ALICE
(A Large Ion Collider Experiment)
results at the LHC

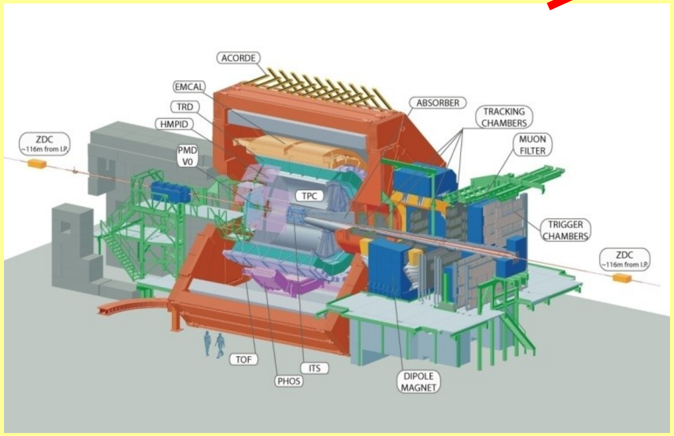
B.V.Batyunya (JINR, VBLHEP)

Seminar, BLTP

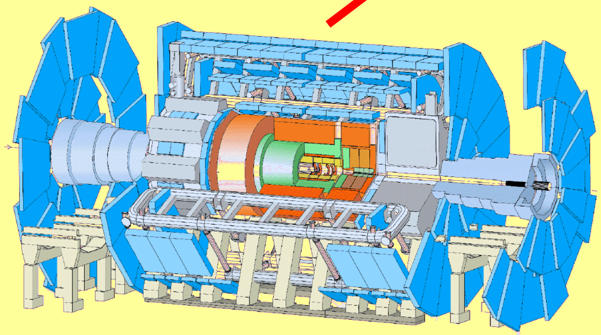
Dubna, 19.02.2014

p+p @ 14 TeV (8 TeV now)
Pb+Pb @ 5.5 A TeV (2.76 A TeV)

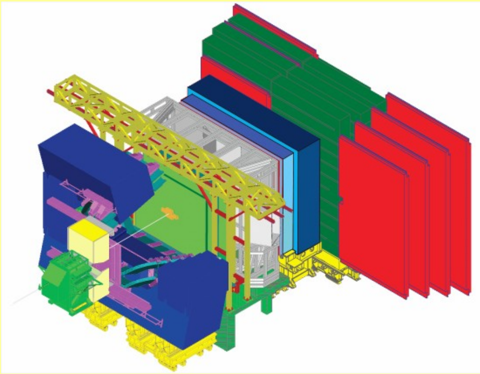
CMS



ALICE

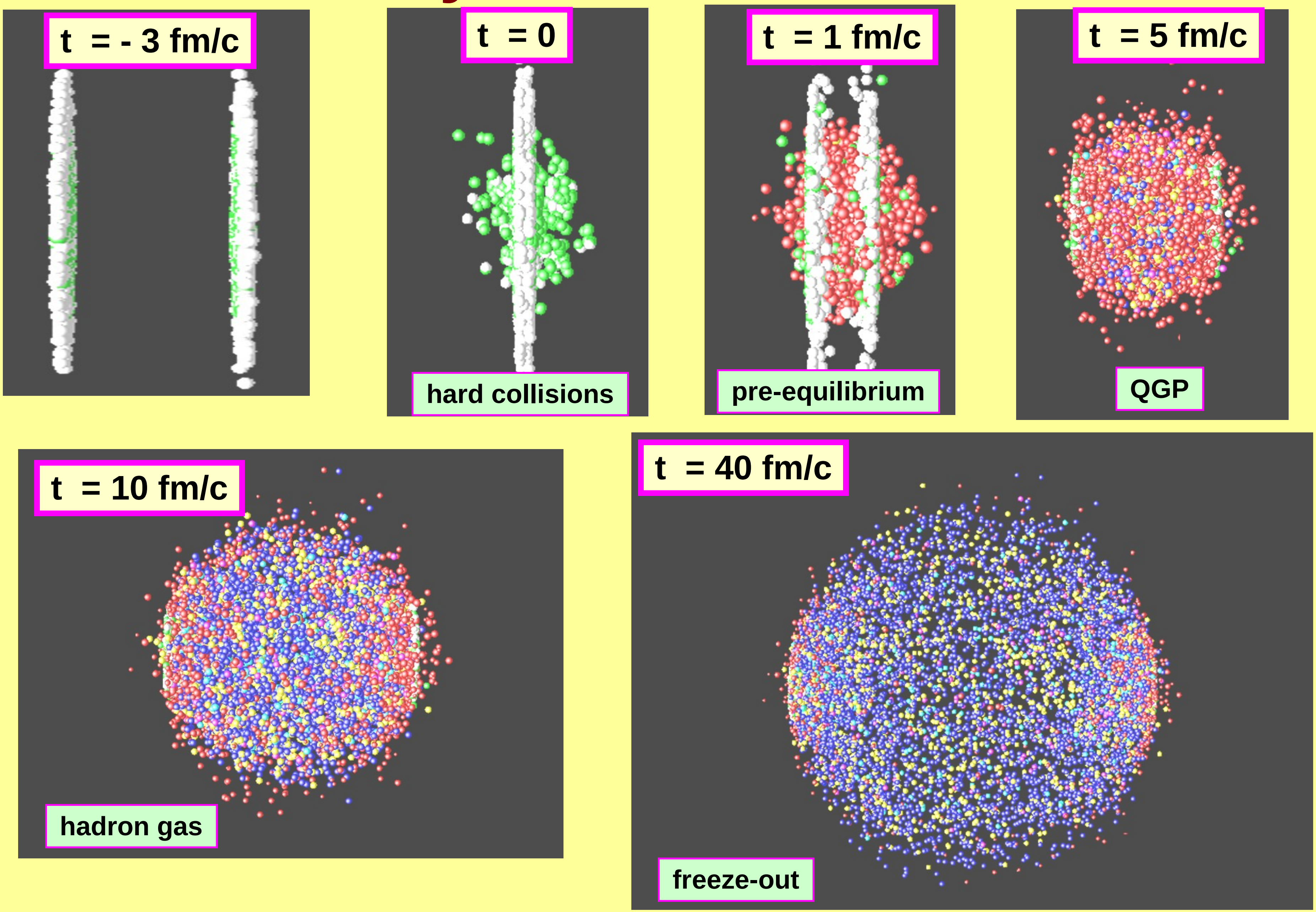


ATLAS



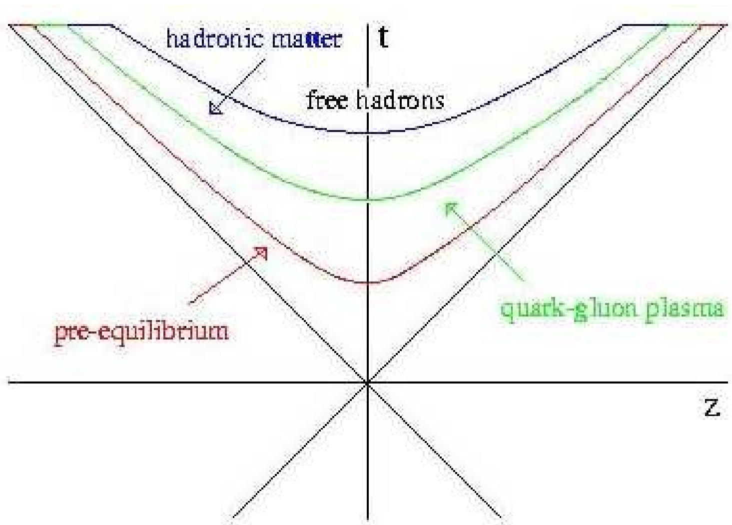
LHCb

Heavy Ion Collision



Parton percolation model.

H. Satz, arXiv:0212046, 2002;
S.Digal et al., arXiv:0207264, 2002.



Full QGP stage is reached if temperature and density is enough, otherwise in the pre-equilibrium stage the local clusters only with QGP inside are created by the percolation mechanism, i.e. the mixed phase (*of* partons and hadrons) eppears .

The expected evolution of nuclear collision.

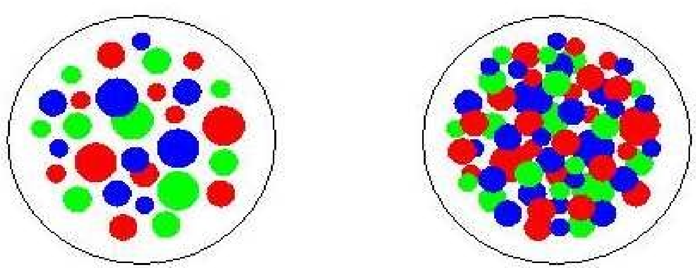
The Lorentz-contraction makes the nuclei as two thin discs during 0.1 fm at RHIC. Parton density increases with overlapping of partons and creation of percolation clusters - *the condensate of deconfined partons*. The percolation condition is

$np = N\pi r^2 / \pi R^2 \cong 1.128$ where

N is number of partons with size r

(r is found from the uncertainty relation $\pi r^2 \cong \pi/\langle k^2T\rangle$, kT - partron momentum),

R is nuclear radius (R » r)

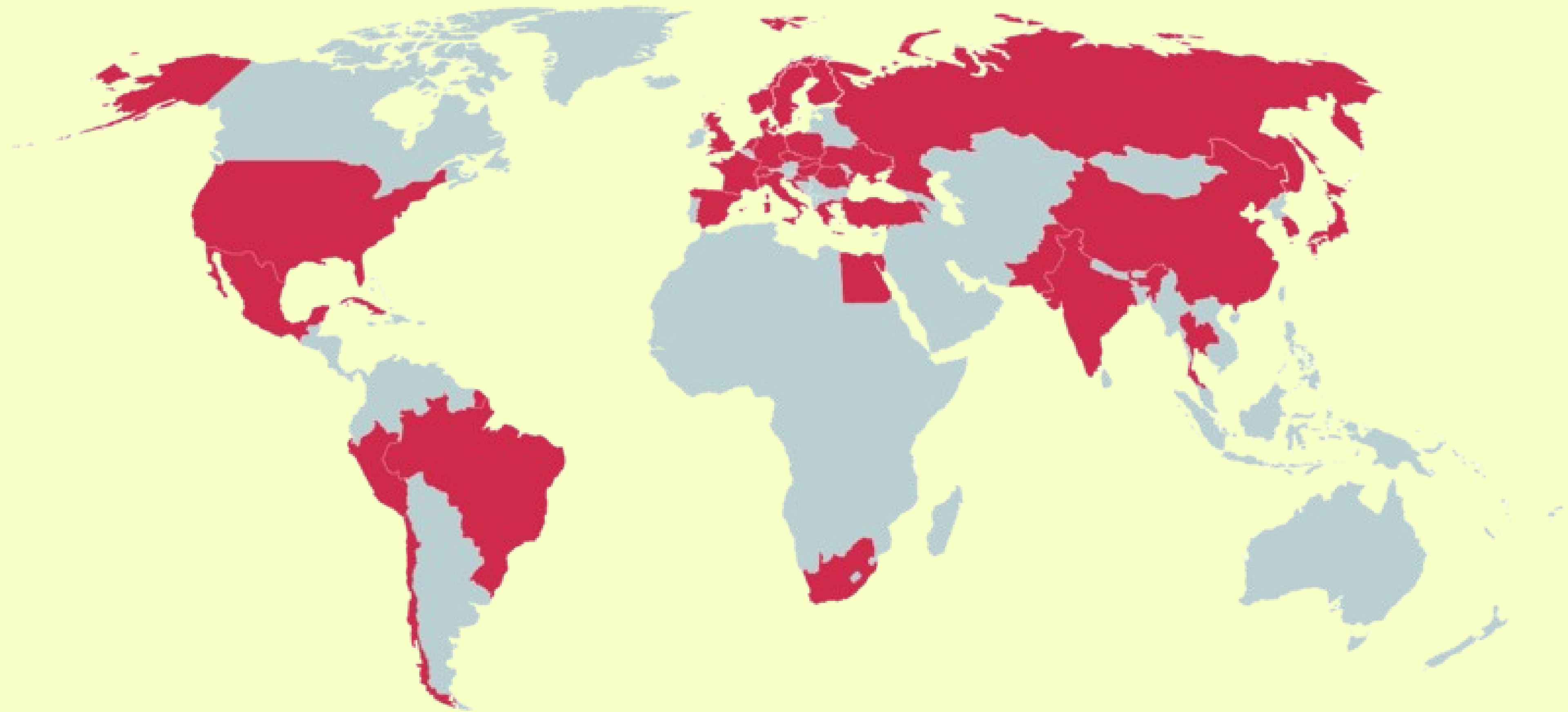


Partonic cluster structure in the transverse collision plane.

