

# NA61/SHINE:

## Current Program and Perspectives

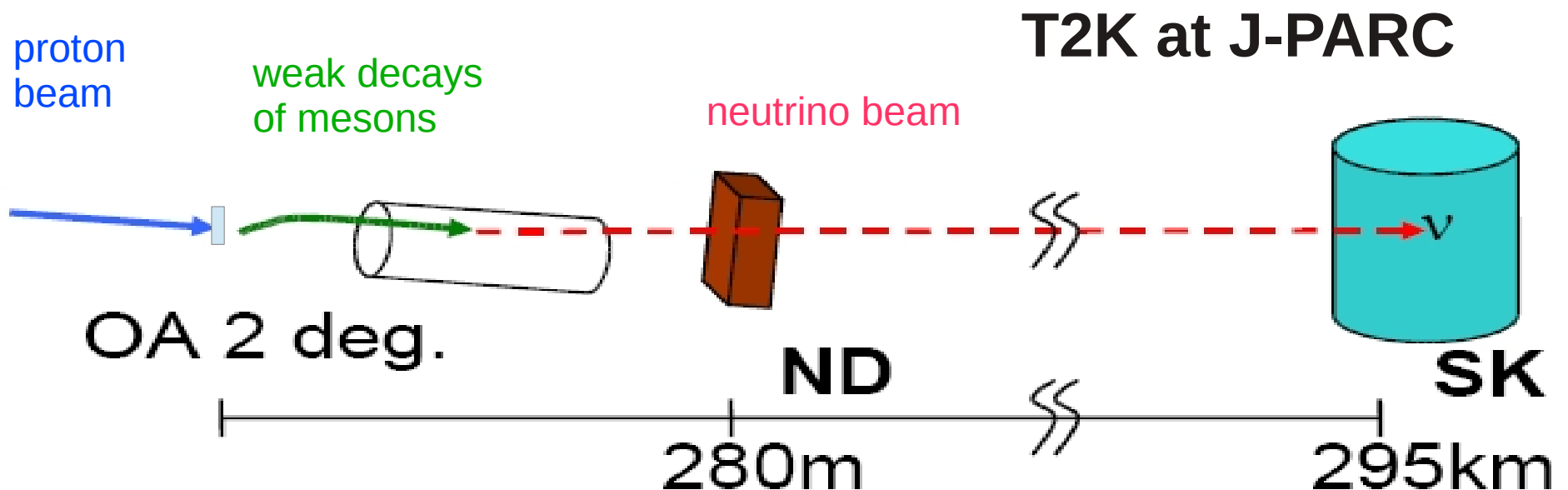
Herbert Ströbele

- **Physics goals**
  - *Auxiliary data for neutrino experiments*
  - *Auxiliary data for cosmic ray experiments*
  - **A+A collisions: Energy and system size scan**
- **Detector**
  - Legacy components
  - New Systems
- **Results**
  - **Hadron beams**
    - Reference p+p,  $\pi$ +C, p+C
  - **Ion beams**
    - $^7\text{Be}+^9\text{Be}$
- **Perspectives**
  - US and European neutrino experiments
  - Pb+Pb collisions

# Physics goals (I)

Auxiliary data for neutrino experiments.

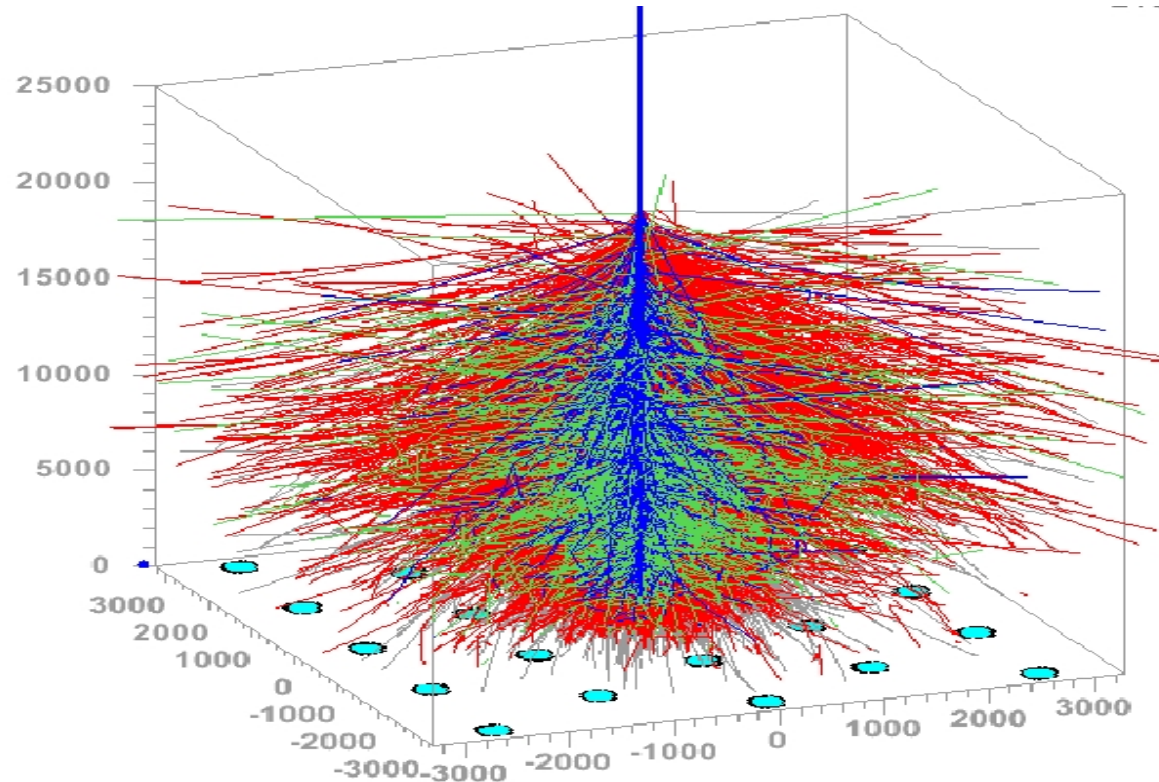
High precision data on pion and kaon production are needed to calculate the initial neutrino flux in neutrino experiments.



# Physics goals (II)

## Auxiliary data for cosmic ray experiments.

High precision data on hadron production (in  $p+^{12}\text{C}$  instead of  $p+^{14}\text{N}$  interactions) are needed to reconstruct air showers from cosmic rays measured for example by the Pierre Auger and KASCADE experiments.



# Physics goals (I+II)

## Publications:

Measurements of Cross Sections and Charged Pion Spectra in Proton-Carbon Interactions at 31 GeV/c.

**Phys.Rev. C84 (2011) 034604.**

Measurement of Production Properties of Positively Charged Kaons in Proton-Carbon Interactions at 31 GeV/c,

**Phys.Rev. C85 (2012) 035210.**

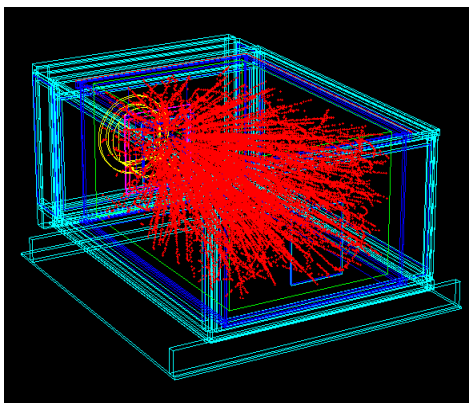
Pion emission from the T2K replica target: method, results and application NA61/SHINE Collaboration (N. Abgrall (Geneva U.) et al.). Jul 2012.

