Beam Requirements for the LHC Heavy Ion Program (Theorist's View)

Urs Achim Wiedemann
Theory Division, CERN

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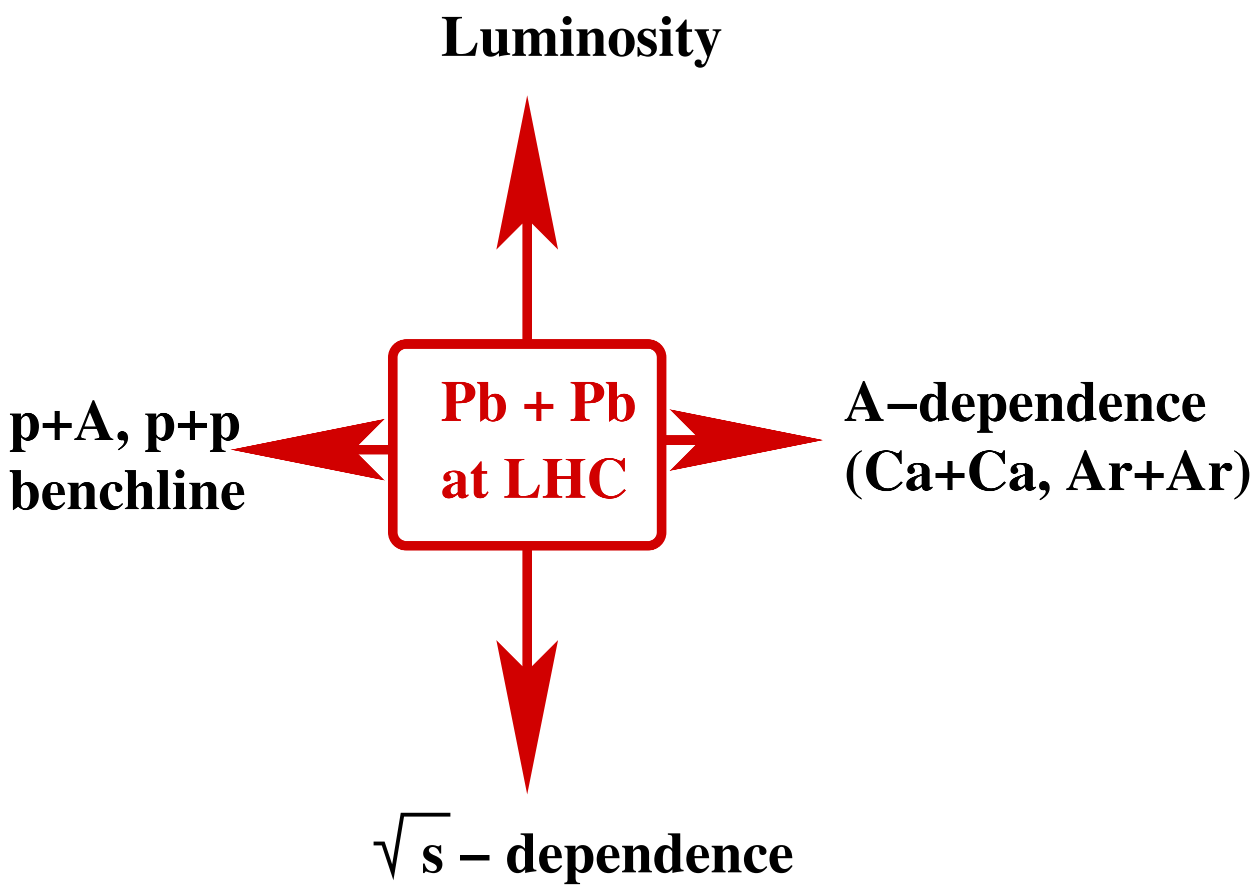
Based on

- CERN TH Workshop:
  "Hard Probes in Heavy Ion Collisions at the LHC"
  work in progress

- Experience from CERN SPS and BNL RHIC


Luminosity
Pb + Pb
at LHC
p+A, p+p
benchline
A−dependence
(Ca+Ca, Ar+Ar)
$\sqrt{s}$ – dependence

Priorities ?

Pb+Pb at LHC: exploratory run

What do we learn from 10000 min. bias events ?

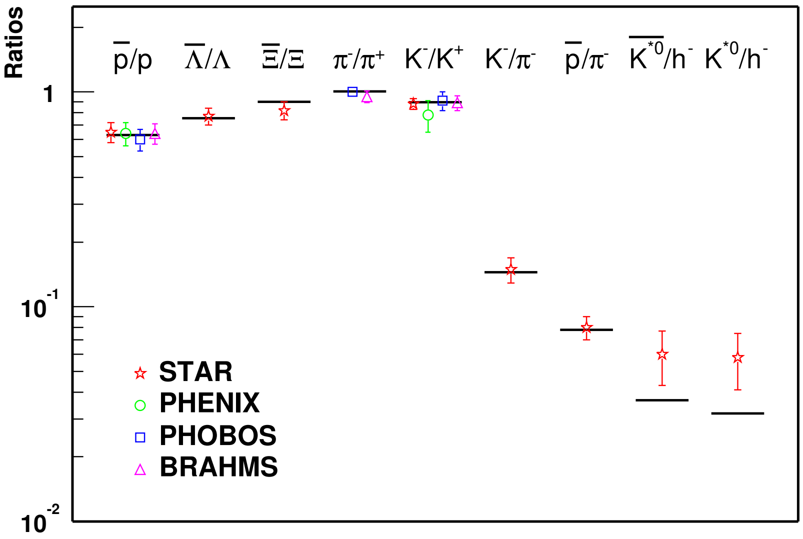
- checking for obvious surprises
- Multiplicity
  "predictions": $1500 < \frac{dN_{ch}}{dy} < 8000$
  $\Longrightarrow$ constrains predictions of almost all other observables

