Global event properties in Pb+Pb collisions at LHC energies from ALICE

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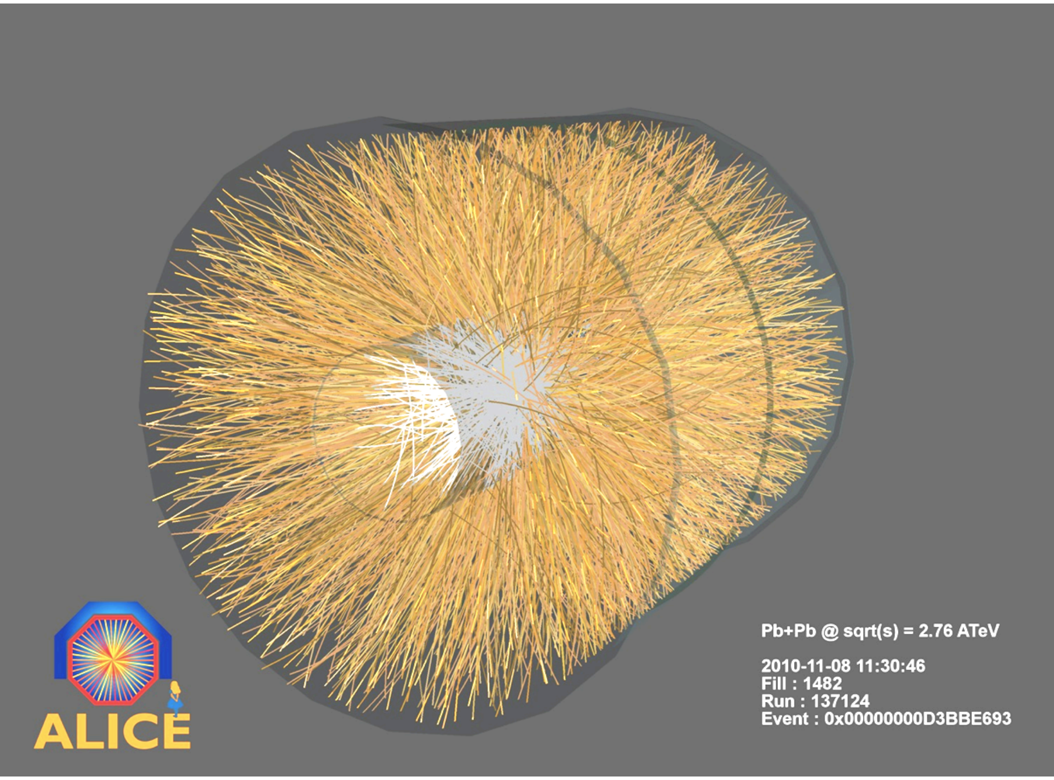
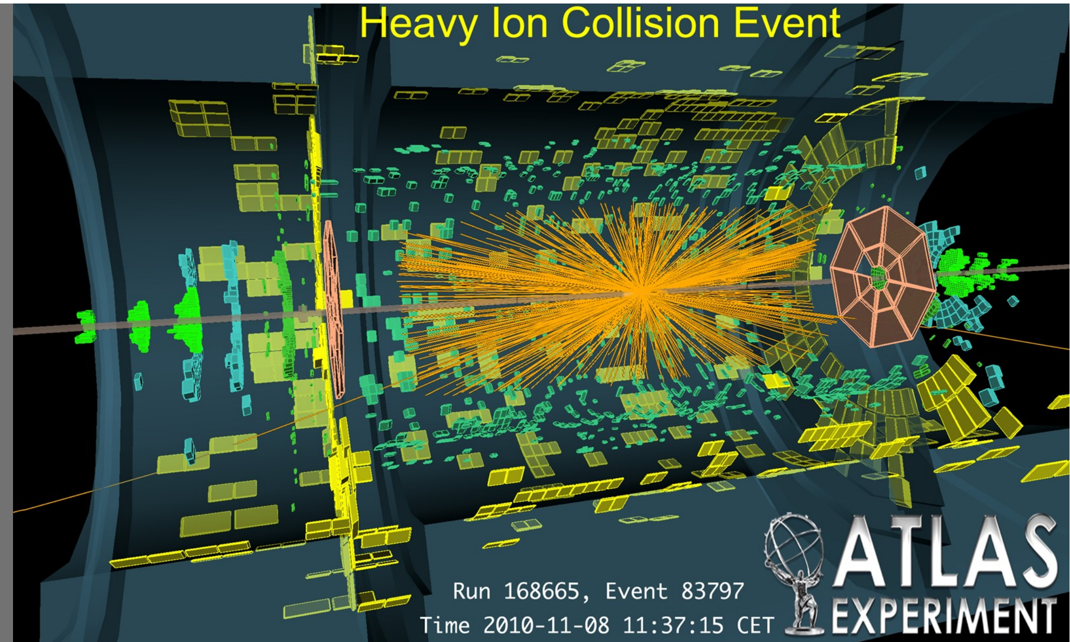
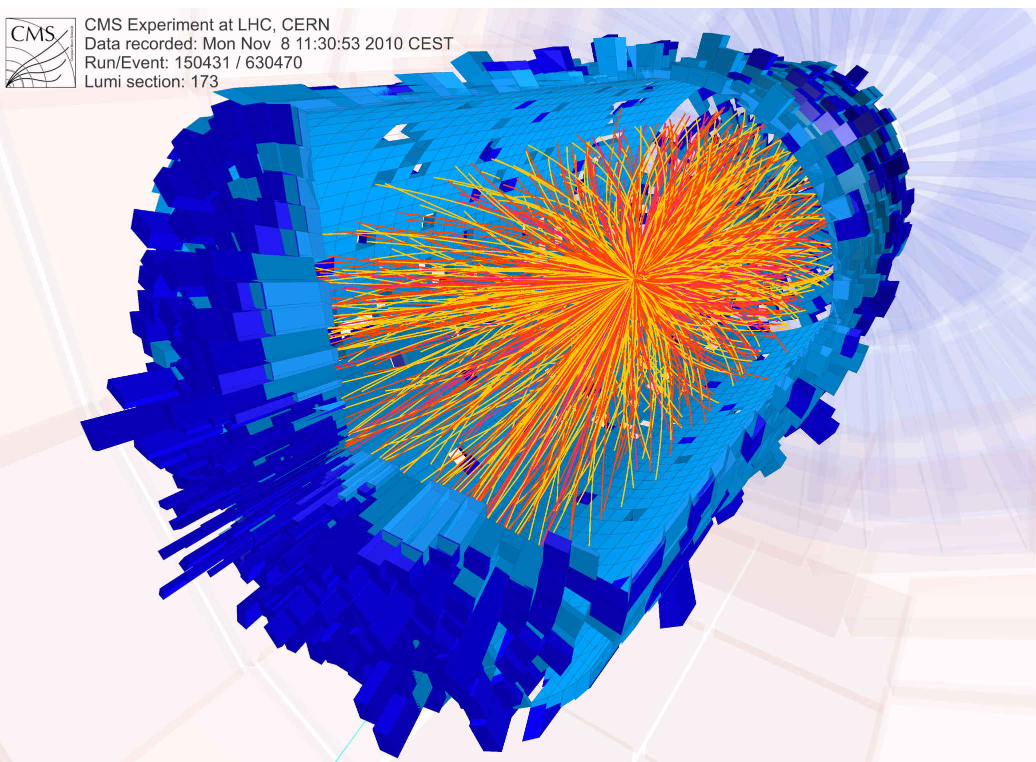
ALICE

ISMD2011, Miyajima, Japan, Sep. 26, 2011







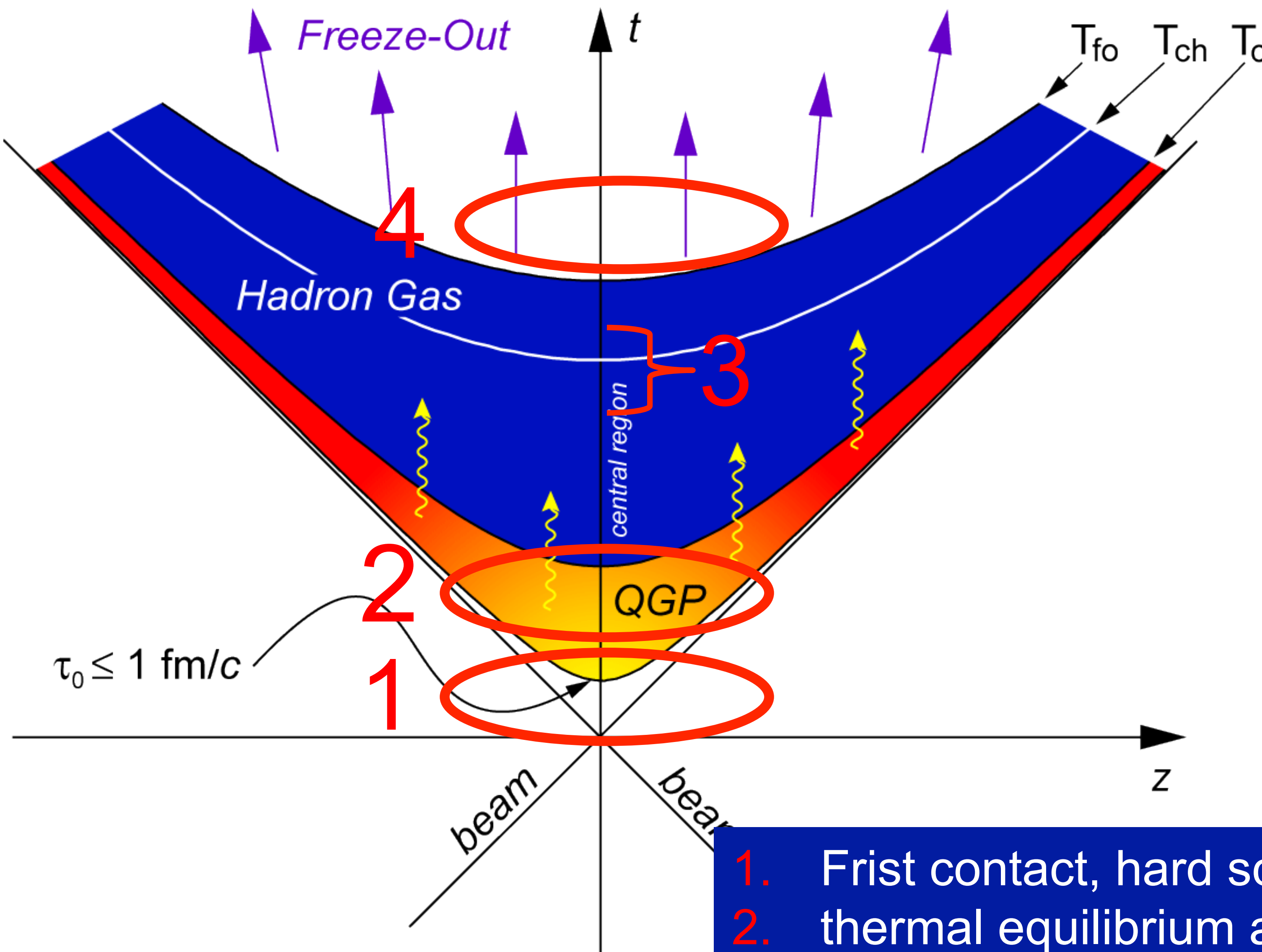
First Pb+Pb collisions at LHC

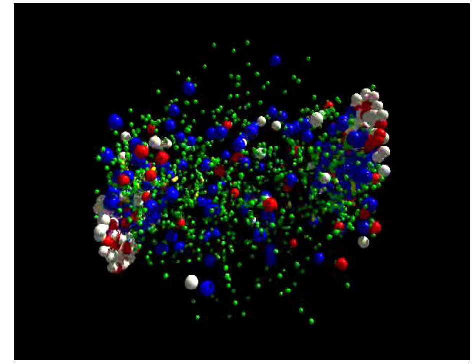
- ✓ **Nov. 8, 2010**
- ✓ **$\sqrt{s_{NN}}$ = 2.76 TeV (14 x RHIC)**
- ✓ **Observed by 3 experiments**
  - ✓ **ALICE, ATLAS, CMS**

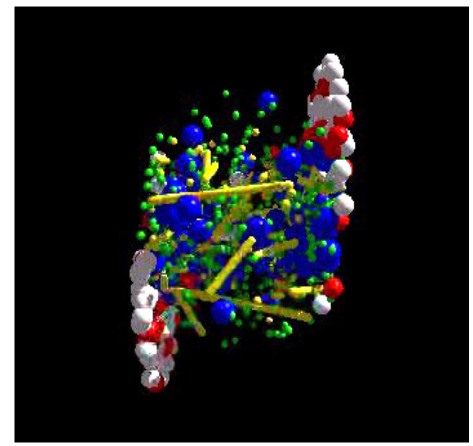
ALICE physics publications (as of Sep. 26, 2011)

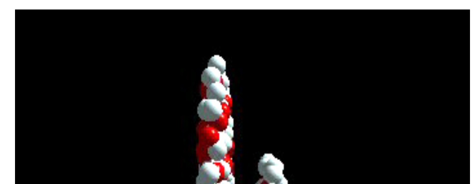
	arxiv date	system	energy (TeV)	observable	published in
1	28/11/09	pp	0.9	charged particle $dN/d\eta$	EPJC 65(2010)111
2	18/04/10	pp	0.9, 2.36	charged particle $dN/d\eta$, mult. distr.	EPJC 68(2010)89
3	20/04/10	pp	7	charged particle $dN/d\eta$, mult. distr.	EPJC 68(2010)345
4	28/06/10	pp	0.9, 7	antiproton/proton ratio	PRL 105(2010)072002
5	03/07/10	pp	0.9	pion HBT	PRD 82(2010)052001
6	05/07/10	pp	0.9	charged particle p_T spectra	PLB 693(2010)53
7	17/11/10	PbPb	2.76	charged particle $dN/d\eta$	PRL 105(2010)252301
8	17/11/10	PbPb	2.76	charged particle v_2	PRL 105(2010)252302
9	05/12/10	PbPb	2.76	charged particle R_{AA}	PLB 696(2011)30
10	08/12/10	PbPb	2.76	centrality dependence of N_{ch}	PRL 106(2011)032301
11	15/12/10	pp	0.9	K^0, ϕ, Λ, cascade	EPJC 71(2011)1594
12	17/12/10	PbPb	2.76	pion HBT	PLB 696(2011)328
13	19/01/11	pp	0.9, 7	pion HBT	arXiv:1101.3665v1
14	21/01/11	pp	0.9	pion, kaon, proton	EPJC 71(2011)1655
15	02/05/11	pp	7	J/Ψ	arXiv:1105.0380v1
16	19/05/11	PbPb	2.76	charged particle v_3, v_4, v_5	arXiv:1105.3865v1
17	12/09/11	PbPb	2.76	angular correlations	arXiv:1109.2501v1

Space-time evolution of HIC and global properties





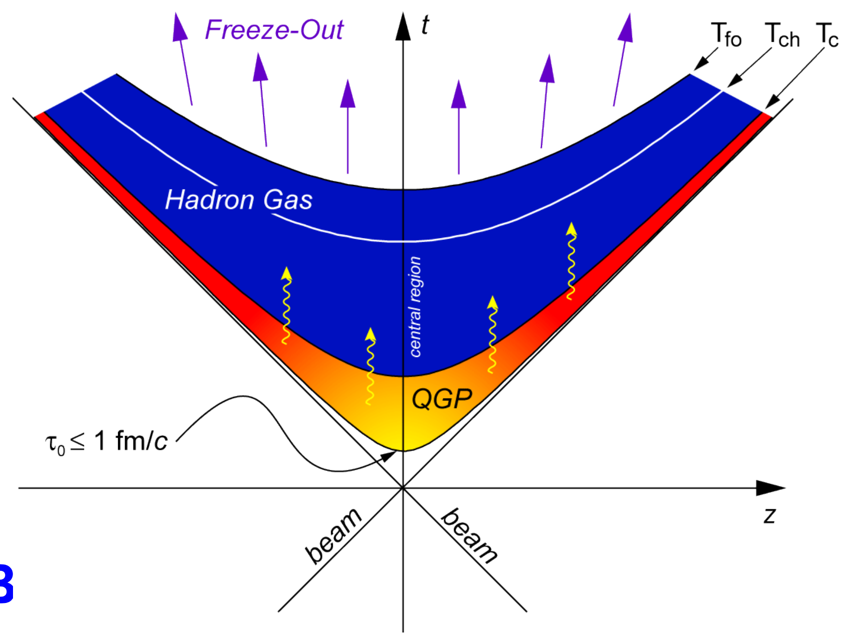




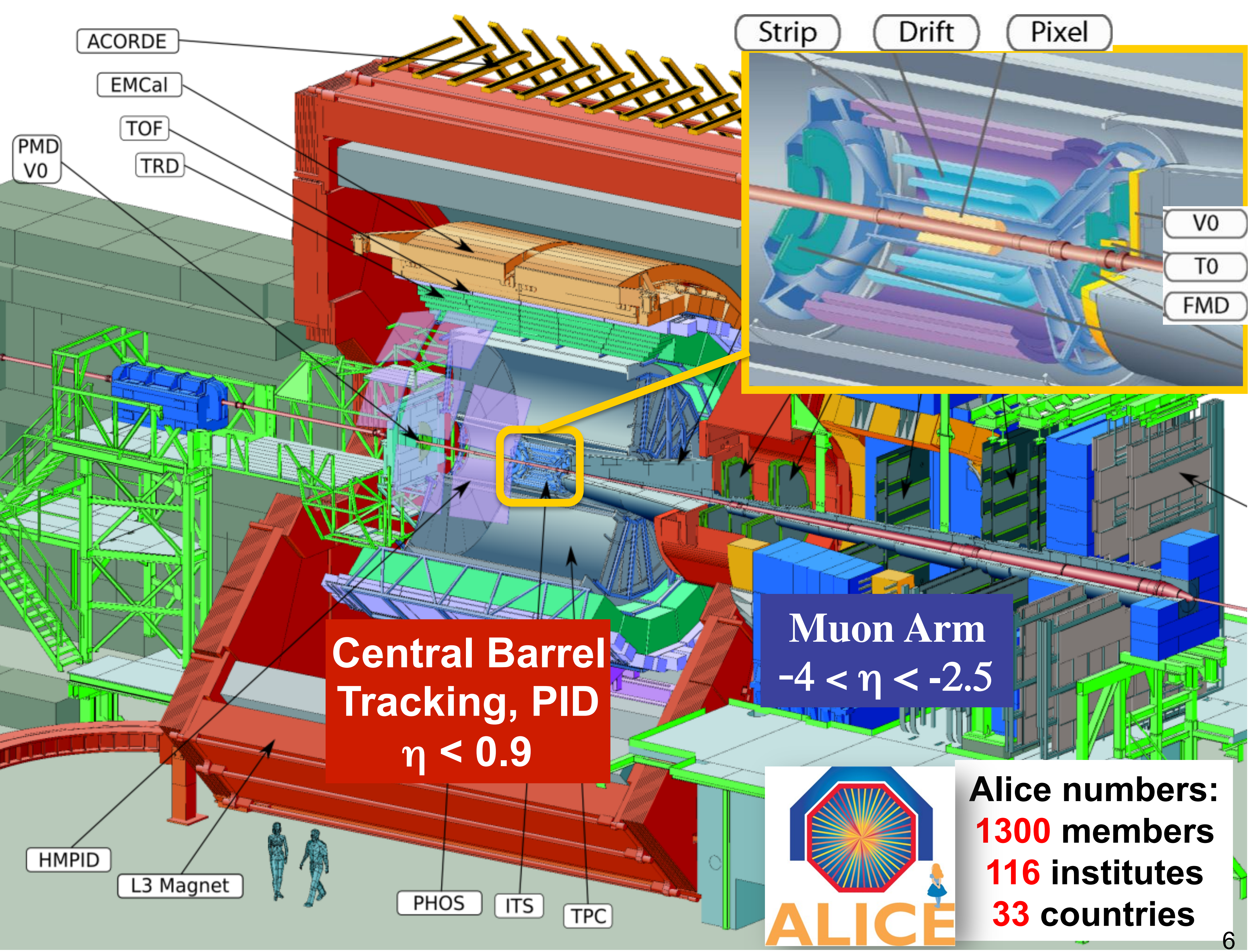
1. Frist contact, hard scattering of partons
2. thermal equilibrium and QGP
3. Chemical freeze-out (fixed particle ratios)
4. Kinetic freeze-out
   (fix particle momentum)