**Nucl.Instrum.Meth. A701 (2013) 99-114**

# Physics goals (III)

Study of the properties of the onset of deconfinement  
and  
Search for the critical point

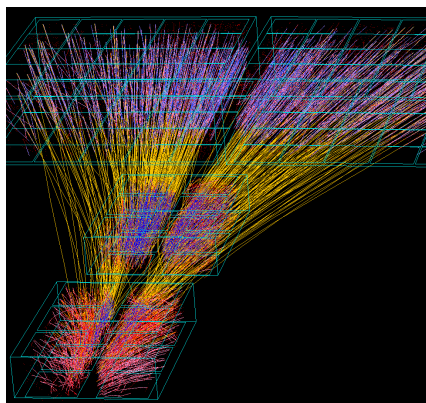
BNL AGS



EOS TPC

Au+Au

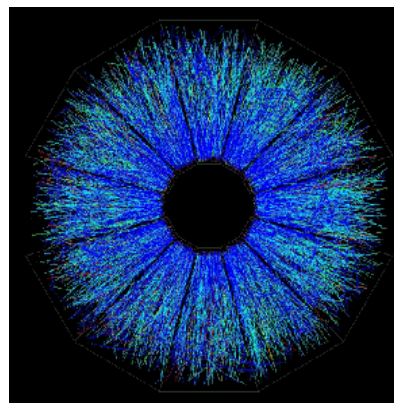
CERN SPS



NA49 TPCs

Pb+Pb

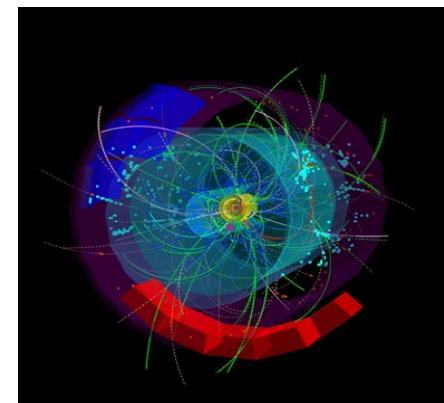
BNL RHIC



STAR TPC

Au+Au

CERN LHC



ALICE TPC

Pb+Pb

# Evidence for the phase transition Hadron gas => Quark Gluon Plasma?

Energy dependence of various observables:

evidence for the onset of deconfinement (1)

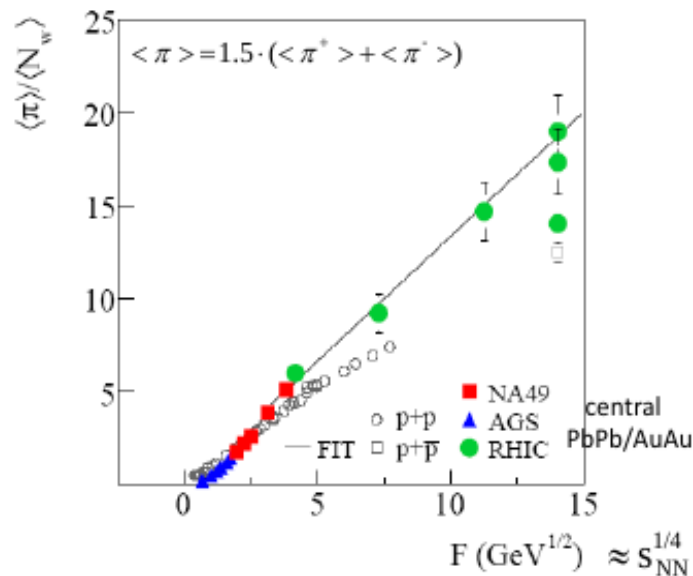
the kink

pion yield per participant

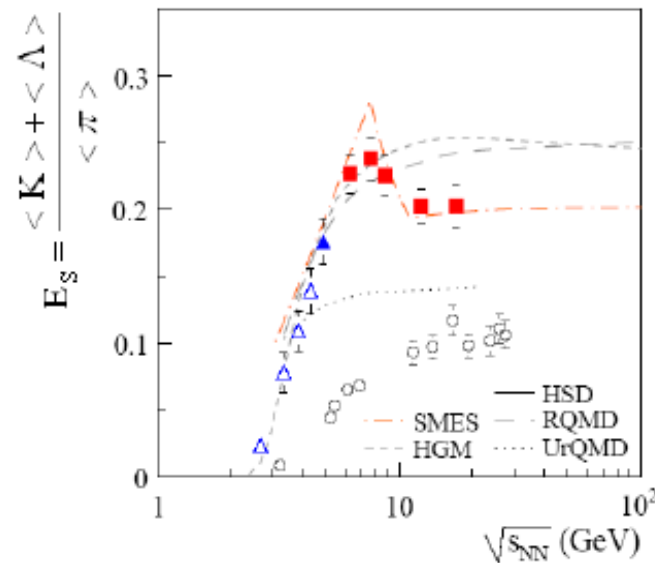
the horn

ratio of strange particle to pion yield

NA49, C. Alt et al., PRC77,024903(2008)



- $\pi$  yield related to entropy production
- steeper increase in A+A suggests 3-fold increase of initial d.o.f



- $E_s$  related to strangeness/entropy ratio
- plateau consistent with prediction for deconfinement

# Evidence for the phase transition: Hadron gas => Quark Gluon Plasma?

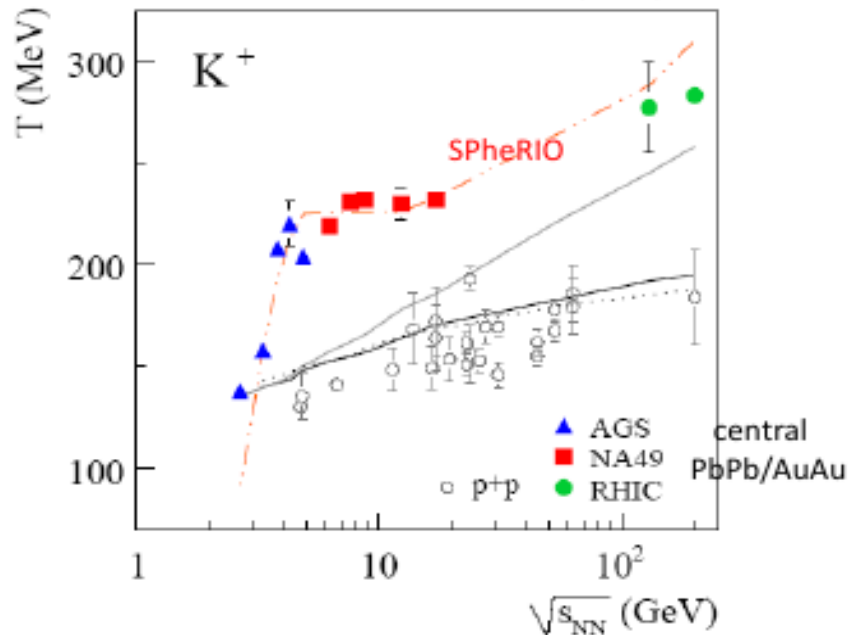
Energy dependence of various observables:

