Energy dependence of hadron production in nuclear collisions

and

the Nuclotron energy range

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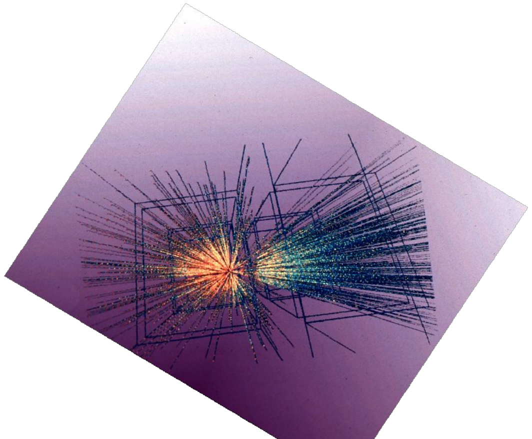
- Introductory remarks
- Energy dependence of hadron production
- The Nuclotron energy range
- Summary



Dubna, July 2005

Introductory remarks

Two basic questions driving physics of high energy nuclear collisions:

What are the phases of strongly interacting matter?

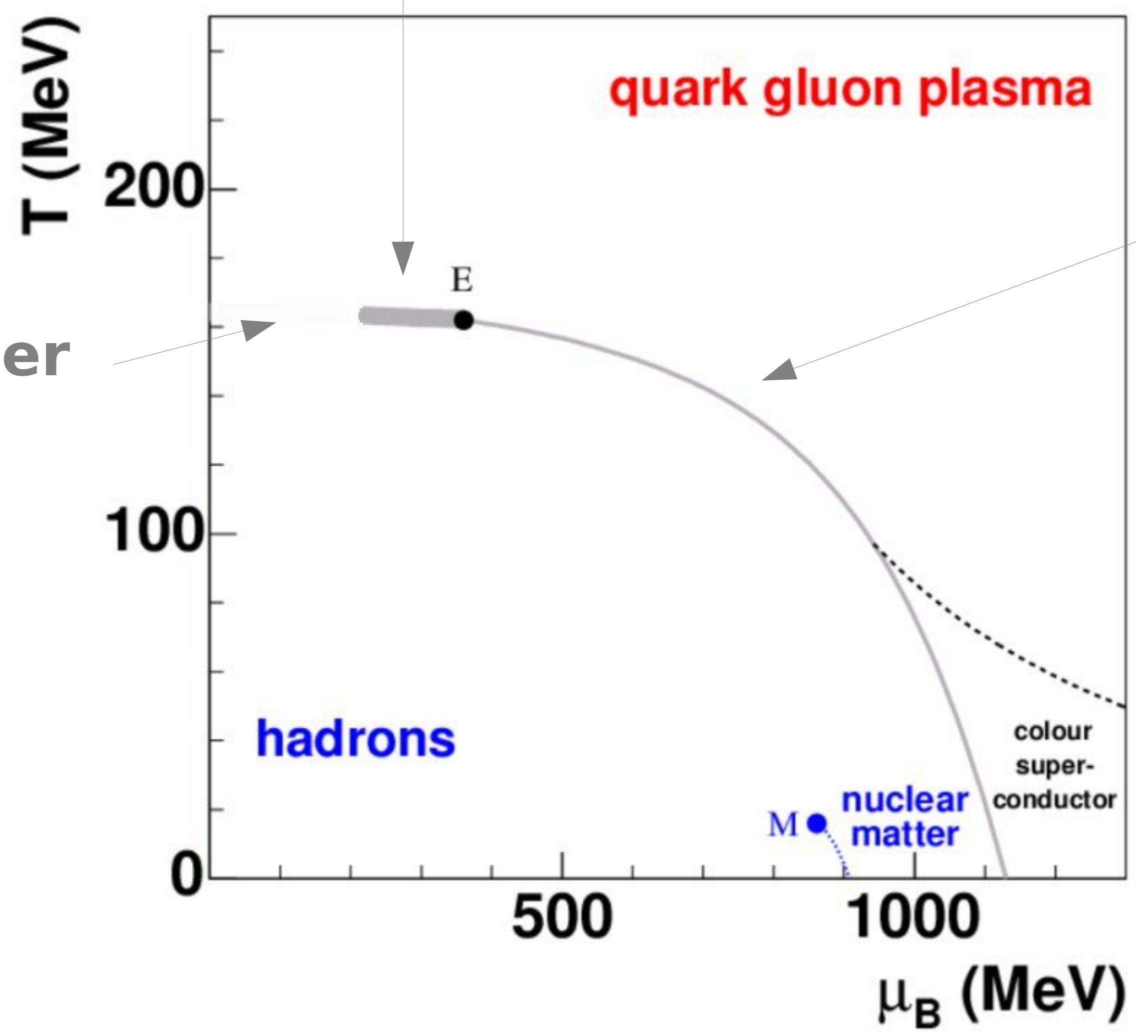
How do the transitions between them look like?

Schematic phase diagram of strongly interacting matter

2nd order PT
(the critical line)

3rd and higher order PT

1st order PT

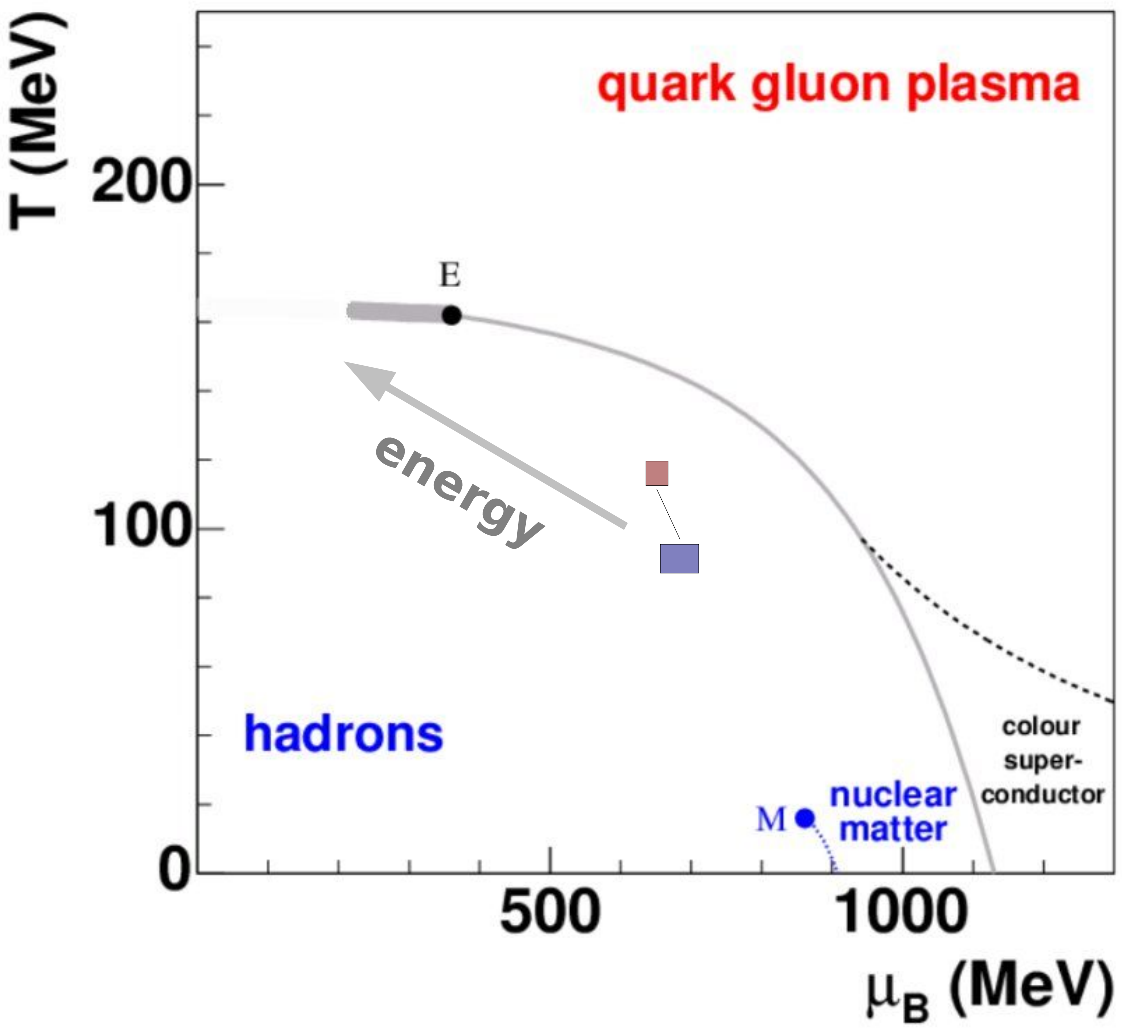


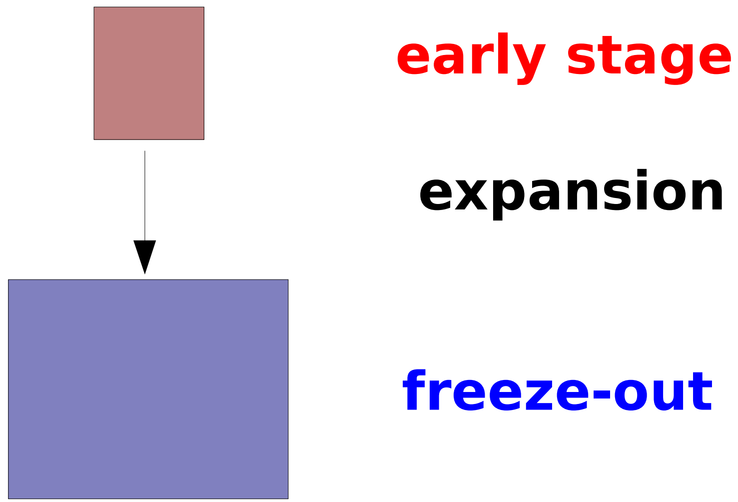
…

…

Gorenstein, M.G., Greiner

... and nucleus-nucleus collisions



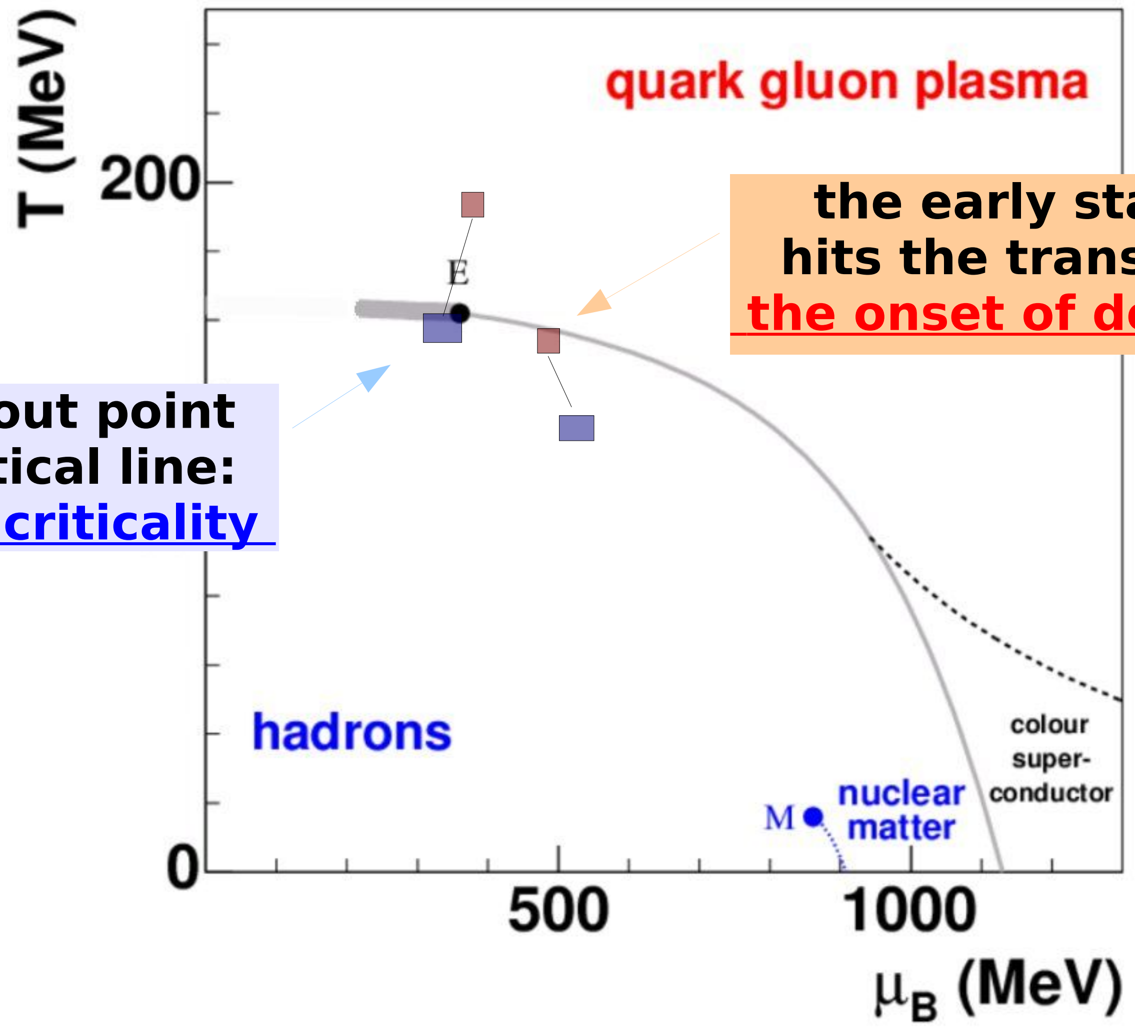


Two basic problems:

Understand mechanism(s) of equilibration in high energy nuclear collisions

Develop and test statistical mechanics of relativistic strongly interacting particles

