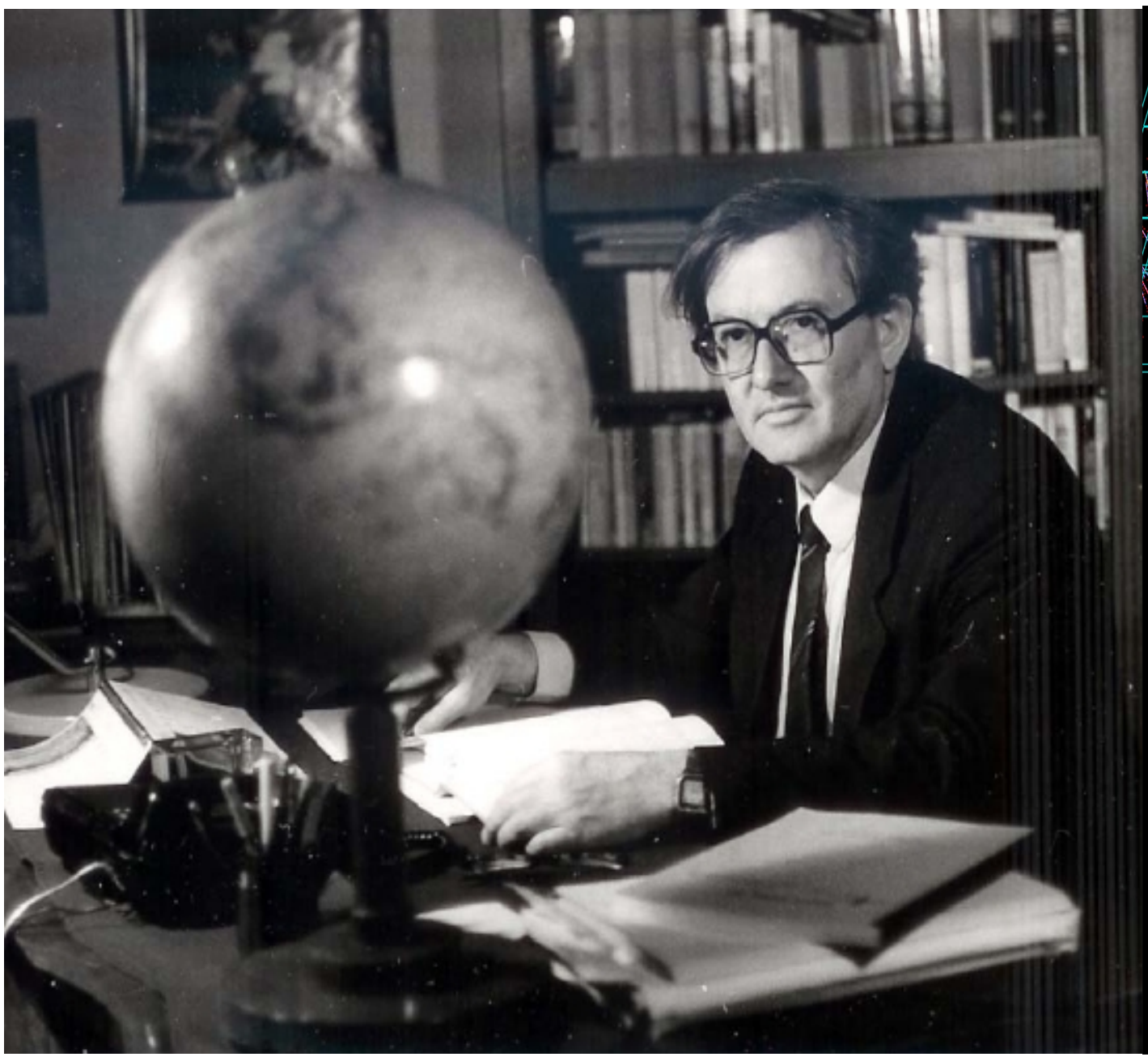
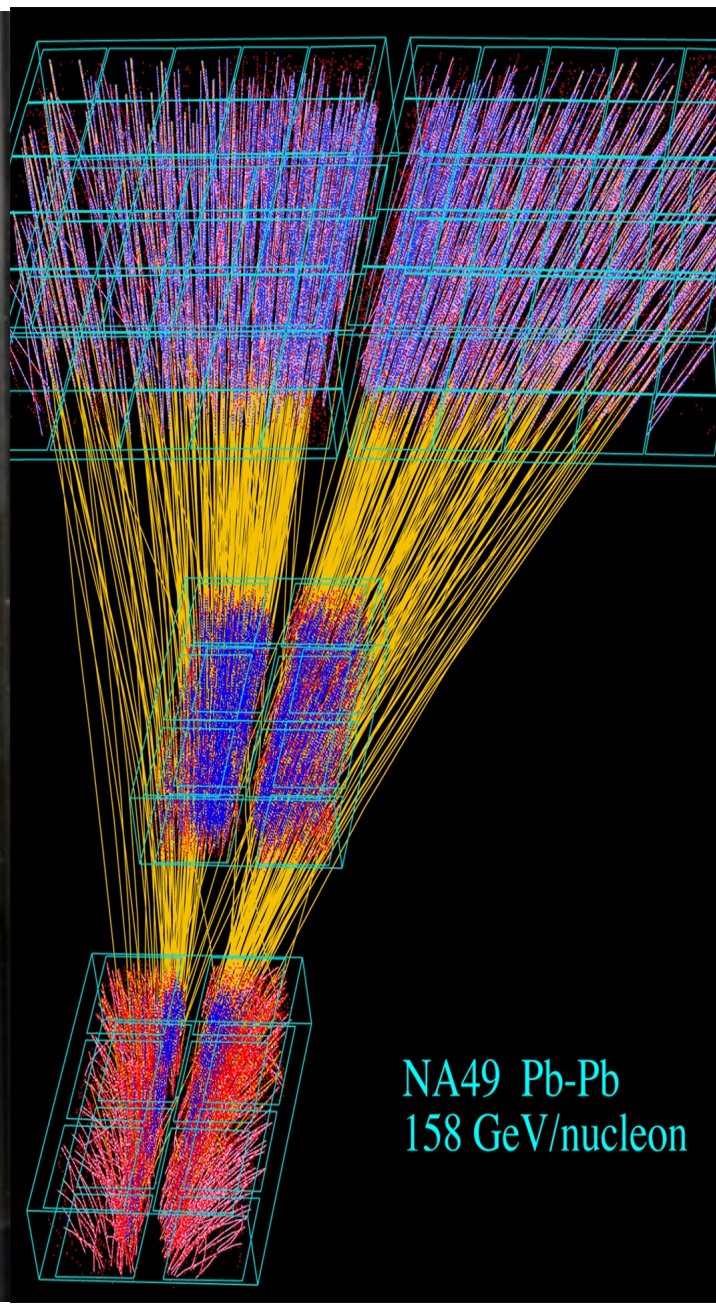
Onset of Deconfinement and Critical Point: NA49 and NA61/SHINE at the CERN SPS

József Zimányi and NA49

- Observation of the onset of deconfinement
- Search for the critical point

M. Gazdzicki
Frankfurt,Kielce





József Zimányi one of the founders of NA49

József Zimányi and NA49:

-established strong scientific and financial participation of the Budapest group in NA49,

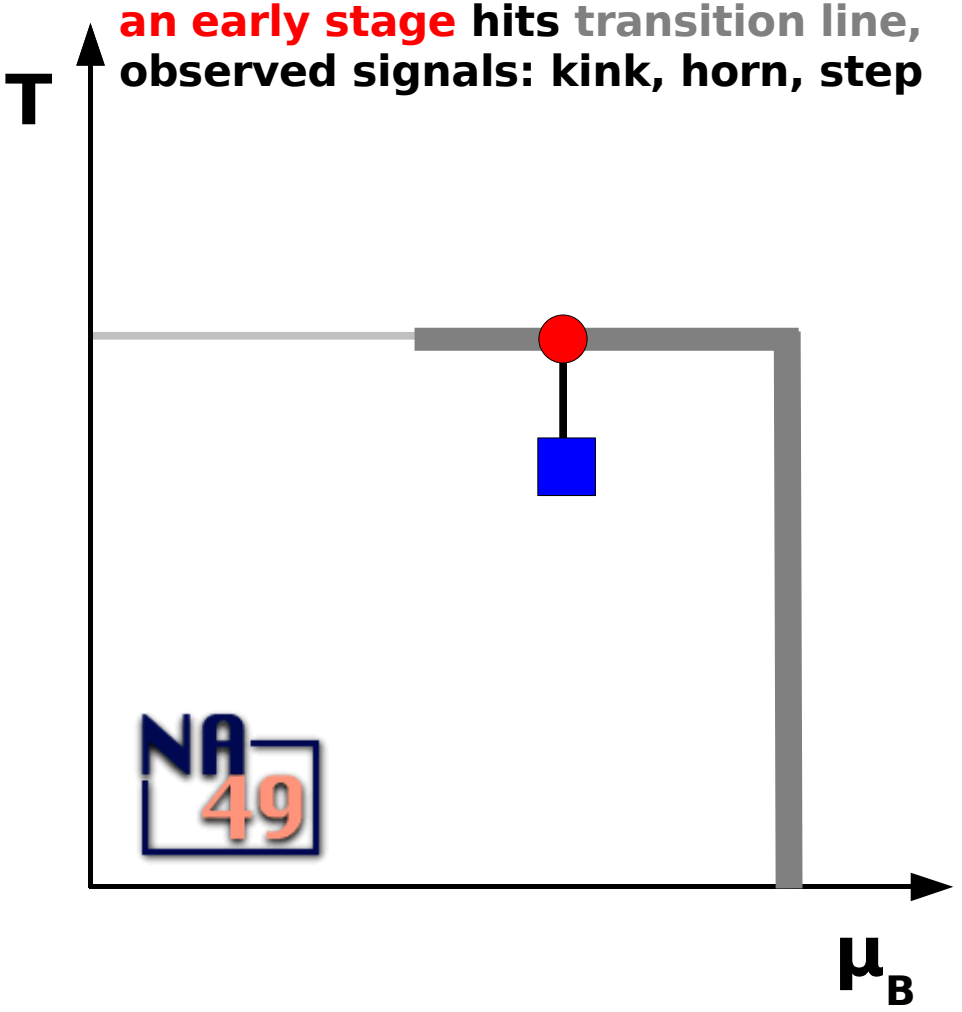
-supported heavy ion program at CERN,

-co-author of about 100 NA49 papers in the period 1995-2007,

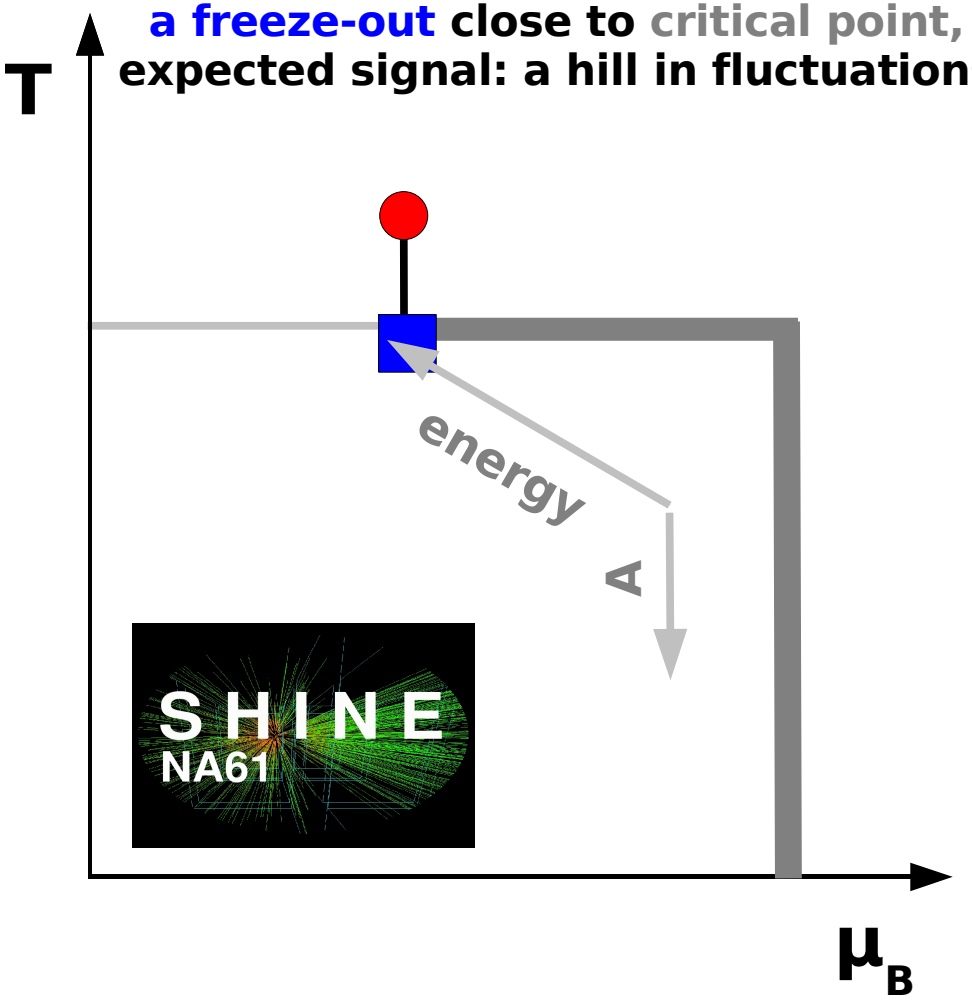
-his enthusiasm and work motivated many of us

Two main events in nucleus-nucleus collisions

Onset of Deconfinement:
an early stage hits transition line,
observed signals: kink, horn, step



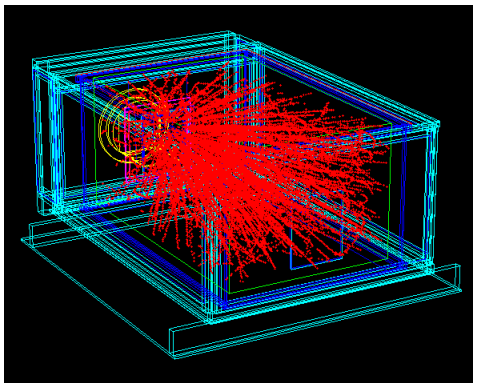
Critical Point:
a freeze-out close to critical point,
expected signal: a hill in fluctuations

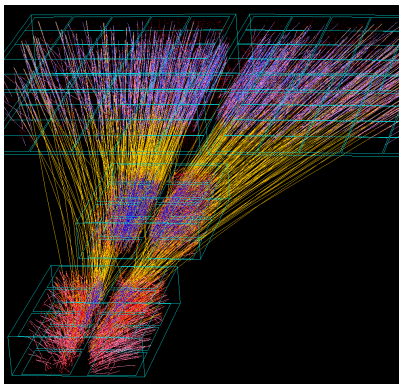


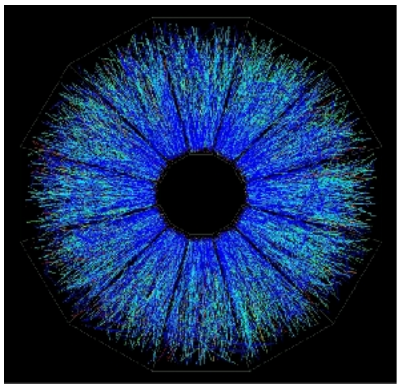
E(OoD) ≈ 30*A* GeV ≤ E(OoC)

Observation of the onset of deconfinement

BNL AGS → CERN SPS → BNL RHIC





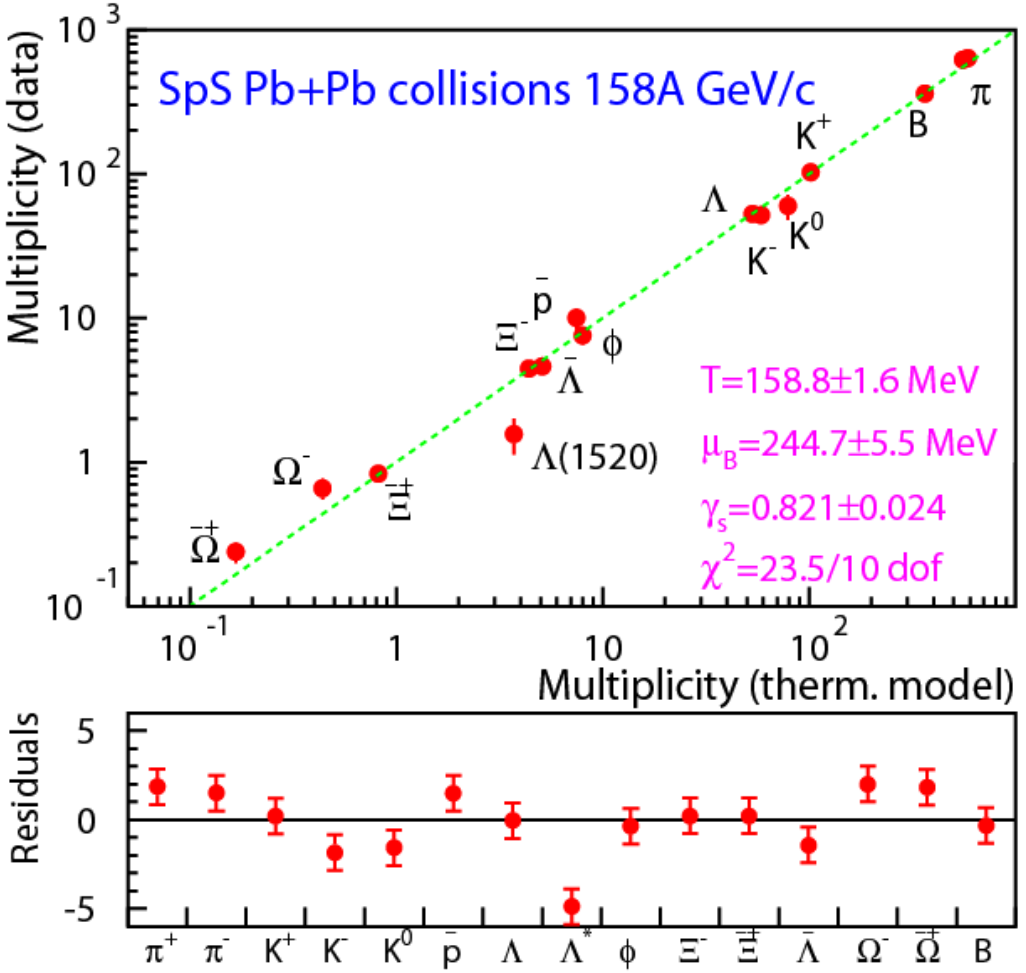


E895 NA49 STAR

Surprising success of statistical models

e.g. the statistical hadronization model:

$$\langle n_i \rangle = \frac{(2J_i+1)\,V}{(2\pi)^3} \int d^3p \; \frac{1}{\gamma_s^{-S_i} exp[(E_i - (\mu_B + \mu_S + \mu_Q))/T] \pm 1}$$

