Recent results from NA61/SHINE

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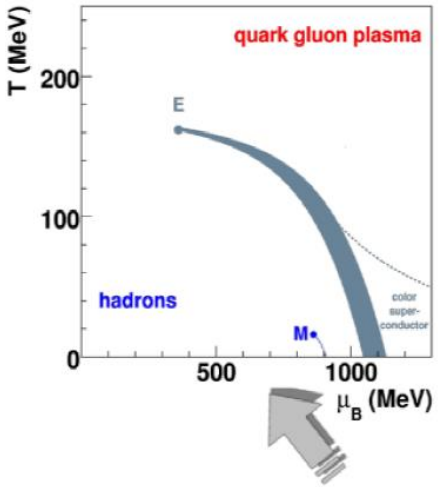
NA61/SHINE – few facts

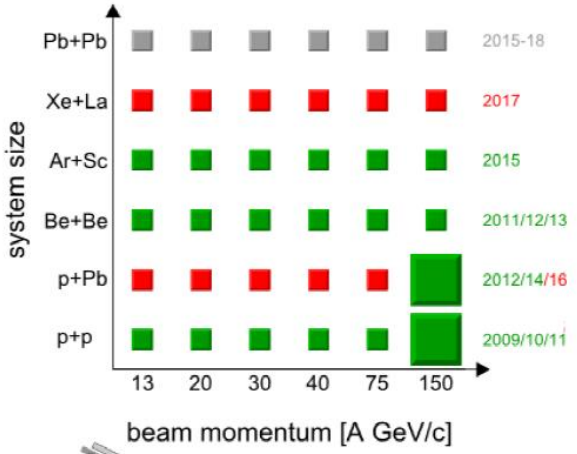
- Located at the CERN SPS
- Successor of NA49
- Large acceptance spectrometer for fixed target experiment on primary (ions) and secondary (ions, hadrons) beams
- Data taking since 2009
- NA61/SHINE is the second largest non-LHC experiment at CERN

Physics program

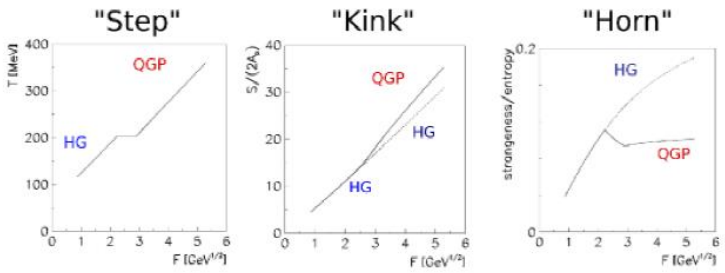
- **Strong interactions program**
  - **search for the critical point of strongly interacting matter**
  - **study of the properties of the onset of deconfinement**
  - **study high p_T particles production (energy dependence of nuclear modification factor)**
- Hadron-production measurements for neutrino experiments
  - reference measurements of p+C interactions for the T2K experiment for computing initial neutrino fluxes at J-PARC
- Hadron-production measurements for cosmic ray experiments
  - reference measurements of p+C, p+p, π+C, and K+C interactions for cosmic-ray physics (Pierre-Auger and KASCADE experiments) for improving air shower simulations

NA61/SHINE 2D scan goals



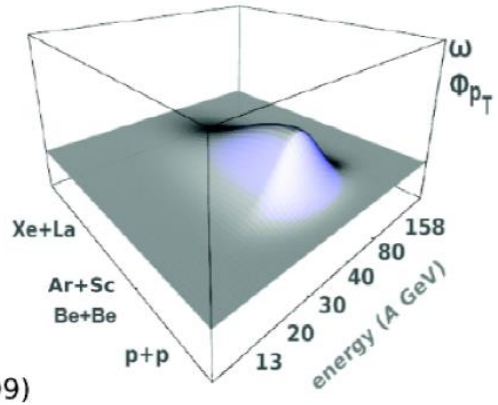


Statistical Model of the Early Stage (SMES)



