Onset of Deconfinement and Critical Point: Nucleus-Nucleus Program of NA61/SHINE

(SHINE – SPS Heavy Ion and Neutrino Experiment)

- Fundamentals
- Physics of strongly interacting matter in NA61
- Upgrades for the ion program
- Plans and experimental landscape

M. Gazdzicki, Frankfurt, Kielce
for the NA61 Collaboration

Fundamentals

Physics goals:

IN THIS TALK

Physics of strongly interacting matter

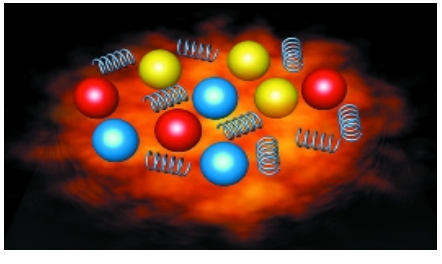
Discovery potential:

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



Data for neutrino and cosmic ray experiments

Precision measurements:

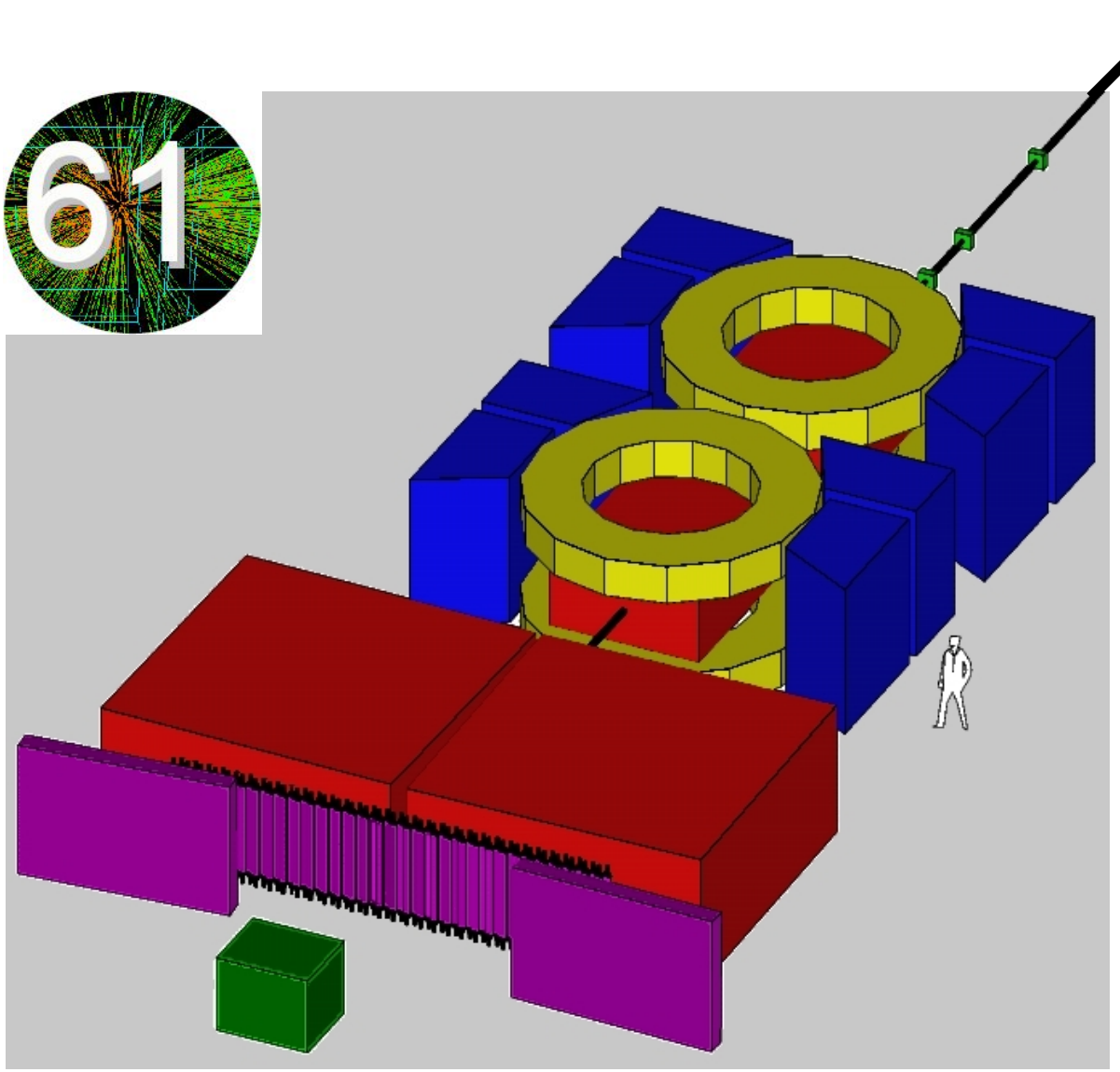
Measure hadron production in the T2K target needed for the T2K (neutrino) physics

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

NA61 Detector:

SPS H2 beam line:

secondary ion and hadron beams



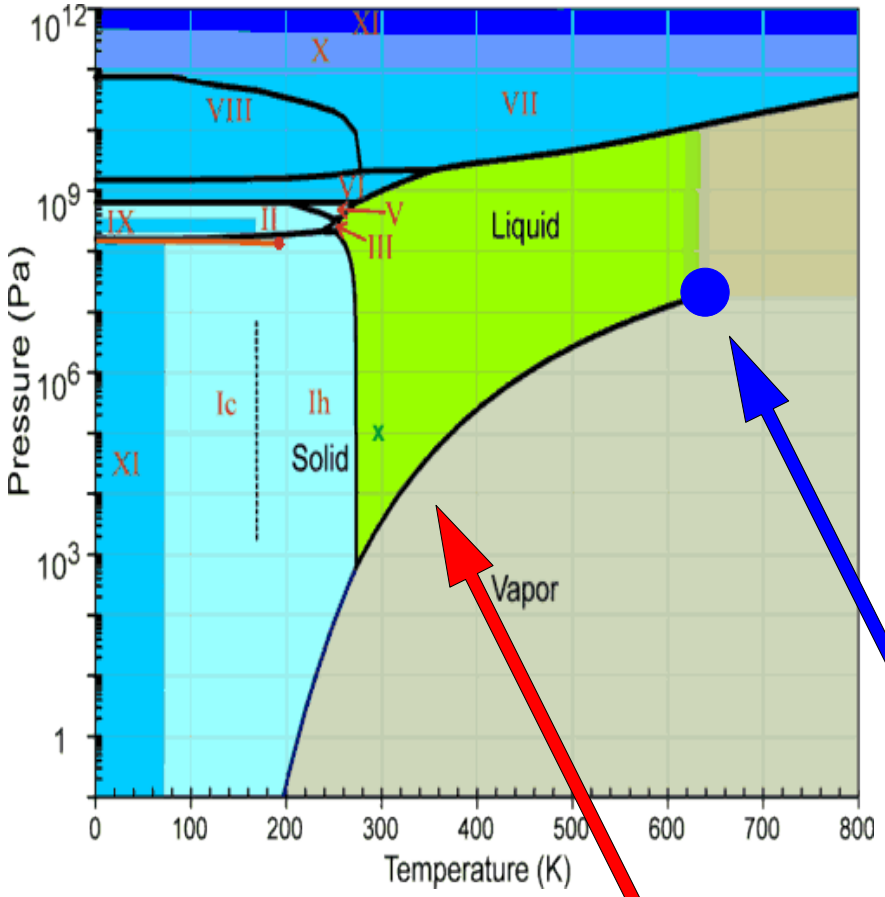
Upgraded NA49 apparatus

NA49: Nucl. Instrum. Meth. A430, 210 (1999)
NA61 upgrades: CERN-SPSC-2006-034, SPSC-P-330

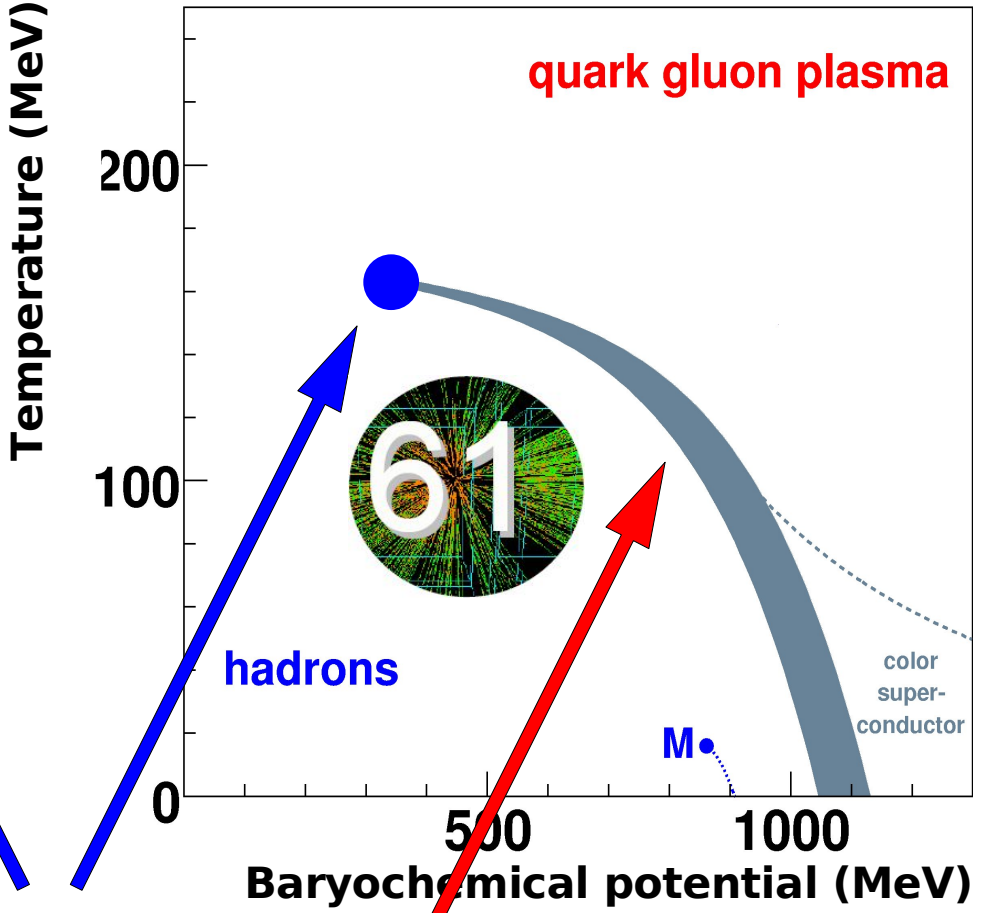
Location:

Physics of strongly interacting matter in NA61

water



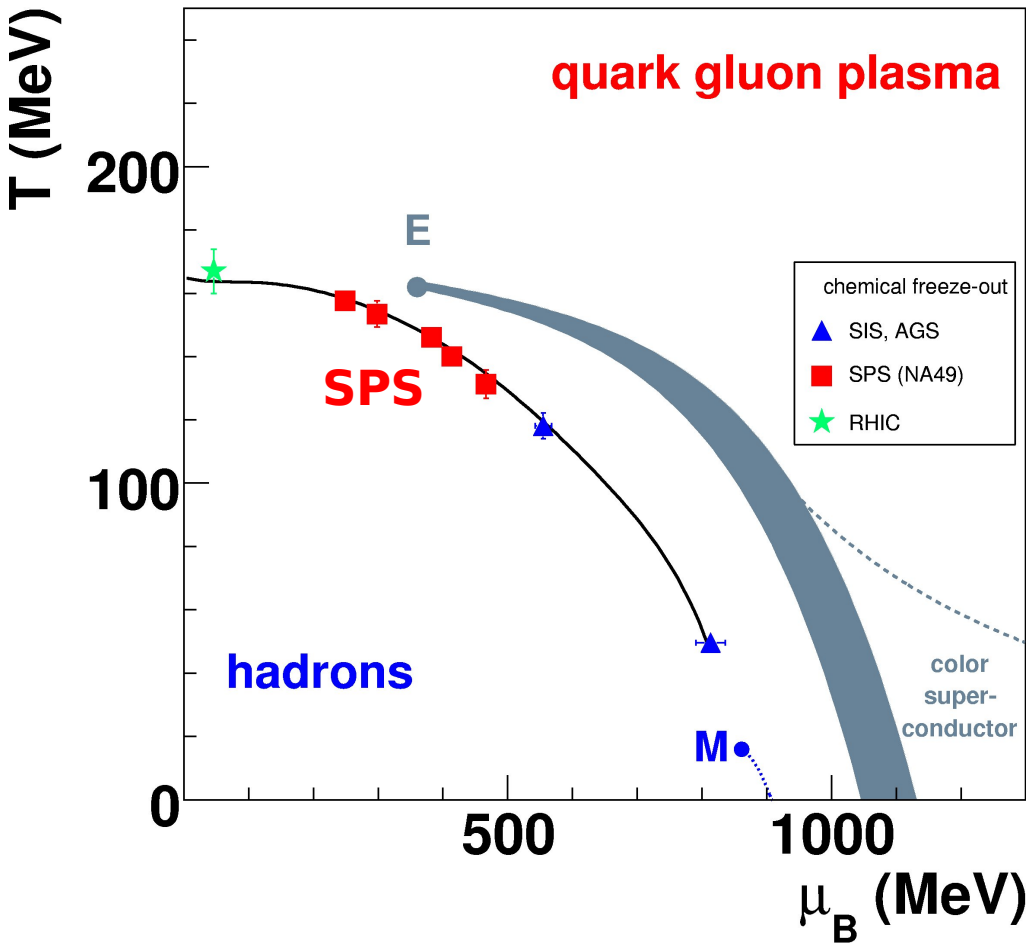
strongly interacting matter



critical point

1st order phase transition

Freeze-out parameters in Pb+Pb collisions:



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

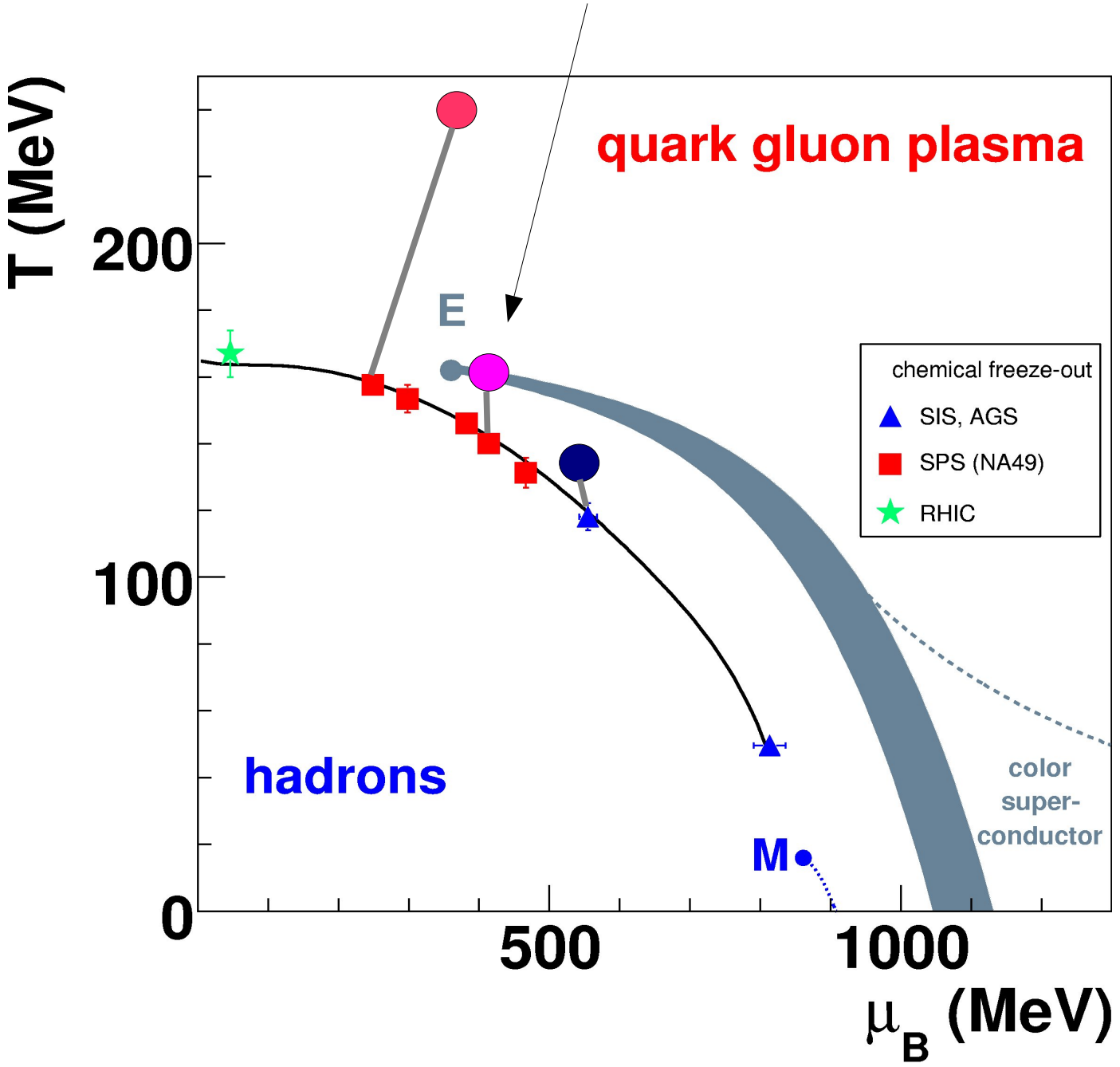
Early stage crosses the phase boundary at SPS energies (onset of deconfinement)

Onset of deconfinement: M.G., Gorenstein

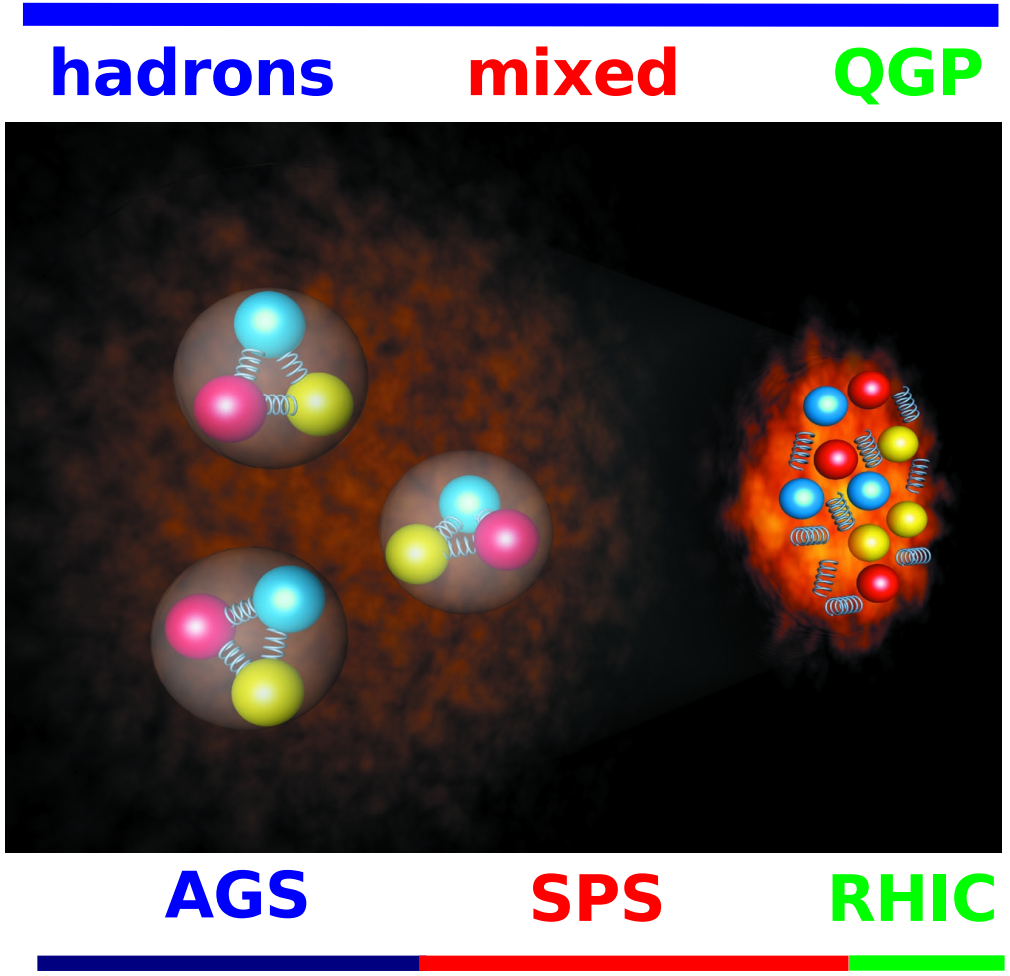
HG fits: Becattini et al., Cleymans, Redlich et al.

CP: Fodor, Katz

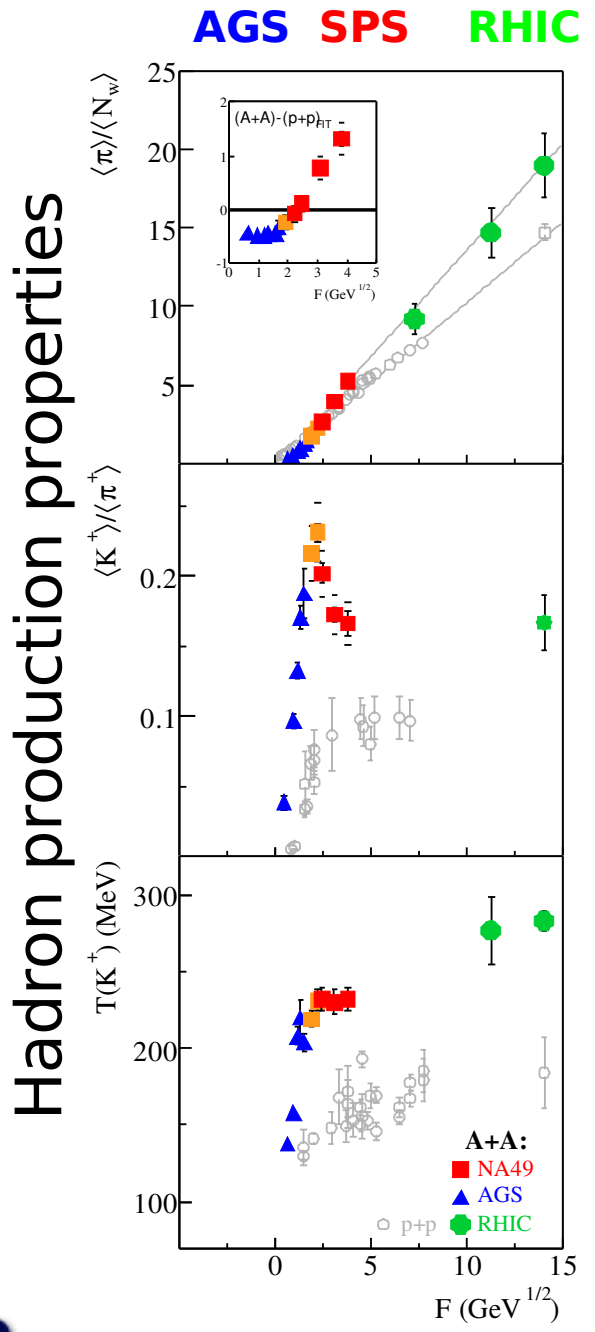
Onset of deconfinement:



Evidence for the onset of deconfinement in central Pb+Pb collisions at the low SPS energies (*PRC66:054902, PRC77:024903*)