Global properties of Heavy Ion Collisions

✓ N_{ch}, E_T	→ ε_{Bj}
✓ PID p_T spectra	→ T_{fo}, β_T
✓ Particle ratios	→ T_{ch}, μ_B
✓ HBT	→ V, τ_{life}
✓ Flow (v_n)	→ η/s, initial condition

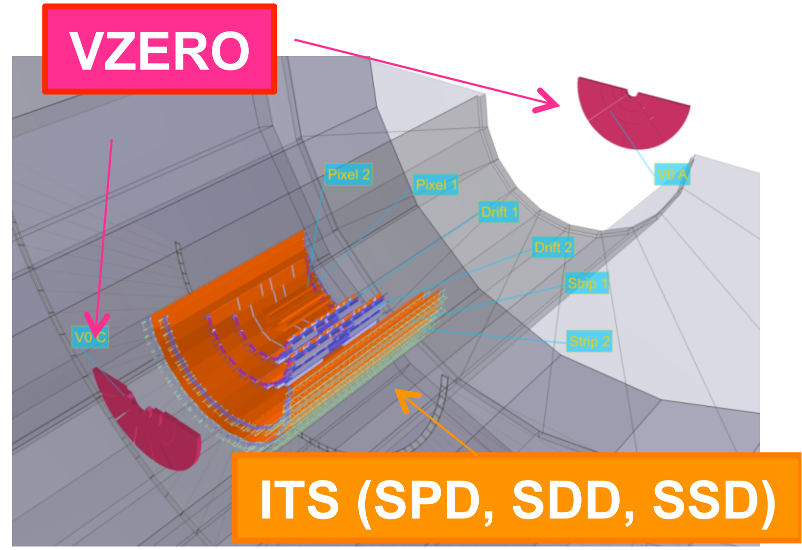


Q: How different and/or similar these global properties at LHC energy compared to those at RHIC?

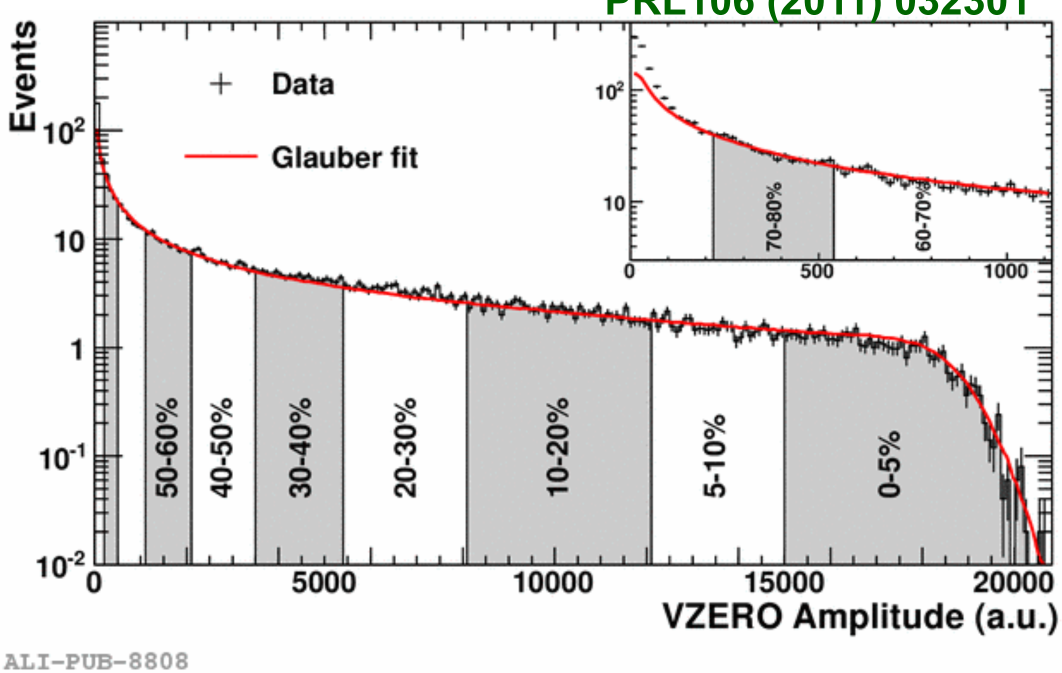

ACORDE
EMCal
TOF
TRD
PMD
V0
Strip
Drift
Pixel
V0
T0
FMD
Central Barrel
Tracking, PID
η < 0.9
Muon Arm
-4 < η < -2.5
HMPID
L3 Magnet
PHOS
ITS
TPC
ALICE
Alice numbers:
1300 members
116 institutes
33 countries

Data samples, statistics

System	Energy (TeV)	Trigger	Analyzed events	∫Ldt
pp	7	MB MUON	300M 130M	5 nb^{-1} 16 nb^{-1}
pp	2.76	MB MUON	65M ~9M	1.1 nb^{-1} 20 nb^{-1}
PbPb	2.76	MB	17M	1.7 mb^{-1}



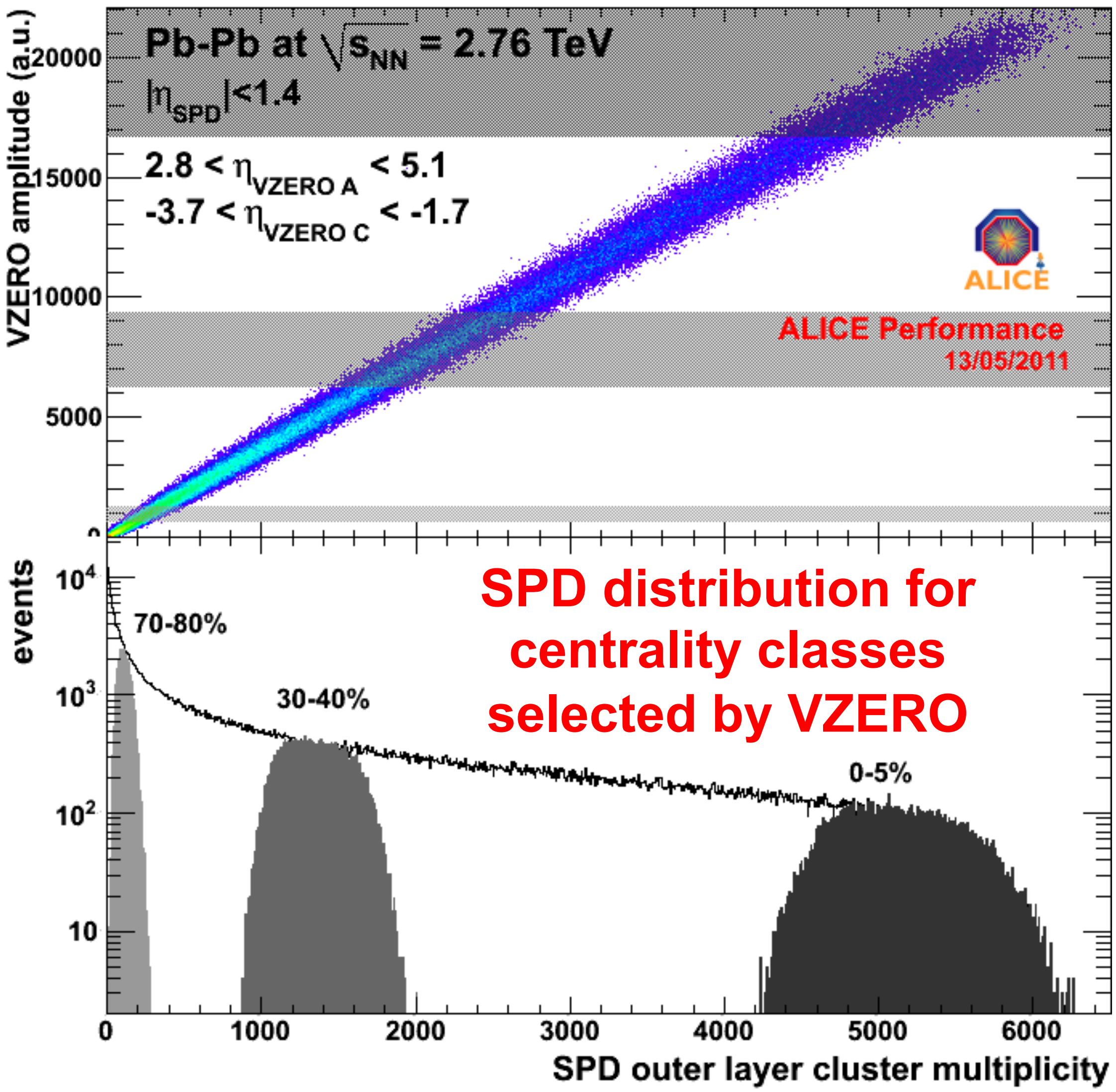
PRL106 (2011) 032301



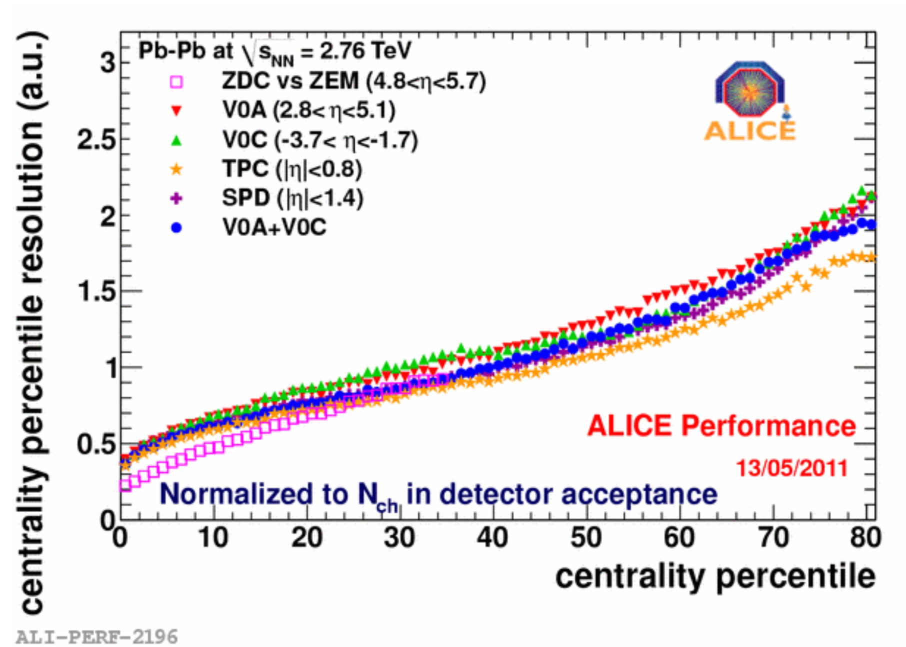
- Triggers
  - ⇨ MB: based on VZERO (A and C) and SPD
- Centrality selection in PbPb
  - ⇨ Amplitudes in the V0 scintillators
  - ⇨ Reproduced by Glauber model fit

Centrality and resolution

Correlation SPD - VZERO

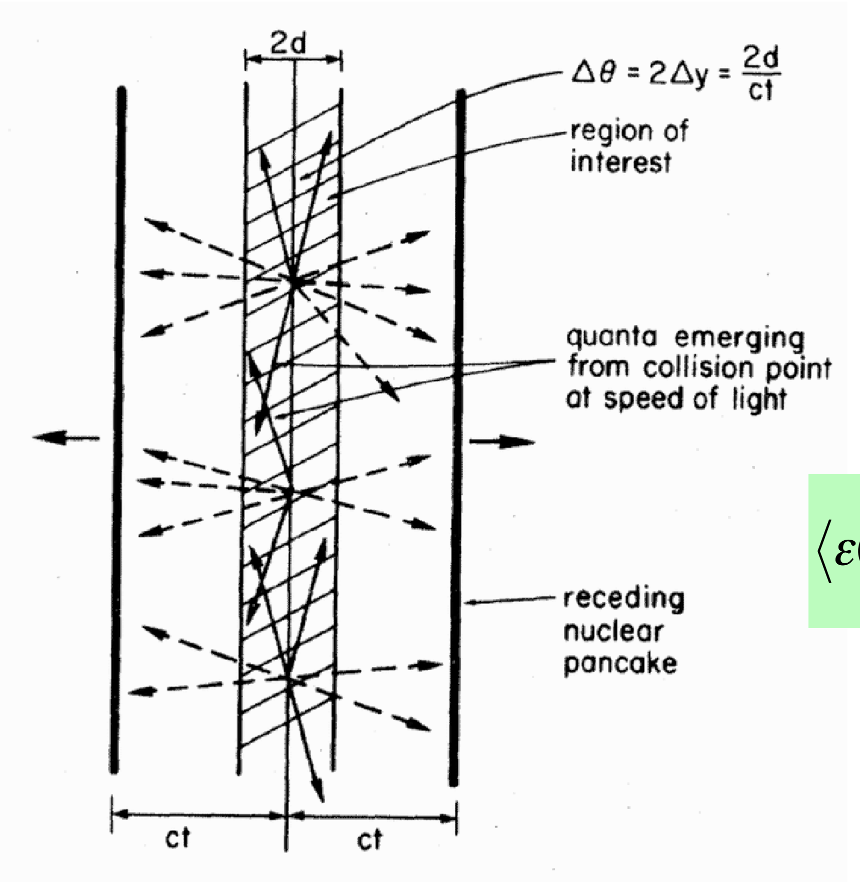


Resolution (RMS)



Centrality resolution scales with $\sqrt{N_{ch}}$
0.5% for central
2% for peripheral

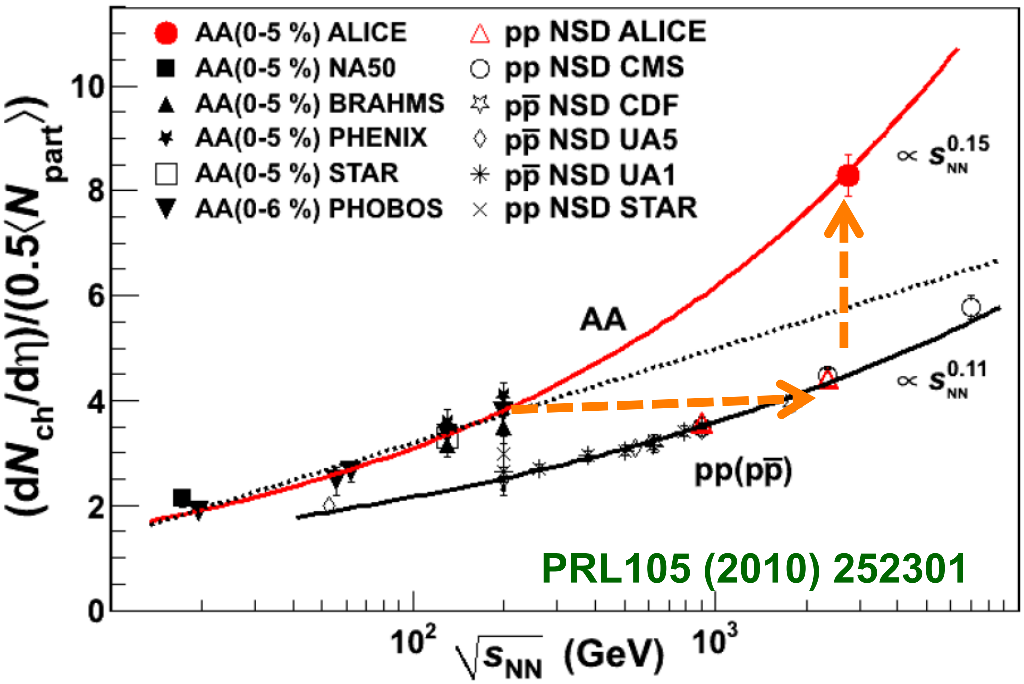
• N_{ch}, E_T give us an insight on initial energy density