two possible distinguished trajectories in the energy dependence



the early stage point hits the transition line: the onset of deconfinement

the freeze-out point hits the critical line: the onset of criticality

A+A physics vs collision energy

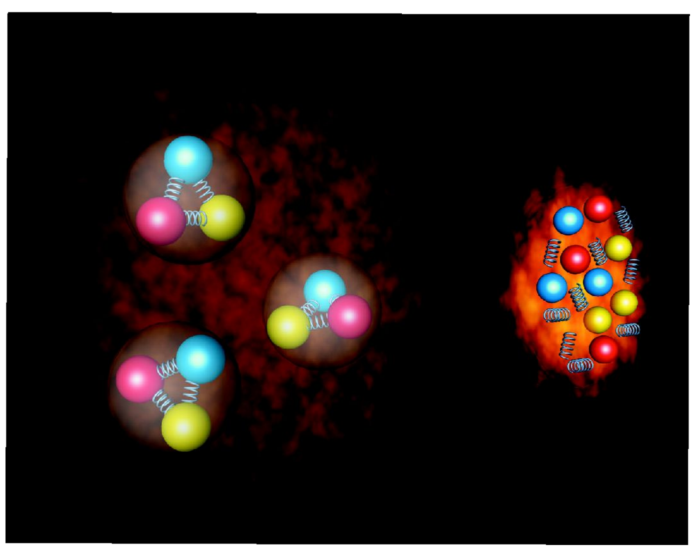
the onset of
deconfinement

dense confined
(hadronic) matter

the onset of
criticality

dense QGP

ENERGY



**The primary goal:
a search for
the onset points**

Energy dependence of hadron production

Experimental landscape

Basic data

Pions and strange hadrons

Transverse mass spectra

Two-pion correlations

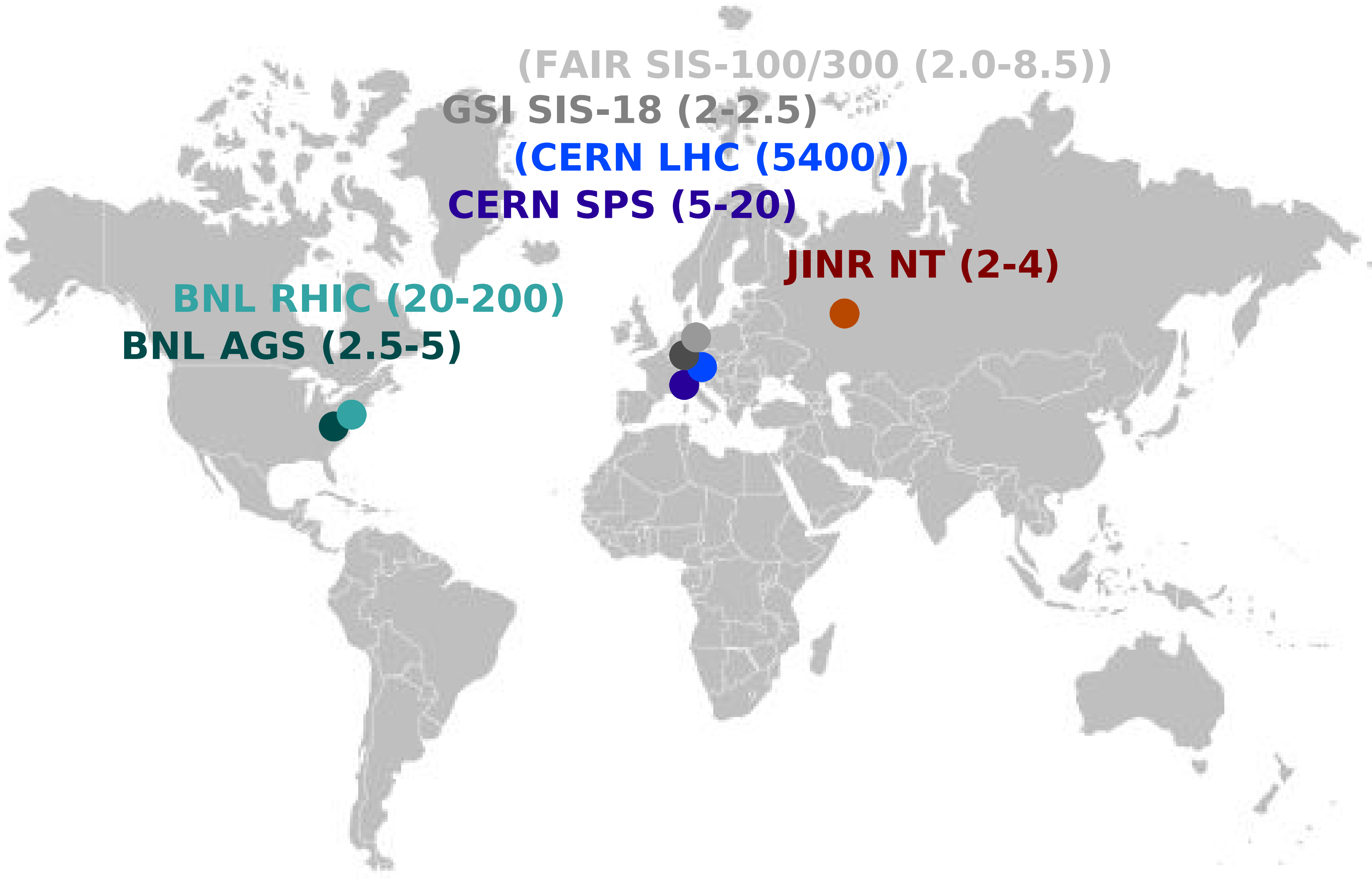
Anisotropic flow

Chemical freeze-out

Onset of deconfinement

Experimental landscape

Heavy Ion Accelerators



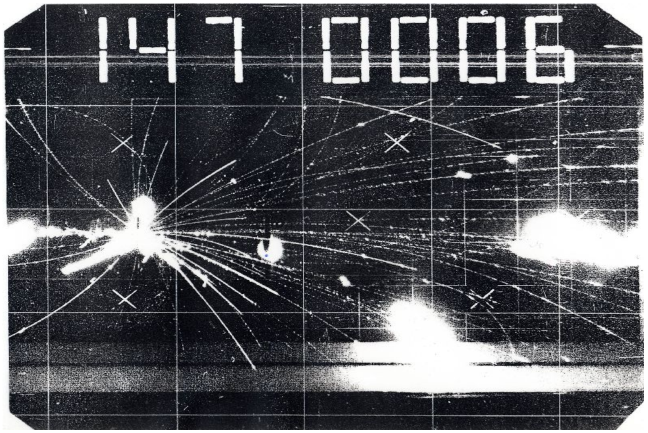
LAB ACC (center of mass energy per nucleon-nucleon pair in GeV)

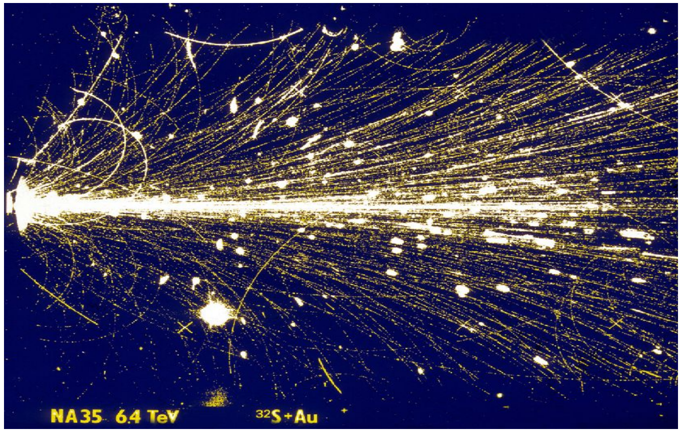
Heavy Ion Detectors

Examples of large acceptance tracking detectors:

before 1990 mainly streamer chambers:

LBL → JINR → CERN



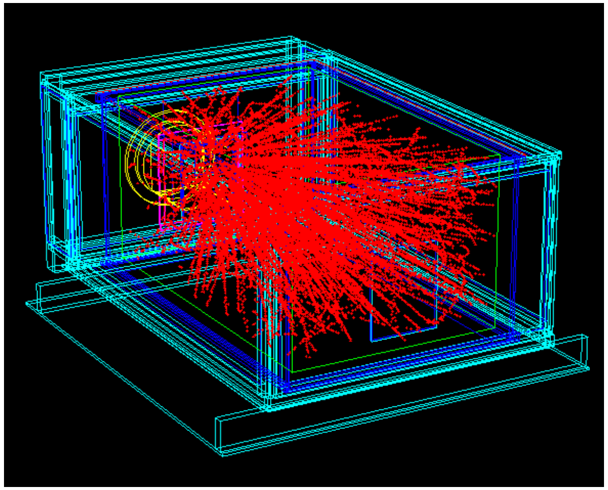


SKM-200

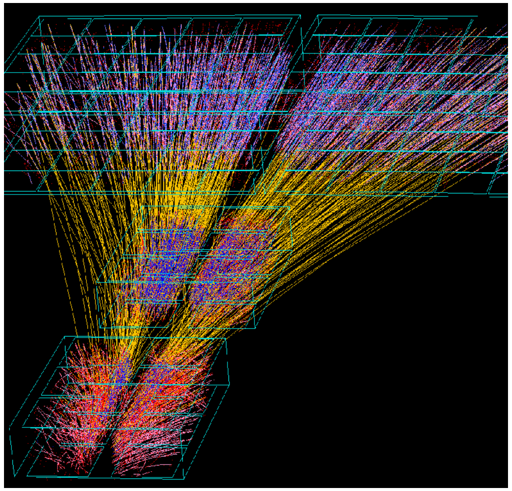
NA35

after 1990 mainly time projection chambers:

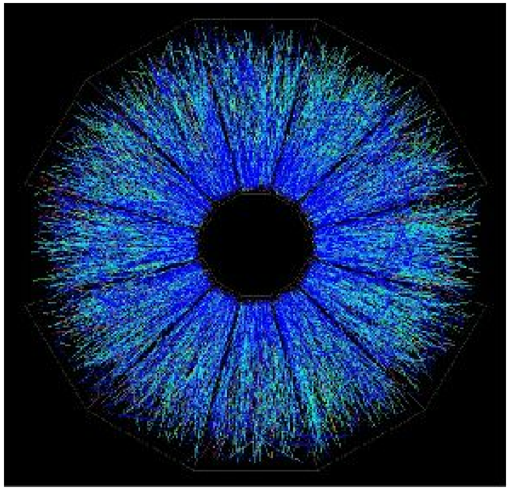
BNL AGS → CERN SPS → BNL RHIC



E895



NA49



STAR

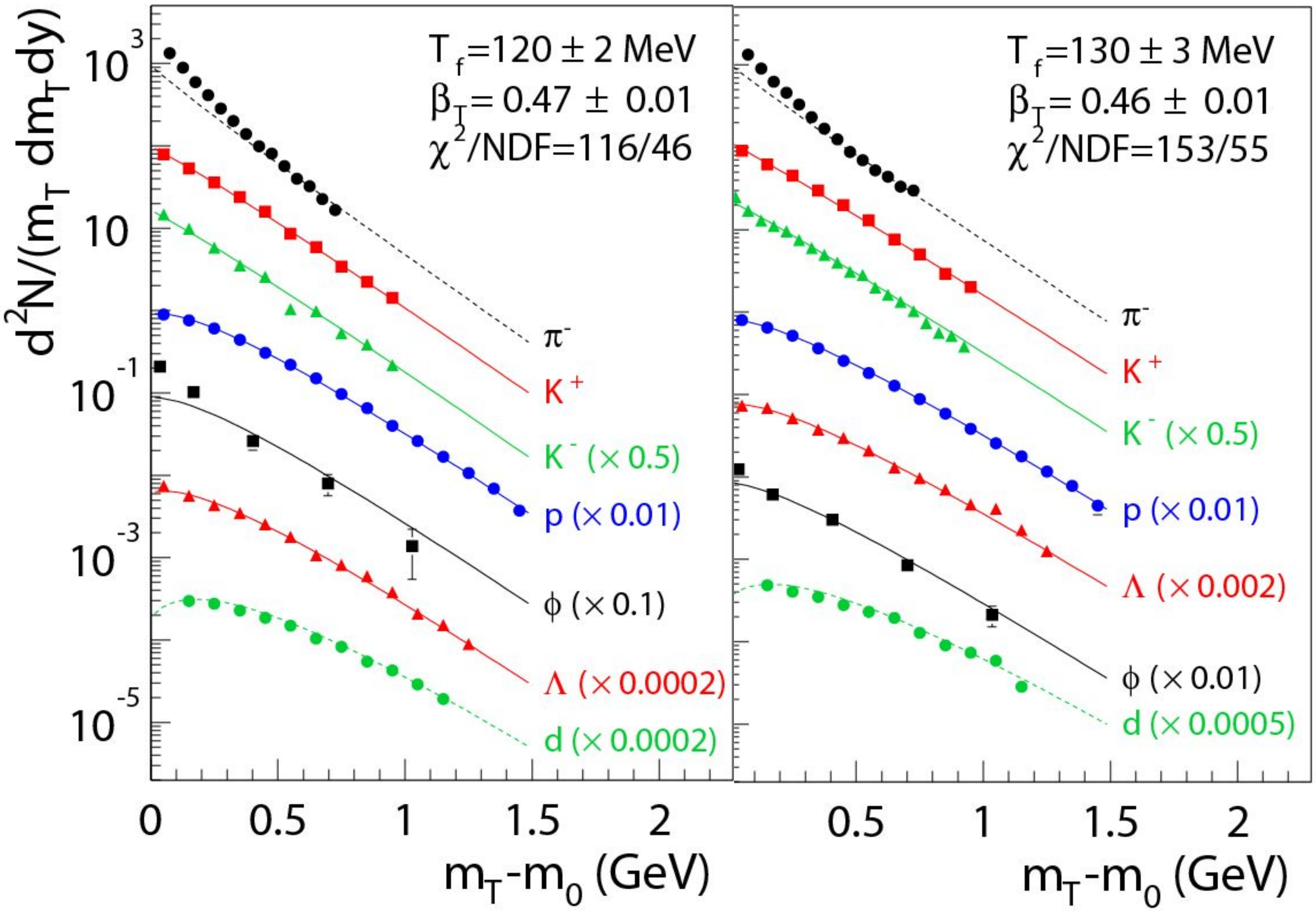
... and many, many other experiments

Basic data

Examples: transverse mass spectra

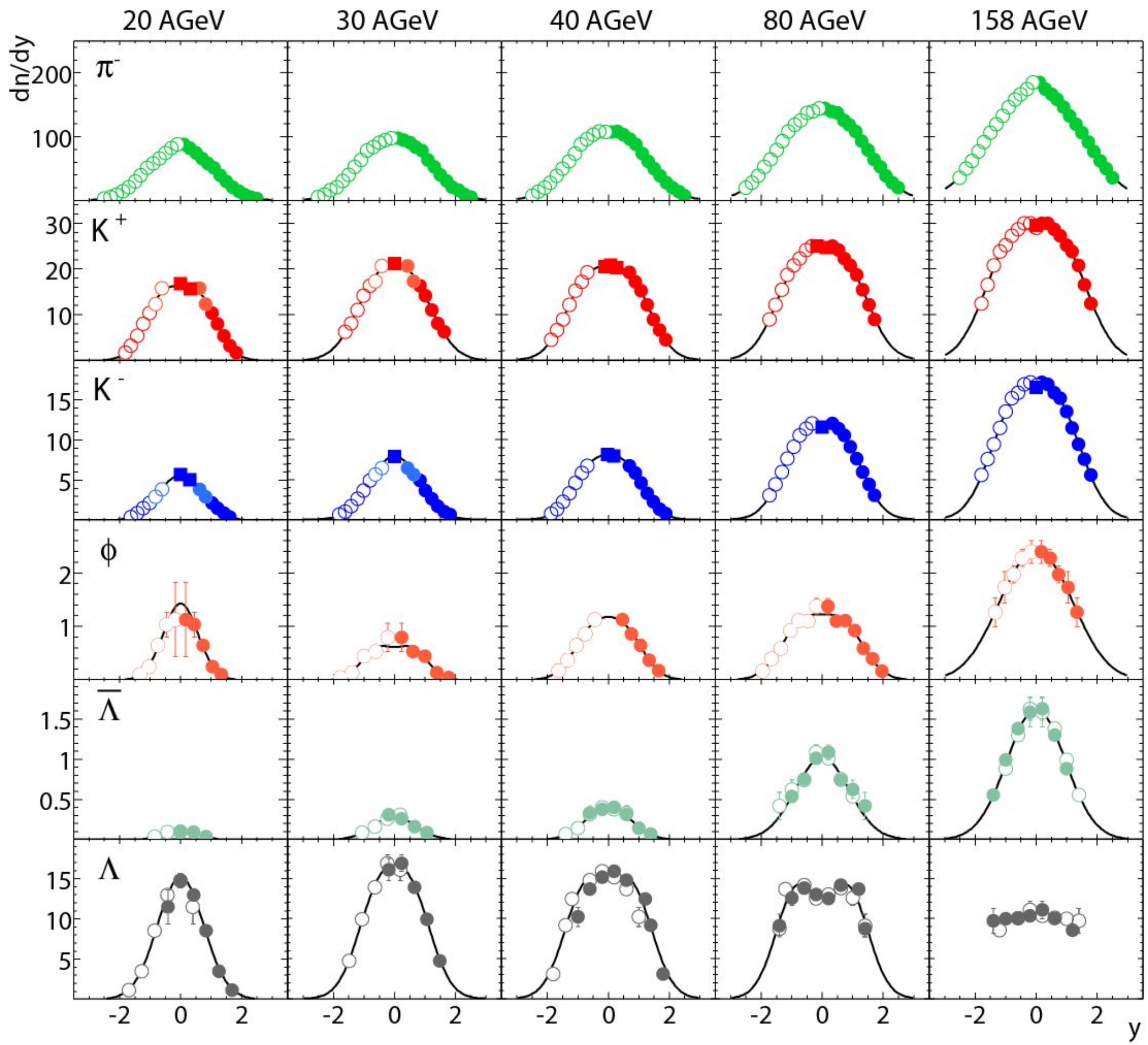
central Pb+Pb collisions

20*A* GeV 30*A* GeV



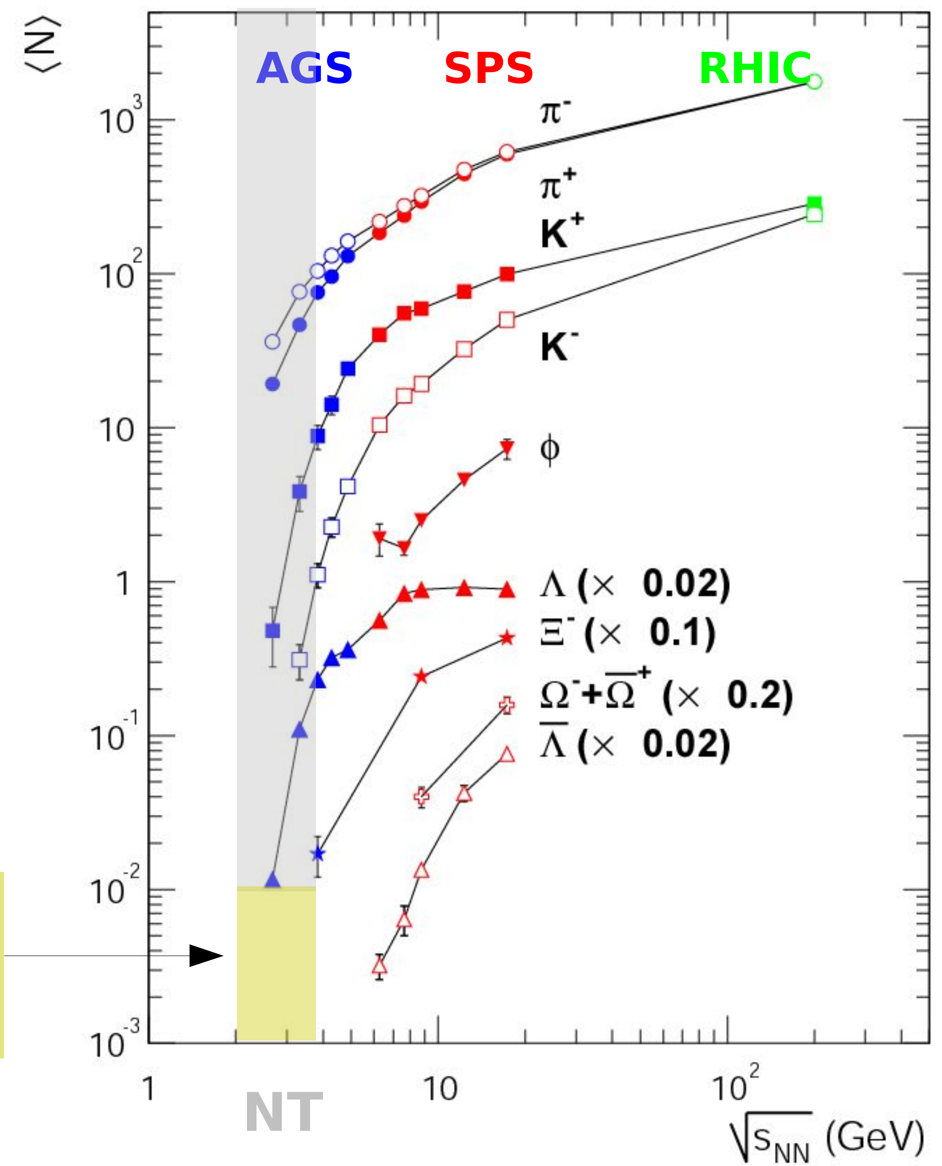
Examples: rapidity spectra

central Pb+Pb collisions



Examples: mean multiplicities

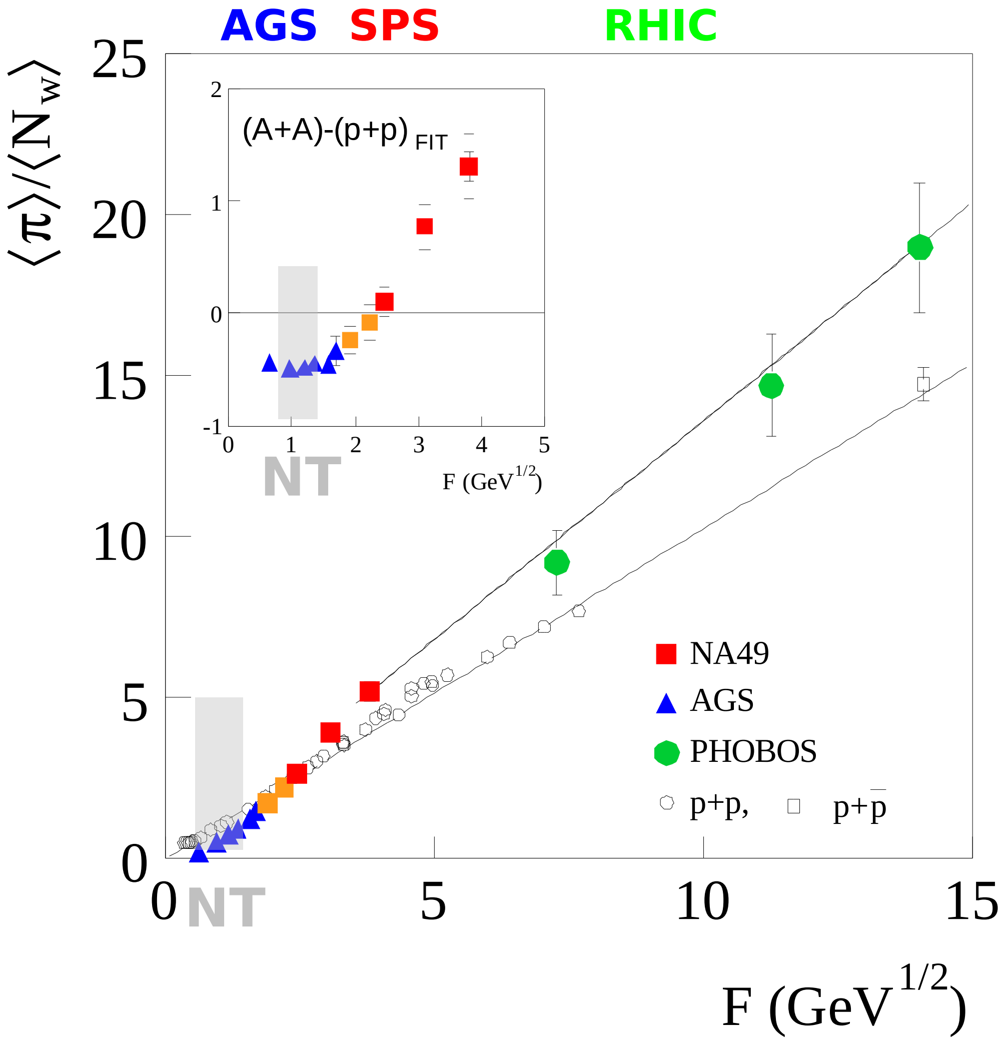
(central Pb+Pb(Au+Au) collisions)



missing data in the Nuclotron energy range

Pions and strange hadrons

Pion yield



central Pb+Pb (Au+Au) collisions

p+p

The kink:
a change from suppression to enhancement at ≈30*A* GeV

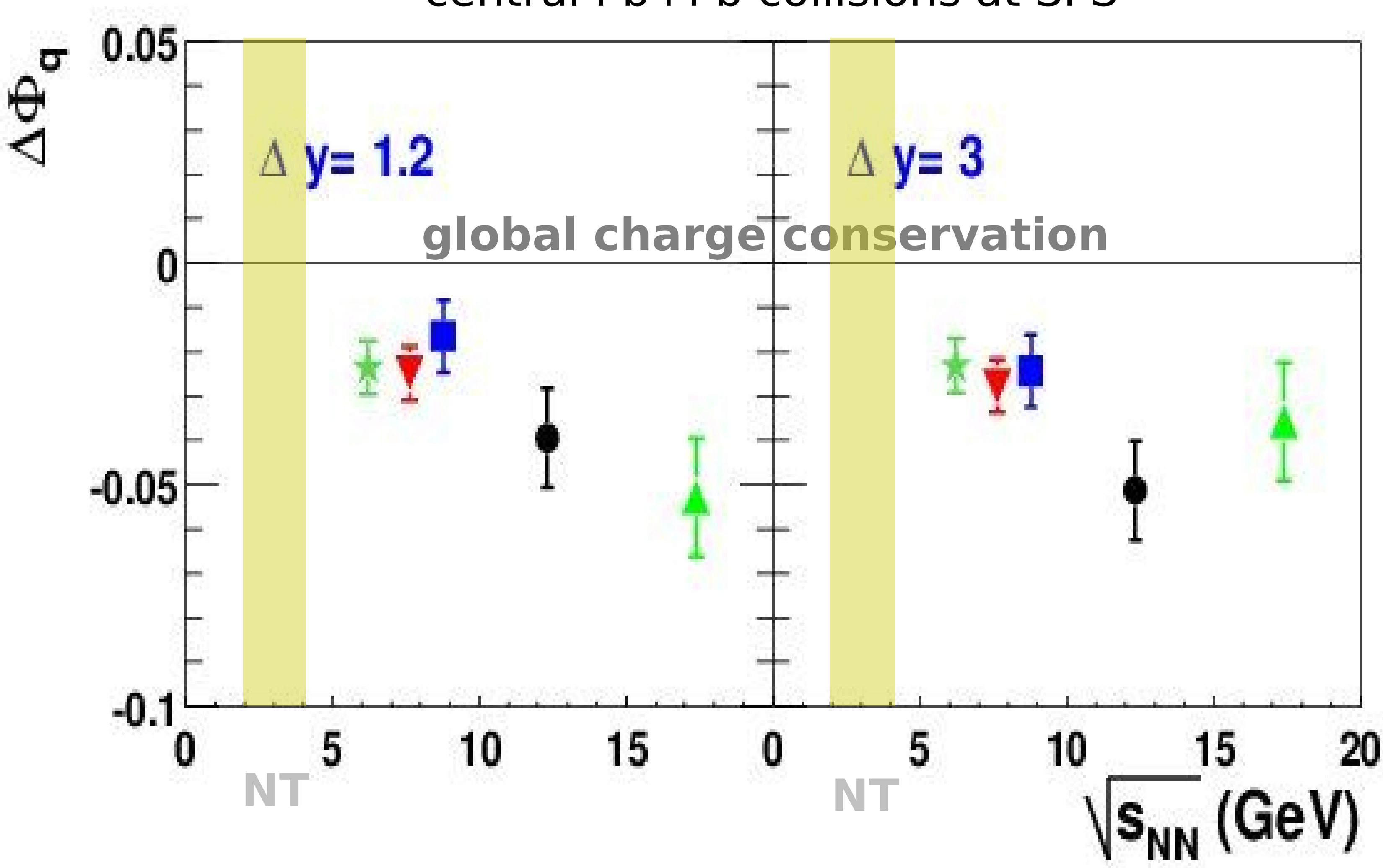
$F \approx \sqrt{\sqrt{s_{NN}}}$

$\langle \pi \rangle$ - total pion multiplicity

$\langle N_W \rangle$ - number of interacting nucleons

Electric charge fluctuations

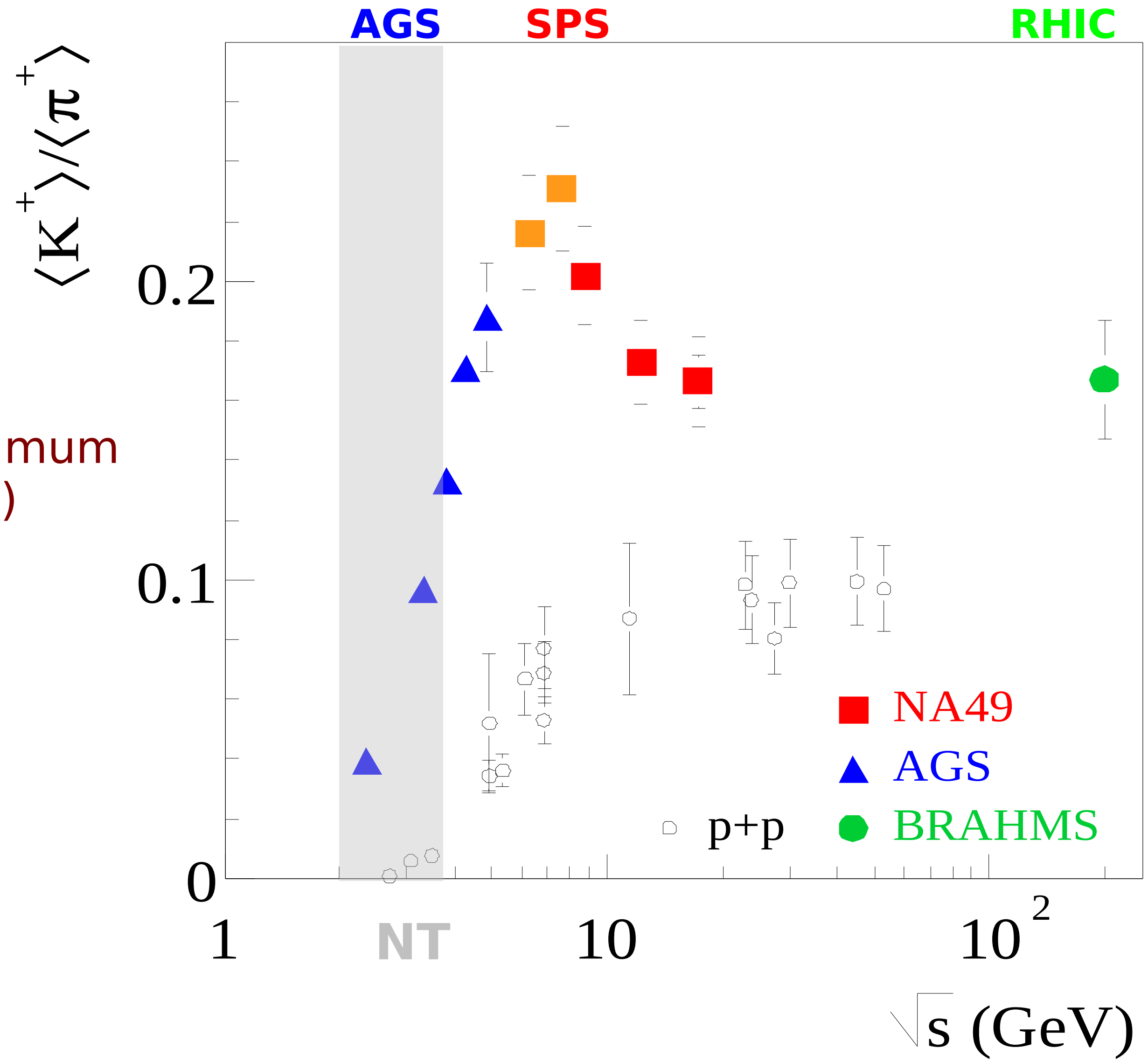
central Pb+Pb collisions at SPS



No significant suppression:
charge fluctuations are significantly increased by resonance decays

Relative strangeness yield

The horn
(a sharp maximum
 at ≈30A GeV)

