Latest QCD results from the ALICE experiment

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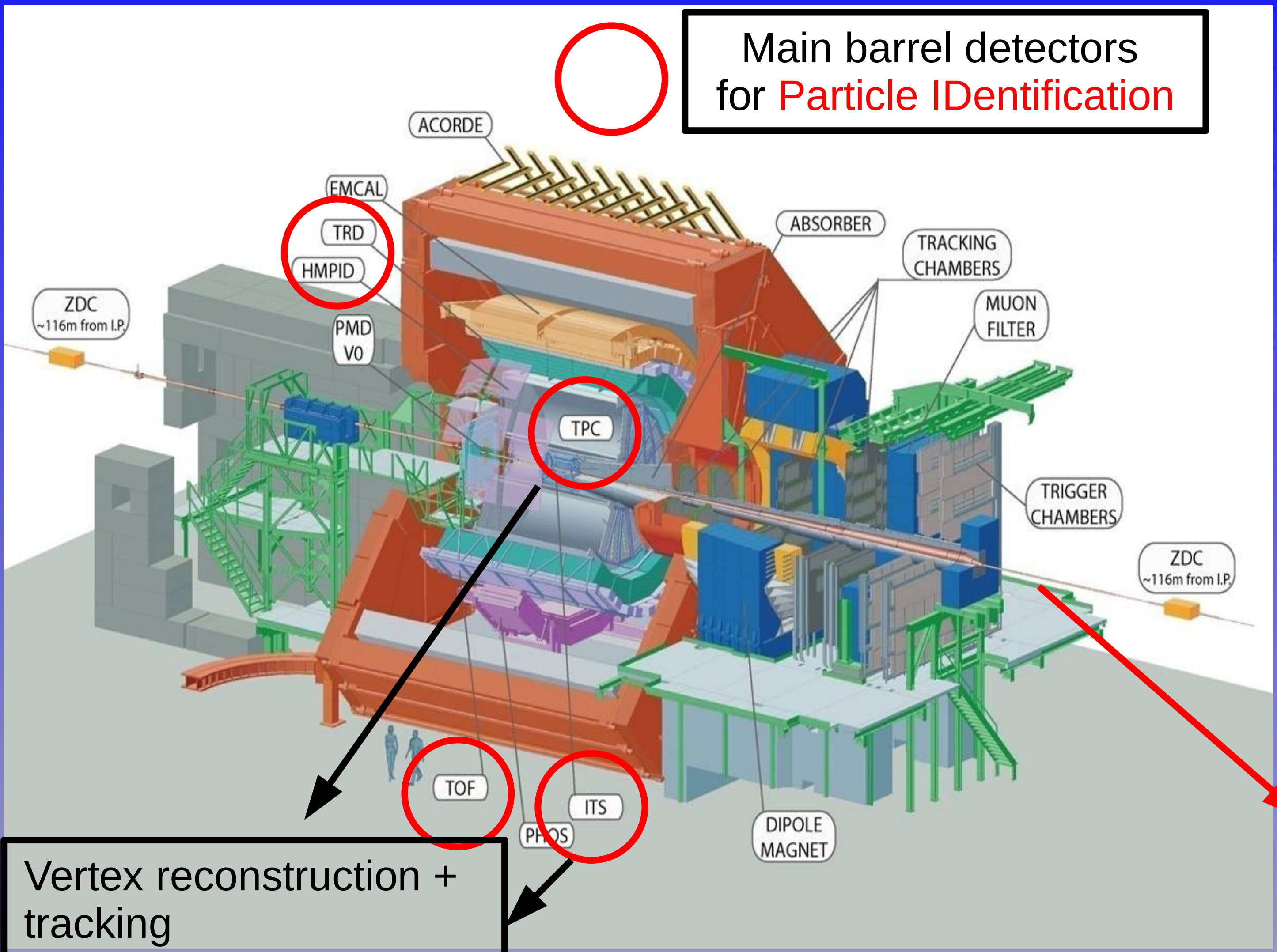
Excited QCD 2012 – Peniche, Portugal – 06-12 May 2012

Outline

- The ALICE experiment: PID Detector Performance
- QCD results:
  - Primary hadron spectra (pp and PbPb)
    - Tuning MC models
    - Kinetic freeze-out parameters
    - Thermal model predictions
  - Strangeness enhancement
  - Baryon/meson ratio
  - Heavy flavours:
    - Charm R_{AA}
    - e and μ from HF decays
    - Inclusive J/Ψ: R_{AA}
  - Elliptic flow
- Conclusions

The ALICE Experiment

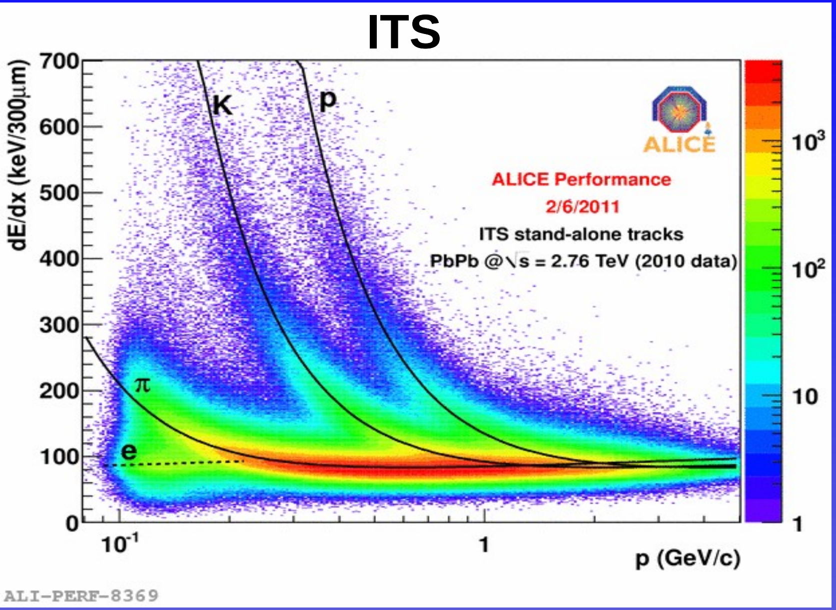


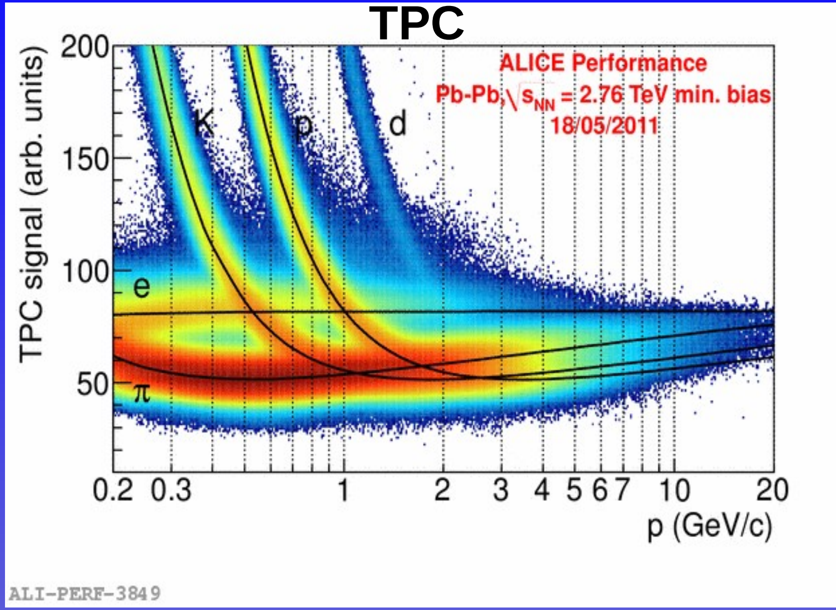
ALICE has several barrel detectors (|η|<0.9) dedicated to PID

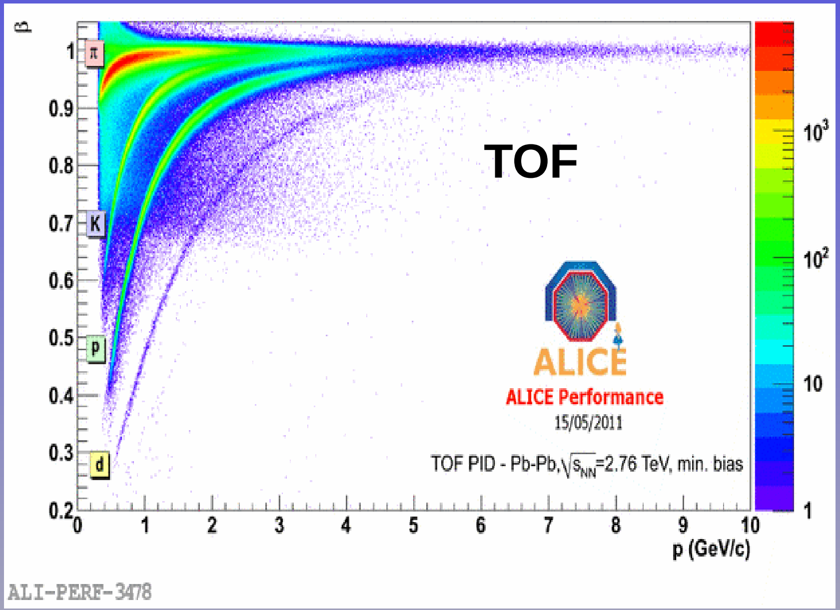
- covering complementary p_t ranges
- using different PID techniques
  - ITS: dE/dx
  - TPC: dE/dx
  - TRD: Transition Radiation
  - TOF: Time-of-Flight
  - HMPID: Cherenkov Radiation

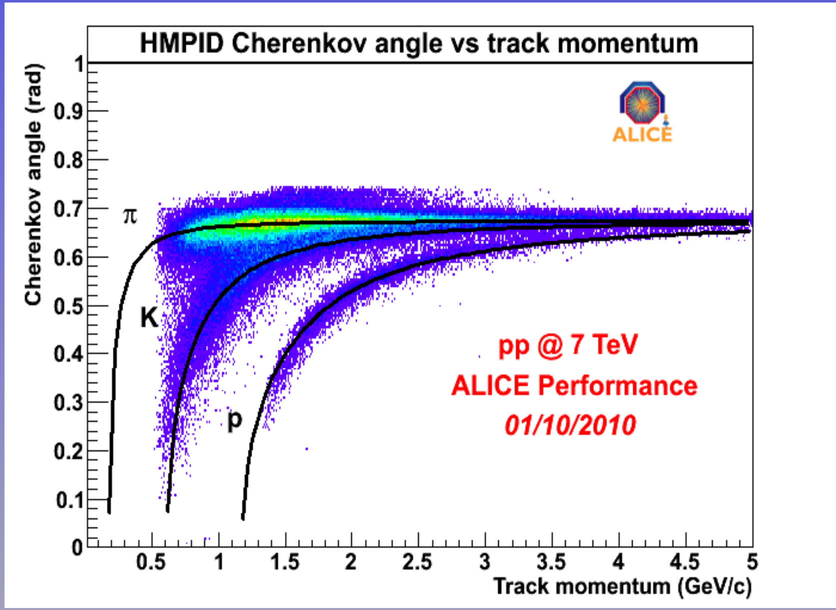
ALICE has a forward muon spectrometer (-4<η<-2.5) for muon ID

