Status of experimental searches at the LHC: ALICE

Heavy-ion Physics at LHC

Luciano Ramello – Università del Piemonte Orientale & INFN

Outline

- Introduction
- The ALICE detector
- Global properties
- Particle production
- Collective effects
- Jet quenching
- Open heavy flavours
- Quarkonia
- Outlook

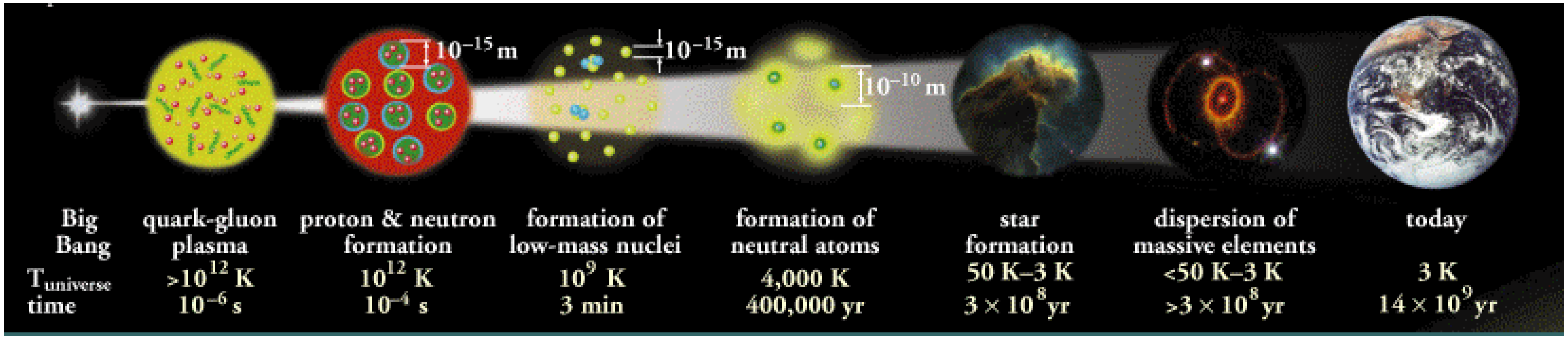
why study heavy ion (A-A) collisions?
what can be learned from pp and p-A collisions?

INTRODUCTION

Why study heavy-ion collisions?

- to understand two fundamental non-pert. aspects of *QCD*:
  - (de-)confinement
  - chiral symmetry breaking/restoration
- to study the *phase diagram* of QCD
- to recreate conditions of the *QCD → hadronic matter phase transition* in the early Universe (~10 μs after the Big Bang)

NATURE



few 10^{-6} s $\quad$ 10^{-4} s $\quad$ 3 min

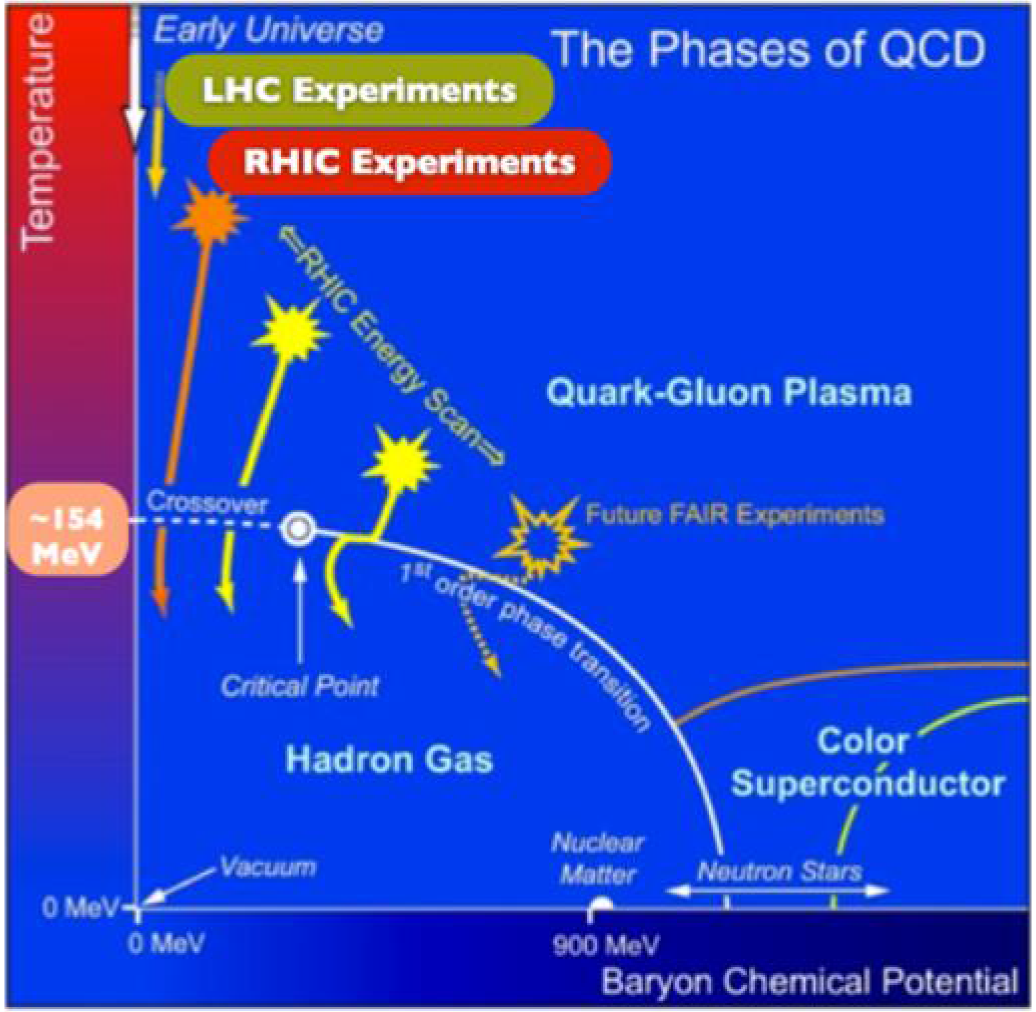
EXPERIMENT

Theoretical/phenomenological tools to interpret observations:

- perturbative QCD and lattice QCD
- Glauber model (to relate centrality to # of collisions, e.g.)
- relativistic hydrodynamics
- hadronization physics (mainly fixed from e^+e^-, pp experiments)

The QCD phase diagram

T



μ_B

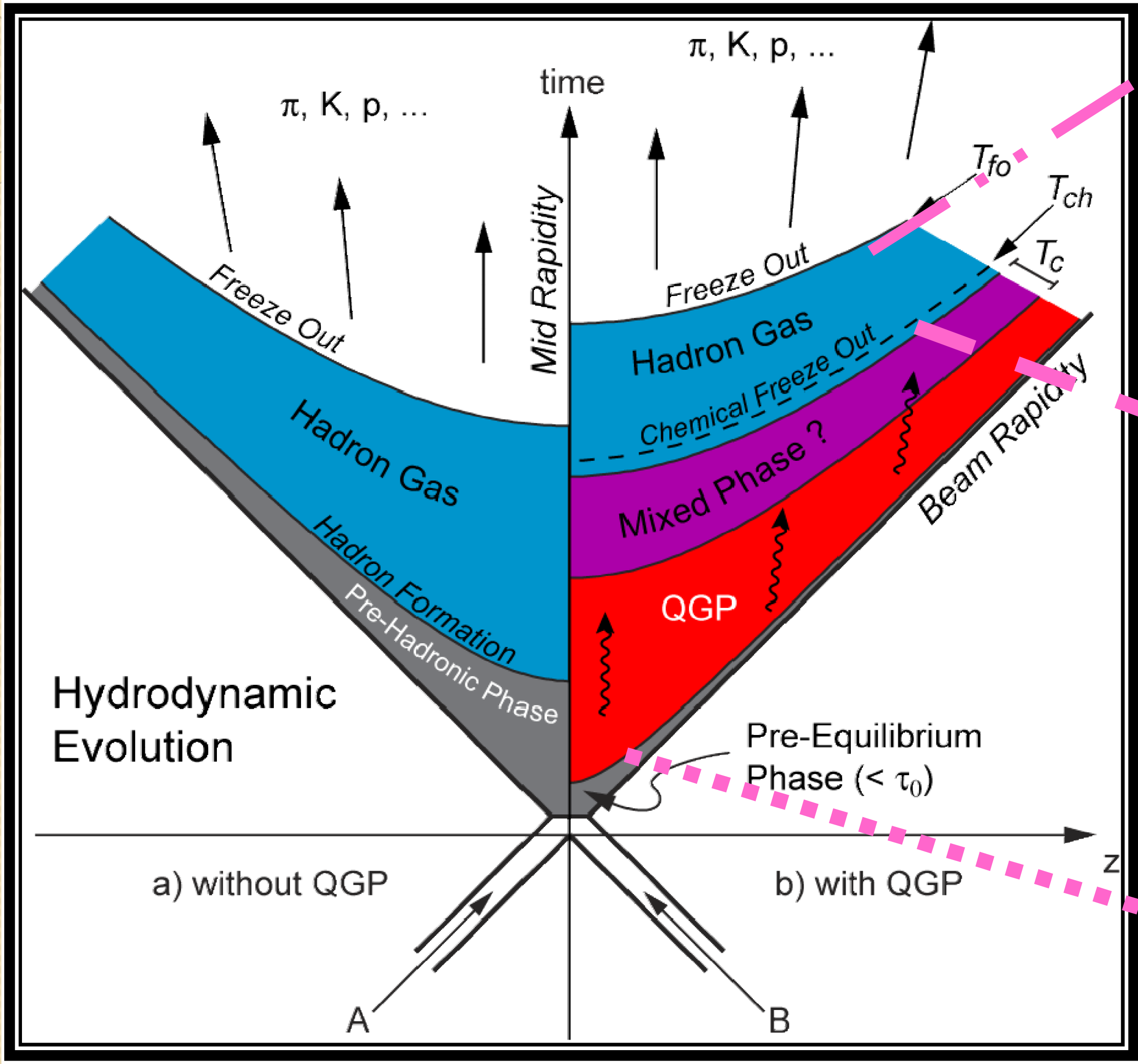
T in MeV units:

kT = 150 MeV

$$T = \frac{150\times10^{6}\times1.6\times10^{-19}}{1.38\times10^{-23}}$$

$$= 1.7\times10^{12}\ \text{K}$$

Space-time evolution of a collision



- Thermal freeze-out
  - Elastic interactions cease
  - Particle dynamics (momentum spectra) are fixed

T_{fo} (RHIC) ~ 110-130 MeV

- Chemical freeze-out
  - Inelastic interactions cease
  - Particle abundances are fixed (except maybe resonances)

T_{ch} (RHIC) ~ 170 MeV

- Thermalization time
  - System reaches local equilibrium

t_{eq} (RHIC) ~ 0.6 fm/c

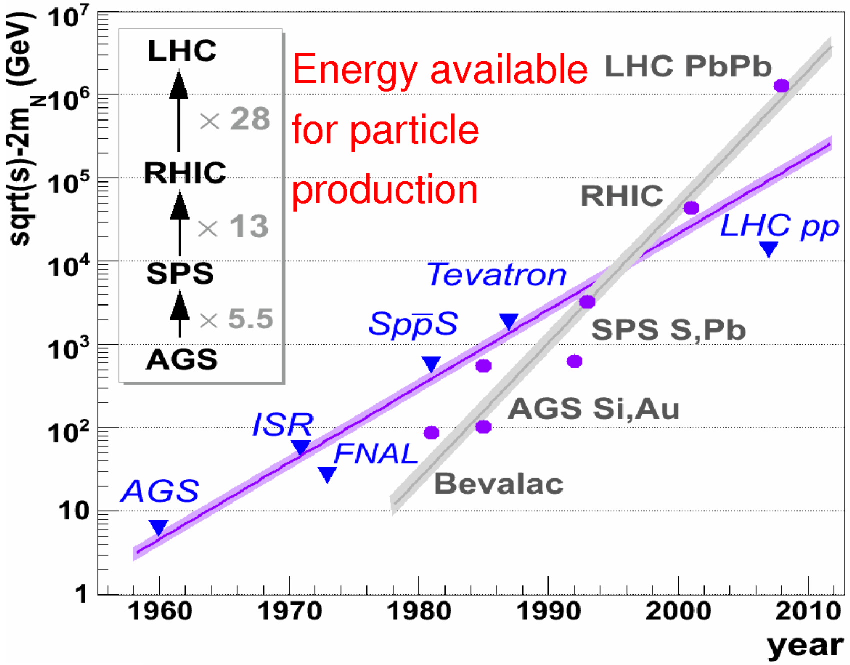
Key control parameters

- collision energy (per nucleon pair) $\sqrt{s_{NN}}$
- centrality percentile (referred to the total inelastic cross-section)
- system size:
  - nuclear species (mostly Cu, Au, Pb, U)
  - pp collisions ⇨ baseline for *hard-probe* observables $\rightarrow$ compare A-A observable to pp one scaled by the # of binary collisions N_{coll}
  - p-A collisions ⇨ possible effects of cold nuclear matter (CNM)

Brief history of HI collisions

- fixed target:
  - ***Bevalac*** *(LBL)* $\sqrt{s}$ *< 2.4 GeV*
  - **SIS** (GSI) $\sqrt{s}$ < 2.7 GeV
  - ***AGS*** *(BNL)* $\sqrt{s}$ *< 5 GeV*
  - ***SPS*** *(CERN)* $\sqrt{s}$ *< 20 GeV*
  - **FAIR** (GSI) $\sqrt{s}$ < 9 GeV

"Livingston plot"
J. Schukraft – arXiv:nucl-ex/0602014



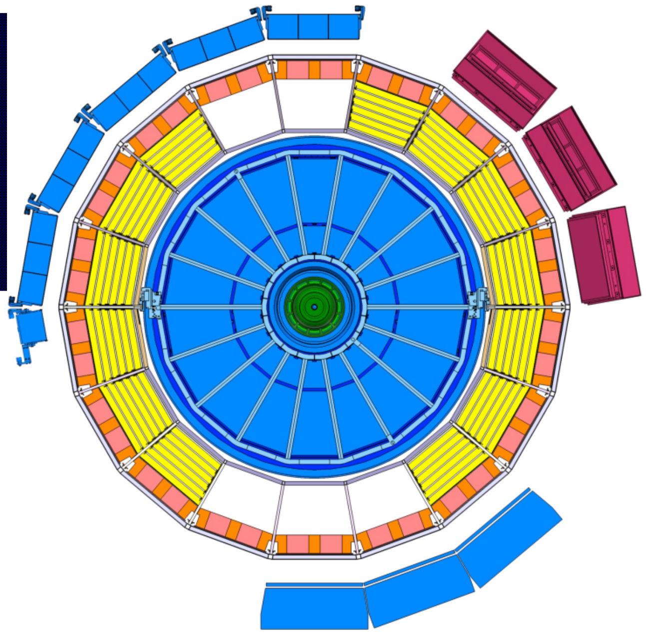
- collider:
  - **RHIC** (BNL) 2000- $\sqrt{s}$ < 200 GeV
  - **LHC** (CERN) 2008- $\sqrt{s}$ < 5500 GeV

energy doubling time:
pp ~4 years
A-A ~1.7 years

an experiment dedicated to heavy-ion physics at the LHC

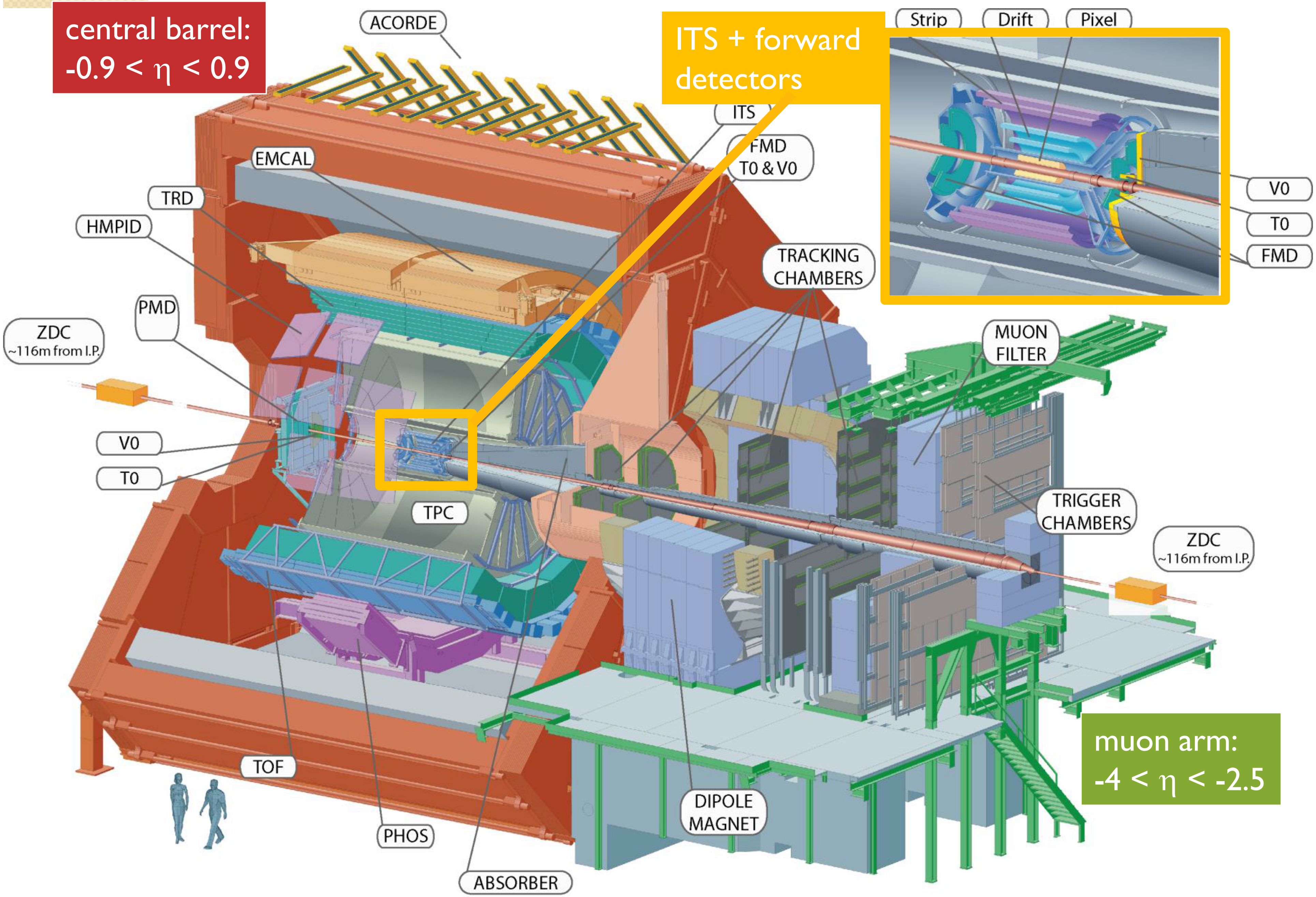
THE ALICE DETECTOR

[redacted]



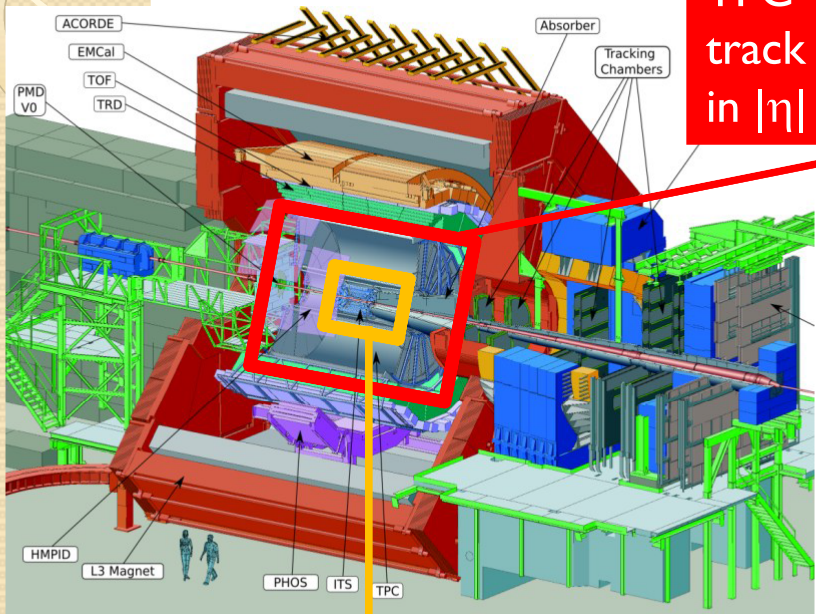
ALICE: the detector concept

- designed for handling central A-A collisions with $dN_{ch}/d\eta$ up to 8000
- central barrel with tracking and PID for charged particles in a 0.5 T B-field (L3 solenoid)
- very low material budget ⇨ high precision tracking down to very low p_T
- photon & jet reconstruction: PHOS & EMCal
- forward muon arm with dipole magnet
- (very) forward detectors including ZDC's for centrality determination and extended rapidity coverage

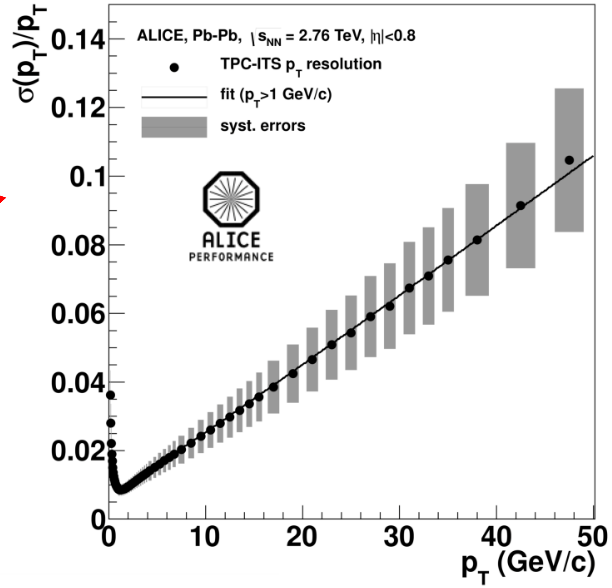

central barrel:
-0.9 < η < 0.9
ACORDE
ITS + forward detectors
Strip
Drift
Pixel
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
PMD
ZDC
~116m from I.P.
V0
T0
FMD
TRACKING CHAMBERS
MUON FILTER
TRIGGER CHAMBERS
TPC
TOF
PHOS
ABSORBER
DIPOLE MAGNET
muon arm:
-4 < η < -2.5

central barrel:
-0.9 < η < 0.9

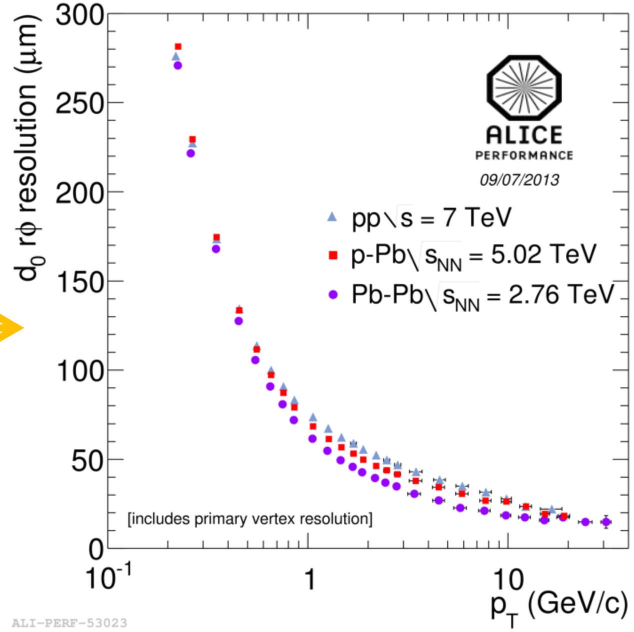
Tracking with ALICE



TPC + ITS: charged track reconstruction in |η| < 0.9



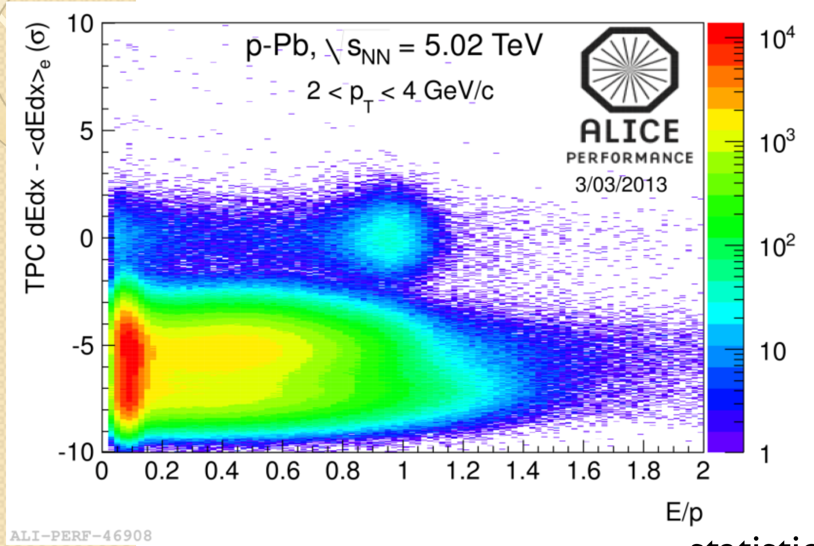
ITS: High precision vertexing and high resolution on track impact parameter d_0



