$\pi^{\pm}$, $K^{\pm}$, p(pbar) p_T distributions in p-Pb collisions measured with the Inner Tracking System of ALICE.

2nd Year seminar

Yasser Corrales Morales
Univ. & INFN, Turin

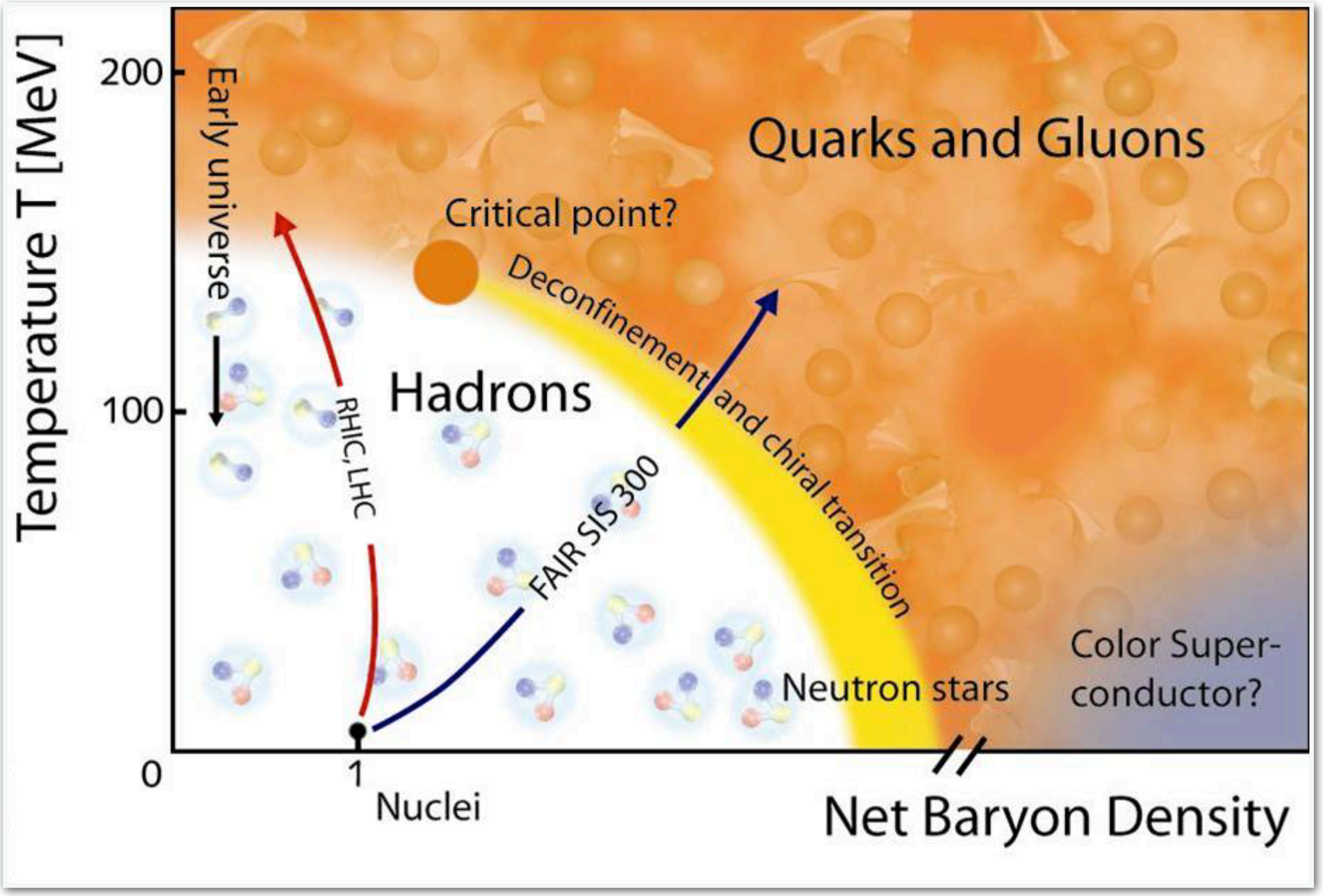
Outline

1. Physics motivation - Quark Gluon Plasma
2. Experimental apparatus - ALICE detector
3. Analysis
   - Method
   - Results
4. Conclusions
5. TODO

Physics motivation
"QGP formation in relativistic heavy ion collisions"

Physics: QGP

lattice-QCD predicts that nuclear matter under extreme conditions of density and temperature undergoes a phase transition into a new state of matter, the Quark Gluon Plasma (QGP)



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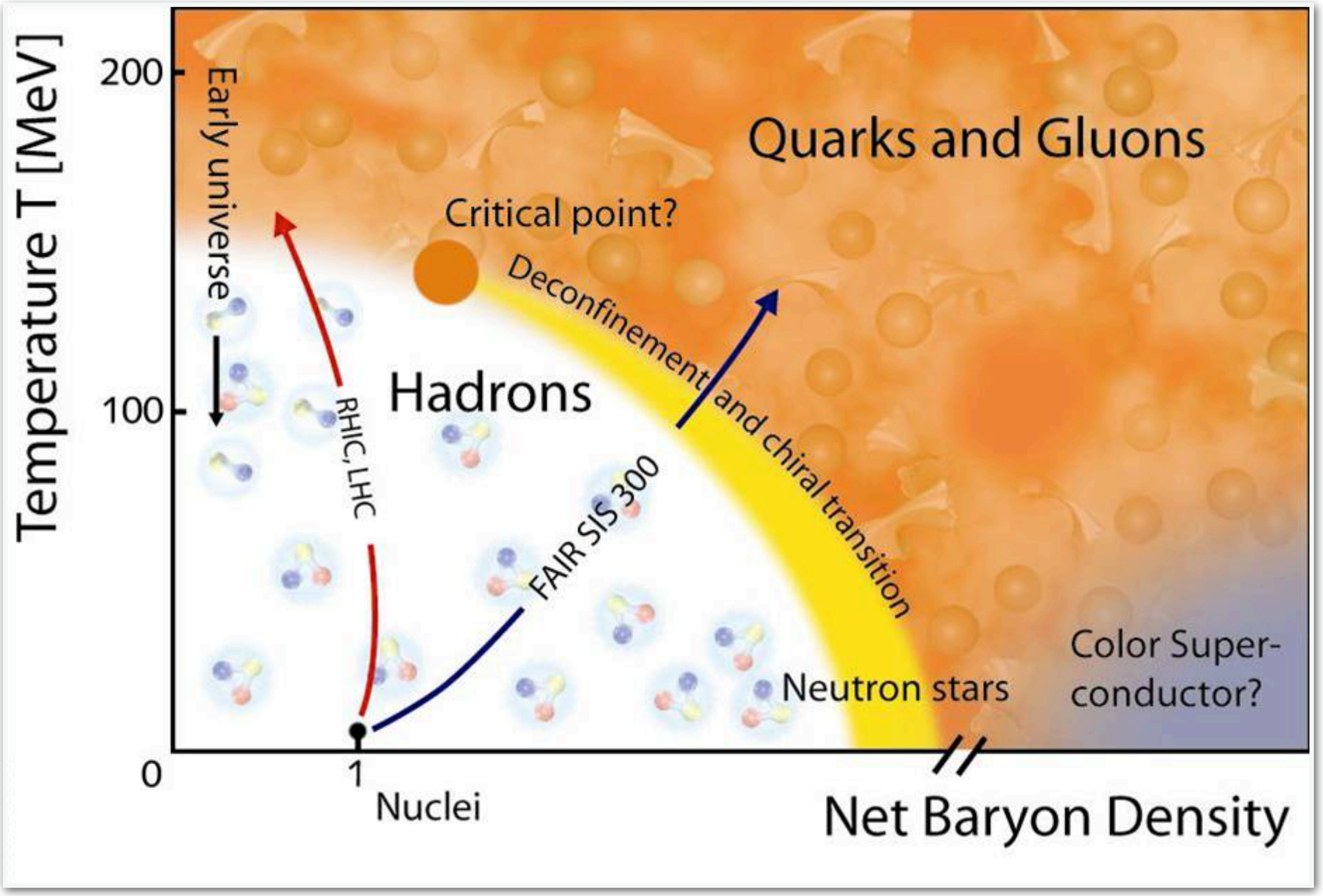


In the QGP quarks and gluons are not longer confined inside the hadron and are free to move over long distance.

Why heavy ion collisions

HIC provide the conditions required to study the QGP system experimentally

Ultra-relativistic Heavy Ion Colisions

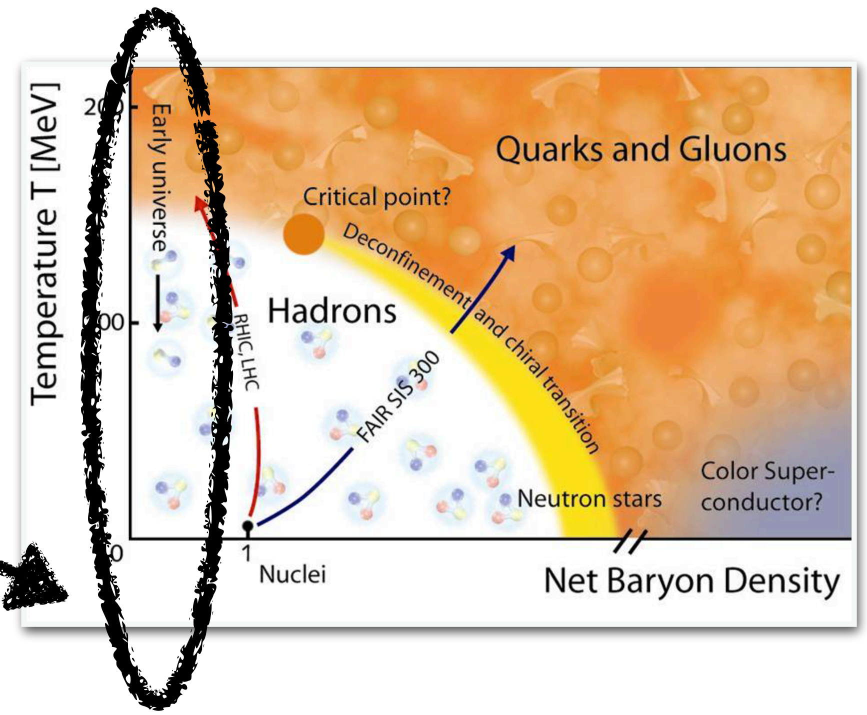
strongly interacting system
(large cross-section for hard scattering)

multiple scattering
(thermal equilibrium)

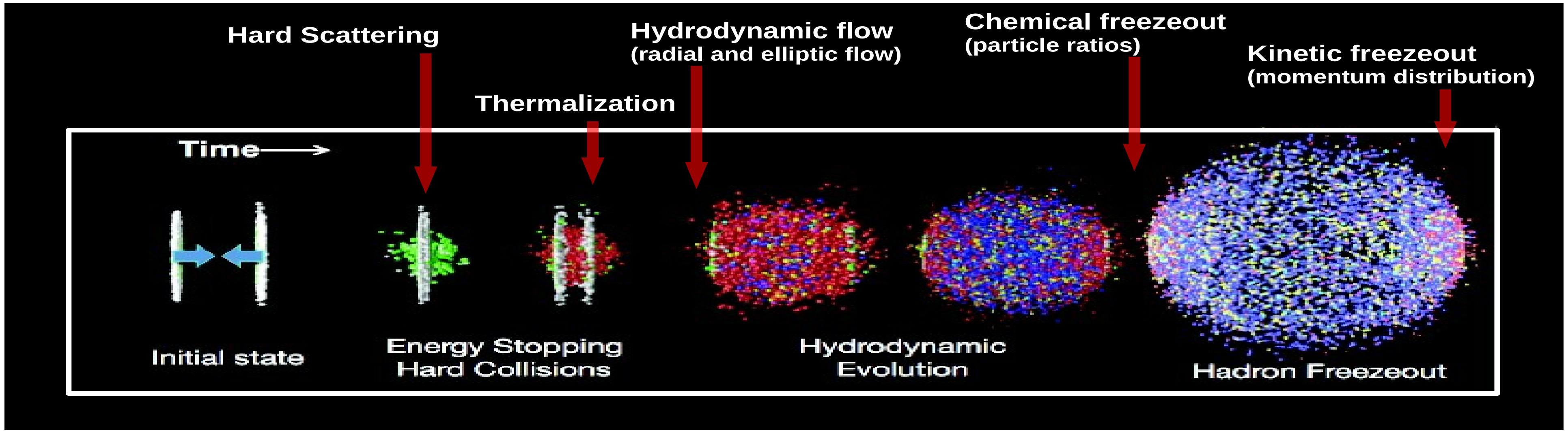
In the LHC condition, the nucleons that suffer collisions with other nucleons have enough energy to move far from the interaction region.

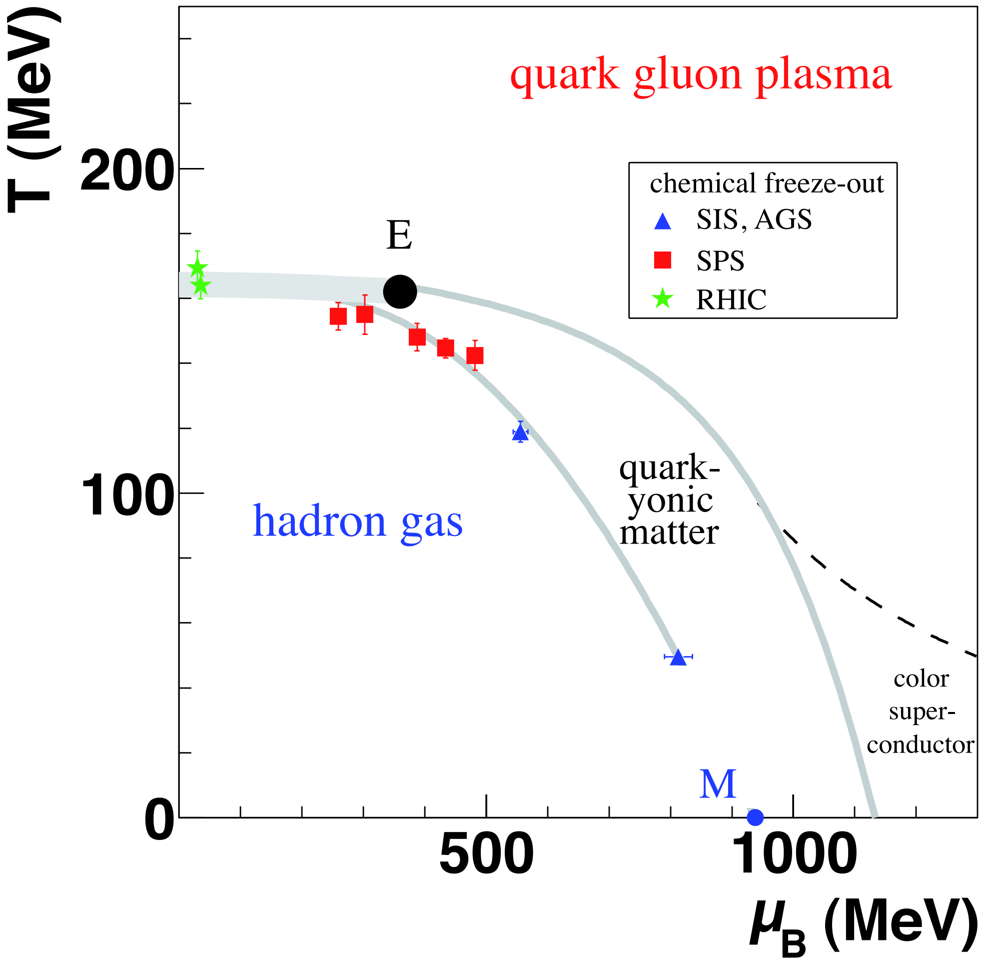
→the system created is characterized by a small net baryon content (at midrapidity)

→at vanishing μ_B, transition is predicted to occur at a $T_c \approx 160$ MeV and $\varepsilon_c \approx 1$ GeV/fm^3



Time evolution in HIC





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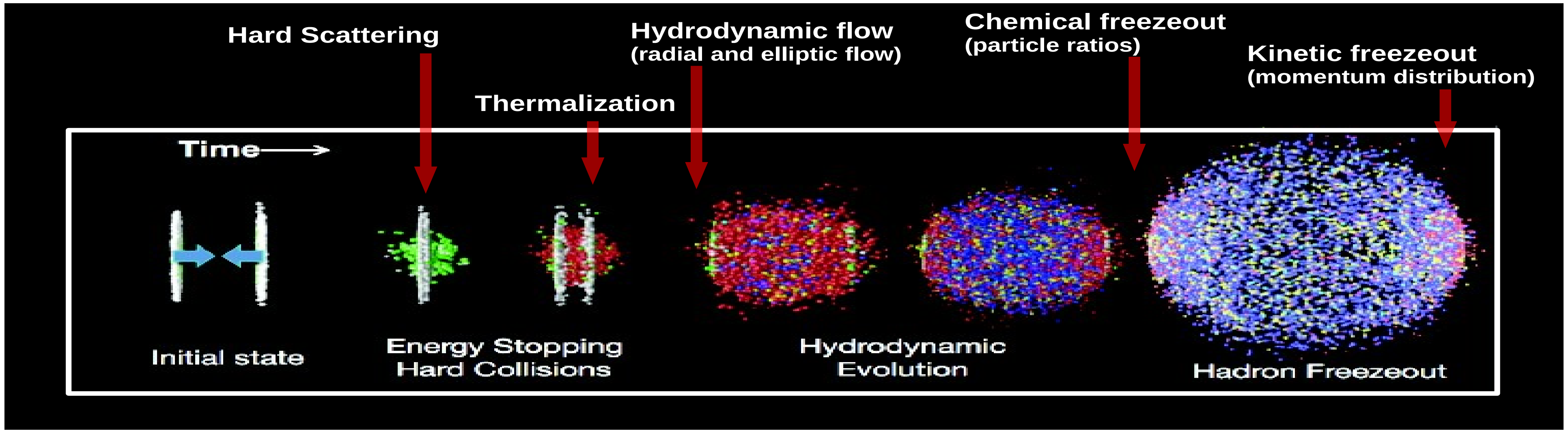

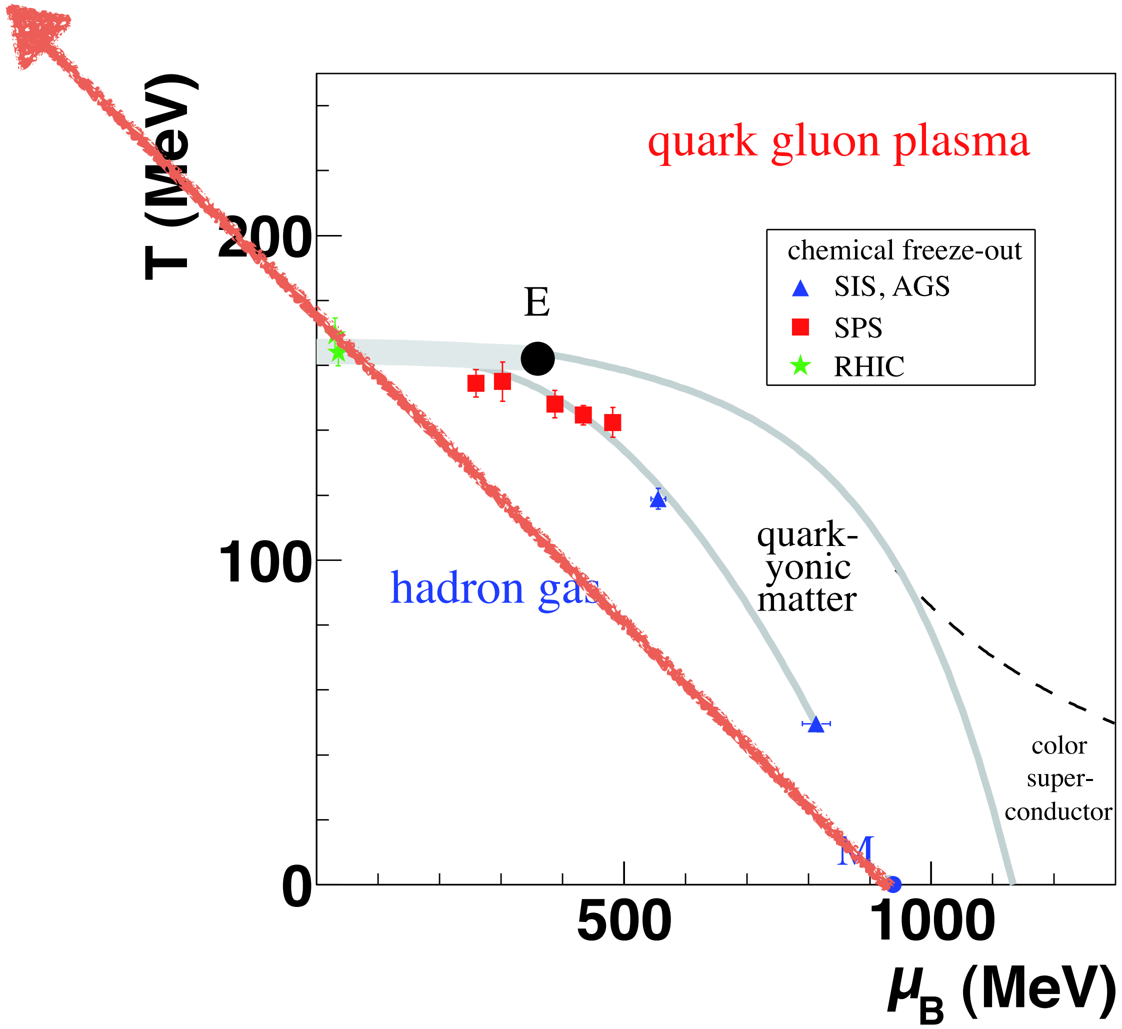

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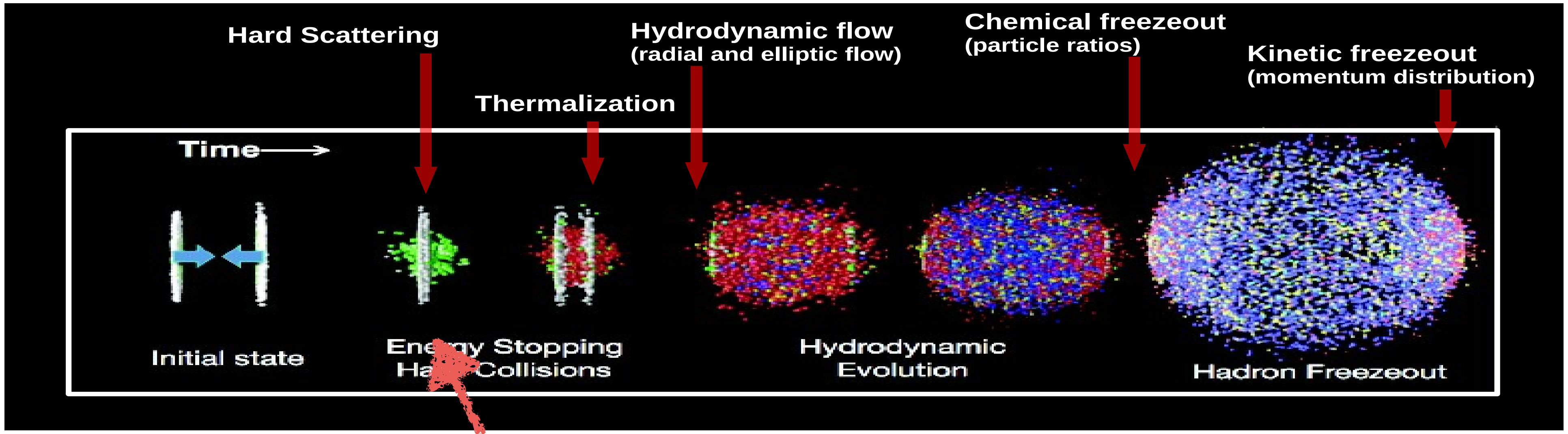

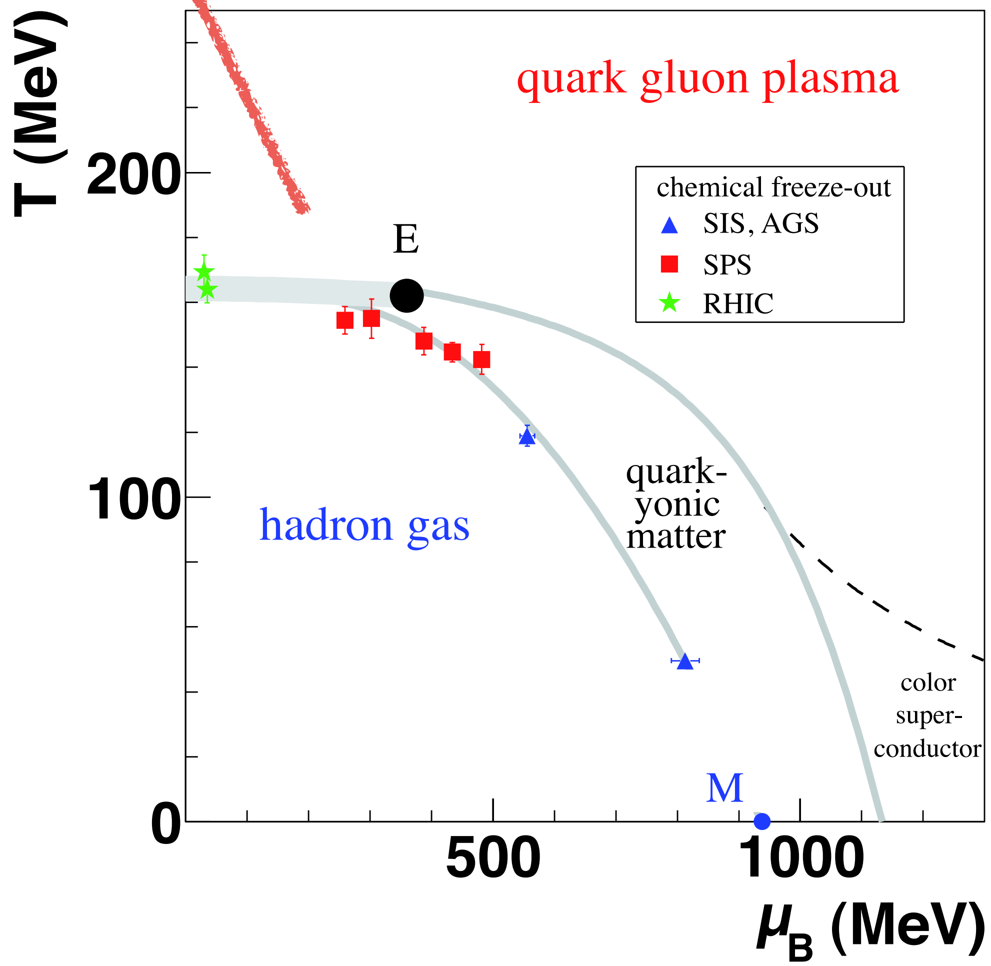

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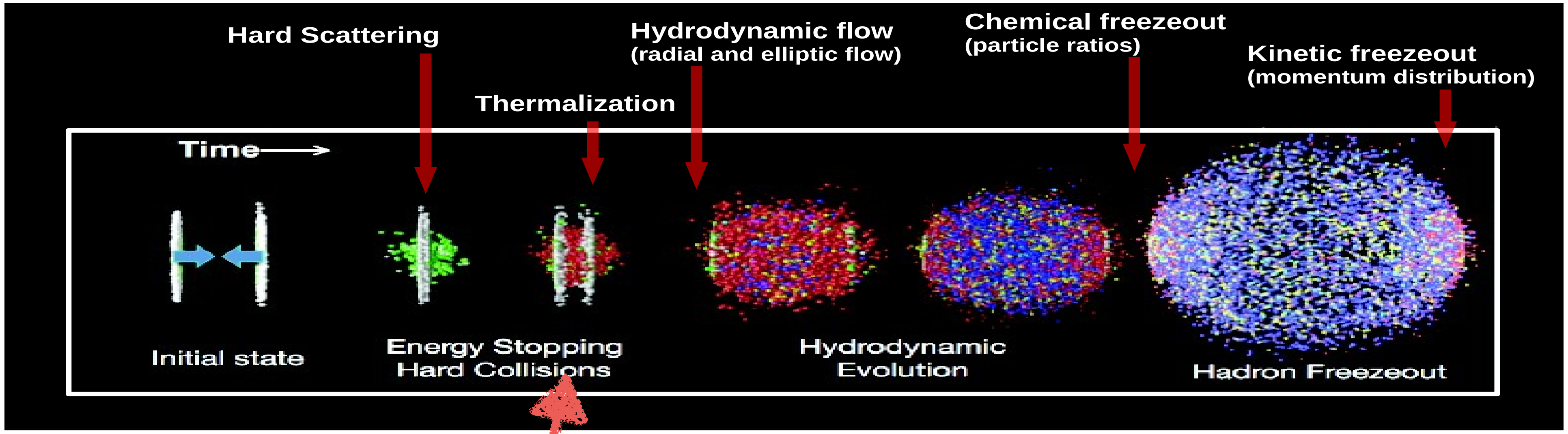

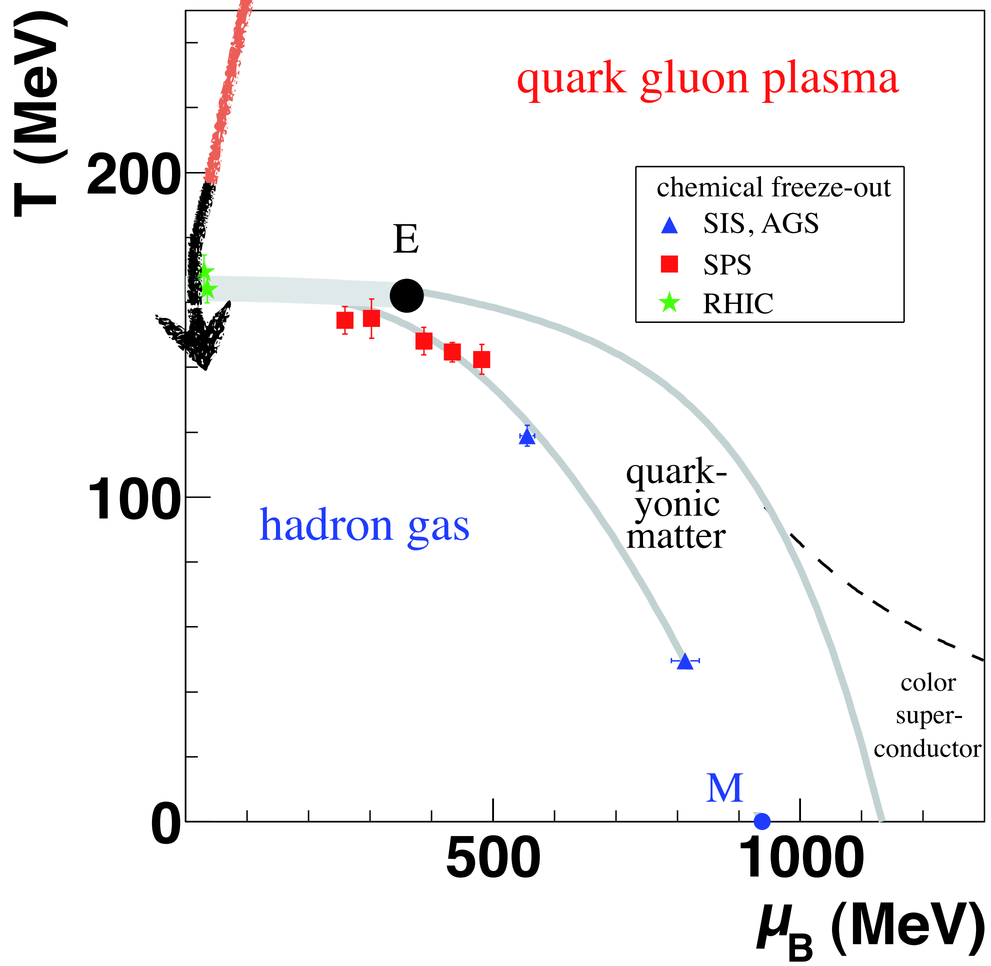

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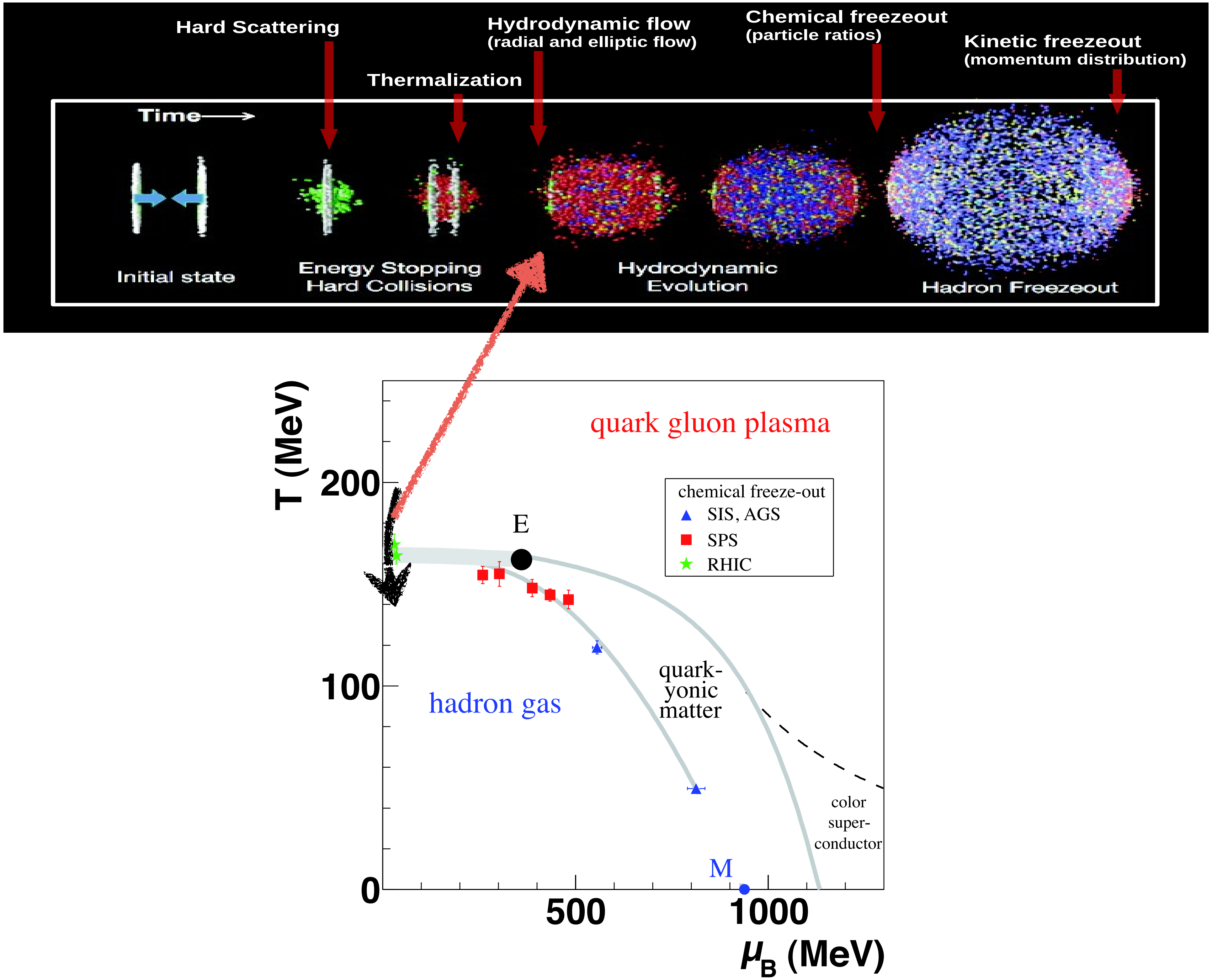

