Results from the *NA61/SHIvE* experiment and future plans

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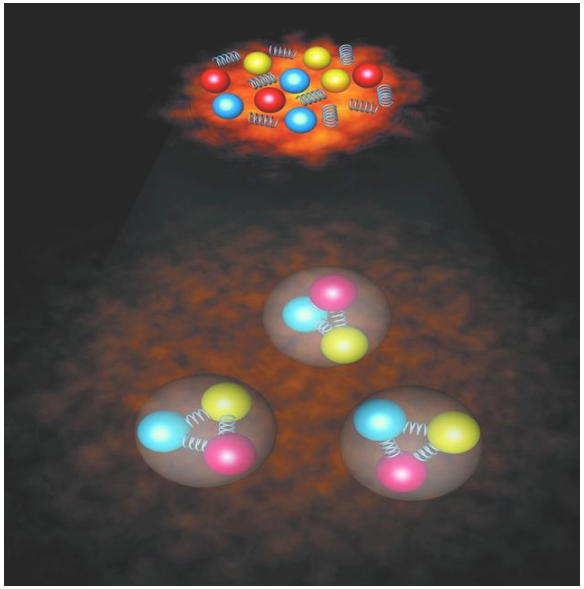
136 members, 27 institutes, 14 countries

SHINE
NA61

SHINE:SPS Heavy Ion & Neutrino Experiment

Heavy Ions

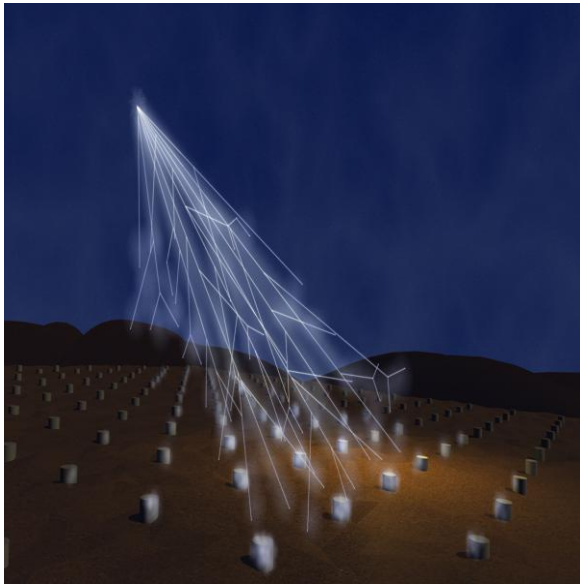
- Search for the critical point of strongly interacting matter
- Study the onset of the deconfinement



Astro-particle

Precise hadro-production measurements for Comic Rays Extensive Air Shower prediction

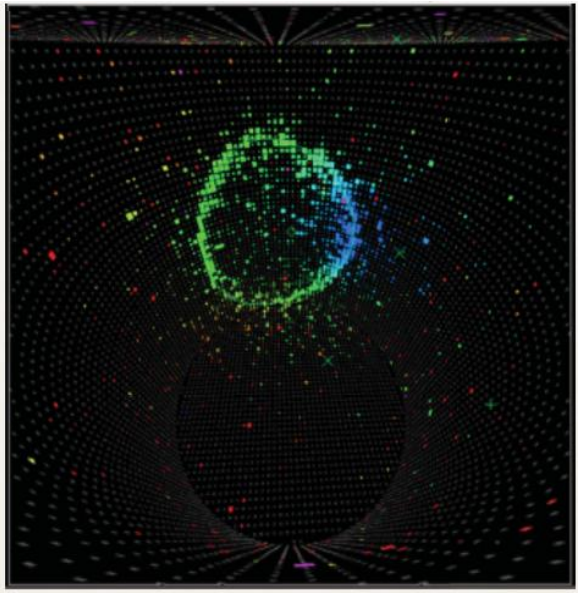
→ ***Pierre Auger Observatory***
→ ***KASCADE***



Neutrinos

Precise hadro-production measurements for precise characterization of the neutrino flux.
→ ***T2K*** experiment (Japan)

Future:
involvement in the Fermilab neutrino program

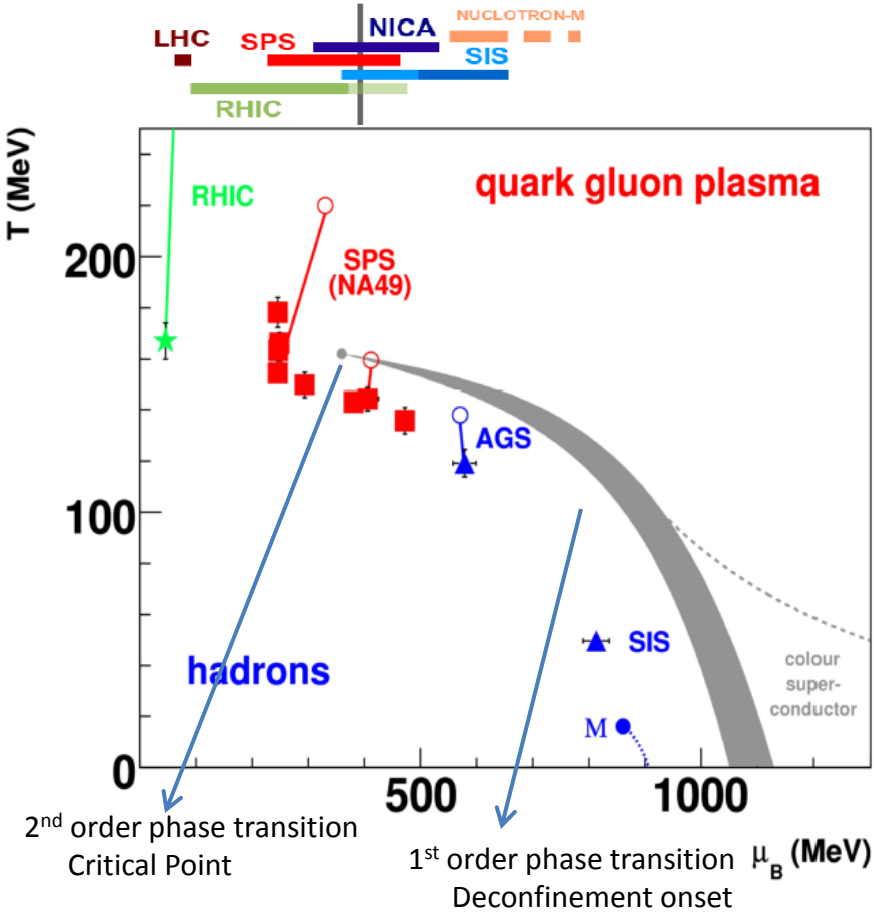


Strongly interacting matter

Structure of the region of transition from Hadron Gas (HG) to Quark Gluon Plasma (QGP).
Lattice QCD calculation:

- 1st order phase boundary (Onset of the Deconfinement)
- the end point of the phase transition line is the Critical Point→2nd order transition

➢ SPS covers the most important region of the Phase Space diagram



✓Evidence for **Onset of the Deconfinement** observed in NA49 at E~30A GeV

✓**Critical Point** should be searched above the Onset of the Deconfinement E >30A GeV

✓Critical Point may be located at SPS energies:

$(T,\mu_B)=(162\pm2,360\pm40)$ MeV
Fodor and Katz JHEP 404 050 (2004)

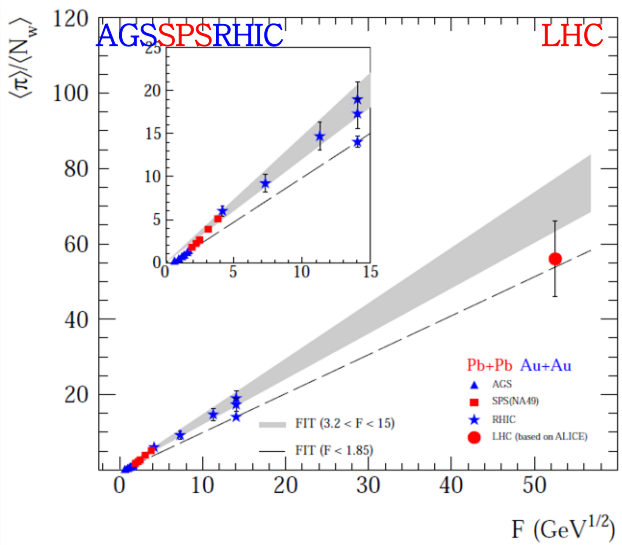
μ_B=360 MeV ⇔ E ~ 50A GeV
Beccatini, Manninen, Gazdzicki
PRC 73 044905 (2006)

Onset of the Deconfinement

status of the observations

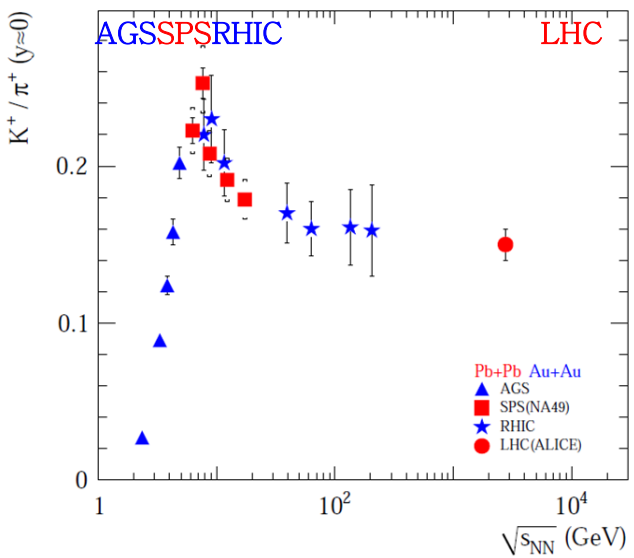
Energy dependence of specific hadron-production properties exhibit peculiar structures which are difficult to explain without including HG-QGP transitions