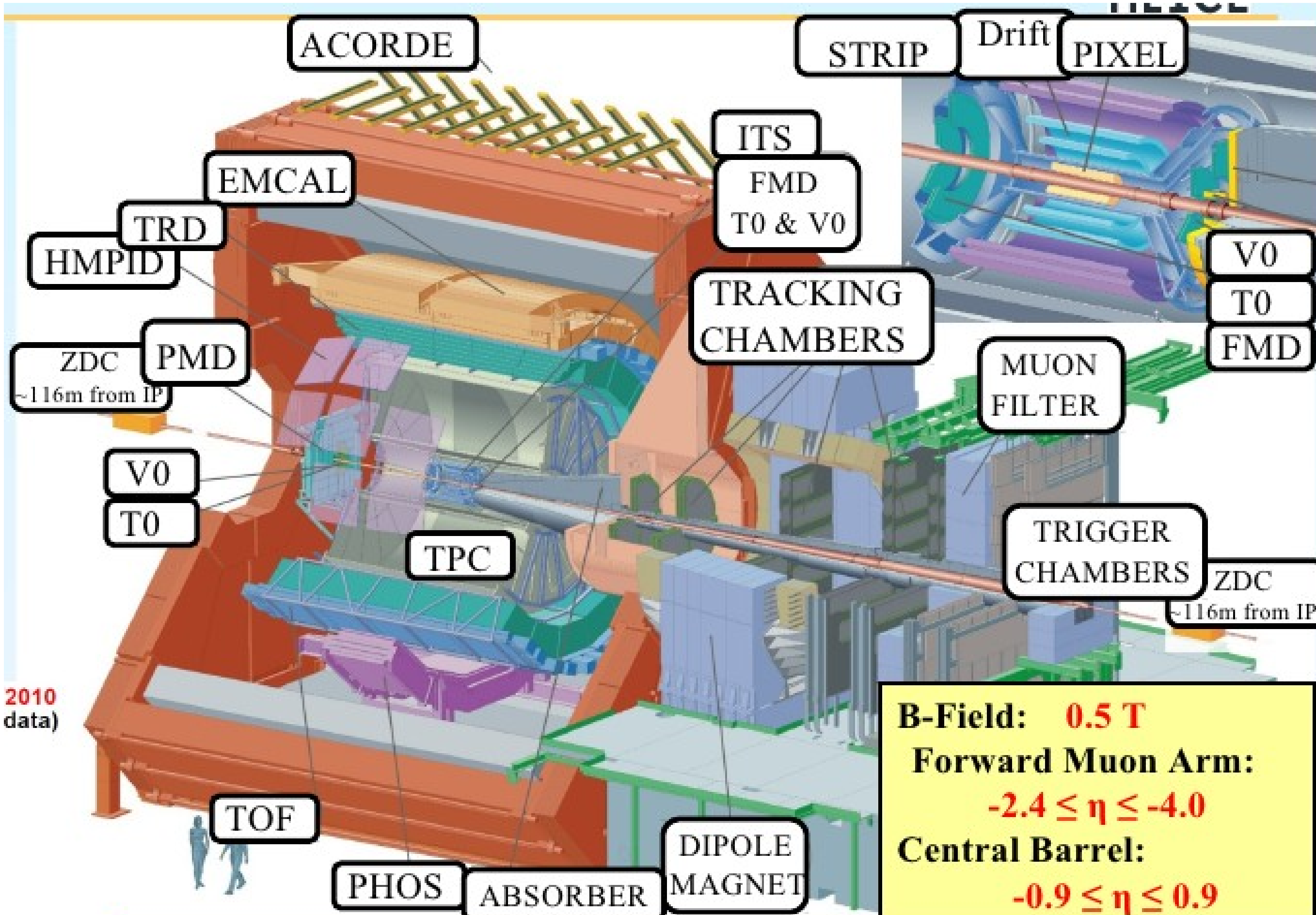
A Large Ion Collider Experiment

European Organisation for Nuclear Research

ALICE Collaboration



> 1000 Members, > 100 Institutes, > 30 Countries



→ Transverse impact parameter resolution < 75(20) μm for p_T > 1(20) GeV/c

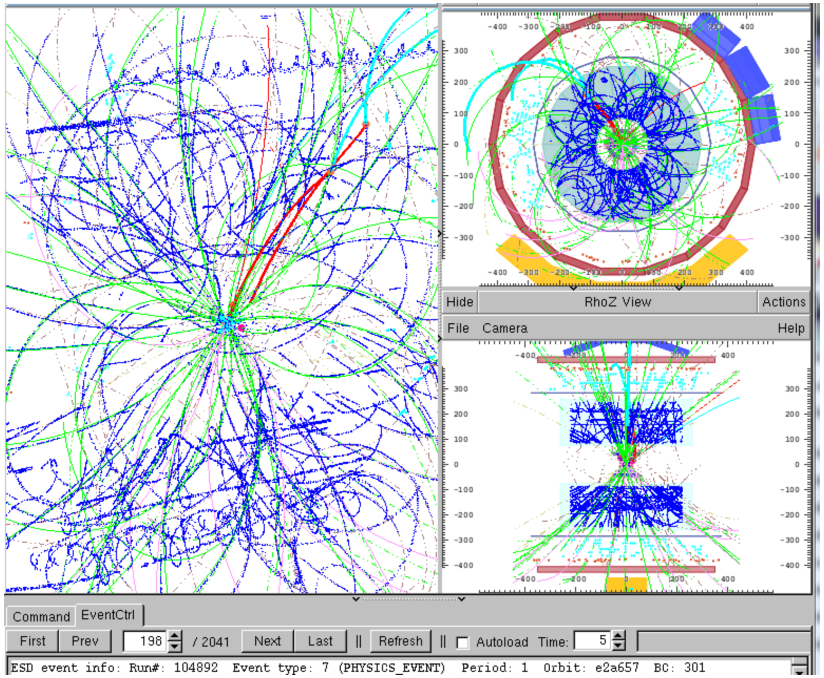
→ Momentum resolution <2% for p < 20 GeV/c

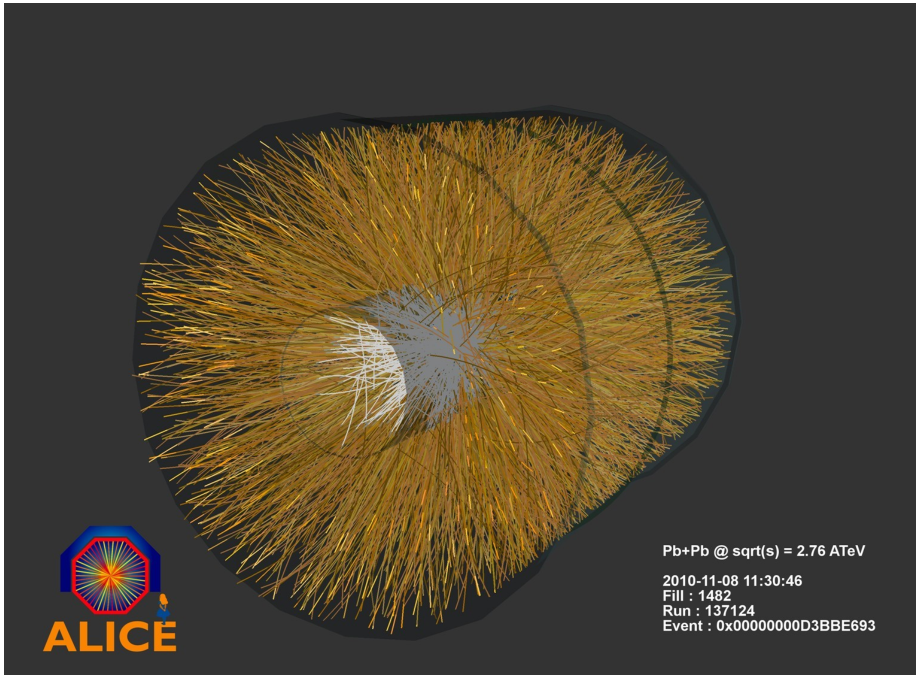
→ Particle identification with various systems

Length: 26 m, Height: 16 m, Weight: 10,000 tons

Display of high multiplicity events

in p-p at 7 TeV | in PbPb at 2.76 ATeV



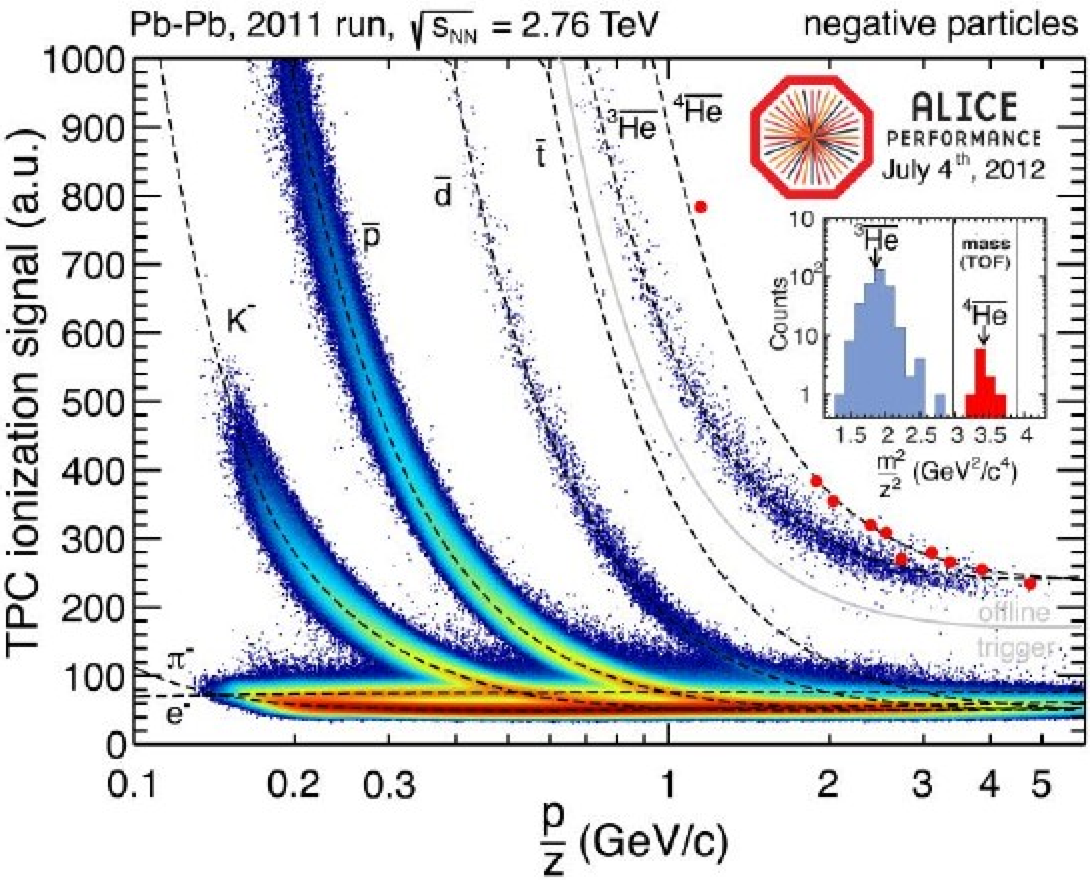


ALICE Physics Teams

- . Event characterization (multiplicity, centrality)
  - Particle species and spectra
  - Correlations
  - Resonance production
  - Jet physics
  - Photons
  - Dileptons
  - Heavy-quark and quarkonium production

- Physics of ultra-peripheral heavy ion collisions
- Contribution of ALICE to cosmic-ray physics

Observation of the anti nucleus using the TPC particle identification capability.

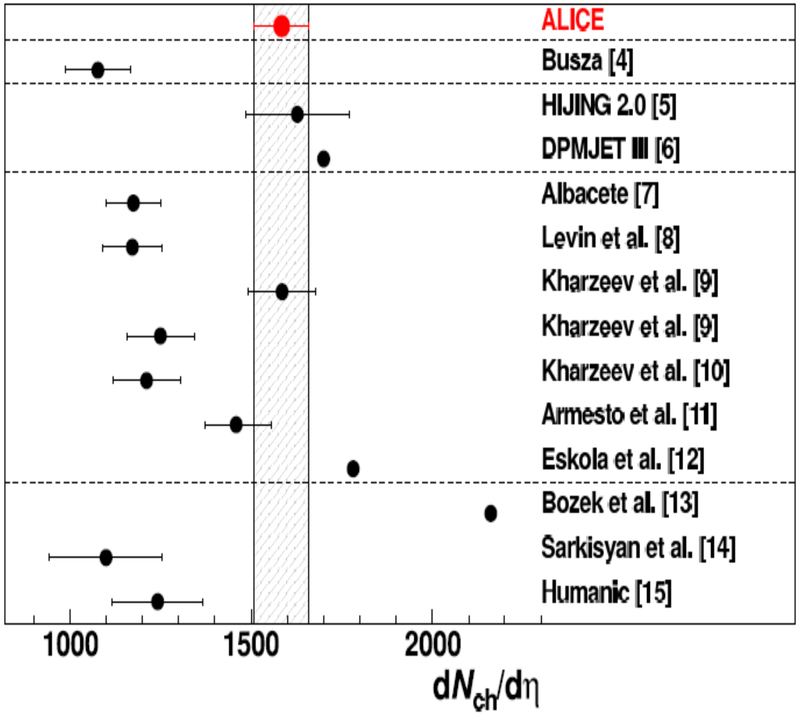


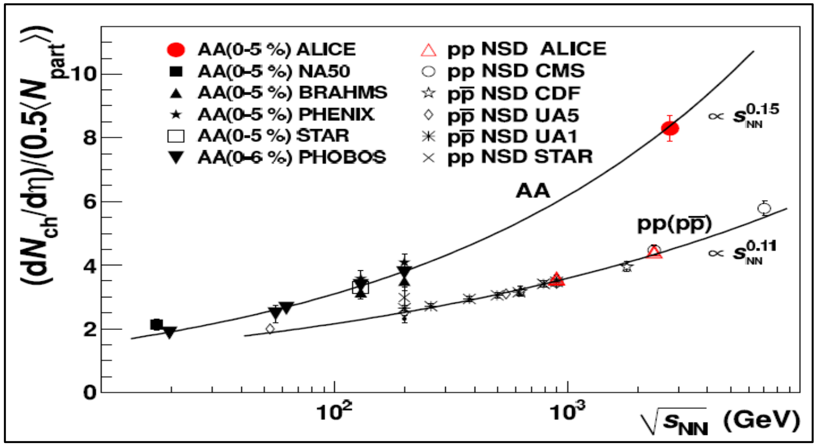
Ten events with the anti alpha particles were found (the first 25 ones have been identified in the STAR experiment).

