Overview of results from ALICE at the LHC

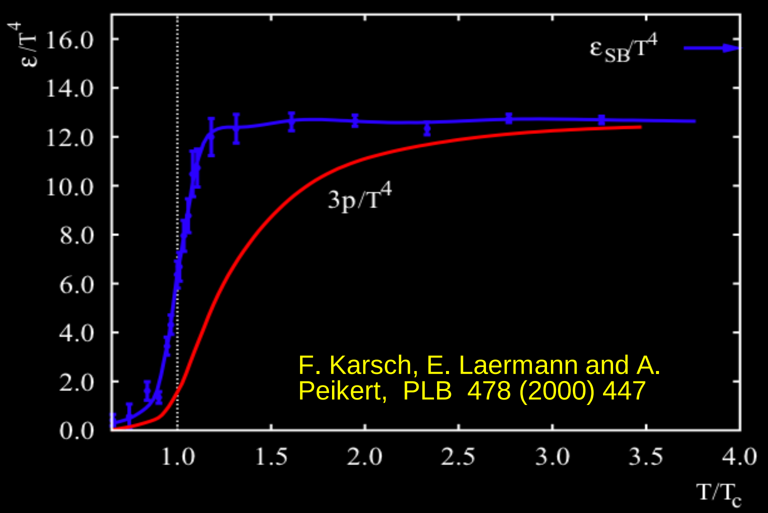
Panos Christakoglou

Nikhef

for the ALICE Collaboration

Introduction

Lattice QCD

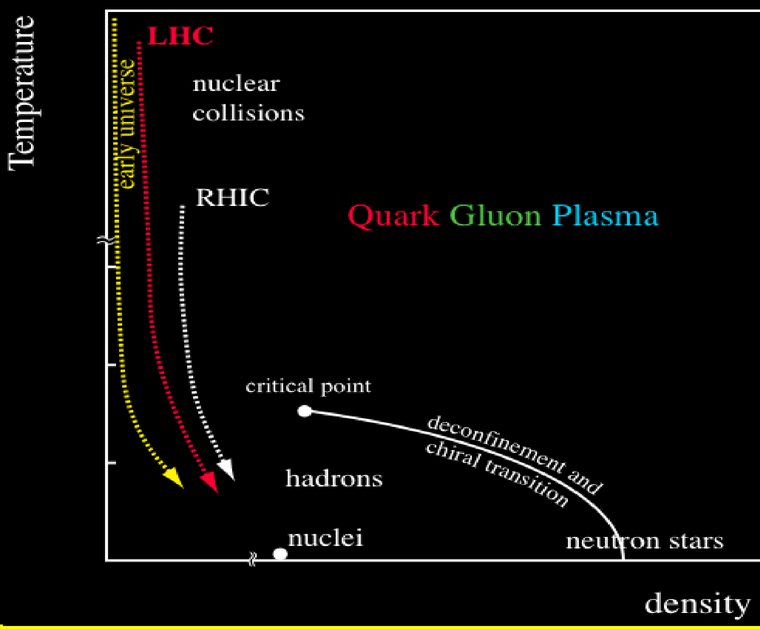


- At the critical temperature a strong increase in the degrees of freedom
  - gluons, quarks ➔ deconfinement
- Transition expected to occur around 0.5 GeV/fm^3

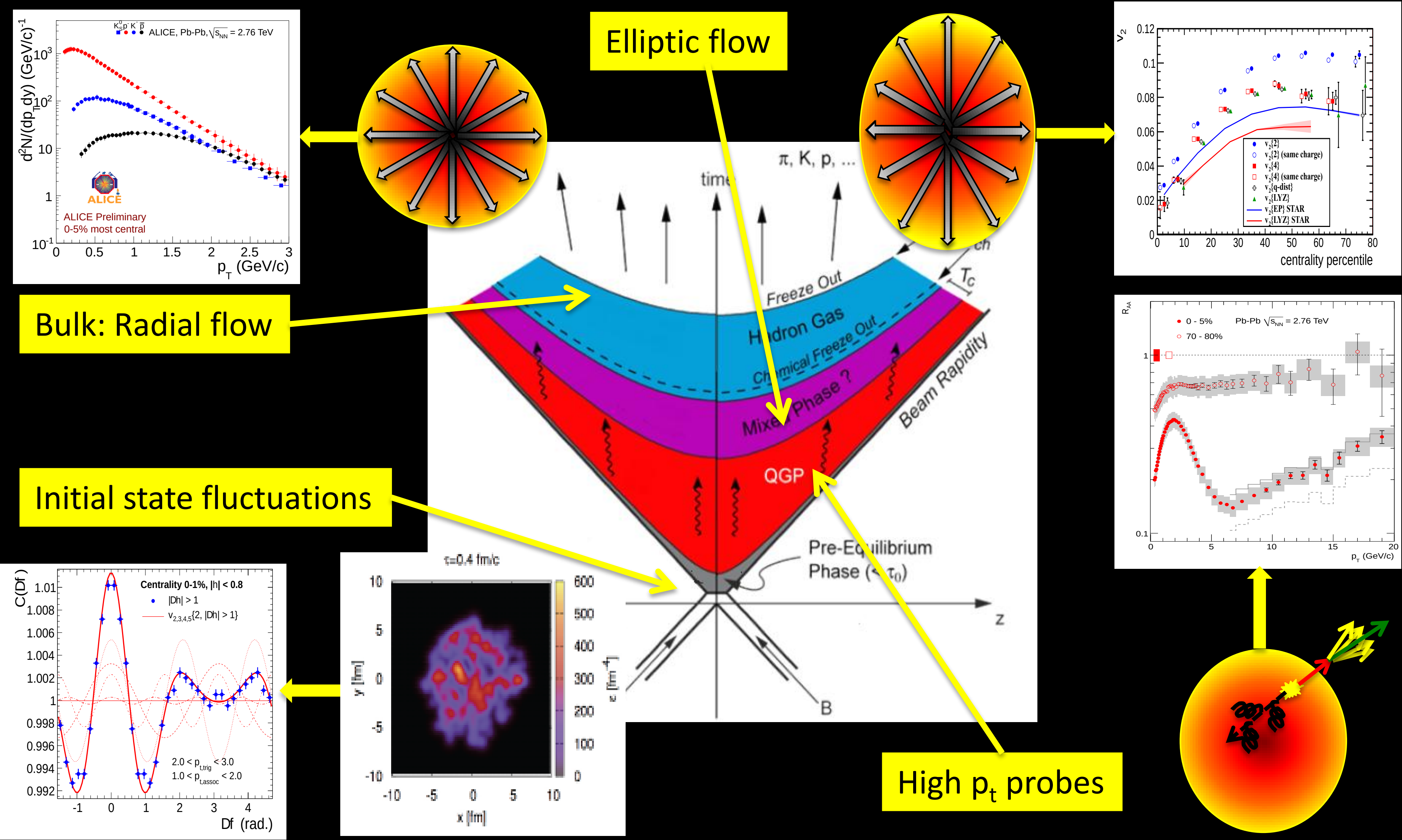
Borsanyi et al. JHEP 11 (2010) 077

Explore the properties of the Quark Gluon Plasma

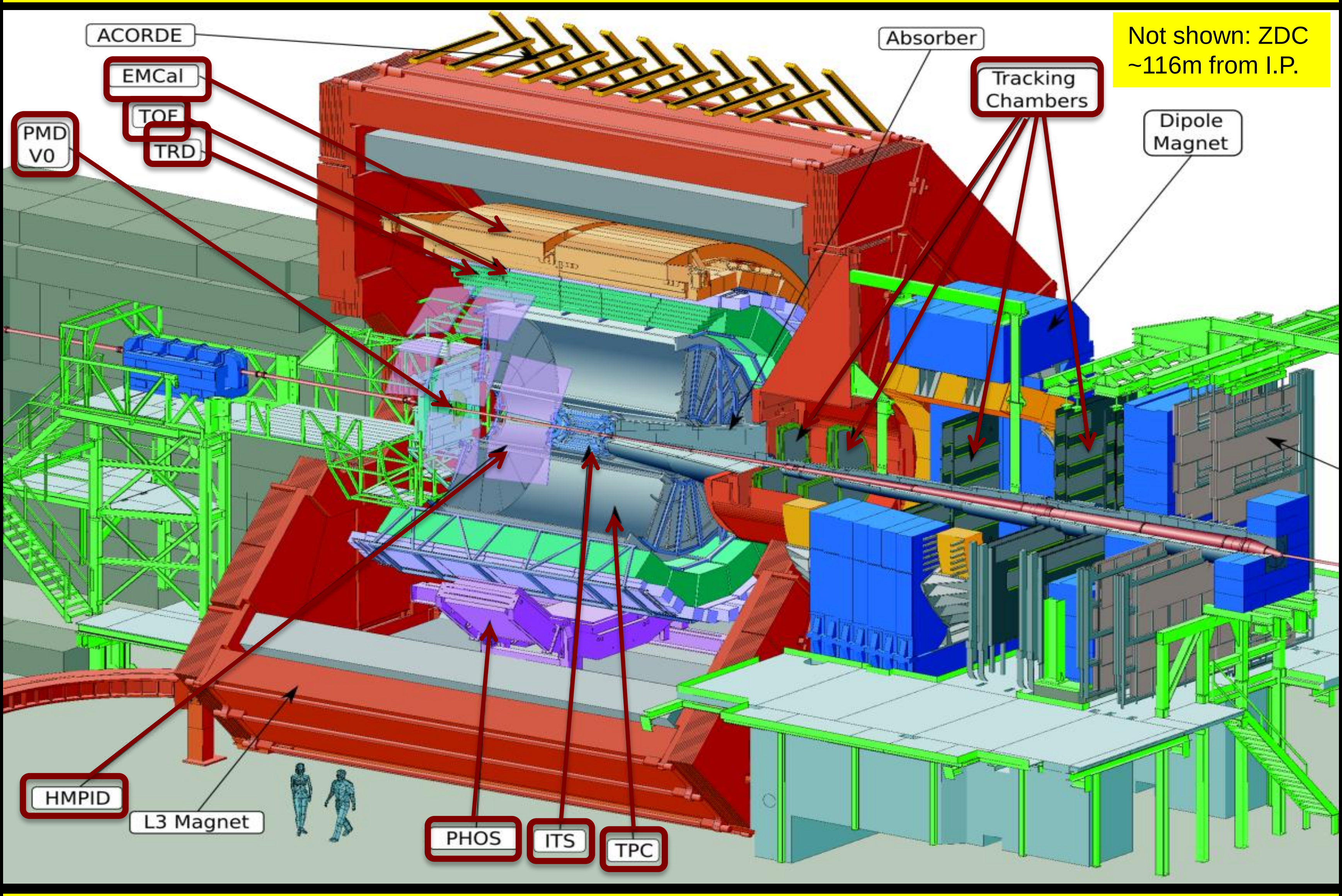
- What happens when you heat and compress matter to very high temperatures and densities?
- The macroscopic quantities of the QGP will give us better understanding of the underlying microscopic theory (QCD) in the non-perturbative regime
- Different accelerators have contributed to the mapping of the "experimental phase diagram"



Outline: Experimental tools covered in this talk

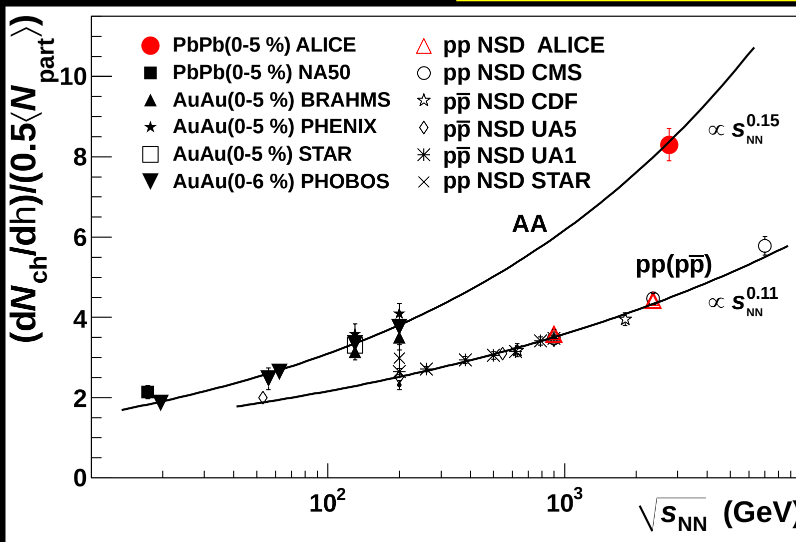


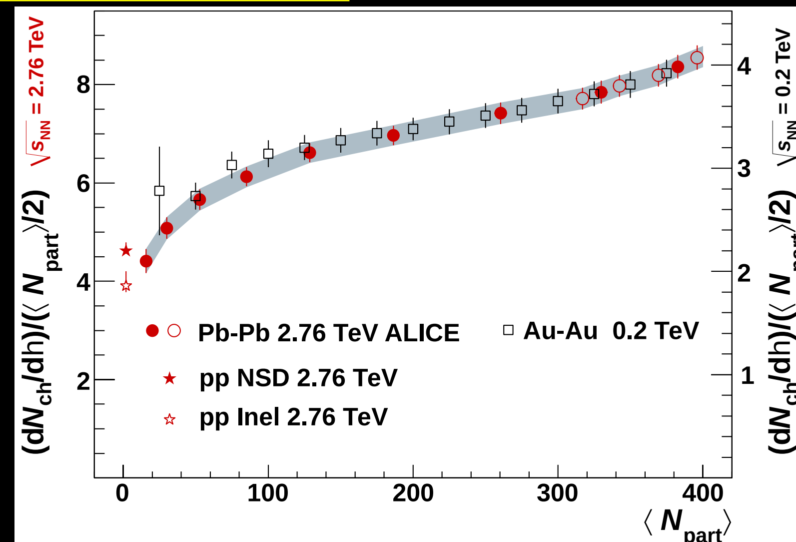
The ALICE detector



Multiplicity measurement

$dN_{ch}/d\eta = 1584 \pm 4\ (\text{stat.}) \pm 76\ (\text{syst.})$





- Increase of $(dN_{ch}/d\eta)$ larger than ln√s as initially suggested by the RHIC measurements
- Increase of $(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$ with √s faster in AA than in p-p
  - $\sim s^{0.11}$ for pp
  - $\sim s^{0.15}$ for Pb-Pb
- Larger value than most models predicted

- Centrality dependence at the LHC similar to the one reported at RHIC energies
  - RHIC points scaled by ~2.1
  - Similarity due to centrality dependent shadowing of the nuclear PDF?

