ALICE latest results from Pb-Pb collisions at the LHC

Javier Castillo

for the

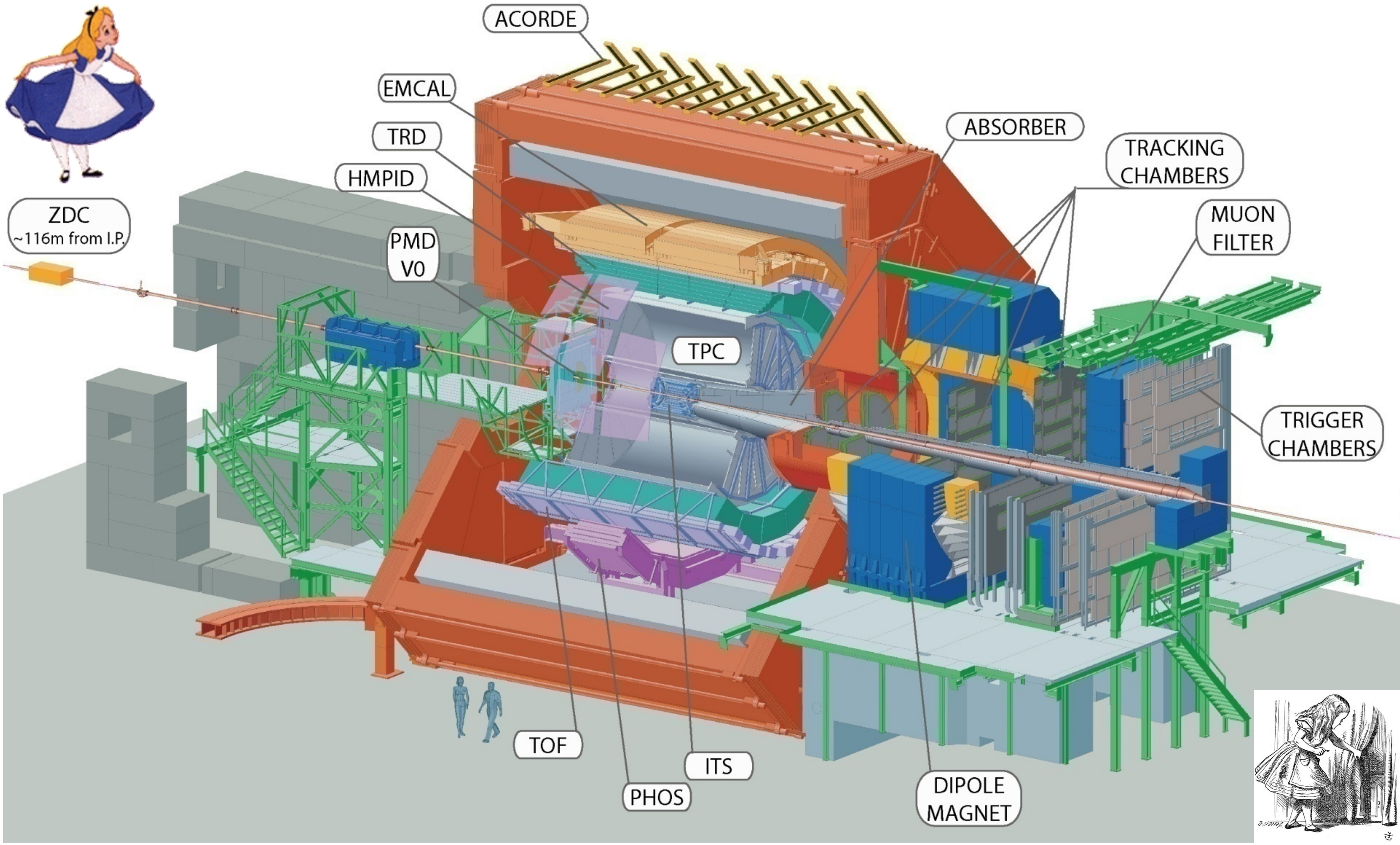
ALICE Collaboration

ALICE @ LHC

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

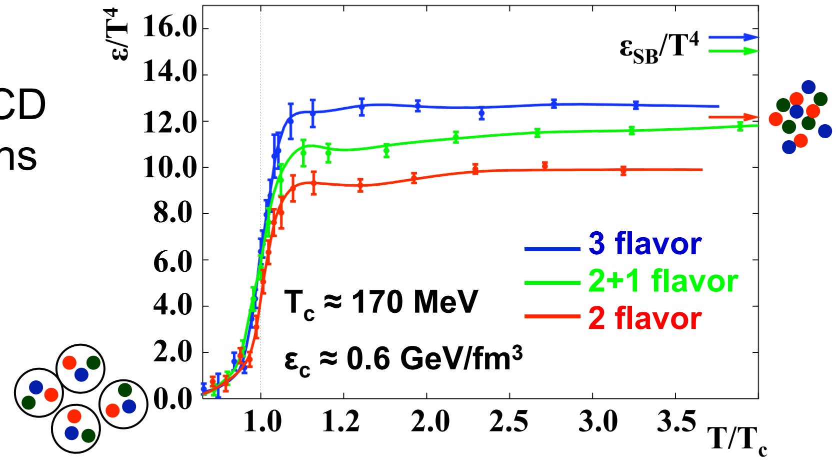
ALICE

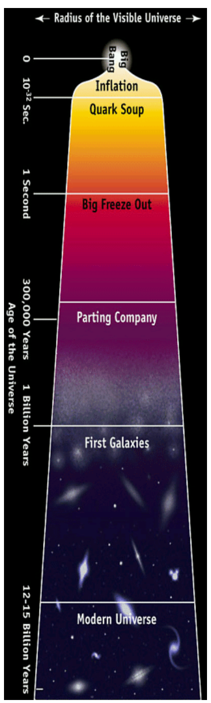
- The LHC experiment devoted to the study of heavy ion collisions
- Designed to track and identify the thousands of particles down to the lowest p_T

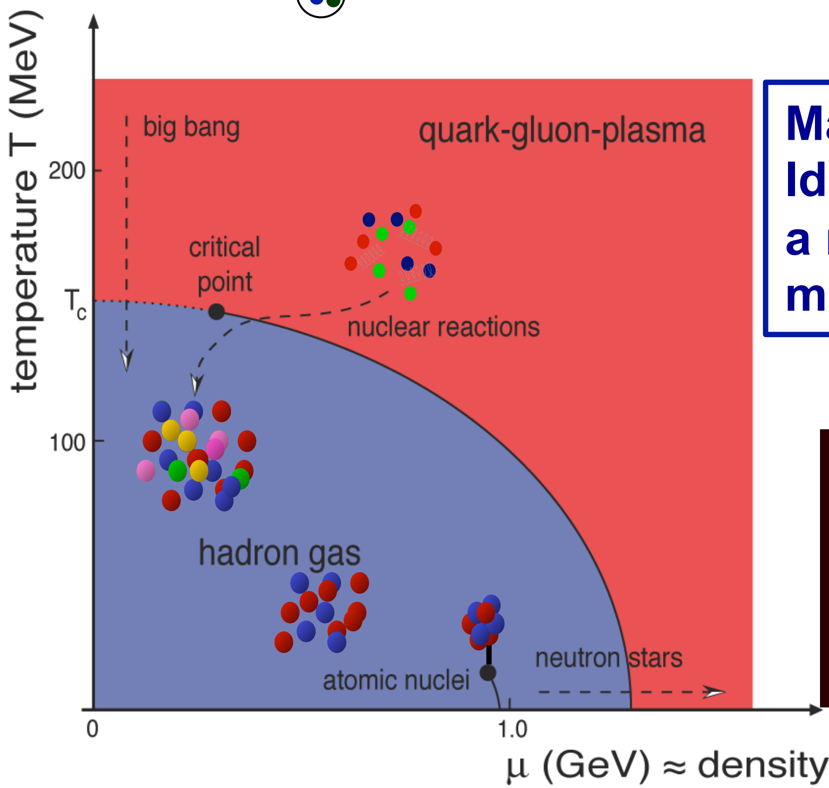


Quark Gluon Plasma

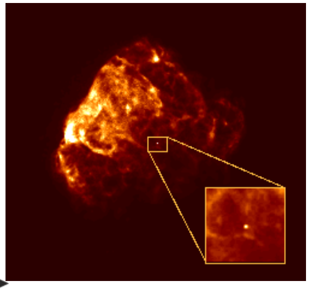
Lattice QCD calculations



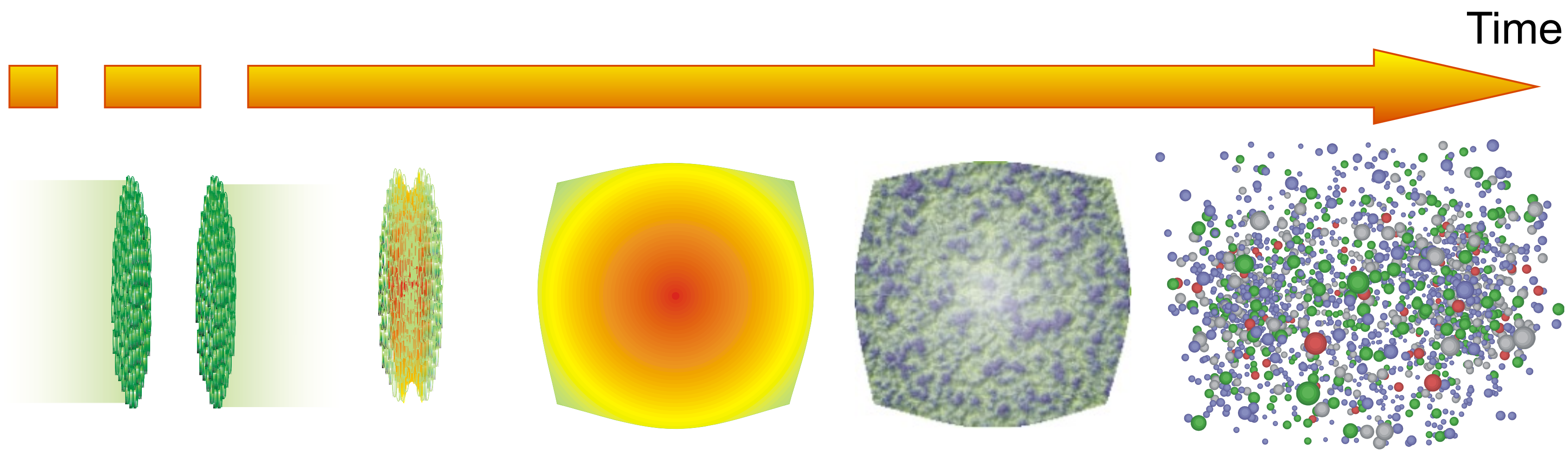




Main goal:
Identify and study the properties of a new state of deconfined nuclear matter, the Quark Gluon Plasma



Heavy ion collisions

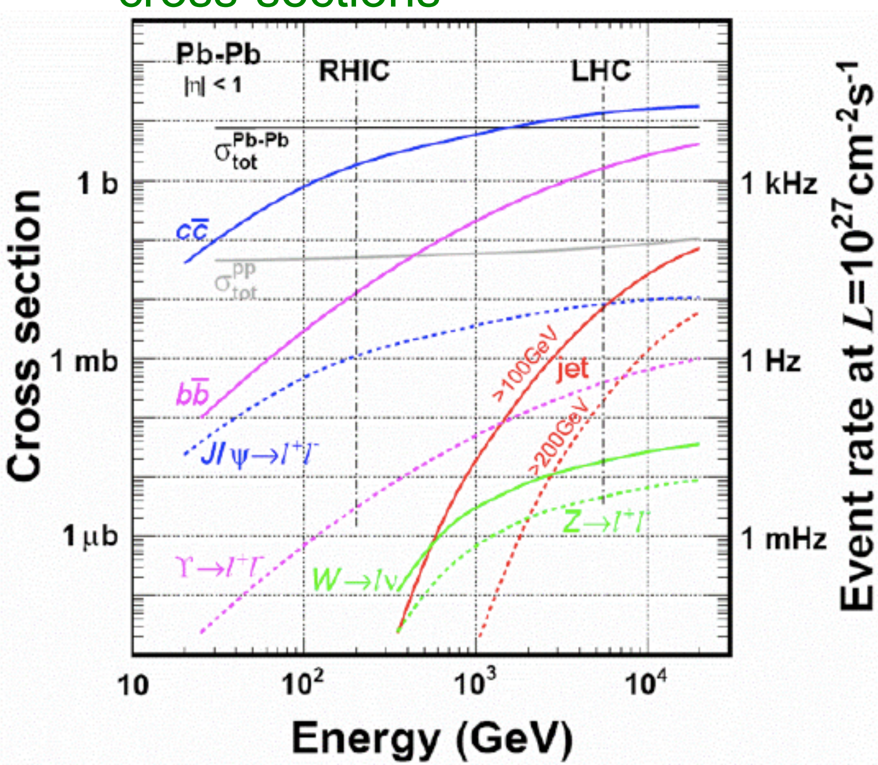


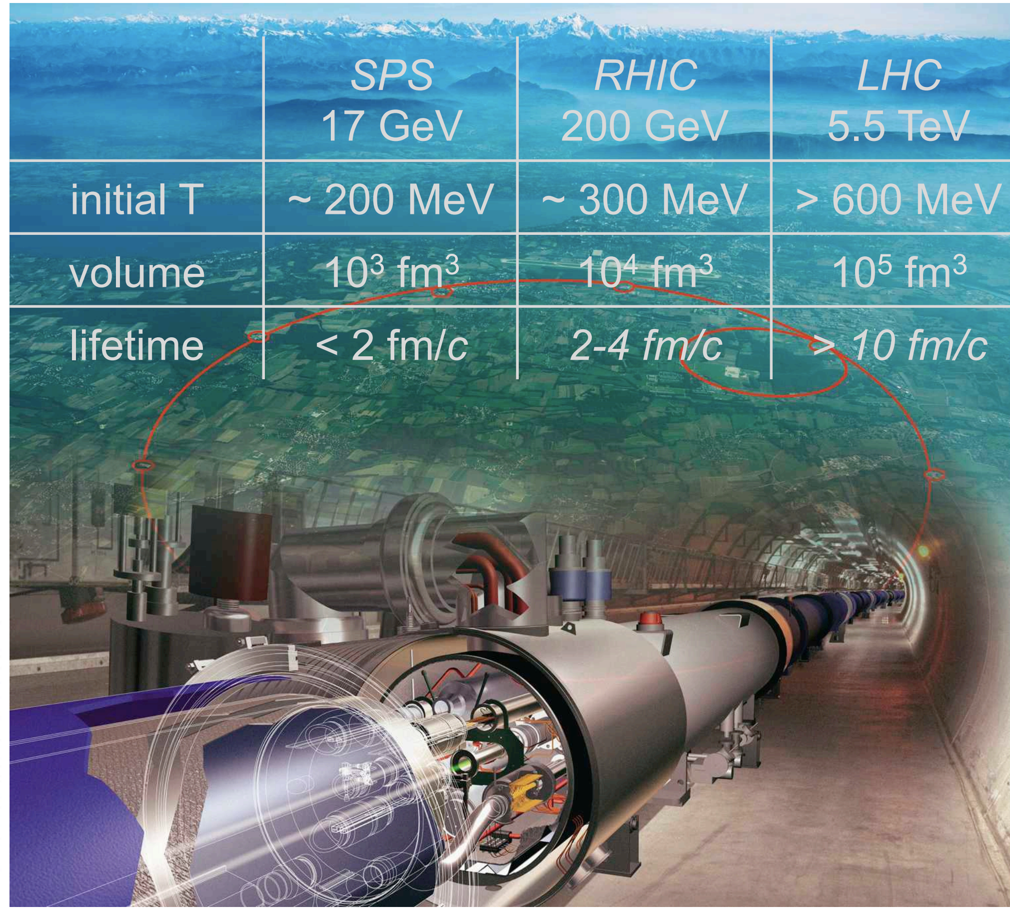
Studies of the created medium

- Bulk properties
  - How does the medium behave
- Probing the medium
  - How does a probe react to the medium

The LHC and its features

- Large energy step (RHIC x30)
  - A QGP that will be
    - hotter,
    - bigger,
    - longer lived,
    - earlier thermalized.
  - Large hard probe production cross-sections





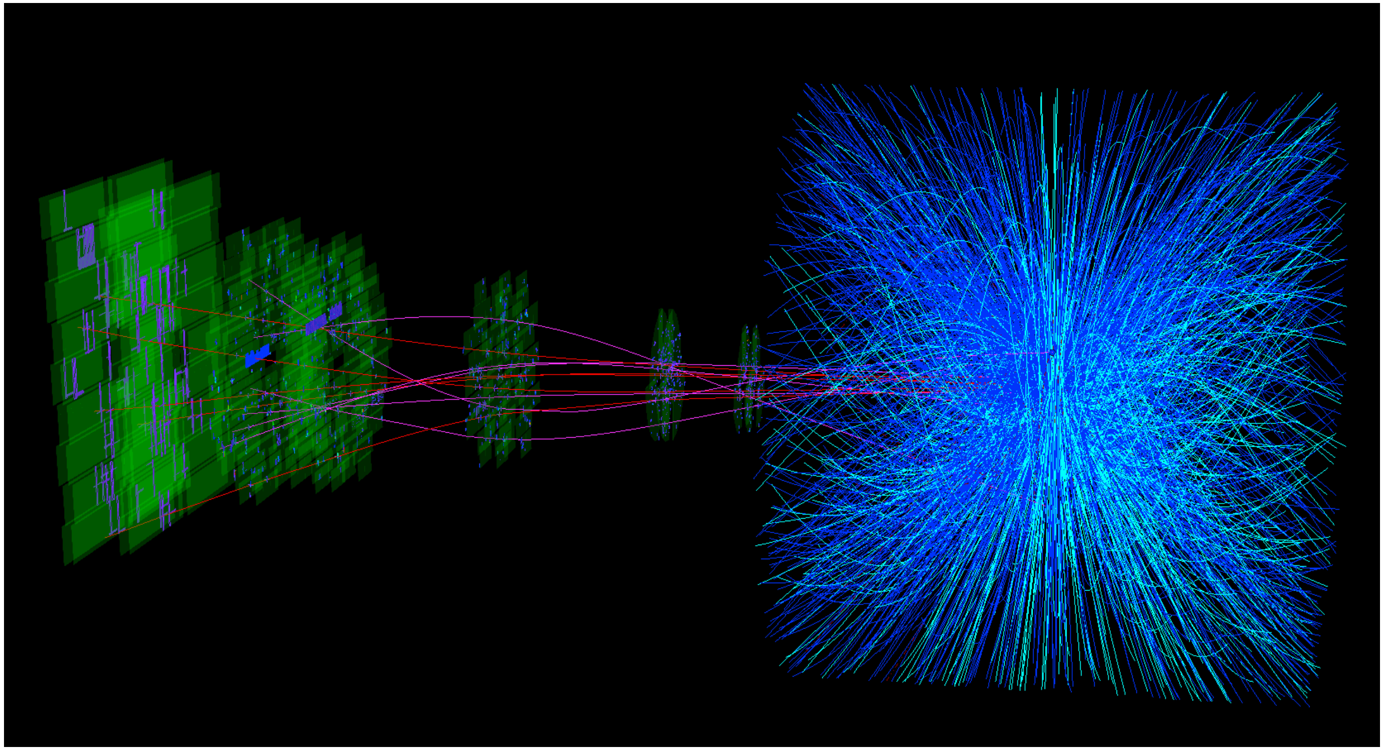
	SPS 17 GeV	RHIC 200 GeV	LHC 5.5 TeV
initial T	~ 200 MeV	~ 300 MeV	> 600 MeV
volume	10^3 fm^3	10^4 fm^3	10^5 fm^3
lifetime	< 2 fm/c	2-4 fm/c	> 10 fm/c

	SPS PbPb Cent	RHIC AuAu Cent	LHC pp	LHC pPb	LHC PbPb Cent
cc	0.2	10	0.2	1	**115**
bb	-	0.05	0.007	0.03	**5**

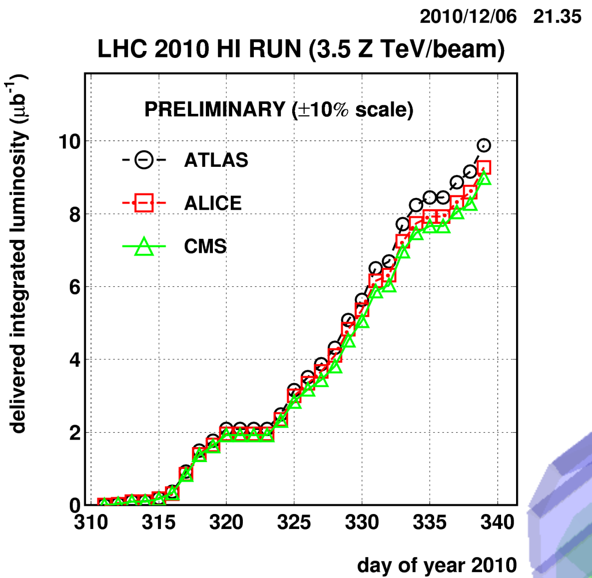
At top energies

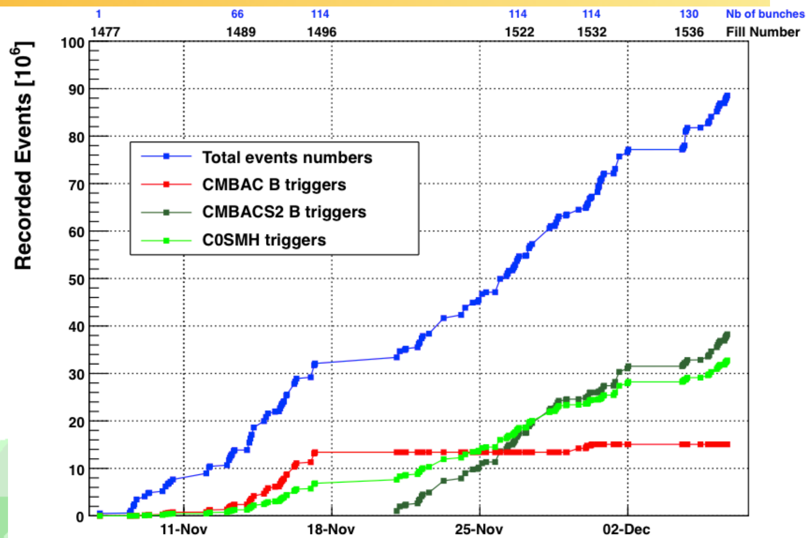
Outline

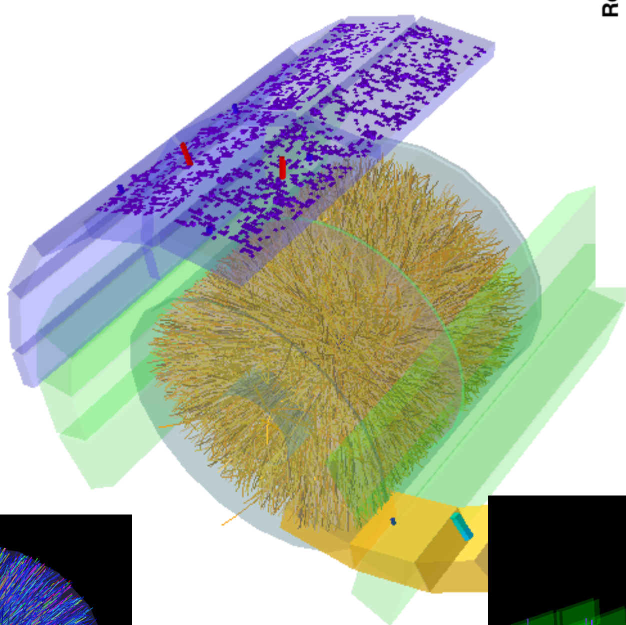
- Physics motivations
- ALICE @ LHC
- First Pb-Pb run
- Properties of the medium
- Probing the medium
- Conclusions

