Transverse momentum spectra of identified charged hadrons with the ALICE detector in Pb-Pb collisions at the LHC

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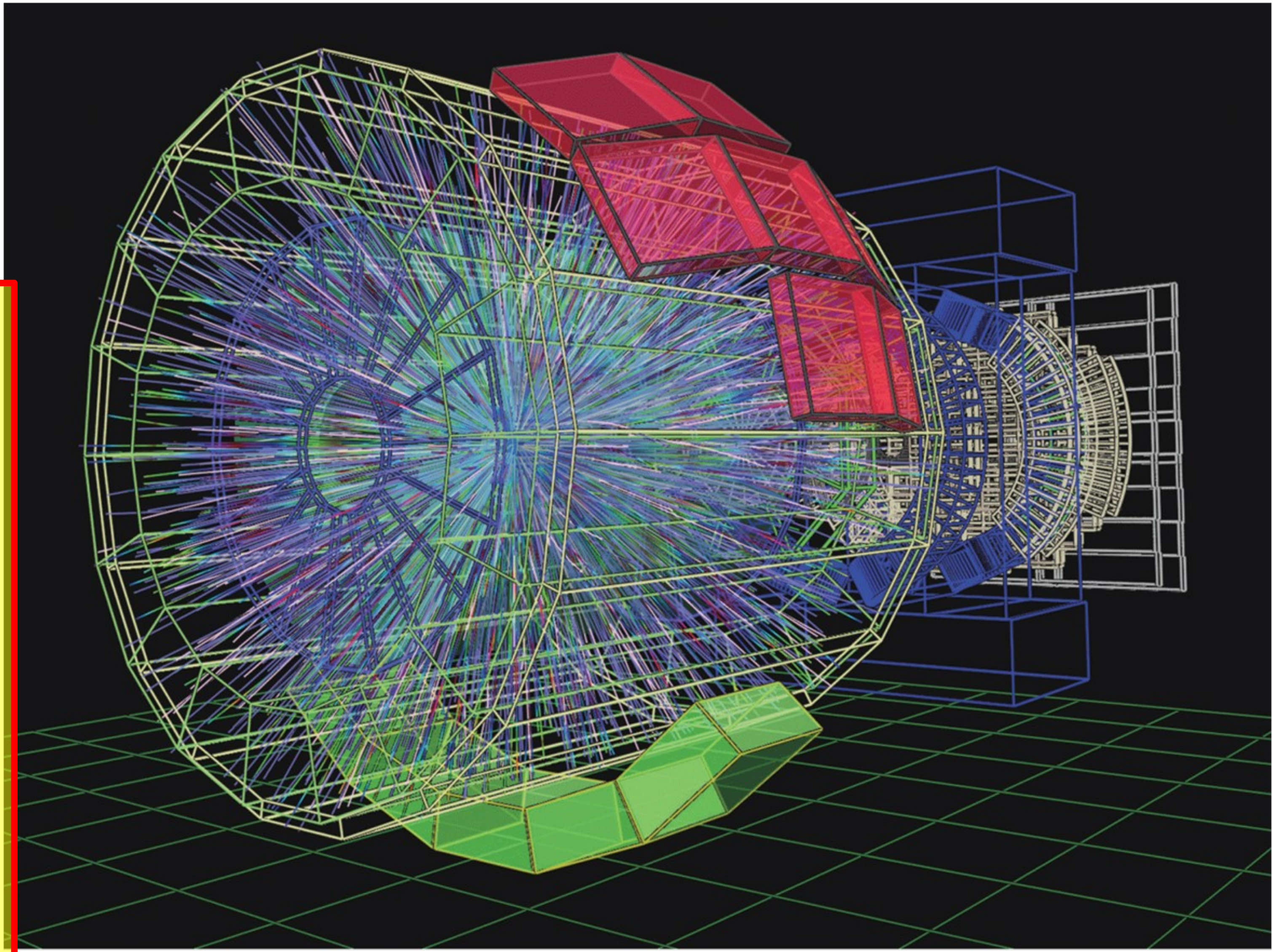
The ALICE experiment at LHC

designed to cope with **very high charged-particle multiplicity** $dN_{ch}/d\eta \leq 8000$

3D **tracking with many points**

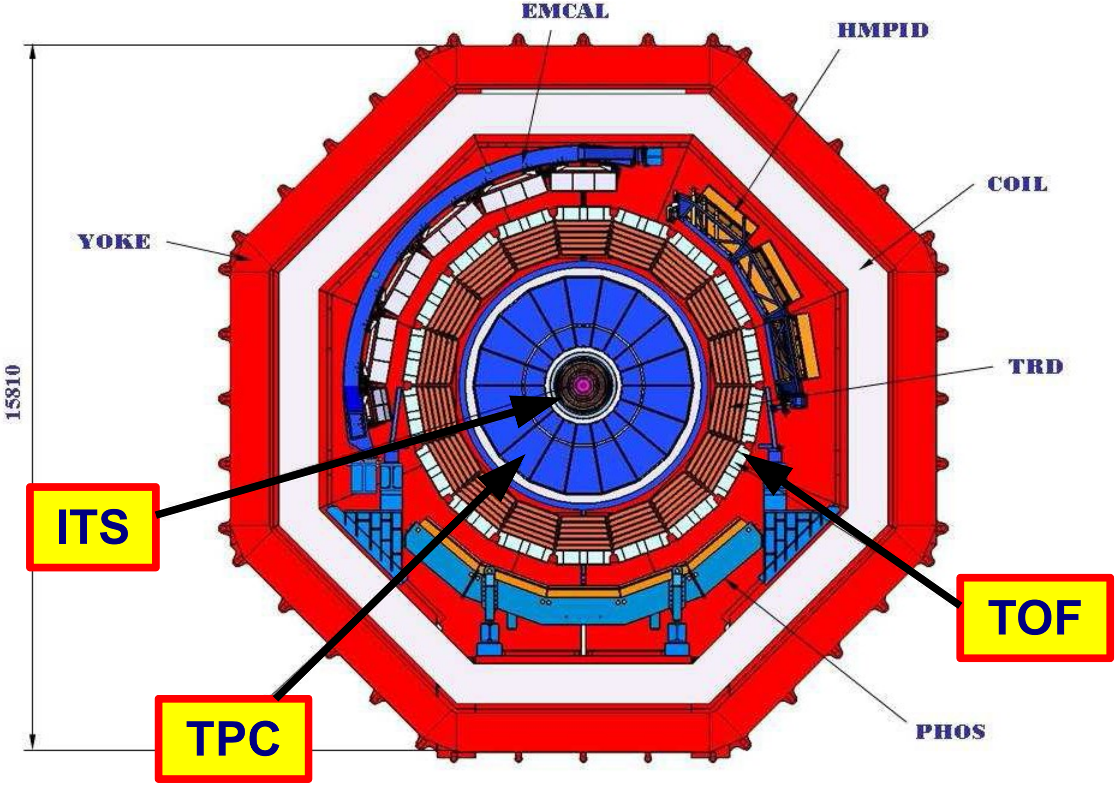
moderate B = 0.5 T
thin materials
for low-p_T particles

uses **all known PID techniques**
dE/dx, TOF, transition radiation, Cherenkov radiation, calorimetry, muon filters, topological decay

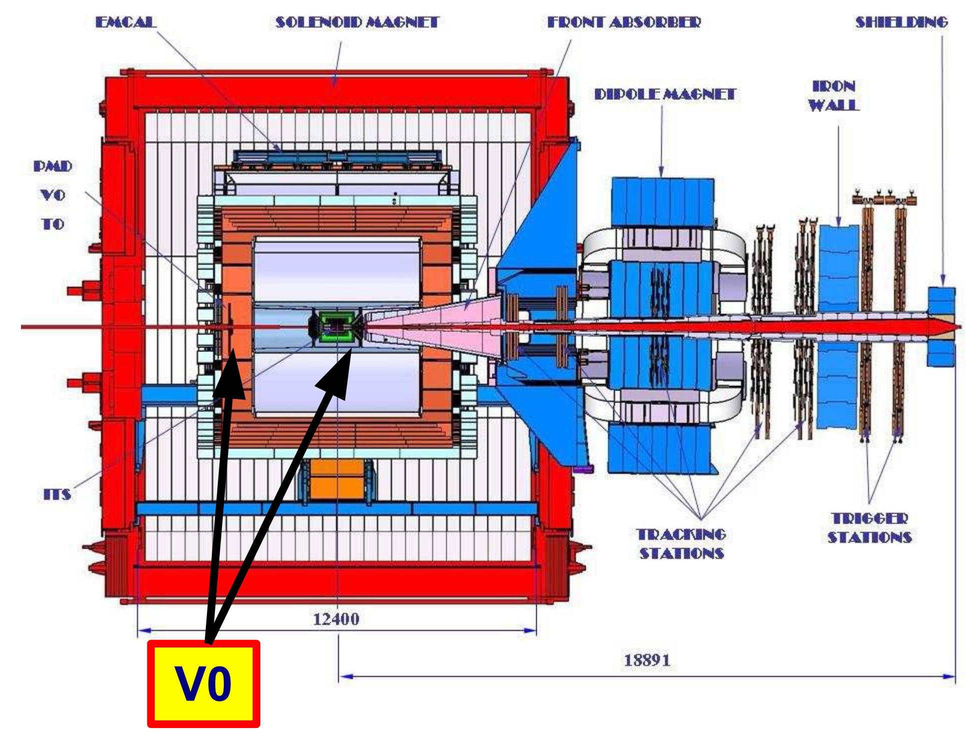


The ALICE detector: central barrel

front view



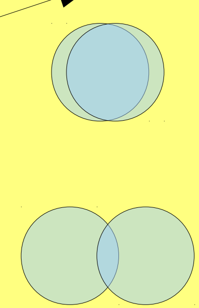
side view



main **ALICE sub-detectors** used for
identified-hadron spectra analysis:

- **V0** → centrality determination
- **ITS** → tracking + vertexing + PID (*dE/dx*)
- **TPC** → tracking + vertexing + PID (*dE/dx*)
- **TOF** → PID (*time-of-flight*)

centrality

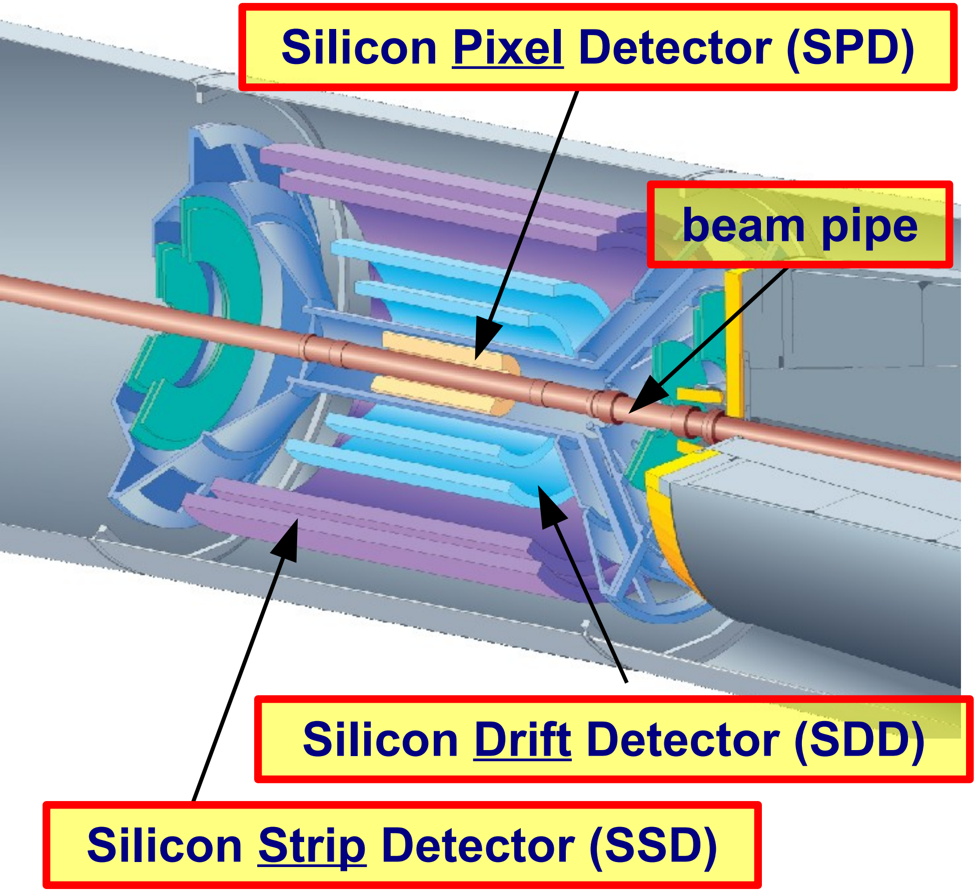


0-5%
(central)

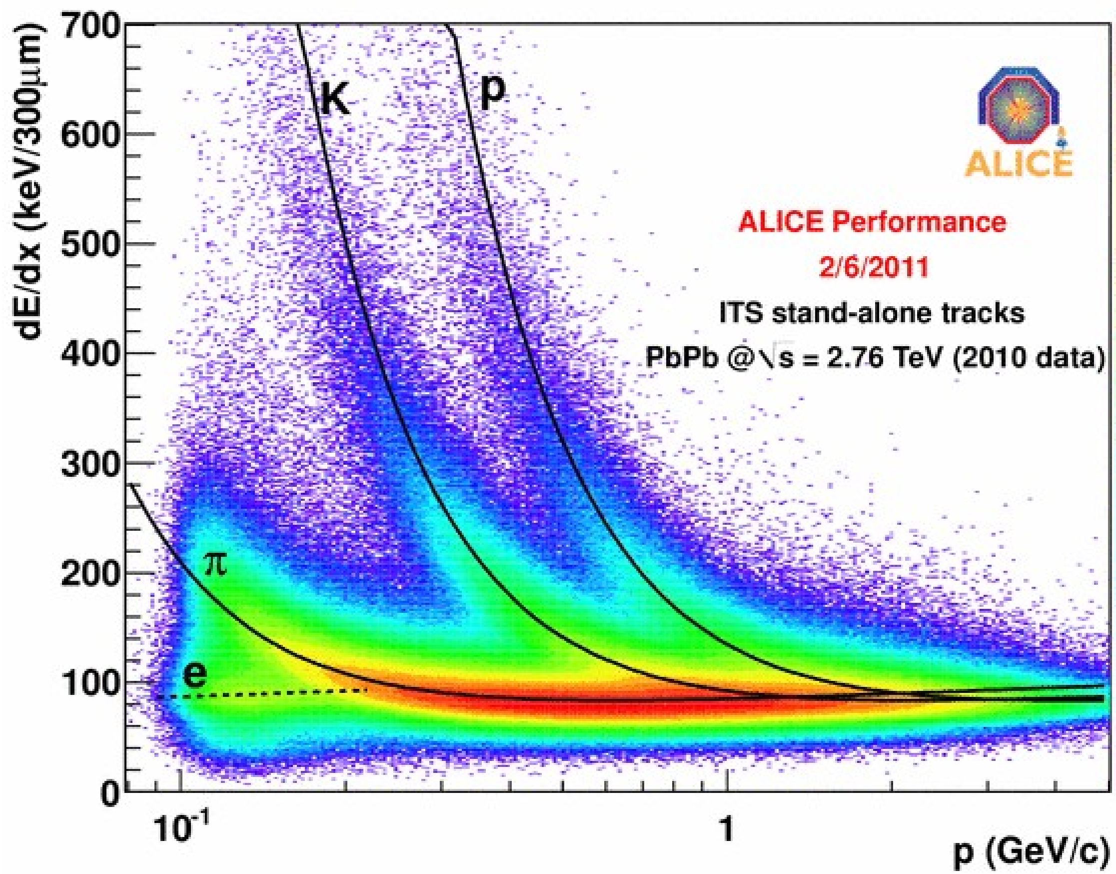
…

60-70%
(peripheral)

Inner Tracking System (ITS) → dE/dx



layer	detector	radius (cm)	length (cm)
1	SPD	3.9	28.2
2	SPD	7.6	28.2
3	SDD	15.0	44.4
4	SDD	23.9	59.4
5	SSD	38.0	86.2
6	SSD	43.0	97.8