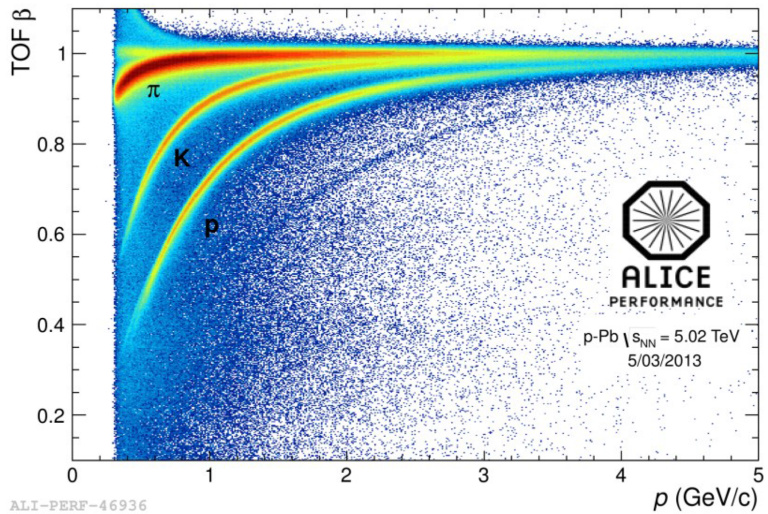
allows one to resolve decay vertices of charm and beauty hadrons

Particle Identification with ALICE

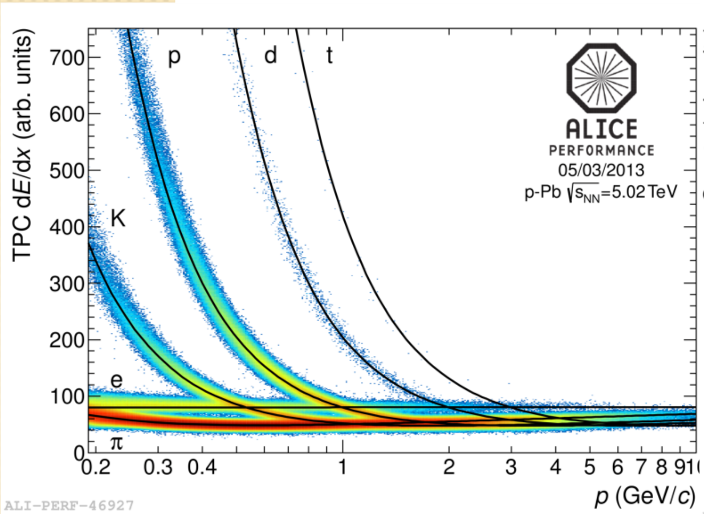
E/p with TPC + EMCal



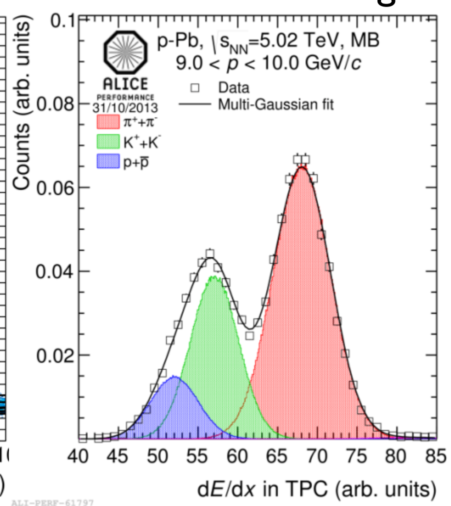
β with Time Of Flight



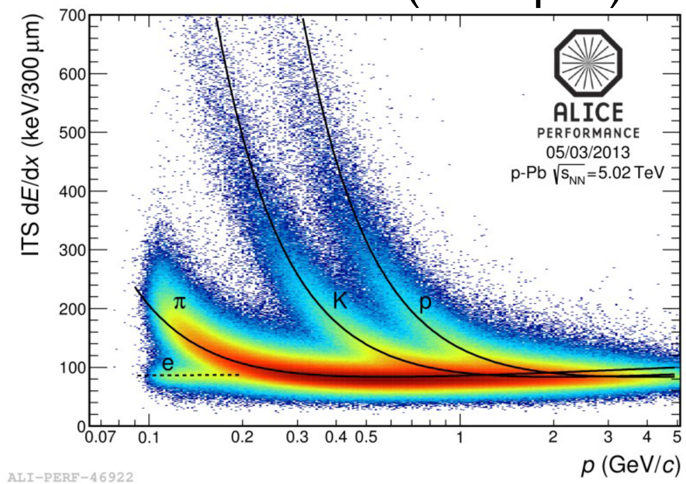
d*E*/dx in TPC



statistical separation
in relativistic rise region

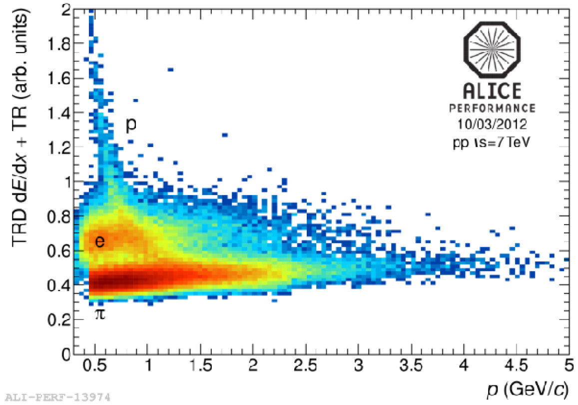


d*E*/dx in ITS (4 samples)

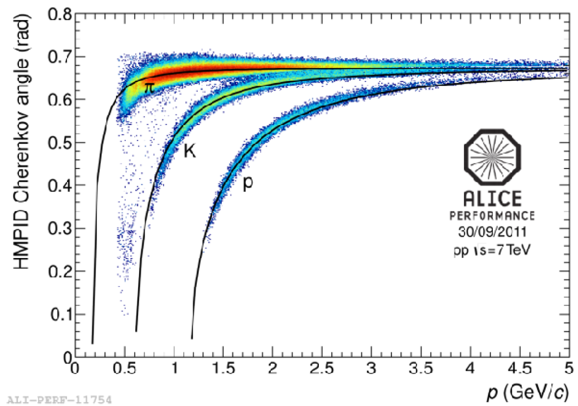


more PID with ALICE

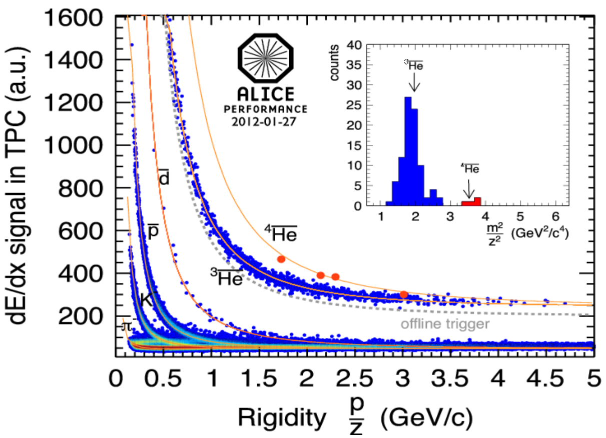
electron/pion separation with TRD

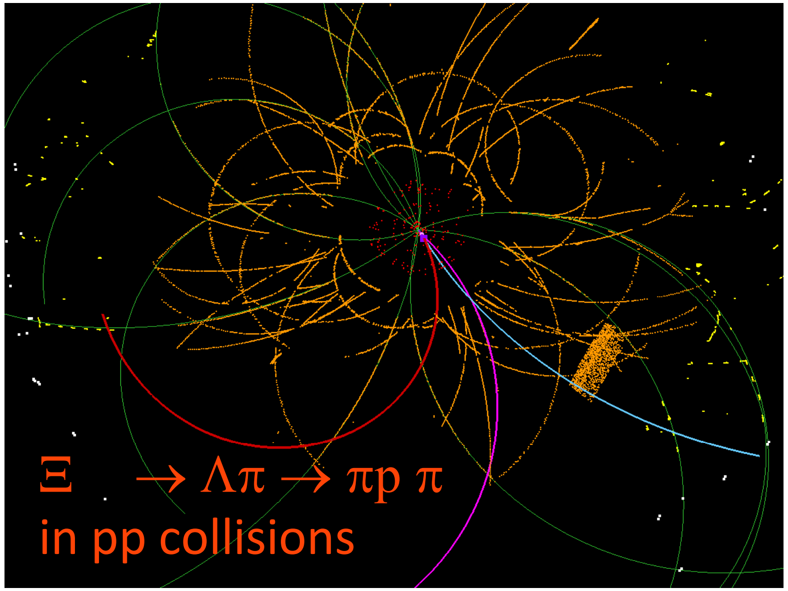


high momentum PID with HMPID (Cherenkov detector)



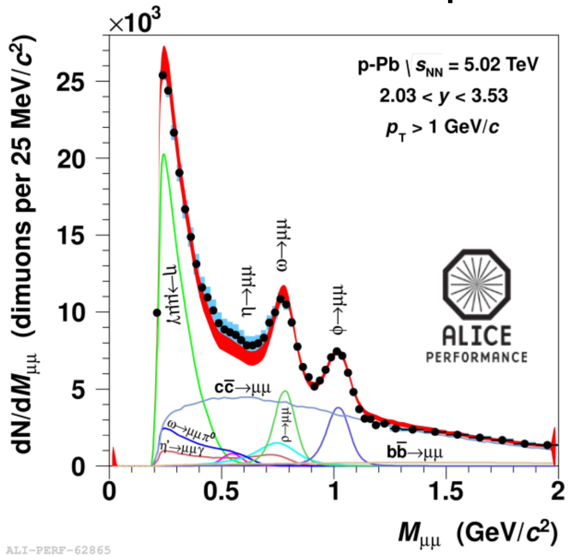
anti-nuclei ID with TPC



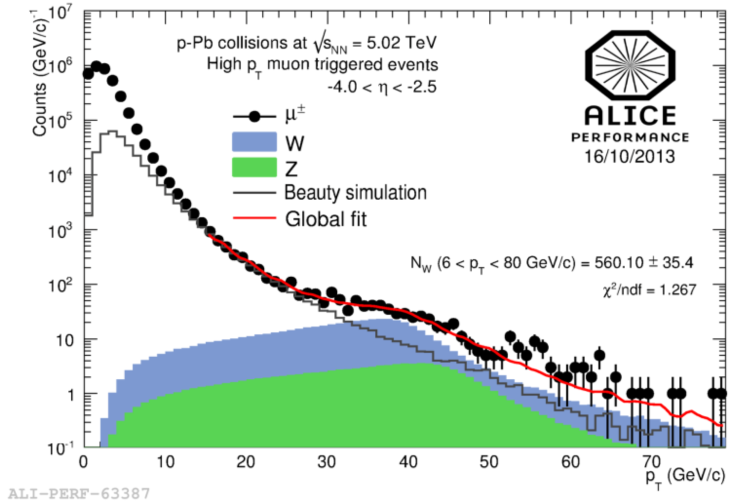


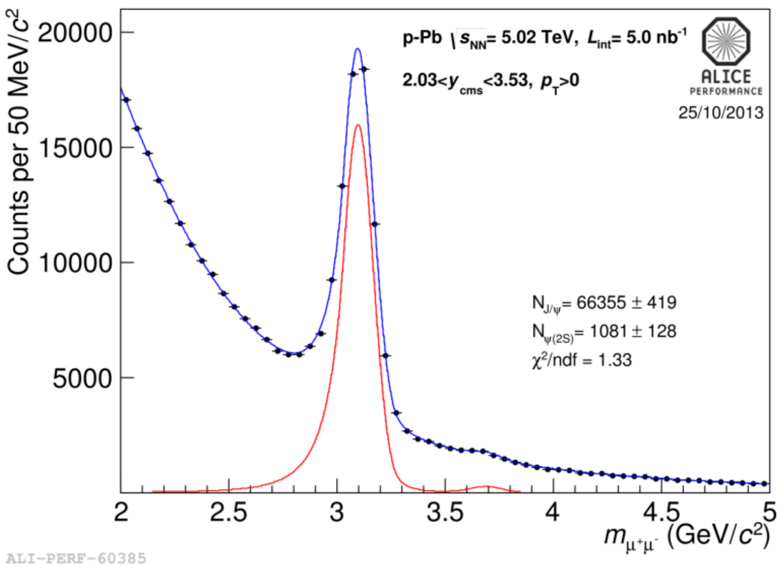
Muons with ALICE

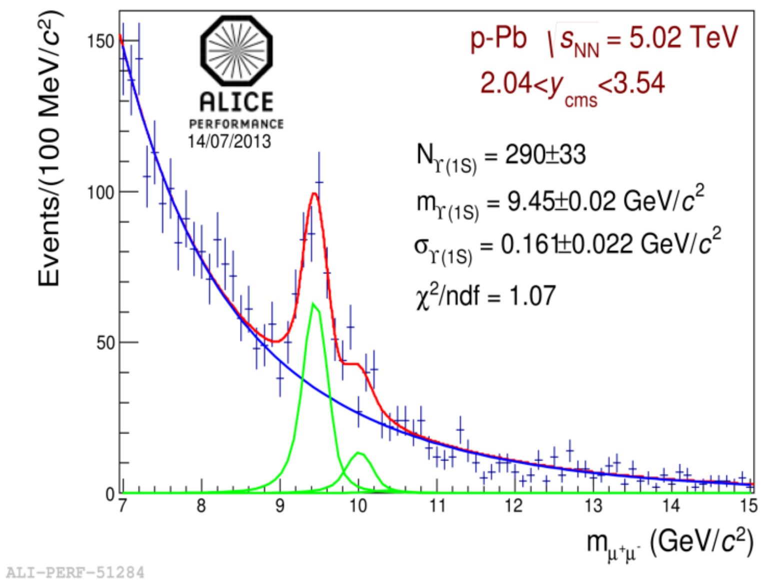
dimuon invariant mass spectra



single muon p_T spectrum





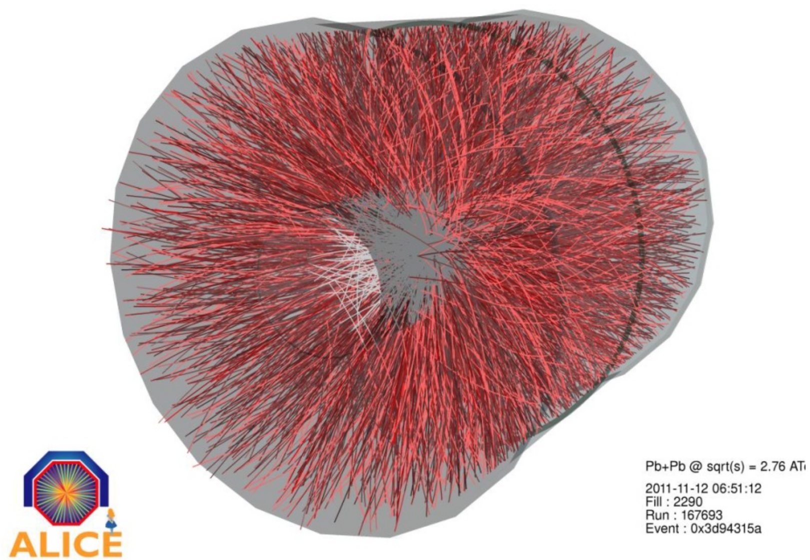


ALICE data samples in LHC Run 1

System	Energy $\sqrt{s_{NN}}$ (TeV)	Year	Integrated luminosity	Main Goal
Pb-Pb	2.76	2010	10 μb^{-1}	First Pb-Pb data taking at LHC
Pb-Pb	2.76	2011	0.1 nb^{-1}	Study hot & dense QCD matter
p-Pb & Pb-p	5.02	2013	15 nb^{-1} 15 nb^{-1}	Study Cold Nuclear Matter effects
pp	0.9	2009-10	0.15 nb^{-1}	Commissioning
pp	7	2010	7 nb^{-1}	Reference for Pb-Pb and p-Pb
pp	2.76	2011	1.1 nb^{-1}	
pp	7	2011	4.8 pb^{-1}	
pp	8	2012	9.7 pb^{-1}	

charged particle multiplicity
transverse energy
…as a function of centrality

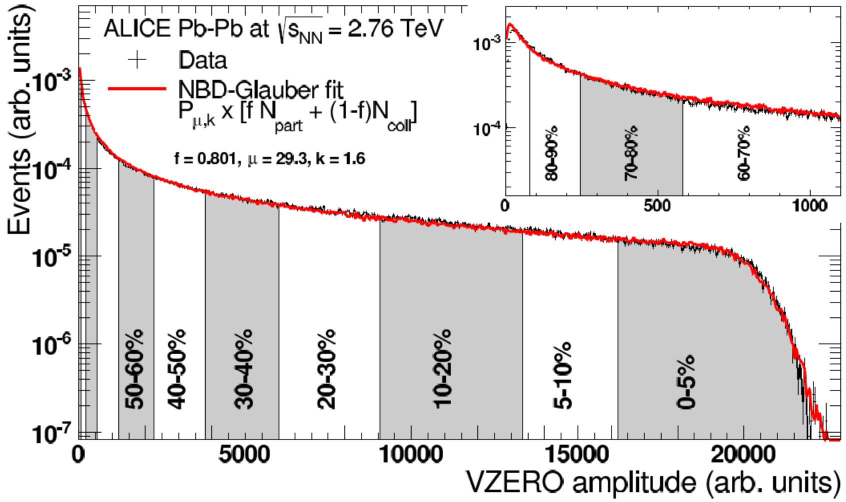
GLOBAL PROPERTIES

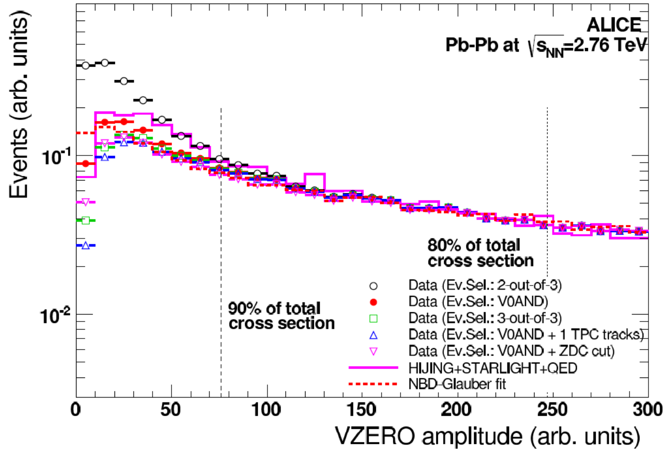


Centrality determination in Pb-Pb

Phys. Rev. C 88, 044909 (2013)

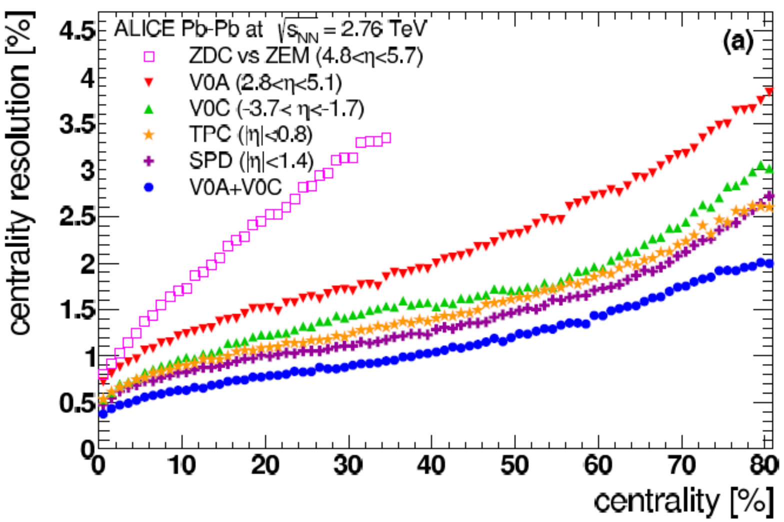
VZERO (scint. hodoscope) ampl. used to determine centrality percentiles from 0% (most central) to 90%

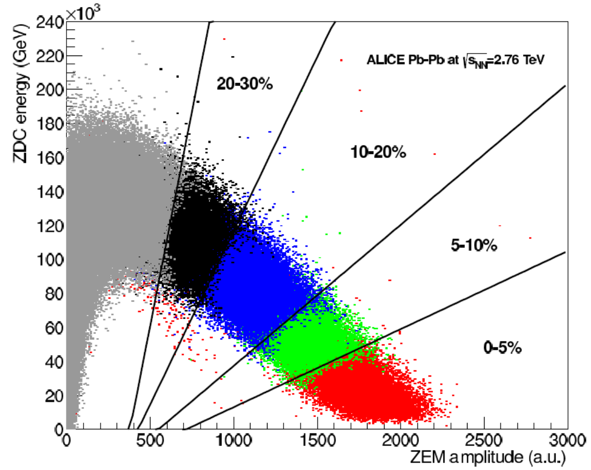




anchor point at 90% centrality

syst. error: 1%

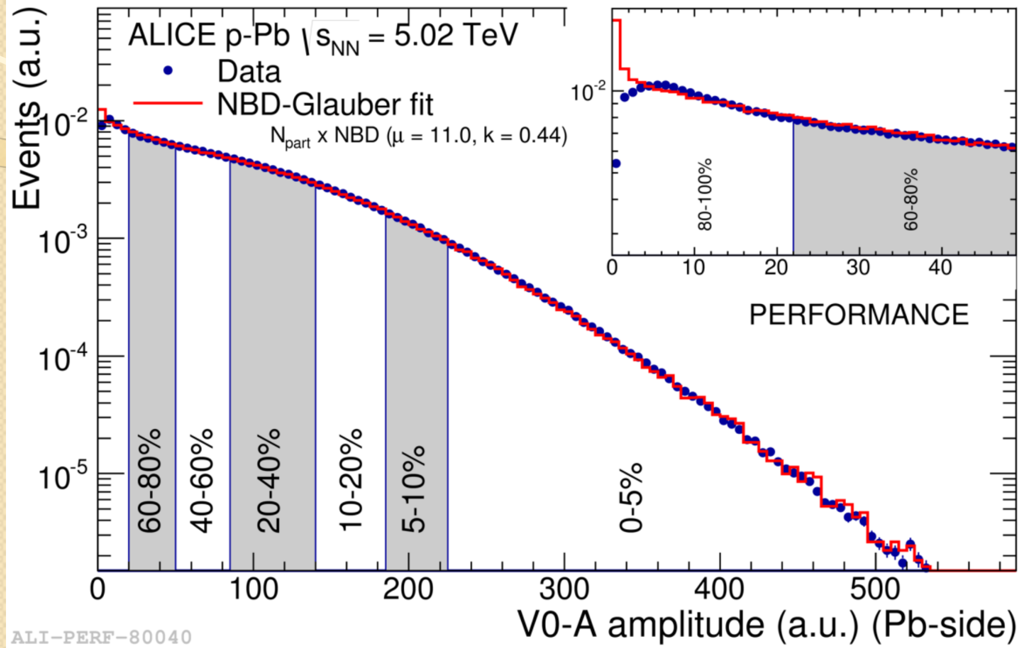




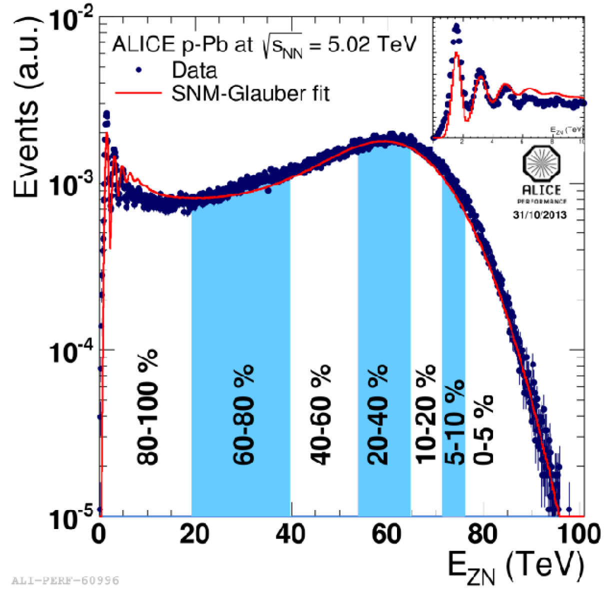
alternative definition based on ZDC+ZEM (0-30%) → analyses not requiring vertex cut

