Holography for NICA

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Outlook

- Physical picture of Quark-Gluon Plasma in heavy-ions collisions

- Why holography?

- Results from holography:

  Fit experimental data via holography;
  top-down (top=string theory)
  bottom-up (bottom=5-dim GR+matter)

  Predict new data

- What is special for NICA

И. Я. Арефьева, “Голографическое описание кварк-глюонной плазмы, образующейся при столкновениях тяжёлых ионов”, УФН, 184:6 (2014), 569–598
I.A,``Holography for Heavy Ions Collisions at LHC and NICA, arXiv:1612.08928

Experiments

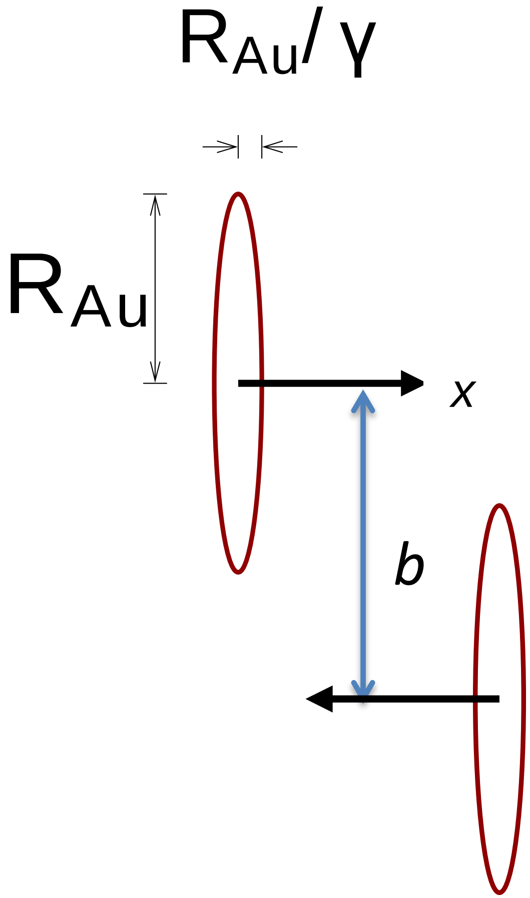
HIC are studied in several experiments:

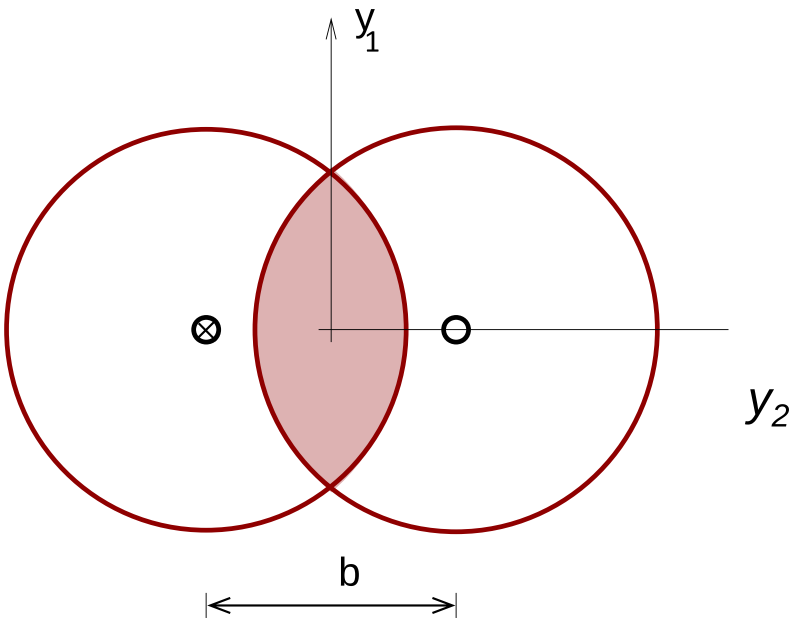
- **started in the 1990's at the Brookhaven Alternating Gradient Synchrotron (AGS),** $\sqrt{s_{NN}} = 4.75\,GeV$
- **the CERN Super Proton Synchrotron (SPS)** $\sqrt{s_{NN}} = 17.2\,GeV$
- **the Brookhaven Relativistic Heavy-Ion Collider (RHIC)** $\sqrt{s_{NN}} = 200\,GeV$
- **the LHC collider at CERN.** $\sqrt{s_{NN}} = 2.76\,TeV$

and (future)

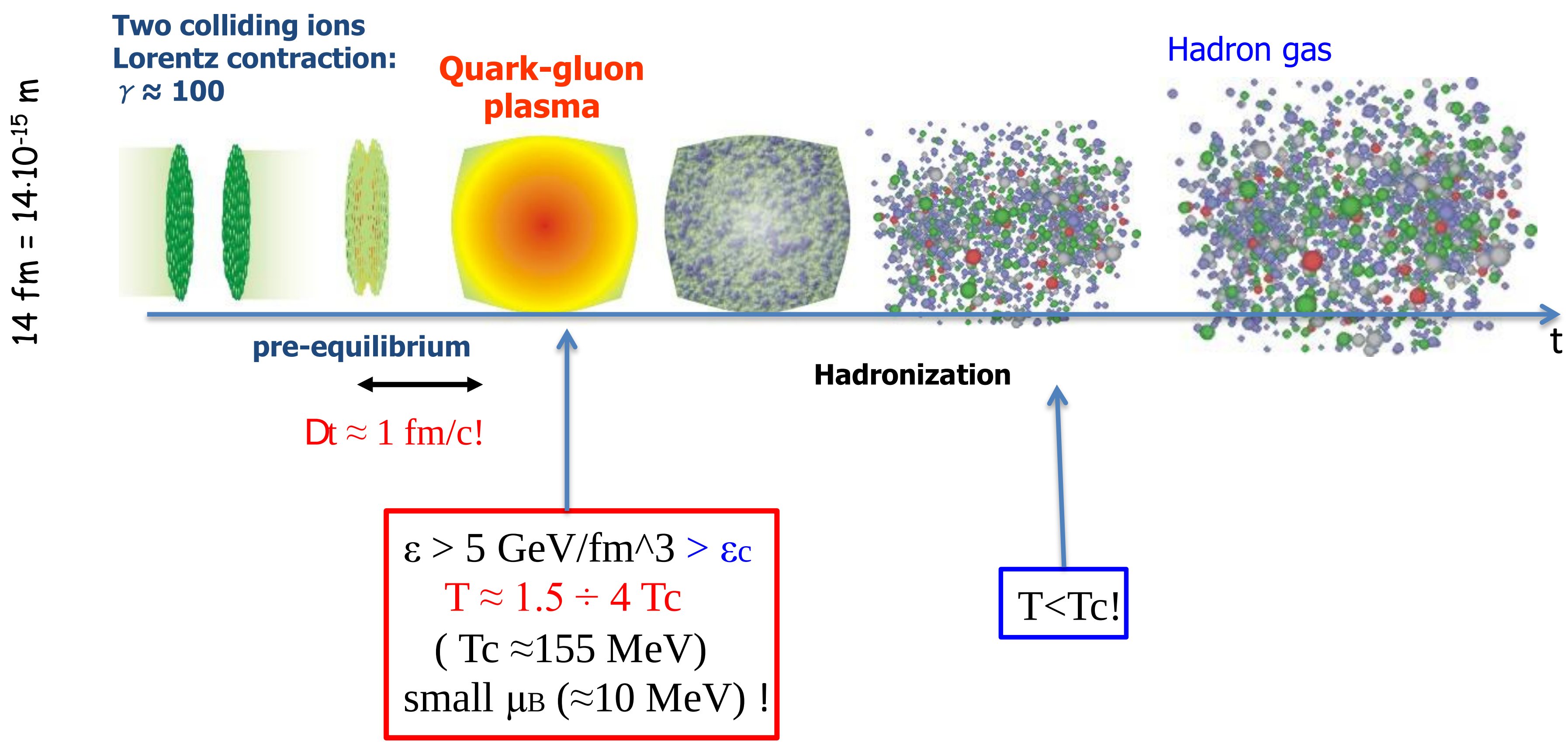
- **NICA (Nuclotron-based Ion Collider fAcility) 4.5 GeV per nucleon**
- **FAIR (Facility for Antiproton and Ion Research)**

Geometry of a high energy heavy ion collision.

