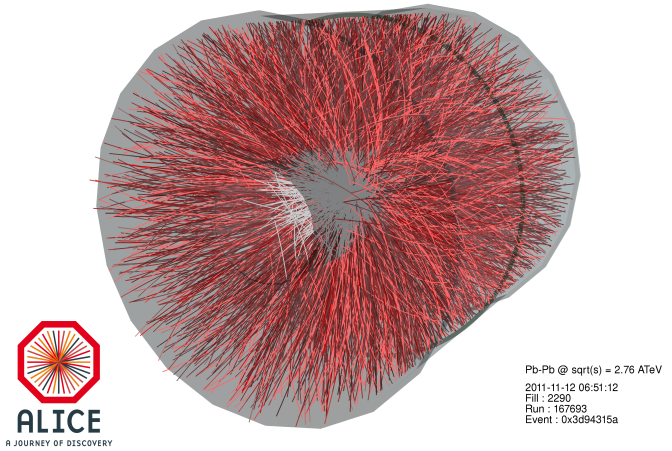
Collectivity phenomena search in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

S. Bufalino (CERN)

on behalf of the ALICE Collaboration

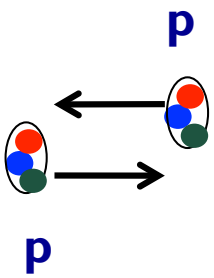
Outline

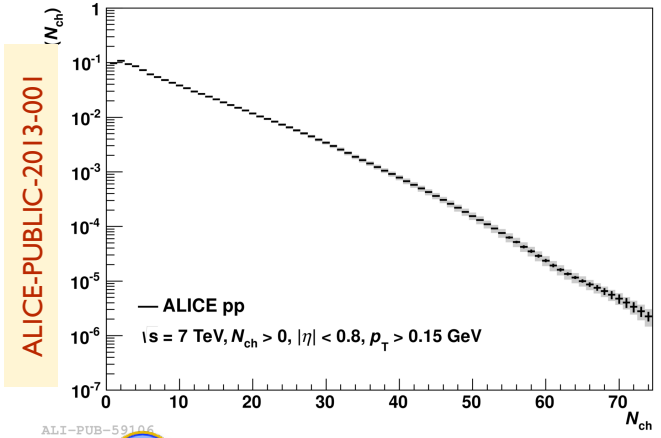
- Introduction and the ALICE experiment @ LHC
- p_T spectra of identified charged hadrons
- Spectra ratios - multiplicity dependence
- Relative yields – p_T and multiplicity dependence
- Boltzmann-Gibbs Blast Wave (BGBW) fits results and expansion profile
- Conclusions

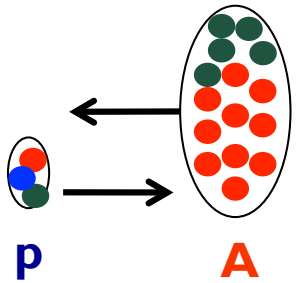


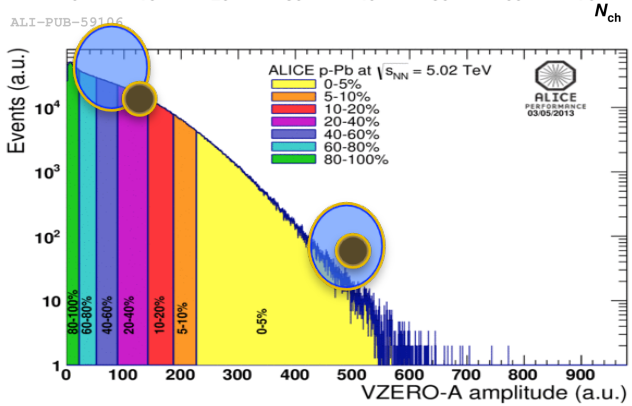
Introduction

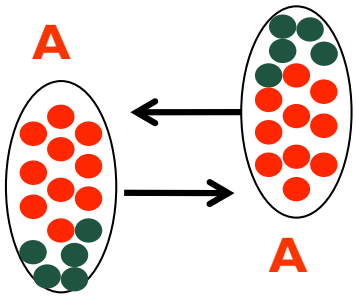
Centrality Selection

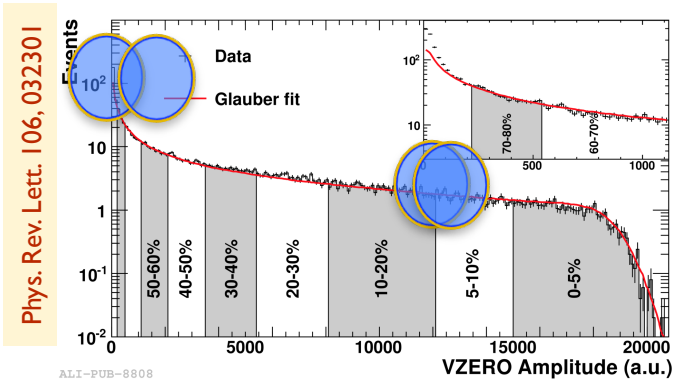


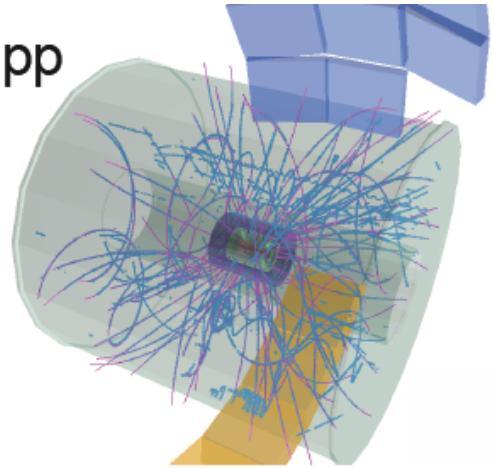


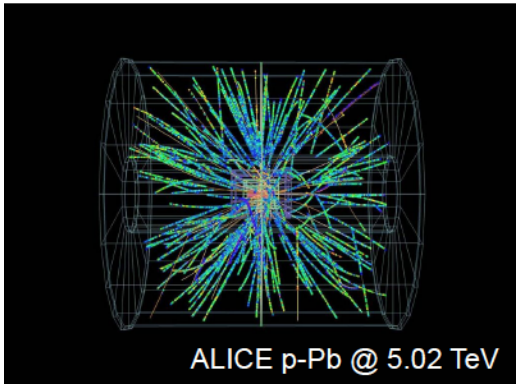


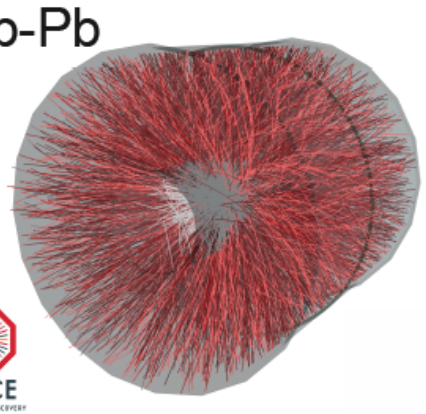








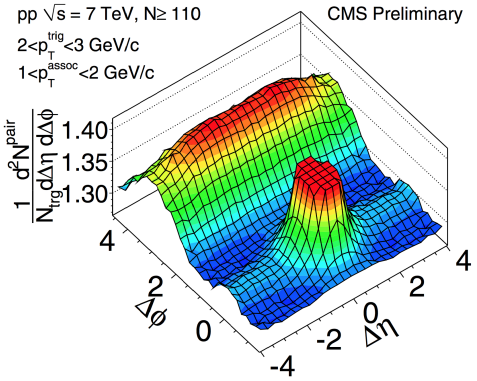




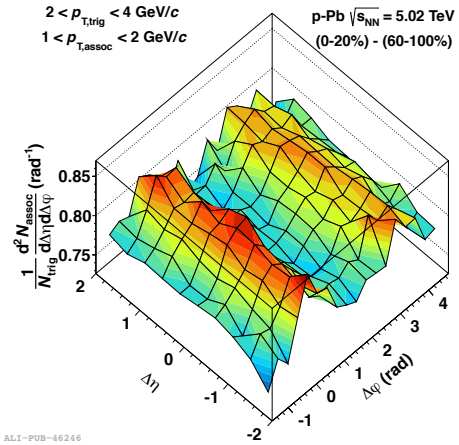
Introduction

Collectivity

J. Phys. G: Nucl. Part. Phys. 38, 124051



Phys. Lett. B 719, 29-41



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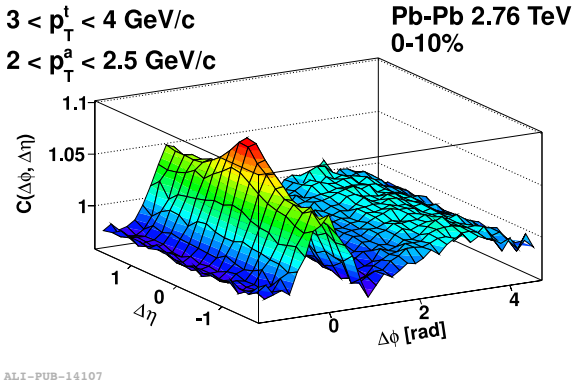

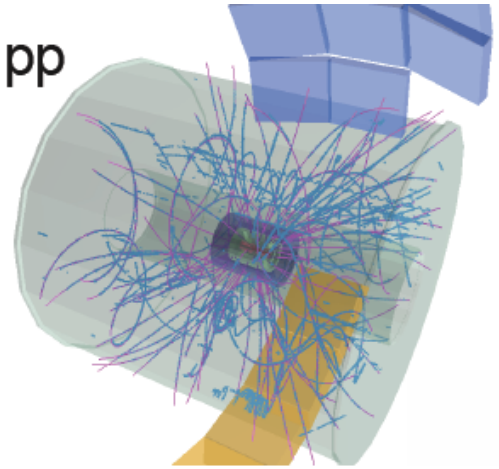

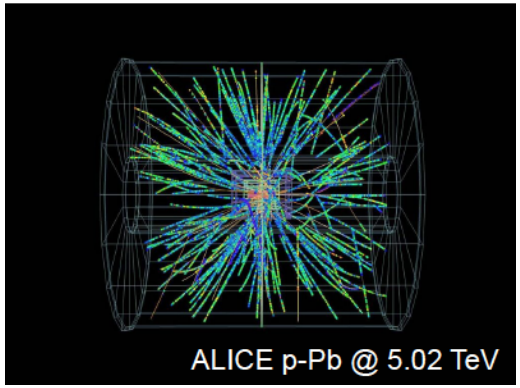

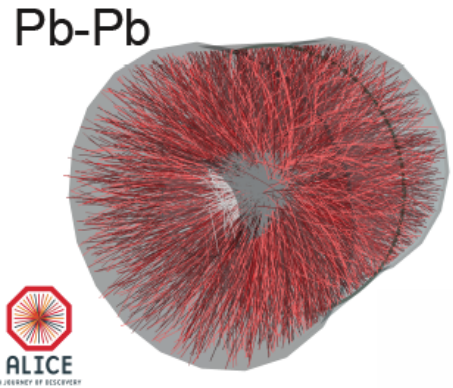

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Introduction

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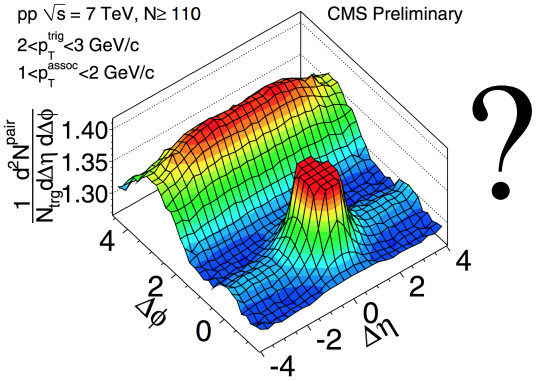

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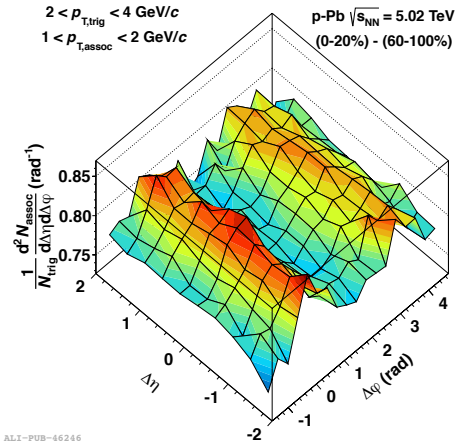

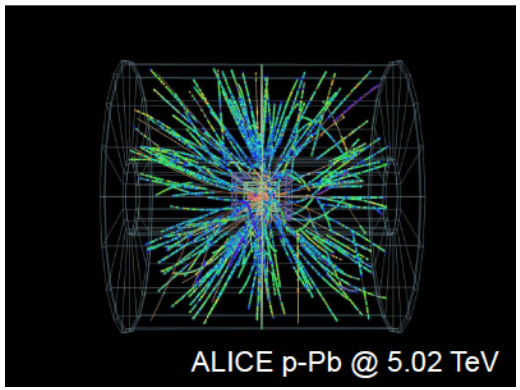

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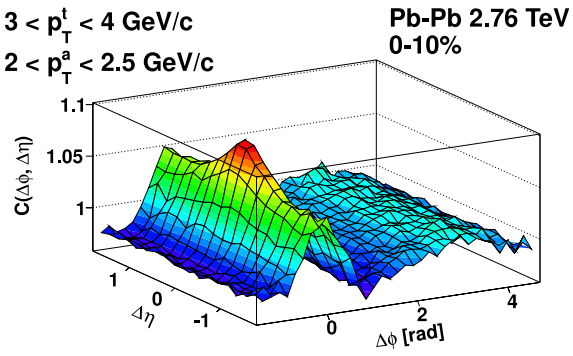

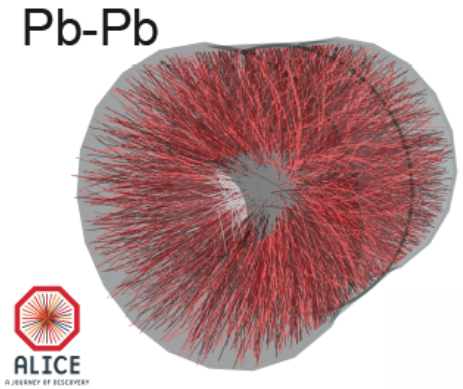

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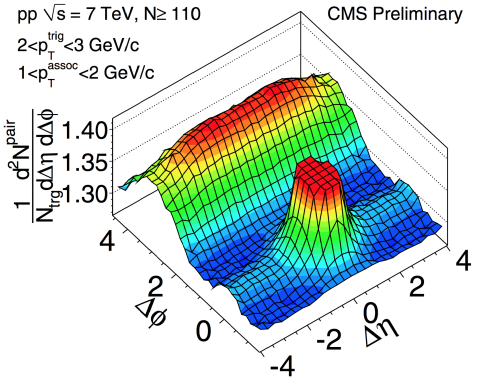

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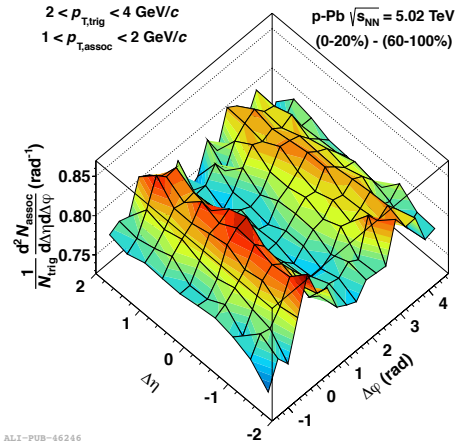

Experimental observations **highly suggestive of collective** effects in **high multiplicity p-Pb collisions**

→Equilibrium in smaller systems such as p-Pb?