Centrality determination in p-Pb

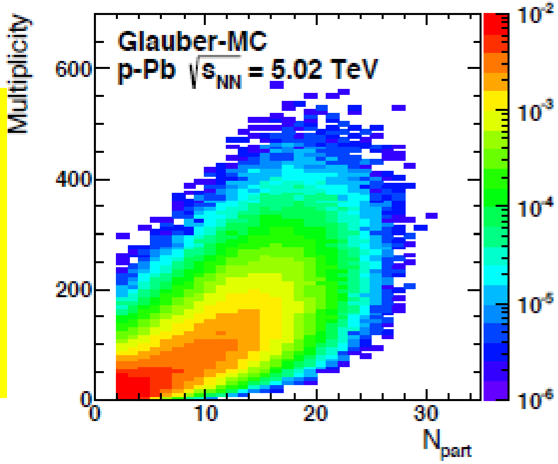
Glauber + NBD for particle production

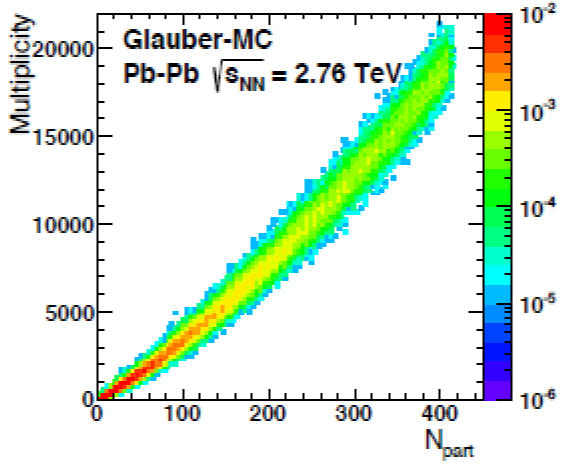


Glauber + Slow Nuclear Model for zero-degree energy



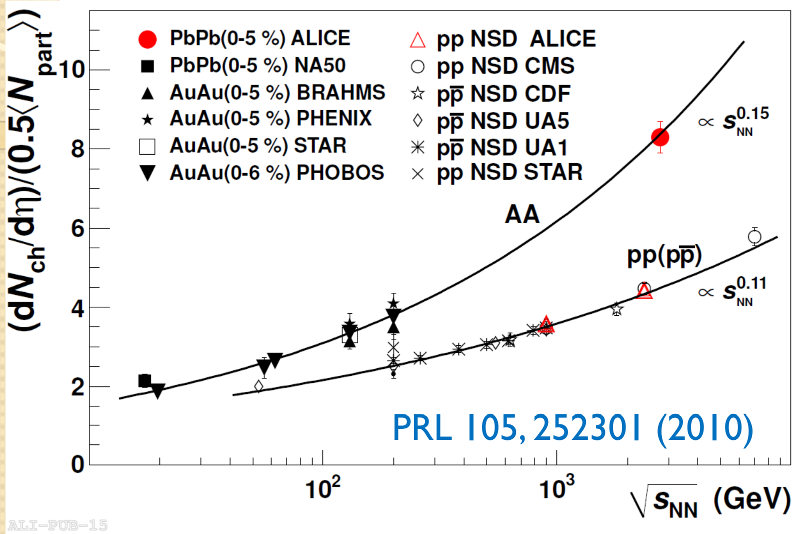
Caveat:
multiplicity bias in p-Pb when using estimators based on multiplicity (like VZERO-A amplitude)





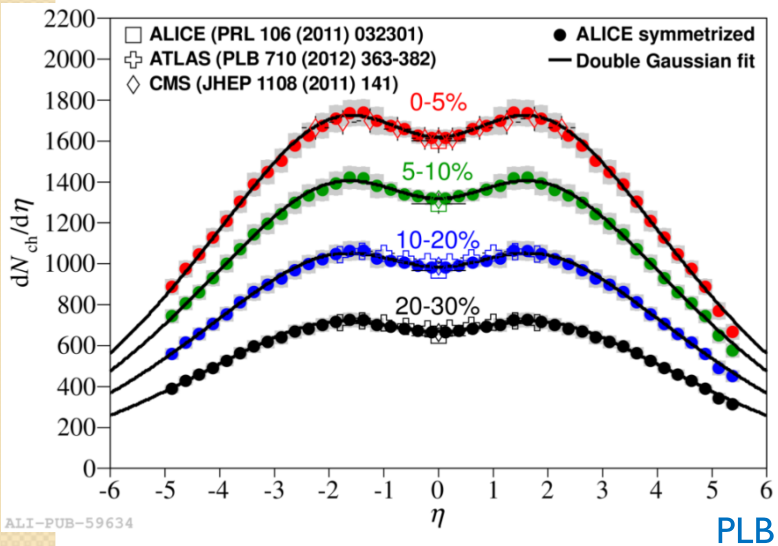
Charged particle multiplicity

Pb-Pb 0-5% centr.: $dN_{ch}/d\eta$ = 1584 ± 4 (stat) ± 76 (syst)

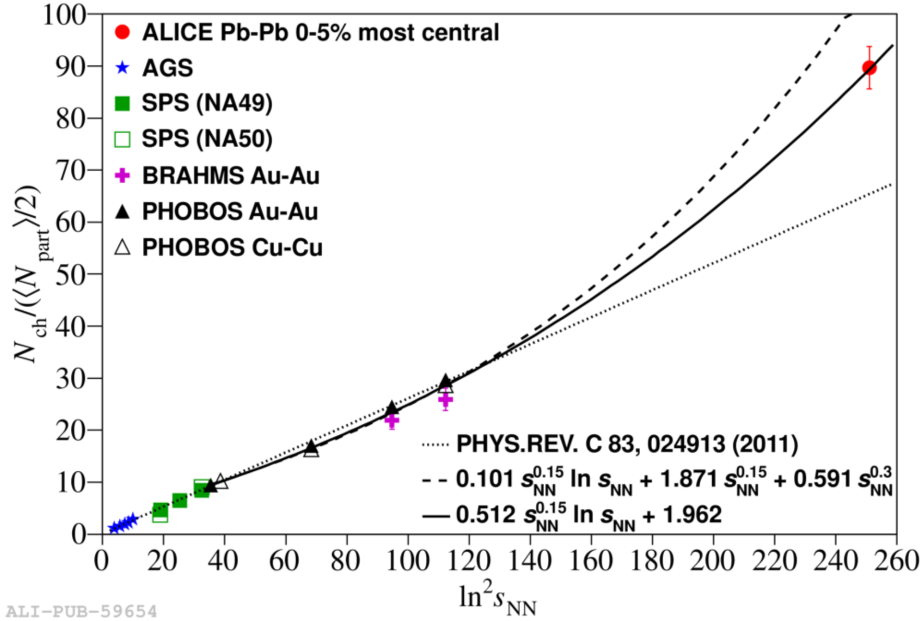


PRL 105, 252301 (2010)

N_{ch} (2.76 TeV) ≈ 2.2×N_{ch} (0.2 TeV)
×1.9 per participant pair wrt pp

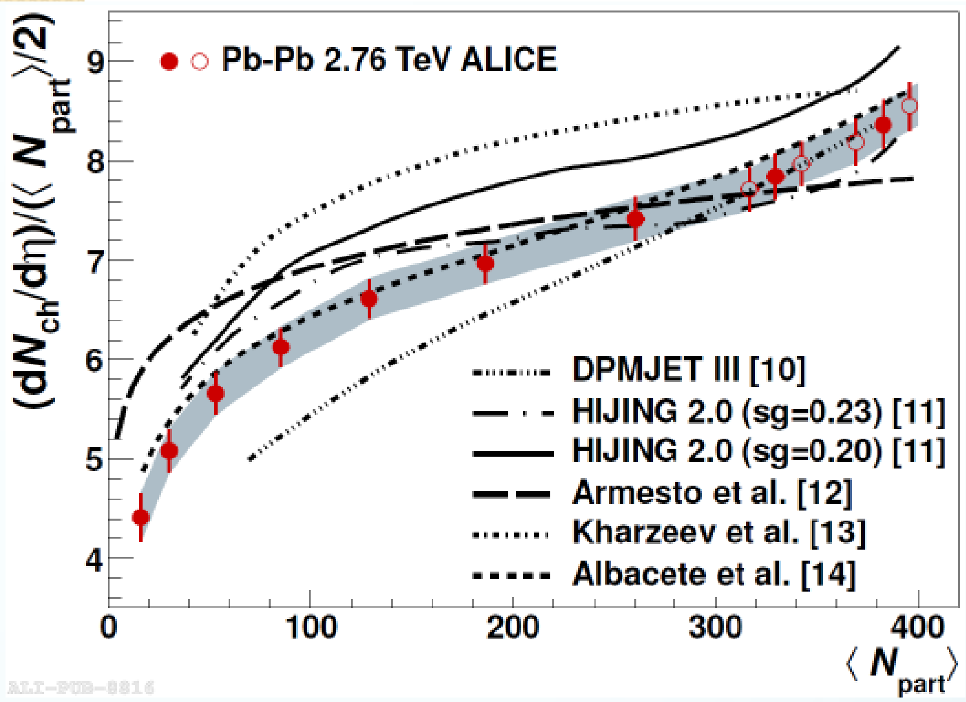


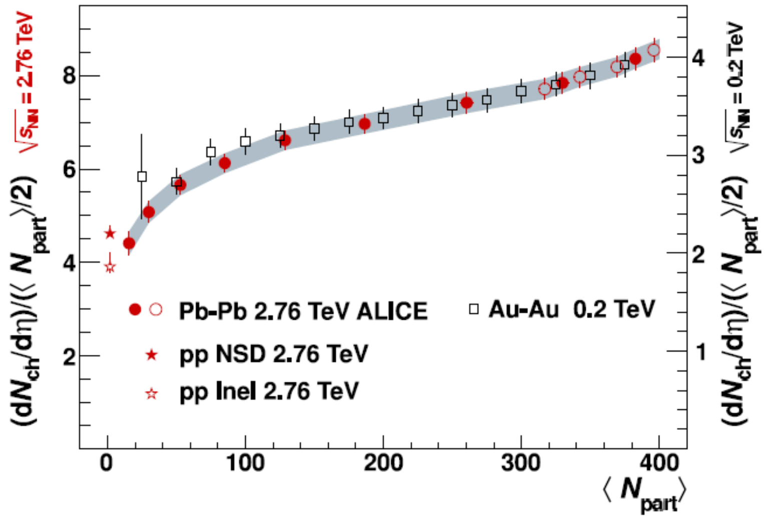
linear trend vs. $\ln^2 s_{NN}$ approximately valid from AGS to RHIC energies, breaks down at LHC



PLB 726, 610 (2013)

$dN_{ch}/d\eta$ vs. centrality in Pb-Pb

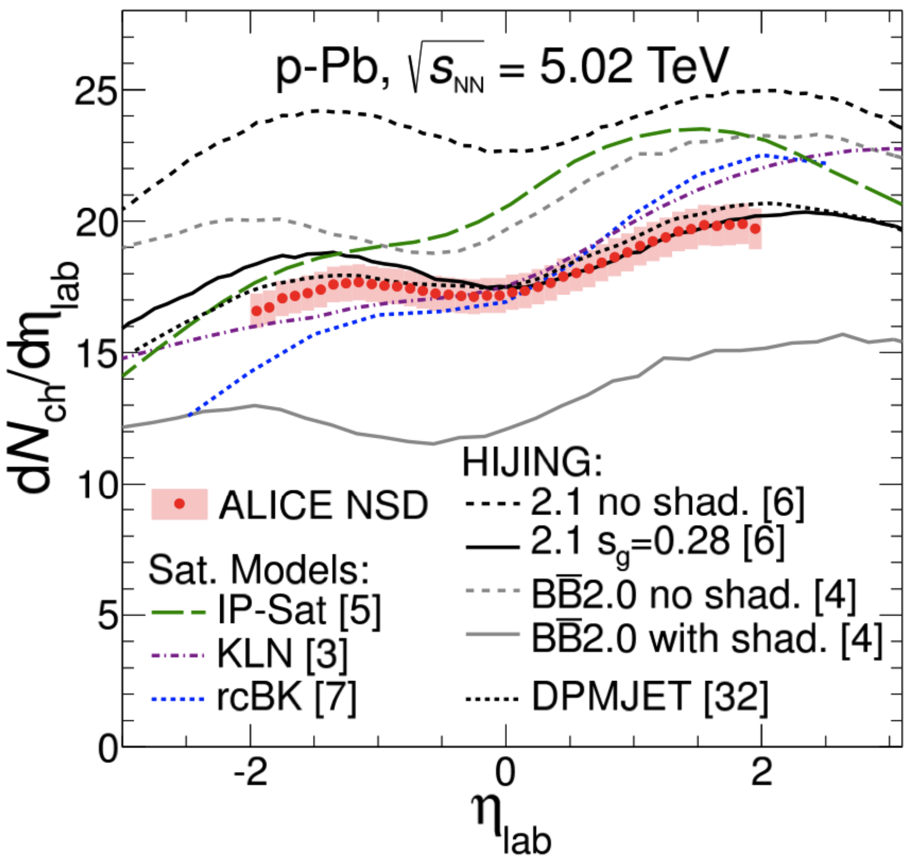




PRL 106, 032301 (2011)

- the yield per participant pair has the same shape vs. N_{part} at RHIC and LHC (with a scale factor of 2.1)
- among 2-component models (pQCD + soft interactions), only HIJING 2.0 tuned to high energy pp and central Pb-Pb data is in agreement with the ALICE result
- models including saturation [13, 14] reproduce well the centrality dependence (though [13] overpredicts the magnitude)

$dN_{ch}/d\eta$ in p-Pb



Phys. Rev. Lett. 110, 032301 (2013)

NSD p-Pb at 5.02 TeV $|\eta| < 2$
$dN_{ch}/d\eta$: 16.95 ± 0.75

Disentangle
- **final state effects : hot QCD matter**
- **initial state effects: cold nuclear matter**

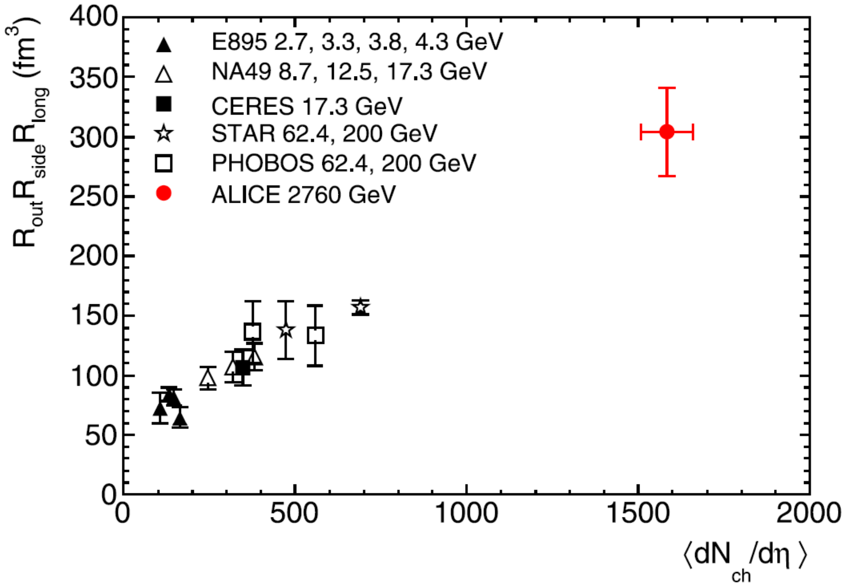
Probe nuclear wave-function at small x

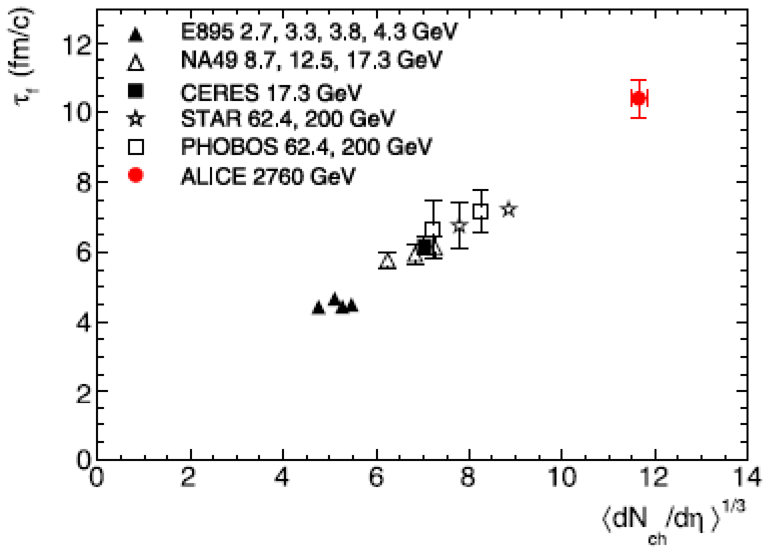
QCD at high gluon density:
parton shadowing, gluon saturation?

- **Models that include shadowing or saturation approximately get right value**
- **HIJING 2.1 (gluon shadowing tuned to RHIC) : closest to the data and describes the rapidity shape rather well**
- **Gluon saturation models: steeper η_{lab} dependence than the data**

Space-time volume of homogeneity region

PLB 696, 328 (2011)





- identical pion interferometry (HBT) in Pb-Pb

  at 0-5% centrality ⇨ freeze-out volume and lifetime:
- freezeout volume ~ $2\times V_{RHIC}$
  - actual volume of homogeneity region is $(2\pi)^3\times$(product of radii)
- lifetime ~1.4 $\times\tau_{RHIC}$

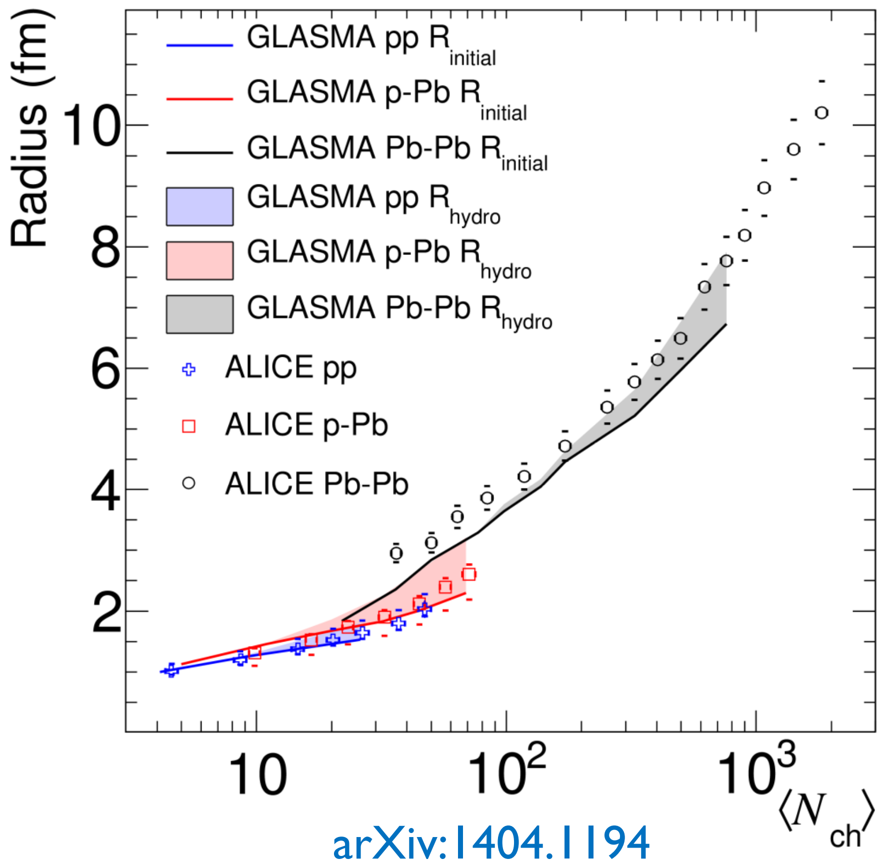
Source radius in pp, p-Pb and Pb-Pb

Comparison of source radii can provide info on the role of:

- initial conditions (p-Pb radii similar to pp)

  vs.

- hydrodynamics (larger radii, p-Pb more similar to Pb-Pb)

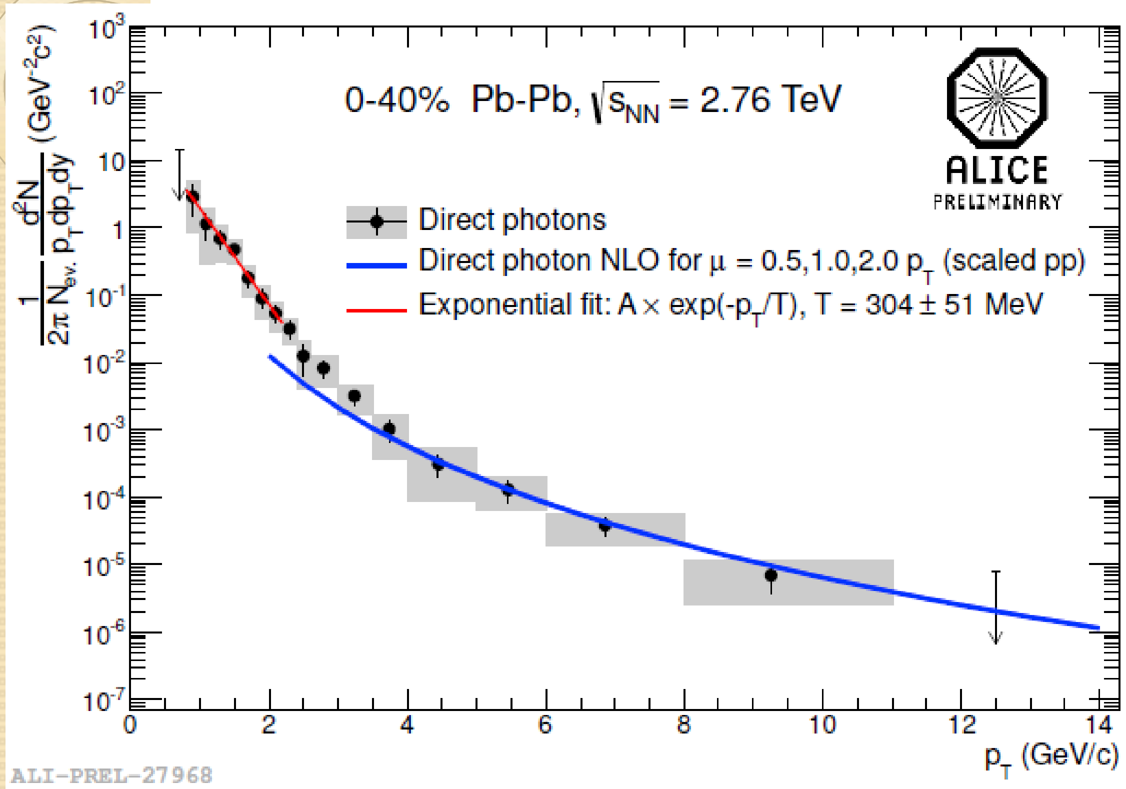


arXiv:1404.1194

- extraction of radii with 3π cumulants
- for a given N_{ch}:
  - p-Pb radii 5-15% larger than in pp
  - Pb-Pb radii 35-45% larger than in p-Pb

p-Pb and pp can be reproduced by initial conditions from saturation (GLASMA) (p-Pb may accommodate also hydro)
Pb-Pb requires hydro-dynamical phase

Direct photon spectrum



Fit spectrum up to 2.2 GeV/c with exponential in p_T

⇨ inverse slope:

T = 304 ± 51 MeV (stat+syst)

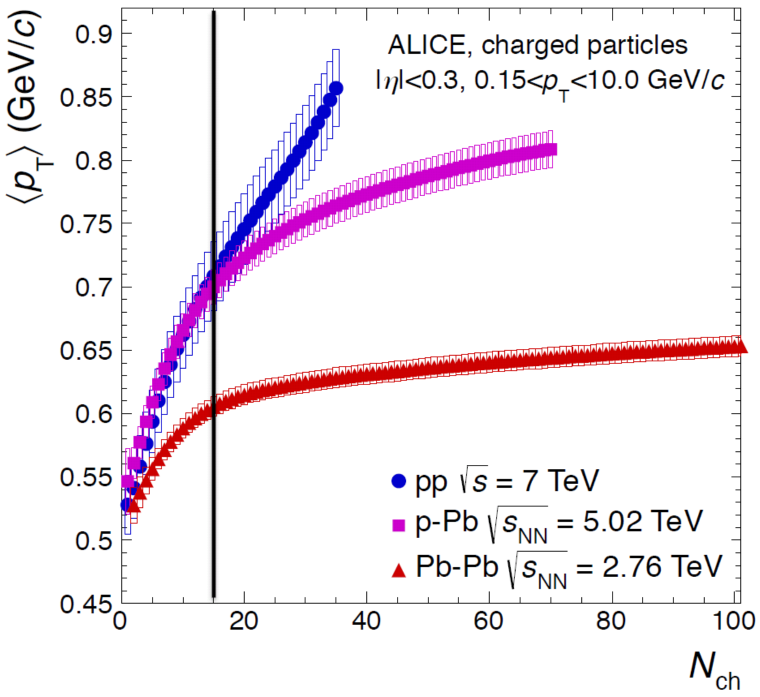
indicates initial temperature of 500-600 MeV

