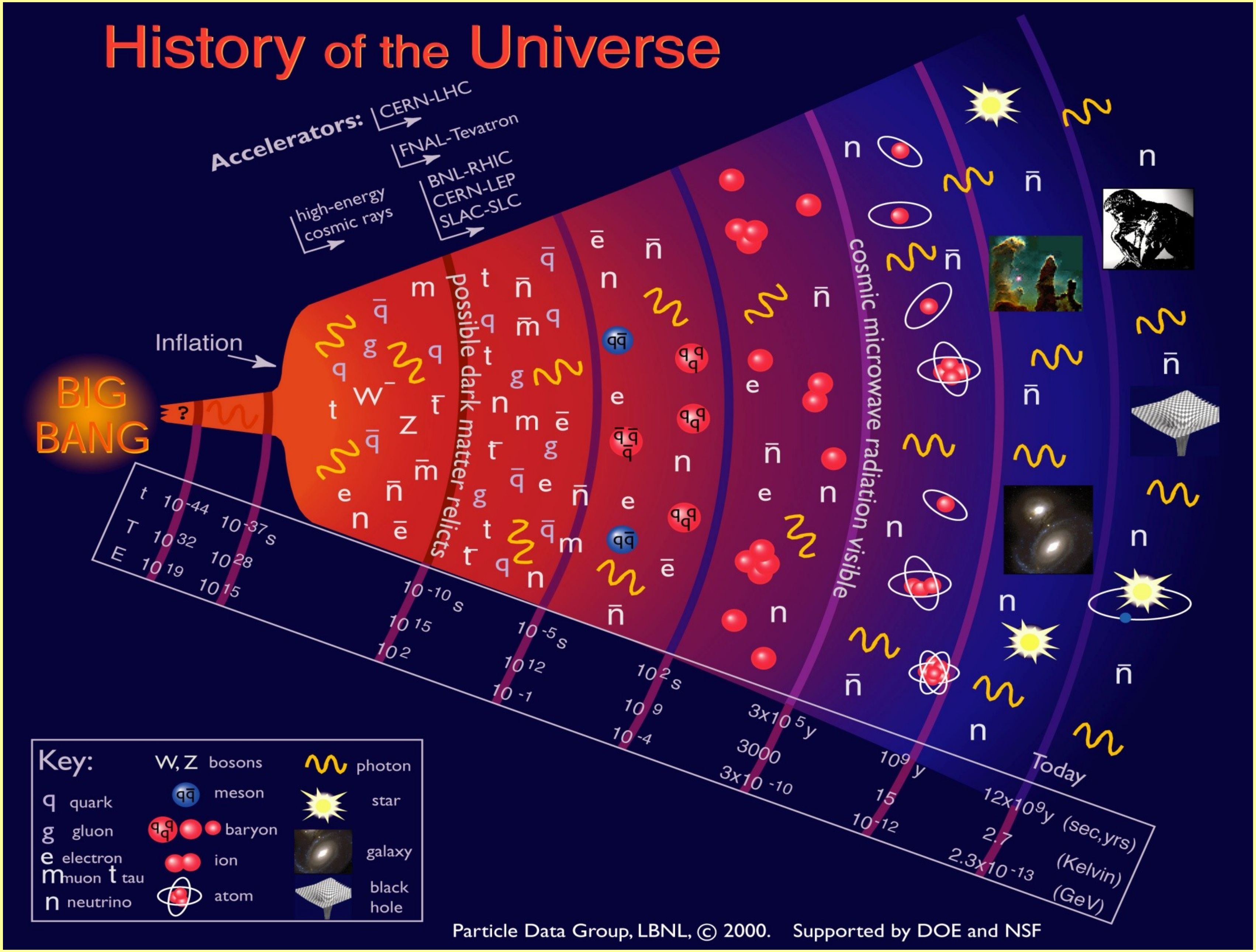
XIII Зимняя школа « Физика тяжёлых ионов: от LHC к NICA «

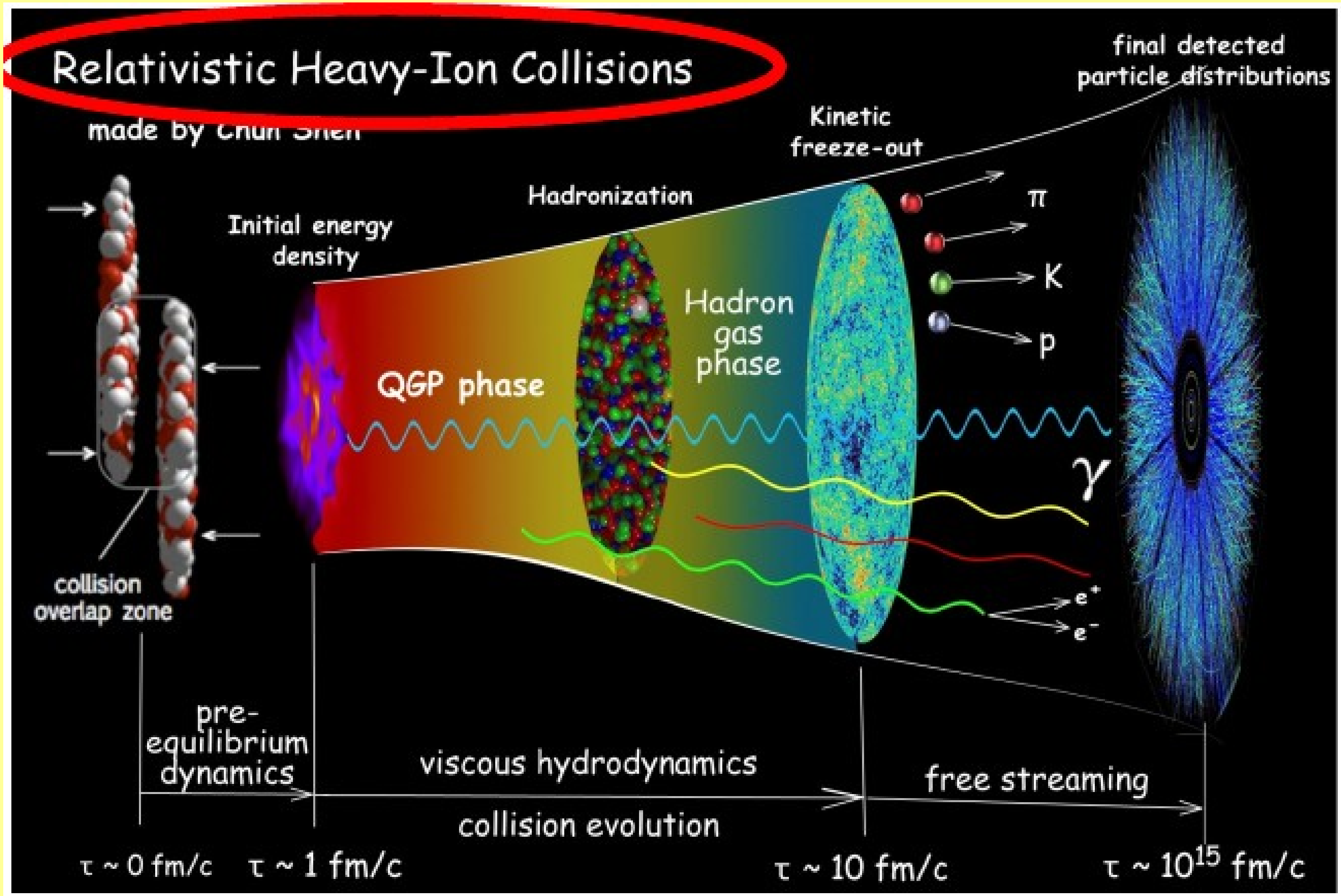
Февраль 3, 2017, Дубна

ALICE (A Large Ion Collider Experiment) на LHC

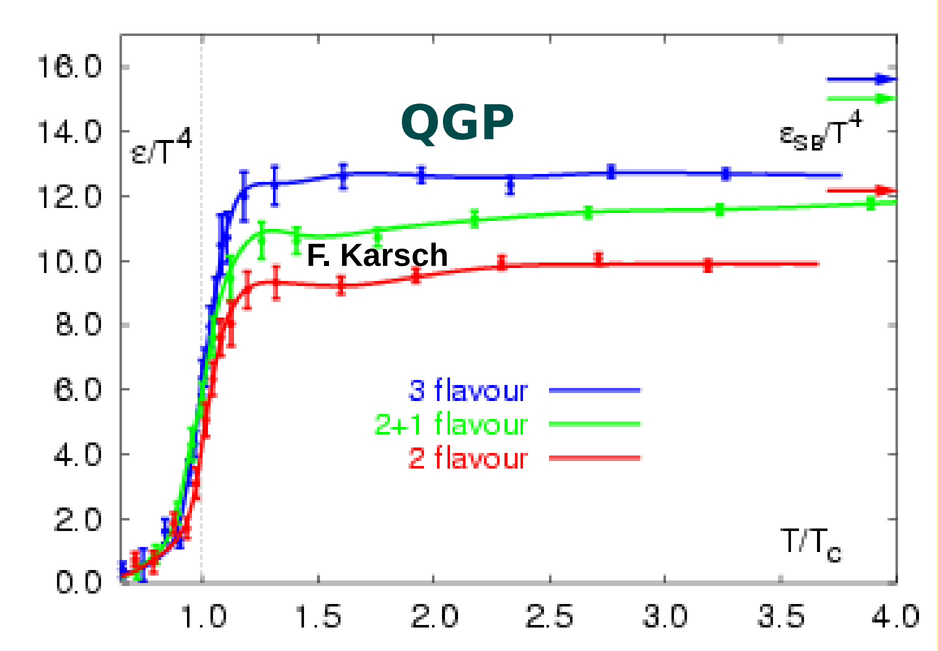
(часть 2, физический анализ)

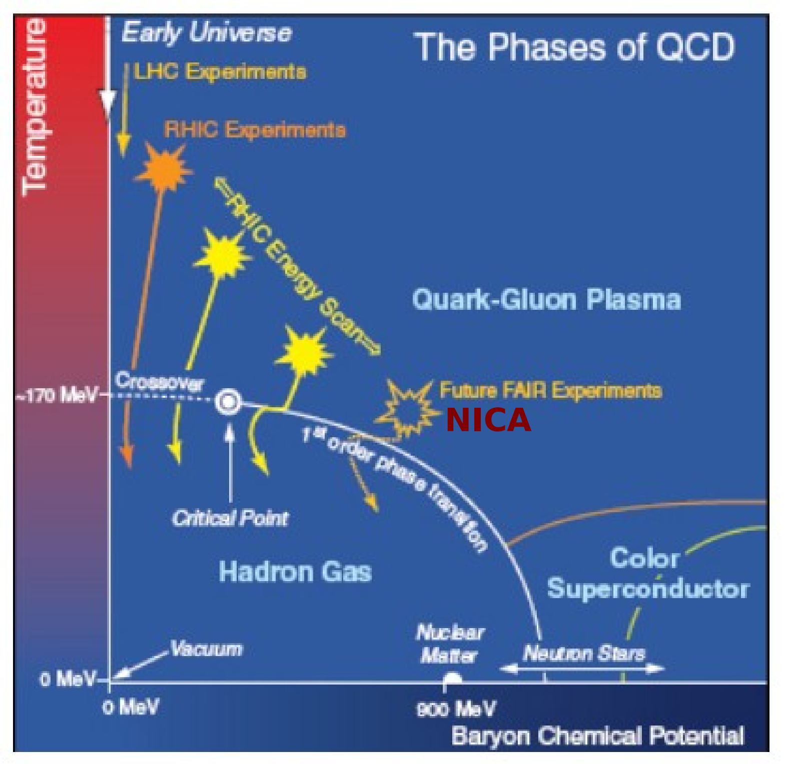
Б. В. Батюня (ОИЯИ)


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relicts
cosmic microwave radiation visible
t 10 -44 10 -37 s 10 -10 s 10 -5 s 10 2 s 3x10 5 y 10 9 y 12x10 9 y (sec,yrs)
T 10 32 10 28 10 15 10 12 10 9 3000 15 2.7 (Kelvin)
E 10 19 10 15 10 2 10 -1 10 -4 3x10 -10 10 -12 2.3x10 -13 (GeV)
Today
Key:
q quark
g gluon
e electron
m muon t tau
n neutrino
W, Z bosons
meson
baryon
ion
atom
photon
star
galaxy
black hole
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF


Relativistic Heavy-Ion Collisions
made by Chun Shen
final detected
particle distributions
Kinetic
freeze-out
Hadronization
Initial energy
density
π
K
p
Hadron
gas
phase
QGP phase
γ
e^+
e^-
collision
overlap zone
pre-
equilibrium
dynamics
viscous hydrodynamics
free streaming
collision evolution
τ ~ 0 fm/c
τ ~ 1 fm/c
τ ~ 10 fm/c
τ ~ 10^{15} fm/c

Quark-Gluon Plasma



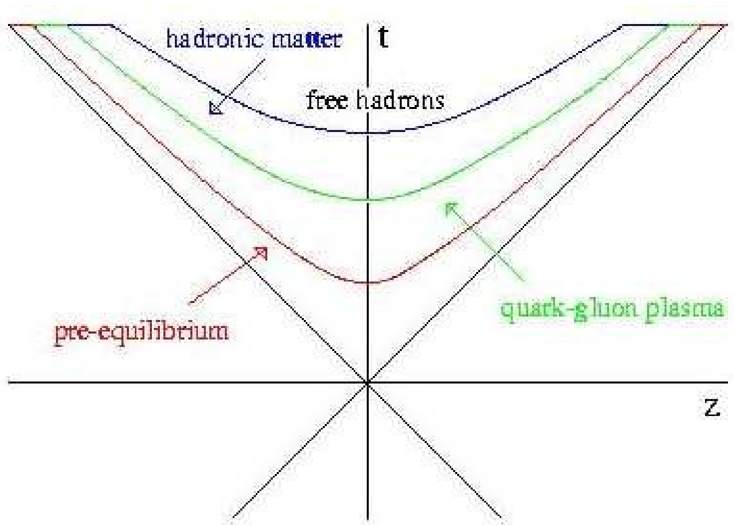


Transition to QGP at T_c= 175 ± 15 MeV; ε_c = 0.7 ± 0.2 GeV/fm^3

"QGP ≡ a (locally) thermally equilibrated state of matter in which quarks and gluons are deconfined from hadrons, so that color degrees of freedom become manifest over nuclear, rather than merely nucleonic, volumes."

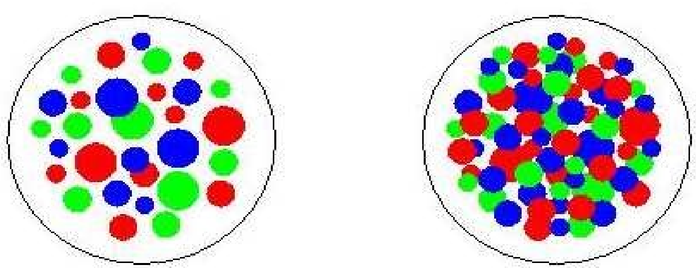
Parton percolation model:

H. Satz



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

The expected evolution of nuclear collision.



Partonic cluster structure in the transverse collision plane.

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

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

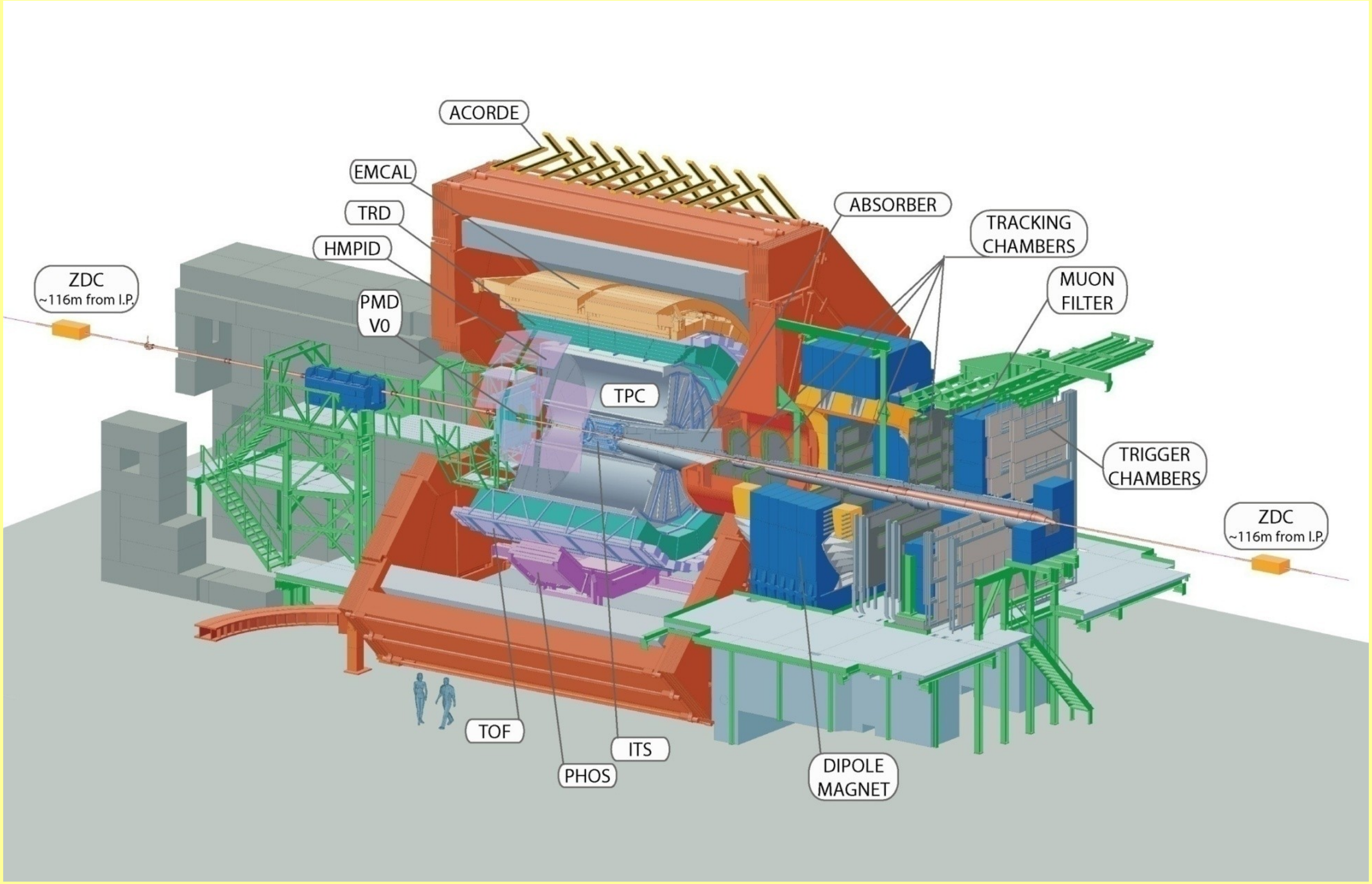
where N is number of partons with size r (r is found from the uncertainty relation $\pi r^2 \cong \pi/\langle k^2T\rangle$, kT - partron momentum), R is nuclear radius $(R \gg r)$

From SPS to RHIC to LHC
‘hotter – bigger – longer lived’

Formation time τ_0 3 times shorter than RHIC
Lifetime of QGP τ_{QGP} factor 3 longer than RHIC
Initial energy density ε_0 3 to 10 higher than RHIC

Central collisions	SPS	RHIC	LHC
$s^{1/2}$(GeV)	17	200	5000
dN_{ch}/dy	500	850	2 $\times 10^3$
ε (GeV/fm^3)	2.5	4–5	15–40
V_f(fm^3)	10^3	7×10^3	2×10^4
τ_{QGP} (fm/c)	<1	1.5–4.0	4–10
τ_0 (fm/c)	~1	~0.5	<0.2

ALICE setup



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

ALICE Physics Teams

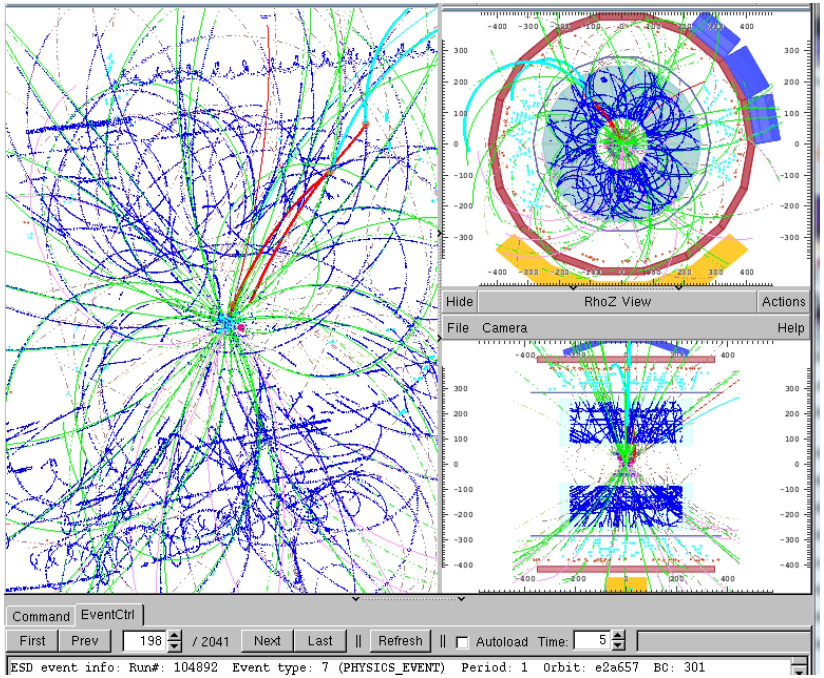
- . Event charactarization (multiplicity, centrality)
  - Particle species and spectra
  - Correlations
  - Resonance production
  - Jet physics
  - Photons
  - Dileptons
  - Heavy-quark and quarkonium production

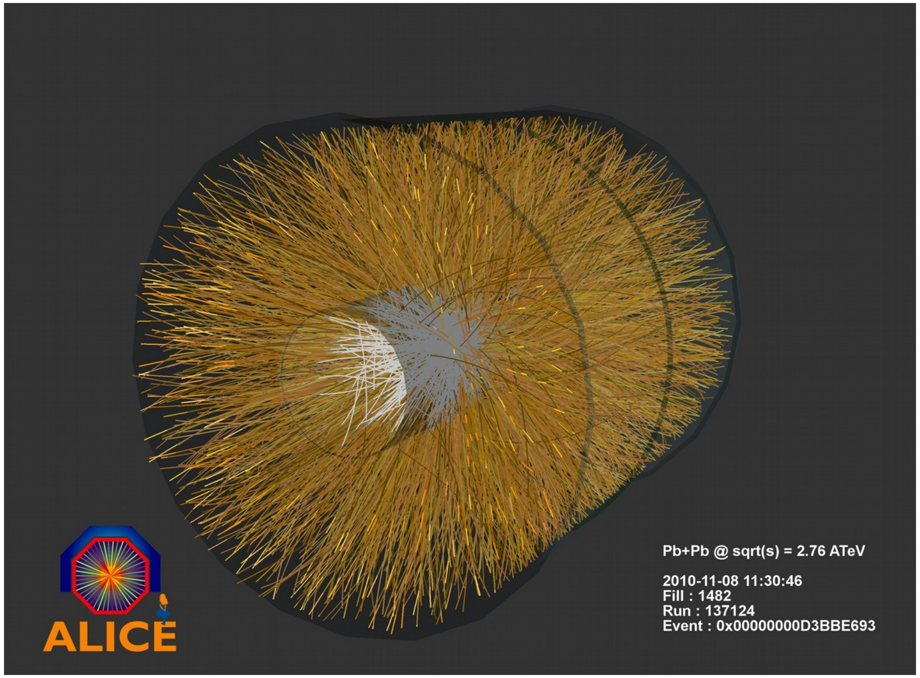
- **Physics of ultra-peripheral heavy ion collisions**
- **Contribution of ALICE to cosmic-ray physics**