Main PID detector: performance

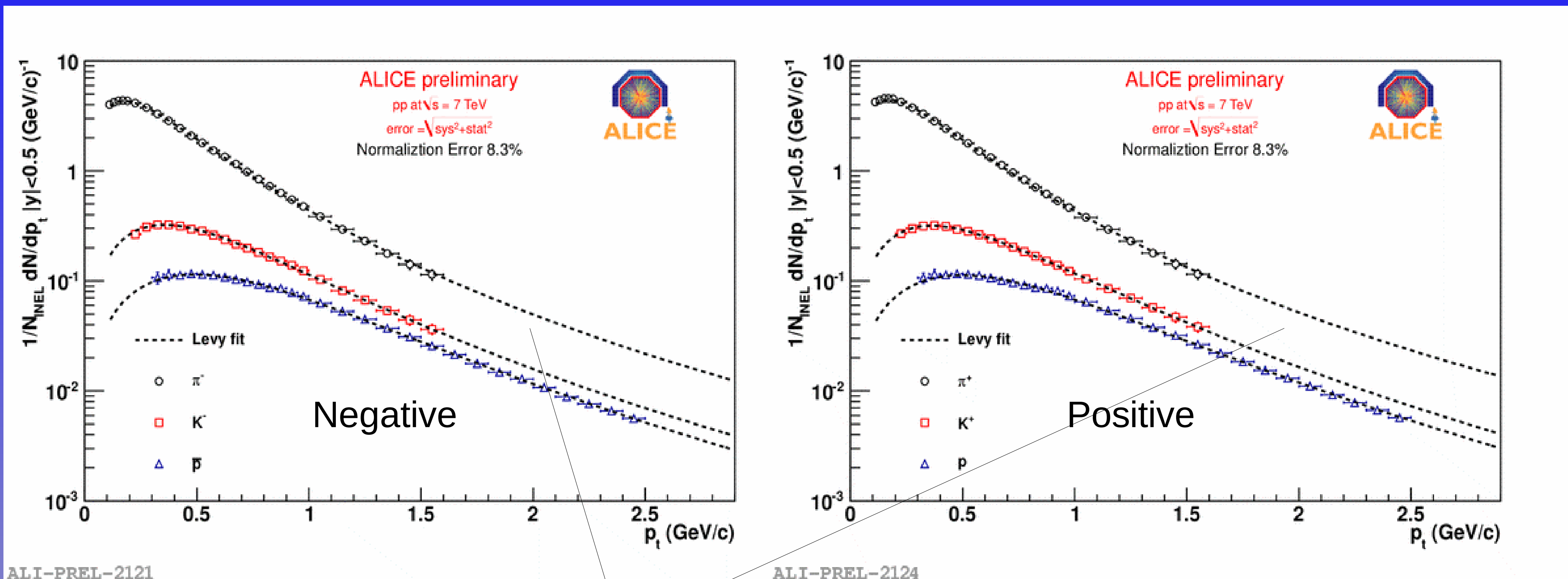








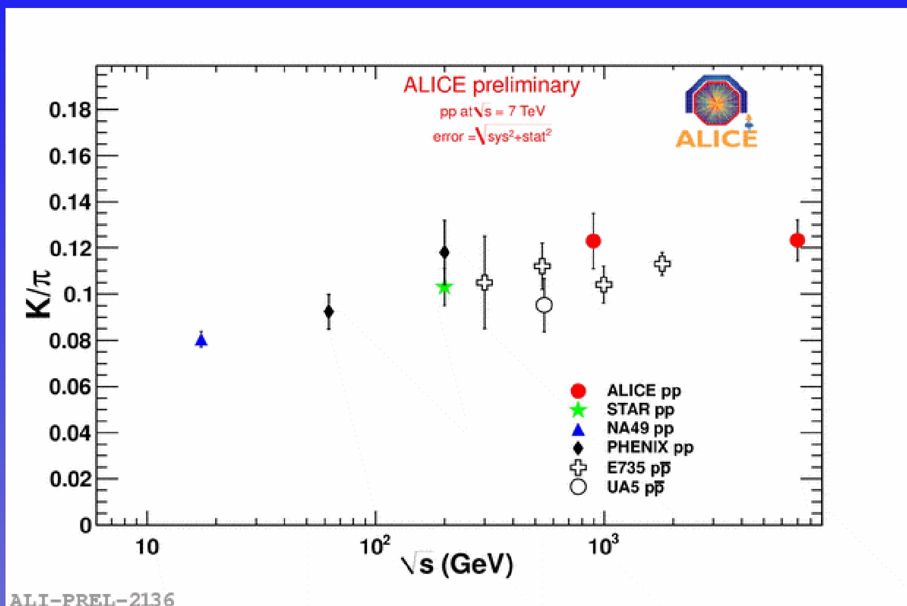
MB primary hadron spectra in pp collisions at √s = 7 TeV

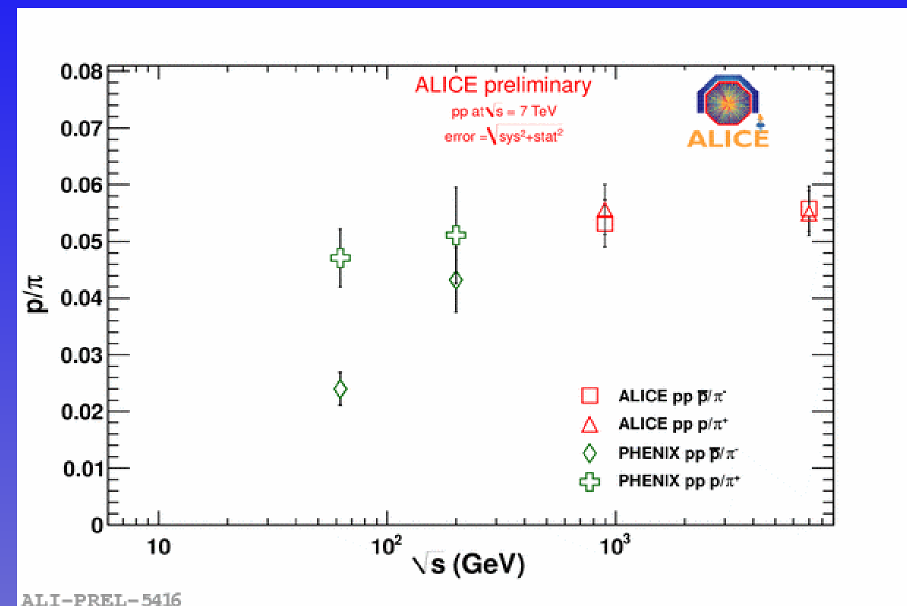


Lévy-Tsallis function
for pp spectra fit to extract
integrated yields and $<p_t>$

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

Inelastic K/π and p/π ratios in pp collisions at √s = 7 TeV





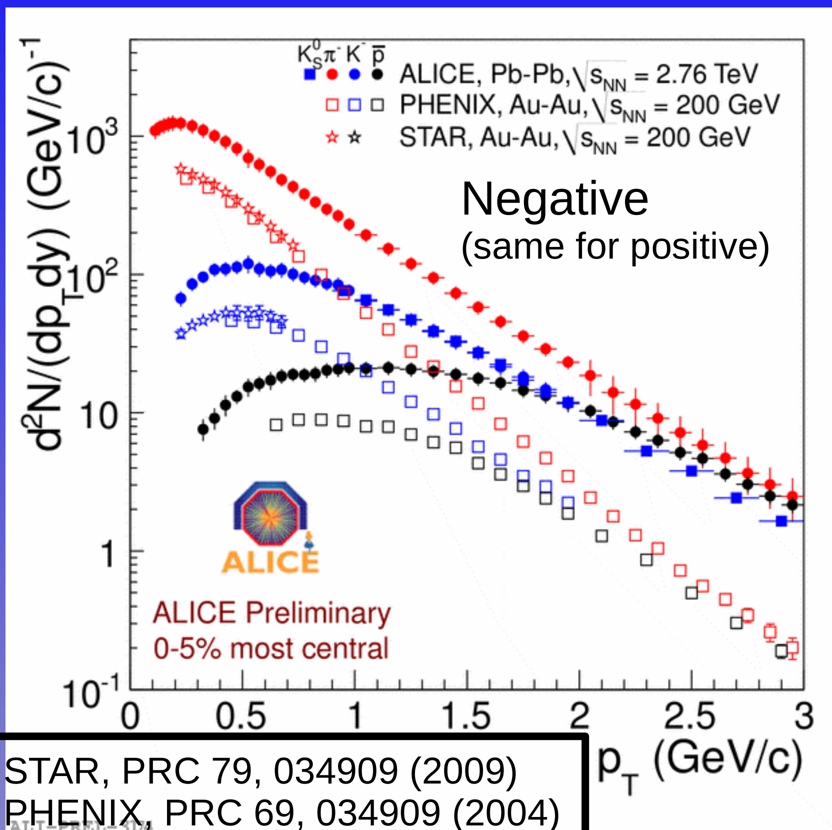
ALICE points: obtained using the yields extracted from the previous Lévy-Tsallis fits
The ratio is constant within errors between 0.9 TeV and 7 TeV data

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

Particle ratios important to tune MC models

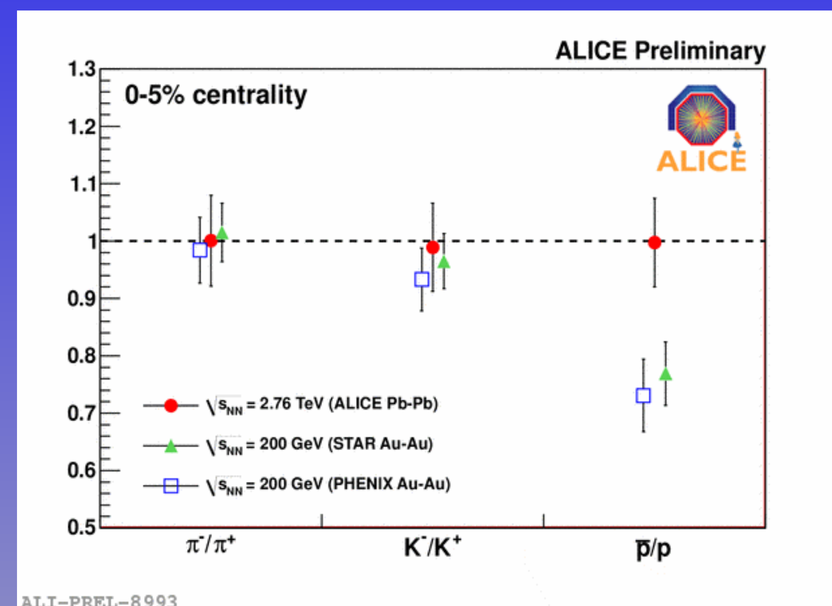
Spectra at √s = 0.9 TeV published in EPJC 71(6), 2011

Primary hadron spectra in central Pb-Pb collisions



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

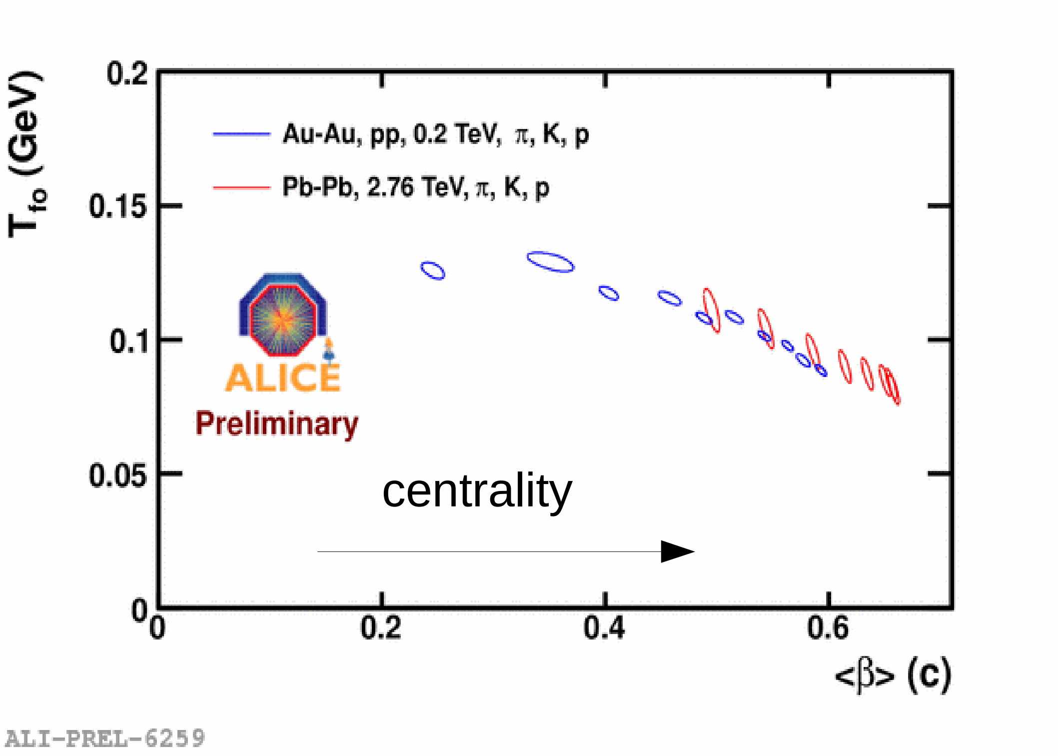
- Harder spectra than at RHIC
- Protons flatter than at RHIC
  → stronger radial flow?