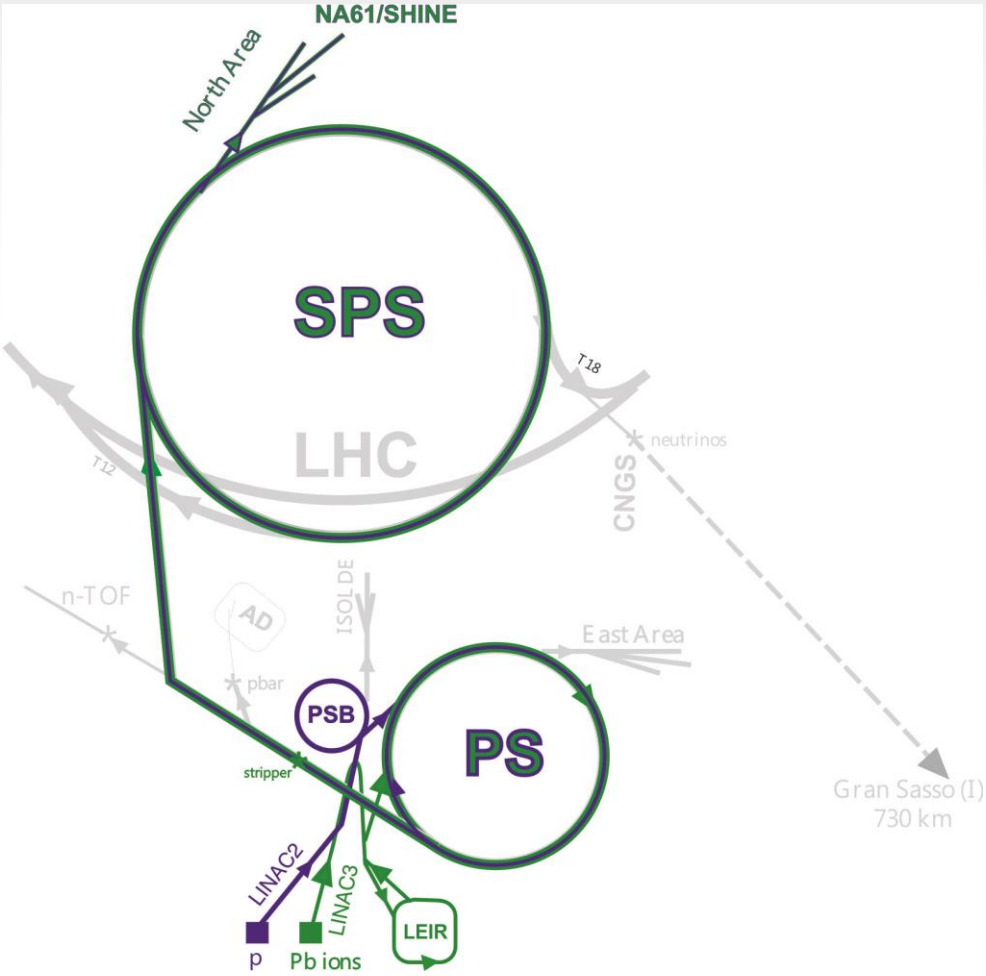
$F \approx \sqrt[4]{s_{NN}}$

Gaździcki, Gorenstein, Acta Phys. Polon. B30, 2705 (1999)



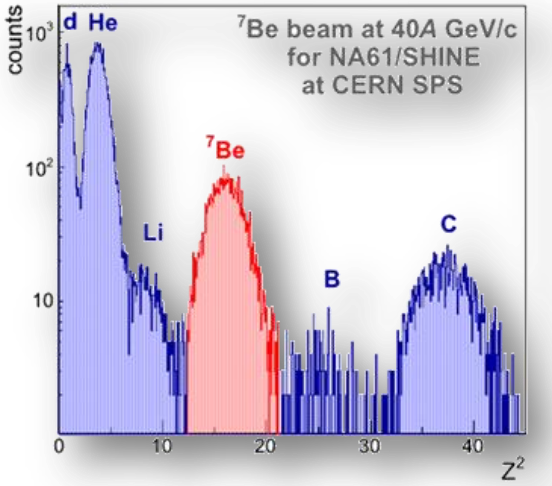
Facility

Beams for NA61/SHINE



Available beams:

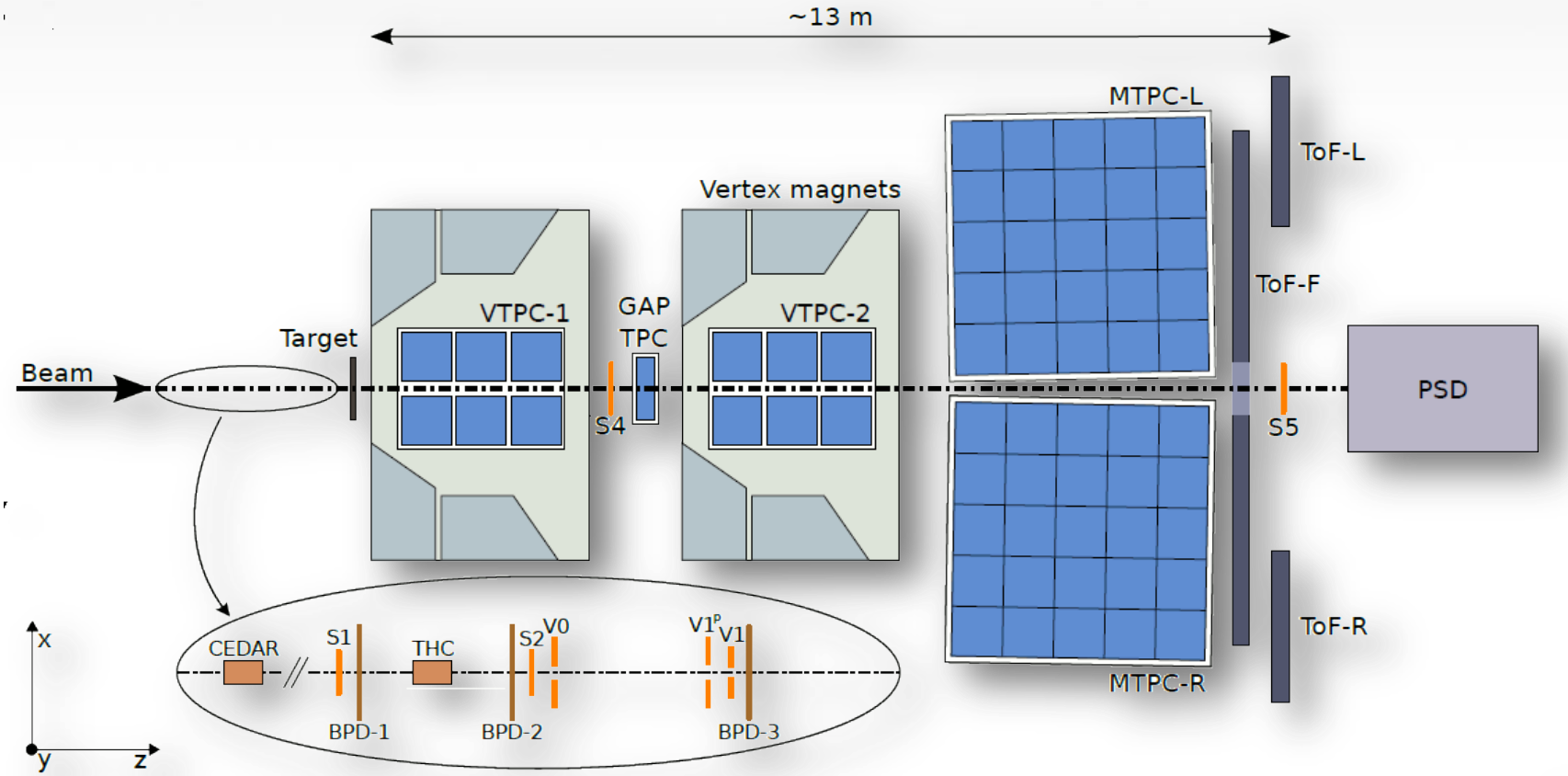
- Primary ions (13A - 158A GeV/c):
  - Argon
  - Xenon
  - Lead
- Secondary:
  - hadrons (p,$\pi^{\pm}$, $K^{\pm}$) 13 - 350 GeV/c
  - ions (Be, . . .) 13A - 150A GeV/c



Secondary ion beam composition
(Pb fragmentation on Be target)