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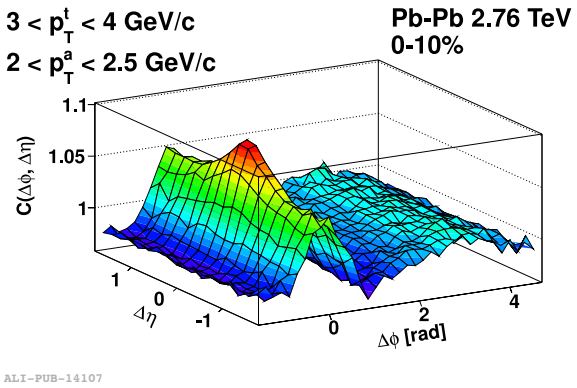

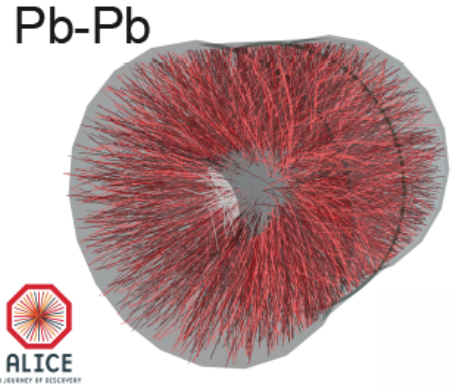

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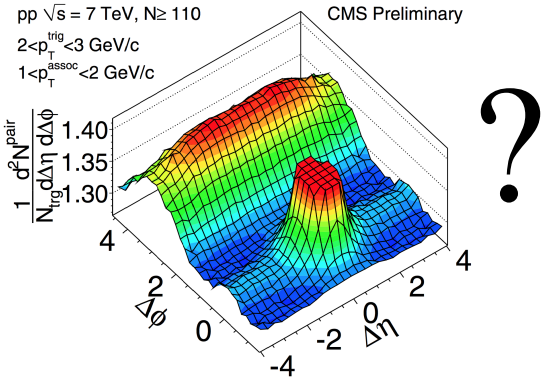

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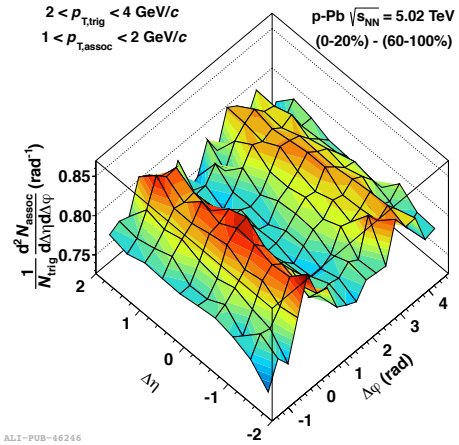

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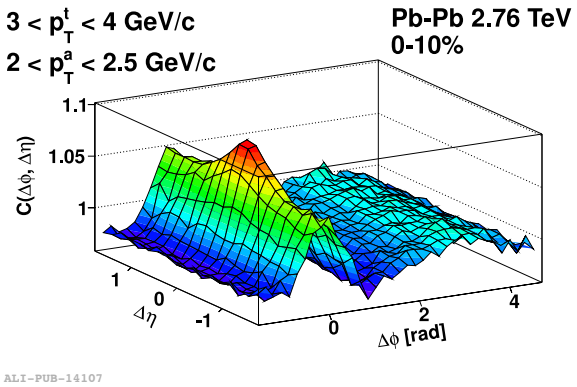

Hadron yields in Pb-Pb well described by **thermal models**

→ matter in local thermal (chemical) equilibrium.

Chemical freeze-out takes place when inelastic collisions cease

Introduction

Collectivity

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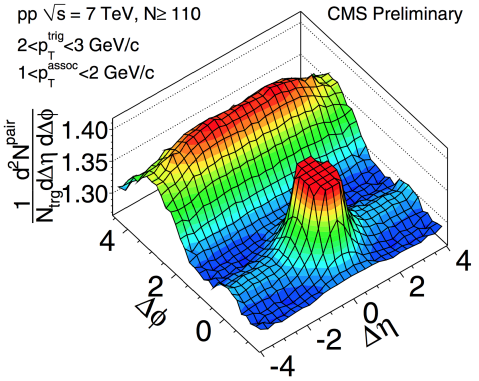

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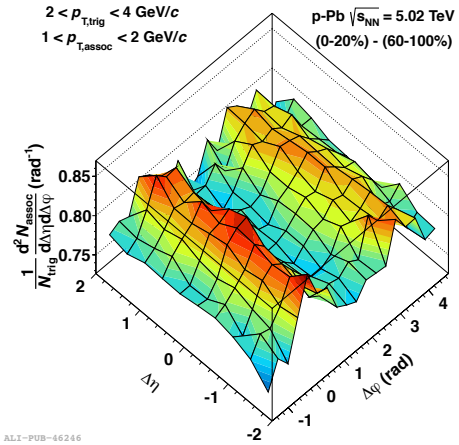

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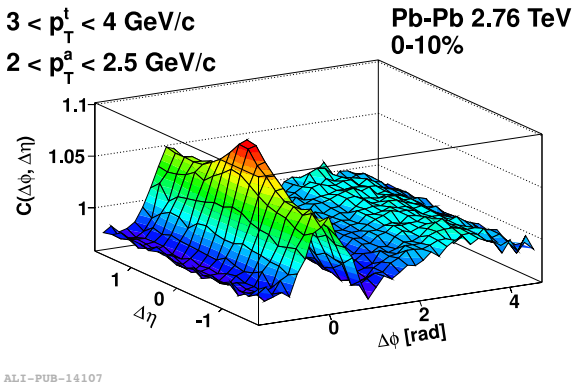
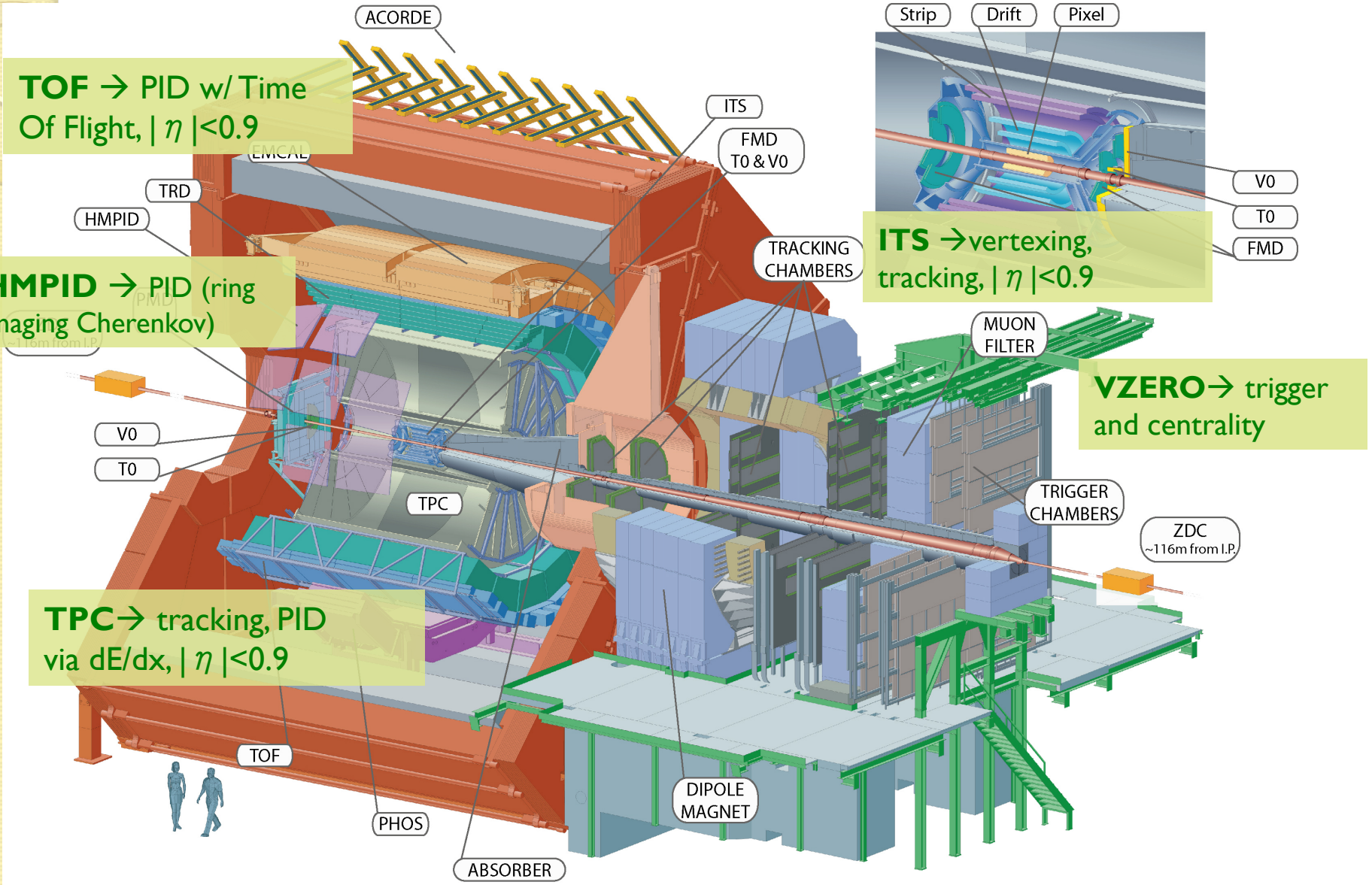


Hydro models successfully explain flow effects in Pb-Pb

→matter in local thermal (kinetic) equilibrium.

Kinetic freeze-out happens after the chemical freeze-out

The ALICE experiment



TOF → PID w/ Time Of Flight, | η |<0.9

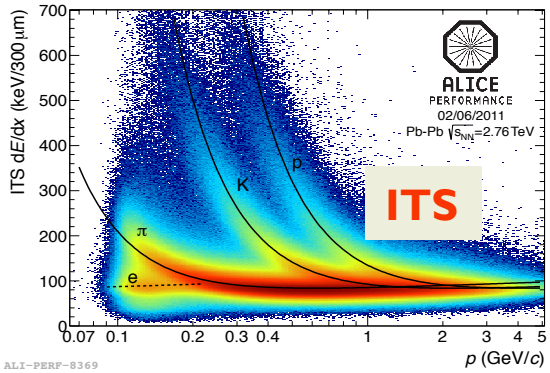
HMPID → PID (ring imaging Cherenkov)

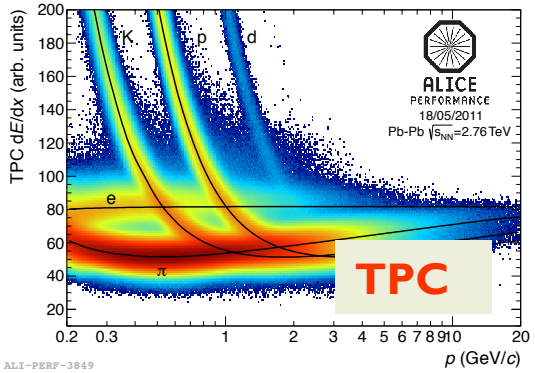
ITS →vertexing, tracking, | η |<0.9

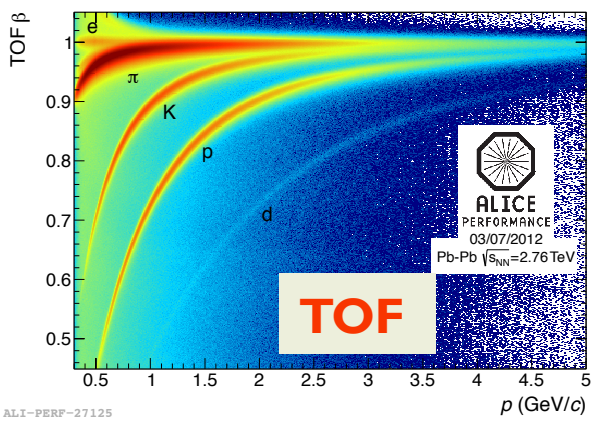
VZERO→ trigger and centrality

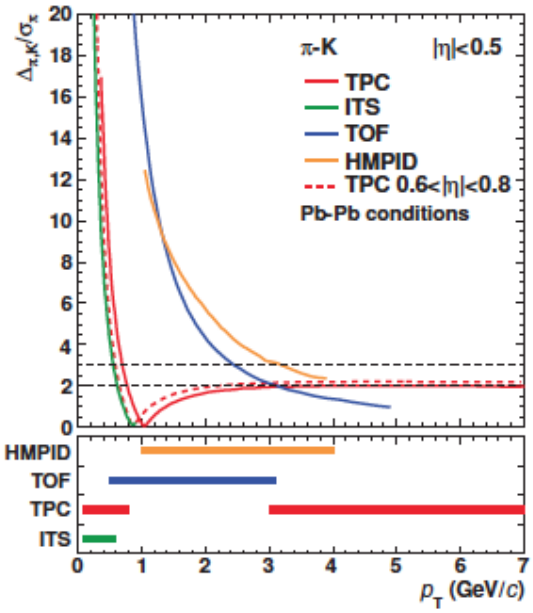
TPC→ tracking, PID via dE/dx, | η |<0.9

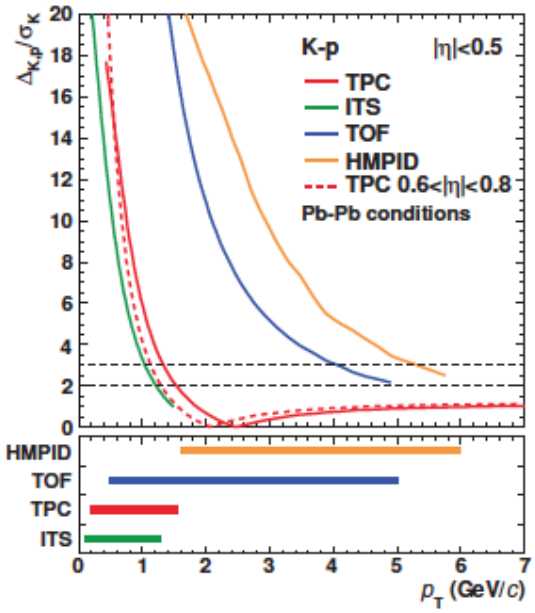
The ALICE experiment
PID performance

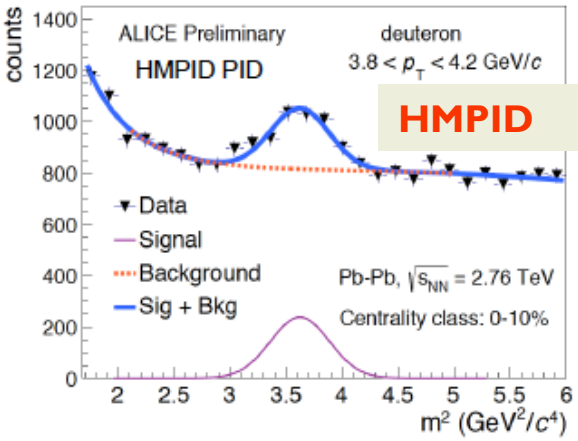








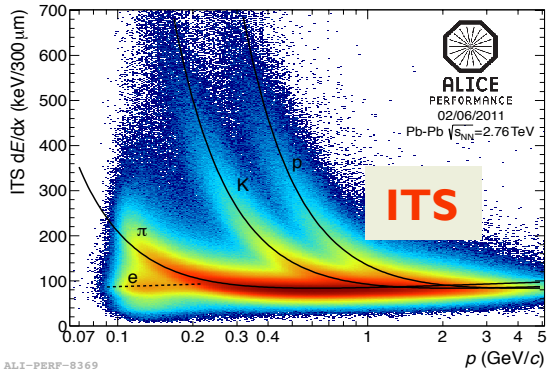


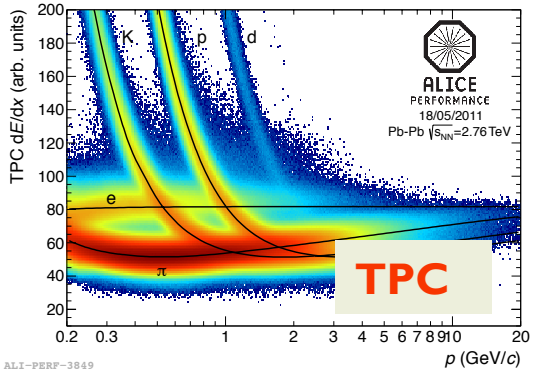


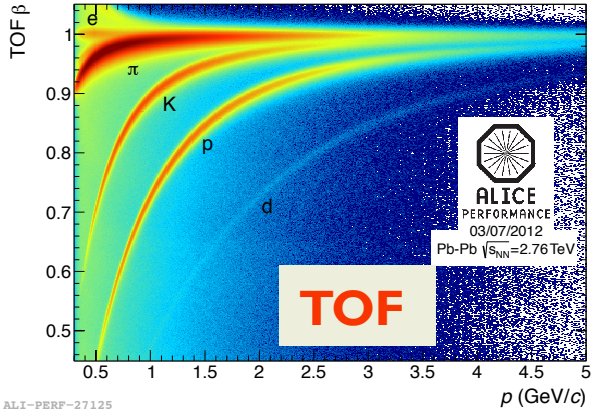
Int. J. Mod. Phys. A 29 (2014) 1430044

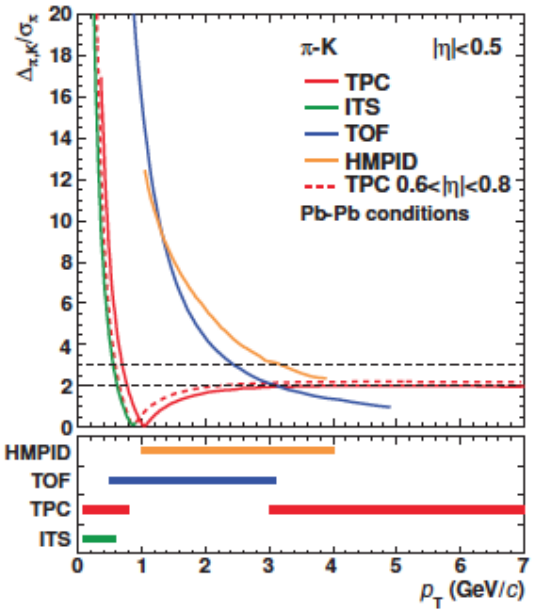
Excellent particle identification and separation power over a wide momentum range (~100 MeV/*c* – 20 GeV/*c* for π, K, p)

