Study of K^{*0} and ϕ Meson Production in proton+proton Collisions with ALICE at the LHC and Universality of Particles Production in HEP

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Physics Topics

- **Resonance Production in pp collisions in ALICE**
- **Pythia MC Simulation Study:**
  - Intriguing similarities between high-p_T particle production in pp and A-A collisions

    [Phys. Rev. C 99, 034911 (2019)]
  - Parton energy loss in pp collisions at very high multiplicity

    [arXiv:1905.06918 (2019)]

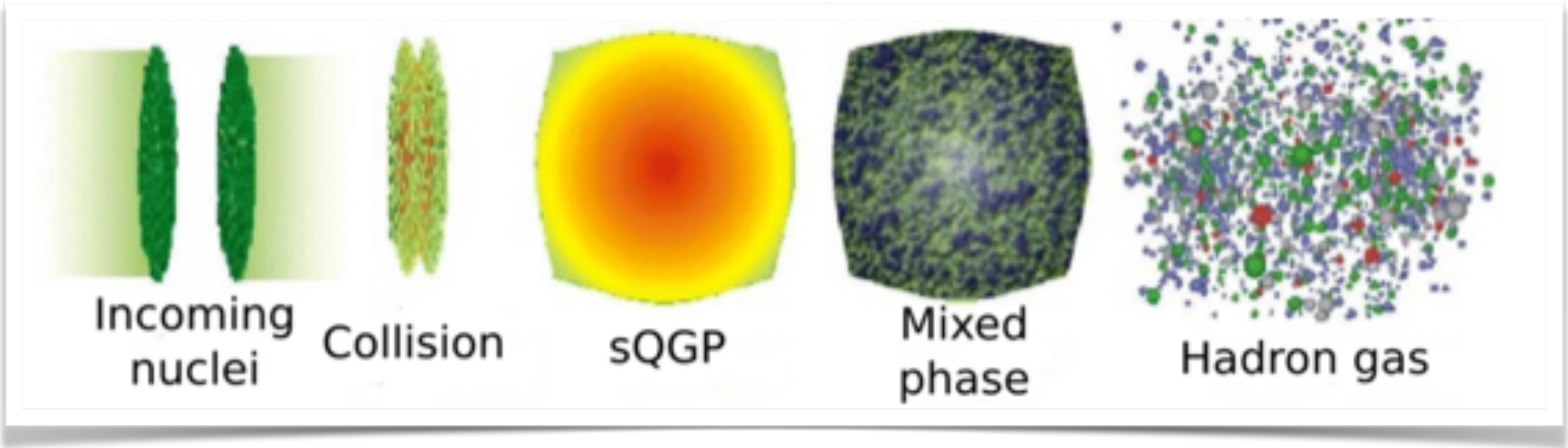
Study of K^{*0} and ϕ Meson Production in proton+proton Collisions with ALICE at the LHC

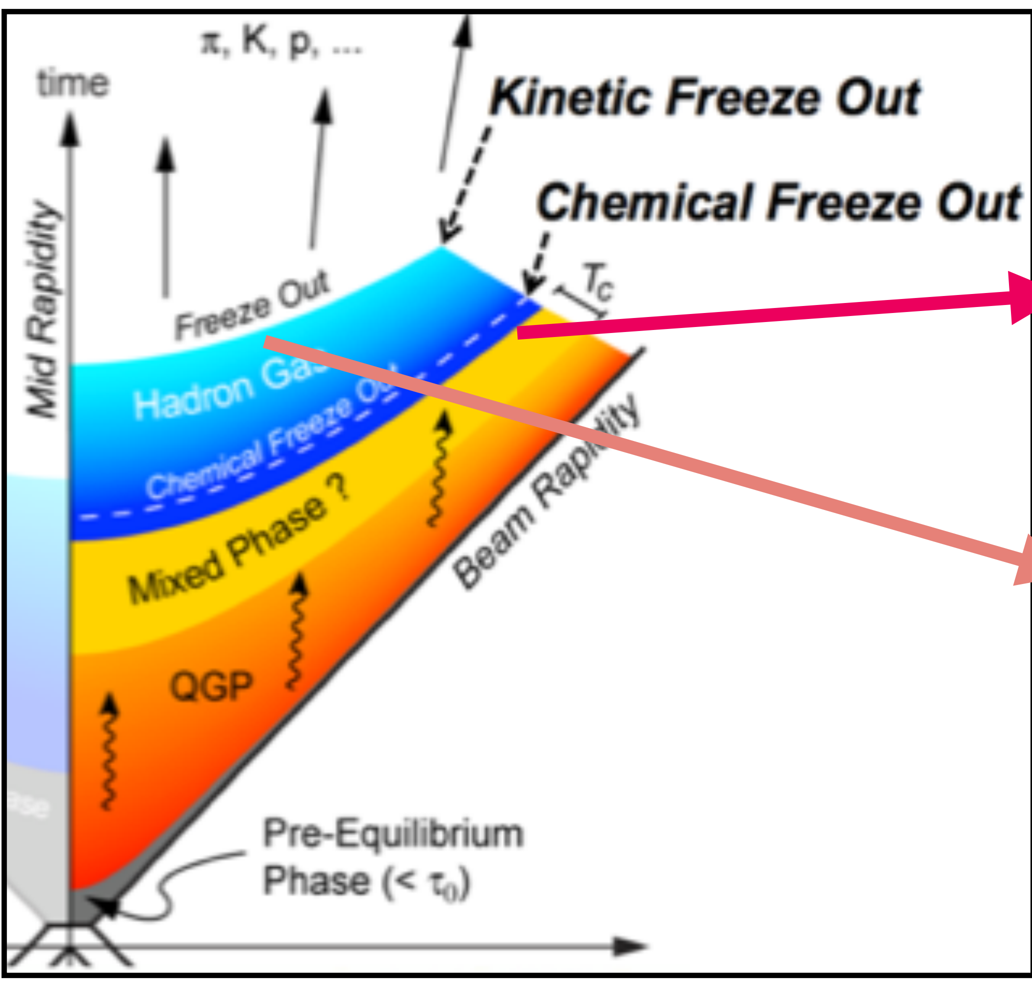
Outline:

[arXiv:1910.14410] (ALICE Collaboration)

- Motivation
- Data Set and Analysis Details
- Systematic Uncertainties Calculation
- Corrected p_T spectra
- dN/dy, $\langle p_T \rangle$, Model Comparison
- Summary

Motivation





Properties of Hadronic phase:
(lifetime, density)

Chemical freeze out:
The inelastic processes cease and the particle yields (and relative abundances) are fixed

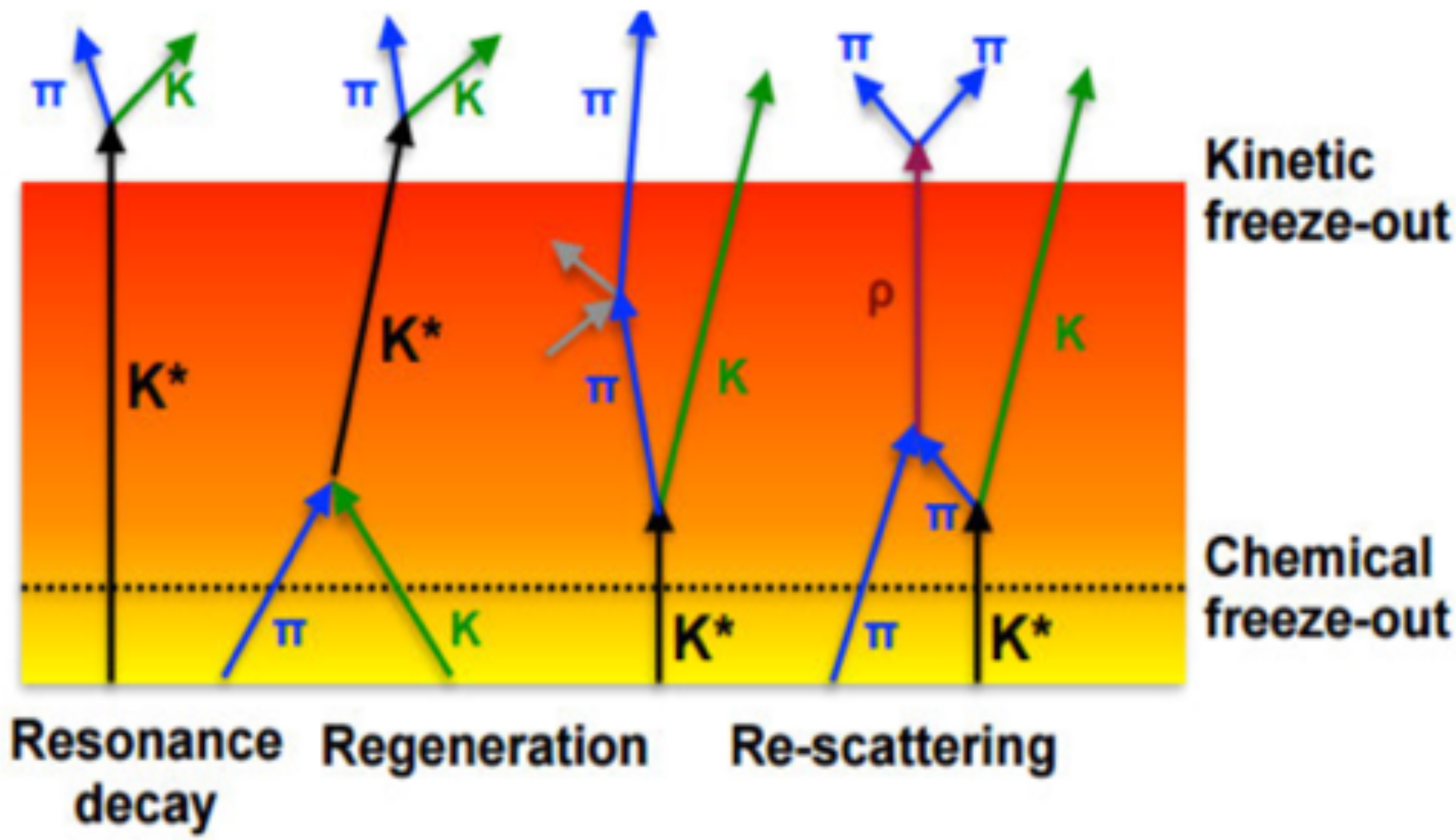
Kinetic freeze out:
The elastic processes cease and the particle p_T spectra are fixed

Hadronic Phase

Resonance yields in heavy-ion collisions are defined by:

Resonance yields at chemical freeze-out

Hadronic processes between chemical and kinetic freeze-outs



Hadronic Phase

Resonance yields in heavy-ion collisions are defined by:

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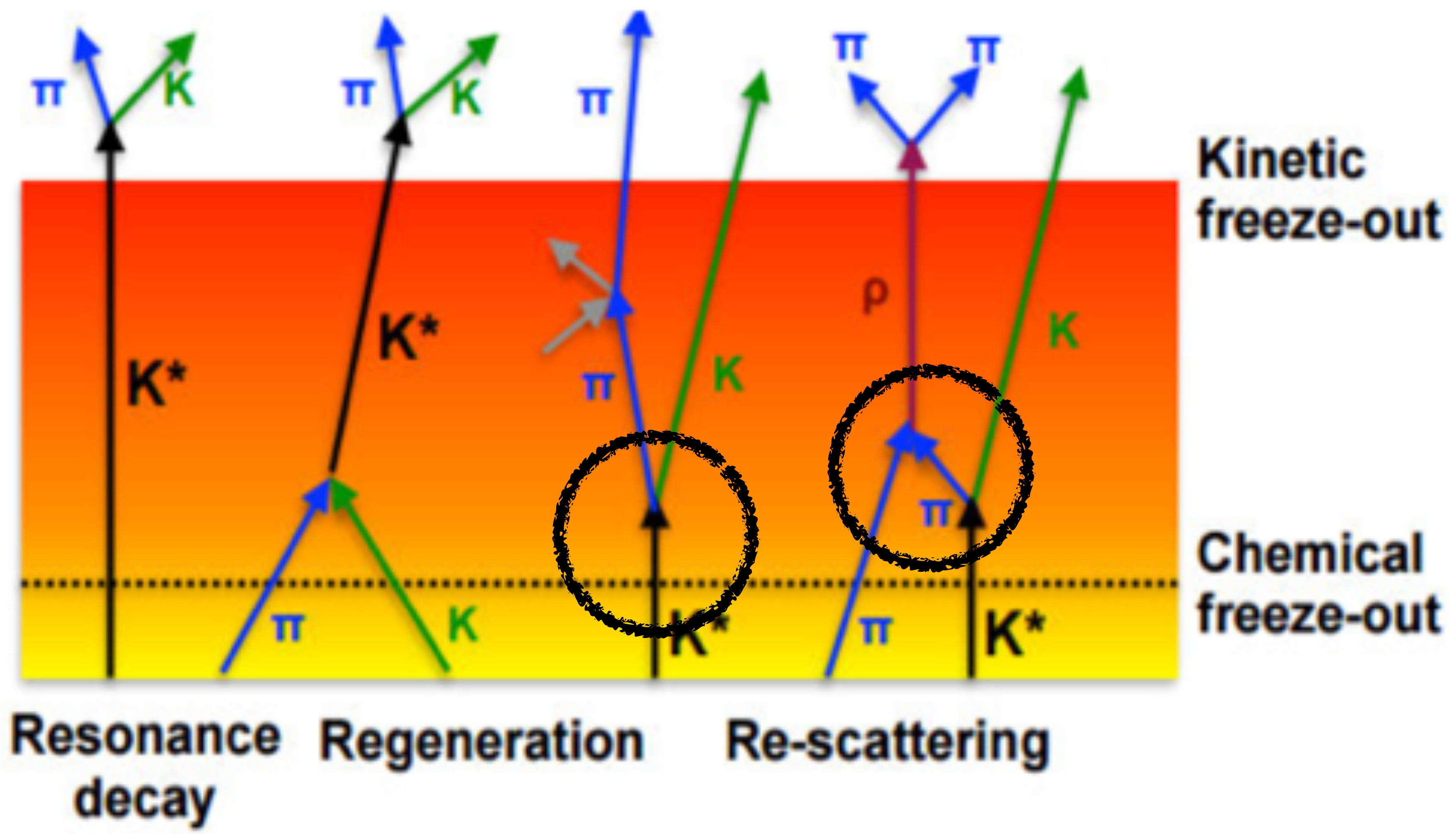
Hadronic processes between chemical and kinetic freeze-outs

1. **Re-scattering:**

   Daughter particles undergo elastic scattering or pseudo-elastic scattering through a different resonance

   Parent particle is not reconstructed —> a loss of signal



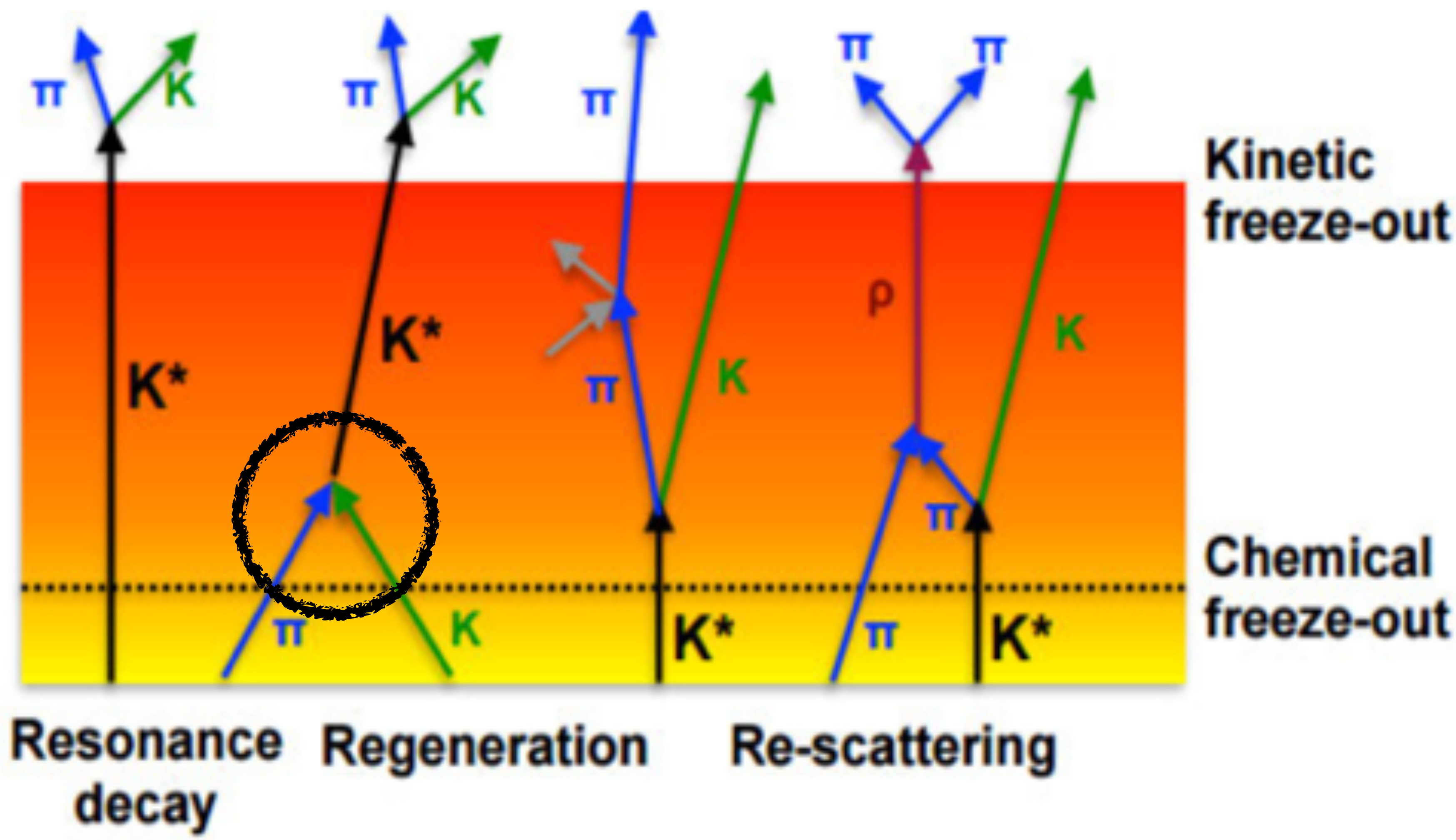
Hadronic Phase

Resonance yields in heavy-ion collisions are defined by:

Resonance yields at chemical freeze-out

Hadronic processes between chemical and kinetic freeze-outs

1. **Re-scattering:**
   Daughter particles undergo elastic scattering or pseudo-elastic scattering through a different resonance
   Parent particle is not reconstructed —> a loss of signal
2. **Regeneration:**
   Pseudo-elastic scattering of decay products (Kπ —> K^{*0}, K^+K^- —> ϕ) —> increase of yields



Effect of hadronic process depends on:

- lifetime of hadronic phase
- resonance lifetime
- scattering cross sections

Resonances with lifetimes comparable to that of the fireball are very promising tools to study properties of the hadronic phase.

Particles	ρ^0	K^{*0}	ϕ	$\Lambda(1520)$	Ξ^{*0}
Mass (MeV/c^2)	770	896	1019	1520	1532
Width (MeV/c^2)	150	47.4	4.27	15.7	9.1
Mean Life-time (fm/c)	1.3	4.2	46.2	12.6	21.7
Decay	$\pi^+\pi^-$	πK	K^+K^-	K^-p	$\pi^+\Xi^-$
BR (%)	~100	66.6	48.9	22.5	66.7

Measurement in pp collisions acts as reference for Pb-Pb and p-Pb collisions and also helps in tuning the MC generators inspired by pQCD.

Particle Yield Ratios to Stable Particles

K^{*0}/K :

Suppression with multiplicity in pp is observed

ϕ/K :

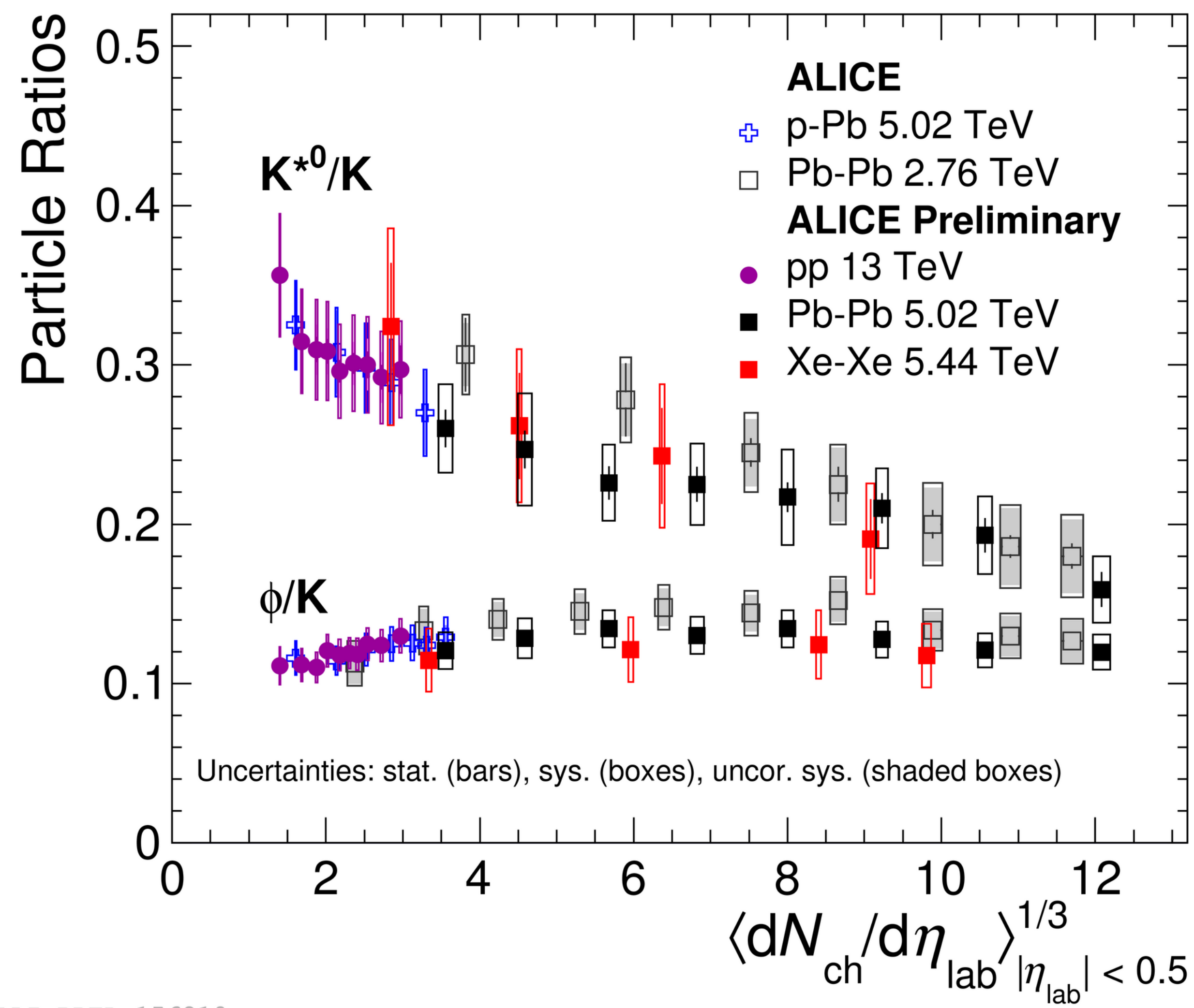
No suppression with multiplicity in pp and Pb-Pb

K^{*0}/K

Rescattering is dominant over regeneration

ϕ/K

Rescattering is not significant due to long lifetime



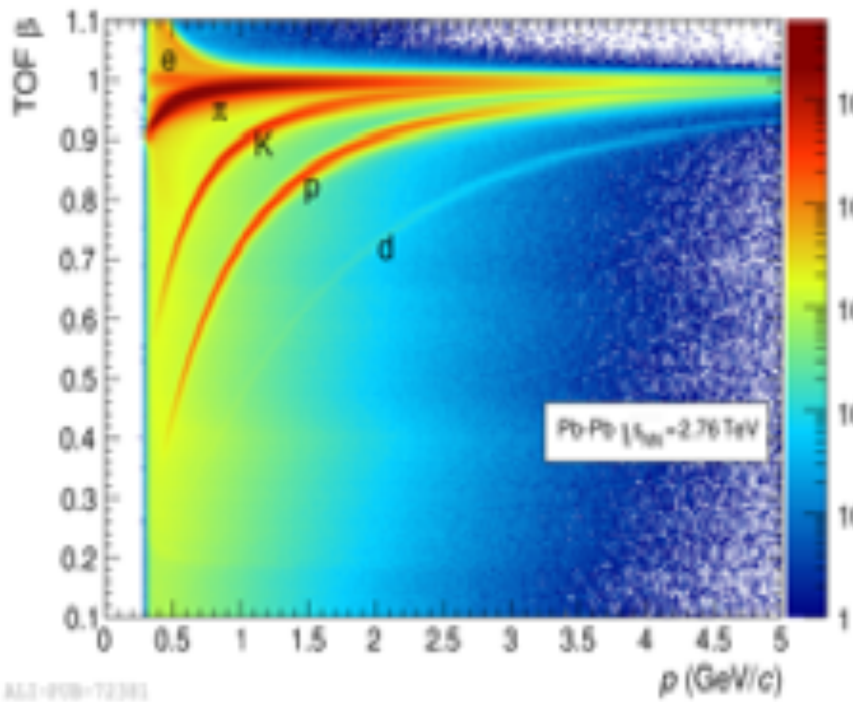
ALI-PREL-156810

Plotted as function of $<dN_{ch}/d\eta>^{1/3}$:

proxy for system radius [2] (cf. femtoscopy studies)