collision energy



Kink

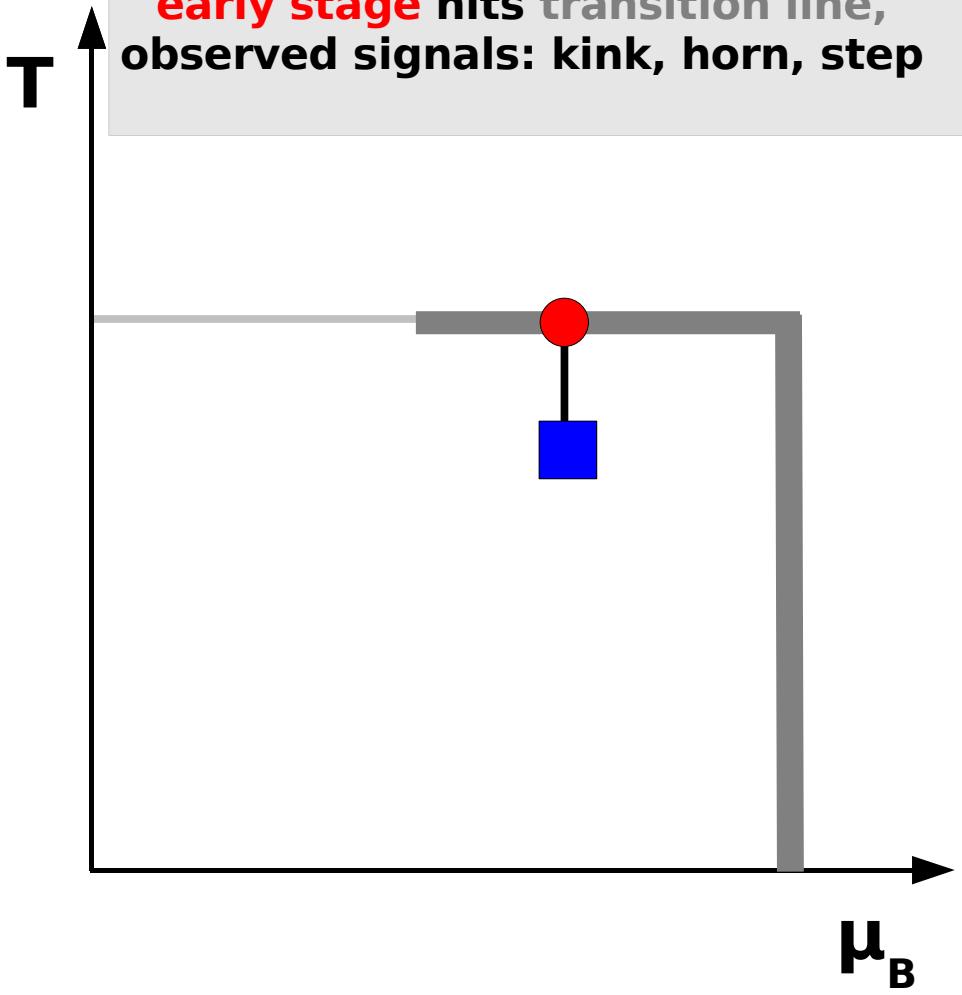
Horn

Step

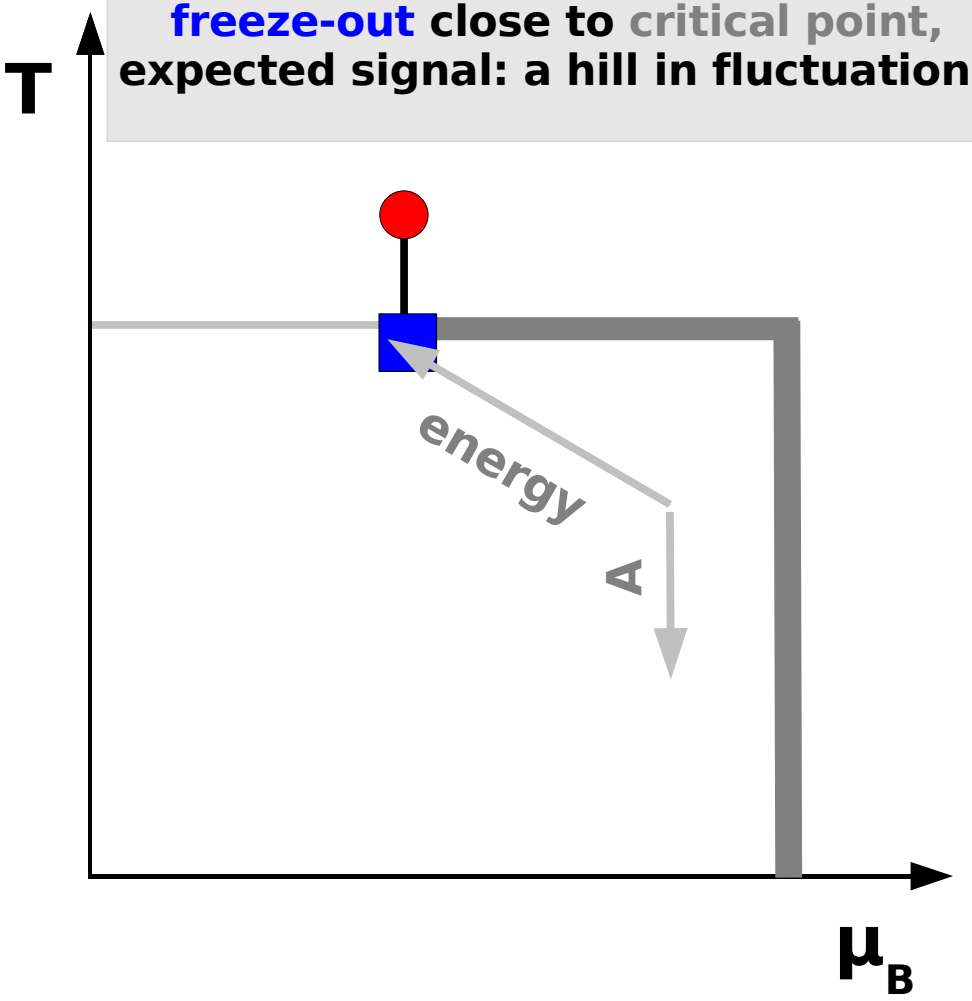
collision energy

Two main events in nucleus-nucleus collisions

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

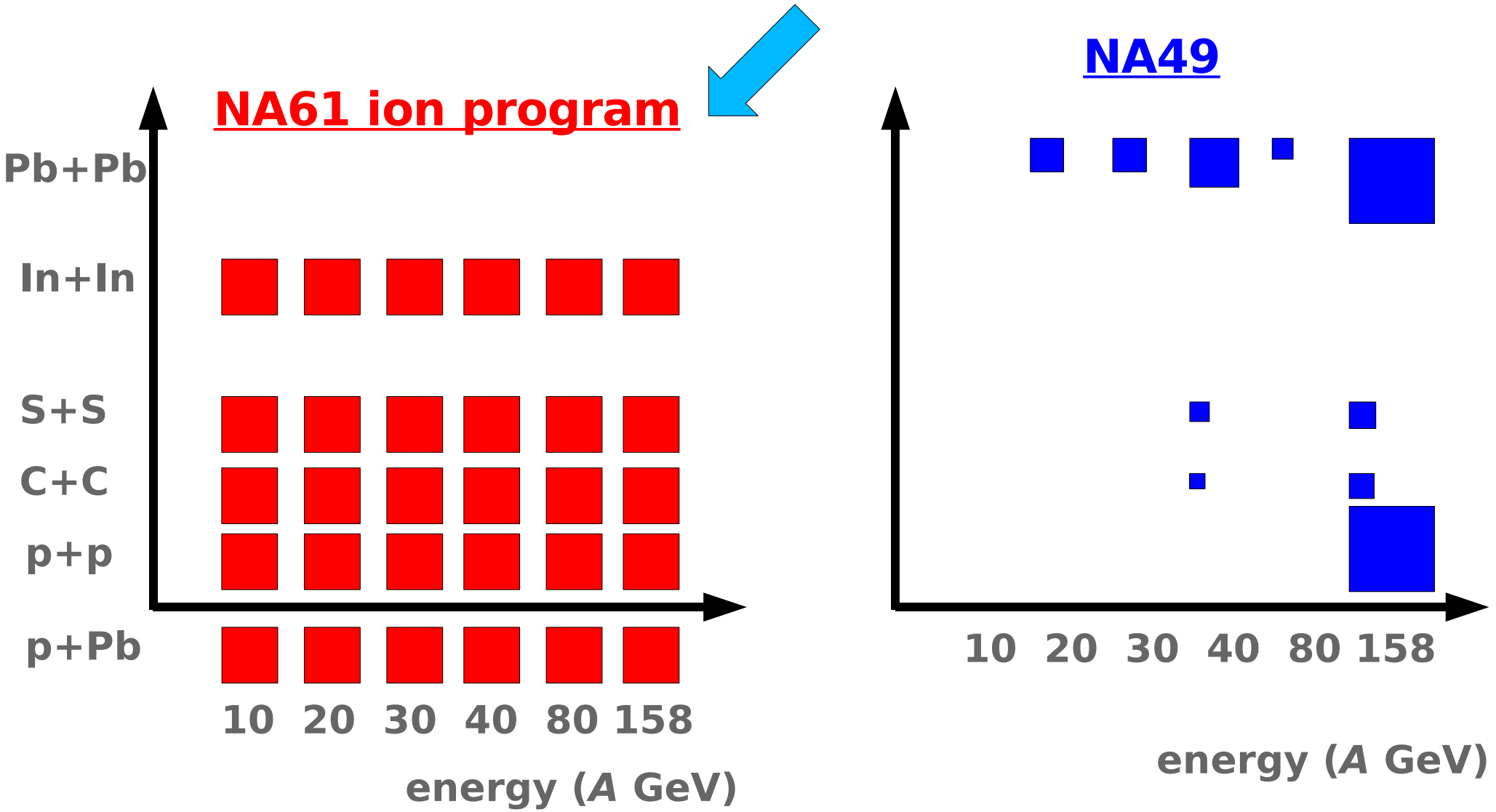


Critical Point:
freeze-out close to critical point,
expected signal: a hill in fluctuations



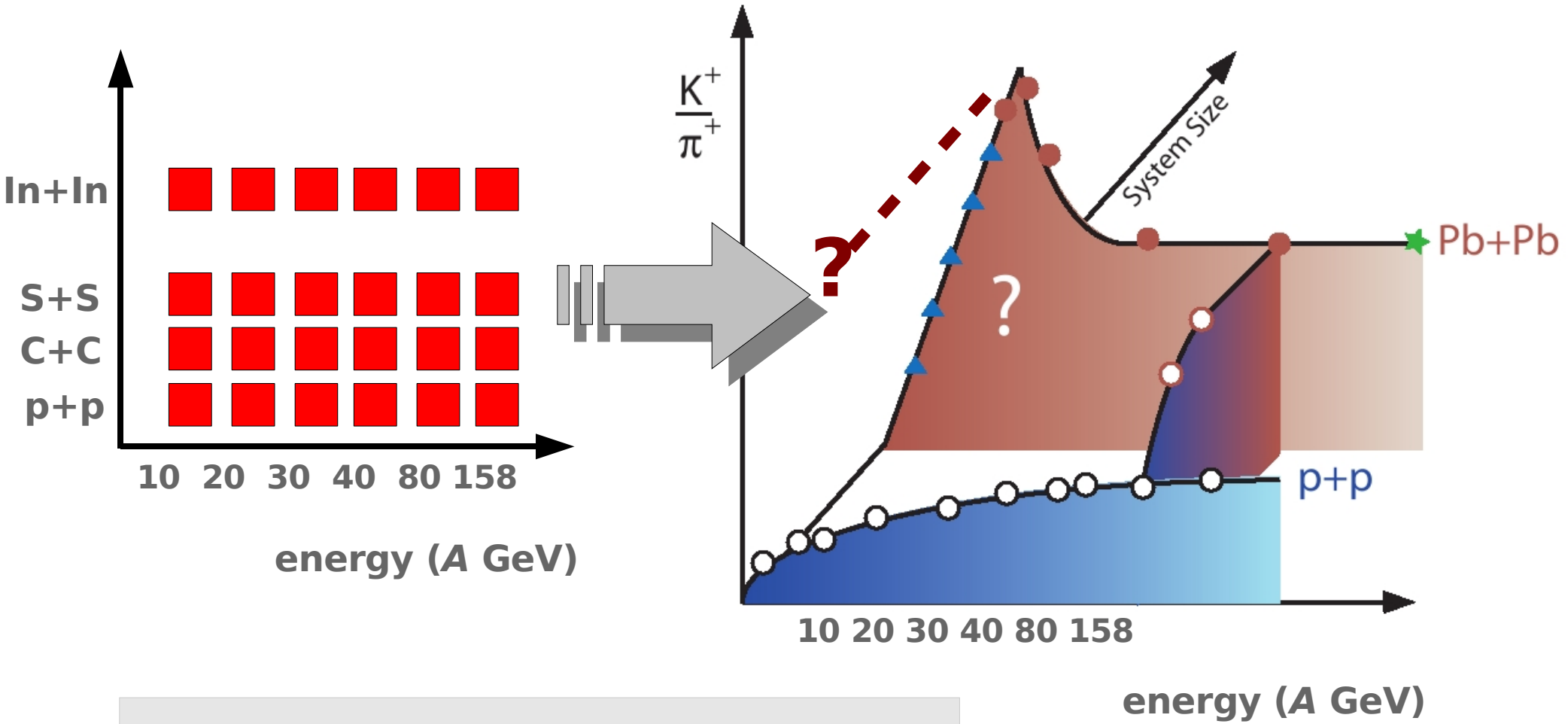
E(OoD) ≈ 30*A* GeV ≤ E(OoC)

NA61/SHINE energy-system size scan:



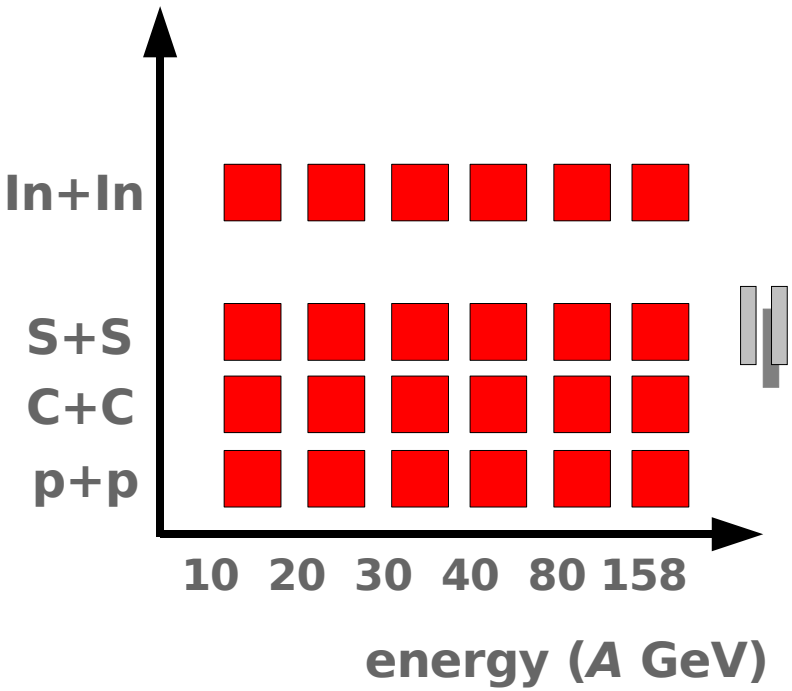
= $2 \cdot 10^6$ registered collisions

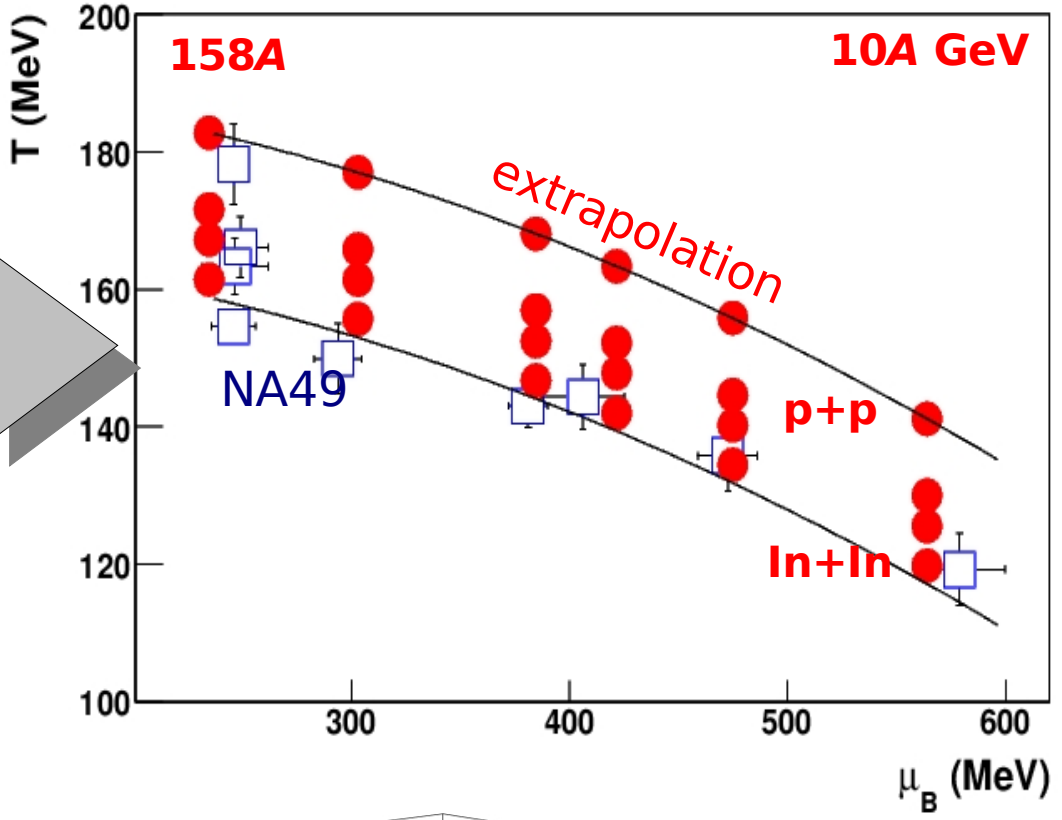
Study the onset of deconfinement:



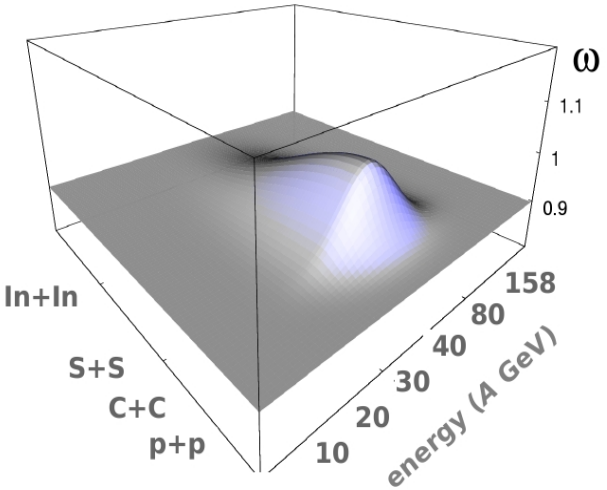
Search for the onset of the horn (kink, step) in collisions of light nuclei

_Search for the critical point:



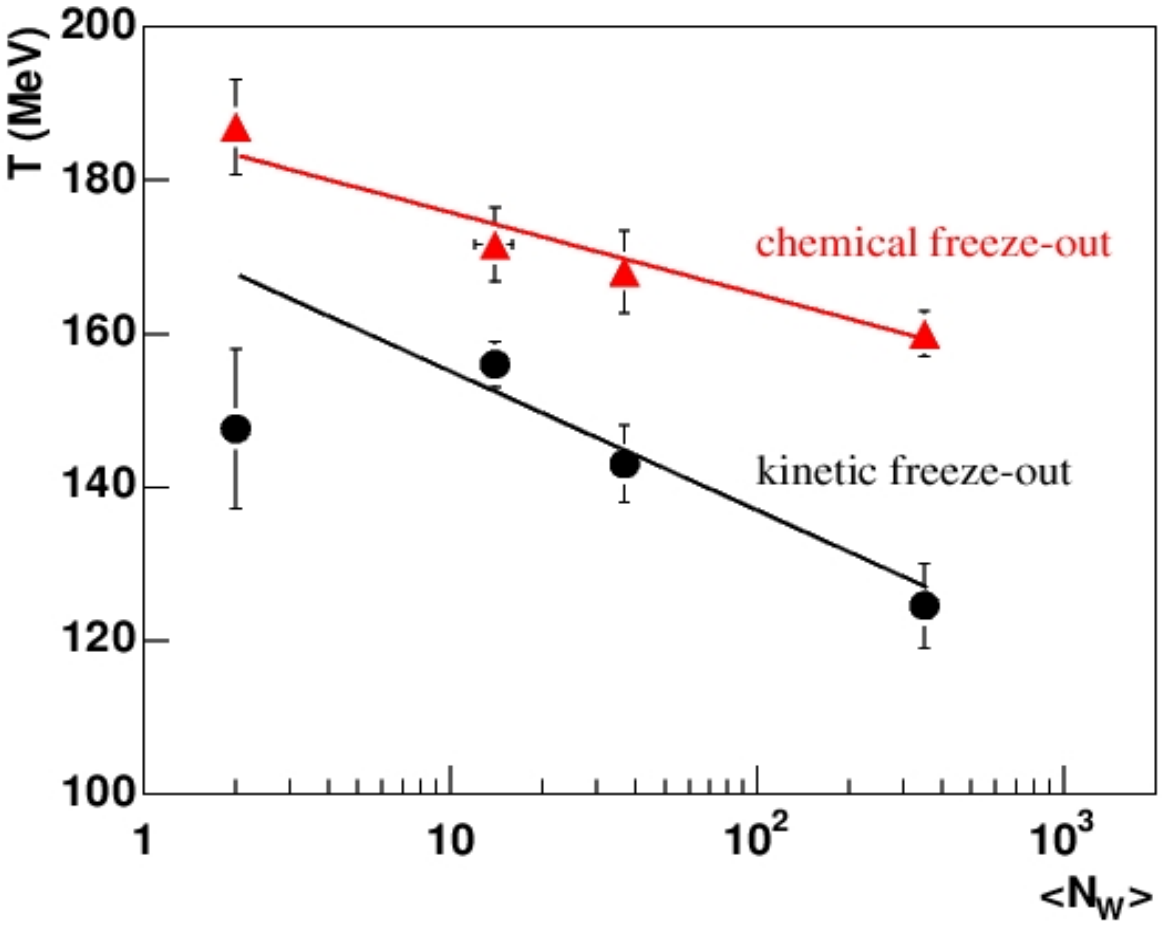


Search for the hill of fluctuations



System size scan:

a change of the freeze-out T at the approximately constant μ_B



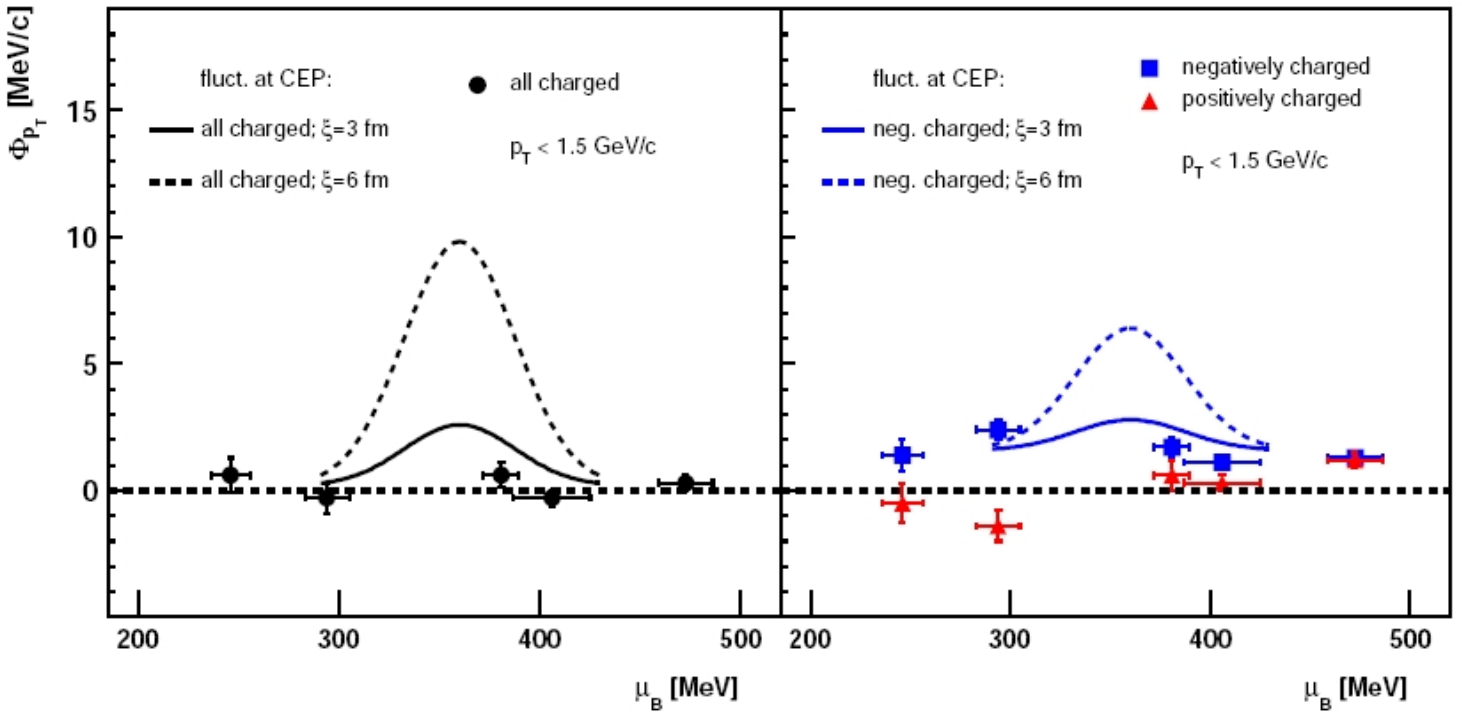
chemical freeze-out:
PRC73:044905

kinetic freeze-out:
JPG31:S147

T ↘ N_W ↗ consistent with the dynamical freeze-out condition: $\lambda \approx R$

Predictions for the critical point vs data (I):

central Pb+Pb collisions (NA49)
transverse momentum fluctuations

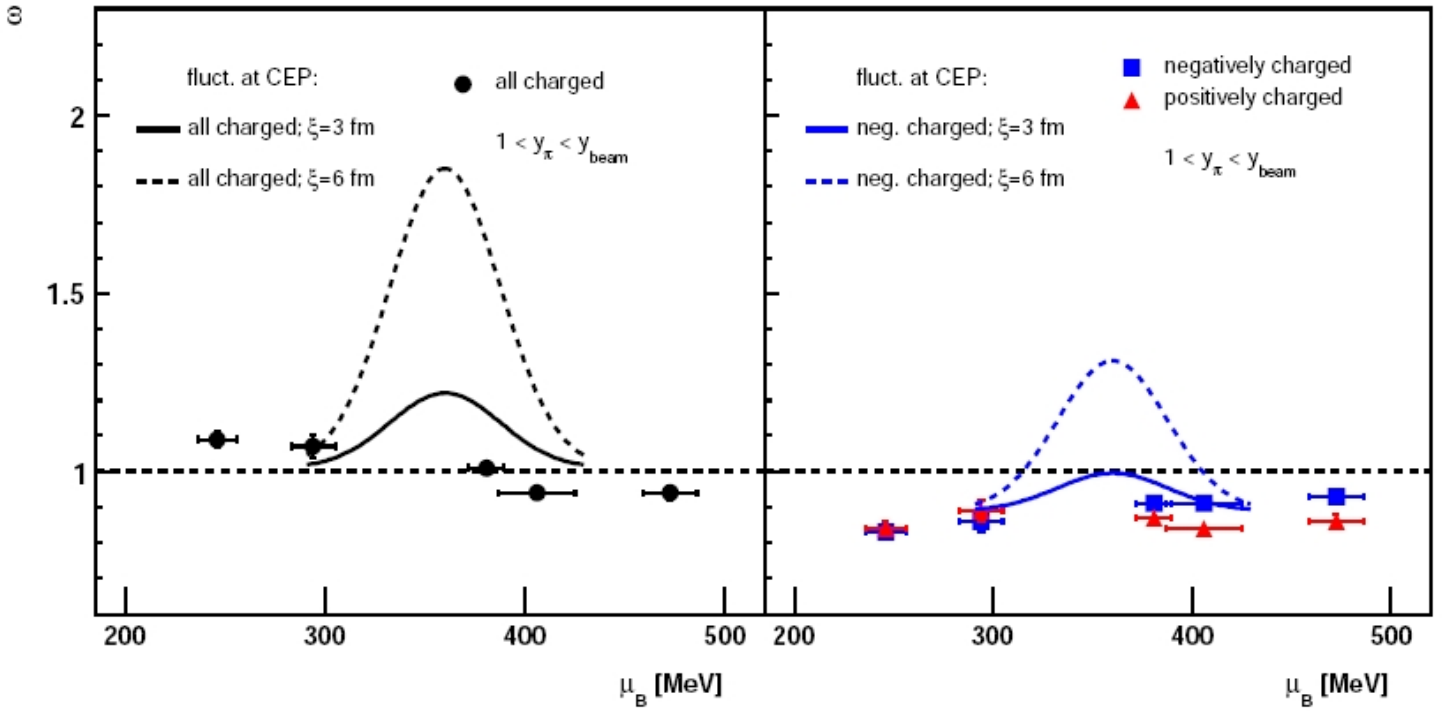


Data: arXiv:0810.5510
CP: *PRD60:114028*

the predicted CP fluctuations are not observed,
freeze-out far from CP?
too large system?

Predictions for the critical point vs data (II):

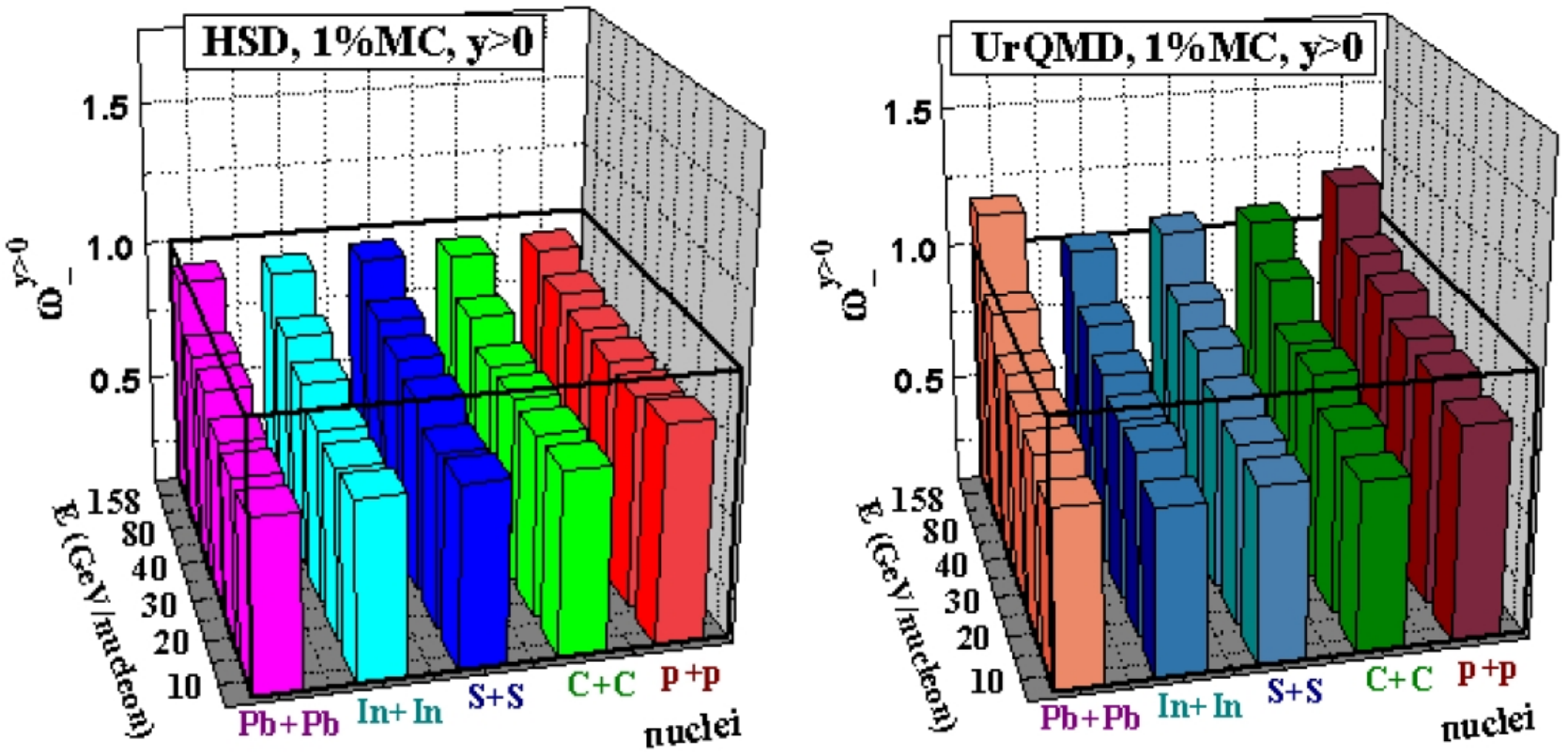
central Pb+Pb collisions (NA49)
multiplicity fluctuations



Data: *PRC78:034914*
CP: *PRD60:114028*

the predicted CP fluctuations are not observed,
freeze-out far from CP?
Pb+Pb - too large system?

