Production of charged pions, kaons and (anti-)protons at high p_T in $\sqrt{s_{NN}}$=2.76 TeV Pb-Pb collisions measured with ALICE

Antonio Ortiz Velasquez
on behalf of the ALICE Collaboration

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Seminario de Física de Altas Energías
ICN-UNAM IF-UNAM

Outline

- Motivation
- Particle identification in ALICE
- Measurement of the π/K/p spectra at high p_T
- Particle ratios
- R_{AA} for identified charged hadrons
- Conclusions

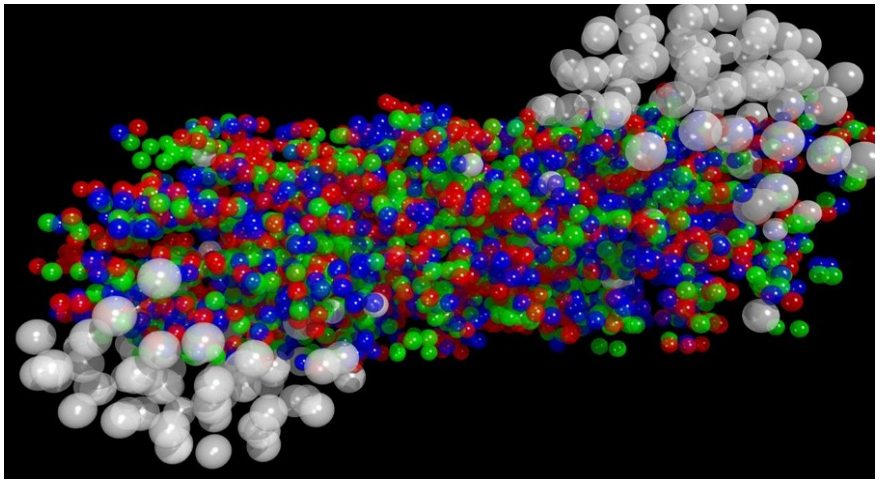
Probe the medium

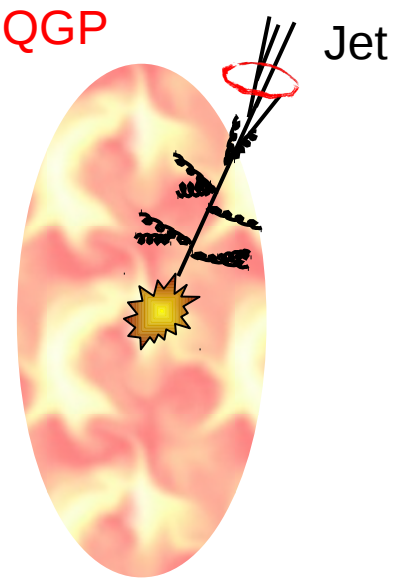
- **Goal:**

  Understand the properties of the medium created in heavy ion collisions (QGP).

- Production of particles at high p_T are important tools for studying the medium formed.

- The observed yield of high p_T particles is much smaller than the expected from binary scaling because of the strong final state interactions with the medium.

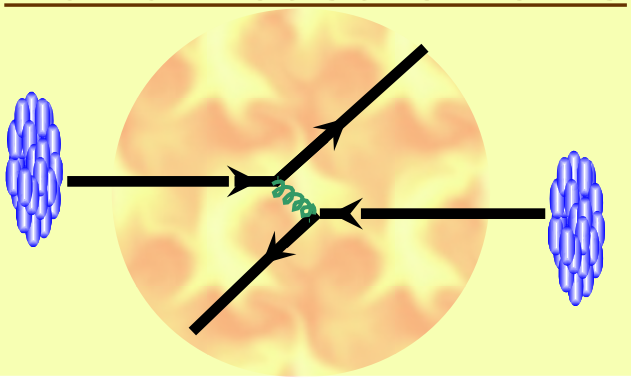




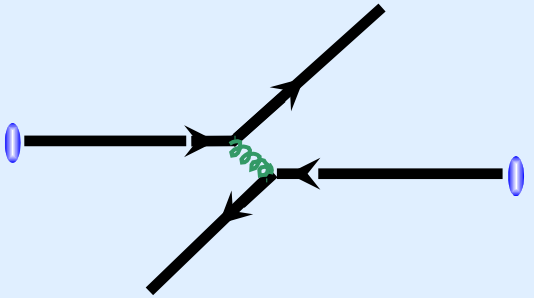
How do we extract the medium effects?

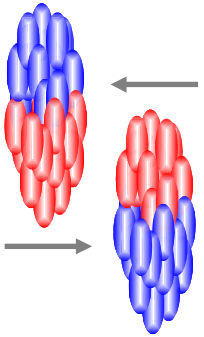
One typical way is to compare PbPb data to pp reference measurement

PbPb measurements



pp reference

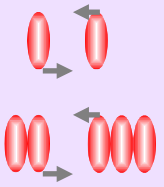




N_{part} → Number of participating nucleons

N_{coll} → Number of binary scatterings

Example:



$N_{part} = 2$ $N_{coll} = 1$

$N_{part} = 5$ $N_{coll} = 6$

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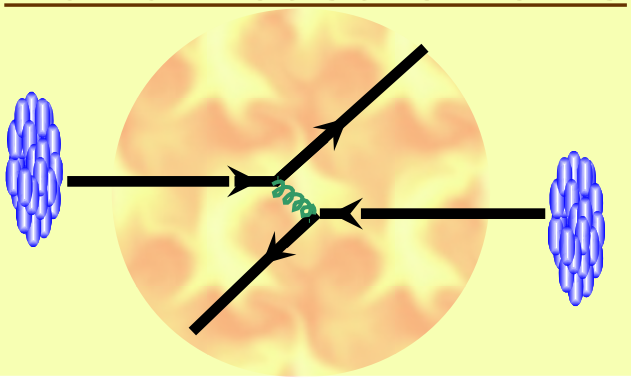
PbPb measurements



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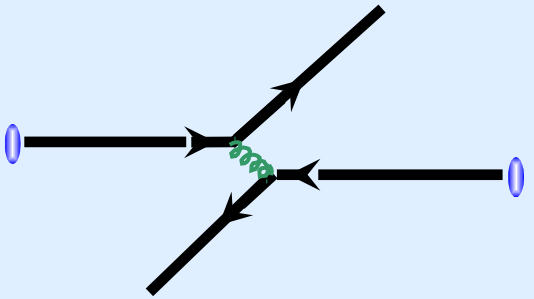


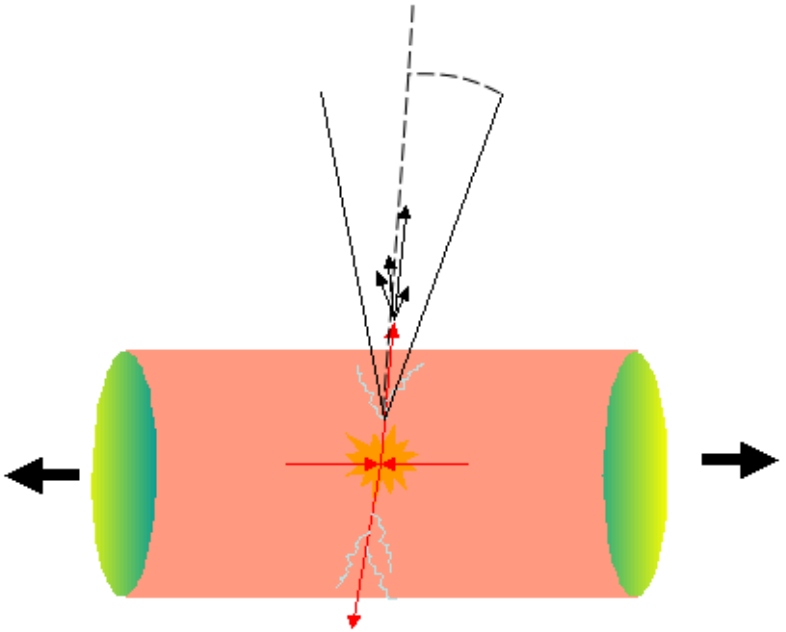
'Nuclear modification factors'

$$R_{AA} = \frac{1/N_{ev}^{AA}\; d^2N_{AA}/dp_T d\eta}{\langle N_{coll}\rangle 1/N_{ev}^{pp}\; d^2N_{pp}/dp_T d\eta} \sim \frac{\text{"QCD Medium"}}{\text{"QCD Vacuum"}}$$

- $R_{AA} > 1$ (enhancement)
- $R_{AA} = 1$ (no medium effect)
- $R_{AA} < 1$ (suppression)

N_{coll} → Averaged number of binary scattering

Does the medium affect the high p_T production and /or fragmentation?



Possible medium-induced modification of jet hadrochemistry:

- Propagation: flavor and baryon number exchange between medium and projectile.
- Energy loss: color transfer effects. Is there an interplay between energy loss and fragmentation?
- Fragmentation in medium?: recombination of partons from jet and medium.

e. g., significant differences in jet hadrochemistry are found if only medium modification of the parton shower is considered even in the absence of the medium-effects at or after hadronization.

(S. Sapeta and U. A. Wiedemann, *Eur. Phys. J.* C. 55,293-302 (2008)).

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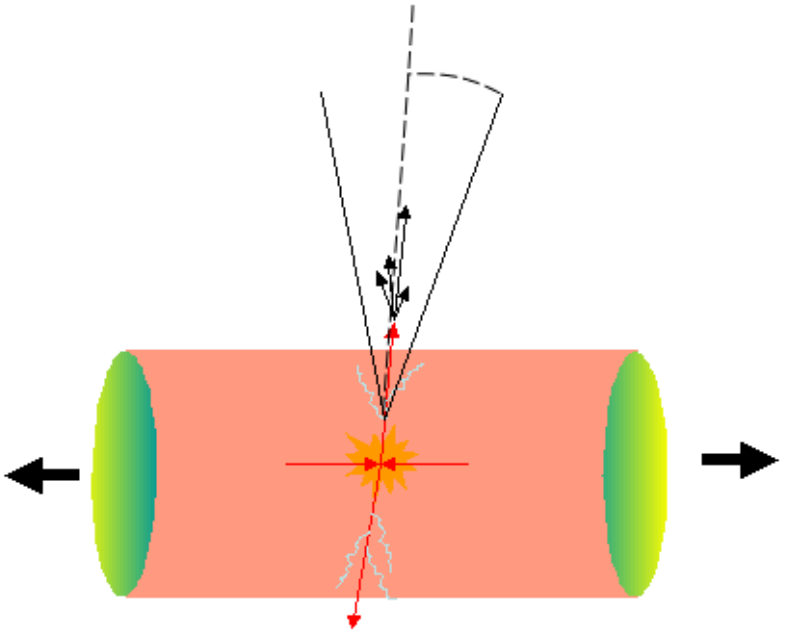

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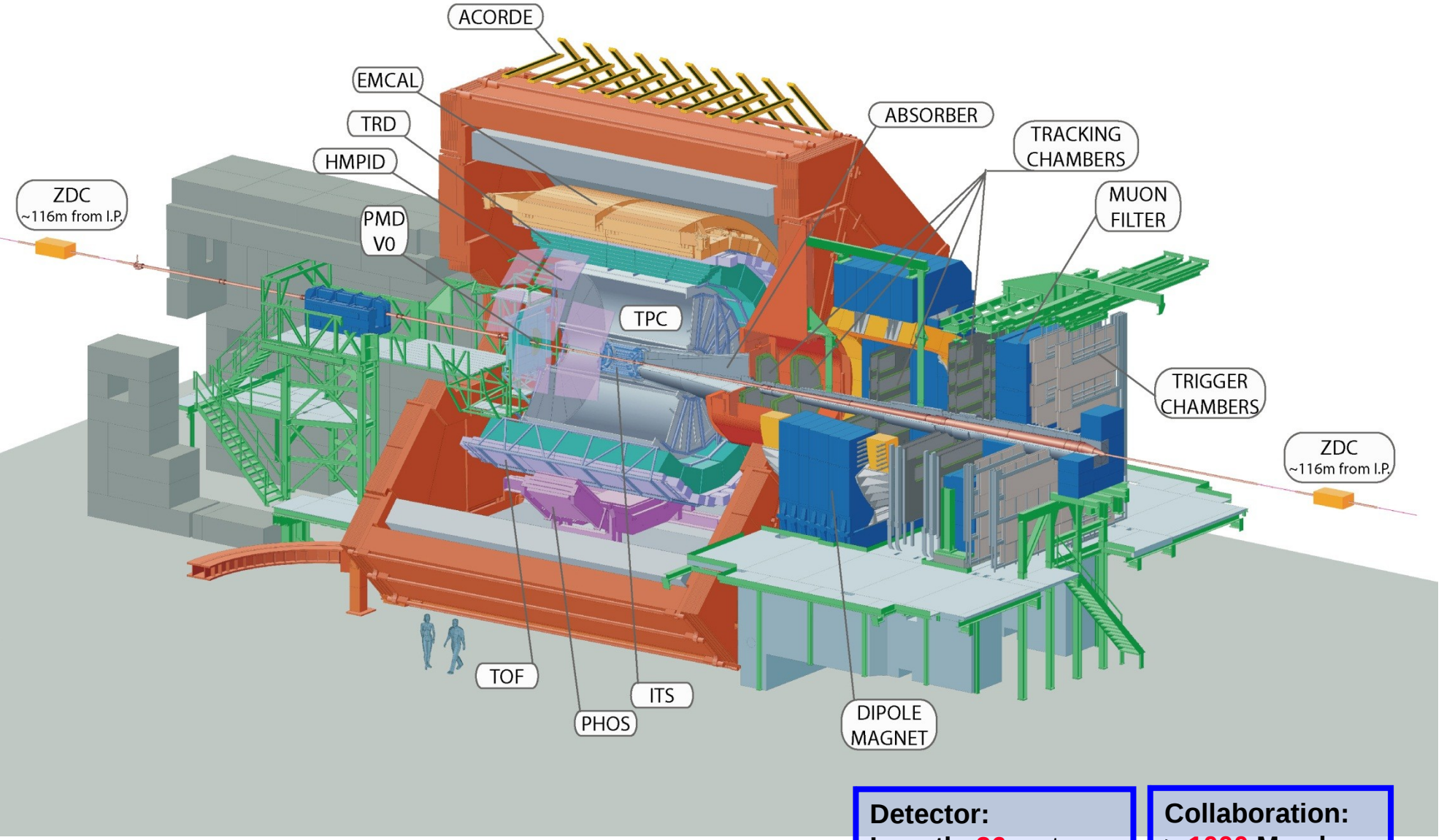
(S. Sapeta and U. A. Wiedemann, *Eur. Phys. J.* C. 55,293-302 (2008)).

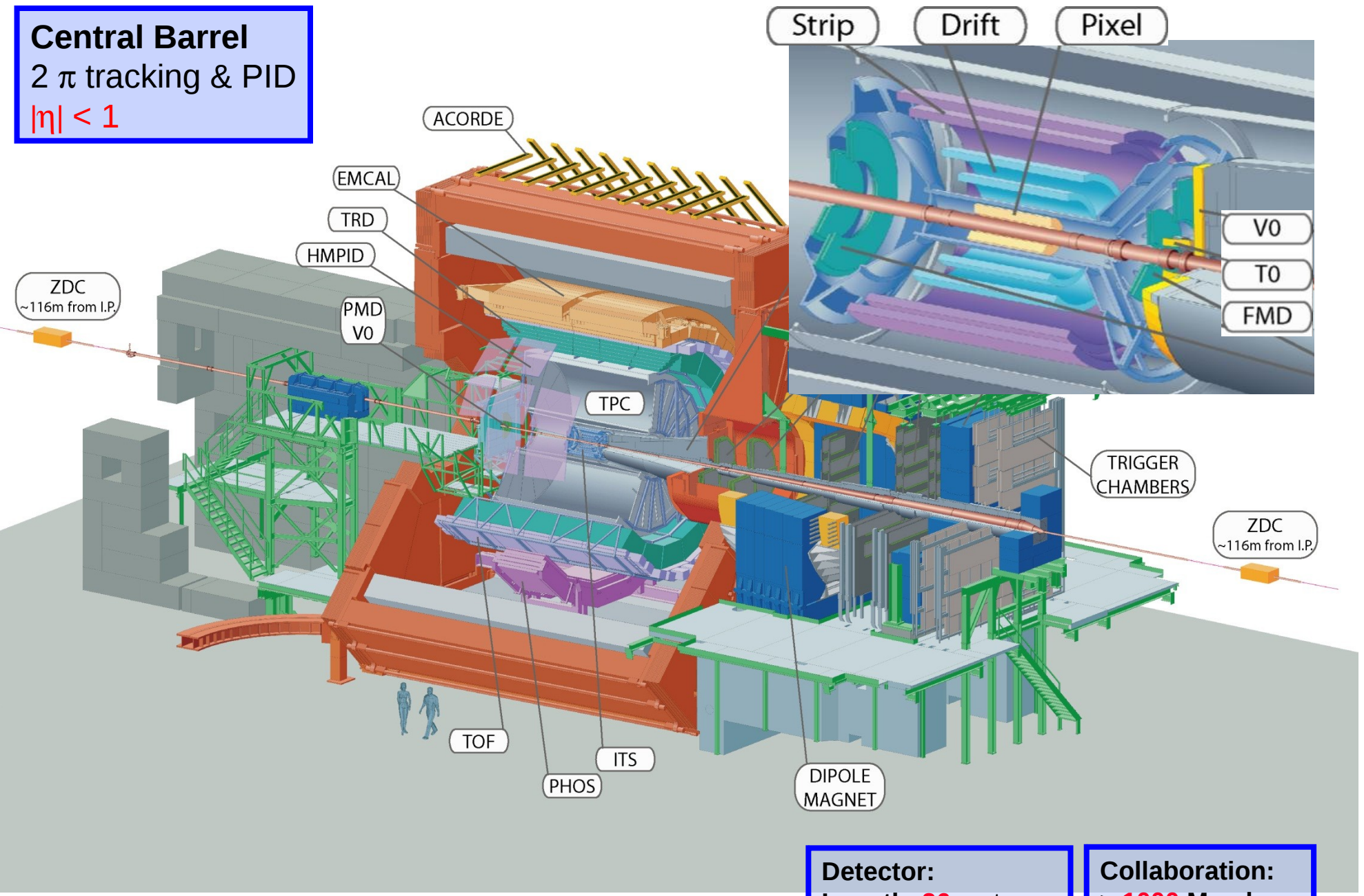
It produces a significant difference of the hadron ratios for medium modified and unmodified jets. It derives a prediction for high p_T (>7 GeV/c): $\mathbf{R_{AA}^{K} > R_{AA}^{\pi}}$ and $\mathbf{R_{AA}^{p} > R_{AA}^{\pi}}$.