Observed in Pb+Pb and Au+Au collisions (in the SPS energy range).
Phenomena not observed for light systems: p+p.
→ study of the intermediate systems → <u>NA61/SHINE Heavy Ion program</u>



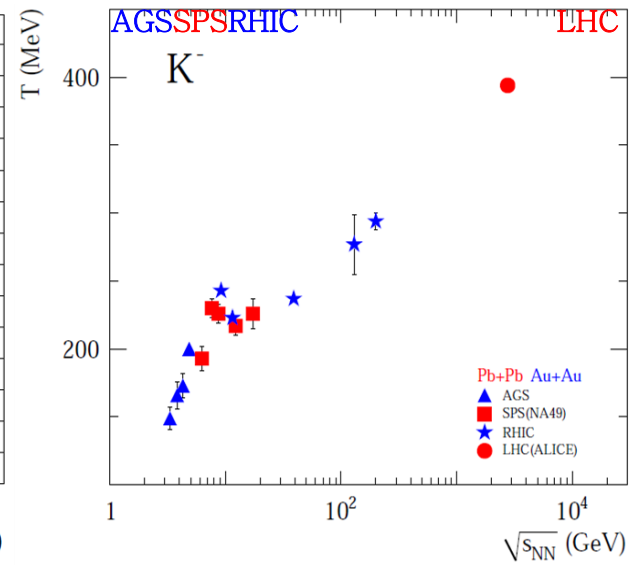
The kink in pion multiplicity

Entropy increase at the onset of the deconfinement



The horn in strangeness yield

K/π yields ratio at high energy approach a constant level as expected
for deconfined matter

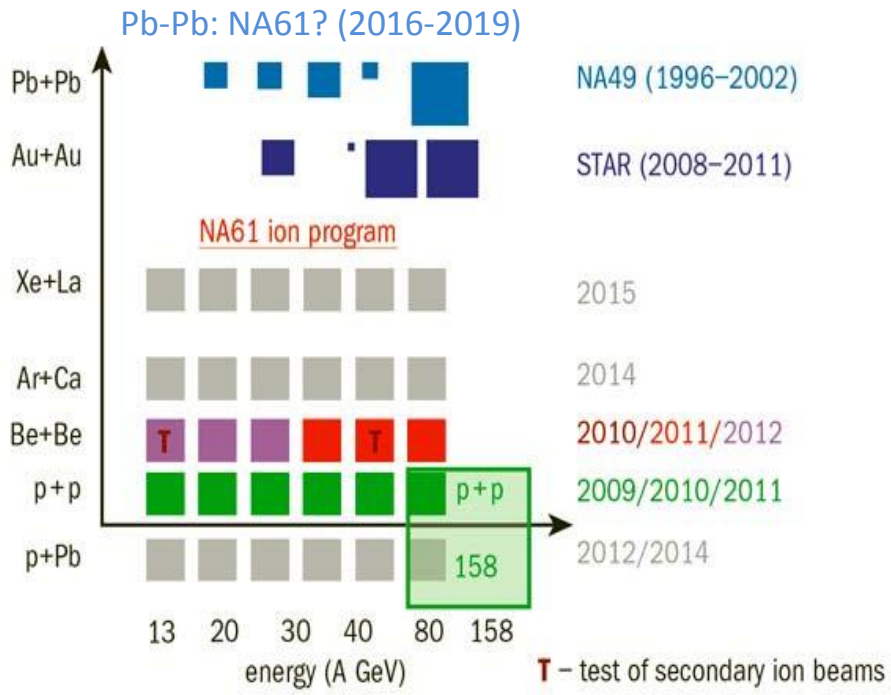


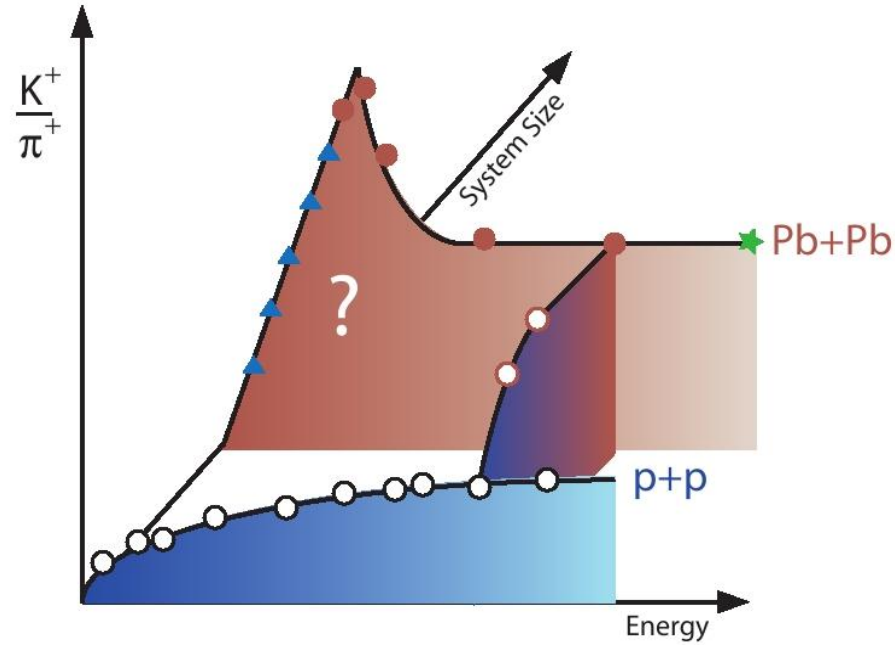
The step in T parameter: inverse slope of m_T

Onset: mixed phase where T do not increase with collision energy

NA61/SHINE Heavy Ion Program -1

Study of the properties of the Onset of the Deconfinement, establishing the system size dependence of its signals

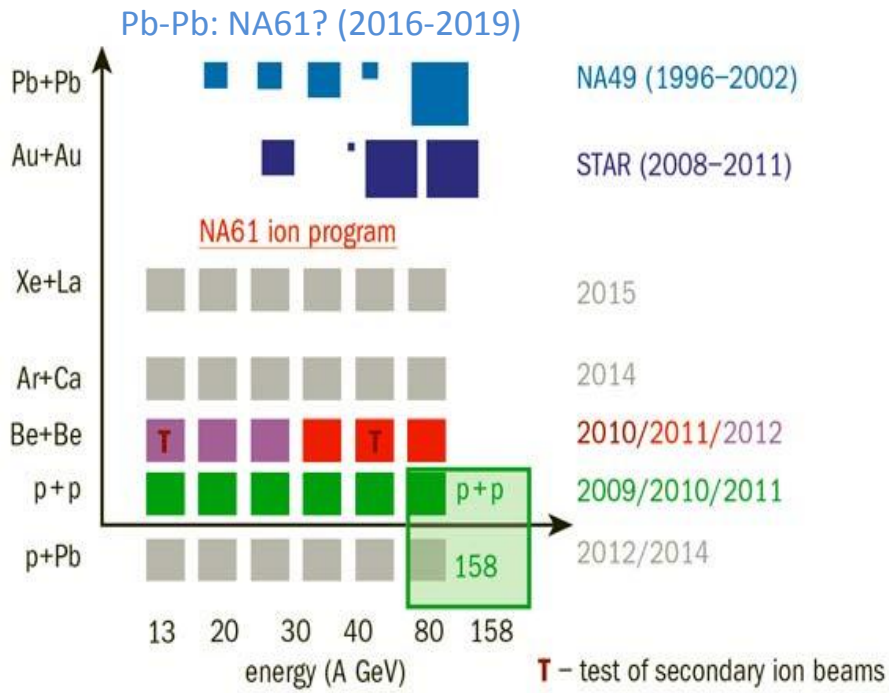


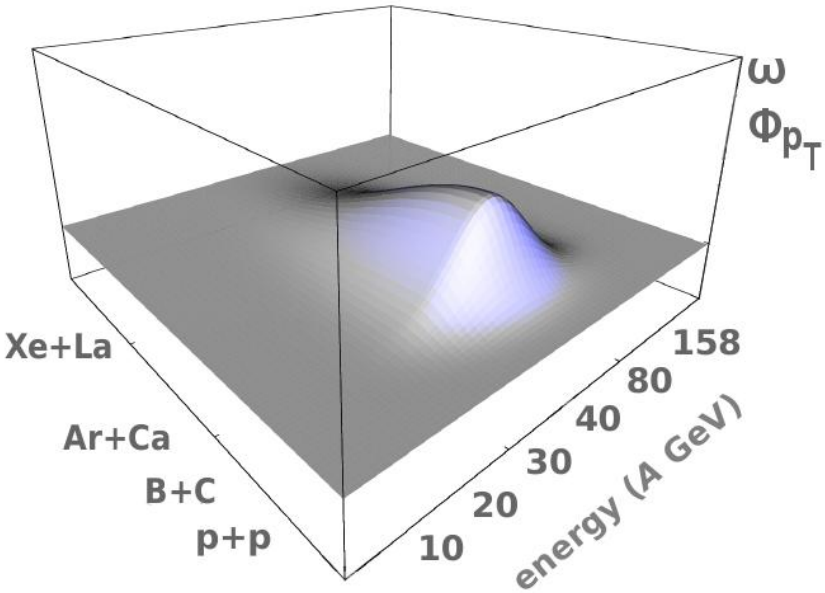


Energy system scan: verify the observation of similar structures (kink, horn,step) vanishing for lighter nuclei