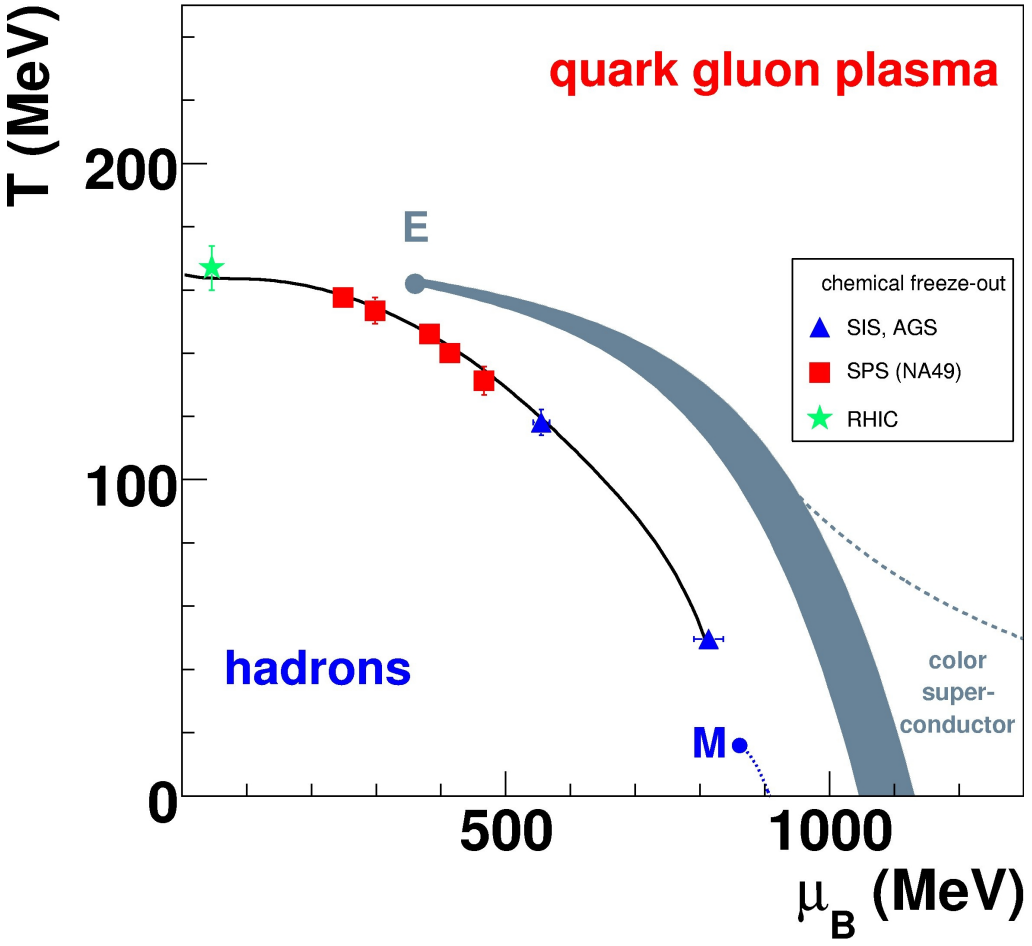


fit parameters

↓

chemical freeze-out of matter created in A+A collisions

Hagedorn, Rafelski, Becattini,, Cleymans Gorenstein, Redlich, Satz, ...



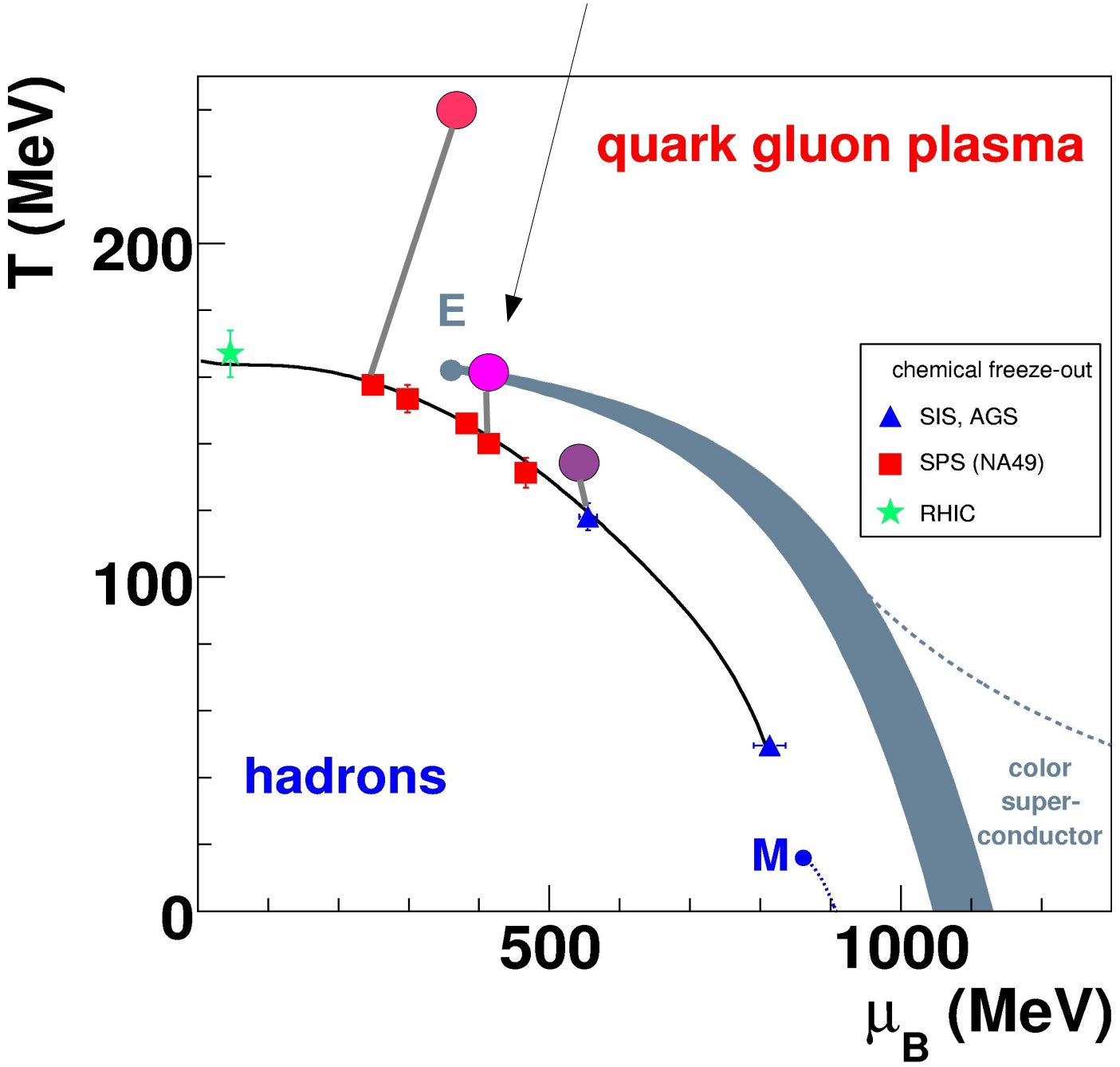
Freeze-out points of central heavy ion collisions at SPS are close to the phase boundary

Its possible that the early stage crosses the phase boundary at SPS energies (onset of deconfinement)

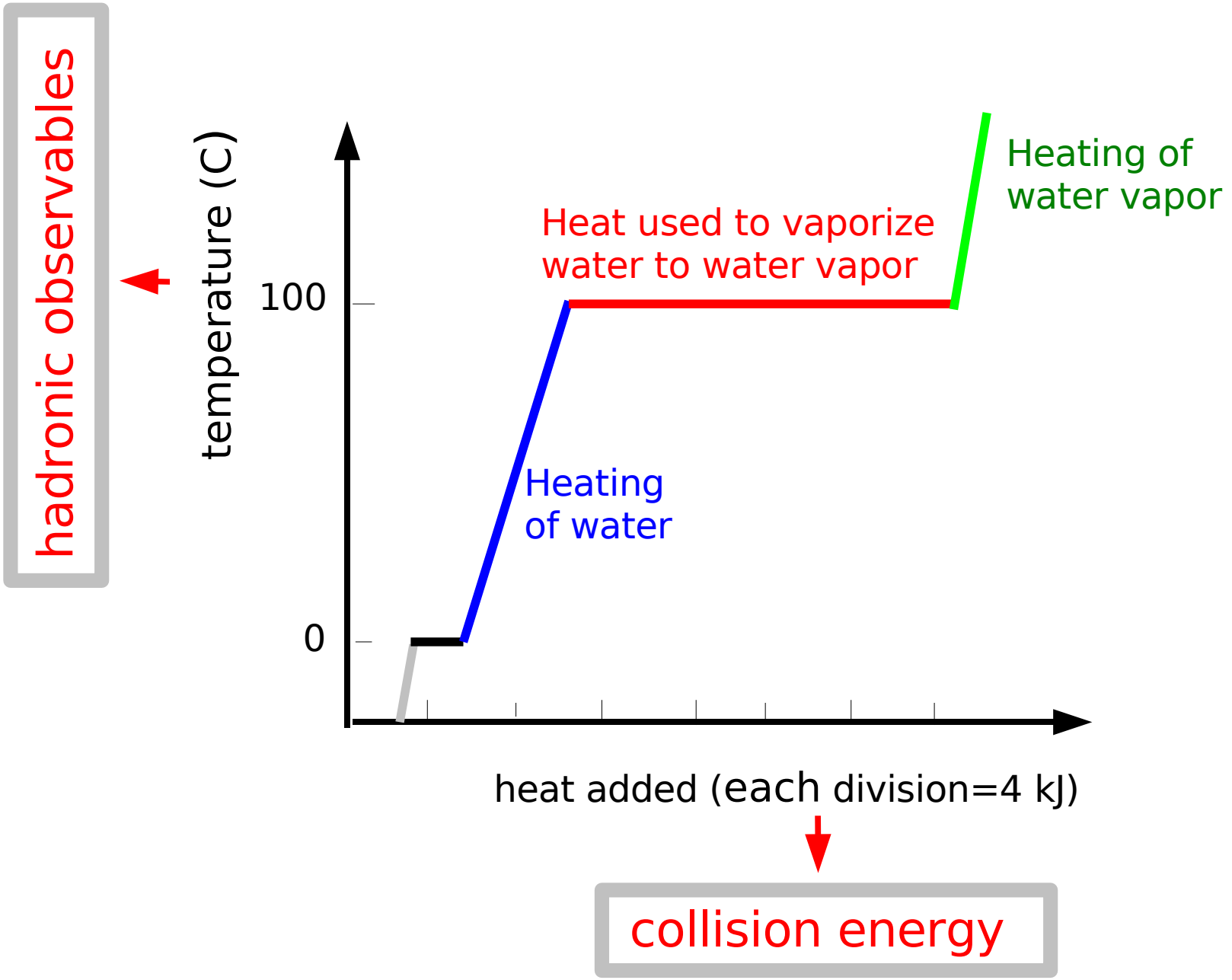
HG fits: Becattini et al., Cleymans, Redlich et al.

CP: Fodor, Katz

Onset of deconfinement: the early stage hits the transition line

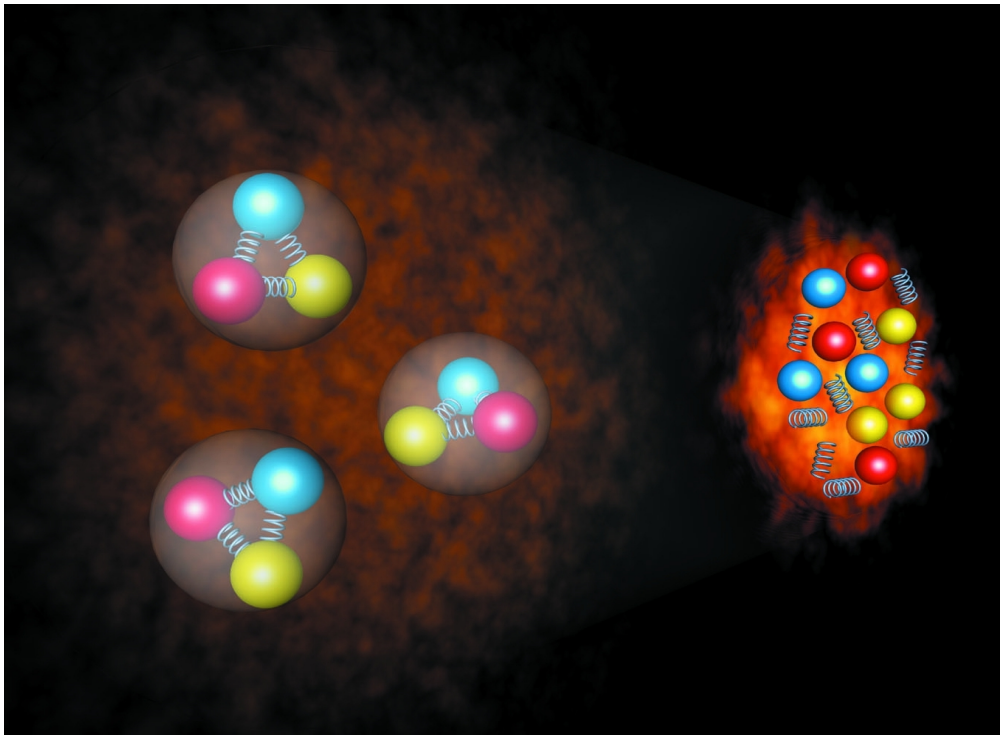


Heating curve of strongly interacting matter may look similar to the heating curve of water



