PHYSICS PRIORITIES IN THE FRENCH HI COMMUNITY

ALICE
CMS
RHIC

and associated theory needs

Yves Schutz
CERN&IN2P3

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CMS
RHIC

and associated theory needs

ask not what theory can do for you - ask what you can do for theory.

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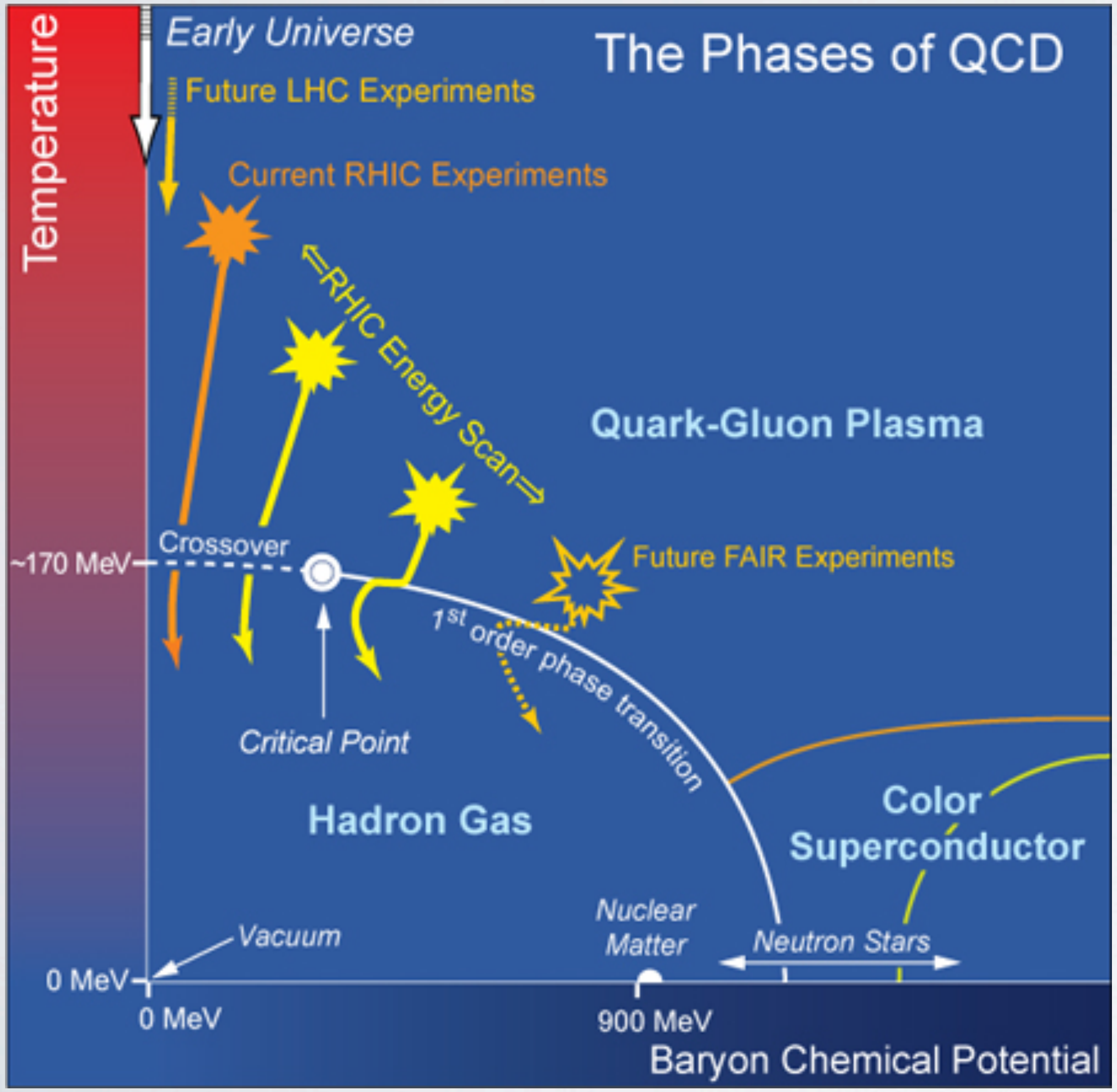
GENERAL REMARKS

concerning nuclear collisions at ultra relativistic energies

- Objective of the HI program at UR energies
  - Explore the phase diagram of QCD matter at very high energy densities
  - Characterize the quark matter at these energies



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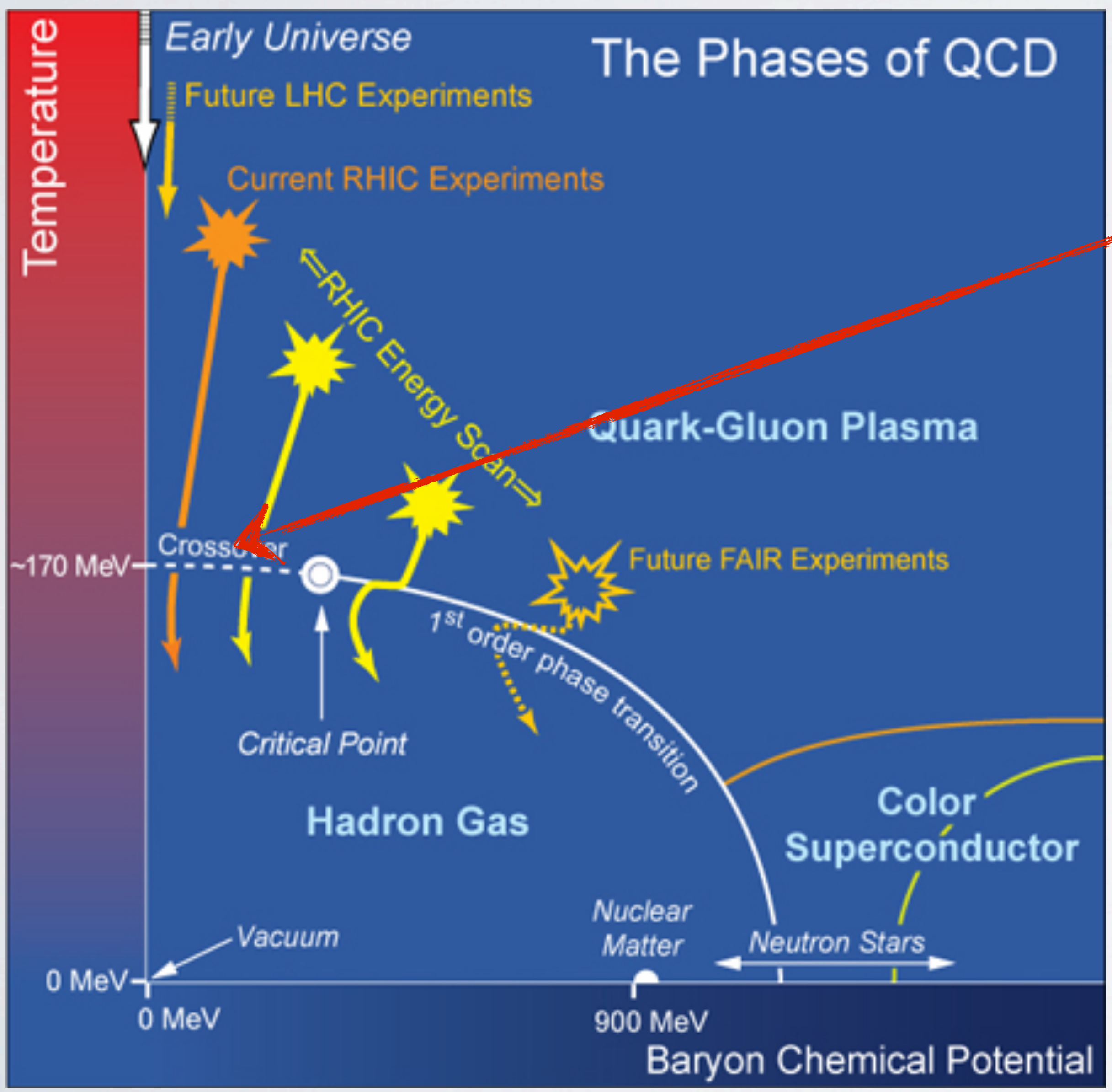
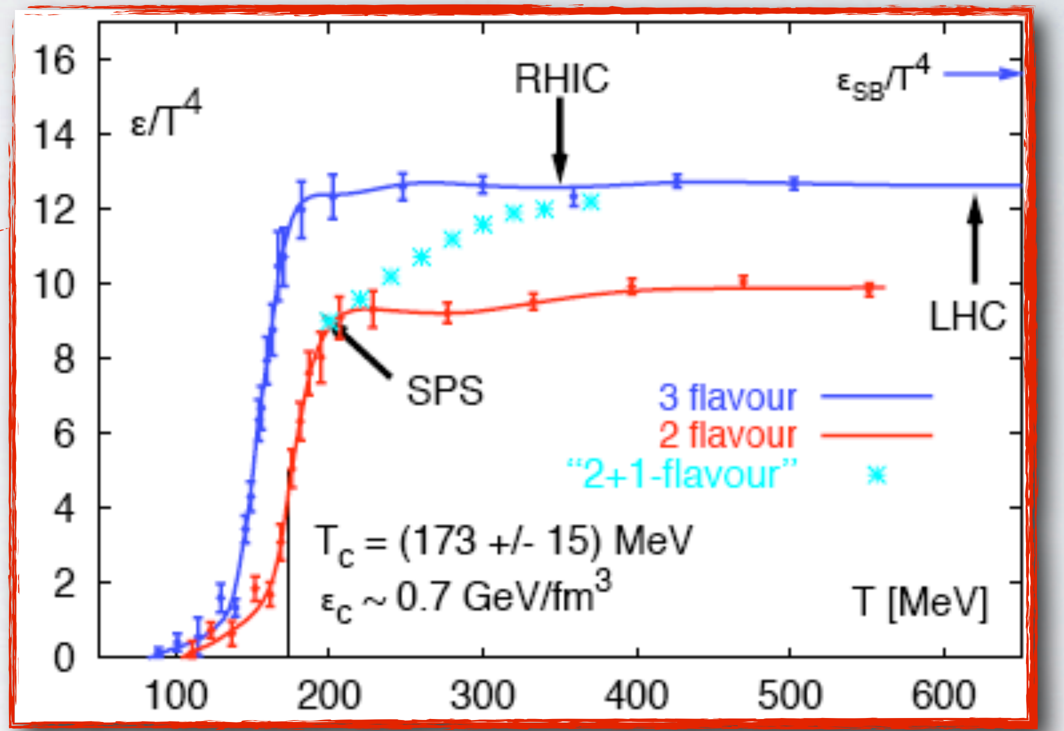
Bielefeld group





QCD thermodynamics on Lattice:
- a continuous rapid cross over transition from QGP matter to hadronic matter

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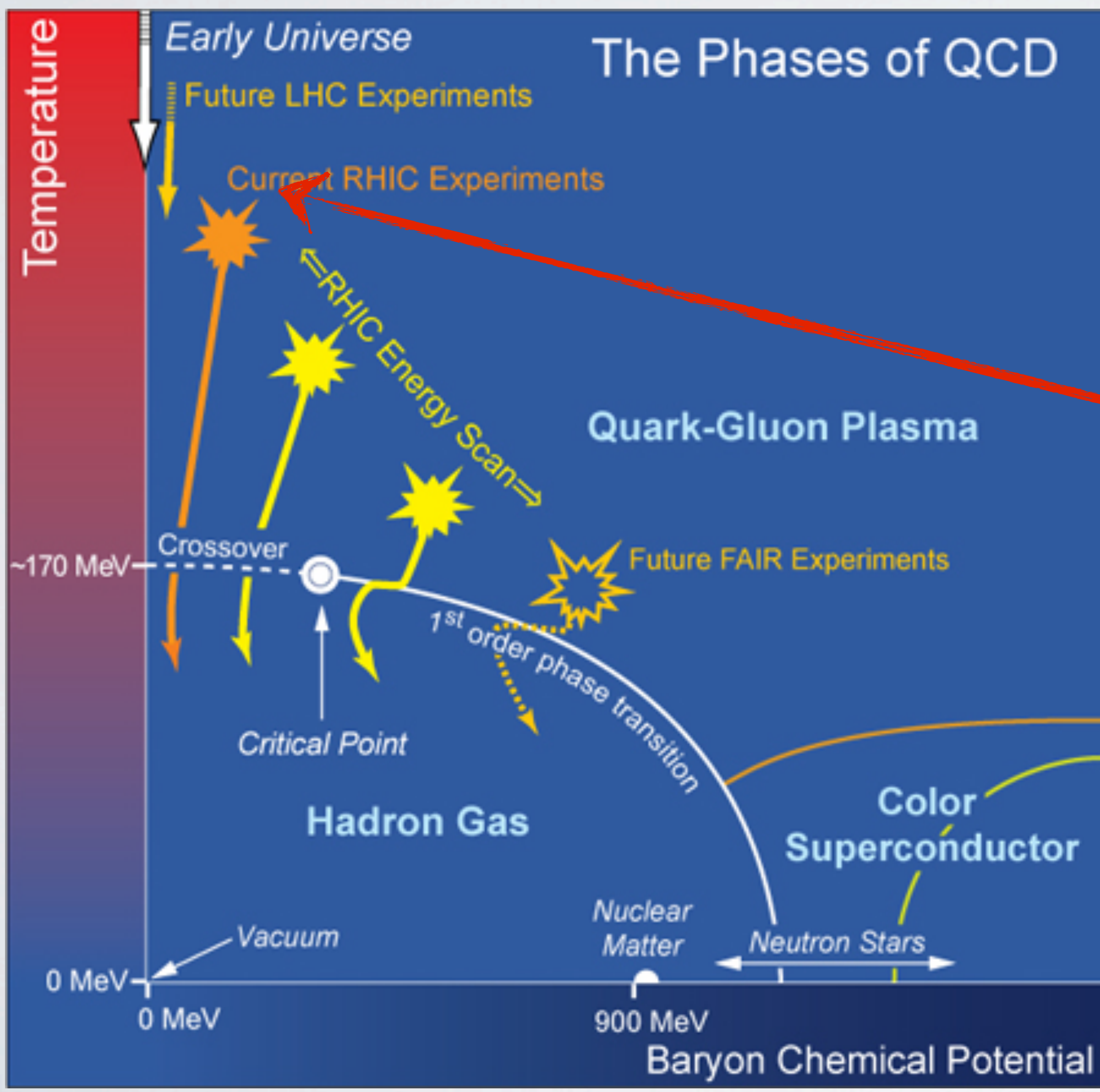
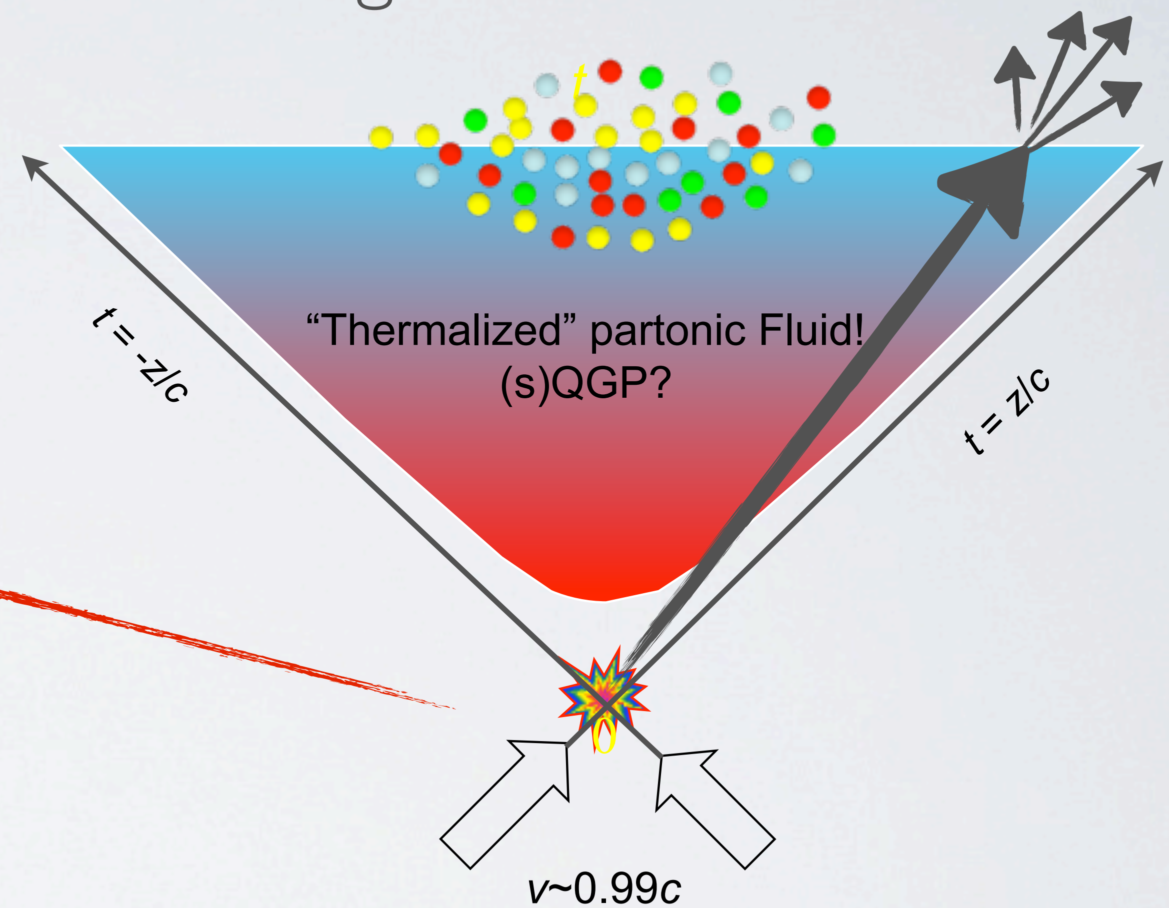




