XV Mexican Workshop on Particles and Fields

2-6 November 2015 Playa Mazatlan Beach Hotel

Overview of recent ALICE results

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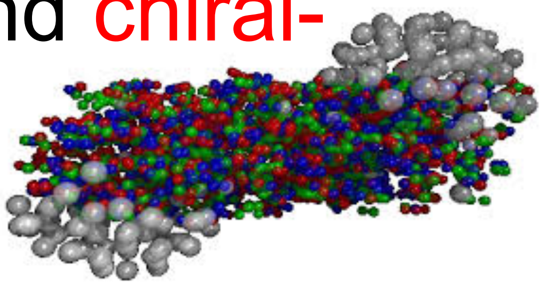
Outline

- Introduction
- The ALICE apparatus
- Main results of heavy-ion run 1
- sQGP-like effects in small systems
- Summary

INTRODUCTION

Goal of heavy-ion collision experiments

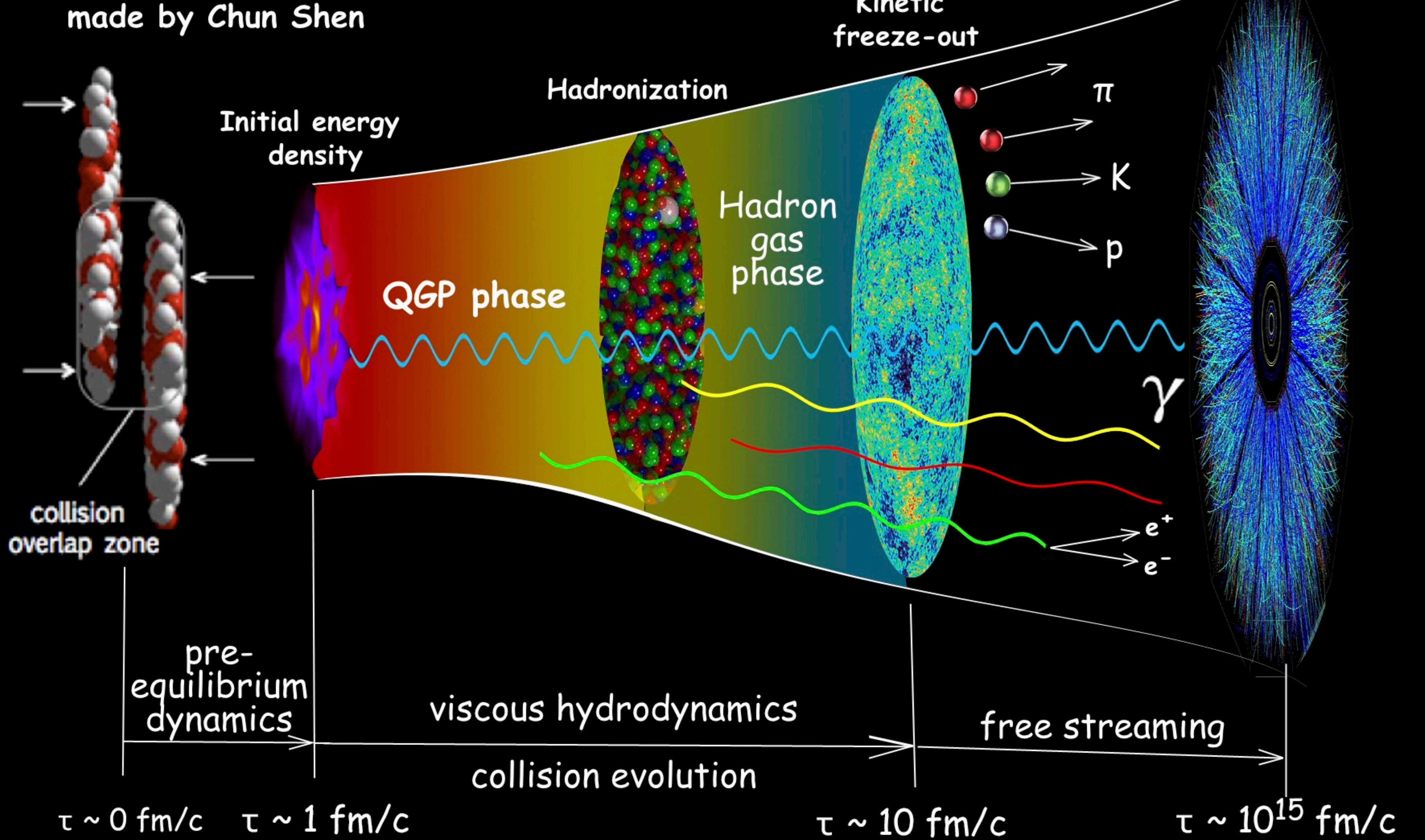
- Study the physics of strongly interacting matter at extreme energy densities, where the formation of quark-gluon plasma (QGP) is expected
- The existence of such a phase and its properties are key issues in QCD for the understanding of confinement and chiral-symmetry restoration



RHIC's results

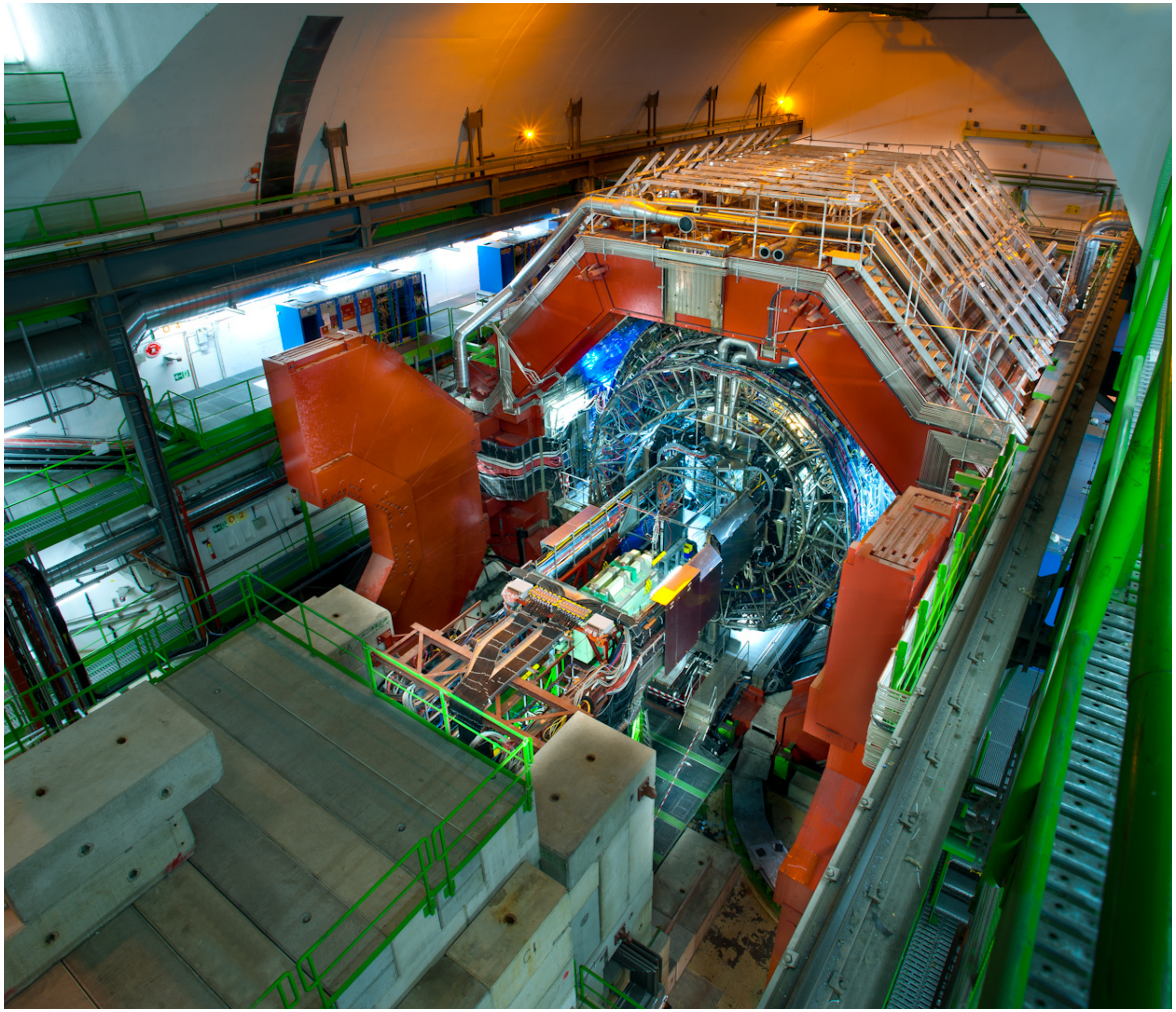
- Experiments at Relativistic Heavy-Ion Collider (RHIC) reported the formation of a new state of matter characterized by a strong collective flow and opacity to jets
- We are therefore studying a strongly coupled QGP (sQGP) whose properties are more interesting than those expected from theory (instead of having a gas with little or no interaction among quarks, we have found a system which behaves as a perfect fluid!)

Relativistic Heavy-Ion Collisions



THE ALICE DETECTORS

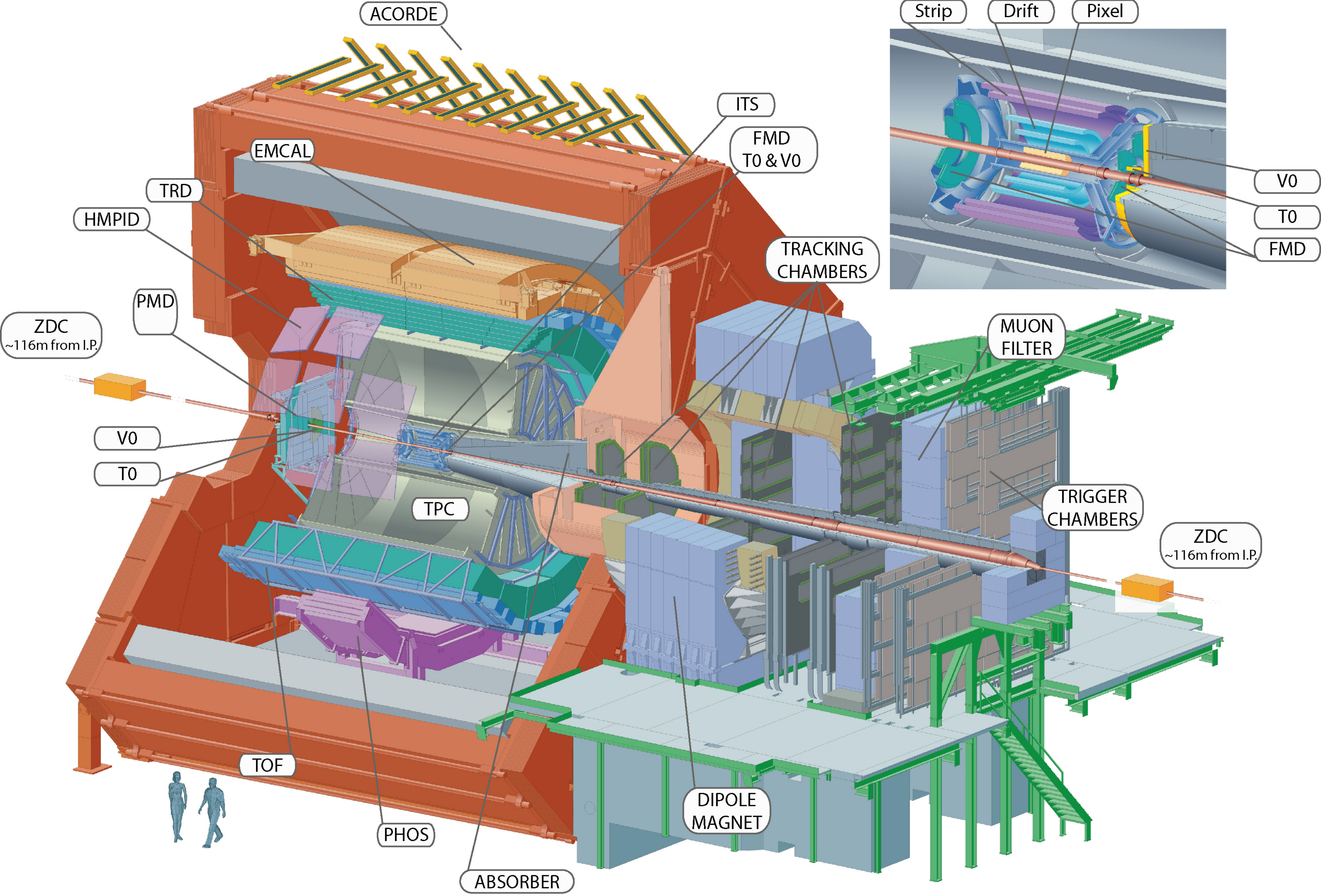
The ALICE apparatus



ALICE is a dedicated heavy-ion experiment at the LHC

- Excellent particle identification (PID) capabilities
- Excellent vertex capability
- Efficient low momentum tracking – down to ~ 150 MeV/*c*

ALICE, IJMPA 29,1430044 (2014)


ACORDE
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
PMD
ZDC
~116m from I.P.
V0
T0
TPC
TRACKING
CHAMBERS
MUON
FILTER
TRIGGER
CHAMBERS
ZDC
~116m from I.P.
TOF
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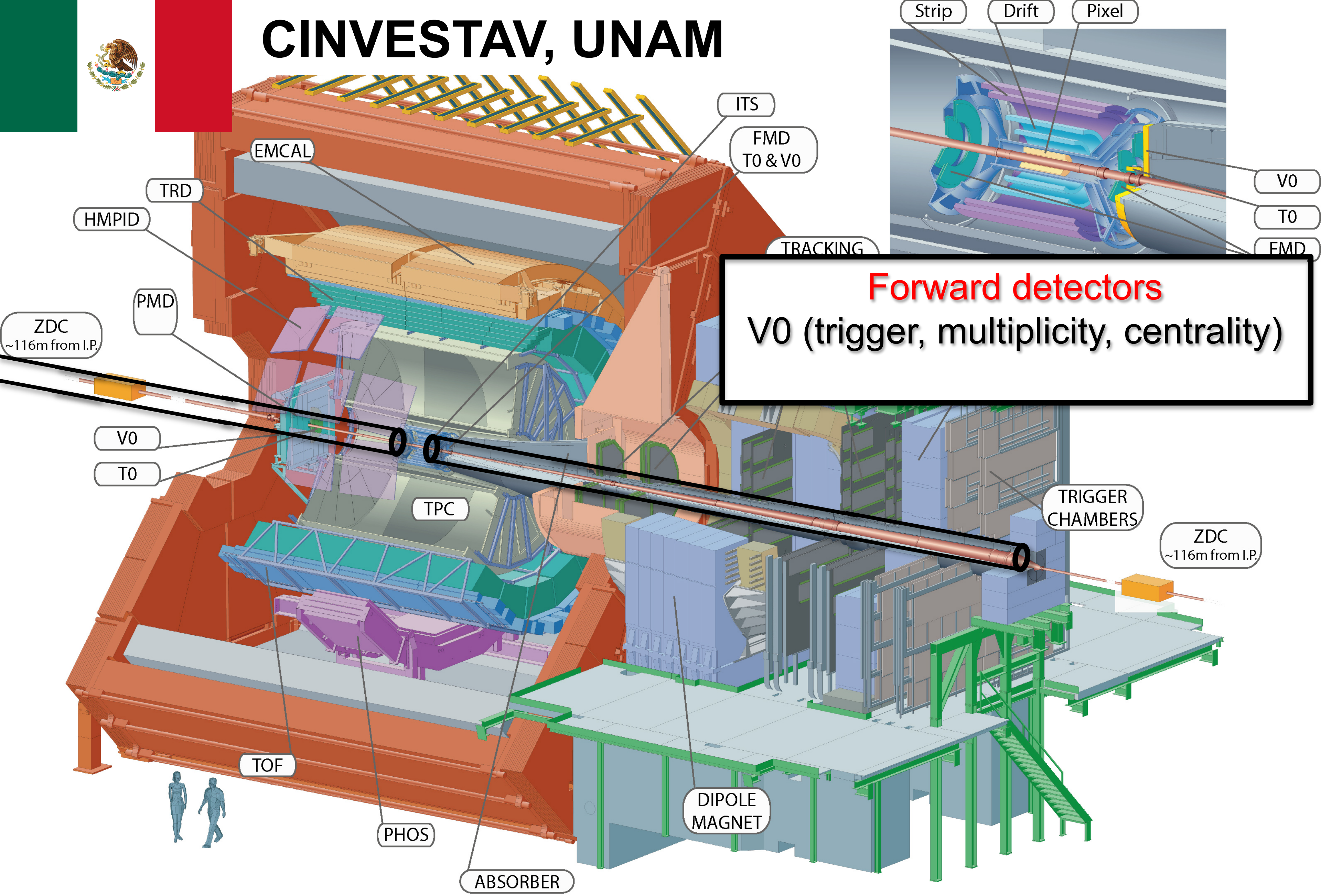
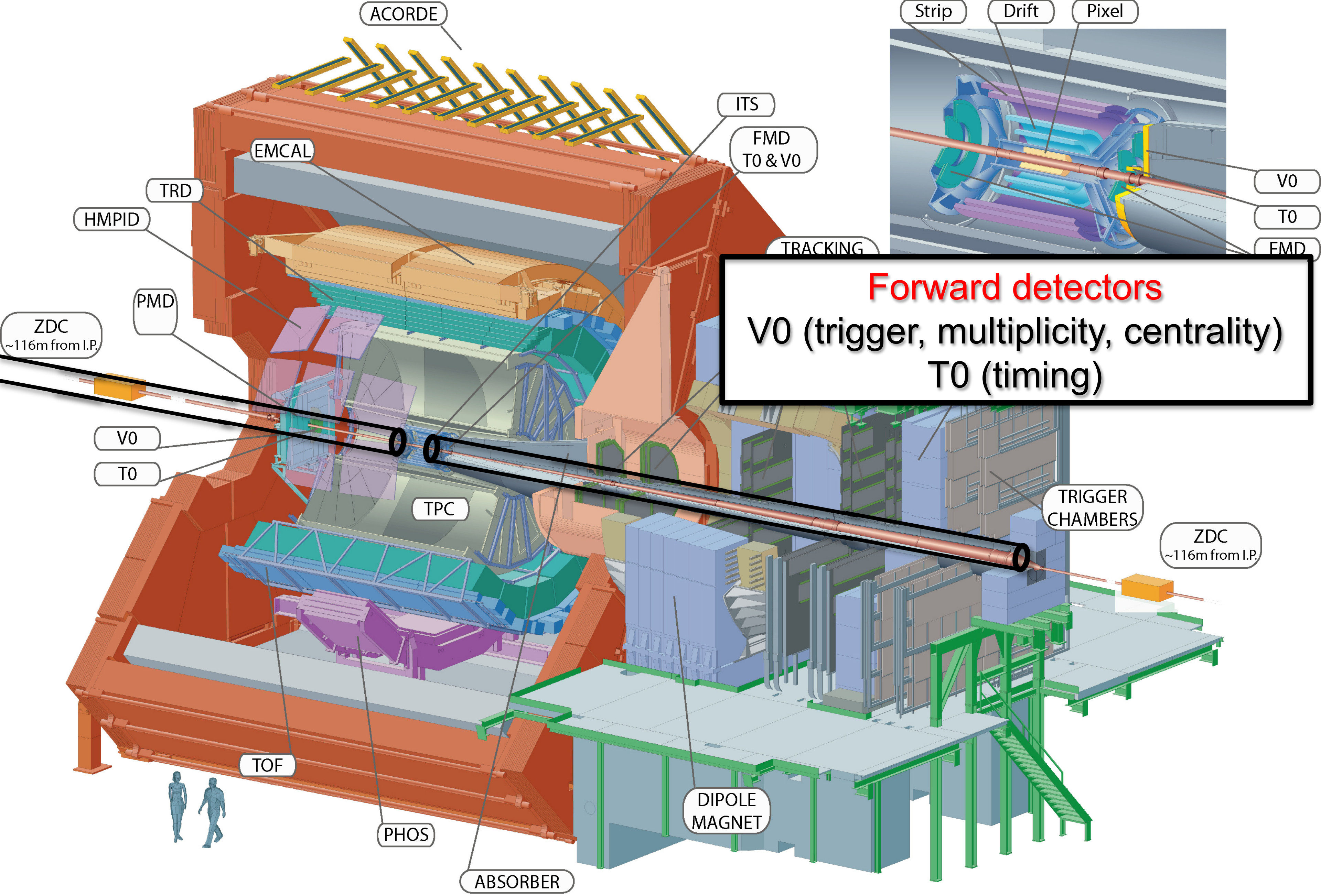
ABSORBER
DIPOLE
MAGNET
Strip
Drift
Pixel
V0
T0
FMD