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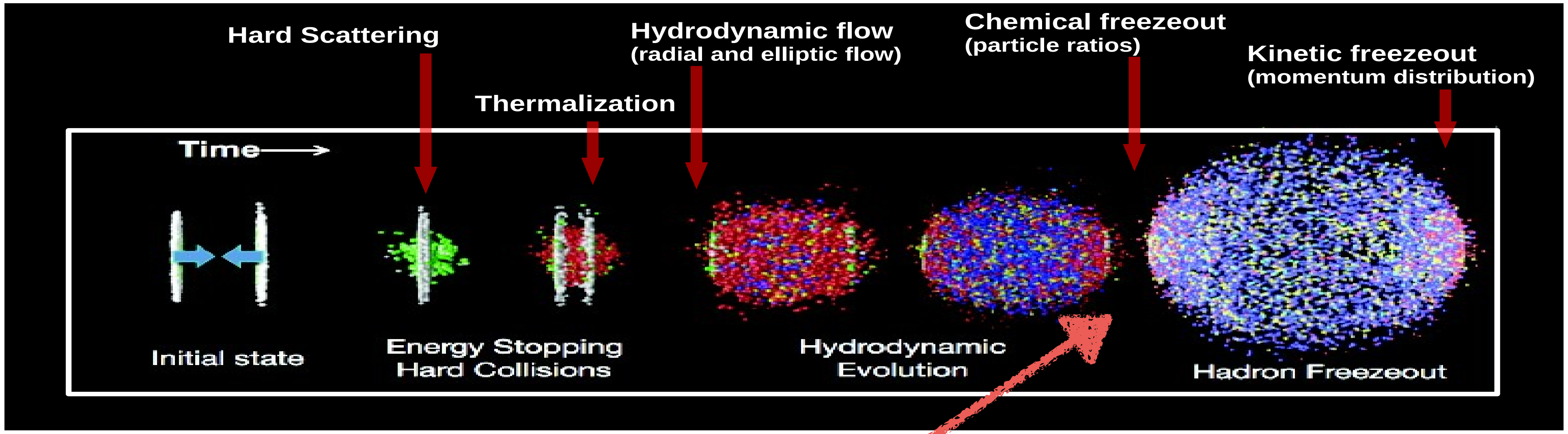
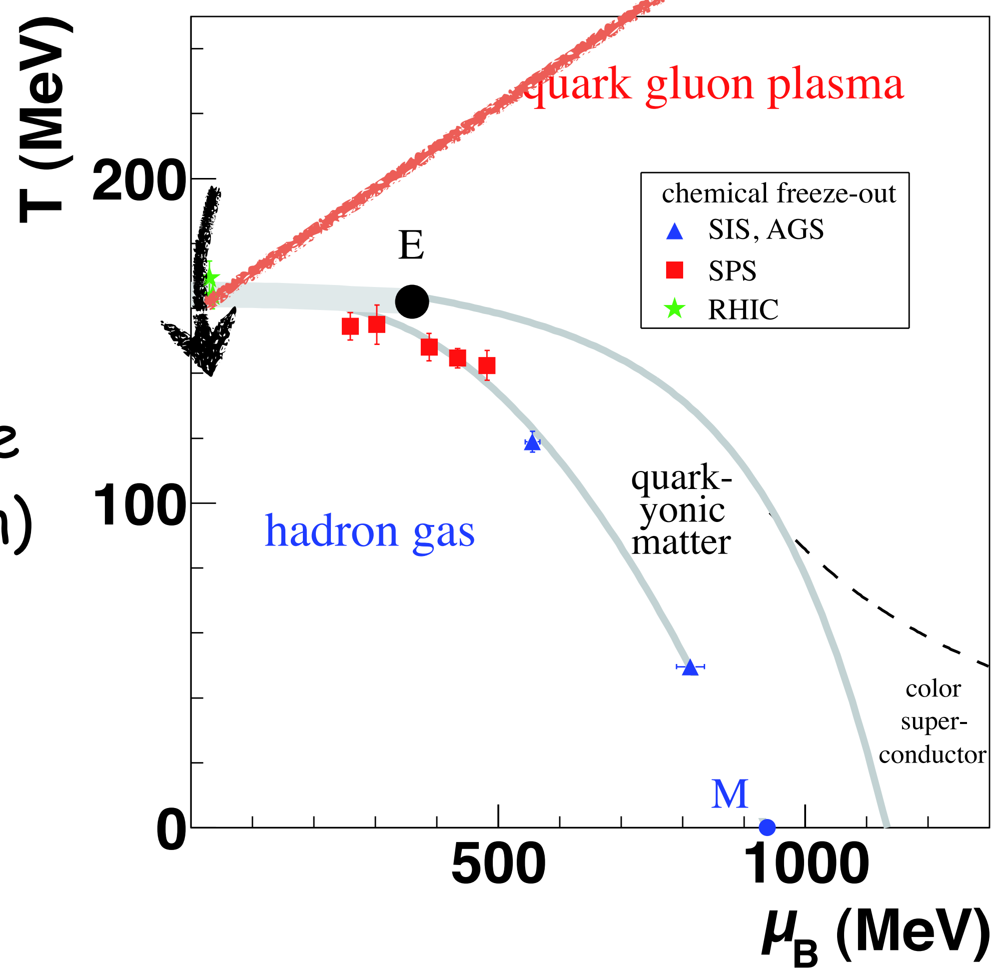
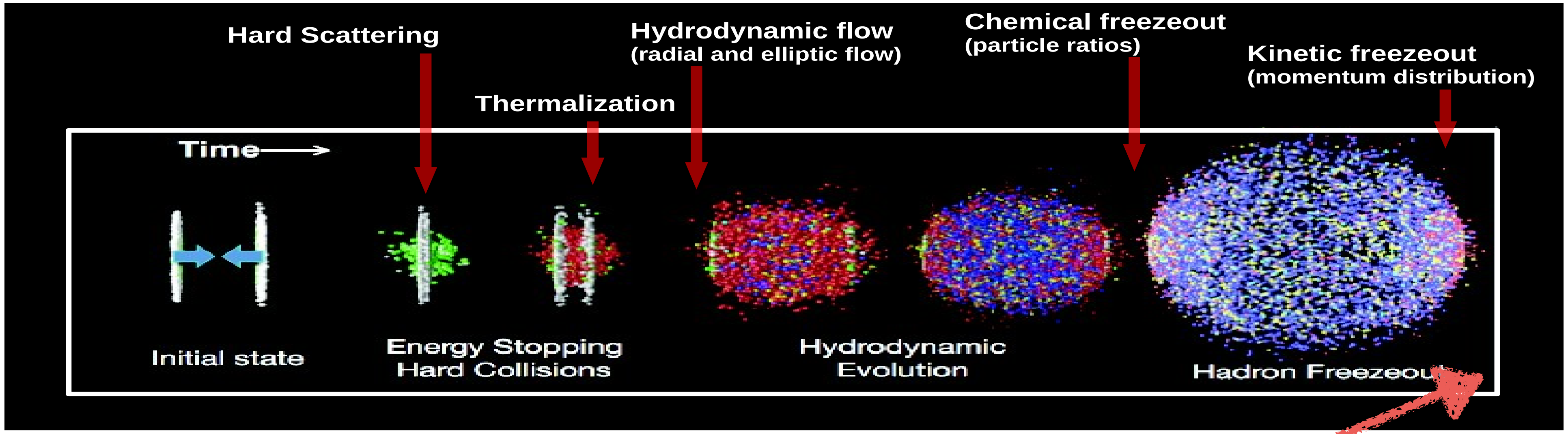


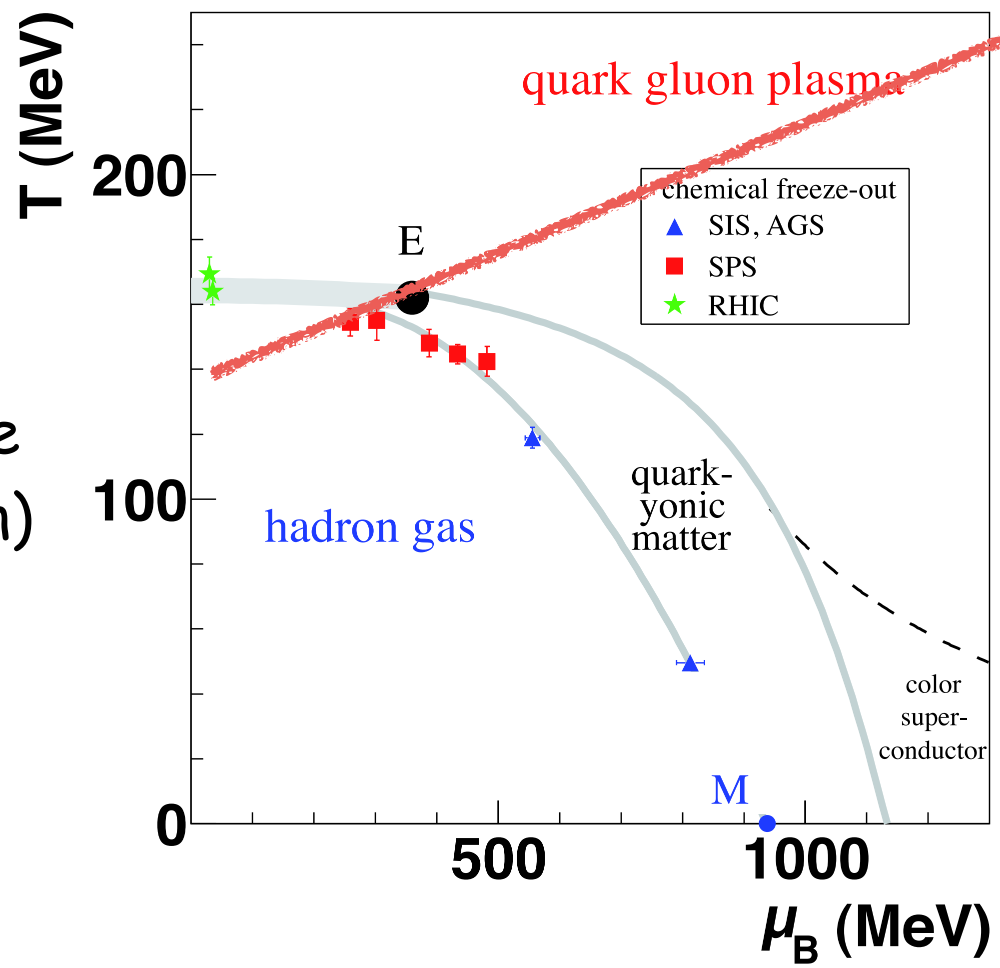


Chemical freeze-out

Inelastic interactions cease
(particle abundances frozen)

Time evolution in HIC





Chemical freeze-out

Inelastic interactions cease
(particle abundances frozen)

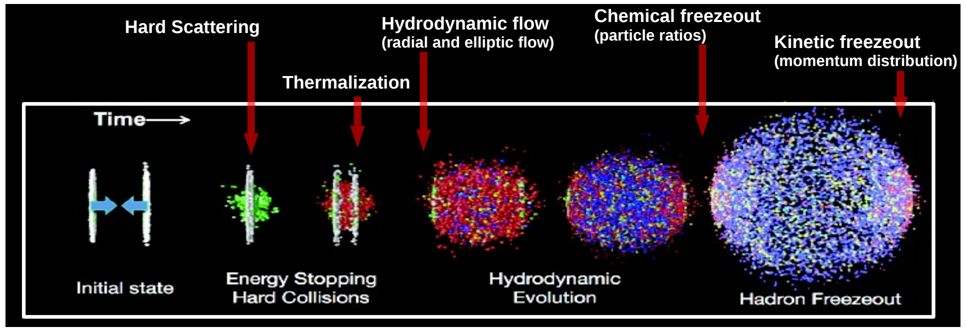
Kinetic freeze-out

elastic interactions cease
(particle spectra frozen)

Why transverse momentum spectra?

The transverse momentum (p_T) spectra of identified hadron is a powerful tool:

to prove that this is indeed the right picture.



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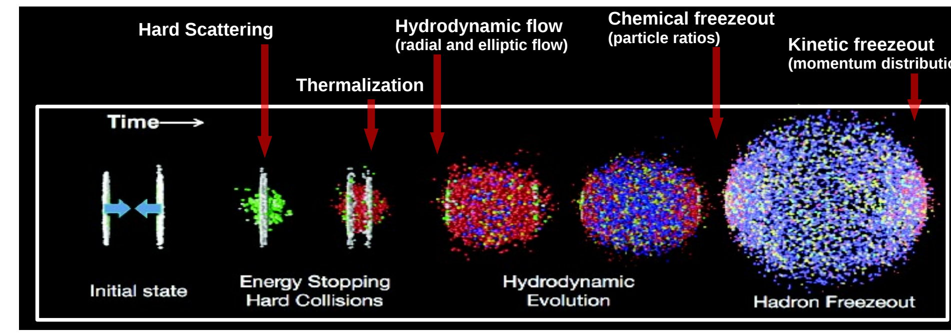
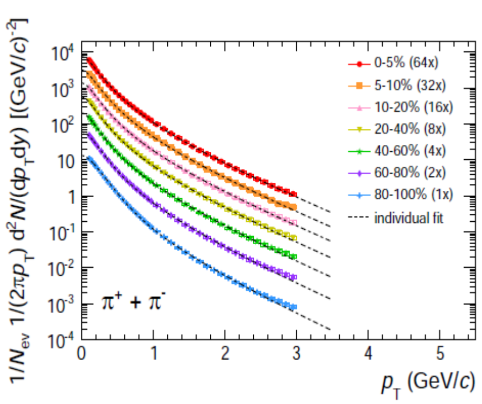


to study the thermal and collective properties of the system



Input

thermodynamical(SHM)
Models
hydrodynamical

Output

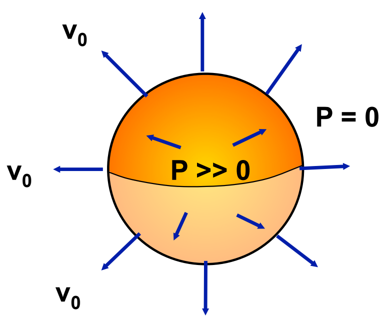
Description
of the system

Qualitative

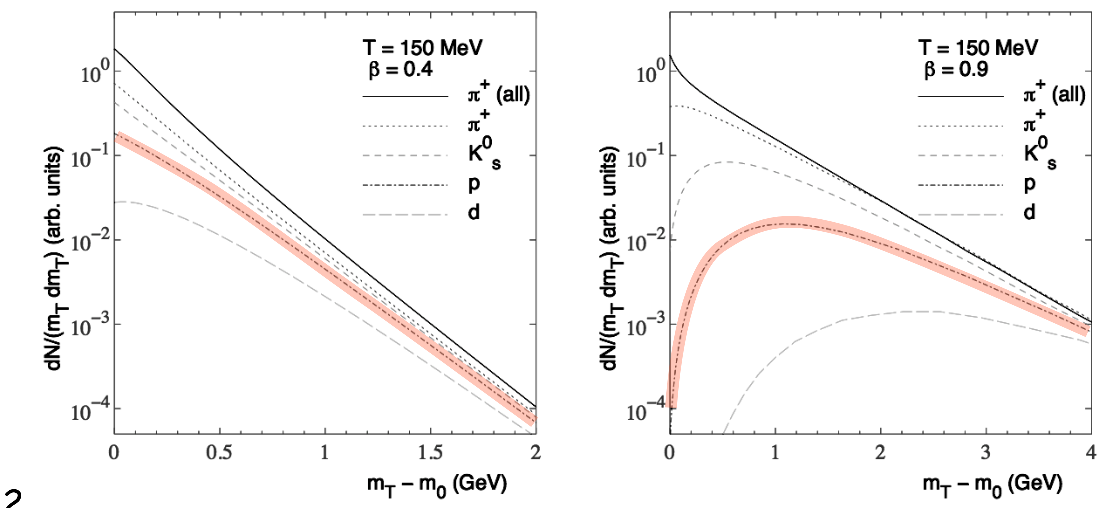
Quantitative

Why transverse momentum spectra?

Radial flow
hydro-evolution



low p_t spectra are sensitive to the temperature of the system and to the radial flow components



$$\frac{dN}{m_T dm_T} \propto e^{-\frac{m_T}{T_{slope}}}$$

$$T_{slope} = T_{frzout} + (1/2)mv^2$$

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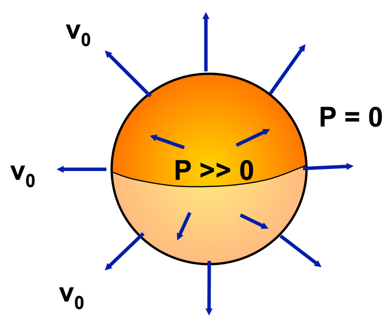

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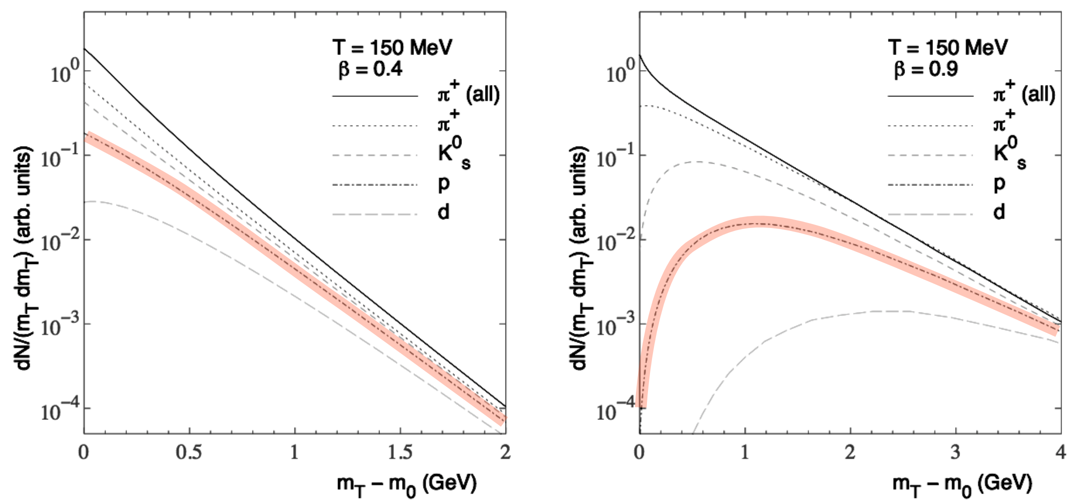
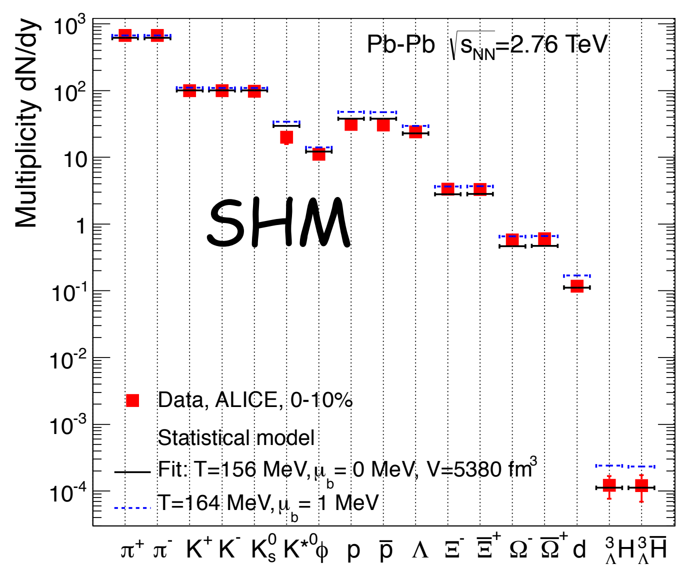


statistical hadronization model

particle abundance



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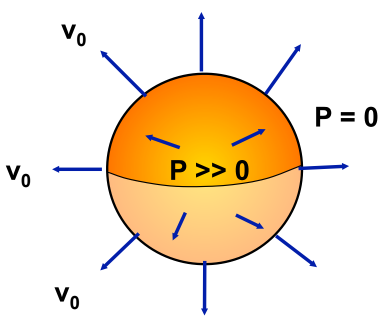

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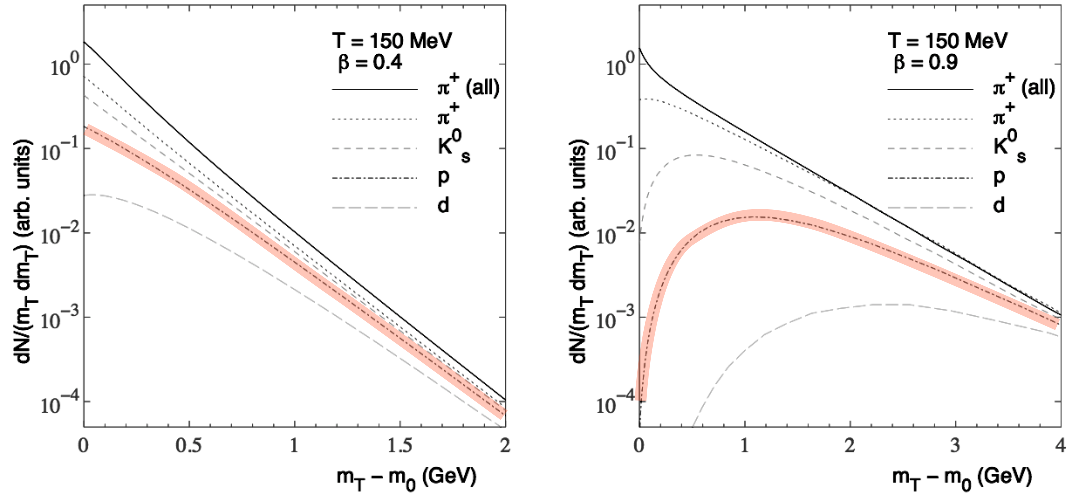

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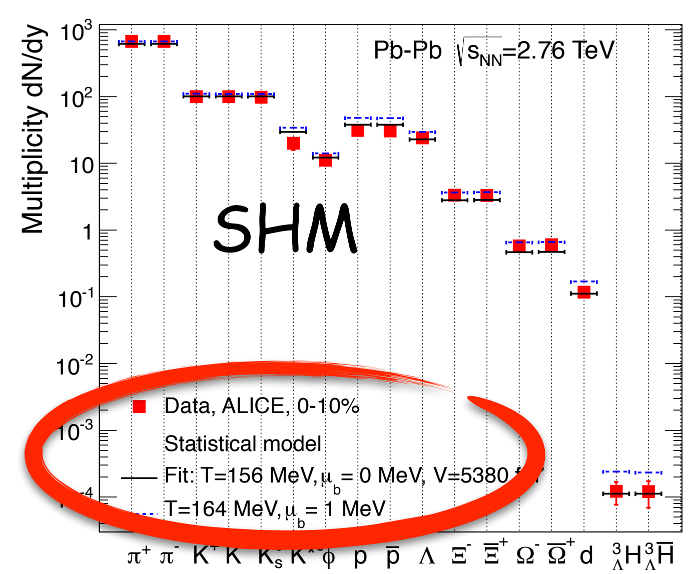

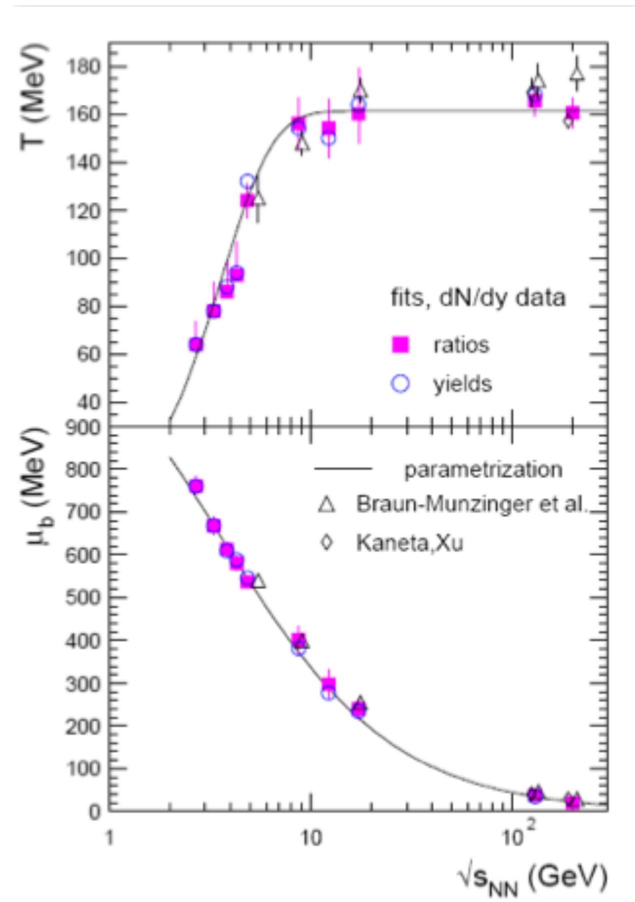

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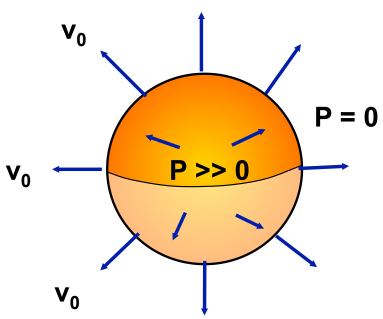

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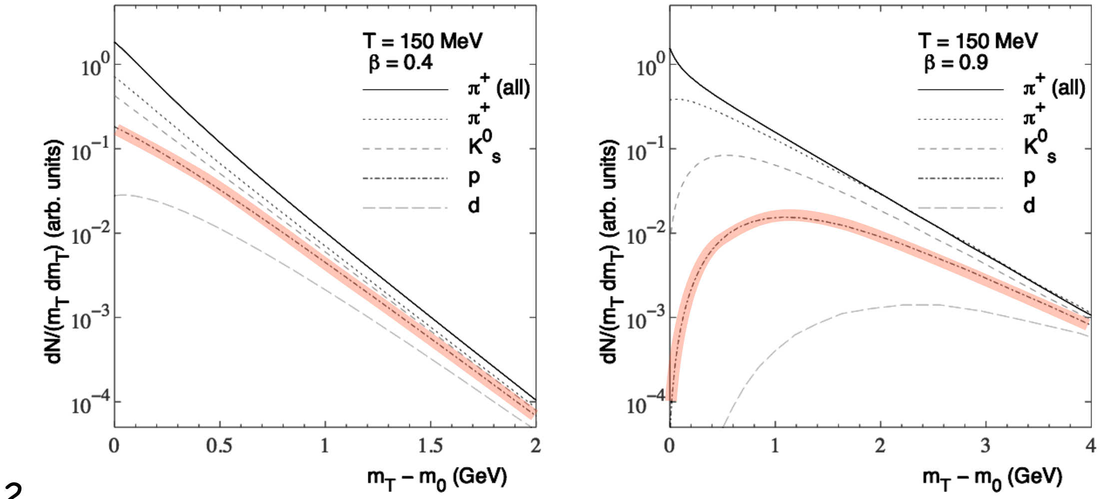

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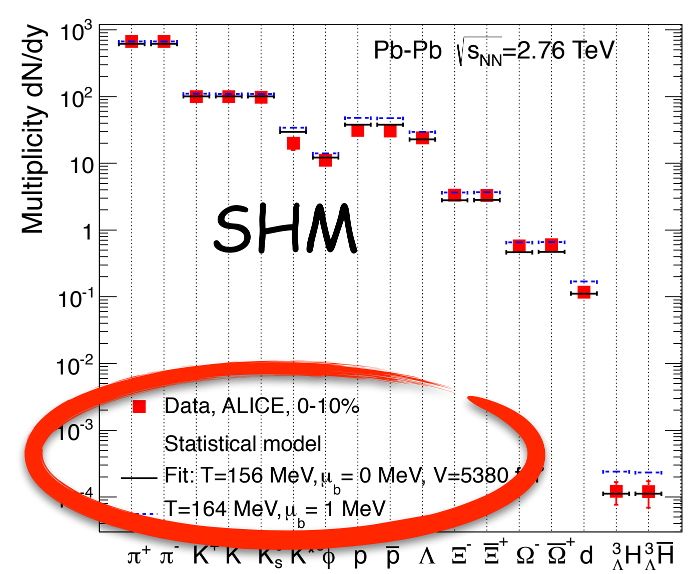
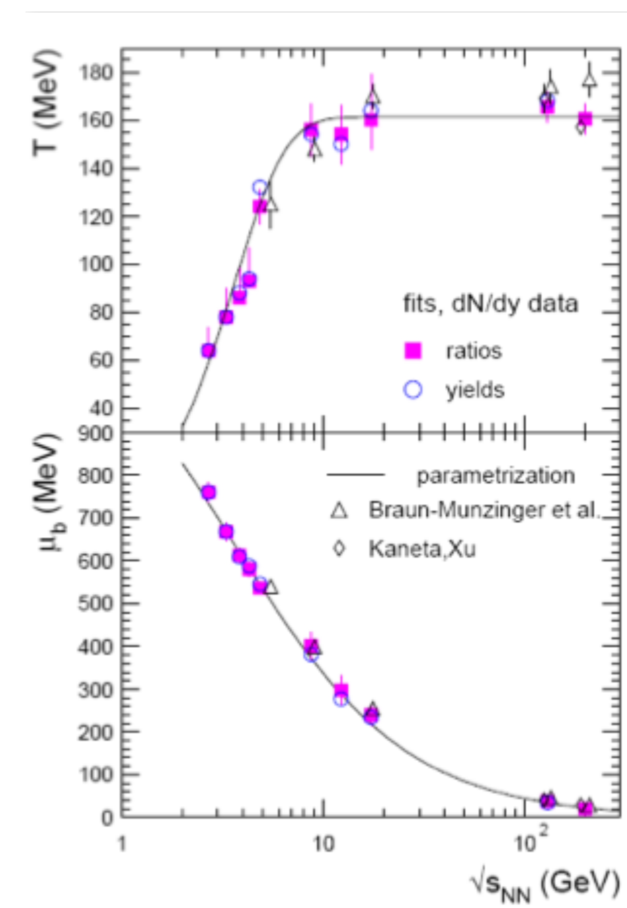




particle/antiparticle → is our system at zero net baryon content?

Why p-Pb collisions at the LHC?

pA collisions are intermediate between pp and AA collisions in terms of size and multiplicity of particles.

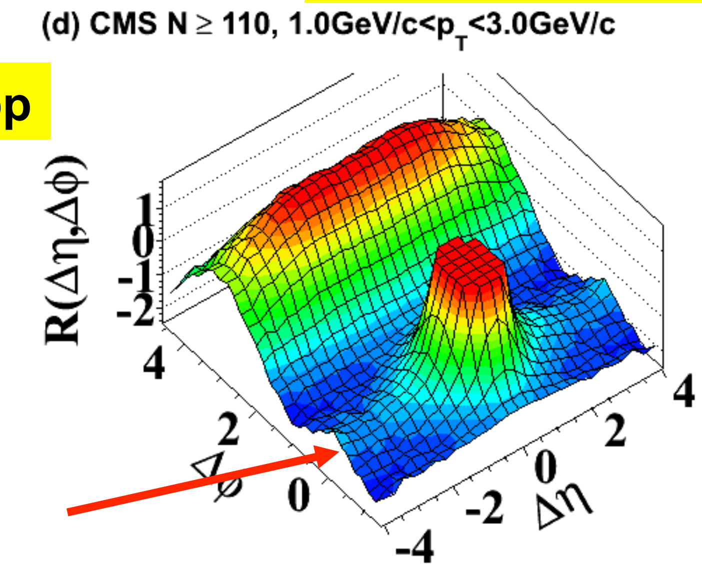
- Heavy Ion reference.
- Study cold nuclear matter effects to separate initial and final state.
- QCD in gluon-saturated at low x regime
  - Nucleus enhances saturation
  - x at LHC 2 orders of magnitude smaller than at RHIC

and more ...

New results in 2 particle correlation study

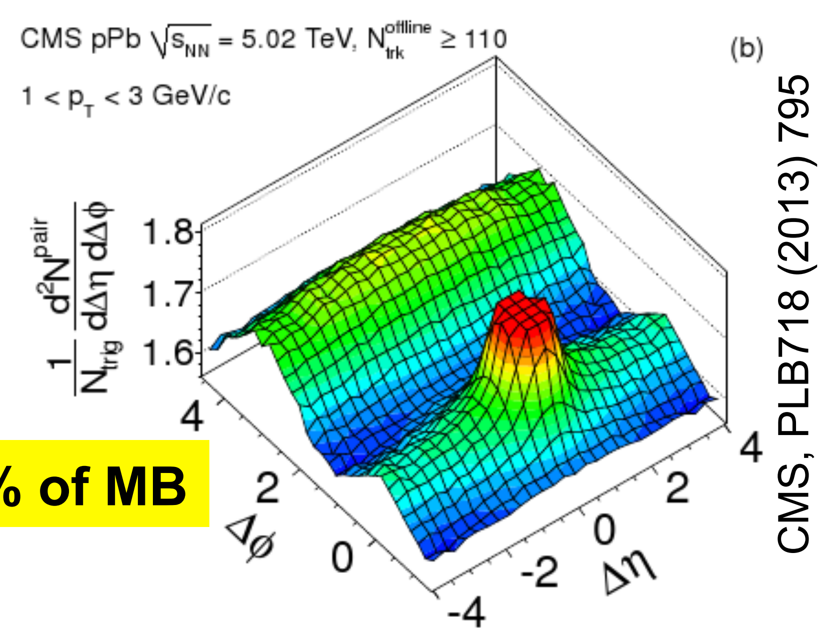
LHC experiments have revealed a near-side long-range "ridge" and "double ridge" in two particle correlation

0.0005% of MB



first, observed in high-multiplicity pp collisions by CMS.

