RICH 2016

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ALICE

Contribution of the High Momentum Particle Identification Detector (HMPID) to the ALICE physics program

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Outline

- ALICE goal
- HMPID PID performance and procedure
- ALICE spectra evaluation strategy
- $\pi^{\pm}$, $K^{\pm}$ and p(anti-p) inclusive spectra results
  - pp 7 TeV results
  - Pb-Pb results
  - p-Pb results
  - pp 13 TeV results
- Deuterons PID
- Conclusions

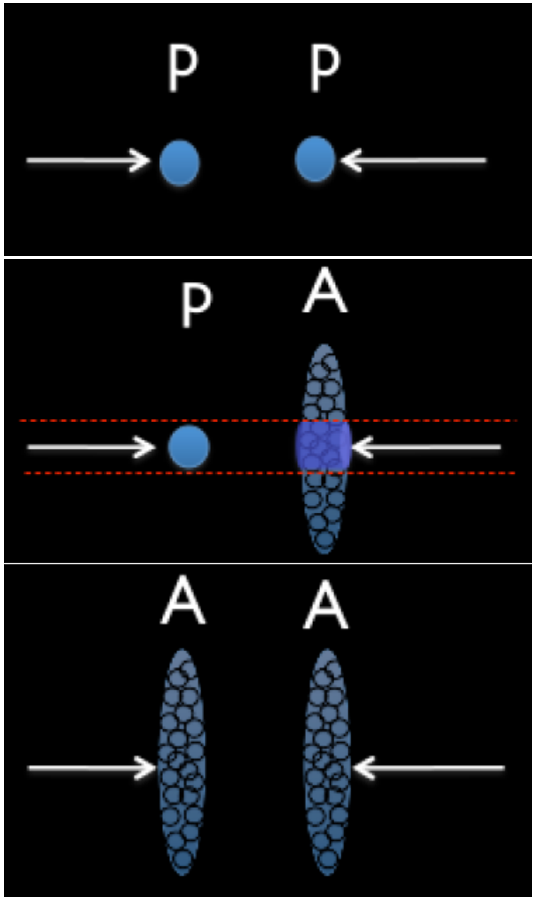
ALICE goal

ALICE is designed to study the physics of strongly interacting matter under extremely high temperature and energy densities to investigate the properties of the quark-gluon plasma.

- Proton-proton collisions:
  - high energy QCD reference.
  - collected pp data at $\sqrt{s}$ = 0.9 TeV, 2.76 TeV, 7 TeV, 8 TeV, 13 TeV (2009, 2010, 2011, 2012, 2016,2016)

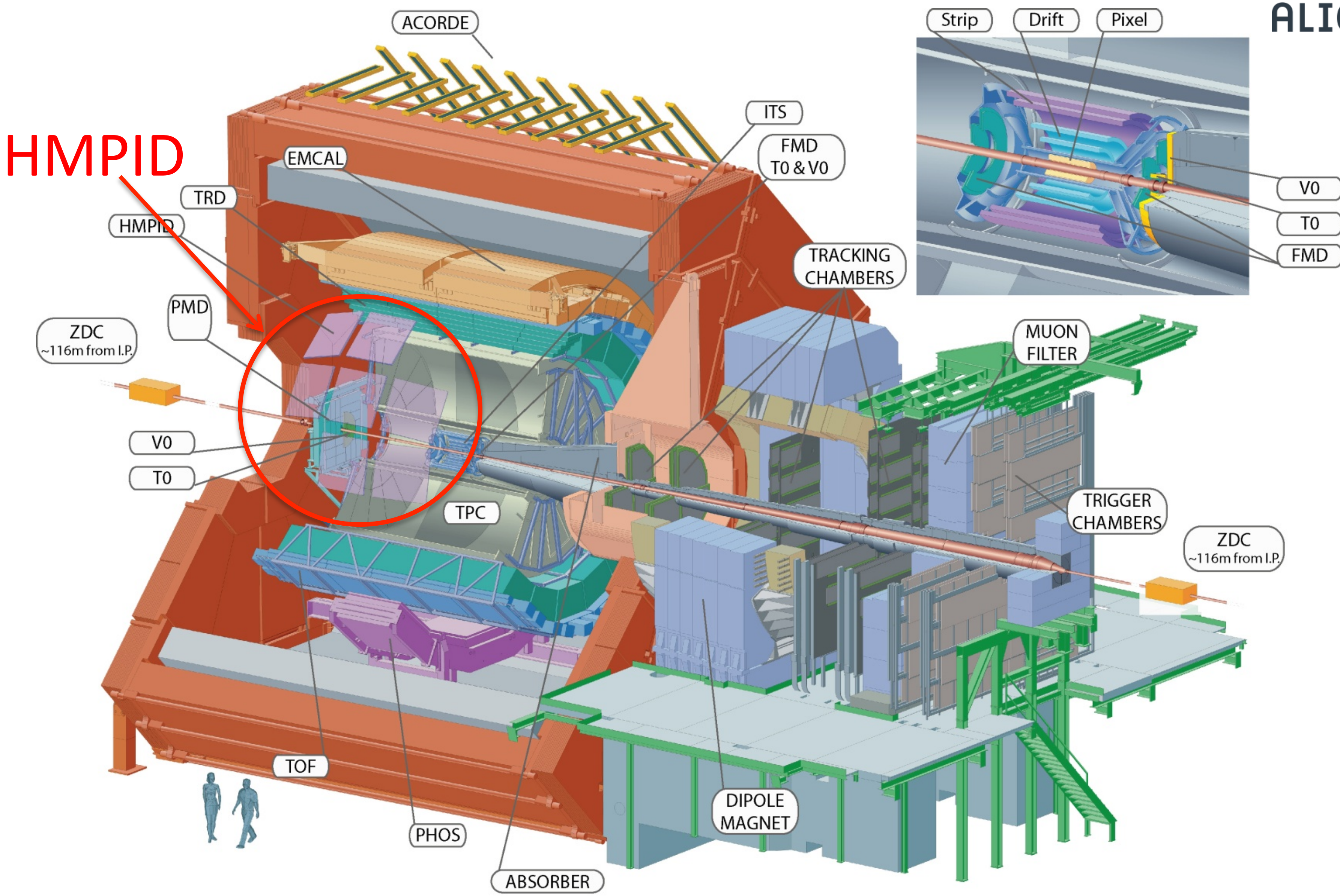
- proton-nucleus collisions:
  - initial state/cold nuclear matter.
  - collected p-Pb data at $\sqrt{s_{NN}}$ = 5.02 TeV (2012, 2013)

- nucleus-nucleus collisions:
  - quark-gluon plasma formation!
  - collected Pb-Pb data at $\sqrt{s_{NN}}$ = 2.76 TeV, 5.02 TeV (2010, 2011, 2015)

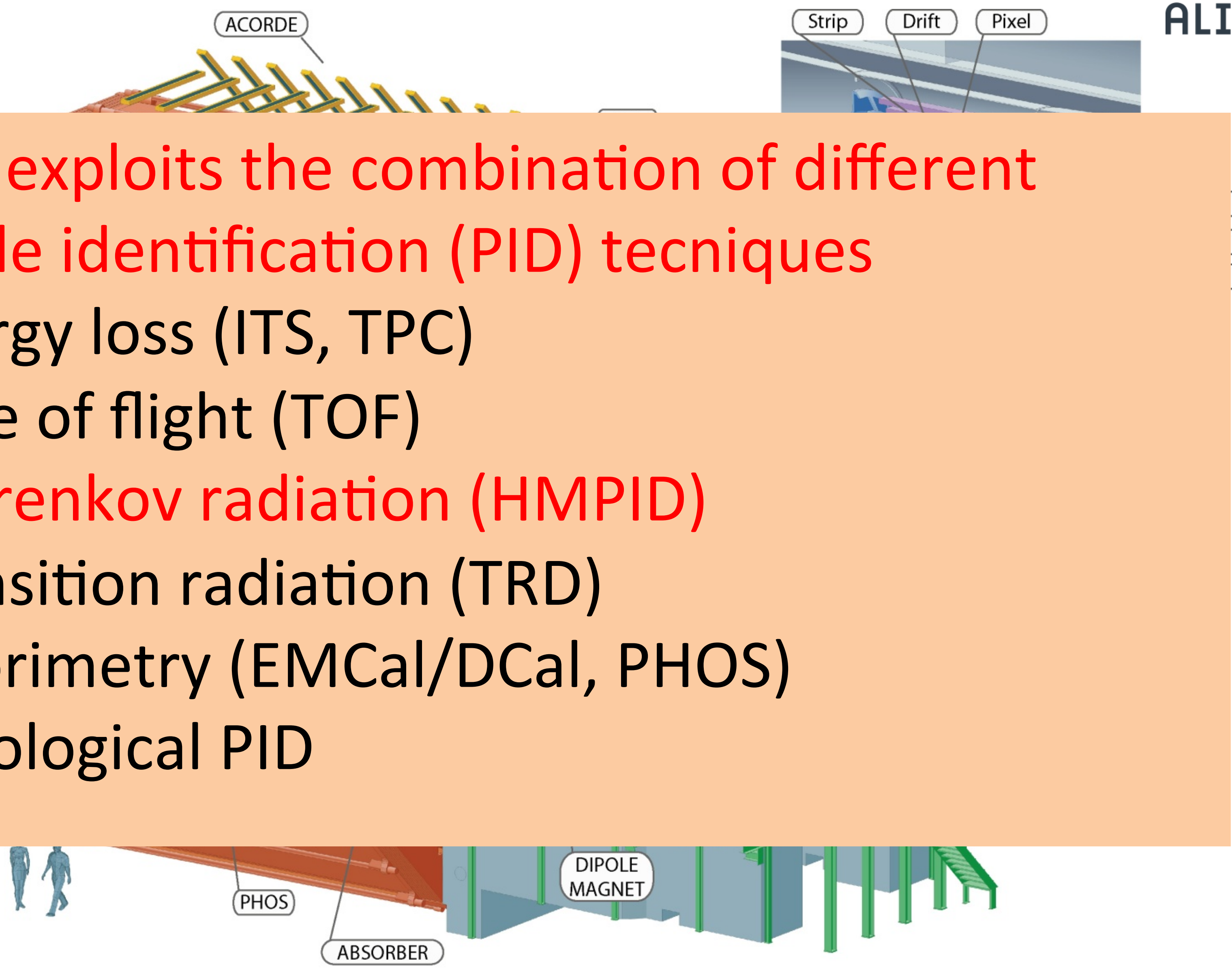


ALICE has measured the yields of produced charged pions, kaons and protons in a wide momentum range and in several colliding systems.

ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID



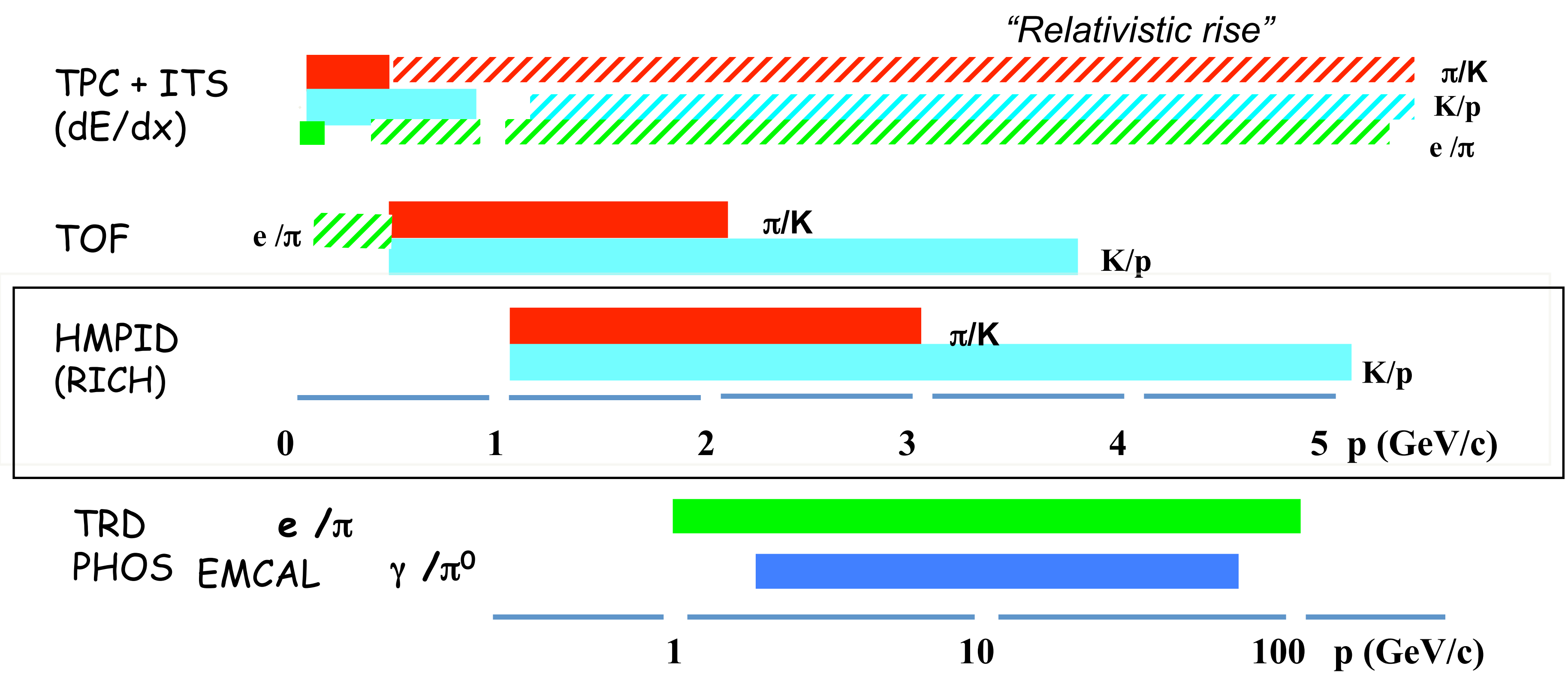
ALICE detectors: $\pi^{\pm}$, $K^{\pm}$ and $p(\bar{p})$ PID



ALICE exploits the combination of different particle identification (PID) tecniques

- Energy loss (ITS, TPC)
- Time of flight (TOF)
- Cherenkov radiation (HMPID)
- Transition radiation (TRD)
- Calorimetry (EMCal/DCal, PHOS)
- Topological PID

Particle Identification in ALICE: momentum ranges



Solid: track-by-track

Dashed: only statistical

HMPID performance

•The ALICE-HMPID (**H**igh **M**omentum **P**article **I**dentification **D**etector) performs charged particle track-by-track identification by means of the measurement of the emission angle of Cherenkov radiation and of the momentum information provided by the tracking devices.

