Recent ALICE & CMS results – One step closer to the edge ….

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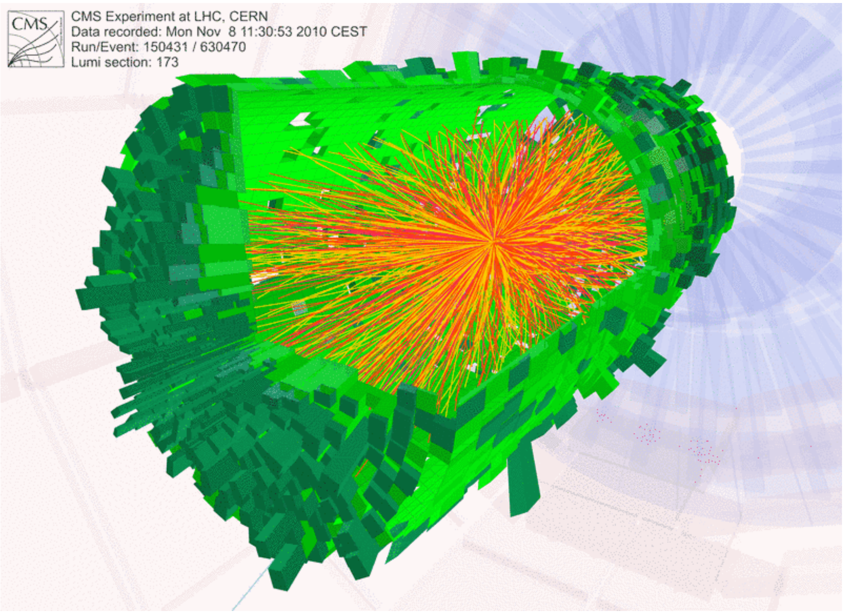
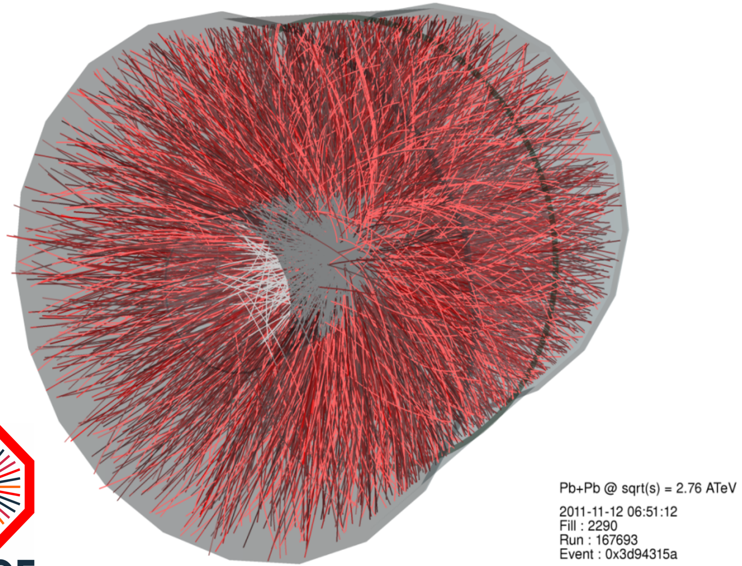


ALICE

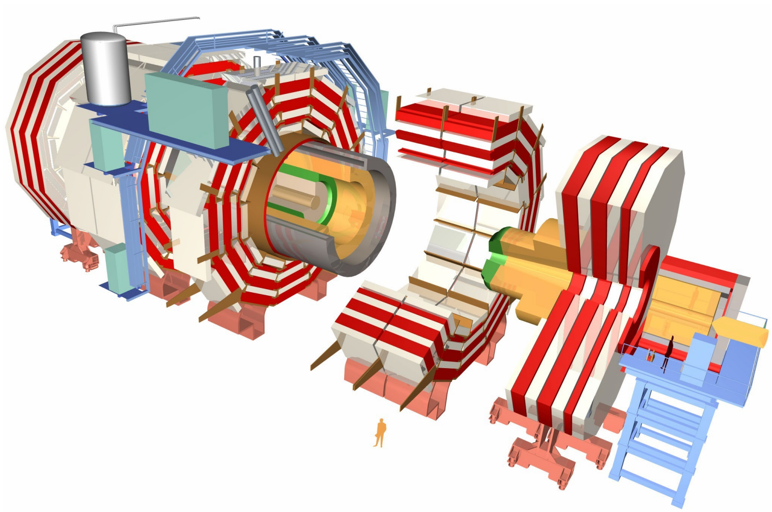


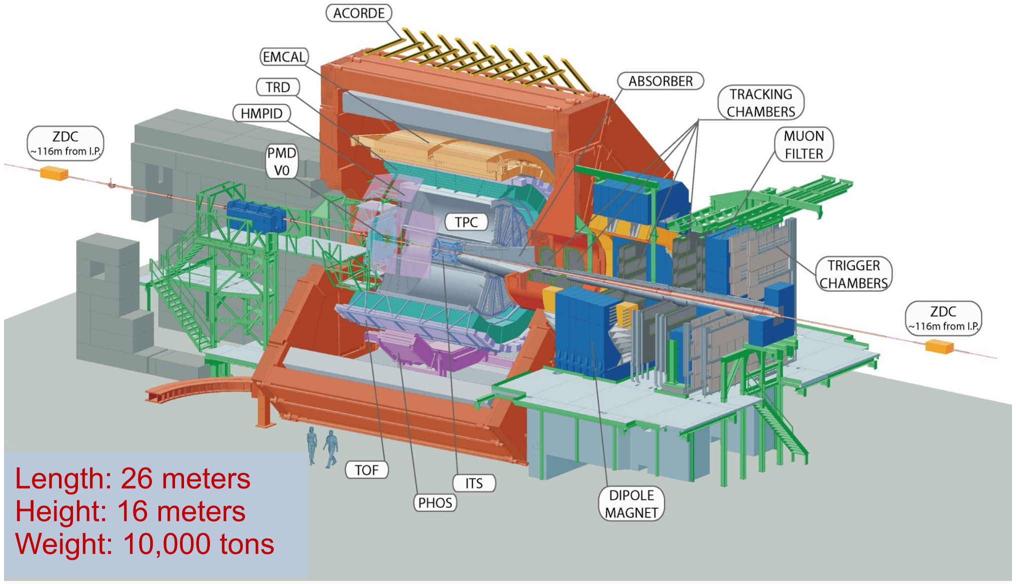
one of those unforgiving talks that read like a shopping list……….

One step closer to the edge….

- How much closer ? Global observables
- The bulk shows new PID features
  - Yields, spectra, ultra-central collisions
- The intermediate p_T puzzle continues
  - Baryon/meson ratios
- The high p_T disappointment or excitement ?
  - Hadro-chemistry, jet quenching (R_{AA}, shapes, FF)
  - The R_{AA} and v2 collections
- Heavy quark zoo and its relevance
- pPb – the next frontier ?
- The future and summary
- ***Many thanks to CMS and G. Roland***

Detectors – An Experimentalists Pride & Joy !





CMS excels at
-Resolution of tracking
and calorimetry
-Trigger selectivity (high lum.)

High magnetic field over a large range *in rapidity* and full azimuth

ALICE excels at
-Resolution of tracking
and particle identification
-Bulk production coverage (low lum.)

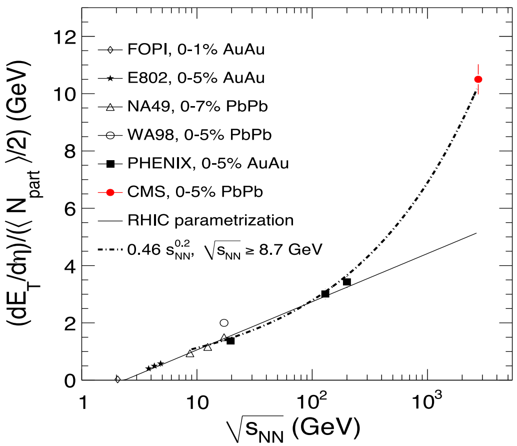
Low magnetic field over a large range *in momentum* and full azimuth

LHC Heavy-Ion Runs

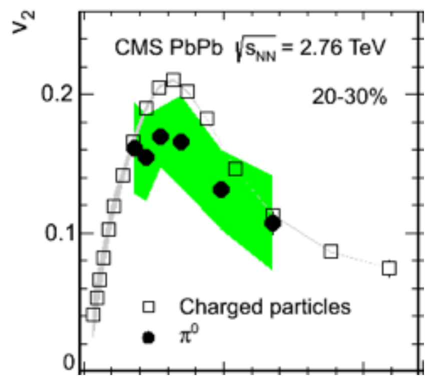
year	system	energy $\sqrt{s_{NN}}$ TeV	integrated luminosity
2010	*Pb – Pb*	*2.76*	~ *10* μb^{-1}
2011	*Pb – Pb*	*2.76*	~ 0.1 nb^{-1}
2013	*p – Pb*	*5.02*	~ 30 nb^{-1}

A bigger bang

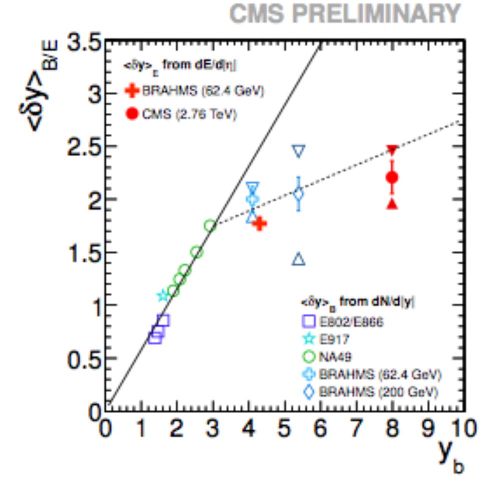
More Transverse energy



More elliptic flow



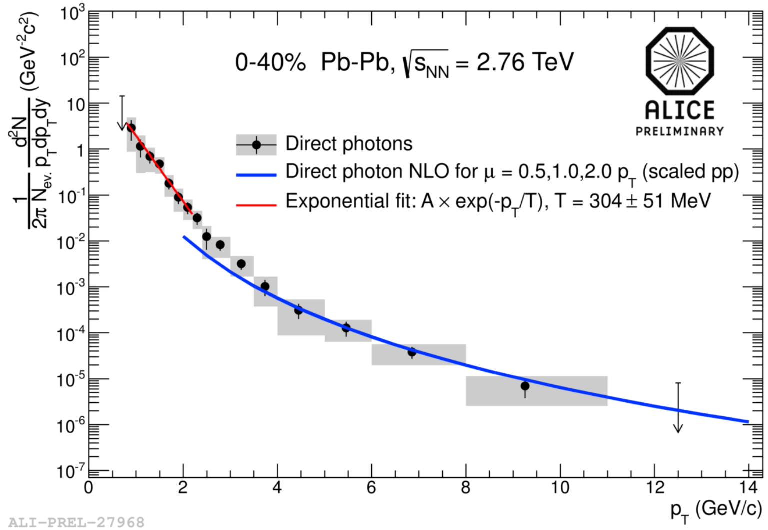
More rapidity transfer



More initial temperature !

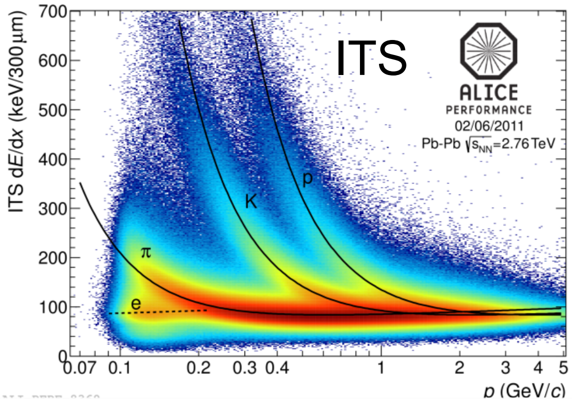
ALICE: T = 304±51 MeV
5.5 Trillion Kelvin !!
(PHENIX: T = 221±19±19 MeV)

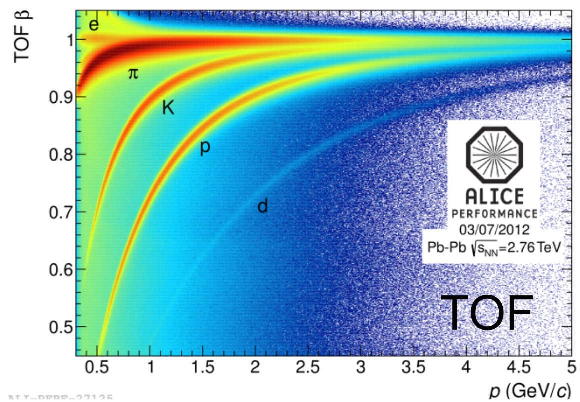
$T_{initial}$ ~ 650 – 700 MeV ?

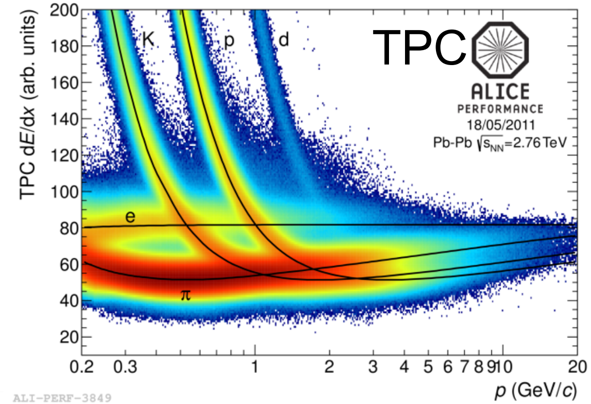


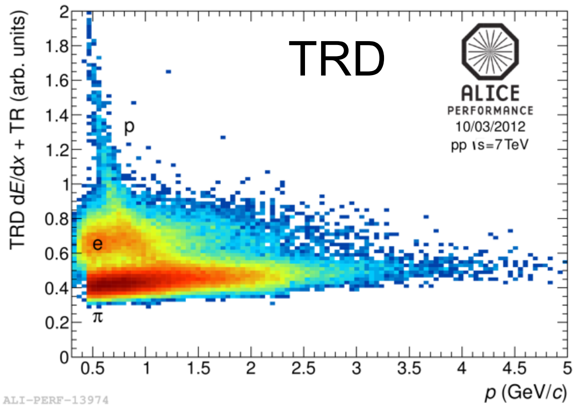
http://www.guinnessworldrecords.com/world-records/10000/highest-man-made-temperature

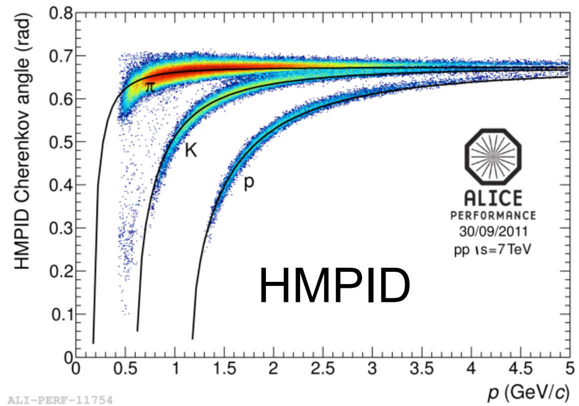
The bulk – let's do PID !







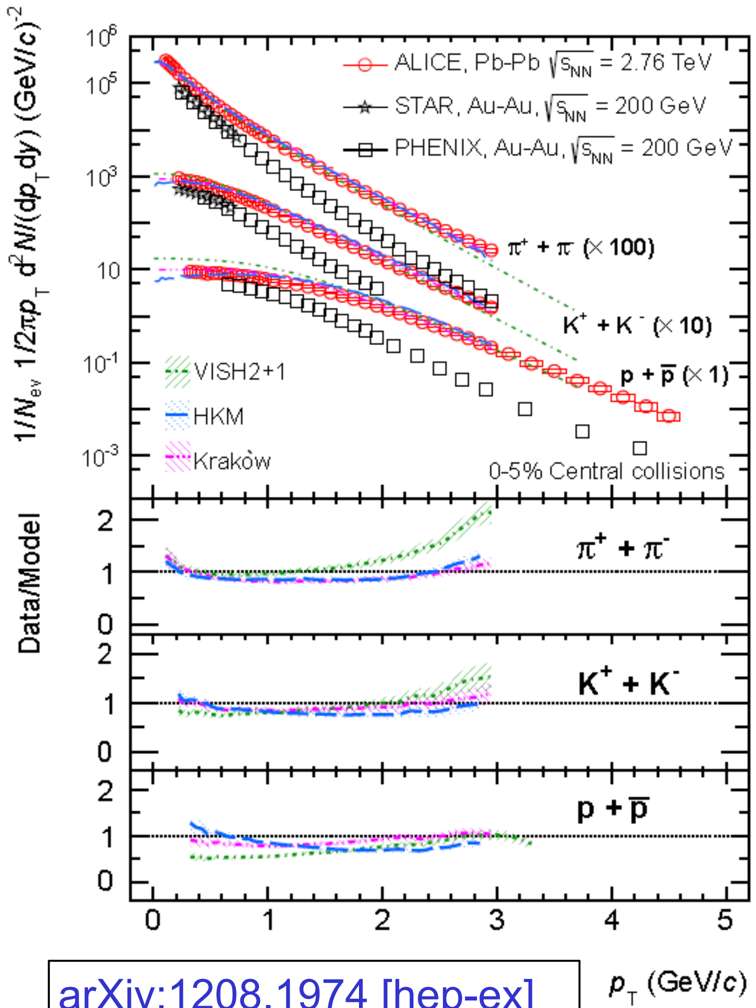


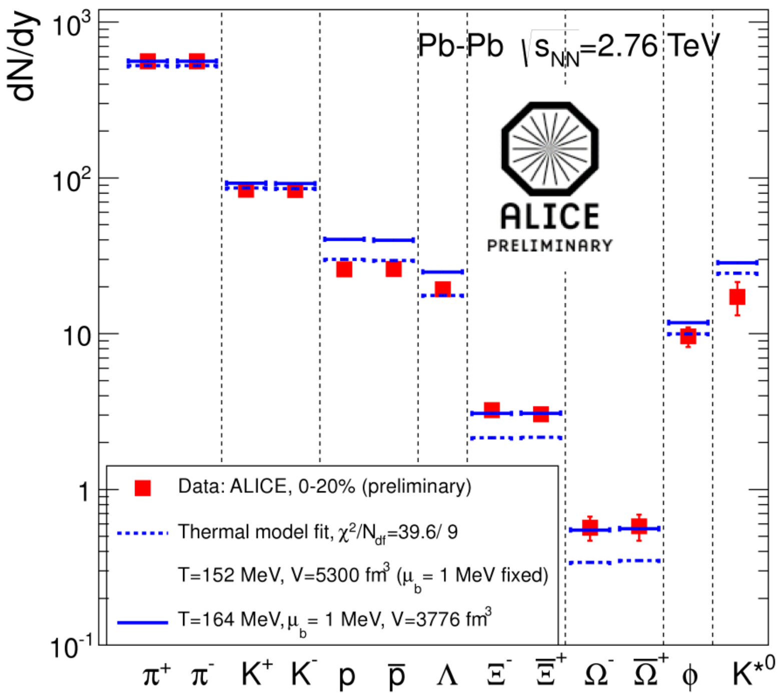


ALICE:
5 independent
PID detectors !