CINVESTAV, UNAM



Forward detectors

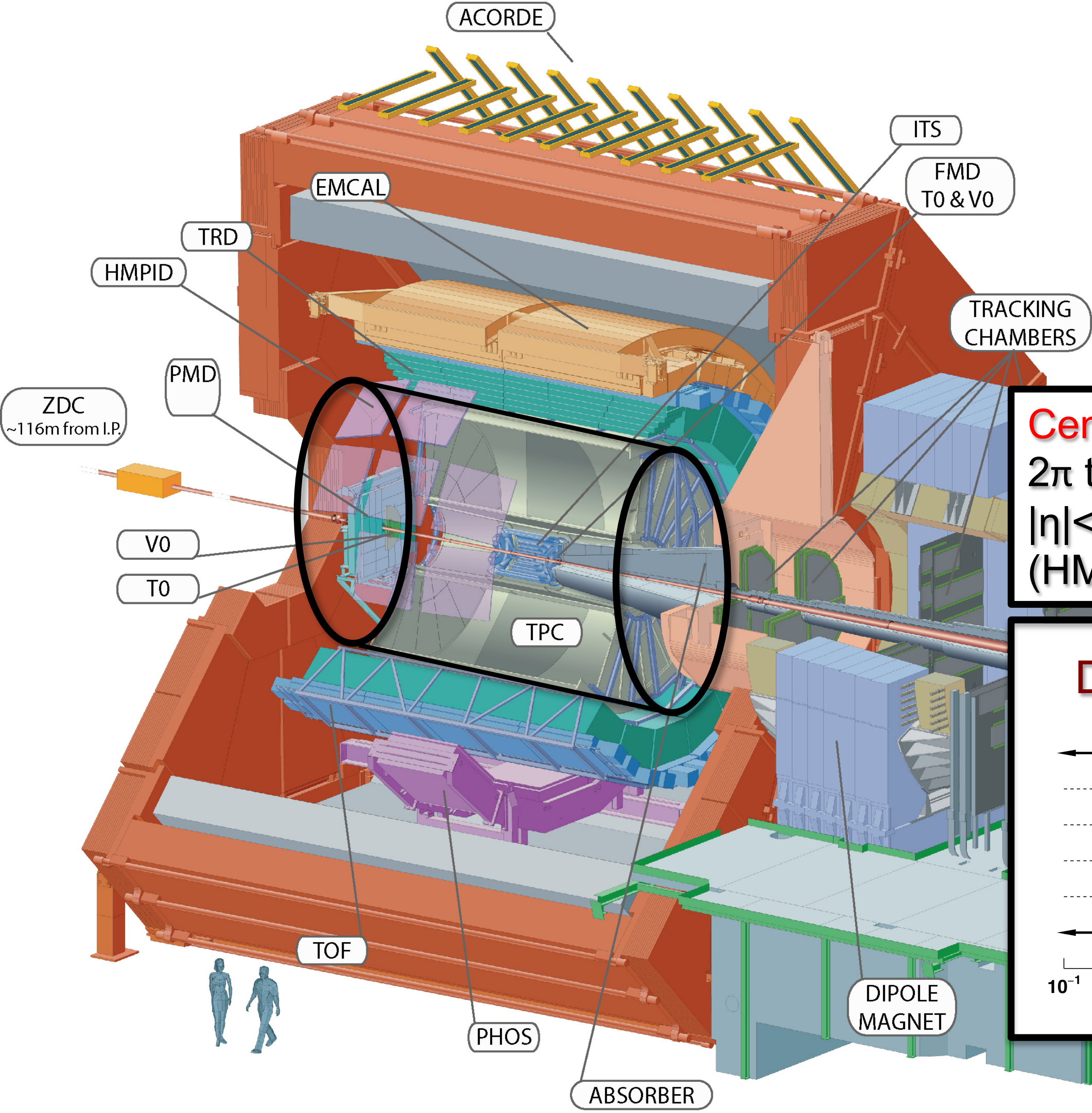
V0 (trigger, multiplicity, centrality)

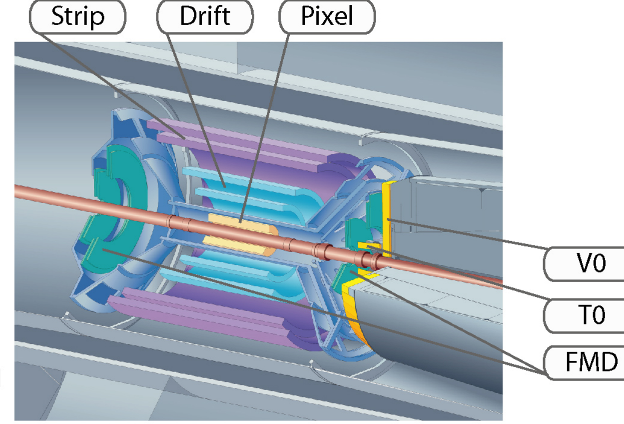


Forward detectors

V0 (trigger, multiplicity, centrality)

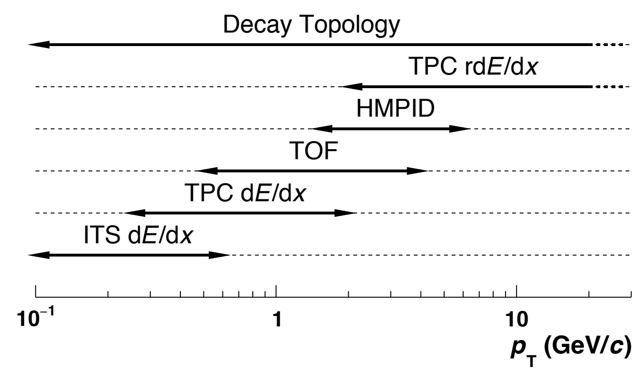
T0 (timing)





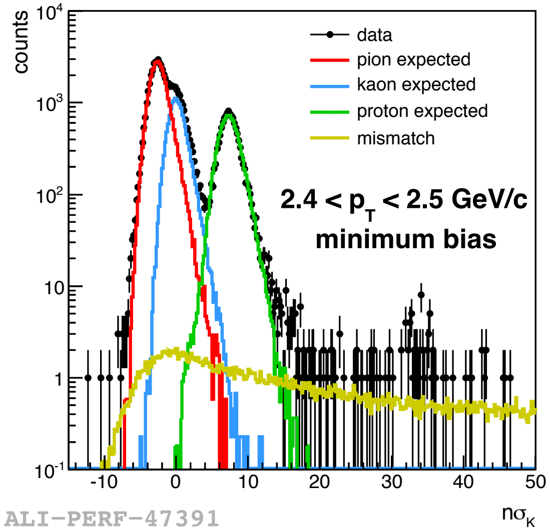
Central barrel:
2π tracking and PID
$|\eta|<1$, B = 0.5 T
(HMPID RICH: $|\eta|<0.6$, $\Delta\phi=57°$)

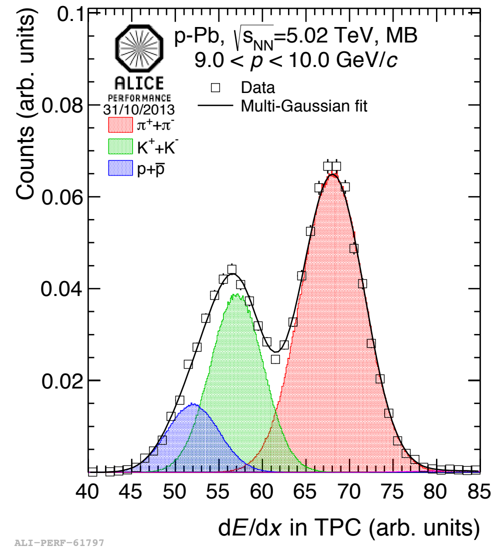
Different PID techniques



Charged pion, kaon and (anti)proton yields extraction using different detectors

TOF
Fits to time of flight distributions





TPC
Fits to TPC dE/dx distributions

Topological identification

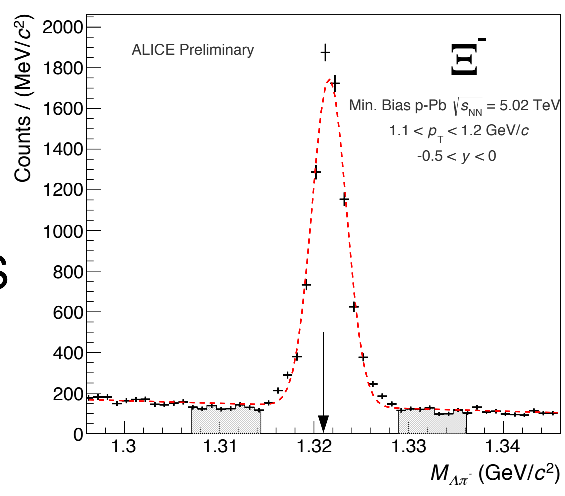
$\Xi^- \longrightarrow \Lambda\pi^-$

$\Omega^- \longrightarrow \Lambda K^-$

$\Lambda \longrightarrow p\pi^-$

Tracking:
TPC and ITS

PID:
TPC dE/dx



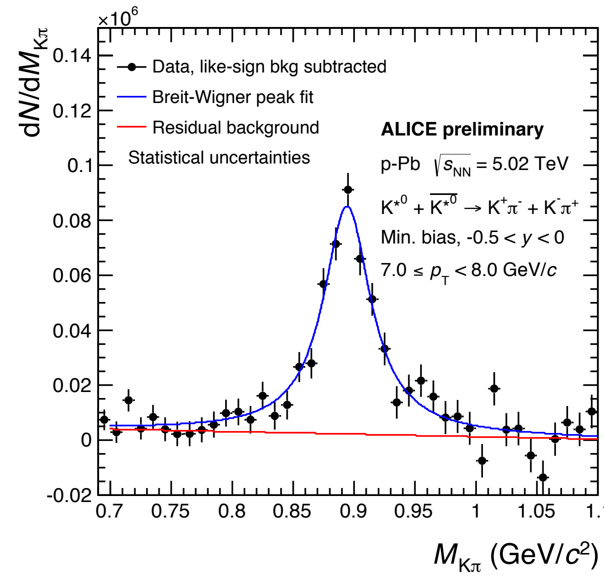
Resonances

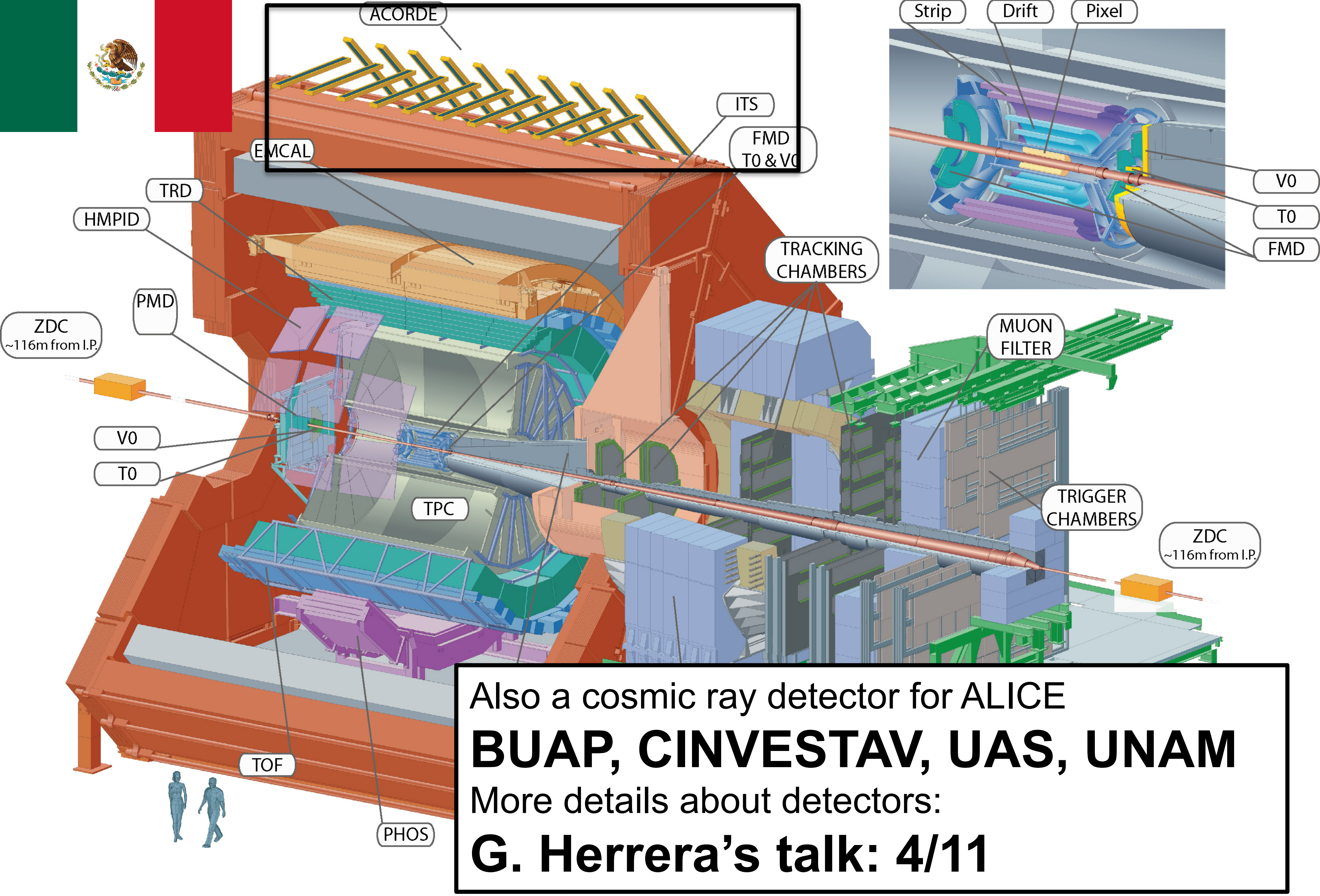
$\phi \longrightarrow K^+K^-$

$K^{*0} \longrightarrow K^{+-}\pi^{-+}$

Tracking:
TPC and ITS

PID:
TOF
TPC dE/dx



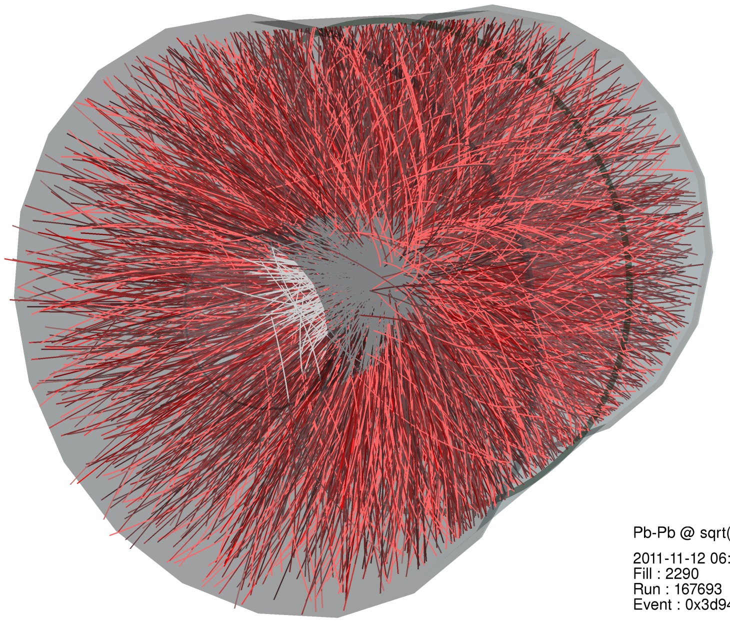


Also a cosmic ray detector for ALICE

BUAP, CINVESTAV, UAS, UNAM

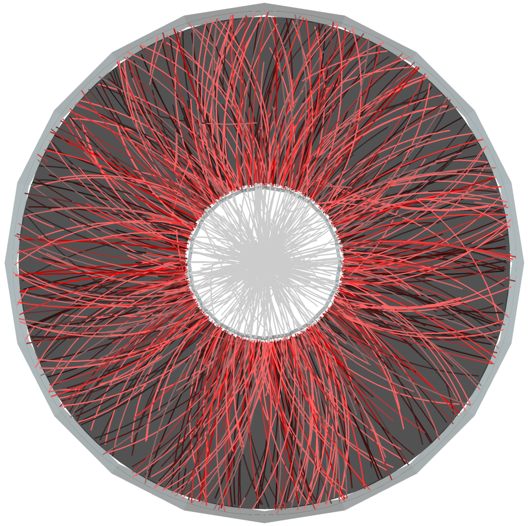
More details about detectors:

G. Herrera's talk: 4/11



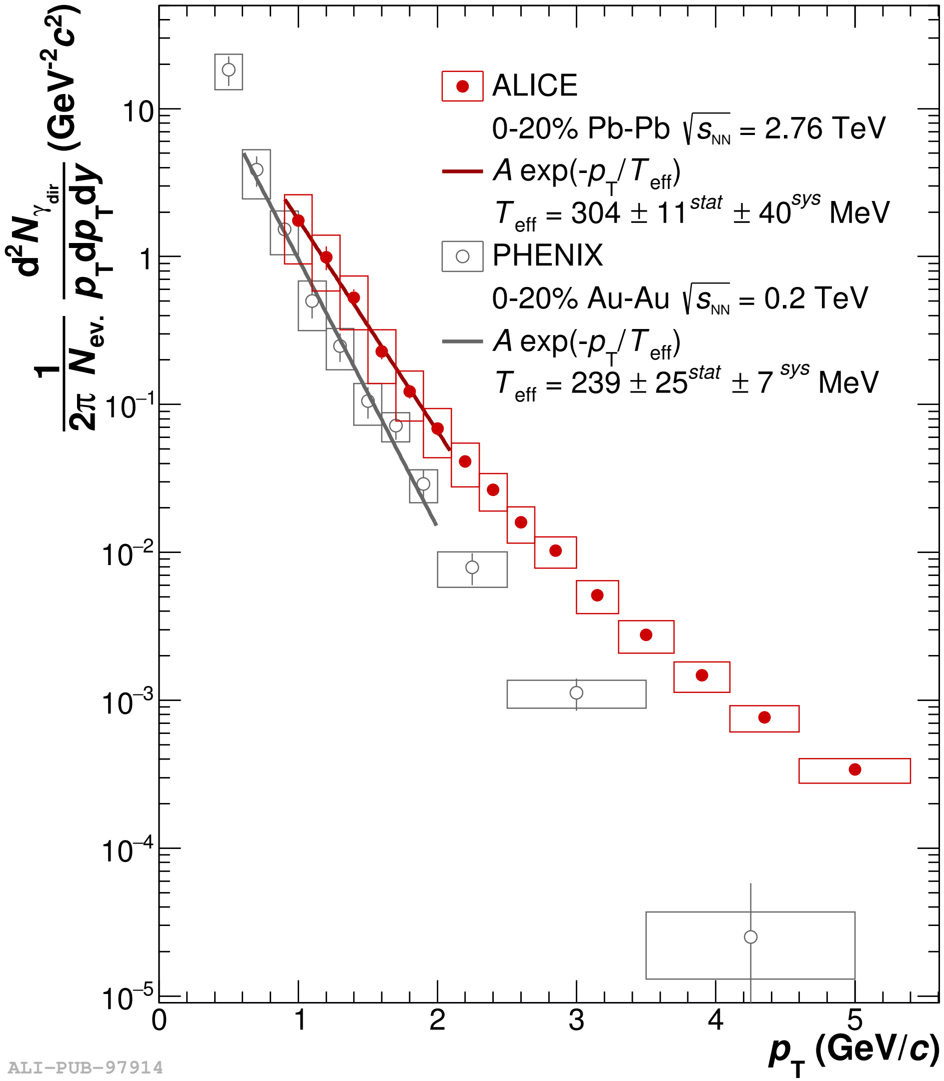
Pb-Pb @ sqrt(s) = 2.76 ATeV

2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a

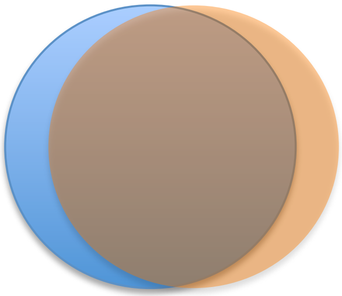


HEAVY-ION RESULTS

We produce a hot system



The direct photon production has been measured in Pb-Pb by ALICE

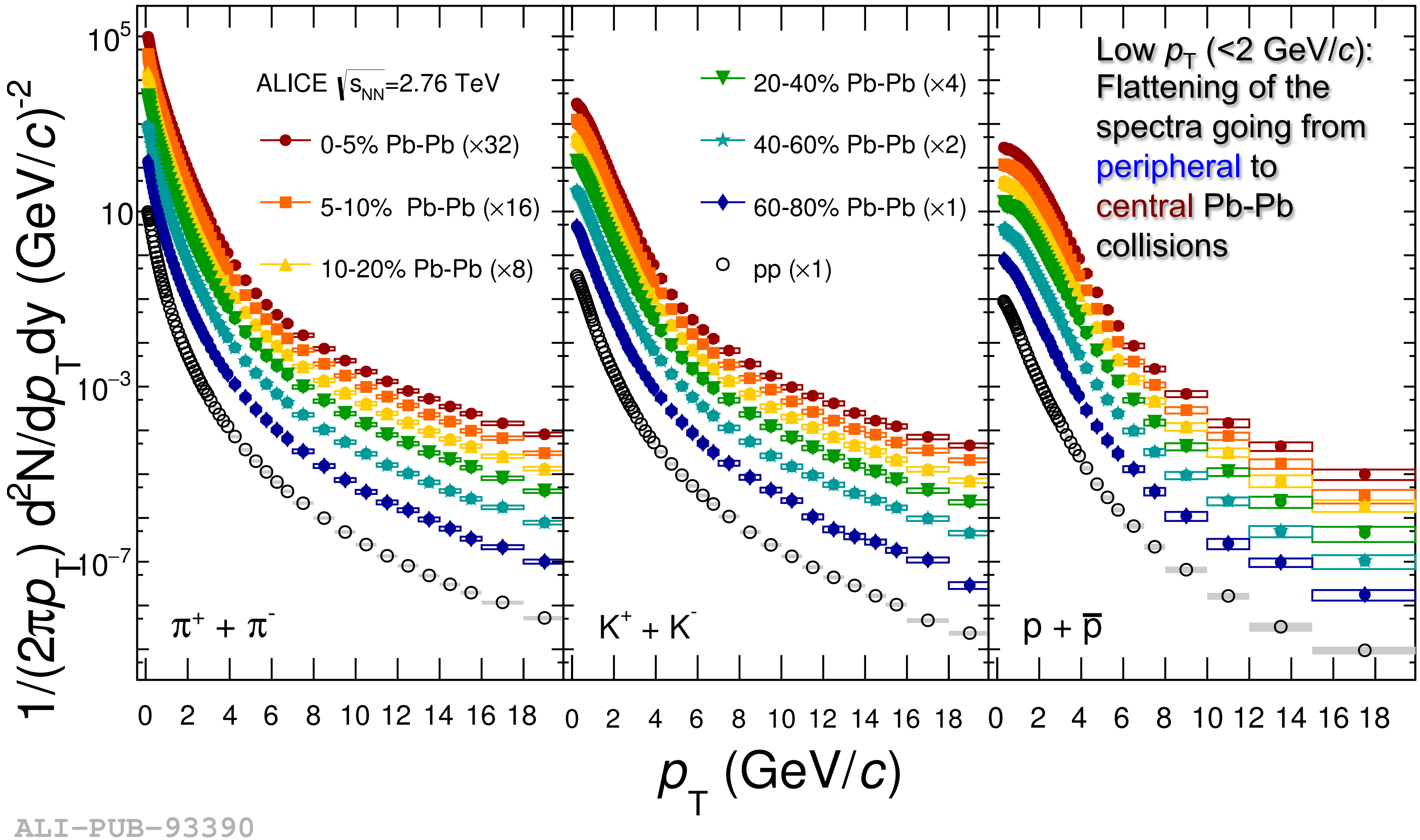


PHENIX, PRC 91, 6, (2015) 064904
ALICE, arXiv:1509.07324

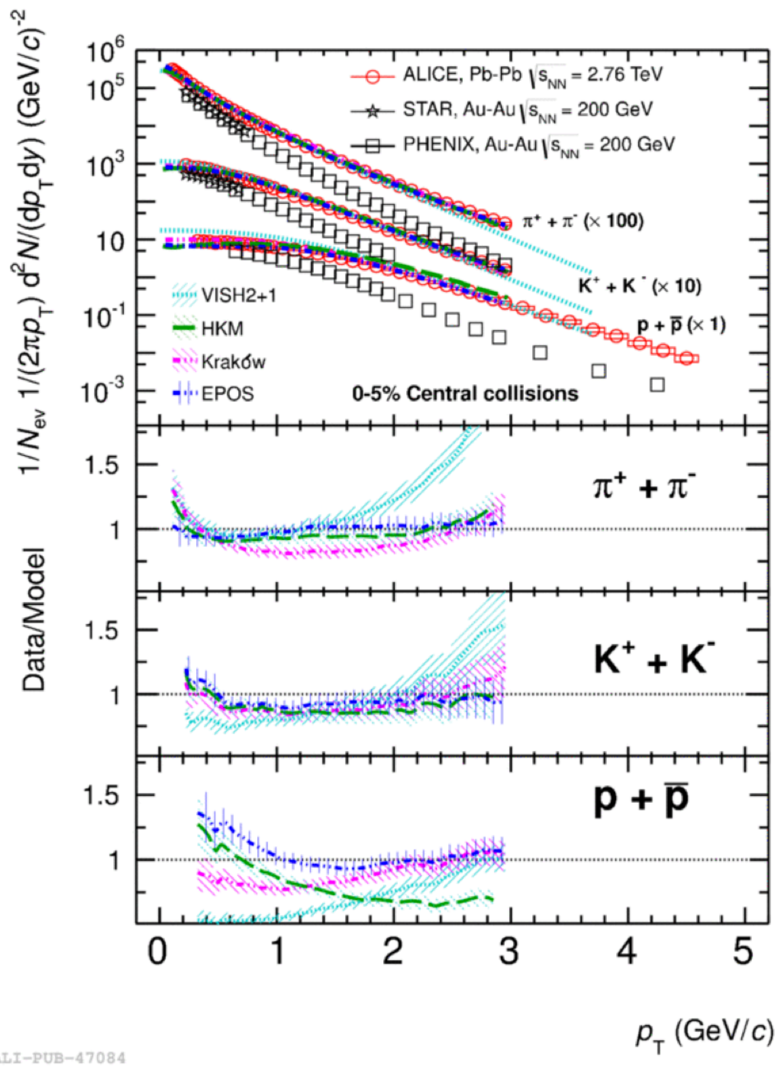
The p_T range 0.9-2.1 GeV/c can be described by an exponential with an inverse slope parameter of 304 MeV