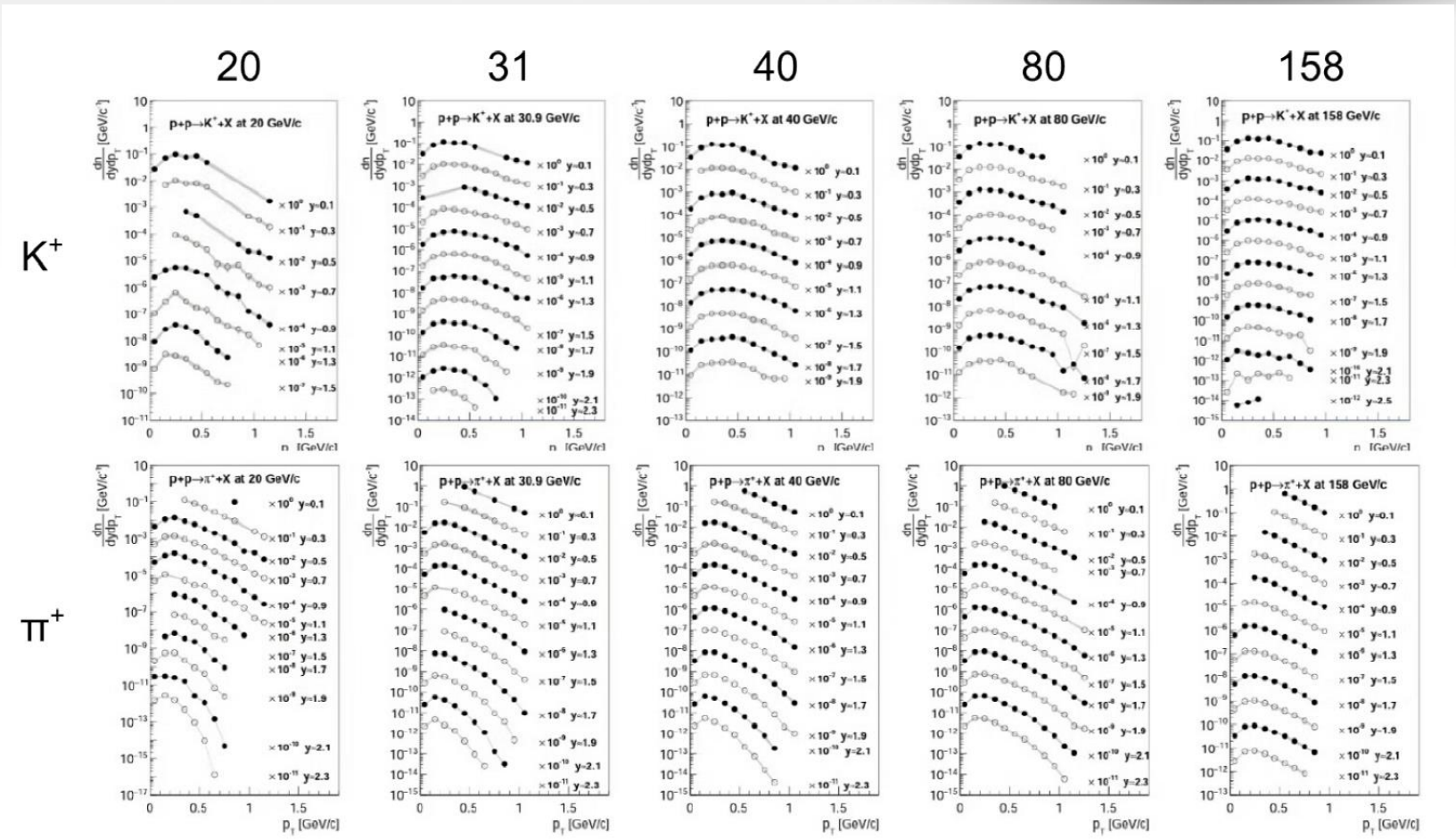
Experimental layout

Unique, multi-purpose facility to study hadron production in hadron-proton, hadron-nucleus and nucleus-nucleus collisions at the CERN SPS