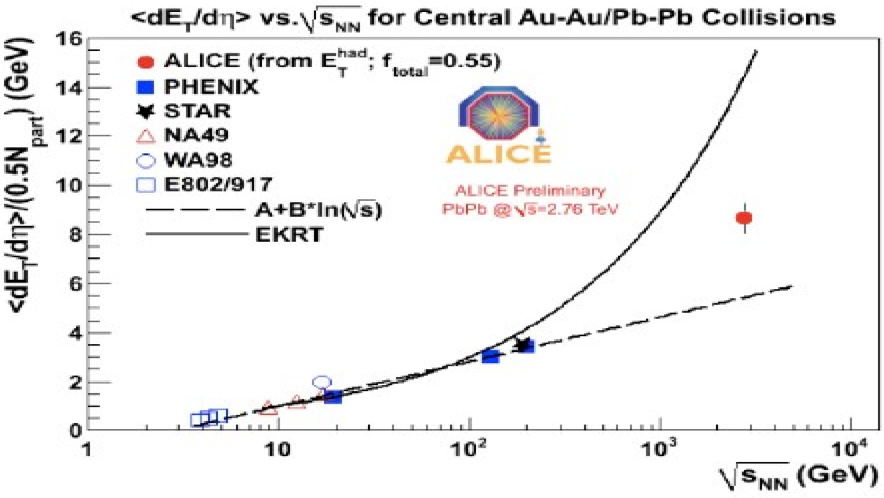
Charged particles density for Pb-Pb at 2.76 TeV

(ALICE, PRL, 105(2010) 252301)

$dN_{ch}/d\eta$ ~ 1600 ± 76 (syst)



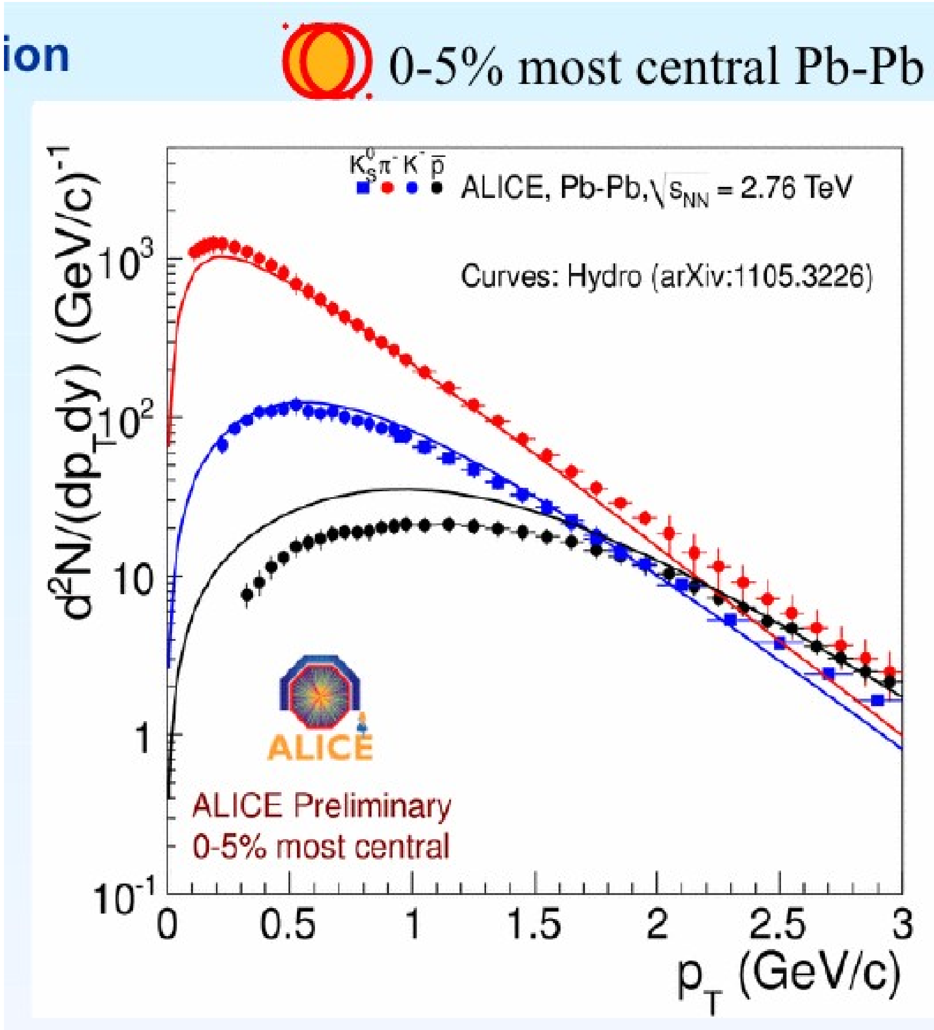




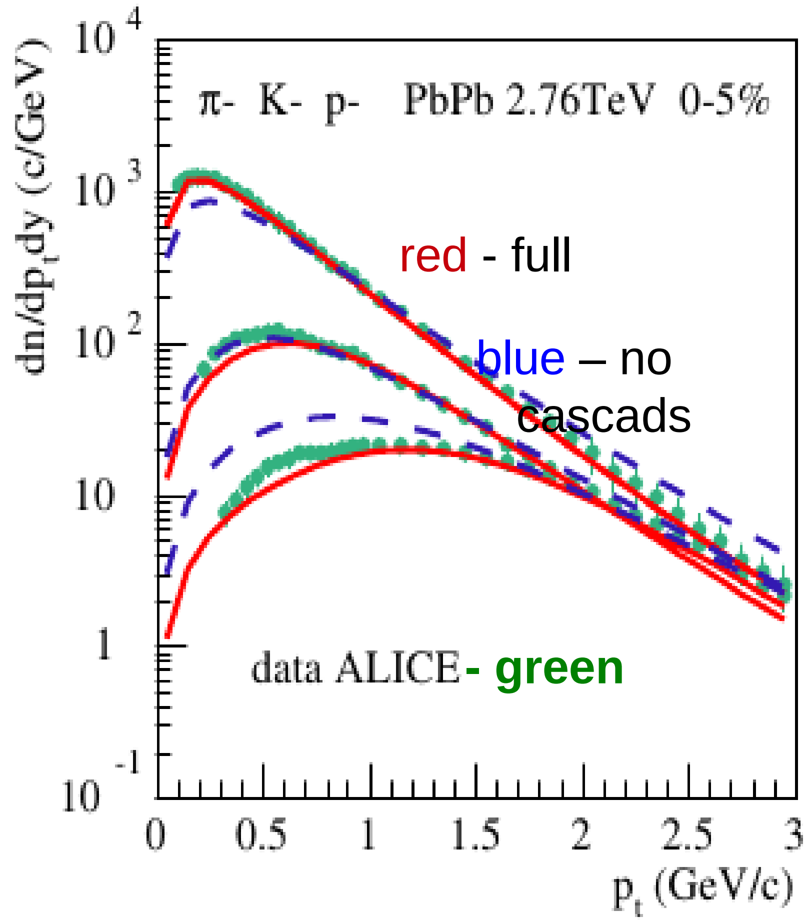
$\varepsilon_{Bj} = (1/\pi R^2\tau)(dE_T/dy)$, τ – the formation time, $R = 1.12A^{1/3}$ [fm],

$\varepsilon_{Bj}\tau$ = 16 GeV/(fm^{2}c), factor 2.7 larger than RHIC value.

