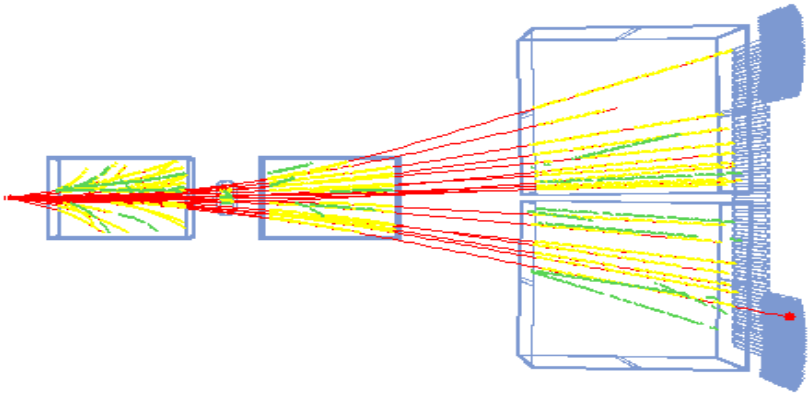


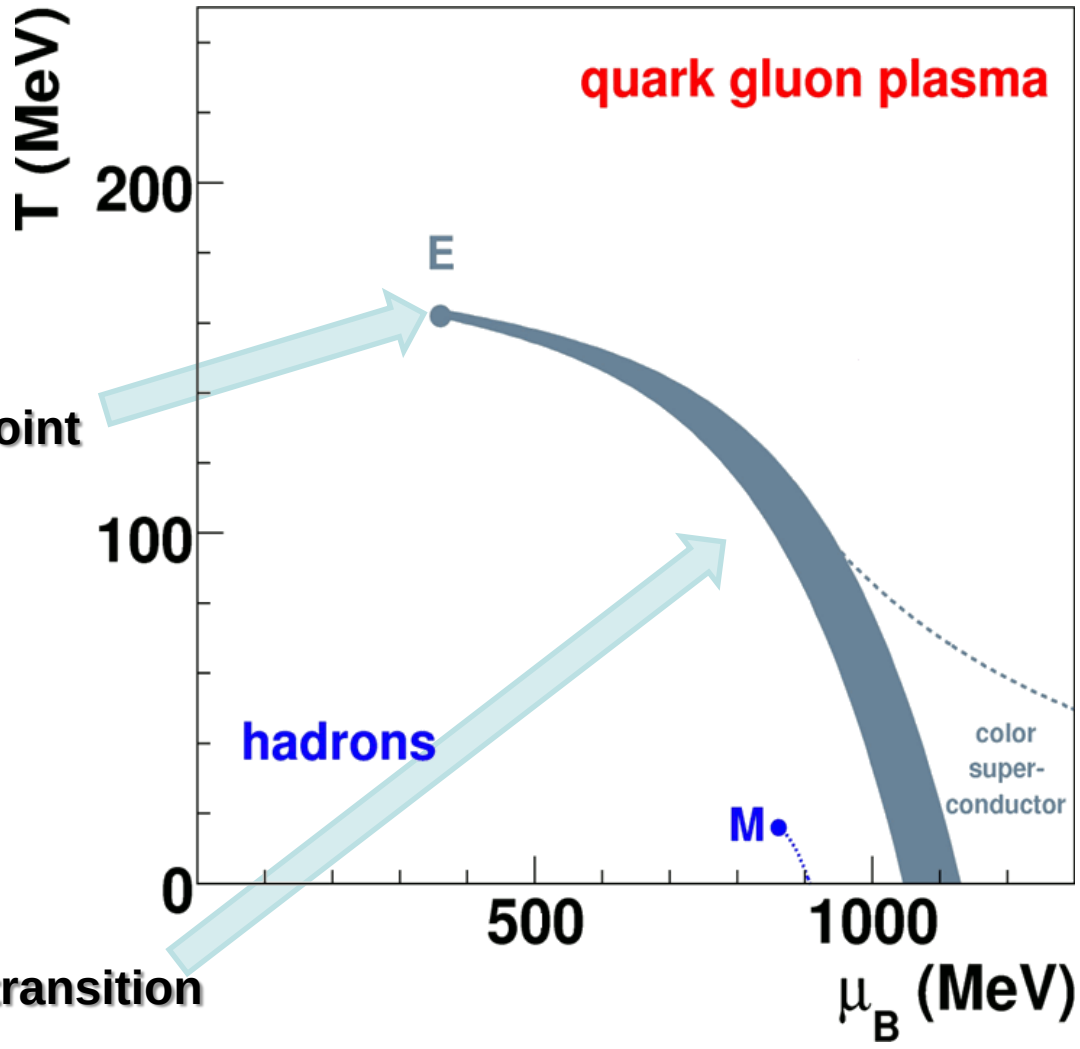
NA61/SHINE results relevant for the QCD phase diagram

Emil Kaptur
for the NA61/SHINE Collaboration
Department of Nuclear Physics
University of Silesia

Outline

- NA61/SHINE study of QCD phase diagram
- Selected results from p+p interactions
- Some technicalities on Be+Be data
- First results from Be+Be interactions, already shown in Kielce

The QCD phase diagram

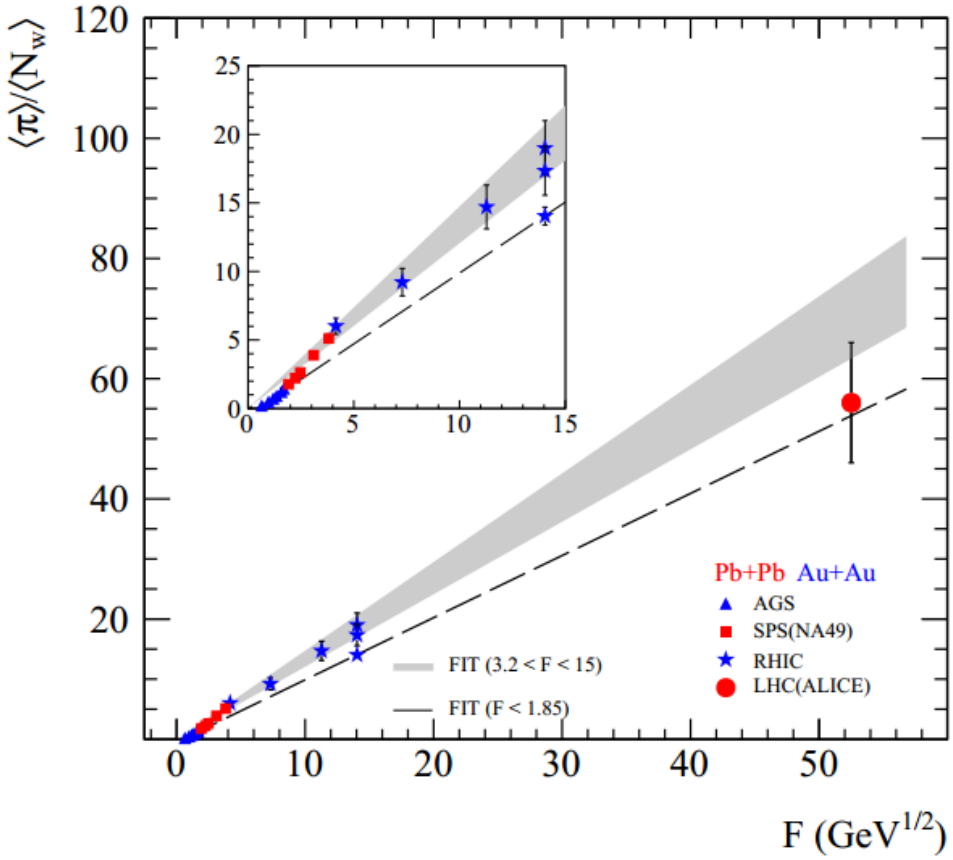


critical point

1st order phase transition

Study of the onset of deconfinement

- Inspired by Statistical Model of Early Stage (SMES)



„Kink”