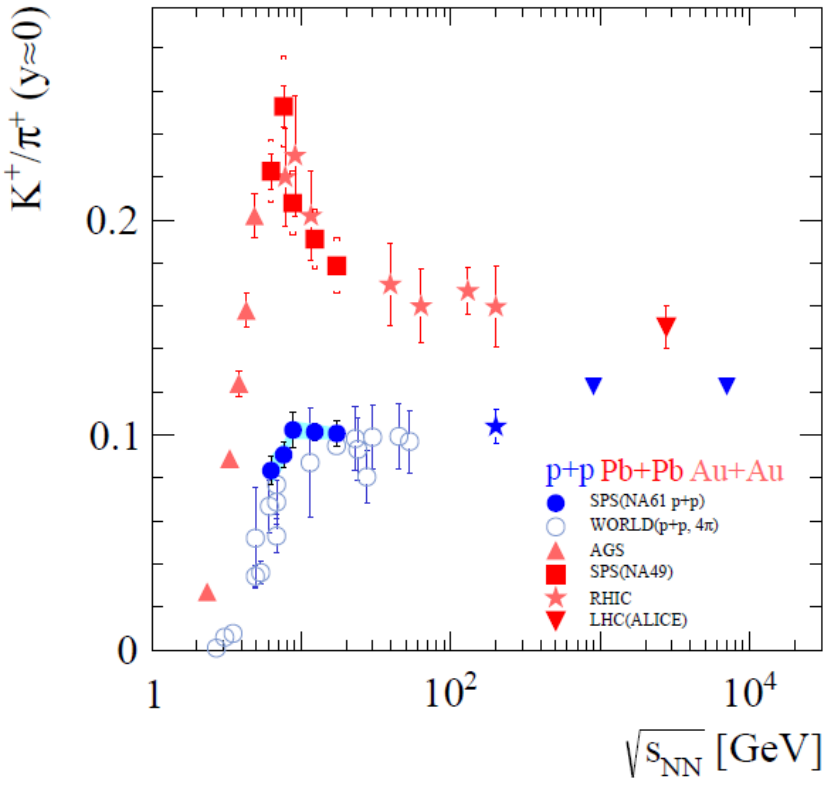


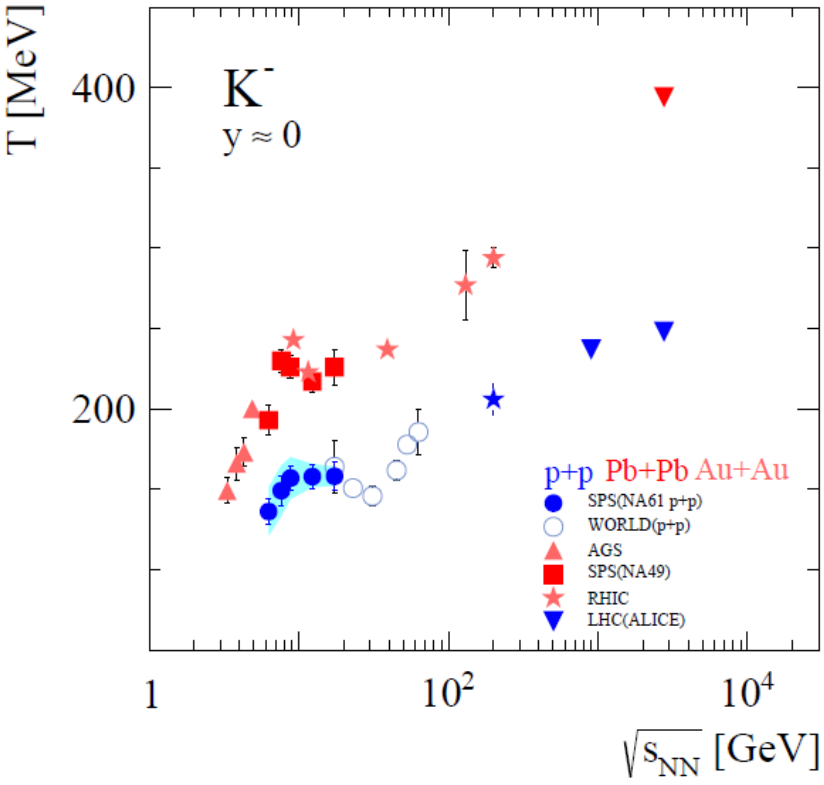
Single particle spectra in p+p

Single particle spectra from p+p interactions



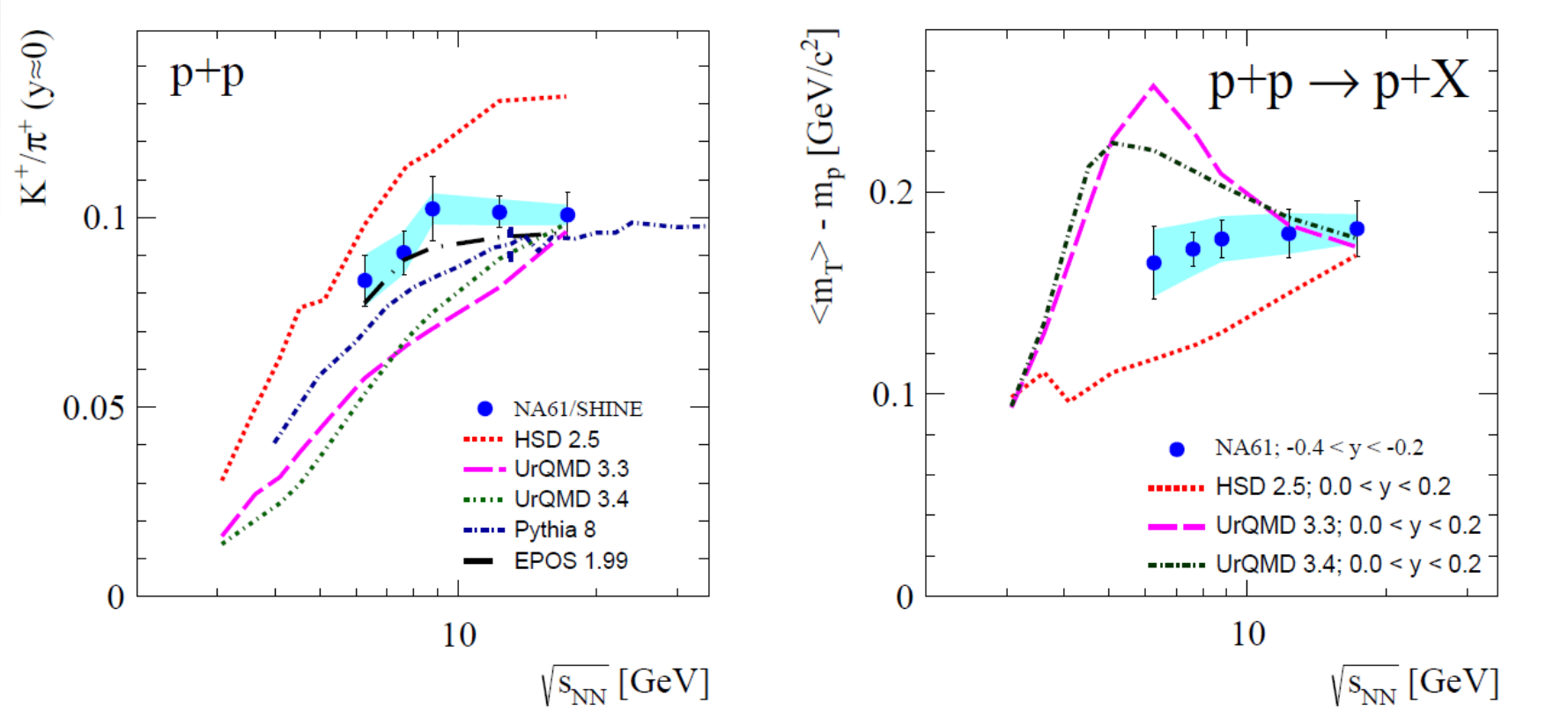
Rapid changes in p+p at SPS





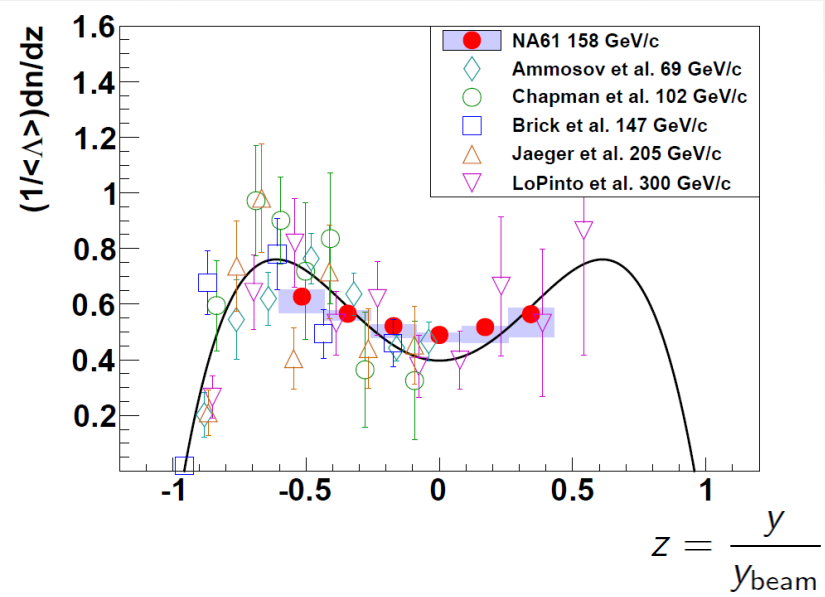
K^+/π^+ ratio and inverse slop parameter of m_T spectrum of K^- exhibits rapid changes in the SPS energy range