[1] Eur. Phys. J. C 76 245 (2016)
[2] Phys.Lett.B 696:328-337,2011

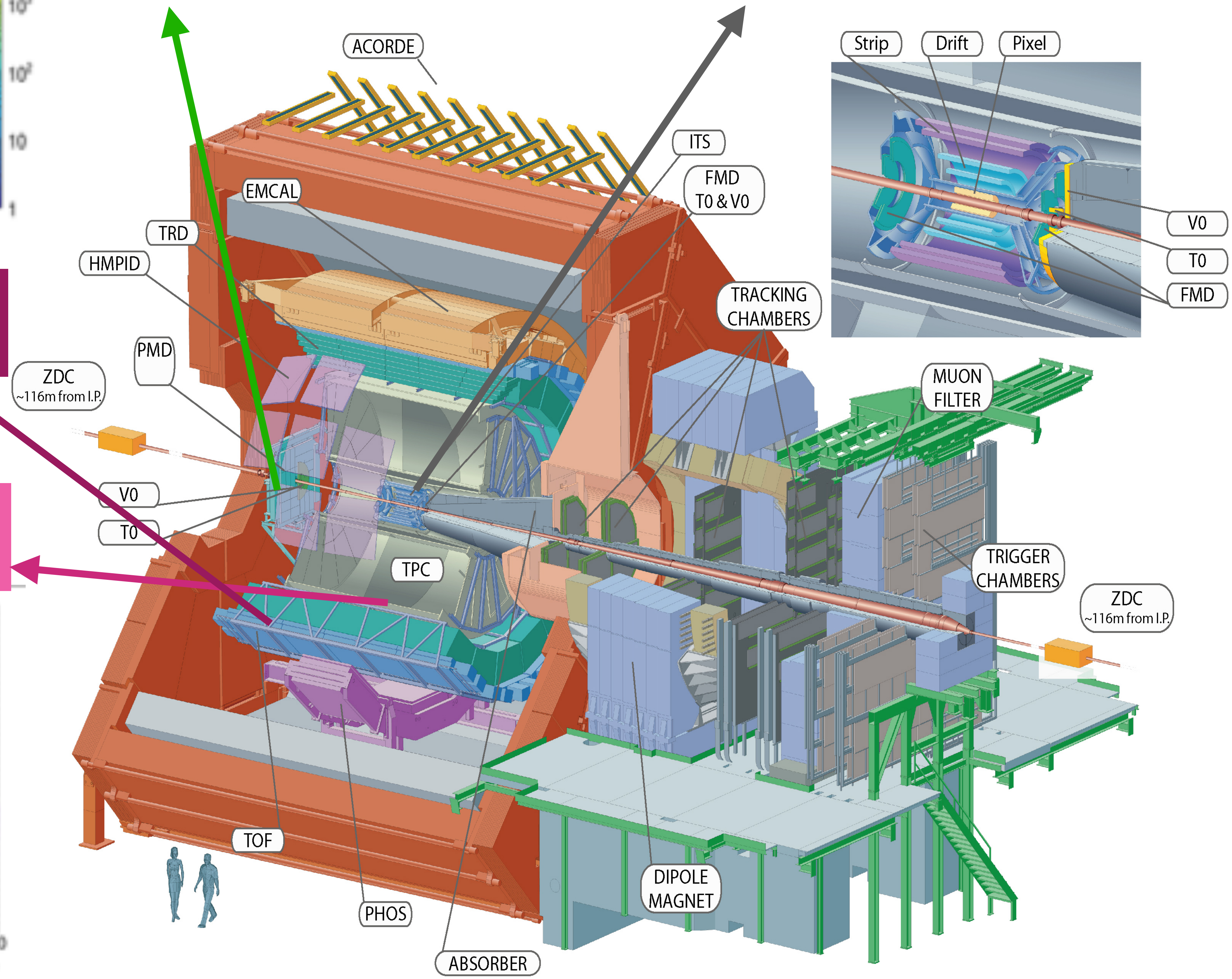
ALICE Detector



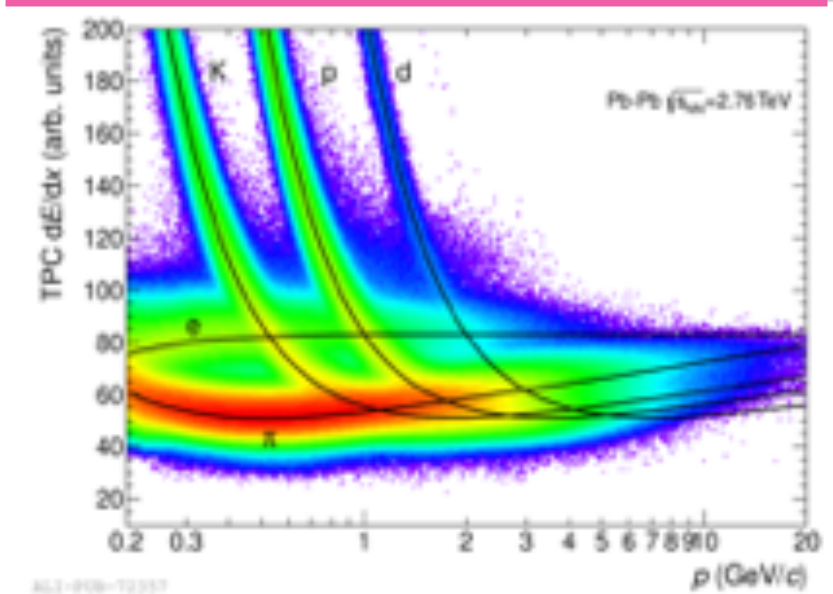
TOF: PID through particle time of flight

V0 (scintillators): centrality estimate through multiplicity in V0 and Min. bias trigger

ITS (silicon): Tracking , Vertexing and PID at very low p_T



TPC: Tracking and PID through dE/dx



Data set and Analysis Cuts

Data

Decay Channel: $K^{*0} \rightarrow K\pi$

$\phi \rightarrow K^+K^-$

Data Period: LHC12 [a-d, h, i] pass2, AOD

Total Accepted events ~ 47 M

Event selection (Standard Run-1 Selection)

kINT7 trigger
Pileup Rejection using AliAnalysisUtils::IsPileUpEvent()
Event has a track or SPD primary vertex identified
Vertex z position: $|V_z| < 10$ cm

Track selection:

Standard ITS TPC TrackCuts 2011
η : -0.8 — 0.8 for reconstructed tracks
$p_T > 0.15$ GeV/c
$|y_{pair}| < 0.5$

PID Selection

$In_{\sigma\pi}$, TPCl < 2σ with a TOF veto of < 3σ

Analysis Details

Decay Channel	Branching ratio	Life-time
$K^{*0} \rightarrow K\pi$	66.6%	4.16 fm/c
$\phi \rightarrow K^+K^-$	48.9%	46.2 fm/c

Background Subtraction:

Event Mixing

Fit Function:

Breit-Wigner for Signal + Pol2 for Residual Background

Fitting Range:

0.7 – 1.2 GeV/c^2 and width is a free parameter

Background Subtraction:

Event Mixing

Fit Function:

Voigtian for Signal + Pol2 for Residual Background

Fitting Range:

1.04 – 1.06 GeV/c^2 and width is fixed to PDG value 4.26 MeV/c^2

Breit-Wigner:

$$\frac{dN}{dm_{K\pi}} = \frac{A}{2\pi} \frac{\Gamma_0}{\left(m_{K\pi} - m_0\right)^2 + \frac{\Gamma^2}{4}}$$

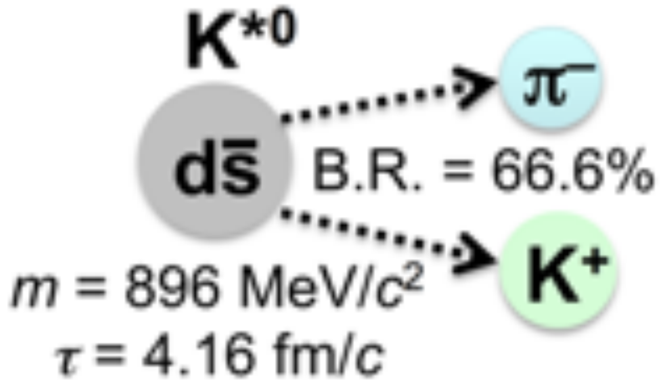
Pol2 :

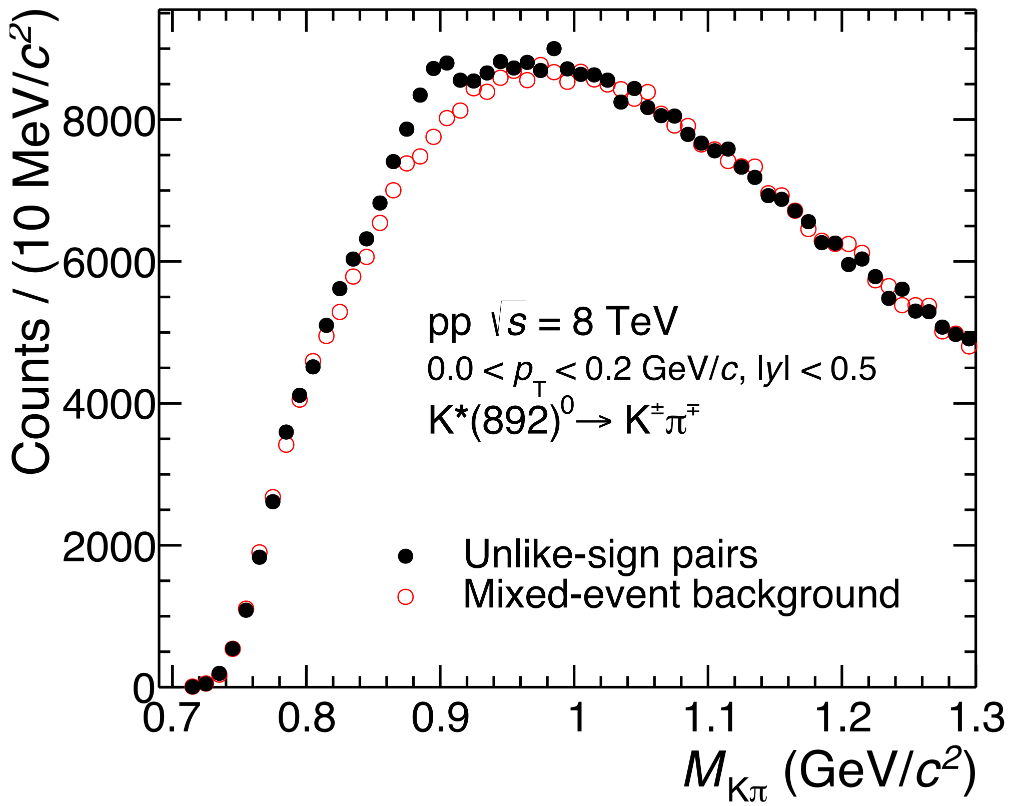
$$f(m) = a + bm + cm^2$$

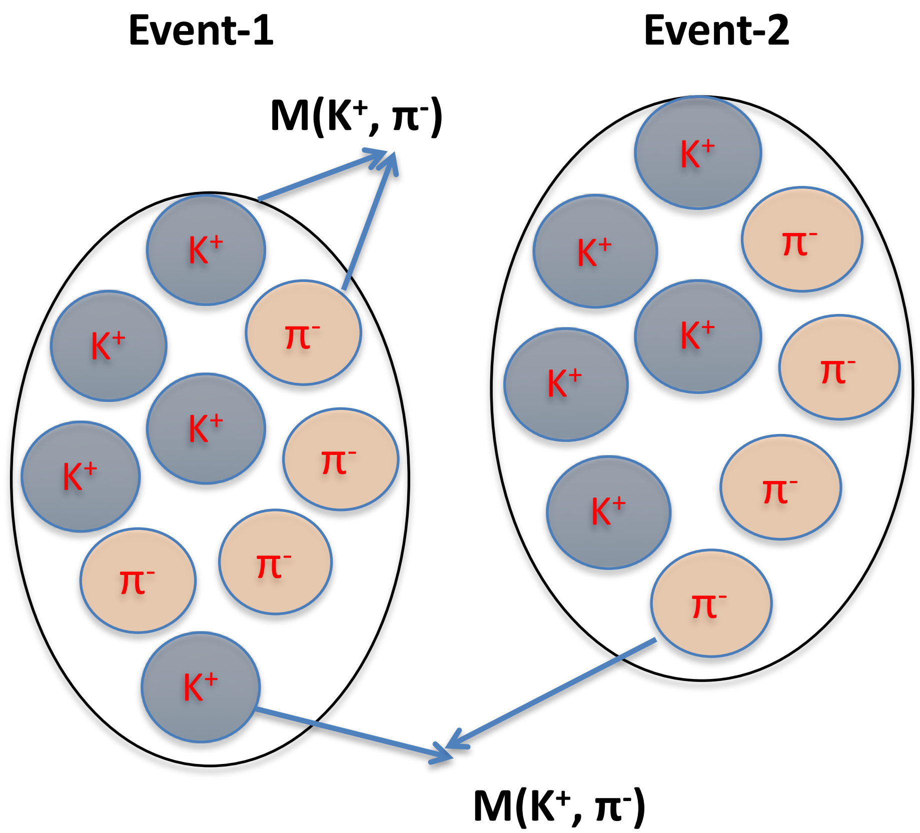
Voigtian:

$$\frac{\mathrm{d}N}{\mathrm{d}M_{\mathrm{KK}}} = \frac{A\Gamma_0}{(2\pi^{3/2})\sigma} \int_{-\infty}^{+\infty} \exp\left(\frac{(M_{\mathrm{KK}} - m')^2}{2\sigma^2}\right) \frac{1}{(m' - m_0)^2 + \frac{\Gamma_0^2}{4}} \mathrm{d}m' + (BM_{\mathrm{KK}}^2 + CM_{\mathrm{KK}} + D)$$