- Good agreement with hydro predictions for pions and kaons
- Better agreement with hydro+UrQMD predictions for protons

Ratios compatible with 1 as expected at LHC energies

Kinetic freeze-out parameters from blast-wave fit of primary spectra



Model parameters:

- T_{fo} (T_{kin}): kinetic (thermal) freezout temperature
- <β>: average transverse expansion velocity

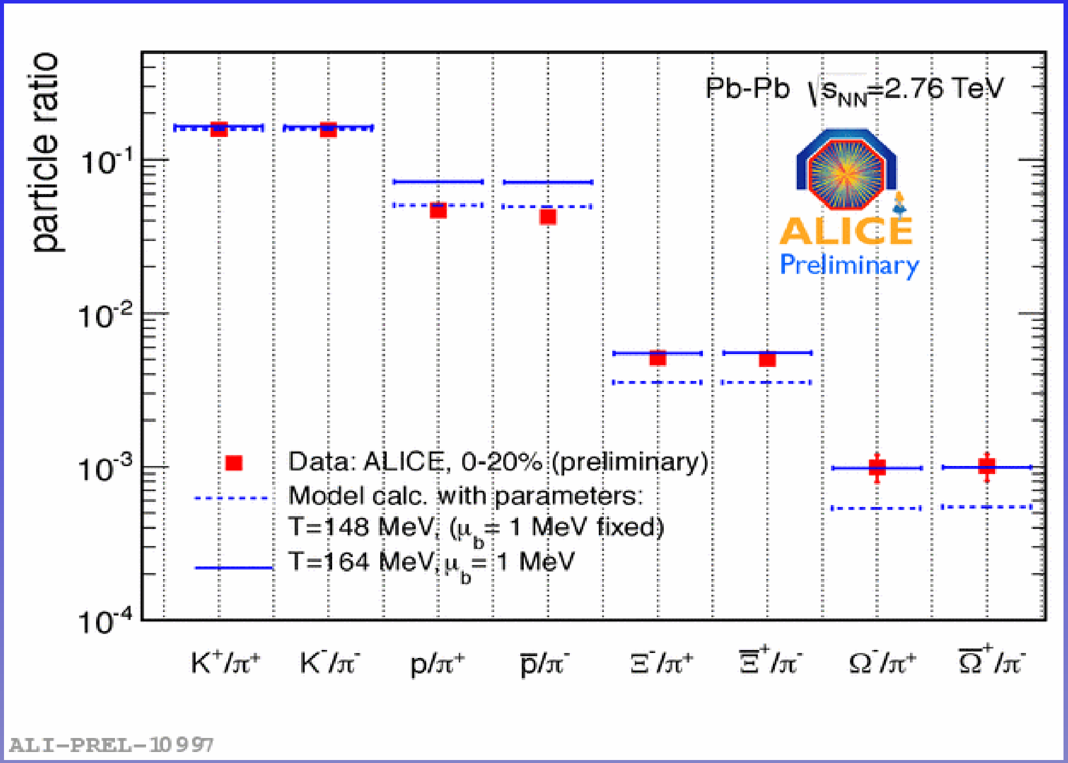
Blast Wave global fits:
T_{fo} and <β> for different centrality bins
-> radial flow ~10% higher than at RHIC
T_{fo} depends on pion fit range
(resonance effect to be investigated)

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

STAR, PRC 79, 034909 (2009)

Schnedermann, PRC 48, 2462 (1993)

Chemical freeze-out parameters from particle ratios: thermal-model prediction

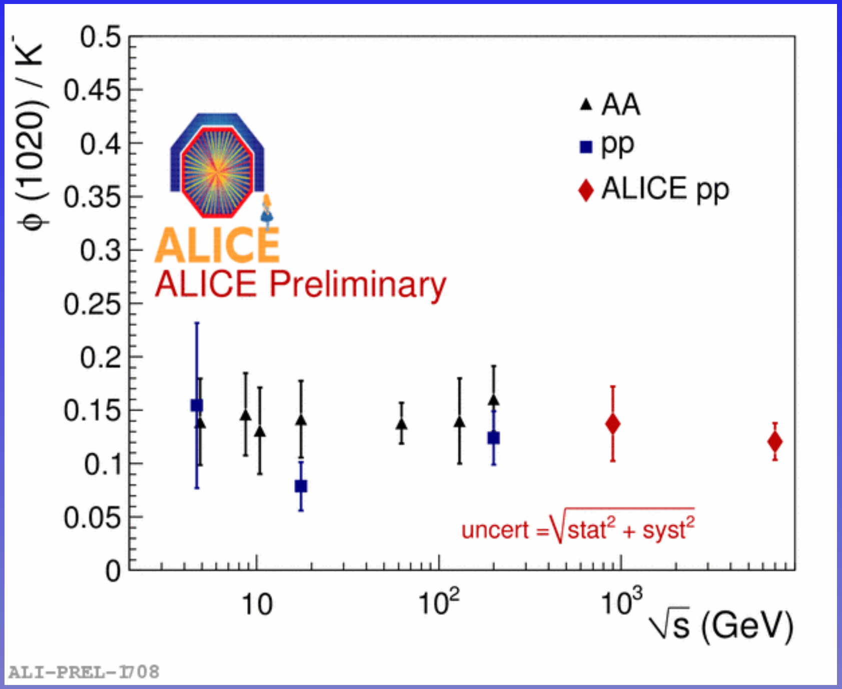


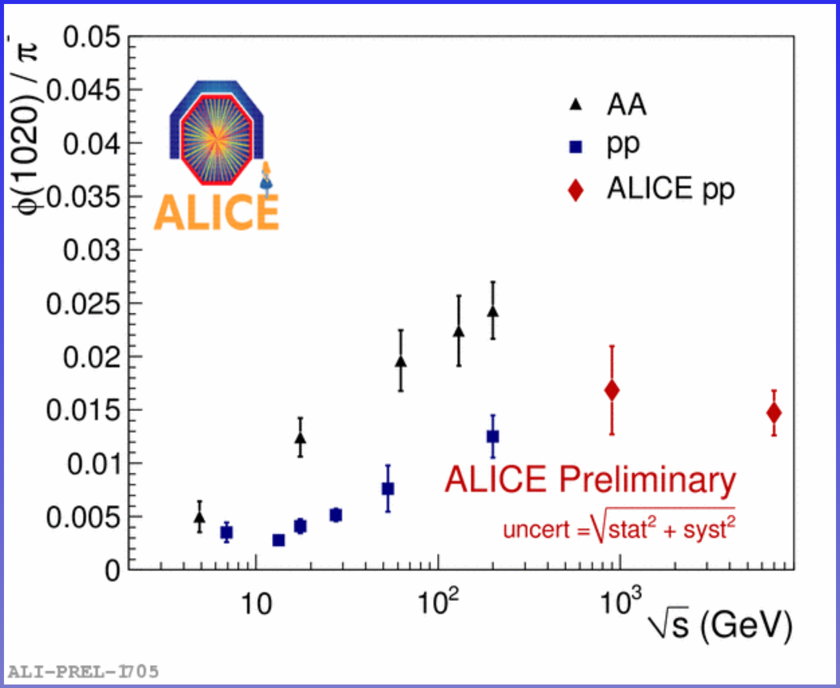
A. Andronic et al.,

Phys.Lett.B 673, 142 (2009)

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

Particle ratios: strange quark suppression factor

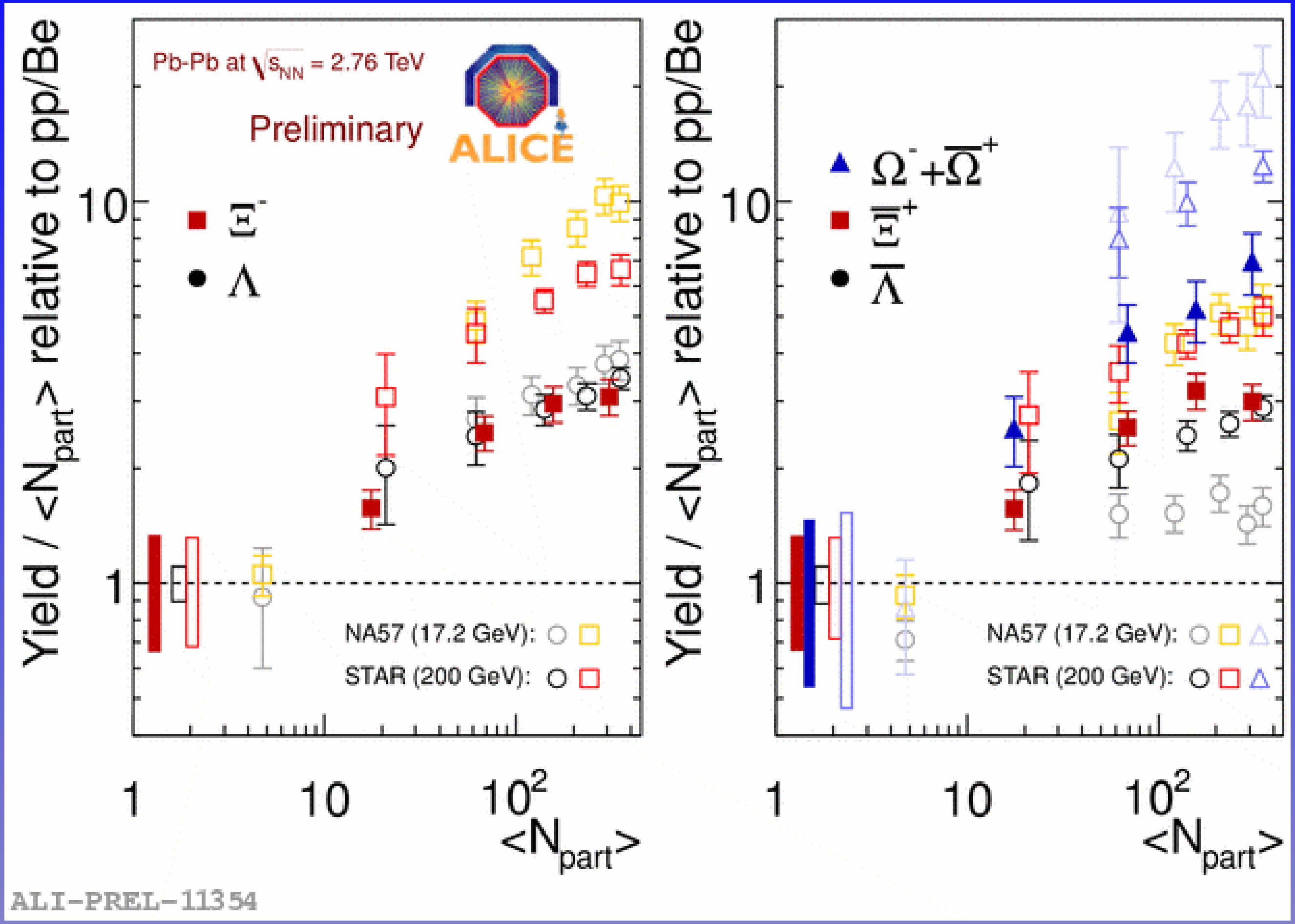




The ϕ/K ratio does not change with the collisions energy
Same for all system sizes

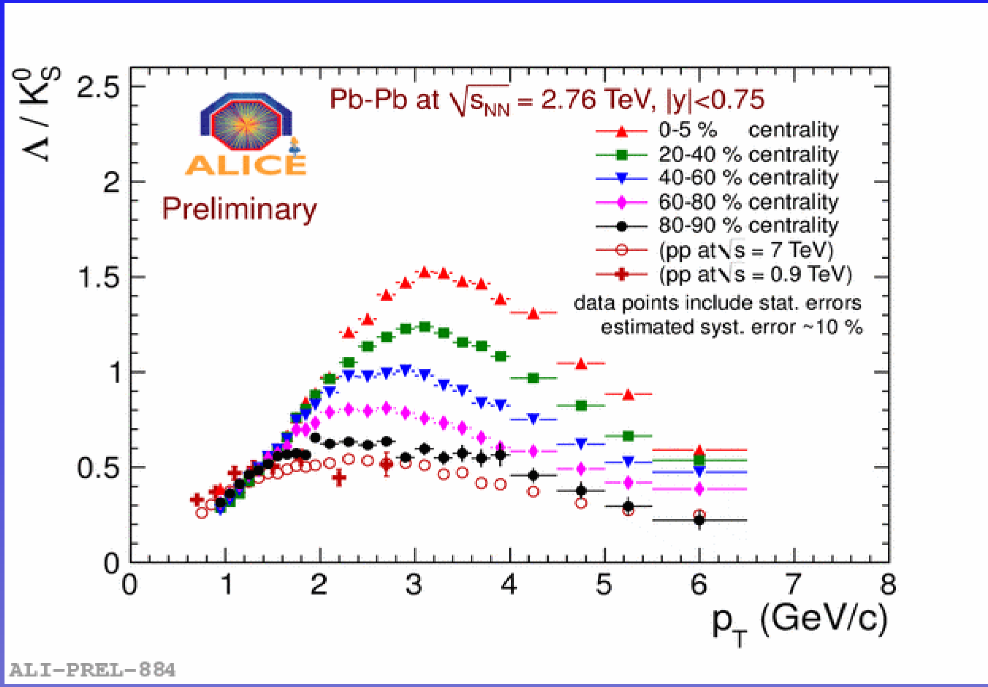
The ϕ/π ratio increases with energy both in heavy-ion and in pp collisions. This trend changes at the energy of ~1 TeV in pp collisions, for which a saturation is observed

