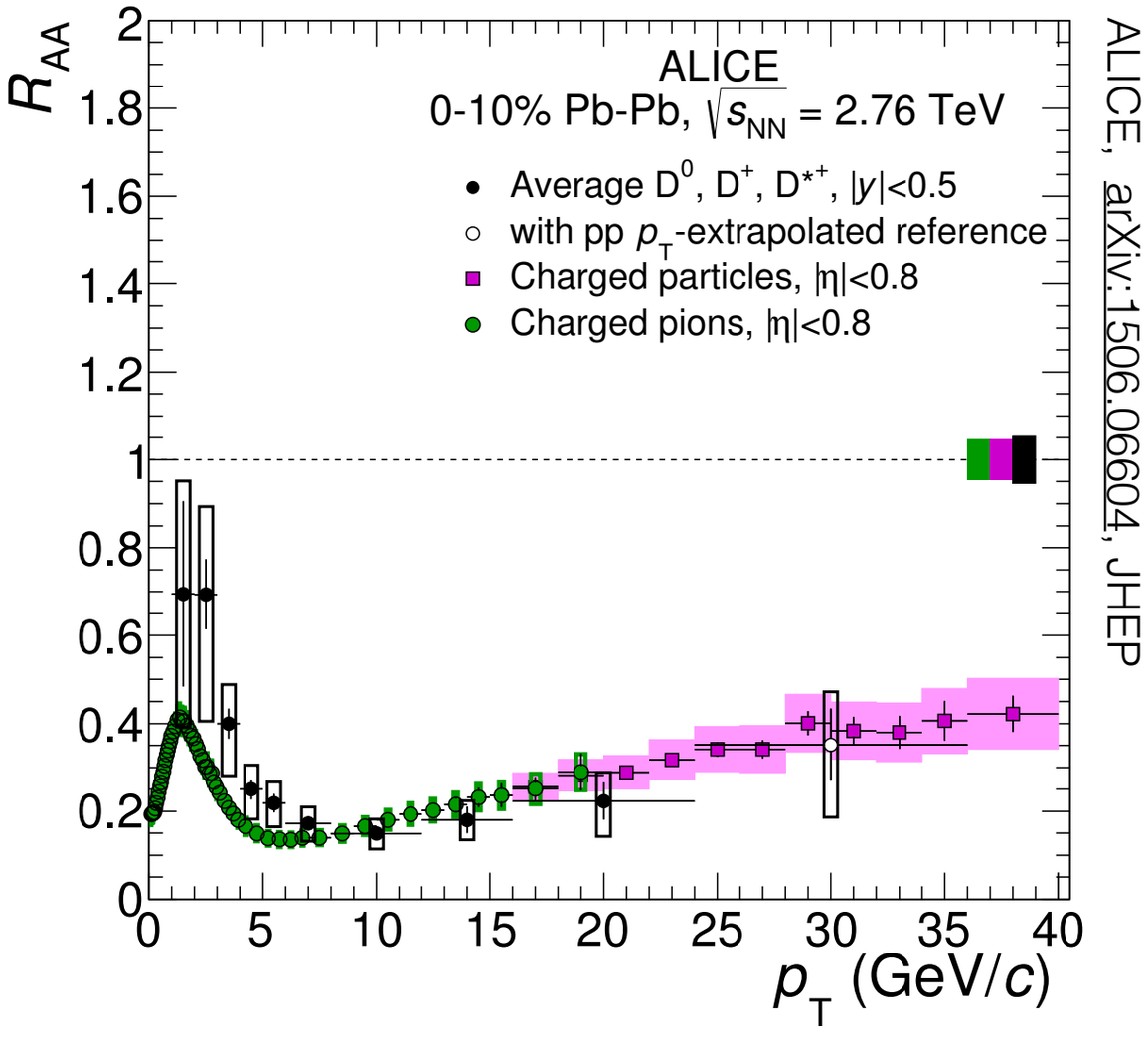

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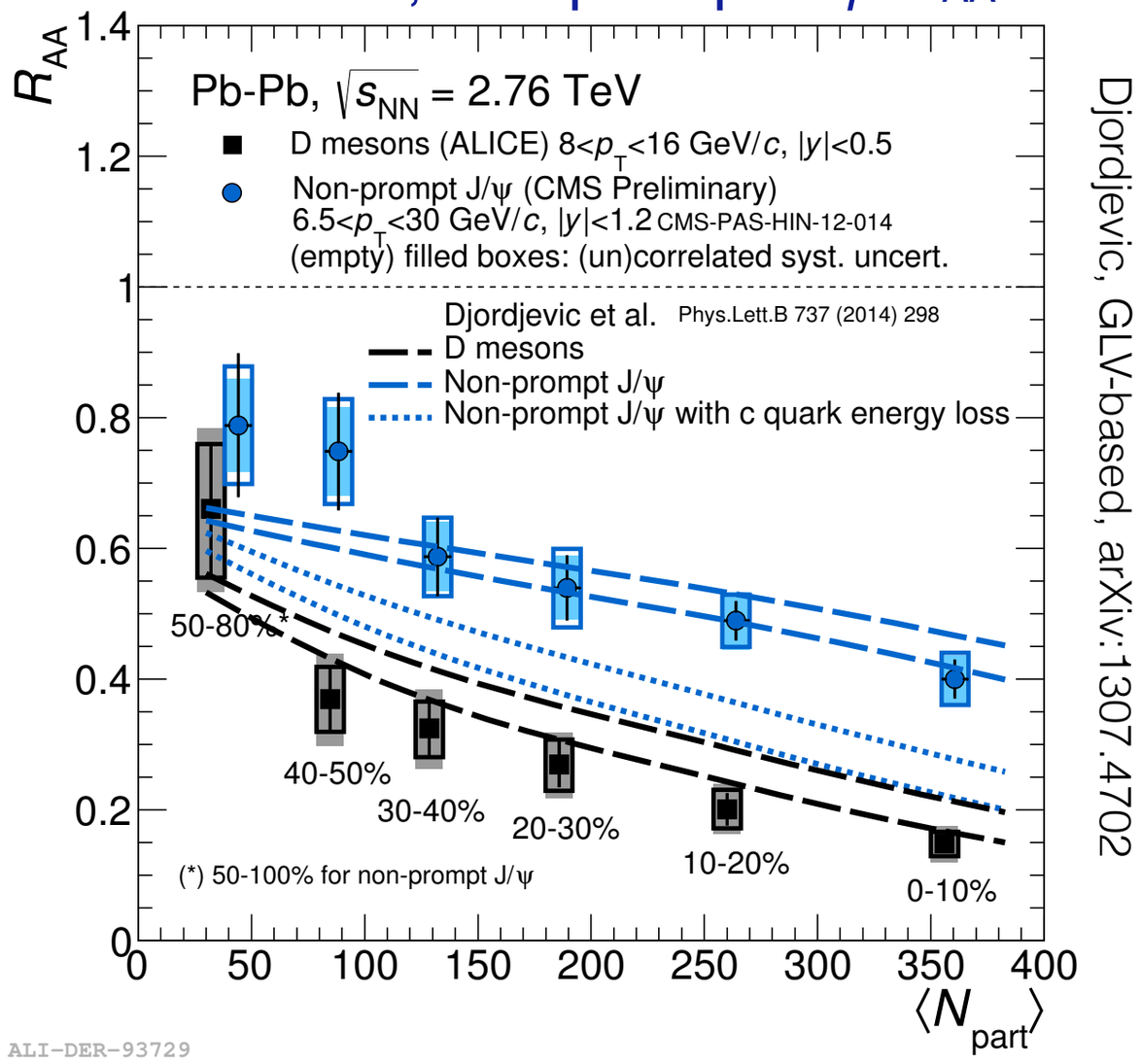