Bulk particle production –

everything as expected until… you look at strangeness



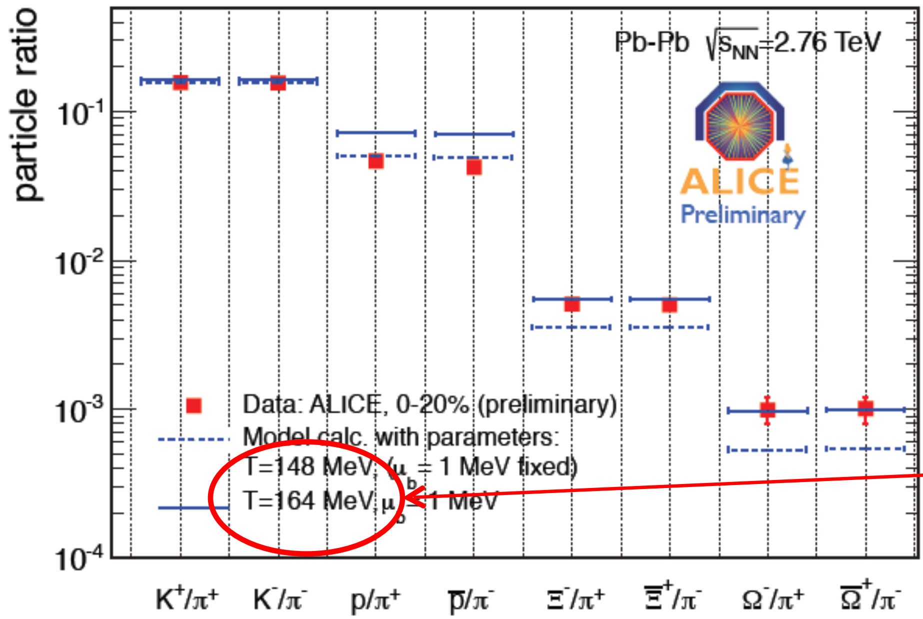


arXiv:1208.1974 [hep-ex]

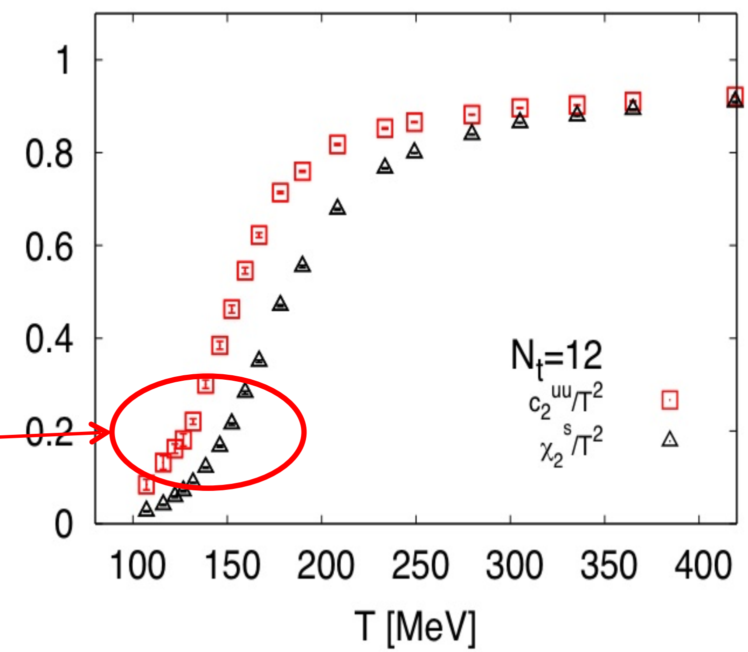
No common SHM fit possible between protons and strange baryons !!

Flavor hierarchy or hadronic annihilation ?

Data: ALICE, SQM 2011



Theory: Ratti et al., QM 2011



Model: A. Andronic et al., Phys. Lett. B 673:142-145,2009

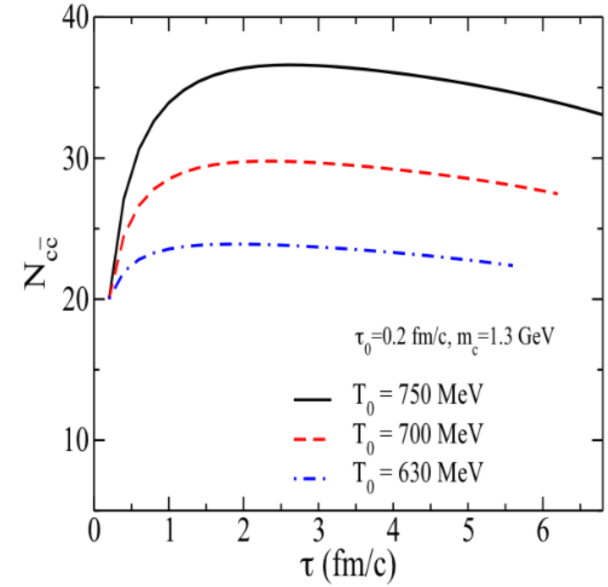
Alternative explanation: proton annihilation in hadronic sector

(issues with centrality dependence and resulting common freeze-out T (too high))

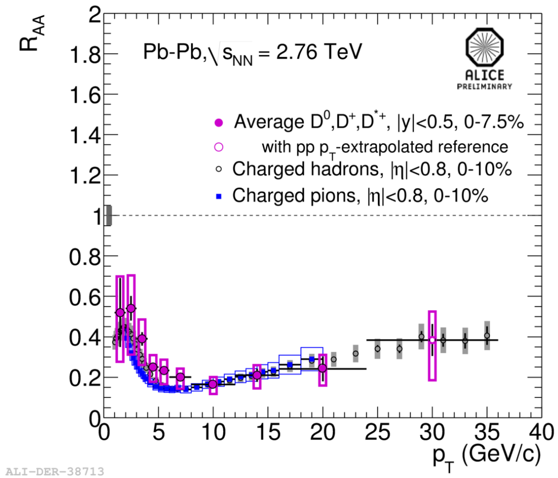
Why could the effect be less at RHIC and SPS ? μ_B

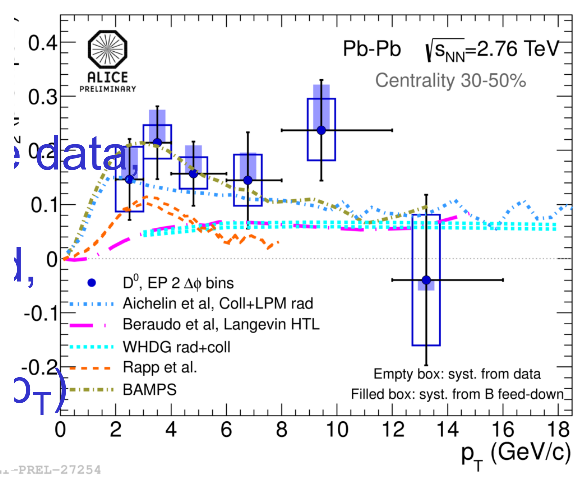
How thermal is the charm ?

Only if charm is in chemical equilibrium at T = 250 MeV
Charm is predominantly produced in first collisions (gluon-gluon interactions)
But, assuming Tinit ~ 700 MeV and Tch = 250 MeV, there might be finite thermal production.
Zhang, Ko, Liu (arXiv:0709.1684)

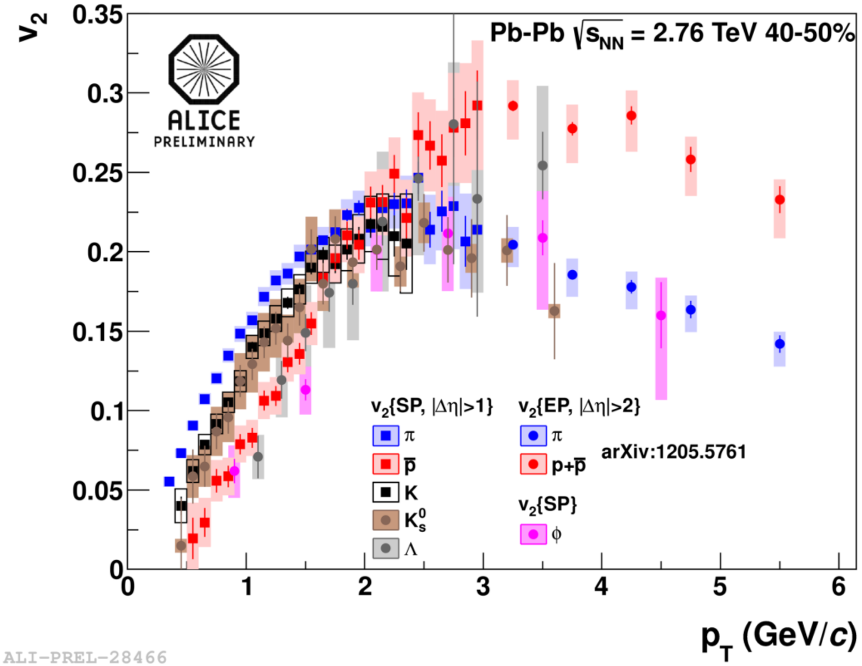


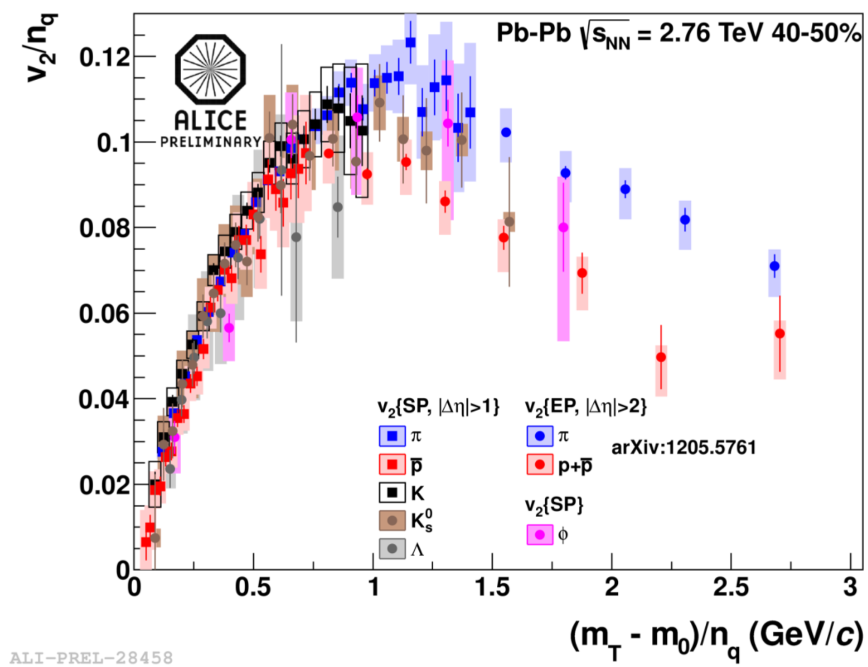
Experiment: charm v_2 & R_{AA}
hints of equilibration through interactions





Identified-particle v_2





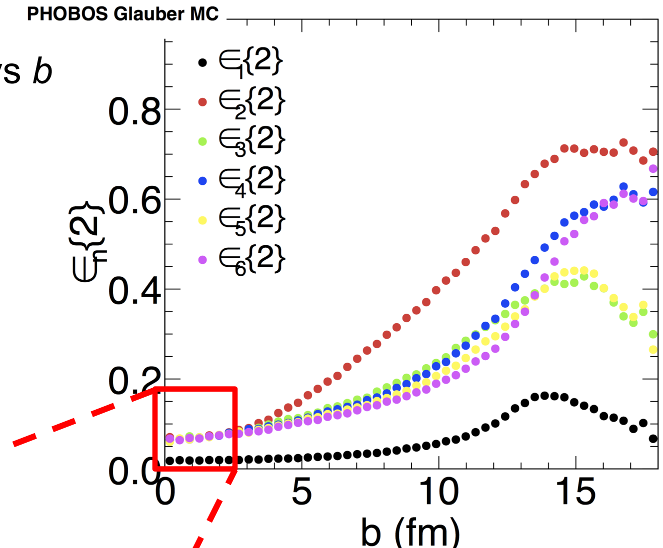
v_2 at low p_T (<3 GeV/c) follows mass hierarchy
overall qualitative agreement with hydro up to p_T 1.5–3 GeV/c (π–p);
quantitative precision needs improvements – hadronic afterburner

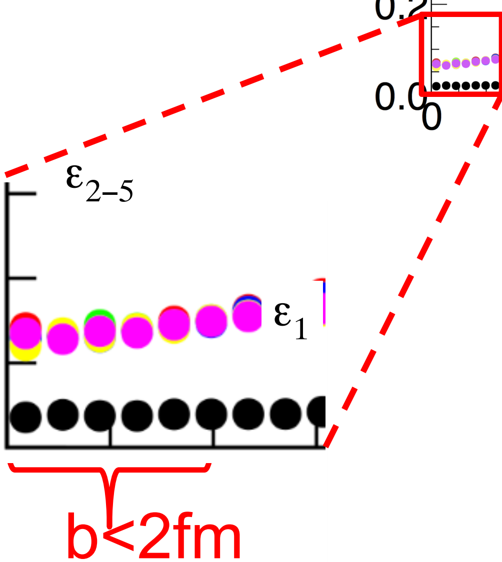
$n_q(m_T)$-scaling worse than at RHIC
$n_q(p_T)$-scaling at p_T > 1.2 GeV/c - violation 10–20%

Ultra-central collisions measured in CMS

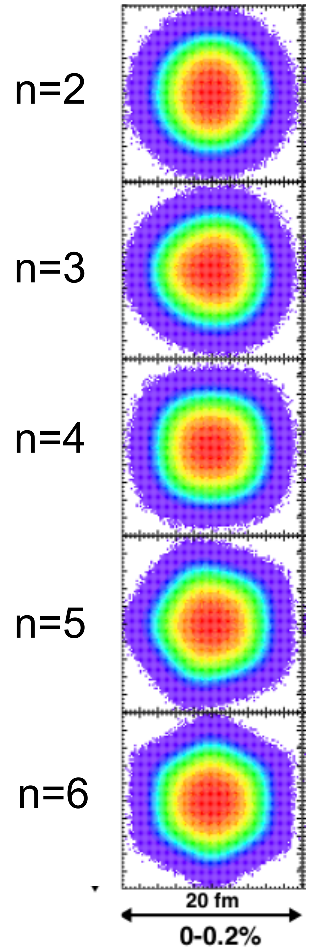
0.2% most central

n^{th} order eccentricities vs b





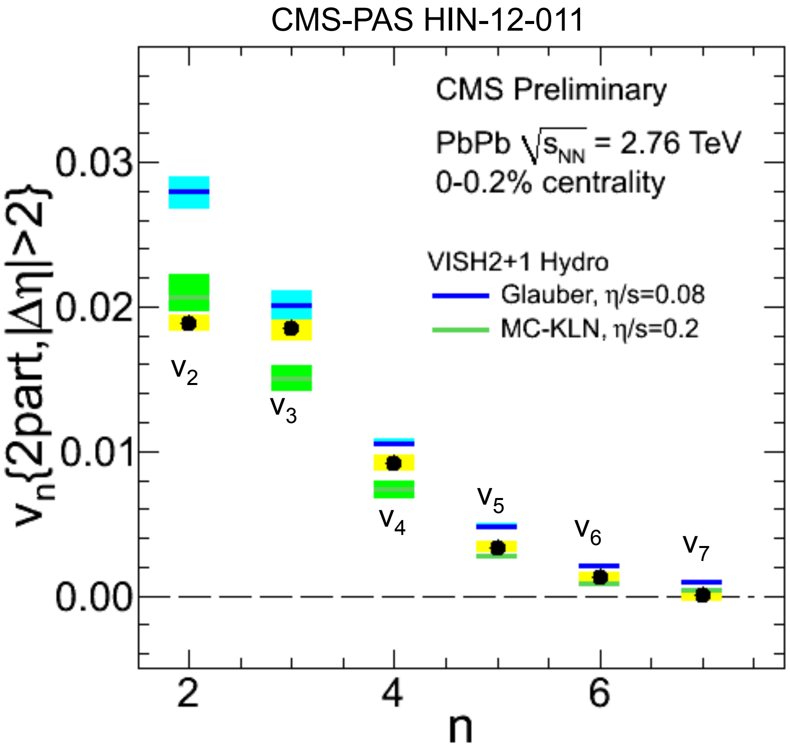
ε_2-ε_5 converge in ultra-central collisions



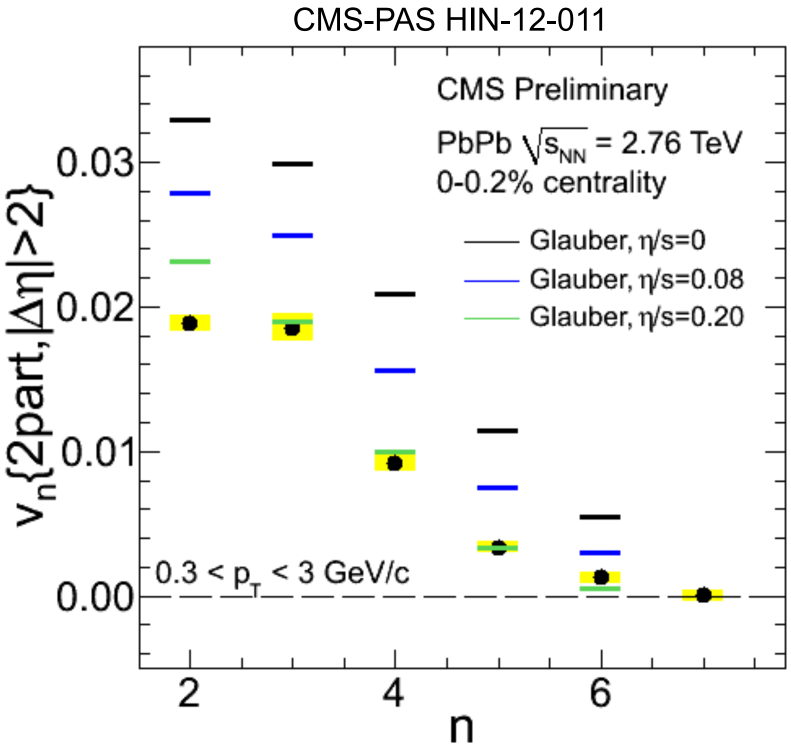
Participant distribution relative to the n^{th} order participant plane

Hydro description of higher moments

Calculation by Heinz et al.



Calculation by Luzum et al.