With a strong radial flow

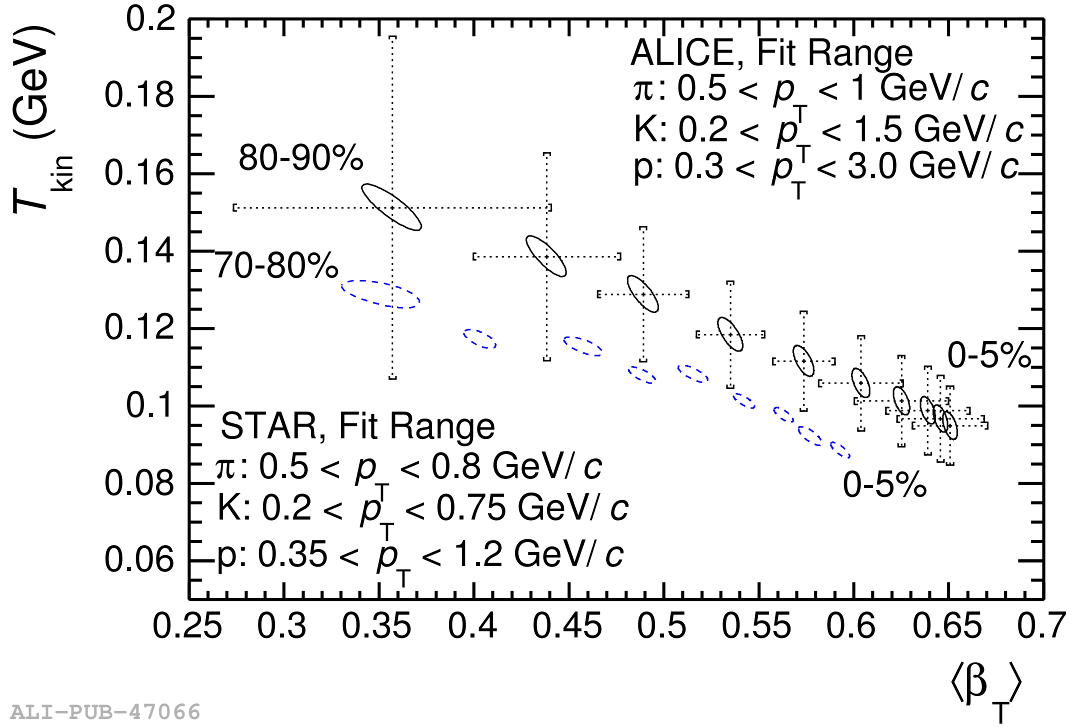
ALICE, PLB 736 (2014) 196-207
ALICE, arXiv:1506.07287



With a strong radial flow

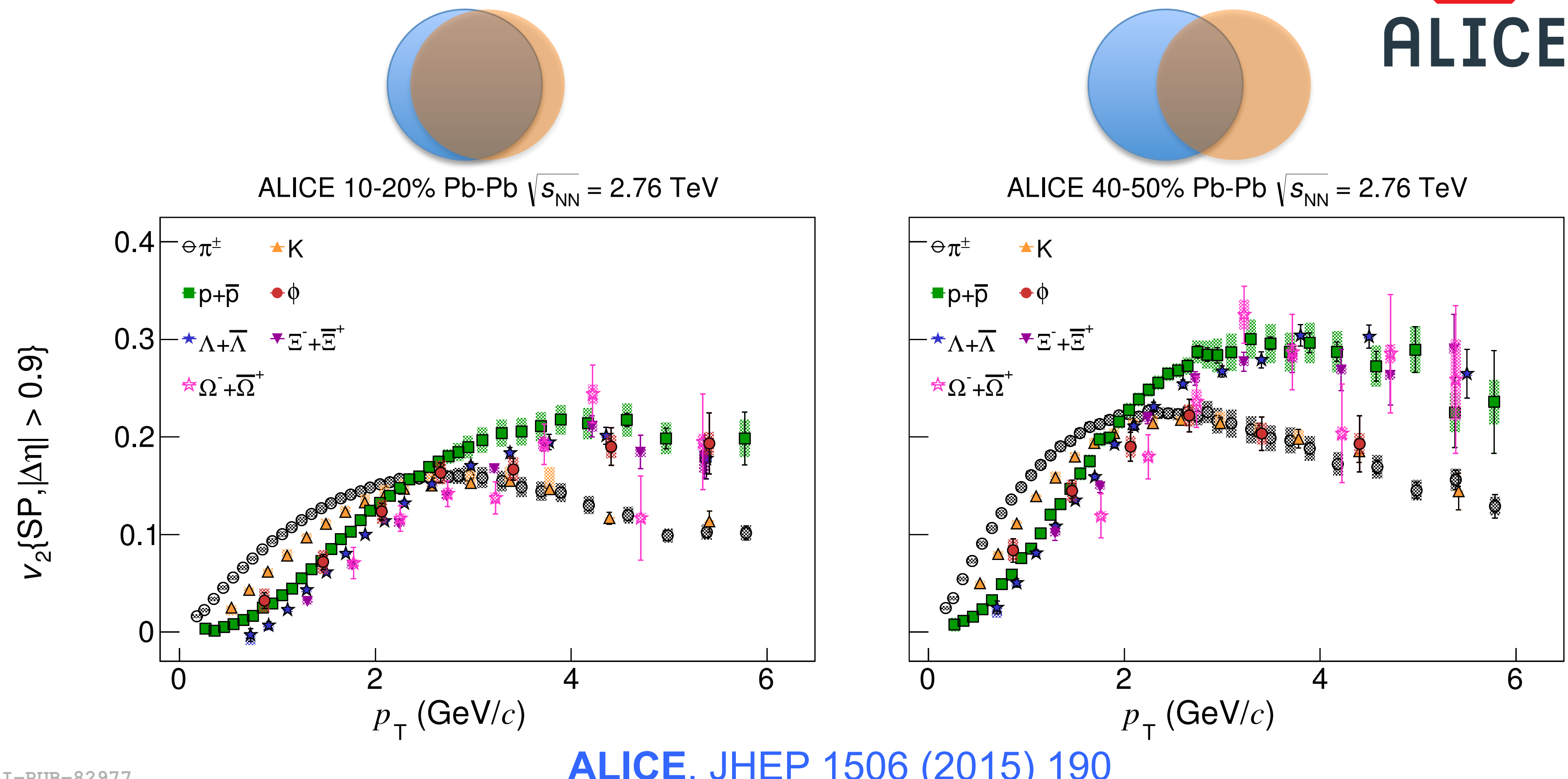


ALICE, PRC 88, 044910 (2013)



Stronger radial flow at LHC than at RHIC

We also see elliptic flow



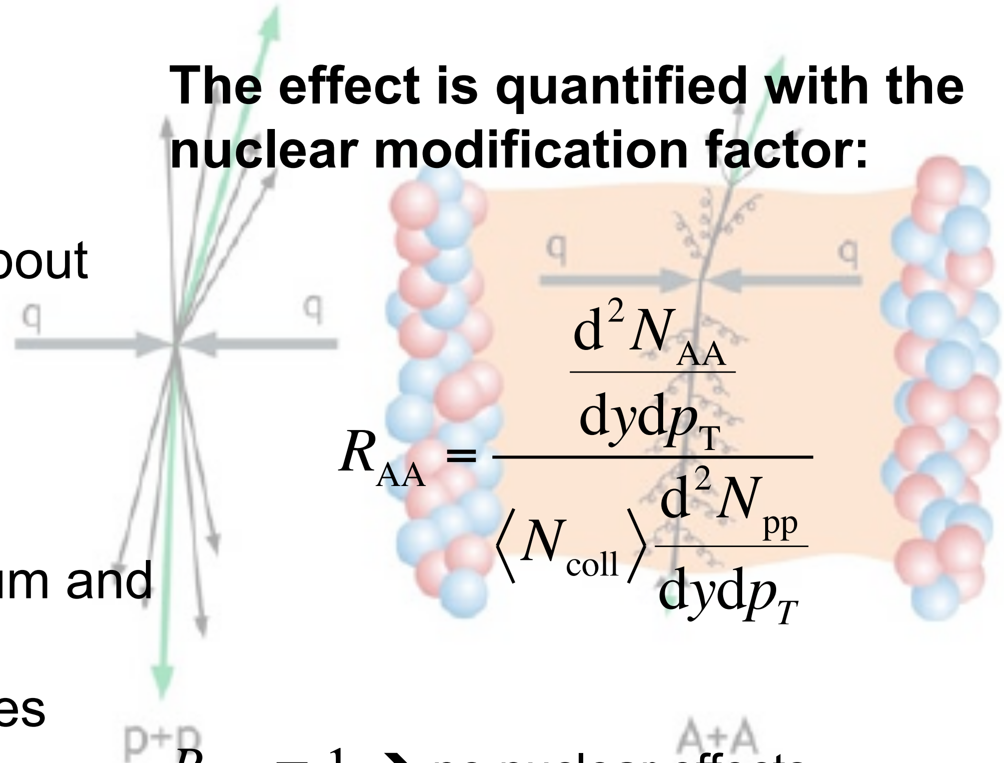
ALICE, JHEP 1506 (2015) 190

Low p_T: particle mass dependence consistent with elliptic flow accompanied by the transverse radial expansion of the system with a common velocity field

Jet quenching

- “Simplest way” to establish the properties of a system:
  - Calibrated probe
  - Calibrated interaction
  - Suppression pattern tells about density profile
- Heavy-ion collisions
  - Hard processes serve as calibrated probe (pQCD)
  - Traverse through the medium and interact
  - Suppression pattern provides density measurement

The effect is quantified with the nuclear modification factor:



$$R_{\mathrm{AA}} = \frac{\dfrac{d^2 N_{\mathrm{AA}}}{dy dp_{\mathrm{T}}}}{\langle N_{\mathrm{coll}} \rangle \dfrac{d^2 N_{\mathrm{pp}}}{dy dp_T}}$$

$R_{\mathrm{AA}} = 1$ ➔ no nuclear effects

$R_{\mathrm{AA}} \neq 1$ ➔ (hot or cold) nuclear effects

Jet quenching

- "Simplest way" to establish the properties of a system:
  - Calibrated probe
  - Calibrated interaction
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- Heavy-ic
  - Harc calib
  - Trav inter
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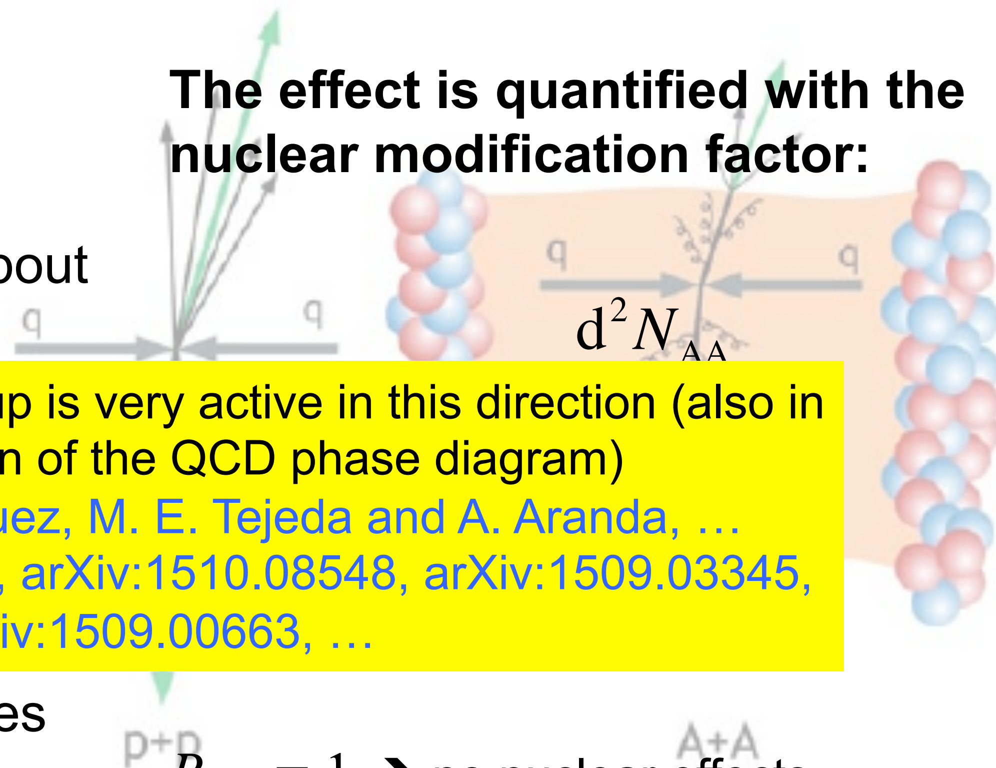


d^2N_{AA}

The Mexican theory group is very active in this direction (also in the investigation of the QCD phase diagram)

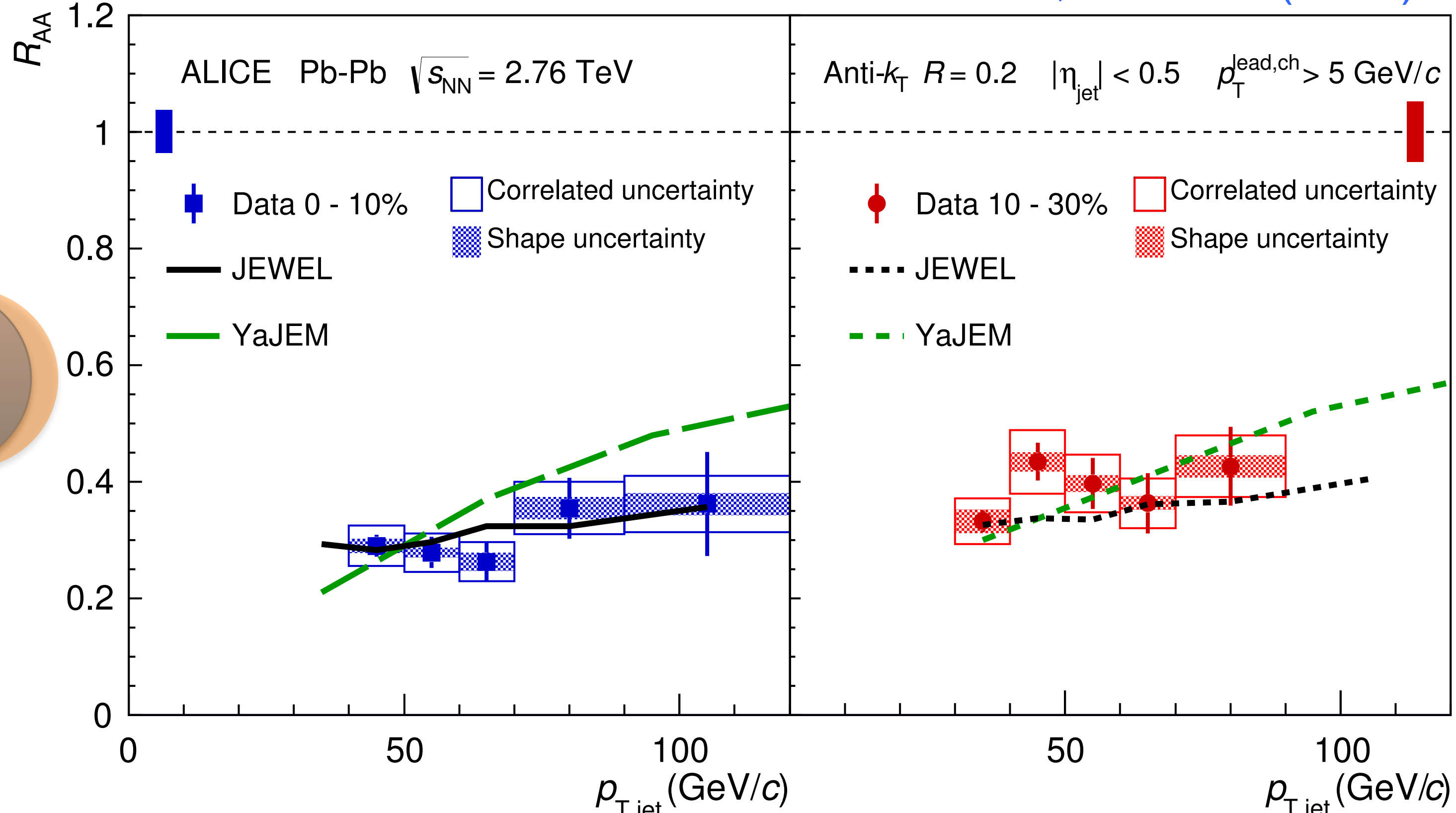
A. Ayala, I. Domínguez, M. E. Tejeda and A. Aranda, …
PRC 92, 024910 (2015), arXiv:1510.08548, arXiv:1509.03345, arXiv:1509.00663, …

$R_{AA} = 1$ ➔ no nuclear effects

$R_{AA} \neq 1$ ➔ (hot or cold) nuclear effects

The medium is opaque to jets

ALICE, PLB 746 (2015) 1



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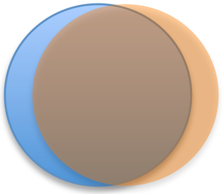
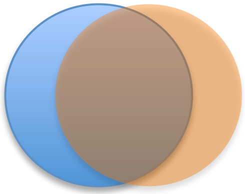
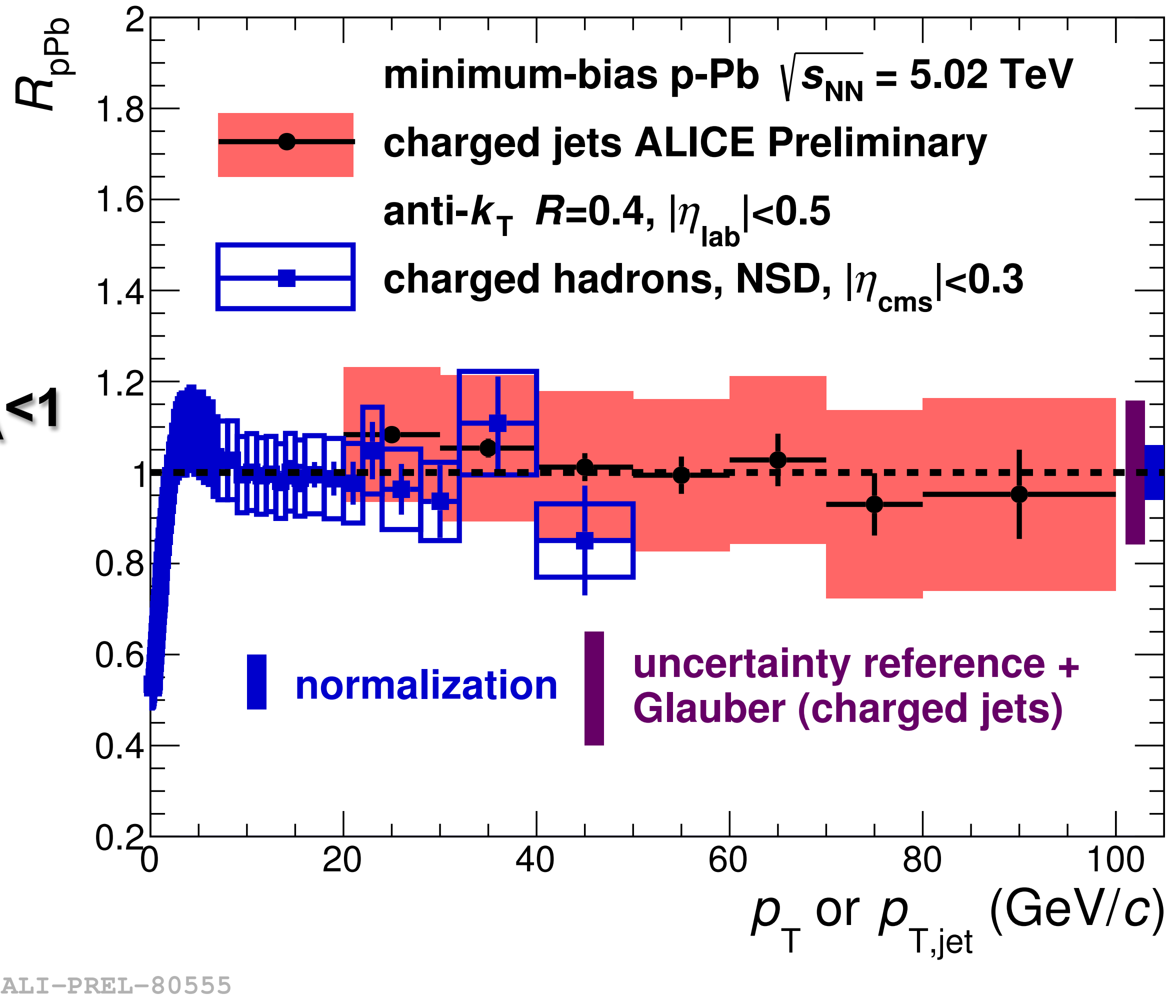