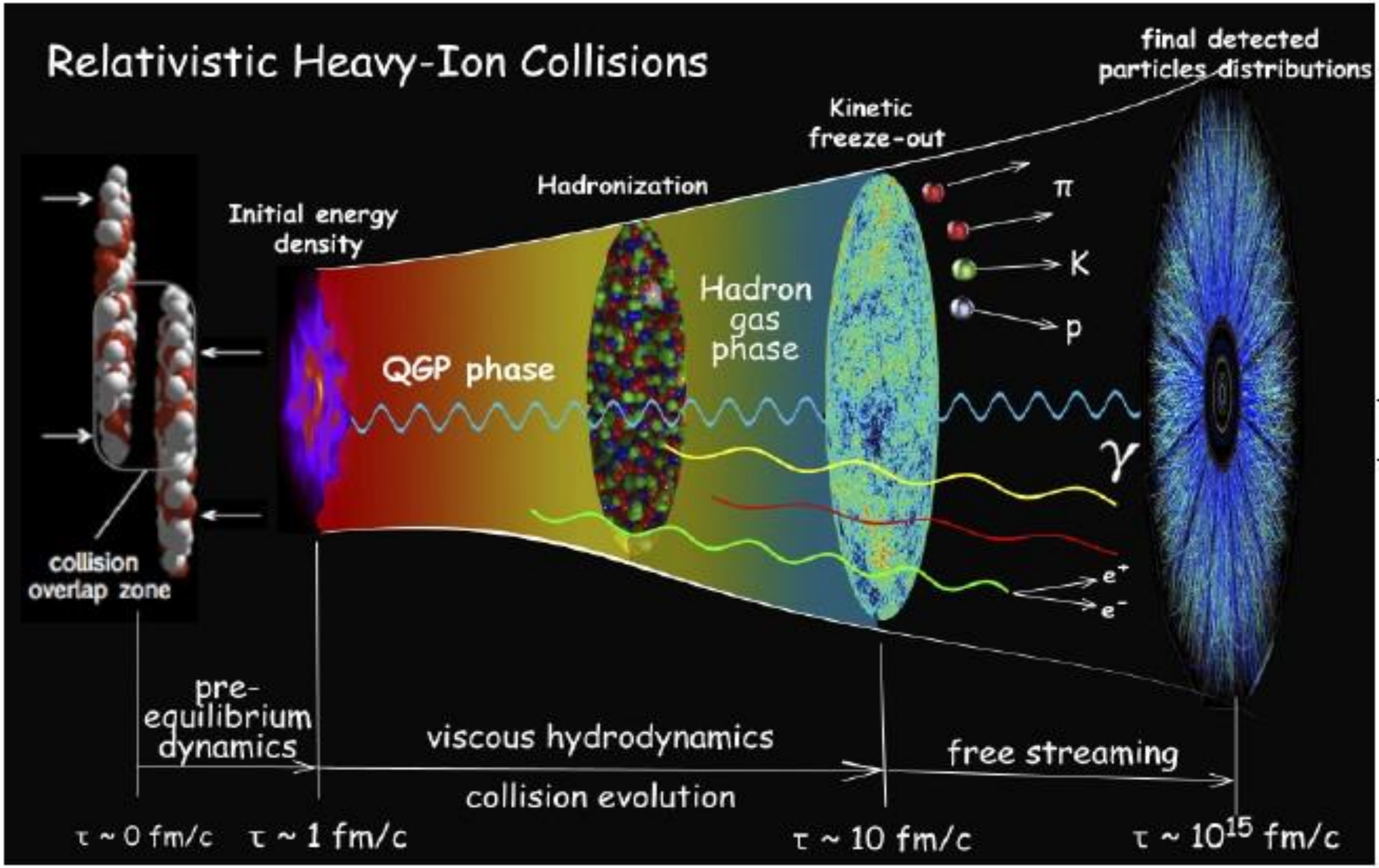




Heavy Ions Collisions



Heavy Ions Collisions



Picture from: P.Sorensen, C.Shen

Experiments: Heavy Ions collisions produced a medium

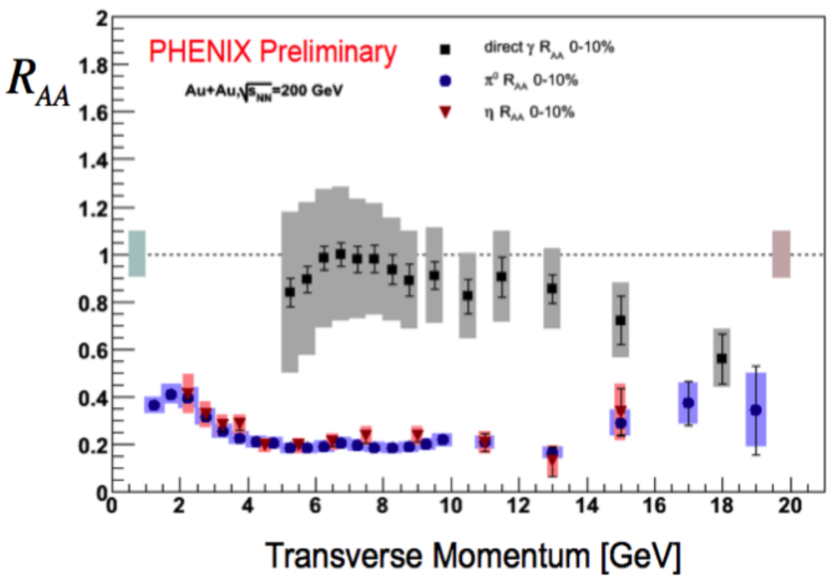
There are strong experimental evidences that RHIC or LHC have created some medium which behaves collectively:

- modification of particle spectra (compared to p+p)
- jet quenching
- high p_T-suppression of hadrons
- elliptic flow
- suppression of quarkonium production

Experiments: Heavy Ions collisions produced a medium

- modification of particle spectra (compared to p+p)

$$R^h_{AA}(p_T, \eta, \text{centrality}) = \frac{\frac{\mathrm{d}N^{AA\to h}_{\text{medium}}}{\mathrm{d}p_T\,\mathrm{d}\eta}}{\langle N^{AA}_{\text{coll}}\rangle \frac{\mathrm{d}N^{pp\to h}_{\text{vacuum}}}{\mathrm{d}p_T\,\mathrm{d}\eta}}$$



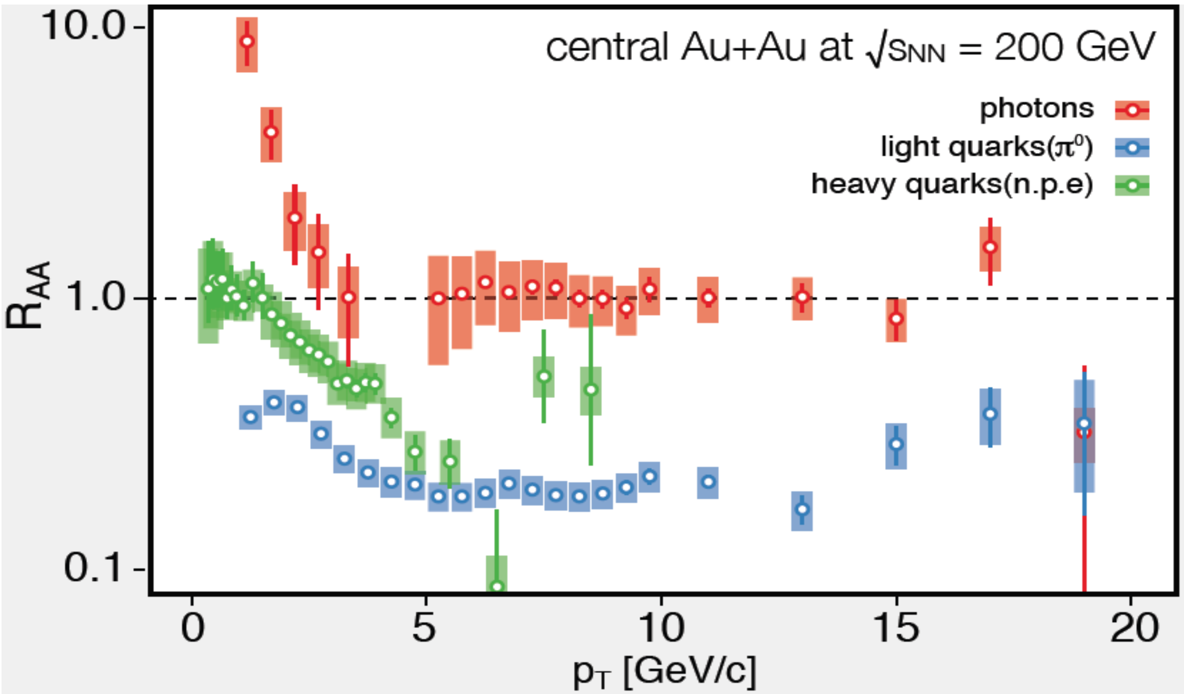
$$y = \frac{1}{2}\log\left(\frac{E+p_z}{E-p_z}\right)$$