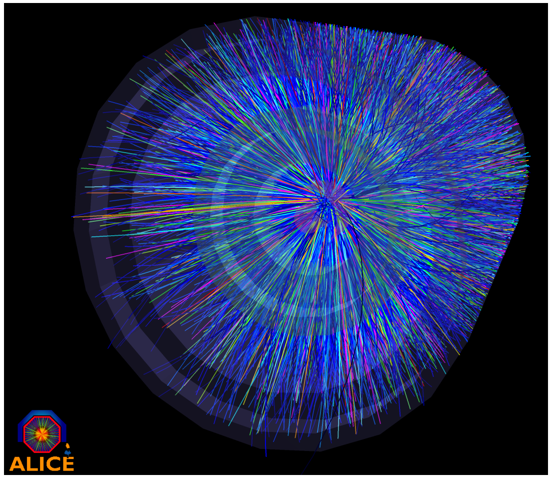


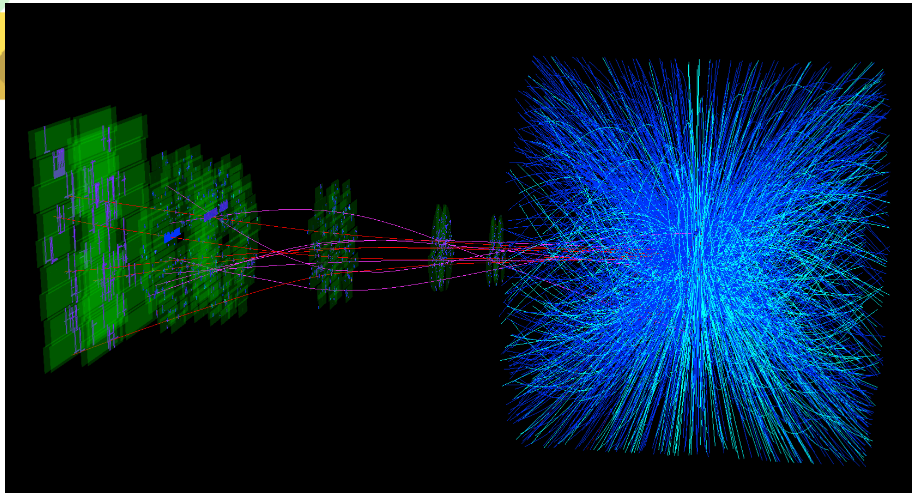
First heavy ion run @ LHC – 2010



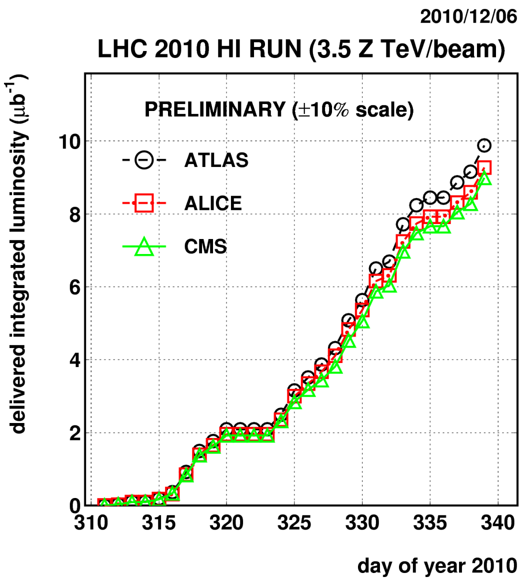


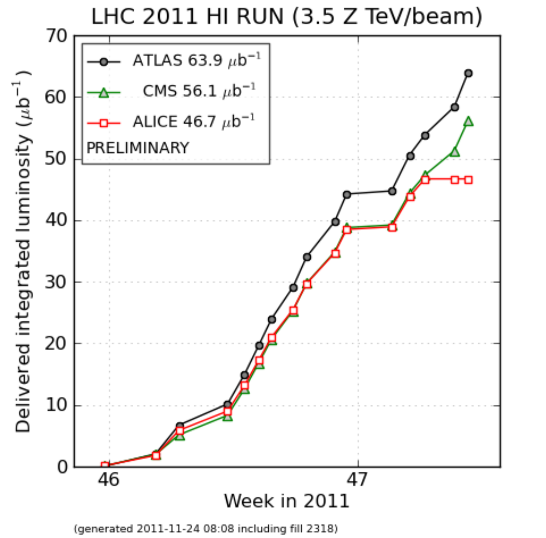


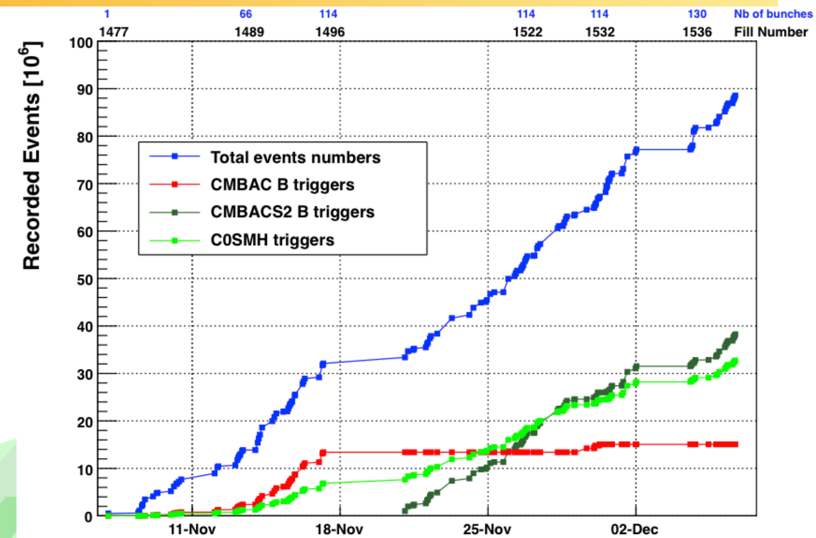


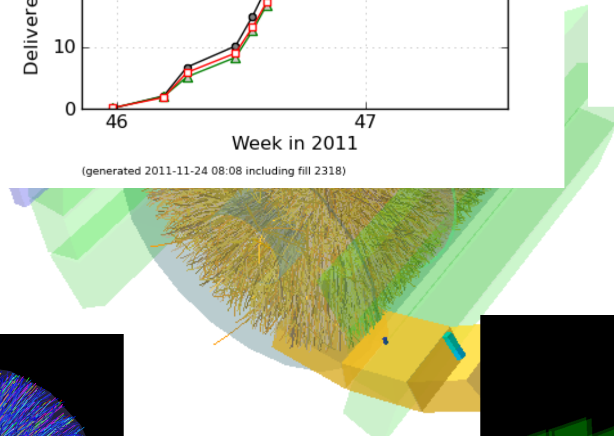


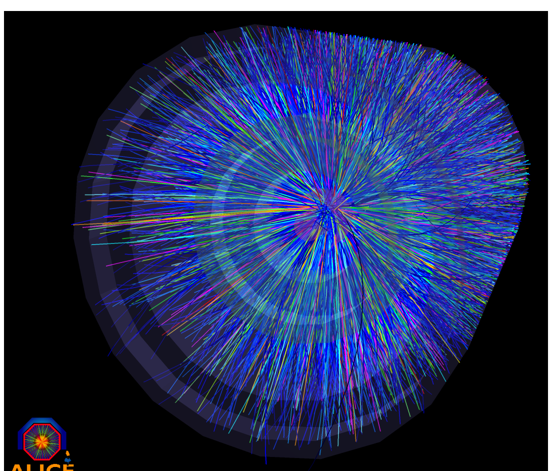
First heavy ion run @ LHC – 2010

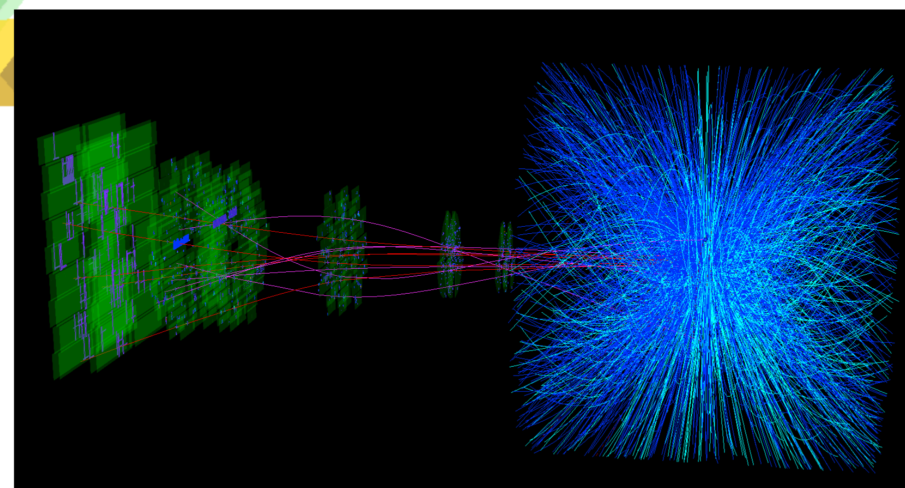






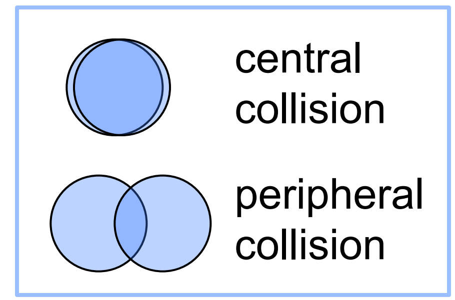


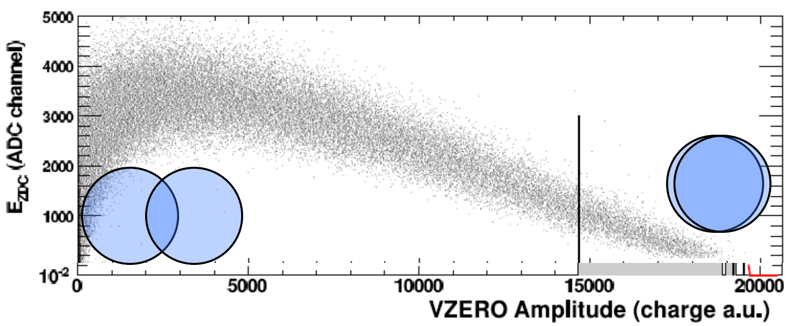


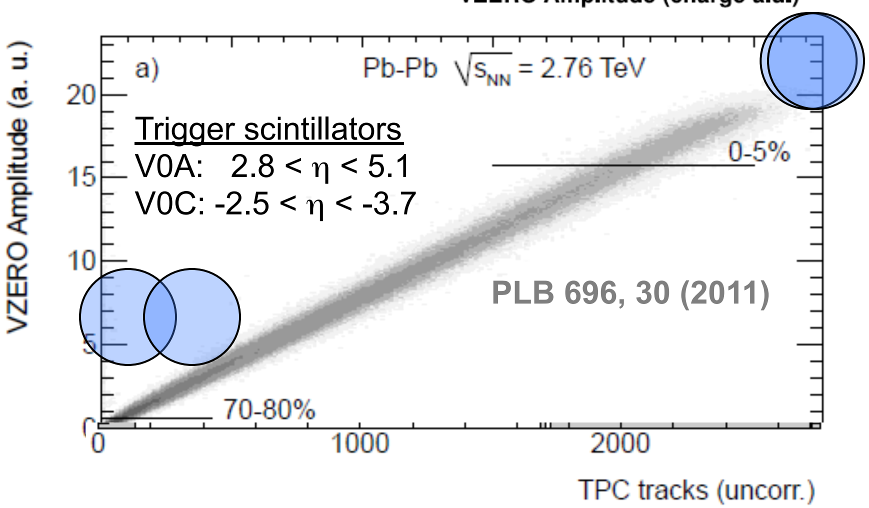


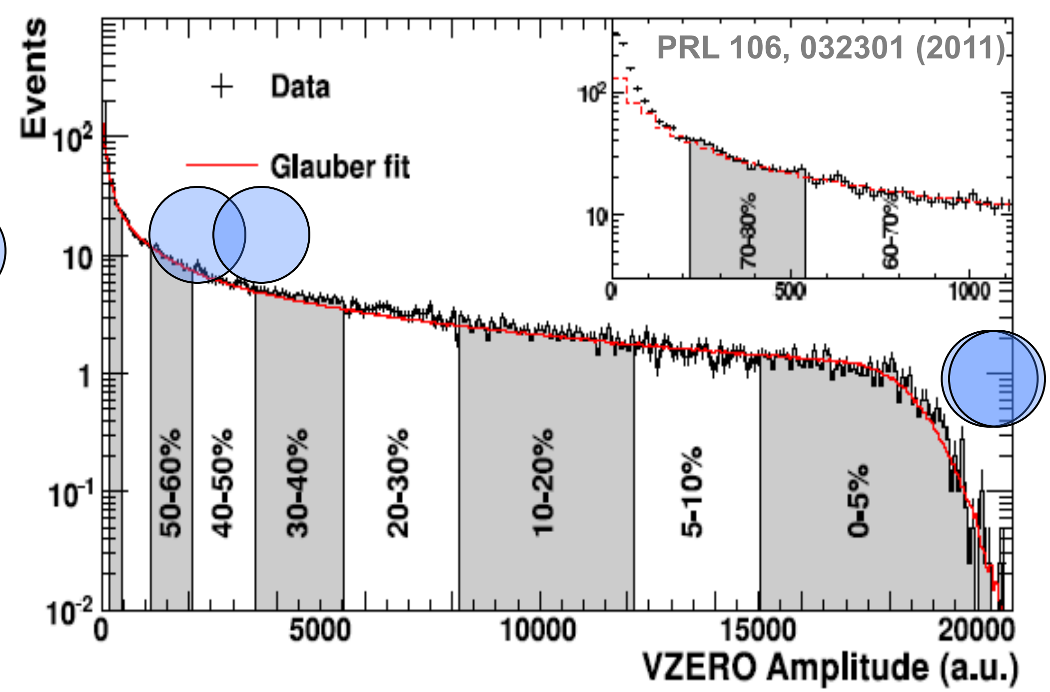
Collision centrality

- Pb-Pb collisions are classified in centrality classes, corresponding to percentiles of the inelastic cross section
- Glauber-model fits to several estimators (hit/track multiplicities + zero degree calorimeter signals)
  - Glauber fit: $N_{ch} \sim f \times N_{part} + (1-f) \times N_{coll}$





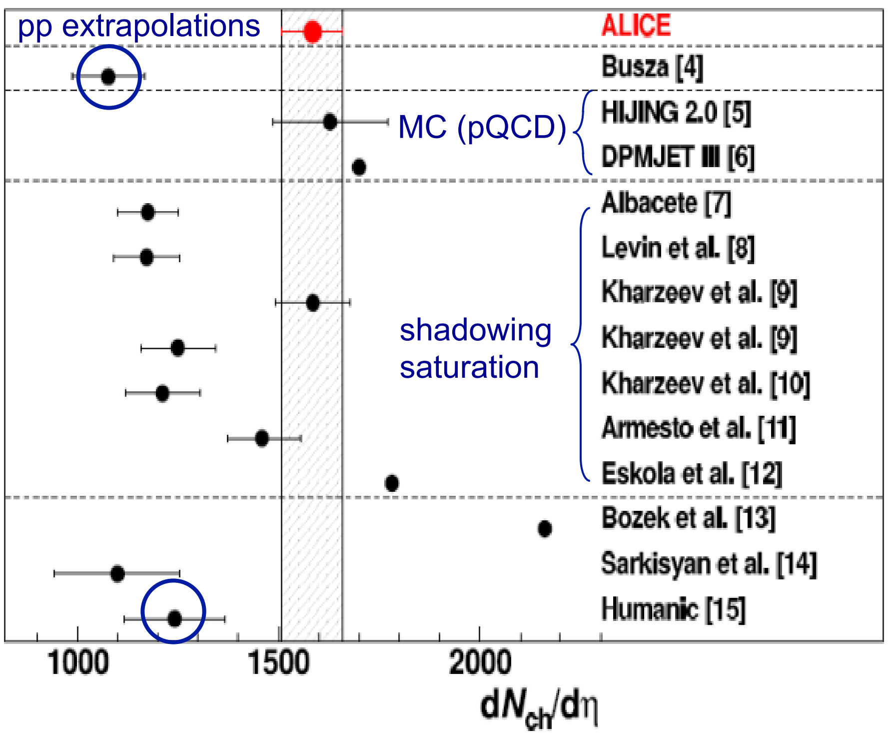


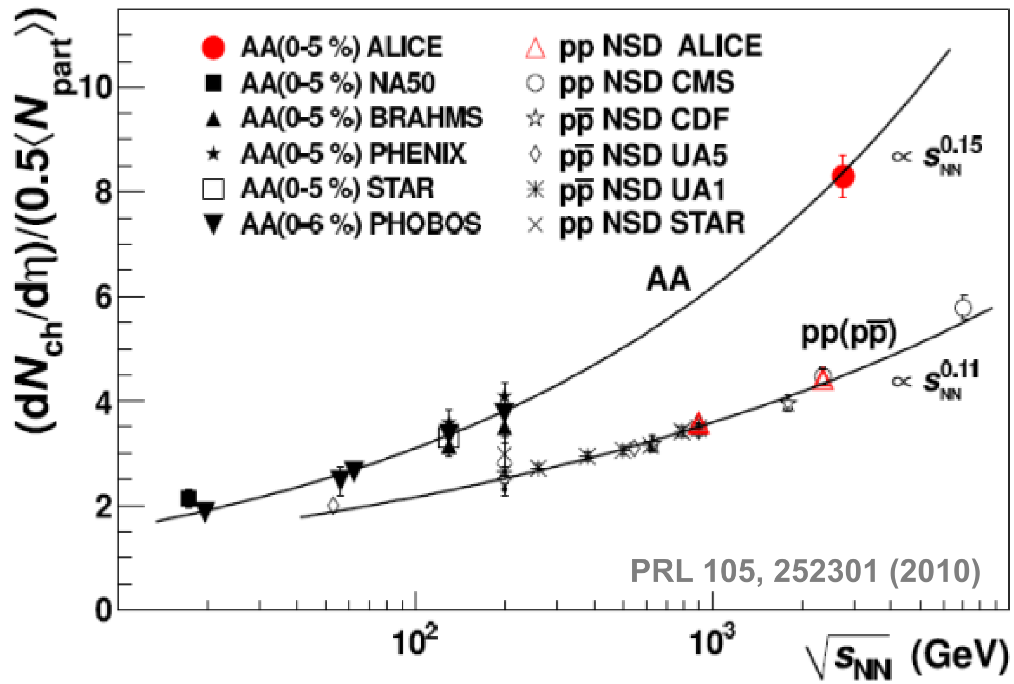


Charged Particle Multiplicity

- Central Pb-Pb (from pixels): $dN_{ch}/d\eta$ = 1584±76 (syst)
  - growth with √s faster in A-A than in p-p
- Energy density ≈ 3×RHIC (at same time τ_0)
  - lower limit, likely τ_0(LHC) < τ_0(RHIC)

$$\varepsilon(\tau_0) = \frac{E}{V} = \frac{1}{\tau_0 A}\frac{dN}{dy} < m_t >$$



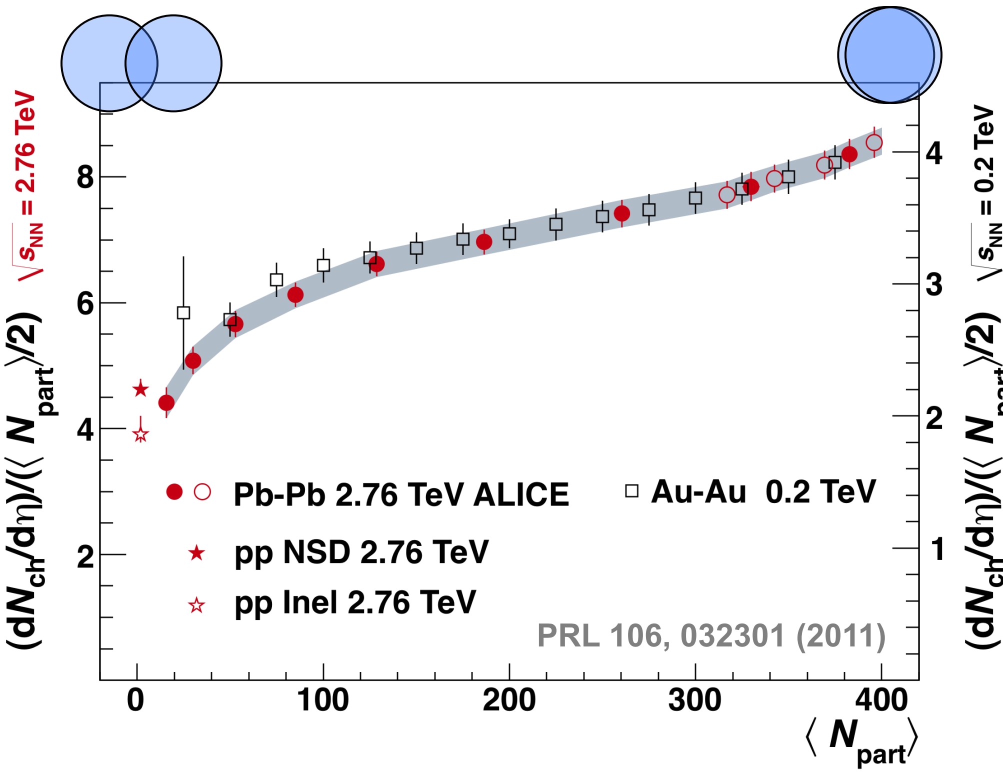


Pb-Pb ($\sqrt{s_{NN}}$=2.76 TeV)

- 1.9 x p-p (NSD) ($\sqrt{s_{NN}}$=2.36 TeV)
- 2.2 x Au-Au ($\sqrt{s_{NN}}$=0.2 TeV)

Centrality dependence of $dN_{ch}/d\eta$

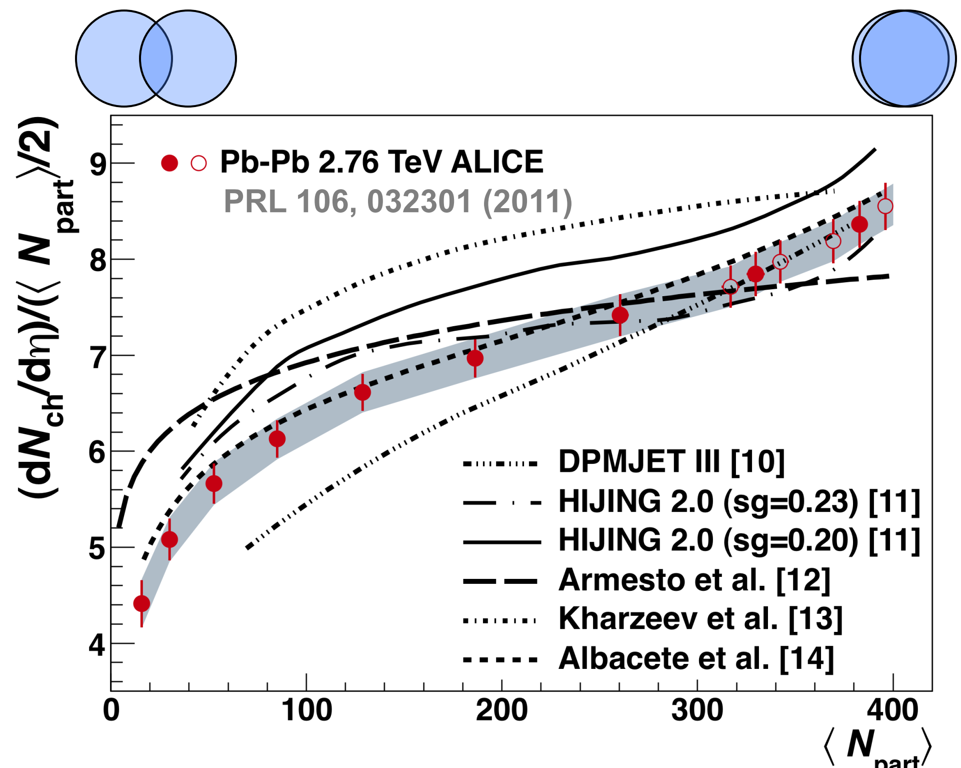
- $dN_{ch}/d\eta$ as function of centrality
  - normalized to 'overlap volume' ~ $N_{participants}$
- Sensitive to degree of gluon saturation in the initial state
- Same trend as at RHIC



- Comparison to models:
  - DPMJET MC
    - fails to describe the data
  - HIJING MC
    - strong centrality dependent gluon shadowing
  - Saturation models [12-14]:
    - some tend to saturate too much

Centrality dependence of $dN_{ch}/d\eta$ – models

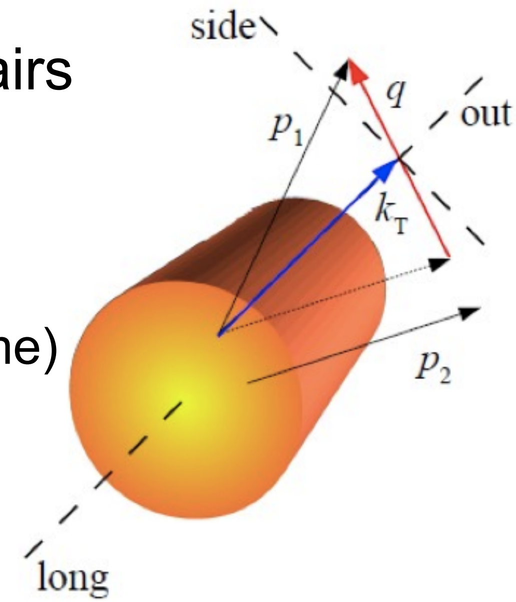
- $dN_{ch}/d\eta$ as function of centrality
  - normalized to 'overlap volume' ~ $N_{participants}$
- Sensitive to degree of gluon saturation in the initial state
- Same trend as at RHIC
- Comparison to models:
  - DPMJET MC
    - fails to describe the data
  - HIJING MC
    - strong centrality dependent gluon shadowing
  - Saturation models [12-14]:
    - some tend to saturate too much