Slightly more suppression in 0-10% Pb-Pb collisions than in 10-30% Pb-Pb collisions

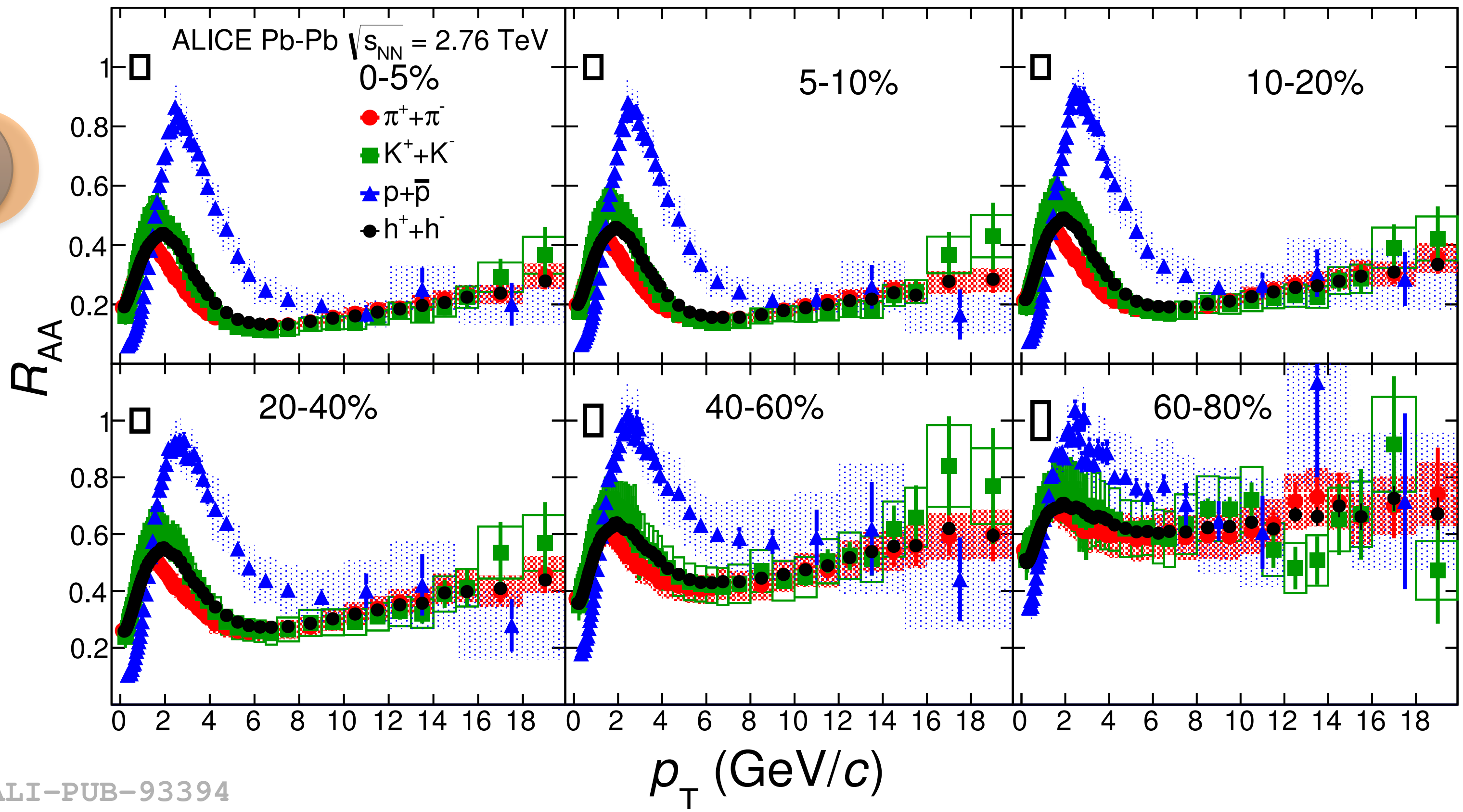
But, R_{pPb} consistent with 1 at high p_T



➔In Pb-Pb collisions, R_{AA}<1 is due to final state effects

R_{AA} for identified hadrons

ALICE, arXiv:1506.07287



At high p_T R_{AA} shows no particle species dependency

Hierarchy of parton energy loss

- Radiative parton energy loss and dense QCD matter is color charge dependent (Casimir coupling factor)
  R. Baier et al., NPB 483, (1997), 291
- Dead-cone effects: gluon radiation suppressed at small angles ($\theta < m_Q/E_Q$)

$$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$$

➔ Expected behavior at high p_T:

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

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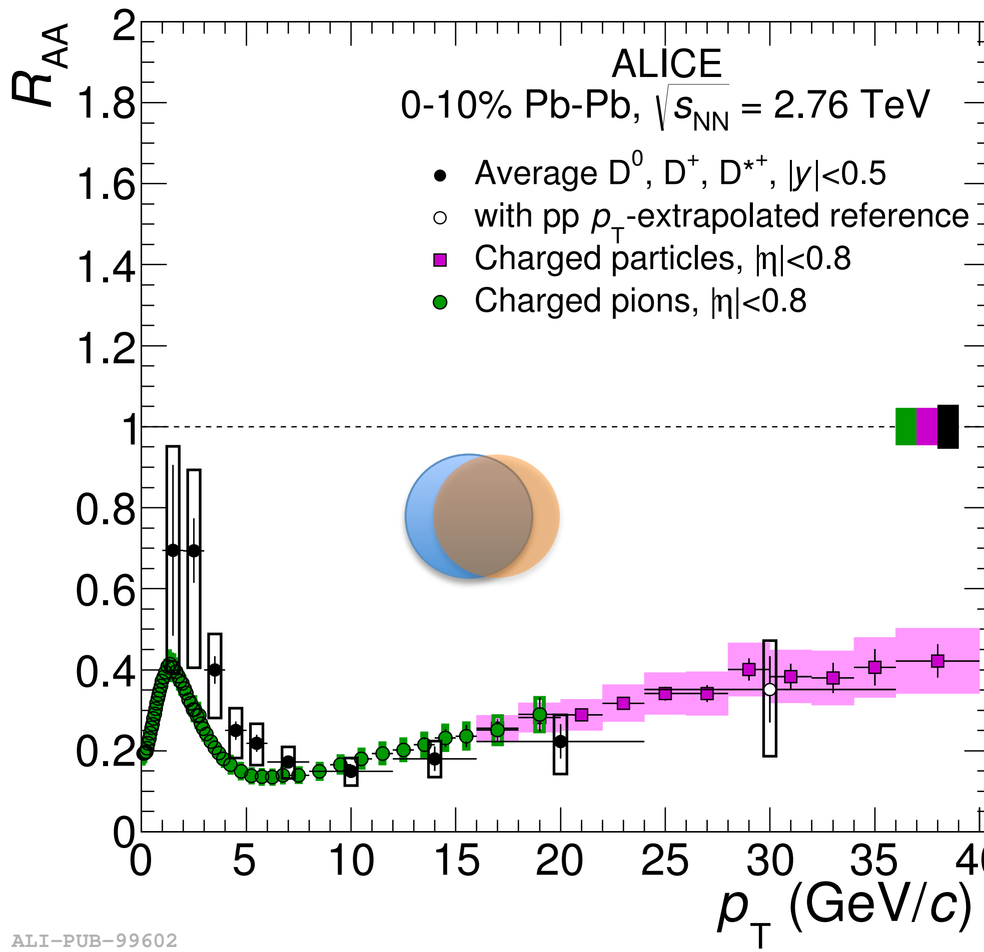
ALICE, arXiv:1509.06888v1



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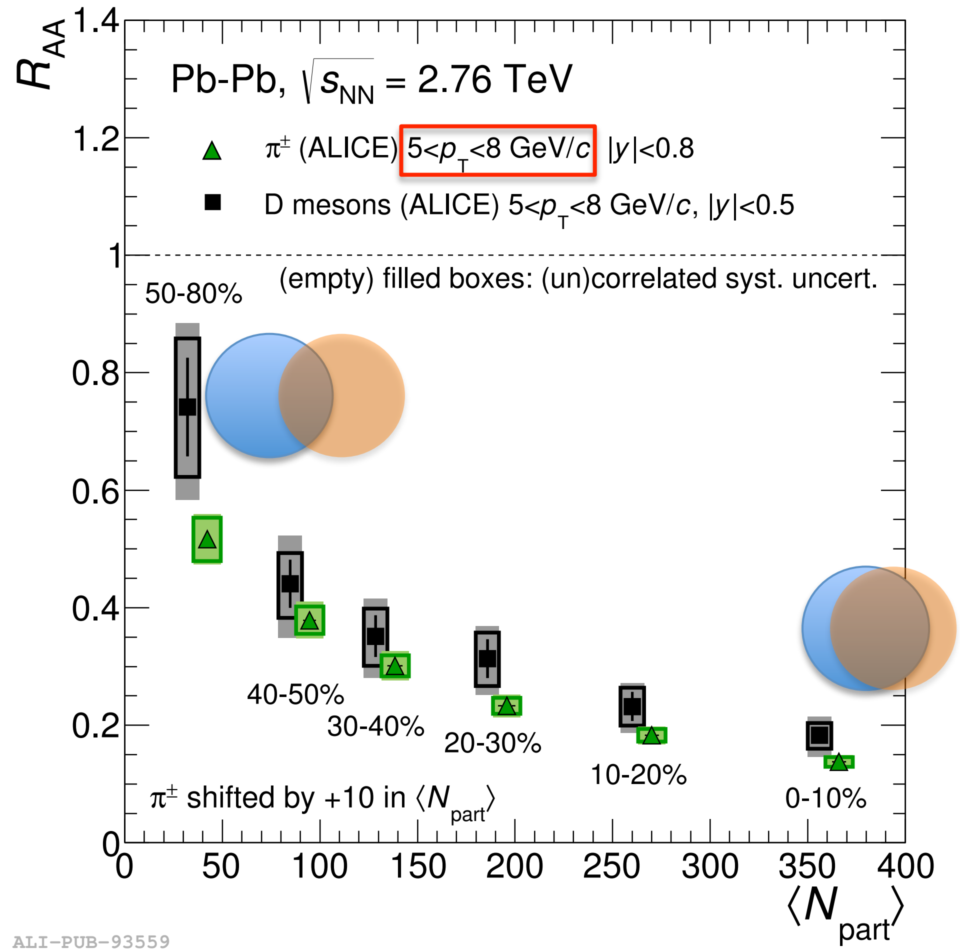
ALICE, arXiv:1506.06604v1



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ALICE, arXiv:1506.06604v1

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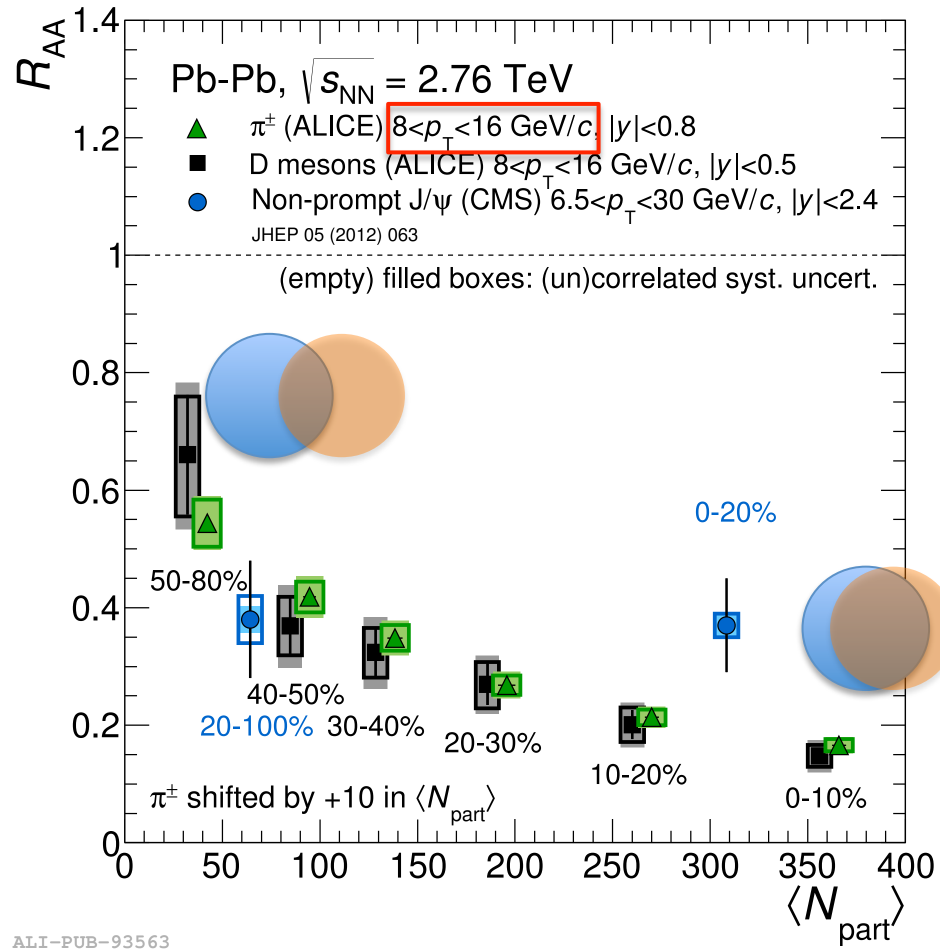
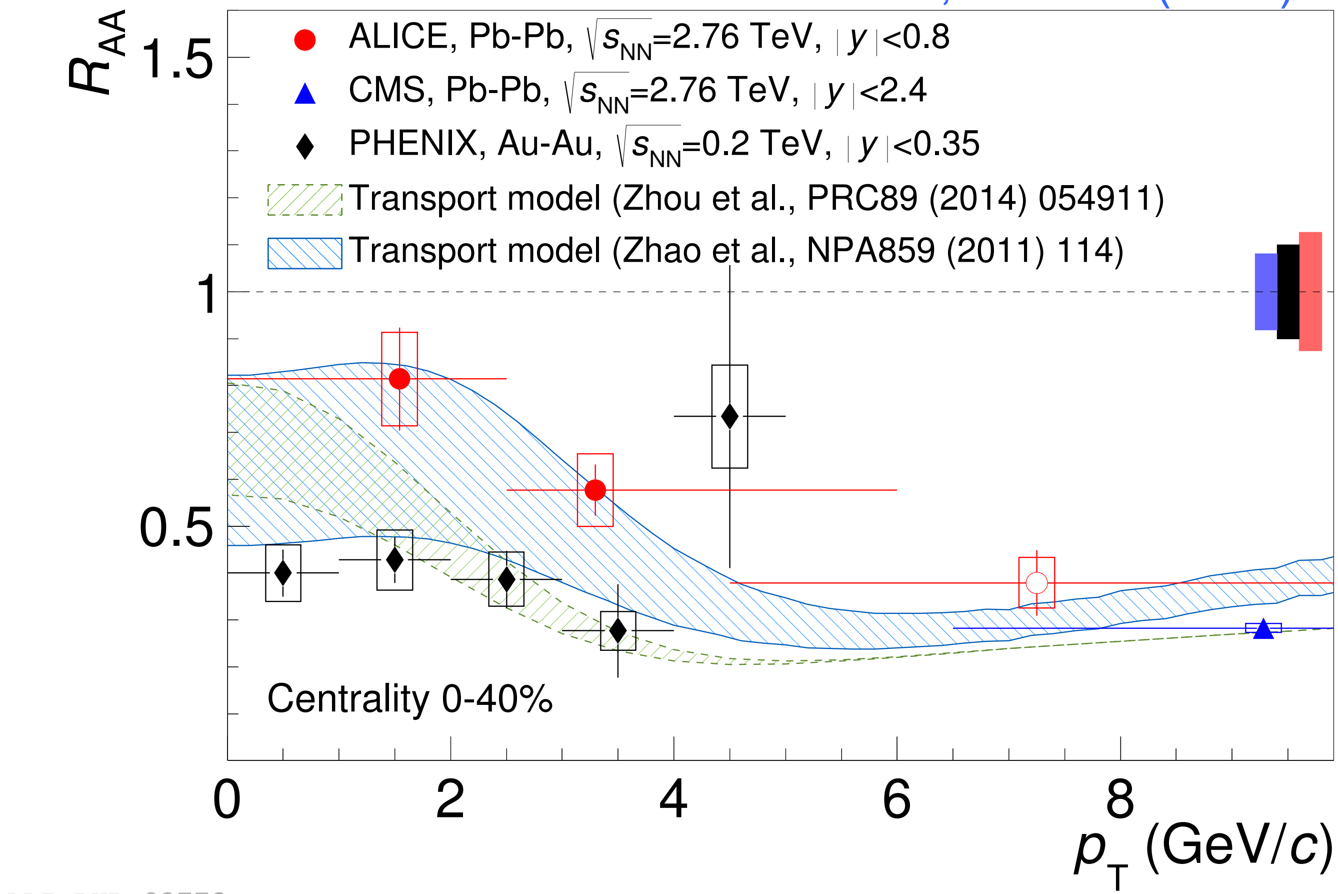


R_{AA} for inclusive J/ψ

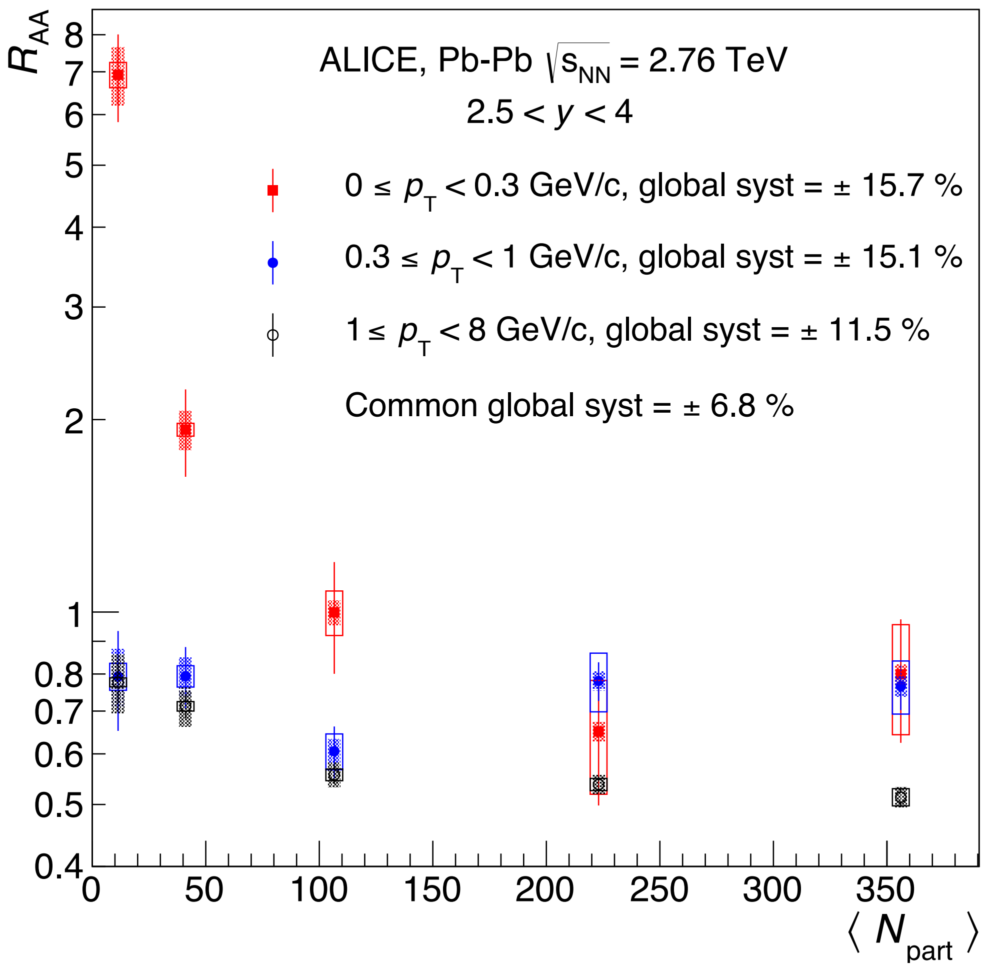
ALICE, JHEP07 (2015) 051



In both models, the rise of R_{AA} towards p_T= 0 is due to the dominant contribution from J/ψ regeneration via coalescence

J/ψ R_{AA} at very low p_T

ALICE, arXiv:1509.08802



Strong enhancement in the p_T interval 0-0.3 GeV/c

R_{AA}~7(2) for the 70-90% (50-70%) centrality

The production cross section associated with the observed excess is obtained under the hypothesis that coherent photoproduction of J/ψ is the underlying physics mechanism

pp and p-Pb physics

p-A collisions together with pp were playing the role of control experiments. Why?

- To disentangle the so-called cold nuclear matter effects from those attributed to sQGP produced in central heavy-ion collisions

But how cold is the "cold matter"?