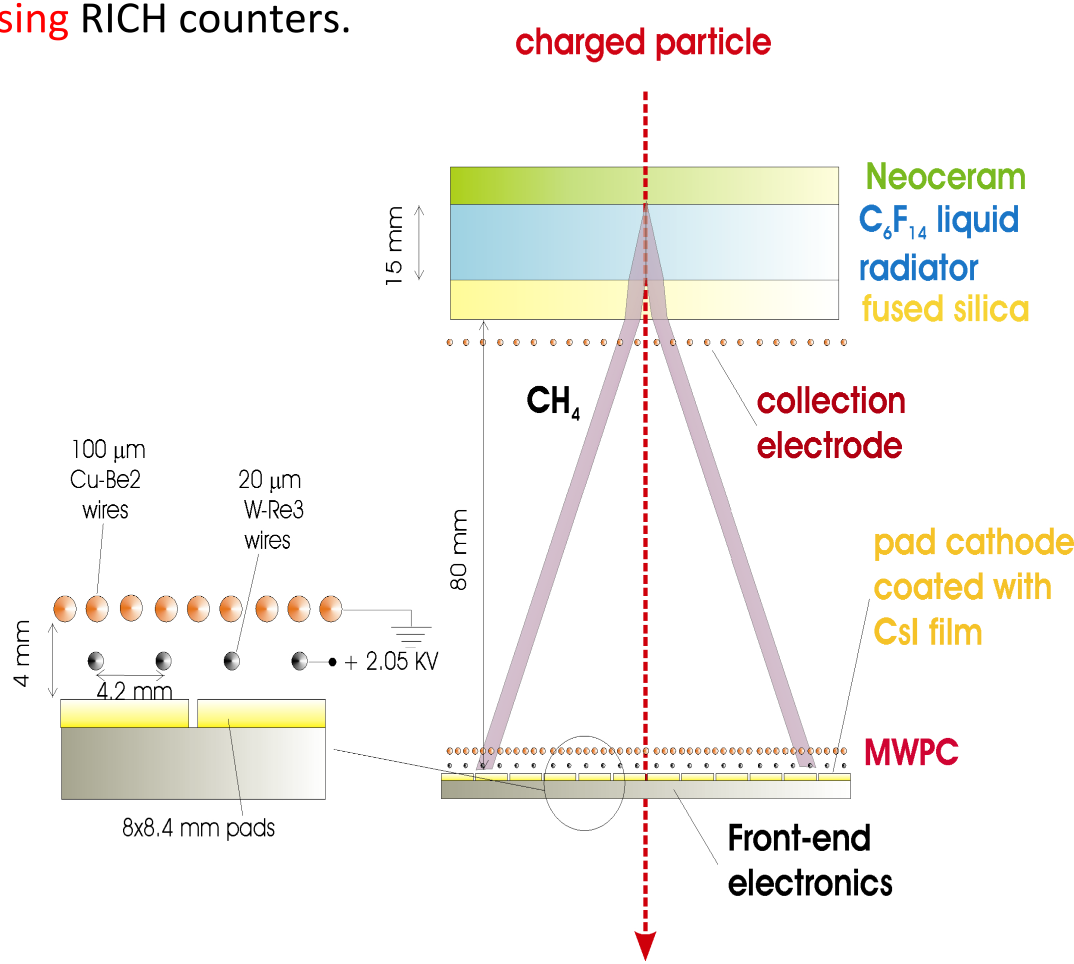
• It consists of seven identical proximity focusing RICH counters.

RADIATOR
15 mm liquid C_6F_{14},
n ~ 1.2989 @ 175nm, β_{th} = 0.77

PHOTON CONVERTER
Reflective layer of CsI
QE ~ 25% @ 175 nm.
The largest scale (11 m^2) application of CsI photo-cathodes in HEP
≈ 5 % of TPC acceptance

PHOTOEL. DETECTOR
- MWPC with CH_4 at atmospheric pressure (4 mm gap) HV = 2050 V.

- Analogue pad readout



For more details on detector structure see G. De Cataldo talk!

PID procedure with HMPID

Identification on statistical basis: low multiplicity events

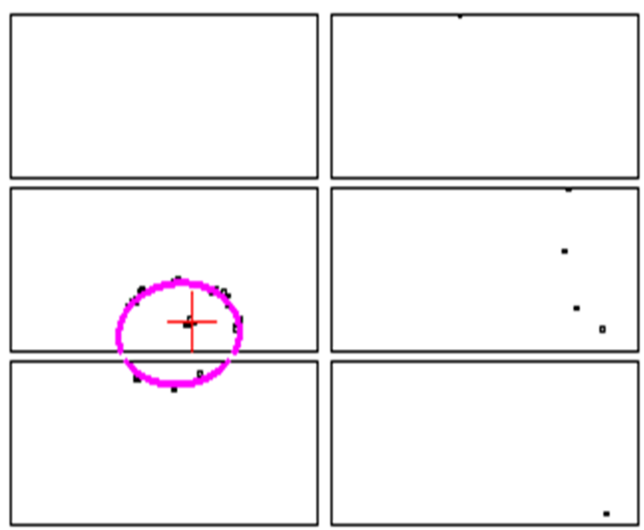
the particle yields are evaluated from a three-Gaussian fit to the Cherenkov angle distribution in a narrow transverse momentum range. The function used is the following:

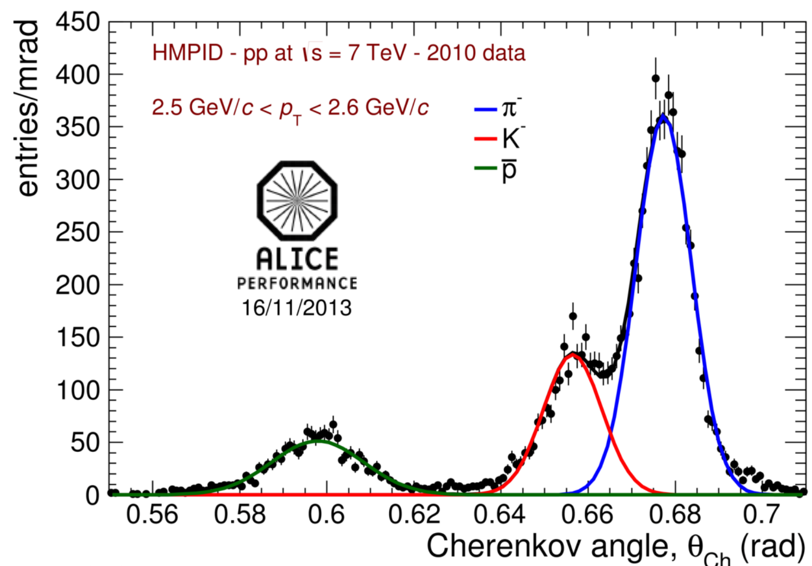
$$f(\theta) = \frac{Y_\pi}{\sigma_\pi\sqrt{2\pi}} e^{-\frac{(\theta-\langle\theta_\pi\rangle)^2}{2\sigma_\pi^2}} + \frac{Y_K}{\sigma_K\sqrt{2\pi}} e^{-\frac{(\theta-\langle\theta_K\rangle)^2}{2\sigma_K^2}} + \frac{Y_p}{\sigma_p\sqrt{2\pi}} e^{-\frac{(\theta-\langle\theta_p\rangle)^2}{2\sigma_p^2}}$$

$<\theta_i>$ = means of the Cherenkov angle distributions
σ_i, = standard deviation of the Cherenkov angle distributions.
Y_i = integral of the single Gaussian functions

- 9 parameters to be calculated, the three mean values, the three sigma values and the three yields.
- Mean and sigma values are know and fixed in the fitting.

pp event display





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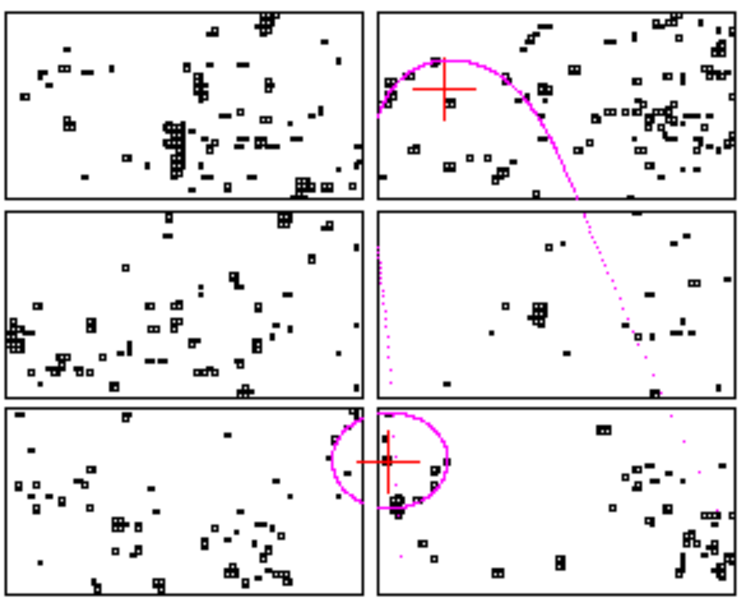
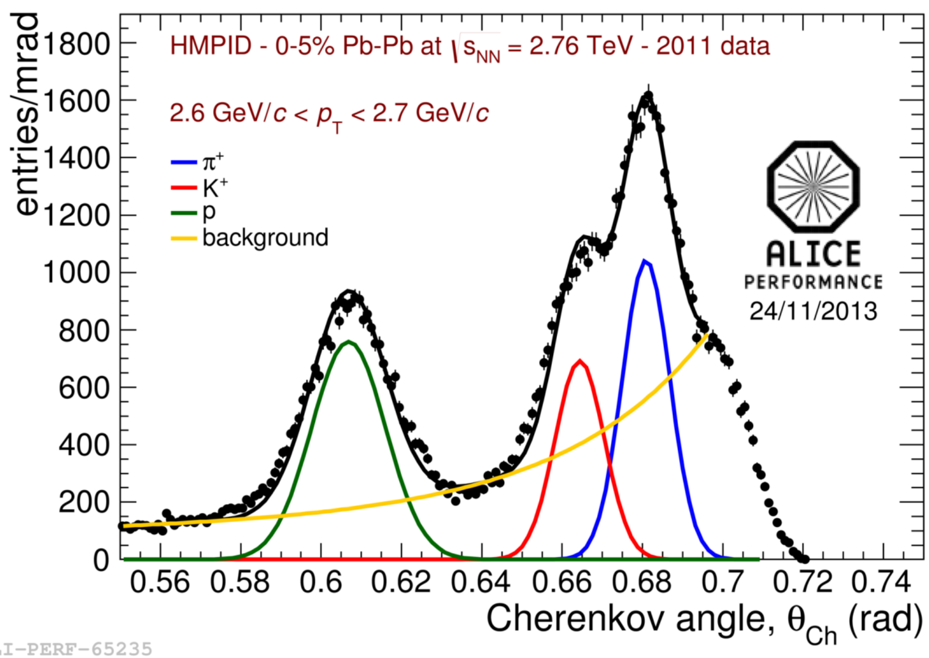
PID procedure with HMPID

Identification on statistical basis: high multiplicity events (central Pb-Pb collisions)

- the three Gaussian distributions in a given transverse momentum bins are convoluted with a background distribution;
- Such distribution increases with the Cherenkov angle value;
- It is due to mis-identification in the high occupancy events:
  - larger is the angle value larger is the probability to find background;
- In the yield extraction procedure the background function has to be convoluted with the three-Gaussian one.

Pb-Pb event display

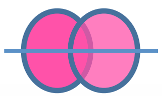




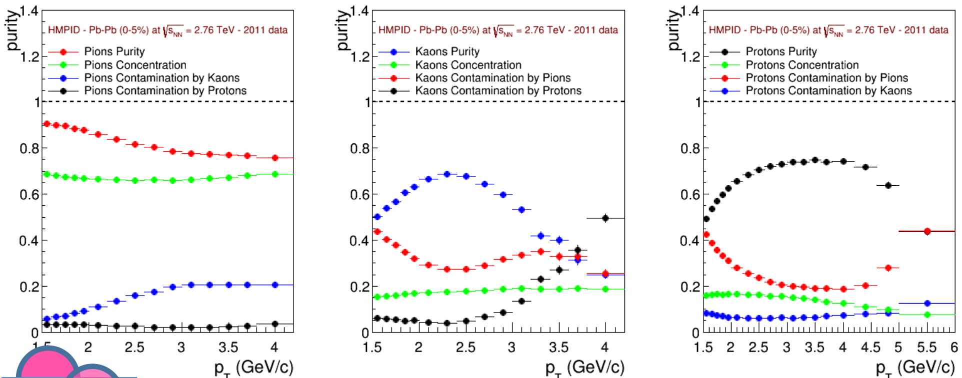
PID procedure with HMPID

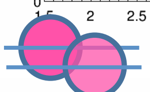
Identification on track-by-track basis

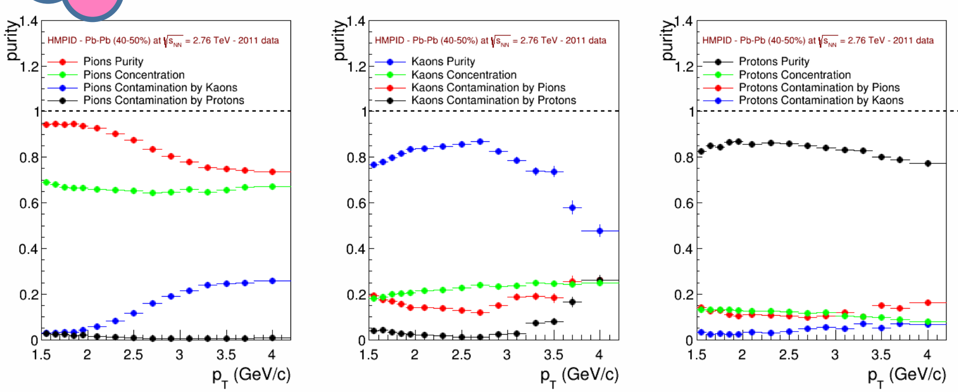
- From the knowledge of the expected Cherenkov angle value and the expected theoretical standard deviation, it is possible to calculate the values of two PID estimators:
  - the probability to be one of the charged hadron specie;
  - the difference between the measured angle value and the expected theoretical one in sigma units;



$$N_{sigmas} < 2$$







$$N^{i}_{sigmas} = \frac{\left|\theta_{exp} - \theta^{i}_{theor}\right|}{\sigma^{i}}$$

$$p_i = \frac{N^{t}_{id}(i)}{N_{id}(i)} \qquad c_i = \frac{N^{w}_{id}(i)}{N_{id}(i)}$$

$$i = \pi, K, p$$

p_i = purity, c_i = contamination
$N_{id}(i)$ = number of particles identified as type i
$N_{id}^{t}(i)$ = number of true particles of type i identified as type i
$N_{id}^{w}(i)$ = number of non-type i particles identified as particles of type i

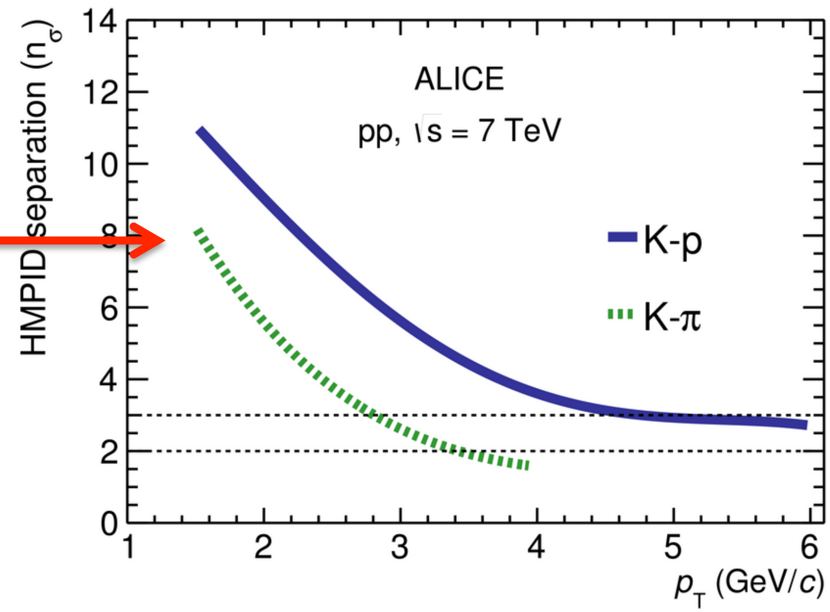
ALICE charged hadrons yields evaluation strategy

- To measure the production of pions, kaons and protons over a wide p_T range, results from five different independent PID techniques/detectors, namely ITS, TPC, TOF, HMPID and kink-topology (for kaons), are combined.