evidence for the onset of deconfinement (2)

the step

shape of transverse mass spectra

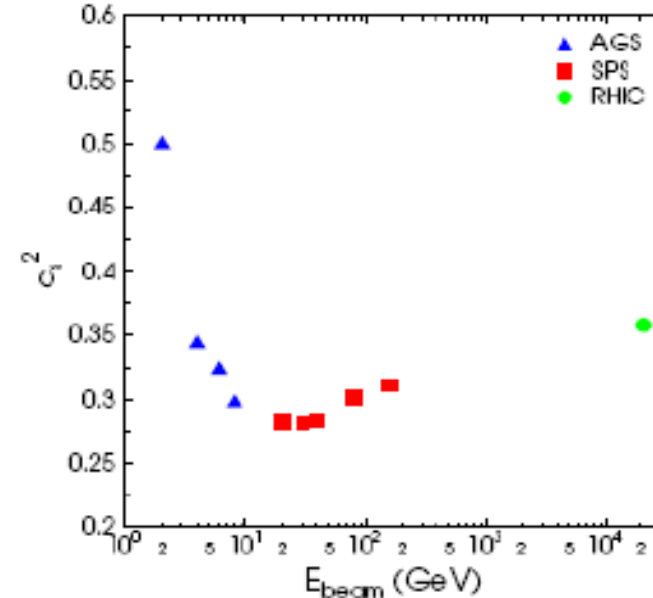
NA49, C. Alt et al., PRC 77, 024903 (2008)



the dale

estimate of sound velocity

(H. Petersen and M. Bleicher, nucl-th/0611001)



softening of transverse (step) and longitudinal (minimum of  $c_s$ ) features of EoS due to mixed phase (soft point of EoS)

## Physics goals (III)

The energy dependence of various observables shows non monotonic behavior in central Pb+Pb (Au+Au) collisions but not in p+p interactions. Data on the latter suffer from large uncertainties .

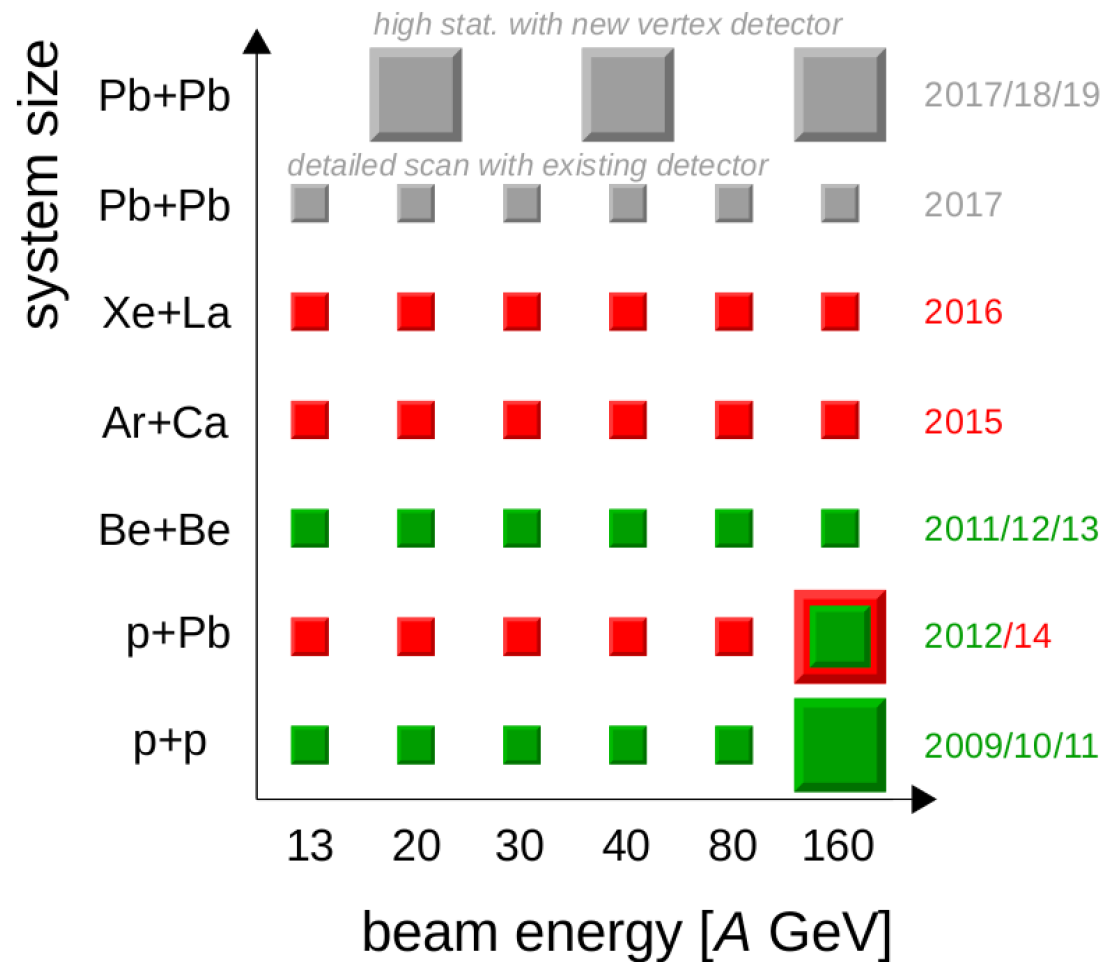
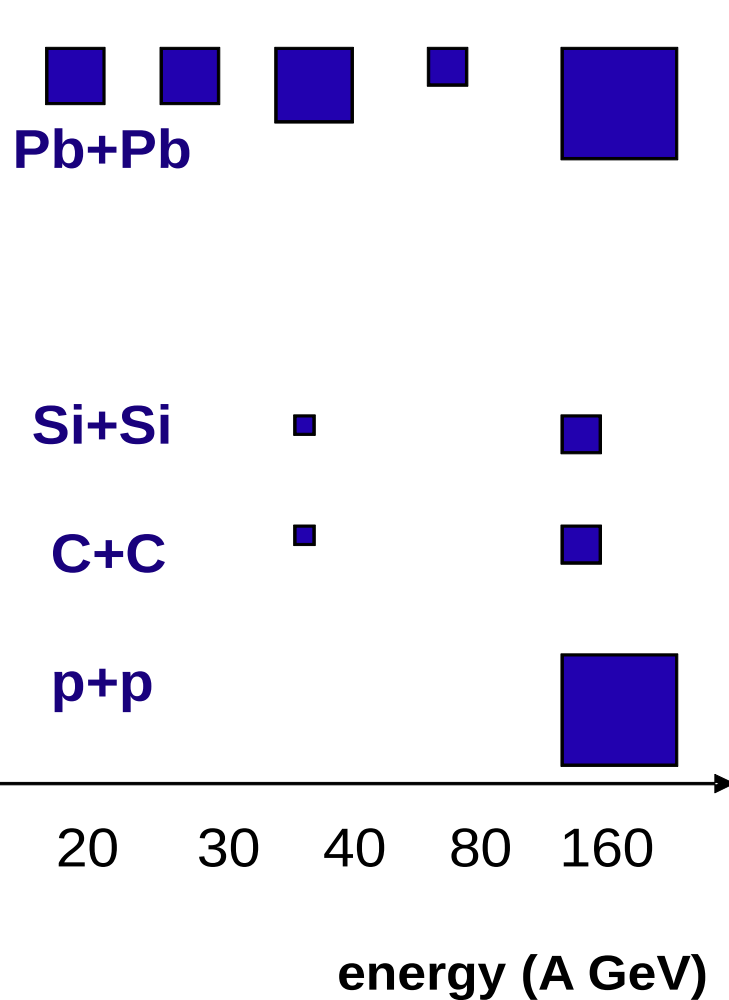
**Establish a precise p+p base line** and measure **the system size dependence of this feature.**