Phys. Rev. Lett. 105, 252301 (2010)
Phys. Rev. Lett. 106, 032301 (2011)

Identified particle spectra

Reconstruction and PID in ALICE:
Jouri Belikov, Tuesday@19:00, Parallel I

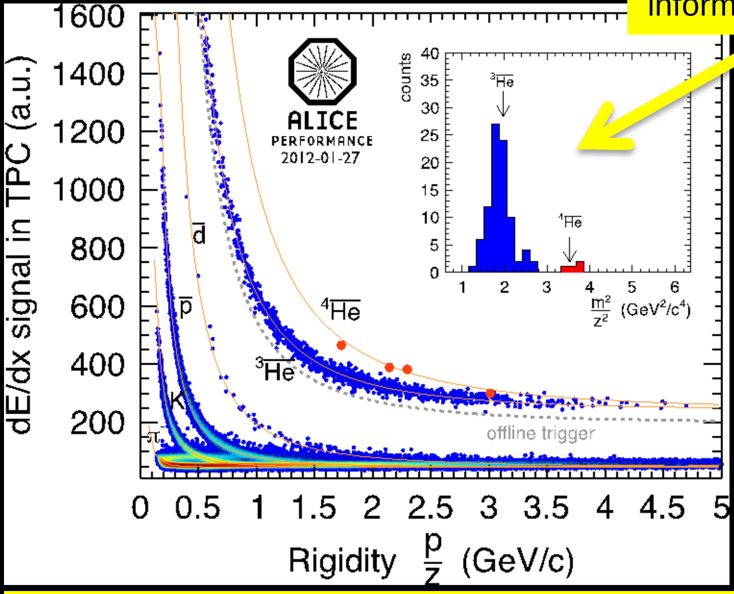
- Particle spectra in pp used to
  - constrain phenomenological models (many input parameters)
  - reference for Pb-Pb (to be discussed later)
- Particle spectra/ratios in A-A described by statistical models with only a handful of parameters (e.g. T_{kin}, T_{chem}, μ_B, γ_s)

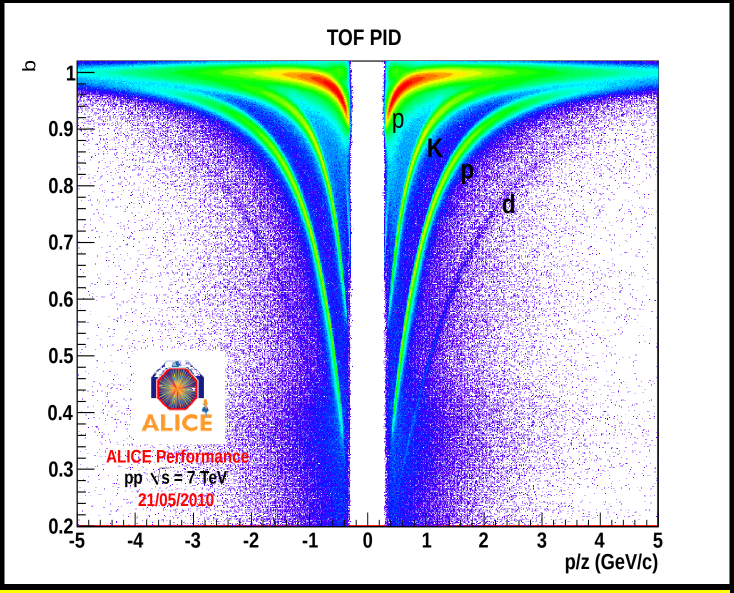
ALICE uses all available PID techniques to provide identification on a track-by-track basis (low momentum) and with statistical approaches (e.g. dE/dx in the relativistic rise)

TPC ($\sigma_{dE/dx}$ ~ 5%)

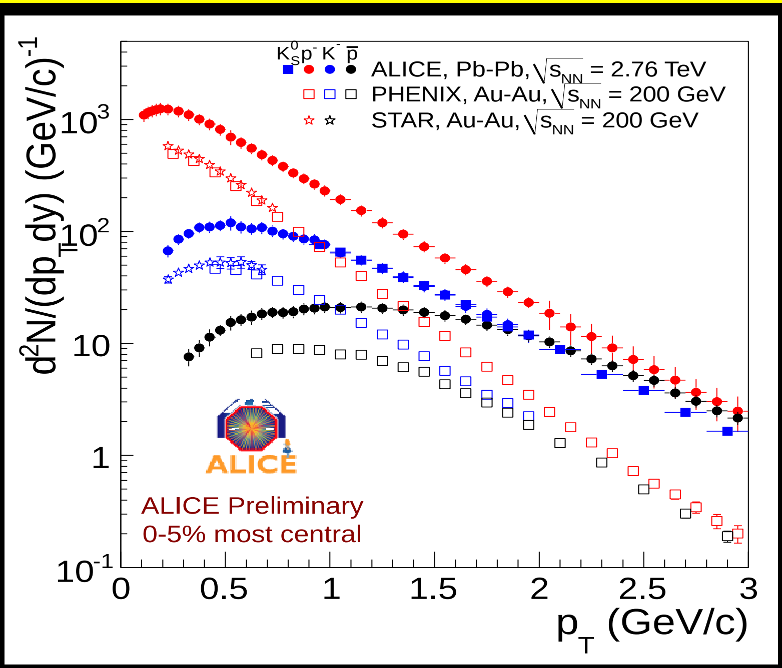
combined TPC and TOF information

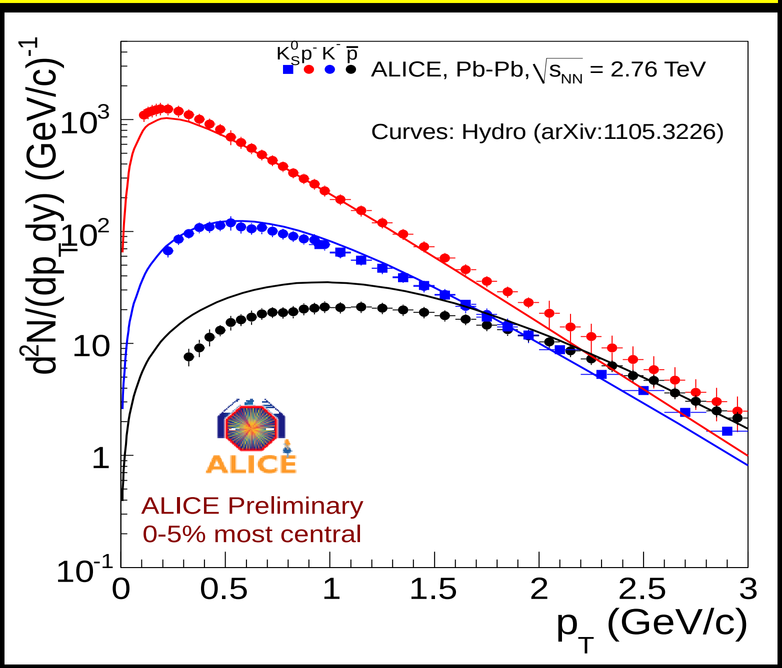
TOF (σ ~ 80 ps)





Identified particle spectra: collective radial flow





- Strongly interacting medium + pressure gradient: isotropic radial flow
- Stronger boost for heavier particles
- Harder spectra at the LHC compared to RHIC
- Blast wave fit ➔ average radial velocity and kinetic freeze-out temperature
  - Central Pb-Pb collisions at the LHC <β>~0.66c
  - ~10% larger <β> at the LHC compared to RHIC

- Spectra compared to hydro calculations
  - Inclusion of the rescattering phase (via UrQMD) essential to describe the spectra for the most central collisions

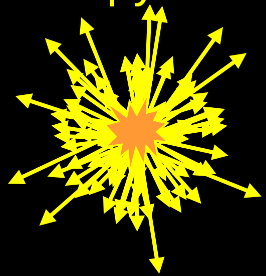
Particle spectra: Martha Spyropoulou Stassinaki, Monday@20:15, Parallel II

Elliptic flow

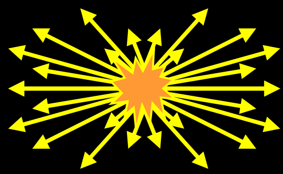
- Pressure gradient transforms the initial spatial … momentum-space anisotropy

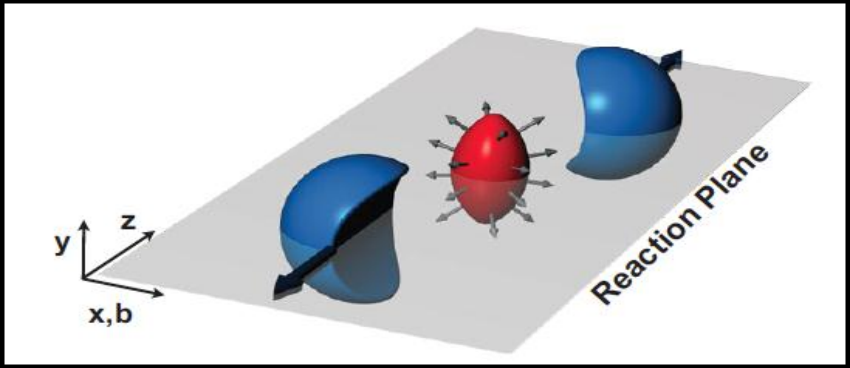
Flow from RHIC to LHC:
Raimond Snellings, Monday@11:20,
Plenary II

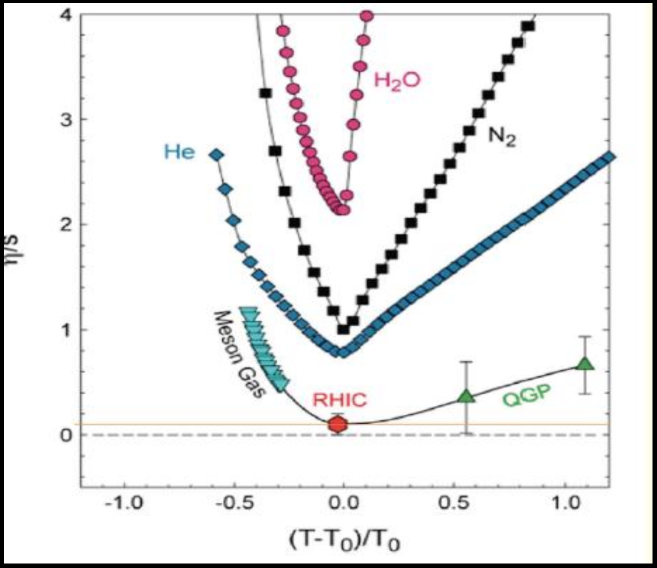
Superposition of independent pp collisions:
momenta pointed at random relative to reaction plane



Evolution as a **bulk system:**
Pressure gradients (larger in-plane) push bulk "out" → "flow"