- In their overlap p_T regions the spectra from the different PID techniques are consistent within uncertainties:
  - the results are combined in the overlapping ranges using a weighted mean with the independent systematic uncertainties as weights.

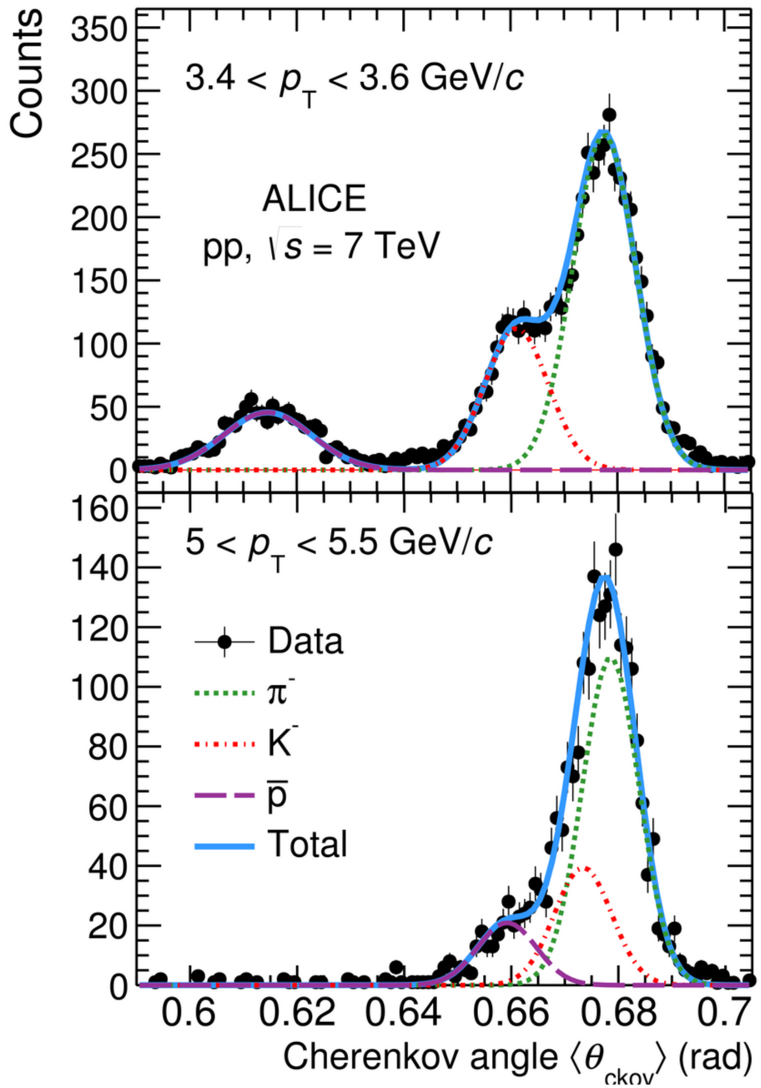
- The HMPID constrains the uncertainty of the measurements in the transition region between the TOF and TPC relativistic rise methods (around p_T = 3 GeV/c). It both improves the precision of the measurement and validates the other methods in the region where they have the worst PID separation.

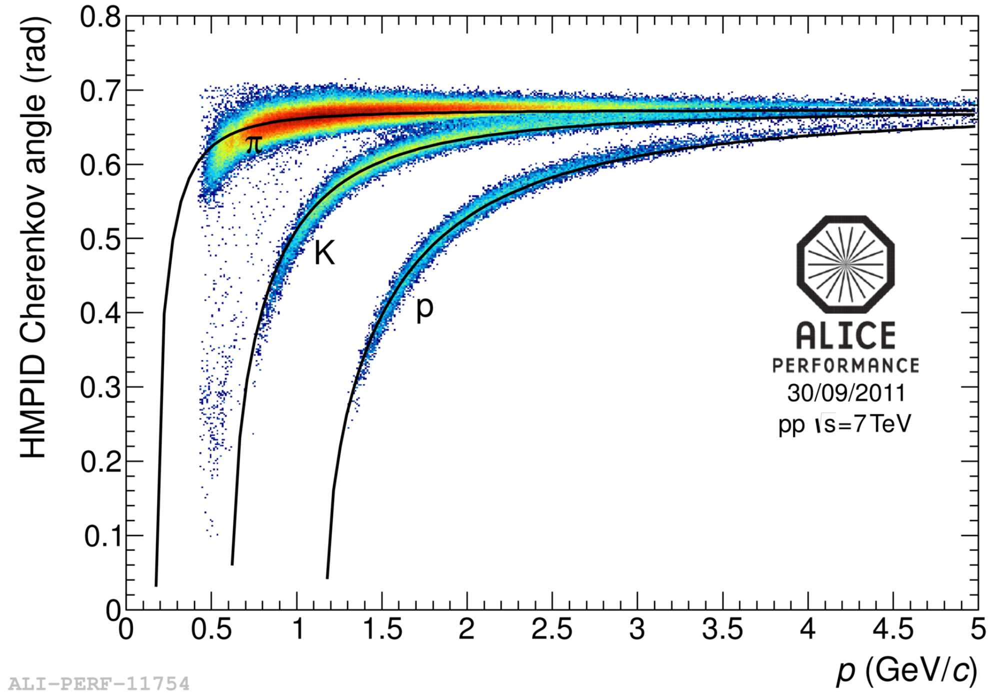
HMPID separation power in σ unit as a function of p_T



Charged hadrons spectra: pp 7 TeV

Eur. Phys. J. C (2015) 75:226





PID range

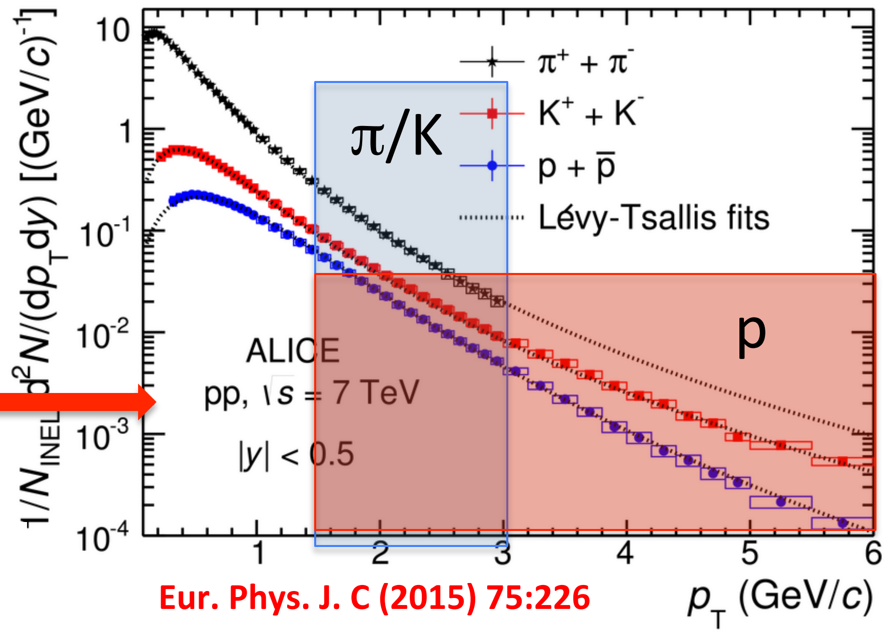
π/K → 1.5 – 3 GeV/c

P → 1.5 – 6 GeV/c

Charged hadrons spectra: pp 7 TeV

π/K HMPID | p HMPID

π, K and p spectra, resulting from the combination of the information provided by 5 different analyses (dE/dx, TOF, Cherenkov, kinks topology for kaons).



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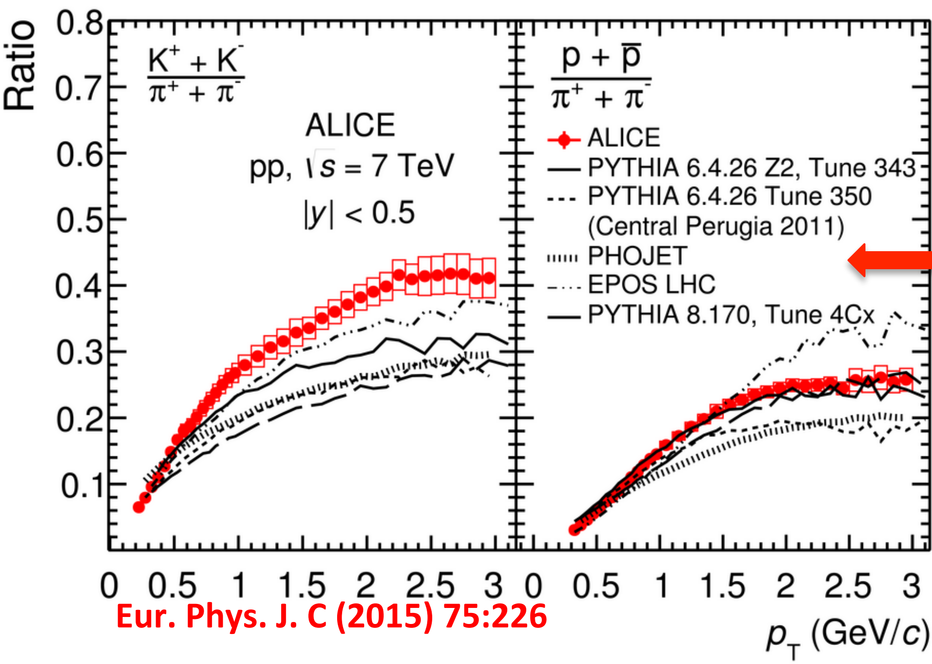
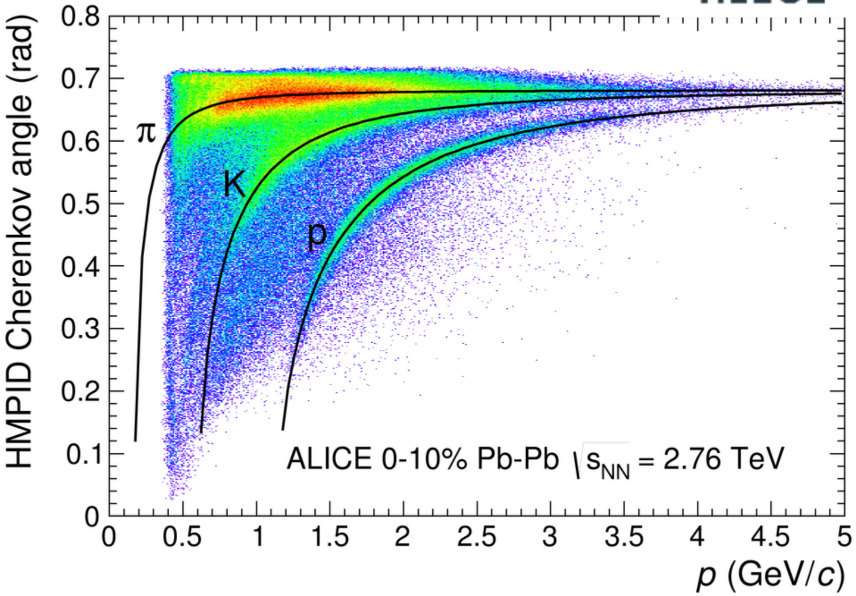


Eur. Phys. J. C (2015) 75:226

- $(K^+ + K^-)/(\pi^+ + \pi^-)$ and $(p + p)/(\pi^+ + \pi^-)$ ratios as a function of p_T compared with some event generators.
- $(K^+ + K^-)/(\pi^+ + \pi^-)$ ratio increases from 0.05 at p_T = 0.2 GeV/c up to 0.45 at p_T ~ 3 GeV/c with a slope that decreases with increasing p_T.

Charged hadrons spectra: Pb-Pb 2.76 ATeV

Performance

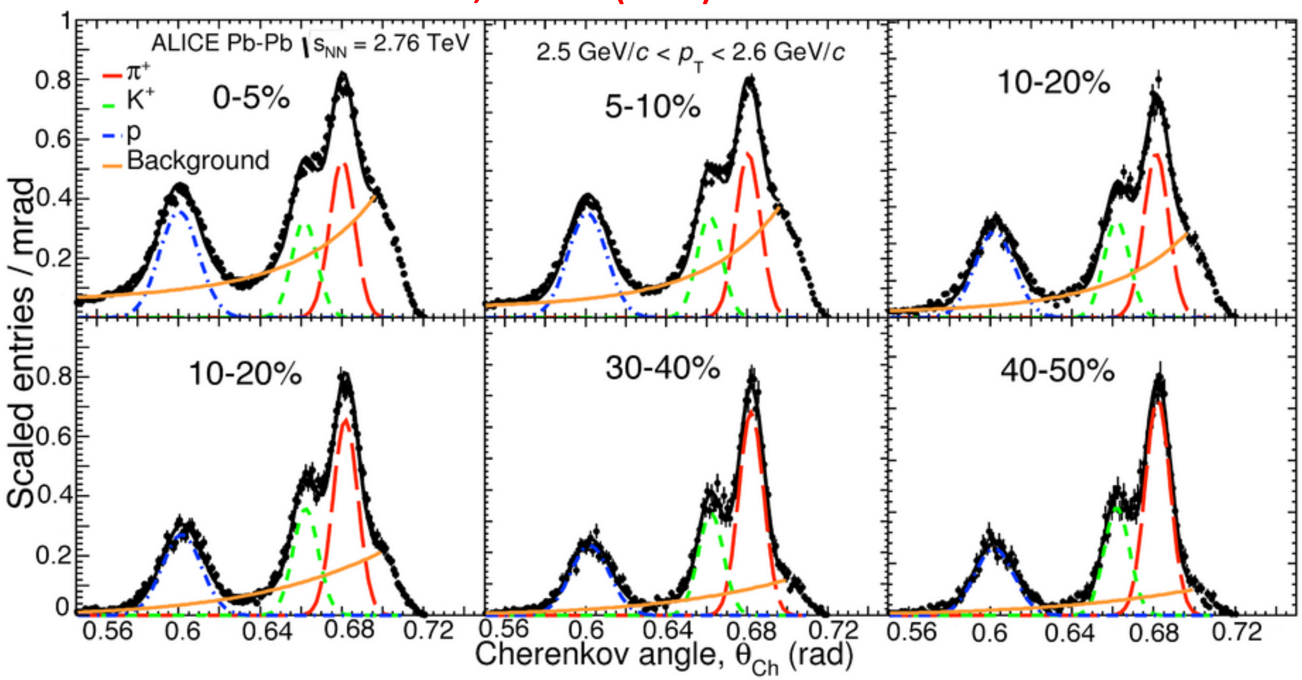


PID range

$\pi/K \rightarrow$ 1.5 – 4 GeV/c

$p \rightarrow$ 1.5 – 6 GeV/c

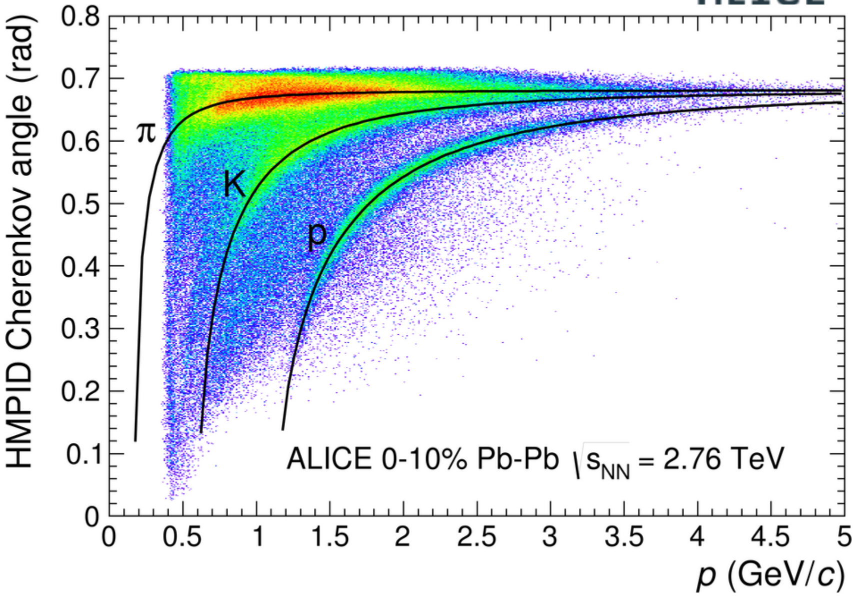
PHYSICAL REVIEW C 93, 034913 (2016)



- HMPID used in collisions centrality range 0-50%
- Centrality estimate based on V0 detector measurements.
- V0: trigger detector at forward rapidity.