Quantitative description of hydrodynamic flow

Hierarchy of coefficients reproduced by hydro

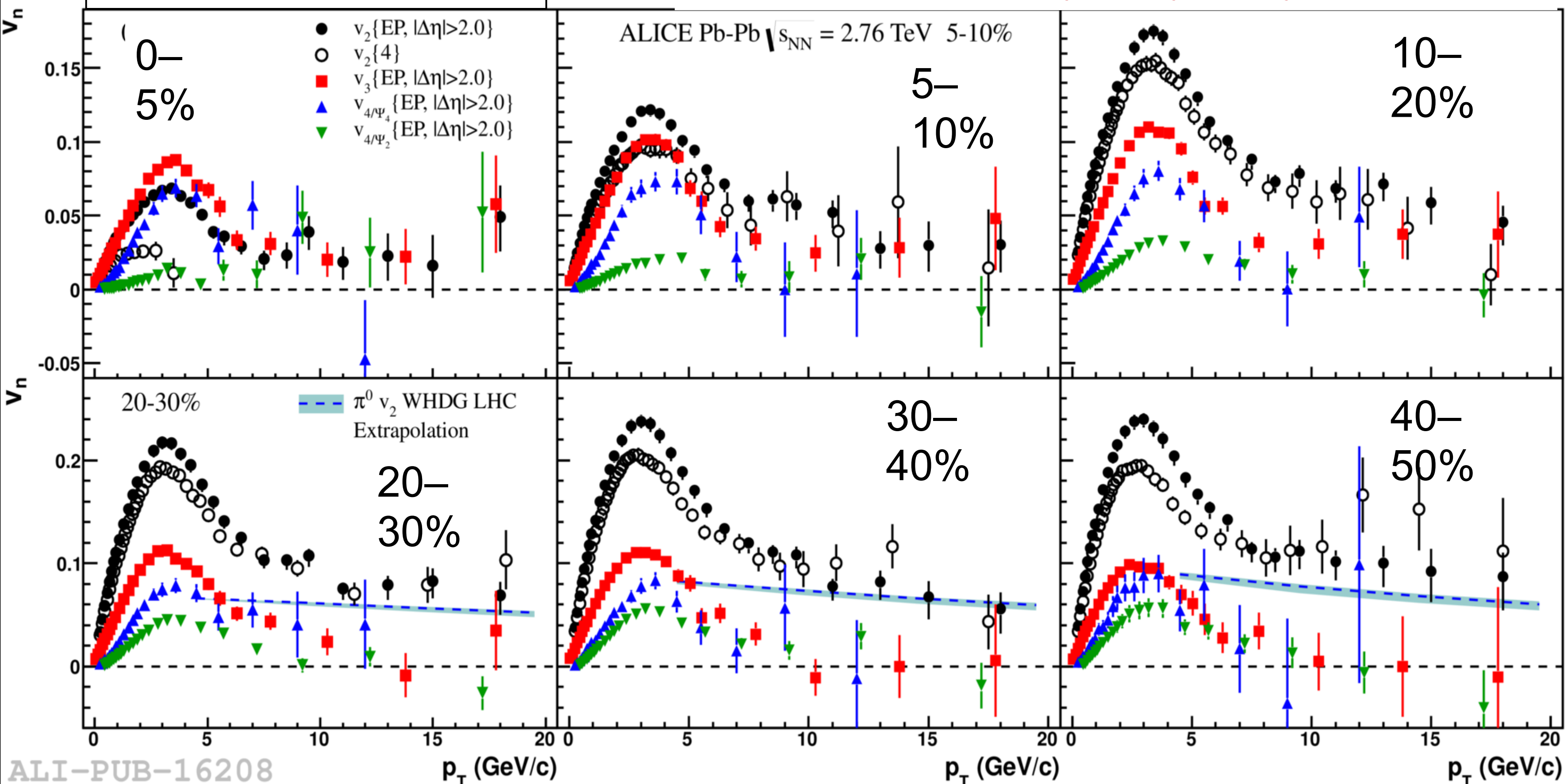
Some difference between v_2 and $v_{3..7}$

Intermediate pT

v_2 , v_3, v_4 versus p_T

arXiv:1205.5761 [hep-ex]

W.Horowitz,M.Gyulassy, J.Phys. G38 124114

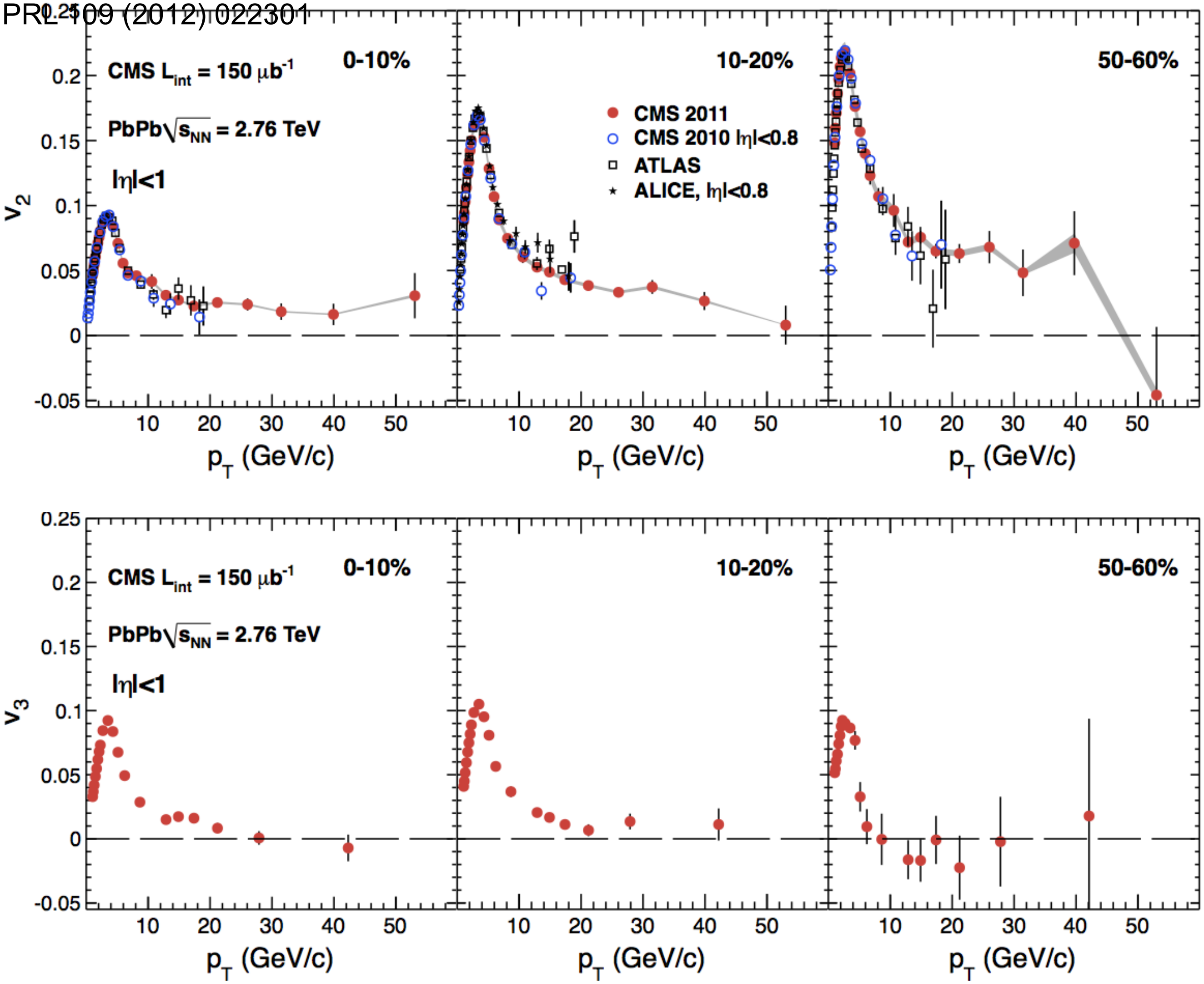


Non-zero value of v_2 at high p_T for 2 and 4-particle cumulant

v_3 and v_4 diminish above 10 GeV/c –no fluctuations at high p_T ?

Confirmation / p_T extension by CMS

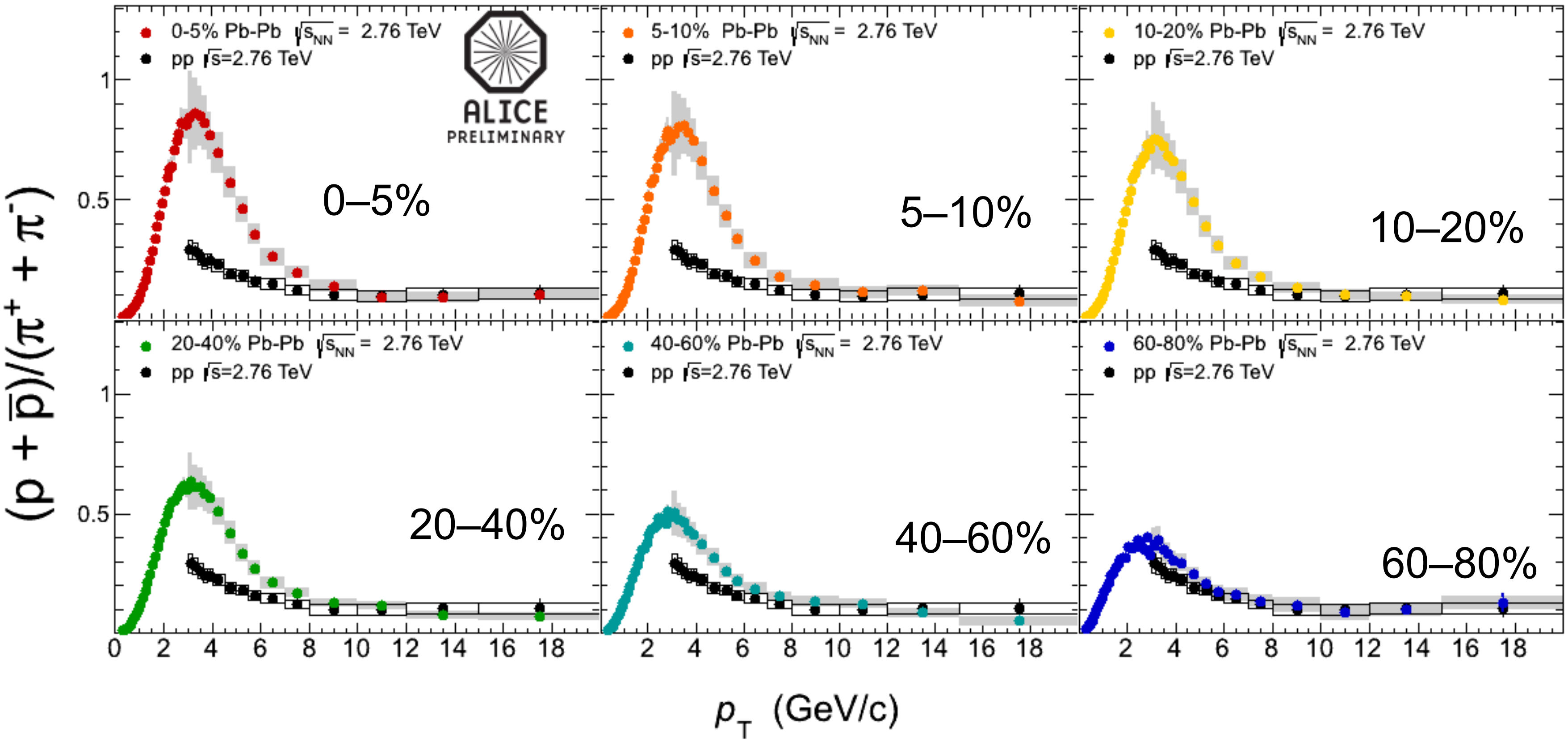
PRL 109 (2012) 022301



v_2 persists to $p_T > 40$GeV

v_3 vanishes for $p_T > 20$ GeV

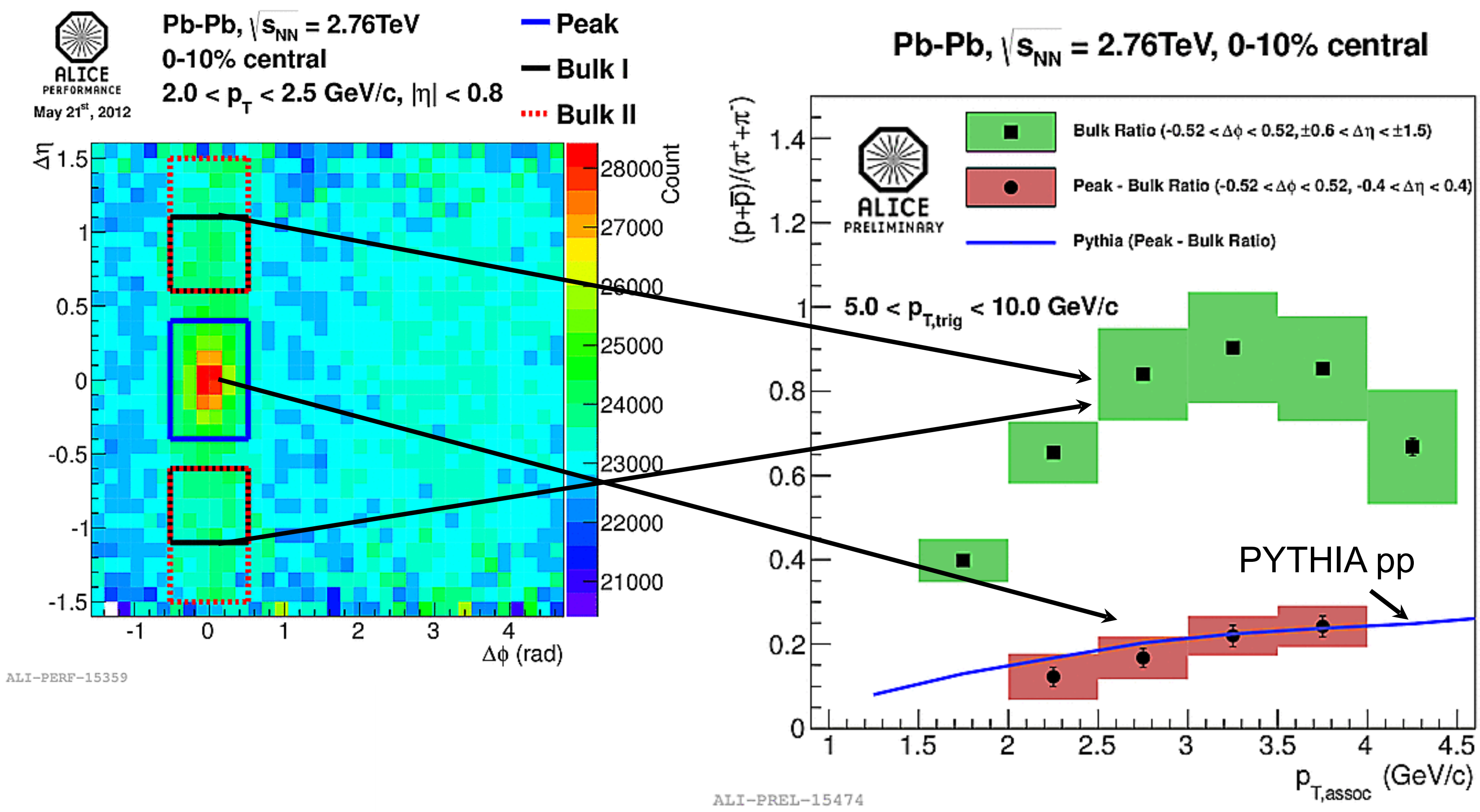
Baryon-to-meson ratio: p/π



p/π ratio enhancement in 2-8 GeV/c range in 0–5% central Pb–Pb collisions up to factor ~ 3 higher than in pp. p_T > 10 GeV/*c* no more medium dependence

Standard explanations: recombination or radial flow/quenching interplay ?

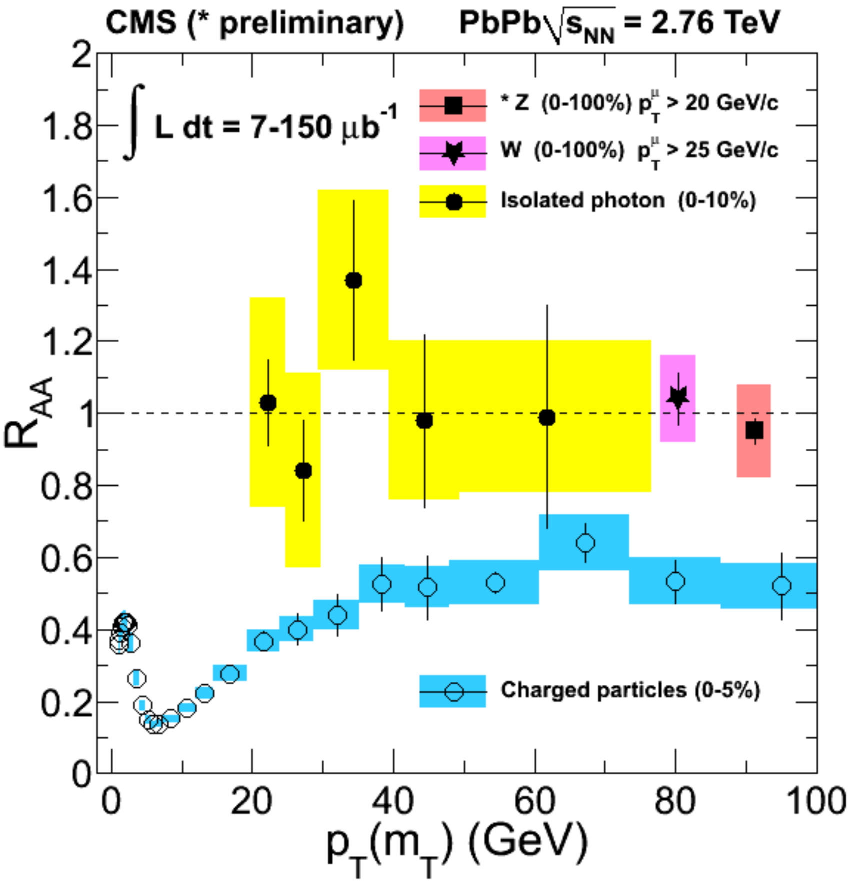
PID in two-particle correlation structures

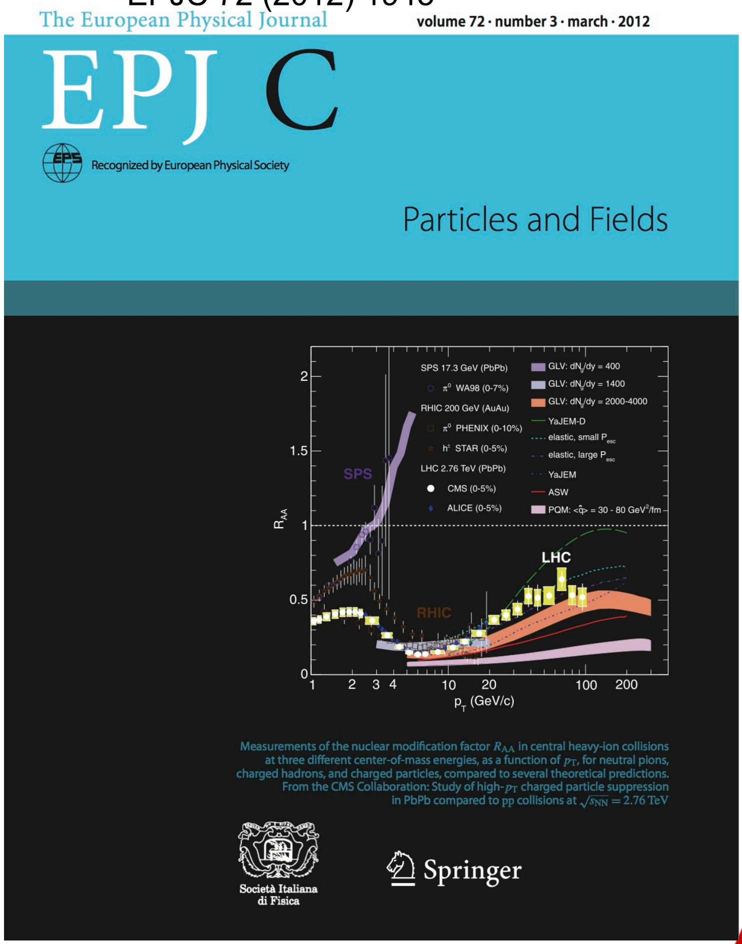


High p_T – disappointment or excitement ?