Azimuthal distribution described by a Fourier expansion

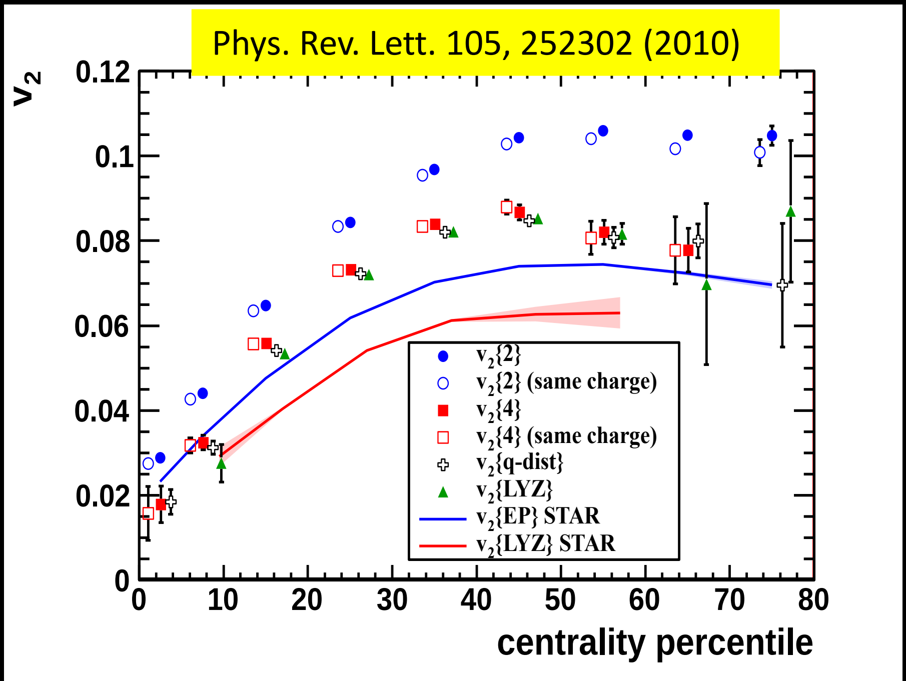
$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+2\sum_{n=1}^{\infty} v_n\cos\left[n(\phi-\Psi_n)\right]\right)$$

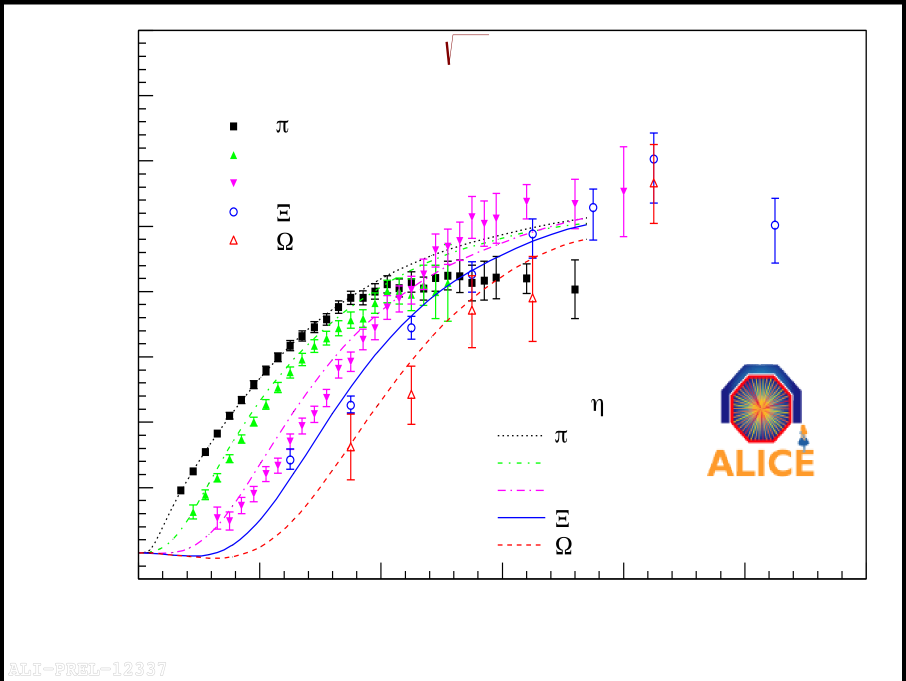
Connection to η/s ➔ RHIC values close to the lower bound of 1/4π (hbar=c=1)

$$v_n(p_t,y)=\left\langle\cos\left[n(\phi-\Psi_n)\right]\right\rangle$$

S. Voloshin and Y. Zhang, Z. Phys. **C70**, 665 (1996)

Elliptic flow: results

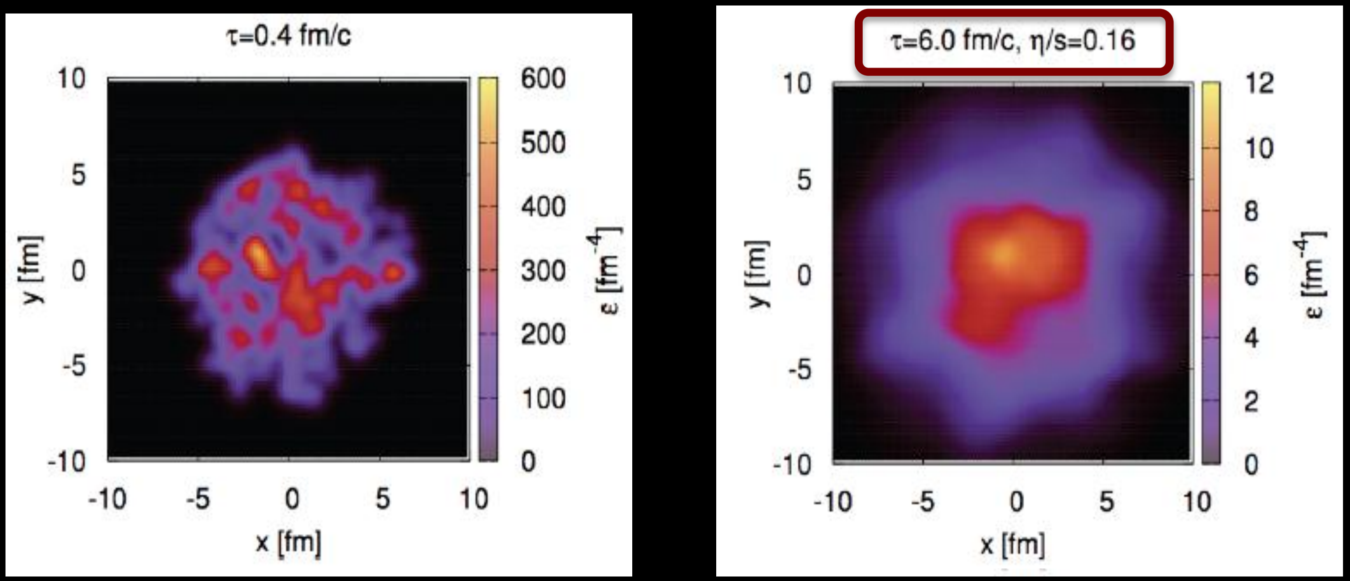




- ❑ Similar centrality dependence but ~30% higher integrated v_2 value wrt RHIC
- ❑ Predicted by hydro for a liquid with small value of shear viscosity
  - ○ "perfect liquid" picture applies also at the LHC
- ❑ Particle mass dependence well reproduced by hydro calculations
  - ○ Stronger push for heavier particles by radial flow
- ❑ Inclusion of a hadronic afterburner essential to match the differential v_2 of protons
- ❑ Pure hydro gives reasonable for Ξ and Ω

Initial state

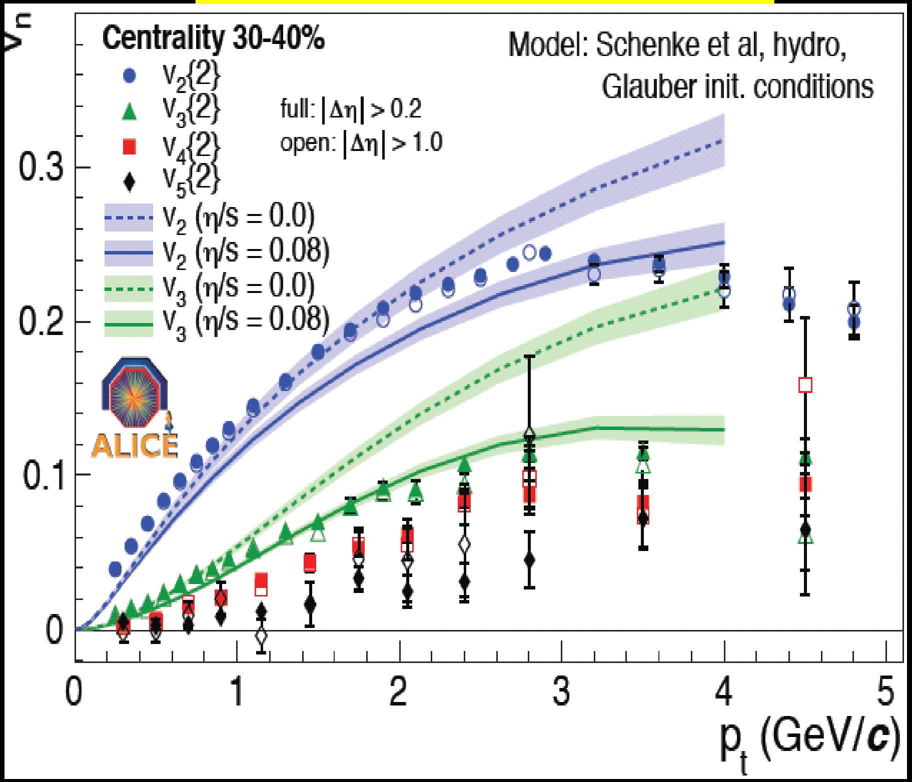
- Initial geometry not described by the ideal almond shape
  - Fluctuations of initial energy/pressure distributions lead to “irregular” shapes that fluctuate event-by-event
  - Higher (odd) harmonics each having its one symmetry plane
- Higher harmonics more sensitive to the value of shear viscosity

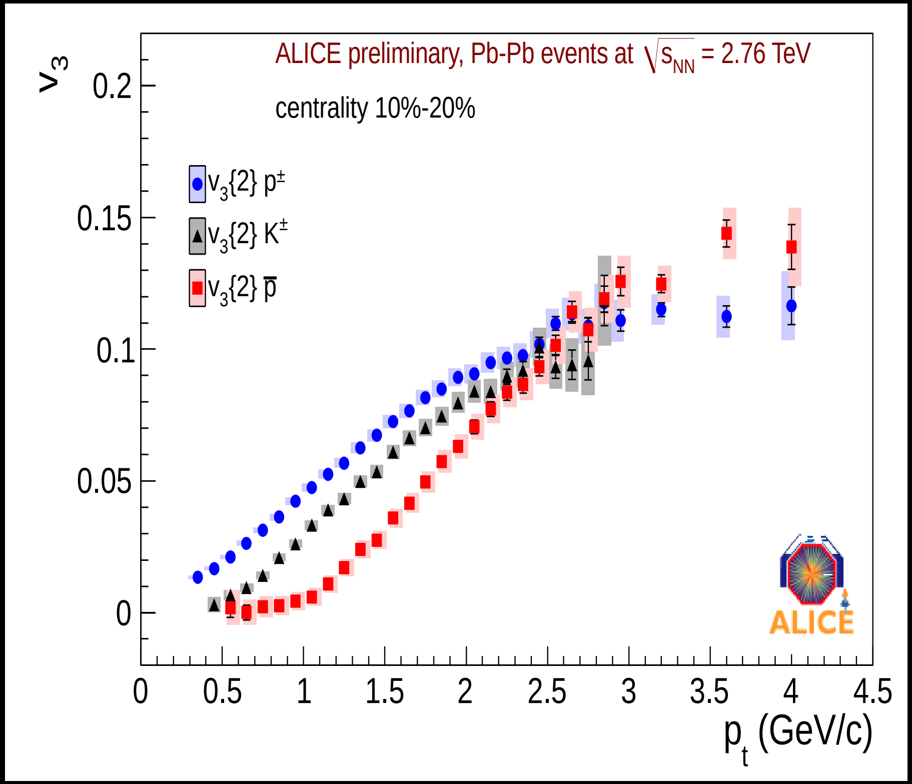


- But…initial conditions not known precisely enough (model dependent)
  - Data can be described by different combinations of initial conditions + η/s

Triangular flow: results

Phys. Rev. Lett. 107, 032301 (2011)

