Light Ion program at the CERN SPS

M. Gazdzicki (Frankfurt, Kielce)
for the NA49-future Collaboration

PAST

- Observation of the onset of deconfinement at the SPS

FUTURE

- Search for the critical point
- Role of volume and density in deconfinement
- Possible experiments: NA49-future and others

Summary

PAST

- Observation of the onset of deconfinement at the SPS

  - Brief history of the SPS ion program

  - Observation of the onset of deconfinement

Brief history of the SPS ion program

Matsui, Satz
Rafelski, Muller

1986-1991: Pioneering study with O and S beams

Strangeness enhancement and J/ψ suppression

⇒ Simple superposition models do not work

1994-2000: Pb+Pb collisions at the top SPS energy

anomalous J/ψ suppression, statistical properties of hadron production, direct photons

⇒ Is a new state of matter created?

M.G., Gorenstein

1998-2002: Pb+Pb collisions at low SPS energies

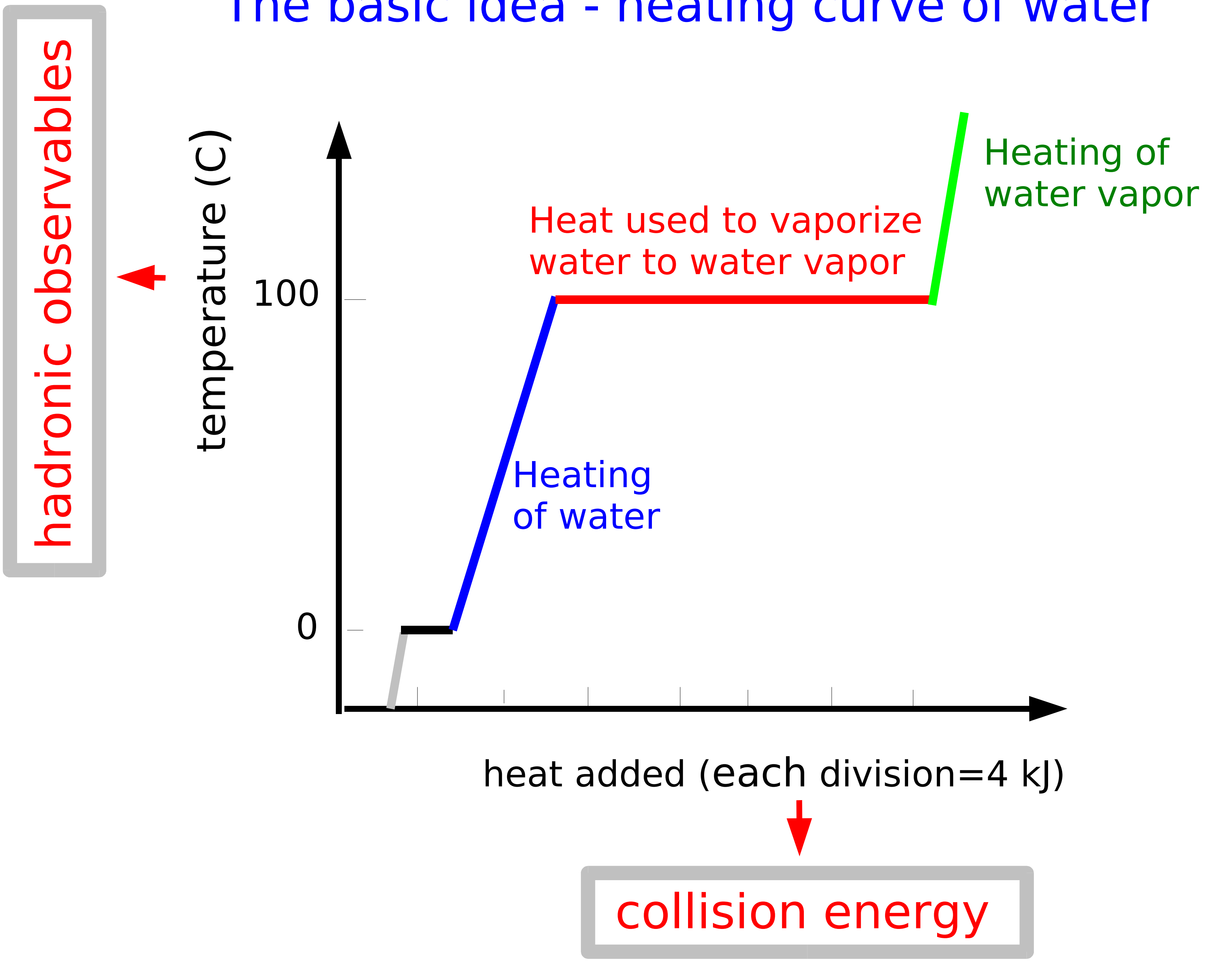
Anomalies in energy dependence of hadron production

⇒ Observation of the onset of deconfinement?