Predictions for the background fluctuations:

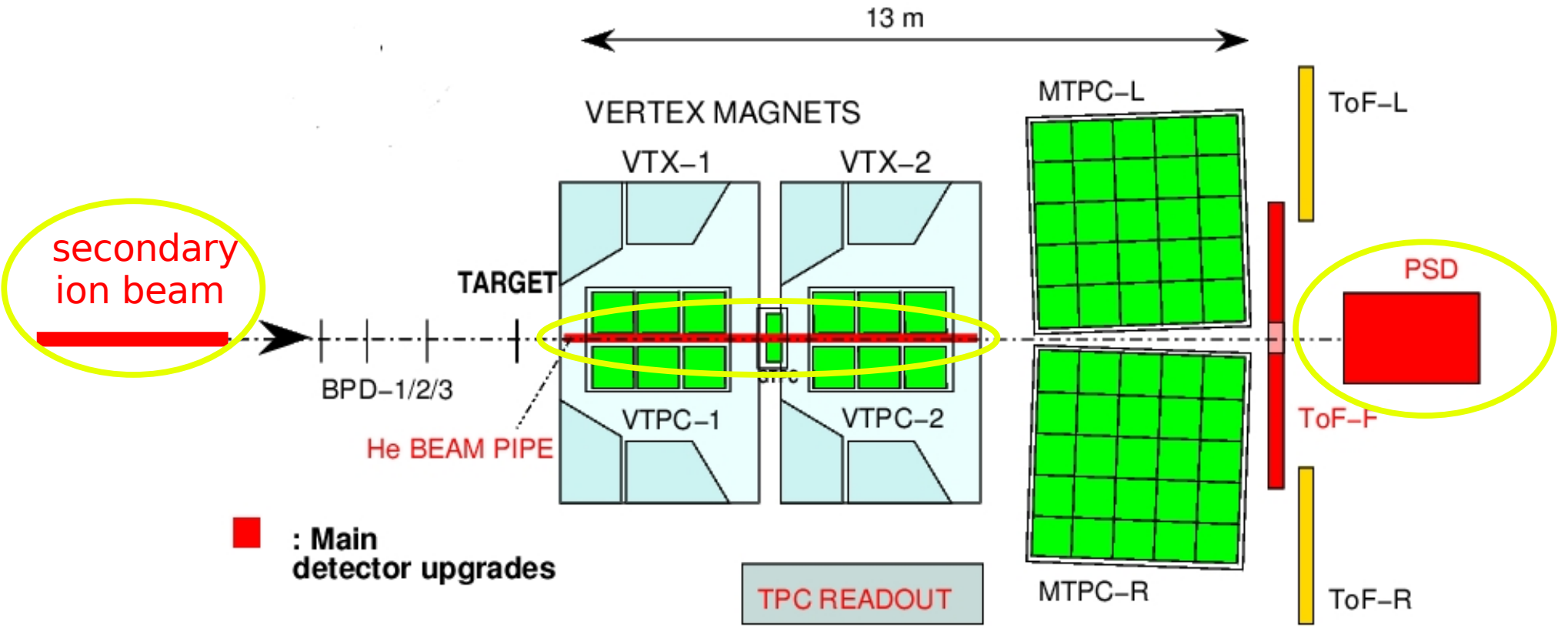


PRC78:024906

Fluctuations in string-hadronic models show smooth dependence on collision energy and mass of the colliding nuclei

Upgrades for the ion program

NA61 apparatus:



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

Upgrades for the ion program:

Secondary Ion Beam Line:

→ light and medium ion beams to NA61 during I-LHC operation with the Pb beam

(total cost 60k CHF)

Projectile Spectator Detector:

→ an increase of the resolution in the measurement of the number of projectile spectators by a factor ≈5 to $\Delta E/E \approx 50\%/E$,

→ *a* possible determination of the reaction plane

(total cost 670k CHF, 300k CHF Polish contribution)

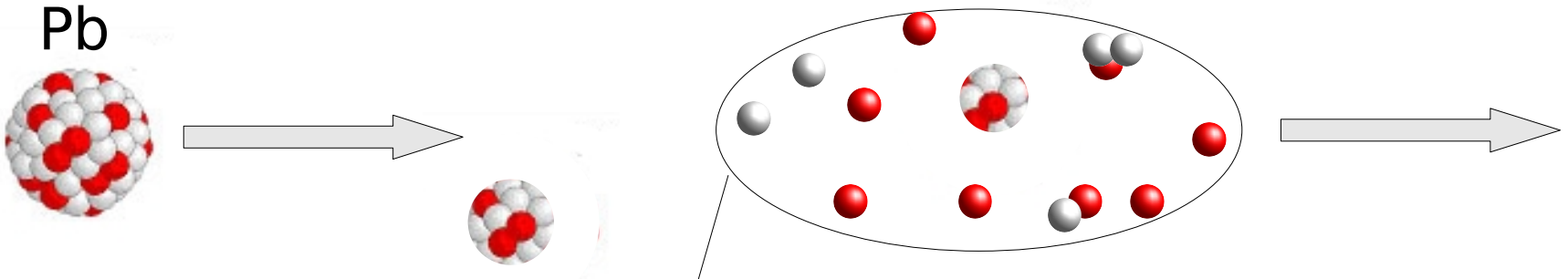
Helium beam pipe in the VTPC cage

→ a reduction of the delta-electron background by a factor of 10

(total cost 50k CHF)

Secondary Ion Beam Line for NA61:

The basic idea

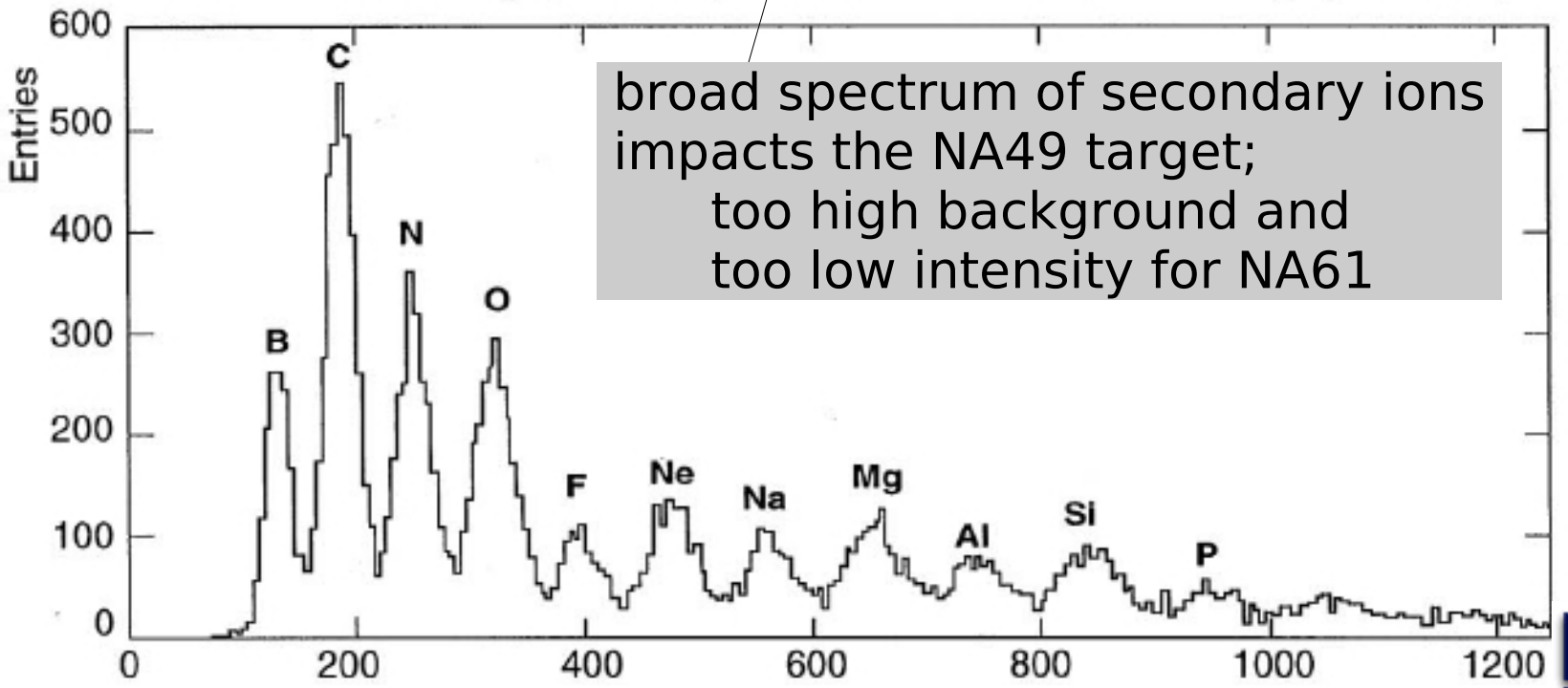


primary Pb beam from the SPS

fragmentation target

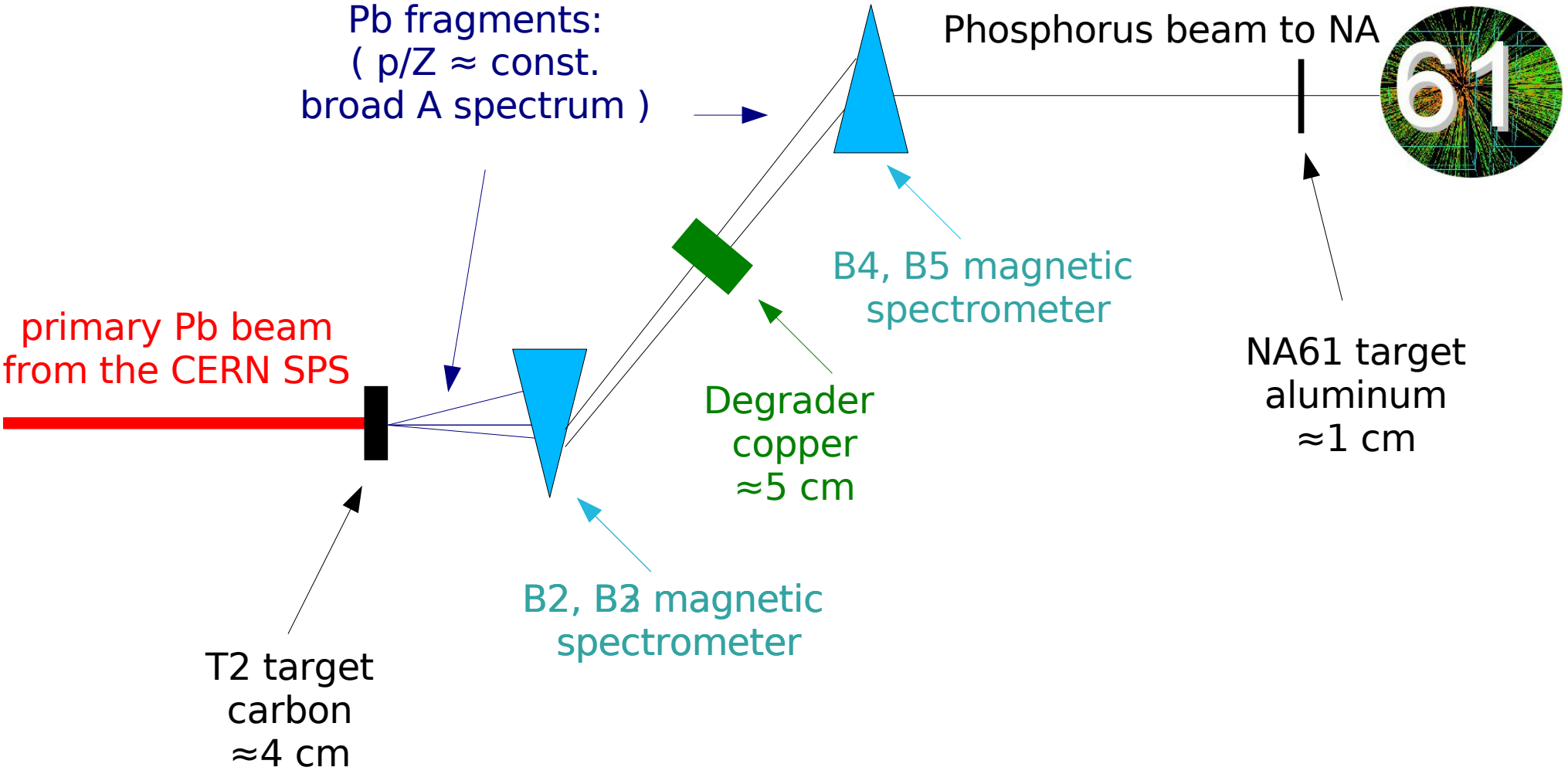
secondary light ion beam to NA49

The pilot NA49 studies



broad spectrum of secondary ions impacts the NA49 target;
too high background and
too low intensity for NA61

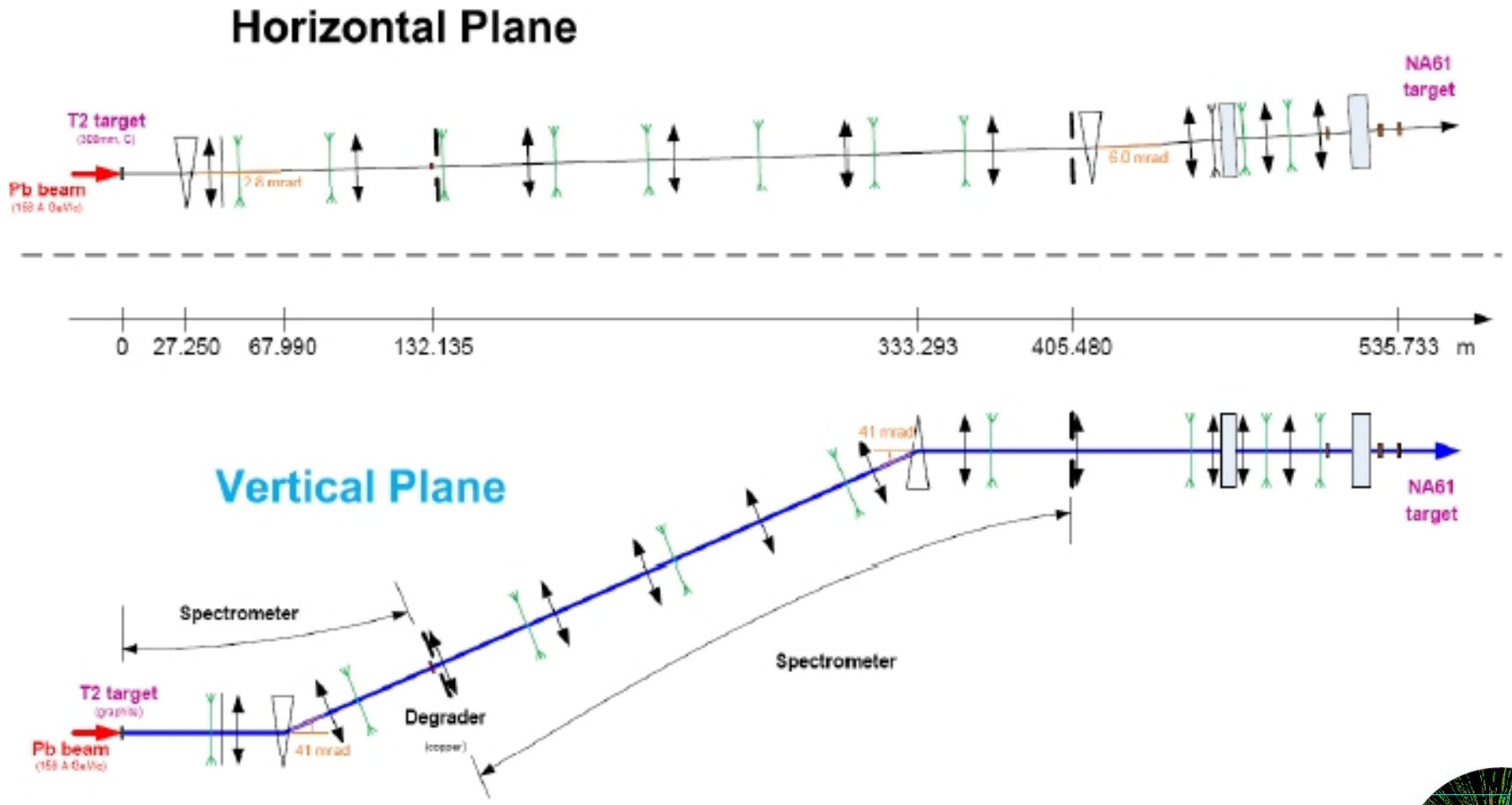
Secondary Ion Beam Line for NA61:



-selects beam of nuclei with close Z and A,
-further ion identification possible by Z (charge) measurements
-momentum per nucleon cannot be changed

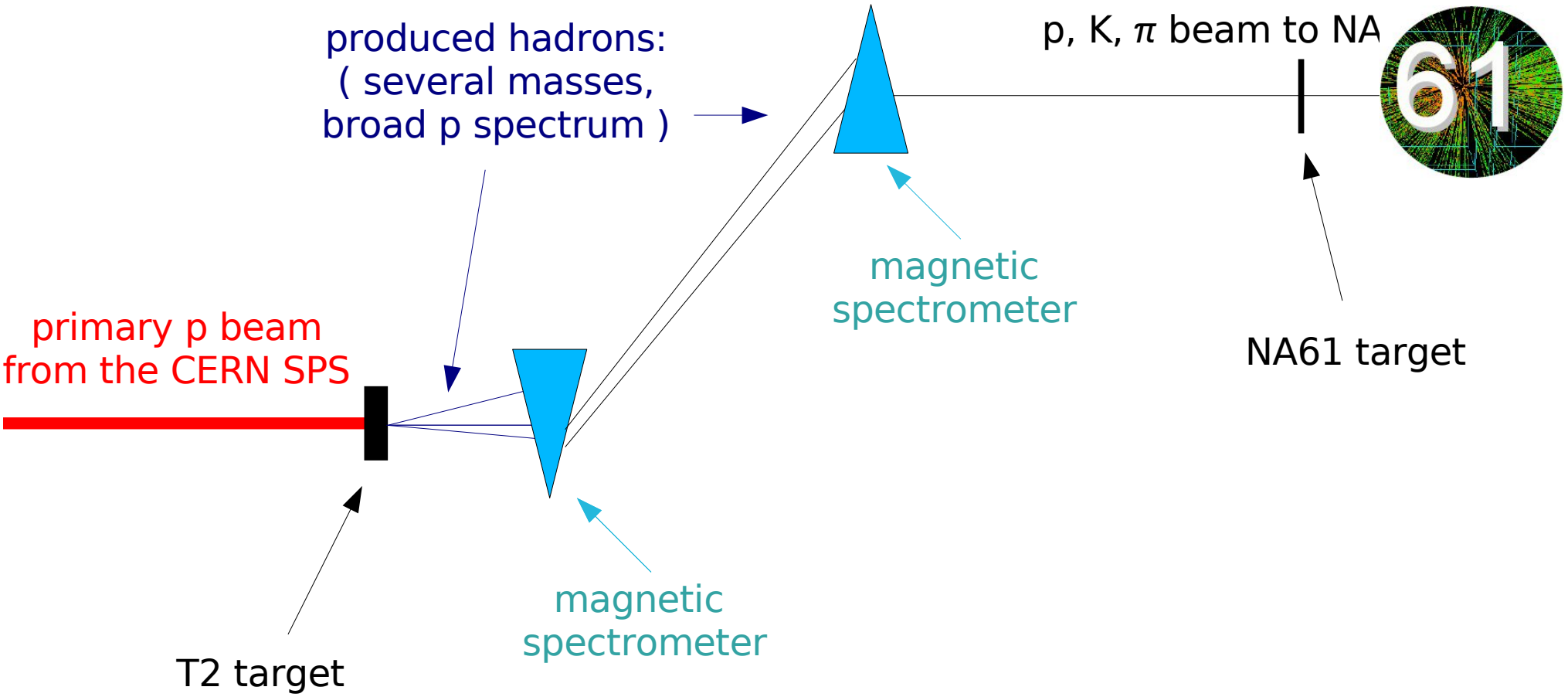
Secondary Ion Beam Line for NA61:

10^9 Pb ions/sec from SPS



10^5 P ions/sec to NA61

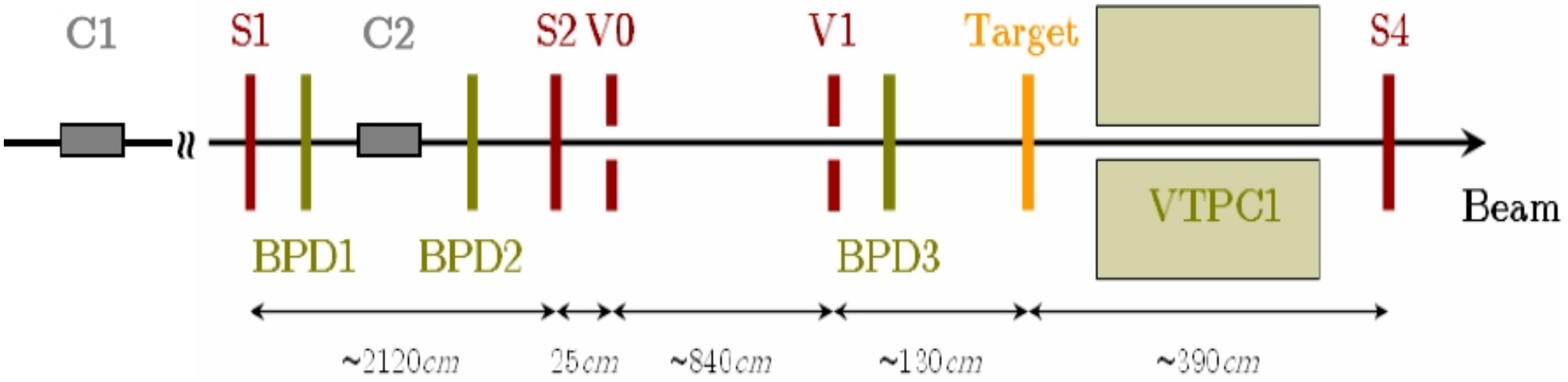
Secondary Hadron Beam Line for NA61:

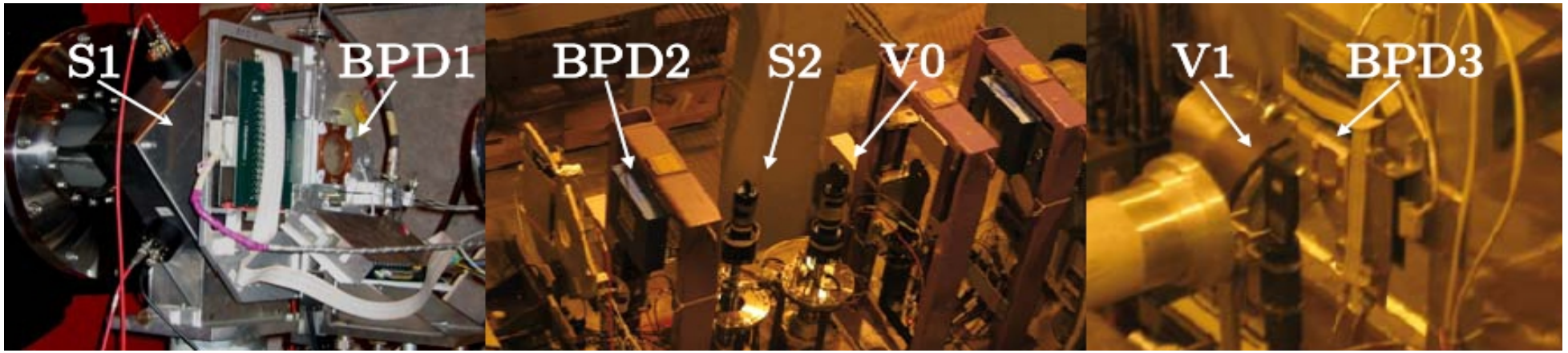


-selects beam of hadrons with a fixed p momentum
-further hadron identification possible by mass measurements

Secondary hadron beam in NA61:

Beam and trigger counters

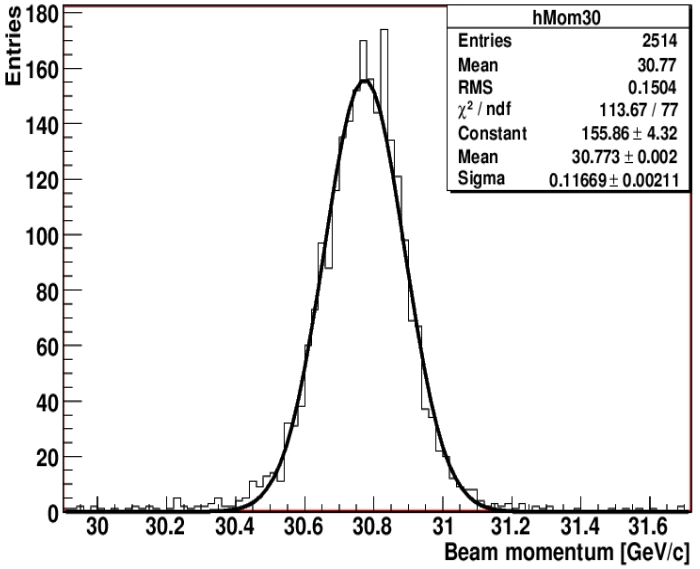




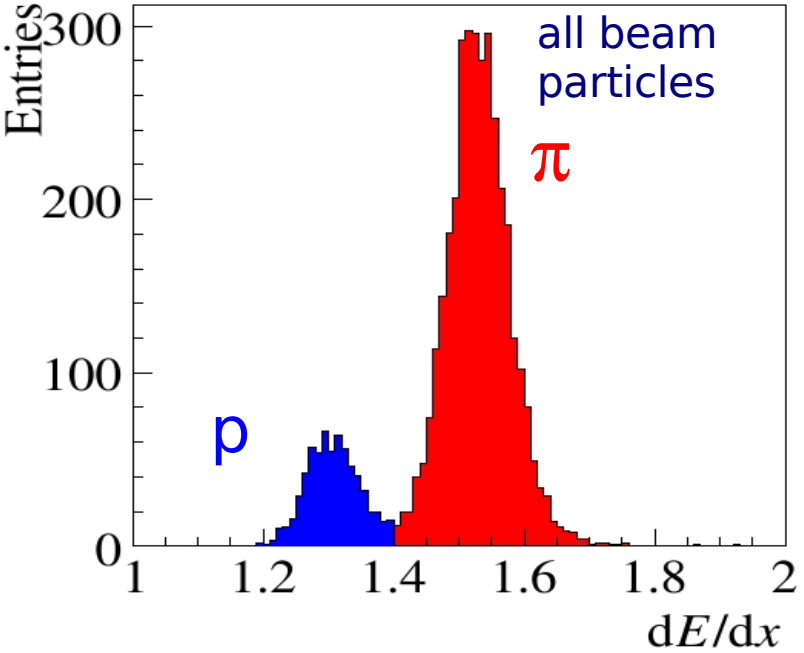
C1 and C2 - proton identification,
S1, S2, V0, V1, BPD1/2/3 – determination of proton trajectory,
S4 – selection of p+target interactions

