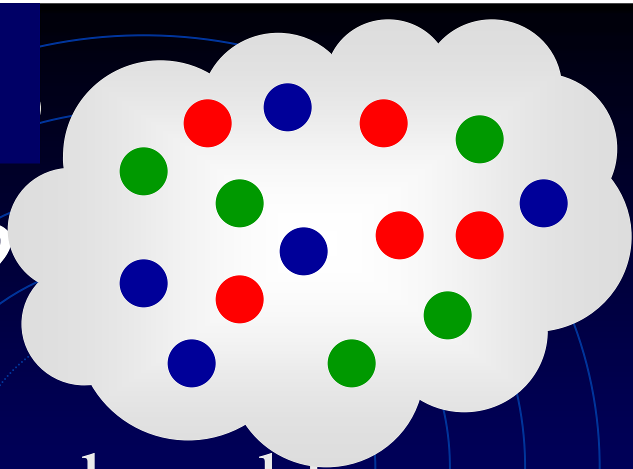
# Relativistic Ion Collisions

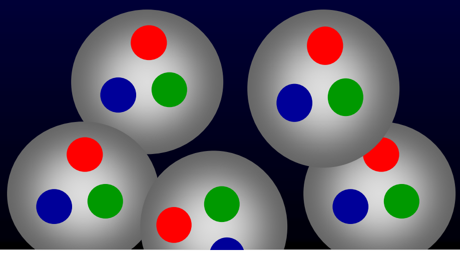
Helena Białkowska
Sołtan Institute for Nuclear Studies
Warsaw

# Why heavy ions?

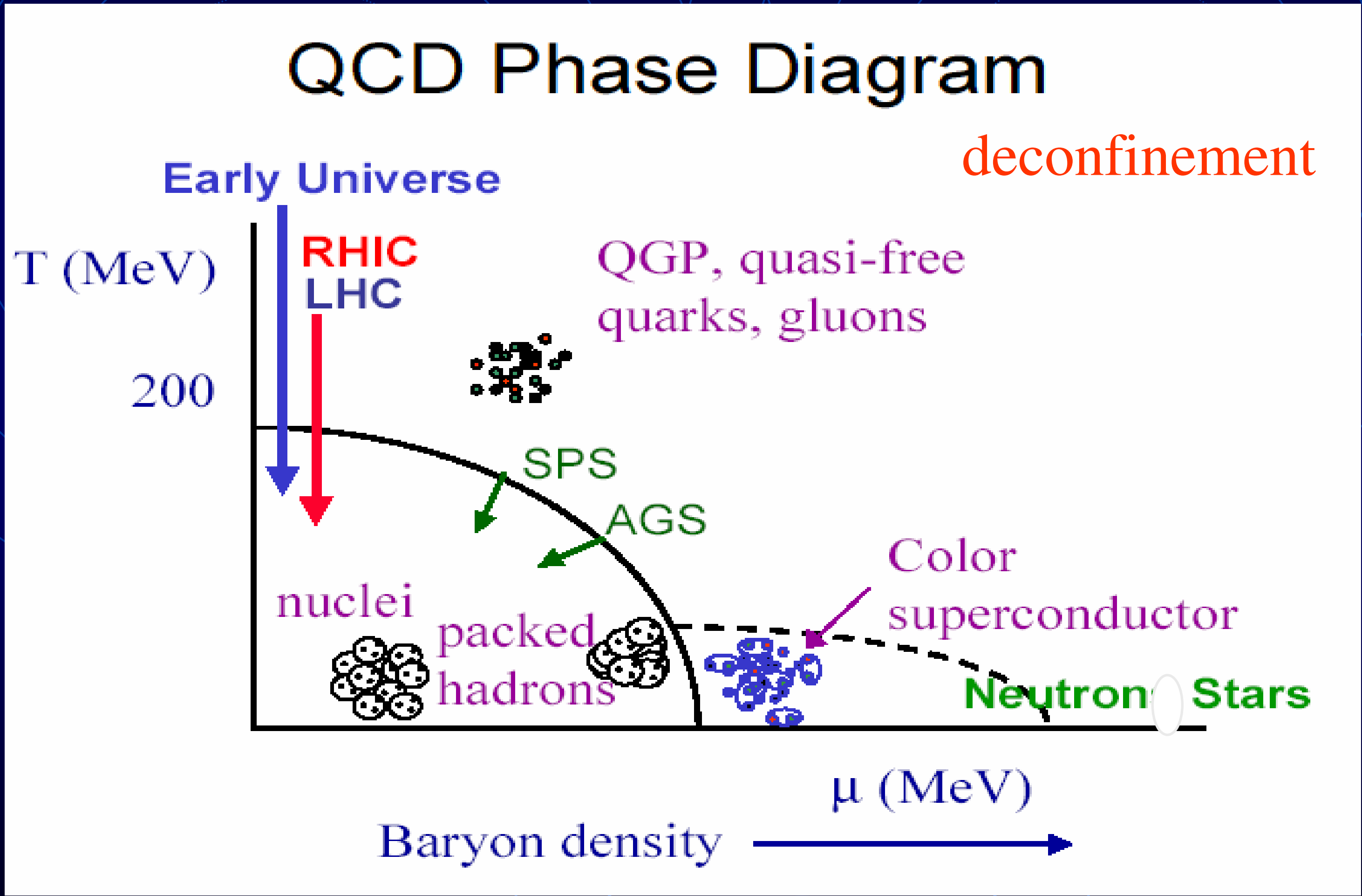


- You could think there are enough problems with elementary collisions...
- Yet if you collide many nucleons together you can perhaps learn more about their constituents and their interactions.

***From dynamics to thermodynamics of strong interactions?***



# QCD: dynamics of strong interactions



# Useful numbers:

## Energy density:

- SPS ~ 3 $GeV/fm^3$
  - RHIC ~ 5-8 $GeV/fm^3$
    - Proton: ~ 0.14$GeV/fm^3$

## Temperature:

(measured in degrees Kelvin
- or in eV, via Boltzmann k)