FUTURE

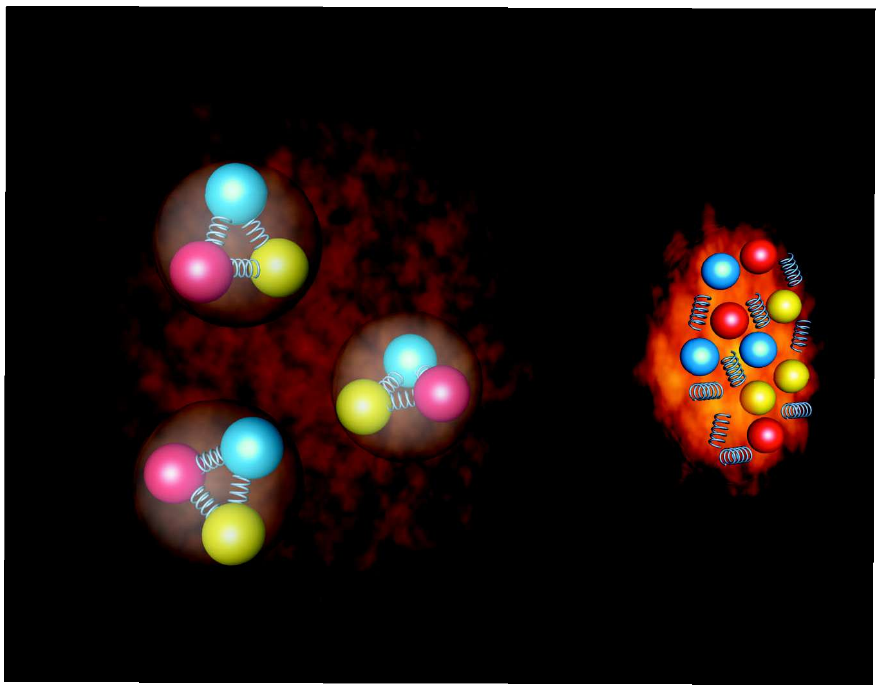
Onset of deconfinement at the CERN SPS

The basic idea - heating curve of water



Heating curves of strongly interacting matter

hadrons **mixed** **QGP**

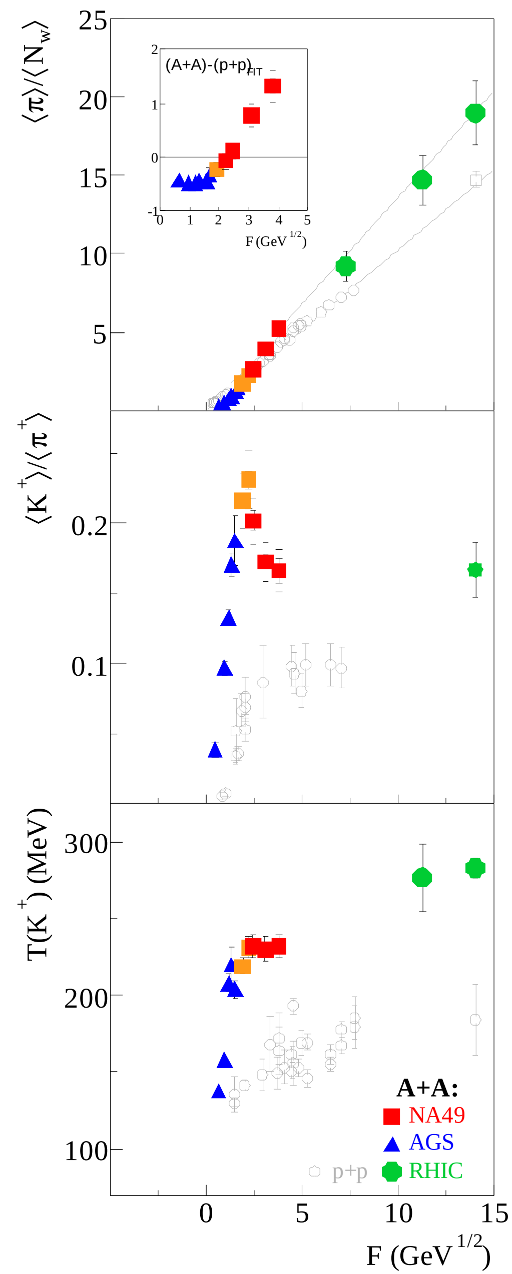


AGS **SPS** **RHIC**

collision energy

AGS **SPS** **RHIC**

hadronic observables



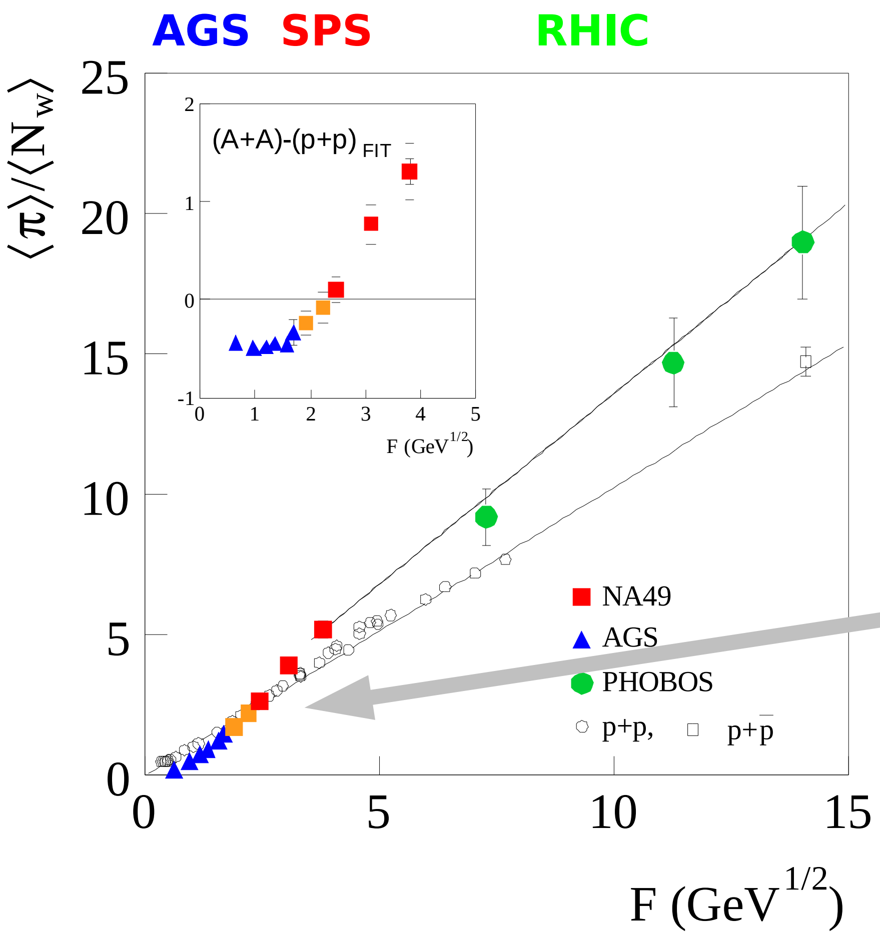
Kink

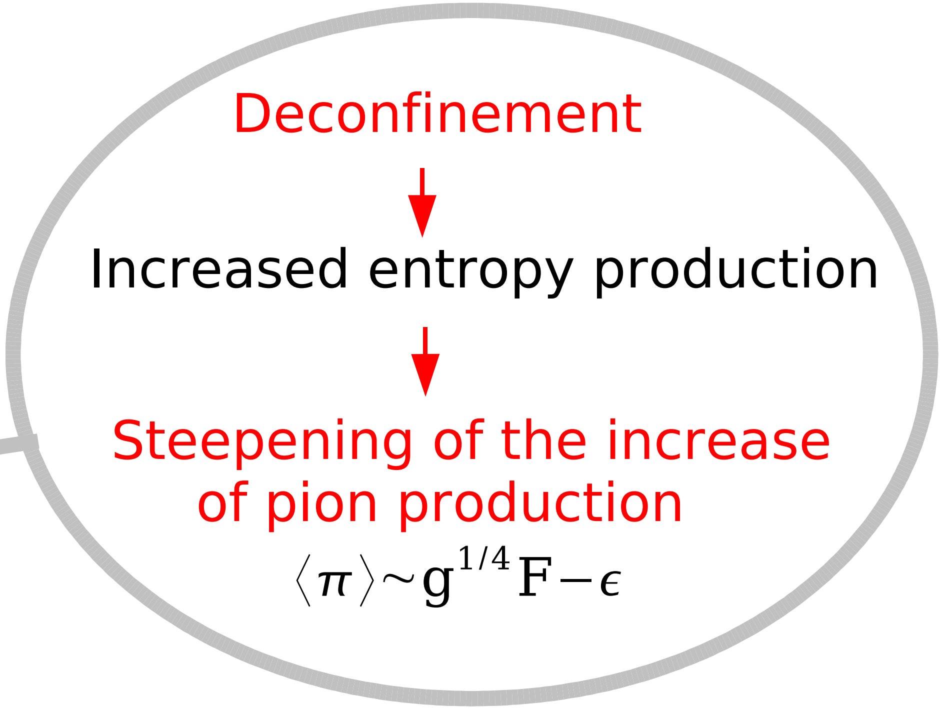
Horn

Step

collision energy

The kink in pion multiplicity





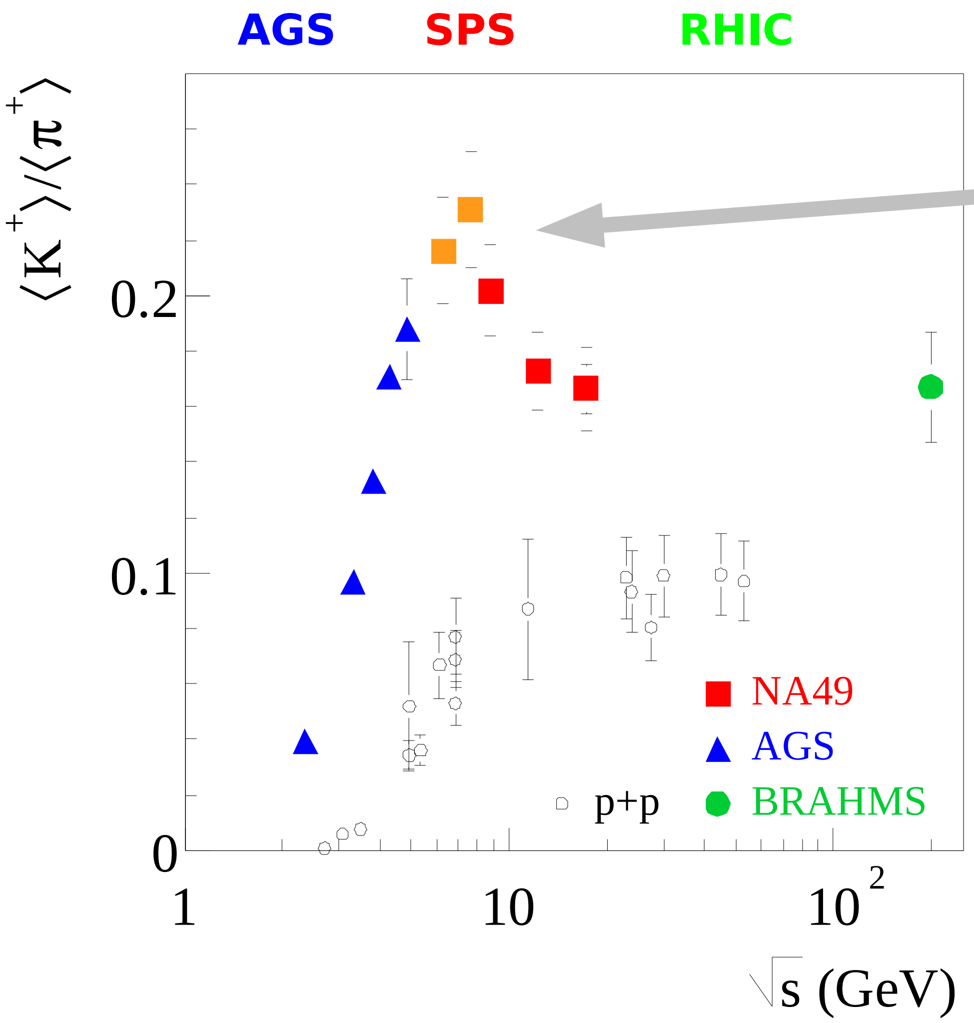
$F \approx \sqrt{\sqrt{s_{NN}}}$

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

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

M.G., Gorenstein

The horn in strangeness yield



Deconfinement

↓

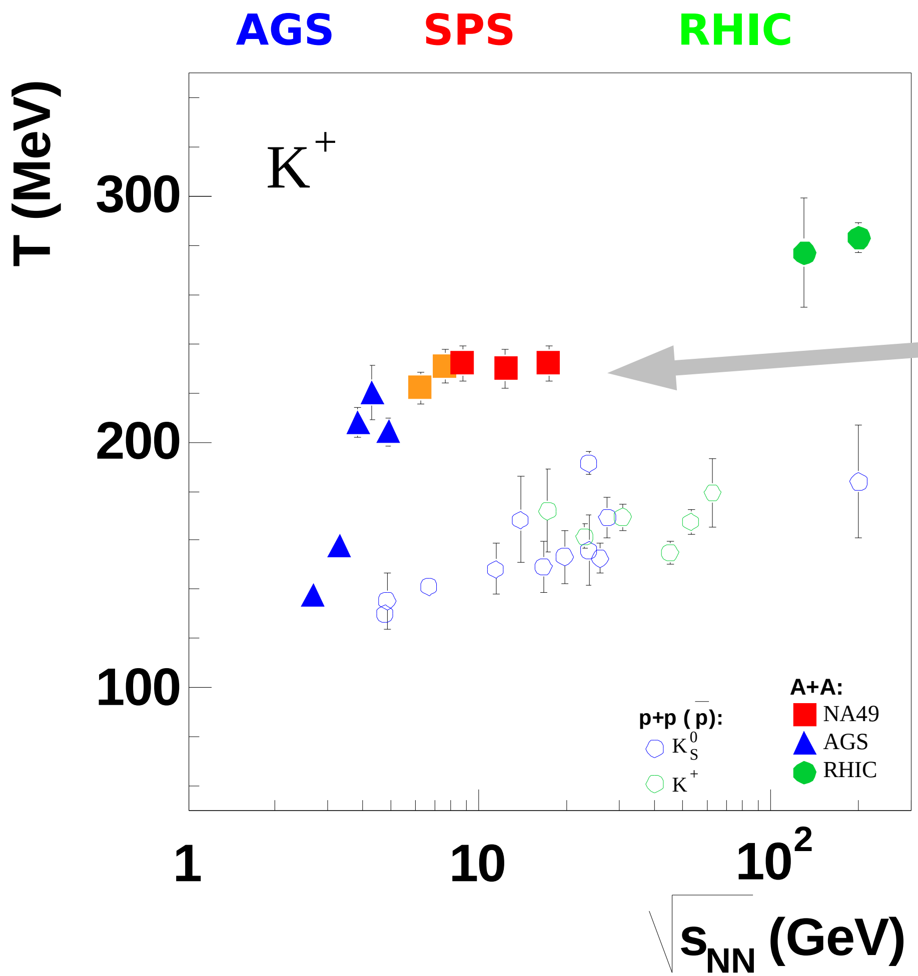
Decrease of masses of strangeness carriers and the number ratio of strange to non-strange degrees of freedom

↓

A sharp maximum in the strangeness to pion ratio

M.G., Gorenstein

The step in m_T slopes



Deconfinement

↓

Constant temperature and pressure in the mixed phase region

↓

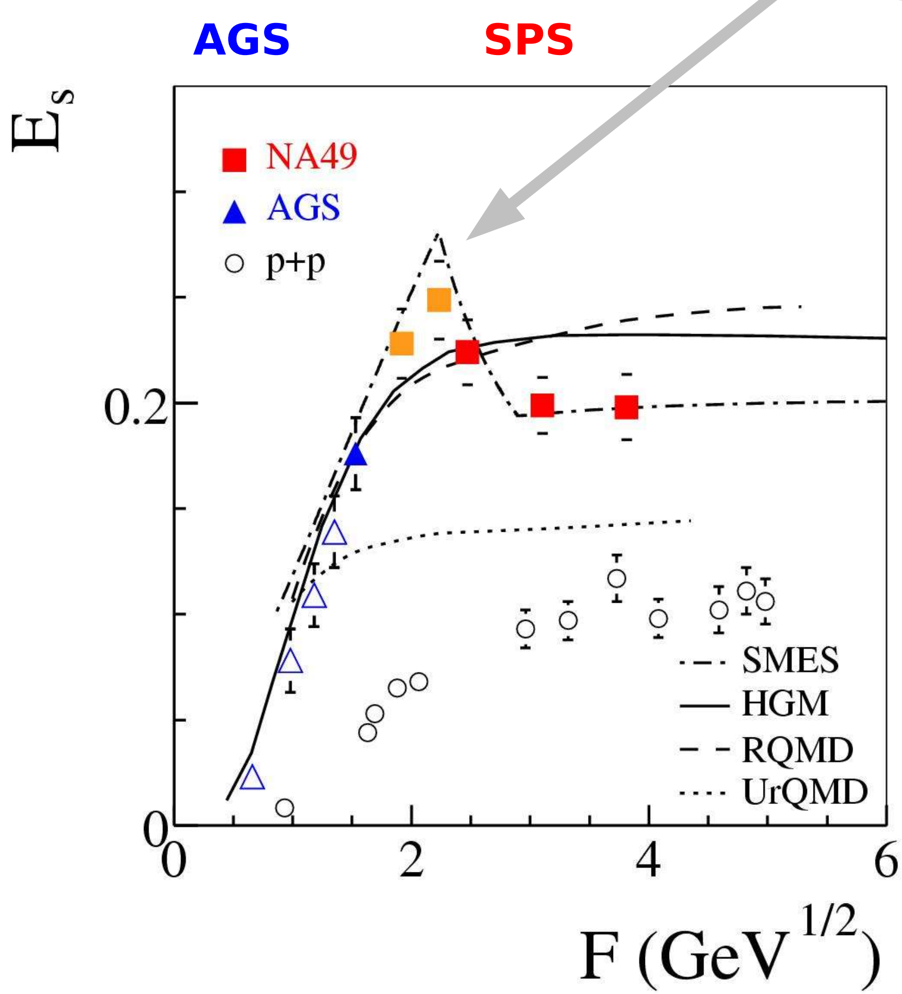
Weaker energy dependence of the shape of transverse mass spectra

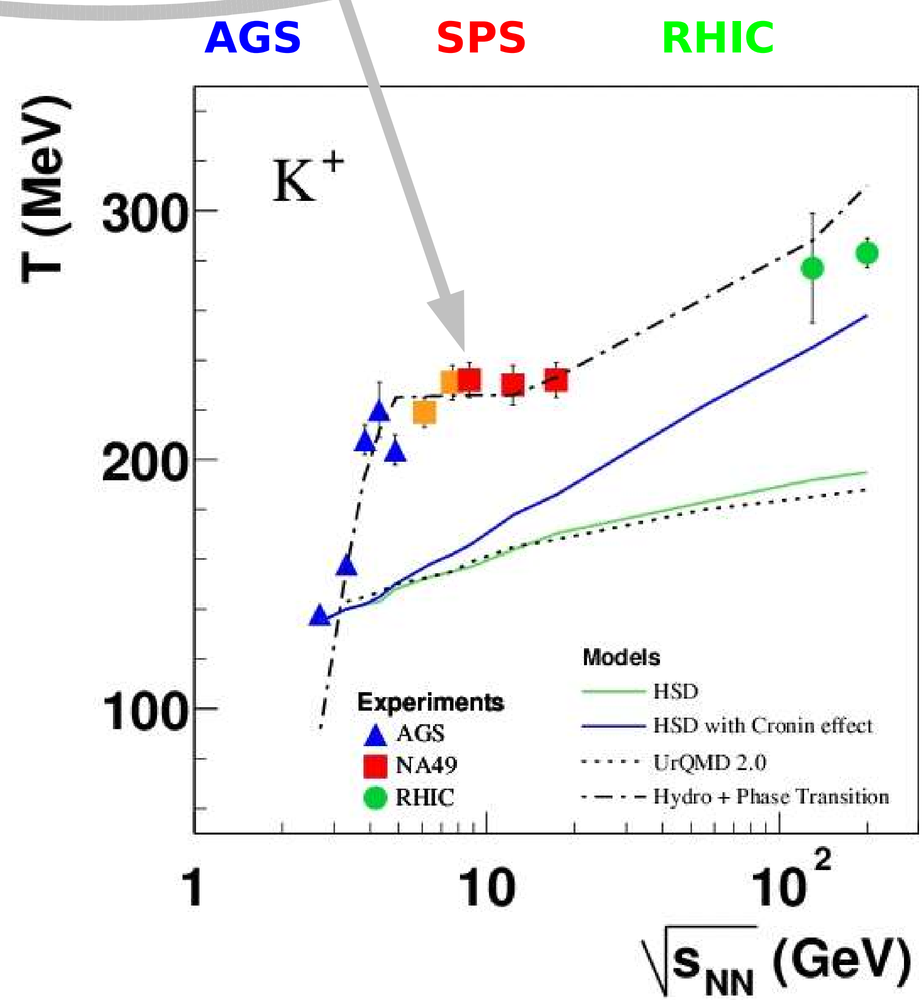
T – inverse slope parameter of transverse mass spectra

Shuryak, van Hove
M.G., Gorenstein

The models

Models with the
1st order phase transition
reproduce the data





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

Summary of ●

I Several anomalies in hadron production are observed at low SPS energies

II The onset of observed anomalies is located at about 30*A* GeV

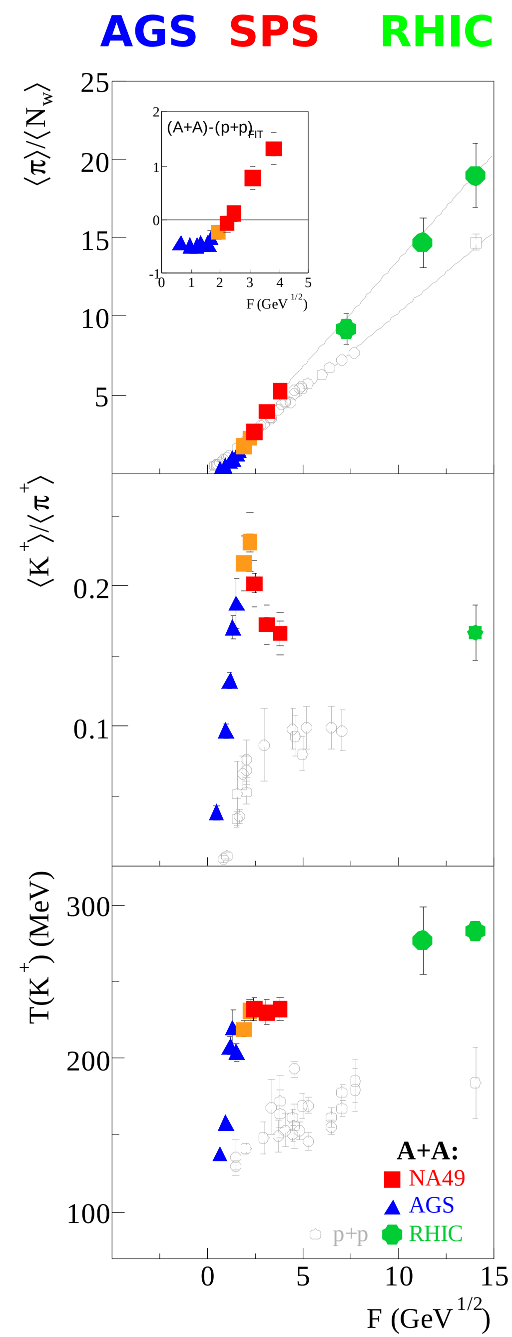
III The anomalies cannot be reproduced by the models without phase transition