Somehow expected in p-Pb, but still surprising, in particular the amplitude



3.1% of MB

also observed by ALICE and ATLAS.

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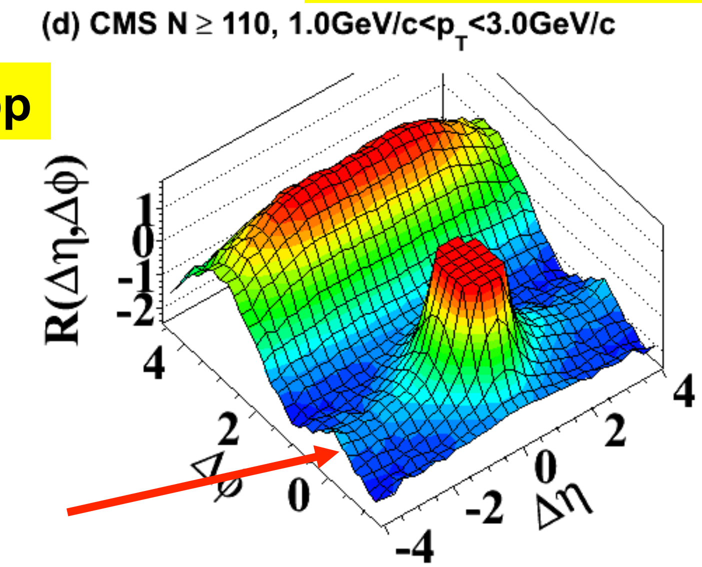

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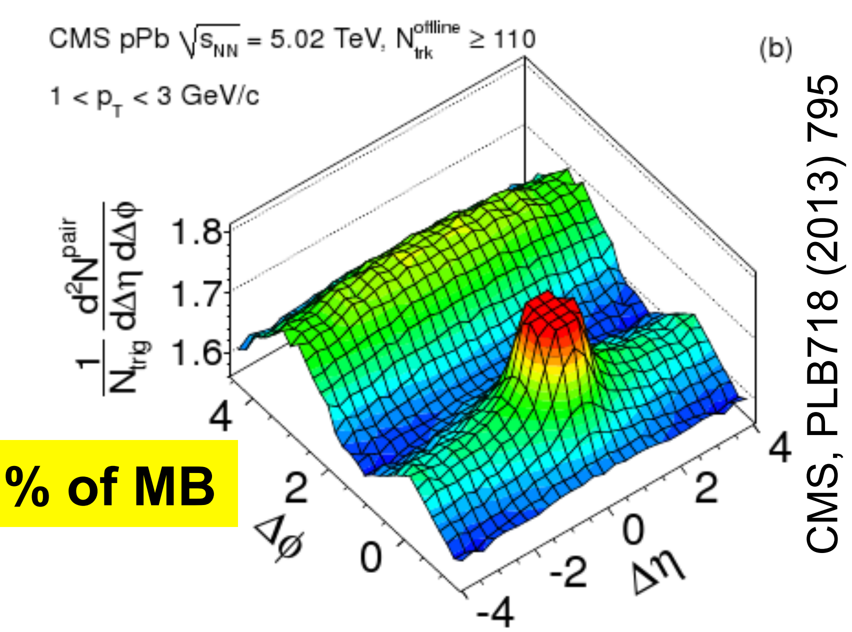
Well known feature from Pb-Pb collisions (collective flow)



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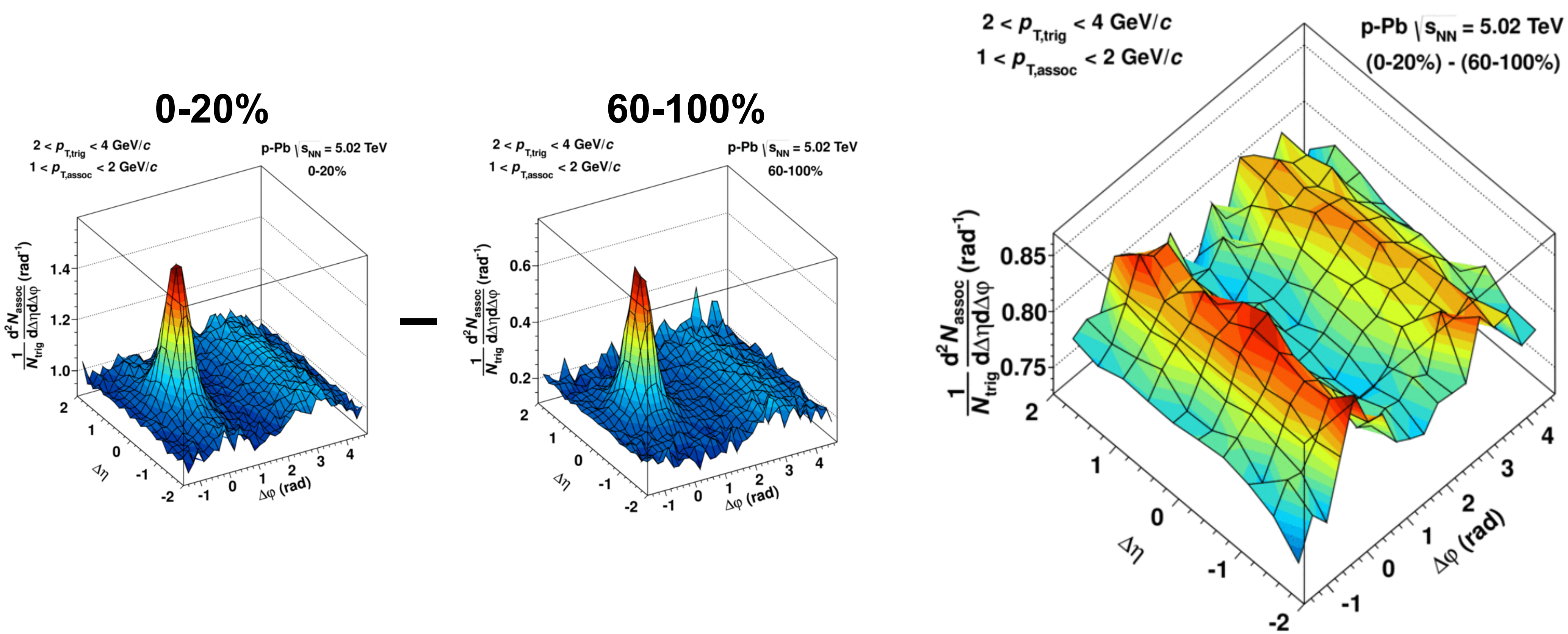
New results in 2 particle correlation study

LHC experiments have revealed a near-side long-range "ridge" and "double ridge" in two particle correlation

Subtraction procedure to “isolate” ridge contribution from jet correlations

No ridge seen in 60-100% and similar to pp



ALICE, PLB719 (2013) 29

Why p_T spectra in p-Pb collisions

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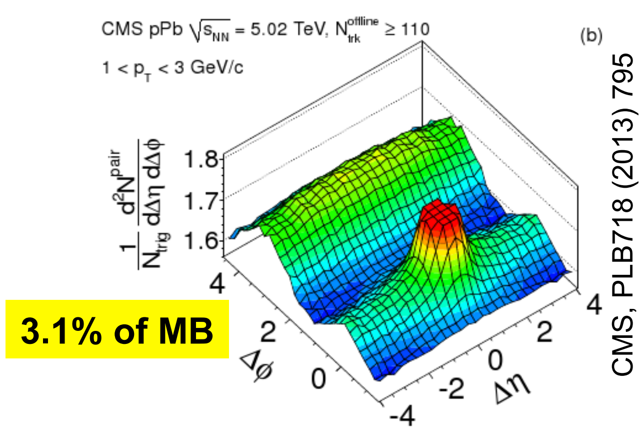

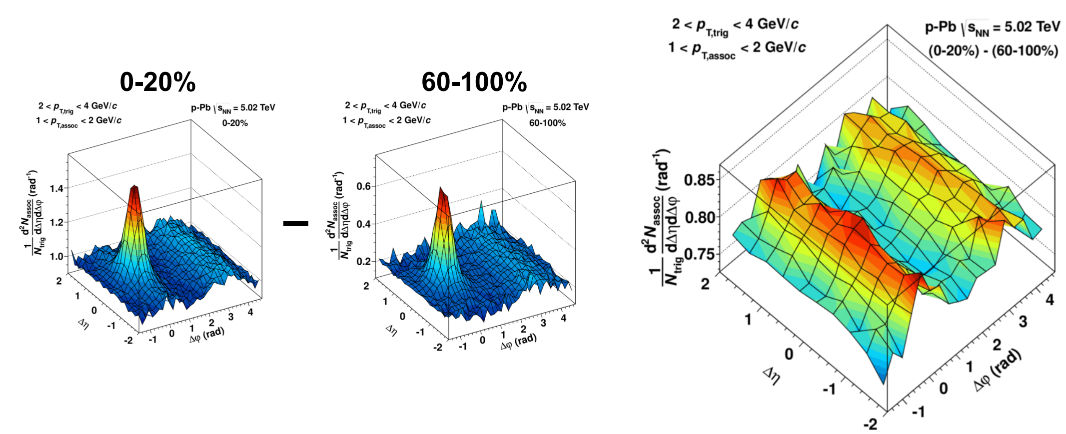

ALICE, PLB719 (2013) 29

Hydrodynamic flow at final state?

initial state effect predicted by CGC model with high gluon saturation at low x?

Dusling and Venugopalan (PRD 87, 094034 (2013))

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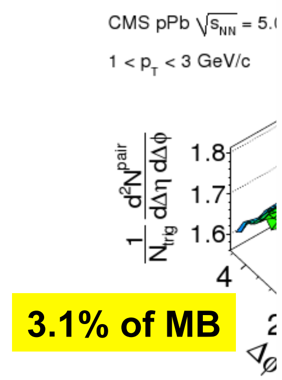
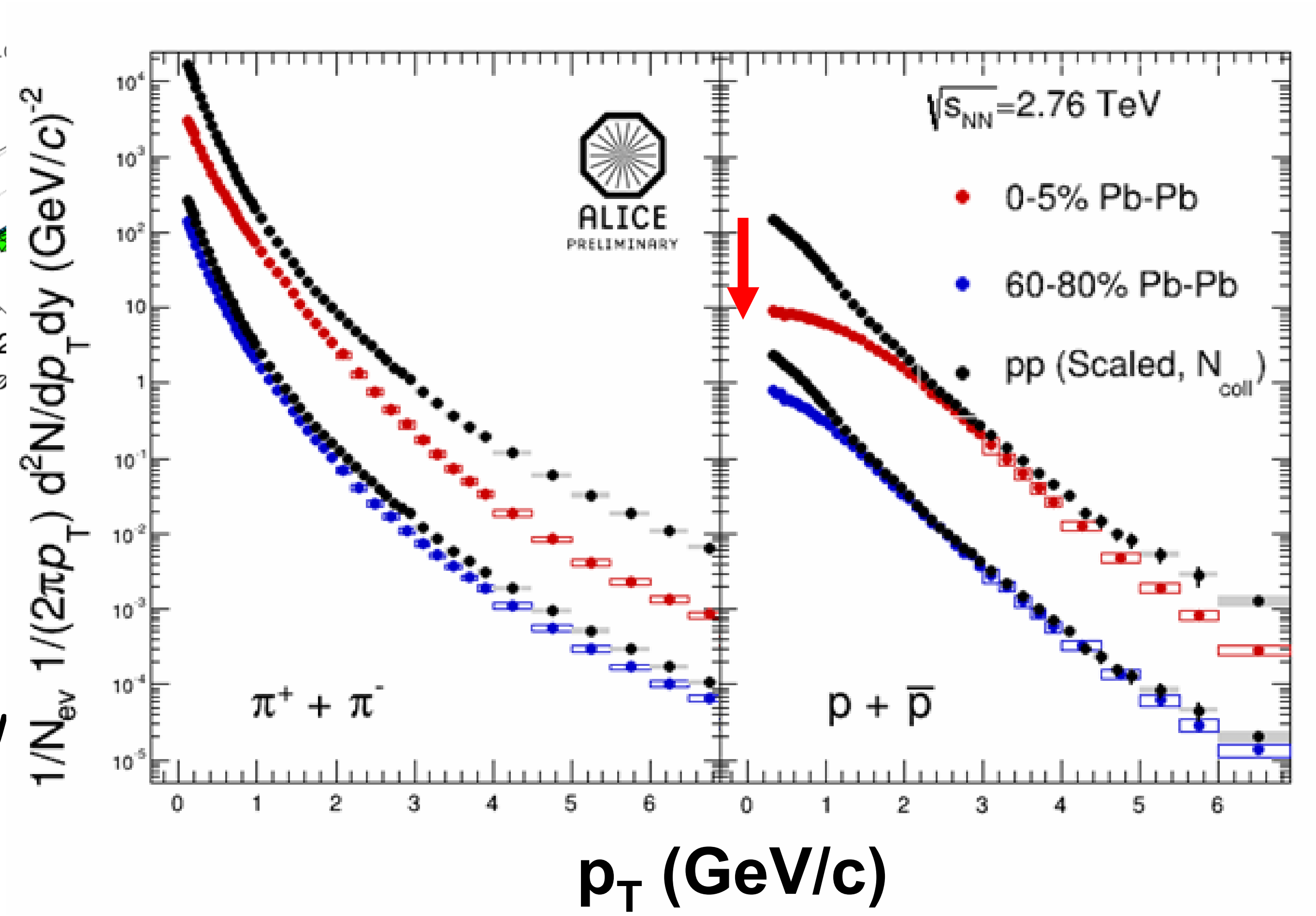
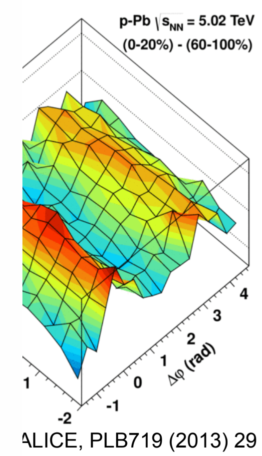
Radial Flow



Hydrodynamic flow





redicted by CGC model
saturation at low x?

nugopalan (PRD 87, 094034 (2013))

Why not study other collective flow pattern already observed in Pb-Pb?
For example, Transverse-momentum spectra of identified particles

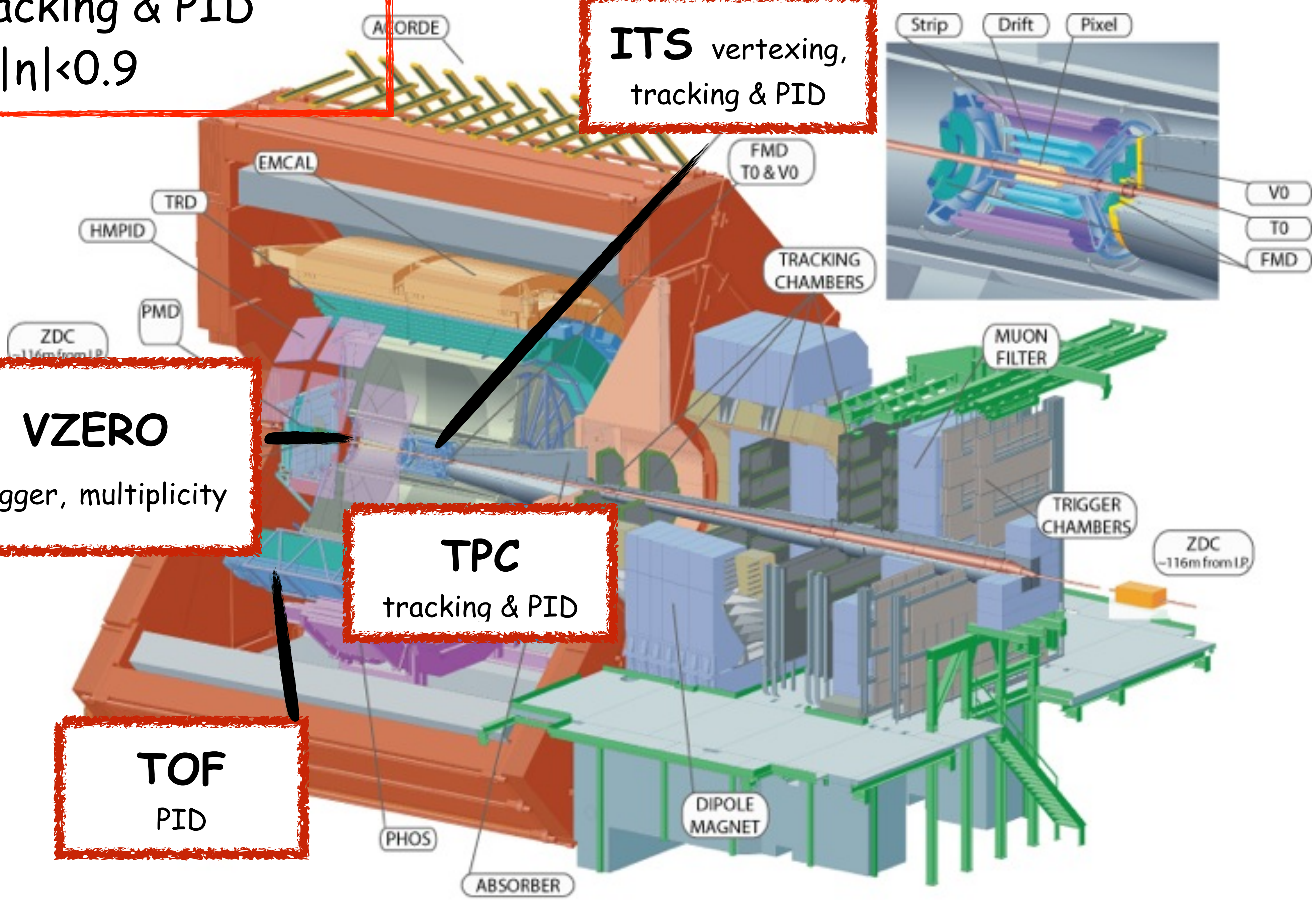
ALICE detector & p-Pb Analysis technique

ITS standalone (ITSsa) analysis step by step

The ALICE detector

the dedicated heavy-ion experiment at the LHC

Central Barrel
2π tracking & PID
|η|<0.9



ITS vertexing, tracking & PID

VZERO
trigger, multiplicity

TPC
tracking & PID

TOF
PID

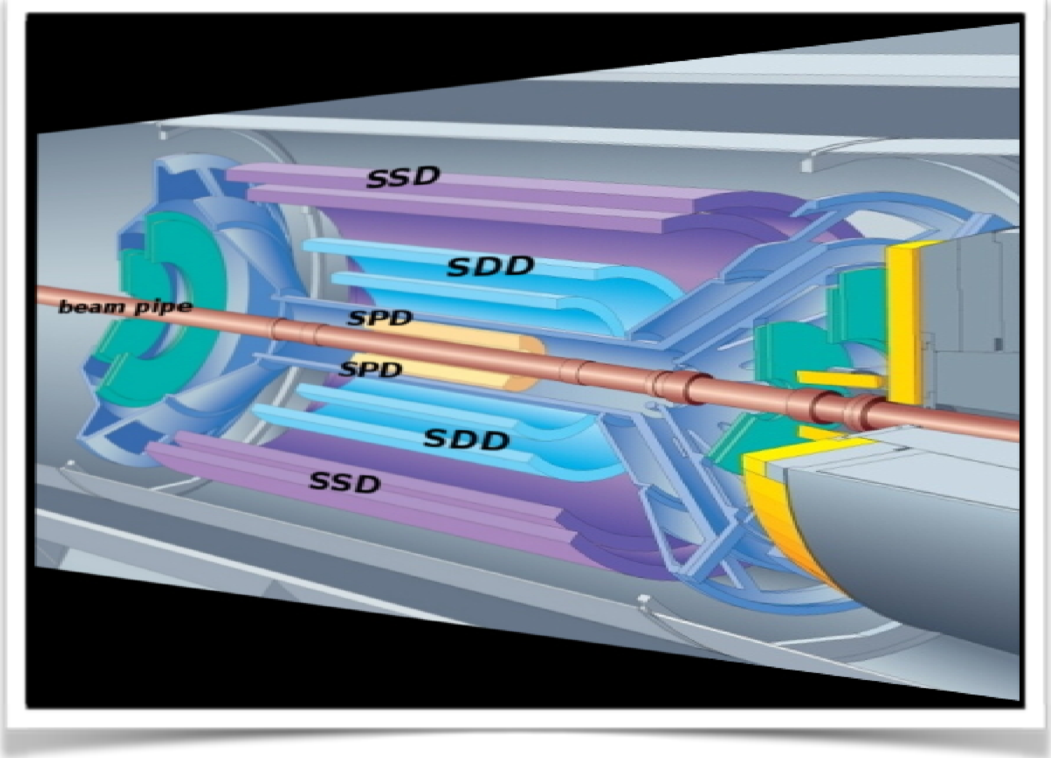
Central barrel detector operates in a 0.5 T solenoid field

ITS detector

Inner Tracking System

Si detector made of 6 layers of three different types

- pixel(SPD) -> 240 modules
- drift(SDD) -> 260 modules
- strip double-side(SSD) 1698 modules



Aims

Vertexing

Primary and secondary (decay particles) vertex reconstruction

Tracking

- low p_T (standalone ITS)

recover low p_T (<200 MeV) tracks that are inaccessible to TPC tracking.

- high p_T

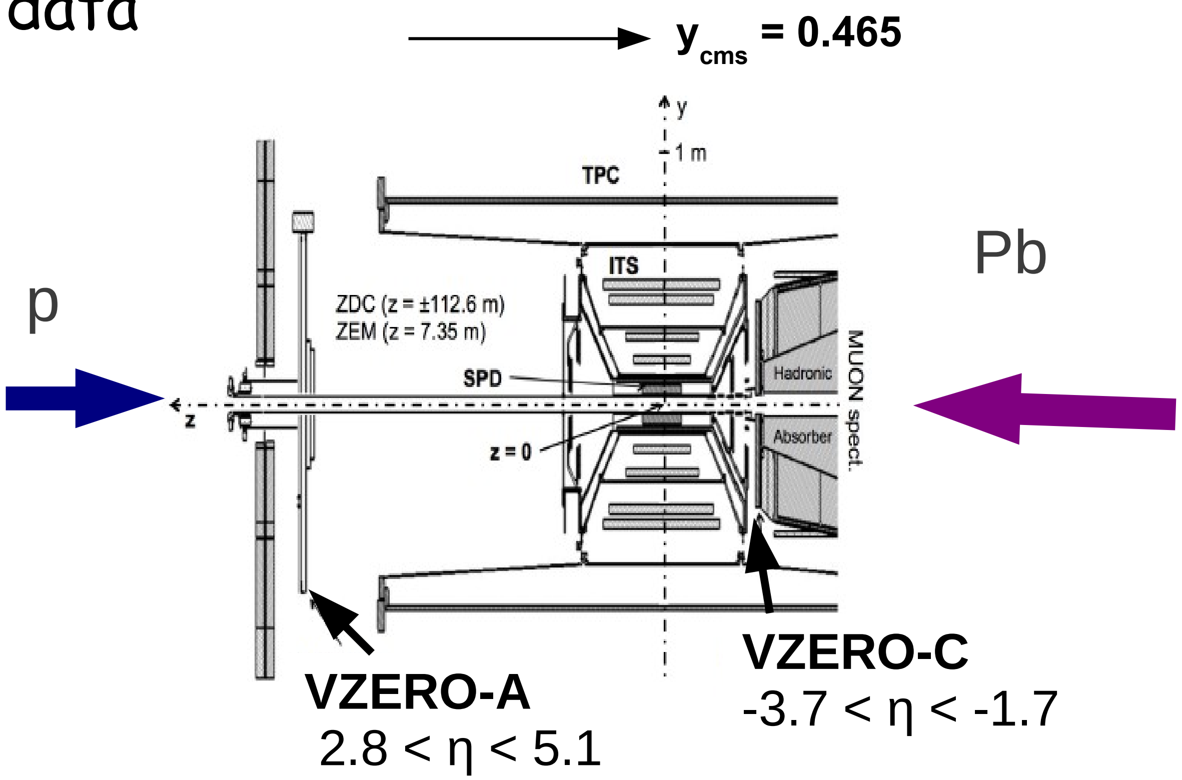
extend TPC lever arm, improve spatial precision and momentum resolution

PID

dE/dx measurement on the SDD & SSD layers

p-Pb analysis and multiplicity

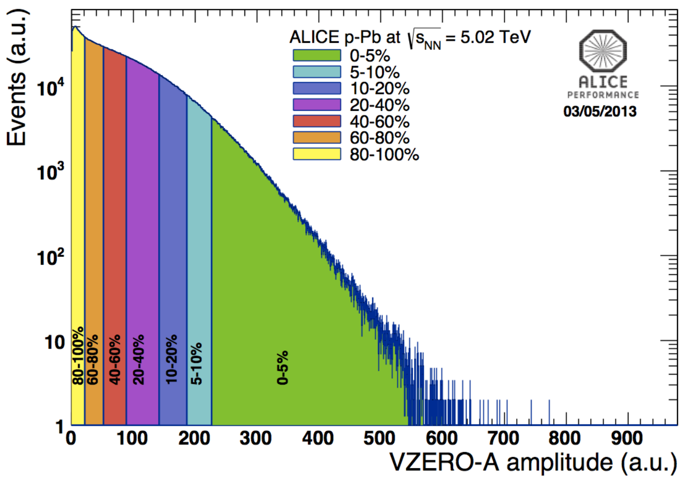
- The analysis was performed with p-Pb collision data collected in 2013 at the LHC $\sqrt{s_{NN}}$ = 5.02 TeV.
- Due to the 2 in 1 magnet design at the LHC, there is an asymmetric energy/nucleon in the beams → shift of the nucleon-nucleon C.M.S w.r.t laboratory frame in the proton direction with a rapidity of $y_{lab}^{cms} = -0.465$
- results obtained in $0.0 < y_{cms} < 0.5$



VZERO (Scintillator hodoscopes)
trigger, beam-BKG rejection

In p-Pb collision:

correlation between proton-nucleus collision geometry and particle multiplicity is not trivial



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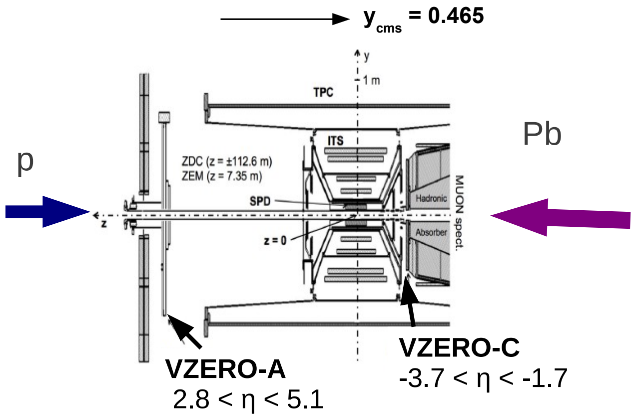

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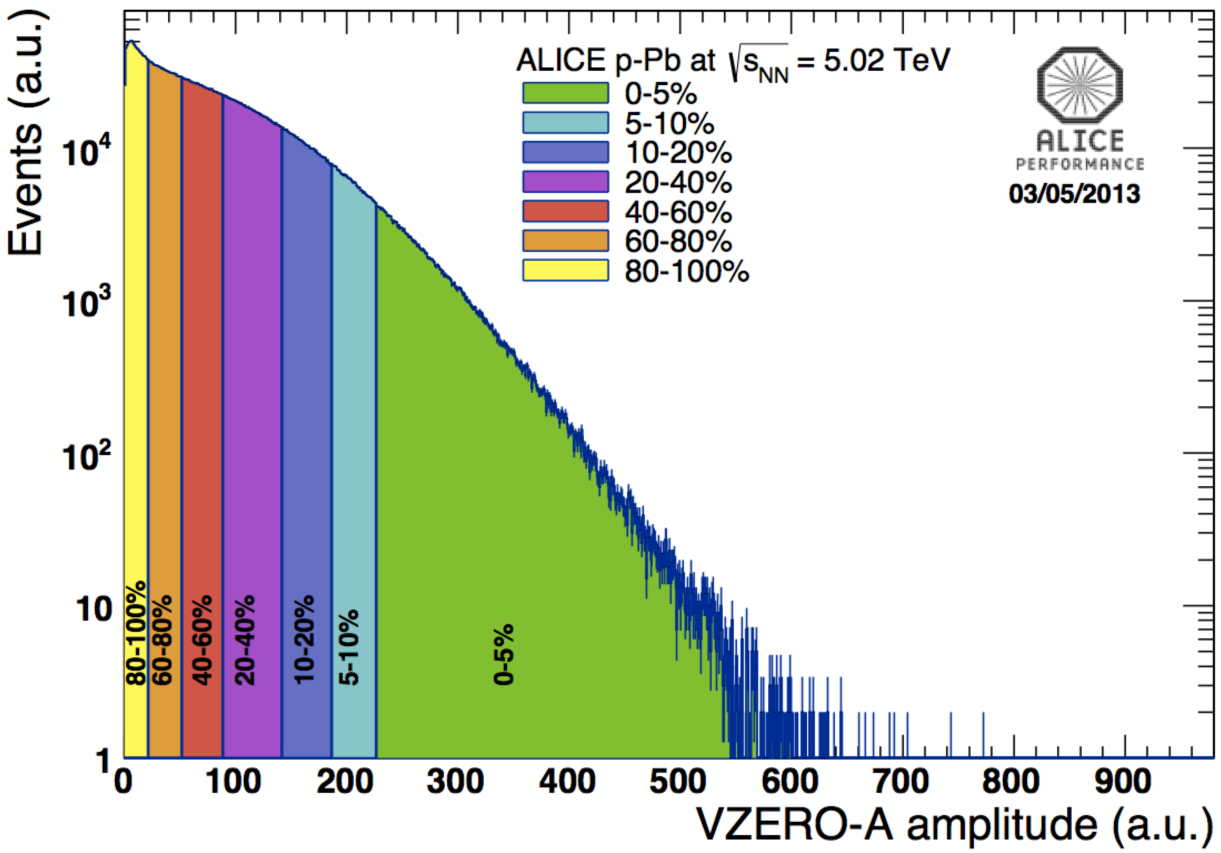
In p-Pb collision:

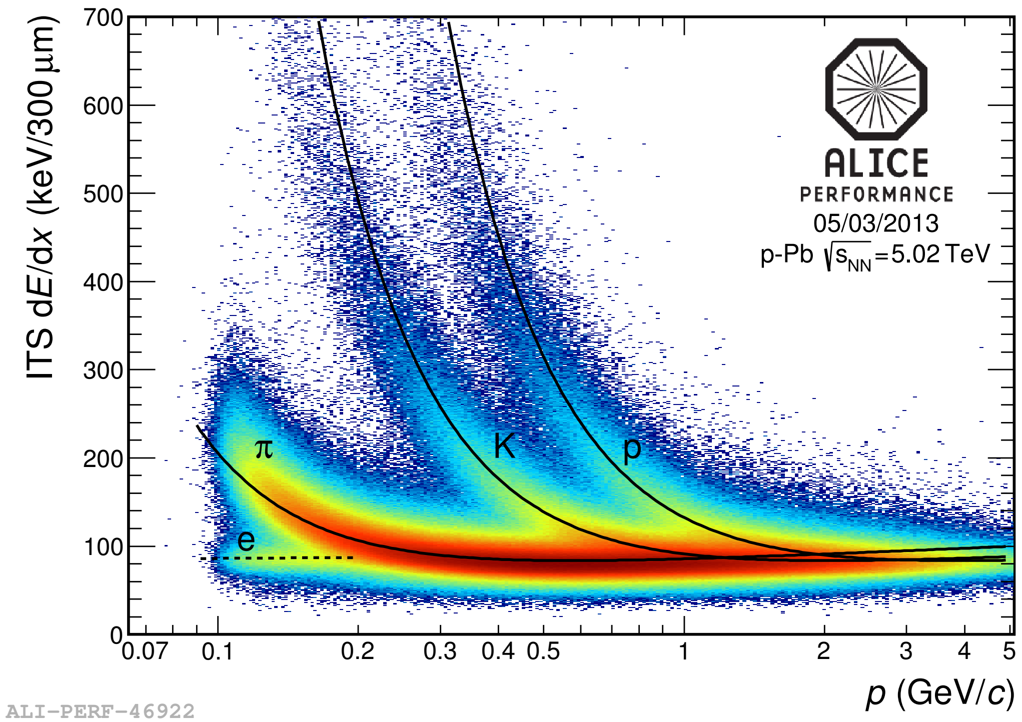
We define seven p-Pb event multiplicity classes based on the amplitude of the signal of VZERO-A (V0A) detector

(A is the direction of Pb beam)

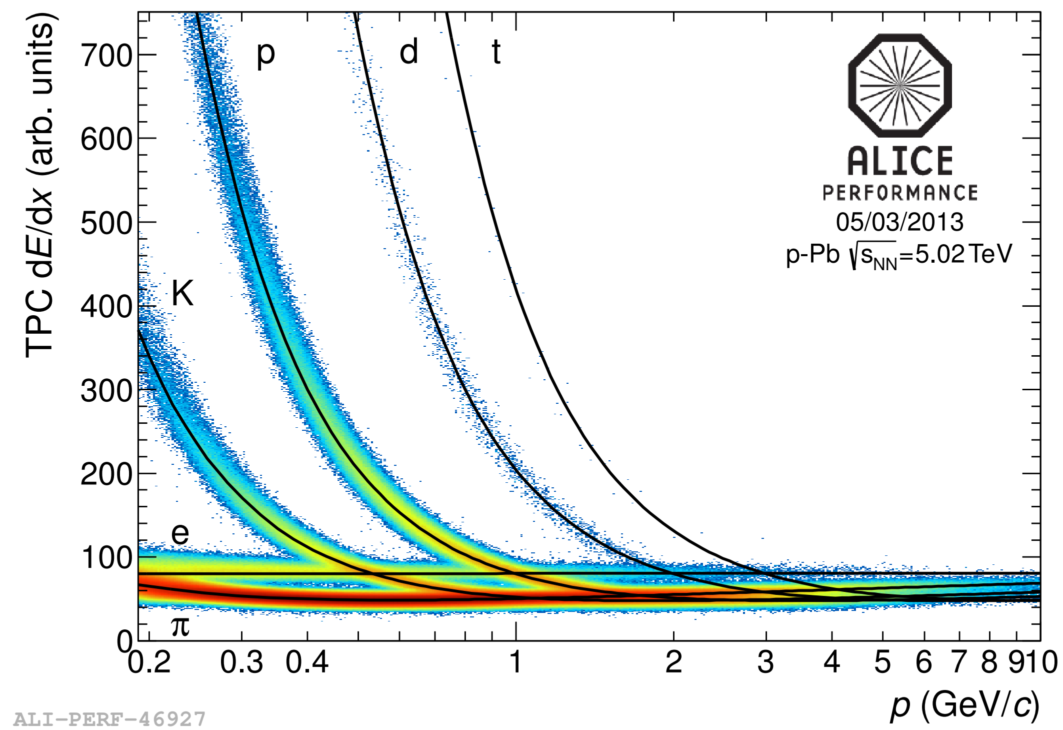


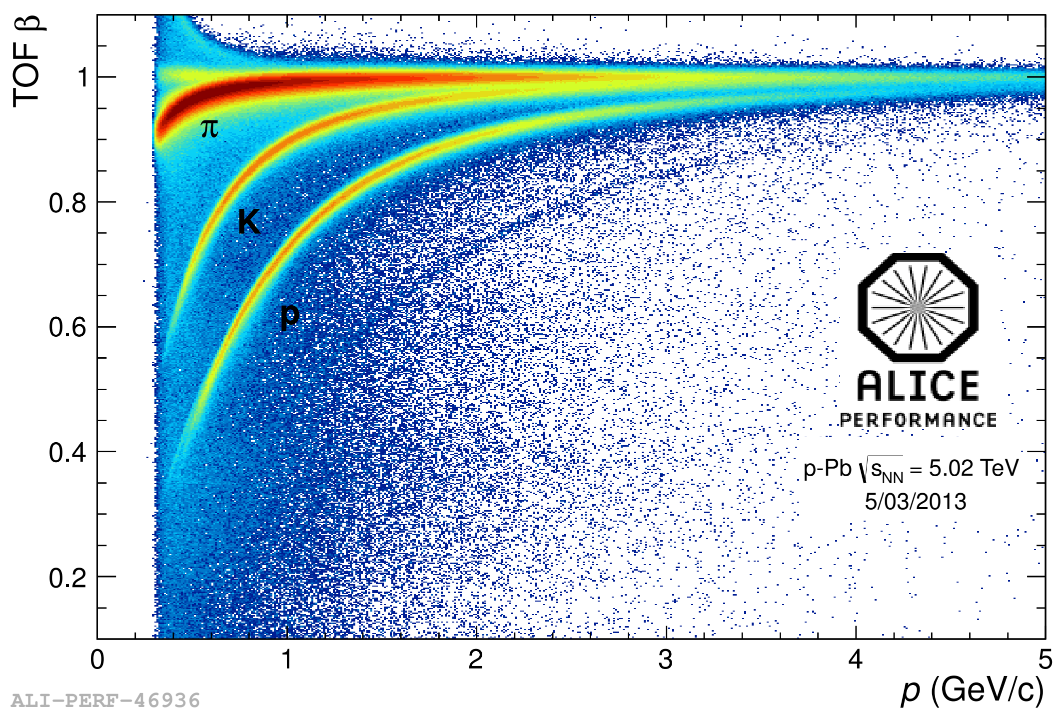
Particle-identification

ITS



TPC





TOF

- low p_T (<200 MeV) only accessible for ITS.
- Good separating power to perform track by track PID up to a p_T of 3-4 GeV/c depending of the particle species.

