# *Identified primary hadron spectra in pp and Pb-Pb collisions with the ALICE detector at the LHC*

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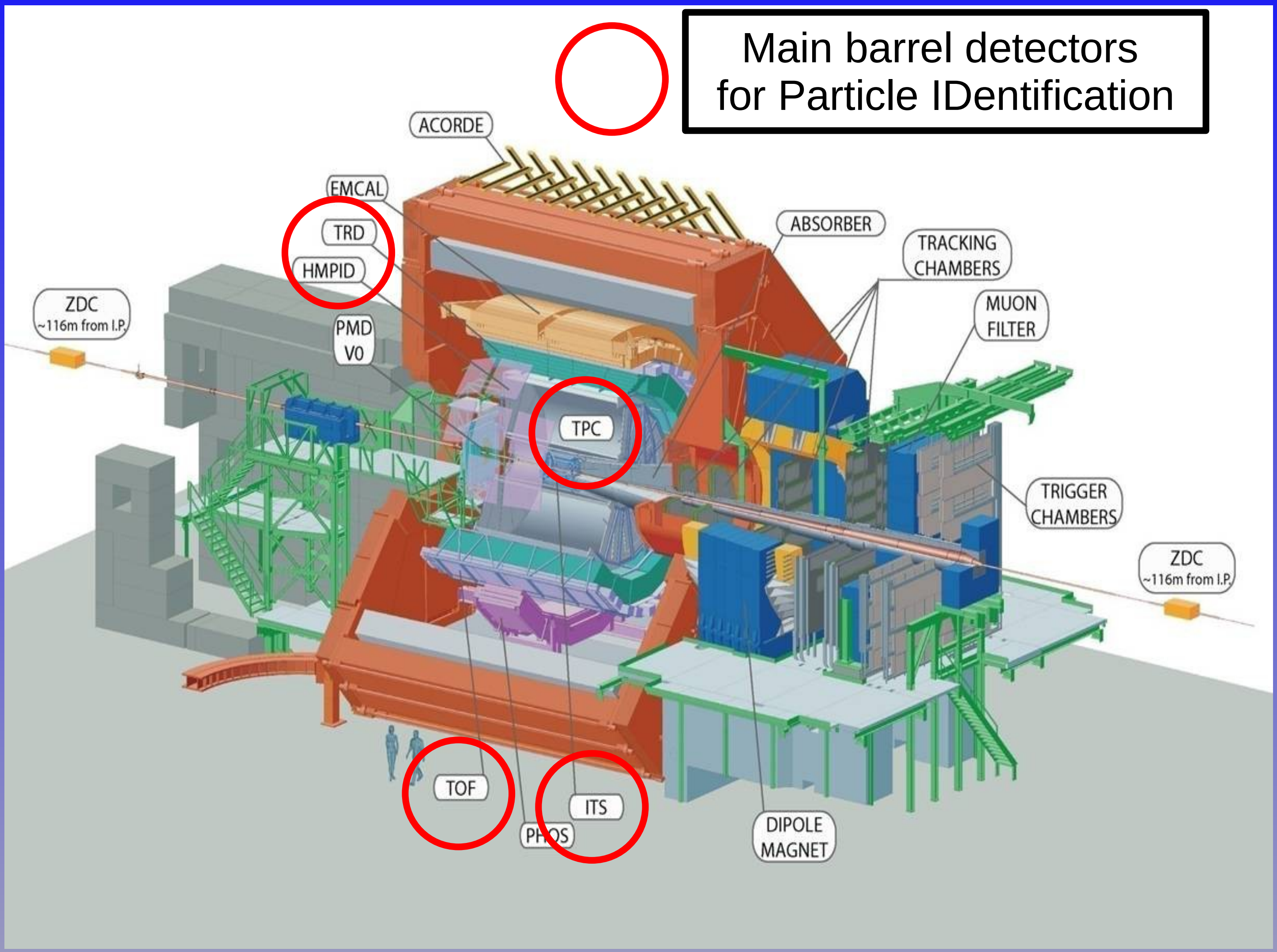
LHC on the March - Protvino, 16/11-18/11 2011

# Outline

- The ALICE experiment
- PID Detector Performance (ITS, TPC, TOF, HMPID)
- Identified primary hadron spectra in pp collisions at $\sqrt{s}$ = 7 TeV
  - MB combined spectra: Lévy-Tsallis fit and MC comparison
  - Particle ratio: K/π and p/π
  - Mean $p_t$
- Identified primary hadron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
  - Combined spectra in centrality bins
  - Particle ratio: K/π and p/π
  - Mean $p_t$
  - Blast-Wave fit
- Conclusions

# The ALICE Experiment



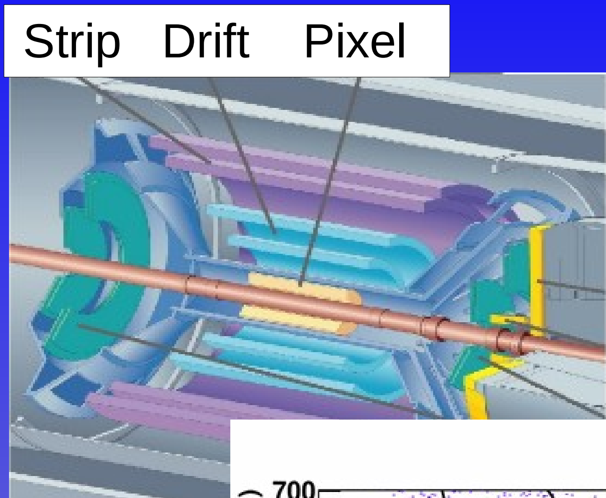

ALICE has several barrel detectors dedicated to PID

- covering complementary $p_t$ ranges
- Using different PID techniques
  - ITS: dE/dx
  - TPC: dE/dx
  - TRD: Transition Radiation
  - TOF: Time-of-Flight
  - HMPID: Cherenkov Radiation

Detector actually used for the reconstruction of the primary hadron spectra

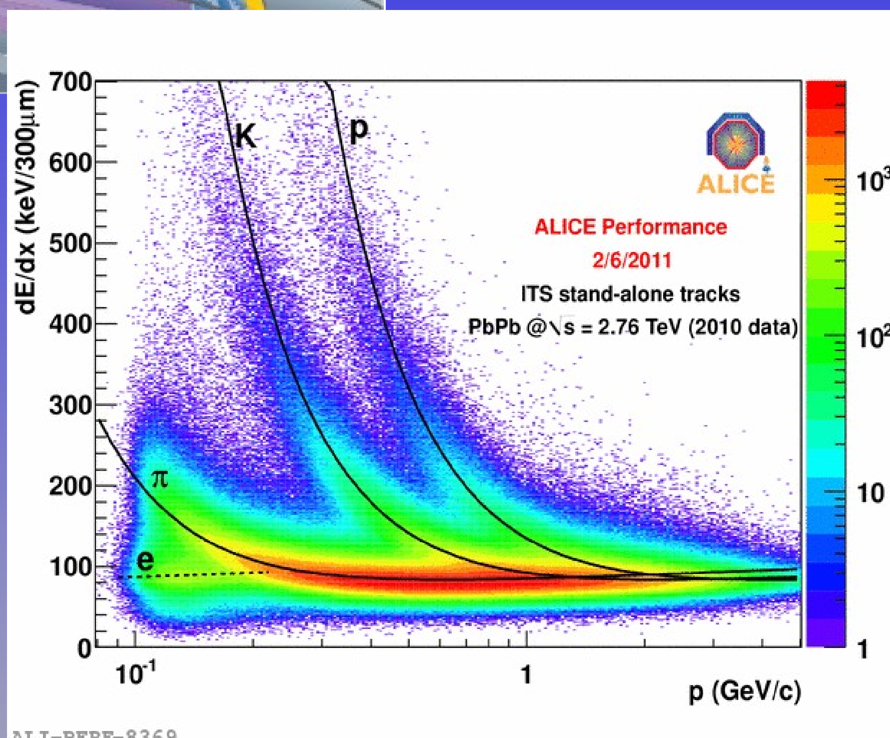
# *PID Detector Performance*

# *Inner Tracking System*




6 layers of silicon detectors:
SPD: Silicon Pixel Detector
SDD: Silicon Drift Detector
SSD: Silicon Strip Detector

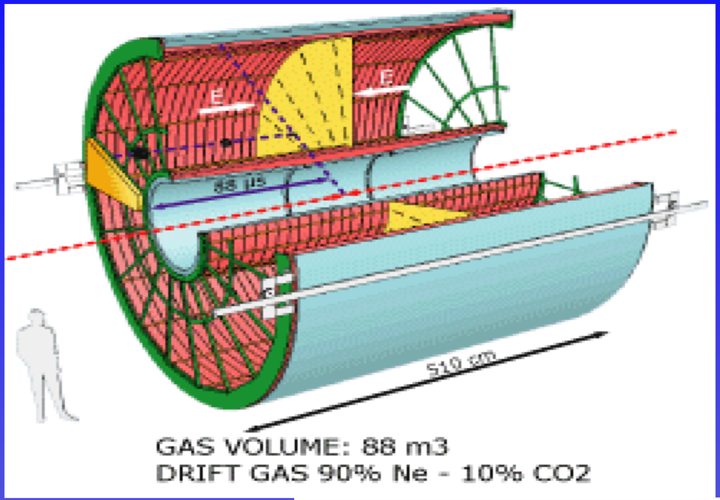
Analog readout:
dE/dx information->
PID in $1/\beta^2$ region



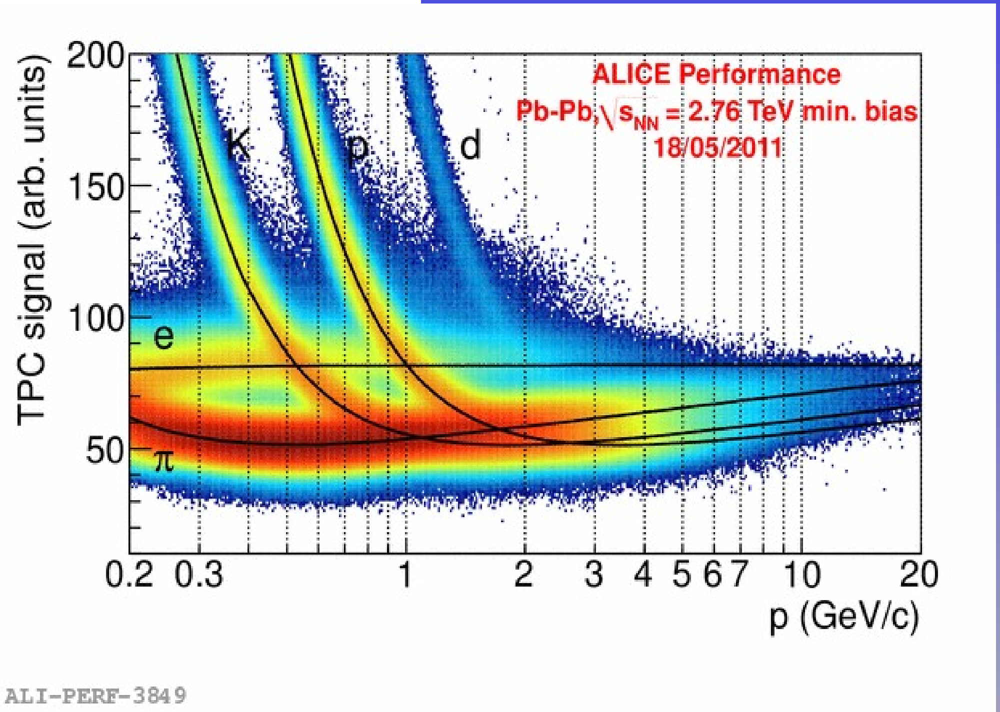

dE/dx of charged particles vs their momentum measured by the ITS stand-alone in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

Lines = parametrization of the detector response based on Bethe-Bloch formula

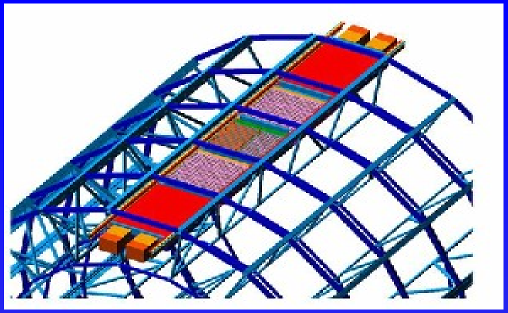
# Time Projection Chamber




Analog readout:
dE/dx information->
PID in $1/\beta^2$ region
PID extended to higher $p_t$
in the relativistic rise region




Specific energy loss in the TPC vs momentum.
Lines = Bethe - Bloch parametrization for charge particles



# Time of Flight

$$\sigma_{tot} = \sqrt{\sigma_{TOF}^2 + \sigma_{t-Zero}^2 + \sigma_{t-Trac}^2}$$

PID thanks to the measurement of the time taken by a particle to reach TOF

$$m = p\sqrt{\frac{t^2}{L^2} - \frac{1}{c^2}}$$

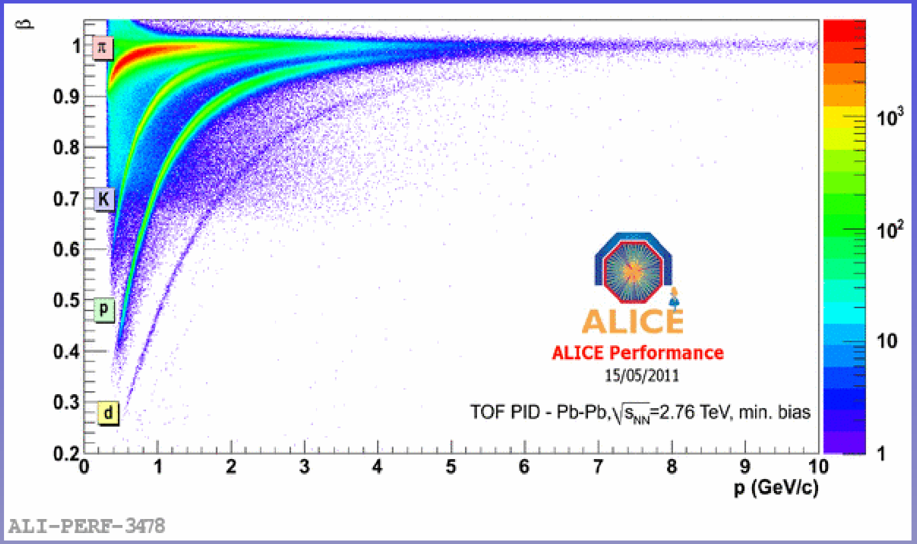
In Pb-Pb:

$\sigma_{t\text{-}Zero} \approx 10$ ps

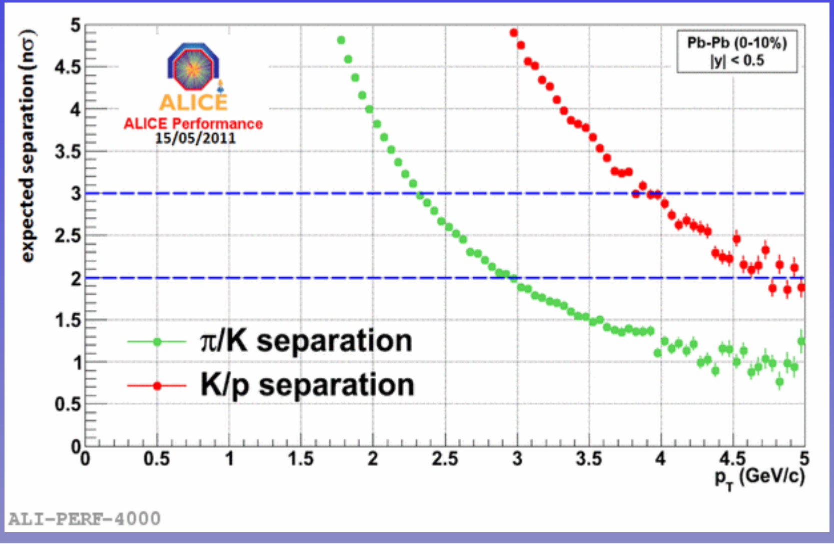
$\sigma_{t\text{-}Track} \approx 20$ ps

$\sigma_{tot} \approx 85$ ps

→ $\sigma_{TOF} \approx 80$ ps design value



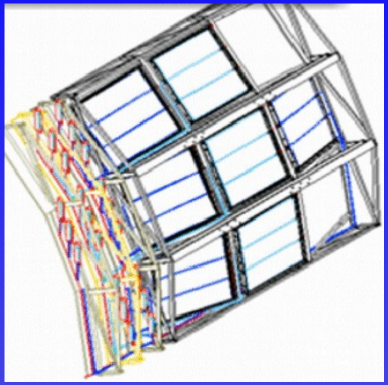

Beta measured by TOF vs momentum. Different species are clearly visible



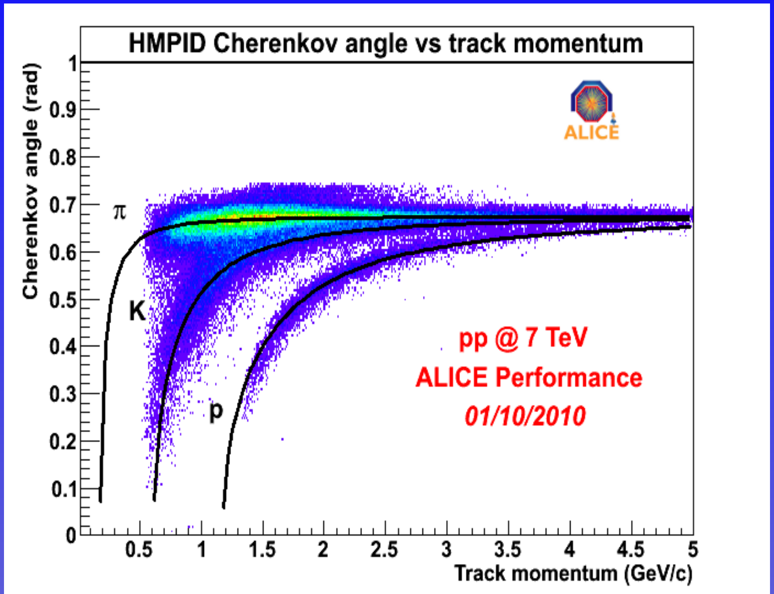

Expected separation for π/K and K/p vs $p_t$.

- π/K 3σ separation up to 2.5 GeV/c
- K/p 3σ separation up to 4 GeV/c

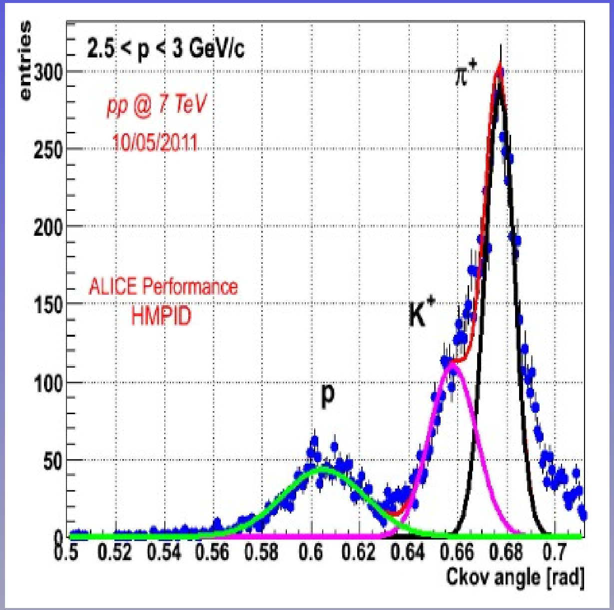
# High Momentum Particle IDentification



HMPID is based on proximity focusing Ring Imaging Cherenkov (RICH) counters



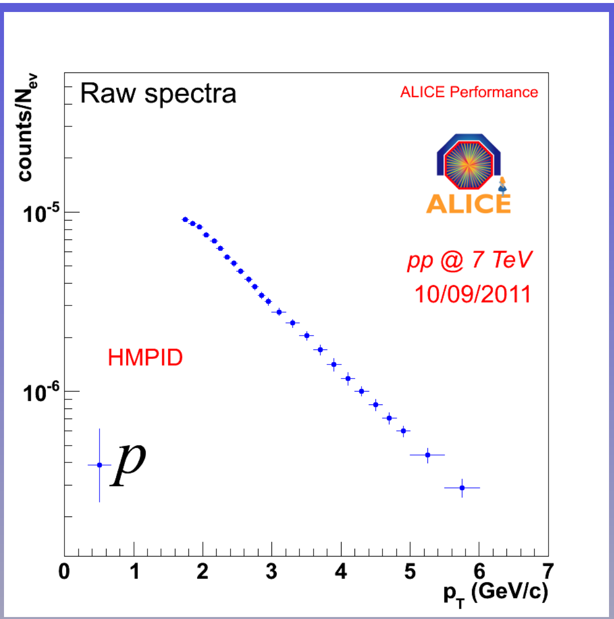

Cherenkov angle measured by HMPID vs momentum. Different species are clearly visible.




Gaussian fit of cherenkov angle

↓

particle spectra (analysis in progress)



# *Identified primary hadron spectra in pp collisions at $\sqrt{s}$ = 7 TeV*

# *pp collisions at $\sqrt{s}$ = 7 TeV: analysis details*

4 independent analysis combined:

- ITSsa: n-σ cut method on ITS dE/dx signal
- ITSTPC: unfolding method on ITS and TPC dE/dx signal
- TPCTOF: n-σ cut method on TPC dE/dx and TOF time signal
- TOF: unfolding method on TOF time signal

} ITS standalone tracks (ITSsa)

} ITS+TPC global tracks (ITSTPC, TPCTOF, TOF)

| $P_t$ ranges (GeV/c) | ITSsa | ITSTPC | TPCTOF | TOF |
|---|---|---|---|---|
| π | 0.1-0.5 | 0.2-0.55 | 0.2-1.4 | 0.5-1.6 |
| K | 0.2-0.5 | 0.25-0.5 | 0.25-1.4 | 0.5-1.6 |
| p | 0.3-0.55 | 0.4-0.85 | 0.45-1.7 | 0.9-2.5 |

# Analysis details: feed-down correction

From the proton primary spectrum we need to remove protons from weak decays of strange particles:

$\Lambda \rightarrow p\, \pi^-$

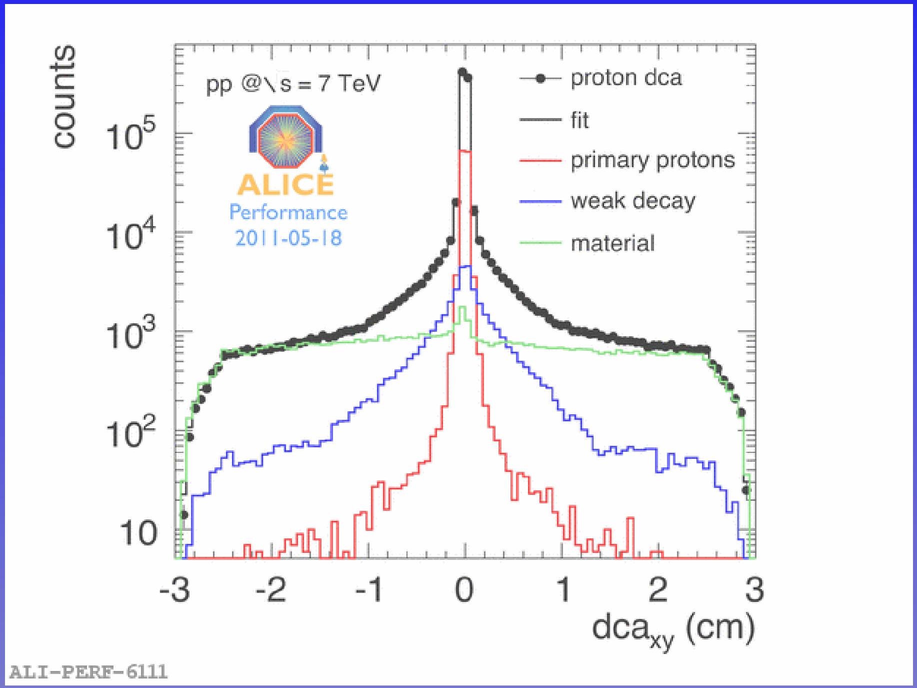
$\Sigma^+ \rightarrow p\, \pi^0$

.............

Distance of closest approach (DCA) in the bending plane. Fit done using MC templates of:

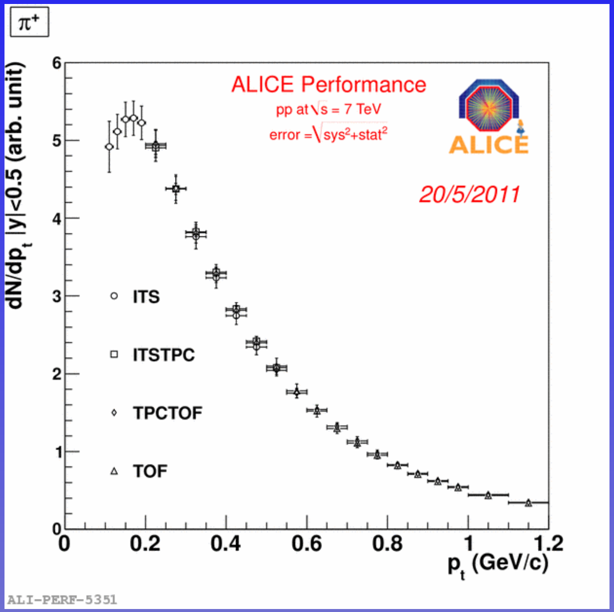
- primaries
- secondaries from weak decay of strange particles
- secondaries from interaction with the material

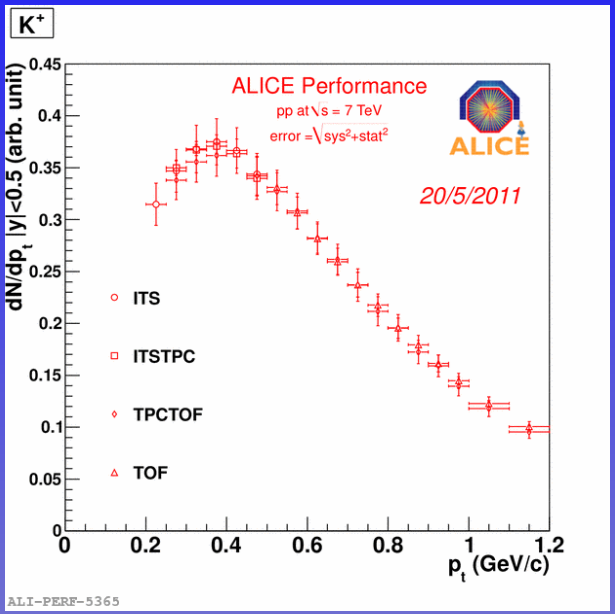
The result of the fit is used to extract the feed-down correction for protons