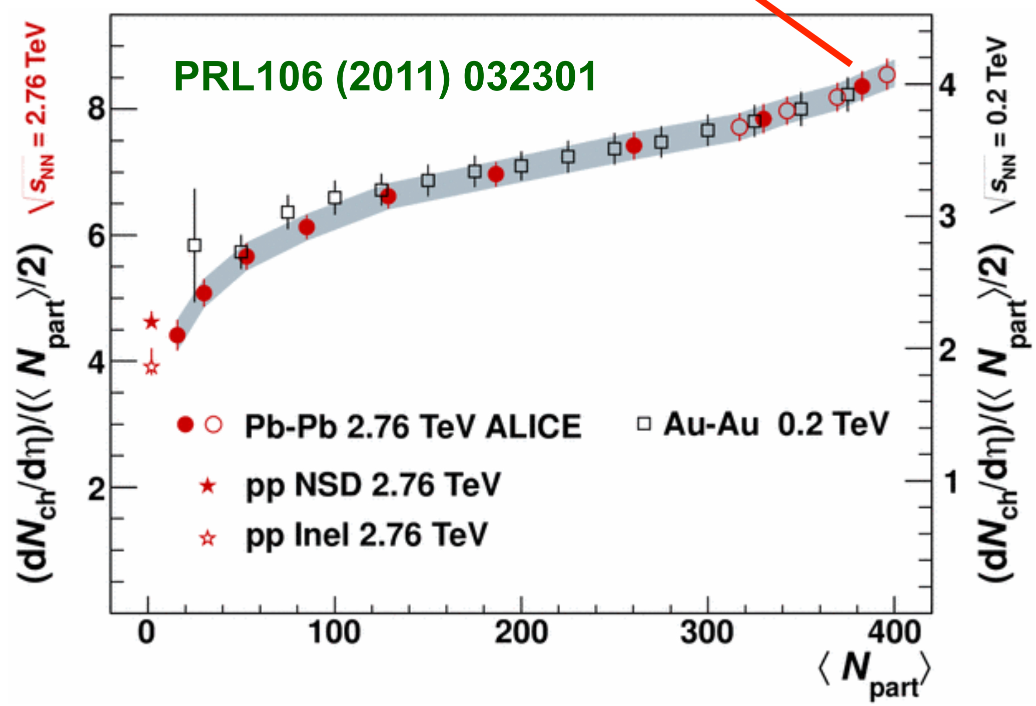
$$\langle \varepsilon(t) \rangle = \frac{\text{Energy}}{\text{Volume}} = \frac{\langle E \rangle dN}{V} = \frac{1}{t\,A}\frac{dN(t)}{dy}\langle m_{\mathrm{T}} \rangle (t) = \frac{1}{t\,A}\frac{dE_{\mathrm{T}}(t)}{dy}$$

$$\frac{dE_T}{dy} = \langle m_T \rangle \frac{dN}{dy}$$

Charged particle multiplicity; $dN_{ch}/d\eta$



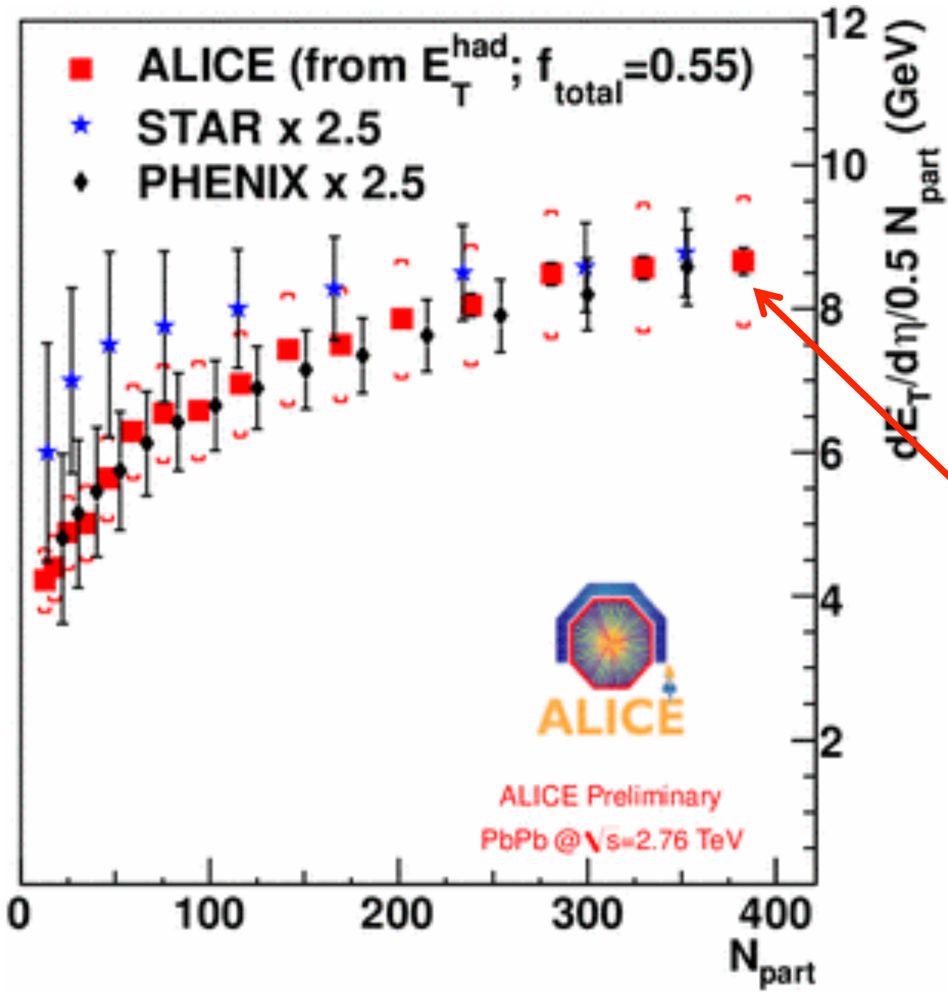
$\varepsilon_{Bj}\tau \cong 15\ \mathrm{GeV/(fm^2c)}$



- $dN_{ch}/d\eta = 1584 \pm 76$
- $(dN_{ch}/d\eta)/(N_{part}/2) = 8.3 \pm 0.4$
  - ≈ 2.1 x central AuAu at $\sqrt{s_{NN}}$=0.2 TeV
  - ≈ 1.9 x pp (NSD) at $\sqrt{s}$=2.36 TeV
- Stronger rise with √s in AA w.r.t. pp
- Stronger rise with √s in AA w.r.t. log extrapolation from lower energies

- **Very similar centrality dependence at LHC & RHIC**
  - ➯ After scaling RHIC results (x2.1) to the multiplicity of central collisions at the LHC

Energy density from E_T



- From RHIC to LHC:
  - increase in $dE_T/d\eta$ per participant pair by a factor 2.5
  - Similar centrality dependence

- Energy density of the medium from Bjorken formula

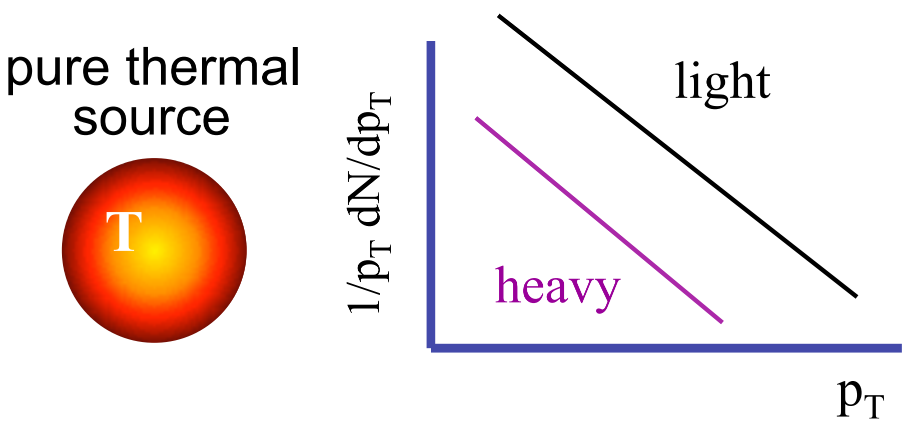
$$\varepsilon_{Bj} = \frac{1}{\tau \pi R^2} \frac{dE_T}{dy} \qquad R = 1.12 A^{1/3}\ fm$$

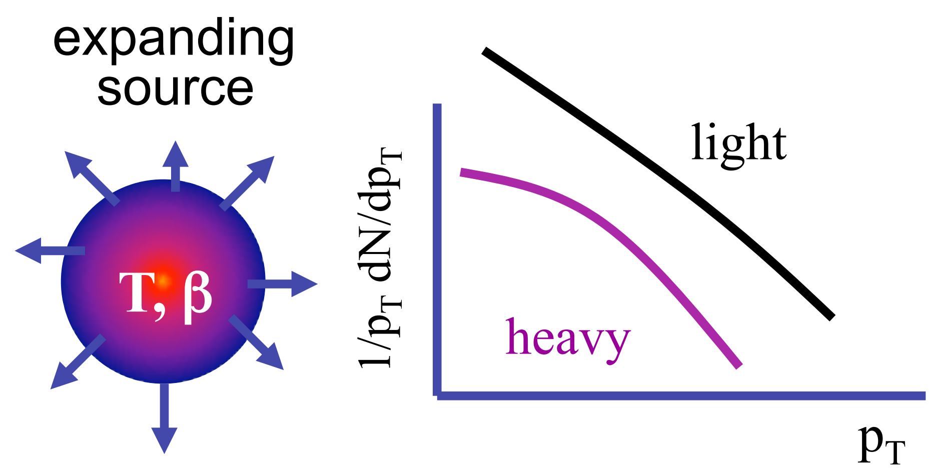
  - Where τ = (unknown) formation time

$$\varepsilon_{Bj}\tau \cong 16\ \mathrm{GeV/(fm^2c)}$$

  - $\approx 3\times\varepsilon_{Bj}\tau$ at RHIC
  - RHIC: $\varepsilon\tau$ =5.4±0.6 GeV/(fm^2c)

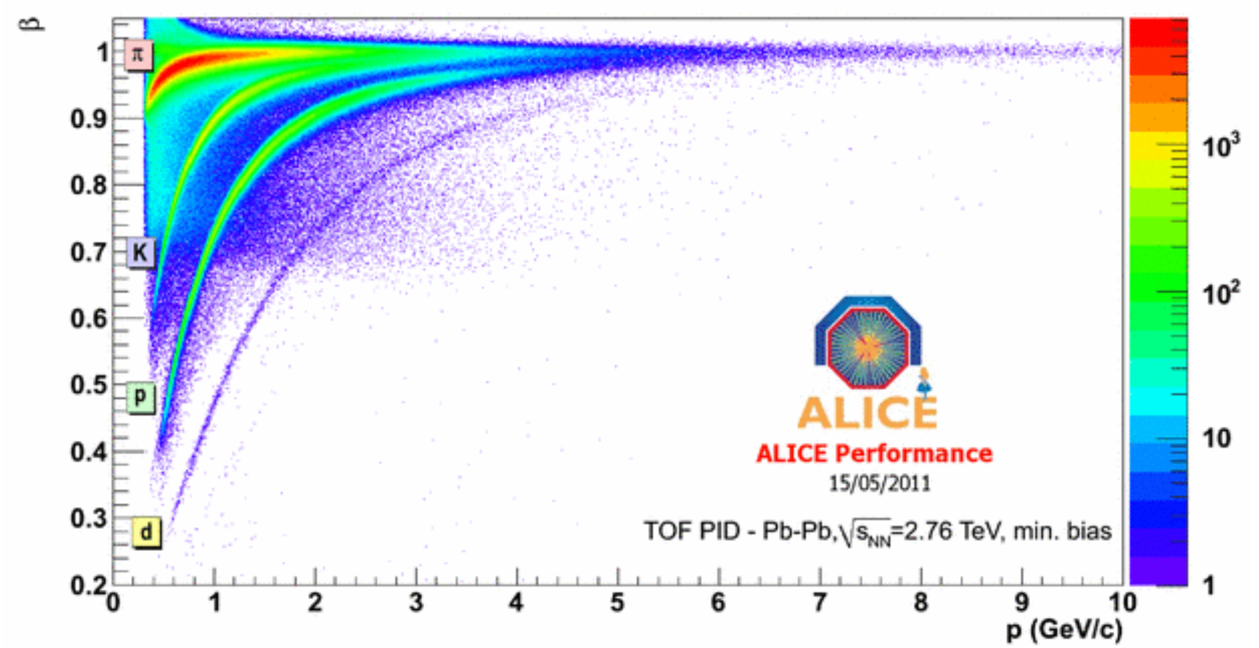
- **To characterize the global properties on expanding source; introduce common "symmetric" velocity field, "radial flow".**

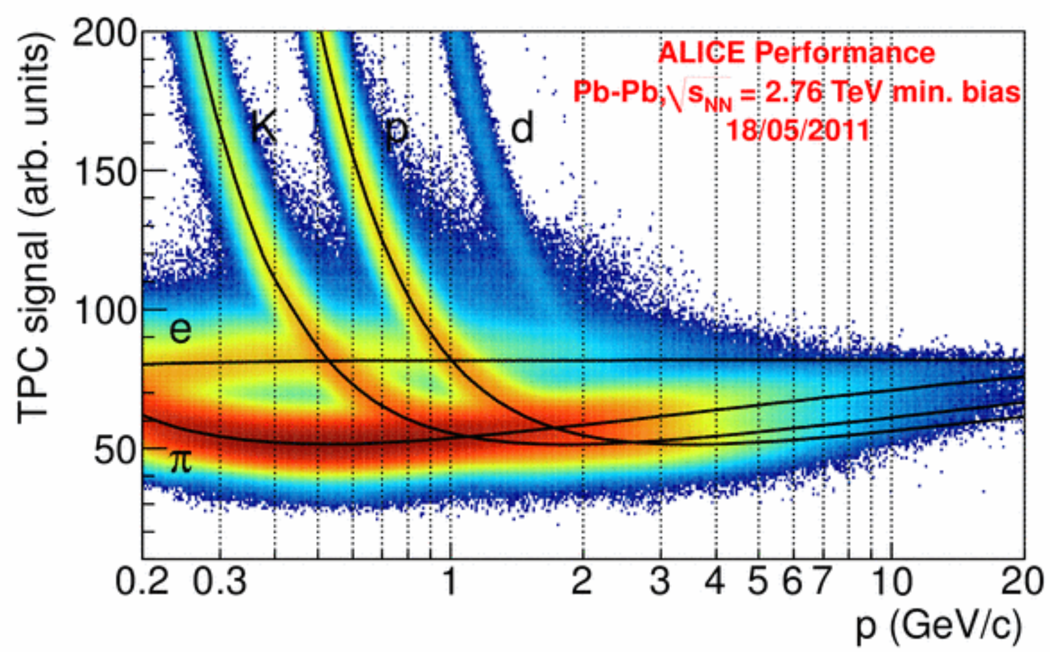


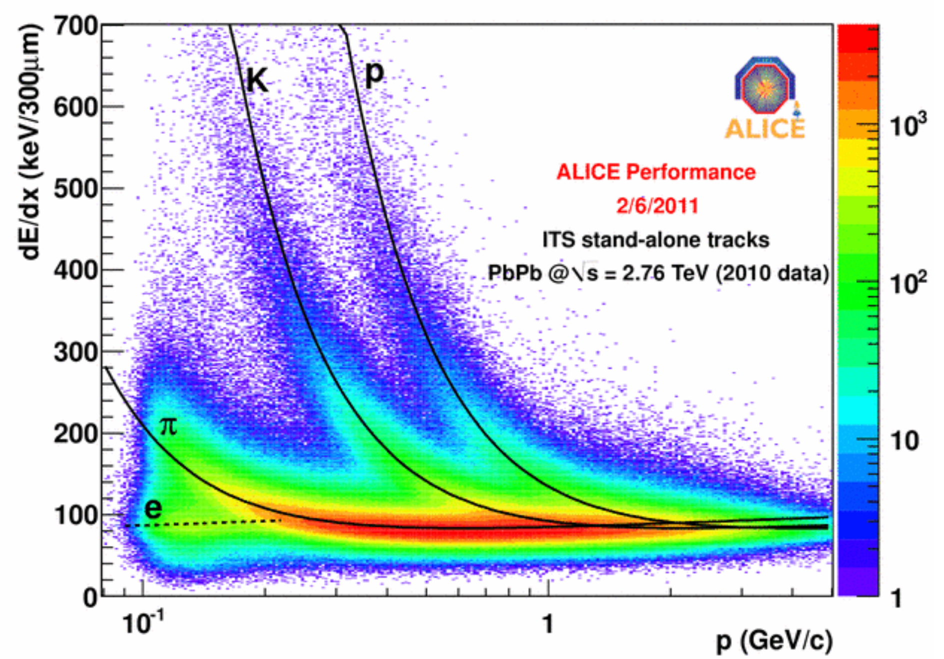


Hadron PID in ALICE

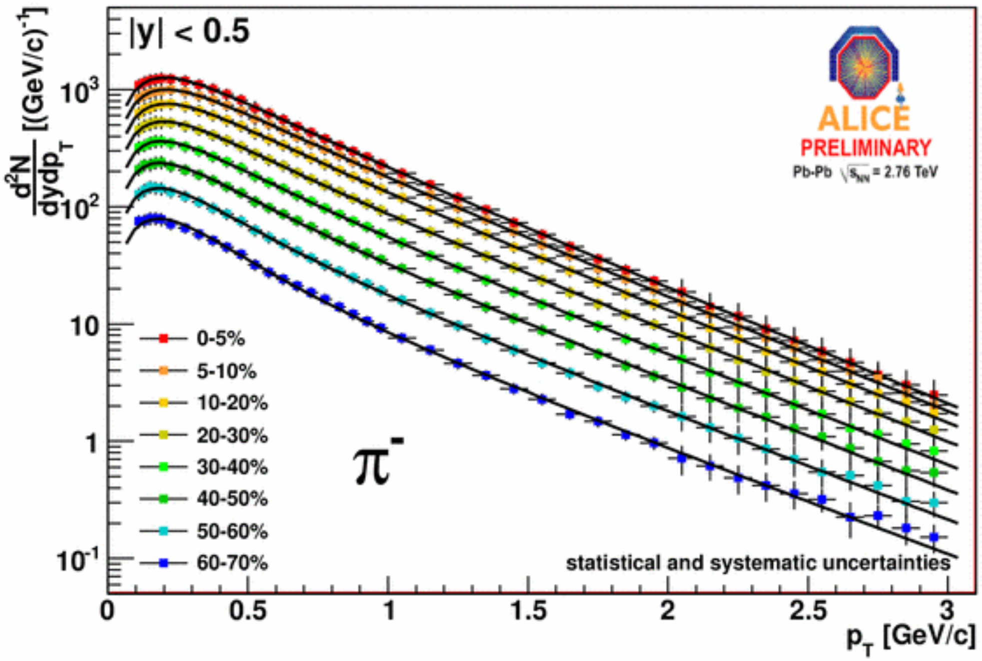
- PID in the central barrel
  - ➪ dE/dx in TPC
    - ✓ Up to 159 samples
    - ✓ Resolution ~ 5%
  - ➪ dE/dx in ITS
    - ✓ Low momentum reach
  - ➪ Time of Flight by TOF
    - ✓ 3σ separation:
      π/K up to 2.5 GeV/c
      p/K up to 4.0 GeV/c