ALICE spectra analyses

Alice is the ideal detector for low p_T PID

Analysis	Tracks	PID signal	p GeV/c	PID approach
ITS standalone	ITS Standalone	dE/dx Si	π: 0.1-0.7 K: 0.2-0.6 p: 0.3-0.65	Bayesian
TPC-TOF	global tracks	dE/dx Gas + Time Of Flight	π: 0.2-1.5 K: 0.3-1.3 p: 0.5-2.0	#σ cuts
TOF	global tracks	Time Of Flight	π: 0.5-3.0 K: 0.5-2.0 p: 0.5-4.0	unfolding

We can combine all results, using the systematic errors as the weights.

Analysis method

1. Charge particle tracking
2. Track selection criteria
3. PID technique (raw spectra)
4. Corrections (MC simulation)
5. Secondary subtraction
6. Systematic errors

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I'll describe each step for the ITS standalone analysis …
but these are common to other analyses

1.Charge particle tracking

2 different sets of tracks in the ITS

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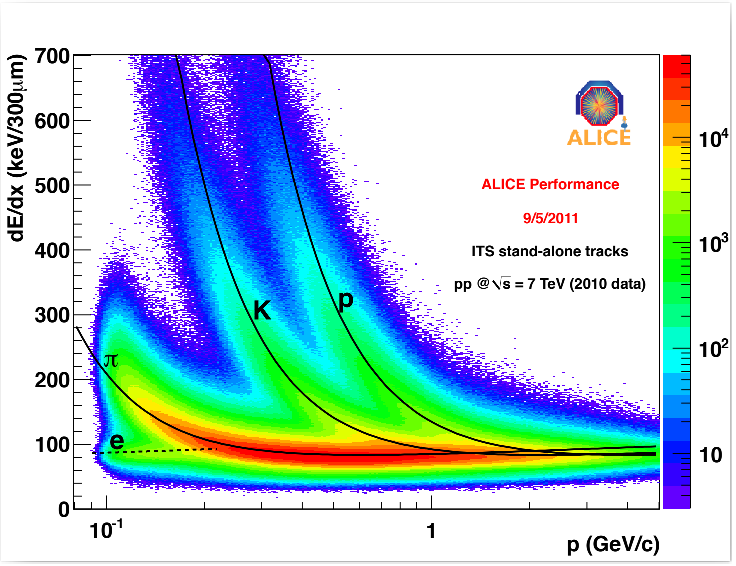
2 different sets of tracks in the ITS

ITS standalone

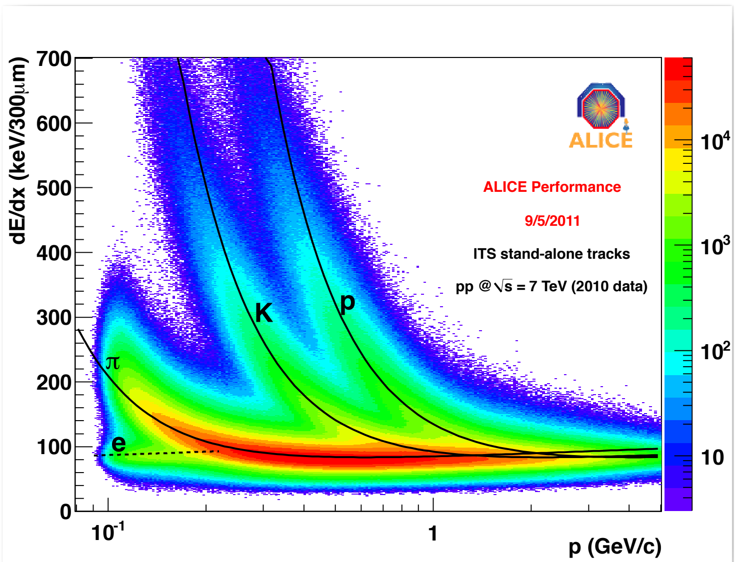


extends ALICE tracking (and PID) capability at low p_T

1.Charge particle tracking

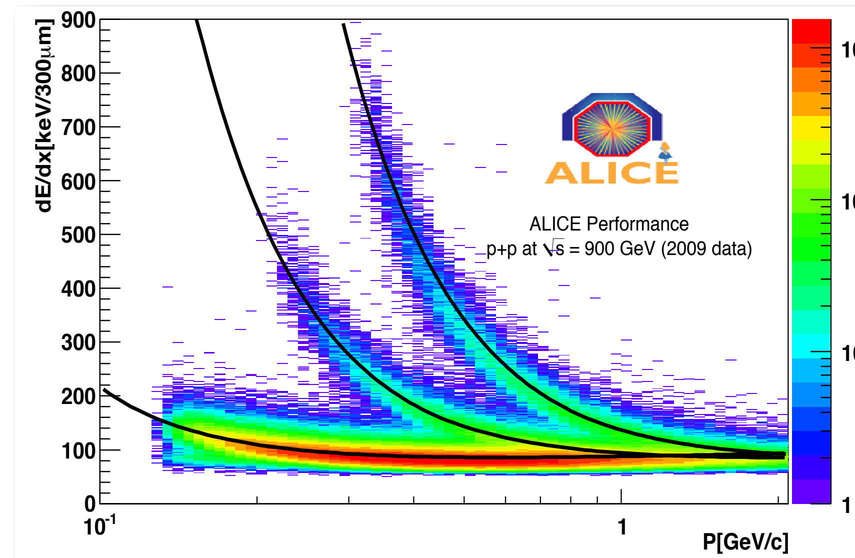
2 different sets of tracks in the ITS

ITS standalone



extends ALICE tracking (and PID) capability at low p_T

ITS-TPC

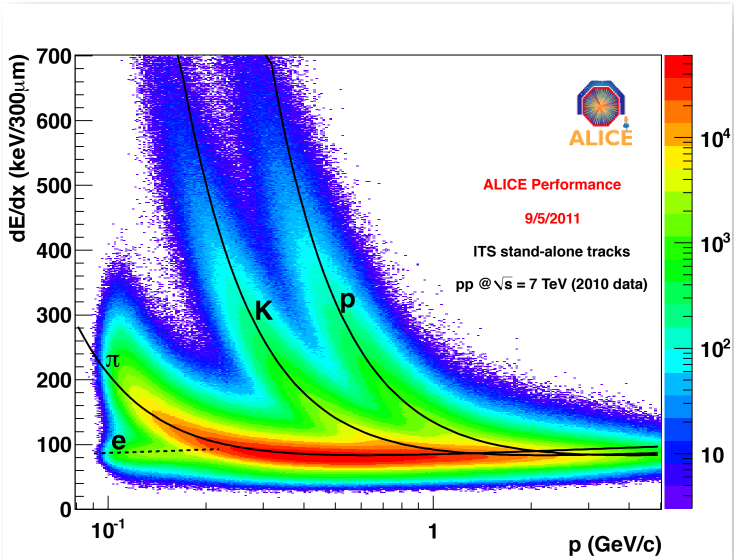


improve track parameters
(impact parameter(d_0) and p_T resolution)
better p_T resolution

1.Charge particle tracking

2 different sets of tracks in the ITS

ITS standalone



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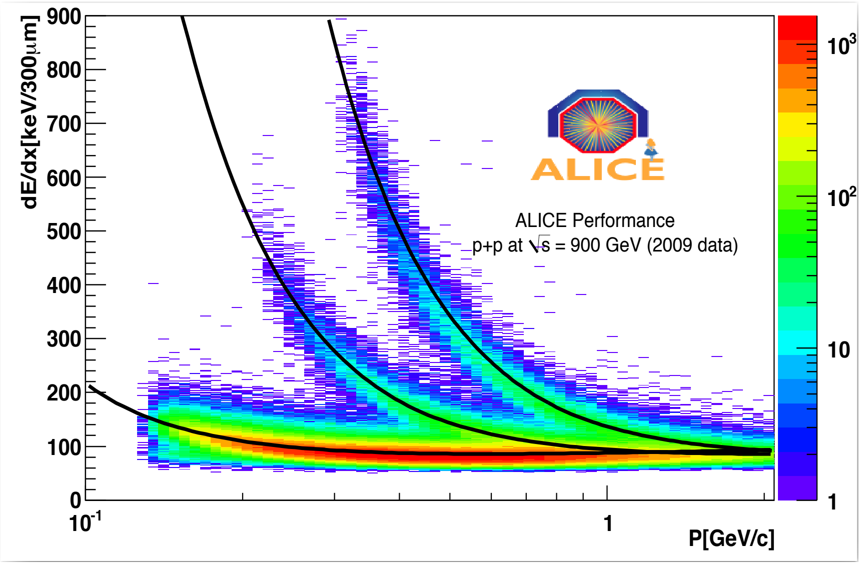

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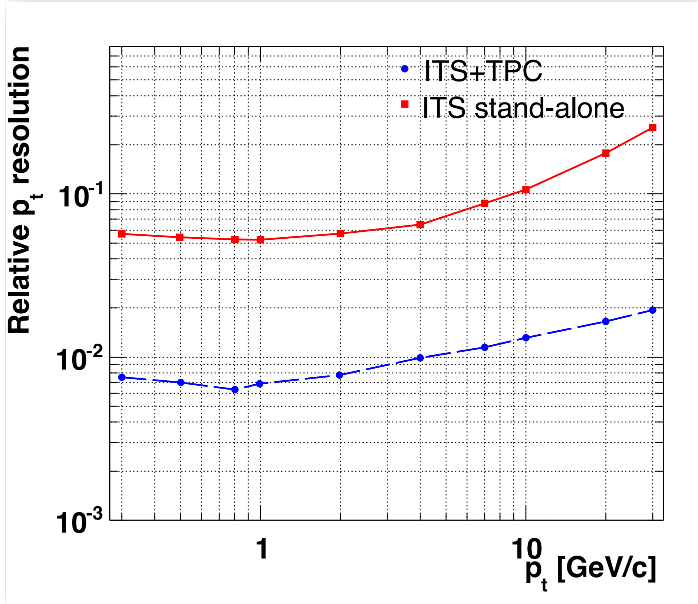


$\Delta p_T/p_T$ resolution
ITS standalone
and ITS-TPC
tracks

2. Track selection criteria (ITSsa)

Quality of the tracks (reduce fake tracks):

- track properly fitted with kalman filter
- X^2/(ITSclusters) < 2.5

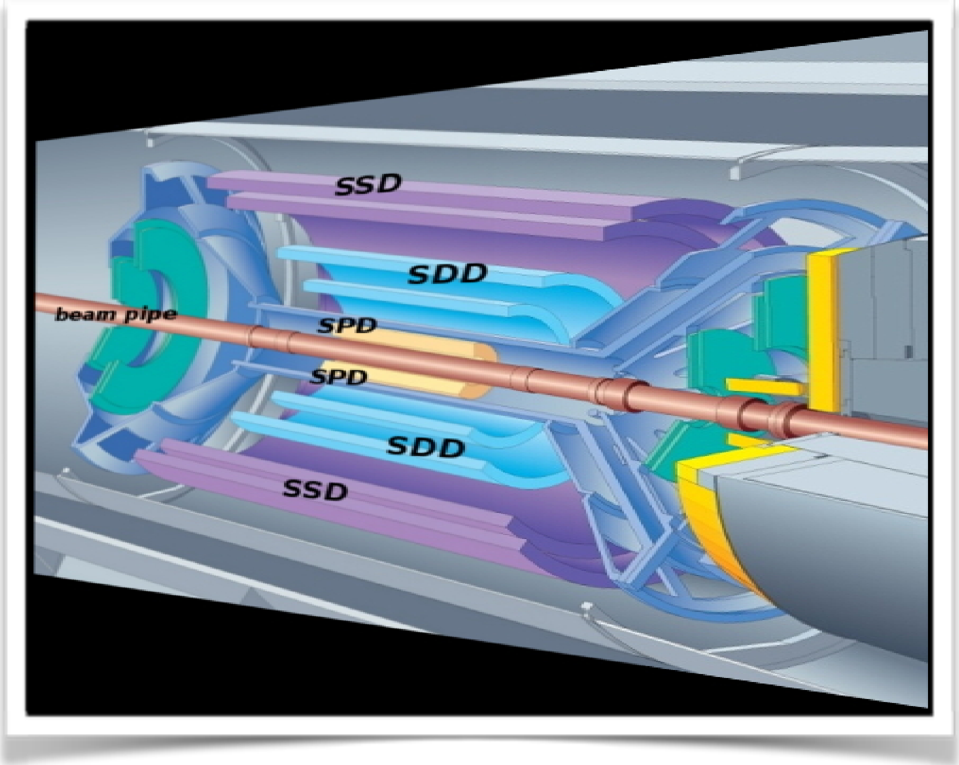
In order to reduce contribution from secondaries:

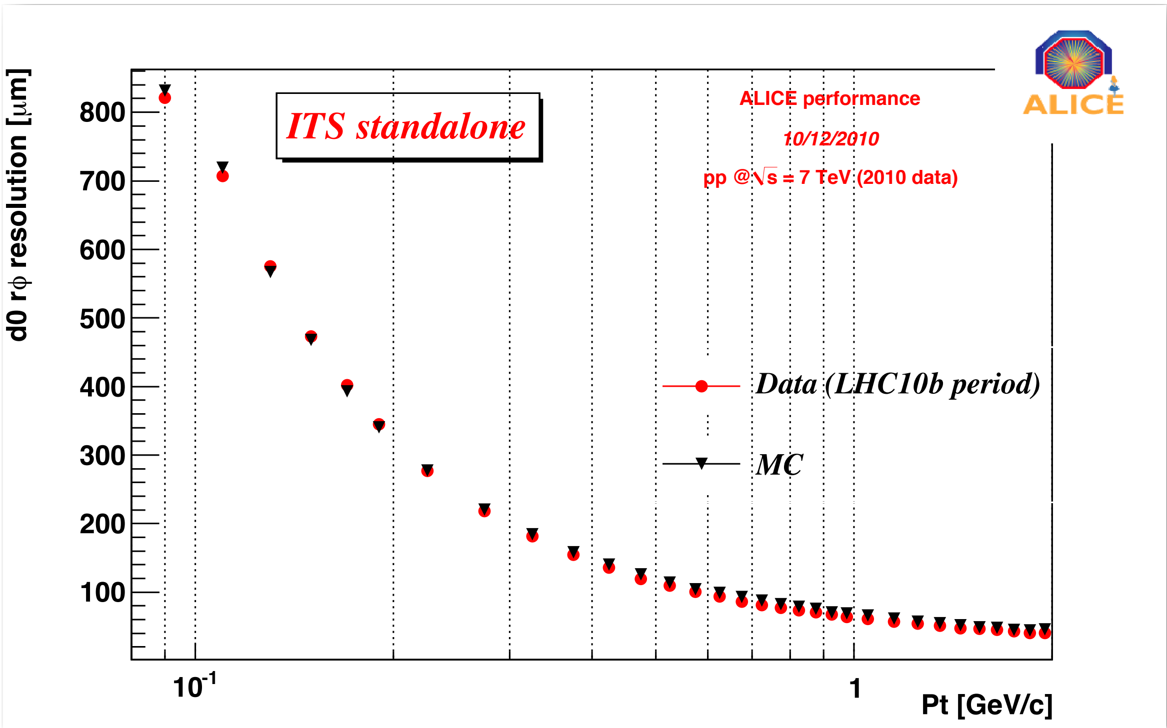
- At least one point SPD (also improve d_0 resolution)
- Track impact parameter or distance of closest approach(dca) $d_0 < 7\sigma$ in the bending plane.

Analysis Requirements

- At least 3 points in SDD+SSD

(improve PID performance)





3. PID techniques

track-by-track Bayesian approach with a parametrized Landau-Gaussian convolution.

$$P(i|S) = \frac{R(S|i)\Pi(i)}{\sum_{t=\pi,K,p} R(S|t)\Pi(t)} \qquad R(S|i) = \prod_{SDD,SSD} f_{Ni}(s|i)$$

layer response function

convoluted landau + gauss

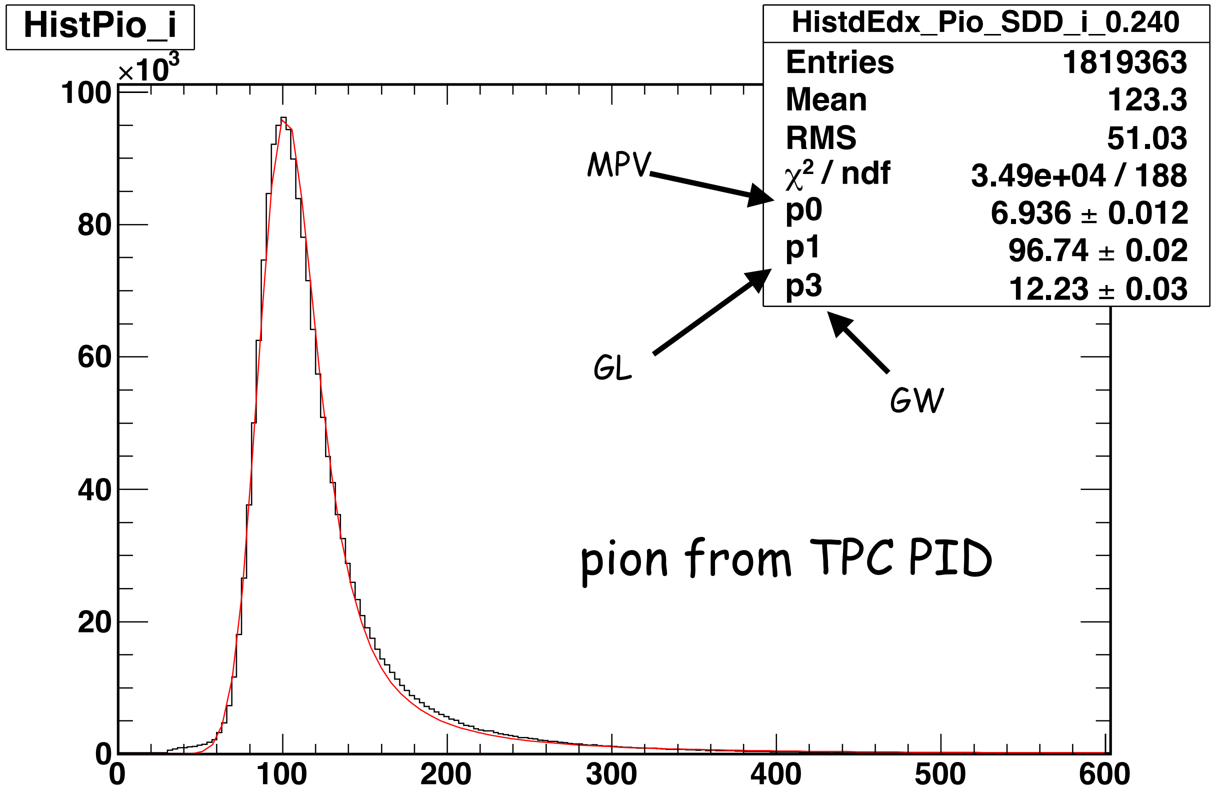
physics interpretation

detector response
(electronic read-out & charge diffusion)

Parametrized (data and MC) in two step procedure

ITS Parameterization

1st step: parametrize in momentum slices the dE/dx distributions for identified particles for each layer and fit with a convoluted Landau-gaussian



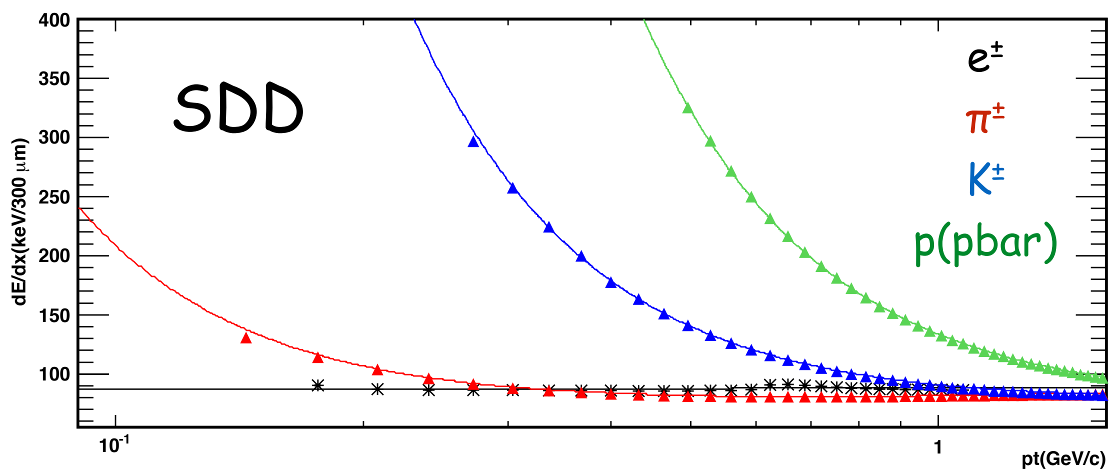
3 Parameters extracted

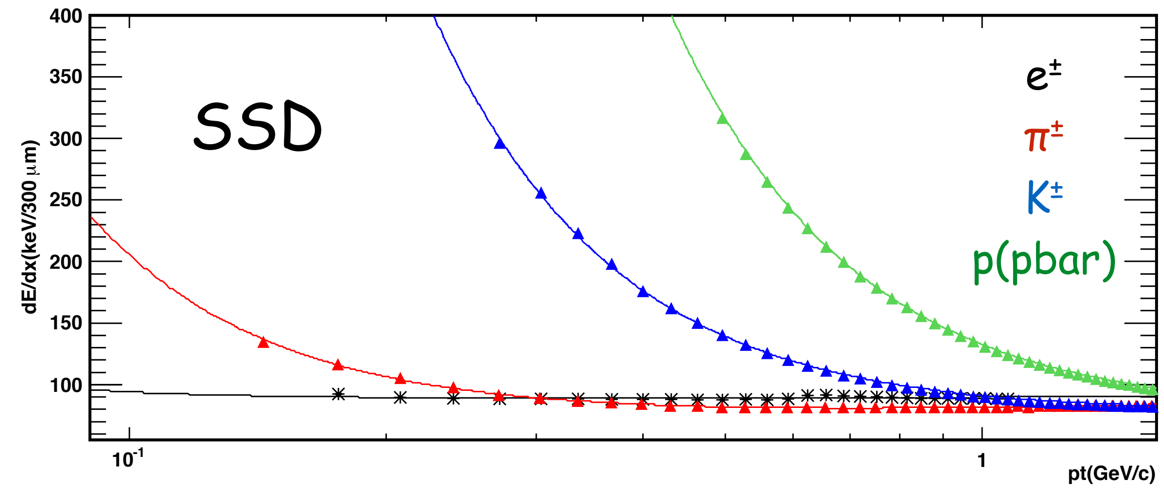
- Most Probable Value (MPV)
- Landau Width (LW)
- Gaussian Width (GW)

high purity sample identified with TPC and TOF PID used for real data

ITS Parameterization

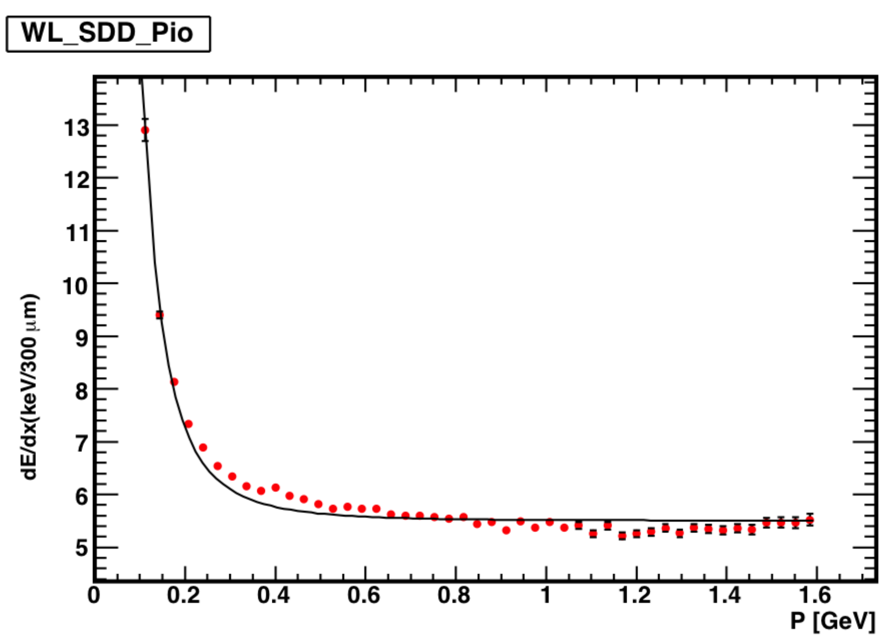
2nd step: parametrize the 3 fit parameters (MPV, WL; WG) vs. p for each detector type and particle species (2 dets x 4 species x 3 parameters functions)

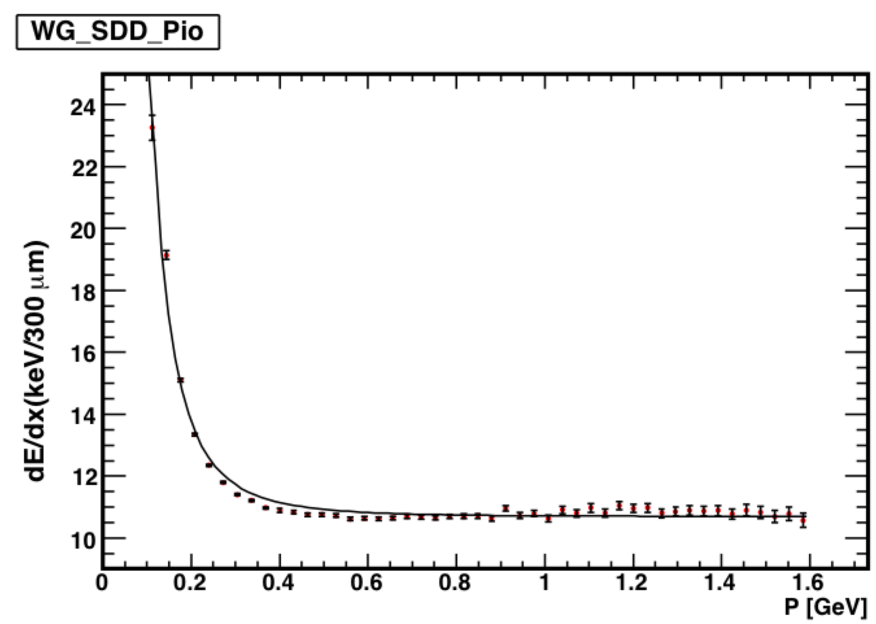




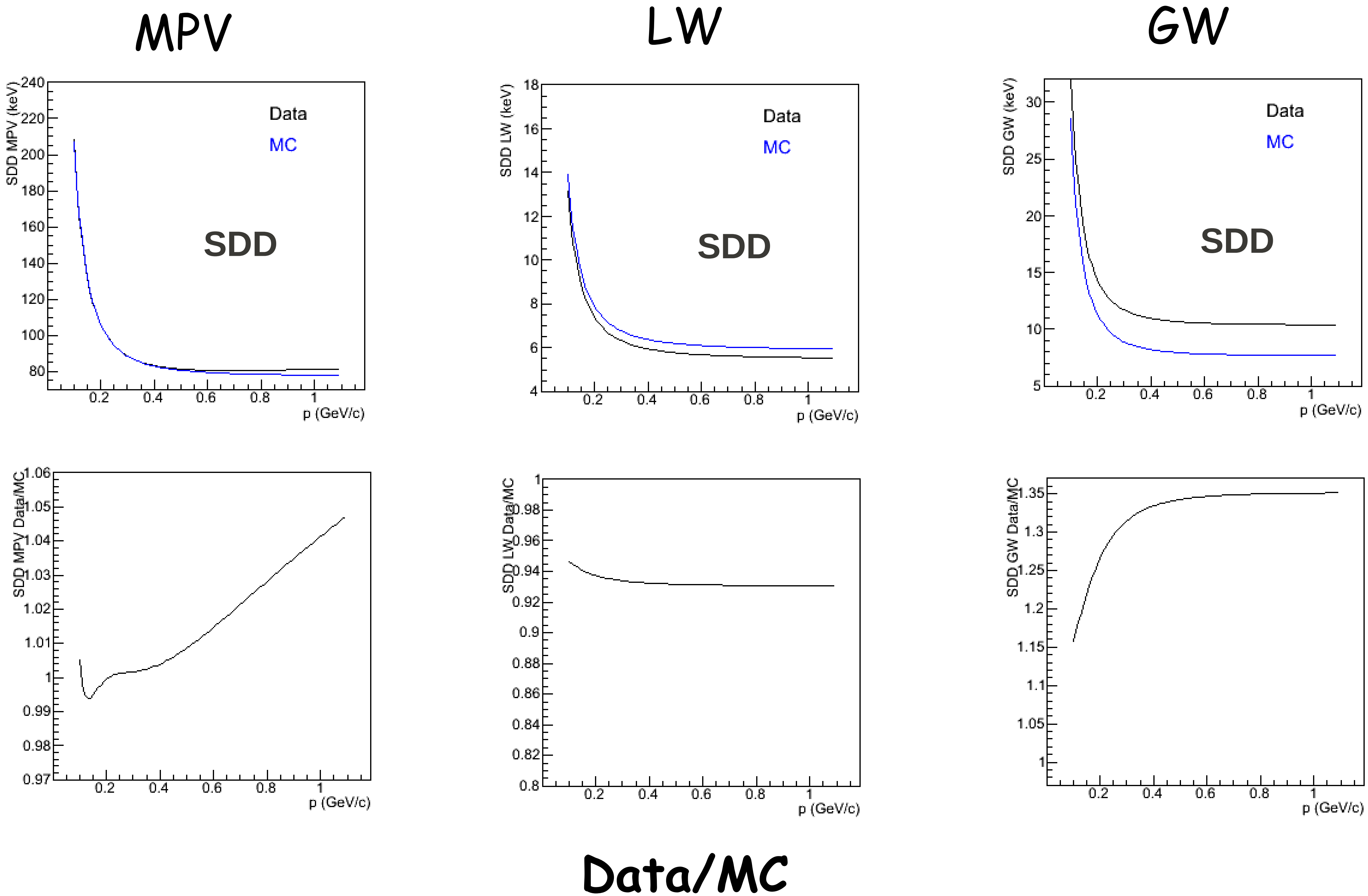
$$f_{MPV}(\beta\gamma) = \frac{p_1}{\beta^{p_4}}\left(p_2 - \beta^{p_4} - \ln\left(p_3 + \frac{1}{(\beta\gamma)^{p_5}}\right)\right)$$

$$f_{WL,WG}(p) = \frac{A_w}{p^2}\ln(p) + B_w$$





Data/MC response function



3. Prior probabilities

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$$P(i|S) = \frac{R(S|i)\Pi(i)}{\sum_{t=\pi,K,p} R(S|t)\Pi(t)}$$

$$\Pi(i;p_T) = \lim_{x\to\infty} \frac{N_i}{N}\Big|_{p_T}$$

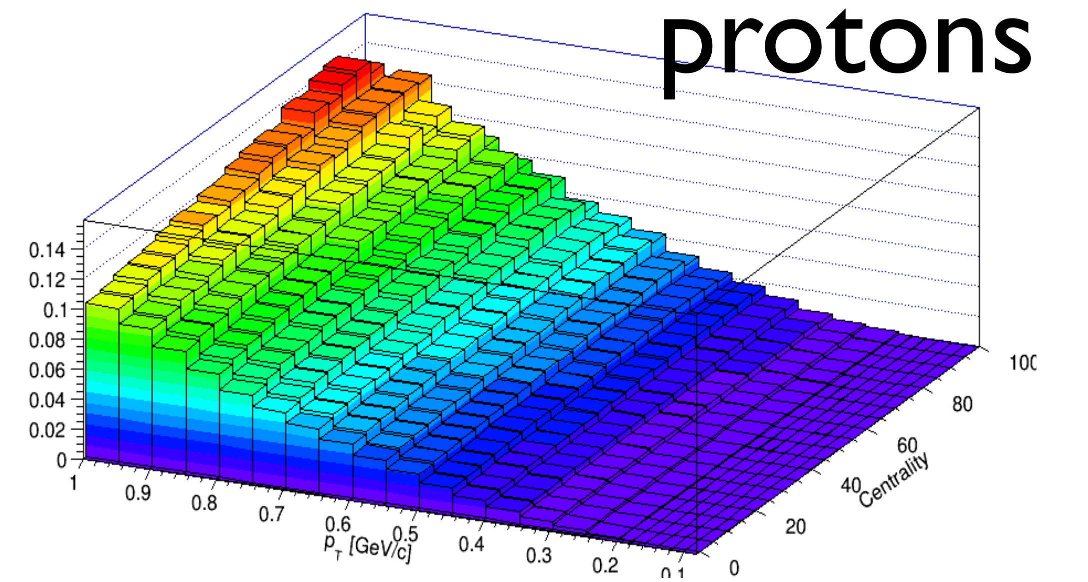
iteration order

Priors estimated for each multiplicity event classes as the relative abundance using an iterative procedure.