Detector:
Length: **26** meters
Height: **16** meters
Weight: **10,000** tons

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

Central Barrel
2 π tracking & PID
$|\eta| < 1$



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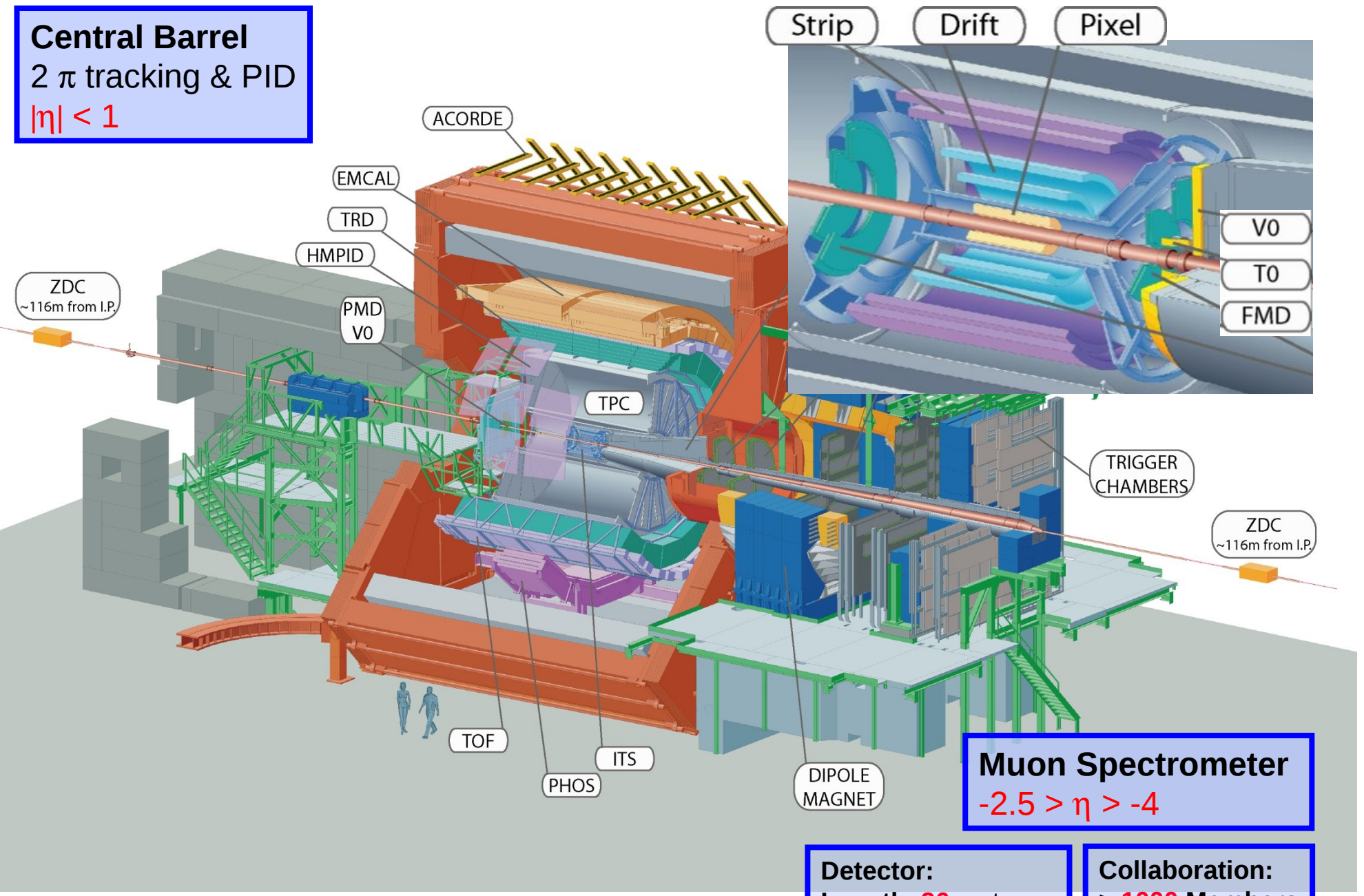

Muon Spectrometer
-2.5 > η > -4

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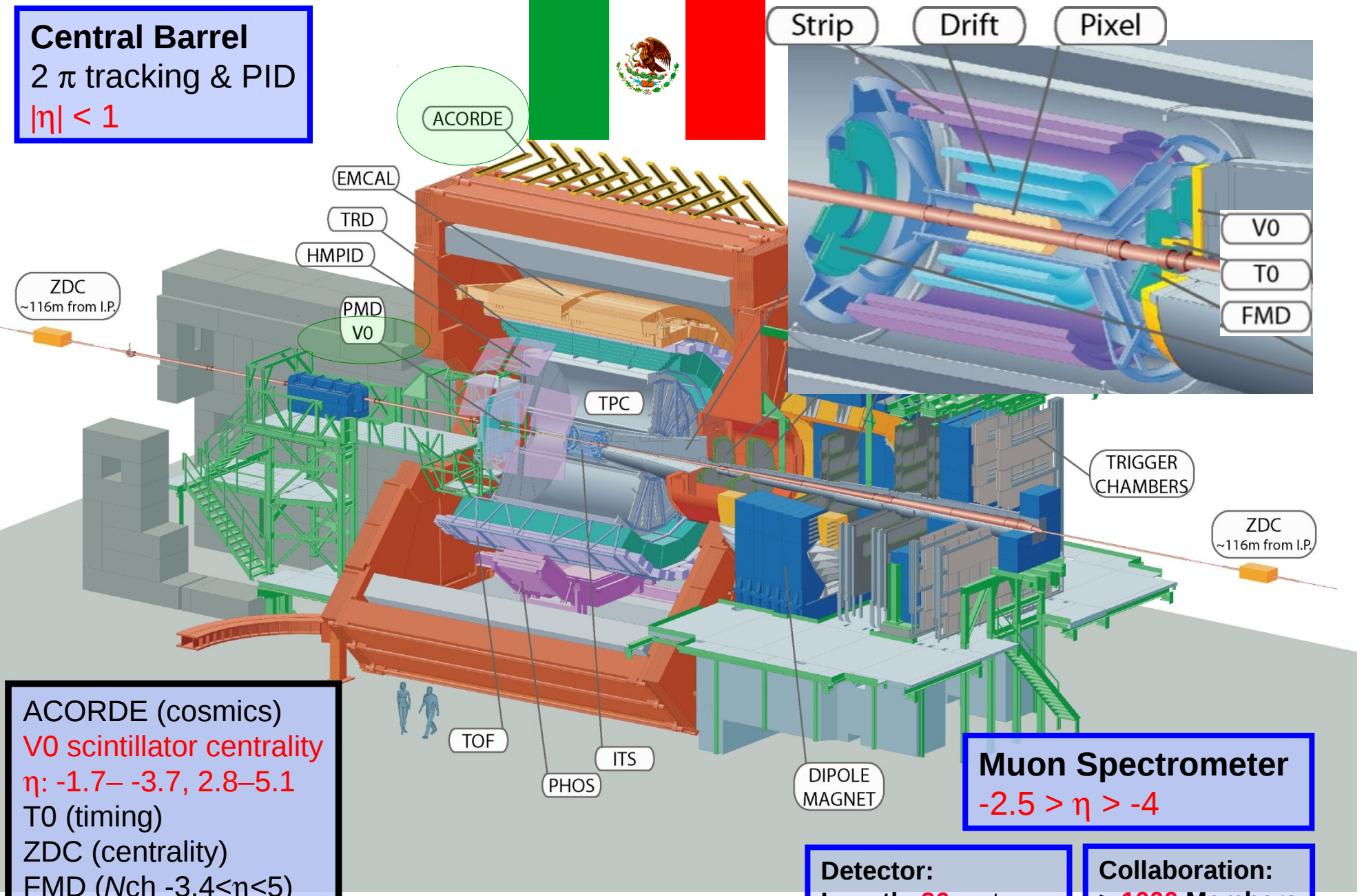

ACORDE (cosmics)
V0 scintillator centrality
η: -1.7– -3.7, 2.8–5.1
T0 (timing)
ZDC (centrality)
FMD (*N*ch -3.4<η<5)
PMD (*N*γ, *N*ch)

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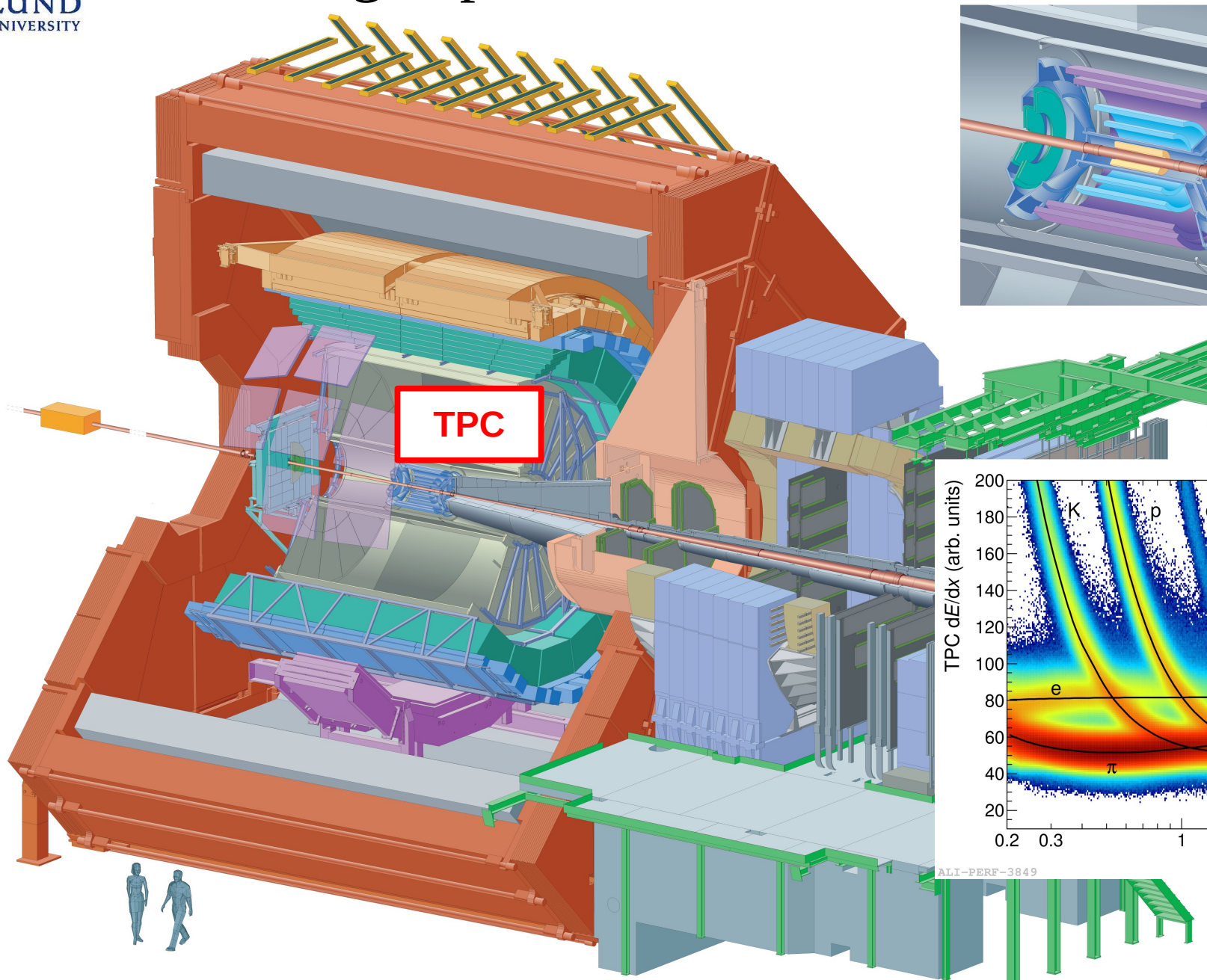
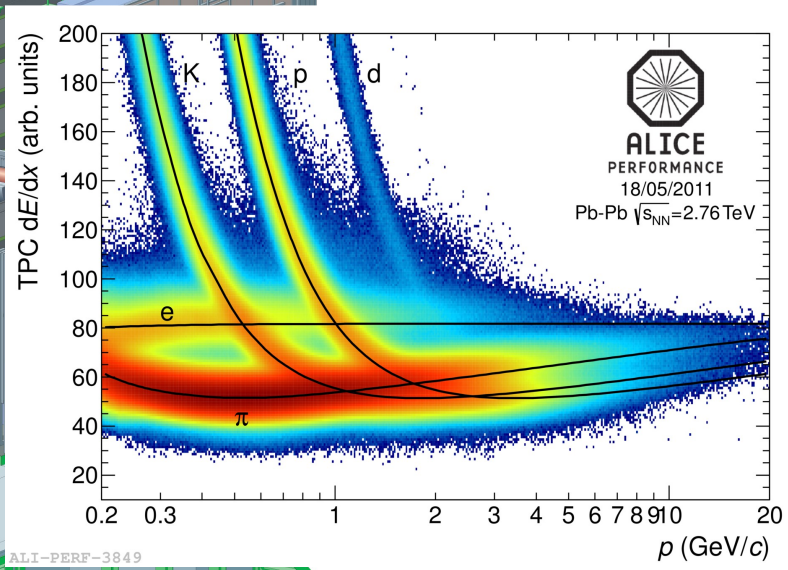
Charged particle identification in ALICE





Light charged hadrons ($\pi^{\pm}$, $K^{\pm}$, (anti-)p): ~150 MeV/c < p_T < 20 GeV/c

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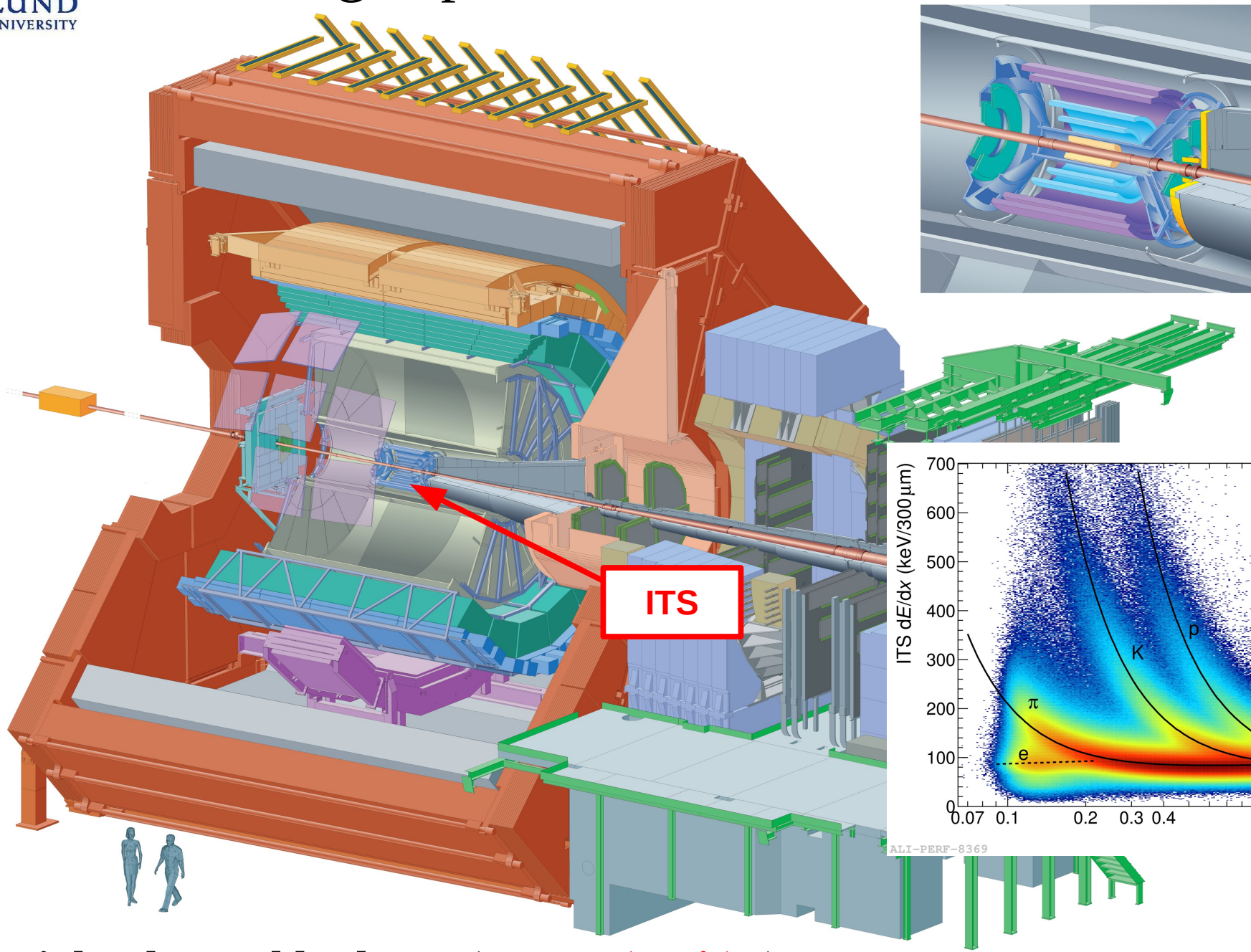

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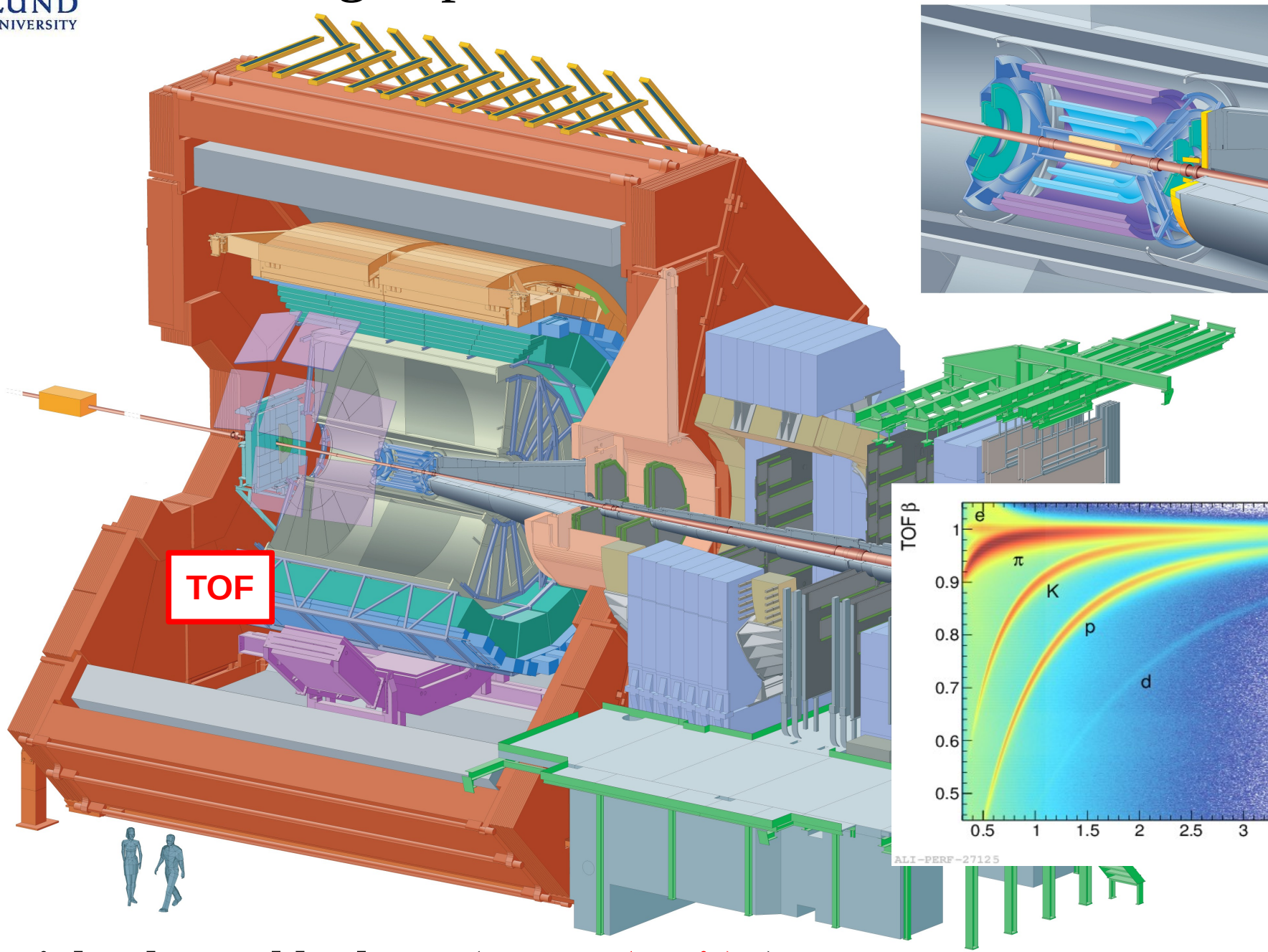