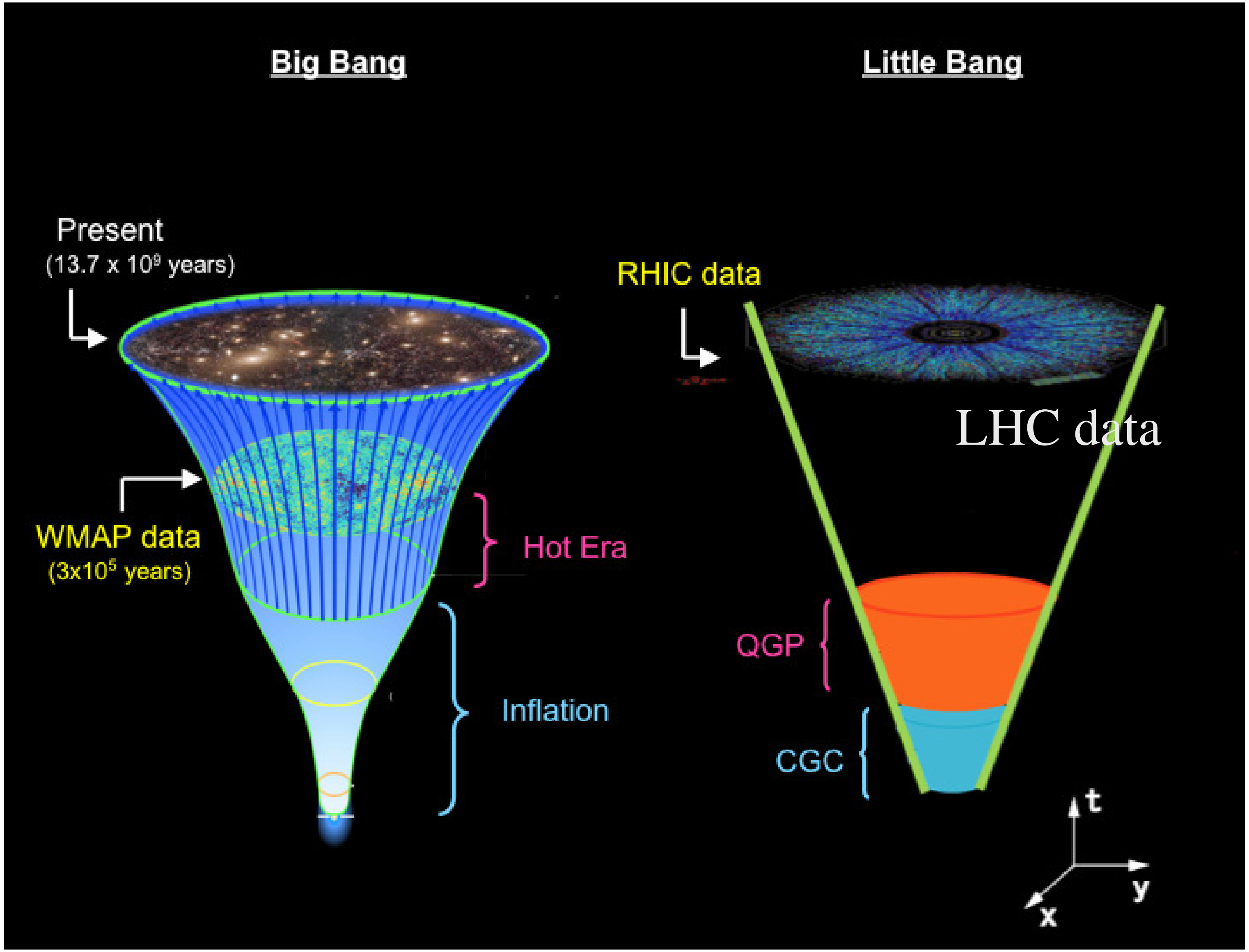
Surface of the Sun: 6000 K

→ 0.52 eV

Nuclear fireball: 150 MeV

→ $2 * 10^{12}$ K

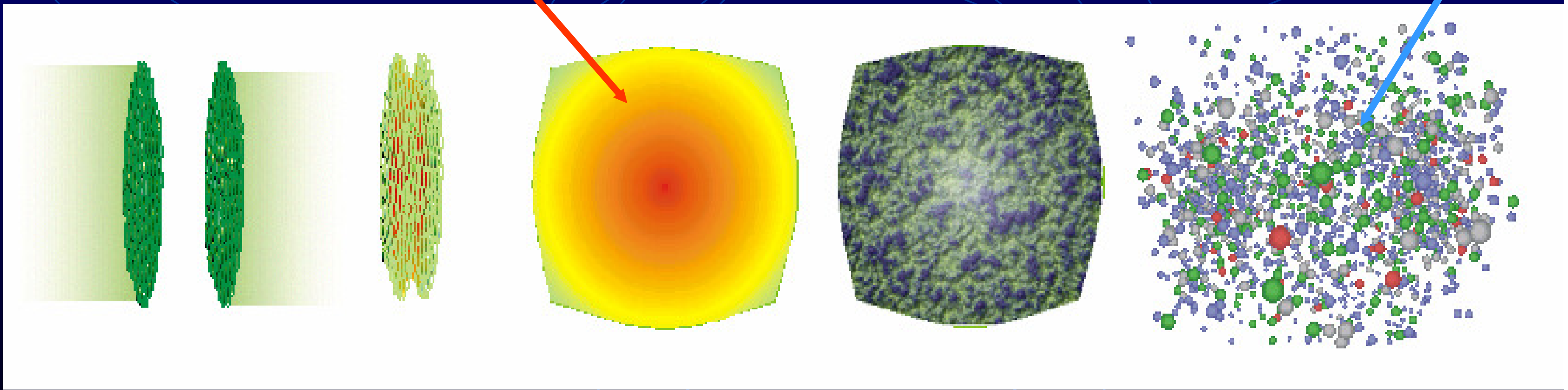
# From Big Bang to Little Bang



# How does an interaction progress:

This is where the 'hot stuff' forms

But we observe it here...



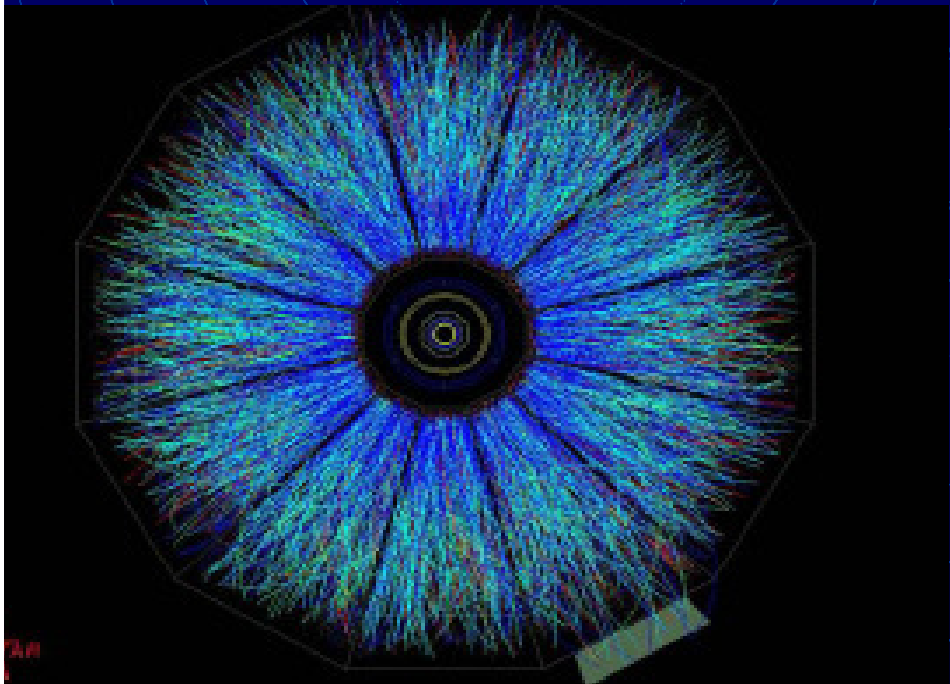
# Big questions:

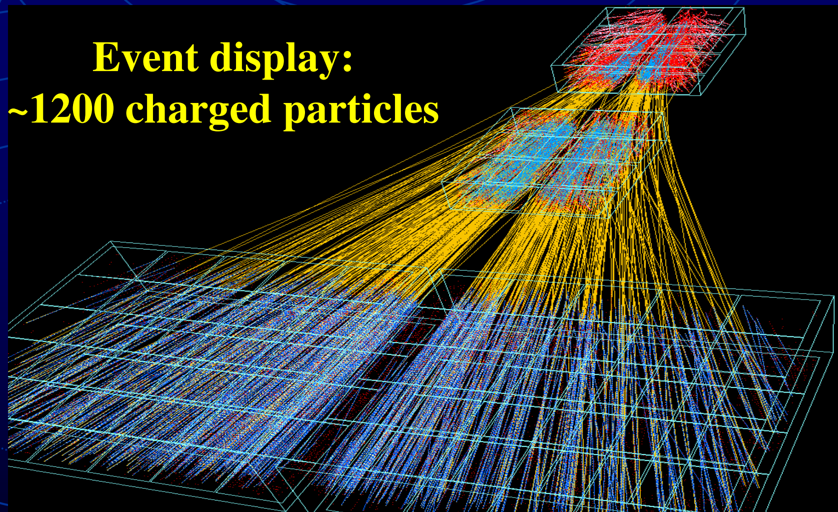
- What have we learned so far?
- What do we want to know?

# Existing data come from two sources:

- The RHIC accelerator
- 100+100 GeV/N
- Au + Au

- The SPS accelerator
- 158 GeV/N
- Pb on stationary Pb

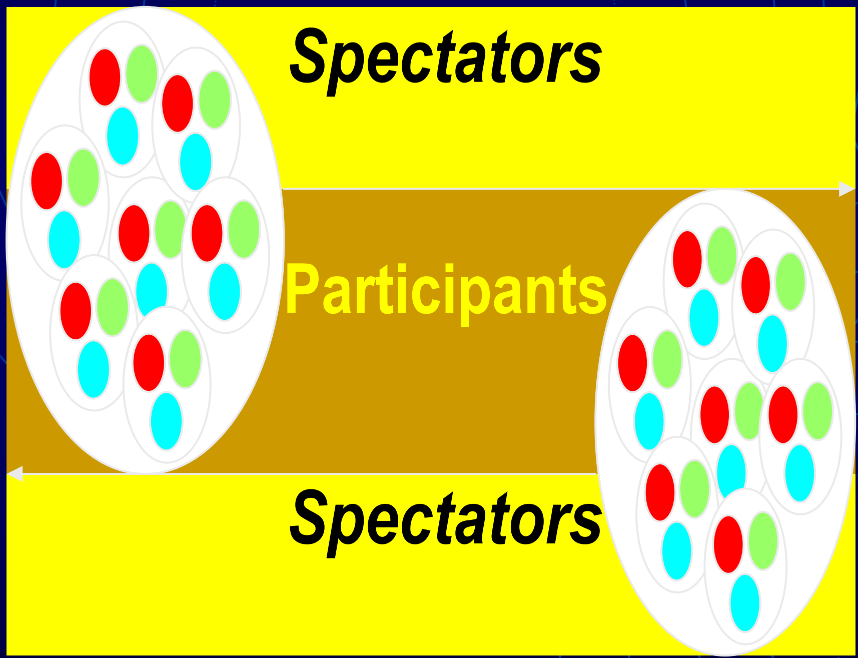




# Basic info on ‘soft’ interactions:

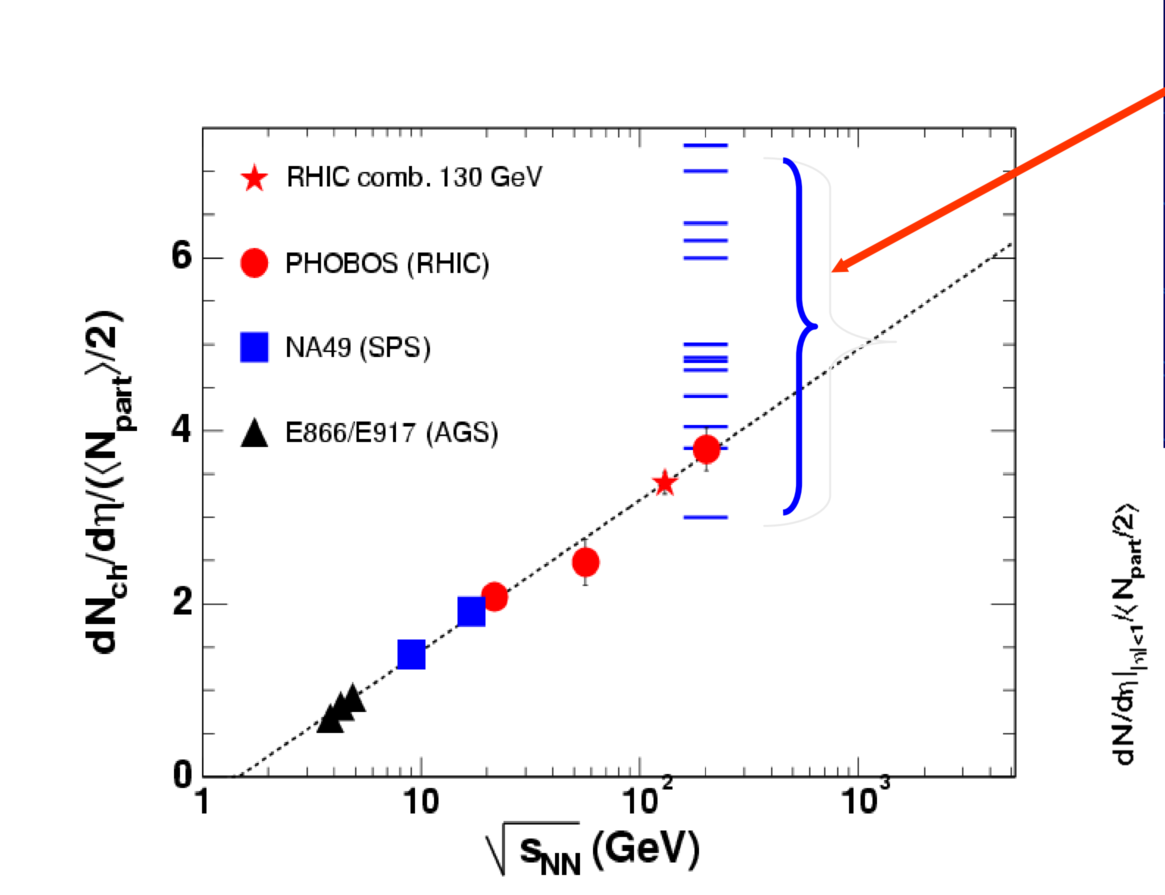
- Multiplicities
- Particle spectra
- Particle composition
- Particle correlations