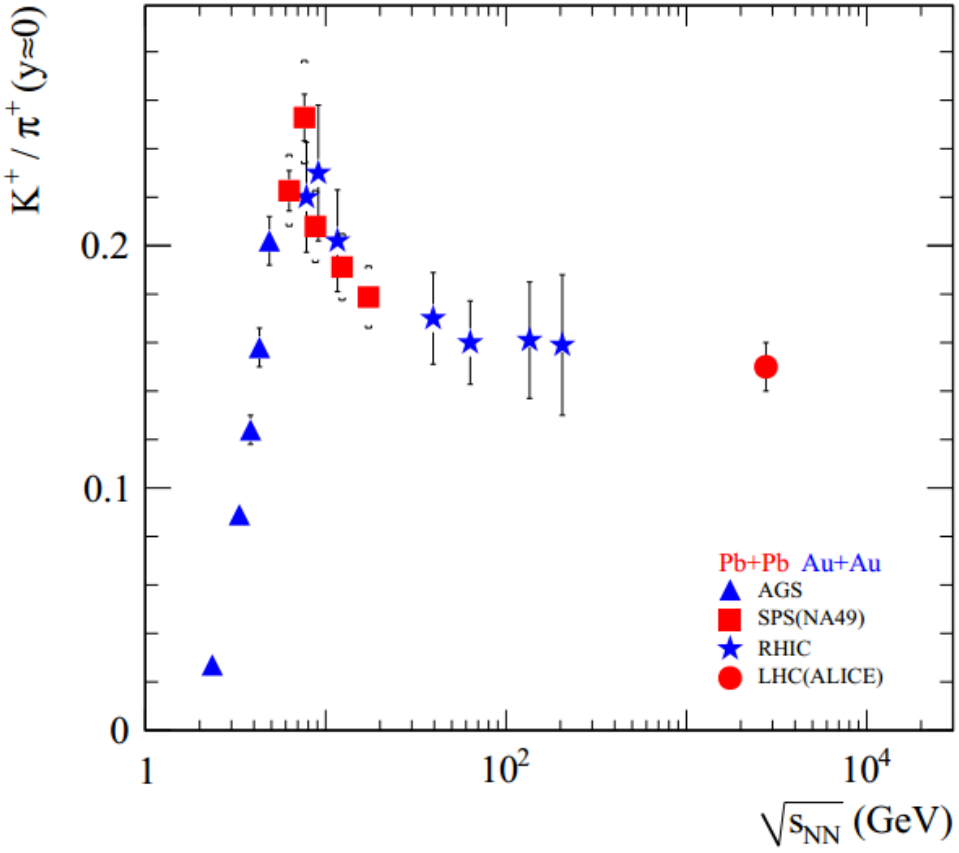
Collision energy dependance of $\langle \pi^- \rangle / \langle N_W \rangle$ (related to entropy) is different in hadronic and deconfined phase.

Change of slope visible in A+A data from SPS (NA49) and RHIC (STAR - BES).

How big a system have to be to observe it? NA61/SHINE will provide answer with the system size scan.
(data from Be+Be collisions will arrive soon)

Study of the onset of deconfinement

- Inspired by Statistical Model of Early Stage (SMES)



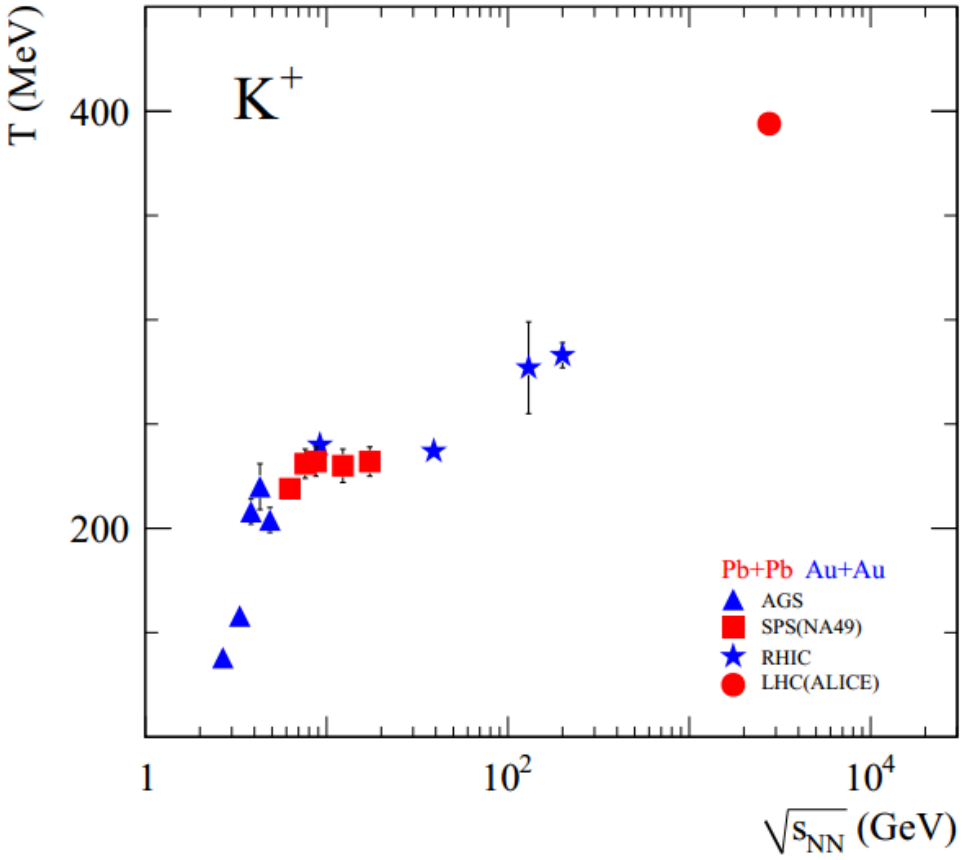
„Horn”

Decrease of mass of strangeness carriers in deconfined phase manifests itself as a sharp peek in K^+/π^+ (related to strangness to entropy ratio).

Sharp peek visible in A+A data from SPS (NA49) and RHIC (STAR - BES). LHC (ALICE) point confirms asymptotic behaviour in larger energies.

Study of the onset of deconfinement

- Inspired by Statistical Model of Early Stage (SMES)



„Step”

Constant pressure and temperature in mixed phase cause weakening of transverse expansion at the onset of deconfinement.

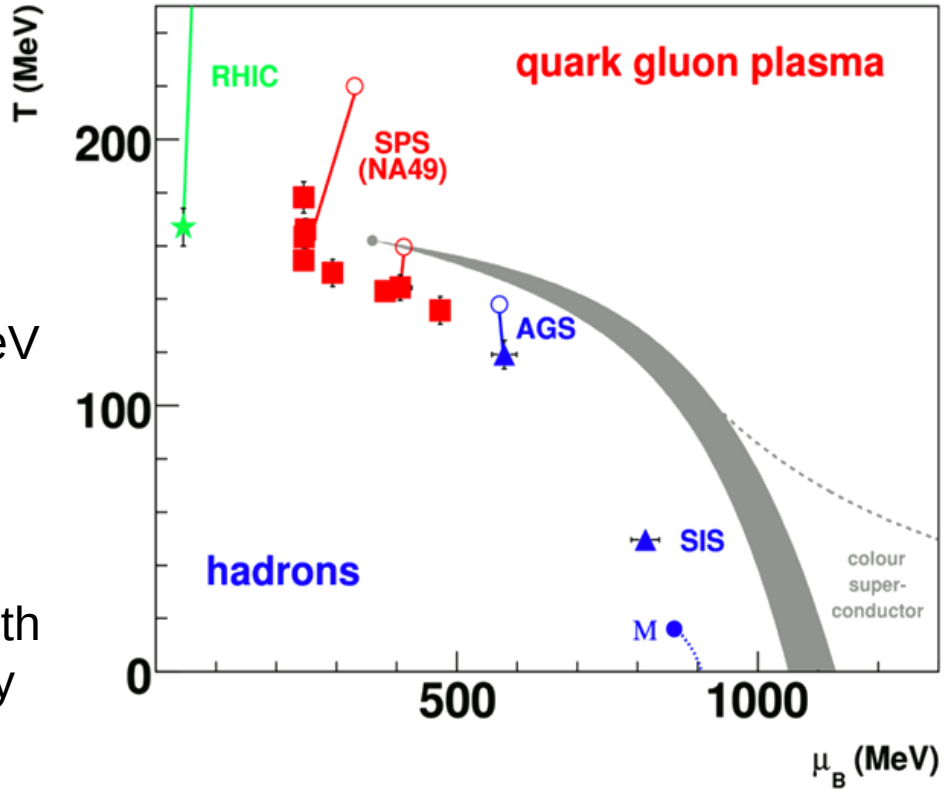
Linear increse in T parameter visible in both hadronic and deconfined phase. Flat data from SPS (NA49) suggests onset of deconfinement.