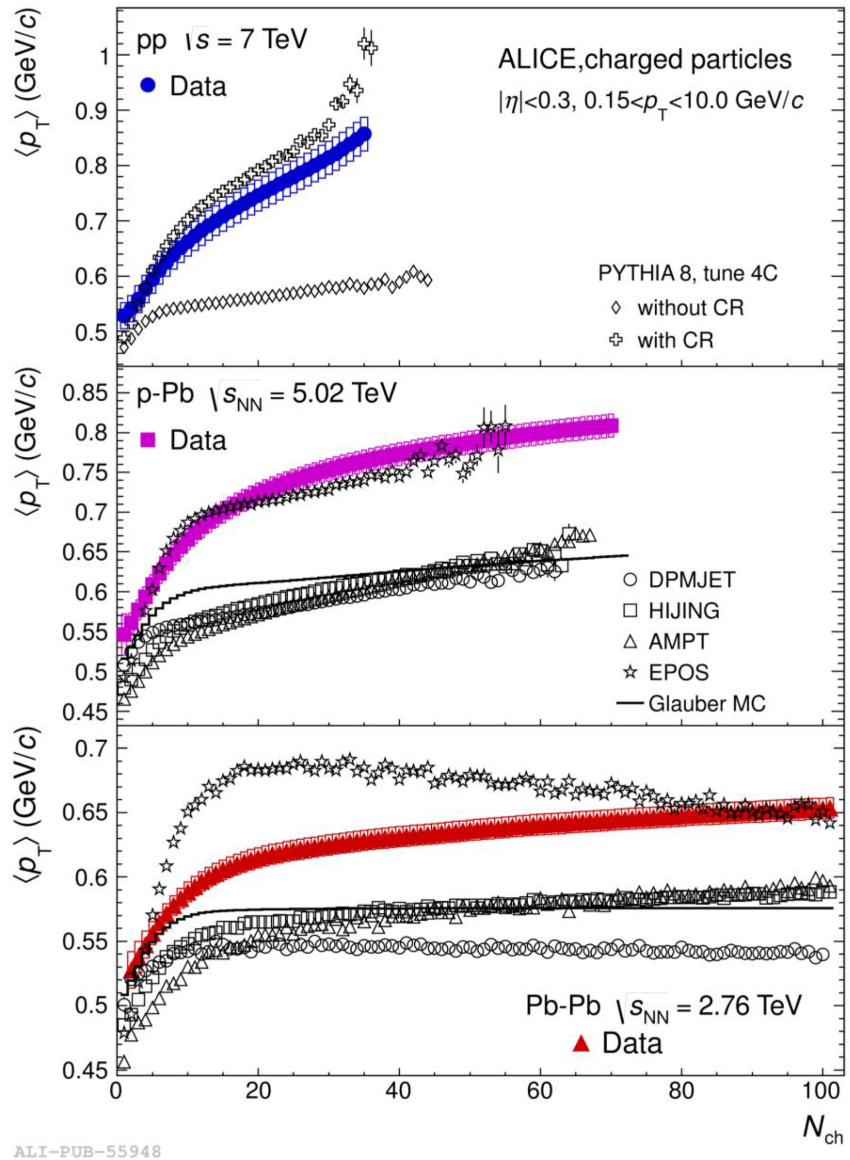
for comparison: PHENIX at RHIC found

T = 221 ± 19 ± 19 MeV

for 0-20% Au-Au collisions at $\sqrt{s_{NN}}$ = 0.2 TeV

Mean p_T vs. multiplicity





pp and p-Pb show much stronger increase than Pb-Pb

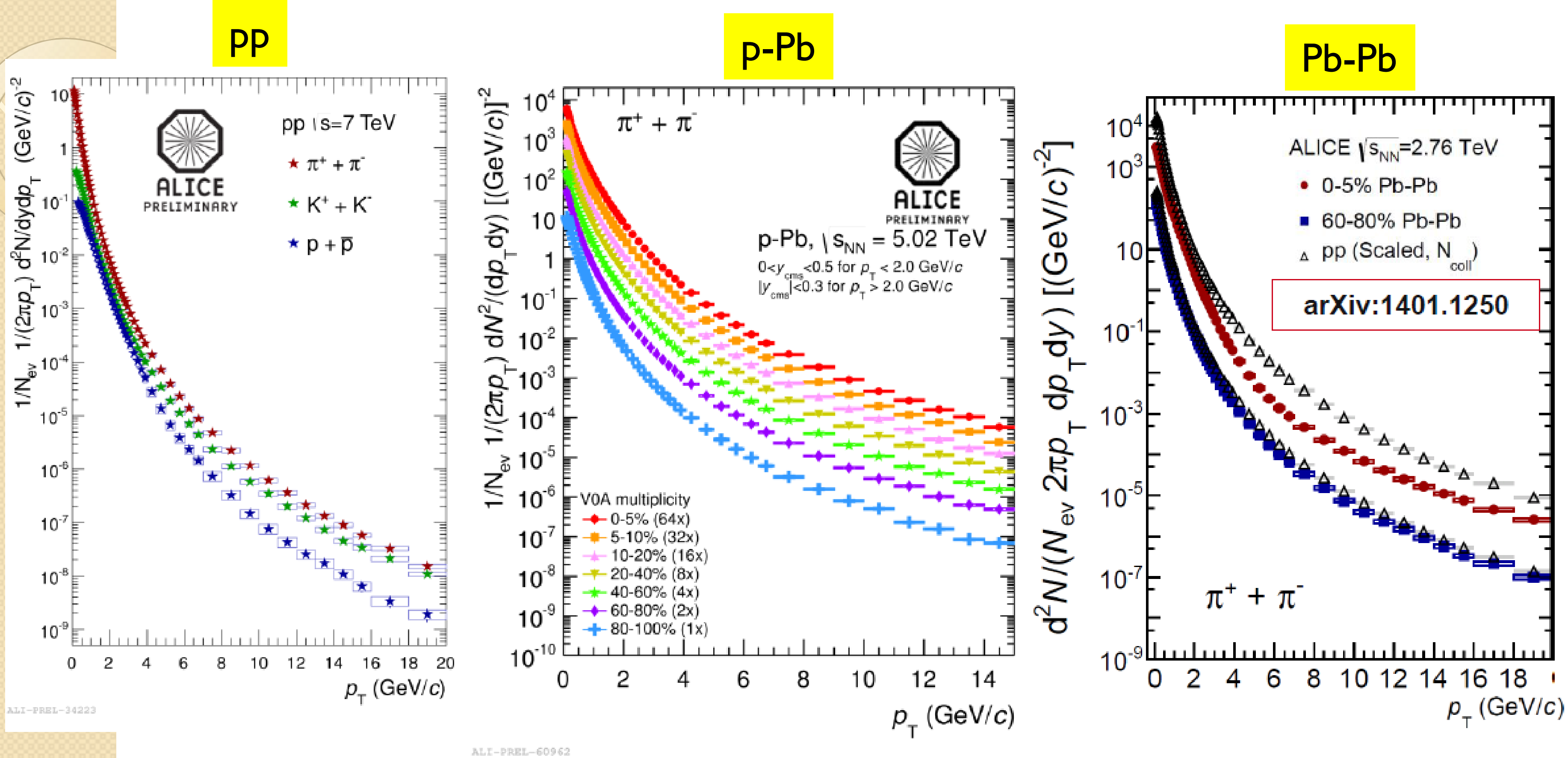
- Color reconnection describes data better in pp
- Glauber MC (sum of indep. pp, pn) fails
- No model can describe p-Pb and Pb-Pb consistently (EPOS close to p-Pb data)

arXiv:1307.1094 PLB 727, 371 (2013)

identified particle yields vs. p_T
yield ratios, comparison to thermal models

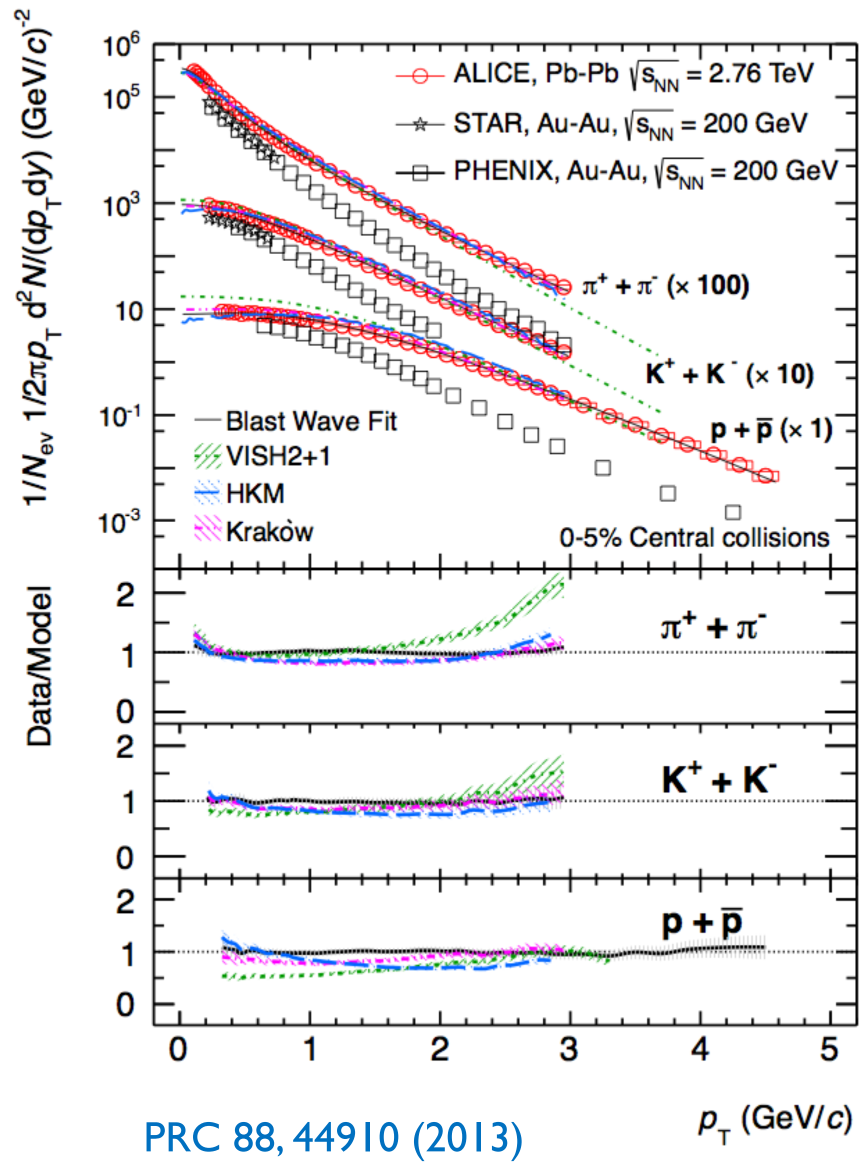
PARTICLE PRODUCTION

Identified hadron spectra



- combined result of tracking detectors (ITS, TPC, TOF, HMPID) ⇨ p_T spectra in a wide range for all three systems
- input for flavour and mass dependence of particle yields
- evolution of yields with colliding system and centrality

Hadron spectra in 0-5% Pb-Pb



PRC 88, 44910 (2013)

Models:

VISH2+1 (viscous hydro)

HKM (hydro + UrQMD)

Krakow (hydro + bulk viscous corrections)

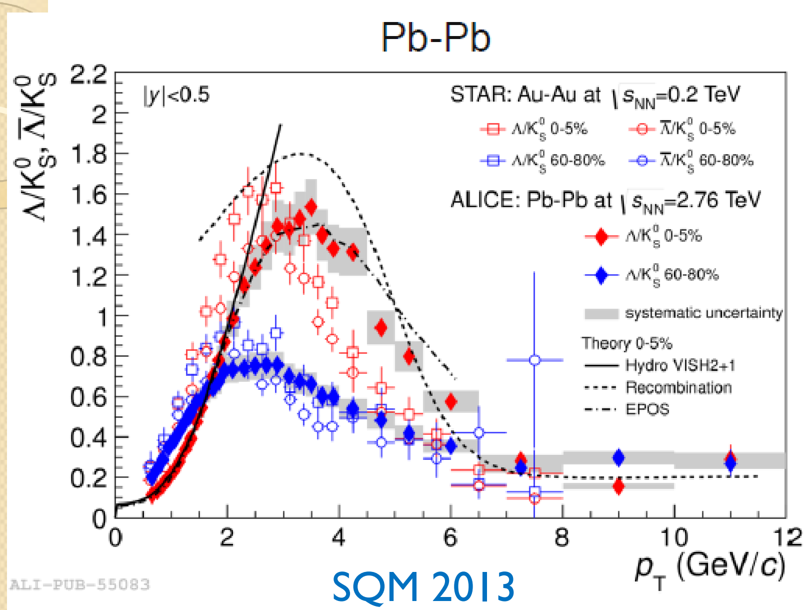
good agreement for central collisions, hydrodynamics give s a good description (also EPOS 2.17 hydro + UrQMD, bulk + jets)

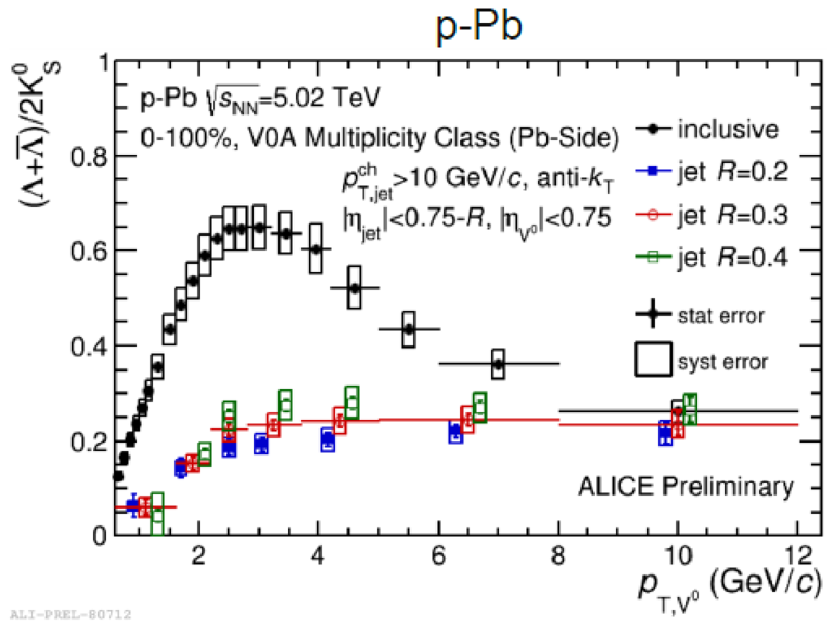
Blast-wave fits to extract:

- kinetic freeze-out temperature
- radial flow velocity

T_{kin} ~ 95 MeV (similar to RHIC)
$<\beta_T>$ ~0.65 c (10% larger than at RHIC)
⇨ larger radial flow than at RHIC

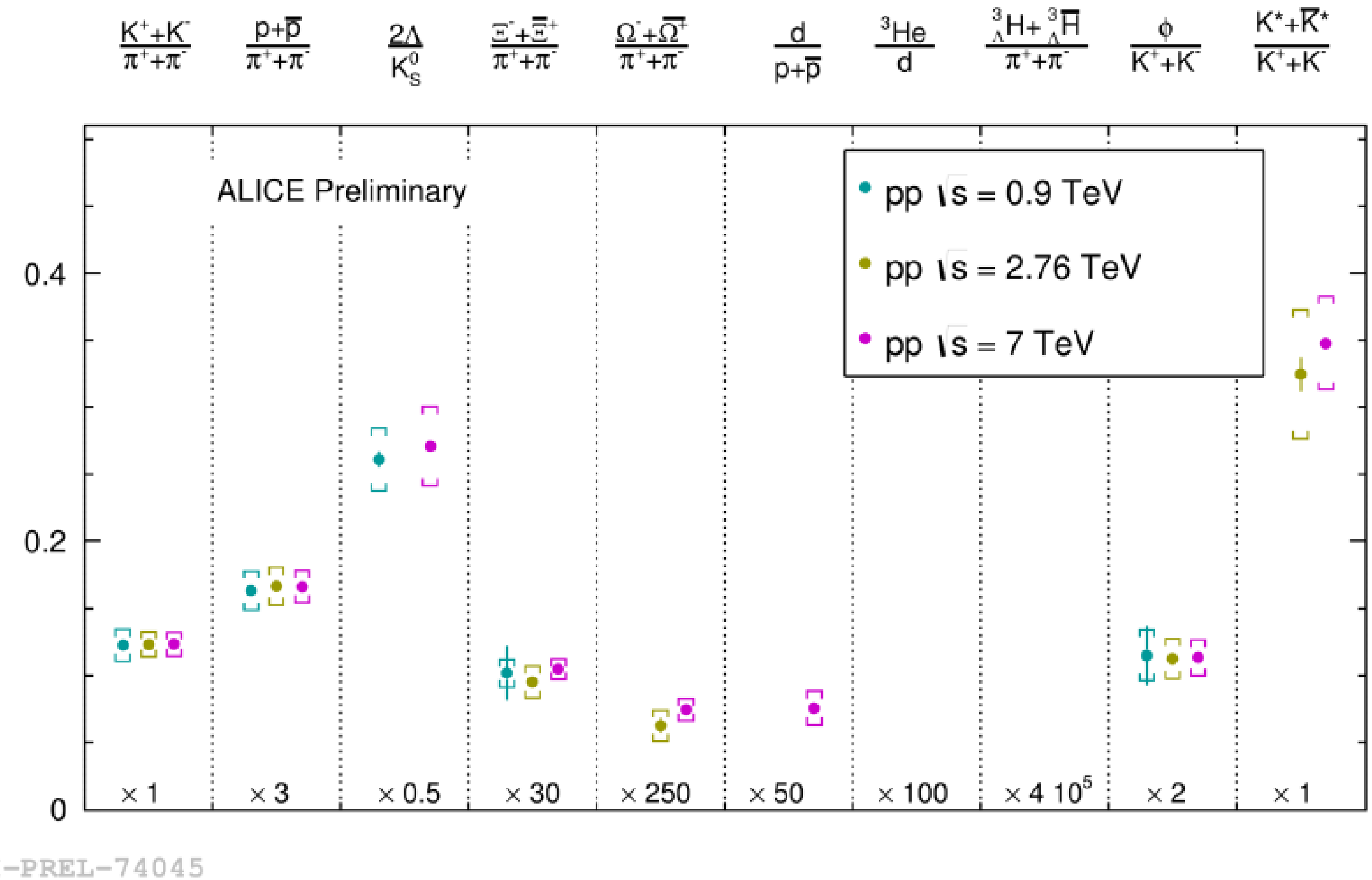
The baryon anomaly





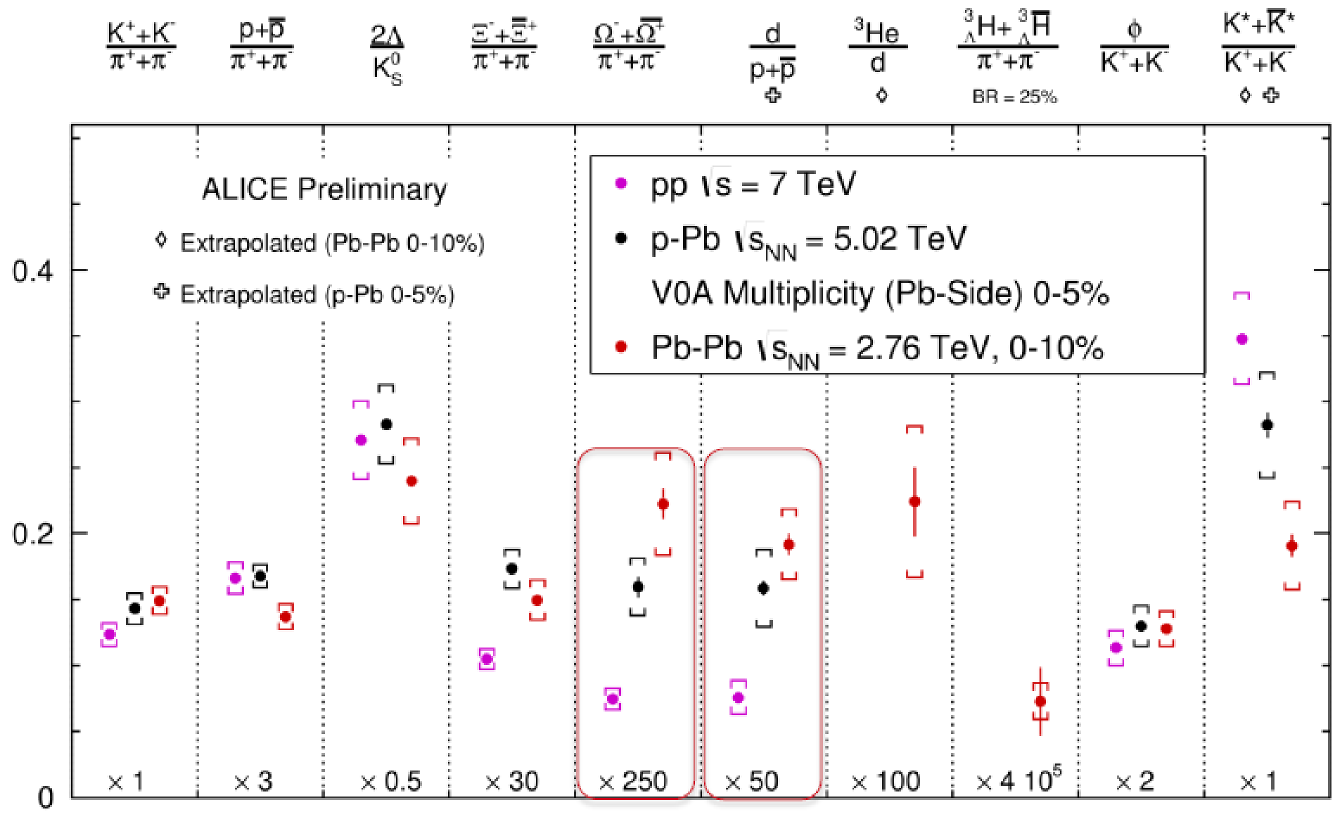
- Λ production is strongly enhanced in central Pb-Pb collisions
- Clear centrality dependence
- Quantitatively the same effect as the one observed earlier at RHIC
- Ratio Λ/K^0_S in p-Pb collisions is similar to that in peripheral Pb-Pb collisions
- No Λ enhancement in jets

Particle yield ratios in pp



Yield ratios among several hadrons (including light nuclei) show weak (if any) energy dependence between 0.9 and 7 TeV

Particle yields: pp, p-Pb & Pb-Pb

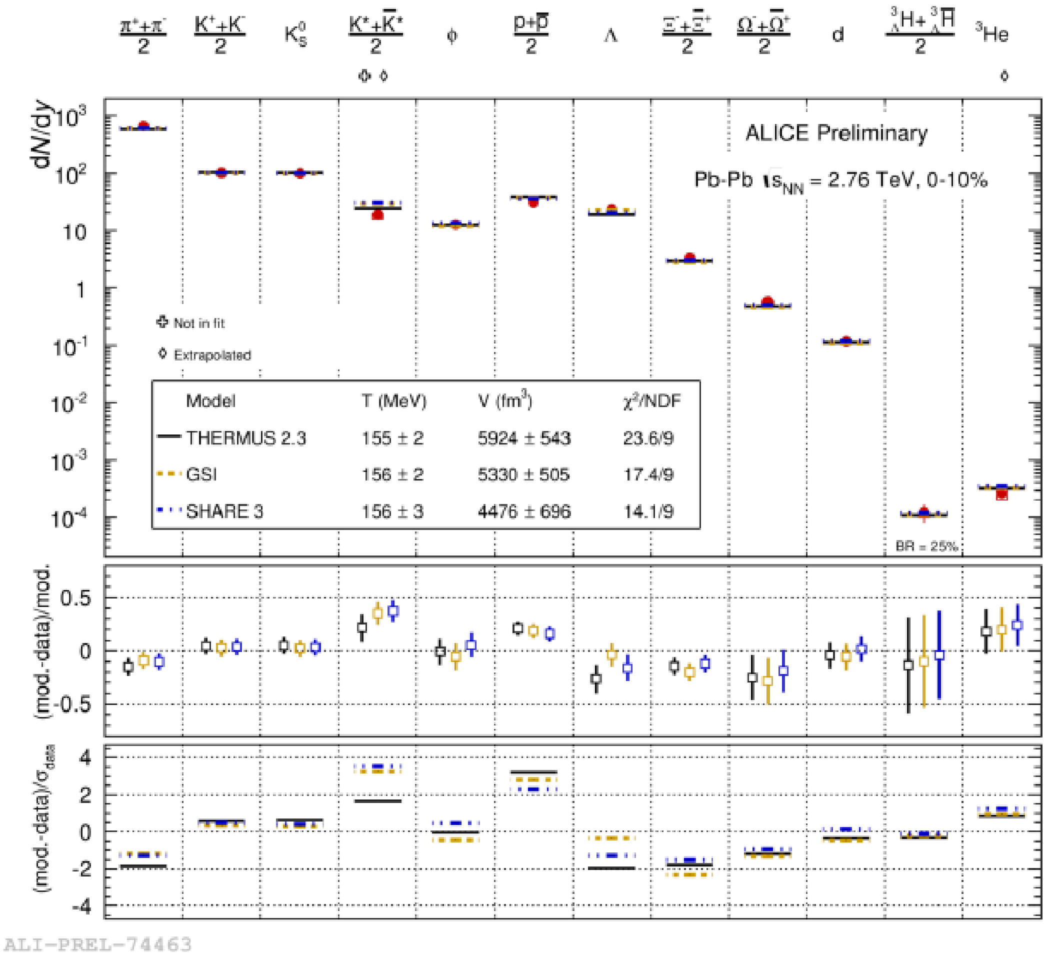


ALI-PREL-74423

Yield ratios look similar among different systems…

… but in Pb-Pb we see an ehancement of Ω and a decrease of p and K*

Particle yields vs. thermal model



Models:
THERMUS: CPC 180 (2009) 84
GSI: PLB 673 (2009) 142
SHARE: arXiv:1310.5108