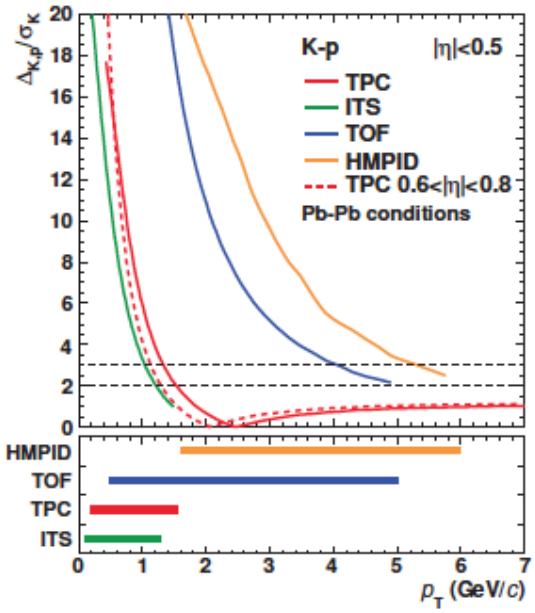
The ALICE experiment
PID performance

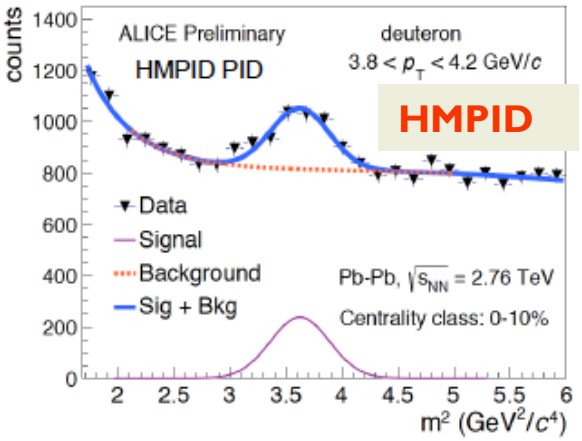












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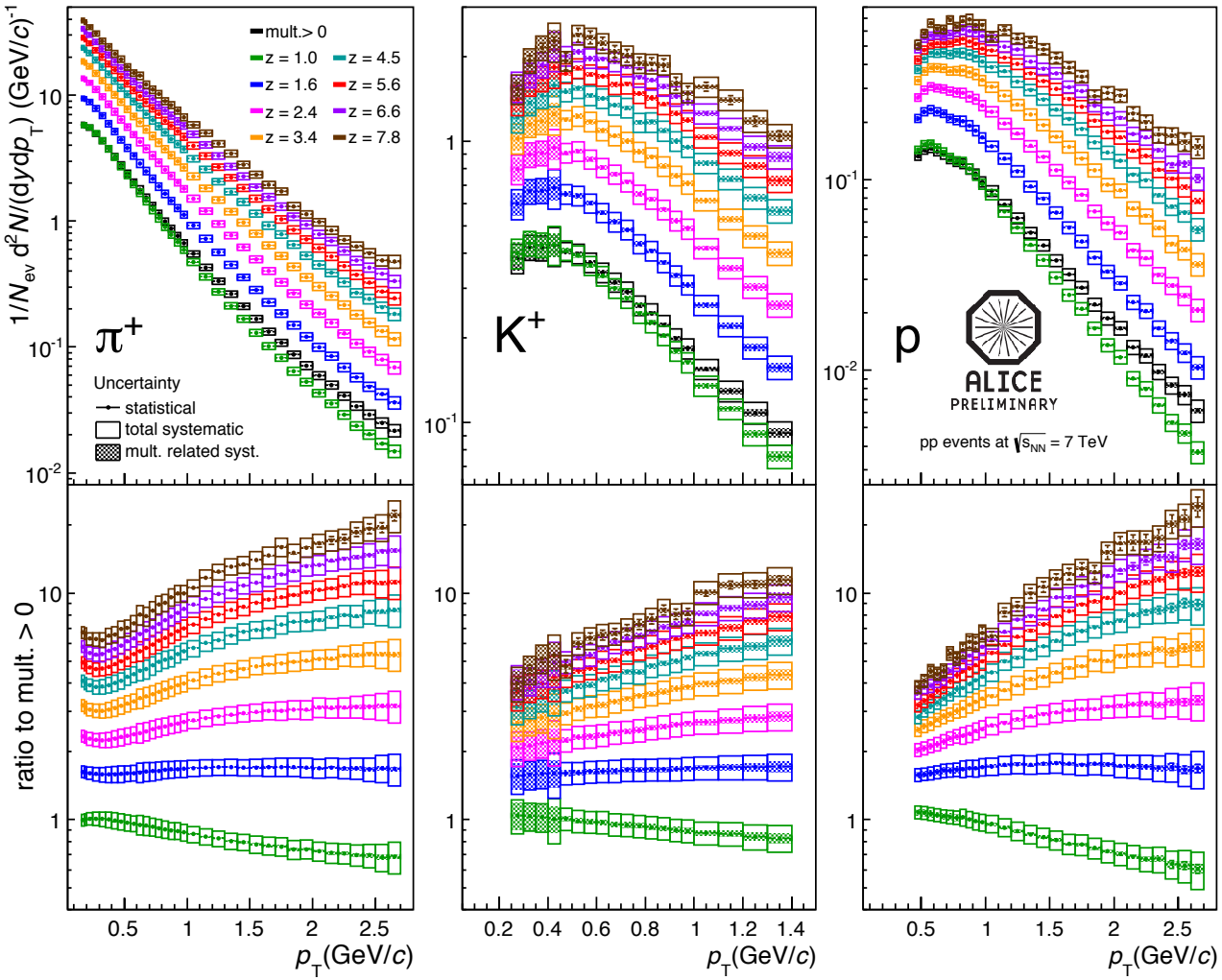
ALICE is ideally suited for the measurement of light flavor hadrons.

p_T spectra-multiplicity dependence
pp @ 7 TeV



ALI-PREL-51115

$$z^{raw} = \frac{\left\langle N_{ch}^{raw} \right\rangle_{curr.bin}}{\left\langle N_{ch}^{raw} \right\rangle_{mult>0}}$$

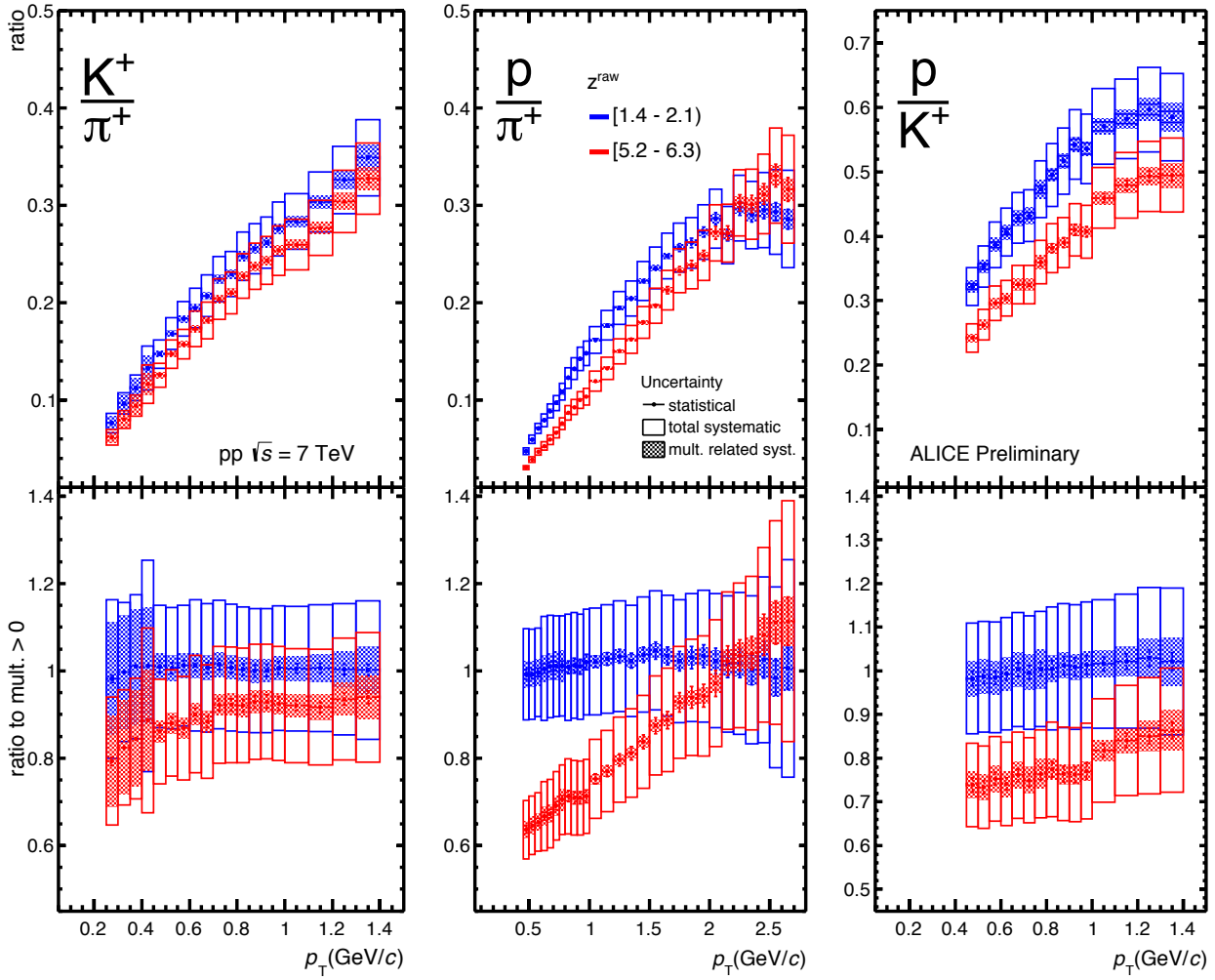
$$\left\langle N_{ch}^{raw} \right\rangle_{mult>0} = 9.6, |\eta| < 0.8$$

z_{raw}	N_{ch}^{raw} bin limits	N_{ch}^{raw} mean
1.0	7-12	9.2
1.6	13-19	15.6
2.4	20-28	23.2
3.4	29-39	32.7
4.5	40-49	43.3
5.6	50-59	53.2
6.6	60-71	63.6
7.8	72-82	75.2

- **spectra shape** – multiplicity dependence
- **low p_T depletion** - multiplicity and mass dependence