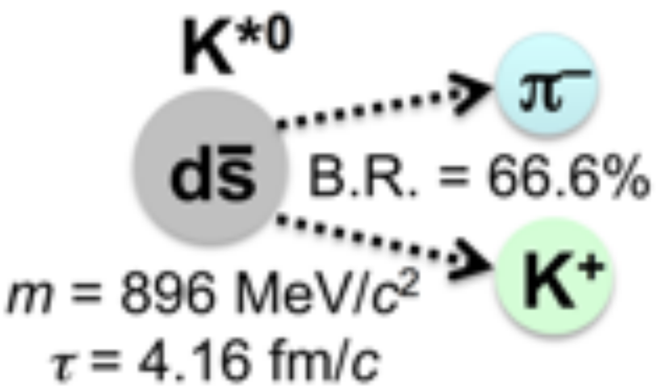
Invariant Mass

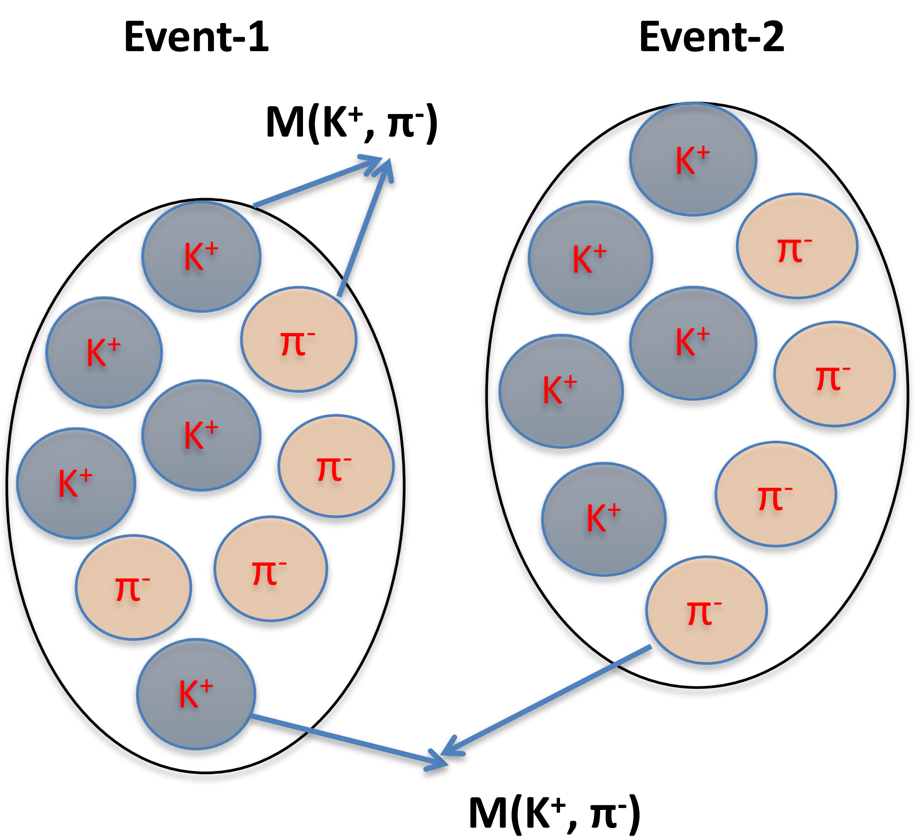


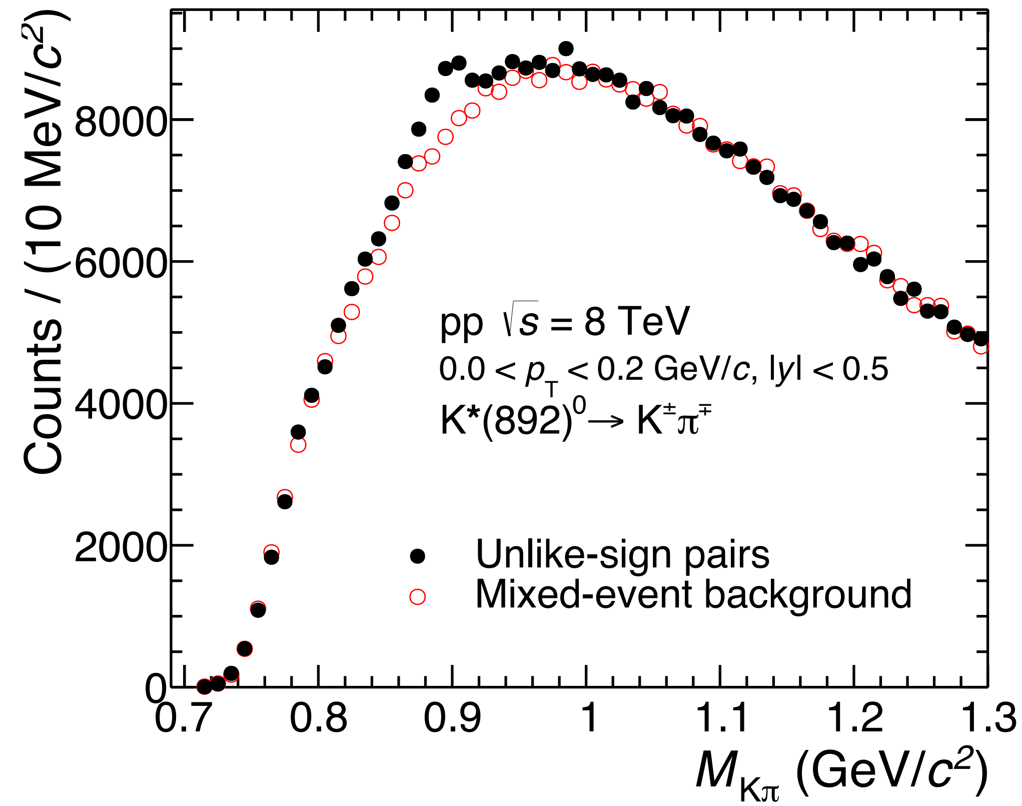


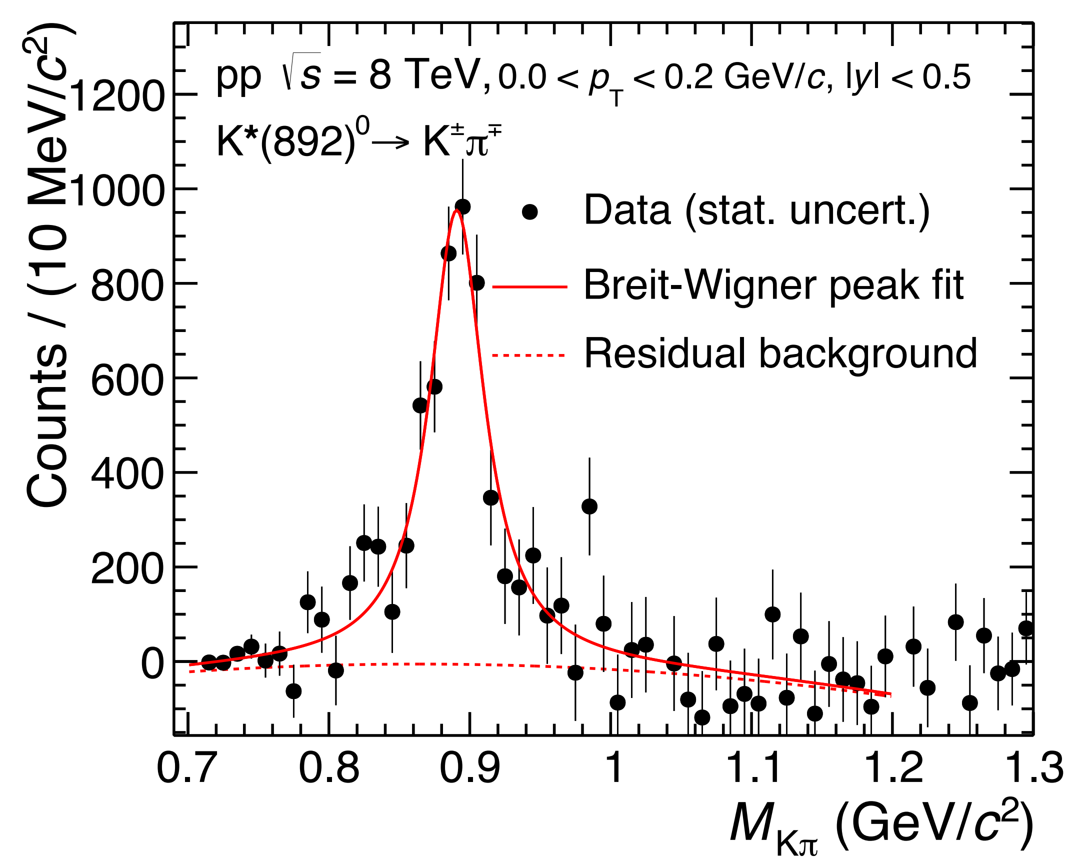


Invariant Mass



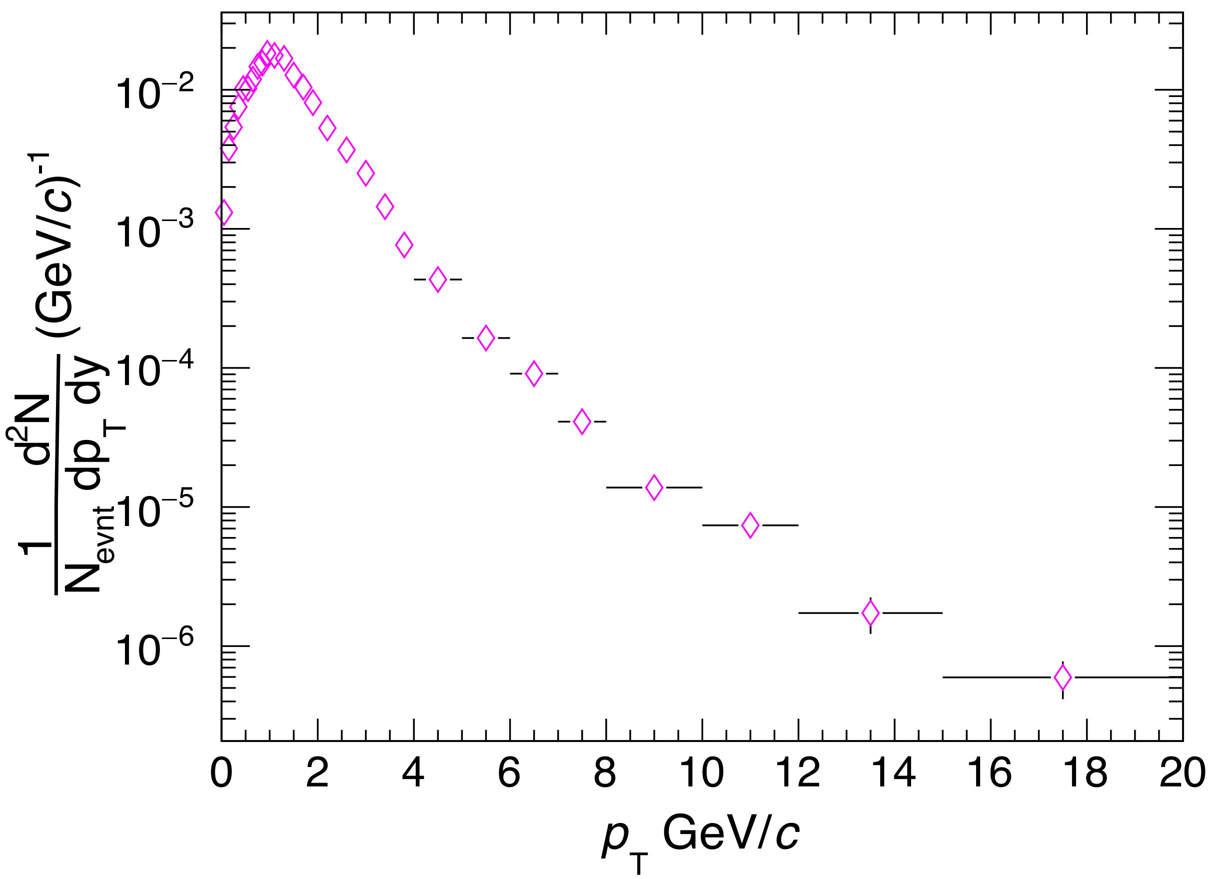




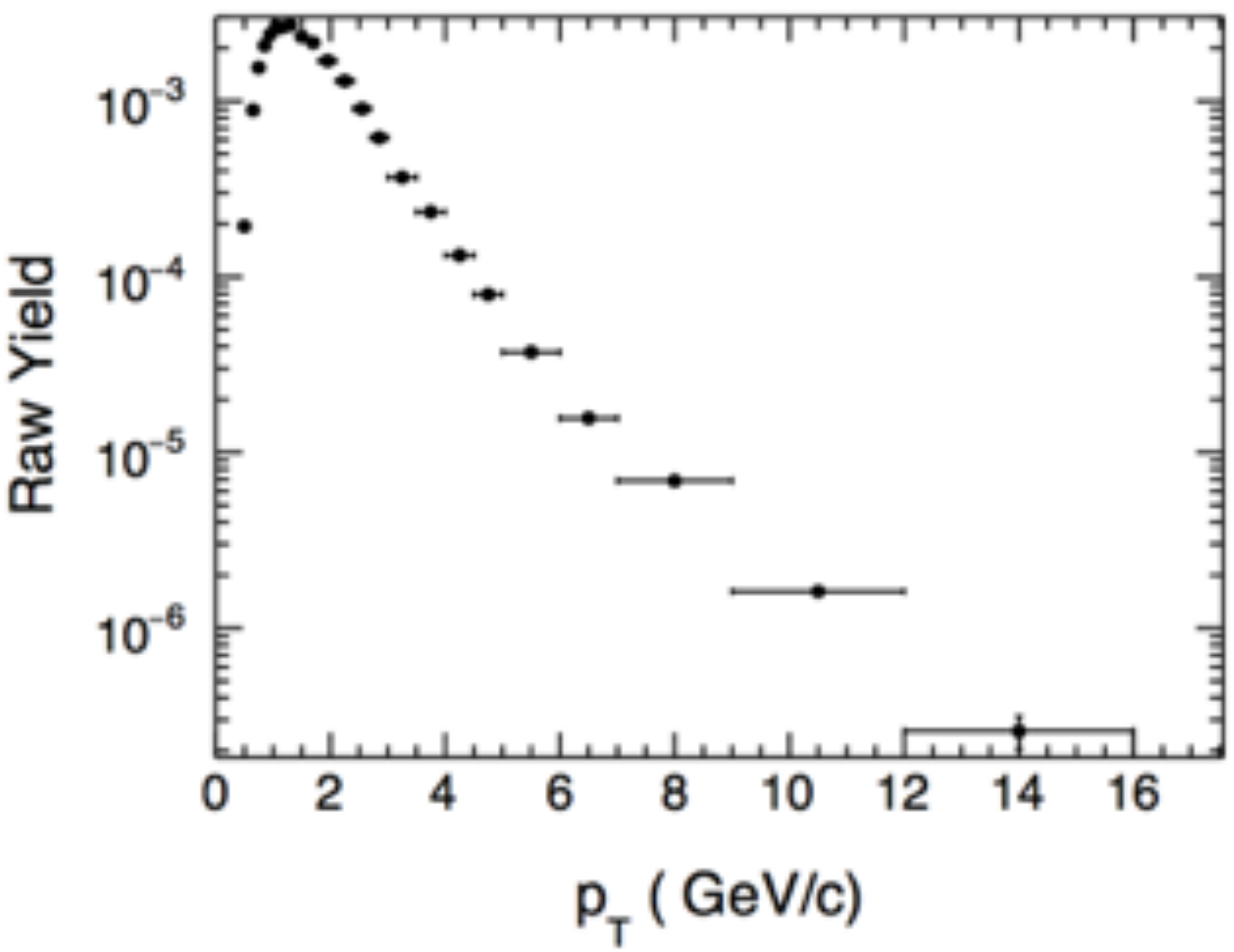


Raw Spectra

K*0



ϕ

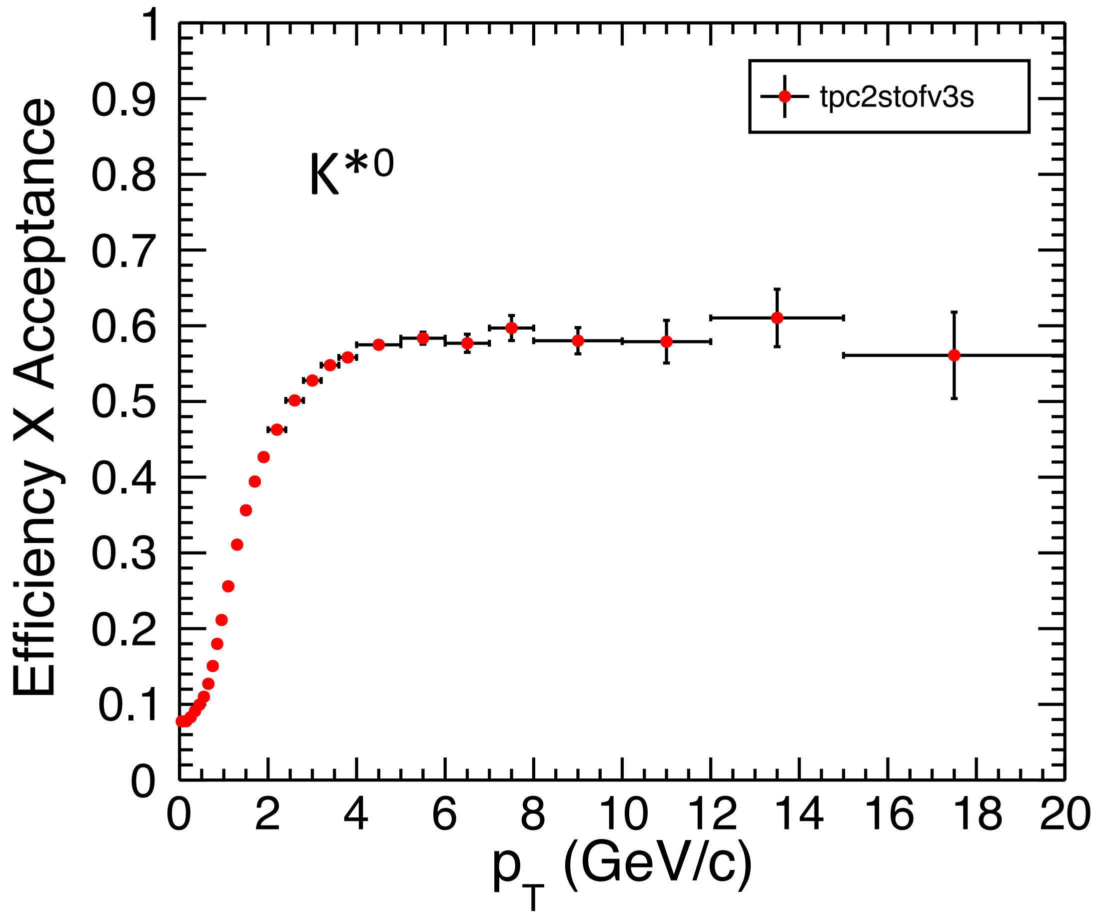


$$\frac{d^2N_{Raw}}{dp_T\ dy} = \frac{1}{2}\frac{Rawcounts}{N_{event}BR\ dp_T\ dy}$$

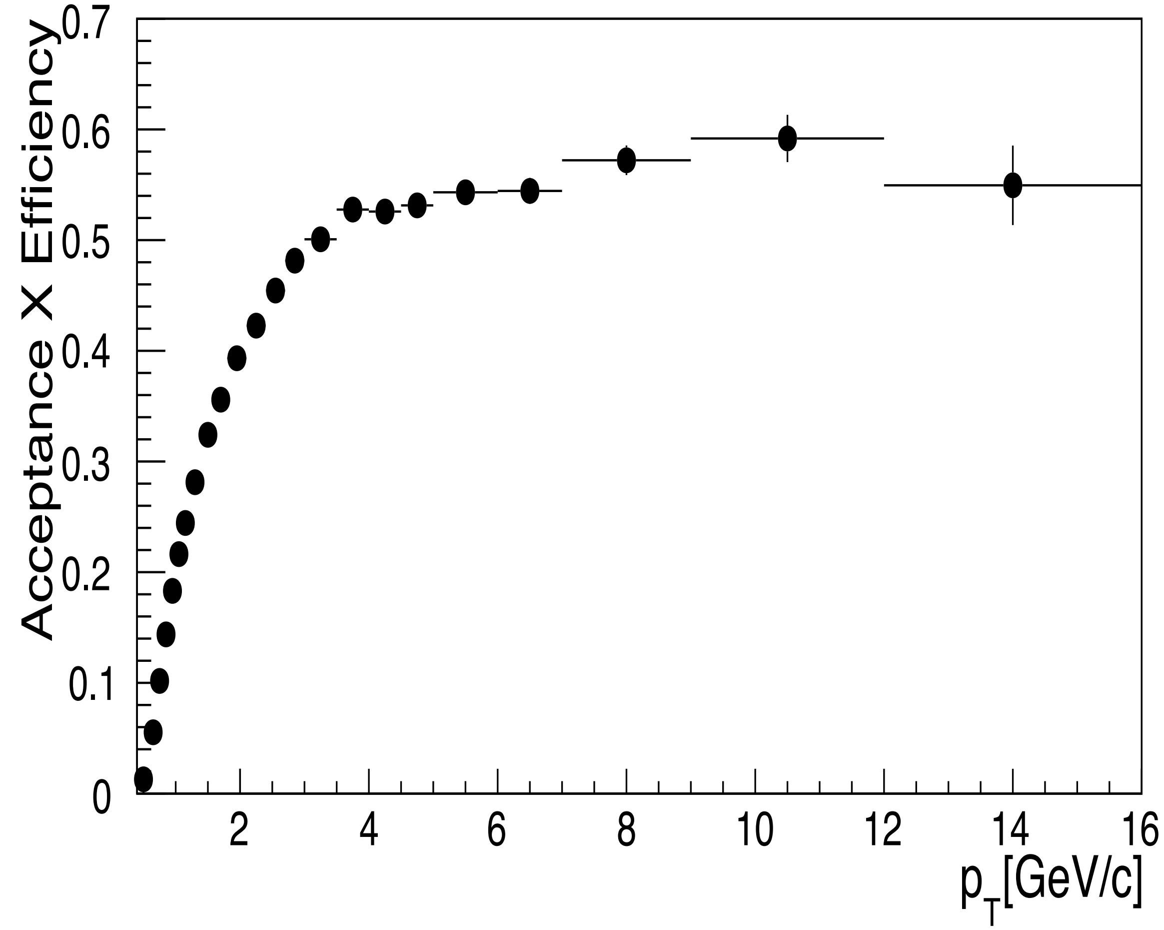
A. N. Mishra et.al: https://aliceinfo.cern.ch/Notes/node/563
S. Tripathy et. al: https://aliceinfo.cern.ch/Notes/node/672

Efficiency X Acceptance

K*0



ϕ



$$Efficiency\ X\ Acceptance = \frac{Reconstructed\ K^{*0}}{Generated\ K^{*0}}$$

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Systematic Uncertainty (K^{*0})

Variations:

1. Signal extraction variation
2. Vertex cut variation
3. Track cut variation
4. PID cut variation

1. Signal extraction variation:

Fitting range (3 ranges)

Normalisation region (3 regions)

Res. background (pol3)(Default: pol2)

Fixed Width (Default: Free width)

Function Integration(Default: Bin count)

2. Vertex cut variation(Default Vz < 10 cm):

|Vz| < 8 cm

|Vz| < 12 cm

3. Track cut variation:

ncr cut | Default ncr >70

variation: ncr >80, ncr > 100

rtpc cut |Default rtpc > 0.8

variation: rtpc > 0.9

dacz cut | Default dcaz < 2 cm

variation: dcaz < 1 cm

dcaxy currently | Default dcaxy < 7σ

variation: dcaxy < 4σ

4. PID cut variations (Default: tpc2σvetoTOF3σ):

tpc1.5σvetoTOF3σ

tpc2.5σvetoTOF3σ

tpc2σvetoTOF4σ

In each group RMS value is taken as the systematic uncertainty

Systematic Uncertainty (ϕ)

Signal Extraction

Event Mixing normalization

Fit Range

Residual background polynomial

Background Subtraction Method

Event-mix

Like-Sign

Track/Event Selection Cuts

Vertex Cuts

Track quality cuts

Other Sources:

Material Budget

Normalization

Signal Loss

Tracking

Branching ratio

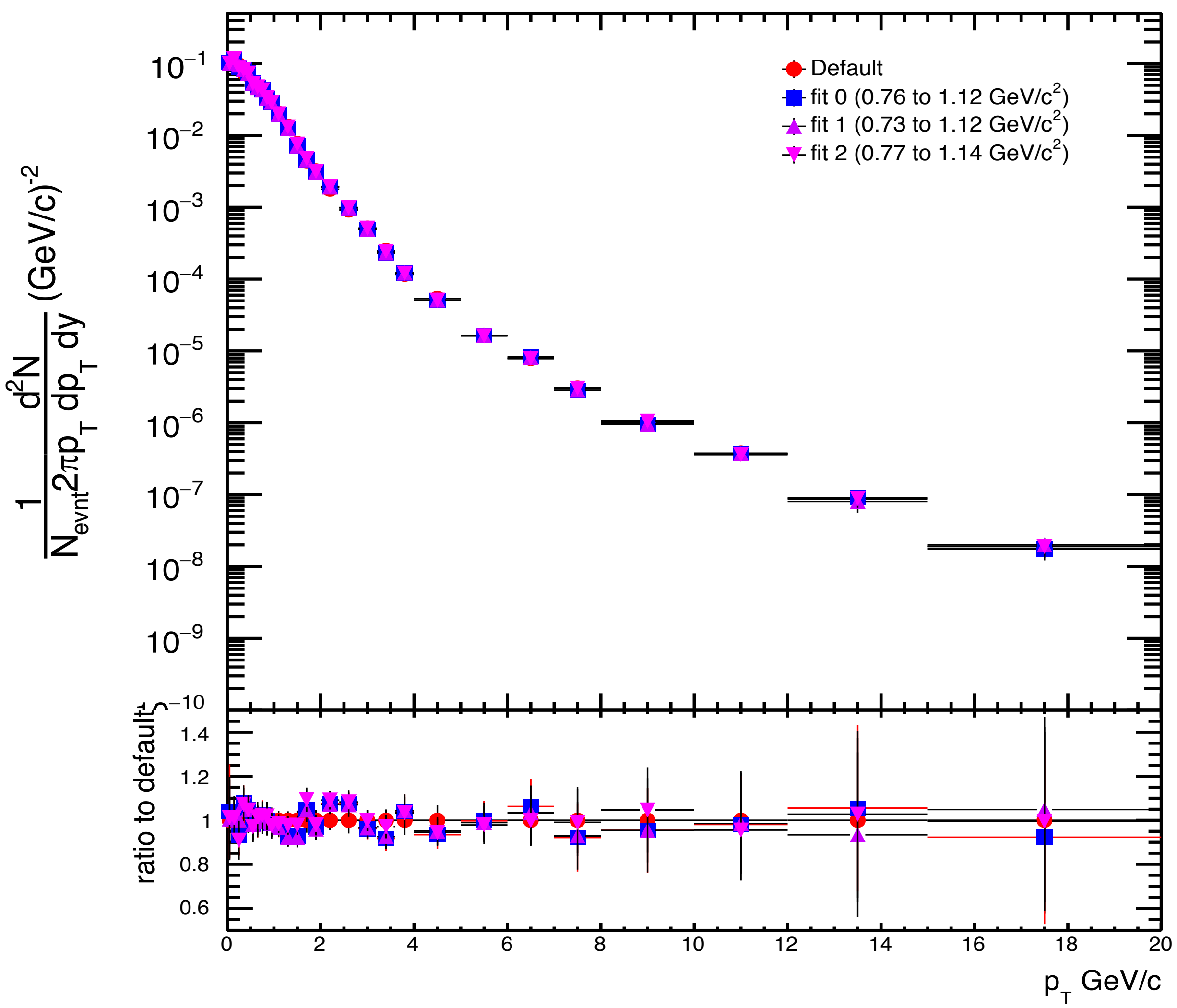
Hadronic interaction

Uncertainties are grouped.

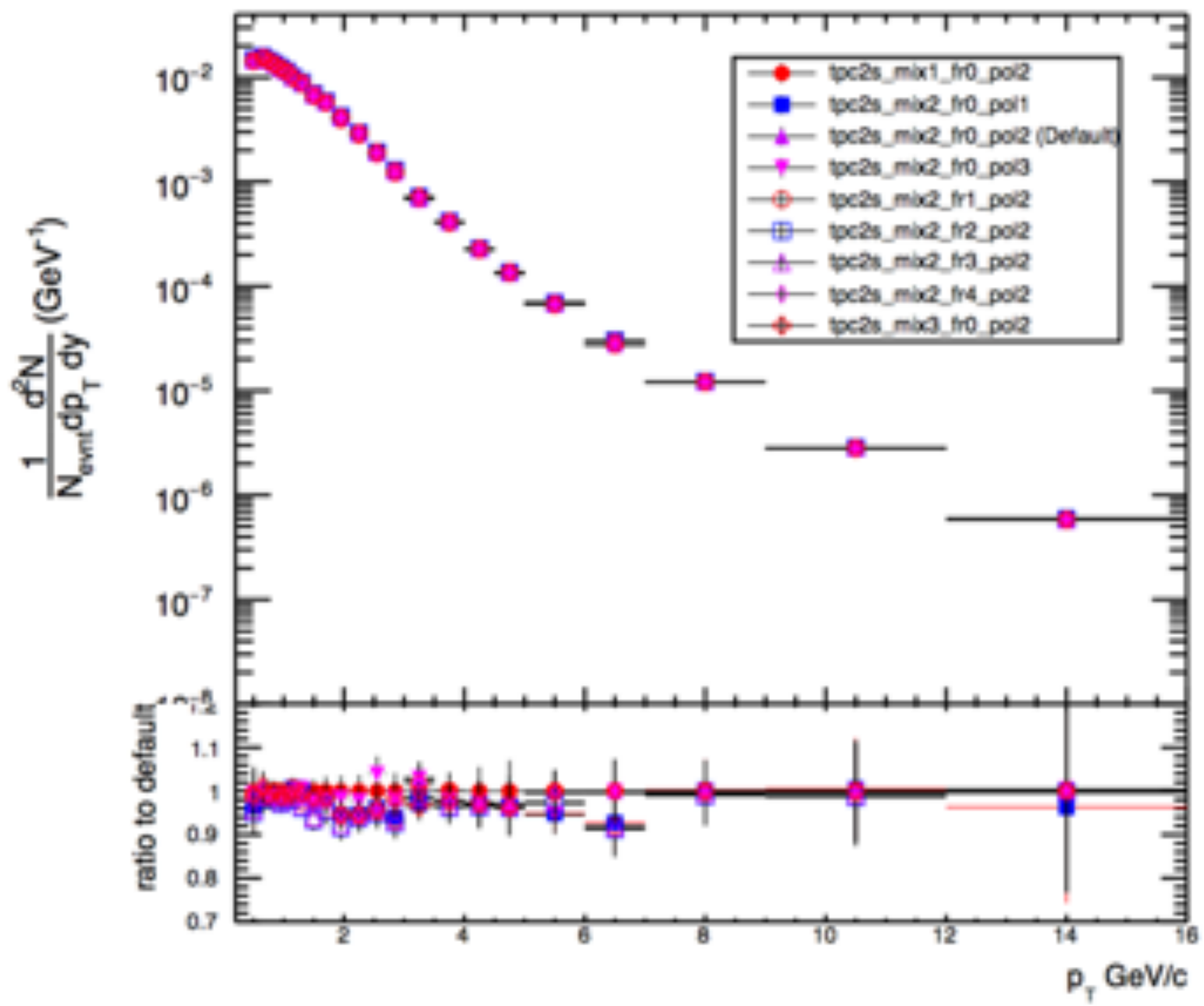
The standard deviation of each group is considered as systematic uncertainty.

Fitting range

K^{*0}



ϕ



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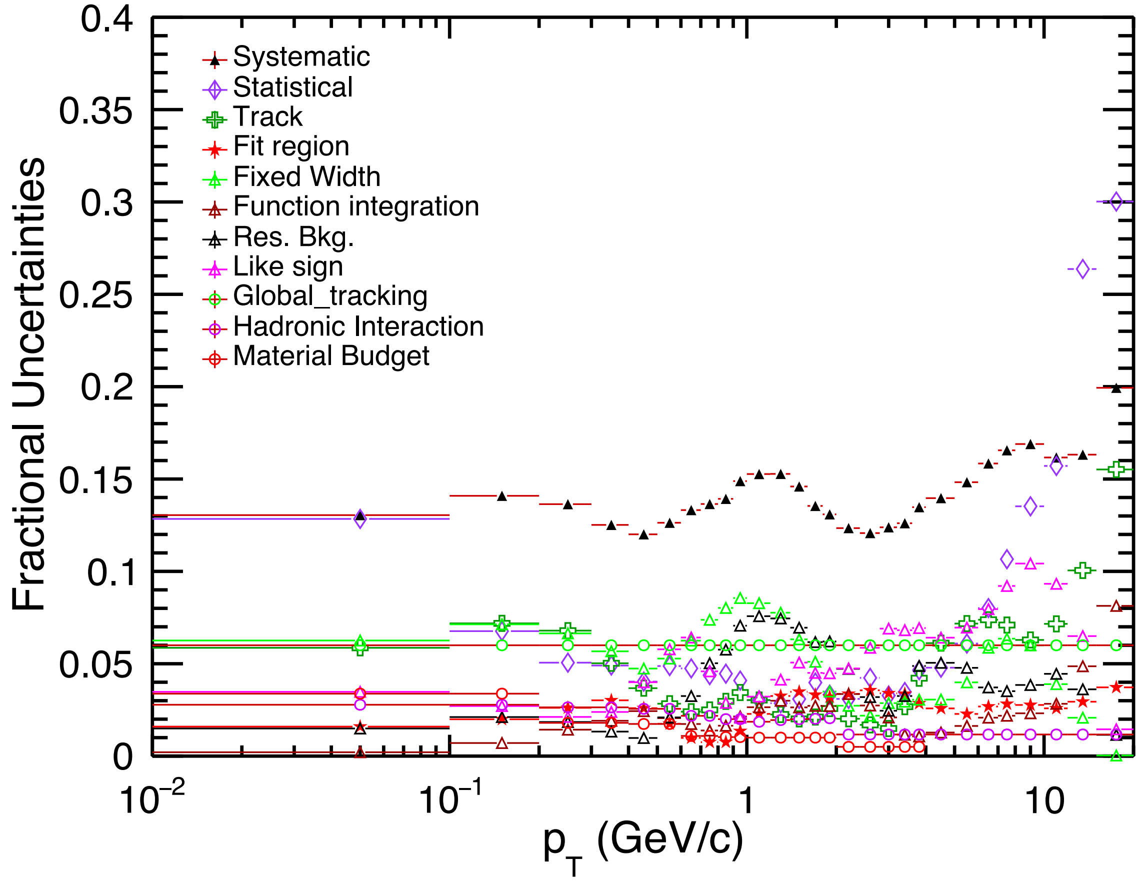
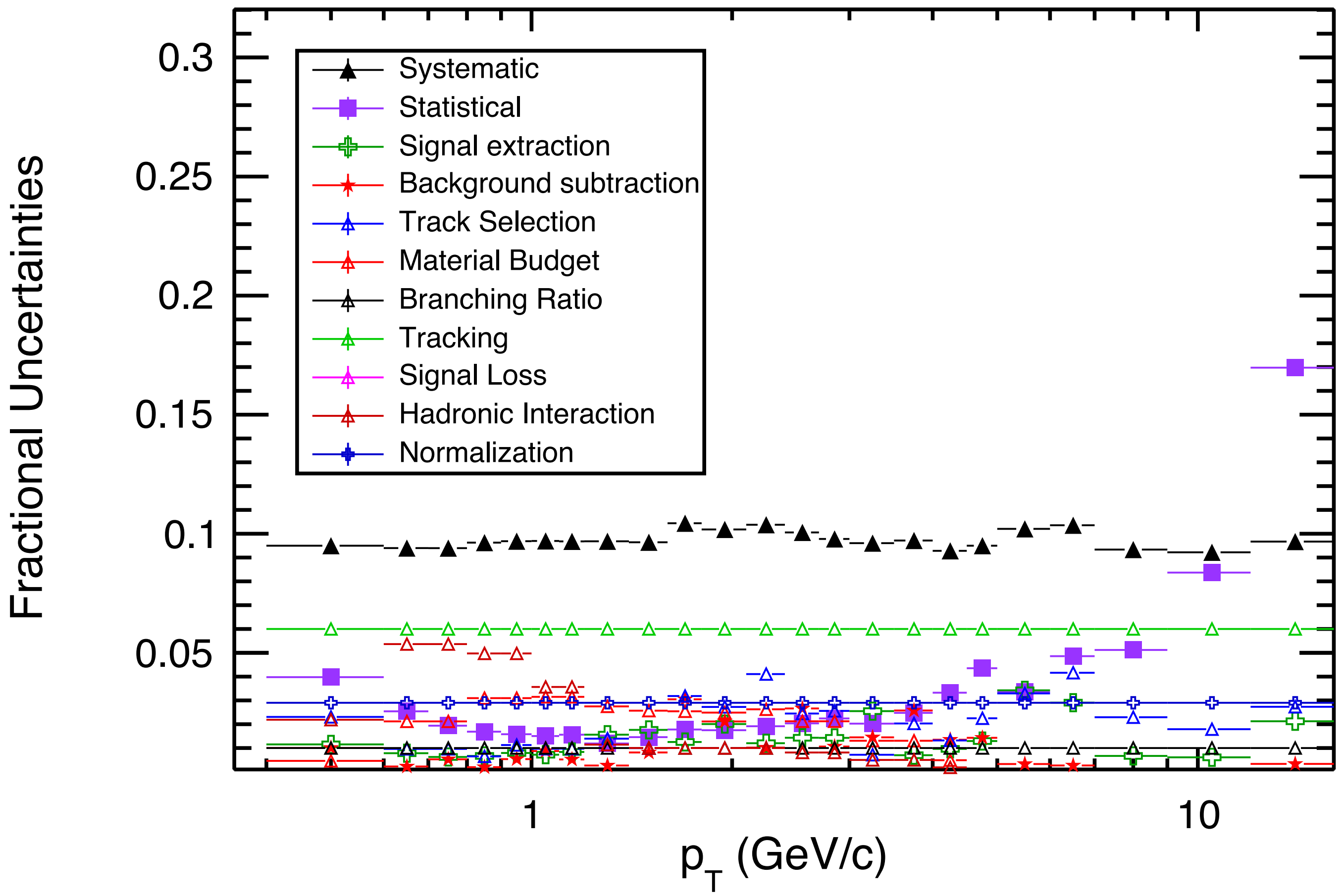
Fractional Uncertainty