Display of high multiplicity events

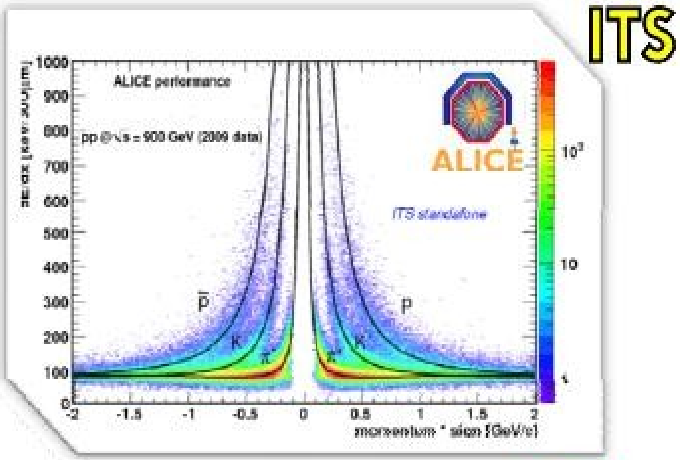
in p-p at 7 TeV

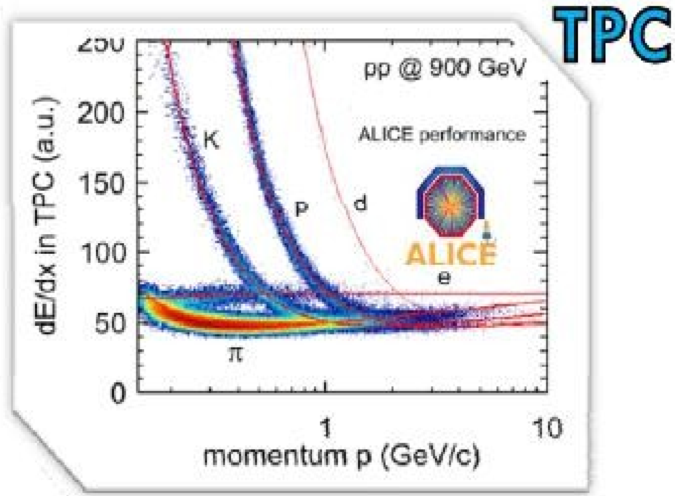
in PbPb at 2.76 ATeV

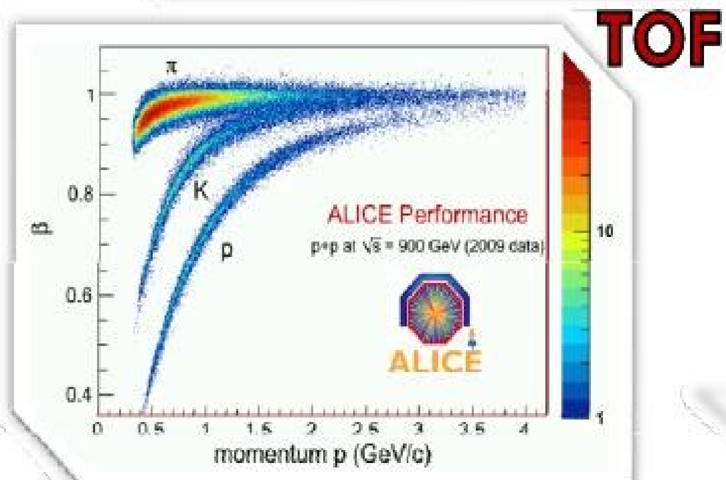


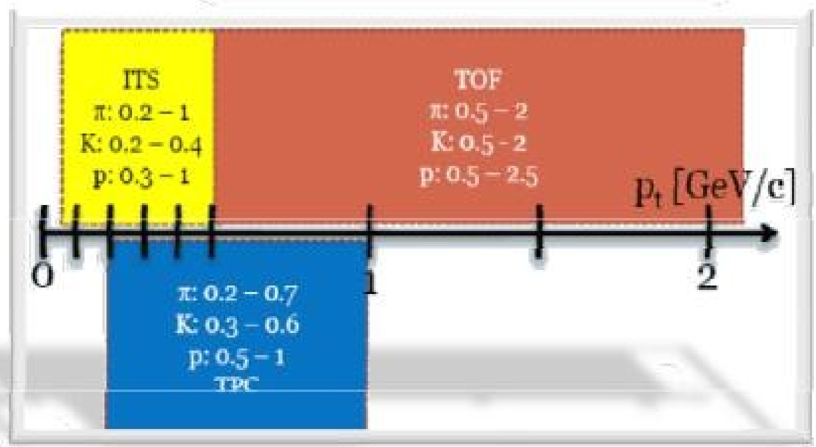


Particle Identification in ALICE

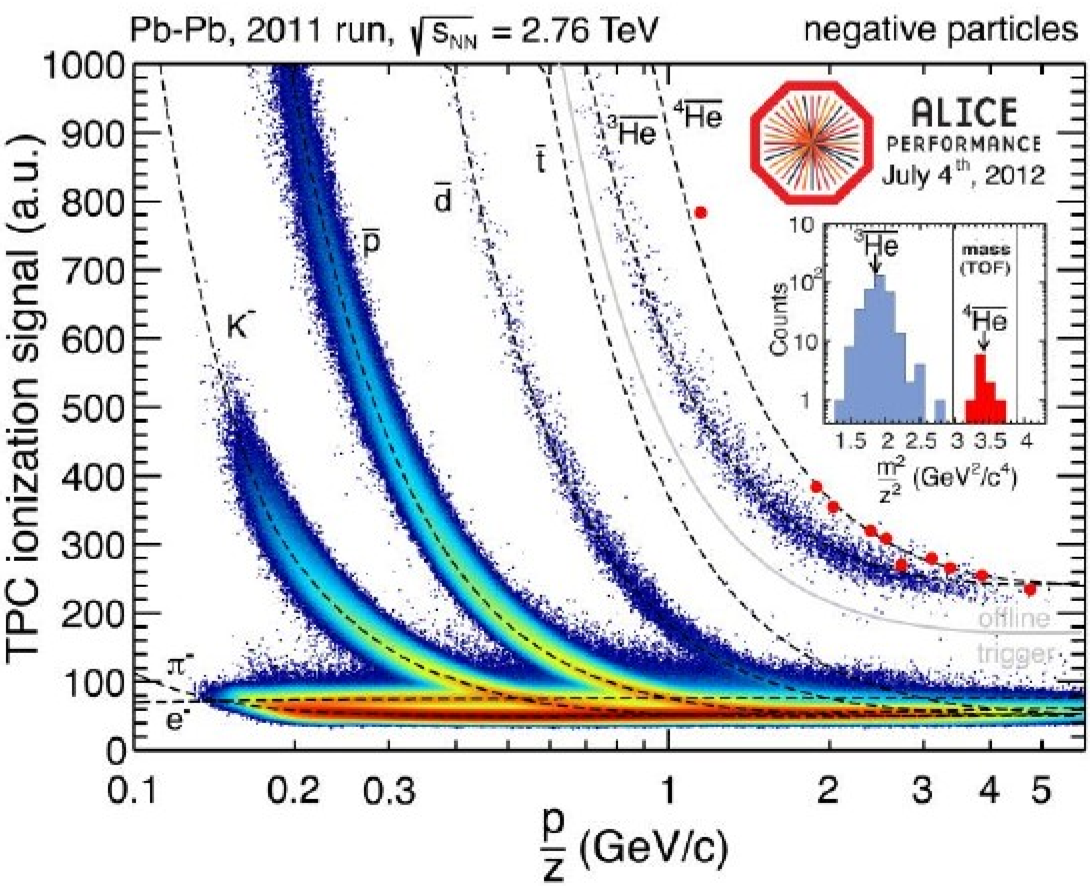








Observation of the anti nucleus using the TPC PID

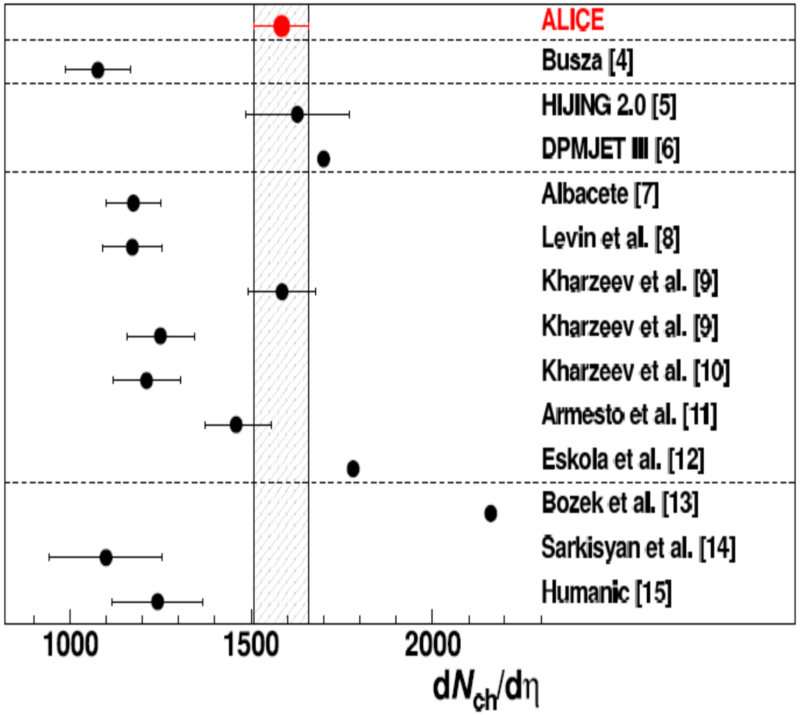


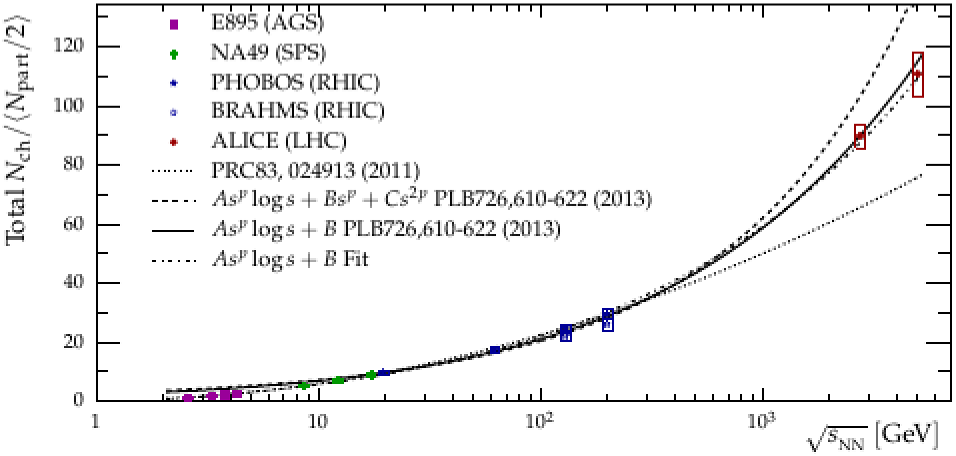
Ten events with the anti alpha particles were found (the first 25 ones have been identified in the STAR experiment).