Search for the critical point

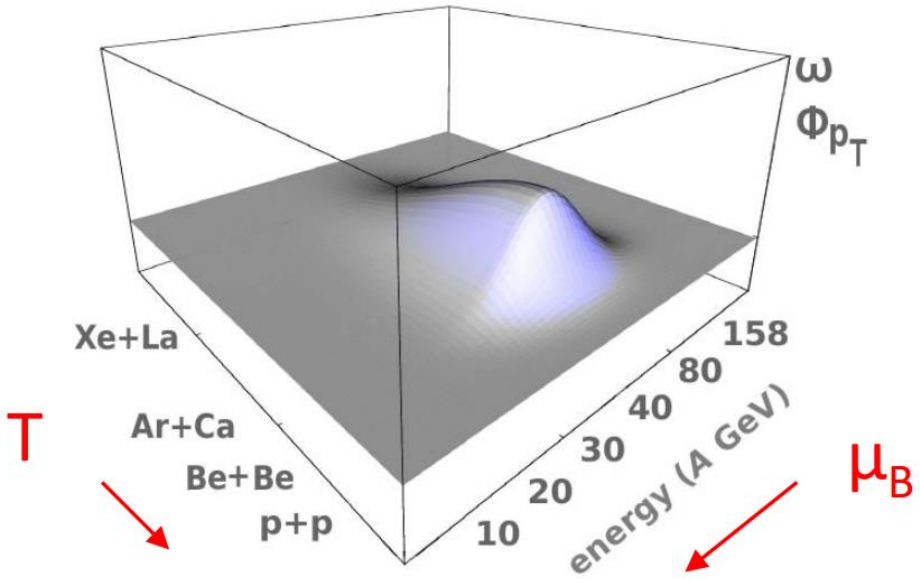
- SPS covers very intresting region of the Phase Space diagram
- Critical point of strongly interacting matter may be located in the SPS energy range
  - Example of the theoretical calculation:
    - (T, μ_B)=(162 $\pm$ 2, 360 $\pm$ 40) MeV

      Fodor and Katz JHEP 404 050 (2004)
    - μ_B = 360 MeV E $\approx$ 50A GeV

      Beccatini, Manninen, Gazdzicki PRC 73 044905 (2006)
- Search for critical point should start with energy of collisions higher than energy of the onset of deconfinement (i.e. $\approx$ 30A GeV).

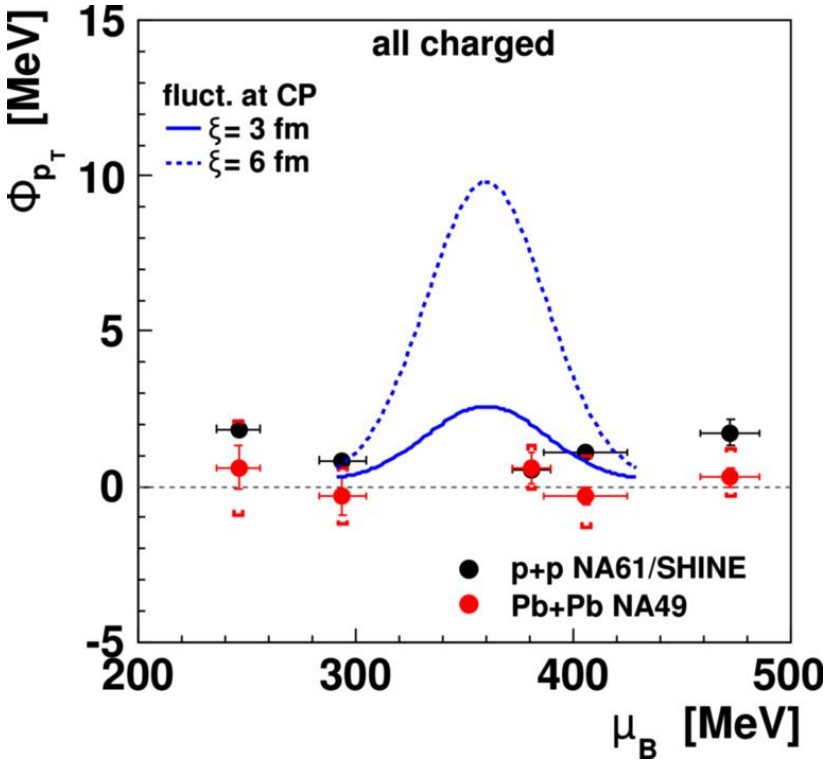


Event-by-event fluctuations as signature of critical point

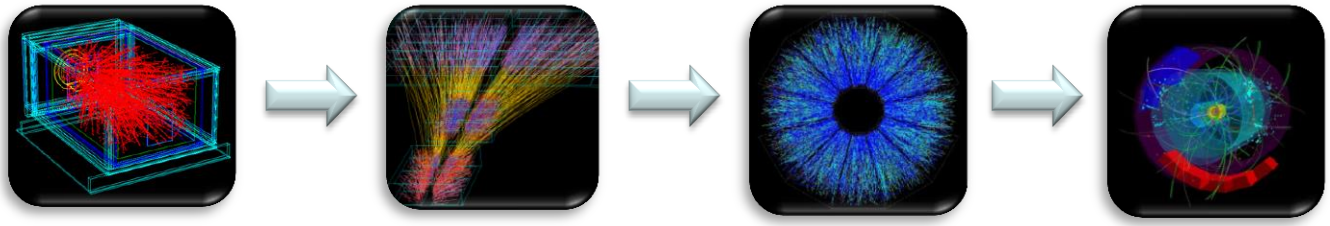


NA61/SHINE measures fluctuations of multiplicity, average p_T, etc. for both identified and non-identified particles.

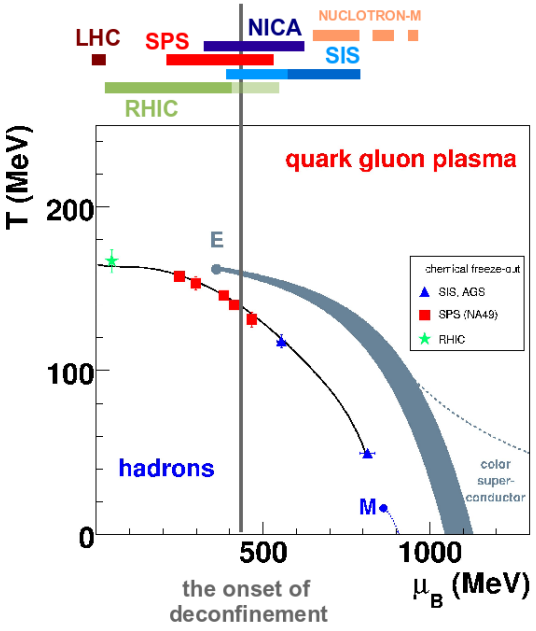
Maximum of these fluctuations is expected near the critical point.



Heavy ion experiments

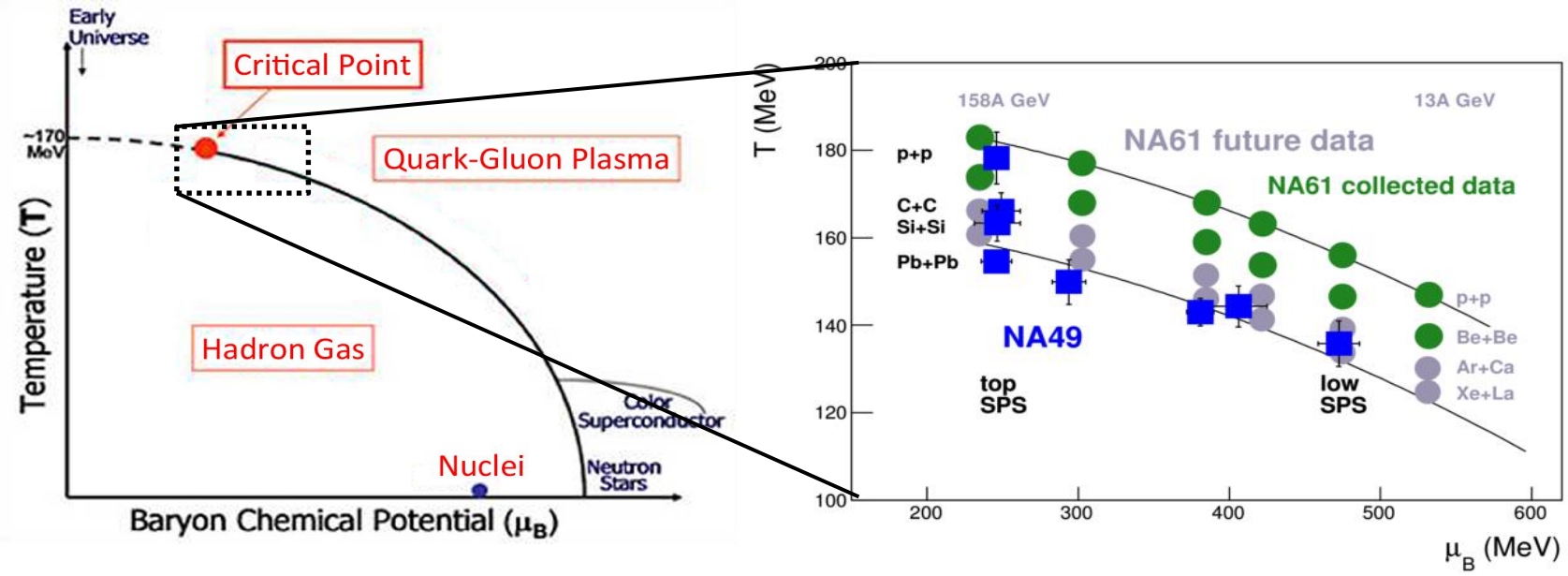


BNL AGS **CERN SPS** **BNL RHIC** **CERN LHC**



Facility	SPS	RHIC	NUCLOTRON-M	NICA	SIS-100/300	LHC
Laboratory	CERN Geneva	BNL Brookhaven	JINR Dubna	JINR Dubna	FAIR GSI Darmstadt	CERN Geneva
Experiment	NA61/SHINE	STAR PHENIX	BM@N	MPD	HADES + CBM CBM	ALICE ATLAS CMS
Start of data taking	2009(11)	2010	2015	2017	2017/18 (2019/20)	2009
cms energy [GeV/(N+N)]	5.1 – 17.3	7.7 (5?) – 200	< ~ 3.5	4 – 11	2.3 – ~4.5 ~4.5 – ~8.5	up to 5500 14000 (p+p)
Physics	CP & OD	CP & OD	HDM	OD & HDM	HDM, OD & CP	PDM