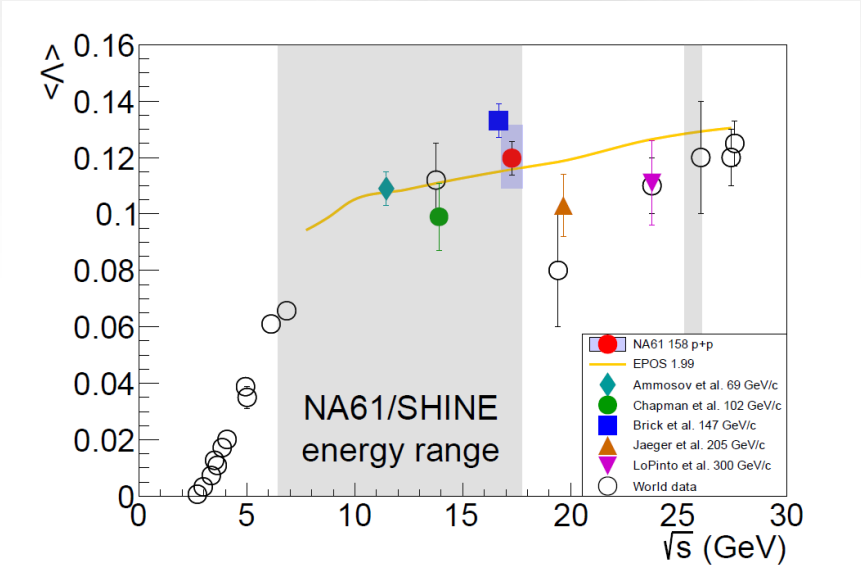
Rapid changes in p+p at SPS – comparison with models



Monte-Carlo models provide poor description of data

Λ spectra in p+p at 158 GeV/c





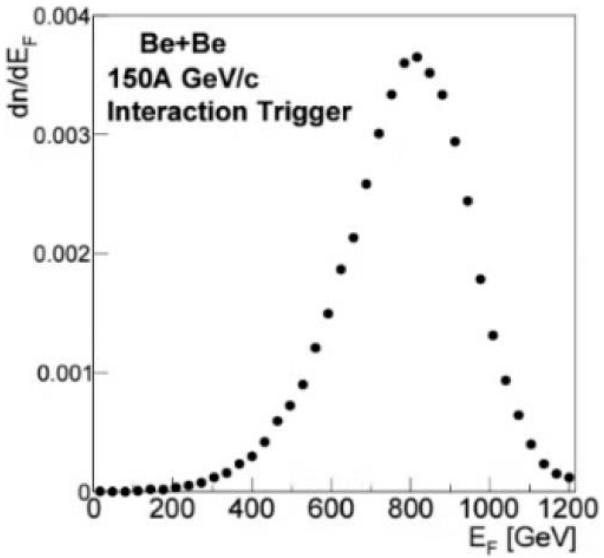
- NA61/SHINE results are consistent with world data
- Other NA61/SHINE energies – work in progress