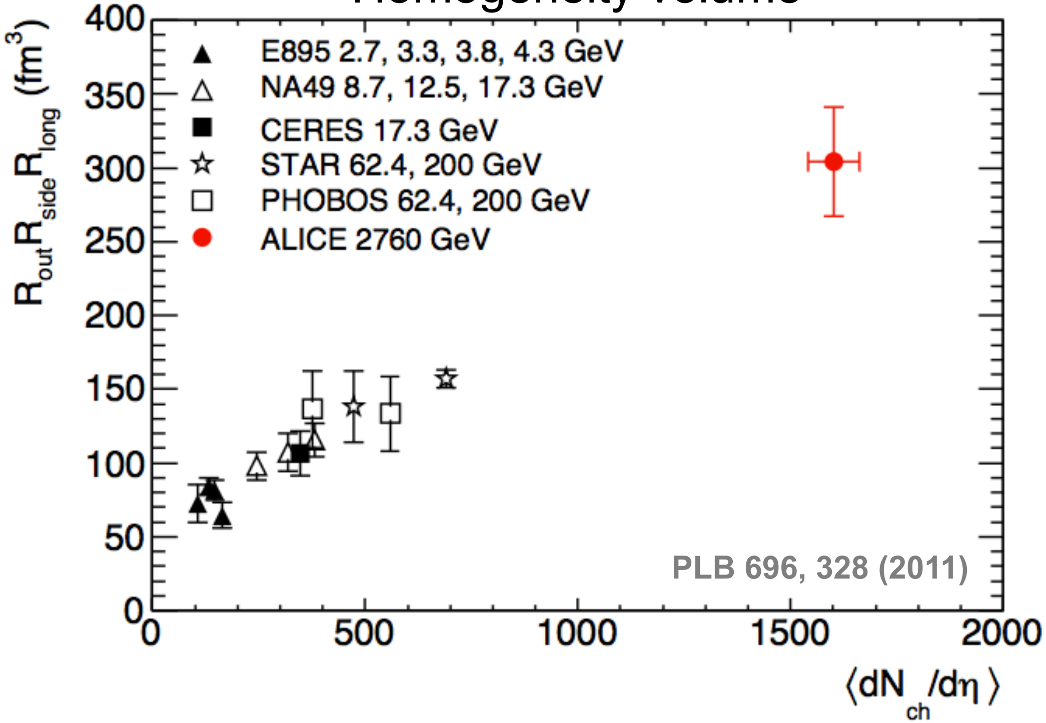
Models incorporating a moderation of the multiplicity with centrality are favored by the data (as at RHIC)

Space-time evolution – freeze-out volume

- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference $q_{inv}=|p1-p2|$, vs. multiplicity
  - Assess the space-time extension of the system that emits particles in Pb-Pb collisions (homogeneity volume)



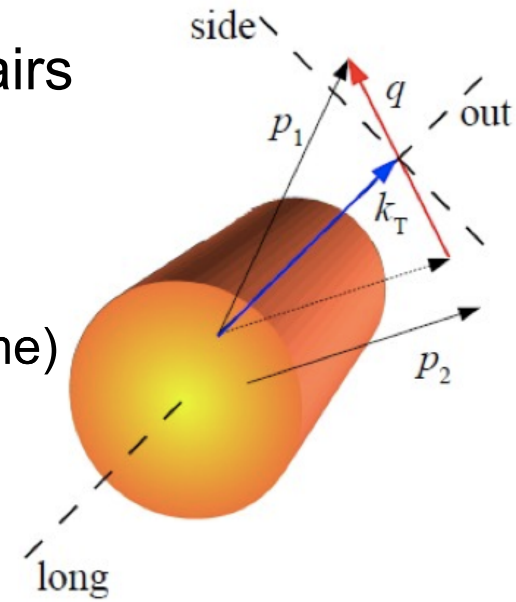
Homogeneity volume



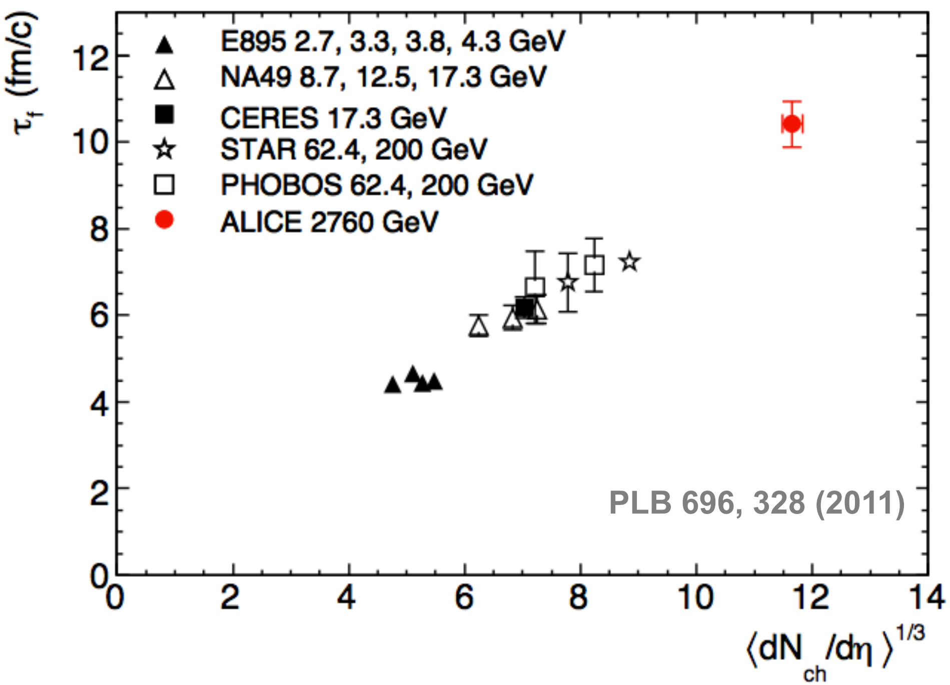
- Linear dependence on multiplicity
- $V_{LHC} \approx 300$ fm^3 ~ ×2 V_{RHIC}

Space-time evolution – decoupling time

- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference $q_{inv}=|p1-p2|$, vs. multiplicity
  - Assess the space-time extension of the system that emits particles in Pb-Pb collisions (homogeneity volume)



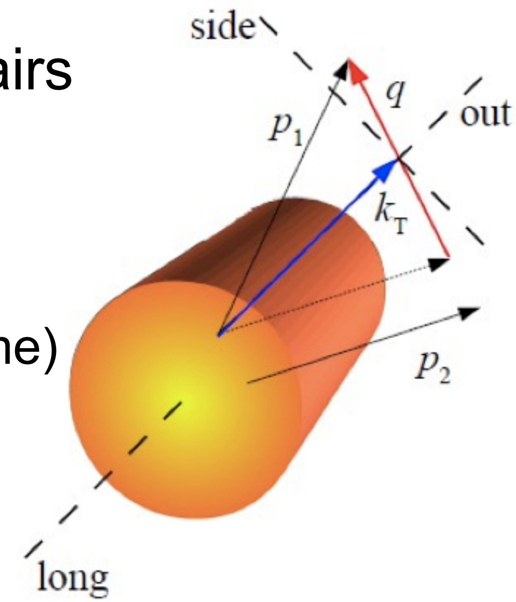
Decoupling time (from collision to hadron freeze-out)

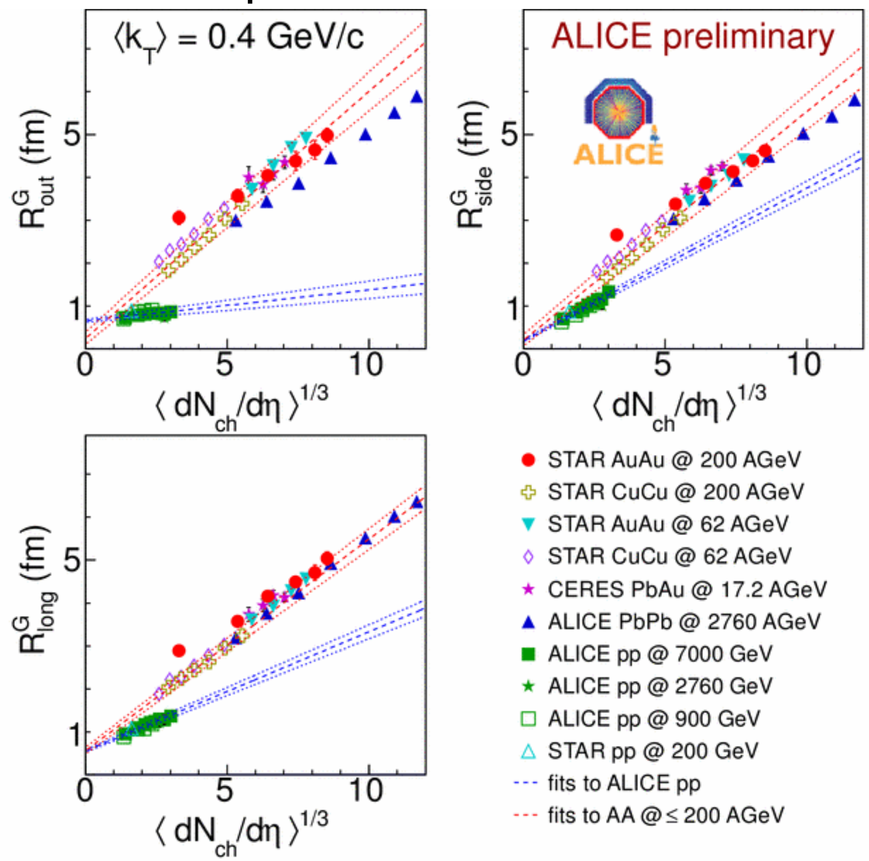


- τ_f(LHC) = 10-11 fm/c ~ ×1.4 τ_f(RHIC)

Space-time evolution – multiplicity dependence

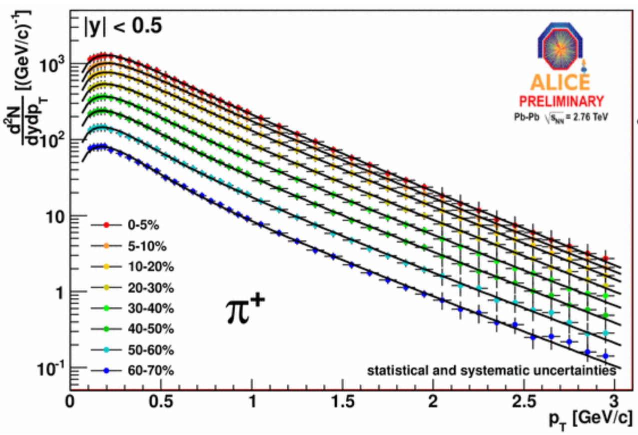
- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference q_{inv}=|p1-p2|, vs. multiplicity
  - – Assess the space-time extension of the system that emits particles in Pb-Pb collisions (homogeneity volume)

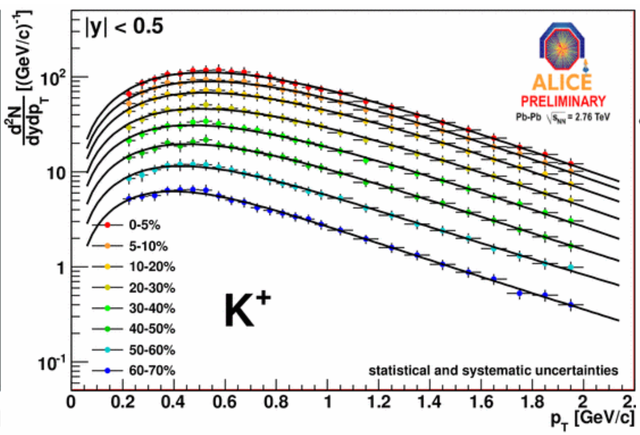


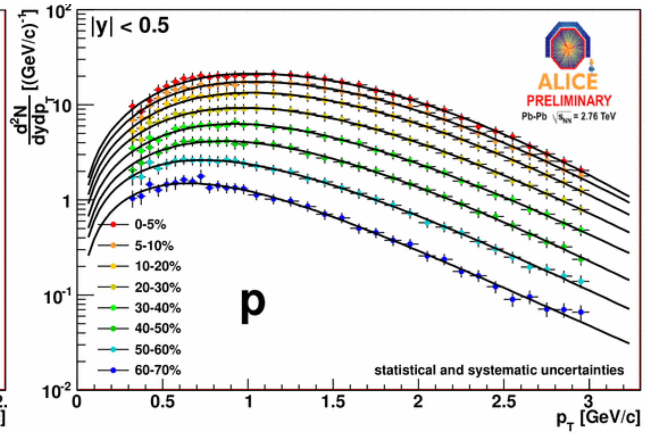


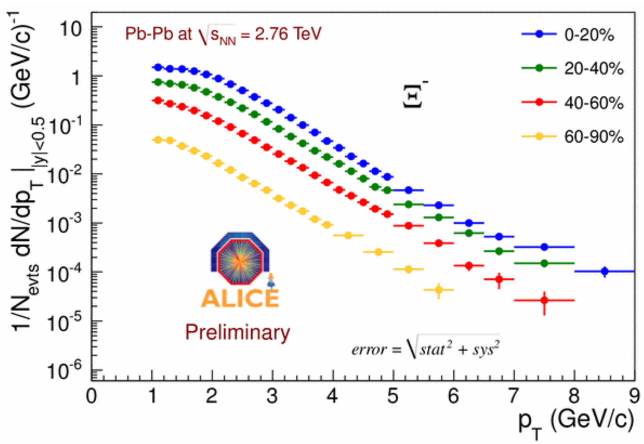
- HBT radii scale with multiplicity$^{1/3}$ in pp and PbPb, but different slope!
- HBT radii in PbPb vs. trend from lower energy AA:
  - –R_{long}: perfectly agree
  - –R_{side}: reasonably agree
  - –R_{out}: clearly below the trend
- Behaviour of all 3 radii in qualitative agreement with hydro expectations
  - –R_{out}/R_{side} decreases with √s due to higher initial temperature

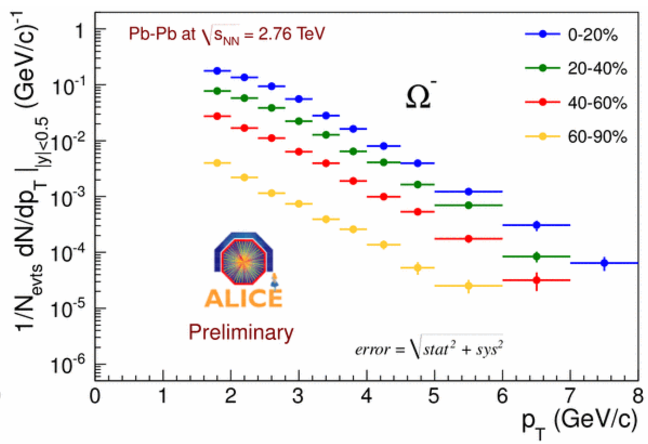
Identified particle spectra









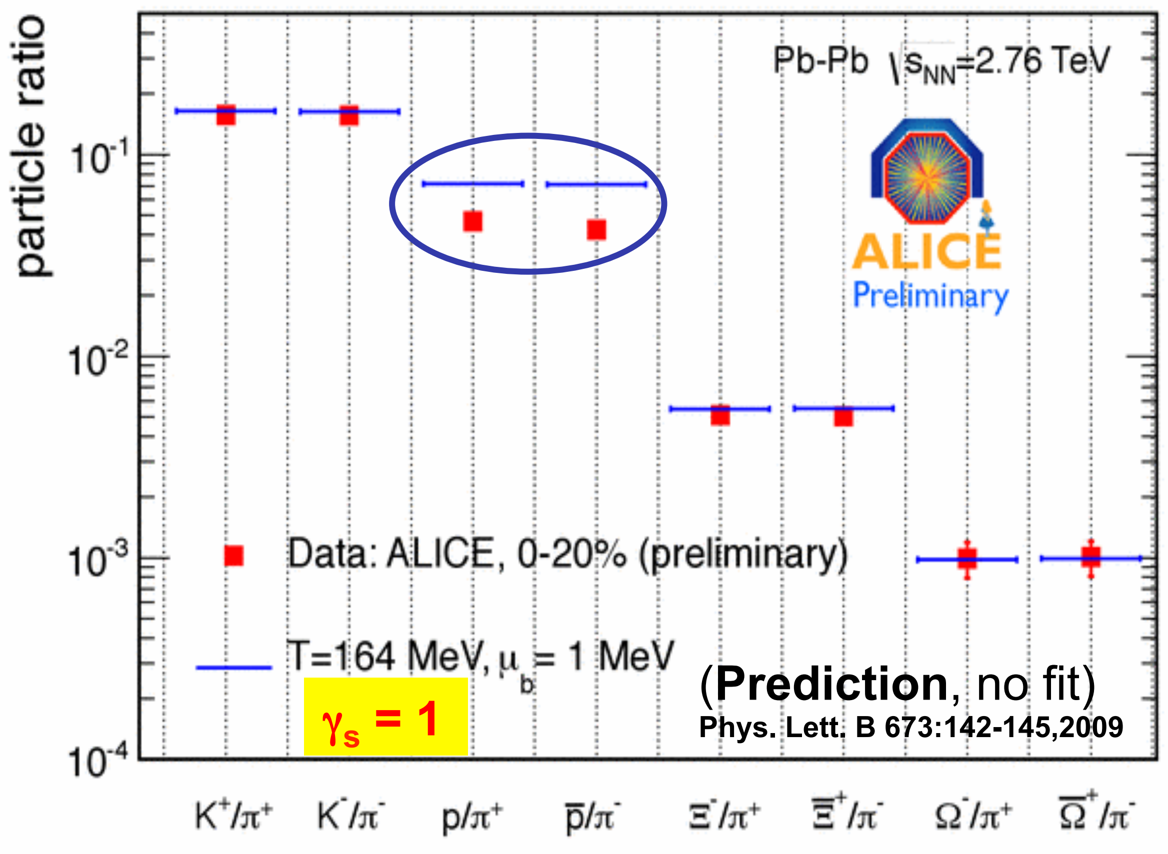


Extract particle yields from a fit to the p_T spectra

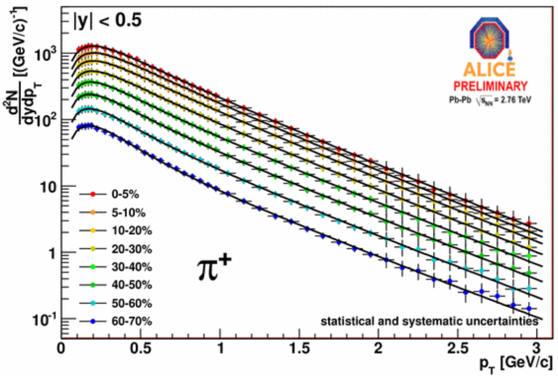
Particle yields and statistical models

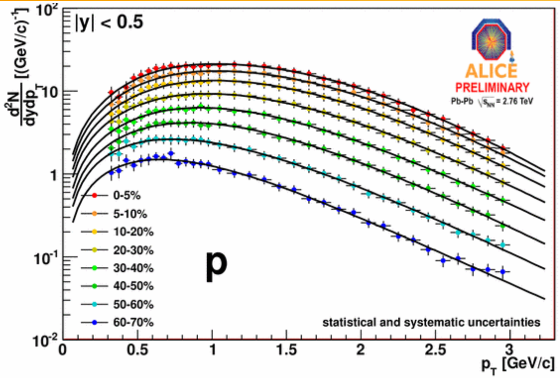
Particle composition defined from a Grand Canonical ensemble with:

- A chemical freeze-out temperature T_{ch}
- A baryo-chemical potential μ_b
- A strangeness saturation factor γ_s



Transverse radial flow

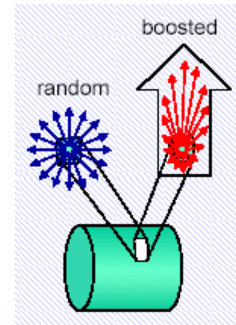


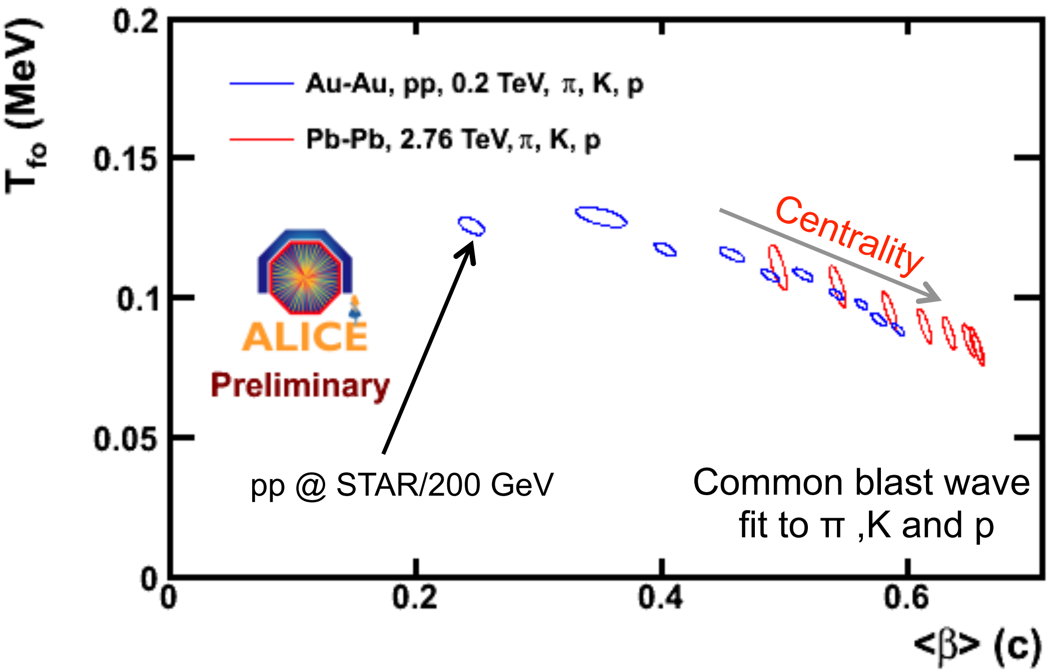


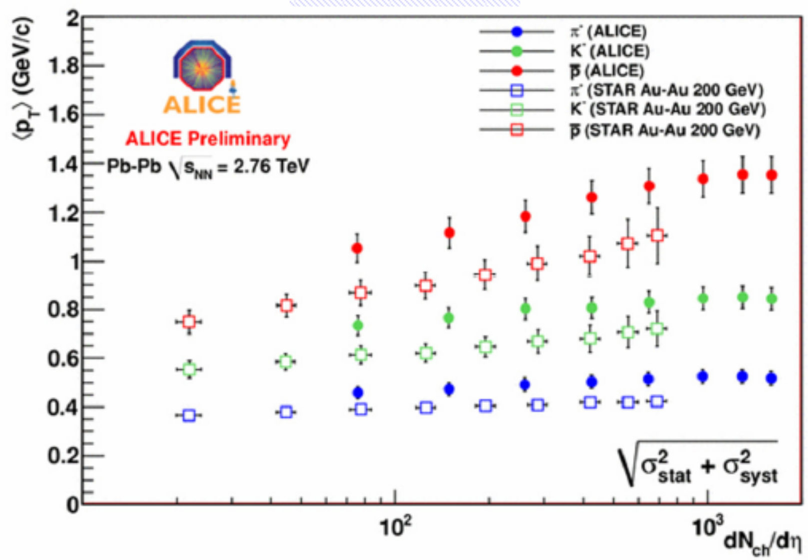
BlastWave fits:

Particles emitted from a source:

- In local thermal equilibrium
  - **Thermal freeze-out temperature T_{fo}**
- In expansion
  - **Transverse flow velocity β**