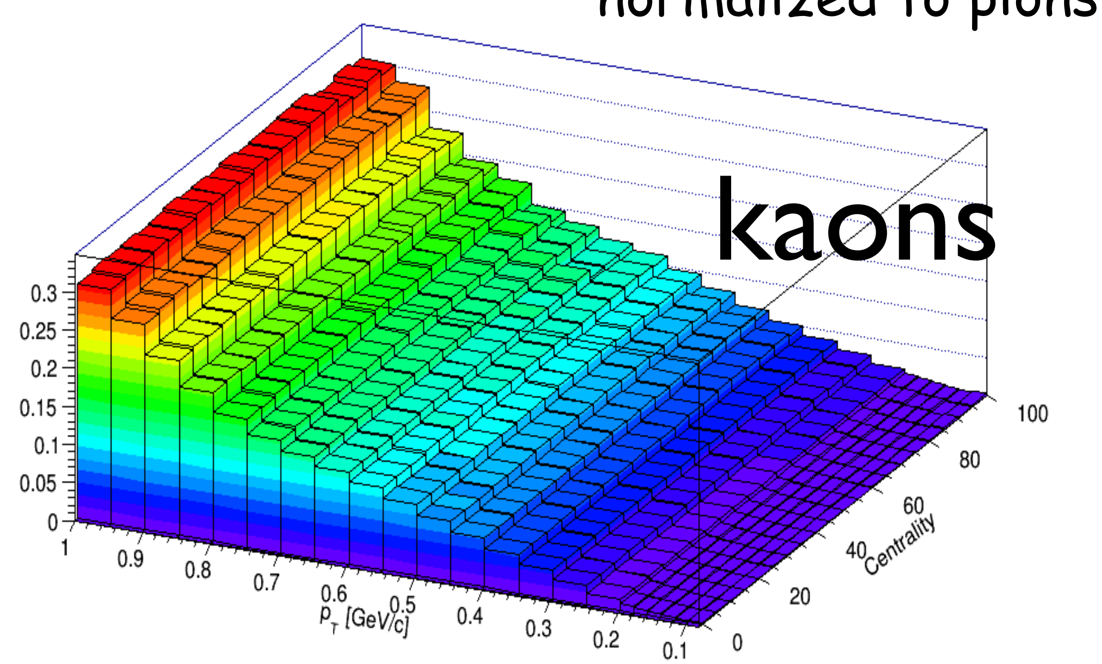
-> equal initial value probability (1st iteration)

-> same selection criteria used in the analysis

(representative sample of the data)



kaons & protons normalized to pions



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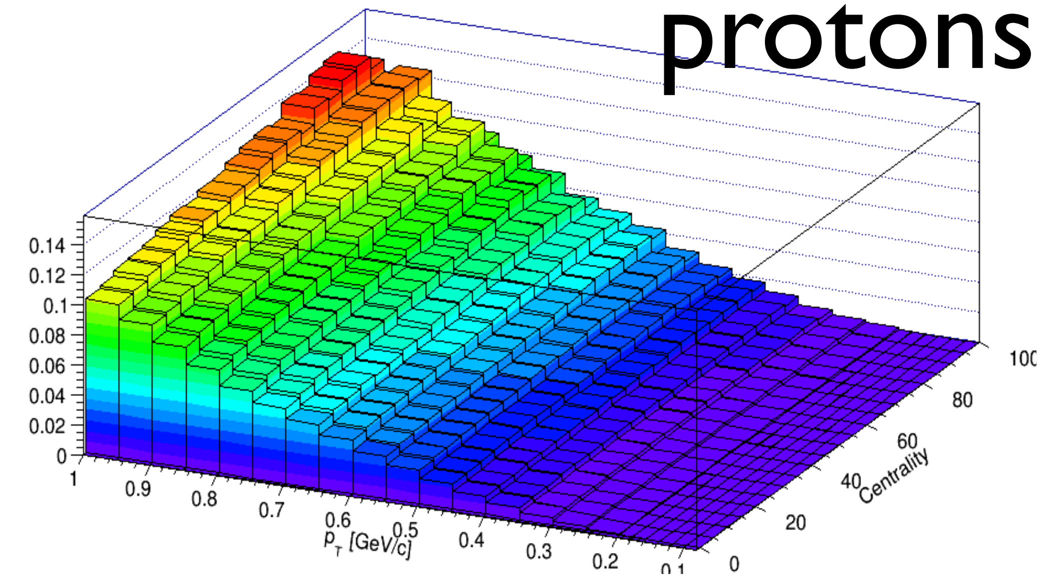

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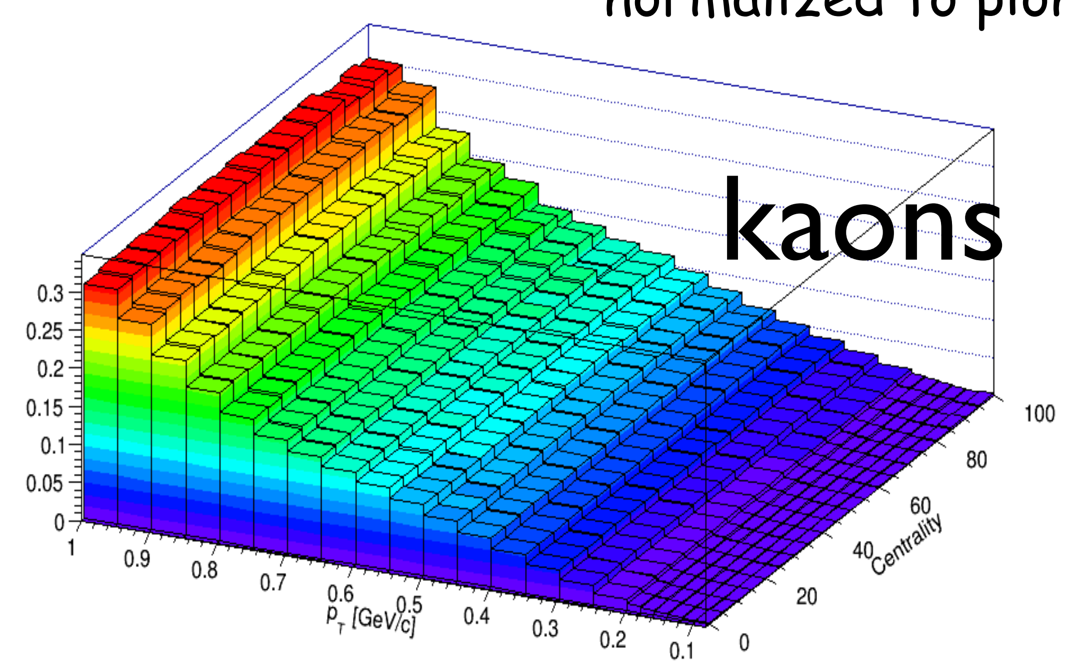

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-> equal initial value probability (1^{st} iteration)

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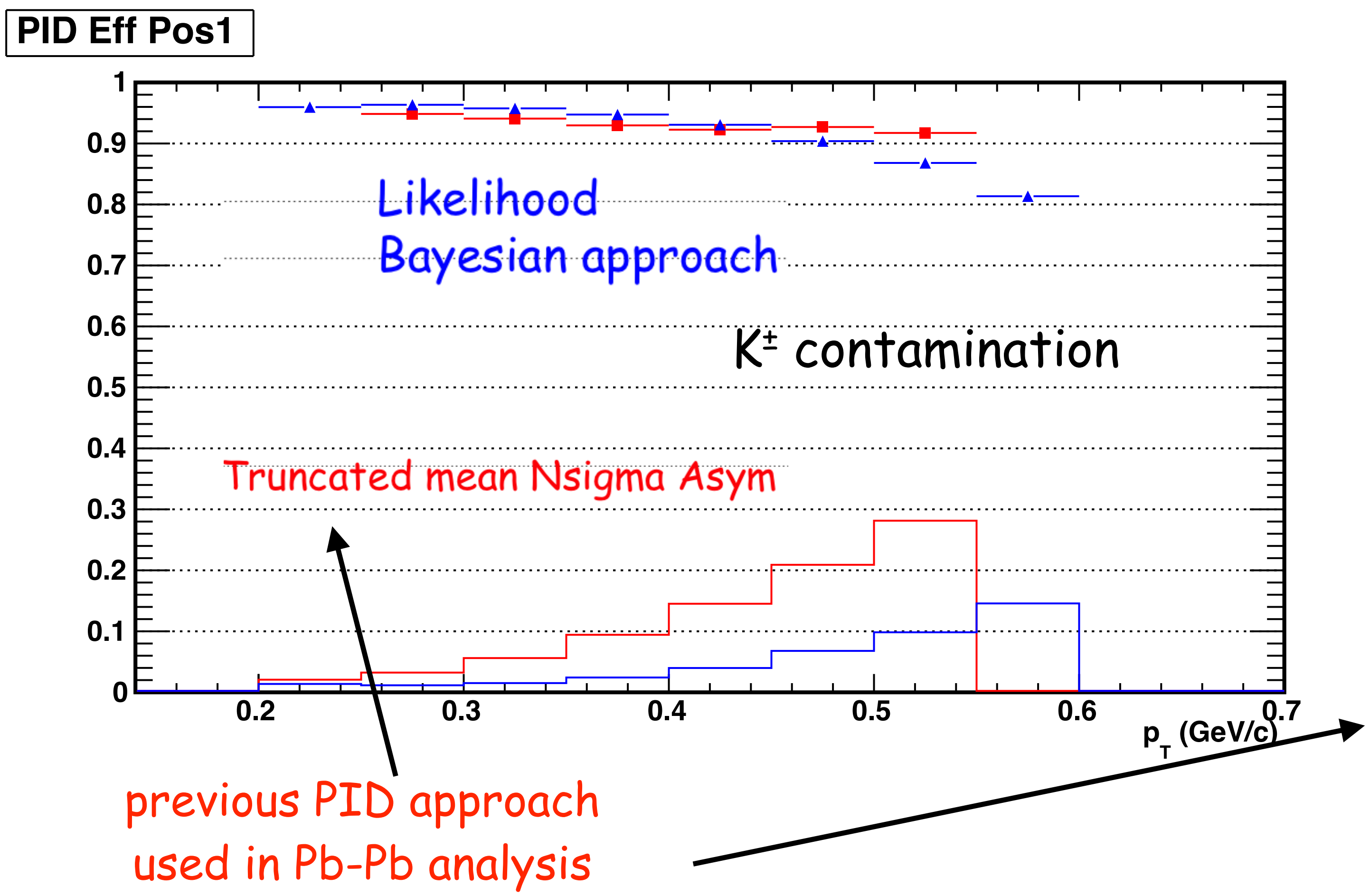
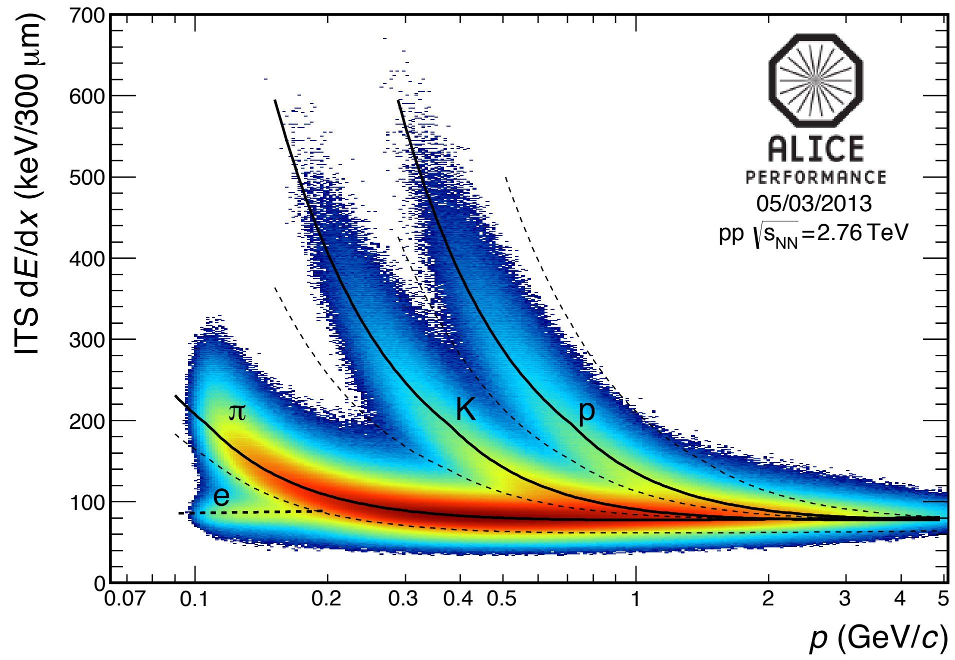
(representative sample of the data)

pid = i : P(i|S) = Max(P(i|s))

Bayesian Vs previous ITSsa method

Bayesian approach PID, according to MC simulations provides slightly better performance (= lower contamination) than previous approach.





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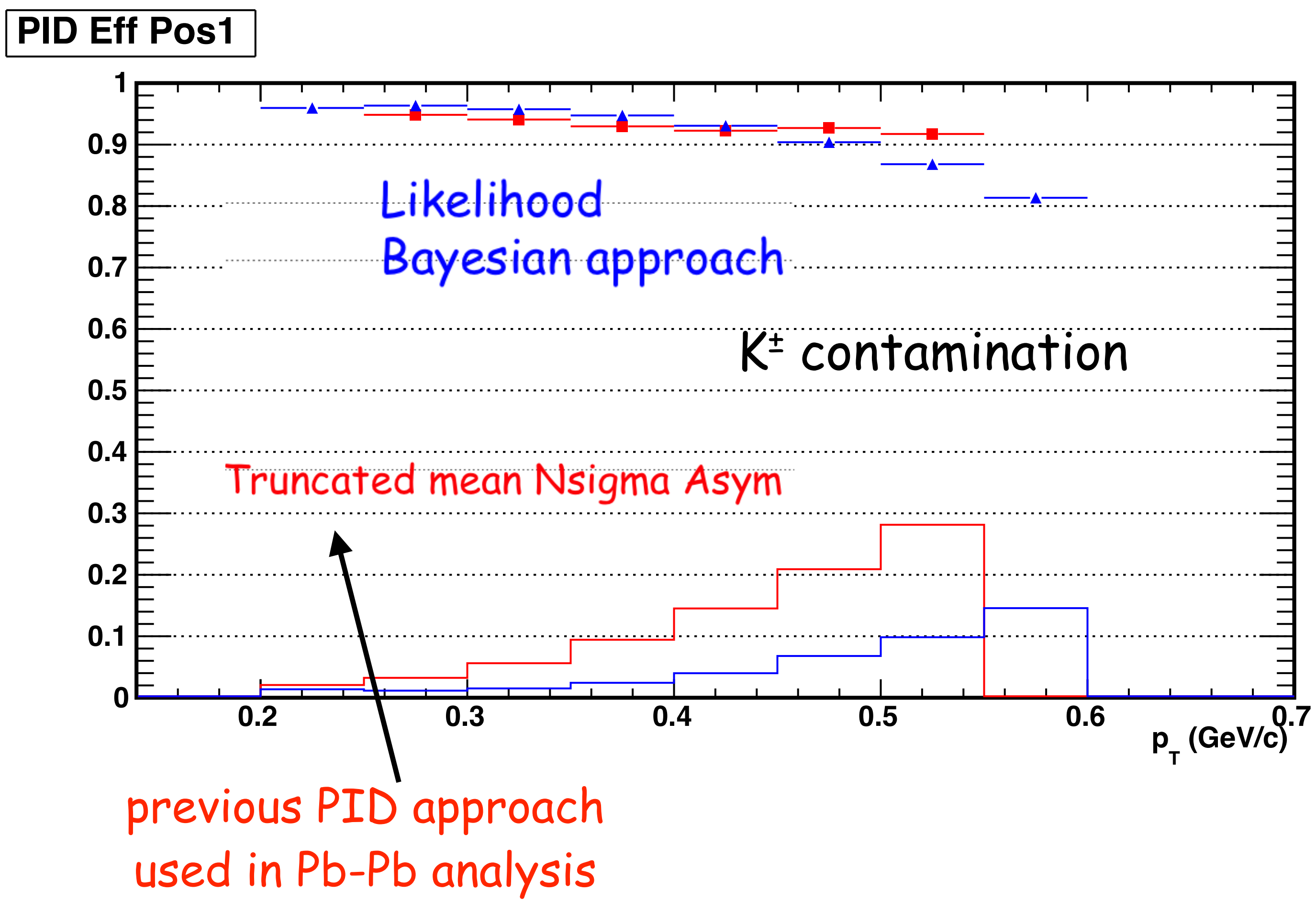

π: 0.1-0.5
K: 0.2-0.5
p: 0.3-0.65
old

π: 0.1-0.7
K: 0.2-0.6
p: 0.3-0.65
new

possibility to extend the ITSsa PID up to 600 MeV for $K^{\pm}$.

we can cover now the region of high $K^{\pm}$ contamination from $e^{\pm}$ in the TPC.

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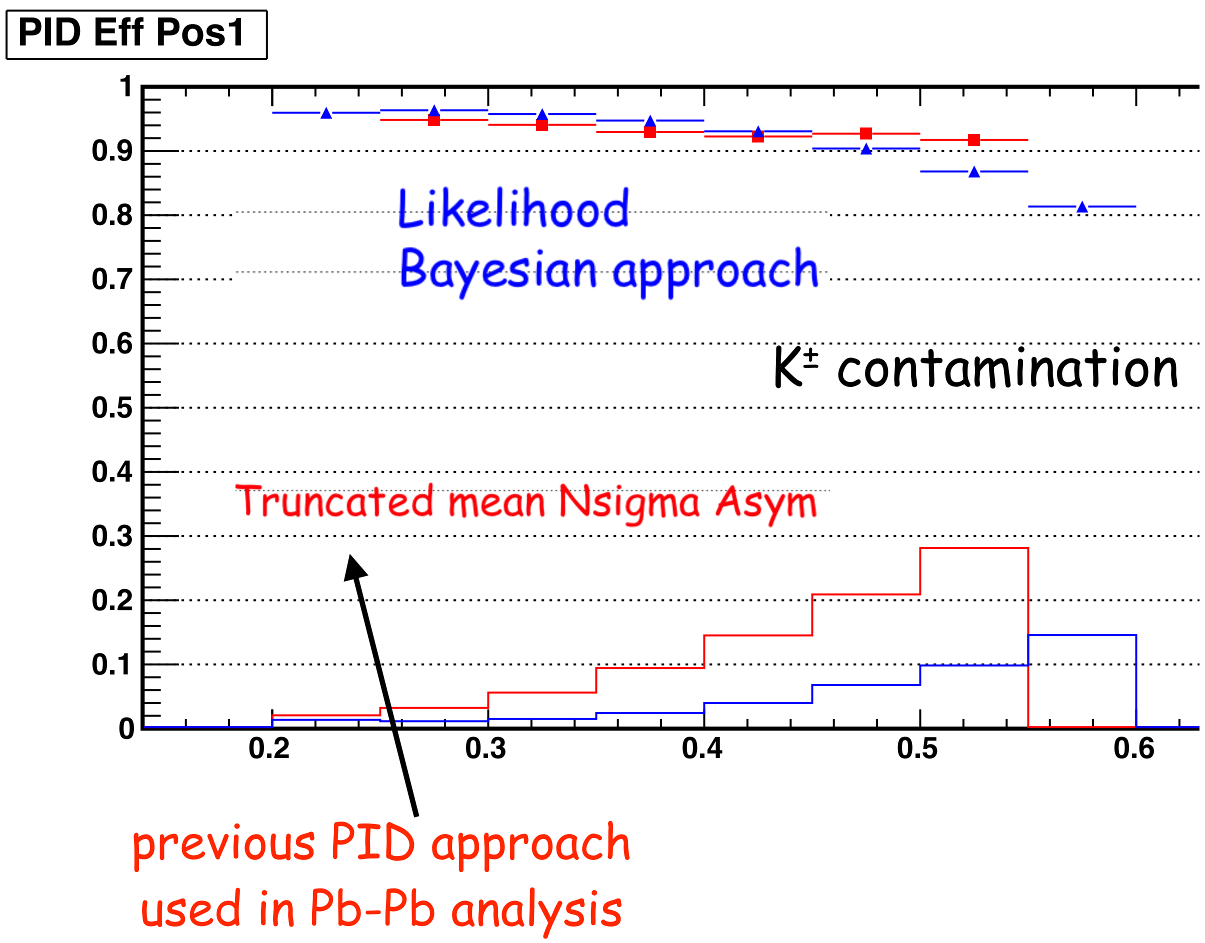
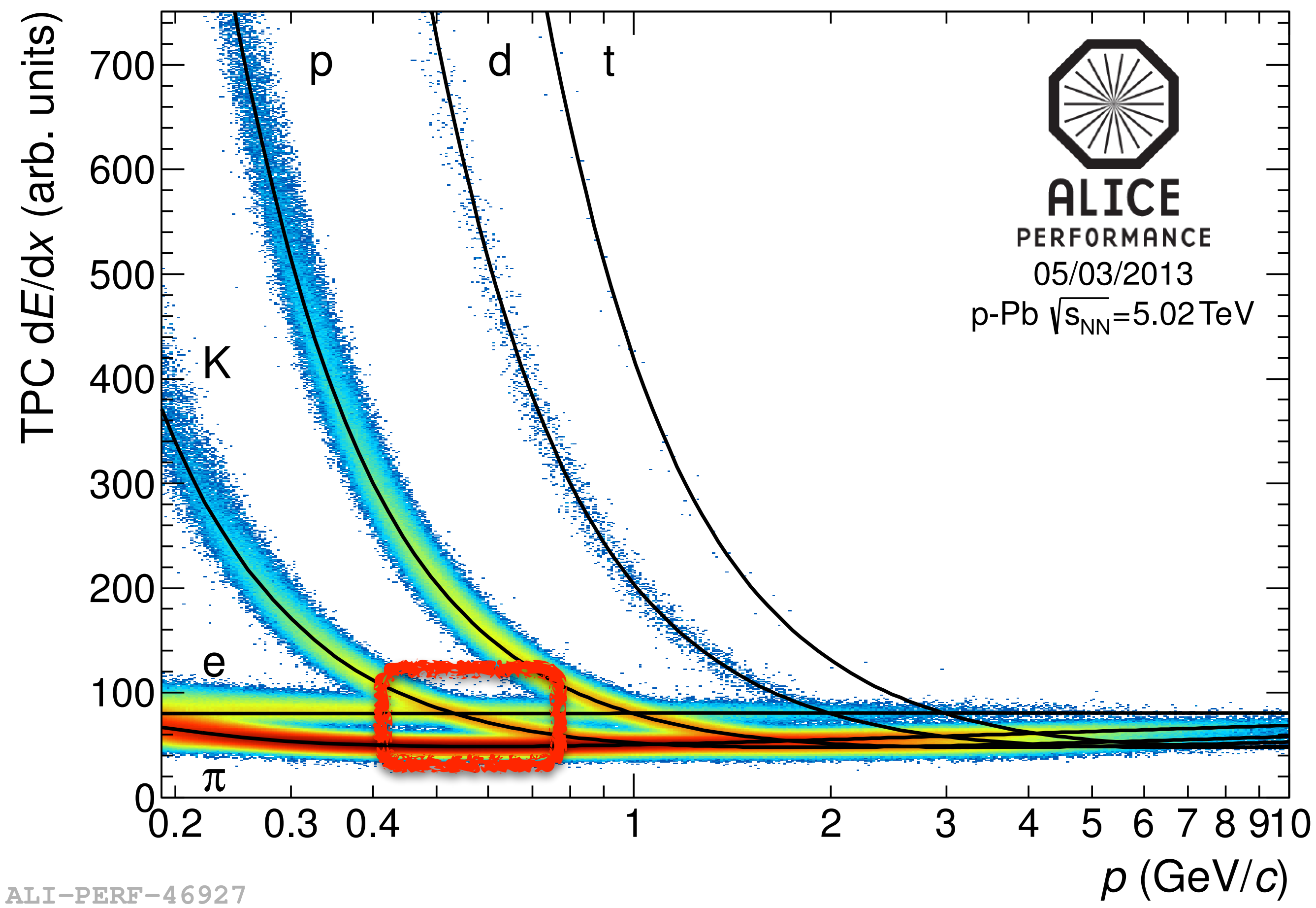


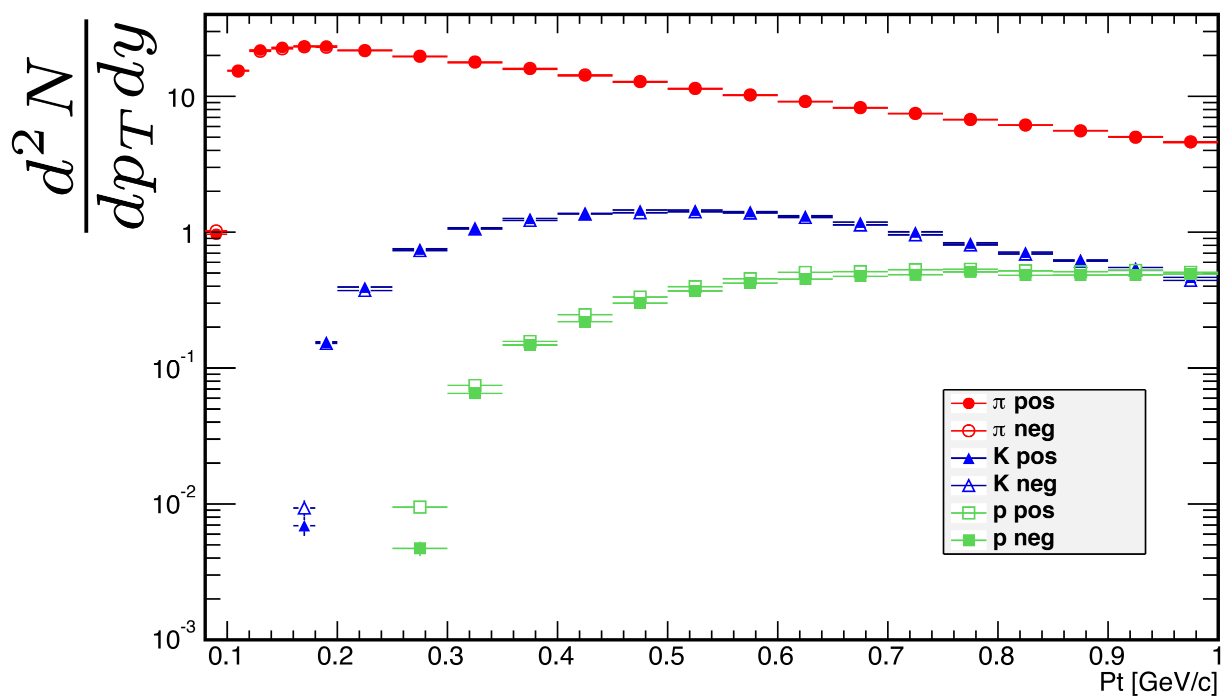


possibility to extend the ITSsa PID up to 600 MeV for K±.

we can cover now the region of high K± contamination from e± in the TPC.

4. Monte Carlo corrections

After the application of PID requirements we have obtained the raw p_T spectra



Minimum Bias (MB) raw data

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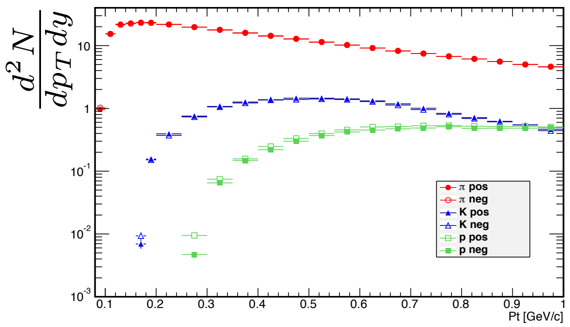

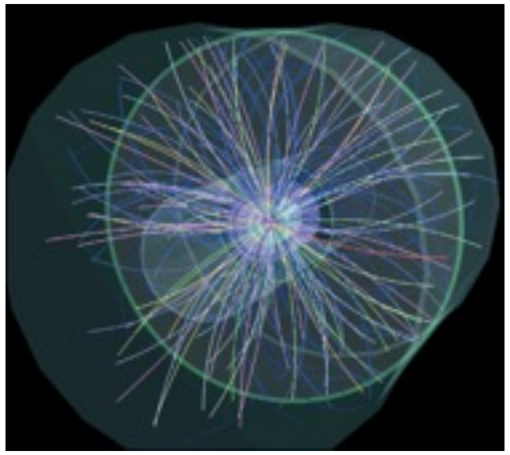

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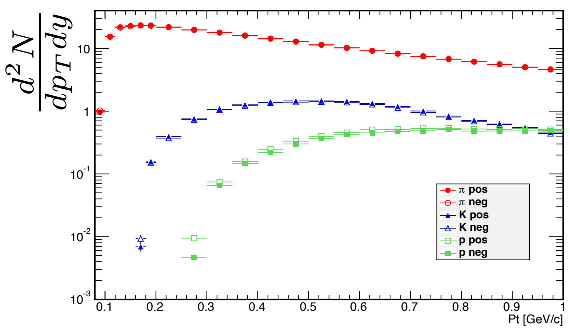

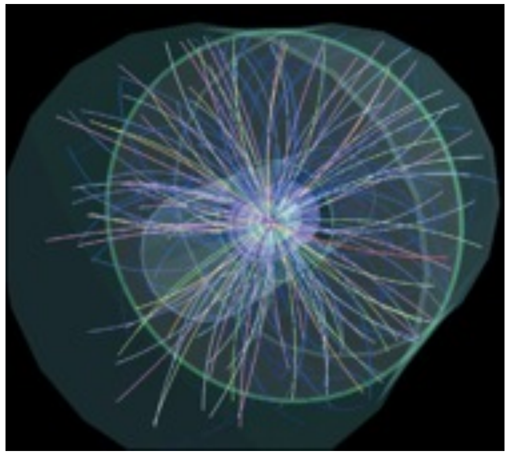

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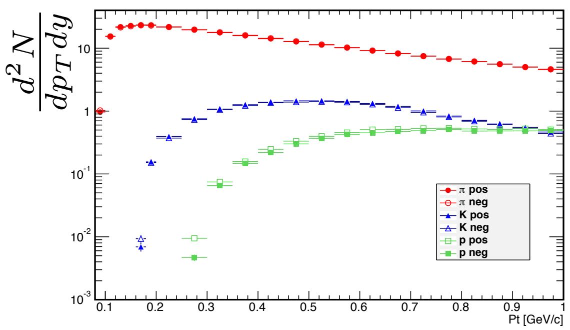
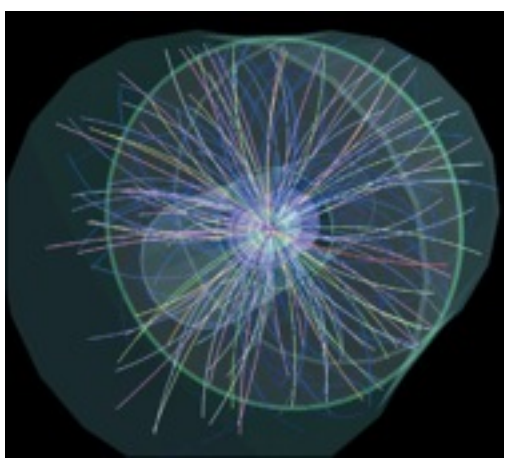


MC simulation ⟶ corrections

acceptance + tracking efficiency + PID efficiency ...