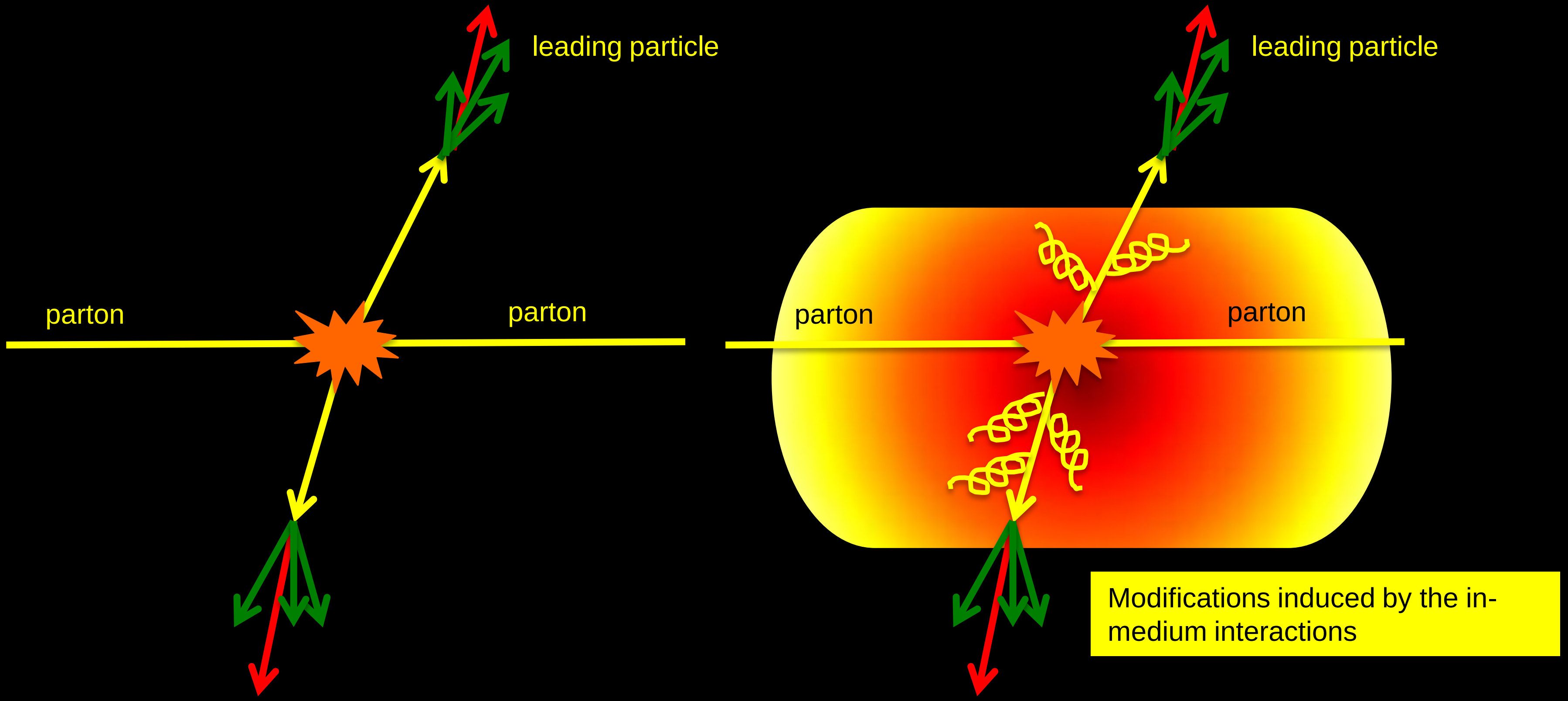




- Models can not describe successfully the elliptic and triangular flow with the same values of η/s
- Similar mass splitting expected by hydro

High pt probes

- LHC offers the possibility to study hard processes
  - larger cross sections for high-p_t and larger mass particles
- Two ways of studying the medium effects
  - Compare yields of high-p_t particles in A-A to pp collisions
  - Jet reconstruction

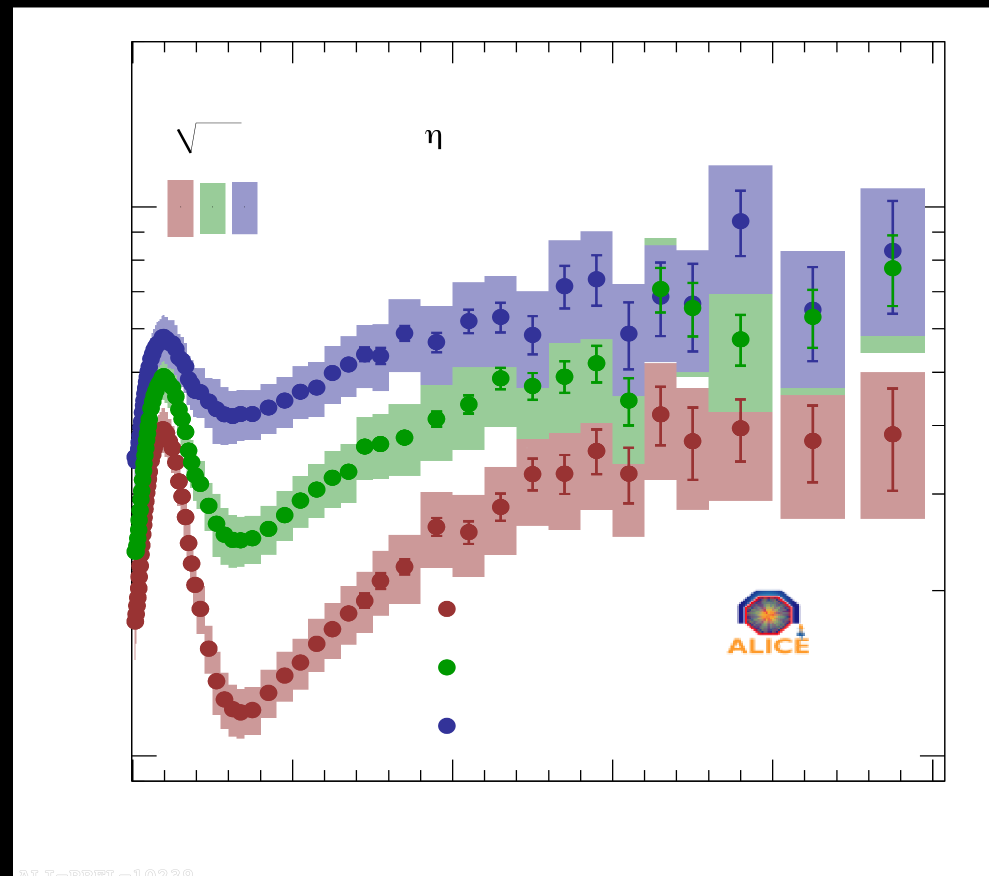


Nuclear modification factor

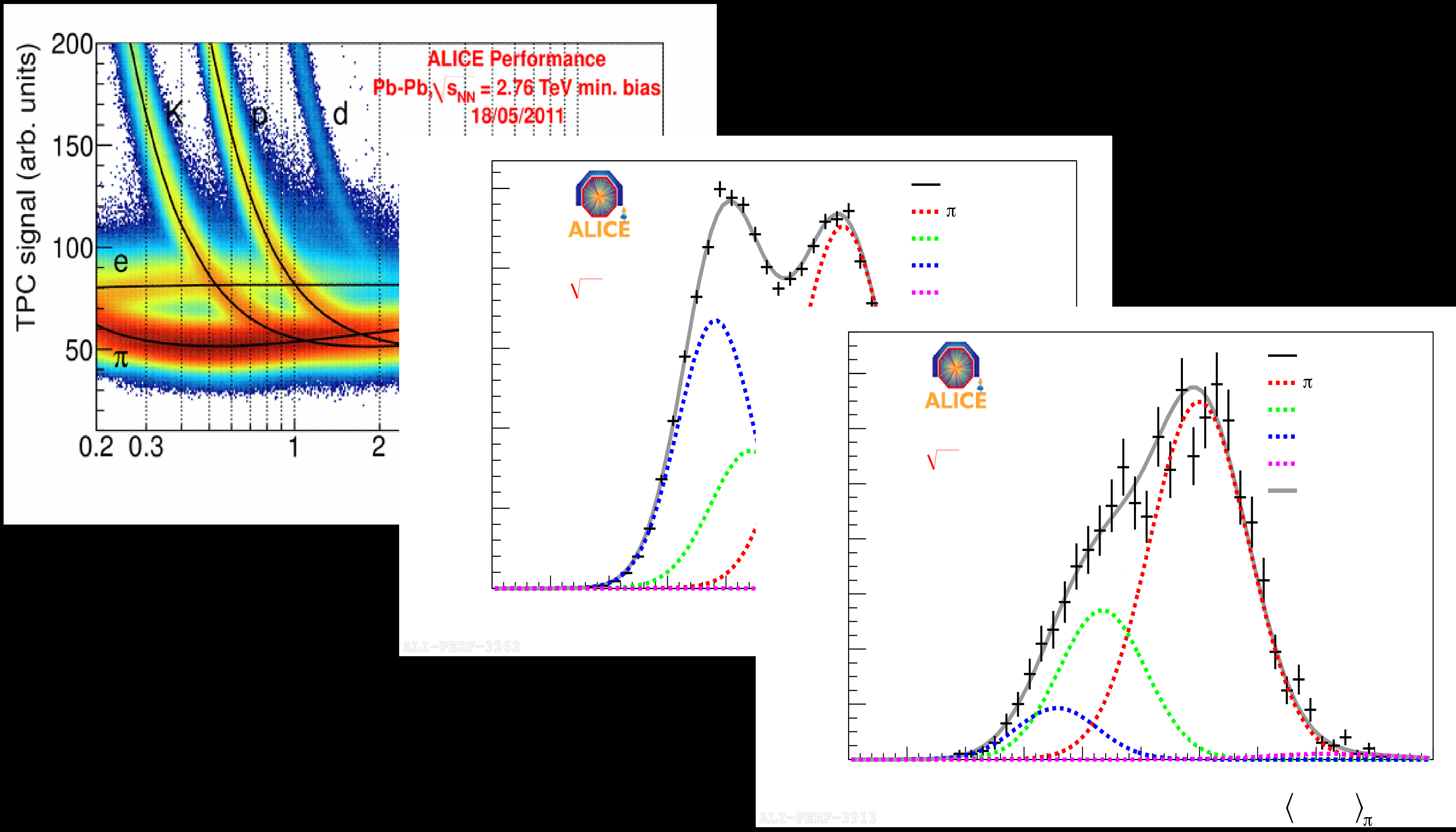
$$R_{AA}(p_t) = \frac{\left(1/N^{AA}_{events}\right) d^2N^{AA}/dp_t dh}{\langle N_{coll}\rangle \left(1/N^{pp}_{events}\right) d^2N^{pp}/dp_t dh}$$

- At low p_t: $R_{AA} < 1$ and rising due to thermal production
- At high p_t: $R_{AA} = 1$ in case there are no modifications from the medium

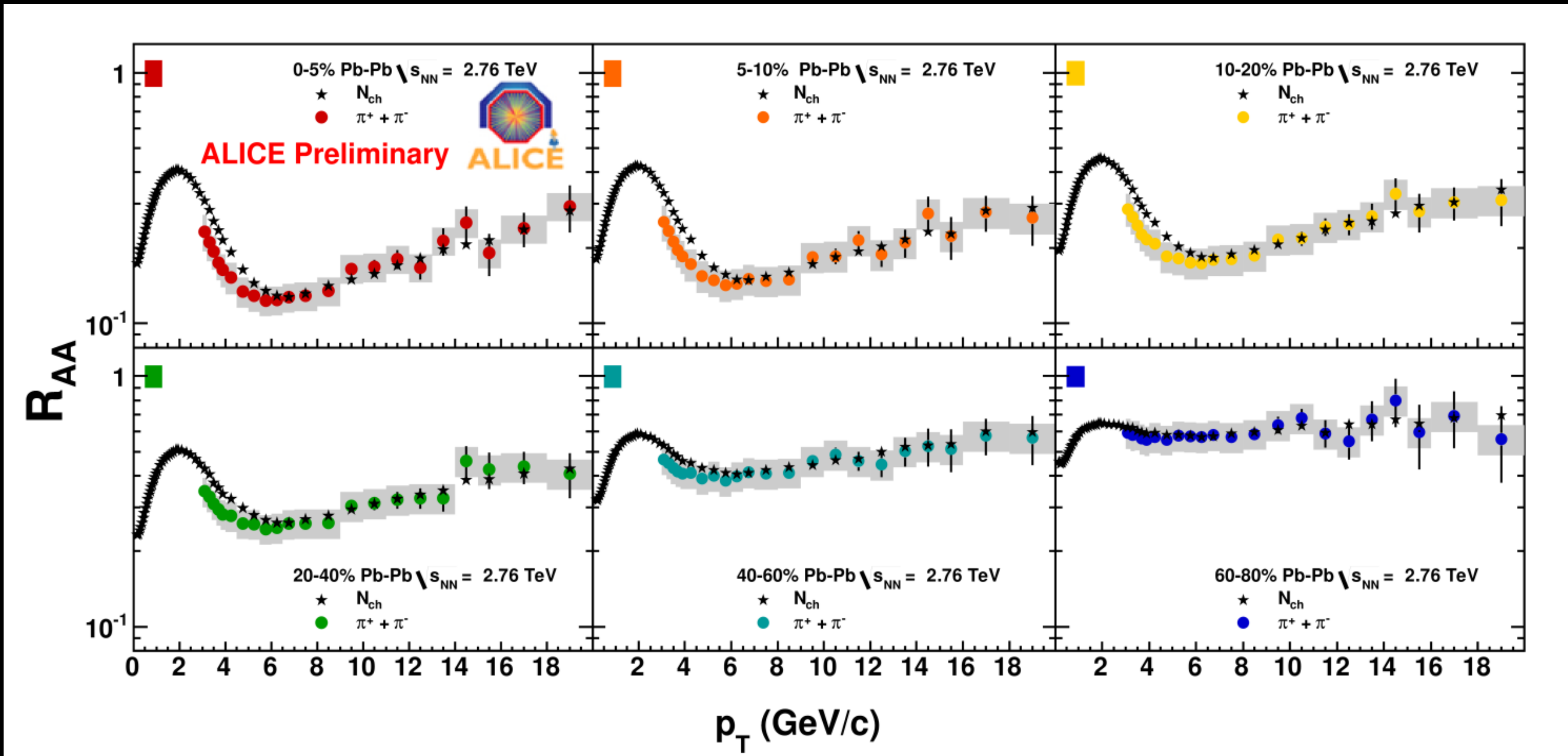
- Clear deviation of R_{AA} from unity, even for peripheral events
- Larger suppression for central collisions
- Consistent with the picture of radiative energy loss due to increasing path length of partons in the medium