Suppression of charged particles

EPJC 72 (2012) 1945

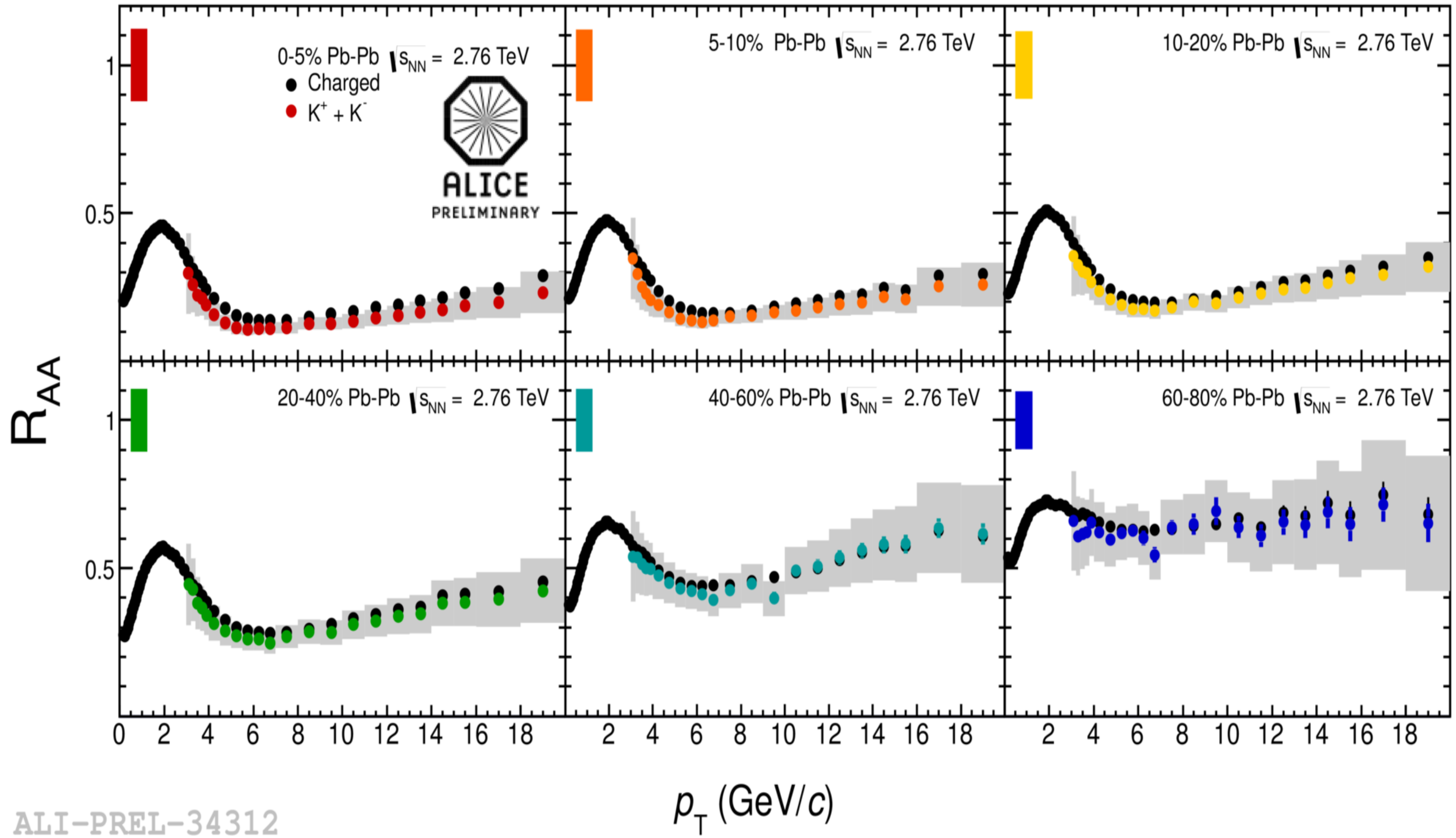




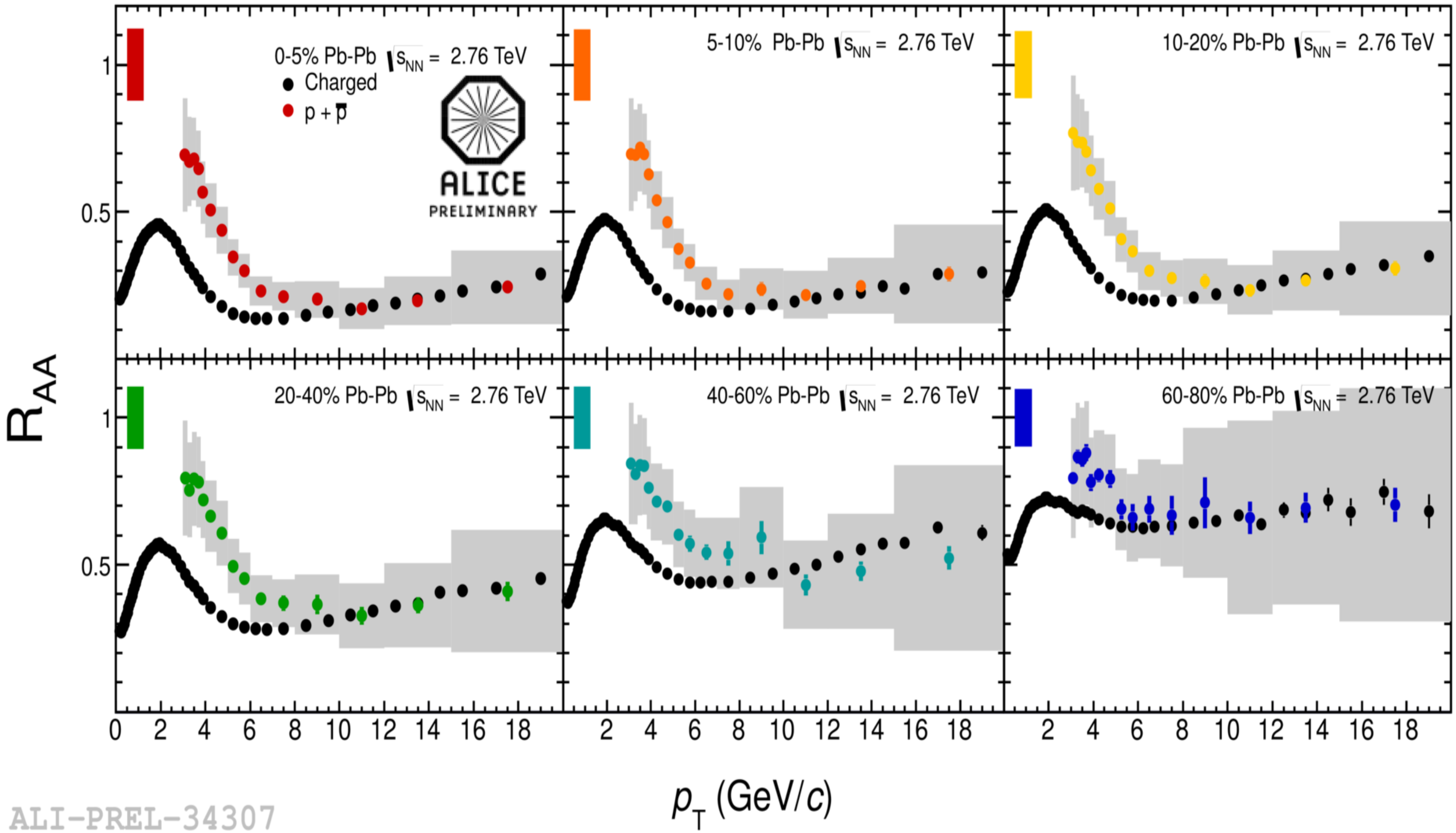
EPJC 72 (2012) 1945

Charged hadron R_{AA} flat from p_T = 30 - 100GeV

No modified hadro-chemistry in fragmentation region for Kaons !!



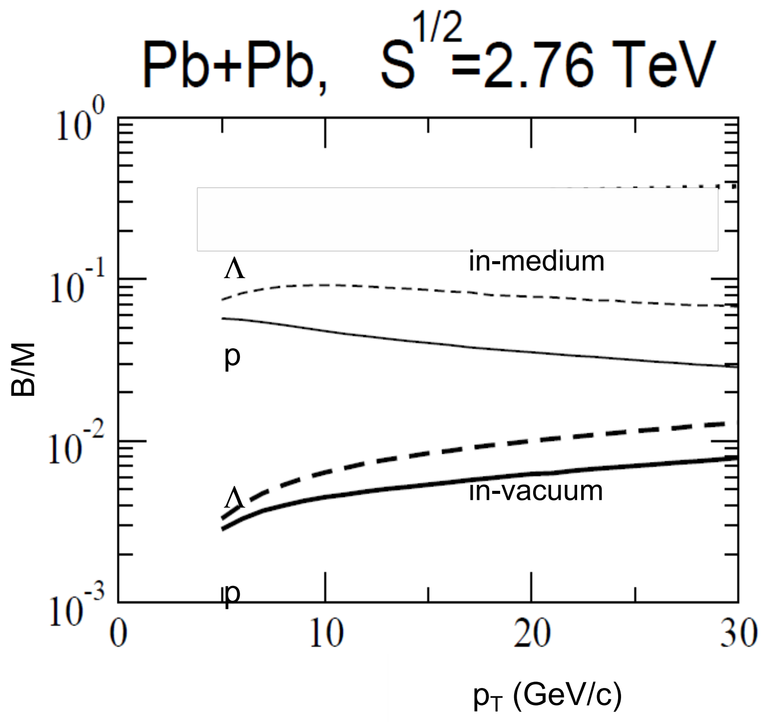
No modified hadro-chemistry in fragmentation region for protons !!

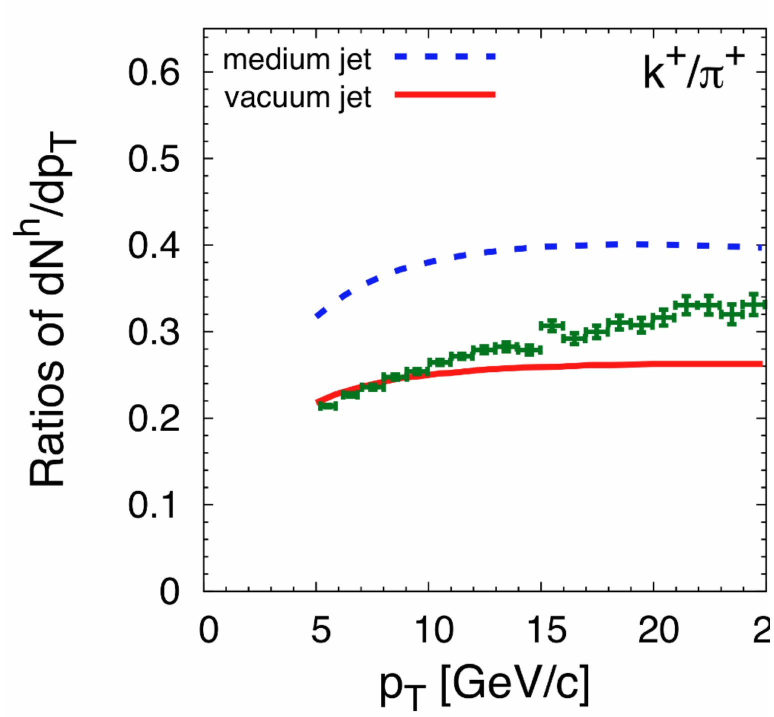


Disprove significant theory predictions

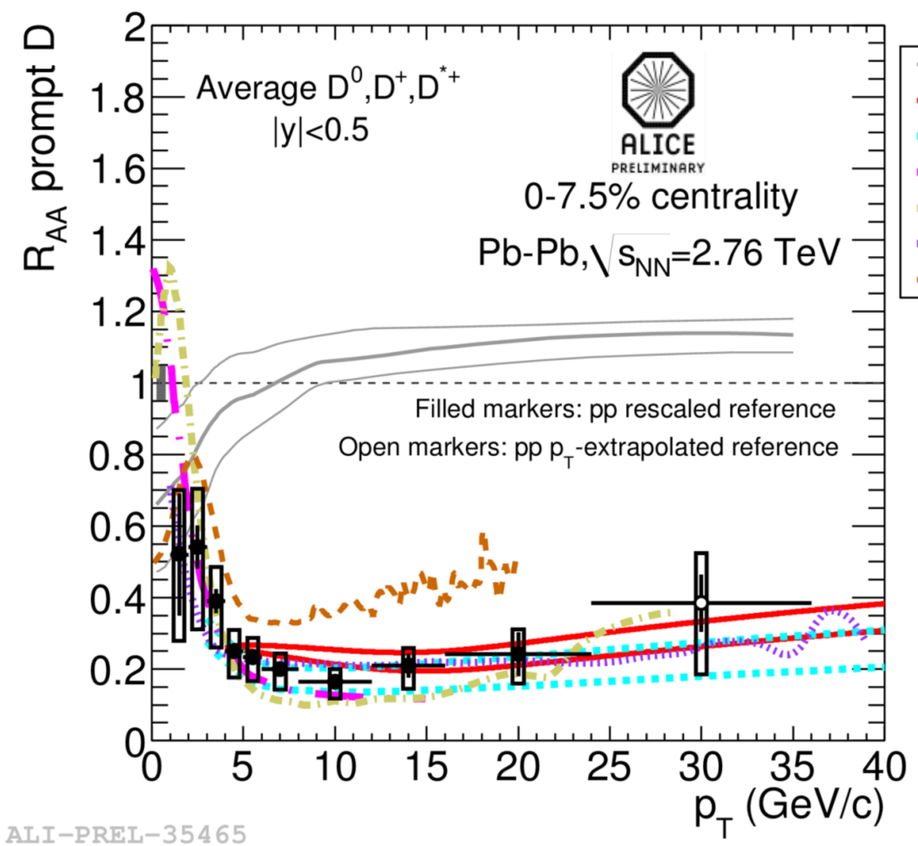
Baryon/meson differences
e.g. Aurenche/Zakharov
arXiv:1109.6819

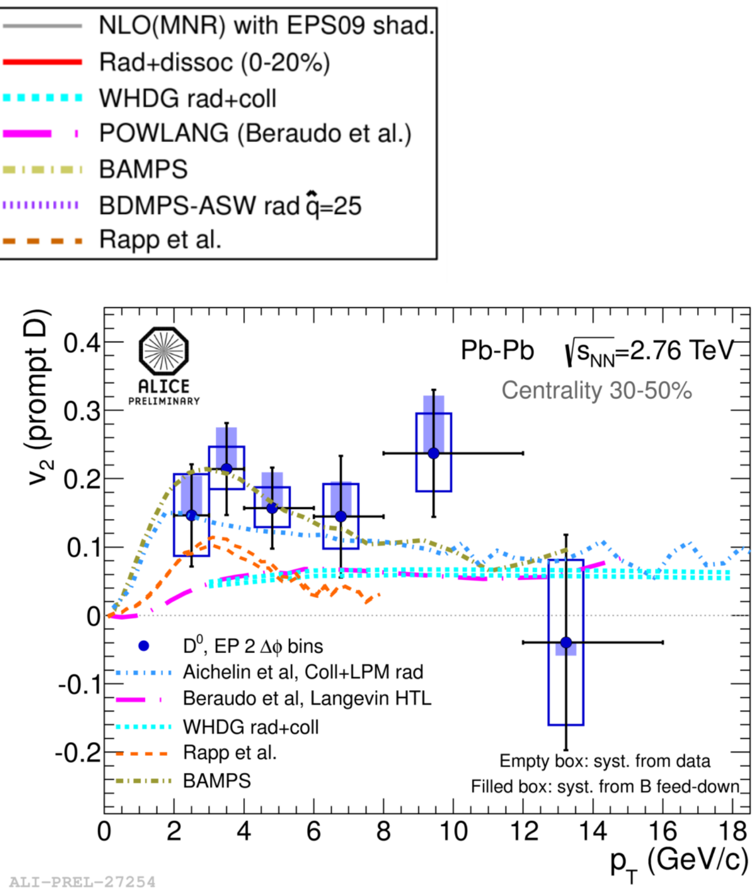
strange/light quark meson differences
e.g. Sapeta/Wiedemann
arXiv:0707.3494