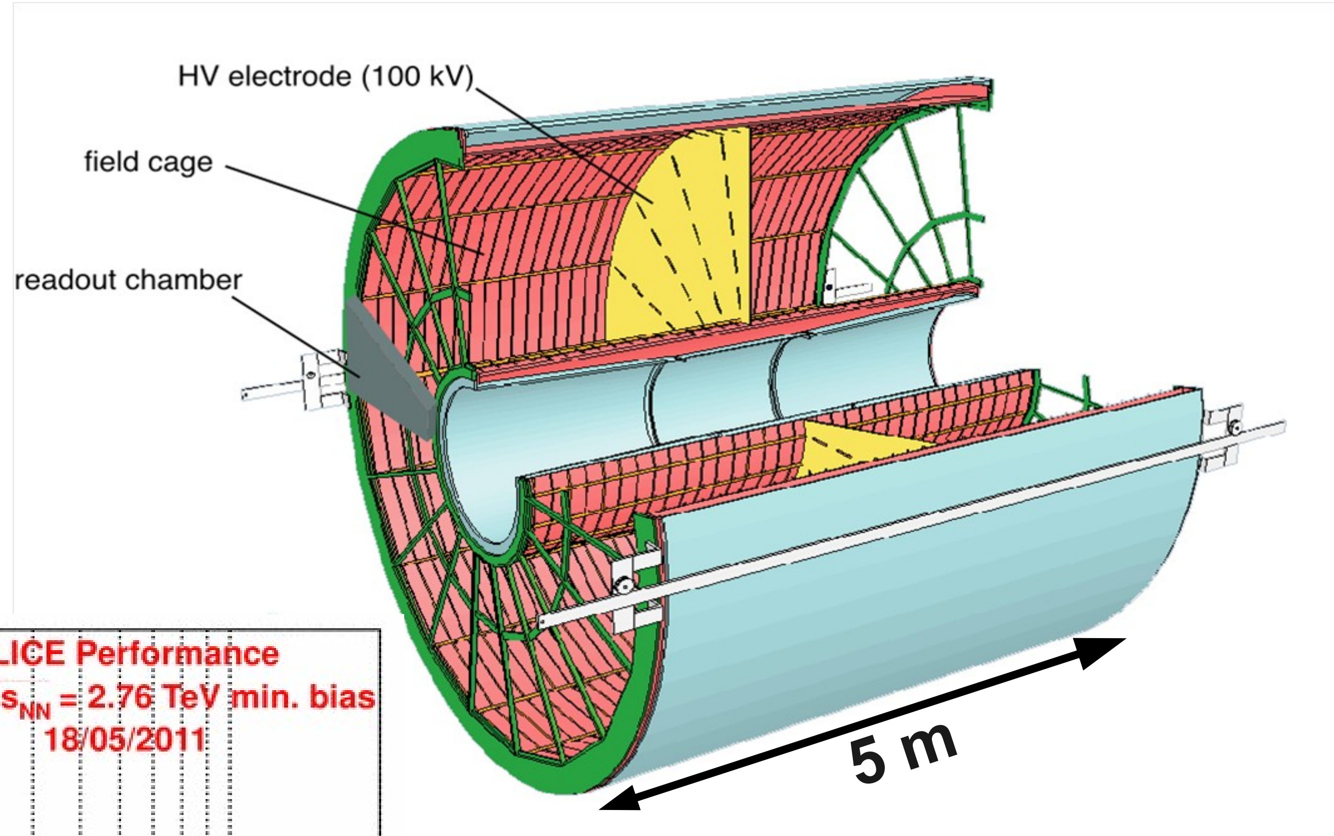


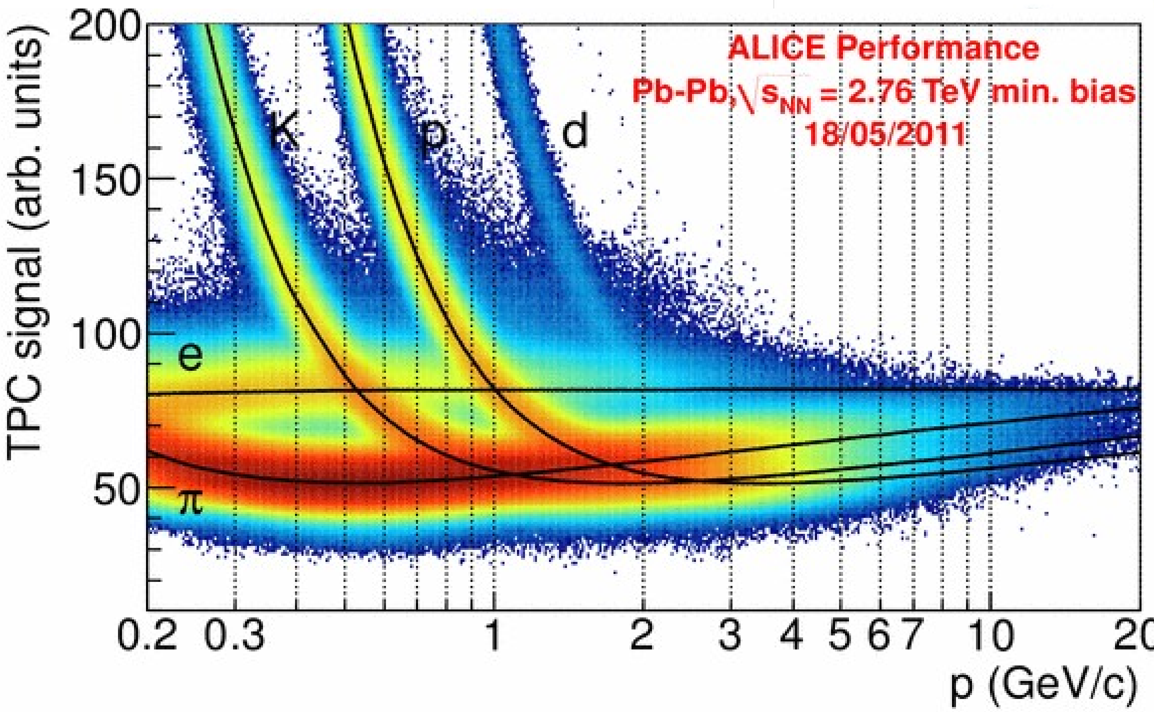
SDD and SSD analog readout
PID at low momentum
up to 4 *dE/dx* samples (σ ~10-15%)

Time-Projection Chamber (TPC) → dE/dx

the largest TPC ever built

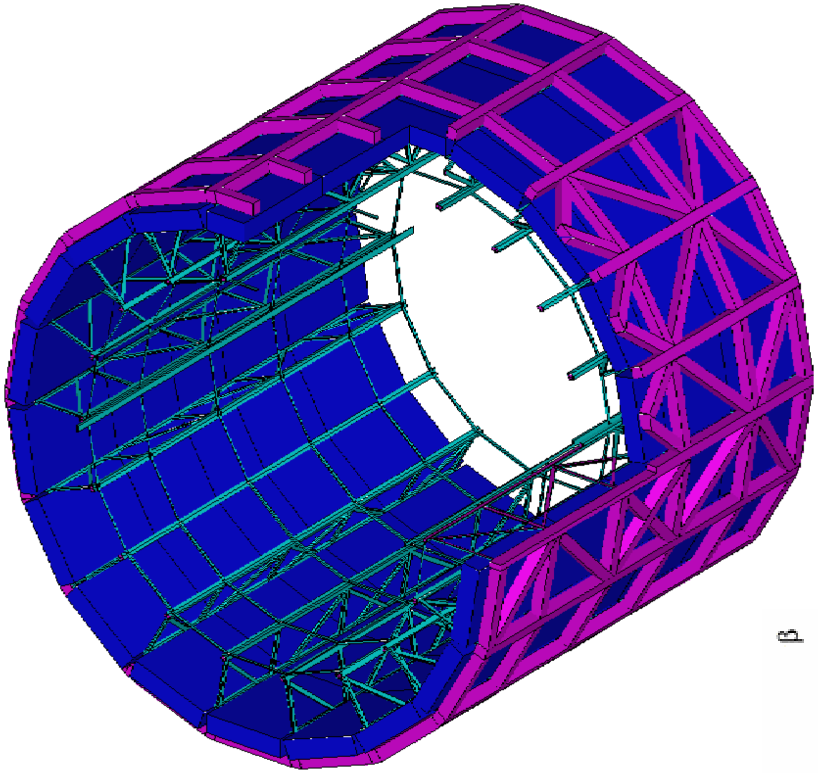
radius	845 – 2466 mm
drift length	2 x 2500 mm
drift time	92 µs
gas mixture	$Ne\text{-}CO_2\text{-}N_2$
gas volume	90 m_3
readout detector	MWPC
readout pads	557568





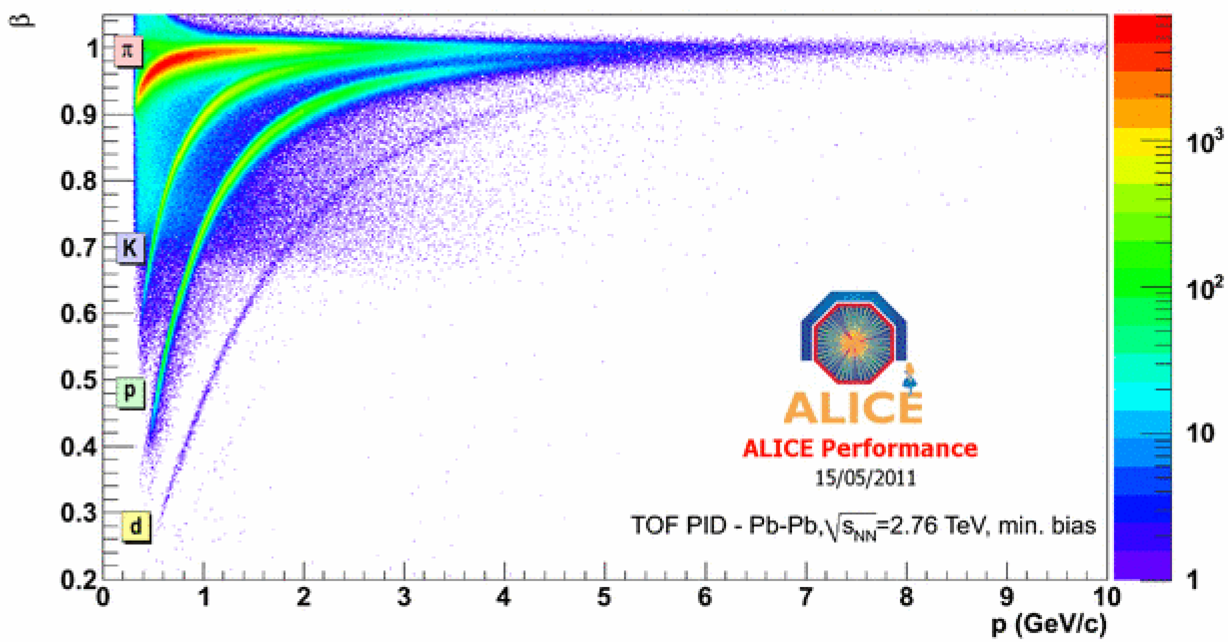
main tracking detector
PID via dE/dx in gas
up to 159 samples (σ ~5%)

Time-Of-Flight detector (TOF)

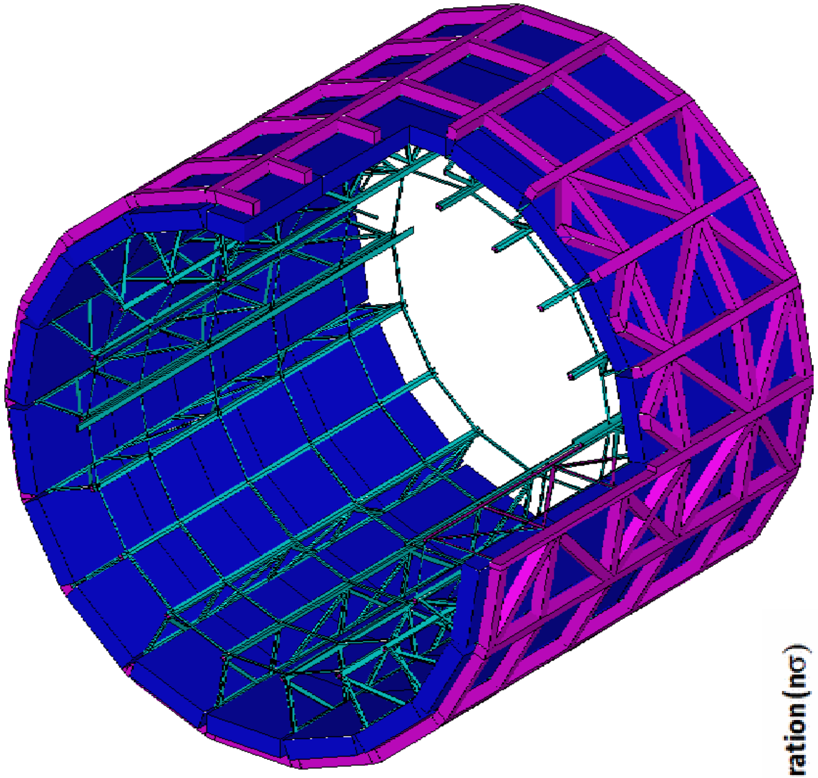


radius	~370 cm
polar acceptance	$\lvert\eta\rvert < 0.9$
azimuthal acceptance	full
coverage area	~140 m^2
detecting element	double-stack MRPC
MRPC efficiency	> 99 % (test beam)
MRPC time resolution	< 50 ps (test beam)
readout segmentation	2.5 x 3.5 cm^2
readout channels	157248

PID via *time-of-flight* technique (σ ~85 ps)
<u>performance better than design</u> (σ < 100 ps)



Time-Of-Flight detector (TOF)



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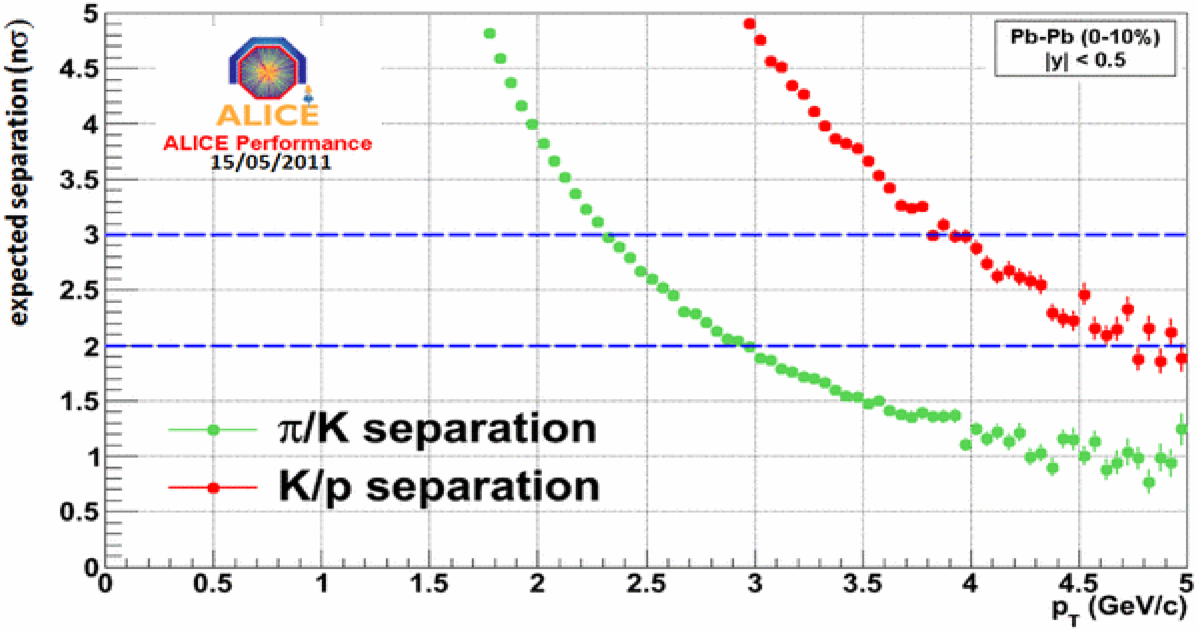
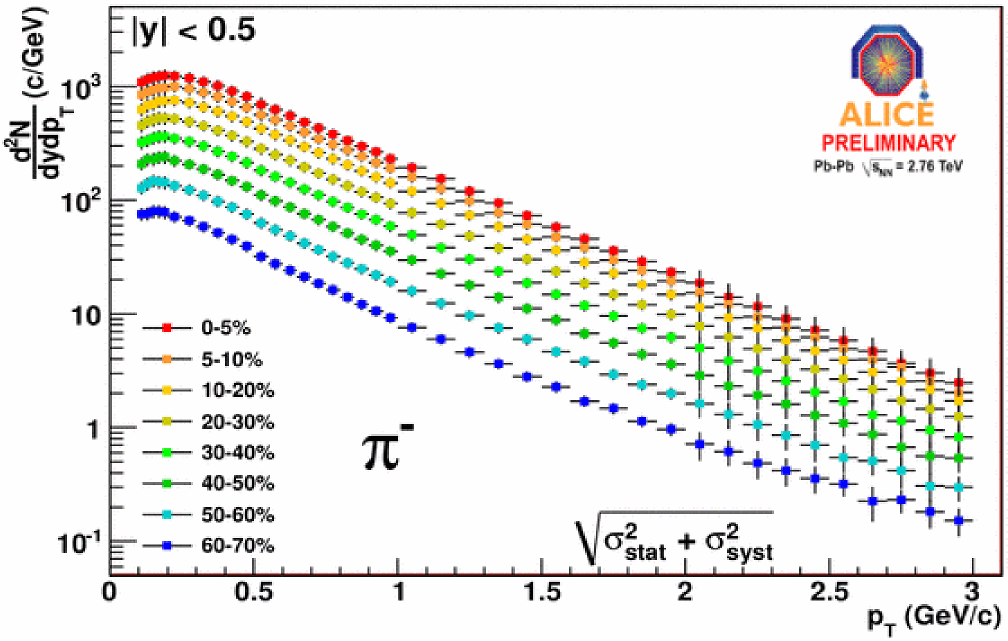
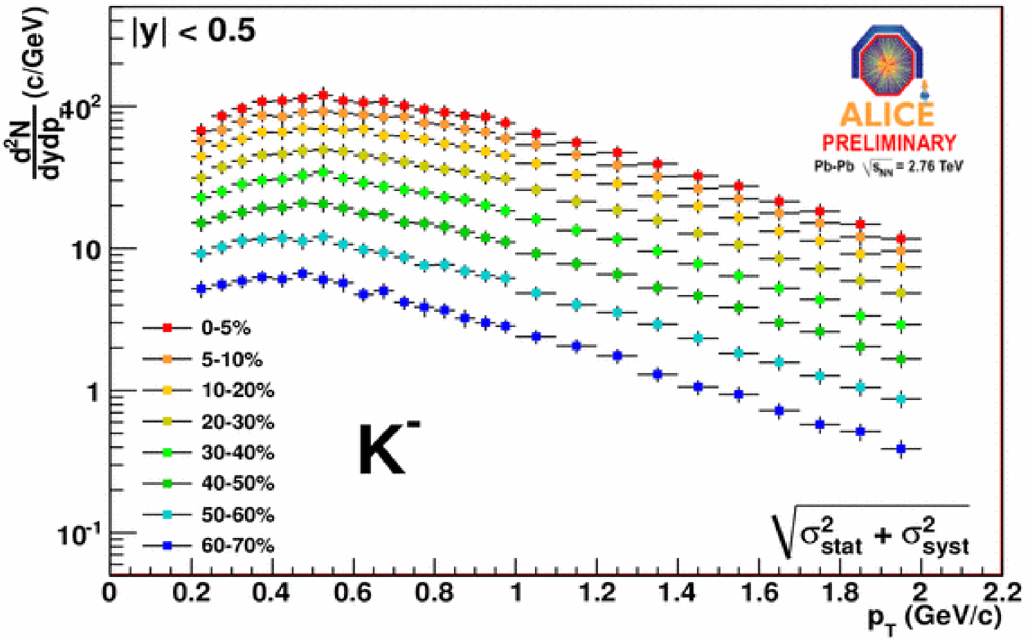


excellent PID separation over wide momentum range:
3σ π/K up to ~2.5 GeV/c
3σ K/p up to ~4.0 GeV/c