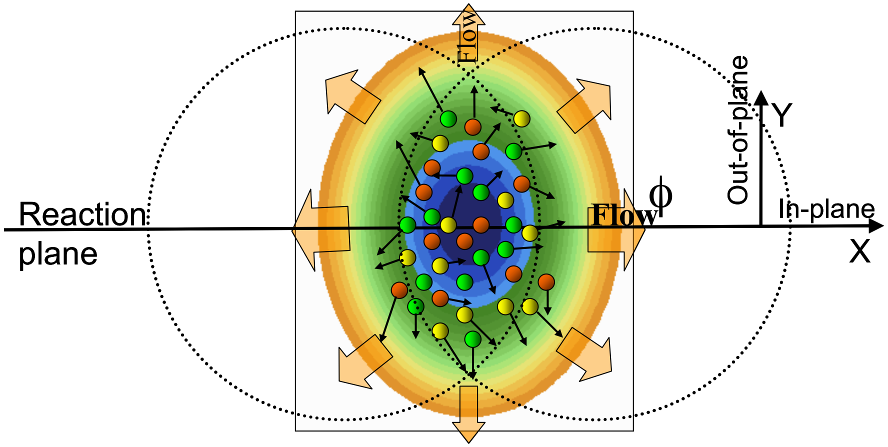






Collective behaviour – elliptic flow

Non-central collisions

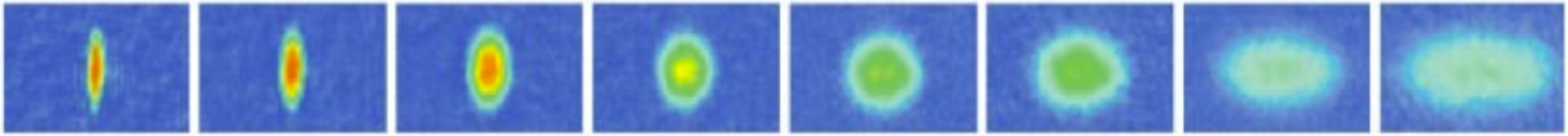


- Non-central collisions
  - Anisotropic overlapping region
  - Stronger pressure gradients in plane than out of plane
  - Anisotropic particle emission
  - Described by hydrodynamic models (viscosity)

- Measured from the particle azimuthal distribution

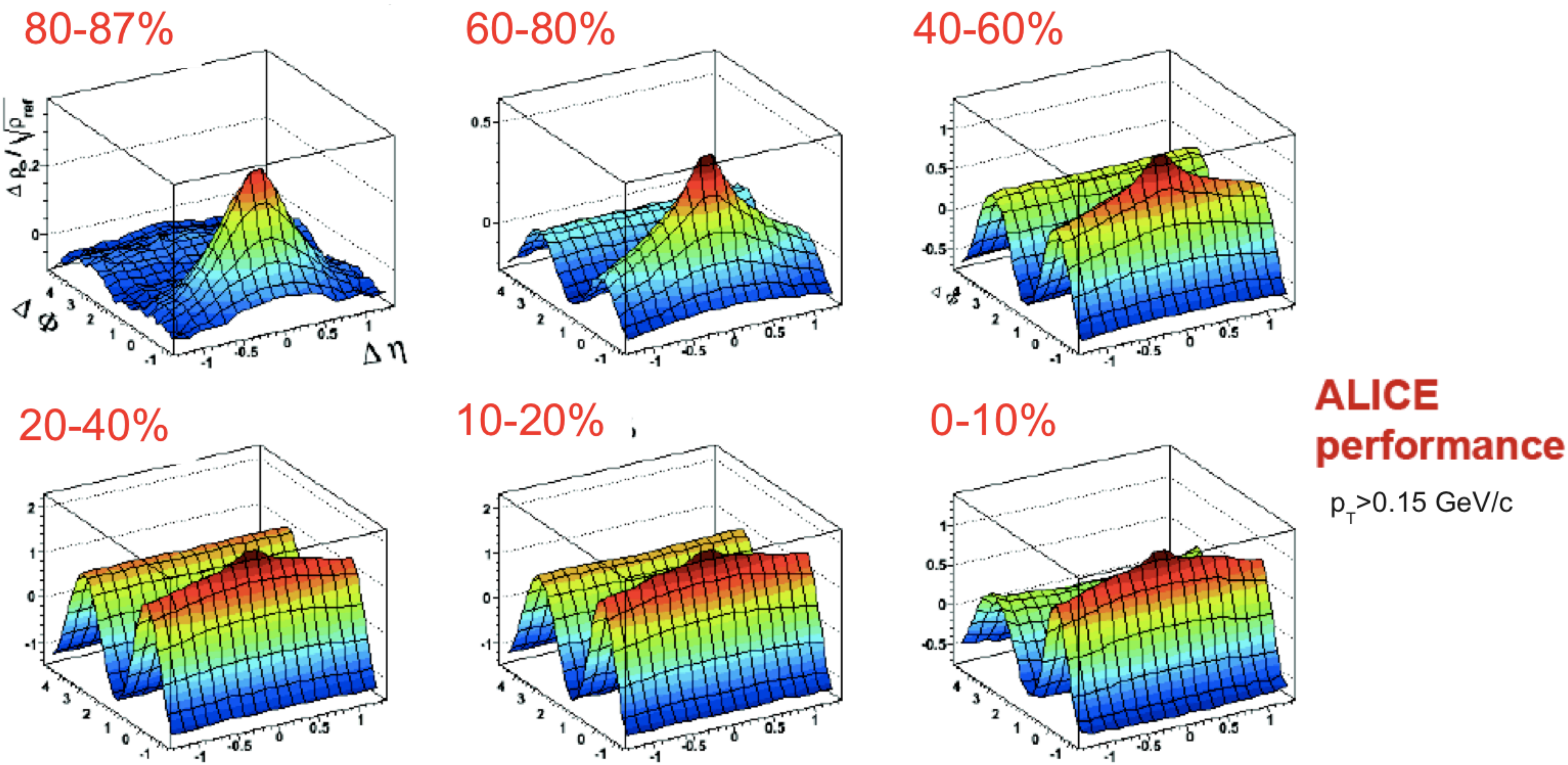
$$\frac{dN}{p_t dp_t dy d\varphi} = \frac{1}{2\pi}\frac{dN}{p_t dp_t dy}\left[1 + \sum_{i=1} 2 v_i \cos(i(\varphi - \Phi_R))\right]$$

- v_2 coefficient is called elliptic flow



An atomic analogue: Liquid Helium explodes in vacuum

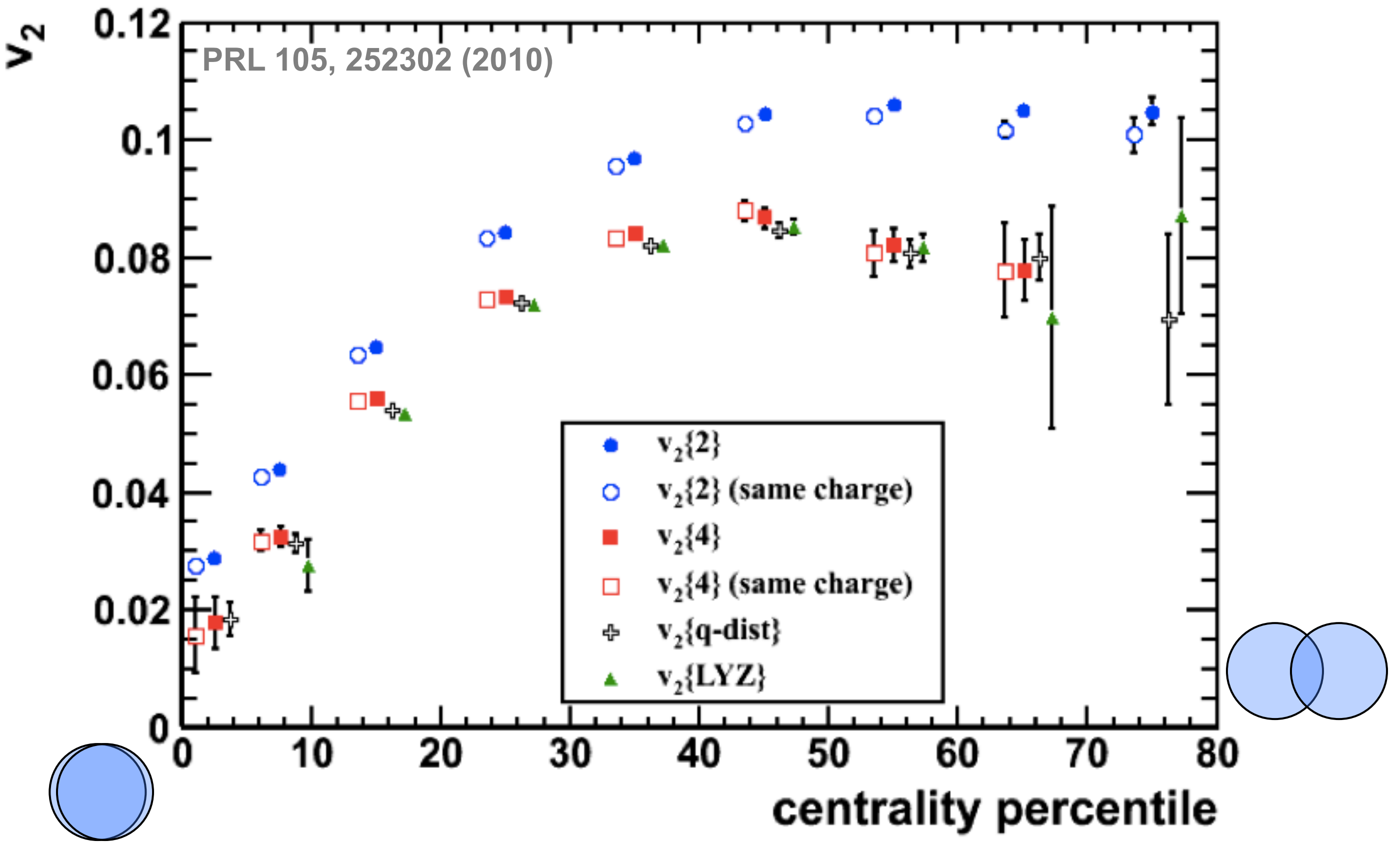
Two particle correlation



Elliptic flow (as well as other non-flow structures) are clearly visible

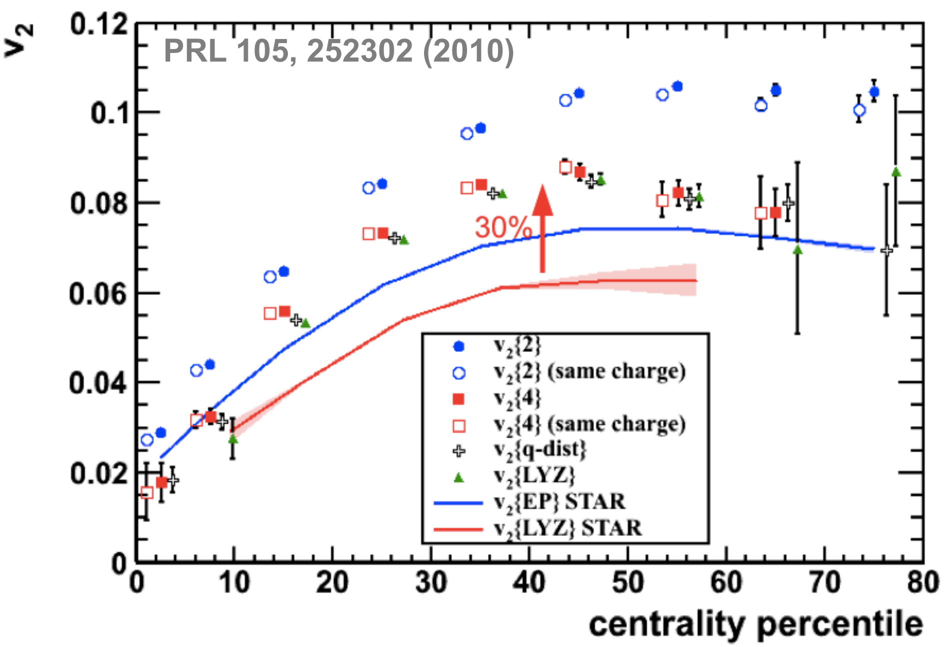
Elliptic flow (v_2) of charged particles

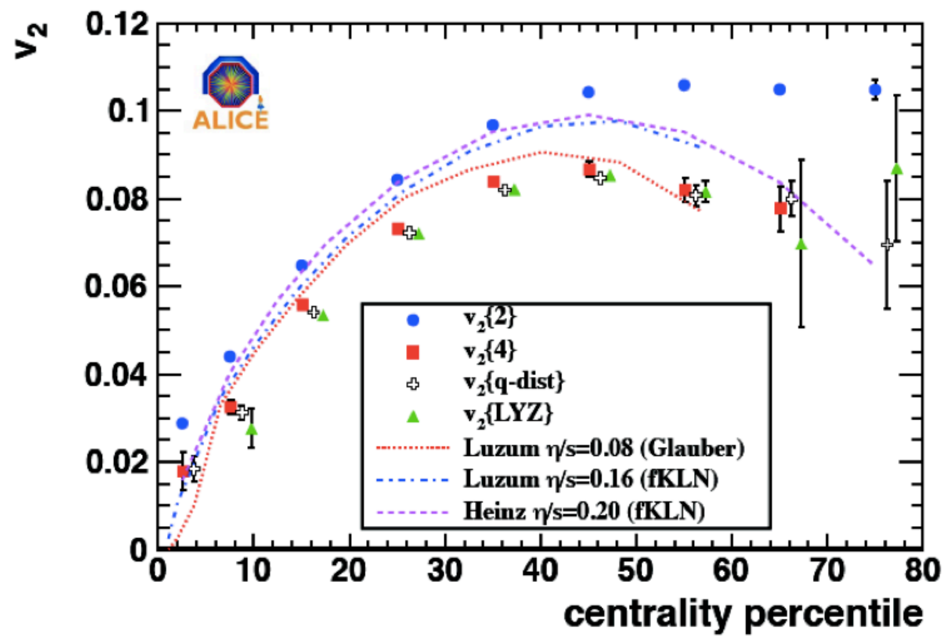
- v_2 extracted using 2 and 4 particle correlations
  - methods well established based on RHIC experience
  - non-flow effects estimated from the difference between 2 and 4 particle correlation methods



Elliptic flow (v_2) of charged particles

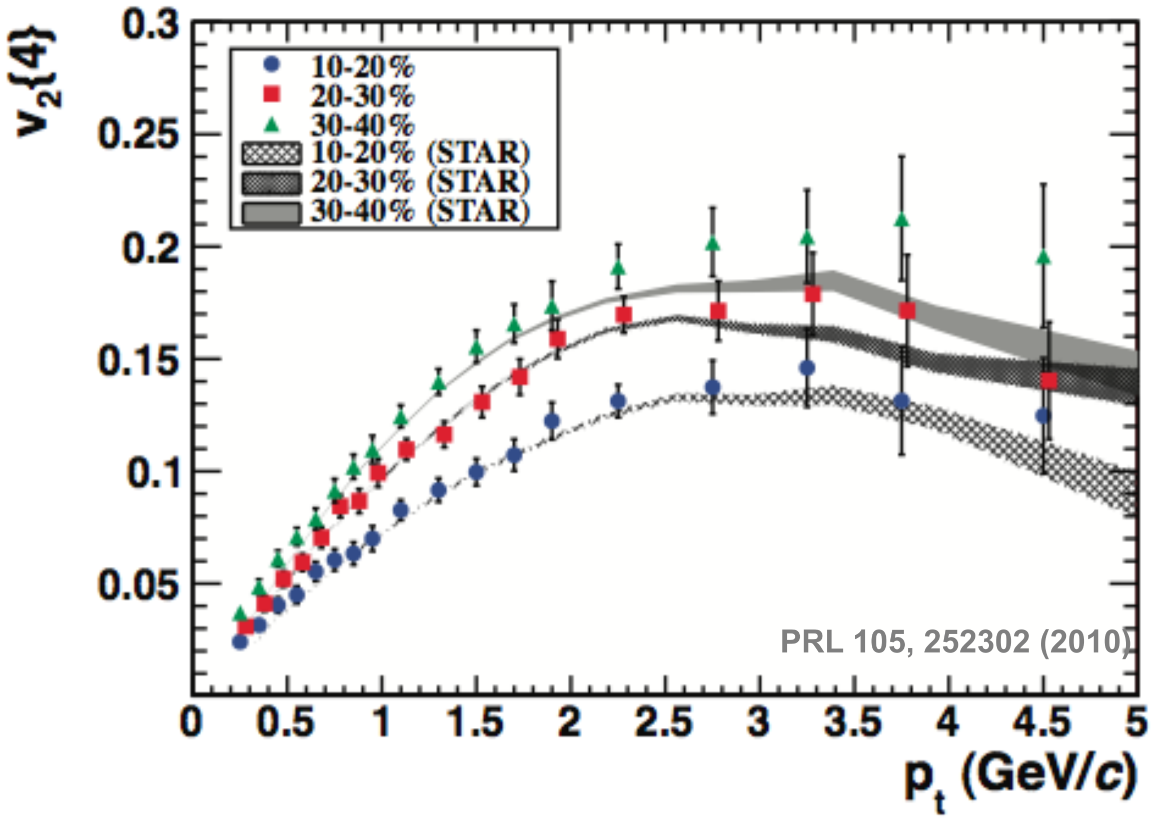
- Integrated v_2 increases by ~30% from RHIC to LHC
  - in all centrality classes
  - due to increase of $\langle p_T \rangle$
  - consistent with viscous hydrodynamics
    - very low viscosity (η/s)





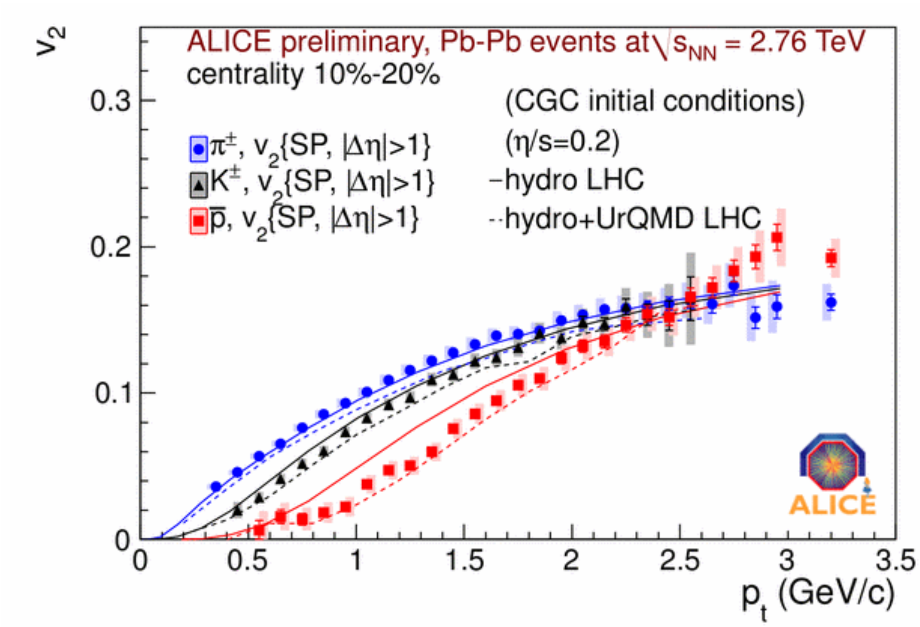
Transverse momentum dependence

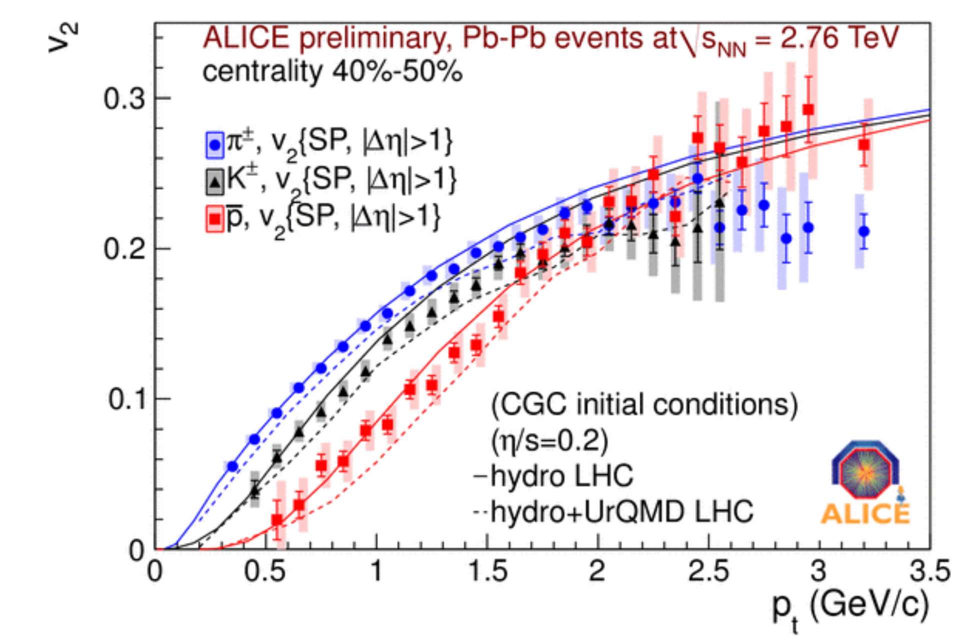
- p_T dependence at LHC is similar to the one at RHIC (in centrality classes)
- Consistent with expectations from hydro models



•The medium behaves collectively

Identified particle v_2

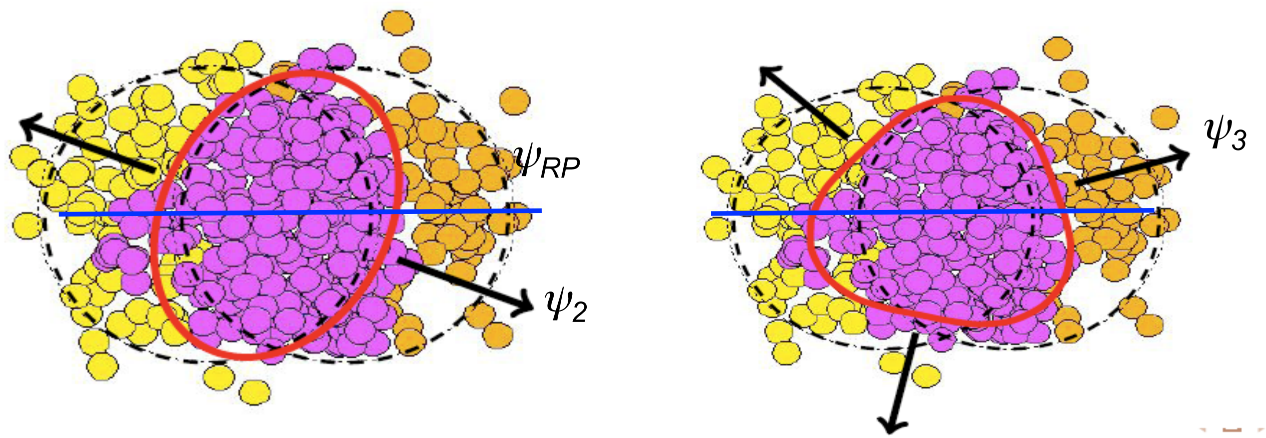




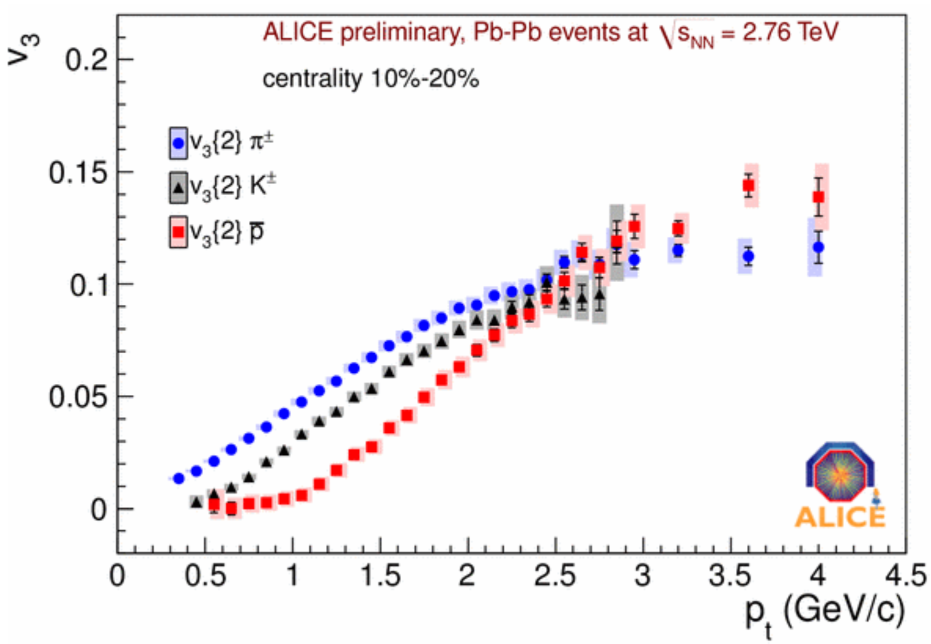
- Stronger radial flow → more pronounced mass dependence of elliptic flow
  - Hydrodynamics predictions describe well the measured $v_2(p_T)$ for π and K for semi-peripheral (40%-50%) and semi-central (10%-20%) collisions
  - Mismatch for anti-protons in the more central bin
    - Larger radial flow in the data than in the Hydro model
    - Rescatterings in the hadronic phase play an important role (arXiv:1108.5323)