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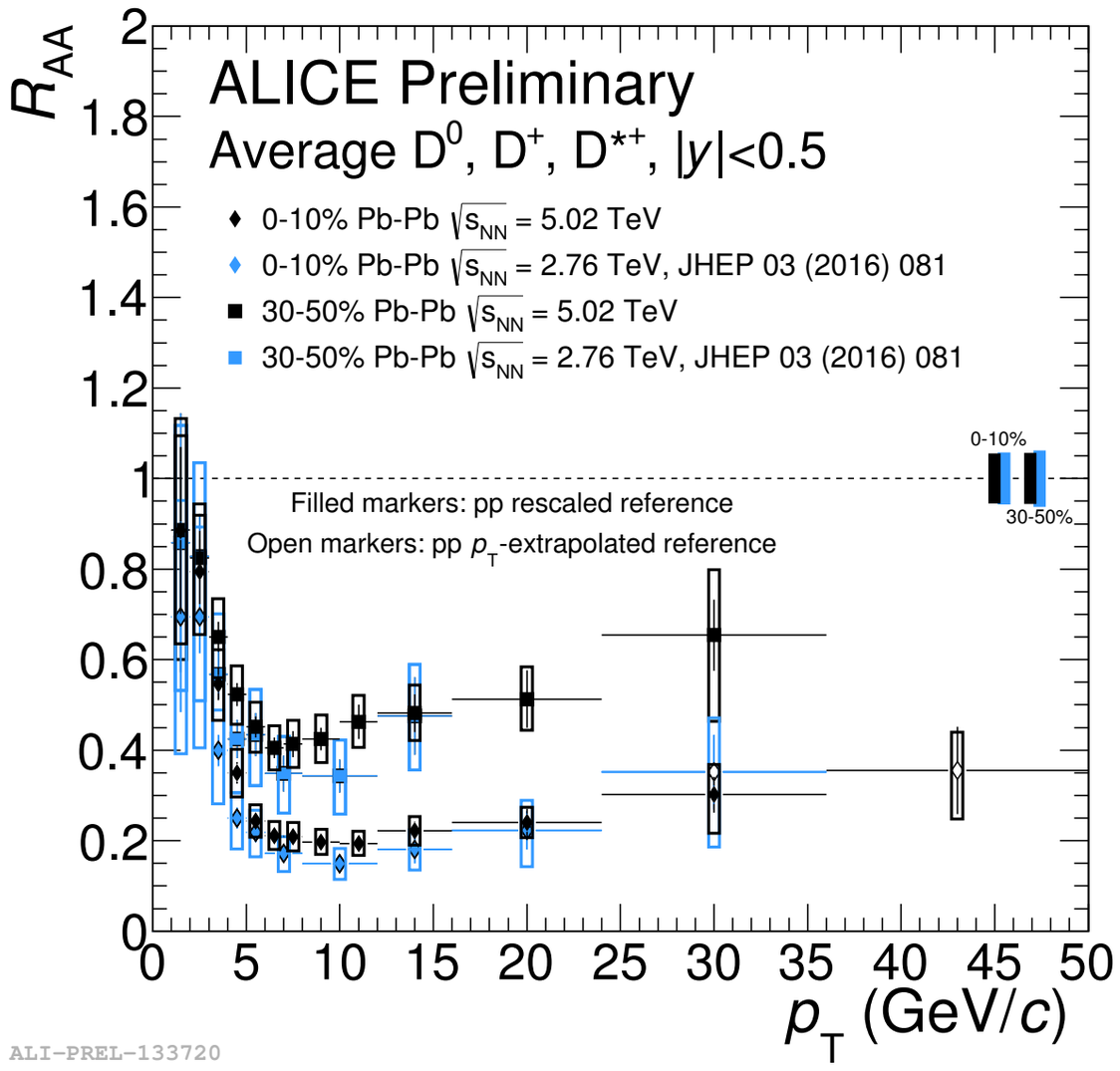
New results from run 2: 5.02 TeV



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