- Select pions/protons using the dE/dx in the relativistic rise

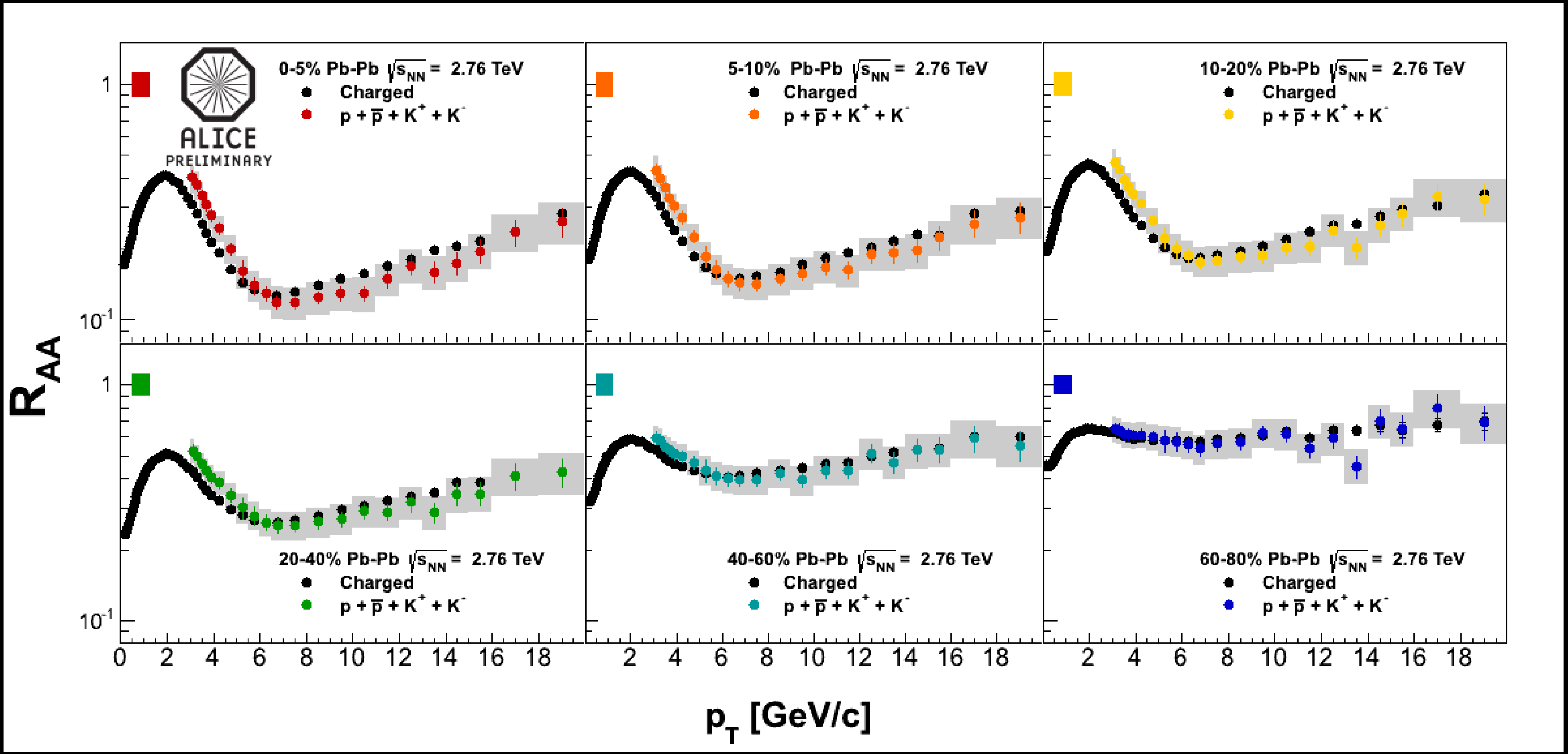


Nuclear modification factor (π): results



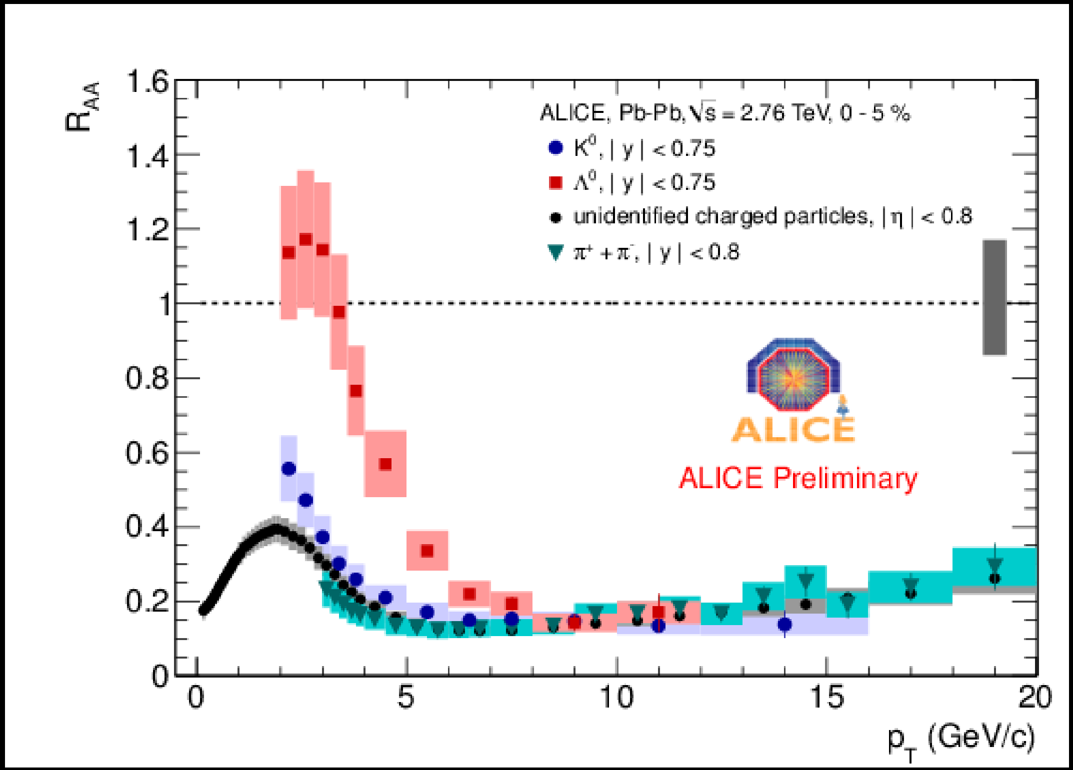
- Smaller R_{AA} than the non-identified particles for p_t < 6GeV/c
- Compatible with the R_{AA} of non-identified particles for p_t > 6GeV/c

Nuclear modification factor (K+p): results



- Larger R_{AA} than the non-identified particles for p_t < 6GeV/c
- Compatible with the R_{AA} of non-identified particles for p_t > 6GeV/c

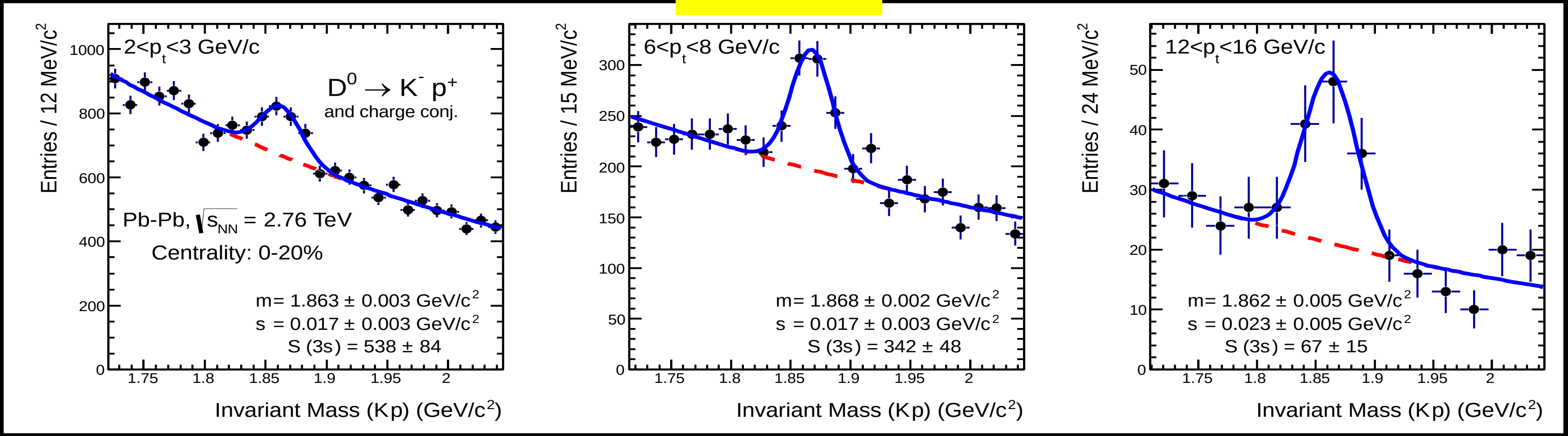
Nuclear modification factor: Summary



- Larger R_{AA} than the non-identified particles for p_t < 6GeV/c for K^0_s and Λ
  - Manifestation of radial flow?
- R_{AA} for K^0_s and Λ compatible with the one for non-identified particles for p_t > 6GeV/c

- Theory predicts a hierarchy in the energy loss for gluons, light and heavy quarks
  - $\Delta E_g > \Delta E(u,d,s) > \Delta E(c,b)$ ➔ $R_{AA}(\pi) < R_{AA}(D) < R_{AA}(B)$ (dead cone effect)
- At the LHC, we can profit from the higher production cross-section for c and b quarks to test this prediction

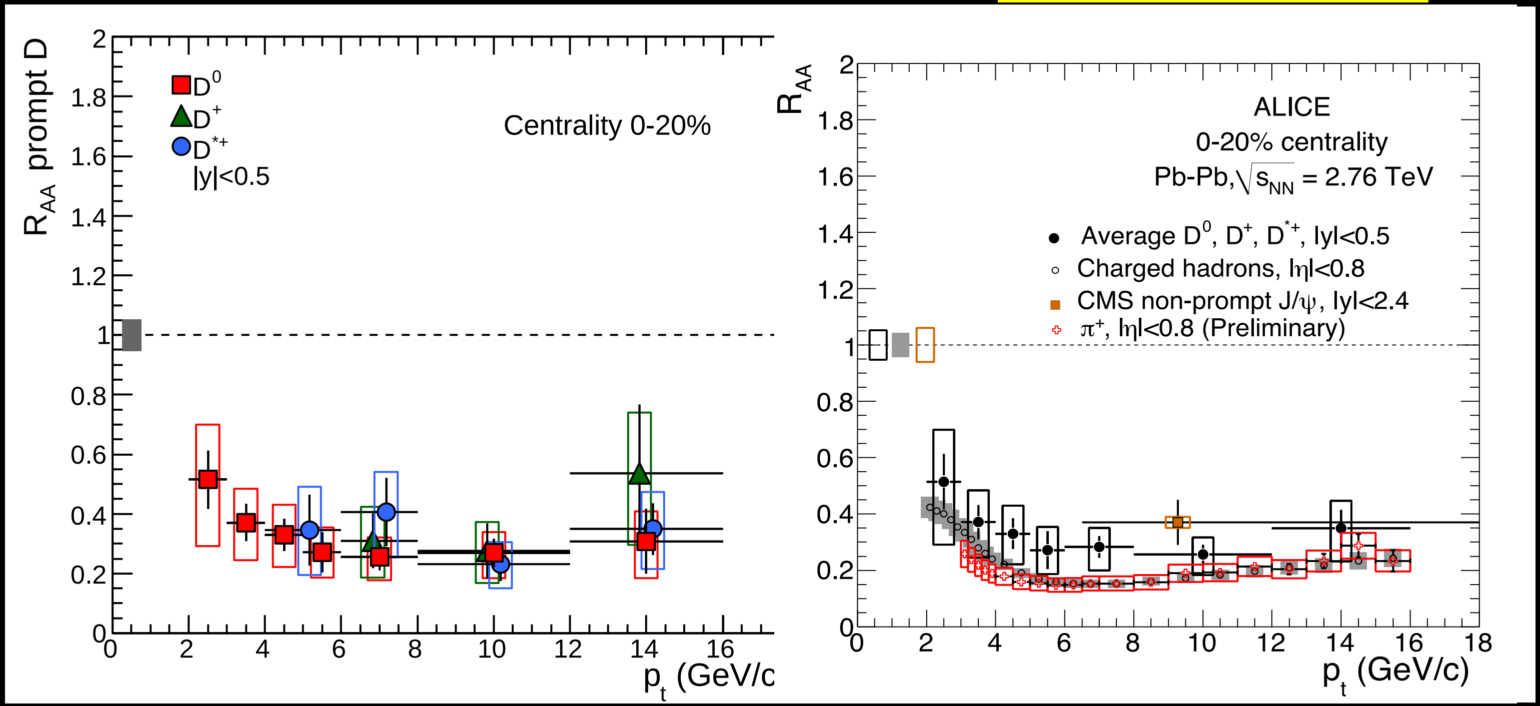
$D^0 \to K\pi$



Open heavy-flavor measurements: Sarah Louise Lapointe, Thursday@19:00, Parallel IV