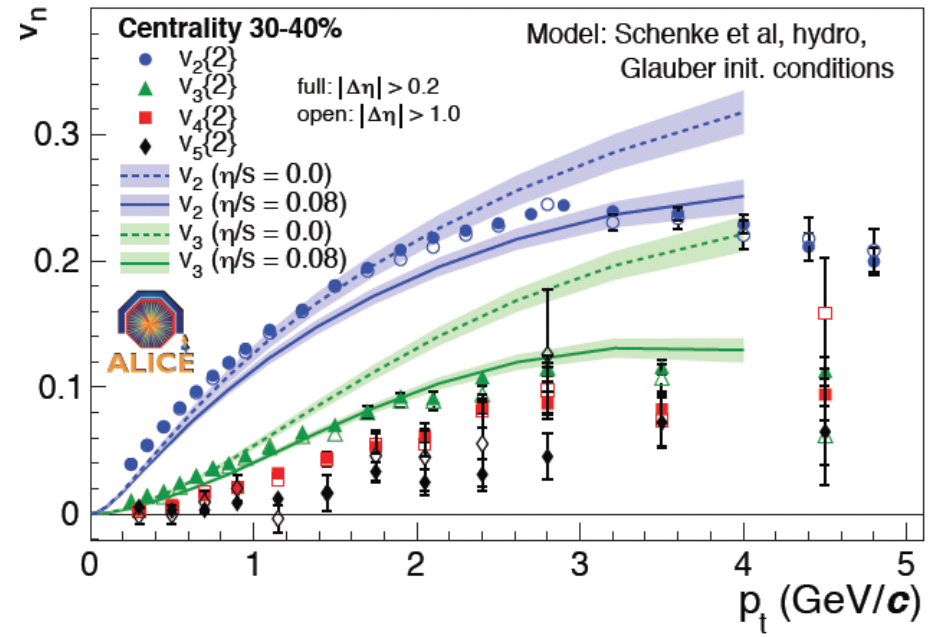
Higher harmonics

- Fluctuations in the initial nucleon distribution
  - Event-by-event fluctuation of the symmetry plane Ψ_n w.r.t. Ψ_{RP}
- Odd harmonics are not null
- In particular, v_3 ("triangular") harmonic appears
- Similar p_T dependence for all harmonics



Higher harmonics





- v_3 shows mass splitting expected from hydro flow !
- Has the magnitude (and p_T dependence) expected from geometry fluctuations
- Has larger sensitivity to η/s than v_2
  - stronger constraints to models

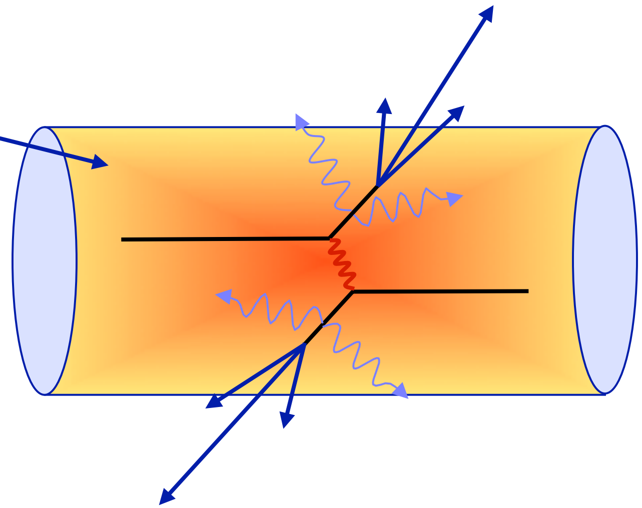
Global properties of QCD matter at the LHC

- Energy density ×3 RHIC → > 15 GeV/fm3 **Hotter**
- Freeze-out volume ~ 300 fm3 → ×2 RHIC **Larger**
- Decoupling time ~11 fm/c → ×1.4 RHIC **Longer-lived**
- Elliptic flow as expected for close-to-perfect liquid
- Initial state gluon saturation less strong than expected

Hard probes of QCD matter

Heavy-ion collisions produce
'quasi-thermal' QCD matter

Dominated by soft partons
p ~ T ~ 100-300 MeV



Hard-scatterings produce 'quasi-free' partons
⇒ Initial-state production known from pQCD
⇒ Probe medium through energy loss

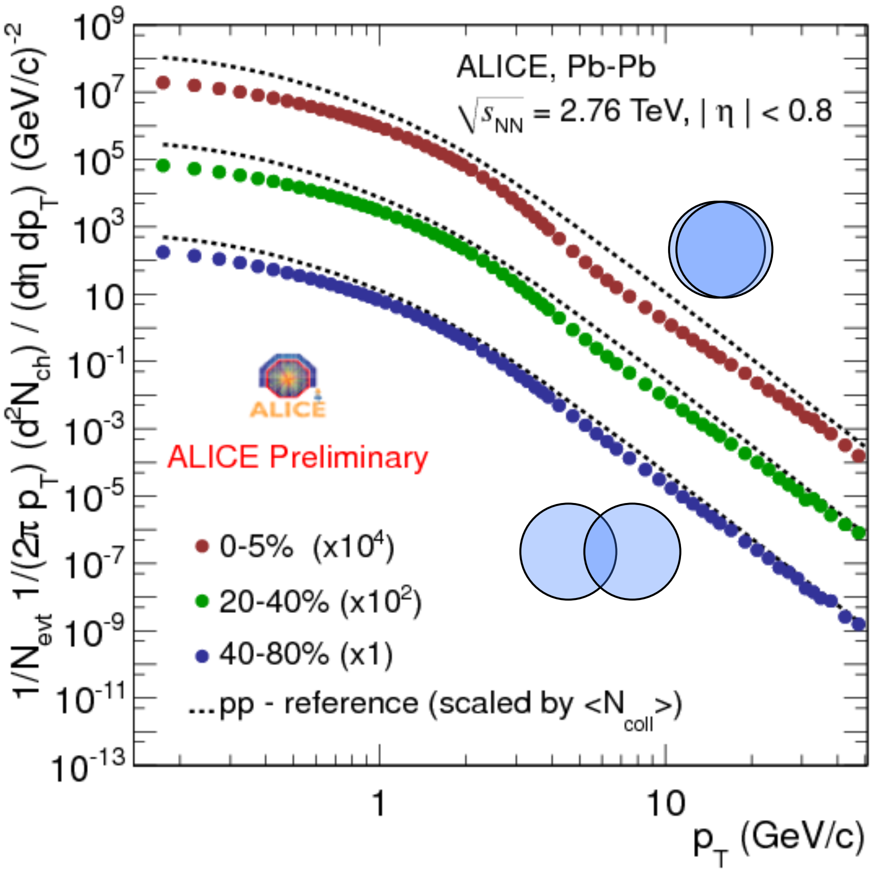
Use the strength of pQCD to explore QCD matter

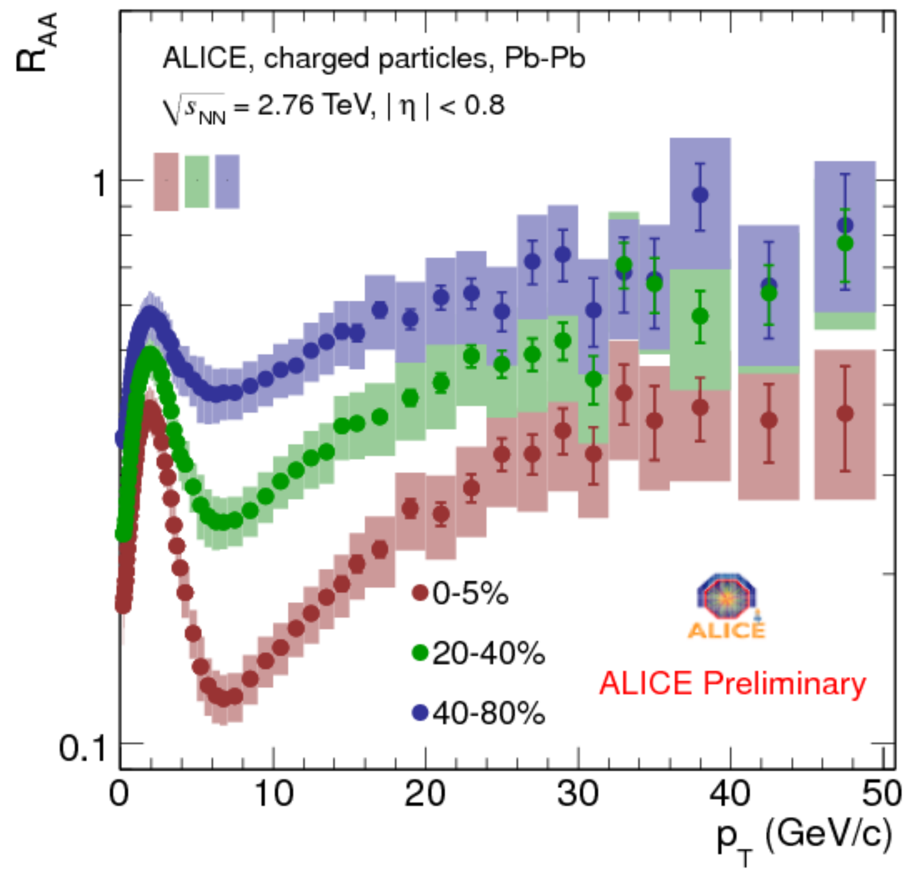
Sensitive to medium density, transport properties

Probing the medium – parton energy loss

- Nuclear modification factor

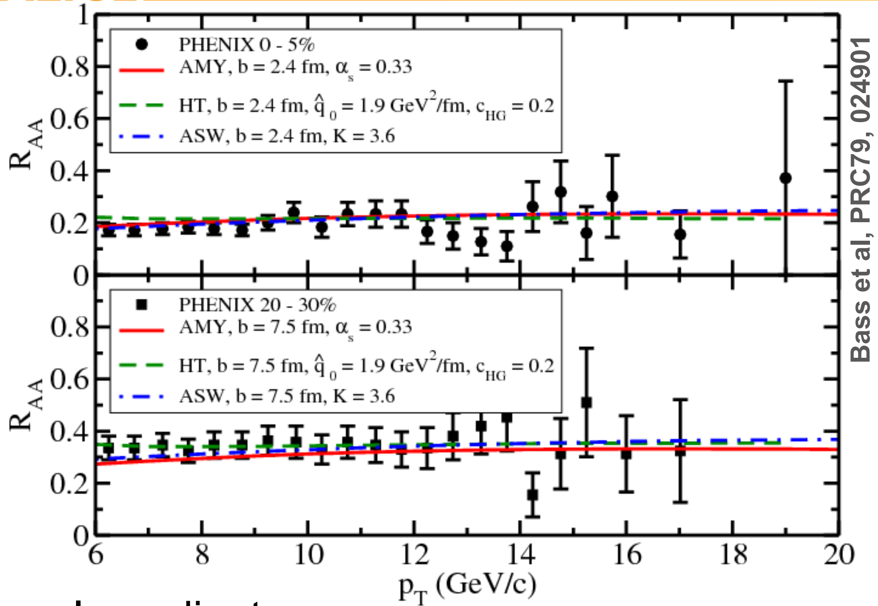
$$R_{AA} = \frac{Yield\ in\ Pb+Pb}{N_{coll} \times Yield\ in\ p+p}$$



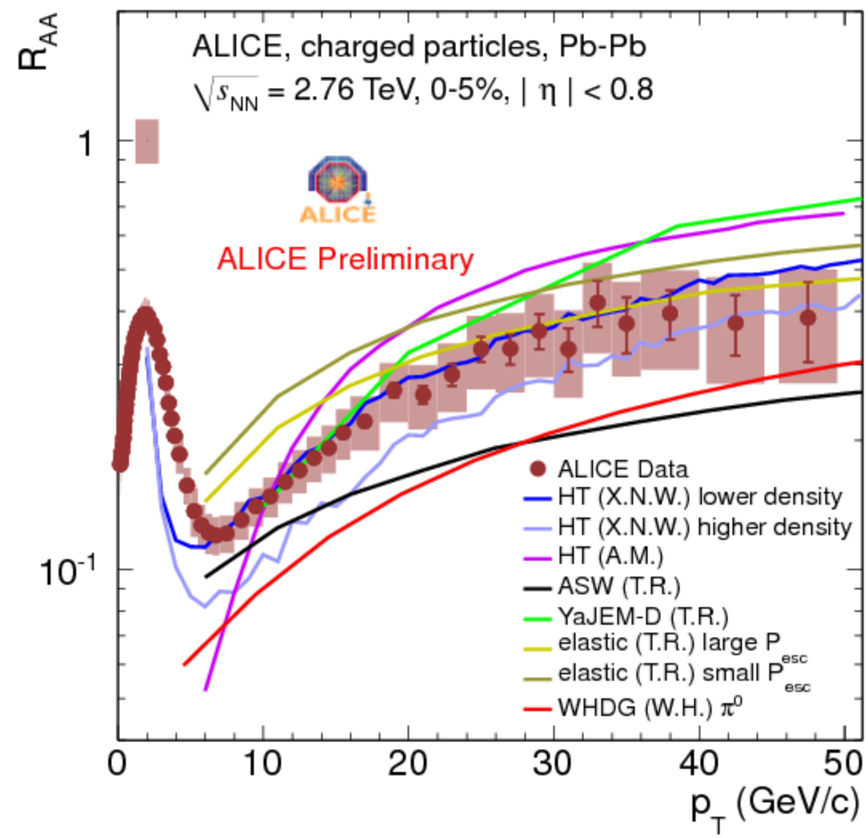


- Peripheral
  - Small suppression
- Central
  - minimum ~0.14
  - steep rise for p_T>8 GeV/c, relative energy loss decreases

Comparing to theory



HT: X-N Wang et al, arXiv:1102.5614 (PRC)
HT: Majumder, Shen, arXiv:1103.0809
TR: T. Renk et al, arXiv:1103.5308 (PRC)
WHDG: Horowitz and Gyulassy, arXiv:1104.4958



Ingredients:

- pQCD production
- Medium density profile tuned to RHIC data, scaled
- Energy loss model

All calculations show increase with p_T

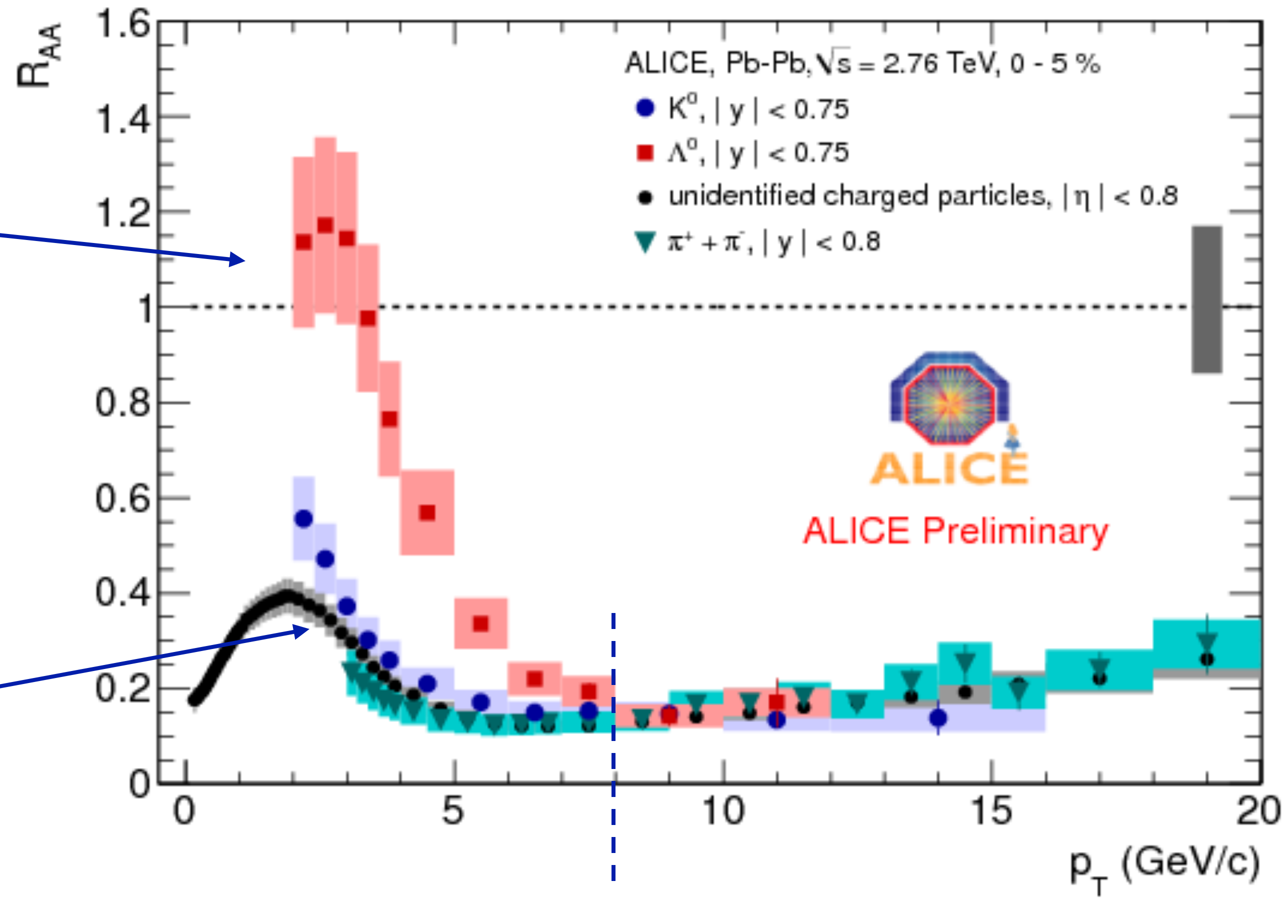
Well-known radiative formalisms
ASW, WHDG predict
too much suppression
(HT better?)

Need time to sort out
theory uncertainties:More to come!

Identified hadron R_{AA} (strangeness)

Λ: R_{AA}~1 at p_T~3 GeV/*c*
Smaller suppression,
Λ/K enhanced at low p_T

Kaon, pion R_{AA}
similar

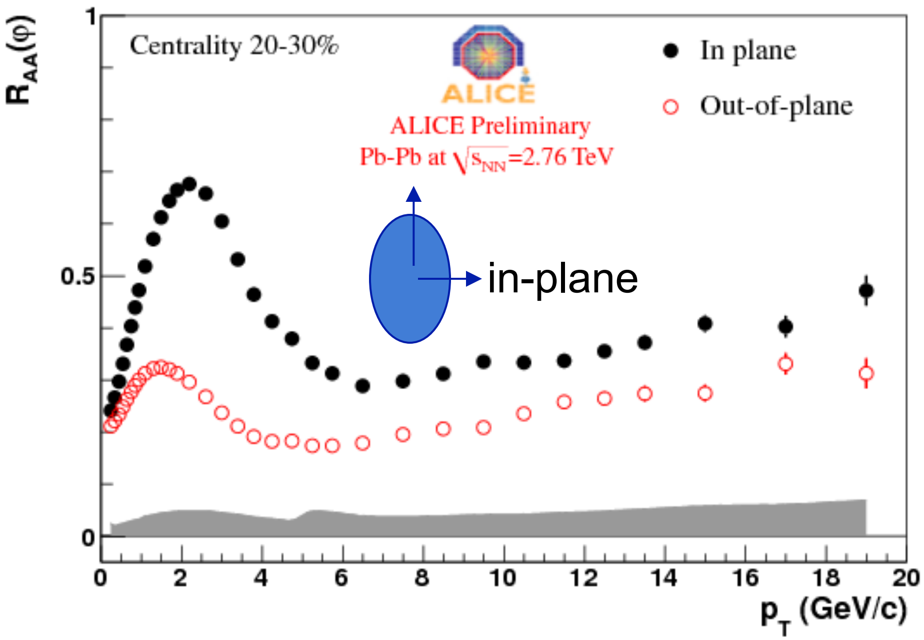


$p_T \geq$ ~8 GeV/*c*:
All hadrons similar

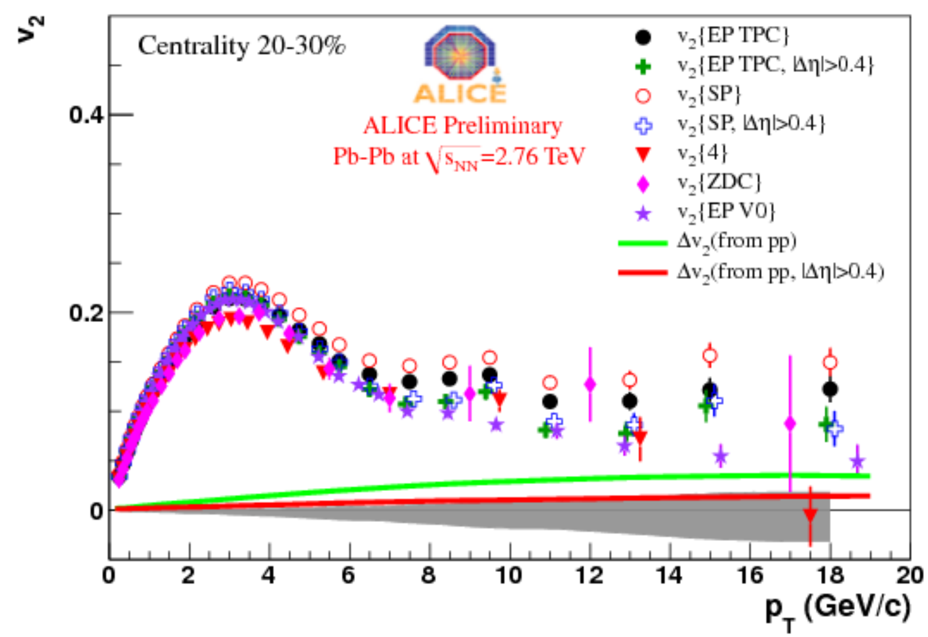
partonic energy loss + pp-like fragmentation?

High-p_T v_2

In-plane, out-of plan R_{AA}



High-p_T v_2



Larger suppression out-of-plane ⇔ v_2 is non-zero at high p_T

multi-particle methods suppress non-flow

Clear path length dependence of energy loss

Theory calculations ongoing

Heavy flavours

- In Pb-Pb collisions: probe the properties of the medium
  - created in the hard initial collisions
    - experience the whole collision history
  - possible comparison heavy quarks/light partons
    - energy loss:

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

dead cone effect (mass)

Casimir factor (colour charge)

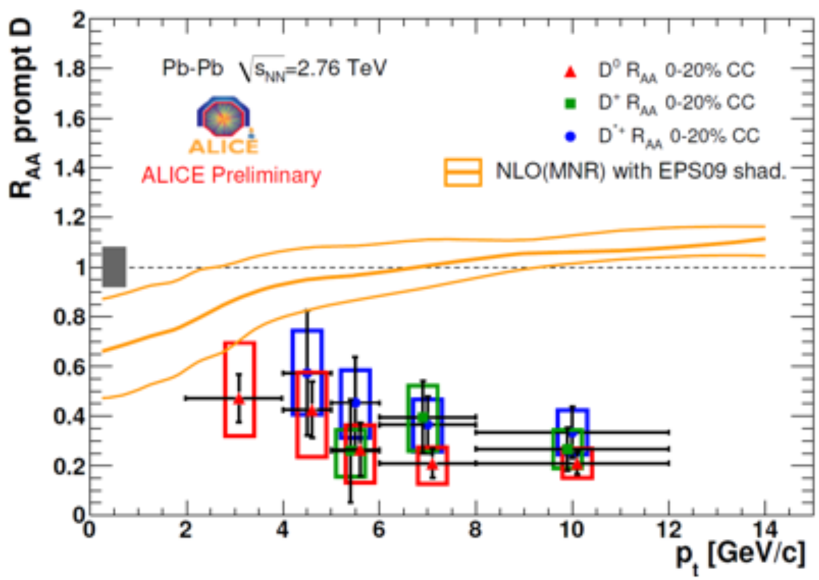
$$R^H_{AA}(p_t) = \frac{1}{<T_{AA}>} \frac{dN^H_{AA}/dp_t}{d\sigma^H_{pp}/dp_t}$$

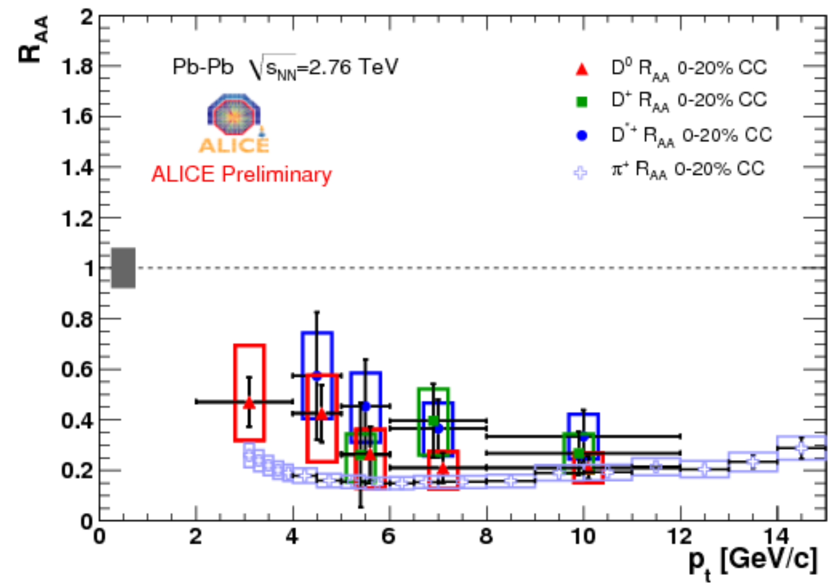
medium density and size $\Rightarrow$ $R^{\pi}_{AA} < R^D_{AA} < R^B_{AA}$

Dokshitzer, Kharzeev, PLB 519 (2001) 199.
Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003.
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493.