# Important for heavy ion collisions: centrality




- 'Centrality' – how many nucleons participate in the collision
- No way to measure directly, but can evaluate
- Often expressed in terms of 'number of participant pairs'

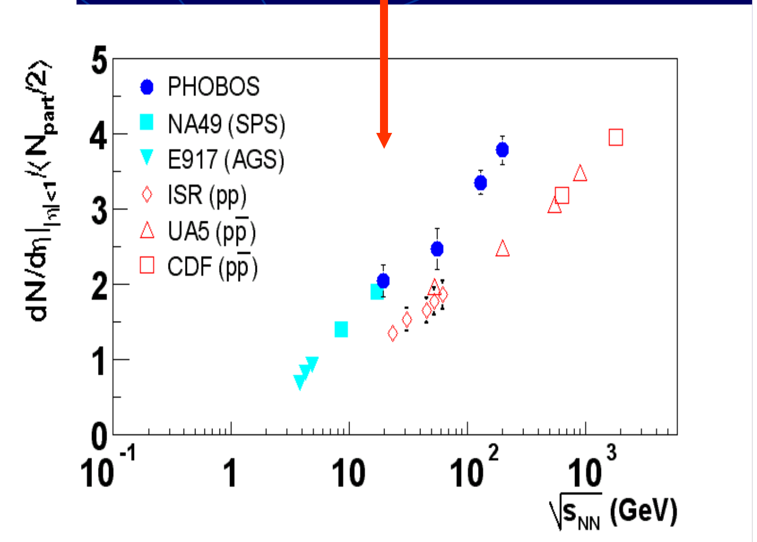
# Back to basic facts: multiplicities (from central collisions)




Two surprises:

Far away from many a prediction

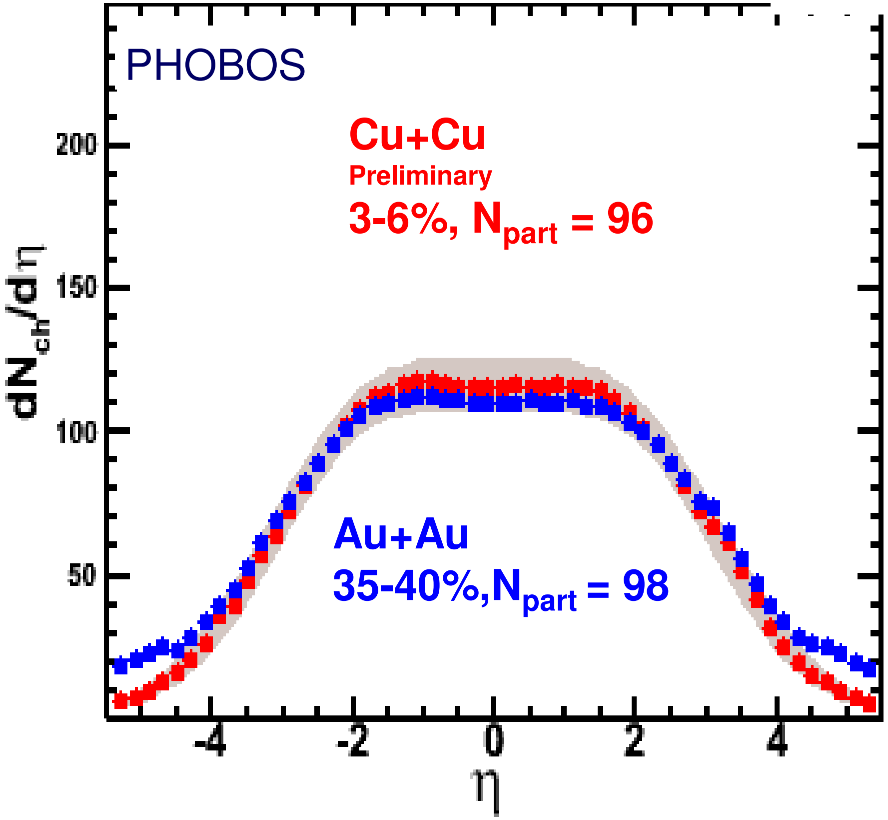
Only ~ 30% more than in pp (per participant)