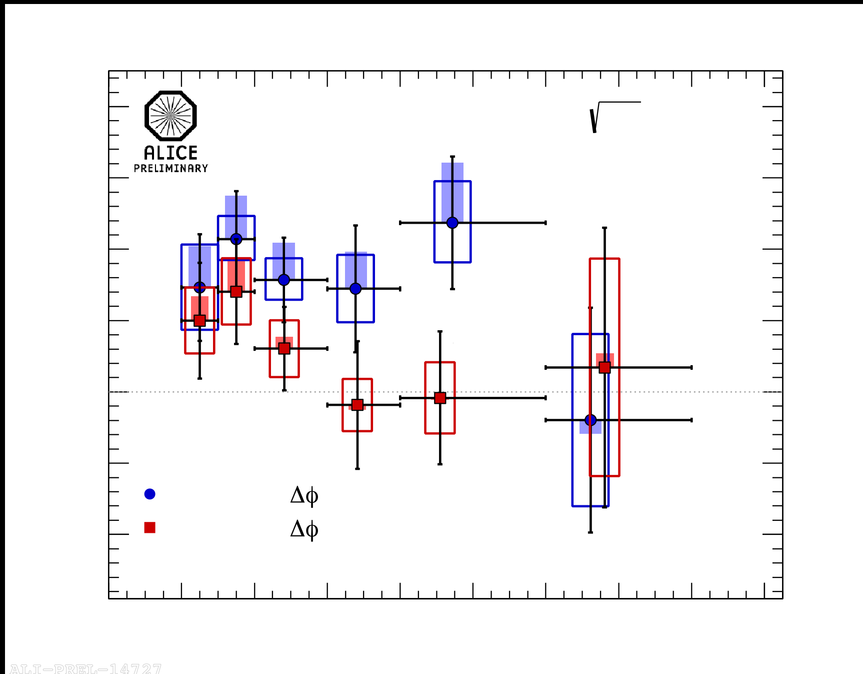
Nuclear modification factor: D-mesons

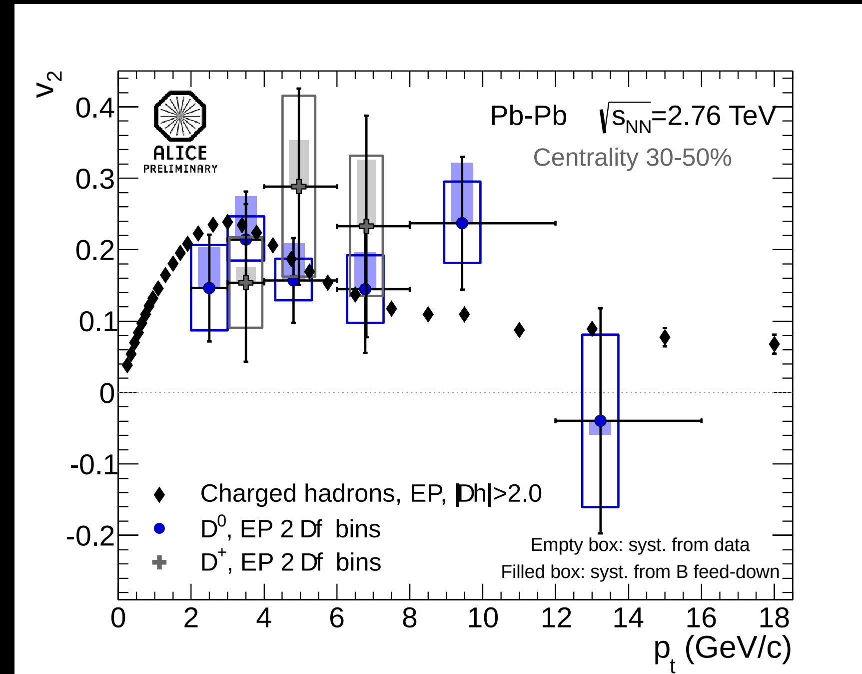
arXiv:1203.2160 [nucl-ex]



- D^0, D^+, D^* R_{AA} compatible within statistical uncertainties
- For 0-20% a suppression of ~3-4 for p_t > 5GeV/c
- For 40-80% a suppression of ~1-3 for p_t > 5GeV/c
- Similar R_{AA} with non-identified charges but systematically higher

Heavy flavor elliptic flow





- Elliptic flow measured with the event plane method at two centralities
- First indication of a non-vanishing v_2 for D^0
- Elliptic flow values compatible with the charged hadrons within the large uncertainties.

ALICE topics @ ICFP not covered in this talk

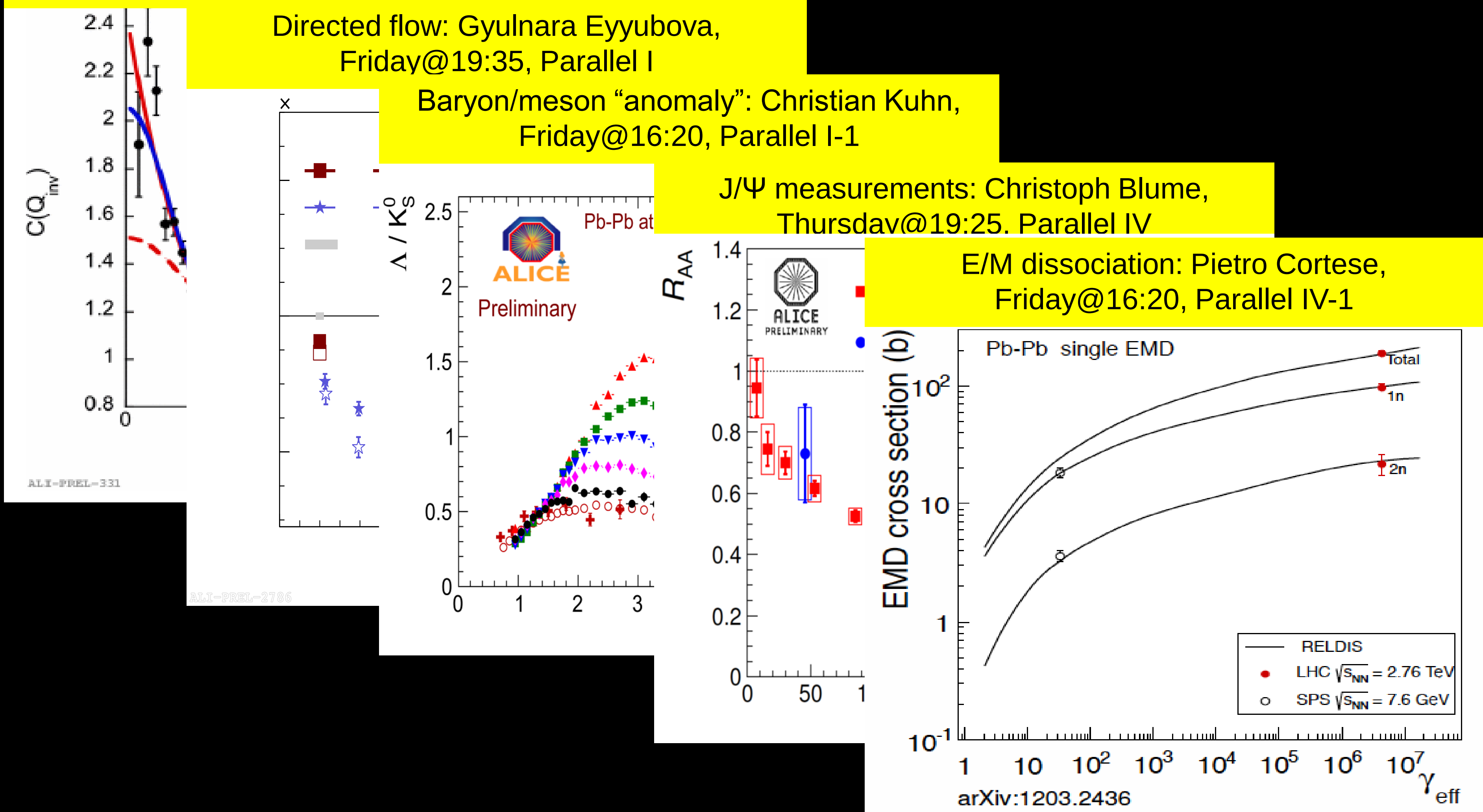
Femtoscopic results: Dhevan Gangadharan, Friday@18:45, Parallel I

Directed flow: Gyulnara Eyyubova, Friday@19:35, Parallel I

Baryon/meson “anomaly”: Christian Kuhn, Friday@16:20, Parallel I-1

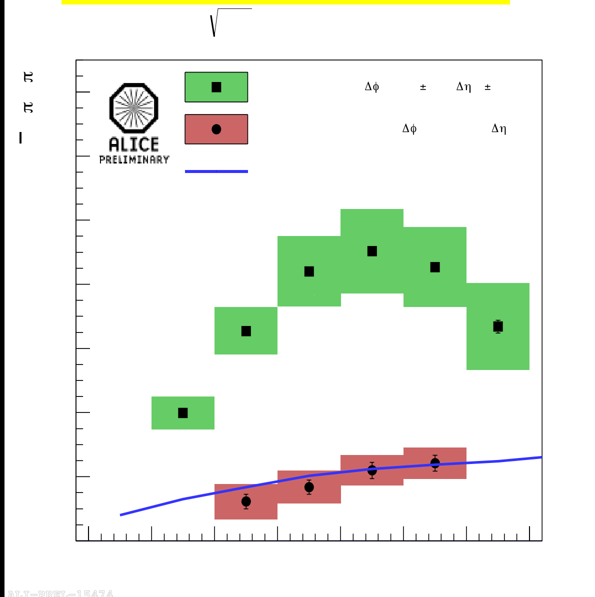
J/Ψ measurements: Christoph Blume, Thursday@19:25, Parallel IV