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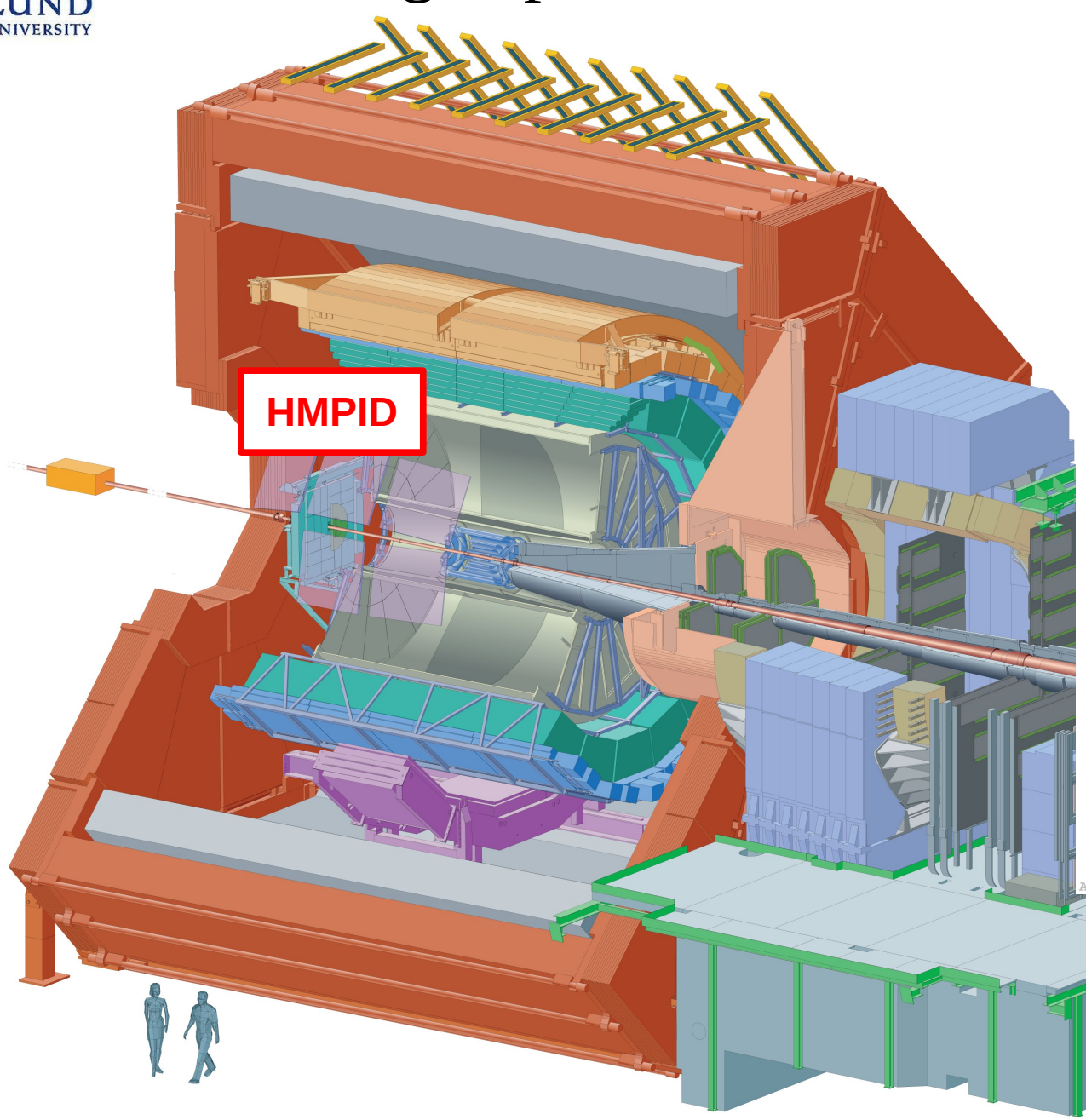
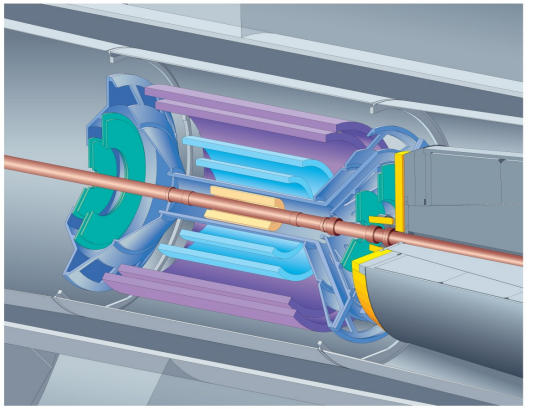
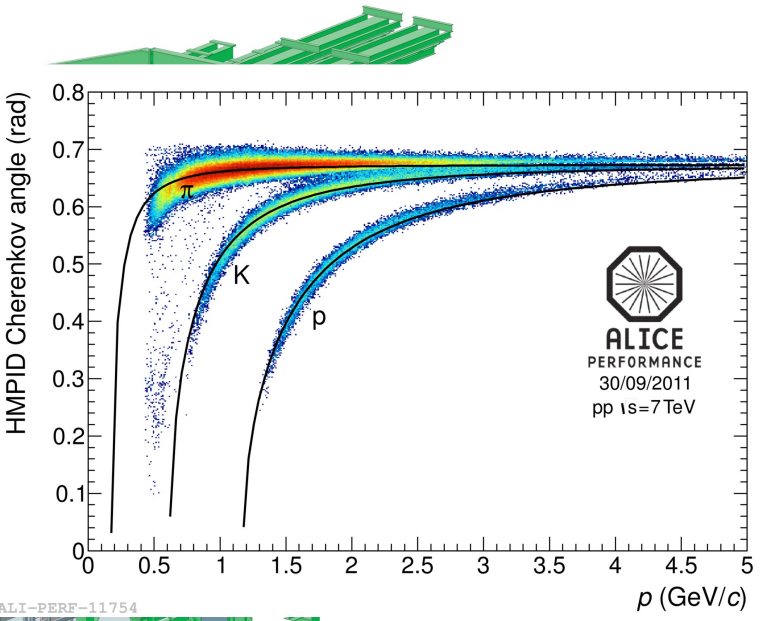


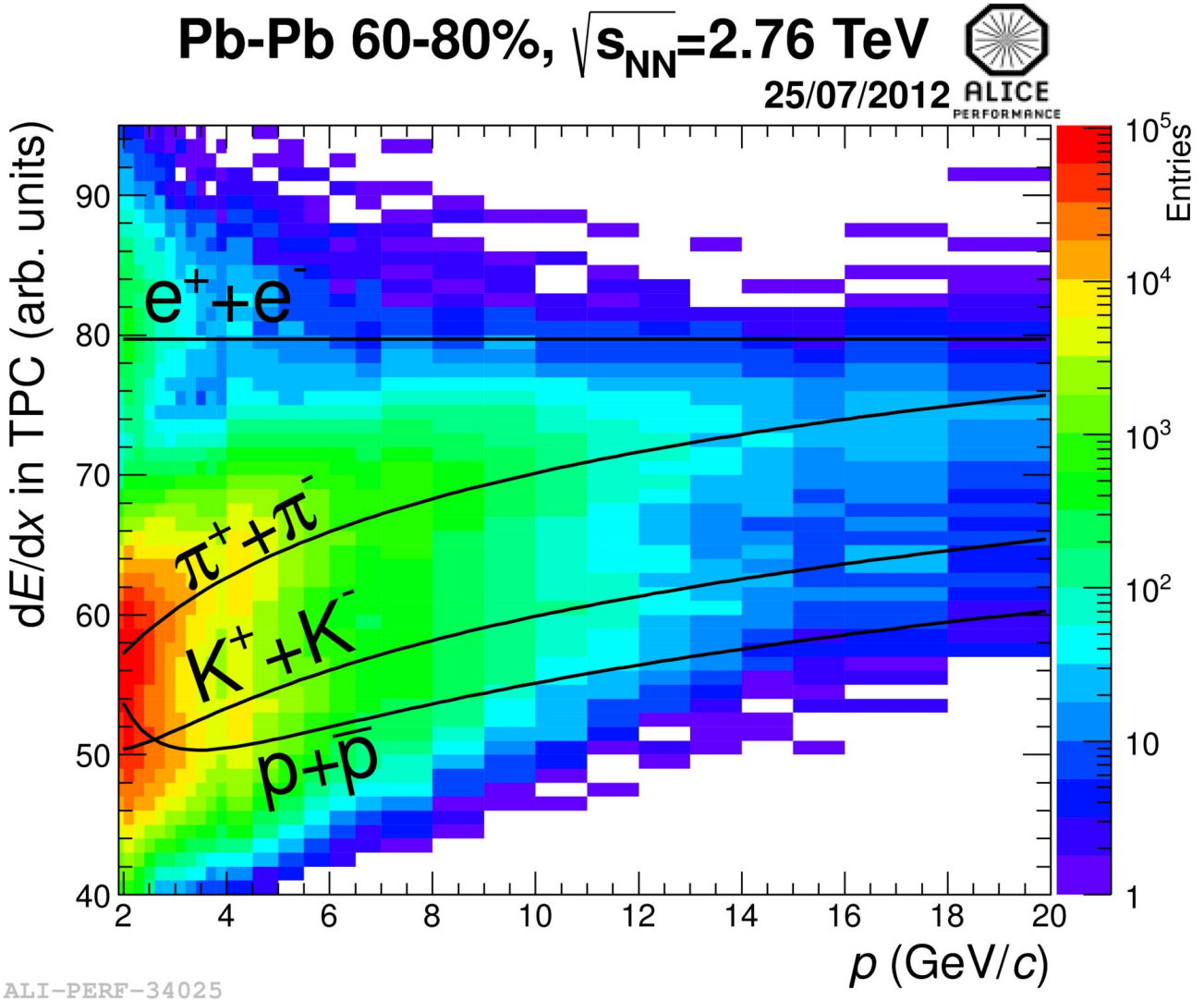




Light charged hadrons ($\pi^{\pm}$, $K^{\pm}$, (anti-)p): ~150 MeV/c < p_T < 20 GeV/c

TPC-d*E*/d*x* in the relativistic rise

- At relativistic rise the particle species are not well separated, so statistical PID is needed.

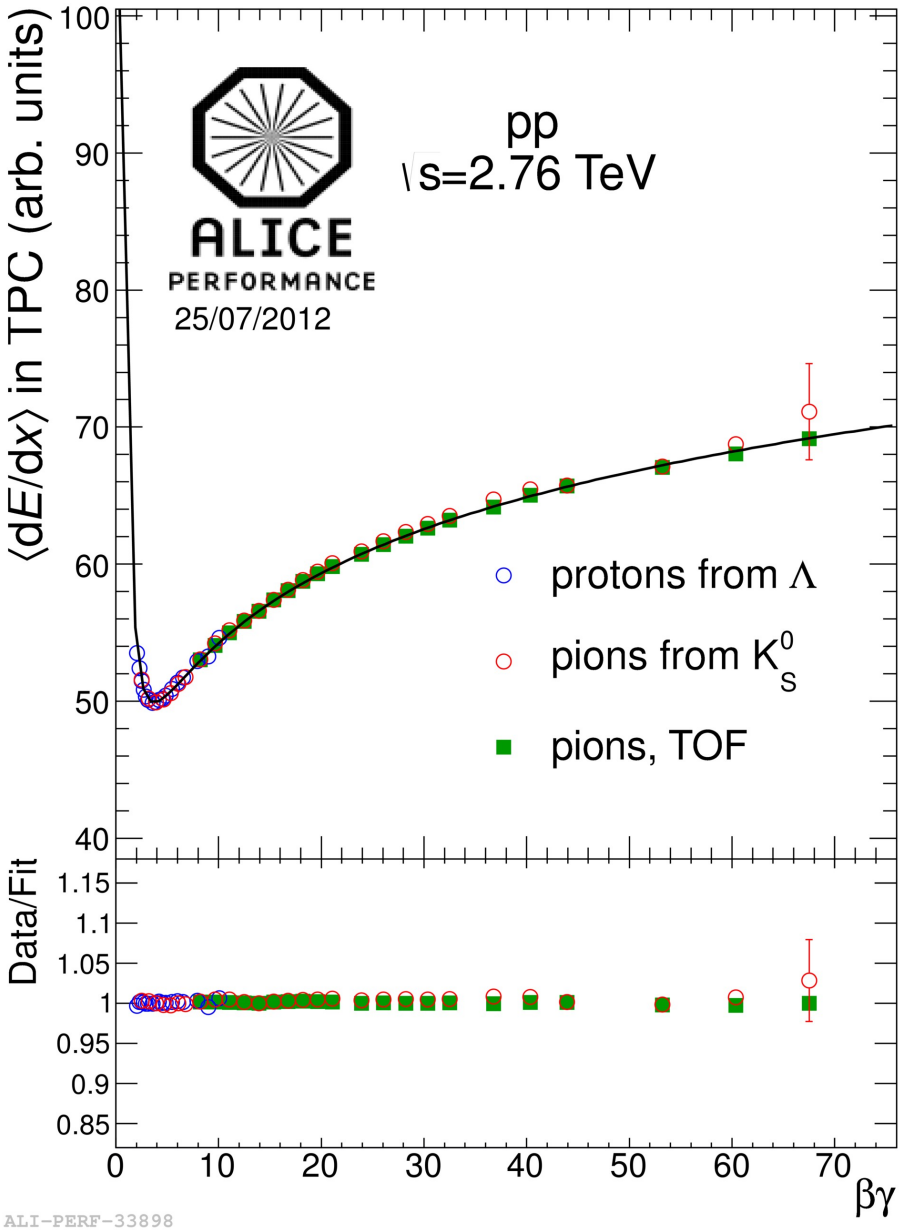


$$\langle \frac{dE}{dx} \rangle (\beta\gamma) \quad \& \quad \sigma^{rel}(\langle \frac{dE}{dx} \rangle)$$

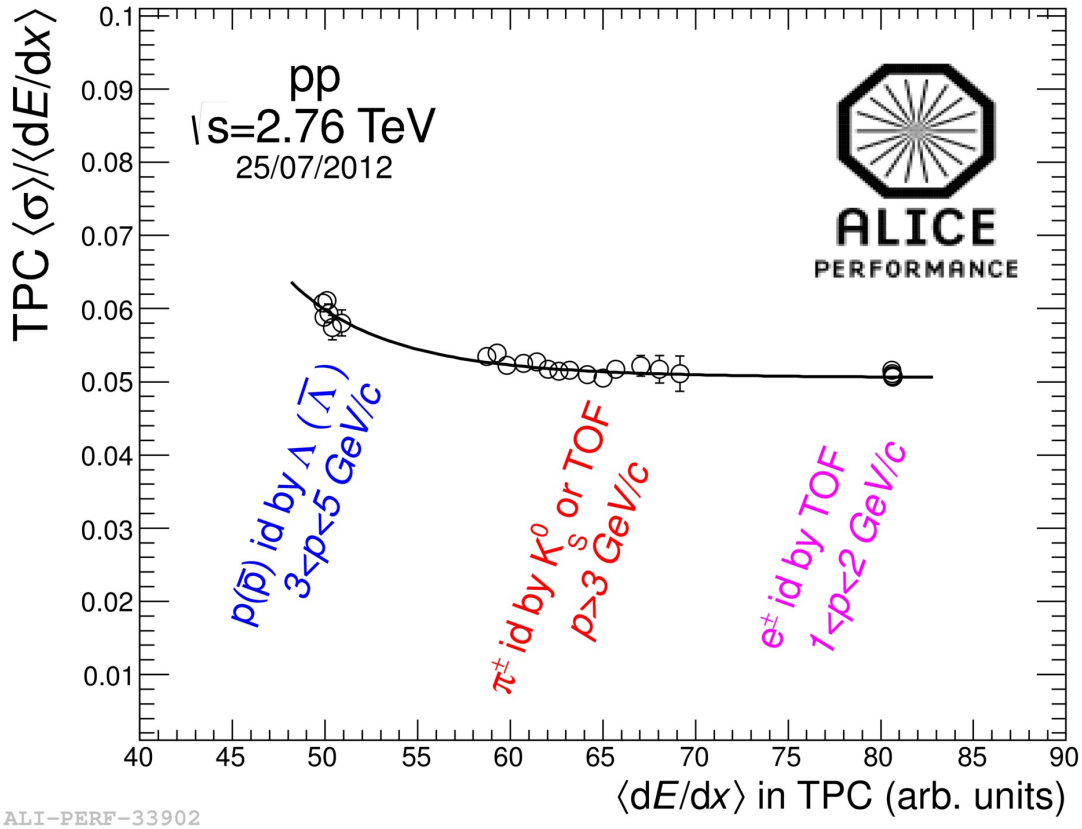
- Are extracted from data using PID: V0s daughters + pions and electrons from TOF.

ALI-PERF-34025

TPC-d*E*/d*x* in the relativistic rise



Low multiplicity, pp



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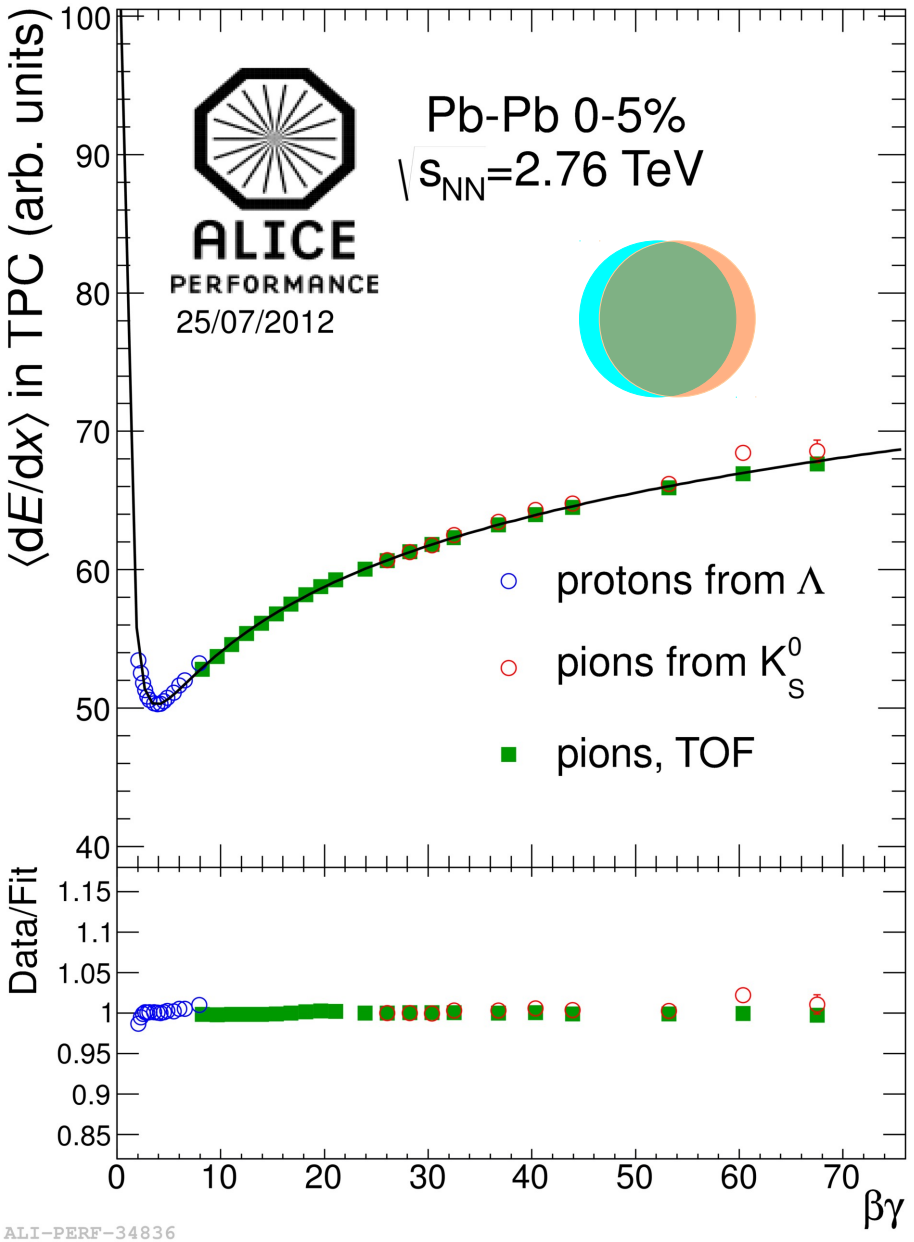
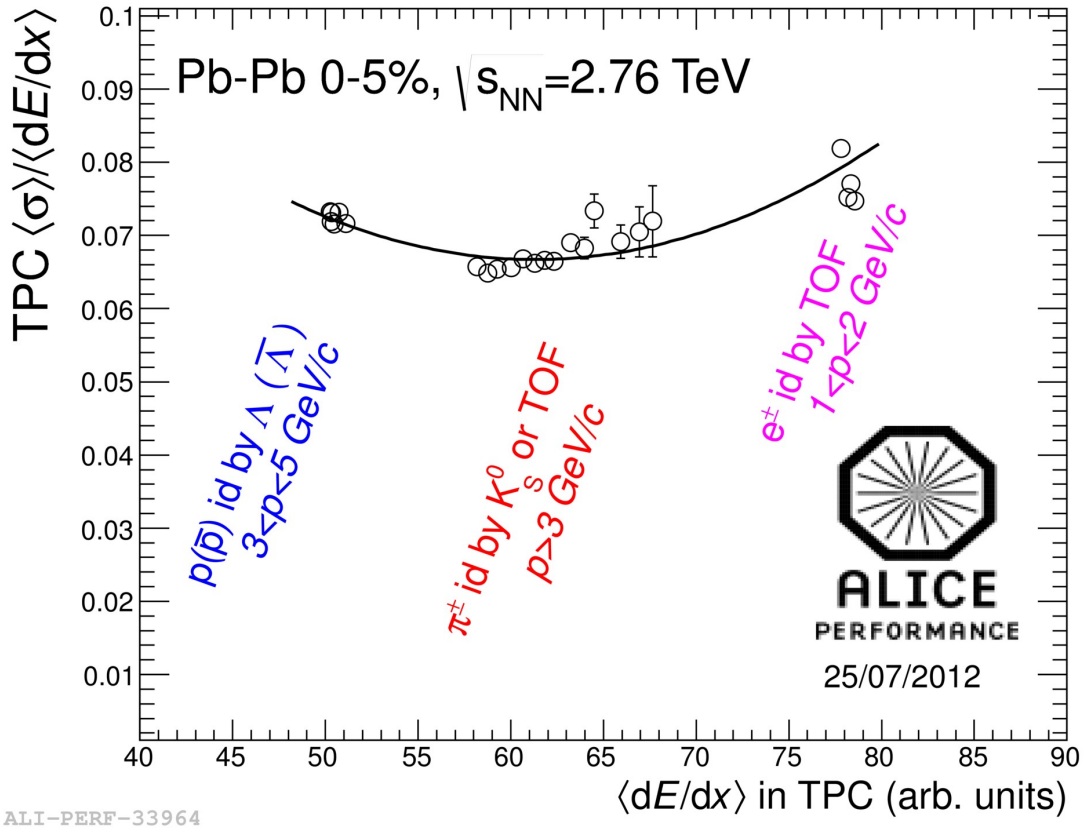