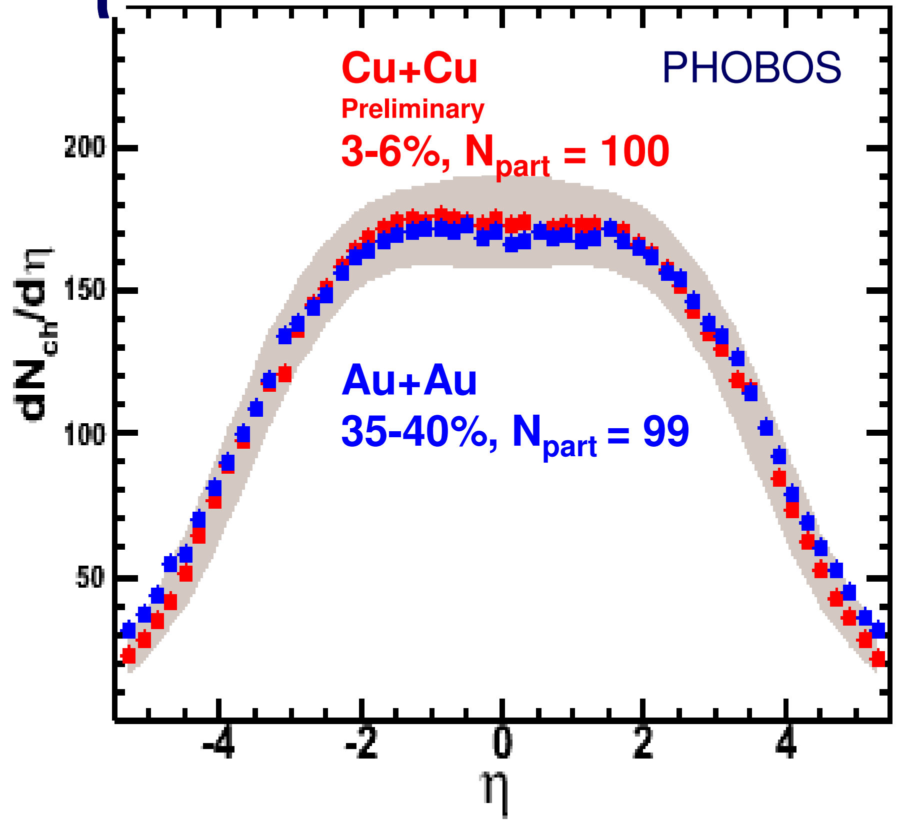
# Basics ctn`d: spectra

## dN/dη

62.4 GeV




200 GeV



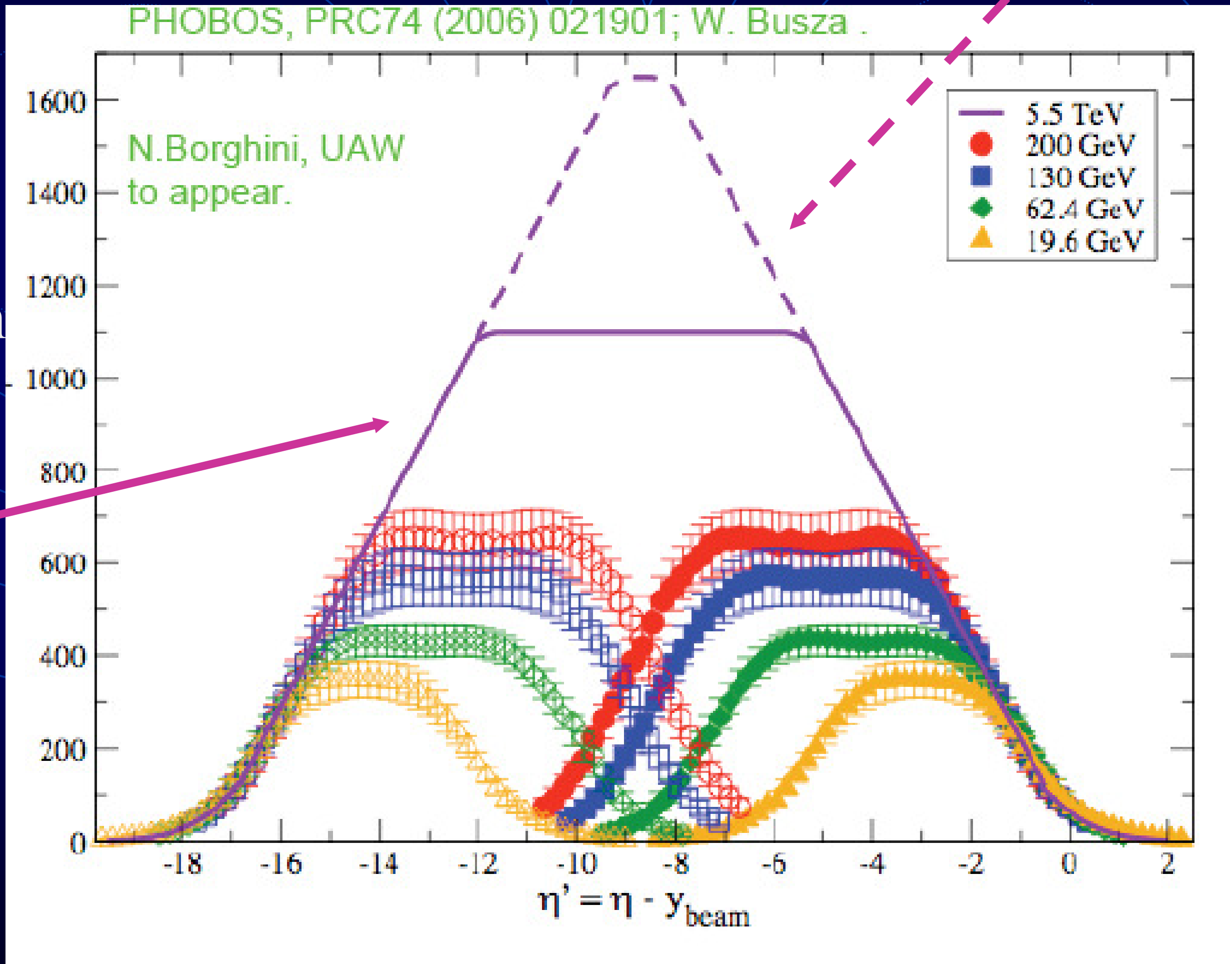

Scaling in participants!

Nuclear geometry determines basic characteristics!

# What can we expect for LHC?

One (of many) models

Simple extrapolation



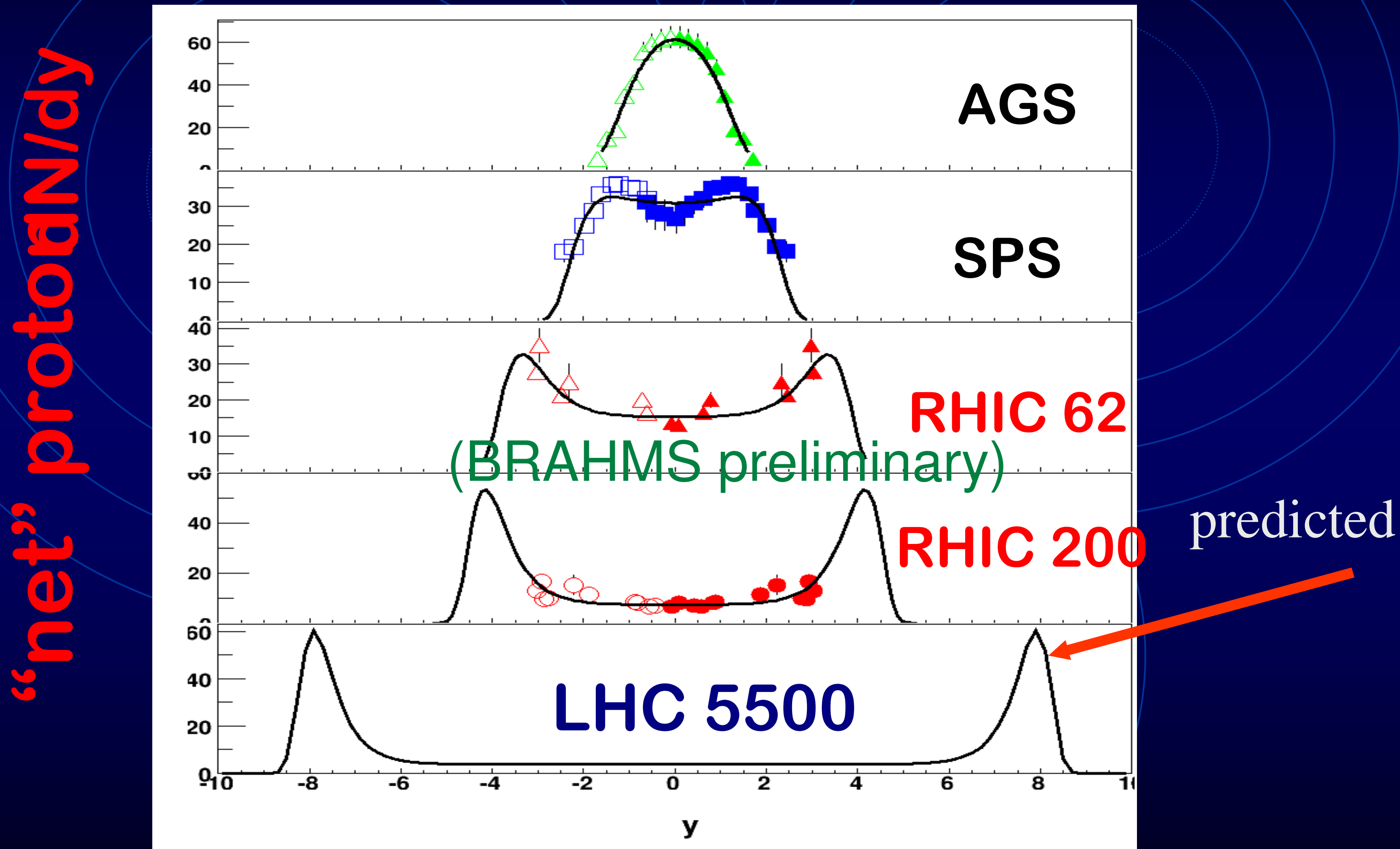
# Basics ctn`d: hadrochemistry

How many particles of different species?
Baryons – antibaryons?
Non-strange, strange, charmed?

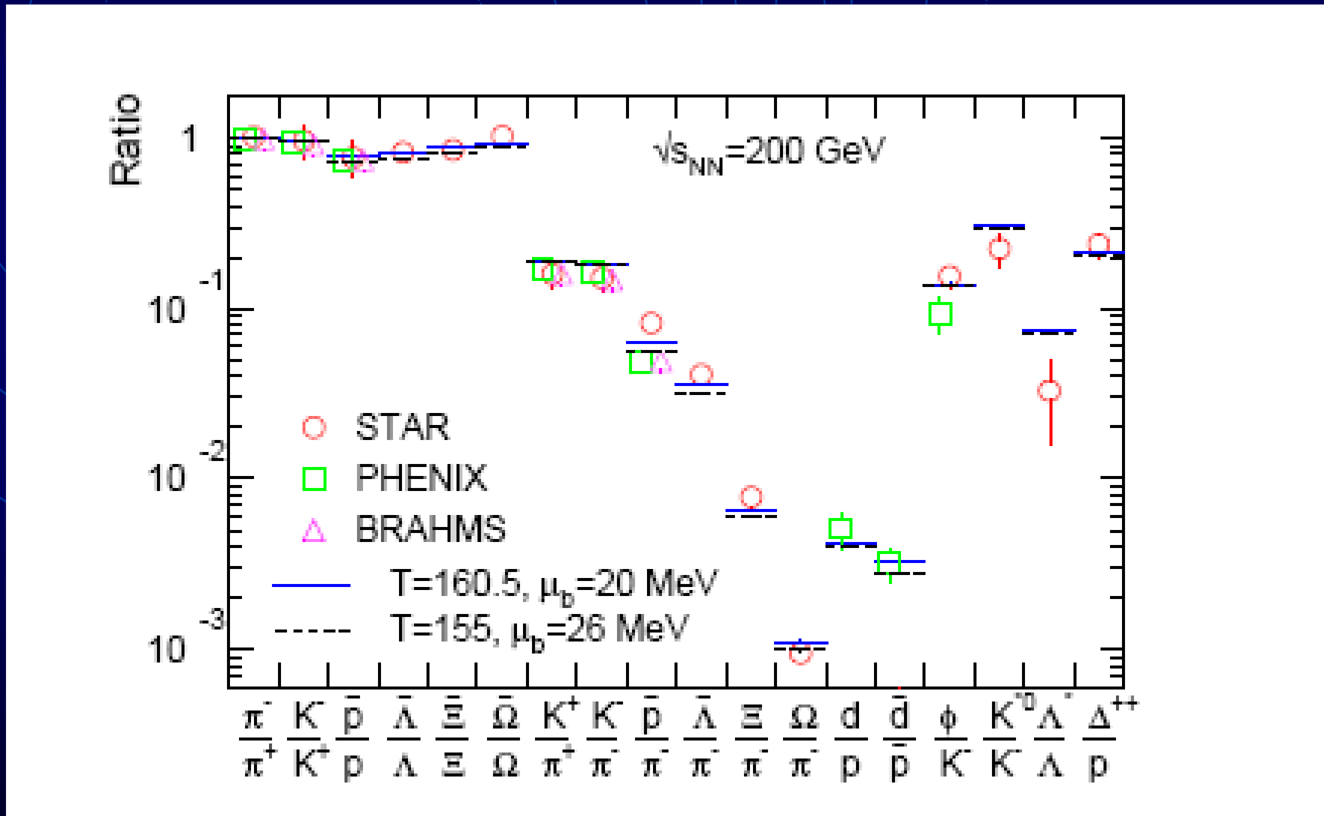
Here come thermodynamical models
Nb of particles determined by two parameters
baryon density $\mu$, temperature T