Heating curves of strongly interacting matter

hadrons **mixed** **QGP**

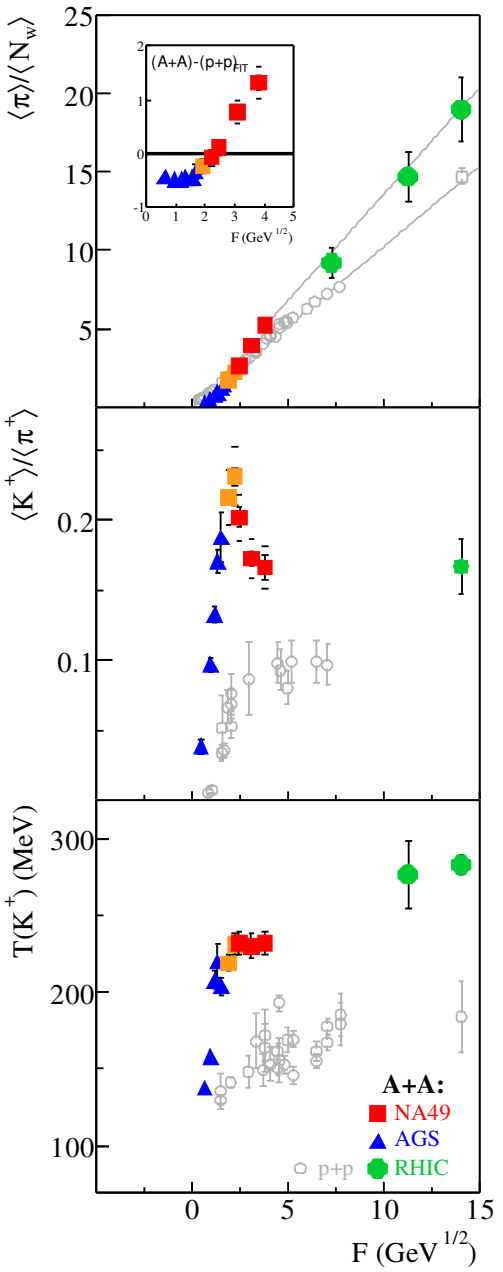


AGS **SPS** **RHIC**

collision energy

AGS **SPS** **RHIC**

hadronic observables



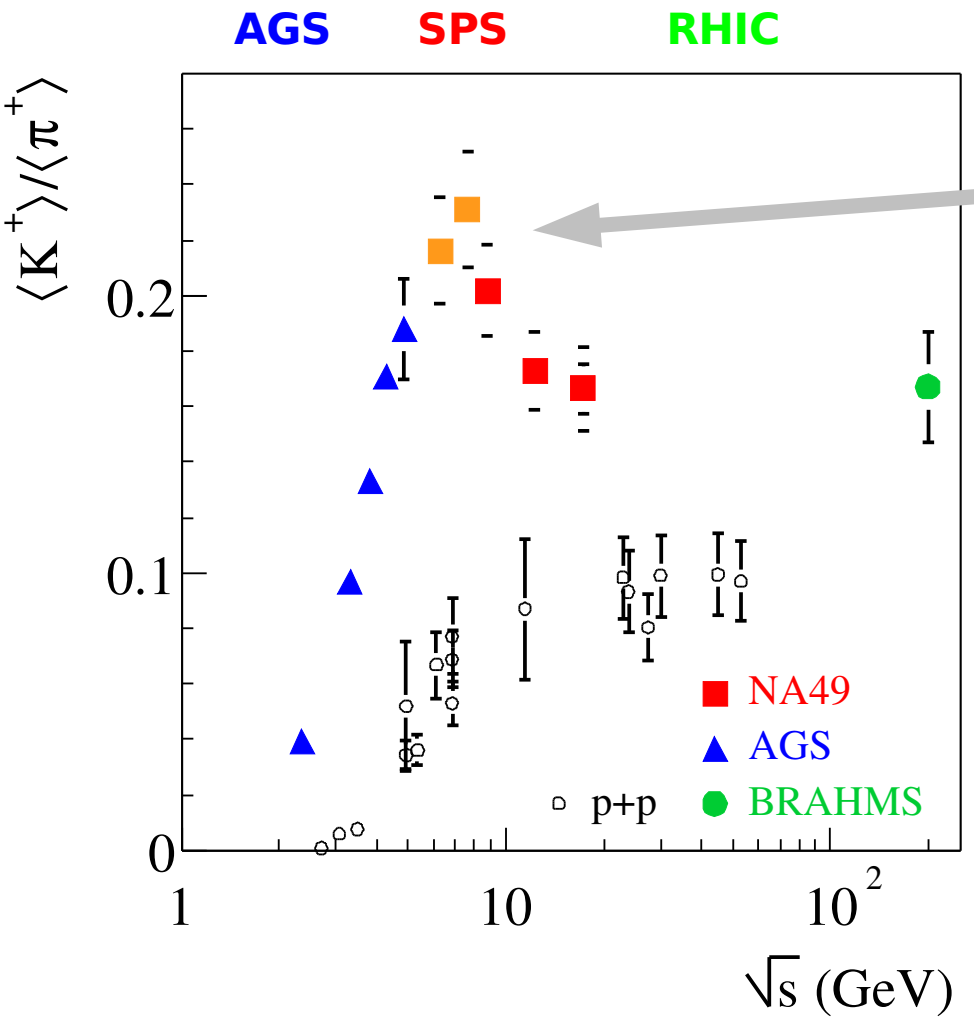
Kink

Horn

Step

collision energy

The horn in strangeness yield



Deconfinement

↓

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

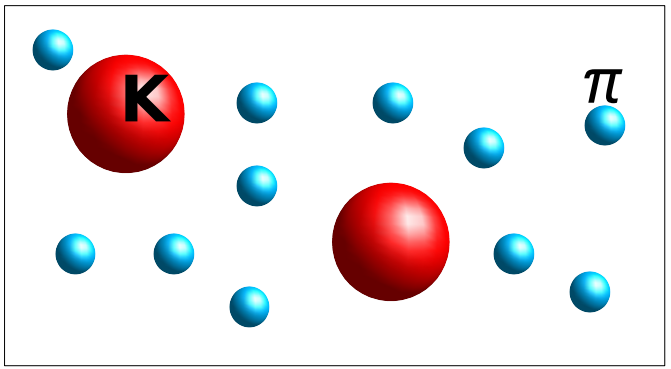
↓

A sharp maximum in the strangeness to pion ratio

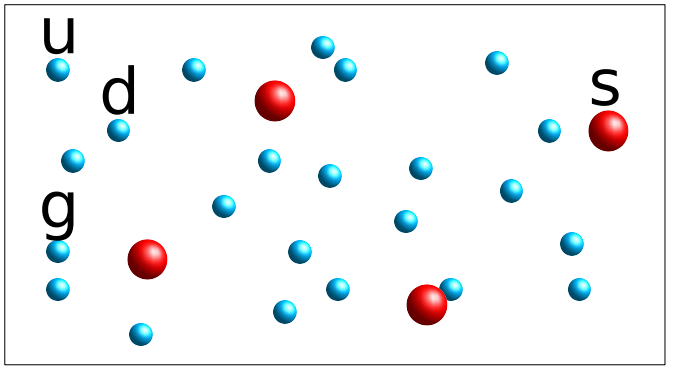
M.G., Gorenstein

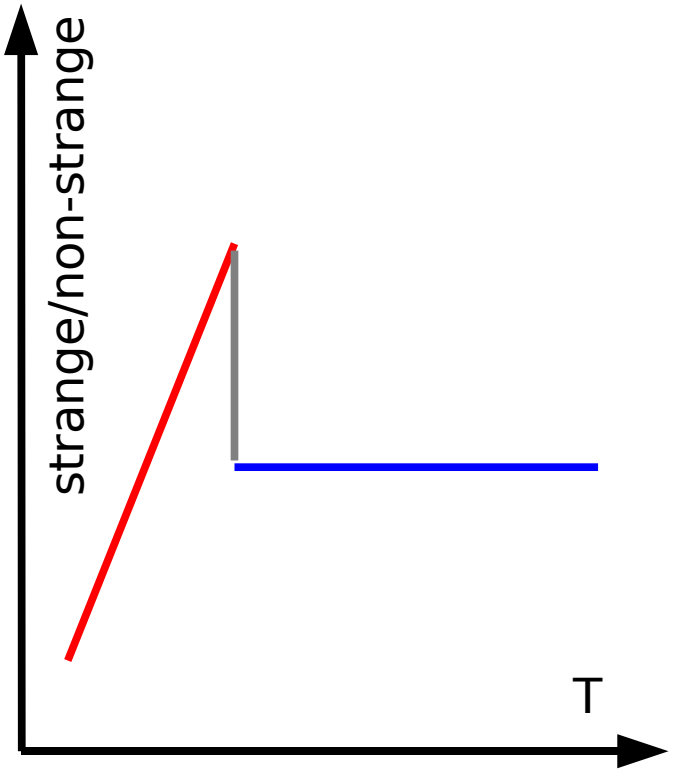
A toy model of the horn

hadron gas



quark-gluon plasma





$$\frac{\langle K\rangle}{\langle \pi\rangle} \propto \frac{MT^{3/2}}{T^3}\cdot e^{-M/T}$$

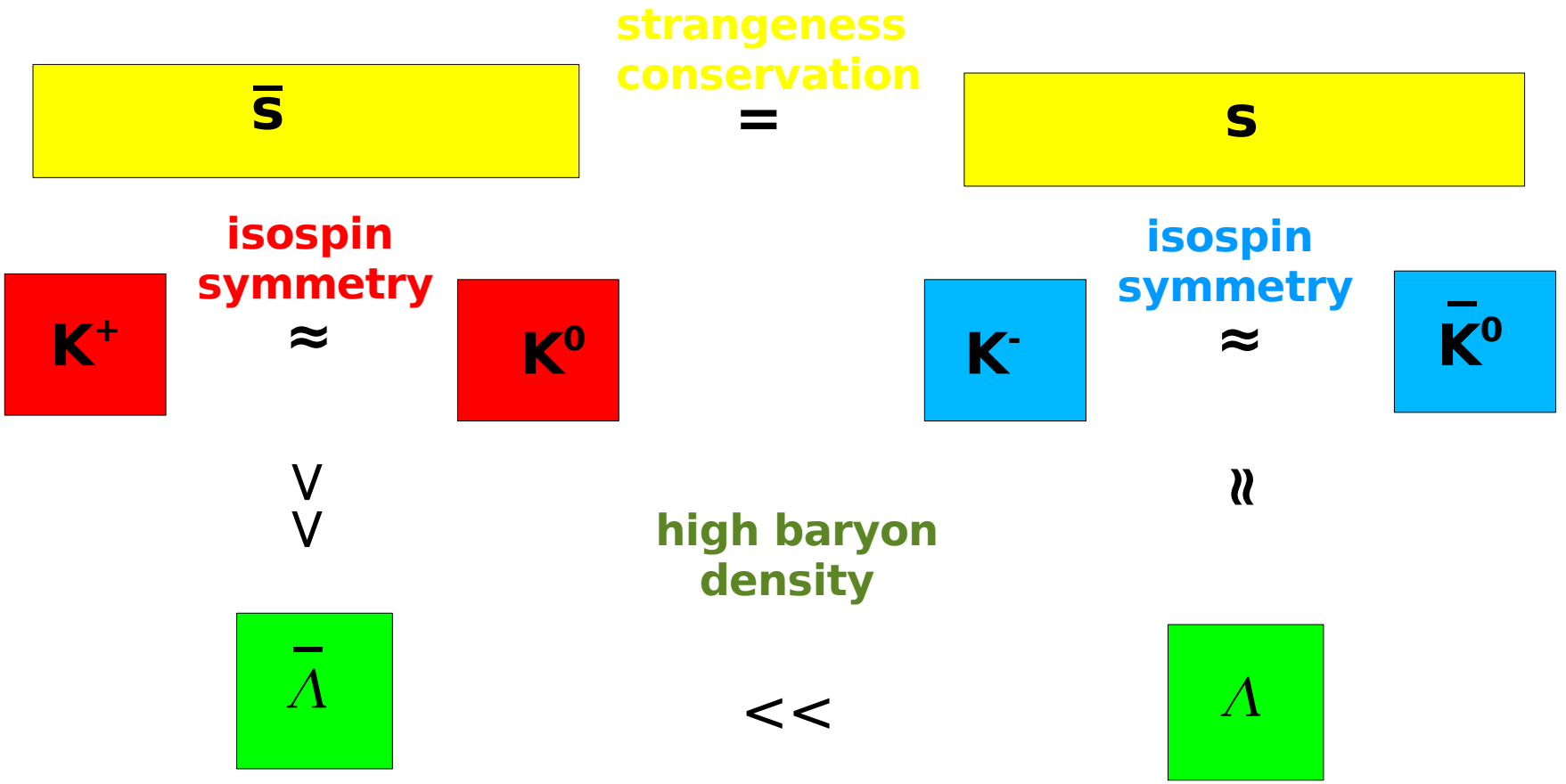
$$\frac{\langle s\rangle}{\langle u+d+g\rangle} \propto \frac{T^3}{T^3} = const(T)$$

$$\langle n\rangle = \frac{gV}{(2\pi)^3}\int d^3p\ \frac{1}{e^{E/T}\pm 1}$$

$$\approx gV\ \frac{2\pi^2}{4\cdot 45}\ T^3$$ for light particles

$$\approx gV\ \left(\frac{MT}{2\pi}\right)^{3/2}\ e^{-M/T}$$ for heavy particles

main strangeness carriers

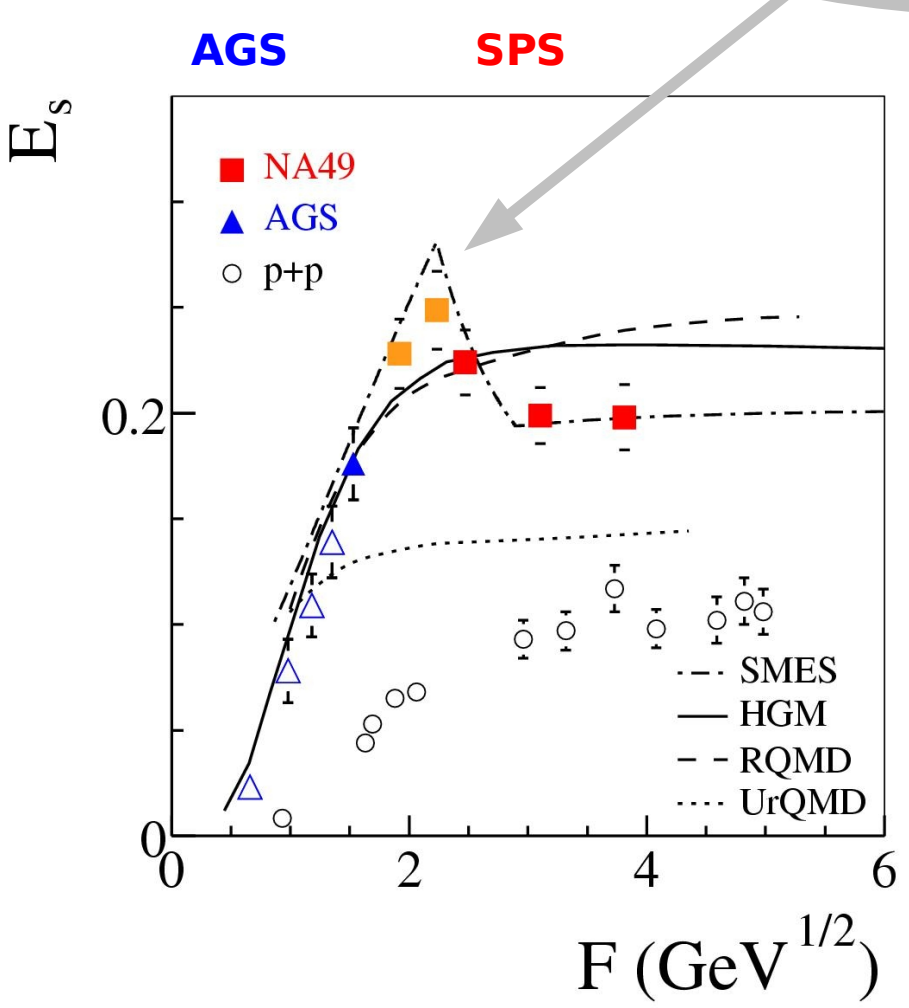


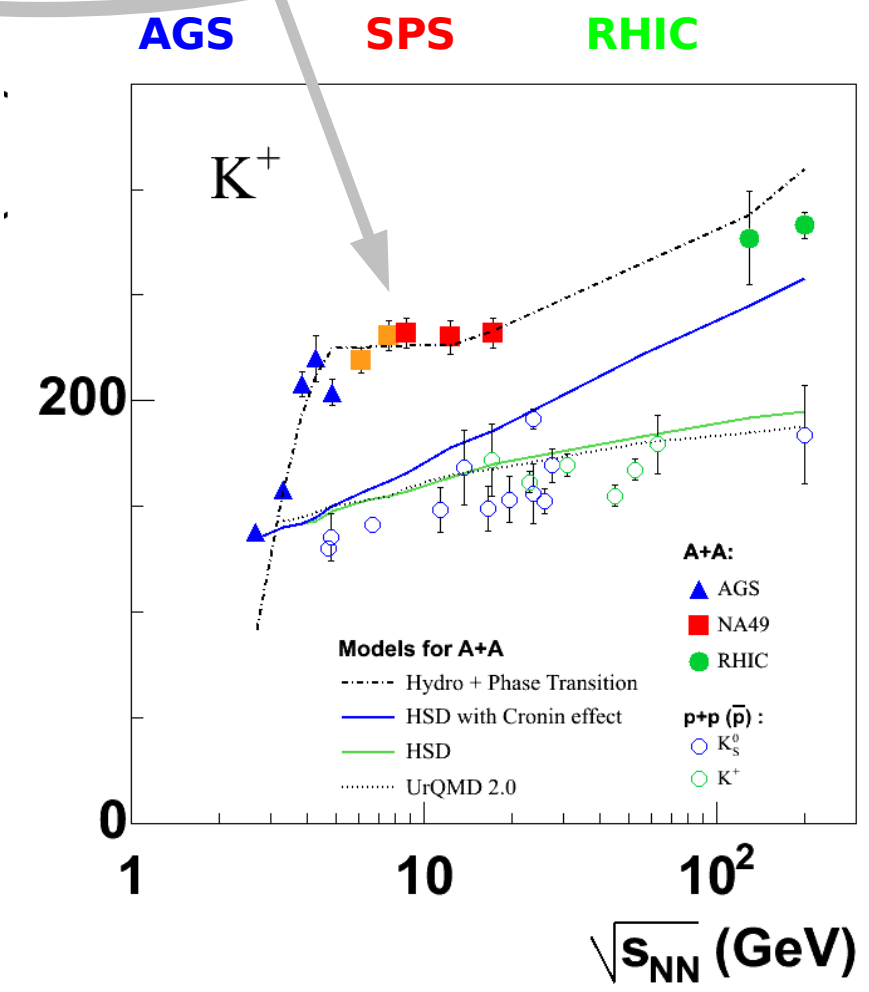
sensitive to strangeness content only

sensitive to strangeness content and baryon density

The models

Models with the
1st order phase transition
reproduce the data





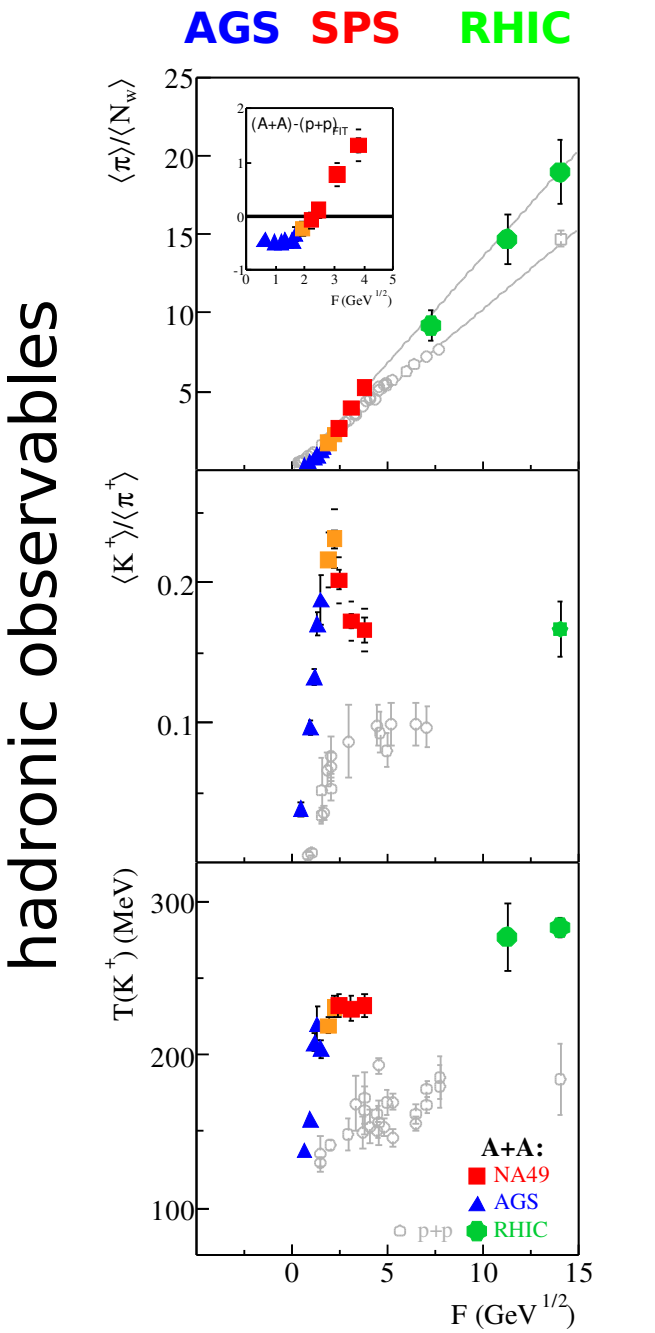
$$E_S=(\langle\Lambda\rangle+\langle K+\overline{K}\rangle)/\langle\pi\rangle$$