High multiplicity, Pb-Pb



Extracting the particle fractions

Spectra for identified charged particles:

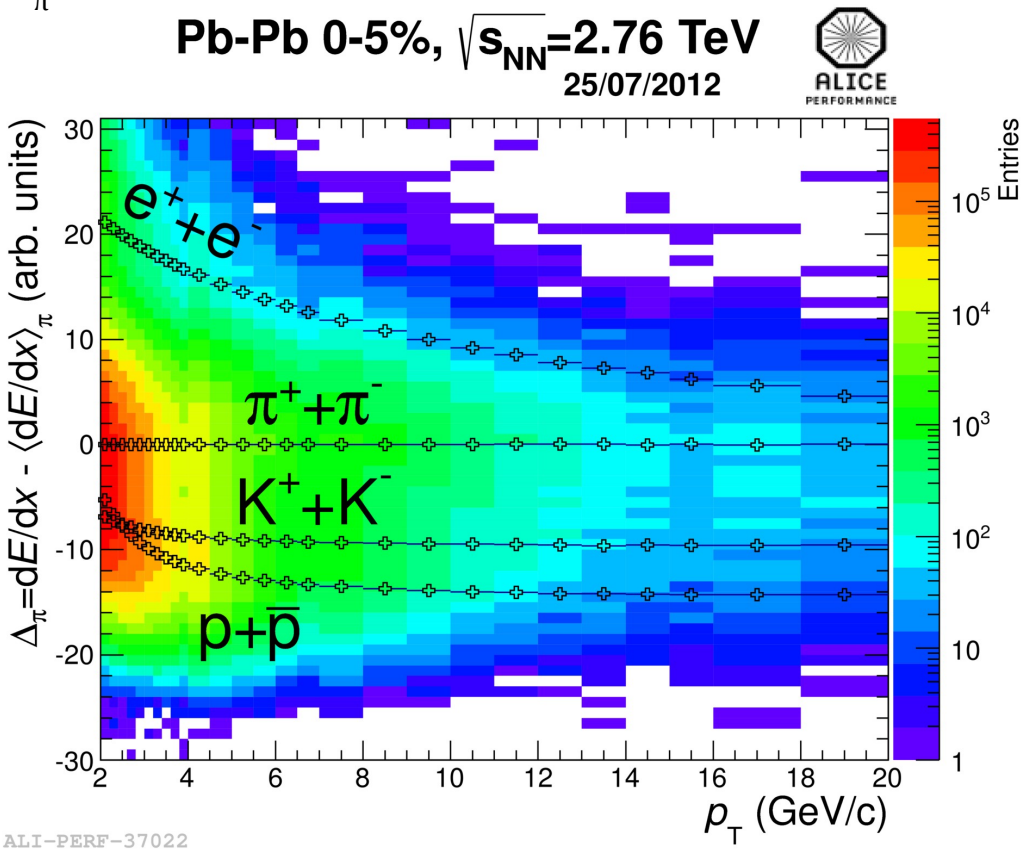
$$\frac{\mathrm{d}^2N_i}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{\mathrm{d}^2N_\mathrm{ch}}{\mathrm{d}\eta\mathrm{d}p_\mathrm{T}} \times \frac{\epsilon_i}{\epsilon_\mathrm{ch}} \times \frac{N_i}{N_\mathrm{ch}} \times \frac{\eta}{\sinh^{-1}\left(\frac{p_\mathrm{T}\sinh(\eta)}{\sqrt{p_\mathrm{T}^2+m_i^2}}\right)}$$

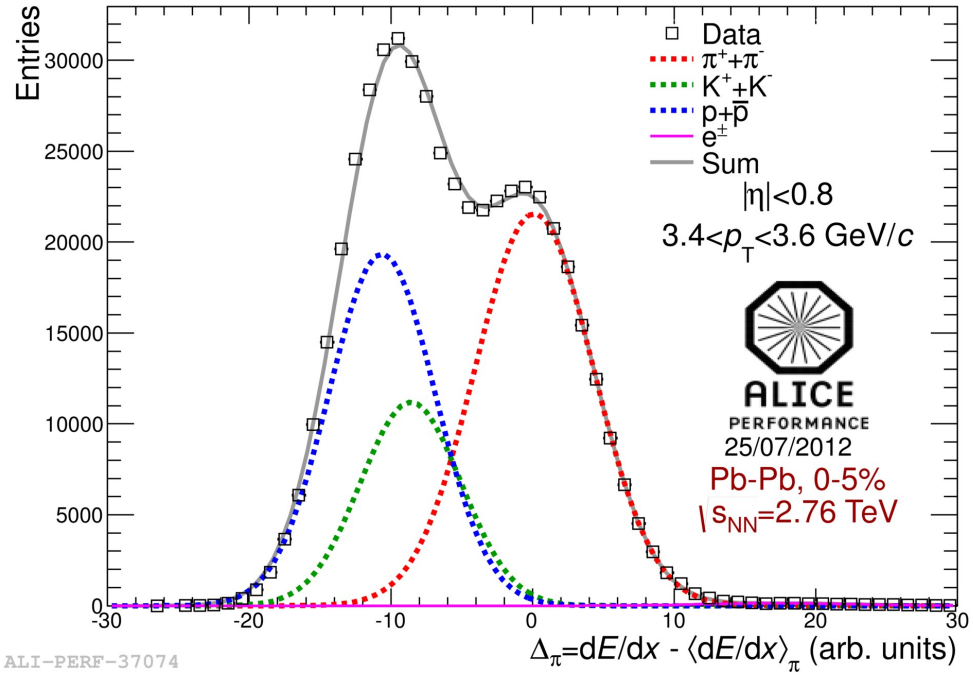
arXiv:1208.2711v1 [hep-ex]

$(i = \pi, \mathrm{K}, \mathrm{p})$

Δ_π is the quantity which was used to extract the particle fractions:

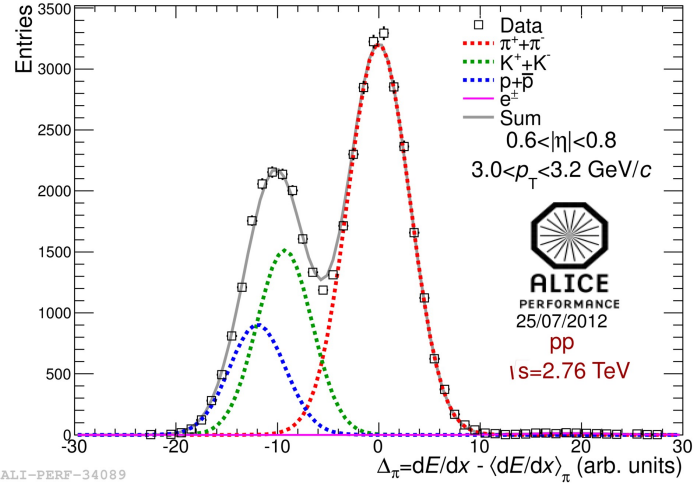
$$\Delta_\pi = \frac{\mathrm{d}E}{\mathrm{d}x} - \left\langle\frac{\mathrm{d}E}{\mathrm{d}x}\right\rangle_\pi$$