D meson R_{AA} and v2

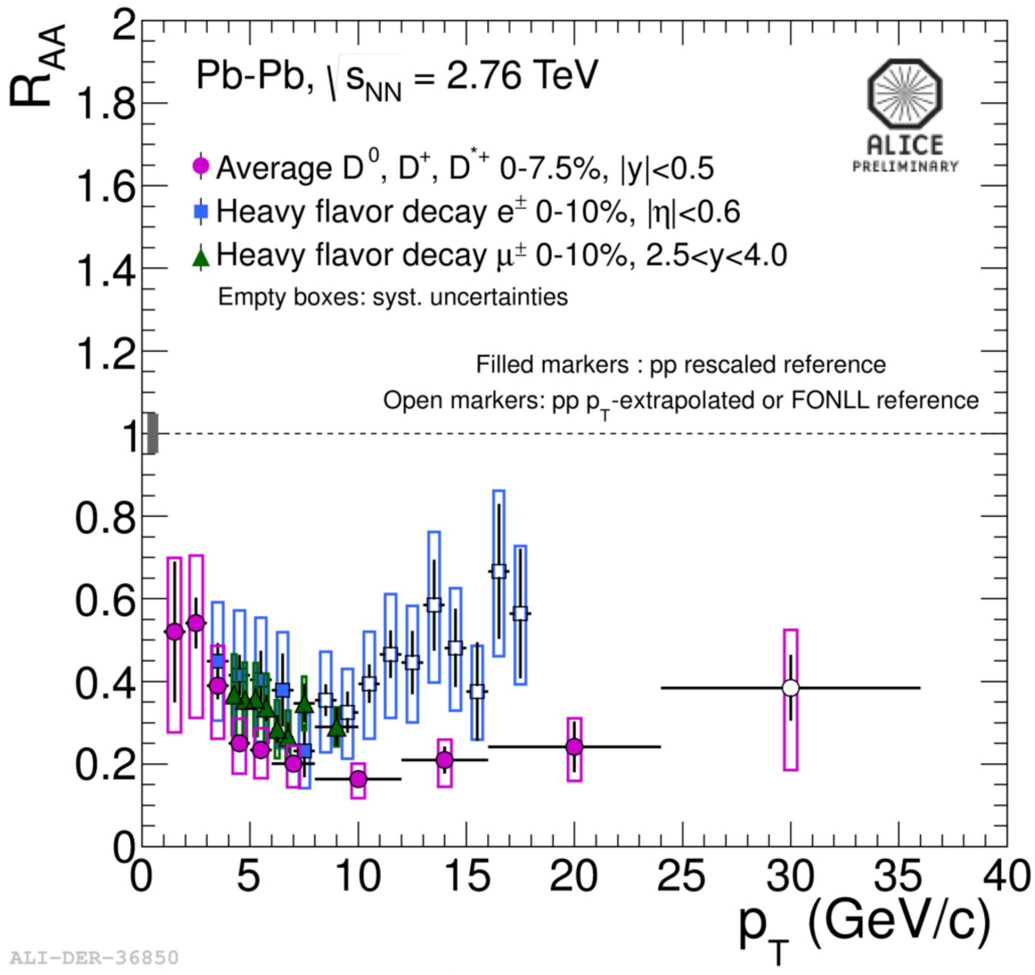




Simultaneous description of R_{AA} and v_2 yields c-quark transport coefficient in medium

No indication of colour charge dependence

Heavy- flavour R_{AA}: D, e, μ



Comparison of heavy-flavour R_{AA}:

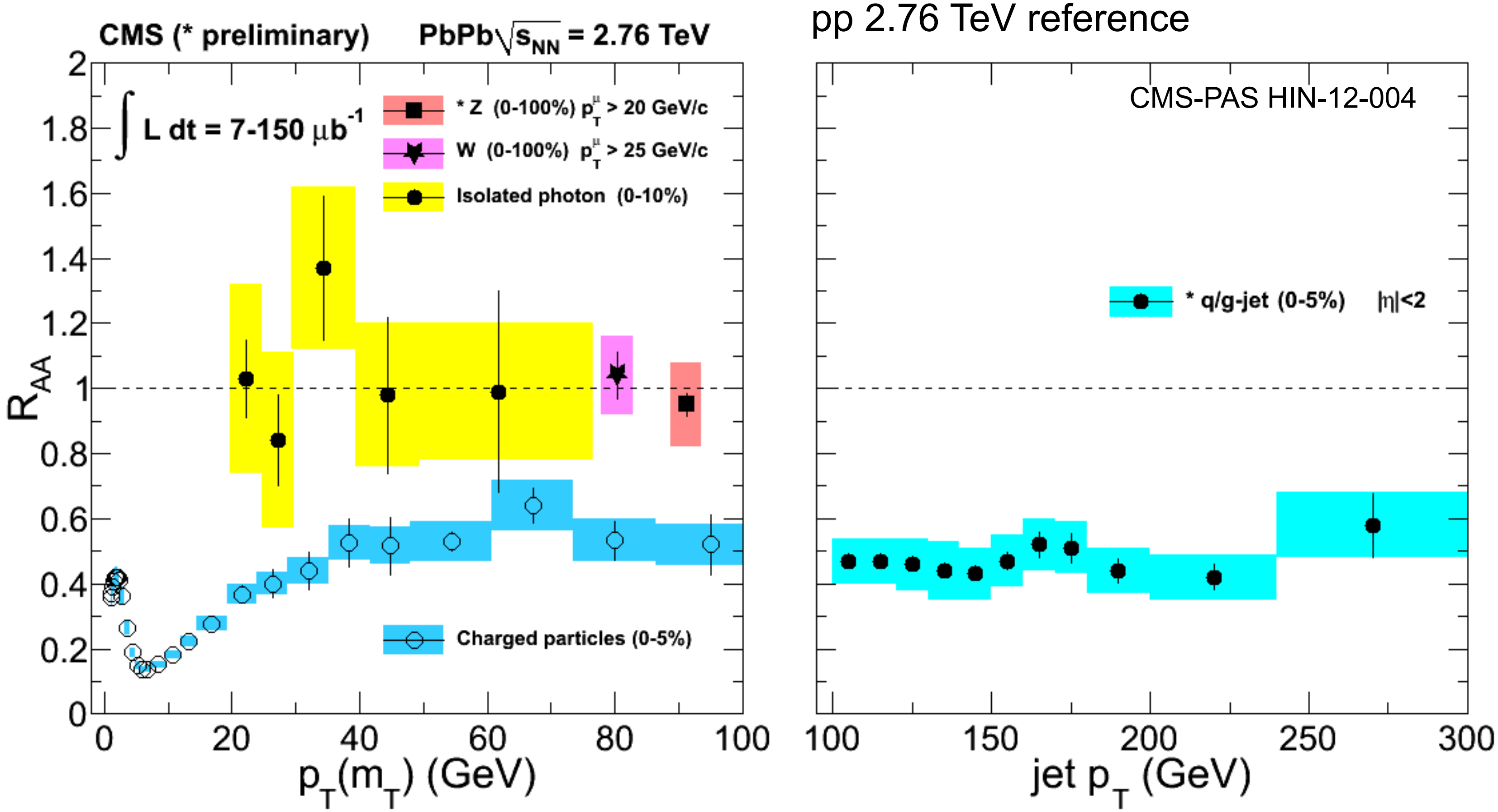
– p_T < 8 GeV/*c* all measurements close together

– p_T > 8 GeV/*c* heavy-flavour e systematically above D meson.

Effect of B meson contribution ?

Suppression of inclusive jets

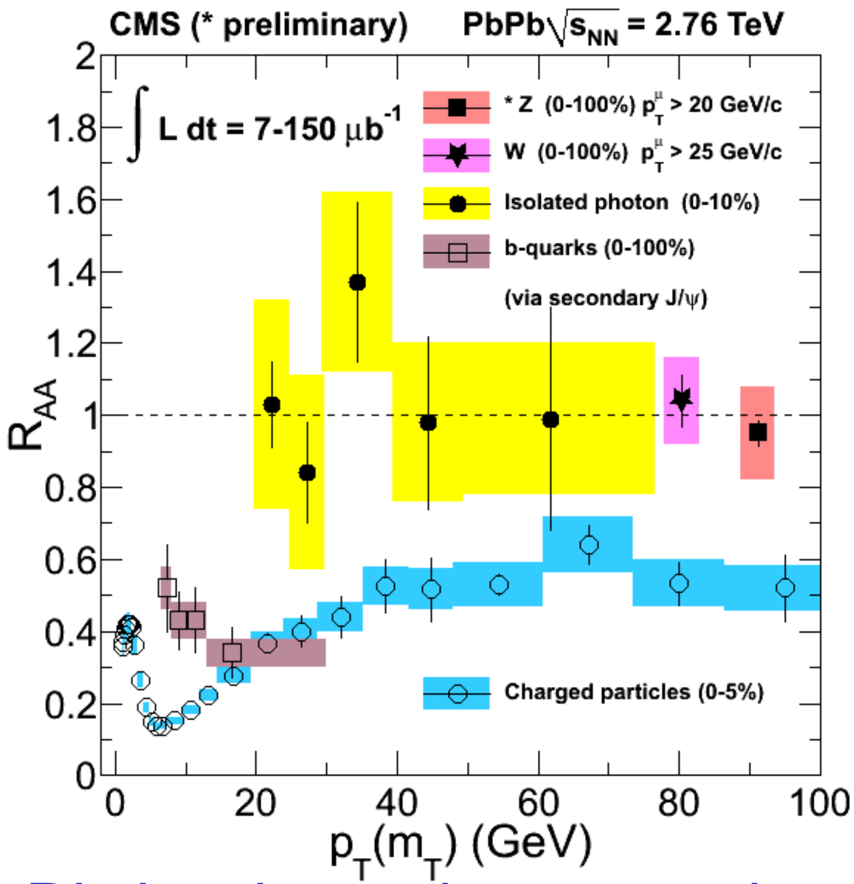
Fully unfolded inclusive jet R_{AA}
pp 2.76 TeV reference



Similar to charged particles, high-p_T jet R_{AA} flat at ≈ 0.5

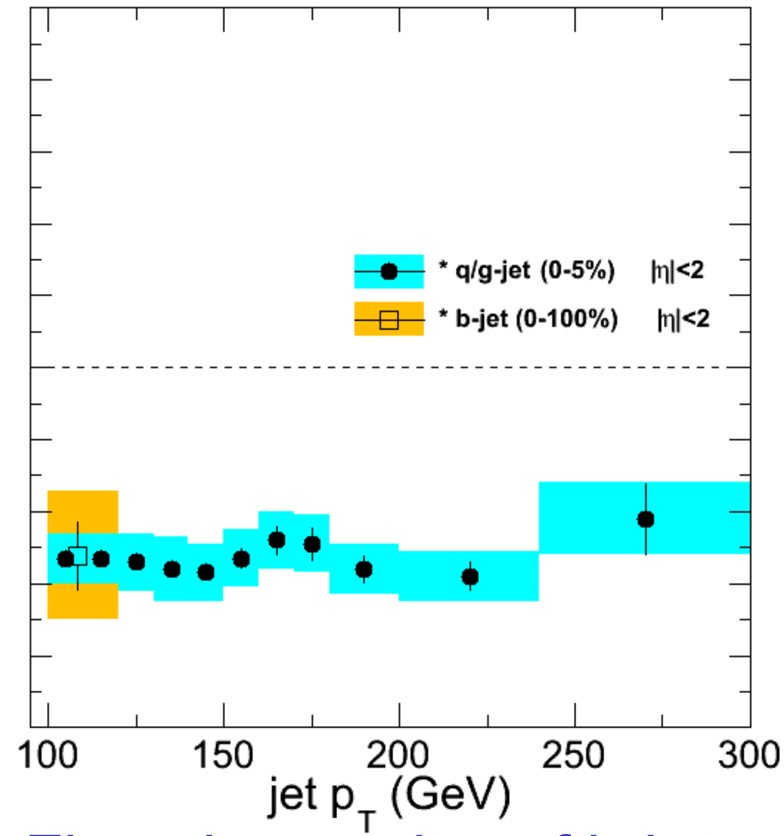
Parton ID: b-quarks

p_T < 30 GeV: via displaced J/ψ to μμ



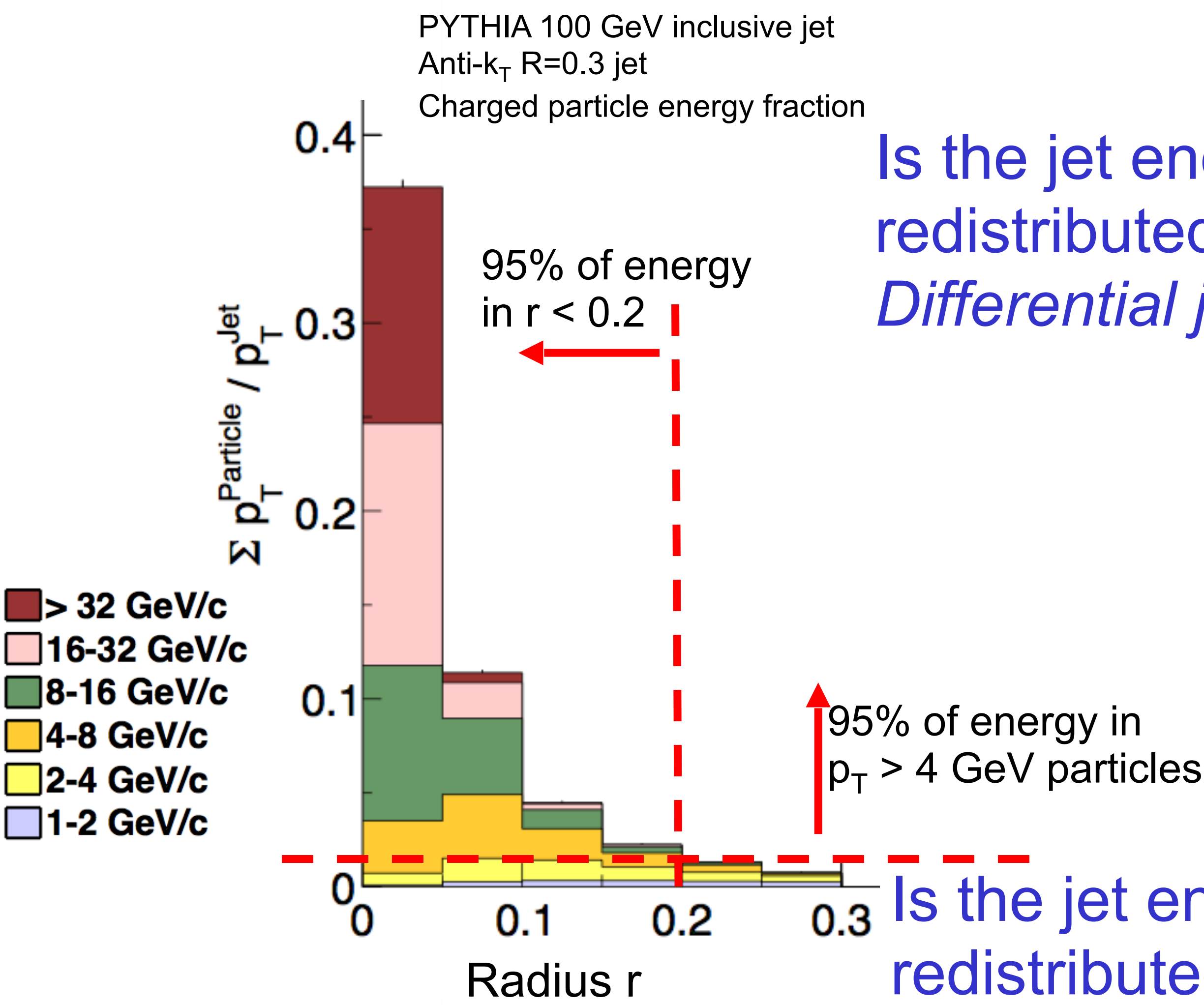
Distinct b-quark suppression pattern at low p_T

p_T > 80GeV: Jet + high mass secondary vertex



First observation of b-jet suppression at high p_T

Anatomy of a jet



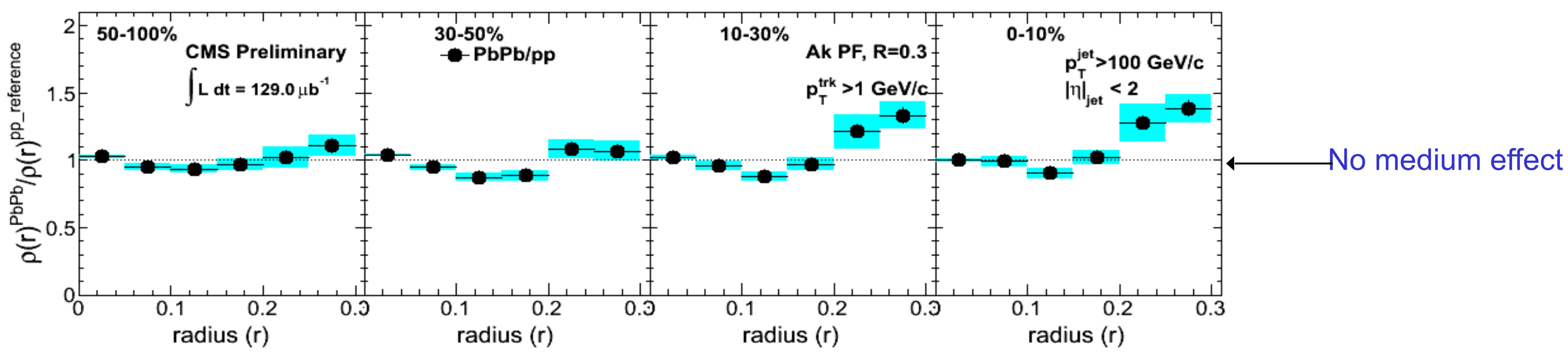
Is the jet energy in PbPb redistributed in radius:
Differential jet-shapes

Is the jet energy in PbPb redistributed in particle p_T:
Fragmentation functions

Anatomy of a jet

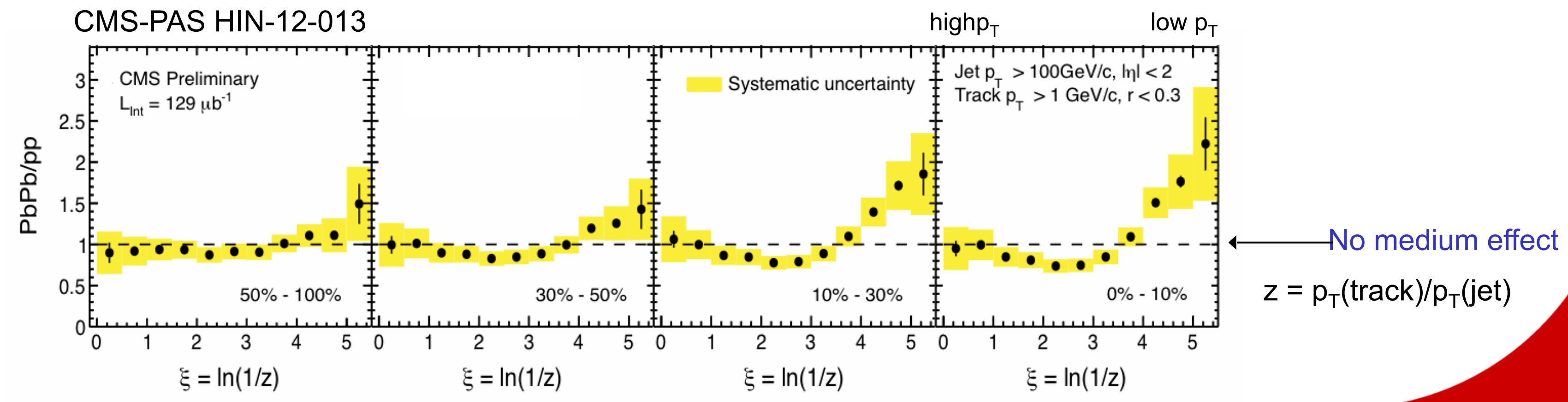
Ratio of PbPb/pp differential jet shapes