Charged particles density for Pb-Pb collisions

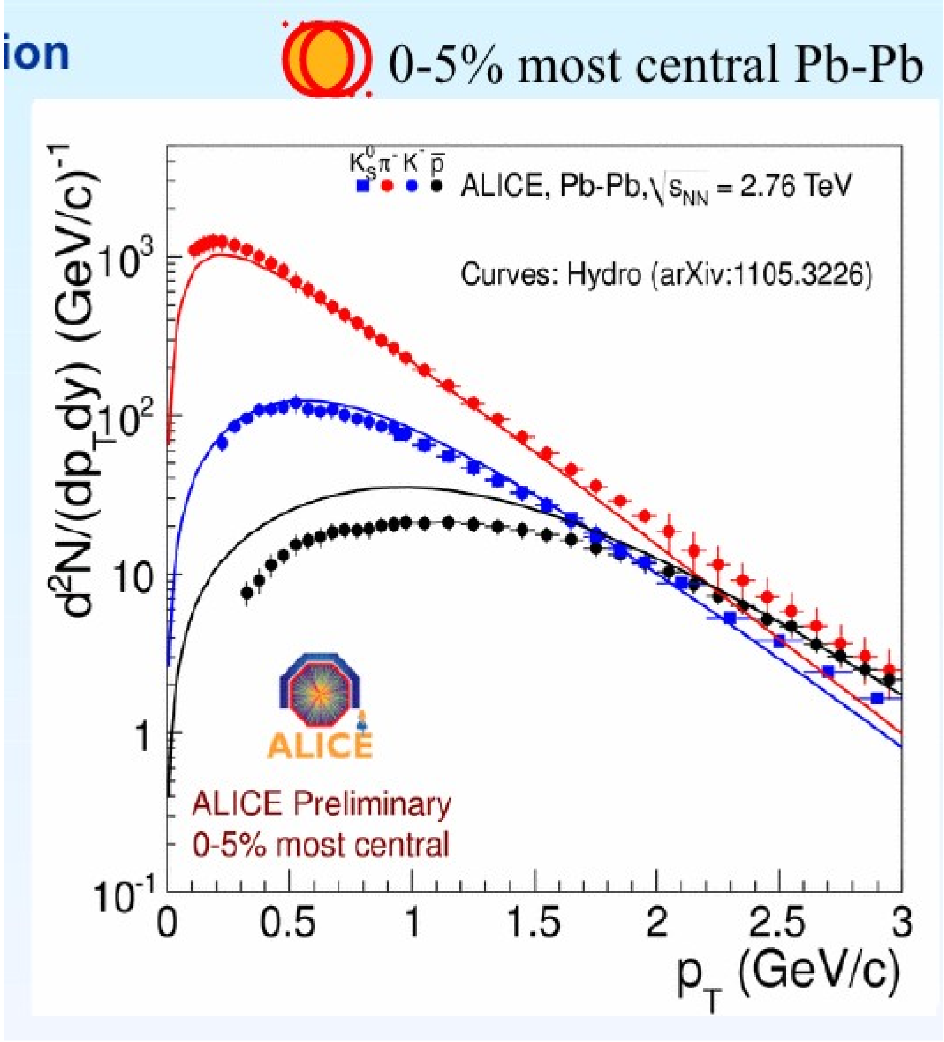
$dN_{ch}/d\eta$ ~ 1600 at 2.76 TeV

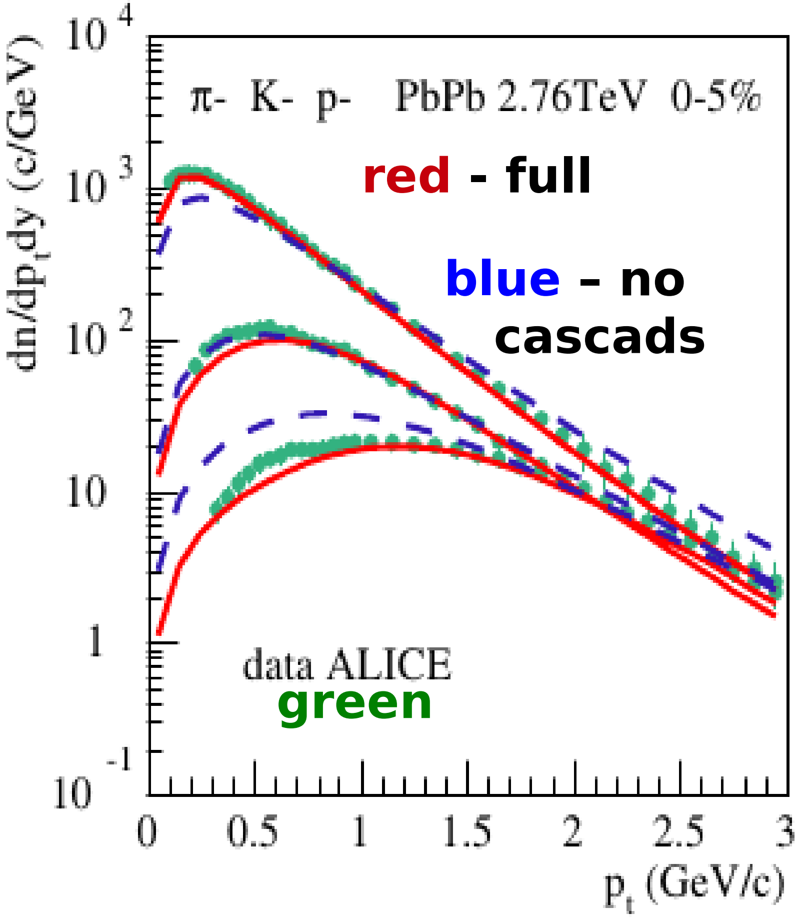
(~ 2000 at 5.02 TeV)