- In p-p collisions:
  - baseline for Pb-Pb
  - measure charm and beauty cross section
  - compare to pQCD predictions

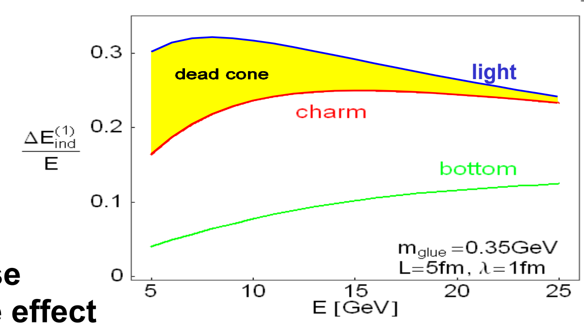
Charm nuclear modification





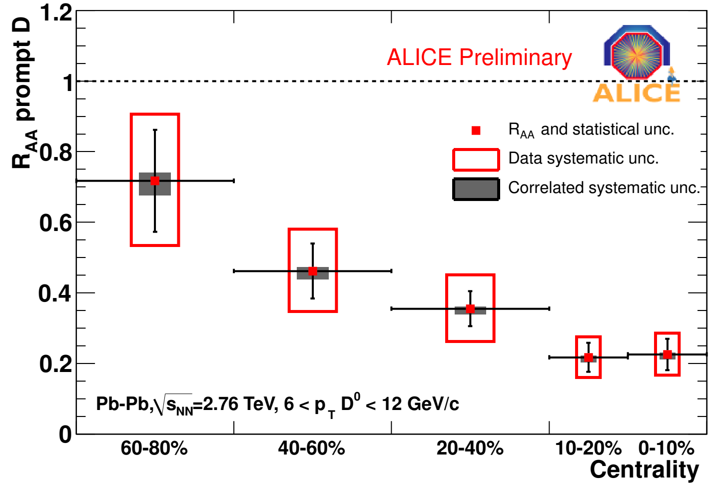
- For $p_T > 5$ GeV/c, significant and genuine hot medium effect.
- For $p_T < 5$ GeV/c, gluon shadowing (EPS09) can play a role
  - → will need to be measured at LHC via p-A collisions

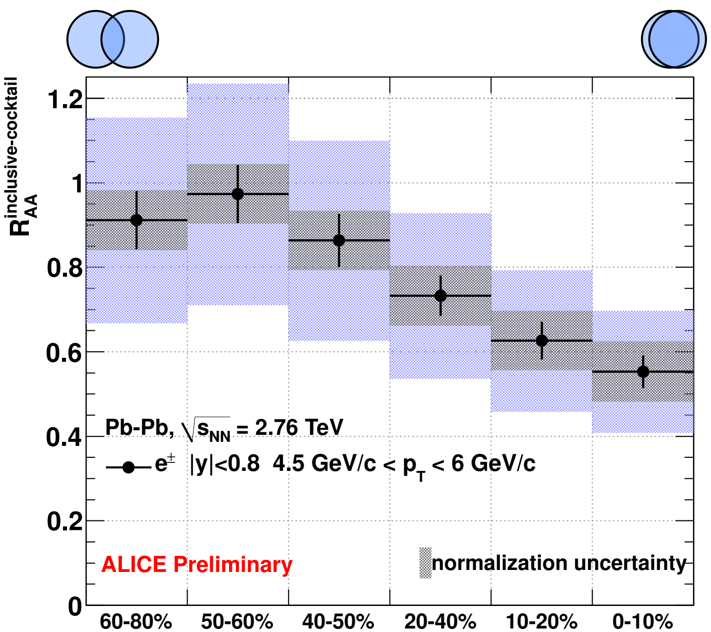
- Light hadrons R_{AA} systematically lower than charm hadrons
- Need R_{AA} of b quarks



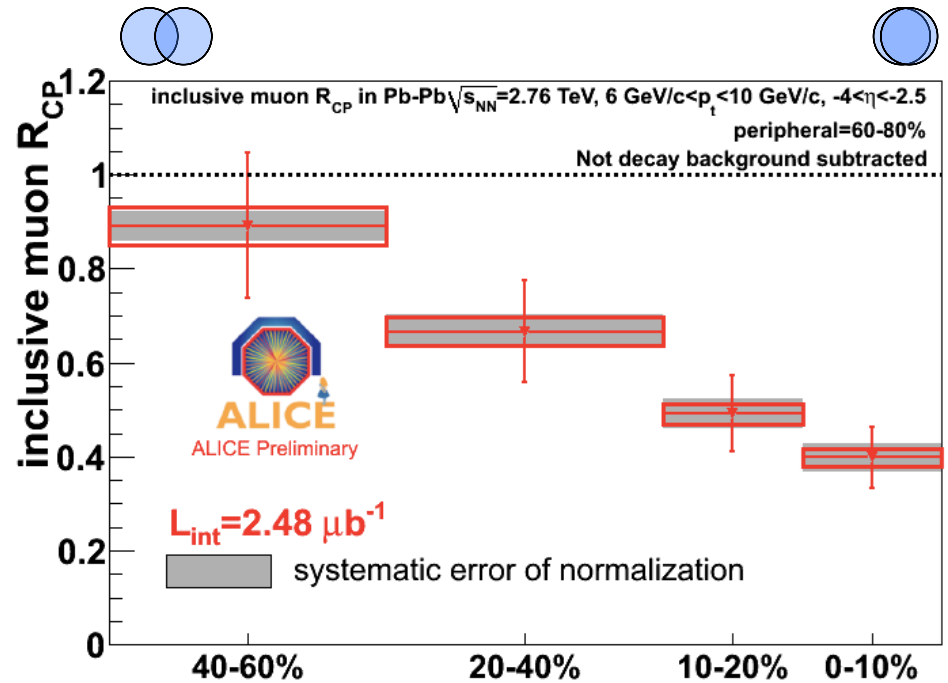
Expect: heavy quarks lose less energy due to dead-cone effect

Open Heavy Flavour R_{AA} & R_{CP} - centrality





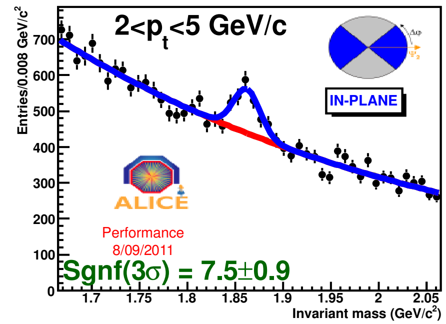
- Clear centrality dependence for all the probes
- Electron (|η| < 0.8) R_{AA} and muon (-4.0 < η < -2.5) R_{CP} show a similar trend
- Prompt D mesons R_{AA} seems smaller than lepton R_{AA} (… but uncertainties are large and p_T , y domains differ)

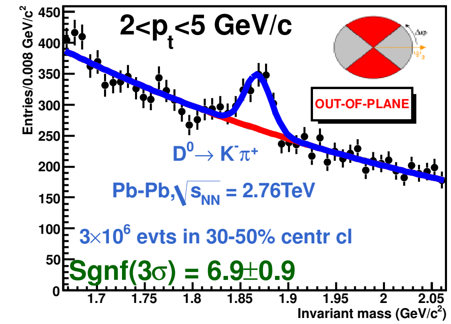


- Inclusive muon spectra dominated by HF decays for p_T above 4 (>85%) - 6 (>90%) GeV/c

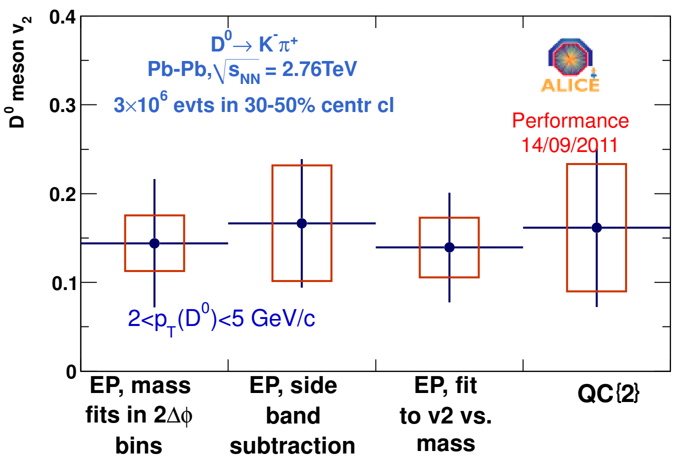
D^0 elliptic flow

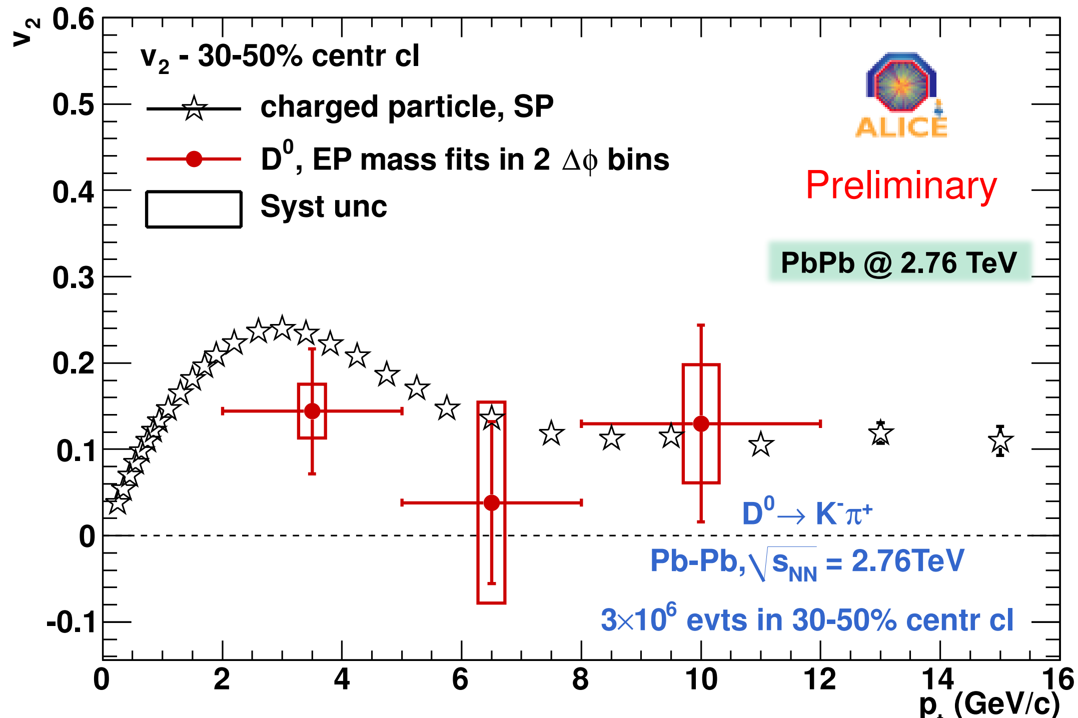
- A measurement of charm flow is crucial to determine the degree of thermalization of the QGP medium





- First measurement of $D^0 \to K\pi$ elliptic flow using yields in plane vs out of plane
- Results cross-checked with other event plane (EP) methods and Q{2} method

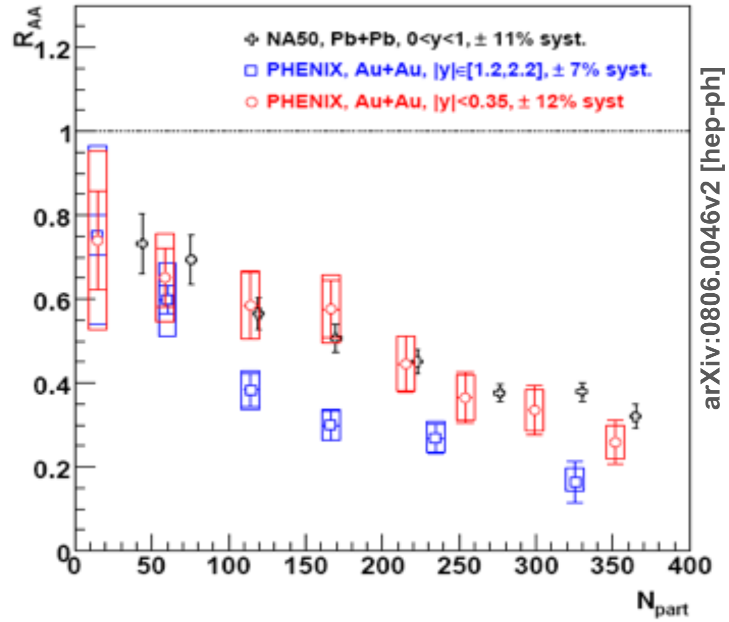




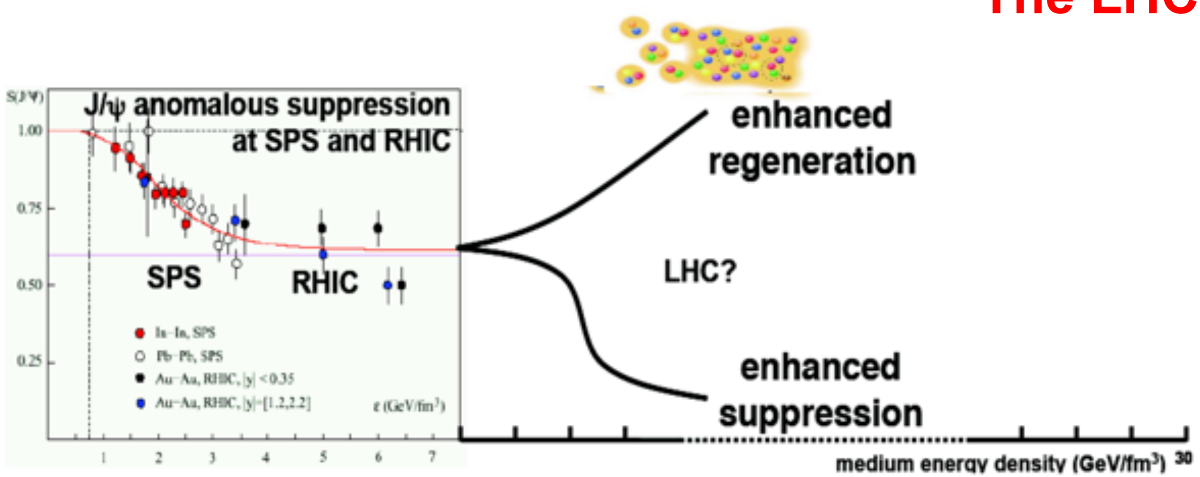
- Looking forward for 2011 Pb-Pb data to reduce stat. and syst. uncertainties

Quarkonia, heavy ions and the QGP?

- A long story…
  - 1986, Matsui and Satz: J/ψ suppression as a QGP signature
  - NA38, NA50, NA60 at SPS
  - PHENIX, STAR at RHIC
- … and many open questions
  - similar suppression at RHIC and at SPS
  - larger suppression at larger rapidities
  - cold nuclear matter effect (still) weakly constrained
  - statistical hadronization, recombination?

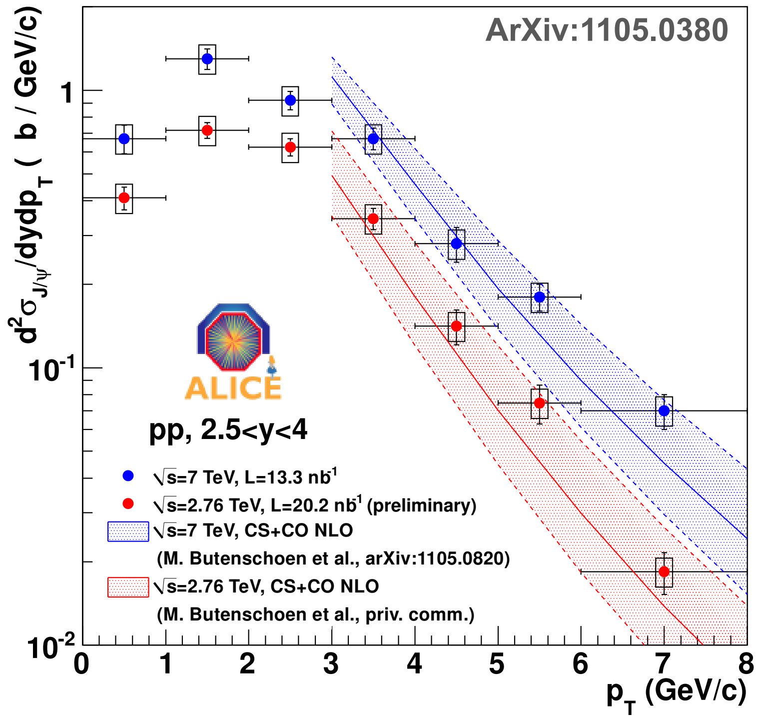


… and then??
The LHC might enlighten us …

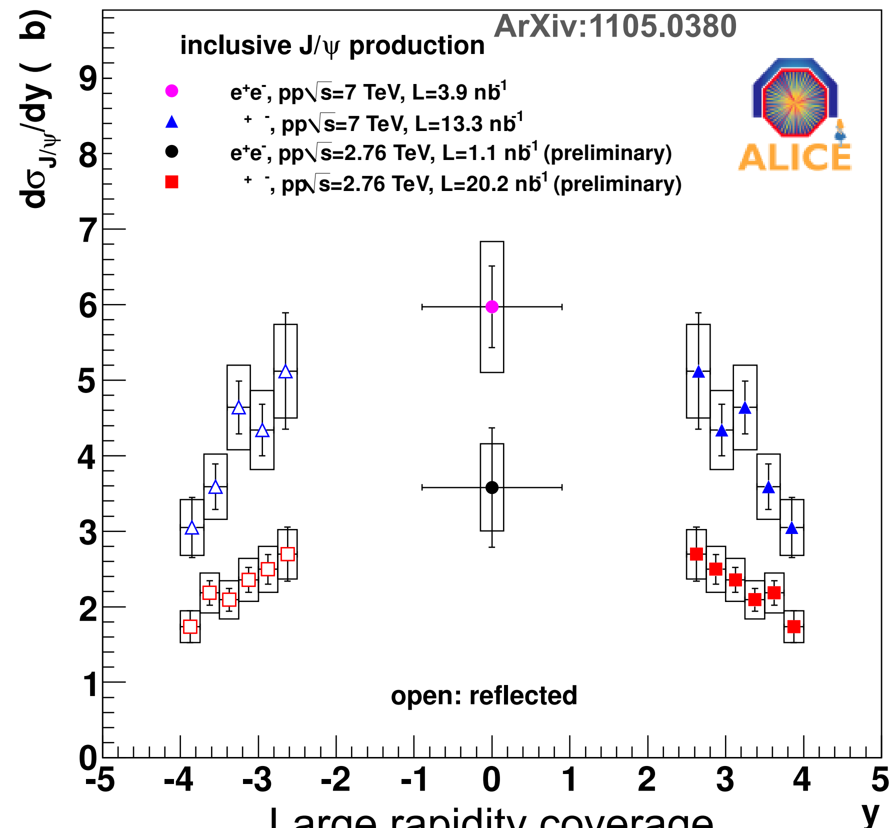


J/ψ cross section

- Inclusive J/ψ cross sections at 7 TeV
  - $\sigma_{J/\psi}$ (|y|<0.9) = 10.7 ± 1.00 (stat) ± 1.70 (syst) + 1.60 (λ_{HE}=+1) -2.30 (λ_{HE}=-1) μb
  - $\sigma_{J/\psi}$ (2.5<y<4) = 6.31 ± 0.25 (stat) ± 0.76 (syst) + 0.95 (λ_{CS}=+1) -1.96 (λ_{CS}=-1) μb
- Inclusive J/ψ cross sections at 2.76 TeV
  - $\sigma_{J/\psi}$ (|y|<0.9) = 6.44 ± 1.42 (stat) ± 0.88 (syst) ± 0.52 (lumi) + 0.64 (λ_{HE}=+1) -1.42 (λ_{HE}=-1) μb
  - $\sigma_{J/\psi}$ (2.5<y<4) = 3.46 ± 0.13 (stat) ± 0.32 (syst) ± 0.28 (lumi) + 0.55 (λ_{CS}=+1) -1.11 (λ_{CS}=-1) μb



NRQCD calculation describes the p_T dependence measured at both 7 TeV and 2.76 TeV

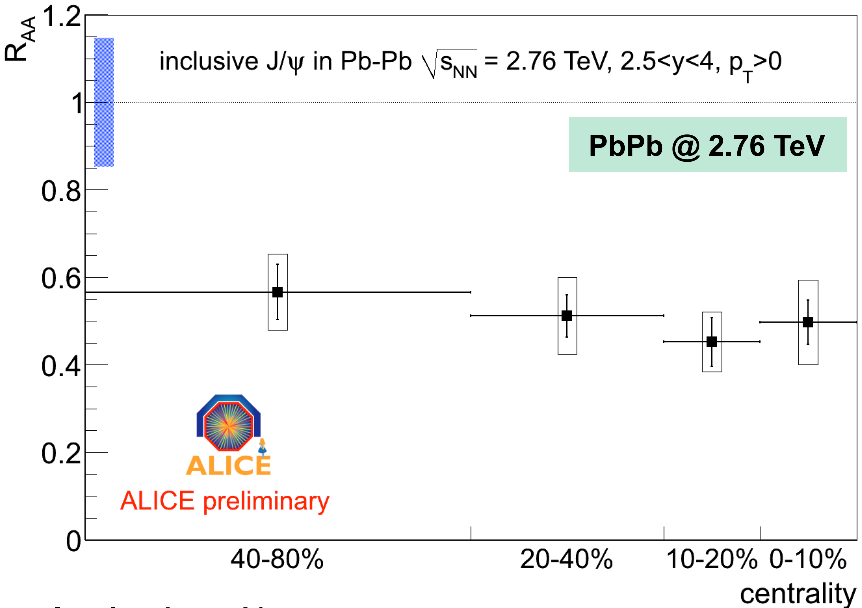


Large rapidity coverage

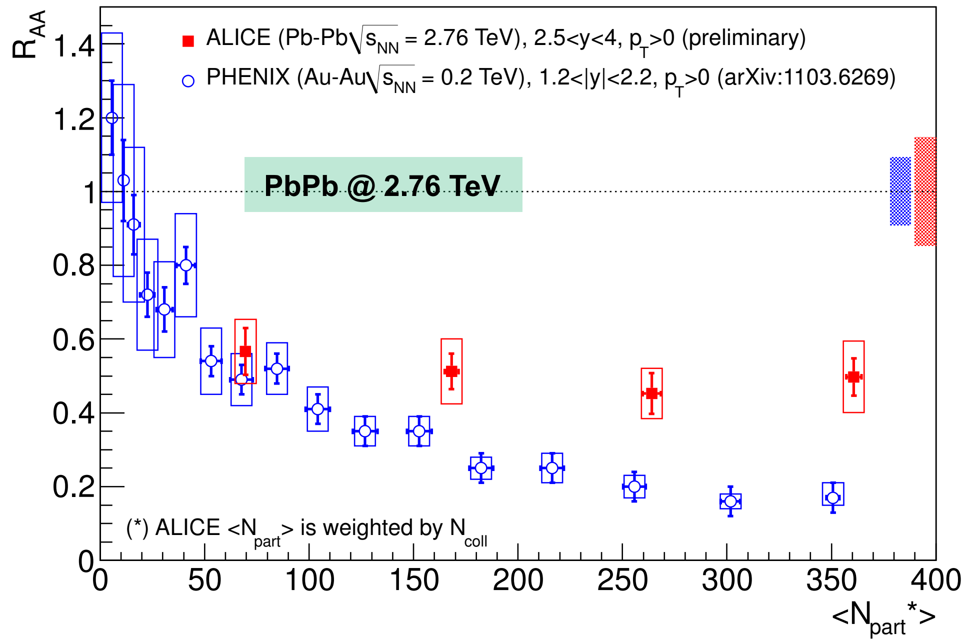
p-p @ 2.76 TeV reference for Pb-Pb

J/ψ R_{AA}

- $J/\psi \rightarrow \mu^+\mu^-$
- $2.5 < y < 4.0$
- $p_T > 0$ GeV/c



Vertical bars: statistical uncertainties
Empty boxes: systematic uncertainties
Full boxes: scaling uncertainty