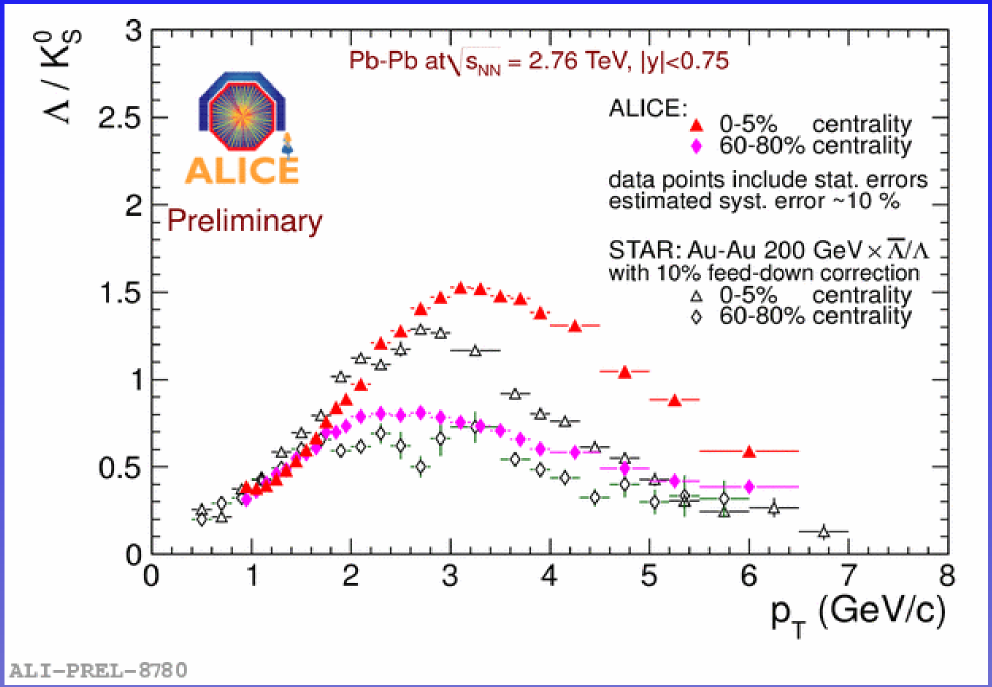
Strangeness enhancement



- Multi-strange baryons enhanced with respect to pp
- Enhancement increases with the strangeness content
- Enhancement decreases with the collisions energy

Baryon/meson ratio



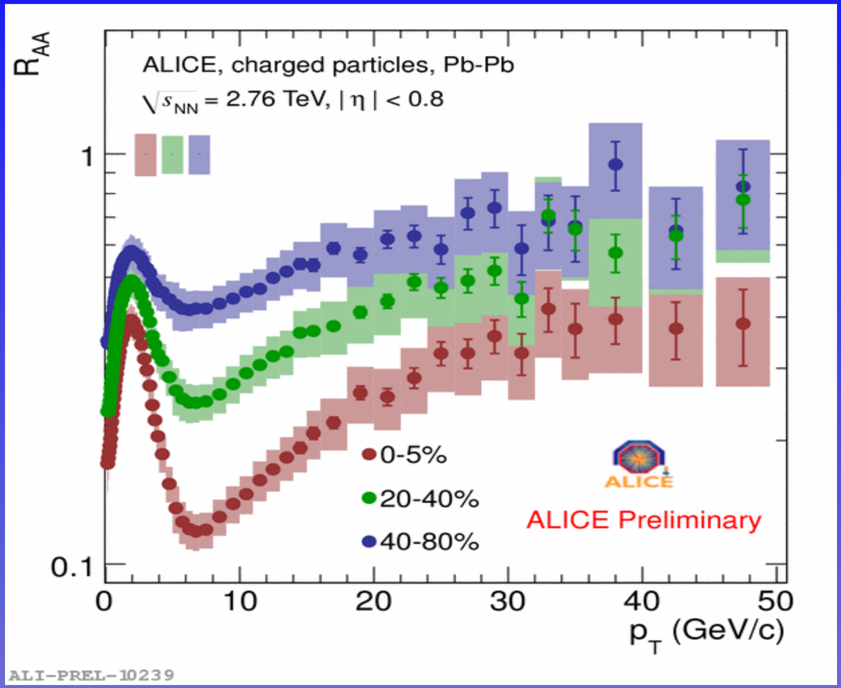


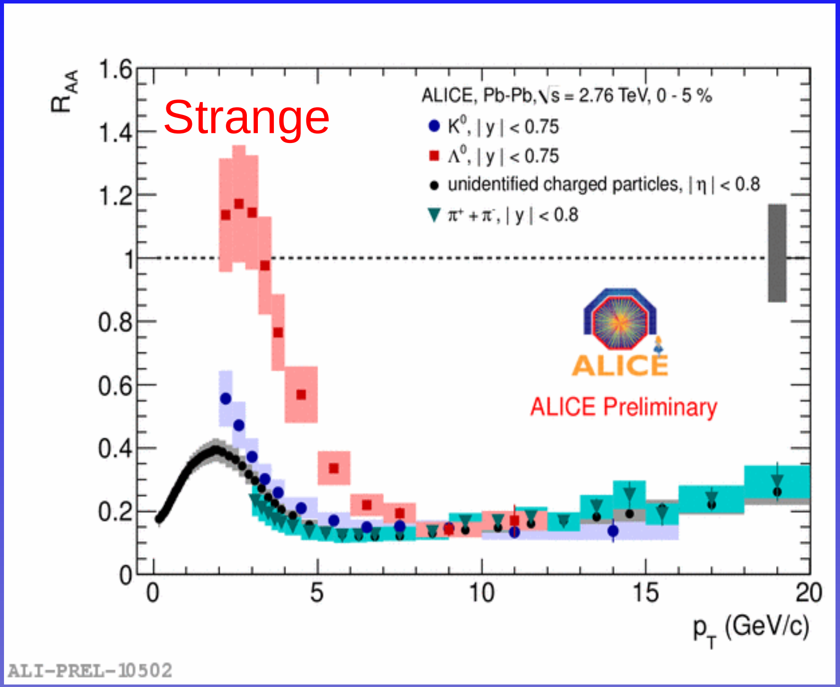
Baryon enhancement at intermediate p_t:

- The ratio is significantly higher than in pp
- Strong centrality dependence

The maximum is higher in magnitude and shifted towards higher momenta compared with RHIC

Charged particle R_{AA}





- Suppression increases with centrality
- Minimum round 6-7 GeV/c
- RAA=1 in hard scattering regime (no nuclear effect)
- RAA affected by:
  - Nuclear shadowing (p_t<10 GeV/c)
  - Parton energy loss

- Different RAA for mesons and baryons at intermediate p_t -> related to baryon enhancement?
- p_t>8-10 GeV/c RAA universality for light hadrons
- For hadrons containing heavy quarks, smaller suppression expected

Heavy flavours

HF decay electrons
at central rapidity |y|<0.8:
D, B -> e + X

Background:
- γ conversion in detector material
- π^0, η, η' Dalitz decays
- ρ, ω, φ decays
- J/Ψ and Y decays
- Drell-Yan and prompt photons

HF decay muons at
forward rapidity -4<y<-2.5
D, B -> μ + X

D mesons at central rapidity |y|<0.8:

- D^0 -> Kπ
- D^+ -> Kππ
- D^* -> D^0π

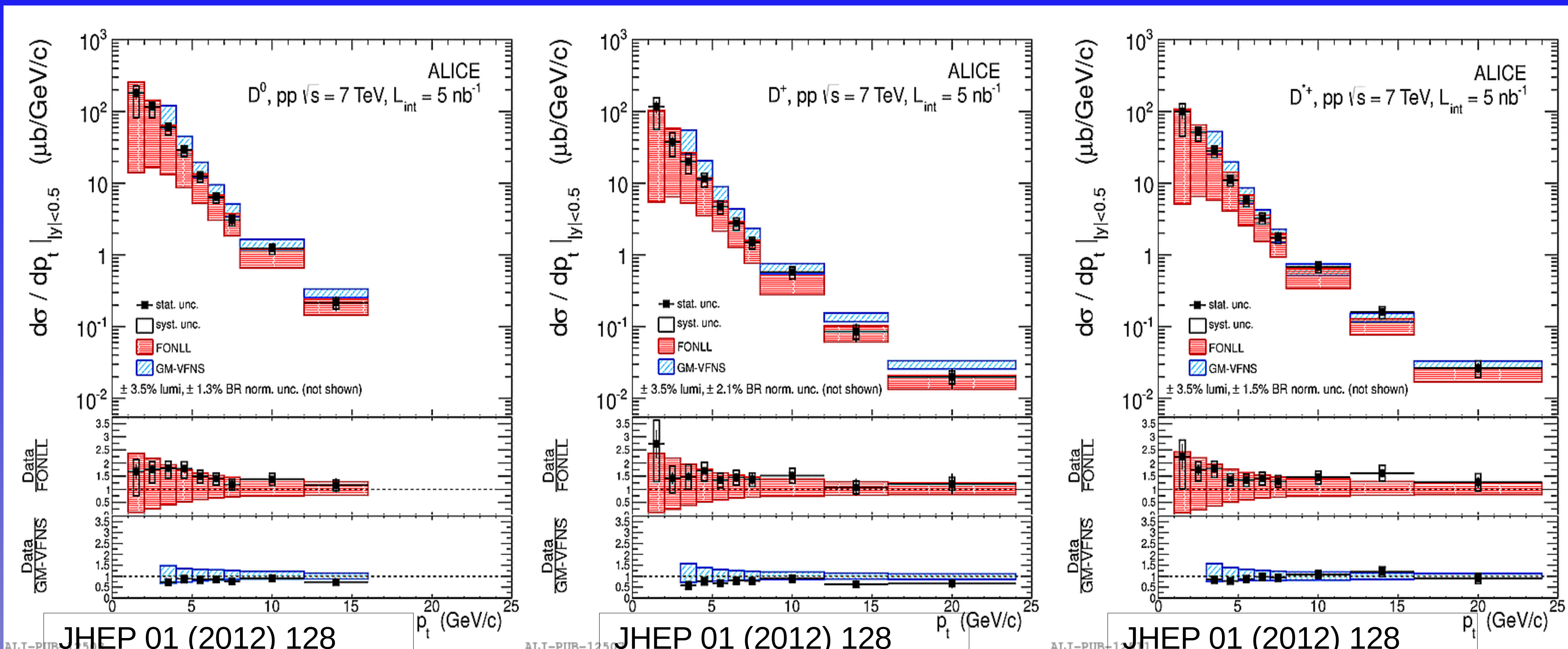
In pp and PbPb

- D_s -> KKπ   in pp, ongoing in PbPb

- Λ_c -> πKp
- D^0 -> Kπππ

ongoing

D mesons cross sections in pp @ 7 TeV, |y|<0.5

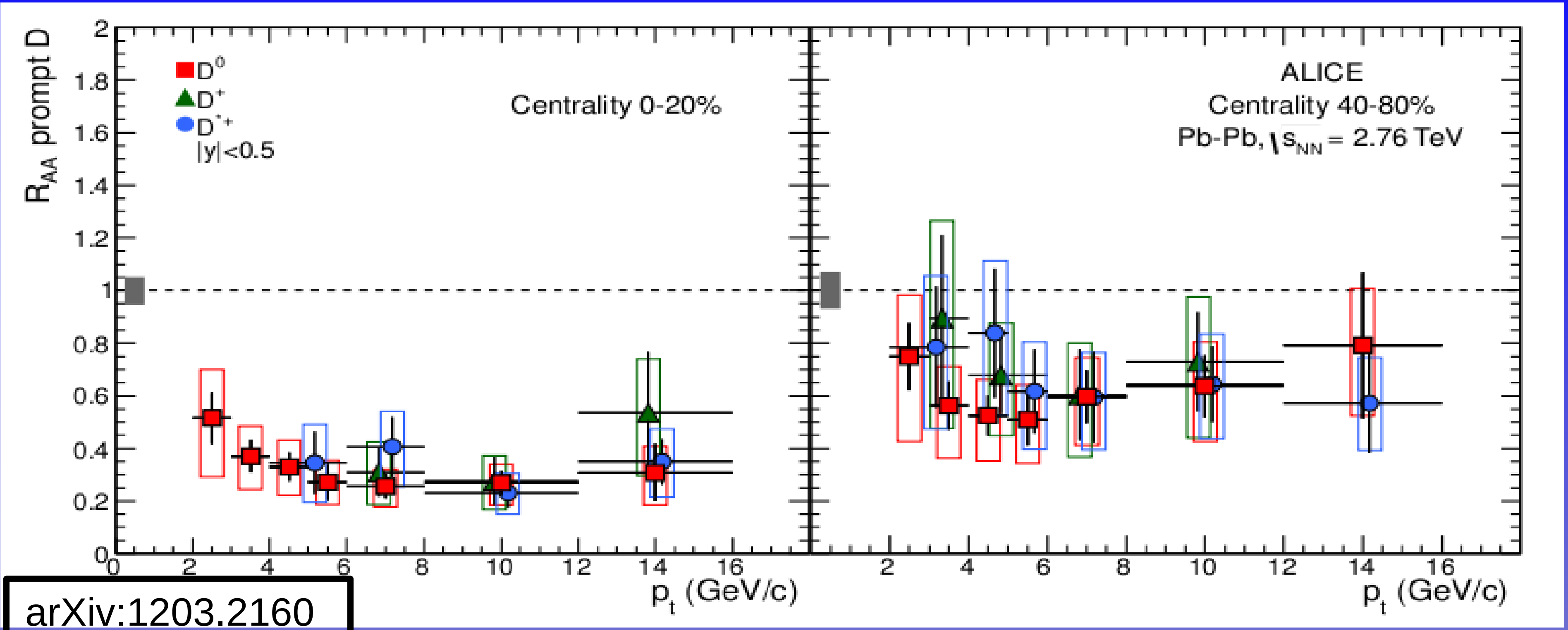


JHEP 01 (2012) 128 | JHEP 01 (2012) 128 | JHEP 01 (2012) 128

$1<p_t<24$ GeV/c, with 5 nb^{-1} (2010 statistics)

p_t differential inclusive production cross sections for prompt D^0, D^+, D^* are well described by the theoretical predictions FONLL (CERN-PH-TH-2011-227 (2011)) and GM-VFNS (Phys. Rev. Lett. 96 (2006))