E/M dissociation: Pietro Cortese, Friday@16:20, Parallel IV-1

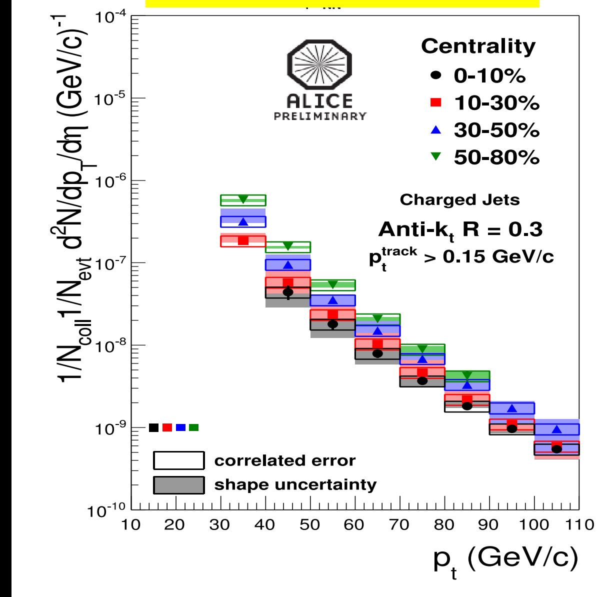


Instead of a summary…

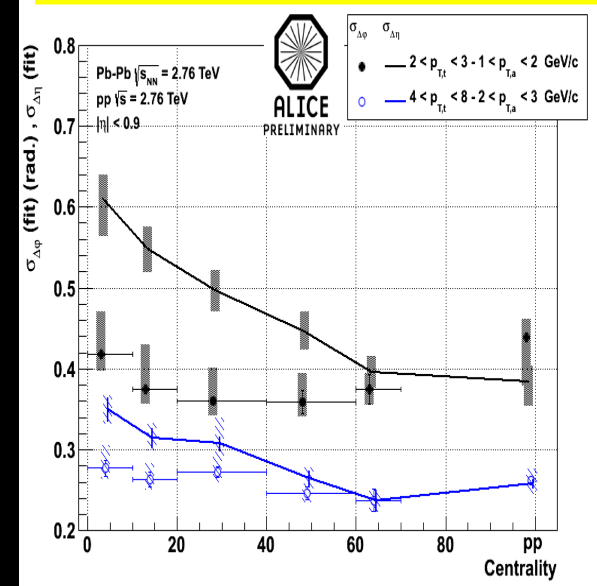
p/π in the jet vs bulk



Charged particle jet



charged hadron correlations



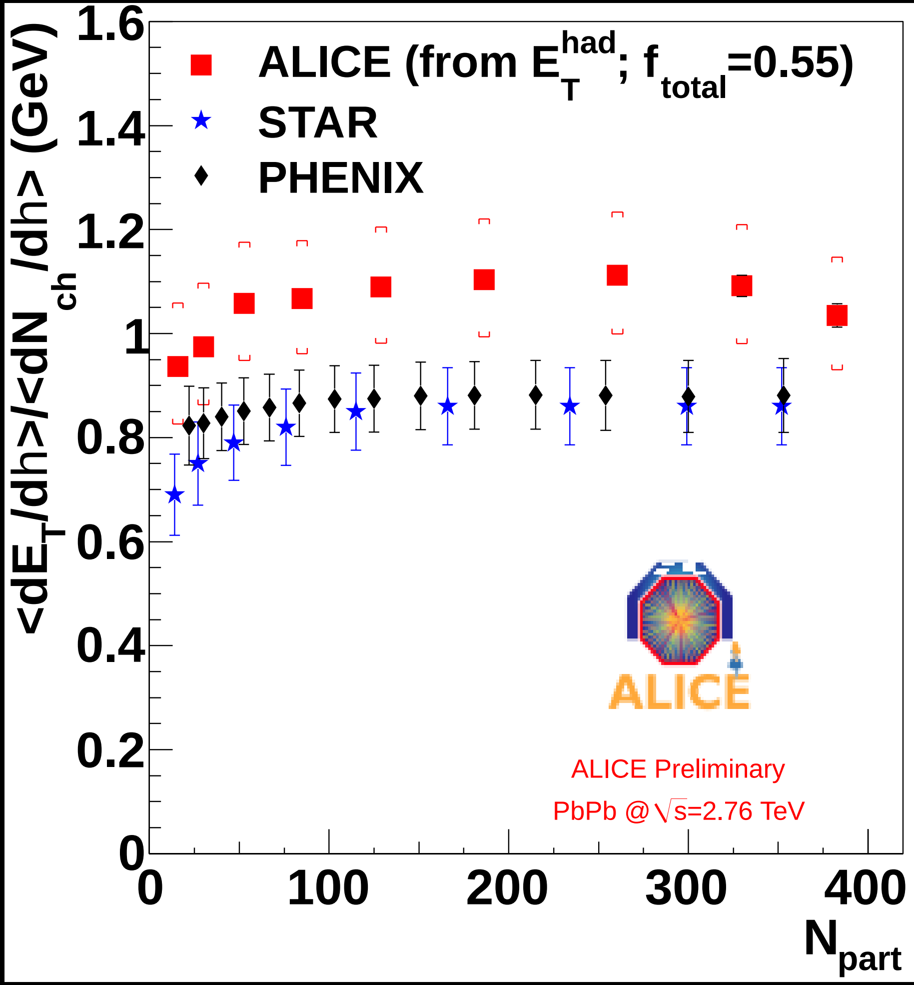
And many more…

- ❑ Chiral magnetic effect studies
- ❑ Charged hadron correlations with the balance functions
- ❑ Fluctuations: electric charge, transverse momentum, multiplicity

p-Pb running in 2012

BACKUP

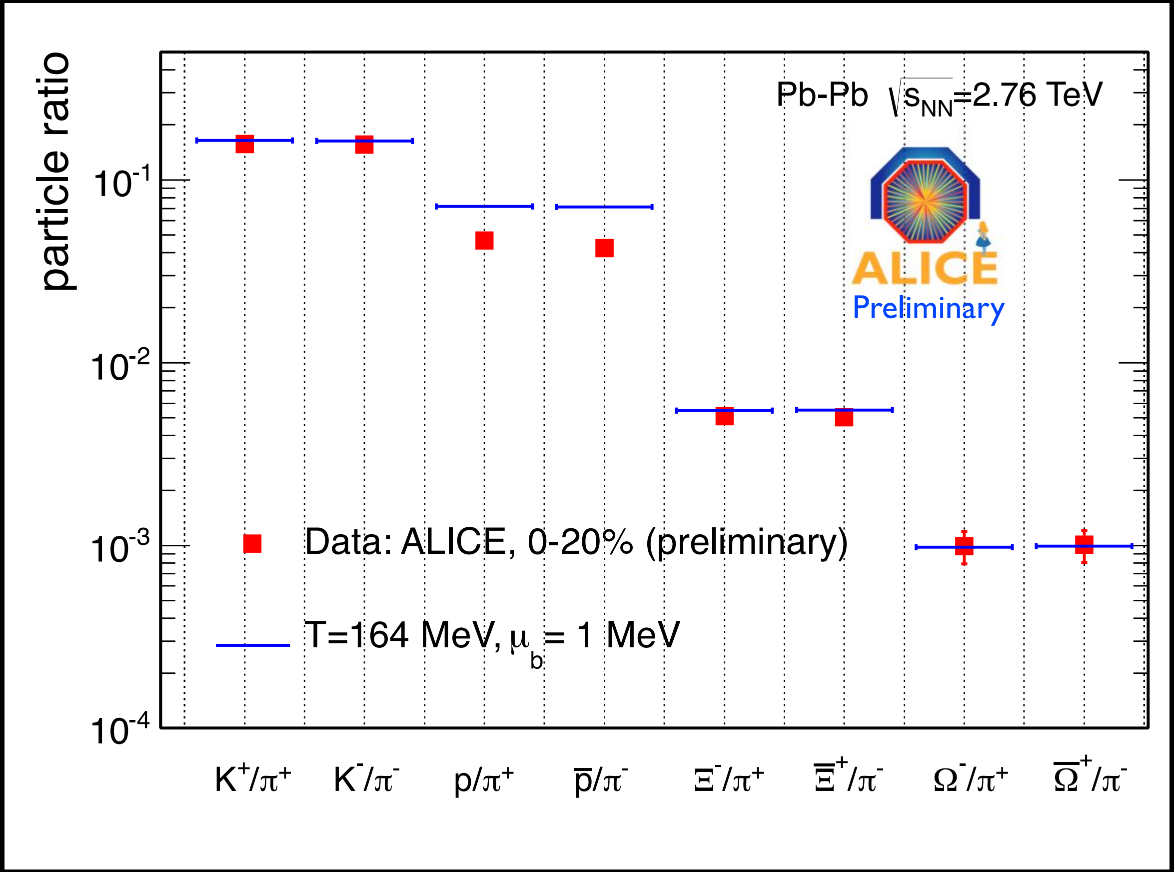
Transverse energy



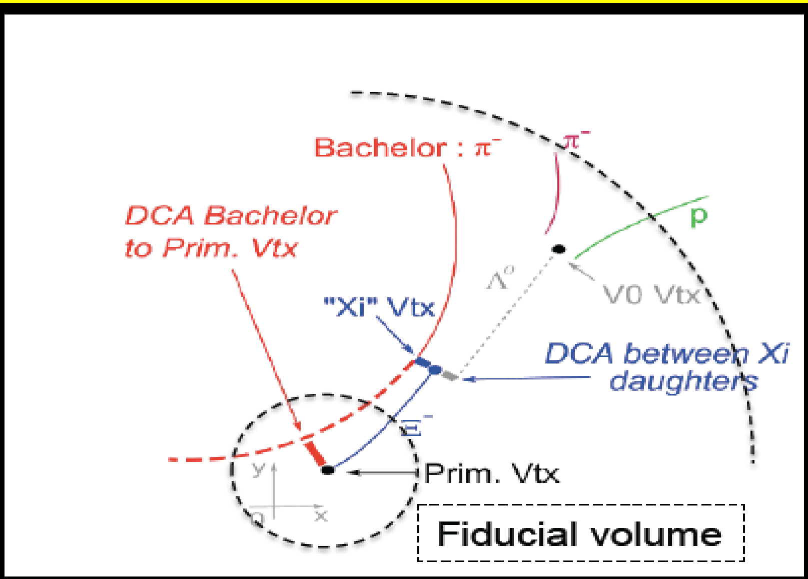
$$\varepsilon(\tau) = \frac{E}{V} \approx \frac{1}{\tau_0 A}\frac{dN}{dy} < m_t > \approx \frac{1}{\tau_0 A}\frac{dE_T}{dy} \approx k_B T^4$$

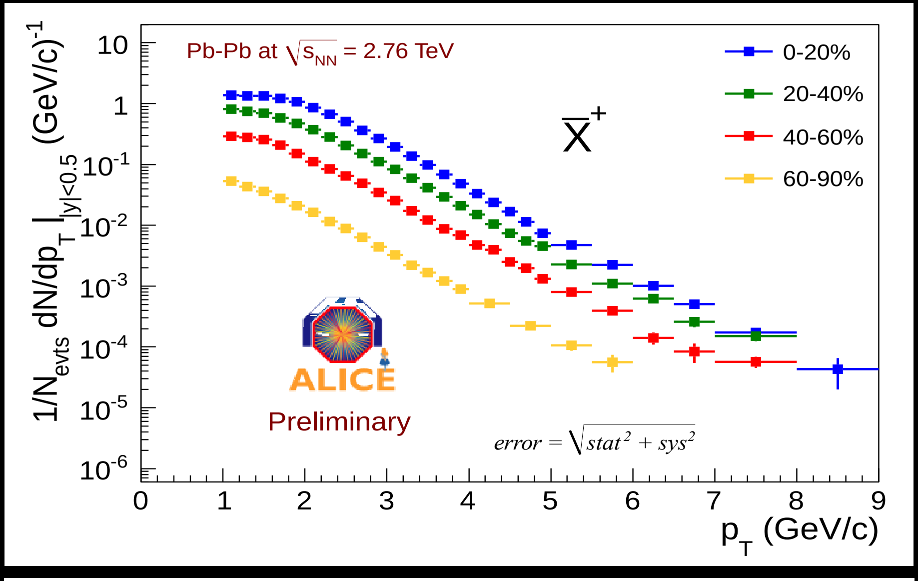
Thermal model

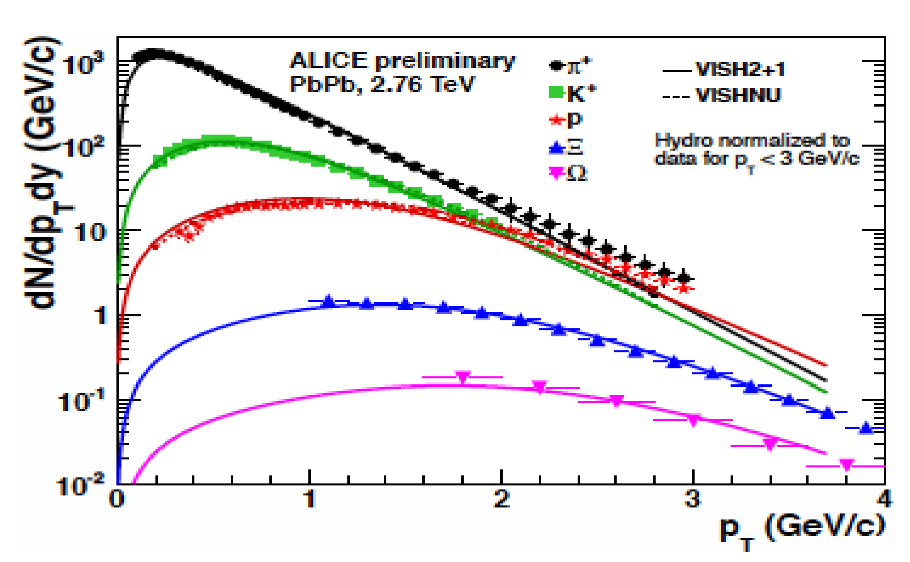
- sdd



Identified particle spectra (cont.)