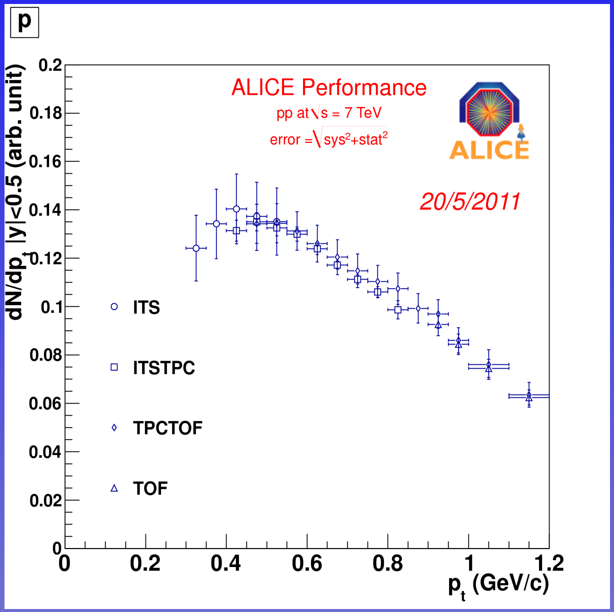



Example from pp collisions for $0.70<p_t<0.75$ GeV/c

# *pp collisions at √s = 7 TeV: analysis details*

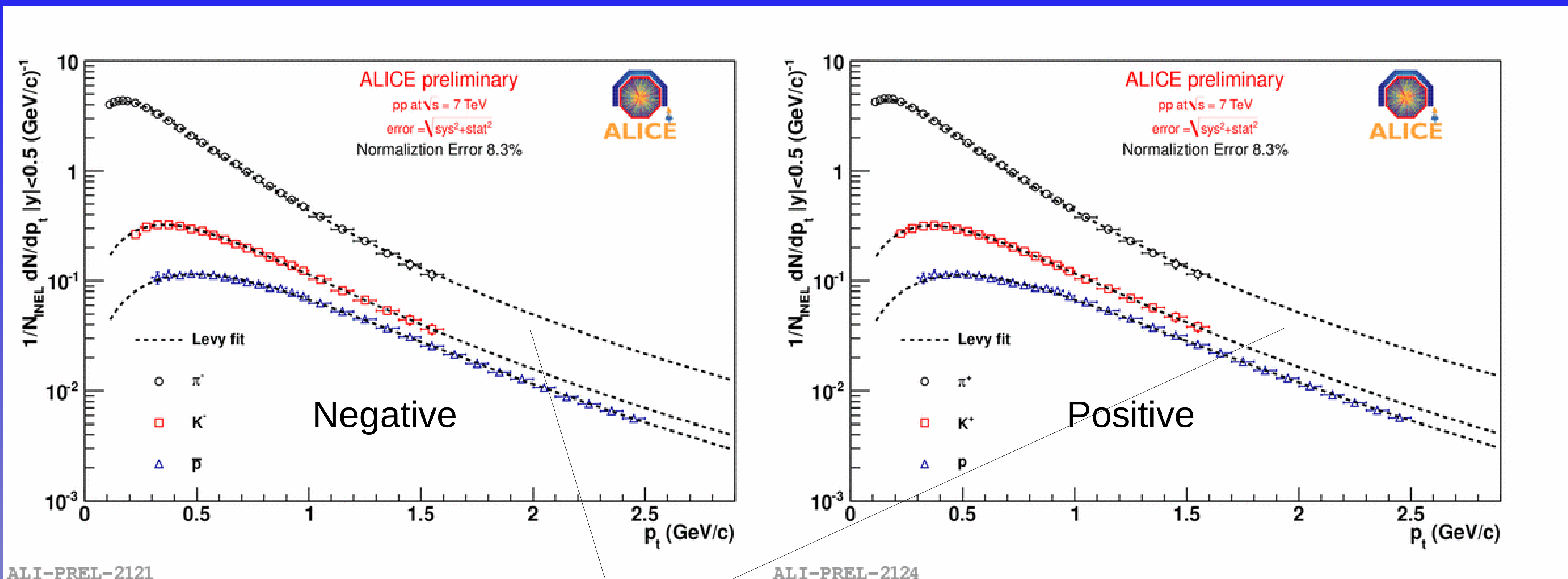



4 methods agree within uncertainties

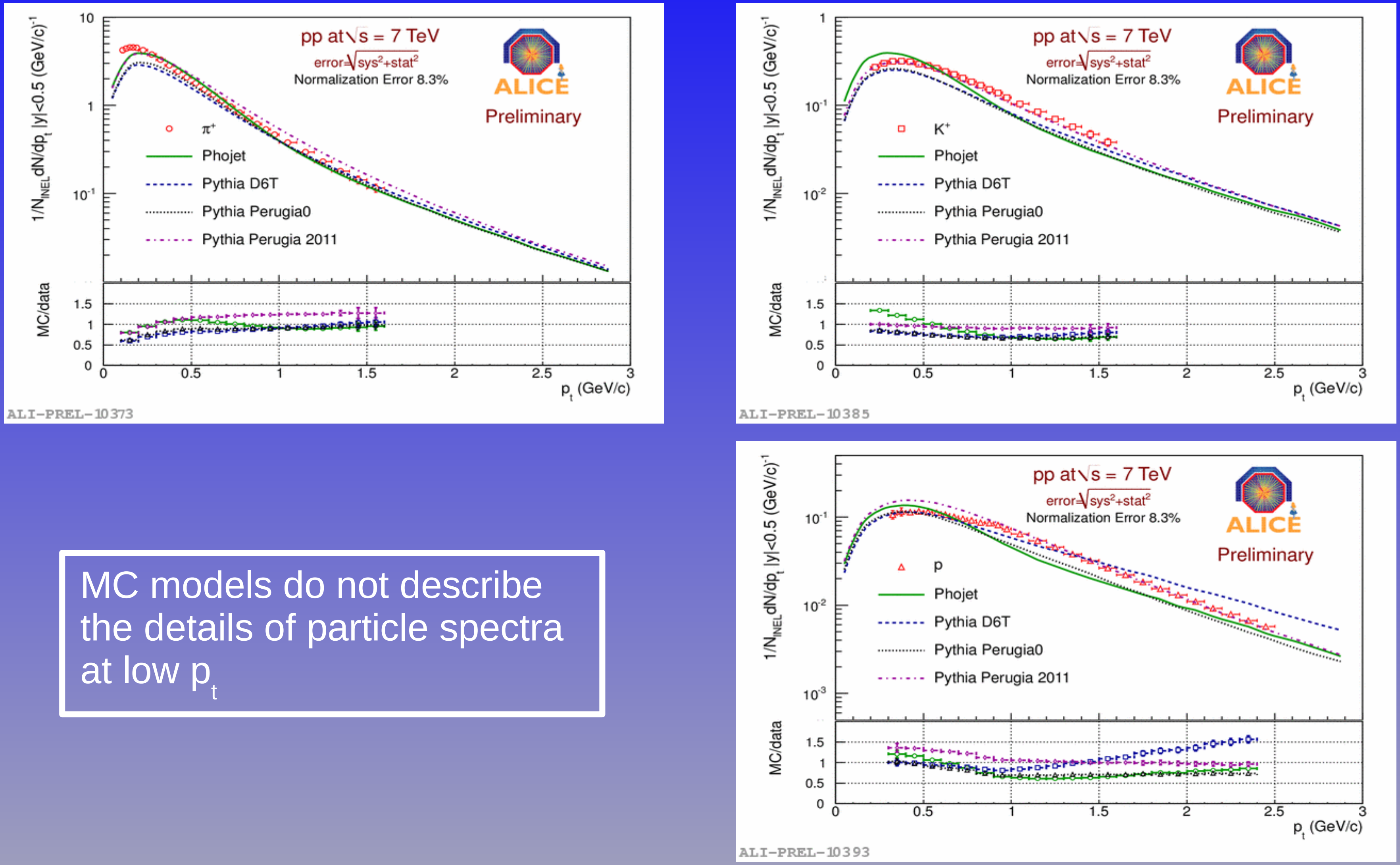
# pp collisions at $\sqrt{s}$ = 7 TeV: MB combined spectra




Lévy-Tsallis function
for pp spectra fit to extract
integrated yields and $\langle p_t \rangle$

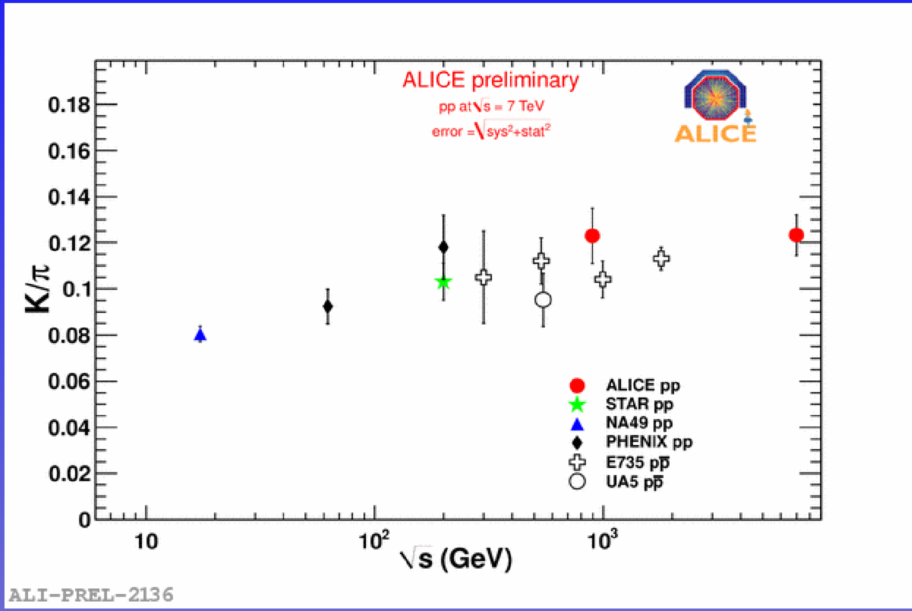
$$\frac{d^2N}{dp_t dy} = p_t \frac{dN}{dy} \frac{(n-1)(n-2)}{nC(nC + m_0(n-2))} \left(1 + \frac{m_t - m_0}{nC}\right)^{-n}$$

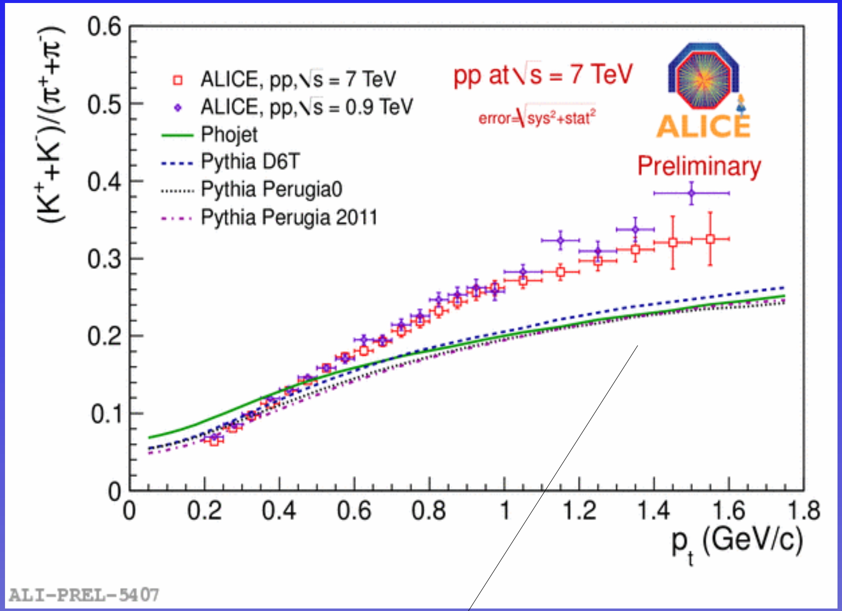
# pp collisions at $\sqrt{s}$ = 7 TeV: MB combined spectra vs MC




MC models do not describe the details of particle spectra at low $p_t$

# *pp collisions √s = 7 TeV: MB particle ratio K/π*



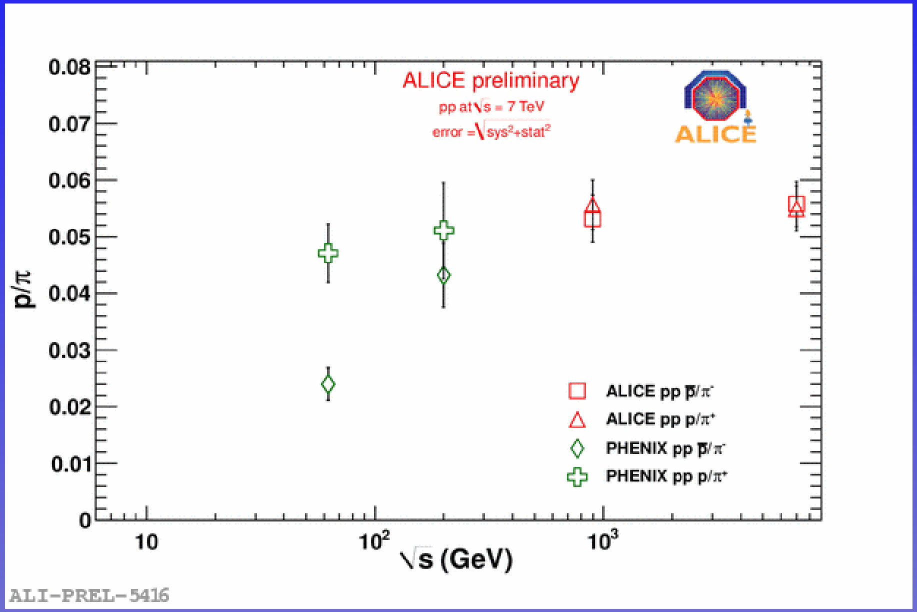



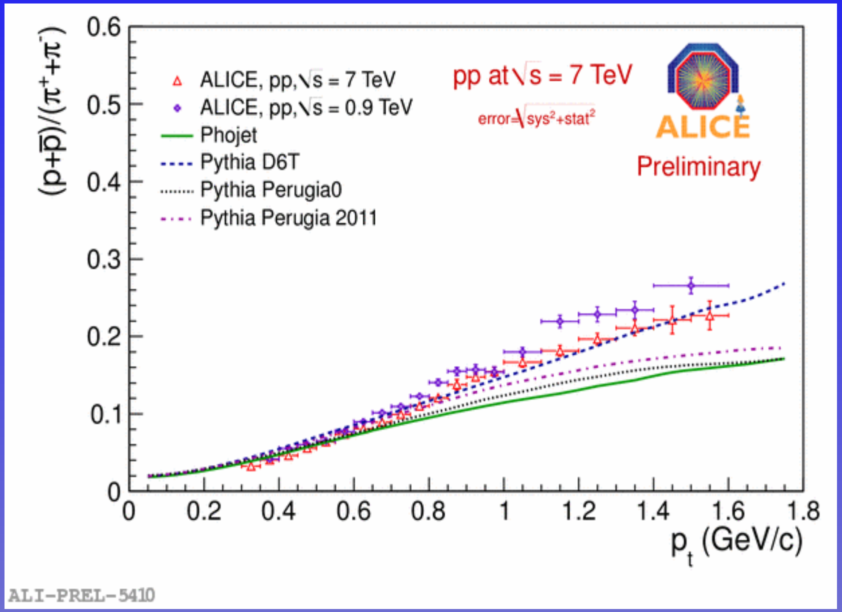

ALICE points: obtained using the yields extracted from the previous Lévy-Tsallis fits
The ratio is constant within errors for 0.9 TeV and 7 TeV data

- ratio not described by MC models
- $p_t$<1.6 GeV/c ratios at 7 TeV and 0.9 TeV compatible within the errors

Spectra at √s = 0.9 TeV published in EPJC 71(6), 2011

# pp collisions at √s = 7 TeV: MB particle ratio p/π



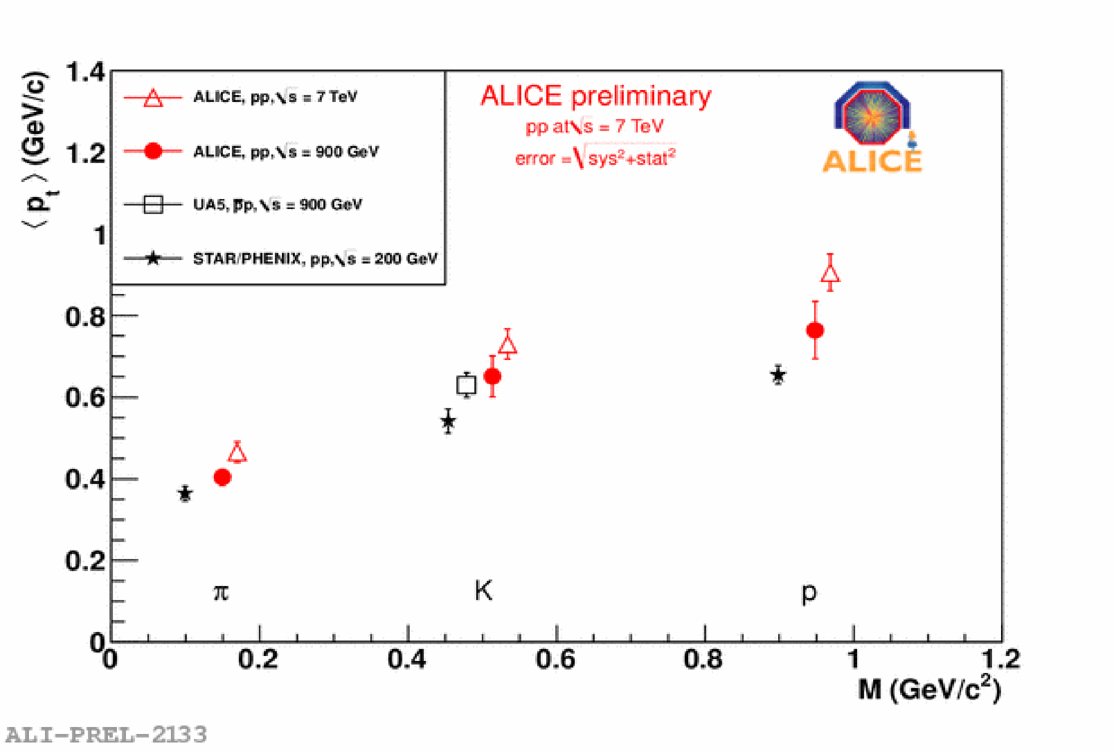




Low energy: baryon/antibaryon asymmetry
LHC energies: constant ratio

- $p_t$<1.6 GeV/c ratio roughly described by Pythia D6T model
- $p_t$<1.6 GeV/c ratios at 7 TeV and 0.9 TeV are similar