Charm R_{AA}



arXiv:1203.2160

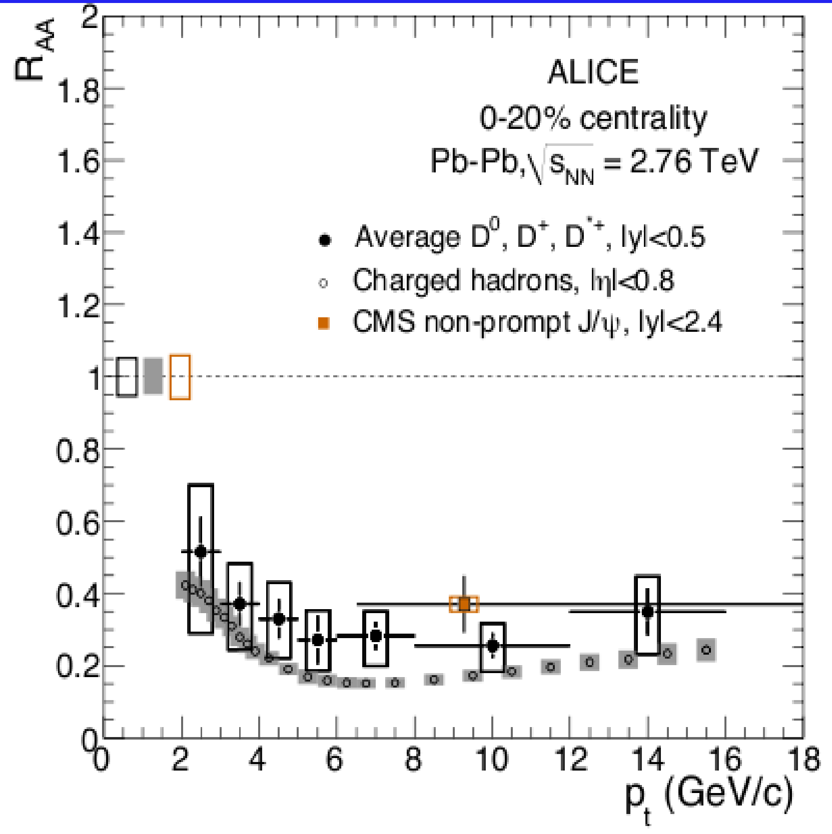
- pp reference from measured D^0, D^+ and D^* p_t differential cross-sections at 7 TeV scaled to 2.76 TeV with a √s-scaling based on FONLL (R. AverbeckarXiv:1107.3243)
- Suppression of prompt D mesons stronger in central than in peripheral collisions
- It reaches a factor 3-4 in central collisions for p_t>5GeV/c
- Strong suppression observed is likely to be a final state effect
- Strong in-medium energy loss for charm quarks

$R_{AA}(\pi)<R_{AA}(D)<R_{AA}(B)$?

Indication of
$R^{D}_{AA} > R^{charged}_{AA*}$
but not conclusive

$R^{J/\Psi}_{AA} < R^{charged}_{AA}$

$R^{J/\Psi}_{AA}$ vs R^{D}_{AA}
not conclusive

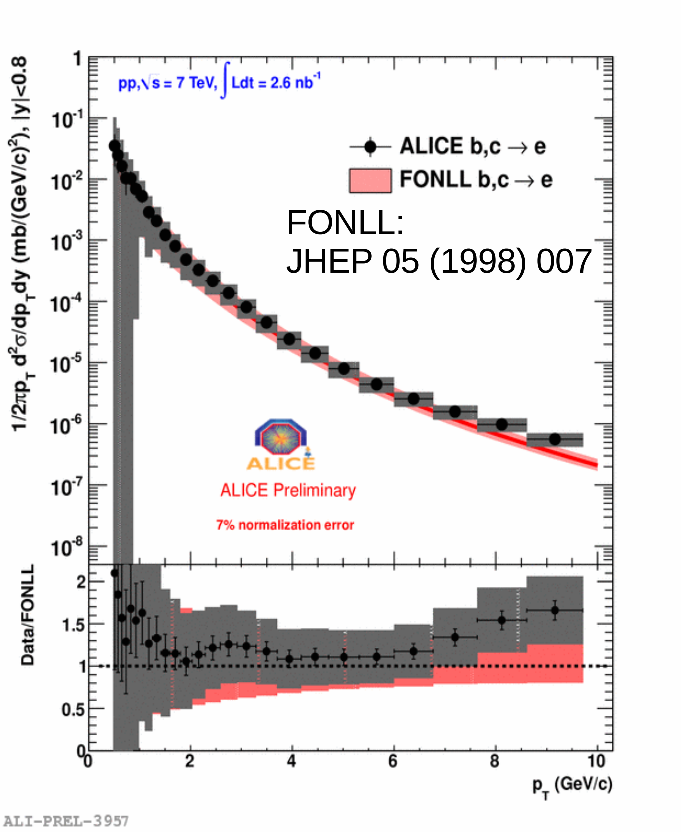


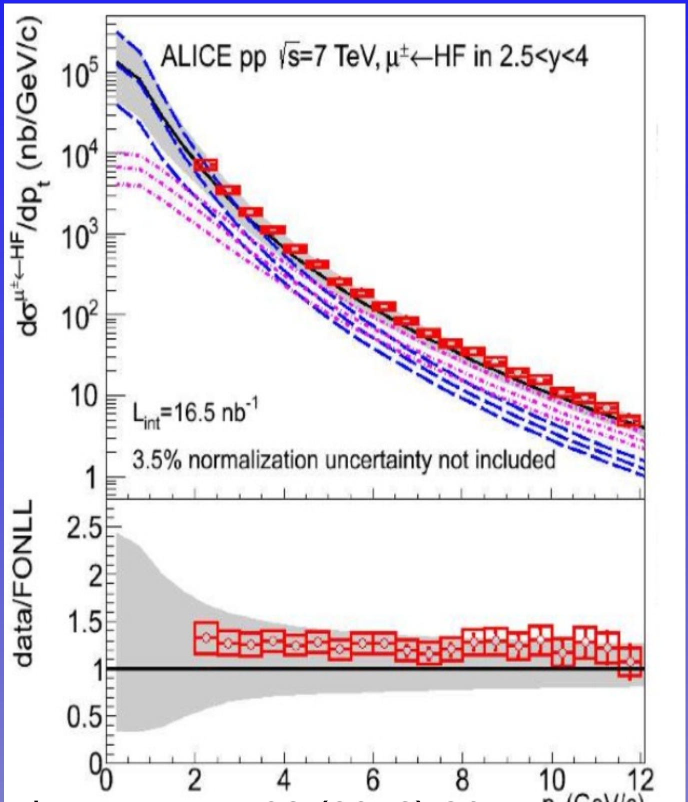
ALICE arXiv:1203.2160
CMS arXiv:1201.5069

*ALICE preliminary results showed that charged pion R_{AA} coincides with charged hadron R_{AA} for p_t>5GeV/c

R_{AA} of D mesons compared to R_{AA} of charged hadrons and non prompt J/Ψ from B decays (CMS data) in central collisions 0-20%

e and μ from HF decays in pp @ 7 TeV





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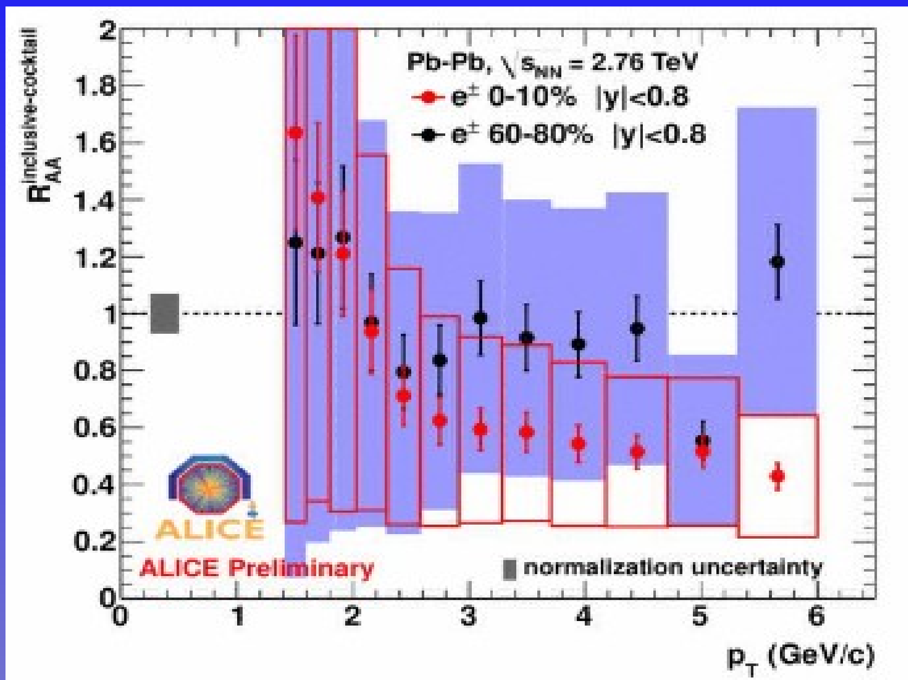
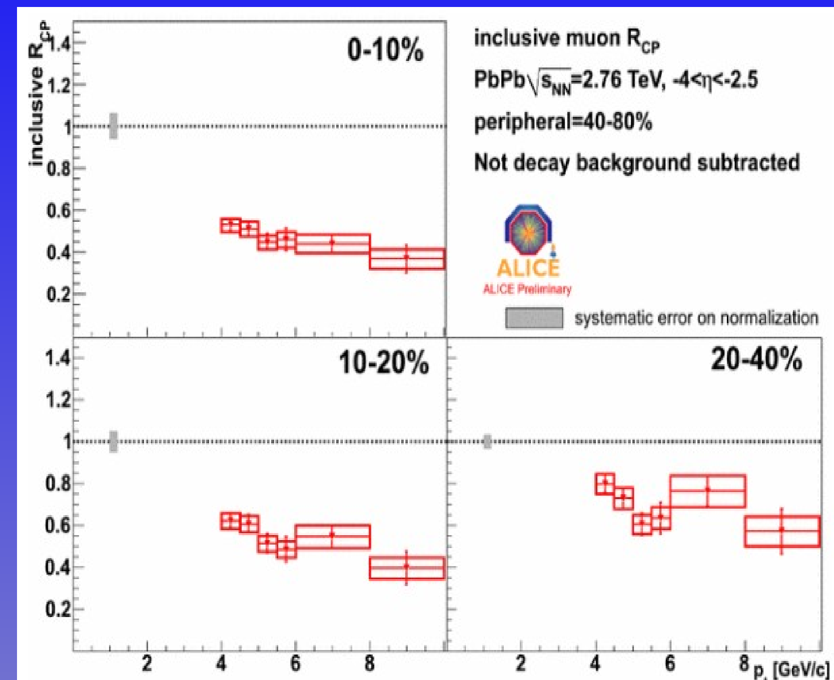
e from HF decays vs the FONLL prediction for inclusive charm and beauty semileptonic decays

p_t differential production cross sections of muons from heavy flavour decays compared to FONLL predictions -> beauty dominance above 6 GeV/c