IIII Measured rapid changes are consistent with models assuming 1st order PT

↓

FUTURE

hadronic observables



collision energy

FUTURE

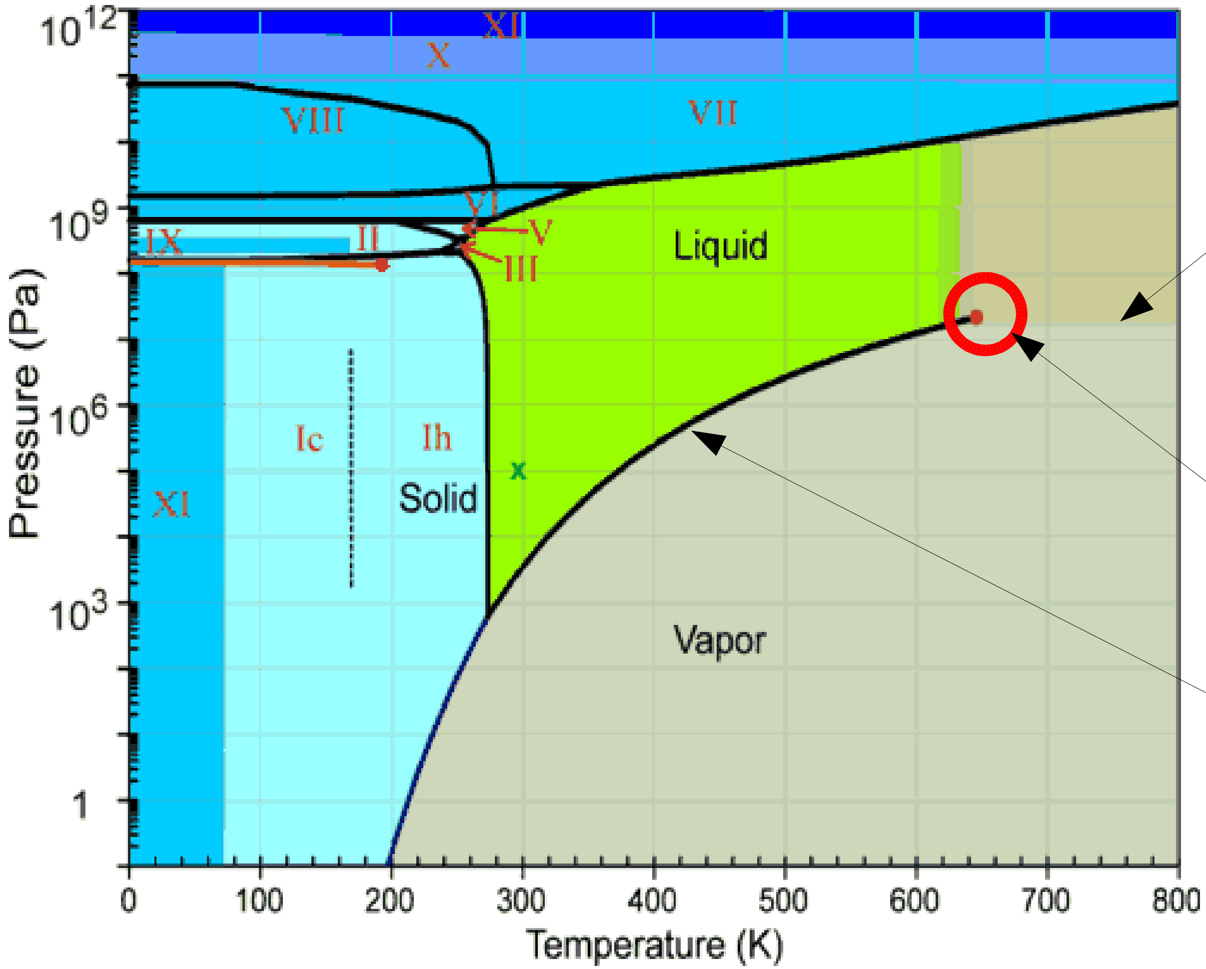
Search for the critical point

- The critical point

- Search for the critical point
  of strongly interacting matter

The critical point

Phase diagram of water



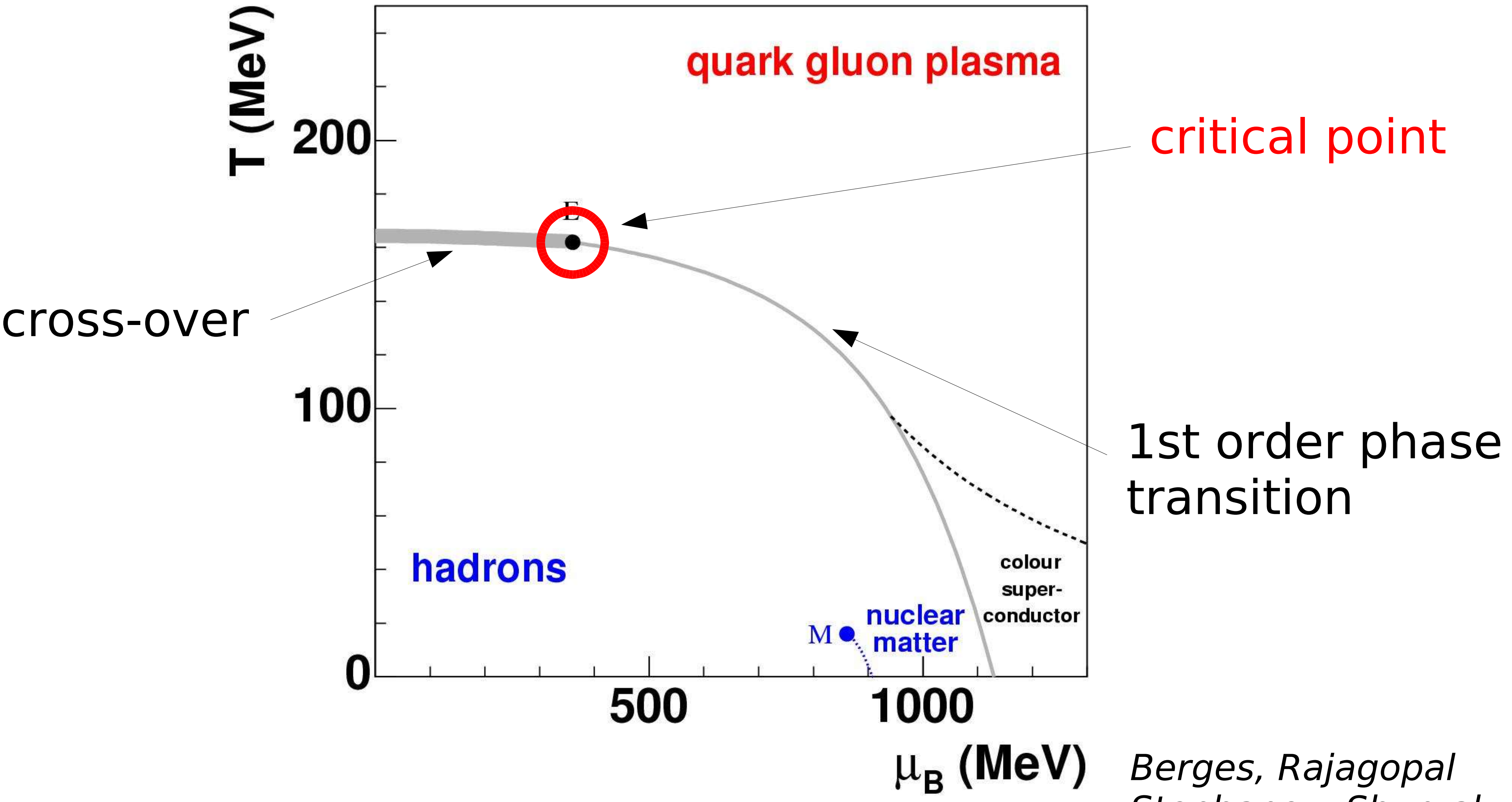
cross-over

critical point

1st order phase transition

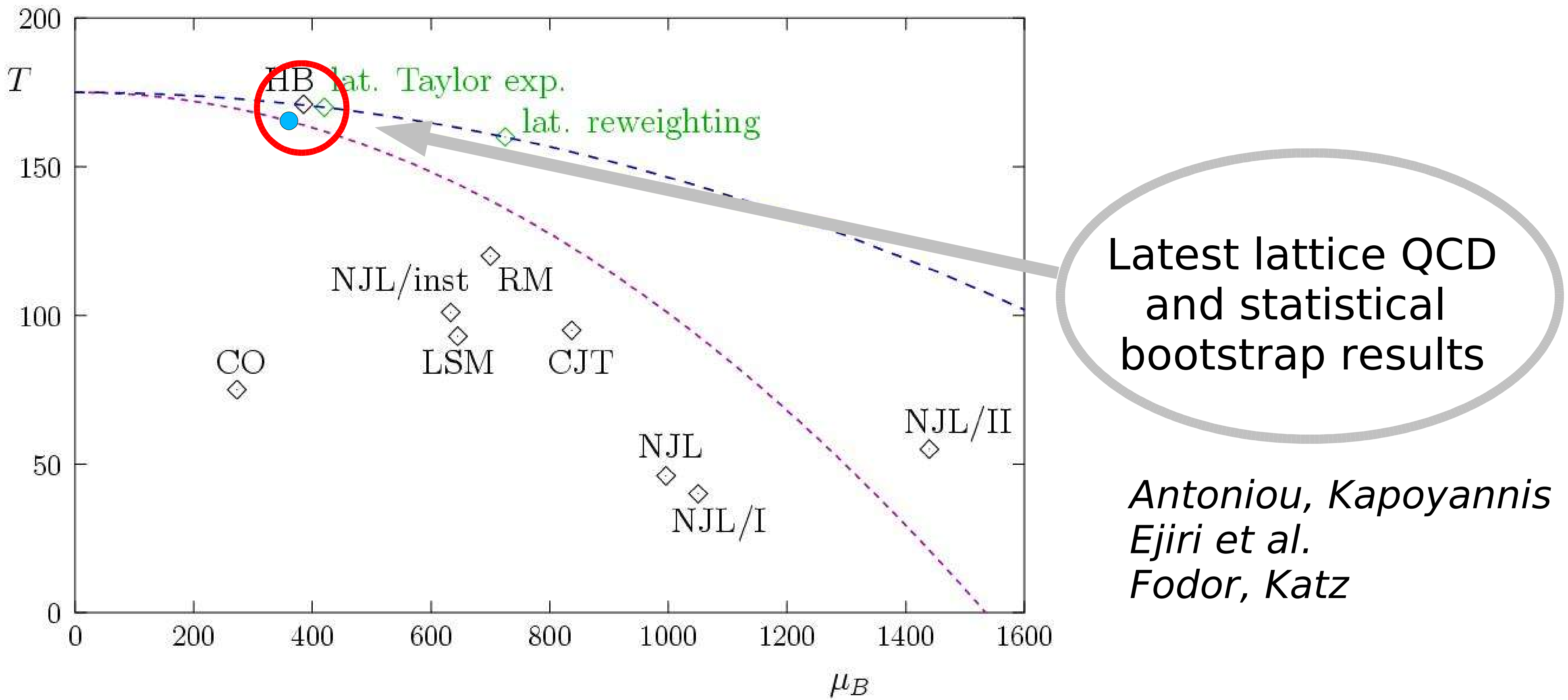
the end point of a 1st order line = a critical point of the 2nd order
(at the critical point the phases start to be indistinguishable)

Phase diagram of strongly interacting matter



Berges, Rajagopal
Stephanov, Shuryak
Wilczek

Location of the critical point - models



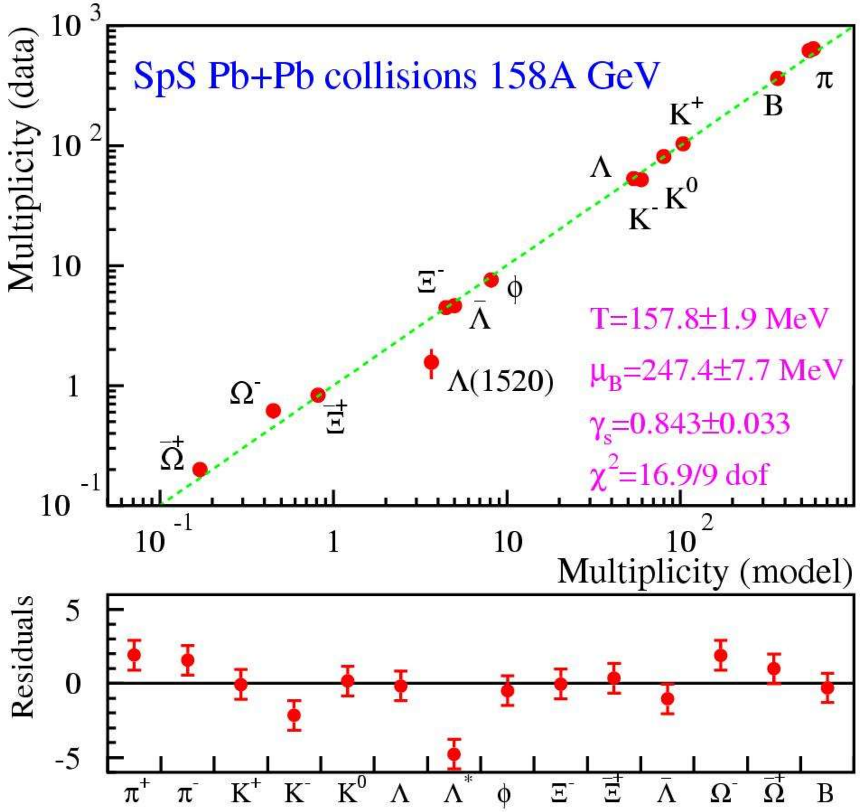
Antoniou, Kapoyannis
Ejiri et al.
Fodor, Katz