Спектры

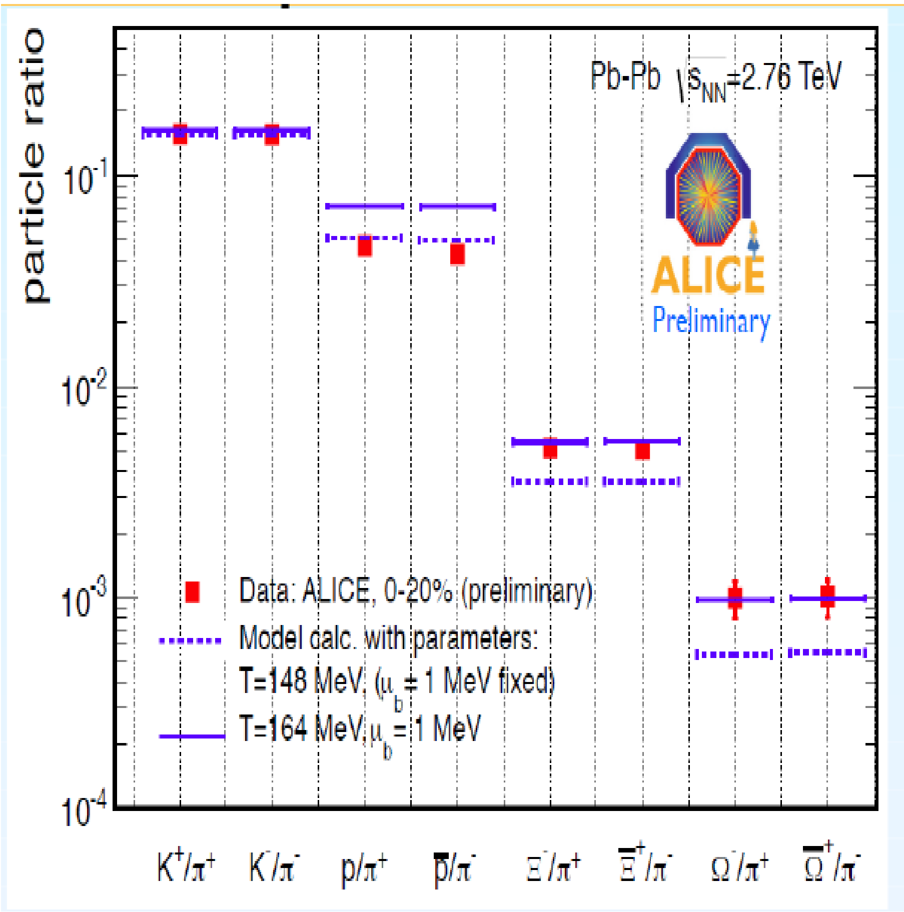


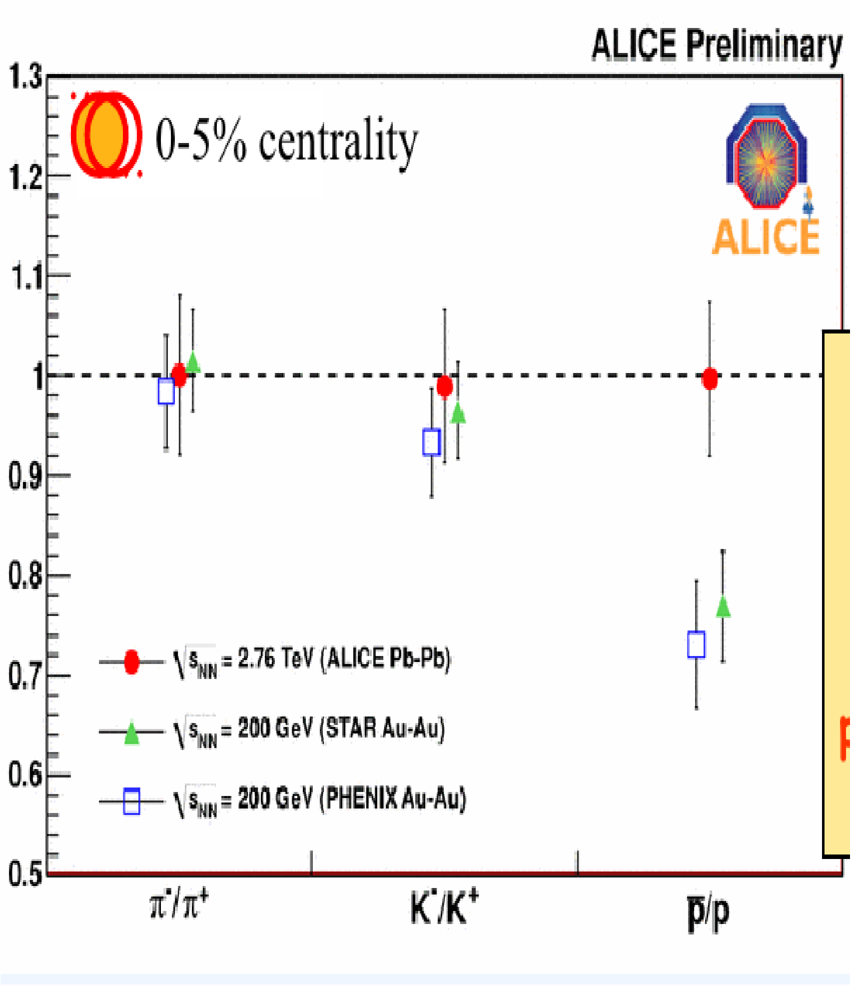


Гидродинамика с учетом вязкости

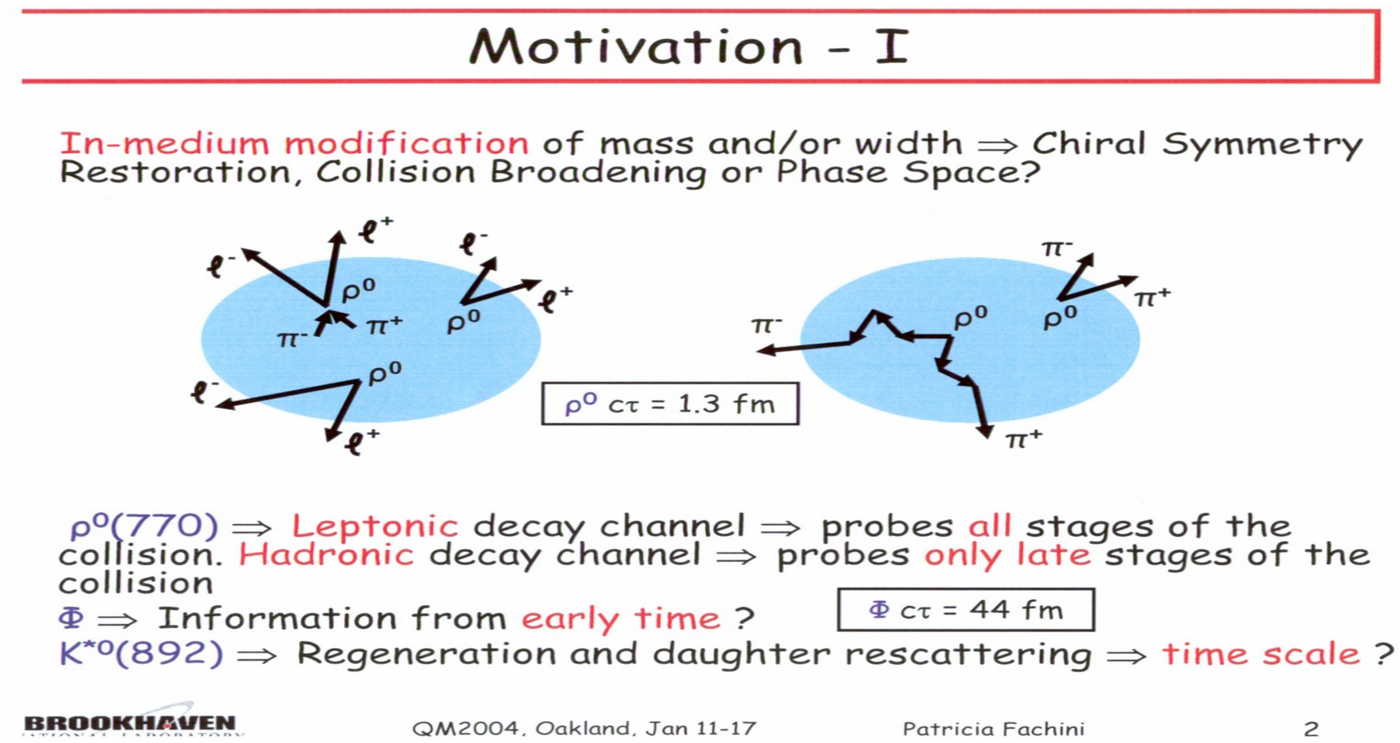
EPOS – струнная модель

Отношения выходов частиц



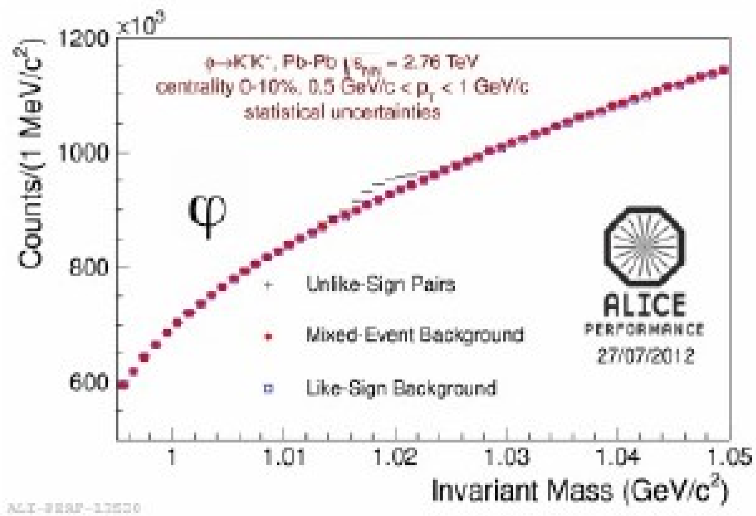


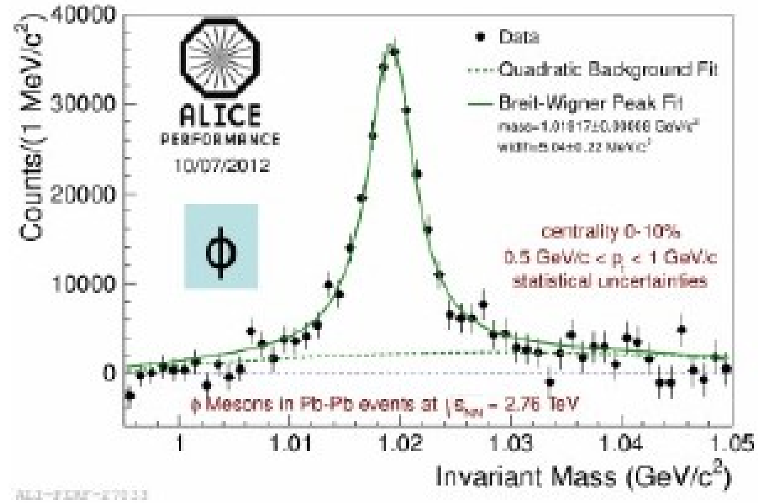
Study of vector meson production.



In-medium modification of resonance mass and width is predicted due to first-order phase transition (or as cross-over) from the QGP to the hadronic phase (M.Asakawa and M.Ko Phys.Lett.B322,p.33,1994), or due to rescattering and absorbtion of the hadrons from decays inside the high density nuclear matter (S.Pal et al. Nucl.Phys. A707 p.525, 2002, R. Rapp, Xiv: nucl-th/0701082, 2002).

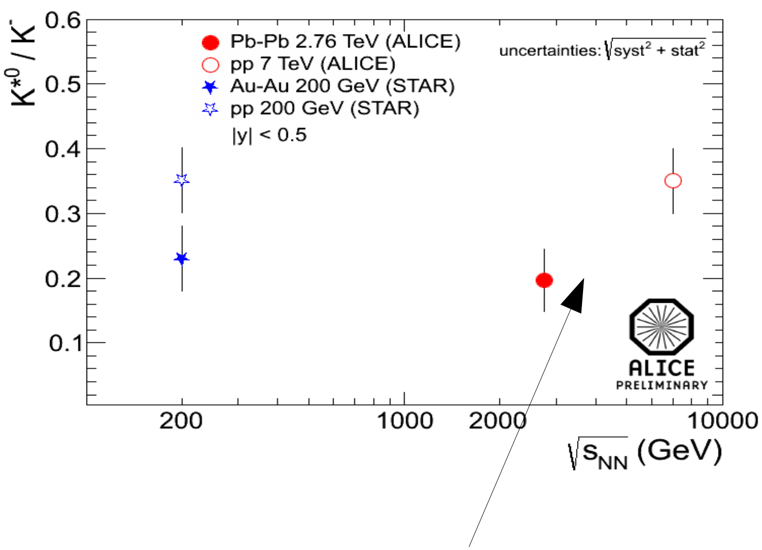
Width broadening up to 3-10 times.

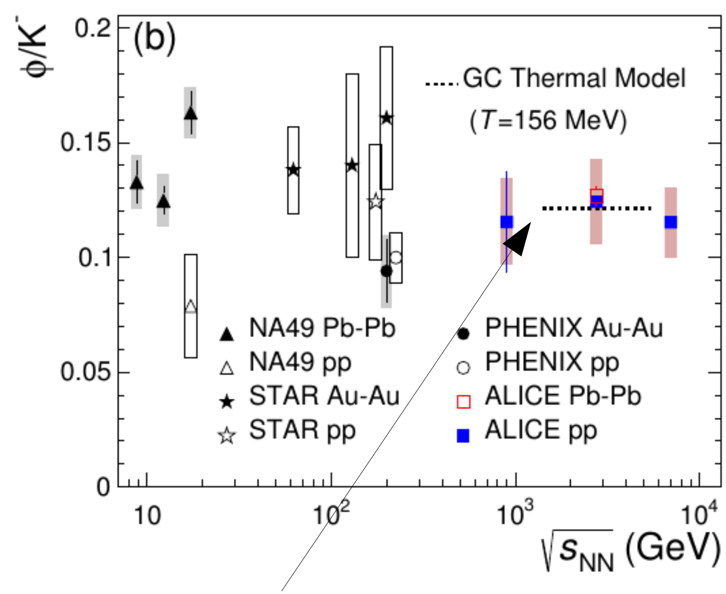




Befor background subtraction

After background subtraction





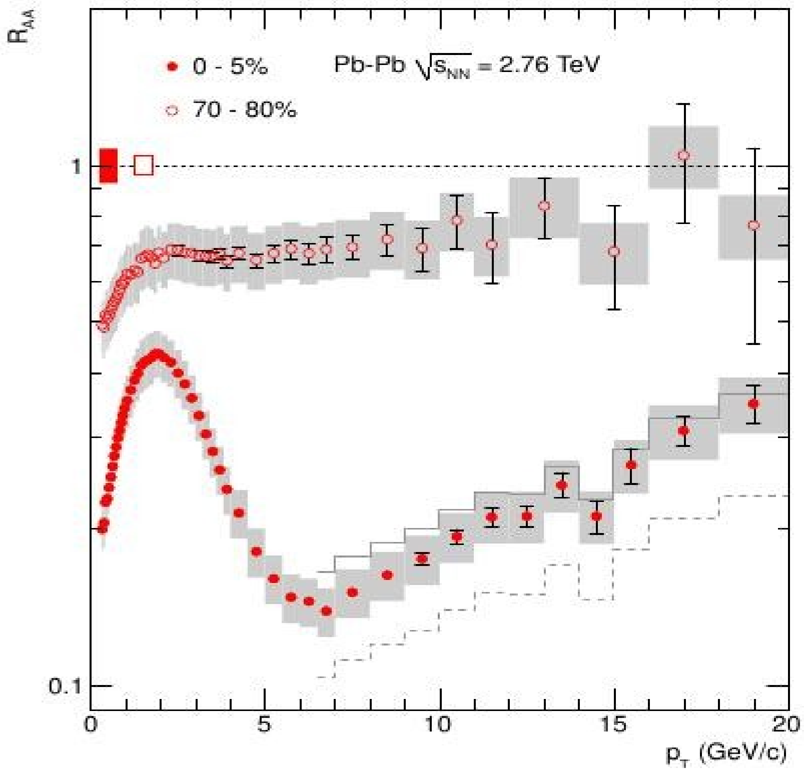
Rescattering

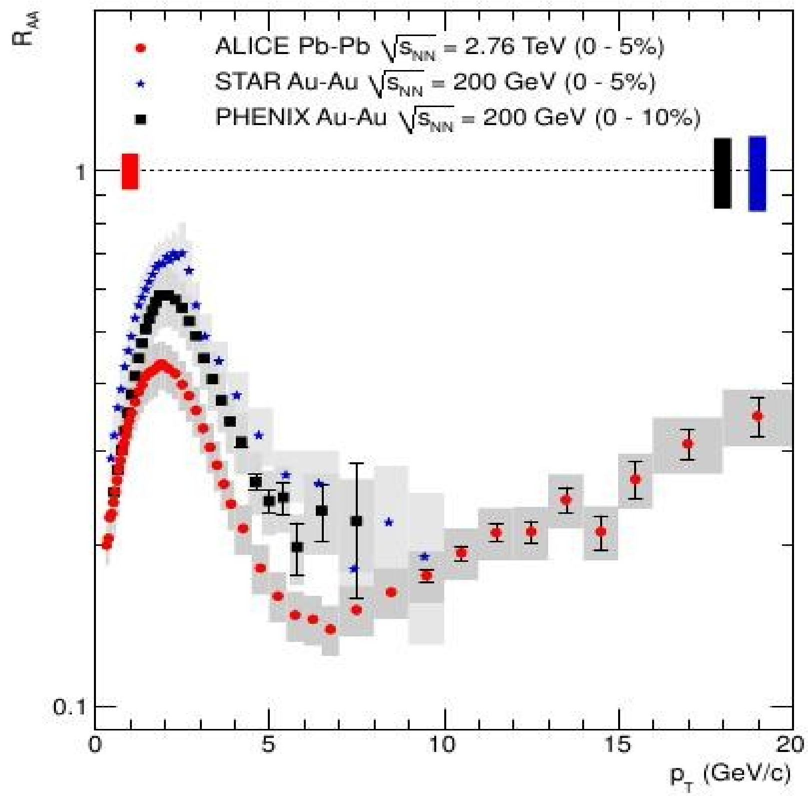
No rescattaring

The nuclear modification factor R_{AA} (supression of particles)

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

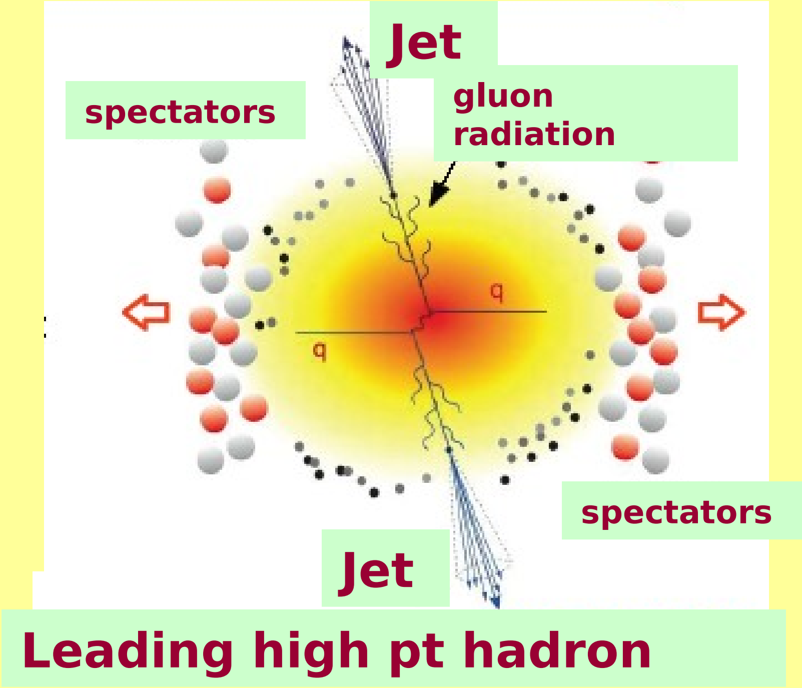
(charged particles).

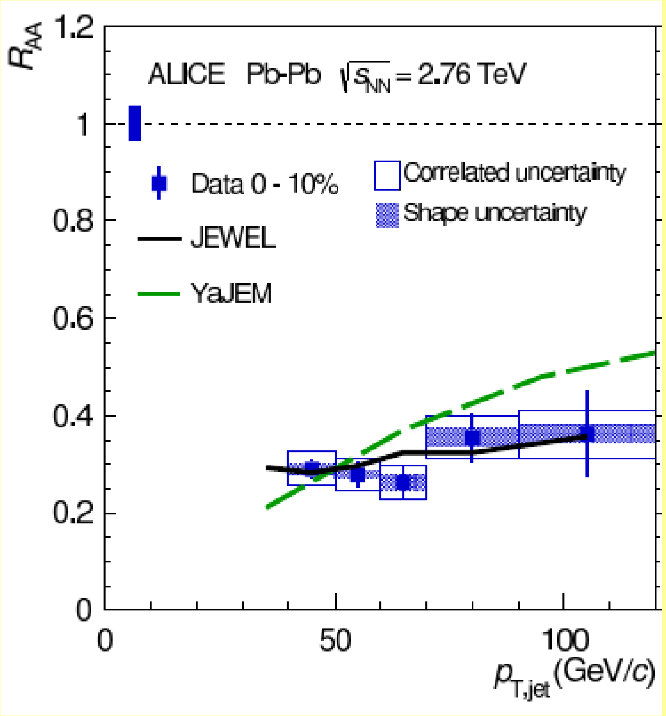




An evidence for stronger parton energy loss and larger medium density at LHC.