HI collisions:

- establish the nature and the transport properties of the fluid

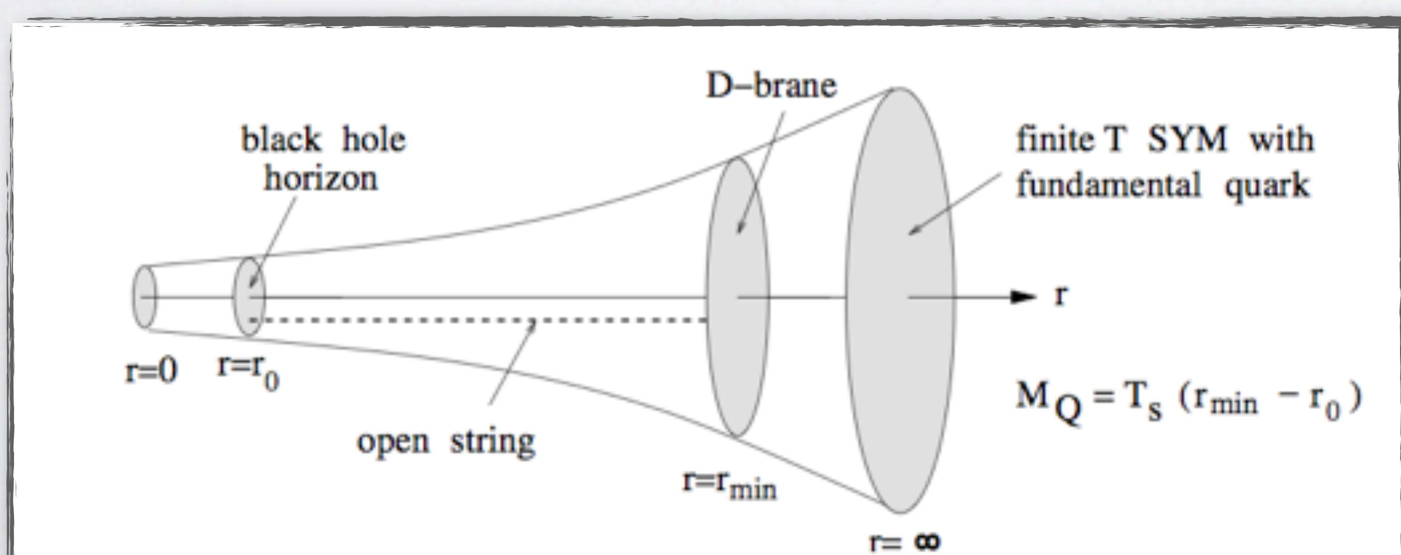
- Objective of the HI program at UR energies
  - Explore the phase diagram of QCD matter at very high energy densities
  - Characterize the quark matter at these energies
    - Equation of state
    - Number of degrees of freedom
    - Viscosity
    - Velocity of sound
    - Parton energy loss and opacity
    - Deconfinement

GENERAL REMARKS

concerning nuclear collisions at LHC

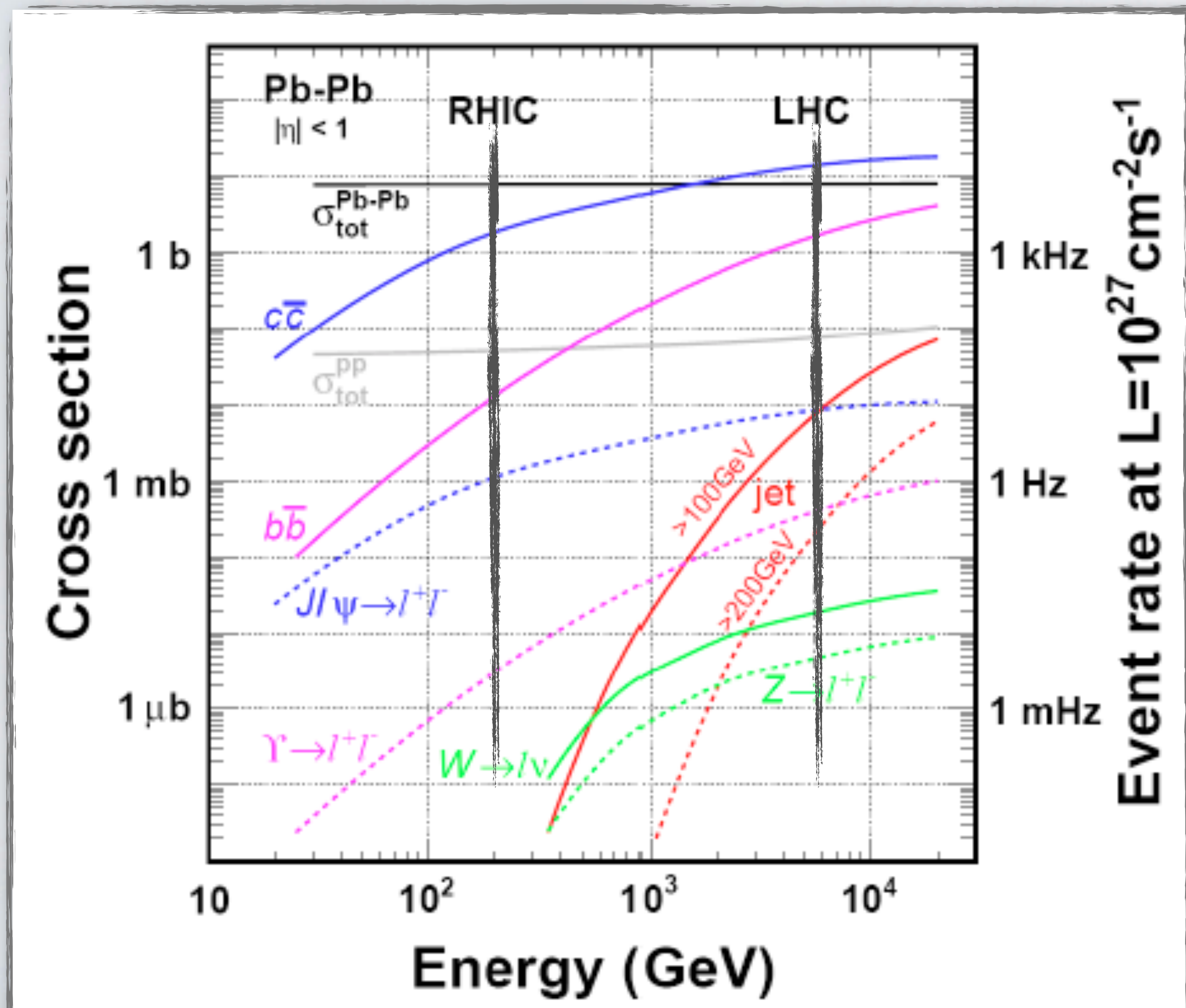
- The 30 times increase of √s at LHC with respect to RHIC provides better conditions to study the QCD matter:
  - Higher energy densities, a longer lived partonic phase, baryon free
  - Approaching the asymptotic properties as predicted by LQCD:
    - a weakly coupled QGP (?) where pQCD applies
    - or a strongly coupled QGP as at RHIC energies
      - Need a theory to calculate the transport properties

        ➡AdS/CFT: a method to study gauge theories at strong coupling using techniques from string theory



S. Peigné

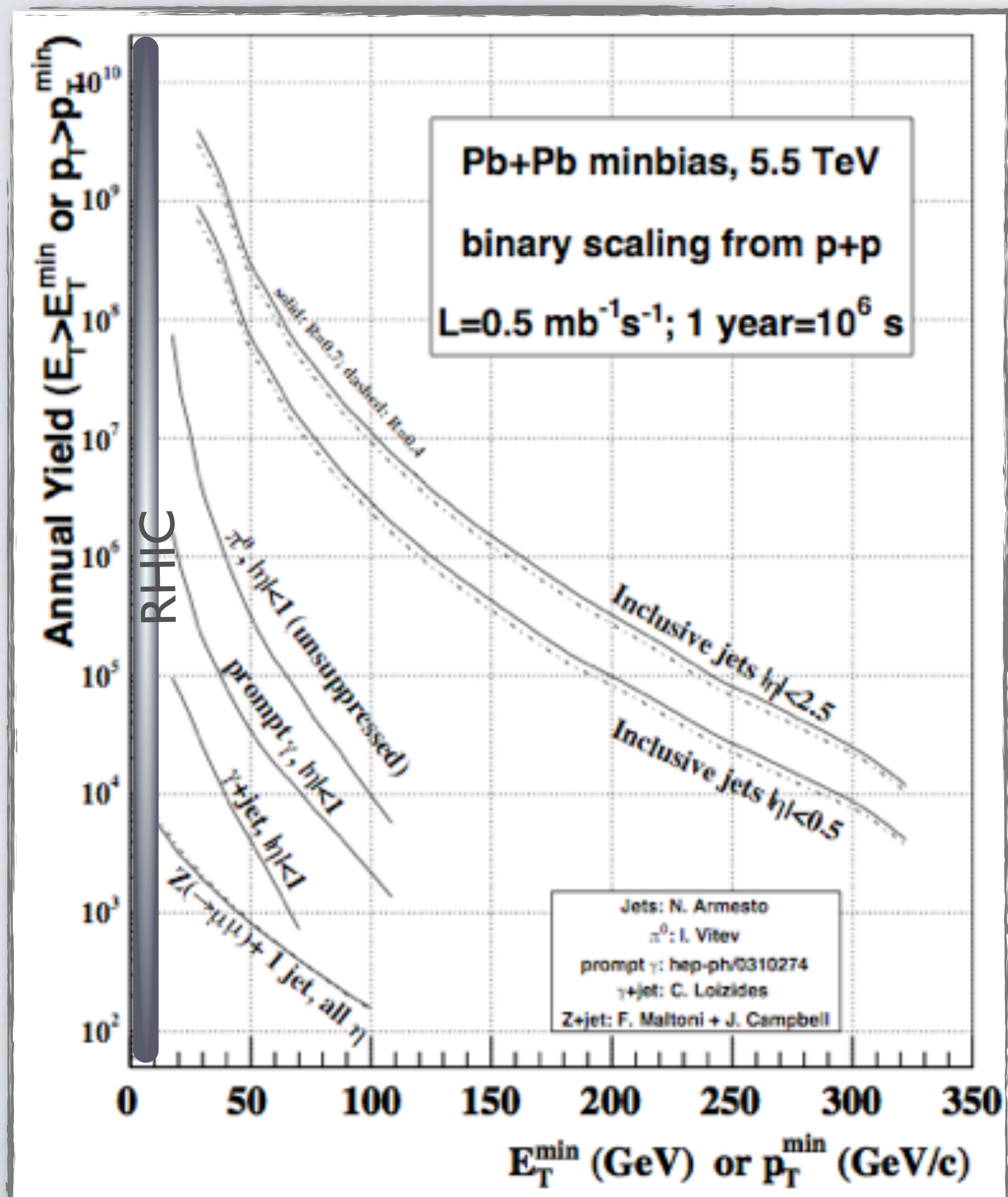
- The 30 times increase of √s at LHC with respect to RHIC provides better conditions to study the QCD matter:
  - Ultra high multiplicities: statistical methods, event-by-event fluctuations
  - Cross section of penetrating probes expected to increase by large factors