CMS-PAS HIN-12-013

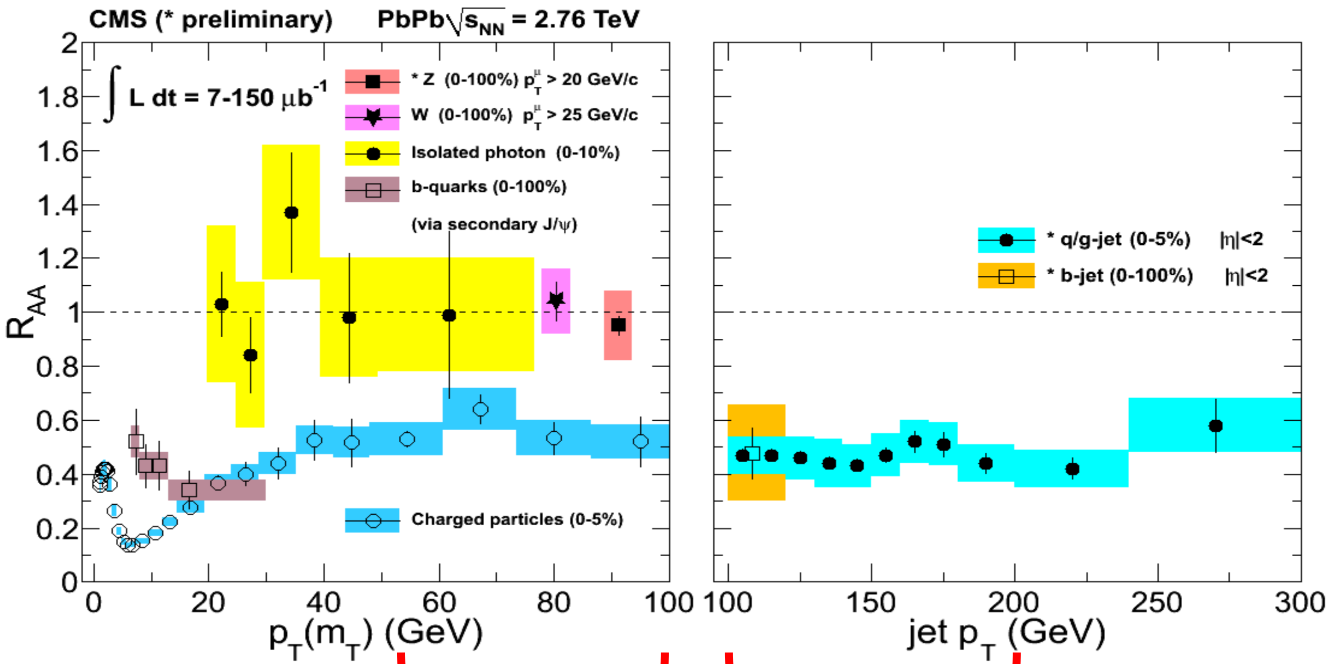


Ratio of PbPb/pp fragmentation functions

CMS-PAS HIN-12-013

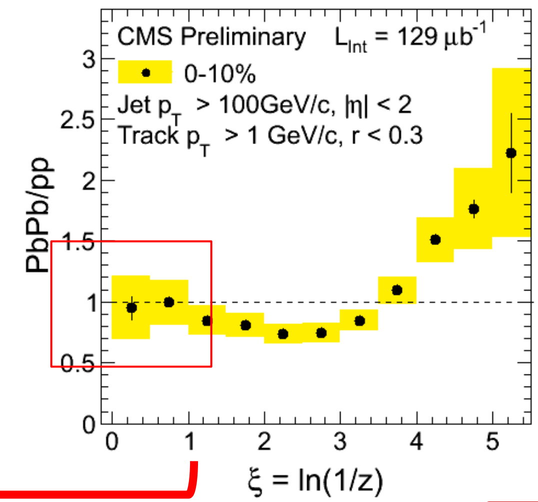


A consistent view of jet quenching



Looking at the same parton p_T range

Charged particles from p_T =50-100 GeV:
$z = p_T(\text{track})/p_T(\text{jet})$ = 0.4-0.6
$\xi < 1$ →

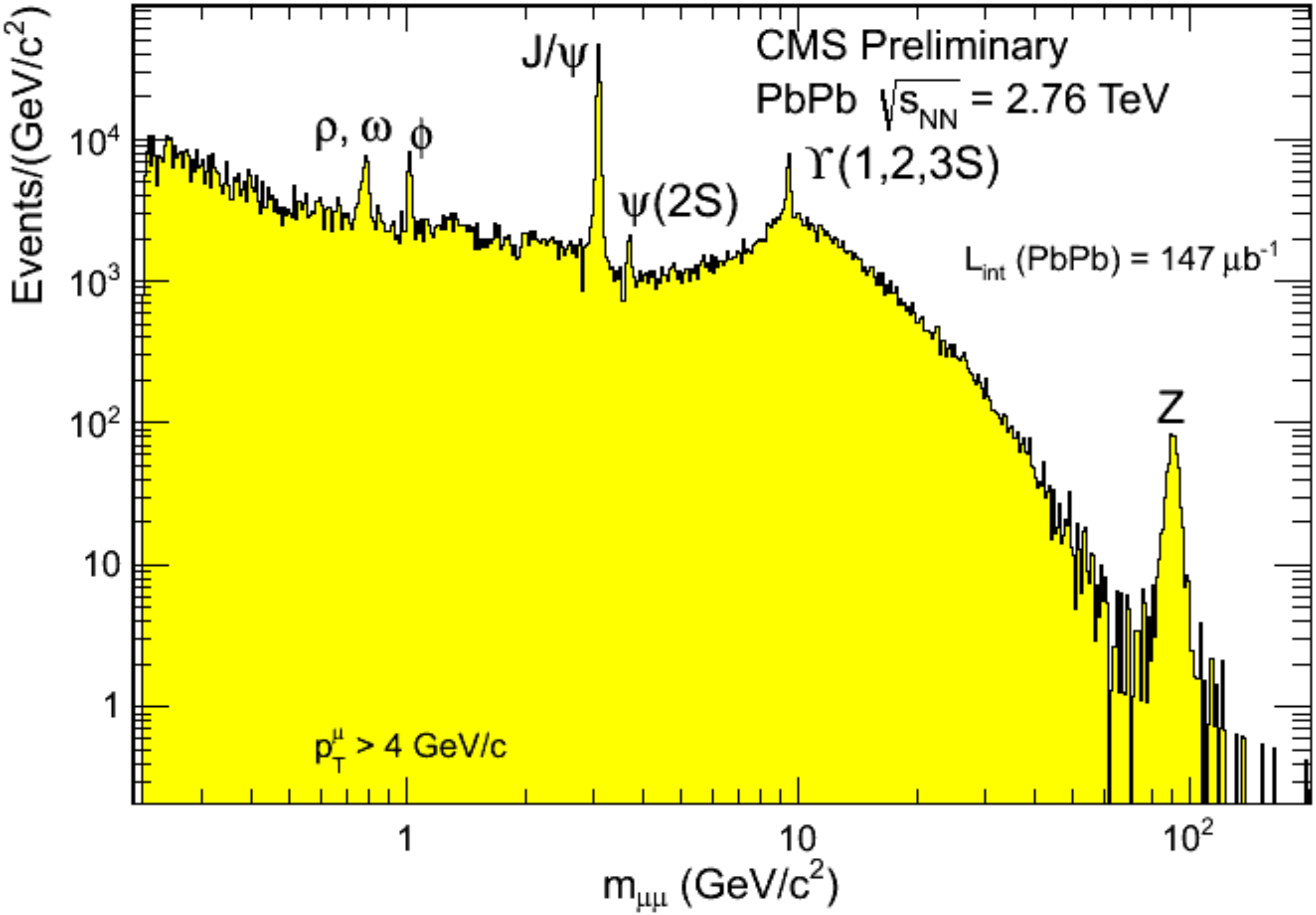


PbPb fragmentation function = pp for ξ <1

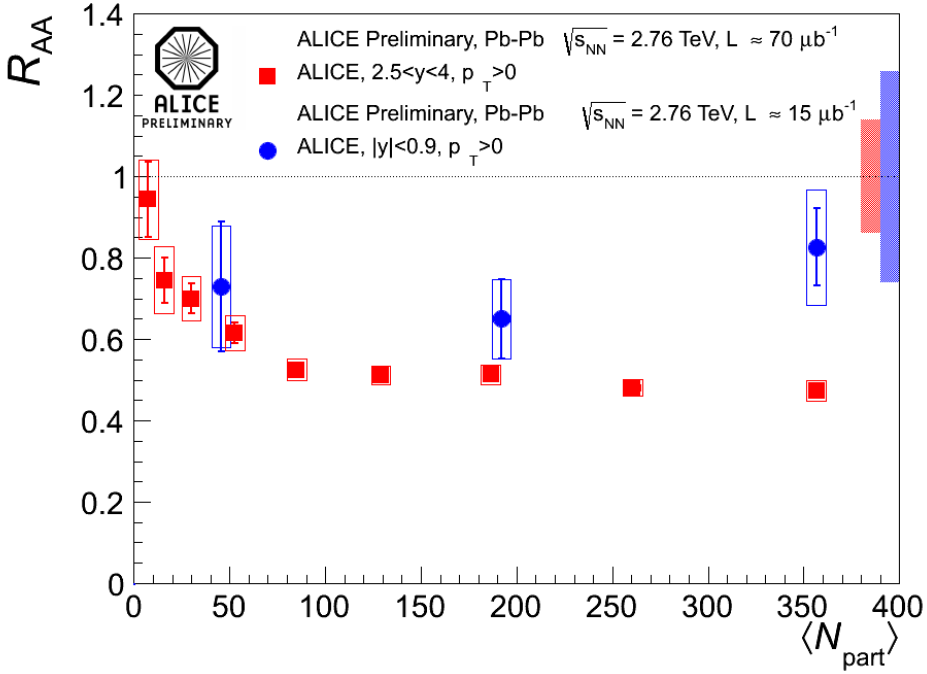
Possible explanation: color coherence (arXiv:1210.7765)

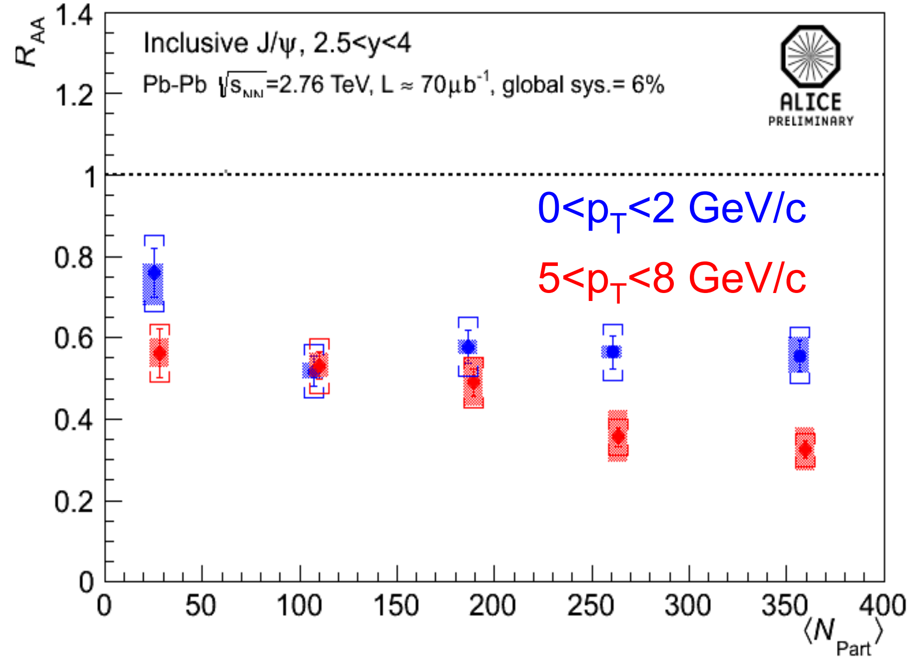
Heavy quark zoo

CMS di-muon spectrum



J/ψ R_{AA} centrality dependence





J/ψ suppression measurements both in central and forward regions

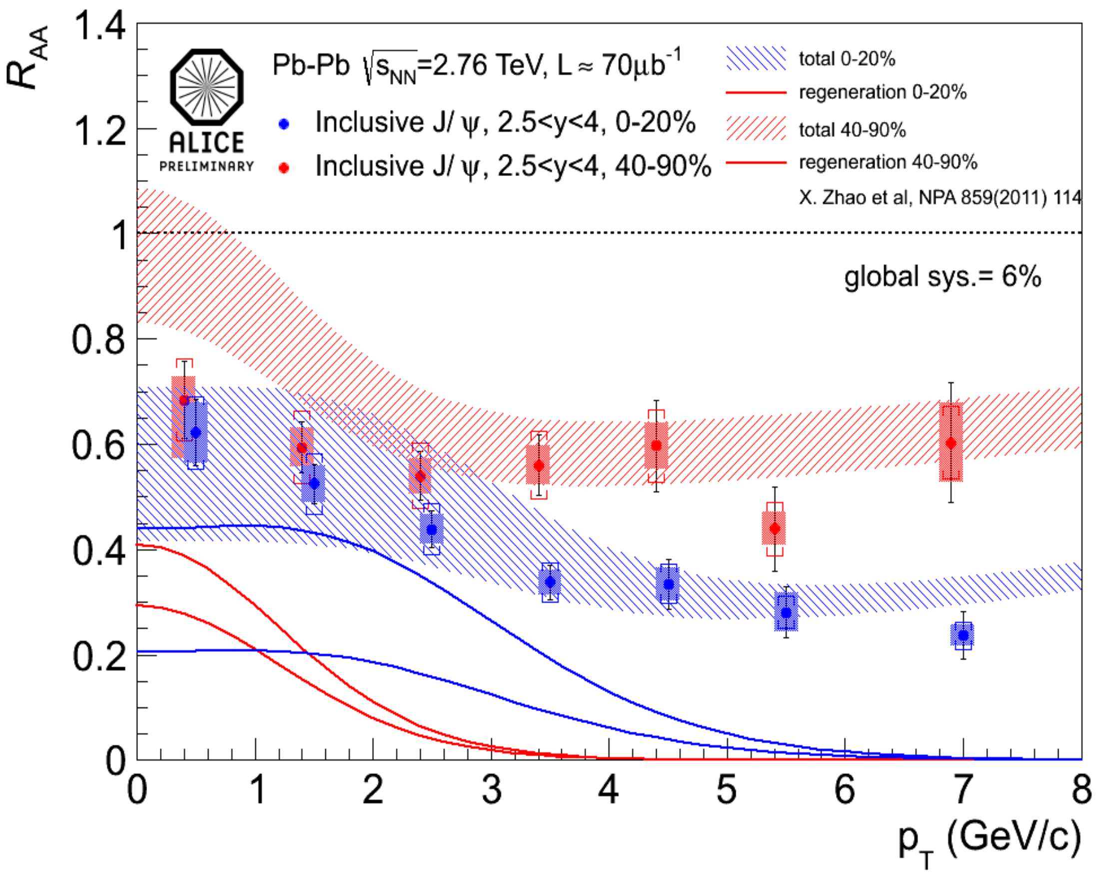
– from N_{part} > 100 suppression independent of centrality

– in central collisions, less suppression than at RHIC

– at low p_T (< 2 GeV/*c*) less suppression than at high p_T in central collisions

Indication of J/ψ regeneration at low p_T ?

J/ψ R_{AA} p_T dependence



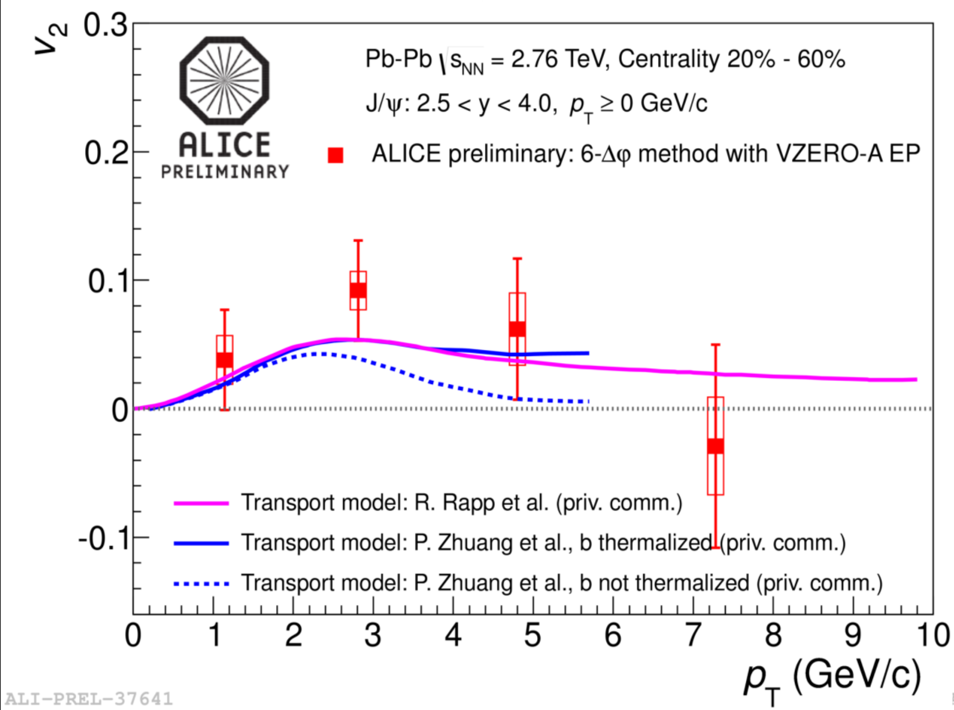
Compare to regeneration model
X.Zhao, R.Rapp NPA 859 114

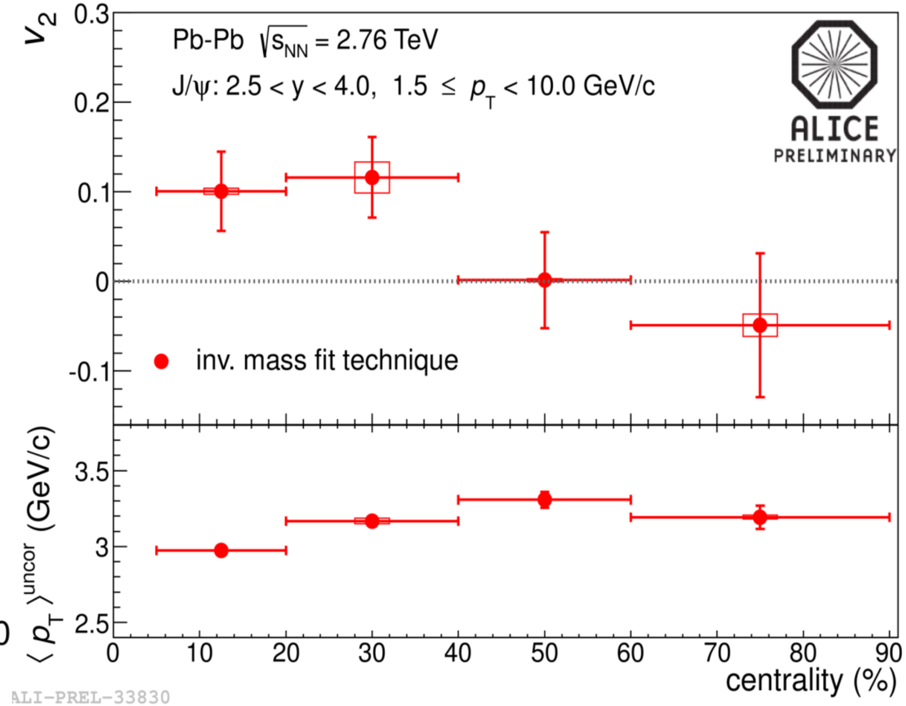
Different suppression pattern at low/high-p_T

At low p_T ~50% J/ψ from recombination
Fair agreement for different centralities

Statistical hadronization model also describes the data:
P.Braun-Munzinger et al.