$$\eta = \frac{1}{2}\log\left(\frac{|p|+p_z}{|p|-p_z}\right)$$

High momentum pions and η-mesons are suppressed by a factor of 5 and the color neutral photons are not

From: P.Sorensen, arXiv:1201.0784

Experiments: Heavy Ions collisions produced a medium

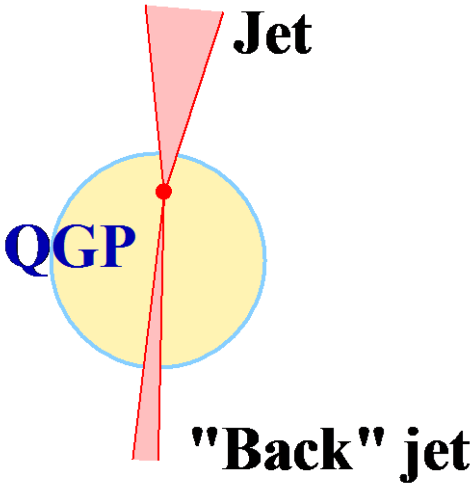


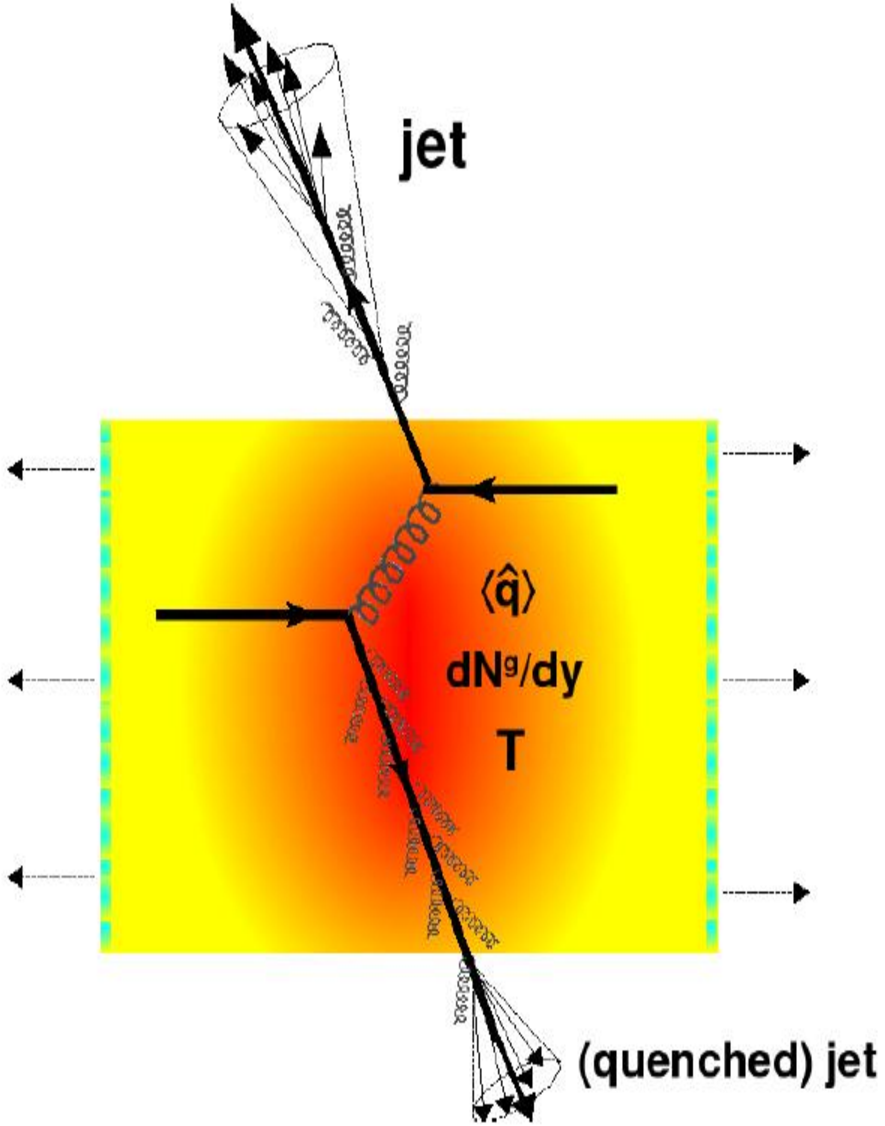
The nuclear modification factors for different particles measured in RHIC