- 100/event ***cc***
- ***c***- and ***b***-quark tagged jets
- transport of ***q*** and ***Q***
- Charmonium and Bottomonium

ALICE PPR

- The 30 times increase of √s at LHC with respect to RHIC provides better conditions to study the QCD matter:
  - Ultra high multiplicities: statistical methods, event-by-event fluctuations
  - Cross section of penetrating probes expected to increase by large factors



- $>10^4$/year jets wit E_T > 150 GeV
- Jet propagation
- Medium modified jet fragmentation

P. Jacobs, M. van Leuwen

- At LHC Pb+Pb at $\sqrt{s_{NN}}$=5.5 TeV is not sufficient for a complete understanding of QCD matter
  - p+p provides the baseline for AA to reveal collective effects

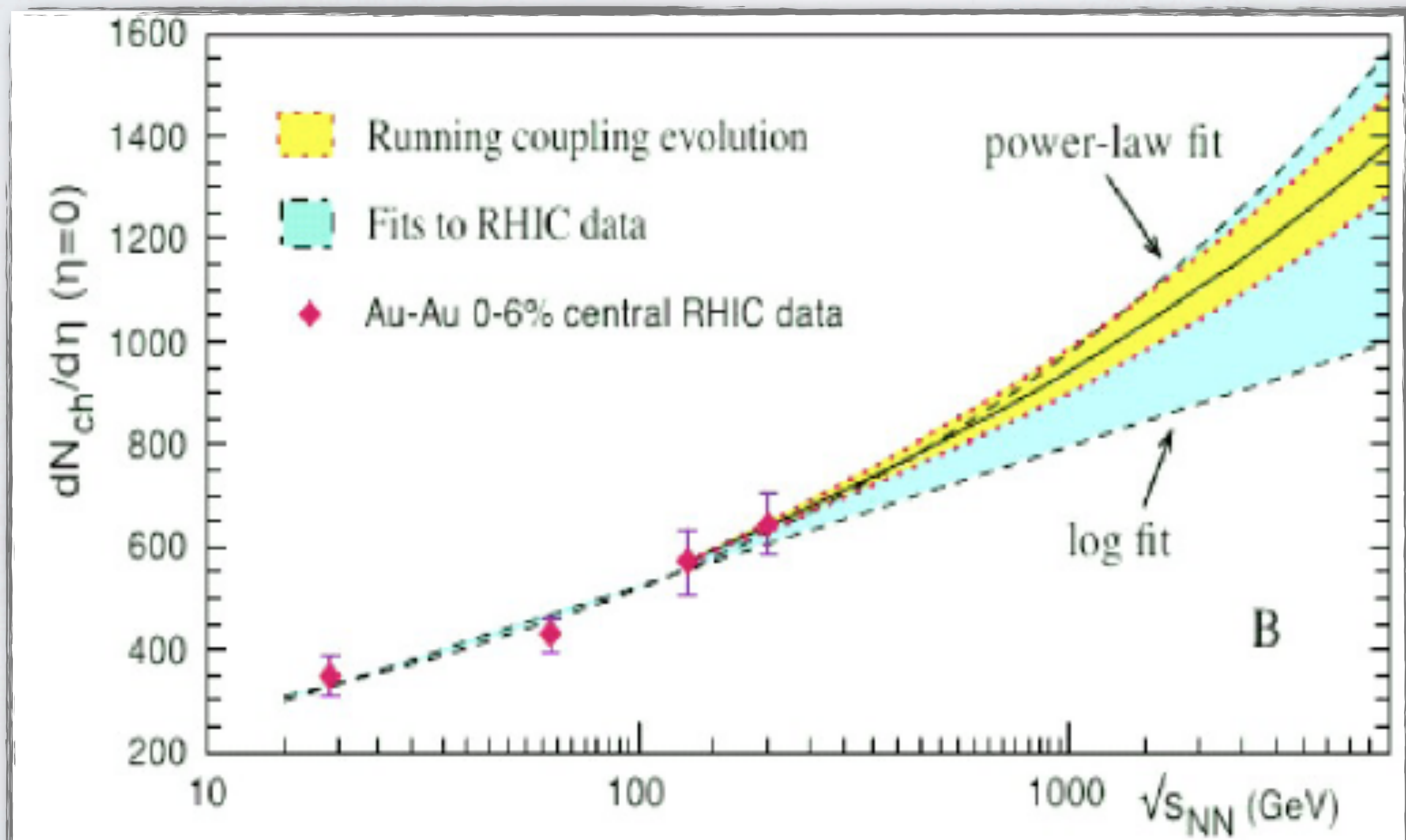
$$\sigma_{AA}/(N_{NN}\times\sigma_{pp}) \neq 1?$$

  - p+A and A+p to study the properties of cold matter (the entrance channel of AA)
    - PDF
    - nuclear PDF: (anti)-shadowing
    - low $x \sim 10^{-5}$ structure of p and A (saturation, CGC,...)
  - Energy and A scan of A+A to vary the entry point in the QCD matter phase diagram
  - A possible surprise: QCD matter formed in very high multiplicity (7-10 times the multiplicity of MB) pp collisions ?

SELECTED TOPICS

1. **p and A structure at low x**
2. QCD phase-transition temperature
3. Hadronisation in pp and AA
4. Deconfinement
5. Transport coefficient

- Charged particle multiplicity, density,
  - Extrapolation from lower $\sqrt{s}$ leads to large uncertainty
  - Crucial tests of various theoretical approaches describing cold nuclear matter, the initial state of AA (saturation, Color Glass Condensate, shadowing,...)



p and A structure at low *x*

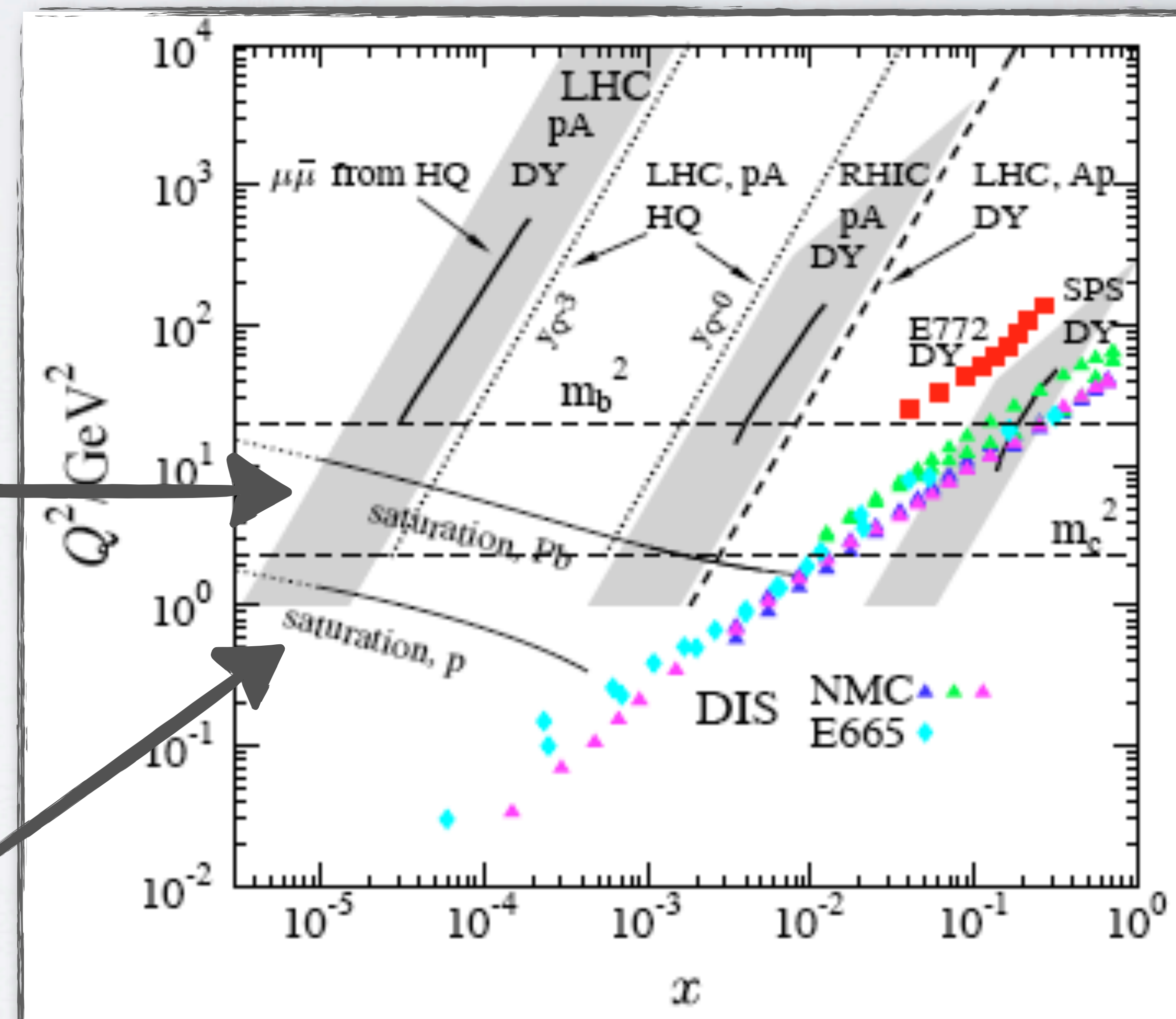
- Hadrons and heavy flavor at large rapidities to probe matter with very high gluon densities
  - cross sections and p_T spectrum
  - compare pp and pA (Ap)
    - $\pi^0 \rightarrow \gamma\gamma$ (Ap)
    - $c \rightarrow D \rightarrow \mu$ and $b \rightarrow B(D) \rightarrow \mu$
    - $c\bar{c}$ and $b\bar{b} \rightarrow \mu\,\bar{\mu}$

M. Malek

$$Q_S^2(A) \sim A^{1/3}\, Q_S^2$$

$$\propto A^{1/3} \times x^{-\lambda}$$

$$Q_S^2 \sim \alpha_s \times xG(x,Q^2)/\pi R^2$$

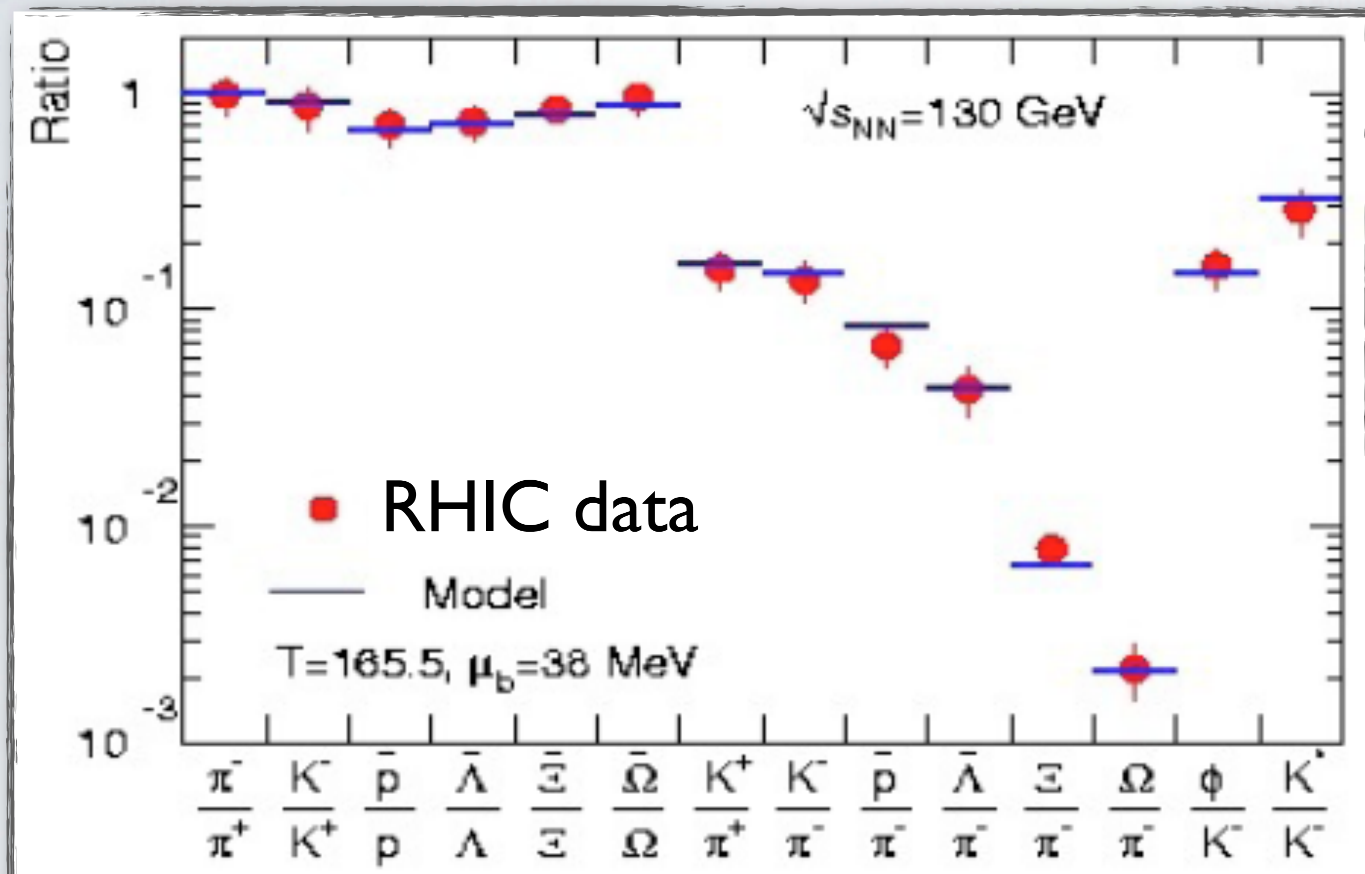


SELECTED TOPICS

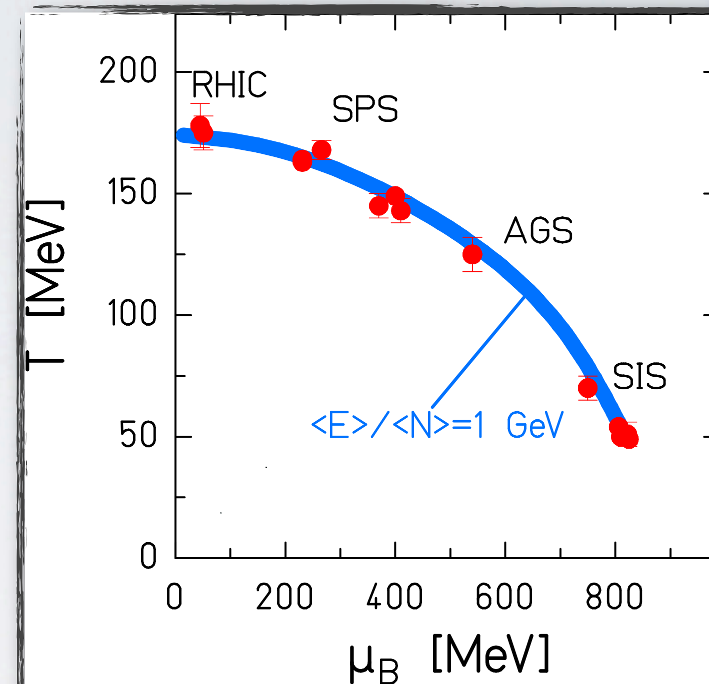
1. p and A structure at low x
2. **QCD phase-transition temperature**
3. Hadronisation in pp and AA
4. Deconfinement
5. Transport coefficient