Large theoretical uncertainties in the determination of the position of the critical point,
but the most recent results cluster close to (360, 160) MeV

A compilation by Stephanov

Location of the critical point - experiment

Chemical freeze-out parameters



Hadron gas model analysis of hadron multiplicities

T - chemical freeze-out temperature

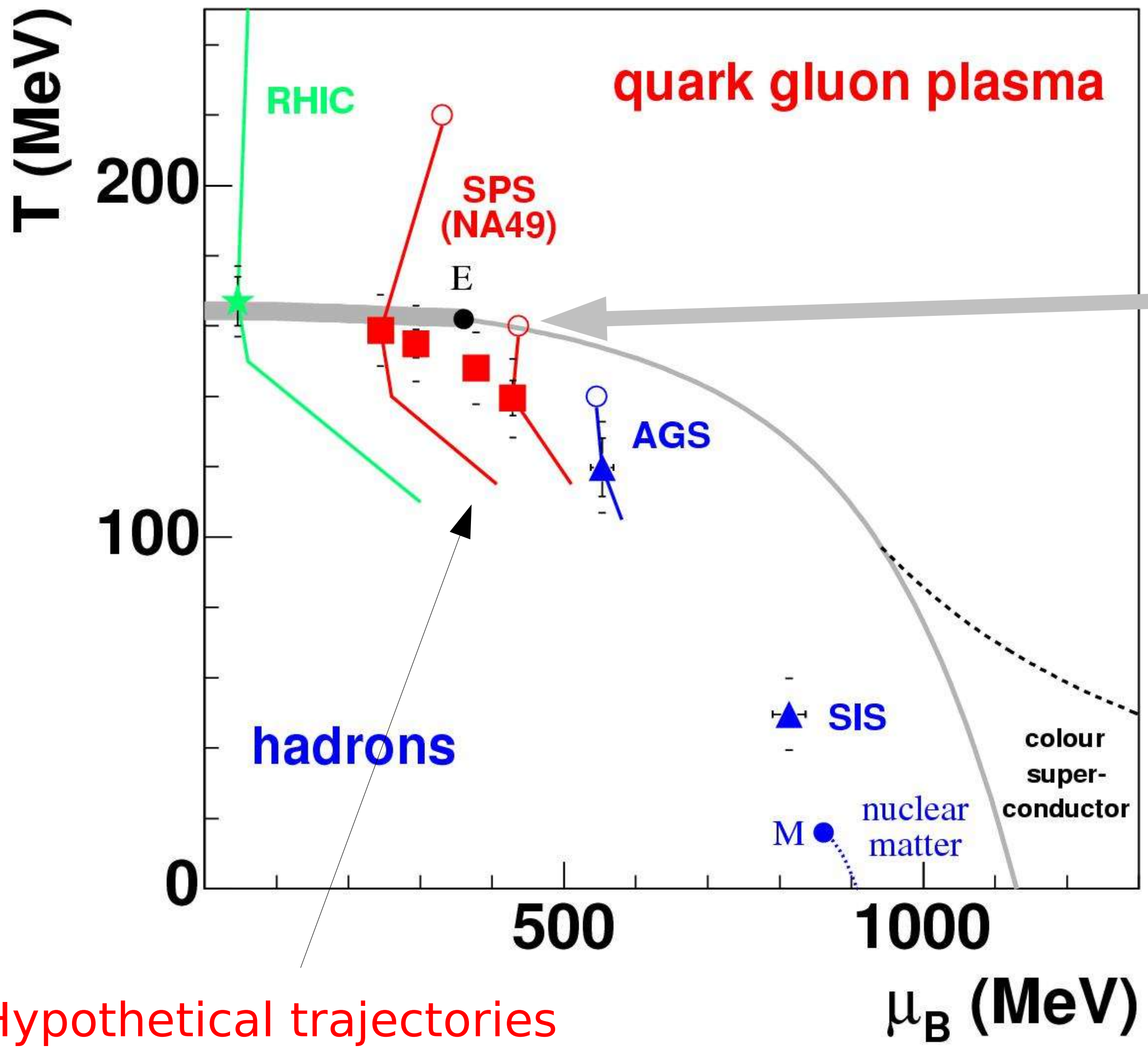
μ_B - baryo-chemical potential

Becattini et al.

Hadrons freeze-out close to chemical equilibrium

T and μ_B mark a point on the trajectory of the expanding matter

Location of the critical point - experiment



Horn, kink, step

Phase boundary reached at 30*A* GeV

If it is a 1st order PT, the critical point should be reachable at higher energies

Hypothetical trajectories of the expanding matter

In the “critical” region matter shows anomalous properties

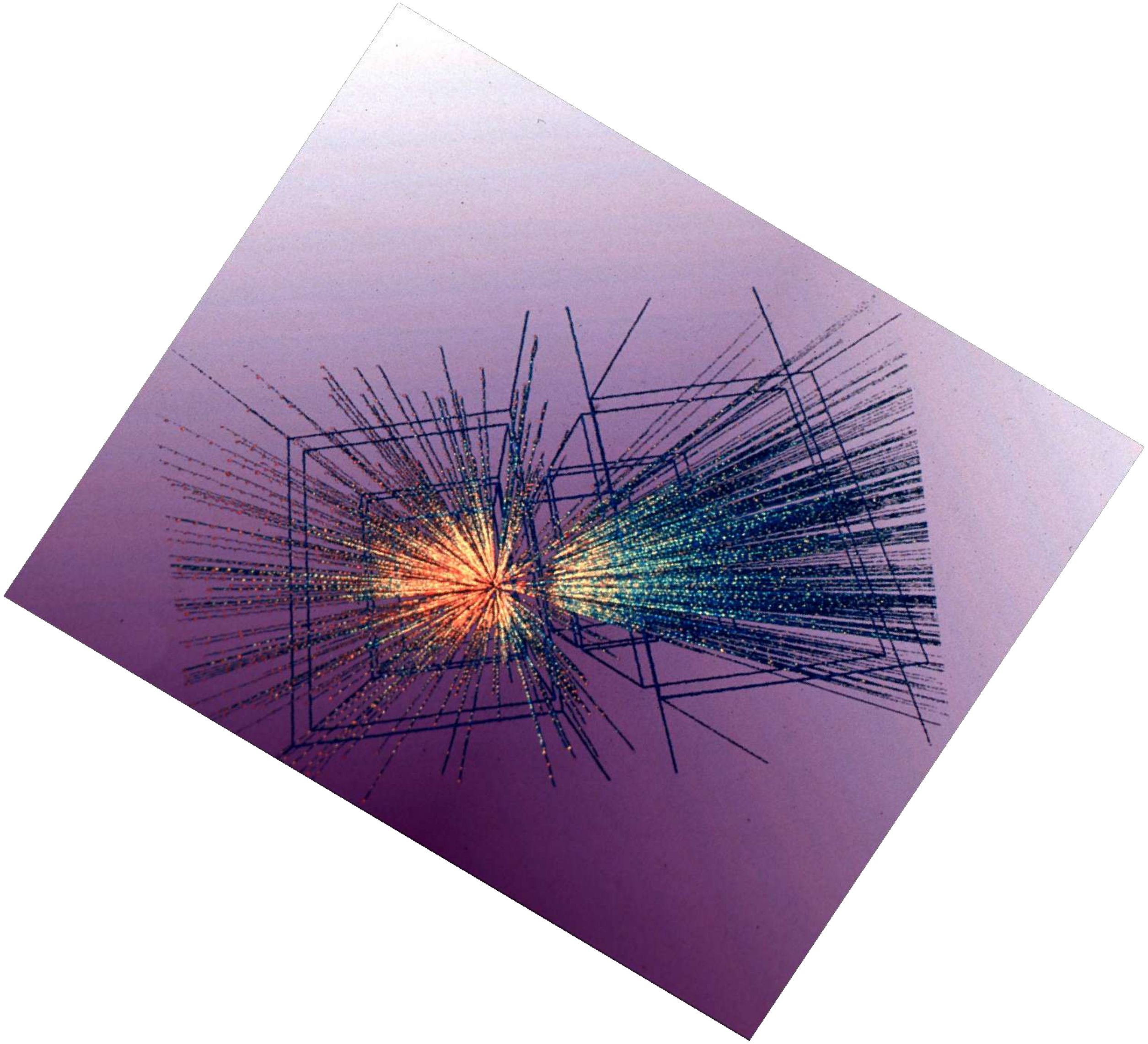
In the case of water large fluctuations in the size of liquid/vapor domains lead to the critical opalescence

Large fluctuations are also expected in the case of strongly interacting matter close to the critical point

Stephanov, Shuryak, Rajagopal
Antoniou, Kapoyannis

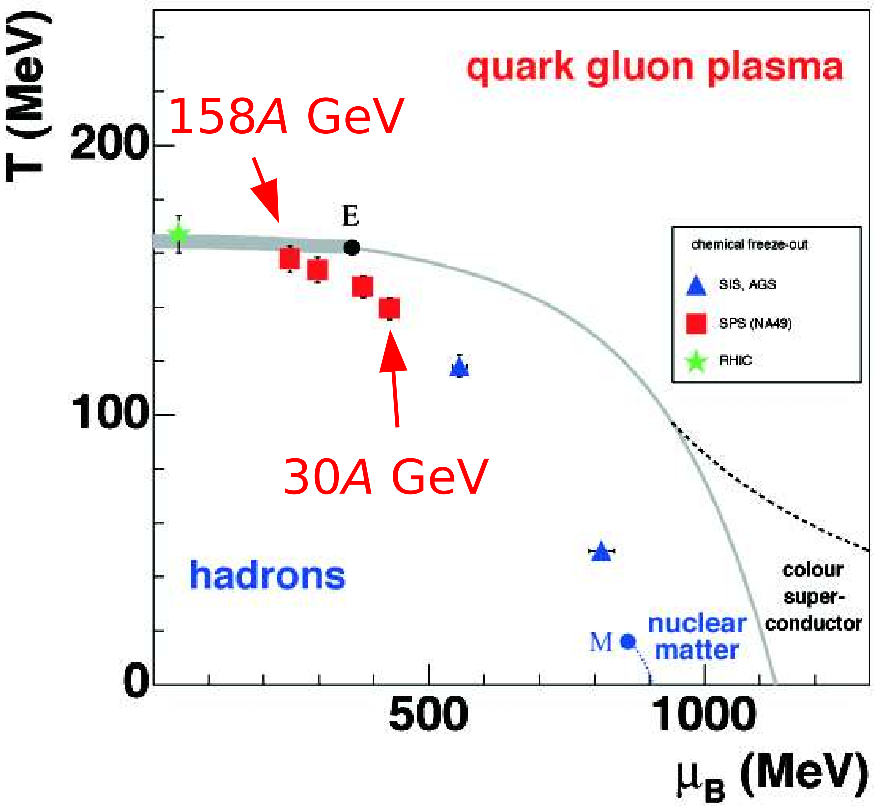
The critical point may be “seen” provided the freeze-out (observation) point is close to it

Search for the critical point of strongly interacting matter

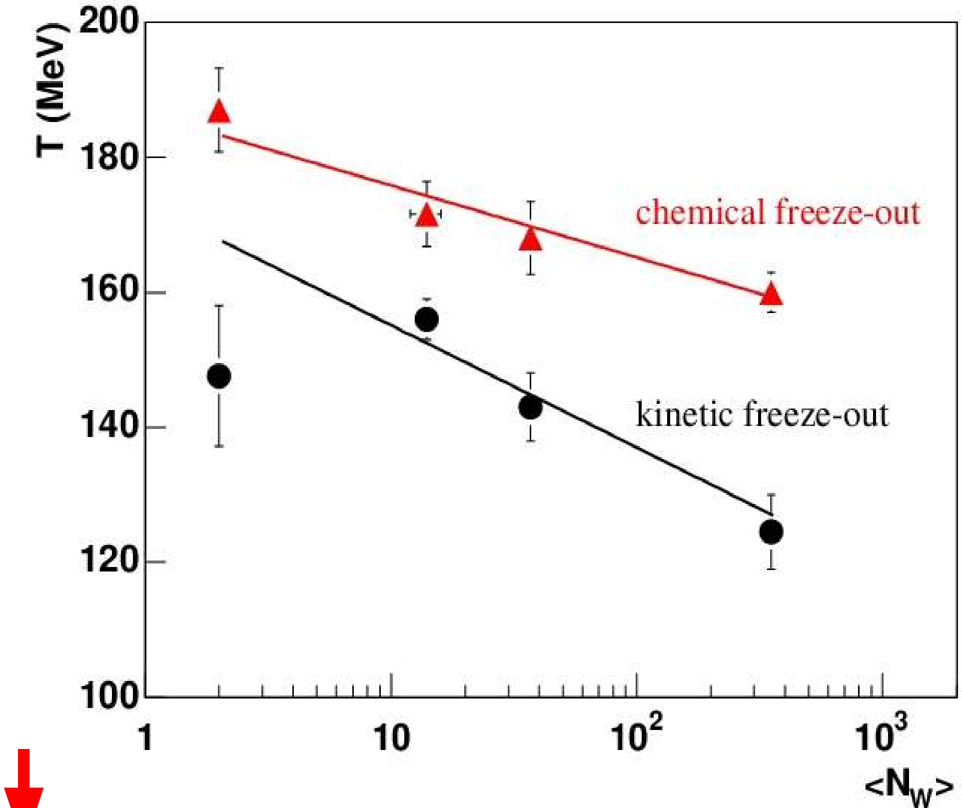


The position of chemical (and kinetic) freeze-out points depends on collision energy and system size