Improved uncertainties; more to come with 2018 data

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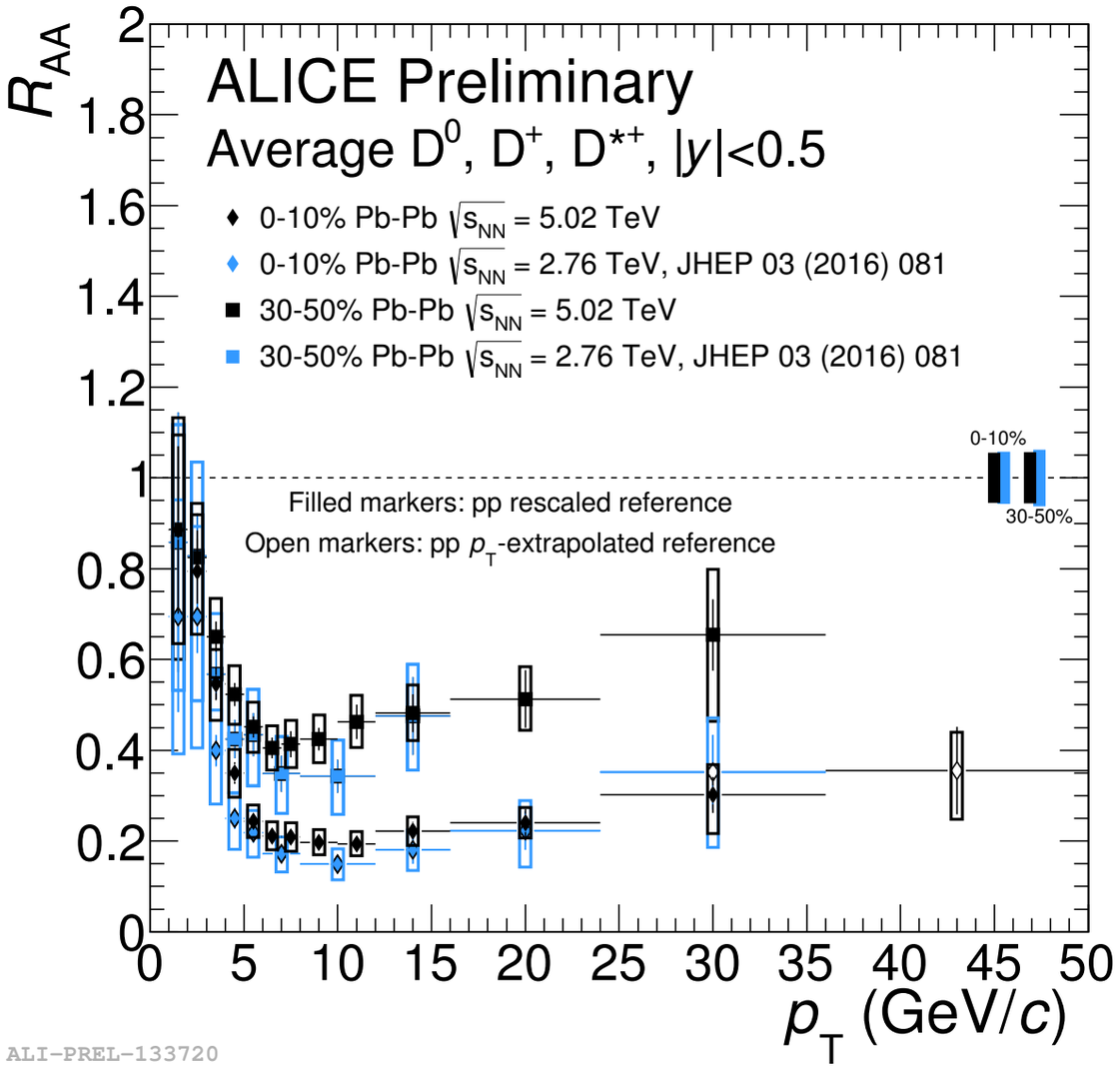