**Look for fluctuations characteristic of the critical point.**

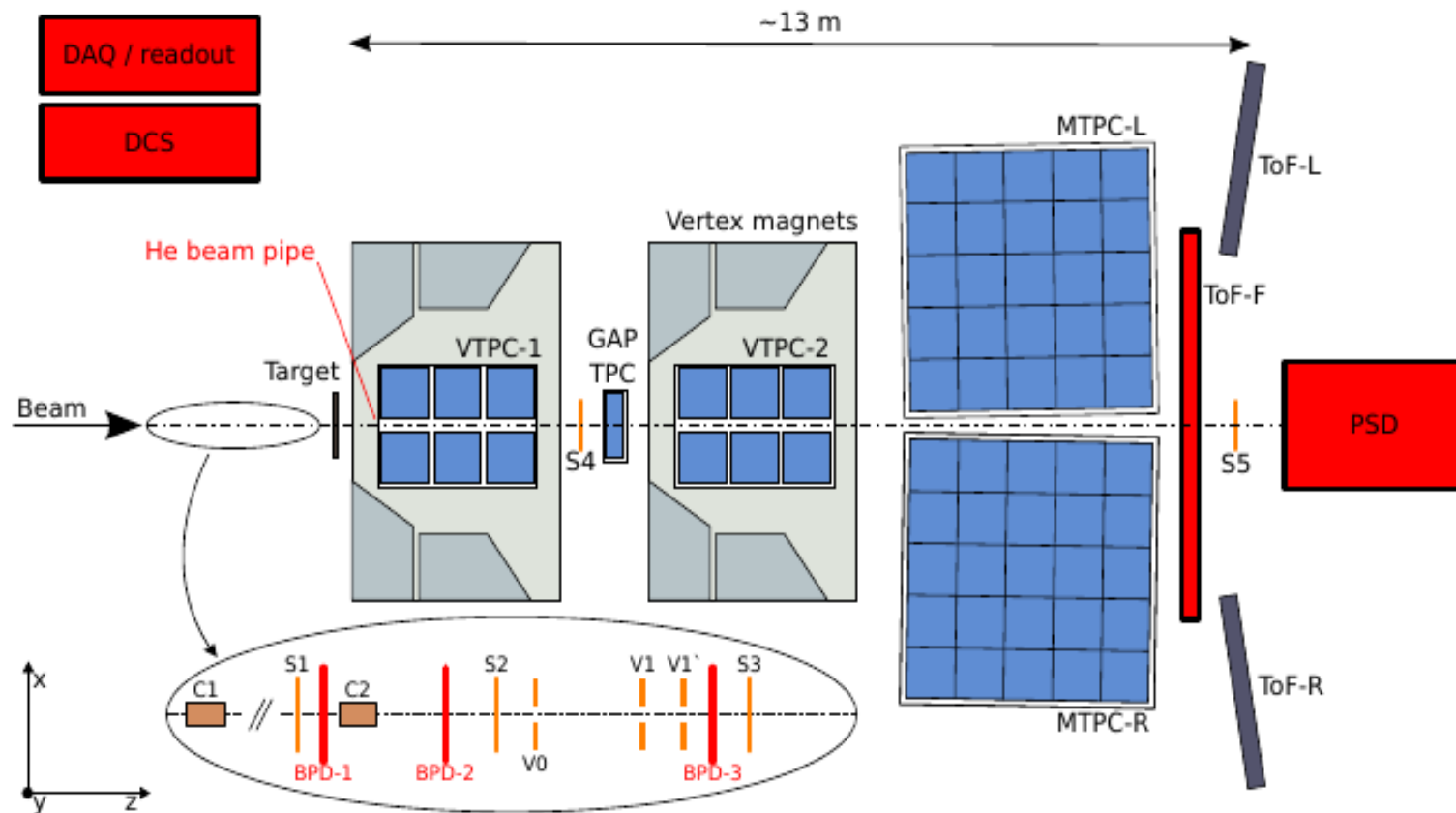
(Non-central collisions of heavy systems are not azimuthally symmetric (in configuration space) and thus only an option.)



# NA61



# Detector



Legacy components and new systems (in red)

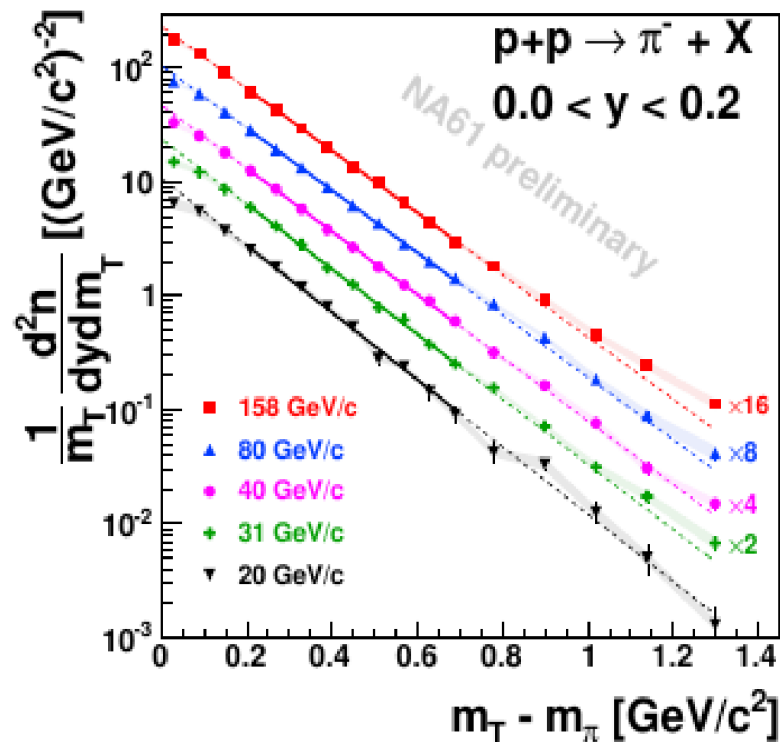
# Detector

The main upgrades:

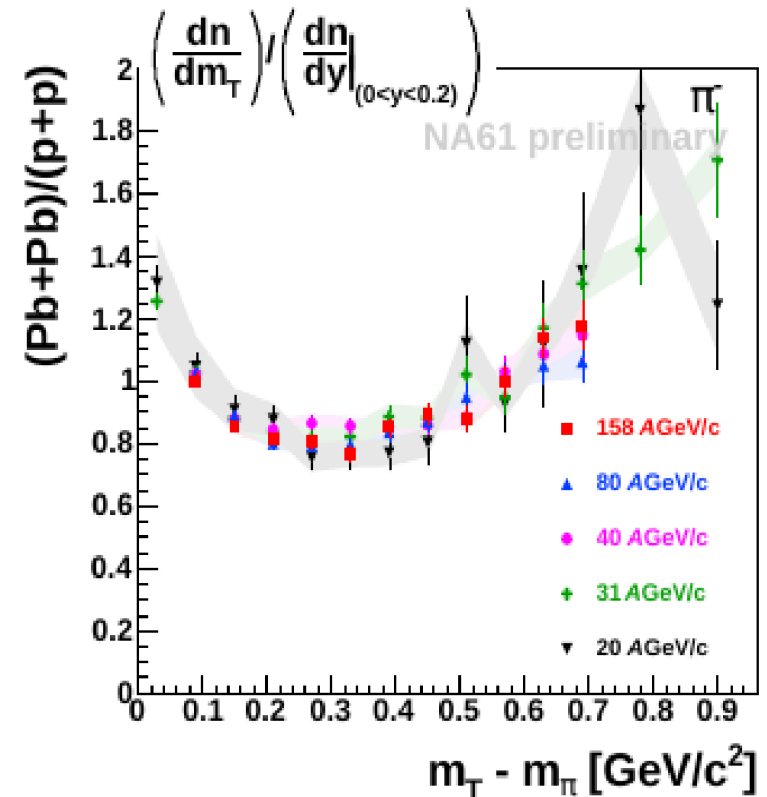
- Forward TOF (for p+C analysis).
- He beam pipe in the VTPCs ( $\delta$ -electron suppression).
- Data acquisition (~15 fold increase of read-out speed).
- Modularized Projectile Spectator Detector PSD (high resolution measurement of centrality).

# Results (p+p)

$m_T$  spectra at mid-rapidity



(NA49 Pb+Pb)/(NA61 p+p)

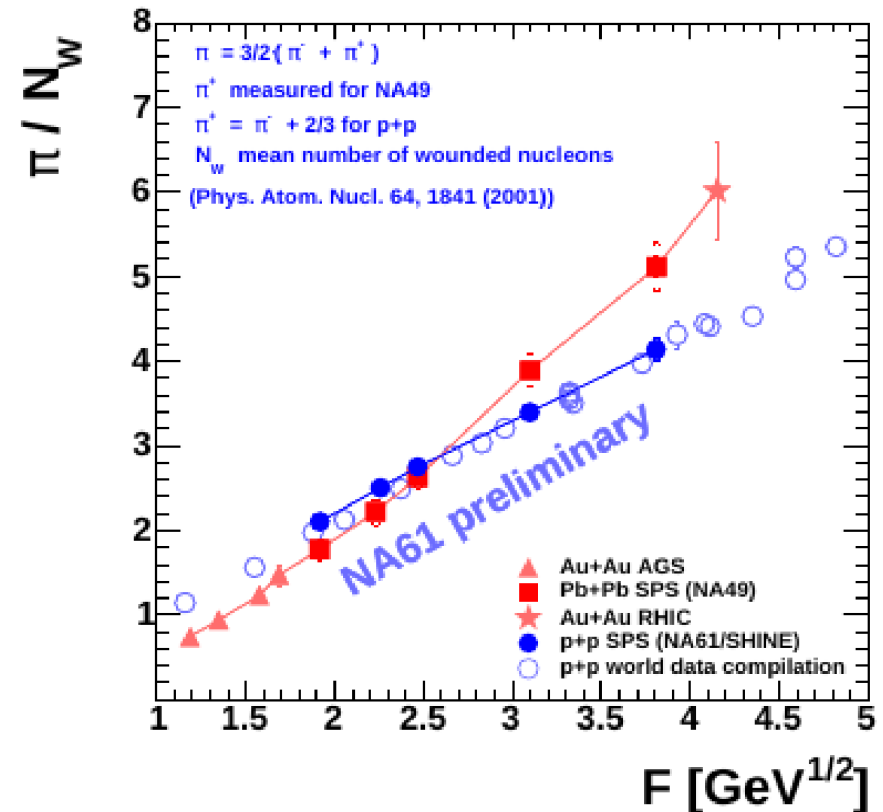
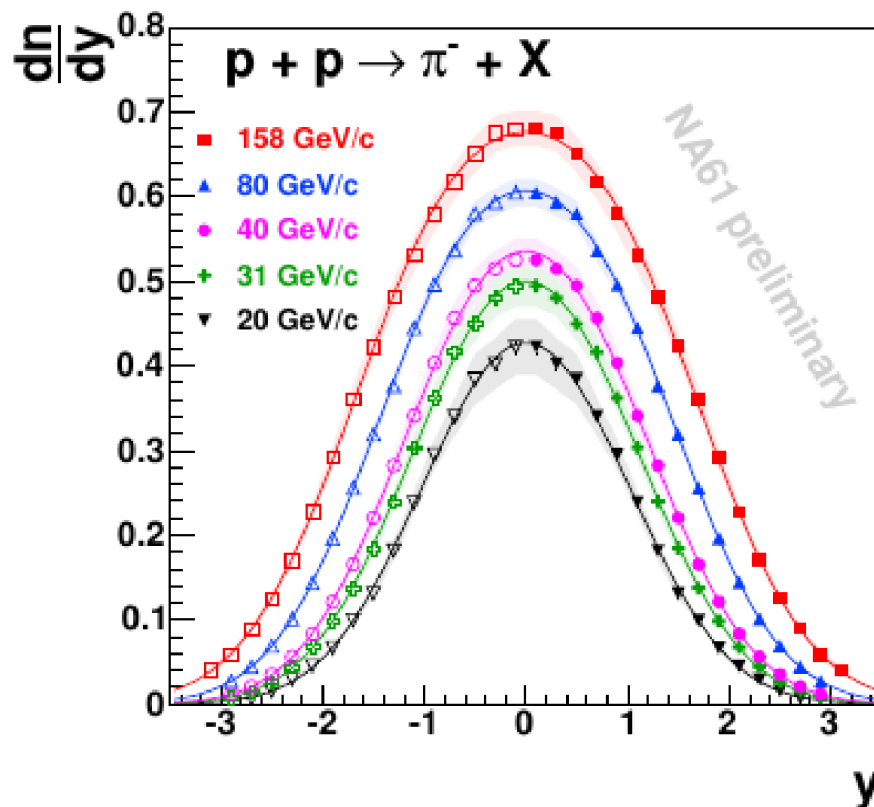


significant shape-difference wrt. Pb+Pb, independent of energy.