Summary (I)

- Several anomalies in hadron production are observed at low SPS energies
- The onset of observed anomalies is located at about 30*A* GeV
- The anomalies cannot be reproduced by the models without phase transition
- Measured rapid changes are consistent with models assuming 1st order PT

↓

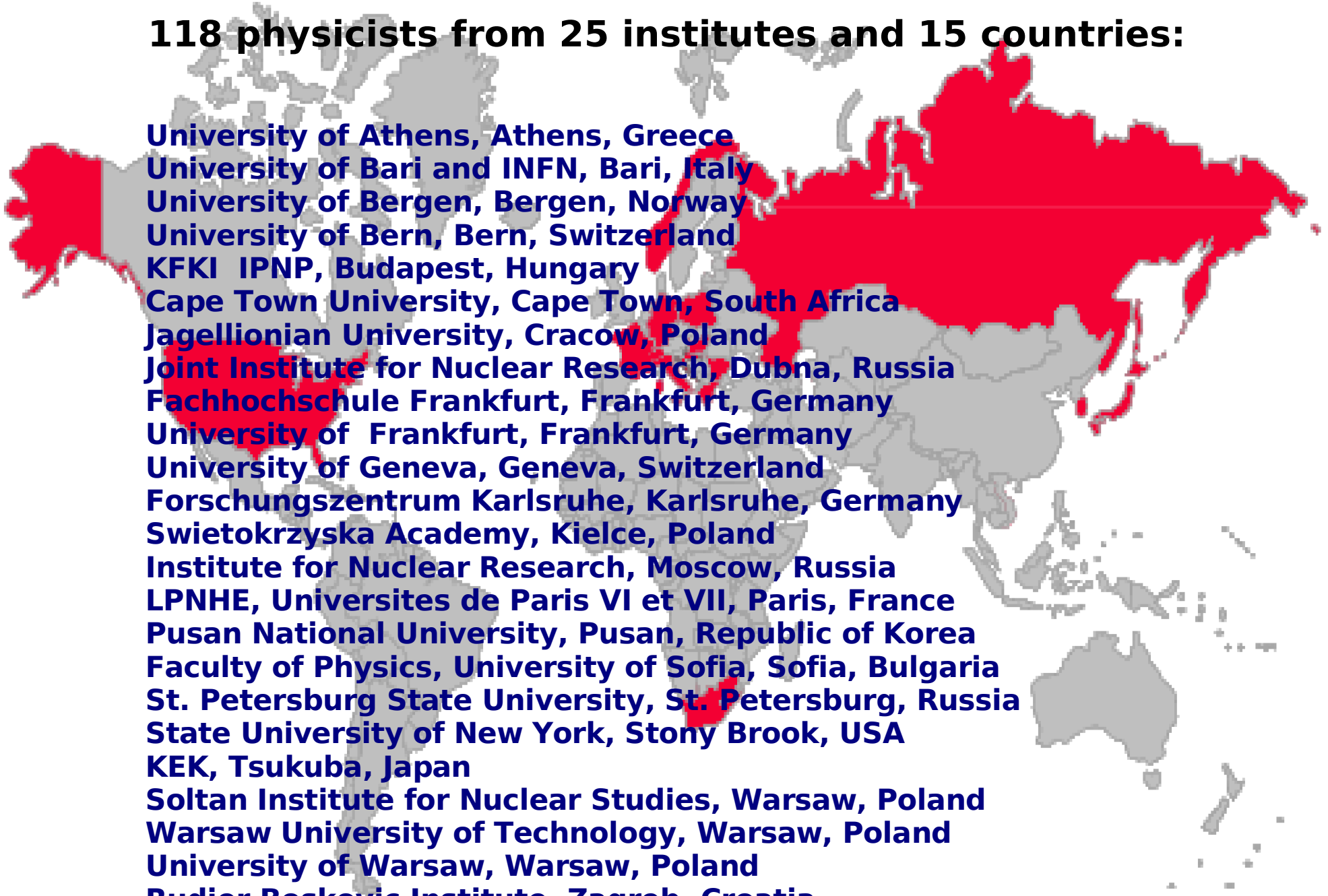
FUTURE



Search for the critical point

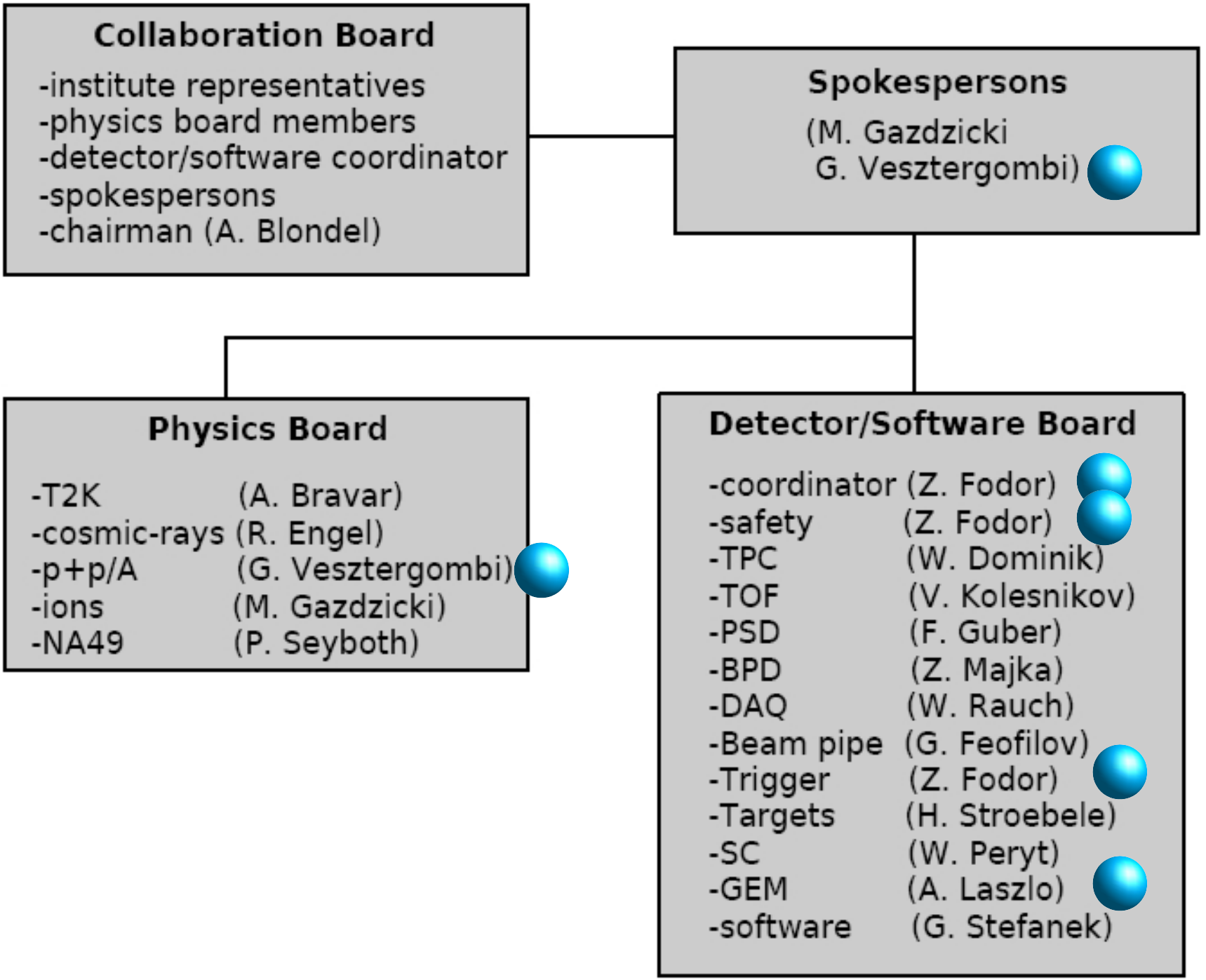
The NA61 Collaboration:

118 physicists from 25 institutes and 15 countries:



University of Athens, Athens, Greece
University of Bari and INFN, Bari, Italy
University of Bergen, Bergen, Norway
University of Bern, Bern, Switzerland
KFKI IPNP, Budapest, Hungary
Cape Town University, Cape Town, South Africa
Jagellionian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Fachhochschule Frankfurt, Frankfurt, Germany
University of Frankfurt, Frankfurt, Germany
University of Geneva, Geneva, Switzerland
Forschungszentrum Karlsruhe, Karlsruhe, Germany
Swietokrzyska Academy, Kielce, Poland
Institute for Nuclear Research, Moscow, Russia
LPNHE, Universites de Paris VI et VII, Paris, France
Pusan National University, Pusan, Republic of Korea
Faculty of Physics, University of Sofia, Sofia, Bulgaria
St. Petersburg State University, St. Petersburg, Russia
State University of New York, Stony Brook, USA
KEK, Tsukuba, Japan
Soltan Institute for Nuclear Studies, Warsaw, Poland
Warsaw University of Technology, Warsaw, Poland
University of Warsaw, Warsaw, Poland
Rudjer Boskovic Institute, Zagreb, Croatia
ETH Zurich, Zurich, Switzerland

Strong Budapest participation



NA61/SHINE physics goals (I):

Physics of strongly interacting matter

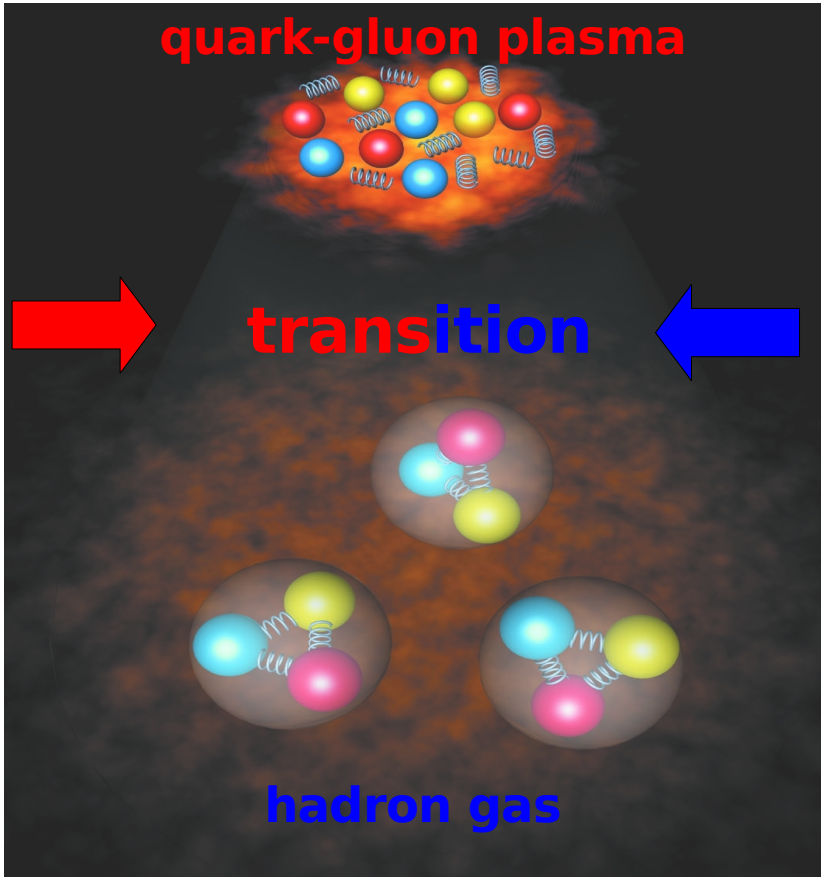
Discovery potential:

Search for the critical point of strongly interacting matter

Precision measurements:

Study the properties of the onset of deconfinement in nucleus-nucleus collisions

Measure hadron production at high transverse momenta in p+p and p+Pb collisions as reference for Pb+Pb results



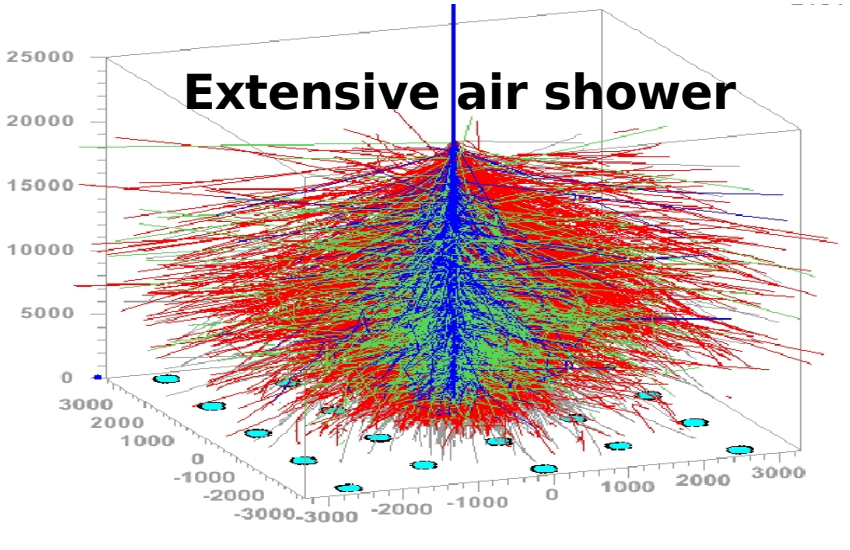
NA61/SHINE Physics goals (II):

Data for neutrino and cosmic ray experiments

Precision measurements:

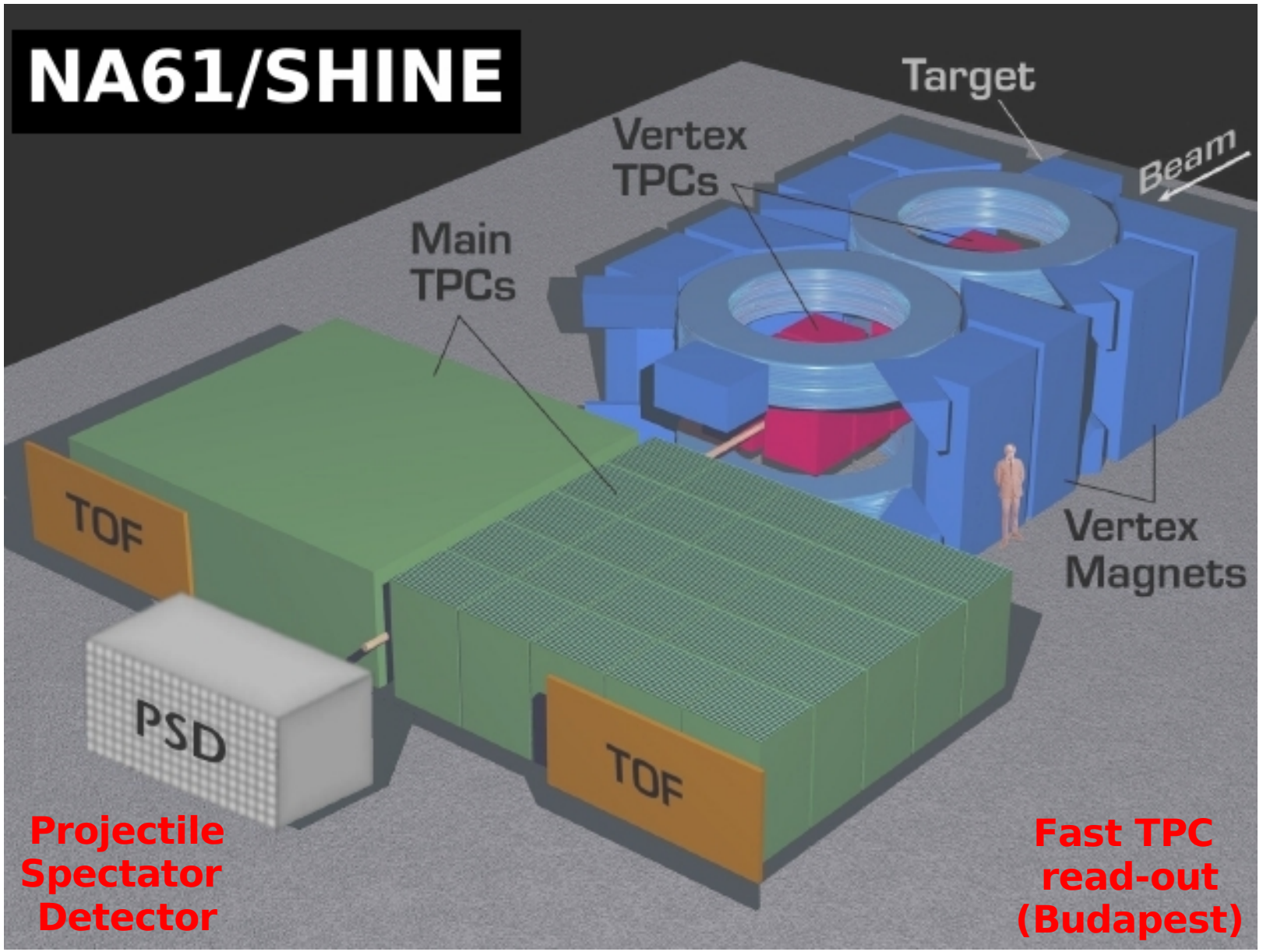
Measure hadron production in the T2K target needed for the T2K (neutrino) physics