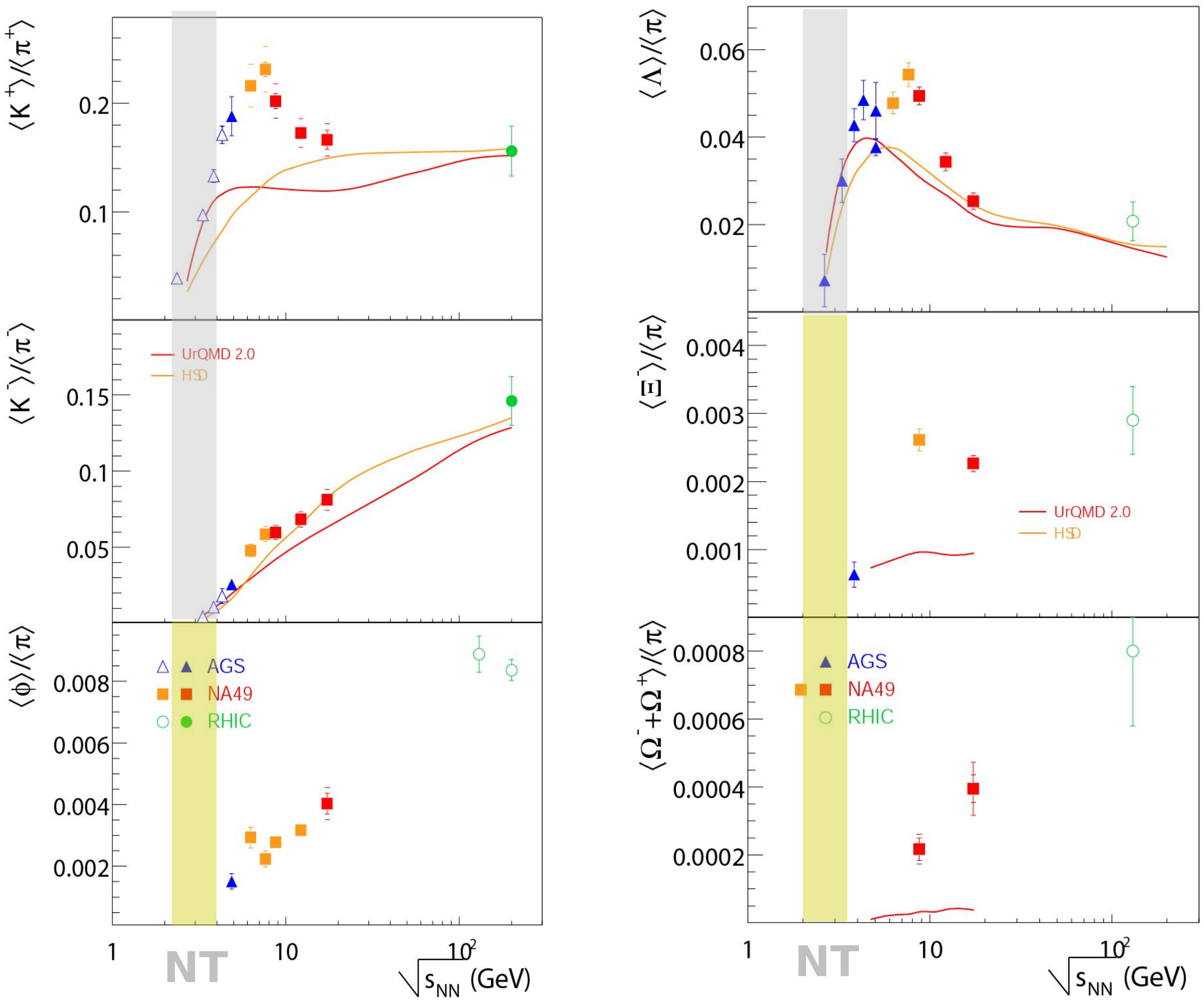


central Pb+Pb
(Au+Au) collisions

p+p

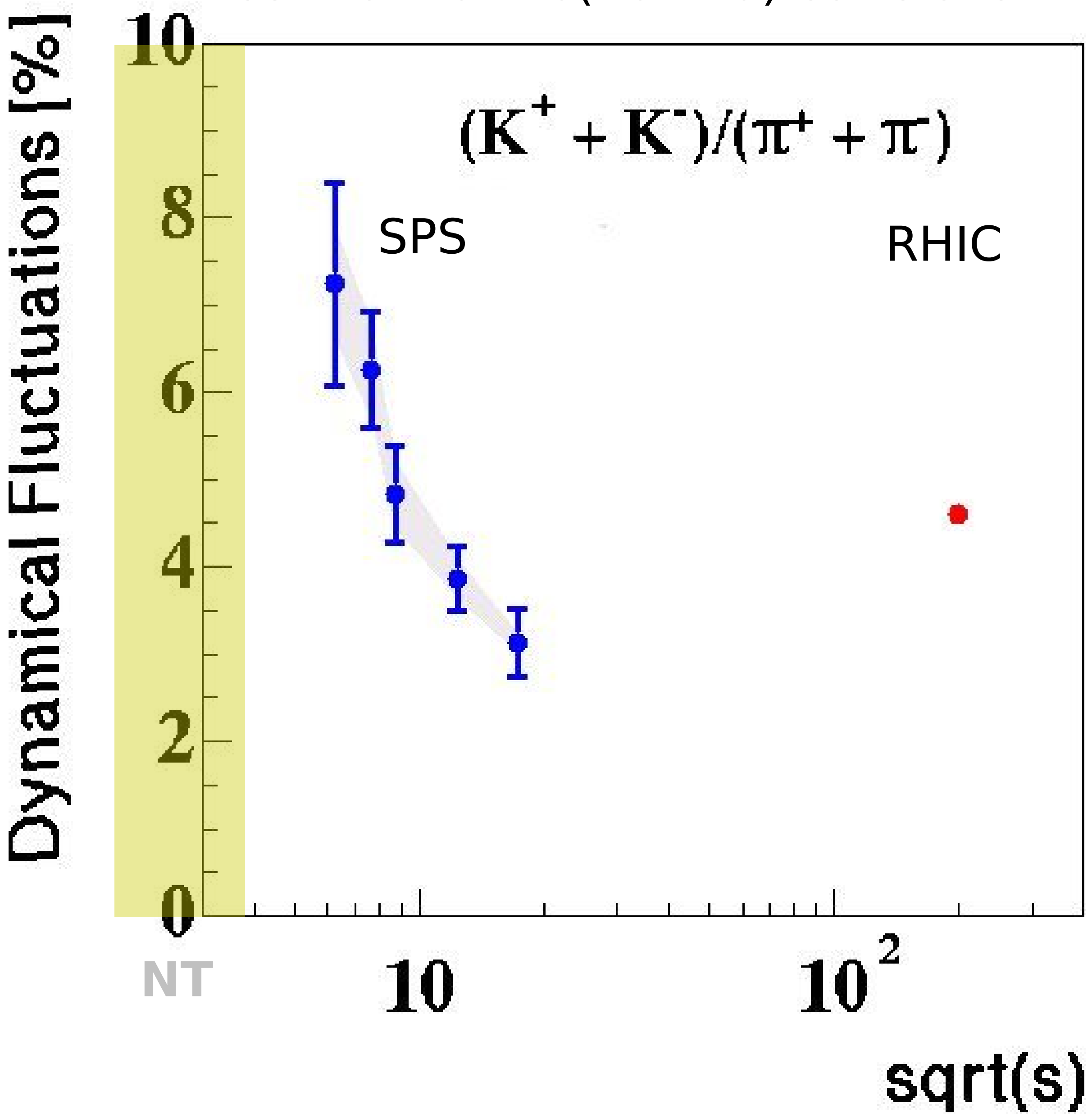
Relative strange hadron yields

central Pb+Pb(Au+Au) collisions



Fluctuations of the kaon to pion ratio

central Pb+Pb(Au+Au) collisions

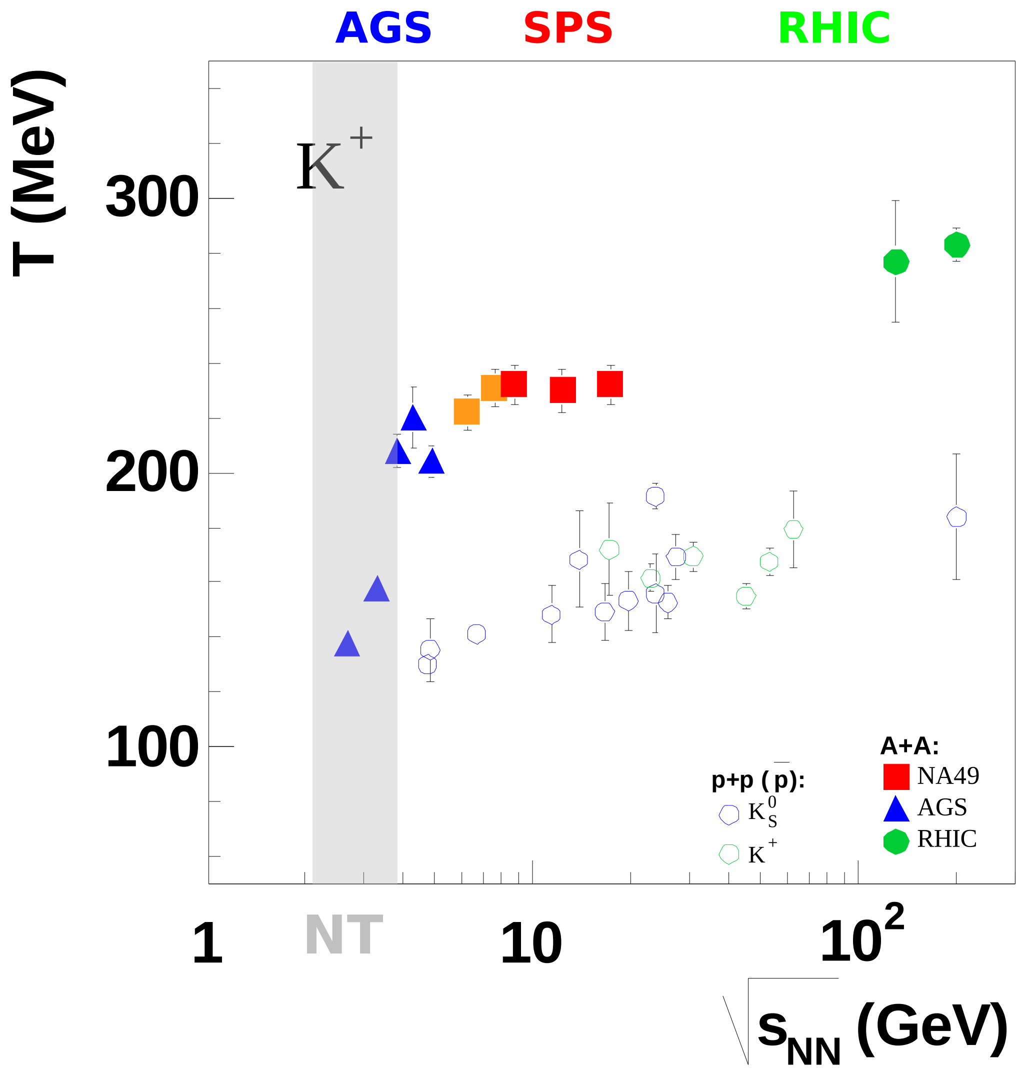


Soon many more results on energy dependence of fluctuations and correlations (multiplicity, transverse momentum, balance functions) at SPS and RHIC.

The corresponding results at lower energies (NT) are missing!

Transverse mass spectra

Inverse slope parameter of kaons



central Pb+Pb (Au+Au) collisions

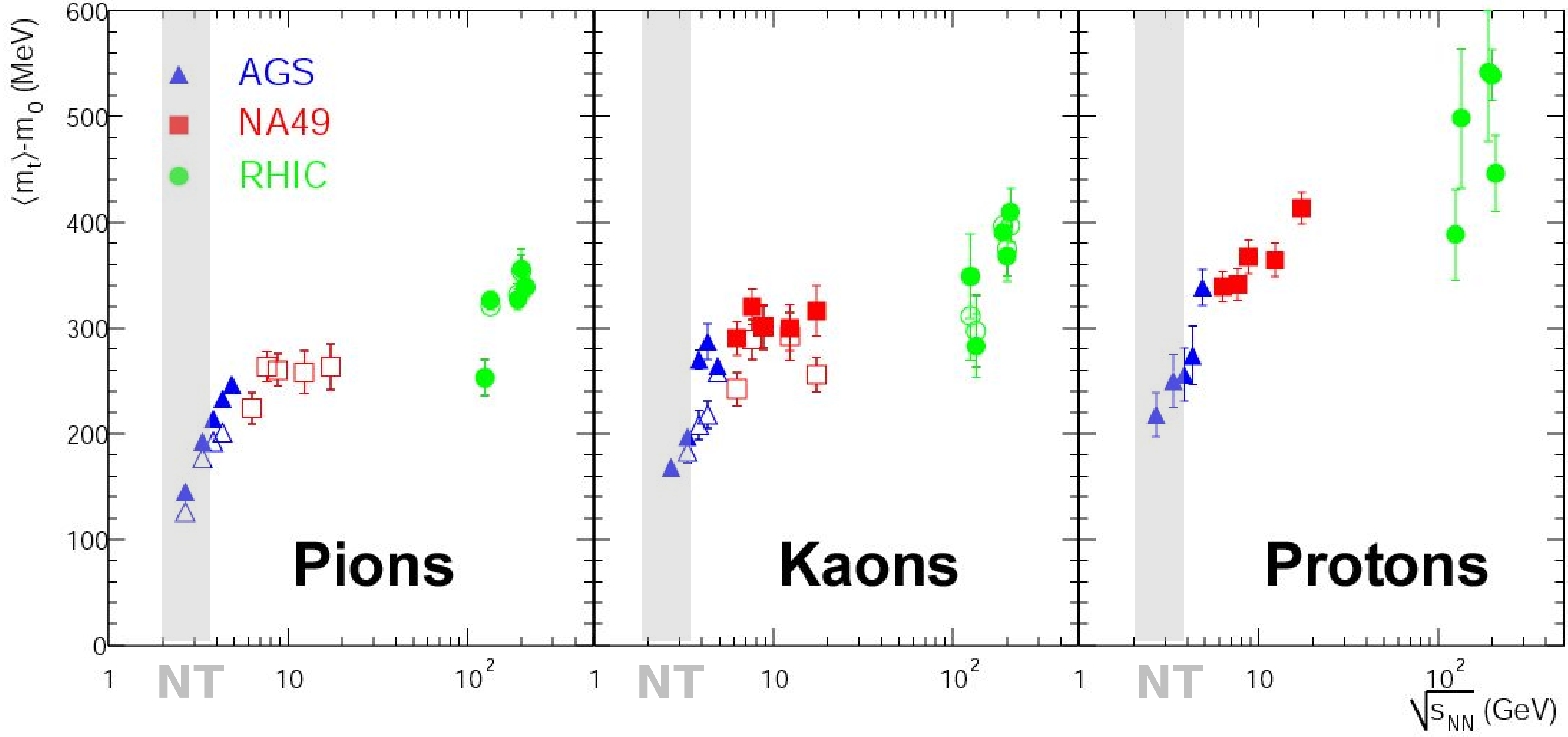
p+p

The step (a plateau at ≈30*A* GeV)

T – inverse slope parameter of transverse mass spectra

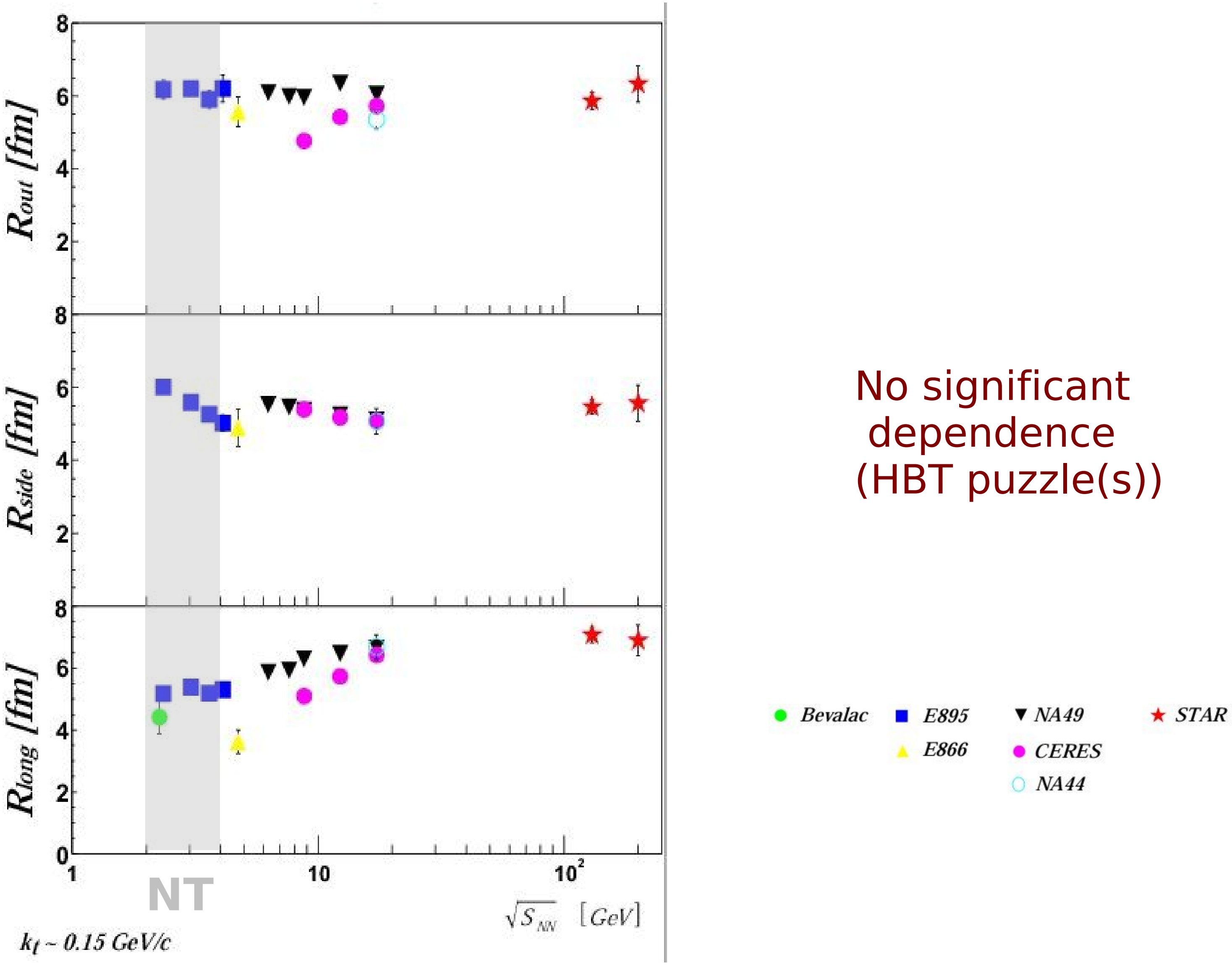
[<m_T> of various hadrons]

central Pb+Pb(Au+Au) collisions



Two-pion correlations

central Pb+Pb (Au+Au) collisions

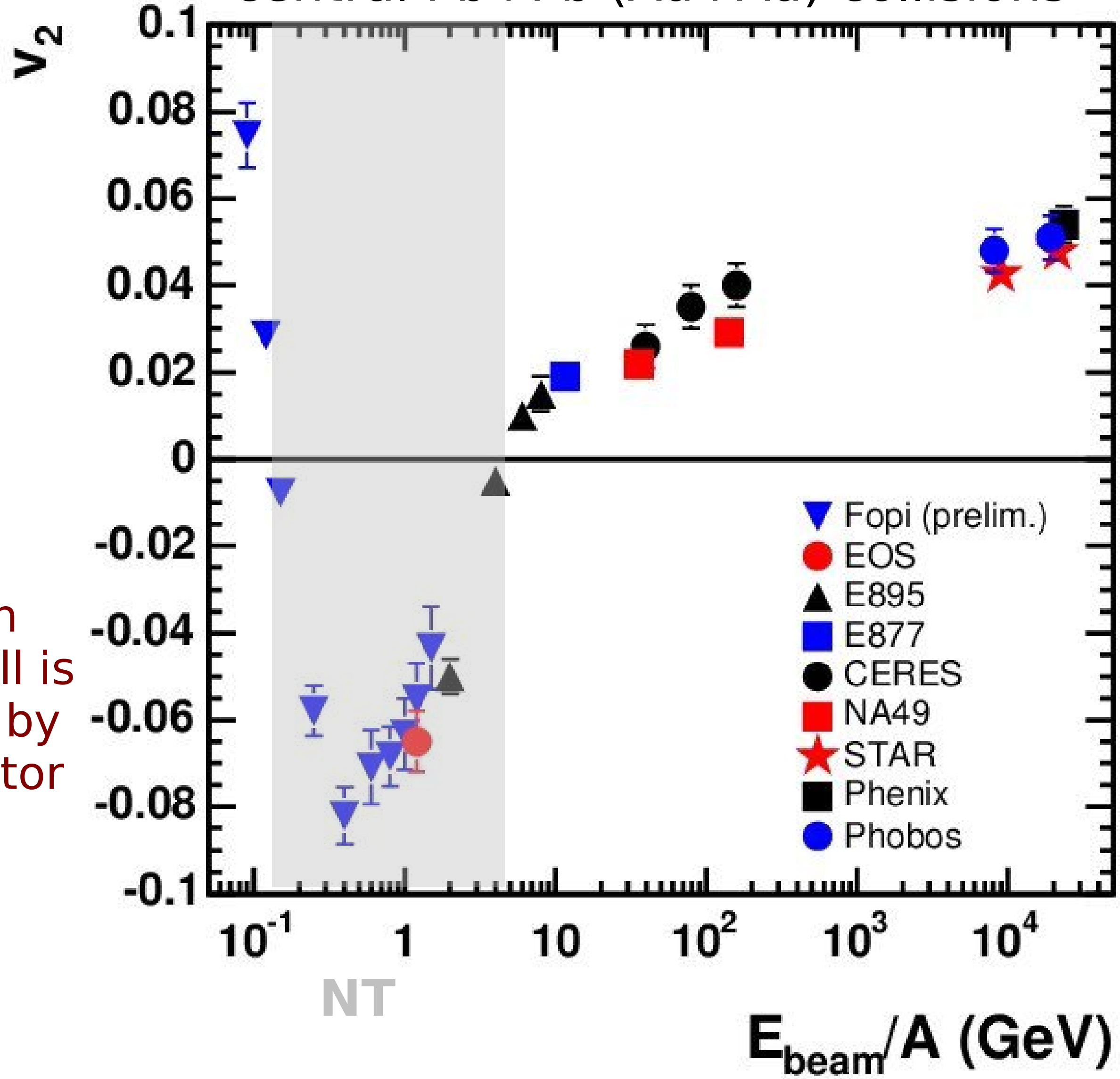


No significant dependence (HBT puzzle(s))