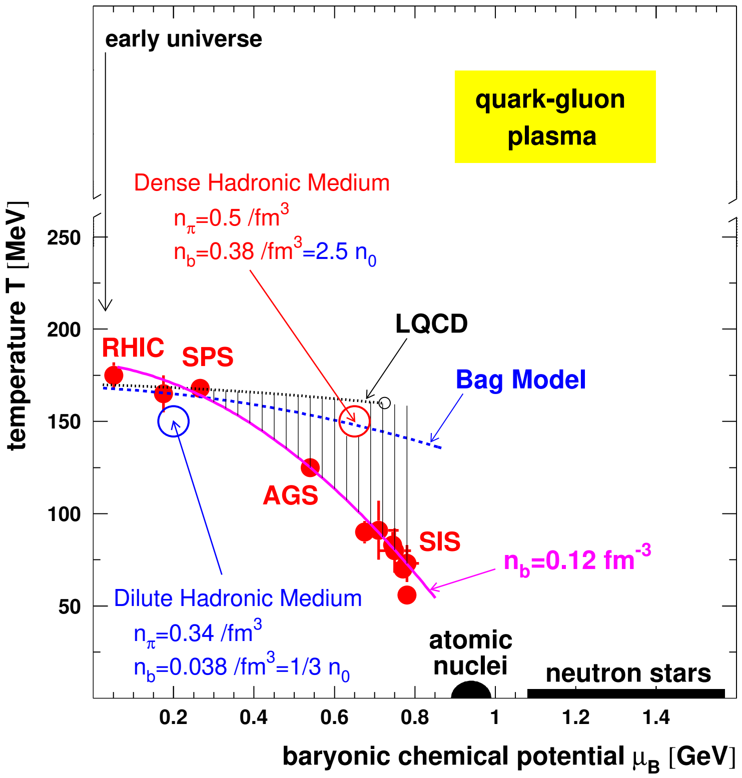
What do we learn from 10^6 min. bias events ?

- "Hadrochemistry" (hadronic particle ratios)
  prediction: chemical freeze-out at $T \simeq 170$ MeV, $\mu_B \simeq 0$
  $\Longrightarrow$ puts LHC-point on the QCD phase diagram

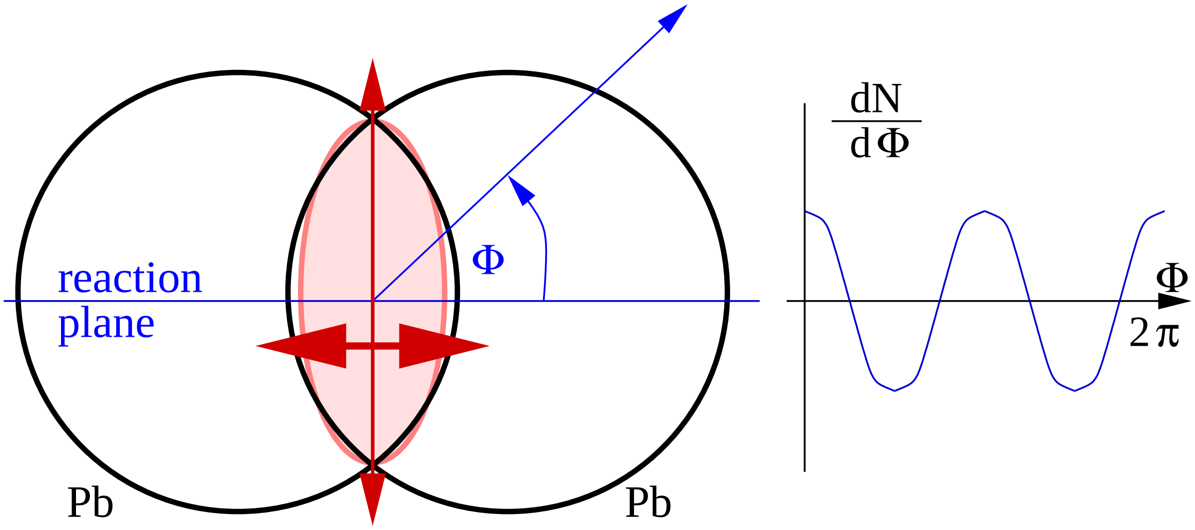
- "Hydrodynamics"
  hadronic momentum spectra,
  radial + elliptic flow, HBT
  $\Longrightarrow$ first indication to what extent zero mean free path picture is applicable