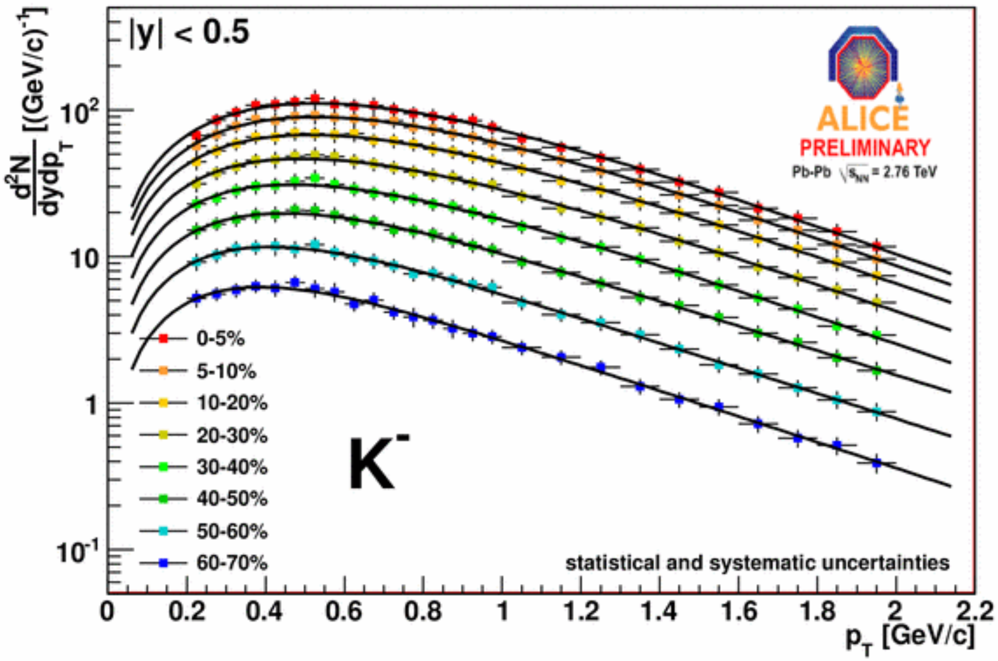




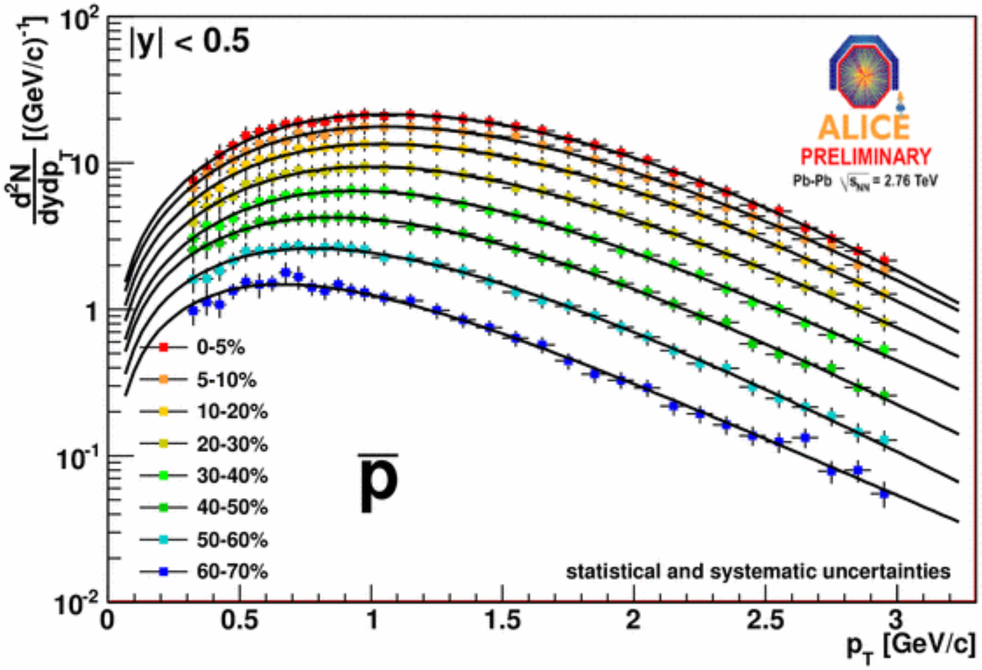


Identified hadron spectra





- Combined analysis with ITS, TPC and TOF
- Lines = blast-wave fits
  - ⇨Integrated Yields
  - ⇨Average p_T
  - ⇨Parameters of the system at the kinetic freeze-out (T_{f0}, β_T)



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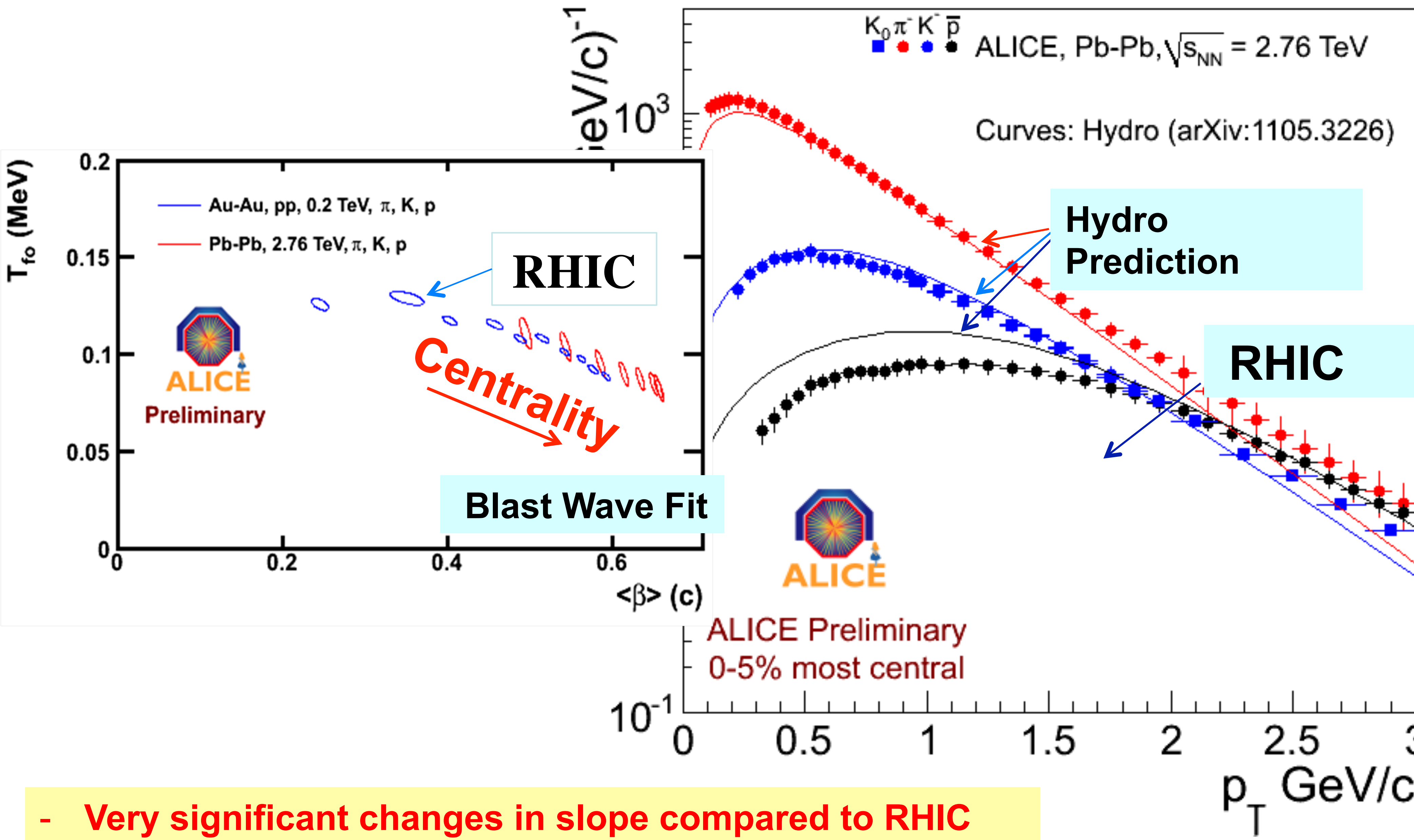
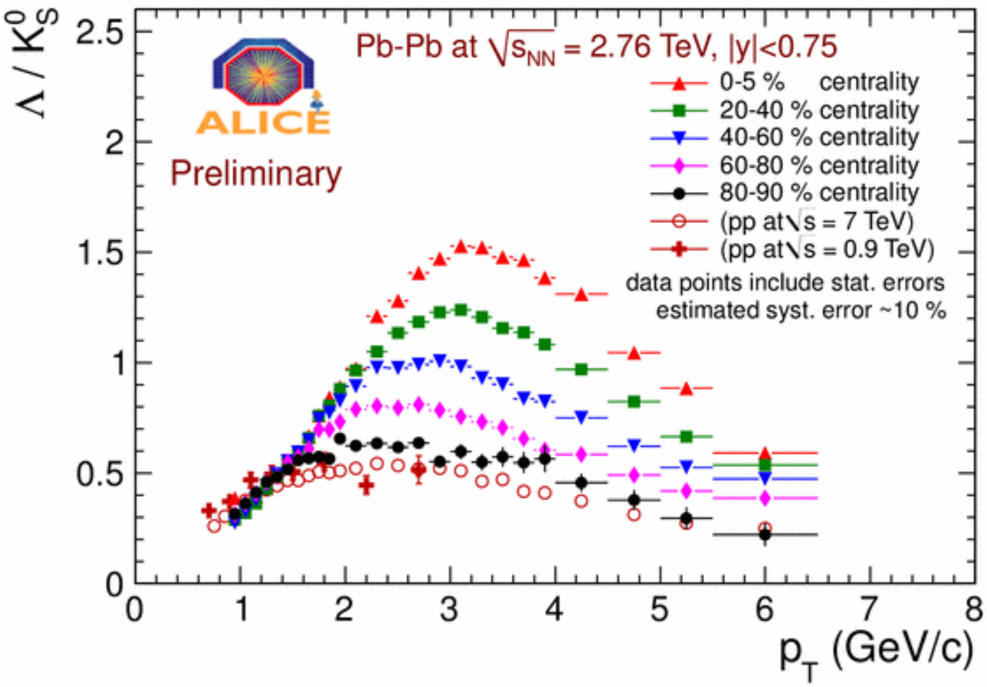
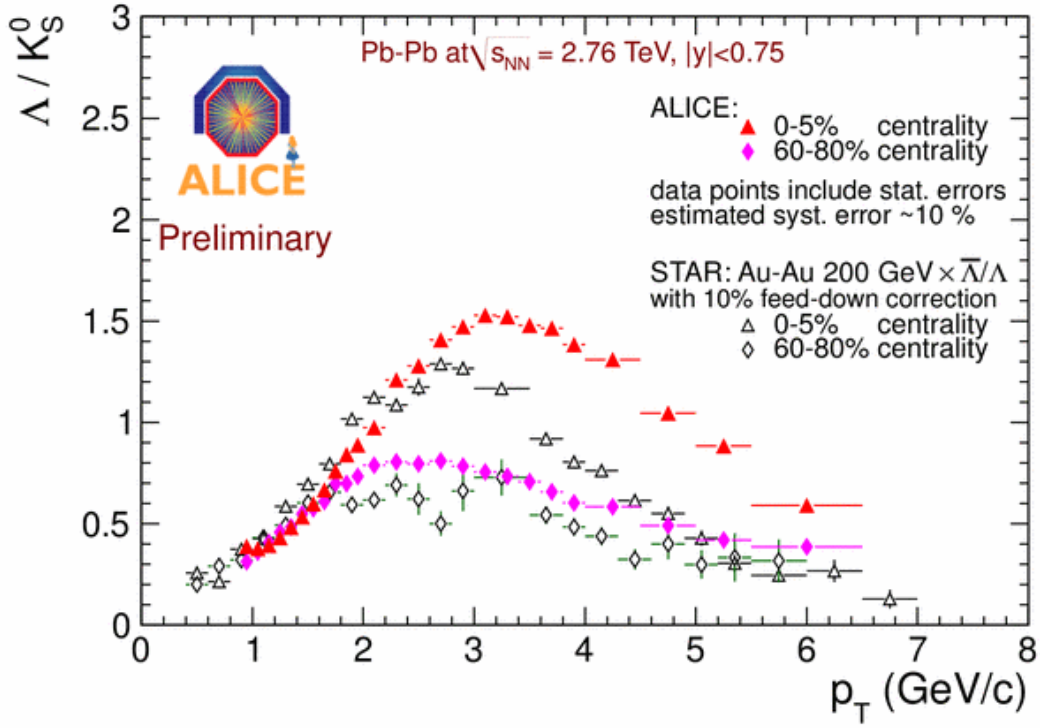
Identified particle spectra



- **Very significant changes in slope compared to RHIC**
- **Most dramatically change for protons**
- Very strong radial flow, **β ≈ 0.66 (10% higher than RHIC)**
- Even larger than predicted by most recent hydro

Baryon to meson ratio: Λ/K_s^0





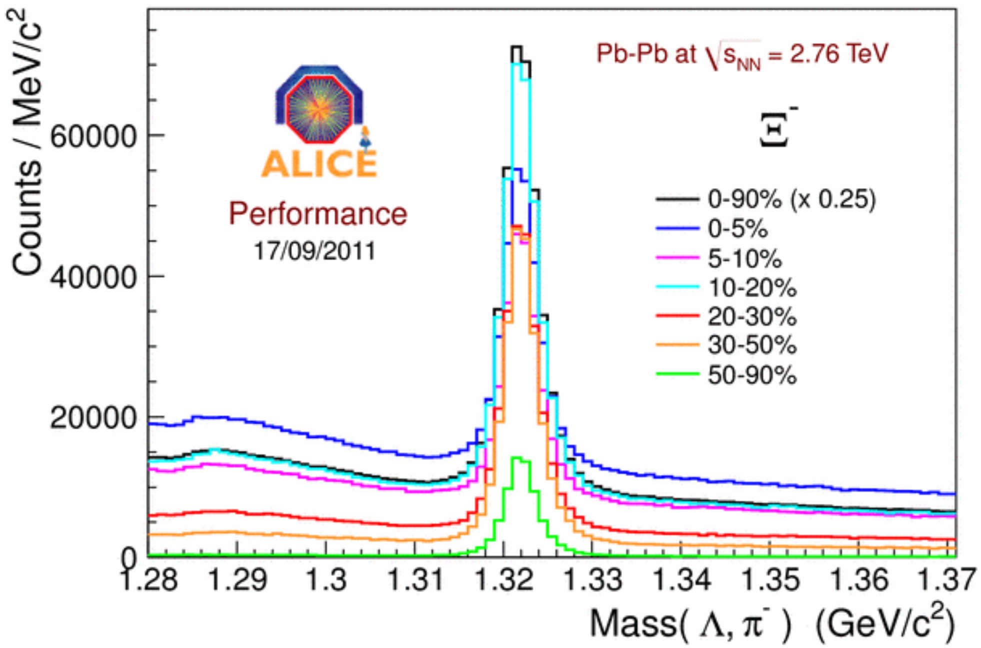
- Baryons more abundant at intermediate p_T
- Baryon/meson ratio increases with centrality
  - Consistent with recombination and/or strong radial flow.

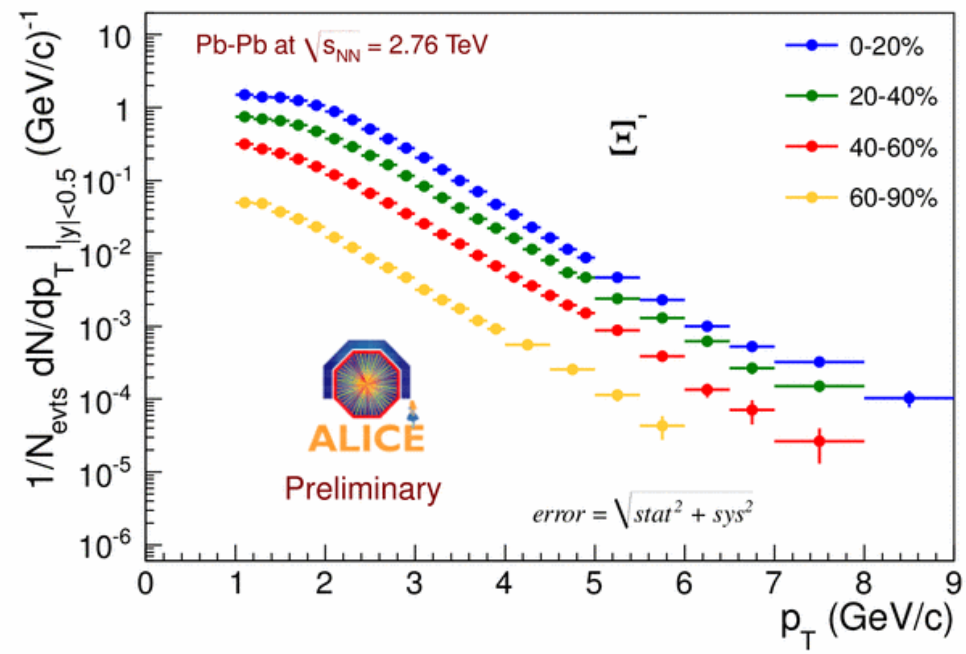
- **Enhancement stronger than at RHIC**
- **Maximum of Λ/K slightly pushed towards higher p_T than at RHIC**