K*0



ϕ



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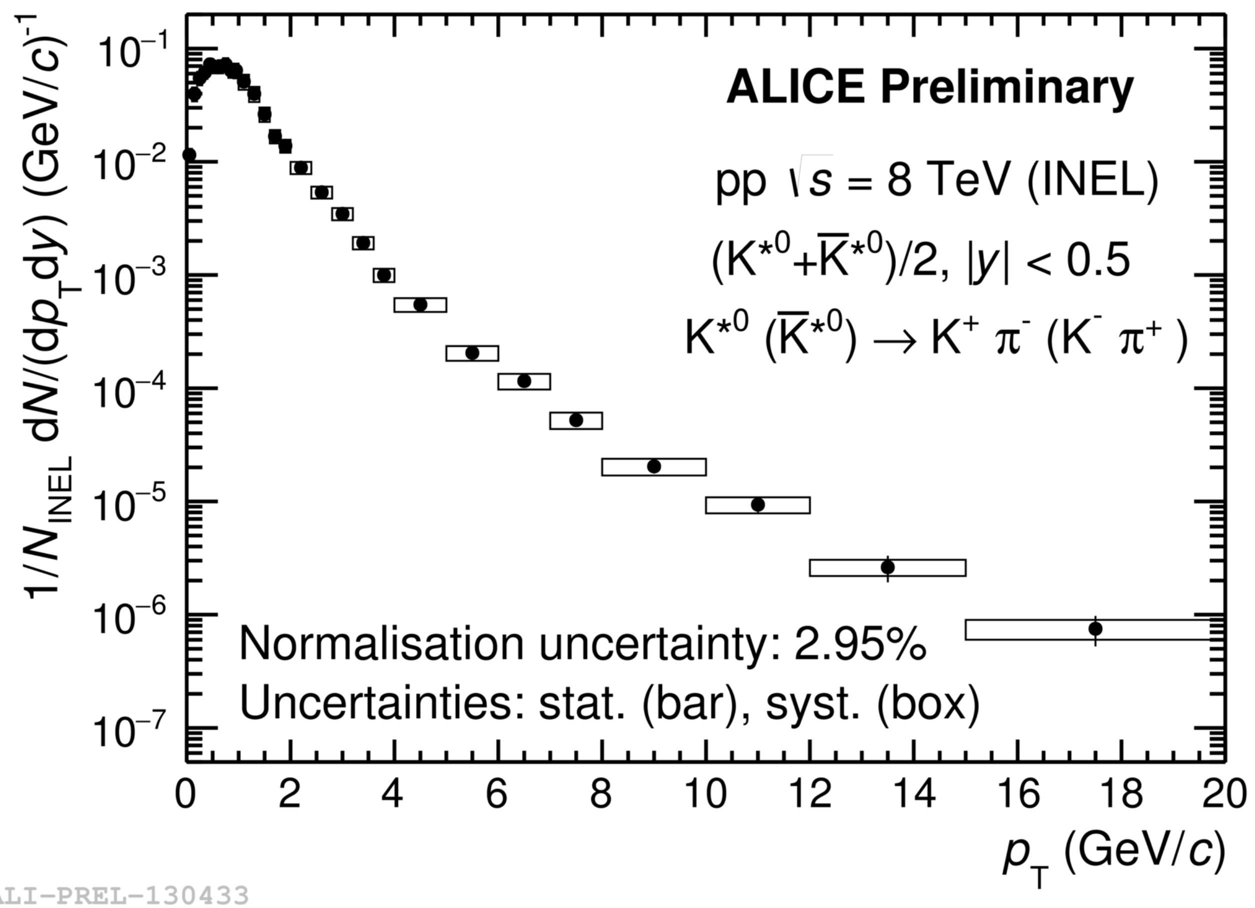
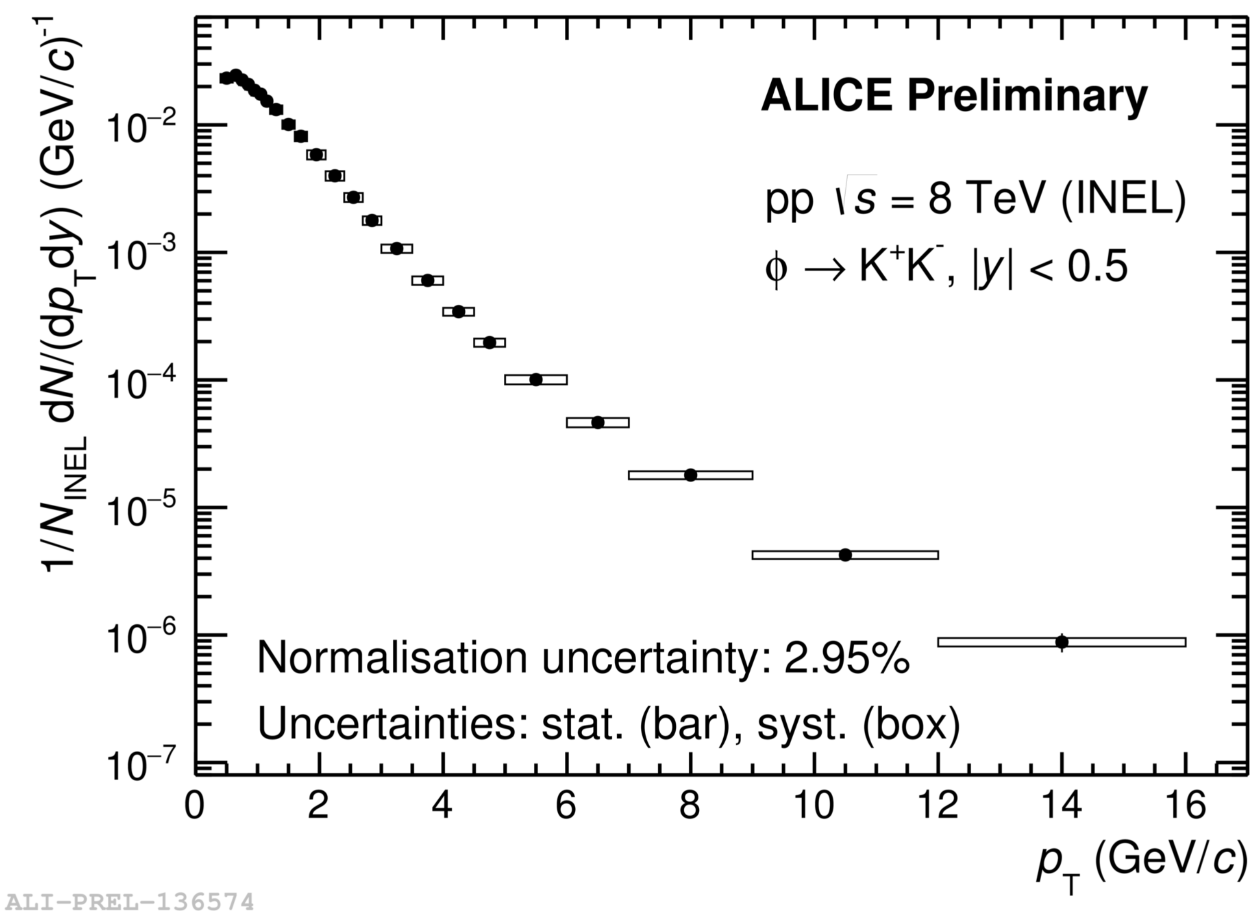
Corrected p_T Spectra

K*0



ϕ



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Comparison to Other Energies

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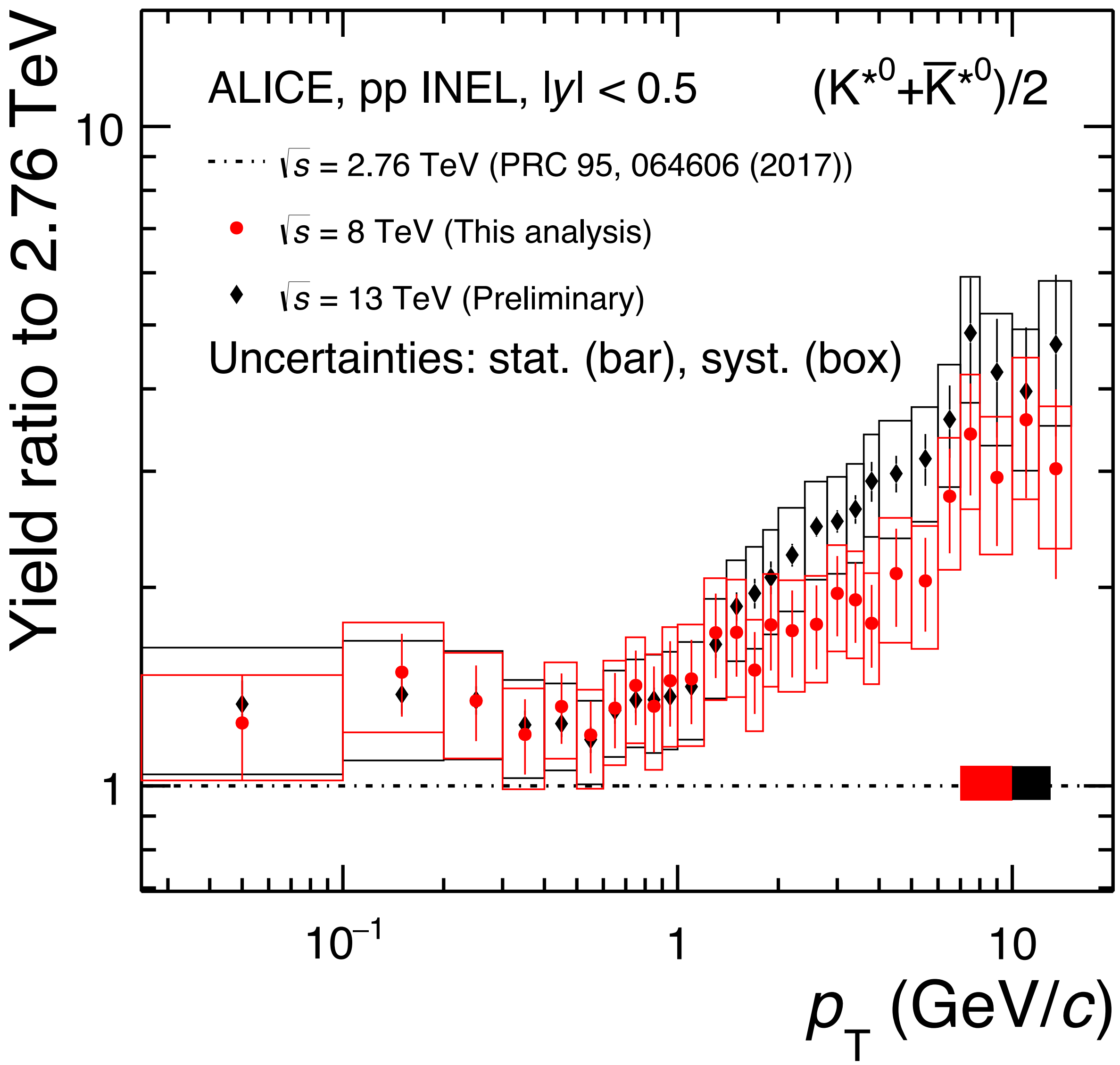

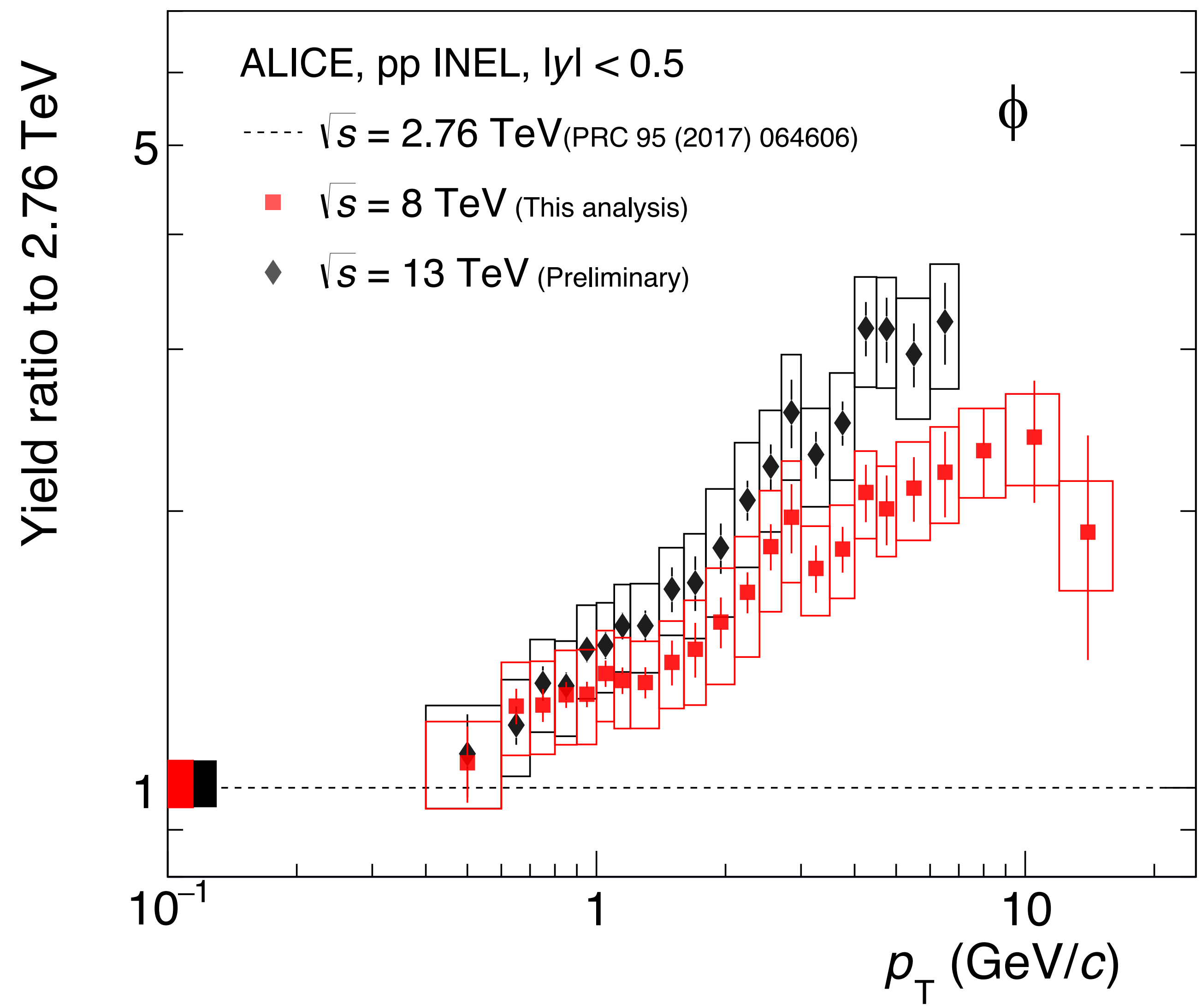

For K^{*0} and ϕ the differential yield ratio is independent of p_T within the systematic uncertainties up to 1 GeV/c for different collision energies.

The particle production mechanism in soft scattering regions is independent of collision energy.

An increase in slope of differential yield ratios is observed for $p_T > 1$ GeV/c, which suggests a larger number of hard scattering as the collision energy increases.

dN/dy and $\langle p_T \rangle$

K^{*0}

Energy	dN/dy	$\langle p_T \rangle$
pp 7 TeV	$0.097 \pm 0.0004^{0.01}_{0.009}$	1.01± 0.003 ± 0.02
pp 8 TeV	0.101± 0.001± 0.012	1.037± 0.006 ± 0.029
pp 13 TeV	0.104 ± 0.0008 ± 0.0108	1.121 ± 0.005 ± 0.032

ϕ

Energy	dN/dy	$\langle p_T \rangle$
pp 7 TeV	$0.032 \pm 0.0004^{0.004}_{0.0035}$	1.07 ± 0.005 ± 0.03
pp 8 TeV	0.0335 ± 0.00025 ± 0.0030	1.146 ± 0.0053 ± 0.040
pp 13 TeV	0.0374 ± 0.0004 ± 0.0024	1.234 ± 0.009 ± 0.032

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dN/dy interpolation for Pion, Kaon and Proton

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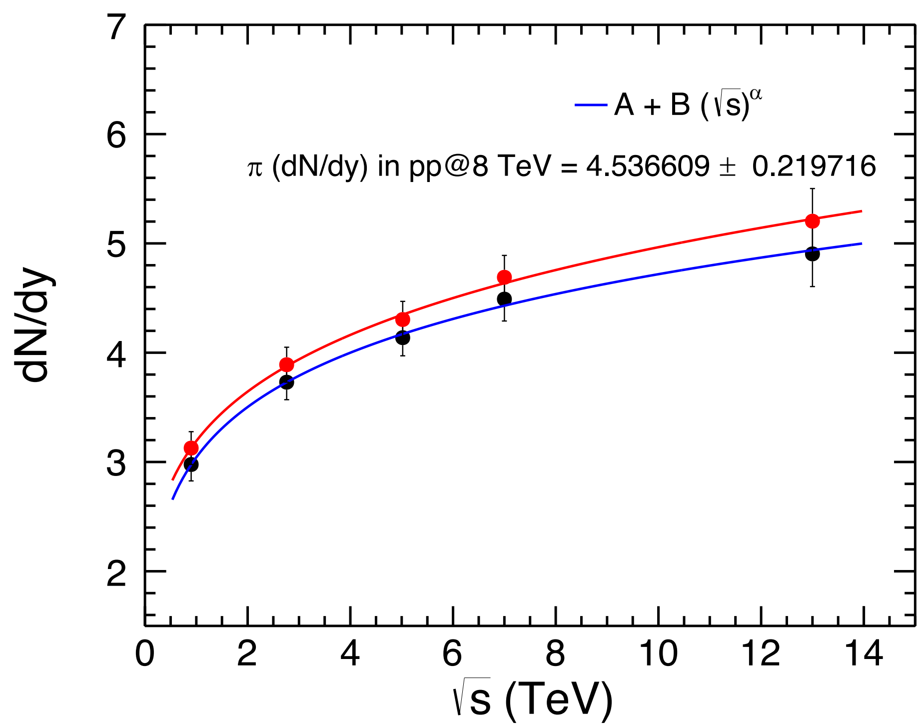
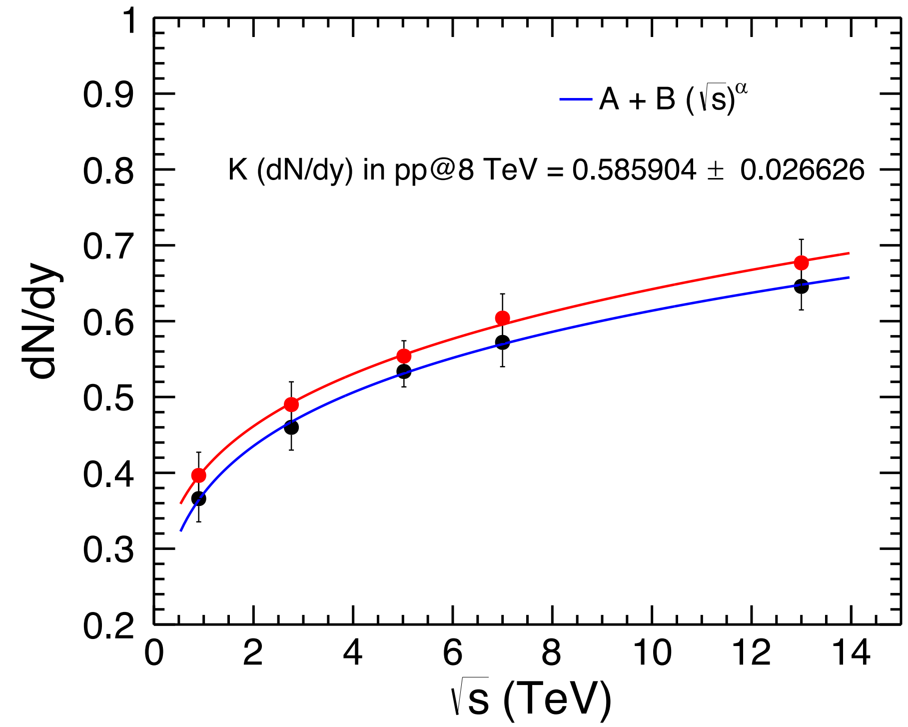
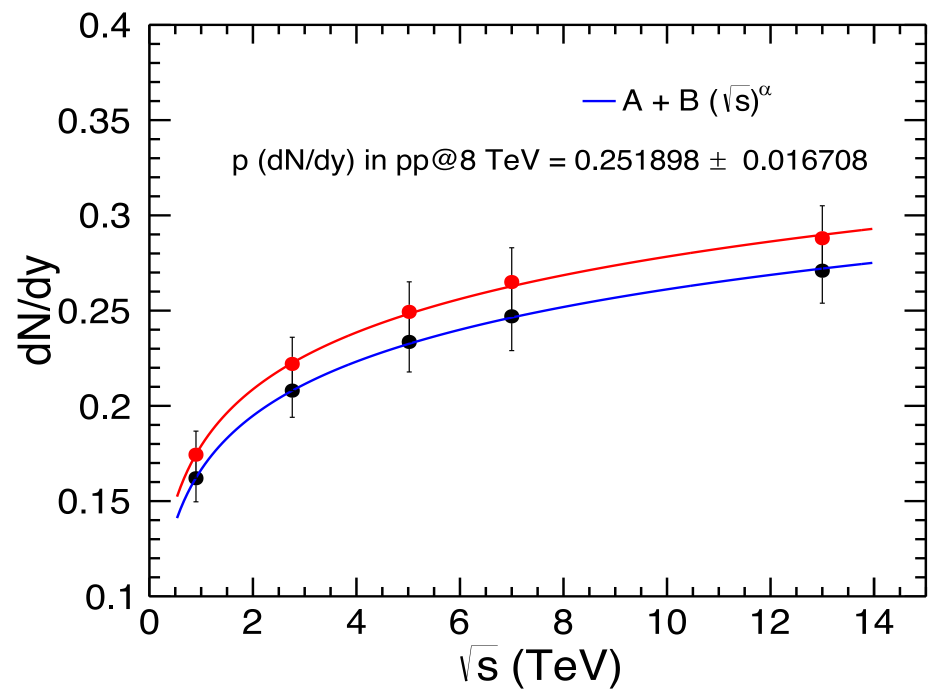


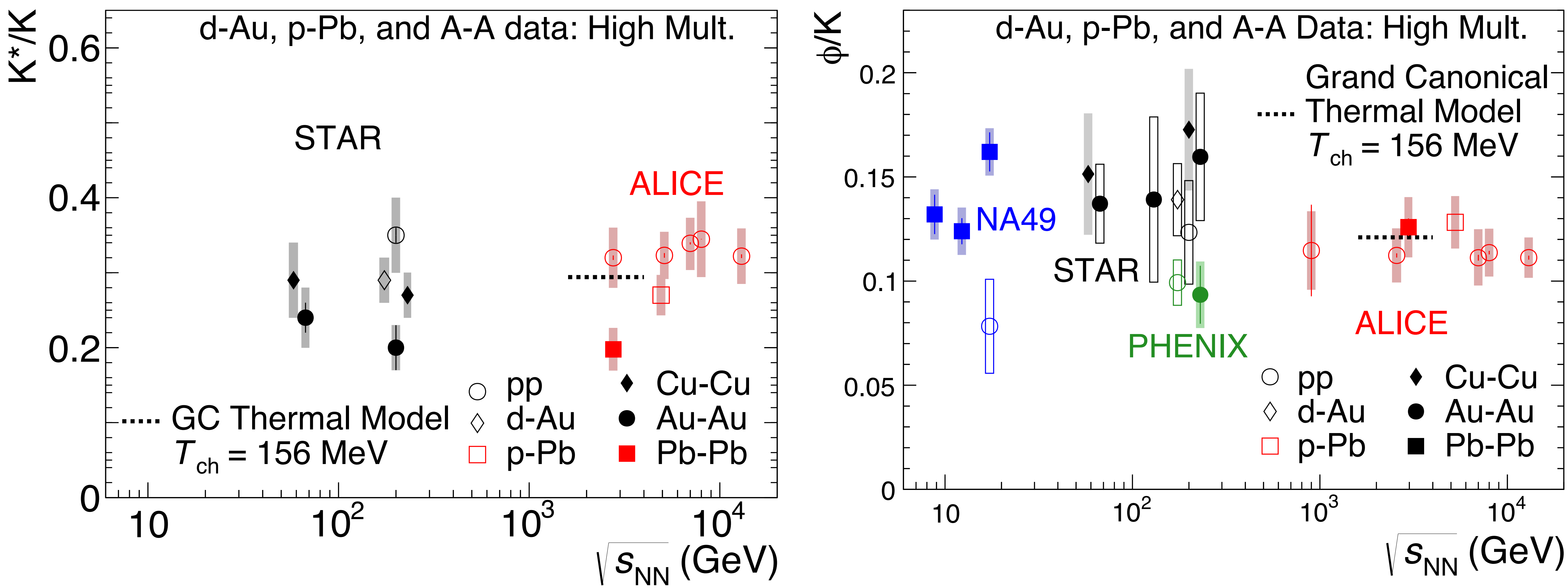




Particle	dN/dy	dN/dy (Sys. uncer.)
Pion	4.5366	0.2197
Kaon	0.5859	0.0266
Proton	0.2519	0.0167

The integrated yields for Pion, Kaon and Proton in pp@8 TeV are interpolated using the values available from other energies.

