St. Petersburg State University
Laboratory of Ultra-High Energy Physics

Centrality and multiparticle production in ultrarelativistic nuclear collisions

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LXV International Conference “Nucleus 2015”.
June 29 – July 3, 2015, Peterhof, Saint-Petersburg

Layout

- Introduction. ”Relativistic Nuclear Physics” : a bit of history
- Modern HI experiment
- From RHIC to LHC: some experimental results and puzzles?
  - charged-particle multiplicity density
  - charged particle elliptic flow, + higher harmonics???
  - suppression of charged particle production at large pt
  - two-pion Bose--Einstein correlations (HBT)
  - ongoing analyses : strange and heavy-flavour particle production,
  - prompt D meson Raa, ridge
  - From RHIC to LHC: theory

Problems:

- Centrality of relativistic heavy ion collision
- Centrality estimators: N_{part} and multiparticle production in MC models
  - Modified Glauber
  - non-Glauber approached event generators in pA
- Classes of centrality in AA and pA
- Conclusion

„Relyativistic Nuclear Physics" : a bit of history

A.M. Baldin

1971: the 1st relativistic nuclear beams with an energy of 4.2 AGeV at the synchrophasotron at the LHE, JINR. One of the 1st studies of nuclear effects in the high energy interactions off nuclei

A.M. Baldin et al. Sov.J. Nucl.Phys.18,41 (1973)

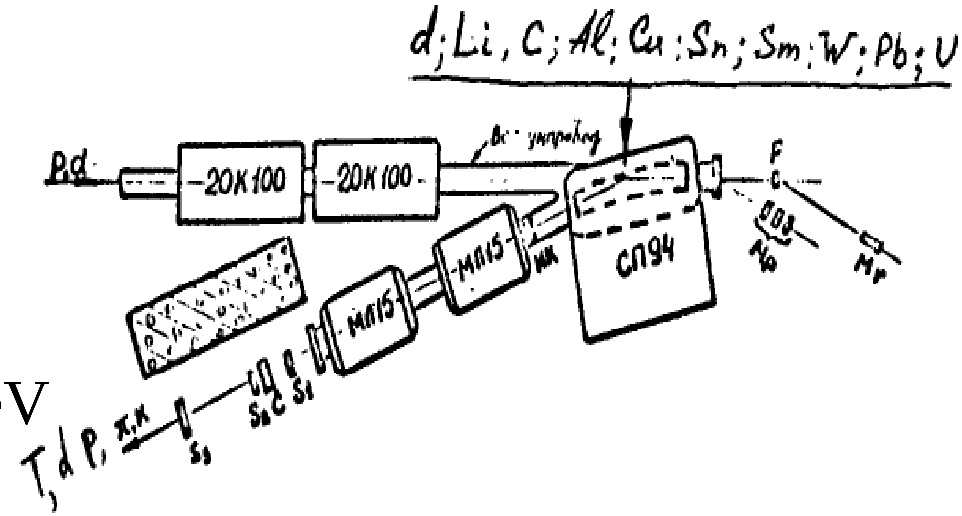


Fig. 2 Experimental layout

A.M. Baldin ,"Heavy Ion Interactions at High Energies", report at AIP Conf. Proc. 26, 621 (1975)

BEVALAC(1974), SPS(1976), RHIC(2000), LHC(2009)

QGP

…J. C, Collins and M. J. Perry -1975, …E.Shuryak 1978…:

QUARK–GLUON PLASMA AND HADRONIC PRODUCTION OF LEPTONS, PHOTONS AND PSIONS

E.V. SHURYAK
Institute of Nuclear Physics, Novosibirsk, USSR

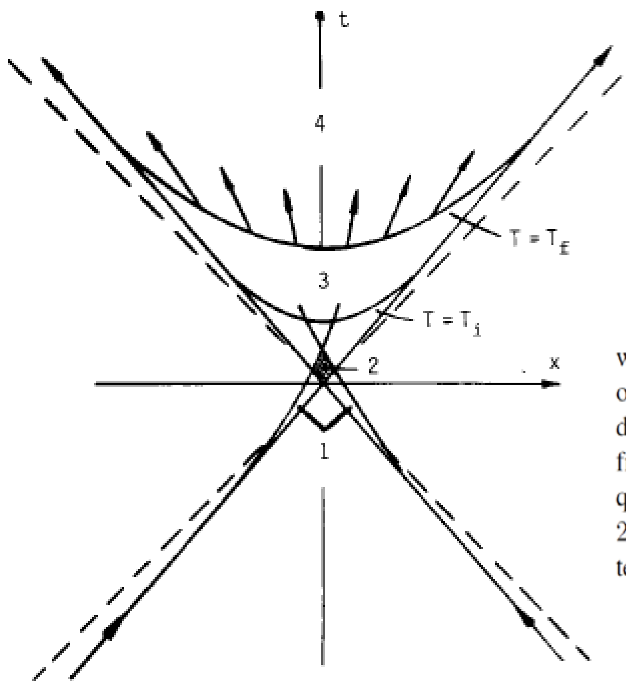


Fig. 1. The space–time picture of hadronic collisions, proceeding through the following stages: (1) structure function formation; (2) hard collisions; (3) final state interaction; (4) free secondaries.

Phys. Lett. *B78 (1978) 150*

Early expectations: QGP like
an ideal gas of quarks and gluons

At very high energy density, the coupling constant of QCD becomes weak. A gas of particles should to a good approximation become an ideal gas. Each species of particle contributes to the energy density of an ideal gas as

$$\epsilon \sim \frac{\pi^2}{30} N T^4$$

where N is the number of particle degrees of freedom. At low temperatures when masses are important, only the lowest mass, strongly interacting particle degree of freedom contributes; the pion, and the energy density approaches zero as $\epsilon \sim e^{-m_\pi/T}$. For an ideal gas of pions, the number of pion degrees of freedom is three. For a QGP there are two helicities and eight colours for each gluon, and for each quark, three colours, two spins, and a quark–antiquark pair. The number of degrees of freedom is $N \sim 2 \times 8 + 4 \times 3 \times N_F$ where N_F is the number of important quark flavours, which is about three if the temperature is below the charm quark mass so that $N \sim 50$.

Relativistic heavy-ion physics: three lectures

L. McLerran
Brookhaven National Laboratory, Upton, NY 11973, USA and RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, NY 11973, USA

Phase diagram of QCD matter

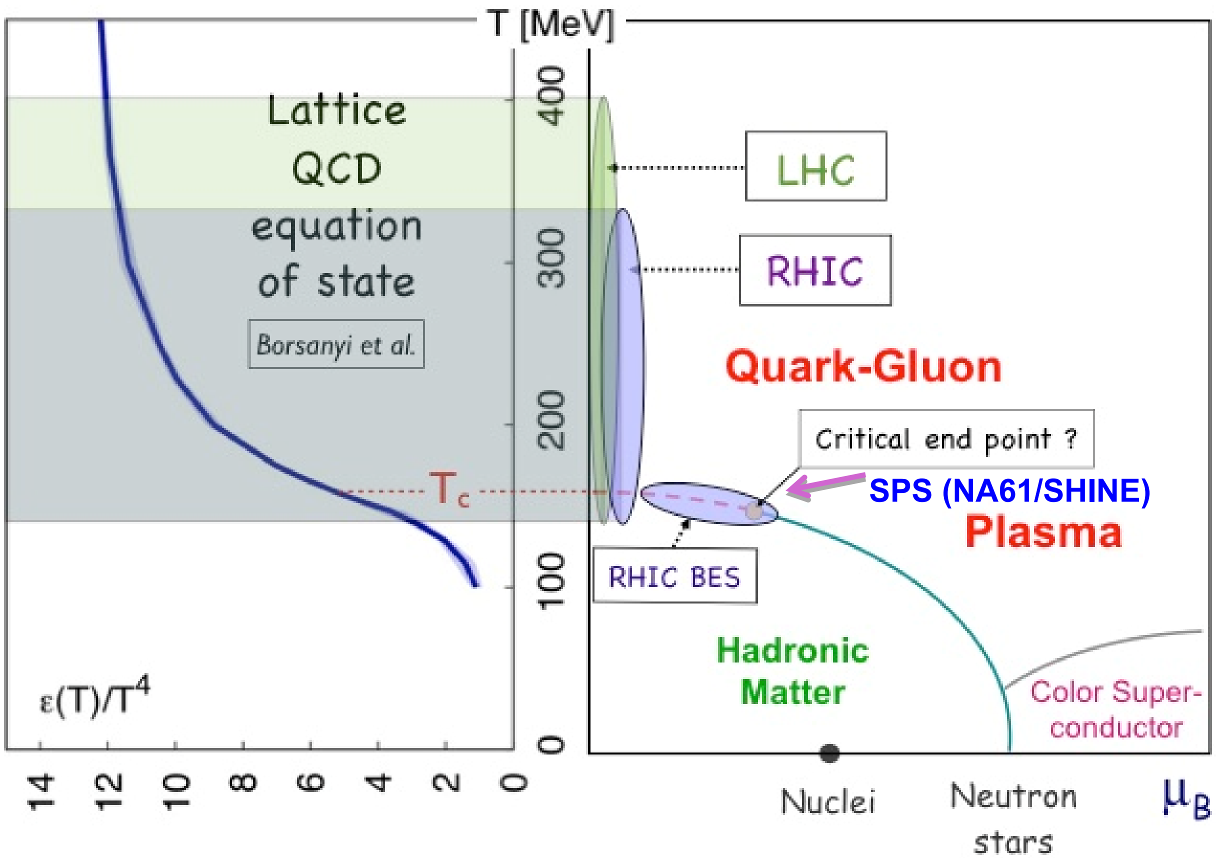
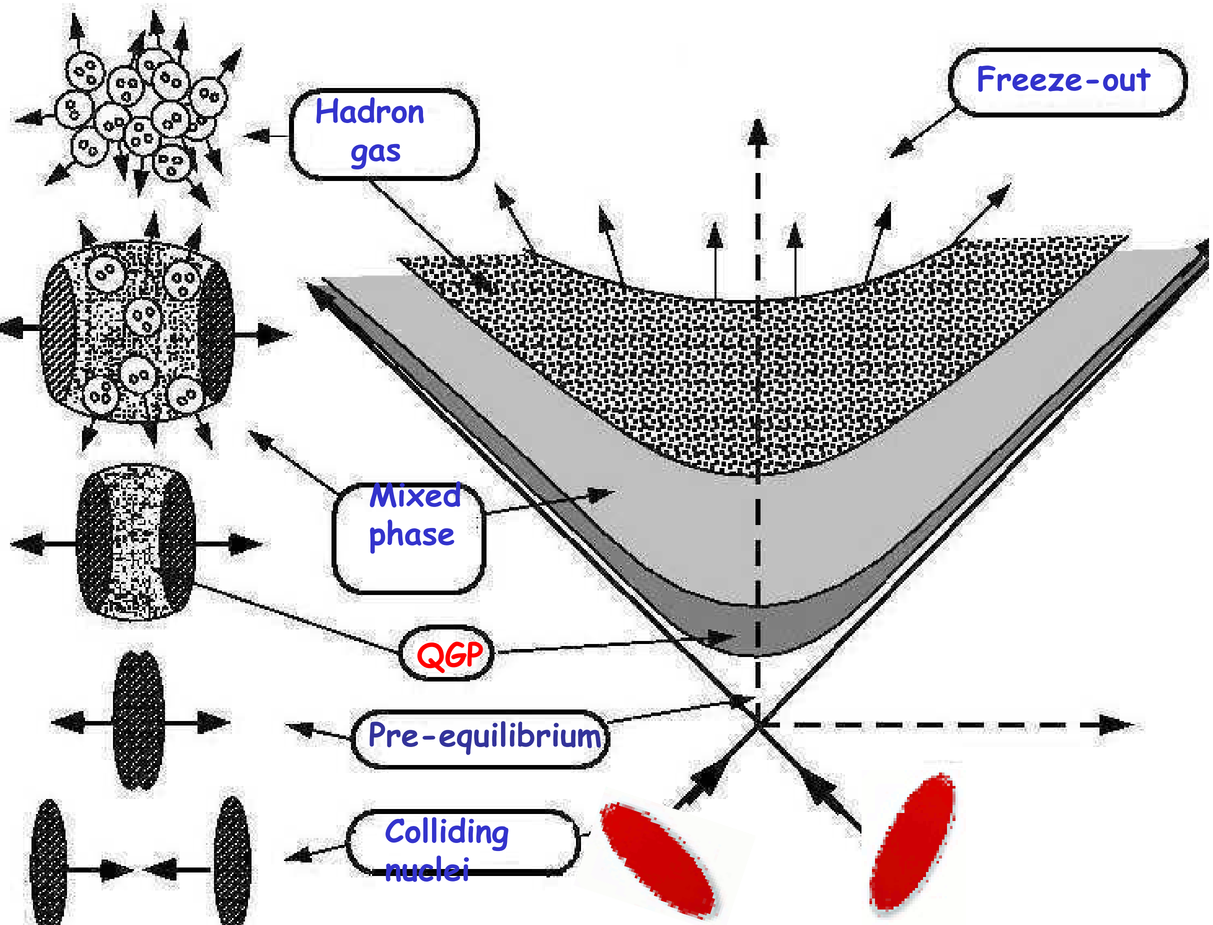


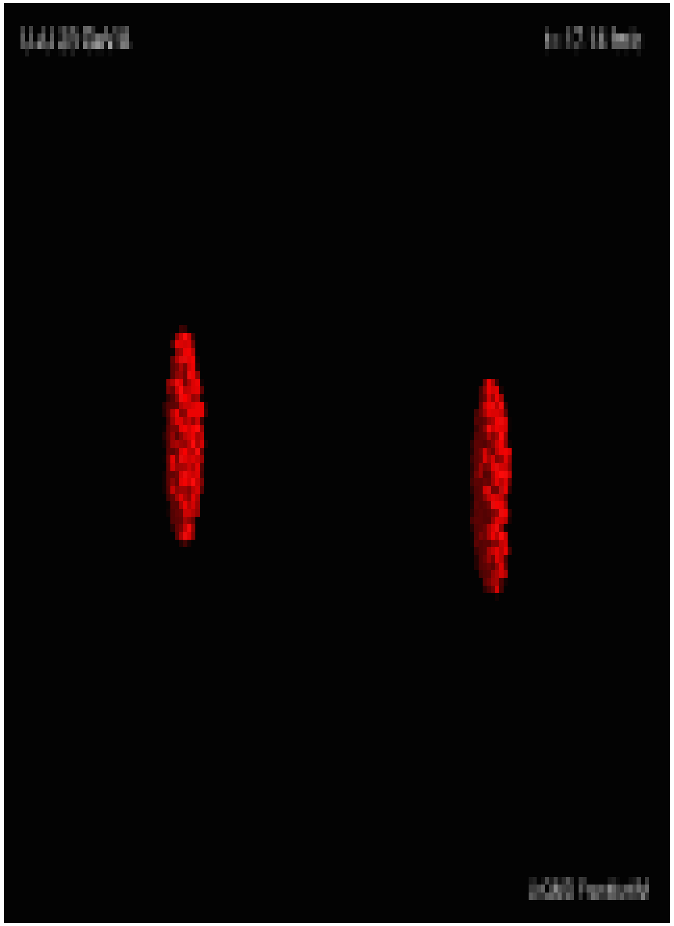
Figure 1. Phase diagram of QCD matter (right panel) overlaid with regions covered by LHC and RHIC. The experimentally covered ranges are projected onto the energy density versus temperature at μ_B = 0 curve calculated by lattice QCD (left panel).

Berndt Mu ̈ller, Arxiv 1309.7612v2 12 Oct2013

Stages of nucleus-nucleus collisions

U+U 23 GeV/N





http://urqmd.org/~weber/CERNmovies/gifviewu.html

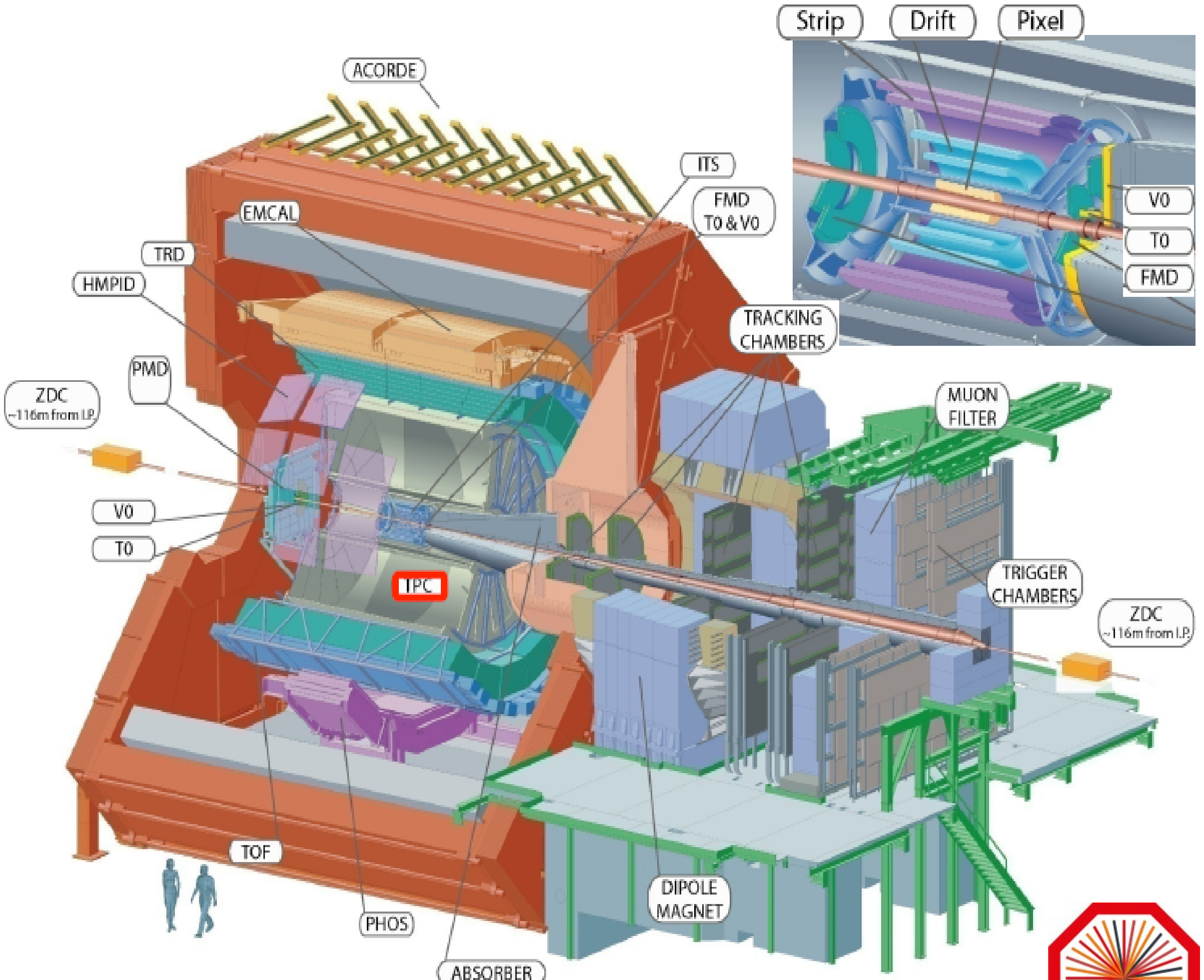
Modern HI experiments

Pb-Pb : study QGP properties
discover new aspects of strongly coupled matter

p-Pb : study "cold" nuclear matter effects

pp : study "reference" for p-Pb and Pb-Pb, basic QCD processes genuine pp physics