Temperature – from transverse spectra
Baryon density (net baryons!) – can count them
(and determine the radius of a fireball
from quantum interference effects)

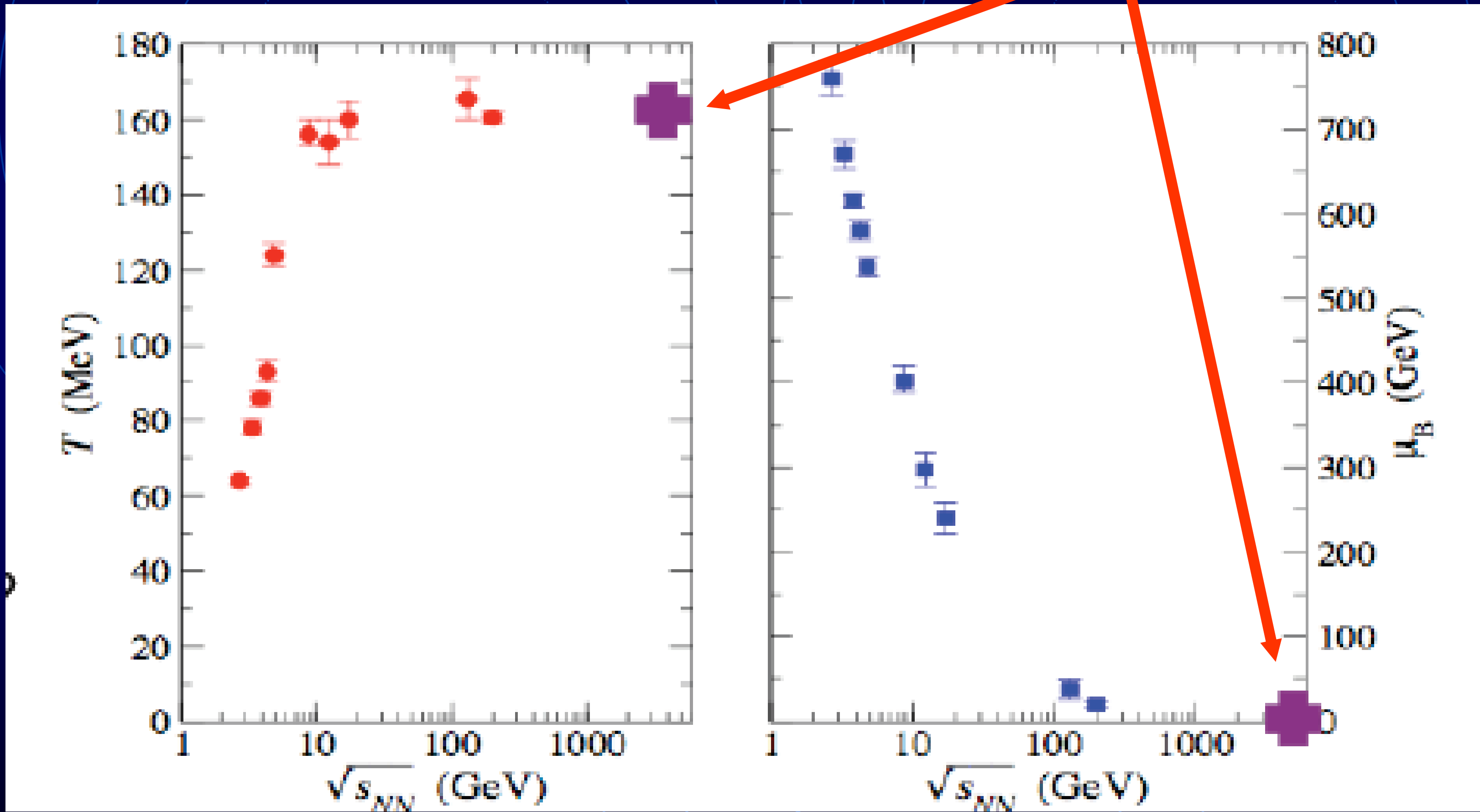
# Counting – and predicting net baryons:



# Thermal models work at RHIC:



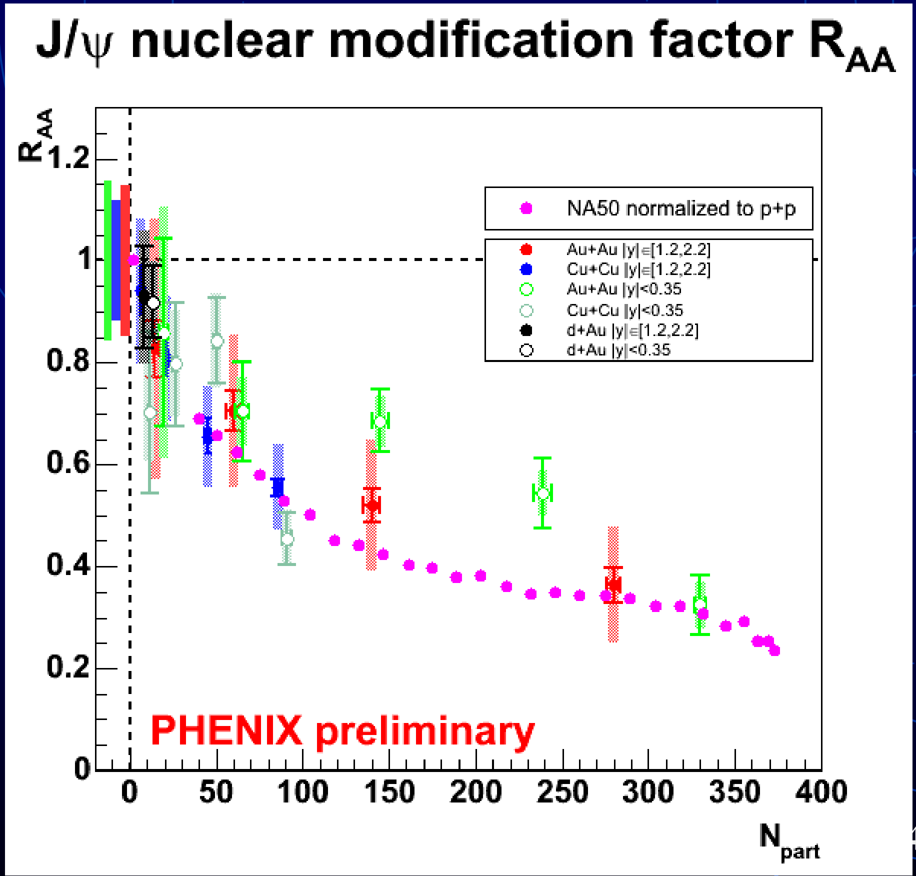
# Baryon density and temperature predictions for LHC:



# Heavy flavor story: strangeness, charm

Strange particles more abundantly produced in nuclear collisions
But real news come from charm:

*J/ψ is charm–anticharm pair*

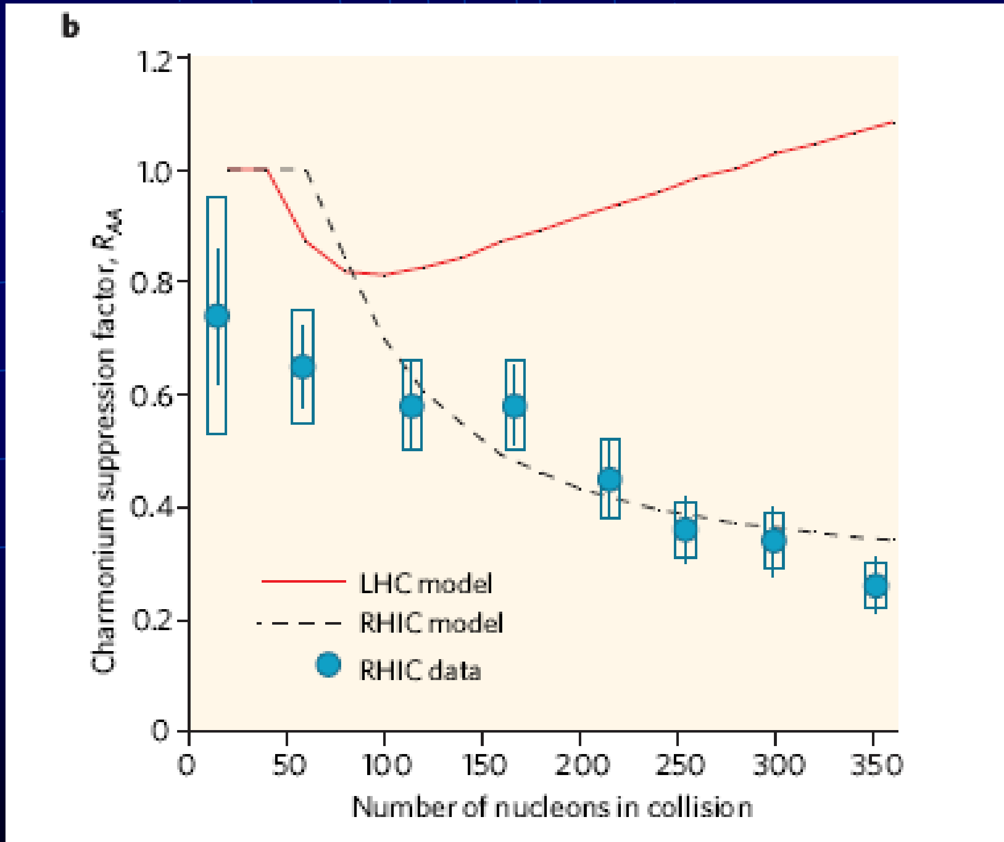



It is suppressed (compared to production in pp) (main SPS discovery)