Ion physics programme

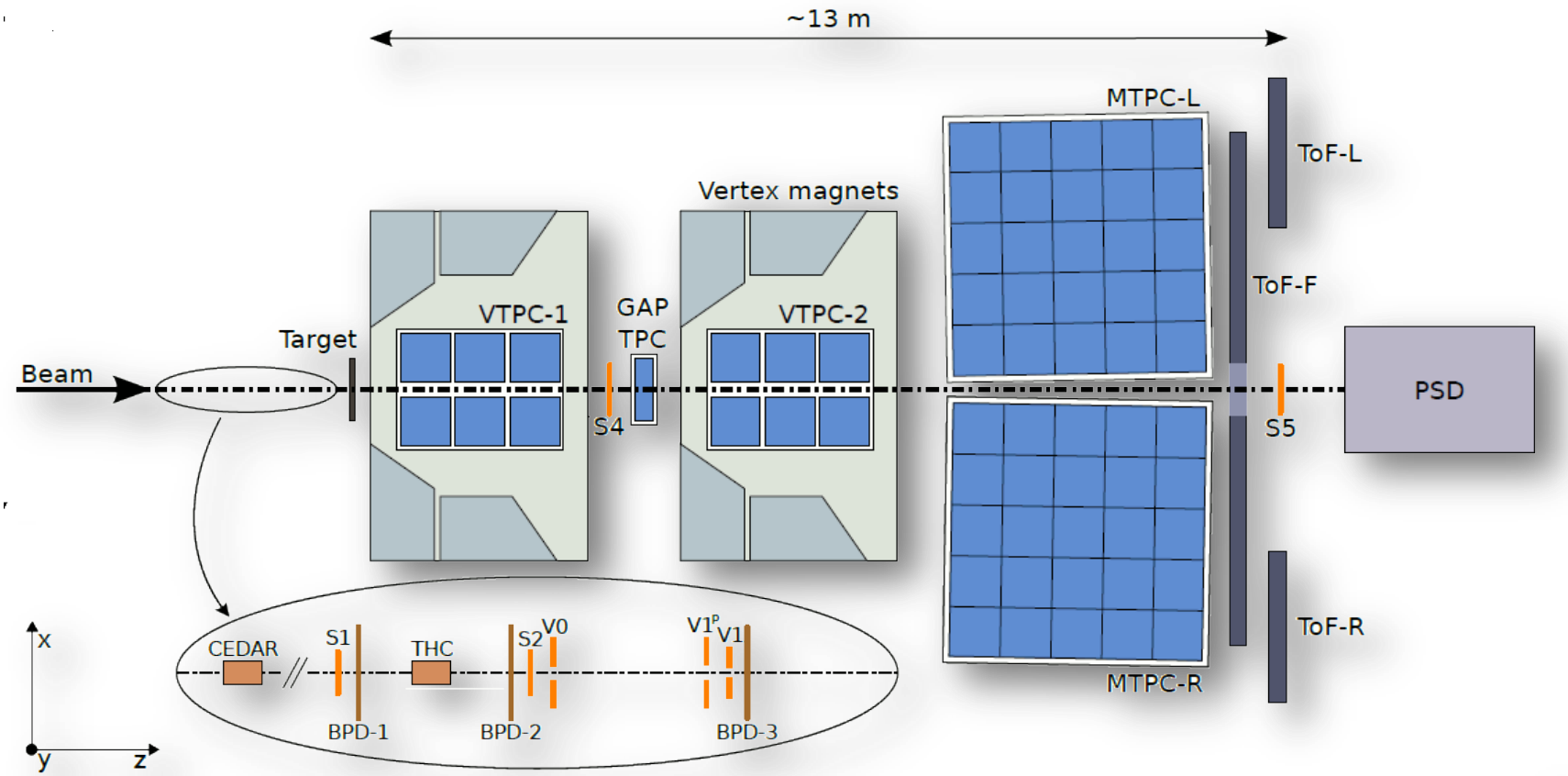


Statistics of taken events (in millions)

	13A GeV/c	20A GeV/c	31A GeV/c	40A GeV/c	80A GeV/c	158A GeV/c
p + p	1.2	1.4	3.5	5.8	5.0	4.0 + 58
	13A GeV/c	20A GeV/c	30A GeV/c	40A GeV/c	75A GeV/c	150A GeV/c
Be + Be	4.6	3.4	4.3	3.4	4.2	3.0

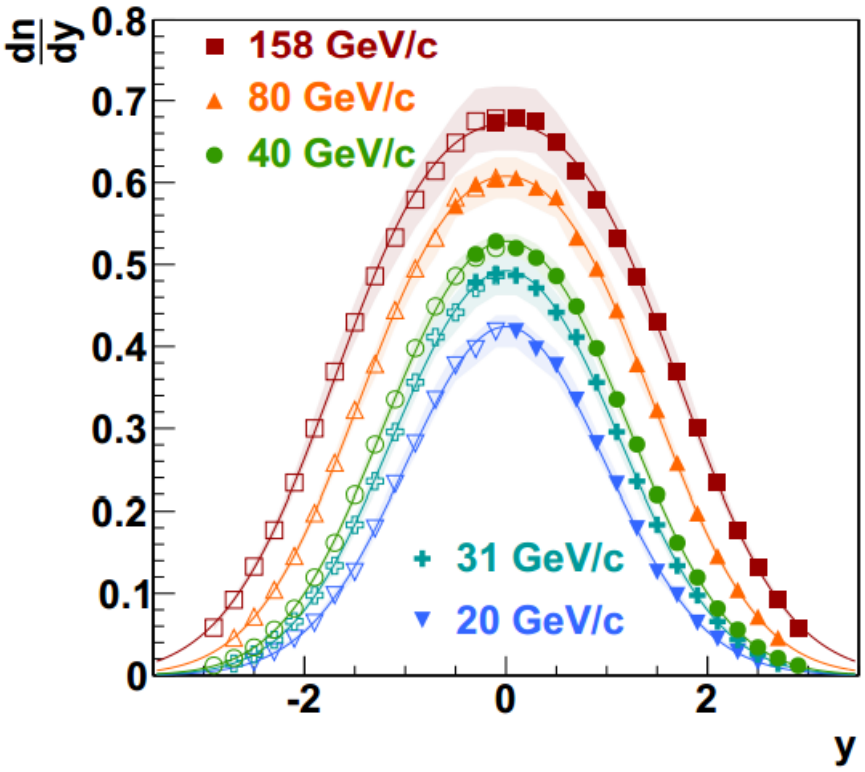
NA61/SHINE facility

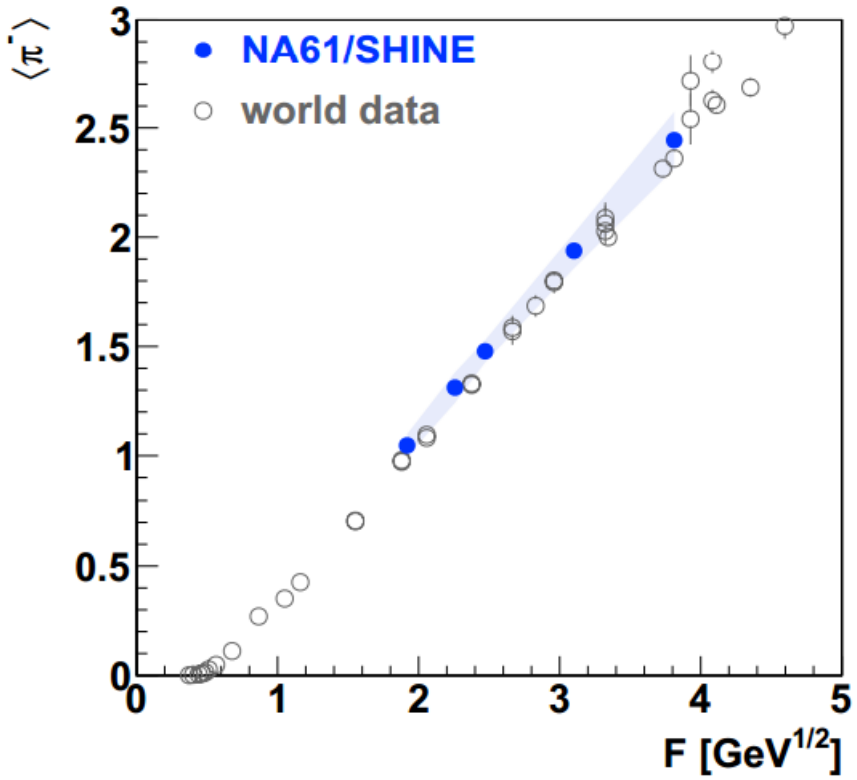
NA61/SHINE (SPS Heavy Ion and Neutrino Experiment)