Example: ALICE installation at LHC



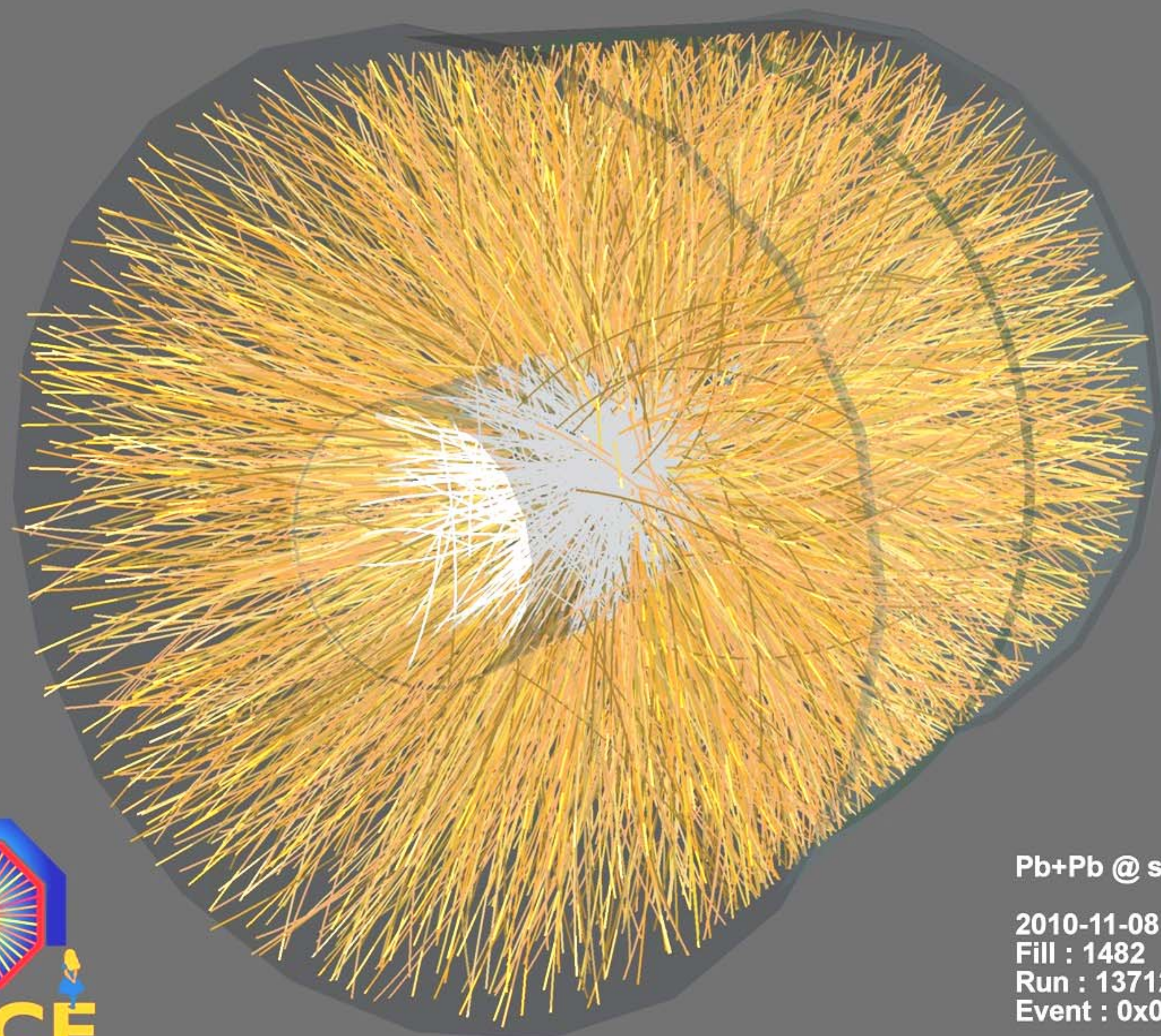
Central Detectors:
Inner Tracking System
Time Projection Chamber
Time-of-Flight
Transition Radiation Detector

Spectrometers:
High Momentum PID (RICH)
Photon Multiplicity
Forward Multiplicity
Muon Spectrometer

Calorimeters:
EM Calorimeter
Photon Spectrometer (PHOS)
Zero Degree Calorimeter

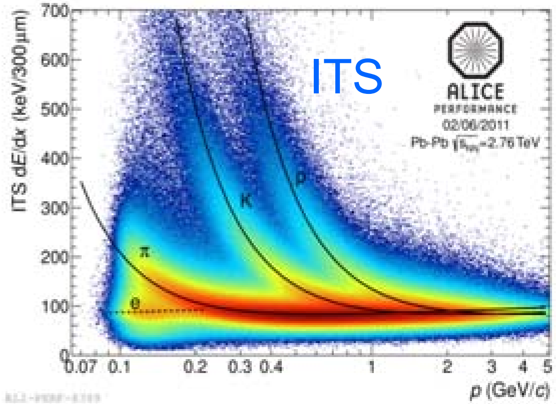
Trigger:
Trigger Detectors
pp High-Level-Trigger

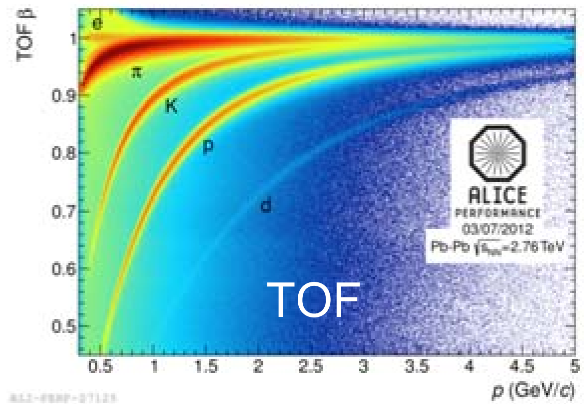
ALICE

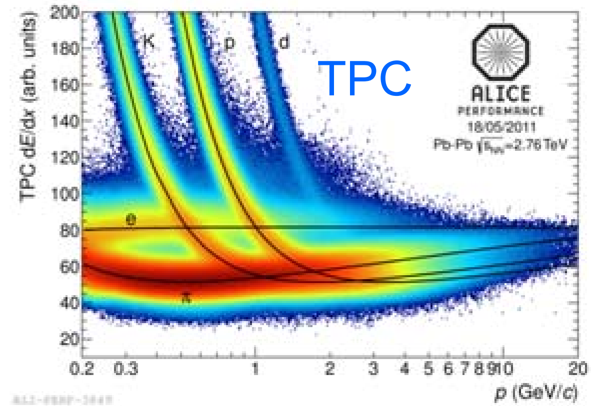

Pb+Pb @ sqrt(s) = 2.76 ATeV
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

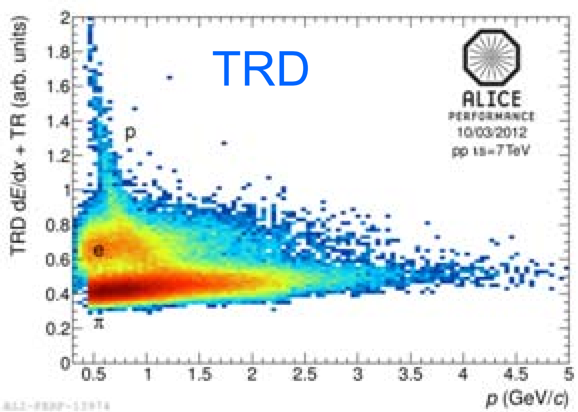
ALICE

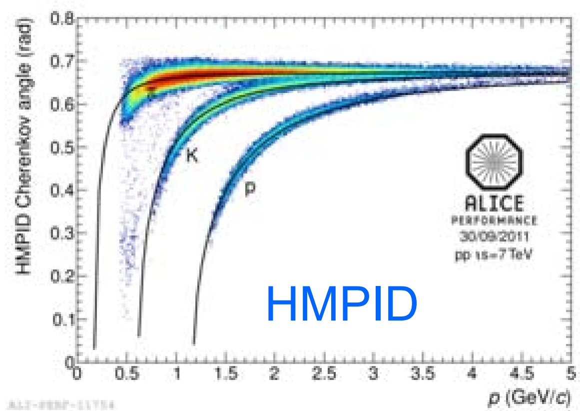
Particle identification

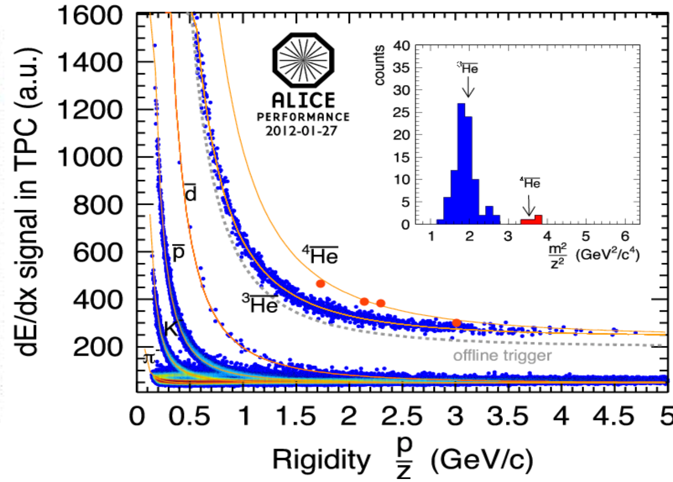








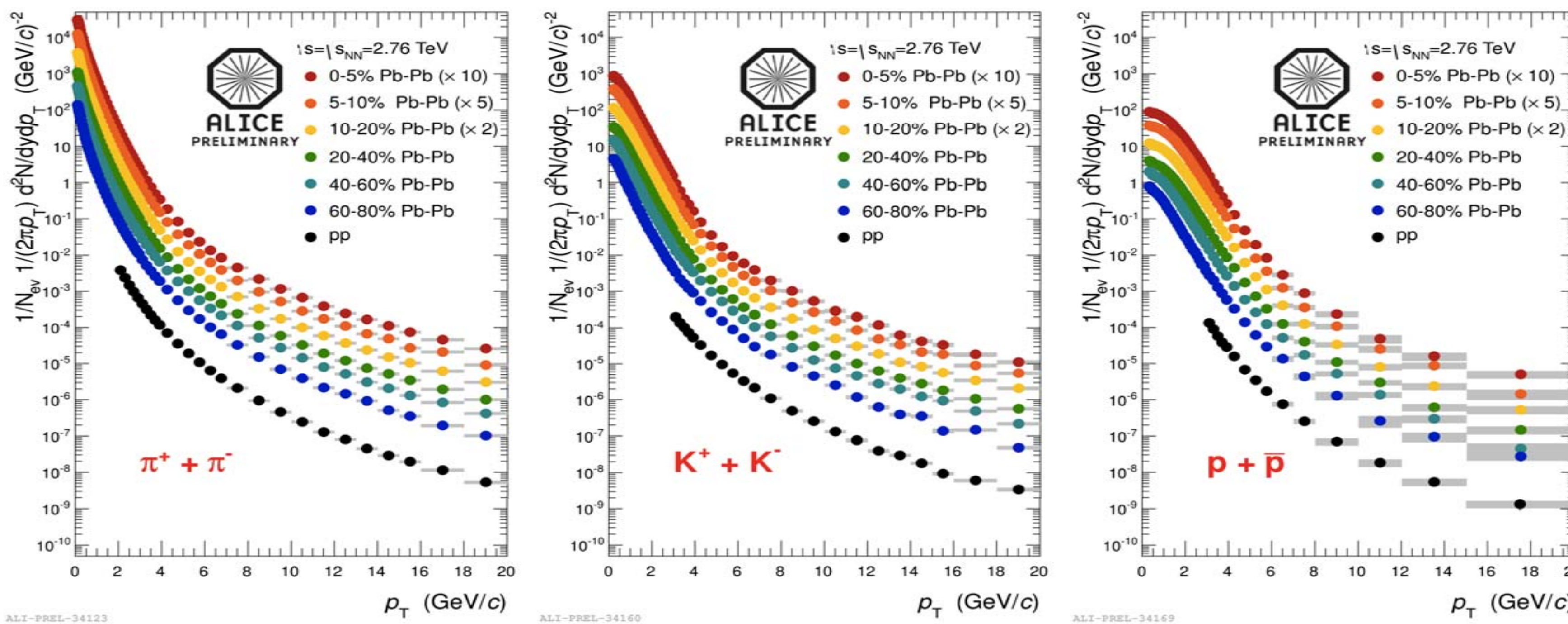




From RHIC to LHC: some experimental results and puzzles

Pb-Pb collisions at LHC

Identified-particle p_T spectra up to 20 GeV/*c*



95 % of all particles below 1.5 GeV/*c* : particle production non-perturbative process

- **Low-p_T < 2 GeV/*c* :** dynamics of bulk matter described by **R**elativistic **H**ydrodynamic **M**odels **(RHD)**
- **High-p_T > 8 GeV/*c* :** spectra reflect interaction of partons from hard scatterings with the medium
- **Intermediate p_T 2 < p_T < 8 GeV/*c* :** interplay of soft and hard processes

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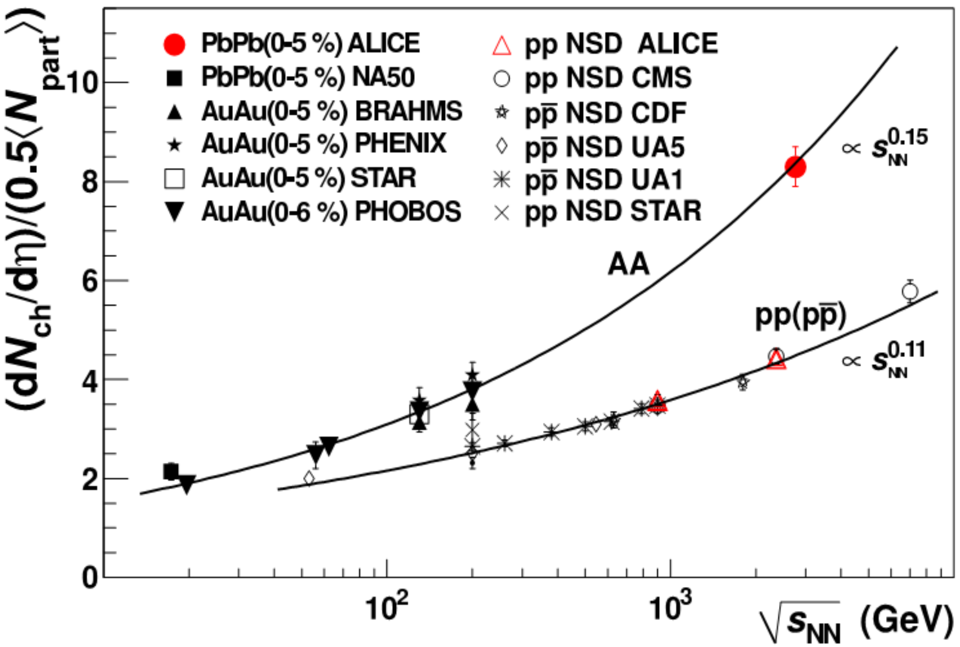
Charged particle pseudo-rapidity density per participant pair for central nucleus-nucleus and non-single diffractive pp (pp) collisions , as a function of $\sqrt{s_{NN}}$

- an increase of about a factor 1.9 relative to **pp** collisions at similar collision energies
- an increase of about a factor 2.2 to central **Au-Au** collisions at $\sqrt{s_{NN}}$ = 0. 2 TeV !



- Faster growth with $\sqrt{s_{NN}}$ in AA than in pp!
- Logarithmic extrapolation is ruled out
- Important constraint for the models!

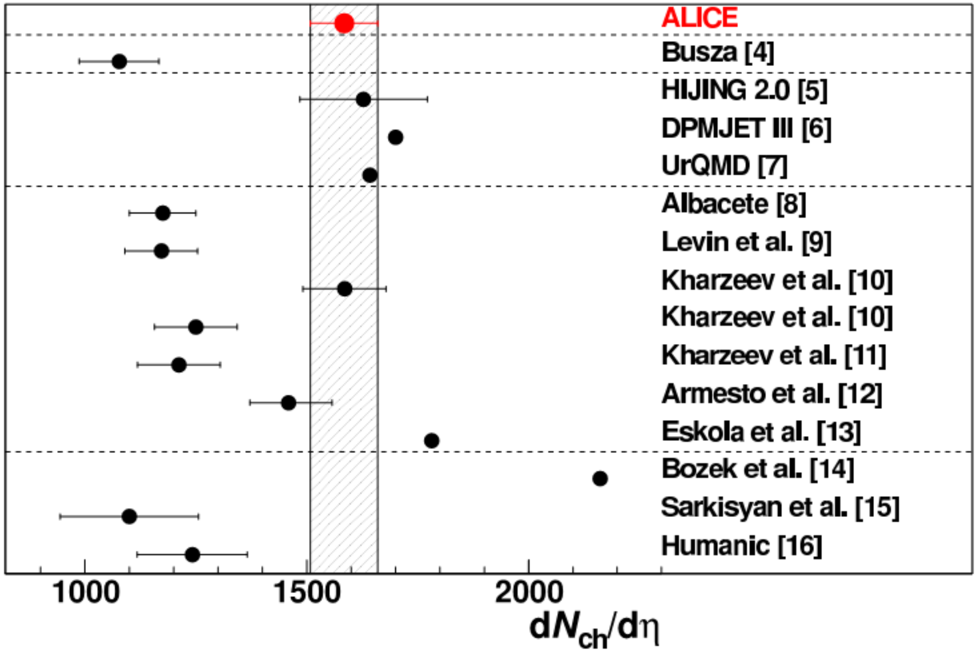
arXiv:1011.3916 [nucl-ex]. *Phys. Rev. Lett.* 105 (2010) 252301

Charged-particle multiplicity density at mid-rapidity in central Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

Multiplicity:

is essential to estimate the initial energy density and it is the 1st important constraint for the models!