Jet supression (quenching)

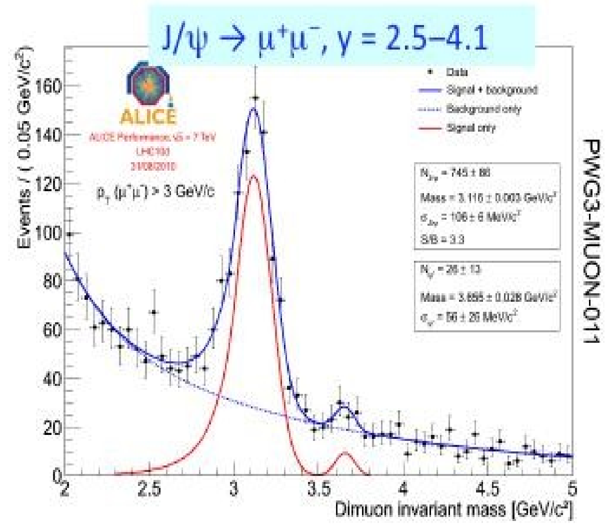


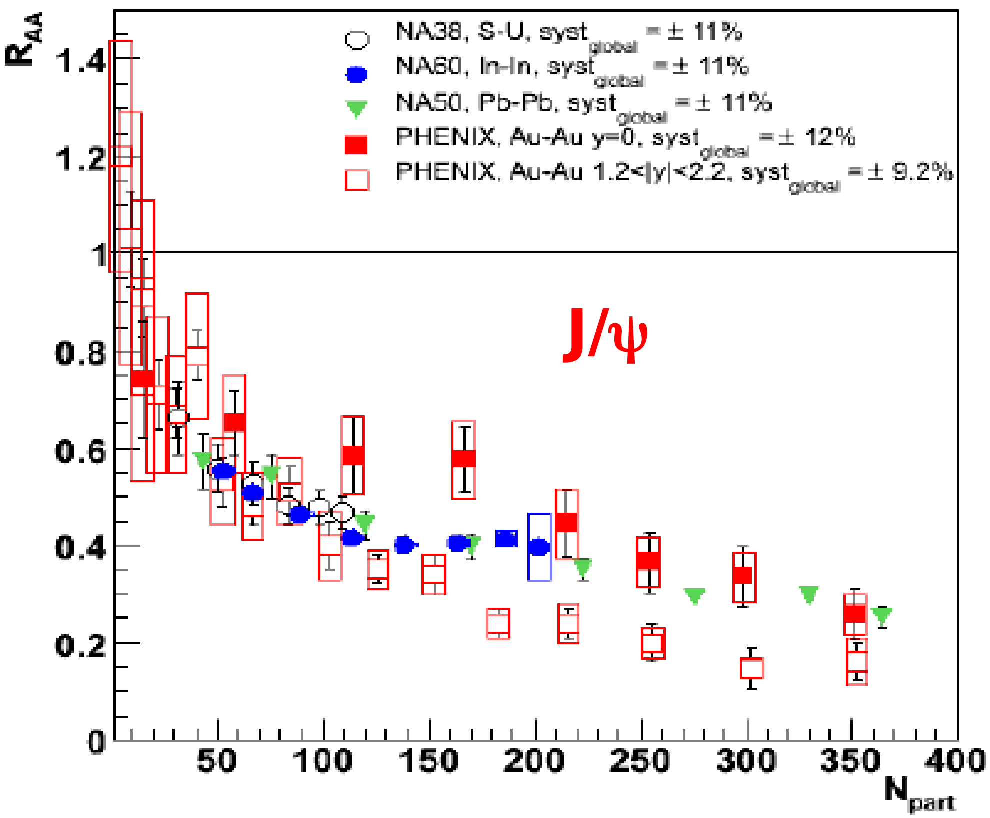


Quarkonia (J/ψ, Υ) suppression

- 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



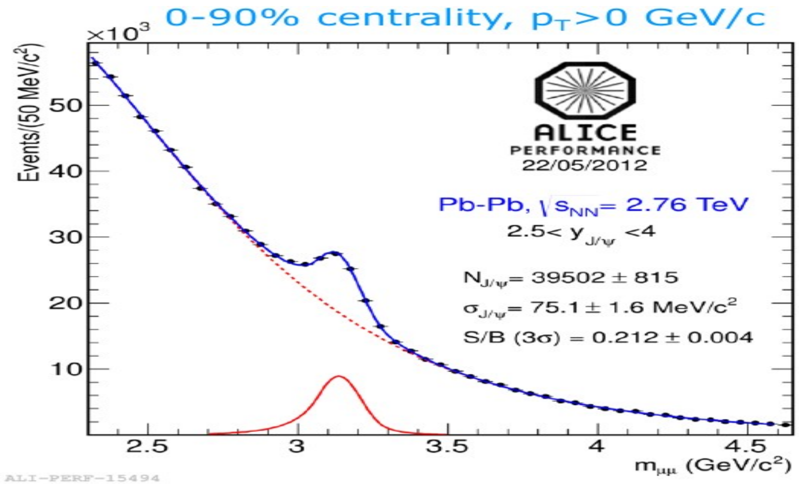


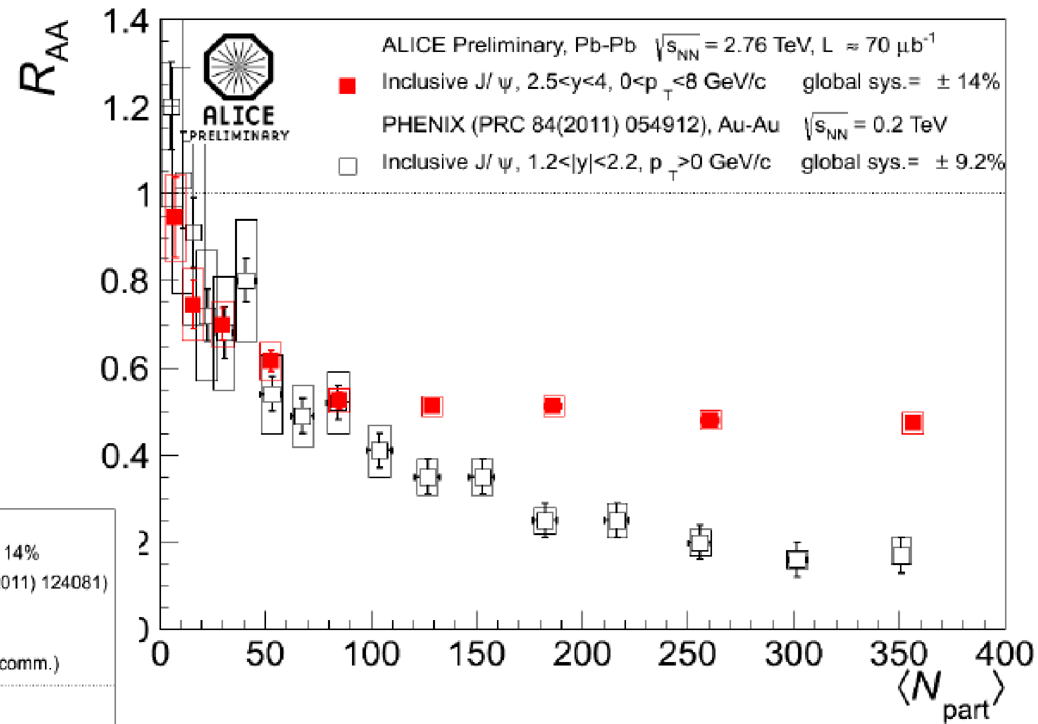
- Puzzles from SPS and RHIC
  - RHIC: stronger suppression at forward rapidities
  - SPS vs. RHIC: similar R_{AA} pattern versus $\sqrt{s}$

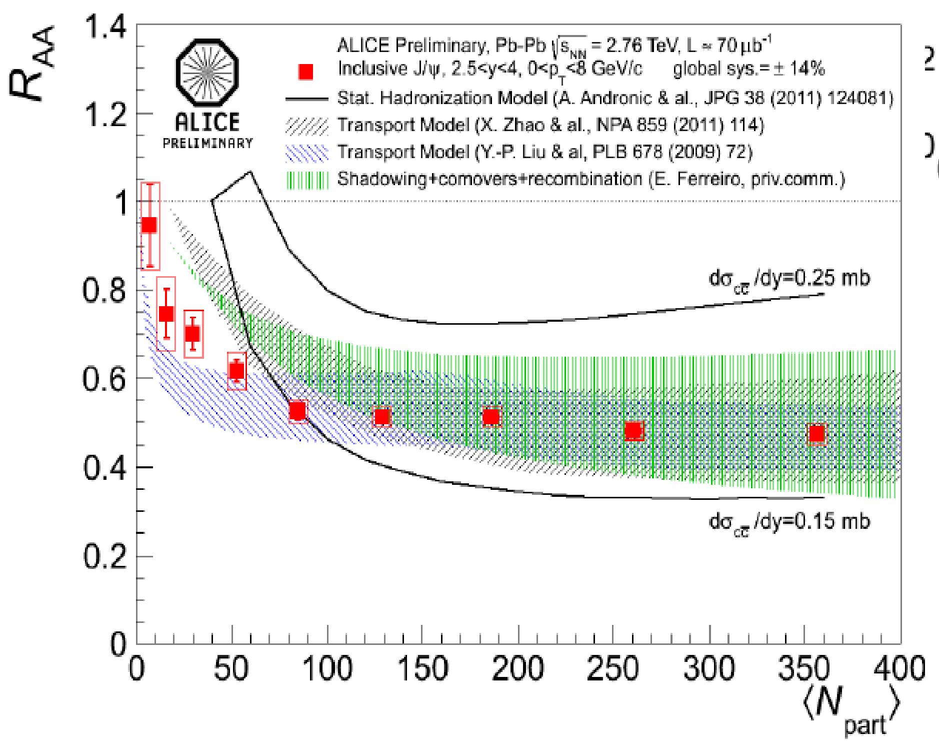
- LHC results can give decisive inputs, investigating the role of
  - the large charm quark multiplicity

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

  - other quarkonia states (bottomonium)

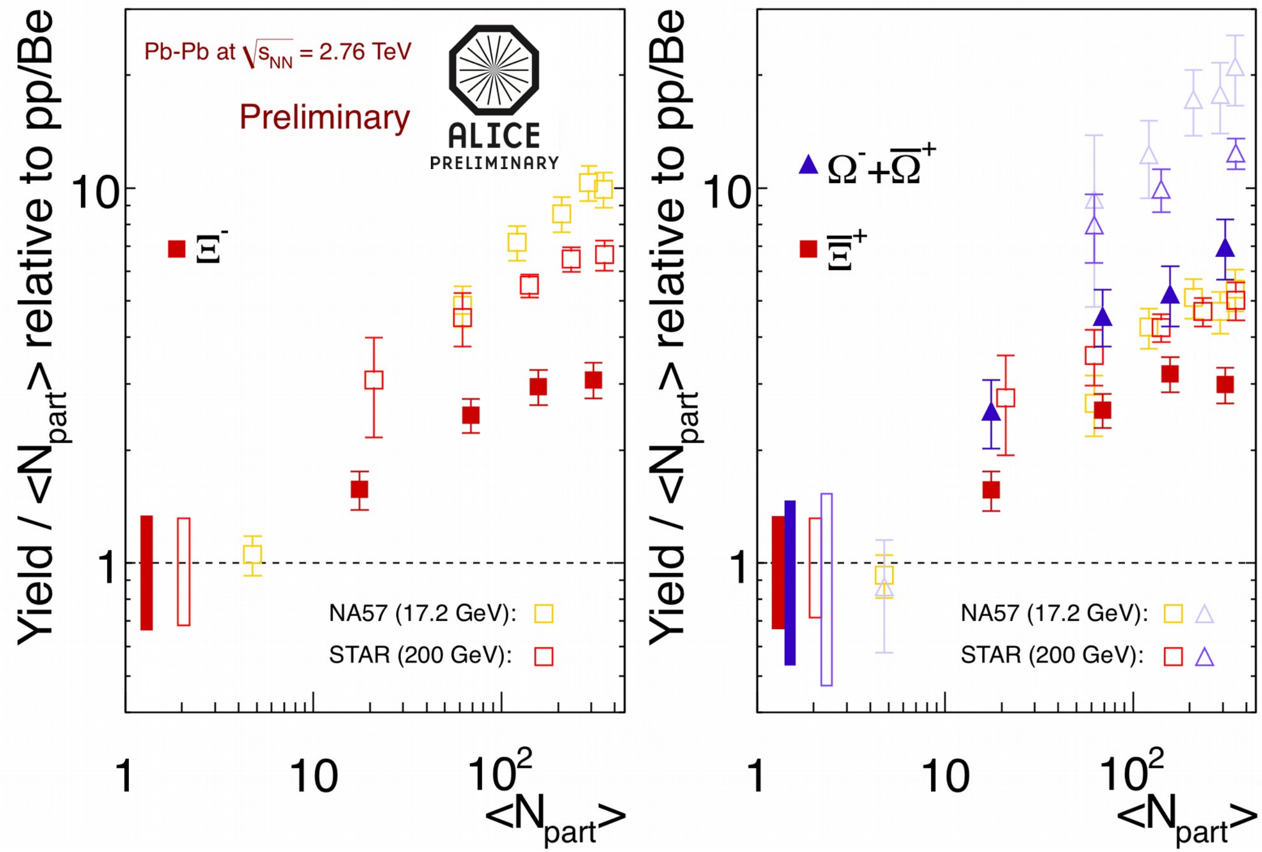






The RAA in the ALICE is almost a factor of three larger then in the PHENIX for $\langle N_{part} \rangle \gtrsim 180$. The theoretical description is with an including of 50% J/ψ regeneration component from deconfined charm quarks in the medium.