Example: beam of positively charged hadrons at 31 GeV/c

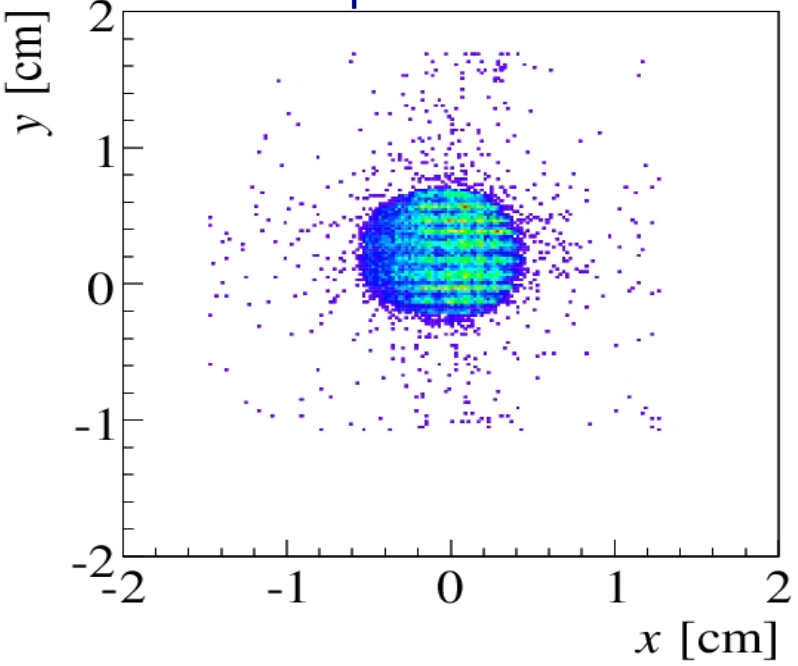
momentum from TPC

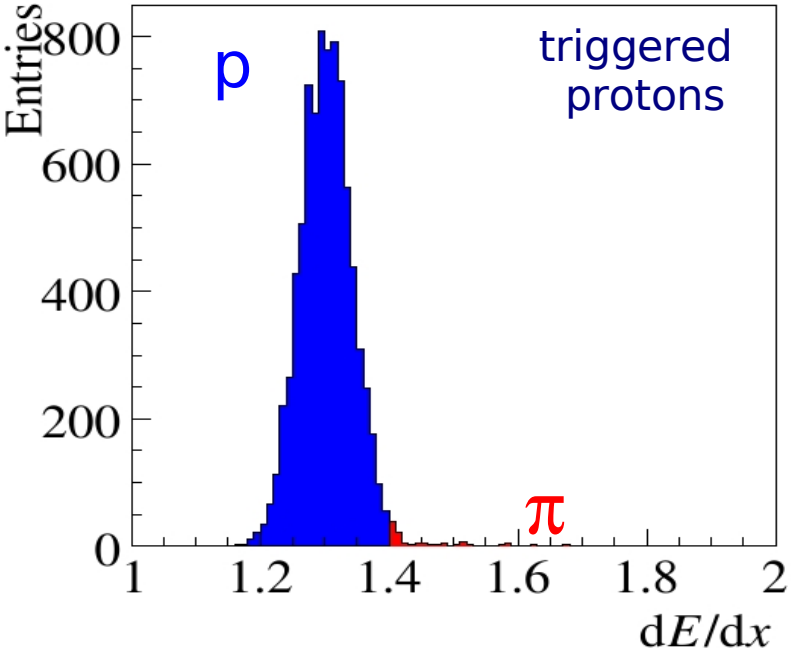


dE/dx from TPC



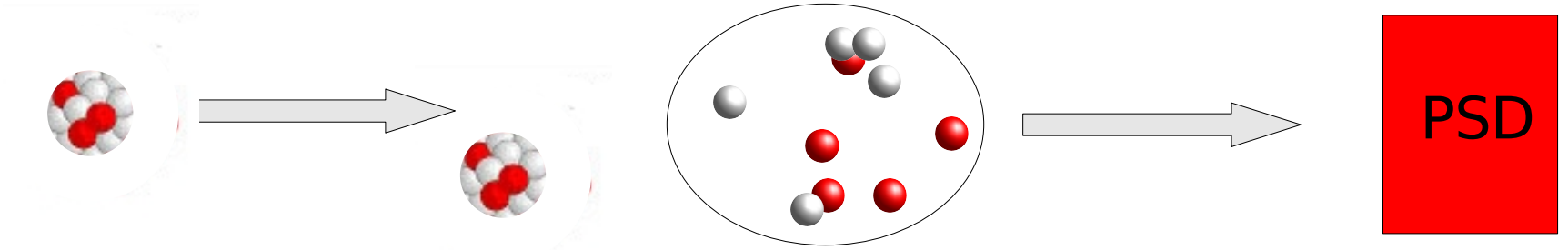
beam spot from BPD-3





Projectile Spectator Detector

The basic idea



projectile P nucleus

target P nucleus

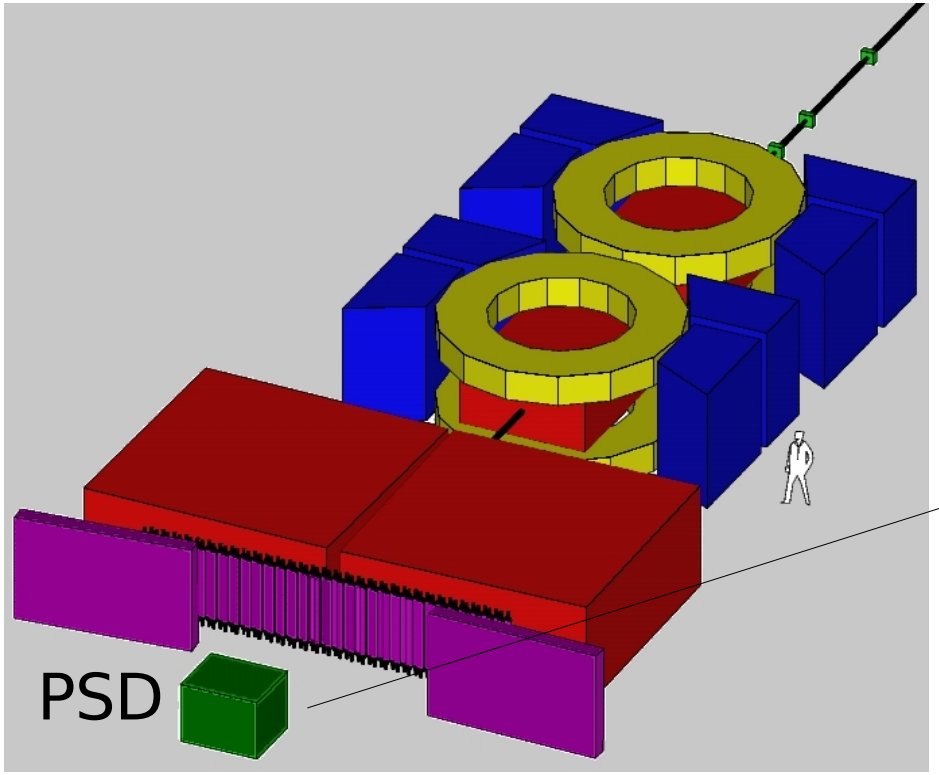
projectile spectators (fragments)

PSD = Projectile Spectator Detector

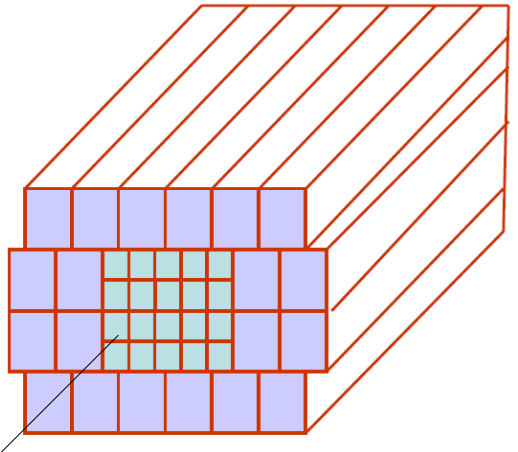
Modular compensating lead/scintillator calorimeter with a MAPD optical read-out

Needed for a precise determination of the number of projectile spectators in the NA61 ion programme

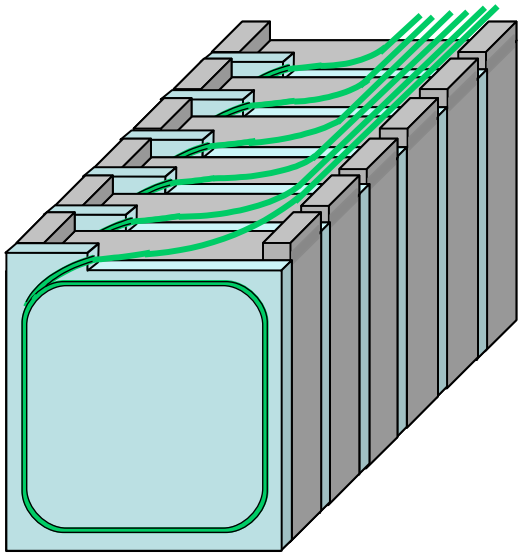
Projectile Spectator Detector



PSD

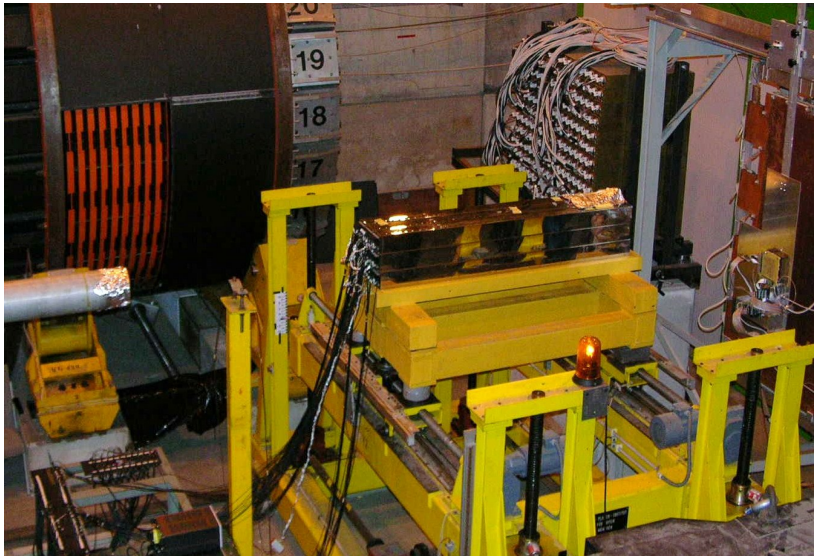


-- 40 modules (20 small +20 large ones)
-- can be used for reaction plane meas



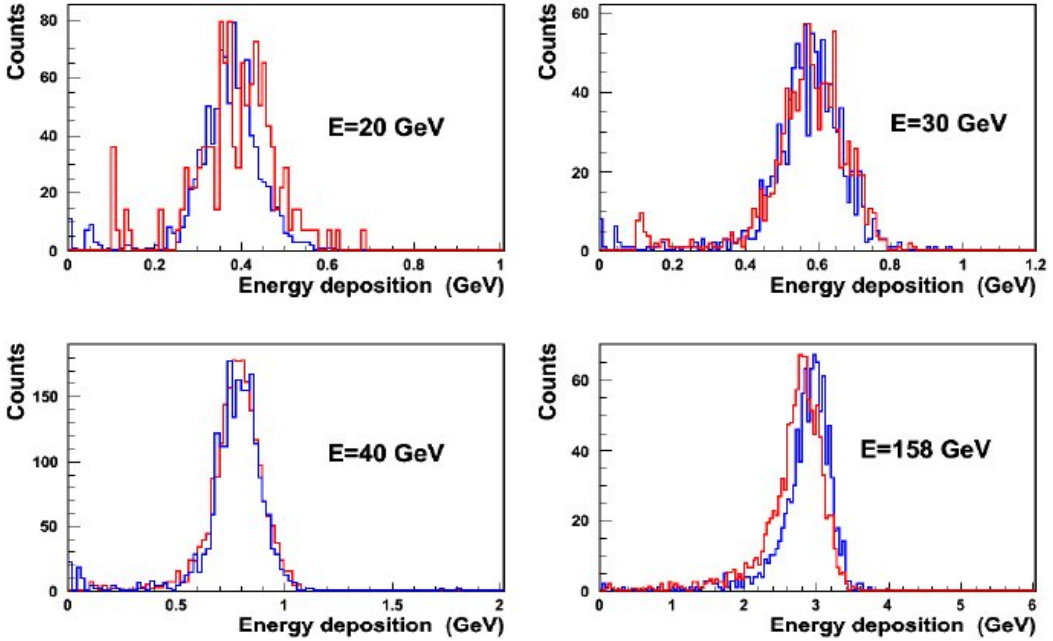
- 60 lead/scintillator sandwiches
- 10 longitudinal sections
- 6 WLS-fiber/MAPD
- 10 MAPDs/module
- 10 Amplifiers with gain~40