Spectra at √s = 0.9 TeV published in EPJC 71(6), 2011

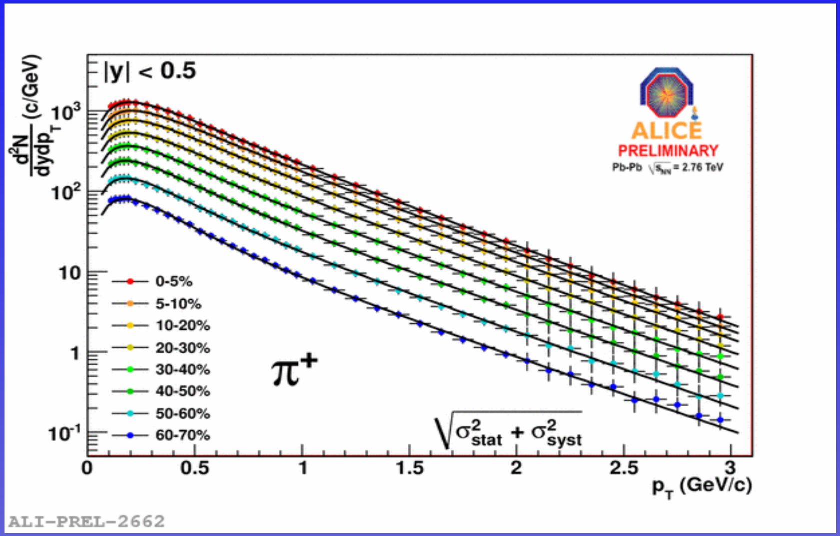
# pp collisions at √s = 7 TeV: mean $p_t$ vs mass

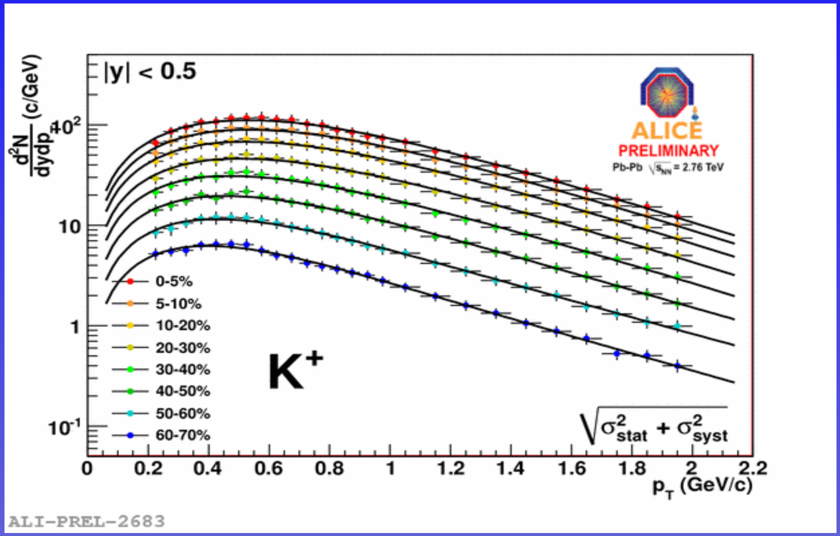



- Linear increase of mean $p_t$ with mass
- Increase of mean $p_t$ (harder spectra) with the collision energy

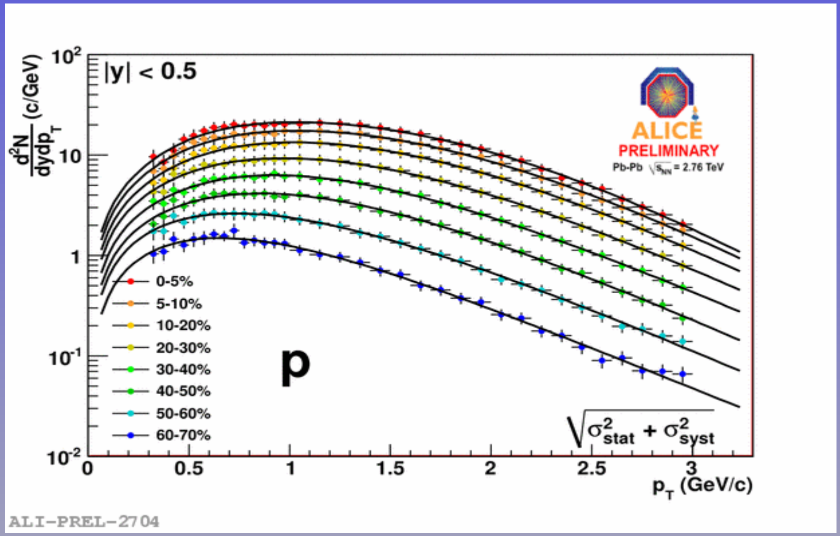
# *Identified primary hadron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV*

# Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV: combined spectra in centrality bins

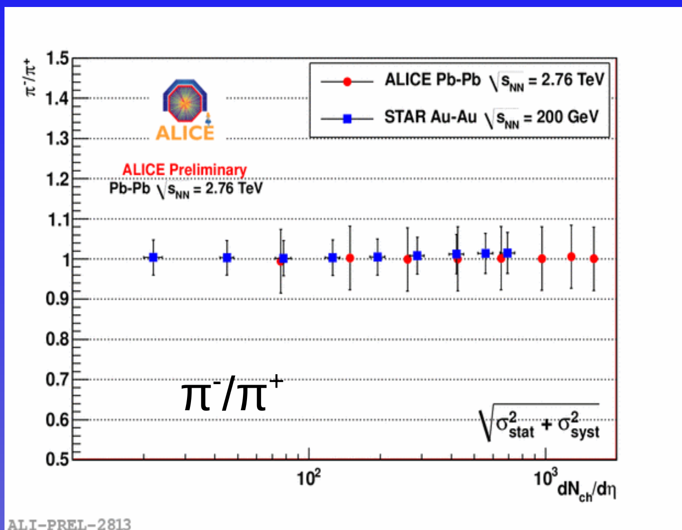


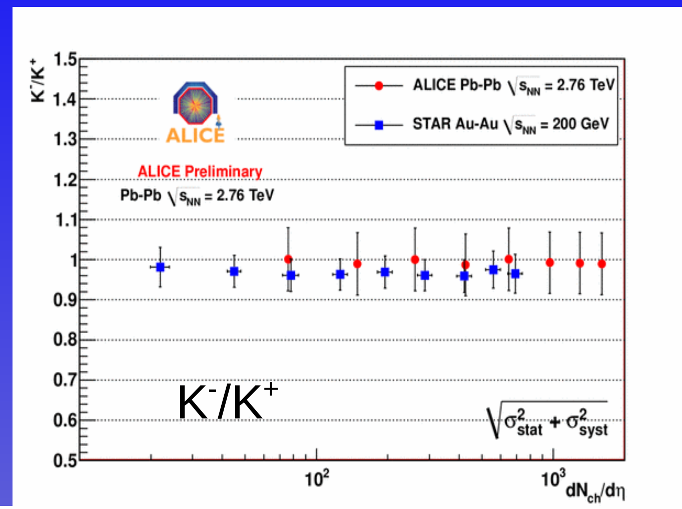



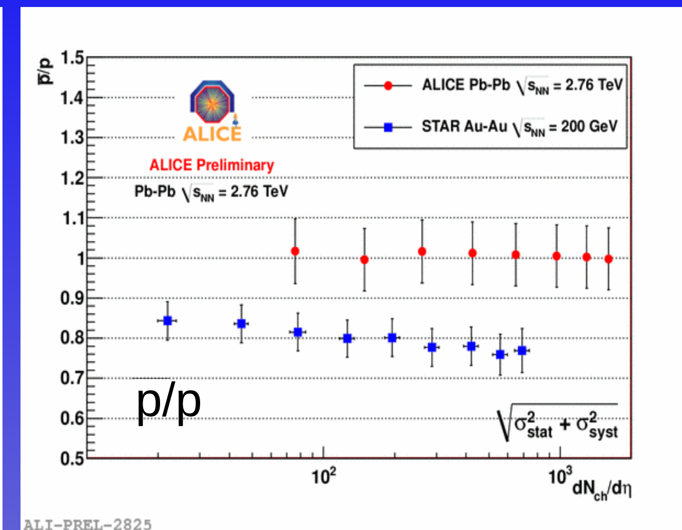

- Spectra of negatively charged particles (backup) really similar to positive one
- combined spectra from the same 4 analysis as in pp
- fit on individual particles with Blast-Wave function-> computation of integrated yields and average $p_t$

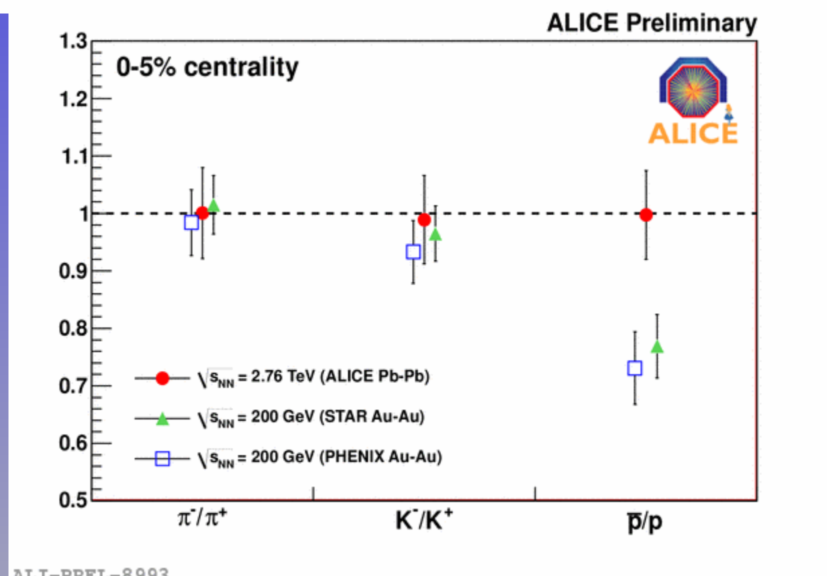


# Pb-Pb collisions at $\sqrt{s}_{NN} = 2.76$ TeV: antiparticle/particle ratios



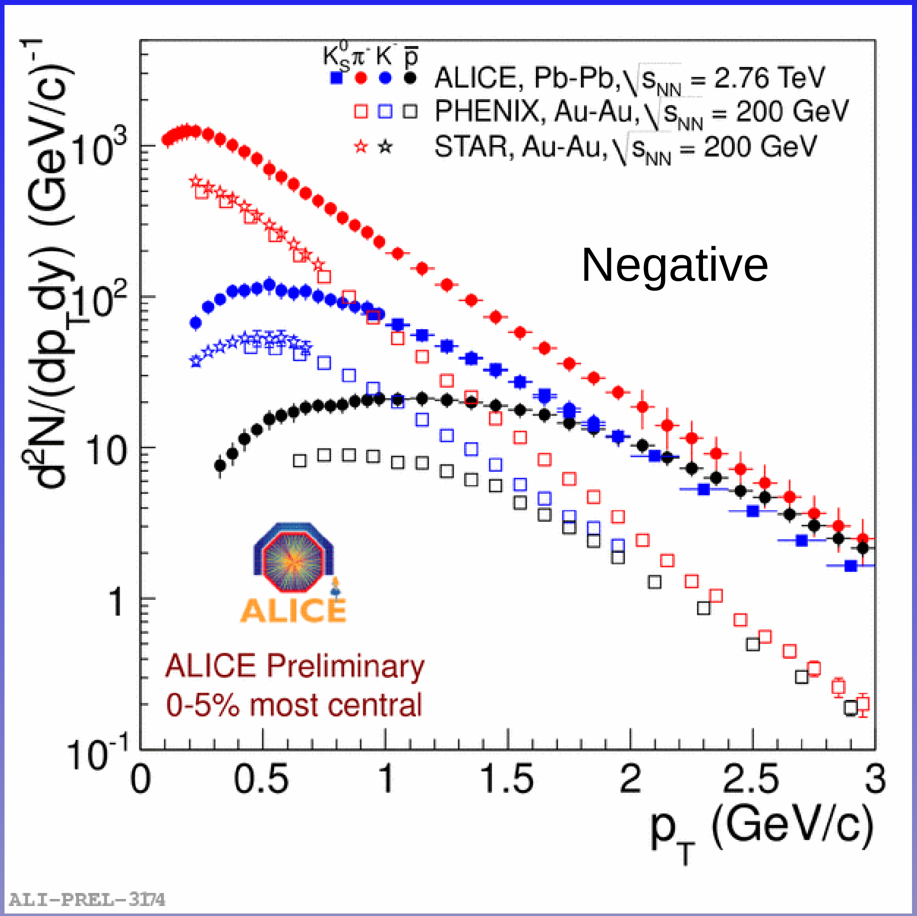



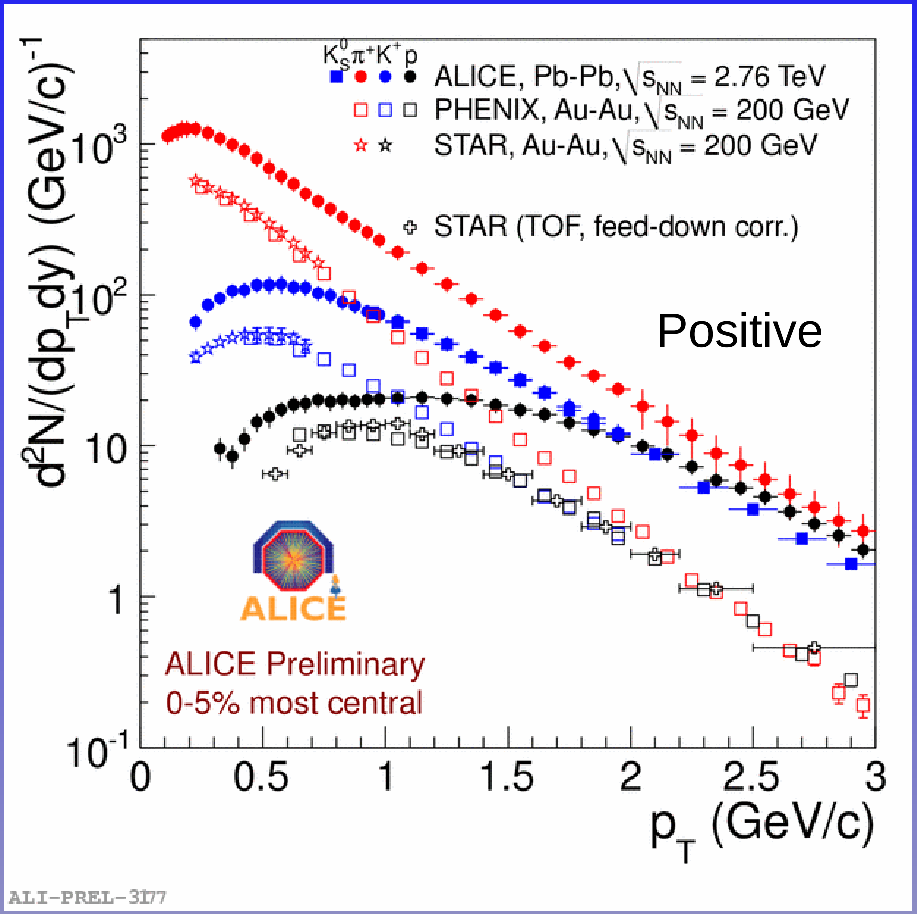




At LHC energy
ratios compatible with 1

STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 034909 (2004)