Strangeness Enhancement



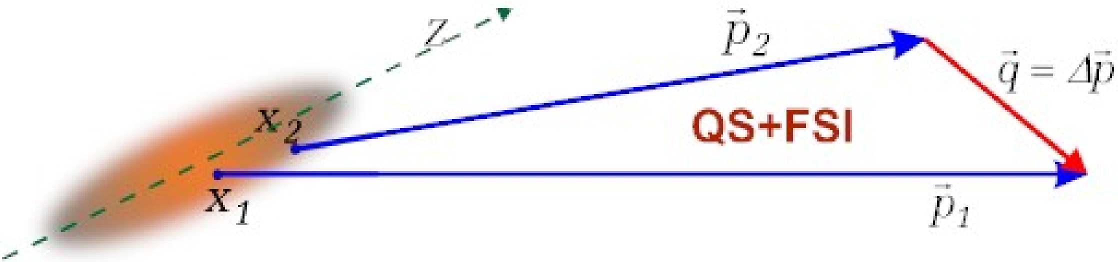
$$E_i = \frac{Yield_i^{AA} / \langle N_{part} \rangle}{Yield_i^{pp} / 2}$$

- **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**

Femtoscopy correlations (HBT)

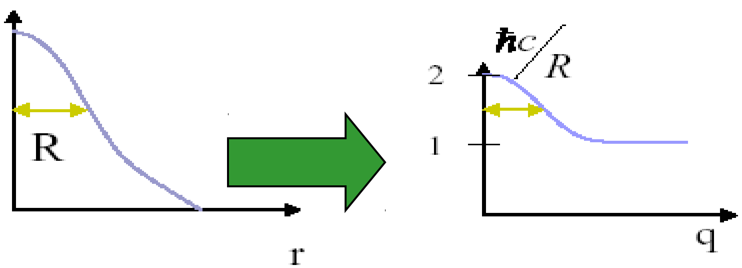
Formalism:

Following to Haunbary Brown-Twiss (HBT) method for an estimation of star sizes (1954-56) some authers (in JINR:



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

In practice:



$CF(q_{inv}) = N \times S(q_{inv})/B(q_{inv})$,

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

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

N normalization factor, u normalize the CF to be unity at large,

$$q_{\text{inv}} = \sqrt{\vec{q}^{\,2} - q_0^2}$$

M.I.Podgorecky, G.I.Kopylov) in the 1970s suggested to study the space - time parameters of the sources emissing identical particles using the correlation function with Bose-Einstein interferometric effect. This correlation effect has been observed firstly (1960) for π-π pairs by G. Goldhaber, S. Goldhaber, W-Y Lee, A. Pais.

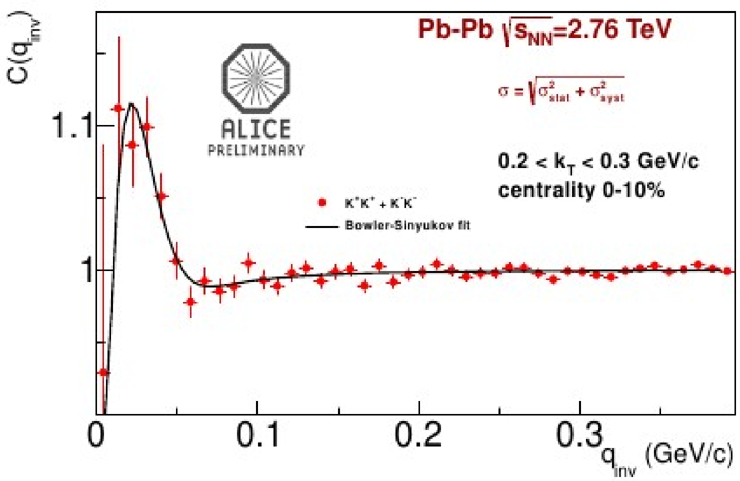
The Correlation Function (CF), is the process probability $W(p_1,p_2)$ and is defined as:

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

where $S = j^2$, j - spin

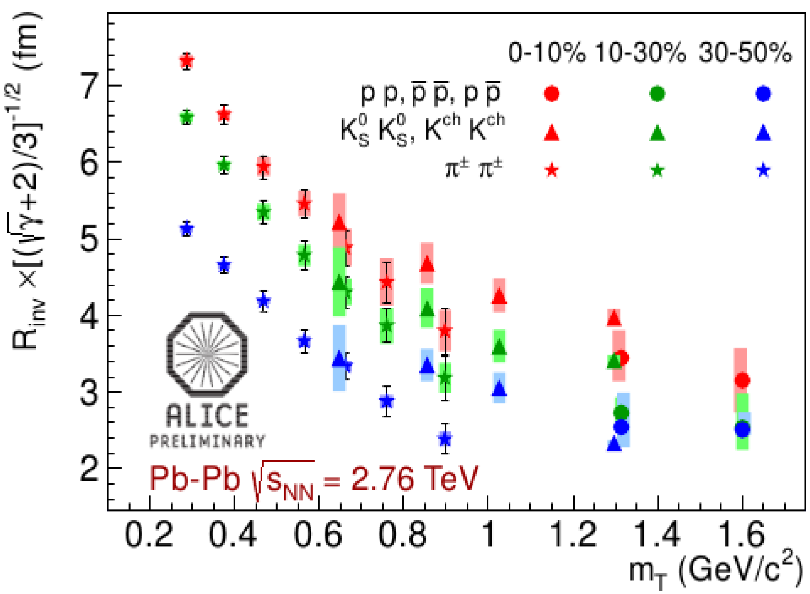
The practical formulas will be shown in the next slides.

Two-particle Femtoscopy Correlation results in Pb-Pb (ALICE, 1D-analysis).



Preliminary measurement of charged kaons Correlation Function $C(q_{inv})$ in Pb-Pb at 2.76 TeV was done by JINR group for different centralities and transverse pair momentum k_T. The typical correlation peak is shown (for example) for the 0.2<kT<0.3 GeV/c and event centrality (0-10)%. The $C(q_{inv})$ is fitted by the equqtion:

$$C(q_{inv}) = 1 - \lambda + \lambda K(q_{inv}) \left(1 + \exp\left(-R_{inv}^2 q_{inv}^2\right)\right)$$

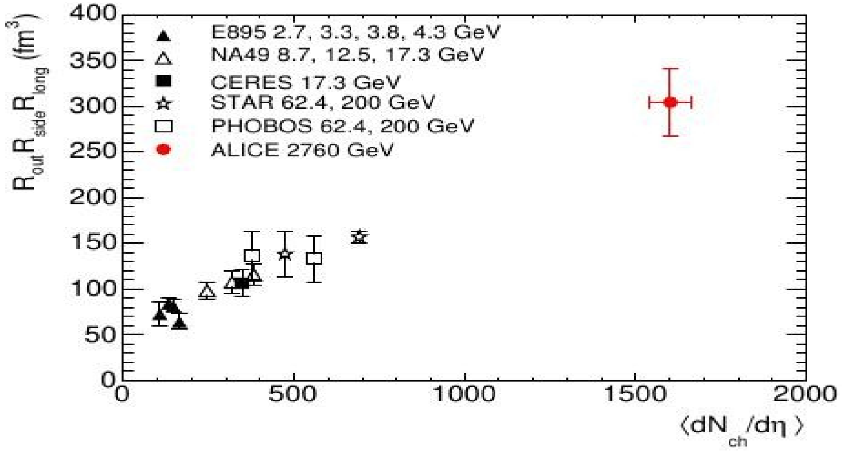


he emitting source radius (R_{inv}) has been extracted ·om the charged kaons $C(q_{inv})$ and compared ·ith the results obtained for the other particles. he dependence of the R_{inv} from the transverse pair ıass m_T demonstrates an approximate m_T-scaling redicted by the Hydrodynamic expansion model. ecause the collective expansion of the source, this ıodel predicts also the strong radius dependence on ıe m_T and event centrality as seen in the lower figure.

'hese results were presented ›y JINR group to the Quark-Matter 2012 Conference.

Two-pion Femtoscopy Correlation results in A-A collisions (3D-analysis).

Volume of the particle source

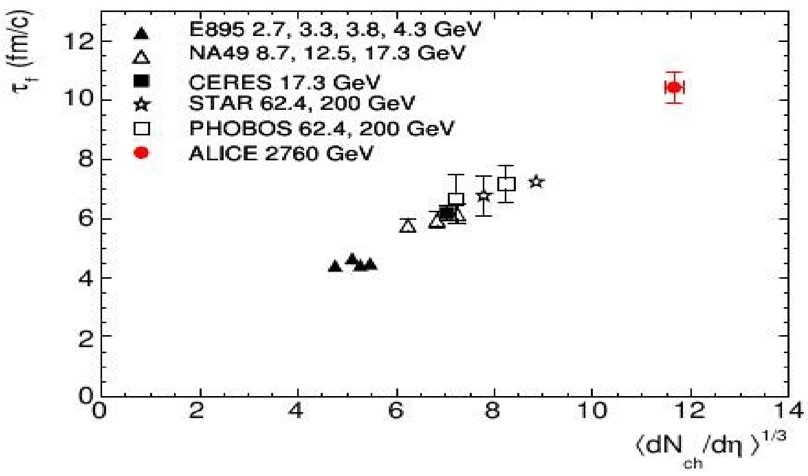


Three-dimensional correlation functions $C(q_{out}, q_{side}, q_{long})$ were considered in the longitudinally co-moving system (LCMS) and fitted by an expression:

$$C(\mathbf{q}) = \mathcal{N}\left[(1-\lambda)+\lambda K(q_{\rm inv})(1+G(\mathbf{q}))\right],$$
$$G(\mathbf{q}) = \exp(-(R_{\rm out}^2 q_{\rm out}^2 + R_{\rm side}^2 q_{\rm side}^2 + R_{\rm long}^2 q_{\rm long}^2 + 2|R_{\rm ol}|R_{\rm ol}q_{\rm out}q_{\rm long})),$$

The “out” exis – along the pair transverse momentum, the “side” axis – perpendicular to it in the transverse plane, the “long” axis – along the beam. K(qinv) is the factor of Coulomb interaction between the two particles and the λ describes the correlation strength.

Hadron formation time



Hadron formation (decoupling) time τ_f is estimated from:

$$R_{\rm long}{}^2(k_T) = \frac{\tau_f^2 T}{m_T}\frac{K_2(m_T/T)}{K_1(m_T/T)}, \quad m_T = \sqrt{m_\pi^2 + k_T^2}$$

T is the kinetic freeze-out temperature (120 MeV) and the K_1, K_2 are Bessel functions.

The source volume and the hadron formation time obtained in ALICE 2 and 1.5 times larger respectively than at RHIC energy.