Projectile Spectator Detector

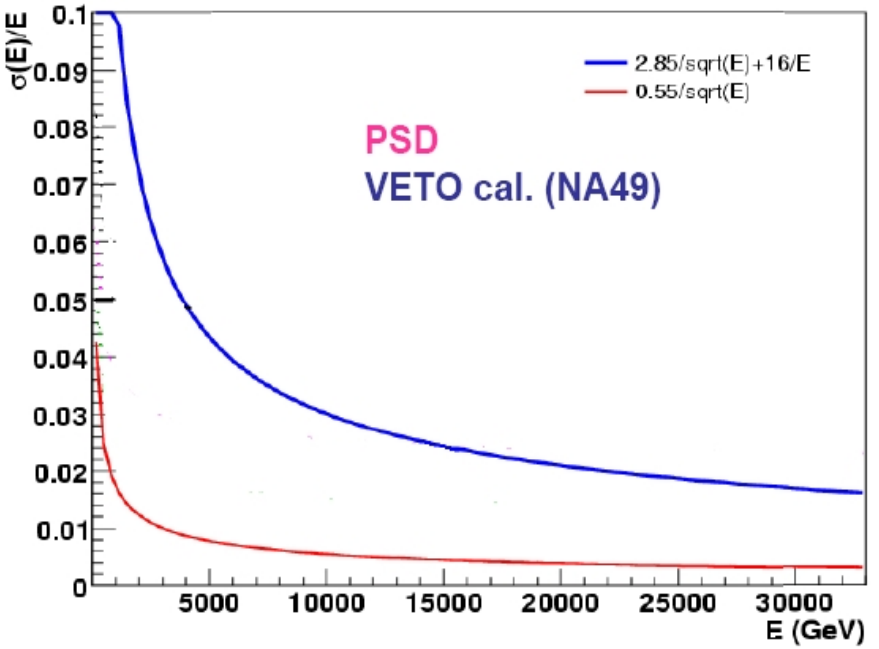


The super-module test during the 2007 run

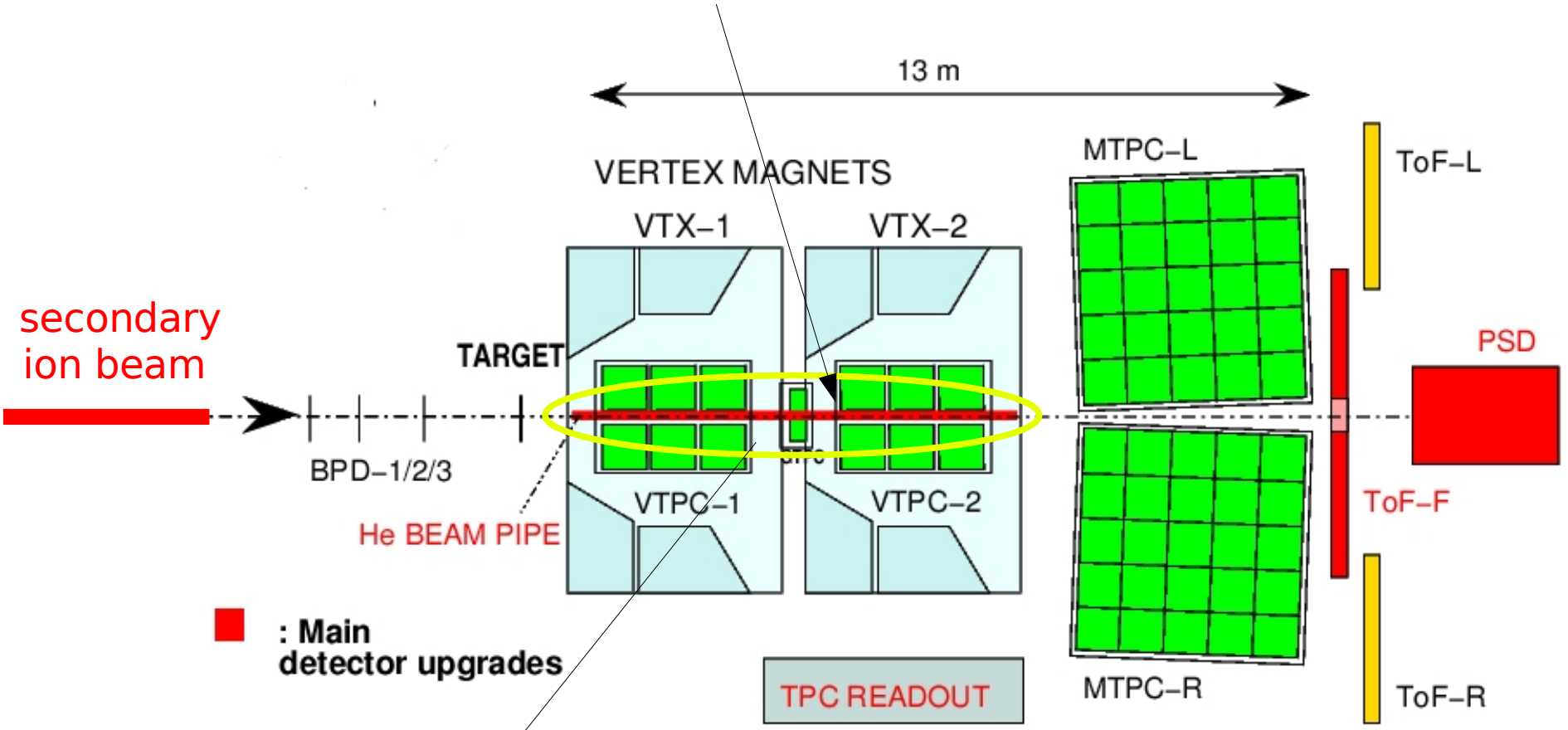
energy spectra: data and simulation

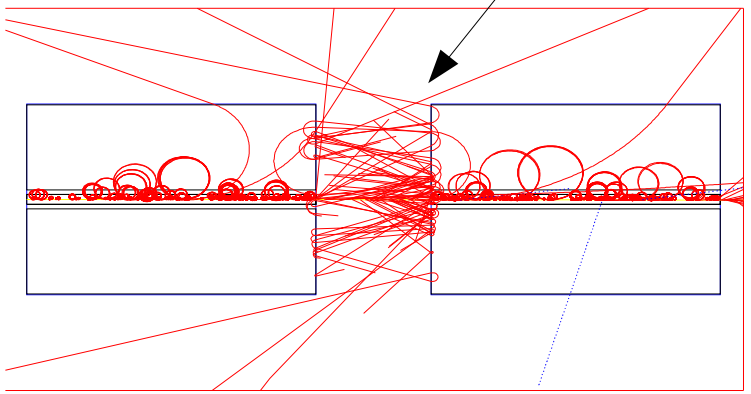


Extrapolated energy resolution for Pb+Pb collisions at 158A GeV



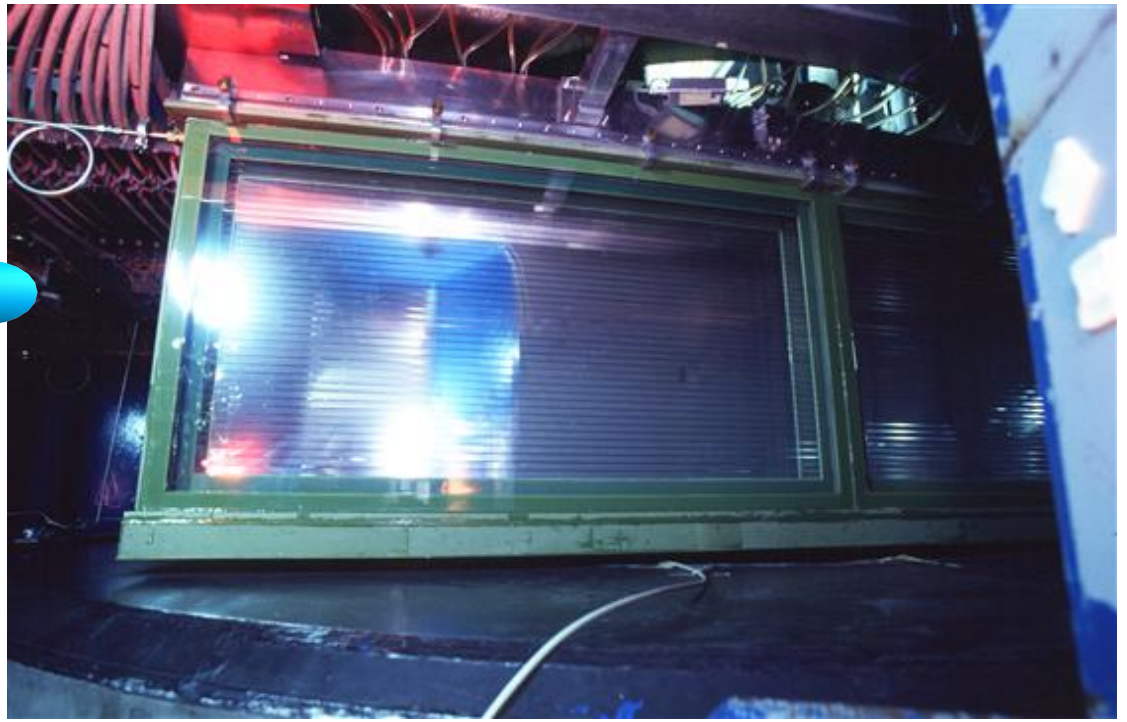
Helium Beam Pipe

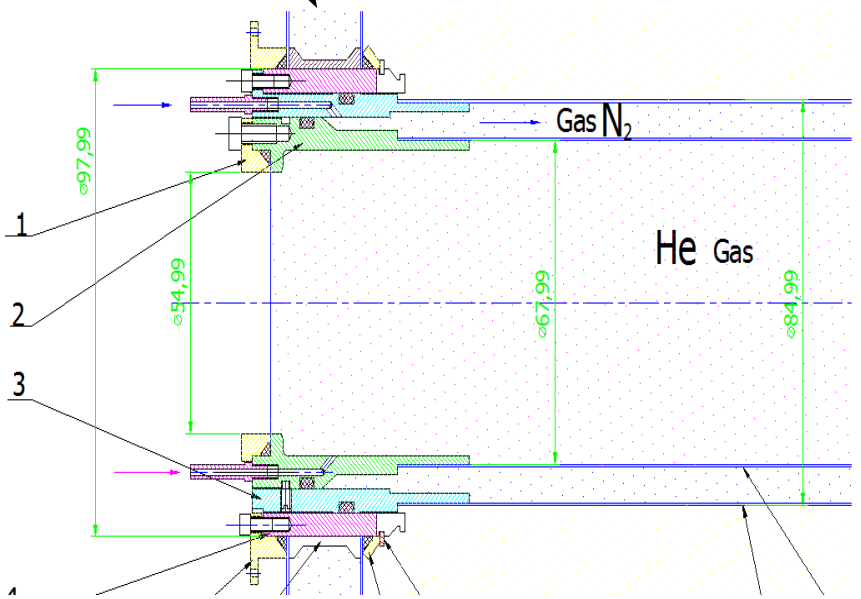




Helium beam pipe in
the VTPC cages will reduce
the delta-electron background
by a factor of 10

Helium Beam Pipe





Plans and experimental landscape

2009	**p+C**	**at 31 GeV**	**21 days**	**T2K, C-R**
	π+C	**at 158, 300 GeV**	**14 days**	**C-R**
	p+p	**at 6 energies***	**30 days**	**e-scan**
2010	**p+p**	**at 158 GeV**	**77 days**	**high p_T**
2011	**30+30**	**at 6 energies***	**42 days**	**e-scan**
	(Pb primary, A≈30 secondary ion beam)			
	p+Pb	**at 158 GeV**	**42 days**	**high p_T**
2012	**10+10**	**at 6 energies***	**30 days**	**e-scan**
	(Pb primary, A≈10 secondary ion beam)			
	p+PB	**at 6 energies***	**42 days**	**e-scan**
2013	**100+100**	**at 6 energies***	**30 days**	**e-scan**
	(A≈100 primary ion beam, to be agreed with I-LHC			

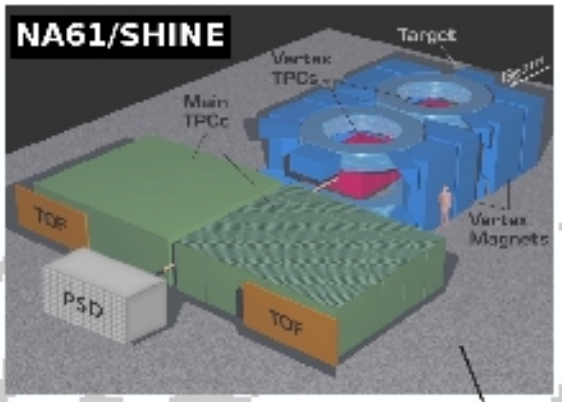
**(6 energies: 10A, 20A, 30A, 40A, 80A and 158A GeV)*

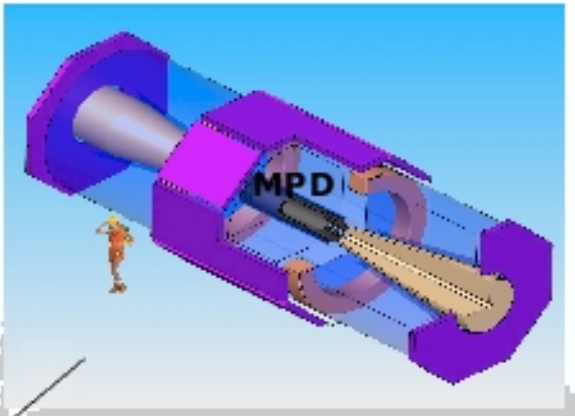
Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies

Facility:	SPS	RHIC	NICA	SIS-100 (SIS-300)
Exp.:	NA61	STAR PHENIX	MPD	CBM
Start:	2011	2011	2014	2014 (2016)
Pb Energy: (GeV/(N+N))	4.9-17.3	4.9-50	≤9	≤5 (<8.5)
Event rate: (at 8 GeV)	100 Hz	1 Hz(?)	≤10 kHz	≤10 MHz
Physics:	CP&OD	CP&OD	OD&HDM	HDM (OD)

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

Experimental landscape of complementary programs of nucleus-nucleus collisions around the SPS energies





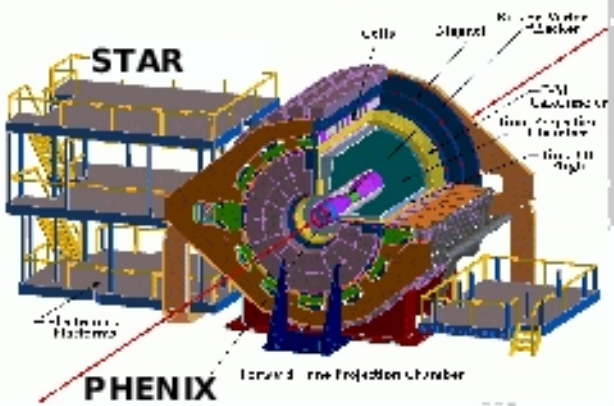
NICA

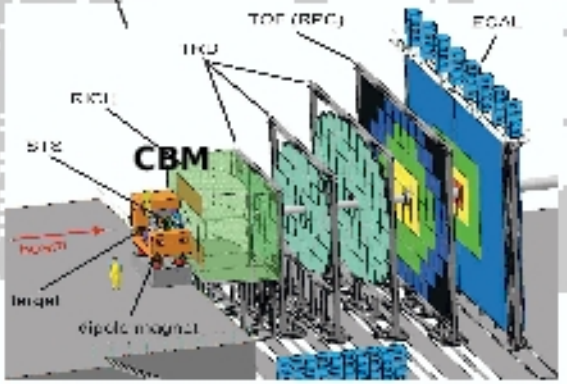
SIS

SPS

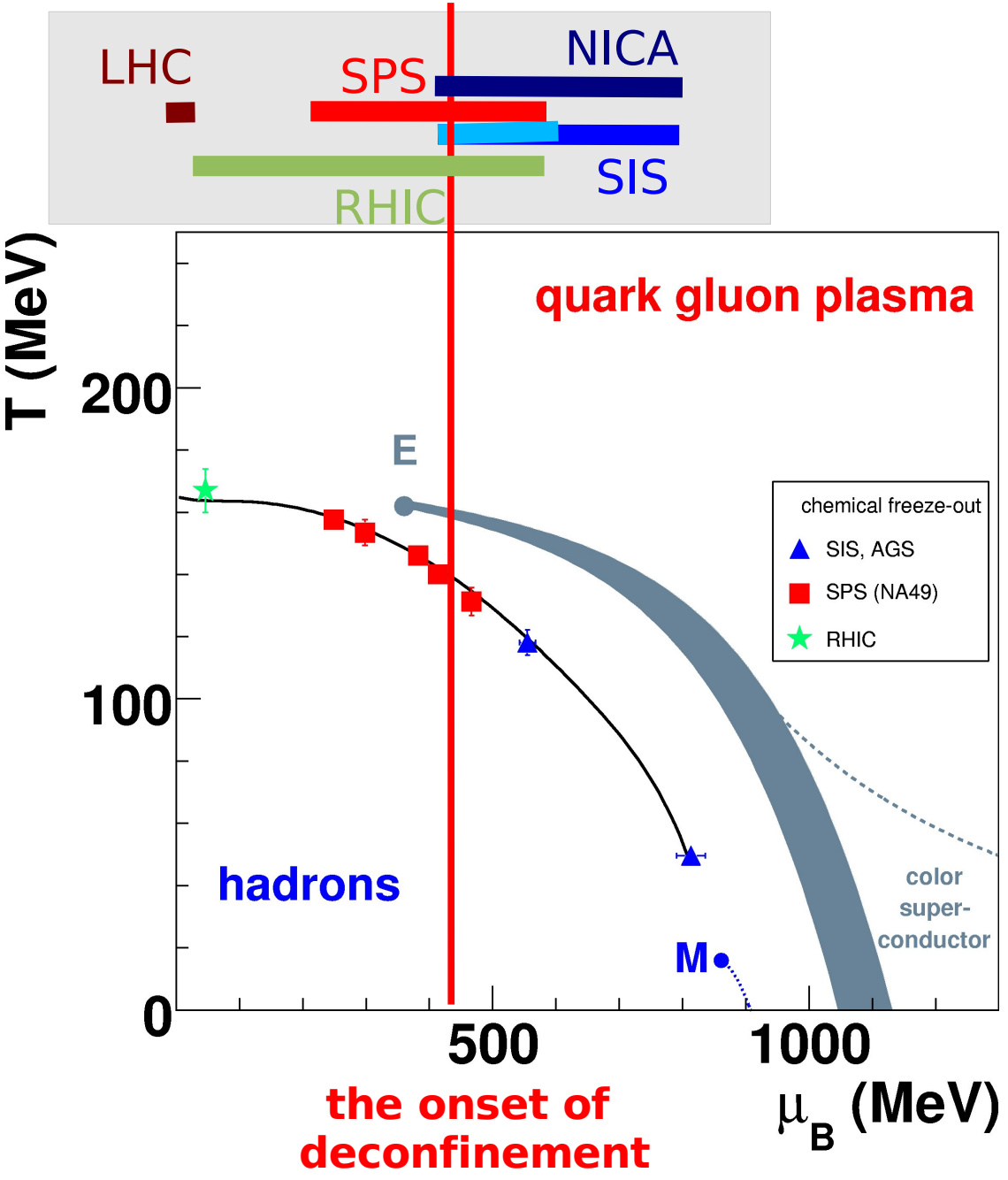
RHIC

STAR Detector





Experimental landscape



Summary

The NA61/SHINE ion program gives the unique opportunity to reach exciting physics goals in a very efficient and cost effective way

It has the potential to discover the critical point of strongly interacting matter and guarantees precision study of the properties of the onset of deconfinement

It is complementary to the efforts of other international and national laboratories, FAIR, JINR and RHIC and to the heavy ion program at the CERN LHC

Additional slides