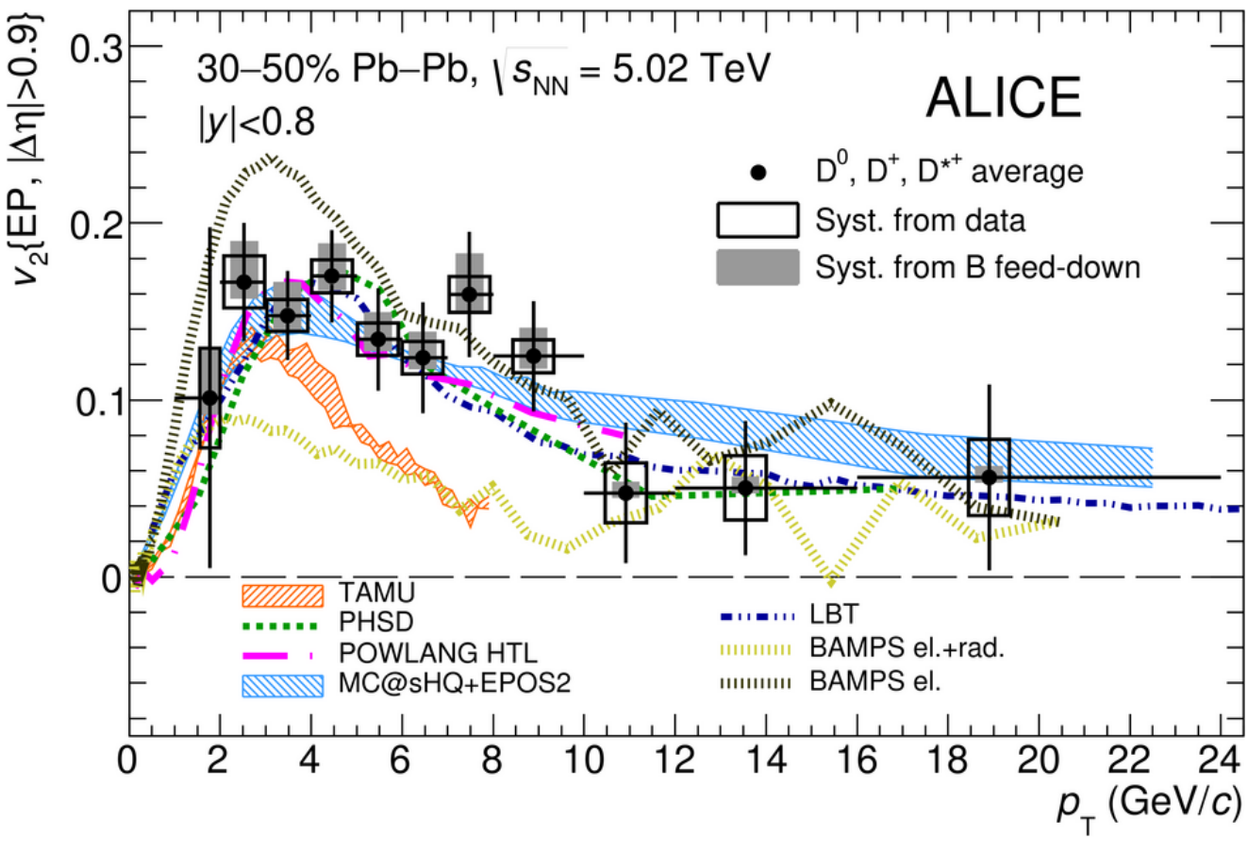

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