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



Comparison of ALICE measurement with model predictions.

- **Bjorken energy density at $\sqrt{s_{NN}}$ = 2.76 TeV :**

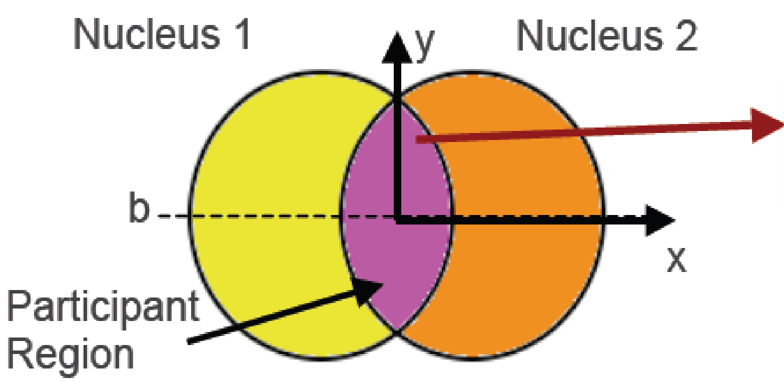
2.8 x RHIC for 5% of most central collisions

arXiv:1011.3916 [nucl-ex]. *Phys. Rev. Lett.* 105 (2010) 252301

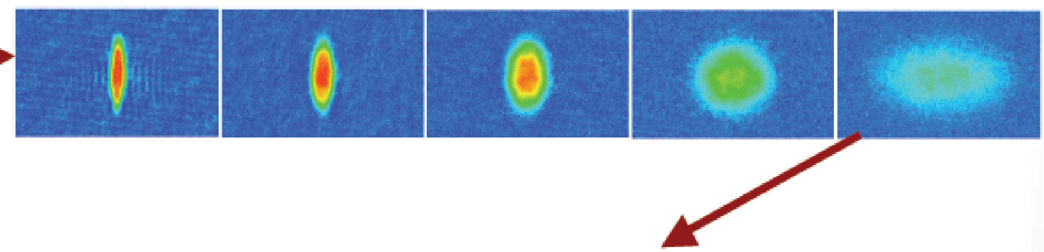
Elliptic flow in Pb-Pb $\sqrt{s_{NN}}$ =2.76 TeV

Initial spatial anisotropy is converted to anisotropy in momentum space

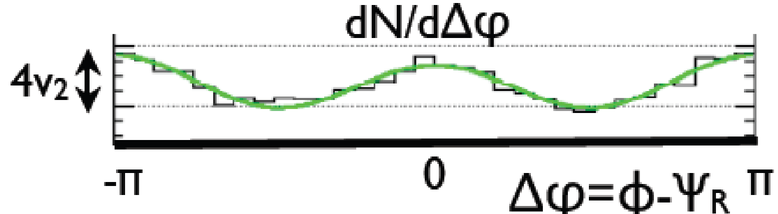
Initial anisotropy



Pressure driven expansion



Final anisotropy



$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum 2v_n \cos\left(n(\phi - \psi_R)\right)\right)$$

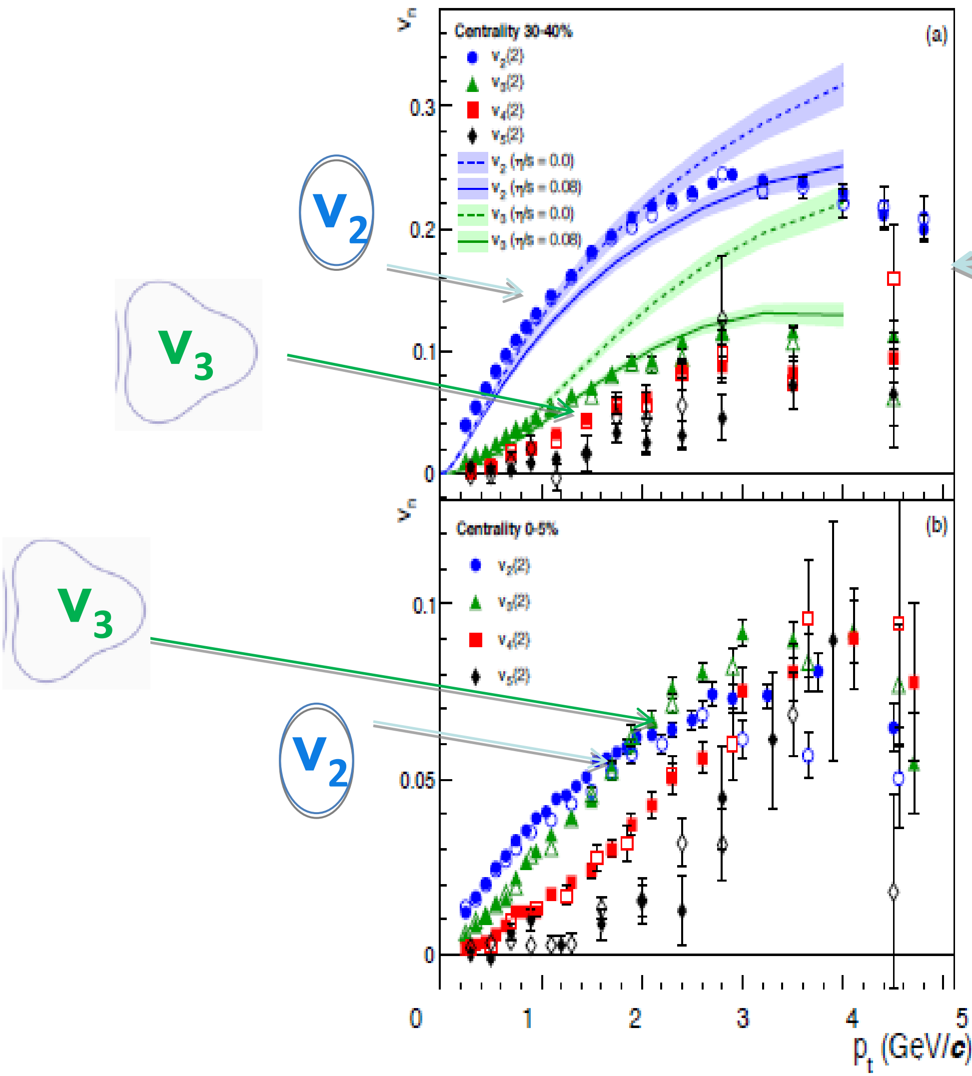
S.Voloshin, Y.Zhang, Z.Phys.C70 (1996) 665

$$v_2 = \left\langle \cos\left(2(\phi - \underline{\psi_R})\right)\right\rangle \propto \varepsilon$$

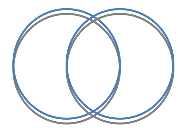
Elliptic flow is quantified by the second Fourier coefficient (v_2) of the observed particle distribution

Higher harmonic anisotropic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV:

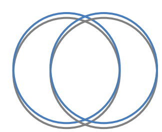
ALICE



v_2 , v_3 , v_4 , v_5 vs. p_t



30-40% centrality

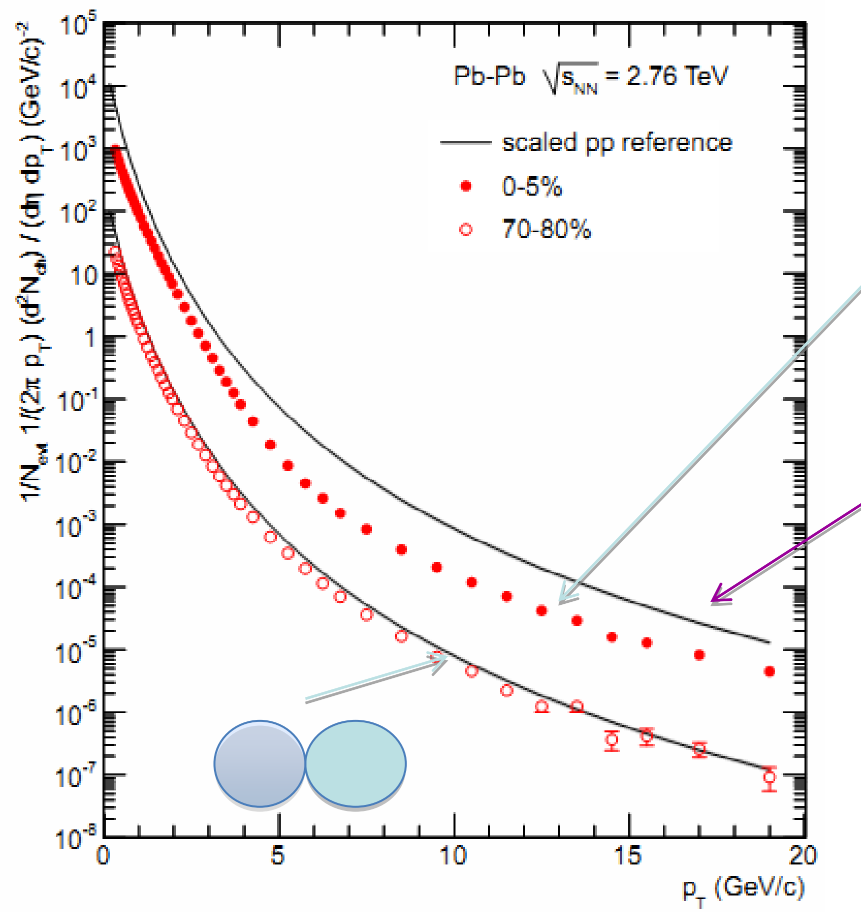


0-5% centrality

- behavior of V_3 changes dramatically for very central collisions
- hydrodynamic prediction for V_3 (pt) with η/s = 0.08→better than η/s = 0.0
- hydro calculations

arXiv:1105.3865 ; CERN-PH-EP-2011-073. - 2011

Suppression of charged particle production at large pT in central Pb-Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV: R_{AA} vs. Pt



Data driven interpolation
900 GeV & 7 TeV
or from NLO
7 TeV * NLO (2.76 TeV)/NLO(7 TeV)

Nuclear modification factor R_{AA}:

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

R_{AA} =1 if no nuclear effects

arXiv:1012.1004v1 [nucl-ex], 5 Dec 2010; *Phys. Lett. B* 696 (2011) 30-39

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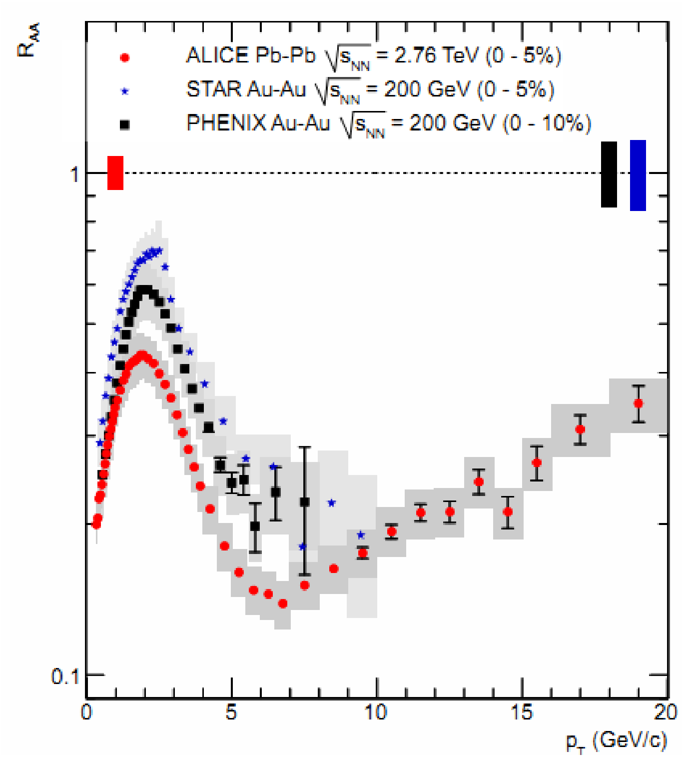
Suppression of charged particle production at large p_t in central Pb-Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV:

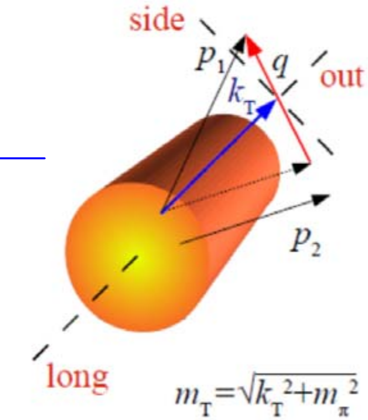


$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta\, dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta\, dp_T},$$

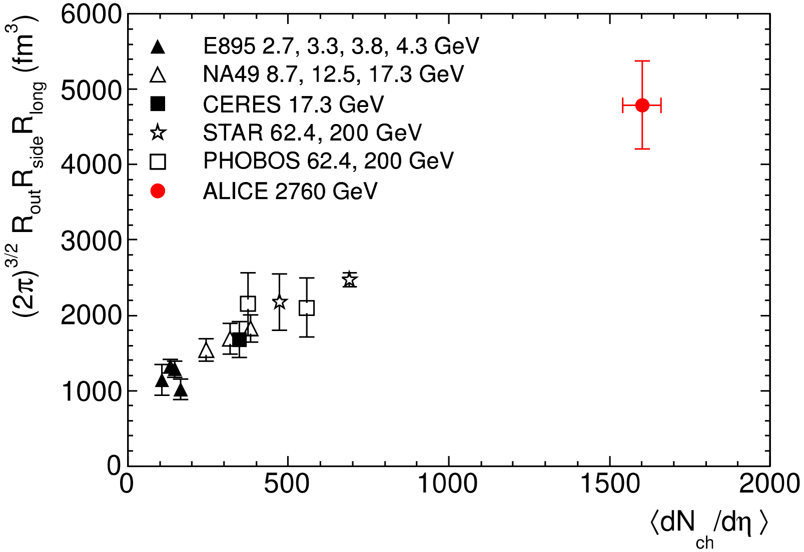
- results are qualitatively similar to the STAR and PHENIX data
- more “dramatic” behavior
- the medium formed in central Pb-Pb collisions is denser than at RHIC

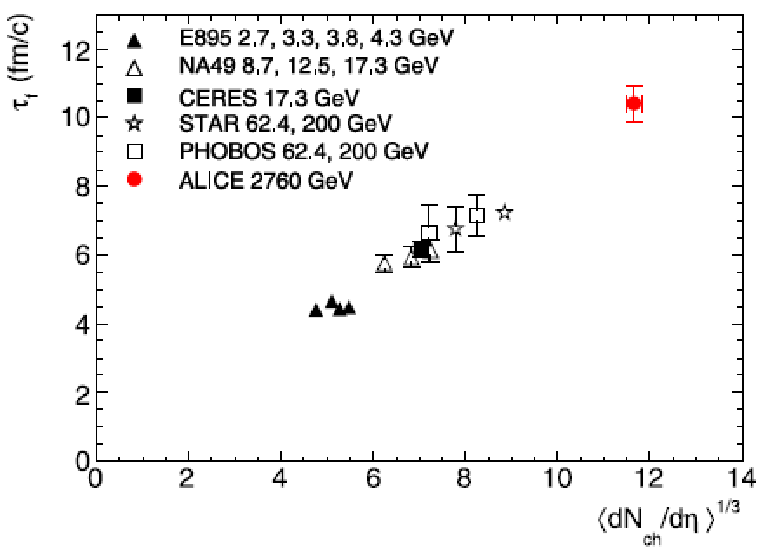
arXiv:1012.1004v1 [nucl-ex], 5 Dec 2010; *Phys. Lett. B* 696 (2011) 30-39

The particle production source



Volume and Lifetime





Volume at freeze out: ~ 5000 fm^3

x2 of RHIC

Initial volume ~ 800 fm^3

Lifetime from collision to freeze out

~ 10 fm/c

30% longer

Hotter, bigger and longer-lived

Source size for hadron emission is determined
by two-pion correlations methods: Hanbury-Brown Twiss (HBT)

PLB 696, 328 (2011)

Summary and outlook -1

We entered a new and unexplored territory of pp, p-Pb and Pb-Pb collisions at the LHC !

The medium produced in Pb-Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV at the LHC has in comparison to 200 GeV data at RHIC:

~ 3 times larger energy density

~ 2 times larger volume of homogenity region

~ Larger lifetime ≈ +20% (≈ 10 fm/c)

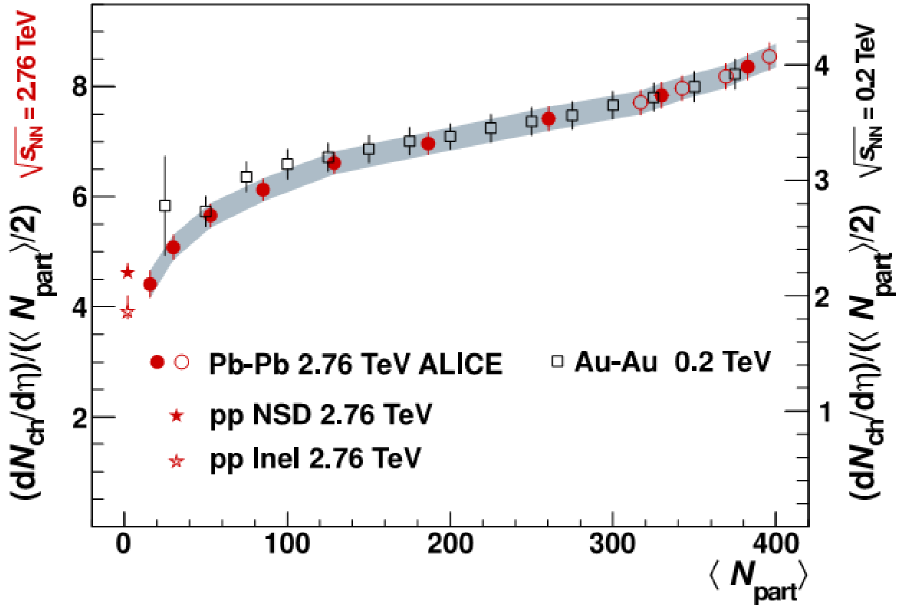
It shows the properties of almost ideal liquid (like at RHIC)

It appears to be denser than at RHIC

(suppression of high- p_t particles is stronger)

Some puzzles:

Centrality dependence of the charged-particle multiplicity density at mid-rapidity in Pb–Pb collisions at $\sqrt{s_{NN}}$ =2.76 TeV

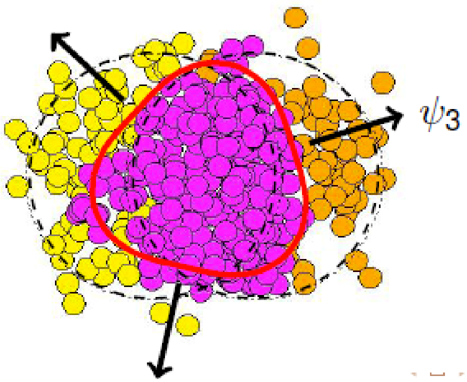


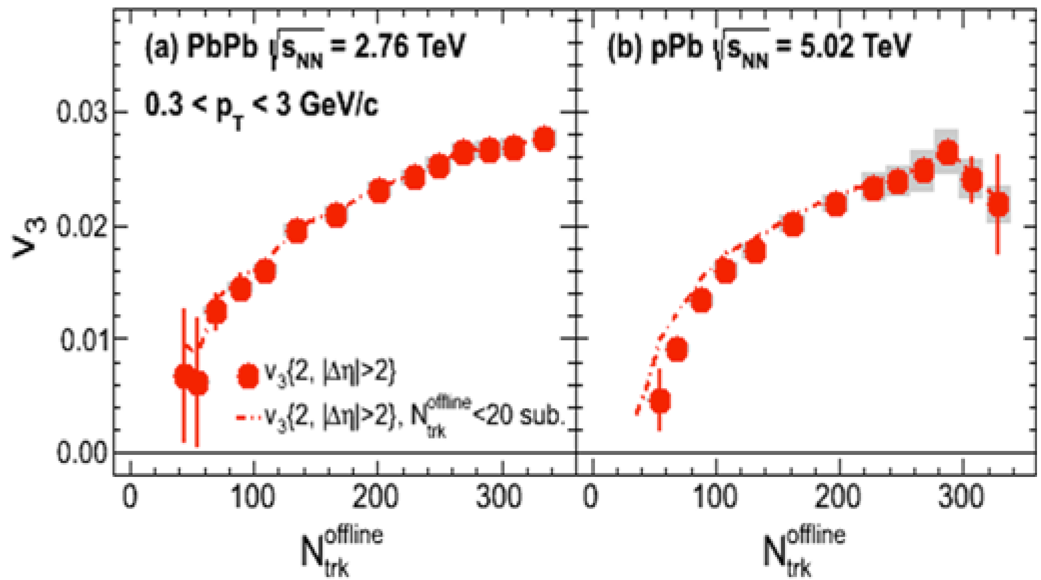
very similar centrality dependence at LHC and RHIC !