Yield ratios-multiplicity dependence

pp @ 7 TeV

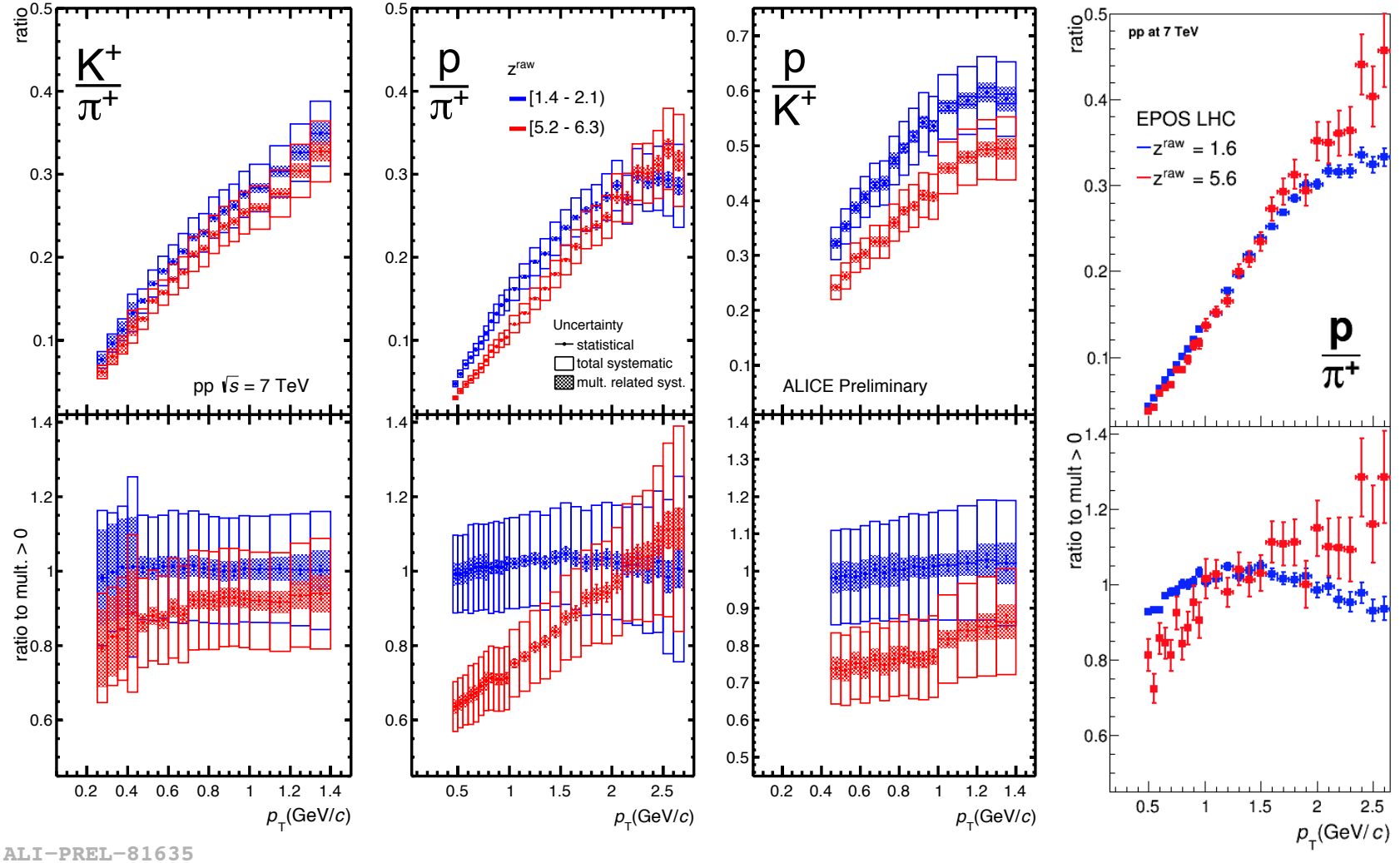


ALI-PREL-81635

✧larger boost for heavier particles and high multiplicity

Yield ratios-multiplicity dependence

pp @ 7 TeV

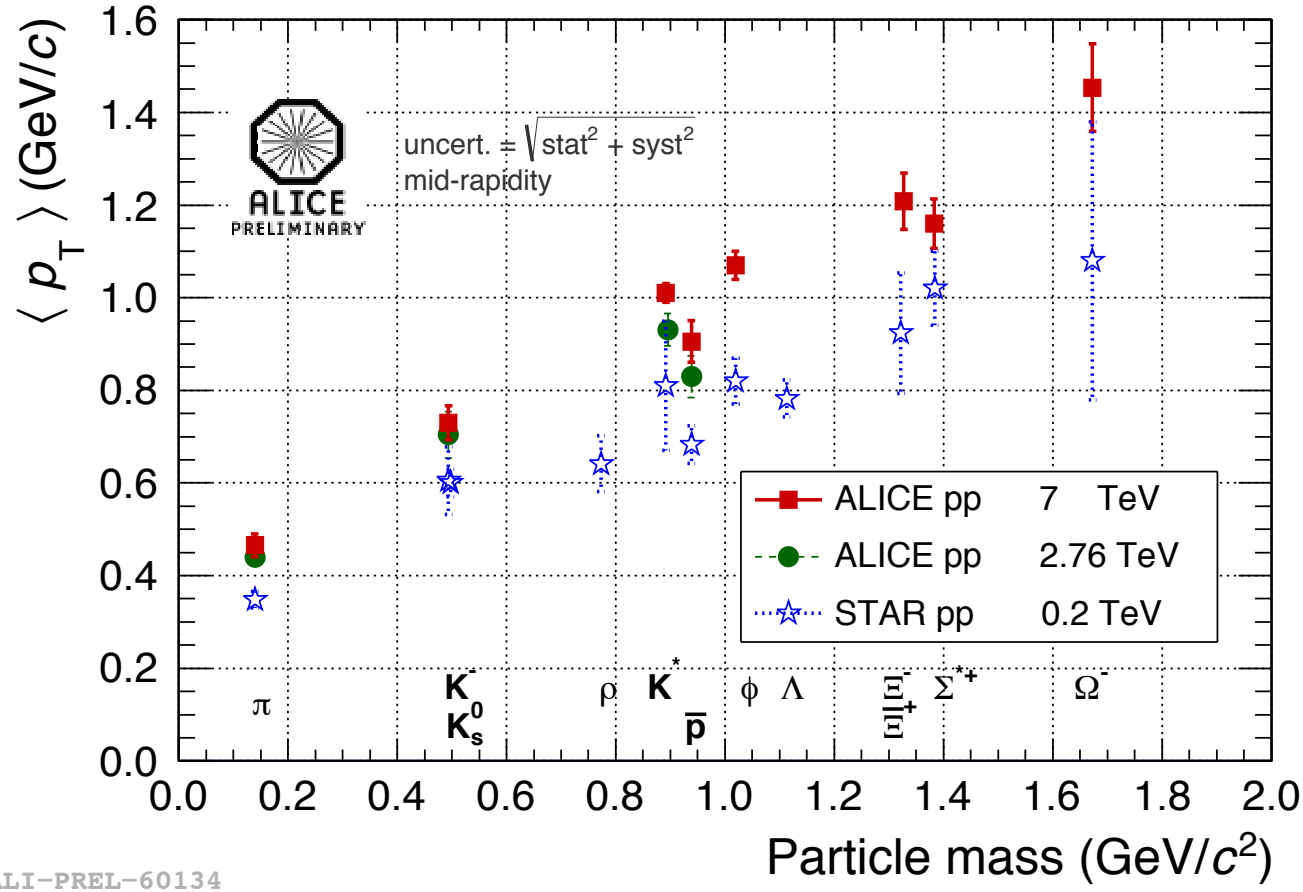


ALI-PREL-81635

✧Qualitatively EPOS follows the same trend

Mean p_T : mass and energy dependence

pp Minimum bias

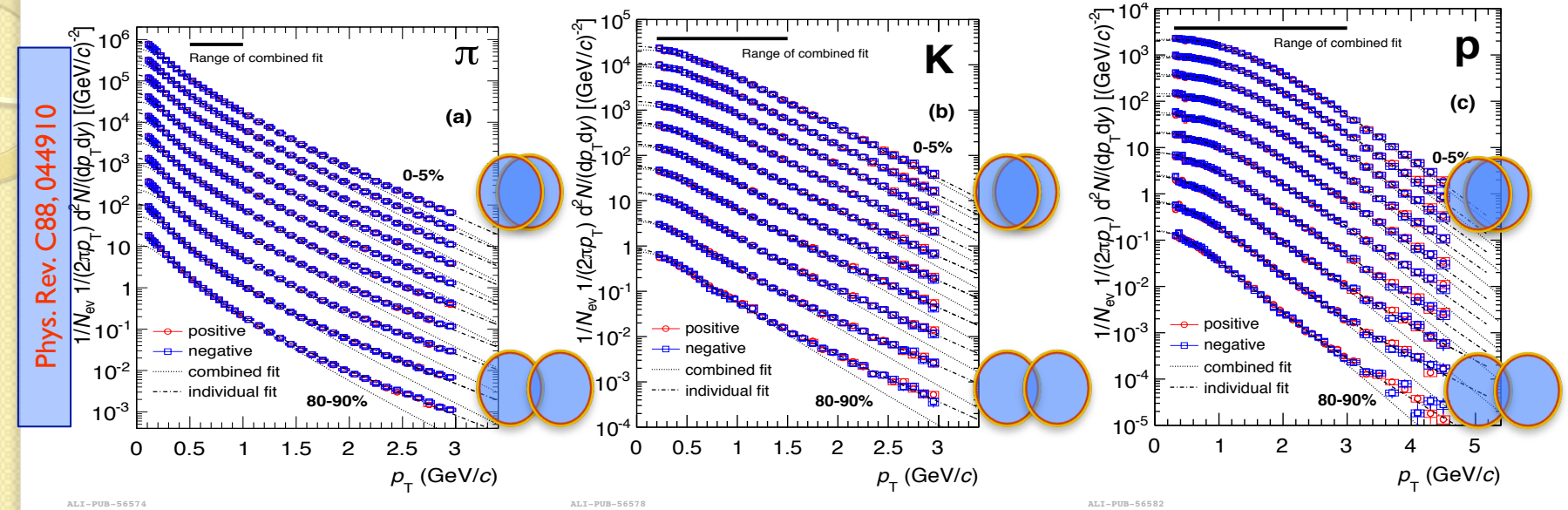


✧ Mean p_T vs mass: the increase is mass and energy dependent

Invariant p_T distributions

Radial flow in Pb-Pb

Phys. Rev. C88, 044910



Hardening of the spectrum with increasing centrality.
It is more pronounced for the heavier particles → ***Mass ordering*** *as* expected from hydrodynamics.

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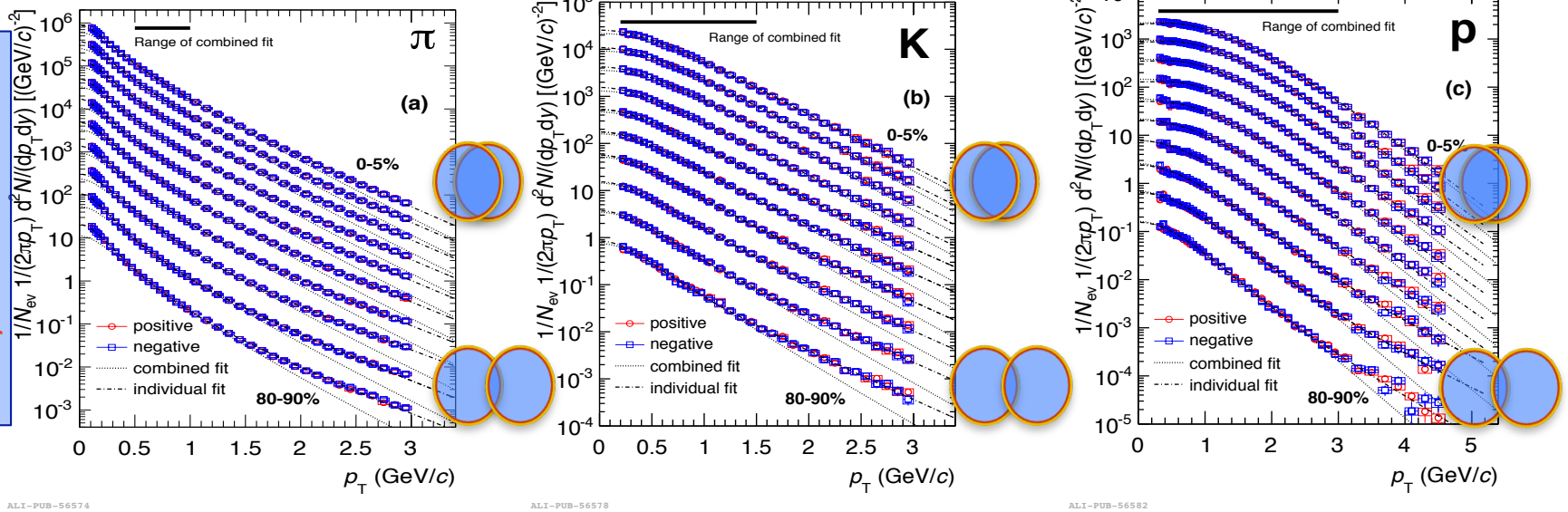

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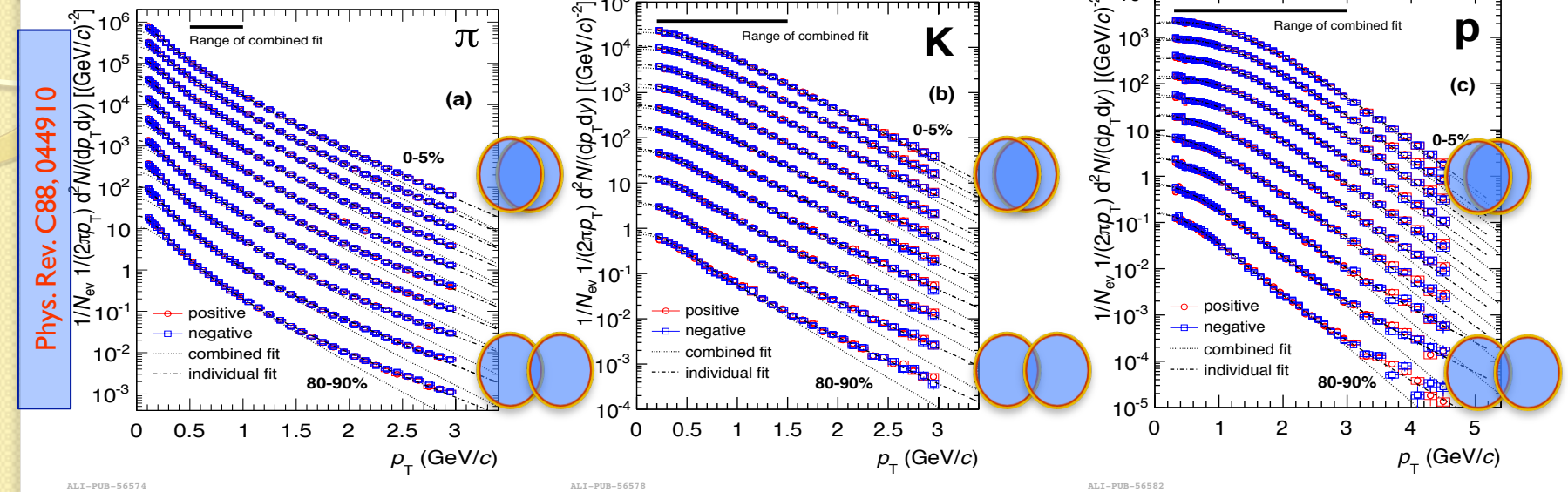

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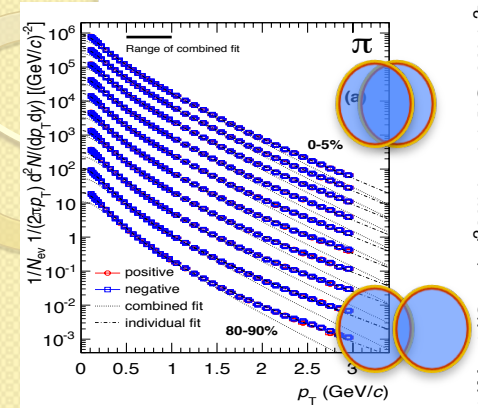
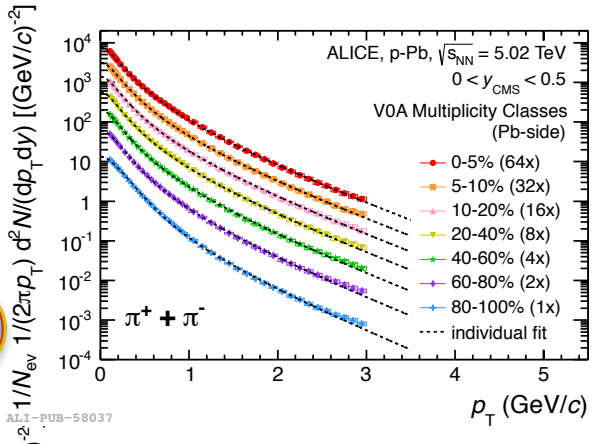
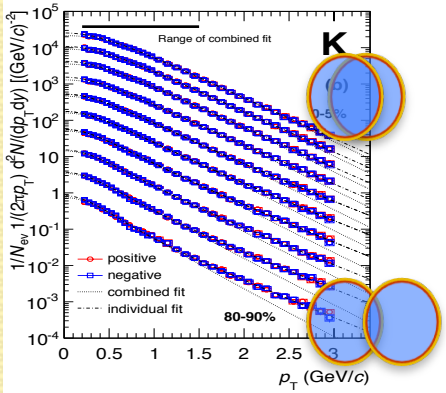
Very clean signature of ***radial flow*** in Pb-Pb collisions.

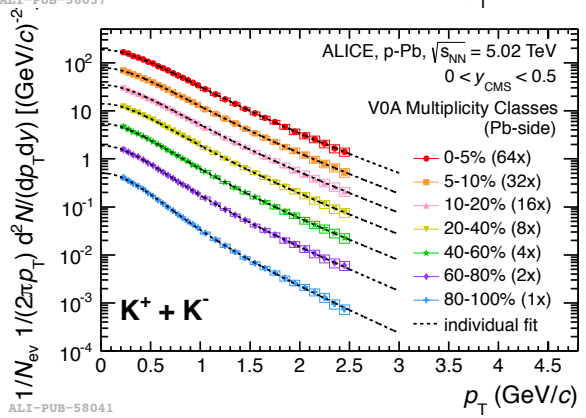
Full hydro models describe spectra fairly well.