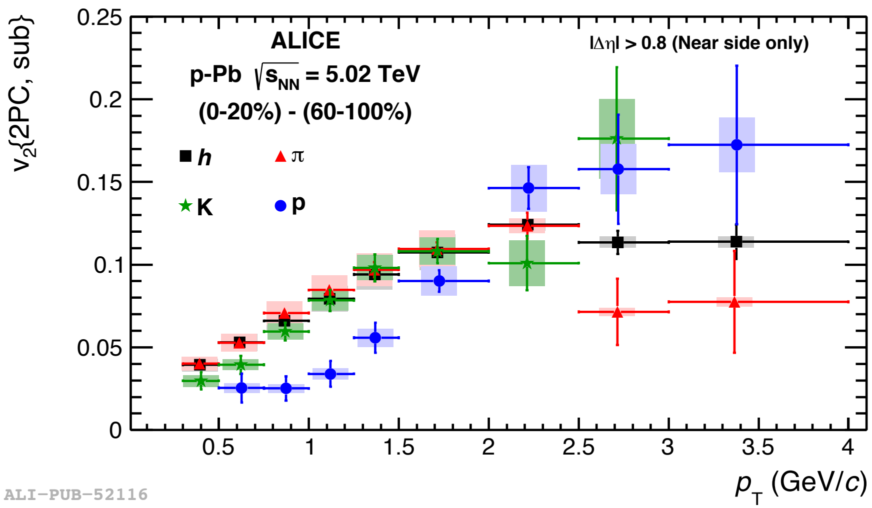
Striking findings in high multiplicity p-Pb events

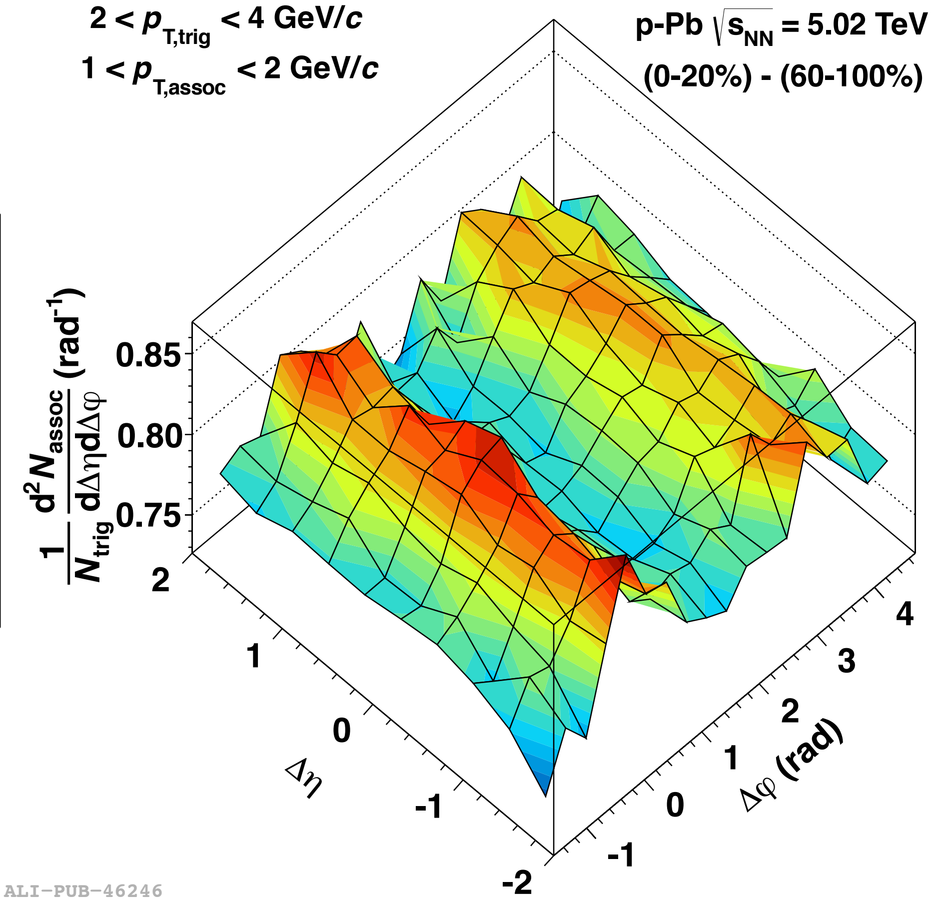
But how cold is the "cold matter"?

ALICE

Striking findings in high multiplicity p-Pb events

- ❑ Long-range angular correlations on the near and away side
- ❑ Azimuthal flow



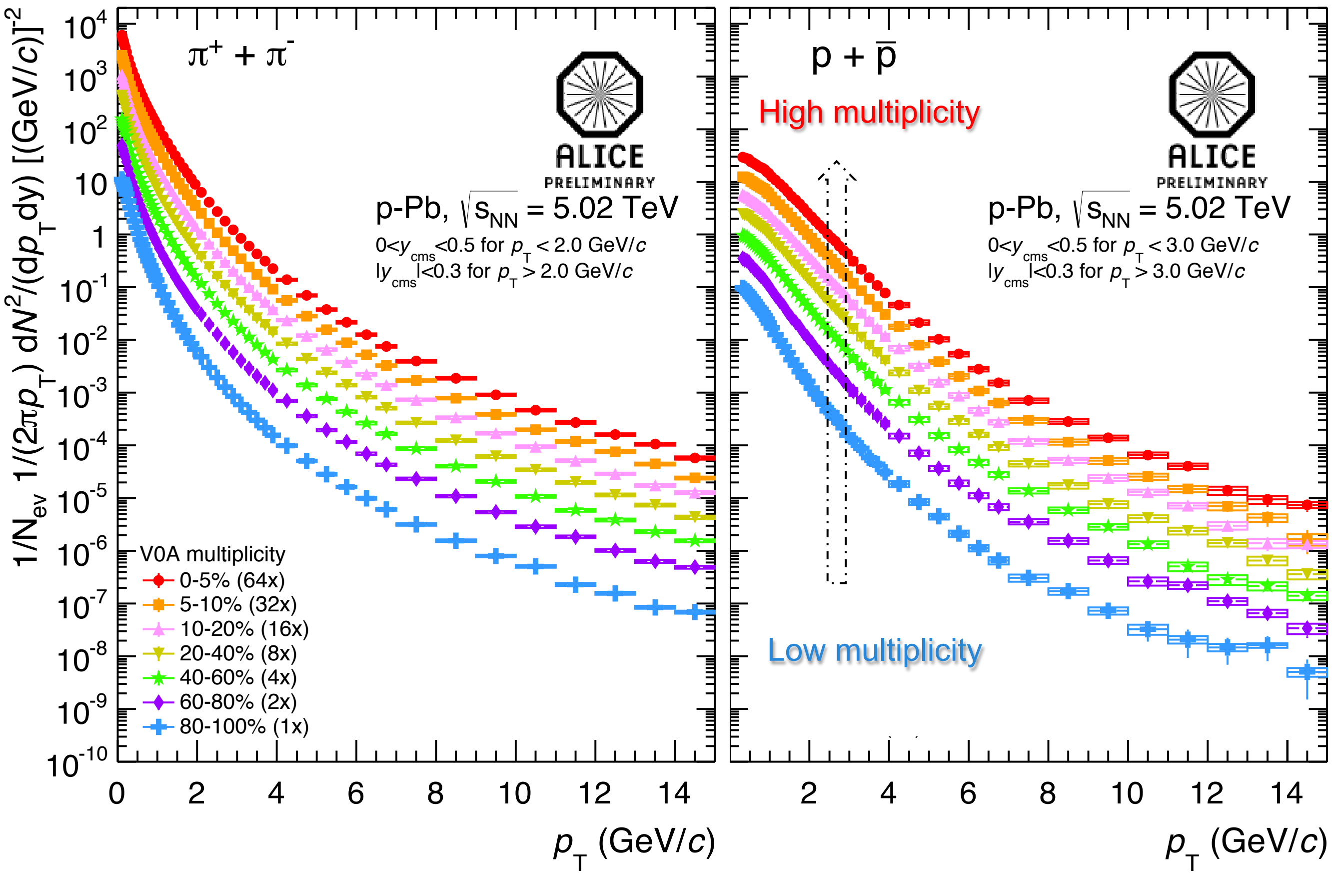


ALICE, PLB 719 (2013) 29-41
CMS, PLB 718 (2013) 795
ALICE, PLB 726 (2013) 164-177
ALICE, PLB 728 (2014) 25-38

p_T spectra *vs.* multiplicity

Similarities to Pb-Pb results are observed:

- A multiplicity- and mass-dependent flattening of the p_T spectra at low p_T (< 2 GeV/c)

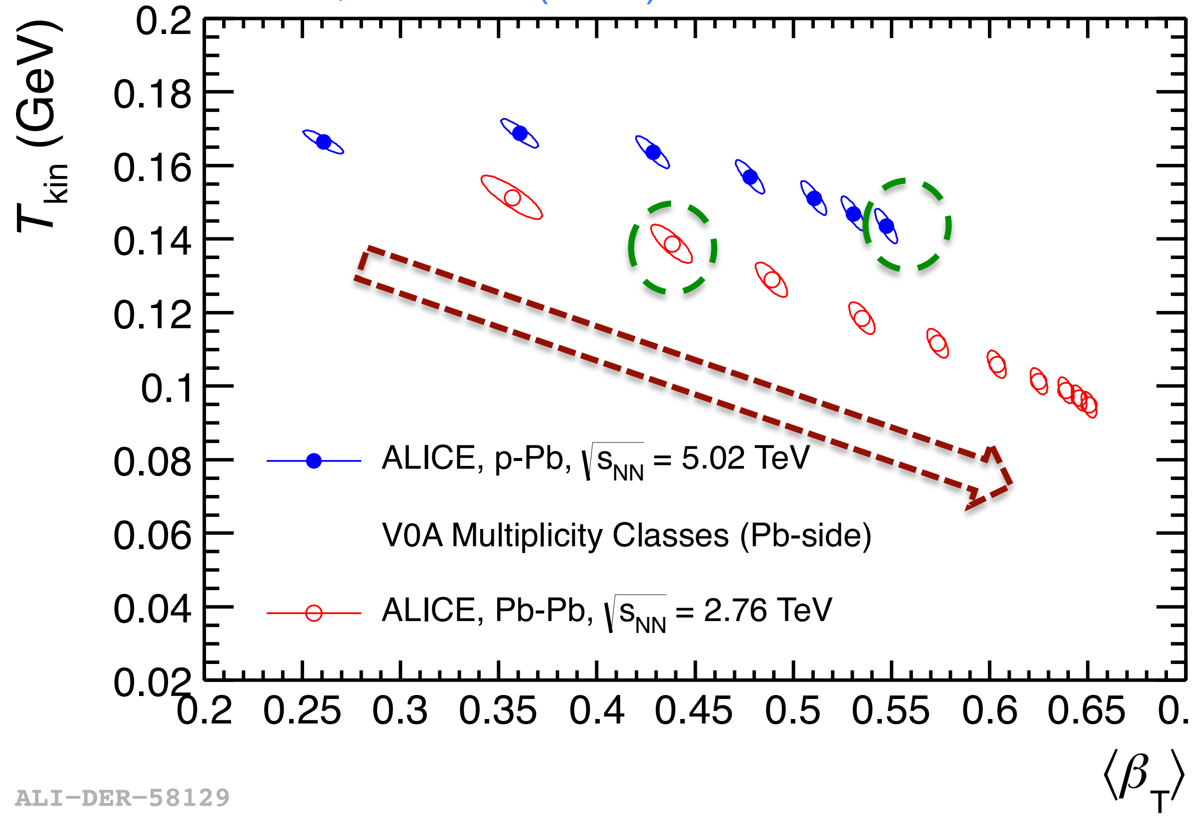


Blast-Wave fit results

To study the multiplicity evolution of the spectral shapes we made a simultaneous Blast-Wave fit to π, K, p and Λ p_T spectra

- ❑ Qualitatively similar behavior observed for p-Pb and Pb-Pb collisions
- ❑ Larger radial flow parameter obtained in p-Pb than in Pb-Pb collisions for a similar multiplicity

ALICE, PLB 728 (2014) 25-38



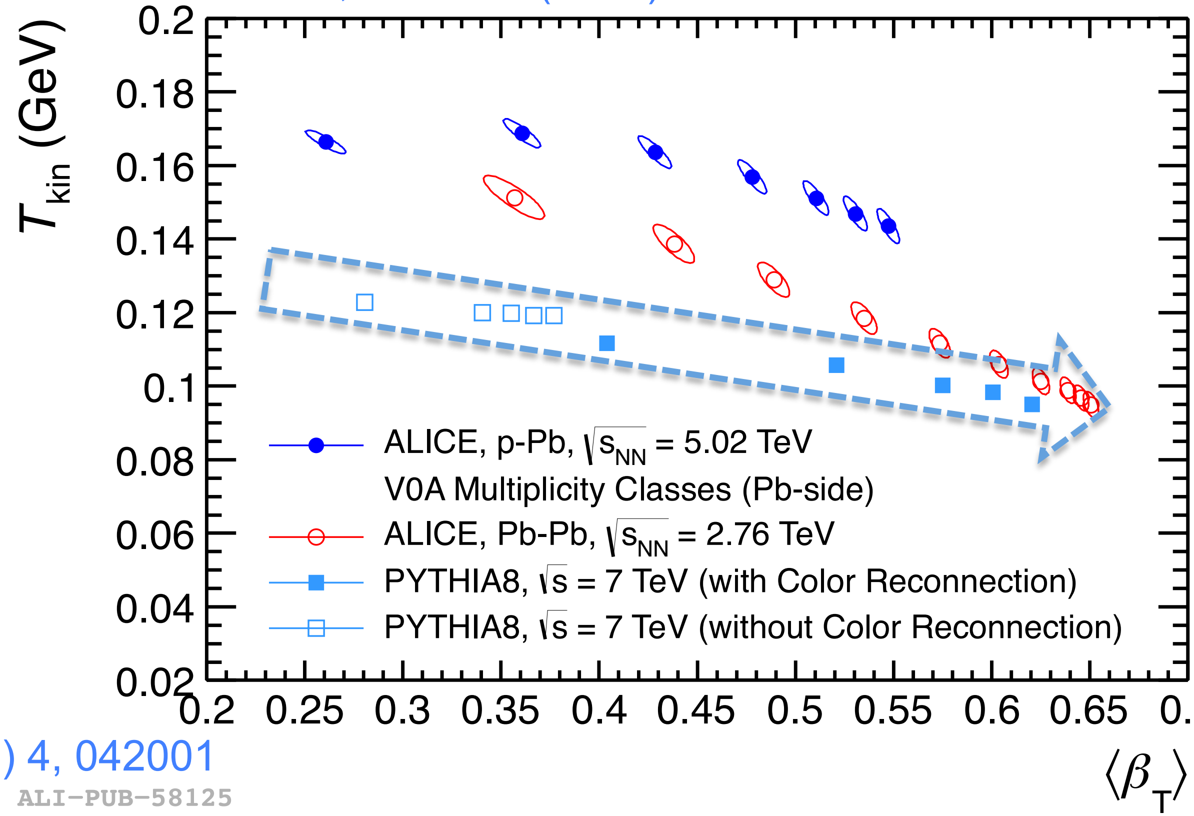
Blast-Wave fit results

To study the multiplicity evolution of the spectral shapes we made a simultaneous Blast-Wave fit to π, K, p and Λ p_T spectra

- But care needs to be taken with the interpretation because the model also describes the p_T spectra of pp events generated with Pythia 8, where no hydro expansion is assumed

ALICE ICN group, PRL 111 (2013) 4, 042001

ALICE, PLB 728 (2014) 25-38



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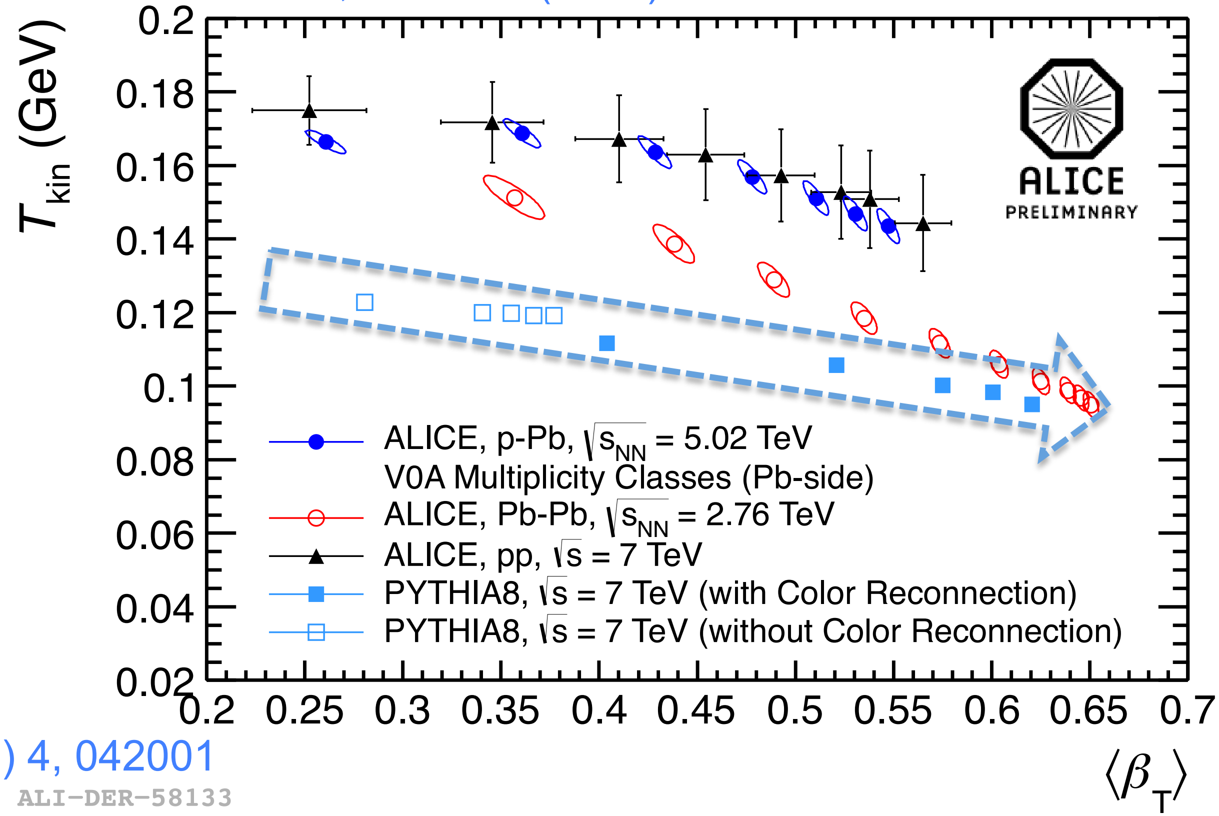
ALICE, PLB 728 (2014) 25-38



ALICE ICN group, PRL 111 (2013) 4, 042001

pp collisions also exhibit the same radial flow-like feature

Blast-Wave fit results

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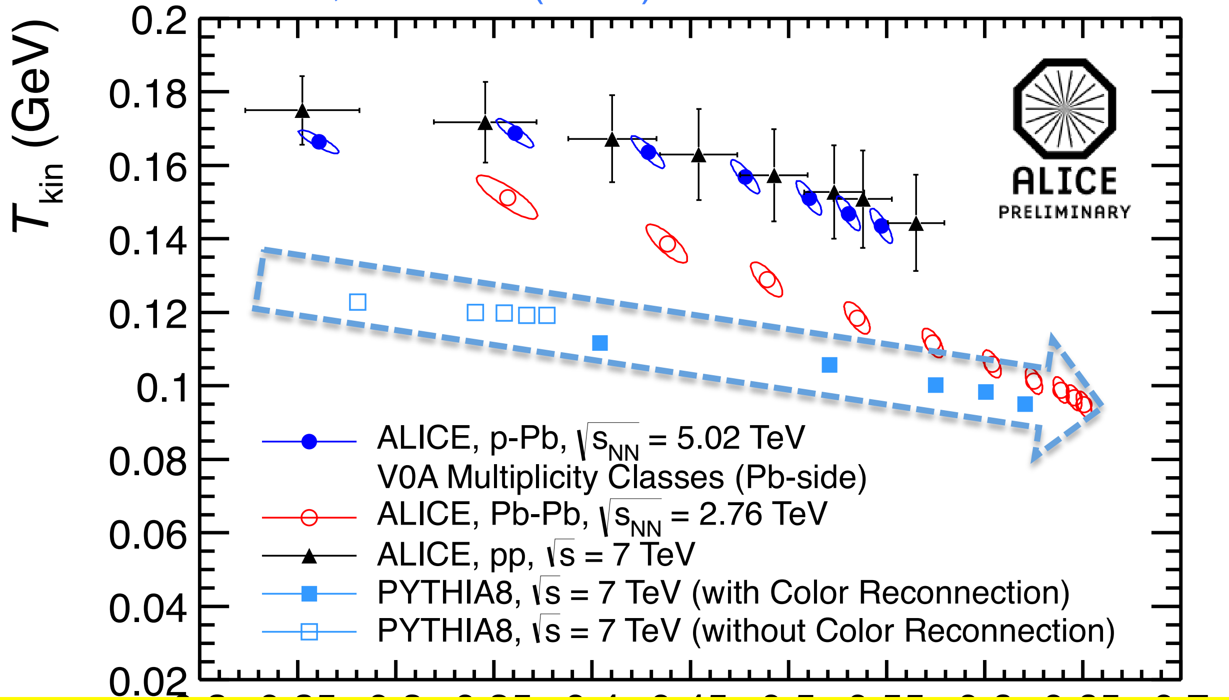
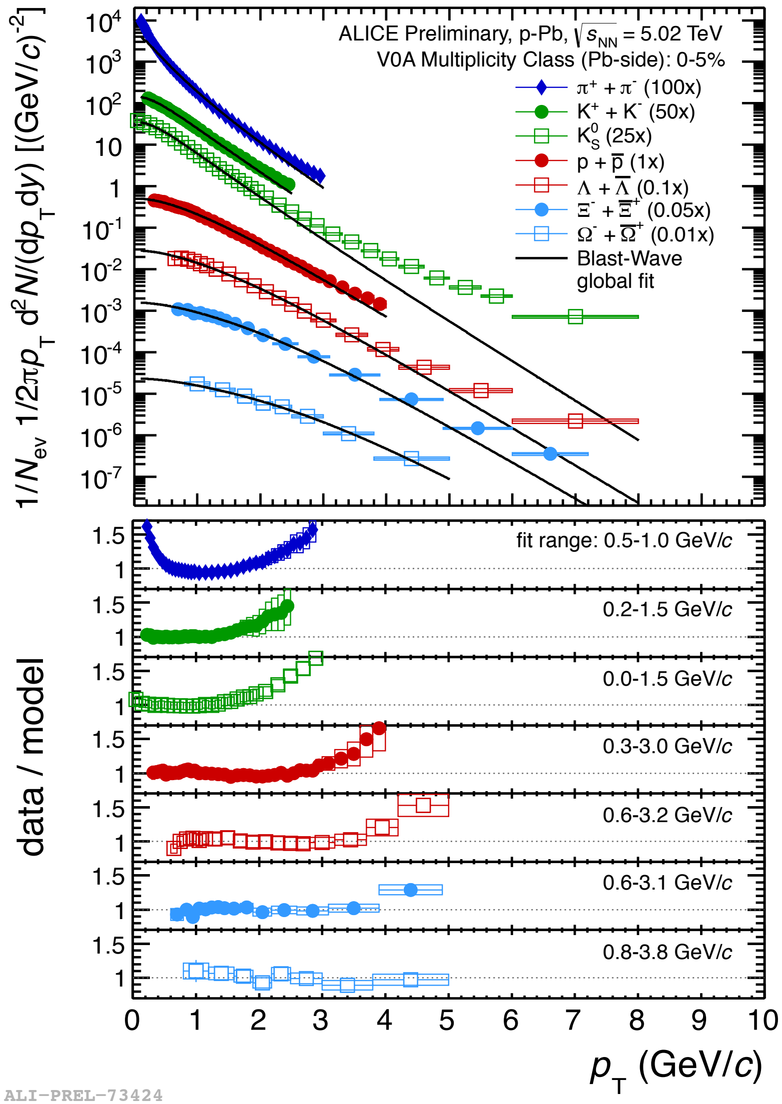
ALICE, PLB 728 (2014) 25-38