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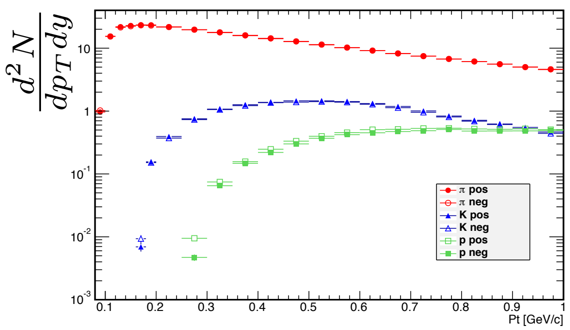

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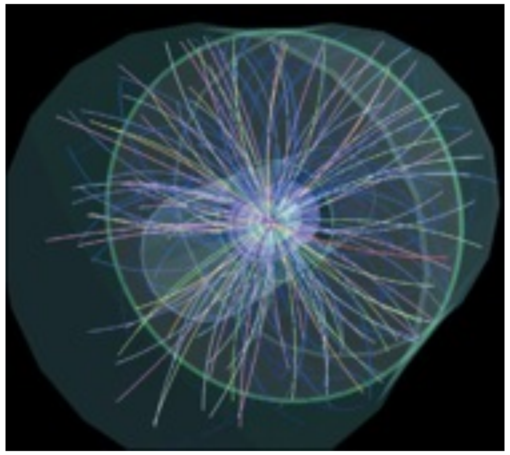

Overall ITS standalone correction

$$\frac{\text{Raw yield}_{MC} \text{ (same approach used on data sample)}}{\text{Primary particles generated}}$$

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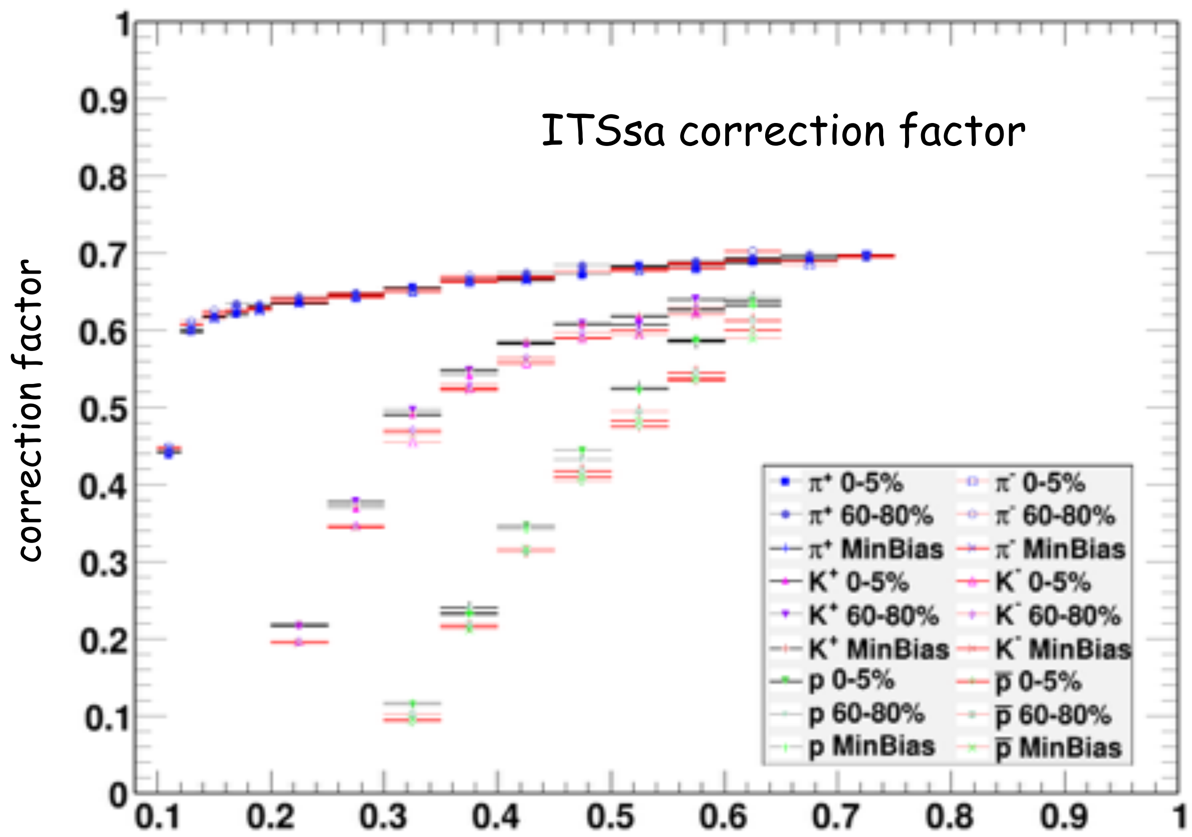

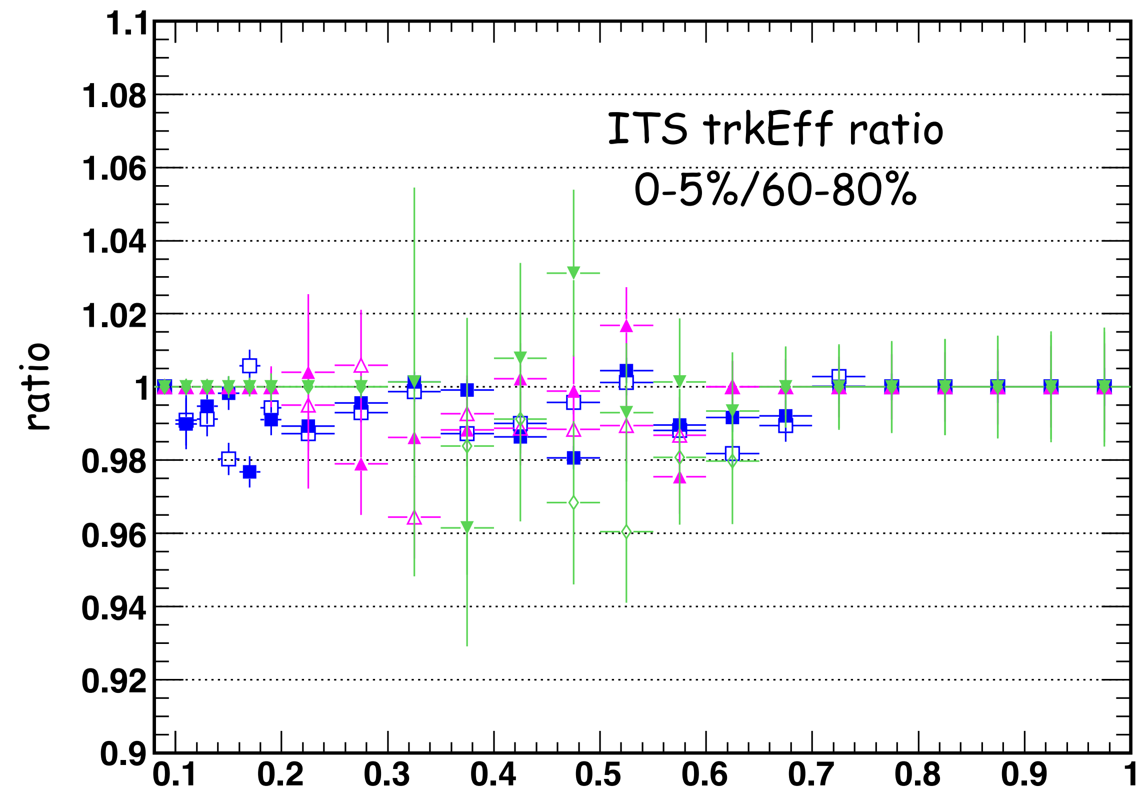

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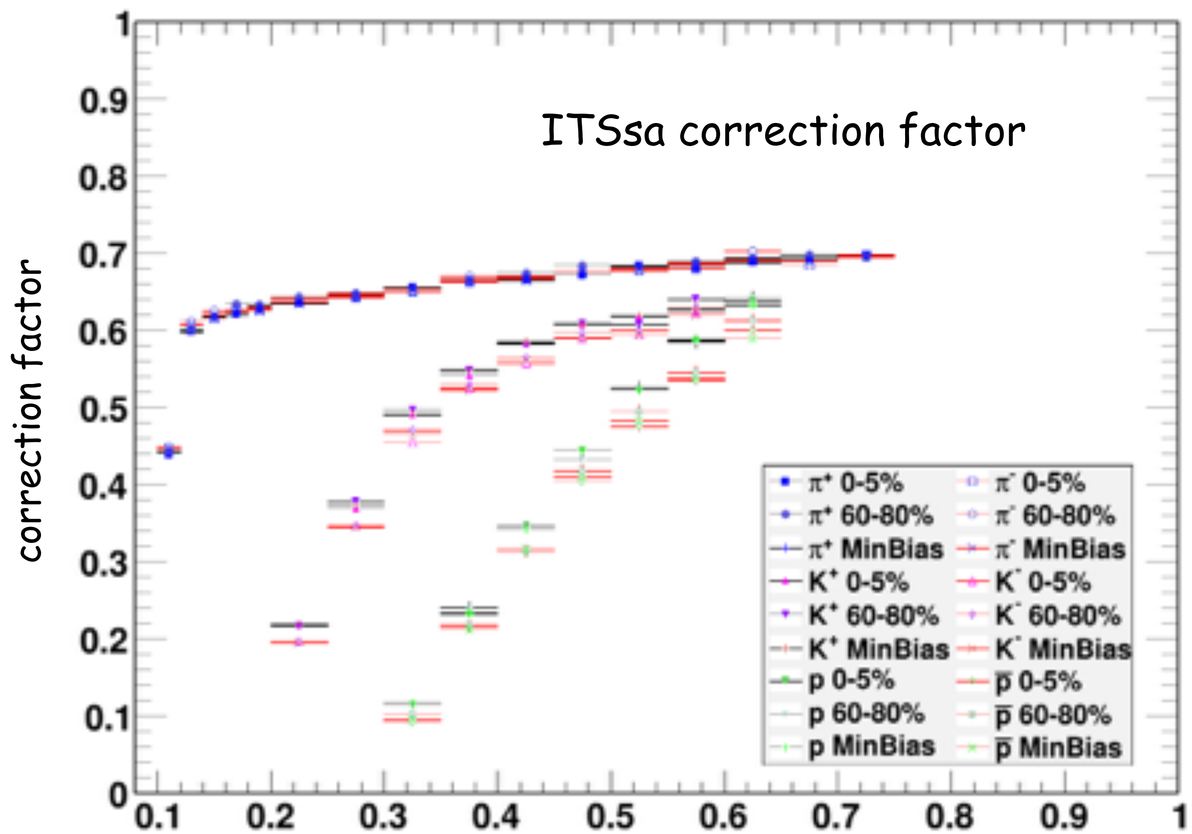

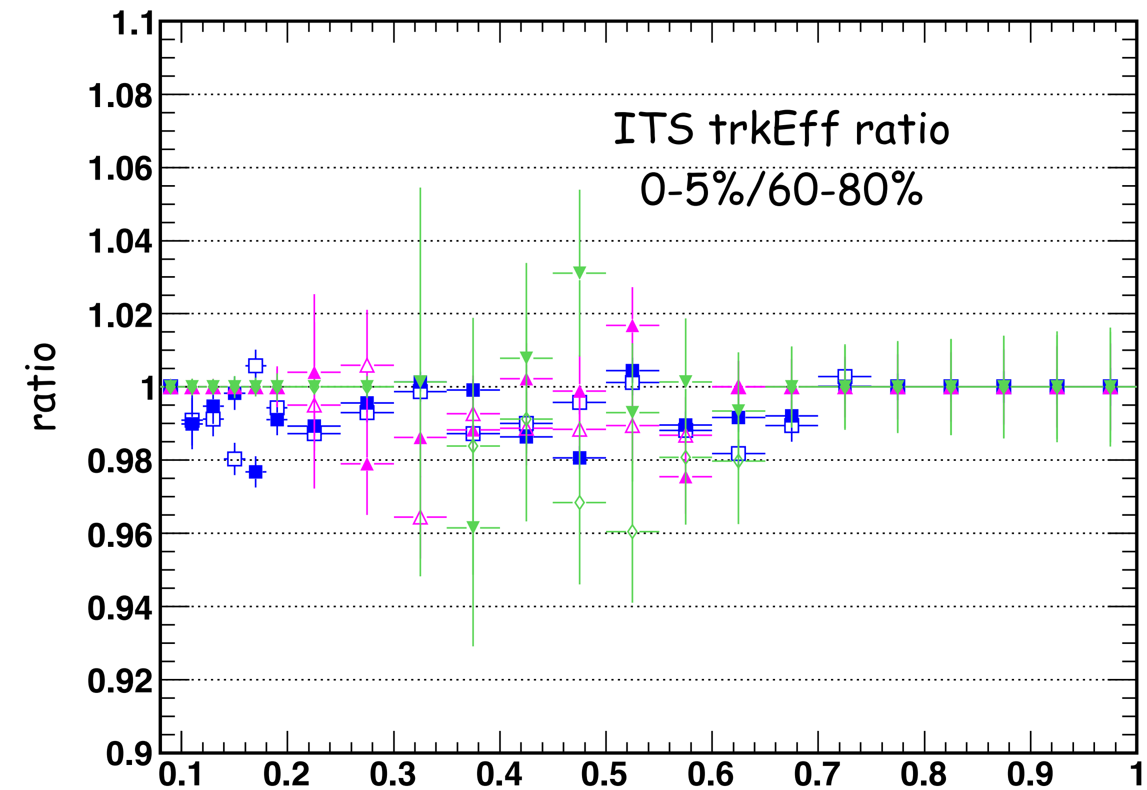

contrary to Pb-Pb No significant "< 2%" multiplicity dependence of the tracking
Therefore, MB correction (high statistics) was used which includes a 2% systematic errors.

5. Subtraction of Secondaries

We want the p_T spectra of PRIMARY particles, we have:

- secondaries from interaction of particles in the detector material
- secondaries from weakly decaying particles

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MC doesn't reproduce secondaries correctly

some weak resonance yields are underestimated ($\Lambda \rightarrow p\,\pi^-$, $\Sigma^+ \rightarrow p\,\pi^0$)

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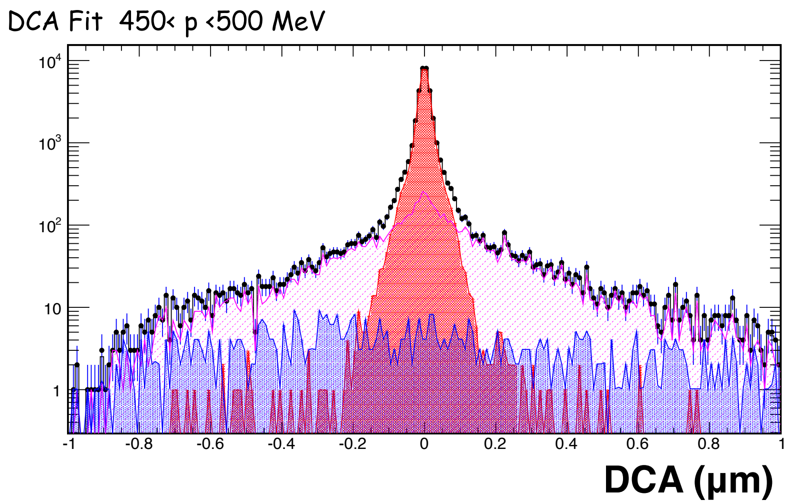

Data DCA distr is fitted with

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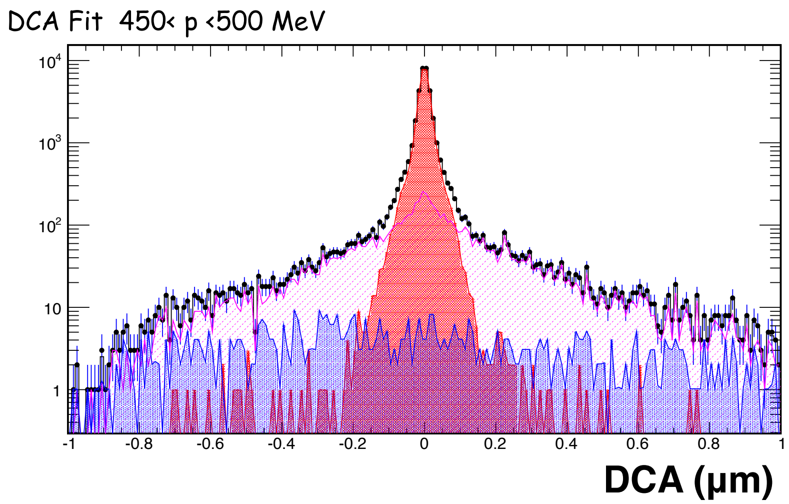

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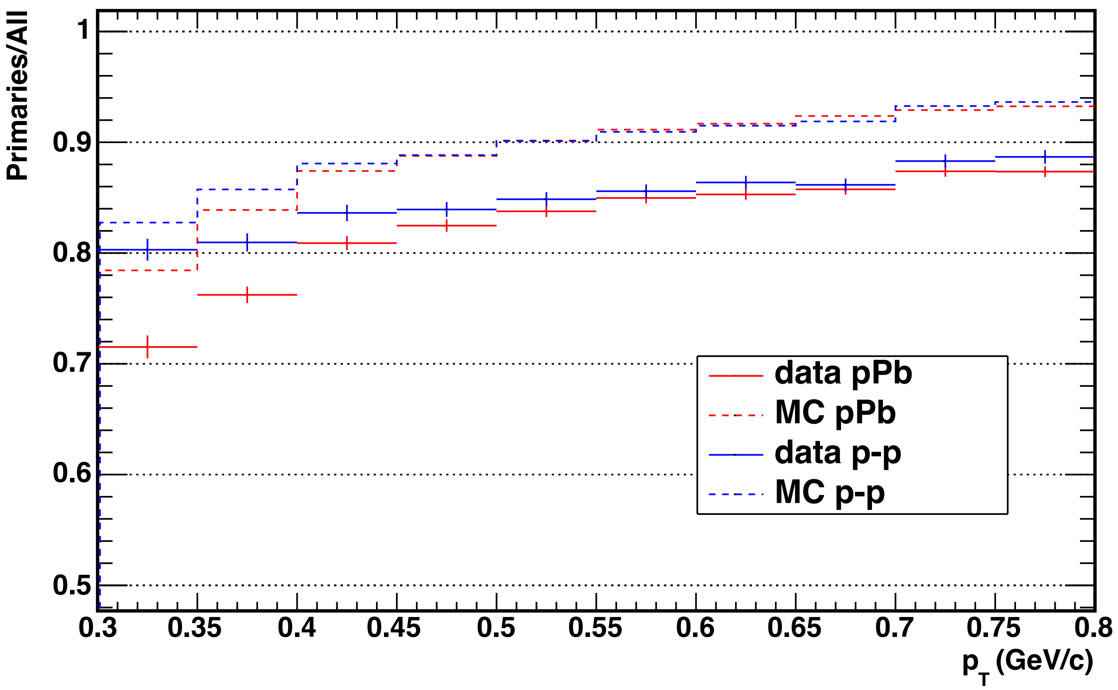
Secondary contribution in the proton yield (from DCA fit)



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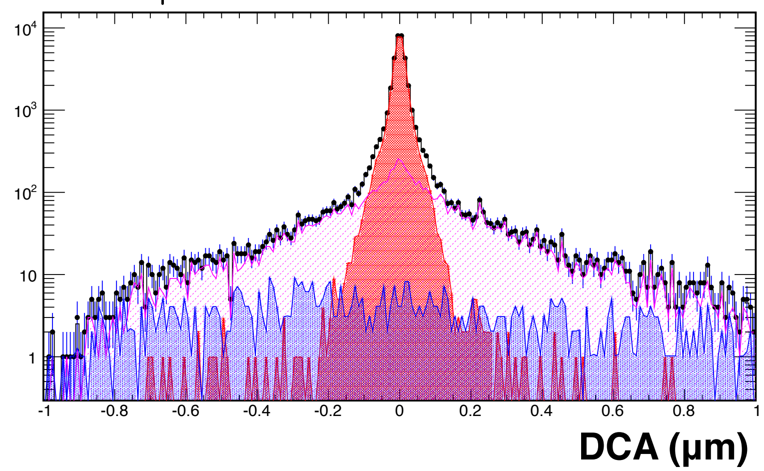
DCA Fit 450< p <500 MeV



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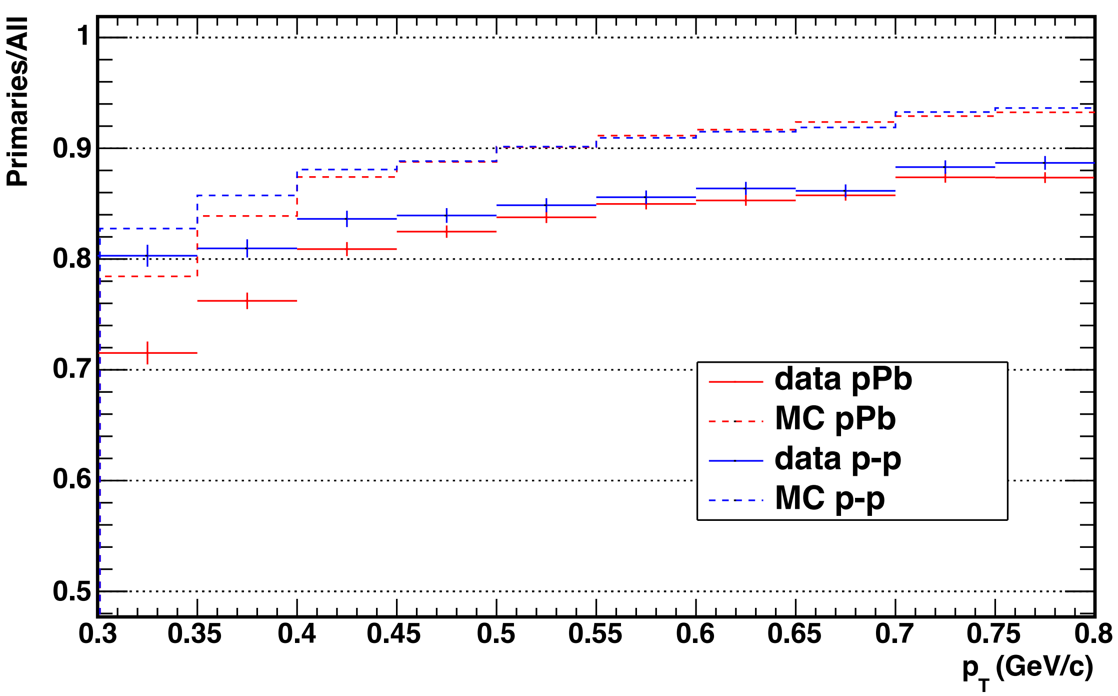


data/MC correction (~%1) for π and then included in the systematic and negligible for K

Systematic Errors

Main source of systematic errors:

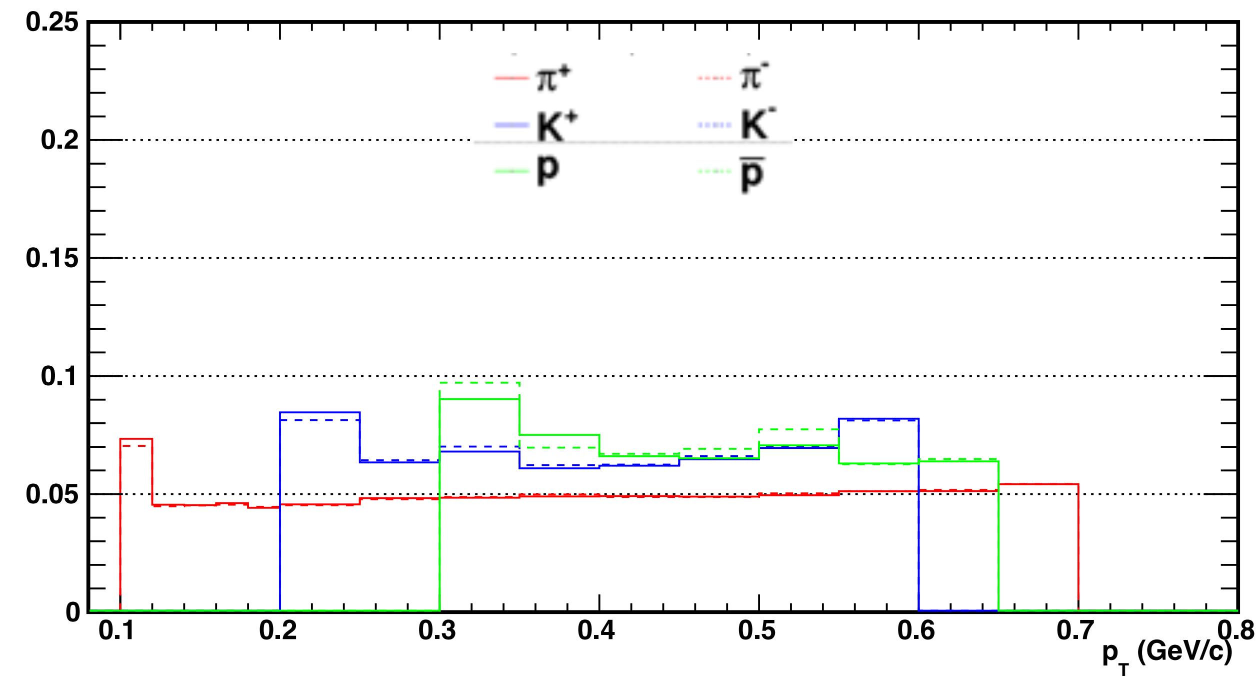
1. ITSsa Tracking
   - Track selection criteria

     (varying track cuts inside a reasonable range)
   - Tracking efficiency
2. PID approach

   (spectra comparison using different PID techniques, **Bayesian PID**/Nsigma PID)
3. Material budget

   (material budget was varied by ± 7.5%)

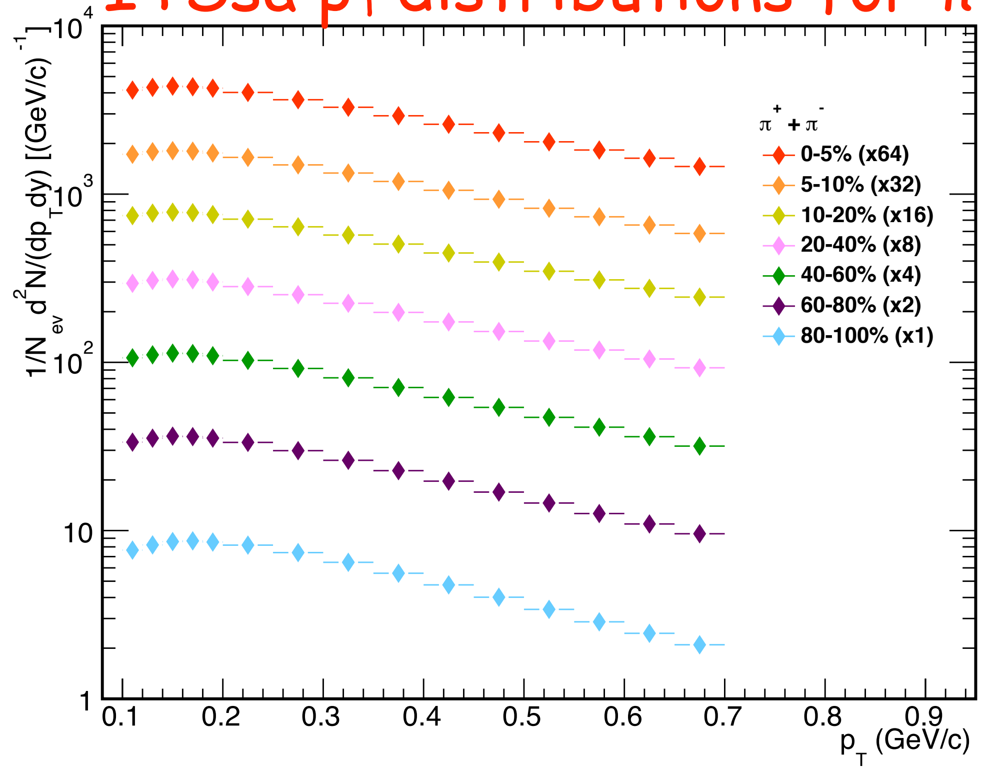
DCA cut (5, **7**, 10 σ)
χ^2/ITS clusters (**2.5**, 5)
ITS clusters (**1SPD + 3 SDD+SSD**,
1 SPD + 4 SDD+SSD,
2 SPD + 4 SDD+SSD)