NA61/SHINE Heavy Ion Program -2

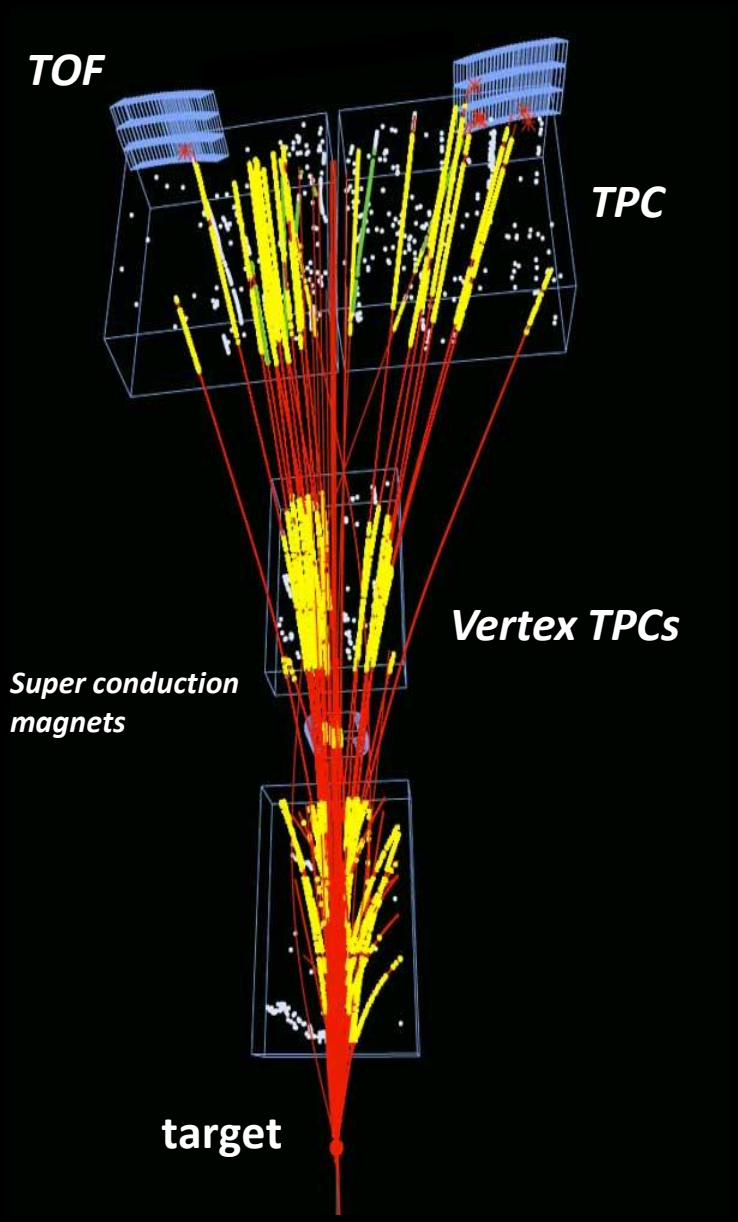
Search for the Critical Point of strongly interacting matter by studying the system size and collision energy dependence of hadron fluctuations and correlations





Search for the hill of fluctuations
Increase of critical point signal (multiplicity and average p_T fluctuations,...)
for system freeze-out close to the critical point

Experimental Apparatus



- Large acceptance: ≈50%
- High momentum resolution:
  $\sigma(p)/p^2 \approx 10^{-4}\left((GeV/c)^{-1}\right)$
  at full magnetic field
- Good particle identification:
  $\sigma(TOF) \approx 100ps,$
  $\sigma(dE/dx)/\langle dE/dx\rangle \approx 0.04,$
  $\sigma(m_{inv}) \approx 5MeV/c^2$
- High detector efficiency:
  > 95%

Several Upgrades of the Detector inherited by NA49

2007: construction of the forward ToF wall to extend particle identification acceptance

2008: replacement of the TPC readout and central DAQ: x10 event rate increase (80 Hz)

2010: modification of beamline for production of fragmented ion beams

2011: replacement of the old calorimeter (VCAL) used for event centrality measurement in A+A spectator energy by the new Projectile Spectator Detector (PSD) to get 1 nucleon precision (x5 improvement)

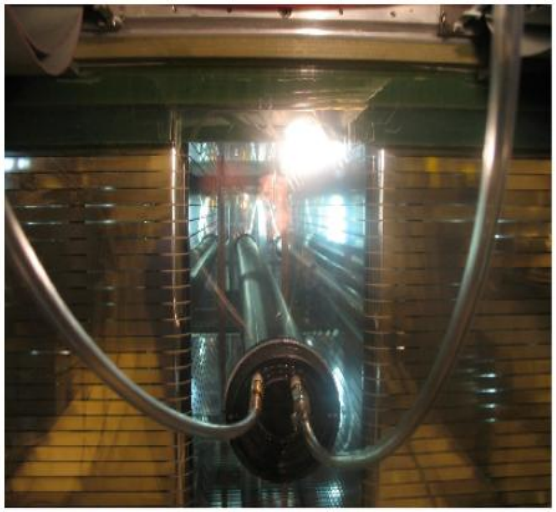
2011: insertion of He beam pipes to VTPCs to reject δ-electrons

2011: Z-detectors (Cerenkov) to measure beam charge of secondary ion beam

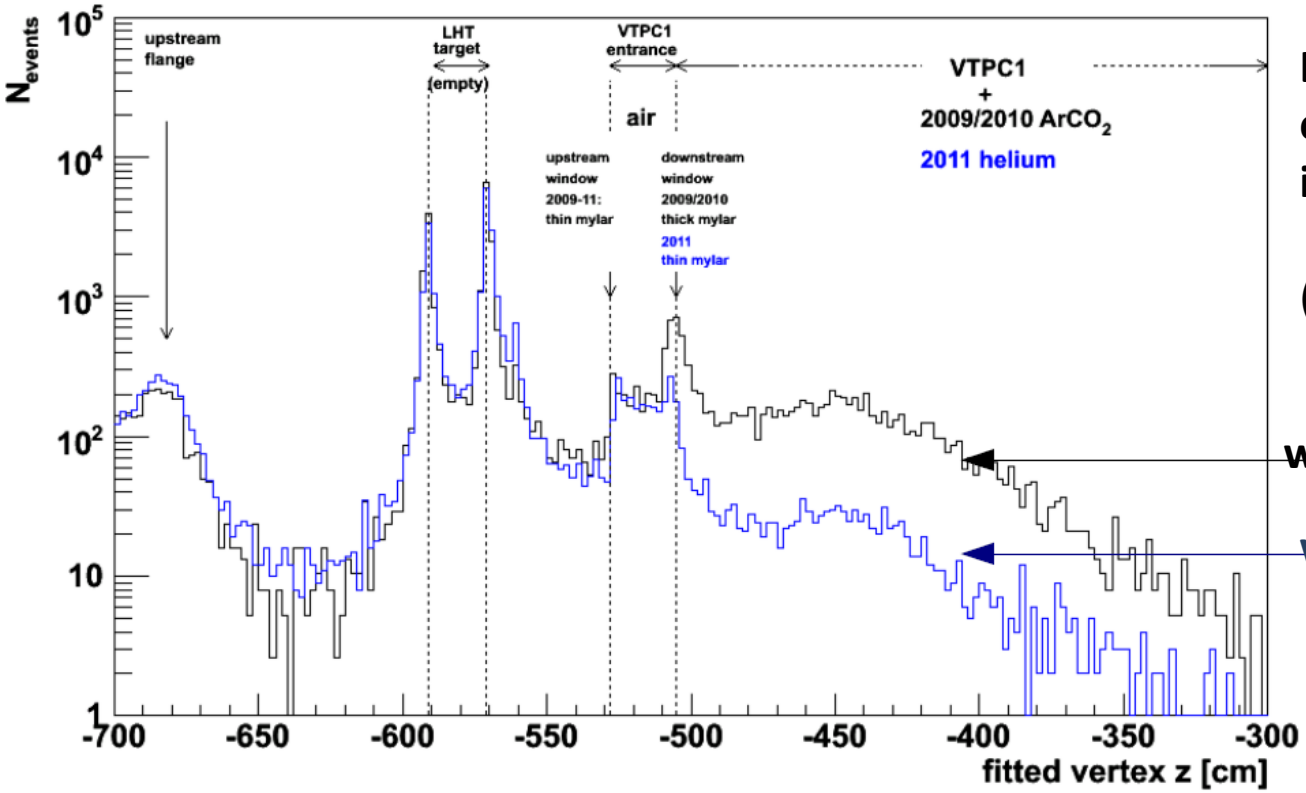
2011: A-detector (time-of-flight) to measure isotope composition of secondary ion beams

2011: construction of Low Momenta Particle Detector (LMPD) to count number of low momentum protons in h+A collision for centrality determination ("target spectator detector")