K^{*0}/K and ϕ/K vs Energy



The K^{*0}/K and ϕ/K ratios in pp collisions are found to be independent of centre of mass energies and in different collision systems, with the only exception of K^{*0} in Pb–Pb collisions, which we attribute to final state effects in the late hadronic stage.

The behaviours of these ratios in pp collisions agree with the thermal model predictions

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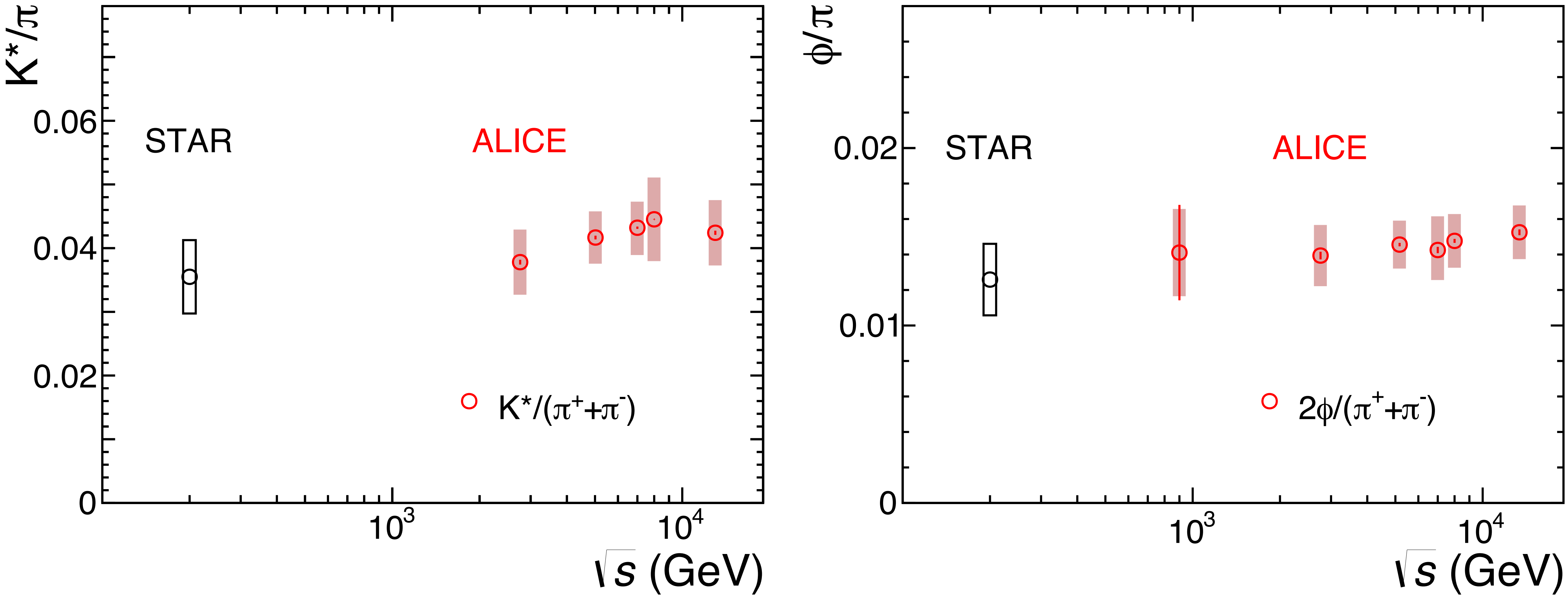
K^{*0}/π and ϕ/π vs Energy



- **It is observed that the K^{*0}/π and ϕ/π is independent of the collision energy within the systematic uncertainty, which indicate the chemistry of the system is independent of energy.**
- **This flat behaviour is not trivial as there are finite increase of dN/dy for π, K^{*0} and ϕ with increase in collision energy.**
- ***It is observed that, the percentage increase of dN/dy for π, K^{*0} and ϕ as a function of collision energies are similar within systematic uncertainties from RHIC to LHC, which results the flat behaviour of K^{*0}/π and ϕ/π.***

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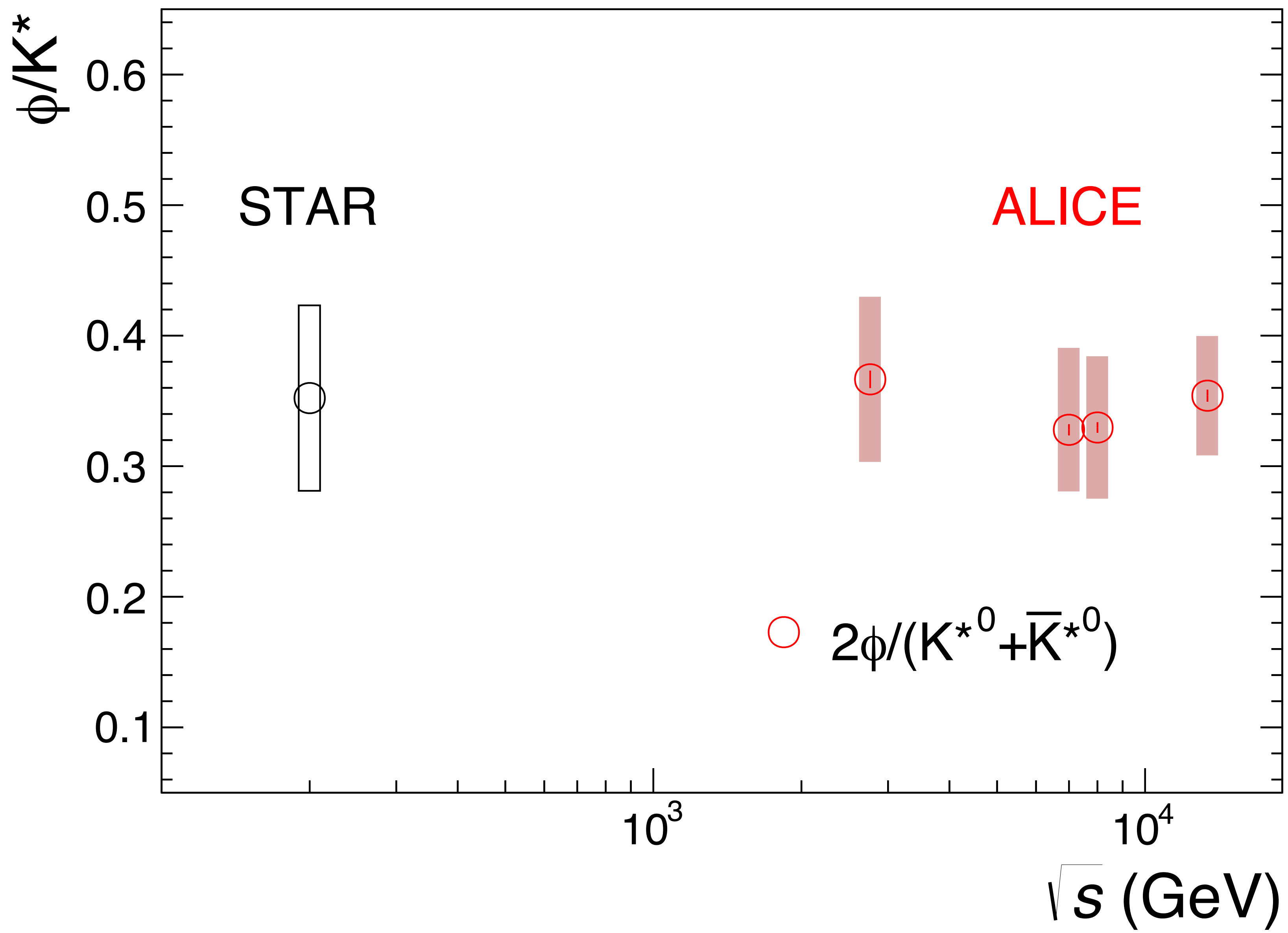
ϕ/K^{*0} ratio



Despite K^{*0} and ϕ having similar masses, the $\phi/K^{*0} \neq 1$. This hints a different particle production mechanisms for K^{*0} and ϕ .

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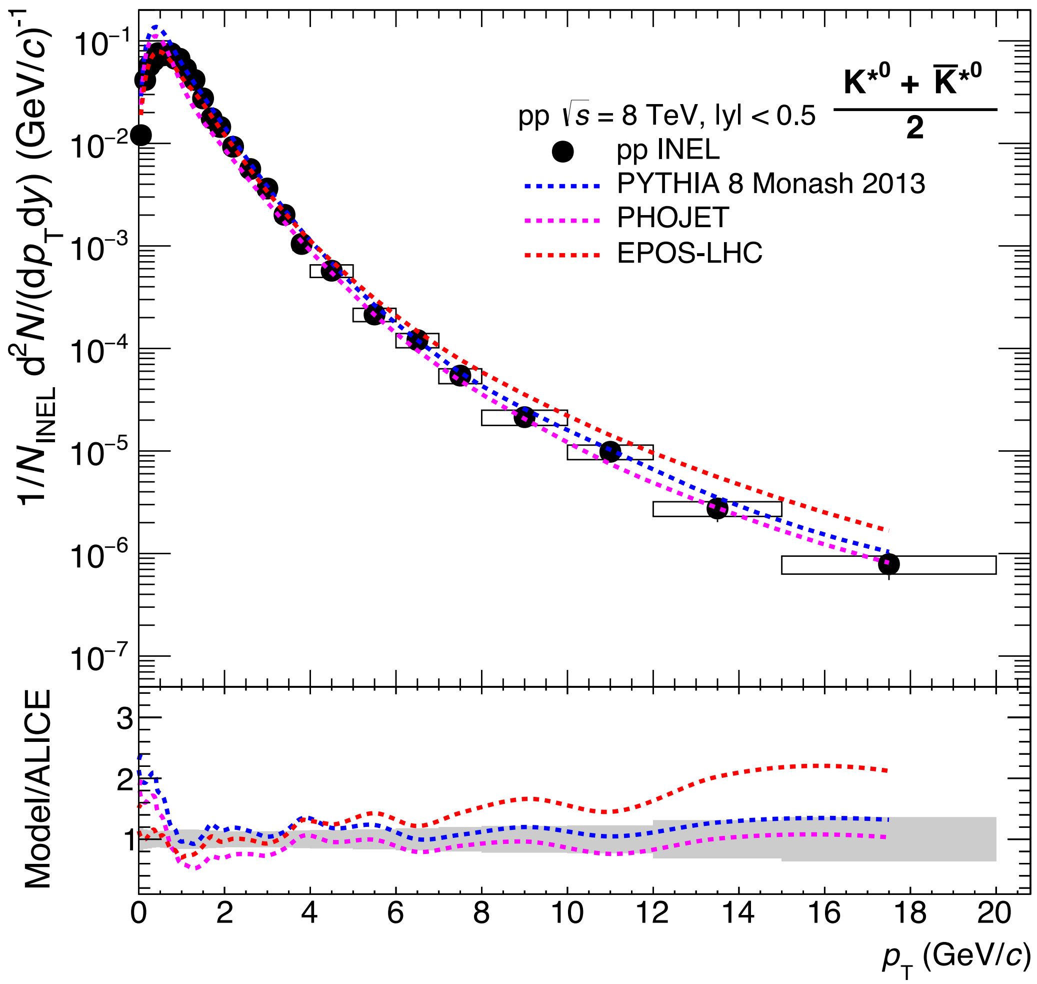
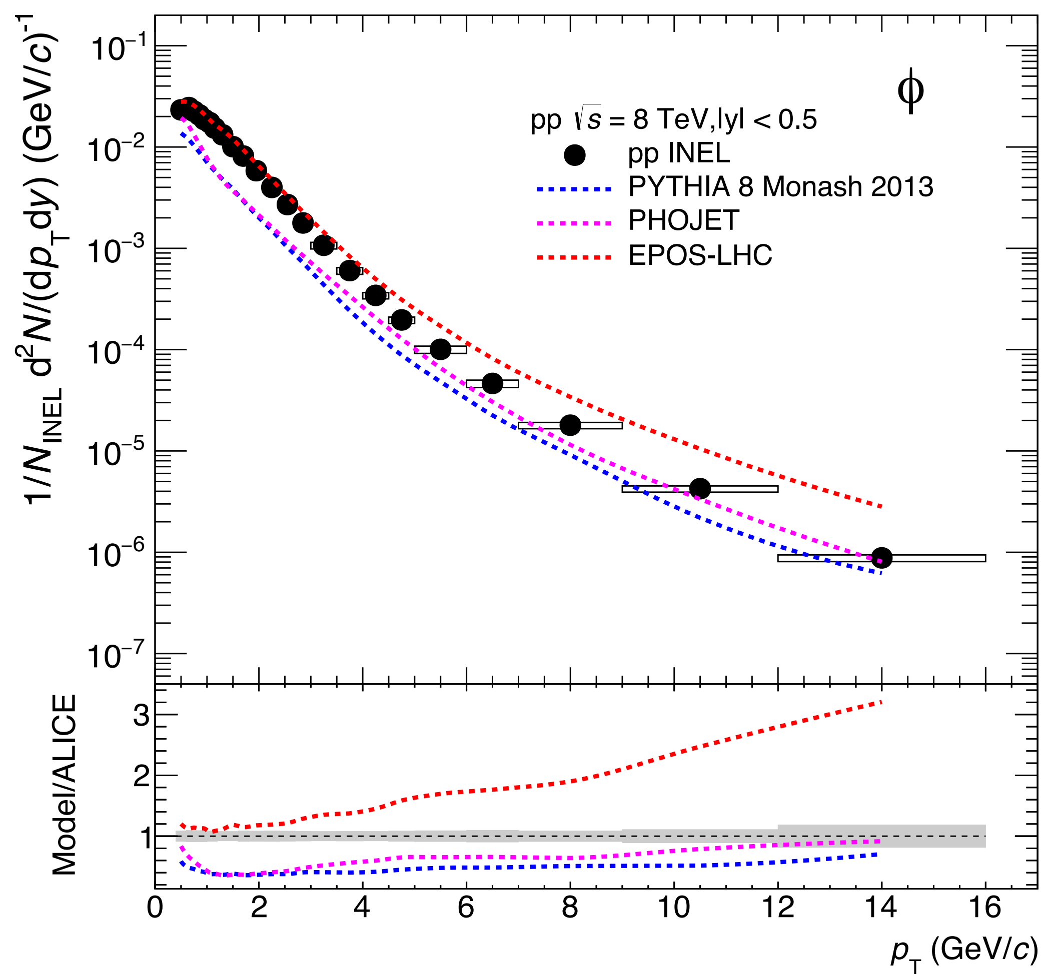
MC Model Comparision





- **PYTHIA 8 (Monash tune) explains the p_T spectra for K^{*0} at very low p_T but under-estimate at intermediate p_T and approaches to experimental data at high p_T. For ϕ meson, PYTHIA 8 (Monash tune) predicts the yields within 40-60 % below the experimental data.**
- **PHOJET has a softer p_T spectra for K^{*0} and it explains the data above p_T > 4 GeV/c within the uncertainties. For ϕ meson, PHOJET predicts the yields similar to PHYTHIA 8 at low p_T, while it approaches to experimental data at higher p_T.**
- **For K^{*0}, EPOS LHC explains the p_T spectra at low p_T and overestimate the data above 4 GeV/*c*. For ϕ meson, the EPOS LHC model agrees marginally with data at low p_T and deviates monotonically from data with increase in p_T.**

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Summary

- The first measurement of the K^{*0} and ϕ production at mid-rapidity in minimum bias pp collisions at $\sqrt{s}$ = 8 TeV in the range 0< pT <20 GeV/c for K^{*0} and 0.4< pT <16 GeV/c for ϕ(1020) are presented.
- Hardening of the pT-spectra is observed with increase in collision energy.
- The particle ratios (K^{*0}/π and ϕ/π) seem to be independent of collision energy within systematic uncertainties.
- Similar behaviour is also observed for K^{*0}/K and ϕ/K ratios as a function of collision energy.
- No significant energy dependence of ϕ /K^{*0} in minimum bias pp collisions in LHC energies is observed. Despite K^{*0} and ϕ having similar masses, the ϕ /K^{*0} ≠ 1. This hints a different particle production mechanisms for K^{*0} and ϕ .
- The p–Pb measurements at the same energy are in preparation and these pp results will contribute to the baseline for the p–Pb collisions.

PYTHIA 8.212 (Monash 2013 tune) STUDY

Intriguing similarities between high-p_T particle production in pp and A-A collisions

Phys. Rev. C99 (2019) 034911

Outline:

Introduction

Results and observations

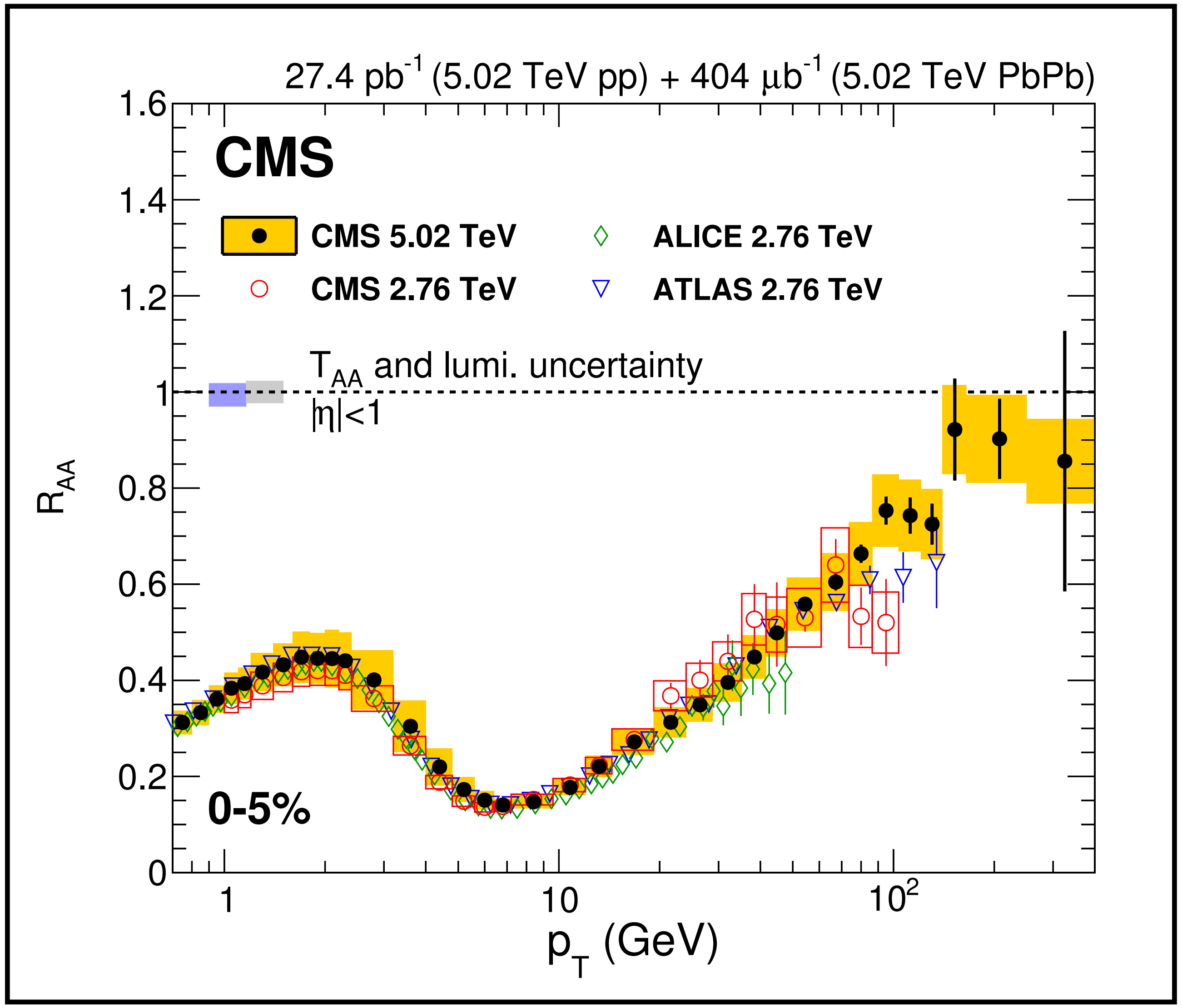
Summary

Introduction

- ✦ The similarity between analogous observables in large (*A*- *A*) and small (*pp* and *p*-*A*) collisions systems was extensively studied by the heavy-ion community.
- ✦ In the present work we do a comprehensive study of the multiplicity dependence of particle production at high transverse momentum ($pT > 8$ GeV/*c*) in *pp* collisions at LHC energies.
- ✦ The Nuclear Modification Factor (R_{AA}) is an important observable in heavy-ion collisions, which gives the information about the parton energy loss in the medium.

$$R_{AA} = \frac{d^2 N_{\mathrm{AA}}/dy d\mathrm{p_T}}{< N_{coll} > d^2 N_{\mathrm{pp}}/dy d\mathrm{p_T}}$$

JHEP 04 (2017) 039



Introduction

- The similarity between analogous observables in large (*A- A*) and small (*pp* and *p-A*) collisions systems was extensively studied by the heavy-ion community.
- In the present work we do a comprehensive study of the multiplicity dependence of particle production at high transverse momentum ($pT > 8$ GeV/c) in *pp* collisions at LHC energies.
- The Nuclear Modification Factor (R_{AA}) is an important observable in heavy-ion collisions, which gives the information about the parton energy loss in the medium.

$$R_{AA} = \frac{d^2N_{\rm AA}/dyd\rm p_T}{< N_{coll} > d^2N_{\rm pp}/dyd\rm p_T}$$

In the absence of Nuclear Effects : $R_{AA} = 1$.

shape of R_{AA} *vs* p_T gives information about the parton energy loss.