Charged hadrons spectra: Pb-Pb 2.76 ATeV

Performance



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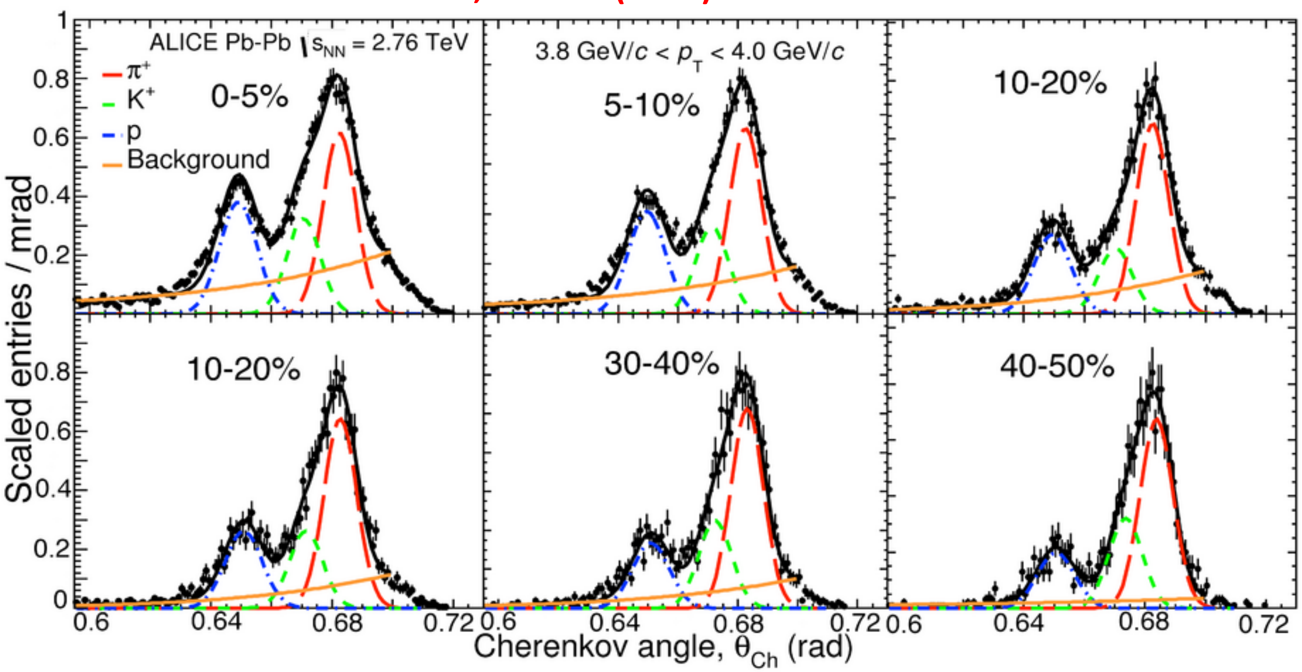

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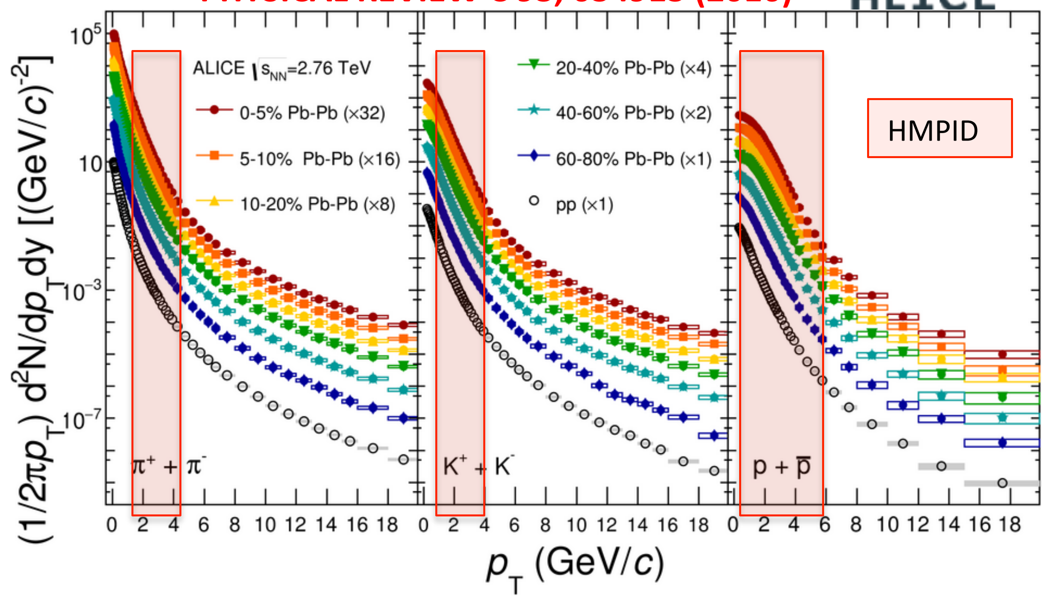
Charged hadrons spectra: Pb-Pb 2.76 ATeV

- For $p_T < 3$ GeV/c a hardening of the spectra is observed going from peripheral to central events. This effect is mass dependent and is characteristic of hydrodynamic flow.

- For high p_T (>10 GeV/c) the spectra follow a power law shape as expected from pQCD.

PHYSICAL REVIEW C 93, 034913 (2016)



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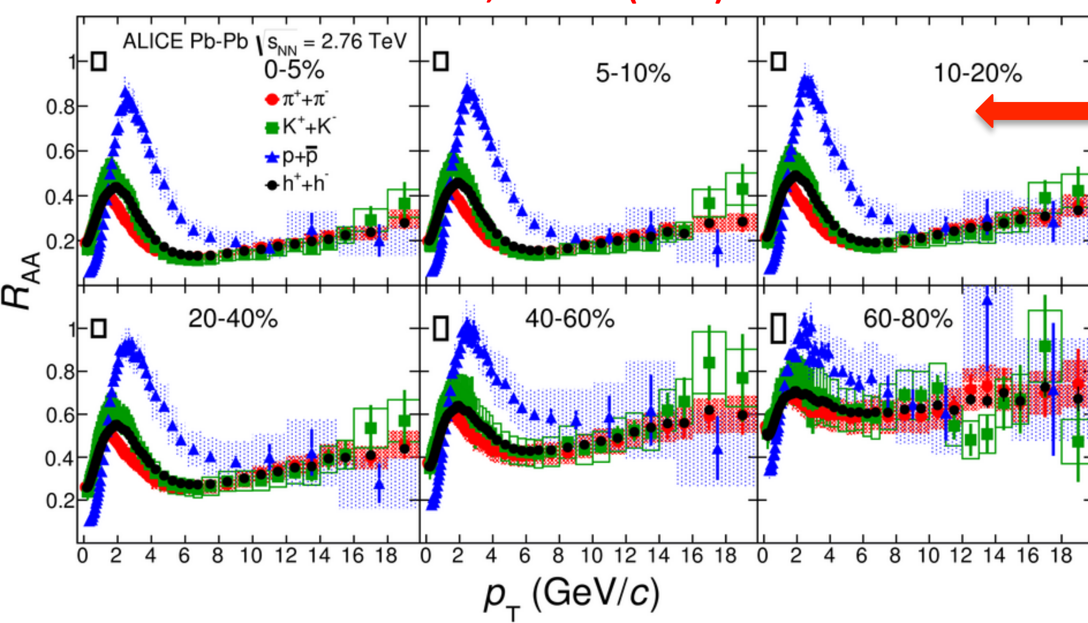


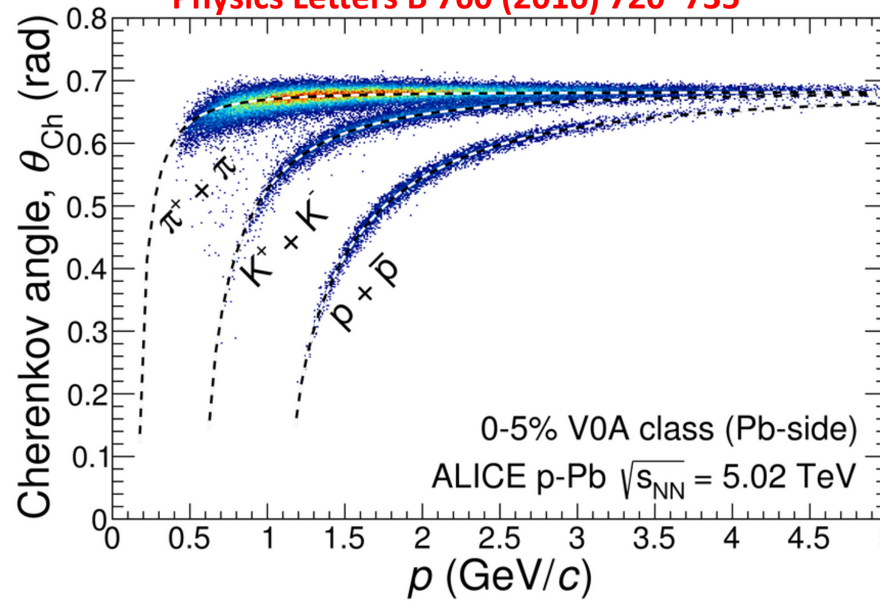
$$R_{AA} = \frac{d^2N_{\mathrm{id}}^{AA}/dy\,dp_{\mathrm{T}}}{\langle T_{AA}\rangle d^2\sigma_{\mathrm{id}}^{\mathrm{pp}}/dy\,dp_{\mathrm{T}}}$$

- For $p_T < \approx 8 - 10$ GeV/c: R_{AA} for π and K are compatible and are smaller than R_{AA} for p.

- At high p_T: R_{AA} for π, K and p are compatible.

Charged hadrons spectra: p-Pb 5.02 TeV

Physics Letters B 760 (2016) 720–735



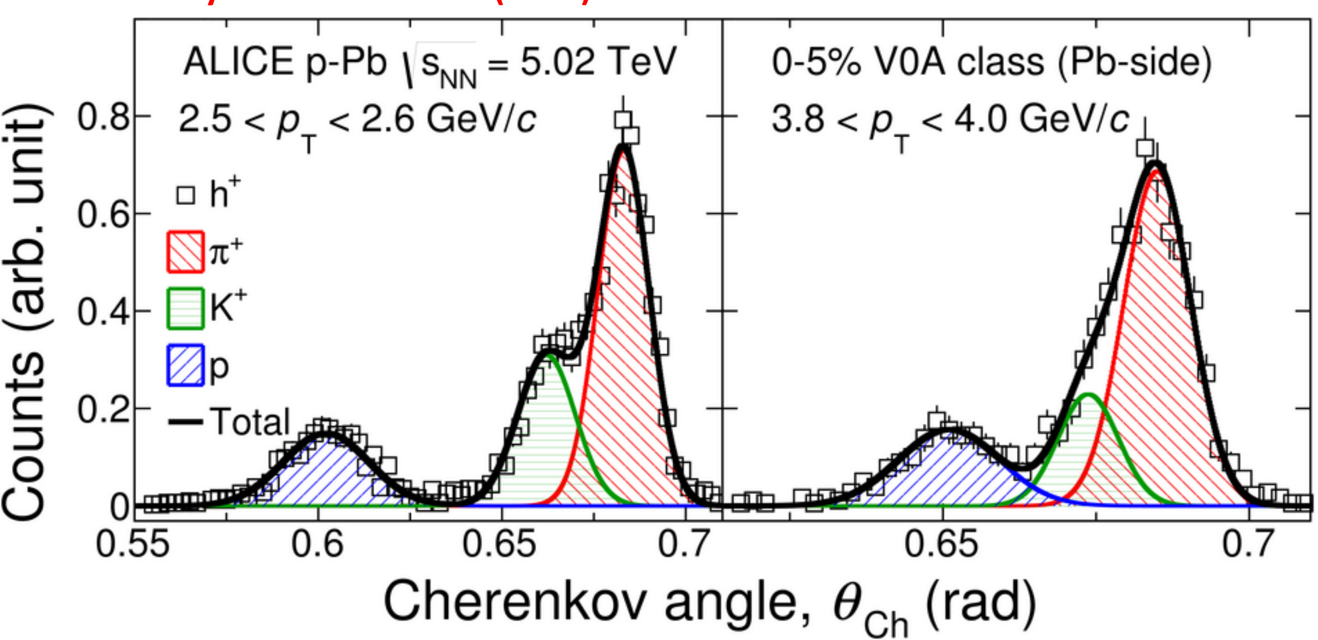
Performance

PID range

π, K: 1.5 – 4 GeV/c

p: 1.5 – 6 GeV/c

Physics Letters B 760 (2016) 720–735

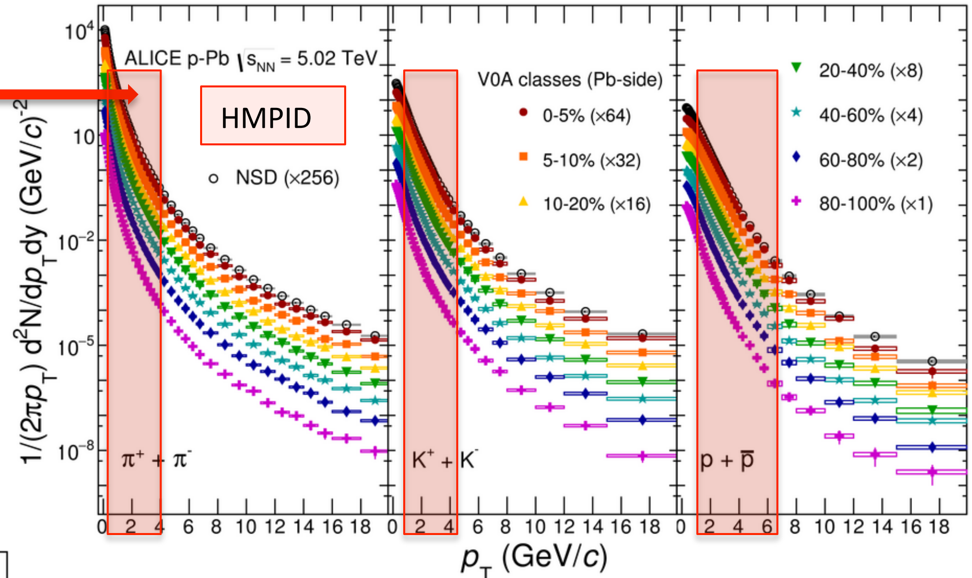


- HMPID used in collisions multiplicity range: 0 – 100 %
- multiplicity estimate based on V0 detector measurements.