The He beam pipe



- ✓ δ-electrons produced along the beam line→ bakground for fluctuations measurement related to the search for the critical point
- ➢ double wall He beam pipes placed inside both Vertex TPCs
- ➢ significant background reduction



Longitudinal position of of the reconstructed interaction vertex

(p+p 30 GeV)

w/o He beam pipe

w/ He bem pipe

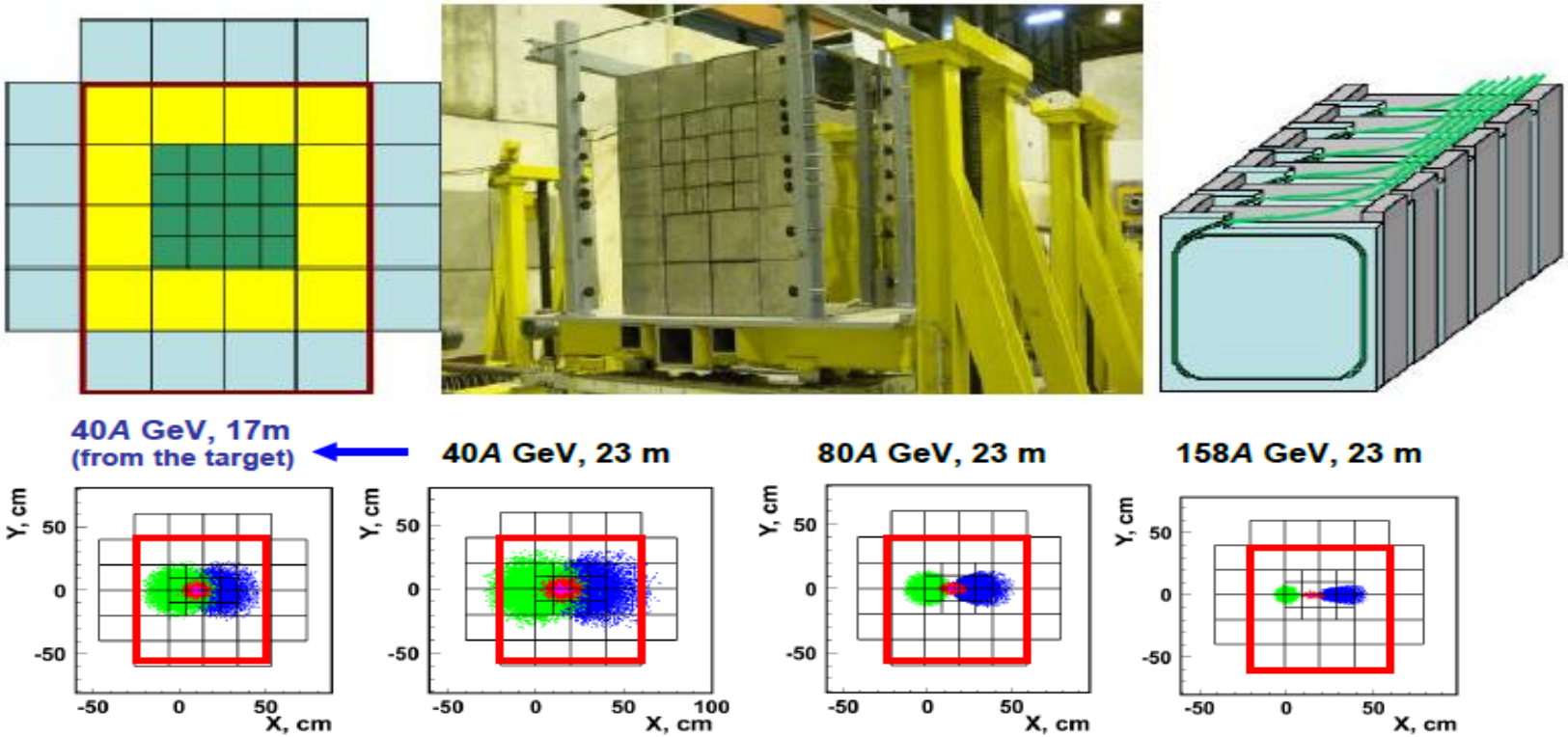
The Projectile Spectator Detector

Precise measurement of the energy of the projectile spectator:

- trigger level centrality selection
- event-by-event fluctuations
- reconstruction of the reaction plane

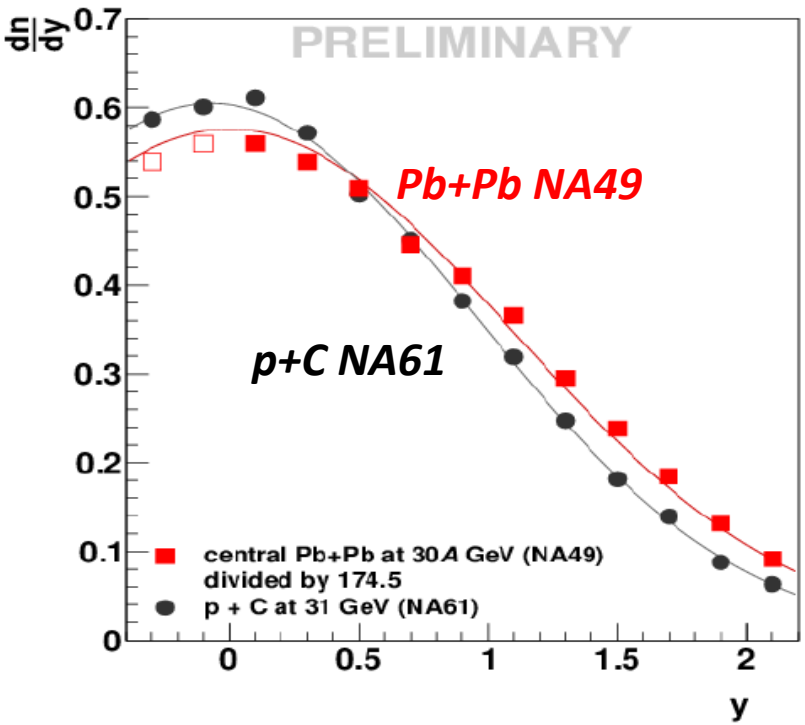
High energy resolution: 55%/√E+2% Resolution of ±1 nucleon

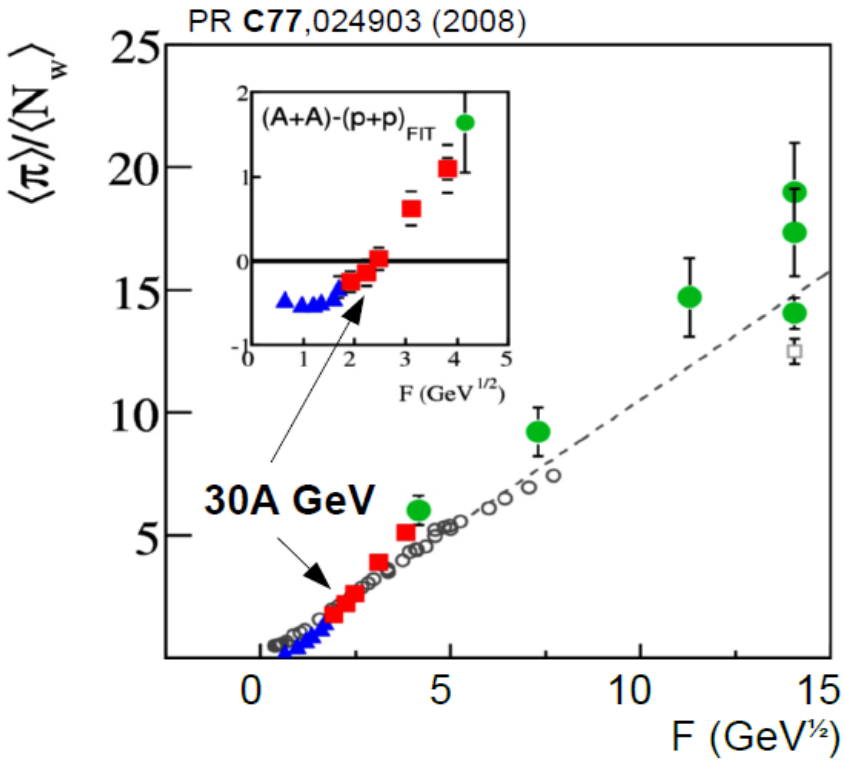
Compensating calorimeter. Pb/Scintillator (4/1) sandwich



π^- from p+C at 31 GeV/c

rapidity spectrum





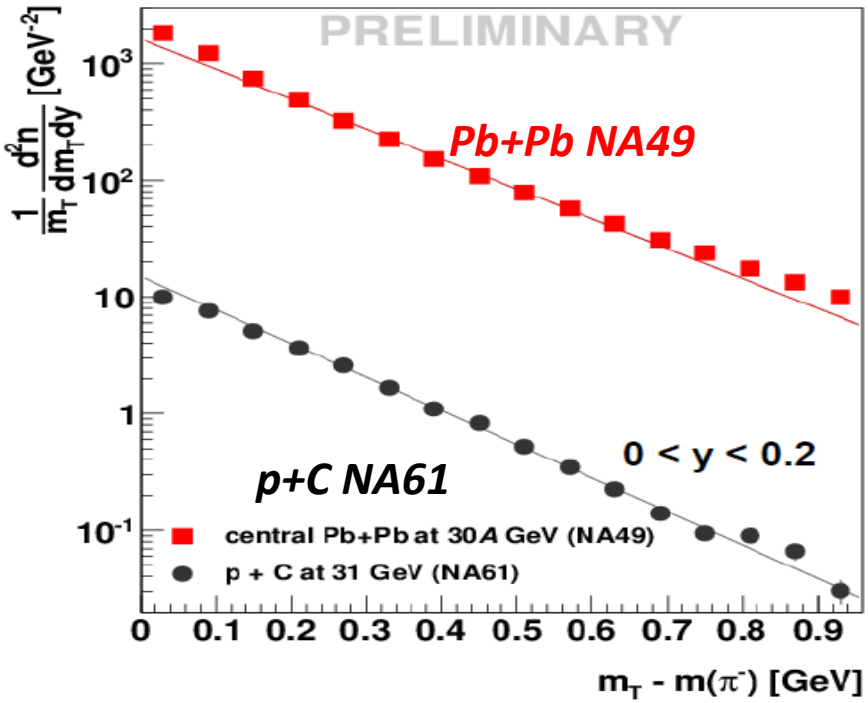
✓ p+C at 31 GeV/c data taken in 2007 pilot run