QCD phase-transition temperature

- Particle yields of identified particles (SIS, AGS, SPS, RHIC) reflect a statistical equilibration (grand canonical ensemble) characterized by a temperature T (chemical freeze out) and a baryonic chemical potential



A. Andronic et al. nucl./th 0511071.

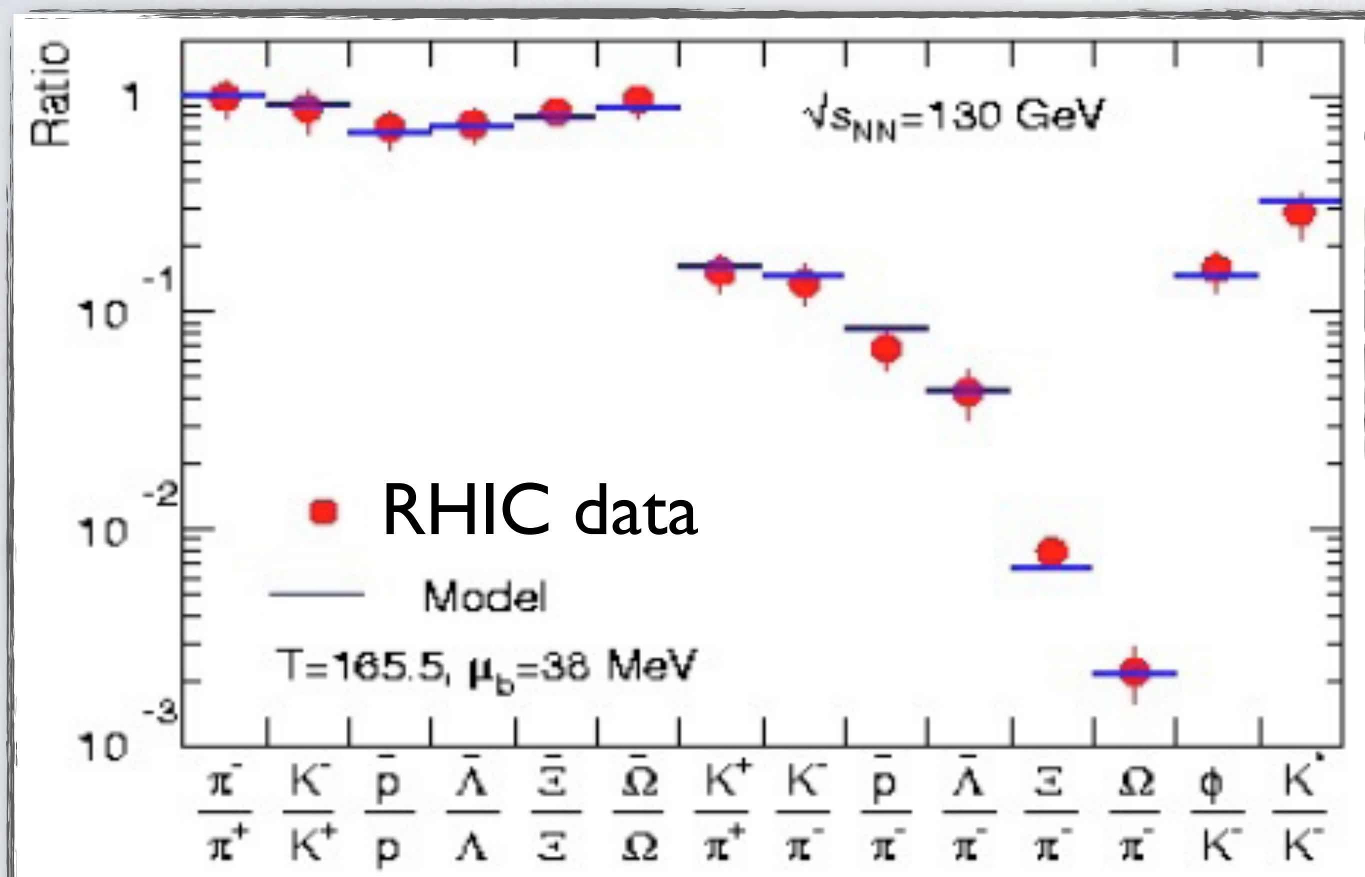


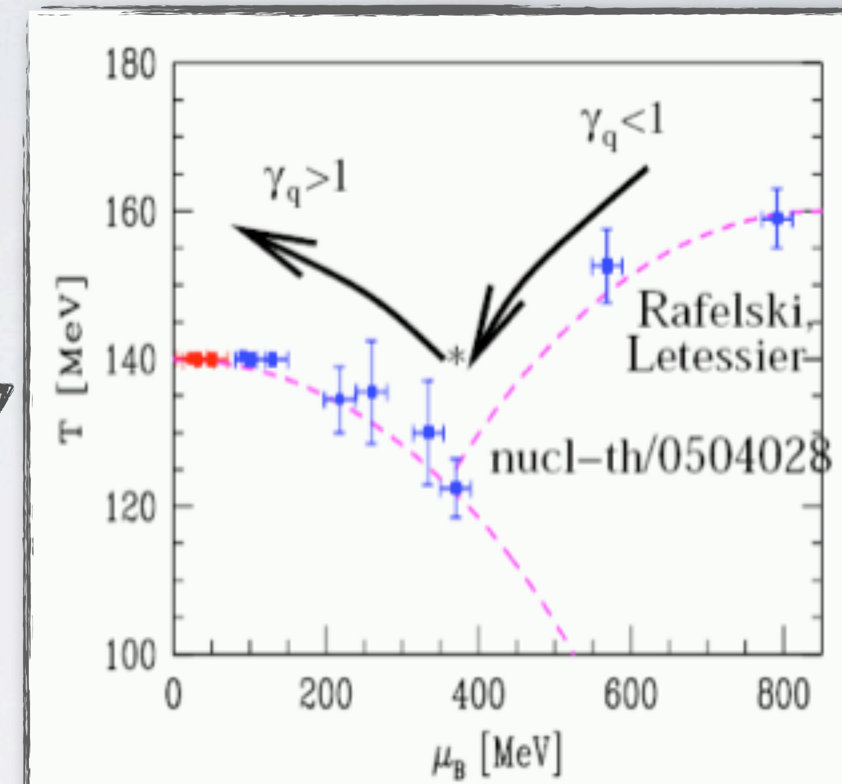
LHC:

- T ~ 170 MeV (=T_c!)
- μ_B ~ 0

QCD phase-transition temperature

- Another scenario predicts particle yields consistent with data: first order phase transition arising in a chemically non-equilibrated hot hadronic-matter system

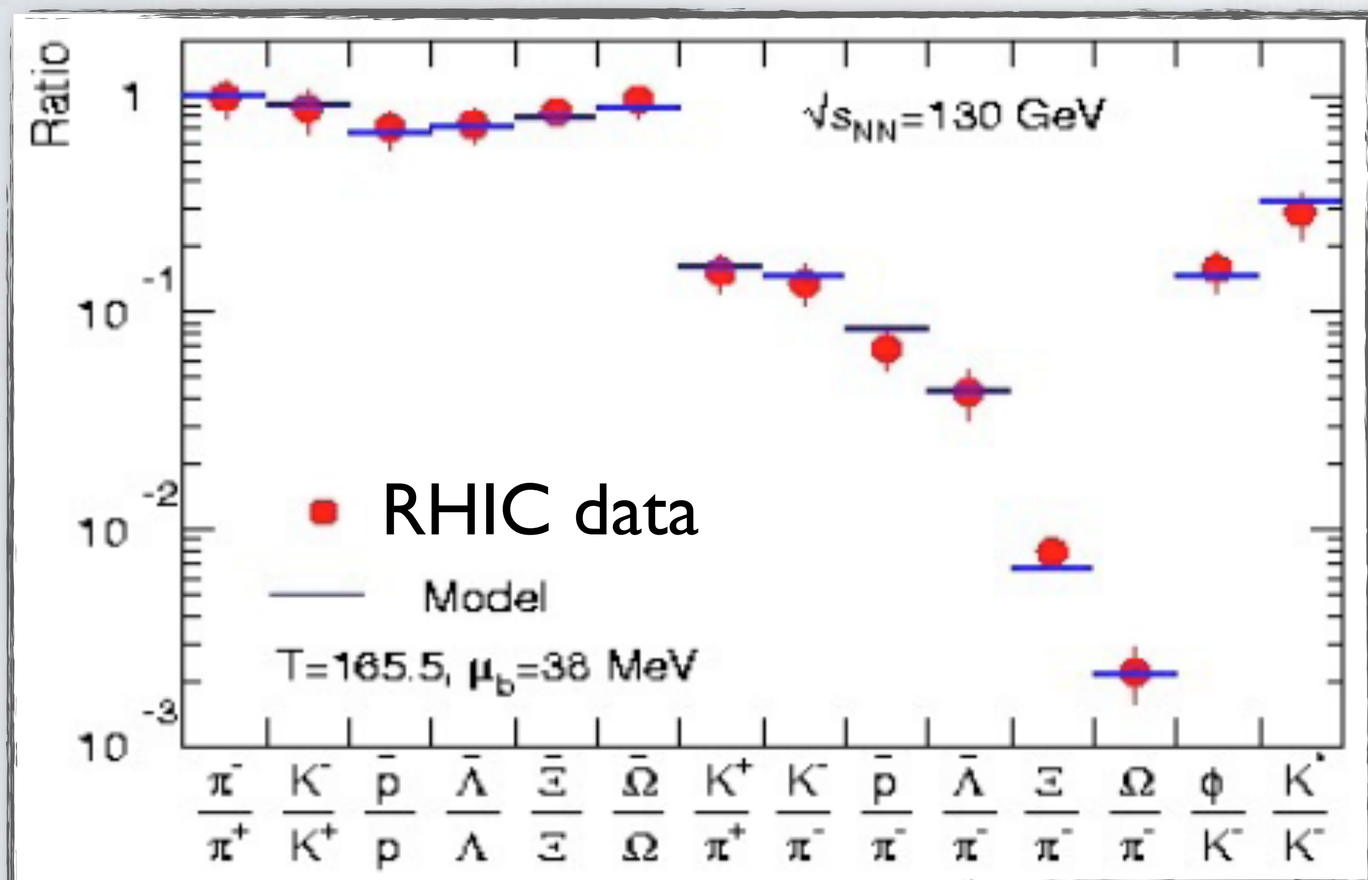


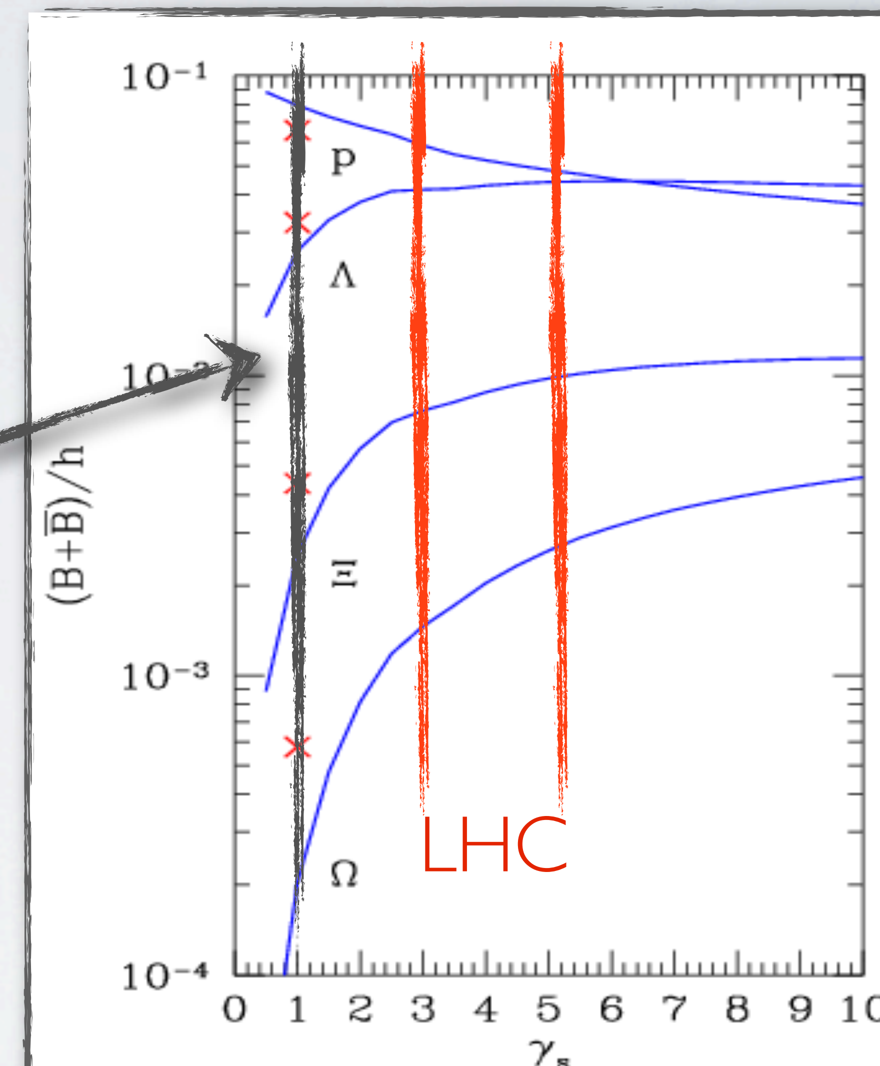


Rafelski, Letessier nucl./th 0504028.