Anisotropic flow

Elliptic flow

central Pb+Pb (Au+Au) collisions

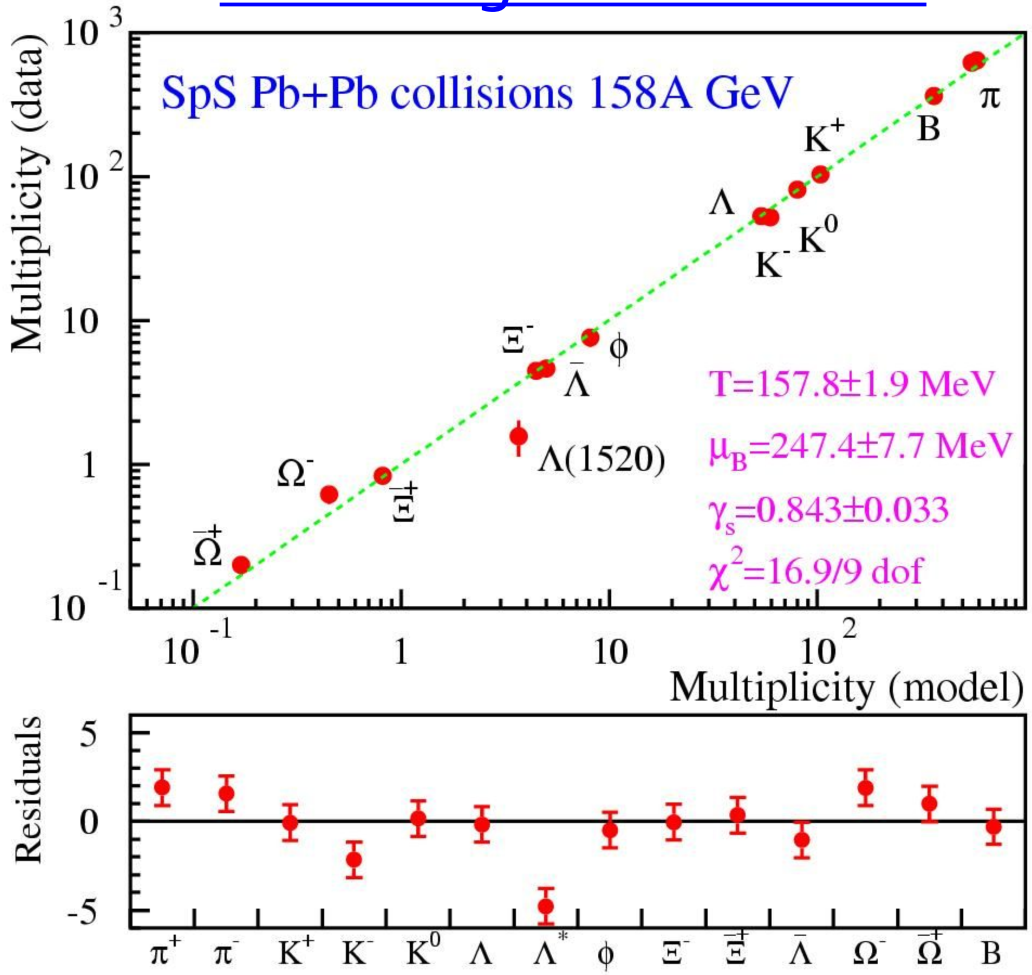


In-plane flow (pressure only driven

Side splash (the fireball is shadowed by the spectator matter)

Chemical freeze-out

Hadron gas model fits



A surprising success of statistical models

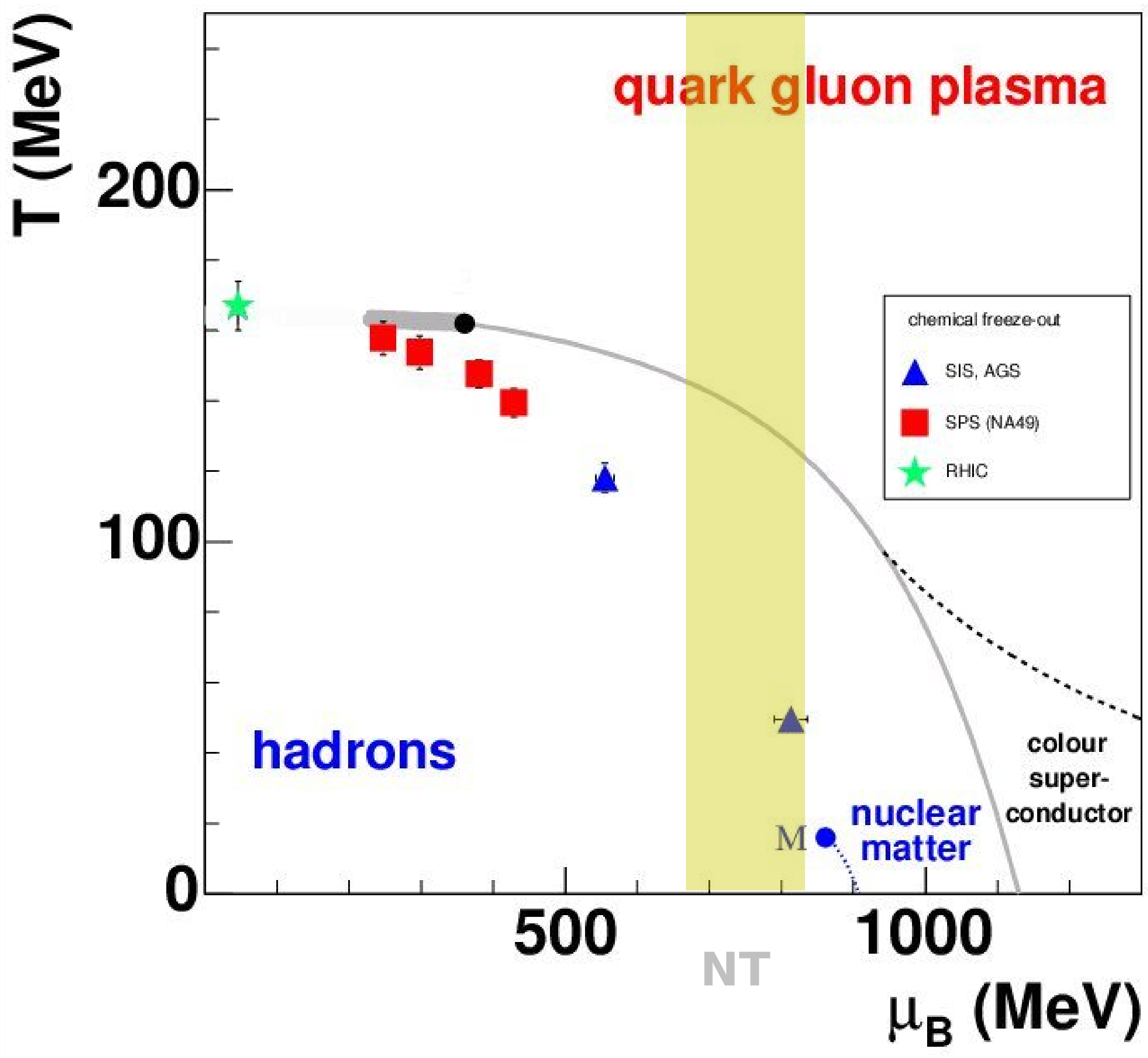
T - chemical freeze-out temperature

μ_B - baryo-chemical potential

Becattini et al.

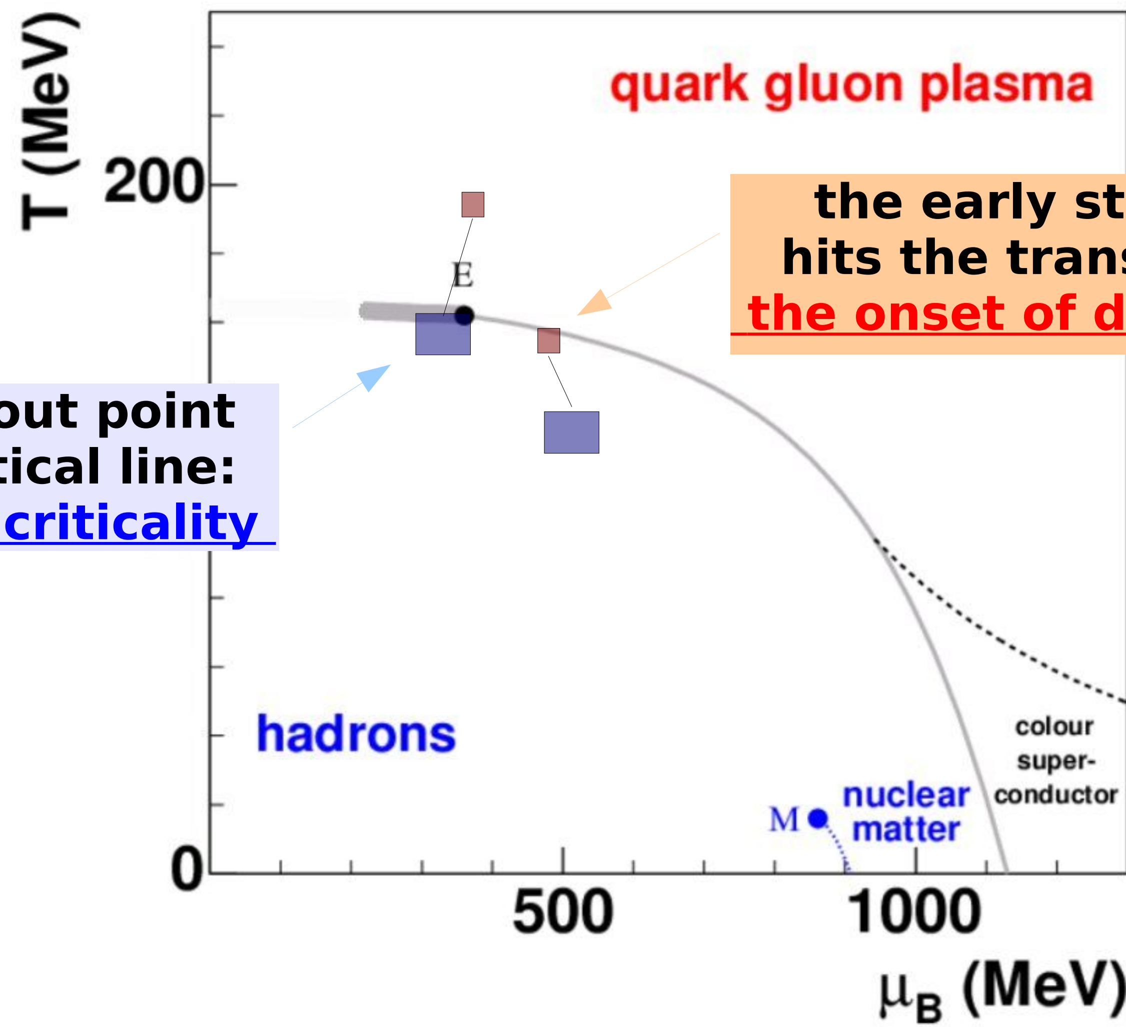
Sketch of the phase diagram and the chemical freeze-out points

central Pb+Pb (Au+Au) collisions



The freeze-out points at SPS approach the phase boundary

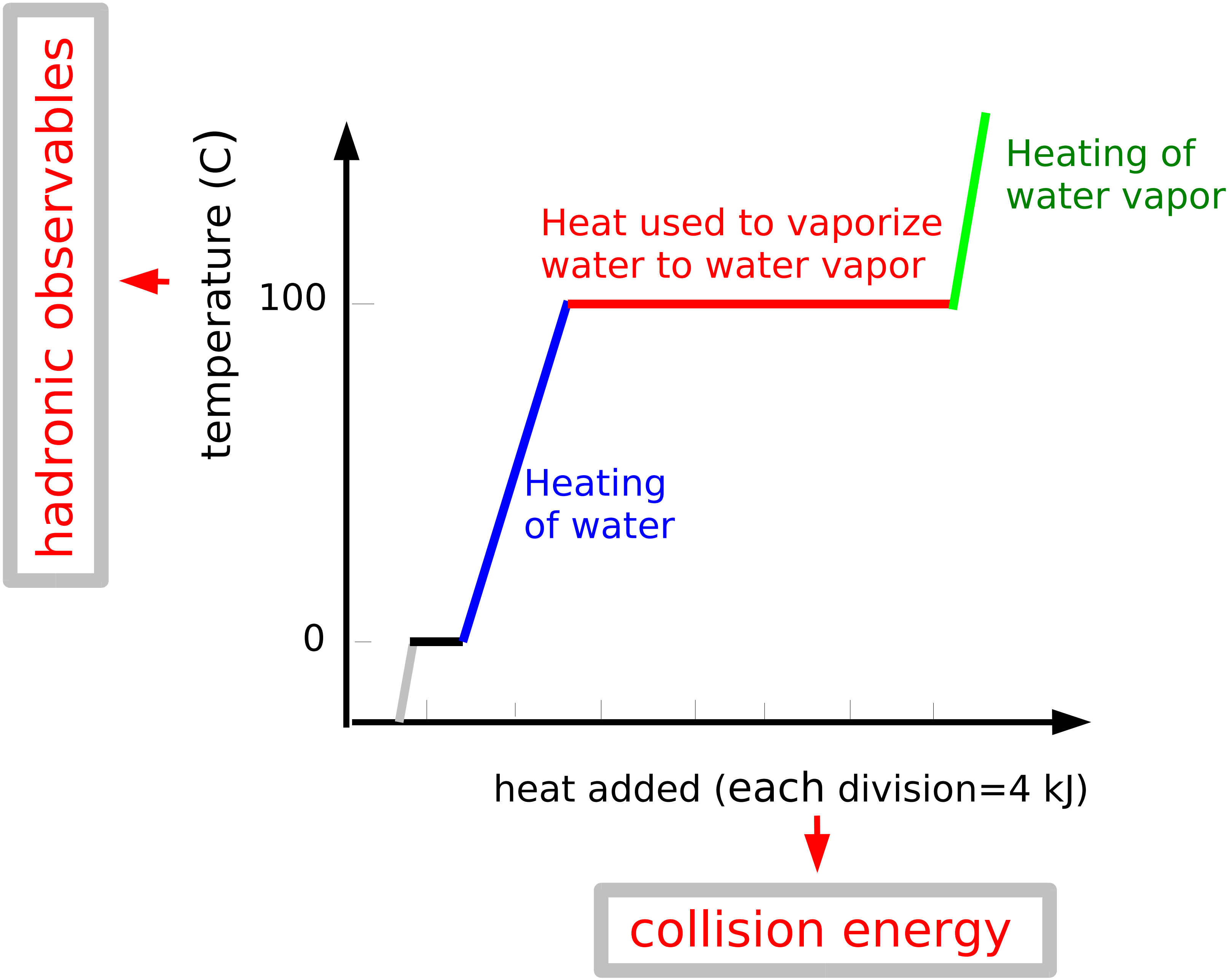
Onset of deconfinement



the early stage point hits the transition line:
the onset of deconfinement

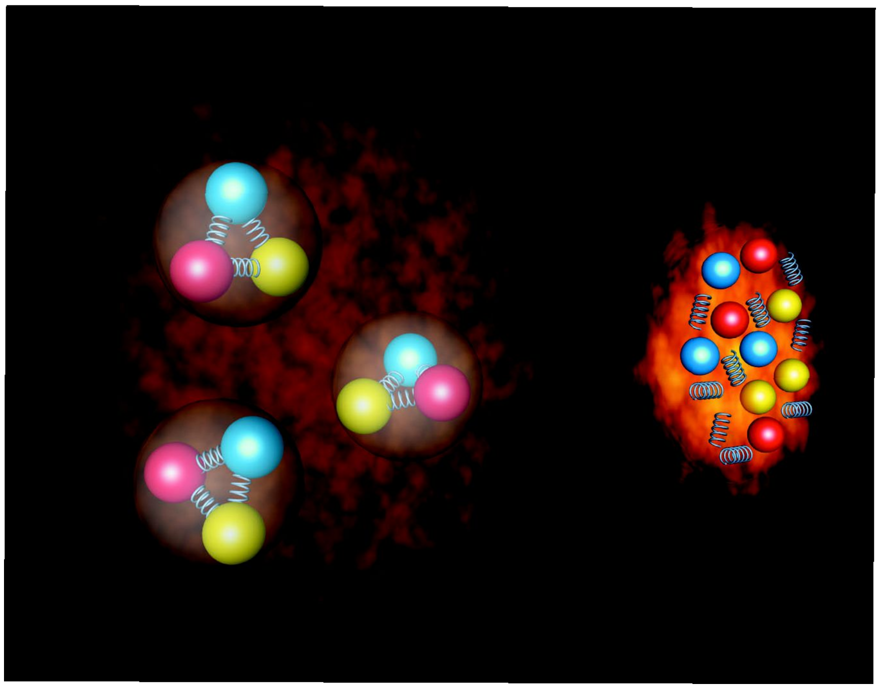
the freeze-out point hits the critical line:
the onset of criticality