Charged hadrons spectra: p-Pb 5.02 TeV

Physics Letters B 760 (2016) 720–735

- Hardening with multiplicity and particle mass
- Reminiscent of observed effects in Pb-Pb Attributed to radial flow/recombination (Indication for collective effects in p-Pb?!)



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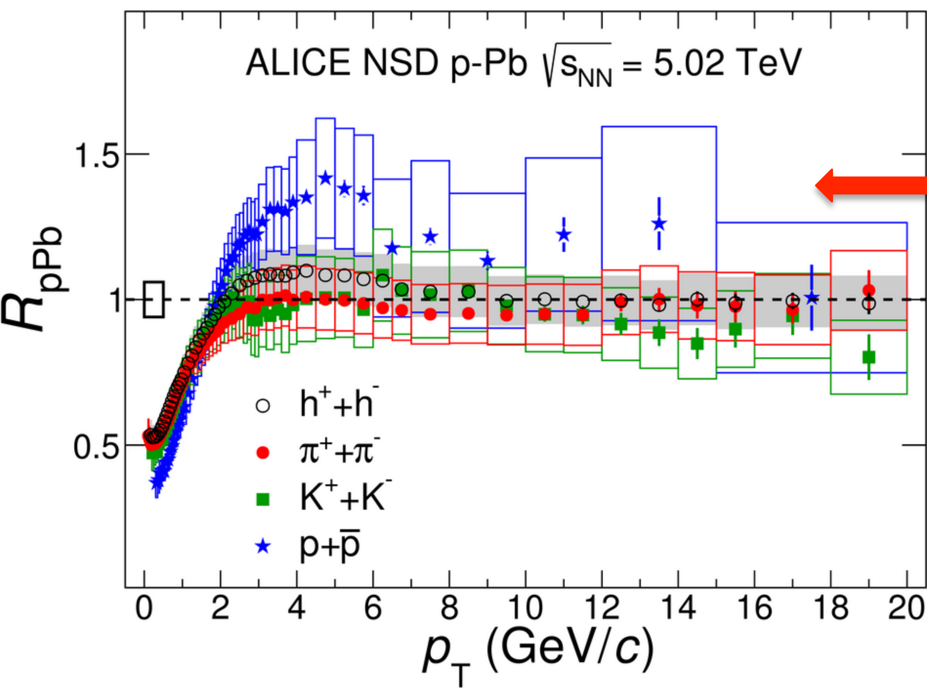
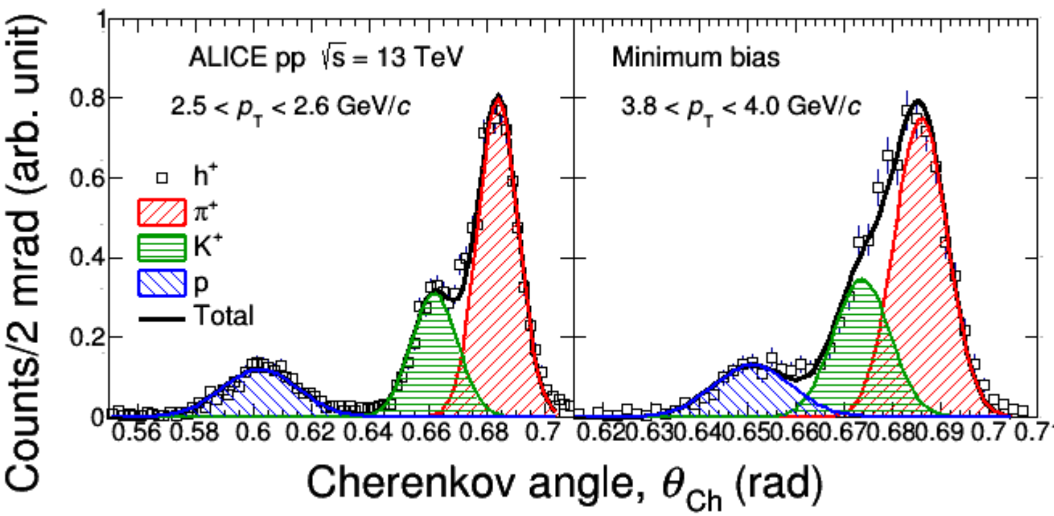


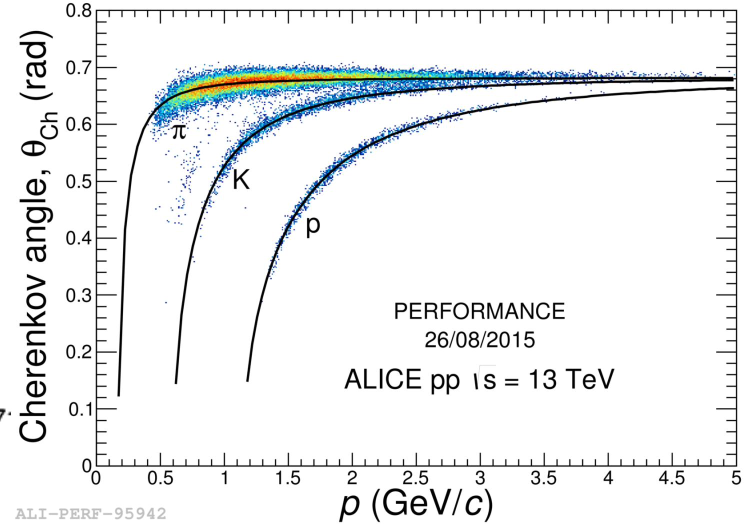
$$R_{pPb} = \frac{d^2N_{pPb}/dy\,dp_T}{\langle T_{pPb}\rangle d^2\sigma_{pp}^{INEL}/dy\,dp_T}$$

- Protons show peak at intermediate p_T
- R_{pPb} of π and K not show peak and flat above 2 GeV/c
- mass ordering in the Cronin peak, strong enhancement of protons
- no suppression at high p_T (> 8-10 GeV/c)

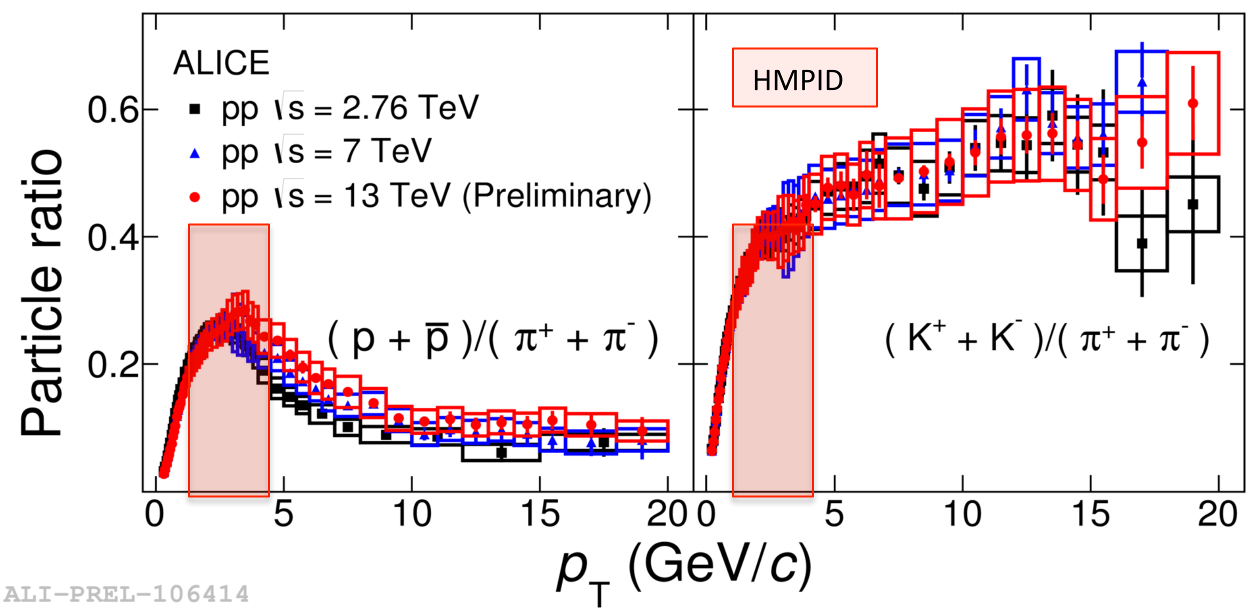
Charged hadrons spectra: pp 13 TeV

Performance





Results



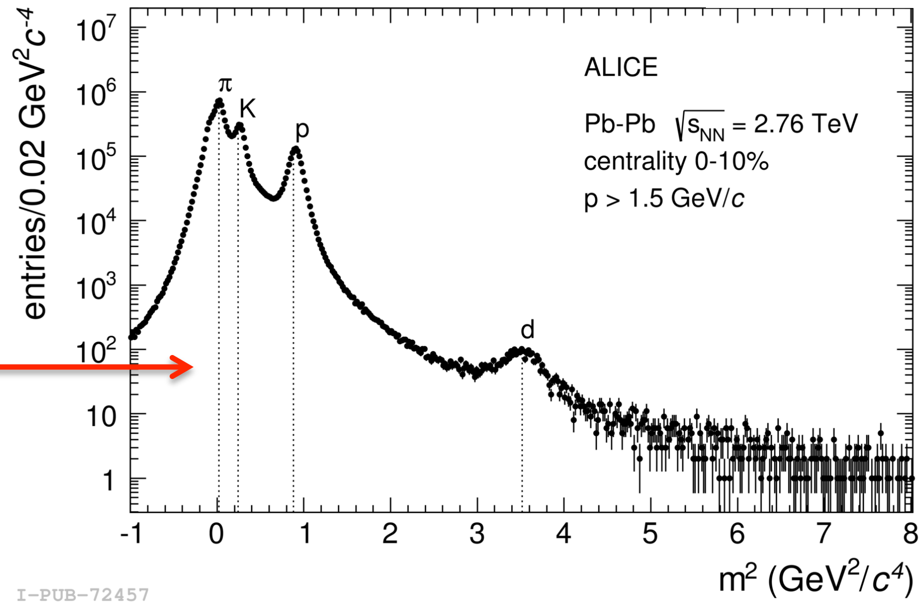
- **p/π ratio** shift towards higher p_T for higher $\sqrt{s}$
- **K/π ratio** no significant modifications

Deuteron identification

Deuterons yield is not enough to allow measurements in HMPID but in central (0-10%) Pb-Pb collisions, by means of statistical unfolding on the mass distribution (not on Cherenkov angle one!)

$$m^2 = p^2(n^2 \cos^2\theta_{ckov} - 1)$$

n = refractive index



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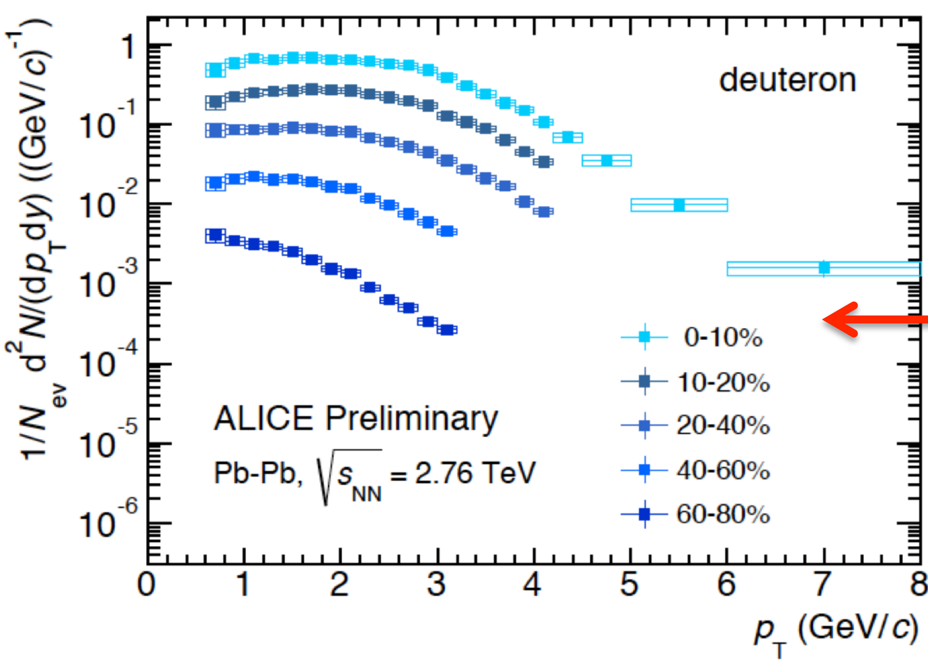

Deuteron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

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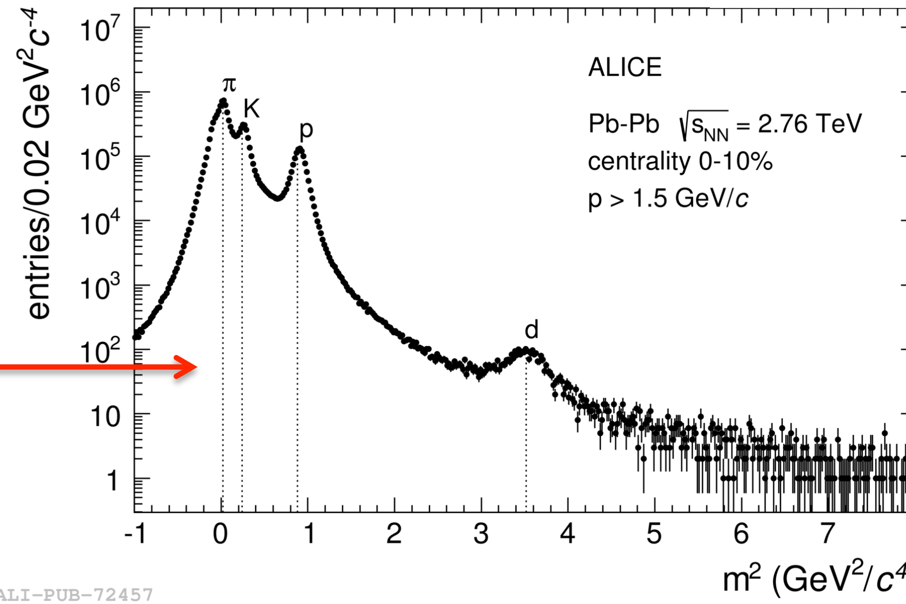
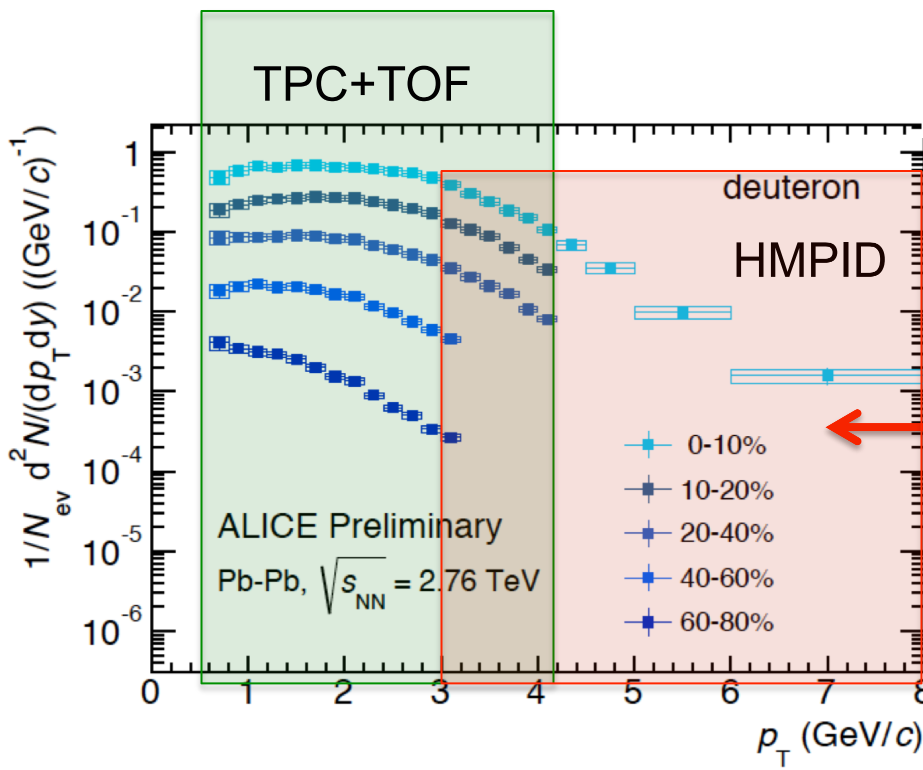




Deuteron spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Good matching with TPC+TOF measurements!