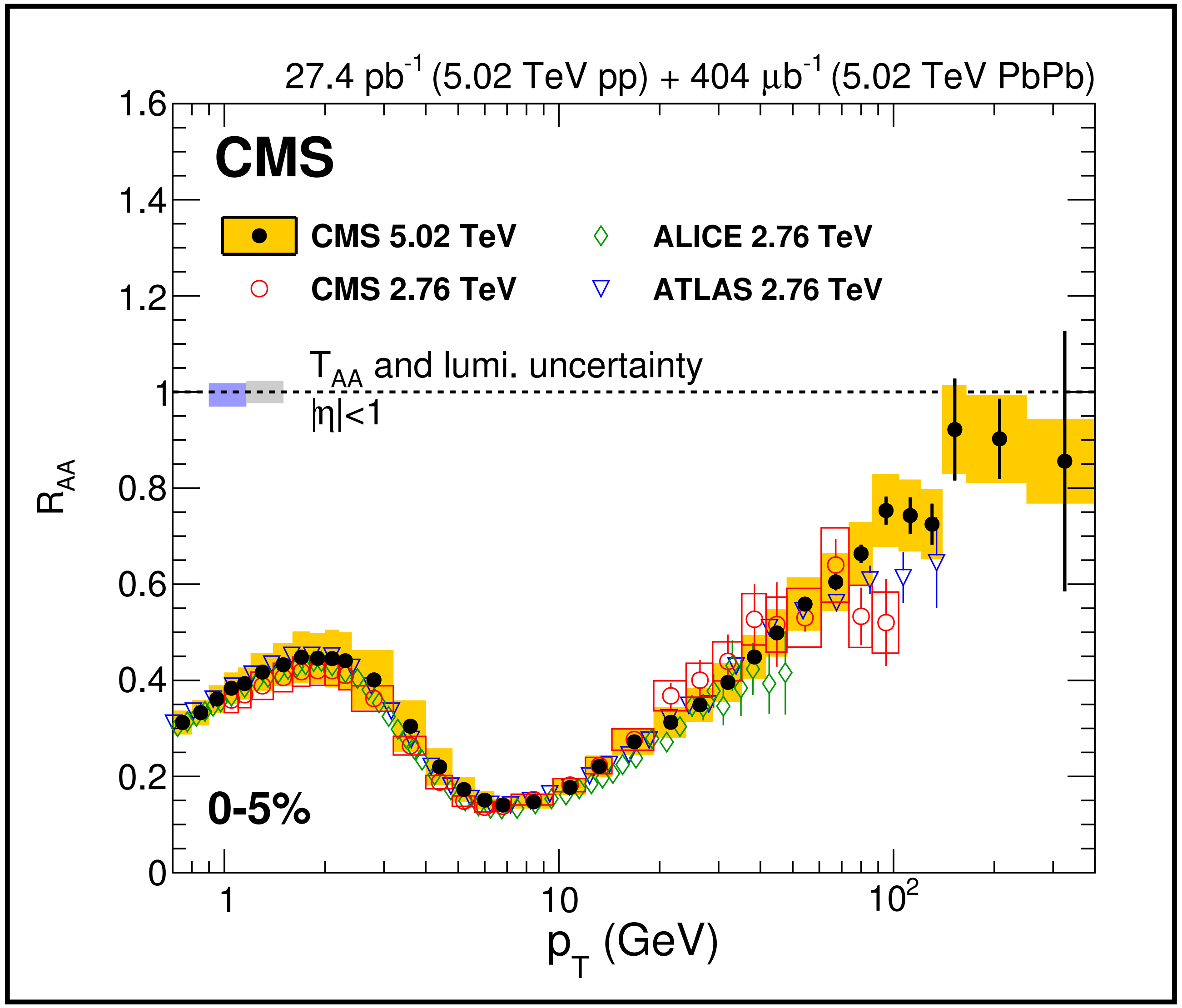
BUT

At High p_T ($p_T > 8$ GeV./C): shape of R_{AA} for high-pT particles is not fully attributed to the parton energy loss.

Because

I will demonstrate here, **a similar shape is observed for the analogous ratios in *pp* collisions, i.e., high-multiplicity *pT* spectra normalized to that for minimum-bias events**.

JHEP 04 (2017) 039



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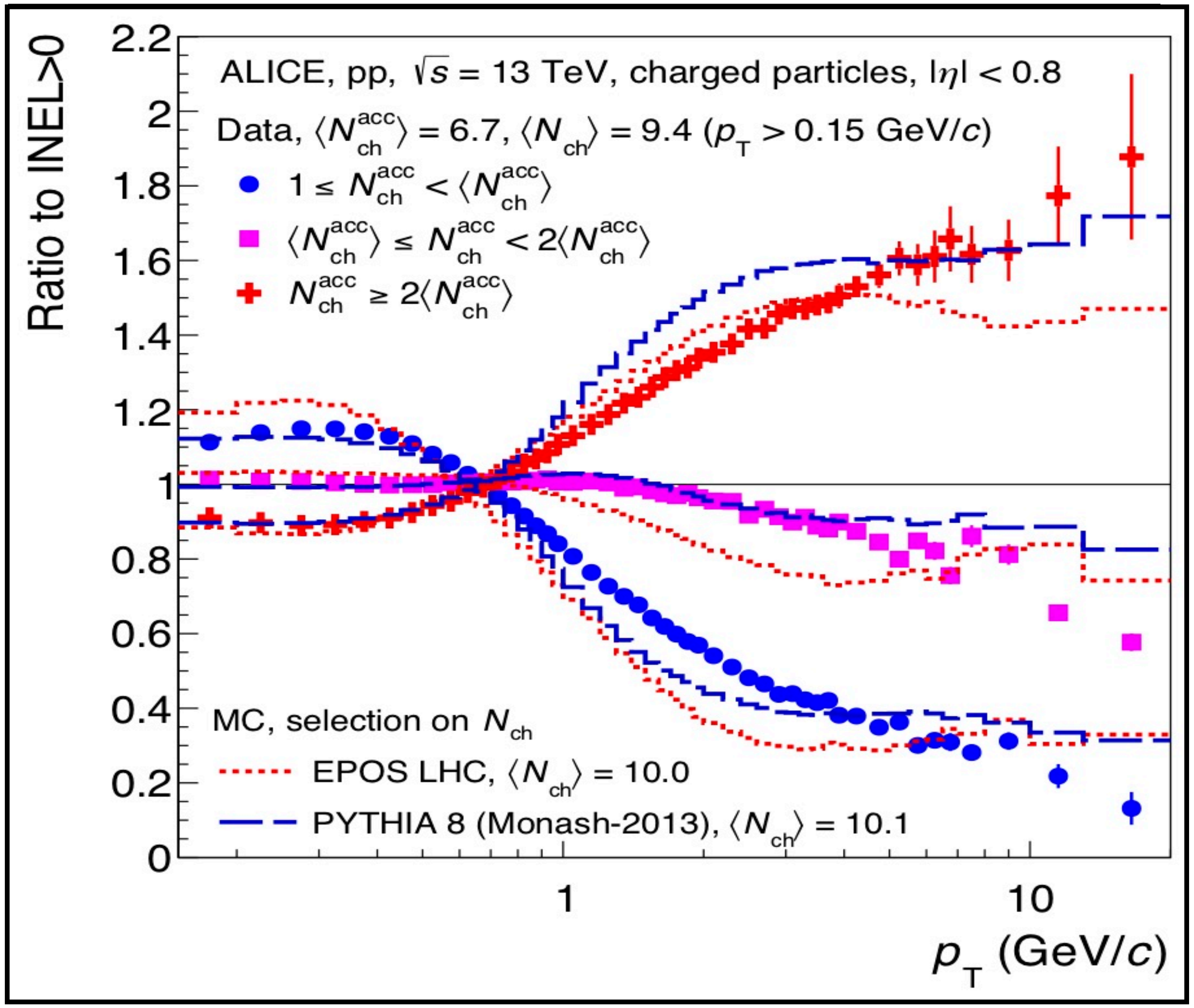
✦Within a limited multiplicity reach, the ALICE Collaboration has shown that such a ratio in pp collisions at 13 TeV exhibits a nonlinear increase with $\mathrm{p_T}$.

Phys. Lett. B 753 (2016) 319-329



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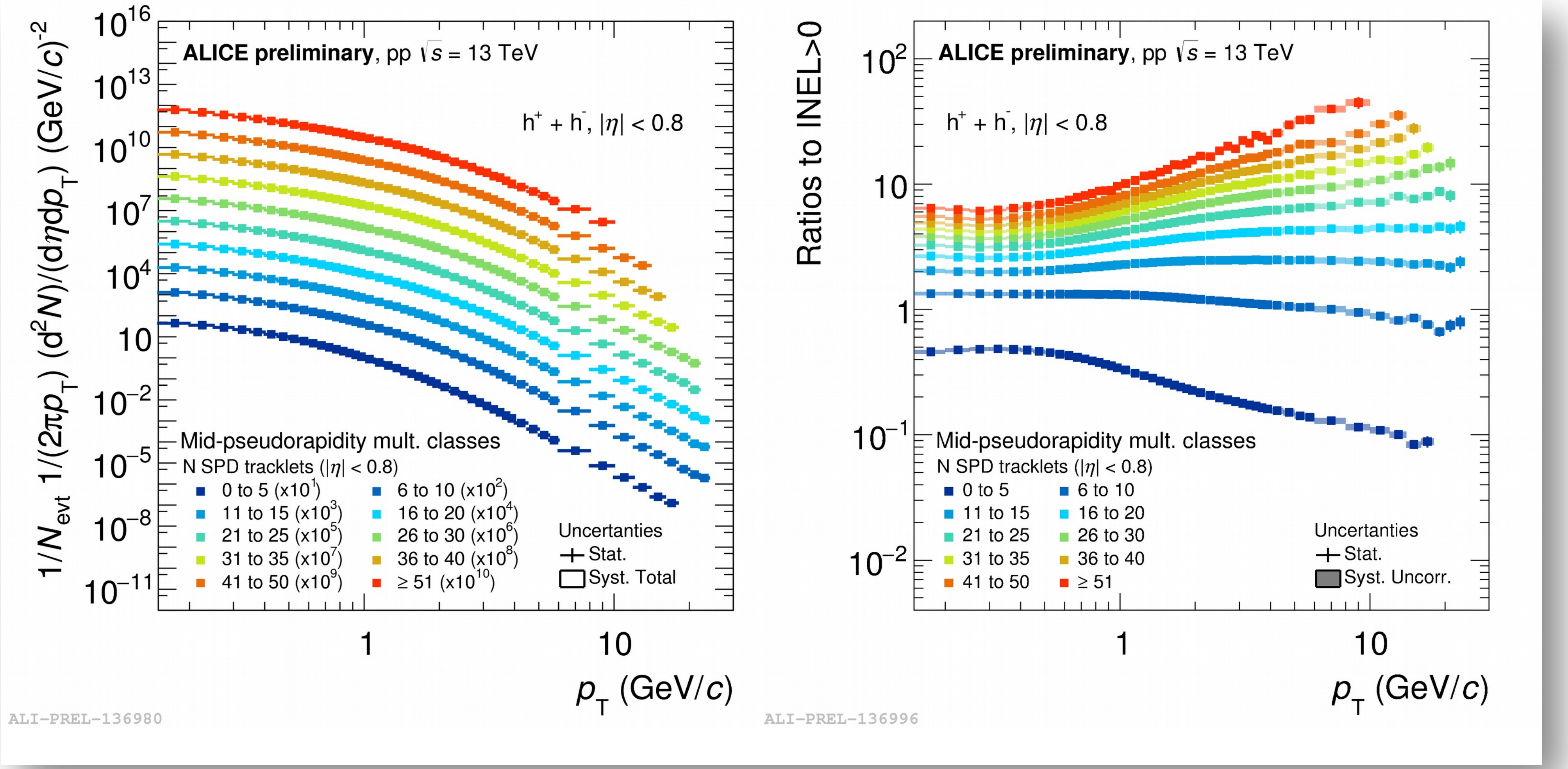
$$R_{AA} = \frac{d^2 N_{\rm AA}/dy dp_{\rm T}}{< N_{coll} > d^2 N_{\rm pp}/dy dp_{\rm T}}$$

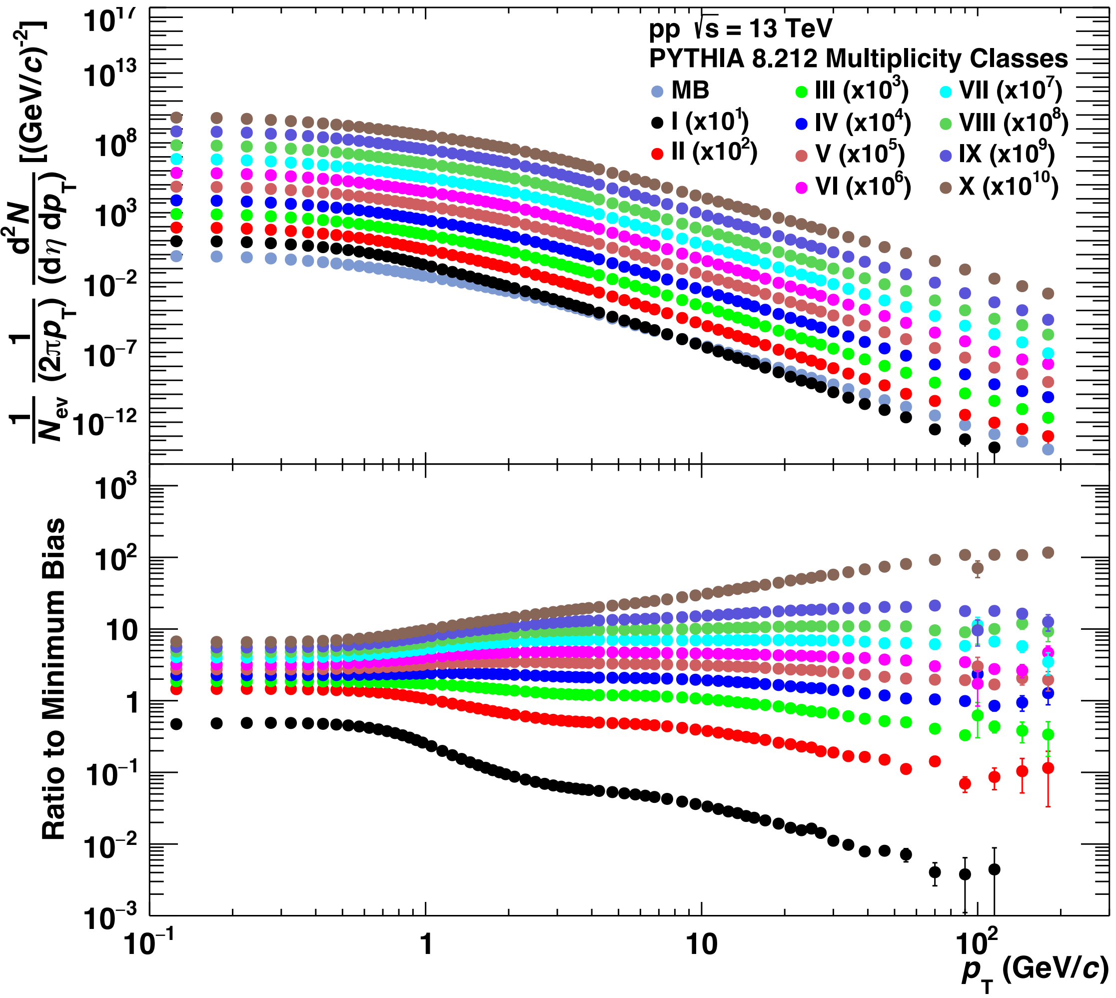
Eur. Phys. J. C (2019) 79:857



Introduction

Event multiplicity classes based on the number of charged particles (N_{ch}) within $|\eta| < 0.8$ for pp 13 TeV simulated with PYTHIA 8.212

Class name	I	II	III	IV	V
N_{ch}	0 – 5	6 – 10	11 – 15	16 – 20	21 – 25
fraction	10.45%	15.68%	14.79%	13.78%	12.34%
Class name	VI	VII	VIII	IX	X
N_{ch}	26 – 30	31 – 35	36 – 40	41 – 50	≥ 51
fraction	10.39%	8.08%	5.78%	6.09%	2.61%



A. N. Mishra: Phys. Rev. C99 (2019) 034911

✦In the absence of experimental data for higher multiplicities, we used pp collisions simulated with **PYTHIA 8.212** (tune Monash 2013).

✦For $pT > 8$ GeV/c the spectra become harder with increasing multiplicity.

✦Ratios of the pT spectra for the different multiplicity classes divided by that for minimum-bias *pp* collisions. **They exhibit an important increase with *pT*, similar to the one observed in the *RAA* measured in Pb-Pb collisions.**

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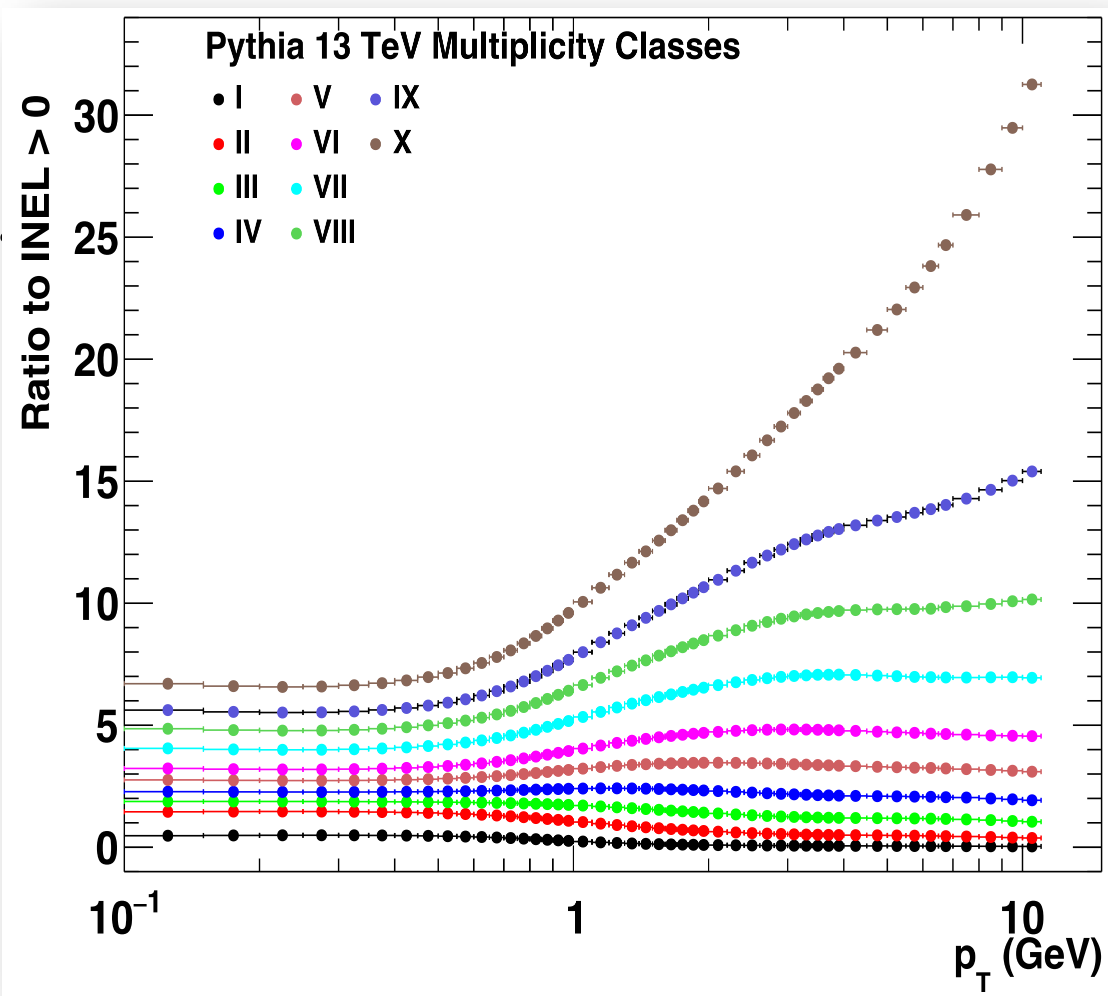

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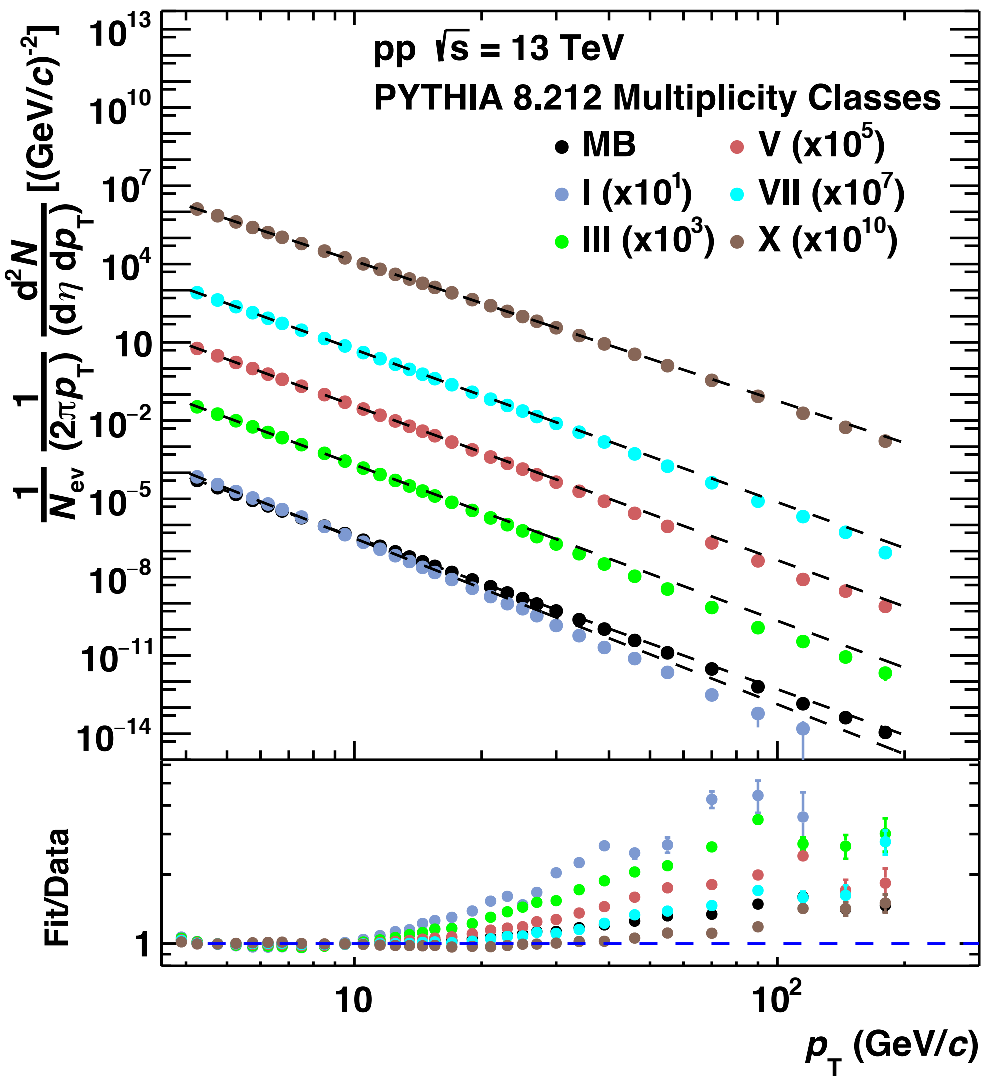
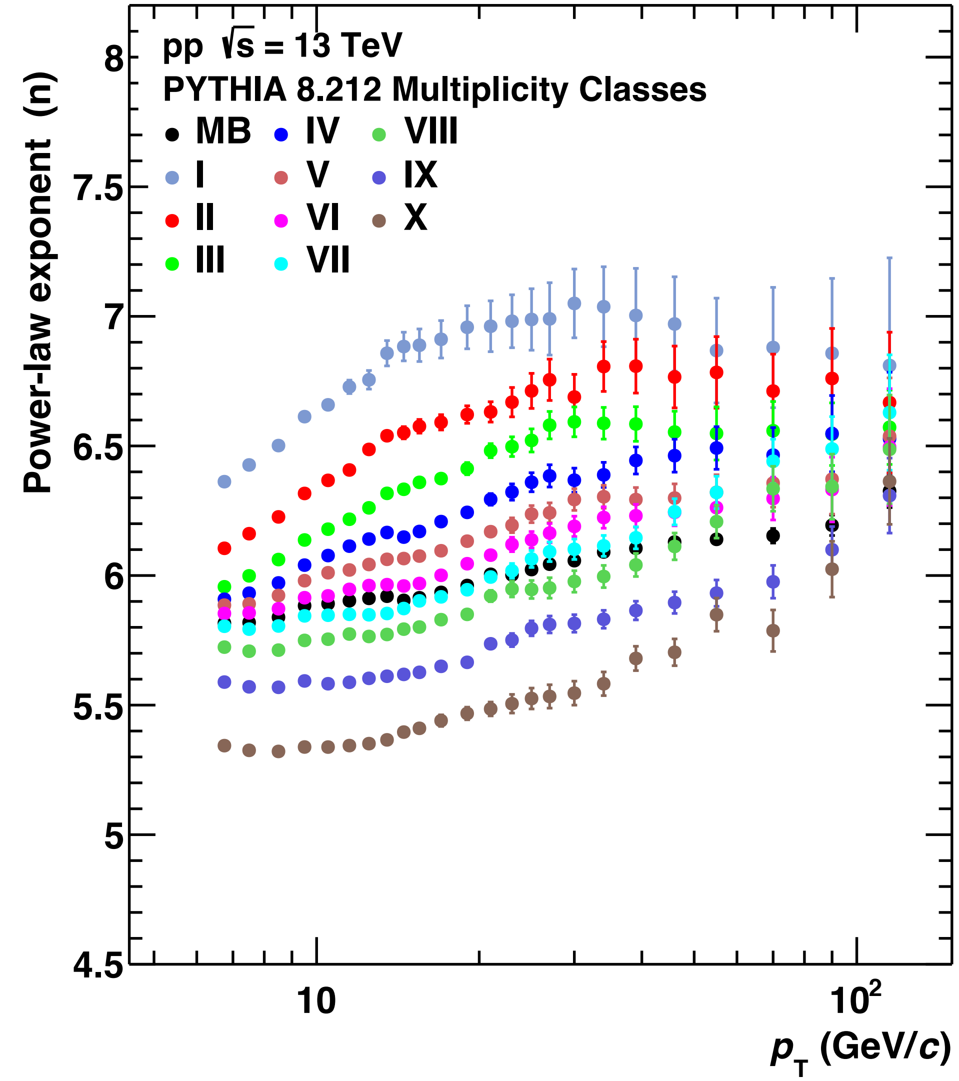
Similar to the ALICE recent result.