J/ψ elliptic flow





J/ψ produced by recombination of thermalized c-quarks should have non-zero elliptic flow

– measurements give a hint for non-zero v_2

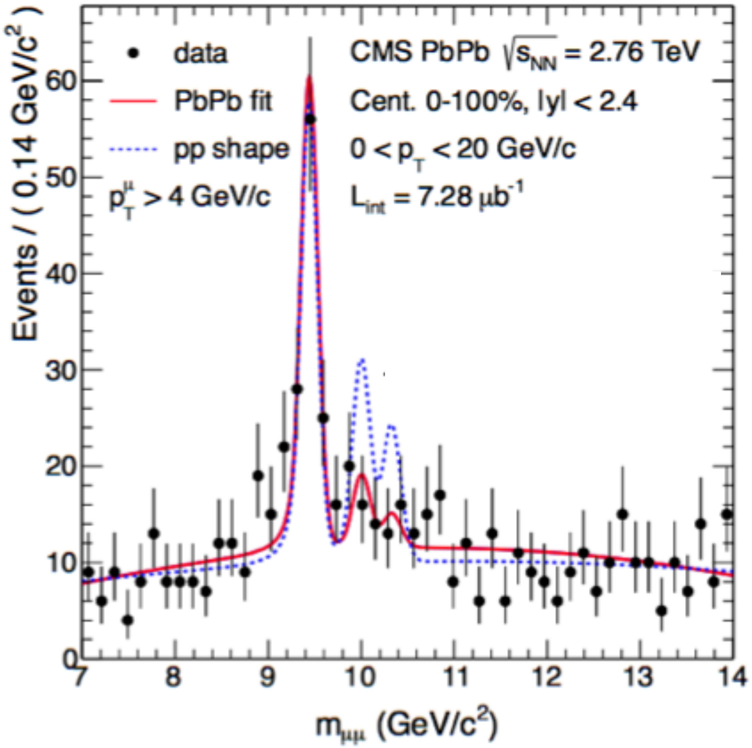
– qualitative agreement with transport models, including regeneration

– complementary to indications obtained from J/ψ R_{AA} studies

Sequential Upsilon suppression

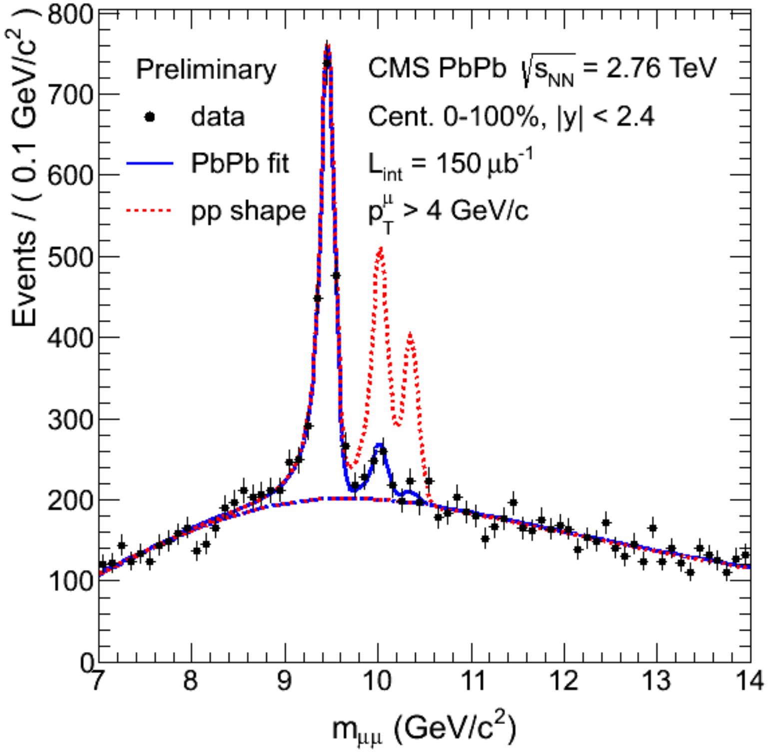
2010 data

PRL 107 (2011) 052302



Indication of suppression
of (Y(2S)+Y(3S)) relative to Y(1S)
2.4σ significance

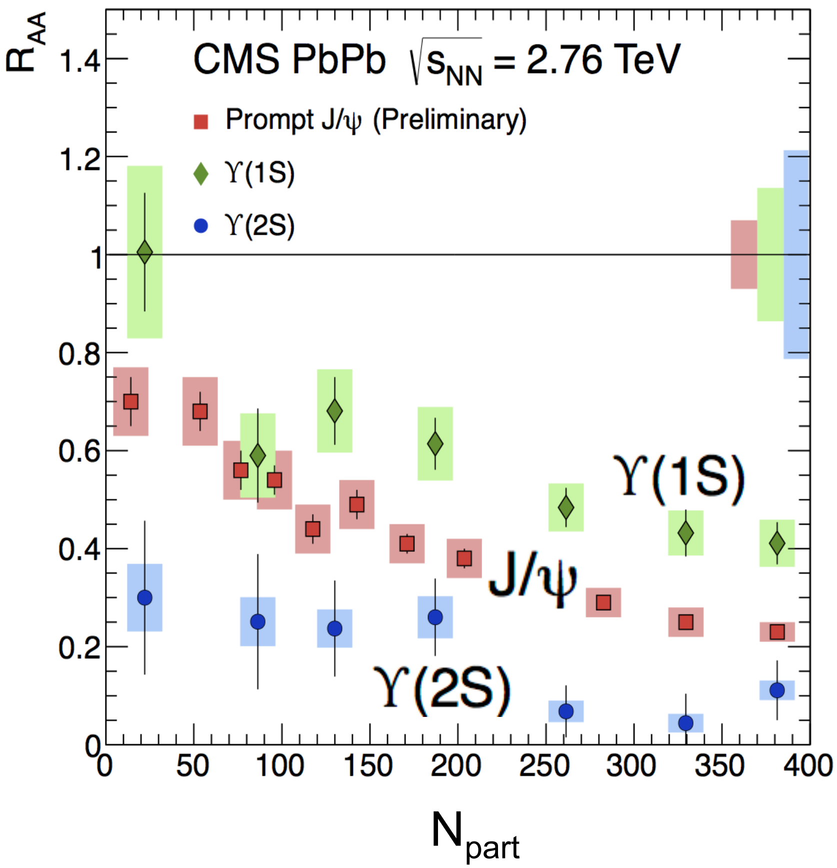
2011 data

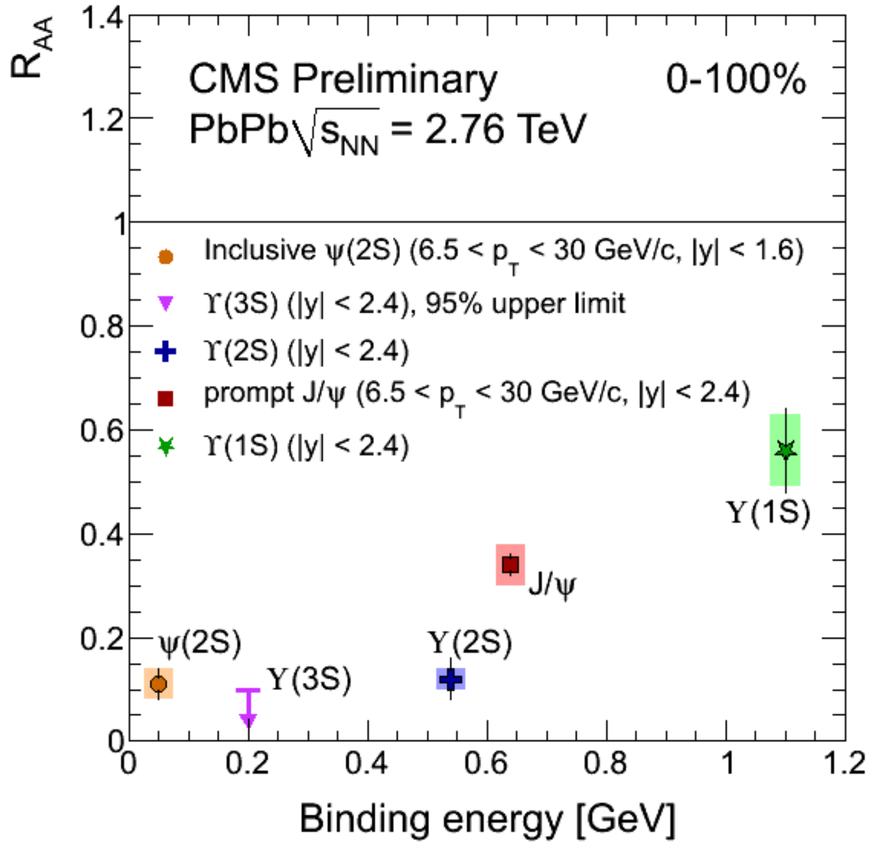


Observation of sequential
suppression of Y family
Detailed studies

Building a quarkonium-thermometer

Note: 6.5<p_T<30 GeV for J/ψ and ψ(2s)



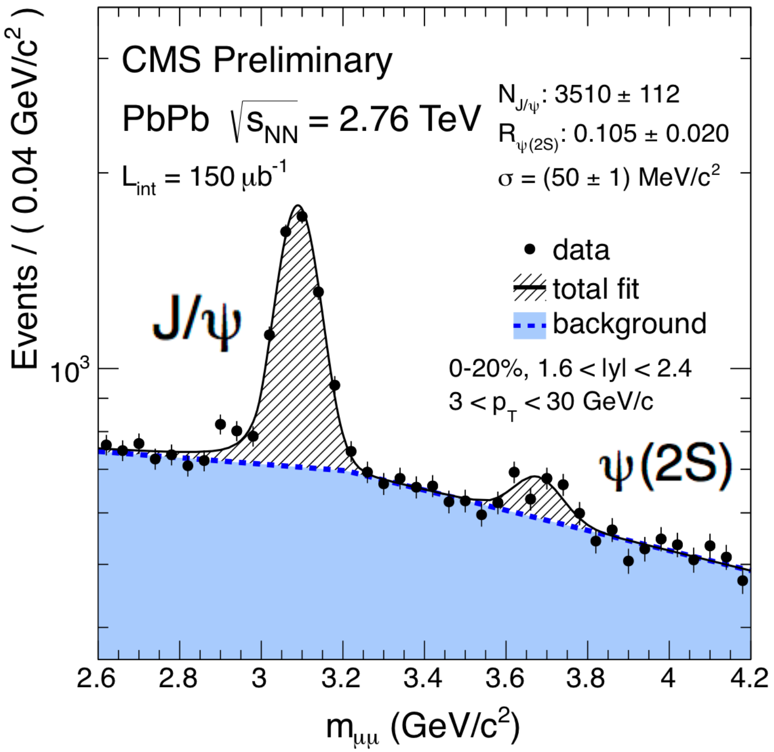


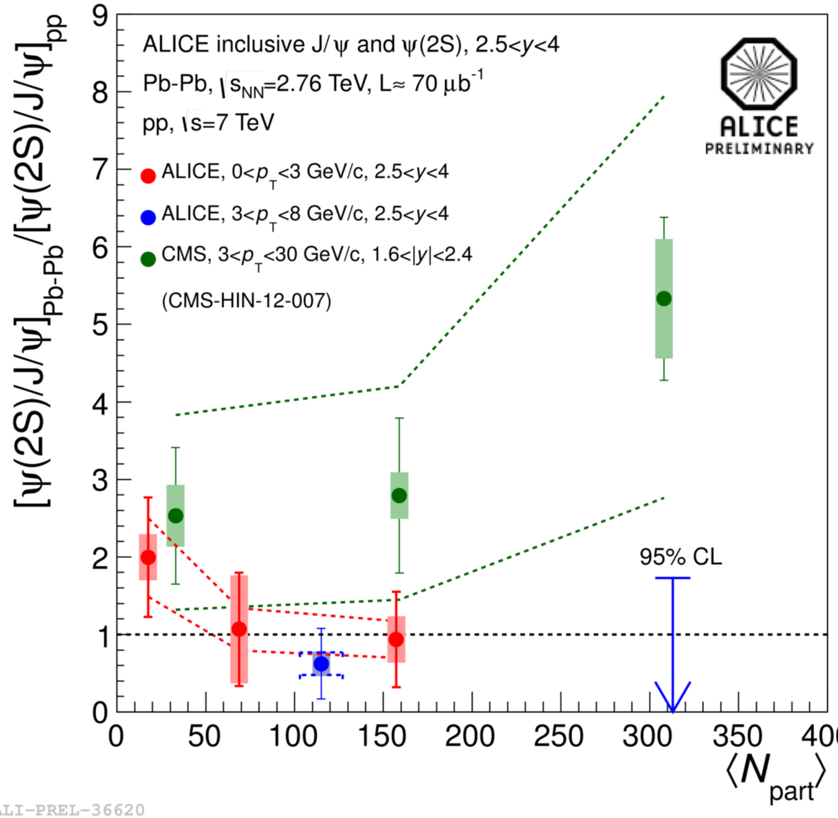
Clear hierarchy in R_{AA} of different quarkonium states

Expected in terms of binding energy

J/ψ vs ψ(2S)

PbPb (p_T > 3GeV)





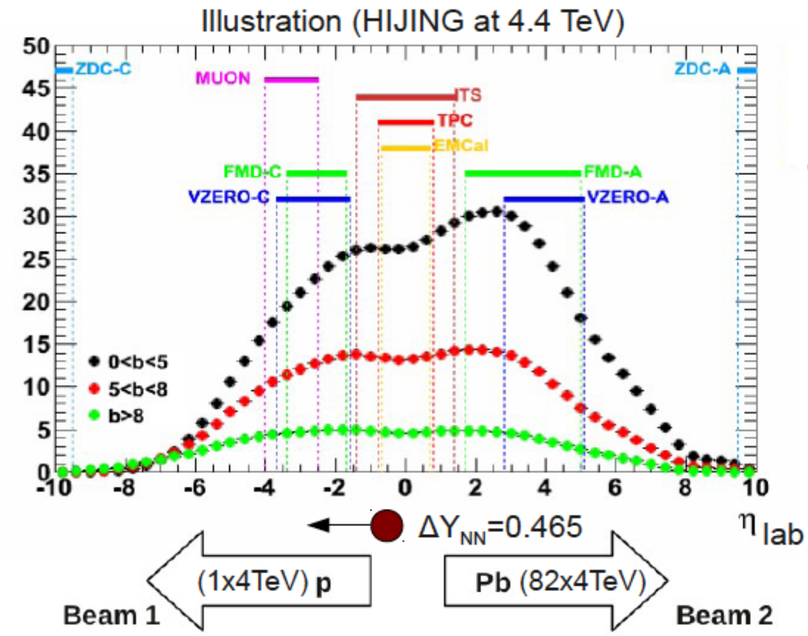
Indication that loosely bound ψ(2S) *less suppressed* than more tightly bound J/ψ for p_T > 3GeV

not more than 2σ significance, limited by pp statistics

not (yet) confirmed by ALICE

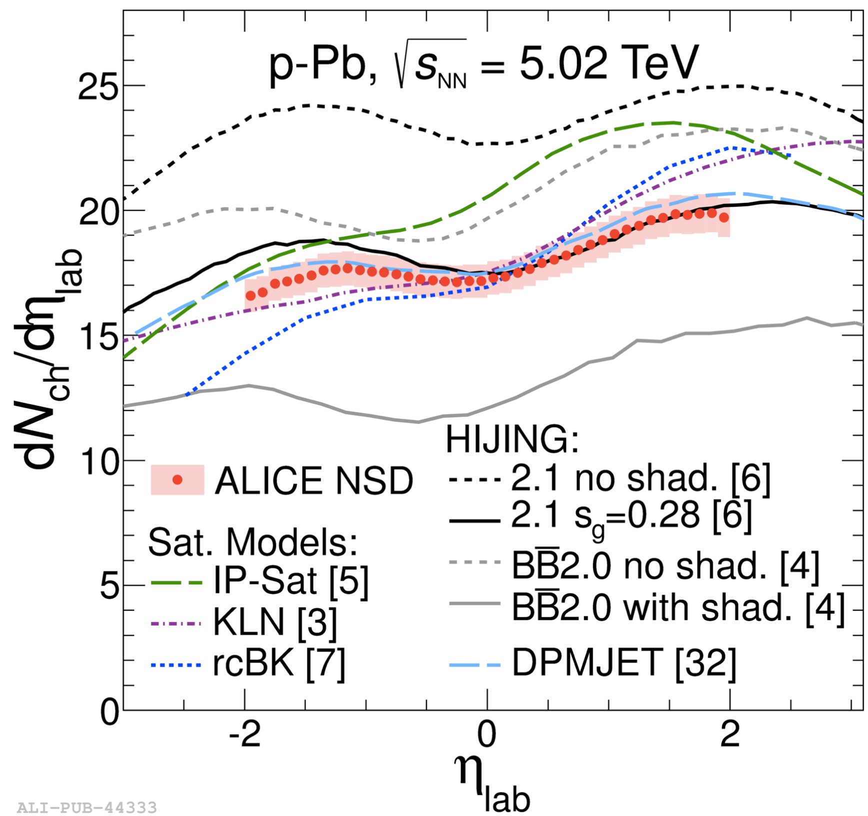
Proton – Pb collisions

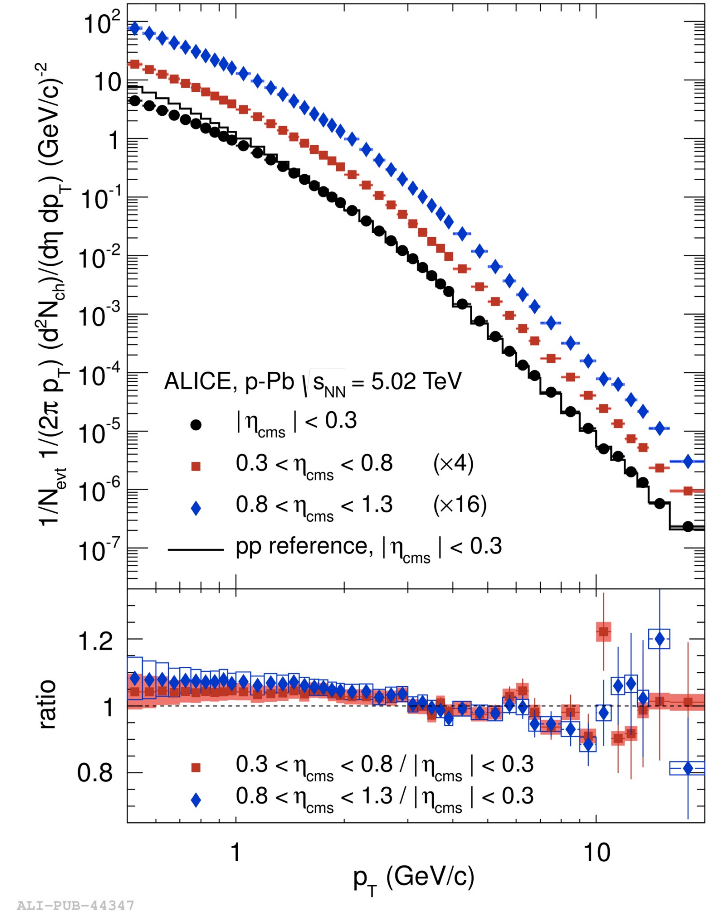
Initial conditions or collectivity ?
CGC or Hydro ?