Measure hadron production in p+C interactions needed for T2K and cosmic-ray, Pierre Auger Observatory and KASCADE, experiments



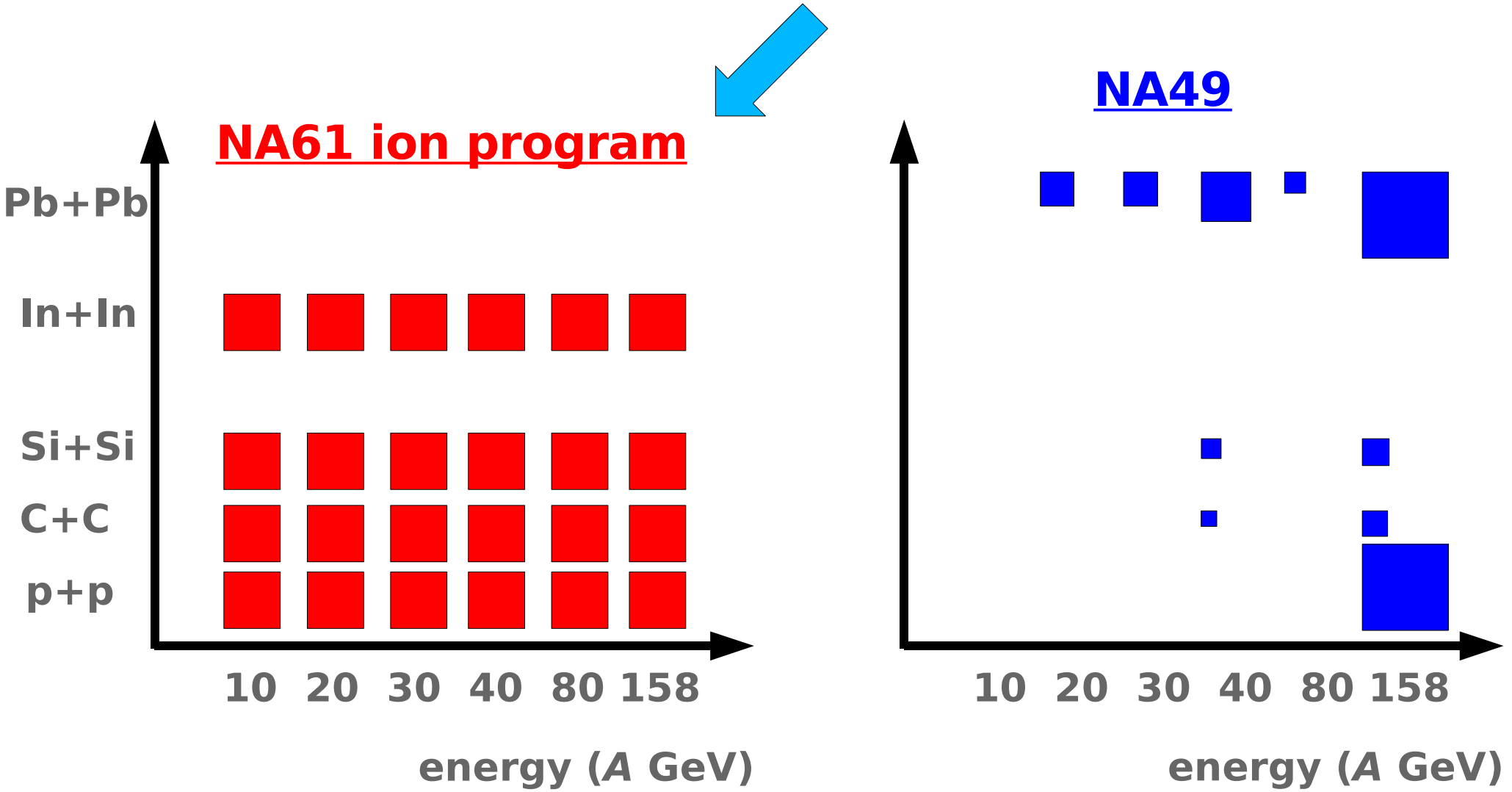
NA61/SHINE Detector

Upgraded NA49 facility



NA49: Nucl. Instrum. Meth. A430, 210 (1999)
Upgrades: CERN-SPSC-2006-034, SPSC-P-330

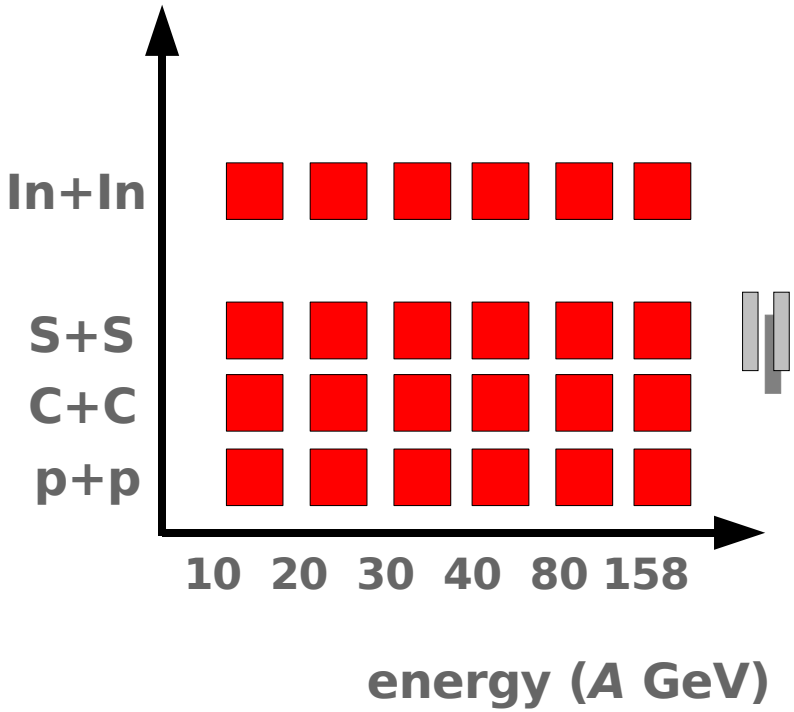
NA61/SHINE plans a comprehensive scan in the two dimensional plane (energy)-(system size) in the CERN SPS energy domain

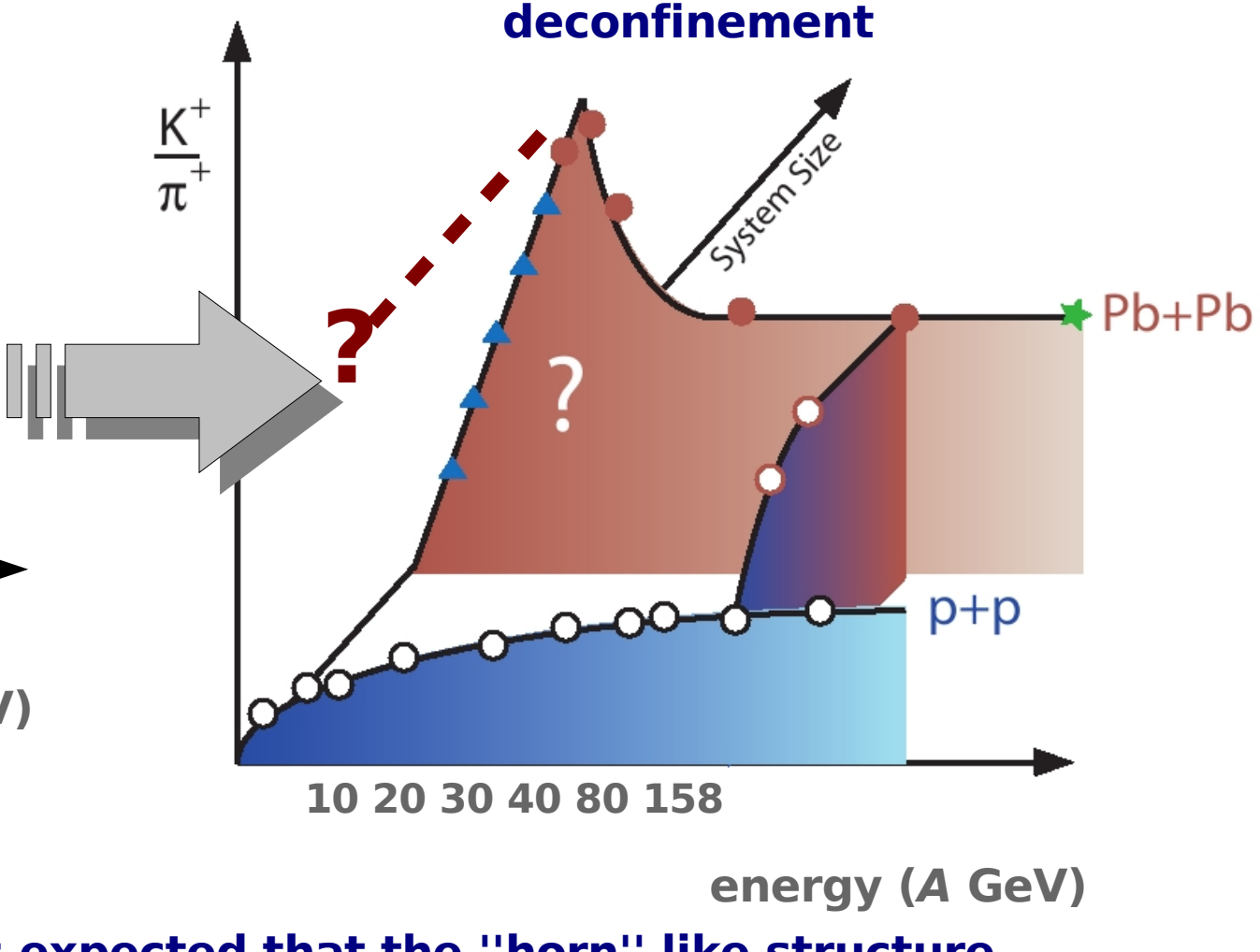


= $2 \cdot 10^6$ registered collisions

New data registered by NA61

will allow to establish the system size dependence of the anomalies observed in Pb+Pb collisions and thus further test their interpretation as due to the onset of deconfinement



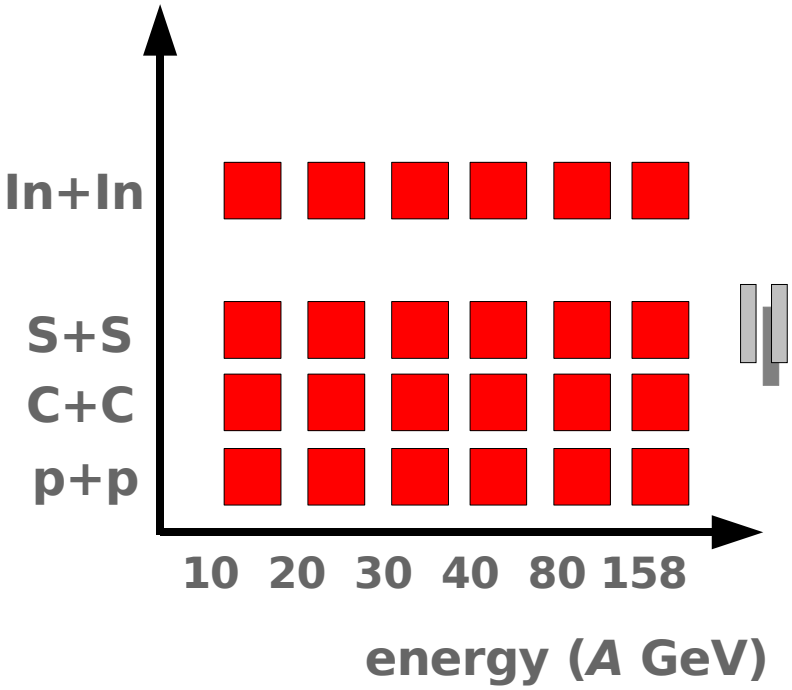


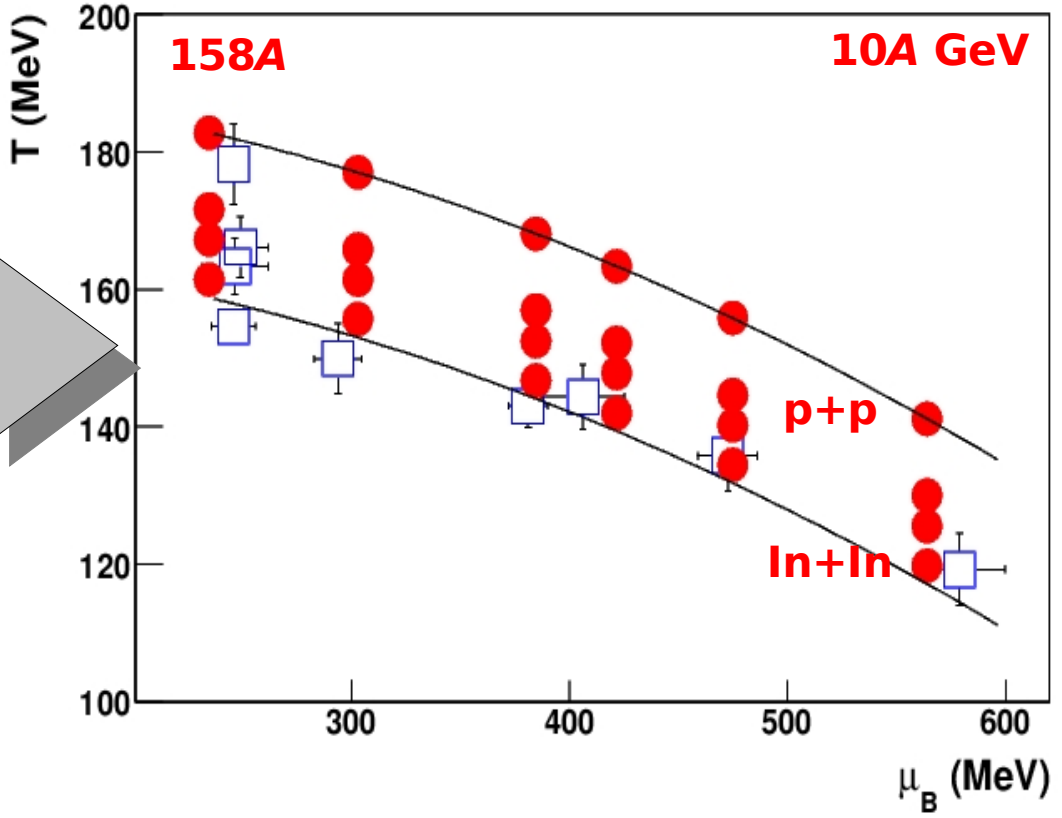
In particular, it is expected that the ''horn'' like structure should be the same for S+S and Pb+Pb collisions and then rapidly disappear for smaller systems

M.G., Gorenstein

New data registered by NA61

may lead to discovery of the critical point of strongly interacting matter by an observation of a hill of fluctuations in two dimensional plane (energy)-(system size) or equivalently (temperature)-(baryo-chemical potential)



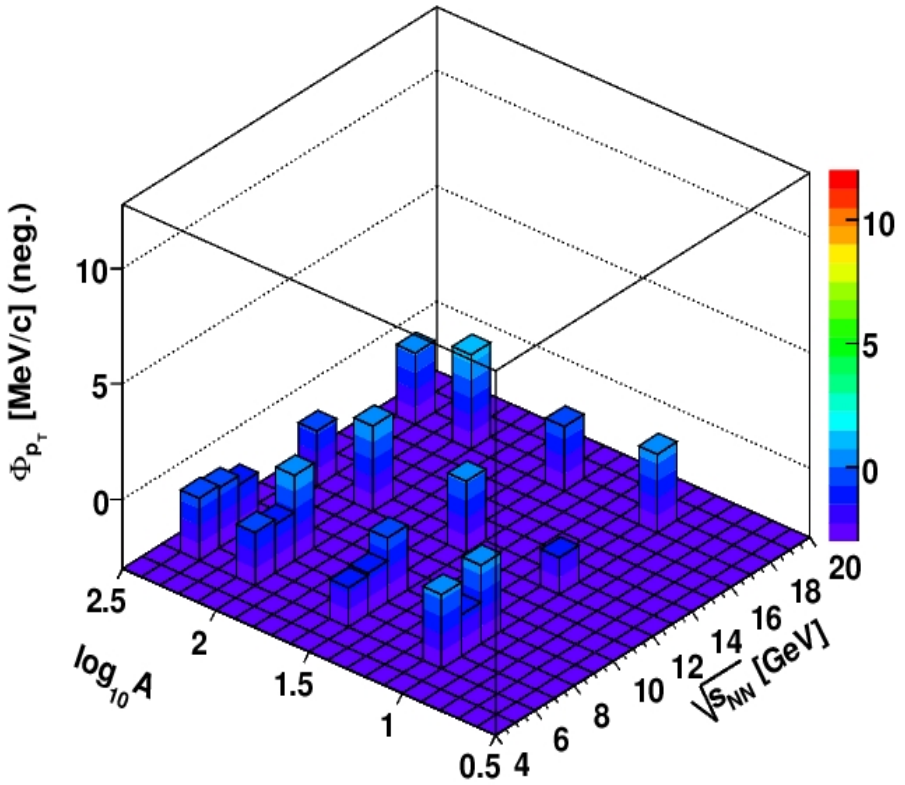


In particular the critical point should lead to an increase of multiplicity and transverse momentum fluctuations