Spectra

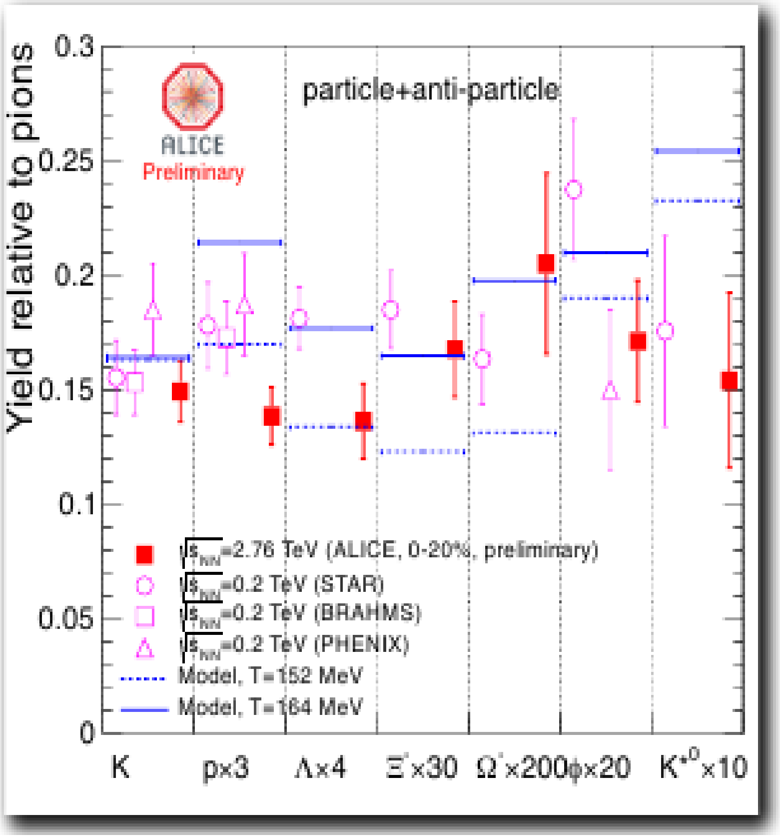


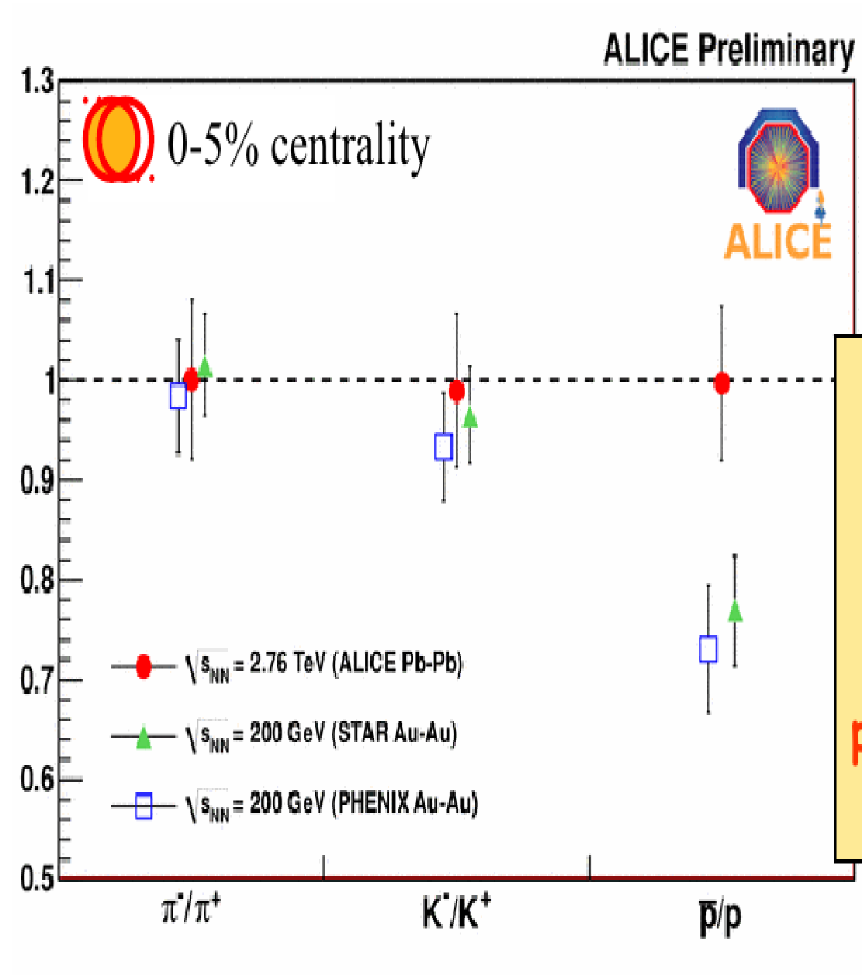
Hydrodynamic using the viscosity



EPOS – string model (flux-tubes),
K.Werner et al., ArXiv:1203.5704, 2012

Particle Ratios





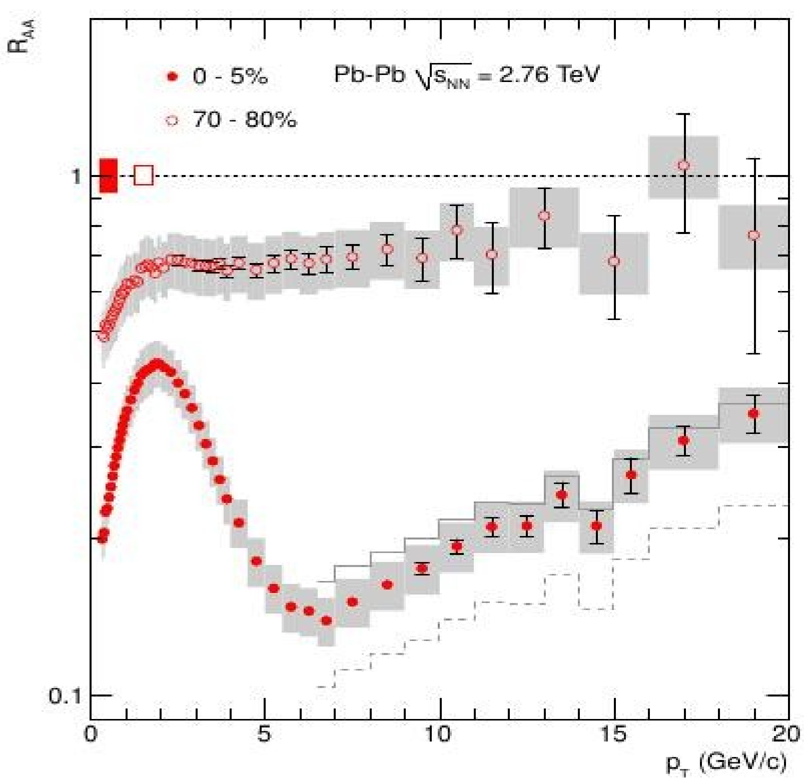
Statistical model (Grand-canonical equation):

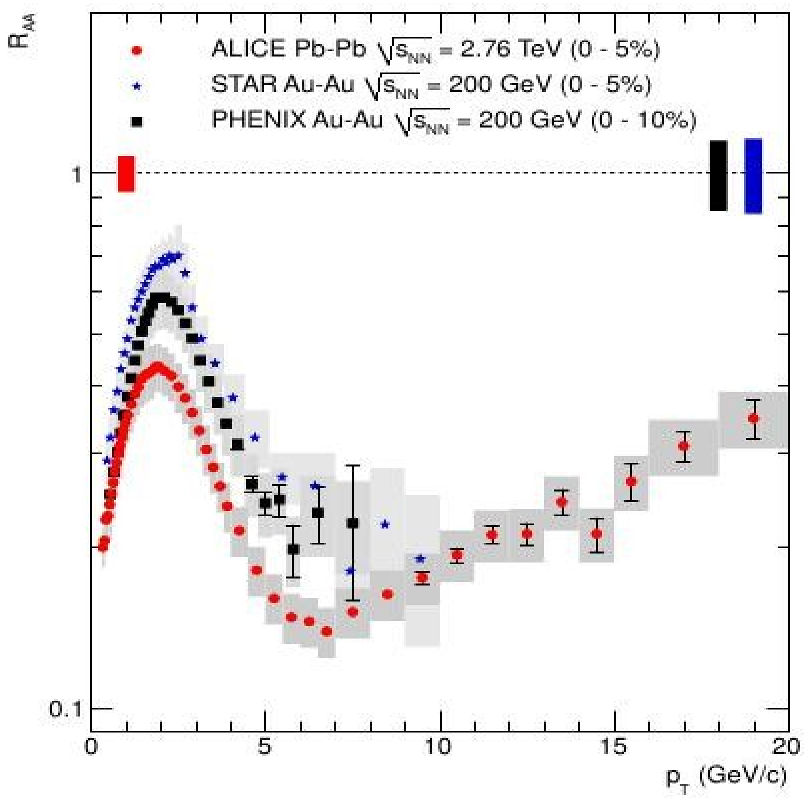
[A.Andronic et al., Nucl. Phys. A772(2006)167]

The nuclear modification factor R_{AA} for charged particles

[ALICE, PL, B696 (2011) 30]

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta\, dp_T}{\langle N_{coll}\rangle\, (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta\, dp_T}$$

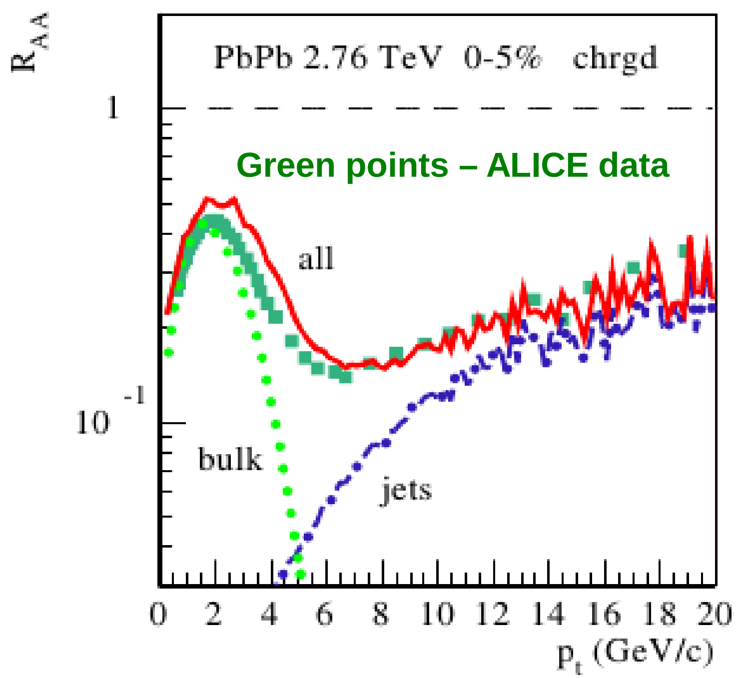


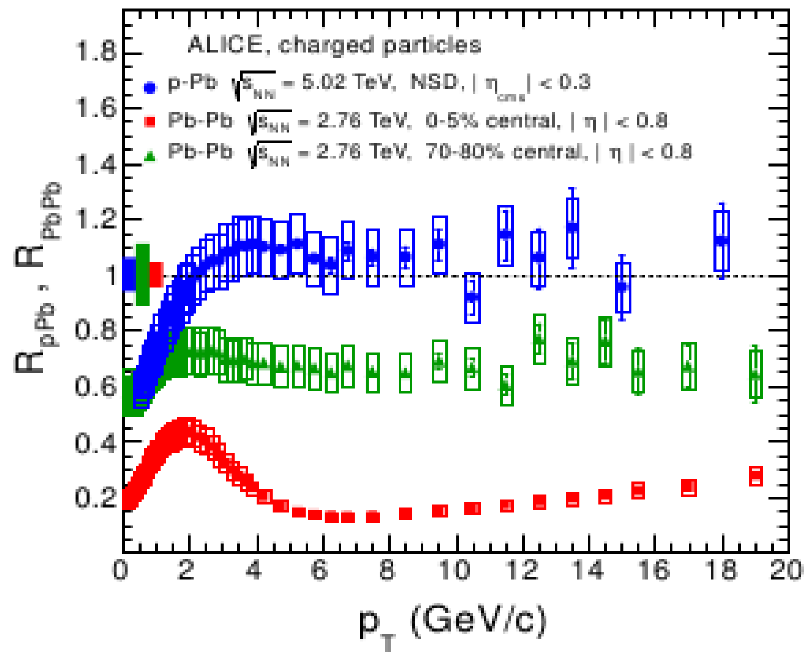


An evidence for stronger parton energy loss and larger medium density at LHC.

[ALICE, PRL,110 (2013) 082302]

EPOS model





EPOS – string model (flux-tubes), K.Werner et al., ArXiv:1203.5704, 2012.

The low values of R_{PbPb} in central collisions is not due an Initial-state nuclear effect but rather a consequence of hot matter created in A-A isions.

The first results for the p-Pb at 5.02 TeV. Only some evidence for the Cronin effect (R_{pPb}>1) is seen (near 1.4 at RHIC).

Quarkonia ($J/\psi, \psi', \Upsilon, \Upsilon', \Upsilon''$) suppression.

Predictions for influence of hot and dense hadronic matter, particulaly of Quark-Gluon plasma (QGP):

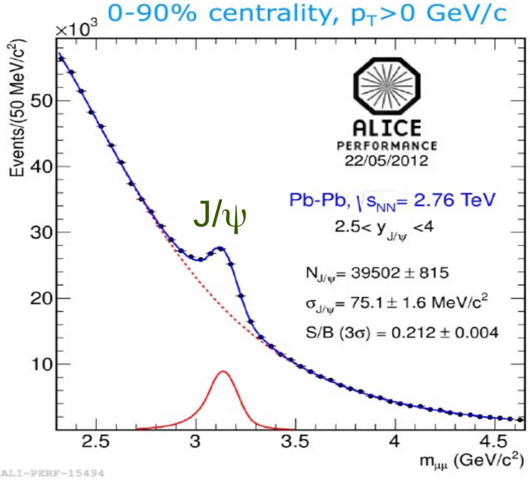
-- Debye screening of the quark colour charge in the QGP stage,
(T.Matsui, H.Satz. Phys.Lett. B178(1986)
or in the pre-QGP stage (mixed phase) with creation of the percolation clusters in the parton percolation model.
(M.Nardi, H.Zatz. Phys.Lett. B 442(1998)14; S.Digal, S.Fortunato, H.Satz. BI-TP 2003/30.).

-- quarconia dissociation by impact of gluons at the pre-resonance stage.
(D. Kharzeev et al. Z. Phys. C 74 (1997) 307.)

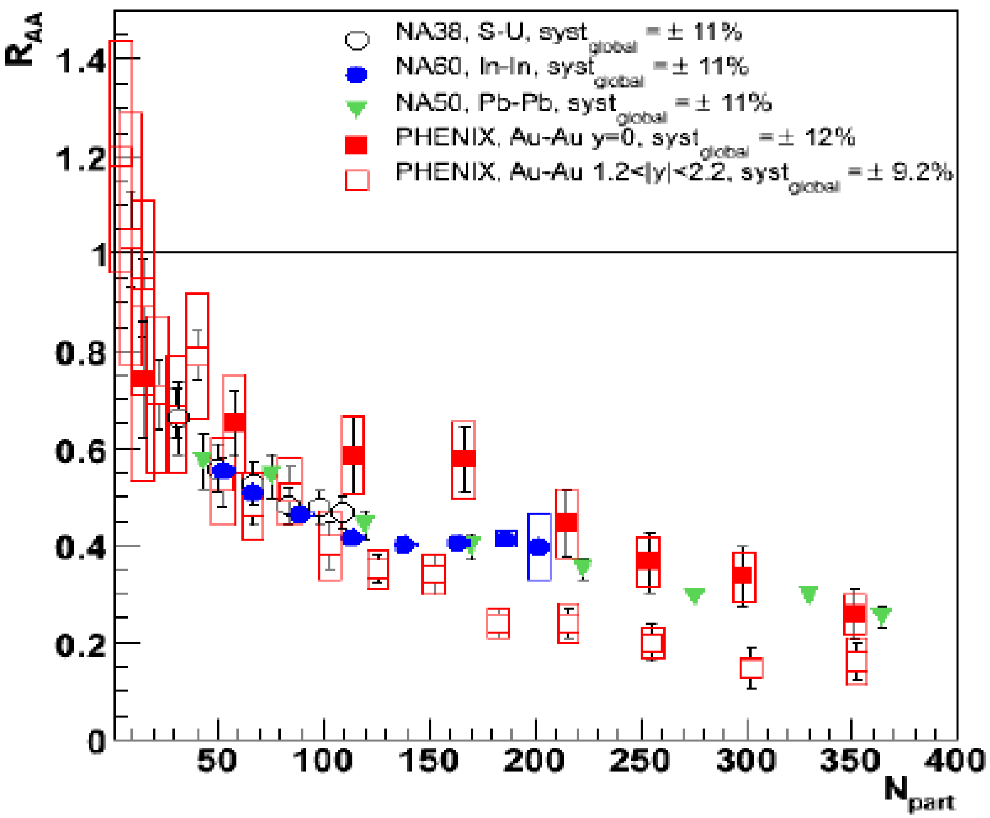
-- an absorbtion by the interaction in the hot and dense nuclear matter.
(N.Armesto et al. Phys.Rev. C 59(1999) 395; J.Geiss et al. Phys.Lett. B 447 (1999) 31)

J/ψ suppression (the observation in SPS, NA-50, 1997)

- Quarkonia suppression is considered, since a long time, as one of the most striking signatures for QGP formation in AA collisions



- Sequential quarkonia suppression:
  - Information on the initial temperature of QGP
    ...but many effects to be taken into account:
    cold nuclear matter, $c\bar{c}$ (re)combination