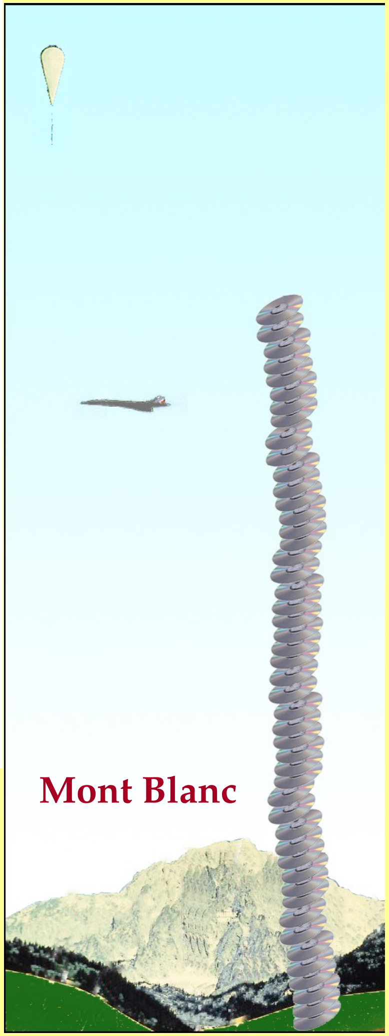
(Phys. Lett. B (2011)328)

ALICE Computing Model

- <u>Three kinds of data analysis:</u>
  - **Fast pilot analysis** of the data "just collected" to tune the first reconstruction at CERN Analysis Facility (CAF)
  - **Scheduled batch analysis** using GRID (Event Summary Data and Analysis Object Data)
  - **End-user interactive analysis** using PROOF and GRID (AOD and ESD)

- CERN, T0
  - Does: first pass reconstruction
  - Stores: one copy of RAW, calibration data and first-pass ESD's
- Tier 1, 4 centres (1 in Russia)
  - Does: reconstructions and <u>scheduled batch analysis</u>
  - Stores: second collective copy of RAW, one copy of all data to be kept, disk replicas of ESD's and AOD's
- Tier 2, 73 centres
  - Does: simulation and <u>end-user interactive analysis</u>
  - Stores: disk replicas of AOD's and ESD's

ALICE computing (GRID)



>47000 cores, 78 centers

Заключение

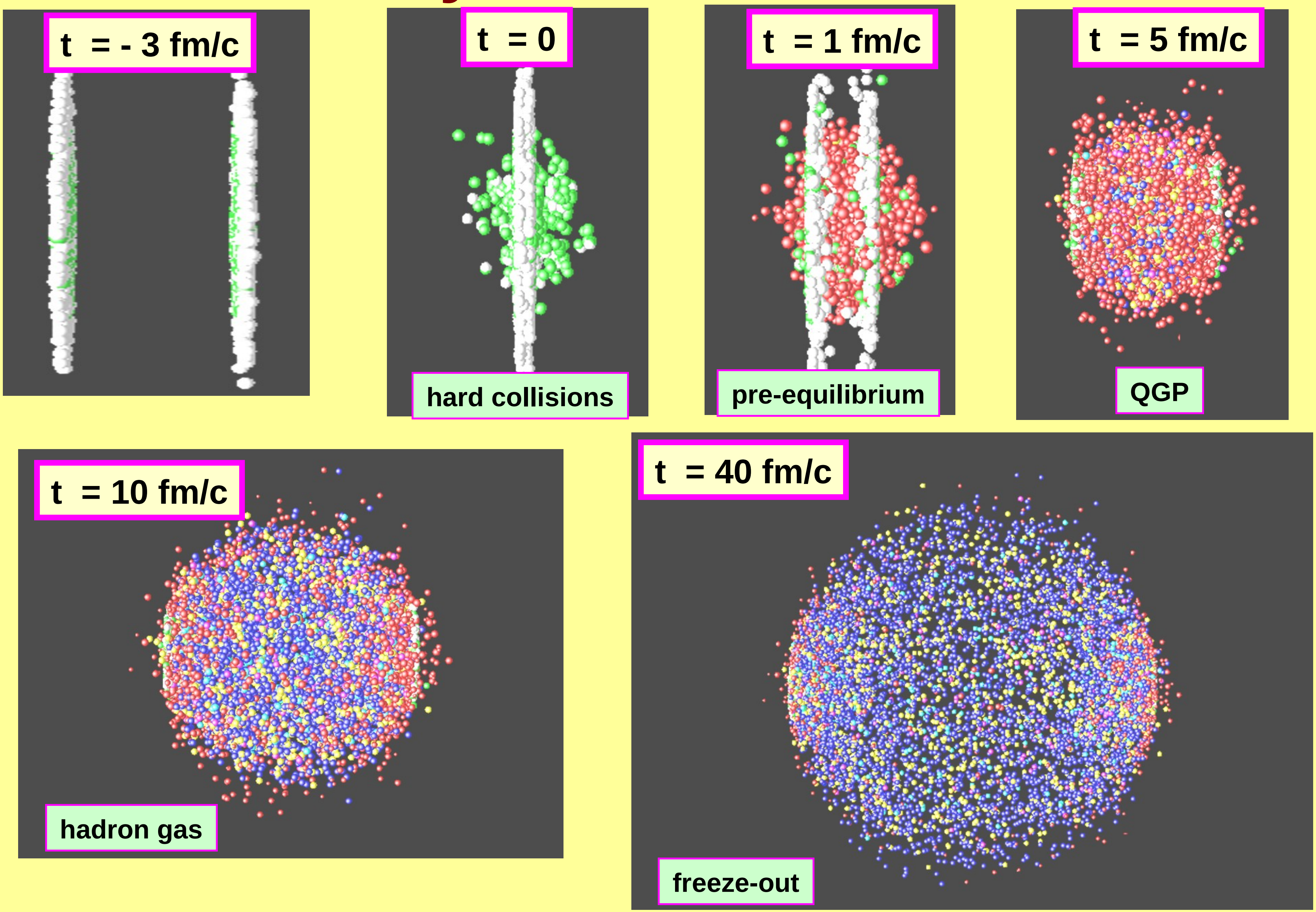
Изучение столкновений релятивистских ядер вплоть до самых тяжёлых позволяет понять сложные механизмы взаимодейтвия нуклонов внутри ядер на кварк-партонном уровне.

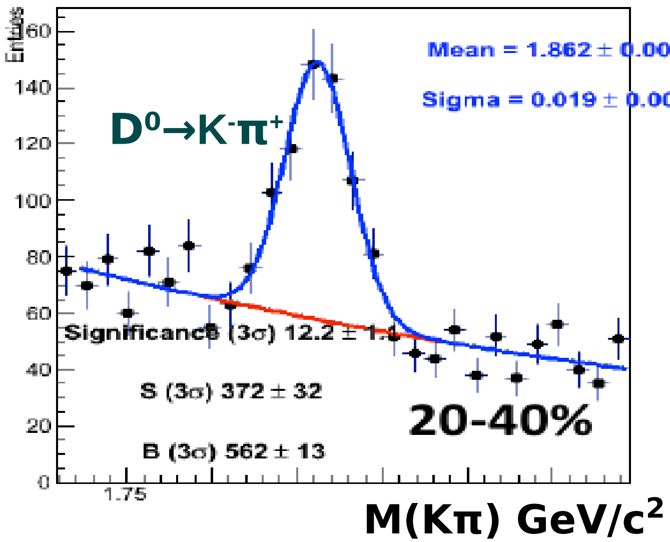
Кварк-глюонная плазма – начало зарождения Вселенной !?

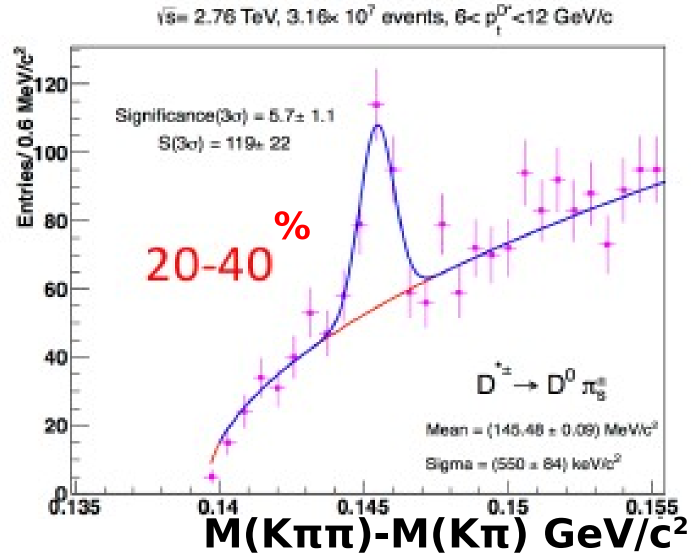
Thanks
for your attention

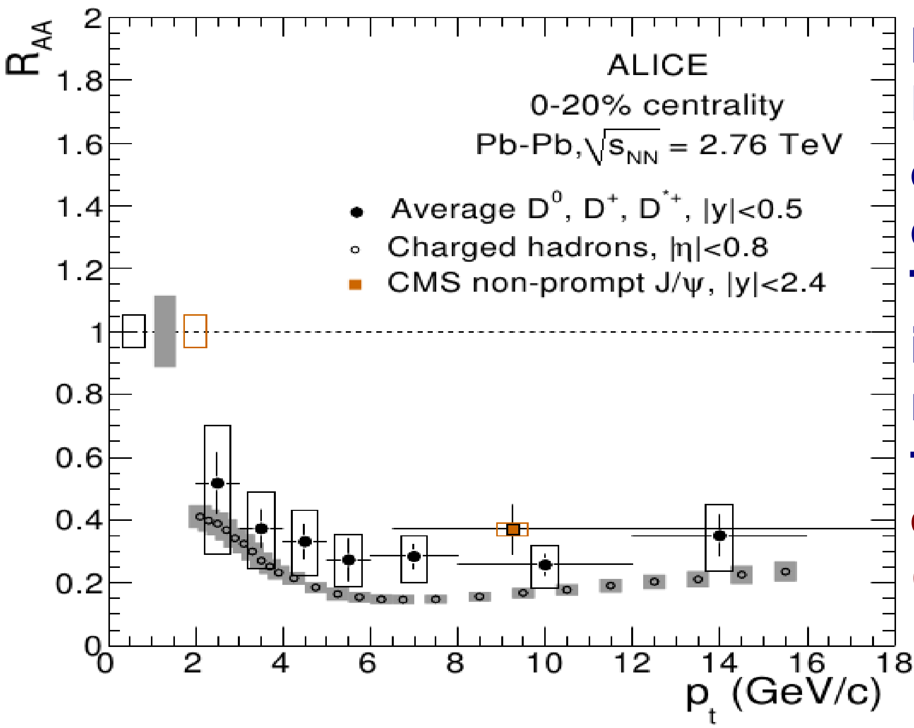
Спасибо
за внимание

Heavy Ion Collision









It is expected in the QCD the $R_{AA}(\pi)<R_{AA}(D)$ 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 bottom figure (not seen at the RHIC energy).

Группа ОИЯИ анализа и моделирования в эксперименте АЛИСА

Начало активной работы в 1993 году (10-12 человек) по созданию следующего програмного обеспечения:

- детального моделироиания кремниевой внутренней трэковой системы (ITS) и мюонного плеча,

- распознования и реконструкции трэков,

- идентификации частиц (PID) в ITS, TPC и TRD

- для моделирования процессов рождения резонансов и кваркониев и для исследования фемтоскопических корреляций; использовались пакеты симуляции детекторов ITS, TPC, TOF, TRD, Muon Arm, для восстановления сигналов (GEANT3), реконструкции трэков и идентификации частиц в общем пакете AliRoot; генераторы HIJING, PITHIA и UHKM и коктейль – генераторы для быстрого моделирования.

Методы анализа и компьютерные фермы

1. ***Анализ в рамках системы GRID – AliEn (AliEn - ALICE production Environment):***

Требует наличие у участника GRID – сертификата и регистрации в виртуальной организации (VO – ALICE).

Требует знание командного пакета GRID-AliEn и умения создать рабочий пакет (библиотеки par-files, макросы, управляющий jdl-file)

Работа – в "batch" режиме на фермах всех центров, зарегистрированных в системе GRID-ALICE (>47000 процессоров PC).

Запись выходных данных на дисках этих центров и в директорию AliEn пользователя.

Использование стандартного пакета анализа с включением специальных программ пользователя.

Методы анализа и компьютерные фермы

Анализ на локальных фермах ОИЯИ

Ферма ЛИТ:

- ***3480 cores CPU,***
- ***Диски: 408 Тб SE и 139 Тб EOS.***

Analysis work-flow