The basic idea - heating curve of water



Heating curves of strongly interacting matter

hadrons **mixed** **QGP**

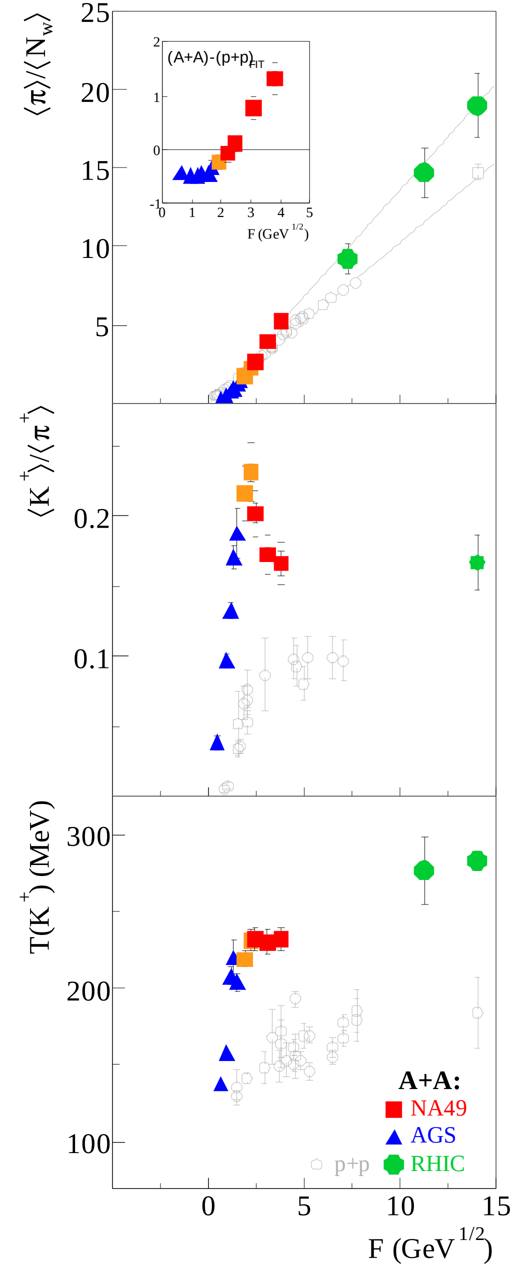


AGS **SPS** **RHIC**

collision energy

AGS **SPS** **RHIC**

hadronic observables



Kink

Horn

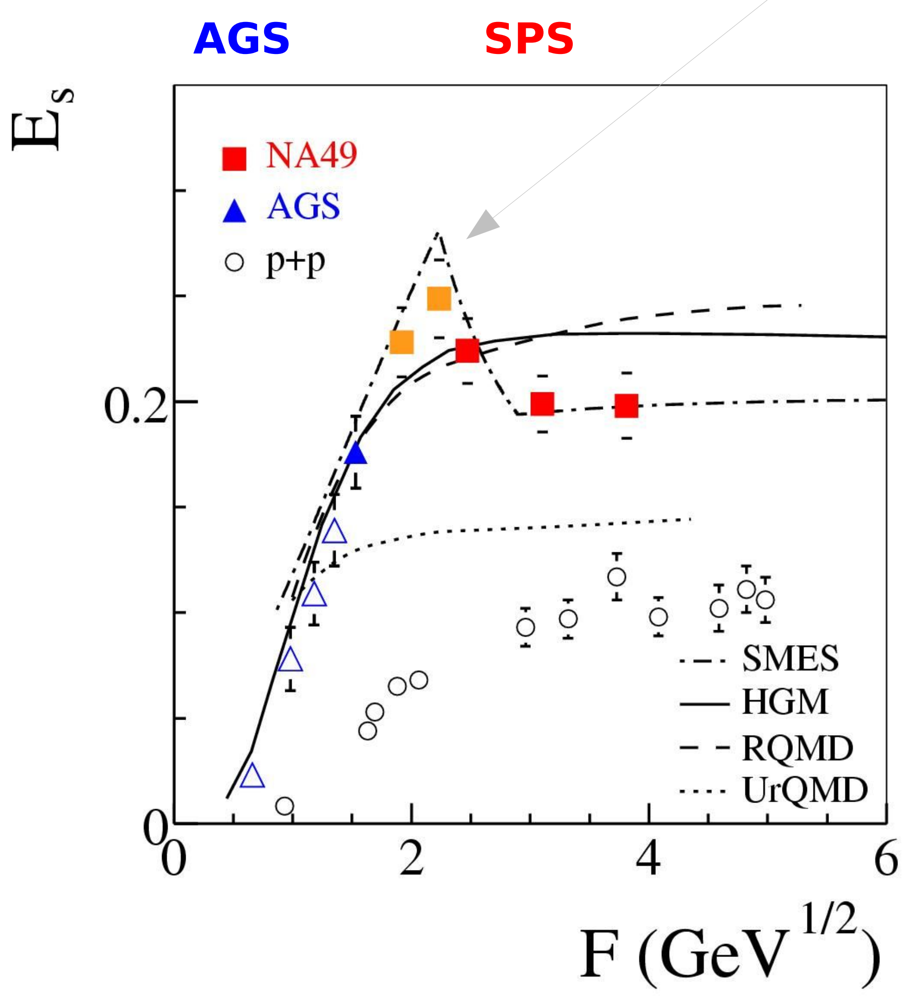
Step

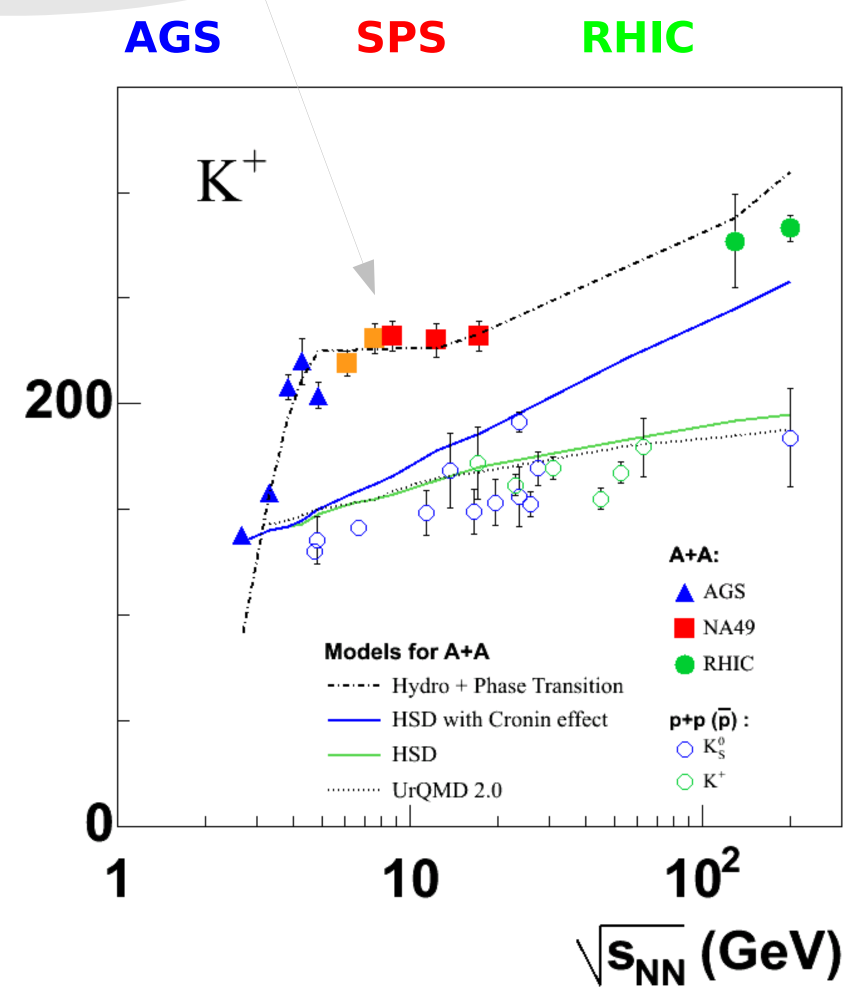
collision energy

M.G., Gorenstein

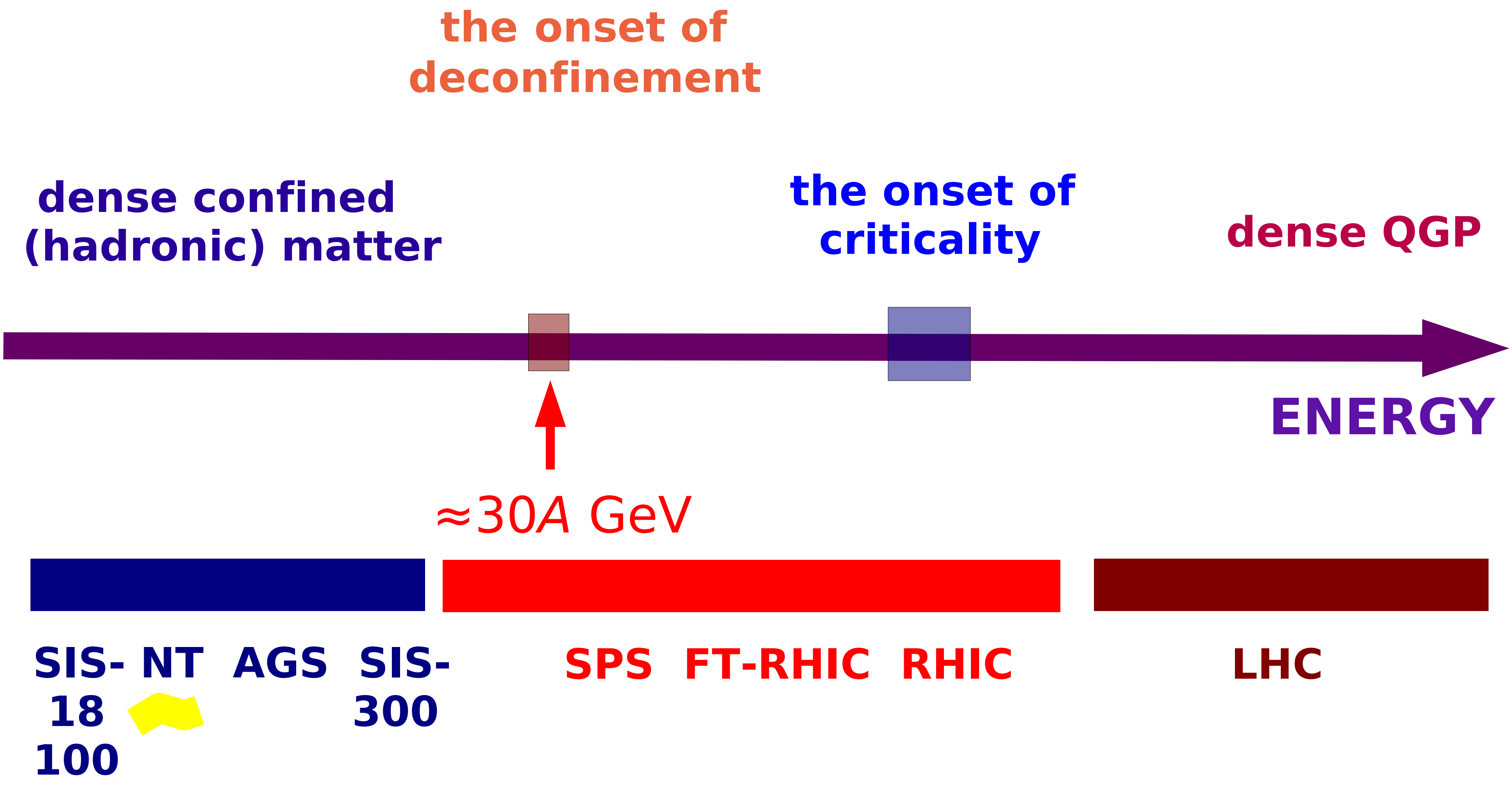
The models

Models with the 1^{st} order phase transition reproduce the data





$$E_S = (\langle \Lambda \rangle + \langle K + \bar{K} \rangle) / \langle \pi \rangle$$


the onset of
deconfinement
dense confined
(hadronic) matter
the onset of
criticality
dense QGP
ENERGY
≈30A GeV
SIS-18
NT
AGS
SIS-300
SIS-100
SPS
FT-RHIC
RHIC
LHC

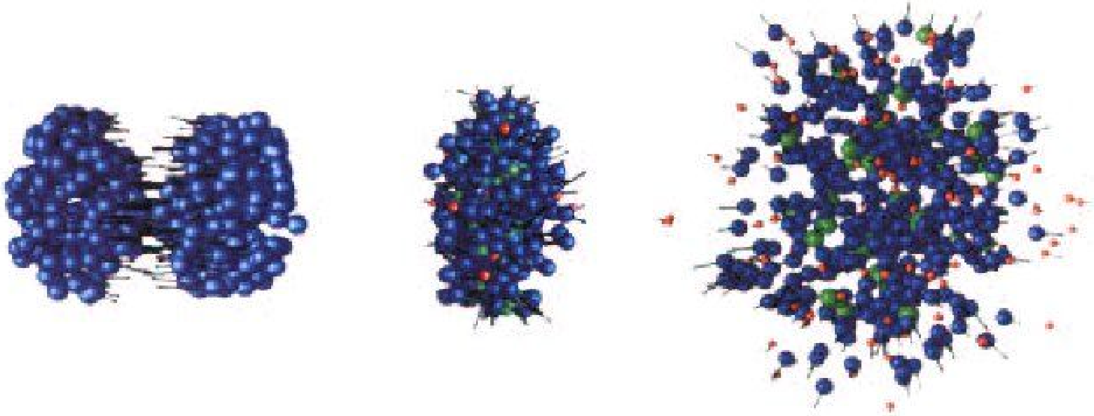
The Nuclotron energy range

The most of the existing data come from the AGS energy scan (1996): 2*A*, 4*A*, 6*A*, 8*A*, 10.8*A* GeV

Experiments:

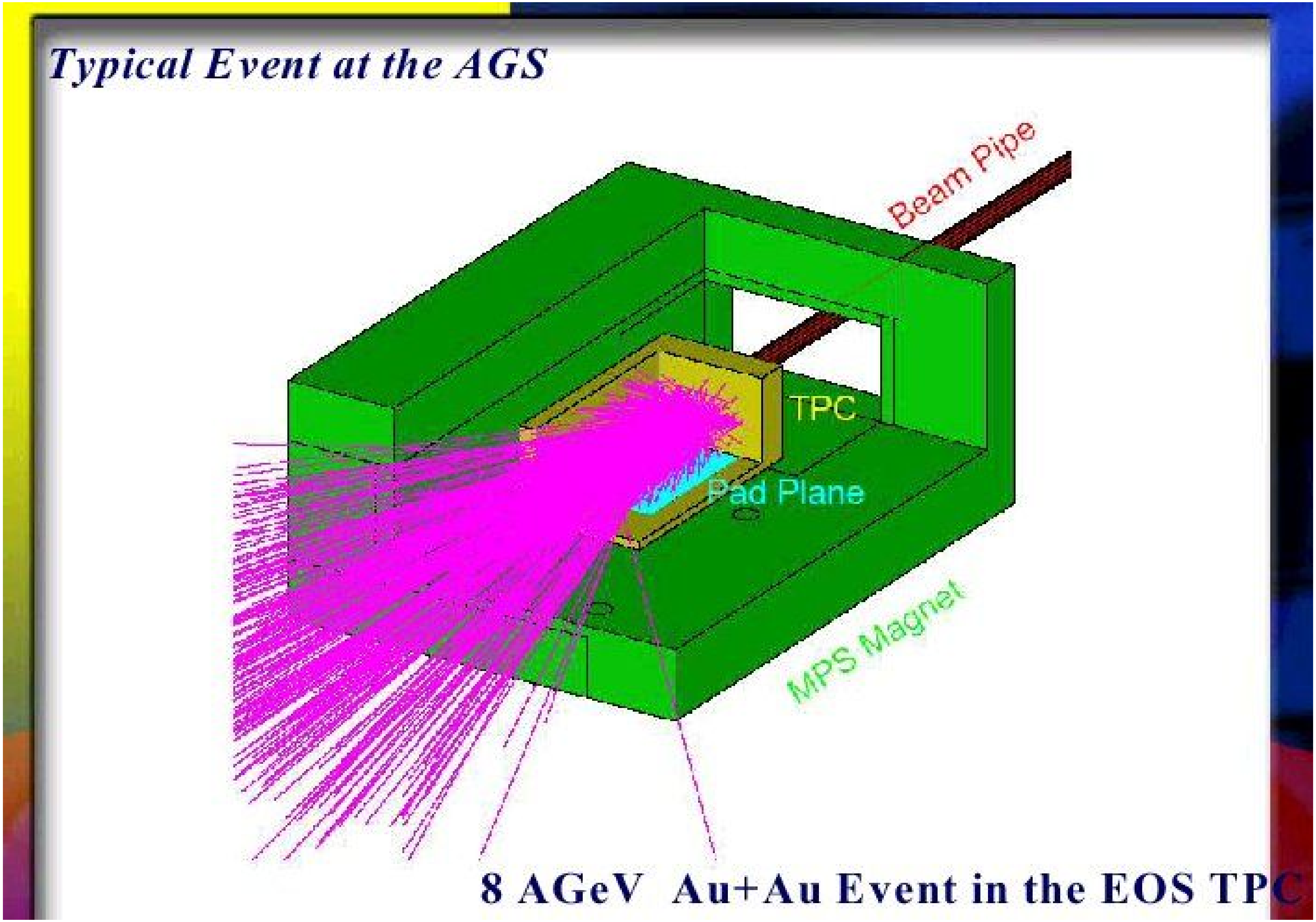
E895 - EOS TPC

E917 – rotatable magnetic spectrometer, E802



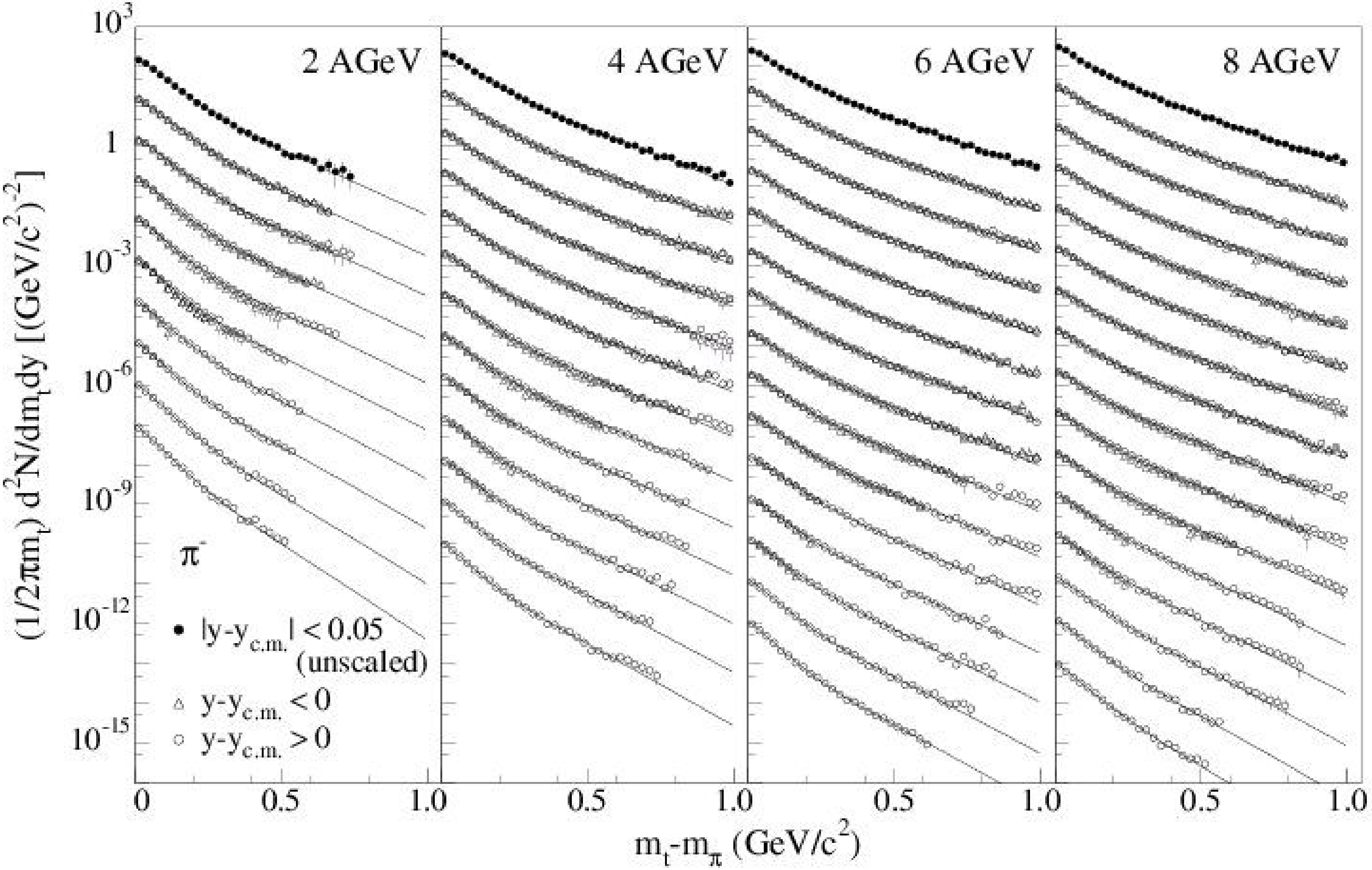
IQMD simulation of Au+Au collision

E895

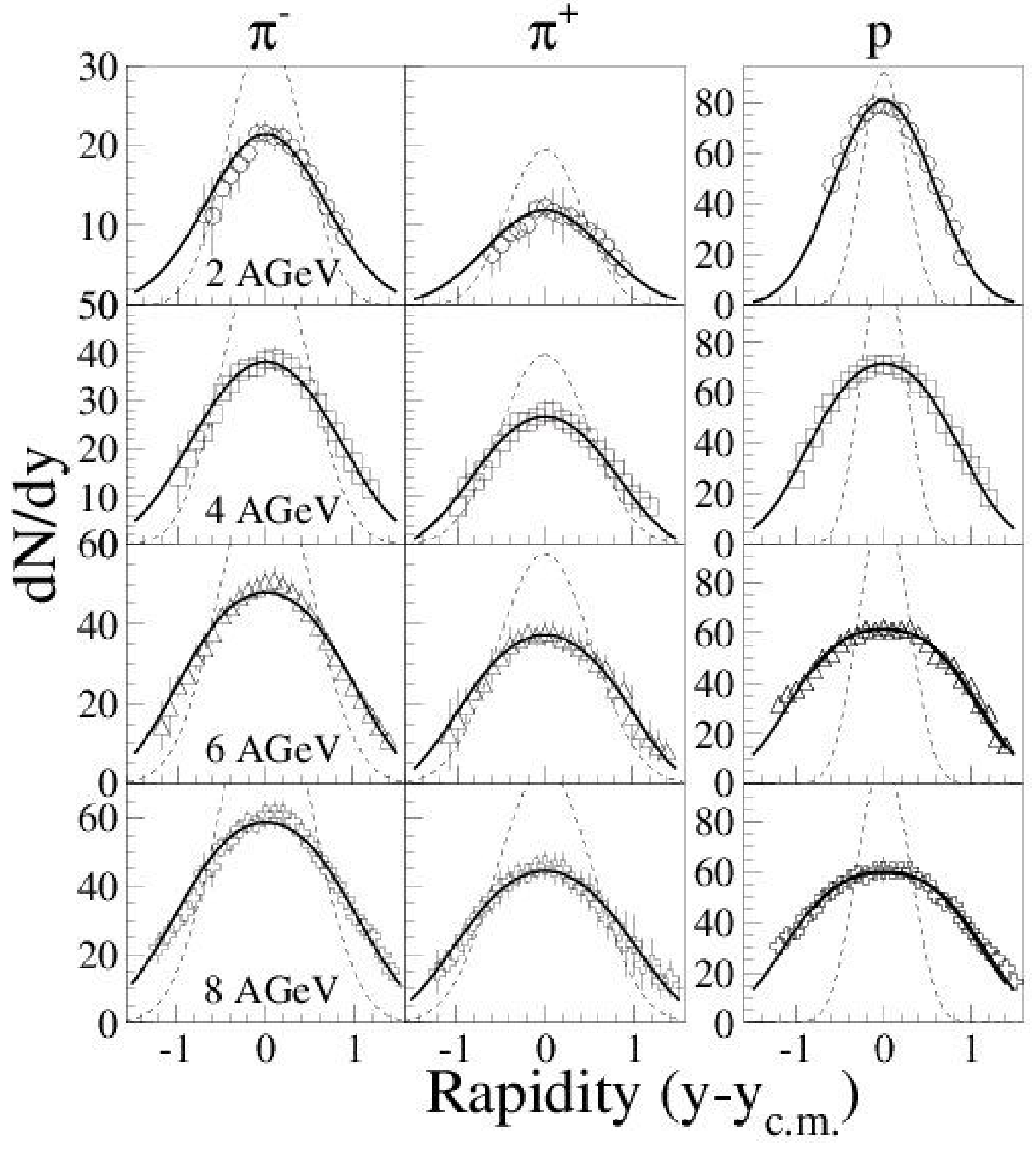

Typical Event at the AGS
Beam Pipe
TPC
Pad Plane
MPS Magnet
8 AGeV Au+Au Event in the EOS TPC