Charged-hadron spectra (negative)

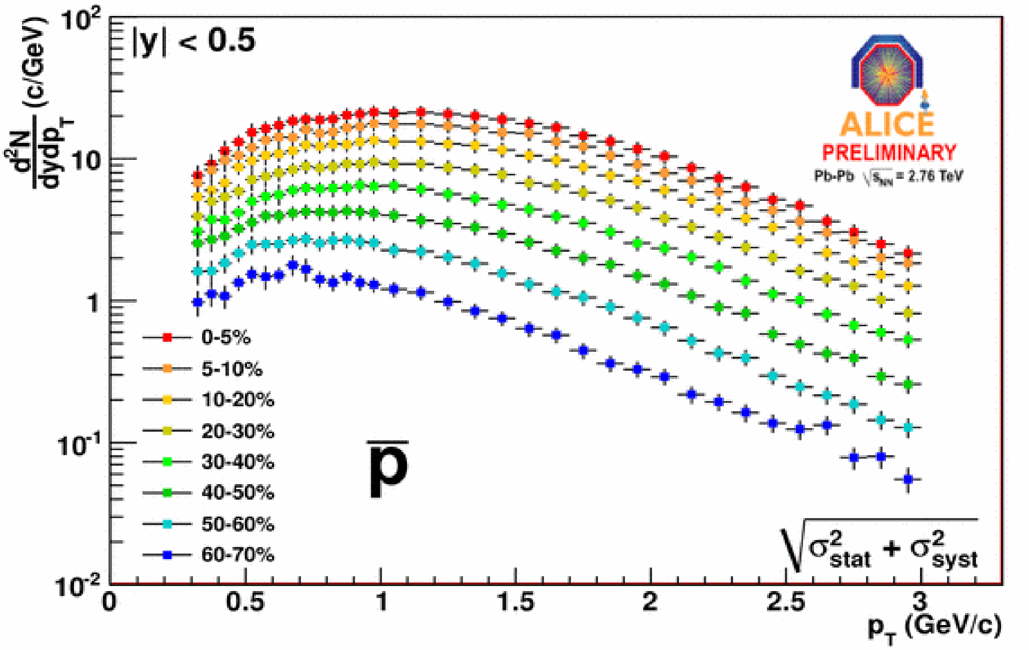




combined analysis in:
Inner Tracking System (ITS)
Time-Projection Chamber (TPC)
Time-Of-Flight (TOF)

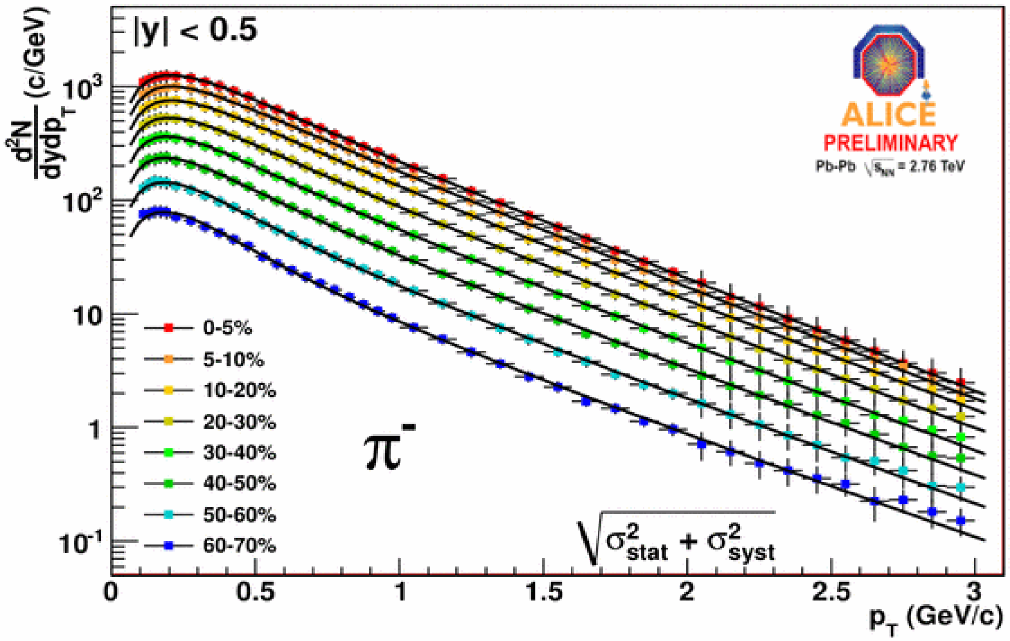
preliminary results in p_T range:

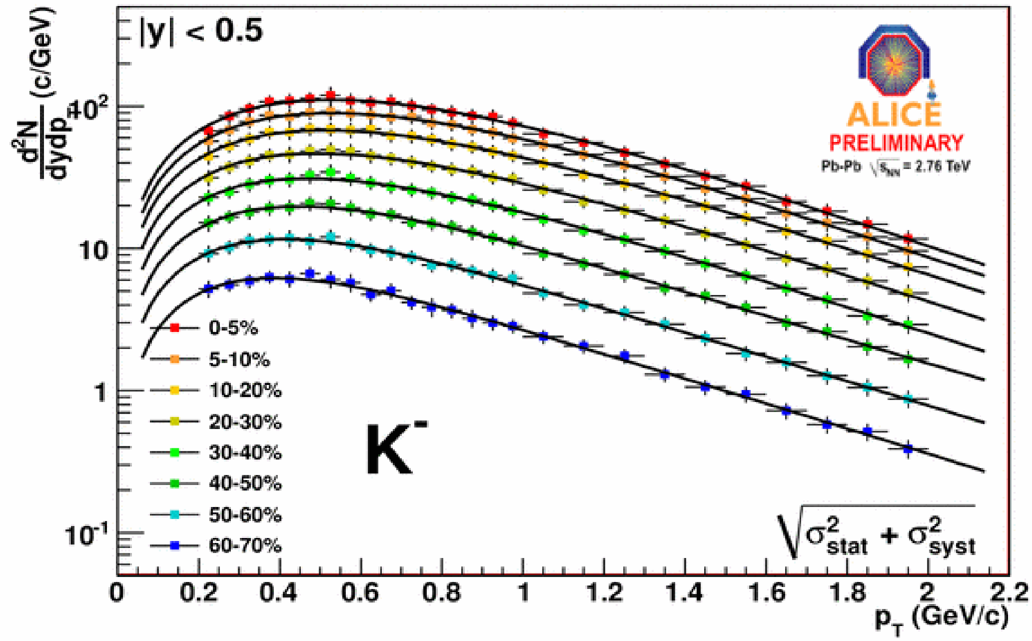
0.1–3.0 GeV/c *π*
0.2–2.0 GeV/c *K*
0.3–3.0 GeV/c *p*



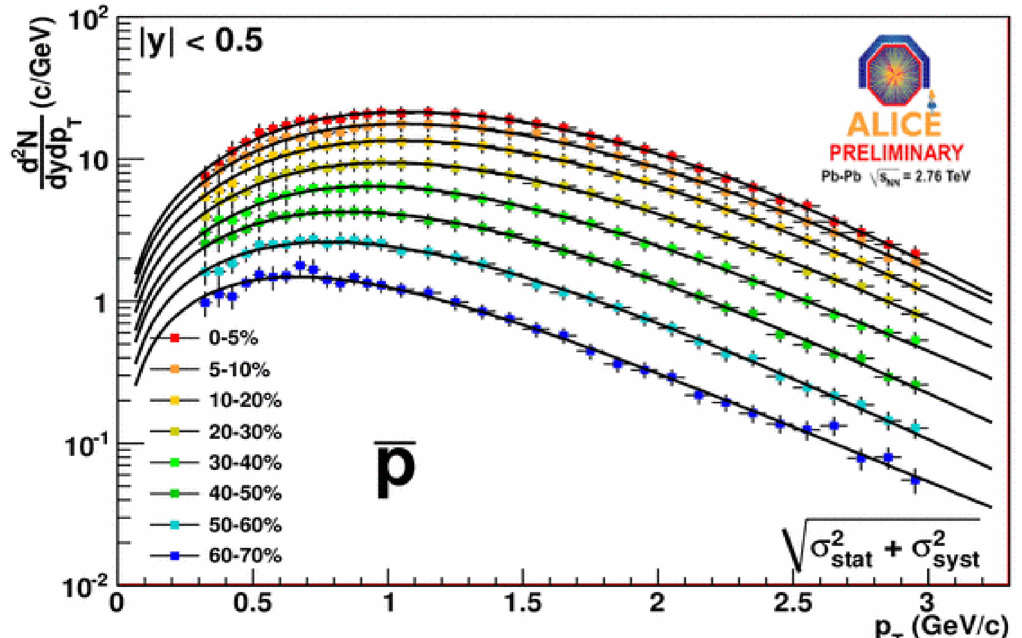
ALICE protons → feed-down corrected

Charged-hadron spectra (negative)





lines are Blast-Wave model fits to identified particle spectra to measure integrated yields and average p_T



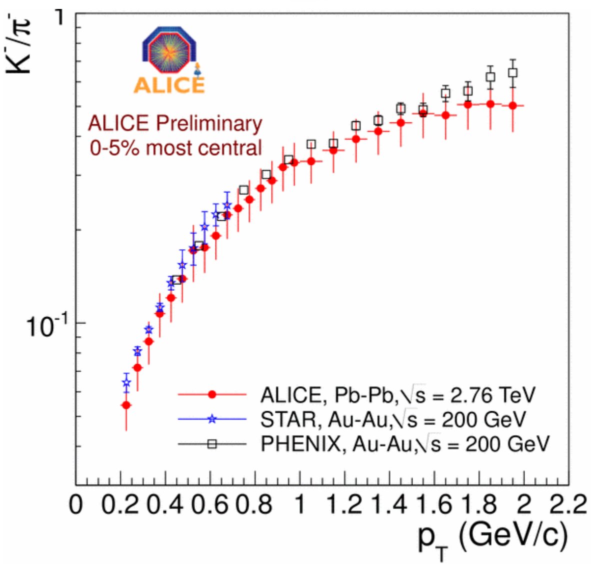
$$\frac{dN}{p_\perp dp_\perp} \propto \int_0^R r dr\, m_\perp I_0\left(\frac{p_\perp \sinh\rho}{T_{\rm kin}}\right) K_1\left(\frac{m_\perp \cosh\rho}{T_{\rm kin}}\right)$$

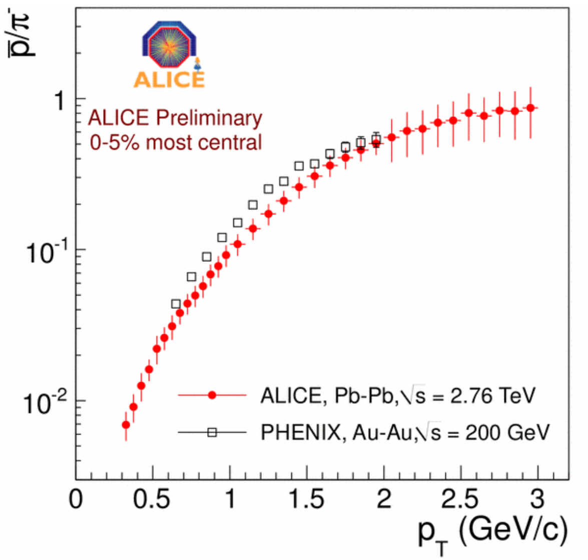
$$\rho = \tanh^{-1}\beta \qquad \beta = \beta_S\,(r/R)^n$$

free parameters: T_{kin} β_S n

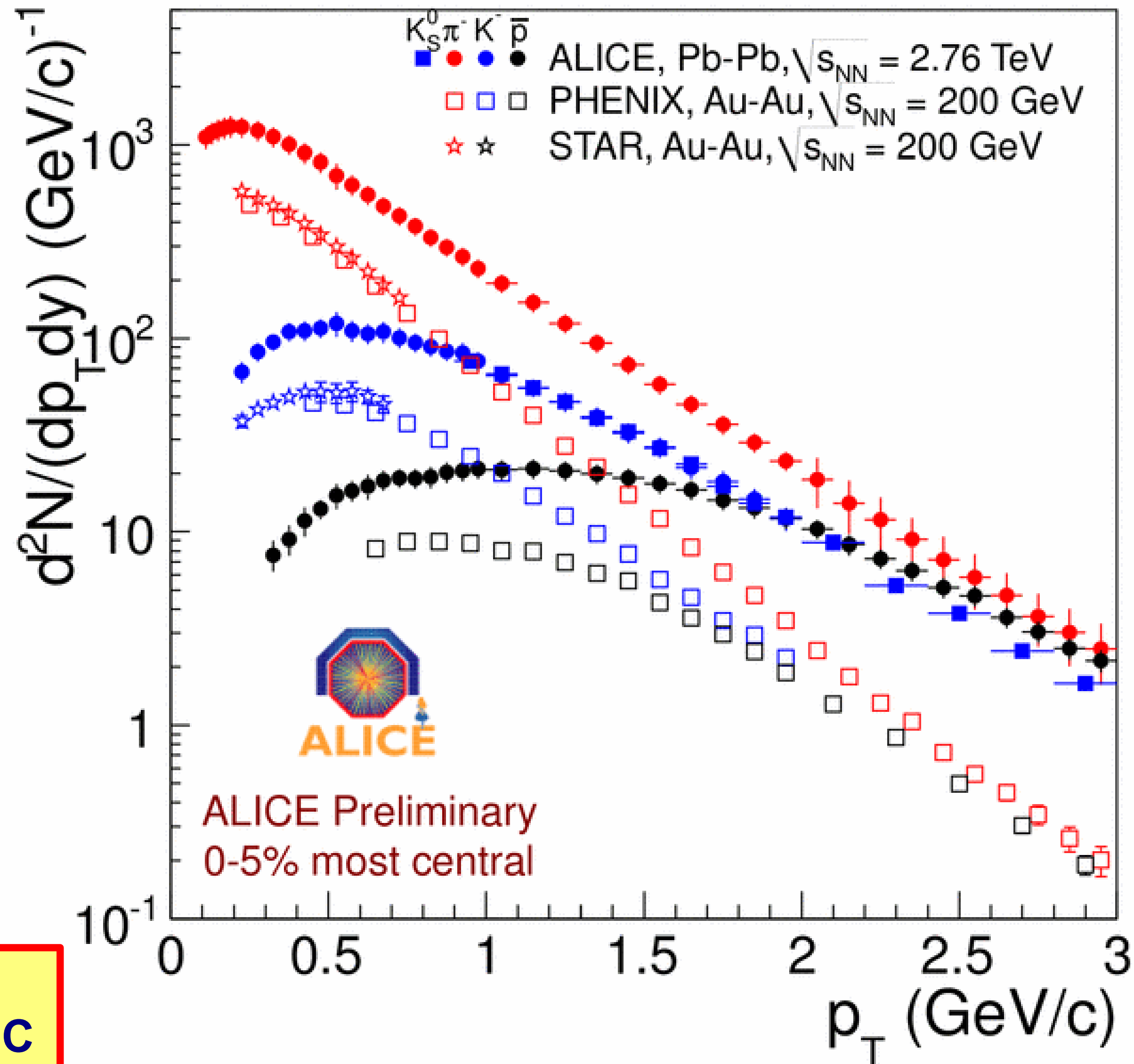
T_{kin} : kinetic (thermal) freezout temperature in the model
no more elastic collisions → fixed spectra

Charged-hadron spectra (negative)





negative particles – 0-5% most central

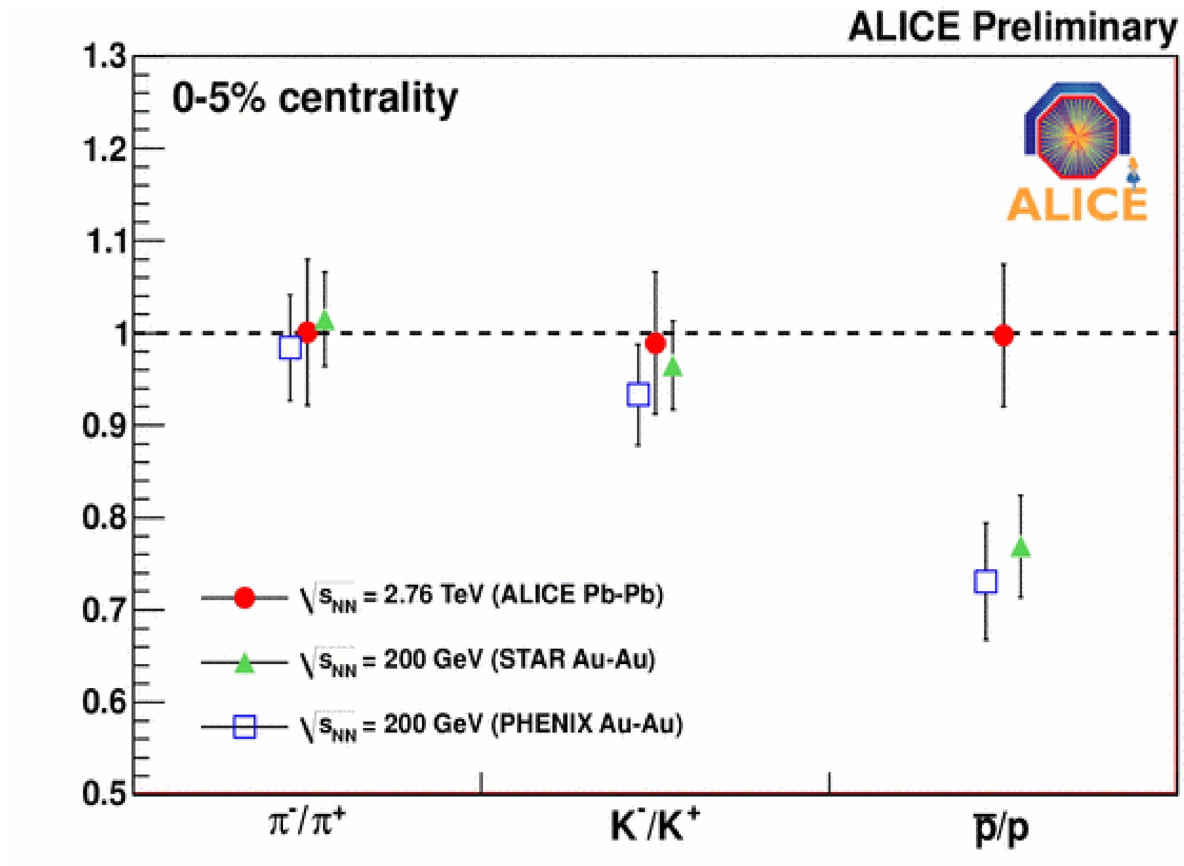


***K/π, p/π*: similar trend at RHIC**
***p/π* saturates at higher p_T than at RHIC**
→ stronger radial flow?

STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 03409 (2004)