From: S. Bass et al., 2012

Experiments: Heavy Ions collisions produced a medium

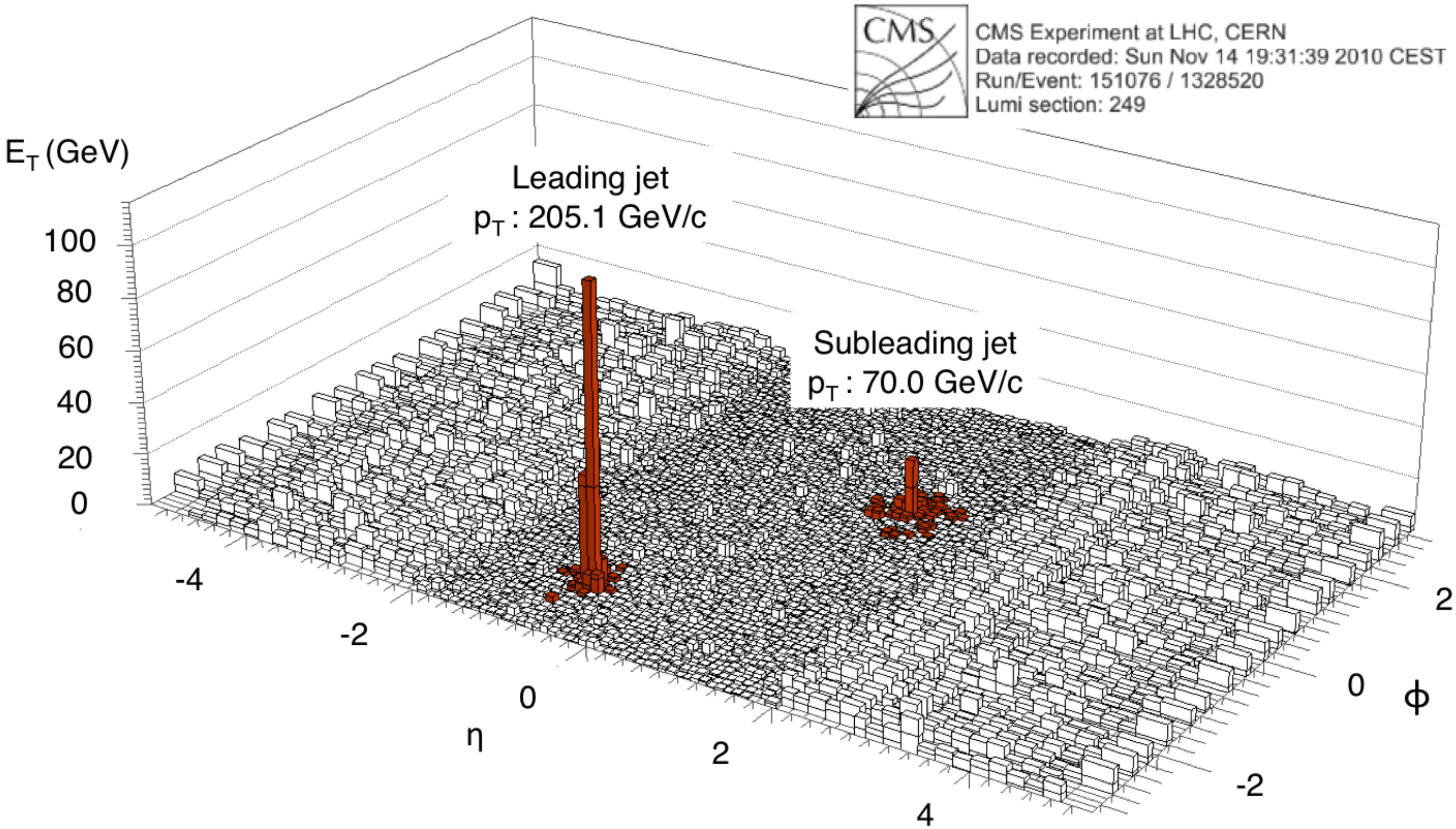
- **jet quenching**





From: D.~d'Enterria, ``Jet quenching,''arXiv:0902.2011

Jet quenching

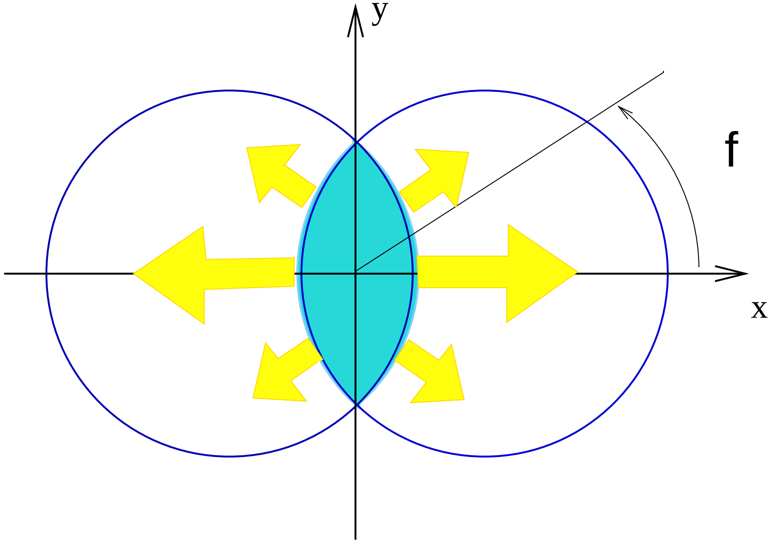


Example of an unbalanced dijet in a PbPb collision event at $s_{NN}^{1/2}$=2.76$ TeV

From:1102.1957

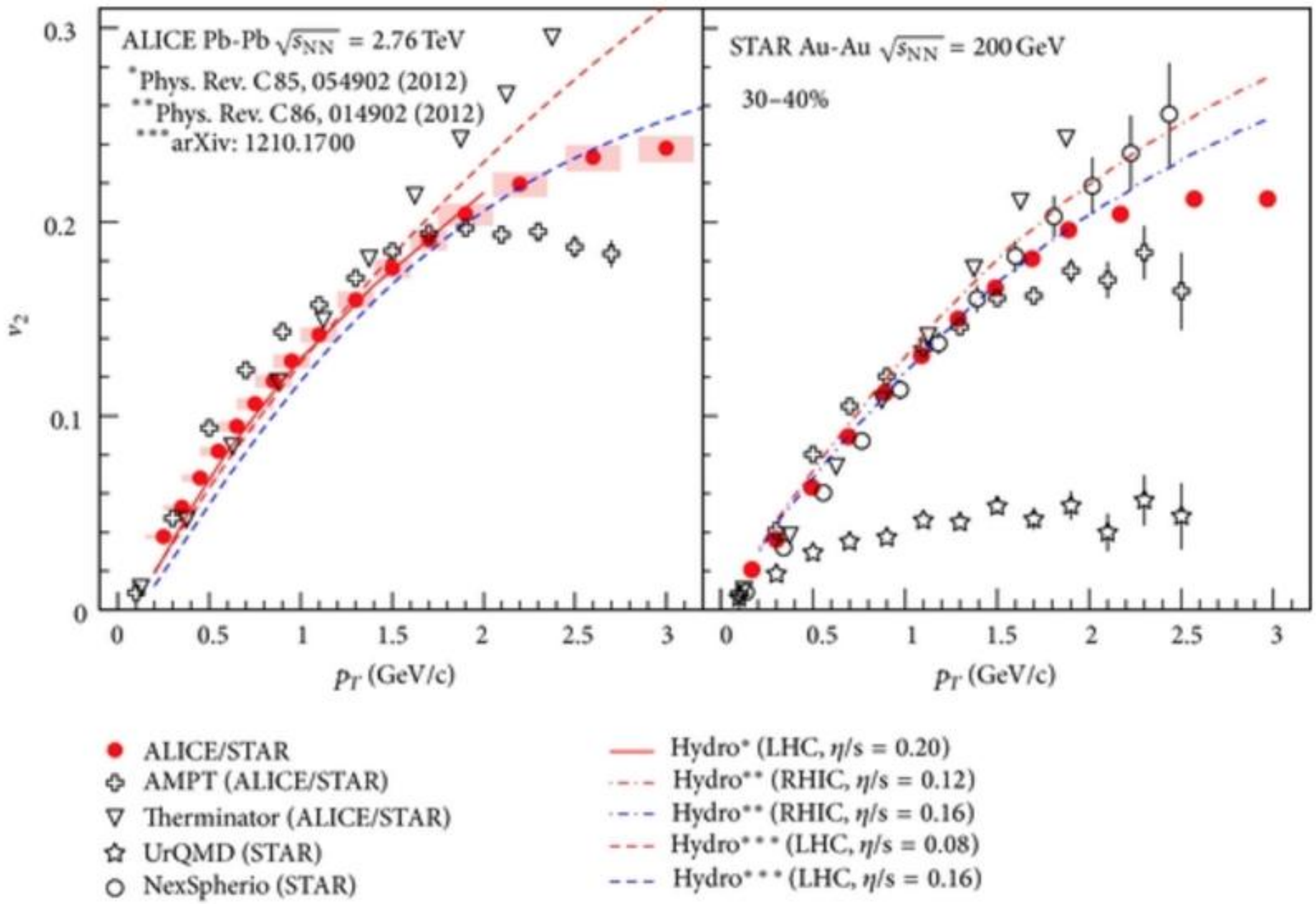
Experiments: Heavy Ions collisions produced a medium