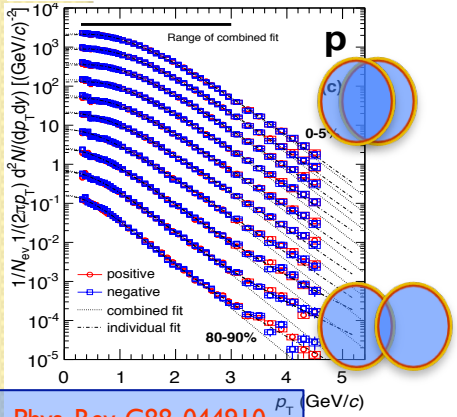
Invariant p_T distributions
Pb-Pb and p-Pb

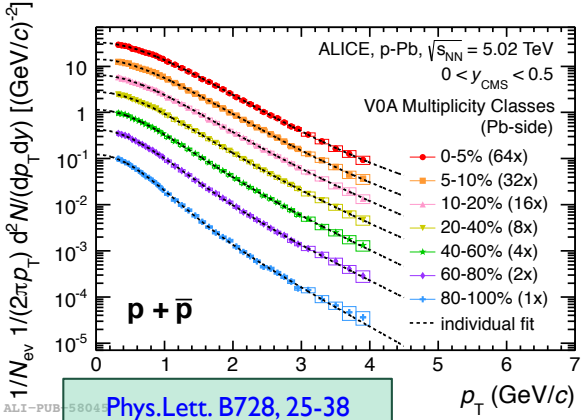










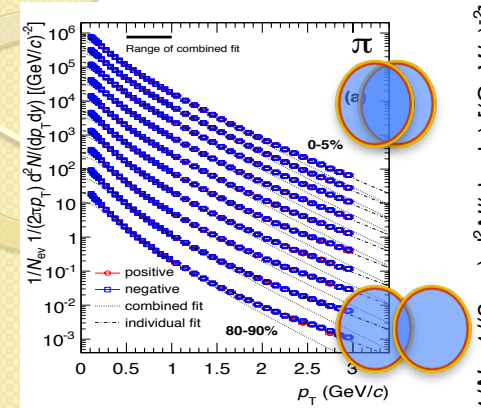


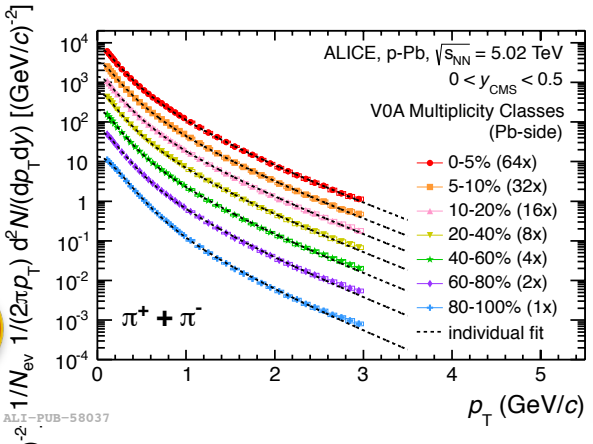
Phys. Rev. C88, 044910

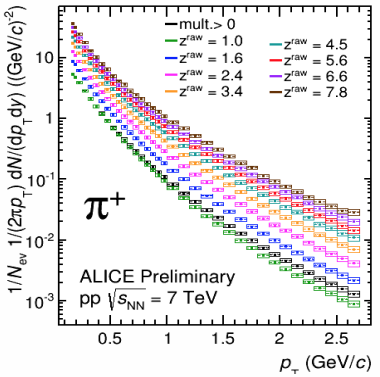
Phys.Lett. B728, 25-38

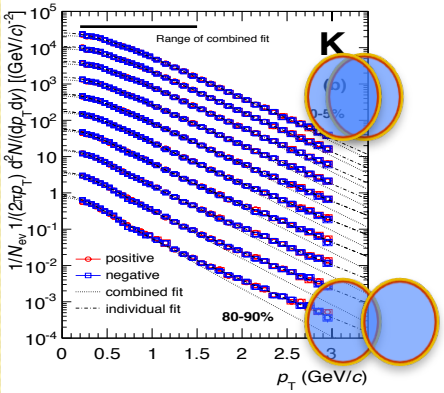
✧**spectra shape:** similar change in the low p_T region as function of the multiplicity

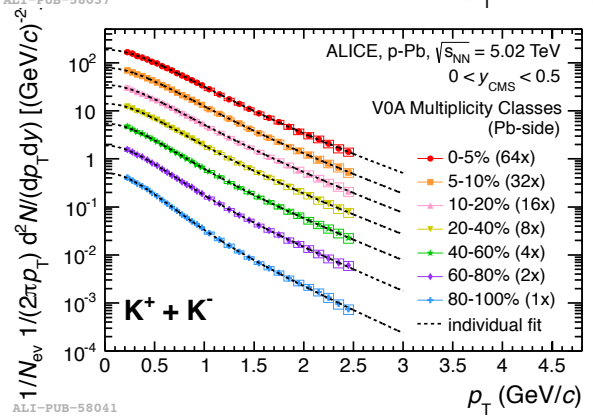
Invariant p_T distributions
Pb-Pb, p-Pb and pp

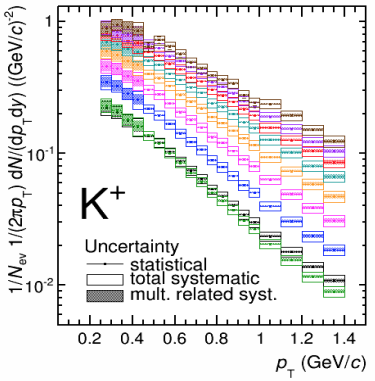


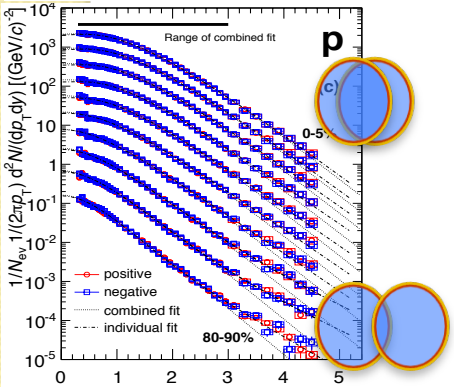


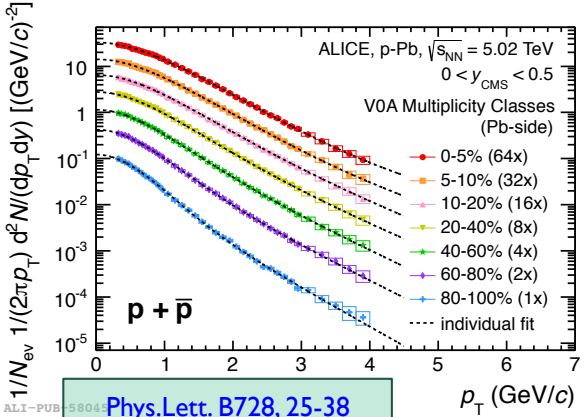


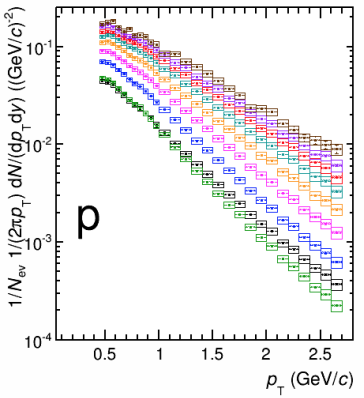












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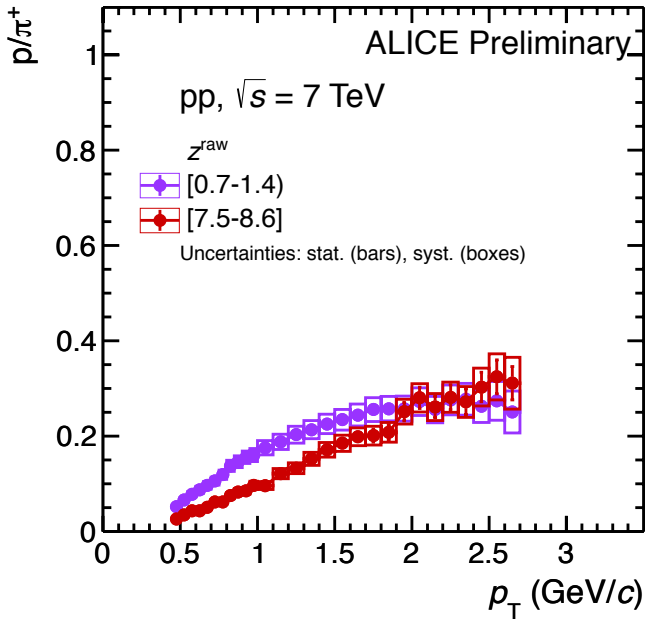
Phys. Rev. C88, 044910

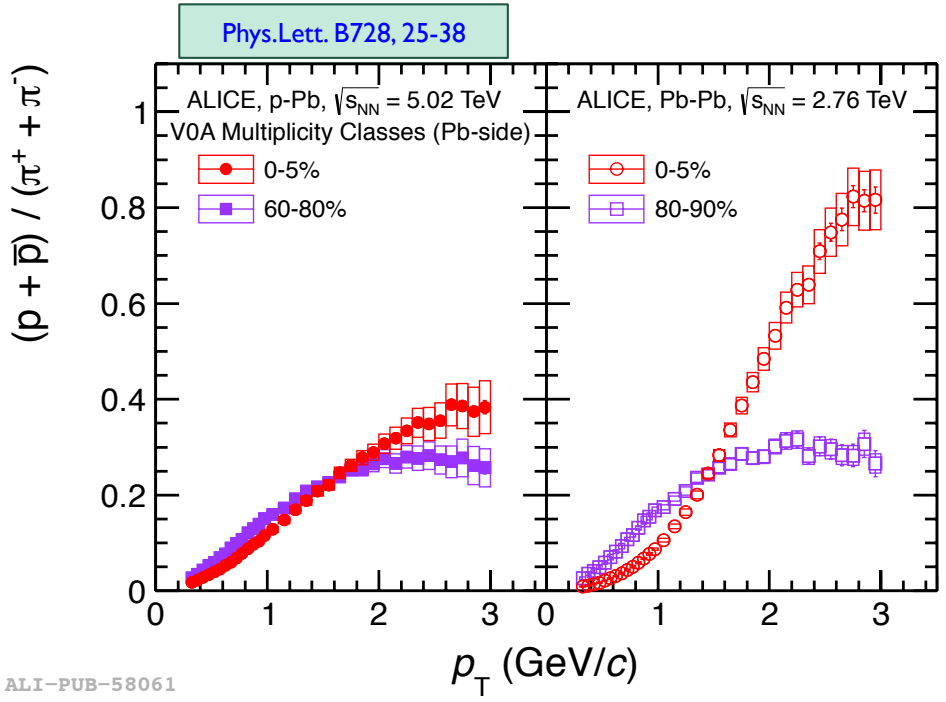
Phys.Lett. B728, 25-38

S. Bufalino - Discovery Physics at the LHC, Kruger 2014

Yield ratios

pp, p-Pb and PbPb



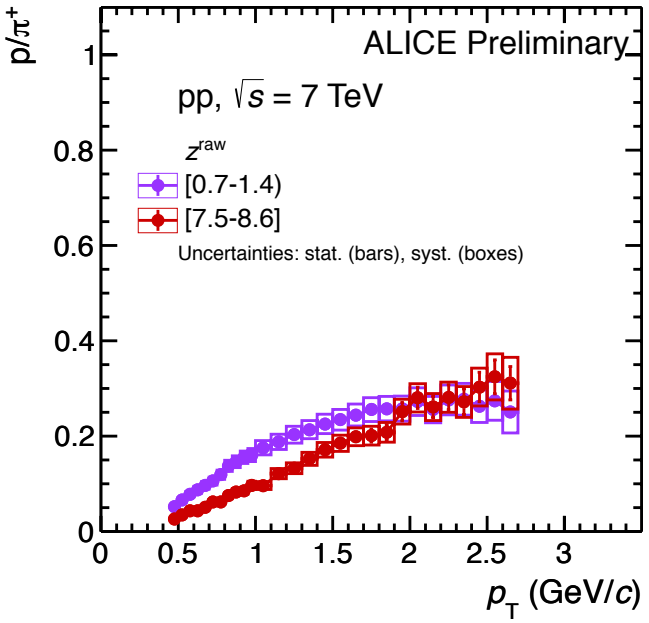


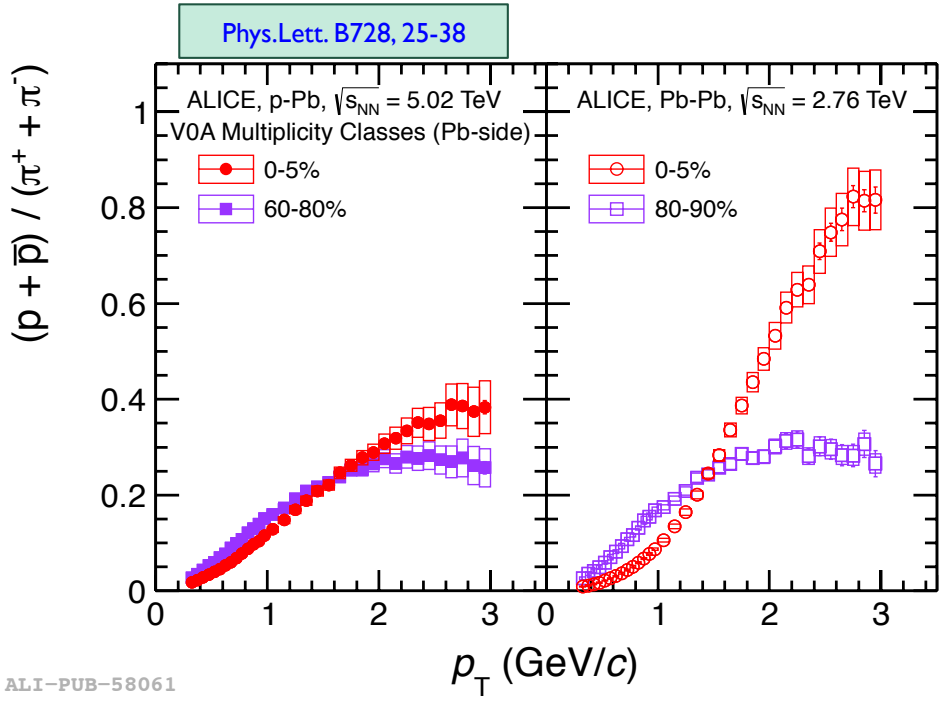
✧ **Similarity** in p-Pb and Pb-Pb: flow in pPb? Thermalized system?

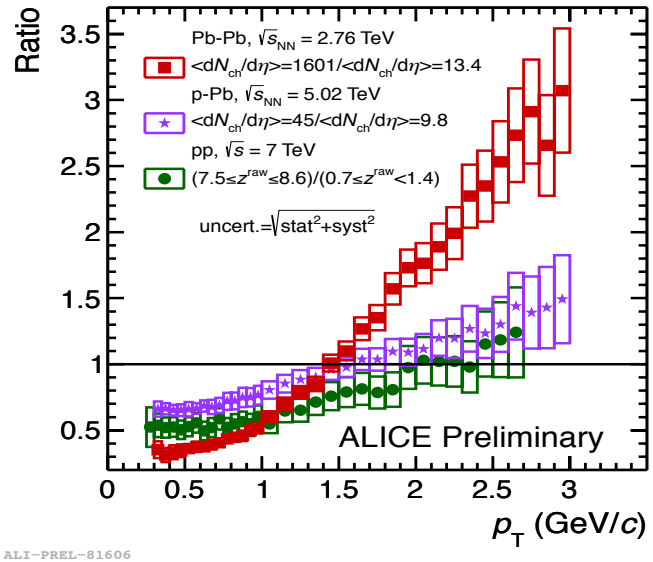
✧ For all the colliding systems it is observed **a push of heavier particles towards larger p_T**

Yield ratios

pp, p-Pb and PbPb







✧ **Similarity** in p-Pb and Pb-Pb: flow in pPb? Thermalized system?

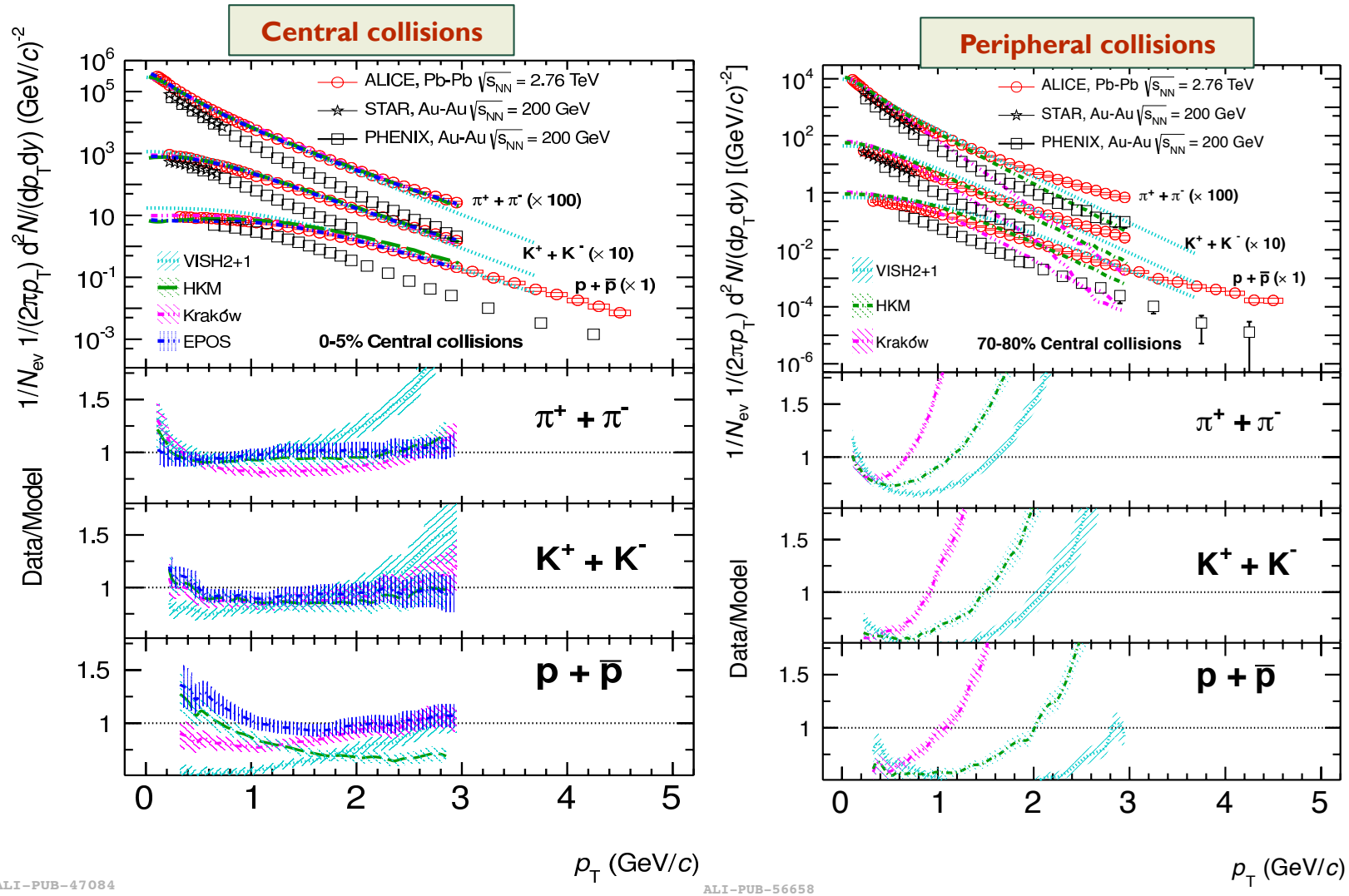
✧ For all the colliding systems it is observed **a push of heavier particles towards larger p_T**