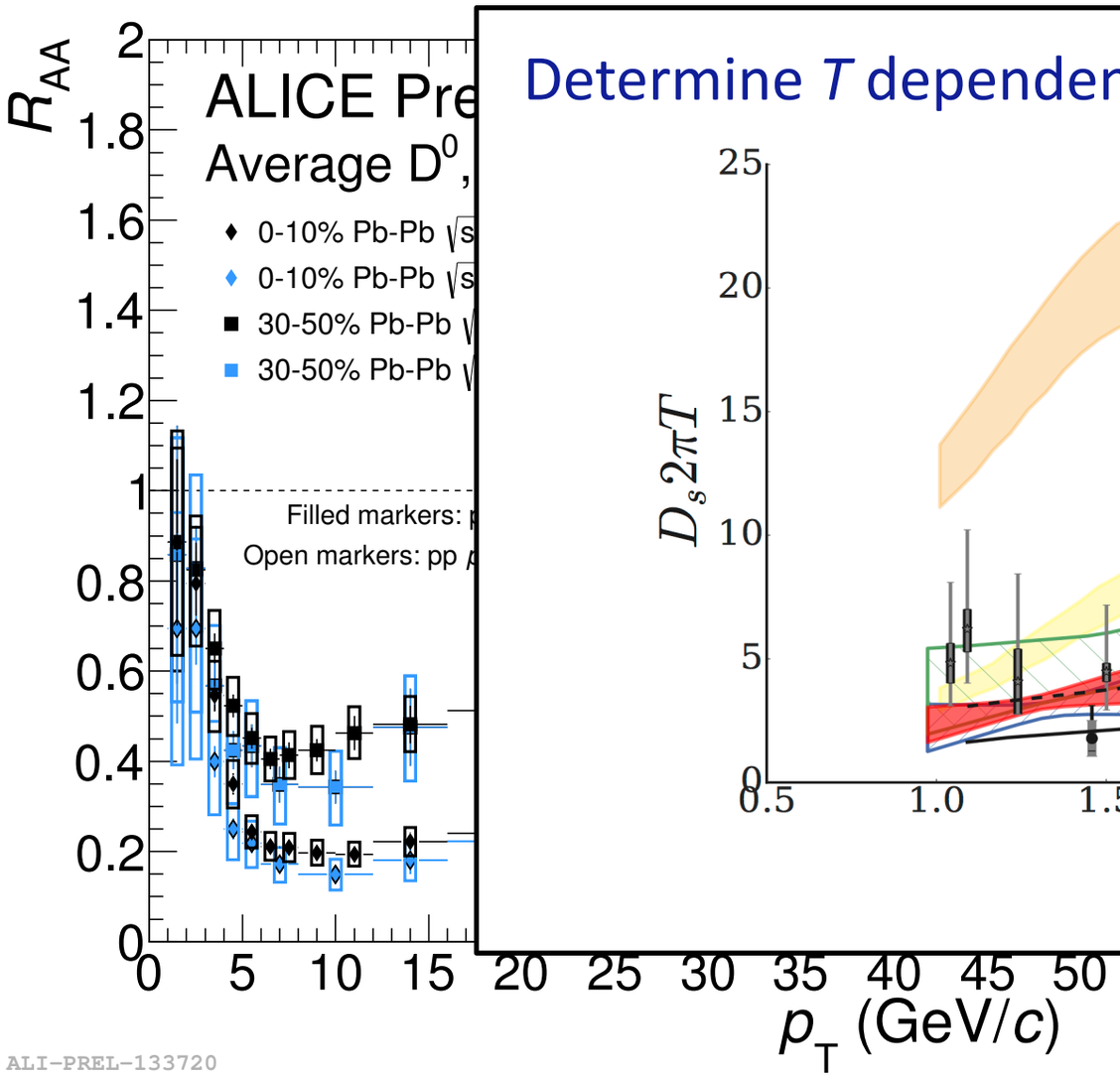