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

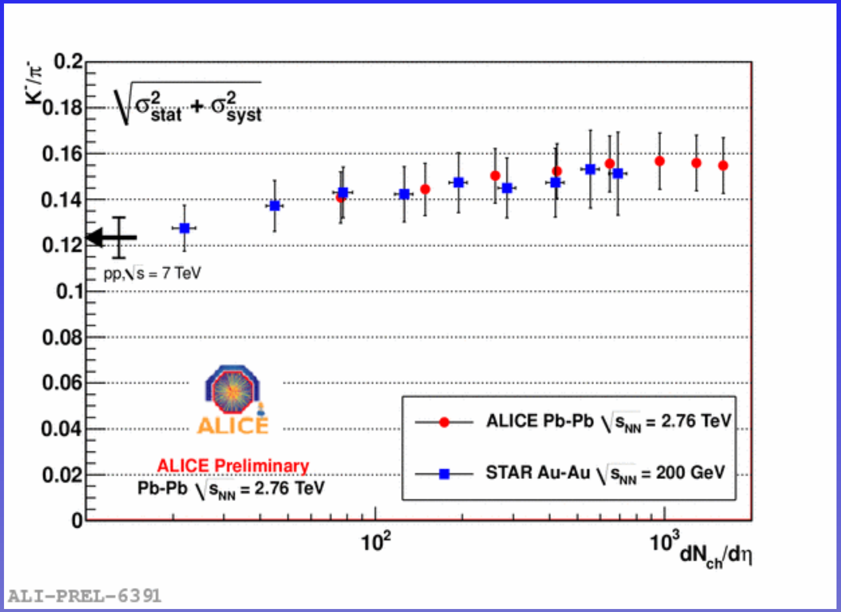


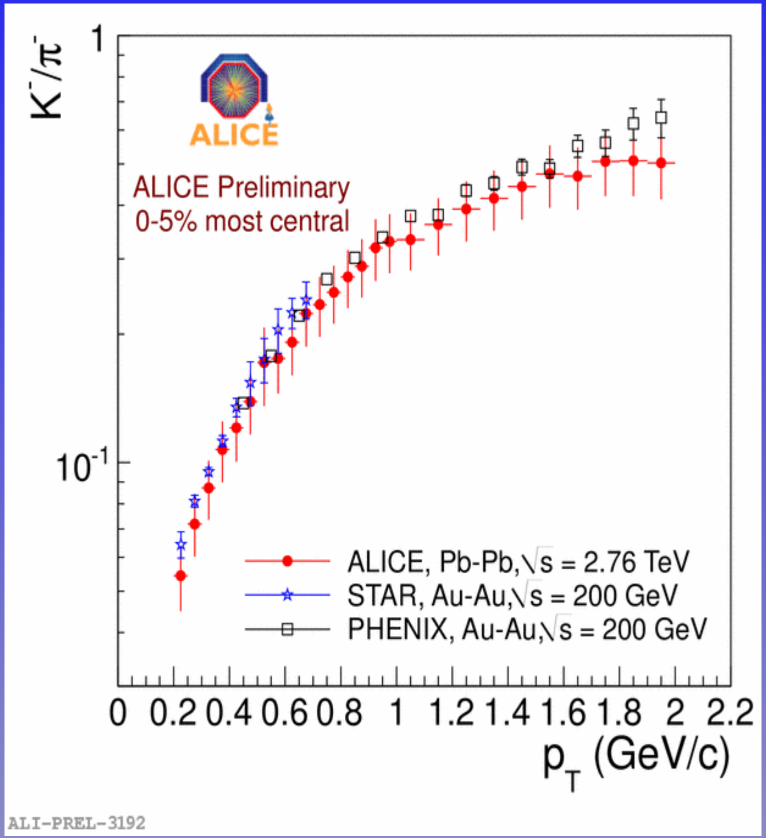




Harder spectra than at RHIC
Protons flatter than at RHIC
→ stronger radial flow?

STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 034909 (2004)

# Pb-Pb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV: $K^-/\pi^-$

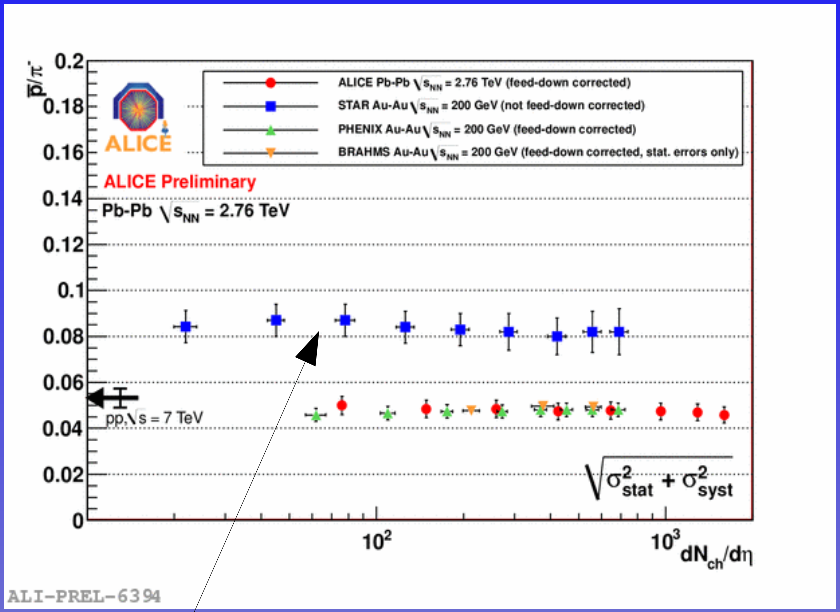


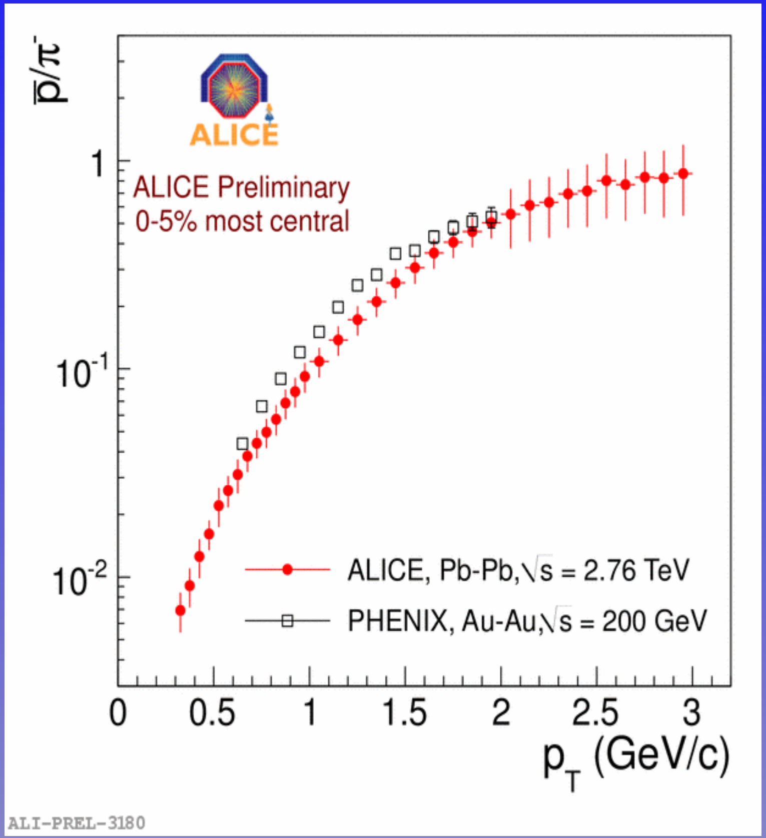




Ratio similar at RHIC and LHC energies

STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 034909 (2004)

# Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV: $\bar{p}/\pi^-$




STAR points:
- Inclusive p
- π feed-down corrected

Ratio similar at RHIC and LHC energies

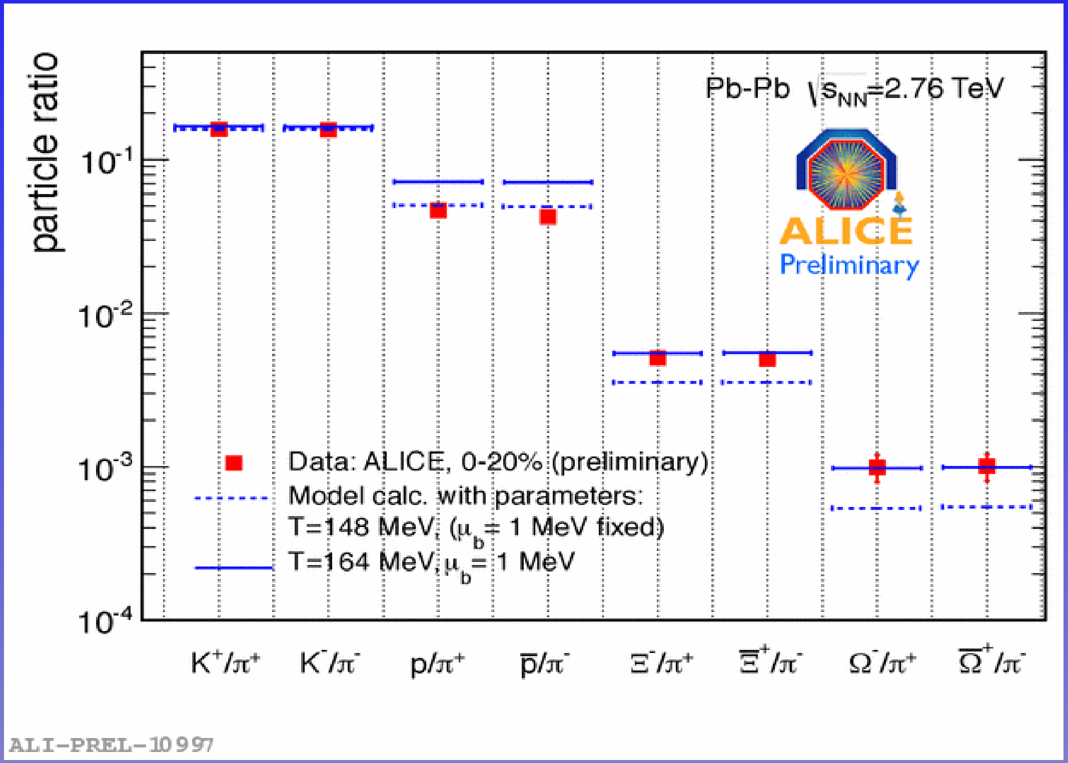
STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 034909 (2004)
BRAHMS, PRC 72, 014908 (2005)

# Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV: thermal-model prediction

| | ALICE data Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV | LHC prediction* $T_{ch}$ = 164 MeV, $\mu_B$ = 1 MeV A.Andronic et al, Phys.Lett.B 673, 142 (2009) | LHC prediction* $T_{ch}$ = (170±5) MeV, $\mu_B$ = (1±4) MeV J. Cleymans et al. PRC 74, 034903 (2006) |
|---|---|---|---|
| $K^+/\pi^+$ | 0.156±0.012 | 0.164 | 0.180±0.001 |
| $K^-/\pi^-$ | 0.154±0.012 | 0.163 | 0.179±0.001 |
| $p/\pi^+$ | 0.0454±0.0036 | 0.072 | 0.091±0.009 |
| $\bar{p}/\pi^-$ | 0.0458±0.0036 | 0.071 | 0.091±0.009 |

*prediction for central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.5 TeV

# Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV: thermal-model prediction

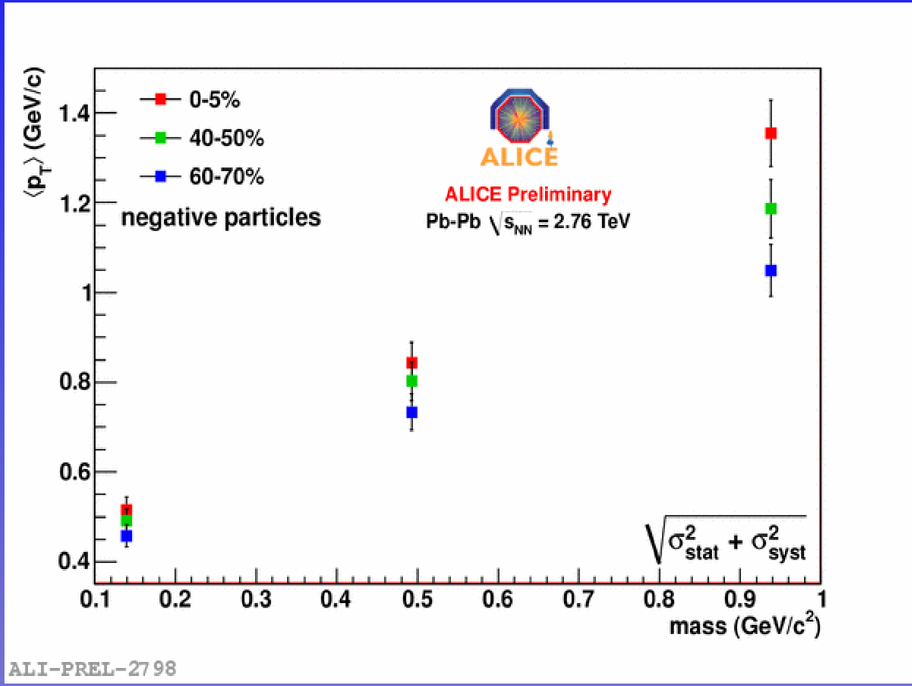


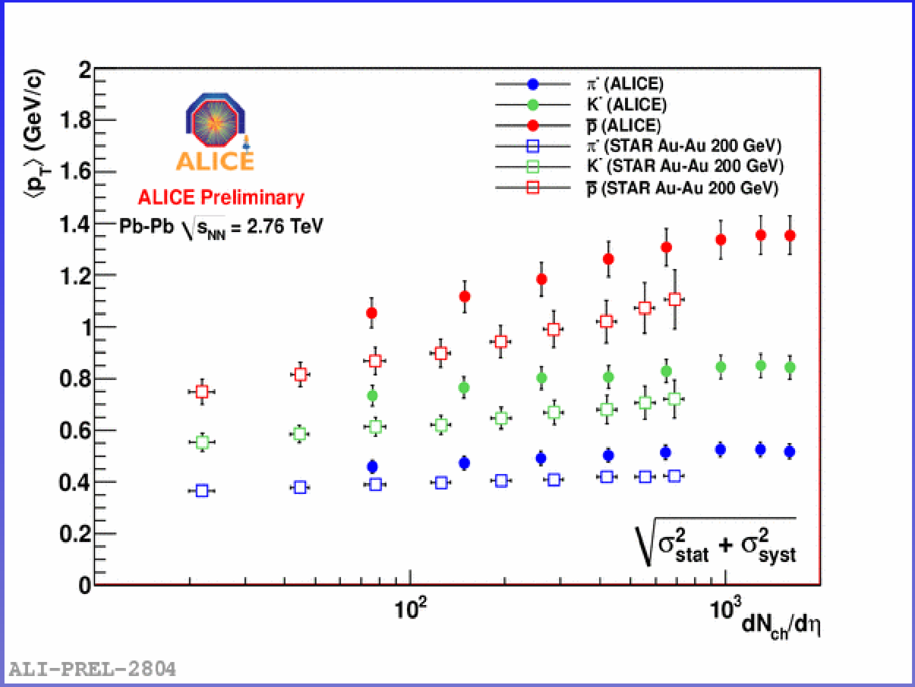

A. Andronic et al.,

Phys.Lett.B 673, 142 (2009)

- Thermal-model at T = 164 MeV:
  - good agreement of kaon and multi-strange particles
  - p/π not described
- Tuning of freeze-out temperature T = 148 MeV:
  - helps for kaons and protons
  - multi-strange underestimated