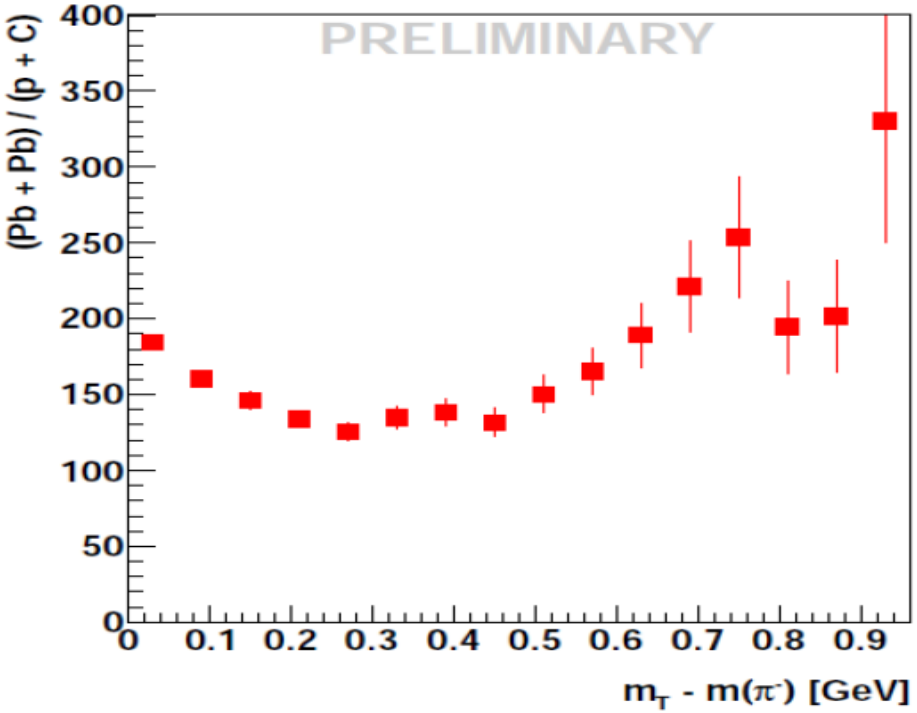
- p+C: projectile-target asymmetry: spectra shifted towards target rapidity

- Pb+Pb points are divided by the number of wounded projectile nucleons
  NA61 points at the energy of the onset of the deconfinement confirm approximate proportionality of the π yield to the mean number of wounded nucleons

π^- from p+C at 31 GeV/c

transverse mass spectrum

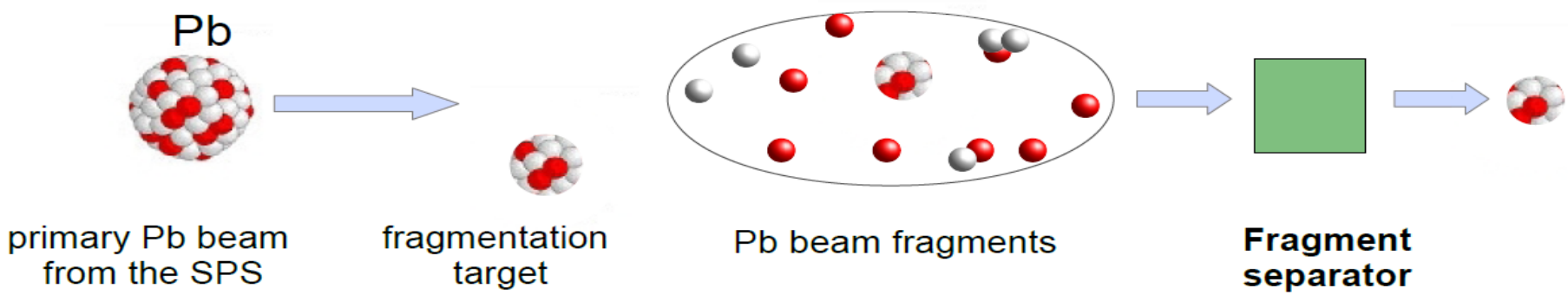




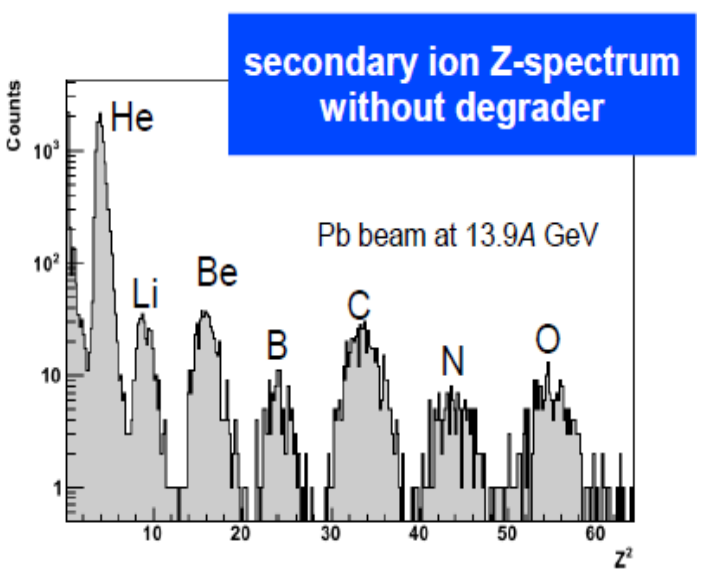
- Shape of m_T spectra at mid-rapidity change form convex in *p+C* to concave in central *Pb+Pb*

- According to hydrodynamical model this is due to strong radial collective flow in Pb+Pb collisions which is absent in p+C collisions.

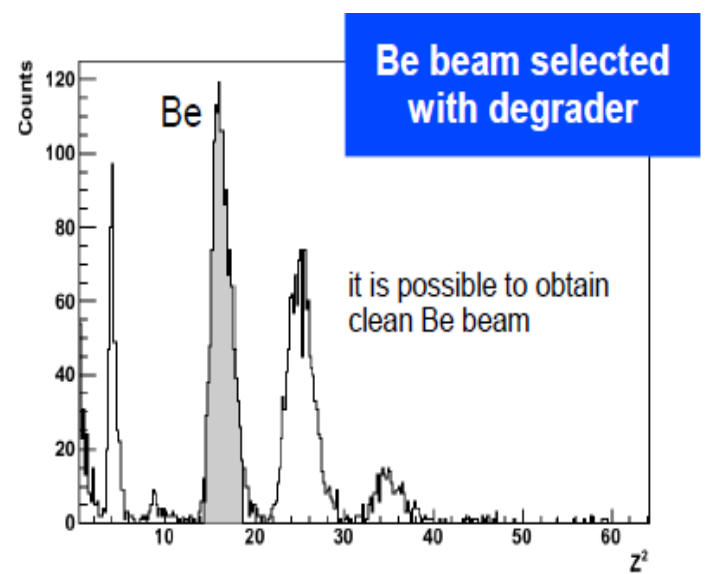
Secondary ion beam



- **Fragmentation target** length optimized to maximize the needed fragment production
- double **magnetic spectrometer** separate fragments according to the selected magnetic rigidity
- **Degrader**, Cu plate where ions lose energy (dE/dx ~Z^2): allows to reach required beam purity



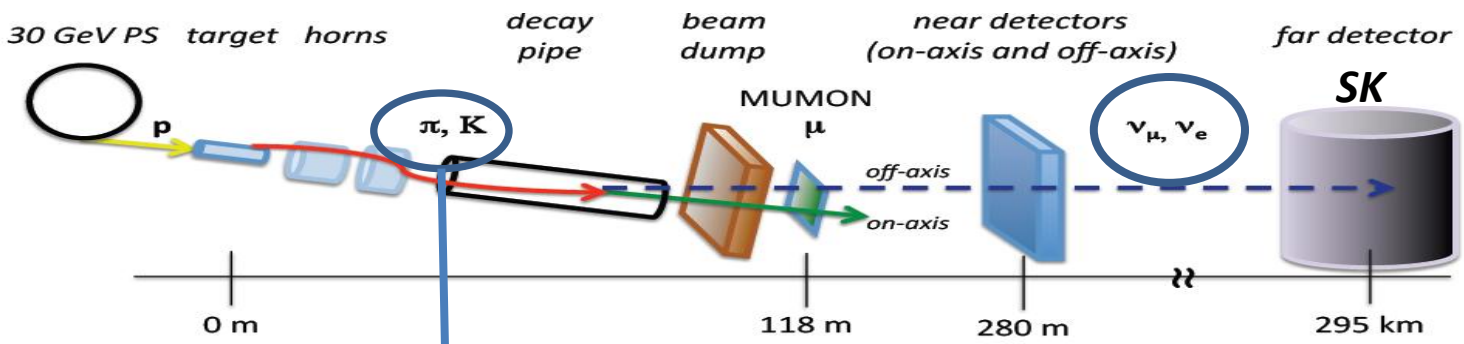
2010 Test :
Successful data taking with secondary Be beam (40A, 75A, 150A GeV/c) from fragmentation of primary Pb beam.