# Results (p+p)

$m_T$ -integrated  $\pi^-$ -spectra

comparison to prev.  $p+p$ , Pb+Pb



- ▶ large  $y$ -acceptance, small syst. and stat.
- ▶ precision (still to be improved) already sufficient for study of onset of deconfinement

# Results (p+C)

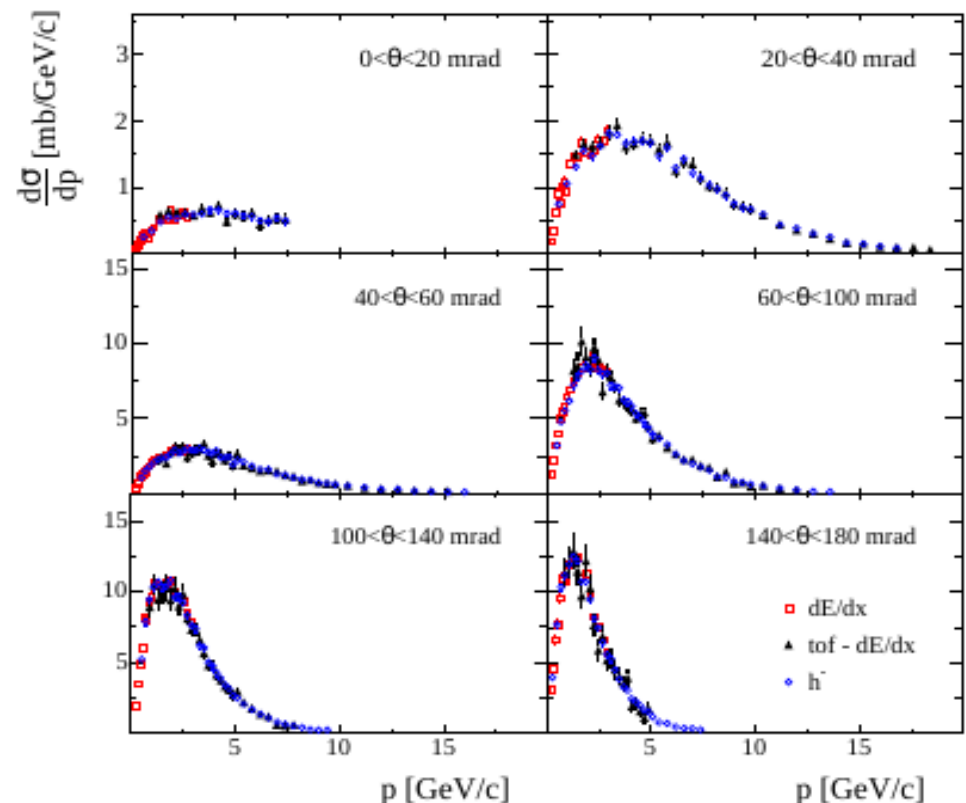
## Analysis of 2007 data (p + C at 31 GeV/c)

three independent analyses:

- ▶ negative hadrons (model corr.)
- ▶ dE/dx-only at low  $p$
- ▶ dE/dx and TOF at medium  $p$

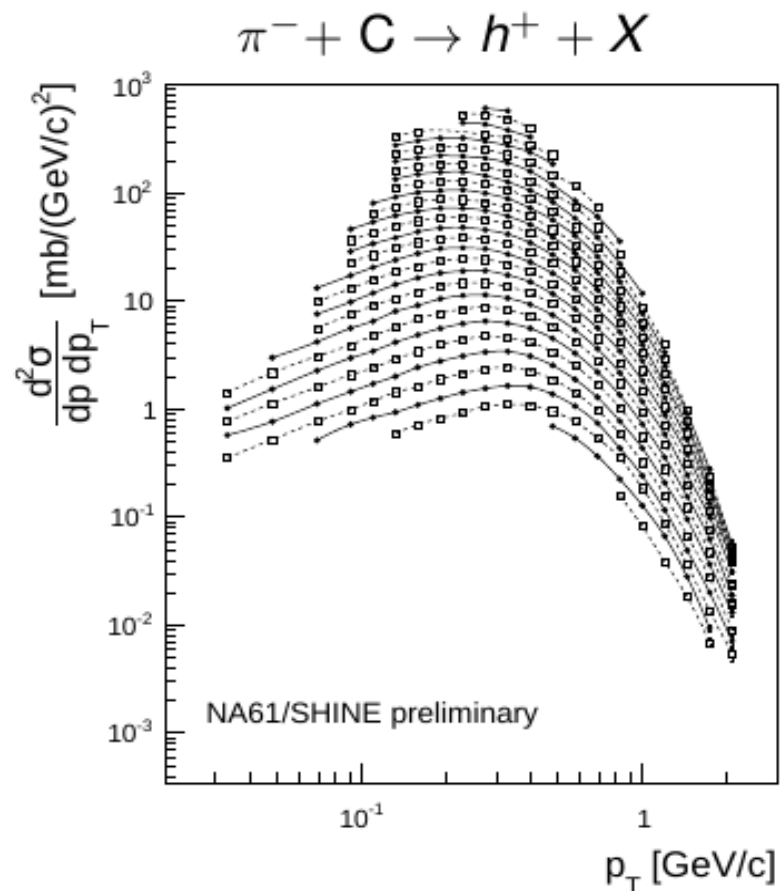
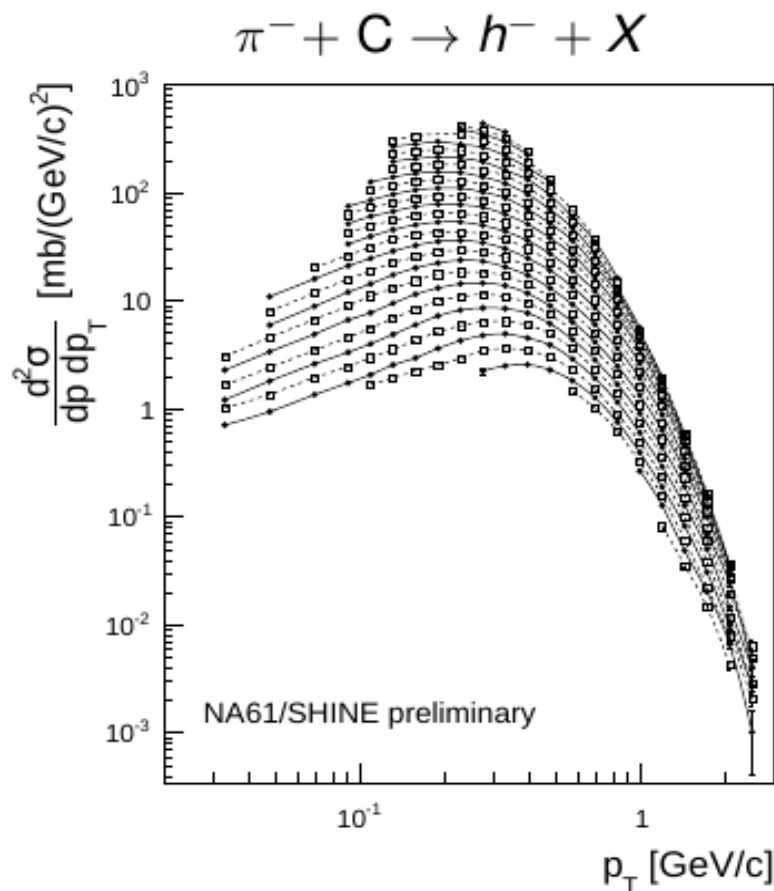
### spectrum corrections

- ▶ acceptance  $\geq 99\%$
- ▶ reconstruction efficiency  $\geq 96\%$
- ▶ pion decay  $\leq 10\%$
- ▶ feed-down  $\leq 10\%$