- **p_T spectra is fitted with power-law function ($\propto p^{-n}$).**
- Not possible to describe the full-p_T (8–200 GeV/c) interval assuming the same power-law exponent.
- **For p_T larger than 20 GeV/c the ratios go beyond 20%**
- This allows the extraction of local power-law exponents for different p_T sub-intervals. **The results indicate that the exponent has an important dependence on pT.**

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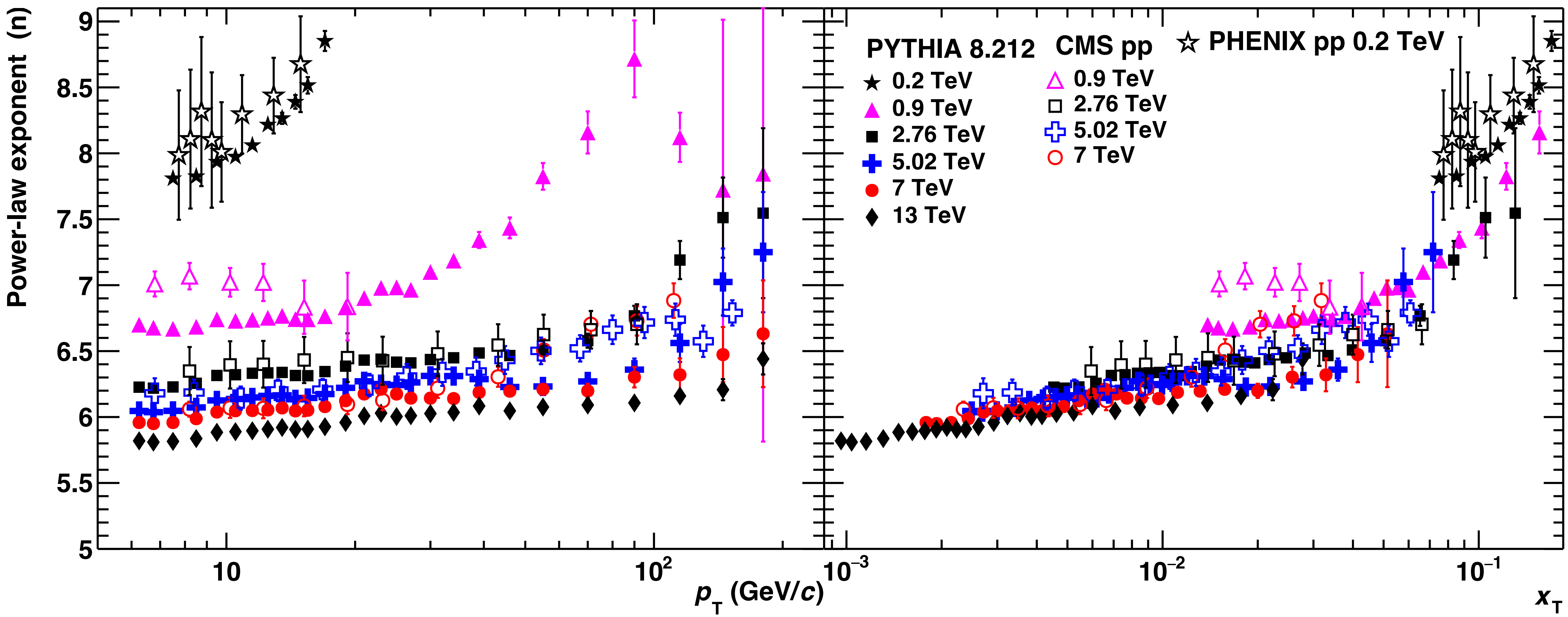
Results

✦ Going from low to high energies the power-law exponent decreases in both data and PYTHIA8.212.

✦ This is expected because at higher energies the production cross sections of hard processes increases resulting in a change in the slope of the spectra at large transverse momenta.

✦ **Within 10% the exponents, that were before distinctly different on p_T scale, fall now approximately on a universal curve in x_T scale.**

✦ The approximate scaling property is well reproduced by PYTHIA 8.212.



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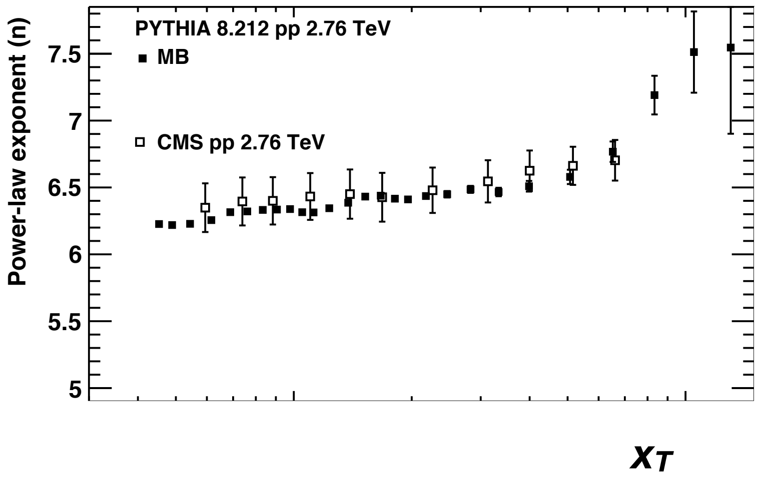
Results:Comparison of PbPb and pp spectra (2.76 TeV)



- **PYTHIA explain CMS Minimum Bias data very well.**

A. N. Mishra: Phys. Rev. C99 (2019) 034911

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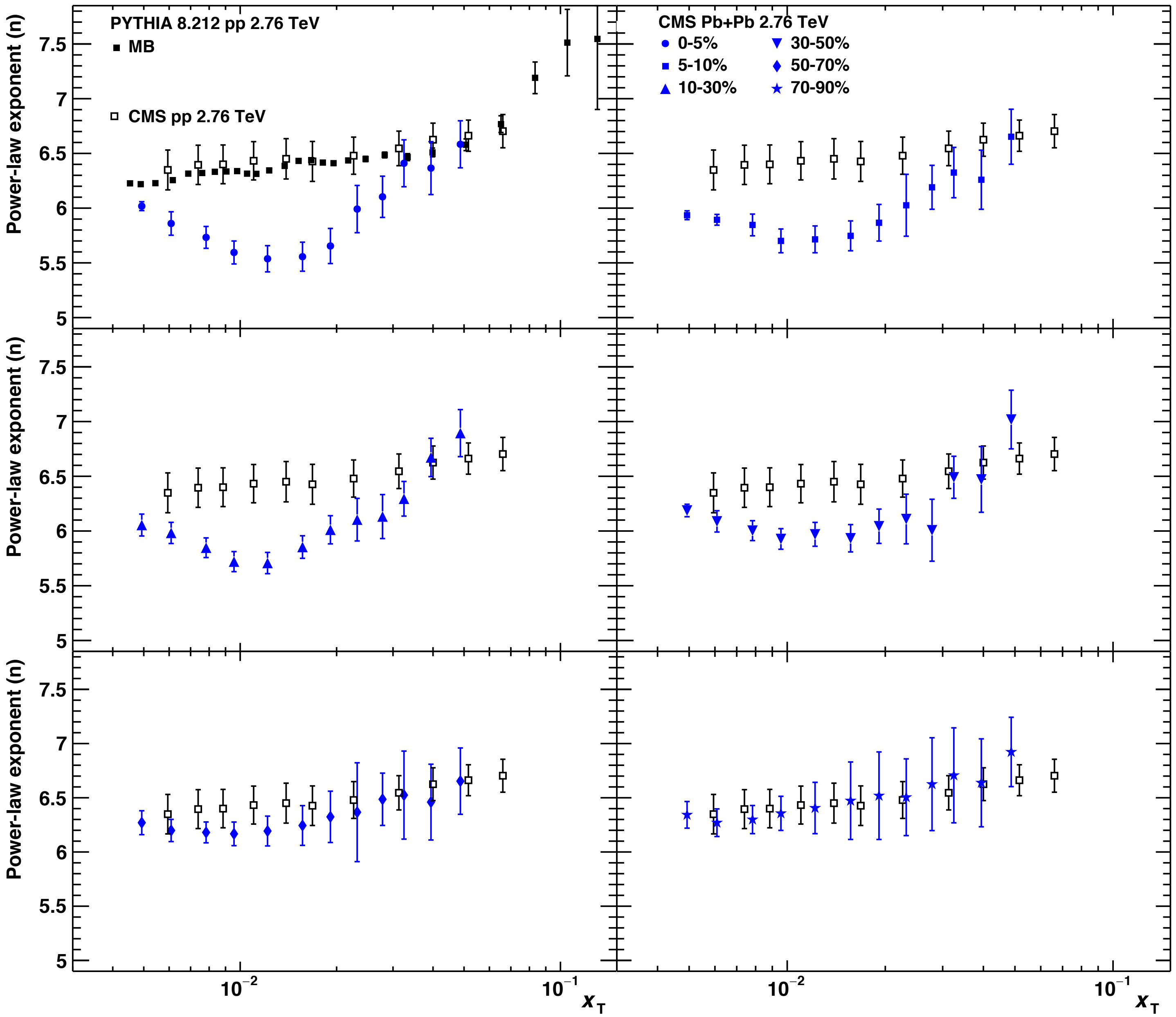

- **PYTHIA explain CMS Minimum Bias data very well.**
- **Pb+Pb spectra have a drastic evolution with centrality.**
- **Most peripheral Pb+Pb spectra has exponents similar to pp MB.**
- **Going towards Most Central collision spectra needs other multiplicity class of pp collisions.**

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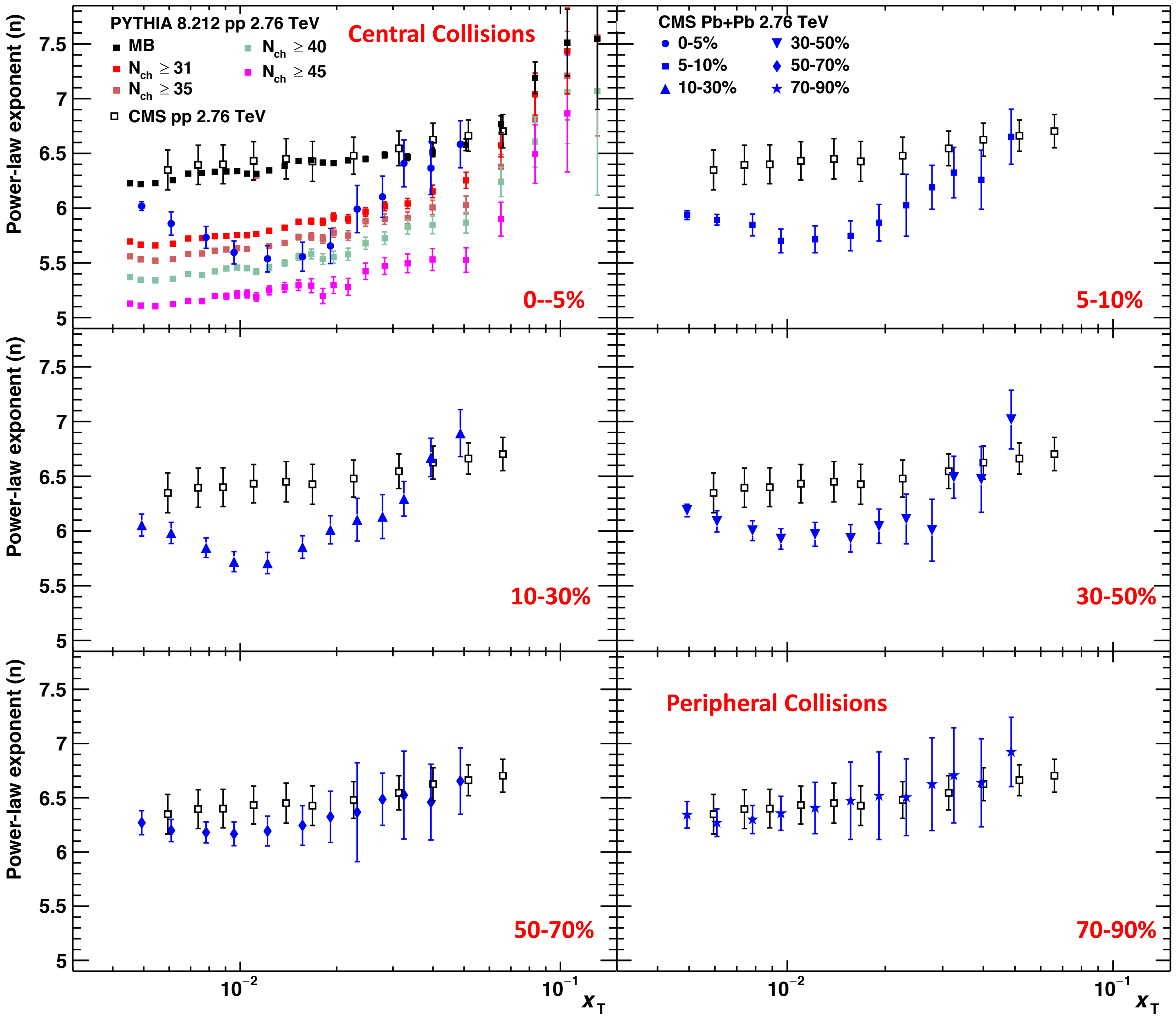

- **PYTHIA explain CMS Minimum Bias data very well.**
- **Pb+Pb spectra have a drastic evolution with centrality.**
- **Most peripheral Pb+Pb spectra has exponents similar to pp MB.**
- **Going towards Most Central collision spectra needs other multiplicity class of pp collisions.**
- **For each centrality in PbPb, there is a multiplicity class in pp, which has similar exponents.**

The particle production doesn't know about the colliding species: It only cares about the "ENERGY DENSITY" of the system.

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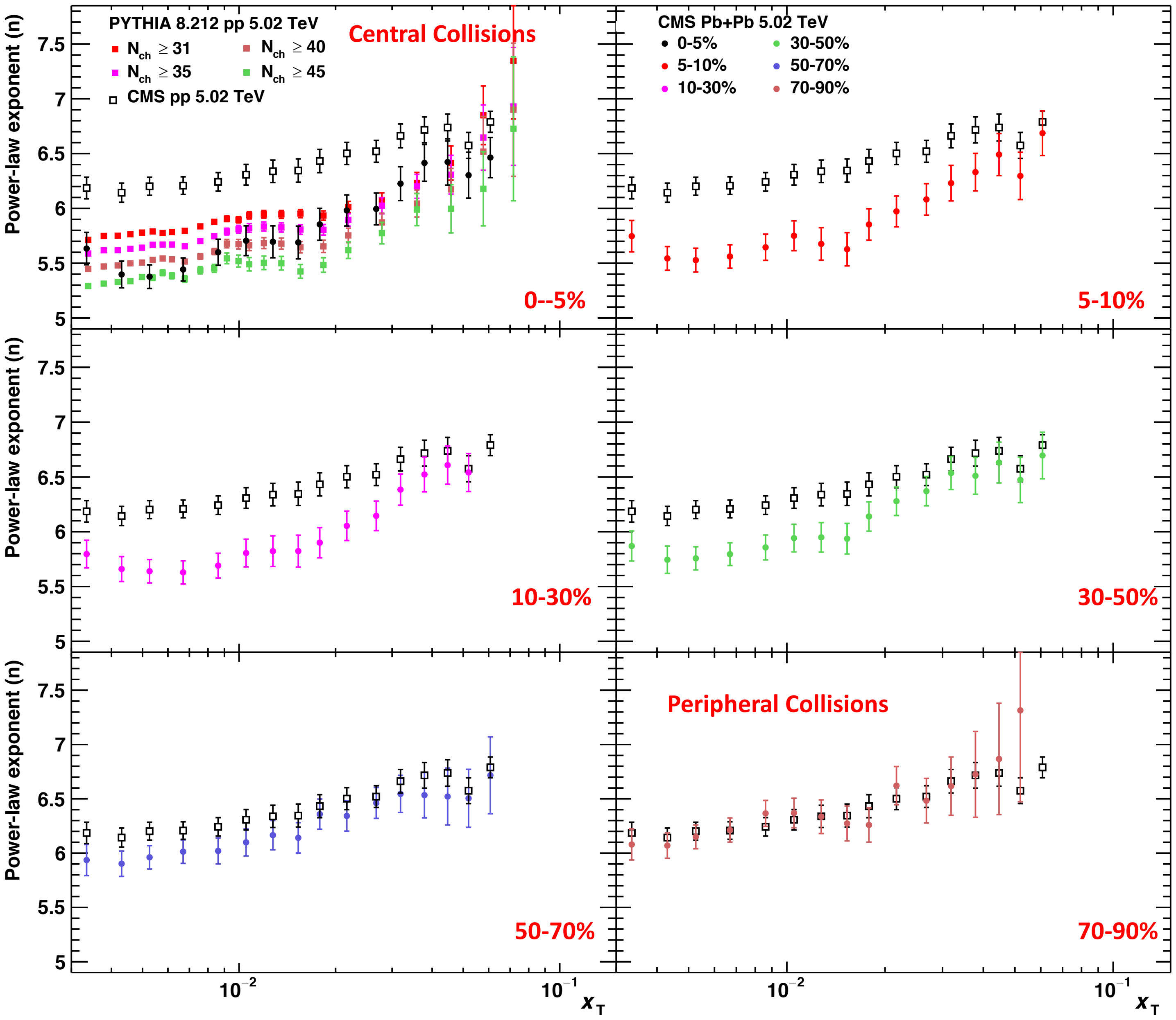
Results:Comparison of PbPb and pp spectra (5.02 TeV)



Similar behavior is also observed for Pb-Pb collisions at 5.02 TeV

The particle production doesn't know about the colliding species: It only cares about the "ENERGY DENSITY" of the system.

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Question arises: Can we have a QGP like medium in pp collisions??

ENERGY DENSITY can give answer!!

QGP phase transition:

- The original idea: energy density based on dE/dy
- QGP critical $\epsilon_c \sim 1$ GeV/fm^3

This is very easy to achieve even in pp collisions

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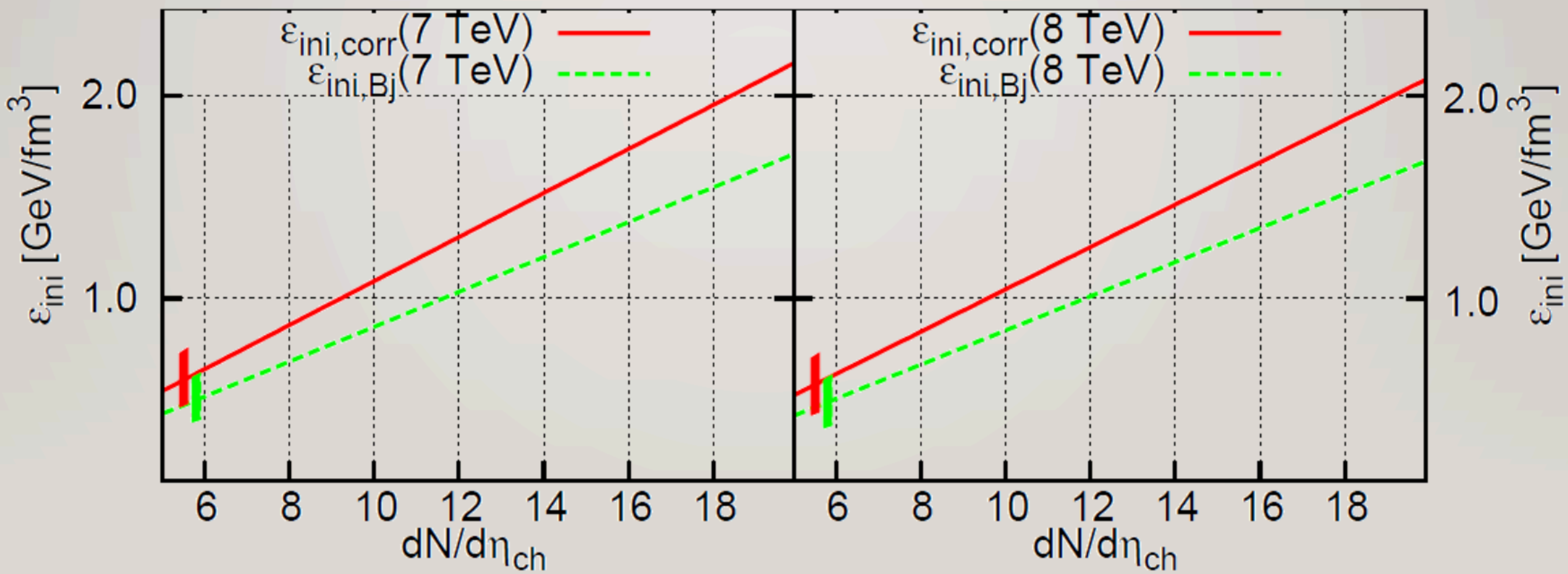
Question arises: Can we have a QGP like medium in pp collisions??

- Initial energy density estimate above 1 GeV/fm^3, if:
  - Bjorken estimate: $dN_{ch}/d\eta > 12$
  - Corrected estimate: $dN_{ch}/d\eta > 9$



In high-multiplicity pp collisions, we reach high energy densities

https://indico.cern.ch/event/684046/contributions/2809620/attachments/1572015/2480526/csanad_zimanyi17_dndeta.pdf

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Summary

- The slopes of the p_T spectra have a marked dependence **on the multiplicity and energy** in pp collisions and on the centrality in heavy ion collisions.
- For every centrality of AA collisions, one may find a multiplicity class in pp collisions which has a the same exponent.
- It has been demonstrated that the characterization of the spectra in function of x_T and of the power law exponent offers interesting observation (scaling behavior).
- The effect of the rise of the RAA at high momenta is not due to an increased transparency of the hot system. The behavior of the rise is solely due to the evolution of the p_T spectra. Rather than working with the ratio of two spectra we should carefully analyse the spectra of each collision system.
- The similarities between pp and PbPb suggest that the high-p_T production in both systems have a common origin, namely, the **density of the system.**

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Parton energy loss in pp collision at very high multiplicity

arXiv:1905.06918

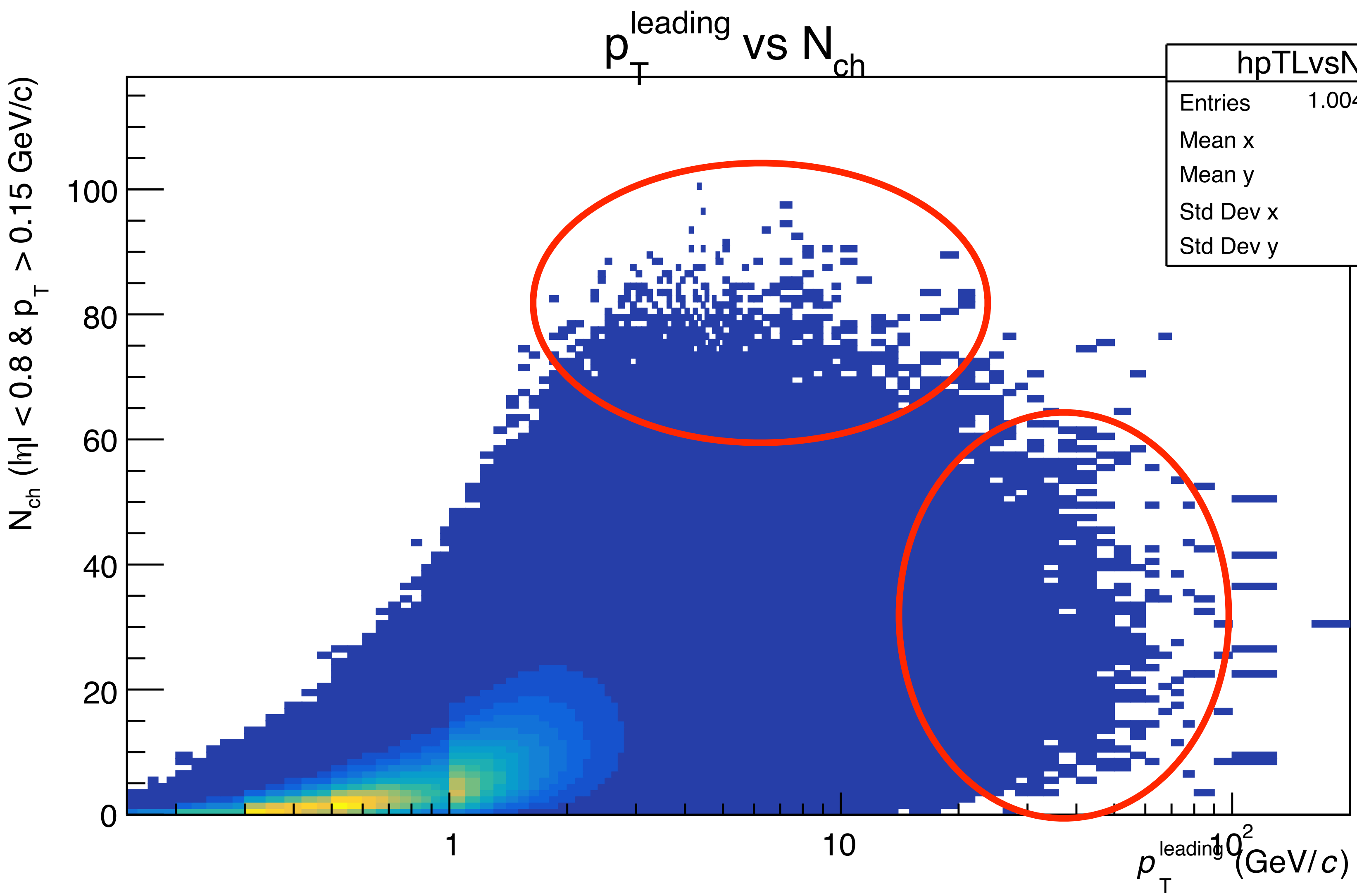
Outline:

Introduction

Observations

Summary

Introduction



Multiplicity increases with Transverse momentum p_T is NOT TRUE always!