“Hadrochemistry” at RHIC





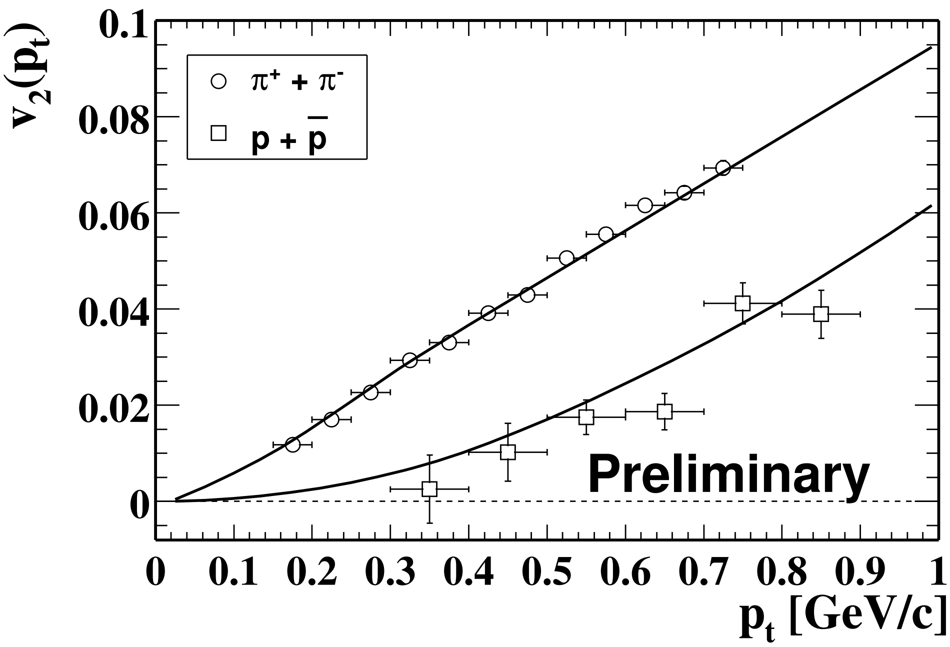
"Hydrodynamics", e.g.: elliptic flow v_2



Pressure gradients depend on azimuth

$$\frac{dN}{d^2p_\perp\, d\Phi} = \frac{dN}{d^2p_\perp}\{1 + v_2(\mathbf{p}_\perp)\ \cos(2\Phi)\}\,.$$

follows hydrodynamical behaviour @ low $p_\perp$



Exploratory run: Summary

Many of the main measurements of RHIC run 1 and run 2 can be done in an exploratory run at LHC $\sqrt{s} = 5.5$ TeV/A.

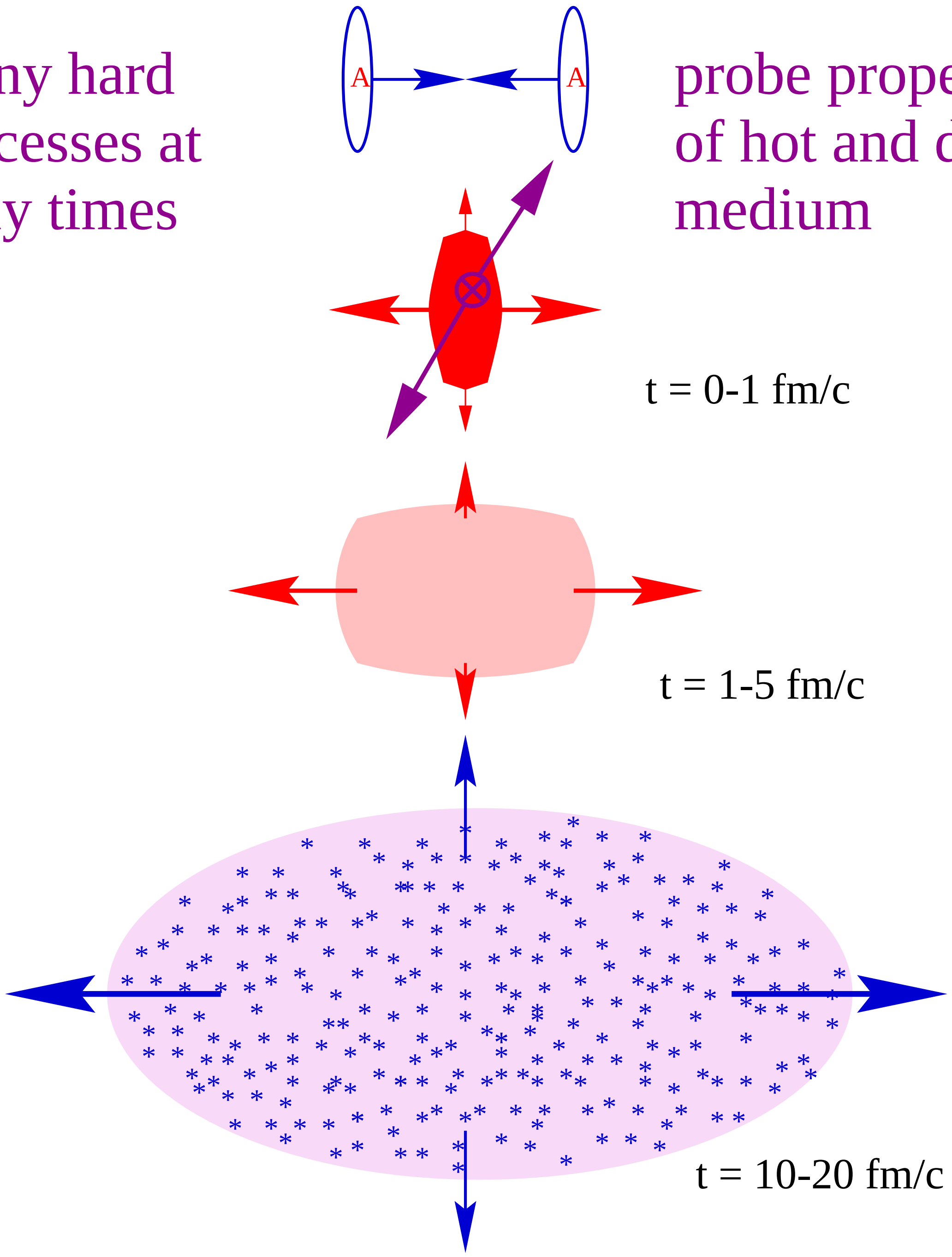
Scheduling a 1-3 day heavy ion run in the start-up phase of LHC would have a large impact on the heavy ion physics community.

Why are rare processes in HICs interesting ?

(They are the closest we get to DIS on the QGP.)