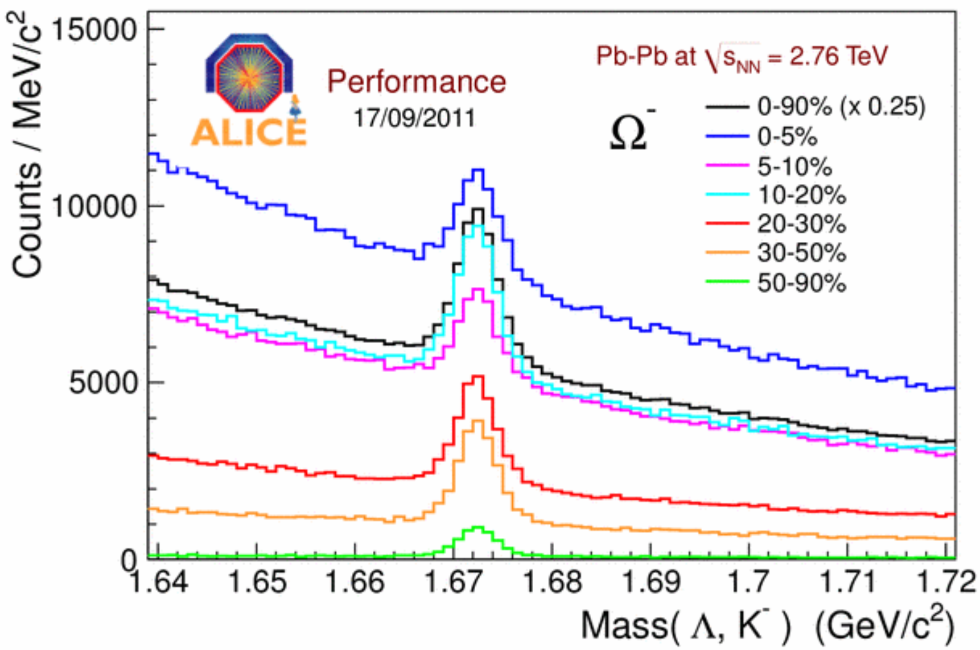
  ⇨ **higher radial flow?**

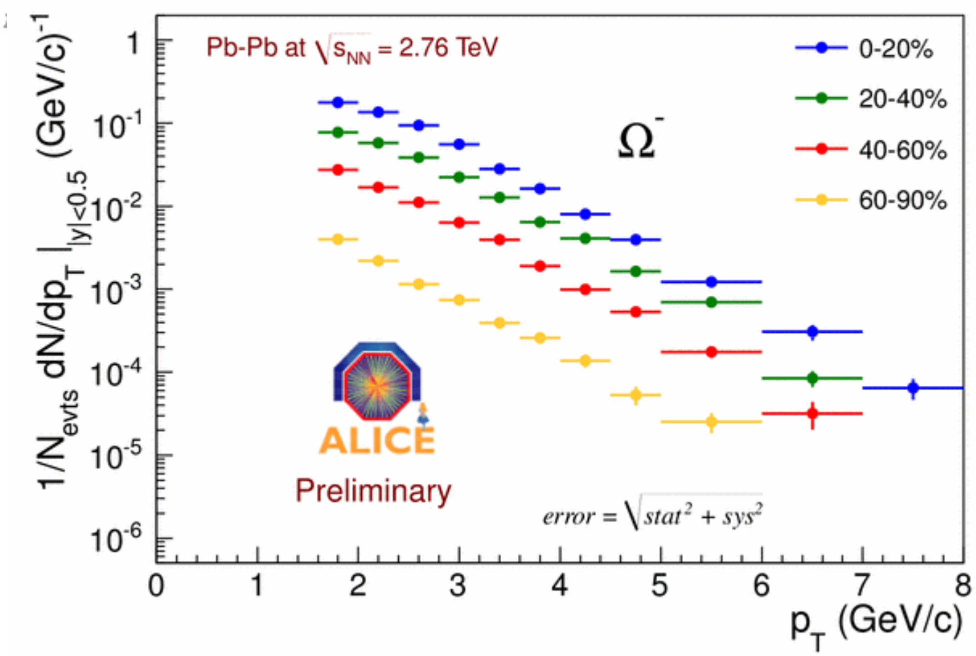
- **Particle ratios; access to the chemical properties of matter**

Multi-strange baryons









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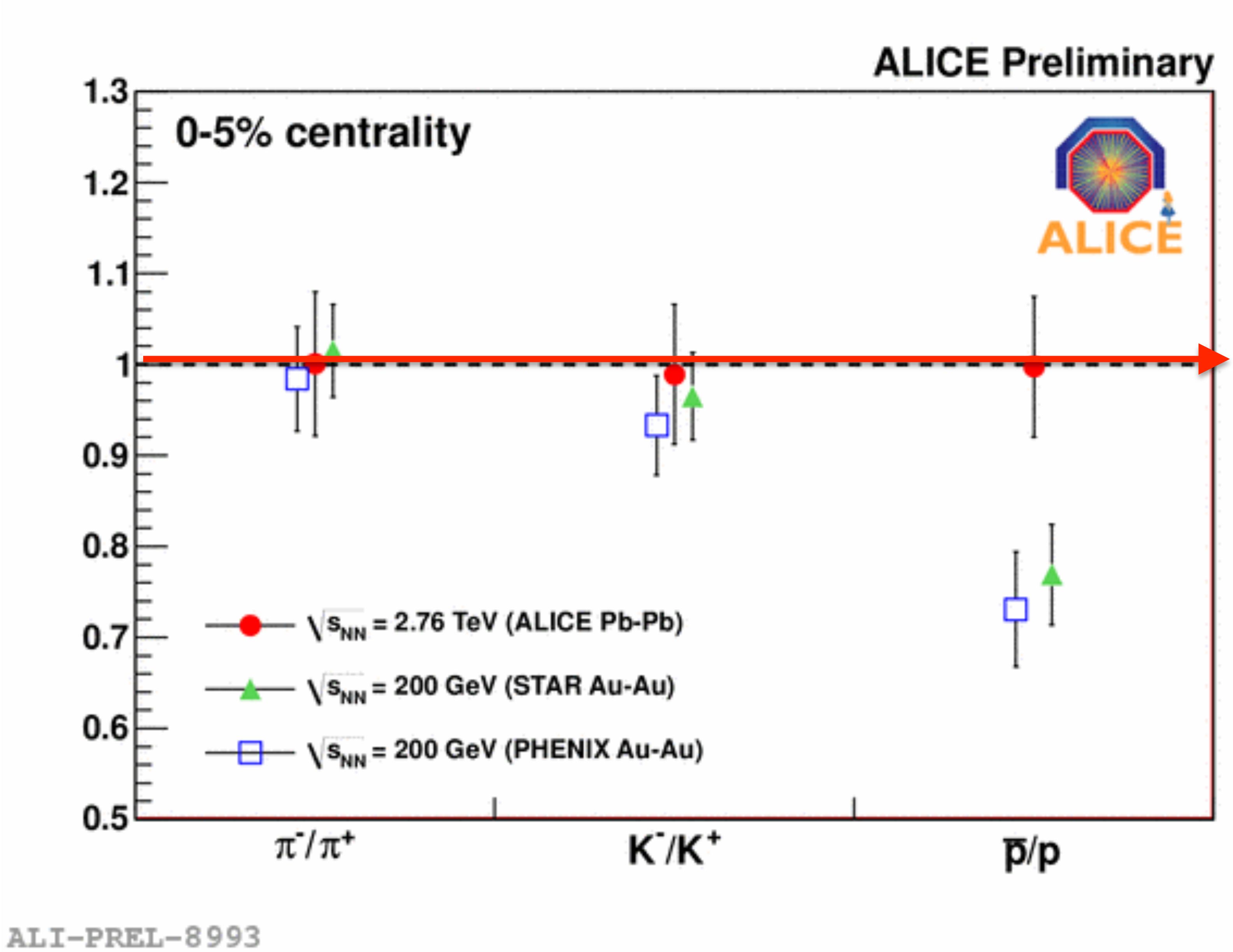
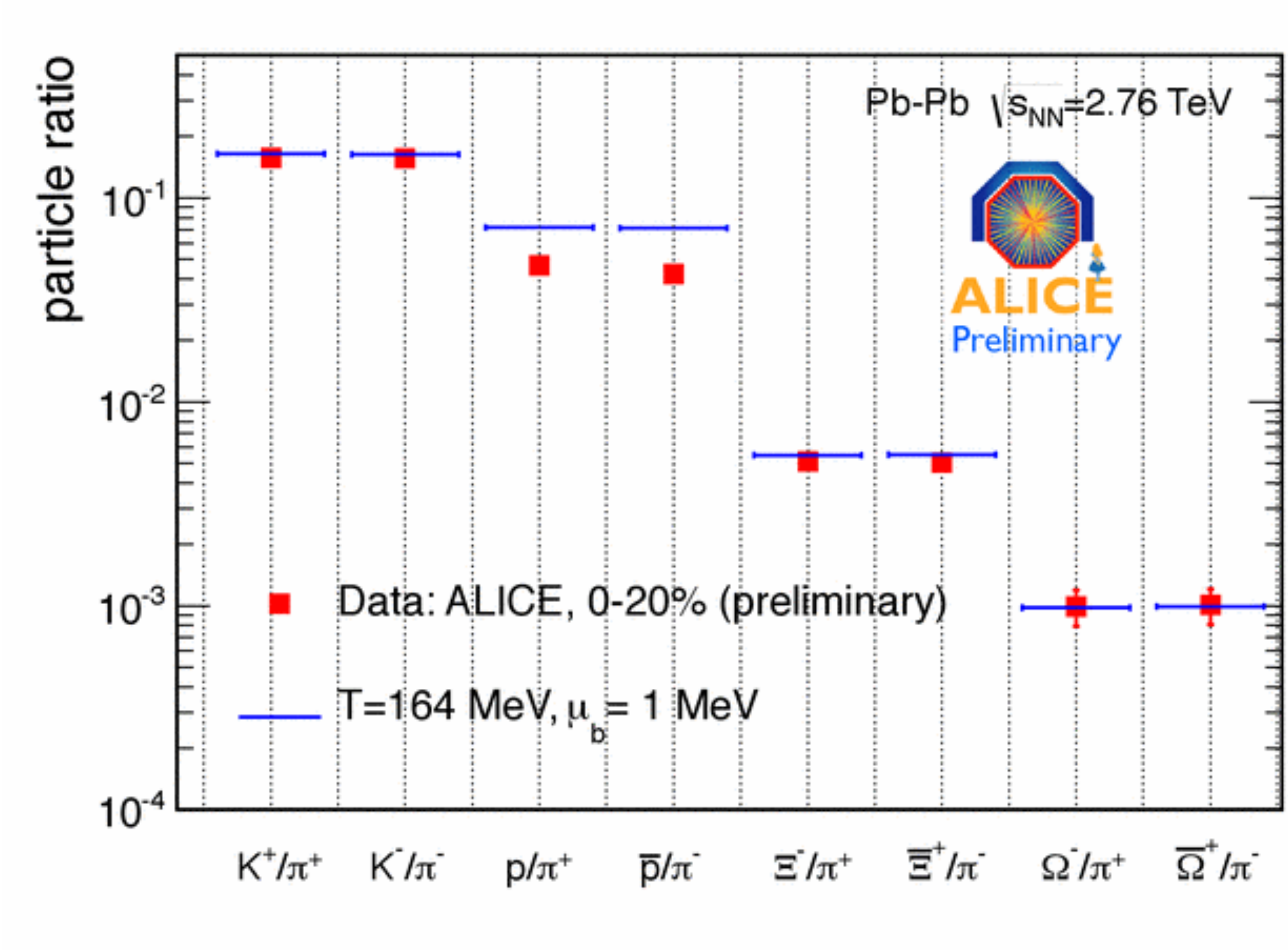
π^-/π^+, K^-/K^+, pbar/p ratios

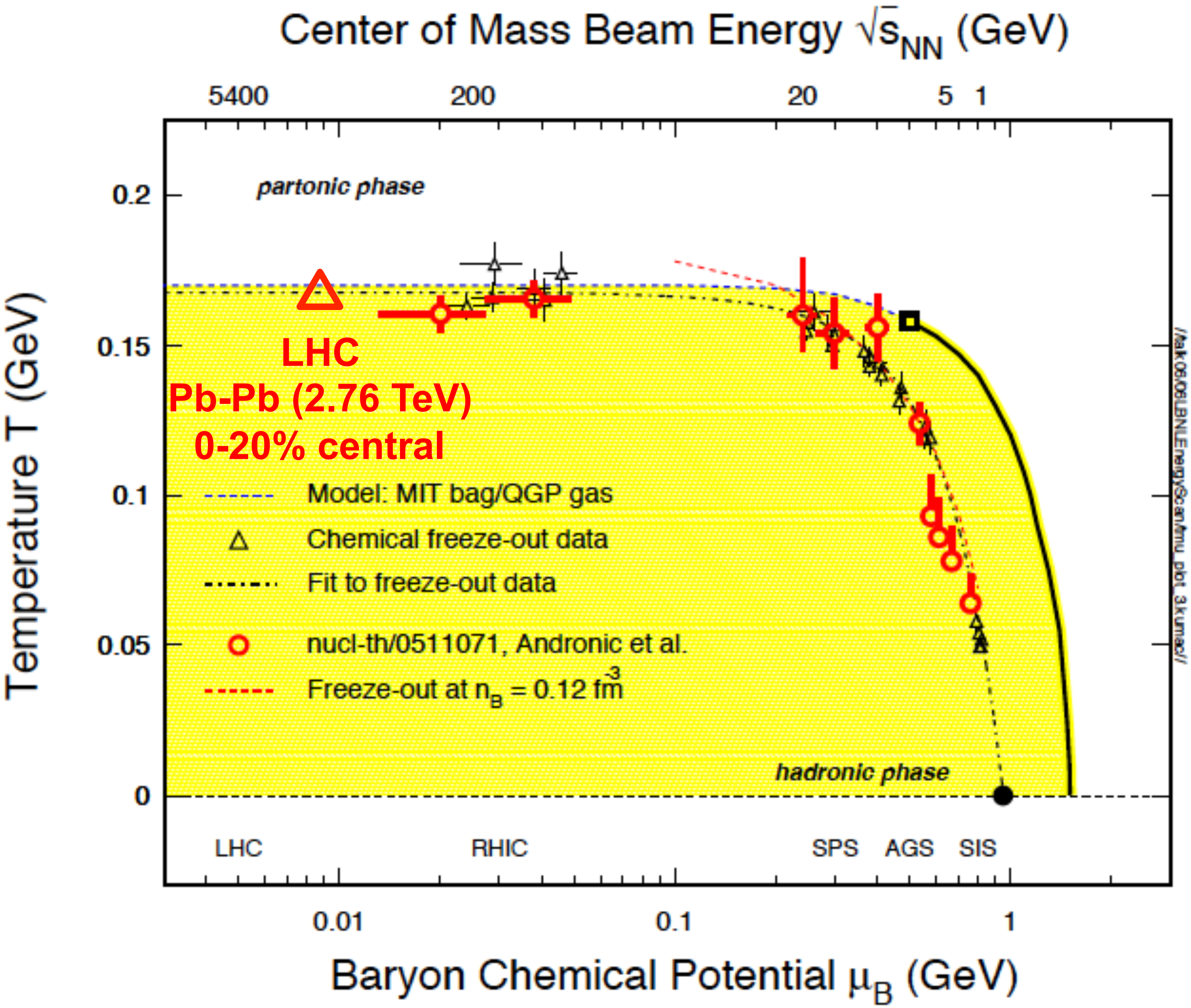


~1.0 for all ratios at LHC

Comparison with thermal model



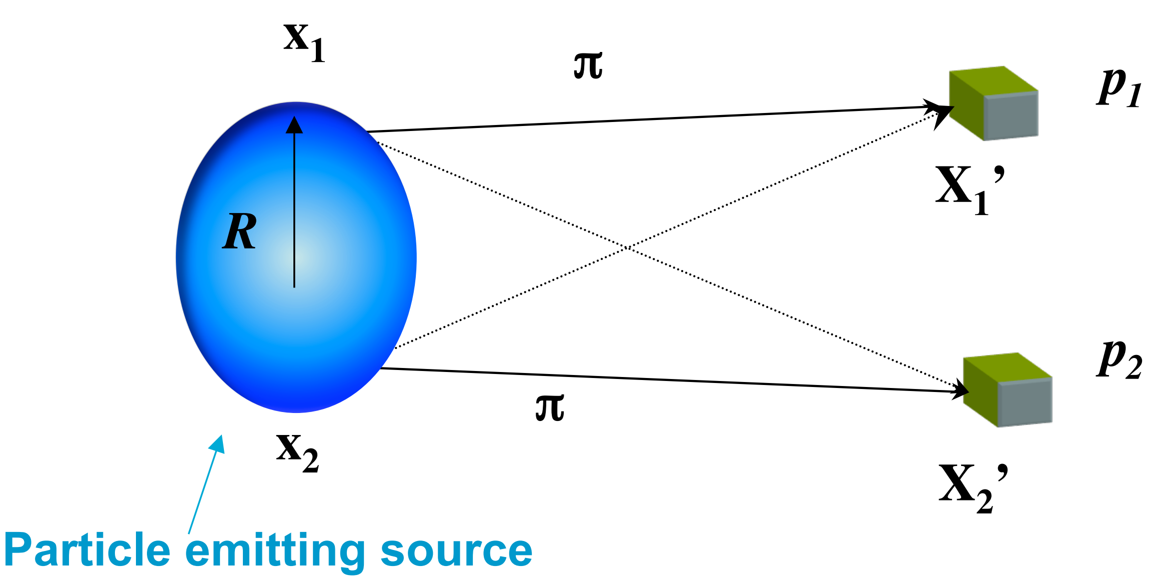
- All yields, except protons, follow thermal model prediction for grand-canonical ensemble and **T_{ch}=164 MeV, μ_B = 1 MeV**.
  - ⇨ Measured proton/pion ratio below thermal model expectation
  - ⇨ Strange particles perfectly agree with thermal model expectation



Braz. J. Phys. vol.37 no.2c São Paulo June 2007
http://dx.doi.org/10.1590/S0103-97332007000500024
N. Xu

- **Extraction of source size "R" using quantum interferometry, HBT.**

How much volume and life time?