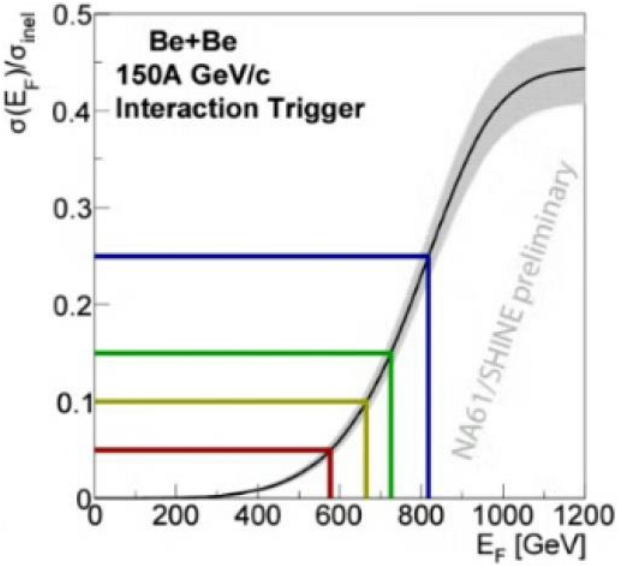
Single particle spectra in Be+Be

Centrality selection in ion collisions

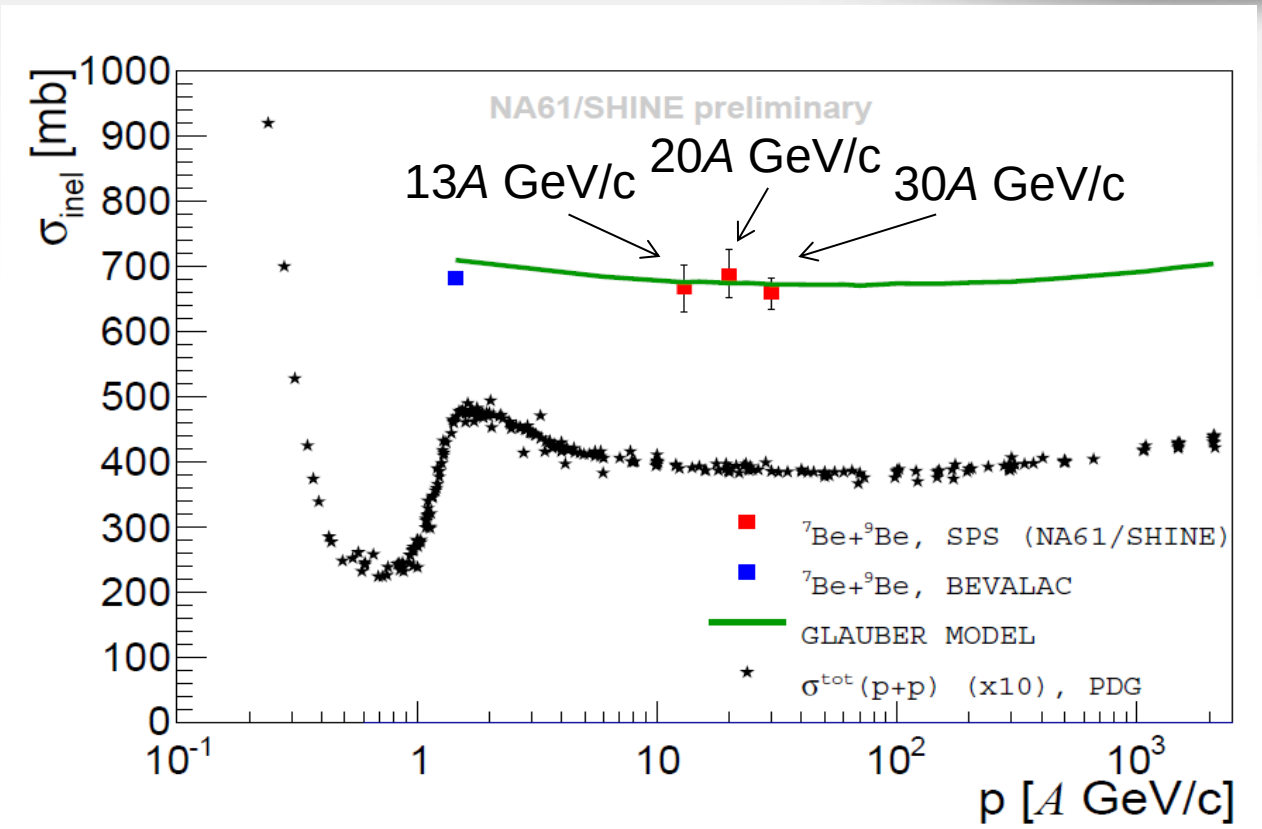
- PSD (Projectile Spectator Detector) is located on the beam axis and measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus
- Cuts on E_F allows to select different centrality classes
- Four event classes