# Pb-Pb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV: mean $p_t$

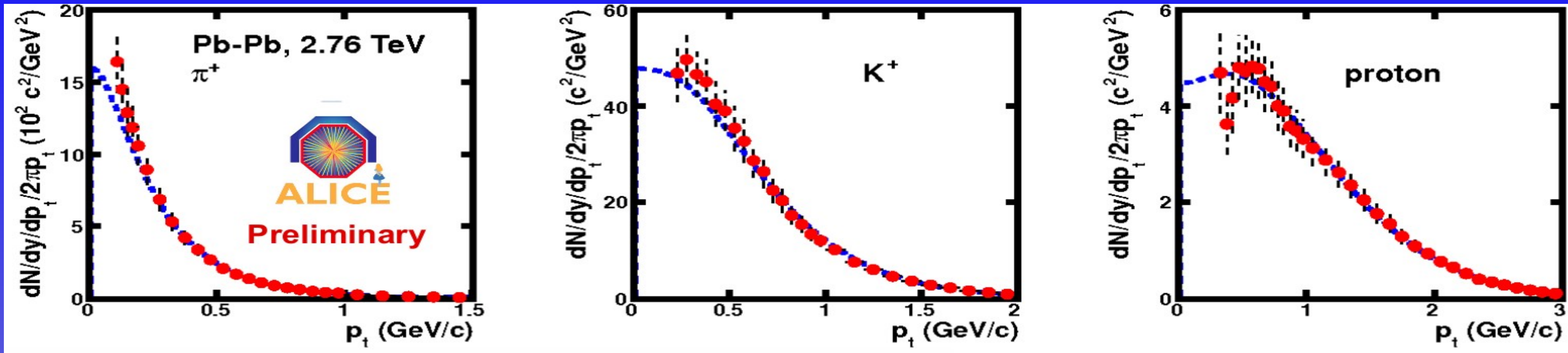



- Linear increase of mean $p_t$ with mass
- Increase of mean $p_t$ (harder spectra) with the collision centrality
- ALICE mean $p_t$ higher than STAR

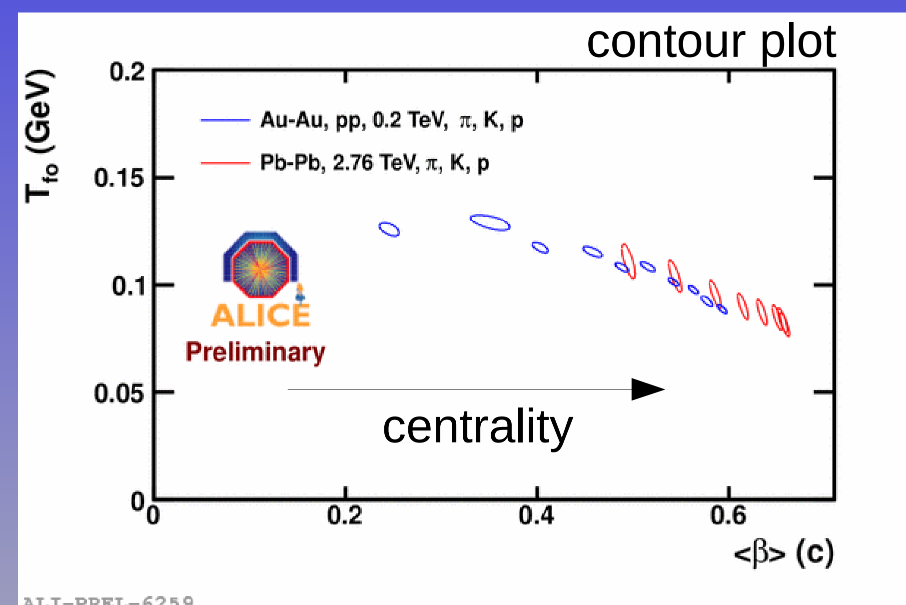
STAR, PRC 79, 034909 (2009)

# Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV: blast-wave fit




Fitted $p_t$ range:
π: 0.3-1.0 GeV/c
K: 0.2-1.5 GeV/c
p: 0.3-3.0 GeV/c

- $T_{fo}$ ($T_{kin}$): kinetic (thermal) freezout temperature parameter in the model ->spectra frozen
- <β>: radial flow parameter in the model




Blast Wave global fits:
$T_{fo}$ and <β> for different centrality bins
-> radial flow ~10% higher than at RHIC
$T_{fo}$ depends on pion fit range
(resonance effect to be investigated)

Schnedermann, PRC 48, 2462 (1993)

STAR, PRC 79, 034909 (2009)

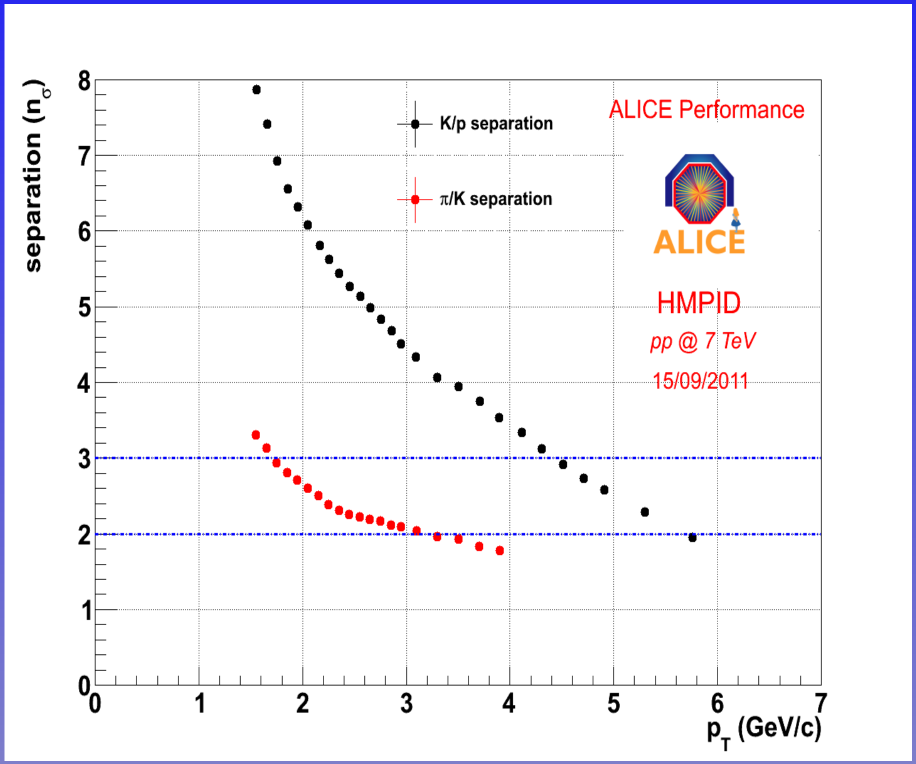
# Conclusions

- ALICE has several detectors with excellent PID performance
- Identified primary hadron spectra in pp collisions at $\sqrt{s}$ = 7 TeV
  - MC models give a poor description of data
  - K/π and p/π are similar in 900 GeV and 7 TeV for $p_t$<1,6 GeV/c
  - Spectra become harder (<$p_t$> increase) with the collision energy
- Identified primary hadron spectra in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV
  - p/π and K/π ratios similar than at RHIC
  - Increase of mean $p_t$ with mass
  - p/π not described by thermal-model at T = 164 MeV
  - Harder spectra with centrality and energy of the collision
  - Radial flow ~10% higher than at RHIC

# ***Backup***

# High Momentum Particle IDentification

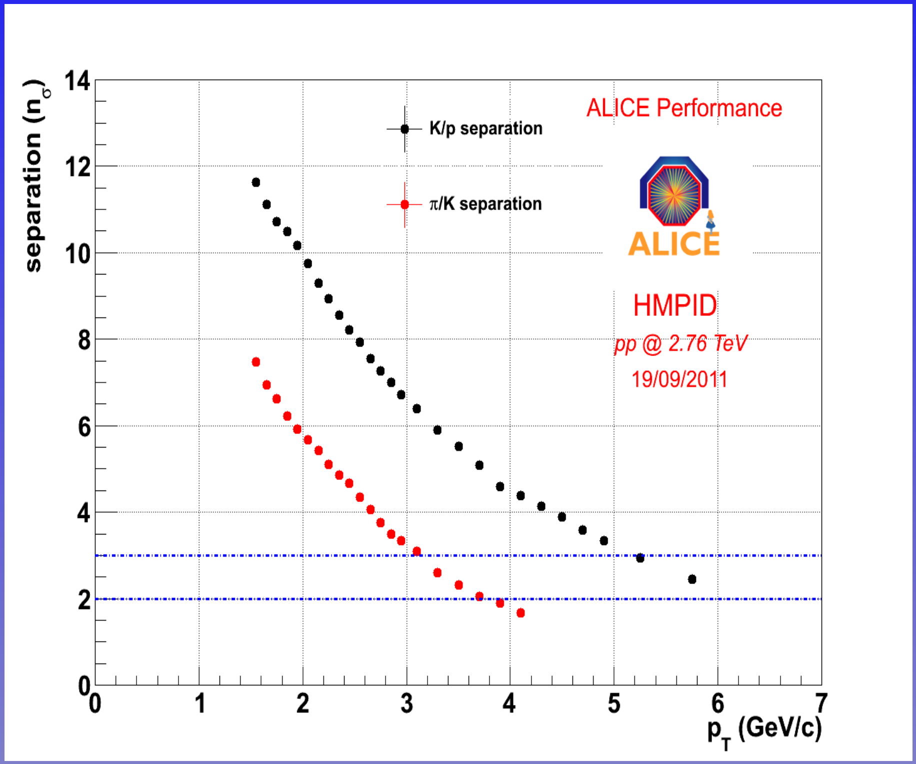
Old tracking




Separation for K/p and π/K vs $p_t$.

- π/K 3σ separation up to 2 GeV/c
- K/p 3σ separation up to 4.5 GeV/c

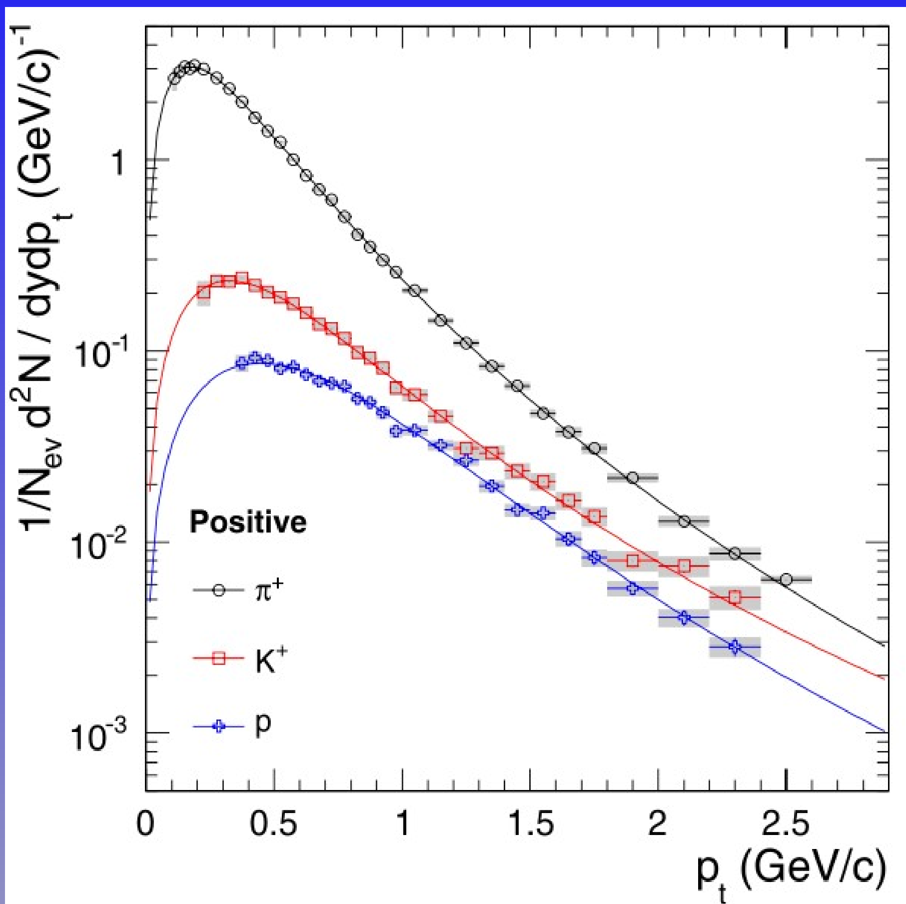
New tracking

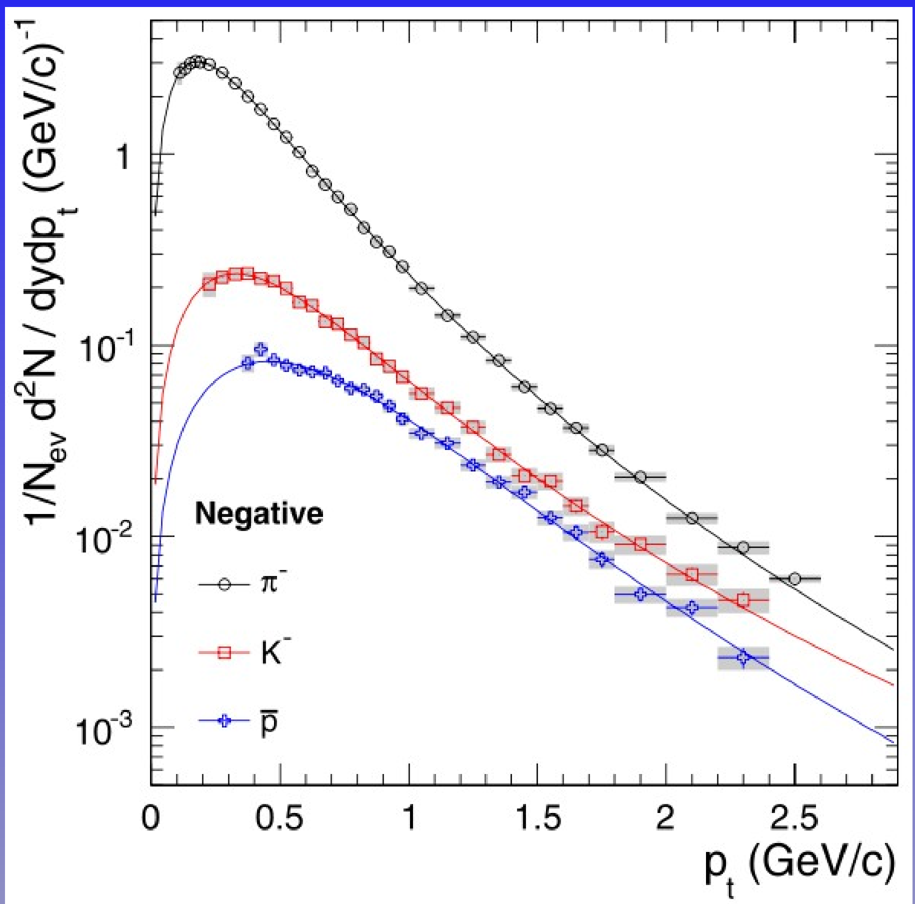



Separation for K/p and π/K vs $p_t$.