QCD phase-transition temperature

- Another scenario predicts particle yields consistent with data: first order phase transition arising in the chemically non-equilibrated hot hadronic-matter system
- Strangeness yield at LHC will be decisive





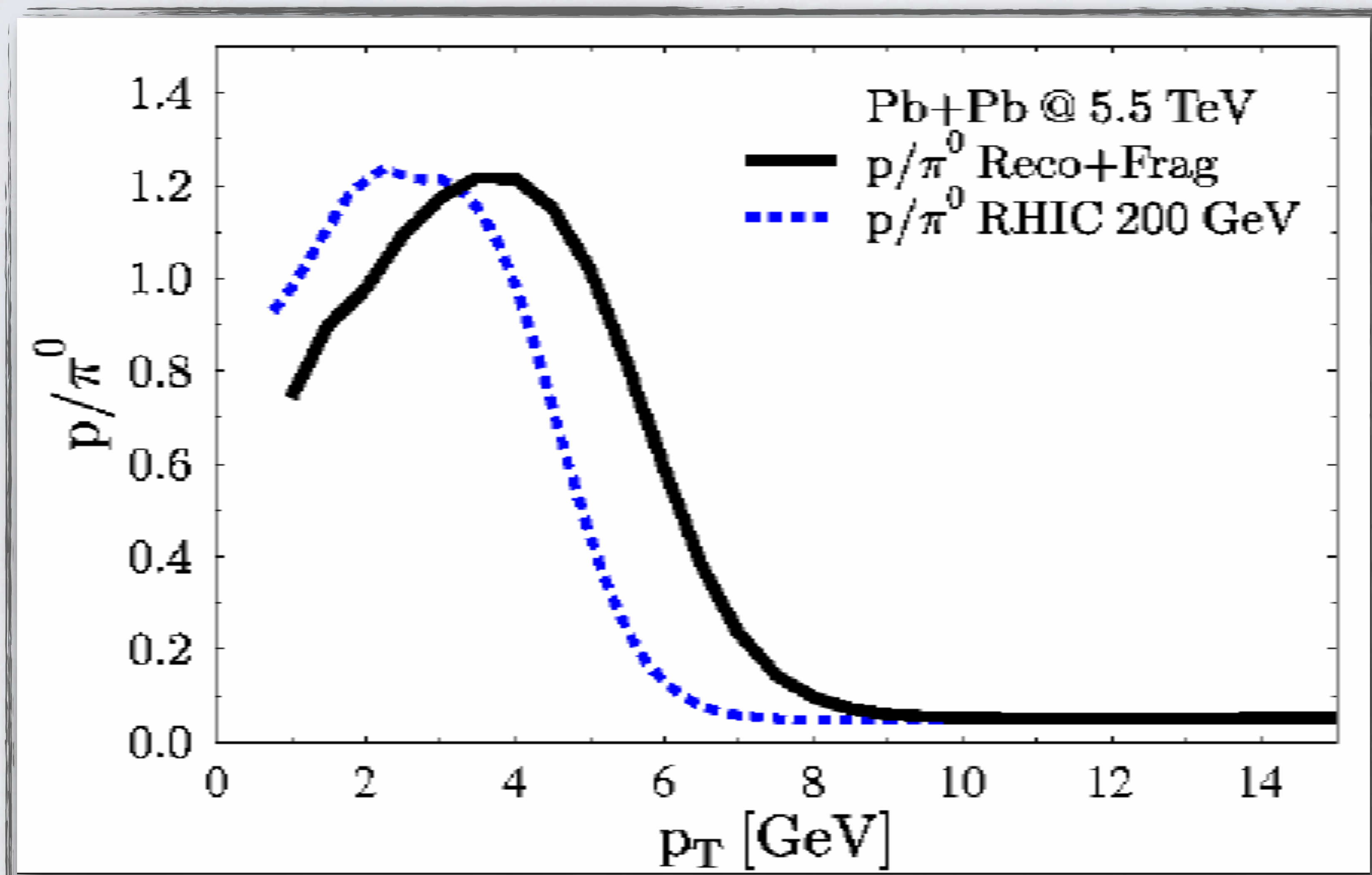
Rafelski, Letessier nucl./th 0504028.

SELECTED TOPICS

1. p and A structure at low x
2. QCD phase-transition temperature
3. **Hadronisation in pp and AA**
4. Deconfinement
5. Transport coefficient

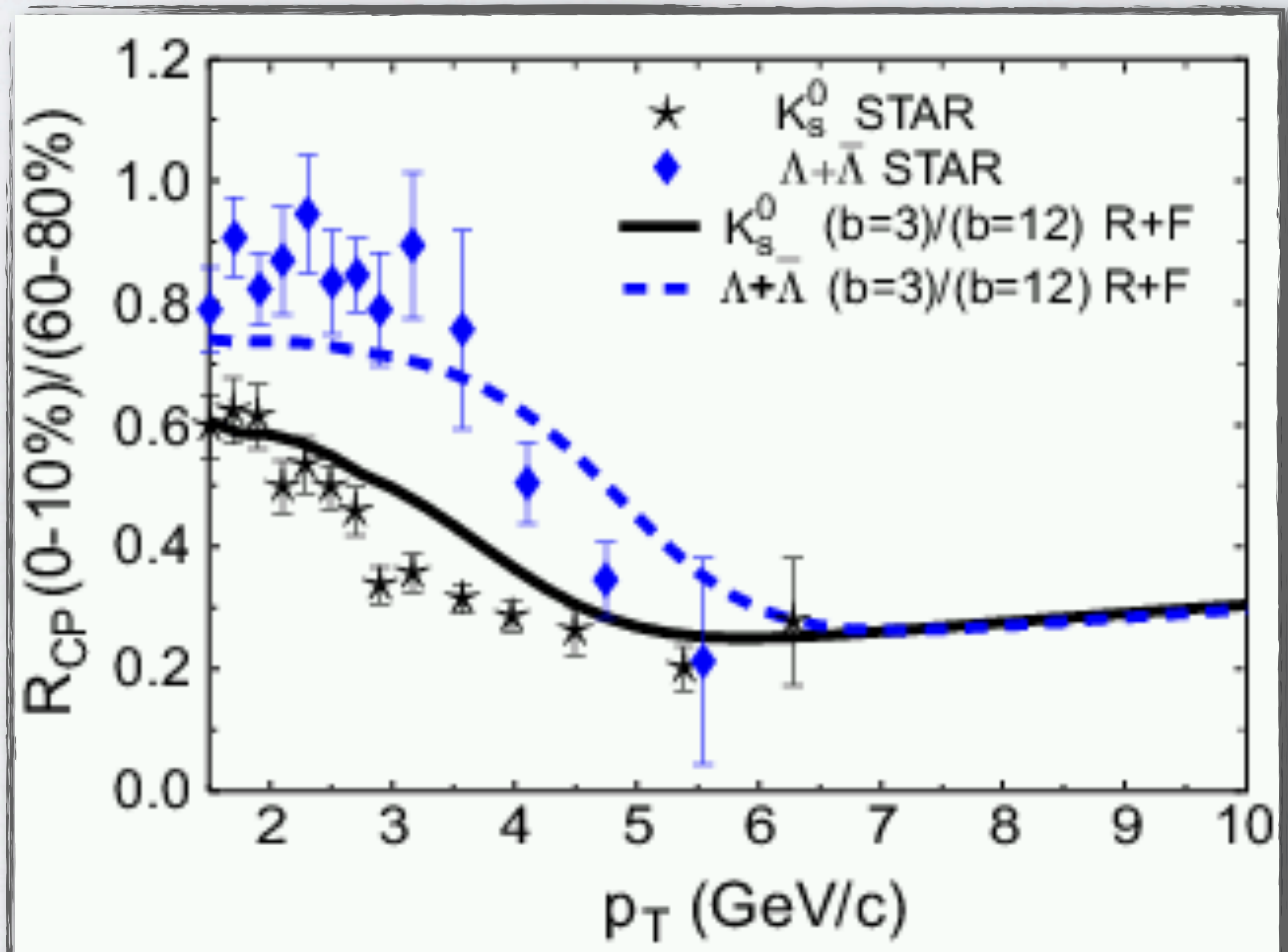
- The baryon to meson ratio measured at intermediate p_T (2-6 GeV/c) in AA collisions at RHIC:
    - deviates from the ratio expected in jet fragmentation

R. Fries et al.



- The baryon to meson ratio measured at intermediate p_T (2-6 GeV/c) in AA collisions at RHIC:
  - deviates from the ratio expected in jet fragmentation
  - the deviation is stronger in central collisions

$R_{cp} = Y_c/(Y_p \times N_{bin})$



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  - the deviation is stronger in central collisions
- Particle yield = QCD parton fragmentation ⊗ coalescence ?

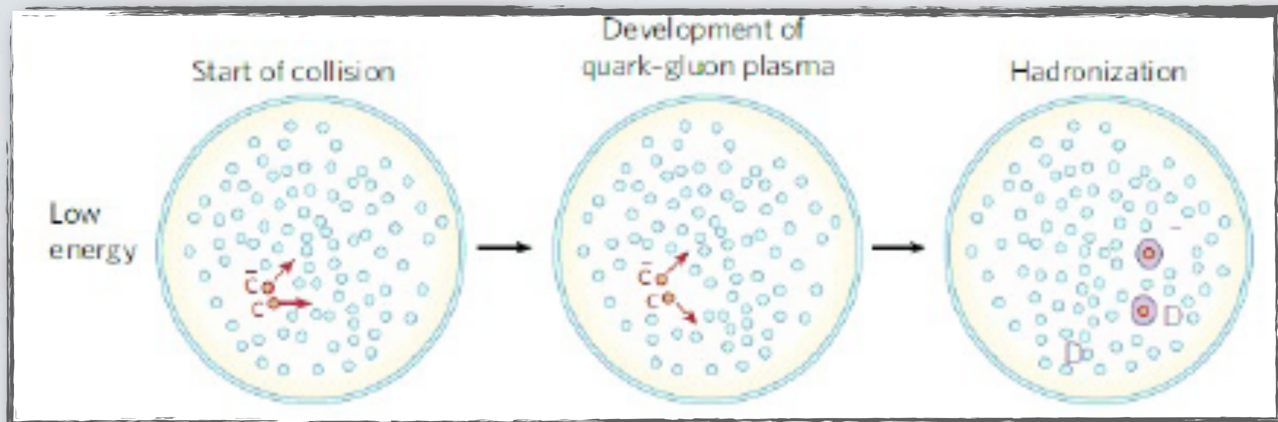
Hadronisation in pp and AA

- The baryon to meson ratio measured at intermediate p_T (2-6 GeV/c) in AA collisions at RHIC:
  - deviates from the ratio expected in jet fragmentation
  - the deviation is stronger in central collisions
- Particle yield = QCD parton fragmentation ⊗ coalescence ?
- pp must be understood first
  - PYTHIA generator does not reproduce the baryon to meson ratio extrapolated from RHIC, UA1, CDF data to LHC energies
  - Multiple parton interactions
  - PDF
  - Interplay between soft and hard processes
  - Collective effects ? (EPOS: multiple parton interactions based on exchange of parton ladders)

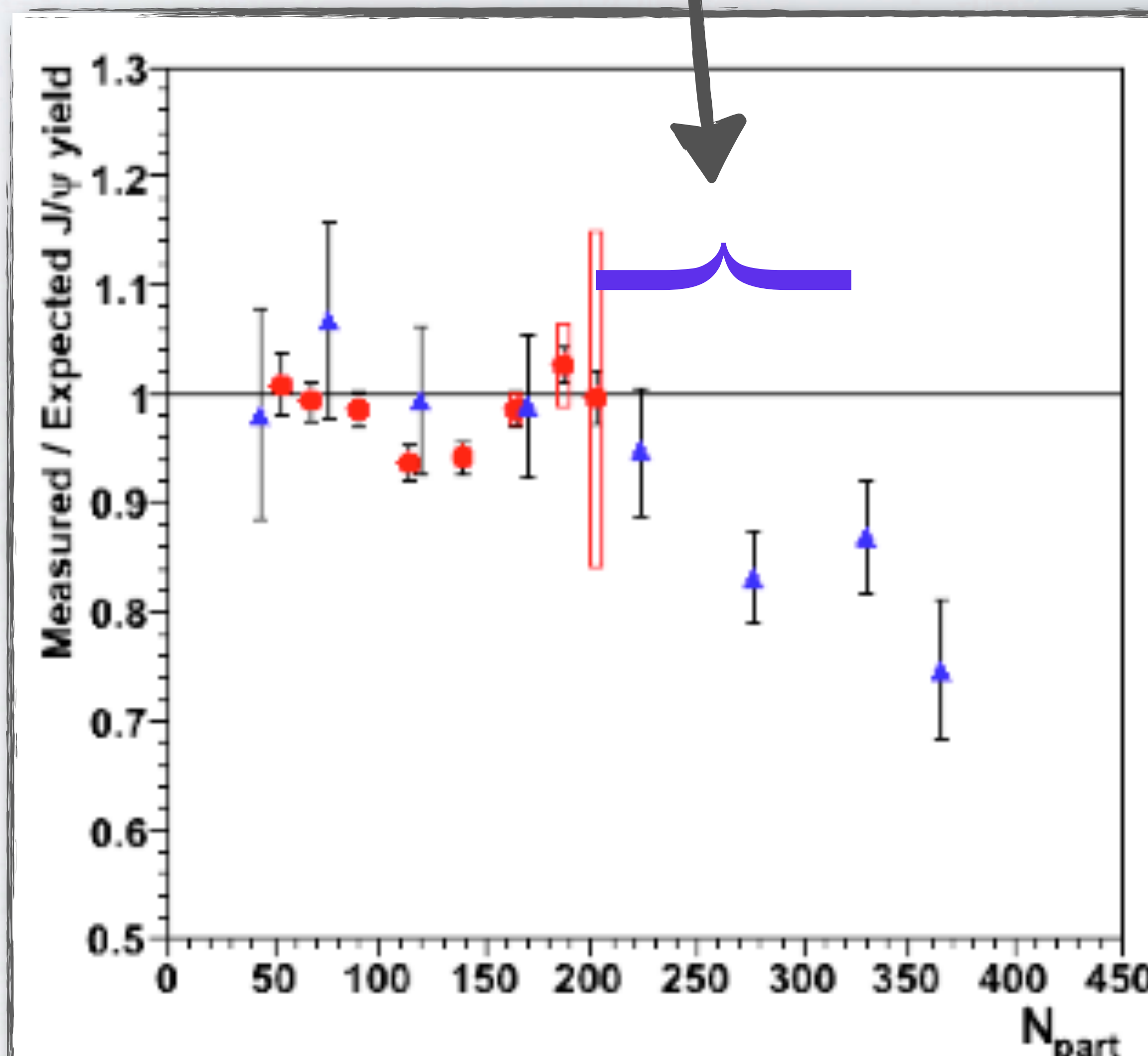
SELECTED TOPICS

1. p and A structure at low x
2. QCD phase-transition temperature
3. Hadronisation in pp and AA
4. **Deconfinement**
5. Transport coefficient