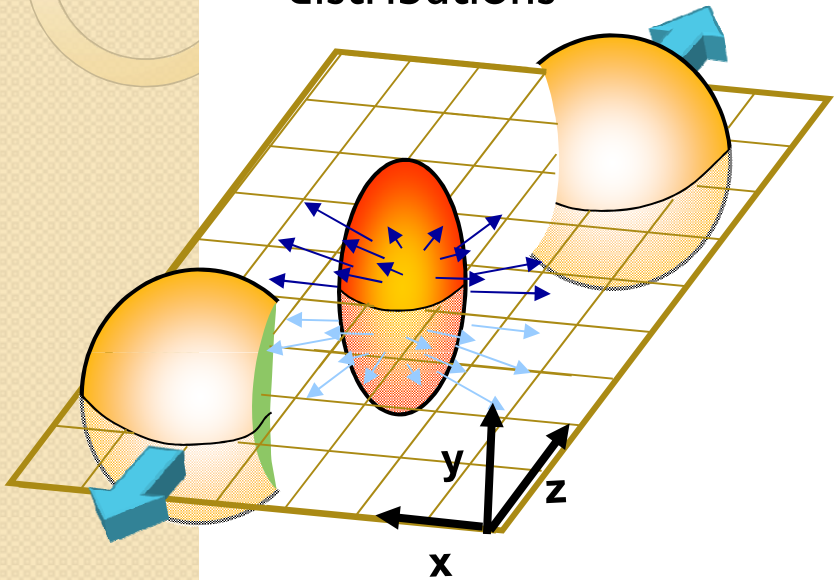
Equilibrium models for Pb-Pb central collisions describe rather well with 2 parameters (T, volume) the yields of all particles…
… including light nuclei

collective flow,
few particle correlations

COLLECTIVE EFFECTS

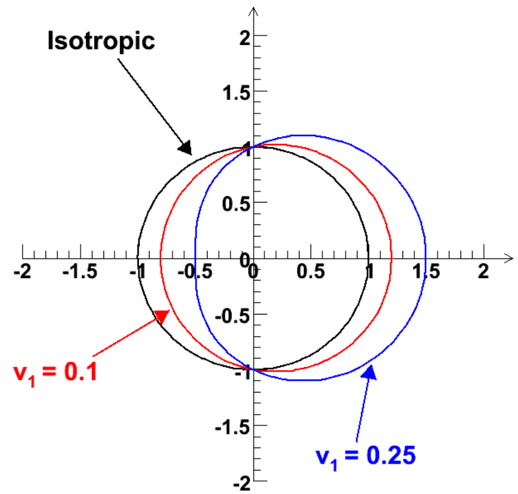
Anisotropic flow

- Basic idea: space anisotropy of initial fireball ⇨ momentum anisotropy in final hadron distributions

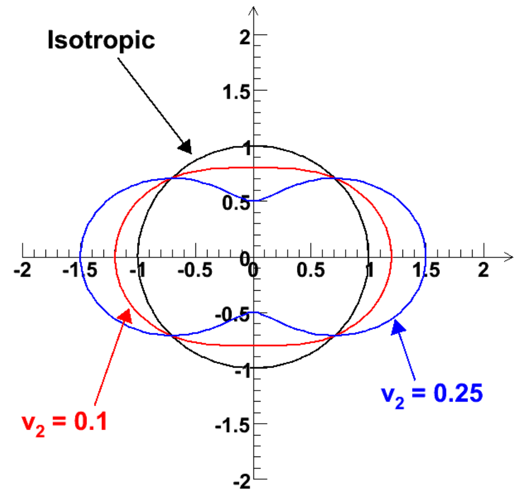


Reaction plane xz

directed flow coeff. v_1



elliptic flow coeff. v_2

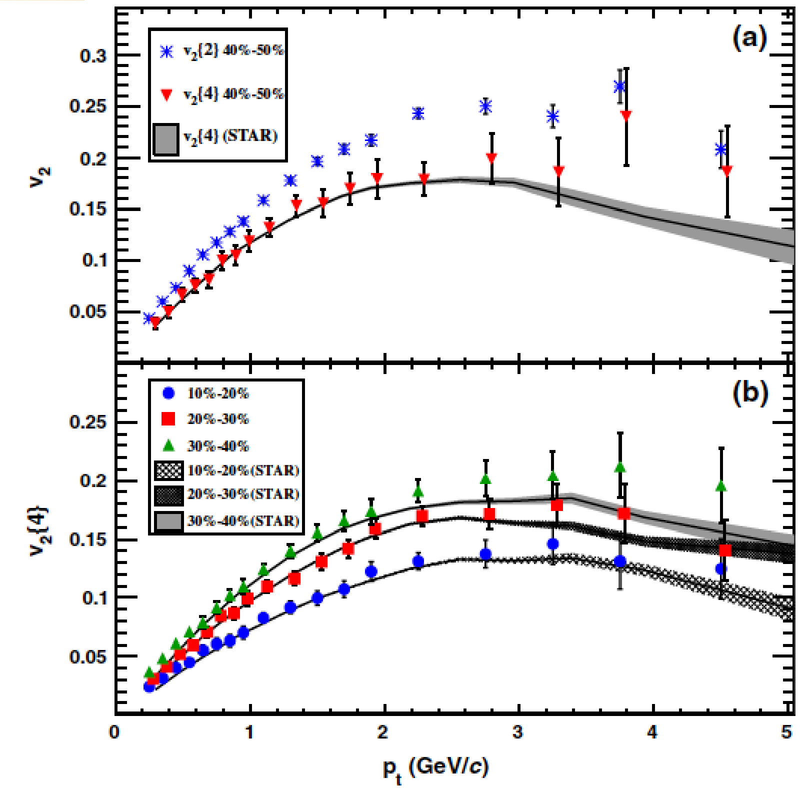


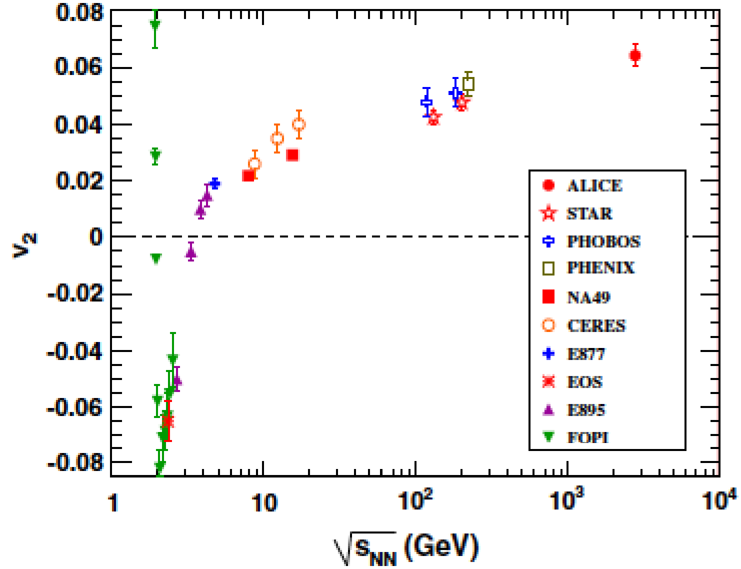
Figures courtesy F. Prino

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left[1 + \sum_{n=1}^{\infty} 2v_n \cos(n\phi)\right]$$

Several methods to extract v_n: event plane, cumulants…
… each with different systematics from 'non-flow'

Charged particle v_2

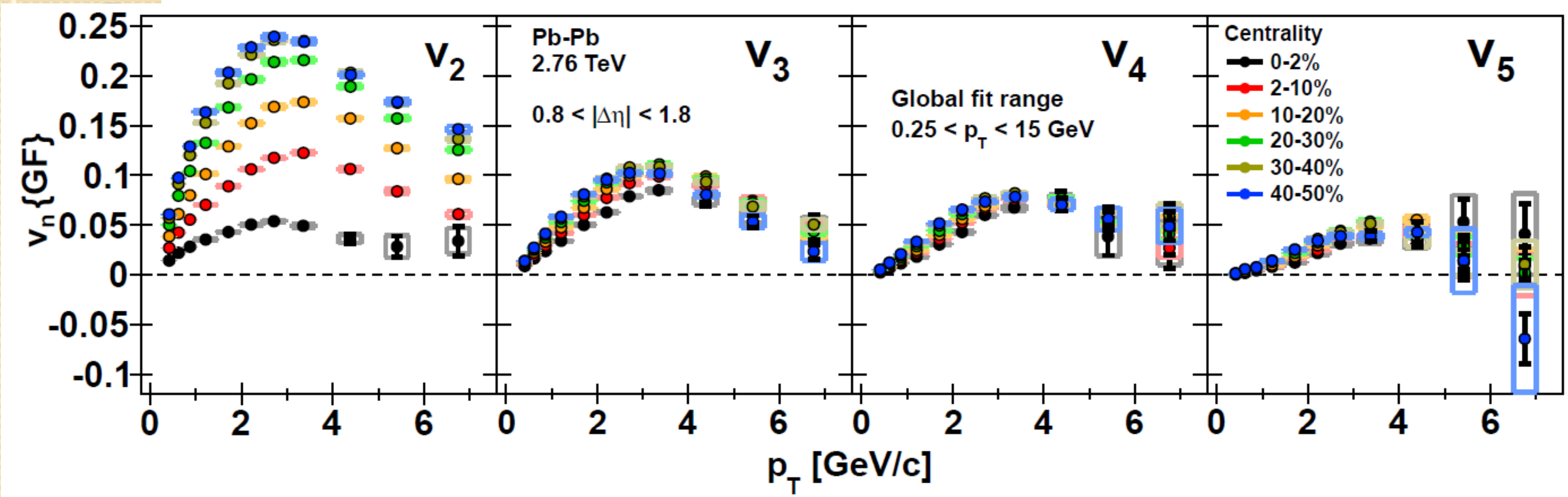




Phys. Rev. Lett. 105, 252302 (2010)

The functional form of $v_2(p_T)$ does not change between RHIC and LHC energies
The overall v_2 is larger at LHC due to the larger average p_T

Charged particle v_n



Phys. Lett B 708, 249 (2012) [see also PRL 107, 032301 (2011)]

- higher Fourier components (n>2) arise due to fluctuations in the initial geometry
- the Fourier components can be extracted via the correlation of produces particles with the n-th symmetry plane Ψn:

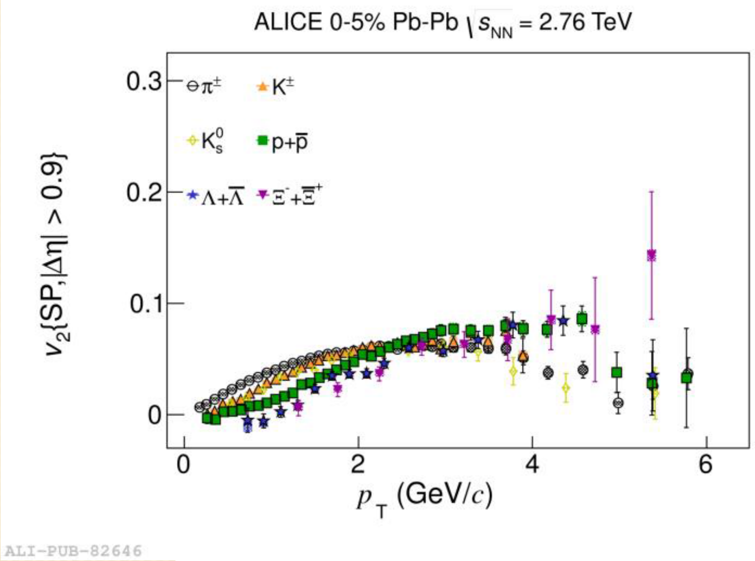
$$\frac{\mathrm{dN}}{\mathrm{d}\phi} \propto 1 + \sum_{n=1}^{\infty} 2v_n(p_T)\cos(n(\phi - \Psi_n))$$

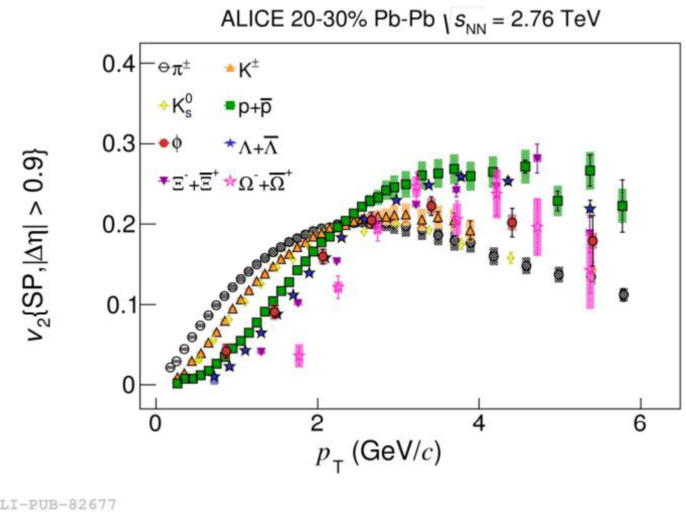
- or via the analysis of 2-particle correlations (trigger and associate particle) separated by a Δη gap (typ. 0.8), under the assumption of factorization:

$$\frac{\mathrm{dN}^{\mathrm{pairs}}}{\mathrm{d}\Delta\phi} \propto 1 + \sum_{n=1}^{\infty} 2V_{n\Delta}(p_T^t, p_T^a)\cos(n\Delta\phi)$$

$$\boxed{V_{n\Delta}(p_T^t, p_T^a) = \langle v_n\{2\}(p_T^t)\, v_n\{2\}(p_T^a)\rangle}$$

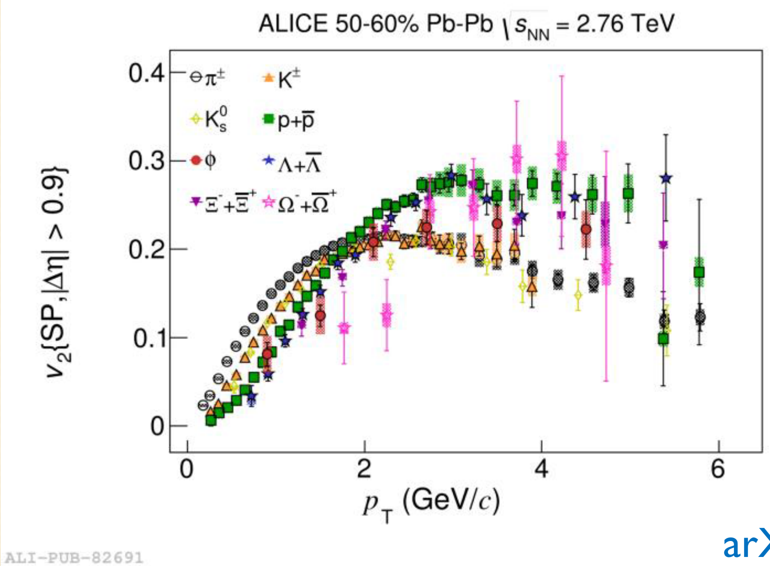
Identified particle v_2

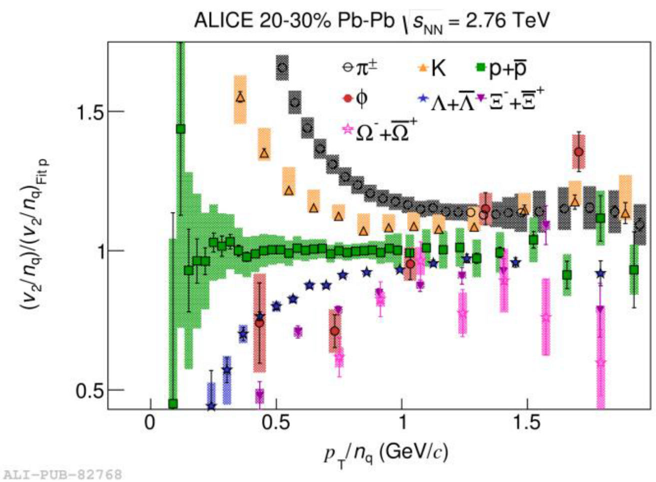




mass ordering
→ common radial expansion velocity

ϕ meson behaves like a baryon

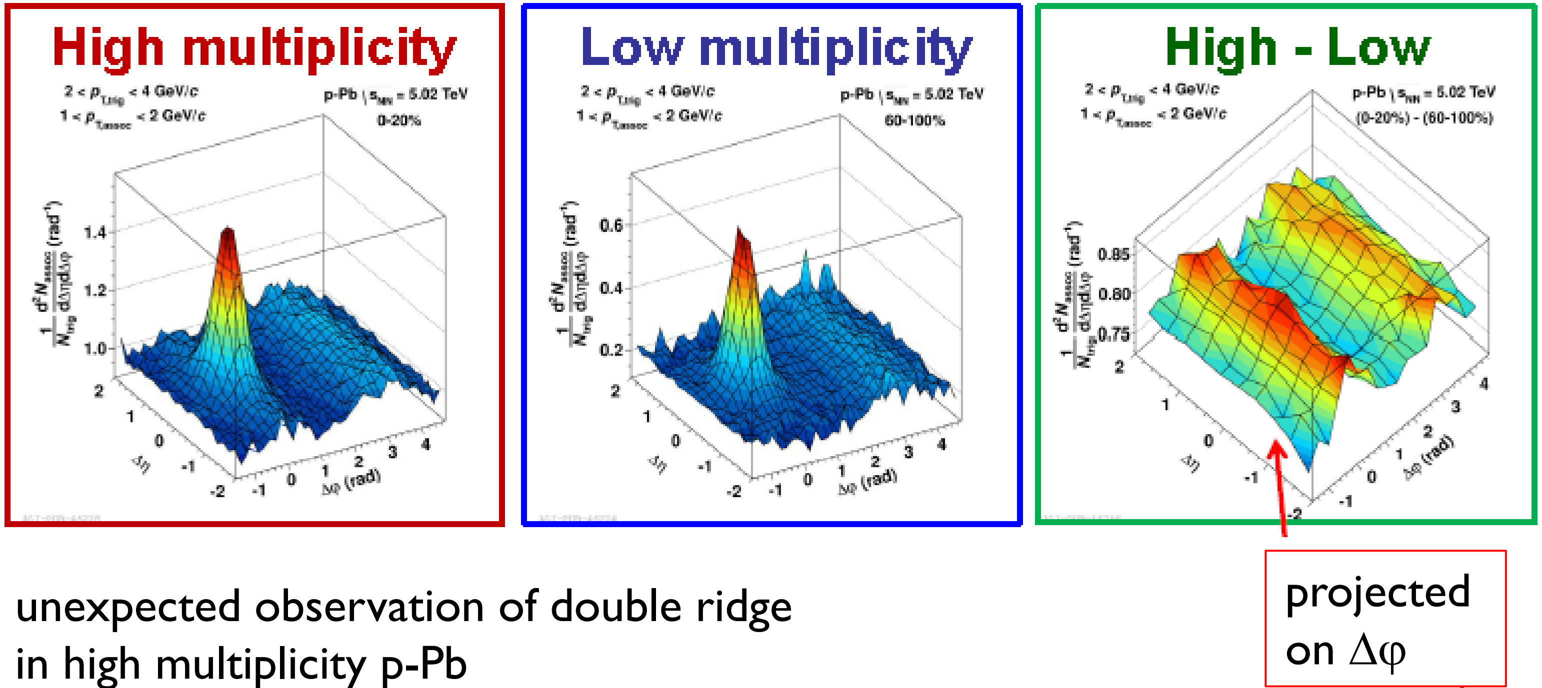




v_2/n_q scaling less obvious at LHC as compared to RHIC

arXiv:1405.4632

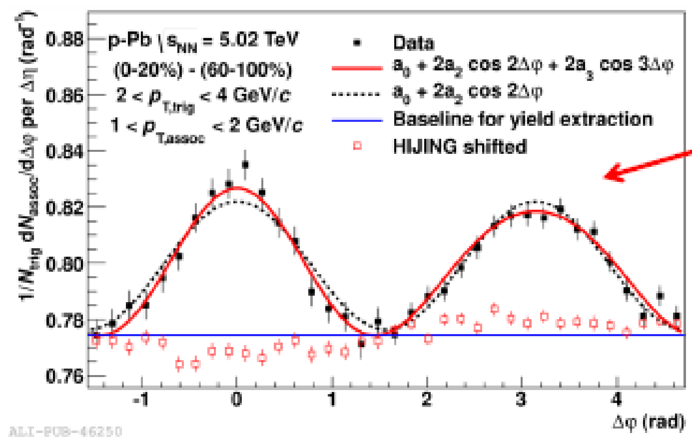
Correlations: double ridge in p-Pb



unexpected observation of double ridge in high multiplicity p-Pb

PLB 719, 29 (2013)

double ridge described by both Color Glass Condensate (initial state effect) or hydrodynamics (final state effect)



modification of jets in the hot medium

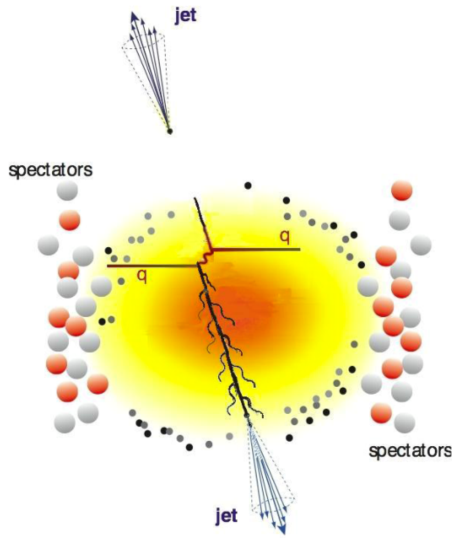
JET QUENCHING

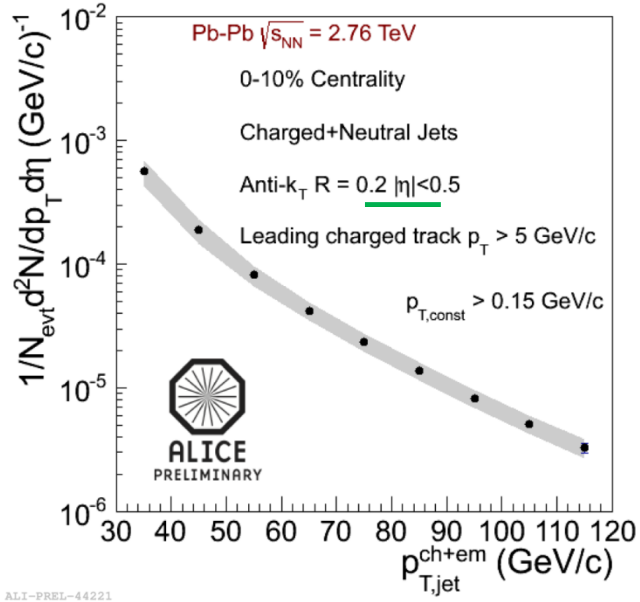
jets in ALICE:
charged particles in barrel (|η|<0.9, full azimuth)
EM energy in EMCal (|η|<0.3, 1/3 azimuth)

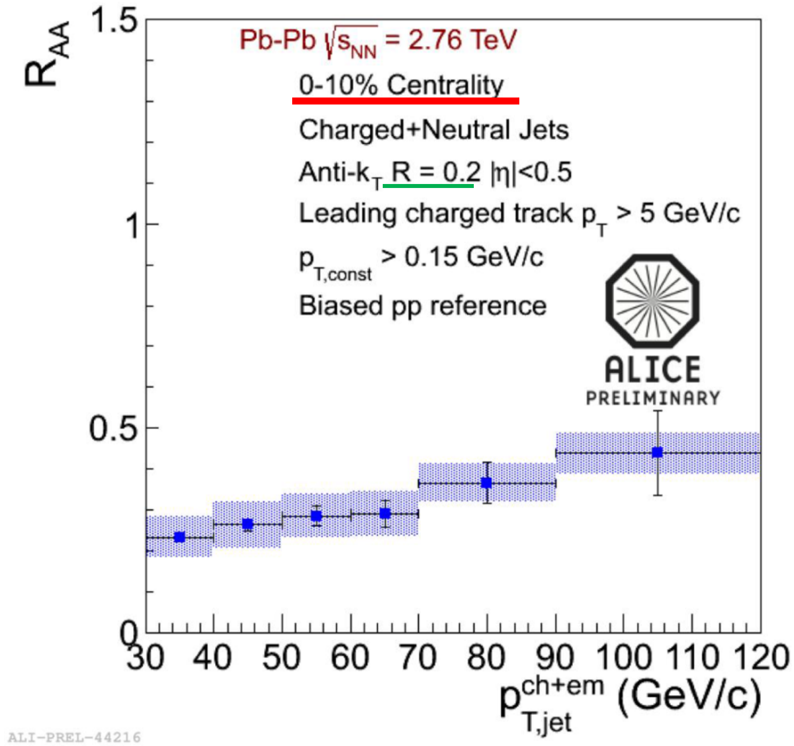
Jet suppression in Pb-Pb

$$R_{AA} = \frac{d^2N^{AA}/dp_T d\eta}{\langle N_{coll}\rangle d^2N^{pp}/dp_T d\eta}$$