Many hard processes at early times

probe properties of hot and dense medium



"Hard Probes"

Physics goal: Testing strong QCD color fields via medium-dependence of hard processes

Probes:

- open charm
- open beauty
- inclusive jets
- tagged jets: γ-jet, jet-jet, $W^{\pm}$,Z-jet
- direct photons
- ratios of leading particles: $\bar{p}/p$, $\bar{\Lambda}/\Lambda$

Physics goal: Testing QCD parton thermalization and evolution of the medium

Probes:

- J/Ψ, Ψ' - suppression, $p_{\perp}$-dependence
- Υ, Υ''s suppression

Role of the CERN TH Workshop on "Hard Probes"

to assess and further develop the theory of hard probes in the hot, strongly interacting environment accessible in HICs at LHC
in particular: to establish benchmarks for comparison

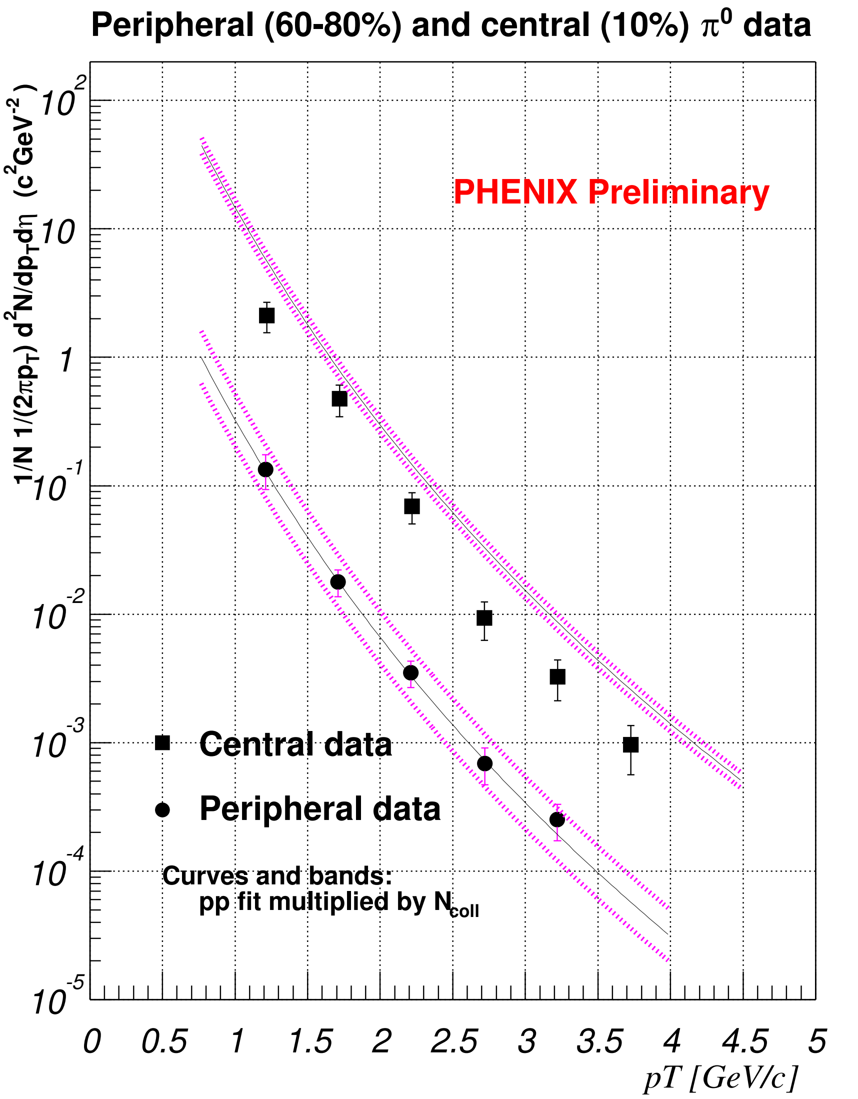
Four working groups:

- PDFs, shadowing and p+A
- Photons
- Heavy Quarks and Quarkonia
- Jet physics

Third plenary meeting: OCT 7-11 2002
organizers: Michelangelo Mangano, Helmut Satz, Urs Wiedemann
http://wwwth.cern.ch/lhcworkshop/lhcworkshop01.html