In the string percolation model, a phase transition can be achieved in high multiplicity events
I. Bautista et. al, PRD 92 (2015) 071504

Blast-Wave fit results



V0A Multiplicity Class: 0-5%

The Blast-wave model is compared to the p_T distributions of Ξ^- and Ω^-

- Using the parameters obtained from the simultaneous fit to π, K, p and Λ, the model describes the Ξ^- and Ω^- p_T spectra

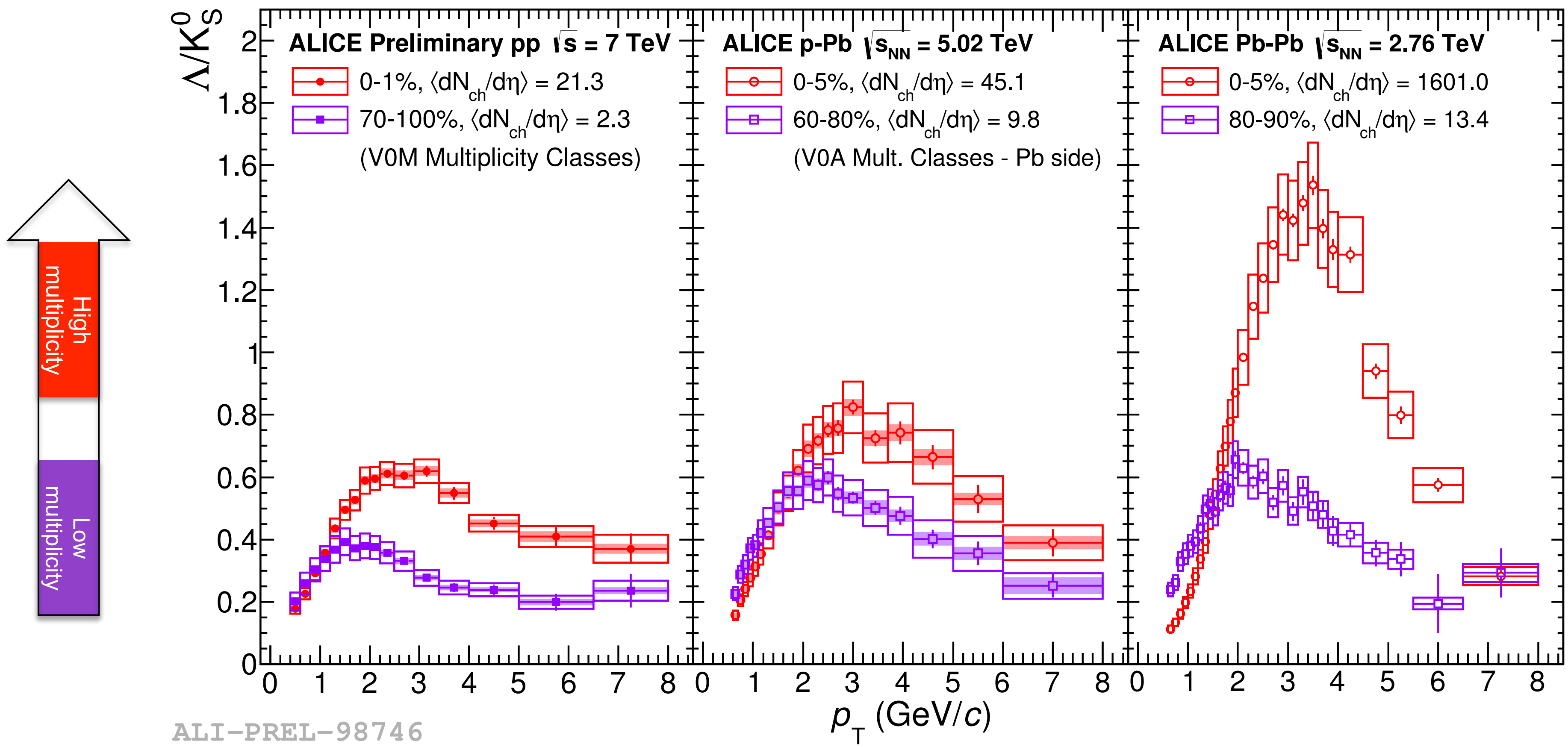
Common kinetic freeze-out describes the spectra in high multiplicity p-Pb collisions

- This feature is also observed in pp events simulated with Pythia 8

- In central heavy-ion collisions, the multi-strange particles experience less transverse flow
PLB 728 (2014) 216-227
PRC 90 (2014) 054912

Particle ratios (Λ/K^0_S)

Similar behavior is observed when we compare the three colliding systems
In Pb-Pb the effect can be explained with flow and coalescence



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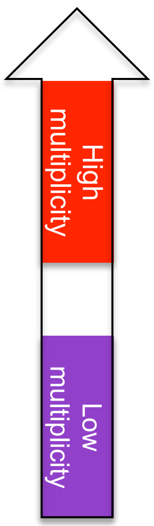
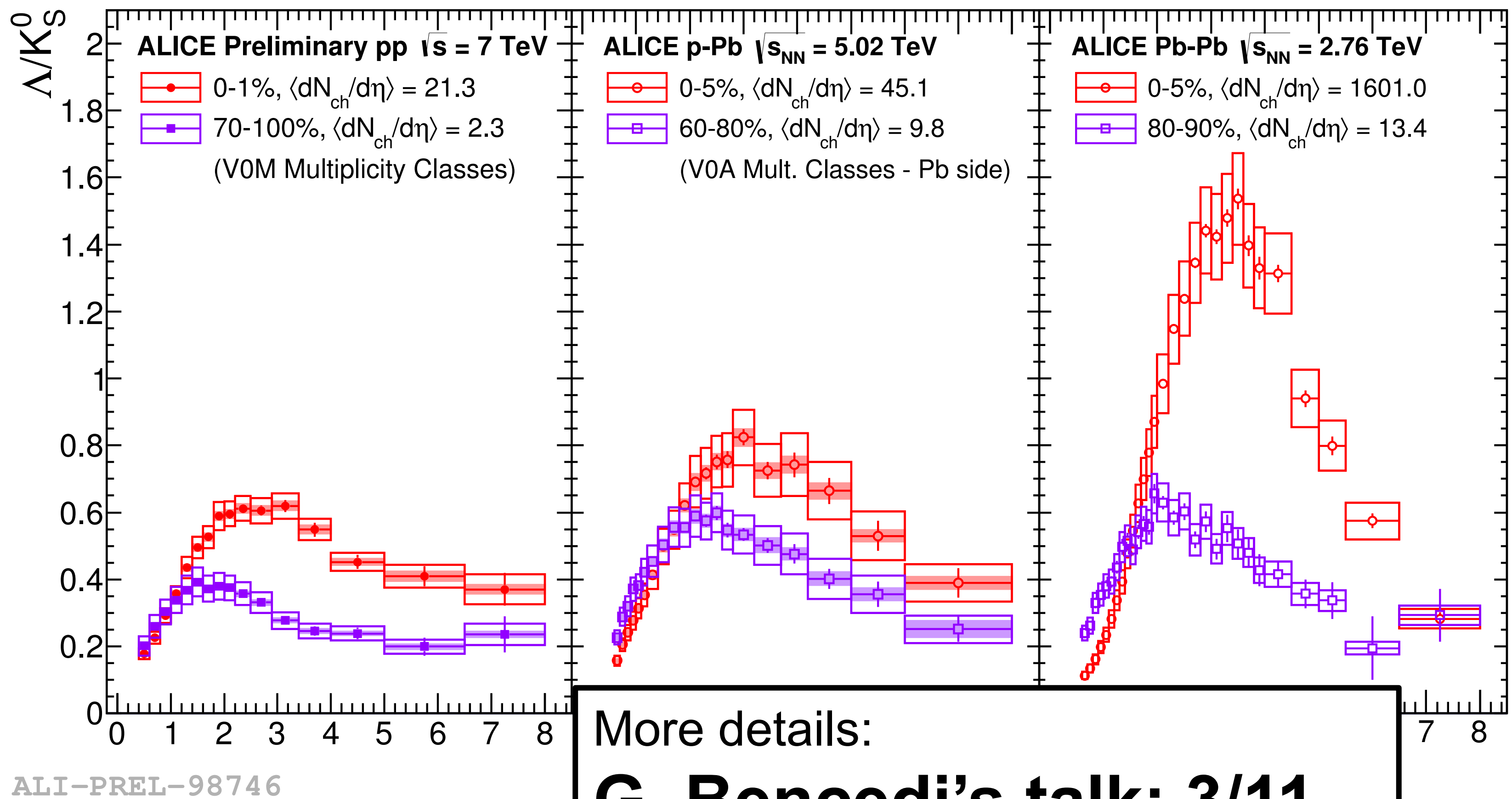




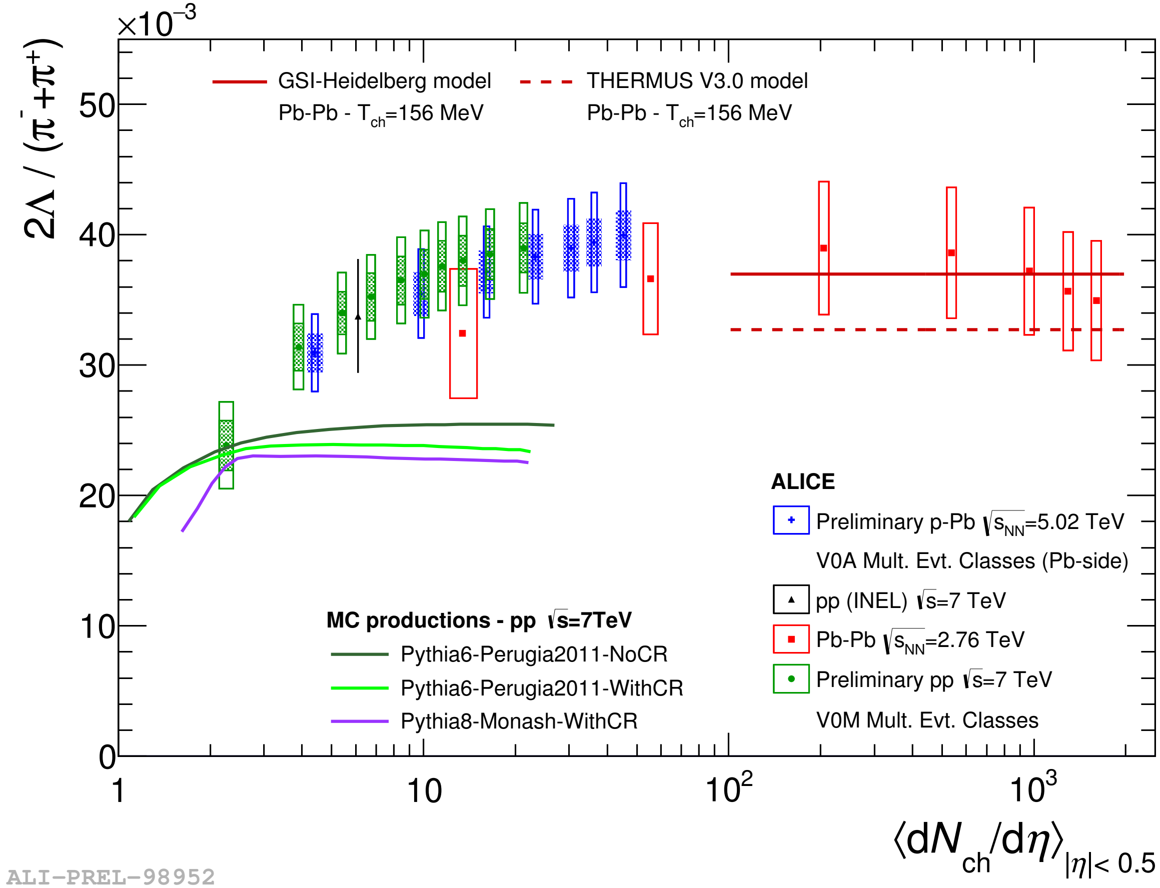
More details:
G. Bencedi's talk: 3/11

Λ/π vs. dN_{ch}/dη

pp

p-Pb

Pb-Pb



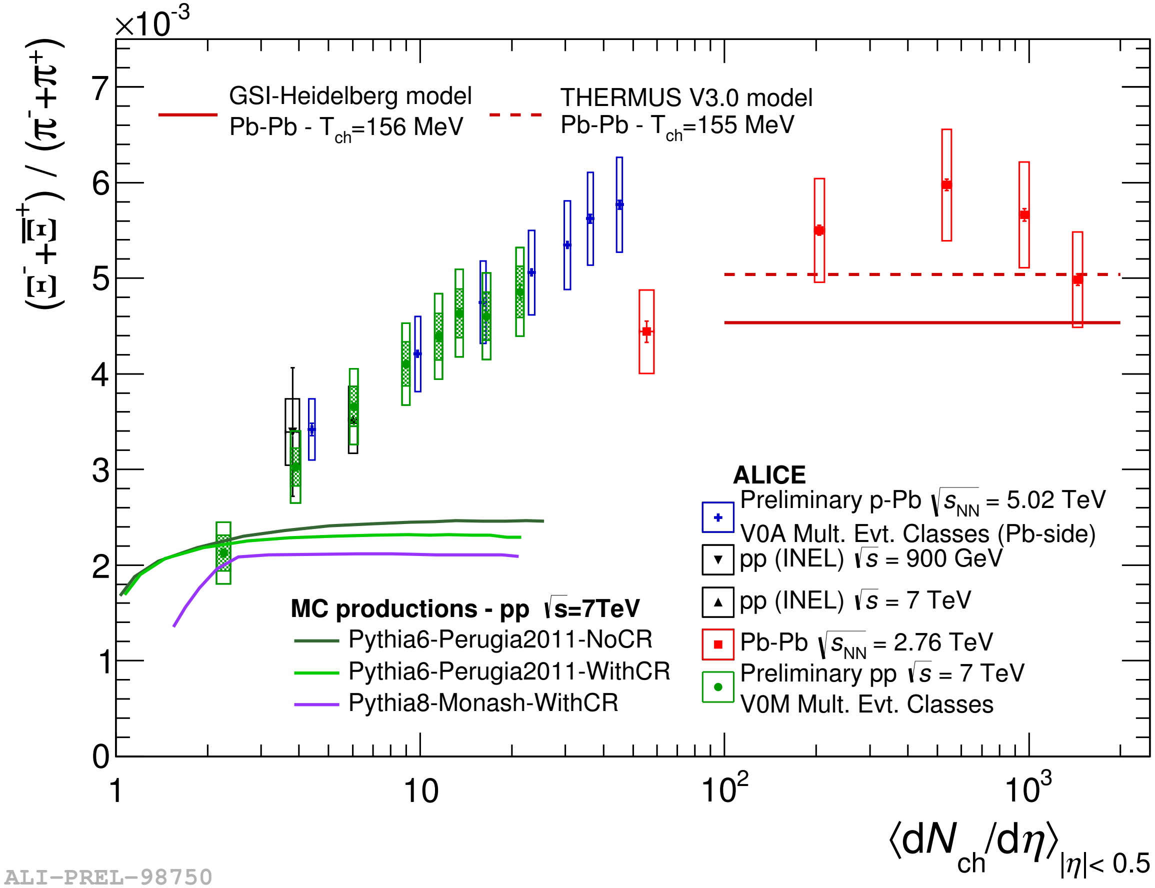
Λ/π ratio increases with multiplicity, similar dependence in pp and p-Pb collisions

Ξ/π vs. $dN_{ch}/d\eta$

pp

p-Pb

Pb-Pb



The effect is strangeness-related and not baryon-related

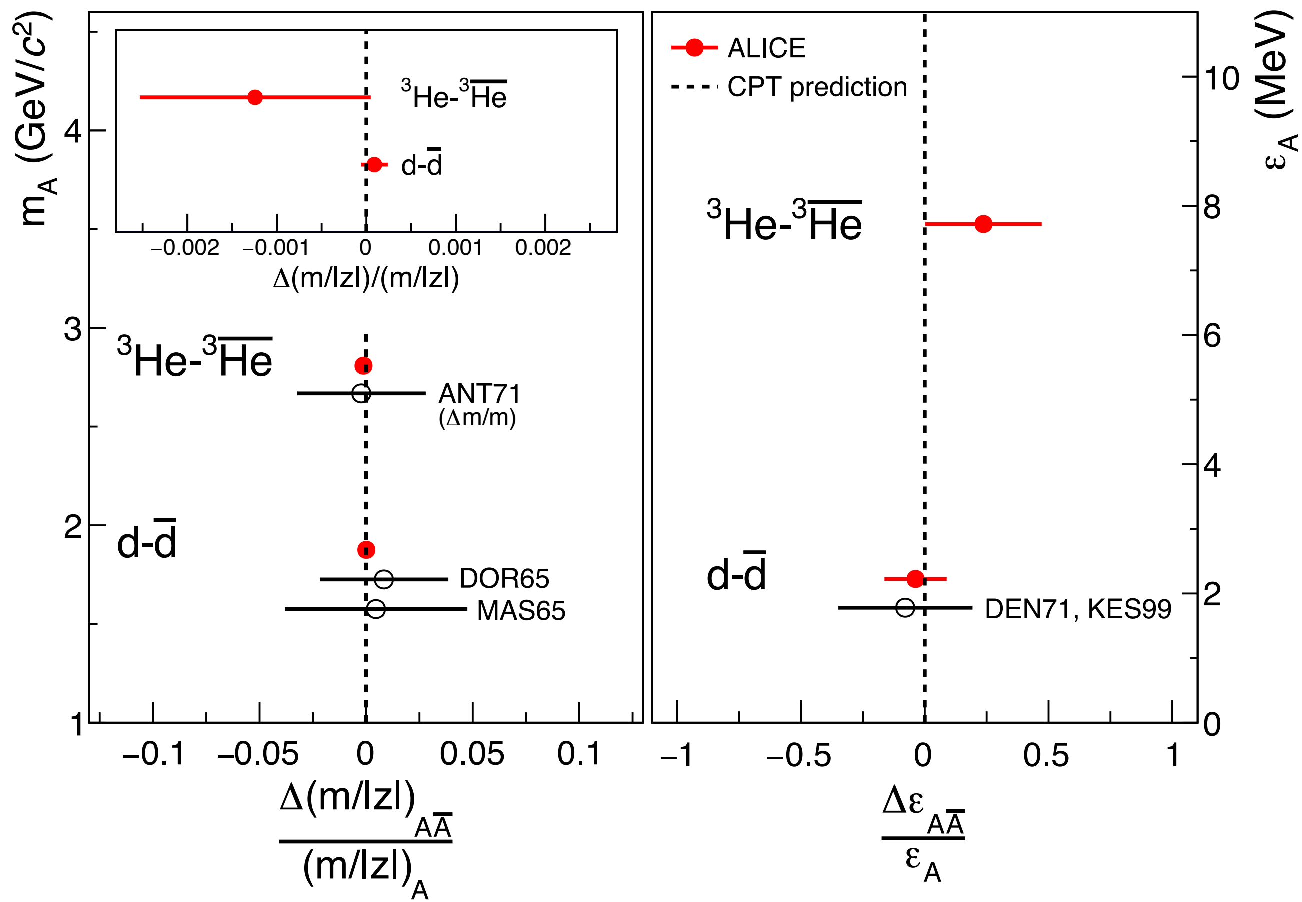
(Strangeness enhancement in pp and p-Pb)

Summary
New exciting results for small systems

Several similarities among pp, p-Pb and Pb-Pb collisions have been reported

- ❑ p_T spectra show flow-like behavior
- ❑ Indication of strangeness enhancement in pp and p-Pb collisions
- ❑ No indication of nuclear modification at high p_T in p-Pb collisions