Fluctuations and CP: Stephanov, Rajagopal, Shuryak, Phys. Rev. D 60, 114028
Freeze-out points: Becattini et al., Phys. Rev. C 73, 044905

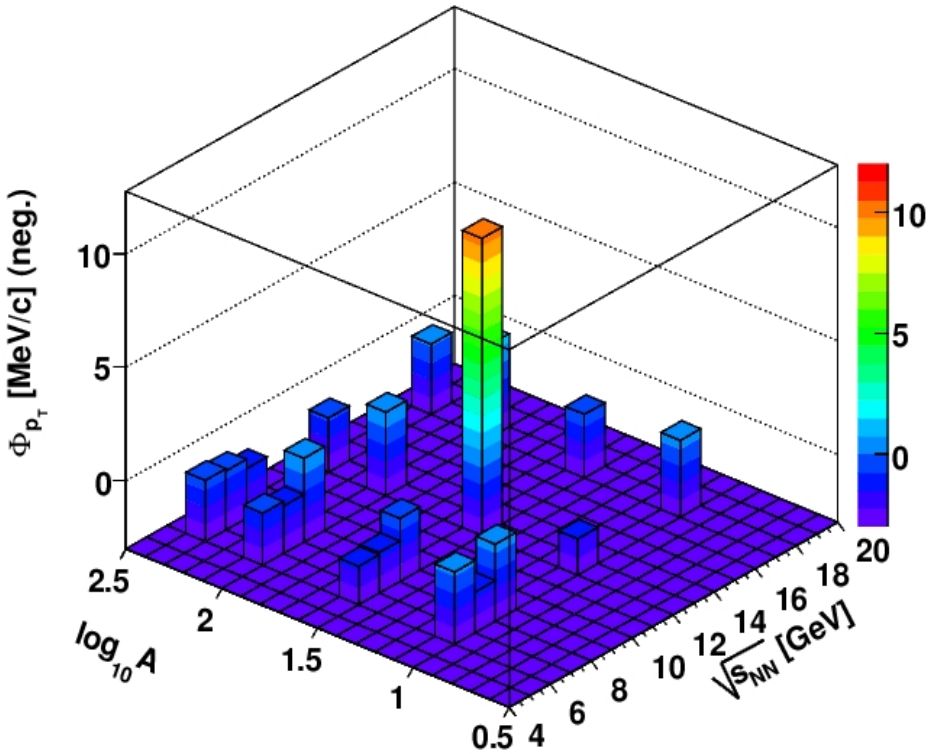
Test of the performance in the search for the critical point by simulating events in the NA49 detector

Transverse momentum fluctuations in the NA61 acceptance within the UrQMD model



Smooth dependence on energy and system size

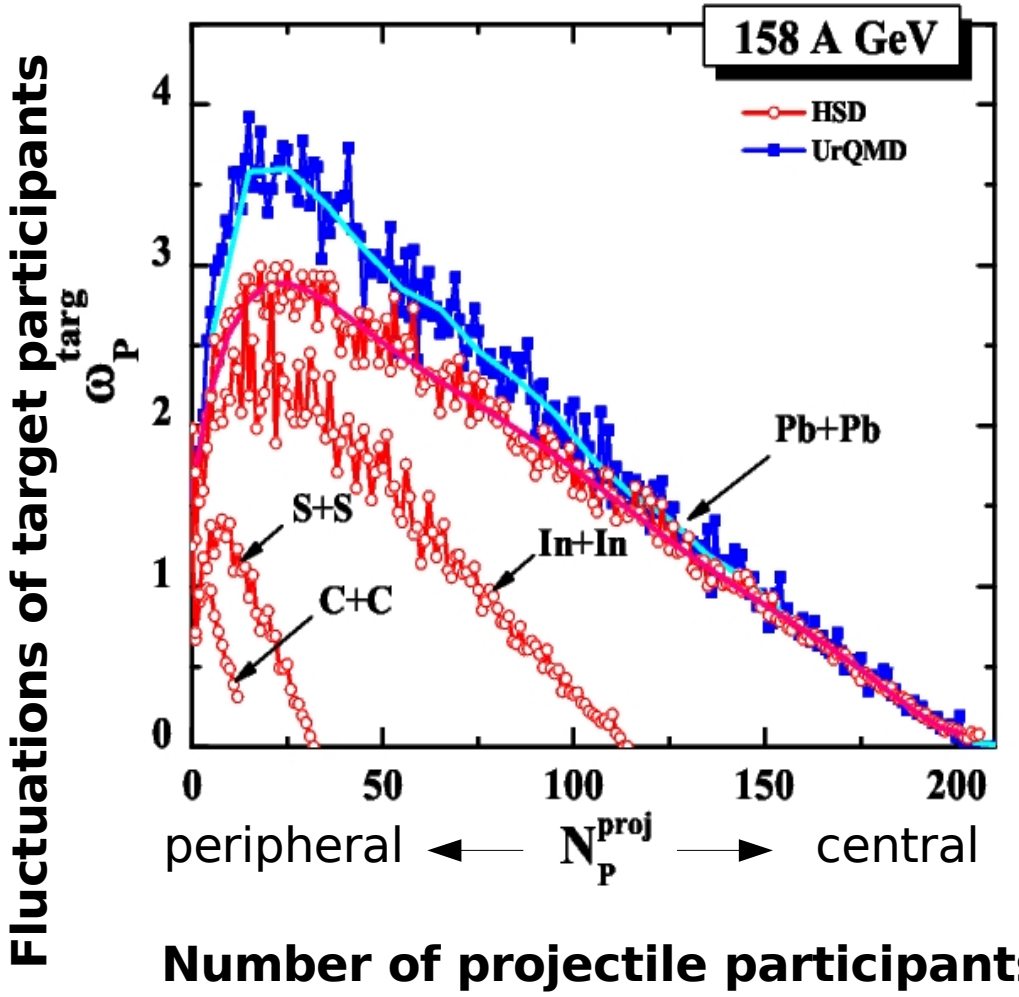
… + an enhancement due to CP added to S+S collisions at 80*A* GeV



Clearly visible maximum (+10 MeV/c) over a smooth background

results from K. Grebieszkow

Central collisions of light and medium size nuclei are required for the proposed fluctuation studies



Event-by-event fluctuations in the number of interacting (participant) nucleons are the main source of the background in the fluctuation studies

The fluctuations of the number of projectile participants are suppressed by selecting collisions with fixed number of projectile spectators (in NA49-future measured by PSD)

The fluctuations of the number of target participants can be suppressed only by selection of very central collisions

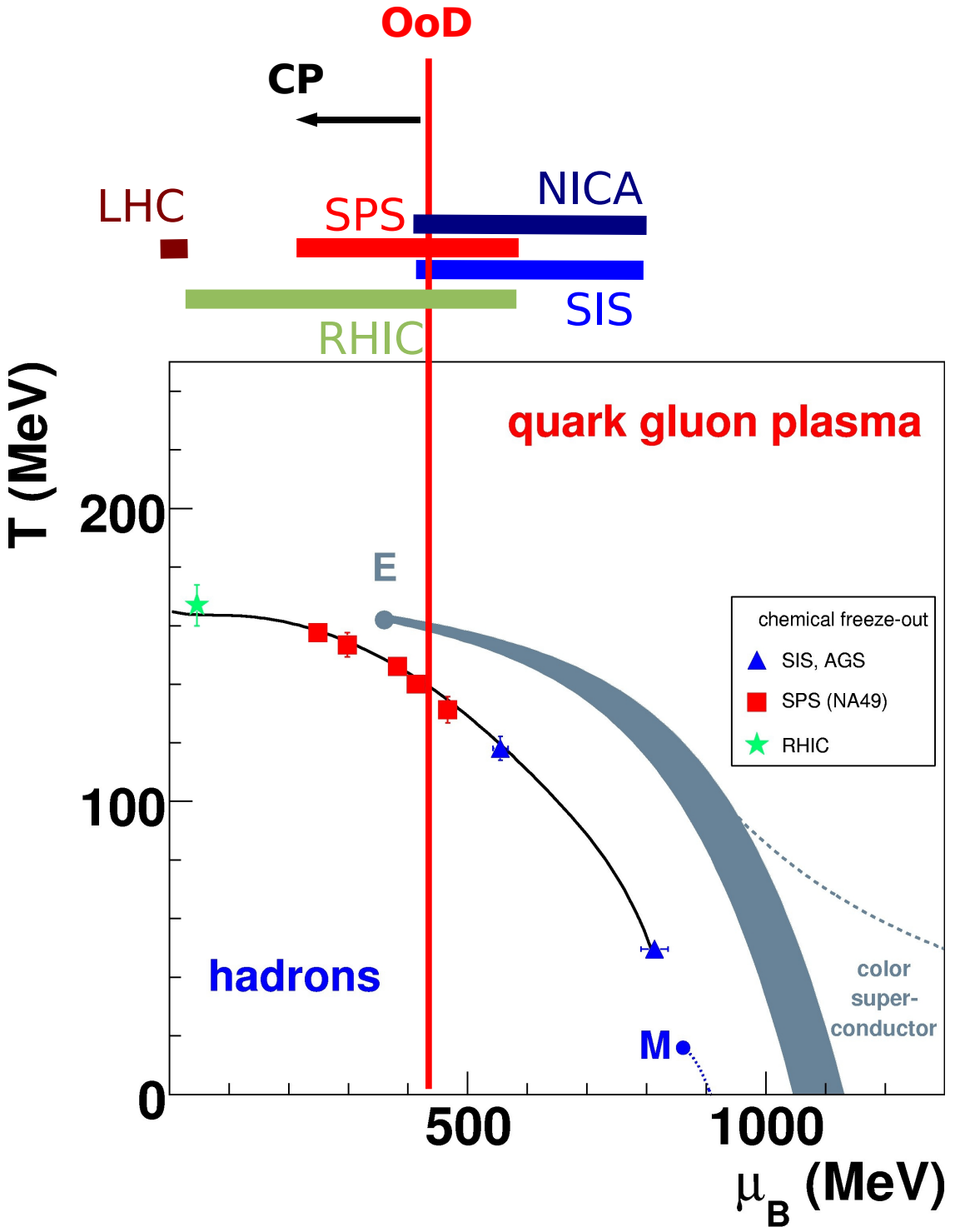
Konchakovski et al., Phys. Rev. C 73, 034902

Run schedule

Beam	Energy (A GeV)	Year	Days	Physics	
p	30	2007	30	T2K, C-R	approved
p	30, 40, 50	2008	14	T2K, C-R	recommended
π^-	158, 350	2008	3	C-R	
p	158	2008	28	High p_T	
S	10, 20, 30, 40, 80, 158	2009	30	CP&OoD	
p	10, 20, 30, 40, 80, 158	2009	30	CP&OoD	recommended
In	10, 20, 30, 40, 80, 158	2010	30	CP&OoD	to be discussed
p	158	2010	30	High p_T	
C	10, 20, 30, 40, 80, 158	2011	30	CP&OoD	
p	10, 20, 30, 40, 80, 158	2011	30	CP&OoD	

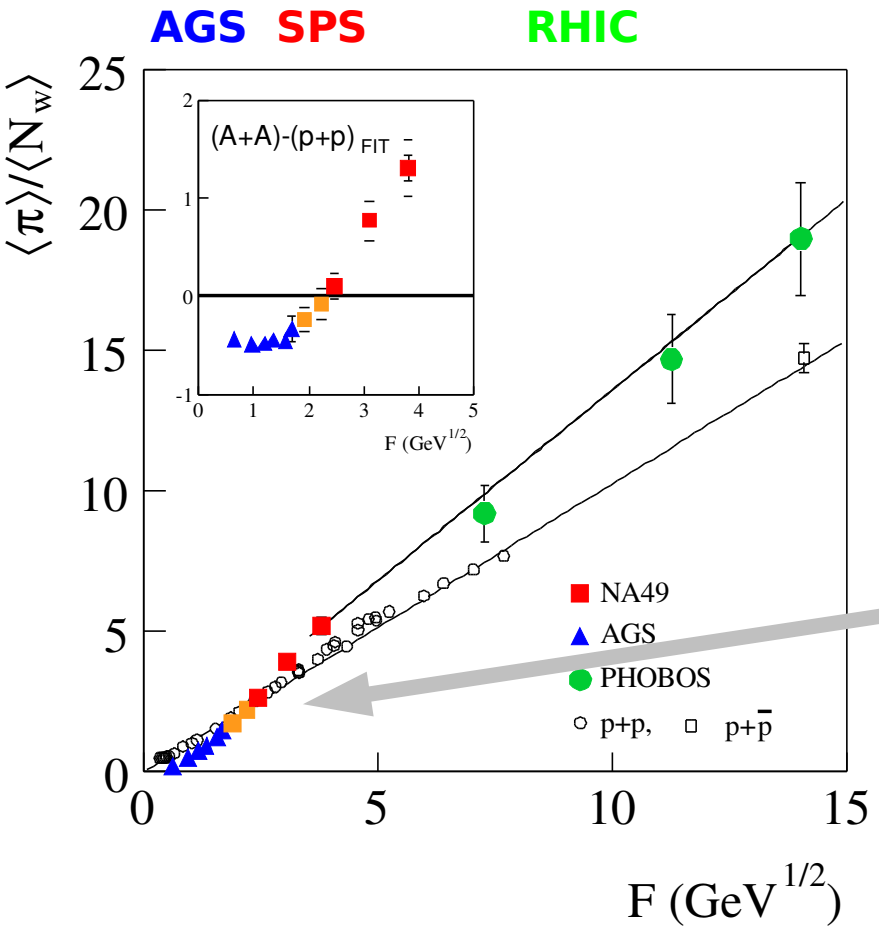
Addendum-2: *CERN-SPSC-2007-019, SPSC-P-330 (June 15, 2007)*
Addendum-1: *CERN-SPSC-2007-004, SPSC-P-330 (January 25, 2007)*
Proposal: *CERN-SPSC-2006-034, SPSC-P-330 (November 3, 2006)*
Status Report: *CERN-SPSC-2006-023, SPSC-SR-010 (September 5, 2006)*
LoI: *CERN-SPSC-2006-001, SPSC-I-235 (January 6, 2006)*
EoI: *CERN-SPSC-2003-031, SPSC-EOI-001 (November 21, 2003)*

Summary (II)


OoD
CP
LHC
SPS
NICA
SIS
RHIC
quark gluon plasma
T (MeV)
200
100
0
E
chemical freeze-out
SIS, AGS
SPS (NA49)
RHIC
hadrons
color
super-
conductor
M
500
1000
μB (MeV)