- π/K 3σ separation up to 3 GeV/c
- K/p 3σ separation up to 5 GeV/c

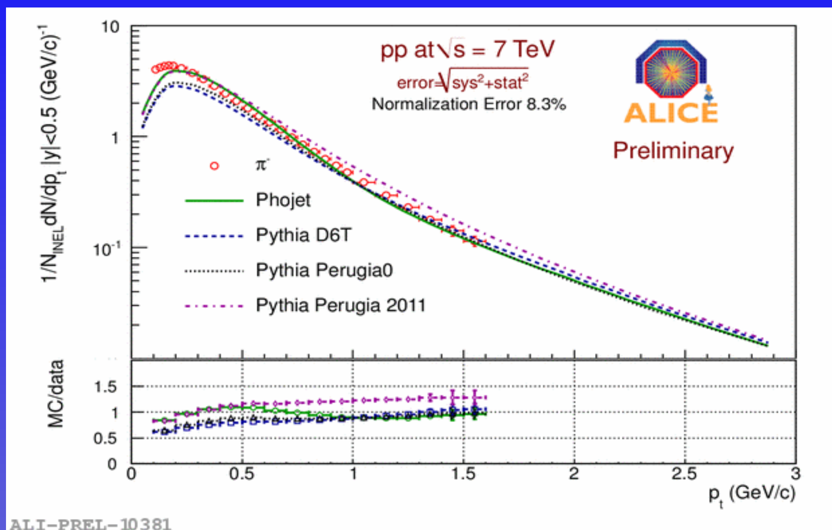
# pp collisions at √s = 0.9 TeV: MB combined spectra

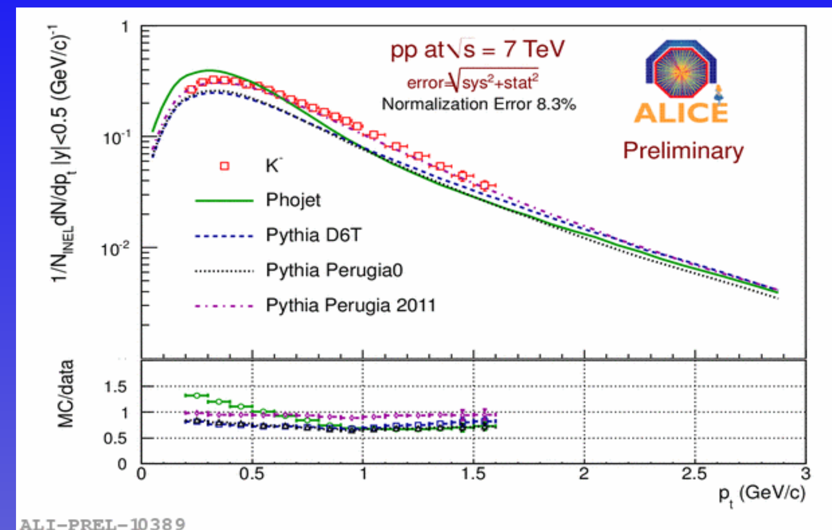


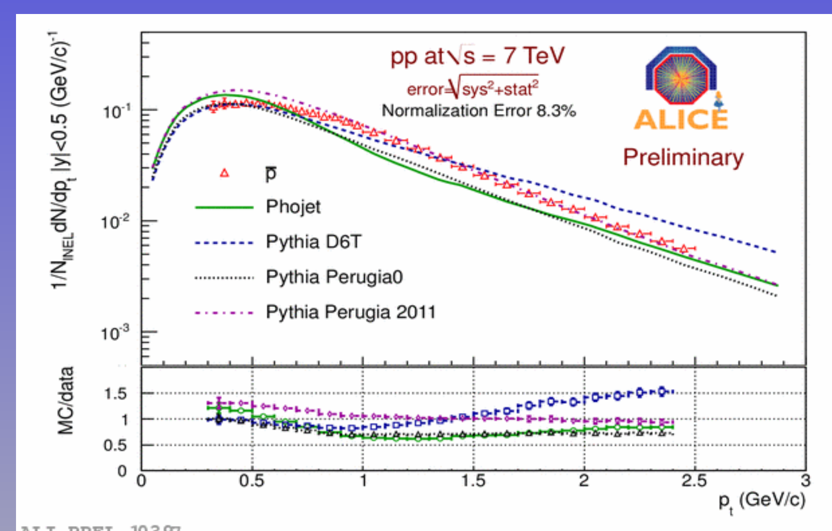

Spectra at √s = 900 GeV published in EPJC 71(6), 2011

# pp collisions at √s = 7 TeV: MB combined spectra vs MC



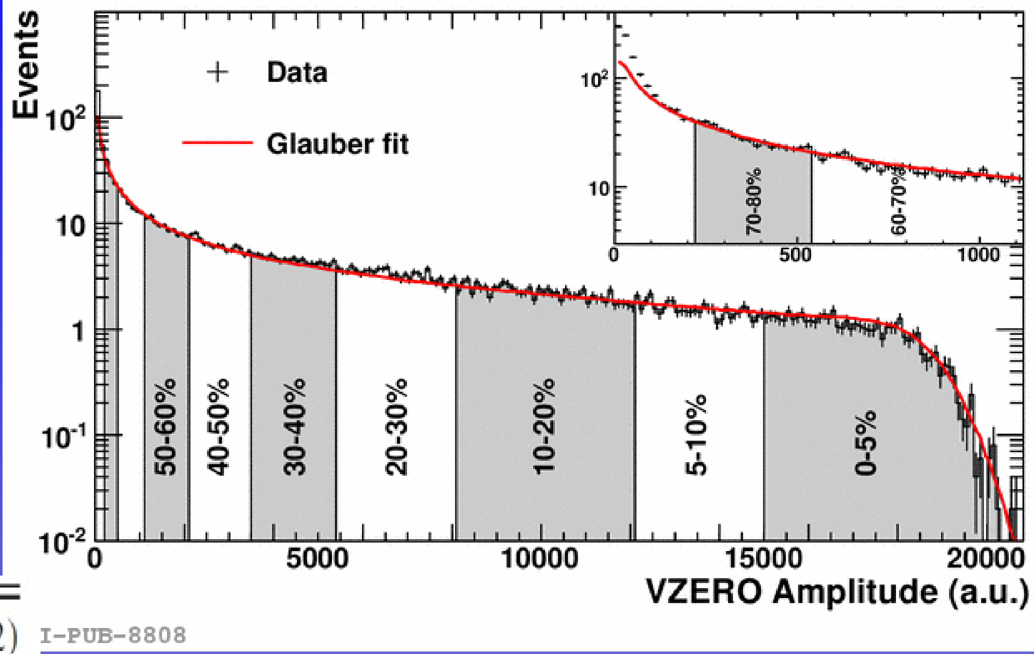




MC models do not describe the details of particle spectra at low $p_t$

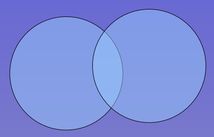


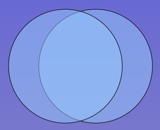
# Centrality selection

VZERO amplitude. Curve: Glauber model fit to the measurement. Vertical lines separate the centrality classes used in the analysis, which in total correspond to the most central 80% of hadronic collisions.

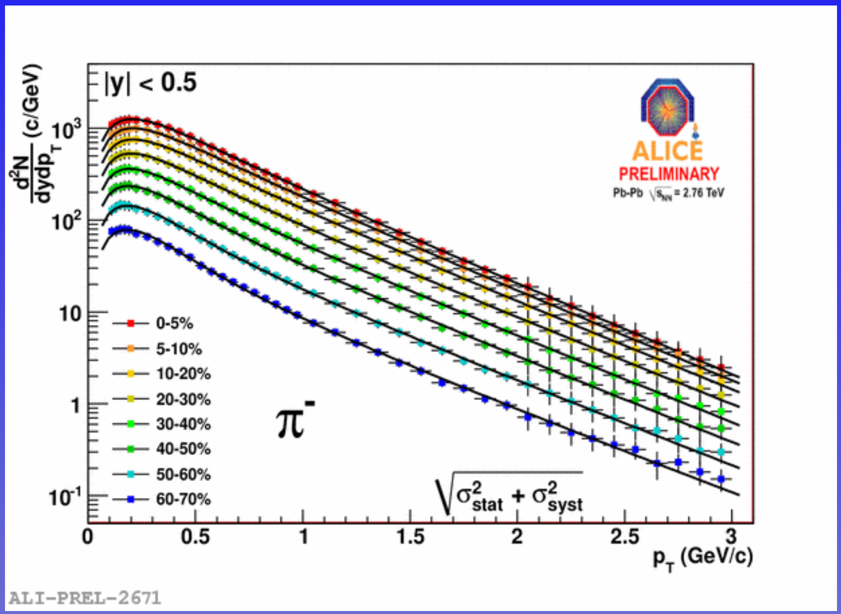


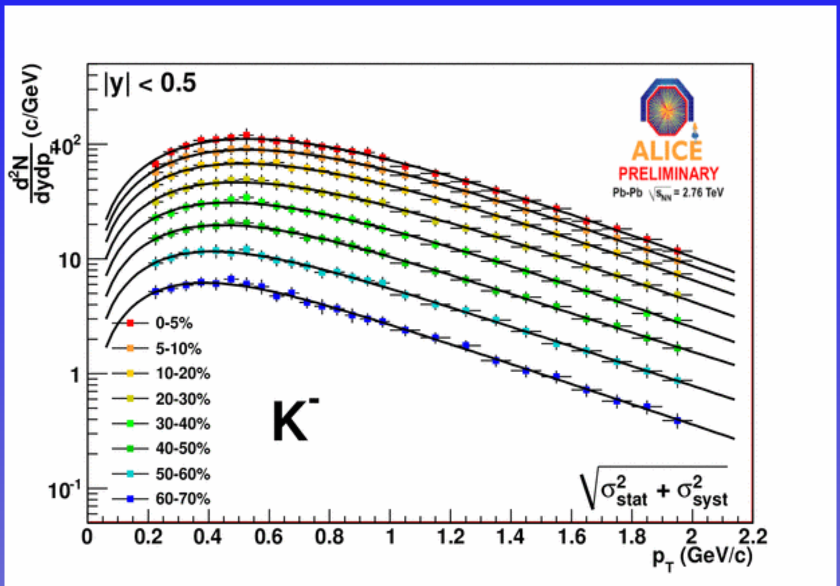

| Centrality | $dN_{ch}/d\eta$ | $\langle N_{part} \rangle$ | $(dN_{ch}/d\eta)/(\langle N_{part} \rangle/2)$ |
|---|---|---|---|
| 0%–5% | 1601 ± 60 | 382.8 ± 3.1 | 8.4 ± 0.3 |
| 5%–10% | 1294 ± 49 | 329.7 ± 4.6 | 7.9 ± 0.3 |
| 10%–20% | 966 ± 37 | 260.5 ± 4.4 | 7.4 ± 0.3 |
| 20%–30% | 649 ± 23 | 186.4 ± 3.9 | 7.0 ± 0.3 |
| 30%–40% | 426 ± 15 | 128.9 ± 3.3 | 6.6 ± 0.3 |
| 40%–50% | 261 ± 9 | 85.0 ± 2.6 | 6.1 ± 0.3 |
| 50%–60% | 149 ± 6 | 52.8 ± 2.0 | 5.7 ± 0.3 |
| 60%–70% | 76 ± 4 | 30.0 ± 1.3 | 5.1 ± 0.3 |
| 70%–80% | 35 ± 2 | 15.8 ± 0.6 | 4.4 ± 0.4 |

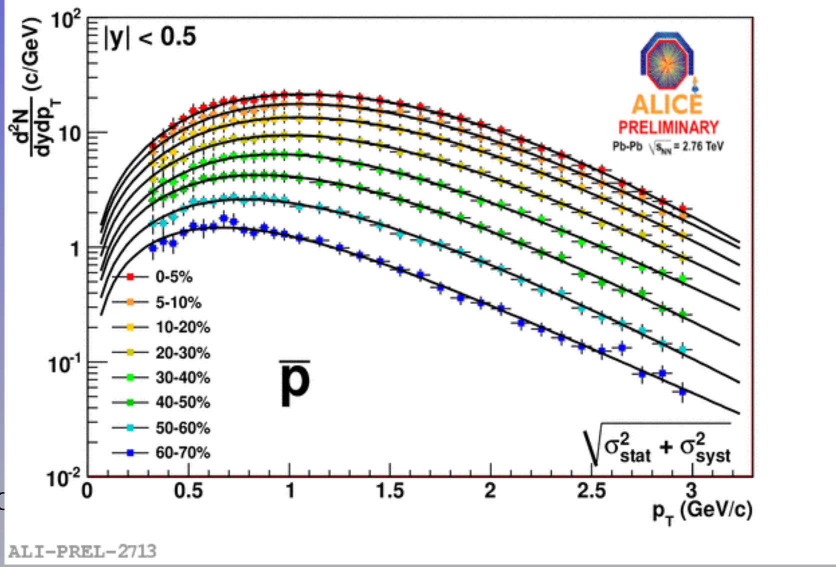

Peripheral


Central

# Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV: combined spectra in centrality bins




- combined spectra from the same 4 analysis as in pp
- fit on individual particles with Blast-Wave function-> definition of integrated yields and average $p_t$

# Blast-Wave model

$$\frac{dN}{p_\perp dp_\perp} \propto \int_0^R r dr m_\perp I_0\left(\frac{p_\perp \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_\perp \cosh\rho}{T_{kin}}\right)$$

$$\rho = \tanh^{-1}\beta \qquad \beta = \beta_S (r/R)^n$$

Free parameters: $T_{kin}$, $\beta_s$, n

$T_{kin}$ = kinetic (thermal) freezout temperature in the model: no more elastic collisions → fixed spectra

β: transverse radial flow velocity

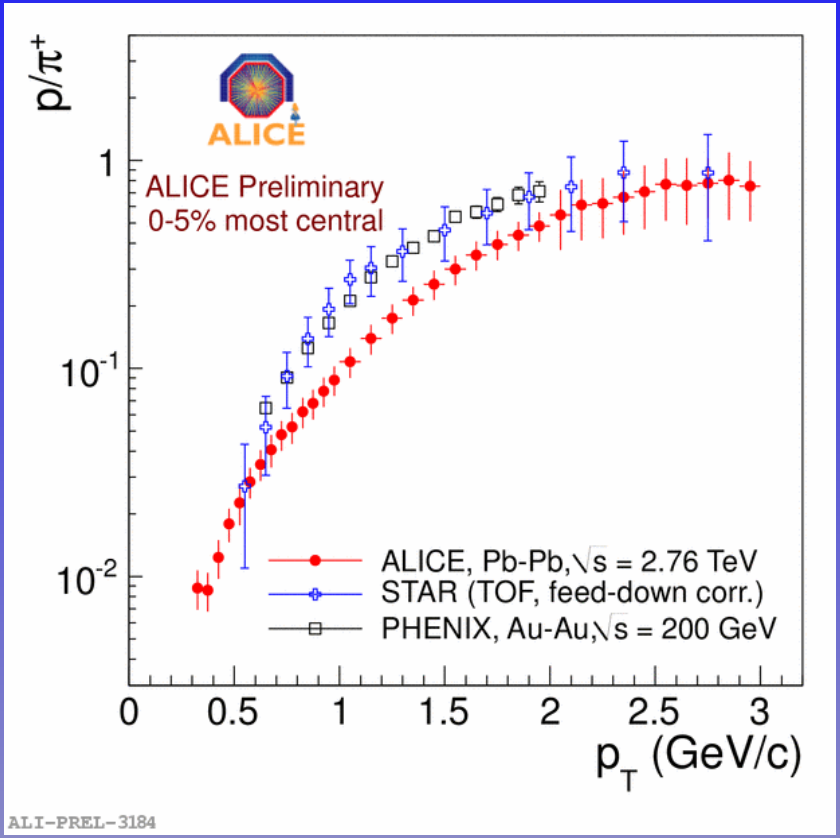
$\beta_s$: surface transverse flow velocity