✧ ratio to the lowest multiplicity: pp is placed between p-Pb and Pb-Pb up to 1 GeV/c

Invariant p_T distributions

Radial flow in Pb-Pb

ALICE, PRL, 109 252301 (2012) ,ALICE, arXiv:1303.0737

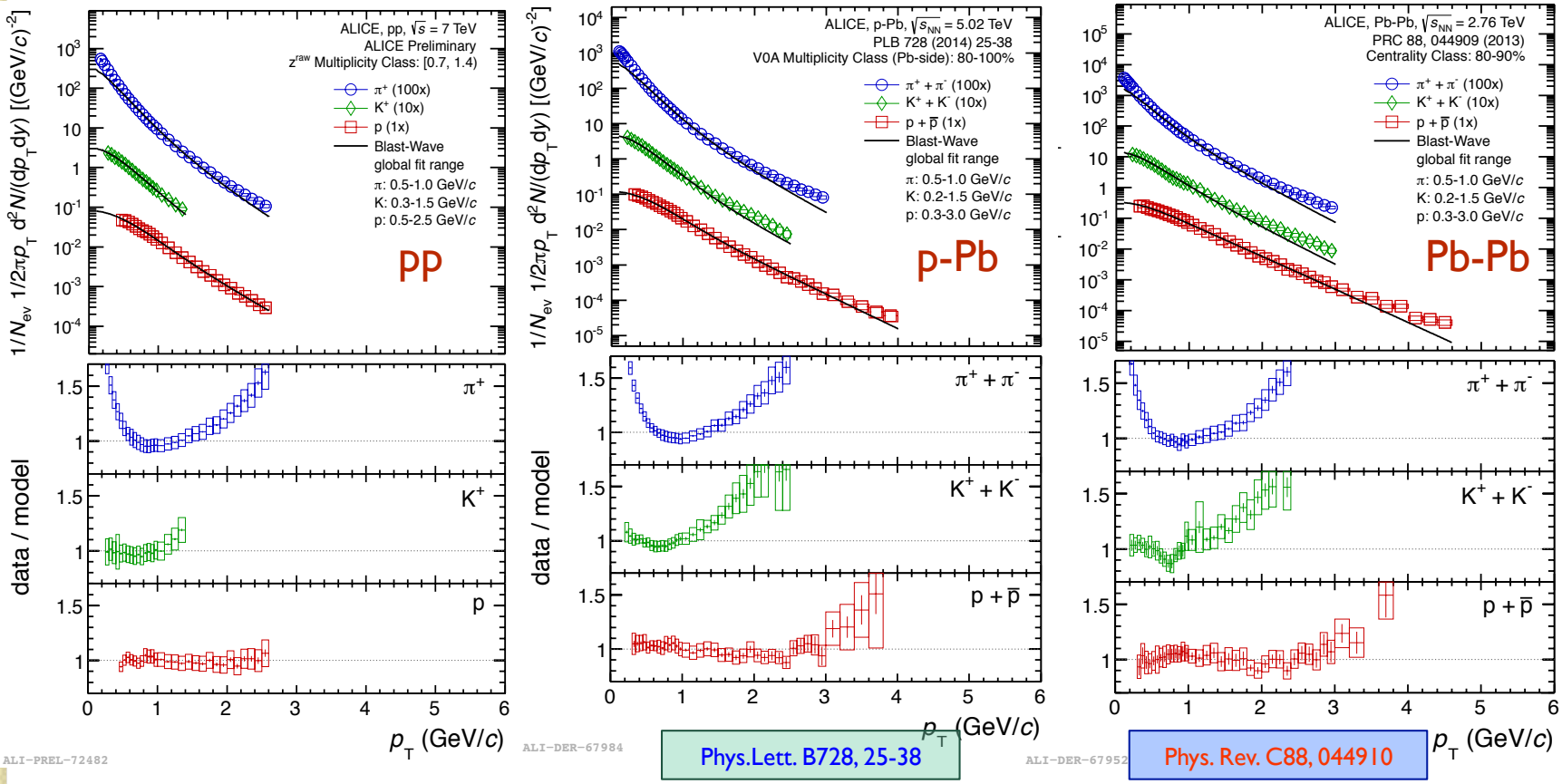


- Hydro models describe spectra fairly well in central collisions
- Not expected to work in peripheral collisions: description of the late stages of the fireball?

BGBW fits

Low Multiplicity

$$E\frac{d^3N}{dp^3} \sim f(p_t) = \int_0^R m_T K_1(m_T cosh\rho/T_{fo}) I_0(p_T sinh\rho/T_{fo}) r dr \quad \text{where } m_T = \sqrt{m^2 + p_T^2};\ \beta_r(r) = \beta_s(\tfrac{r}{R})^n;\ \rho = tanh^{-1}\beta_r$$



Phys.Lett. B728, 25-38

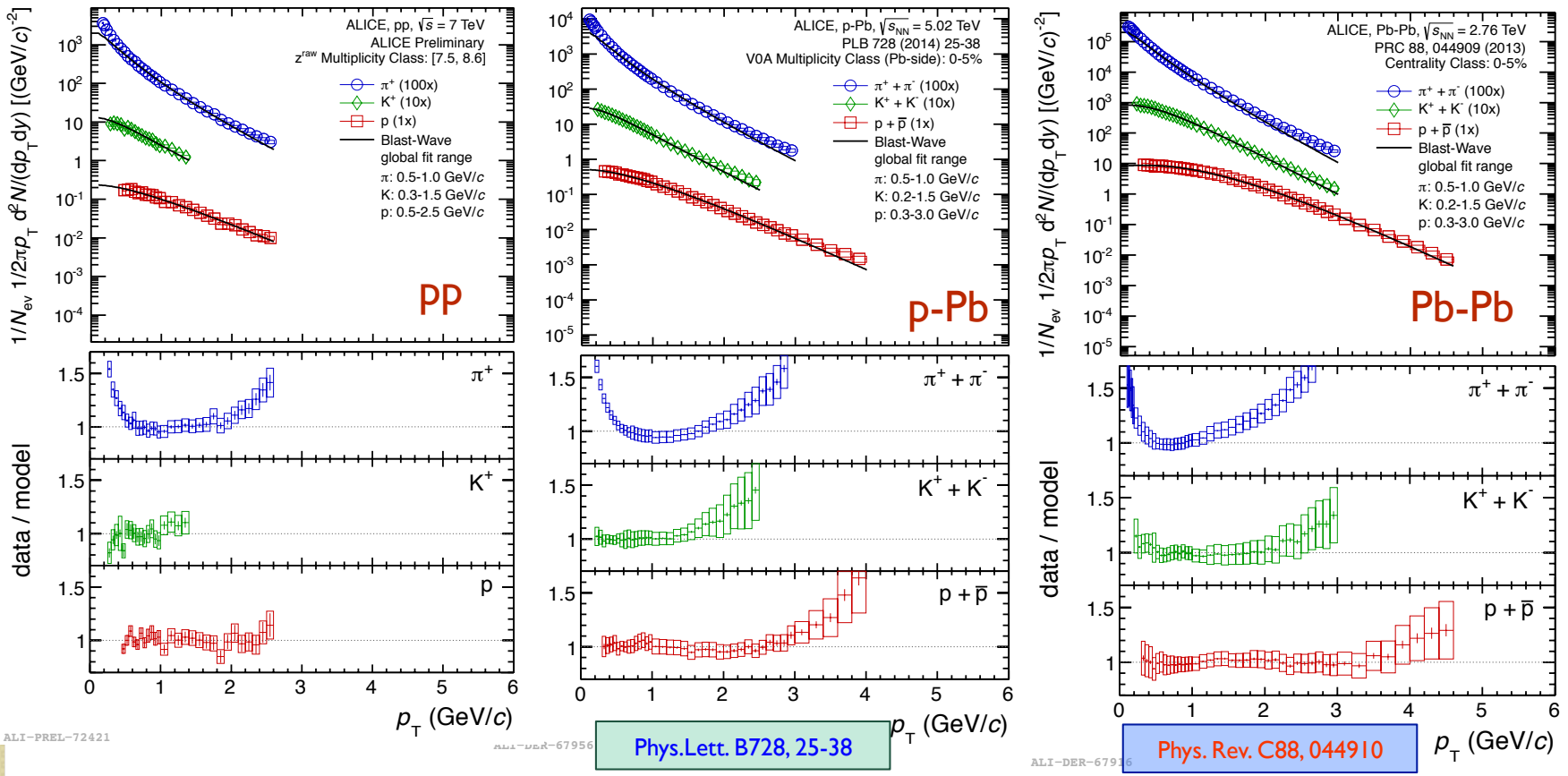
Phys. Rev. C88, 044910

✧ The degree of agreement between the data and the fits is comparable for all three colliding systems

BGBW fits

High Multiplicity

$$E\frac{d^3N}{dp^3} \sim f(p_t) = \int_0^R m_T K_1(m_T cosh\rho/T_{fo}) I_0(p_T sinh\rho/T_{fo}) r dr \quad \text{where } m_T = \sqrt{m^2 + p_T^2};\ \beta_r(r) = \beta_s(\tfrac{r}{R})^n;\ \rho = tanh^{-1}\beta_r$$



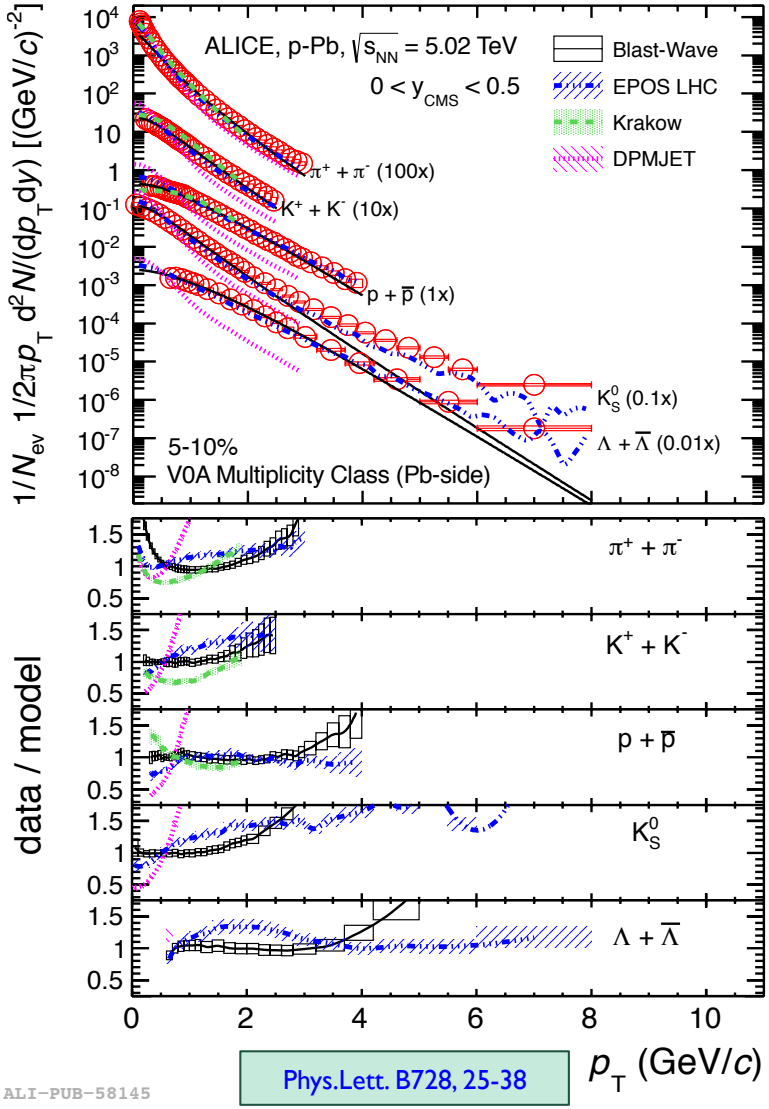
Phys.Lett. B728, 25-38

Phys. Rev. C88, 044910

✧ The degree of agreement between the data and the fits is comparable for all three colliding systems

✧ The fit quality improves going to higher multiplicity

p-Pb @ 5.02 TeV

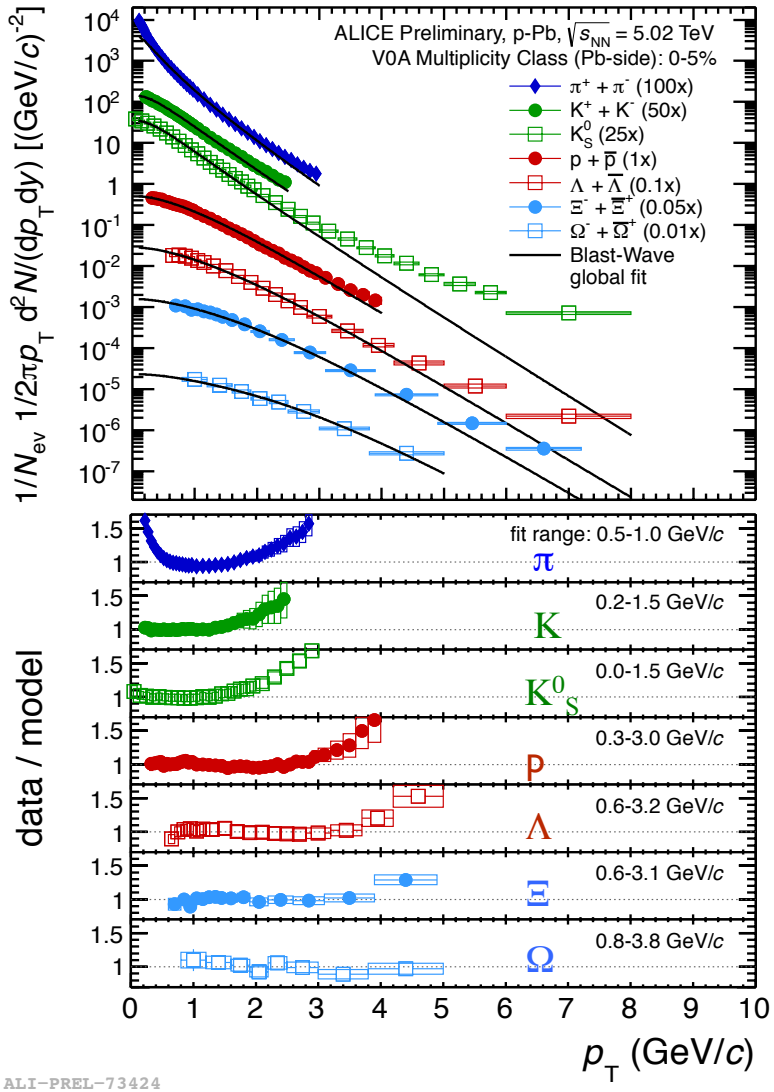


ALI-PUB-58145

Phys.Lett. B728, 25-38

Hydro models (kraków EPOS) reproduce data better than QCD inspired models (DPMJET)