Additional slides

The kink in pion multiplicity



Deconfinement

↓

Increased entropy production

↓

Steepening of the increase of pion production

$\langle\pi\rangle \sim g^{1/4} F - \epsilon$

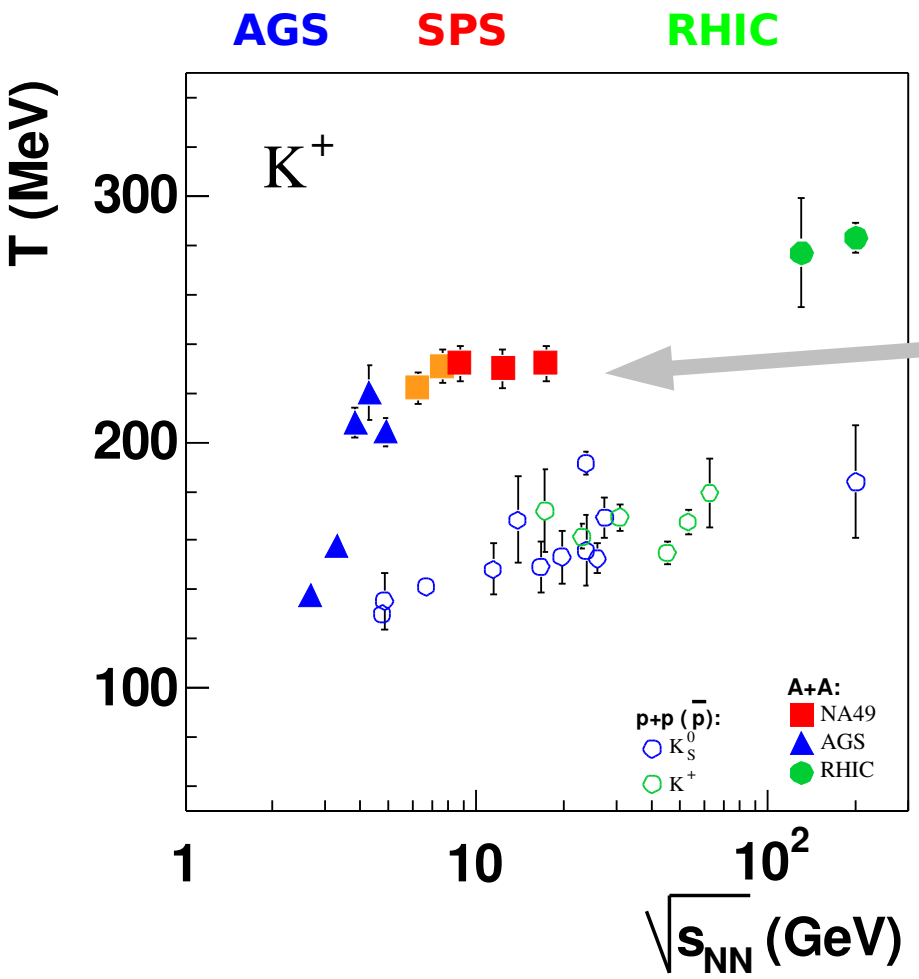
$F \approx \sqrt{\sqrt{s_{NN}}}$

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

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

M.G., Gorenstein

The step in m_T slopes



Deconfinement

↓

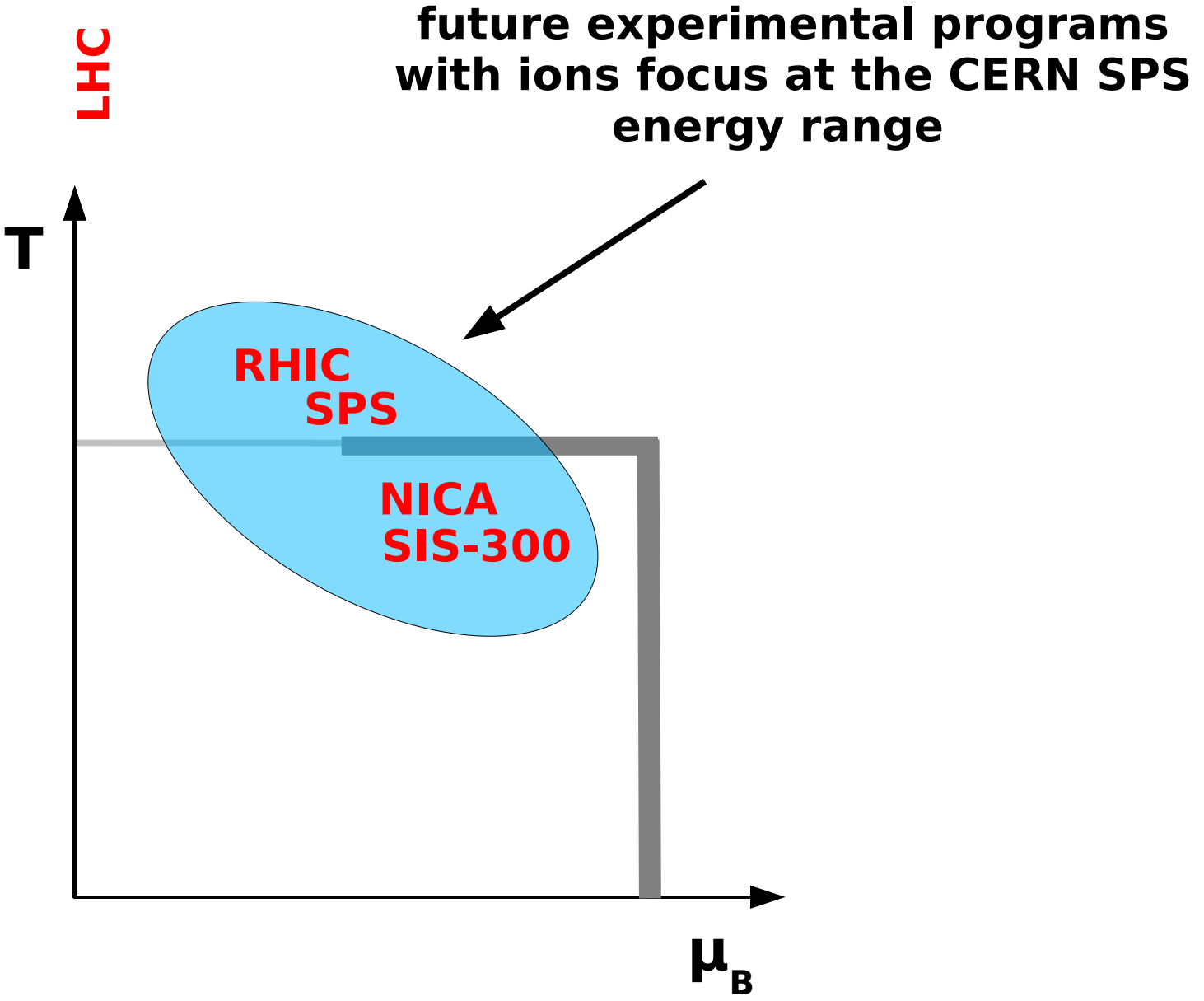
Constant temperature and pressure in the mixed phase region

↓

Weaker energy dependence of the shape of transverse mass spectra

T – inverse slope parameter of transverse mass spectra

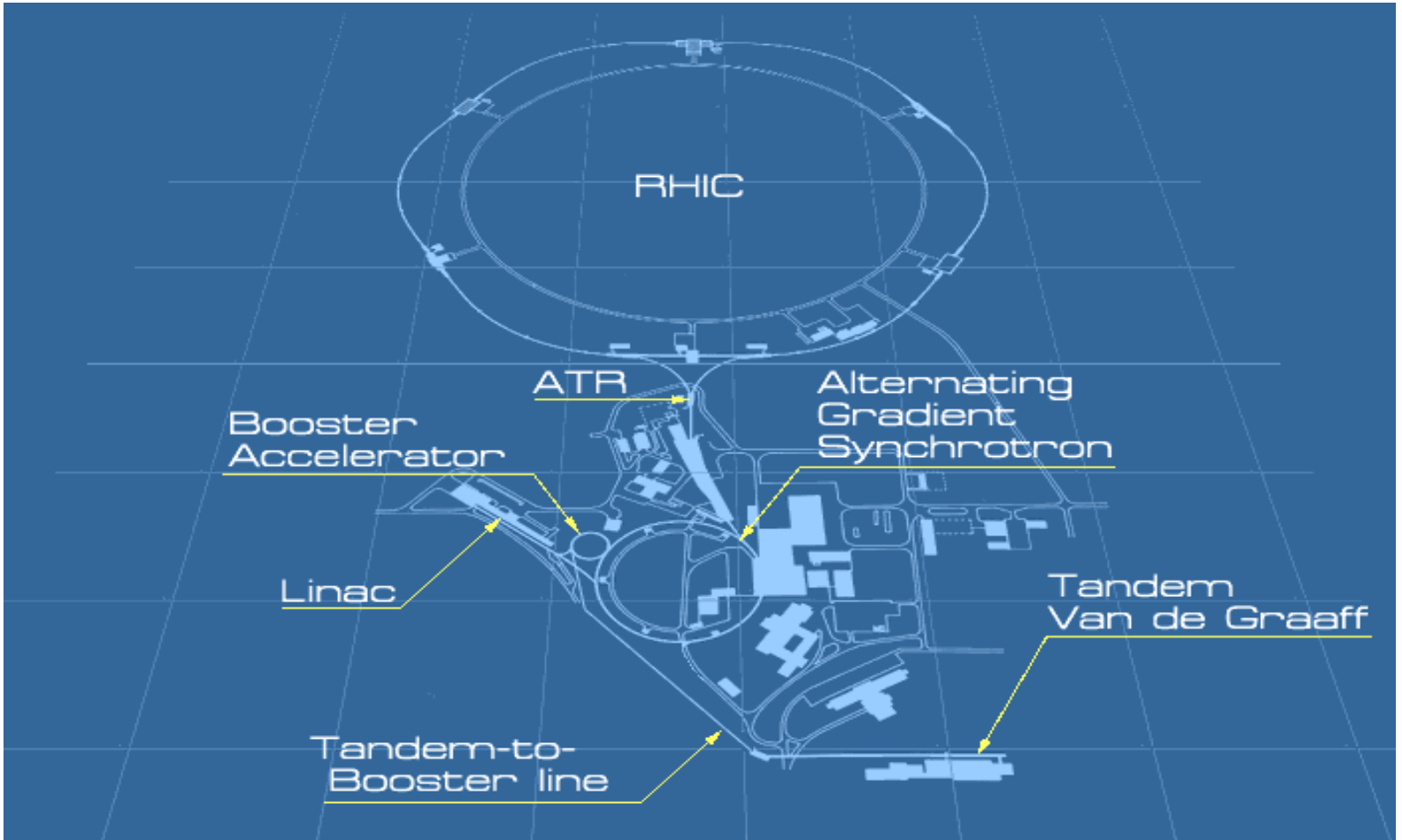
Shuryak, van Hove
Gorenstein, M.G., Bugaev


future experimental programs
with ions focus at the CERN SPS
energy range
LHC
T
RHIC
SPS
NICA
SIS-300
μB

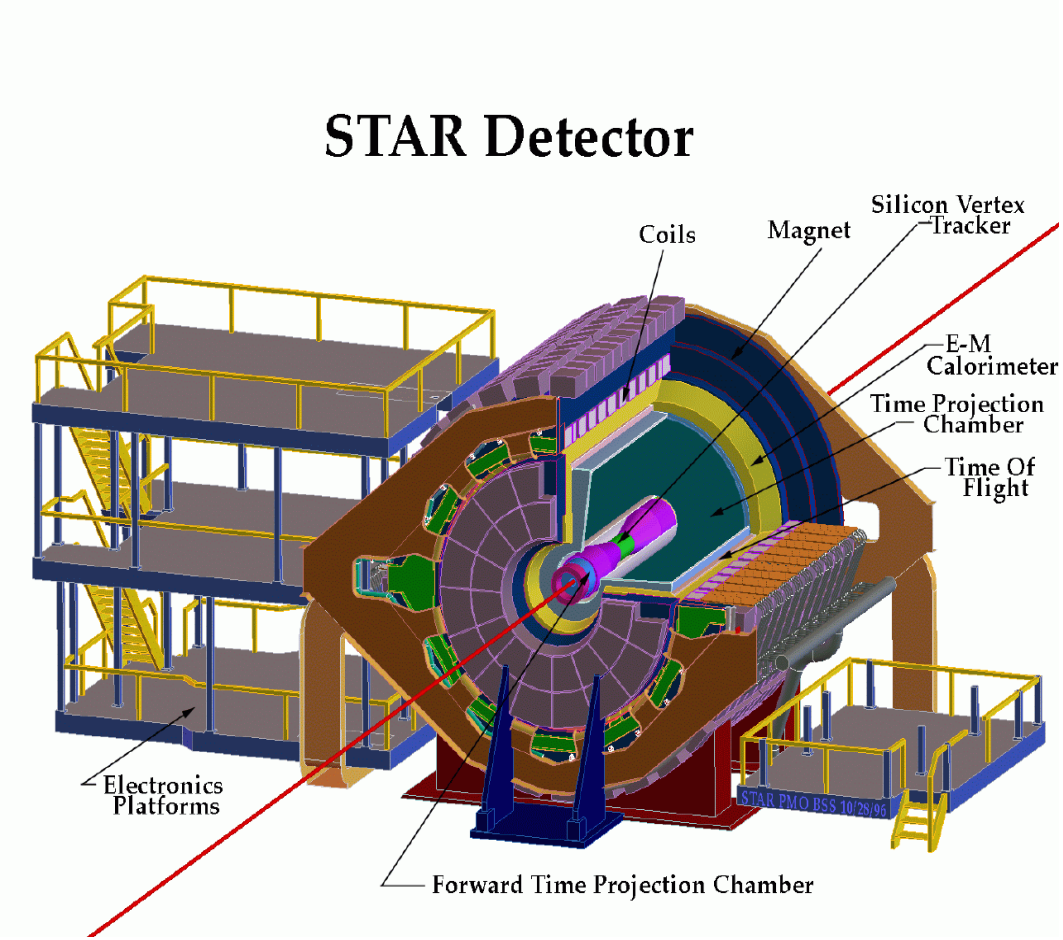
RHIC Low Energy Scan

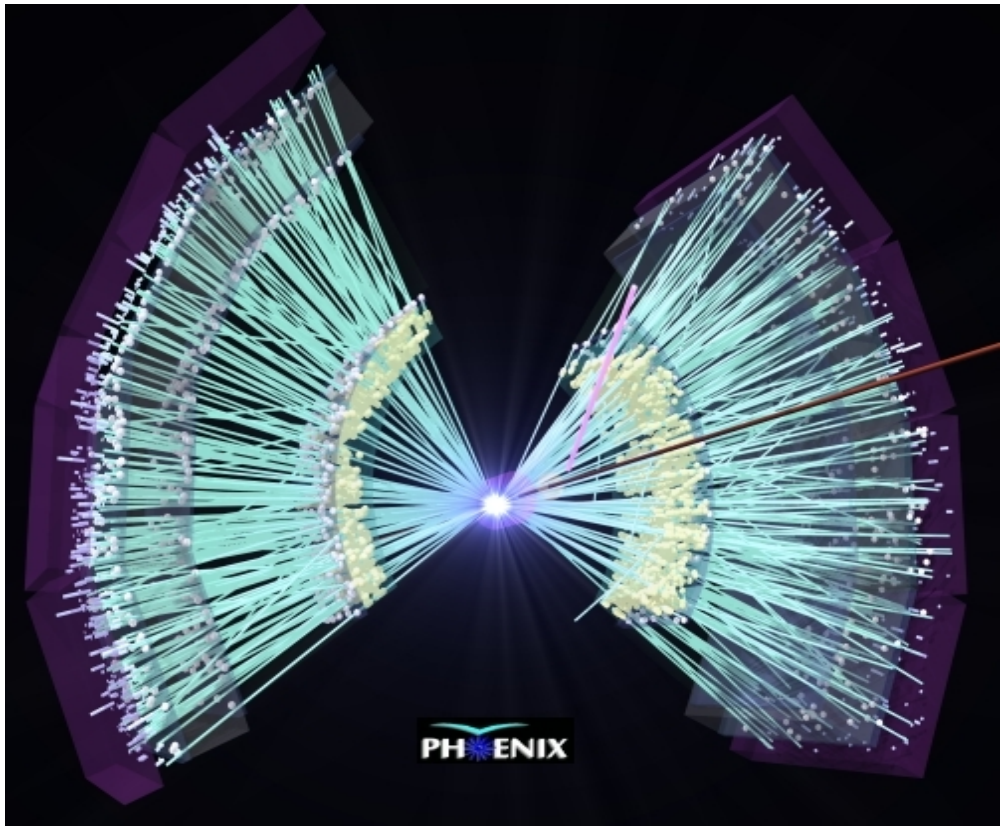
Based on:

H. G. Ritter, PoS(CPOD2007) 015,
P. Sorensen, APS DNP 2004 Long Range Plan
T. Satogata, BNL internal report



Experiments





Project schedule:

- Low energy (5 GeV/u) test run with Au, June 2007

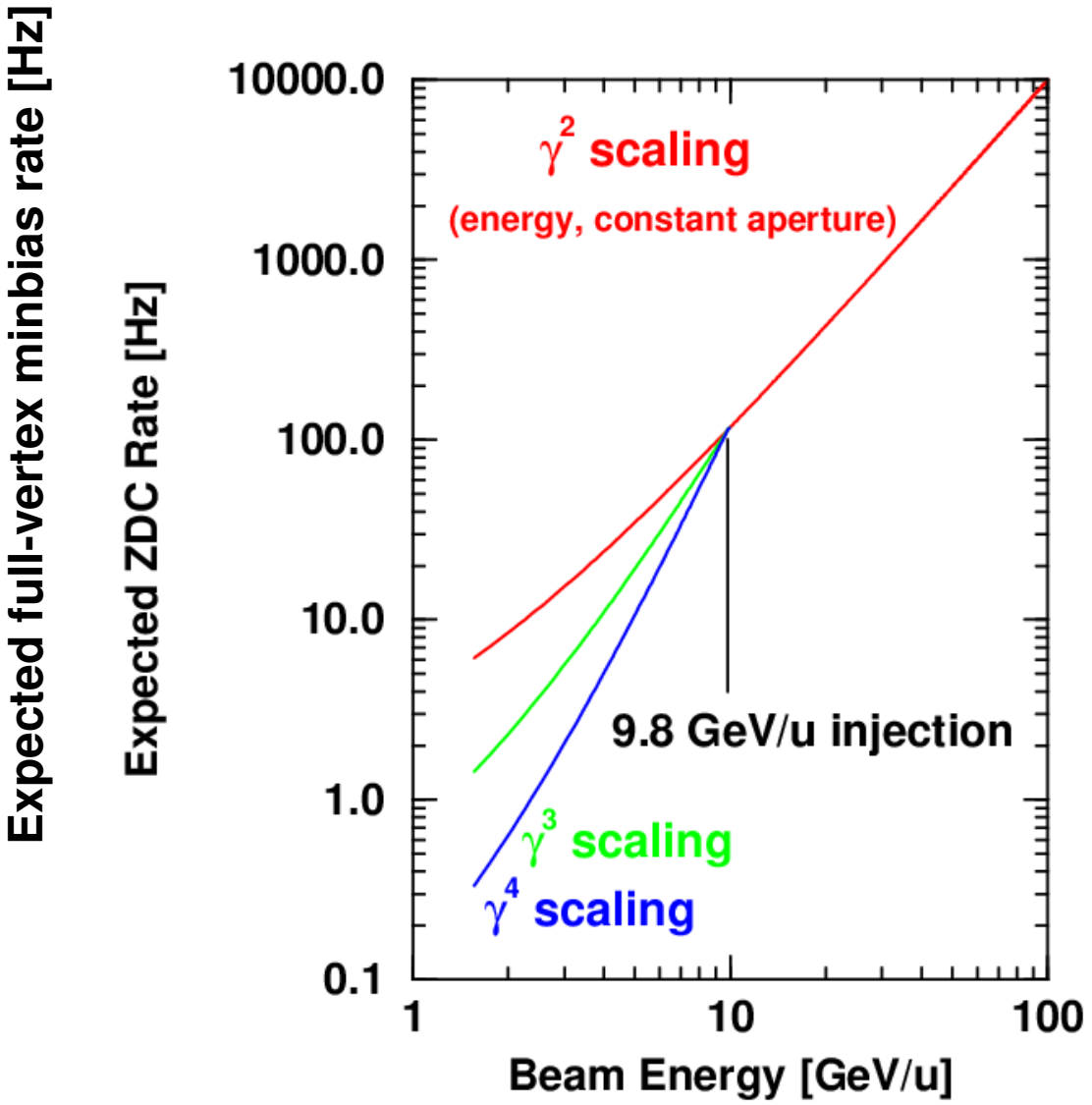
- First physics run in 2010:
Au+Au collisions at the NA49/61 energies
(c.m. Energy per N+N pair = 4.86, 6.27, 7.62, 8.77
12.3 and 17.3) and 50 GeV