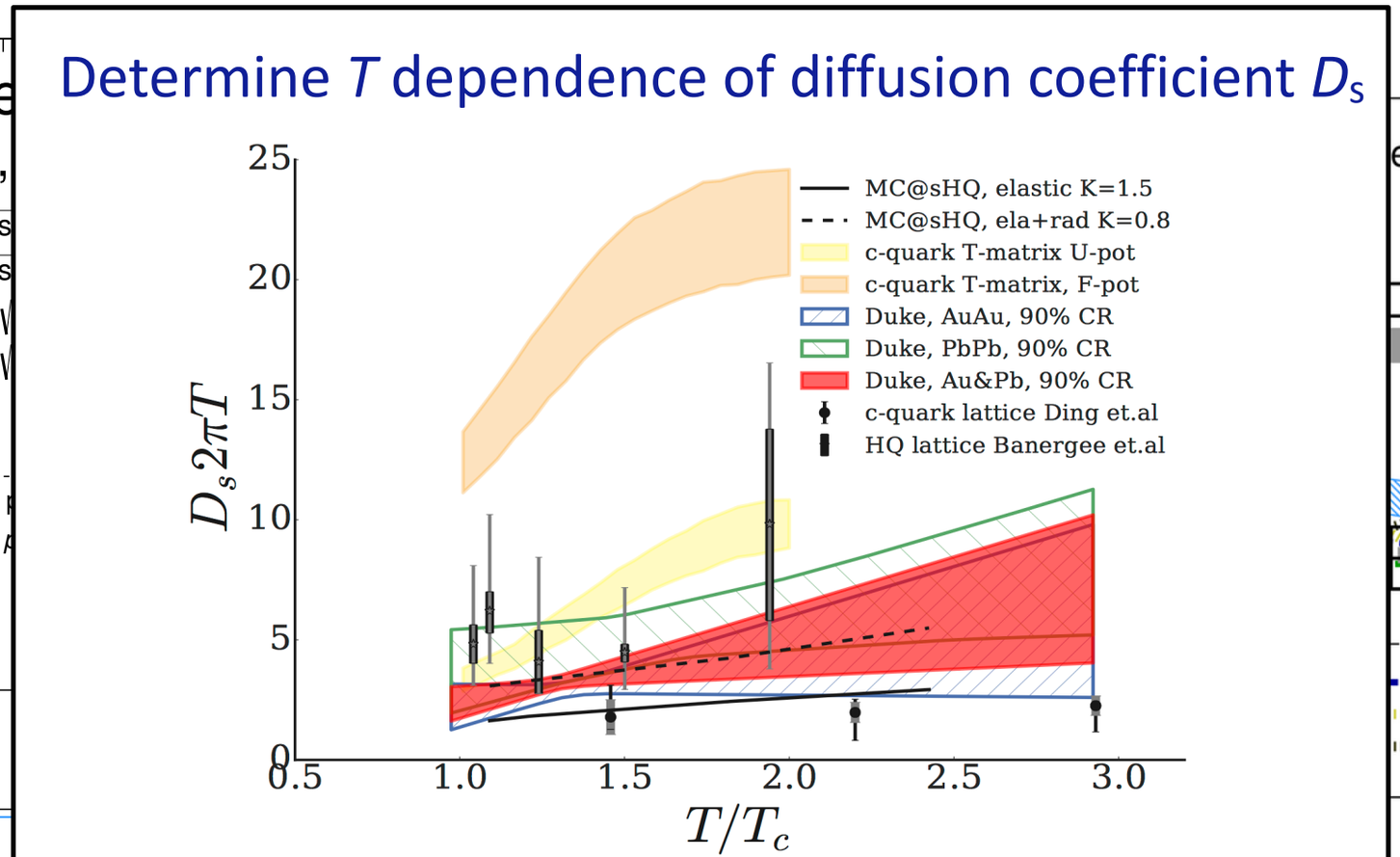
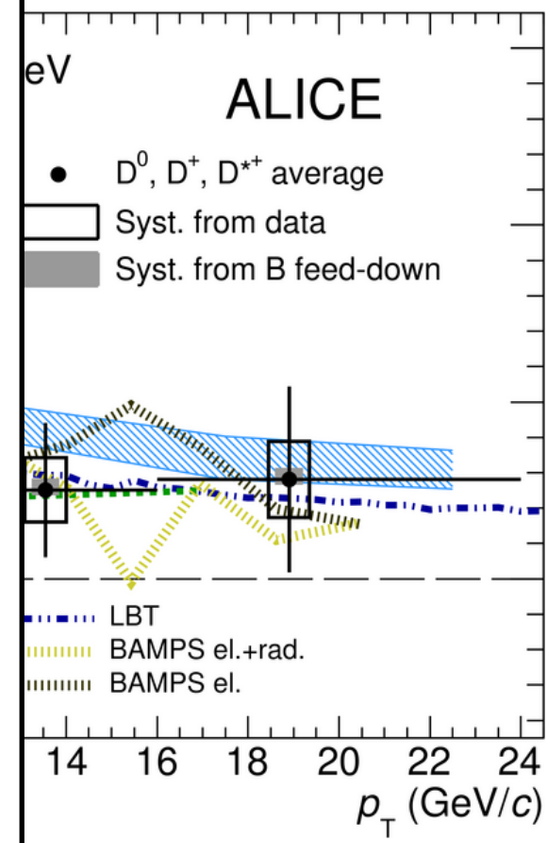