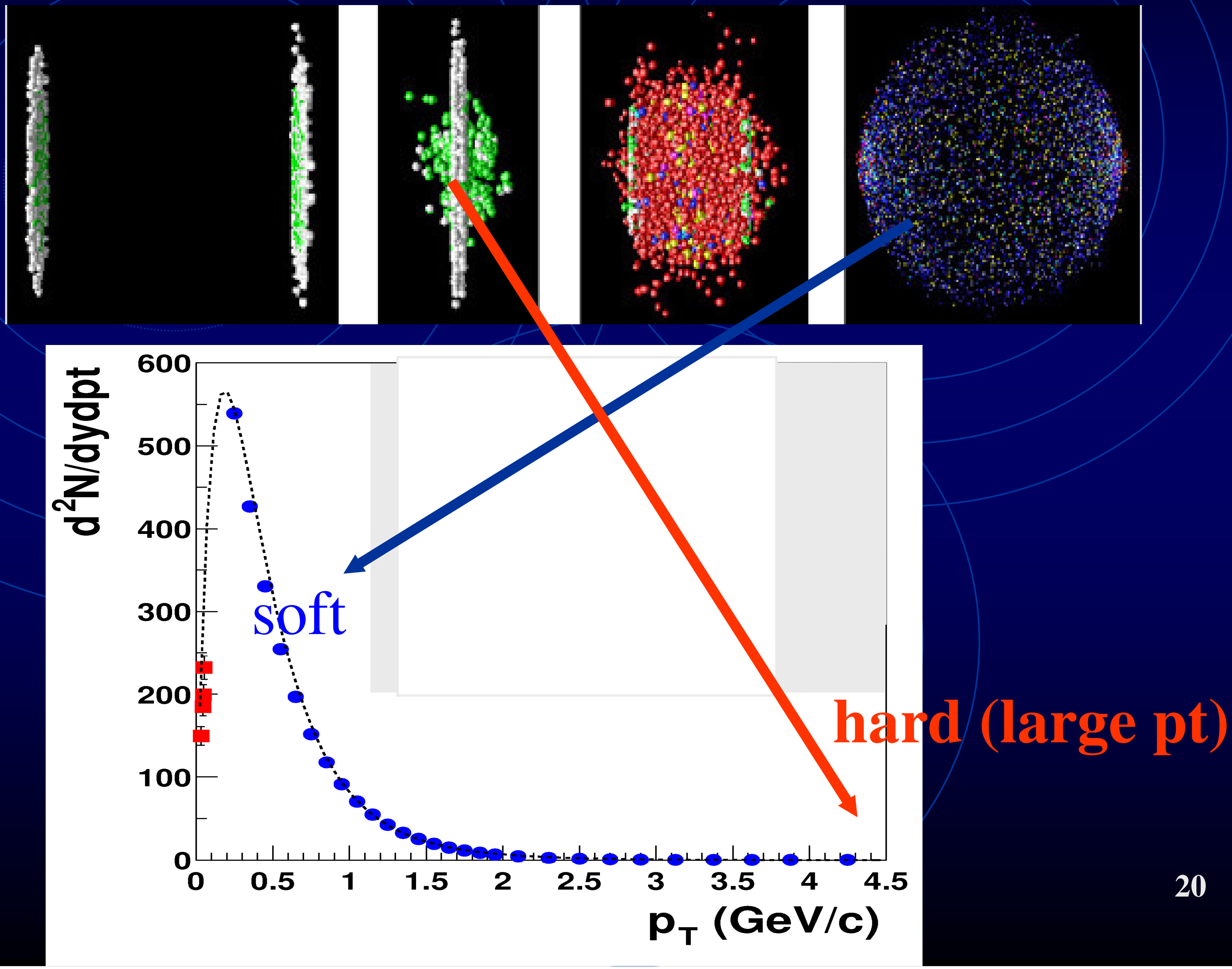
Why?
Presumably – hot & dense nuclear matter (is it plasma?) 'melts' the charmonium

# Will J/Ψ 'melt' more (be more suppressed) at LHC?

Not necessarily so...



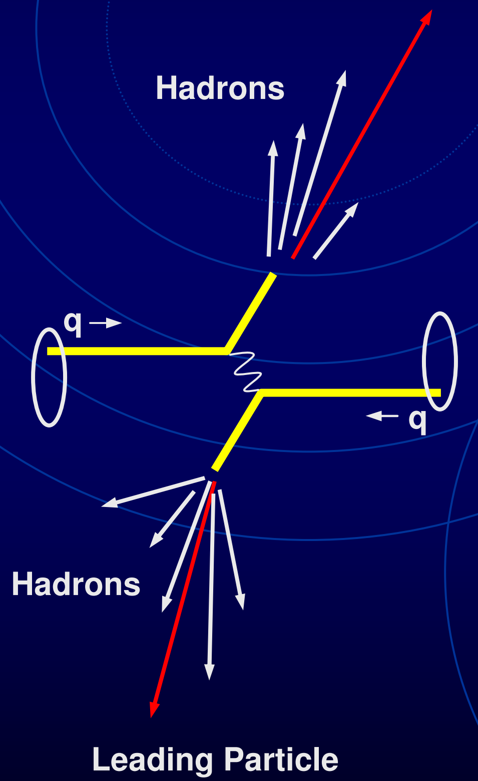
# Now for the hard stuff: jets



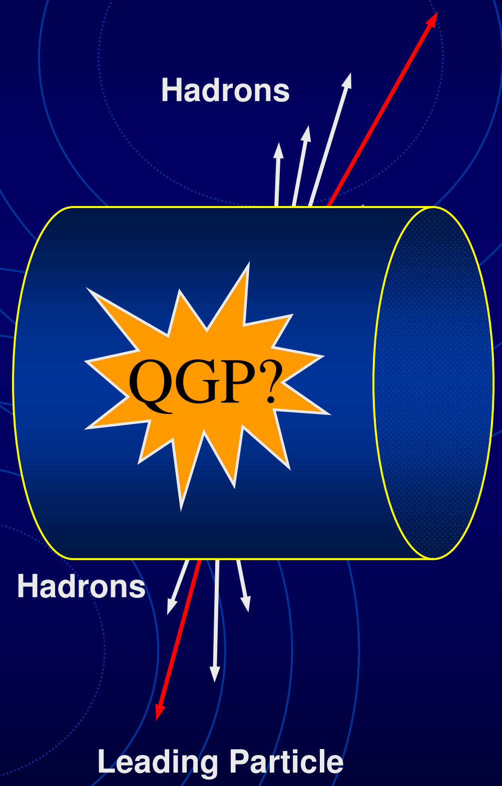
# Jets from pp and AA:

Study of jets: study of large $p_T$

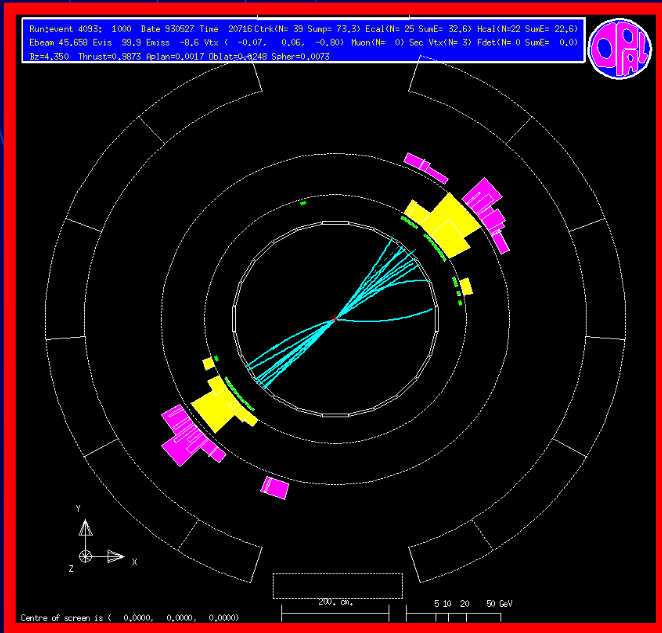
Direct probe
of partonic phase $\tau \sim 1/p_t$



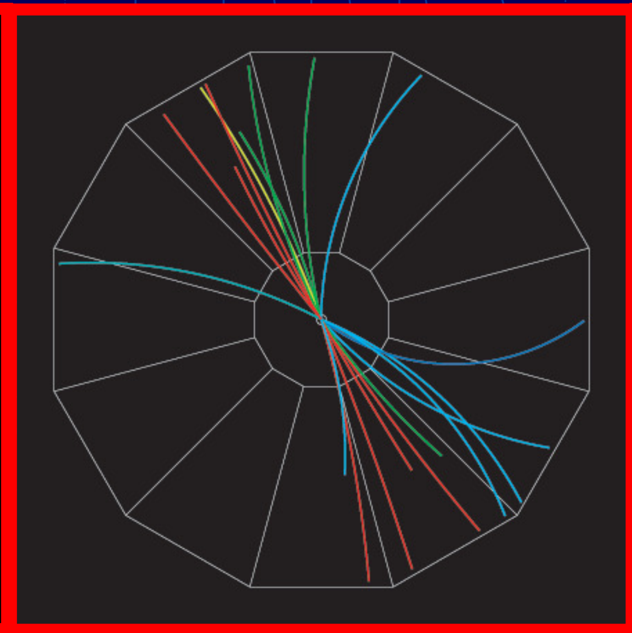

$p$



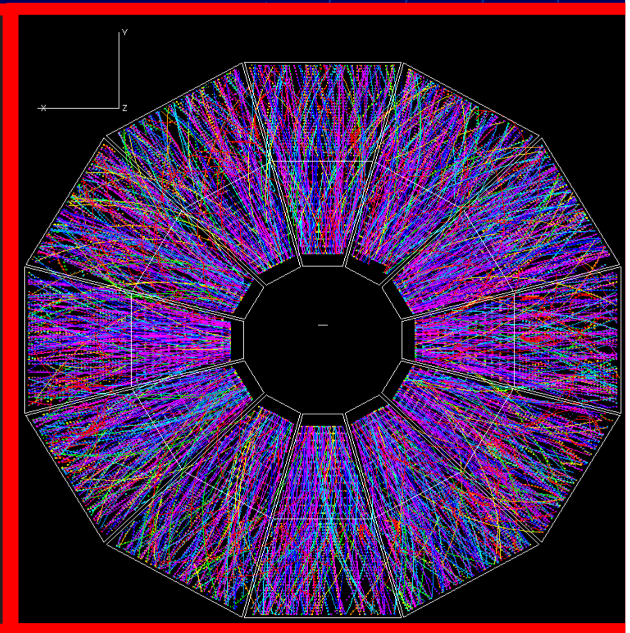
# How to study jets:




$e^+ + e^- \rightarrow$ jet + jet

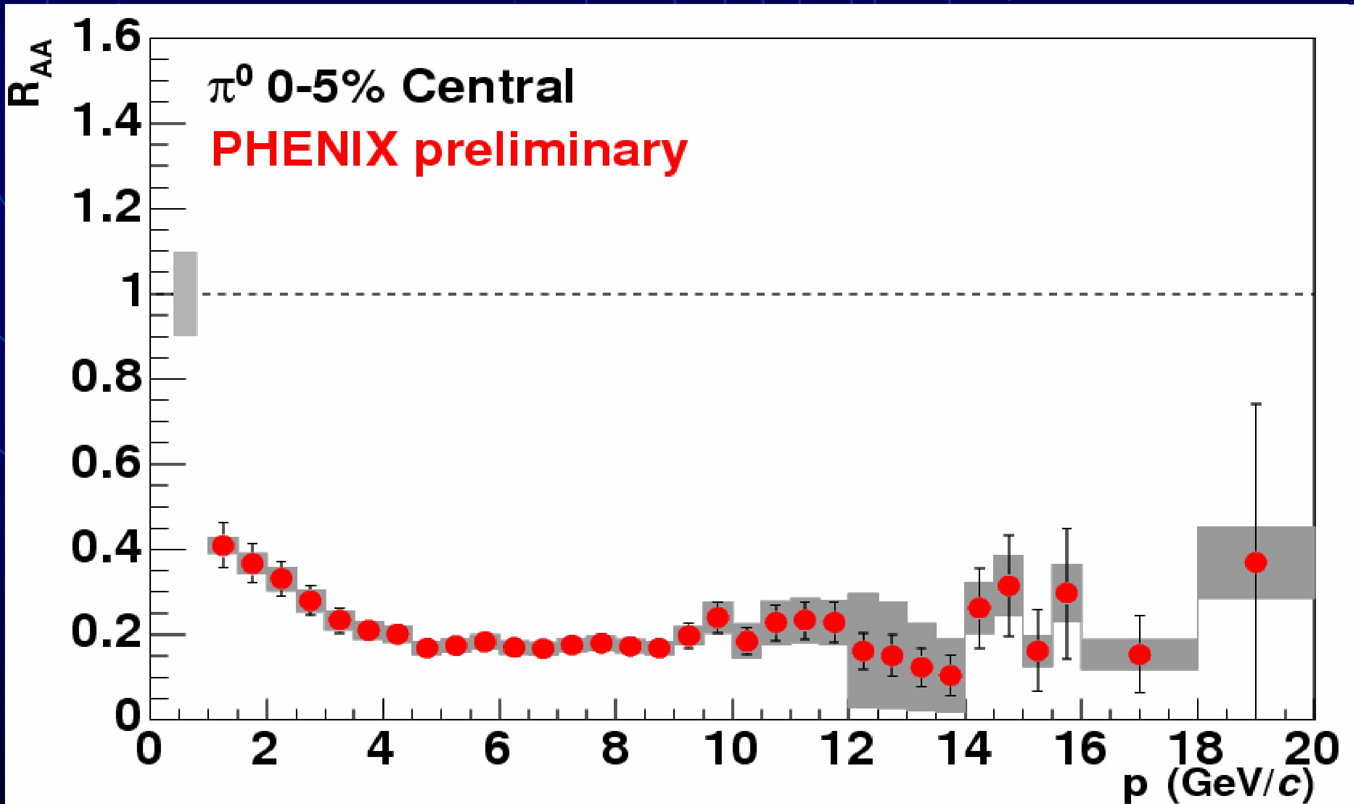


$p + p \rightarrow$ jet + jet

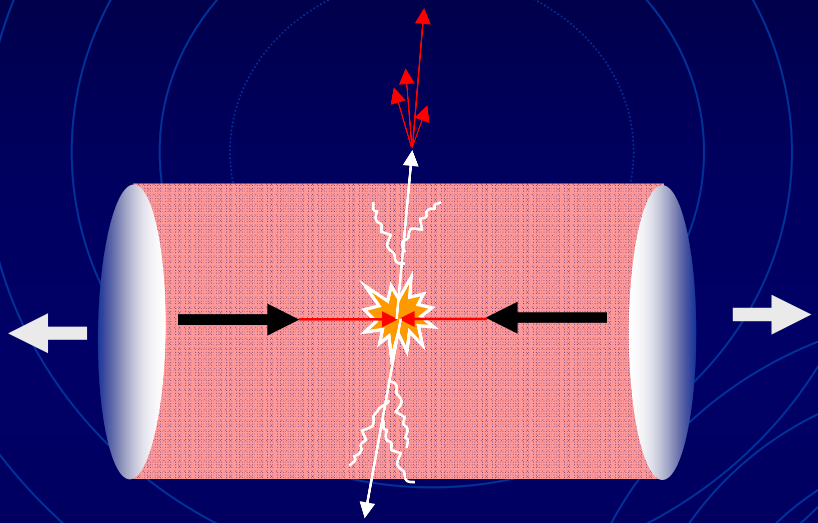


Au + Au $\rightarrow$ stuff + jet + jet

# Compare large pt spectra for pp and AA (scaled by number of collisions):



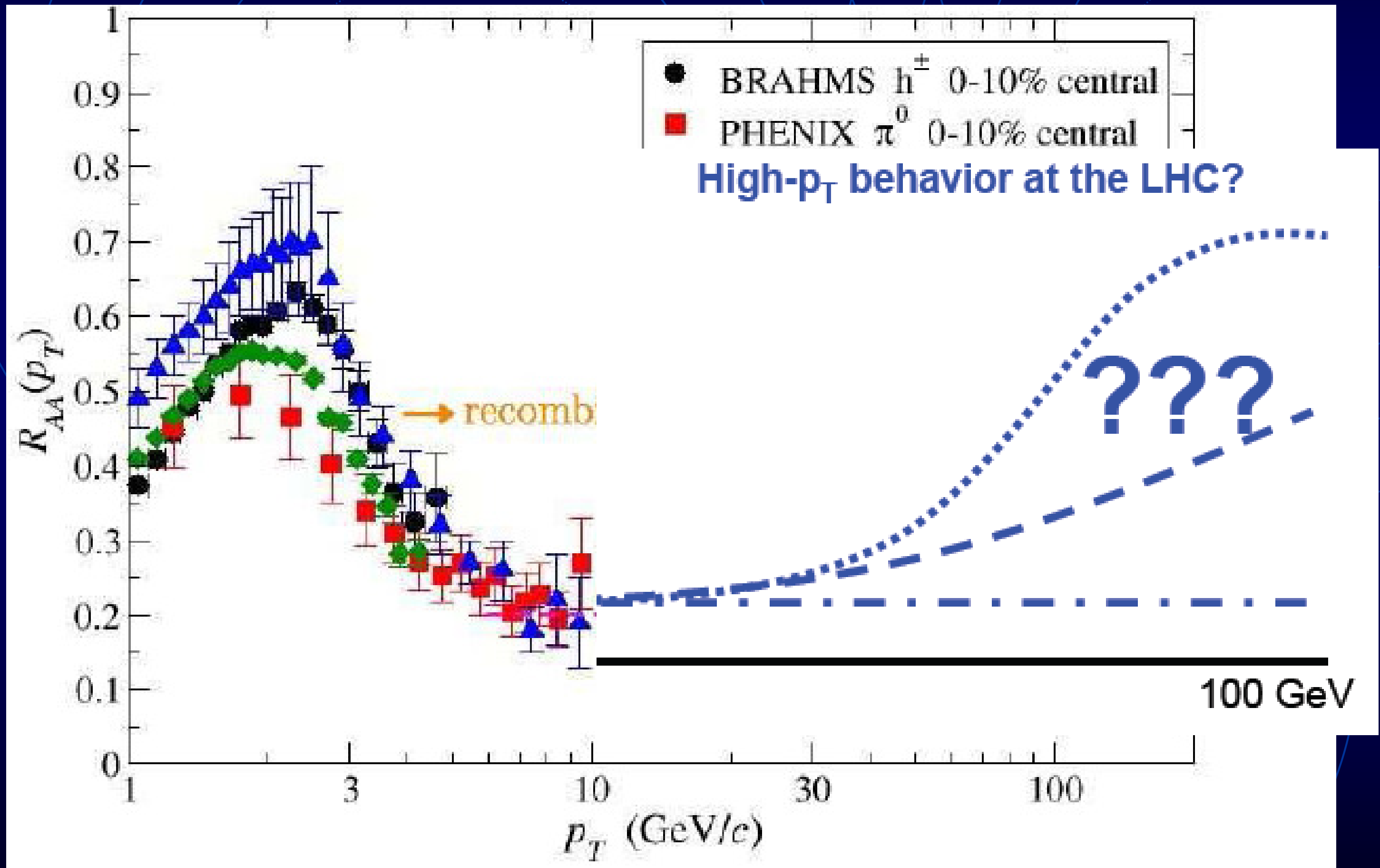
# What is 'jet quenching'?