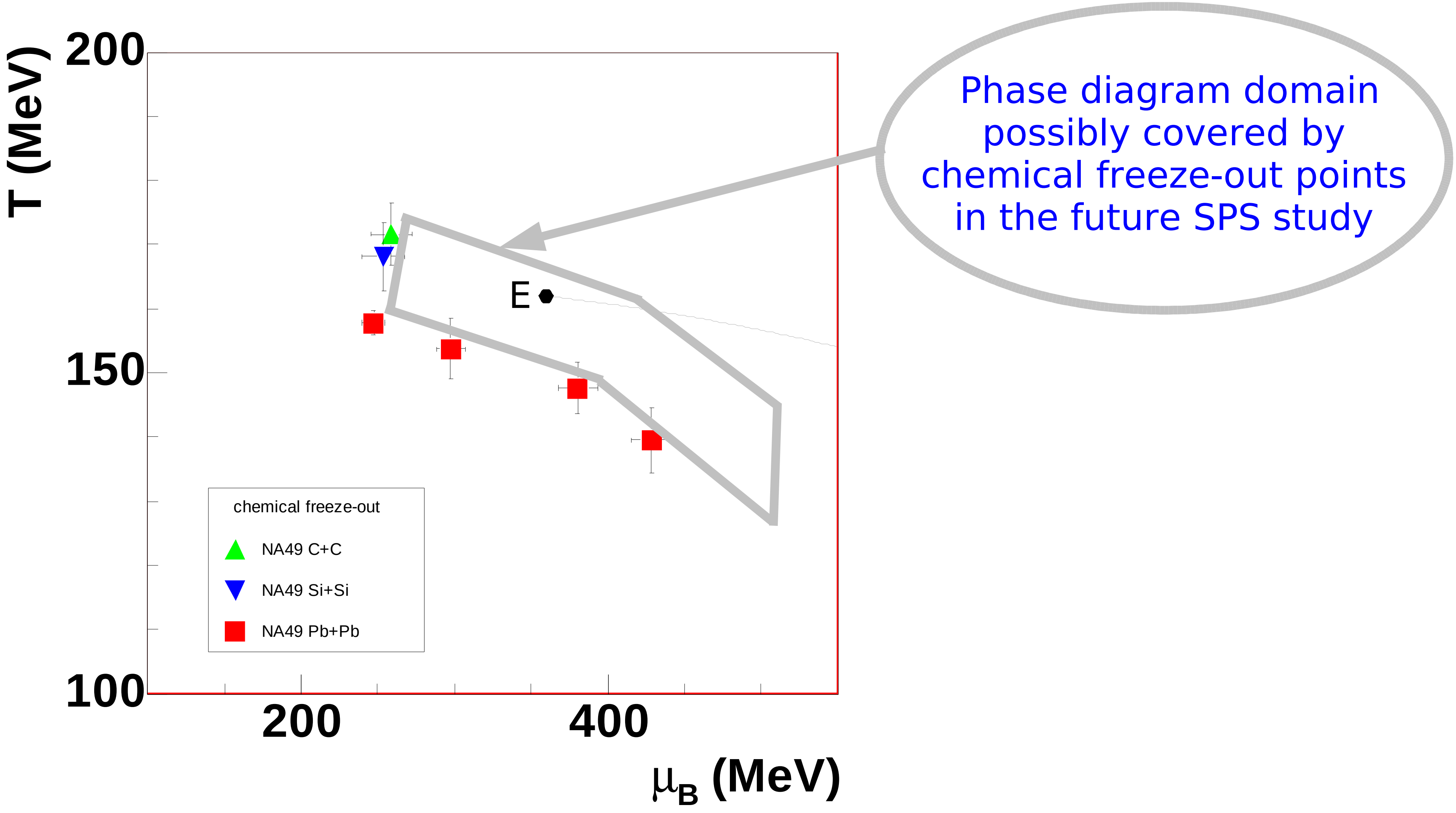
central Pb+Pb collisions at different energies



p+p, C+C, Si+Si, Pb+Pb collisions at 158*A* GeV

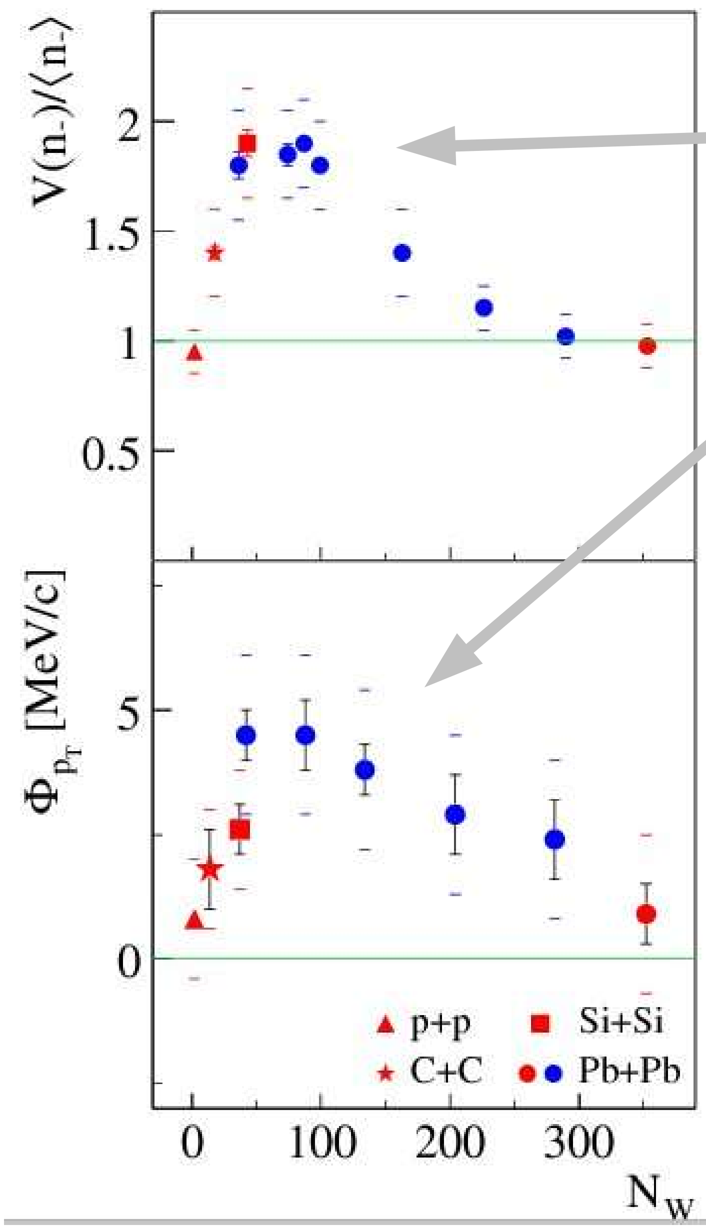


(collision energy) - (system size) scan = T - μ_B scan


T (MeV)
200
150
100
200
400
μ_B (MeV)
E
chemical freeze-out
NA49 C+C
NA49 Si+Si
NA49 Pb+Pb
Phase diagram domain possibly covered by chemical freeze-out points in the future SPS study

Pilot data on fluctuations

A+A at 158*A* GeV

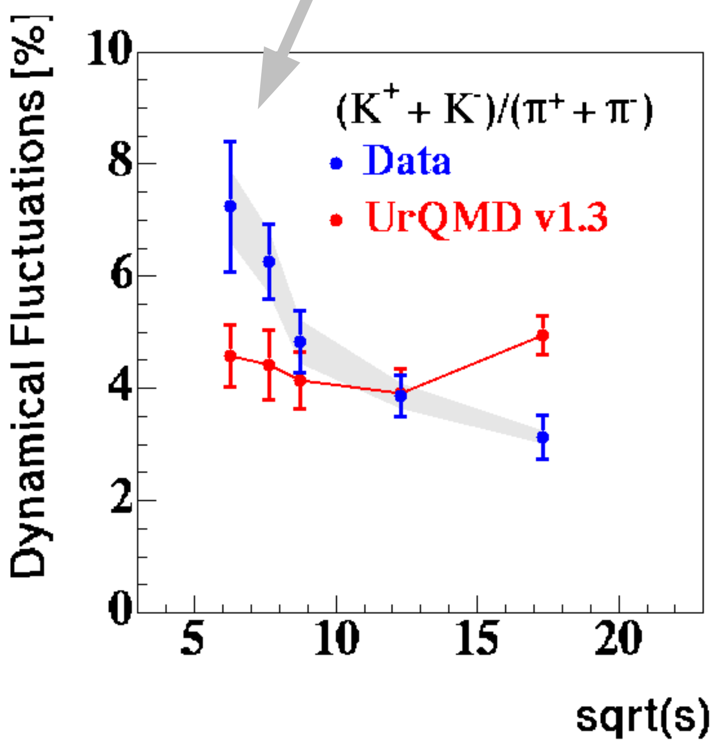


What is the physics of the measured large fluctuations?

The critical point?

The onset of deconfinement?