ALI-PREL-133720





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Summary/conclusion

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  - Correlations: particle production and **hadronisation**
  - Photons: (early stage) **temperature** and **pressure** gradients
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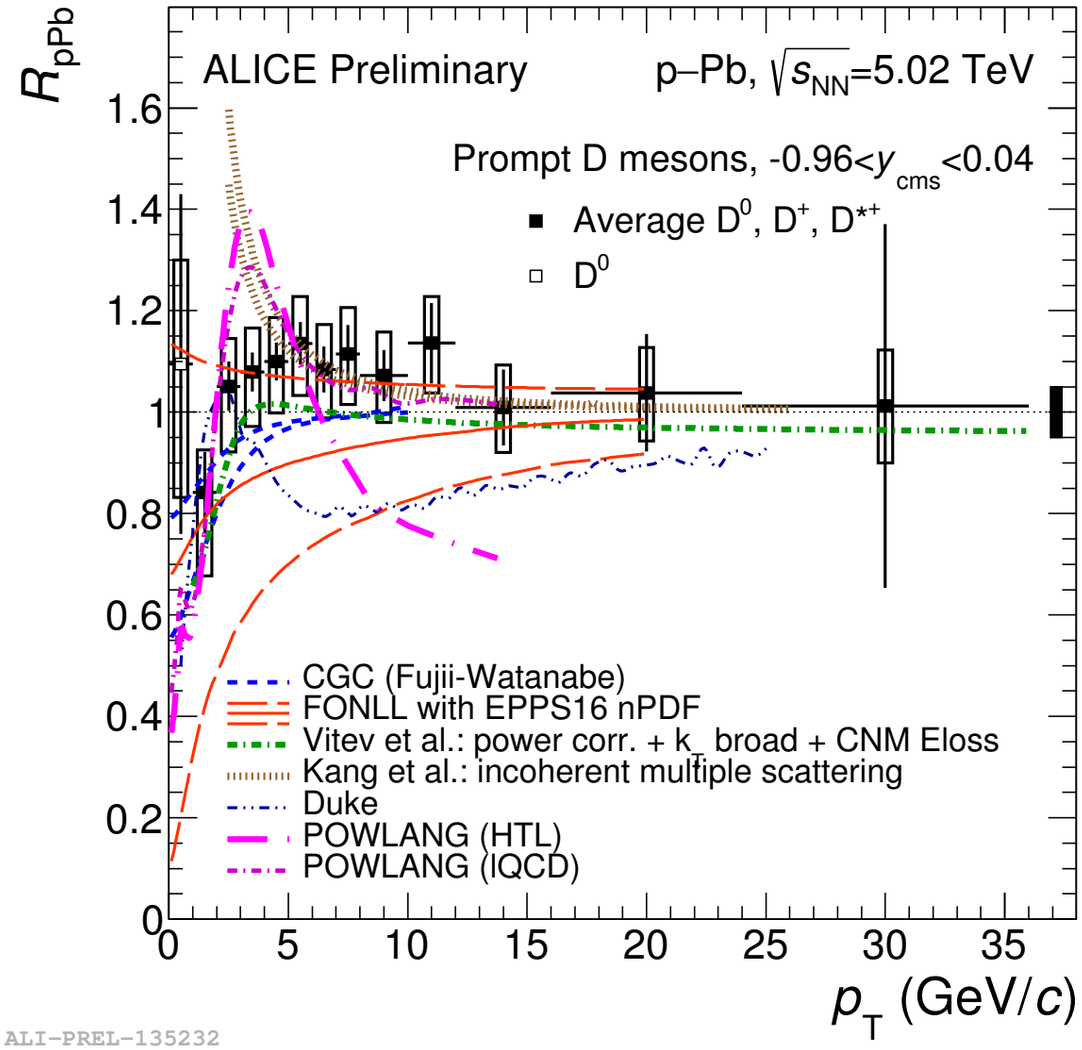
Run 2018 and upgrades:

- Improved precision for key measurements:
  heavy flavour, photons, jets, magnetic effects
- Plus new ones: heavy favour baryons, magnetic effects in charm sector, etc