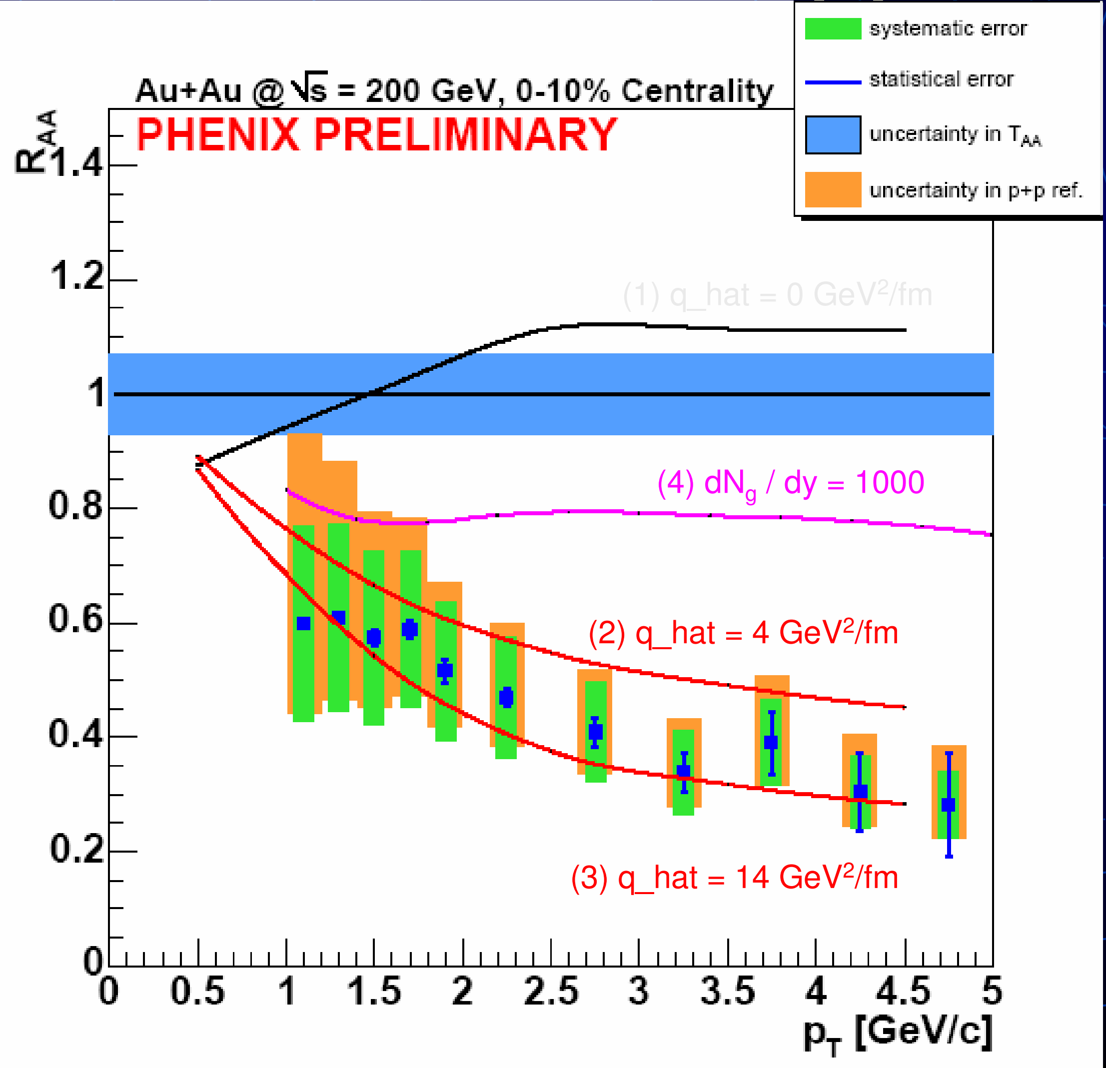
Radiation energy loss
by high energy partons
moving in a
dense partonic medium

High gluon density requires deconfined matter
 - 'indirect' QGP signature

# LHC will extend considerably the $p_t$ range:



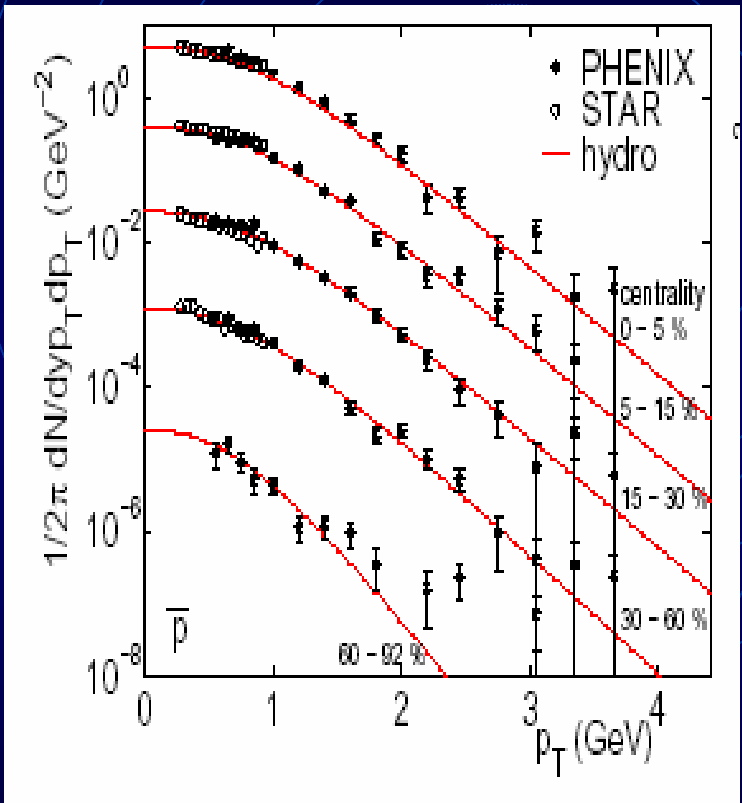
# Even charmed particles suppressed



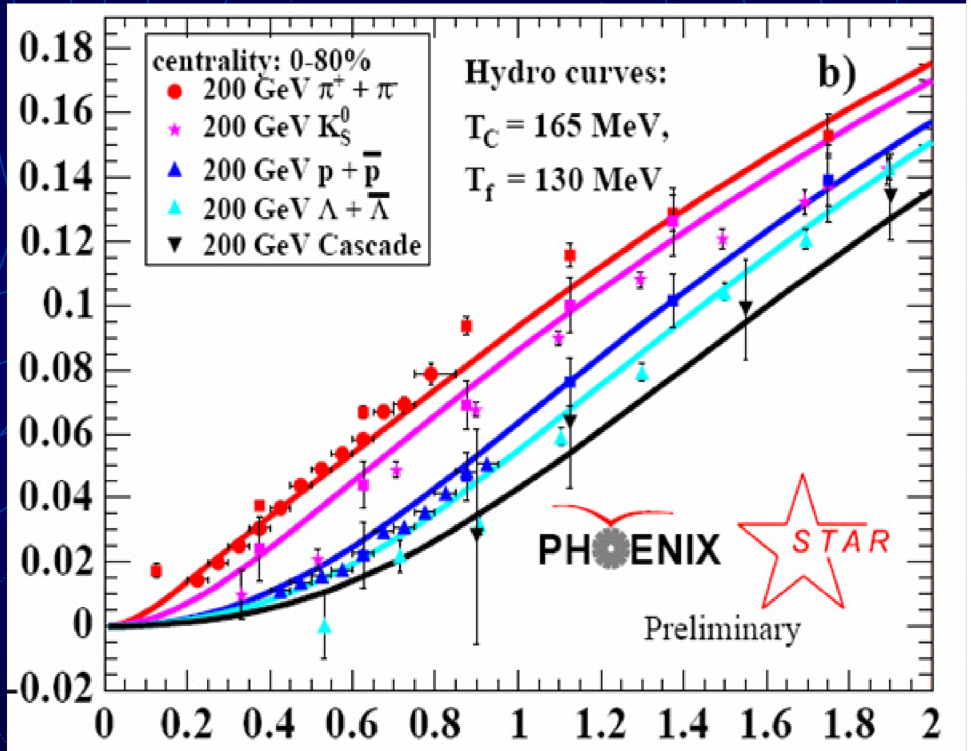

The data suggest large c-quark-medium cross section;
evidence for strongly coupled QGP?
(not a gas of free-flowing quarks and gluons)
More evidence for QGP as a 'perfect liquid' comes from azimuthal correlations
- particles flow

# First time hydrodynamics without any viscosity describes heavy ion reactions.

Transverse spectra




'Flow' – azimuthal correlation




Thermalization time t=0.6 fm/c and $\varepsilon$=20 GeV/fm$^3$

'Plasma' – an ideal liquid?

# Heavy ions at the LHC: ~2 years after pp
# 5.5TeV Pb + 5.5 TeV Pb

One dedicated experiment, ALICE, but CMS and ATLAS also

- The first 15 minutes; $L_{int} = 1\mu b^{-1}$
  - Event multiplicity, low $p_t$ hadronic spectra, particle ratios
- The first month; $L_{int} = 0.1 - 1nb^{-1}$
  - Rare high $p_t$ processes: jets, D and B particles, quarkonia, photons, electrons
- The following years:
  - pA, A scan, E scan

# Progress/summary:

- from “oh wow!” **(SPS, RHIC)**
  - we have found a surprising new form of matter

(certainly partonic, but not ‘soup of free quarks & gluons’
rather – ‘perfect liquid’

- to “aha!”
  - here is how it works
  - how QGP relates to and helps progress in other fields

**Hopefully - LHC**



(quotation from Barbara Jacak, one of the leaders in QGP search)