# Results ( $\pi+C$ )

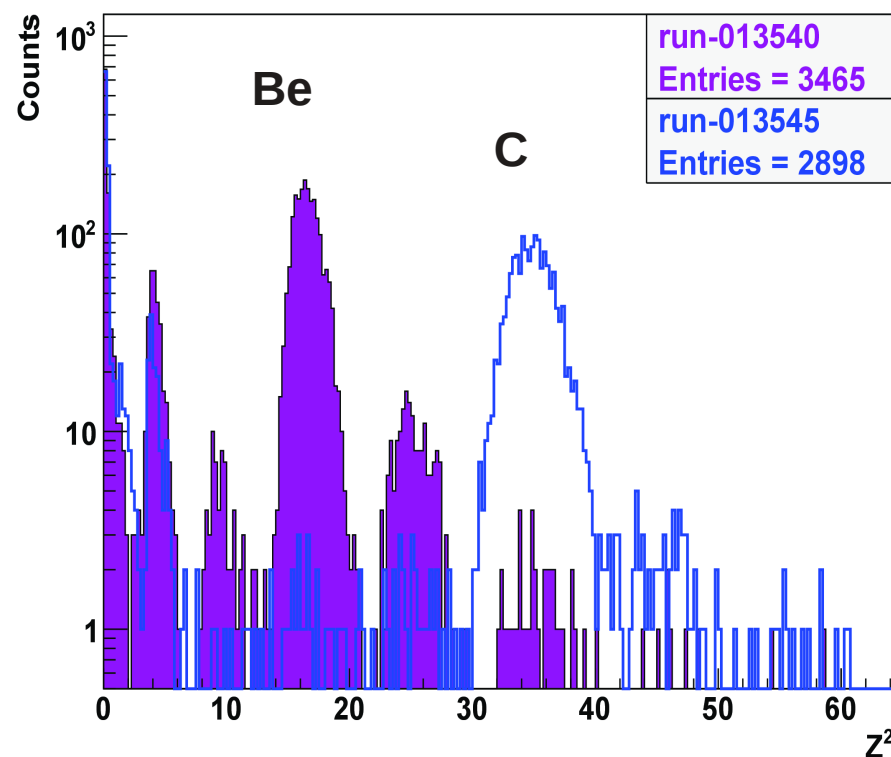
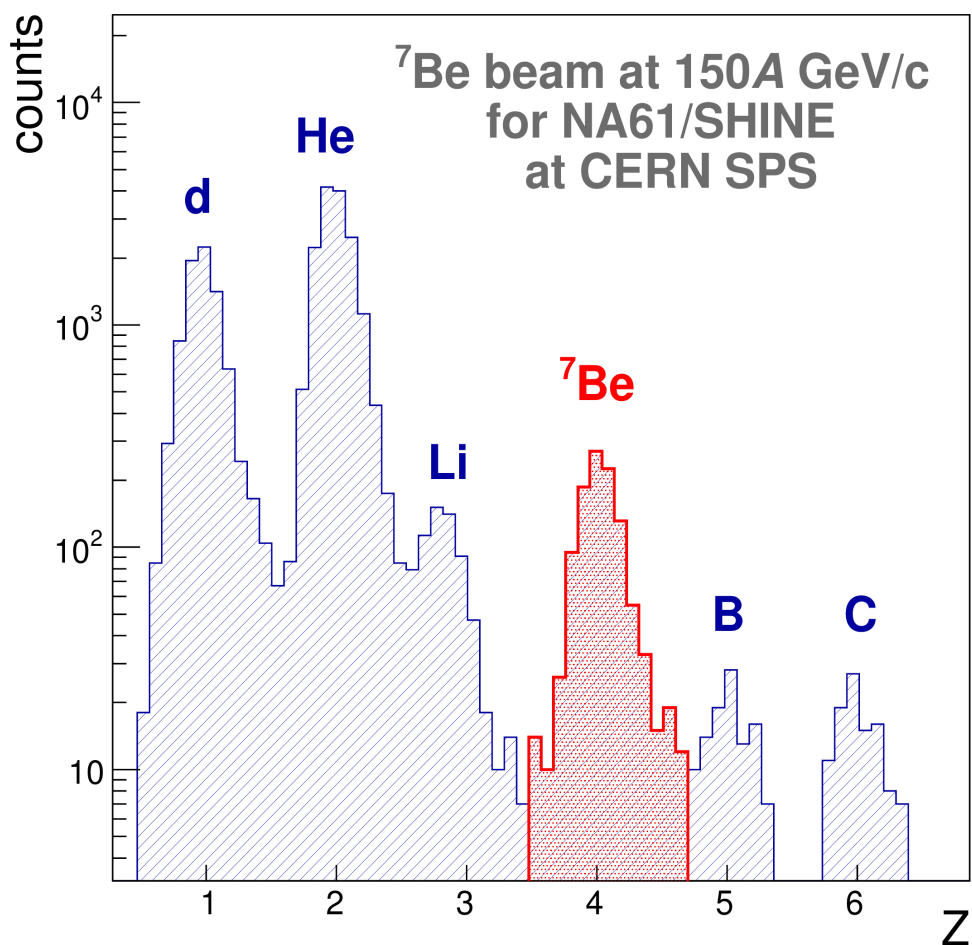
## Charged Hadron Production in $\pi^-+C$ at 350 GeV/c



$p = 0.6 \dots 121 \text{ GeV}/c$  in steps of  $\lg p/(\text{GeV}/c) = 0.08$

# Results (fragment beam)

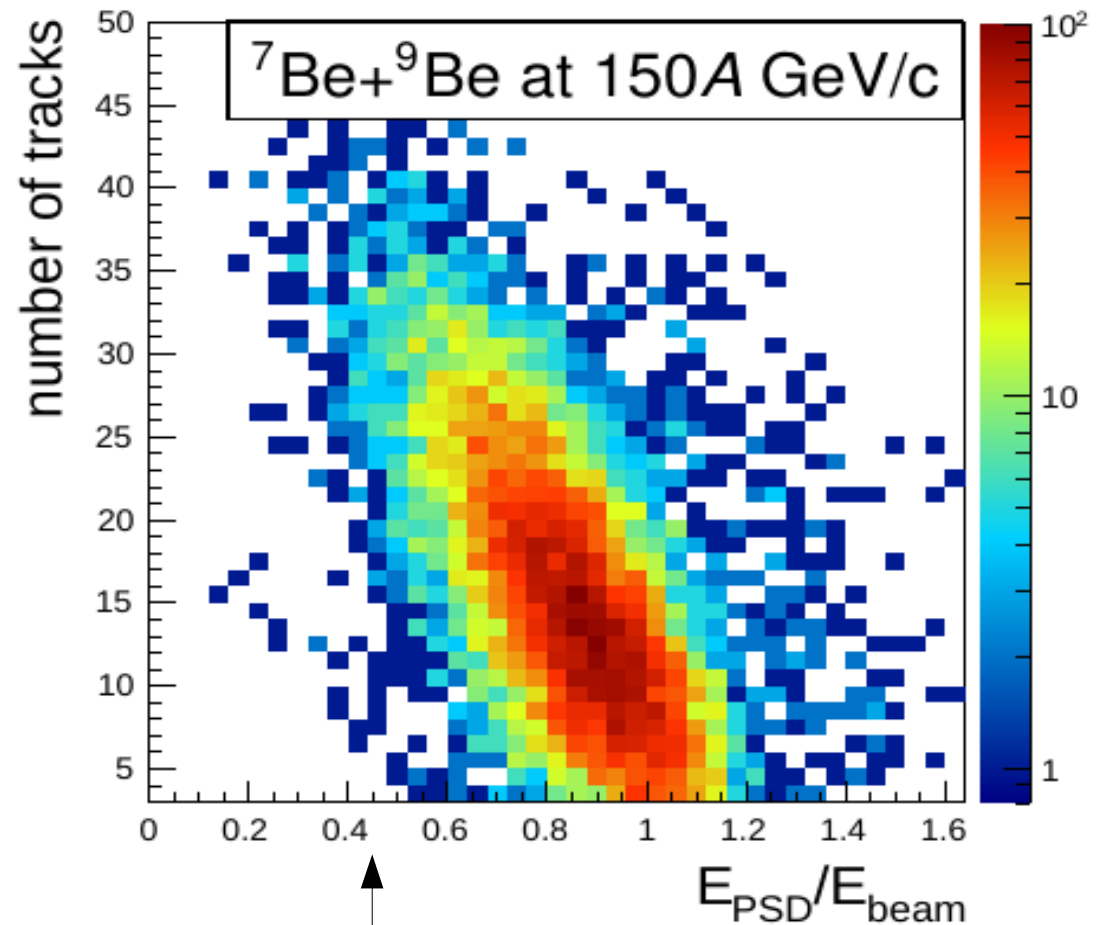
13 GeV/u primary beam.  
Fragment separator mode  
optimized for  ${}^7\text{Be}$  (filled histogram)  
and for  ${}^{11}\text{C}$  fragments.