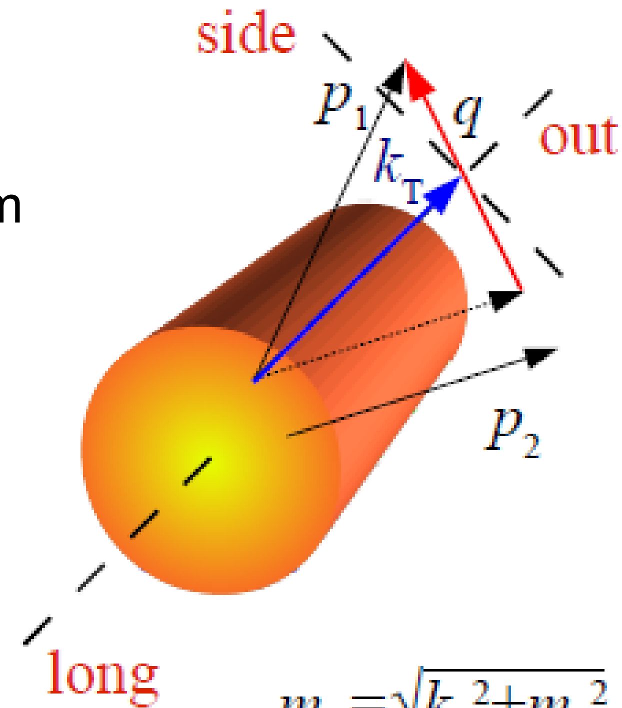
$$C_2 \equiv \frac{P(p_1, p_2)}{P(p_1)\cdot P(p_2)}$$

$$= 1 + \left|\tilde{\rho}_{eff}(\mathbf{q})\right|^2$$

$$= 1 + \lambda \exp(-R^2\mathbf{q}^2)$$

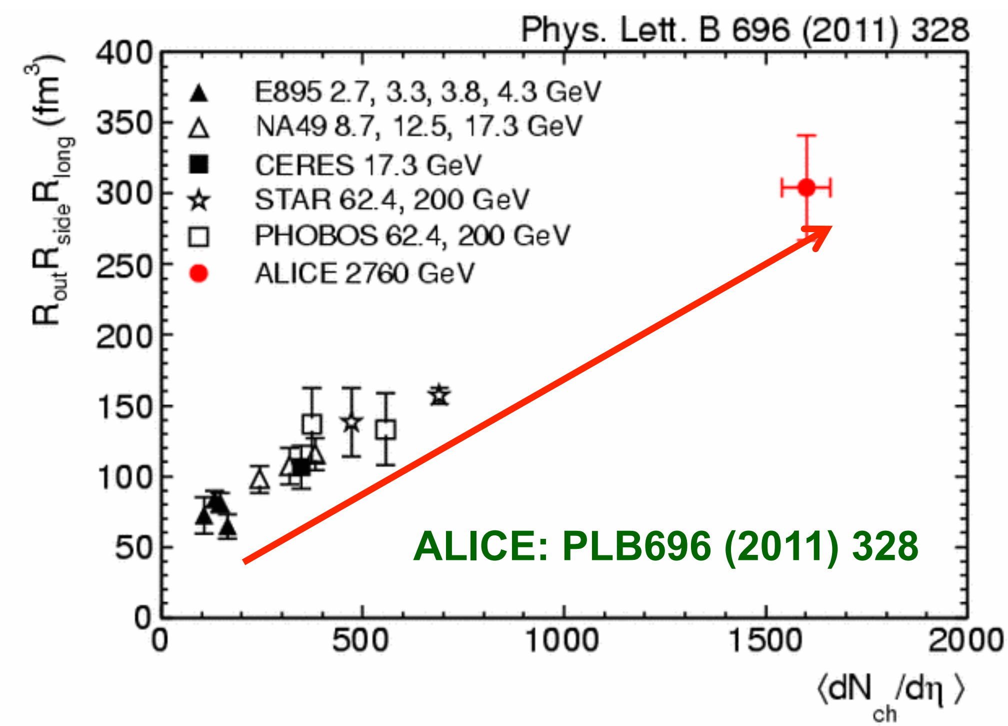
HBT correlations

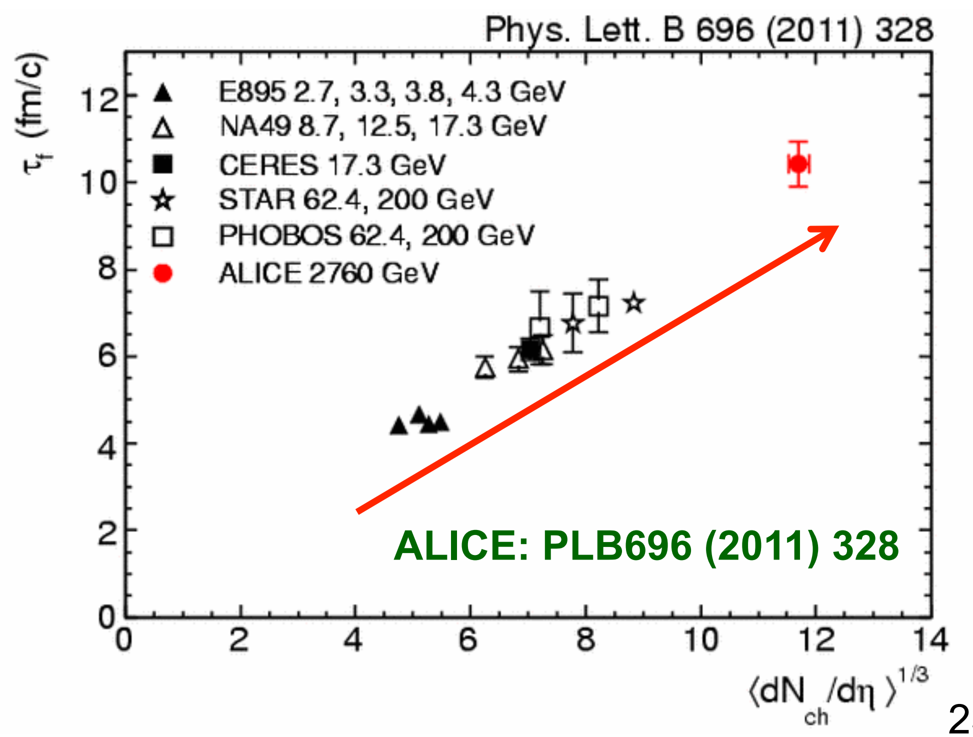
- Spatial extent of the particle emitting source extracted from interferometry of identical bosons
  - Two-particle momentum correlations in 3 orthogonal directions → HBT radii (R_{long}, R_{side}, R_{out})
  - **Volume: x2 compared to RHIC**
  - **Lifetime from R_{long}: 40% higher than that at RHIC**



$$R^2_{long}(k_T) = \frac{\tau_f^2 T}{m_T} \frac{K_2(m_T/T)}{K_1(m_T/T)},$$

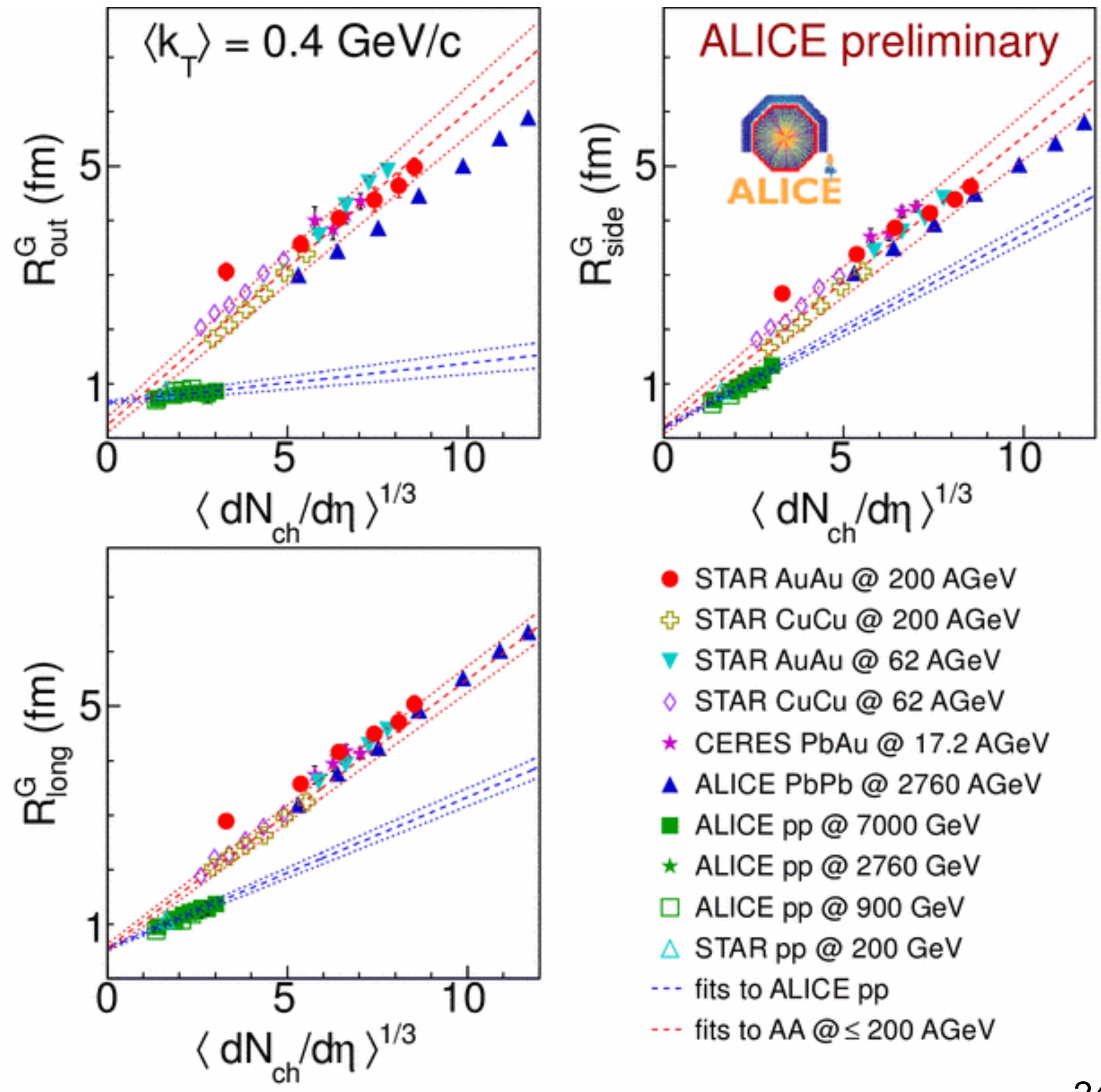
$$m_T = \sqrt{k_T^2 + m_\pi^2}$$



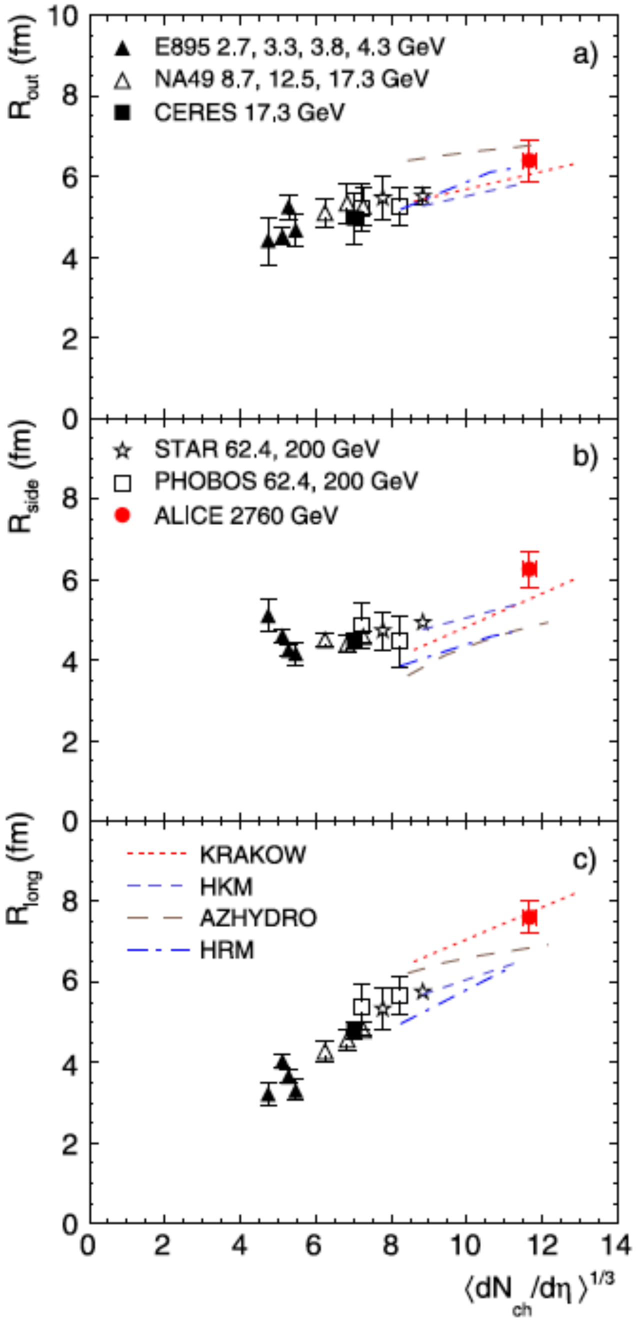


System size vs. multiplicity

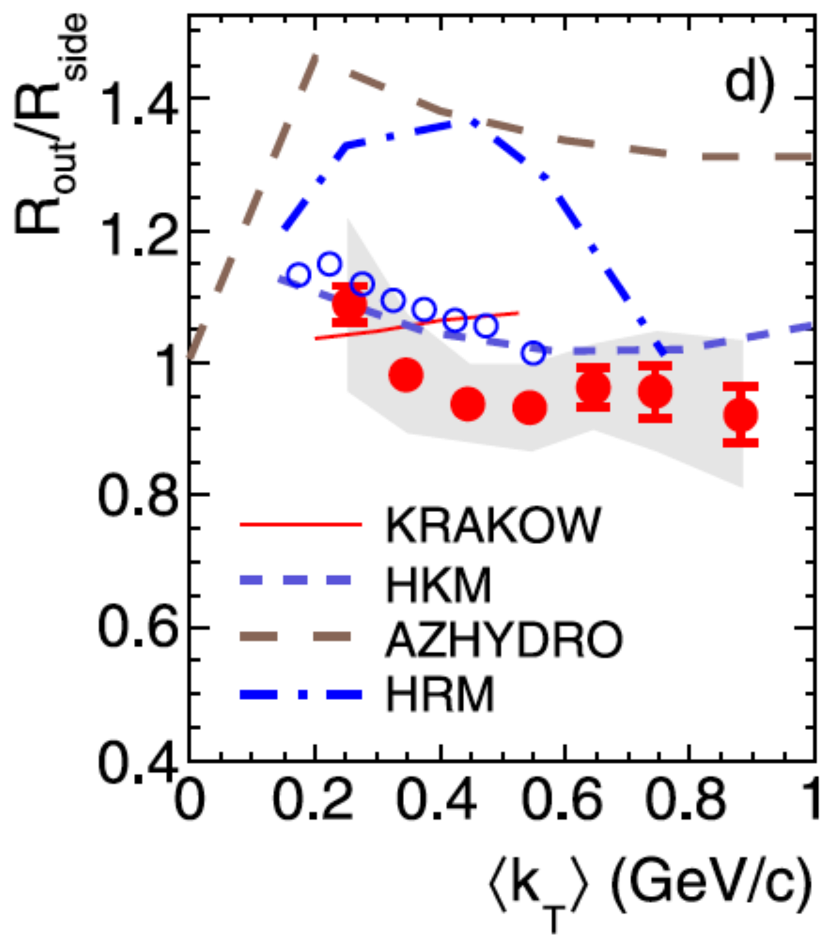
- HBT radii scale linearly with $<N>^{1/3}$ in pp and PbPb, but with different slopes.
- HBT radii in PbPb vs. trend from lower energy AA:
  - R_{long}: perfectly agree
  - R_{side}: reasonably agree
  - R_{out}: clearly below the trend



HBT vs. Hydro



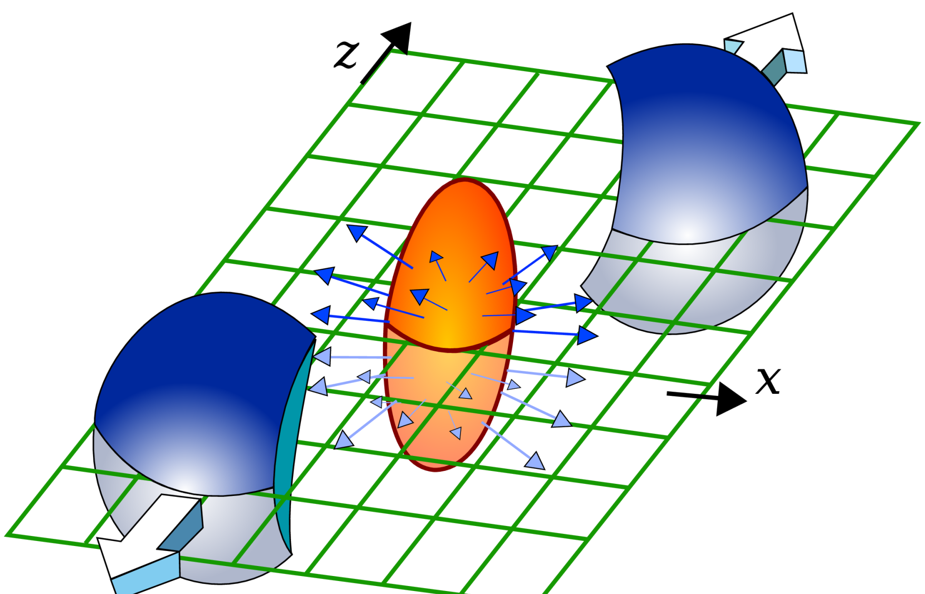
- Behaviour of all 3 radii in qualitative agreement with hydro expectations
- R_{out}/R_{side}: some model cannot describe the data.



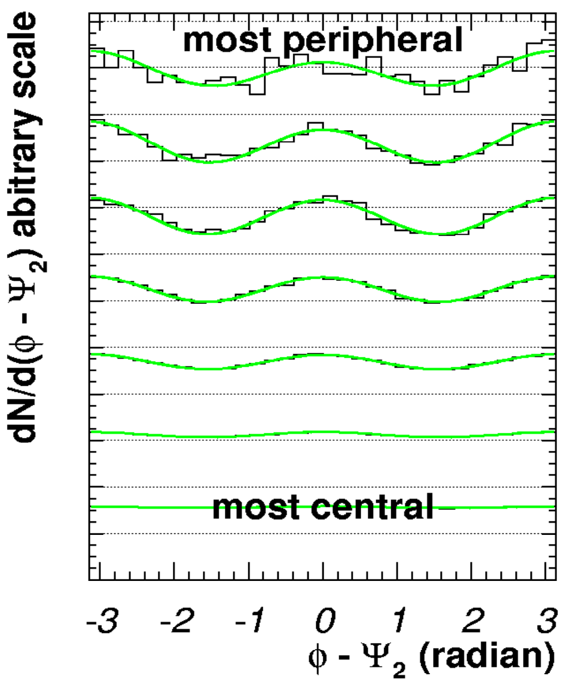
ALICE: PLB696 (2011) 328

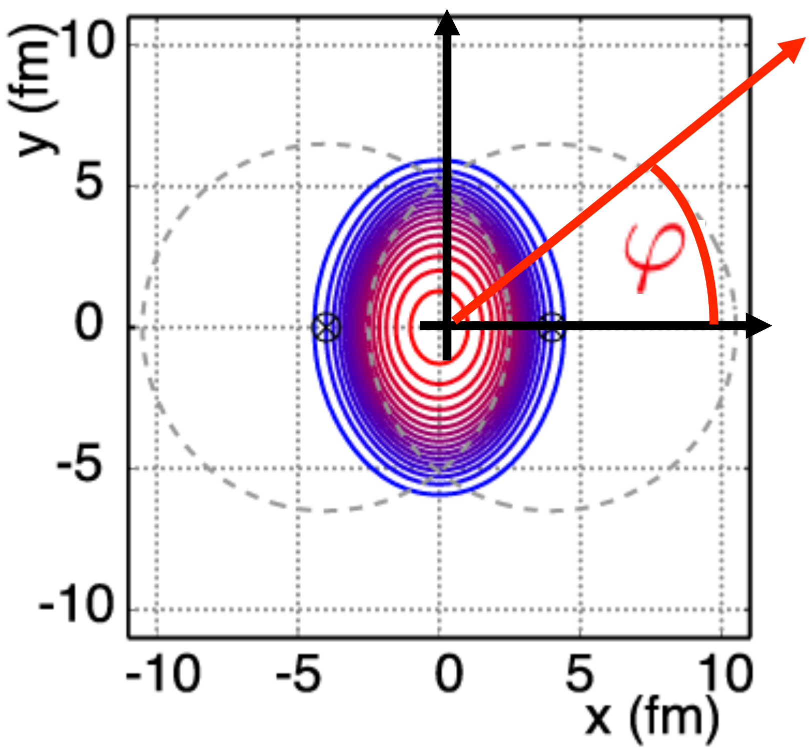
- **Anisotropic flow;**

sensitive to the early time of collisions, pressure gradients, and EOS.