Analysis Strategy for Hard Processes

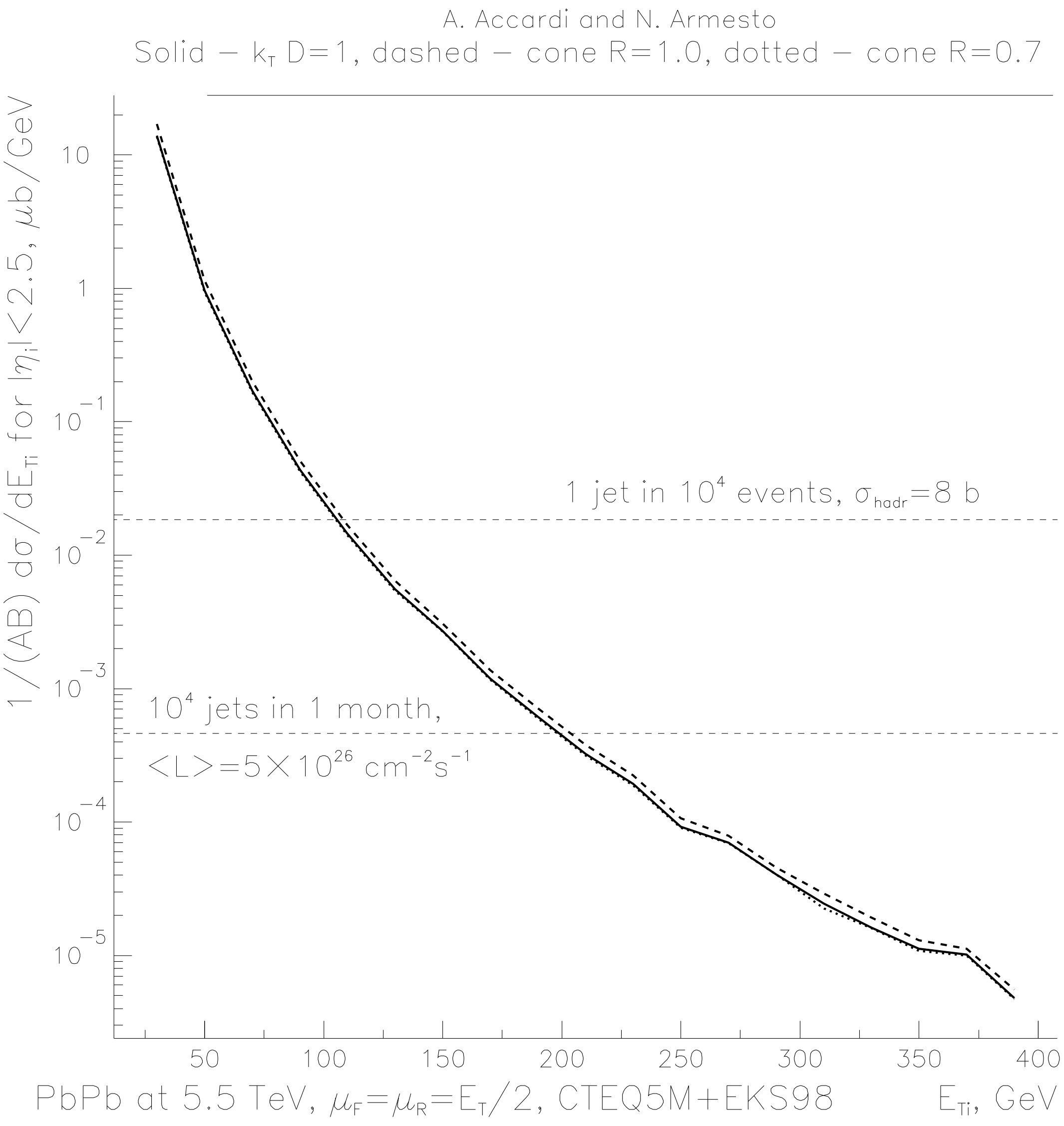
Establish medium-dependence by comparing to benchmark result. Example from RHIC: suppression of p_t-spectra in comparison to $p-p$ as a function of centrality:



But this is not yet "hard" ...

Jet production at LHC, Pb+Pb

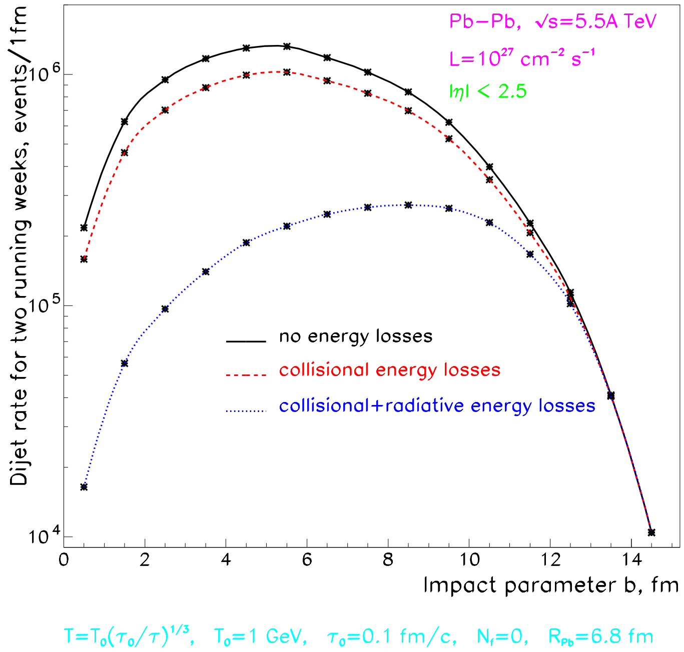
sufficient statistics after one month of running at design luminosity



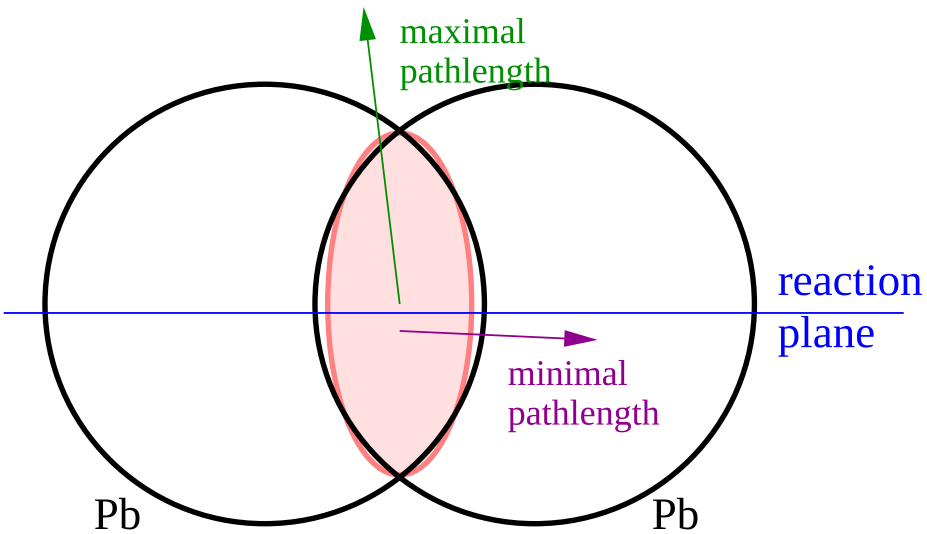
Hard Probes vs. nuclear geometry

- impact parameter dependence

Lokhtin + Snigirev, Eur. Phys. J. **C16** (2000) 527.