ALICE measurements:
Pseudo-rapidity density of charged particles (arXiv:1210.3615)
p_T spectra and nuclear modification factors (arXiv:1210.4520)
Long range angular correlations on same/away side (arXiv:1212.2001)

Proton – Pb: $dN_{ch}/d\eta$ and p_T distributions





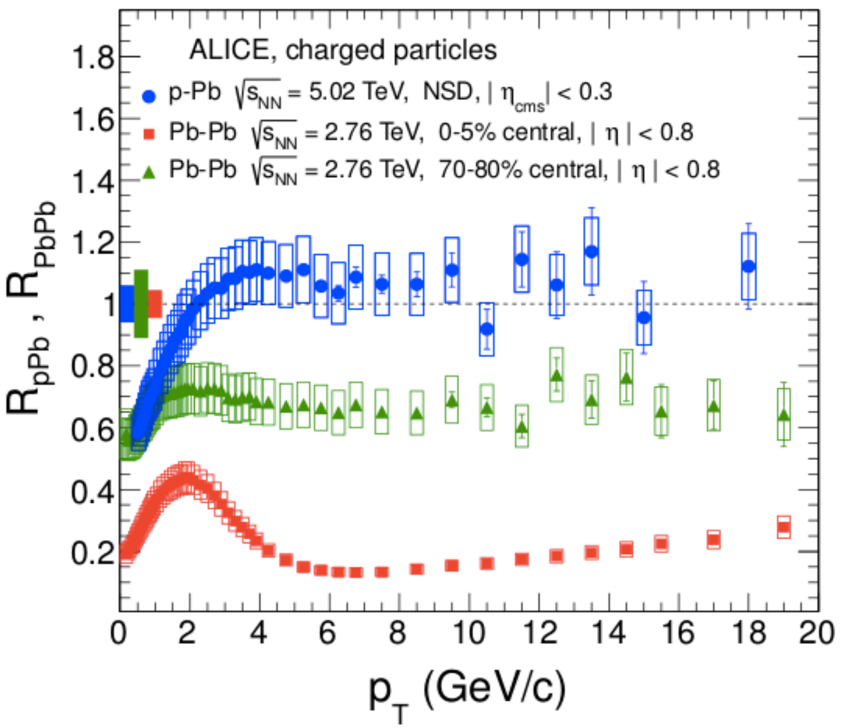
Most models within 20% of data

Saturation models rise too steeply
pQCD based models do well

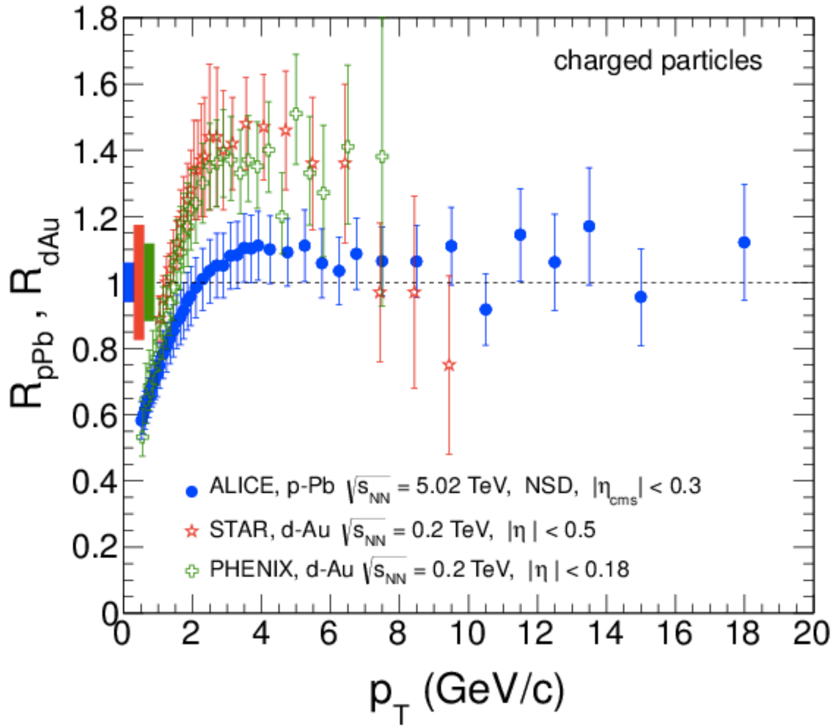
Spectrum slightly softer than in pp

Proton – Pb: R_{AA} distributions

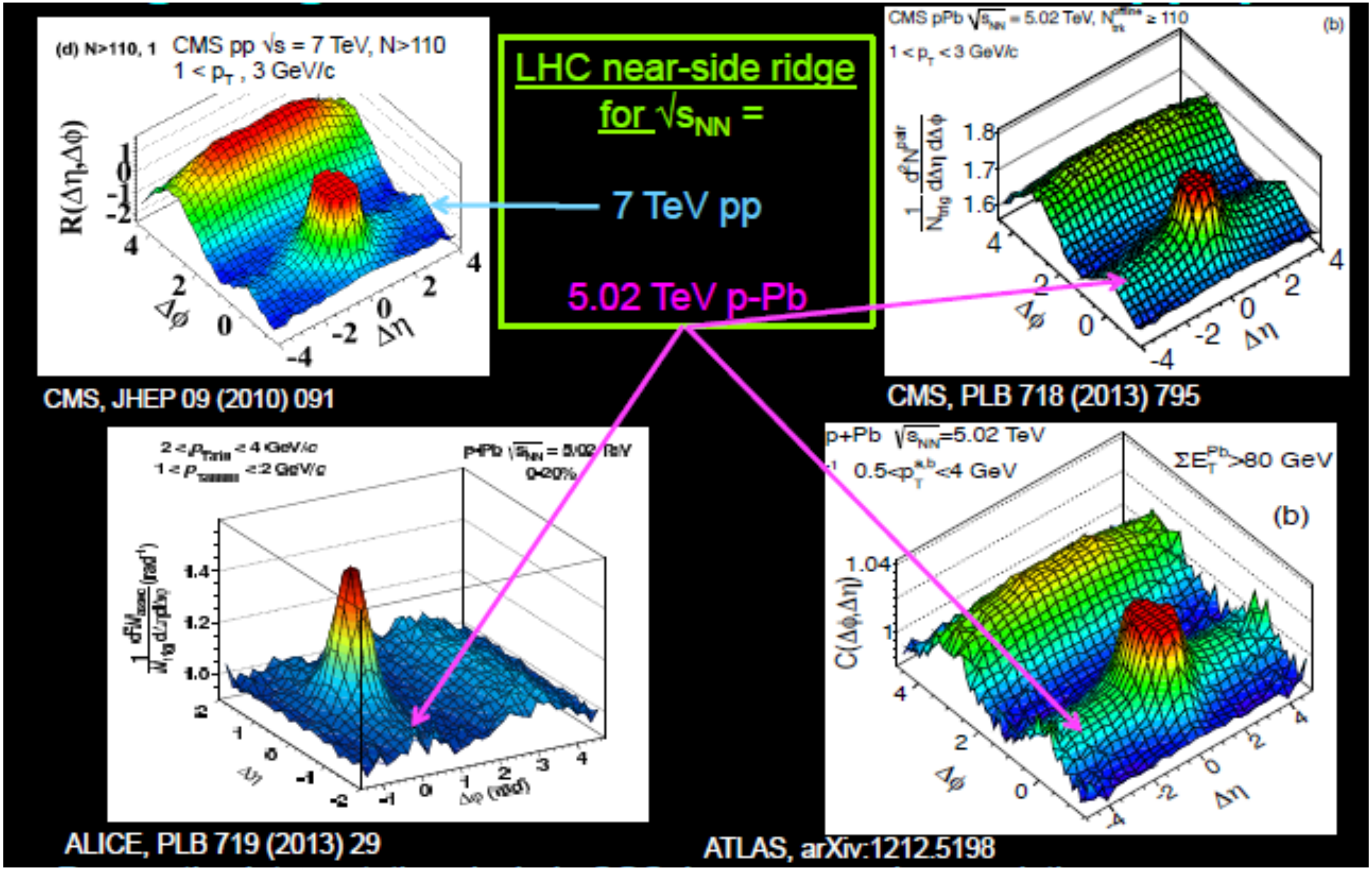
Comparison: p-Pb vs PbPb



Comparison: LHC p-Pb vs RHIC d-Au

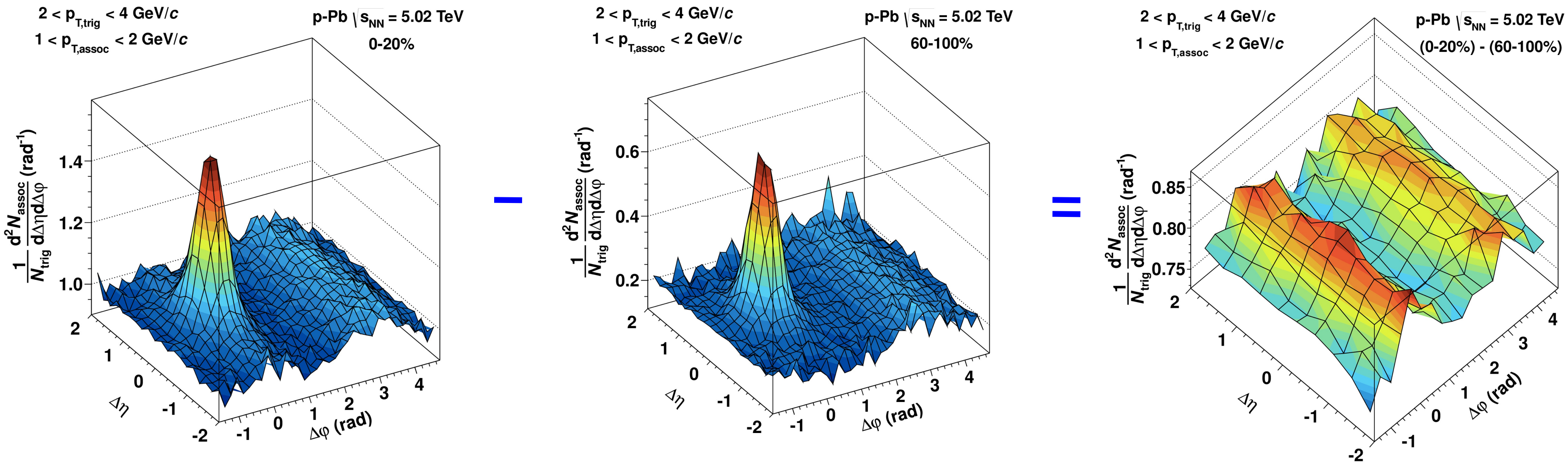


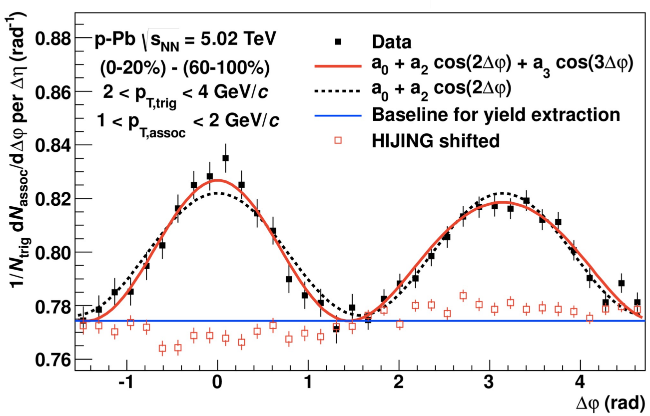
Proton – Pb: long range di-hadron correlations

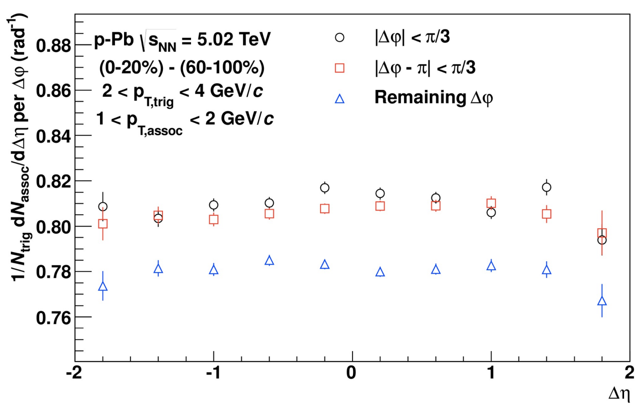


Getting to the heart of it

Subtracting high multiplicity events from low multiplicity events reveals the structure







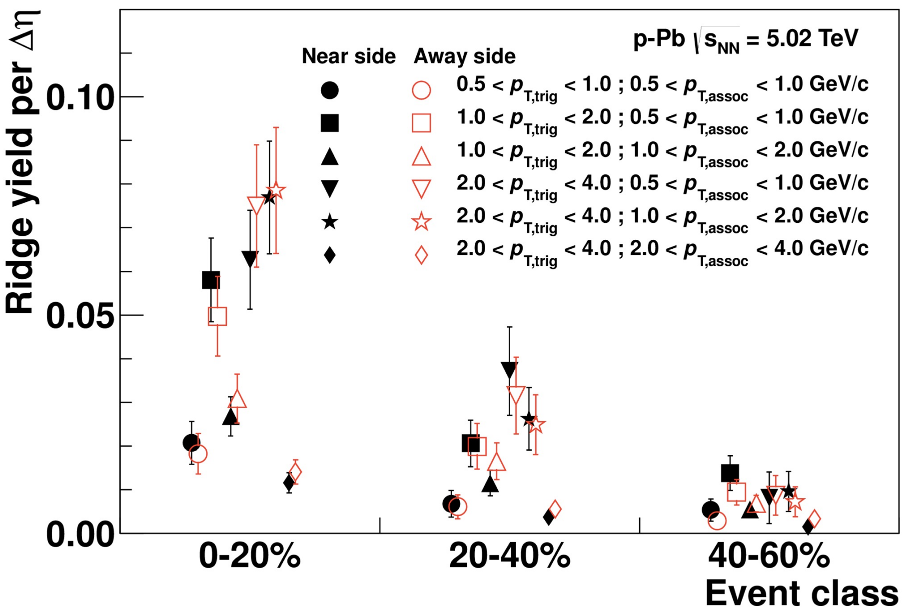
Two nearly identical ridges

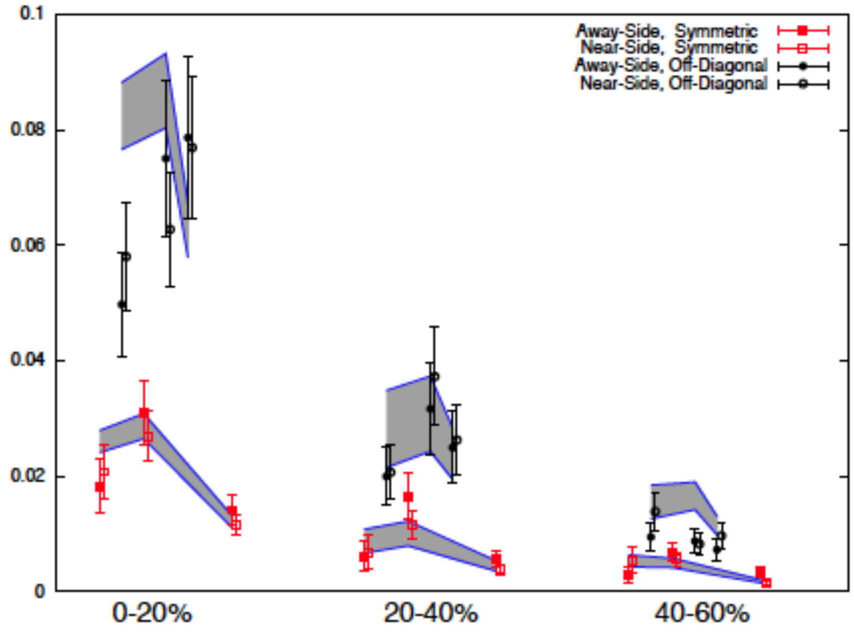
Same amplitude flat in Δη

Integrated ridge yields

Data:
Integrated yields vary over large range
But near and away side agree
for each pT and multiplicity class

Theory:
Dusling, Venugopolan (arXiv:1211.3701)
CGC predicts double ridge and
shows good agreement for yields





Theory alternative: hydrodynamics (Bozek et al., arXiv:1211.0845)
Good agreement with v_2 and v_3

The future and summary

Future LHC program (preliminary)

ALICE heavy-ion program approved for ~ 1 nb^{-1}:

- 2013–14 Long Shutdown 1 (LS1)
- 2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV
- 2016–17 (maybe combined in one year) Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV
- 2018 Long Shutdown 2 (LS2)
- 2019 probably light nuclei (Ar–Ar) high-luminosity run
- 2020 p–Pb comparison run at full energy
- 2021 Pb–Pb run to complete initial ALICE programme
- 2022 Long Shutdown 3 (LS3)

Detector upgrades planned for LS2
(central barrel upgrade: ITS/TPC to improve low momentum coverage and luminosity upgrade)

Luminosity upgrade to 50 kHz in PbPb, 2 MHz in pp

Summary

- ALICE/CMS have obtained a wealth of physics results from the first two LHC heavy-ion runs and the most recent pPb run:
  - **bulk, soft probes:**
    - thermal photons signal the highest initial temperature ever recorded
    - Strangeness seems to hadronize earlier than light particles
    - V2 and higher harmonics in line with hydro expectations
  - **Intermediate / high-p_T probes:**
    - Baryon enhancement still remains at intermediate pT
    - RAA and v2 show surprisingly little flavor dependence
    - v2 out to high pT, higher harmonics die out at high pt
    - Jets quench, but shapes and FF almost unaffected by medium
  - **heavy-flavour physics:**
    - suppression and flow of D mesons, leptons,
    - J/ψ and Y suppression and recombination. Towards a thermometer.
- **pA program**: first results that can be interpreted with CGC or hydro !!
- **Long term future**
  - before LS2 (2018): p–Pb and Pb–Pb, higher energy and complete approved
  - during LS2: major detector upgrade of central barrel in ALICE
  - after LS2: major luminosity upgrade and continued physics program