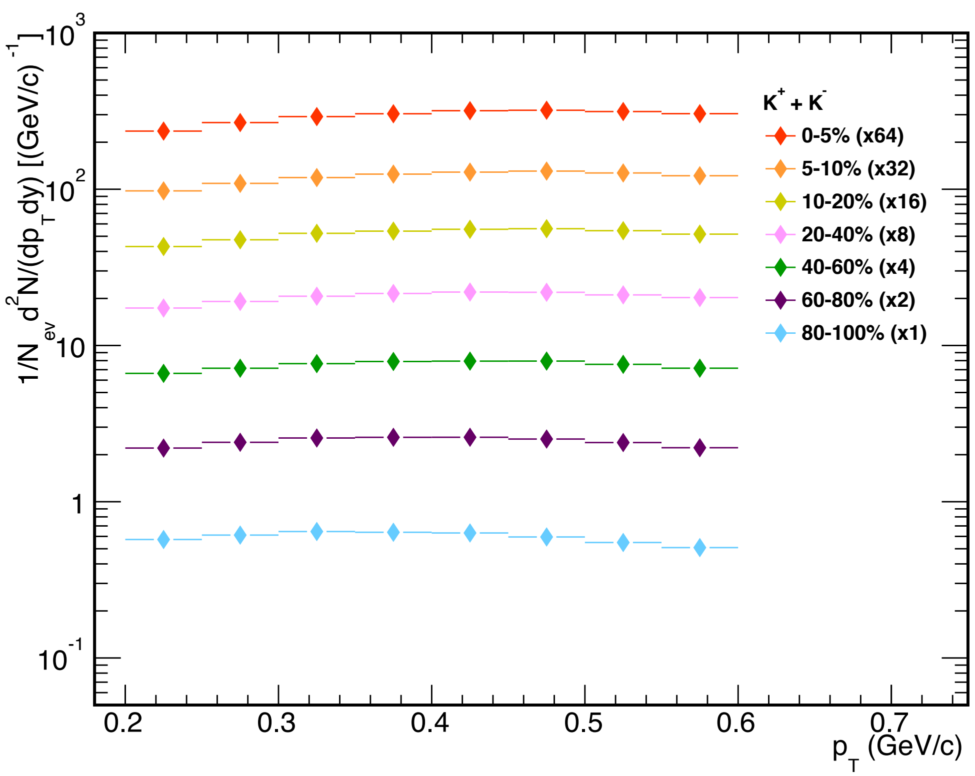


Total systematic obtained by summing in quadrature

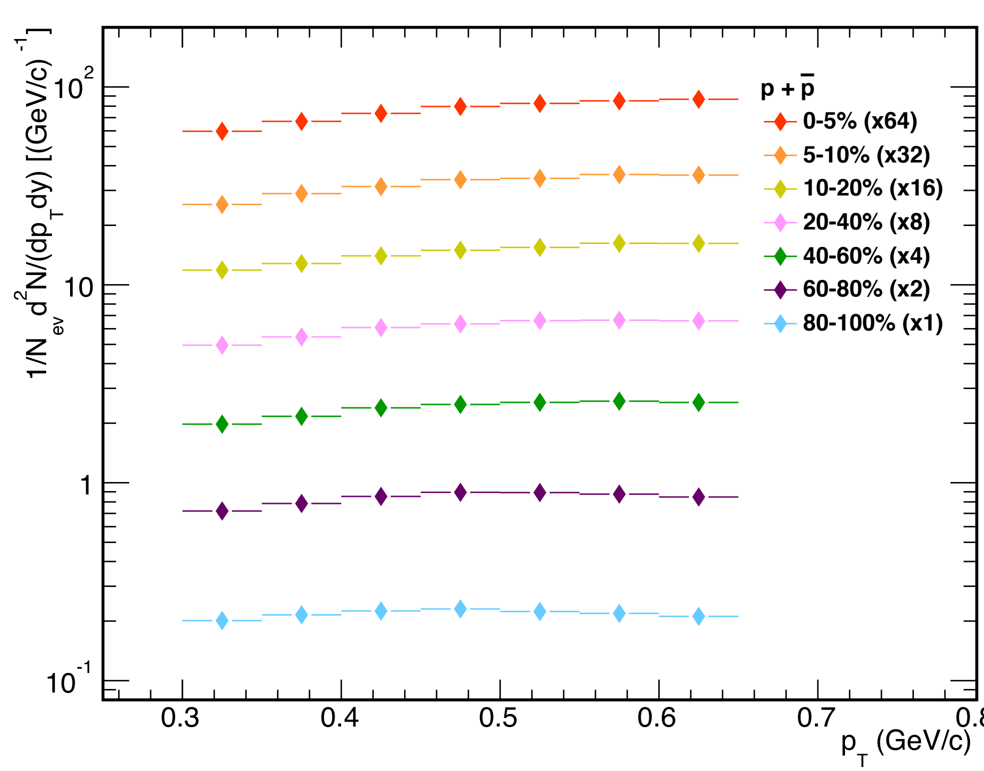
Finally… ITSsa p_T spectra

ITSsa p_T distributions for π



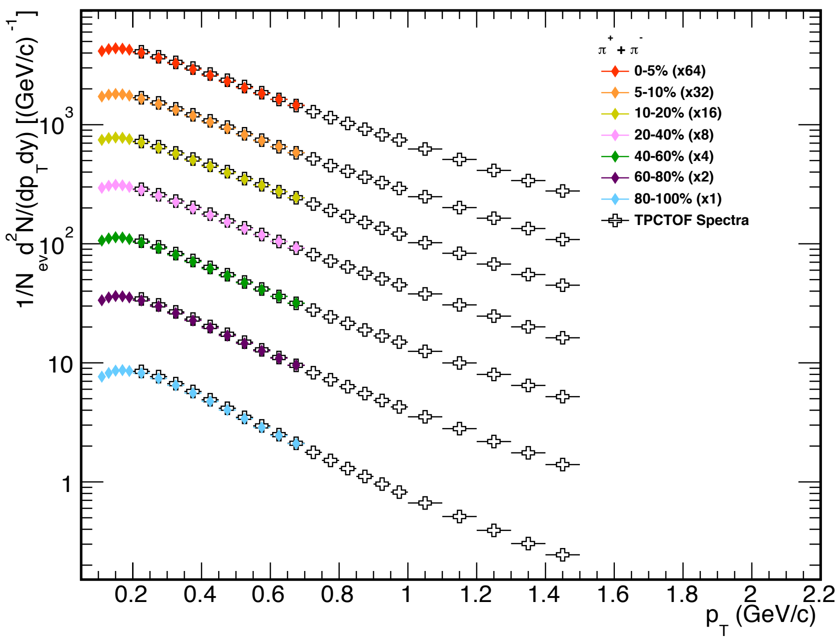


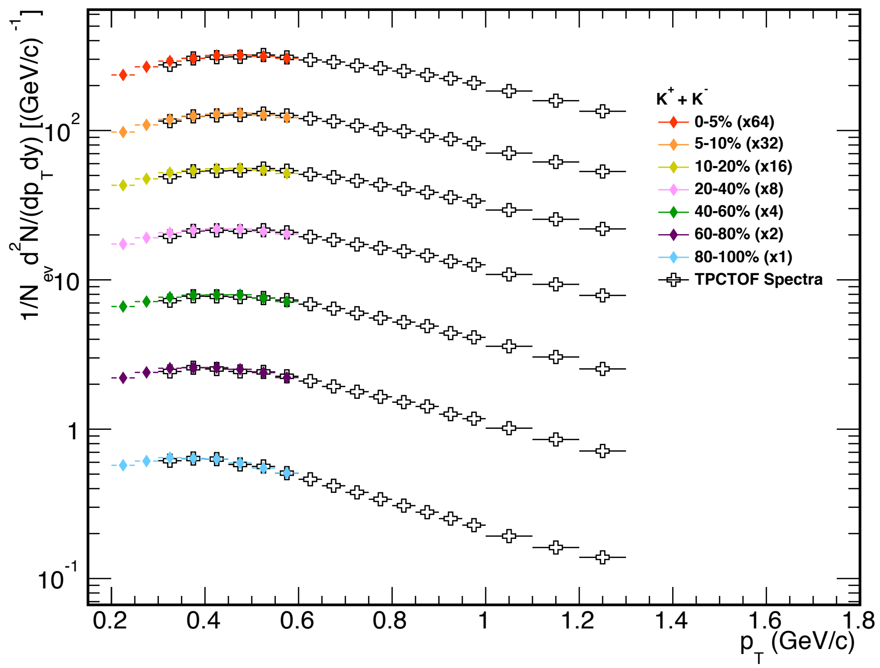
ITSsa p_T distributions for K

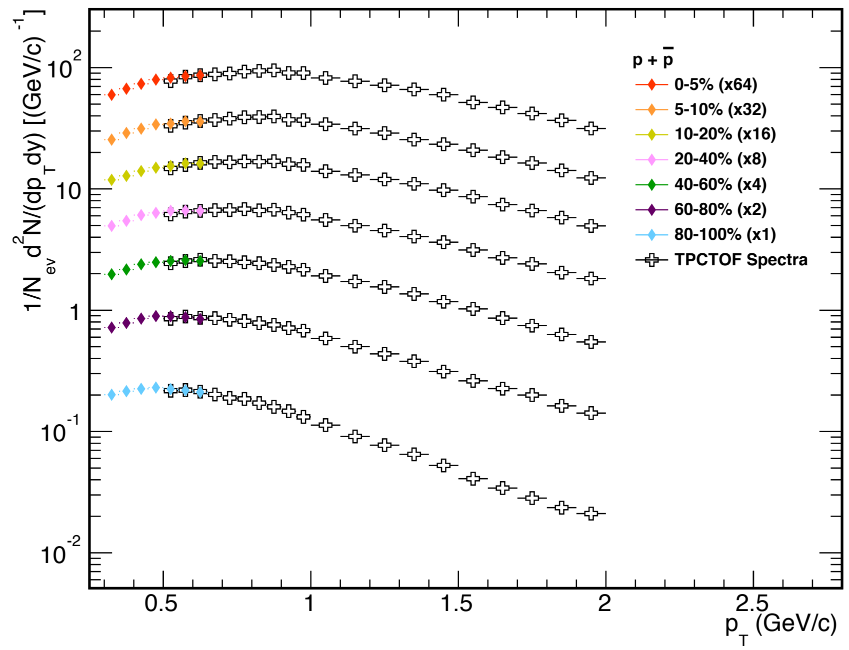


ITSsa p_T distributions for p

ITSsa/TPC-TOF cross check

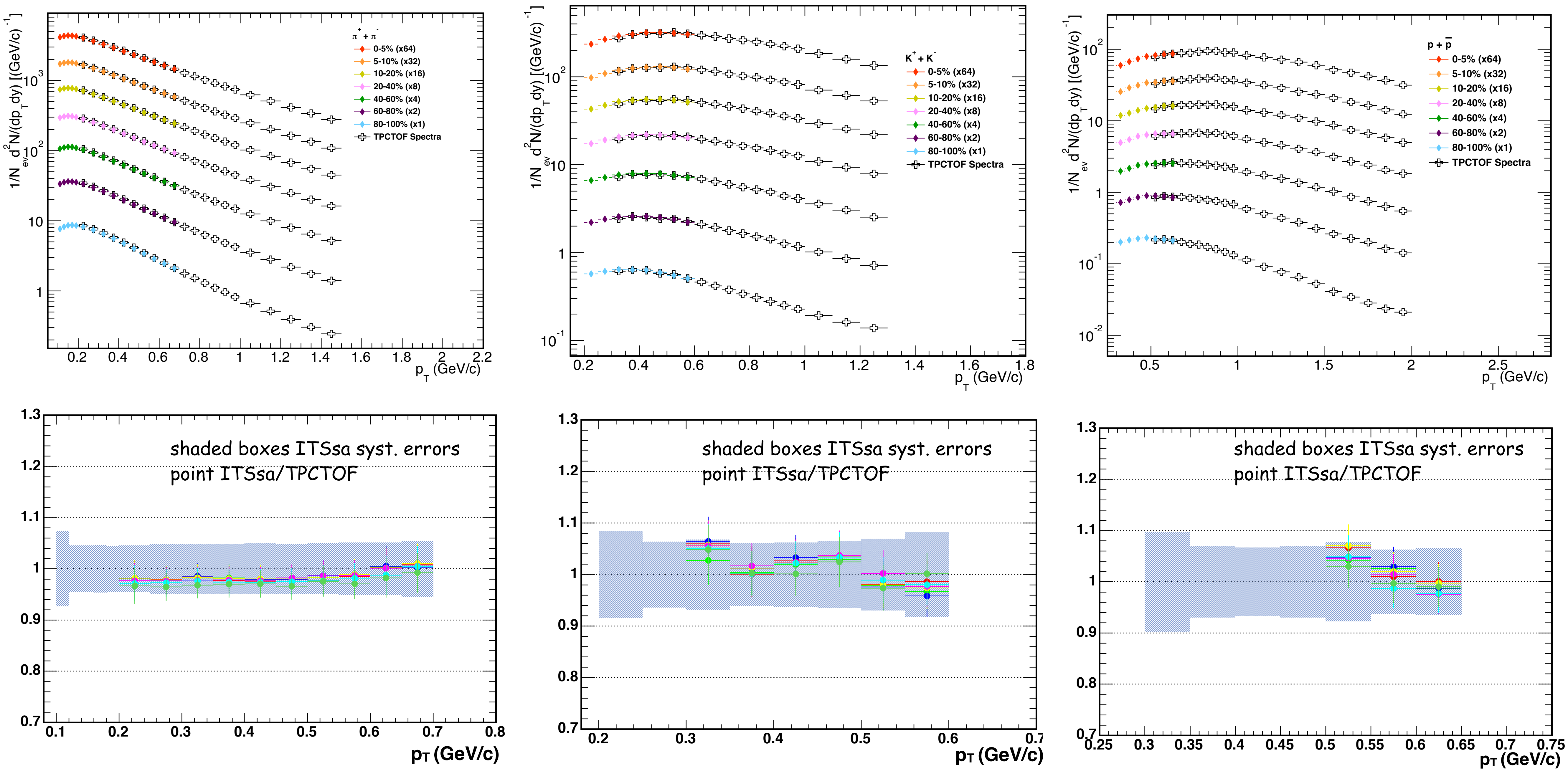






ITSsa/TPC-TOF comparison.

ITSsa/TPC-TOF cross check



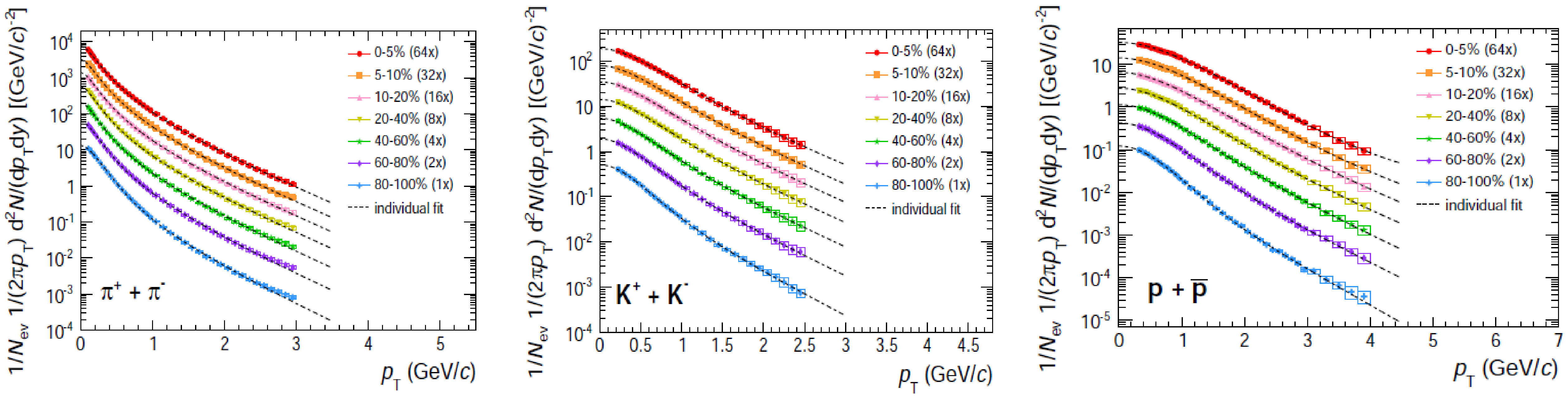
ITSsa/TPC-TOF comparison.

very good agreement between ITSsa and TPC-TOF in the common p_T range for all multiplicity classes

Combined Spectra Results

Transverse momentum distributions in p-Pb

Physics Letters B 728 (2014) 25–38

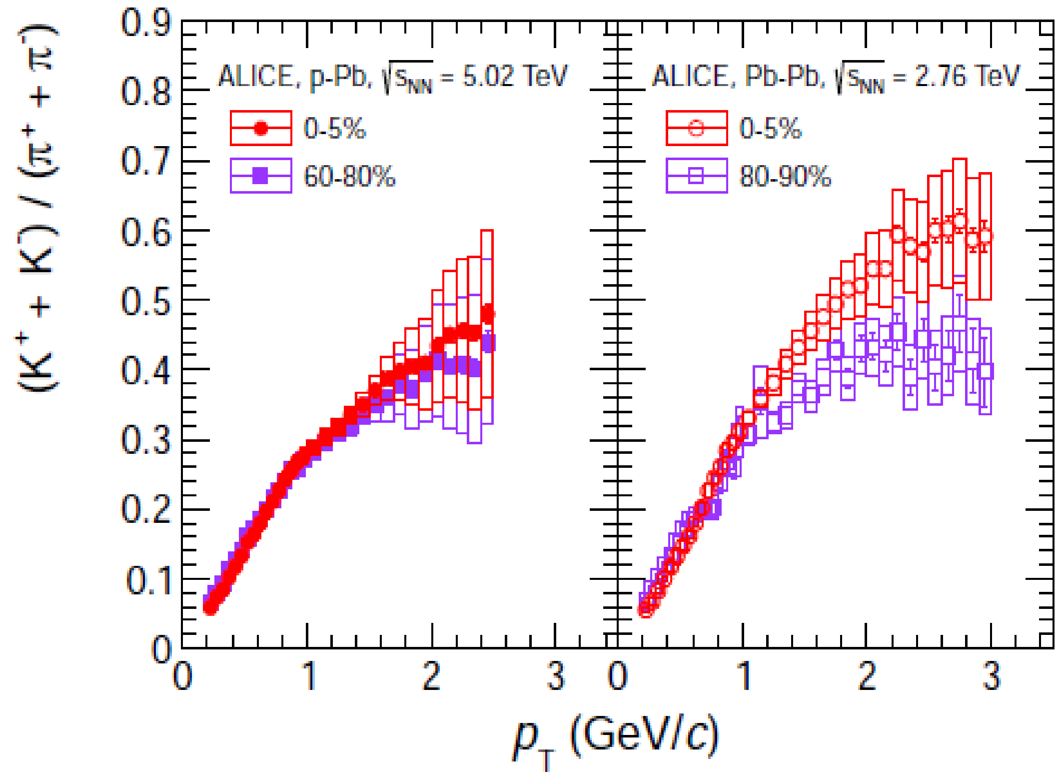


- p_T distribution in several VZERO-A multiplicity classes ($0 < y_{cms} < 0.5$)
  - The dotted lines represent individual Blast-Wave fits for low/high p_T extrapolation
- The p_T distribution shows a clear evolution, becoming harder as the multiplicity increases (in particular for p).
- Increase of the slope at low p_T(similar in Pb-Pb)
  - This trend is evident looking at the ratios, K/π, p/π, as a function of p_T

Particle ratio vs. transverse momentum

Physics Letters B 728 (2014) 25–38

systematic errors are largely correlated across multiplicity



K/π vs p_T

- Weak evolution with multiplicity in p-Pb
  - → small increase at intermediate p_T with increasing VZERO-A multiplicity
  - → corresponding small depletion in the low p_T region
- hint at similar behavior to that observed in Pb-Pb collisions

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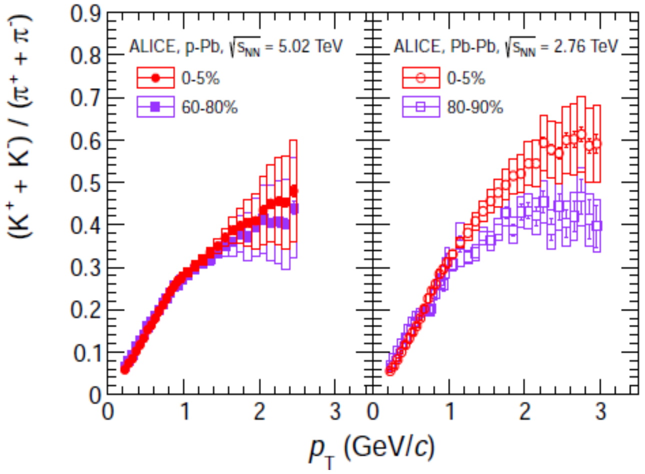
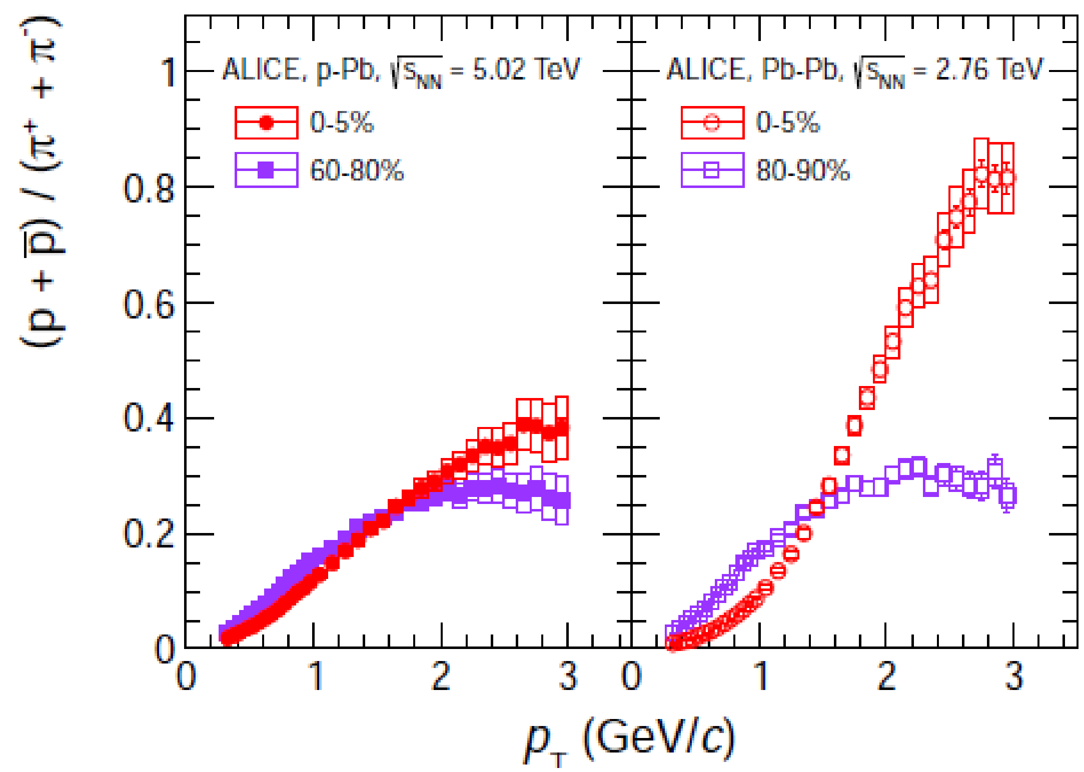
systematic errors are largely correlated across multiplicity





p/π vs p_T

- ➢ show similar behavior as observed in Pb-Pb collisions, but much weaker
  - → significant increase at intermediate p_T with increasing VZERO-A multiplicity
  - → corresponding significant depletion in the low p_T region
  - → stronger enhancement than K/π
- ➢ Pb-Pb generally understood in terms of collective flow and/or recombination?

Mean p_T vs. charged multiplicity

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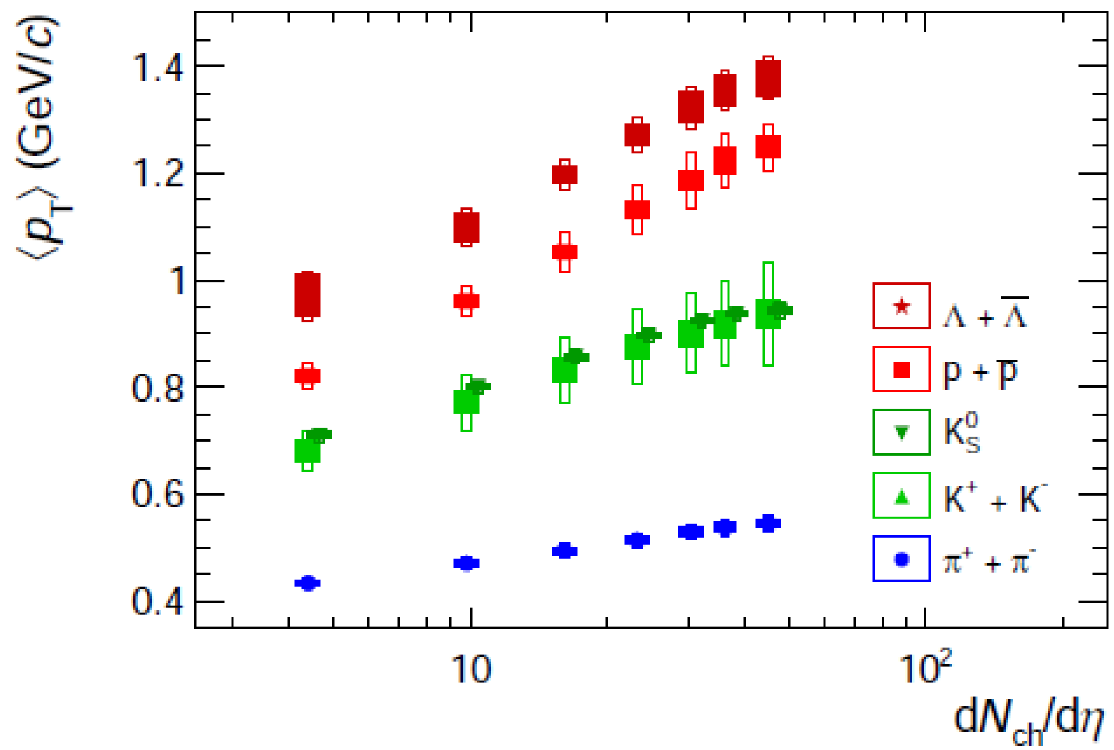
systematic errors are largely correlated across multiplicity



<pT > vs. dNch/dη   Extrapolation: 0 - 10 GeV/c

➢ <pT > increases with multiplicity (stronger for heavier particles)
Mass ordering: larger mass → larger <pT >

➢ Trend already observed in Pb-Pb collisions as a function of the multiplicity

Global Blast-wave fit parameters

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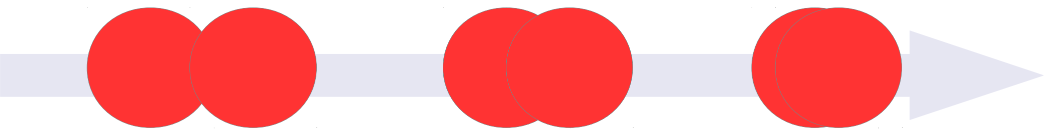


π/K/p Blast-wave analysis Schnedermann, PRC 48, 2462 (1993)

➢ p-Pb presents similar features as observed in Pb-Pb

→ parameters evolve with increasing multiplicity:

larger $\langle \beta_T \rangle$, smaller T_{fo}

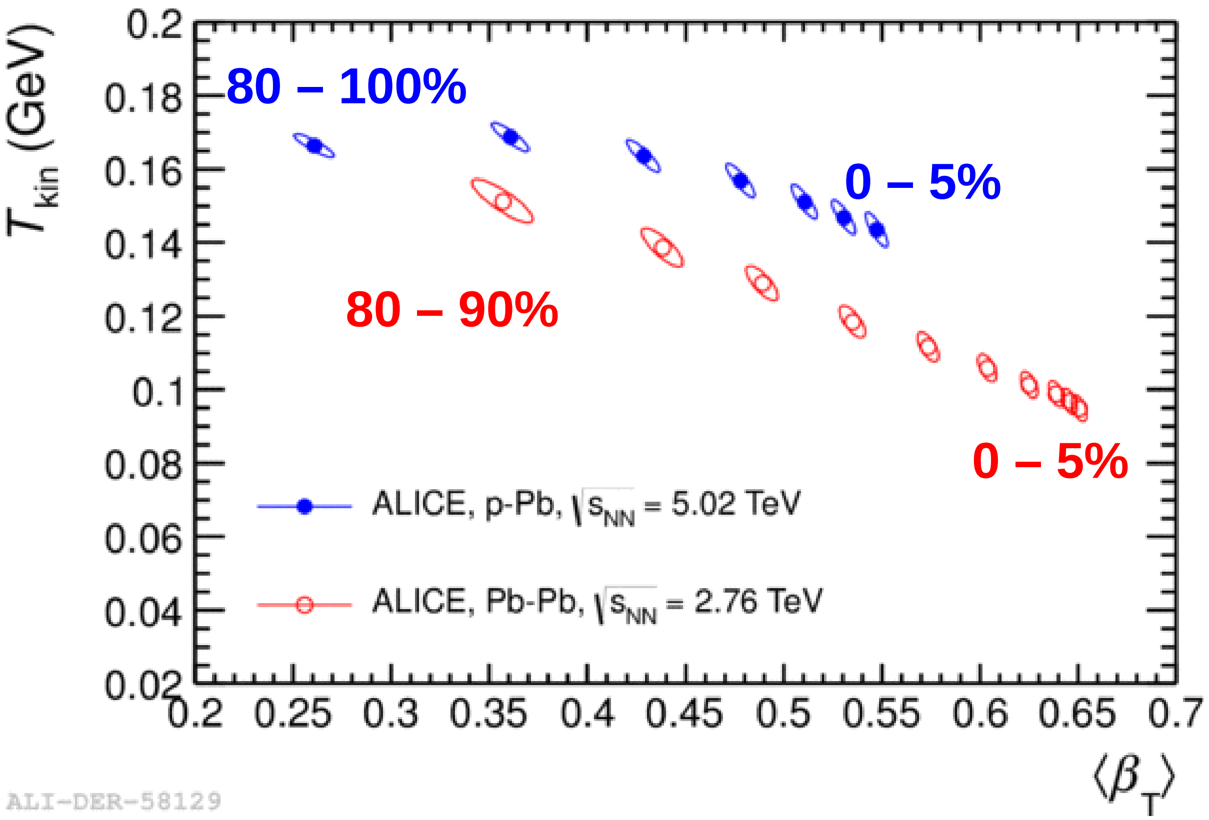
in Pb-Pb: hints at a more rapid expansion with increasing centrality.

→ T_{fo} is similar to Pb-Pb for similar multiplicity,

$\langle \beta_T \rangle$ is larger in p-Pb

in p-Pb: hints at a strong collective flow for small system size?

Shuryak, arXiv:1301.4470 [hep-ph]



Global fit performed in the p_T ranges:

same for p-Pb and Pb-Pb

π	→	0.5 – 1.0 GeV/c
K	→	0.2 – 1.5 GeV/c
p	→	0.3 – 3.0 GeV/c
K^0_S	→	0.0 – 1.5 GeV/c
Λ	→	0.6 – 3.0 GeV/c

Caveat: the extracted values of the fit parameters depend substantially on the fit range

Global Blast-wave fit parameters

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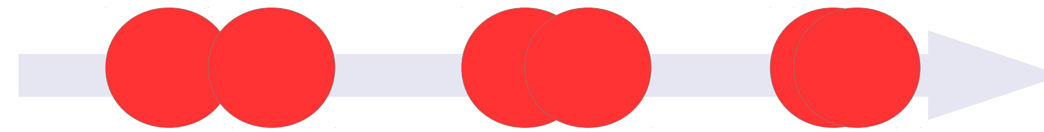

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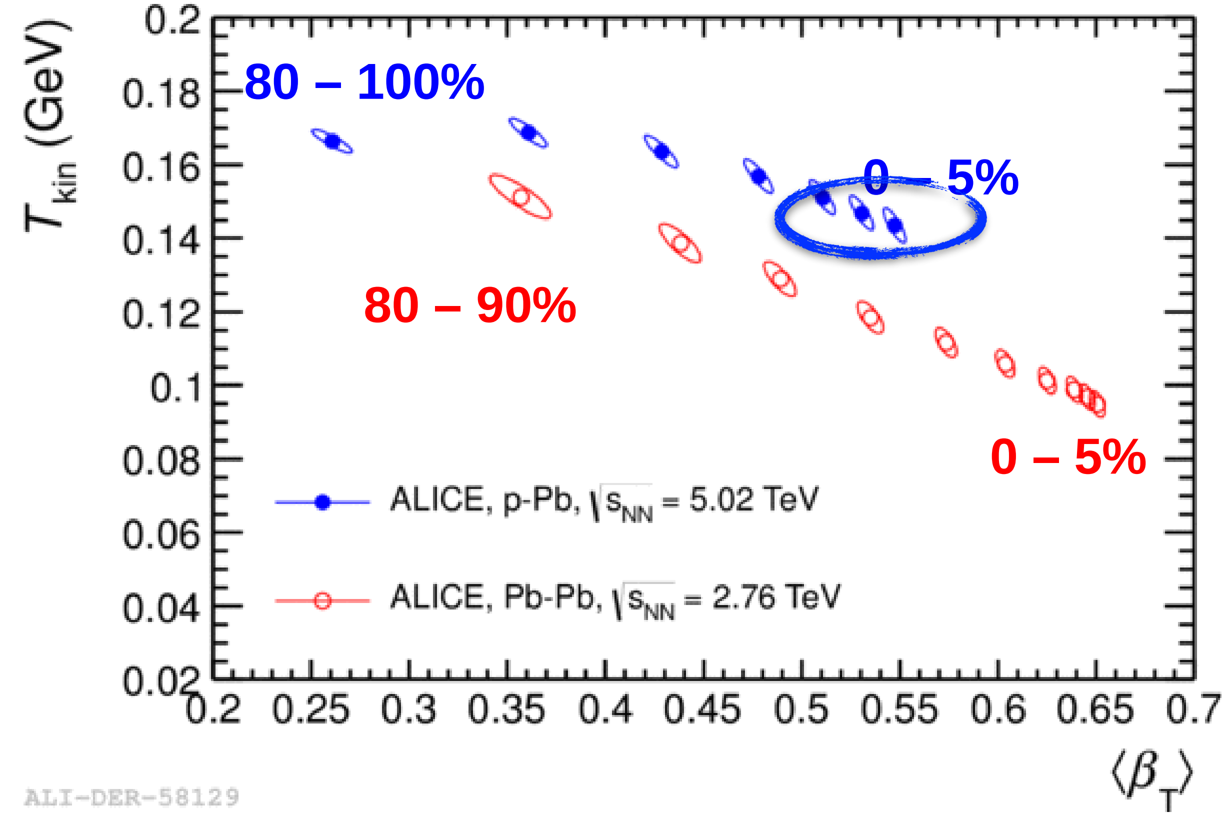

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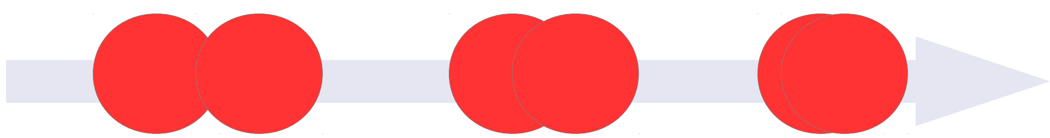

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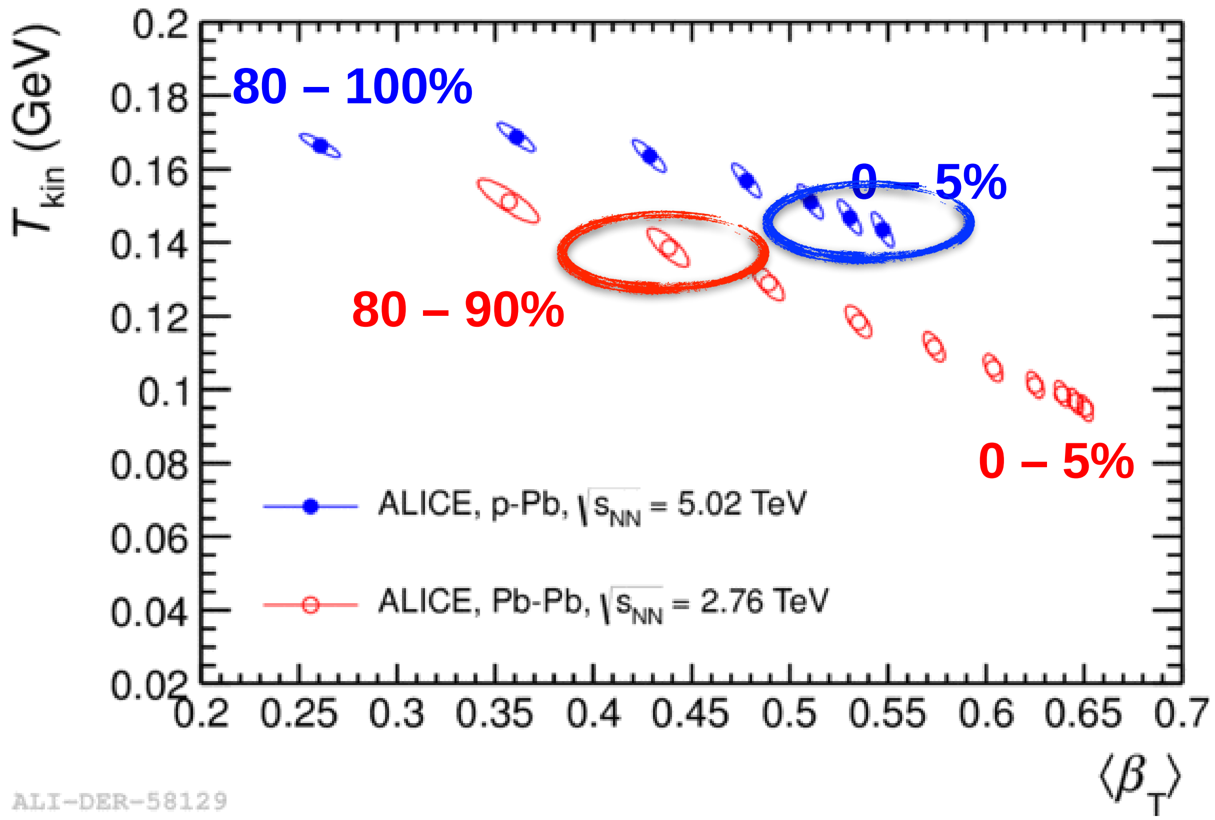

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Caveat: the extracted values of the fit parameters depend substantially on the fit range

Global Blast-wave fit parameters

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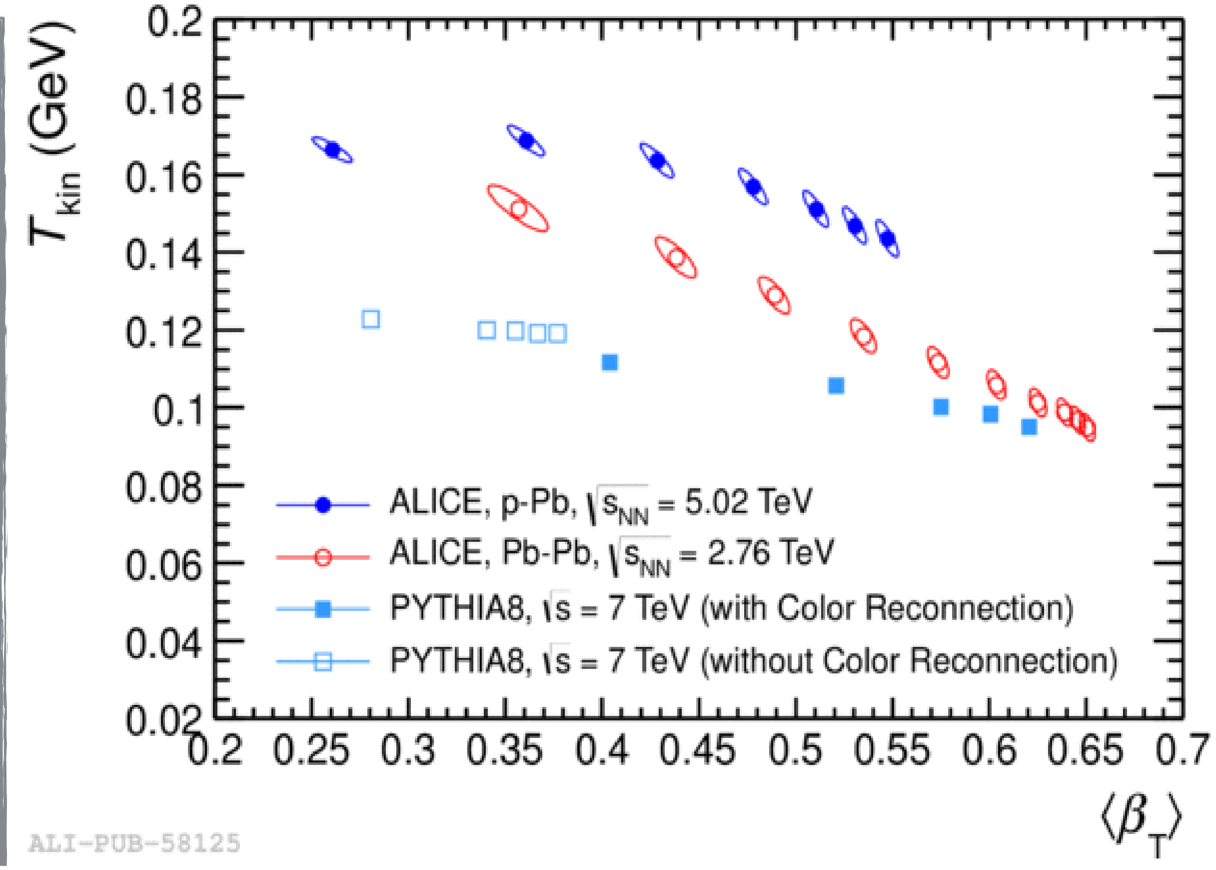
π/K/p Blast-wave analysis

➢Applied to output from the PYTHIA8 event generator with and without color reconnection (CR) (arXiv:1303.6326)

➢ If CR enabled: shows the same qualitative behavior.