Conclusions

- ALICE successfully collected the pp, p-Pb and Pb-Pb collisions data provided by LHC.

- Inclusive hadrons spectra are relevant tools to study the properties of the medium created in the high energy collisions.

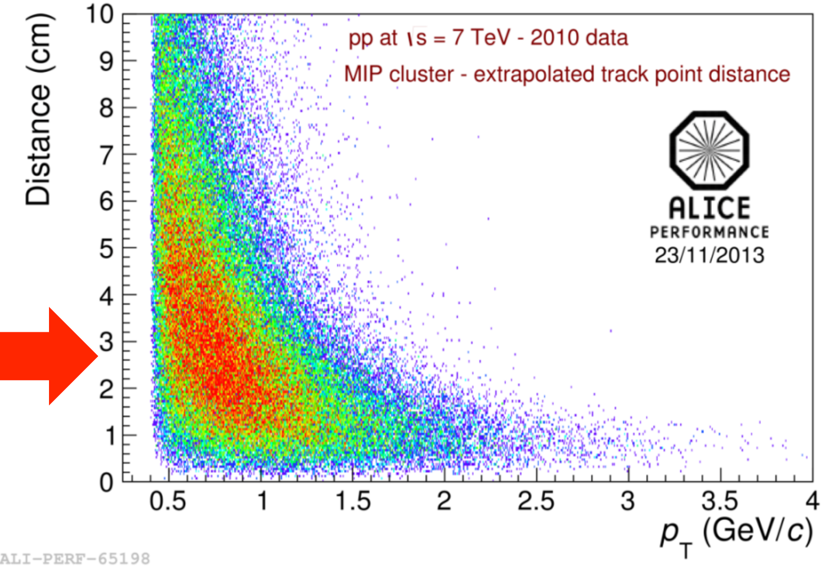
- HMPID detector presented so far optimal PID performance, successfully participating to the ALICE physics program
  - by means of statistical unfolding HMPID data constrains the charged hadrons measurements in the p_T region around 3 GeV/c where other technique present poor capability.
  - Results from LHC RUN1 data has been presented; RUN2 data analysis already started, more results in the next future.

- Track-by-track identification with HMPID is exploited for two particle correlation study to evaluate protons/pions ratio in the bulk and jets.

Backup

Pattern recognition with HMPID

- A primary track extrapolated from the internal tracking devices has to match with a MIP cluster. This is mandatory for an efficient reconstruction in events with high occupancy in HMPID
- For every cluster in the event, the Cherenkov angle is evaluated (if exists)



$D_{trk\text{-}MIP}$ (cm)

impact track parameter

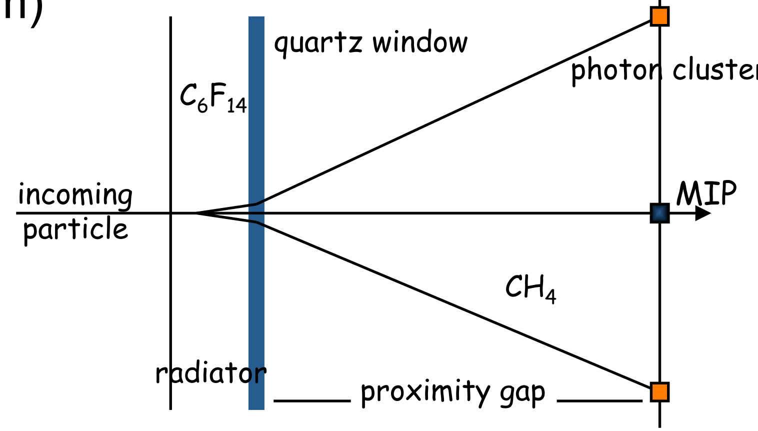
$$(x,y) \rightarrow ((x_p, y_p, \theta_p, \varphi_p), \eta_c)$$

cluster coordinate

Cherenkov angle

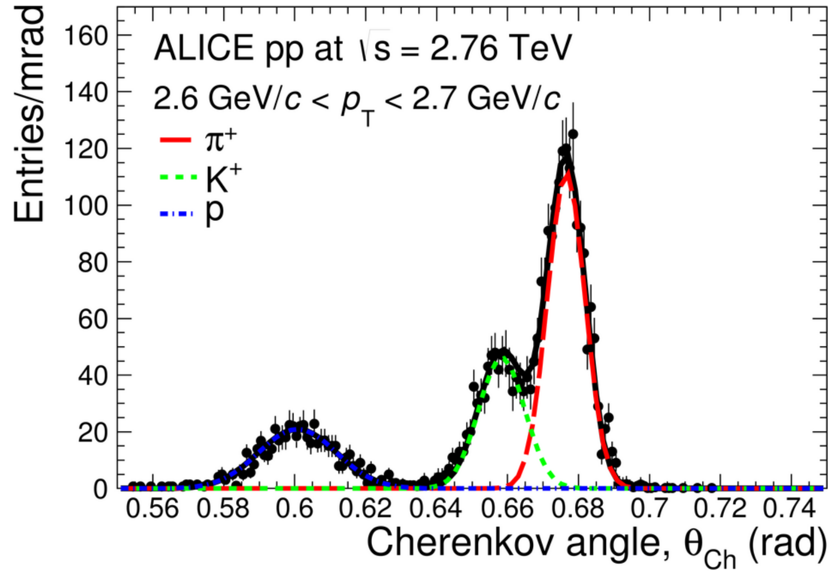
$\Downarrow$

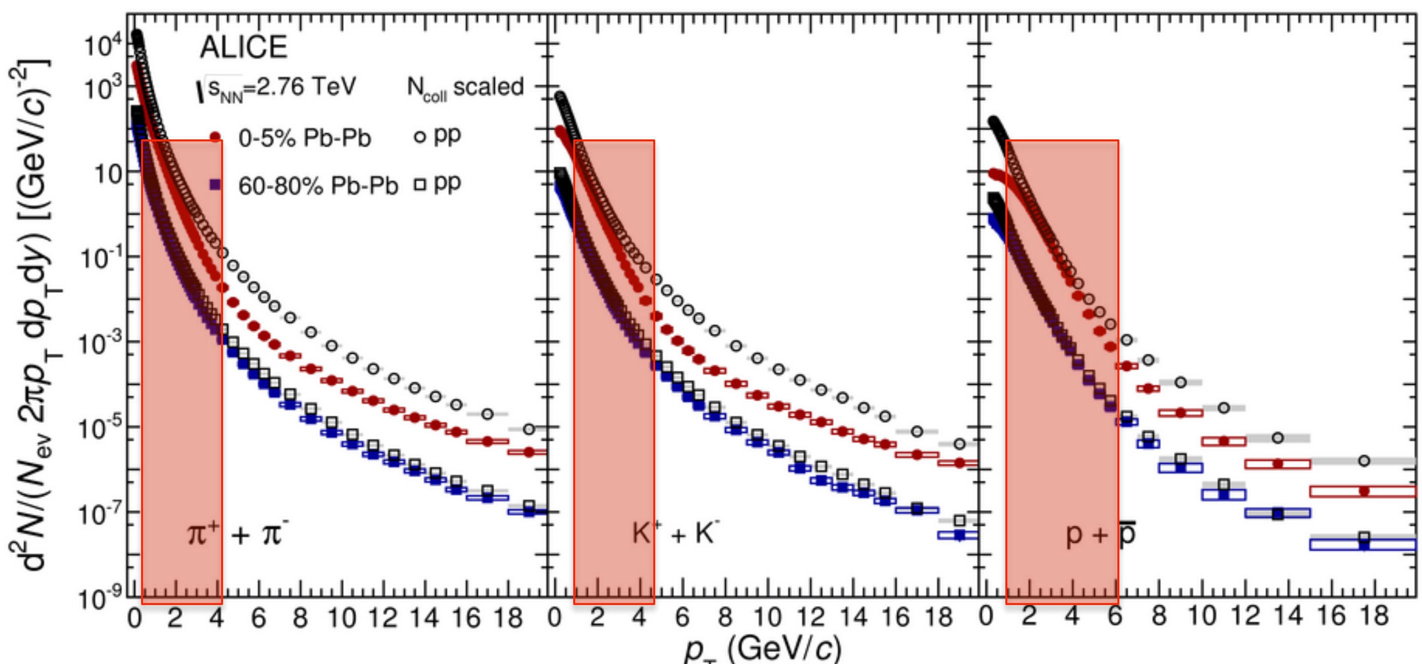
solution in one dimensional mapping space η_c



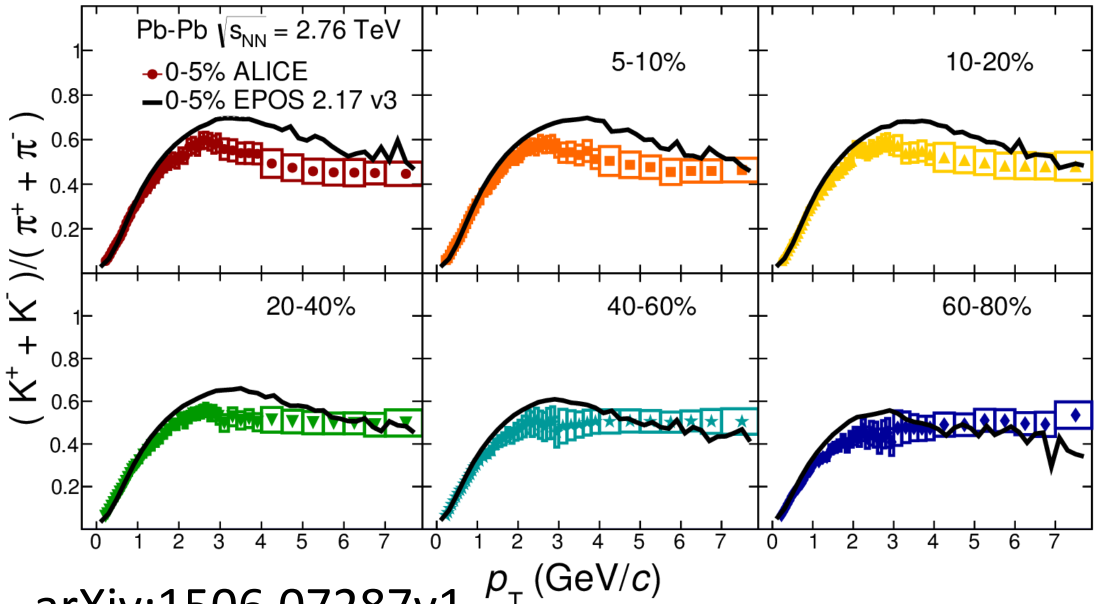
The pattern recognition (based on Hough Transform) tends to find the «best» pattern (according to the impact track parameter) with the highest number of photon candidates (more efficient when bkg is not negligible)