Physics goals:

- search for the critical point

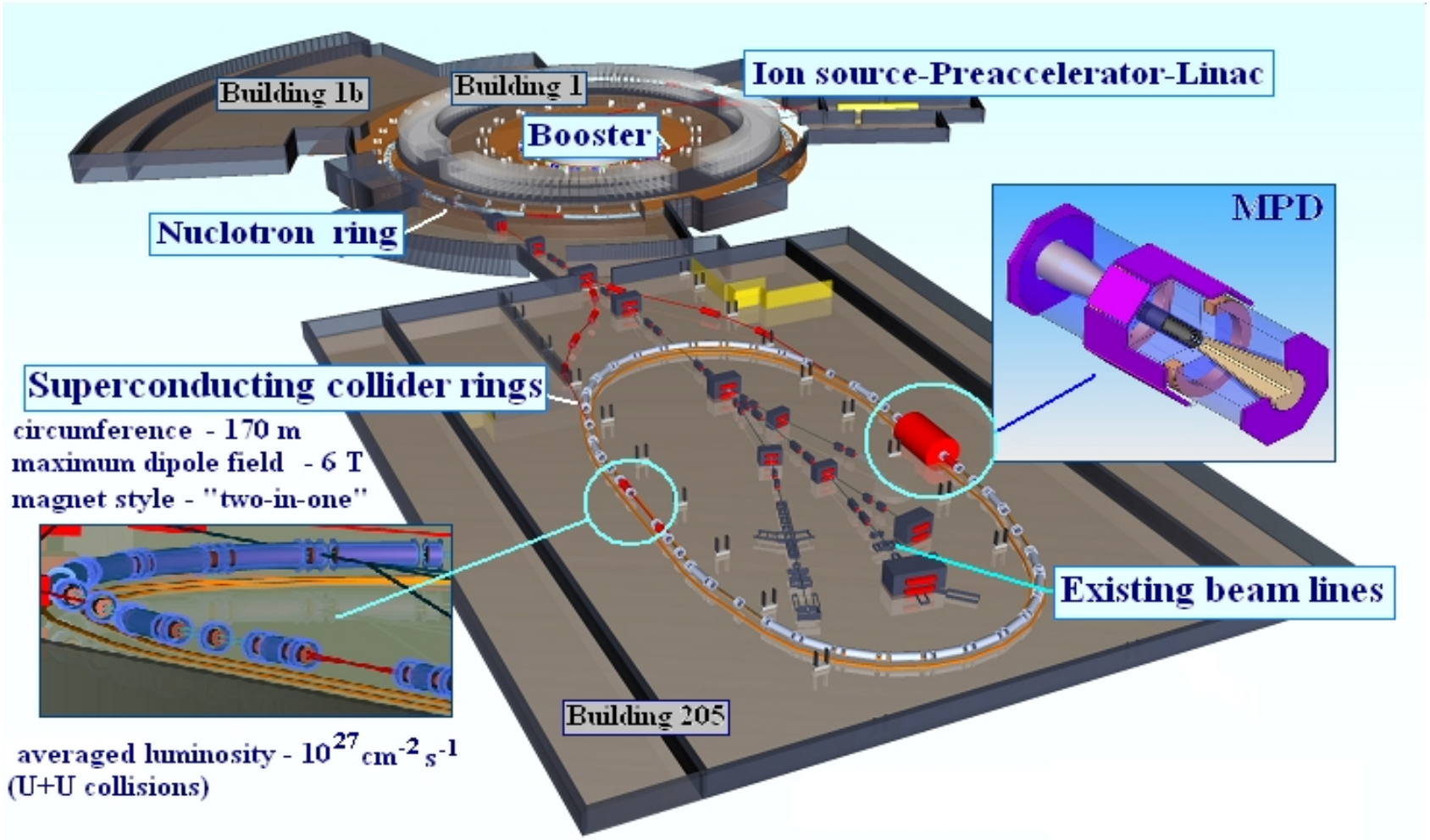
- turn off the signals of deconfinement

The 2007 test will establish the event rate at lower energies (1 Hz?)

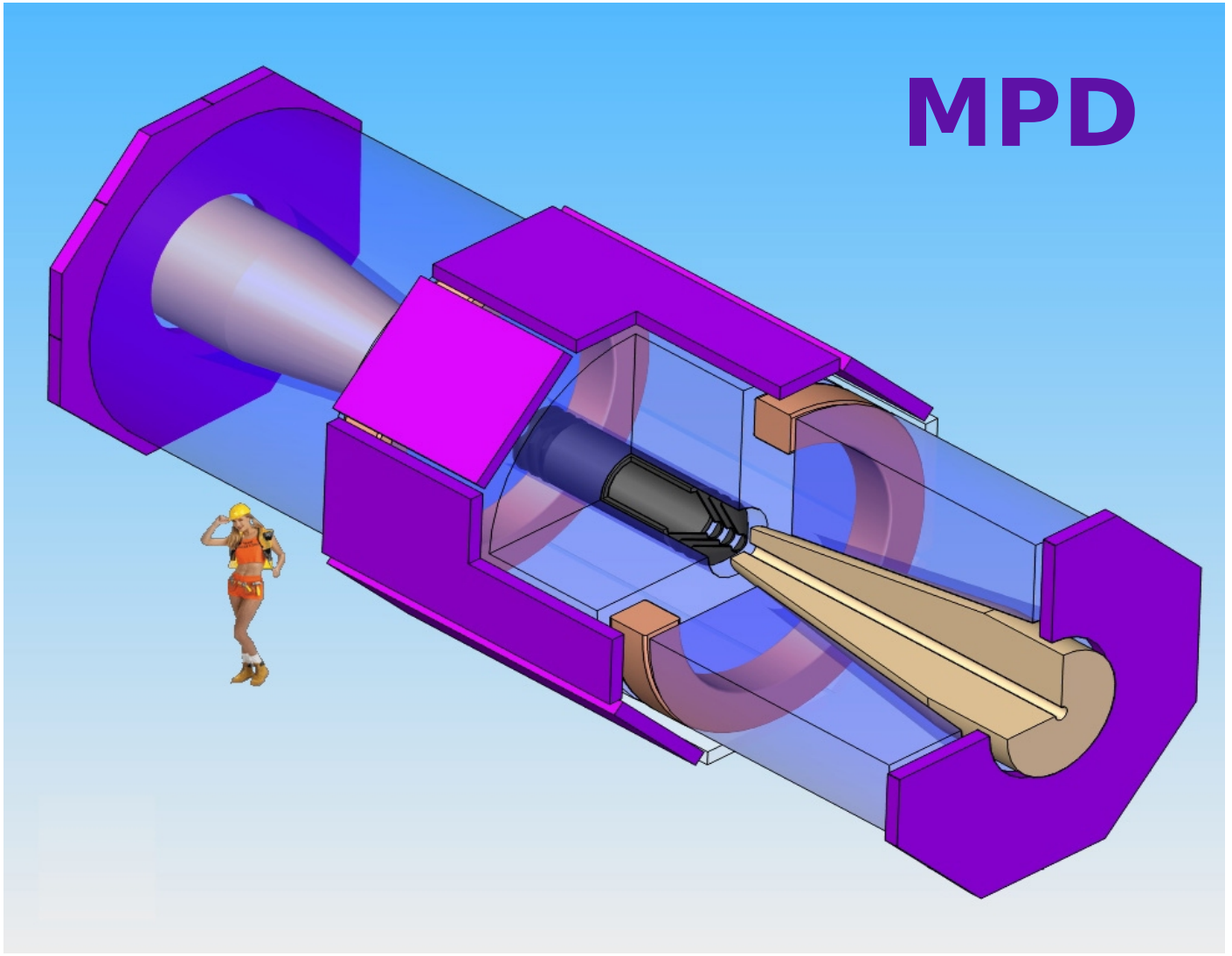


Nuclotron-based Ion Collider fAcility and MultiPurpose Detector (NICA/MPD)

Based on:
NICA/MPD Booklet



Experiment



(TPC, SVS, TOF, ZDC)

Commissioning of NICA and MPD planned for 2013

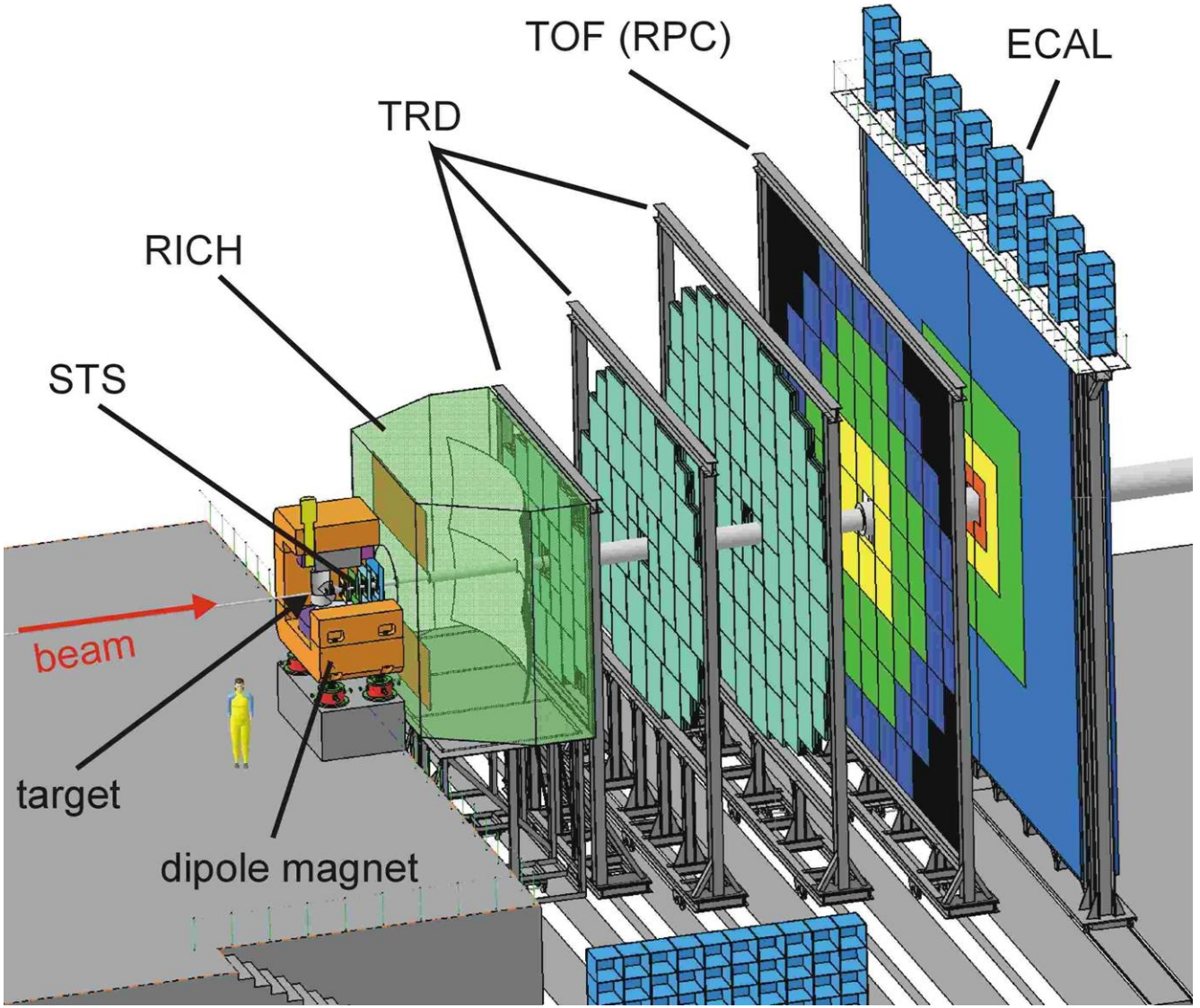
$\sqrt{s_{NN}} \leq 9$ GeV, $A \leq U$, luminocity = $10^{27}\,cm^{-2}\,s^{-1}$

Physics goal:

- search for the mixed phase of strongly interacting matter

Facility for Antiproton and Ion Research and the CBM experiment (FAIR/CBM)

The CBM experiment



Commissioning of SIS-300 and CBM planned for 2015

$\sqrt{s_{NN}} \leq 8.5$ GeV, A $\leq$ Au, event rate ≤ 10 MHz

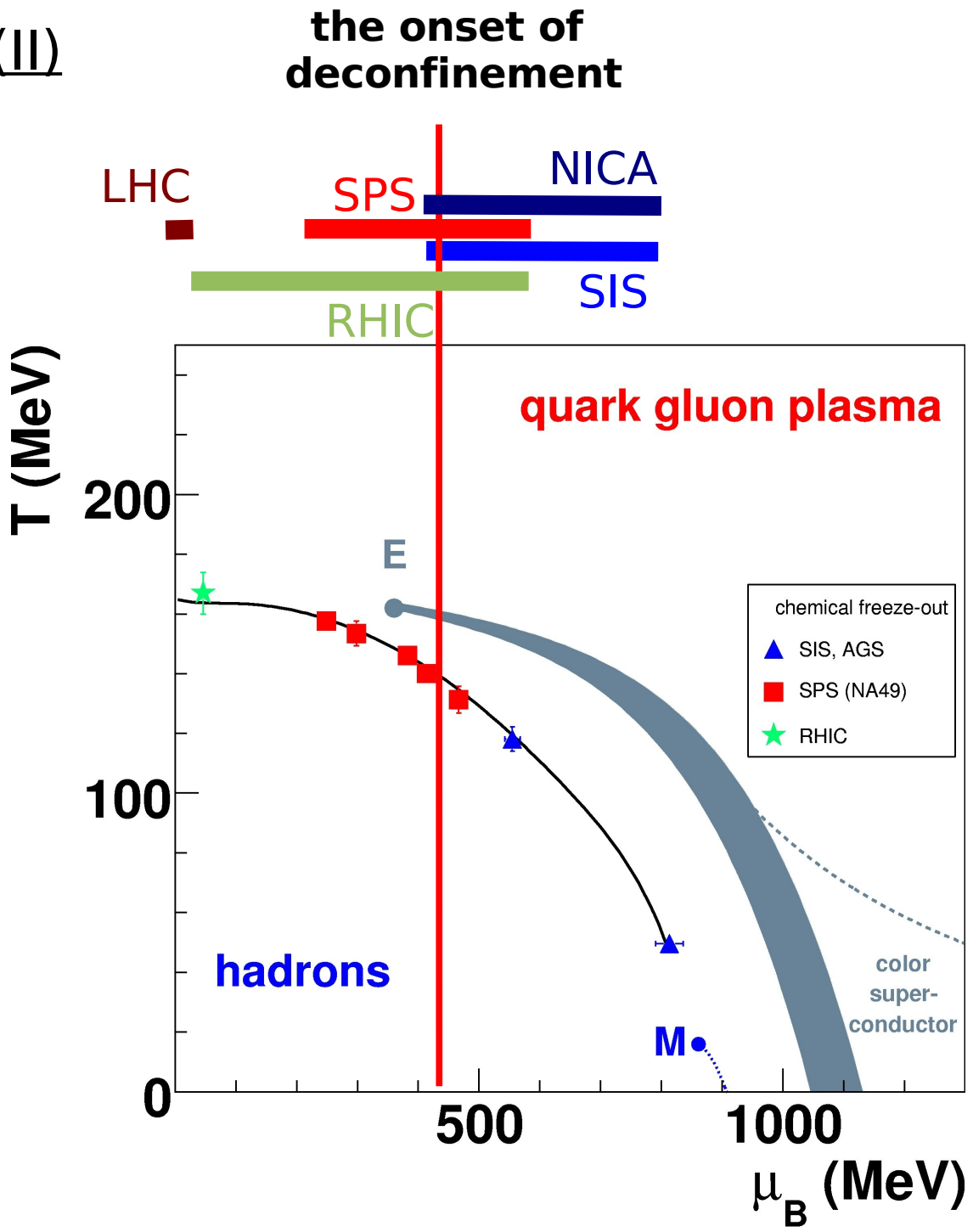
Physics goal:

- first order phase transition,

- hadrons in dense matter, rare probes (open and hidden charm)

- critical point

Summary (II)


the onset of deconfinement
LHC
SPS
NICA
SIS
RHIC
quark gluon plasma
T (MeV)
200
100
0
E
chemical freeze-out
SIS, AGS
SPS (NA49)
RHIC
hadrons
color super-conductor
M
500
1000
μB (MeV)

Summary (III)

Facility:	**SPS**	**RHIC**	**NICA**	**SIS-300**
Exp.:	**NA61**	**STAR** **PHENIX**	**MPD**	**CBM**
Start:	**2009**	**2010**	**2013**	**2015**
Pb Energy: **(GeV/(N+N))**	**4.9-17.3**	**4.9-50**	**≤9**	**≤8.5**
Event rate: **(at 8 GeV)**	**100 Hz**	**1 Hz(?)**	**≤10 kHz**	**≤10 MHz**
Physics:	**CP&OD**	**CP&OD**	**OD&HDM**	**OD&HDM**

CP – critical point
OD – onset of deconfinement, mixed phase, 1st order PT
HDM – hadrons in dense matter