e and μ from HF decays R_{AA} and R_{CP}



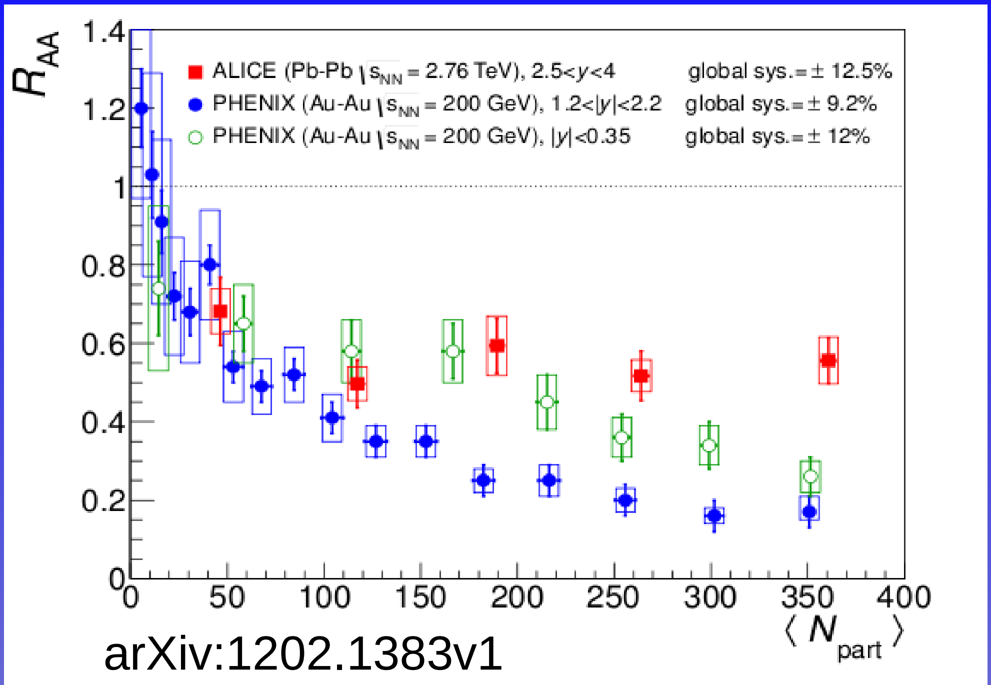


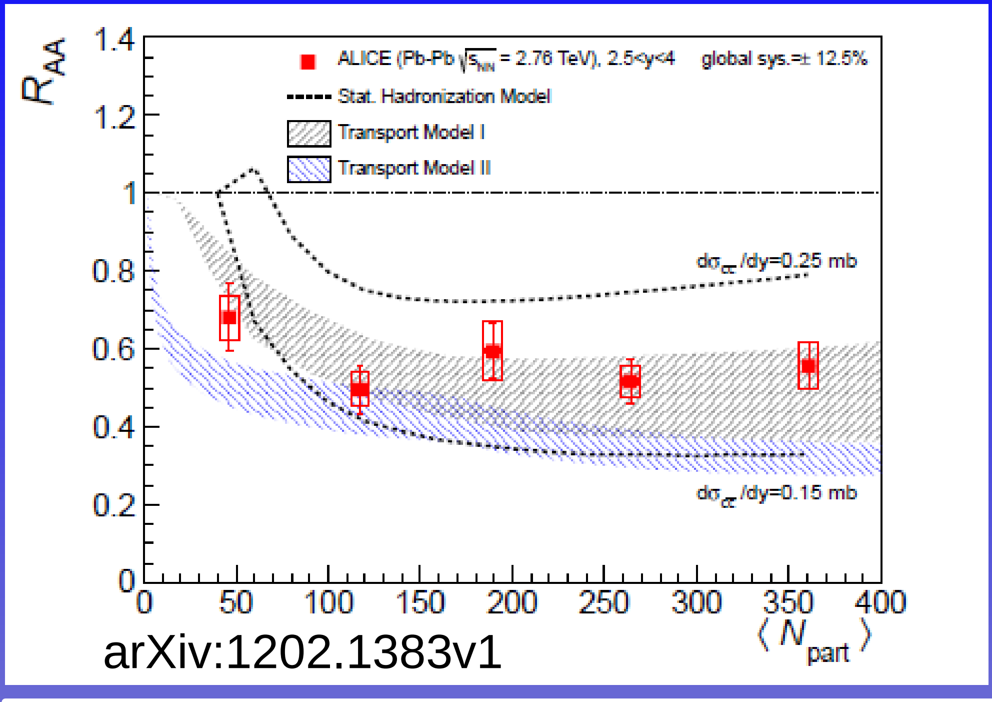
- Inclusive – cocktail = e from HF hadron decays (D, B -> e + X)
- p_t>3.5 GeV/c dominated by charm and beauty decays
- Centrality dependence

- Inclusive muons: background from π and K decays not subtracted. Background estimated (from HIJING) to be below 15% for p_t> 4 GeV
- Suppression of μ from HF decays at forward rapidity increases with the centrality of the collisions

Mid-rapidity electrons and forward muons have similar suppression trend vs centrality

Quarkonia: inclusive J/Ψ

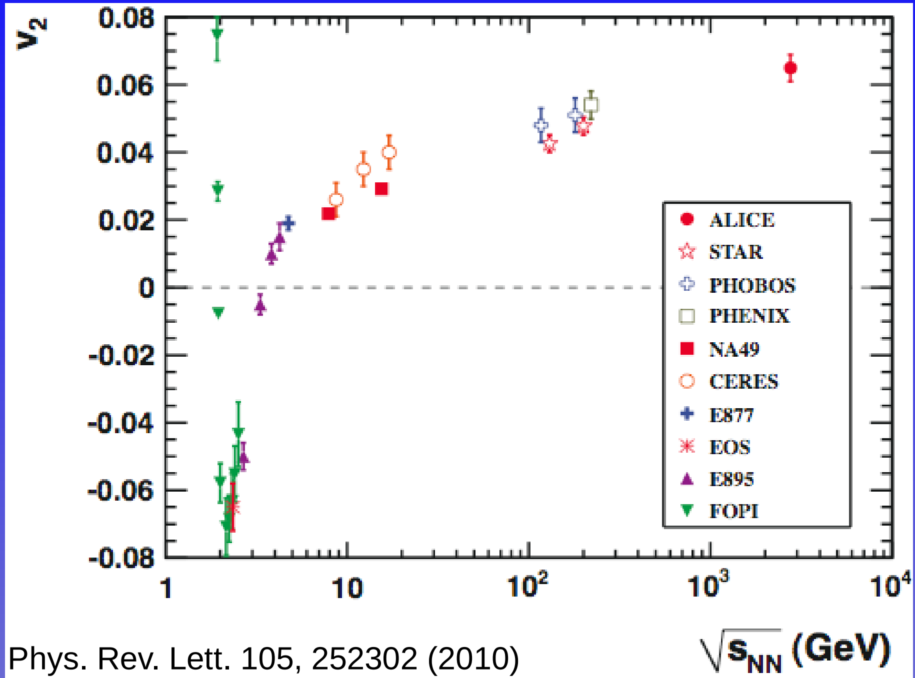




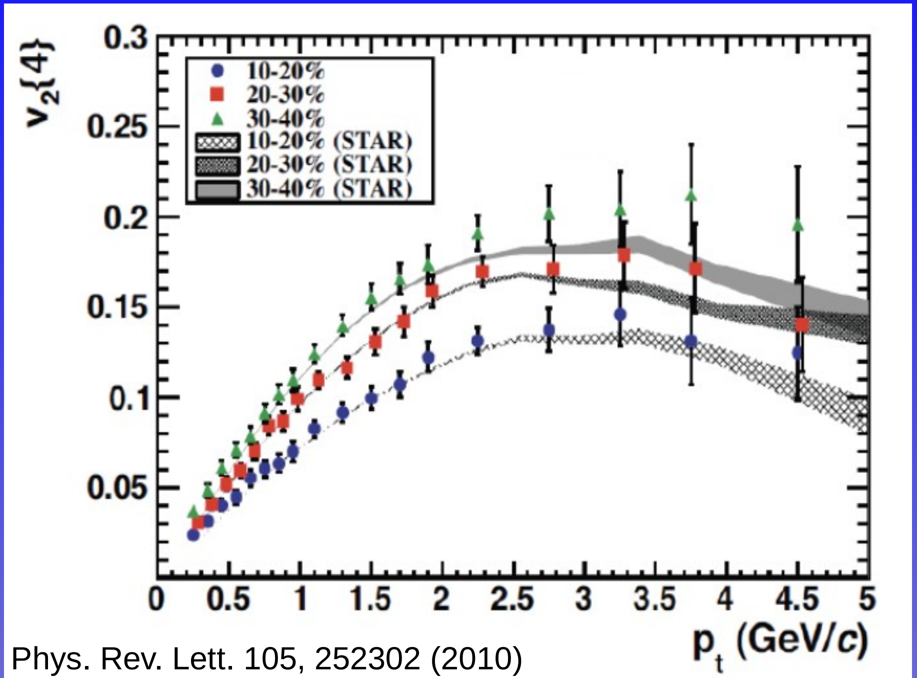
- J/Ψ inclusive suppression observed with no centrality dependence
- Centrality integrated J/Ψ R_{AA}:
  $R_{AA}^{0\%-80\%}$ = 0.545±0.032 (stat.)±0.084 (syst.)
- R_{AA} 3 times larger than PHENIX in forward rapidity for N_{part}>180
- inclusive J/ψ: ~10% B feed-down

- J/Ψ R_{AA} compared with theoretical models that include J/Ψ regeneration
- Statistical hadronization and transport models which feature a full or partial J/Ψ production from c quark in the QGP phase can describe the data:
  - J/Ψ regeneration?
  - Need of a precise charm cross-section
  - Need of a better knowledge of shadowing (pA collisions)

Elliptic flow



Phys. Rev. Lett. 105, 252302 (2010)



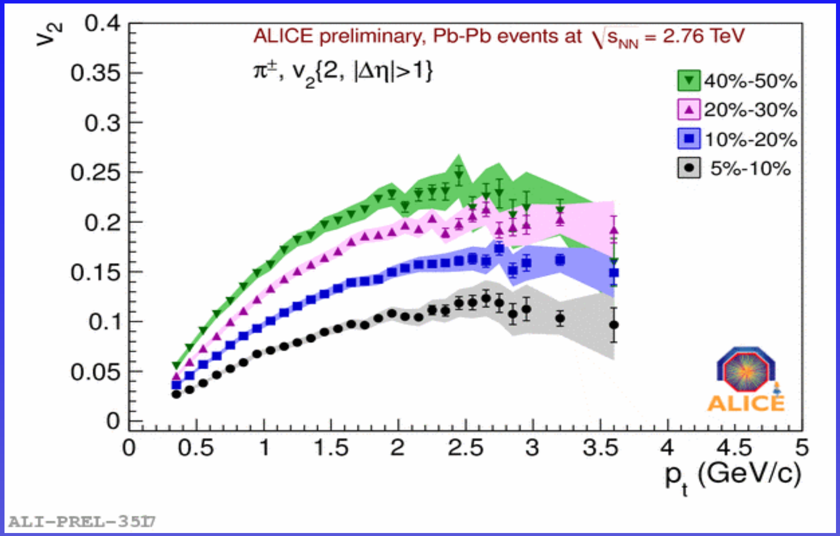
Phys. Rev. Lett. 105, 252302 (2010)

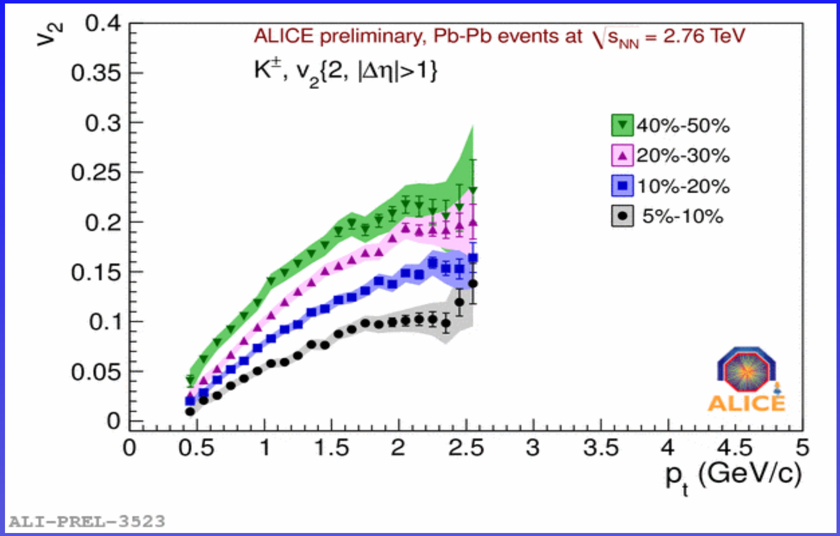
- p_t integrated v_2 at LHC ~30% larger than RHIC
- System produced at LHC behaves as a very low viscosity fluid -> constraints of η/s

v_2 shape vs p_t same at RHIC

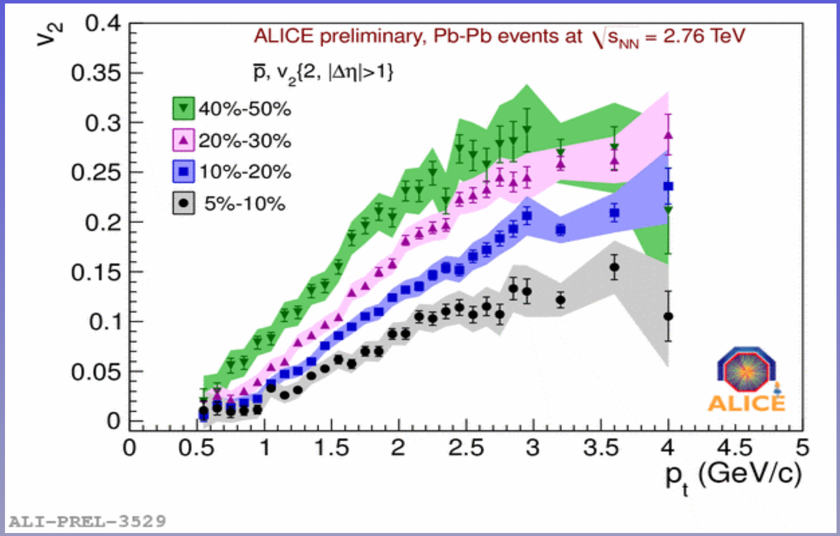
Shift of mean p_t responsible for the increase of integral V_2