- **elliptic flow**



$$\frac{dN}{d\phi} = \frac{N}{2\pi}\left(1 + \sum_{n=1} v_n(p_\perp, b)\cos(n(\phi - \Phi_n)\right)$$

v_2



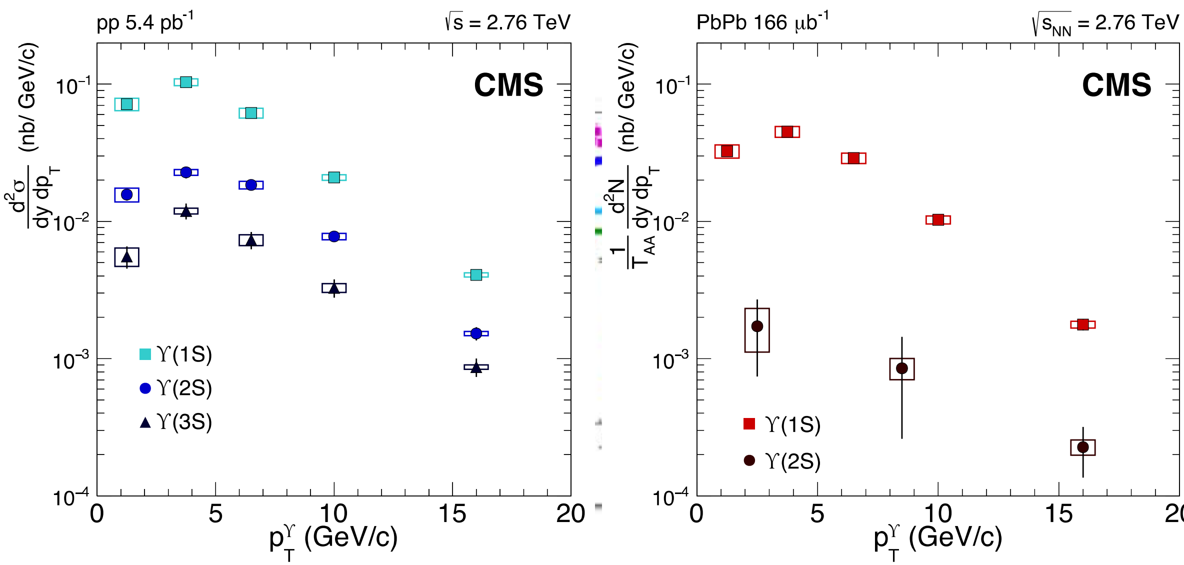
The azimuthal anisotropy parameter v2, measured in noncentral heavy-ion collisions at midrapidity for RHIC and LHC energies.

For comparison, shown are the various theoretical calculations based on hydrodynamic

Experiments: Heavy Ions collisions produced a medium

- **suppression of quarkonium production**

From:1611.01 510



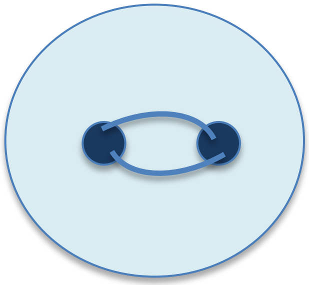
A suppression of a factor of ≈2 for Υ(1S)

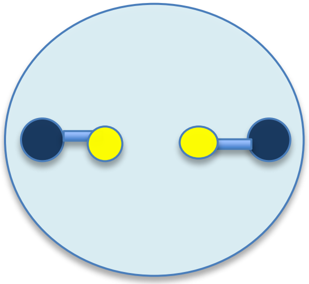
and 8 for

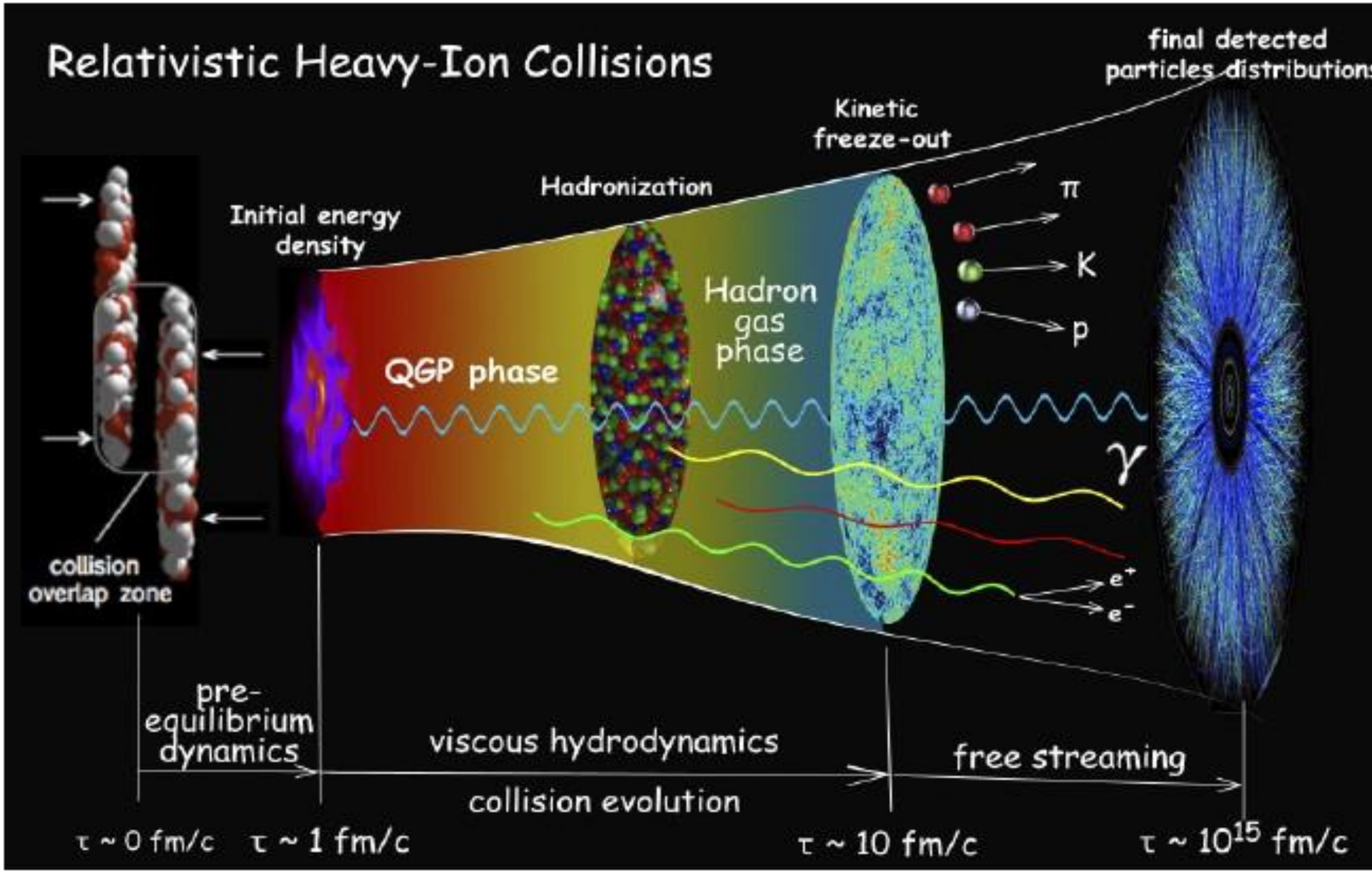
Υ(2S) states

Screening of the free energy for heavy quark and anti-quark pairs at finite temperature.
The sequential melting of states can provide a thermometer for the QGP
[The less bound quarkonium states melt at low temperatures.
J/ψ is suppressed at RHIC]