Particle-antiparticle production

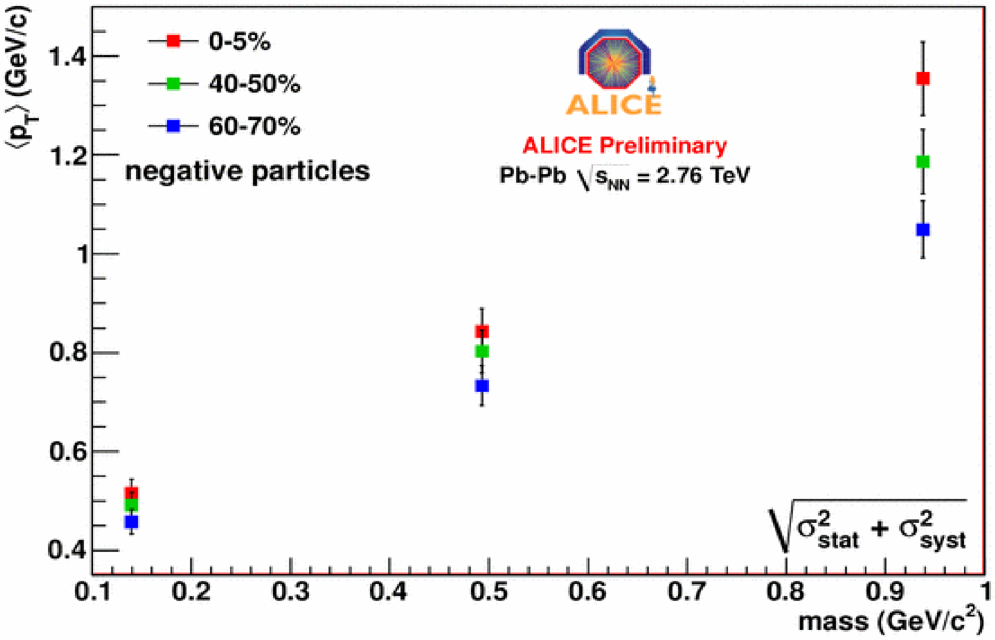
positive spectra are very similar to negative ones
positive spectra in backup slides

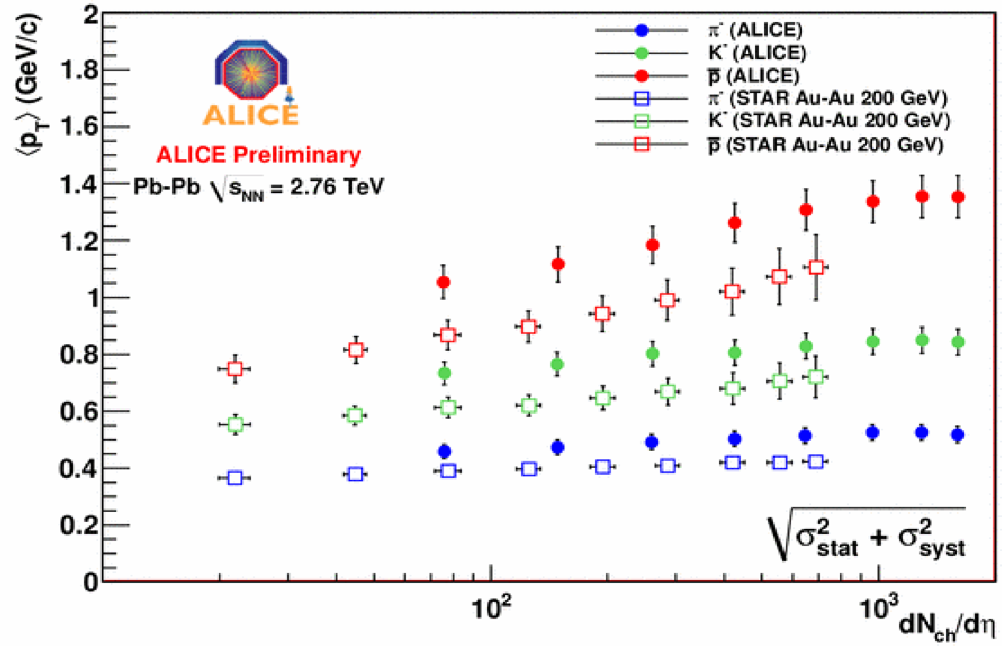


very similar particle and antiparticle production as expected at the LHC
only negative particles shown in the following slides

STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 03409 (2004)

Average hadron momenta (negative)





mean p_T increases linearly with mass

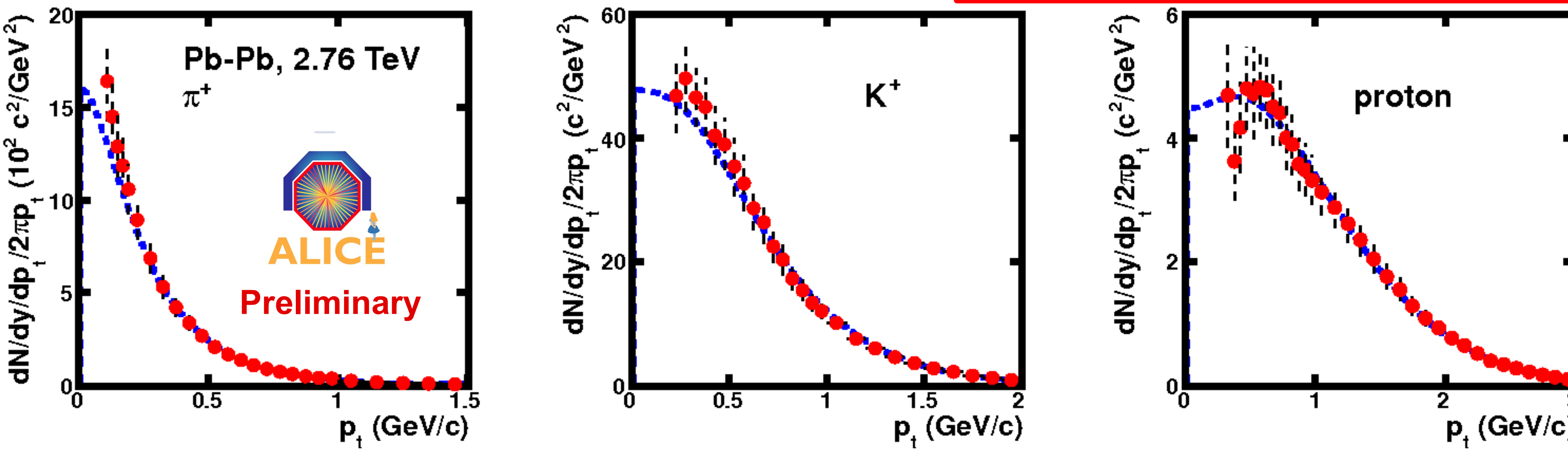
mean p_T increases with $dN_{ch}/d\eta$ (i.e. collision centrality)

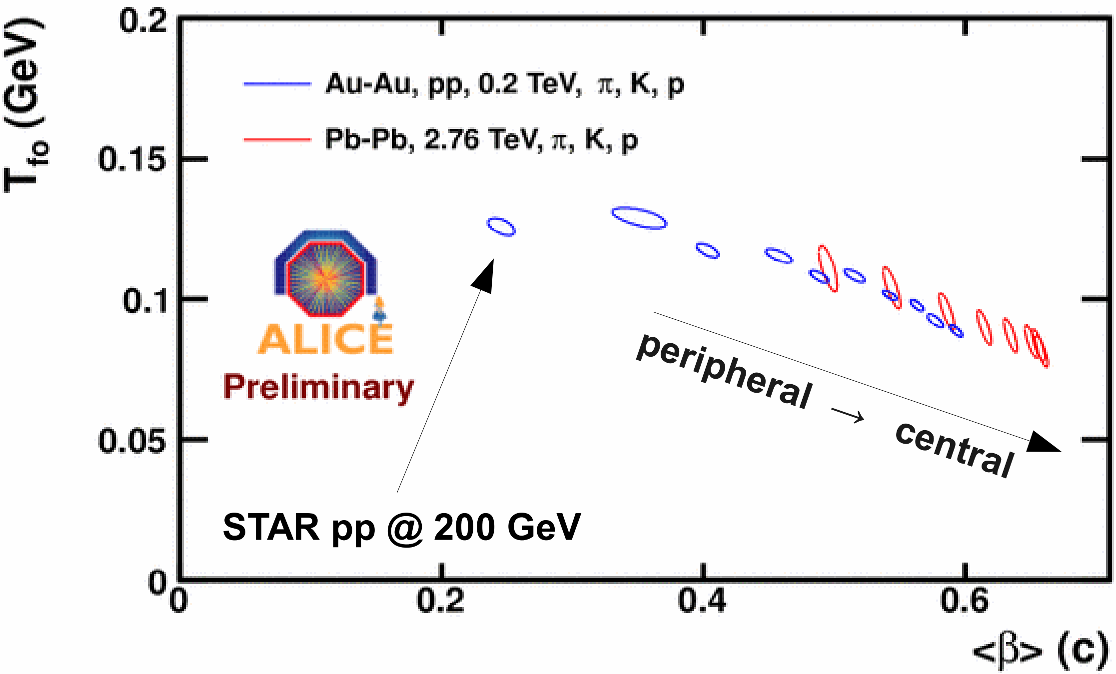
mean p_T higher than at RHIC for similar $dN_{ch}/d\eta$
→ harder spectra, stronger radial flow?

STAR, PRC 79, 034909 (2009)

Blast-Wave global fit to *π*/*K*/*p*

Schnedermann et al, PRC 48, 2462 (1993)





fitted p_T range (<u>both charges are fitted</u>):

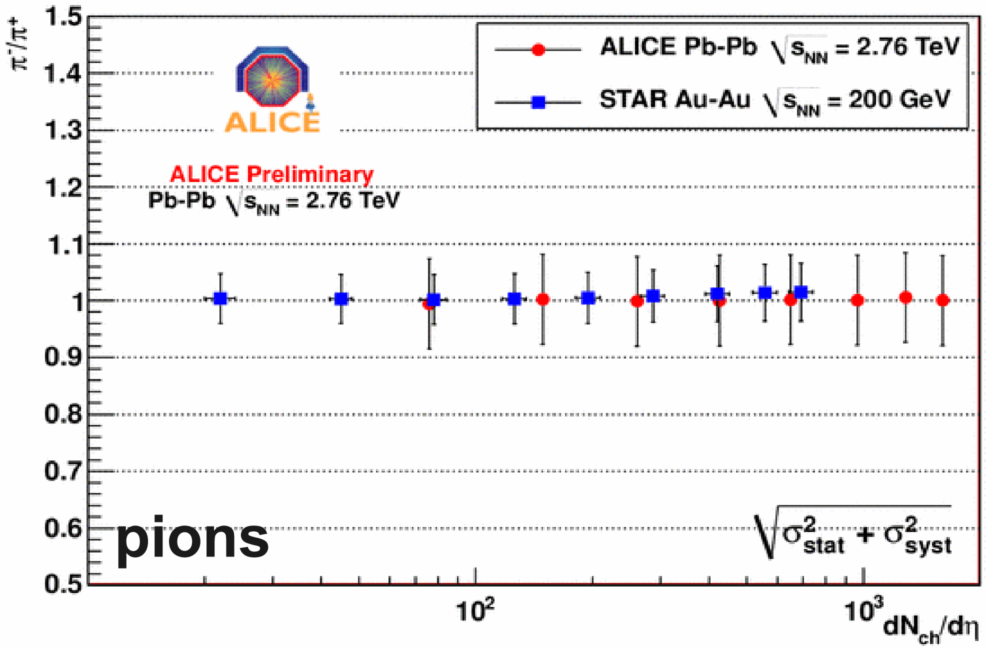
0.3–1.0 GeV/c	*π*
0.2–1.5 GeV/c	*K*
0.3–3.0 GeV/c	*p*

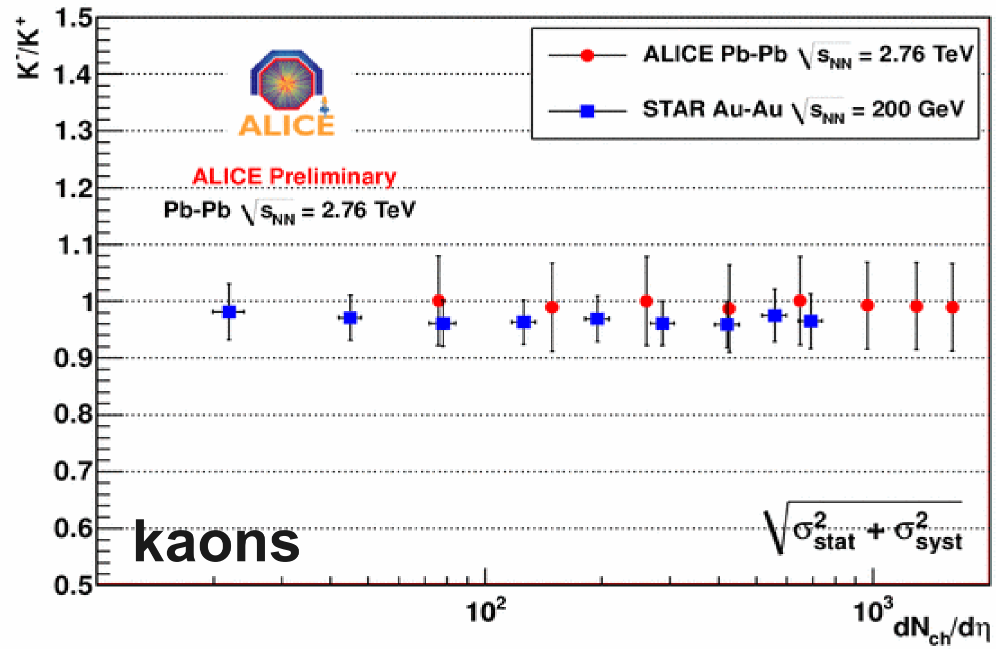
global fit output: radial flow ‹β› ~10% higher than at RHIC

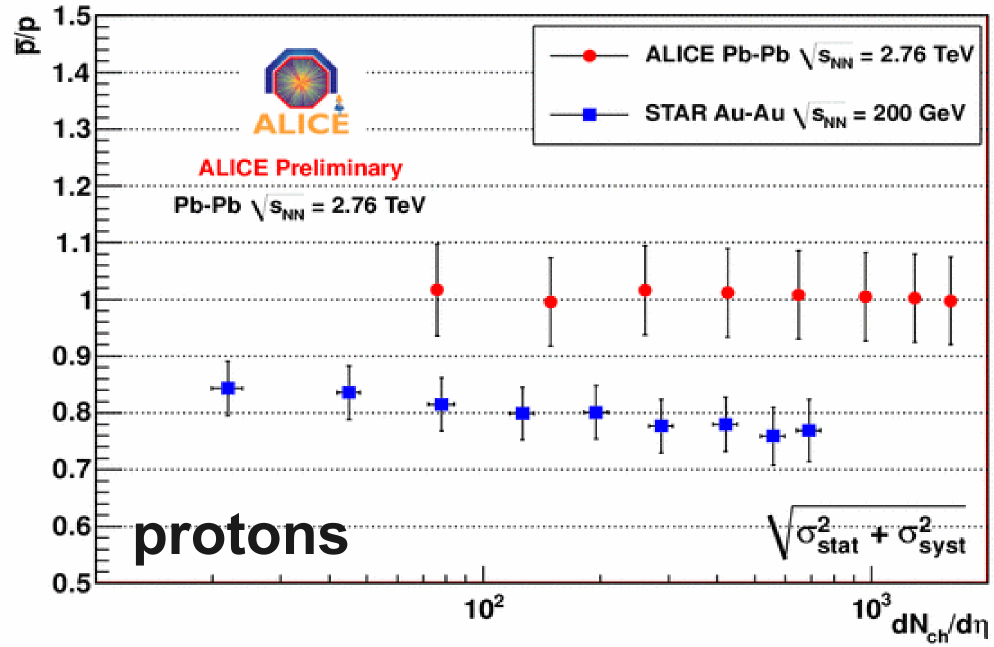
T_{fo} (T_{kin}) parameter of the model depends on pion fit range (effect of resonances to be investigated)