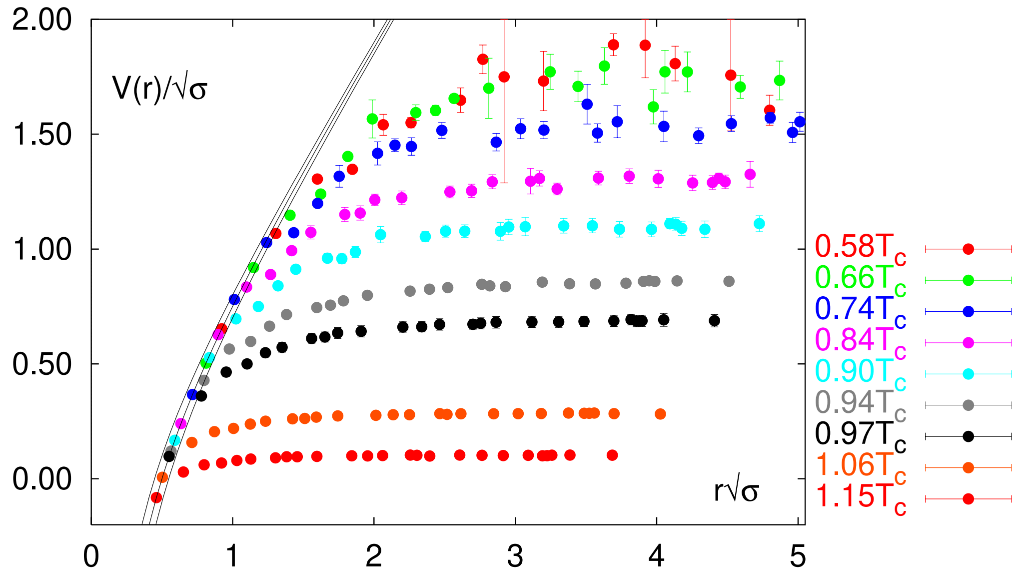


- exploit nuclear geometry as discriminatory tool: $\Longrightarrow$ **reaction plane reconstruction**

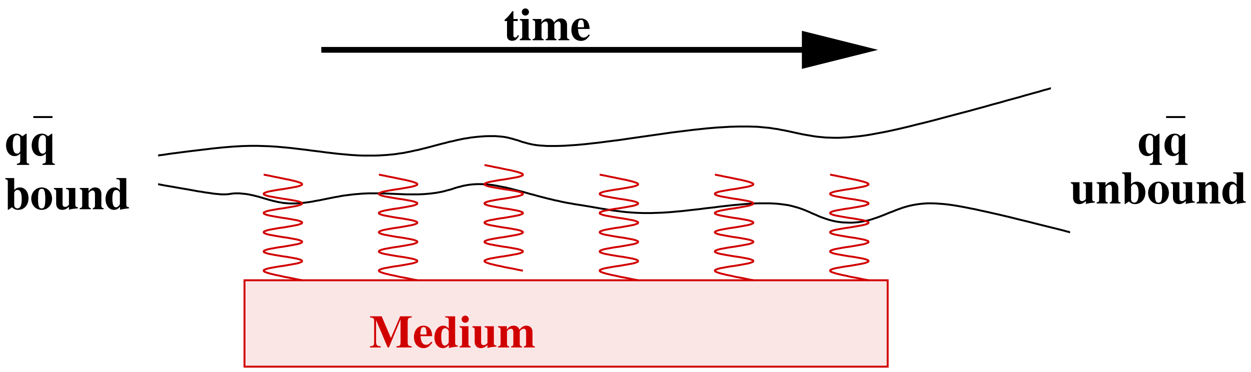


Quarkonium production

Heavy Quark bound states dissolve in a thermalized QGP F. Karsch, hep-ph/0103314



Dynamical picture:



Pb+Pb run at LHC: requirements

The Pb beam program at LHC remains incomplete without a study of the sequential suppression/enhancement of all quarkonium bound states. Ideally:

- as a function of centrality

  explores energy density dependence

- w.r.t. the reaction plane

  dependence on in-medium pathlength fixes time integral over "fireball history"

- together with open charm and bottom

  the most natural normalization because of the same production mechanism

- as a function of $p_\perp$

  discriminates between different models

- as a function of system size (A-dependence)

  NA50-experience, "normal vs. abnormal suppression"