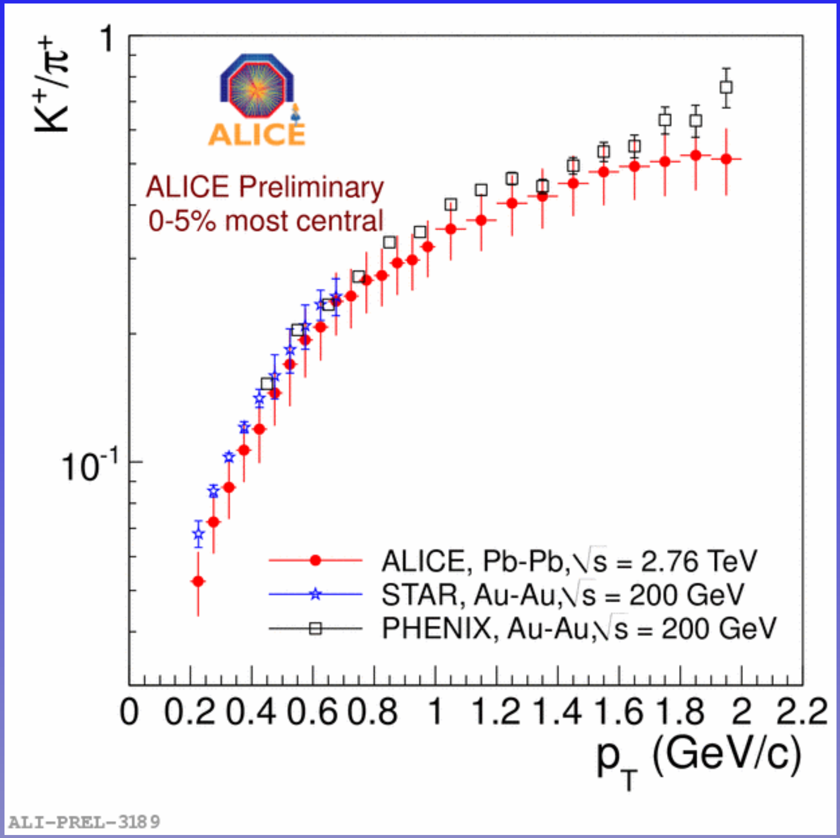
n: velocity profile

$\rho_r$: transverse boost

R: transverse geometric radius of the source at the freeze-out

# Pb-Pb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV: particle ratio (positive particle)

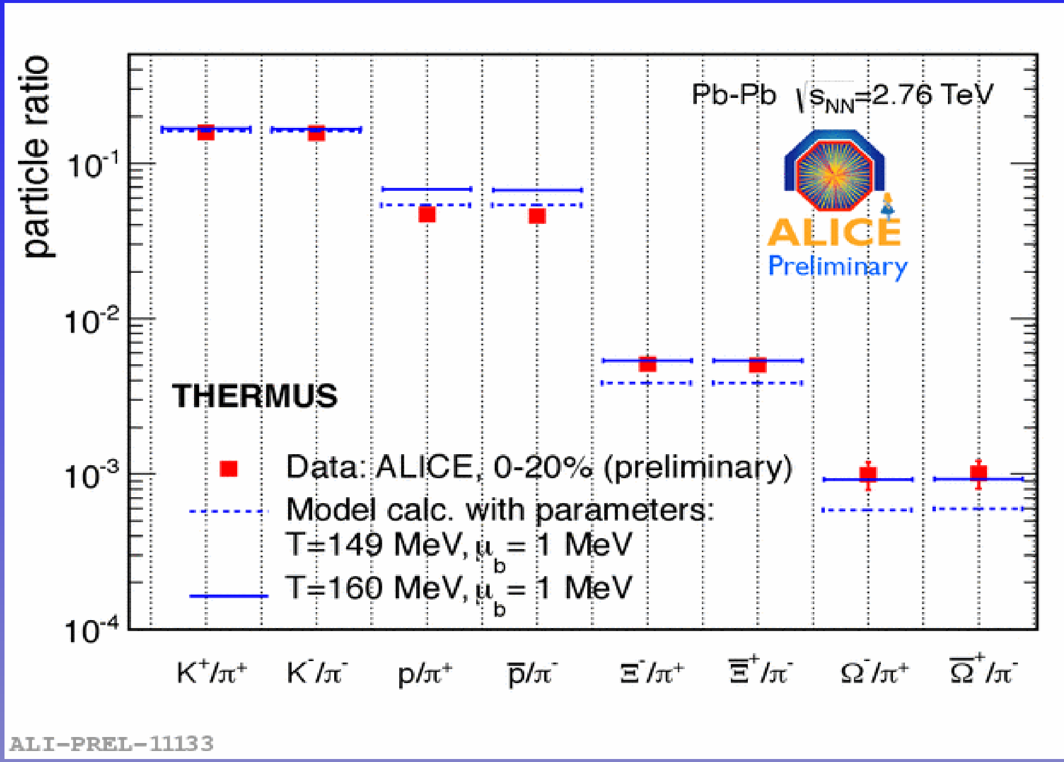



Saturation at higher $p_t$ compared with RHIC

Ratio similar at RHIC and LHC energies

# Pb-Pb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV: thermal-model prediction (2)

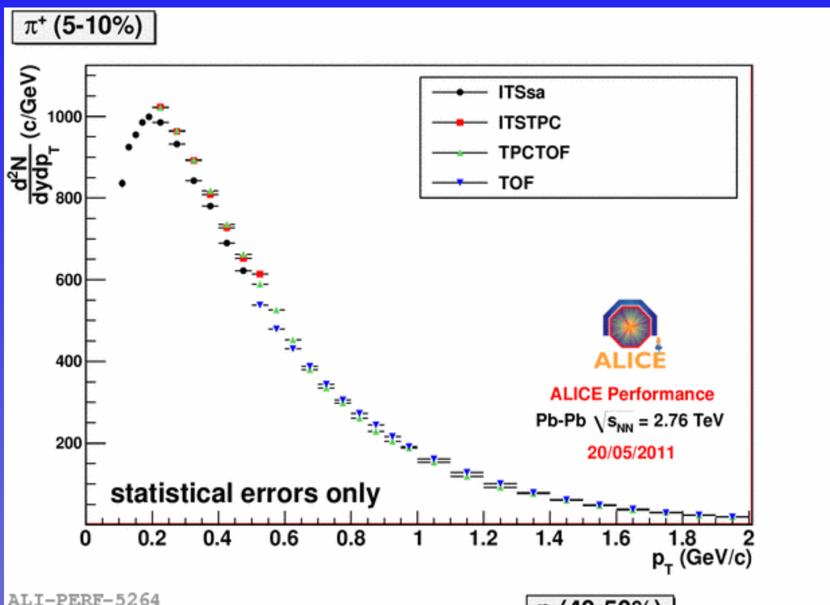


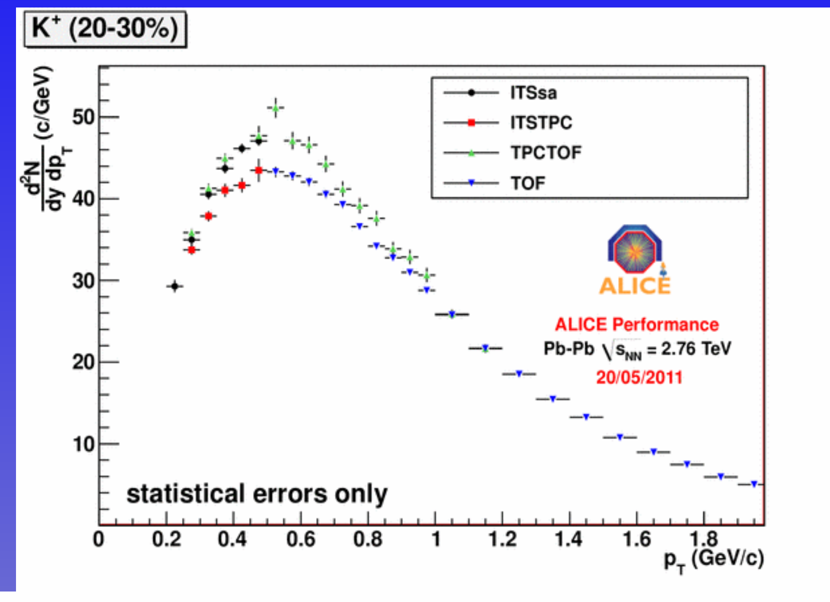

Same behaviour of the previous thermal model (see slide 25)

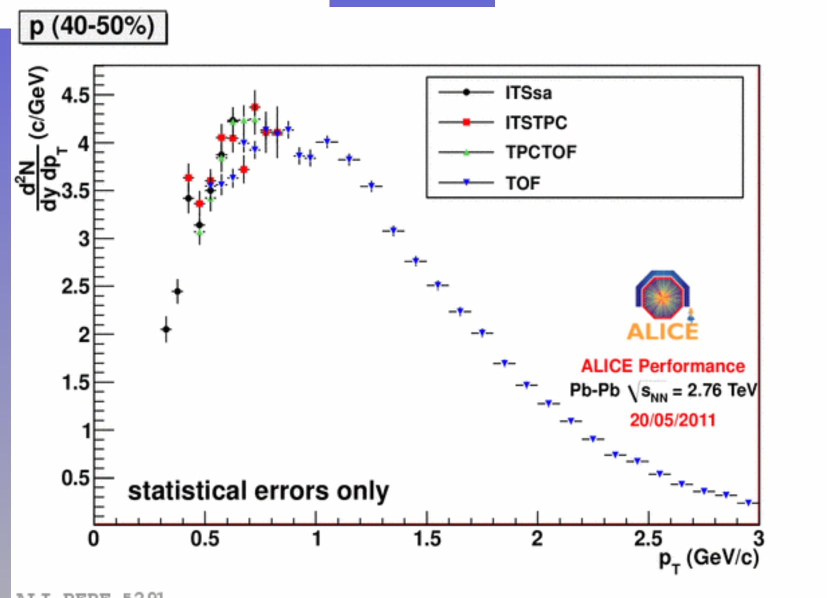
S. Wheaton, J. Cleymans and M. Hauer,

Comput. Phys. Commun. 180 (2009) 84-106.

# *Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV: analysis details (positive particles)*

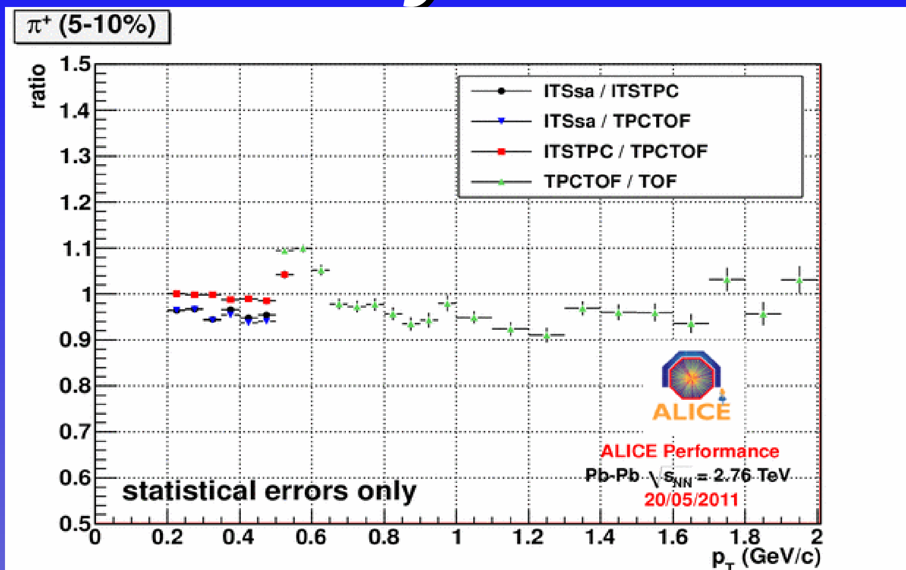


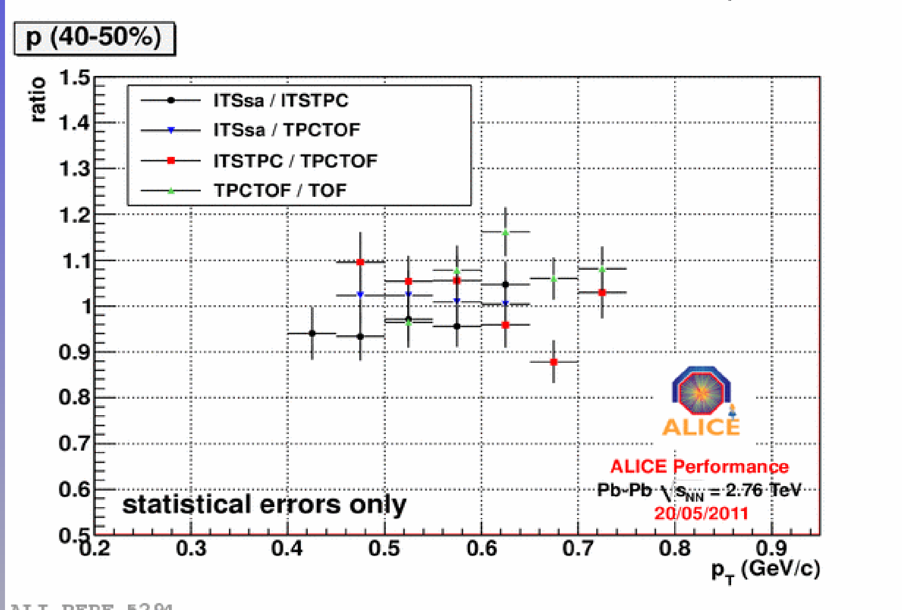



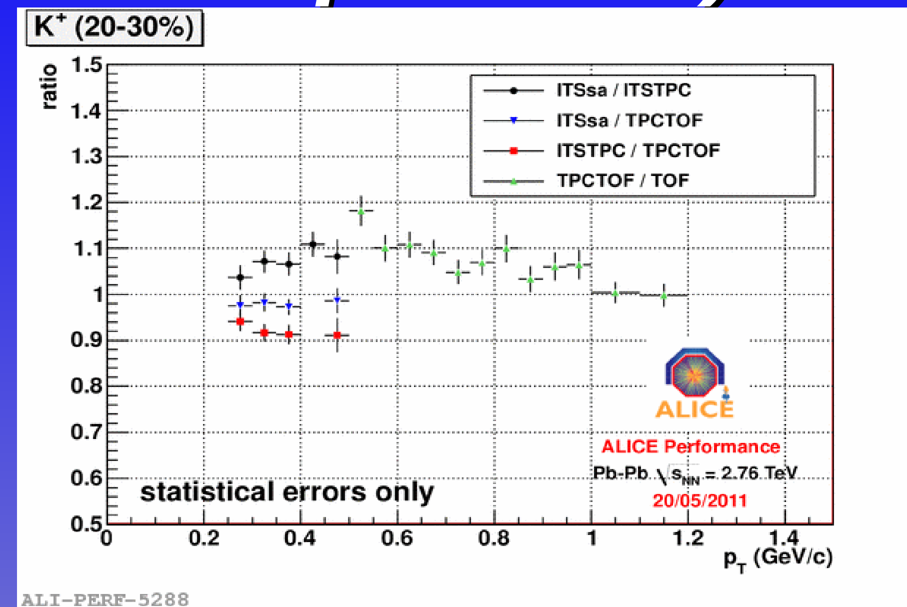




Most disagreements now understood

# *Pb-Pb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV: analysis details (positive particles)*




Most disagreements now understood