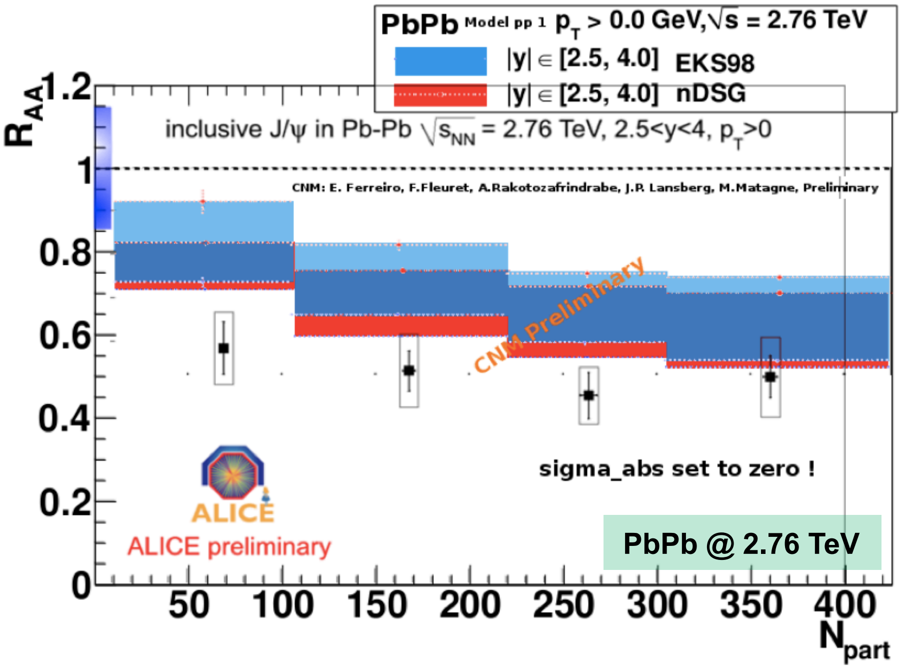
- Inclusive J/ψ
  - $R_{AA}^{0\text{-}80\%} = 0.49 \pm 0.03$ (stat.) ± 0.11 (sys.)
  - Little to no dependence on centrality
- Contribution from B feed-down:
  - ~ 10% from p-p measurement **[LHCb arXiv:1103.0423]**
  - Rough estimation assuming simple N_{coll} scaling: ~ 11% reduction of $R_{AA}^{0\text{-}80\%}$

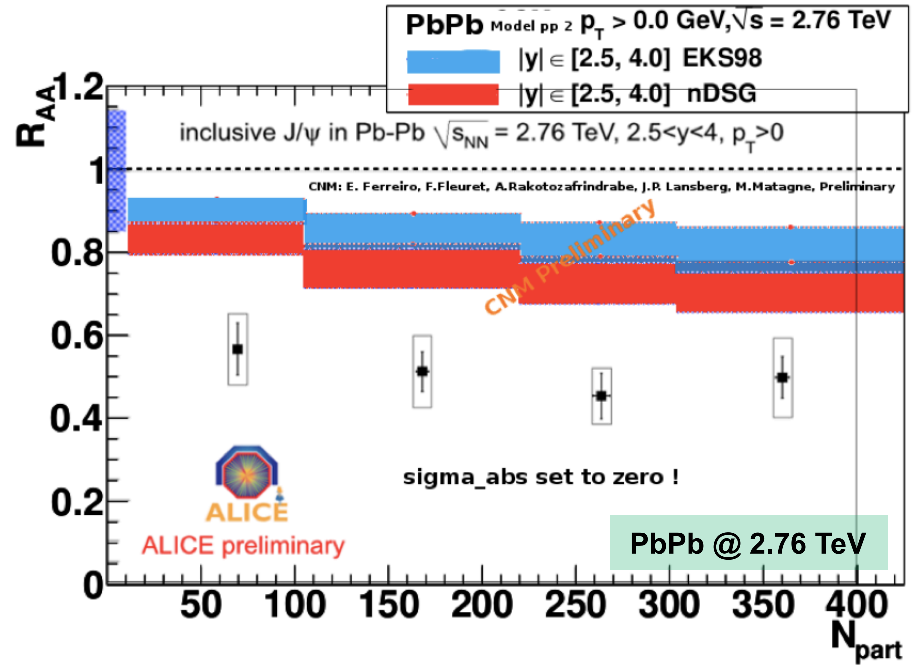
- Less suppression observed at LHC than at RHIC (forward rapidity),
  - but cold nuclear matter effects could be quite different (more shadowing at LHC, but less to no nuclear absorption)

J/ψ R_{AA} - CNM

- Cold Nuclear Matter effetcs

J.P. Lansberg – Quark Matter 2011





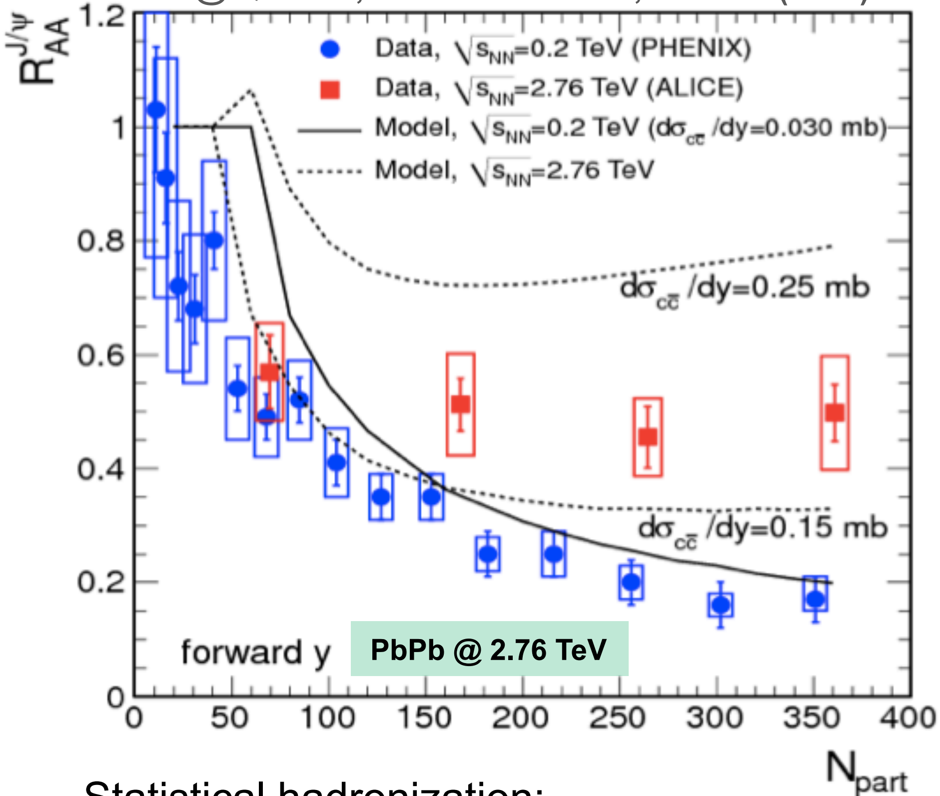
- Two production models tested, with (left) and without (right) k_T smearing
- Two npdf parametrizations: EKS98 (blue), nDSG (red).
- No absorption cross-section added
- Large uncertainties on the calculation

- Stronger centrality dependence for CNM than for the data
- Difference between CNM and data is smaller for more central collisions

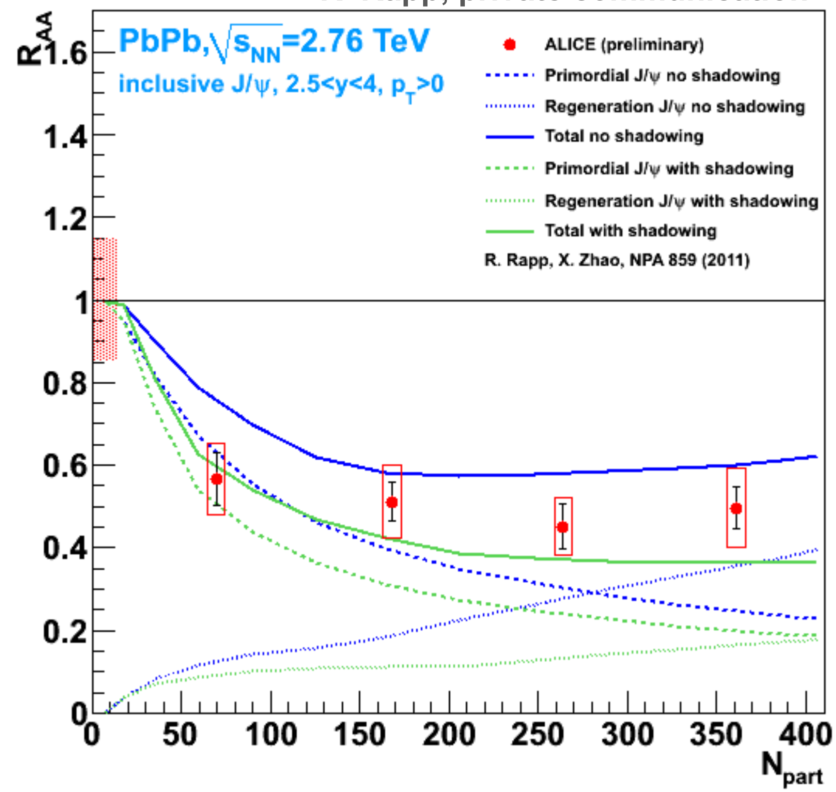
J/ψ R_{AA} - models

- Hot Nuclear Matter

P. Braun-Münzinger & J. Stachel, PLB490 (2000) 196
A. Andronic @ QM2011, A. Andronic et al., PLB571 (2003) 36



X. Zhao, R. Rapp, NPA859 (2011) 114-125
R. Rapp, private communication



Statistical hadronization:

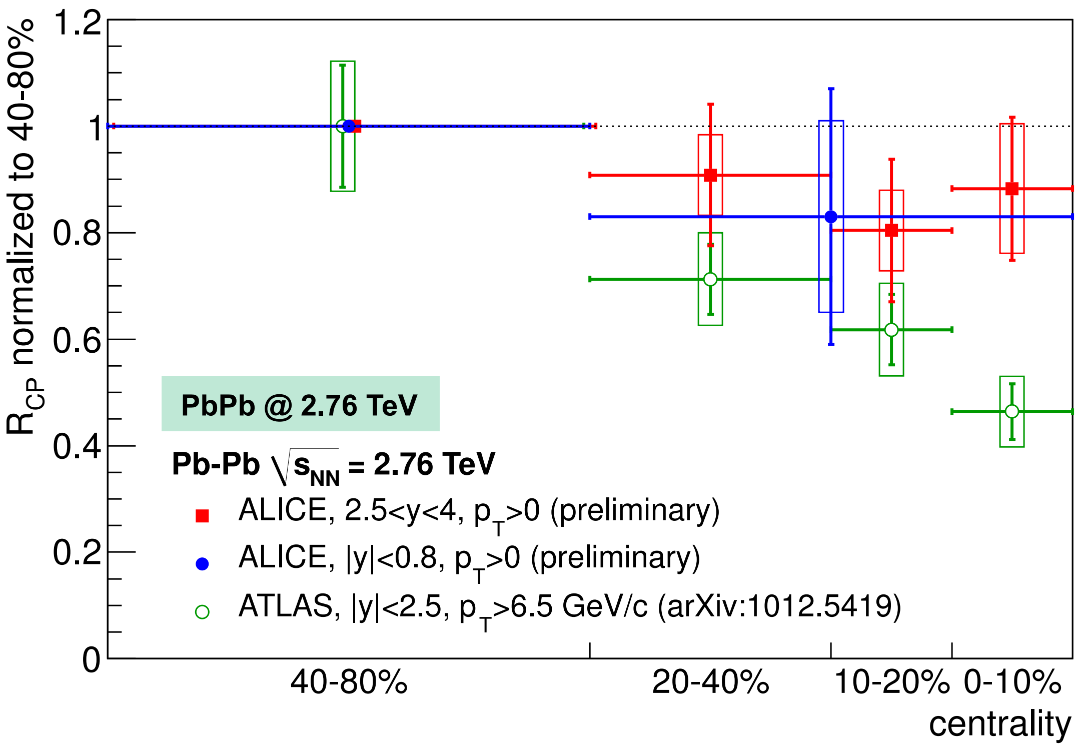
- Screening by QGP of **all** direct J/ψ's
- CNM (shadowing) on open charm
- Charmonium production at phase boundary by statistical combination of uncorrelated charm quarks

Ingredients to Rapp et al

- Shadowing effect
- prompt J/ψ dissociation in QGP
- J/ψ regeneration by charm quark pair recombination
- Feed-down contributions from B

J/ψ R_{CP}

- Inclusive J/ψ R_{CP} can also be measured in ALICE at mid-rapidity in the di-electron channel



Statistical and systematic uncertainties have not been propagated for ATLAS

ALICE-μ:
- 2.5<y<4
- p_T > 0

ALICE-e:
- |y|<0.8
- p_T > 0

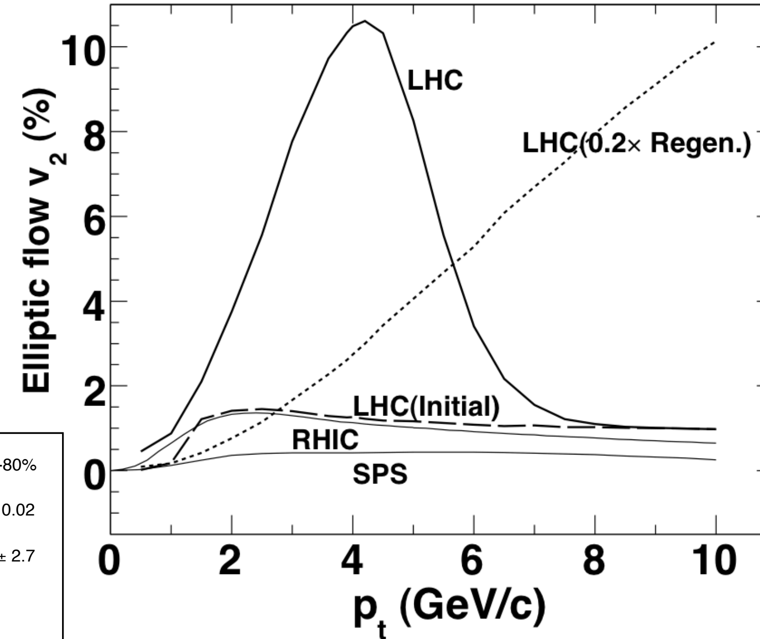
ATLAS:
- |y|<2.5
- 80% of J/ψ with p_T > 6.5 GeV/c

J/ψ R_{CP} larger for ALICE than for ATLAS in the most central collisions…
… But different rapidity and p_T coverage

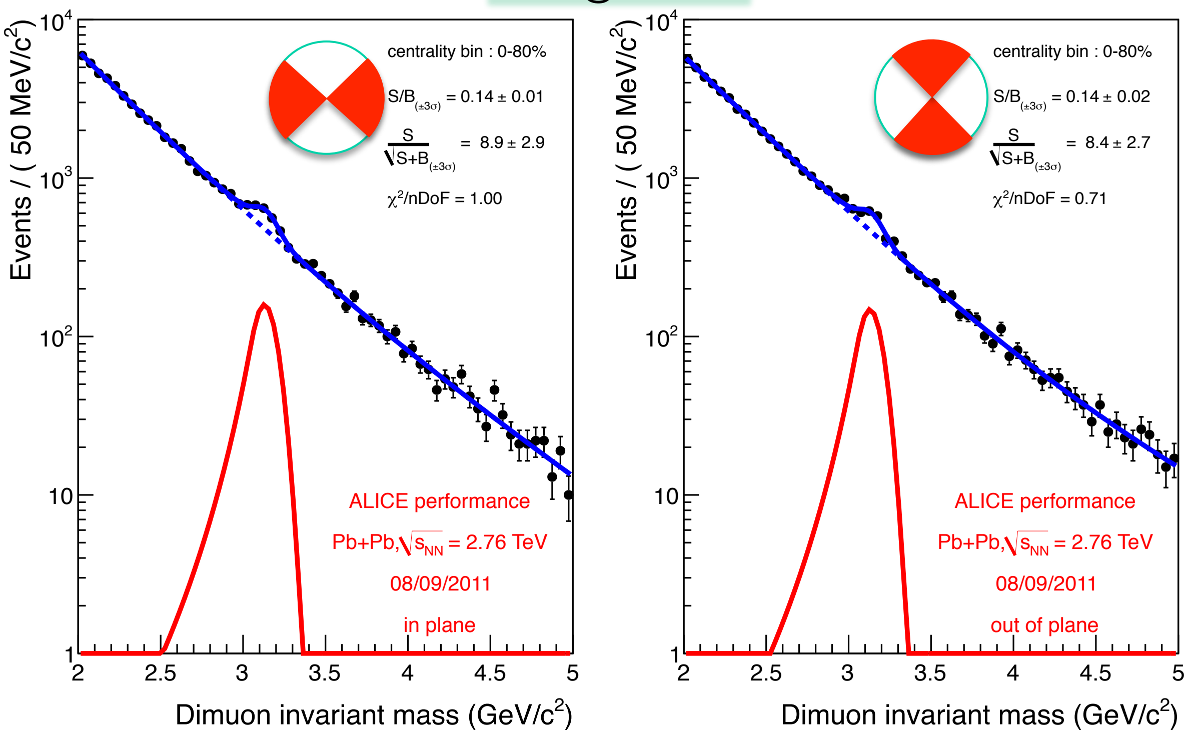
J/ψ elliptic flow

- J/ψ v_2 could help to discriminate the production mechanism
- At LHC, if regeneration dominates the J/ψ production
  - Larger J/ψ v_2
  - Non trivial p_T dependence

Y. Liu, N. Xu, P. Zhuang, Nucl.Phys.A834 (2010) 317c



PbPb @ 2.76 TeV



- Several methods being explored
- Shown here
  - $J/\psi \rightarrow \mu^+\mu^-$ using event plane from TPC
- Ready for larger data sample of 2011

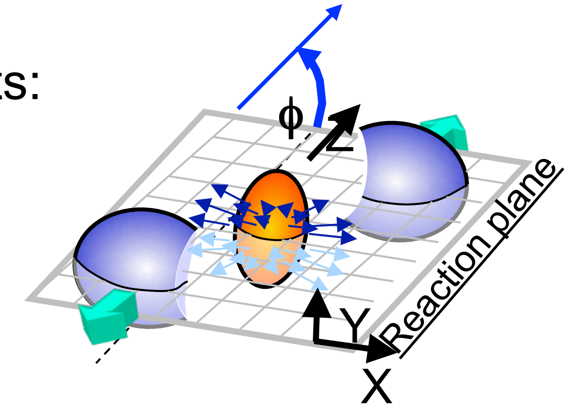
Conclusions

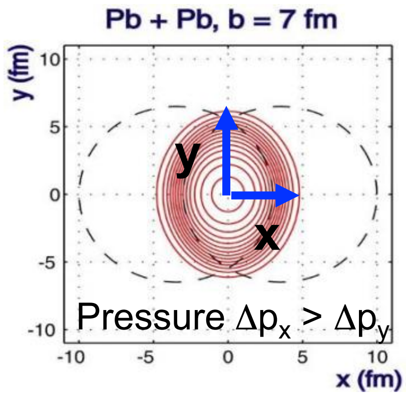
- LHC and ALICE performed well in the first Pb-Pb run
- Global properties of QCD matter at LHC
  - Highest charged particle density ever reached
  - Its centrality dependence saturates
  - Large volume and long decoupling time of particle emitting source
  - Hadrons flow consistent with hydro description of the medium
- High p_T partons lose energy in the medium
  - Light hadrons show same RAA for p_T > 8 GeV
  - Smaller R_{AA} for charm quarks?
- J/ψ R_{AA} measured at forward rapidity.
  - It is ~0.5 and
  - shows little to no dependence on centrality
- Expect many exciting results from current Pb-Pb run

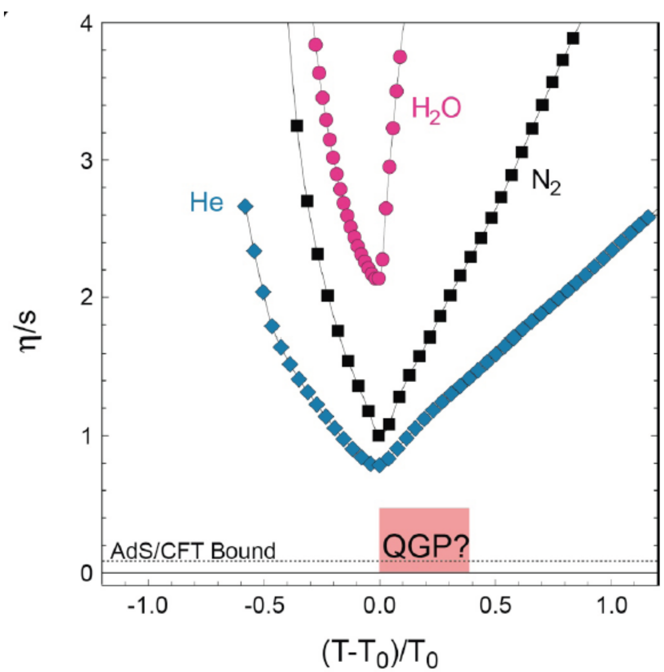
Back-Up

Elliptic flow and viscosity

- Spatial eccentricity $e = (y^2-x^2)/(y^2+x^2)$ source
- Anisotropic particle distributions due to pressure gradients:
- Describe by Fourier analysis of the angular distribution $dN/d\varphi = 1 + 2\, v_2 \cos(2\varphi) + \ldots\ldots$
- Measure coefficients using (two or more) particle correlations
- The second (elliptic flow) coefficient v_2 depends on the eccentricity and the equation of state.
- Viscosity reduces the elliptic flow



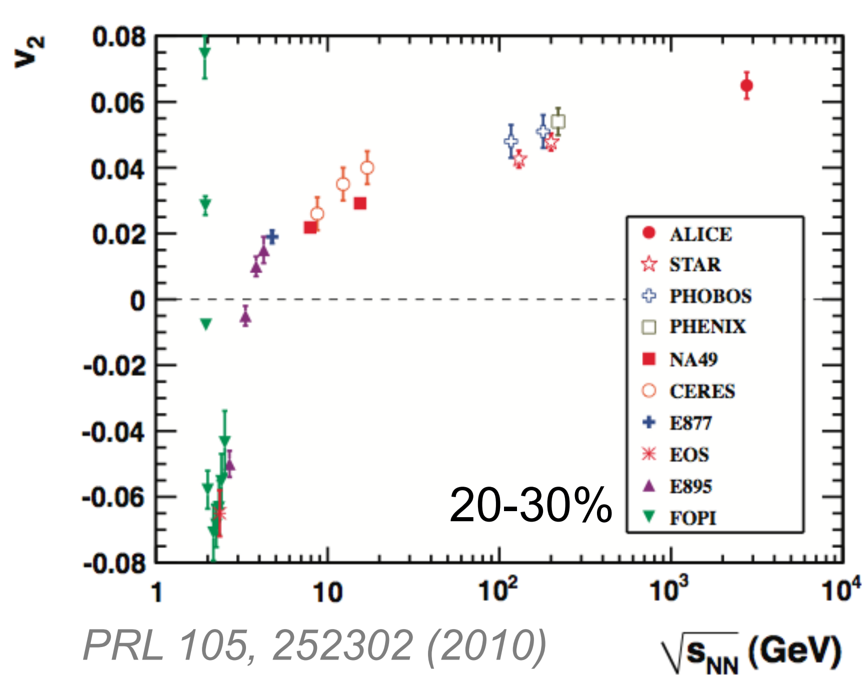




RHIC v_2 results indicate that the viscosity of the QGP is very small (less than 4 times the Ads/CFT limit)

$\eta/s > 1/4\pi \approx 0.08$ suggested by AdS/CFT

Elliptic Flow and the Perfect-Liquid QGP



PRL 105, 252302 (2010)

p_t-integrated v_2 in semi-central increases by 30% wrt RHIC

- Large elliptic flow reaches hydro-dynamical limit
  - –strong pressure gradient, system close to full thermalization
- Increase with energy larger than predicted for perfect liquid (zero viscosity)
  - –need viscous corrections (more important at RHIC than LHC)
  - –closer to perfect liquid at LHC than at RHIC?