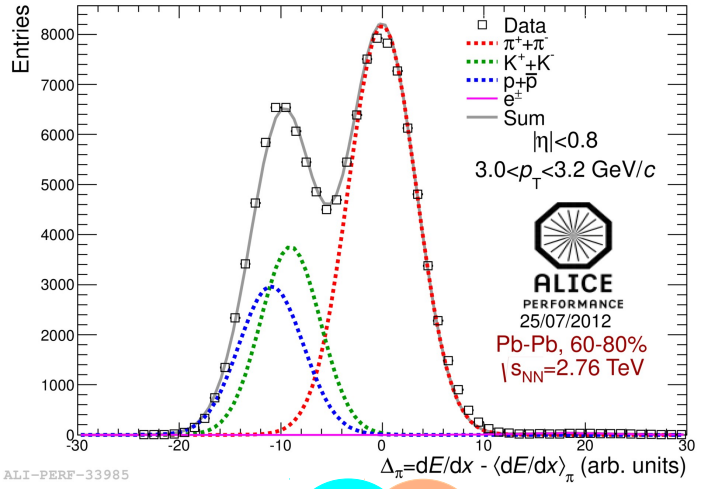


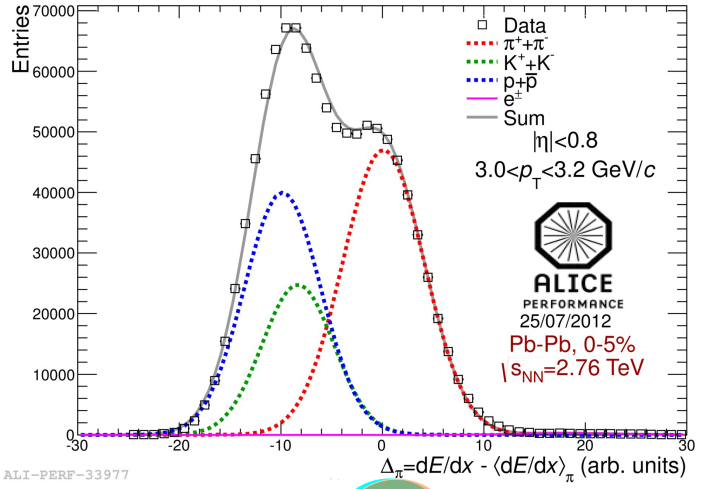


Particle fractions

$3 < p_T < 3.2$ GeV/c





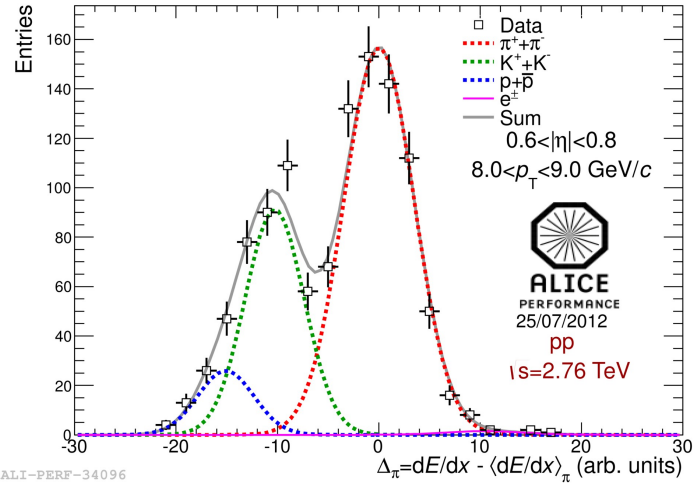


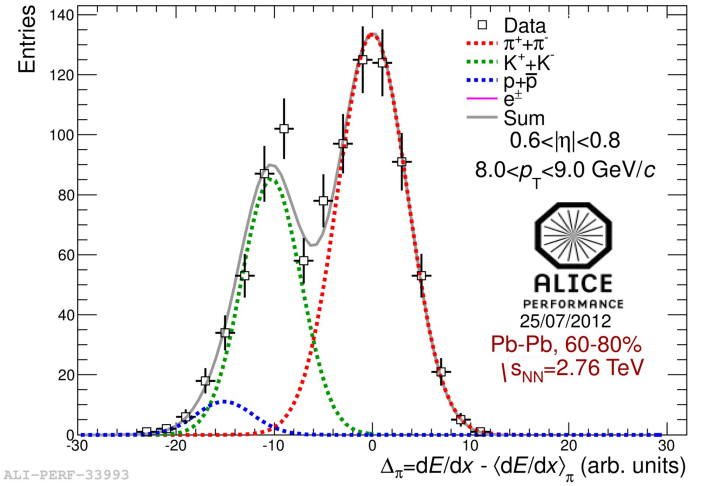
pp

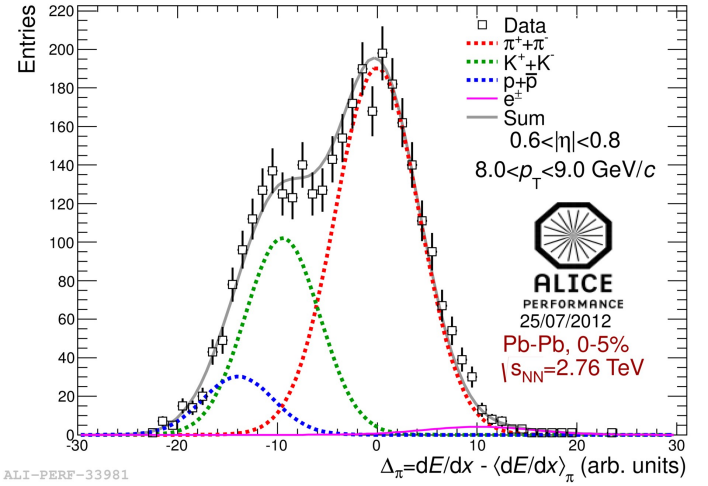
Peripheral

Central

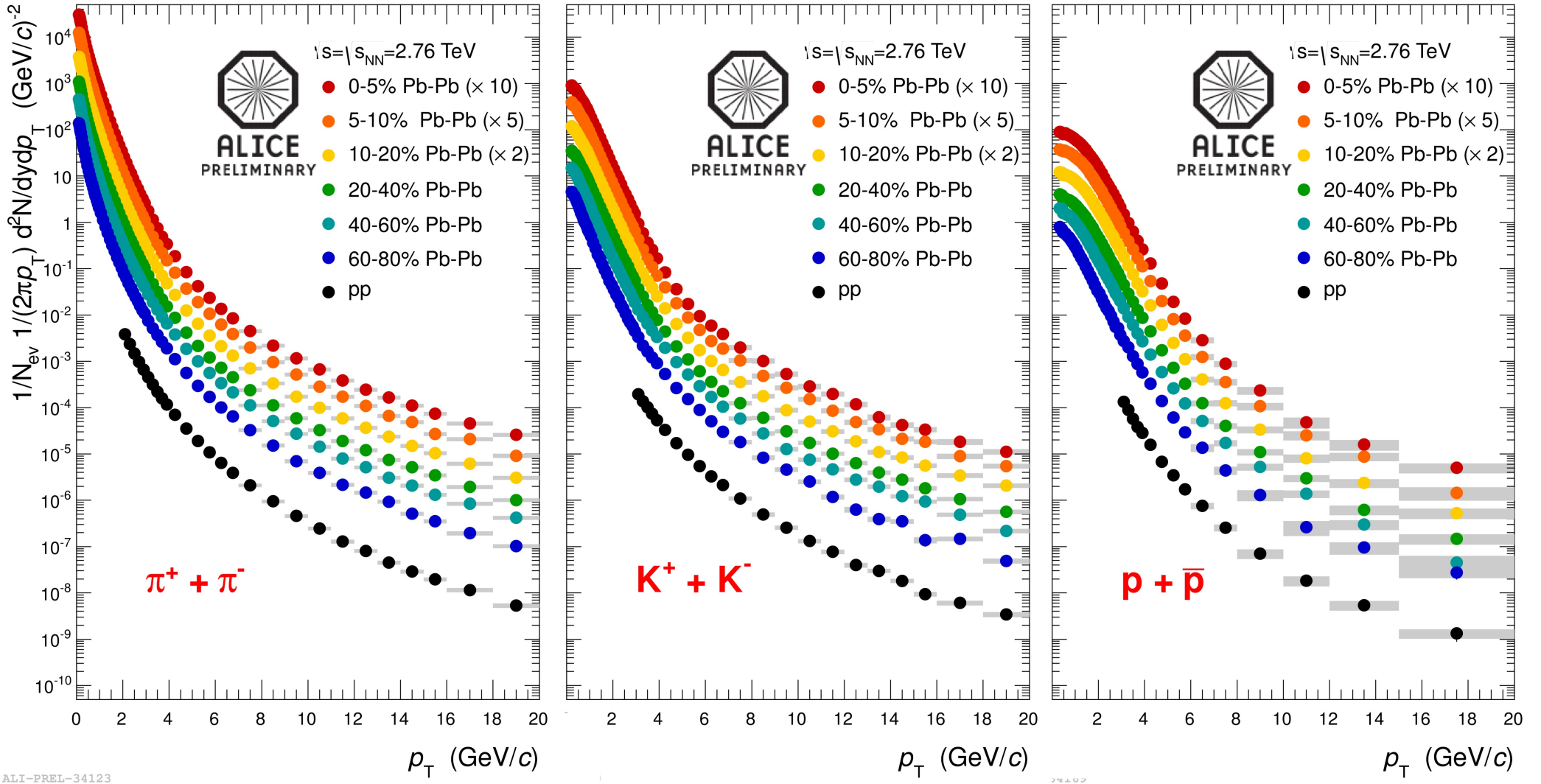
$8 < p_T < 9$ GeV/c







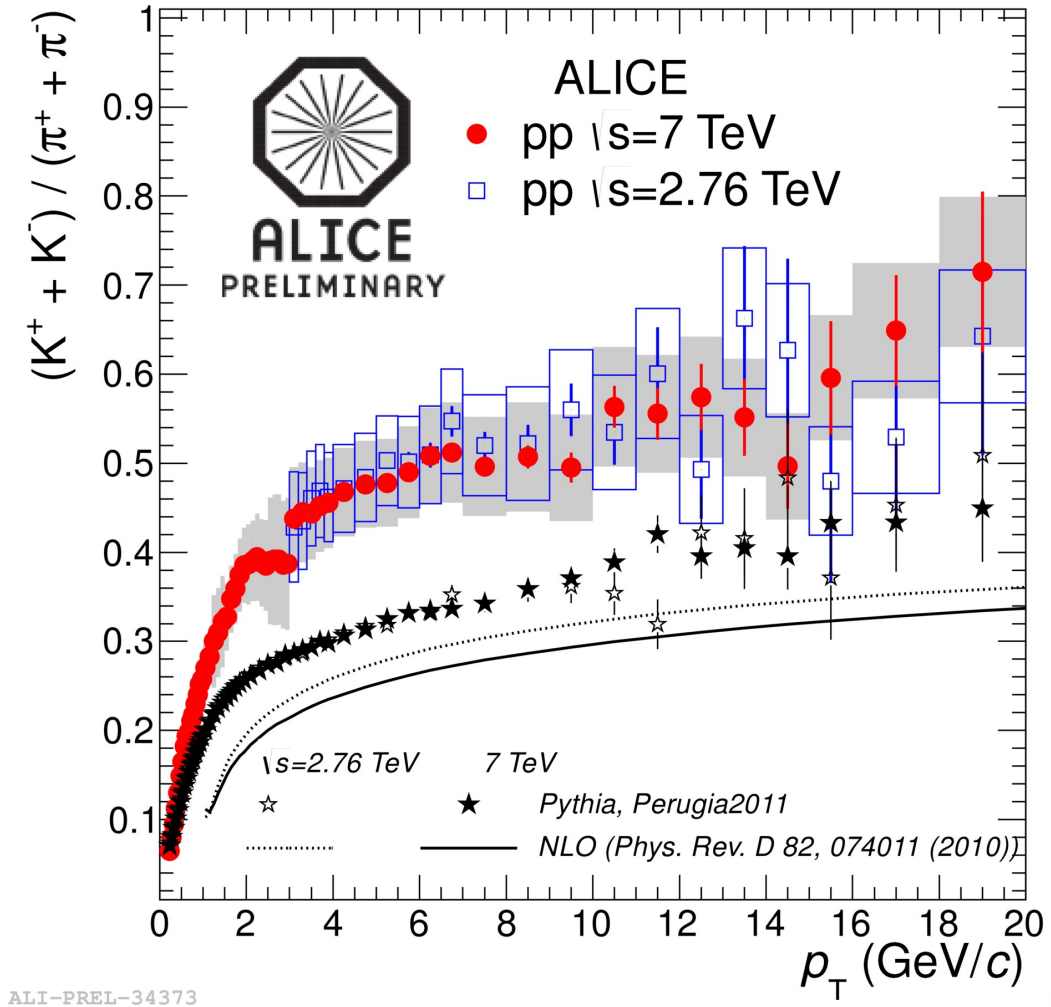
π/K/p spectra

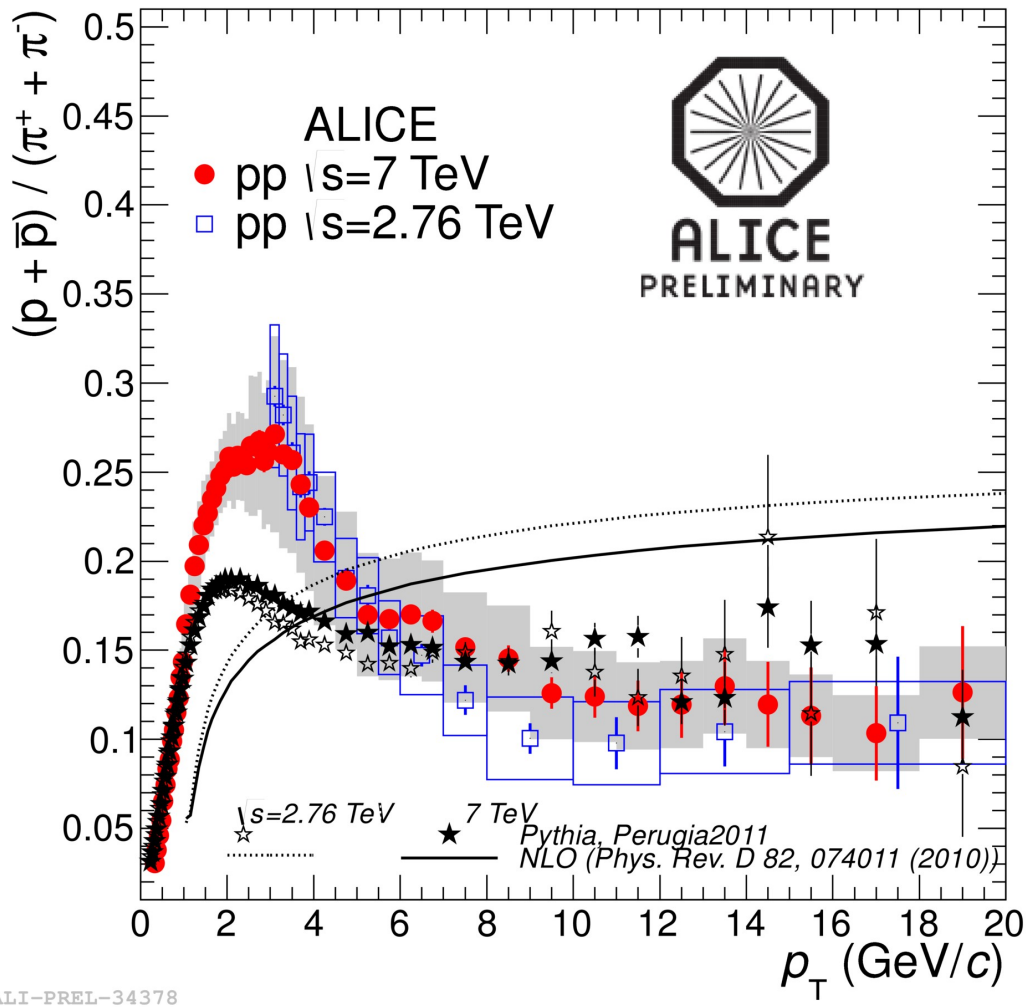


Pions: p_T >2 GeV/c,

Protons and Kaons: p_T> 3 GeV/c come from the relativistic rise analysis.

Particle Ratios in pp

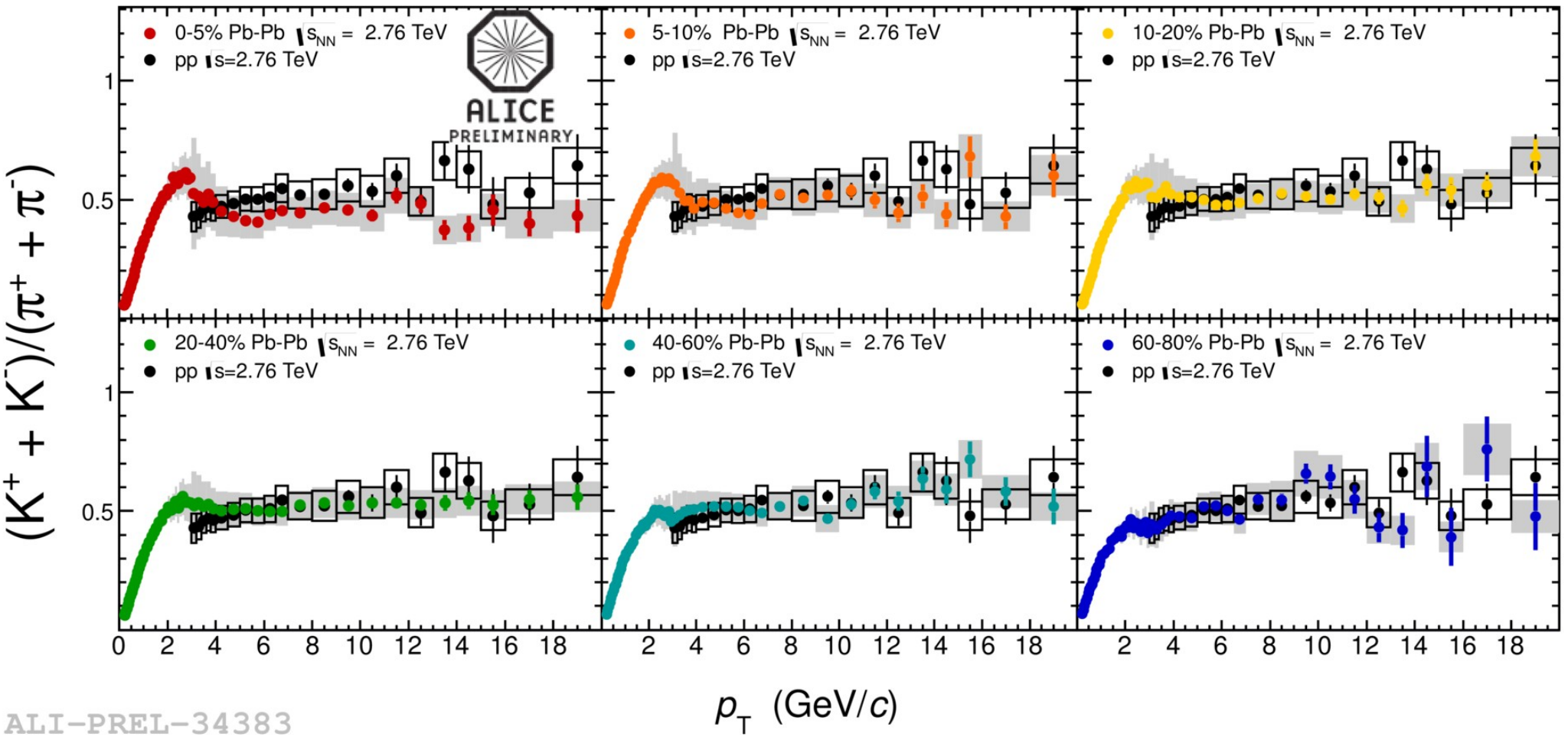




No energy dependence observed within the systematic uncertainties.

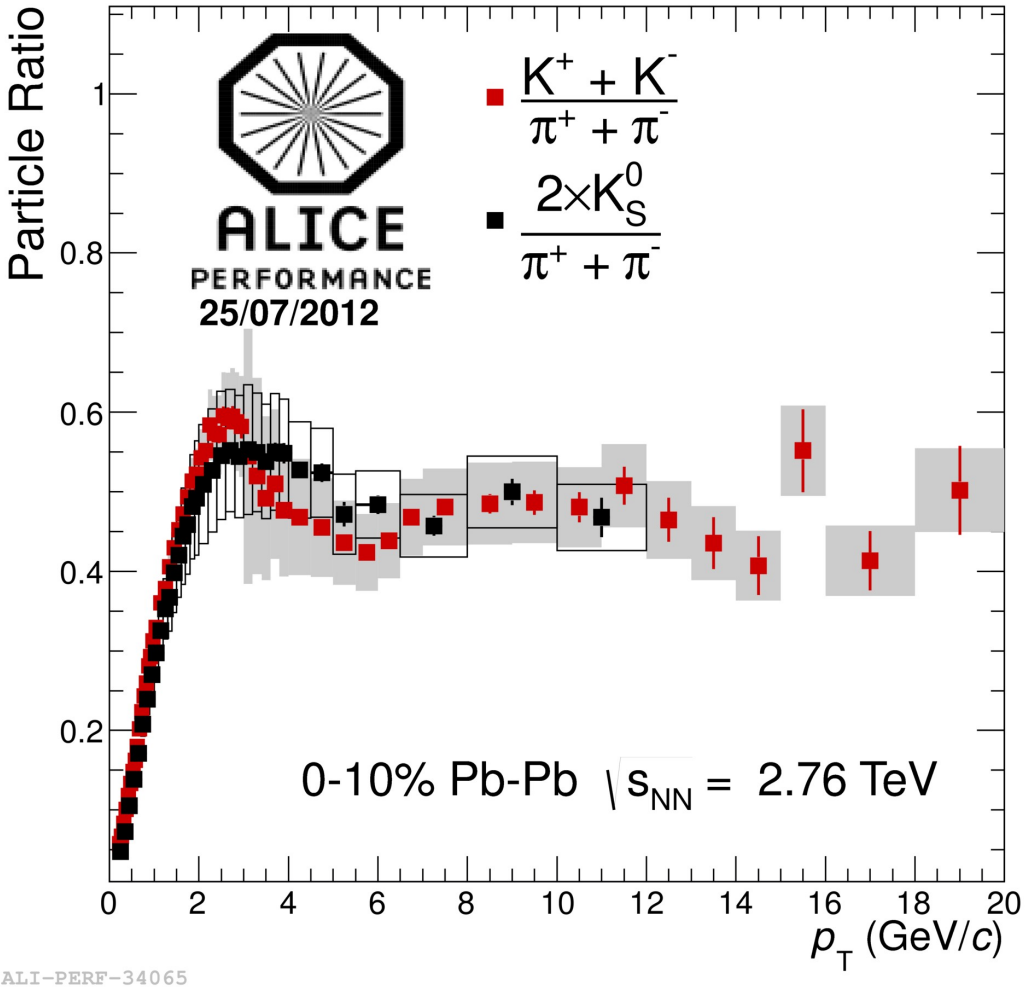
HMPID used for protons up to 6 GeV/c.

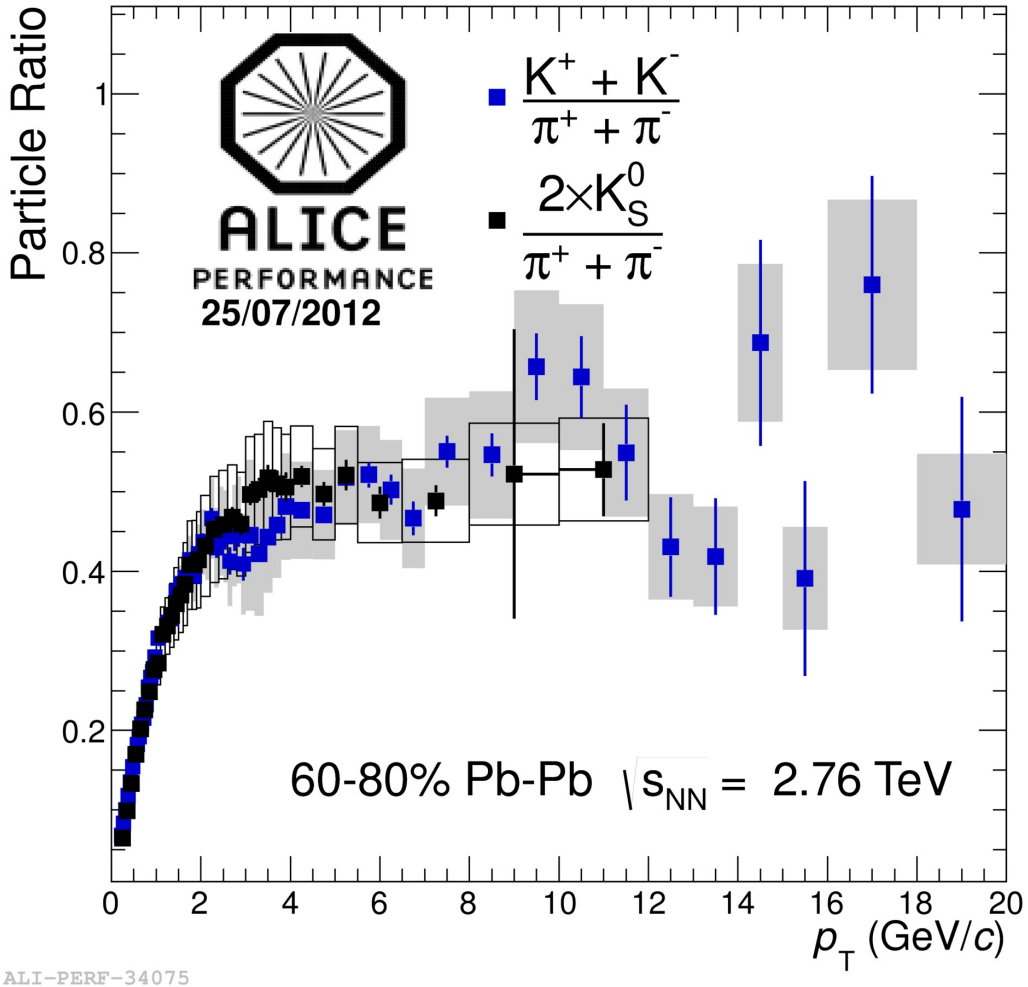
Kaon/Pion (Pb-Pb, I)



In the intermediate p_T region: 2-7 GeV/c, the ratio exhibits an evolution from the most central to the most peripheral Pb-Pb collisions.

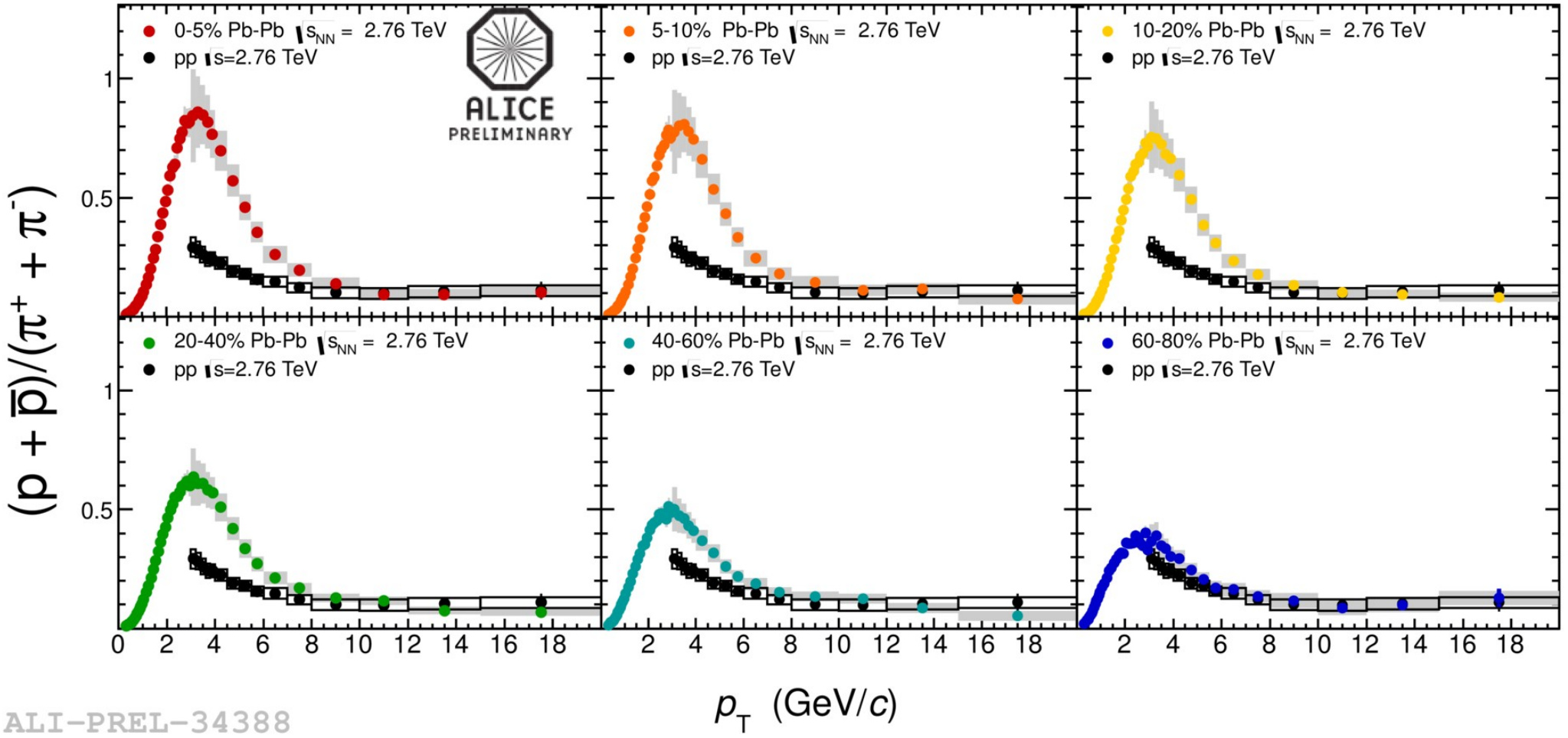
Kaon/Pion (Pb-Pb, II)





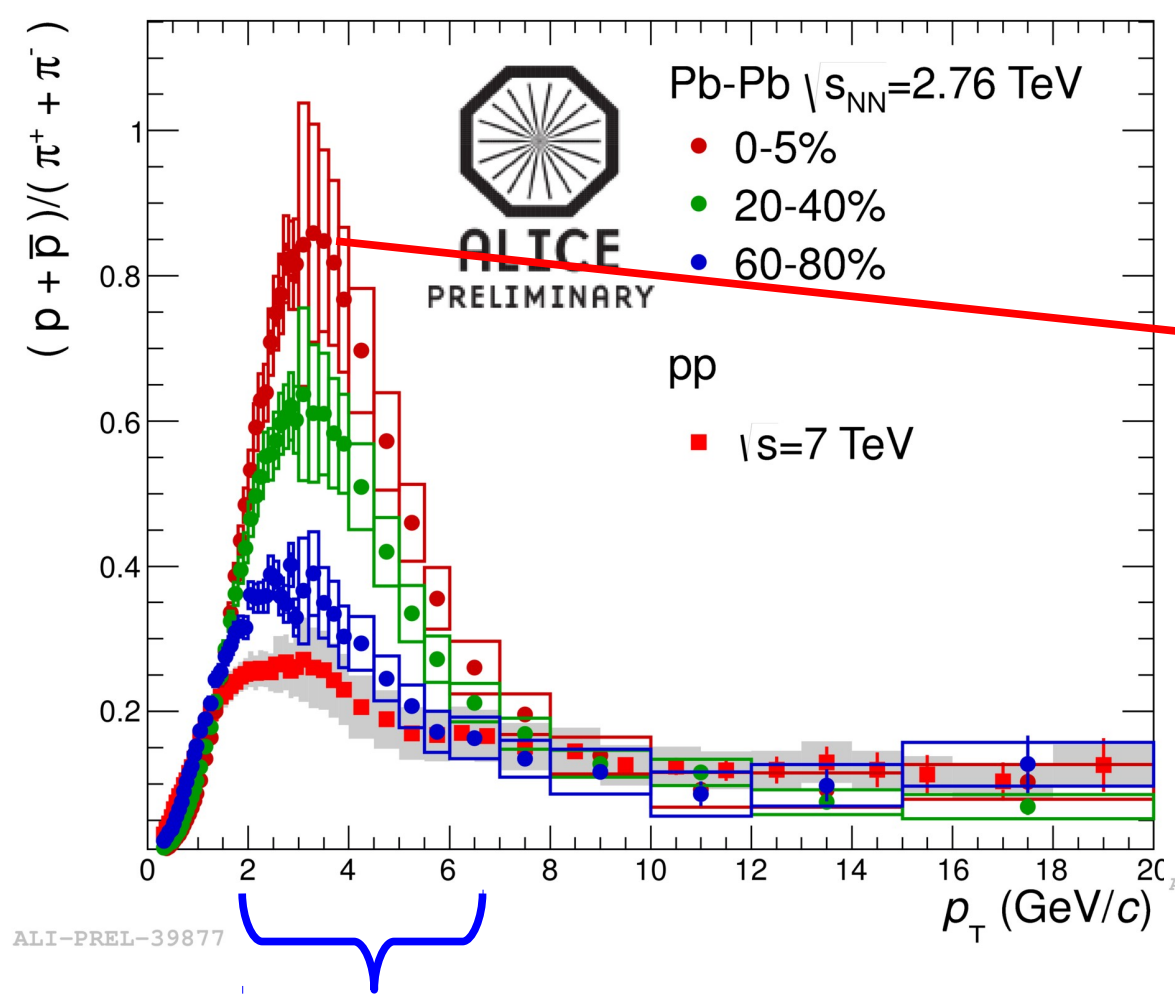
Same dependence is observed if we consider K^0_S