Other highlights



Nature Physics 11 (2015) 811-814

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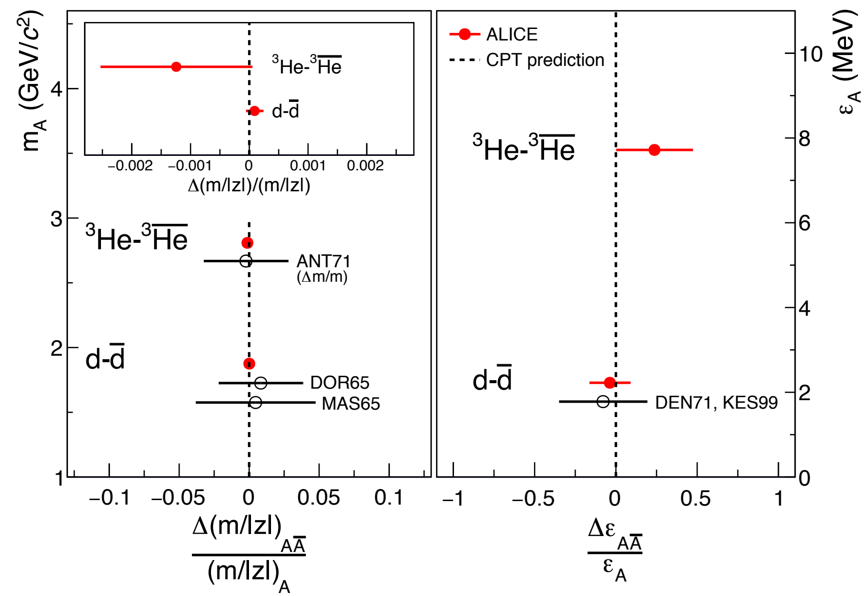
Other highlights

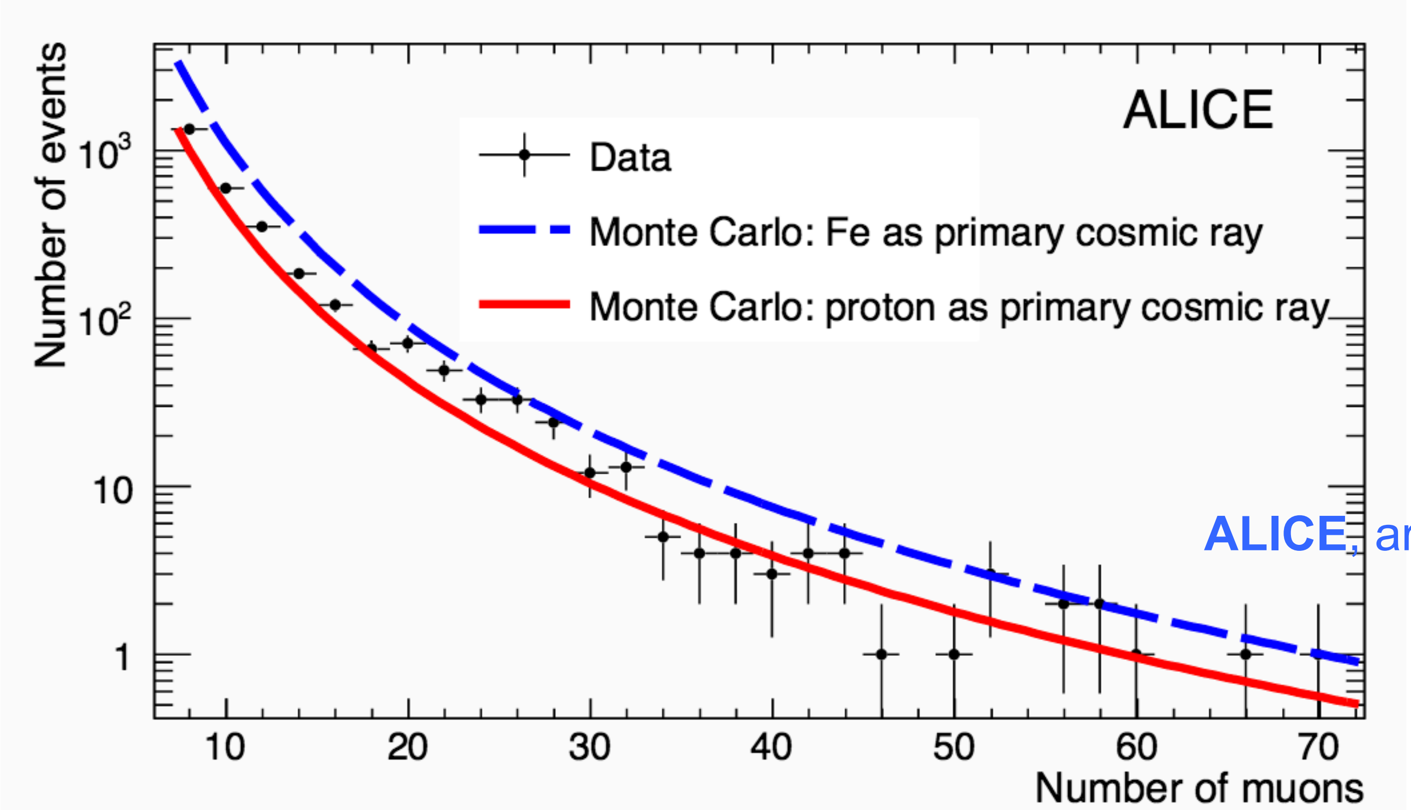
Mass difference of (anti)Nuclei

- ❑ Highest precision measurement of mass difference in the nuclei sector
- ❑ Improvement by 1-2 orders of magnitude compared to earlier measurements
- ❑ Constrain on CPT symmetry violation improved by a factor 2 for deuteron. First measurement of $\Delta\varepsilon$ for (anti)^{3}He



ALICE, Nature Physics 11 (2015) 811-814

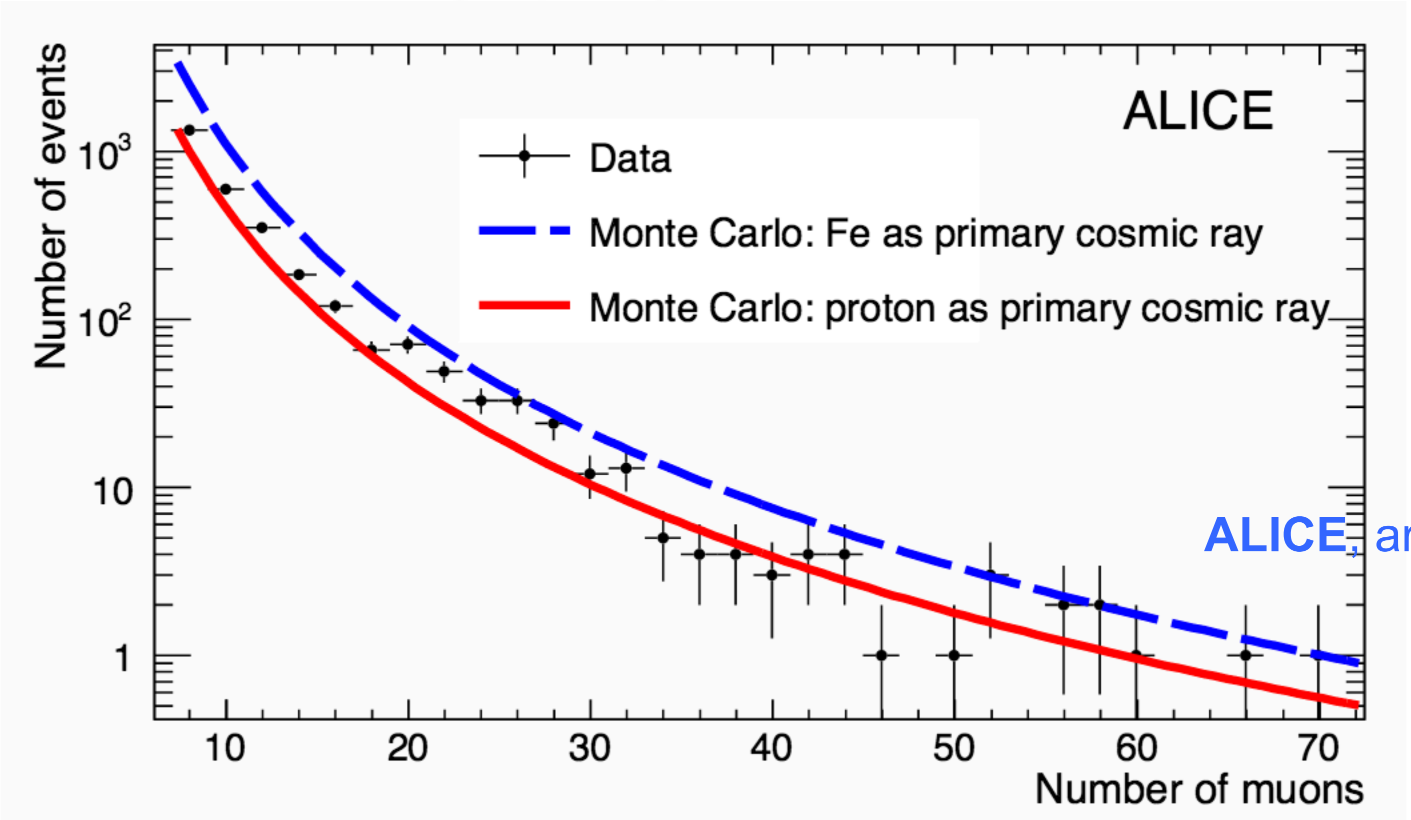
Cosmic ray physics with ALICE



ALICE, arXiv:1507.07577

- The high multiplicity events observed in ALICE stem from primary cosmic rays with energies above 10^{16} eV
- The frequency of these events can be successfully described by assuming a heavy mass composition of primary cosmic rays in this energy range

Cosmic ray physics with ALICE



ALICE, arXiv:1507.07577

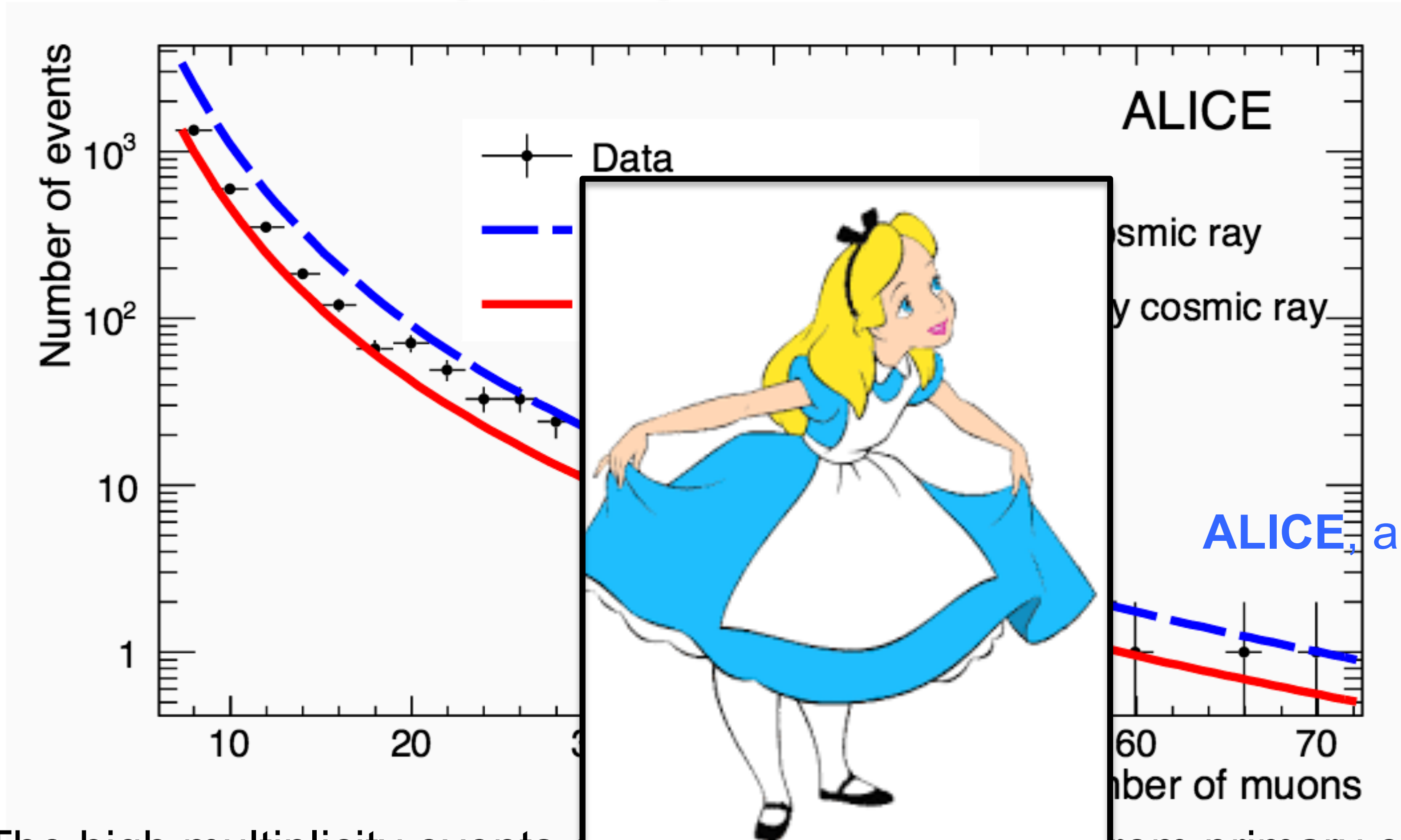
- ❑ The high multiplicity events observe energies above 10^{16} eV
- ❑ The frequency of these events can b mass composition of primary cosmic

More details:

M. Rodríguez's talk: 2/11

E. González's poster: 2/11

Cosmic ray physics with ALICE



ALICE, arXiv:1507.07577

- The high mult … rom primary cosmic rays with energies abov …
- The frequenc … uming a heavy mass composition of primary cosmic rays in this energy range

Thanks!

January 18-22, 2016 **Taxco, Mexico**

- Latest results on pp, pA and AA collisions at the RHIC and at the LHC
  - QCD systems with high density of color charges
    - QCD inspired MC generators

International advisory committee

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Peter Christiansen (Lund, Sweden)
Paolo Giubellino (CERN, Switzerland)
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Andreas Morsch (CERN, Switzerland)
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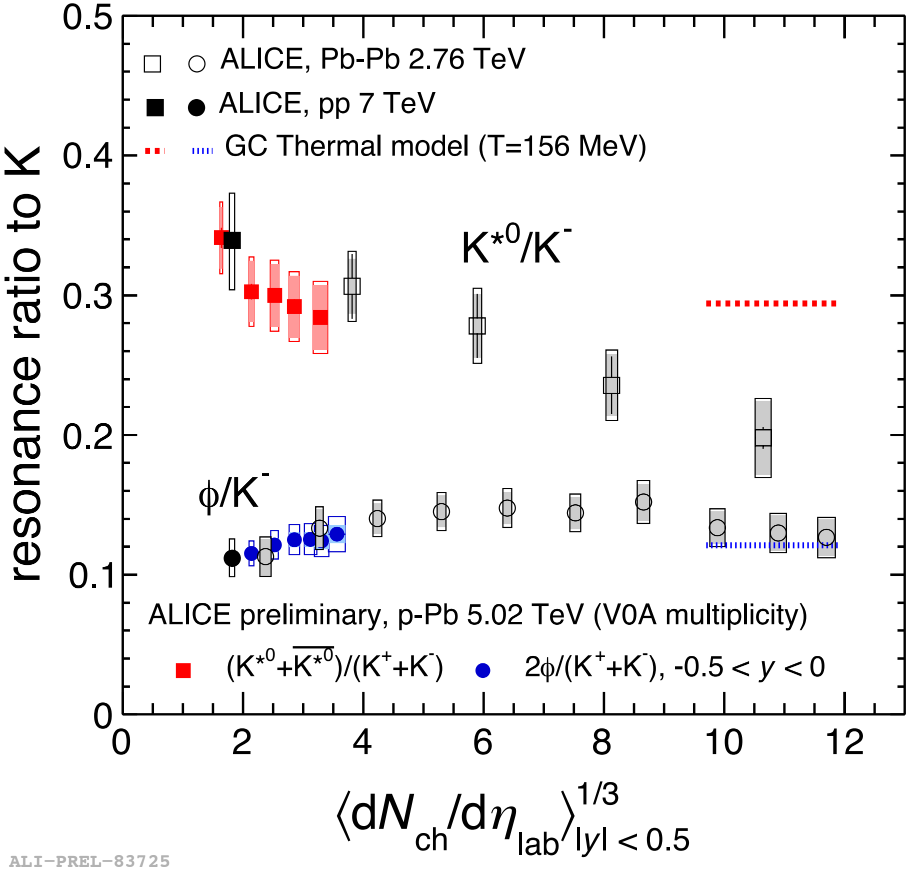
CONACYT 45 años

https://indico.nucleares.unam.mx/event/qcdchallenges2015

BACKUP

Resonances in p-Pb collisions



The reduction of the K^{*0}/K^{-} ratio going from pp to central Pb-Pb collisions is usually attributed to be a consequence of re-scattering of K^{*0} decay daughters in the hadronic phase. ALICE, PRC 91 (2015) 024609

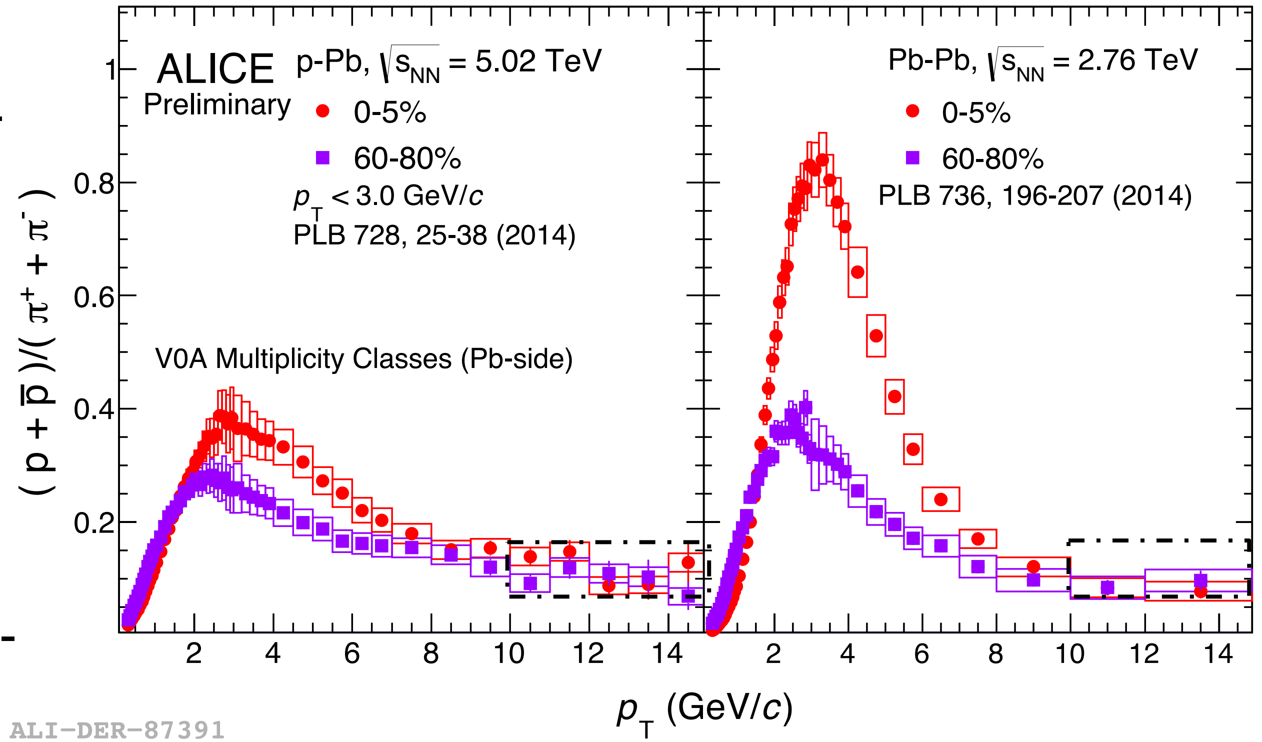
Results for p-Pb collisions are consistent with peripheral Pb-Pb collisions

Particle ratios

At intermediate p_T ($2<p_T<10$ GeV/c), the proton-to-pion ratio increases with event multiplicity

The behavior of this increase is qualitatively similar to that observed in Pb-Pb collisions

At high p_T (>10 GeV/c) the particle ratios in p-Pb and Pb-Pb are consistent



Particle ratios

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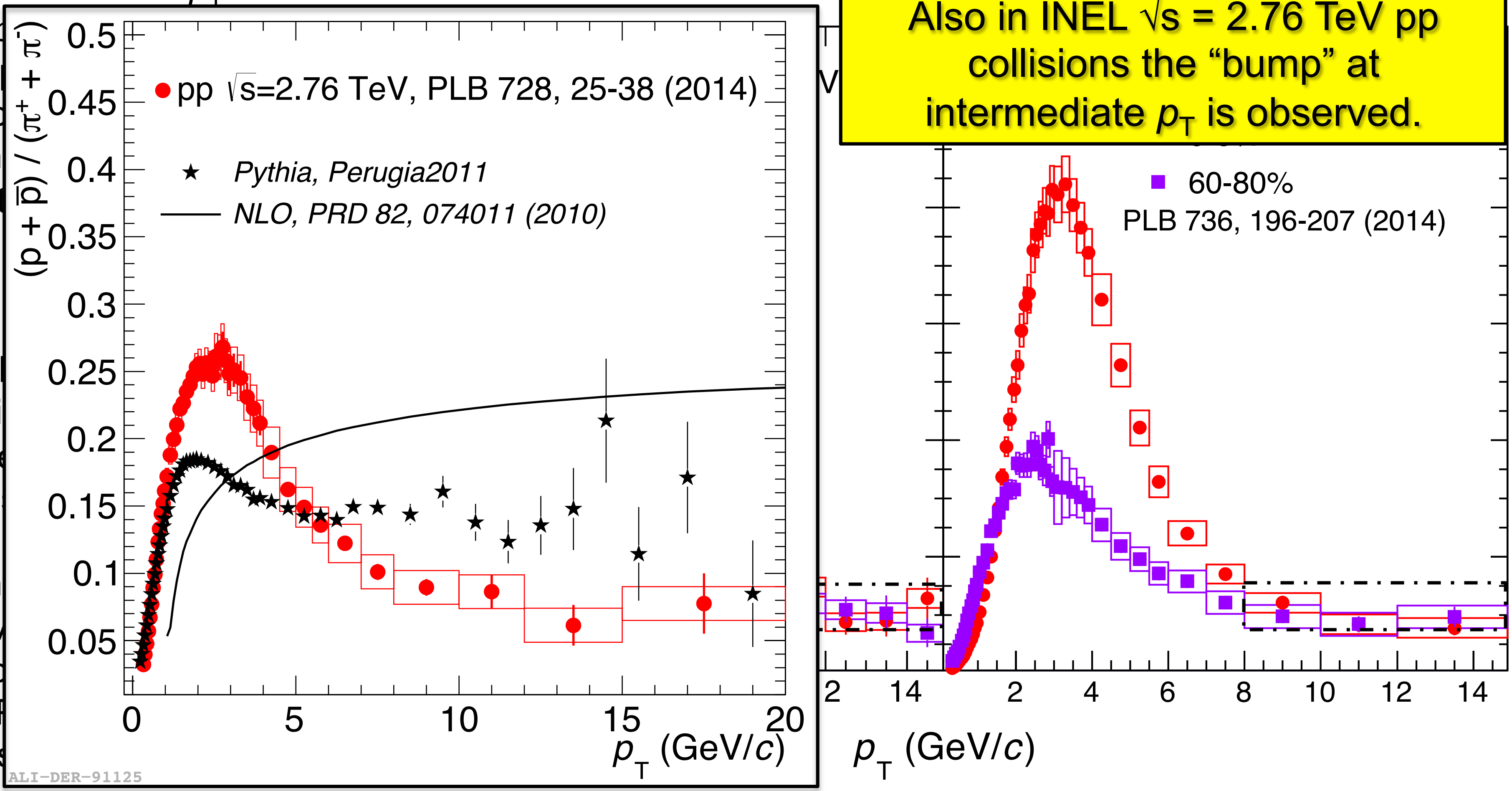
Also in INEL $\sqrt{s}$ = 2.76 TeV pp collisions the “bump” at intermediate p_T is observed.