Di-hadron correlations

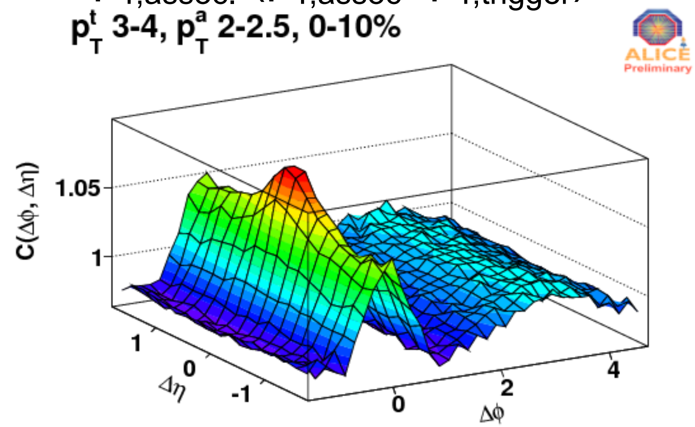
Triggered correlations: a particle belonging to a p_T region (= trigger particle) is associated to particles belonging to another p_T region (= associated particles)

→ 2D histos in $\Delta\eta\Delta\phi$ are then built in bins of $p_{T,trigger}$ and $p_{T,assoc.}$ ($p_{T,assoc}<p_{T,trigger}$)

Low p_T region:

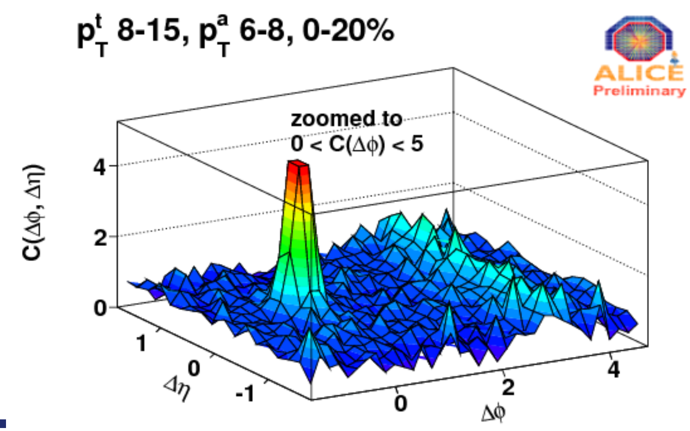
$$C(\Delta\phi, \Delta\eta) = \frac{N^{AB}_{mixed}}{N^{AB}_{same}} \frac{dN^{AB}_{same}/d\Delta\phi\Delta\eta}{dN^{AB}_{mixed}/d\Delta\phi\Delta\eta}$$

- Soft process
- Collective phenomena: flow
- Near side ridge
  - ✓ Observed at RHIC
  - ✓ Observed in p-p @ 7 TeV by CMS
- Away side broad structure



High p_T region:

- Hard processes
- Dominated by jets
- Suppression of the away side jet: parton interactions in the medium

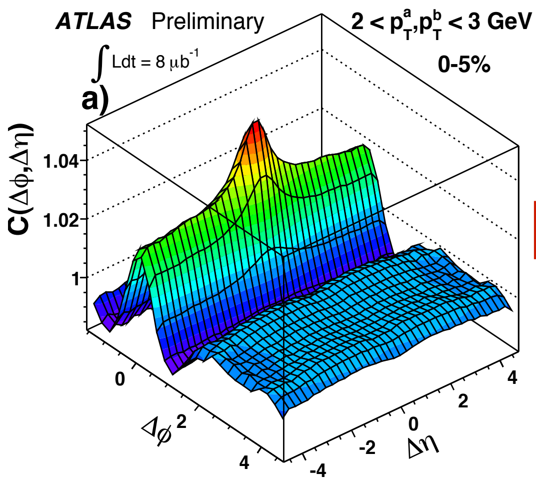


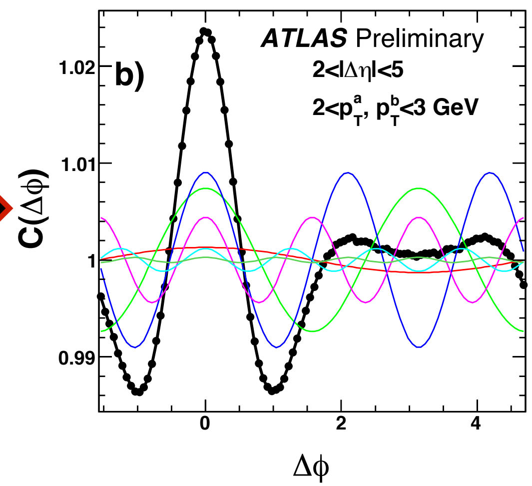
Fourier analysis

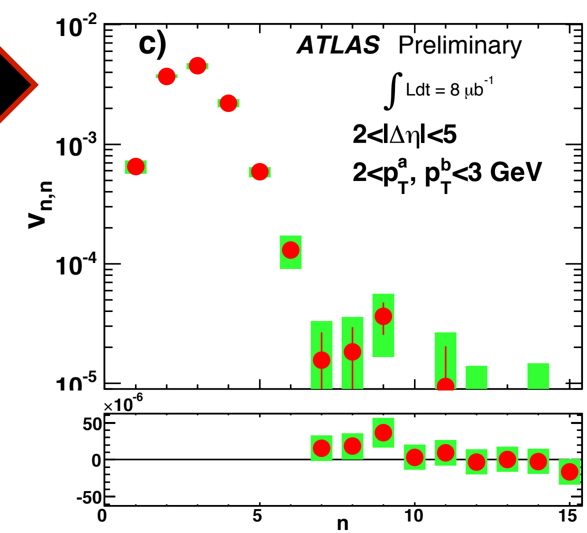
- Extract 1D Δφ correlations by integrating the C(Δη,Δφ) in a given Δη range and do a Fourier decomposition

$$C(\Delta\varphi) = \frac{1}{\Delta\eta_{\max} - \Delta\eta_{\min}} \int_{\Delta\eta_{\min}}^{\Delta\eta_{\max}} C(\Delta\eta,\Delta\varphi) \propto 1 + 2\sum_{n=1} v_{n,n} \cos(n\Delta\varphi)$$

$$v_{n,n} = \langle \cos(n\Delta\varphi) \rangle = \frac{\int C(\Delta\varphi)\cos(n\Delta\varphi)d(\Delta\varphi)}{\int C(\Delta\varphi)d(\Delta\varphi)}$$







- 5 components describe completely the correlations at large Δη and low p_T
  - Strong near-side ridge + double-peaked structure on away side

Correlations & collective flow

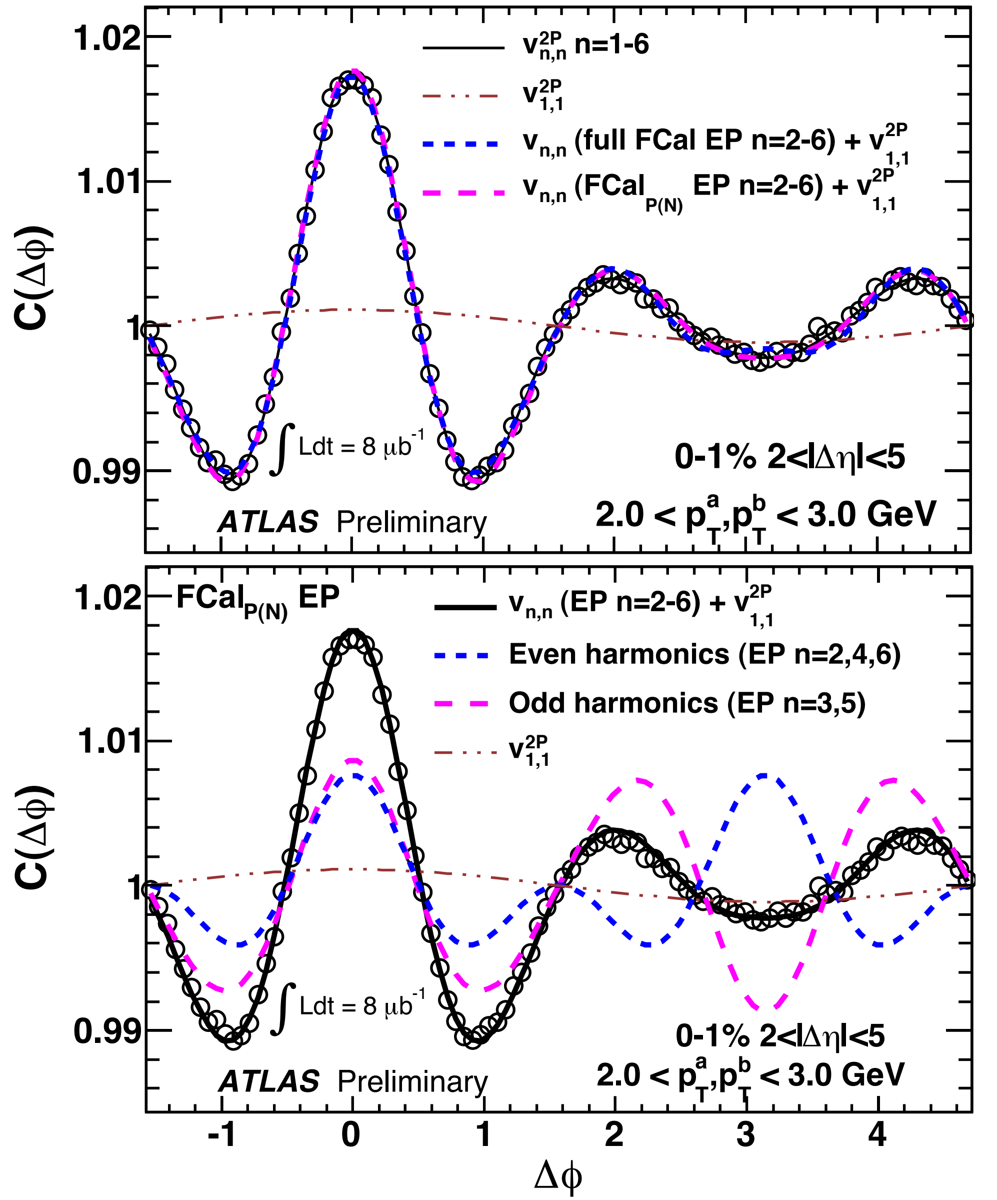
- If the observed di-hadron correlation comes from the single particle azimuthal anisotropy due to the collective flow, the $v_{n,n}$ extracted from C(Δφ) should be related with the flow coefficients v_n:

$$v_{n,n} = \langle \cos(n\Delta\varphi) \rangle = \left\langle \cos\left[n\left(\varphi_{trig} - \varphi_{assoc}\right)\right]\right\rangle$$

$$= \left\langle \cos\left[n\left(\varphi_{trig} - \Psi_n\right)\right]\right\rangle \left\langle \cos\left[n\left(\varphi_{assoc} - \Psi_n\right)\right]\right\rangle =$$

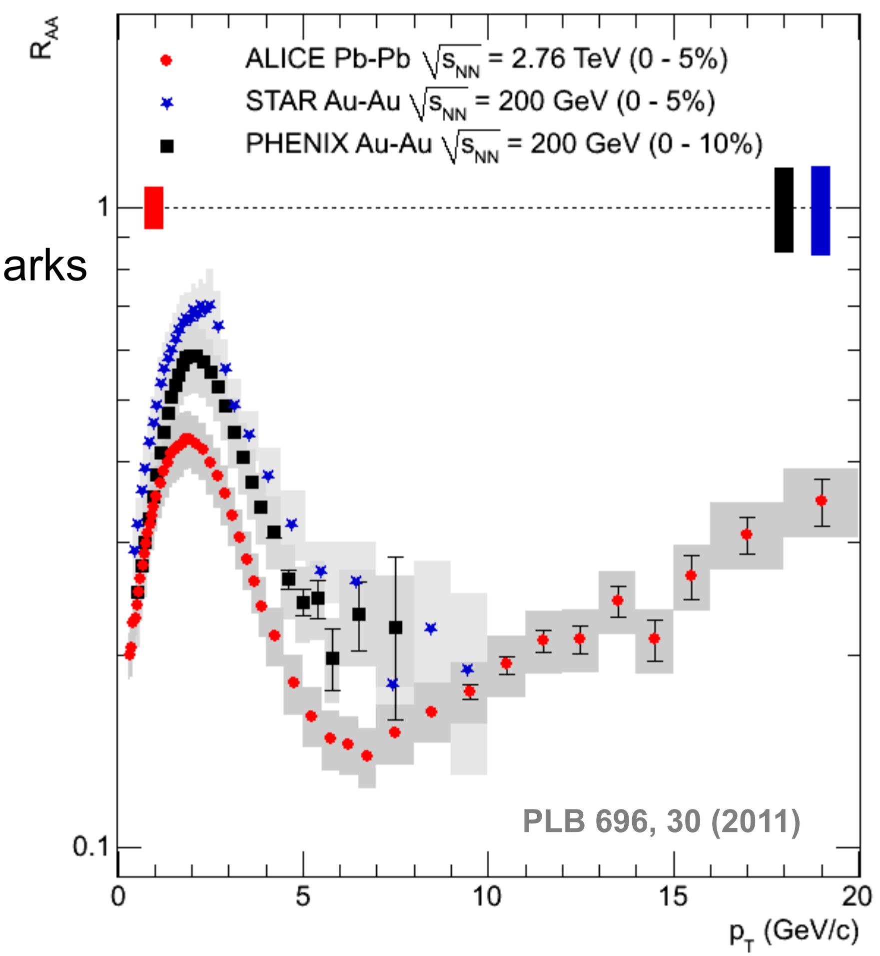
$$= v_n(p_t^{trig}) \cdot v_n(p_t^{assoc})$$

  - The two-particle correlation is due to the correlation with a common plane of symmetry
- Good description of C(Δφ) for central collisions at low p_T with the single particle v_n
  - Does not hold at high p_T where away-side jet dominates



R_{AA} LHC vs. RHIC

- Similar structures for p_T < 5 GeV/c
  - RHIC: Different p/π ratio in central Au+Au
- Intermediate p_T
  - LHC: ~20% stronger suppression
    - RHIC: high p_T hadrons hadronize from quarks
    - LHC: from gluons (larger color charge)
- High p_T
  - No direct comparison data
  - Highest p_T only π^0 (PHENIX PRL 101 (2008) 232301)

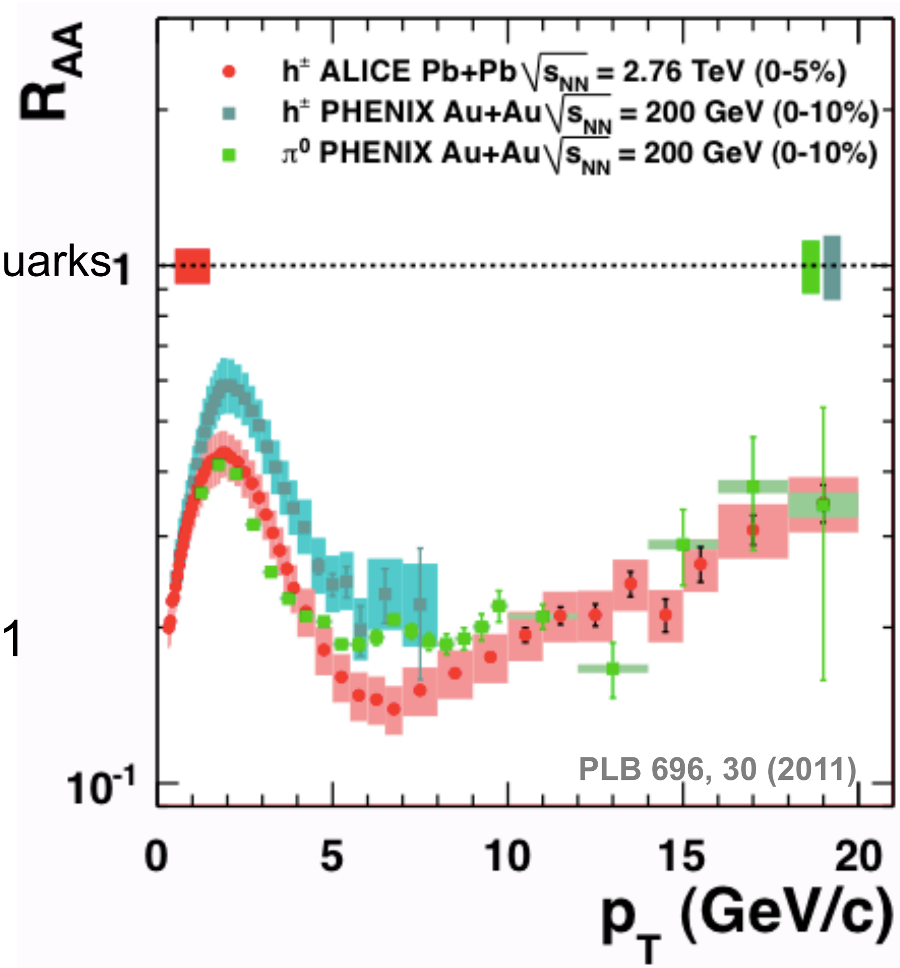


R_{AA} LHC vs. RHIC

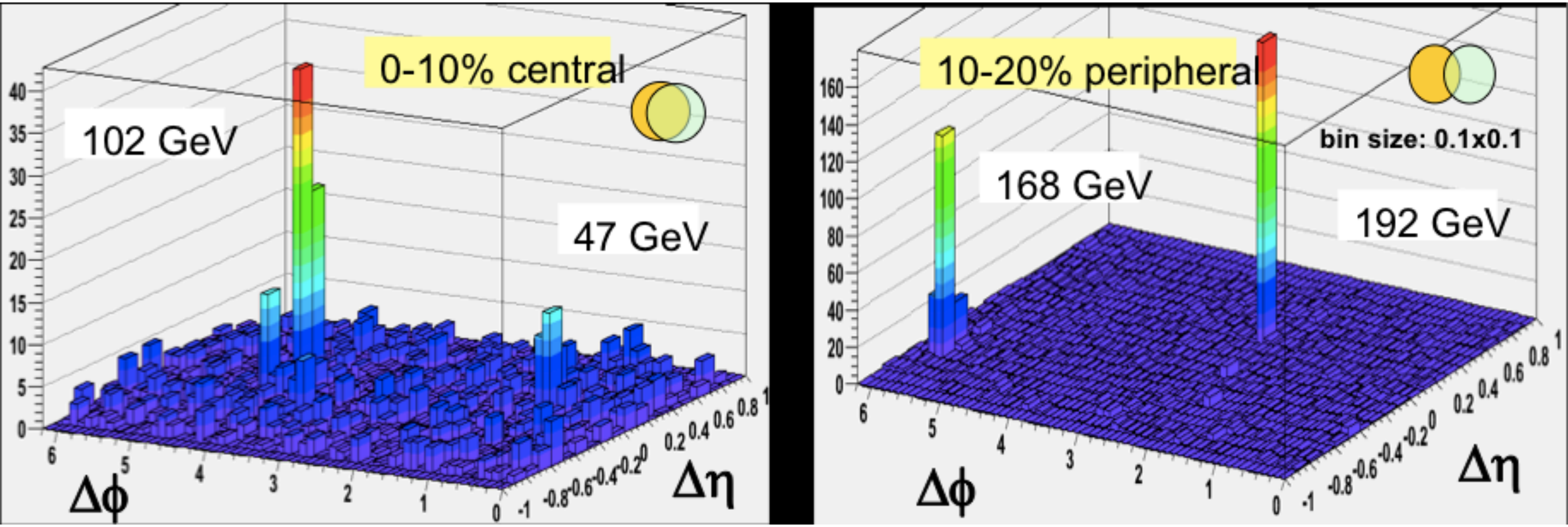
- Similar structures for p_T < 5 GeV/c
  - RHIC: Different p/π ratio in central Au+Au

- Intermediate p_T
  - LHC: ~20% stronger suppression
    - RHIC: high p_T hadrons hadronize from quarks
    - LHC: from gluons (larger color charge)

- High p_T
  - No direct comparison data
  - Highest p_T only π^0 (PHENIX PRL 101 (2008) 232301)



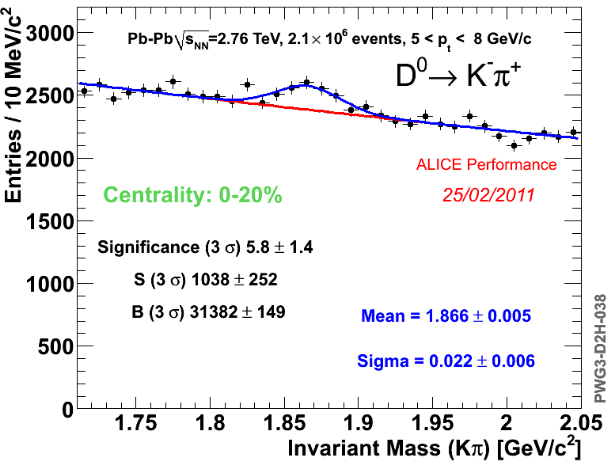
Full jet reconstruction



- di-jet imbalance observed by ATLAS and CMS
- ALICE: Jet reconstruction with charged tracks from TPC (|η|<1)
  - we see qualitatively a similar effect
  - goal: study effect down to low pt, study onset of di-jet imbalance
- ALICE EMCal coverage was limited in 2010, extended for 2011

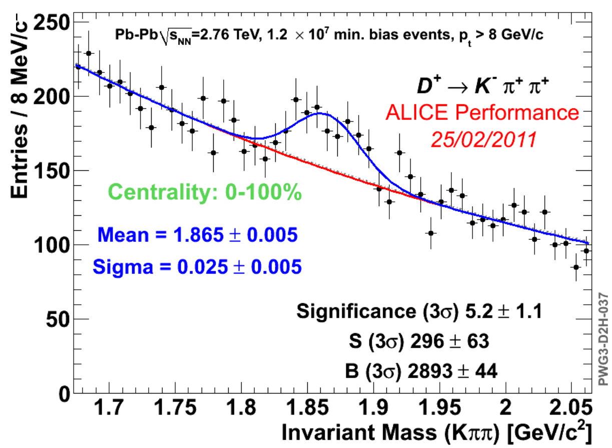
Outlook: heavy quarks

- Colour charge and mass dependence of energy loss
  - Charm
    - via D mesons,
  - Beauty
    - via leptons (e, μ):



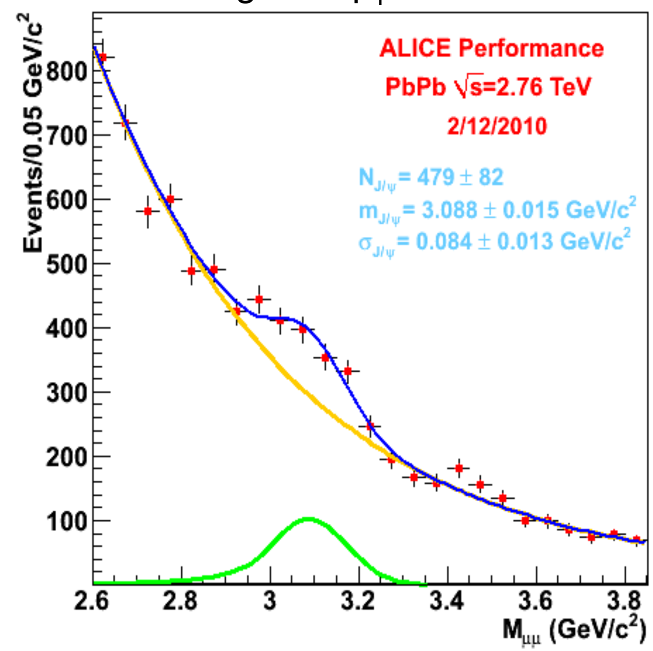
Expect coverage $5<p_t<15$ GeV/c

$D^0 \to K\pi$, $D^+ \to K\pi\pi$ via secondary vertex reconstruction



- Quarkonia: suppression or regeneration?
  - At both mid- and forward-rapidity

$J/\psi \to \mu\mu$ at forward rapidity, starting from $p_T \sim 0$



Expect few 1000 J/ψ from full 2010 statistics