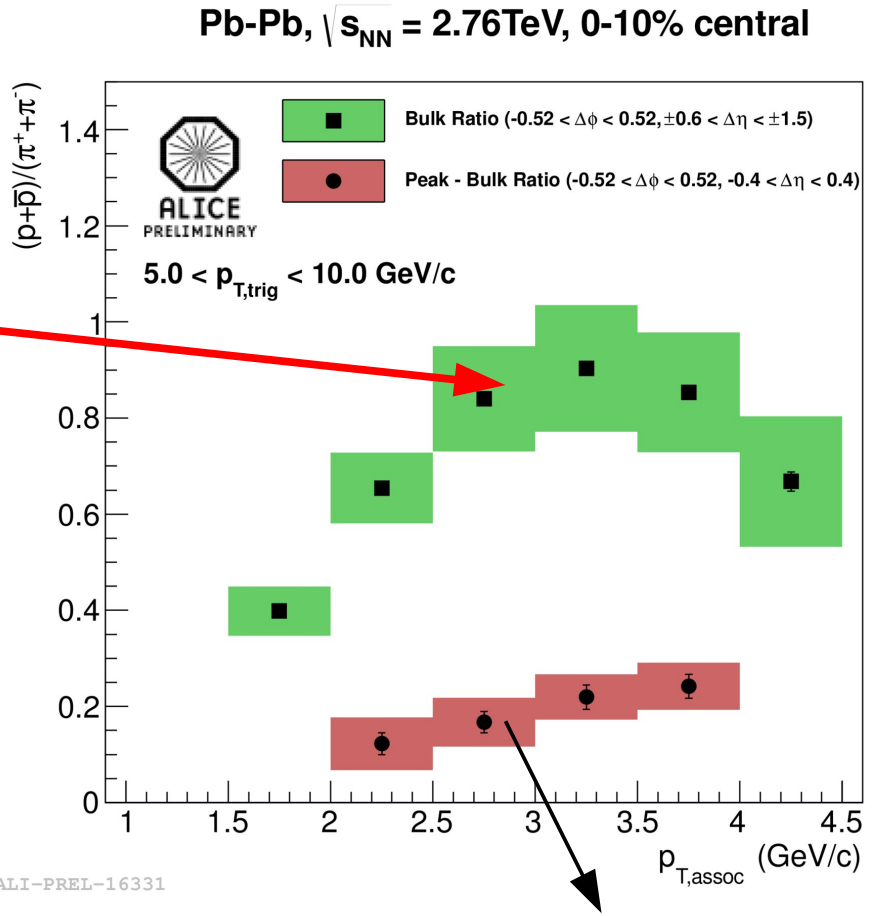
Proton/Pion (Pb-Pb)



Intermediate p_T: 2-7 GeV/c, enhancement of the baryon to meson ratio.

Is it a bulk or jet effect?





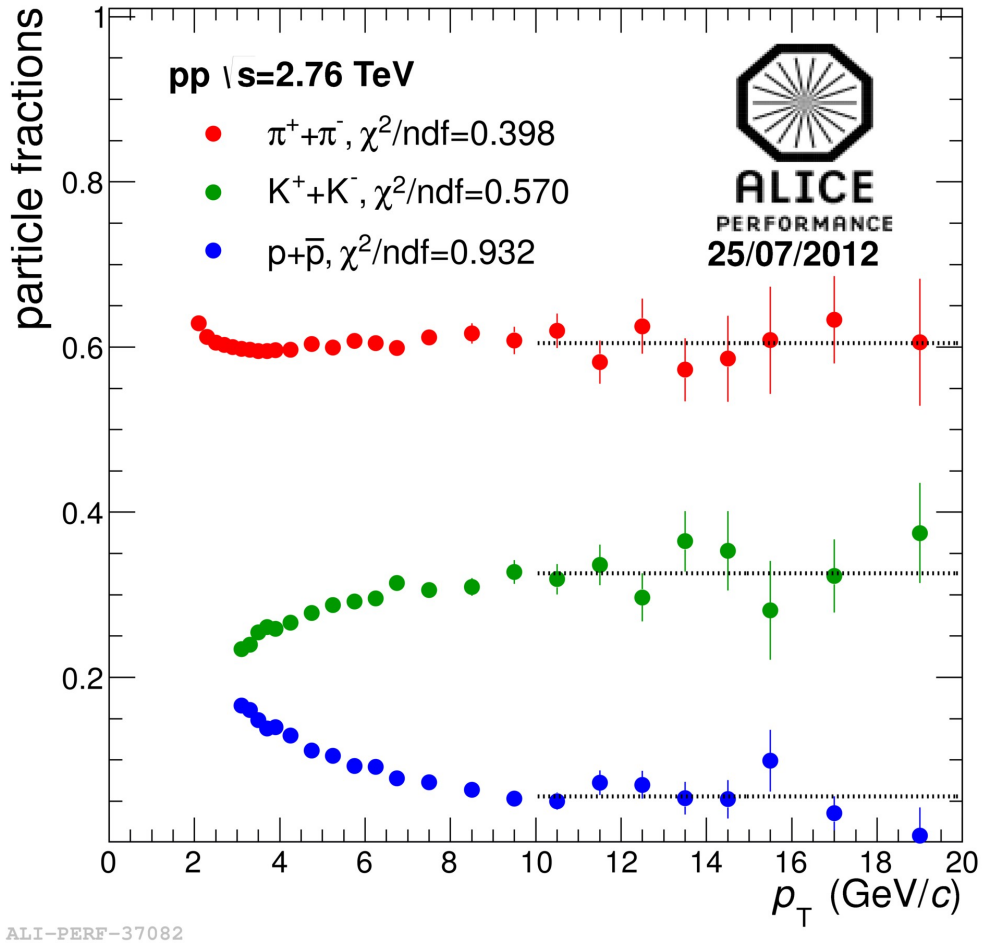
The enhancement seems to be a bulk effect (Misha Veldhoen, arXiv:1207.7195).

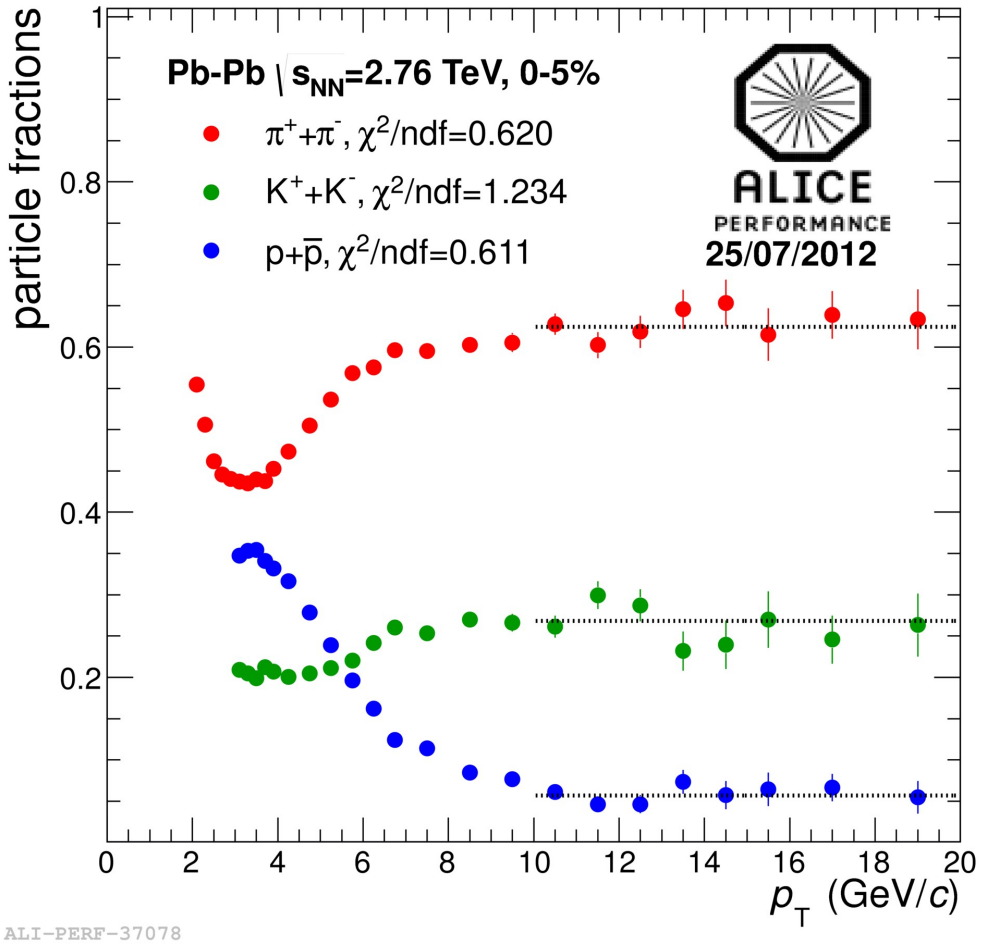
Particle production in jets is not affected by medium.

Smoothing the particle fractions to prevent fluctuations on R_{AA} at high p_T

pp

0-5%

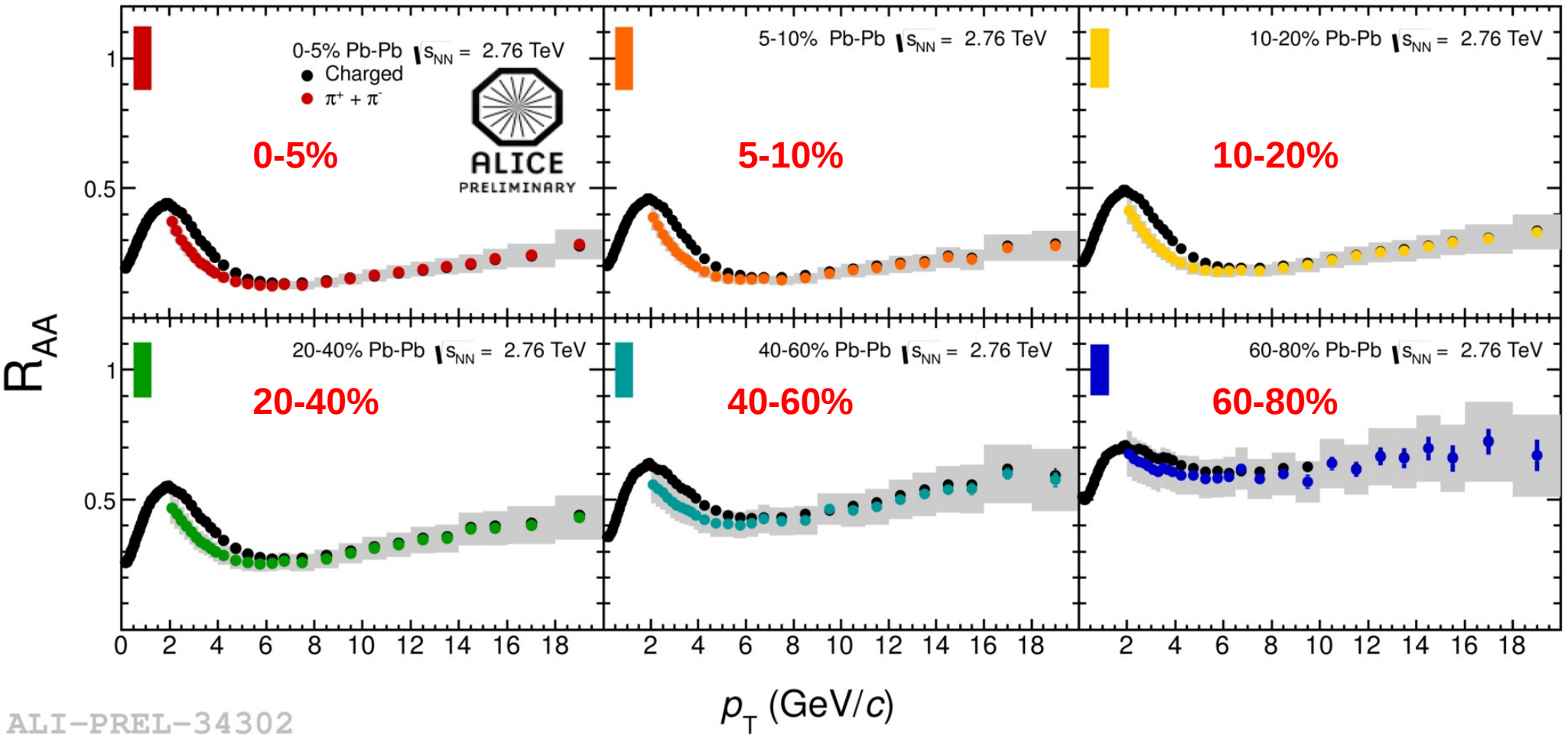




Systematic error from smoothing was included in the R_{AA} results.

R_{AA} for charged pions

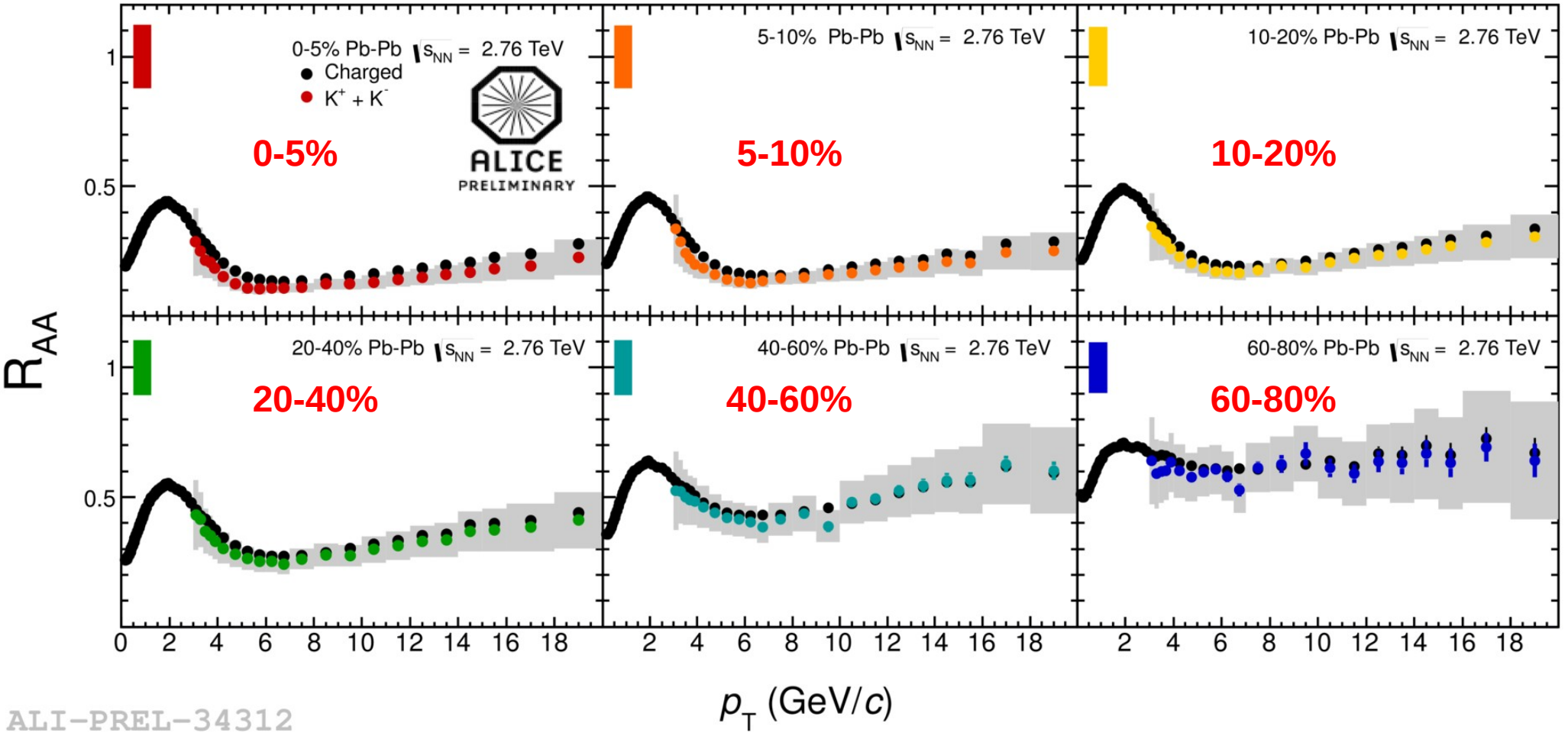
Results for inclusive charged particles: arXiv:1208.2711v1 [hep-ex]



p_T < 7 GeV/c, R_{AA} for charged pions < R_{AA} for inclusive charged particles.

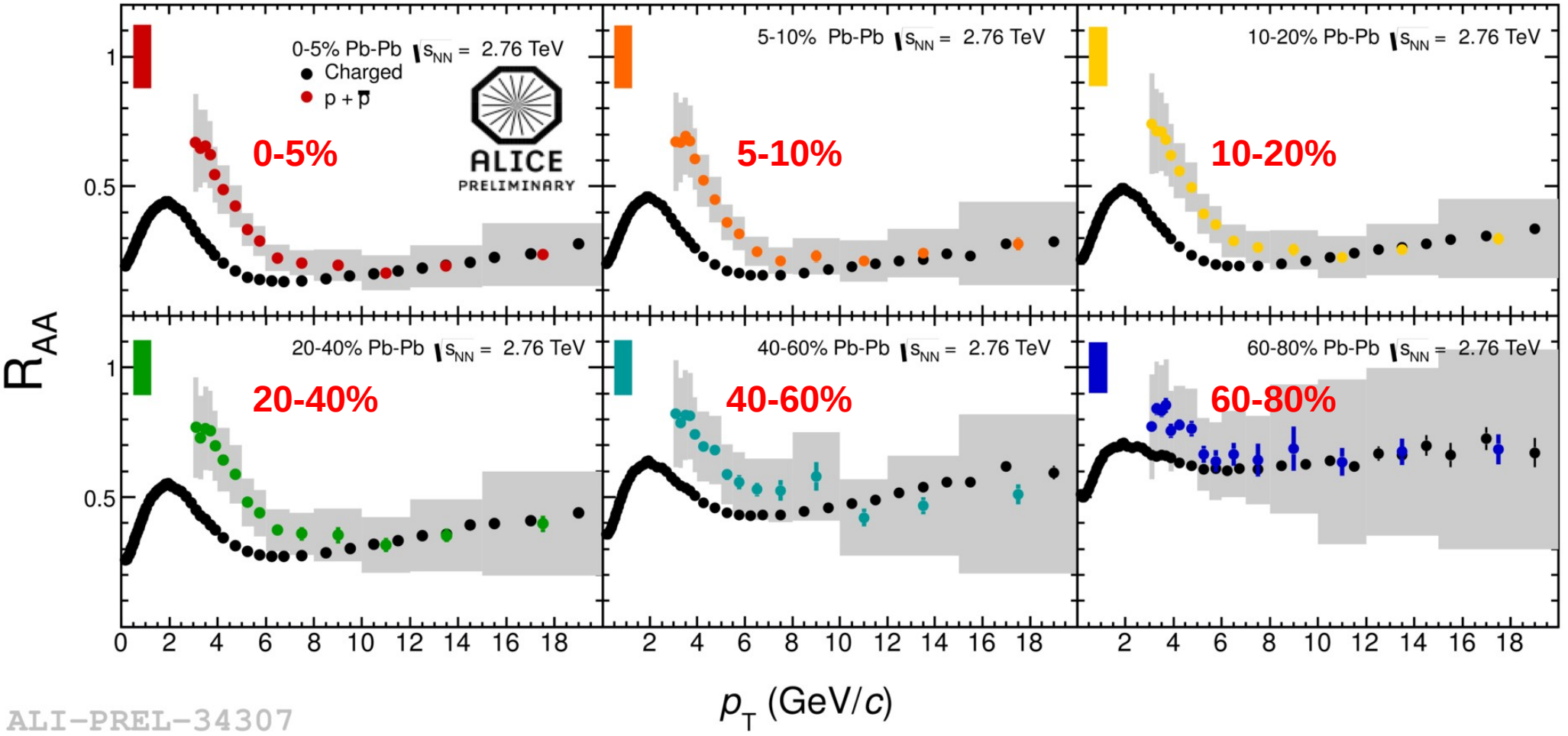
p_T > 7 GeV/c, R_{AA} for charged pions ~ R_{AA} for inclusive charged particles.