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

Particle-antiparticle production ratios





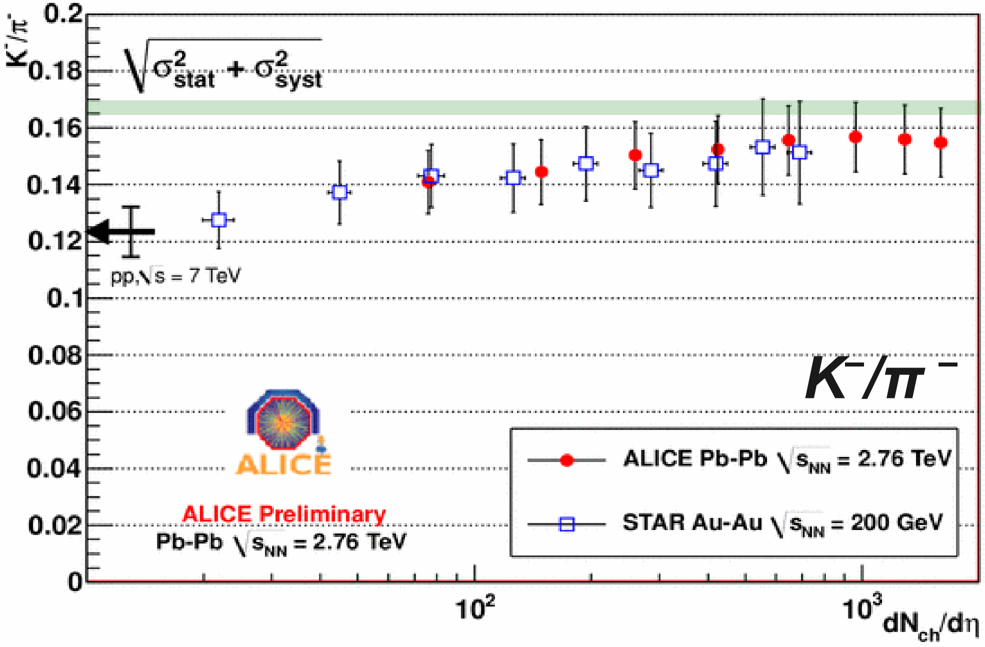


as expected at LHC energies, particle-antiparticle ratios are all compatible with 1 at all centralities

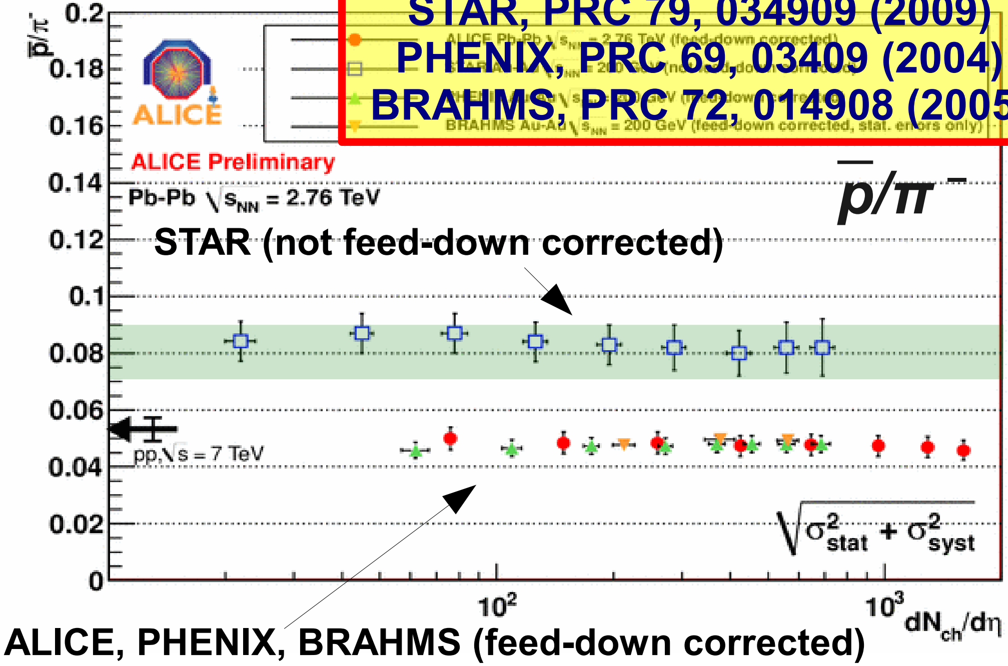
μ_B is close to zero at the LHC

STAR, PRC 79, 034909 (2009)

K/π and p/π production ratios



STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 03409 (2004)
BRAHMS, PRC 72, 014908 (2005)



	ALICE data these results	LHC prediction* T_{ch} = 164 MeV, μ_B =1 MeV A.Andronic et al, Phys.Lett.B 673, 142 (2009)	LHC prediction* T_{ch} = (170 ± 5) MeV, μ_B = (1 ± 4) MeV J.Cleymans et al, PRC 74, 034903 (2006)
K^+/π^+	0.156 ± 0.012	0.164	0.180 ± 0.001
K^-/π^-	0.154 ± 0.012	0.163	0.179 ± 0.001
$\bar{p}/\pi^+$	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

T_{ch} : chemical freezout (hadronization) temperature in the model
no more inelastic collisions → fixed chemical composition

Conclusions

ALICE has measured transverse momentum spectra of identified charged hadrons in Pb-Pb collisions as a function of collision centrality

Spectral shapes and average momenta seem to indicate a stronger radial flow that at RHIC
$\langle\beta\rangle$ ~10% higher

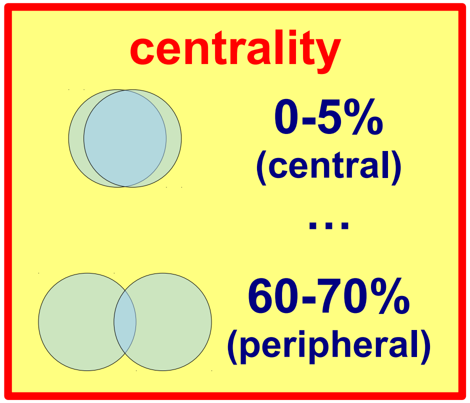
Particle-antiparticle production ratios consistent with 1
μ_B is close to zero at the LHC

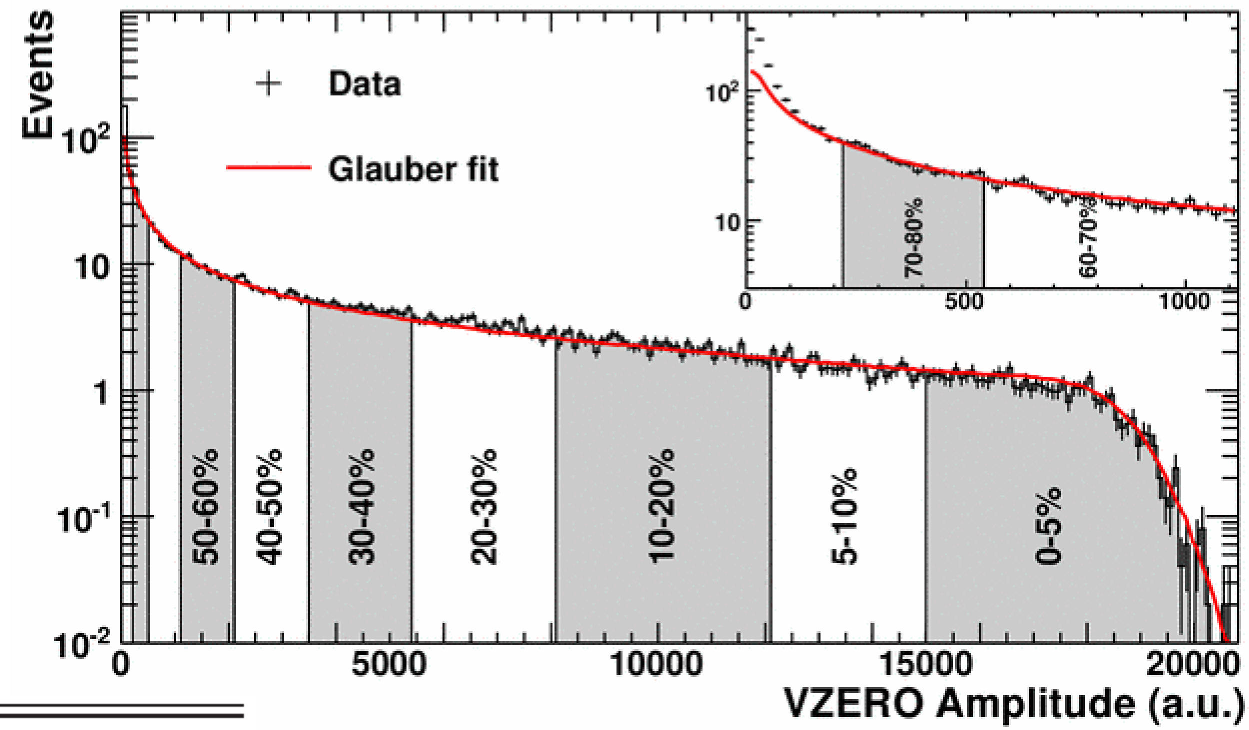
Integrated K/π and p/π production ratios similar to RHIC (when proton feed-down is taken into account)

p/π ~0.05 difficult to understand in thermal-model predictions with T_{ch} = 160-170 MeV

END

Centrality selection and measurement

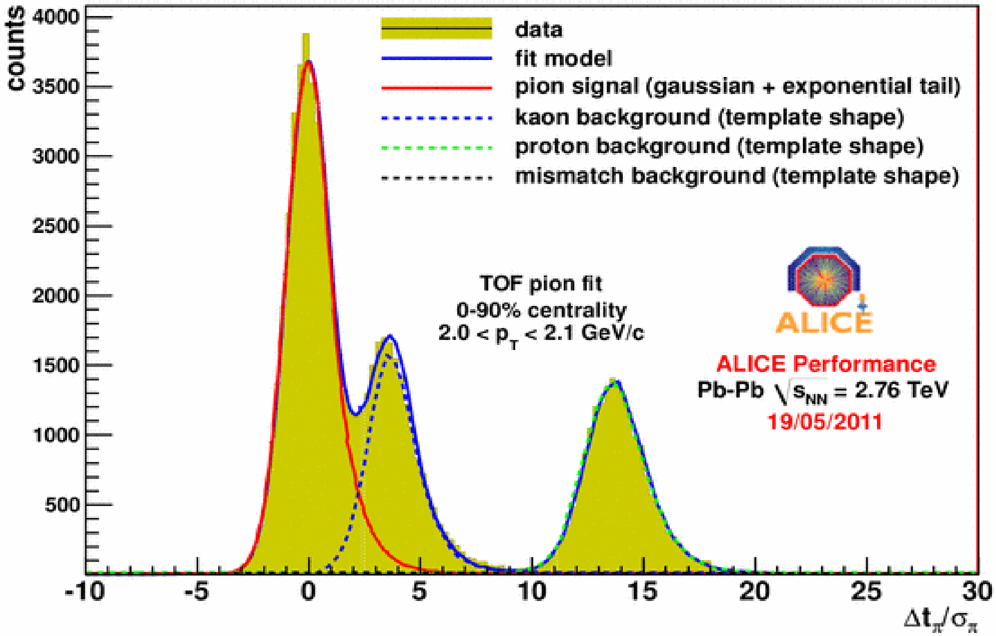


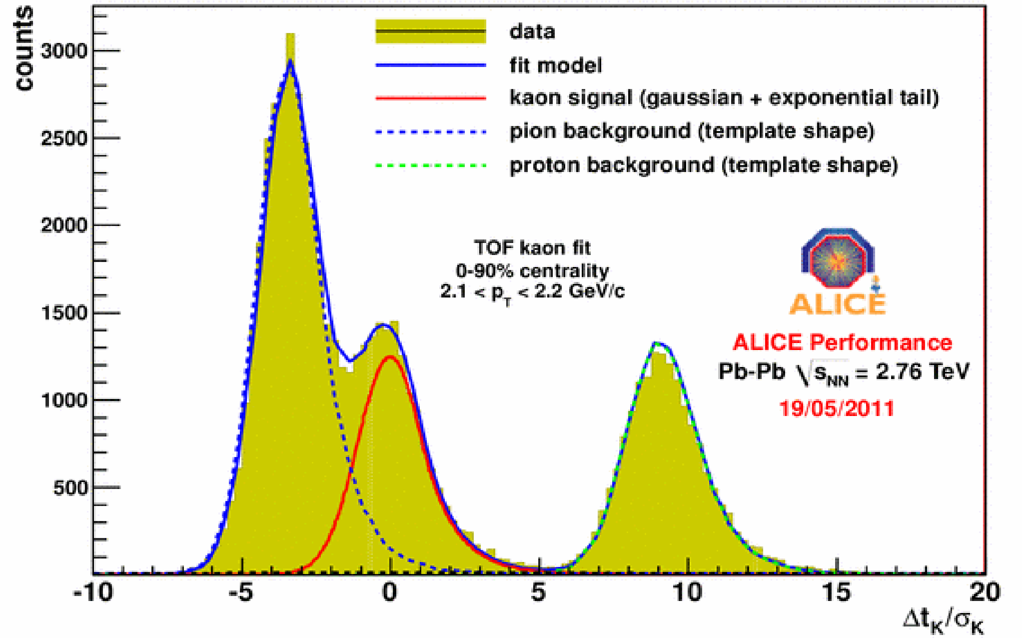


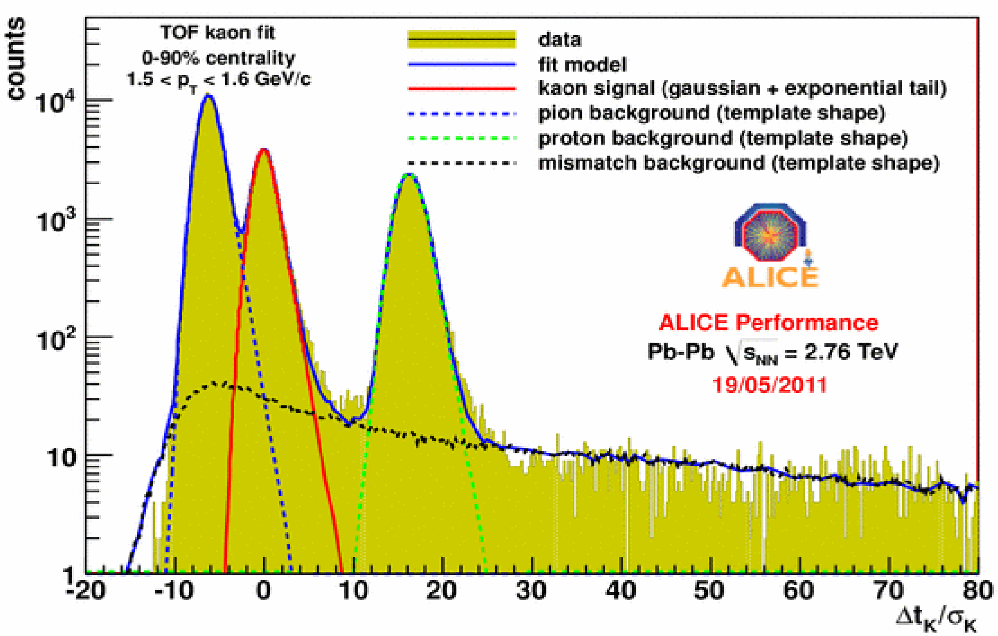
Centrality	$dN_{ch}/d\eta$	$\langle N_{part}\rangle$	$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	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

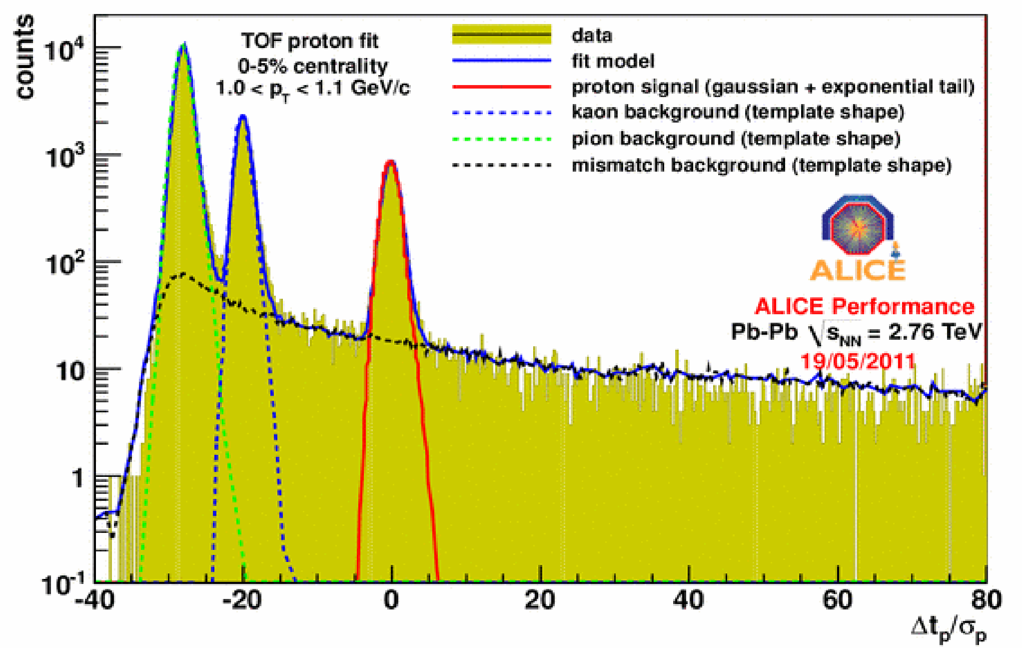
ALICE, PRL 106, 032301 (2011)

Raw yield measurement (TOF)