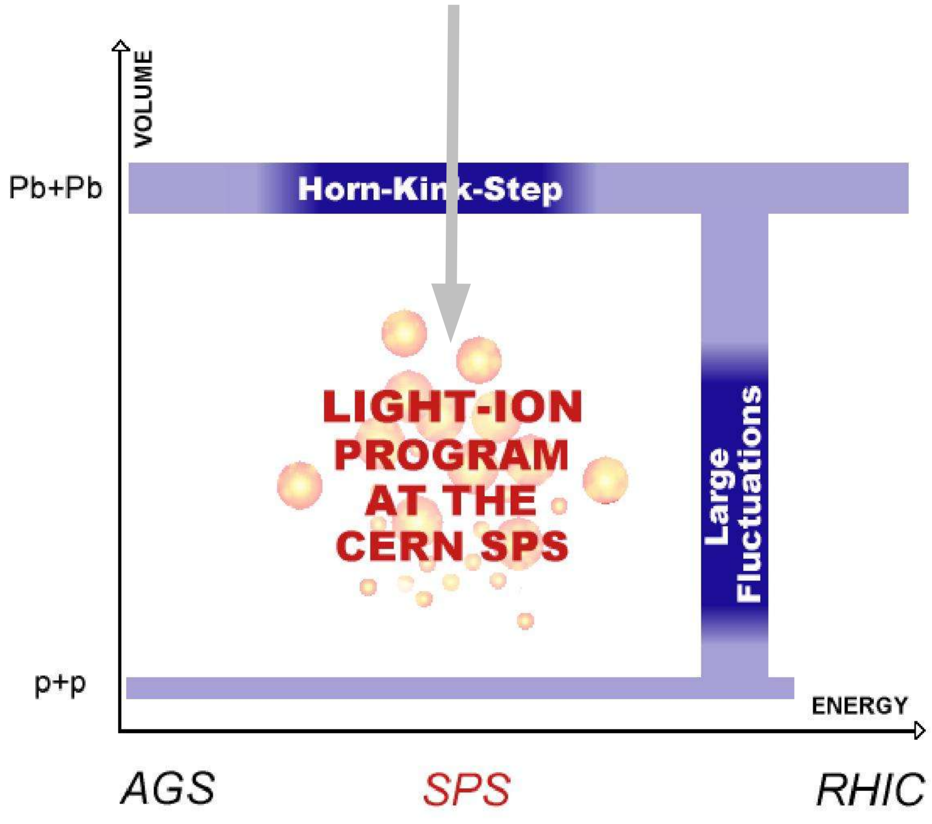
cent. Pb+Pb at 20-158*A* GeV



Summary of ● ●

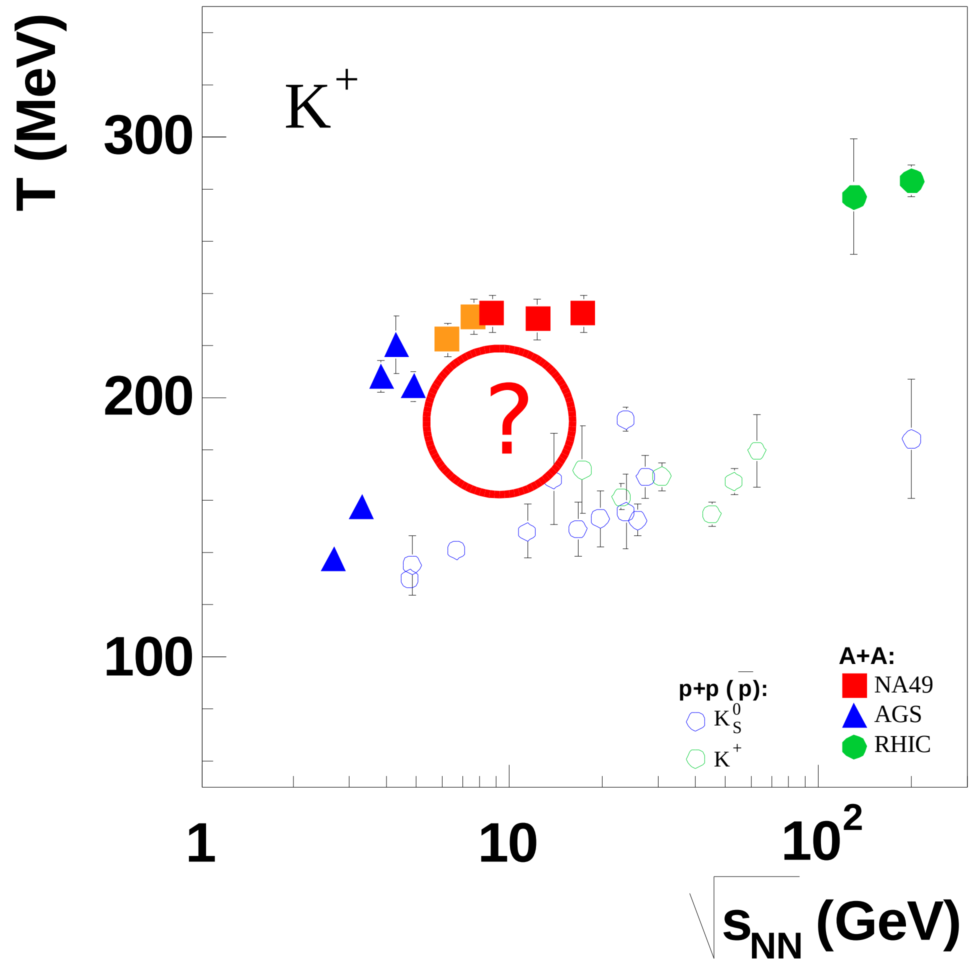
Search for the critical point

(collision energy)-(system size) scan



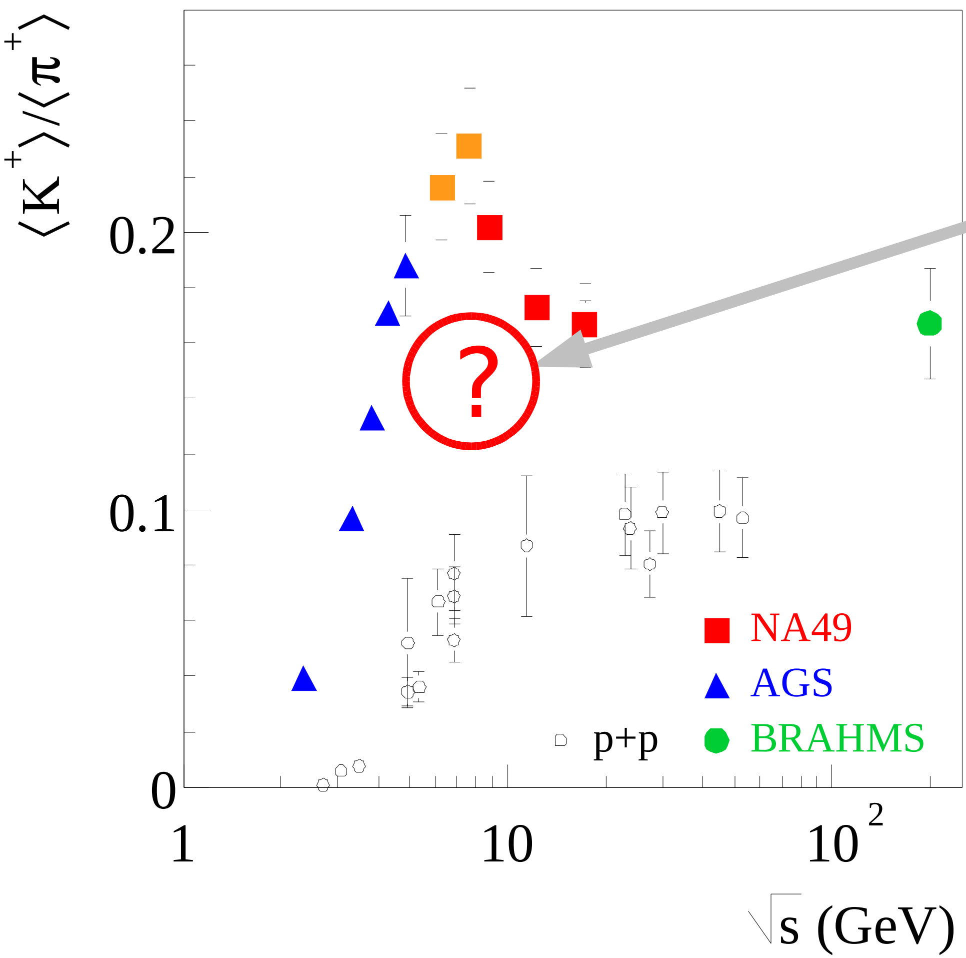
FUTURE

Role of volume and density in deconfinement



Pb+Pb

p+p

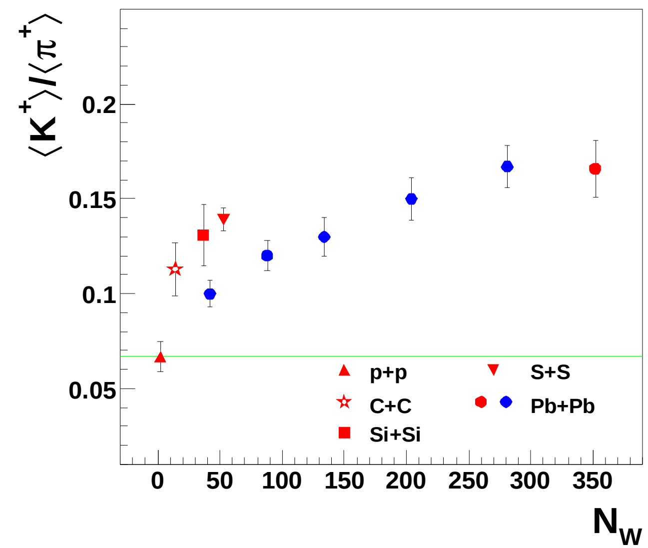


Pb+Pb

p+p

How does the transition from p+p to Pb+Pb look like?
What is the physics of it?

First data on A+A at 158*A* GeV



Steep rise followed by a saturation

increase of the volume of matter

p+p $\longrightarrow$ central Pb+Pb

increase of the density of matter

Related physics,

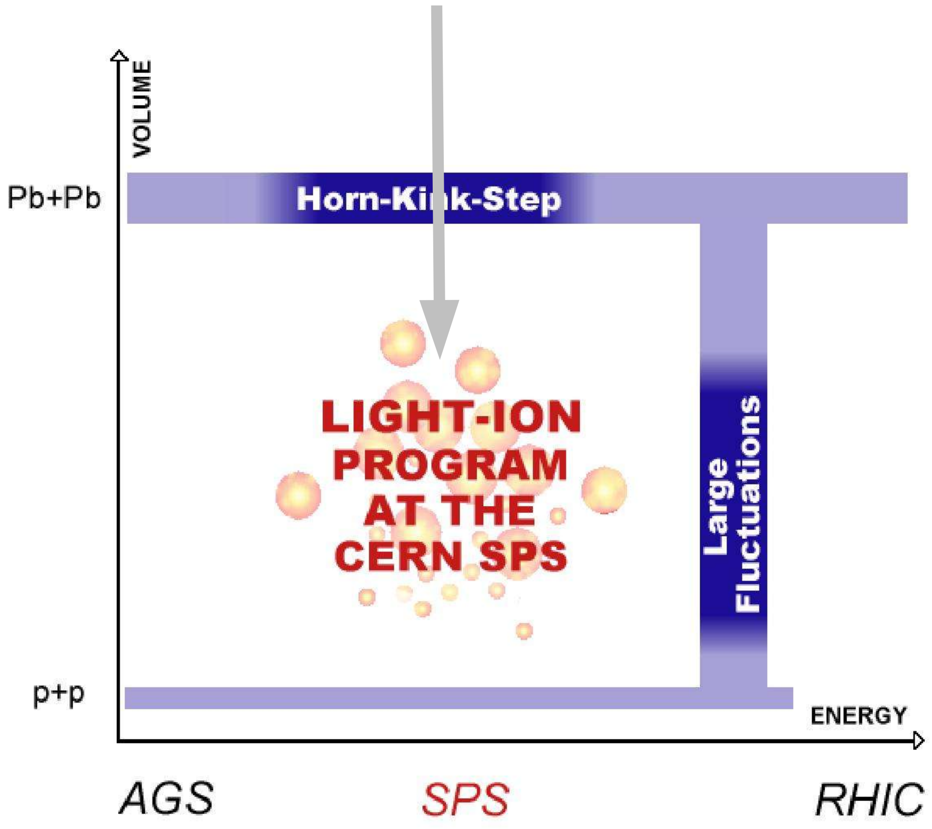
- deconfinement PT, *Becattini, Bugaev*
- percolation, *Satz*
- influence of conservation laws, *Rafelski, Redlich* *Becattini*
- ?,

has to be studied for a full understanding of the deconfinement phase transition in central Pb+Pb collisions