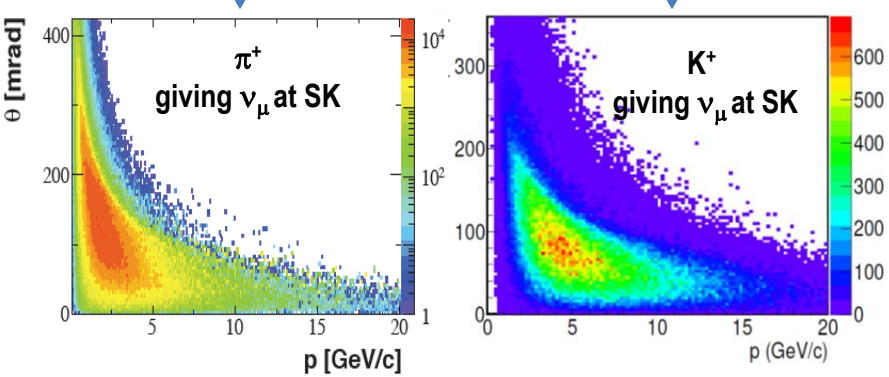


T2K neutrino oscillation experiment

Main physics goal:
measurement of the last unknown neutrino flavor mixing angle ϑ_{13}

Observe the oscillation
$\nu_\mu \rightarrow \nu_e$ (ν_e appearance)



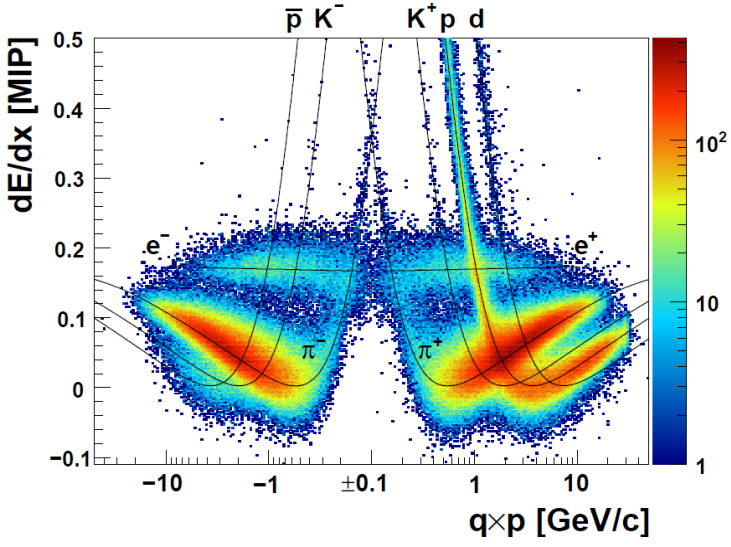


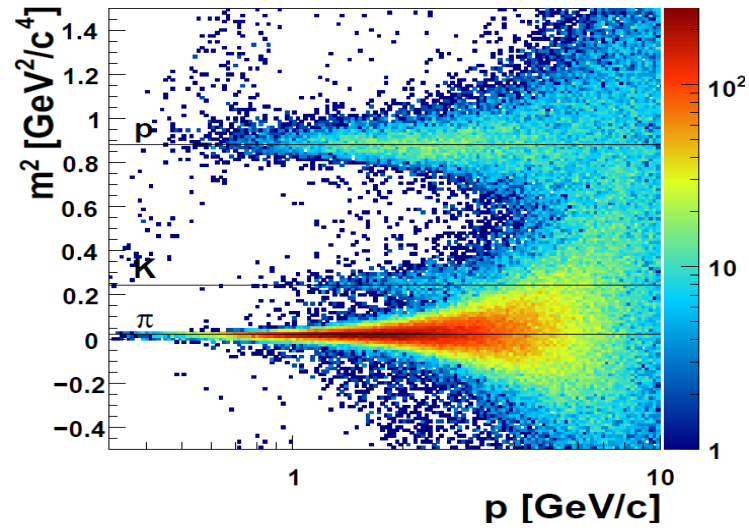
High precision data on
Pion and Kaon
production in the T2K target needed to determine the initial neutrino flux

Proton production important to measure reinteractions in the target

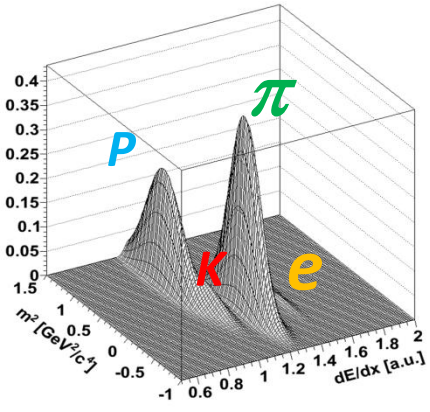
NA61/SHINE Particle Identification

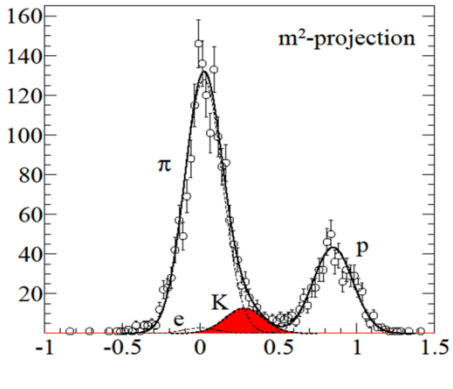
***dE/dx or dE/dx+ToF* information needed for particle identification over a wide momentum range**

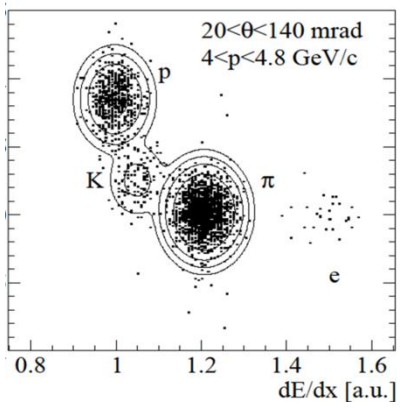


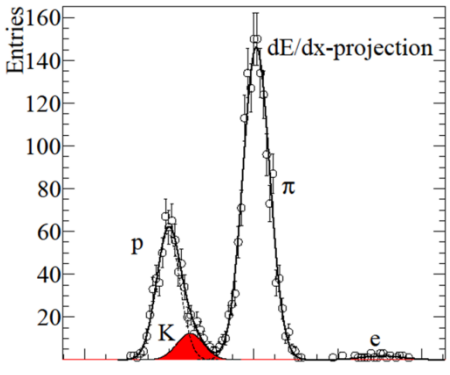


p+C @ 31 GeV/c (2007 pilot run)





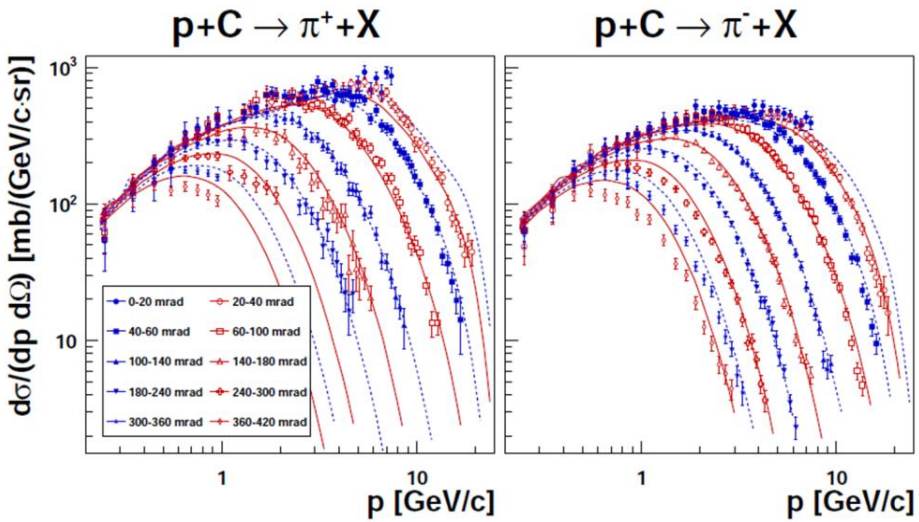




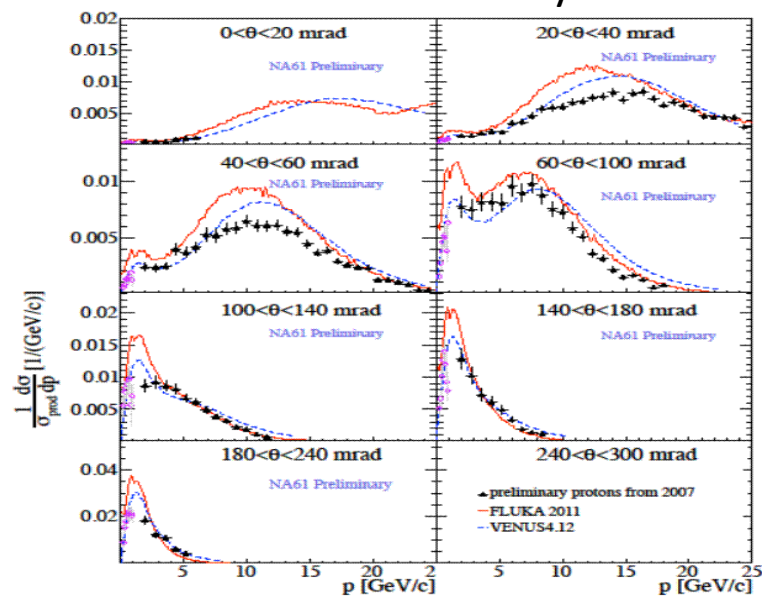
Results on hadroproduction

Data: p+C at 31 GeV/c.