Feed-down corrected primary protons

remove **protons from weak decays**

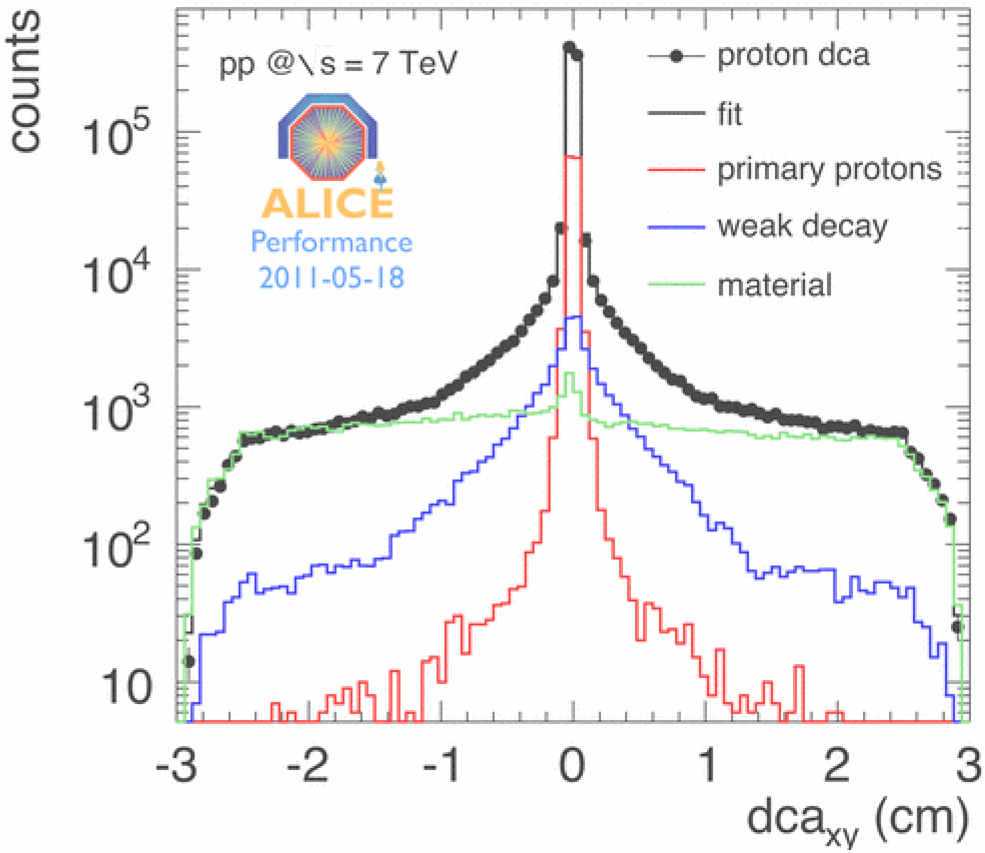
$\Lambda \rightarrow p \pi^-$

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

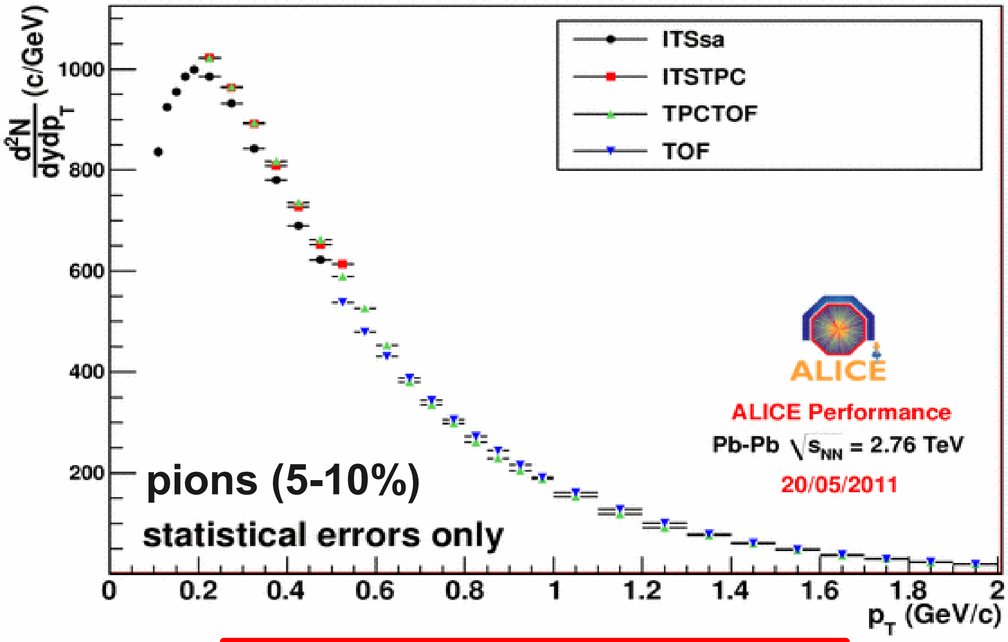
remove **protons knocked out from the material**

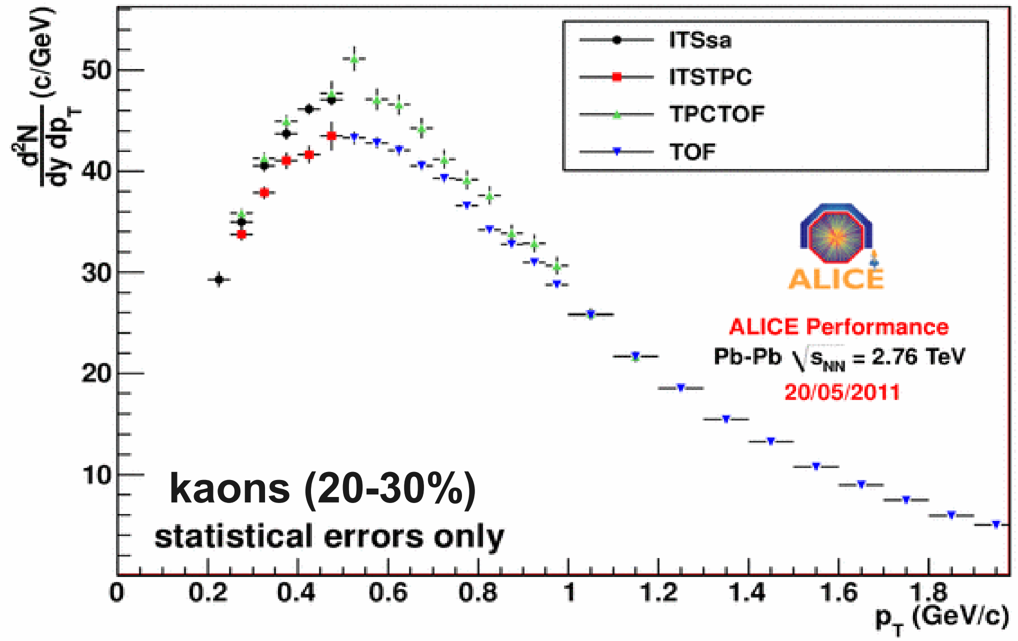
use measured DCA distribution and fit it with MC templates

example from *pp* collisions for p_T [0.70, 0.75] GeV/c



Comparison of PID analyses



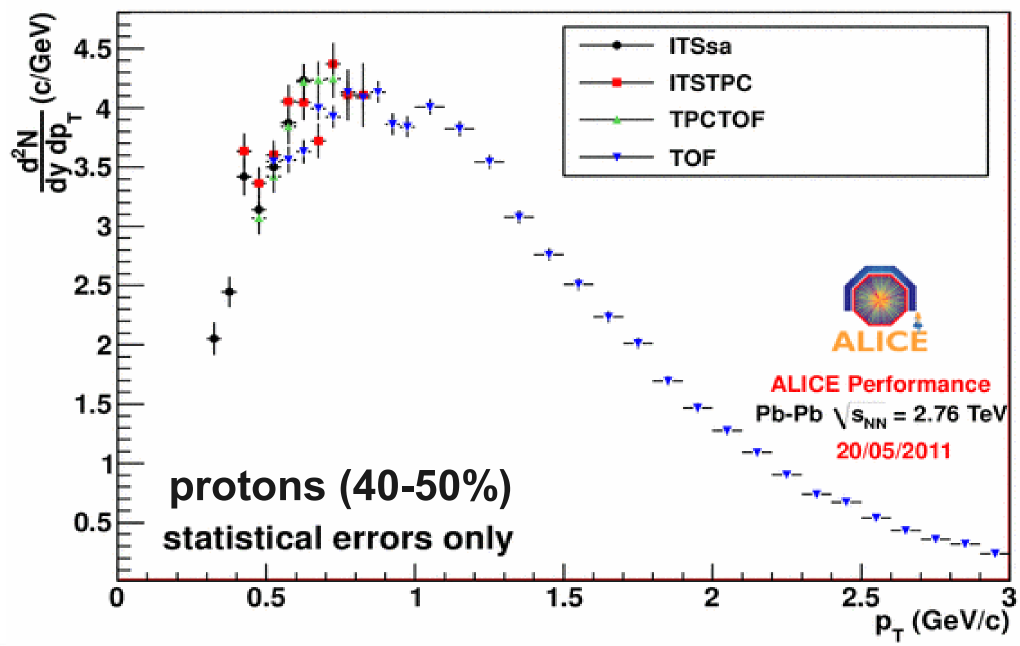


ITSsa
ITS standalone track
ITS PID (N_σ cuts)

ITSTPC
global tracks
ITS PID (data fits)

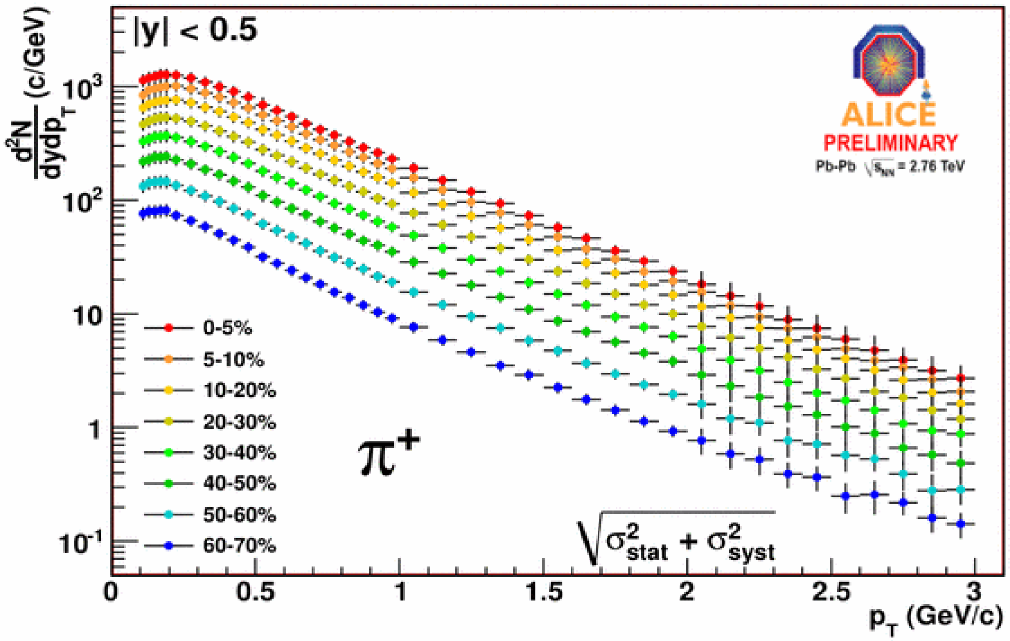
TPCTOF
global tracks
TPC+TOF PID (N_σ cuts)

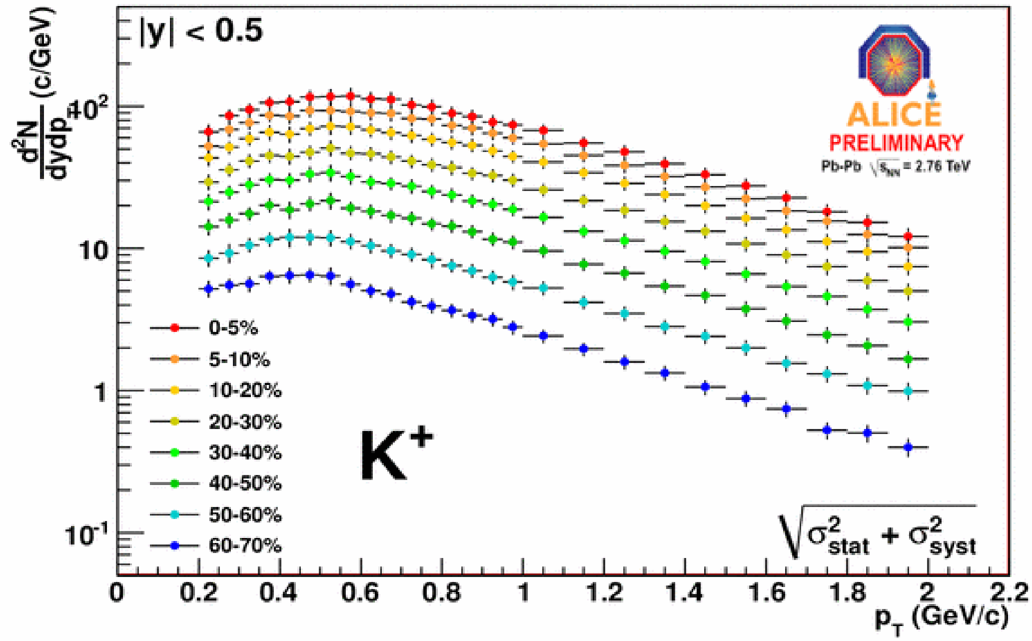
TOF
global tracks
TOF PID (data fits)



ALICE protons → feed-down corrected

Charged-hadron spectra (positive)

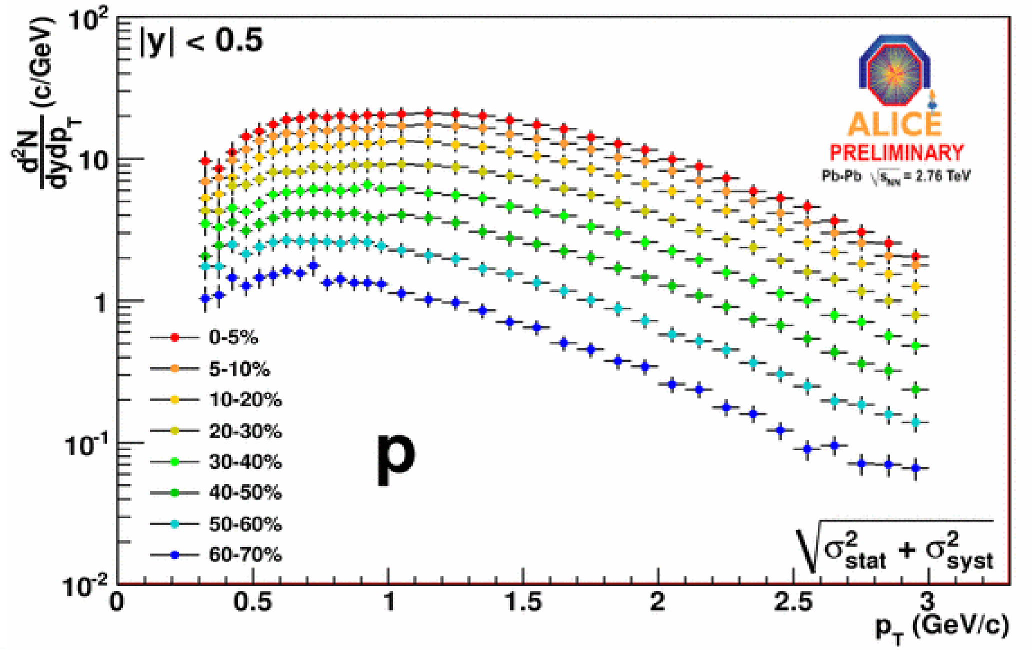




combined analysis in:
Inner Tracking System (ITS)
Time-Projection Chamber (TPC)
Time-Of-Flight (TOF)

preliminary results in p_T range:

0.1–3.0 GeV/c ***π***
0.2–2.0 GeV/c ***K***
0.3–3.0 GeV/c ***p***



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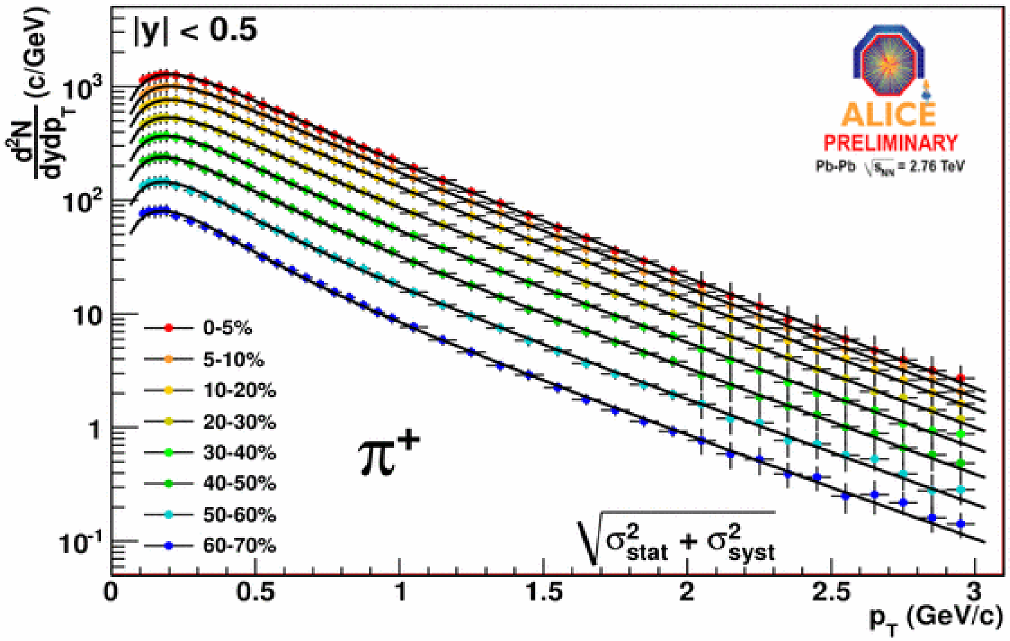
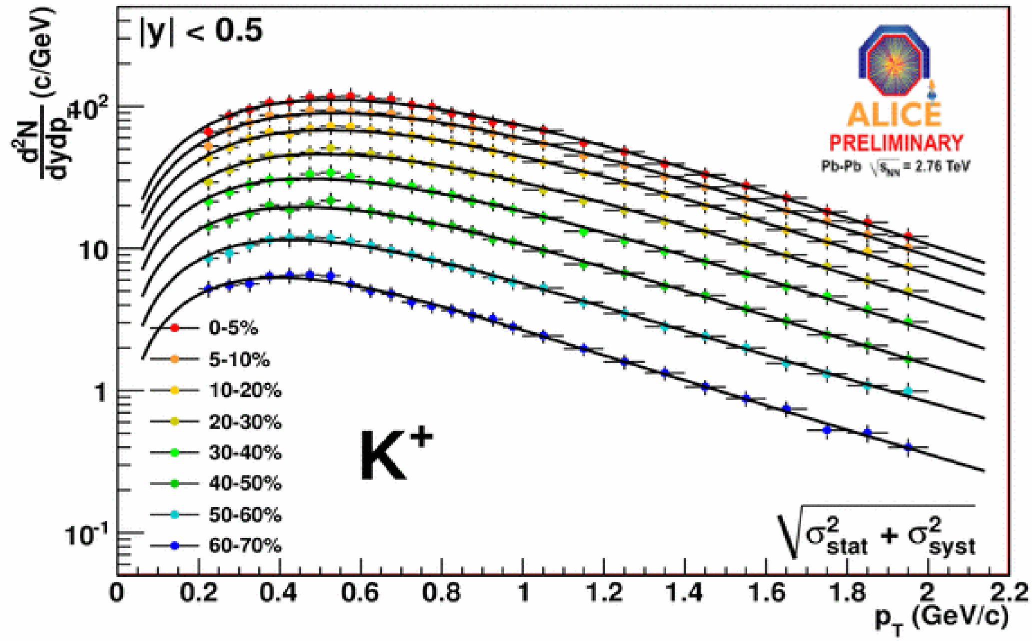
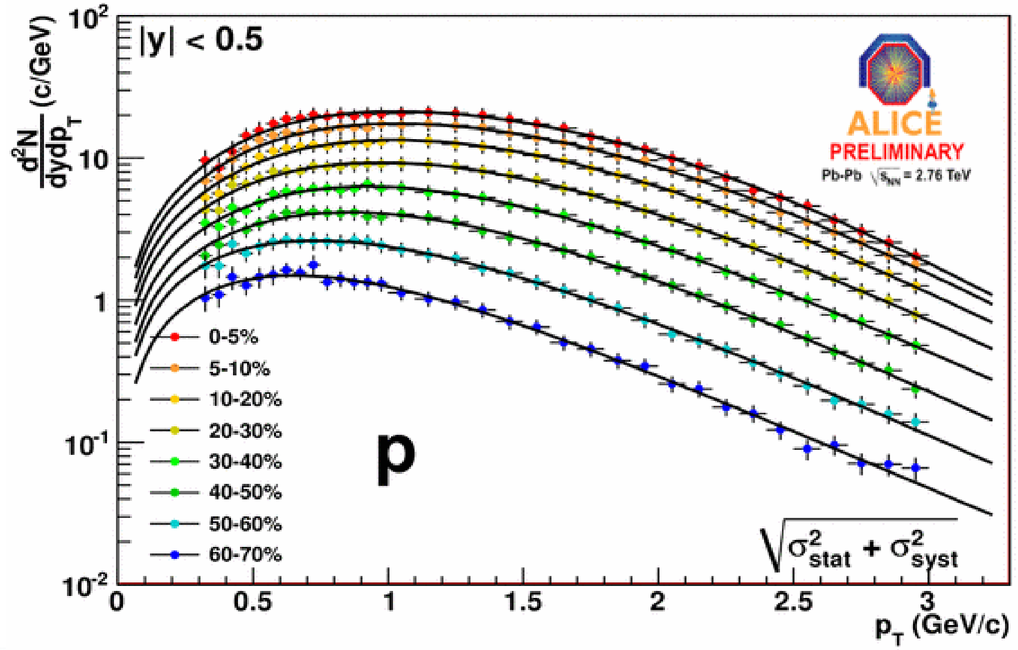




lines are **Blast-Wave fits** to individual particles to measure **integrated yields** and **average p_T**

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

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



ALICE protons → feed-down corrected

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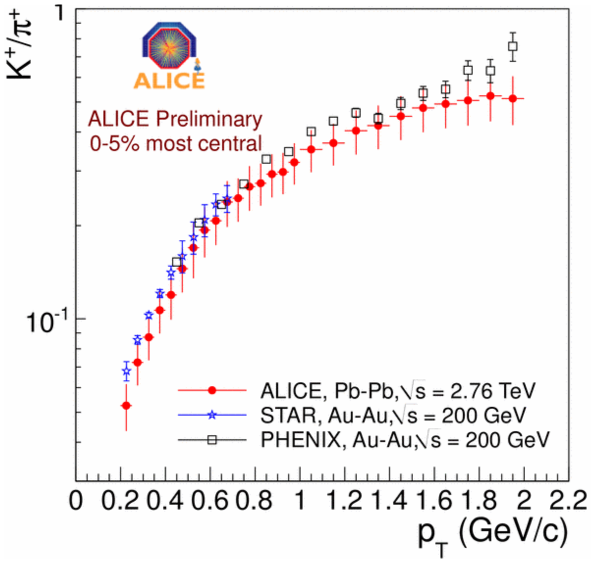
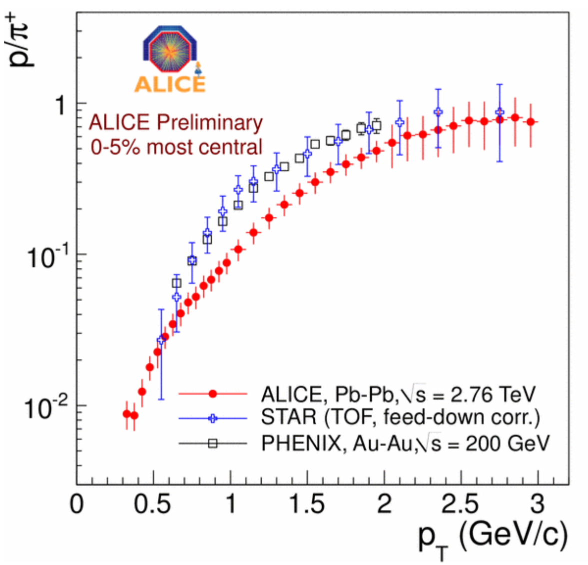
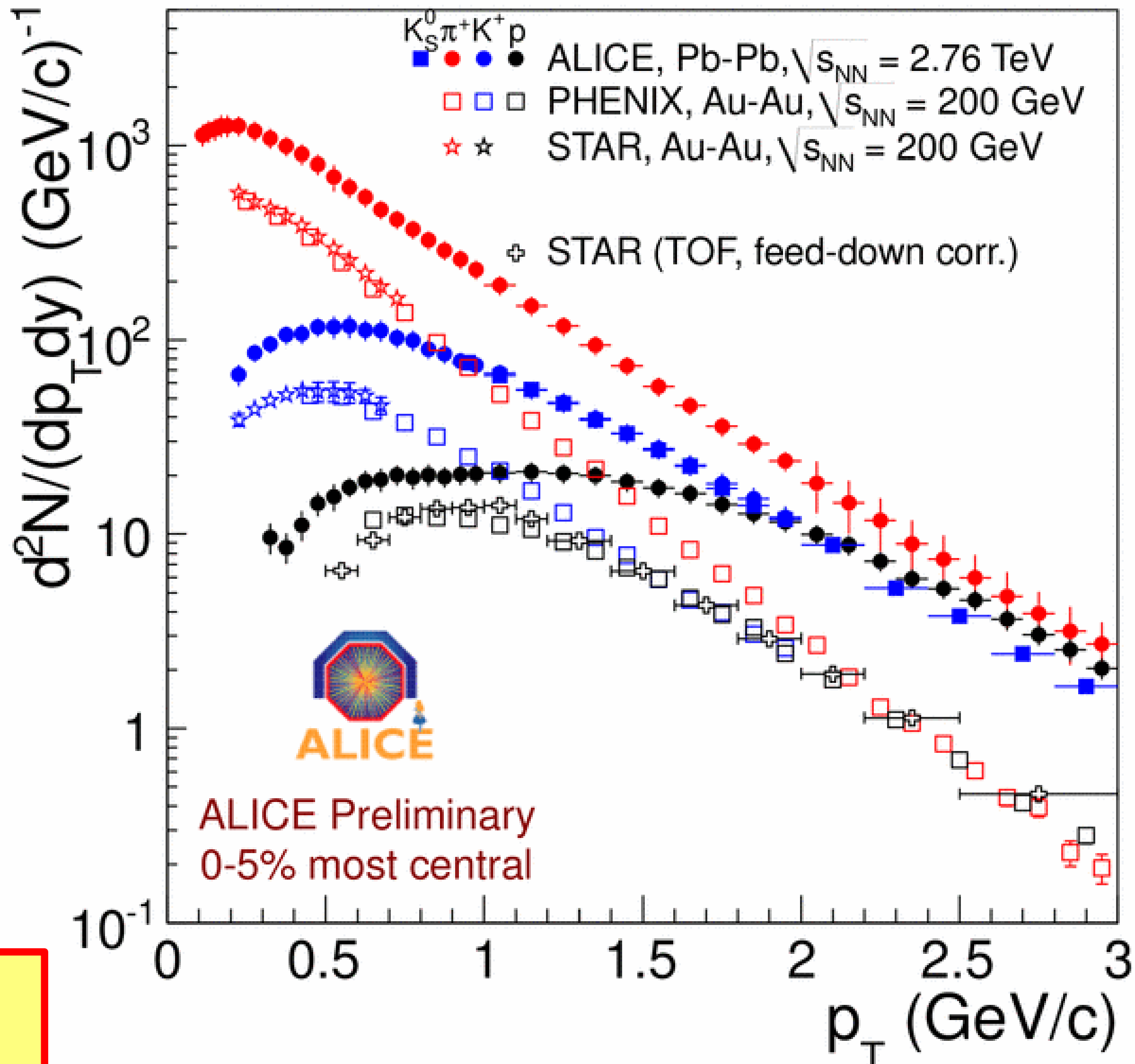




positive particles – 0-5% most central

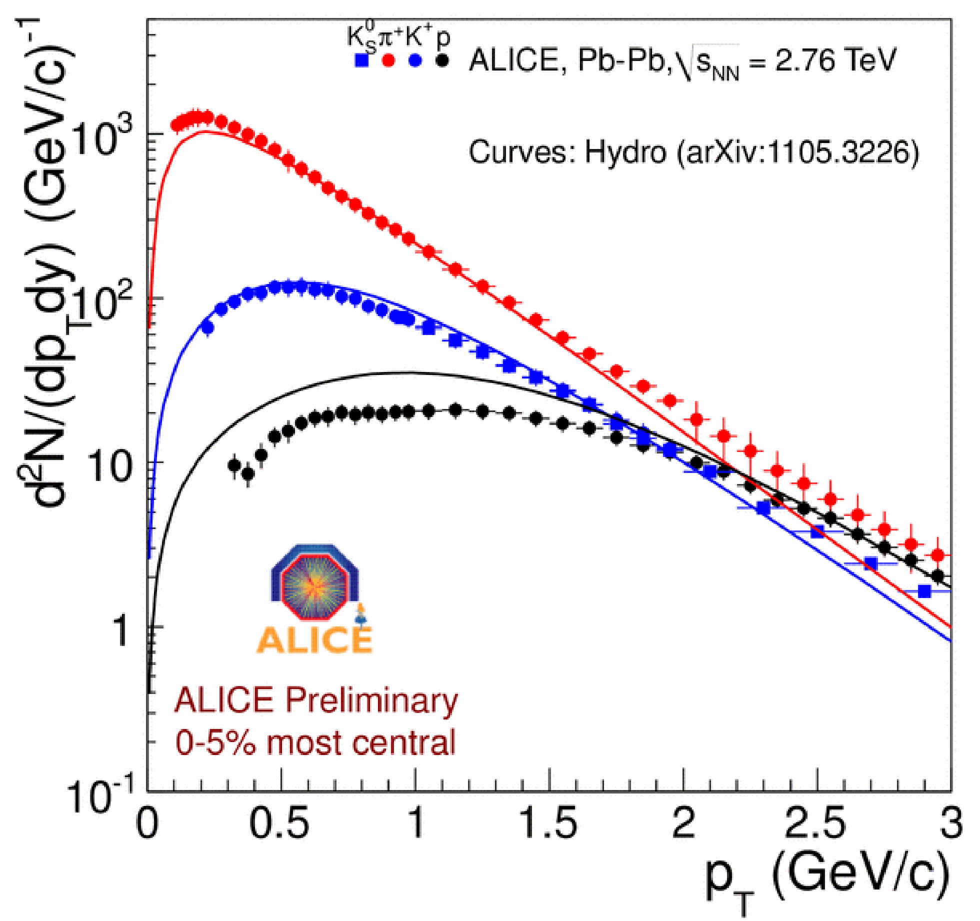


***K/π*, *p/π*: similar trend at RHIC**
***p/π* saturates at higher pT**
→ stronger radial flow?

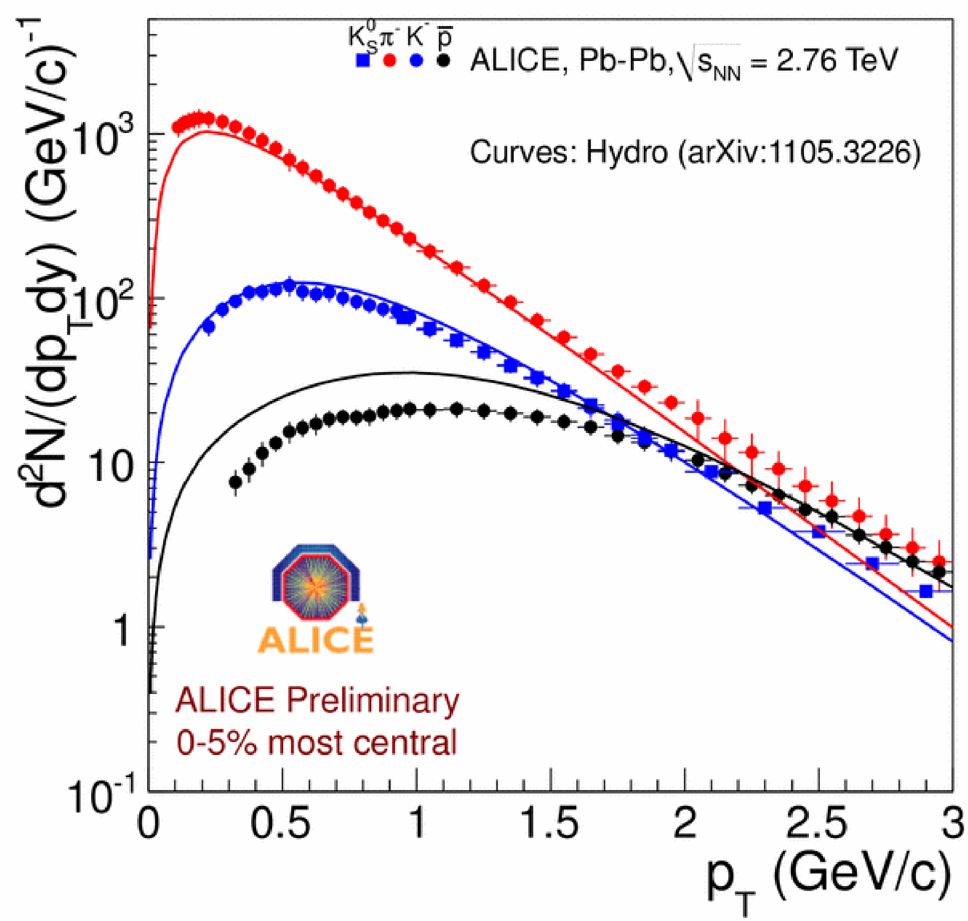
STAR, PRC 79, 034909 (2009)
PHENIX, PRC 69, 03409 (2004)