→ but this model has no collective flow



➢Blast-Wave fit spectral analysis not yet conclusive to shed light on possible collective features (radial flow) predicted in high-multiplicity p-Pb

→ data do not exclude hydro-like collective behavior

→ other final state mechanisms (CR) can mimic the radial flow

Models

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DPMJET (Roesler et al, arXiv:hep-ph/0012252)

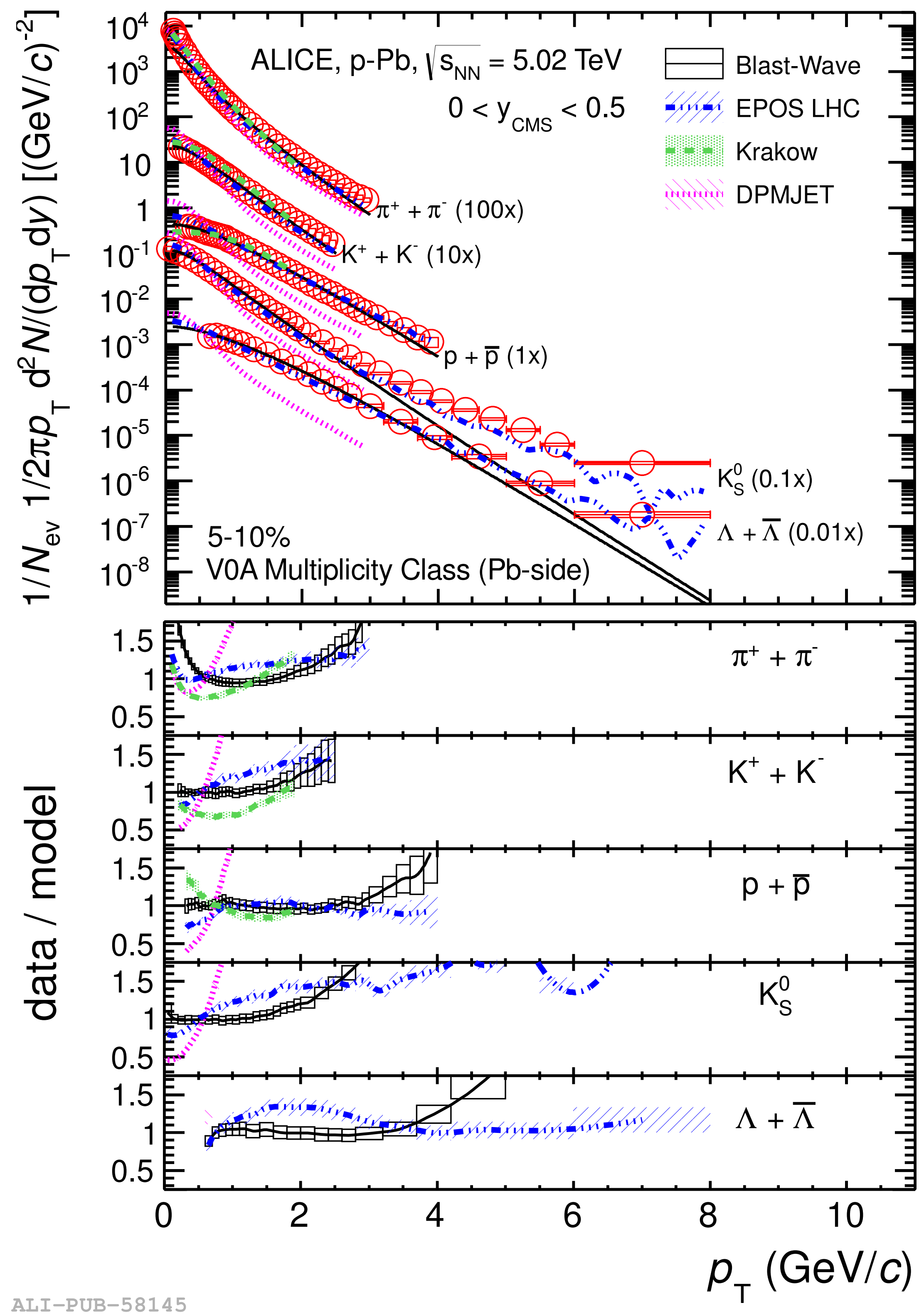
- Fails at low p_T
- Shape right above 1-1.5 GeV/c

Krakow (Bozek, PRC85, 014911 (2012))

- Glauber MC and 3+1 hydro
- Reasonable for π, K
- Good for p

EPOS LHC 1.99 v3400 (Pierog et al., arXiv:1306:0121)

- Flux tubes hadronizing as jets or contribution to the bulk (hydro)
- Reasonable for π
- Good for p
- Deviations for K and Λ



Summary and conclusions

About the ITS standalone:

- ➢ ITSsa has been used to extract identified hadron spectra at low p_T in ALICE.
- ➢ Bayesian approach provides better performance (lower contamination).

About the p-Pb combined spectra:

- ➢ ALICE has measured the p_T distributions of identified hadron in p-Pb for different multiplicity events.
- ➢ to Flow or not to Flow?
  - Data are consistent with the presence of radial flow in p–Pb collisions.
  - Other final state mechanisms (CR) can mimic the effect of radial flow.

- ➢ Models incorporating final state effects give a better description of the data. (Krakow & EPOS)

That's all …

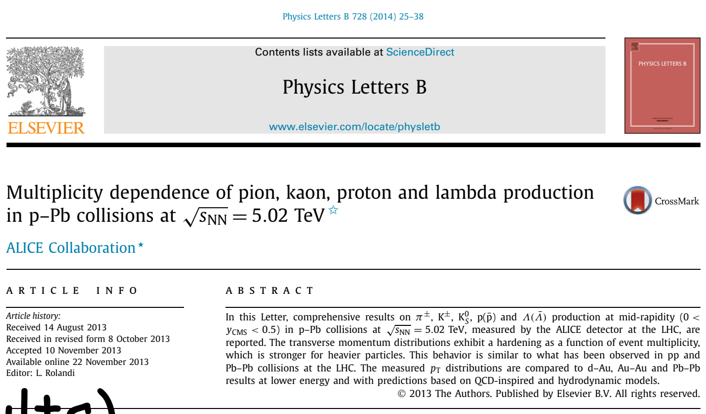
Thanks

My Work in detail…

up to now

PHYSICS ANALYSIS

- ITS PID (all the steps described here)
- Physics analysis from combined spectra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Physics Letters B

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Multiplicity dependence of pion, kaon, proton and lambda production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV ☆

ALICE Collaboration *

ARTICLE INFO

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ABSTRACT

In this Letter, comprehensive results on $\pi^{\pm}$, $K^{\pm}$, K^0_S, $p(\bar{p})$ and $\Lambda(\bar{\Lambda})$ production at mid-rapidity ($0 < y_{CMS} < 0.5$) in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV, measured by the ALICE detector at the LHC, are reported. The transverse momentum distributions exhibit a hardening as a function of event multiplicity, which is stronger for heavier particles. This behavior is similar to what has been observed in pp and Pb–Pb collisions at the LHC. The measured p_T distributions are compared to d–Au, Au–Au and Pb–Pb results at lower energy and with predictions based on QCD-inspired and hydrodynamic models.

p-Pb (final and published) & p-p @ 2.76 TeV (preliminary results)

ITS performance

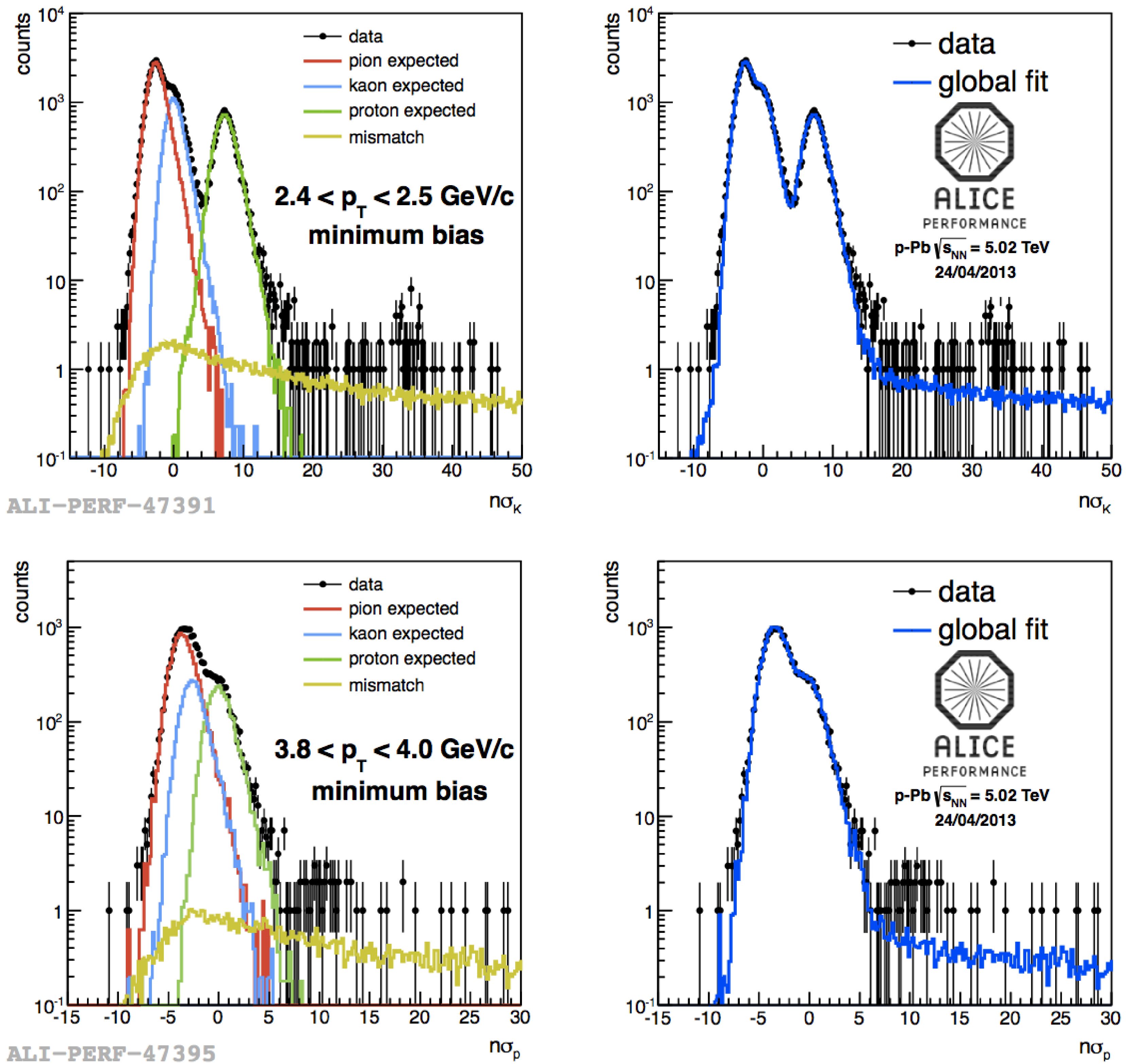
- Bayesian approach PID (parameterization, priors estimation…)
- test on new SDD acquisition card (superCARLOSrx)

future work…

ITSsa analysis on p-p @ 900 GeV Re-Analysis & final results for p-p @ 2.76 TeV

paper on p-p (comparison for all energy)

Backup…



counts
data
pion expected
kaon expected
proton expected
mismatch
2.4 < p_T < 2.5 GeV/c
minimum bias
nσ_K
ALI-PERF-47391
global fit
ALICE
PERFORMANCE
p-Pb √s_NN = 5.02 TeV
24/04/2013
3.8 < p_T < 4.0 GeV/c
minimum bias
nσ_p
ALI-PERF-47395

Blast-wave (p-Pb spectra-shape) analysis.

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Hydro-motivated Blast-wave model

(assumption: locally thermalized medium, expanding collectively with a common velocity field and undergoing an instantaneous common freeze-out)

Schnedermann, PRC 48, 2462 (1993)

aims at characterizing spectral shapes in V0A multiplicity classes with a small set of parameters

Simultaneous fits to all particles

with 3 common parameters:

$\langle\beta_T\rangle$ radial flow

T_{fo} thermal freezeout temperature

n velocity profile

Global fit performed in the p_T ranges:

- π → 0.5 – 1.0 GeV/c
- K → 0.2 – 1.5 GeV/c
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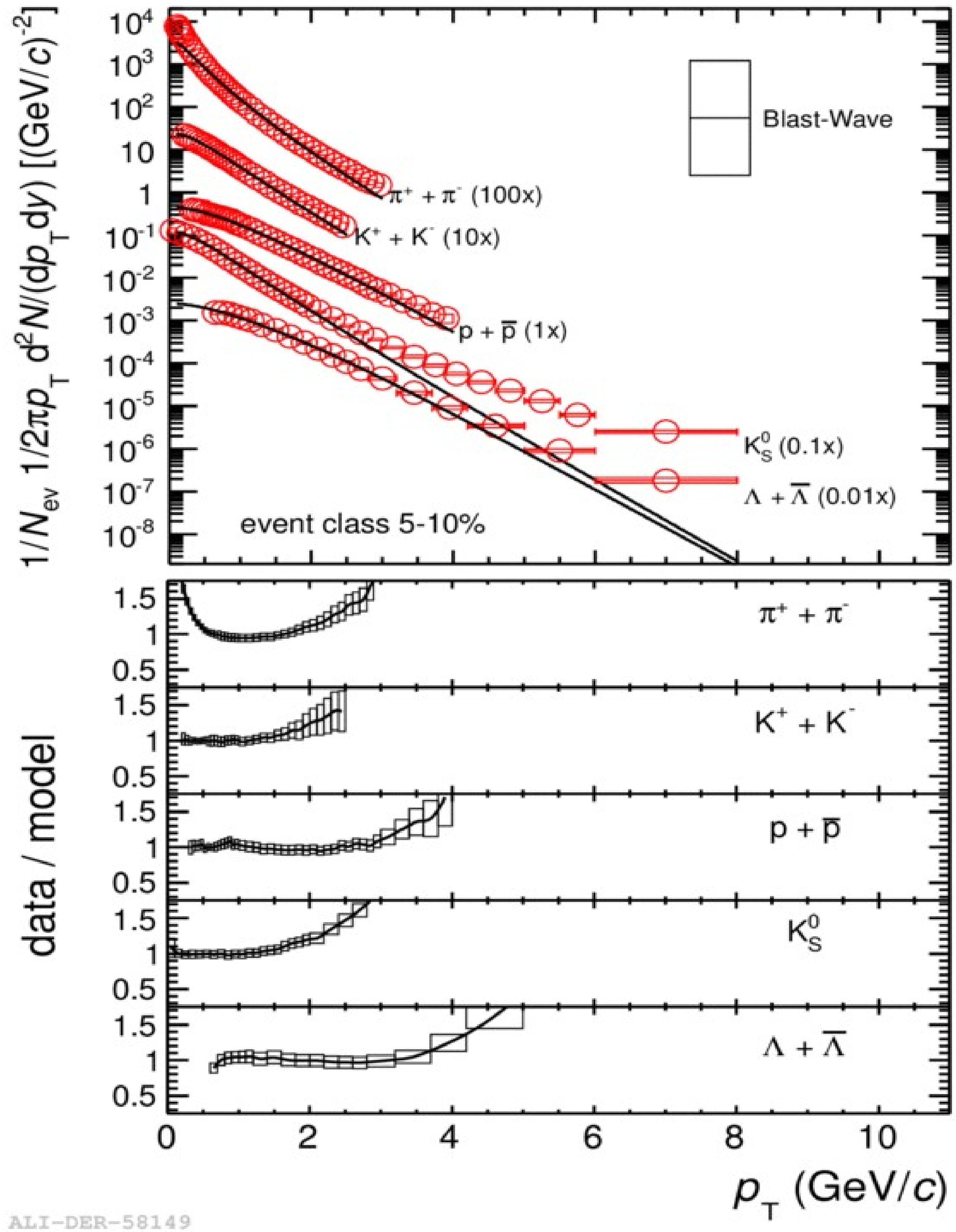

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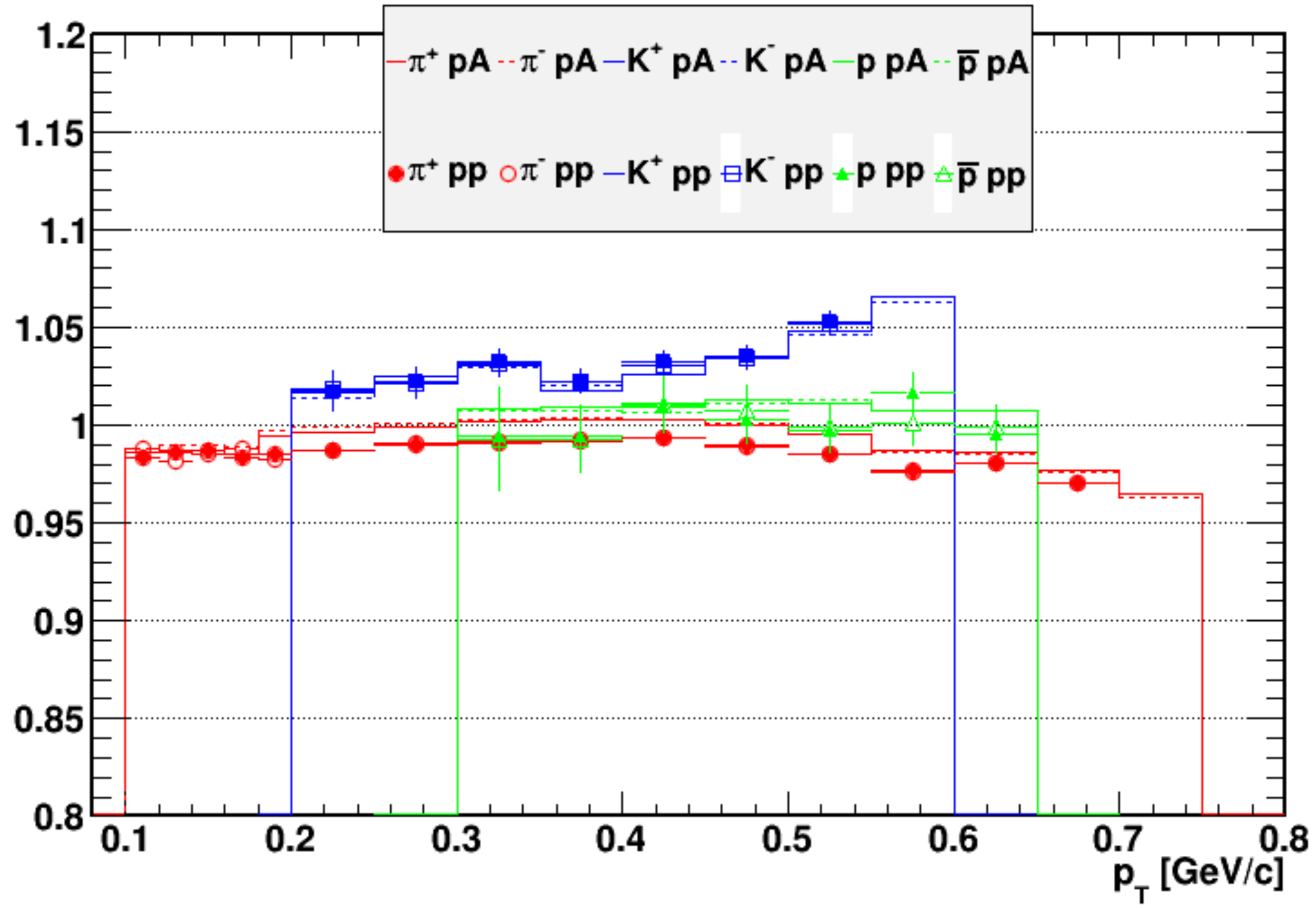
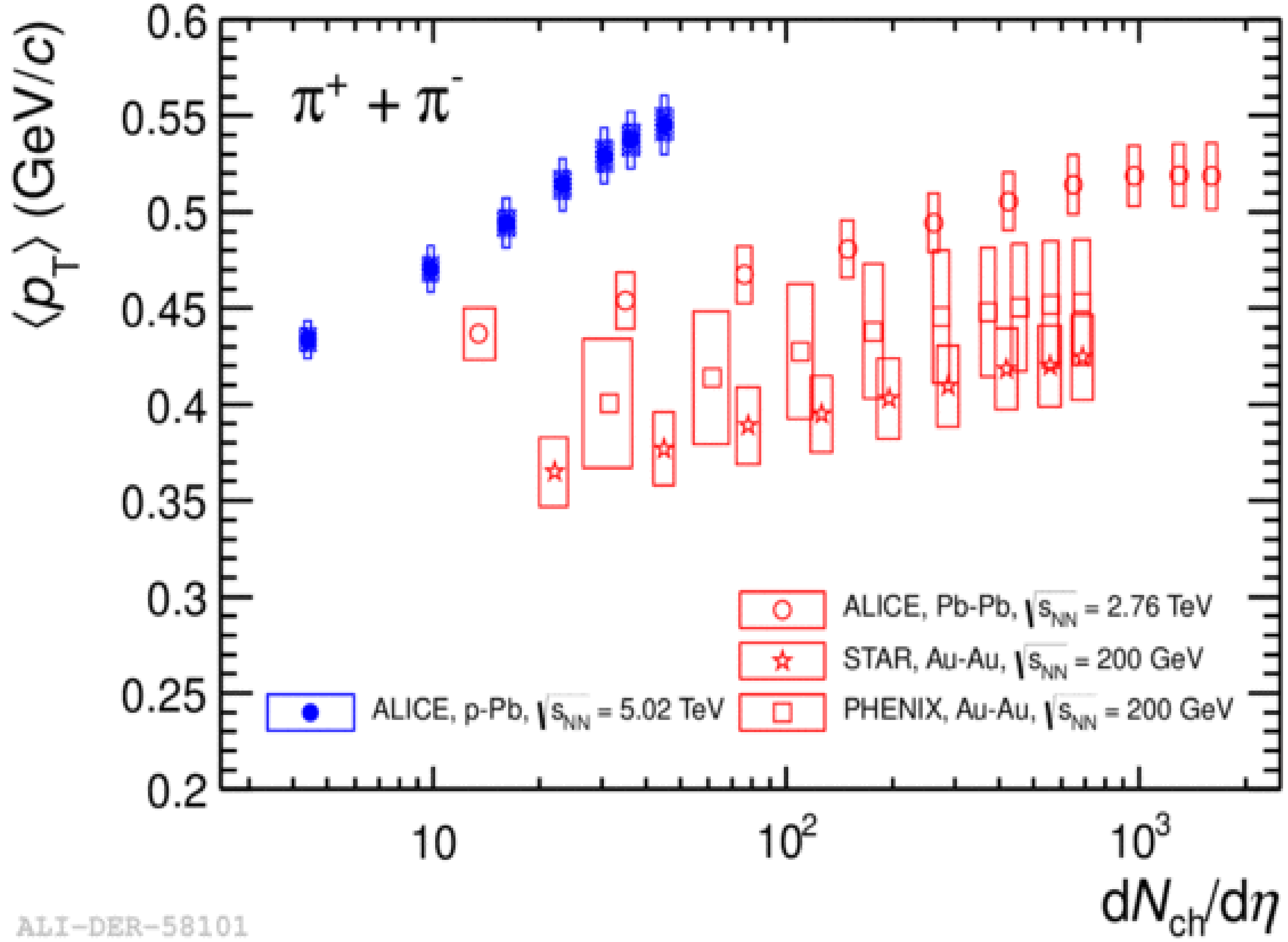


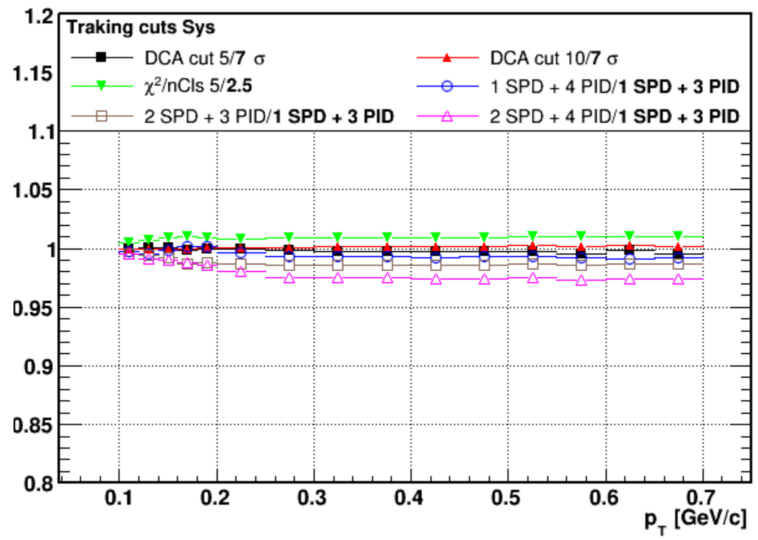
π^+ pA
π^- pA
K^+ pA
K^- pA
p pA
$\bar{p}$ pA
π^+ pp
π^- pp
K^+ pp
K^- pp
p pp
$\bar{p}$ pp
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
p_T [GeV/c]

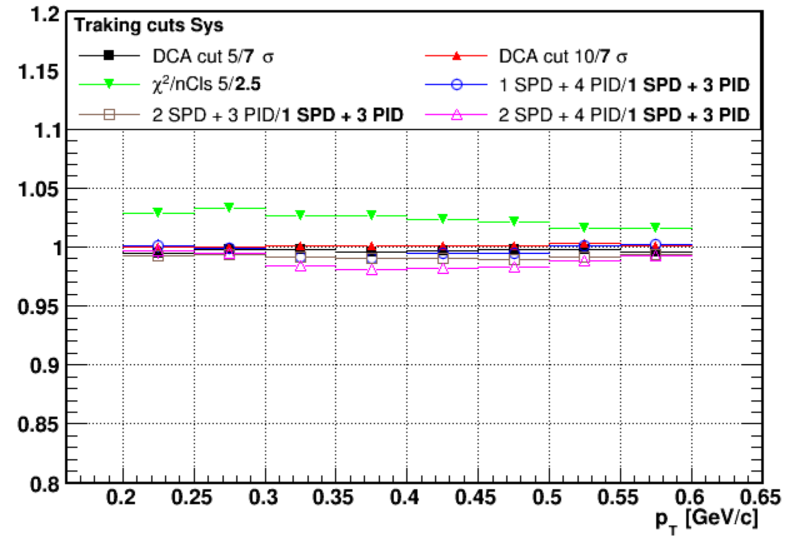
Backup…

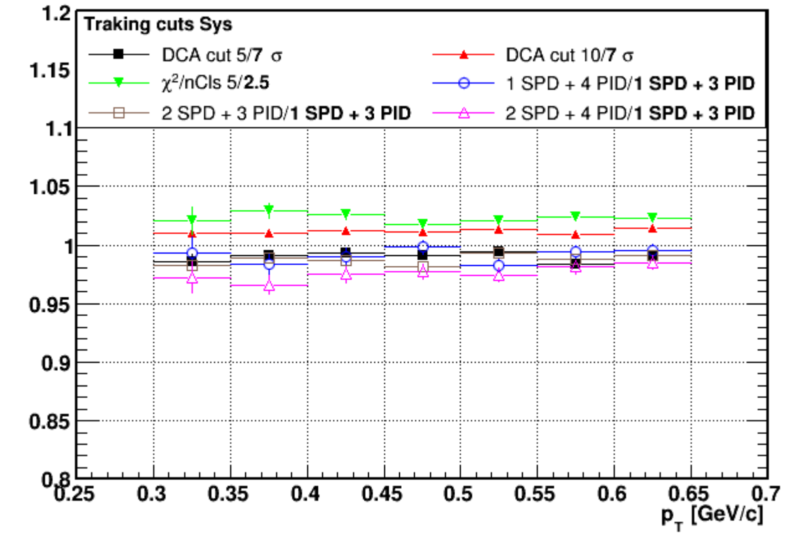


$\pi^+ + \pi^-$
$\langle p_T \rangle$ (GeV/c)
$dN_{ch}/d\eta$
ALICE, p-Pb, $\sqrt{s_{NN}}$ = 5.02 TeV
ALICE, Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
STAR, Au-Au, $\sqrt{s_{NN}}$ = 200 GeV
PHENIX, Au-Au, $\sqrt{s_{NN}}$ = 200 GeV
ALI-DER-58101

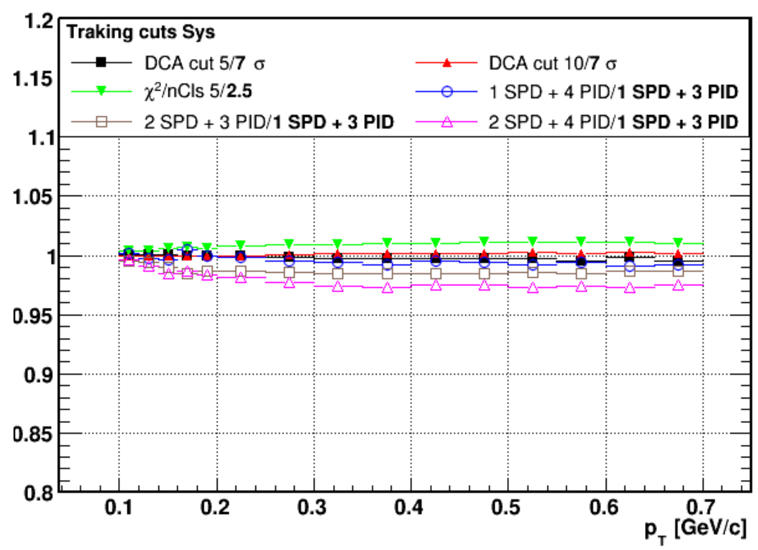
Trk sys. positive particles

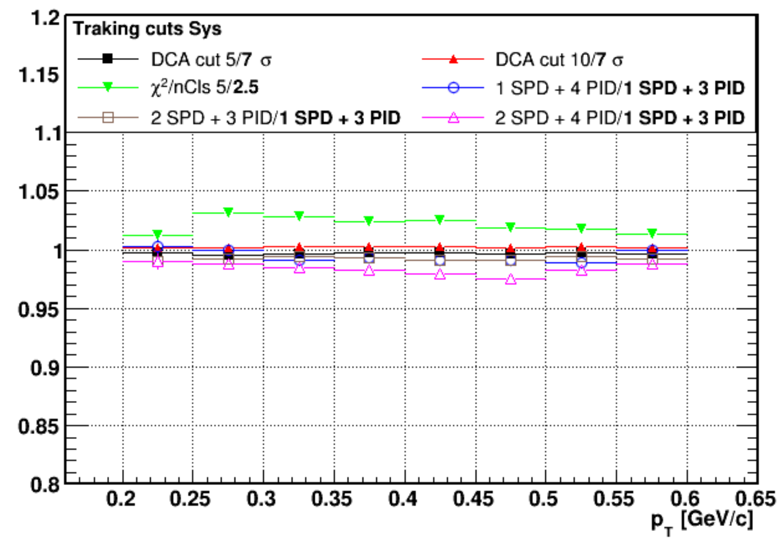


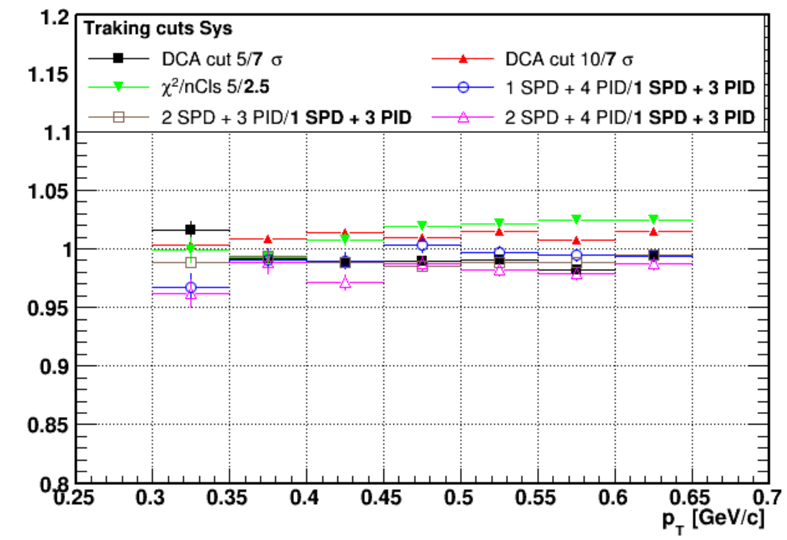




Pion Kaon Proton







Trk sys. negative particles