p-Pb @ 5.02 TeV



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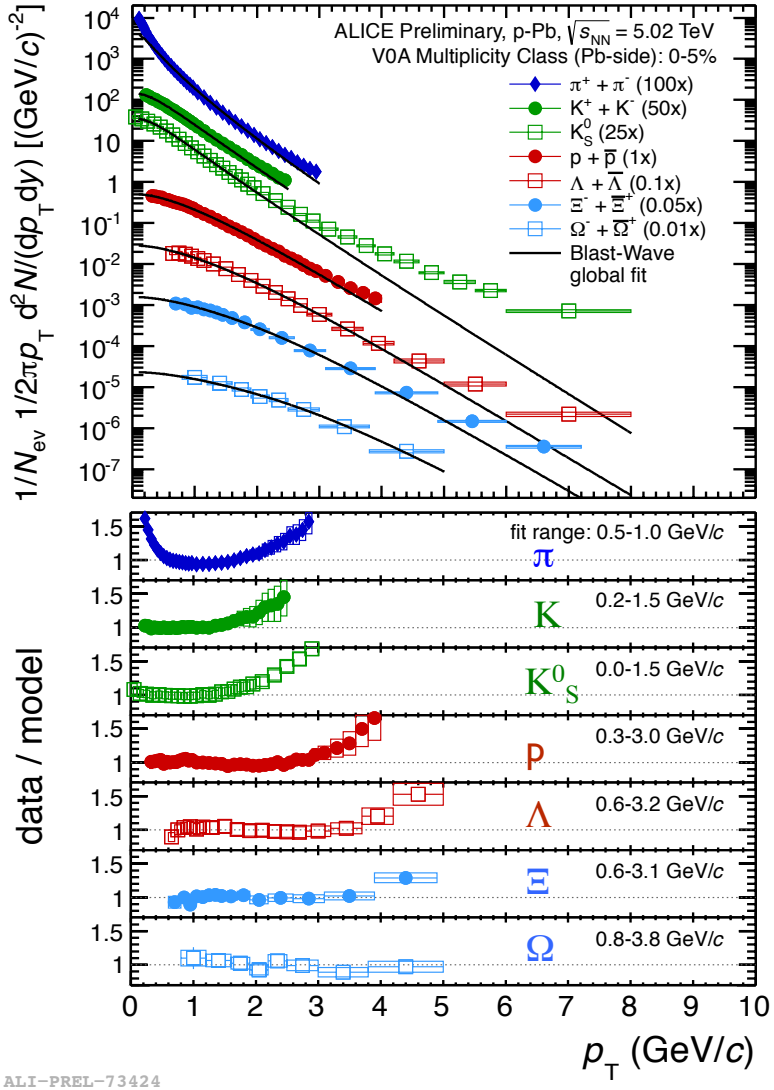
A combined BW fit describes the spectra fairly well also in p-Pb

p-Pb @ 5.02 TeV



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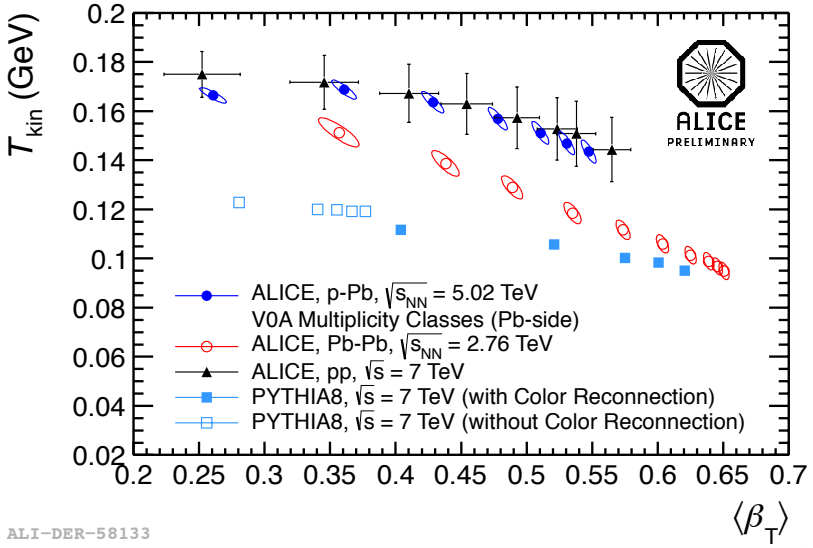
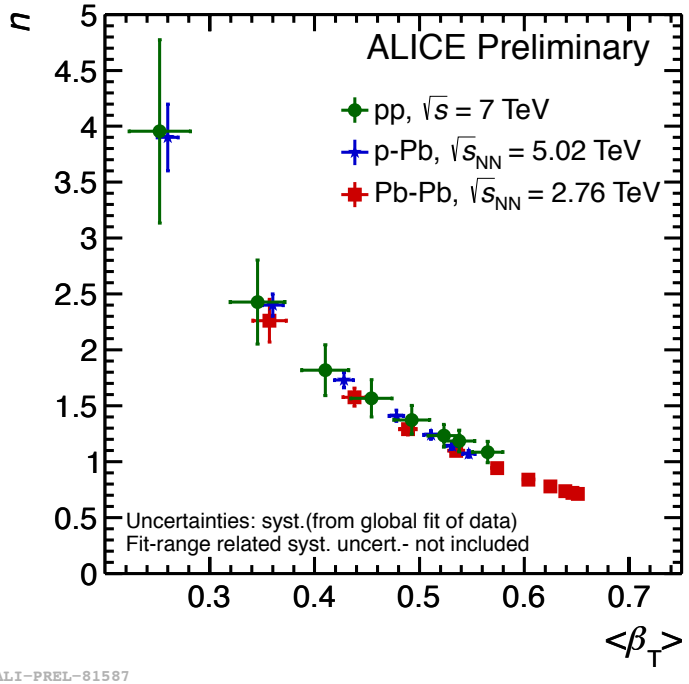


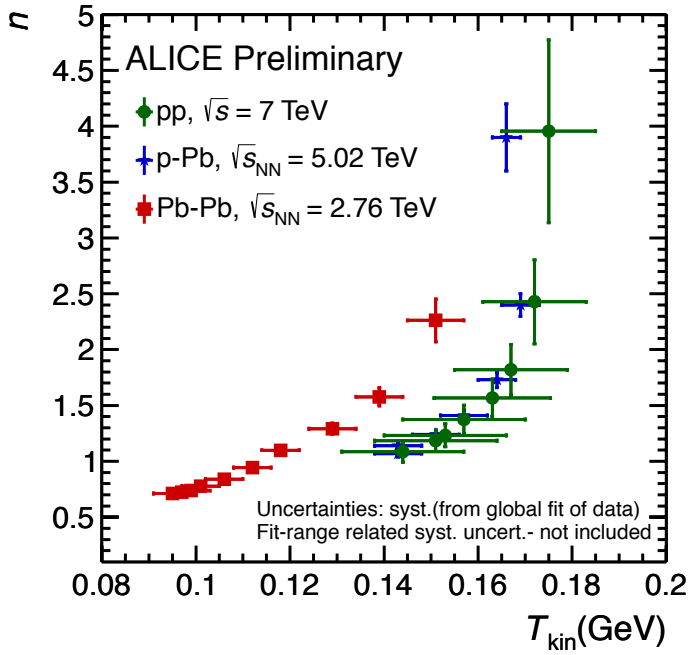
similar trends in the T_{kin}-$<\beta_T>$ correlation for **pp and p-Pb**

Qualitatively PYTHIA-CR shows a similar trend as the data
→ other final state mechanisms can mimic the effects of radial flow!

pp, p-Pb and Pb-Pb comparison

expansion profile

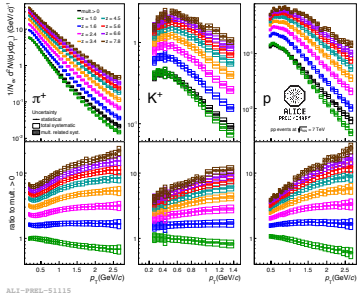


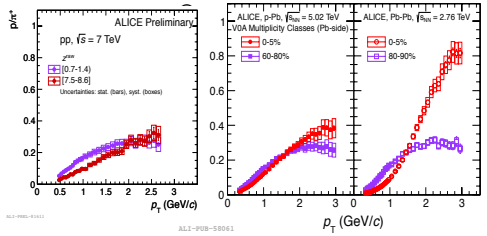


- n-$<\beta_T>$ correlation compatible within the errors for pp, p-Pb and Pb-Pb
- n-T_{kin} correlation shows lower T_{kin} values for Pb-Pb and it has a similar trend in pp and p-Pb

Conclusions

- p_T spectra and their ratios presented as a function of multiplicity in pp collisions at 7 TeV





Conclusions

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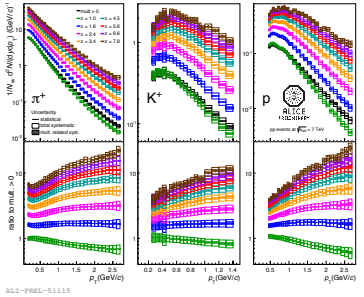

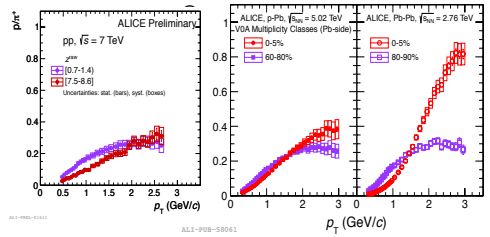

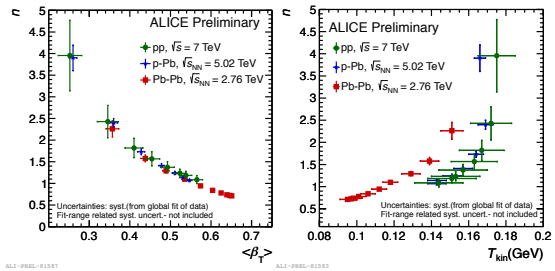

Conclusions

- p_T spectra and their ratios presented as a function of multiplicity in pp collisions at 7 TeV
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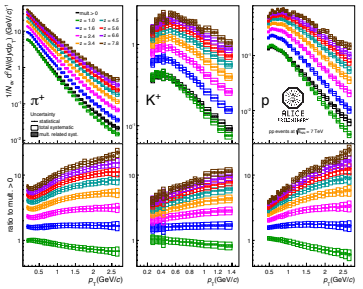
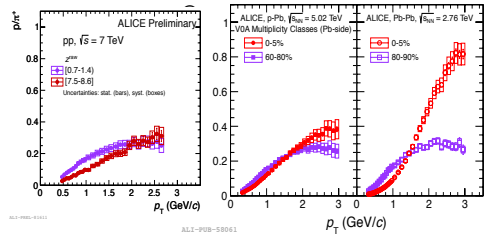
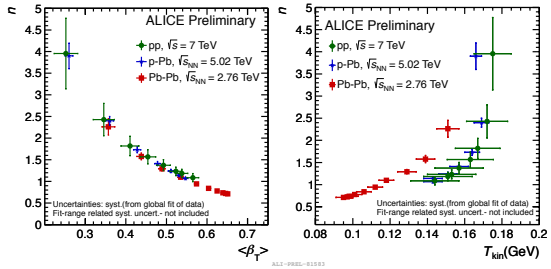
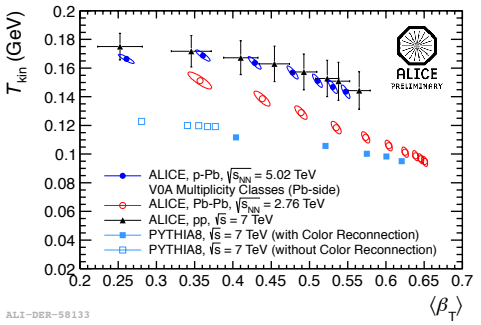
- Similar trends observed for the three colliding systems and hints for collective effects in p-Pb collisions (not a final word!)



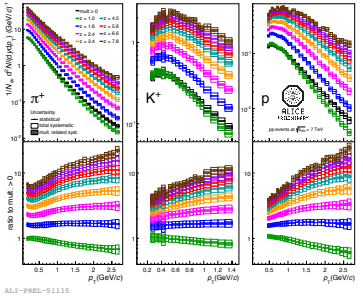




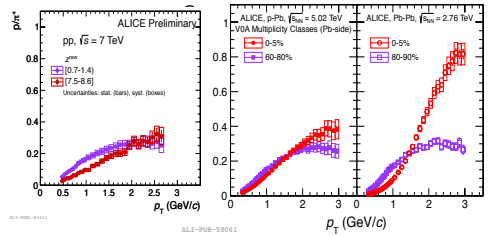


Conclusions

- p_T spectra and their ratios presented as a function of multiplicity in pp collisions at 7 TeV



- Comparison of pp, p-Pb and Pb-Pb systems pointing out similarities for the three systems as a function of the charged particle multiplicity



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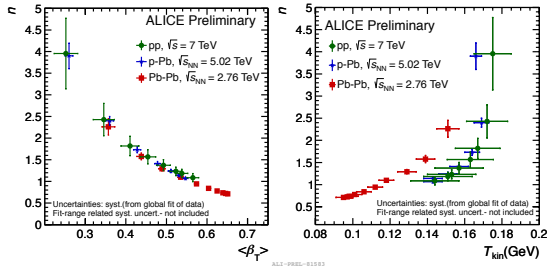
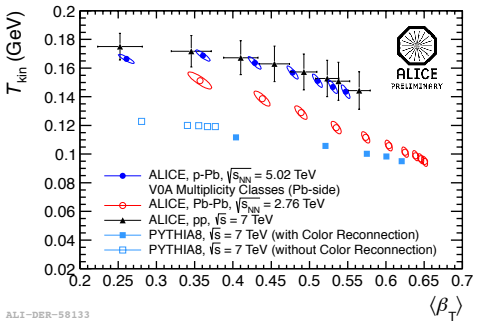


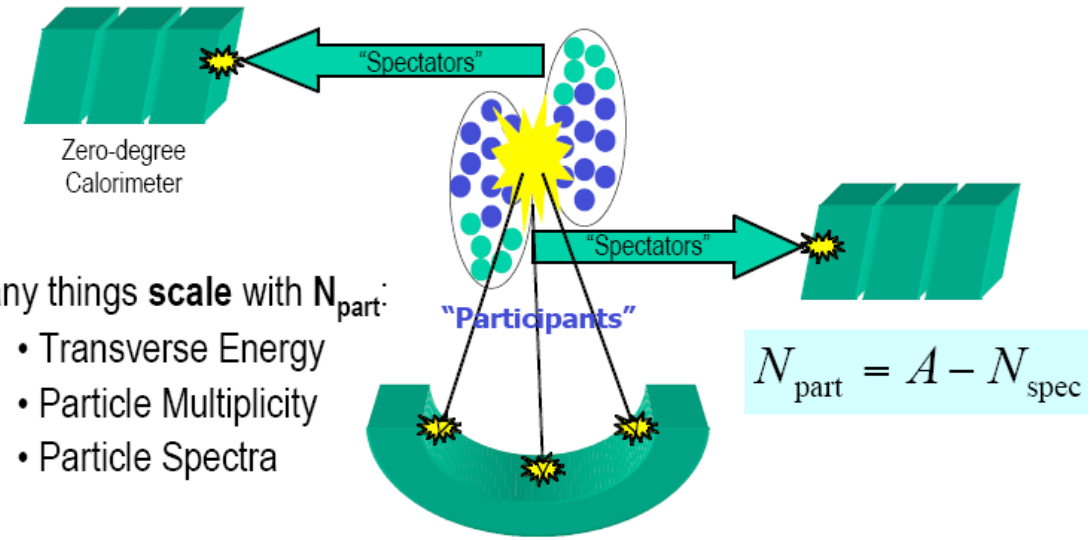
- Many inputs for further theoretical investigation of the phenomena seen at the LHC



Thank you for your attention!