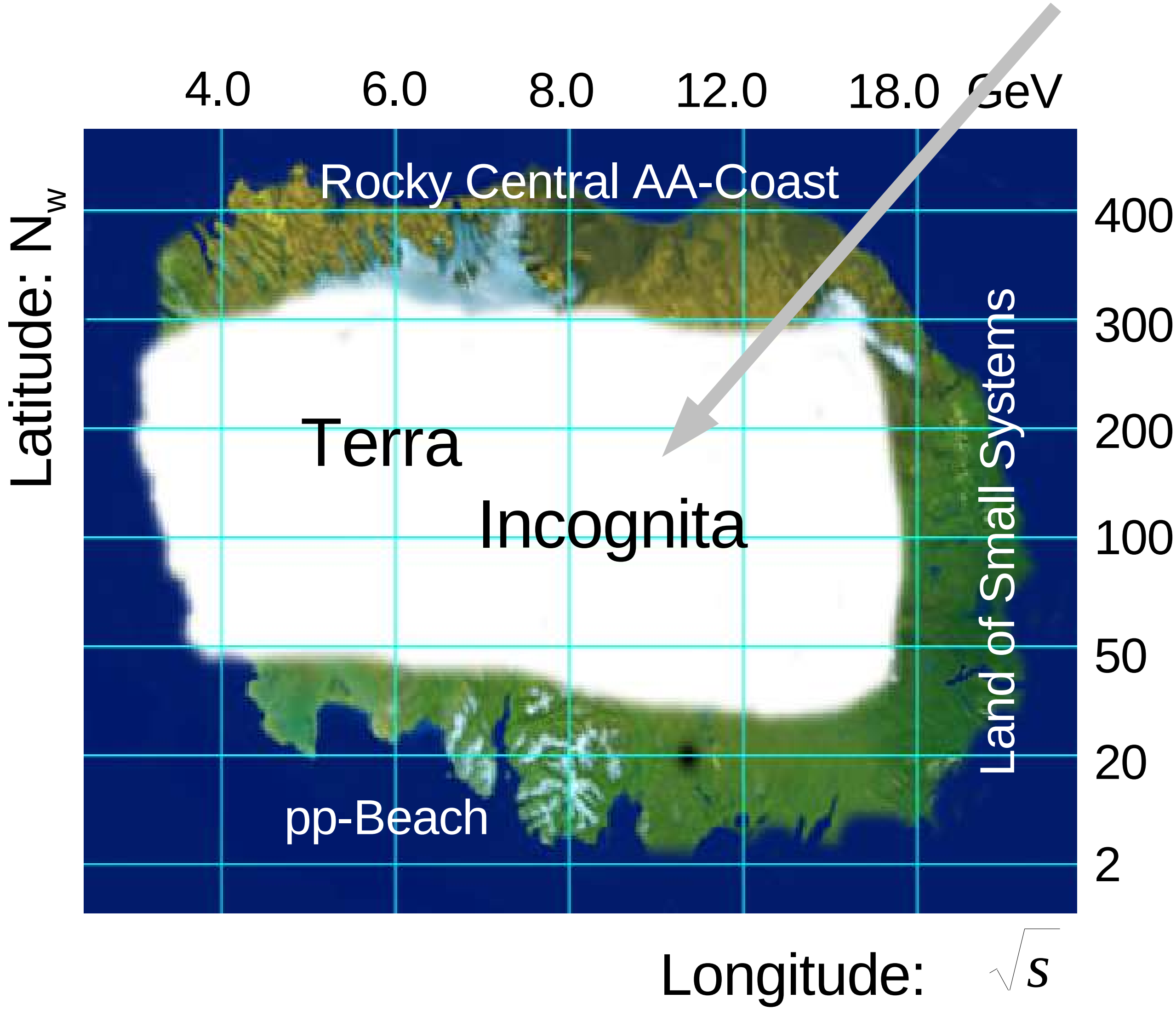
Summary of ●●●

Role of volume and density in deconfinement

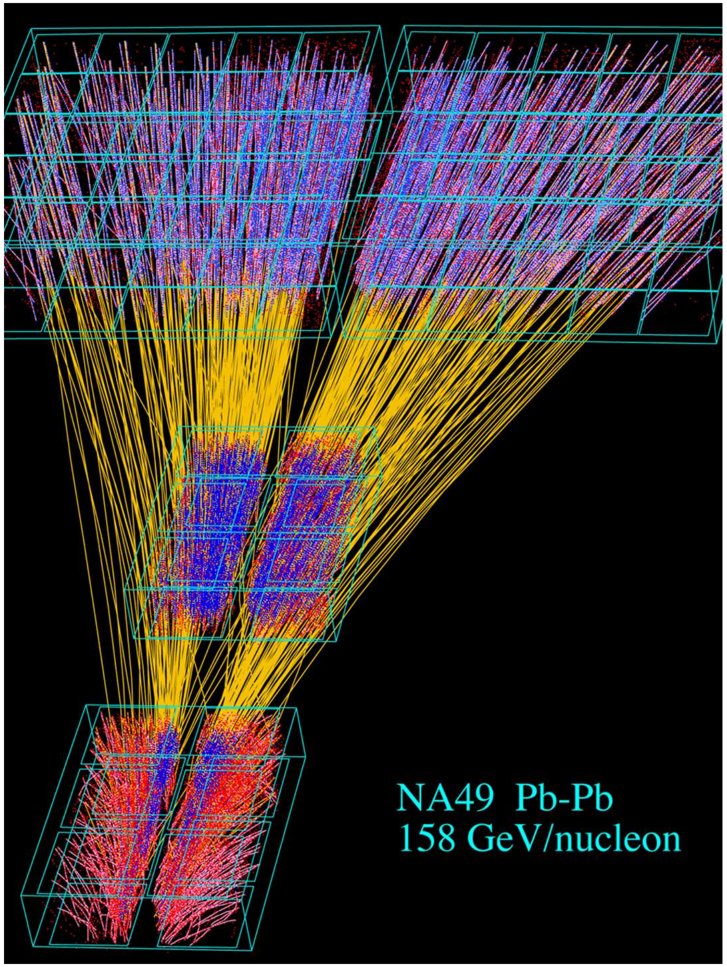
(collision energy)-(system size) scan



Possible experiments: NA49-future and others



NA49-future at the CERN SPS

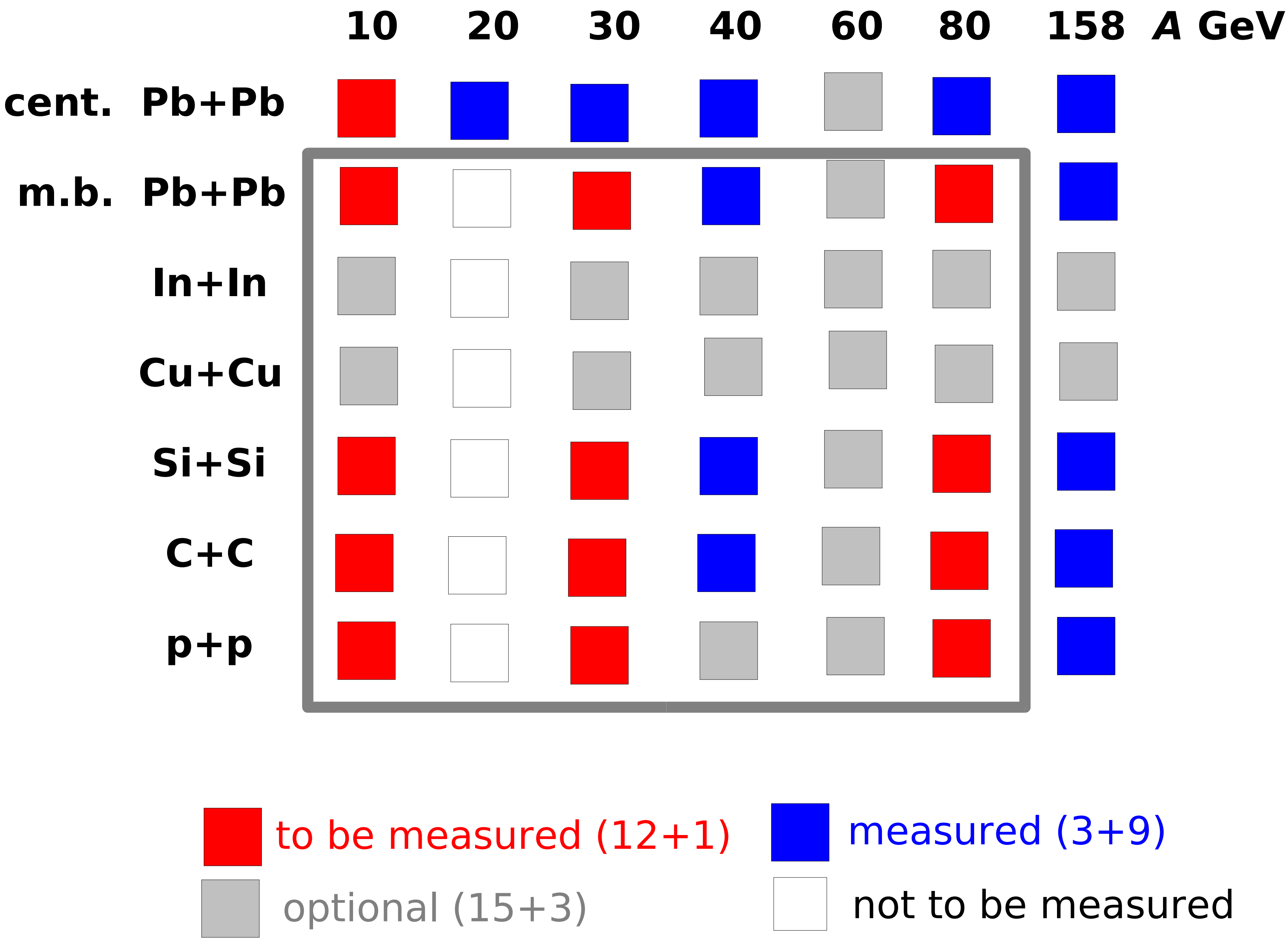


NA49 at the CERN SPS
is almost the ideal facility for
the measurements needed
in the near future (2006-...)

SPS covers the most important energy domain (10 - 158*A* GeV) and it allows the acceleration of nuclei from p to Pb

NA49, due to large acceptance, high momentum resolution and good particle identification, allows to measure the relevant observables (inclusive spectra and fluctuations)

Light ion program at the CERN SPS



Requested ions in SPS:

- minimal request: p and Pb
  (C and Si from Pb fragmentation)
- maximal request: p, C, Si, Cu, In and Pb

Requested energies:

- minimal request: 10, 30, 80 *A* GeV
- maximal request: 10, 30, 40, 60, 80, 158 *A* GeV

Total running time (minimal request):

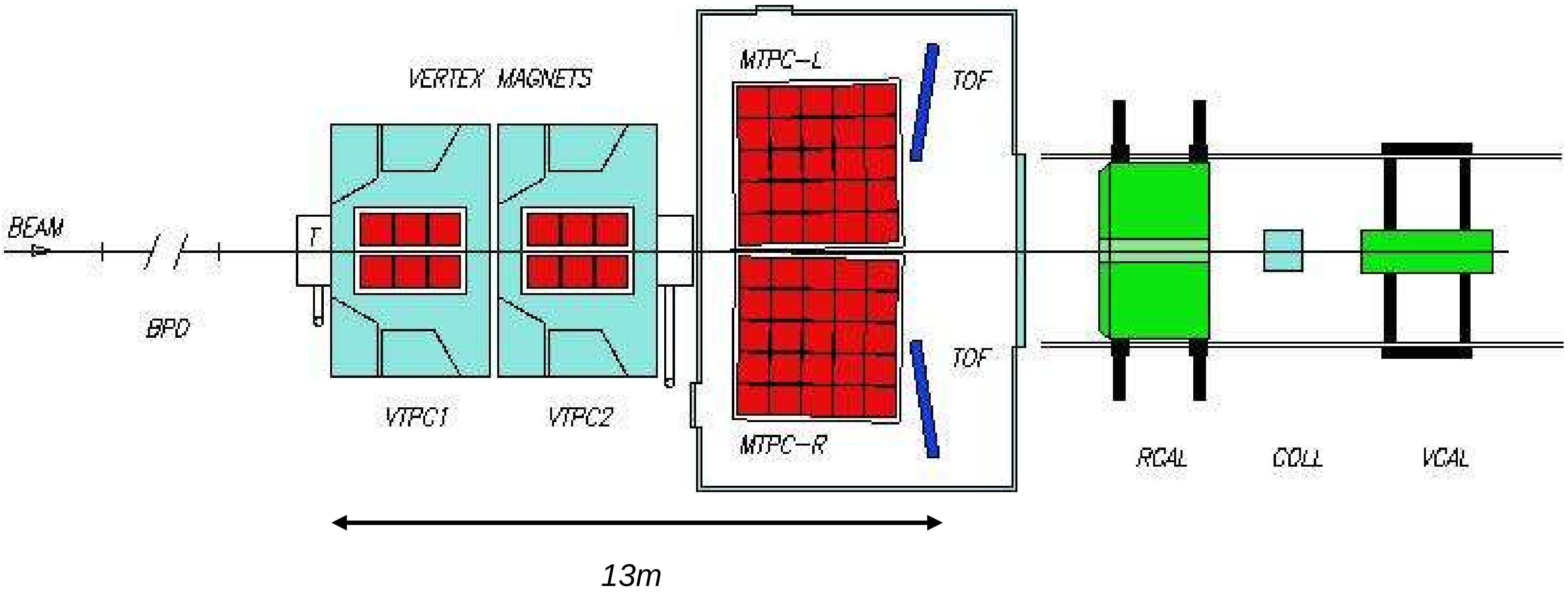
- about 2 months of Pb beam
  (4 days per point, 500k events)
- about 1 month of p beam
  (10 days per point, 1M events)

NA49 detector upgrades and maintenance:

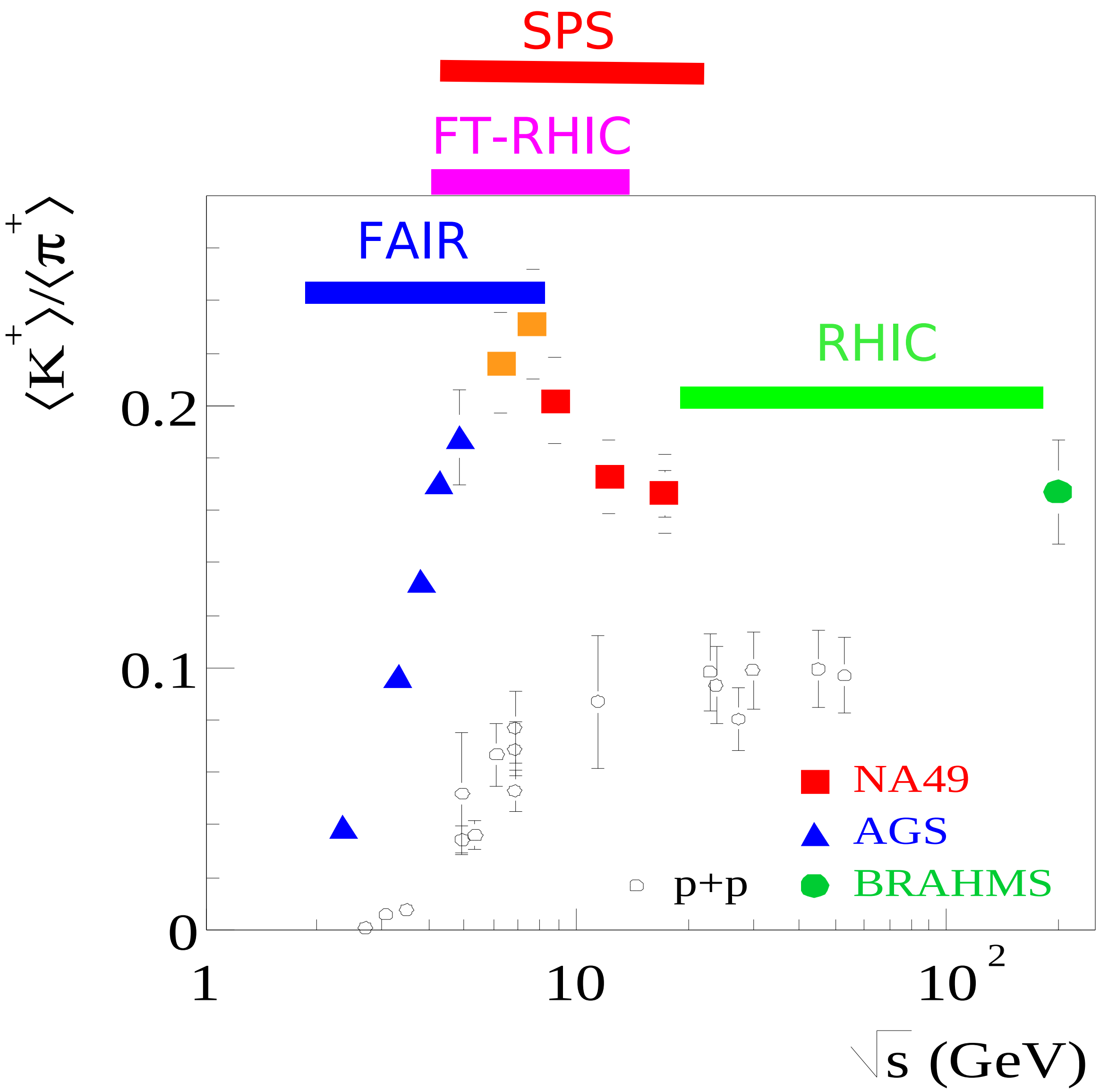
-material cost about 500k CHF

-manpower 5 man-years

-duration about 1.5 years



Possible future experimental landscape



FT-RHIC – Fixed Target program at RHIC

under discussion is the use of the BRAHMS detector and a jet target which should allow to study identified hadron spectra in A+A collisions in the energy range 10-100*A* GeV

+can be performed parallel to the collider runs

+almost continuous energy spectrum

- low priority as a parasitic program
- narrow acceptance, only inclusive spectra of identified charged hadrons, no fluctuations!