Elliptic flow; v_2

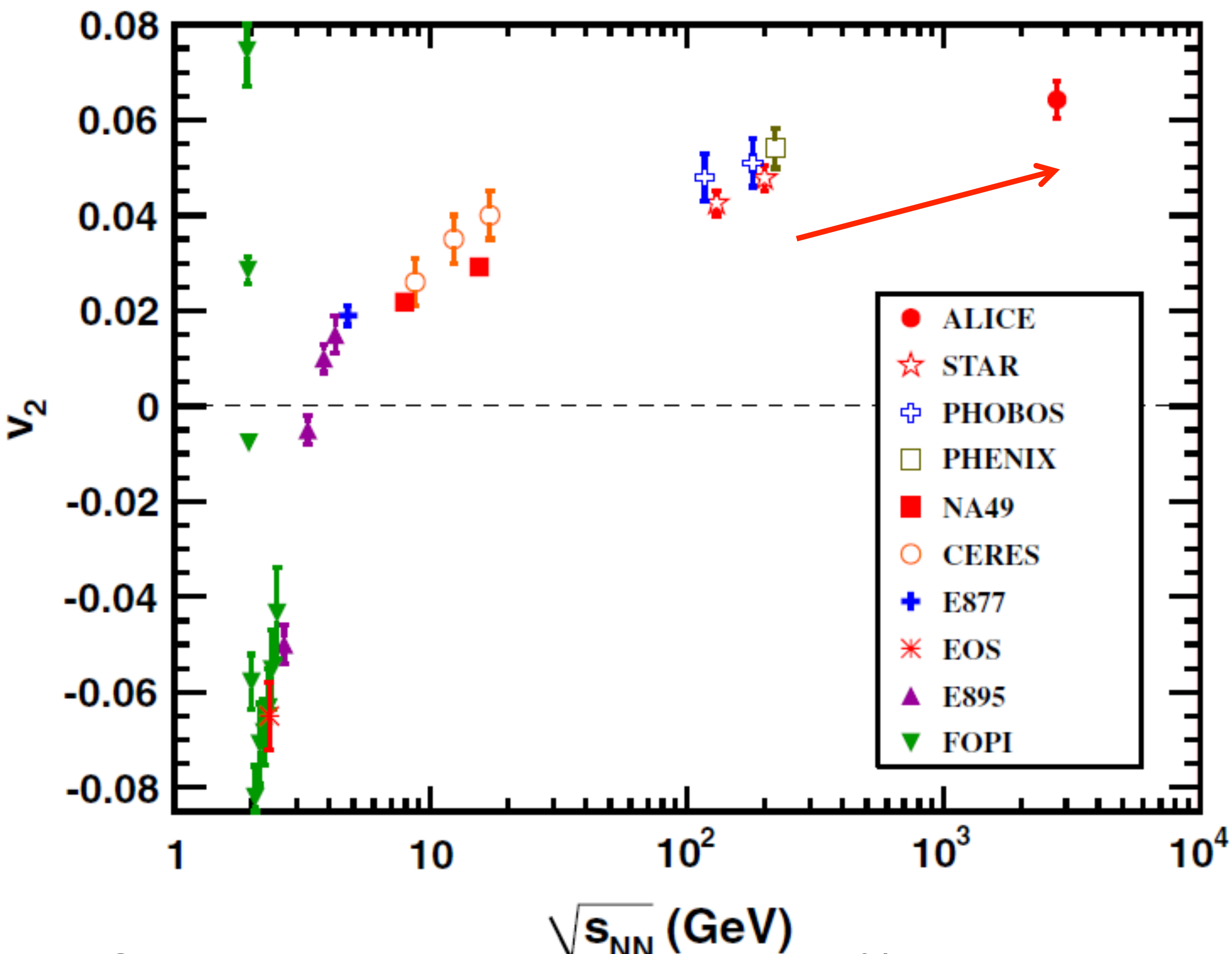




$$\frac{dN}{p_T dp_T dy d\varphi}(p_T, \varphi; b) = \frac{dN}{2\pi p_T dp_T dy}\left(1 + 2\underline{v_2}(p_T; b)\cos(2\varphi) + \ldots\right)$$

v_2 vs. $\sqrt{s_{NN}}$

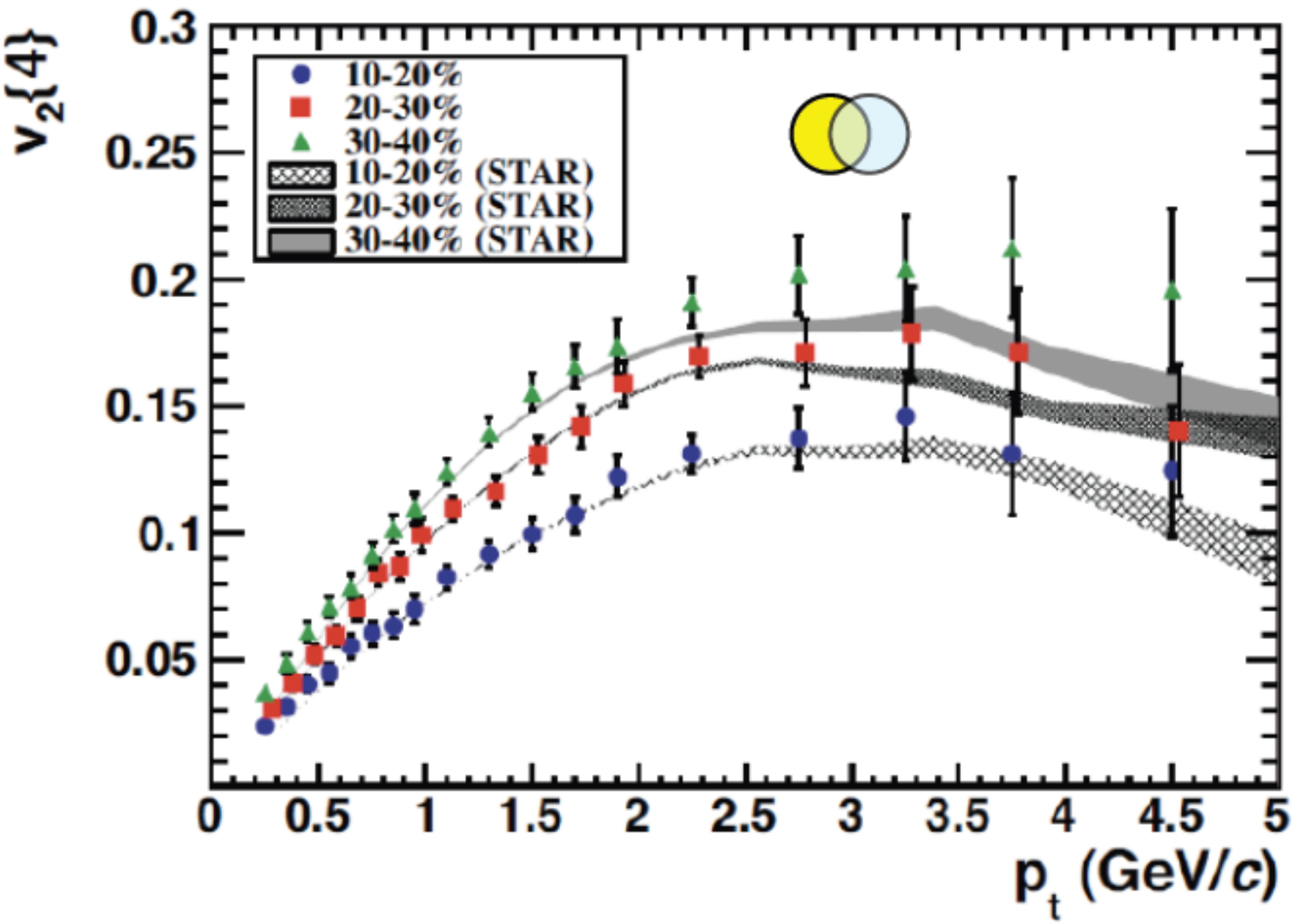
PRL 105 (2010) 252302



- At LHC, p_T integrated v_2 increases by 30% compared to RHIC data at $\sqrt{s_{NN}}$=200 GeV.

p_T dependence of v_2 RHIC vs. LHC

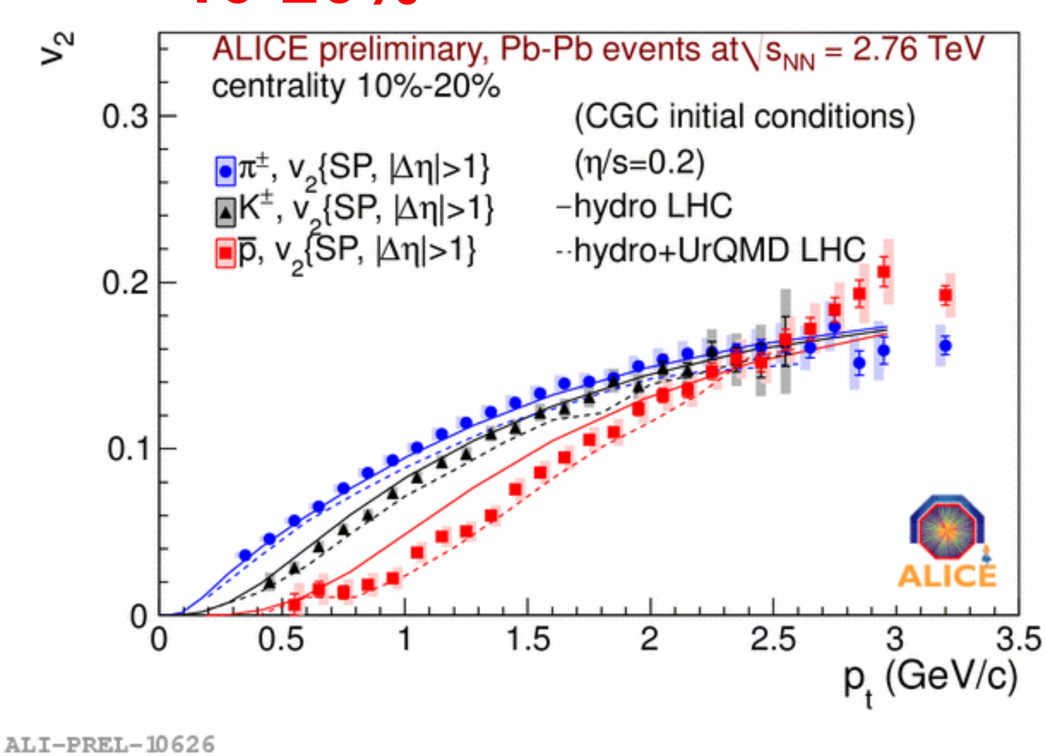
- v_2 vs. p_T does not change within uncertainties between $\sqrt{s_{NN}}$=200 GeV and 2.76 TeV
  - 30% increase of p_T integrated flow explained by higher mean p_T due to stronger radial flow at higher energies



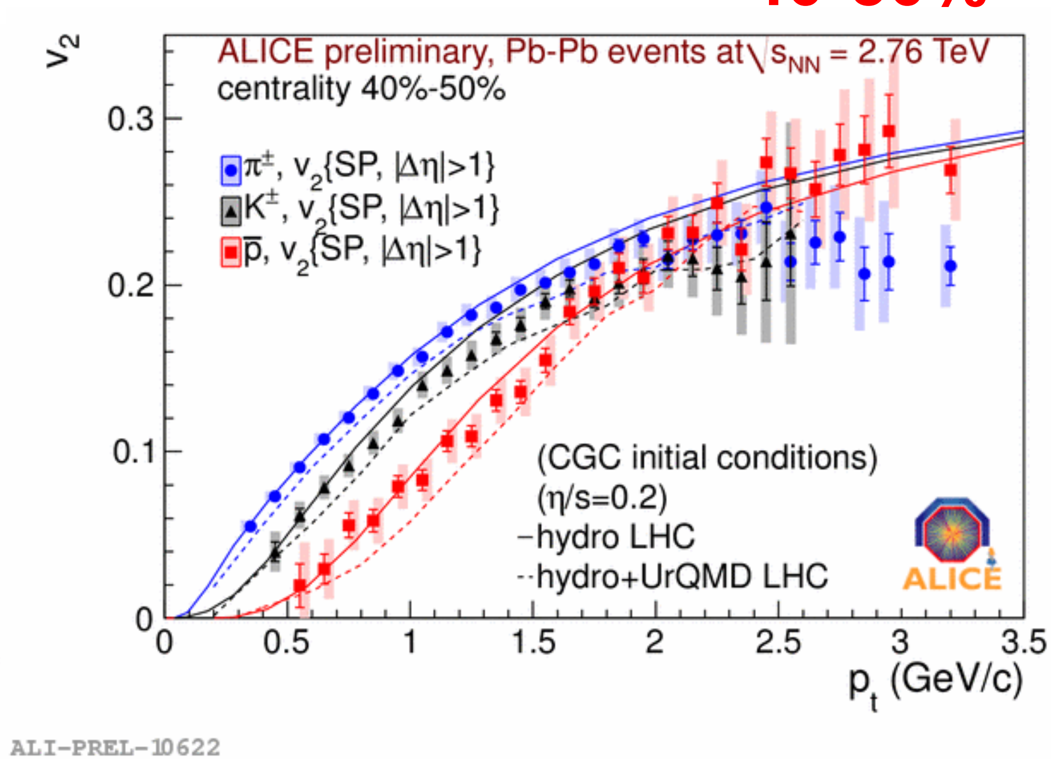
PRL 105 (2010) 252302

Identified particle v_2

10-20%



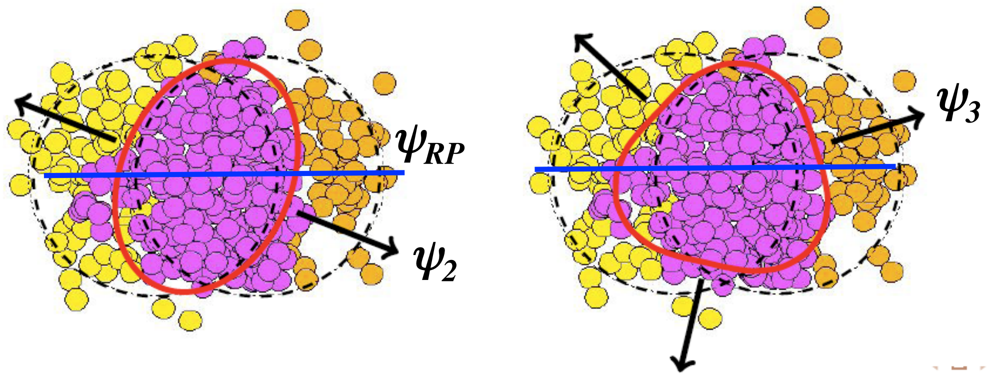
40-50%

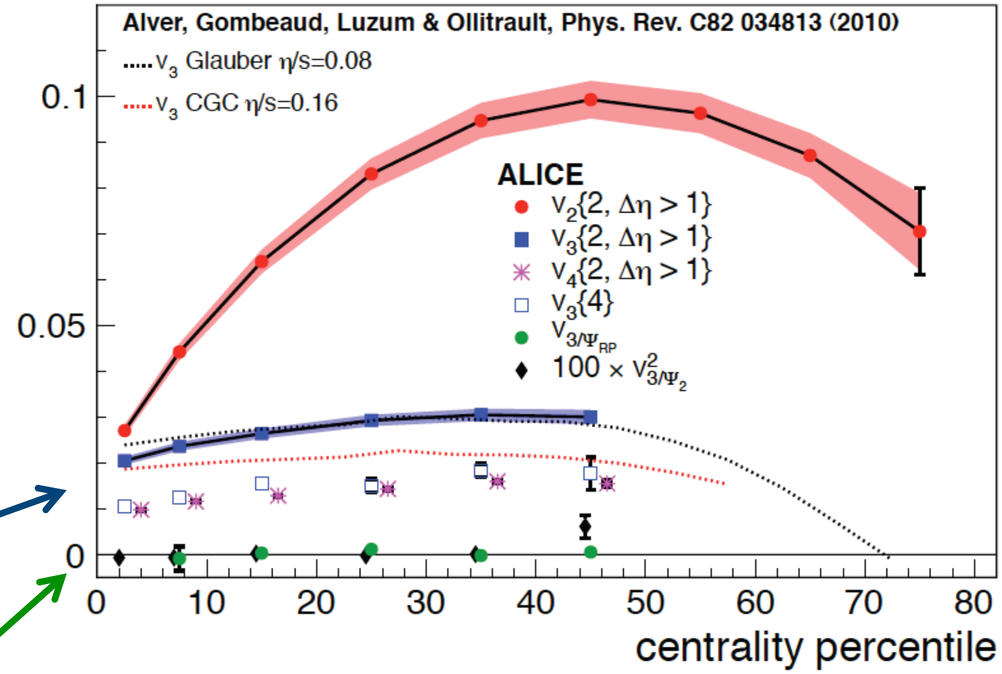


- **Stronger radial flow** → more pronounced mass dependence of v_2
  - ⇨ Hydrodynamics predictions describe well the measured $v_2(p_T)$ for π and K.
  - ⇨ **Disagreement for anti-protons in the more central bin**
    - ✓ Larger radial flow than in the Hydro model
    - ✓ Rescatterings in the hadronic phase play an important role (arXiv:1108.5323)