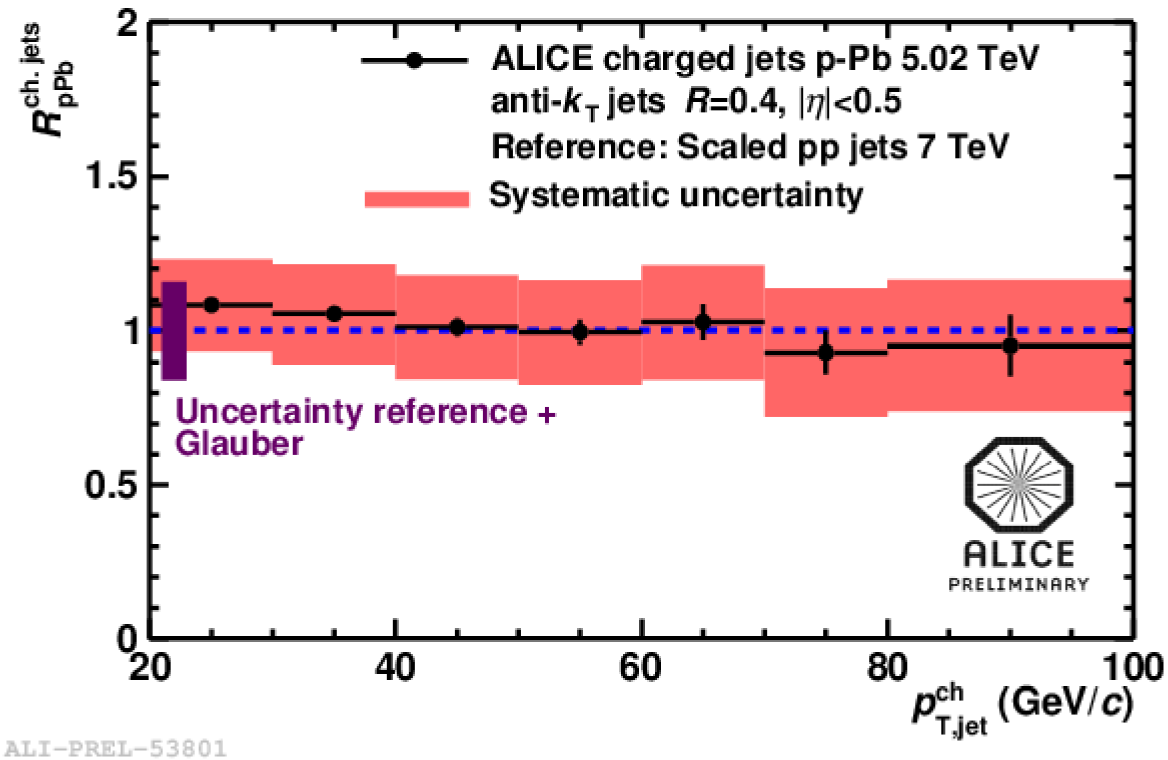
$$\langle N_{coll}\rangle = \langle T_{AA}\rangle \cdot \sigma_{pp}^{INEL}$$







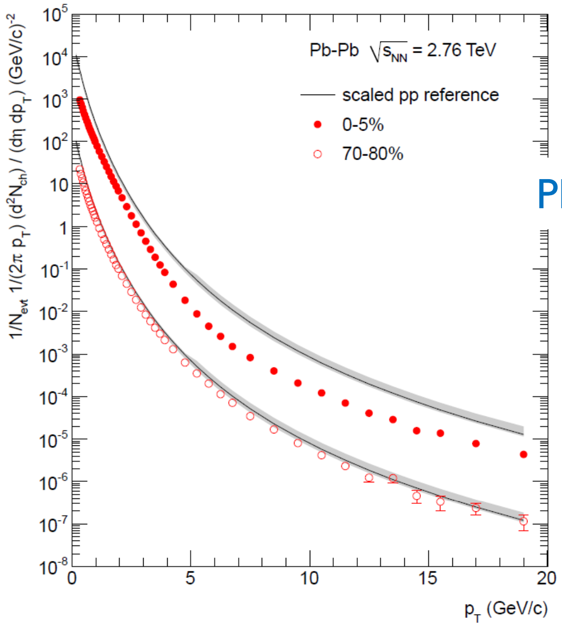
Charged jets in p-Pb



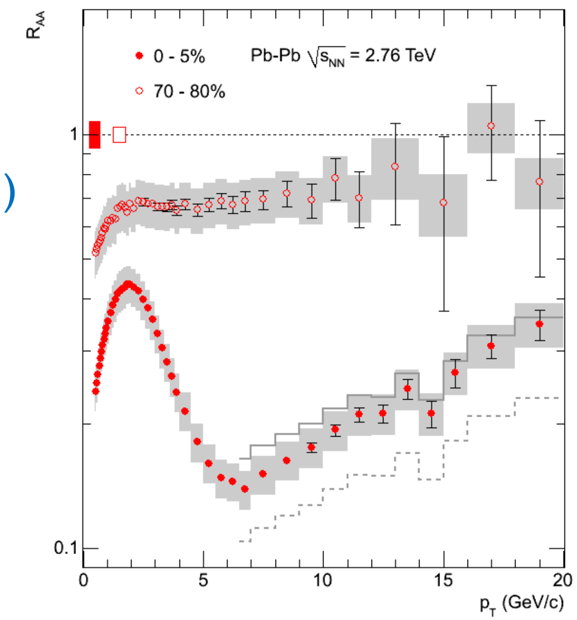
No modification of jet cross section in p-Pb relative to pp
⇨ no significant cold nuclear matter effects observed in jet measurements in p-Pb

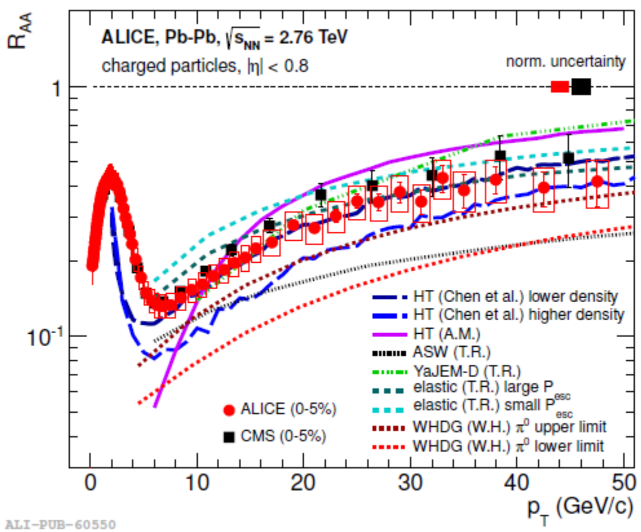
pp reference for R_{pPb} at the needed energy of 5.02 TeV obtained by scaling the measured jet spectrum in pp collisions at 7 TeV

Charged particle suppression in Pb-Pb



PLB 696, 30 (2011)

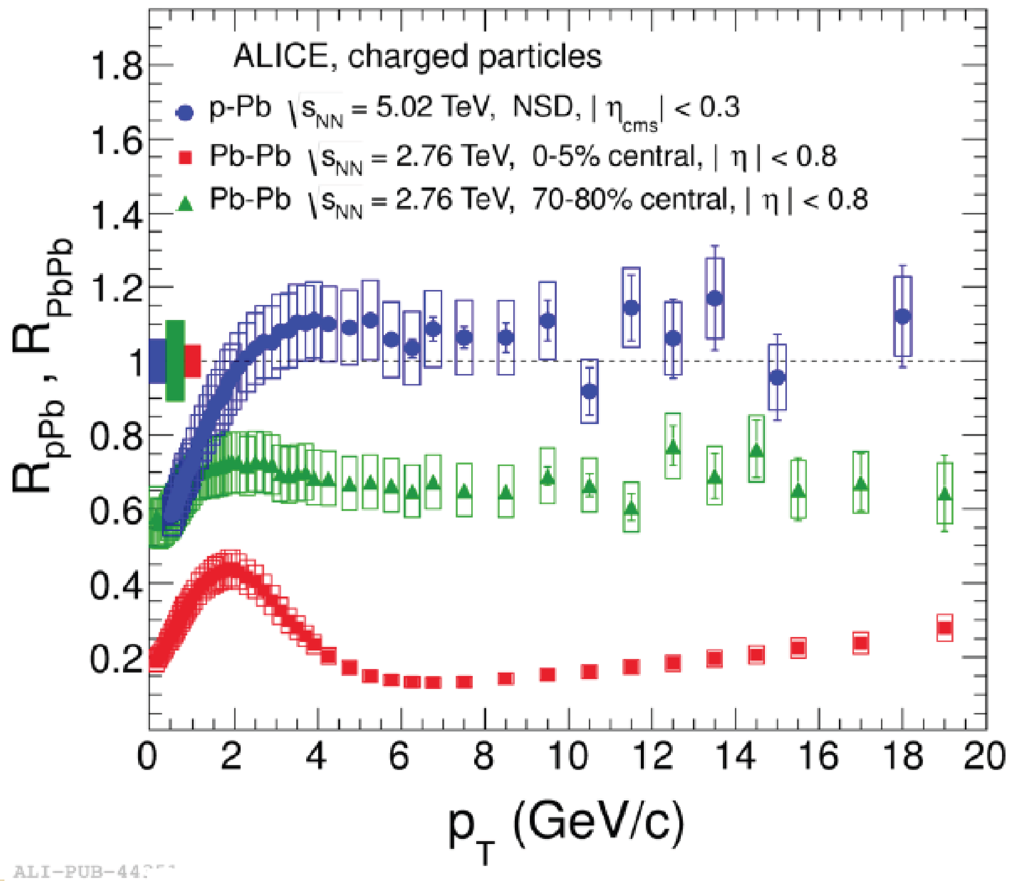




PLB 720, 52 (2013)

Strong suppression of charged particles in central Pb-Pb collisions up to p_T of 50 GeV/c roughly matching the one observed for jets (beware: different meaning of p_T for leading charged particle and jet)

Charged particle suppression in p-Pb

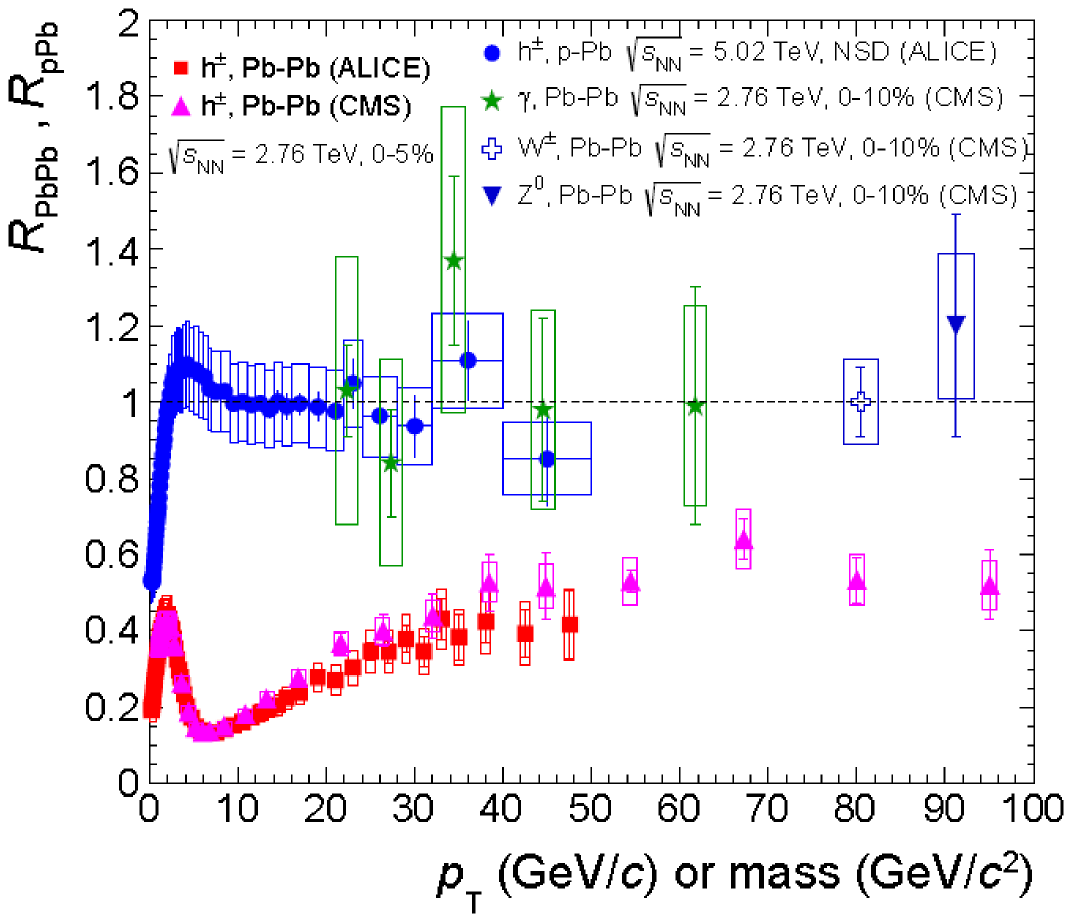


PRL 110, 082302 (2013)

- Strong suppression of charged hadrons in Pb-Pb (wrt pp) up to very high momenta

- p-Pb results confirm that strong suppression in Pb-Pb is due to hot nuclear matter effects

Charged particles at high p_T



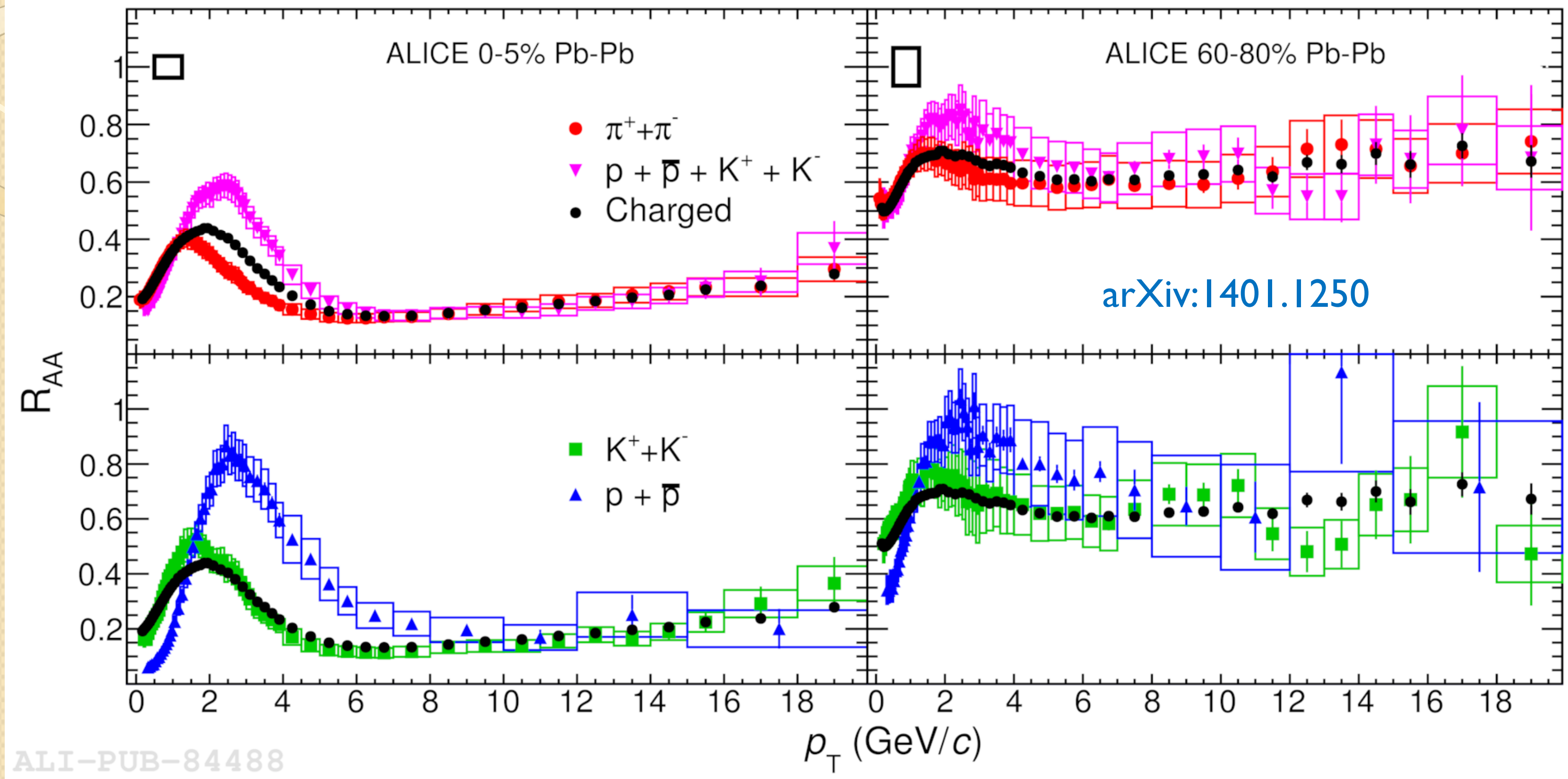
arXiv: 1405.2737

R_{pA} consistent with unity up to 50 GeV/c:

charged particle (jet) quenching is a genuine hot matter effect

check of N_{coll} scaling in Pb-Pb extended up to 100 GeV/c$^{(2)}$ by CMS using direct photons, W and Z as reference particles

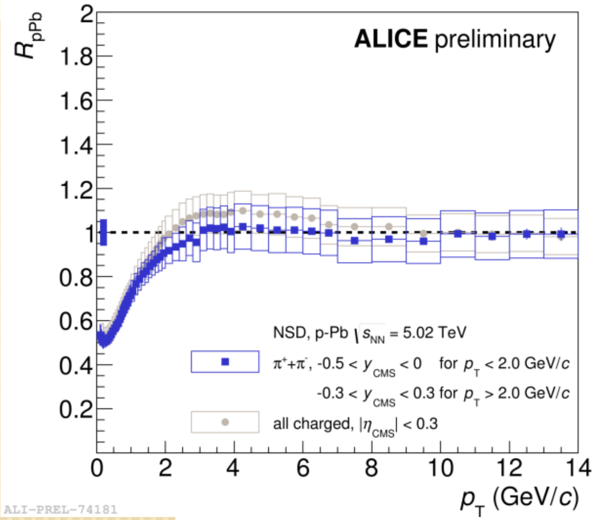
Identified particle suppression

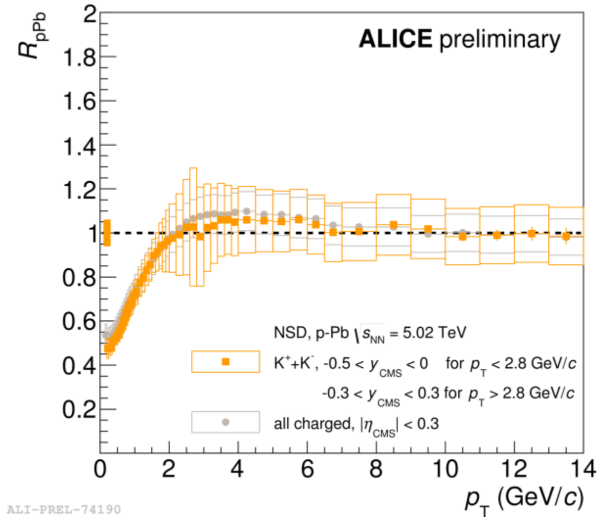


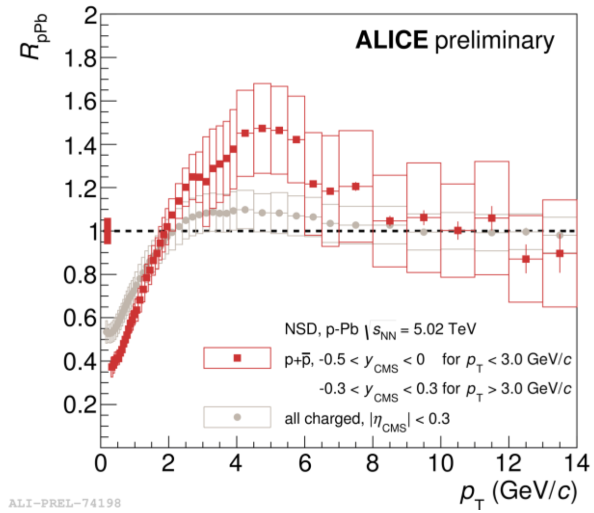
- p_T < 3 GeV/c: ratios K/π and p/π in agreement with hydro
- p_T > 8-10 GeV/c: ratios similar in pp and Pb-Pb ⇨ particle composition of in-medium jets similar to those in vacuum

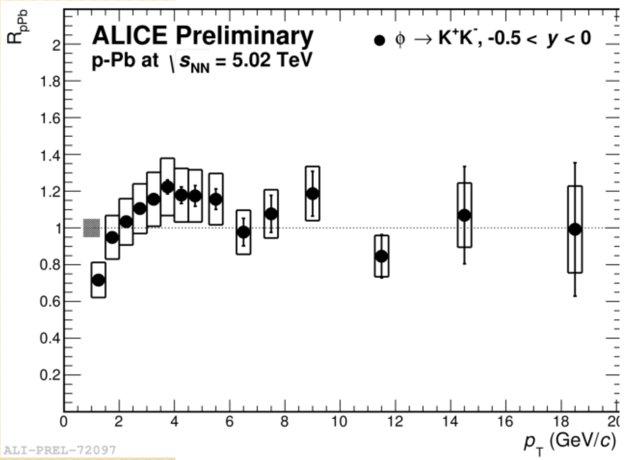
predictions of significant modifications of high-p_T hadrochemistry induced by jet quenching disfavoured

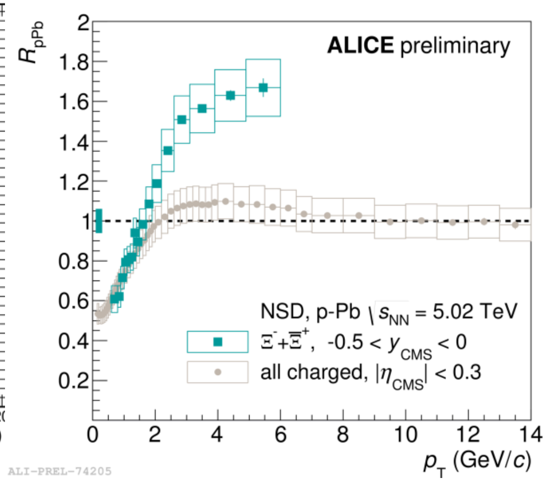
Identified particle spectra in p-Pb











"Cronin enhancement" for baryons at p_T=3-5 GeV/c

Mass dependence of $R_{p\text{-}Pb}$?