(Note 2 scales: "left" (for 2.76 TeV and "right" - for 200 GeV data)

arXiv:1012.1657 [nucl-ex], 4 Feb 2011; *Phys.Rev.Lett.* 106 (2011) 032301

v_3 harmonic anisotropic flow in Pb-Pb and in p-Pb collisions ?



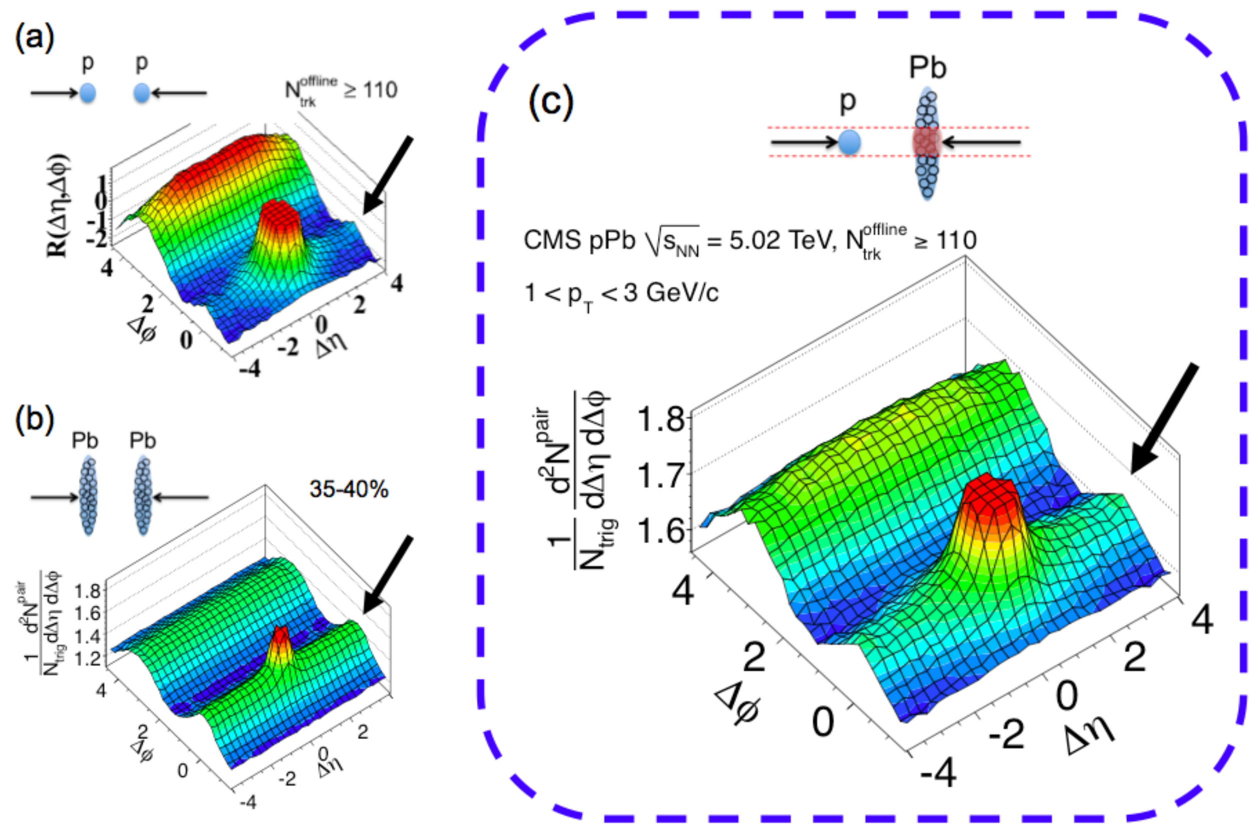


The CMS Collaboration

Monika Sharma for the CMS collaboration,
Flow and Correlations in PbPb and pPb Collisions from CMS Experiment
EPJ Web of Conferences **66**, 04027 (2014)

(2015), http://arxiv.org/pdf/1502.05382v1.pdf

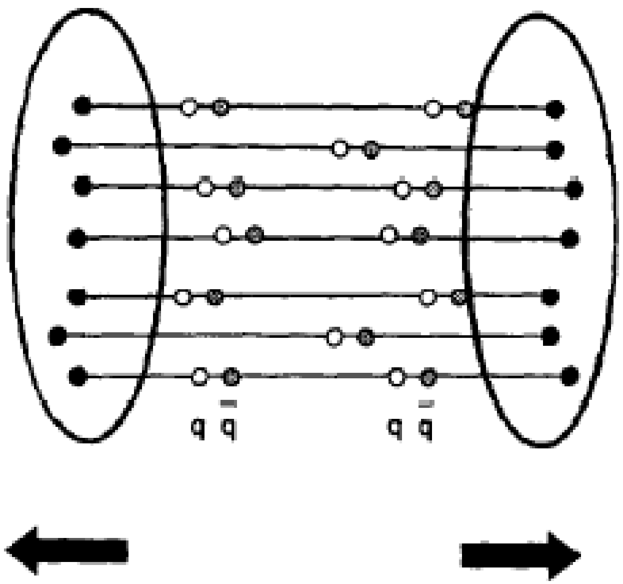
Unexplained long-range correlations "Ridge" by CMS in p-Pb at LHC similar to pp and Pb-Pb !



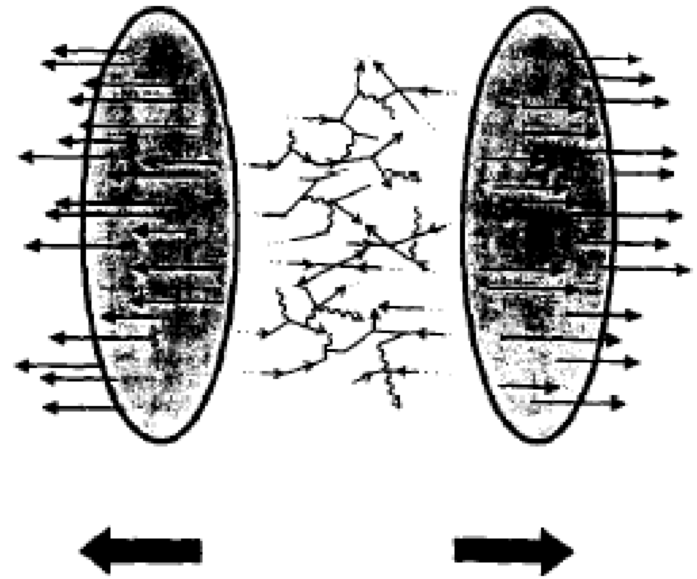
Phys. Lett. B 718 (2013) 795 http://arxiv.org/abs/1210.5482

From RHIC to LHC: theory

Multiparticle production: two approaches



a)



b)

(a) String picture: primary interactions lead to color flux tubes (strings) which break by qq production.

(b) Parton approach: multiple scatterings accompanied by emission and absorption of quarks and gluons are described as intermitted parton cascades.

K. Geiger, SPACE-TIME DESCRIPTION OF ULTRA-RELATIVISTIC NUCLEAR COLLISIONS IN THE QCD PARTON PICTURE, *CERN, TH-Division, CH-121 I Geneva 23, Switzerland,* ELSEVIER Physics Reports 258 (1995) 237-376

The quark-gluon plasma produced in nuclear collisions at LHC and RHIC

"a new form of matter with unique properties" [1]

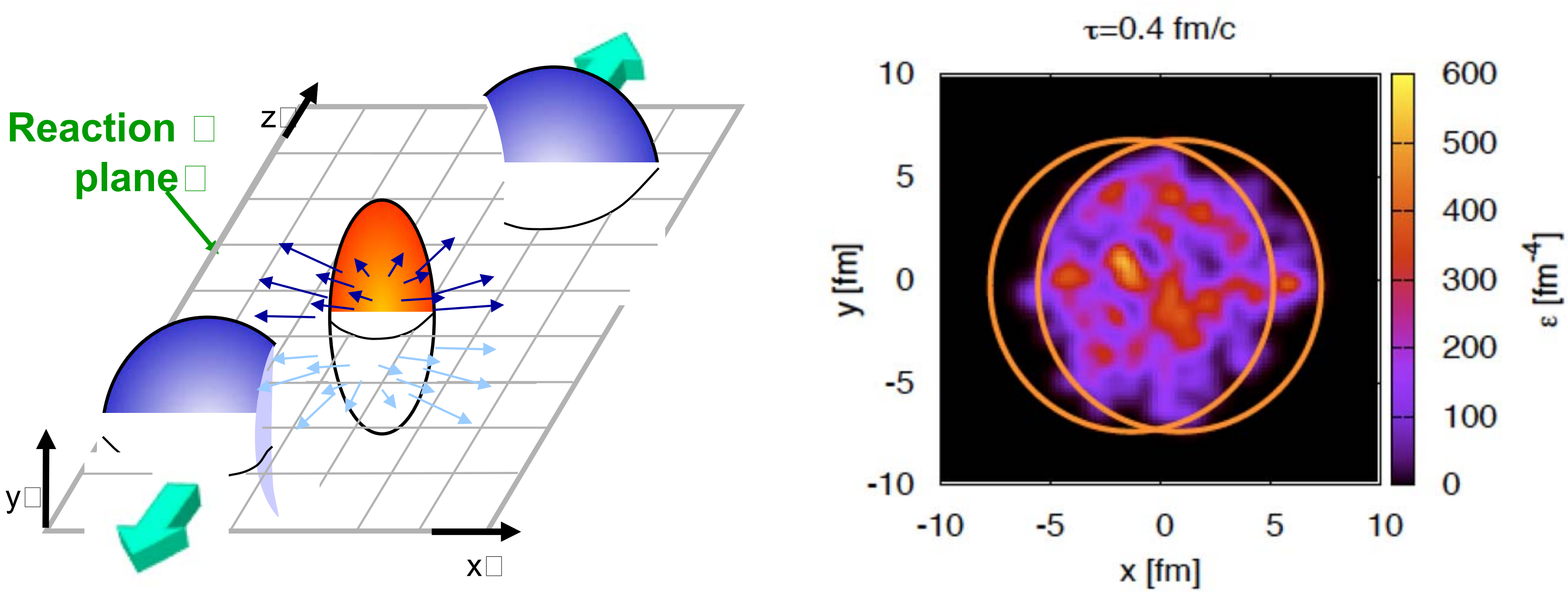
- It is relativistic, yet strongly coupled;
- it is a liquid that cools into a gas;
- it is a nearly "perfect" liquid near the quantum limit of shear viscosity;
- it thermalizes as fast as causality permits;
- it creates its own new vacuum state to exist.

[1] B. V. Jacak and B. Mu ̈ller, Science 337, 310 (2012). Berndt Muller arxiv:1309.7612v2 12 Oct2013
[2] Resent overview CONFX "Strong Doc" http://arxiv.org/pdf/1404.3723.pdf
[3] QM 2014 at Darmstadt updates http://qm2014.gsi.de
[4] E.Shuryak, Heavy Ion Collision: Achievments and Challenges, arXiv:1412.8393 29 Dec.204

Problems:

Centrality and widths of centrality classes in relativistic heavy ion collisions

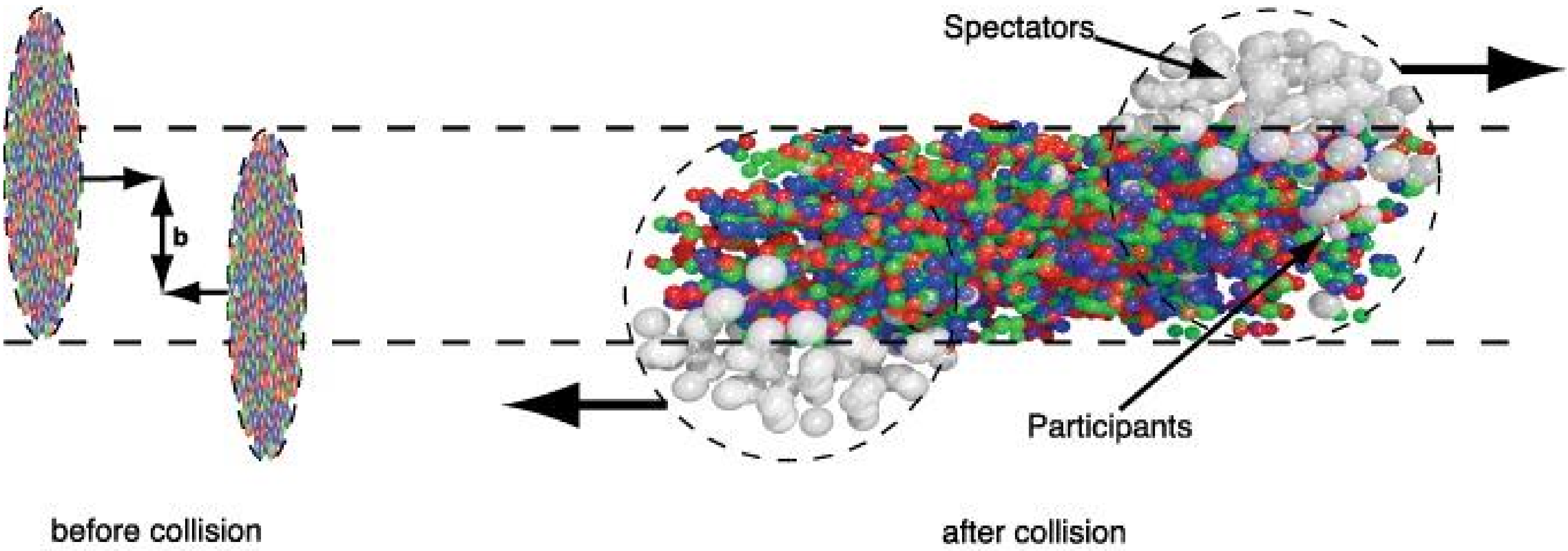
Centrality and widths of centrality class in relativistic heavy ion collisions



Geometry of a non-central heavy ion collision (left panel). Density fluctuations in the transverse plane in a sample collision event (right panel).

Berndt Müller, Arxiv 1309.7612v2 12 Oct2013

Terminology

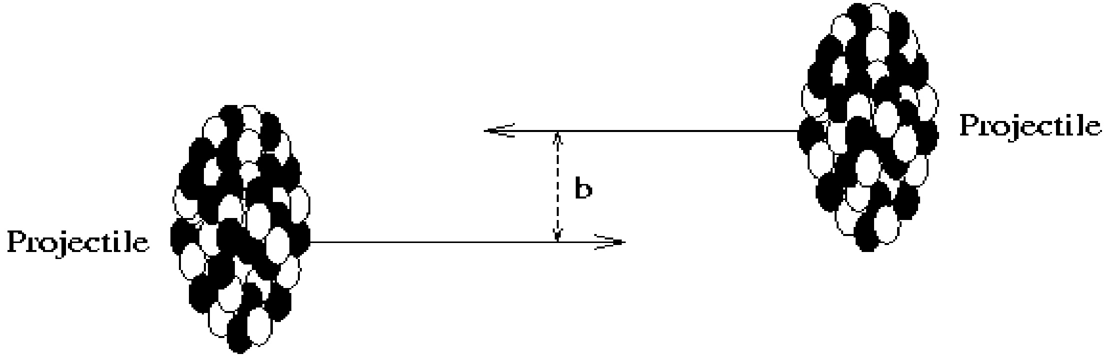


- Nucleon-participants N_{part} - nucleons collided at least once
- Nucleon-spectators N_{spect} - nucleons, which didn't interact
- Number of nucleon-nucleon collisions N_{coll}
- Multiplicity of charge particles N_{ch}

Why centrality is important?
What is the width of centrality class?

--- global observables and event mean values
--- fluctuations
--- correlations
--- flow
--- event shape engineering
--- …..