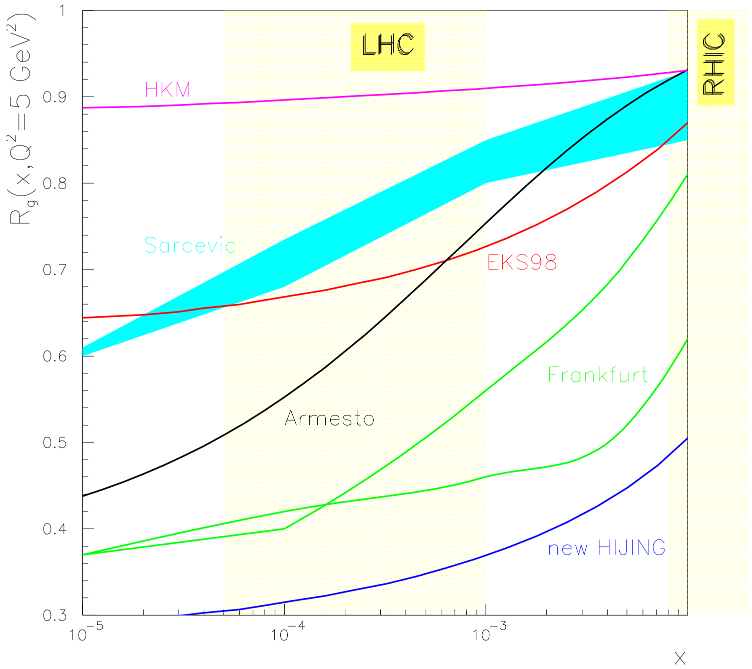
$\Longrightarrow$ Bottonium spectroscopy sets the statistics requirements for a successful Pb-beam program.

Importance of p+Pb (d+A)

Comparing p+A to A+A

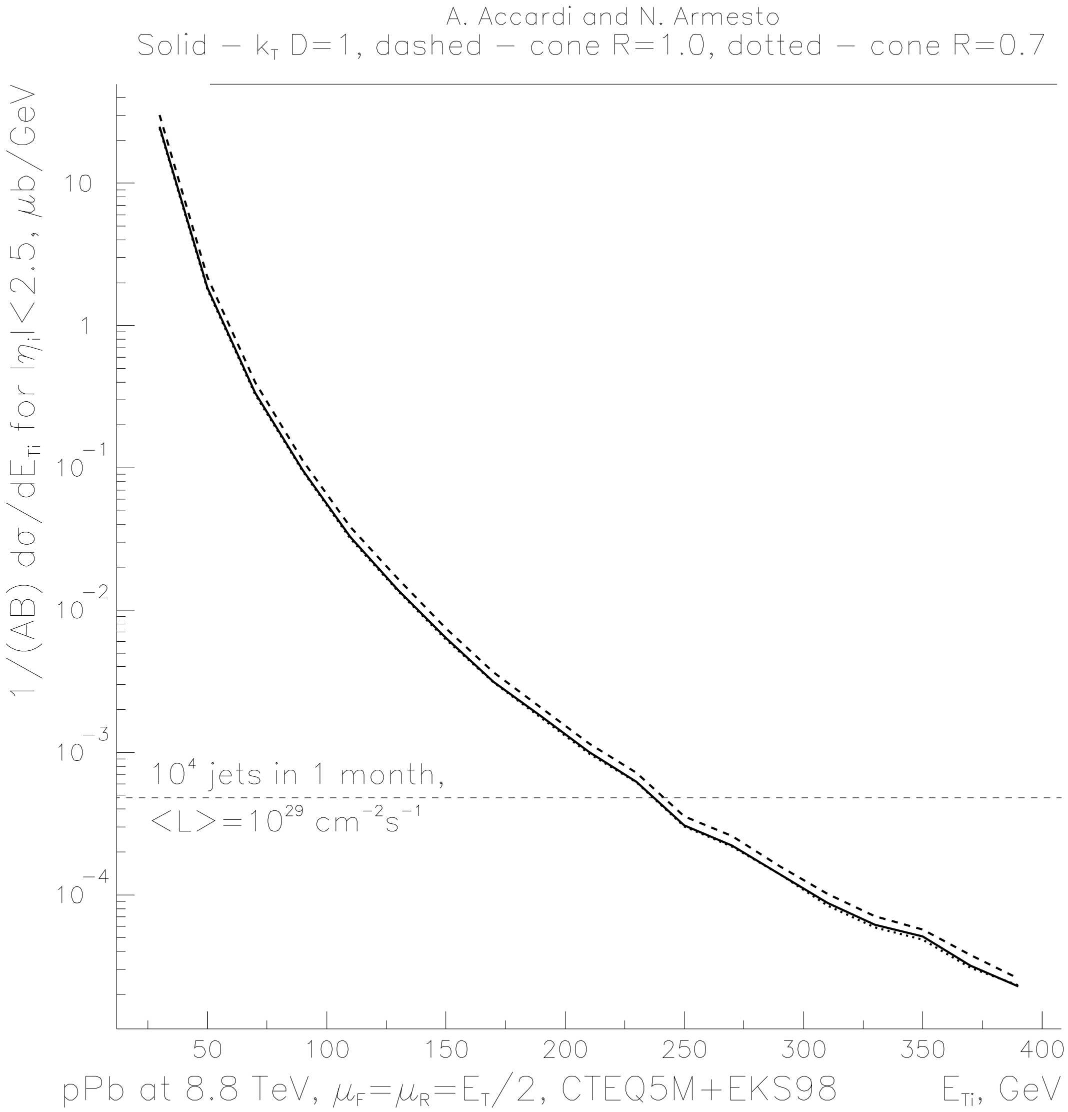
- allows to disentangle <u>initial</u> from <u>final</u> state medium effects nuclear shadowing of pdfs, $A^{1/3}$-enhanced $p_\perp$-broadening
- allows to disentangle medium-modification of hard processes in <u>hot versus cold</u> nuclear matter
- tests QCD in the small x (parton saturation) regime

complementary to physics accessible in e-A, e-p



Jet production at LHC, p+Pb

sufficient statistics after one month of running at design luminosity
crucial benchmark for theoretical interpretation of hard processes



p+Pb (d+A): Summary

- p+A is compulsory benchmark for separating different nuclear effects observed in A+A
  $\Longrightarrow$ after one month A+A at design luminosity, a complementary p+A run should be considered.