R_{AA} for charged kaons



R_{AA} for charged kaons compatible with R_{AA} for inclusive charged particles.

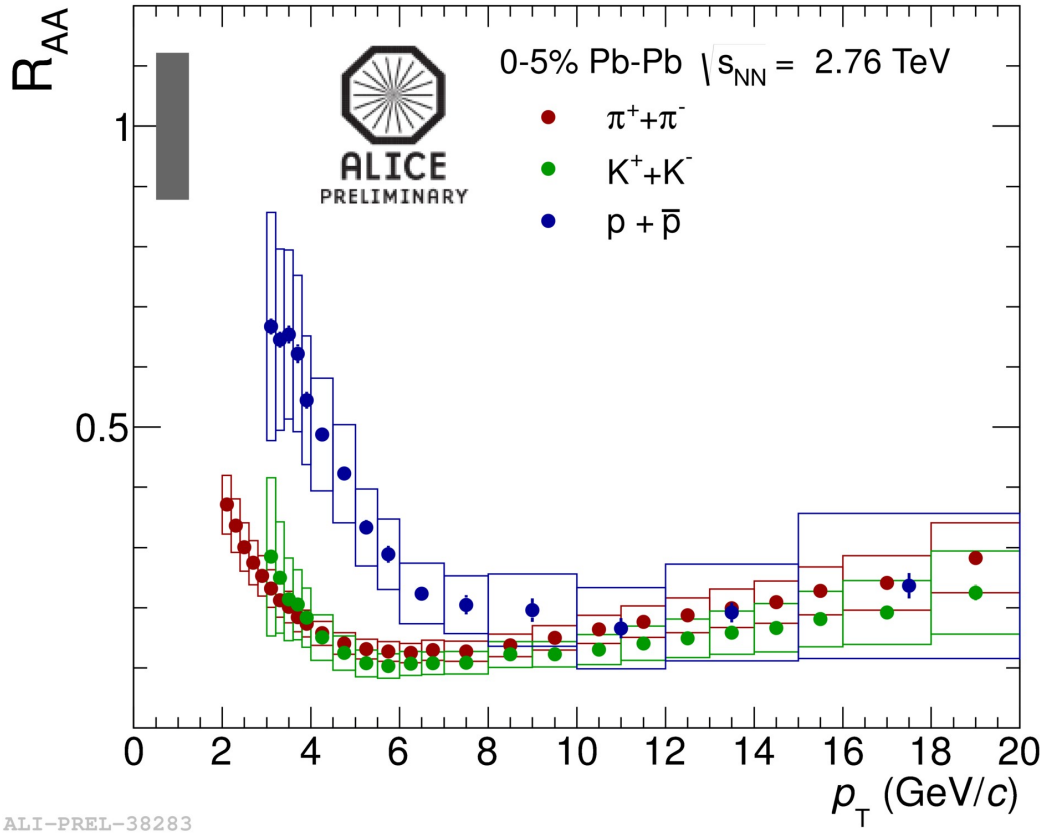
R_{AA} for (anti-)protons

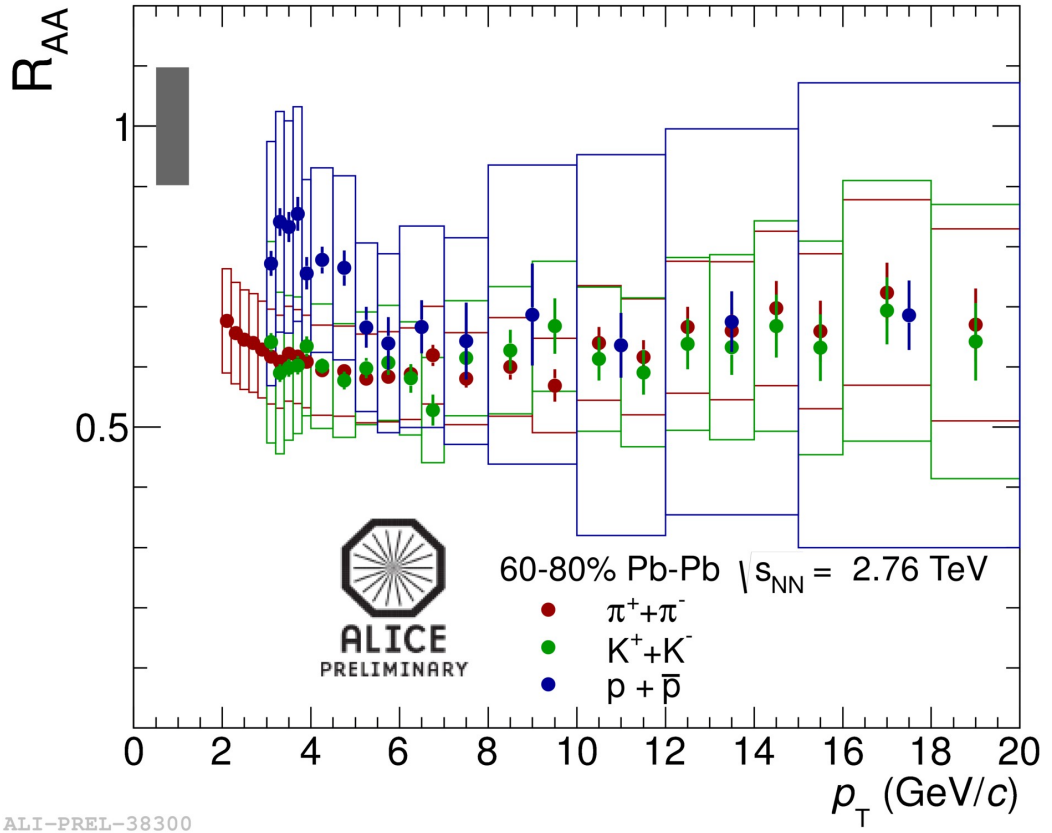


p_T < 7 GeV/c, R_{AA} for (anti-)protons > R_{AA} for charged pions.

p_T > 7 GeV/c, R_{AA} for (anti-)protons compatible with R_{AA} for inclusive charged particles.

R_{AA} for π/K/p


R_AA
0-5% Pb-Pb √s_NN = 2.76 TeV
ALICE
PRELIMINARY
π⁺+π⁻
K⁺+K⁻
p + p̄
1
0.5
0 2 4 6 8 10 12 14 16 18 20
p_T (GeV/c)
ALI-PREL-38283


R_AA
60-80% Pb-Pb √s_NN = 2.76 TeV
ALICE
PRELIMINARY
π⁺+π⁻
K⁺+K⁻
p + p̄
1
0.5
0 2 4 6 8 10 12 14 16 18 20
p_T (GeV/c)
ALI-PREL-38300

Conclusions

pp data:

- Particle ratios seem to be energy independent.
- NLO calculations and Pythia6 (Perugia2011) do not reproduce the particle ratios at high p_T.

Pb-Pb data:

- In the intermediate p_T region (2-7 GeV/c):

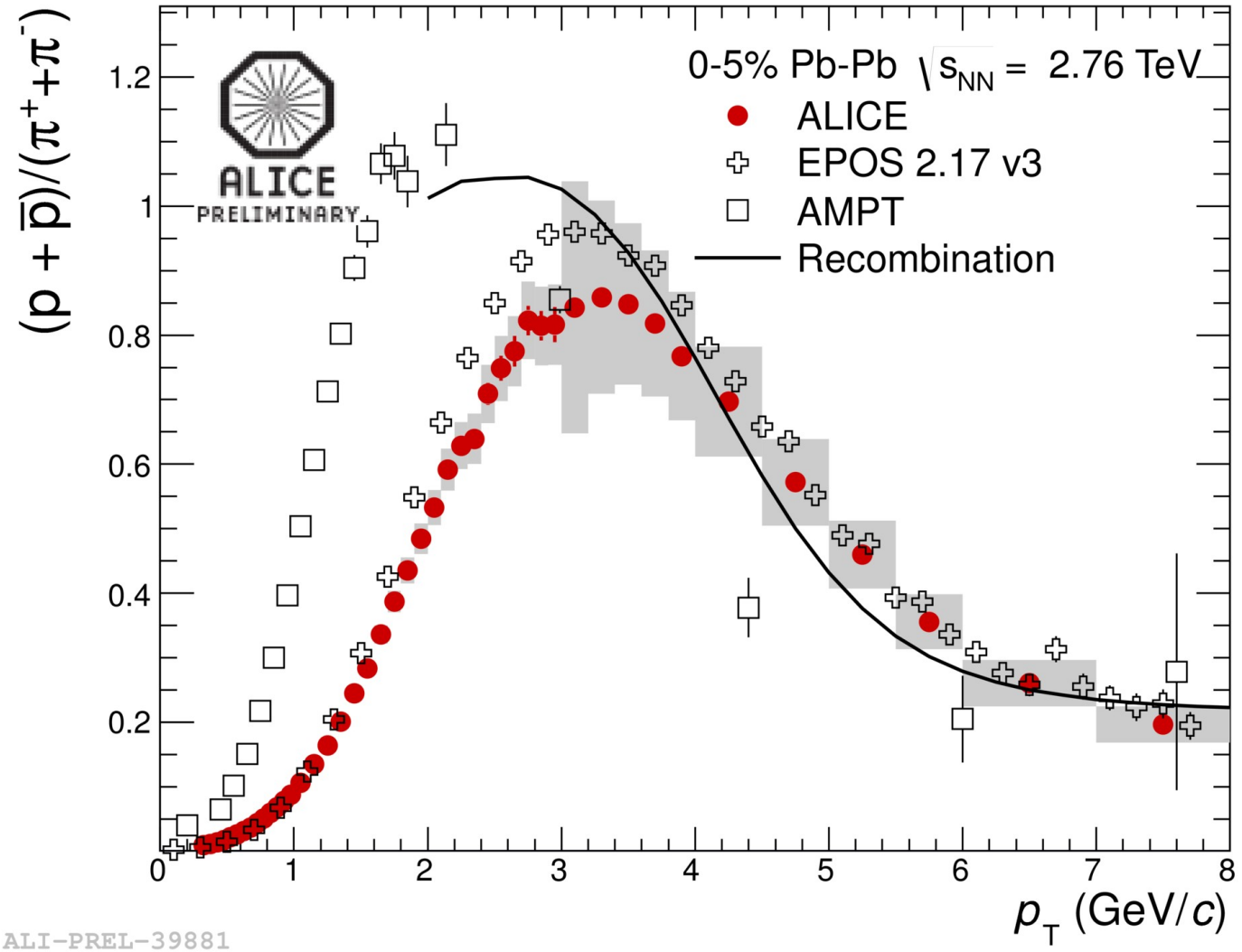
The ratio K/π evolves with centrality. Same dependence is observed for K^0_S.

The enhancement of the baryon to meson ratio observed at RHIC, is also present at LHC energies. The enhancement seems to be a bulk effect.

- At high p_T (>7 GeV/c) the $\boldsymbol{R_{AA}}$ **for π/K/p are compatible, this suggests that the medium does not affect the fragmentation.**

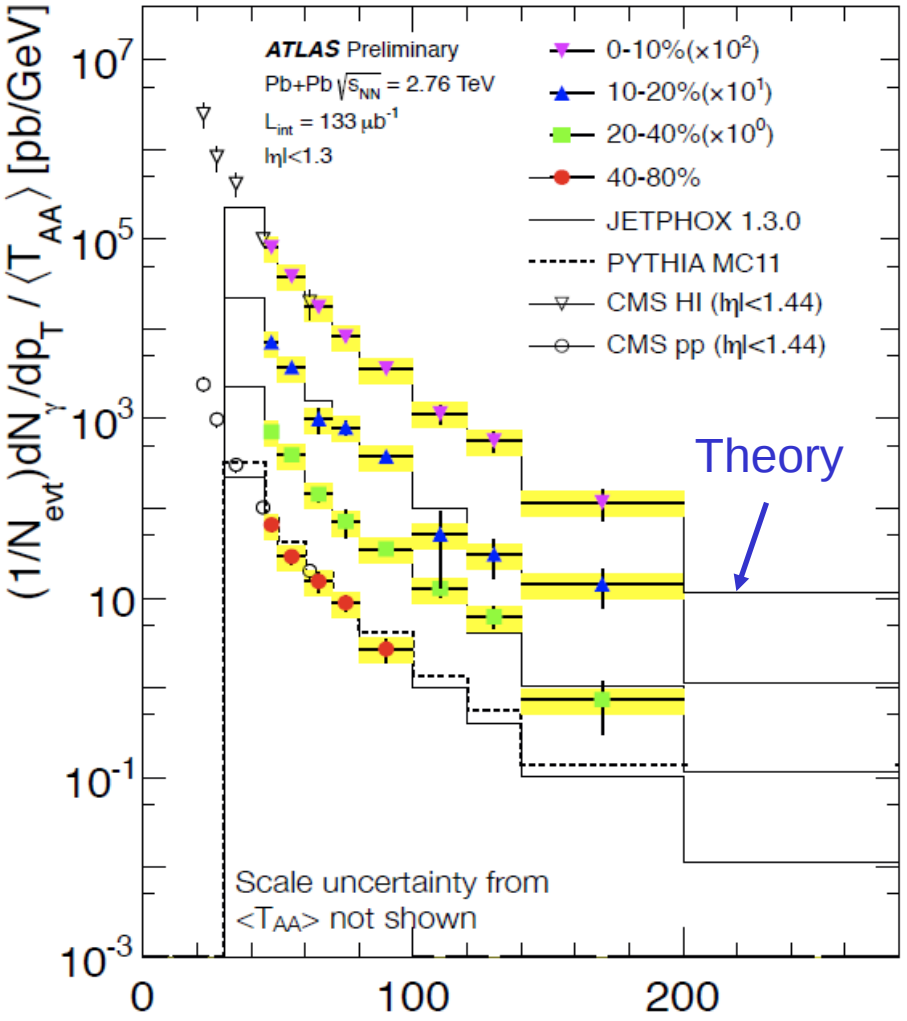
Backup

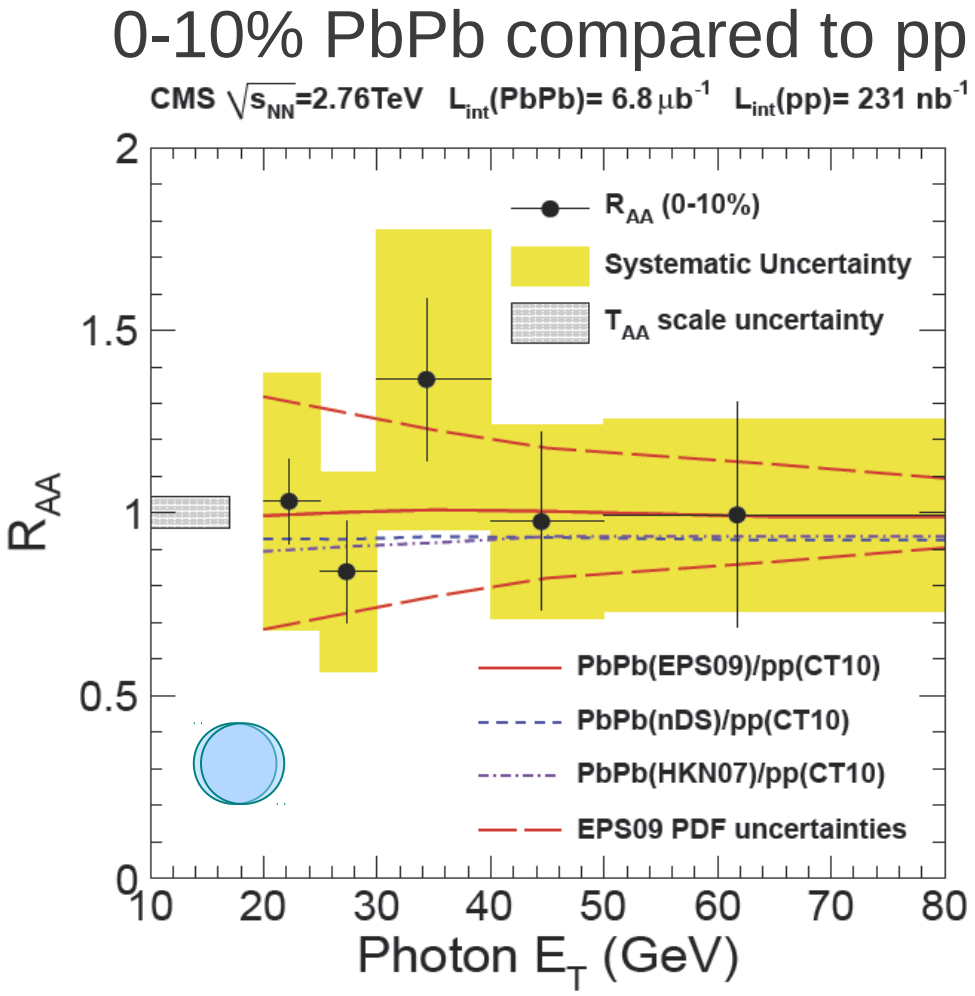
Proton/Pion (ALICE vs models)



EPOS: Klaus Werner, arXiv:1204.1394, arXiv:1205.3379.
AMPT: Jun Xu and Che Ming Ko, *Phys. Rev.* C 83, 034904 (2011).
Recombination: R. J. Fries et al., *Phys. Rev. Lett.* 90, 202303 (2003) and private communication

Isolated photon R_{AA}



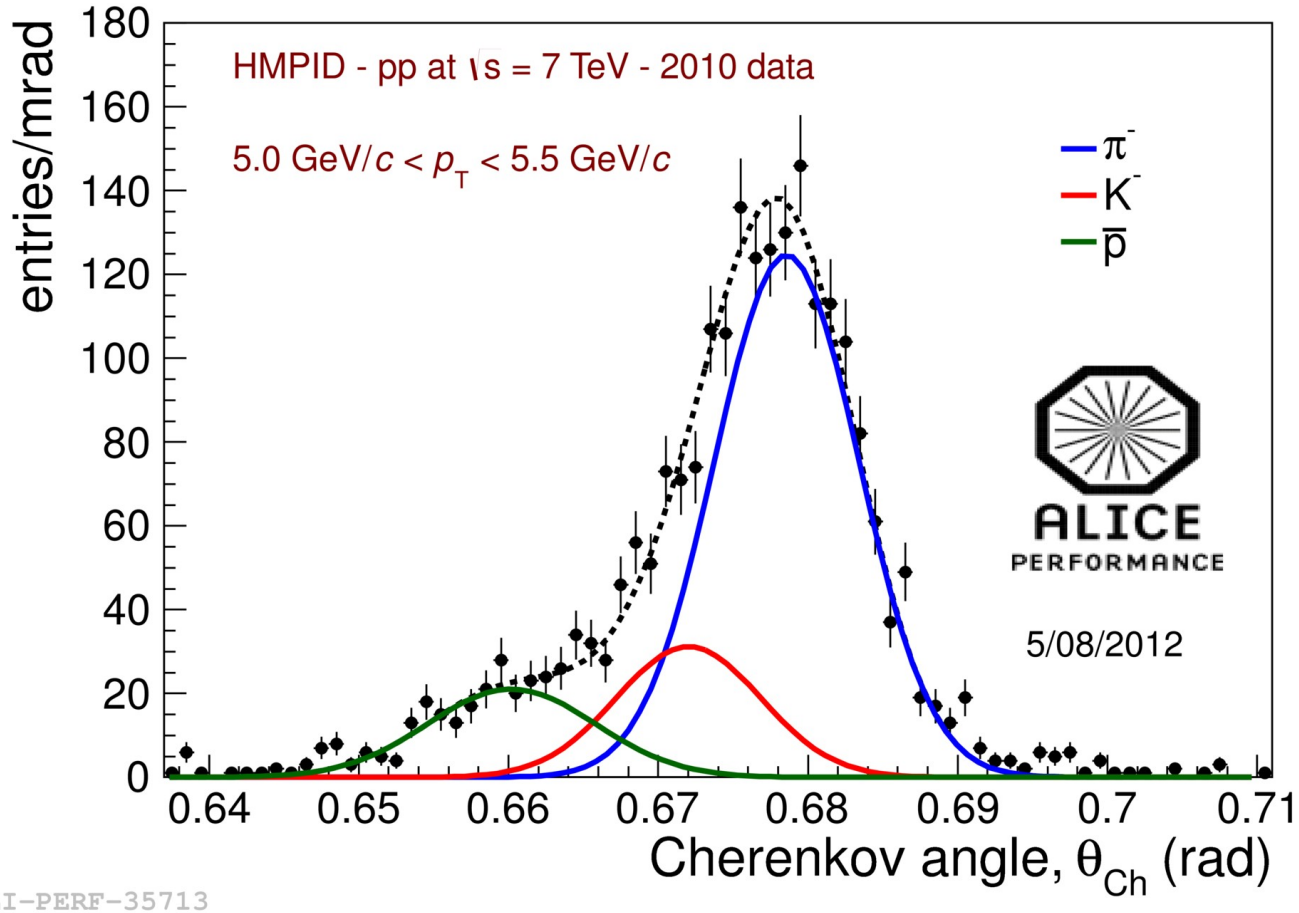


- No modification of the photons as expected!