E895

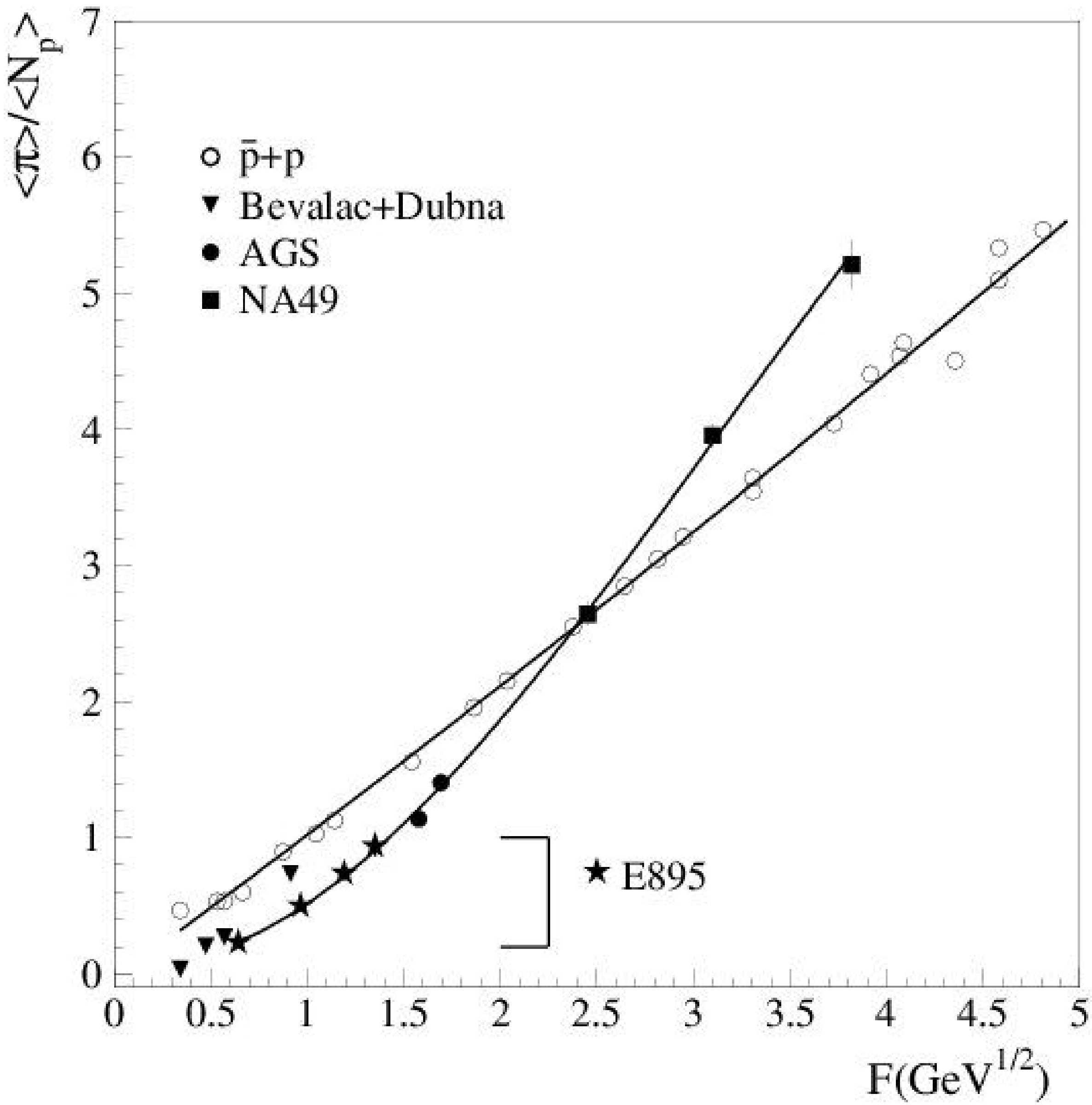
Pions in central Au+Au collisions



Pions and protons in central Au+Au collisions

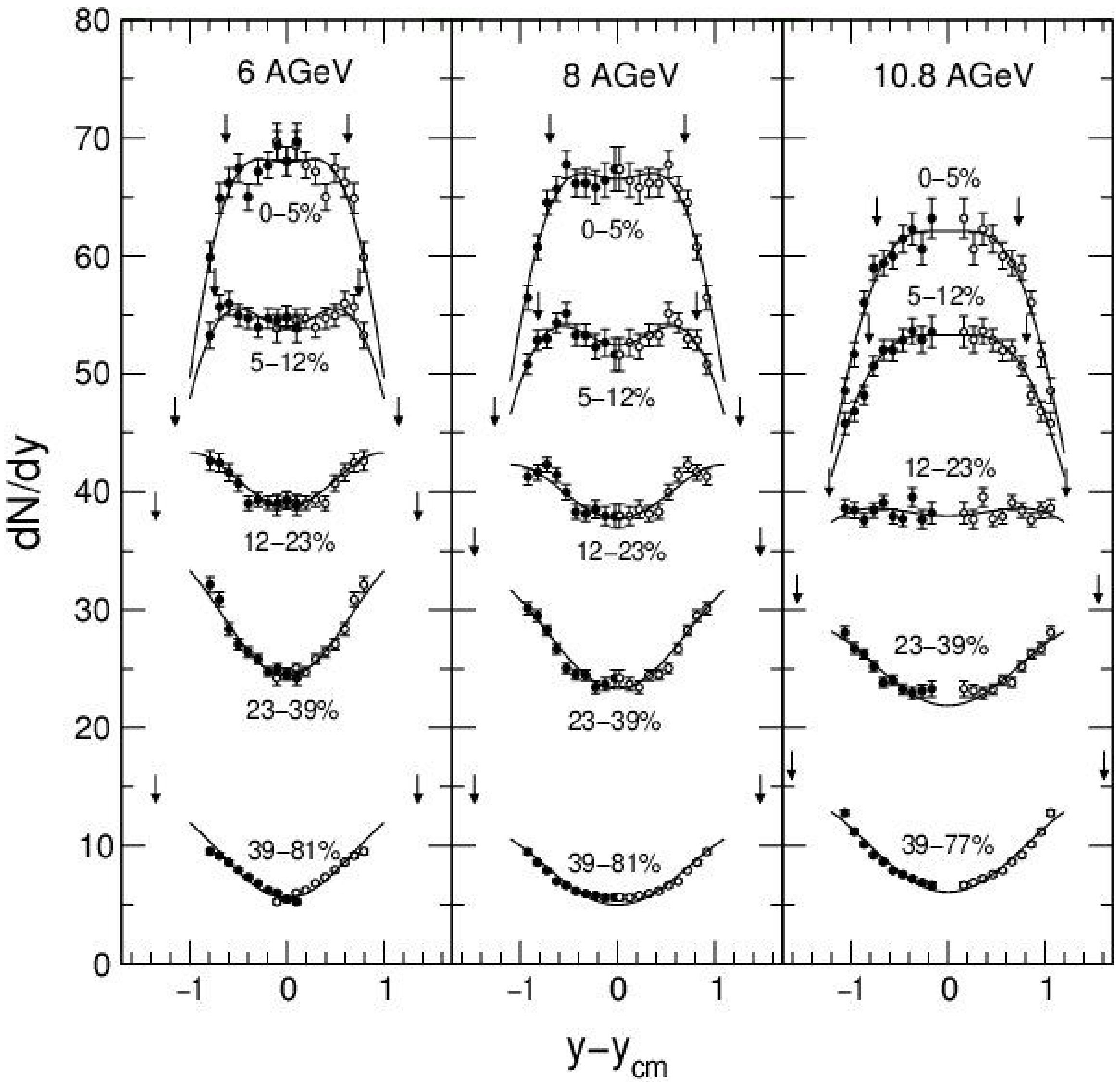


Pions in central Au+Au collisions

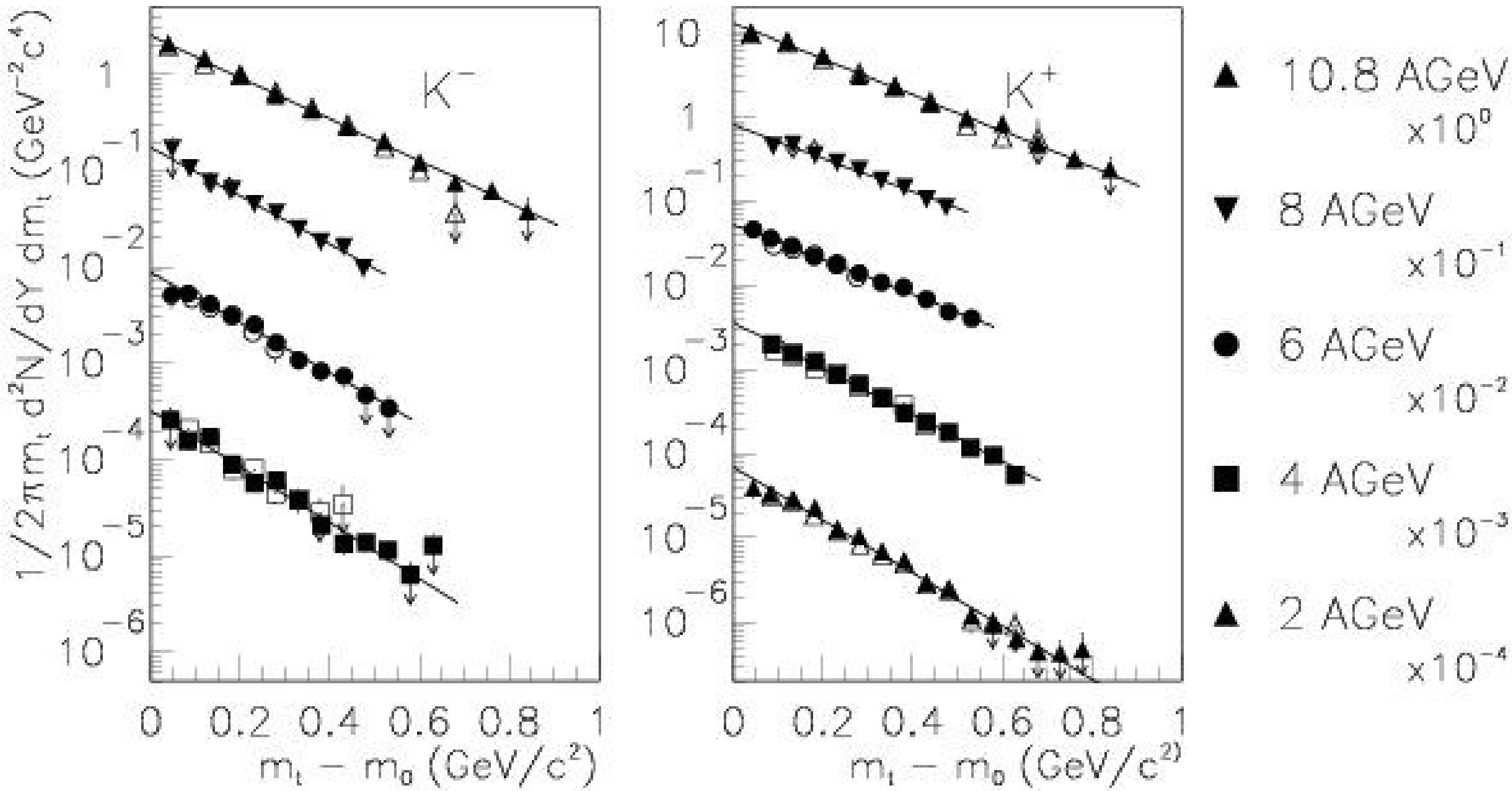


E917

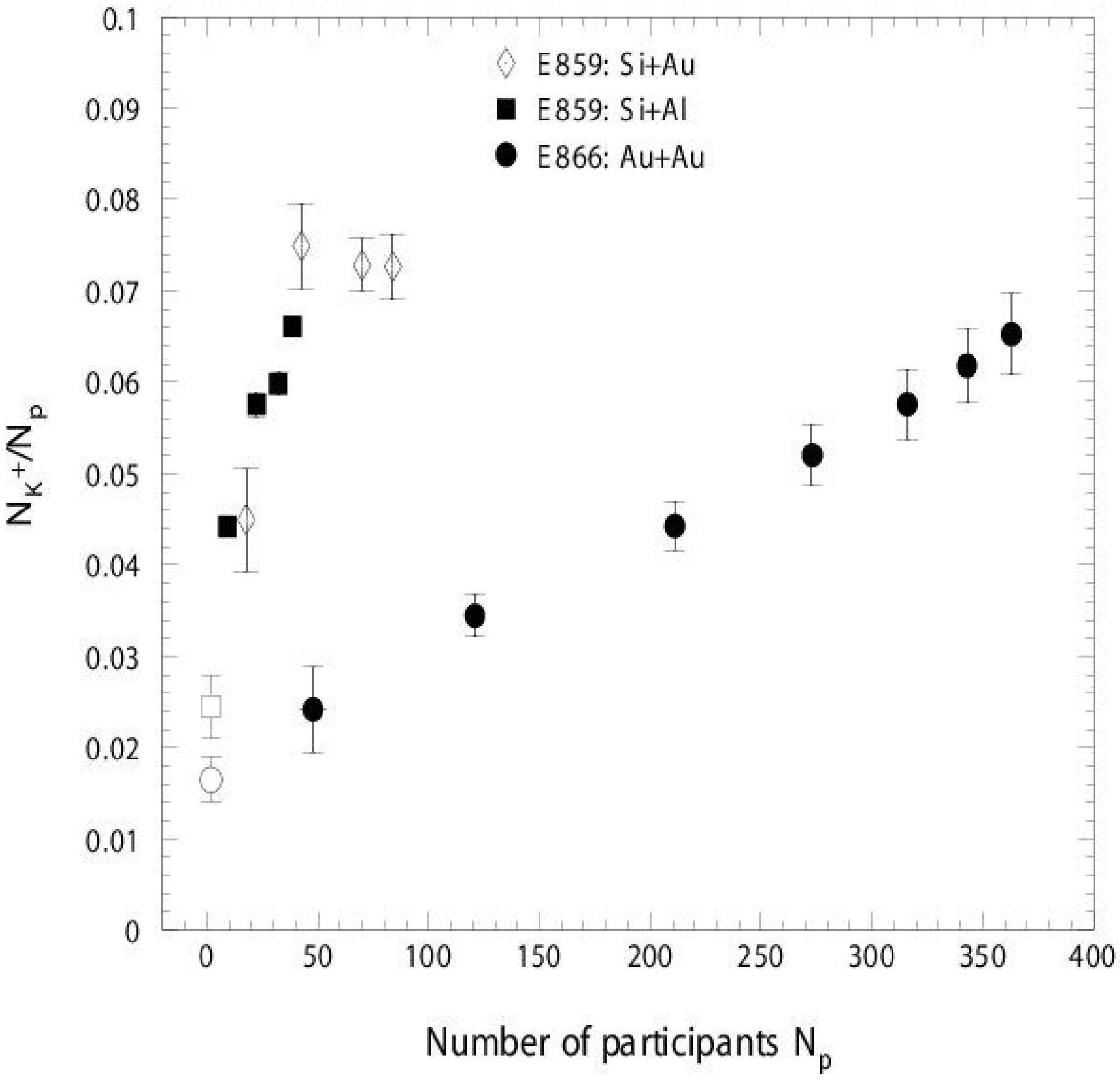
Protons in Au+Au collisions



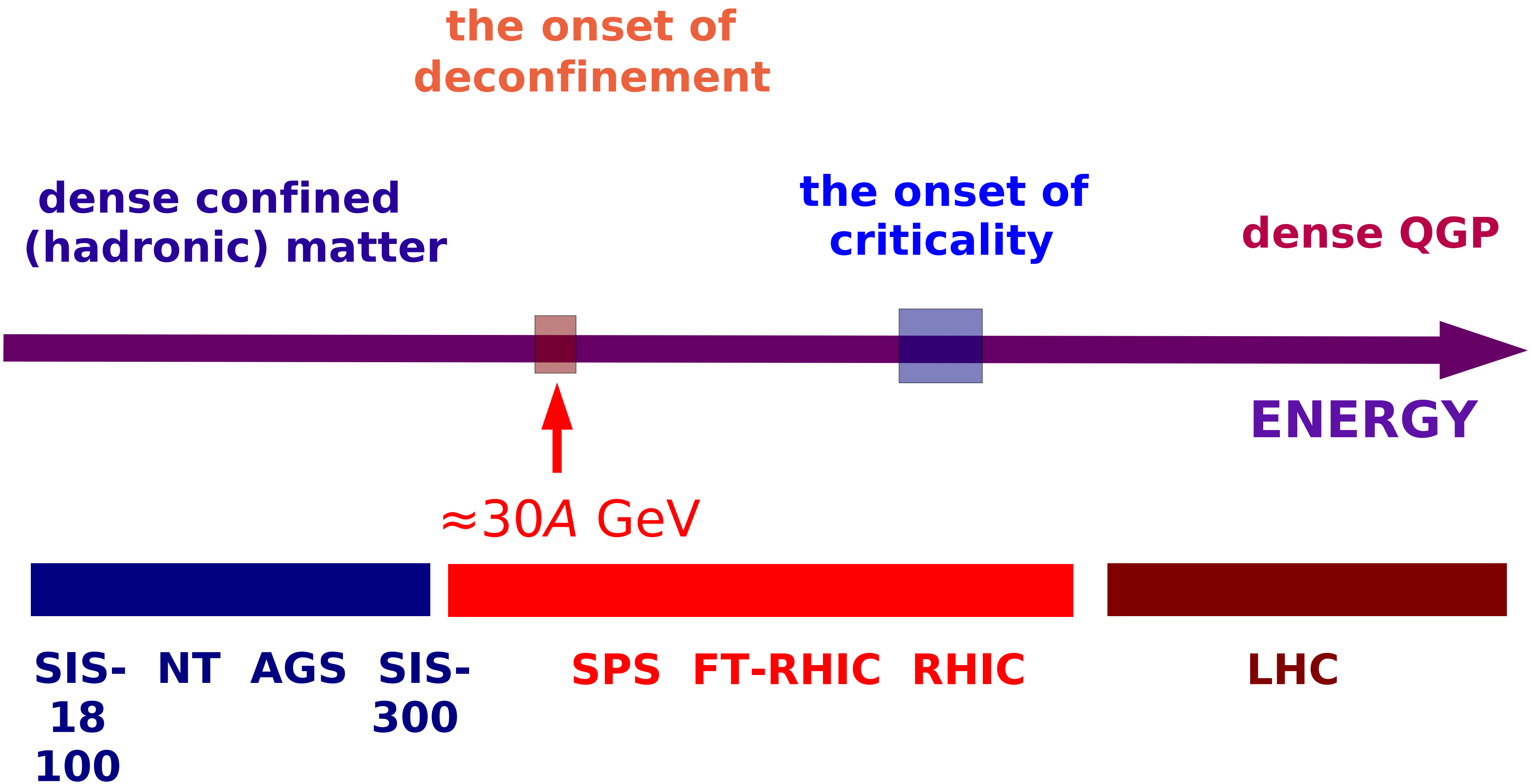
Kaons in Au+Au collisions



System size dependence at the top AGS energy



Summary and conclusions



The Nuclotron energy range may be ideal to:

Understand mechanism(s) of equilibration in high energy nuclear collisions

Develop and test statistical mechanics of relativistic strongly interacting particles

They are also urgently needed as a reference for the SPS and RHIC data

Missing and needed hadron data in the Nuclotron energy range:

- fluctuations and long range correlations in central Pb+Pb collisions:
  - urgently needed reference for the SPS and RHIC results,
  - test of statistical mechanics of relativistic strongly interacting particles

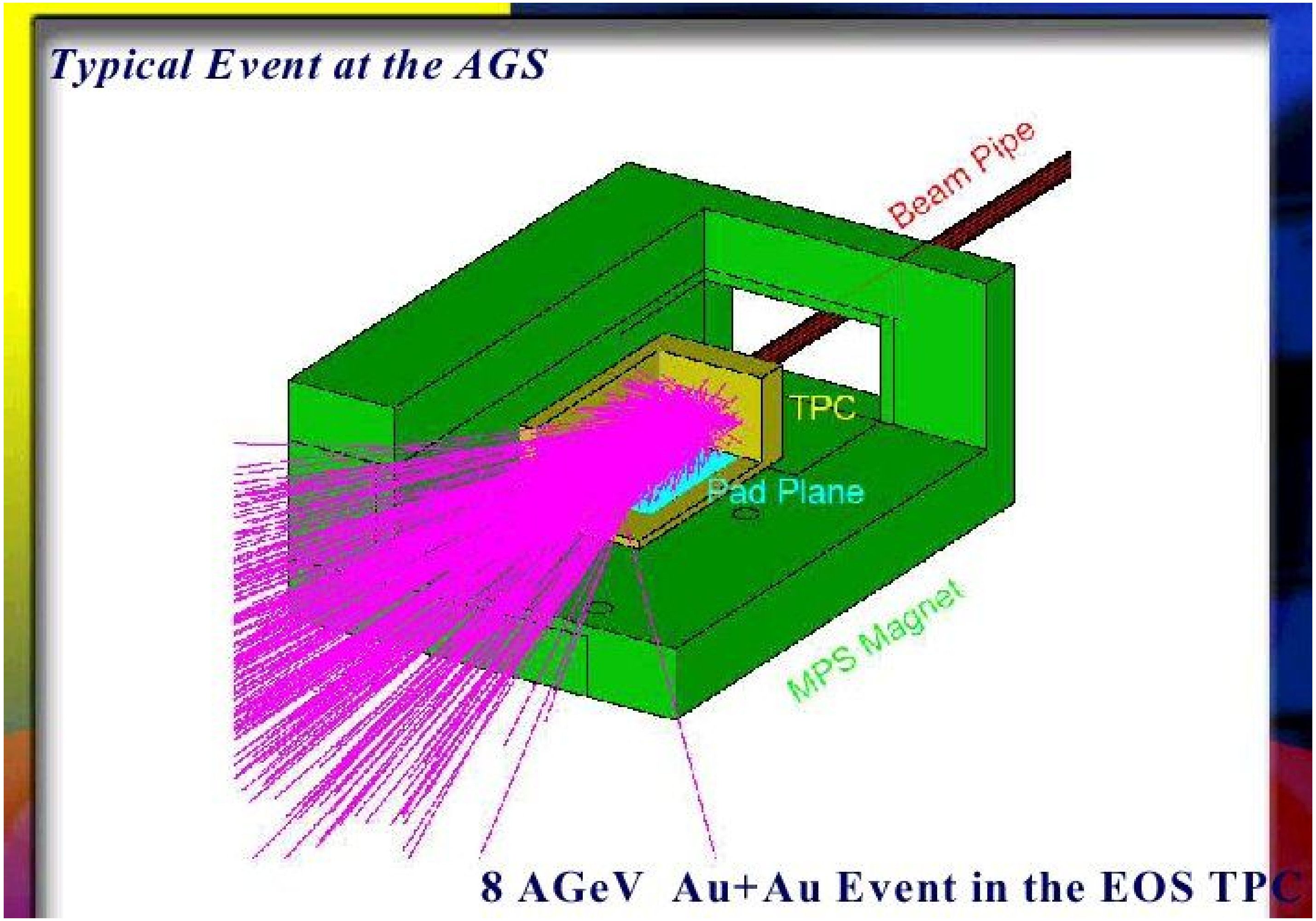
- heavy hadron production and resonances in central Pb+Pb collisions:
  - statistical vs dynamical models,
  - freeze-out conditions

- system size dependence (starting from p+p)
  - mechanism(s) of equilibration,
  - reference for the SPS and RHIC data

Experimental requirements:

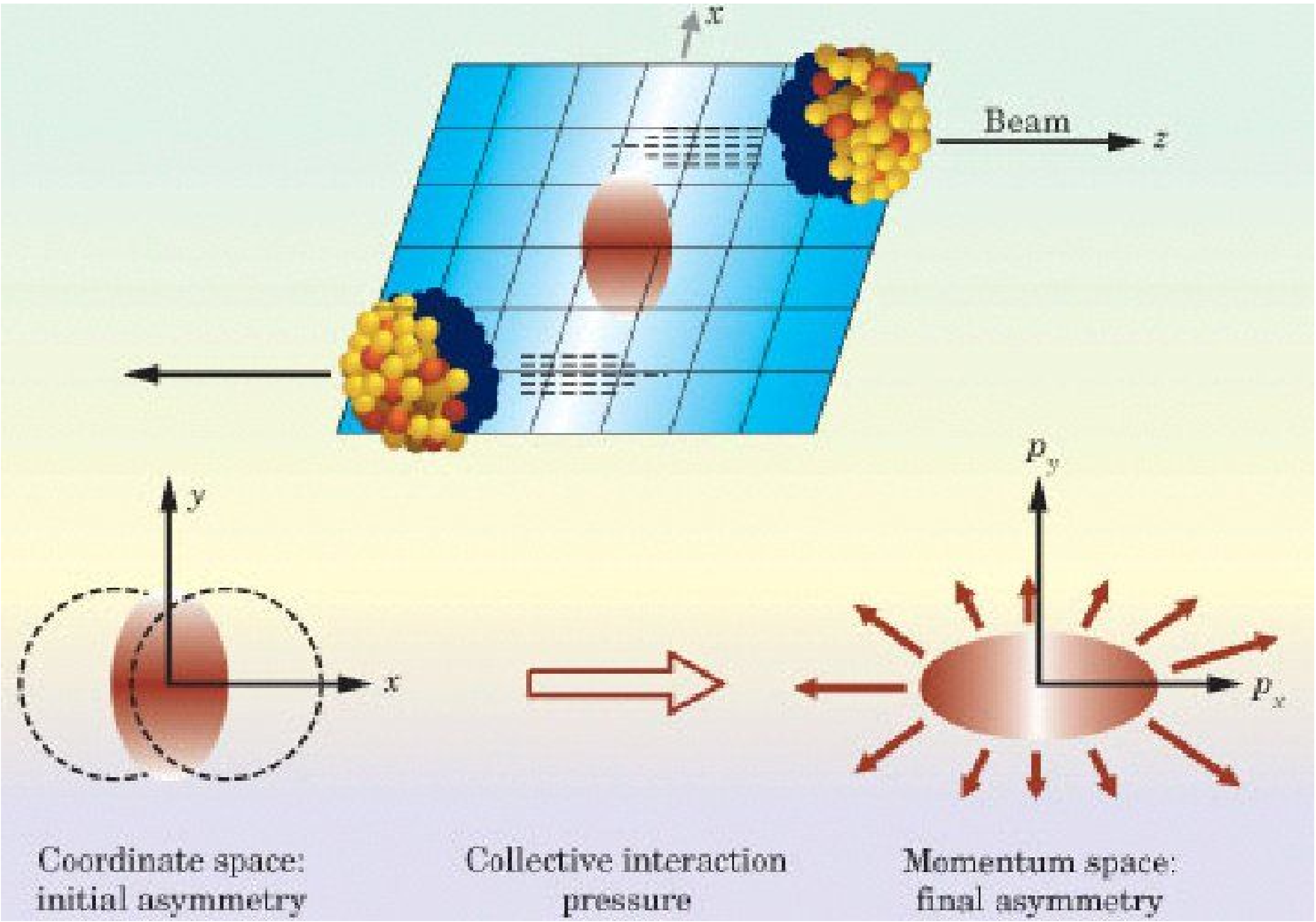
-large acceptance (≈100%),
-good centrality determination,
-high event rate: event statistics per reaction $\approx 10^6$

EOS TPC at NT?



Typical Event at the AGS
Beam Pipe
TPC
Pad Plane
MPS Magnet
8 AGeV Au+Au Event in the EOS TPC

Additional slides


x
Beam
z
y
x
p_y
p_x
Coordinate space:
initial asymmetry
Collective interaction
pressure
Momentum space:
final asymmetry