http://arxiv.org/abs/1401.4699

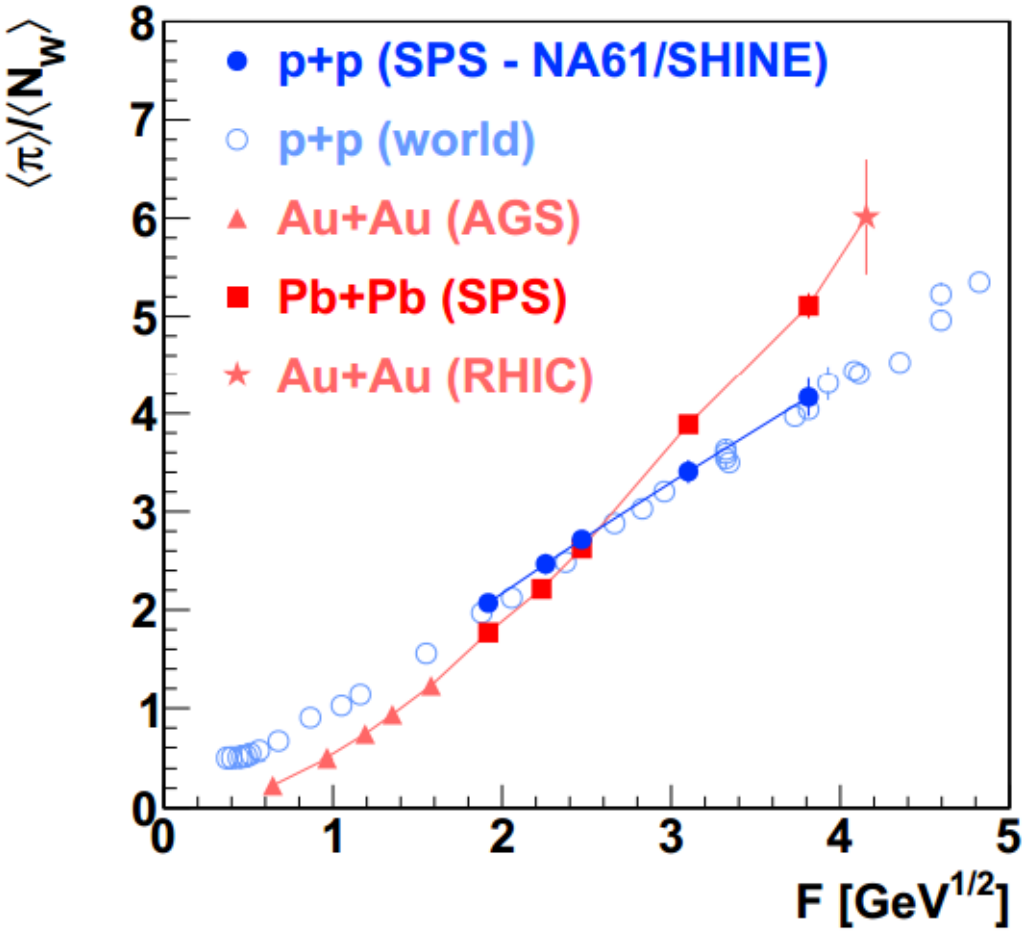
Reference data from p+p interactions





Two dimensional (y, p_T) π^- spectra at 5 beam momenta
published in Eur.Phys.J. C74 (2014) 2794
K^+, K^-, p from dE/dx indentification released as preliminary.

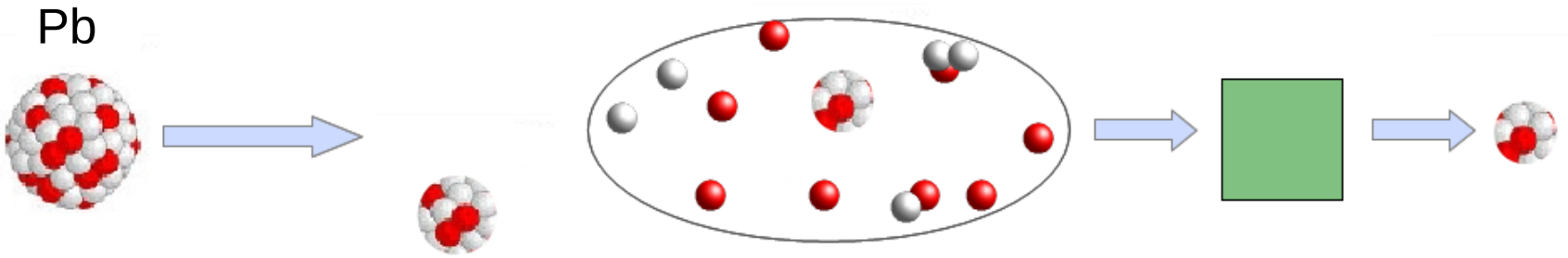
Kink with NA61/SHINE data



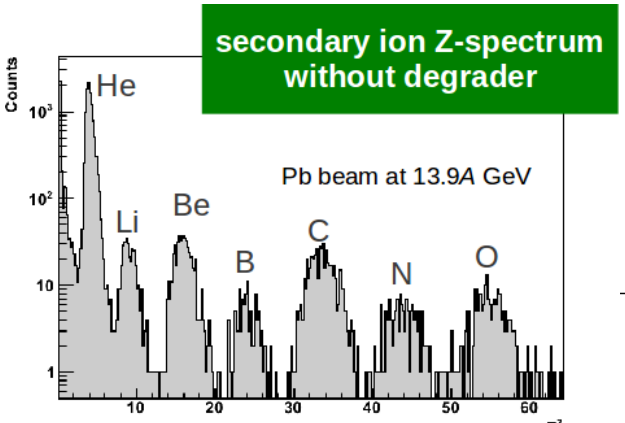
Precise measurements of pion production properties in p+p interactions at the same beam momenta per nucleon as the corresponding A+A data are avaliable from NA61/SHINE.

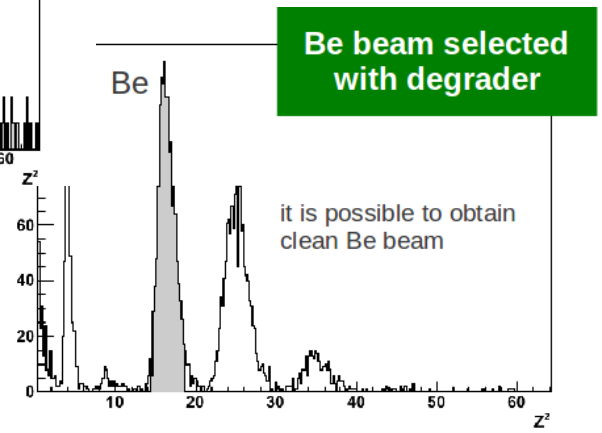
Now the job of NA61/SHINE is to fill this plot with colour, adding points from Be+Be, Ar+Sc and Xe+La.

Beryllium beam



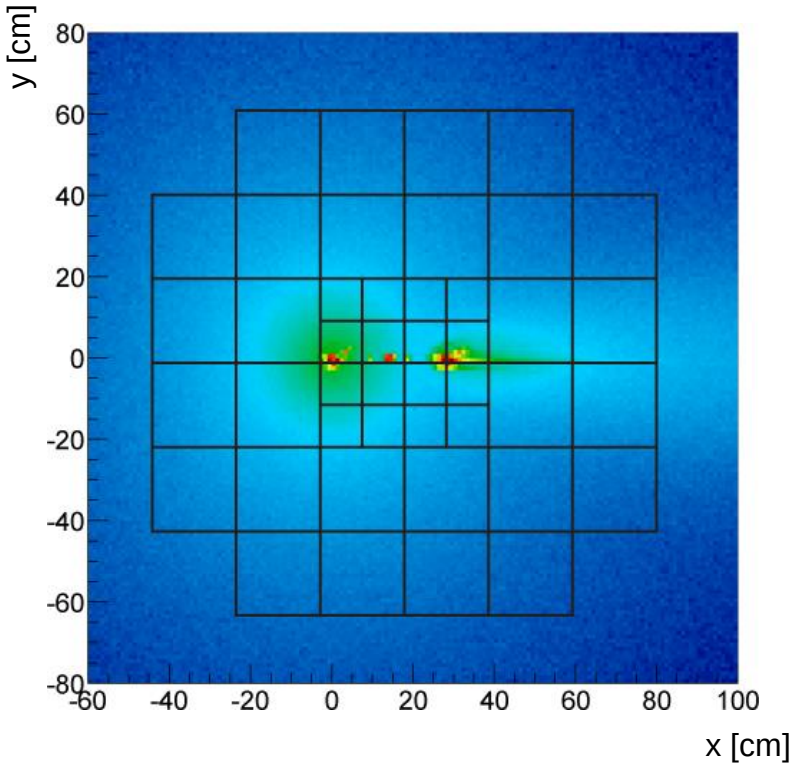
- Fragmentation target optimized for the desired fragment production
- Double magnetic spectrometer separates fragments according to the selected magnetic rigidity
- Degrader (Cu plate where ions lose energy dE/dx ~ Z^2) allows to reach required beam purity