Backup

Centrality: experimentally

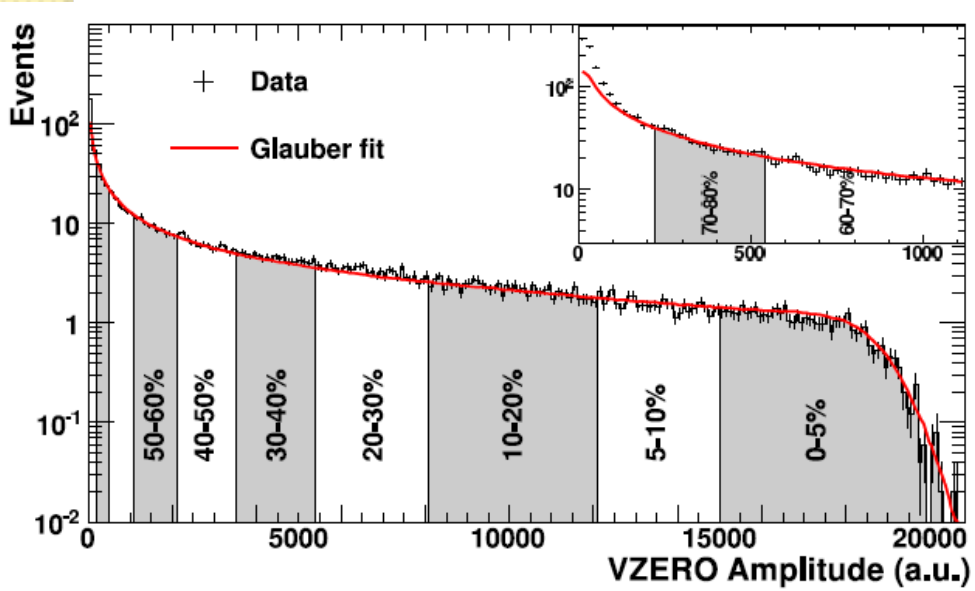


Many things **scale** with N_{part}:

- Transverse Energy
- Particle Multiplicity
- Particle Spectra

$$N_{\text{part}} = A - N_{\text{spec}}$$

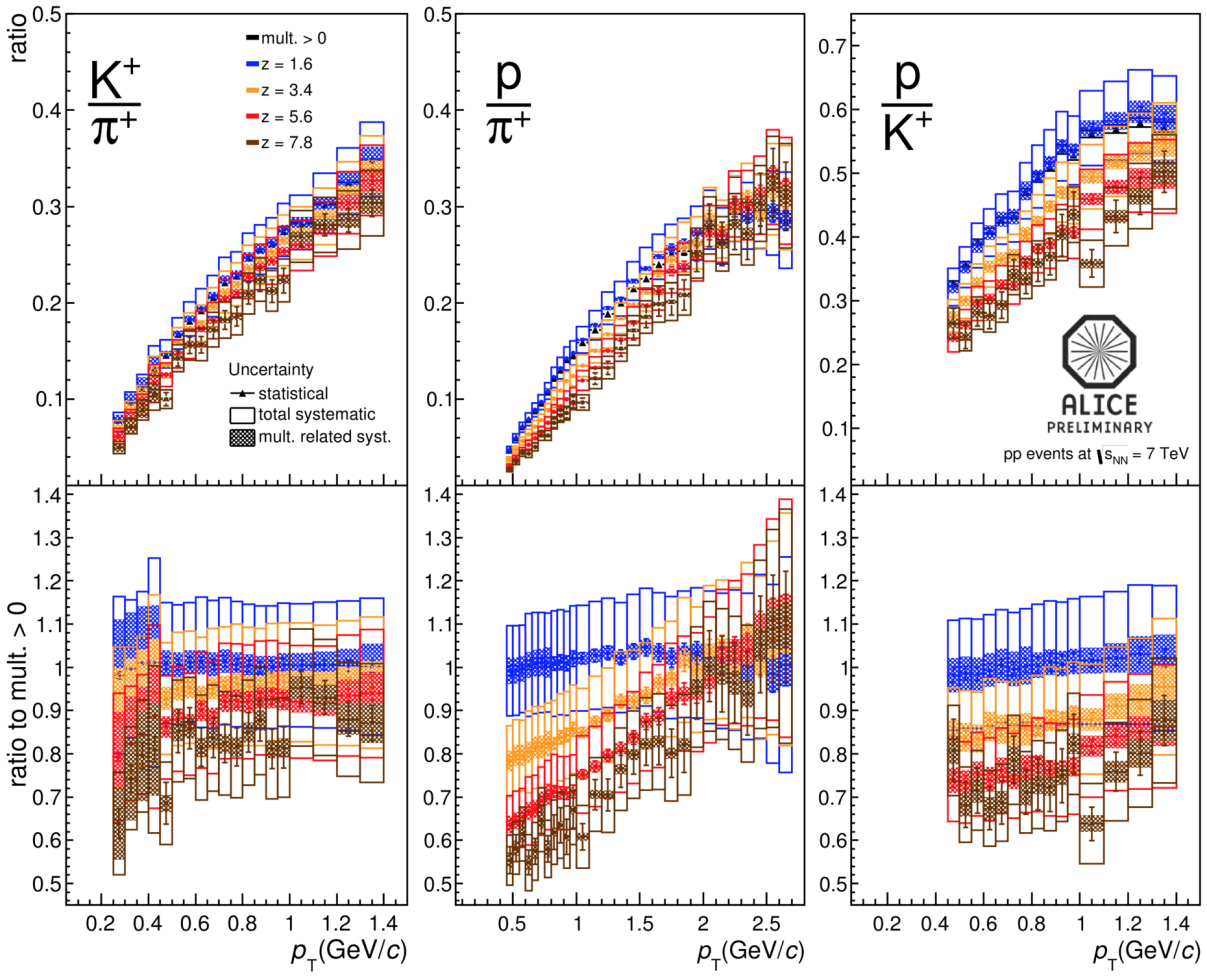
ALICE: PRL106 (2011) 032301



- For example: sum of the amplitudes in the ALICE V0 scintillators
  - ⇨ reproduced by Glauber model fit
  - ⇨ deviation at very low amplitude expected due to non-nuclear (electromagnetic) processes

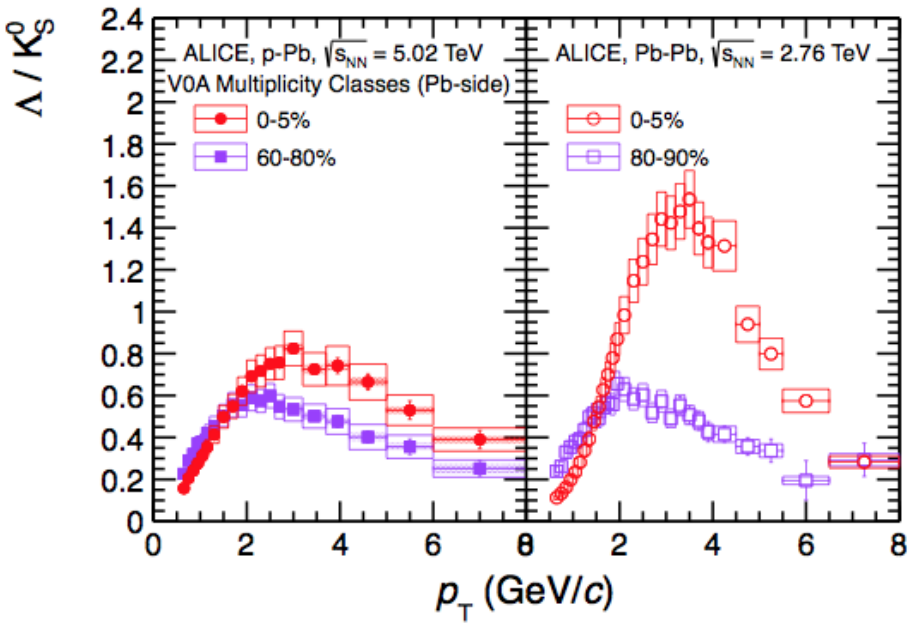
Yield ratios-multiplicity dependence

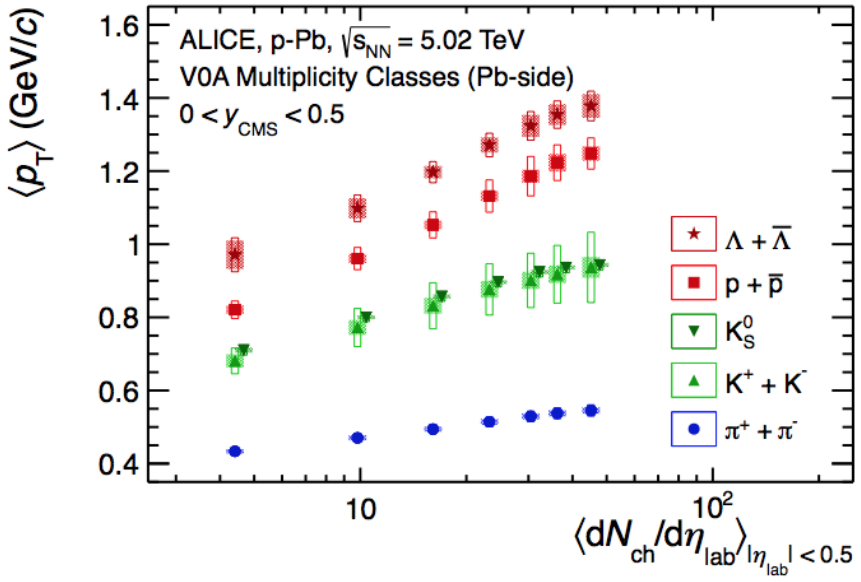
pp @ 7 TeV



ALI-PREL-51119

Further hints of collective behavior





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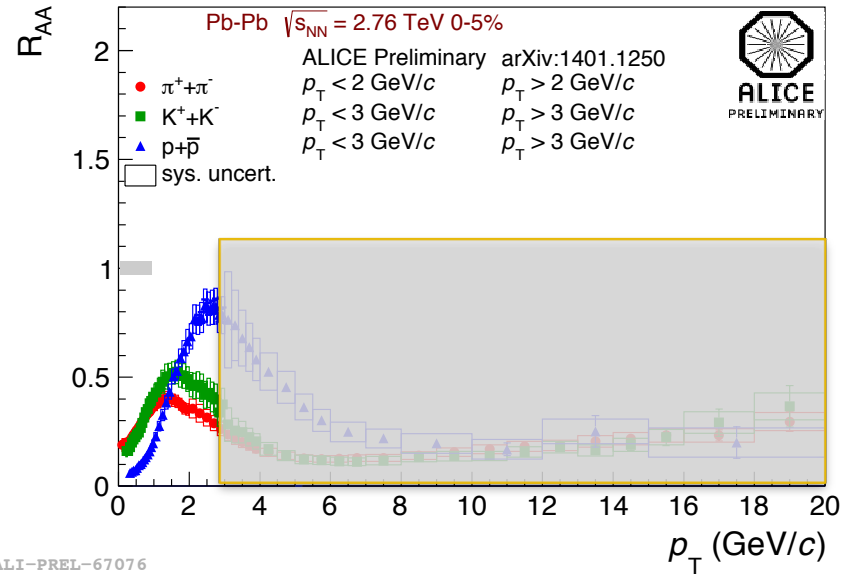
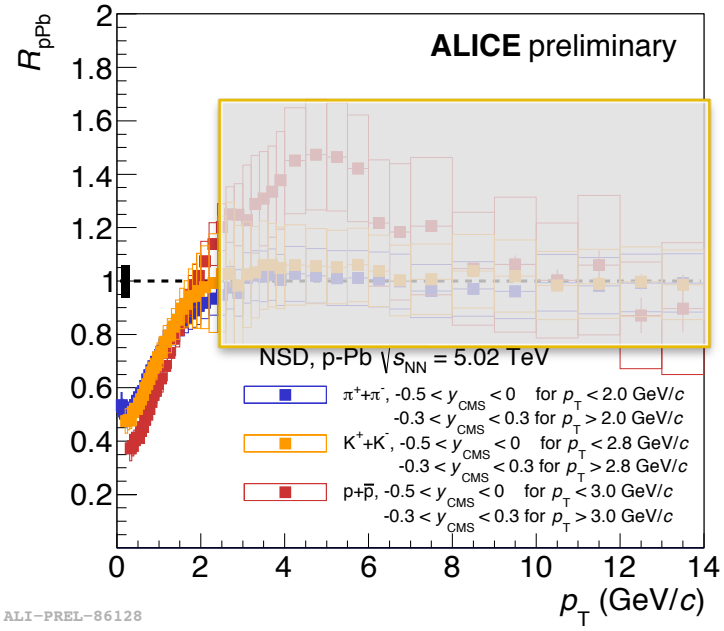
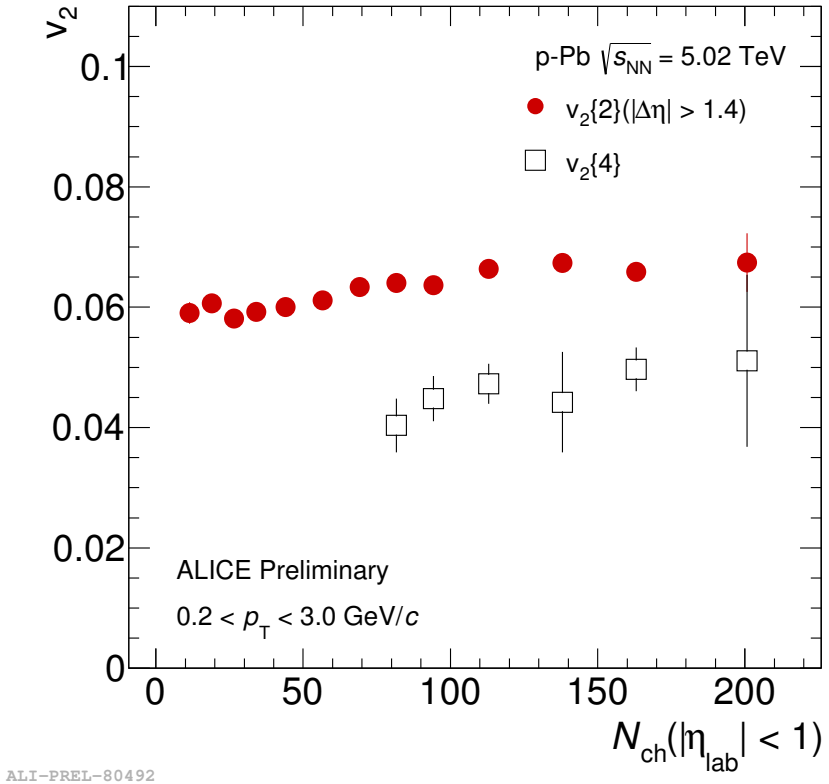
R_{AA} and R_{pA} comparison

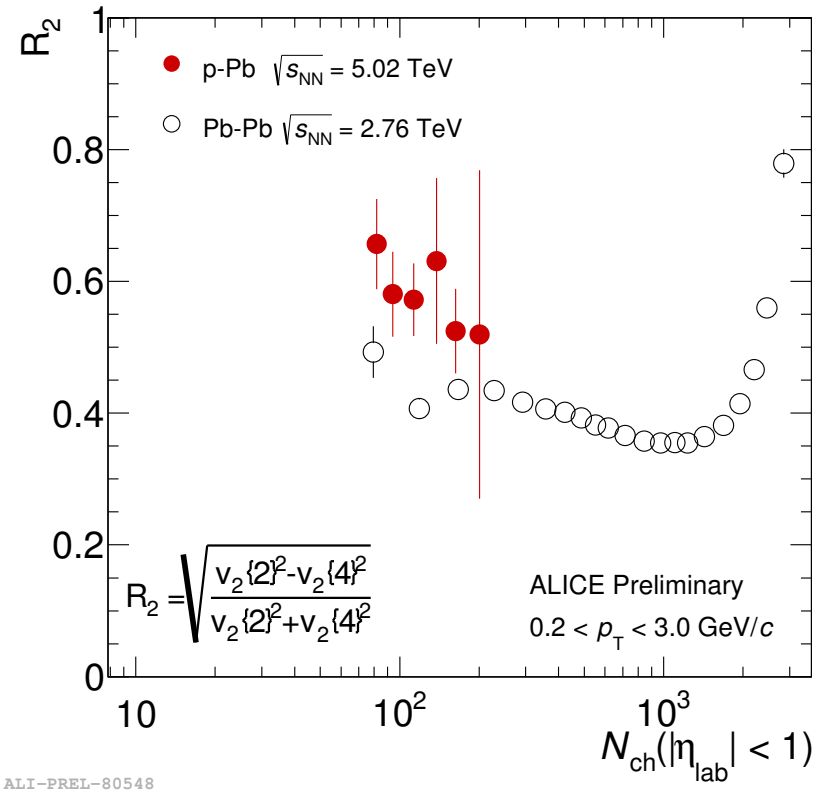




- ✧Nuclear modification effects explain Pb-Pb data
- ✧p-Pb results: not a simple case!

$v_2\{2\}$ and $v_2\{4\}$ in p-Pb





- v2{2} > v2{4} in p-Pb -> Indicative of flow fluctuations?
- R2 approximates $\sigma_{v2}/\langle v2\rangle$. Fluctuations larger in p-Pb compared to Pb-Pb.