- Quarkonia states are suppressed following temperature dependent dissociation of $Q\bar{Q}$ due to screening by color charges (SPS, RHIC)



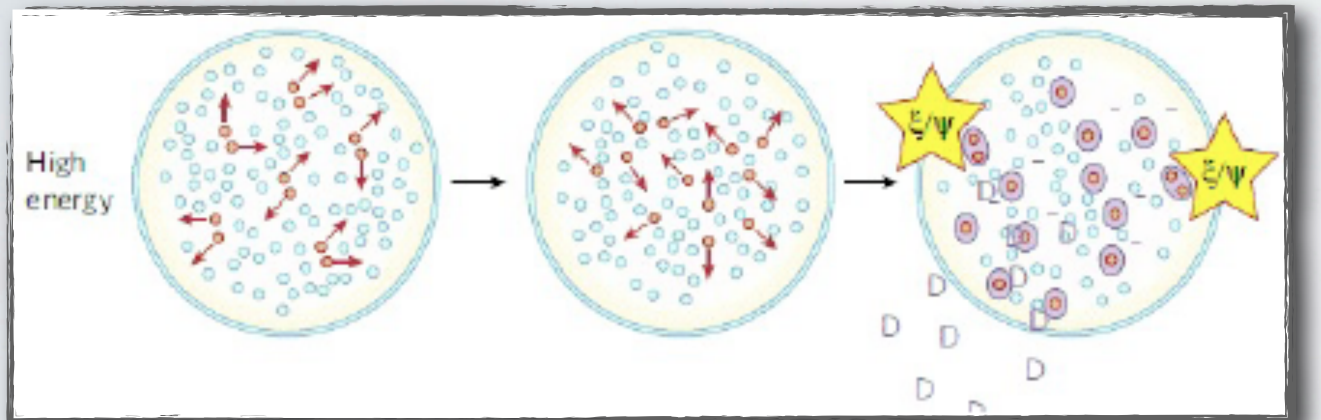
«anomalous» suppression

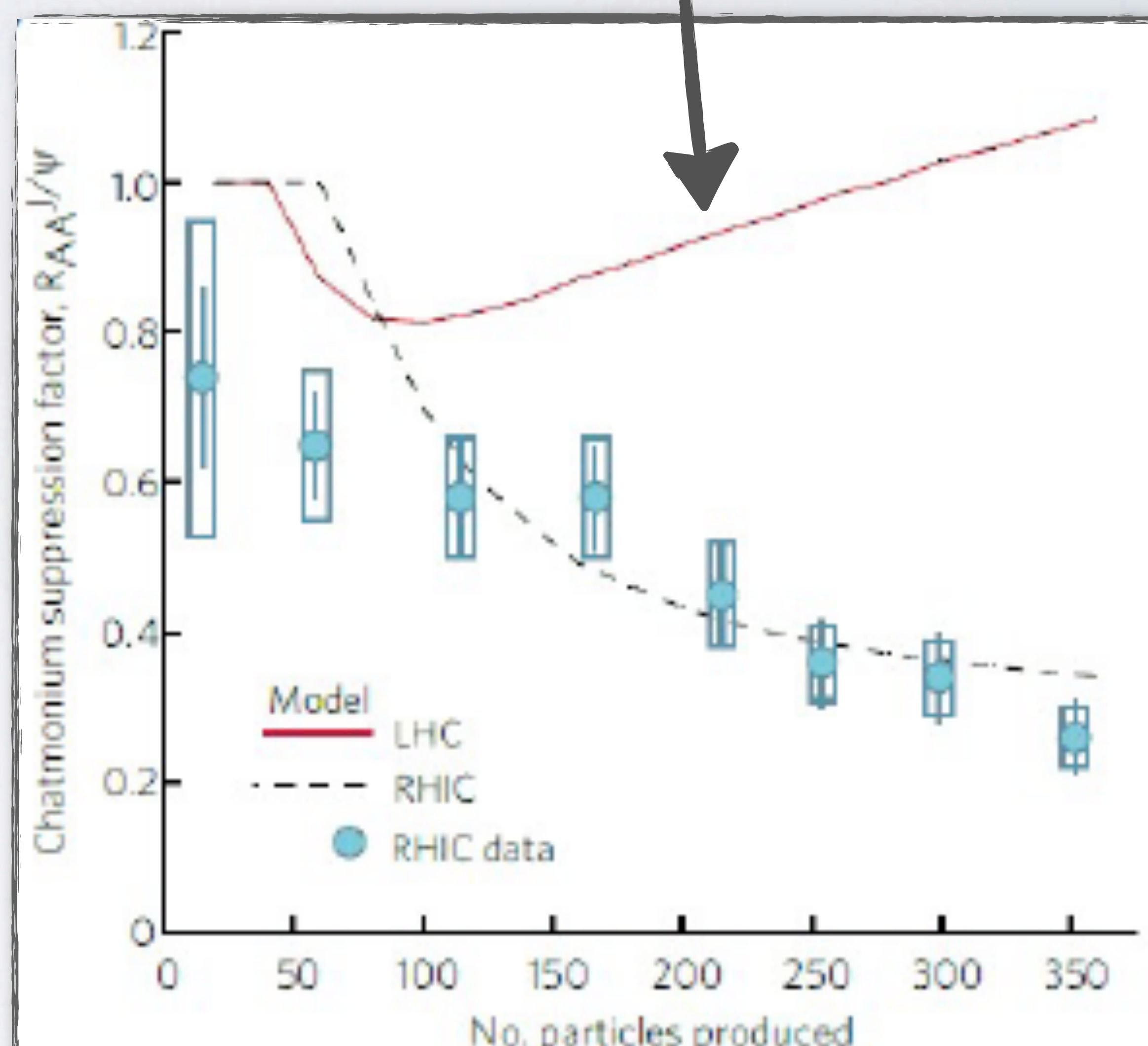


R. Arnaldi et al. arXiv0909.2199

- If number of $Q\bar{Q}$ pairs is large enough quarkonia states can form again from deconfined quarks (RHIC, LHC)
  - charmonium enhancement, a fingerprint of deconfinement

enhancement





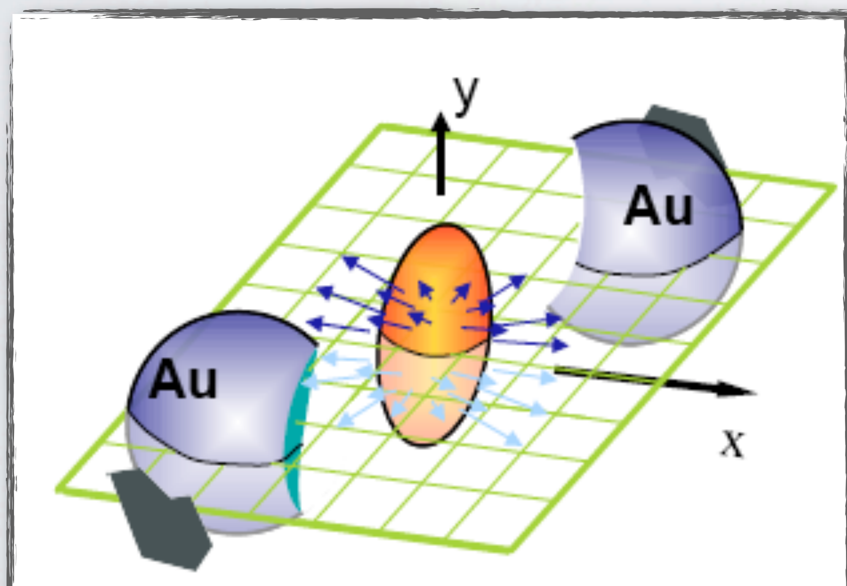
A. Andronic et al. Phys. Lett. B652 (2007) 659

SELECTED TOPICS

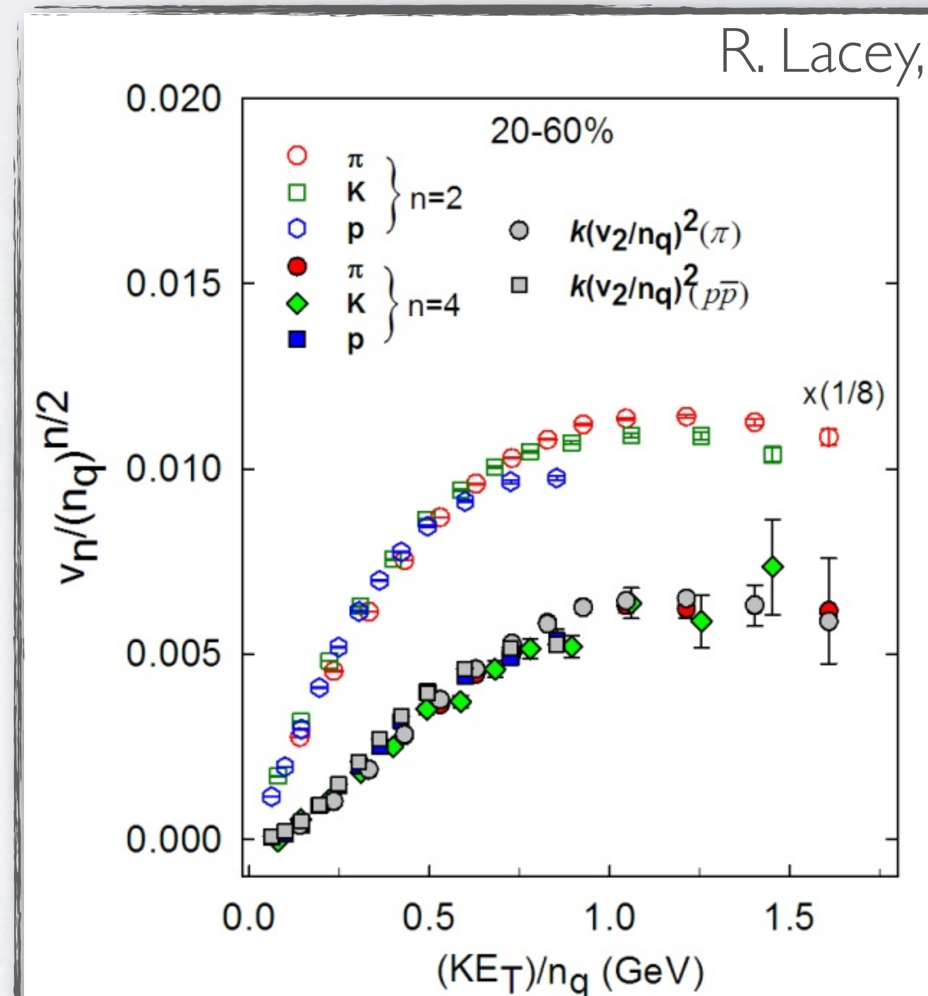
1. p and A structure at low x
2. QCD phase-transition temperature
3. Hadronisation in pp and AA
4. **Transport coefficient**

- The fluid (sQGP) formed at RHIC
  - leads to a large collective flow (v2, v4 measurement)
  - exhibiting a quark scaling (flow for mesons and baryons)
  - has a very small viscosity (η/S) deduced
- Initial condition (ε_0, τ_0, G) + hydrodynamic evolution + strong coupling + transport properties

R. Lacey, PHENIX

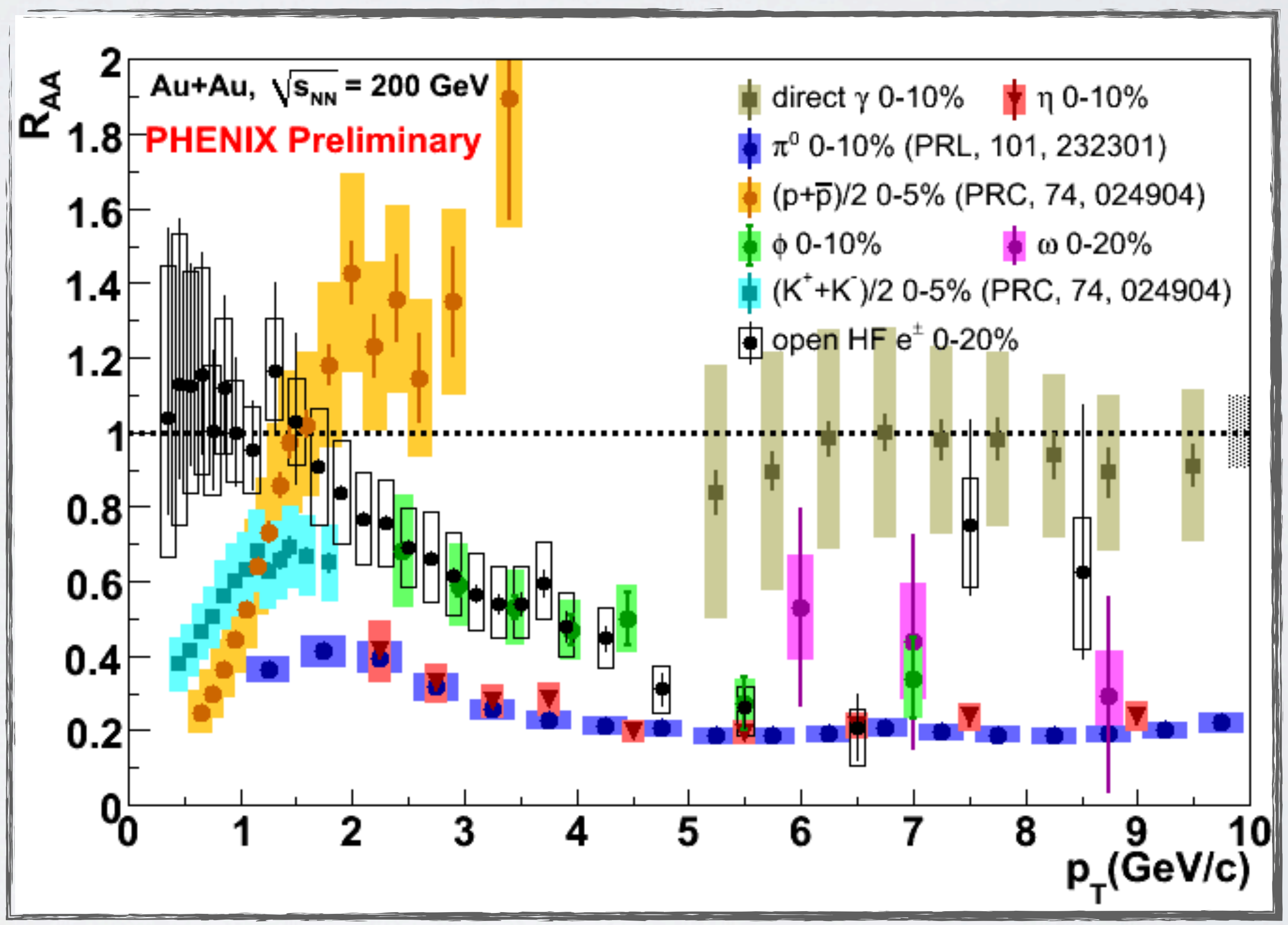


$$dN/d\phi = 1 + 2\, V_2 \cos 2\, (\phi - \psi) + \ldots$$



- The fluid (sQGP) formed at RHIC
  - leads to the suppression of any particles (q, Q, $Q\bar{Q}$) at high p_T
  - the disappearance of the away side jet (in 2→2 process)
  - long range **Δη** correlations