Interesting to study the multiplicity dependence of Underlying events at intermediate and higher leading transverse momentum (p_T^L).

Introduction

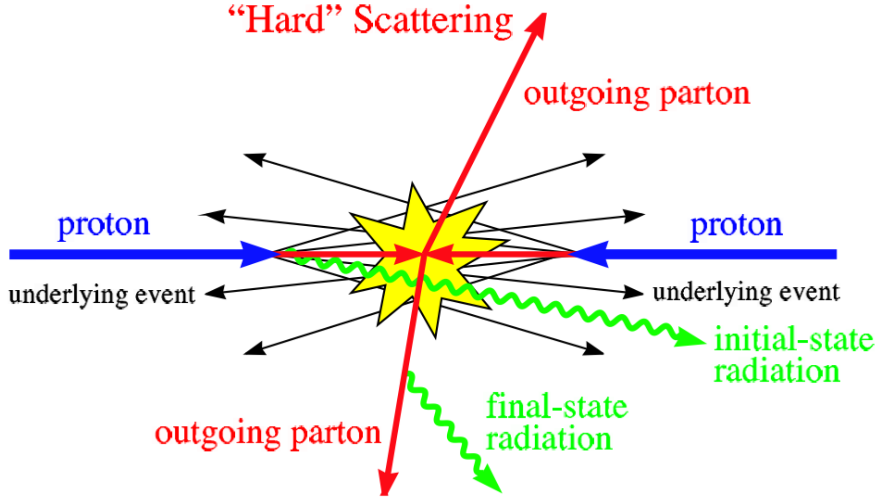
Leading Particle:

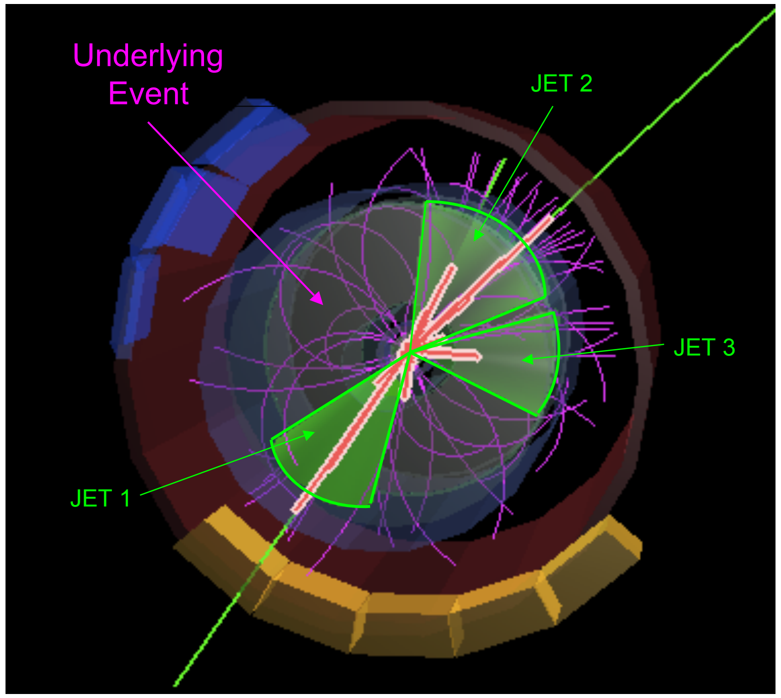
Particle with highest p_T in the particular event is assigned as a leading pT of the event. The azimuthal angle with the leading particle will be the new reference for other particles belonging to the event.

Underlying Event (UE): In parton-parton scattering, the UE is usually defined to be everything except the two outgoing hard scattered partons:

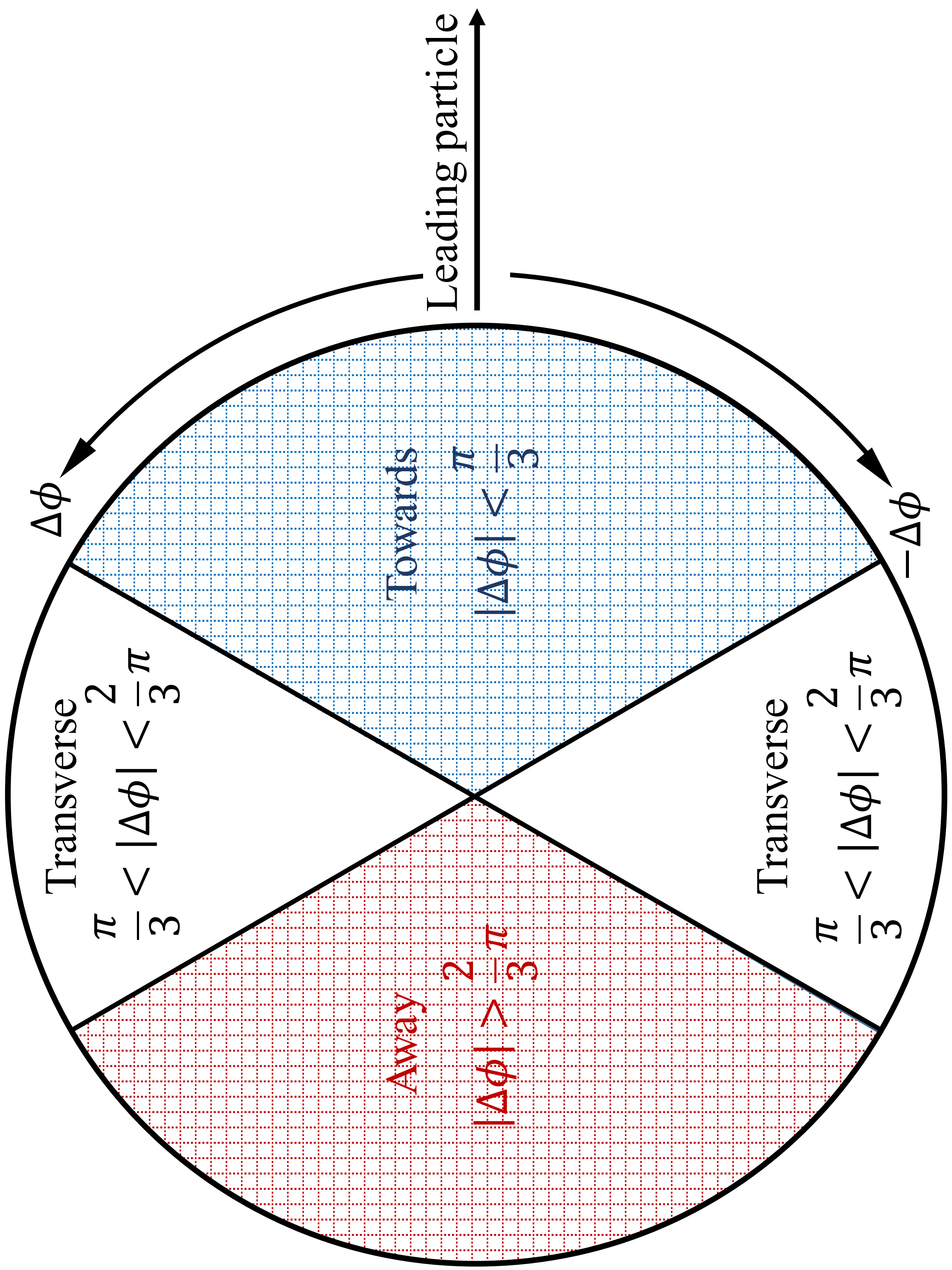
- Beam-beam remnants.
- Additional parton-parton interactions.
- Initial and final state radiations

etc…..





Observables: Leading Particles:

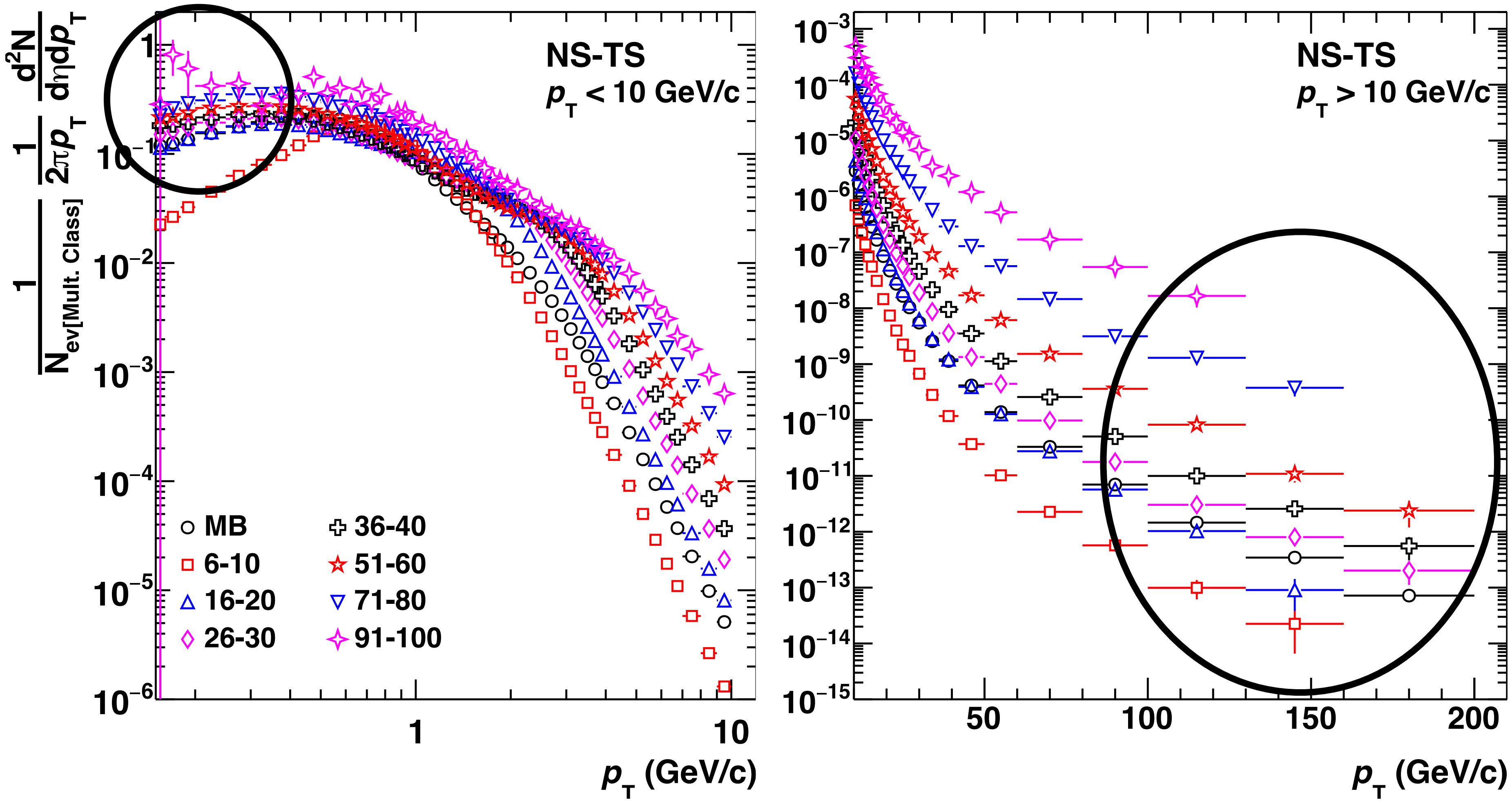


- Particle with highest p_T in the particular event is assigned as a leading pT of the event. The azimuthal angle with the leading particle will be the new reference for other particles belonging to the event.

- **Traditional UE measurement:** according to the azimuthal direction of leading charged particle, three distinct topological regions are defined:
  - Toward: $|\Delta\Phi| < \pi/3$
  - Away: $|\Delta\Phi| > 2\pi/3$

    } (sensitive to Jet fragmentation)
  - Transverse: $\pi/3 < |\Delta\Phi| < 2\pi/3$ (sensitive to UE)

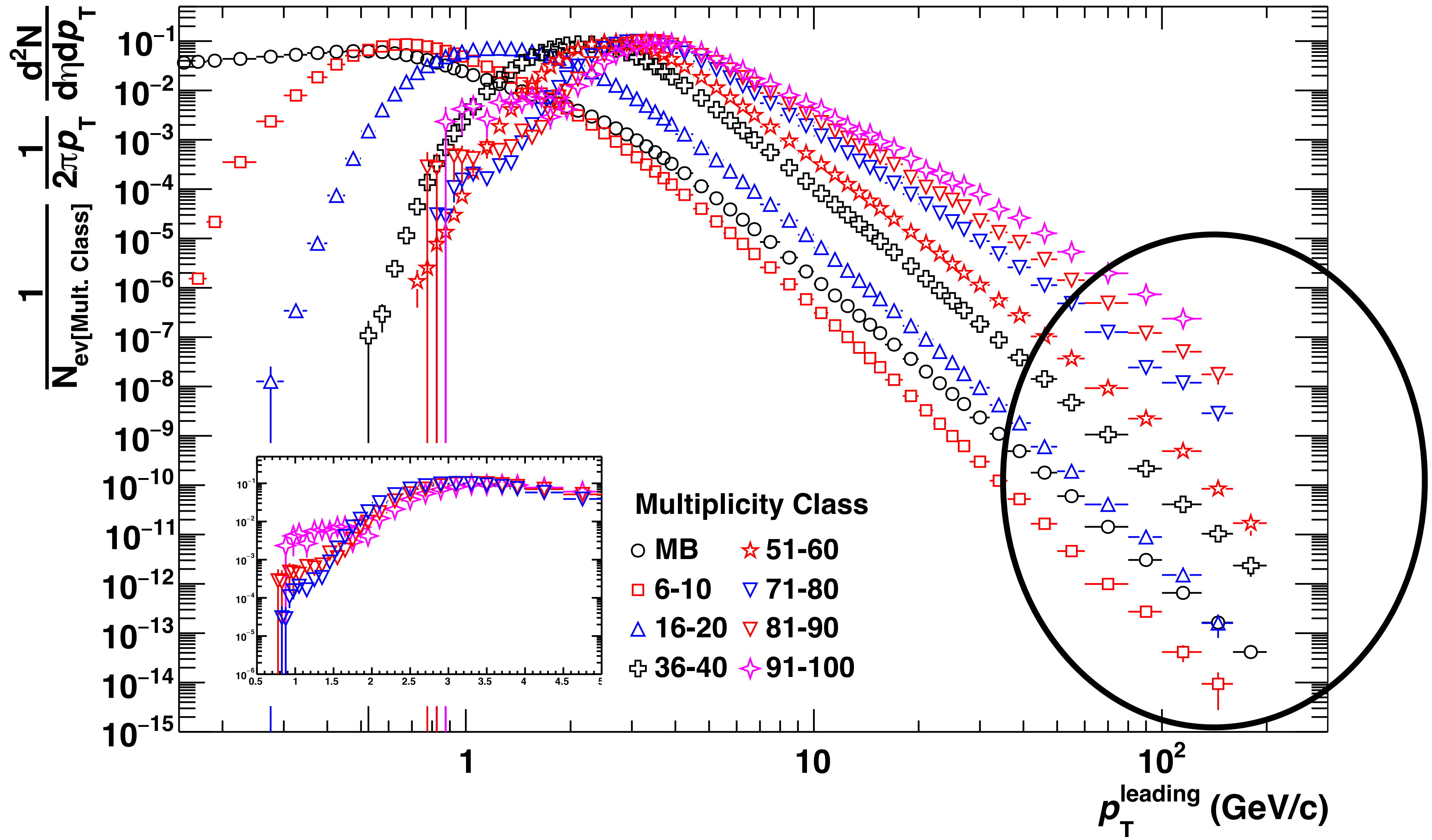
Observation: Hard/Jetty spectra (NS-TS)



- NS-TS spectra, which is obtained by subtracting the Transverse Side (TS) spectrum from the Near Side (NS) spectrum since the TS one is supposed to run also in the NS region.
- The spectra exhibit a hardening with multiplicity.
- At higher multiplicities the slope of the spectra continues decreasing without producing higher momentum particles! higher multiplicities the slope of the spectra continues decreasing without producing higher momentum particles!

Missing high-pT particle and getting access of particles at low-pT is not a coincident!

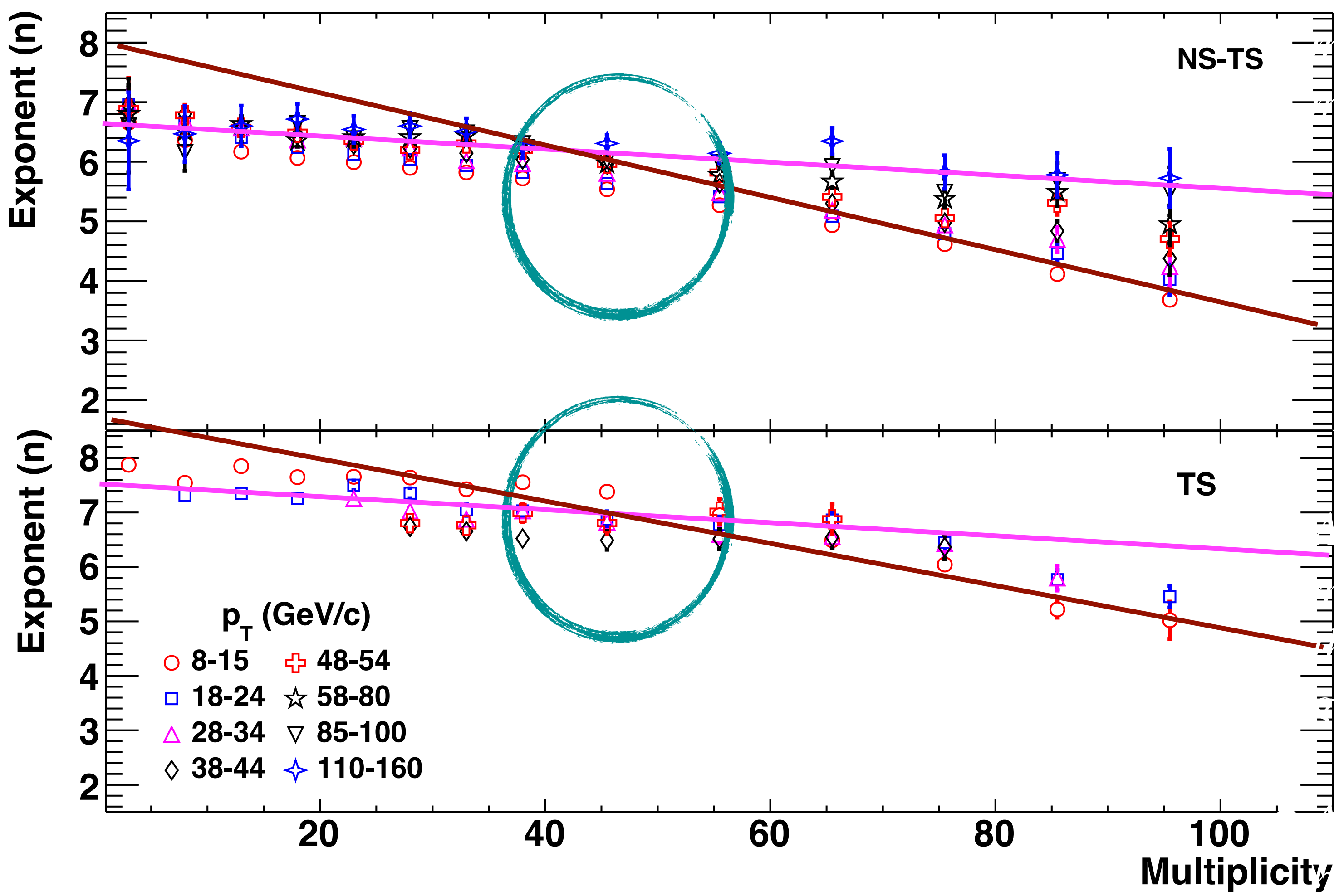
Observation: Leading Particles Spectra



✦ The low pT-part of the highest multiplicity bins spectra develop a “kink” at around 1 GeV/c

✦ **This supports the previous observation that the leading particles have been “degraded”?**

Observation: Exponents



In the low pt region ($8<p_T<15$ GeV/c), a rather important variation in the power-law exponent beyond the multiplicities corresponding to the maximum leading transverse momenta, while in the higher pt bin ($48<p_T<54$ GeVc)) this tendency is much smaller.

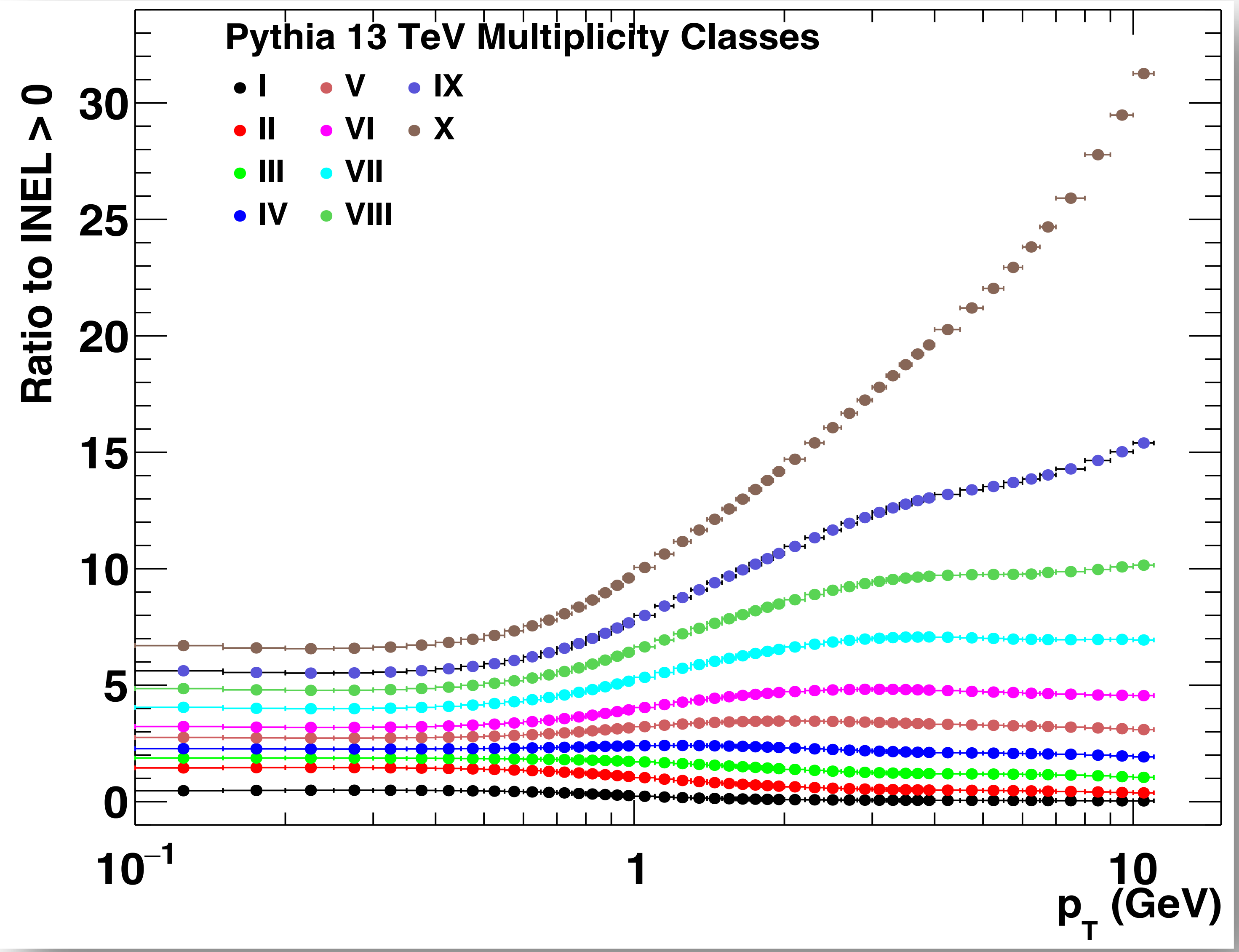
The observations invite an important question: **are we observing some kind of melting of the highest momentum particles – them "melting" and producing particles at lower momenta increasing thus the multiplicity and mean momentum?**

Summary

- The maximum reachable multiplicities are not accompanied by an increase in the maximum leading particle momentum. The proportionality between maximum pT and increasing multiplicity breaks down at multiplicity densities of around ~50.
- Beyond multiplicity density ~ 50, the NS-TS spectra continue to get flatter, increasing the mean transverse momentum, seemingly at the expense of the maximum reachable momentum
- Beyond the particle density corresponding to the maximum p_T reach both the TS and the NS-TS regions suffer a sudden hardening.
- At very low momenta the high multiplicity events present also a specific evolution by augmenting the yield of the smallest transverse momenta . The feature is observed both in the NS-TS spectra as well as in the leading particle spectra

Thank you very much for your kind attention

Backup Slide



Visible in Nonlinear scale!

Similar to the ALICE recent result.

Similar to the one observed in the RAA measured in Pb-Pb collisions.

Comparison of exponents obtained from ALICE data and PYTHIA 8.212 in pp 13 TeV