Extending the PID using HMPID

The identification is obtained by means of the Cherenkov angle θ measured by HMPID

With this technique we can identify protons with 3σ separation up to p_T~5 GeV/c, and with ~2σ separation up to 6 GeV/c



ALI-PERF-35713

Predictions for R_{AA} at high p_T for identified charged hadrons

Particle ratios inside jets.

Significant difference of hadron ratios for medium modified and unmodified jets at high momenta.

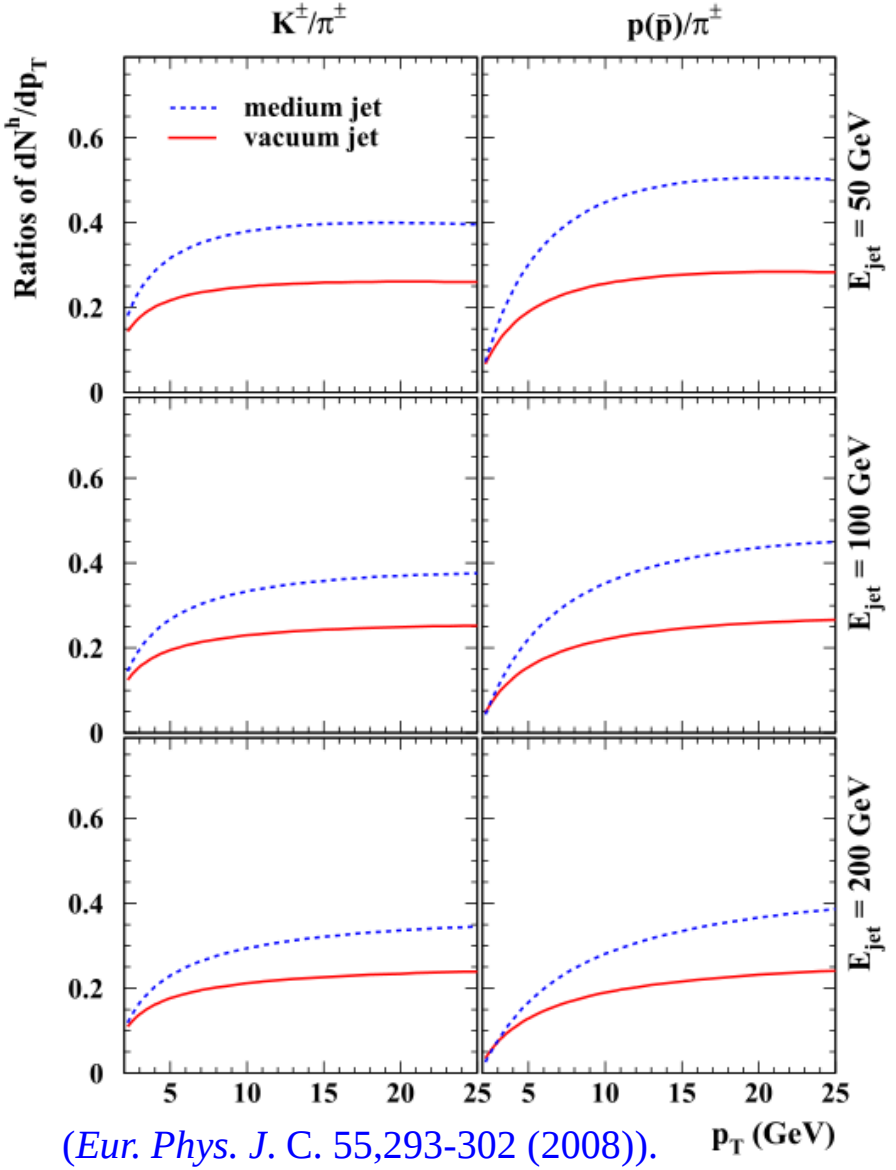
~50 – 100% medium effect

If we assume that at high p_T hadrons come from jets, then we have a prediction for R_{AA}:

$$\frac{\left(\frac{dN^{K^\pm}}{dp_T}/\frac{dN^{\pi^\pm}}{dp_T}\right)^{\text{medium}}}{\left(\frac{dN^{K^\pm}}{dp_T}/\frac{dN^{\pi^\pm}}{dp_T}\right)^{\text{vacuum}}} > 1$$

$$\frac{\left(\frac{dN^{K^\pm}}{dp_T}\right)^{\text{medium}}}{\left(\frac{dN^{K^\pm}}{dp_T}\right)^{\text{vacuum}}} > \frac{\left(\frac{dN^{\pi^\pm}}{dp_T}\right)^{\text{medium}}}{\left(\frac{dN^{\pi^\pm}}{dp_T}\right)^{\text{vacuum}}}$$

$$R_{AA}^{K^\pm} > R_{AA}^{\pi^\pm}$$



(*Eur. Phys. J.* C. 55,293-302 (2008)).

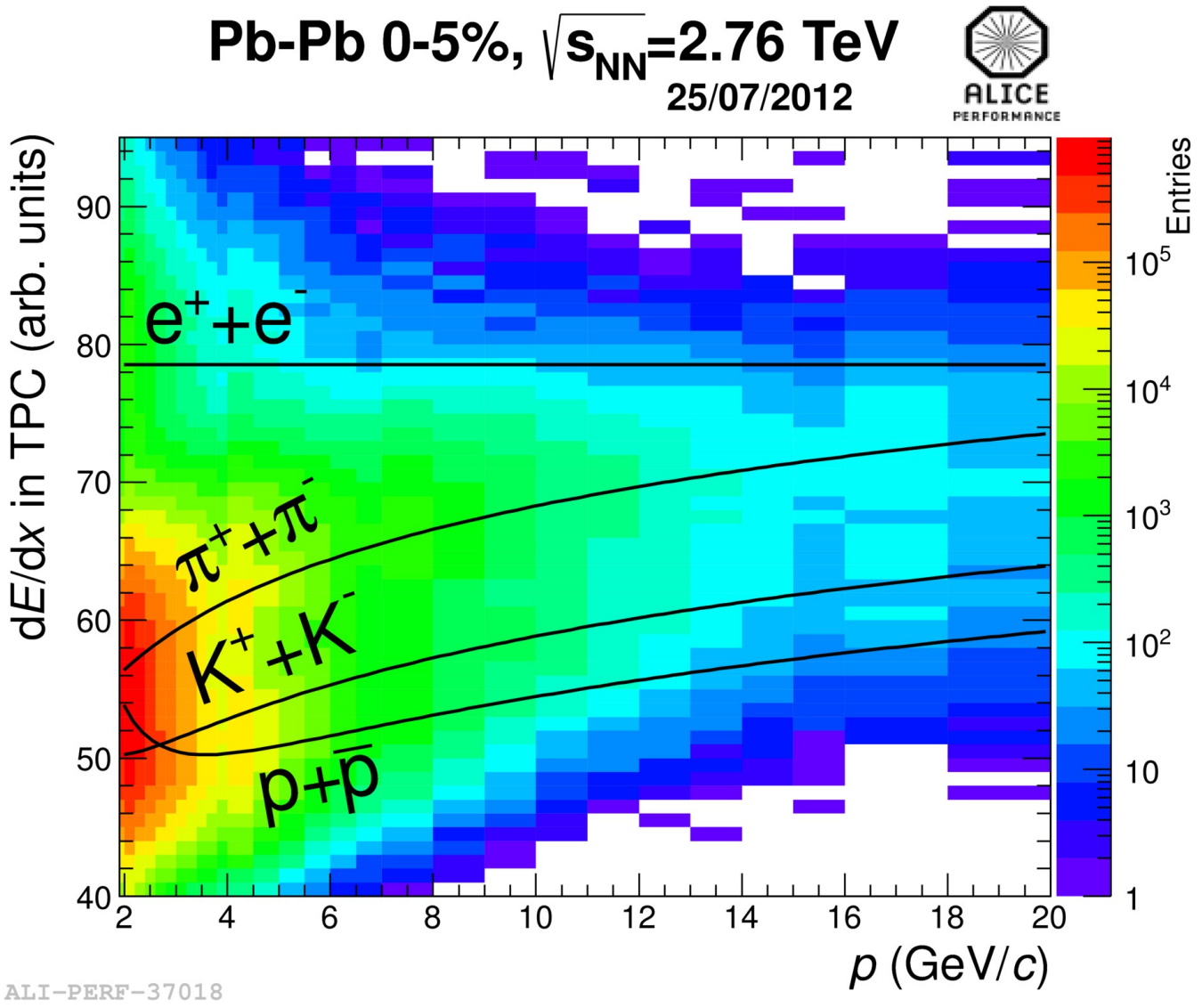
PID at high p_T, TPC-dE/dx

All particle species are described by just two curves:

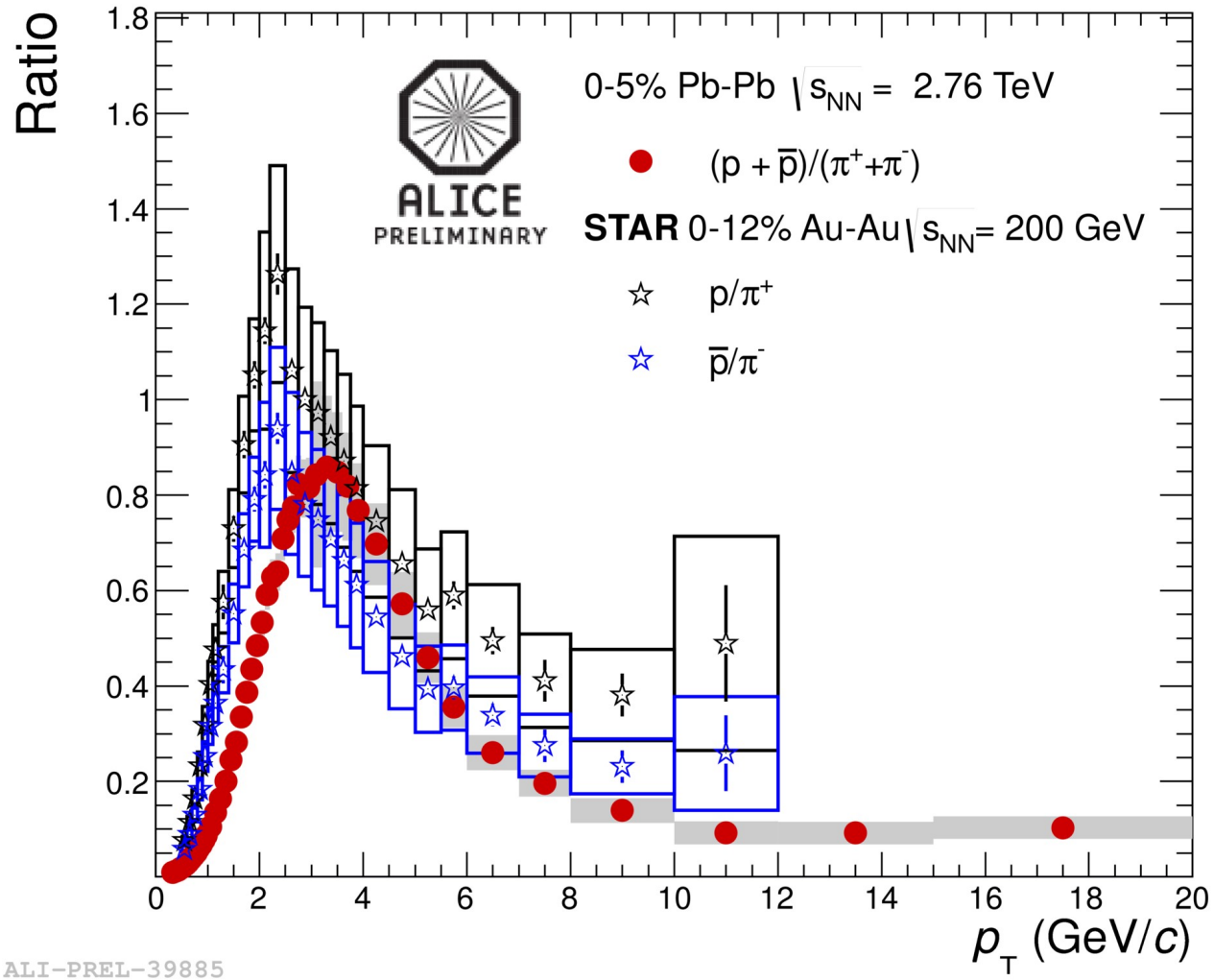
$$\langle \frac{\mathrm{d}E}{\mathrm{d}x} \rangle (\beta\gamma)$$

$$\sigma^{rel}(\langle \frac{\mathrm{d}E}{\mathrm{d}x} \rangle)$$

This is quite important for: kaons and the high p_T region where no PID can be used.

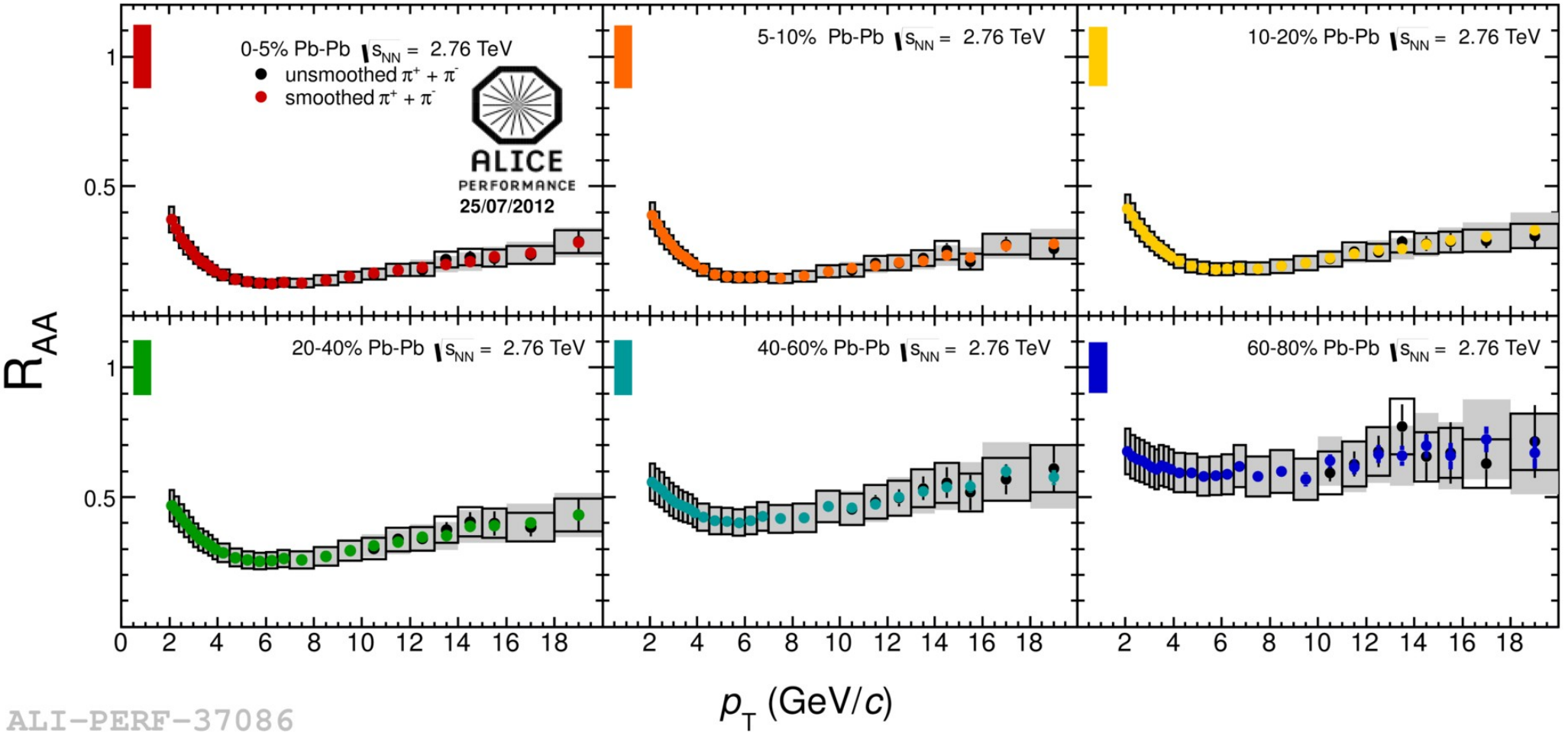


Proton/Pion (ALICE vs STAR)

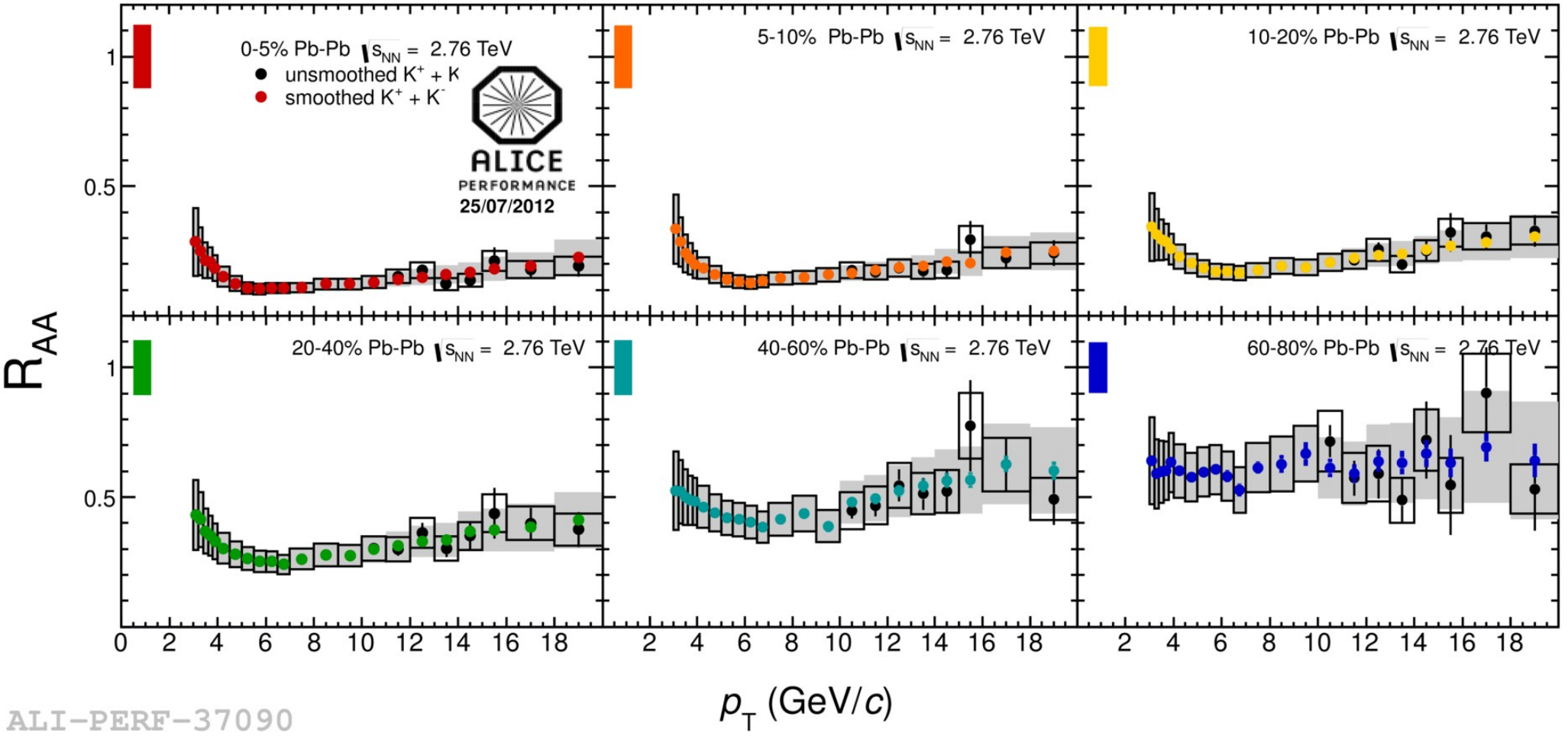


Protons from STAR not feed-down corrected.

R_{AA} for charged pions



R_{AA} for charged kaons



R_{AA} for (anti-)protons