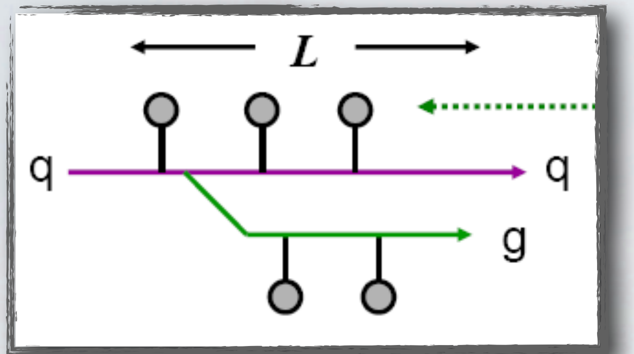
$$R_{AA} = \frac{Yield_{AA}/\langle N_{binary}\rangle_{AA}}{Yield_{pp}}$$



jeudi 24 septembre 2009

- The fluid (sQGP) formed at RHIC
- pQCD + radiative & collision energy loss+ transport coefficient + medium response + dynamics + fragmentation

R. Lacey, PHENIX



Radiative:

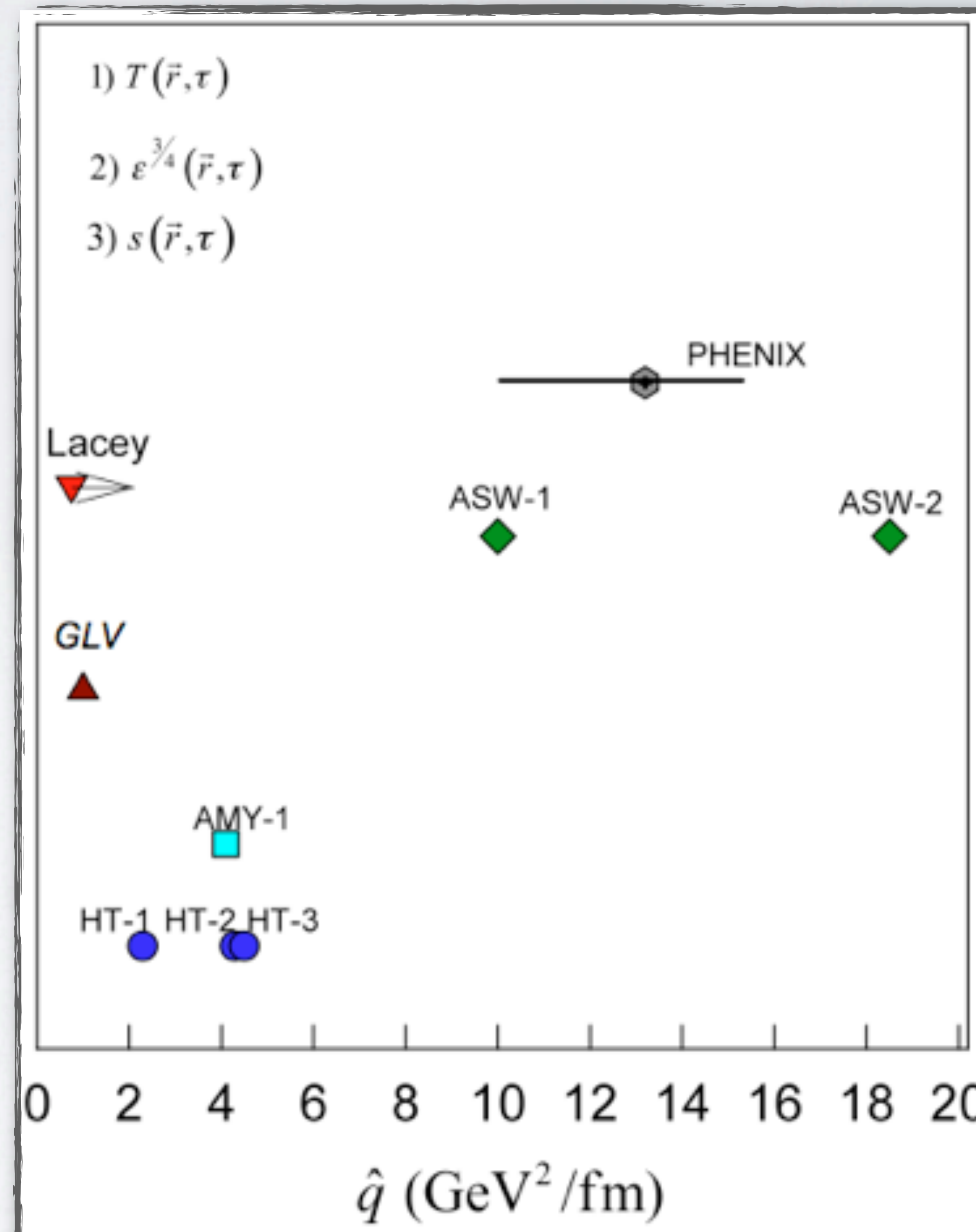
$$\frac{dE}{dx} \sim \sigma\rho L\left\langle k_T^2 \right\rangle$$

$$\hat{q} \sim \rho\sigma\left\langle k_T^2 \right\rangle$$

transport coefficient

range of color force

density of scattering centers



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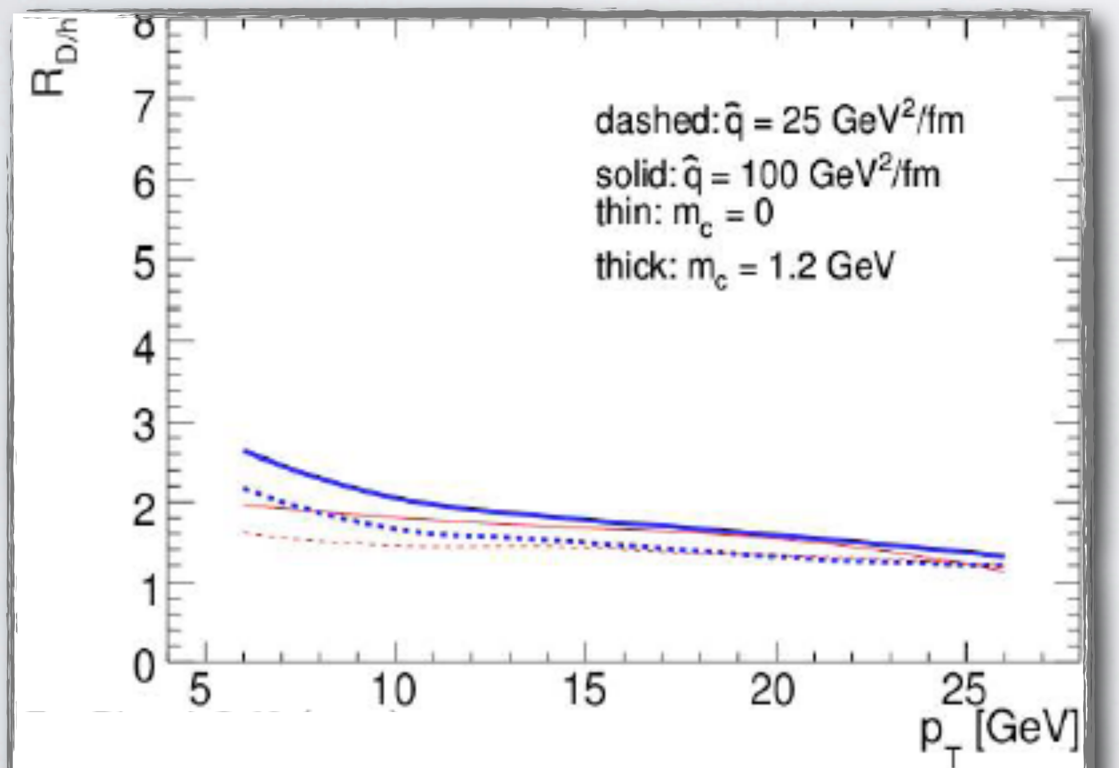
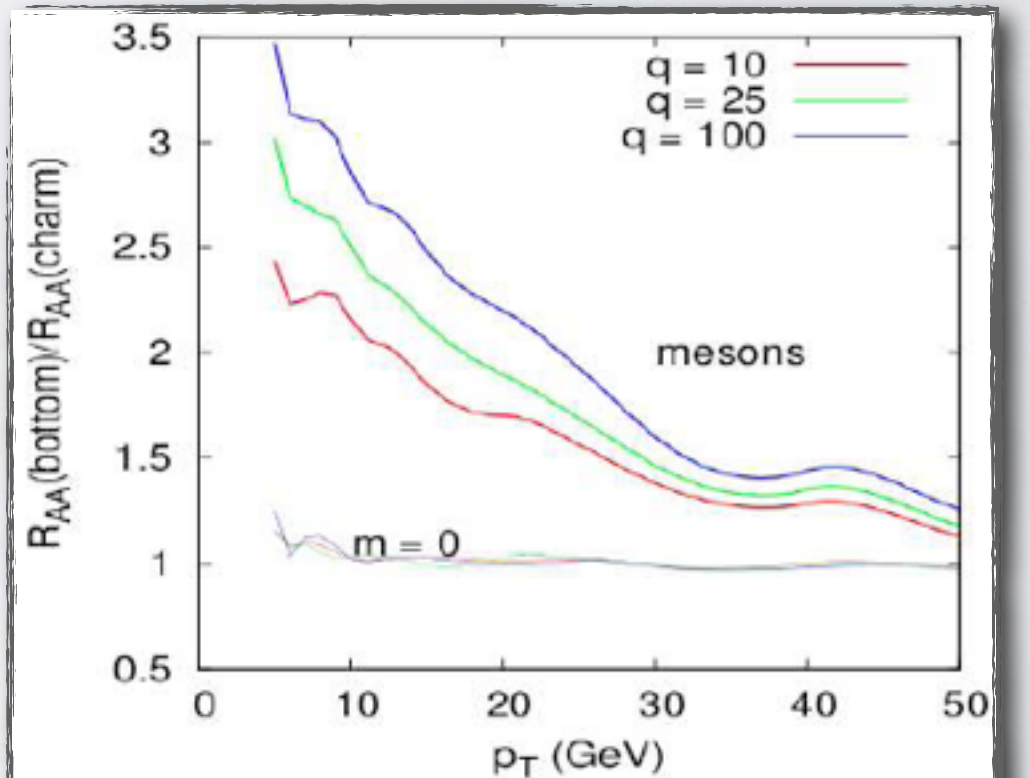
- At LHC, Q and jet measurements will open new avenues
  - Test the hierarchy: $\Delta E_g > \Delta E_q > \Delta E_Q$ and constrain $\hat{q}$