Comparison to hydro-prediction

positive particles – 0-5% most central



negative particles – 0-5% most central

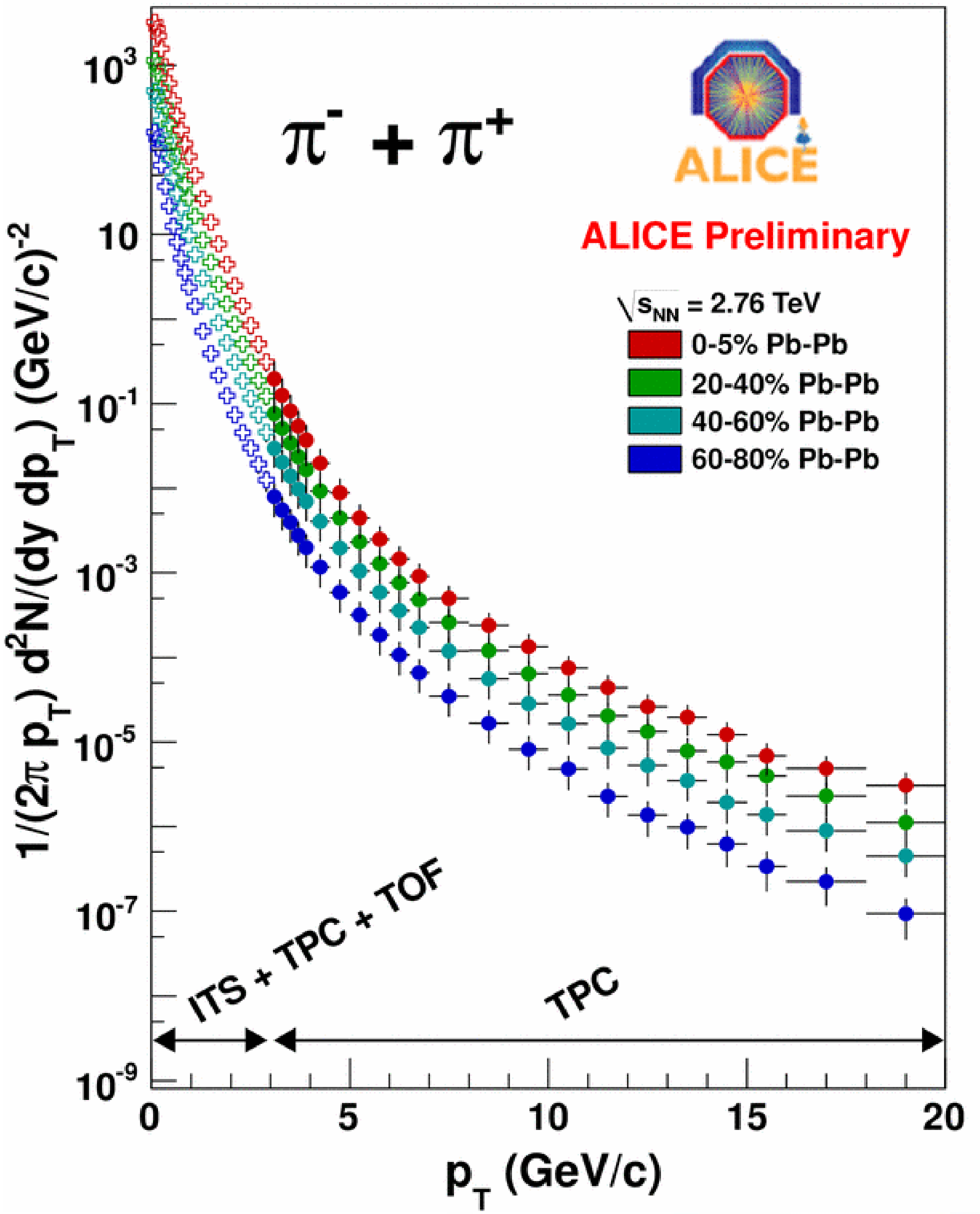


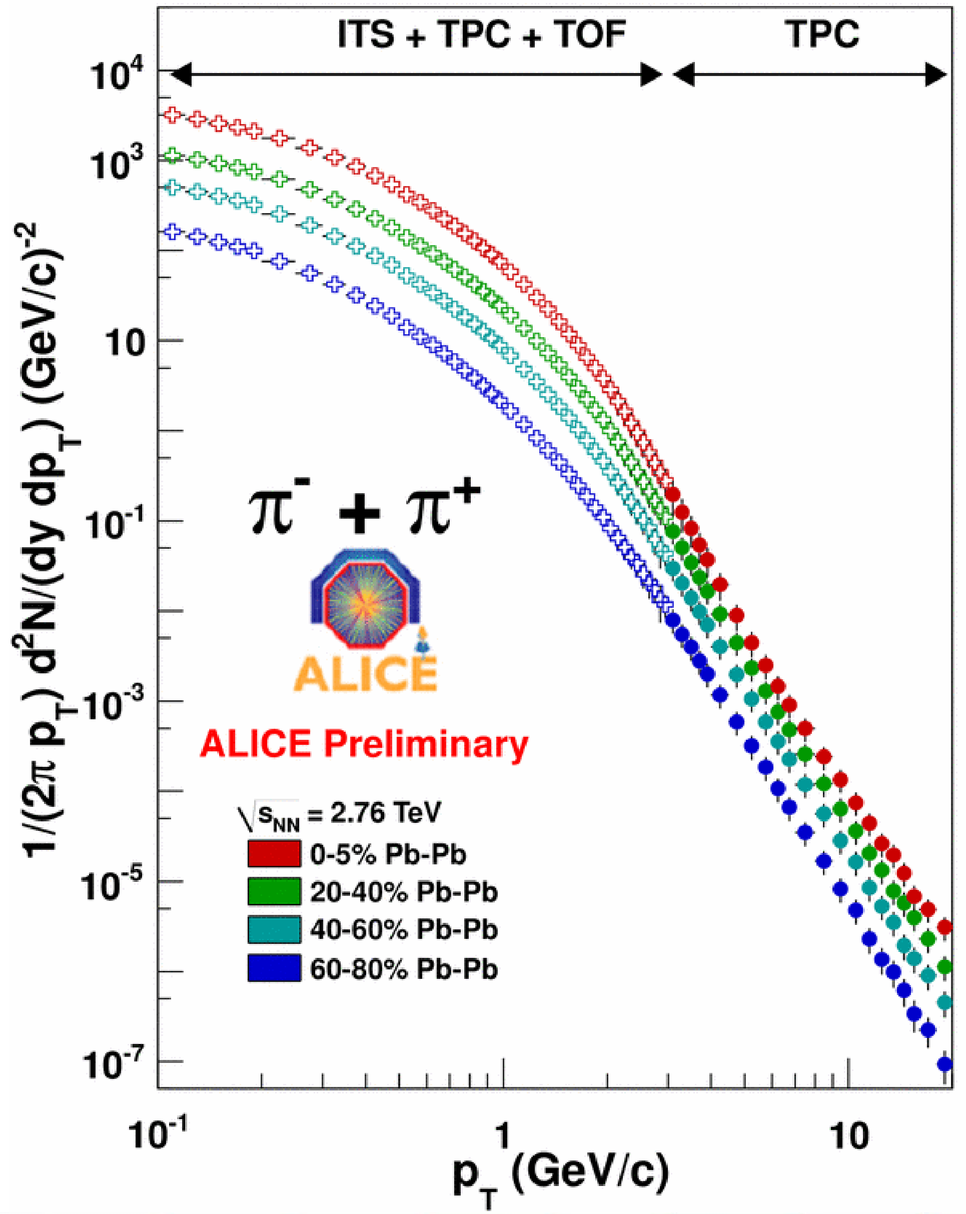
ALICE protons → feed-down corrected

arXiv:1105.3226 [nucl-th]

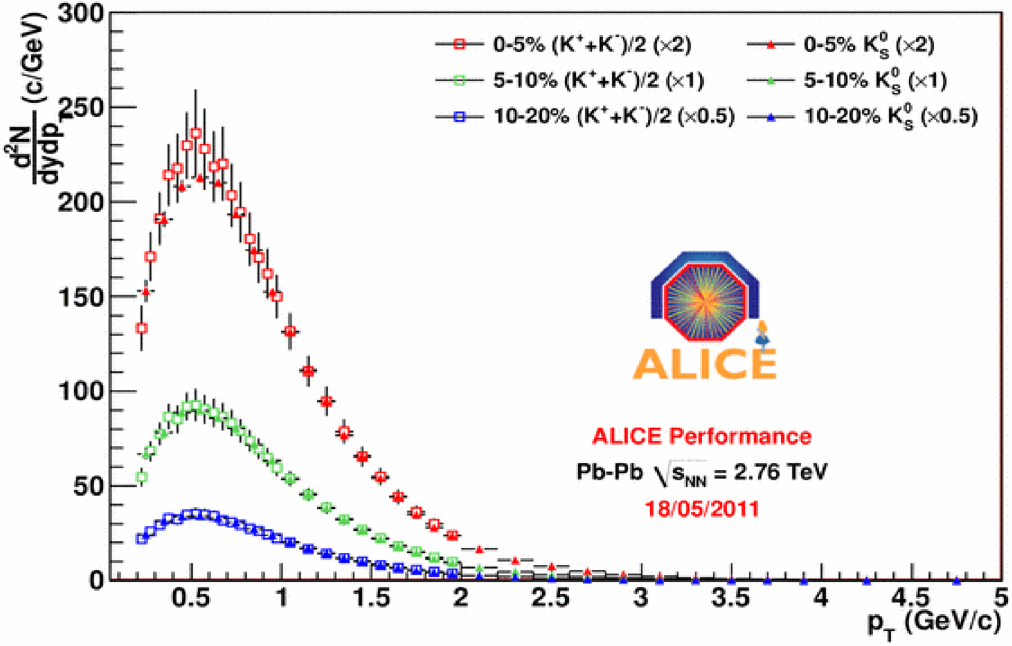
High-p_T charged pion comparison

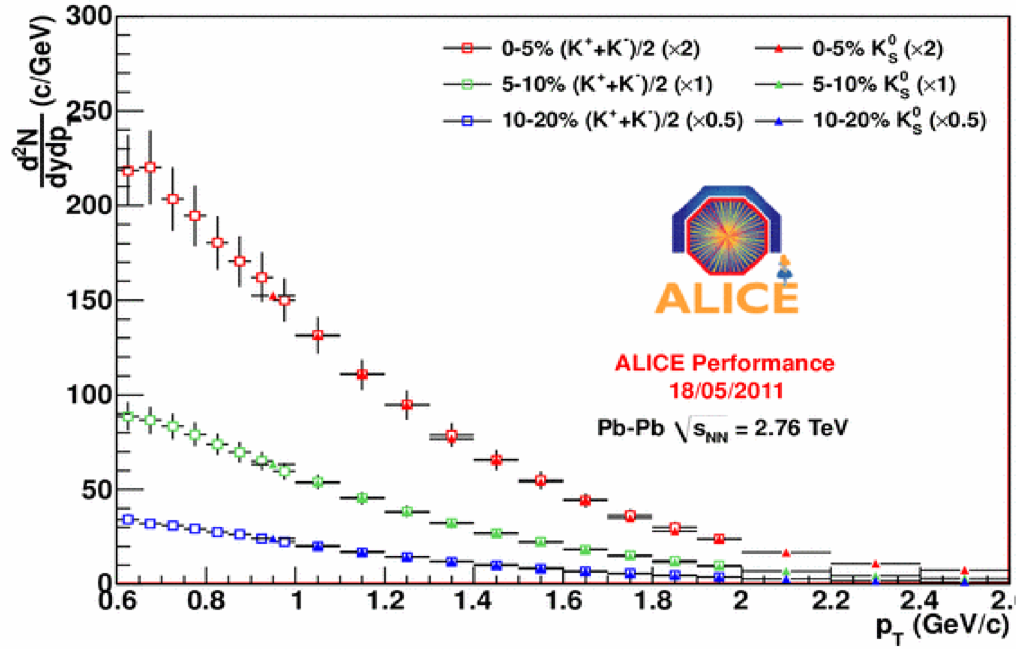
high-p_T analysis (TPC relativistic rise): nice continuation of low-p_T (ITS+TPC+TOF)





Charged/neutral kaon comparison

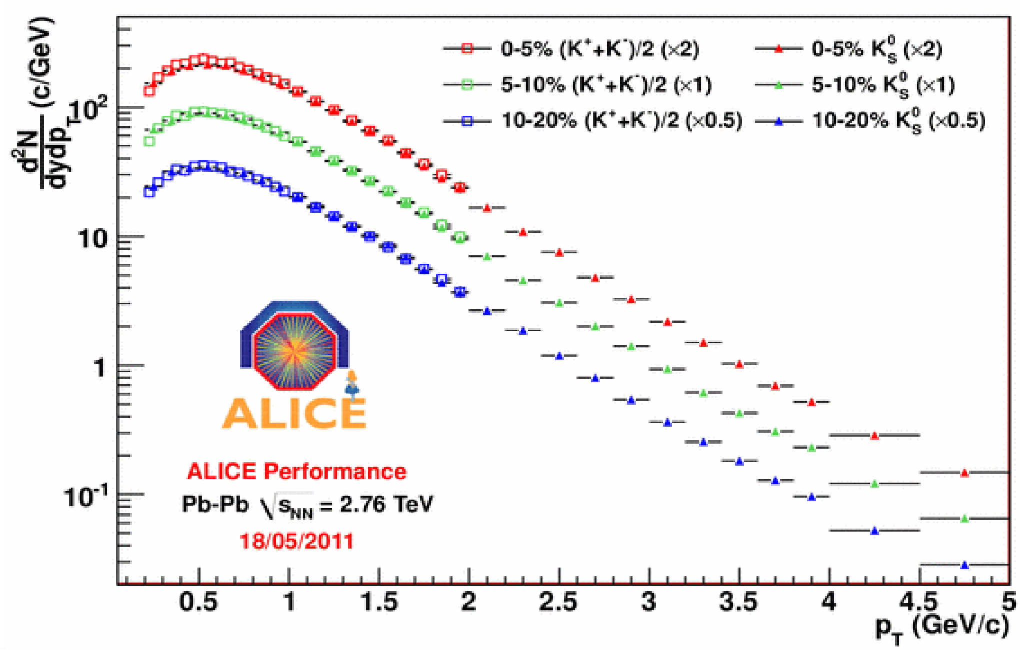




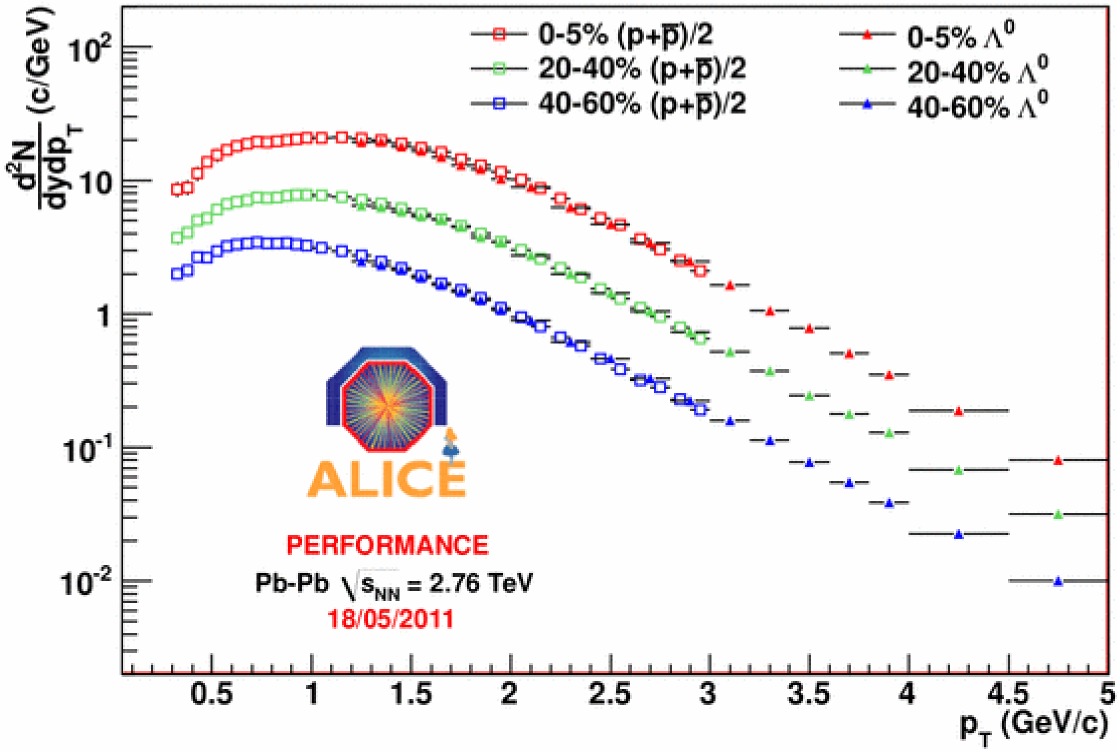
nice agreement of charged kaons and K^0_S

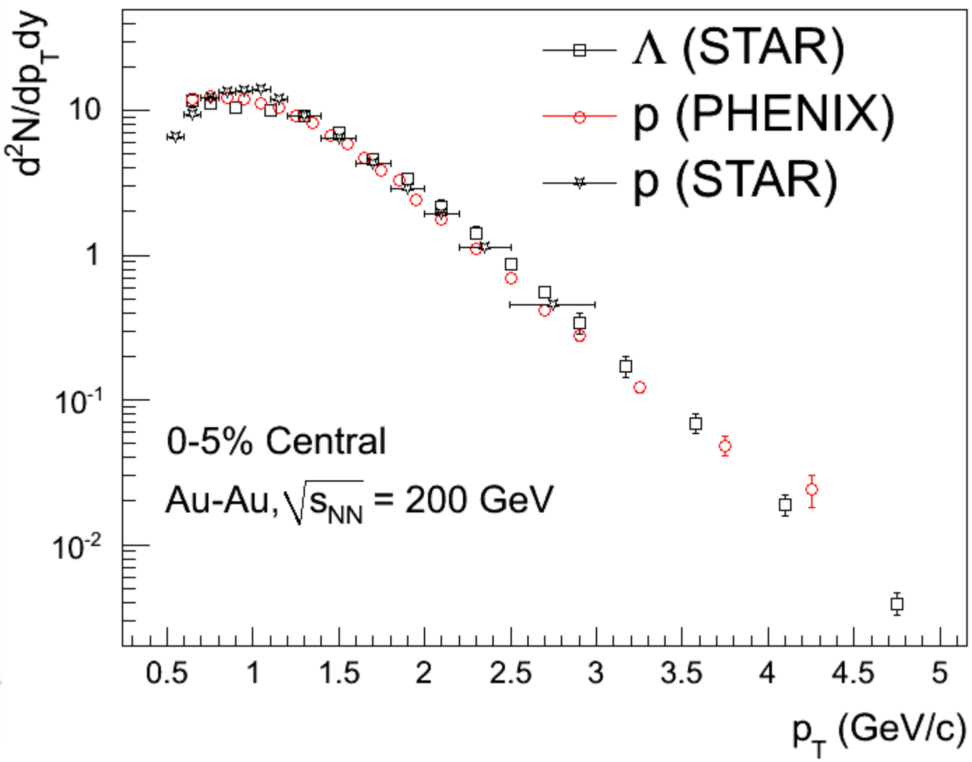
independent analyses and techniques

K^0_S via topological decay reconstruction + invariant mass analysis for yields



Comparison between proton and Λ





Lambda very similar to proton in shape and yield

protons feed-down corrected for weak-decay

lambdas feed-down corrected for Ξ decay

this was very similar at RHIC, when comparing feed-down corrected spectra

STAR, PRL 98, 062301 (2007)
PHENIX, PRC 69, 03409 (2004)

Blast-Wave model

hydrodynamics-inspired model: assume a hard-sphere uniform density particle source with a temperature T and collective transverse radial flow velocity β

→ spectrum from thermal sources boosted in the transverse direction

$\beta_r(r)$ describes the transverse velocity distribution in the region $0 \le r \le R$, parametrized by

- **β_s → surface velocity**
- **n → velocity profile**

$$\beta_r(r) = \beta_s \left(\frac{r}{R}\right)^n$$

the resulting spectrum is a superposition of the individual thermal components, each boosted with the boost angle ρ

$$\rho = \tanh^{-1} \beta_r$$

that is (I_0 and K_1 are modified Bessel functions)

$$\frac{dn}{m_T\, dm_T} \propto \int_0^R r\, dr\, m_T I_0\Big(\frac{p_T \sinh \rho}{T}\Big) K_1\Big(\frac{m_T \cosh \rho}{T}\Big)$$

Schnedermann et al, PRC 48, 2462 (1993)