ϕ meson is similar to π and K

$R_{pPb} \rightarrow 1$ for all particles species: suppression observed in Pb-Pb is a hot matter effect another class of hard probes

Dokshitzer and Kharzeev, PLB 519, 199 (2001)

measured via fully reconstructed decay modes…

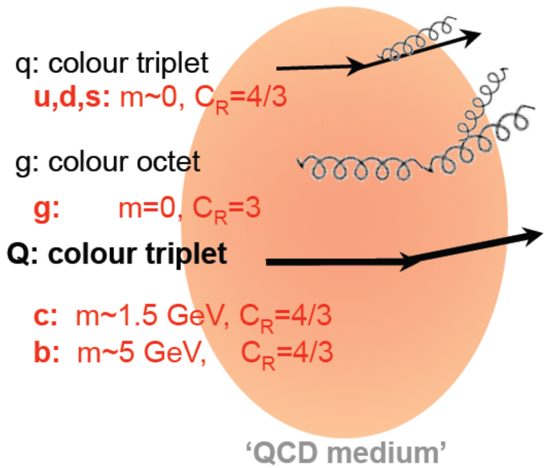
…or via semileptonic decays

OPEN HEAVY FLAVOURS

Importance of Heavy Flavours

- Heavy quarks produced in initial hard scattering, experience full system evolution
- the number of HQ is conserved ⇨ unique tool to characterize the medium
- at LHC HQ are produced copiously ⇨ precision measurements
- Partons lose energy by:
  - medium-induced gluon radiation
  - elastic collisions with other partons
- Energy loss ΔE in the medium depends on:
  - medium properties (transport coefficients $\hat{q}$)
  - parton properties (mass*, colour charge)
  - path length L

$$\langle \Delta E \rangle \propto \alpha_s C_R \hat{q} L^2$$



Expectation from radiative energy loss:

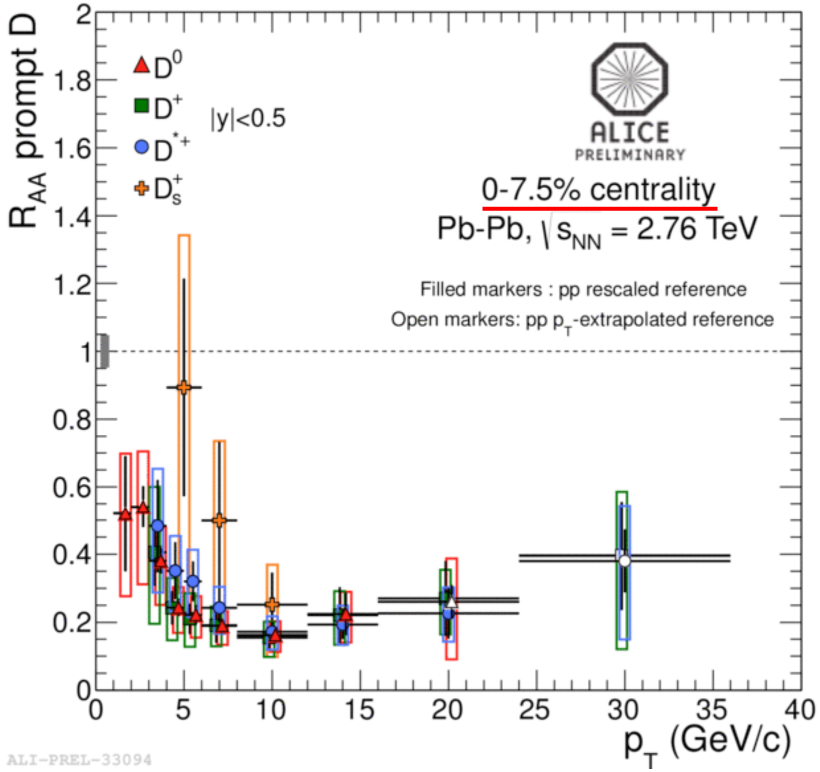
$\Delta E_g > \Delta E_{u,d,s} > \Delta E_c > \Delta E_b$

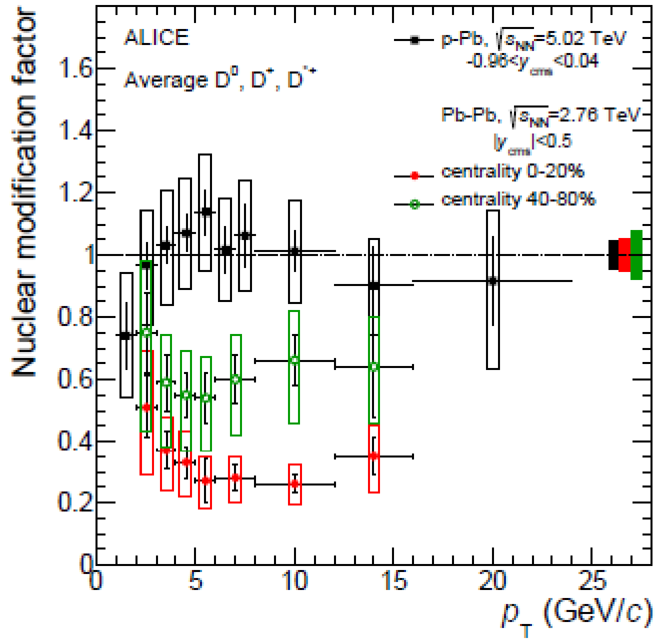
Could be reflected in a hierarchy of meson R_{AA}:

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

* Gluon radiation is suppressed for angles $\theta < M_Q/E_Q$

D-meson R_{AA} and R_{pA}





arXiv:1405.3452

Pb-Pb:

D^0, D^+ and D^{*+} R_{AA} agree within uncertainties

Strong suppression of prompt D mesons in central collisions, up to a factor 5 for p_T ~10 GeV/c

Hint of higher R_{AA} for D_s^+ at low p_T

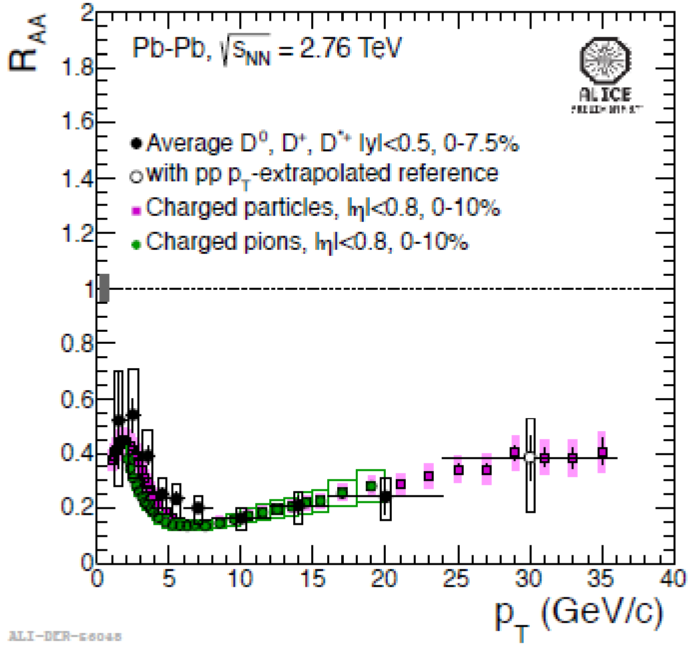
p-Pb vs. Pb-Pb:

Suppression observed in central Pb-Pb due to strong final state effects induced by hot partonic matter

see also (Pb-Pb 0-20% centr.) JHEP 09 (2012) 112

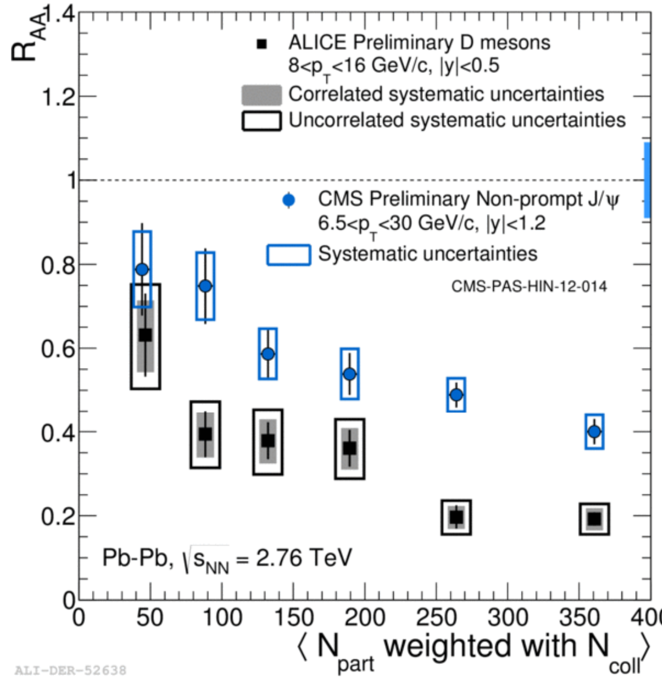
Mass ordering of energy loss?

- **D vs. light hadrons**



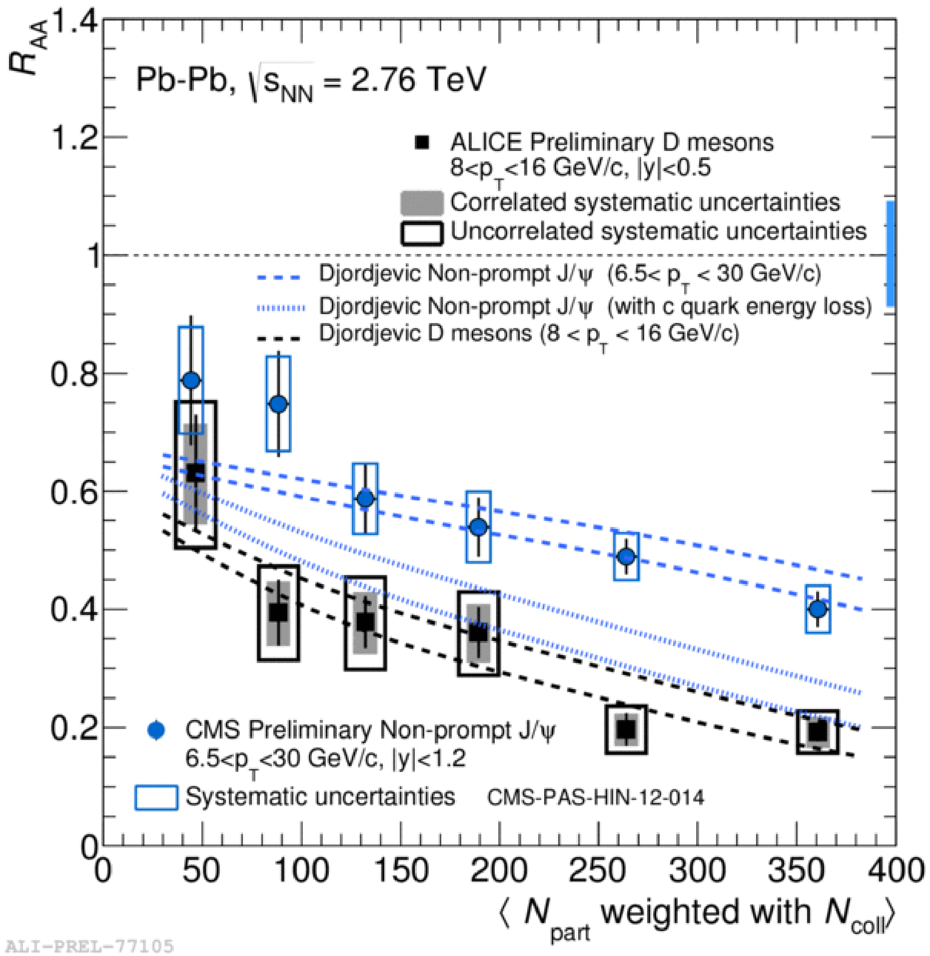
- D consistent with π within errors but improved accuracy needed to conclude (consistency described by theory taking into account different p_T *shapes and fragmentation functions)*

- **Charm vs. beauty**



- Comparing D with (non prompt) J/ψ from B decay with p_T ranges tuned to have same average p_T for both mesons, the expected mass ordering is observed

Charm vs. beauty

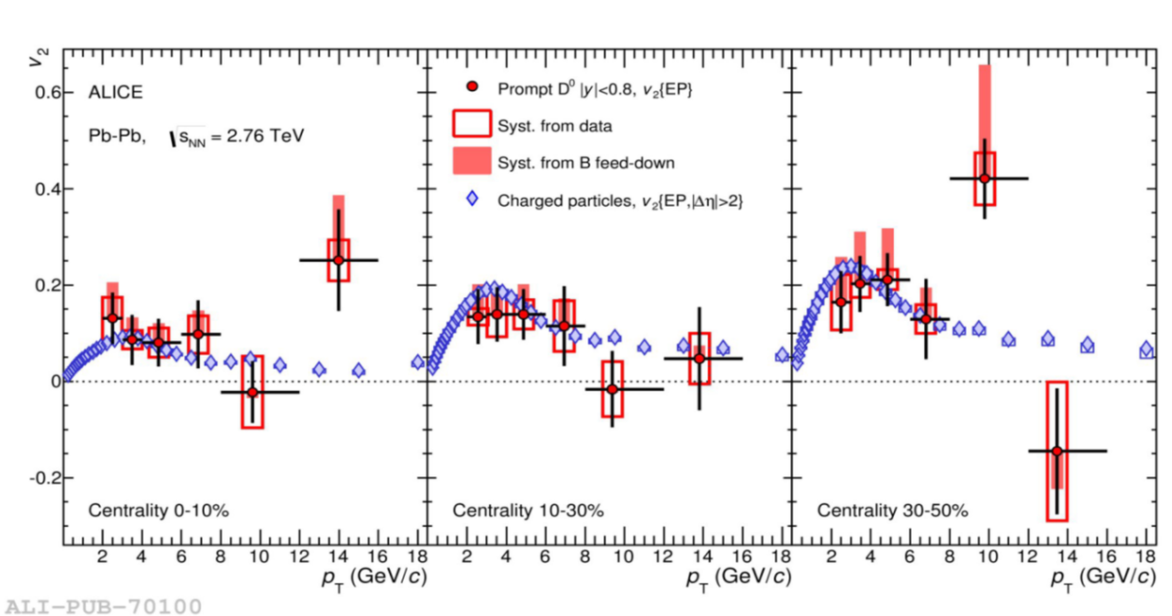


pQCD models including mass dependent radiative and collisional en. loss predict a difference similar to the one observed in data

Results very similar to the ones just shown for D and B mesons have been obtained from leptons from Heavy Flavour decays, both in the central barrel (e, μ) and in the muon spectrometer (μ)

Elliptic flow of heavy flavours

- Due to their large mass, b and c quarks should take longer to be influenced by the collective expansion of the medium, with $v_2^b < v_2^c$
- Measurements of HF v_2 probe:
  - at low p_T, collective motion and thermalization of heavy quarks
  - at high p_T, path-length dependence of energy loss



arXiv: 1405.2001

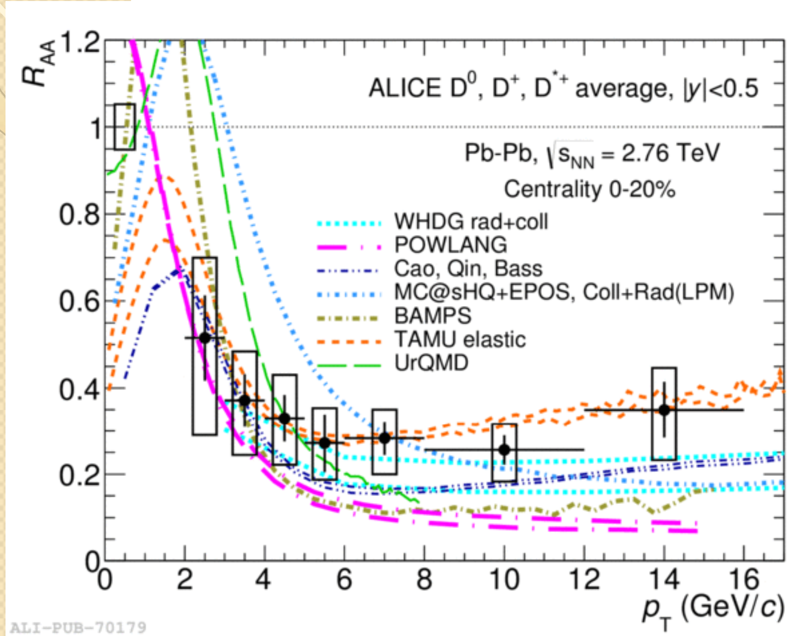
Non-zero v_2 observed in semi-central Pb-Pb collisions

v_2(D) similar to charged particle v_2

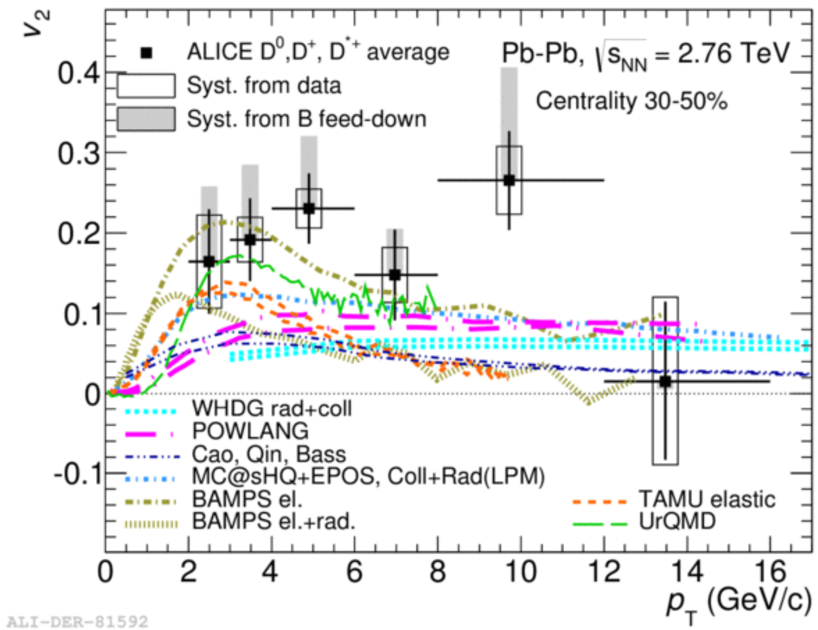
Significant interaction of charm quarks with the medium → suggest collective motion of low p_T charm quarks in the expanding fireball

Heavy flavour R_{AA} and v_2: models

R_{AA} in central Pb-Pb



v_2 in semi-central Pb-Pb



arXiv: 1405.2001

Challenging description, for theory, of nuclear modification and charm flow measurements together

WHDG: Horowitz et al., J Phys. G38 (2011) 124114
POWLANG: Alberico et al., EPJ C71 (2011) 1666
Cao, Qin, Bass, arXiv:1308.0617
Aichelin et al.:PRC79 (2009) 044906,
J. Phys. G37 (2010) 094019
BAMPS: Fochler et al., J. Phys. G38 (2011) 124152
TAMU: Rapp, He et al., PRC 86 (2012) 014903
UrQMD: Lang et al, arXiv:1211.6912, arXiv:1212.0696

the historical hard probe for QGP temperature

Matsui and Satz, PLB 178, 416 (1986)

Digal et al., PRD 64, 094015 (2001)

Braun-Munzinger and Stachel, PLB 490, 196 (2000)

QUARKONIA

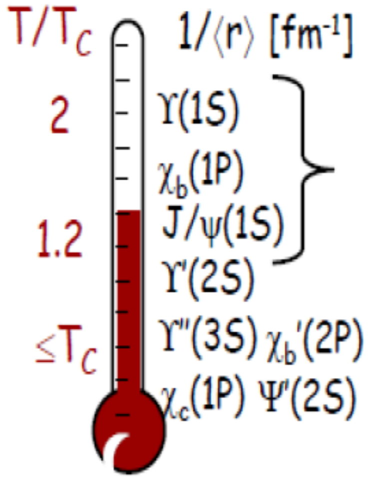
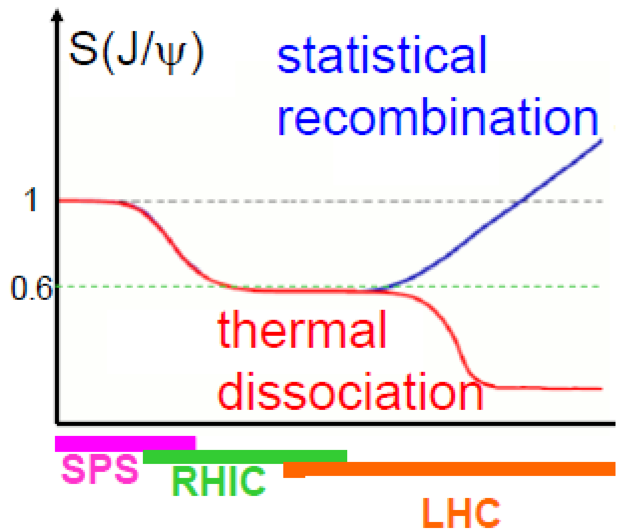


figure from A. Mocsy

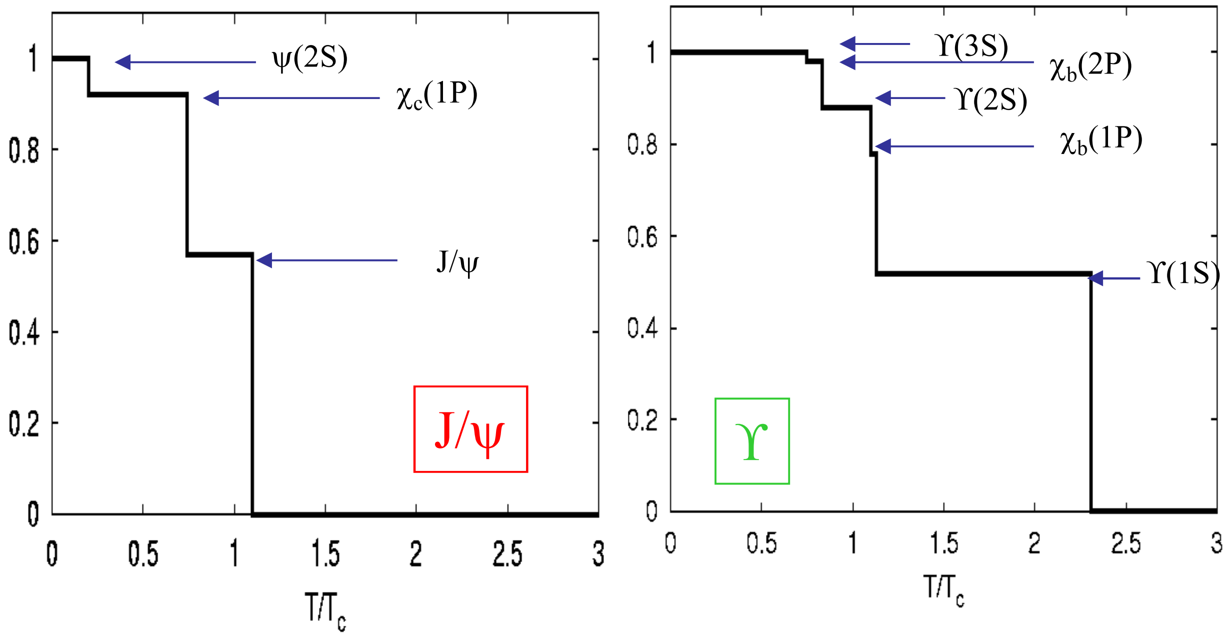


Importance of quarkonia

- Binding of a $q\bar{q}$ pair is subject to the effect of colour screening in the QGP
- If the radius of the state is > screening radius $\lambda_D(T)$
  - the state cannot be formed above a certain temperature
  - therefore, J/ψ suppression was proposed as a signature of QGP formation (Matsui and Satz, 1986)
- Differences in binding energies / screenign lengths of different states ⇨ 'sequential' melting of charmonium and bottomonium states
- Suppression of J/ψ first seen at SPS in central Pb-Pb collisions (NA50 experiment), then at RHIC
- Furthermore, at RHIC/LHC energies, thermal regeneration of $q\bar{q}$ pairs becomes important

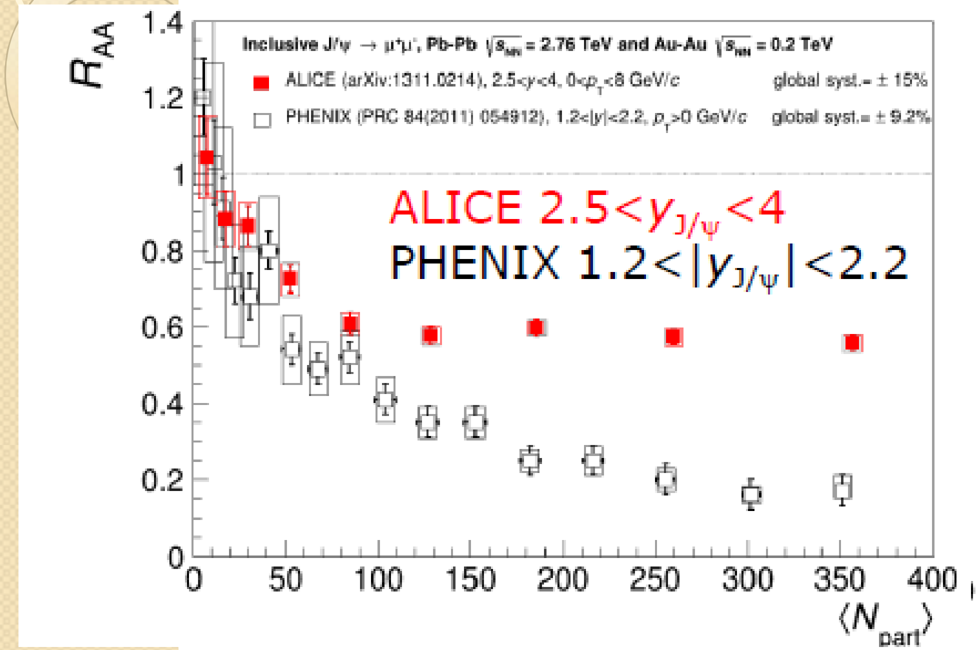
Sequential dissociation of $Q\bar{Q}$ states