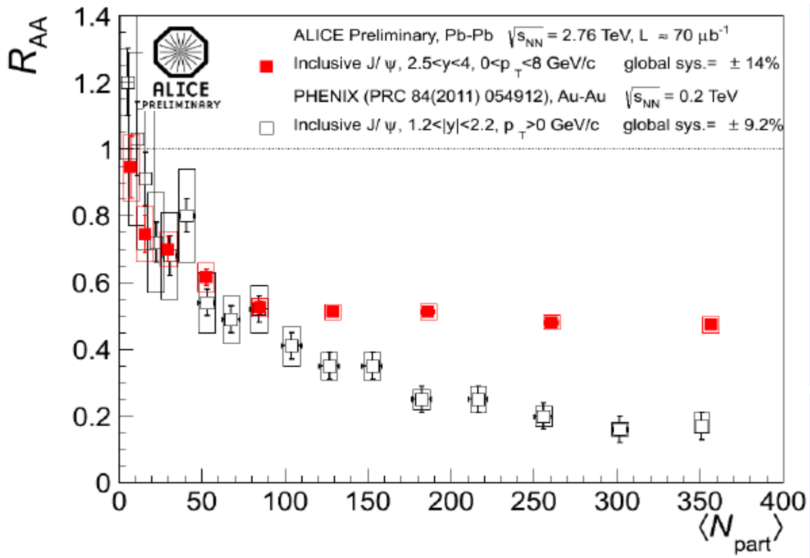
- Puzzles from SPS and RHIC
  - RHIC: stronger suppression at forward rapidities
  - SPS vs. RHIC: similar R_{AA} pattern versus $\sqrt{s}$

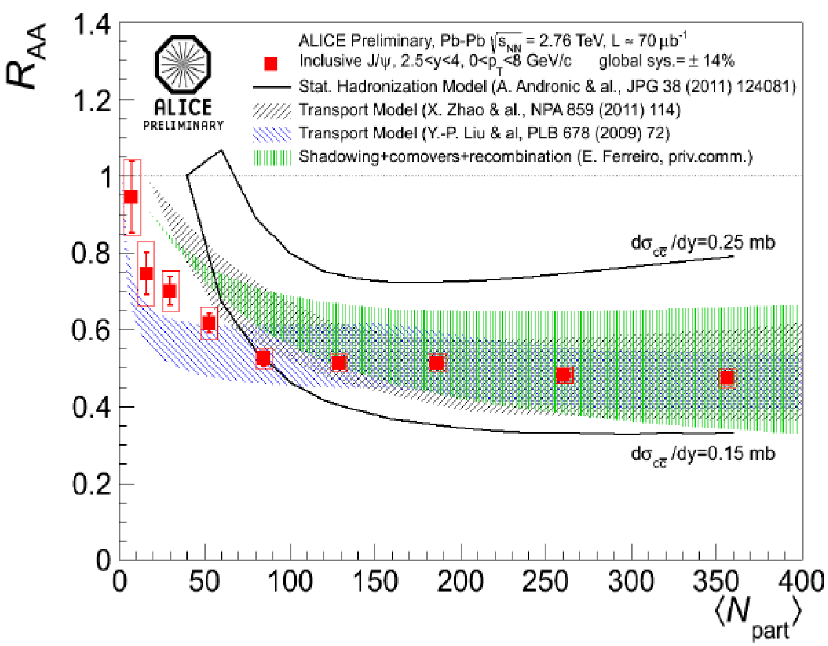
- LHC results can give decisive inputs, investigating the role of
  - the large charm quark multiplicity

$$\sigma c\bar{c}\,(LHC) = 10 \times \sigma c\bar{c}\,(RHIC)$$

  - other quarkonia states (bottomonium)

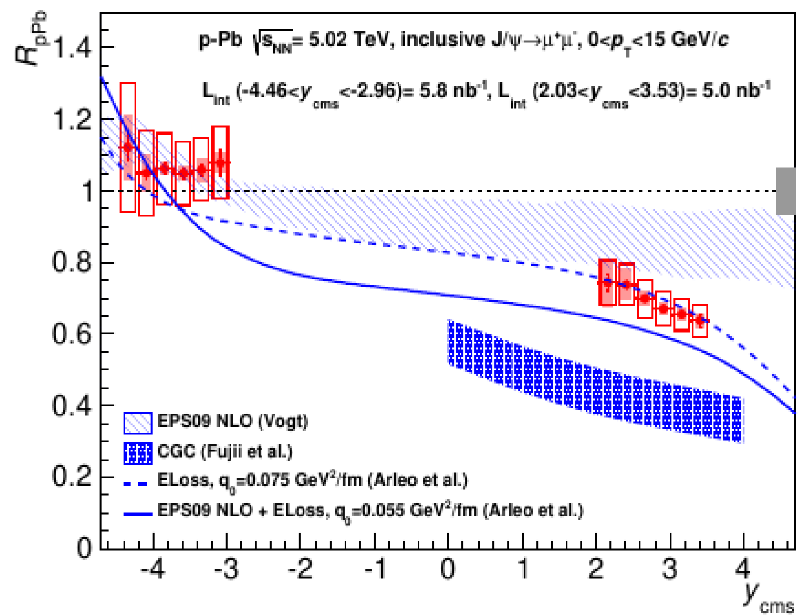
[ALICE, PRL, 109 (2012) 072301]





The RAA in the ALICE is almost a factor of three larger then in the PHENIX for $<N_{part}> \gtrsim 180$. The theoretical description is with an including of 50% J/ψ regeneration component from deconfined charm quarks in the medium.

[ALICE, arXiv:1308.6726 (2013)]

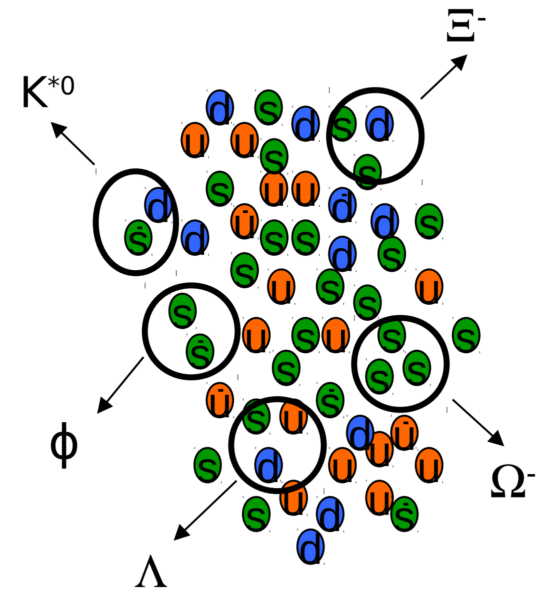


The suppression (R_{pPb}<1) is seen in the proton direction only. The well prediction is based on a nuclear shadowing scenario Including a coherent parton energy loss. The R_{pPb} (~0.75) is larger than R_{PbPb} (~0.57), i.e. the suppression in Pb-Pb can't be ascribed to cold nuclear matter effect alone.

Motivation

Strange Hadrons:

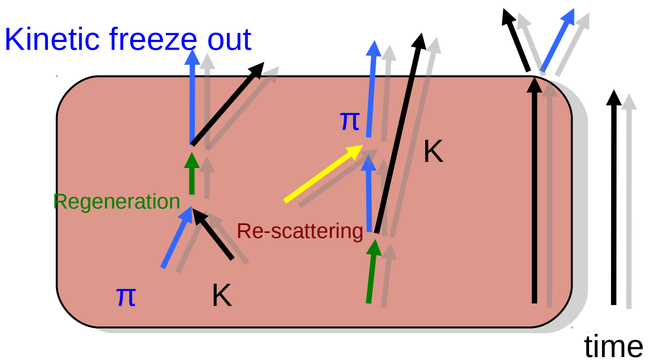
- ❑ Strangeness enhancement → one of the predicted signatures of Quark Gluon Plasma formation.
  - ➢ Strangeness enhancement increases with strangeness content.
    Ω(sss) > Ξ(ssd) > Λ(sud)

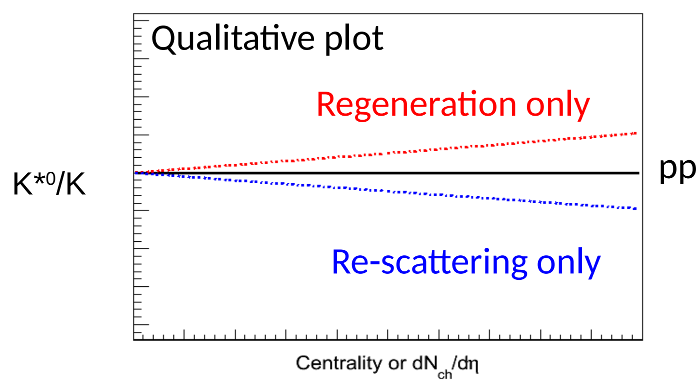


Strange Resonances:

- ❑ Lifetime comparable to the lifetime of fireball → sensitive to the properties of the medium.

Re-scattering and regeneration:



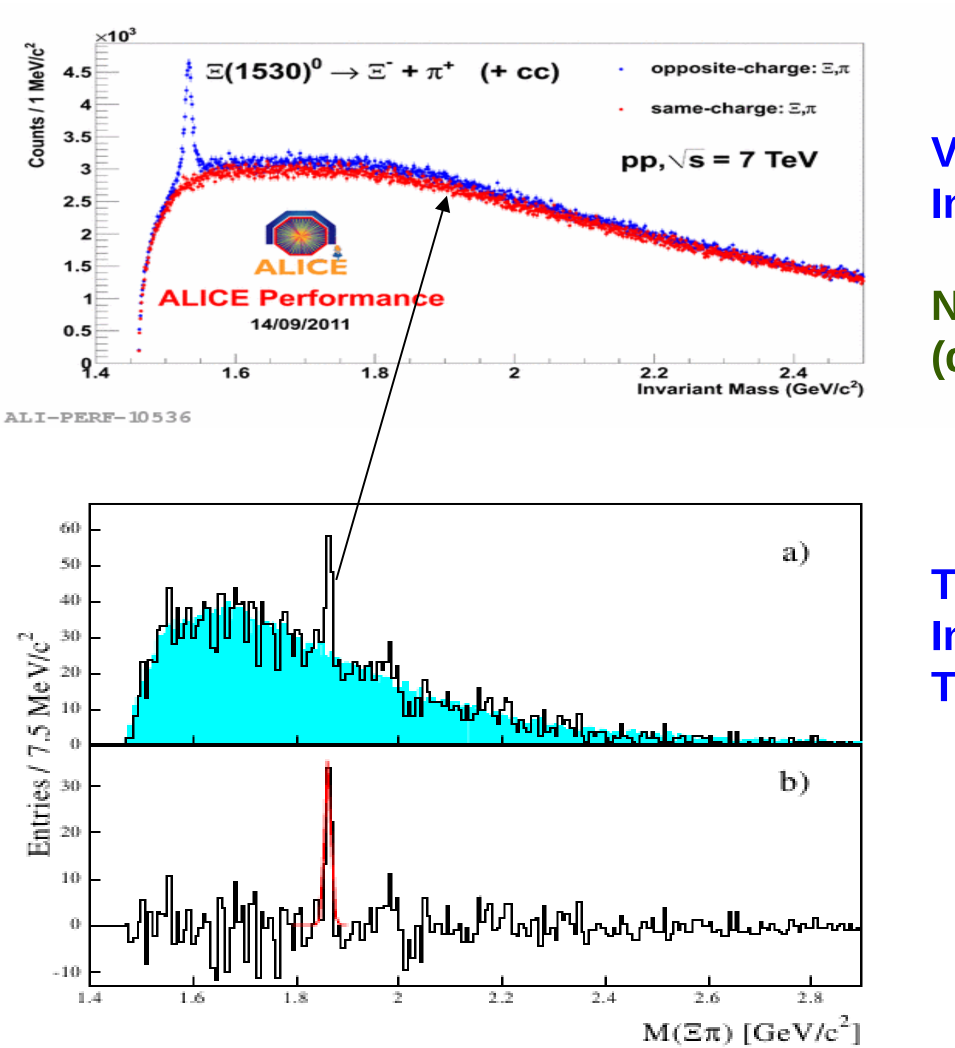


Lifetime :
K* - 4 fm/c,
φ - 45 fm/c

- ➢ $(K^{*0}/K)_{AA}$ and $(K^{*0}/K)_{pp}$ → re-scattering / regeneration effects.
- ➢ (ϕ/K) independent of centrality → rules out ϕ production mainly through kaon coalescence.

Ref: Phys Rev C79, 064903 (2009); J Phys G36, 064022(2009)

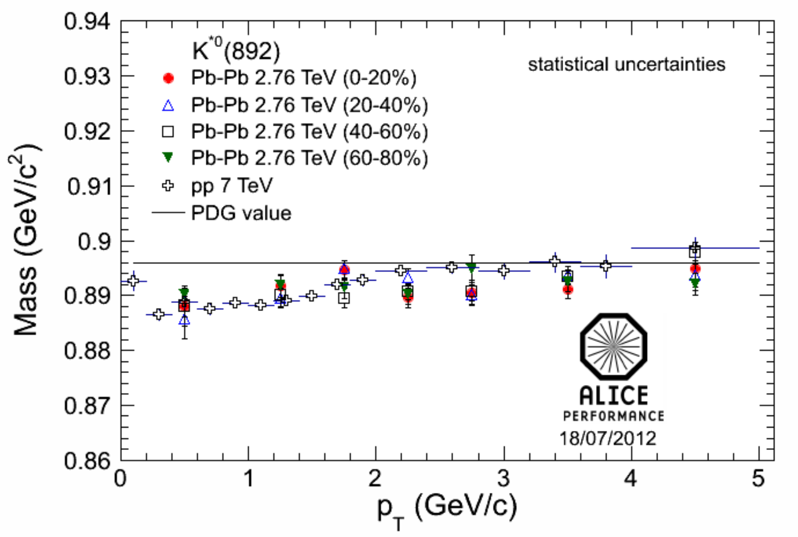
The Ξ(1530) resonance analysis in p-p collisions at 7 TeV (ALICE resonance group).