We have to minimize **"the trivial Volume Fluctuations"**
if we wish to study any fluctuations or correlations



The centrality percentile c of an A-A collision with an impact parameter b is defined as :

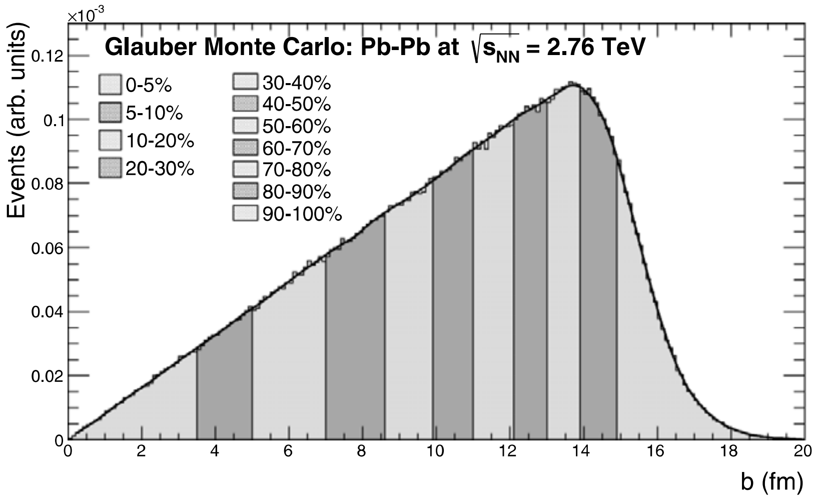
Theory:

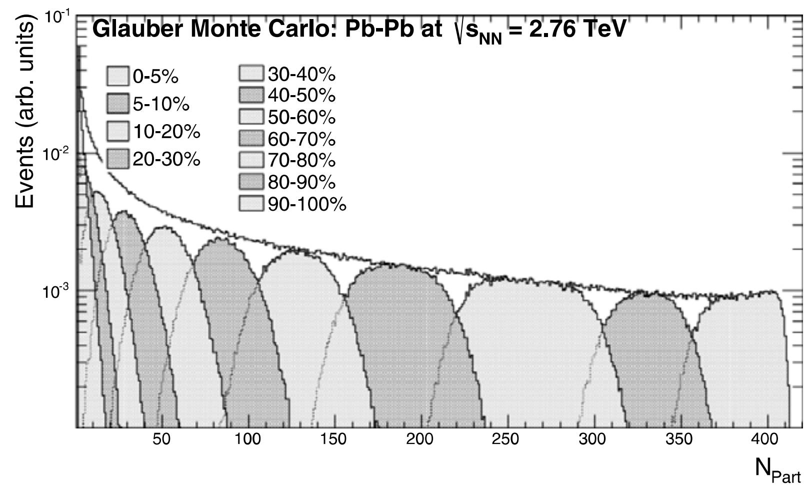
$$c = \frac{\int_0^b d\sigma/db'\, db'}{\int_0^\infty d\sigma/db'\, db'} = \frac{1}{\sigma_{AA}} \int_0^b \frac{d\sigma}{db'}\, db'. \qquad (1)$$

Experiment:

$$c \approx \frac{1}{\sigma_{AA}} \int_{N_{\mathrm{ch}}^{\mathrm{THR}}}^{\infty} \frac{d\sigma}{dN'_{\mathrm{ch}}}\, dN'_{\mathrm{ch}} \approx \frac{1}{\sigma_{AA}} \int_0^{E_{\mathrm{ZDC}}^{\mathrm{THR}}} \frac{d\sigma}{dE'_{\mathrm{ZDC}}}\, dE'_{\mathrm{ZDC}}. \qquad (2)$$

Centrality of relativistic heavy ion collisions In various experiments: ALICE as an example





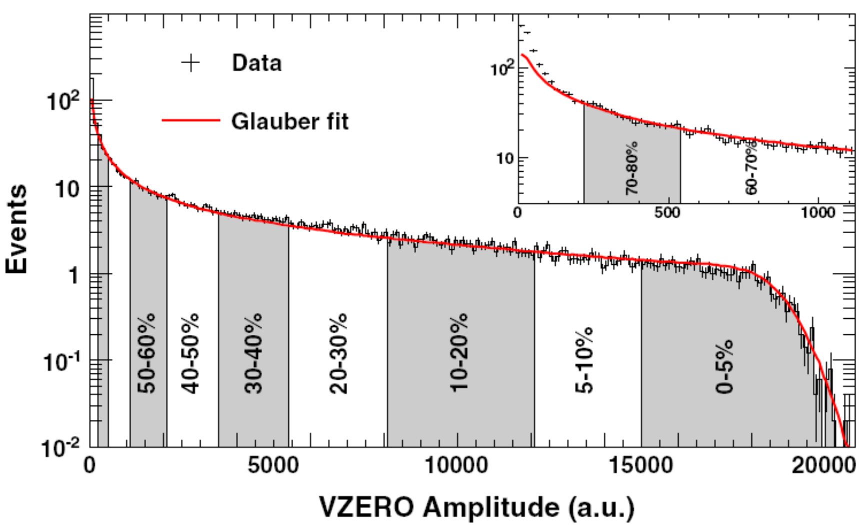
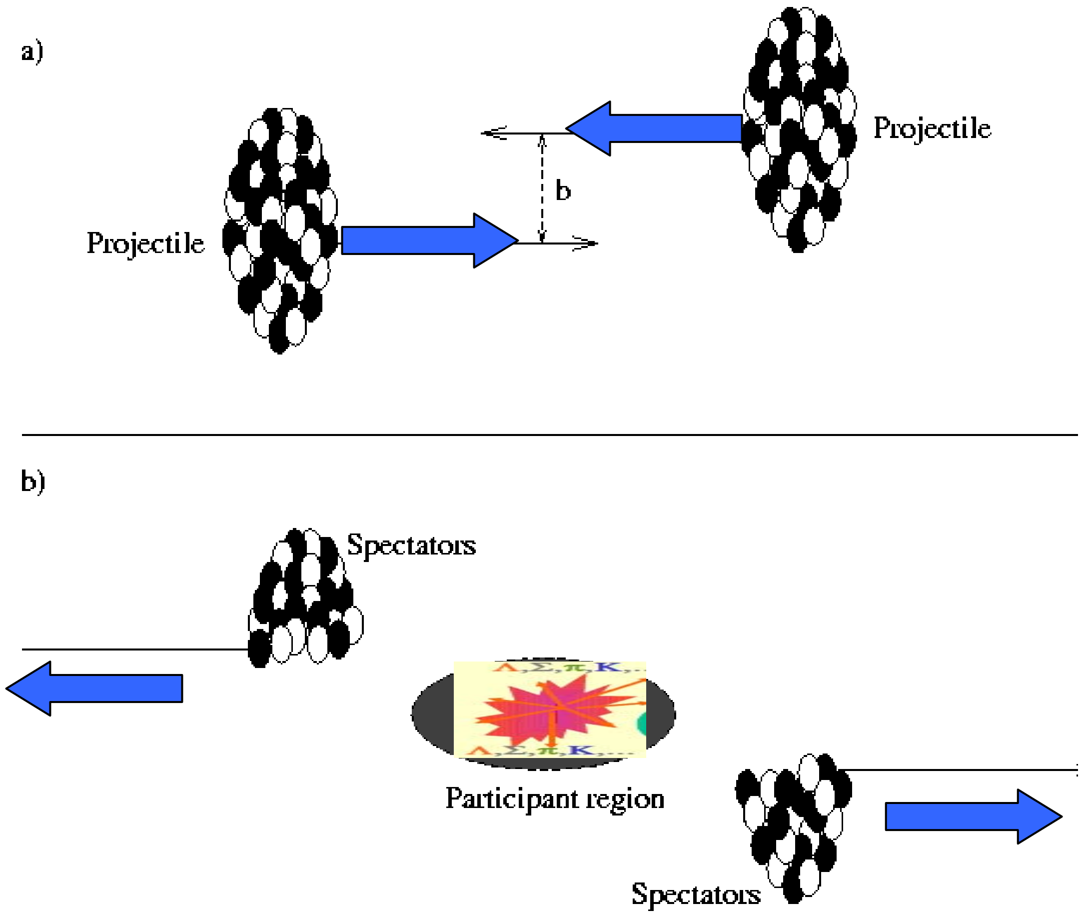


FIG. 10. (Color online) Distribution of the sum of amplitudes in the VZERO scintillators. The distribution is fitted with the NBD-Glauber fit (explained in the text), shown as a line. The centrality classes used in the analysis are indicated in the figure. The inset shows a zoom of the most peripheral region.

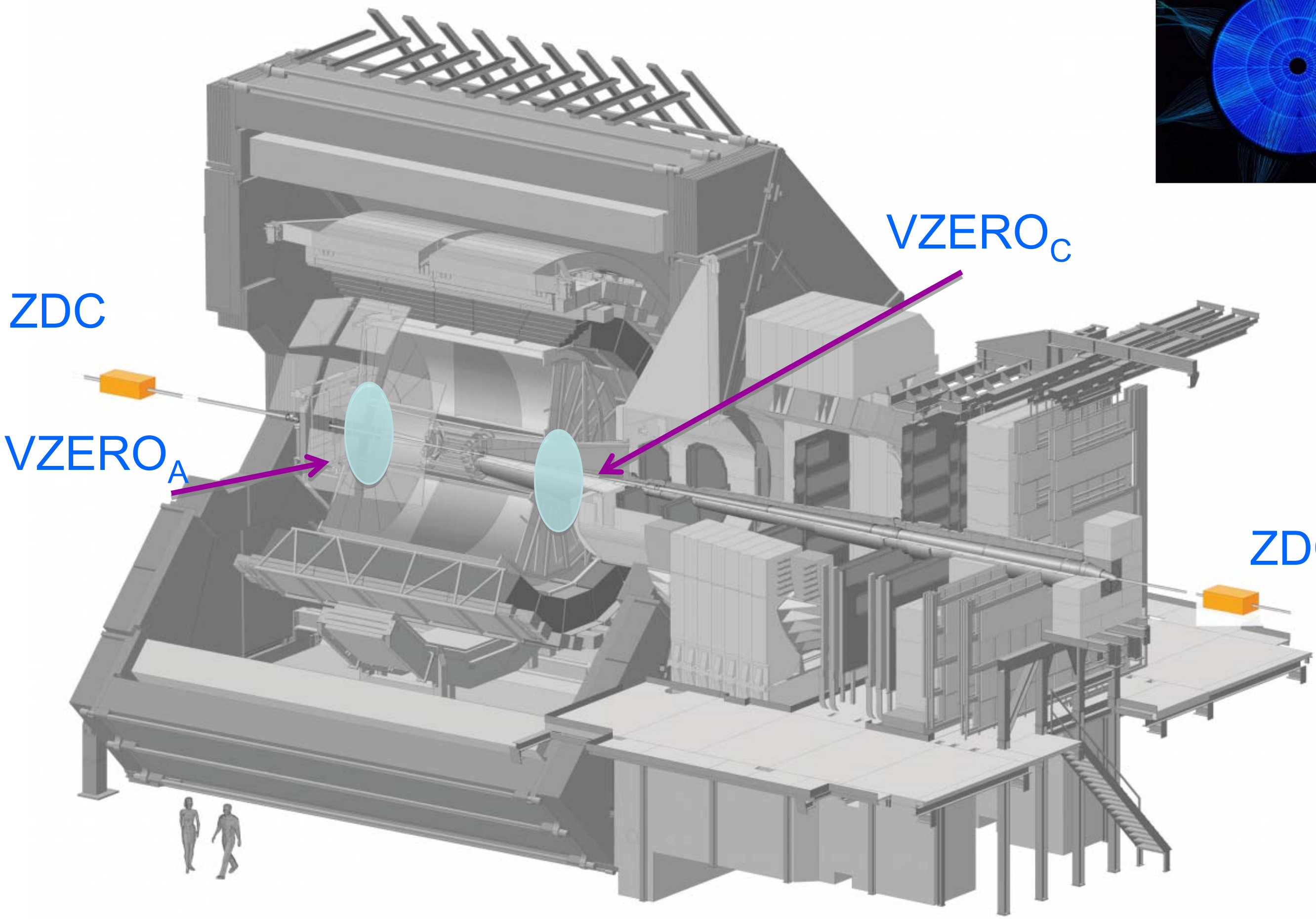
PHYSICAL REVIEW C **88**, 044909 (2013)

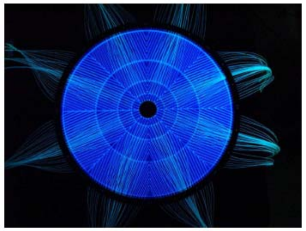
Centrality estimators: N_{part}



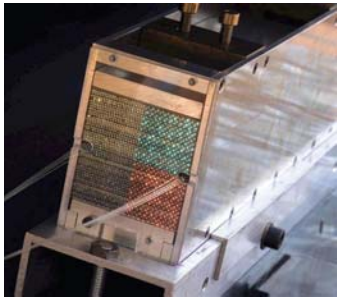
$$E_{ZDC}(\mathrm{TeV}) = 2.76 \times N_{\mathrm{spectators}}$$
$$N_{\mathrm{participants}} = A - N_{\mathrm{spectators}}$$

Centrality in ALICE: Zero Degree Calorimeters and VZERO multiplicty detectors



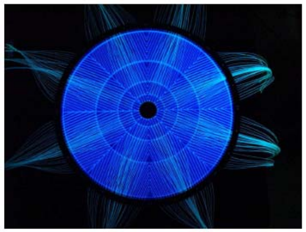



Hodoscopes
of scintillator cells

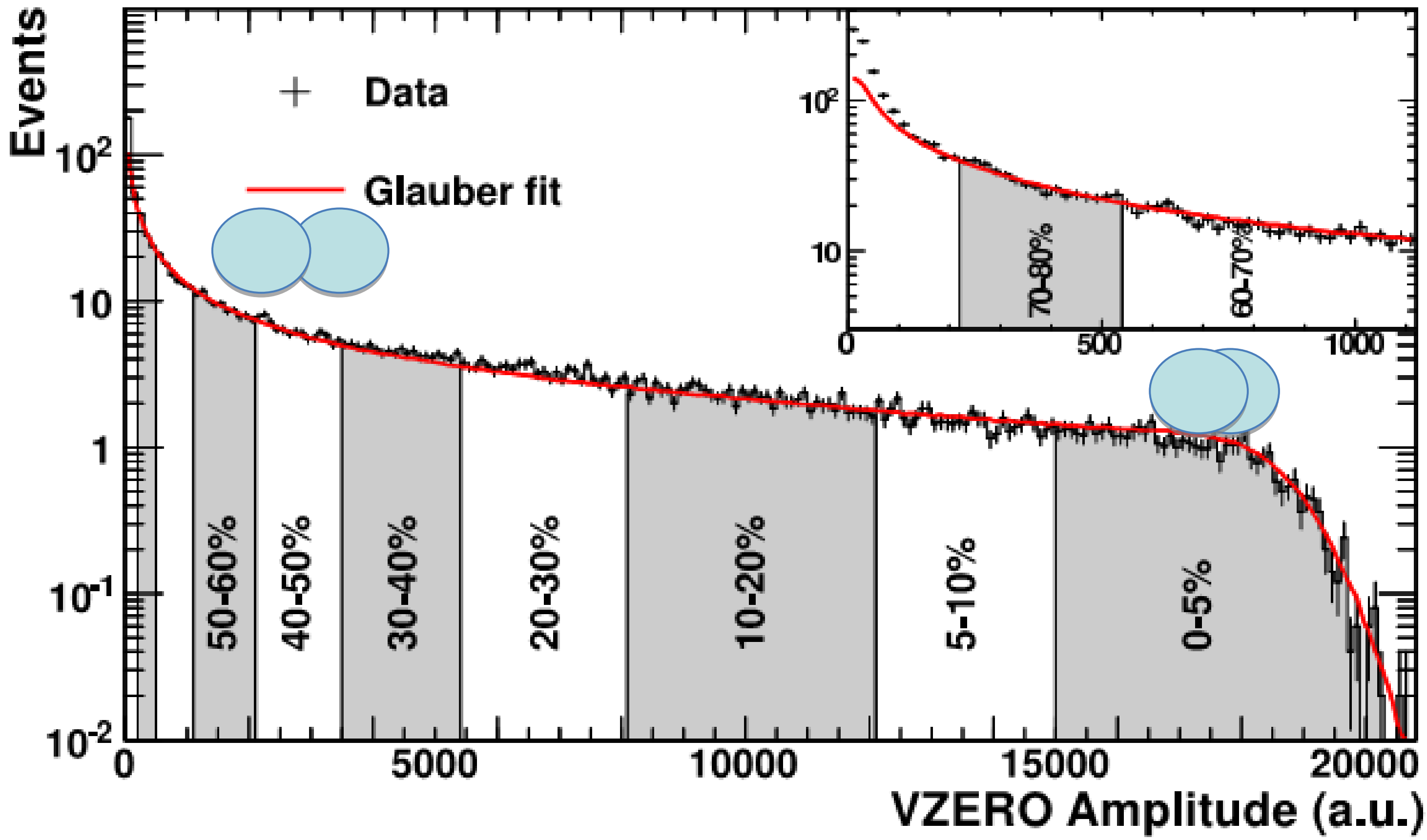


quartz-fiber
spaghetti calorimeters

Centrality estimators: multiplicity



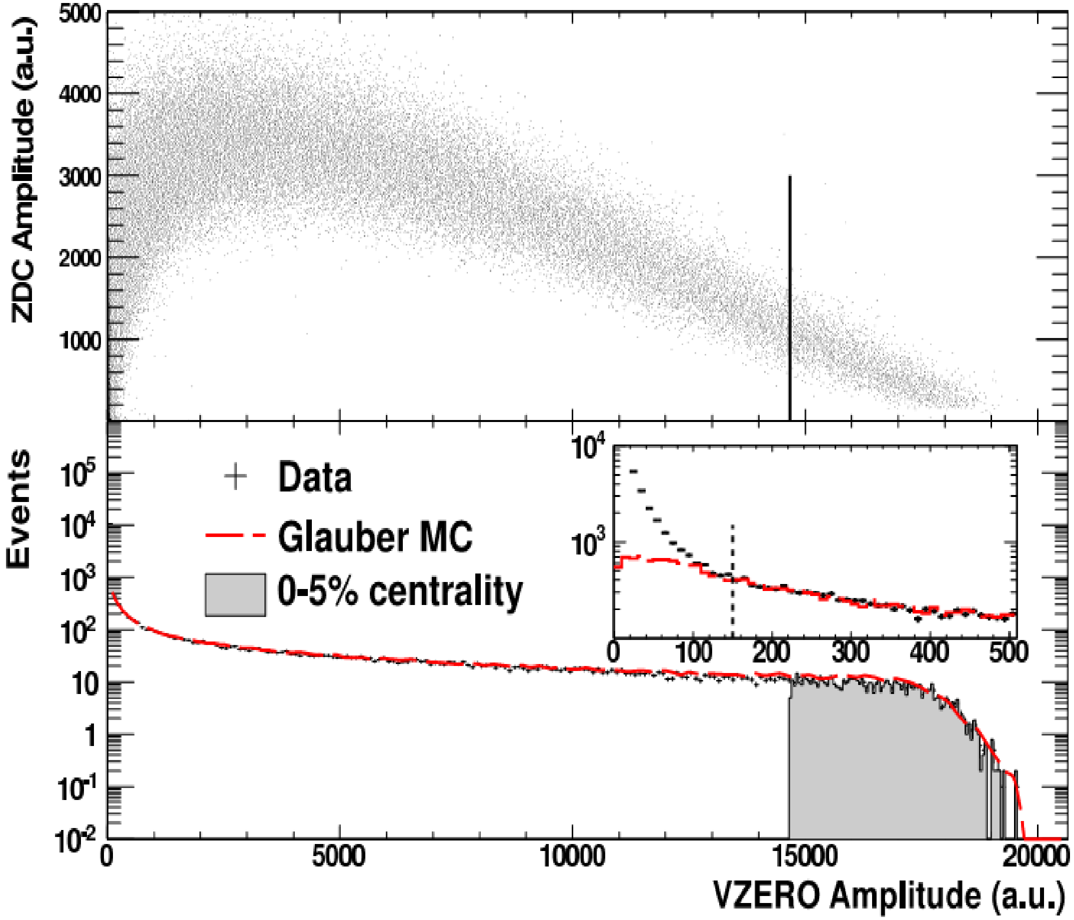
VZERO:
Front view of V0A and V0C arrays
$2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$



arXiv:1011.3916 [nucl-ex]. *Phys. Rev. Lett.* 105 (2010) 252301

K. Aamodt et al. (ALICE), JINST, 3 , S08002 (2008)

Centrality estimators: ZDC and multiplicity signal - (anti)correlation plot



ZDC

VZERO

arXiv:1011.3916 [nucl-ex]. *Phys. Rev. Lett.* 105 (2010) 252301

K. Aamodt et al. (ALICE), JINST, 3 , S08002 (2008)

Centrality estimators:
N_{part} and multiparticle production in MC models

Pb-Pb collisions in MC Glauber model

Pb-Pb collisions

$\sqrt{s_{NN}} = 2.76 TeV$

Nuclear density
-- Woods-Saxon distribution:

$$\rho(r) = \rho_0 \left\{1 + \exp\left(\frac{r - R_A}{a}\right)\right\}^{-1}$$

$$R_A = R_0 \cdot A^{\frac{1}{3}}$$

$$R_0 = 1.07\ fm$$
$$a = 0.545\ fm$$

Multiplicity of charged particles
in **Δ** y rapidity region: $\rho = m_f \cdot N_{str}(\beta)$

$$m_f = \Delta y \cdot \omega$$

$$N_{str}(\beta) = x N_{str}^{NN} N_c(\beta) + (1 - x) N_{AB}(\beta)$$

$$N_{str}^{NN} = 2.56 - 0.478 \ln E + 0.084 (\ln E)^2$$

In “two-component” model:

N_{part} : $N_{AB}(\beta)$ N_{coll} : $N_C(\beta)$

$$x \in [0, 1]$$

Poisson disctribution of particles from string hadronization :

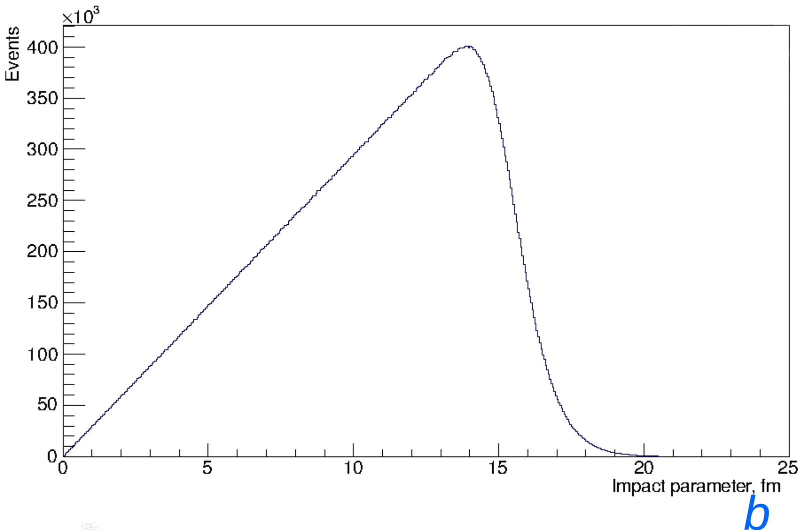
$$P(M_c) = e^{-\rho} \frac{\rho^{M_c}}{M_c!}$$

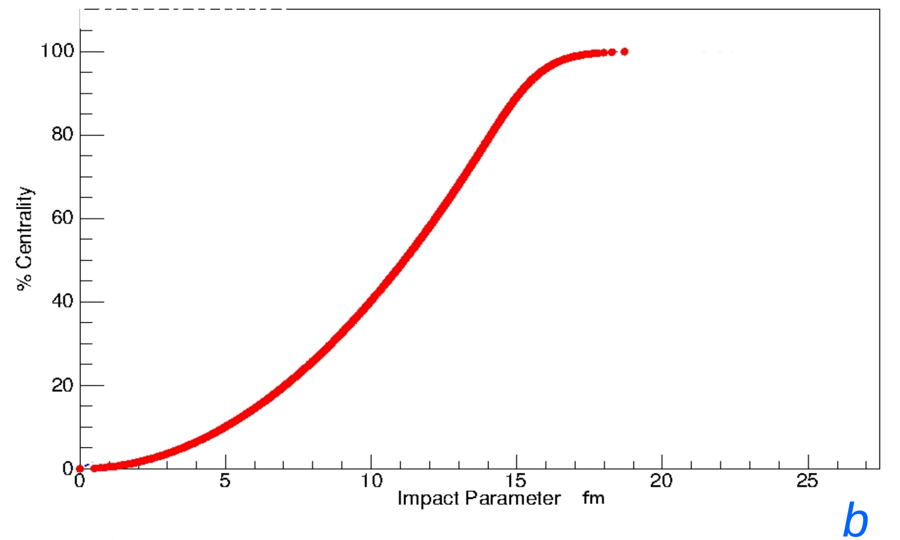
Particle production sources: strings

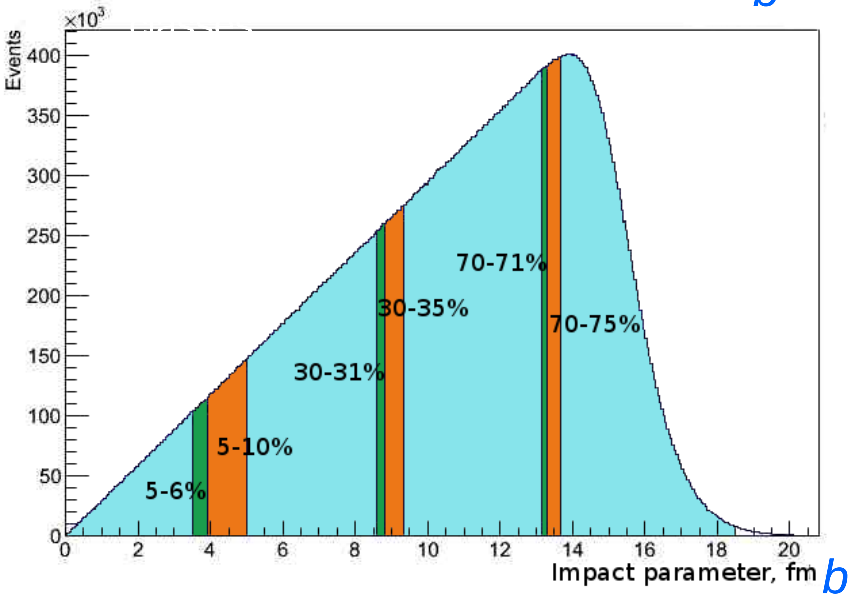
$$\langle M_c \rangle = \rho,$$

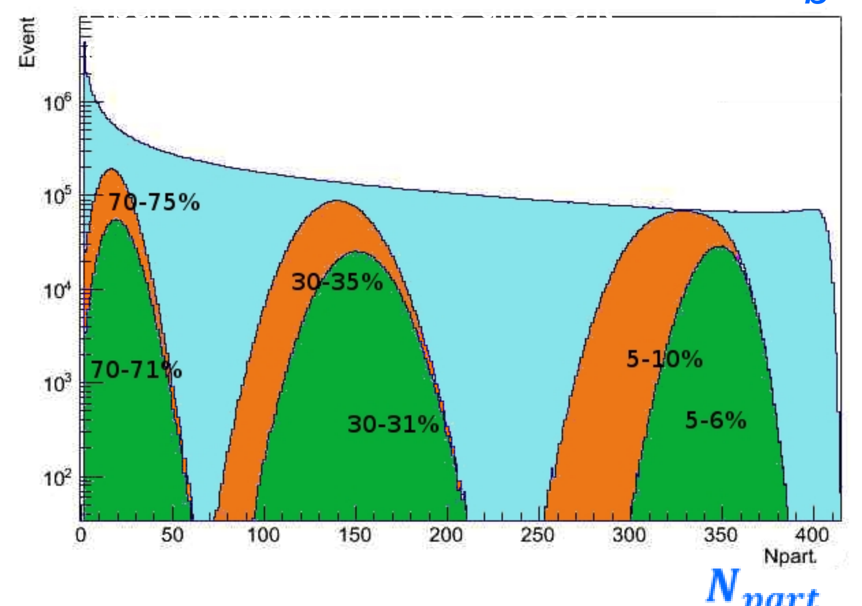
Impact parameter b and N_{part} in MC Glauber model

MC Glauber, PbPb 2.76TeV

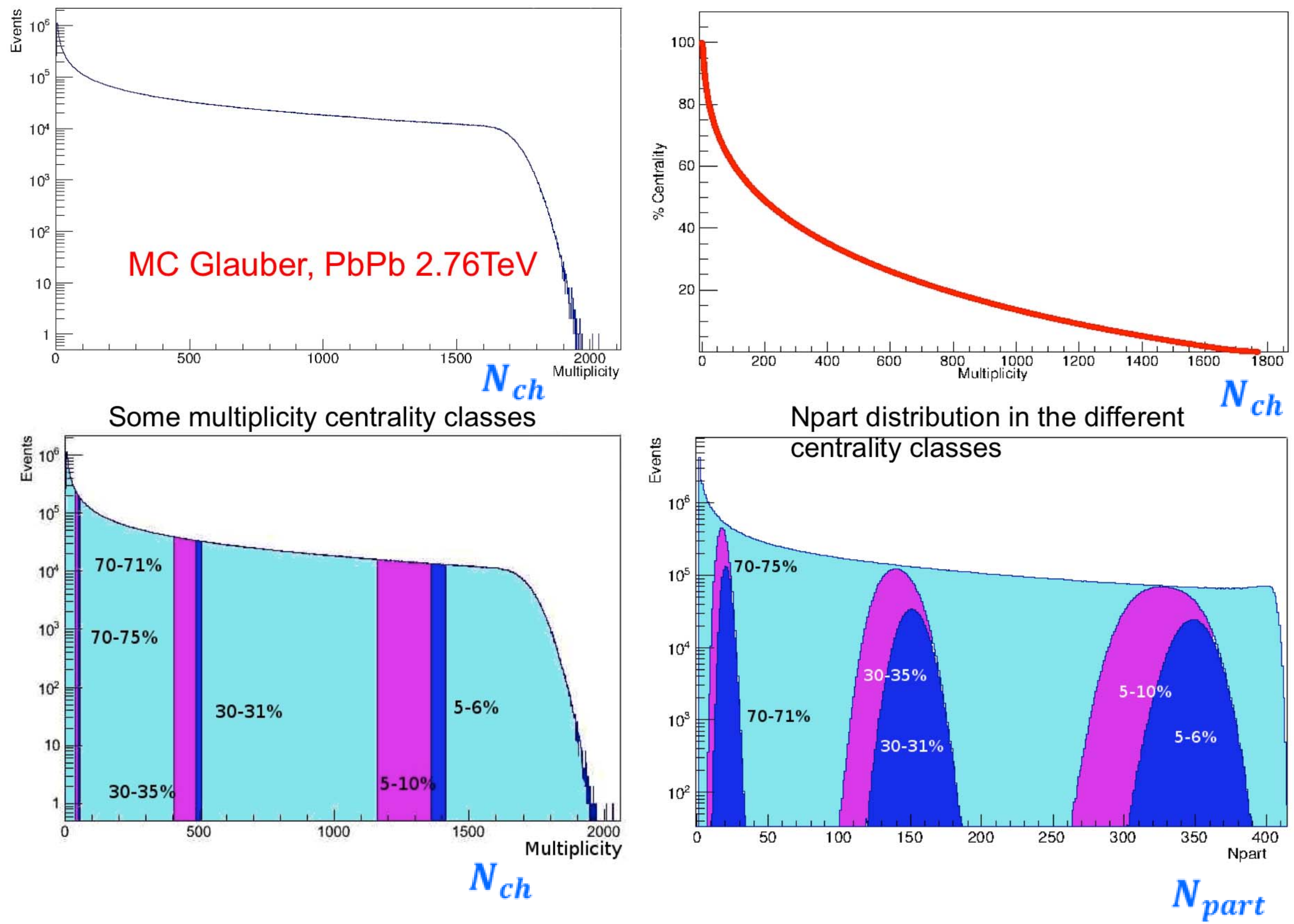




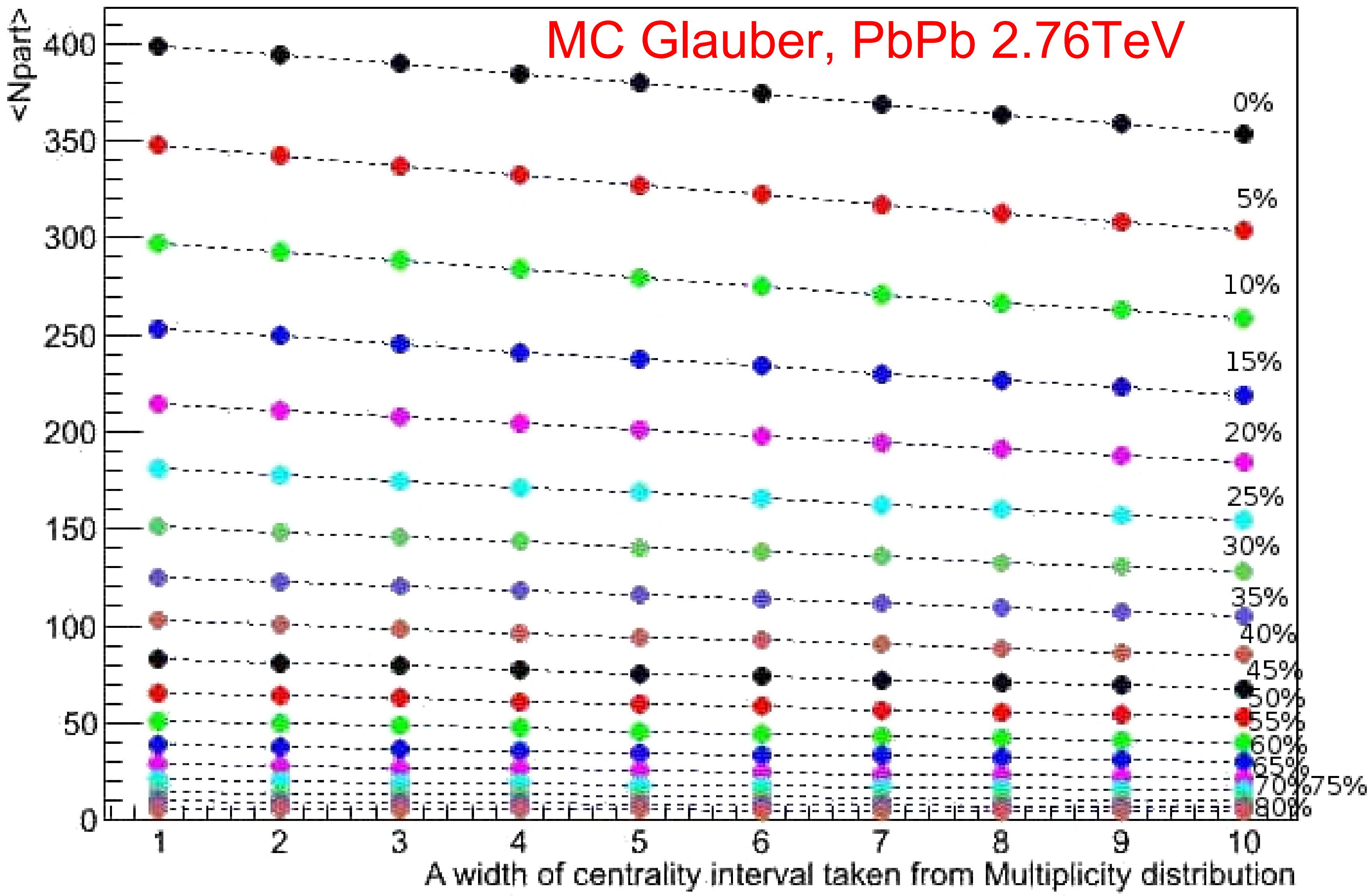




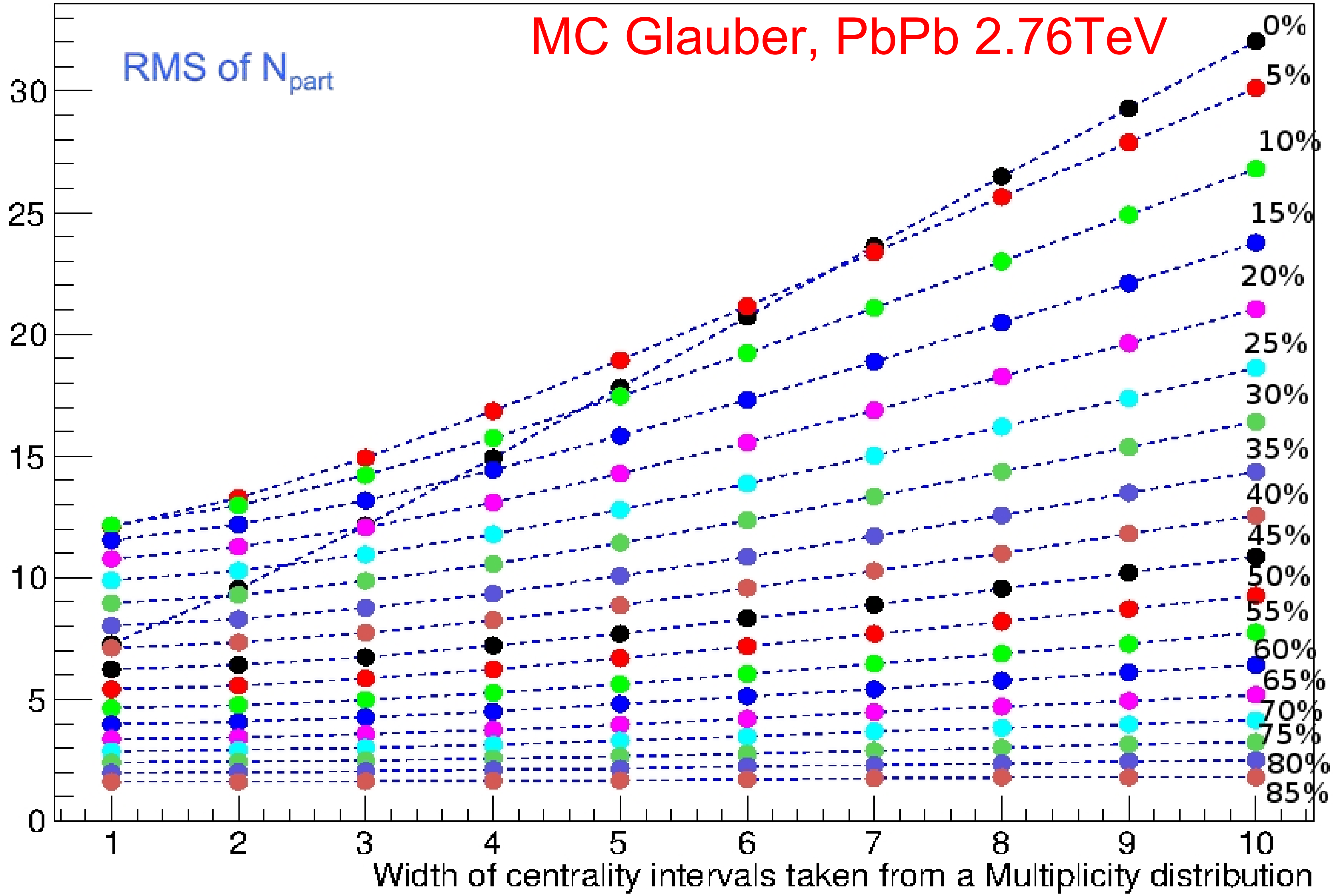
Multiplicity and N_{part} in MC Glauber model