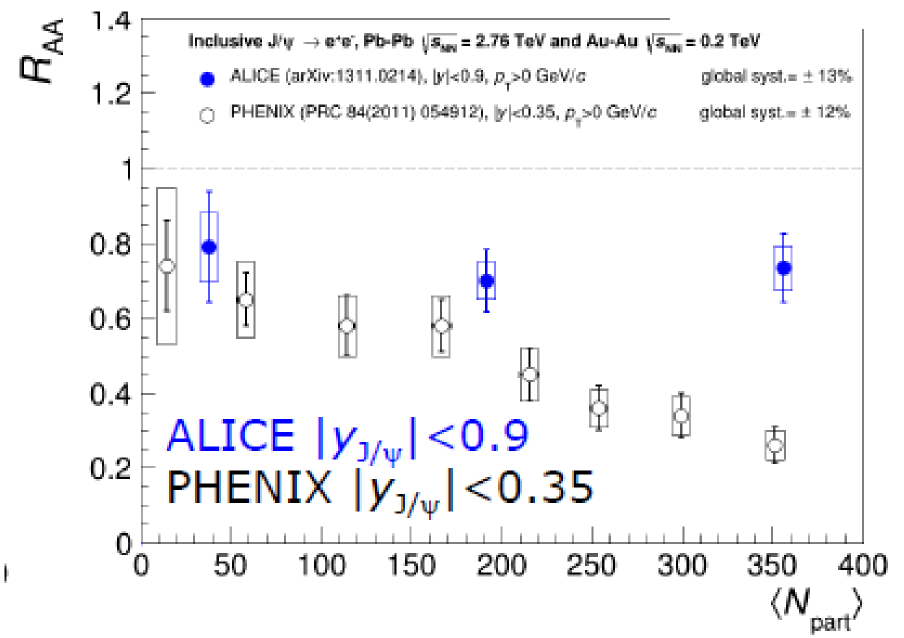
Digal et al., PRD 64, 094015 (2001)



Quarkonia in Pb-Pb and p-Pb (I)

ALICE: PLB 743 (2014) 314

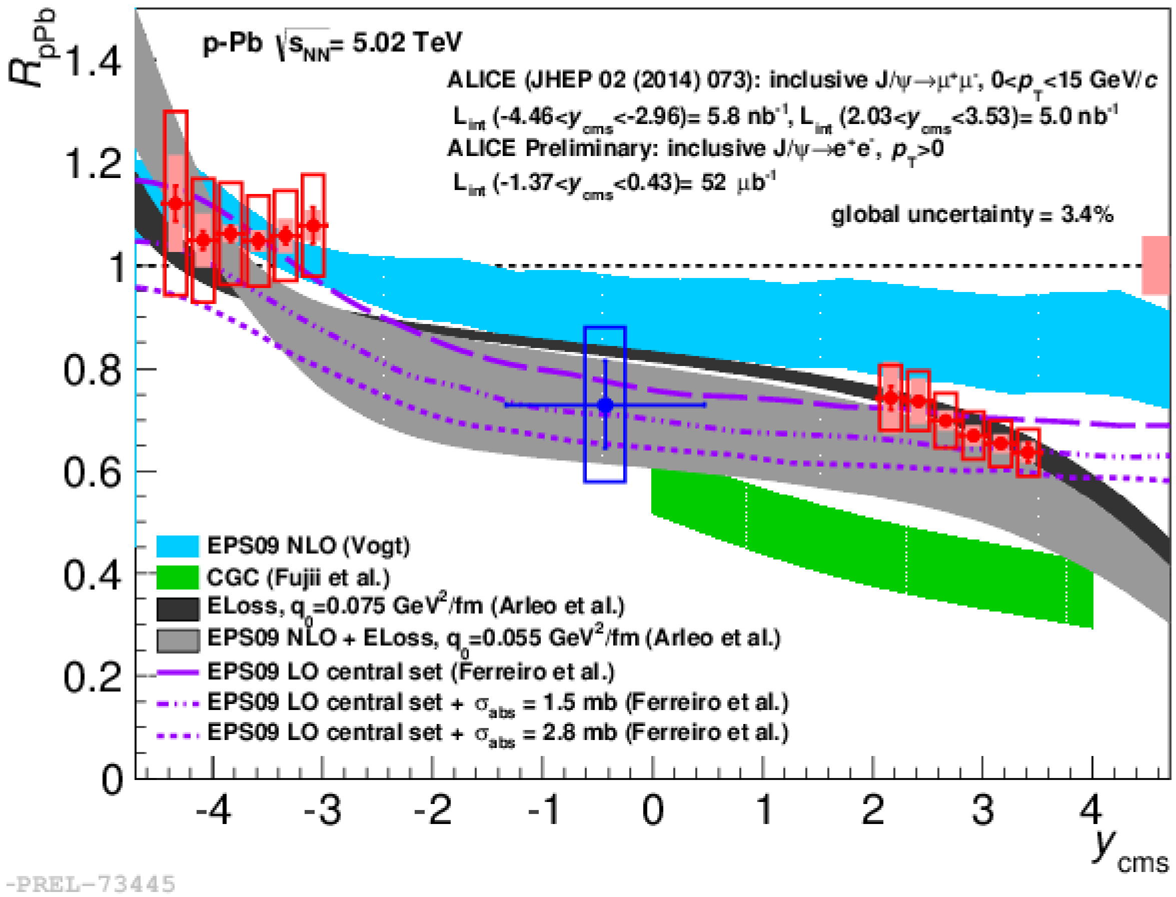




Pb-Pb: clear J/ψ suppression with almost no centrality dependence above N_{part}~100.
Less suppression at mid-y wrt forward y for central events.

Comparison with PHENIX [PRC 84 (2011) 054912]: ALICE results show weaker centrality dependence and smaller suppression for central events
⇨ at LHC the contribution to J/ψ from statistical recombination is larger

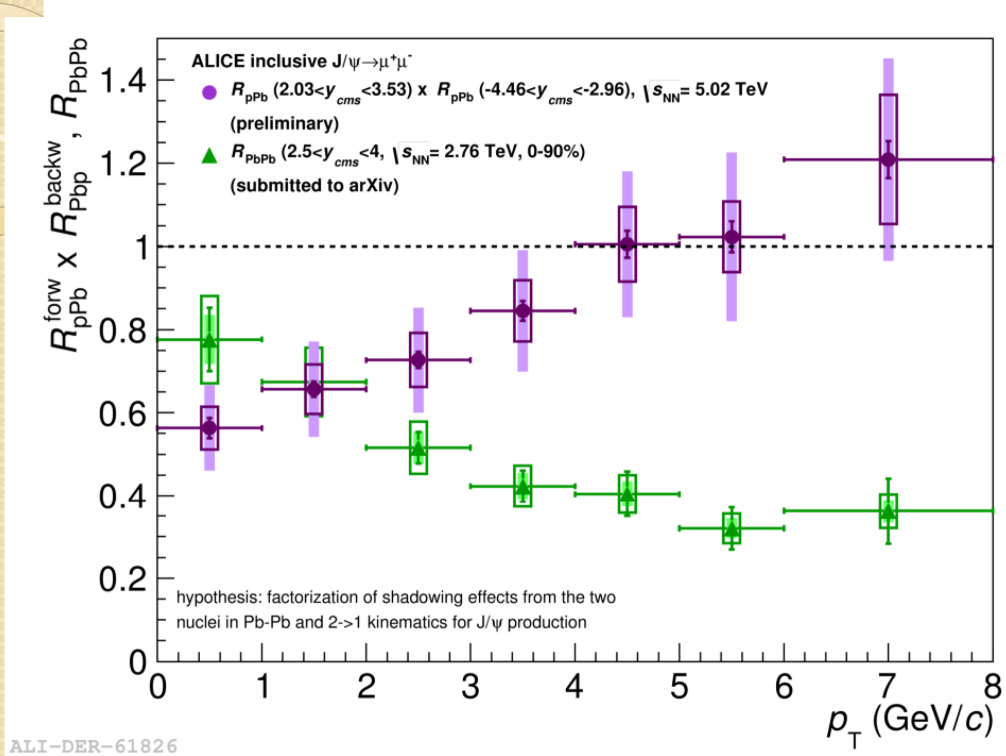
Quarkonia in Pb-Pb and p-Pb (2)



also in **p-Pb**, the J/ψ production is heavily modified due to Cold Nuclear Matter effects

R_{pA} decreases towards forward rapidity, in agreement with shadowing and coherent energy-loss models

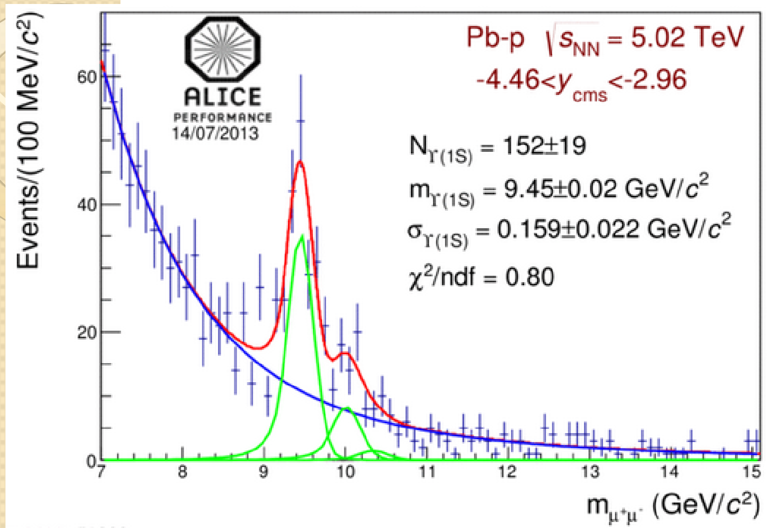
Quarkonia in Pb-Pb and p-Pb (3)

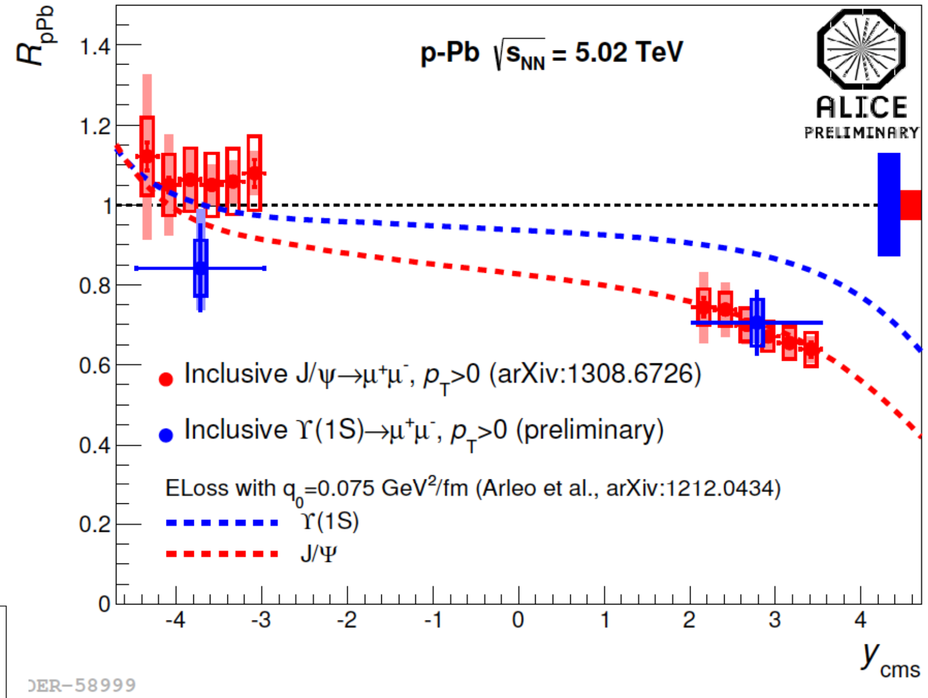


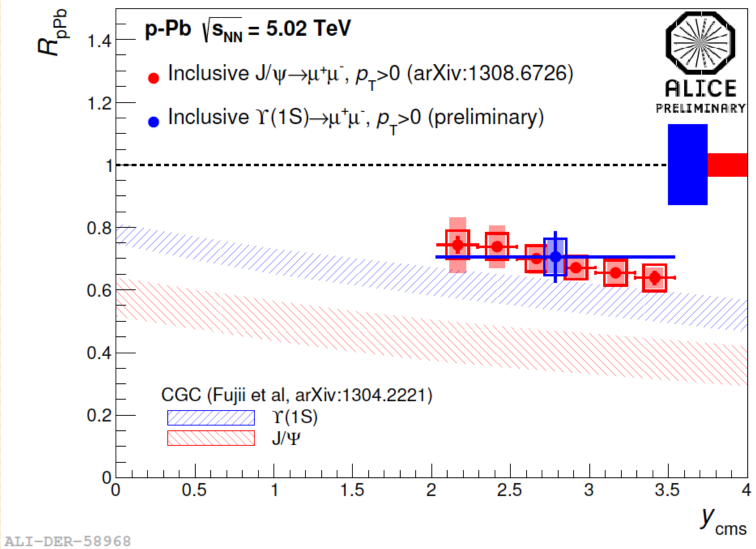
rough extrapolation of CNM effects, evaluated in p-Pb and Pb-p, to the Pb-Pb kinematical range

⇨ evidence of hot matter effects in Pb-Pb!

Bottomonium in p-Pb







ALICE dataset provides strong constraint to models what next?

OUTLOOK

- Run2 in 2015 – 2017
  - Complete geometry for all detectors
  - Upgraded detectors, readout, trigger
  - LHC energy up to 13 TeV for pp (~5.1 TeV for Pb-Pb)
  - Collect 10 pb^{-1} with pp rare triggers, 70 nb^{-1} with pp minimum bias trigger, 1 nb^{-1} with Pb-Pb.
- Run3 2020-2022 and beyond:
  - Major detector upgrade: new ITS and new TPC readout
  - Improvement in vertexing capability and tracking a low p_T
  - Increase data-taking rate by factor 100! (→ 50kHz Pb-Pb)
  - Precision studies of charm and beauty mesons and baryons and quarkonia at low p_T
  - Low mass lepton pairs and thermal photons
  - γ-jet and dijets with particle identification in a large kinematic range
  - Heavy nuclear states

The ALICE Collaboration:
37 countries, 151 institutes, 1550 members

THANK YOU FOR YOUR ATTENTION!

BACKUP

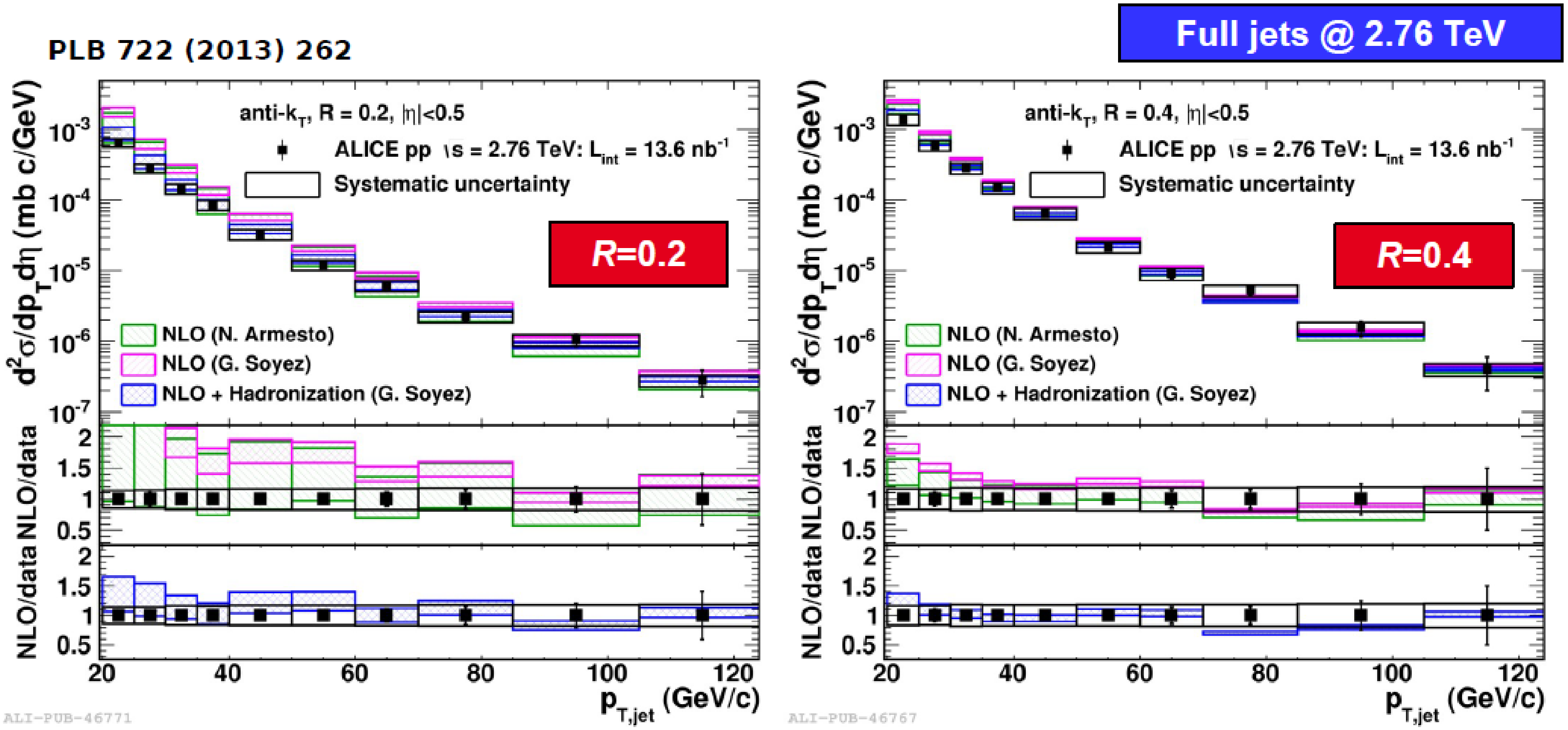
Jet reconstruction

- FastJet[1] is used for jet finding
  - anti-k_T algorithm for signal jets
  - k_T algorithm for background correction
  - Resolution parameters R = 0.2–0.6
  - Transverse momentum calculated by using FastJet's p_T particle recombination scheme
- Jets are corrected for background + fluctuations
  - depending on collision system
- Additionally, calorimeter clusters are corrected for energy from charged tracks to avoid double-counting:

$$E_{\mathrm{clus}}^{\mathrm{corr}} = E_{\mathrm{clus}}^{\mathrm{orig}} - \sum p^{\mathrm{matched}}$$

[1] Cacciari, Salam. Phys. Lett. B641(2006), `arXiv:0512210` [hep-ph]

Jets in pp collisions



- At 2.76 TeV: Cross sections for *R*=0.2 and *R*=0.4 measured and compared to NLO calculations
- Important reference for heavy-ion collisions
- Good agreement with NLO calculations including hadronization

Radial jet structure in pp collisions

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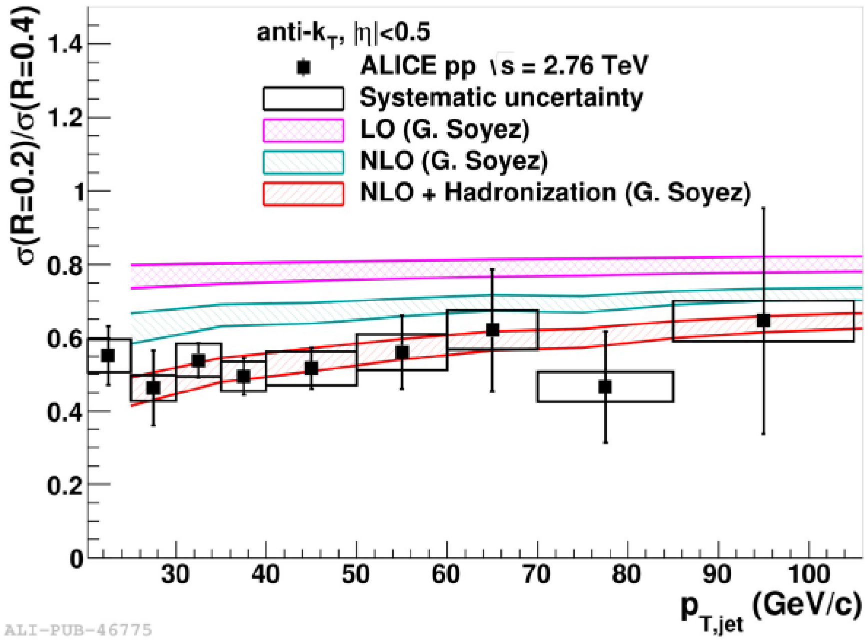
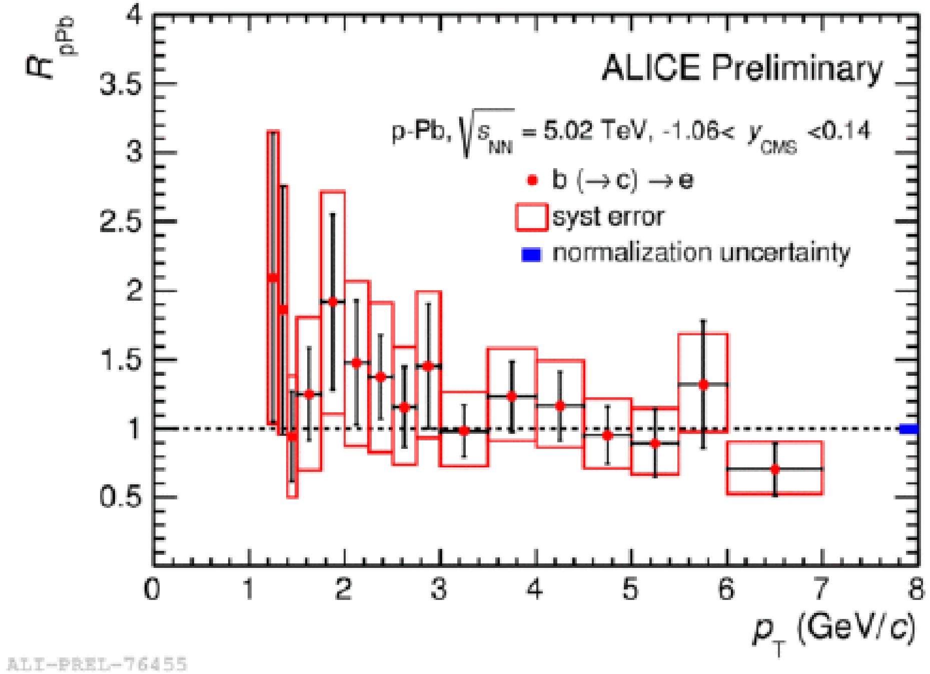
Full jets @ 2.76 TeV



- Ratio was measured for full jets with *R*=0.2/*R*=0.4
- Best theory-data agreement for NLO calculations taking hadronization effects into account

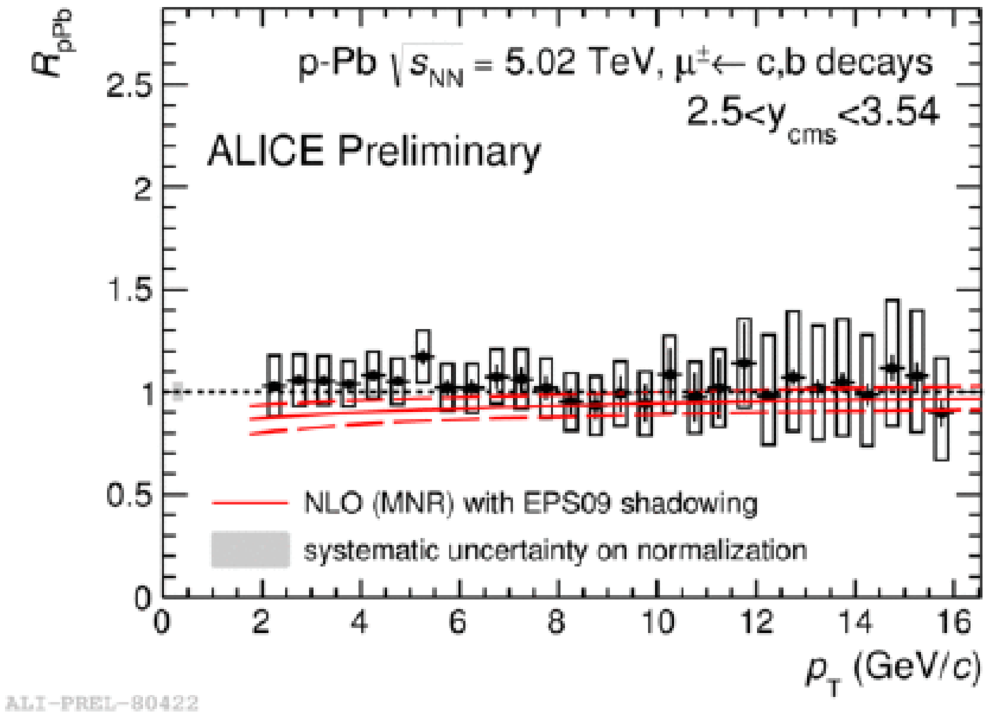
R_{pA} of electrons from beauty decays



further check of binary scaling (Ncoll) in p-Pb:

also electrons from beauty decays show R_{pA} consistent with unity as do:
- charged hadrons for p_T > 10 GeV/c,
- charged jets up to 100 GeV/c,
- D mesons

R_{pA} of muons from HF decays



further check of binary scaling (Ncoll) in p-Pb:

also muons from charm, beauty decays show R_{pA} consistent with unity as do:

- charged hadrons for p_T > 10 GeV/c,
- charged jets up to 100 GeV/c,
- D mesons