$$R_{AA} = Y_{AA}/(Y_{pp} \times N_{coll})$$

color charge dependence: $R^{D/h} > 1$

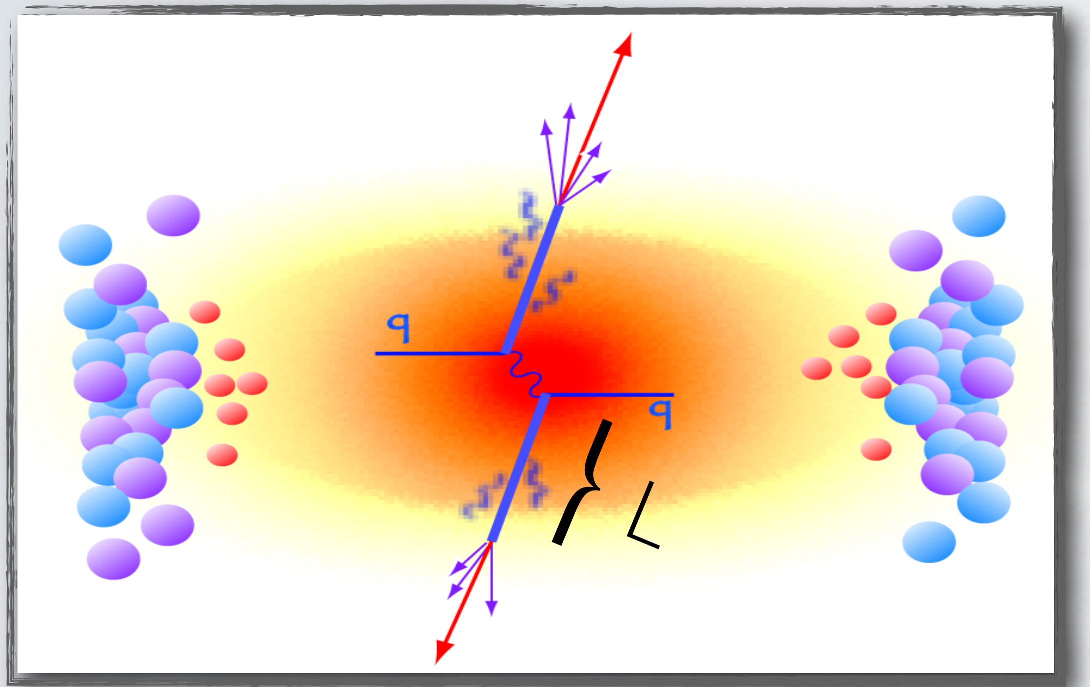
mass dependence: $R^{B/D} > 1$



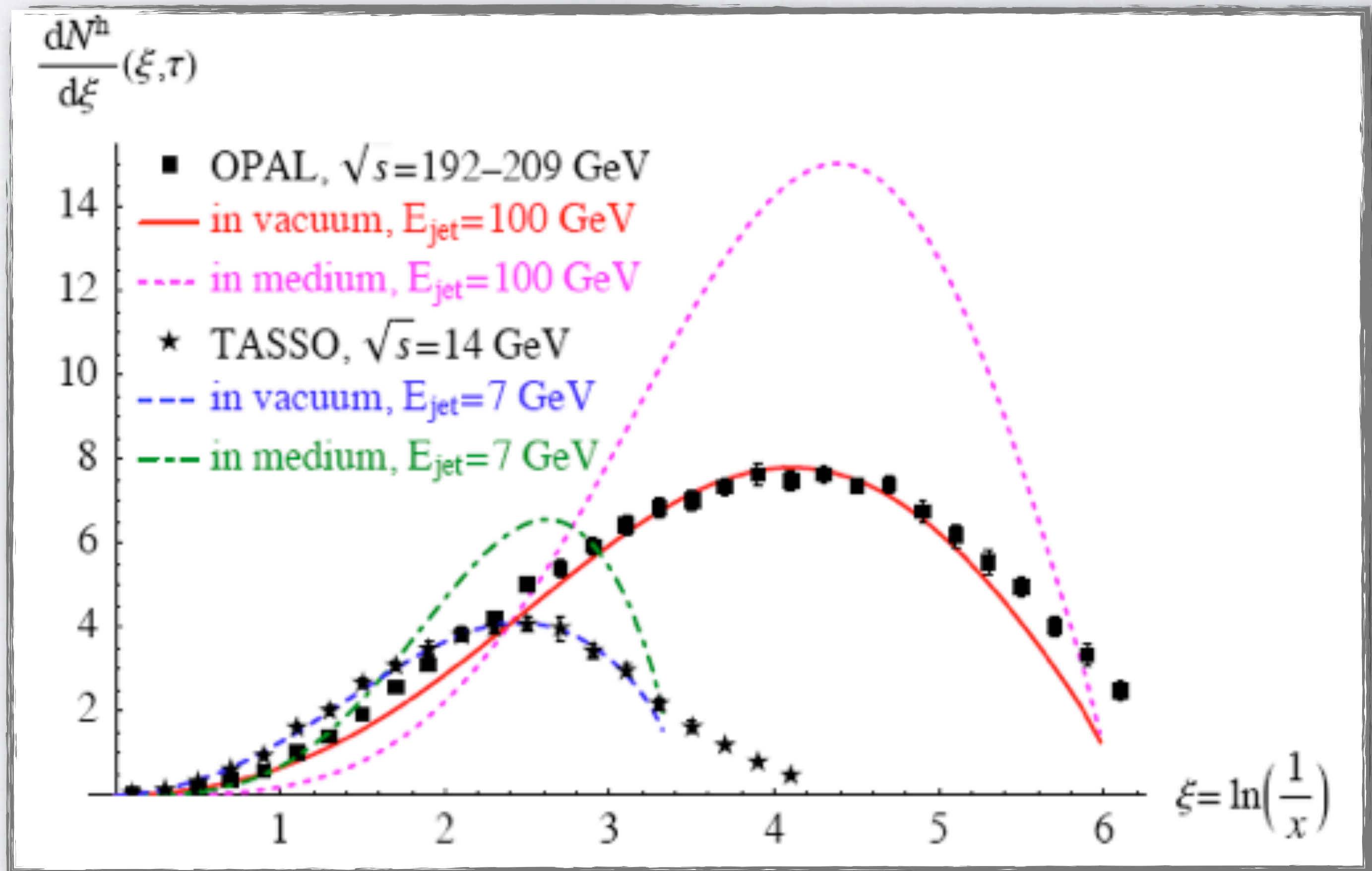


A. Dainese, Eur. Phys. J. C49 (2007) 135
N. Armesto et al. J. Phys. G35 (2008) 054002

- At LHC, Q and jet measurements will open new avenues
  - Modification of the fragmentation function and jet shape: energy loss + radiated energy
  - More sensitive: scales with $\hat{q}L$ rather than $\hat{q}L^2$

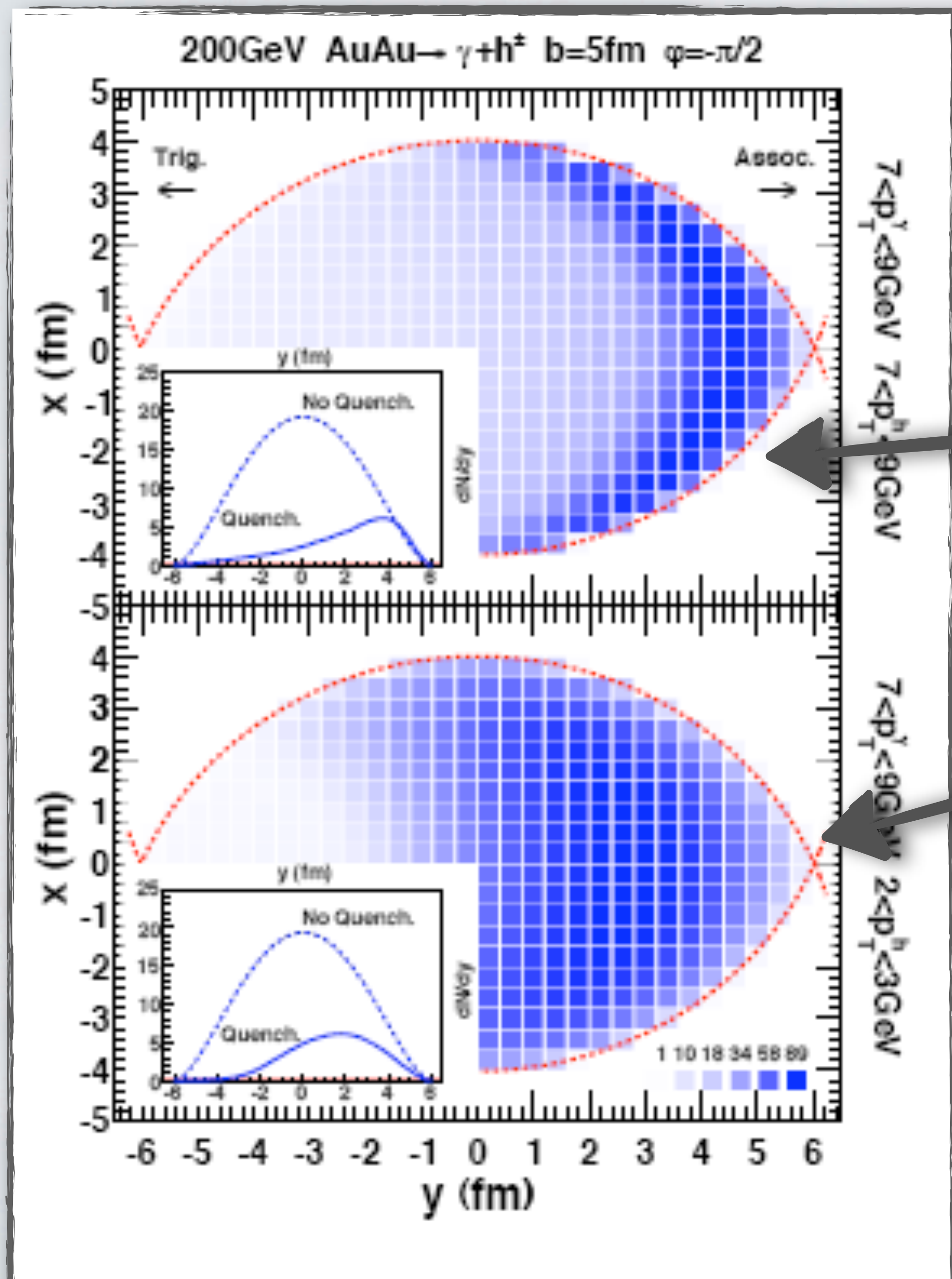


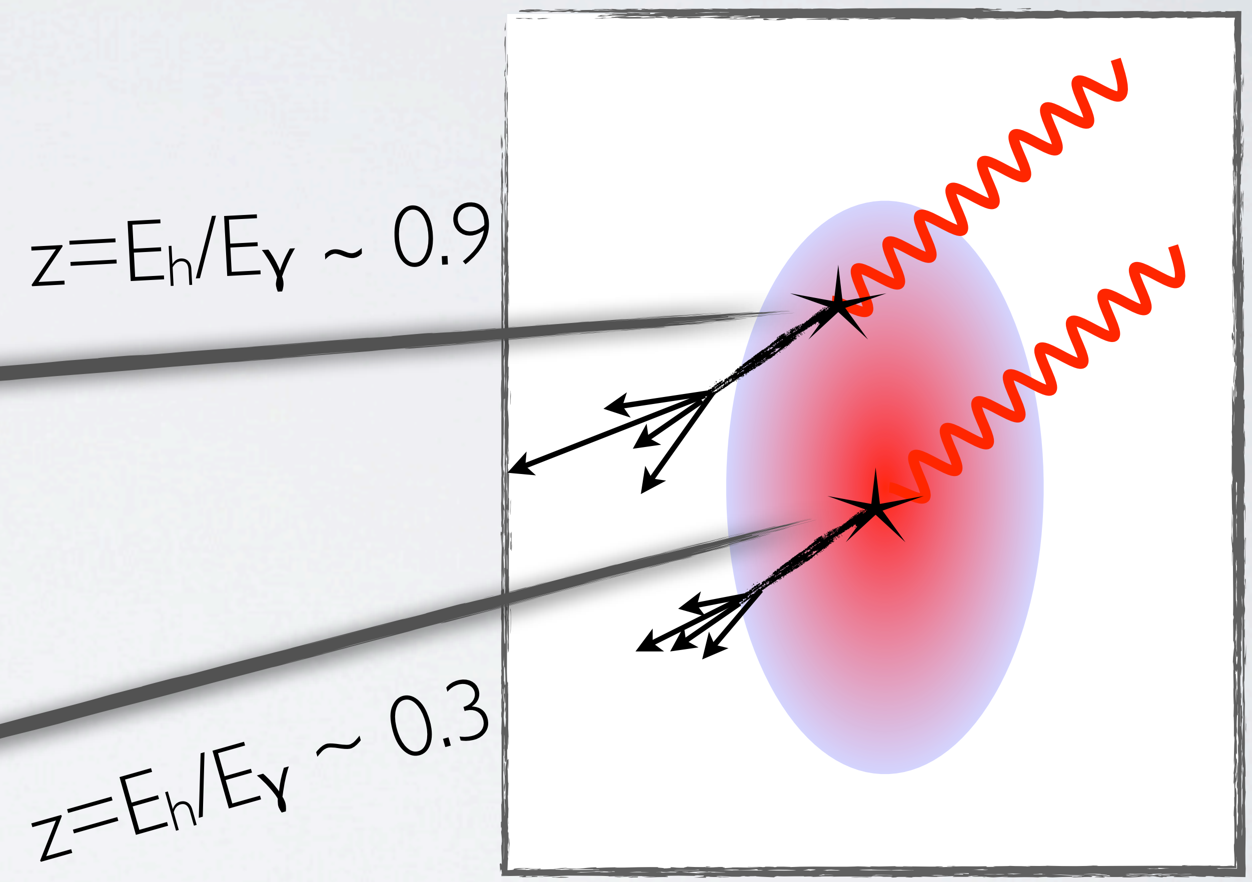
N. Borghini & U. Wiedemann hep-ph/0506218



$$\xi = \ln(E_{jet}/E_h)$$

- At LHC, Q and jet measurements will open new avenues
  - QGP tomography of the QCD matter with γ-jet, π-jet, jet-jet
    - measure $\Delta E(L) = \hat{q}L^2$

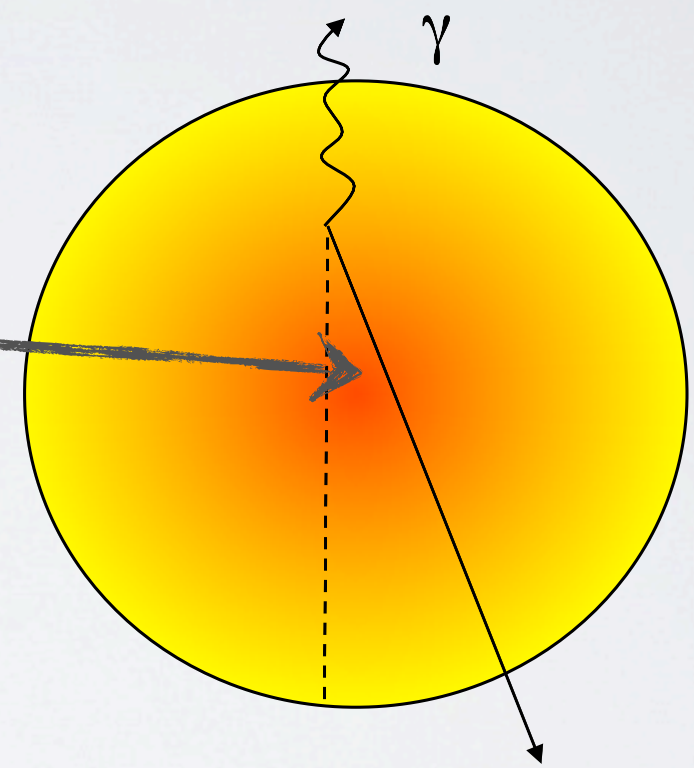




X.N. Wang et al. arXiv0902.4000v1[hep-ph]

- At LHC, Q and jet measurements will open new avenues
  - Direct measurement of $\hat{q}$ through the measurement of the acoplanarity of direct trigger photon and jet

$$\langle \Delta q_T^2 \rangle = \int dy \hat{q}(y,E)$$



X.N. Wang et al. arXiv0705.1352[hep-ph]

FINAL WORDS

- RHIC has paved the road for an empirical method to study the QCD matter formed in heavy-ion collisions, a nearly perfect liquid
- The LHC experiments will follow the same road but the exploration tools at hand will be much more powerful allowing to study QCD matter in yet may be an other phase, closer to the theory expectation.