Inclusive hadrons spectra: pp 2.76 TeV

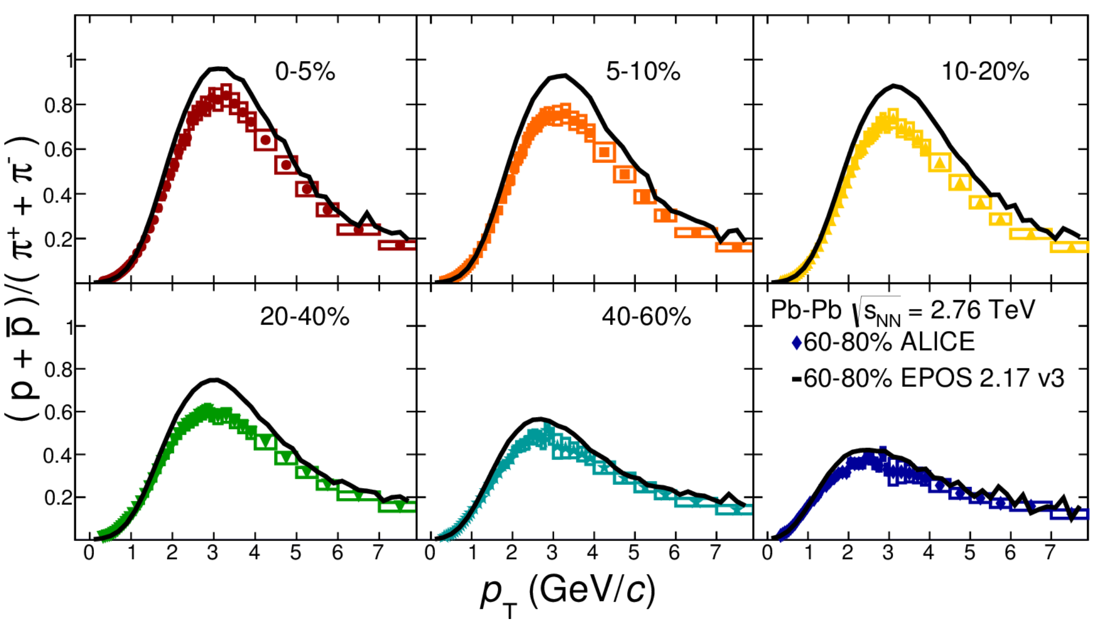




Intermediate p_T: comparison with EPOS



arXiv:1506.07287v1



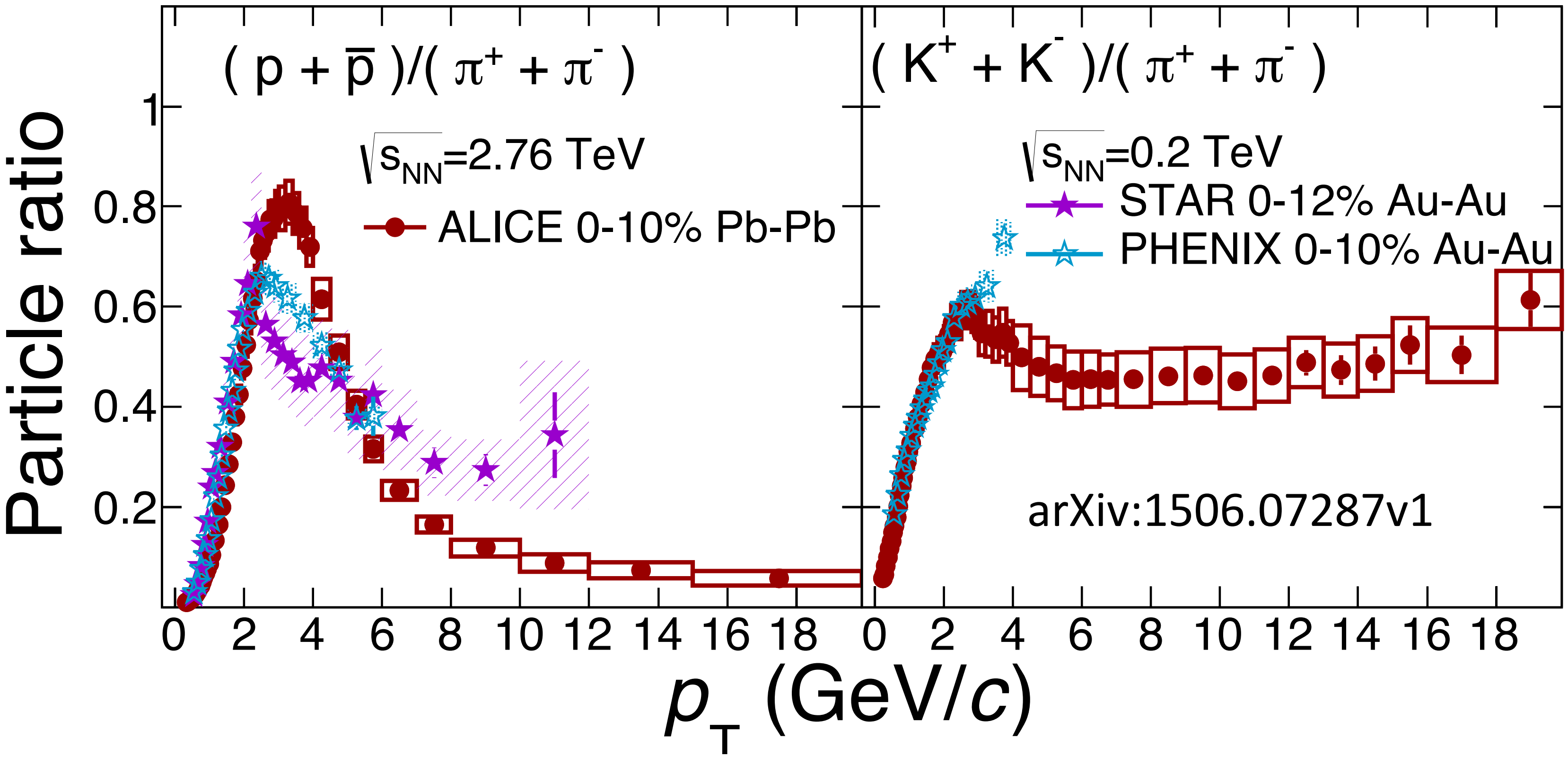
EPOS model 2.17-3
K. Werner, PRL 109, 102301 (2012) "fluid-jet interaction". Works over the entire p_T range.

Hydrodynamical phase + hadronization processes at intermediate p_T where the interaction between bulk matter and jets is considered

Baryon-meson effect where a quenched jet hadronizes with flowing medium quarks

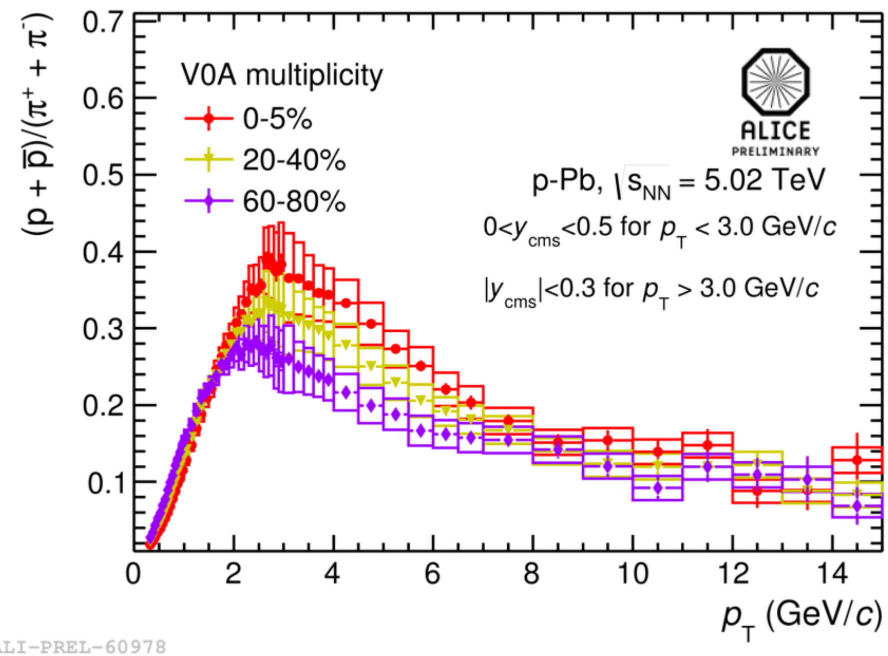
- centrality dependence well reproduced, even for very peripheral events.
- magnitude of both the p-to-π and the K-to-π peak is overpredicted.

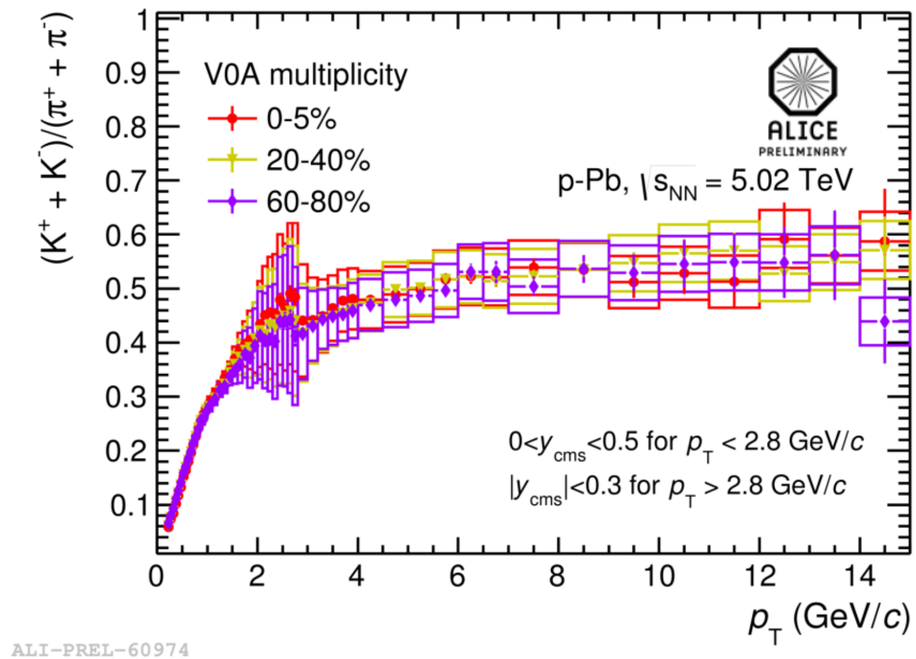
Intermediate p_T: comparison to RHIC



- The p-to-π peak at LHC is approximately 20% larger than at RHIC, consistent with an average larger radial flow velocity.
- The K-to-π ratio measured by PHENIX is similar to the ALICE one

Particle ratios in p-Pb collisions

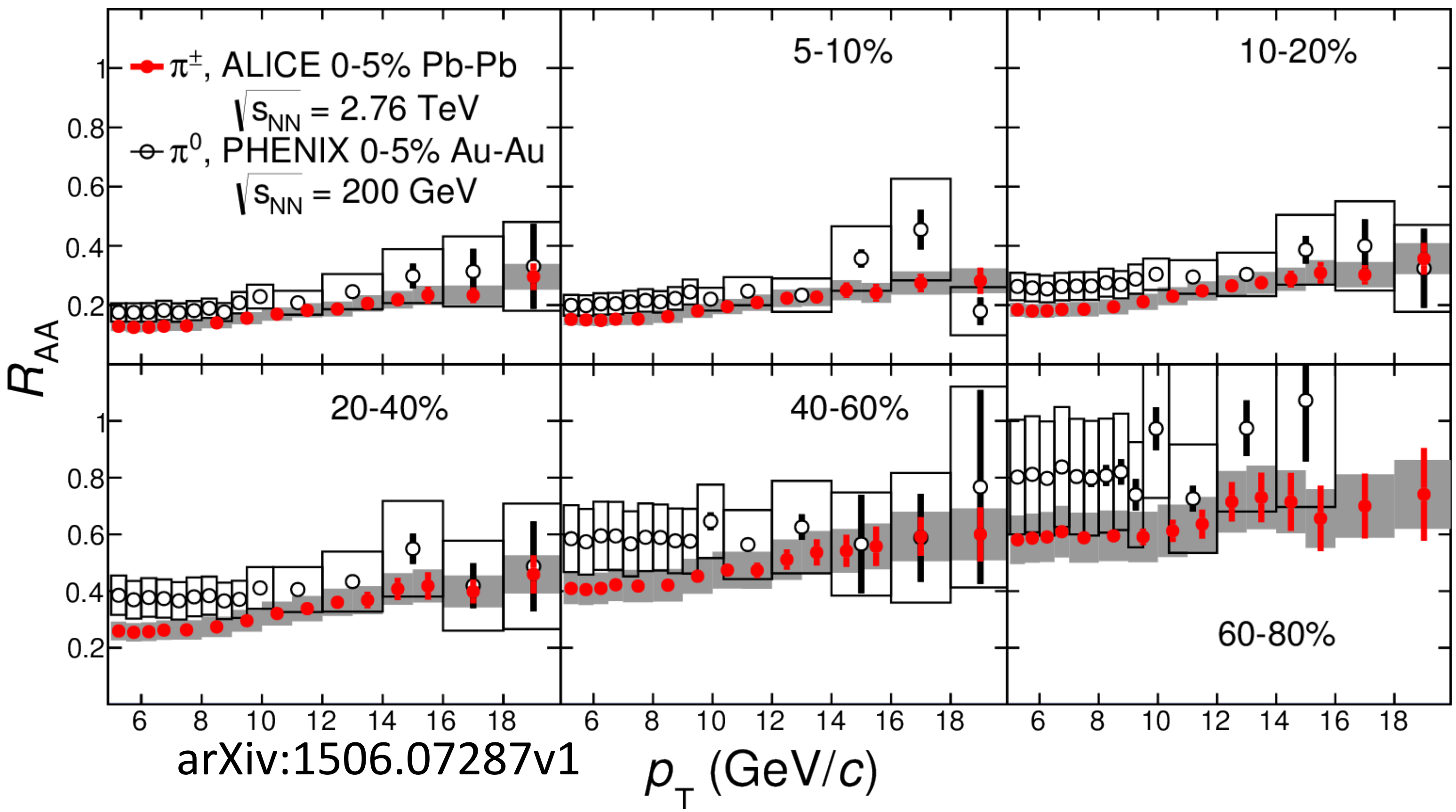




- p-to-π ratio:
  - shows a peak, which is more pronounced for higher multiplicities
  - drops to 0.1 at high p_T (as in Pb-Pb)

- K-to-π ratio:
  - saturates at 0.5 for high p_T (as in Pb-Pb)
  - does not shows strong multiplicity dependence

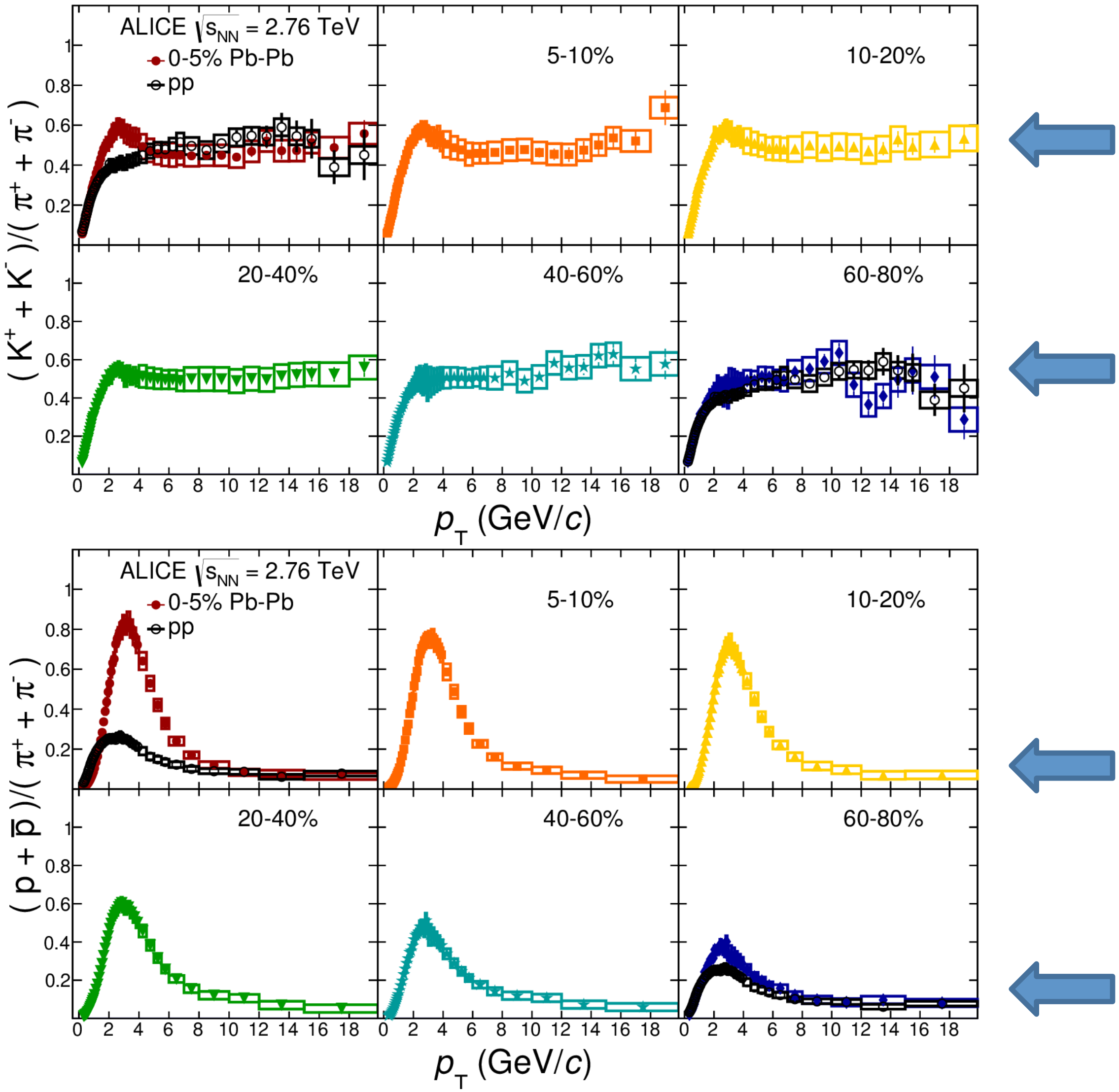
The pion R_{AA} at RHIC and at LHC



arXiv:1506.07287v1

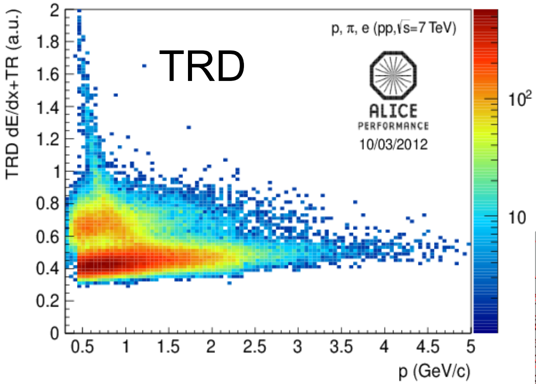
- ALICE results are below the PHENIX values
- Centrality evolution very similar
- Energy loss is ”scaled up” at the LHC
    - the pp spectra at LHC energies are significantly harder, so a larger energy loss is needed to get a similar R_{AA}.