Elliptic flow with PID

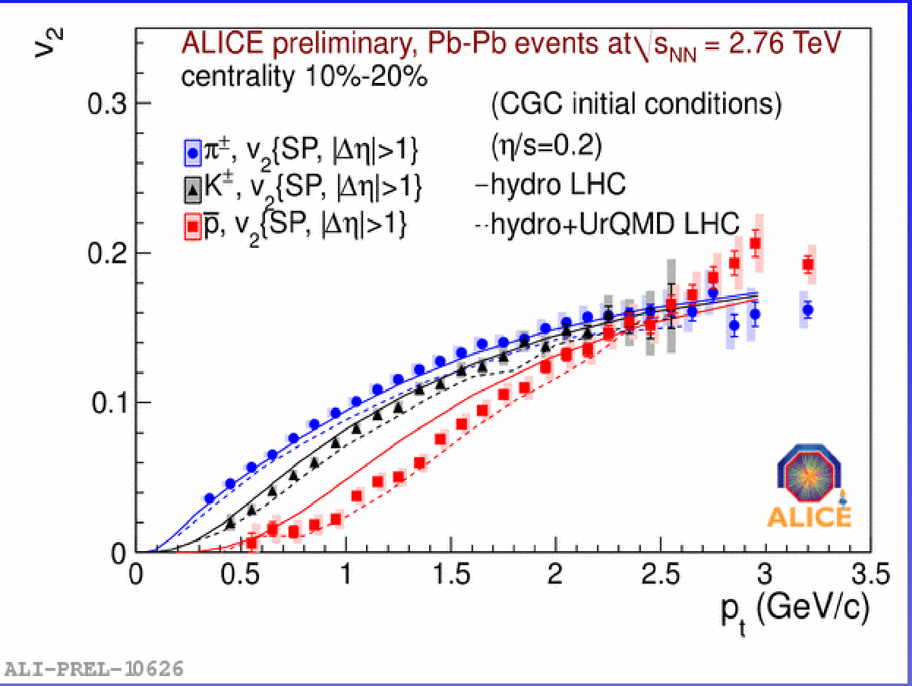


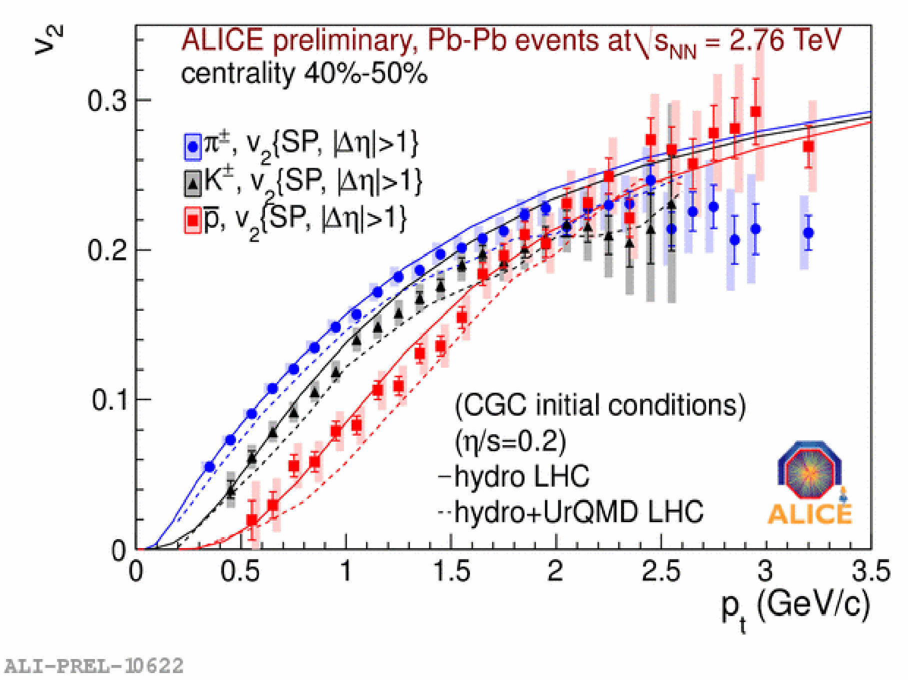


Centrality dependence of the elliptic flow



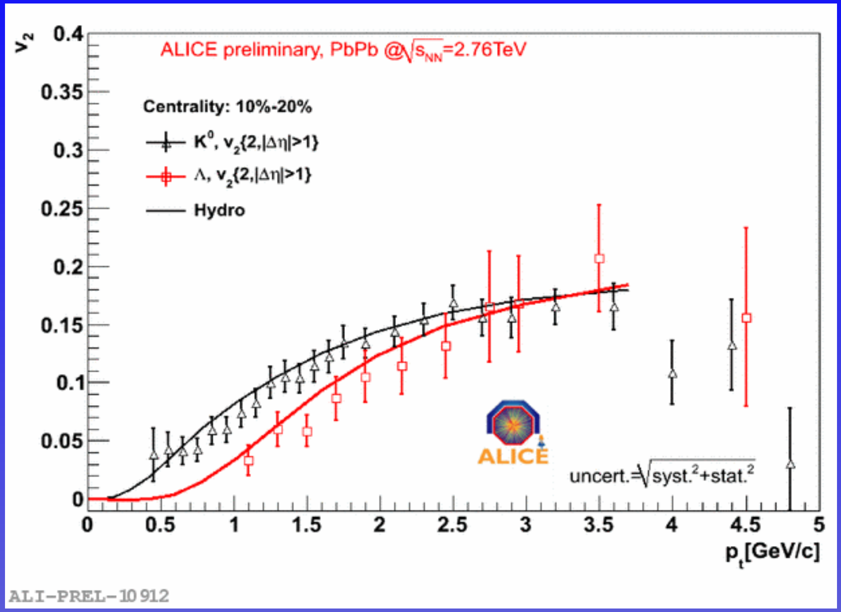
Elliptic flow

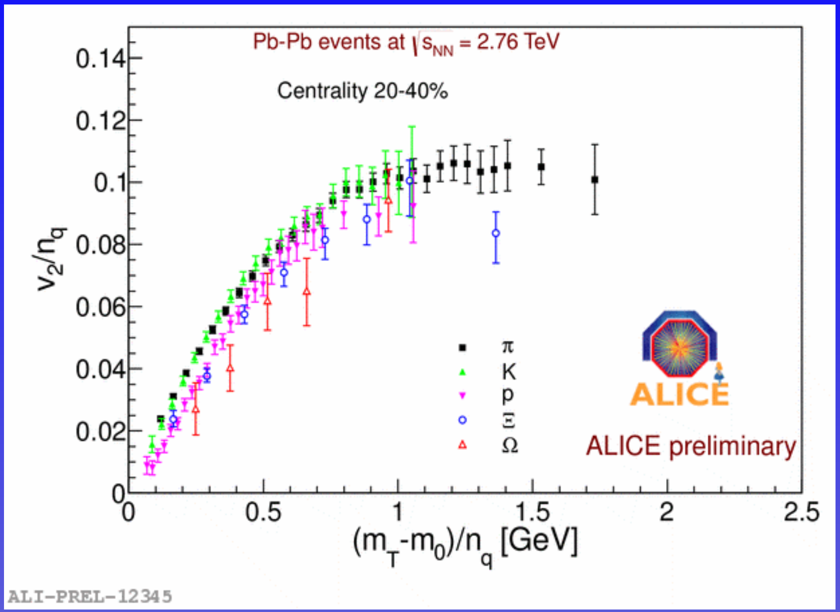




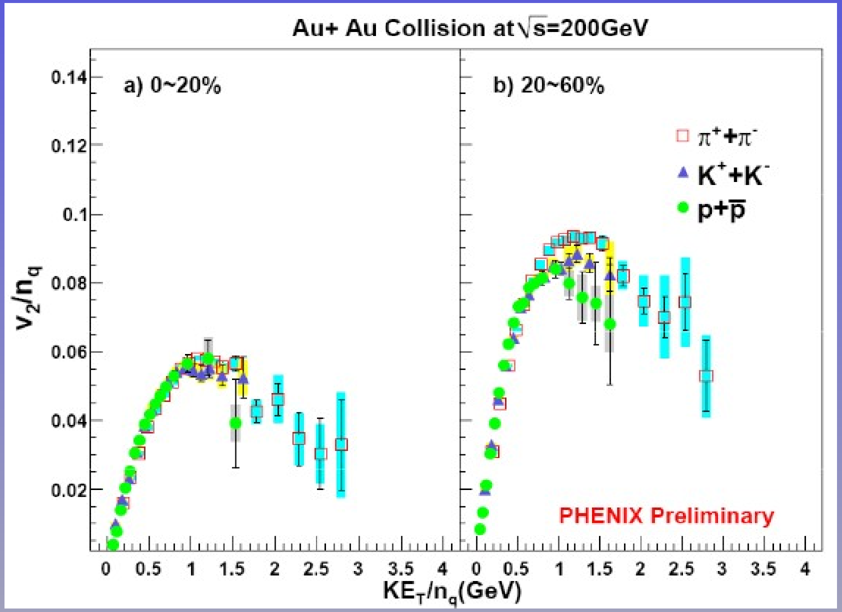
- Hydro models predict mass splitting
- Pure hydro disagrees with antiprotons in central collisions
- Hydro coupled with UrQMD (Heintz et al, arXiv: 1108.5323v1) better describe the data w.r.t. pure hydro model
- Still some open issues with antiprotons in peripheral collisions

Elliptic flow





Also for K^0_s and Λ the same mass splitting of the other hadrons is observed



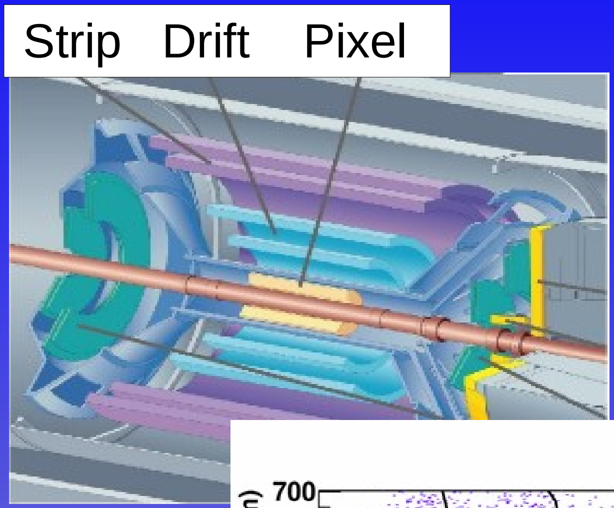
V2 scaling with the number of constituent quarks doesn't work for anti-protons and strange baryons at LHC as at RHIC

Conclusions

- Thanks to its PID performance, ALICE can measure hadron and lepton production over a wide momentum range -> this allows QCD studies
- Primary hadron spectra:
  - pp: tuning of MC models
  - PbPb: test of thermal and hydrodinamical models for chemical and kinetical freeze-out
- Strangeness enhancement decreasing with collisions energy
- Baryon vs meson enhancement
- Heavy flavours:
  - Strong interaction of c and b quarks with the medium
  - J/Ψ regeneration?
- Elliptic flow:
  - Agreement with hydro models: mass splitting
  - V2 scaling with the number of quarks doesn't work for anti-protons

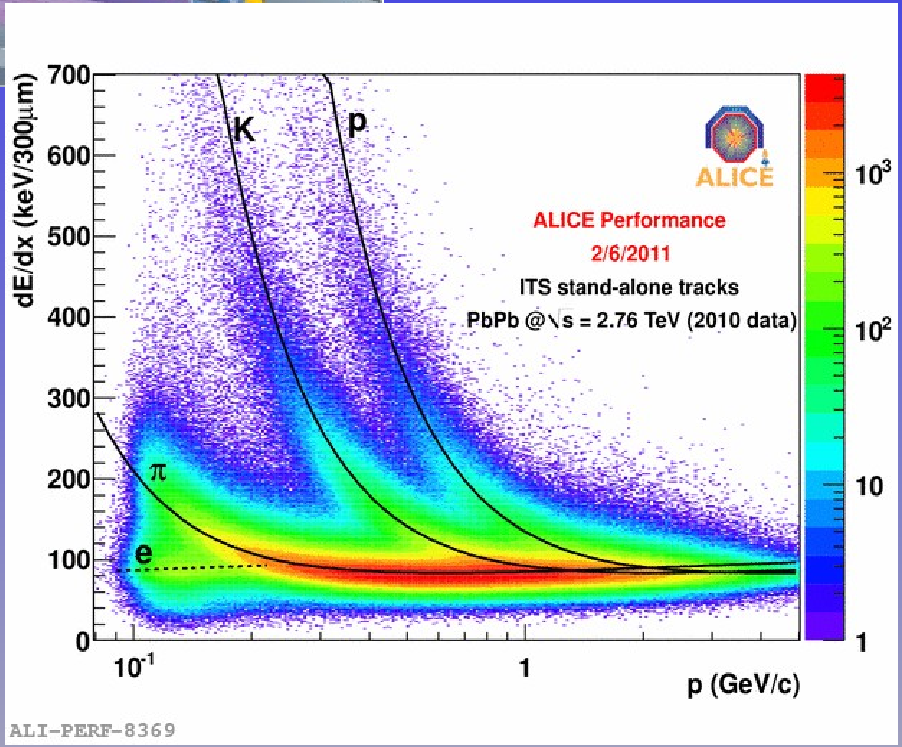
Backup

Inner Tracking System



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

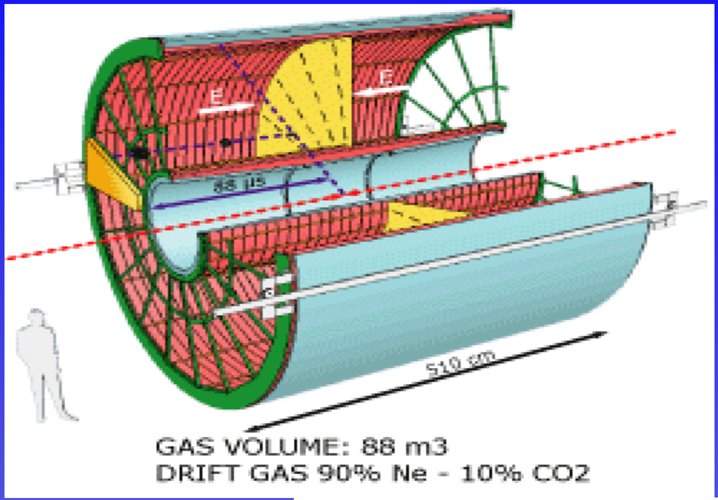
Analog readout:
dE/dx information->
PID in $1/\beta^2$ region