From: 1201.0784

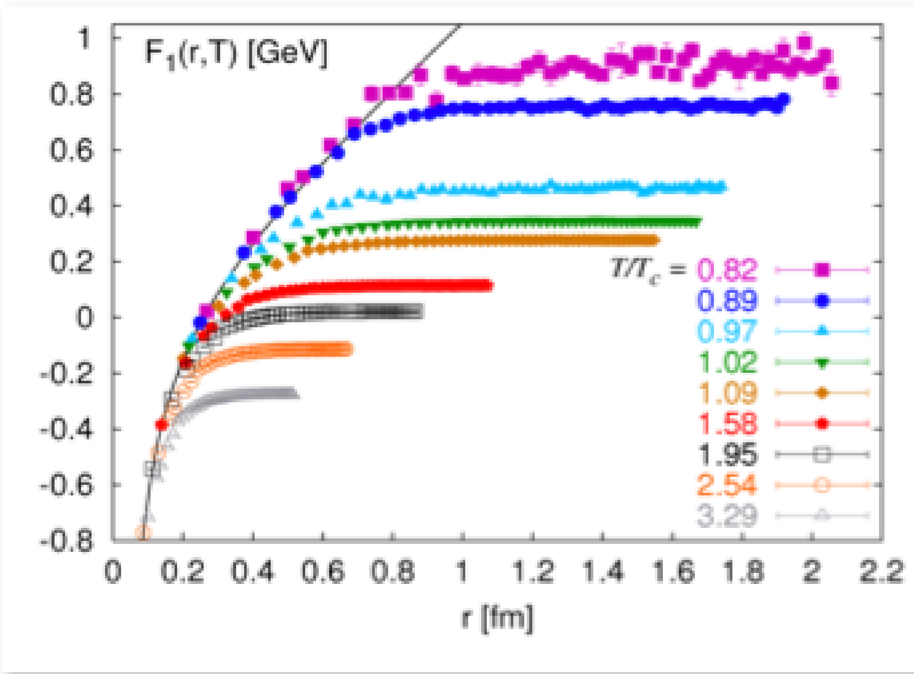


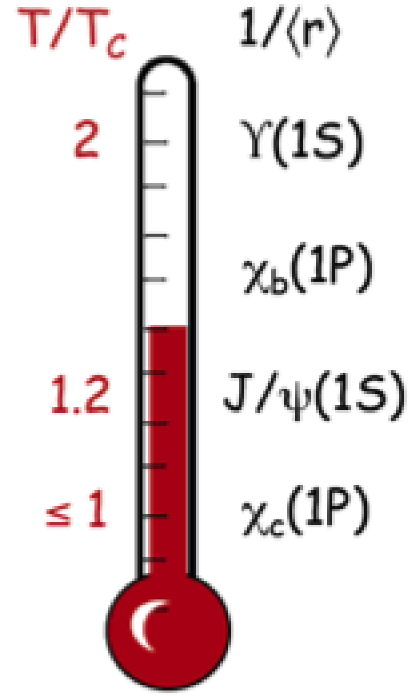




Picture from: P.Sorensen, C.Shen

Quarkonium as a tool to measure the temperature.

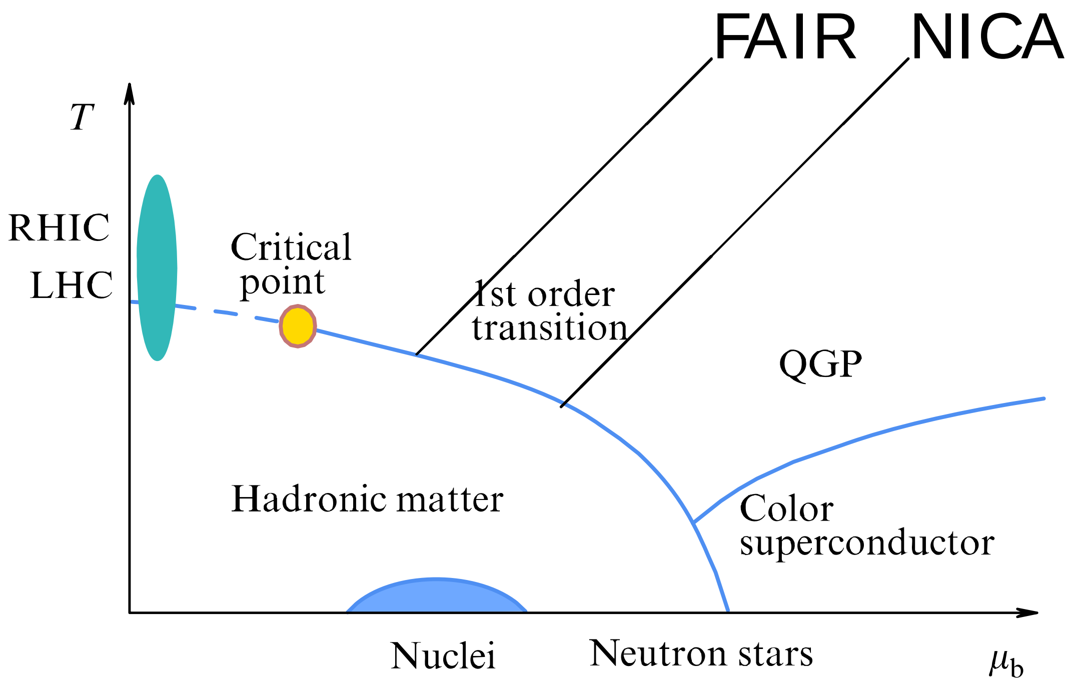




The screening of the free energy for heavy quark and anti-quark pairs at finite temperature.