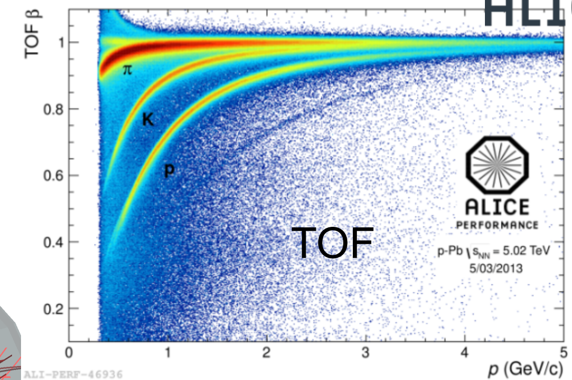
Particle ratios in Pb-Pb collisions at high p_T

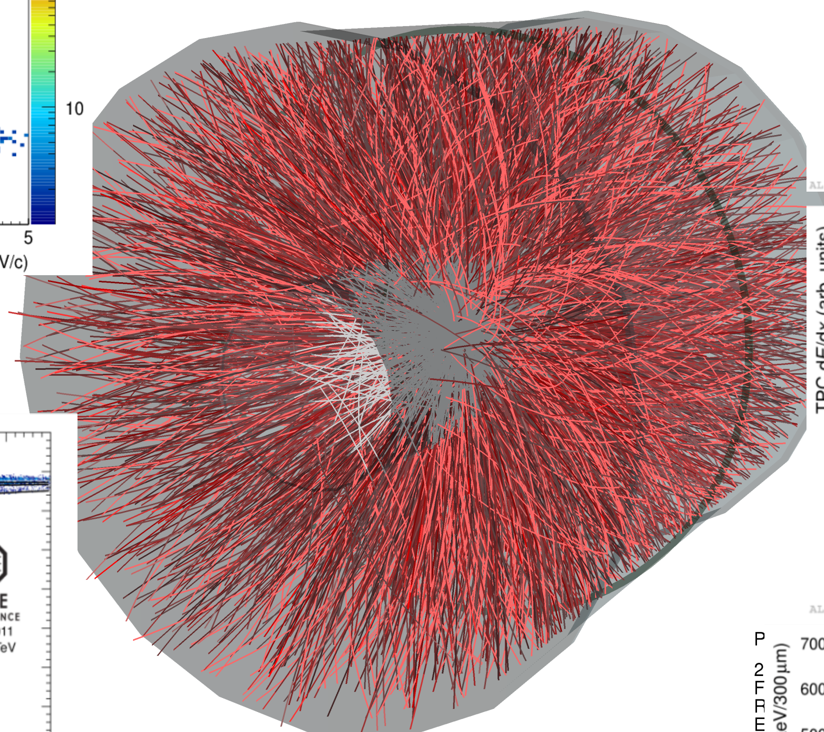


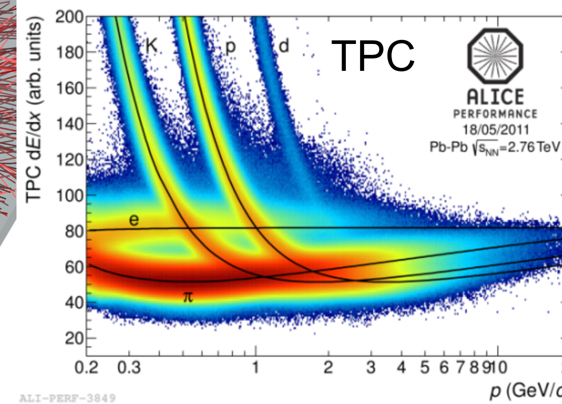
The behavior at high p_T (p_T>10 GeV/c) is independent of centrality (and the same as in pp collisions)

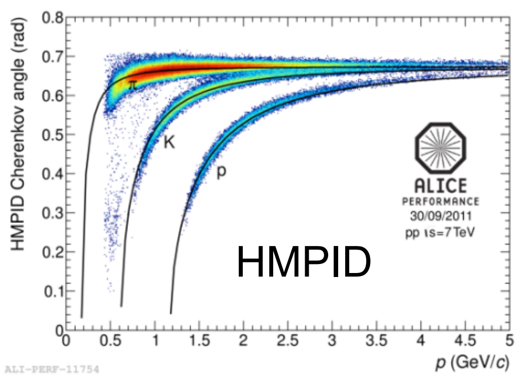
Charged particle PID in ALICE (central barrel)

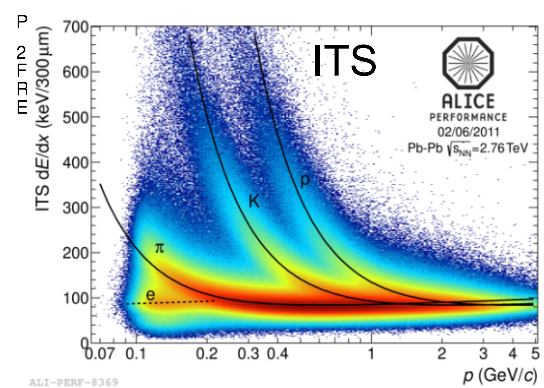






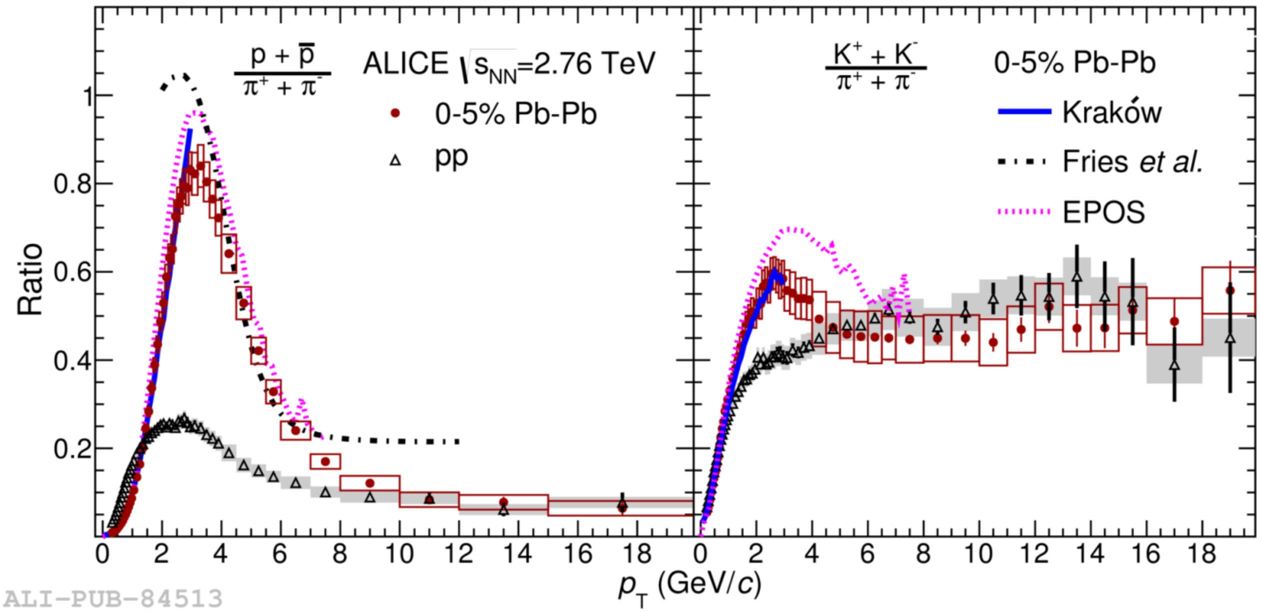






The ALICE experiment is optimized for charged particle tracking
and hadron identification for |η|<0.8

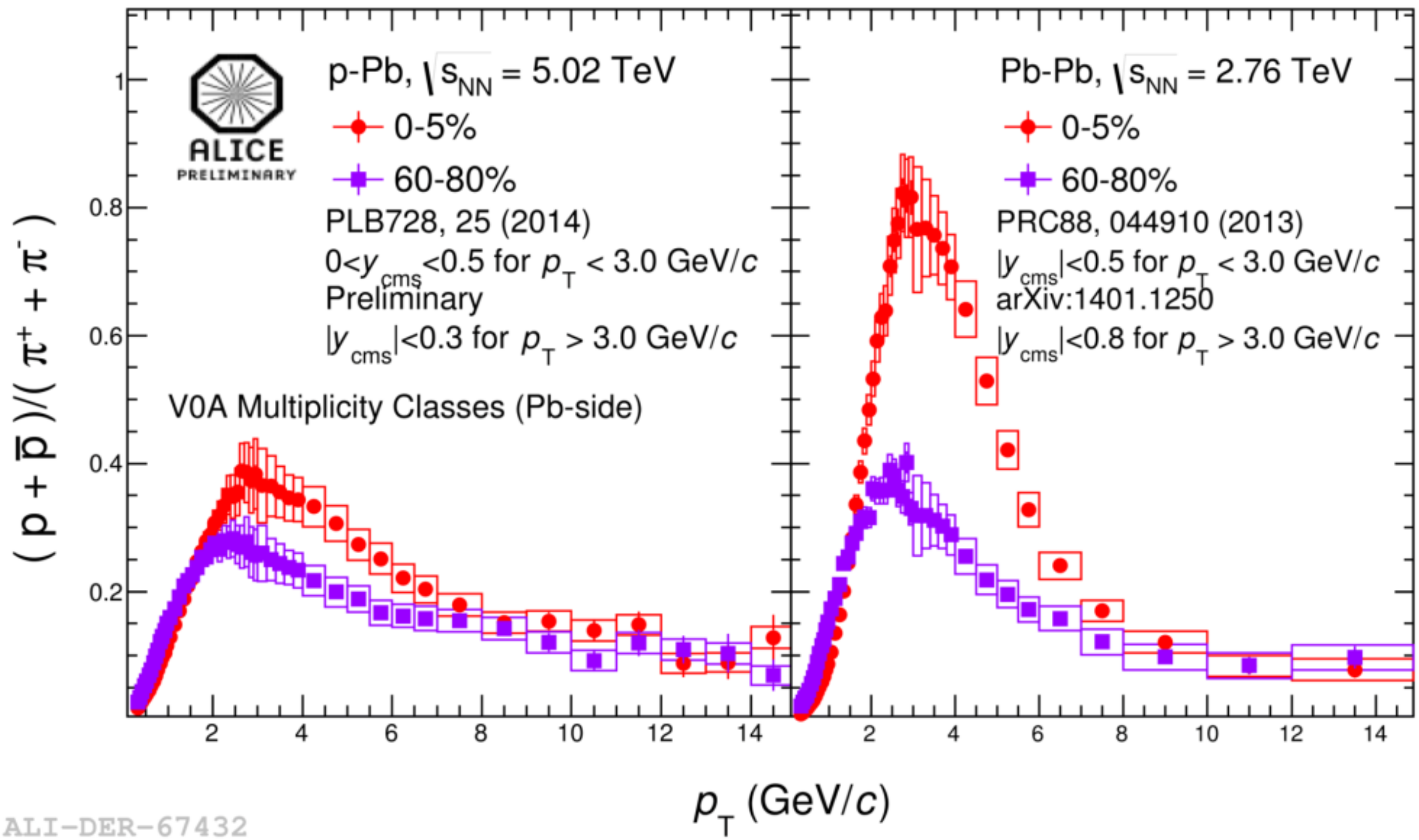
Particle ratios compared to models



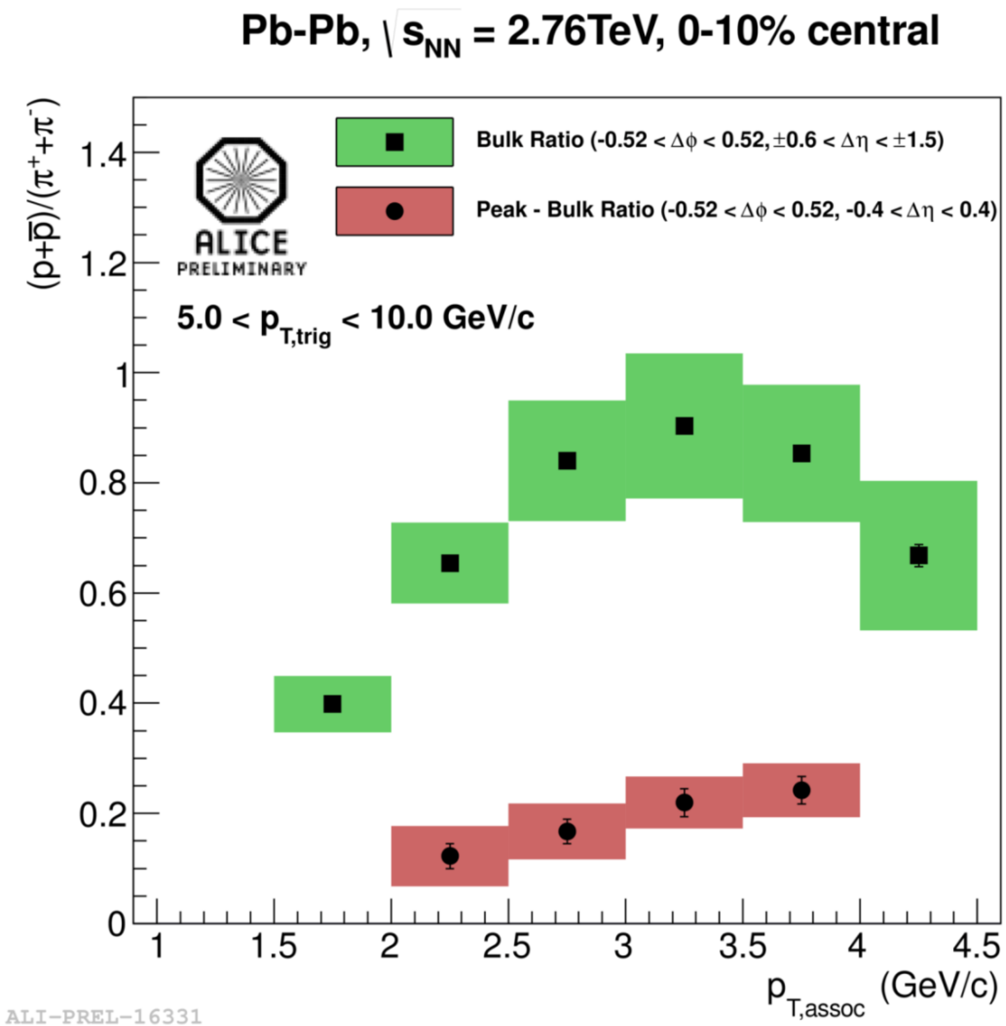
- Kraków: PRC85, 064915 (2012)
- HKM: PRC87, 024914 (2013)
- Fries: PRL90, 202303 (2003) and private communication
- EPOS: PRL109, 102301 (2012) and private communications

Kraków+HKM: hydrodynamic (low p_T) models
Fries: recombination
3 quarks → baryon,
2 quarks → meson
EPOS: hydrodynamics (low p_T) → medium modified fragmentation for quenched jets (intermediate p_T) → vacuum fragmentation (high p_T)

Comparisons between the different colliding systems: high p_T particle ratios in p-Pb and Pb-Pb



p/π ratio in peak-bulk



When the p/π ratio in the peak is corrected for bulk effects using an η gap one finds that the ratio is dominated by the bulk.

So the ratio does not seem to be driven by hard physics.