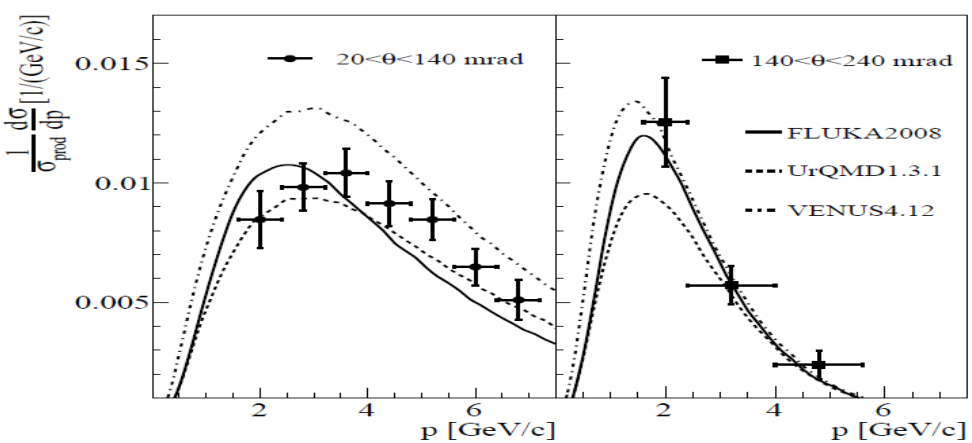
$\pi^{\pm}$ *Phys. Rev. C 84 (2011) 034604*



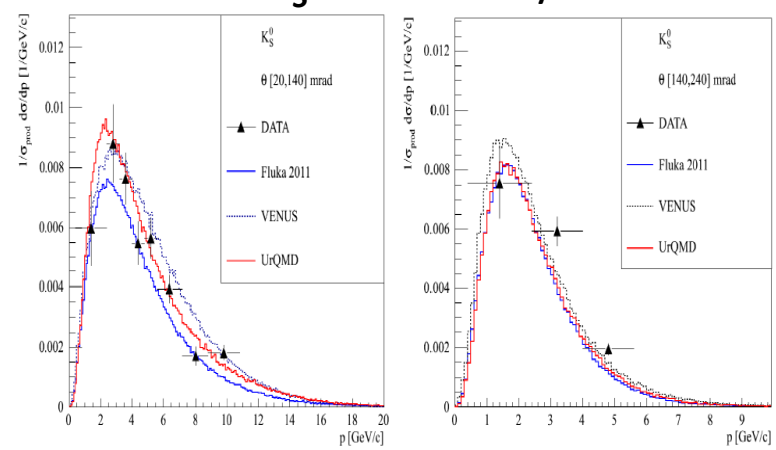
Protons. Preliminary



K^+ *Phys. Rev. C 85 (2012) 035210*



K^0_S. Preliminary



Summary

Ion program:

- p-p energy scan completed
- Be-Be to be completed in 2012: successful secondary ion beam
- Next: Ar and Xe primary ion beam scan

Future plans:

- measurement of open charm production
- Pb+Pb energy scan: improve NA49 measurement with high precision NA61 measurements

Neutrino program:p+C 31 GeV/c

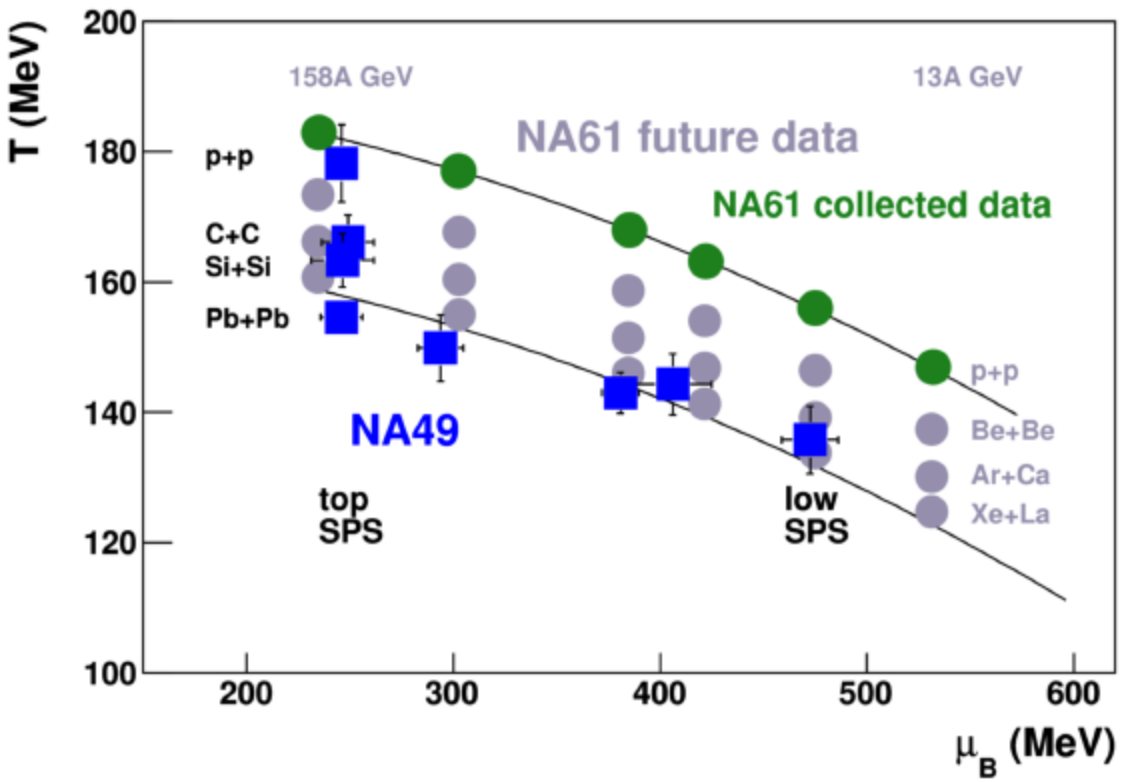
- $\pi^{\pm}$, K^{+} production cross sections
- p, K^{0}:preliminary
- ongoing analysis on high statistics runs