Projectile Spectator Detector

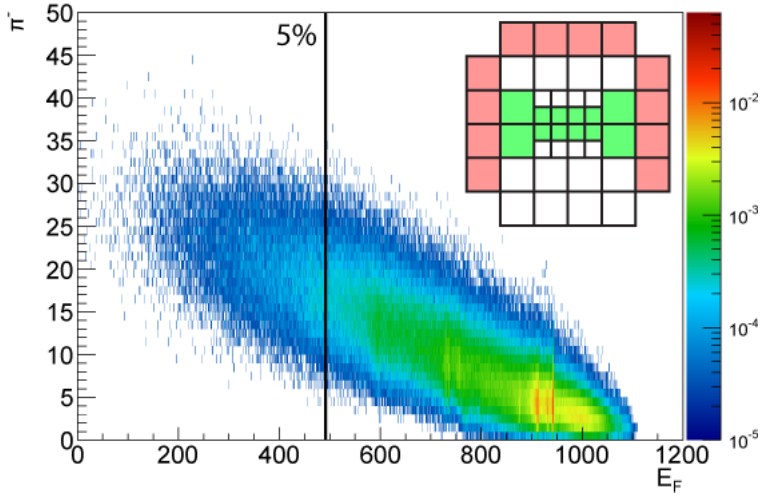
PSD during 2011 data taking
(40*A*, 75*A* and 150*A* GeV/c Be+Be)



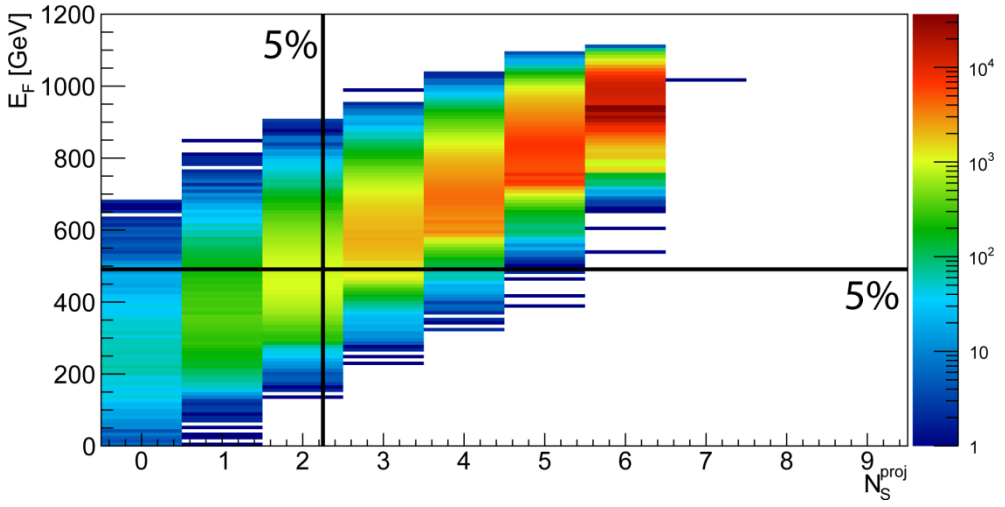
Particles spatial distribution
on the PSD front face
for Be+Be at 150*A* GeV/c

Centrality selection in Be+Be collisions

Centrality in Be+Be (preliminary) defined by the energy deposited in the PSD as percent of total inelastic cross section



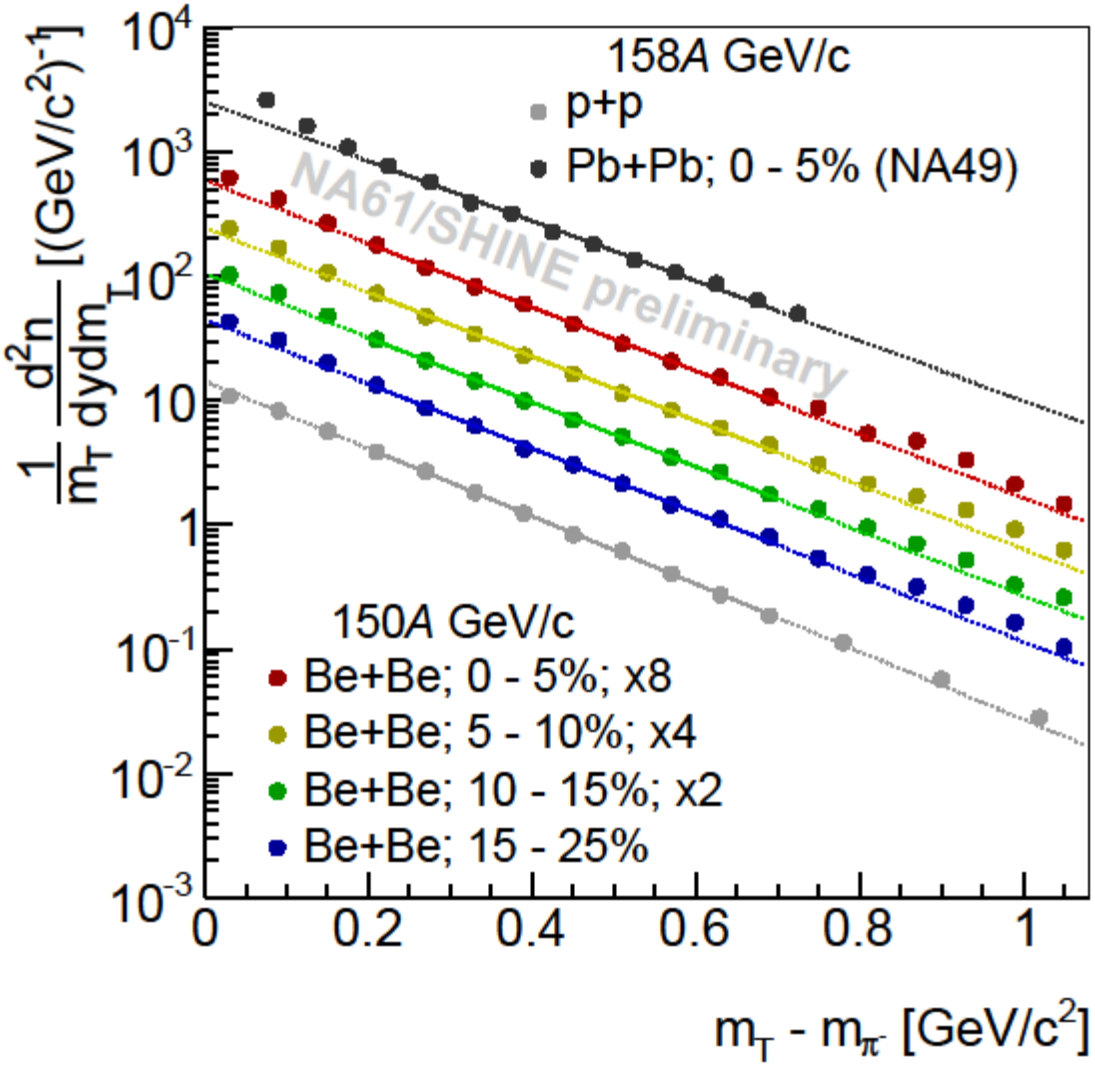
(based on MC) Multiplicity of π^- vs. energy deposited in the PSD



Correlation between energy deposited in the PSD and the number of projectile spectator (MC)

The analysis to obtain number of spectators on an event-by-event basis is ongoing.