The sequential melting of states provides a thermometer for the QGP

QCD Phase Diagram



Подгонка статистической модели

P.Braun-Munzinger, J.Stachel
nulc-th/9606017

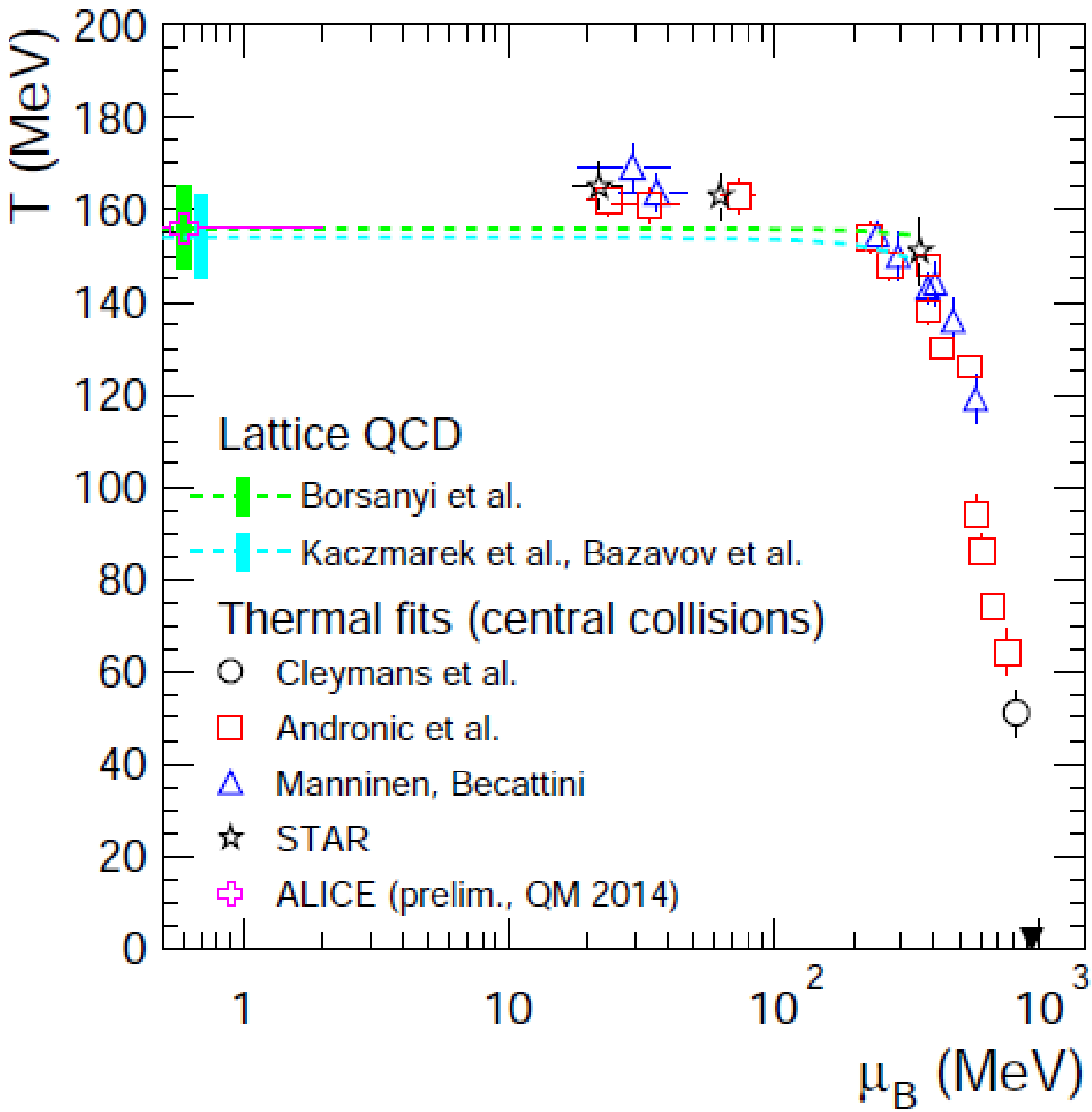
HRM

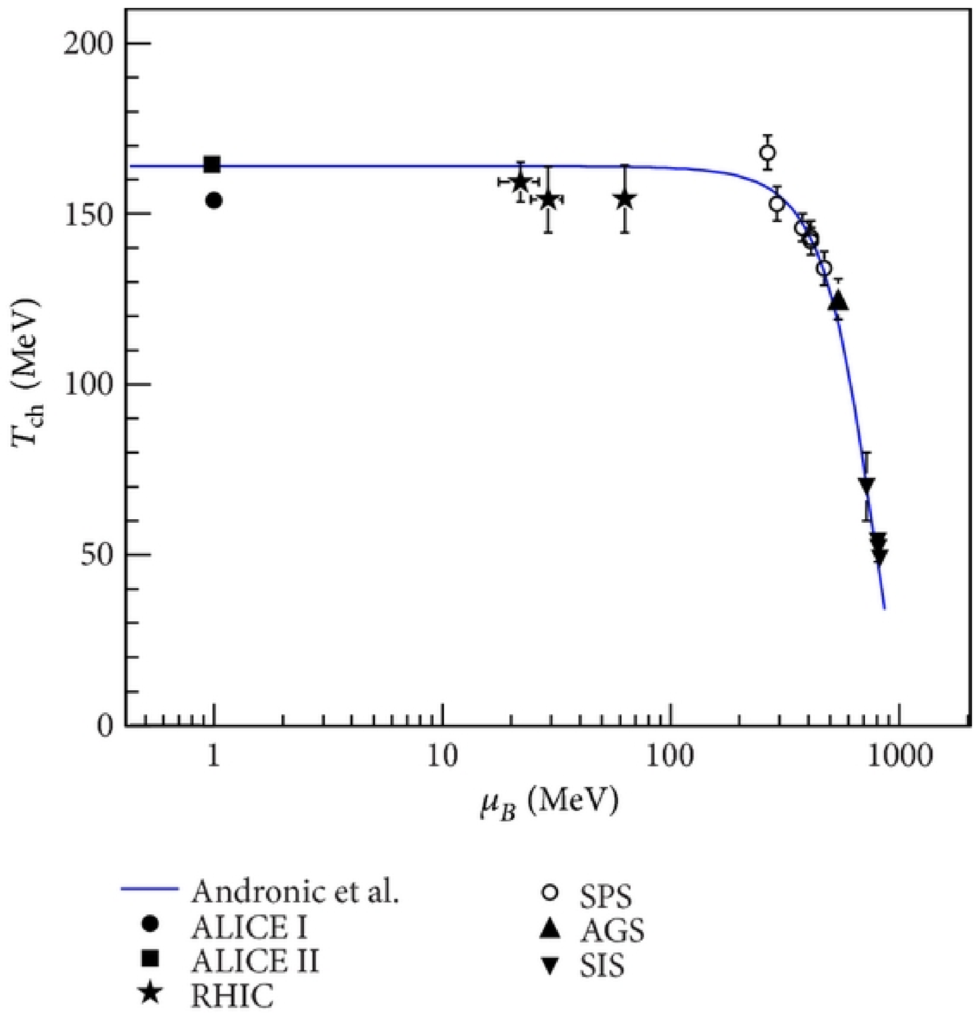
$$n_i = \frac{g}{2\pi^2}\int_0^\infty \frac{p^2 dp}{e^{(E_i-\mu_i)/T} \pm 1}, \quad E_i = \sqrt{p^2 + m_i^2}$$

$$i = B, S, I$$

At chemical equilibrium (conjecture) the particle ratios are well described by at least two parameters - the baryon chemical potential and the freezeout temperature

QCD diagram and beams scanning



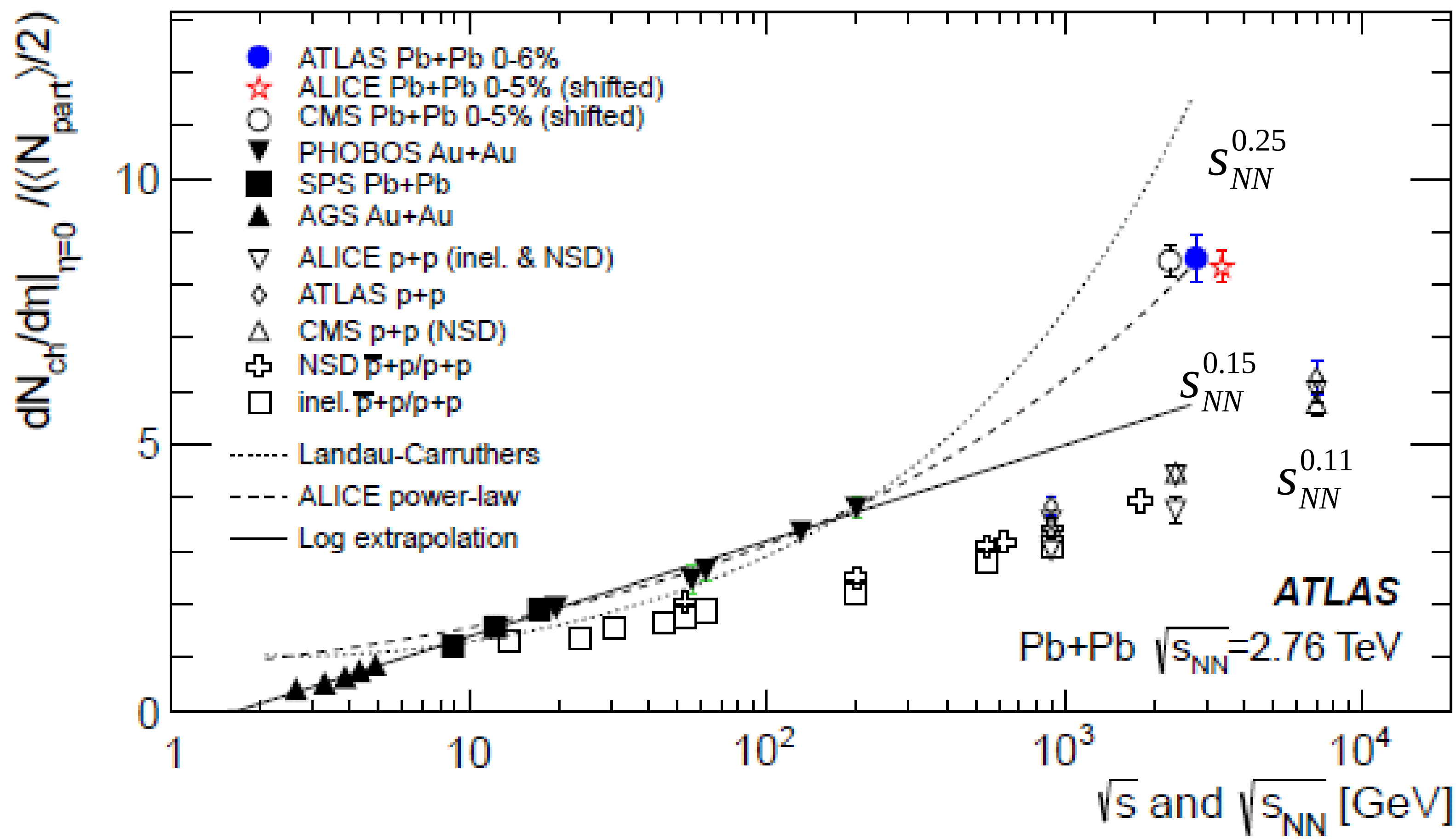


From 1304.2969

Chemical freeze-out temperature versus baryon chemical potential in central HIC [41, 55, 78–85]
The curve corresponds to model calculations from [78, 79]