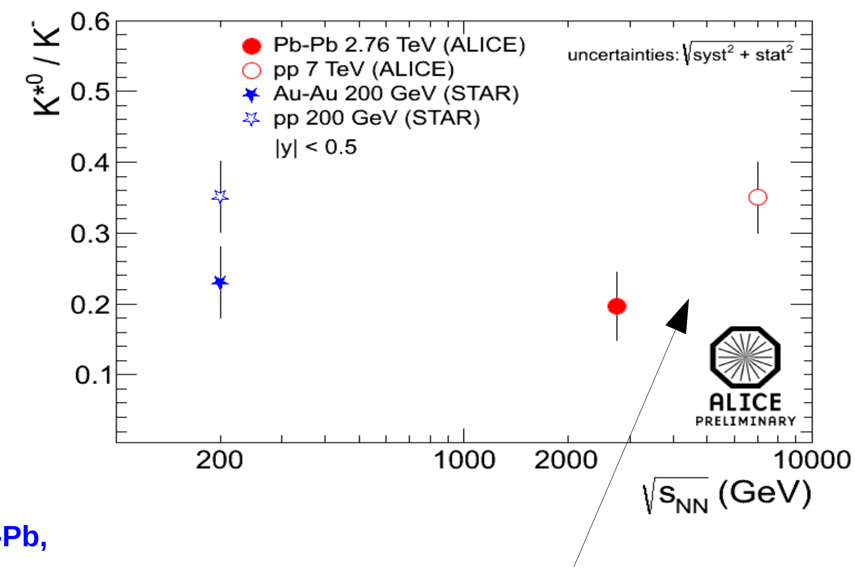


Very good peak of $\Xi(1530)^0$ is seen
In ALICE analysis.

No evidence to the pentaquark (1.862)
(dsusđ)

The pentaquark (1.862) was detected
In the NA49 experiment (SPS) with
The mass 1.862 ± 0.002 GeV/c2.

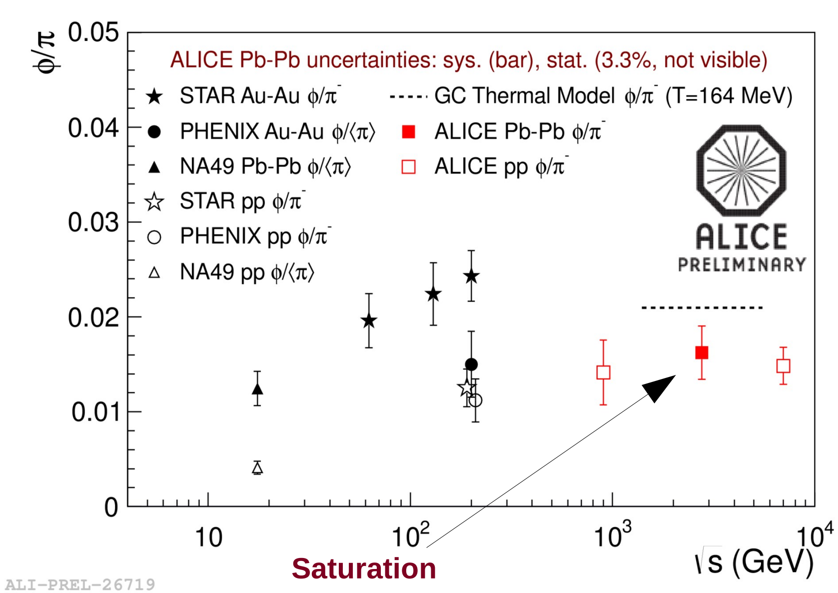




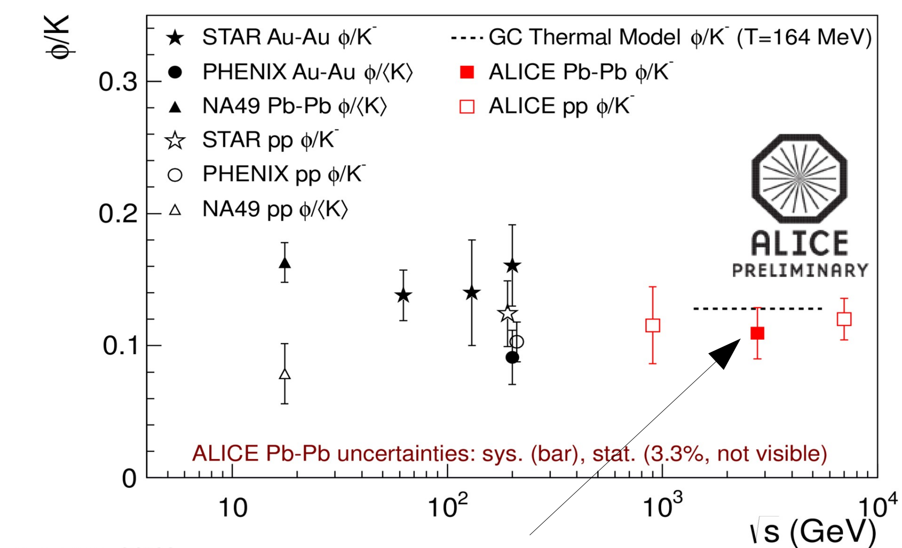
Mass shifts at low p_T: up to 1.0% for K* is the same in pp and Pb-Pb, no medium effect but the detector methodical ones.

(up to 6.5% and 9% for ρ^0 in p-p and Au-Au of STAR).

Rescattering

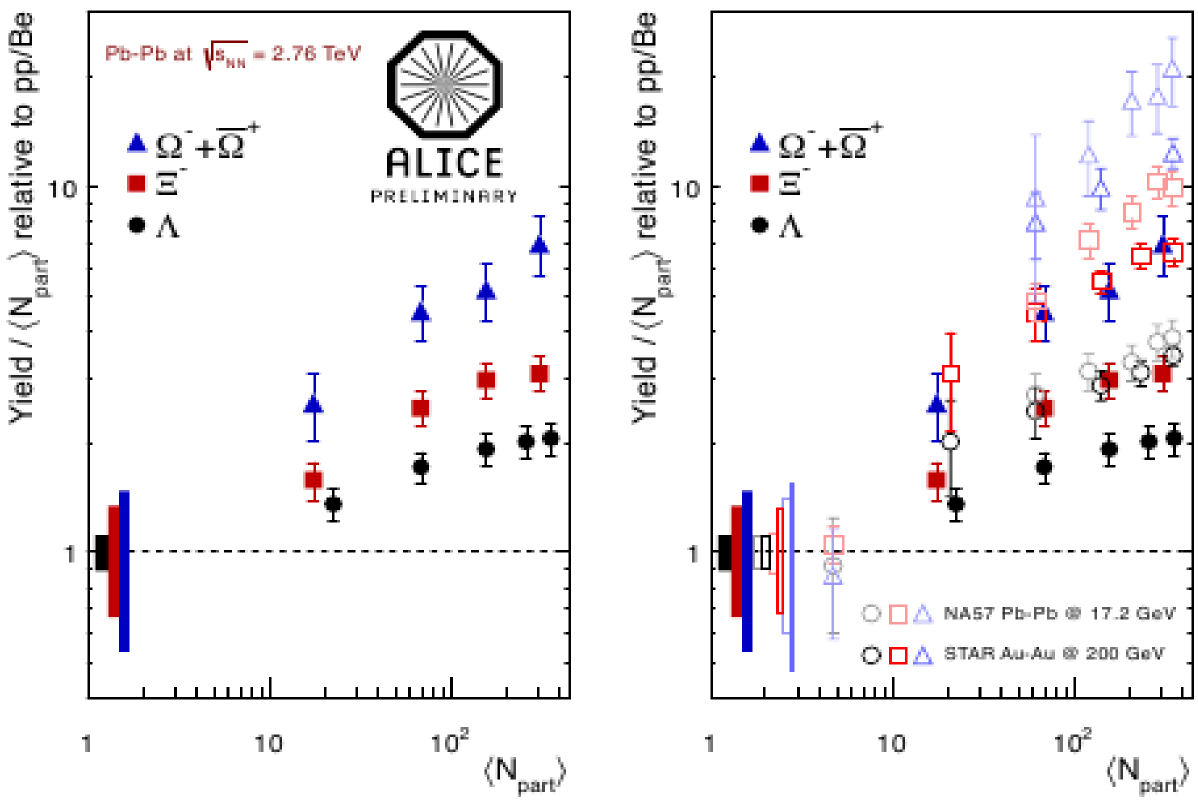


Saturation



No rescattaring

Strangeness Enhancement



Strangeness enhancement

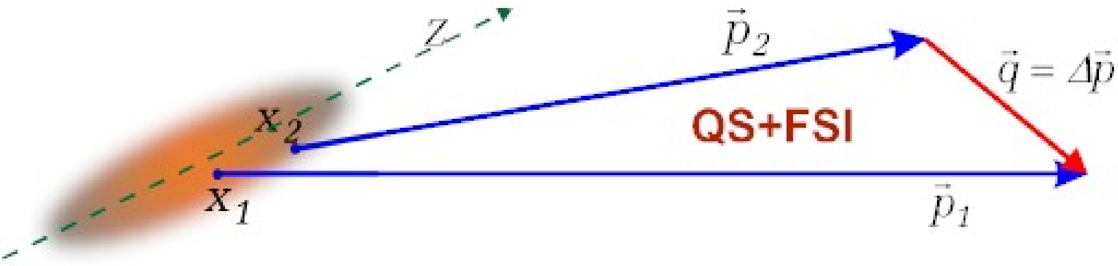
$$E_i = \frac{Yield_i^{AA} / \langle N_{part} \rangle}{Yield_i^{pp} / 2}$$

- Strangeness enhancement with respect to pp collisions following the hierarchy based on the strangeness content of the particle.
- Enhancement decreases with increase in beam energy from SPS → RHIC → LHC

Femtoscopic correlations (HBT)

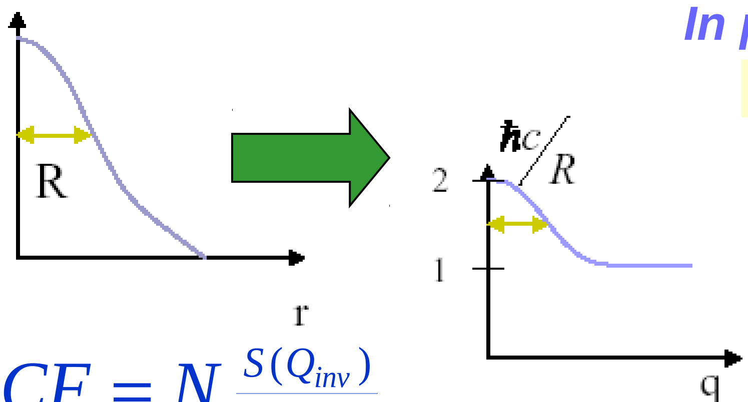
Formalism:

Following to Haunbary Brown and Twiss (HBT) method for an estimation of star angle sizes G.I.Kopylov and M.I.Podgorecky suggested to study the space - time parameters of the sources emission of identical particles using the correlation function with Bose-Einstein interferometric effect :



4-vectors: $q = p_1 - p_2$, $\Delta x = x_1 - x_2$

$CF = 1 + (-1)^S \langle \cos q\Delta x \rangle$, where $S = j^2$, j - spin



In practice: $C(q) = 1 + \lambda \exp(-R^2 q^2)$ for 1D analysis

$CF = 1 + \lambda \exp(-R_o^2 q_o^2 - R_s^2 q_s^2 - R_l^2 q_l^2)$ for 3D analysis

R – source radii, λ – the correlation strength parameter

$$CF = N \frac{S(Q_{inv})}{B(Q_{inv})}$$

$S(Q_{inv})$ yield of pairs from same event

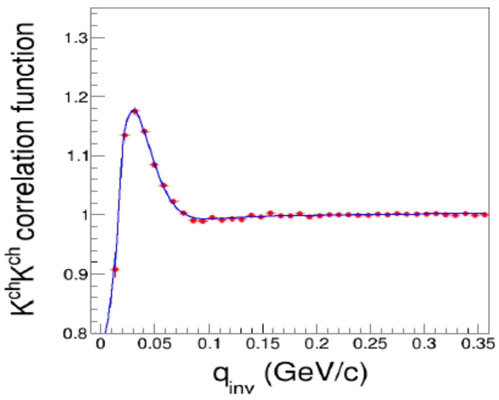
$B(Q_{inv})$ pairs from "mixed" event

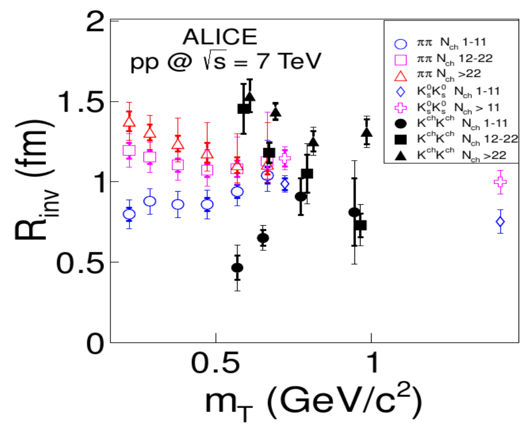
N normalization factor, used to normalize the CF to be unity at large, $Q_{inv} = \sqrt{q^2}$