First results from Be+Be interactions
Transverse mass spectra of π^- mesons



Convex shape of
Pb+Pb and Be+Be spectra

p+p spectra exponential

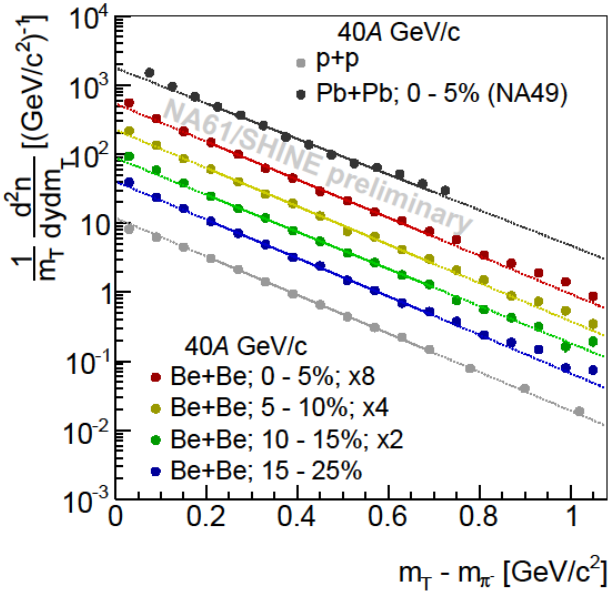
$$\frac{\mathrm{d}n}{\mathrm{d}m_\mathrm{T}} = A\, m_\mathrm{T} \exp\left(-\frac{m_\mathrm{T}}{T}\right)$$

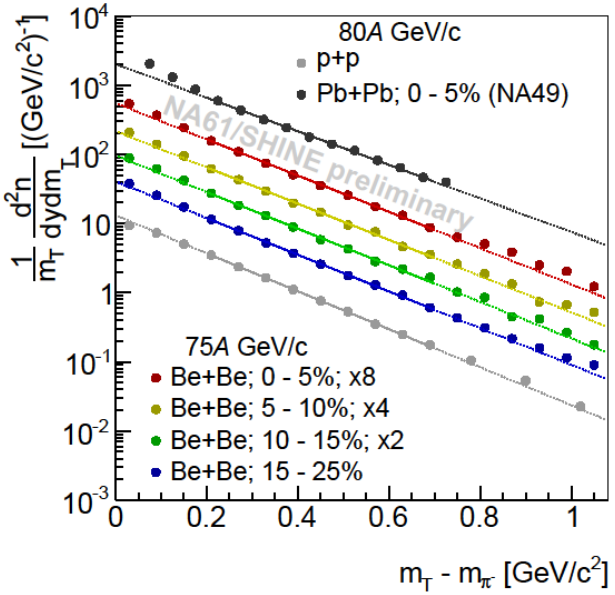
fitted in range
$0.2 < m_T - m_\pi < 0.7$ GeV/c^2

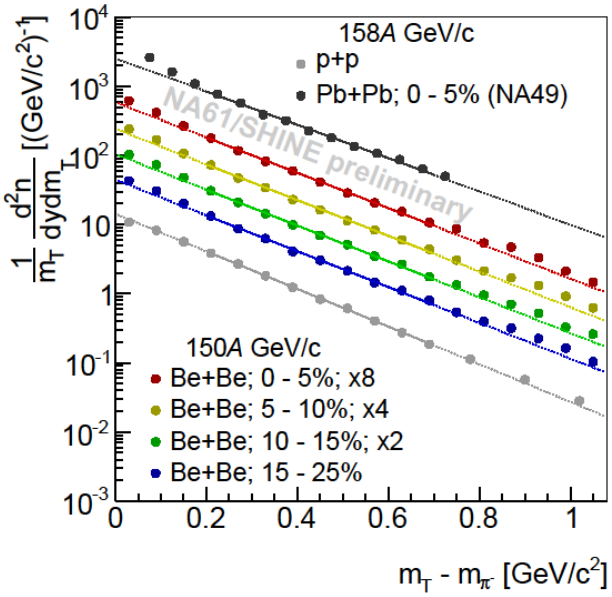
mid-rapidity $(0.0 < y < 0.2)$

Transverse mass spectra of π^- mesons

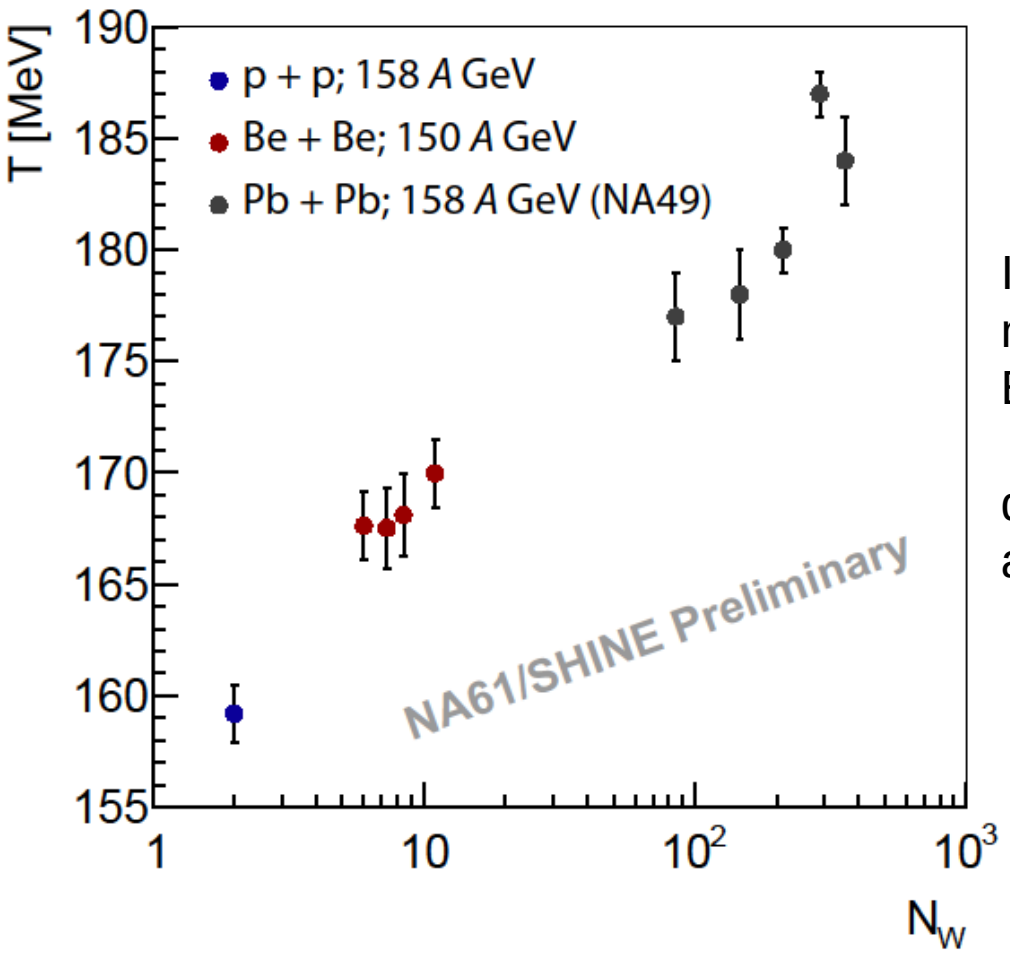
mid-rapidity *(0.0 < y < 0.2)*







Transverse mass spectra of π^- mesons
Inverse slope parameter T



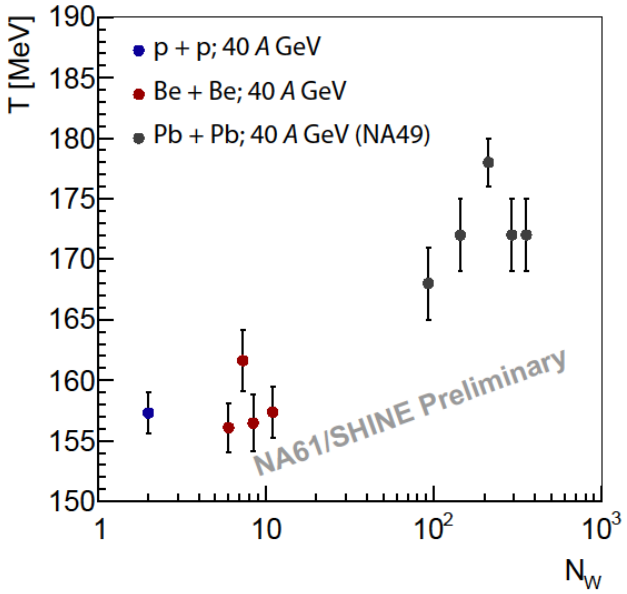
Fitted in range
$0.2 < m_T - m_\pi < 0.7$ GeV/c^2

Inverse slope parameter of transverse mass spectra is significantly larger in Be+Be than in p+p

dE/dx identification will provide Kaon and Proton results soon.