Thank you for your attention

Heavy flavour mesons in p-Pb

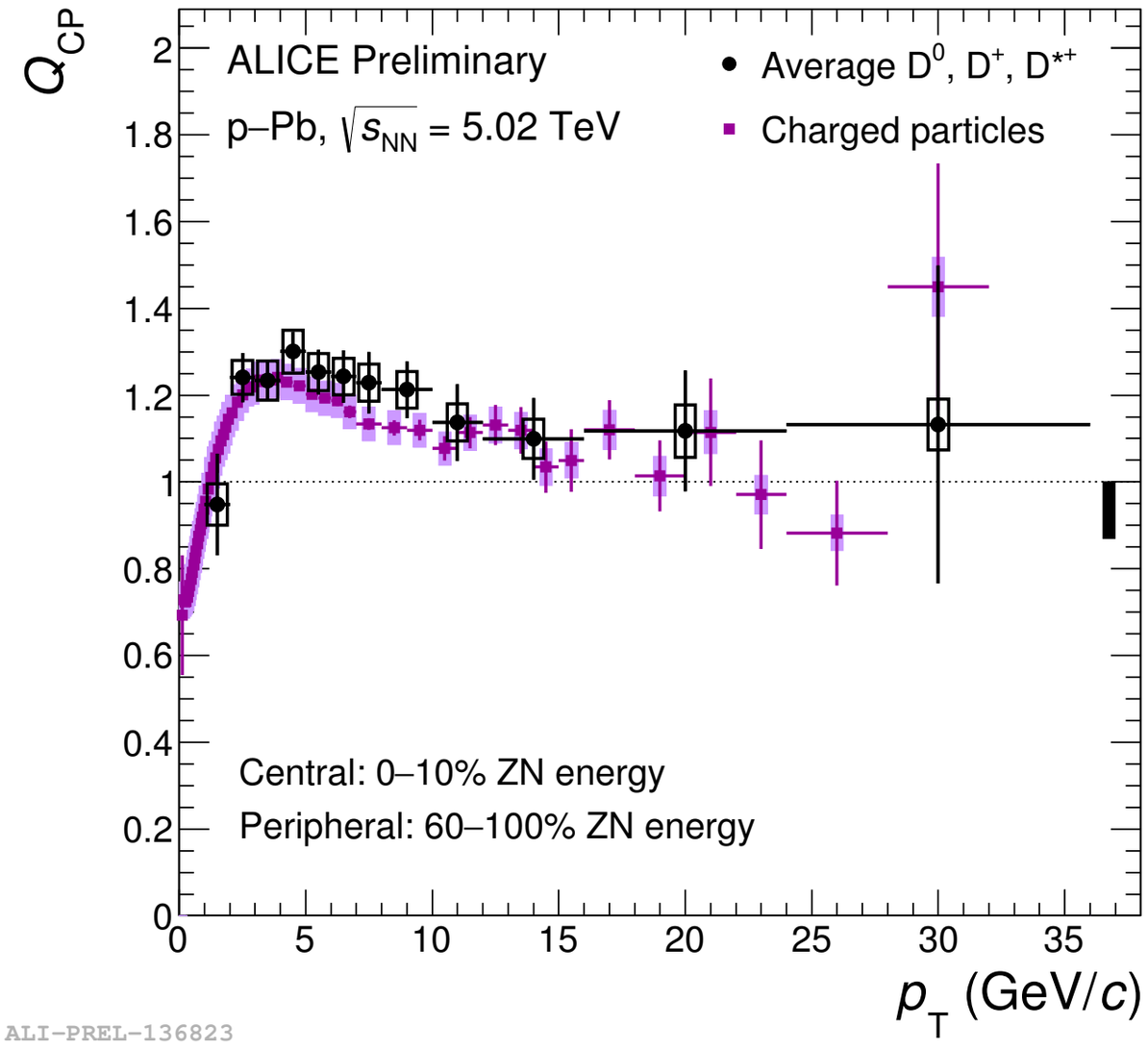
Nuclear modification factor



ALI-PREL-135232

Nuclear modification factor ~1
No sign of final state effects

Central/peripheral ratio



ALI-PREL-136823

Enhancement in central collisions
p_T 2-10 GeV
Is this (radial) flow?

Flow effects in small systems

Many aspects of the observed ridge have
a natural explanation in hydrodynamics:

- Long range correlation
- 2- and 3-fold symmetries
- Dependence on initial geometry
- Many-particle correlations
- Particle mass dependence

Why would the system behave as a fluid?

Is there enough time, volume to thermalise?

- Hydrodynamisation (isotropisation) of a dense gluon system?
- Partonic/hadronic rescattering?
- How many scatterings/what density is needed to approximate fluid behaviour?