- Very little TH preference for p+Pb or d+Pb
  - pro p+A: generic p+A physics
  - pro d+A: isospin averaged

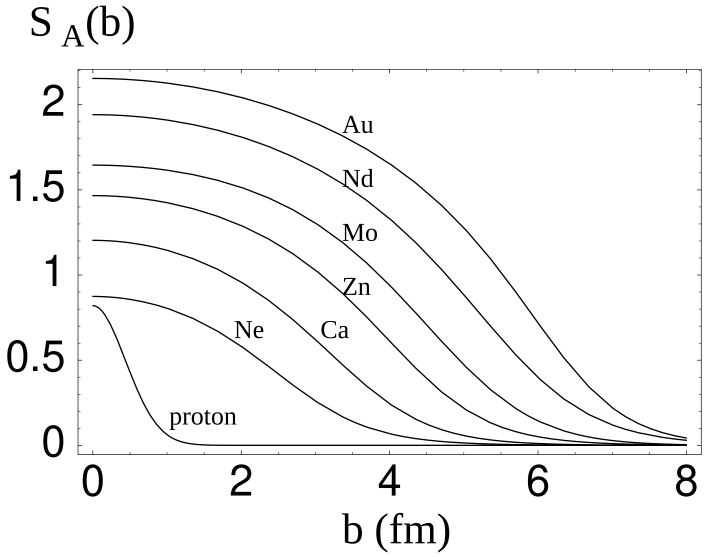
A-dependence

Motivation:

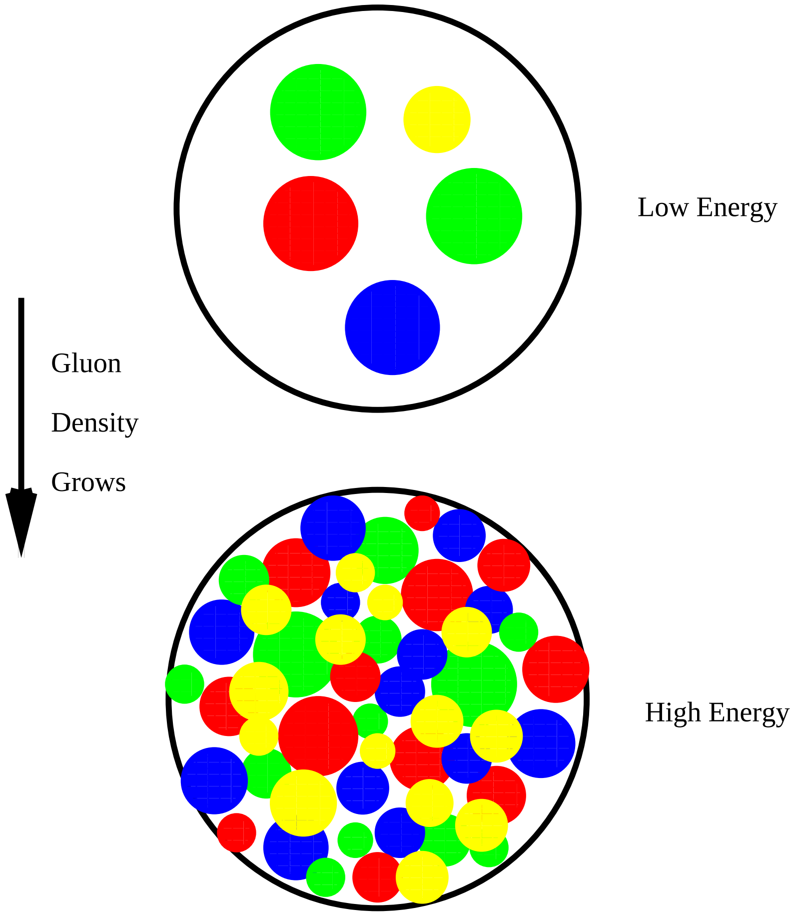
- varying system size better controlled than varying centrality in Pb+Pb

- Locally in impact parameter space, gluon density grows like $\sim A^{1/3}$
  $\Longrightarrow$ saturation physics

Which A ? Such that parton density at $b = 0$ is scanned between p and Pb (i.e. Oxygen is disfavoured)
Ca+Ca (or Ar+Ar) and one heavier system (Sn+Sn) is favoured



QCD of High Parton Densities



Gluon distribution stops growing, saturates at scale

$$Q_{\mathrm{sat}}^2 = \frac{8\pi\,\alpha_s\,N_c}{N_c^2-1}\rho_A\,x\,G(x,Q_{\mathrm{sat}})\,,$$

$$\rho_A \propto \frac{A}{\pi R^2} \propto A^{1/3}\,, \qquad A^{1/3}\text{-enhancement !!}$$

At LHC, $Q_{\mathrm{sat}} > 2$ GeV
$\Longrightarrow$ HIC = physics of colliding dense gluon walls.

$\sqrt{s}$-dependence

Traditional HI physics arguments for $\sqrt{s}$-scan:

- varying baryochemical potential
- measuring excitation functions (e.g. v_2)
  searching for threshold behaviour

are weak. May become strong if global observables show unexpected "jumps" between RHIC and LHC energies.

Benchline measurements in p+p and p+A in principle preferable at same $\sqrt{s}$ as A+A, but extrapolation errors are rather small.

One could consider to run $p + A$ at $\sqrt{s} = 5.5$ TeV/A.

Priorities (current view)

1. Pb+Pb: accumulate $\sim O(1)$ nb^{-1} integrated luminosity
   (1 months at design luminosity)

2. p+A: establish benchmark
   (2-4 weeks at design luminosity)

3. Pb+Pb: increase statistics

4. A-dependence: e.g. Ca+Ca and Sn+Sn

5. $\sqrt{s}$-dependence