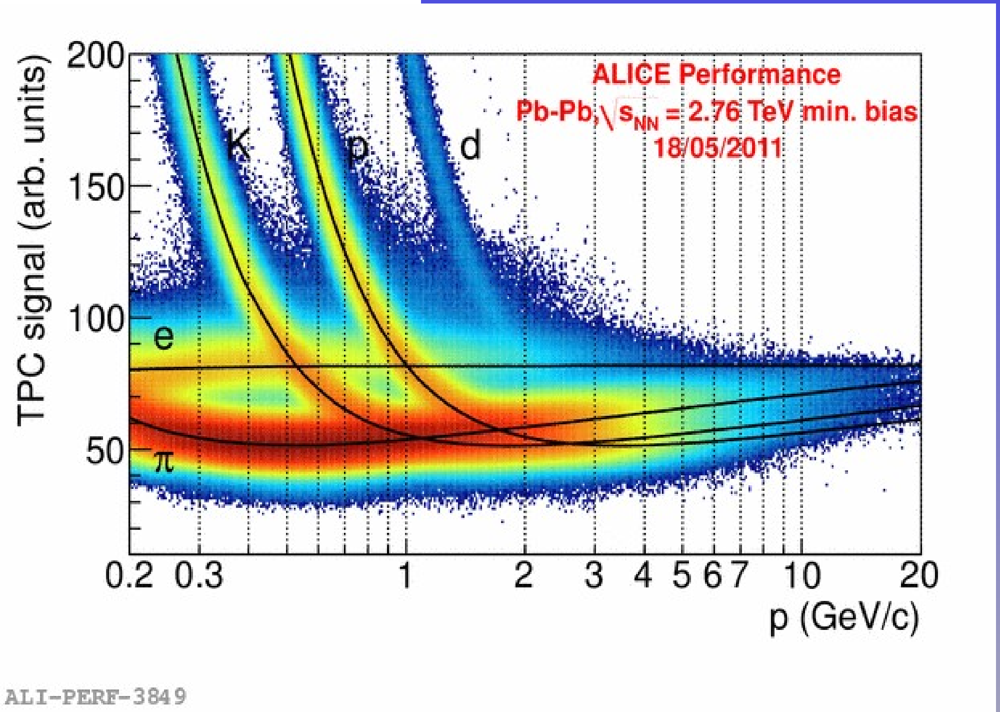
dE/dx of charged particles vs their momentum measured by the ITS stand-alone in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

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

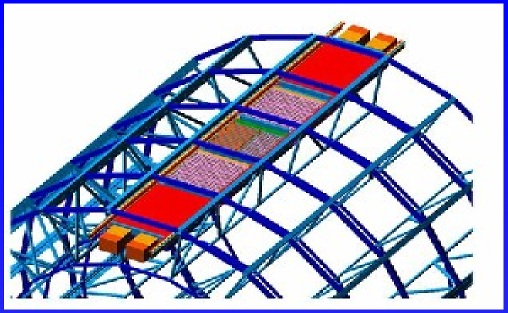
Time Projection Chamber



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

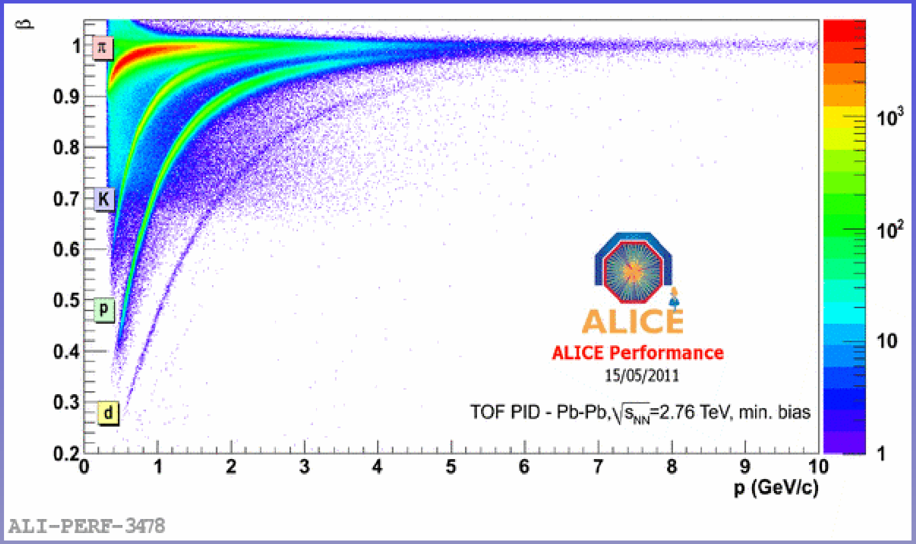
$$m = p\sqrt{\frac{t^2}{L^2} - \frac{1}{c^2}}$$

In Pb-Pb:

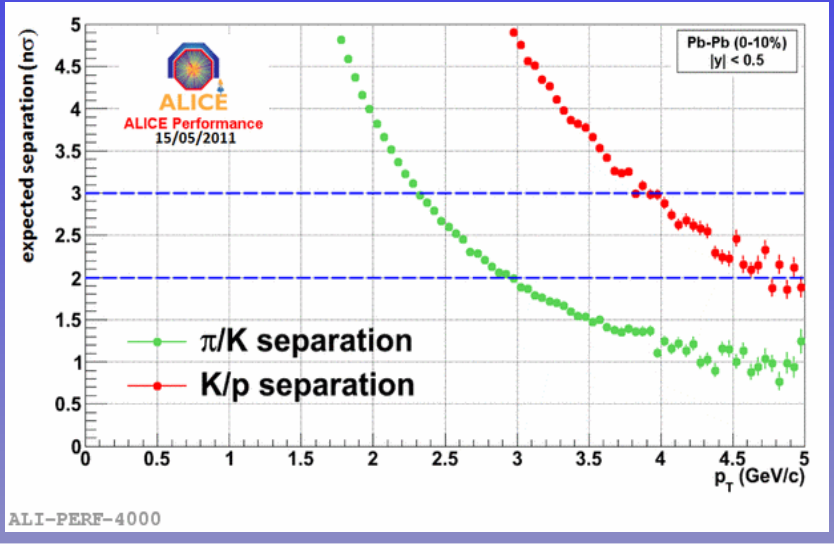
$\sigma_{t\text{-}Zero} \approx 10$ ps

$\sigma_{t\text{-}Track} \approx 20$ ps → $\sigma_{TOF} \approx 80$ ps design value

$\sigma_{tot} \approx 85$ ps



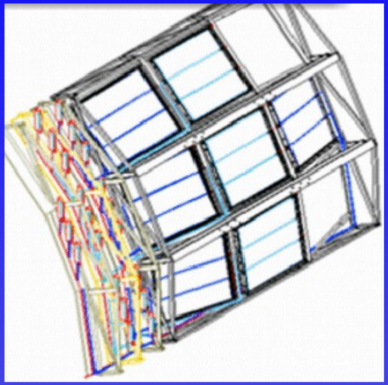
Beta measured by TOF vs momentum.
Different species are clearly visible



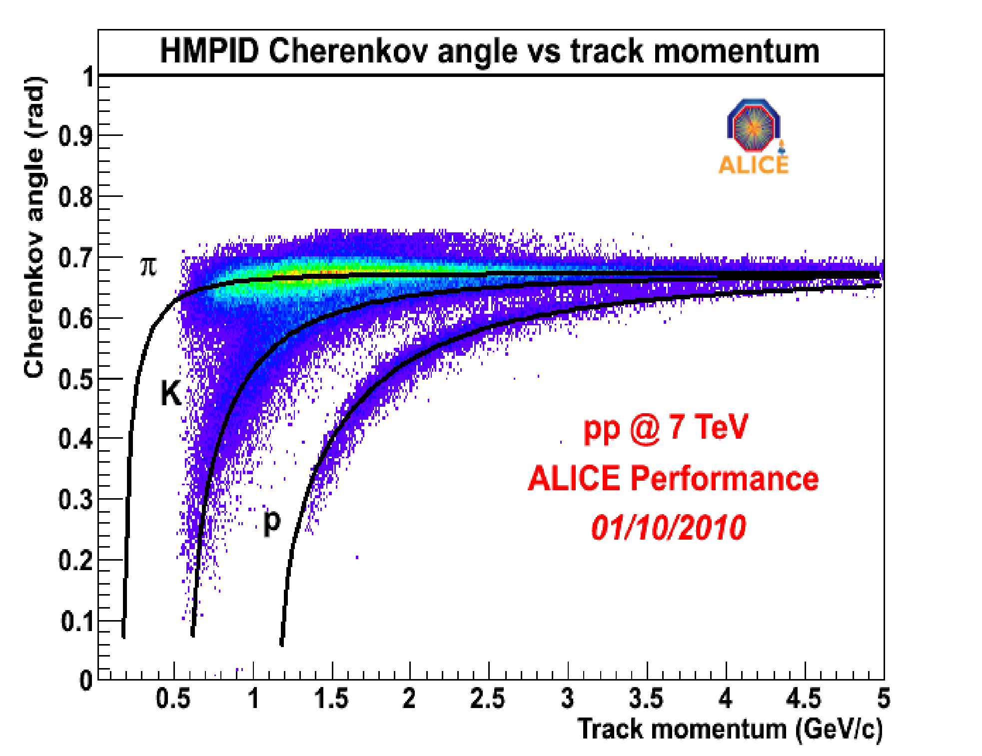
Expected separation for π/K and K/p vs p_t.

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

High Momentum Particle IDentification



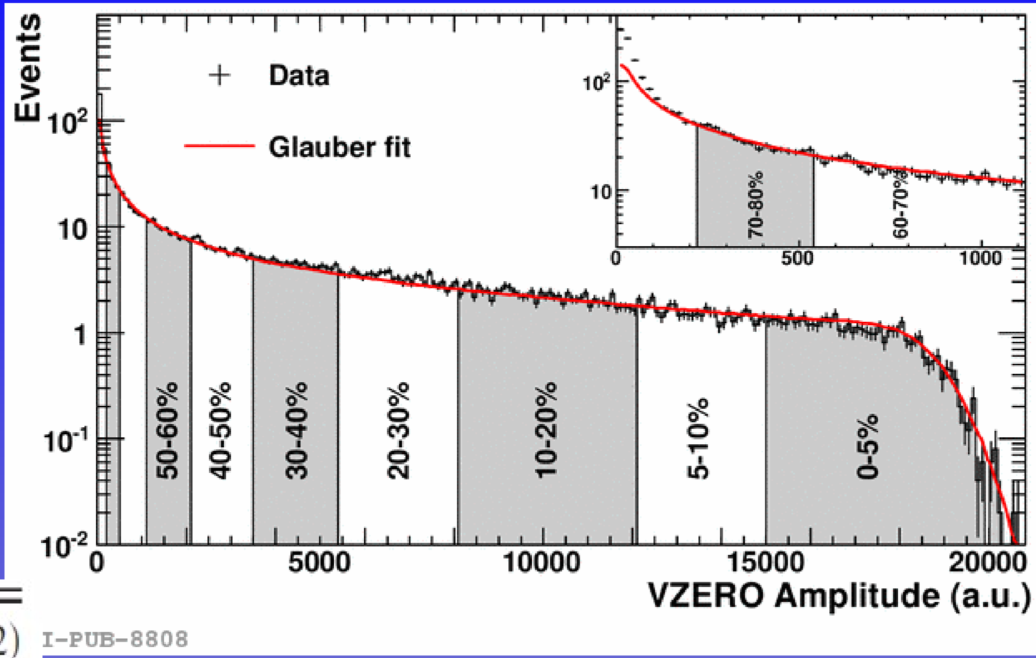
HMPID is based on proximity focusing Ring Imaging Cherenkov (RICH) counters



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

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

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}, β_s, n

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

β: transverse radial flow velocity

β_s: surface transverse flow velocity

n: velocity profile

ρ_r: transverse boost

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