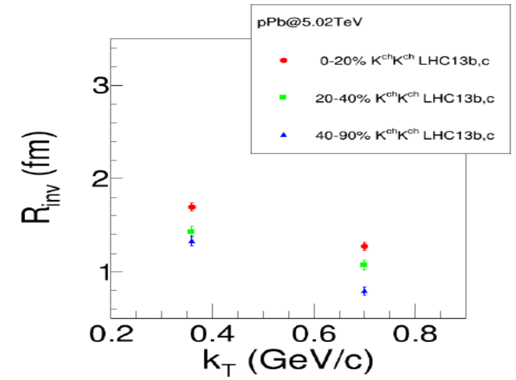
Projections of the momentum difference q_l, q_o, q_s are used to the correspondence axis:

l - 'longitudinal' (beam) direction
o - 'outward' direction parallel to transverse pair velocity,
s - 'side-ward' direction transverse to 'longitudinal' and 'outward'

1D - femtoscopical analysis

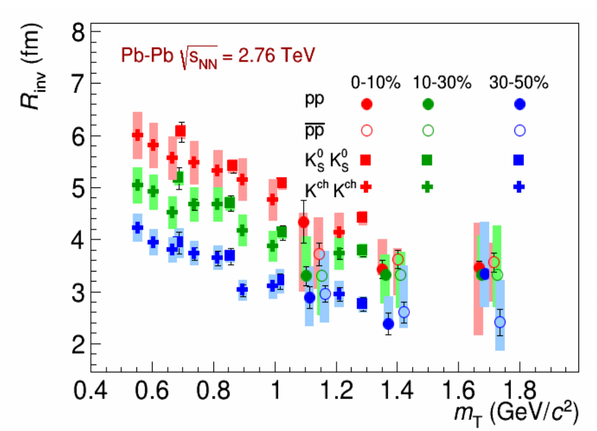


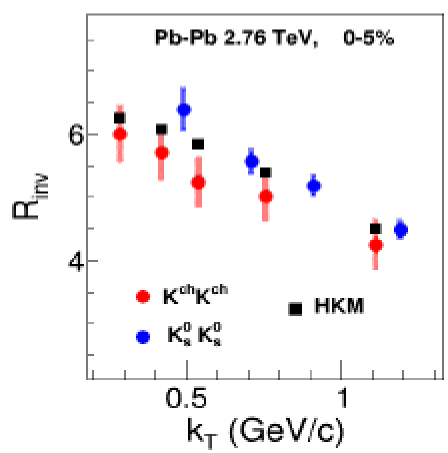




$CF(q)=\{(1-\lambda)+\lambda*K(q)*[1+\exp(-R^2q^2)]\}*D(q)$ [M.G. Bowler, PL B270 (1991)69; Y. Sinyukov et al., PL B432 (1998) 248],

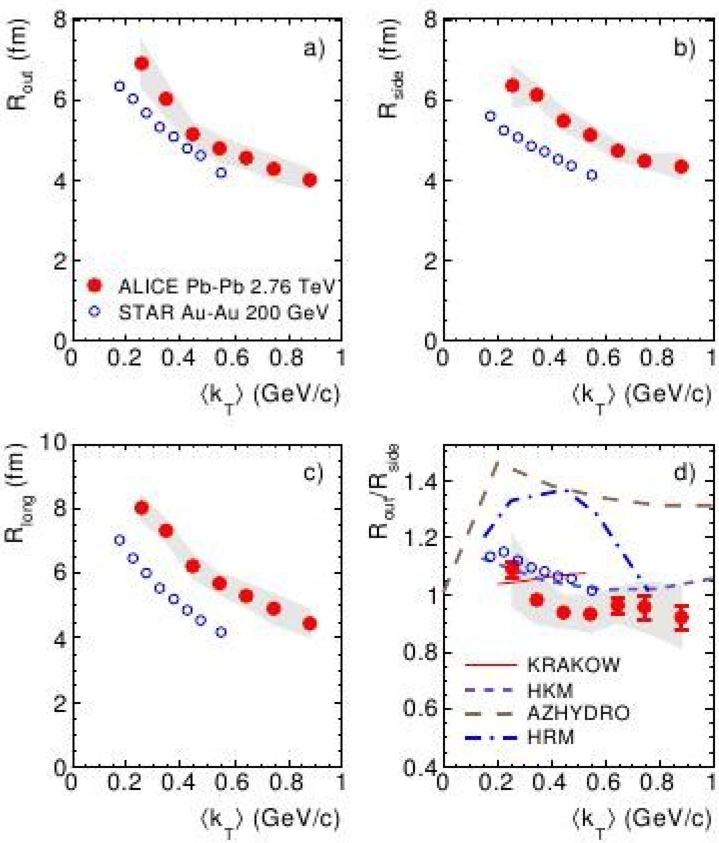
K(q) – Coulomb factor, **D(q) –** baseline from MC simulation.





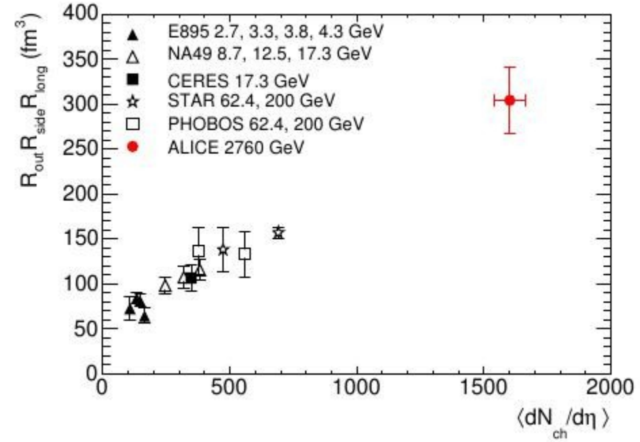
-- The R_{inv} increases with increase of event multiplicity as expected in geometrical picture and decreases with m_T(k_T) increase according of collective flow effect predicted by Hydrodynamic (HKM) model (V.M. Shapoval,et al. PRC 88(2013)064904).
-- Such a behaviour is seen for p-p events at higher multiplicities and is the contrary one for the lowest multiplicity (ALICE, PRD, 87(2013)052016).
-- The emission source sizes of kaons and protons exhibit m_T scaling which is consistent with the Hydrodynamic model prediction.

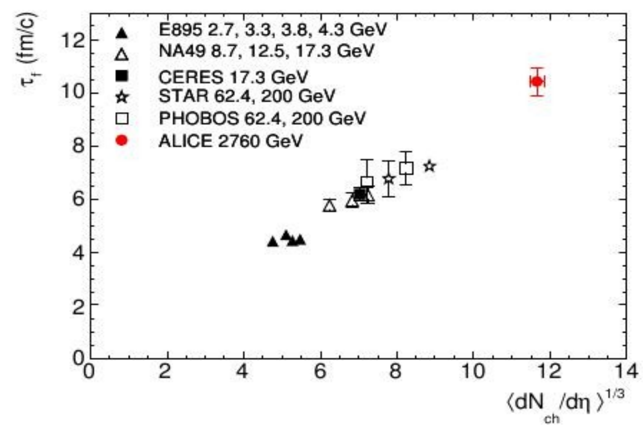
3D - femtoscopical analysis for pairs of charged pions



3D radii increase at LHC energy.

(HKM: Iu.Karpenko, Yu.Sinyukov, arXiv:1103.5125,2011)





The source volume ($R_{out}R_{side}R_{long}$) and the hadron formation time (τ) obtained in ALICE 2 and 1.5 times larger respectively than at RHIC energy. [Phys. Lett. B696 (2011)328]

Azimuthal anisotropic flow

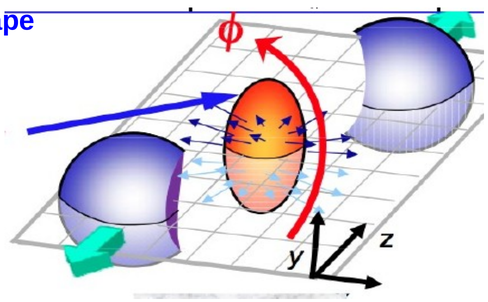
Fourier series of particle azimuth dependence:

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

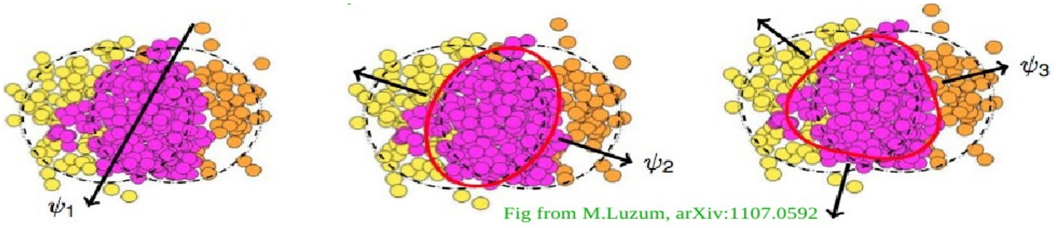
v_n = <cos[n(ϕ – Ψ_R)]> - Fourier coefficients, ϕ – azimuth,
Ψ_R- reaction plane angle, n – a harmonic order [S.Voloshin, Y.Zhang, Z.Phys., C70 (1996) 665].

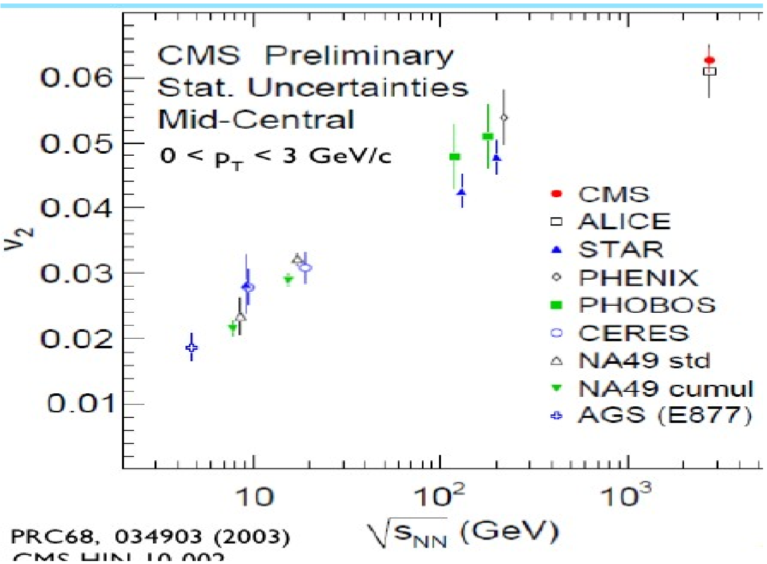
Triangular v3: should be zero because smooth matter distribution but is not zero due to ev-by-ev fluctuations of the matter distribution.

almond shape



Directed v1 **Elliptic v2**

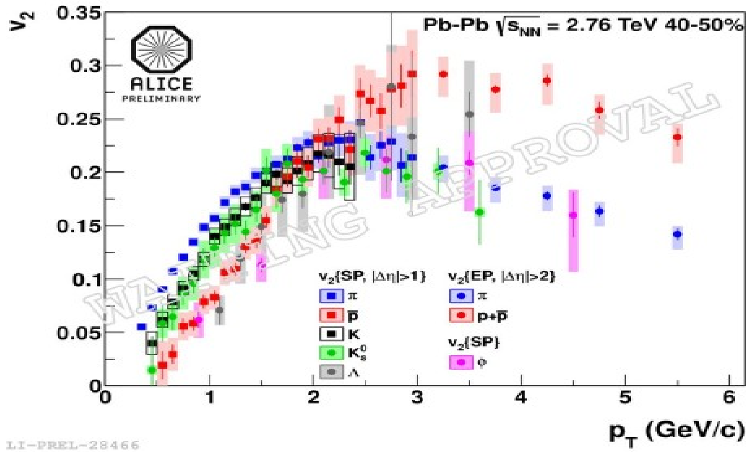


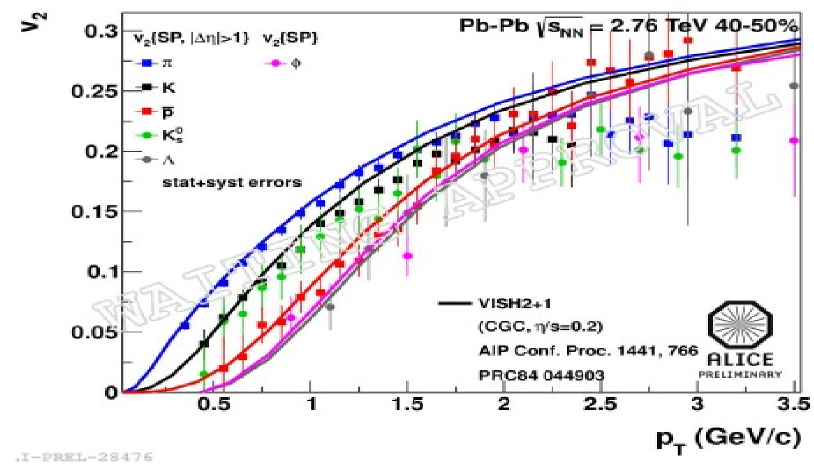


-- Integrated elliptic flow at 20% centrality for the ALICE increase ~30% as compared with RHIC energy.
[ALICE, PRL, 105 (2010) 252302)]