FAIR – Facility for Antiproton and Ion Research in Darmstadt

the proposed project should allow to study nuclear collisions in the energy range 2-35*A* GeV starting from 2012

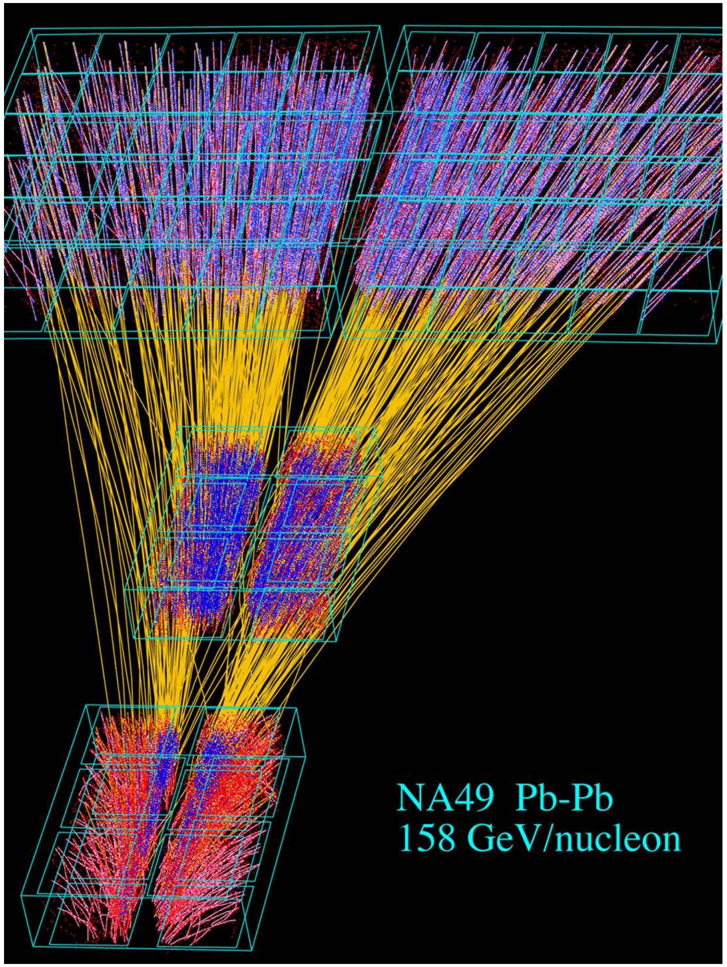
+very high intensity beams, low cross section observables

+study of the properties of dense hadronic medium

-transition energy range is not covered, the critical point is probably not reachable

-first data after 2012

NA49-future at the CERN SPS



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Summary

Light Ion program at the CERN SPS

urgently needed

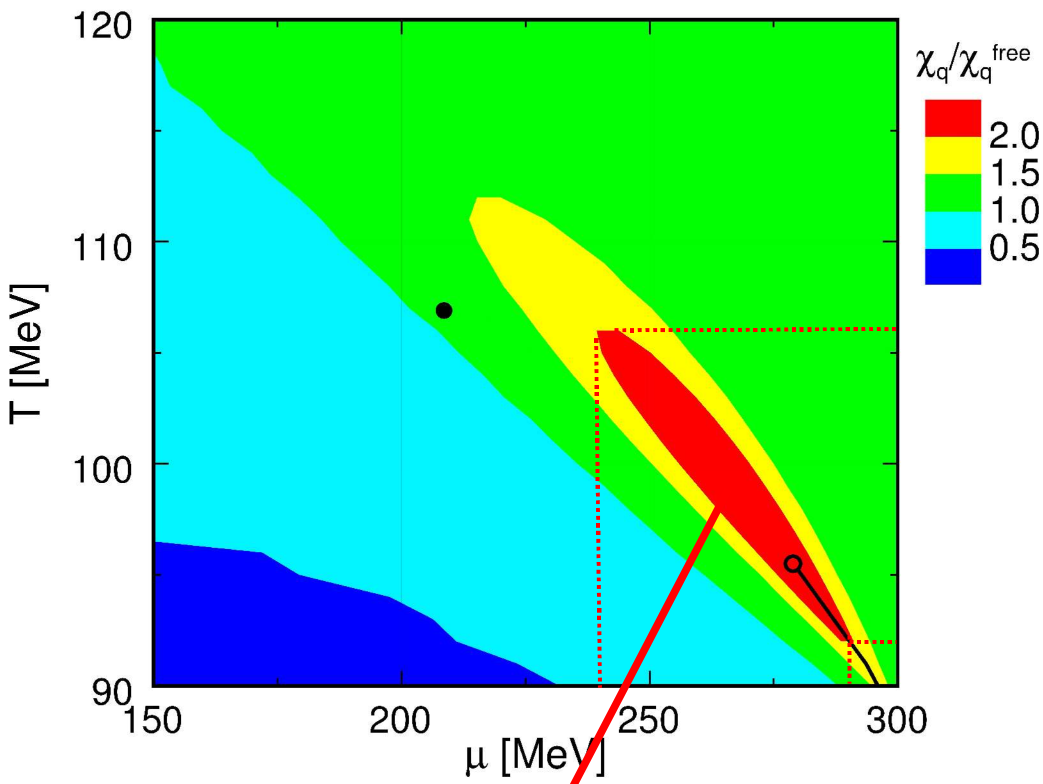
to discover the critical point
of strongly interacting matter

to uncover the properties of deconfinement

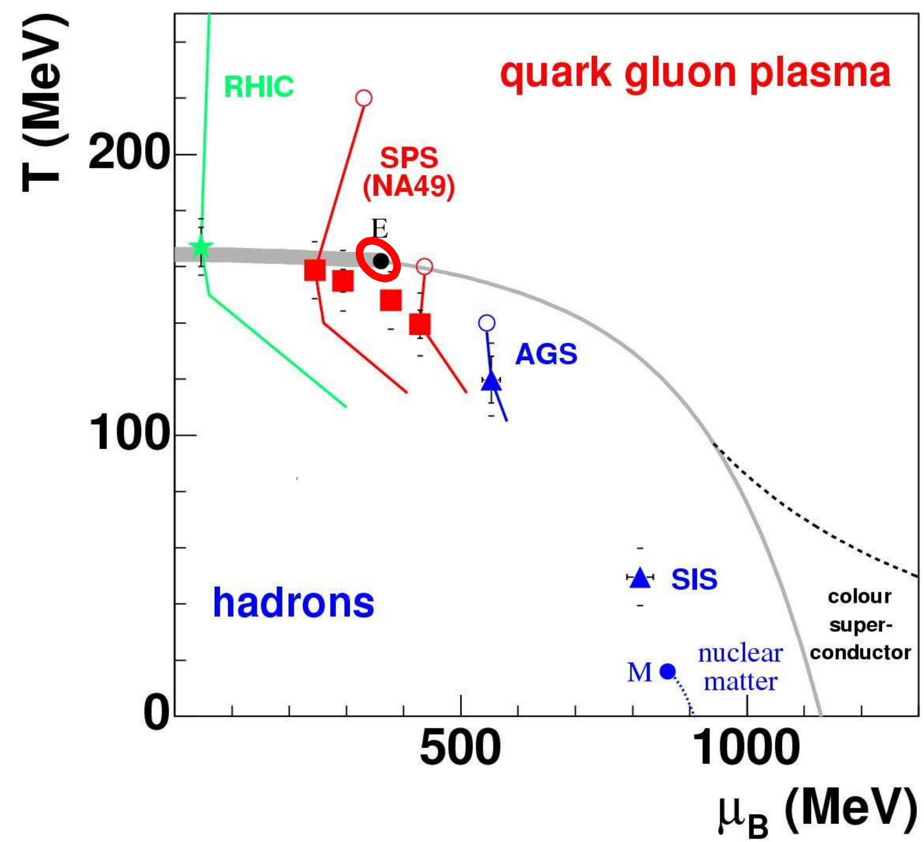
We have the unique opportunity for
a new exciting study at the CERN SPS

Additional slides

Size of the "critical" region



Hatta, Ikeda

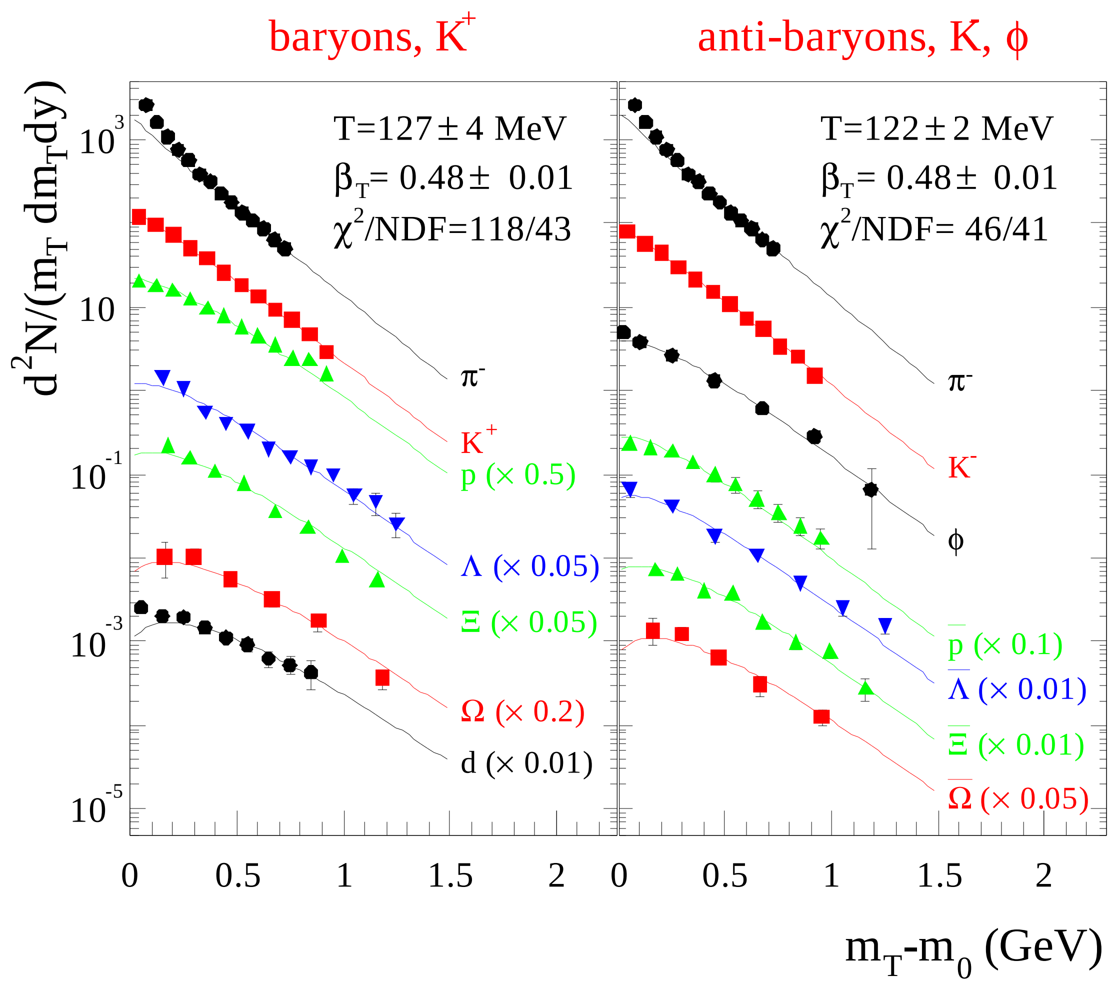


$$\Delta T \approx 15\,\mathrm{MeV}$$

$$\Delta \mu_B \approx 50\,\mathrm{MeV}$$

The size of the critical region is comparable with the distance between the chemical freeze-out points measured at 40 and 80*A* GeV

Kinetic freeze-out parameters



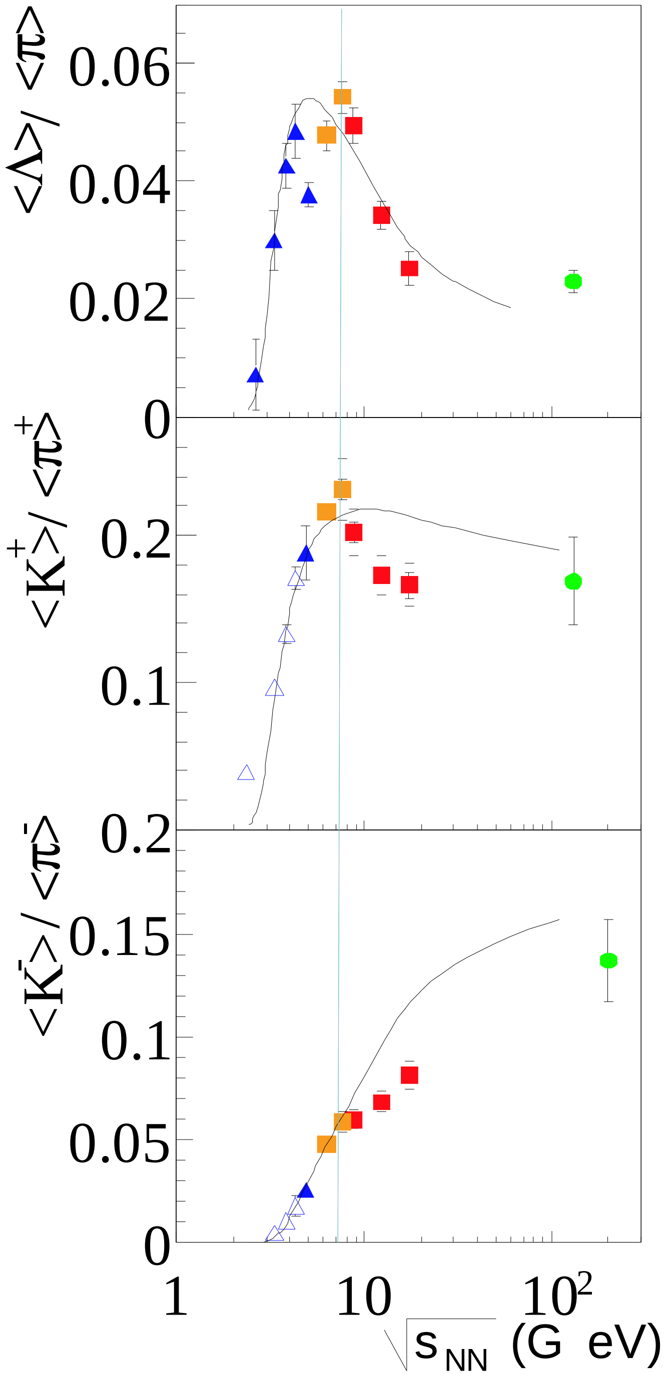
fits of hydrodynamic inspired parametrization

T - kinetic freeze-out temperature

β_T - transverse flow velocity

Schnederman, Heinz

Hadrons freeze-out close to local kinetic equilibrium



<Λ>/<π>
0.06
0.04
0.02
0
<K+>/<π+>
0.2
0.1
<K->/<π->
0.2
0.15
0.1
0.05
0
1
10
10^2
√sNN (G eV)

main strangeness carriers

strangeness conservation

s = $\bar{s}$

isospin symmetry

$K^+ \approx K^0$

isospin symmetry

$K^- \approx \bar{K}^0$

$\vee$
$\vee$

$\wr\wr$

high baryon density

$\bar{\Lambda}$ << Λ

sensitive to strangeness content only

sensitive to strangeness content and baryon density

Isospin effect