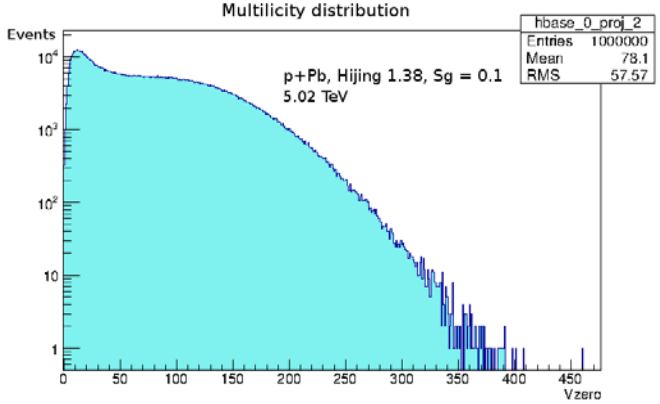
N_{part} in the different centrality classes taken from Multiplicity

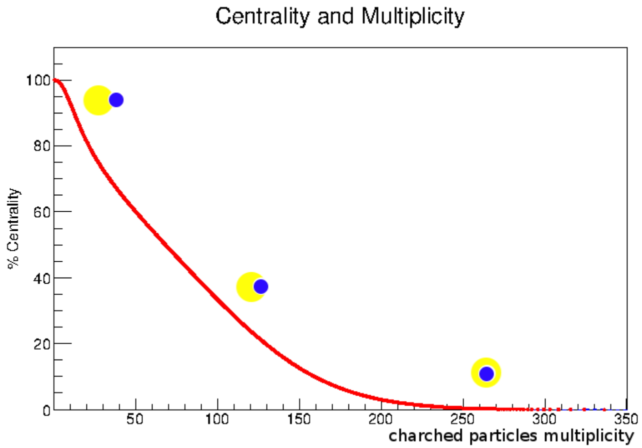


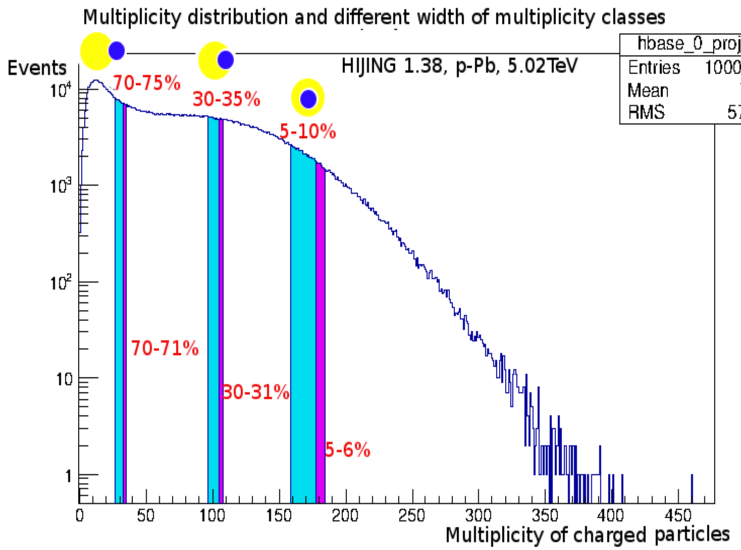
RMS of N_{part} in the different centrality classes from Multiplicity centrality selection

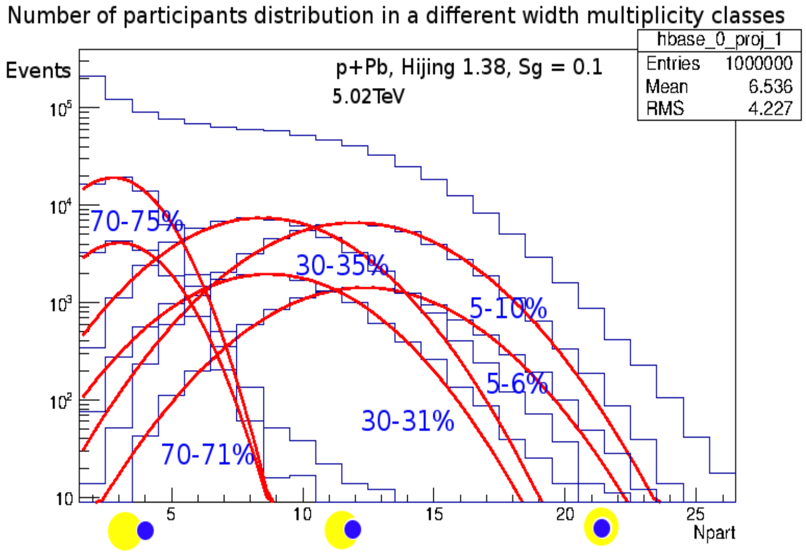


N_{part} for p-Pb collisions centrality classes from Multiplicity selection





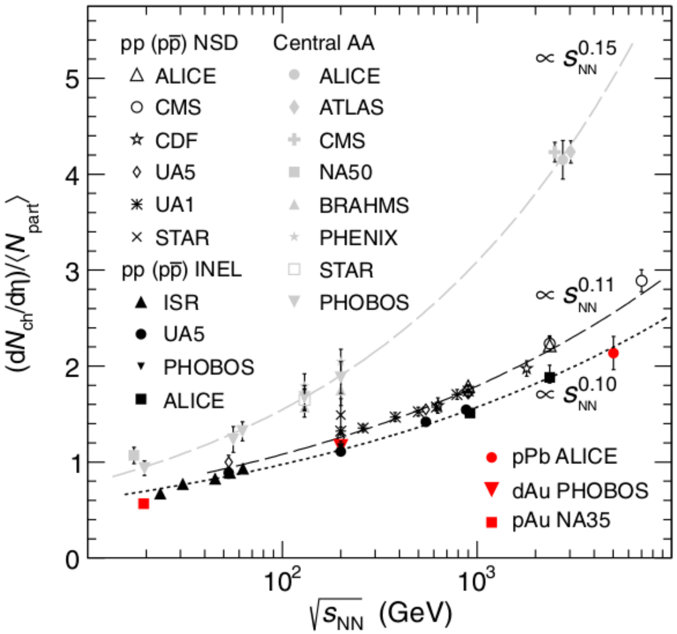


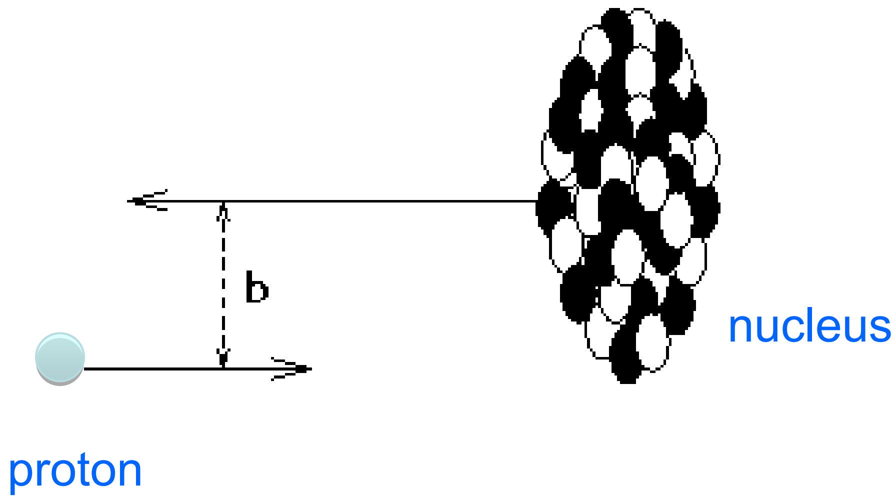


Conclusions from MC Glauber calculations:

- Two centrality determination procedures (by multiplicity distribution and by impact parameter) were tested
- Results indicate that selection of a narrow centrality class in multiplicity does not assume real selection of very central events in terms of the impact parameter
- At the same time RMS of distributions in N_{part} could be very large unless the narrow centrality class in multiplicity is selected - this is important for any study of fluctuations
- In case of p-Pb collisions centrality classes from Multiplicity selection should not be used - the results could be ambiguous

Centrality classes in p-A collisions



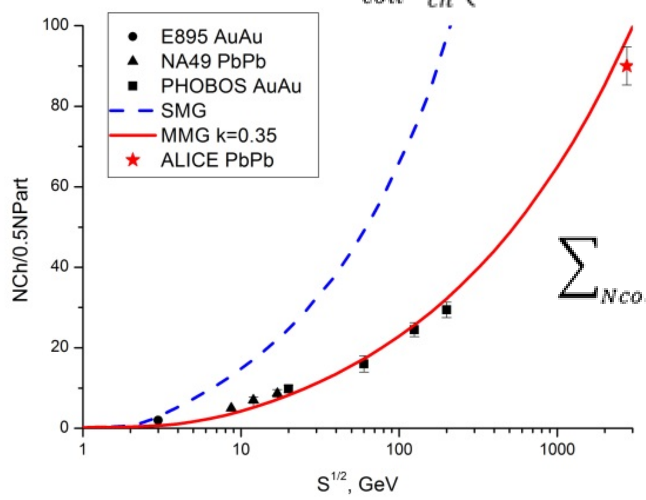


PRL 110,032301

Modified Glauber Model[1]

- Each nucleon in collisions loses in the inelastic collision
the fixed portion (1-k) of momentum in the center of mass system [1].
- This loss of momentum goes to the production of charged and neutral particles
- One can define parameter k by fitting the available experimental data on charged-particle multiplicity yields in AA collisions

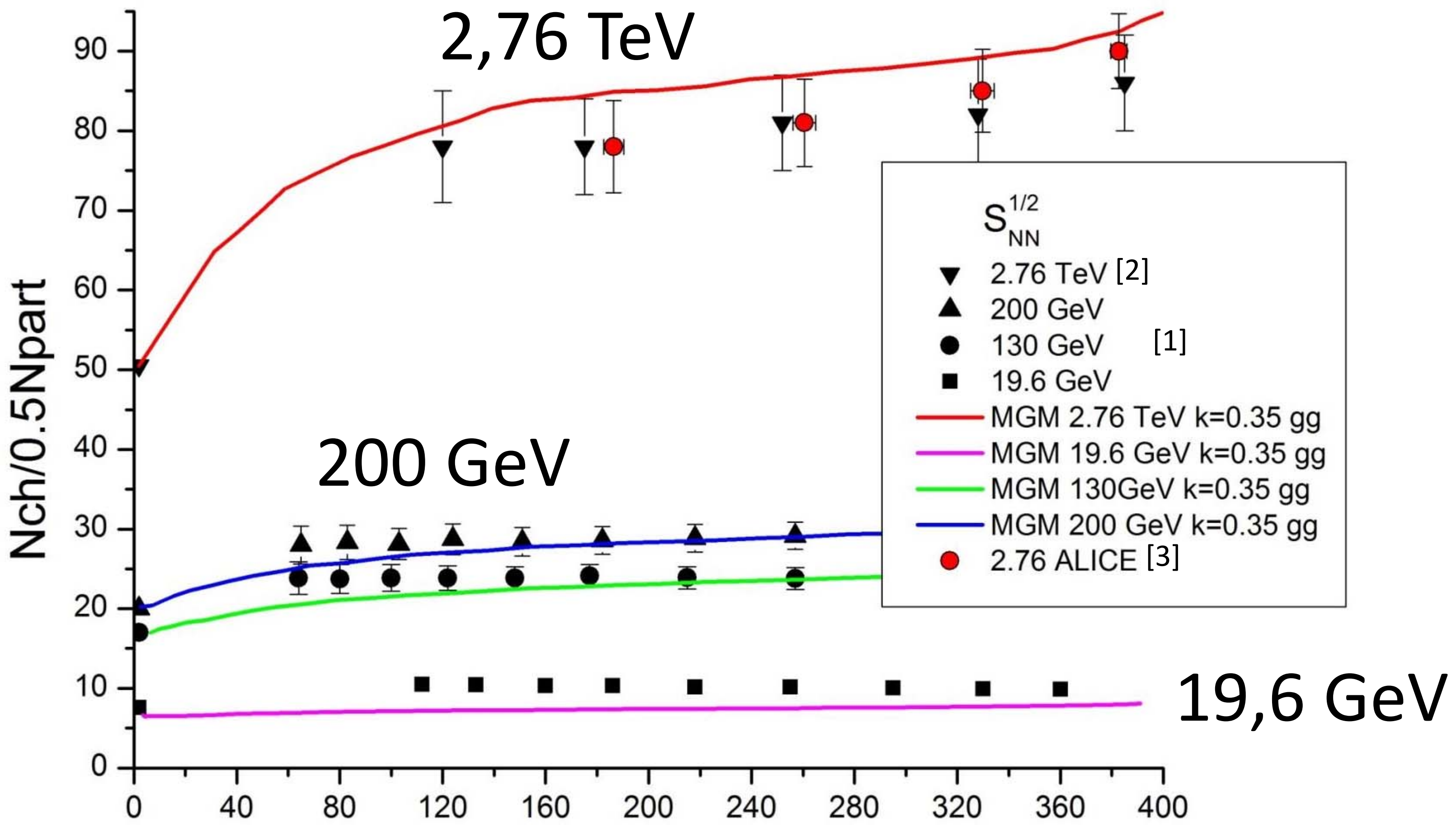
$N_{coll}N_{ch}^{pp}($



$\sum_{N coll} N_{ch}^{pp}(\sqrt{s_i})$

[1] G.Feofilov, A.Seryakov, A new look on signals of collective effects in AA and pA at LHC based on Modified Glauber Model, AIP, 2015.
[2] PHOBOS Collaboration, arXiv:nucl-ex/0301017.
[3] ALICE Collaboration, Centrality dependence of the pseudorapidity density distribution for charged particles in Pb–Pb collisions at √S = 2.76 TeV, arXiv:1304.0347v2 [nucl-ex] , 2013.

MGM for Pb-Pb collisions



A Seryakov, pA collisions at LHC in Modified Glauber model, St.Petersburg: Proceedings of the International Student Conference «Science and Progress», 2012.

Non-Glauber MC model (V. Kovalenko)

V. Kovalenko, Phys. Atom Nucl 76 (accepted), arXiv:1211.6209 [hep-ph];
V. Kovalenko, V. Vechernin. PoS (Baldin ISHEPP XXI) 077, 2012, arXiv:1212.2590 [nucl-th]

- Partonic picture of nucleons interaction.
- Every parton can interact with other one only once

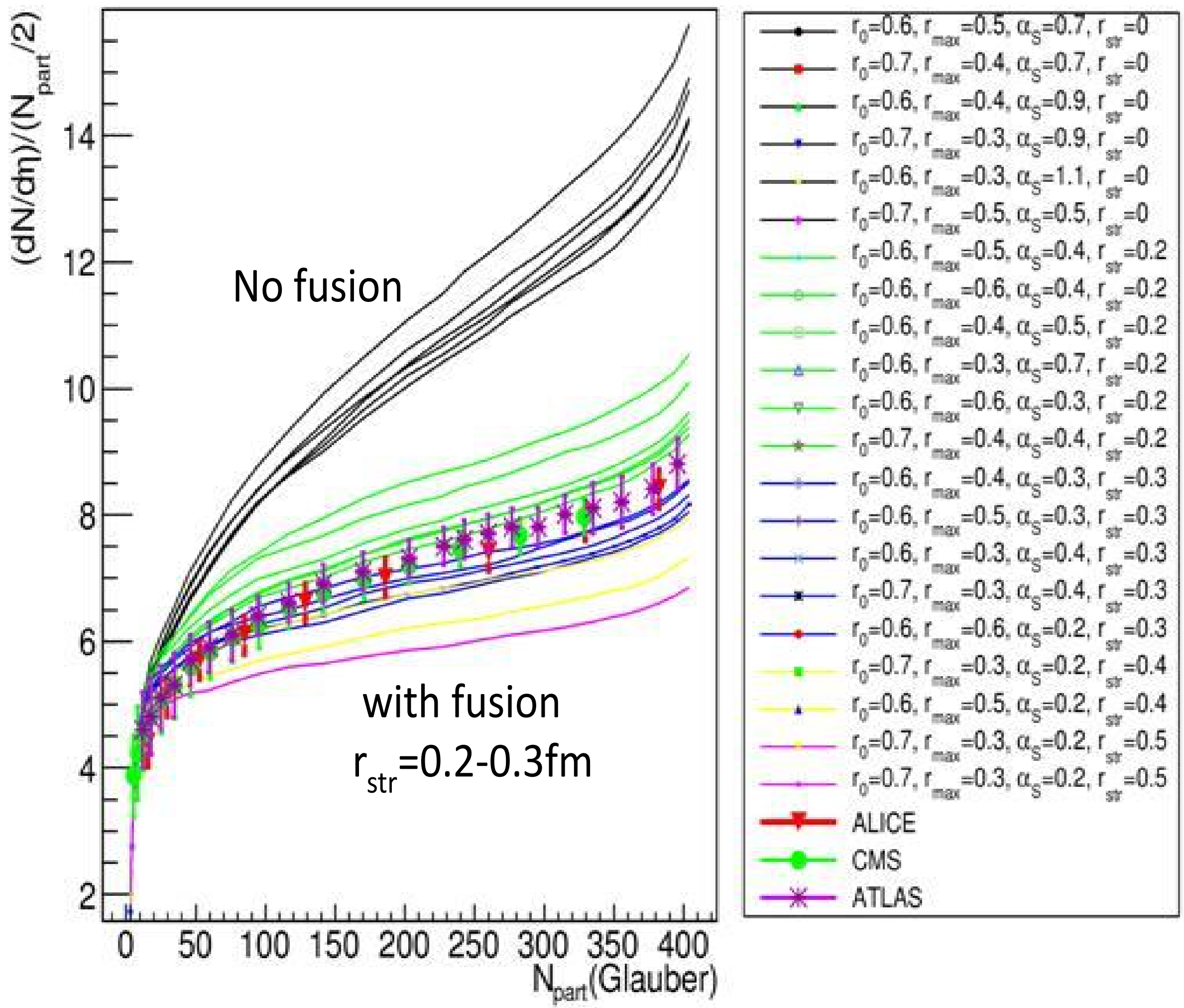
(contrary to Glauber supposition of constant nucleon cross section)