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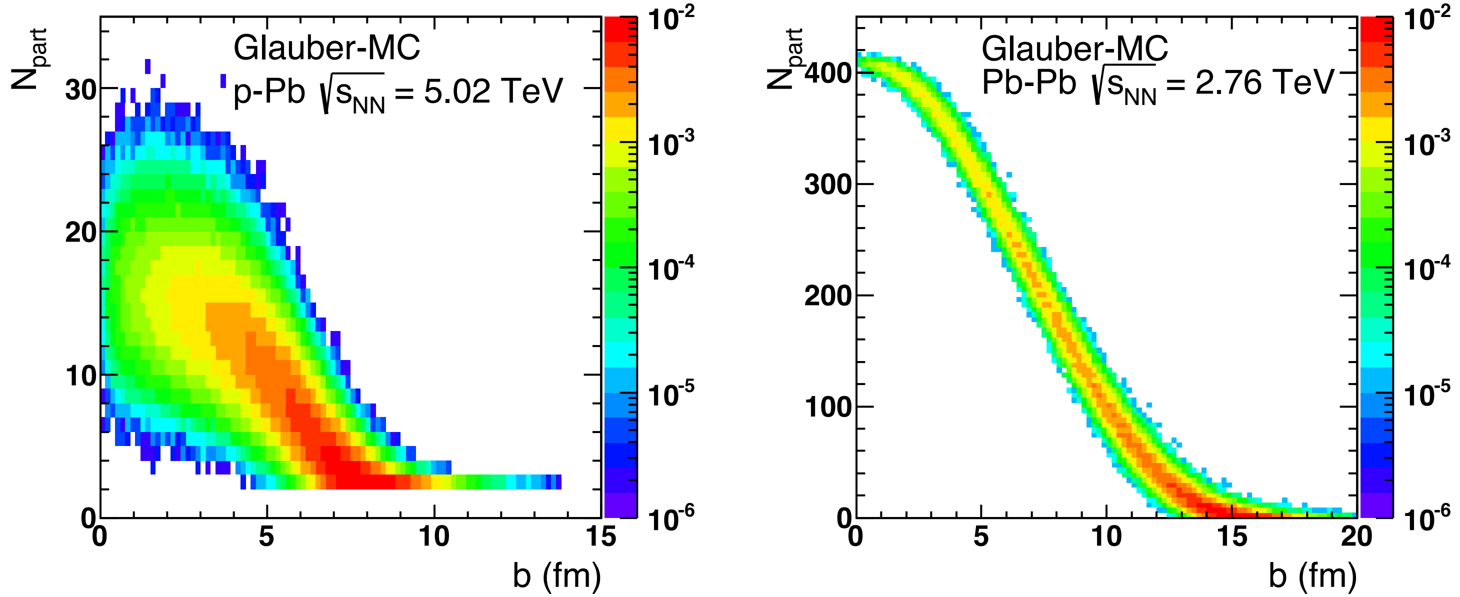
The V0A multiplicity estimator

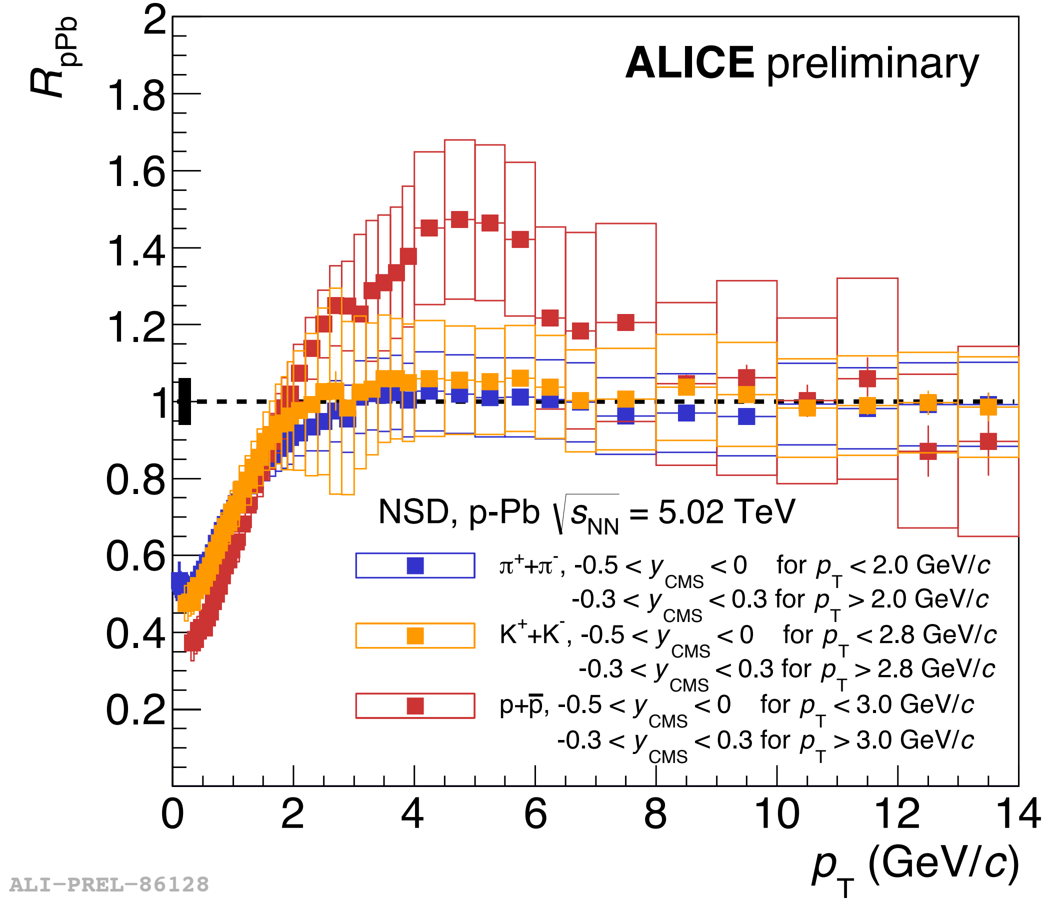
ALICE PRC 91 (2015) 064905



- For small systems, the impact parameter (b) is weakly correlated with the number of participants (N_{part})
- Particle production is therefore studied in intervals of event multiplicity. We use the same estimator (V0A) used in the first ALICE publication on identified hadron production in p-Pb collisions

ALICE, PLB 728 (2014) 25-38

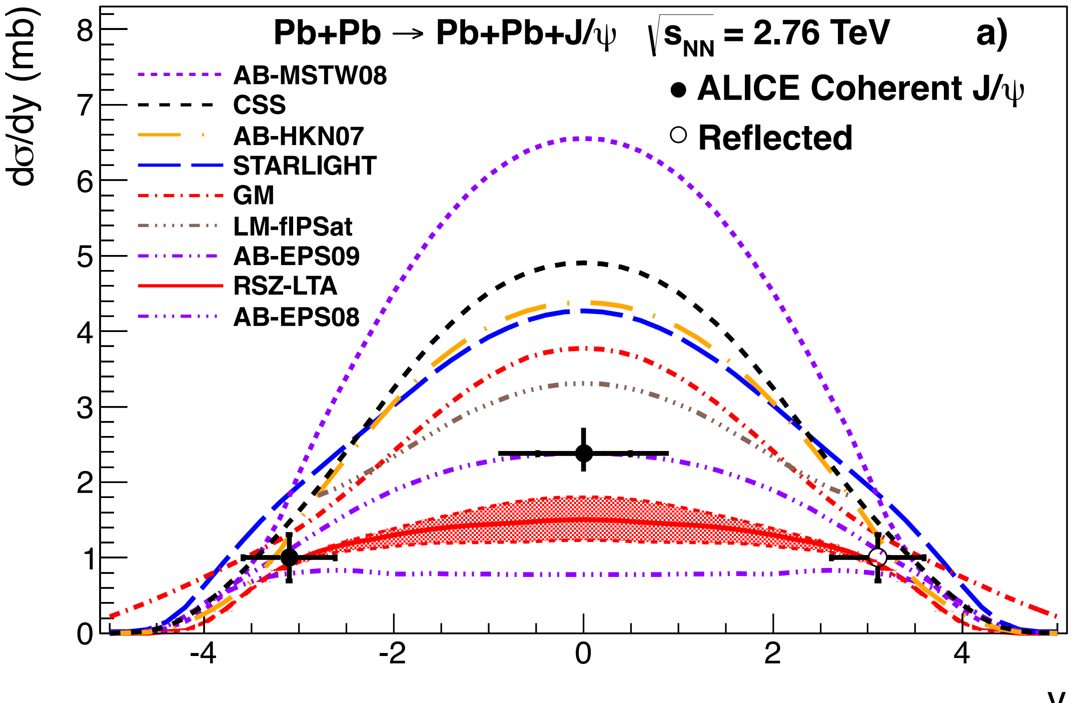
Nuclear modification factor

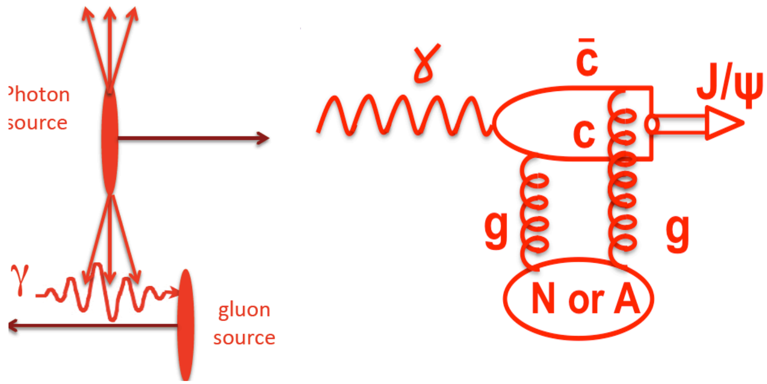


At intermediate p_T the proton R_{pPb} shows a Cronin-like enhancement, while pions and kaons show little or no nuclear modification

At higher p_T, the pion, kaon and proton R_{pPb} are consistent with unity

Photoproduction in Pb-Pb UPC





Good agreement with the model which incorporates the nuclear gluon shadowing according to the EPS09 parameterization (AB-EPS09)

ALICE, PLB 718 (2013) 1273
ALICE, EPJ 73 (2013) 11

- Photon from the Pb EM field interacts with the Pb nucleus (coherent) or with a nucleon (incoherent)
- Measured in Pb-Pb ultra peripheral collisions (b>2 $R_{\rm Pb}$)
- Sensitive to gluon nPDF

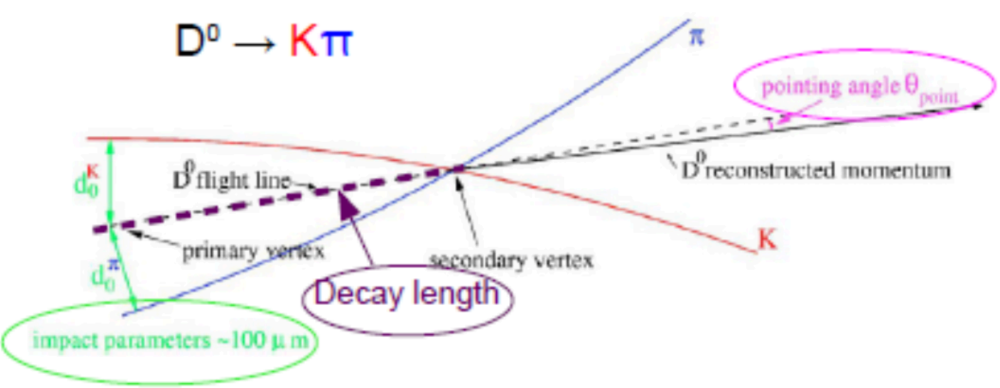
Reconstruction of D mesons

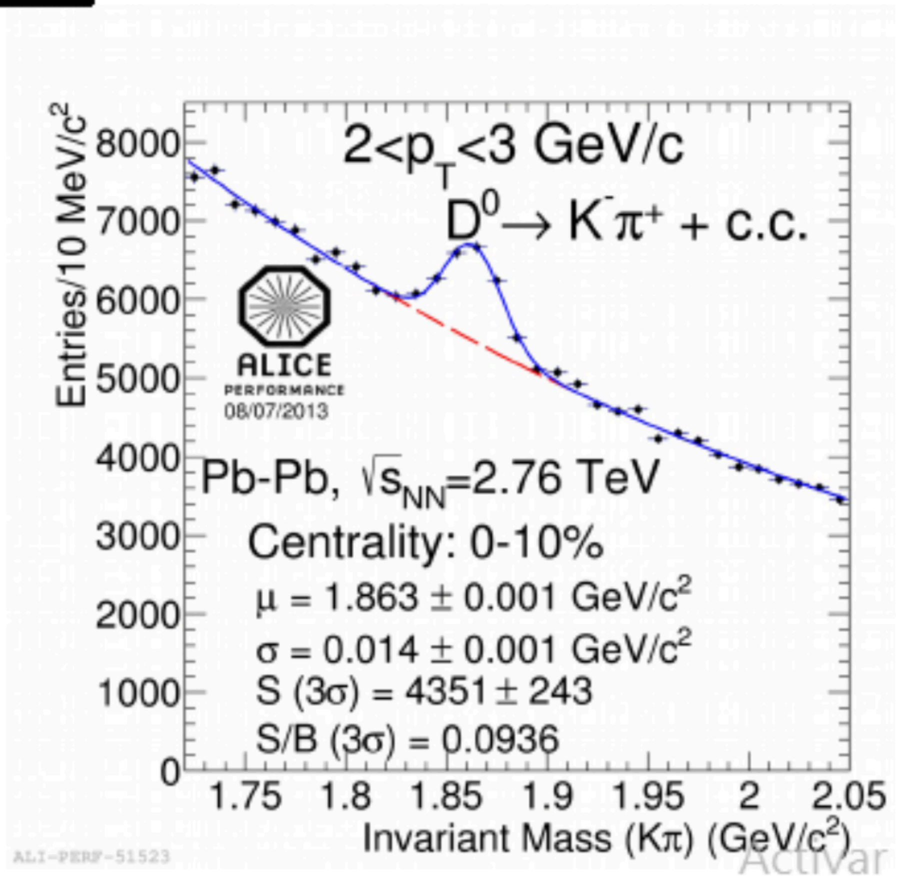
Central barrel
$|\eta| < 0.8$

- D mesons reconstructed via hadronic decay channels

$D^0 \rightarrow K^- \pi^+$	$c\tau = 123 \mu m$	BR=3.88%
$D^+ \rightarrow K^- \pi^+ \pi^+$	$c\tau = 312 \mu m$	BR=9.13%
$D^{*+} \rightarrow D^0 \pi^+ \rightarrow K^- \pi^+ \pi^-$		BR=2.63%

- Reconstructed secondary vertices



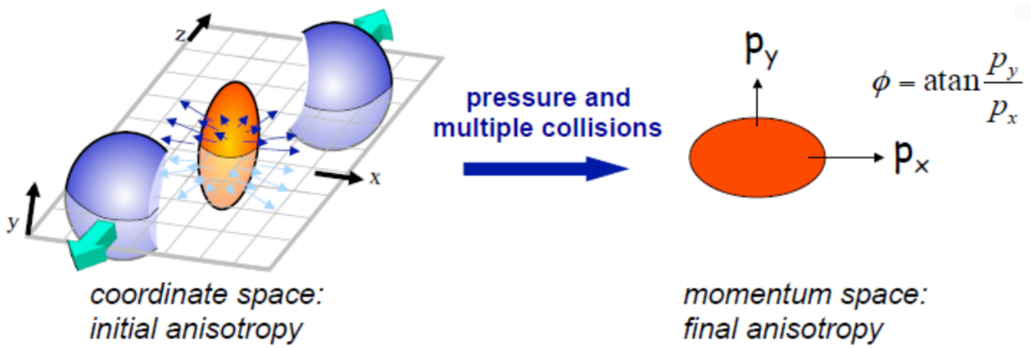


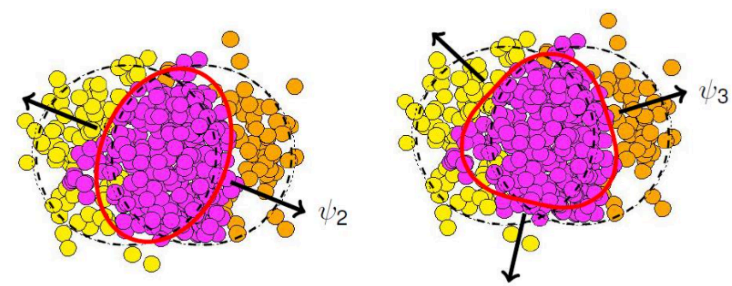
- TPC and TOF used to identify π and K to reduce combinatorial background

- An invariant mass analysis performed to extract the signal yield

Anisotropic flow

Pressure gradient generates collective flow → anisotropy in momentum space





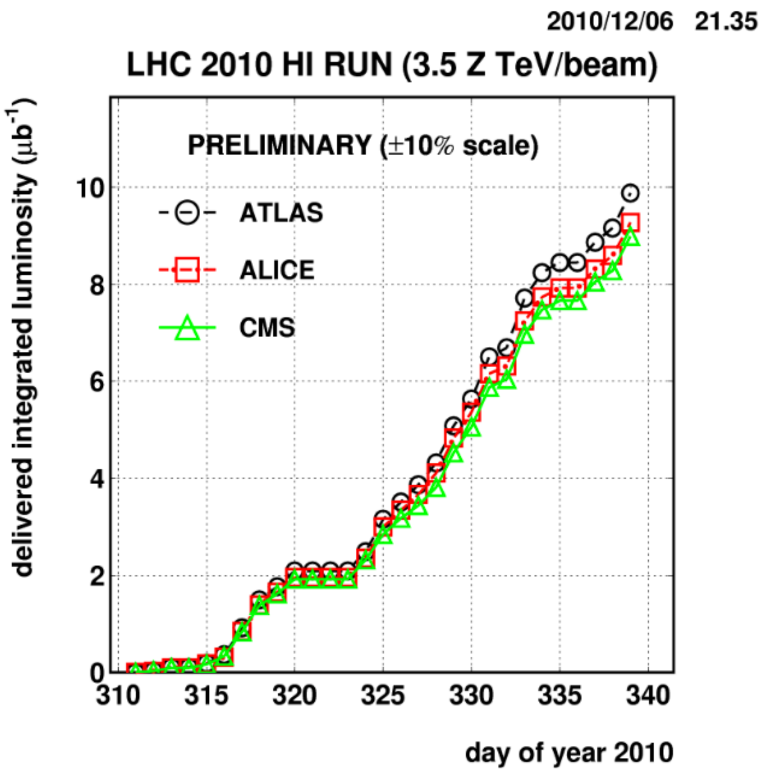
M. Luzum, J. Phys. G: Nucl. Part. Phys. 38 (2011) 124026

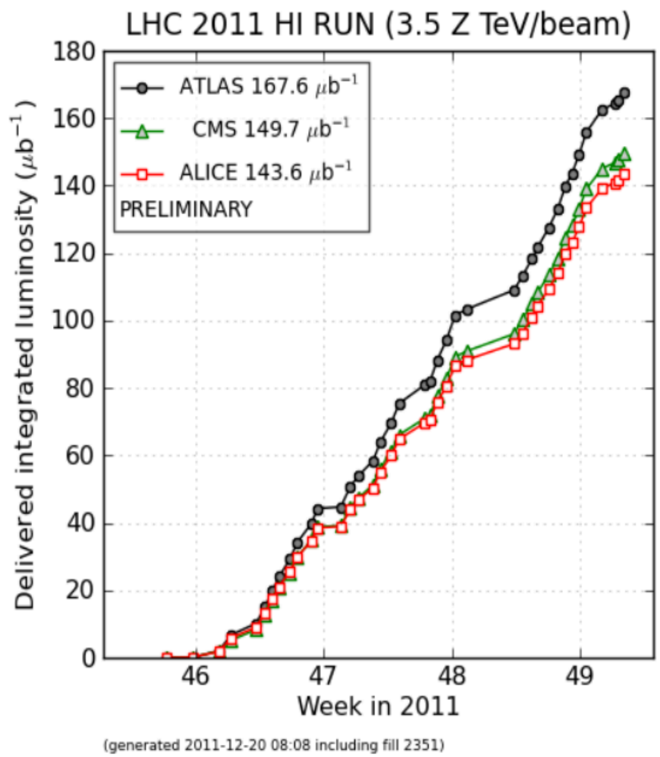
$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1 + \sum_{n=1}^{\infty} 2v_n cos\left(n(\varphi - \Psi_n)\right)\right)$$

Importance of v_2:

- Constraints to initial conditions, such as particle production mechanisms.
- Probes freeze-out conditions of the system.
- Checks number of constituents quarks scaling.

Heavy ion run





p-Pb: 30 nb^{-1}