-- The hydrodynamic models which incorporate viscous corrections do allow for such an increase of v2 at the LHC energy. [H. Masui et al., NP, A830 (2009) 463c]

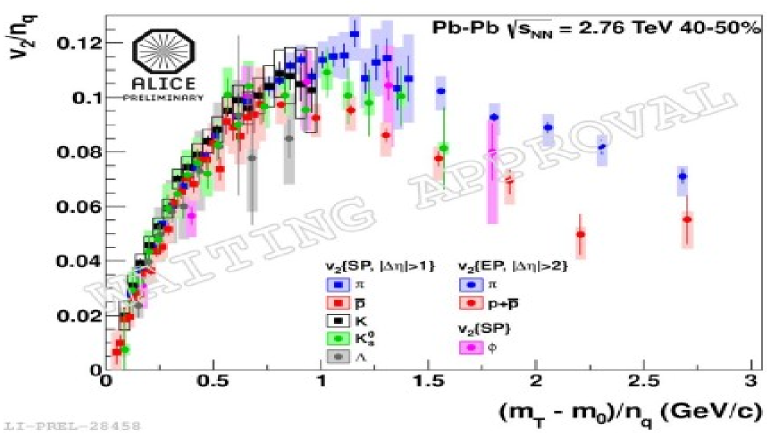
Flow dependence on the particle masses (F.Noferini, IX WPCF, Acireale, Italy, 2013)

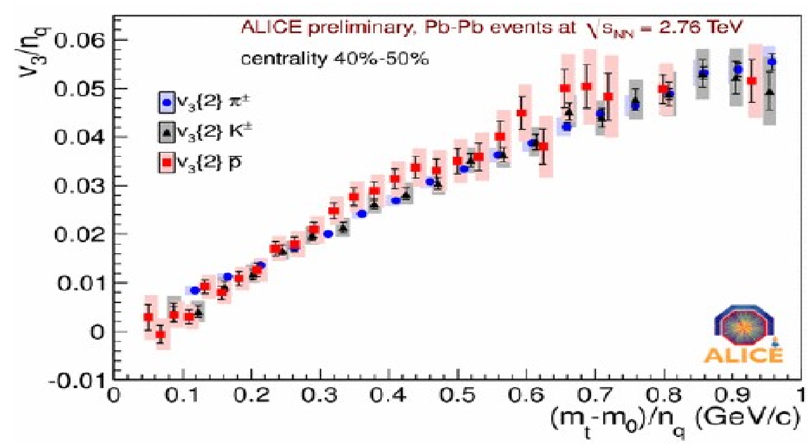




The mass ordering: heavier mass → smaller v2 at p_T< 2.5 GeV/c, is described by the hydrodynamic with shear viscosity parameter $(\eta/s)_{QGP}$= 0.2 (η and s are the viscosity and entropy density respectively).

At p_T> 2.5 GeV/c φ meson follows to the π and K^0_s, i.e. quark coalescence prediction.





The Number of Quark (NQ) scaling for v_i/nq is within 15-20% at transverse kinetic energy smaller of 1 GeV.

Conclusions

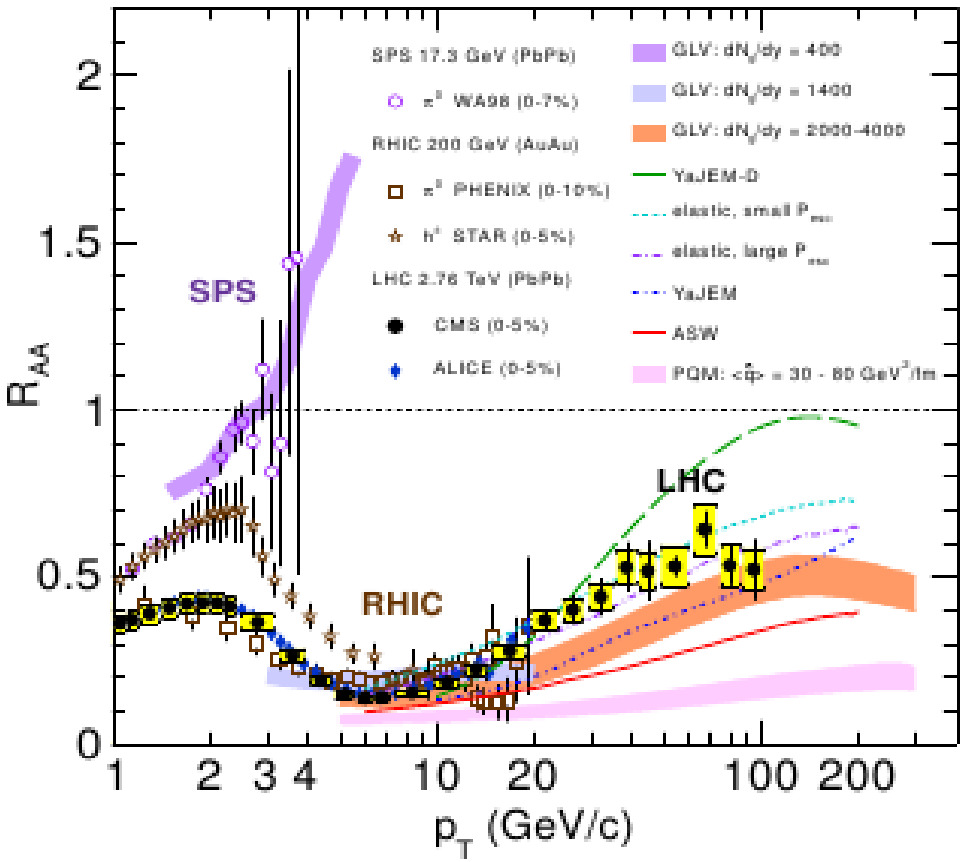
– A lot of interesting results have been obtained in the ALICE for p-p p-Pb and Pb-Pb collisions at the LHC energies.

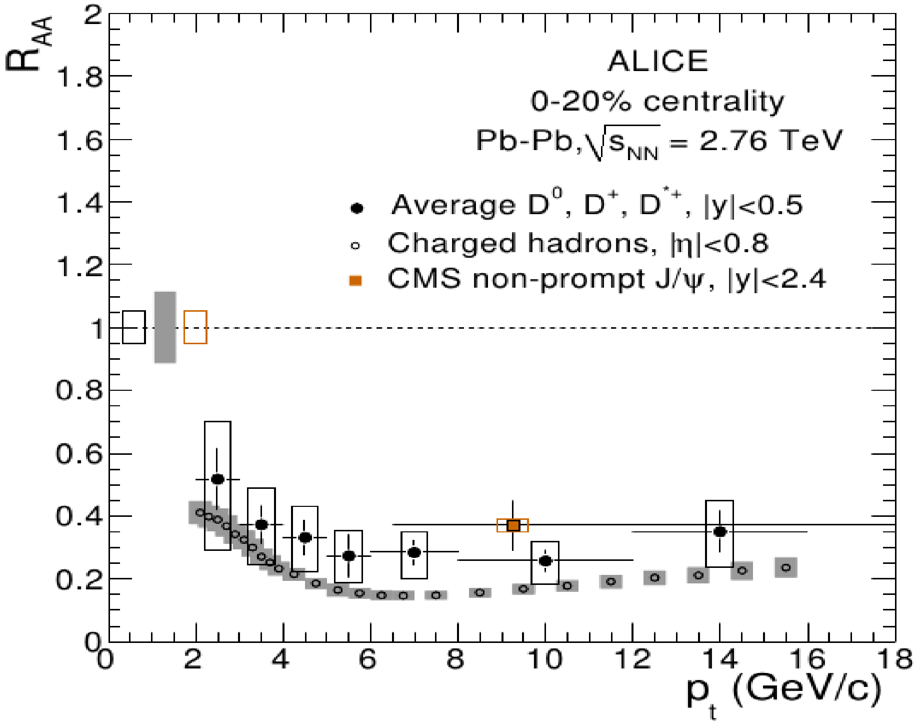
– Some new effects were found and have to be understood with the theoretical point of view as a signatures of very hot and dense nuclear matter.

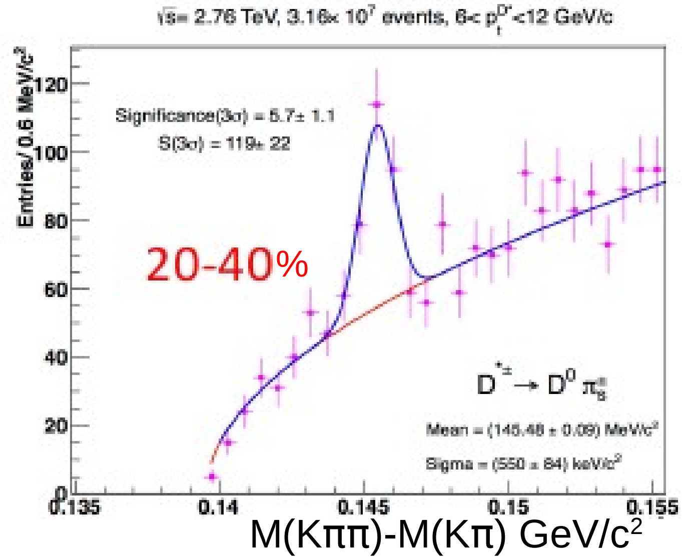
– The QGP stage used in the theoretical model to understand most of the Pb-Pb results.

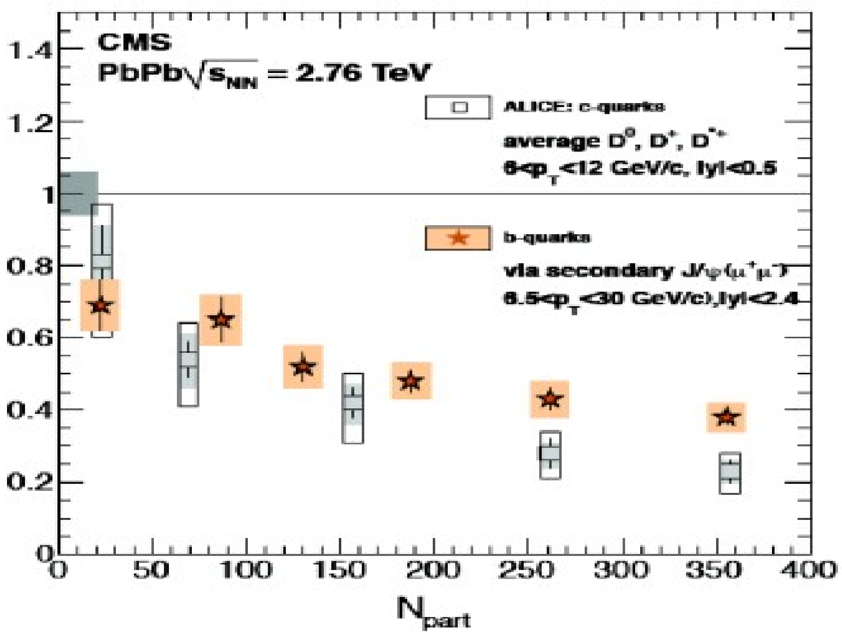
Thank you for your attention

Backup


SPS 17.3 GeV (PbPb)
π⁰ WA98 (0-7%)
RHIC 200 GeV (AuAu)
π⁰ PHENIX (0-10%)
h± STAR (0-5%)
LHC 2.76 TeV (PbPb)
CMS (0-5%)
ALICE (0-5%)
GLV: dNg/dy = 400
GLV: dNg/dy = 1400
GLV: dNg/dy = 2000-4000
YaJEM-D
elastic, small Pesc
elastic, large Pesc
YaJEM
ASW
PQM: <q̂> = 30 - 80 GeV²/fm
SPS
RHIC
LHC
RAA
pT (GeV/c)







It is expected in the QCD the $R_{AA}(\pi)<R_{AA}(D)<R_{AA}(B)$ because the gluon energy loss is larger than for the quark one (less colour charge). This effect has to be stronger in the QGP phase with a large number of deconfined heavy flavor quarks. The evidence of this effect is seen in the left side figures (not seen at the RHIC energy).

COMPUTING

– 30,000 cores
– 70 computer centres (1T0, 5T1, 64T2)
– America, Europe, Africa and Asia

– Stable and smooth operation 24 x 7
– Operated according to the Computing Model