Multiplicity

Plot from: ATLAS Collaboration 1108.6027



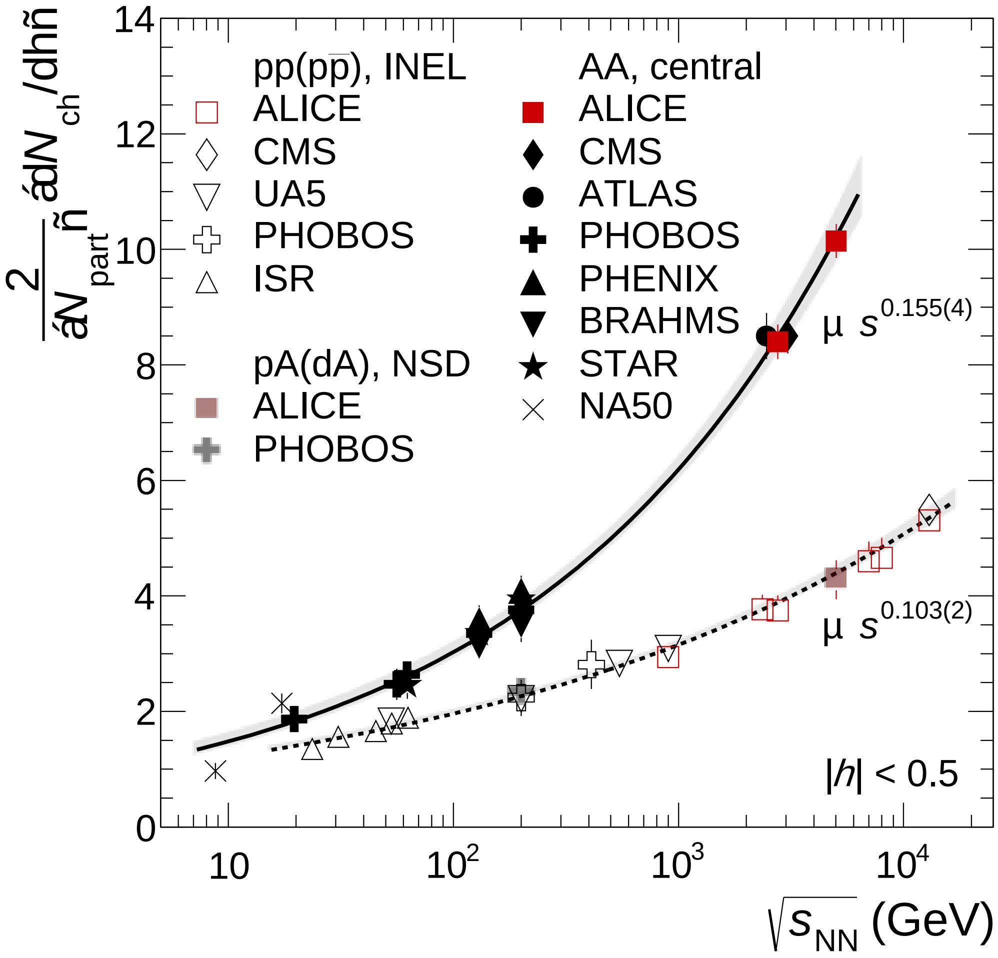
PbPb

$$\mathcal{M} \sim s_{NN}^{0.15}$$

pp:

$$\mathcal{M} \sim s^{0.11}$$

Multiplicity



Plot from1512.06104 (ALICE).

$$\mathcal{M} \sim s_{NN}^{0.155(4)}$$

Thermalizarion time

Assuming that entropy is conserved the Bjorken estimate for the initial entropy density

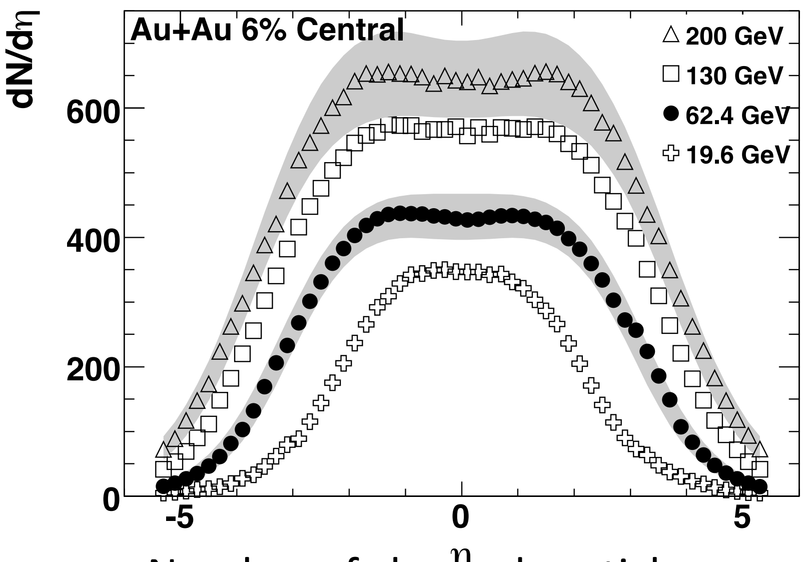
$$s_0 = \frac{3.6}{\pi R^2 \tau_0} \left(\frac{dN}{dy} \right)$$

$$N(\mathrm{all}) = 1.5 N(\mathrm{charged})$$

$$s_0 \simeq 30\,\mathrm{fm}^{-3}$$

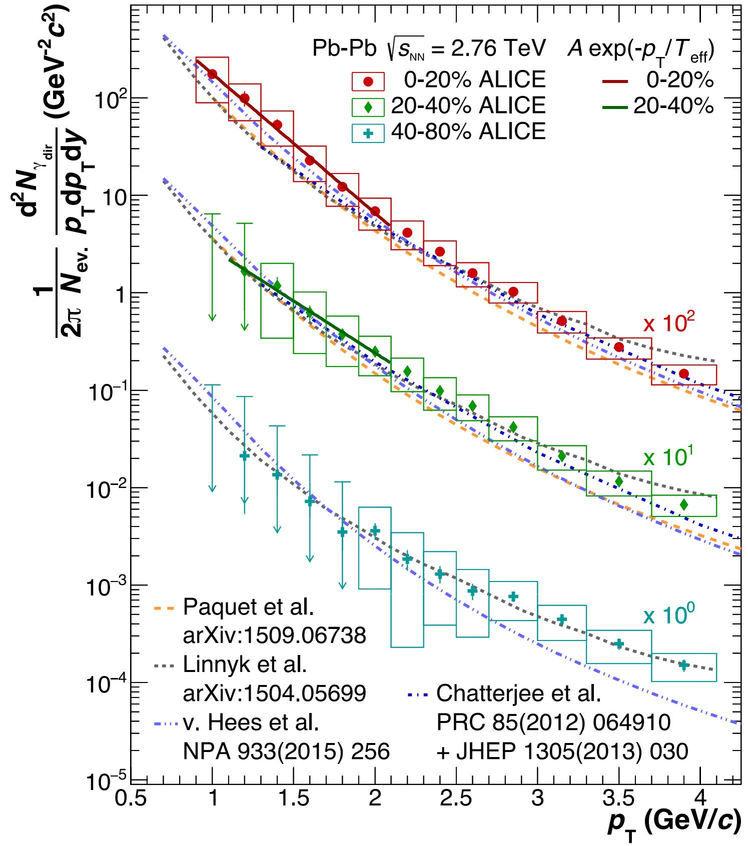
$$dN/dy|_{y=0} \simeq 10^3$$

$$\tau_0 = 1\, fm/c$$



Number of charged particles per Unit pseudorapidity

Direct photons (electric conductivity)



Comparison of model calculations with the direct photon spectra in PbPb collisions at $s_{NN}^{1/2}$=2.76 TeV

From: 1509.07324

From observations in HIC

- QGP strong interacting fluid
- Measurement of energy lost (jet quenching, R_{AA}-factor, J/Psi suppressions
- Transport coefficients, extremely small eta/s
- Phase transition (still near small mu)
- Energy dependence of the total multiplicity $s^{0.155}$
- Thermalization time
- Direct photons (electric conductivity)