# Results (A+A)

uncorrected distribution, less than 1% of total statistics:



Central collisions:  
40 tracks = 40 charged particles

9 participants  $\Rightarrow$  4.5 protons

$35.5 / 9 = 3.9$  charged mesons/participant.

To be compared to 3.9 in central Pb+Pb.  
and 2.9 in p+p.

Three projectile spectators

# Perspectives

NA61/SHINE plans beyond the approved program:

Data taking  
for Fermilab and planned CERN **neutrino**  
experiments.

High statistics Pb+Pb data (10-100 increase wrt NA49)  
to allow for the study of the energy dependence of  
**Open charm** and **multi strange baryon production**  
as well as **high transverse momenta** up to 7 GeV/c.

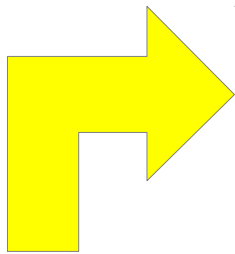
## Perspectives (Neutrinos)

The NA61/SHINE set-up turned out to be **the** experimental facility to measure charged meson production needed for the calculation of the neutrino beam characteristics.

NA61 is currently considering to measure reference data for

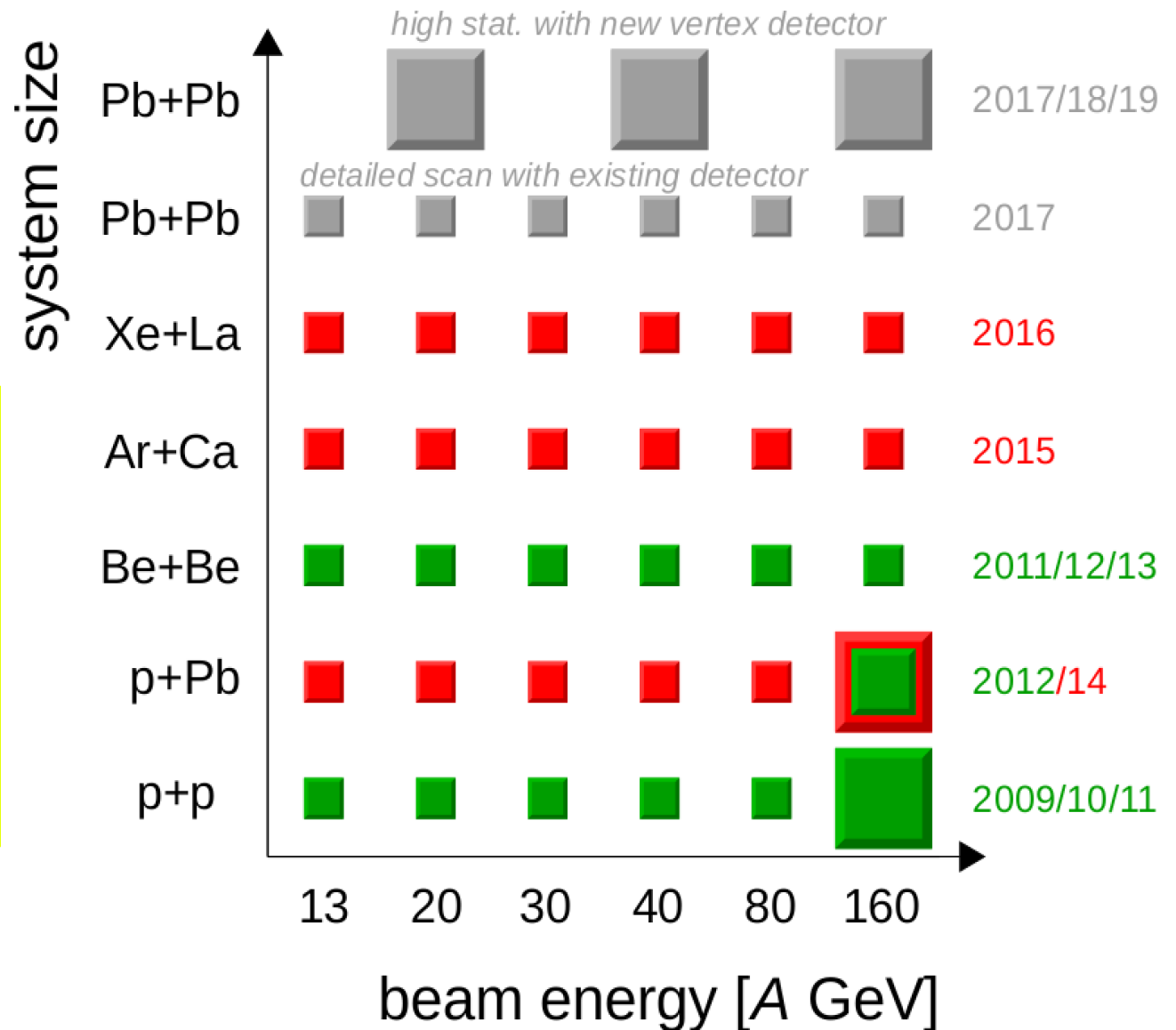
- the future long base-line neutrino oscillation experiment in Europe, **LAGUNA-LBNO** [CERN-SPSC-2012-021 (SPSC-EOI-007)] and
- the current upcoming accelerator neutrino programs in the United States: **MINERvA** , **MINOS**, **MINOS+**, **NOvA** and the future Long Baseline Neutrino Experiment (**LBNE**).

# Perspectives (A+A) current schedule



High statistic Pb+Pb  
experiment with new  
vertex detector

Up to  $5 \times 10^9$  Pb ions  
in the SPS possible.



Thank you