- Nucleon is participating in the collision if at least one of it's partons collides with parton from another nucleus.
- Parameters of the model are constrained from the p-p

data on total inelastic cross section and multiplicity

- Additional requirement is consistent description of the multiplicity in min. bias p-Pb collisions

Non-Glauber MC model (V. Kovalenko)

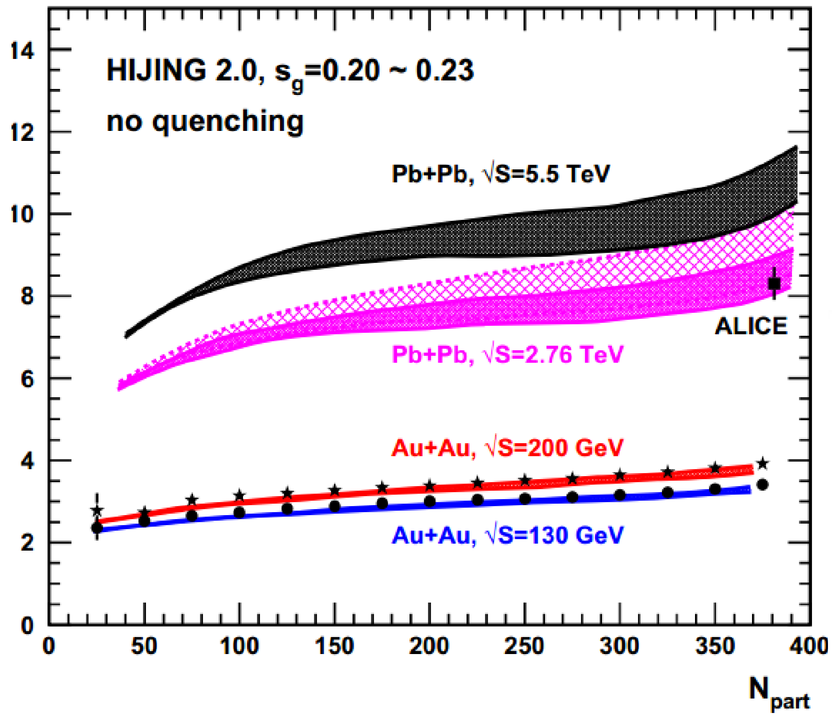


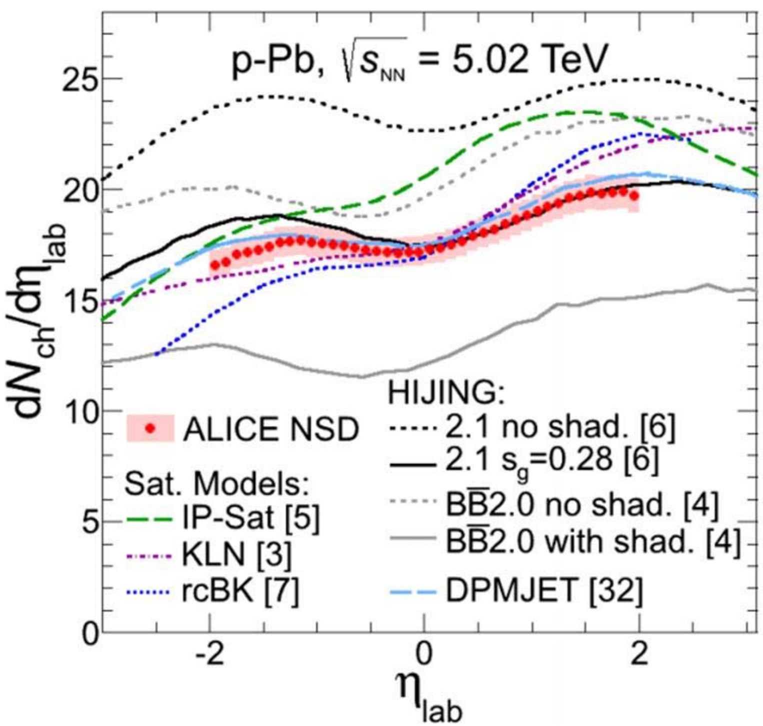
V. Kovalenko, Phys. Atom. Nucl. 76, 1189–1195 (2013).

HIJING

• HIJING is the MC event generator for hadron production in high energy pp, pA, AA collisions.

• Gives reasonable description of multiplicity yields.

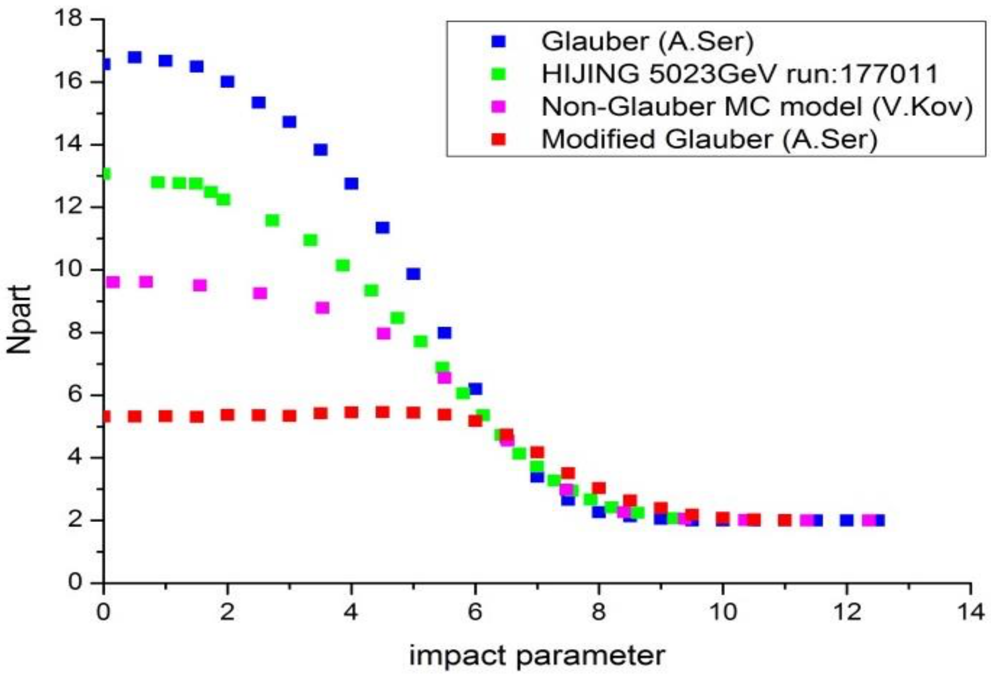




G. R. Xu, W.-T. Deng, and X.-N. Wang, arXiv:1204.1998

Stopping of nucleons in AA and pA interactions at the LHC energies

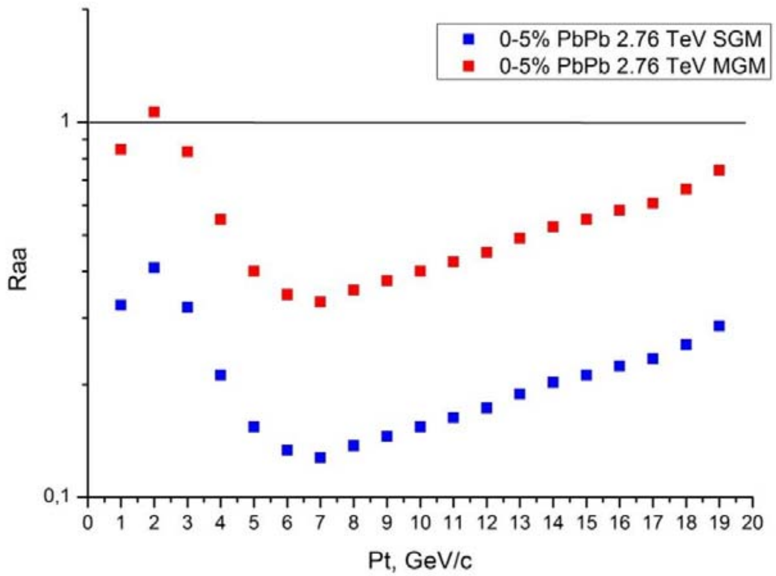
MinBias	<Npart> at 5.02 TeV *ALICE p-Pb*
Glauber	**7.87 (A.Ser) 7.9±0.6 (ALICE)**
MGM	**4.3±0.3**
Non-Glauber	**6.2±0.6**
HIJING	**6.5**

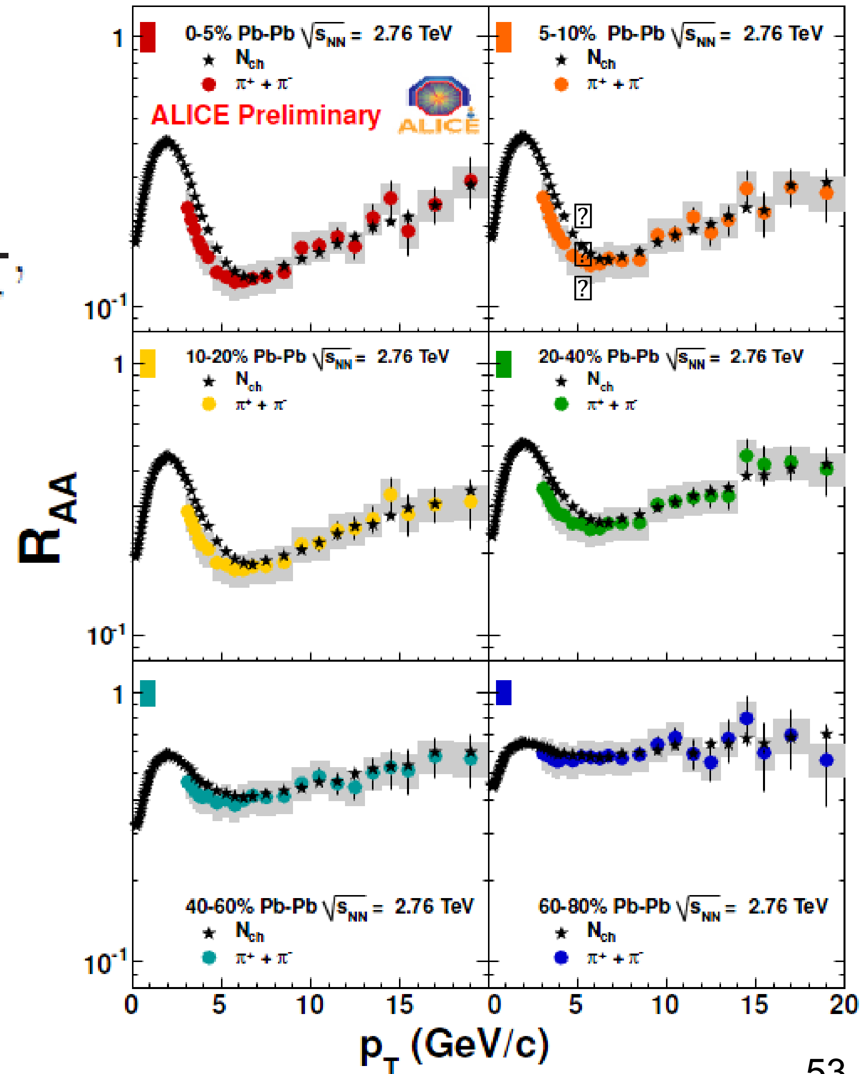


MGM, non-Glauber, HIJING **and AMPT (???)** – all these models gives smaller values of $\langle N_{part} \rangle$ compared to Glauber

R_{AA} and <Ncoll>

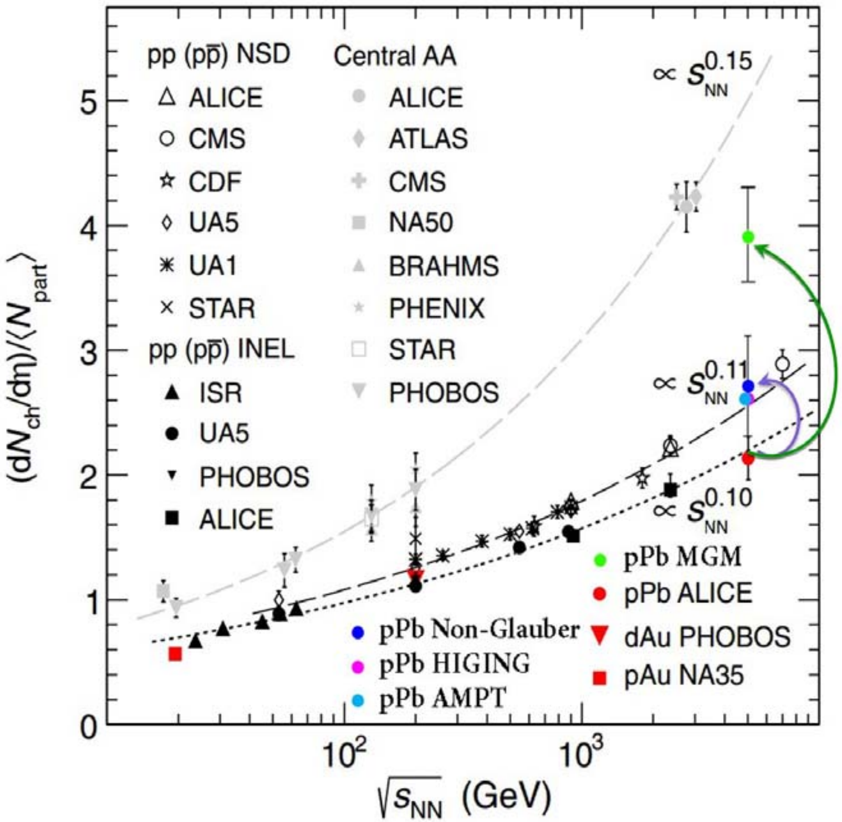
$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta dp_T},$$





Results for p-Pb

Charged-particle pseudorapidity density at midrapidity normalized to Npart



MinBias	*<Npart> at 5.02 TeV* *ALICE p-Pb*
Glauber	7.87 (A.Ser) 7.9±0.6 (ALICE)
MGM	4.3±0.3
Non-Glauber	6.2±0.6
HIJING	6.5

Data from: PRL 110,032301

T. Drozhzhova, G. Feofilov, V. Kovalenko, A. Seryakov, Geometric properties and charged particles yields behind Glauber model in high energy pA and AA collisions. Proceedings of the "The XXI International Workshop High Energy Physics and Quantum Field Theory" in St.Petesburg Area, in June 23–30 2013.

Summary and outlook -2

- The initial conditions of nucleus-nucleus and proton-nucleus collisions at high energies are important for any analysis and haracterization of the expected quark-gluon plasma formation

- The impact parameter *b,* and its relevant values N_{part} and so-called binary collisions N_{coll}, are widely used to normalize the measured fractional cross sections both of soft and hard processes of particle production in collisions of heavy ions

- We compare methods of centrallity determination based on the Glauber model and multiplicity estimators to the modified Glauber, HIJING and AMPT MC event generators and to non-Glauber approach calculations. We show that the correct inclusion of energy-momentum consevation in multiprticle production process decreases considerably values of N_{coll}, the result is especially striking for **p-Pb collisions**

- Binary collisions N_{coll} should be treated differently for soft and hard processes in order to exclude in the analysis any possible biases to initial conditions

BACK-UP SLIDES

CENTRALITY AND MULTIPARTICLE PRODUCTION IN ULTRARELATIVISTIC NUCLEAR COLLISIONS

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Saint-Petersburg State University, St. Petersburg, Russia
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Understanding of the initial conditions of nucleus-nucleus and proton-nucleus collisions at high energies is important for any analysis and characterization of the expected quark-gluon plasma formation. Measurements of fluctuations and correlations of global observables allow studying a broad region of QCD phase diagram. Interpretation of experimental data requires information about impact parameter and the number of participating nucleons. In this report we present the critical review of widely applied methods of centrality determination based on the Glauber model.

Using MC simulations we analyze the consistency of the concept of centrality in the cases of pA and AA collisions for heavy and light ions and present a method for the numerical qualification of the centrality estimators. This allows to select the classes of events where background fluctuations related to event-by-event variance in the impact parameter and/or the number of nucleons-participants are minimized.

This approach is checked in non-Glauber Monte Carlo model with string fusion [1] by studying the dependence of multiplicity fluctuations and correlations on the width of the centrality class.

By model calculations [1, 2] we also obtained that the account of the energy-momentum conservation in soft particles production leads to noticeable decrease in the number of nucleon collisions (N_{coll}) in Pb-Pb and p-Pb interactions relative to Glauber model values. Similar effects are intrinsically present in the models [3, 4] which aim to describe consistently the collisions of small (pp) and large (AA) systems. We conclude that the decrease in N_{coll} is important for low transverse momentum phenomena, contrary to rare processes where approximate Glauber scaling remains applicable. Overall, the results suggest reconsidering the general use of Glauber normalization of the multiplicity yields in experimental studies.

The authors acknowledge Saint-Petersburg State University for a research grant 11.38.193.2014.

1. V.Kovalenko // Phys. Atom. Nucl. 2013. V.76. P.1189; V.Kovalenko, V.Vechernin // PoS (BaldinISHEPP XXI) 077, 2012; V.N.Kovalenko // arXiv:1308.1932.
2. G.Feofilov, A.Ivanov // J. Phys. Conf. Ser. 2005. V.5. 230237; T.Drozhzhova, G.Feofilov, V.Kovalenko, A.Seryakov. PoS QFTHEP2013 053.
3. R.Xu, W.-T.Deng, X.-N.Wang // arXiv:1204.1998.
4. J.Albaete, N.Armesto, R.Baier *et al.* // Int. J. Mod. Phys. E. 2013. V.22. 1330007.