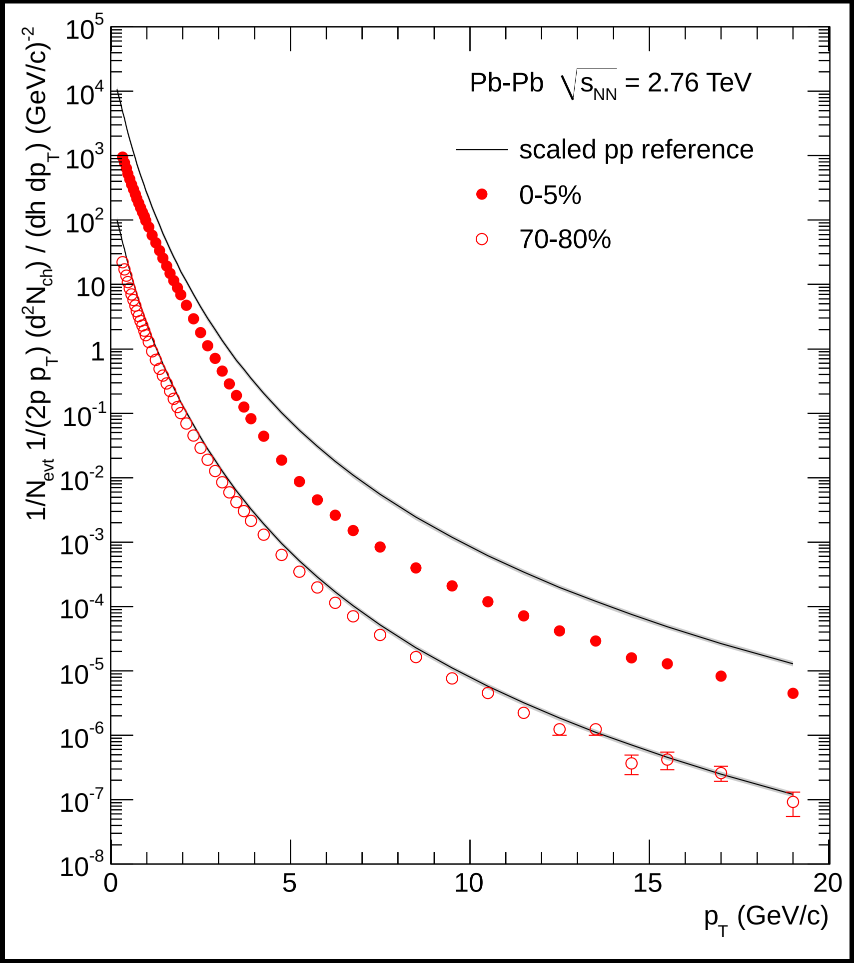


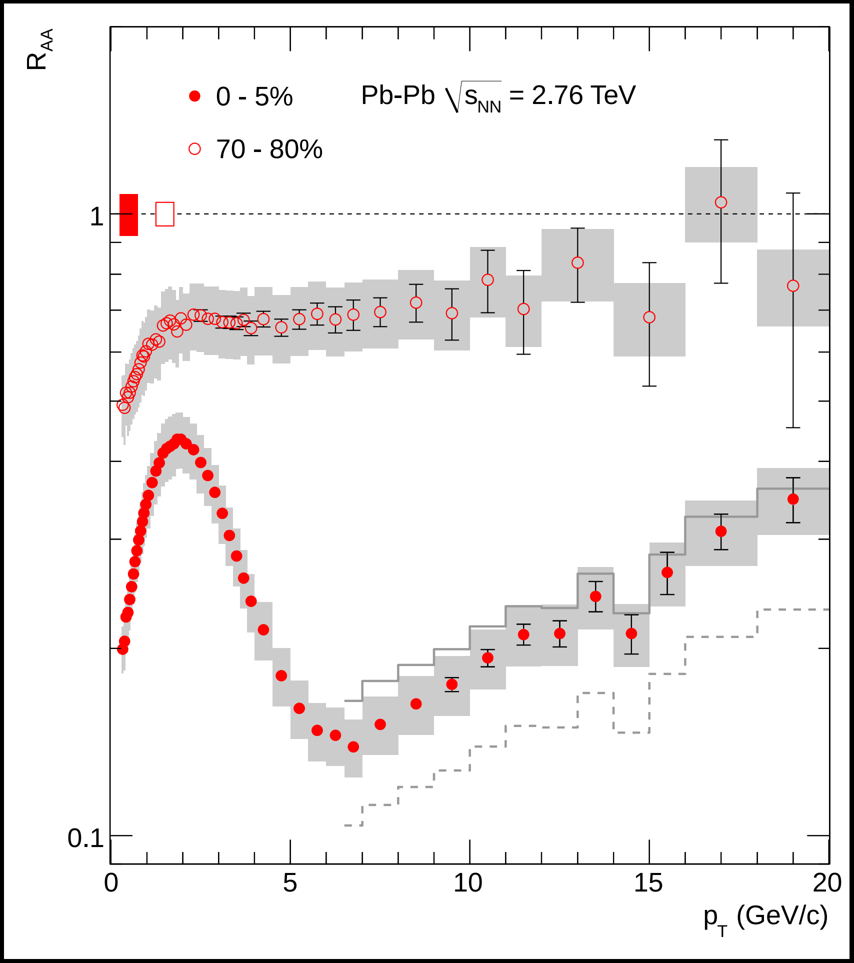




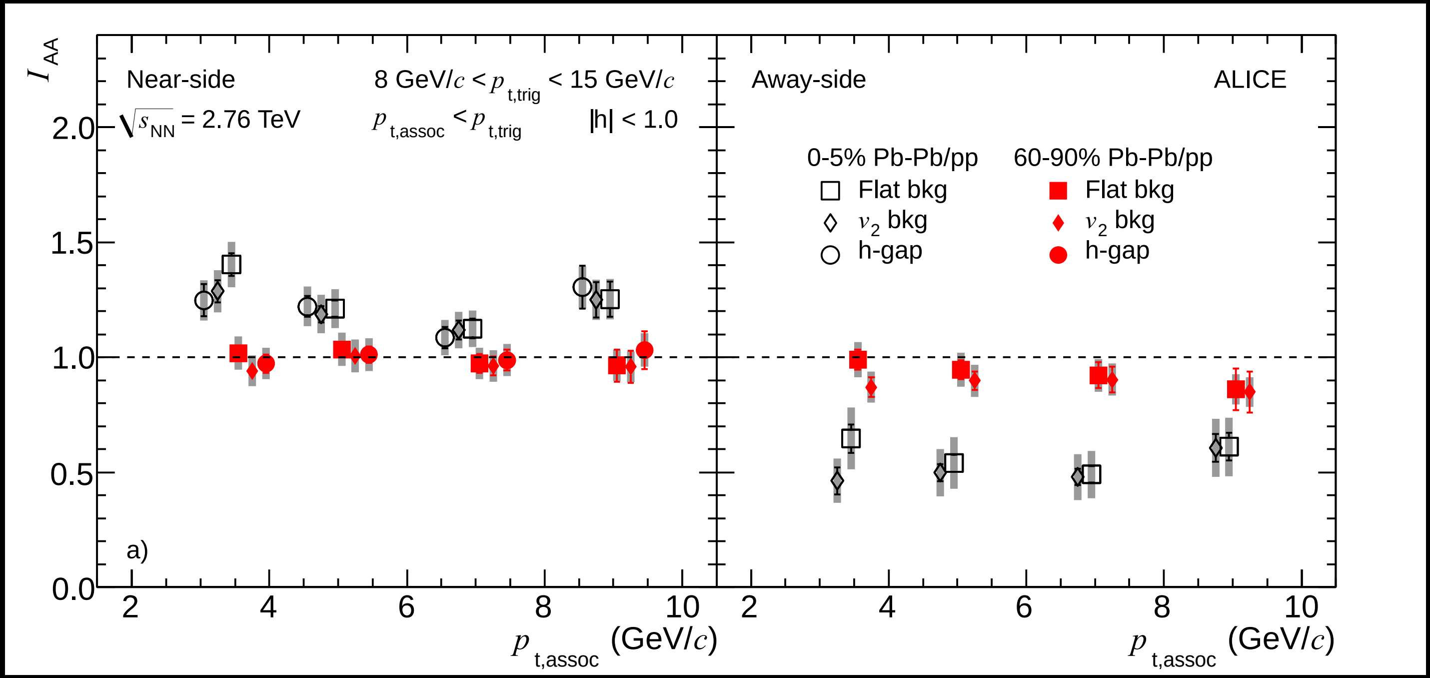
- Spectra compared to hydro calculations
  - VISH2+1: pure hydro
  - VISHNU: hydro coupled to the hadronic afterburner
- Reasonable description from pure hydro

Nuclear modification factor



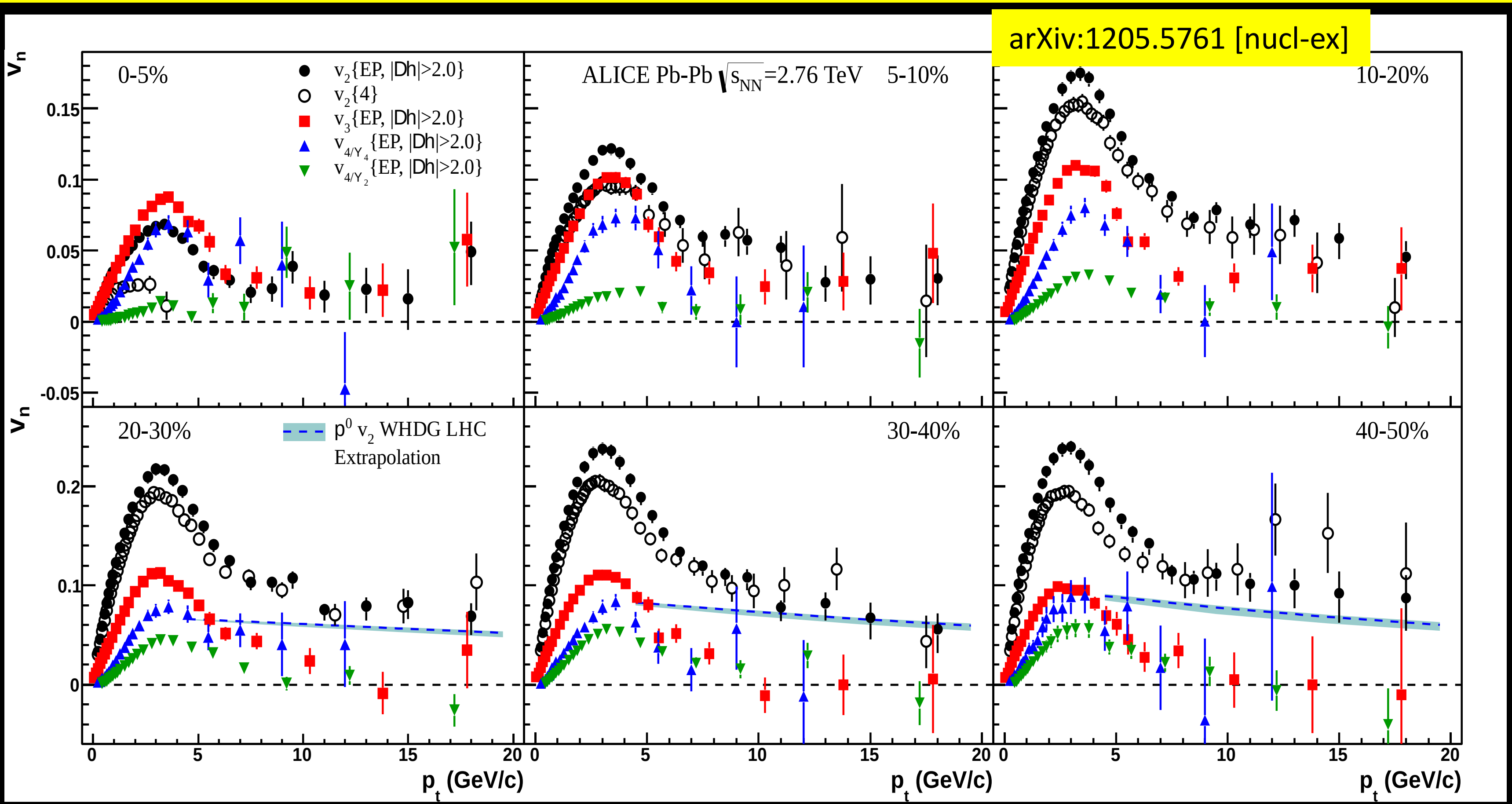


I_{AA}



I_{AA}
Near-side
8 GeV/c < $p_{t,trig}$ < 15 GeV/c
$\sqrt{s_{NN}}$ = 2.76 TeV
$p_{t,assoc}$ < $p_{t,trig}$
|η| < 1.0
Away-side
ALICE
0-5% Pb-Pb/pp
60-90% Pb-Pb/pp
Flat bkg
v_2 bkg
η-gap
Flat bkg
v_2 bkg
η-gap
a)
2.0
1.5
1.0
0.5
0.0
2
4
6
8
10
2
4
6
8
10
$p_{t,assoc}$ (GeV/c)
$p_{t,assoc}$ (GeV/c)

Elliptic flow at high pt



- Sensitive to path length dependence of jet quenching
- Finite v_2 and v_3 even for p_t > 8GeV/c
- Quadrangular flow (v_4) ~ 0 for p_t > 8GeV/c

- Mass dependence visible even at high pt