Higher order harmonics; v_n

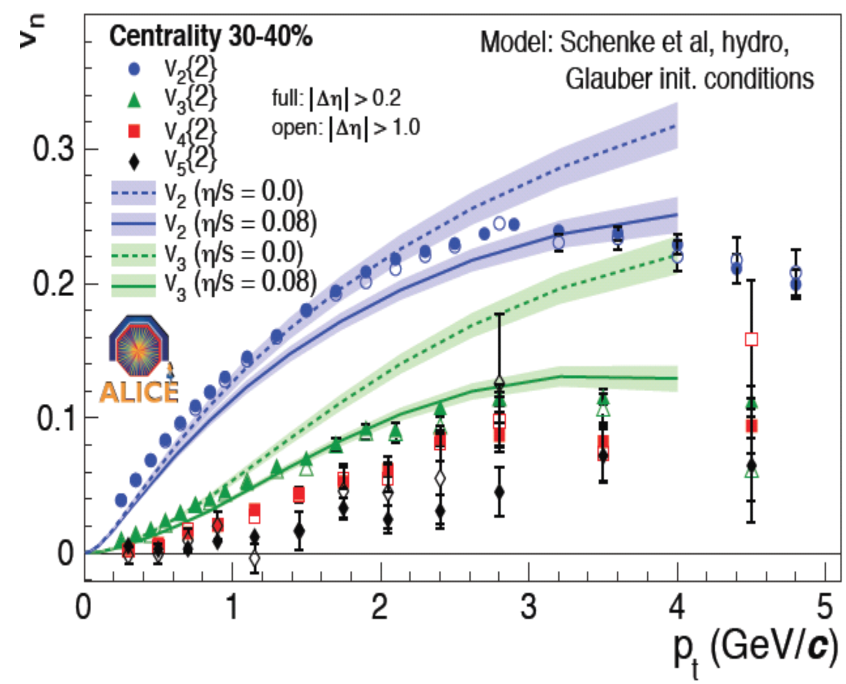
arXiv:1105.3865



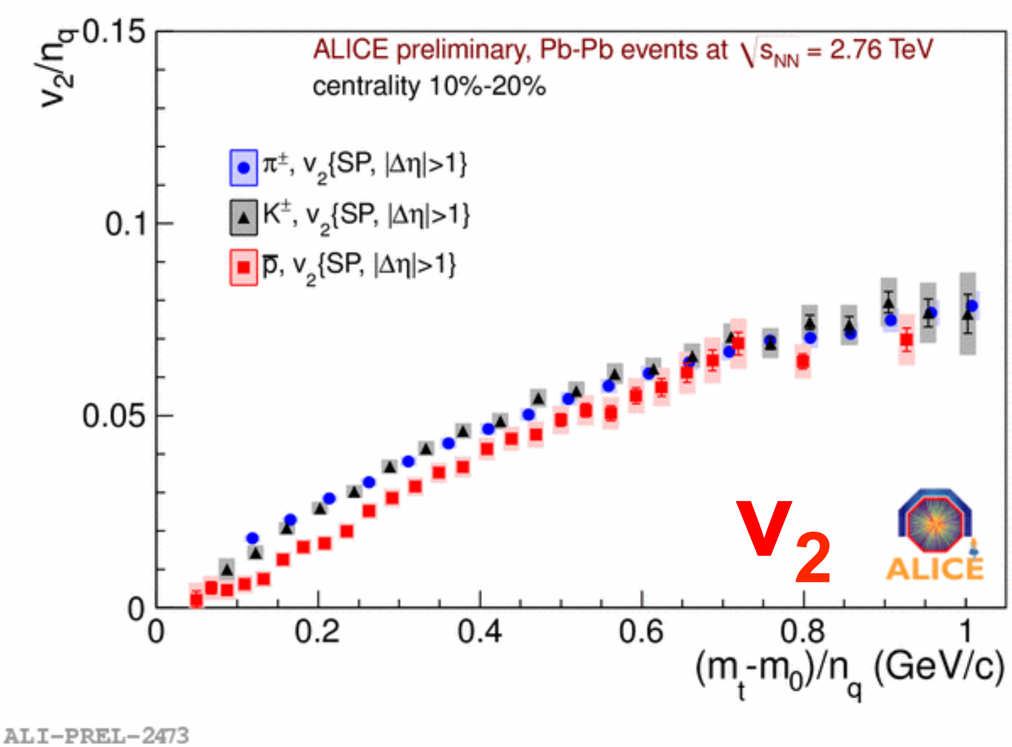


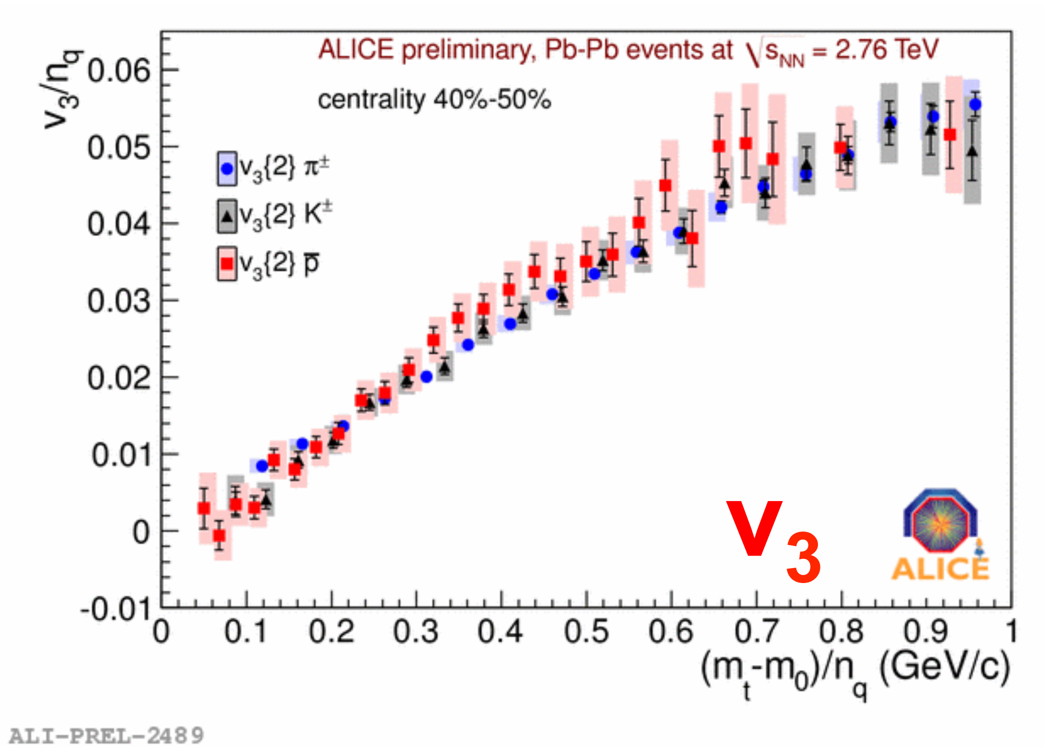
- v_3 ("triangular") harmonic:
  - v_3 has weaker centrality dependence than v_2
  - When calculated w.r.t. participant plane, v_3 vanishes due to fluctuations.

- p_T dependence for v_2, v_3, v_4, v_5
  - v_3 sensitive to shear viscosity η/s and to initial conditions (Glauber, CGC)



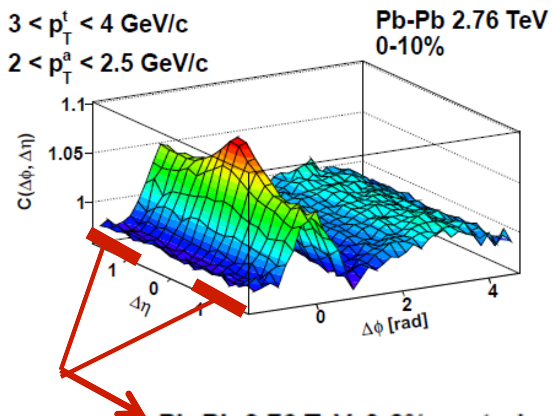
Quark number scaling for v_2 and v_3





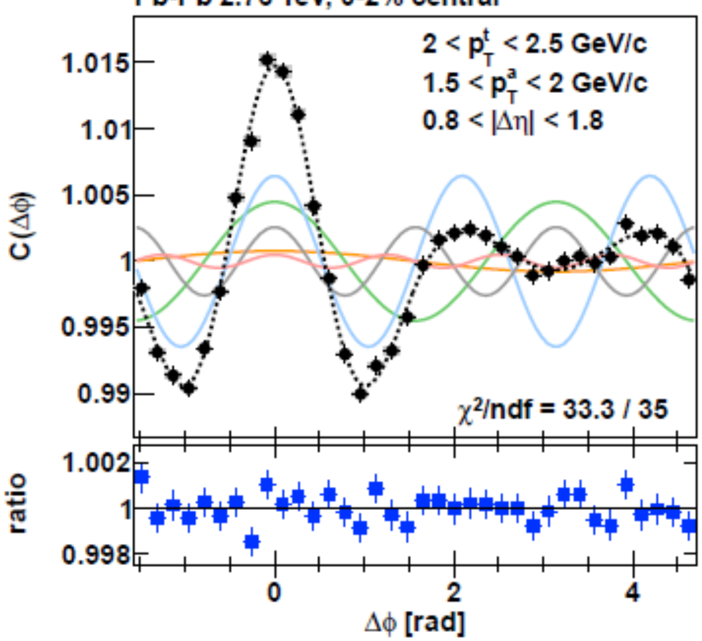
- v_2 scaling with number of constituent quarks.
  - Holds for π and K.
  - Again, anti-protons do not follow the scaling.
    - Breakup more pronounced for more central collisions

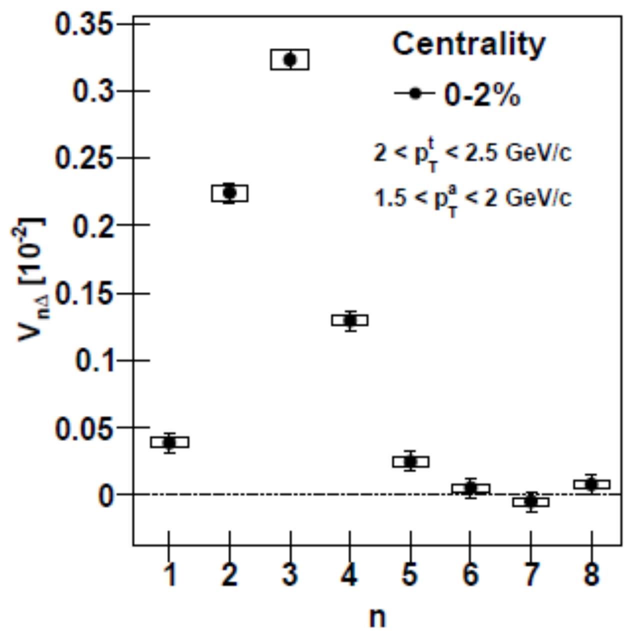
Fourier decomposition in di-hadron corr.

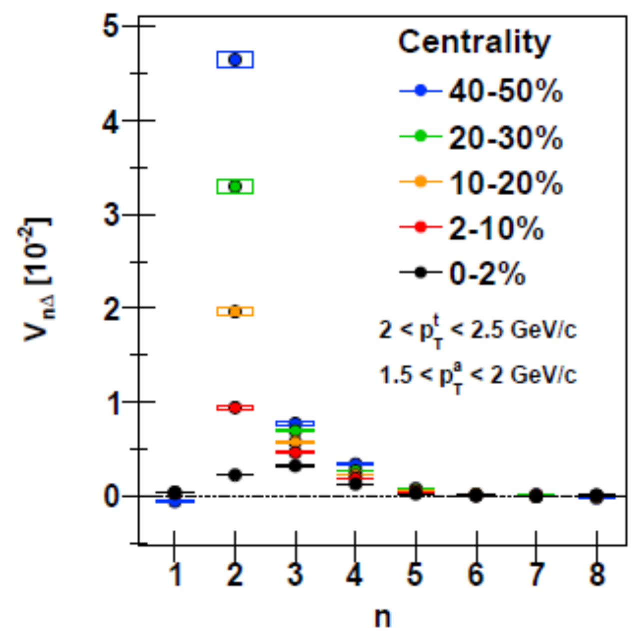


- Extract 1D $\Delta\varphi$ correlations by integrating the $C(\Delta\eta,\Delta\varphi)$ in $0.8<|\Delta\eta|<1.8$ range and do a Fourier decomposition

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







- 5 components describe completely the correlations at large $\Delta\eta$ and low p_T
  - ➩ Strong near-side ridge + double-peaked structure on away side

arXiv:1109.2501

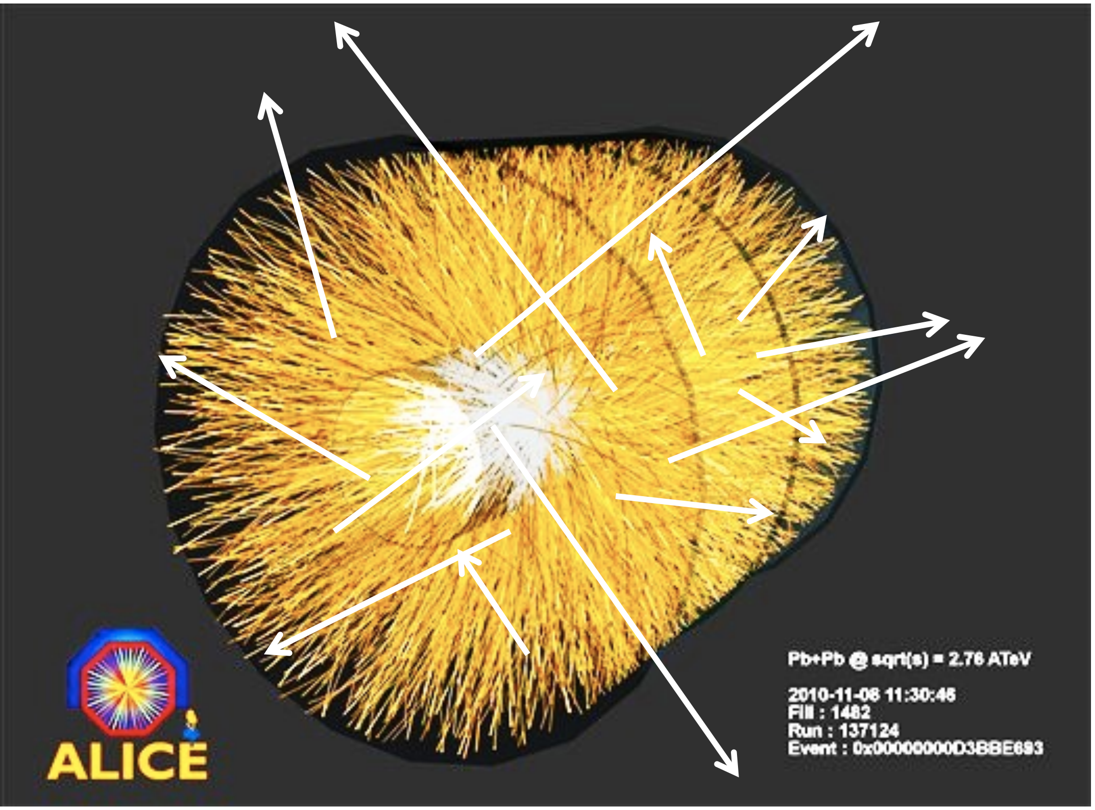
Summary

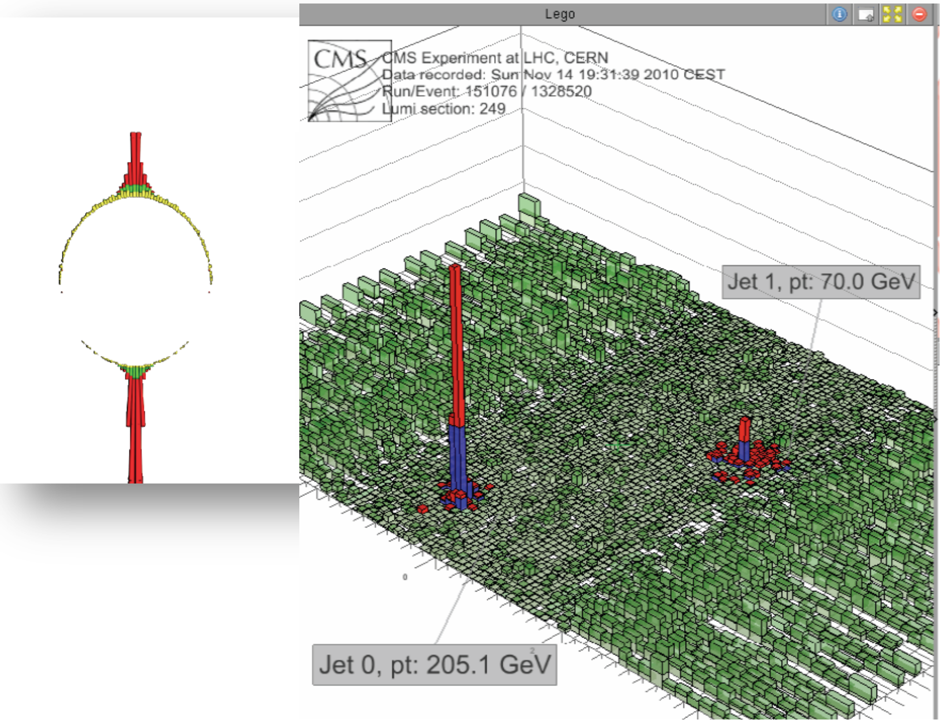
- ✓ **First data in Pb+Pb collisions at 2.76 TeV by ALICE provides an important baseline on global properties.**
  - Smooth transition from RHIC to LHC.
    - Hotter, Larger, Longer, less μ_B, similar v_2…
  - Many global observables are affected by the strong radial flow at LHC energies.

- ✓ **Enter the new era to study hot and dense matter at LHC energy, i.e. era of precision measurements by many hard probes.**

For example…

Bulk particle production with jets





Lost energy is used for the low p_T bulk particle production at large angle (by CMS).

Q: reheating the matter?

Need to explore bulk properties with jets (No. of jets, jet axis)

Also jet quenching in high multiplicity events in p+p.

Thank you for your attention.

BACKUP

- I would like to thank Francesco Prino (ALICE) for his nice set of slides at SQM 2011.