Backup slides

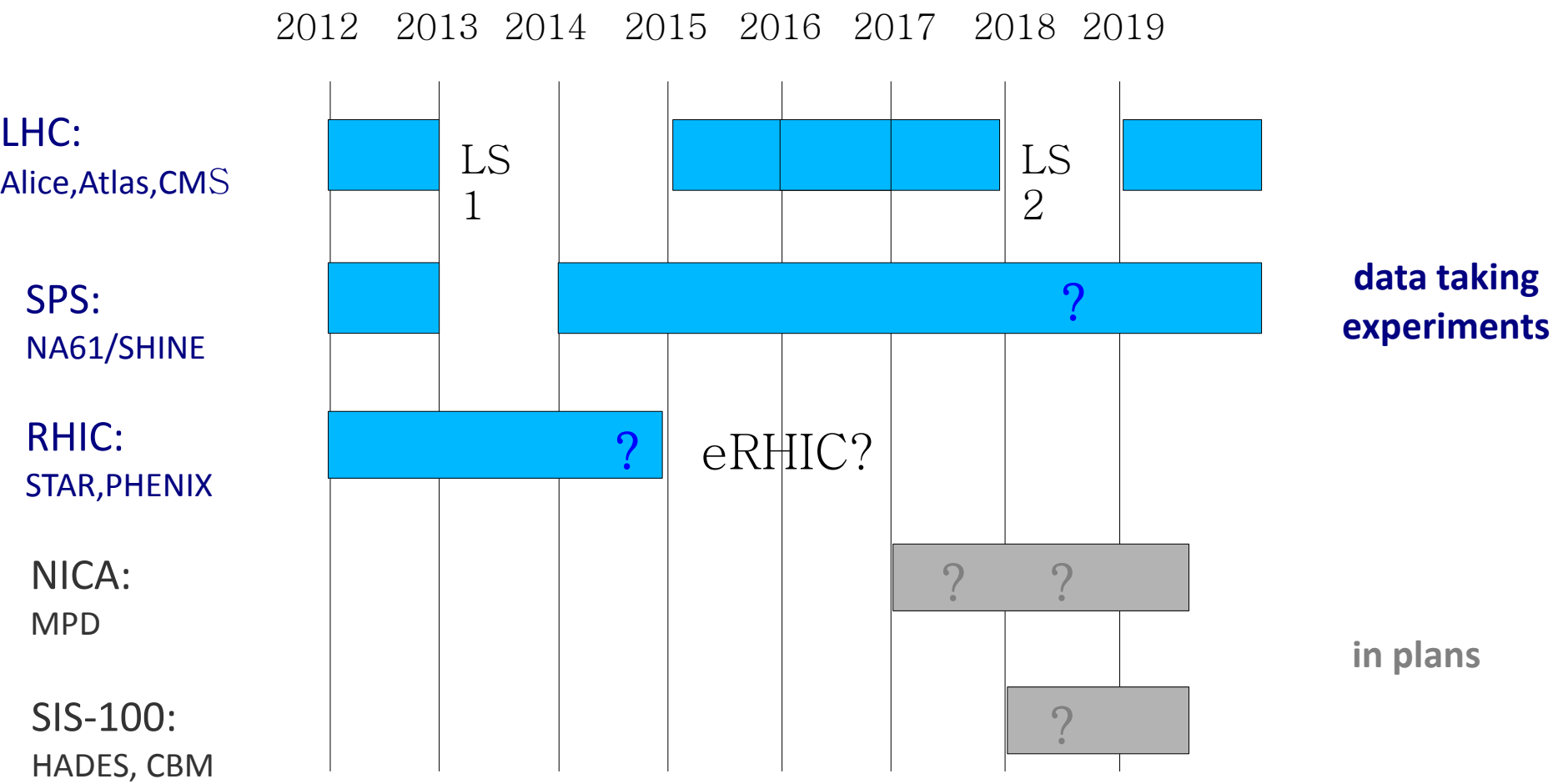
NA61/SHINE Heavy Ion Program

Study of the properties of the Onset of the Deconfinement, establishing the system size dependence of its signals

Search for the Critical Point of strongly interacting matter by studying the system size and collision energy dependence of hadron fluctuations and correlations

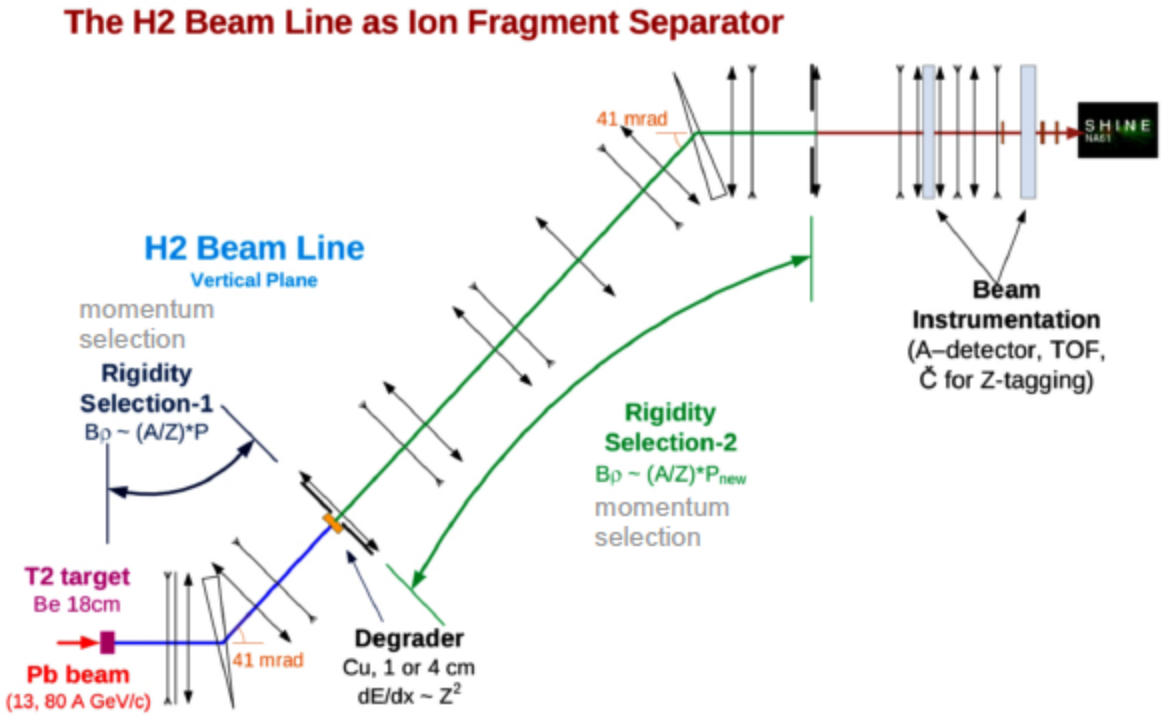


Global plans for data taking on high energy nucleus-nucleus collisions



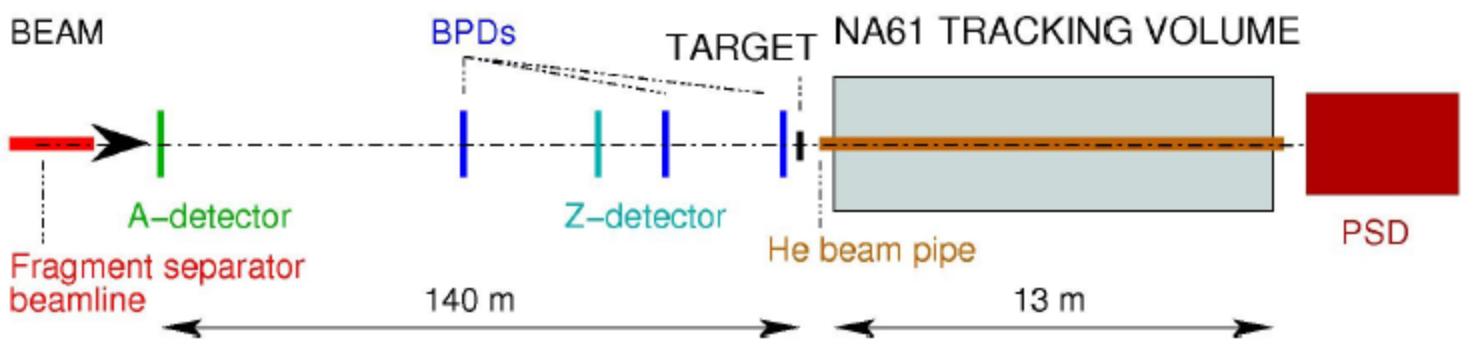
In near future NA61/SHINE may remain the only large acceptance hadron spectrometer at the non-LHC energies

Secondary Ion beam line for NA61



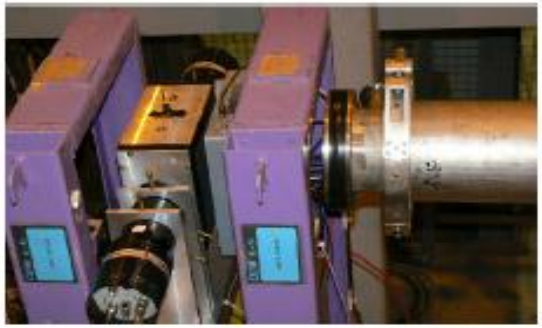
- Double magnetic spectrometer to separate ion fragments corresponding to selected magnetic rigidity Bρ
- Fragmentation target (T2) length optimized to the desired fragment production
- Degrader (Cu plate where ions lose energy dE/dx ~ Z^2) allow to reach required beam purity

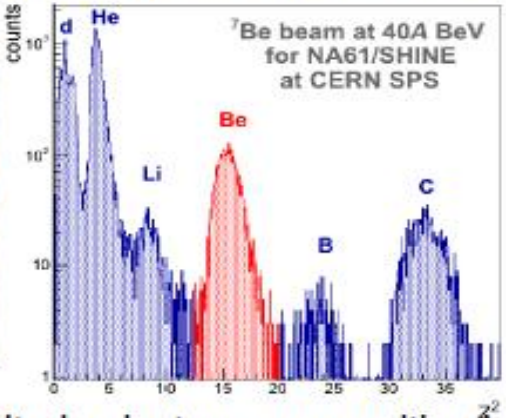
Tested in 2010 for 13.9*A* and 80*A* GeV Pb ion beams



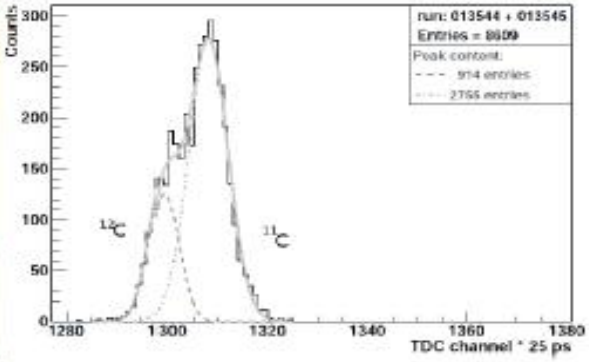
Recent important upgrades – Z and A detectors (2011)

- For secondary ion beams, triggering on charge of beam nucleus is necessary.
- Constructed Z-detectors (gas and quartz Cerenkov, sensitive to Z^2):





- For secondary ion beams, monitoring isotope composition is necessary (given the Z).
- Constructed diagnostic A-detector (ToF on 140m) to monitor purity:



Recent important upgrades – Low Momentum Particle Detector (2011)

- Counts number of low momentum protons in h+A collisions for centrality determination ("target spectator detector").
- Two small size TPCs with 4 absorber layers. PID + momentum determination by $\mathrm{d}E/\mathrm{d}x$ + range measurement.