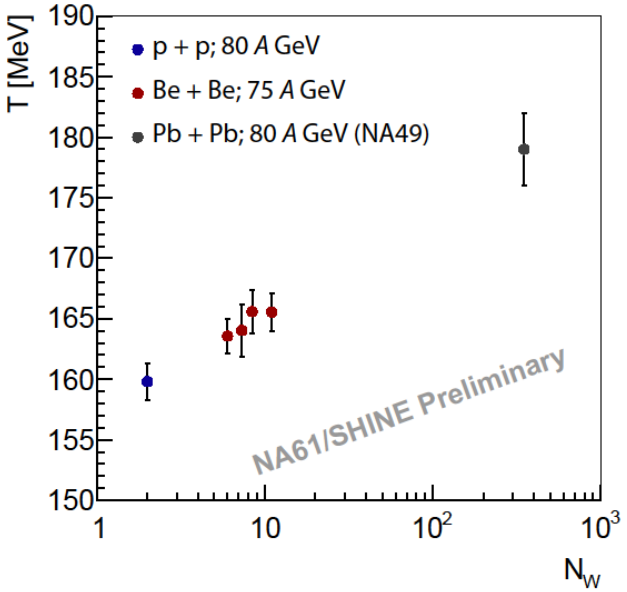
Number of wounded nucleons in Beryllium obtained by Glauber (Glissando, Kielce, Comput.Phys.Commun. 180 (2009) 69-83) Model (preliminary)

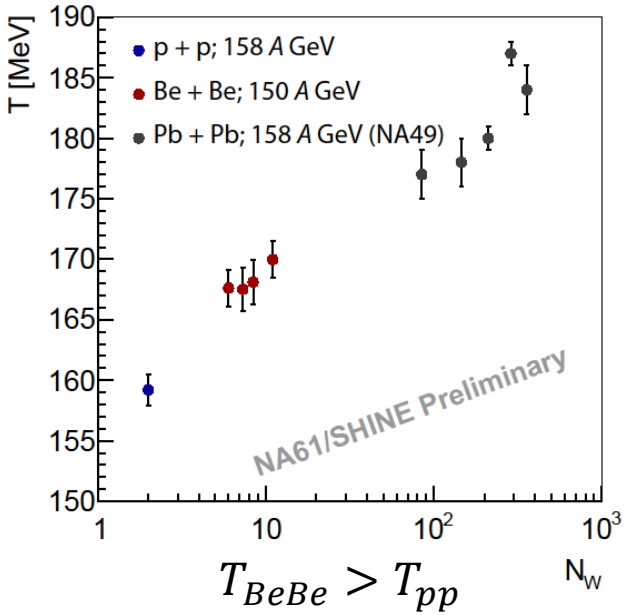
Transverse mass spectra of π^- mesons
Inverse slope parameter T



$T_{BeBe} \approx T_{pp}$

Inverse slope parameter in Be+Be changes with beam momentum

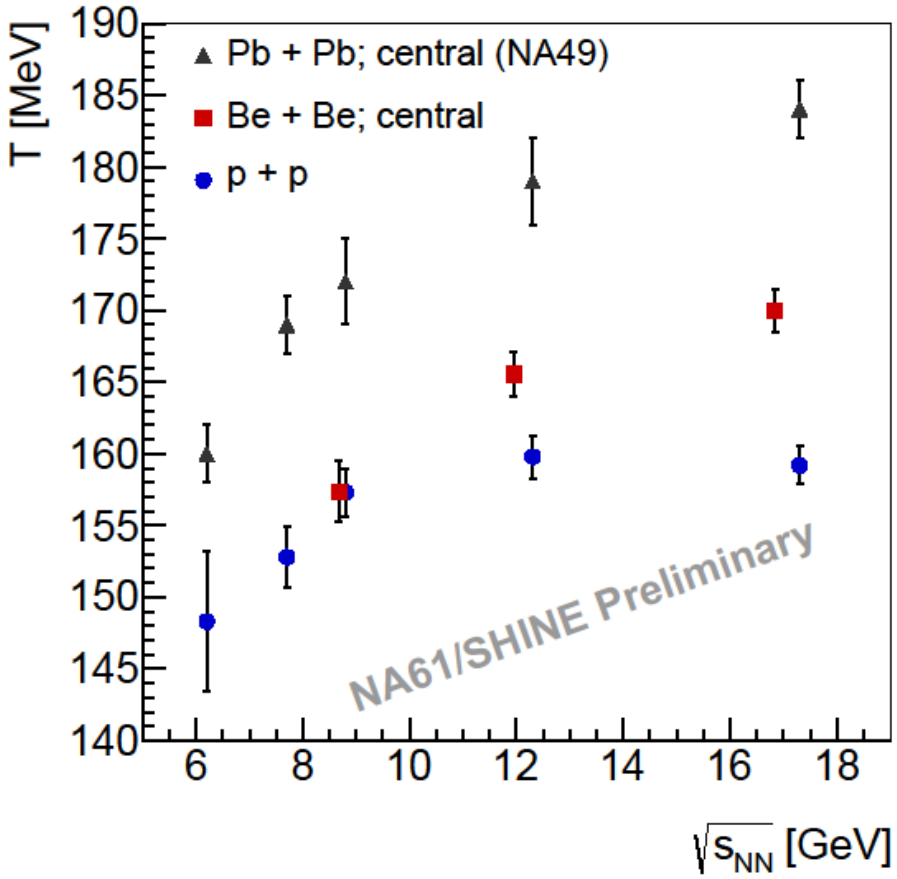




$T_{BeBe} > T_{pp}$

Number of wounded nucleons in Beryllium obtained by Glauber (Glissando, Kielce, Comput.Phys.Commun. 180 (2009) 69-83) Model (preliminary)

Transverse mass spectra of π^- mesons
Inverse slope parameter



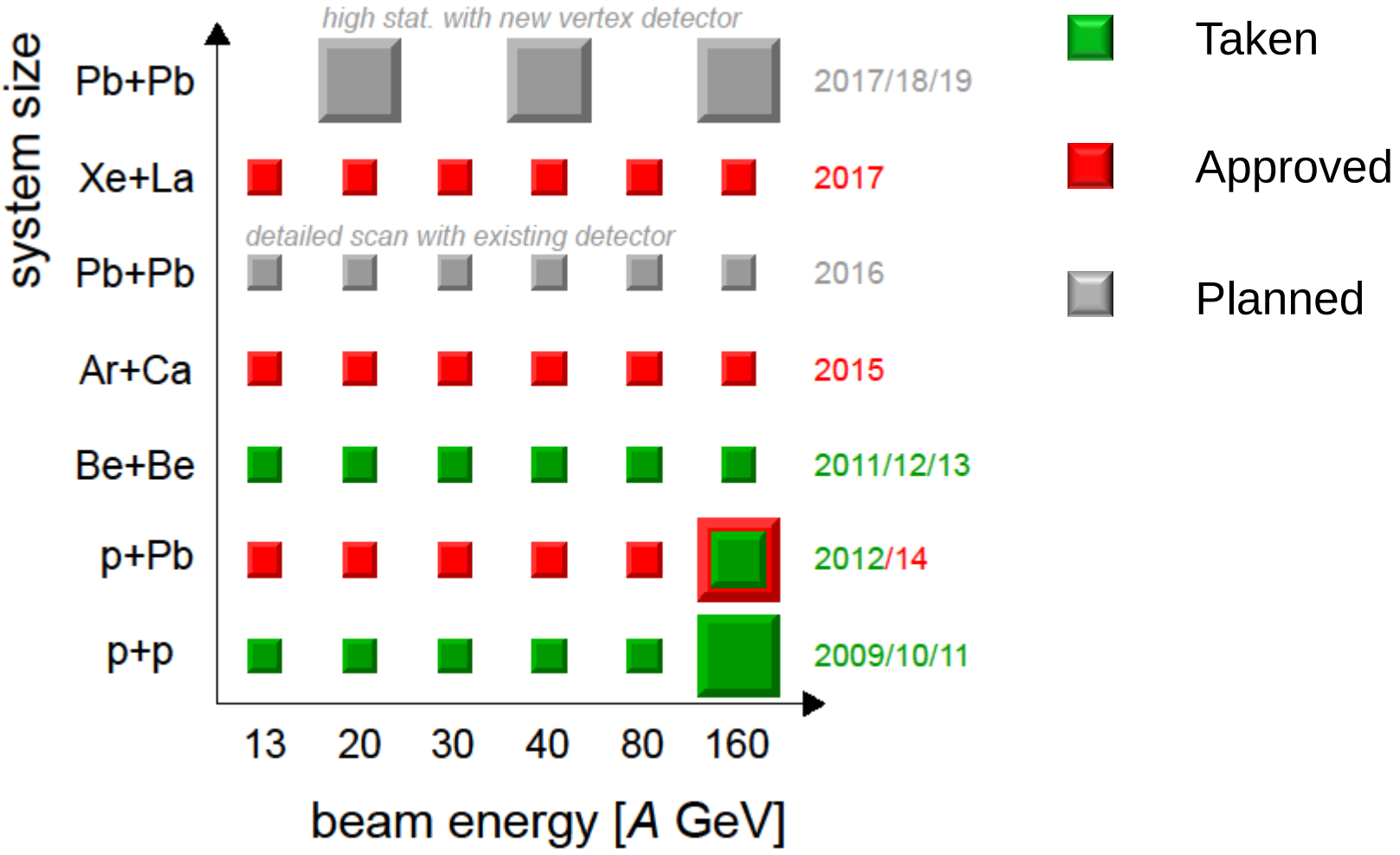
Beryllium looks heavy at 150*A* GeV/c!

Energy dependance of T parameter in Be+Be simillar to Pb+Pb

Summary

- NA61/SHINE studies properties of the phase diagram of strongly interacting matter:
  - to establish system size dependence of the onset of deconfinemnet and thus uncover its properties,
  - to discover the critical point
- Precise measurements of pion production properties in p+p interactions at the same beam momenta per nucleon as the corresponding A+A data are available from NA61/SHINE.
- First results on Be+Be interactions are realized and suggest presence of collective effects.
  Soon many more results.

Future plans



THANK YOU

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