0 - 5% **5 - 10%** **10 - 15%** **15 - 25%**



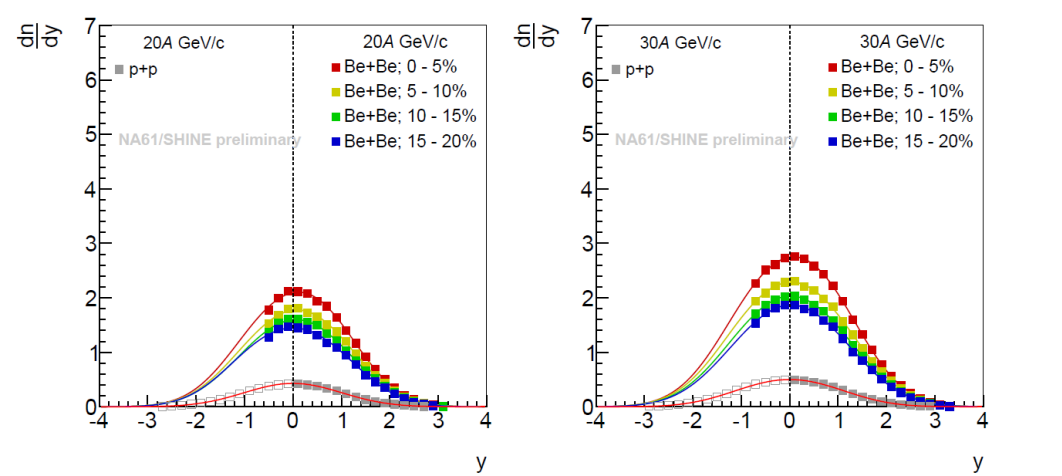


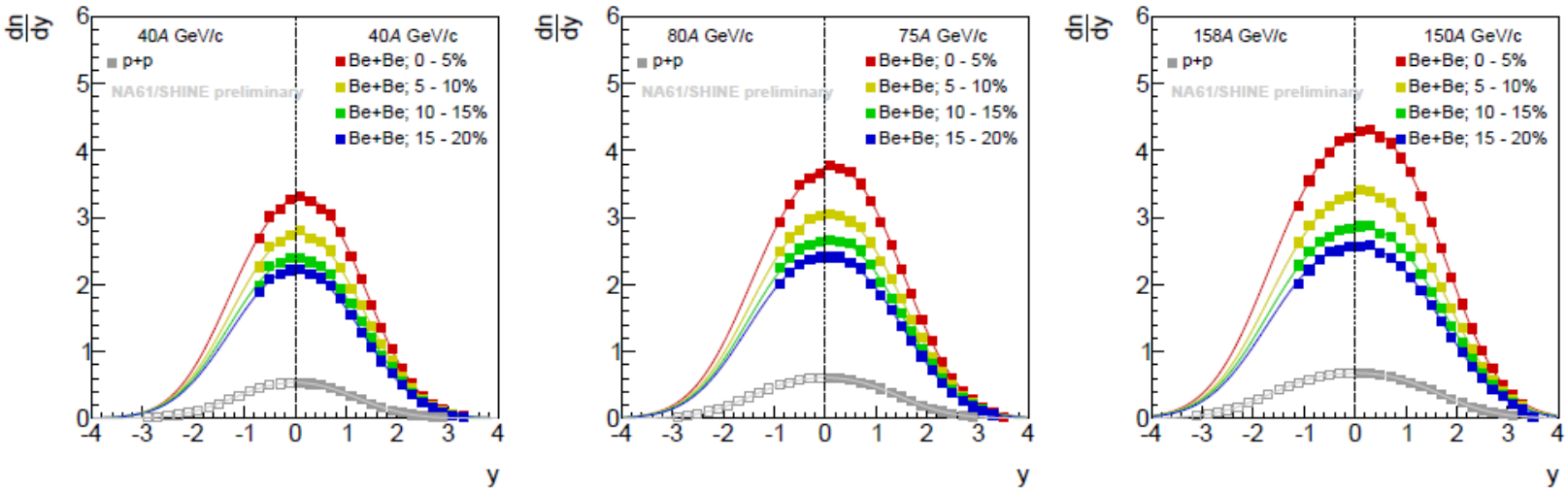
Inelastic ^{7}Be+^{9}Be cross section



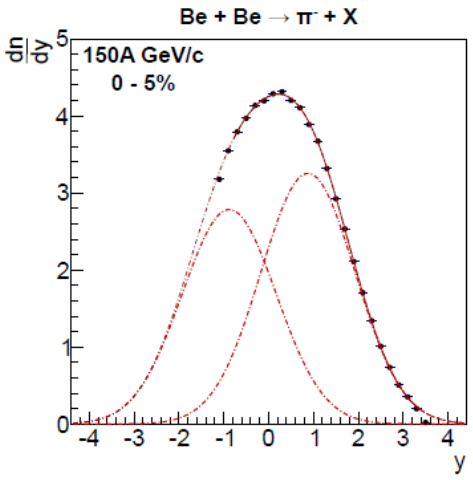
- NA61 measurements together with 1*A* GeV/c Bevalac data established energy dependence of the inelastic cross section

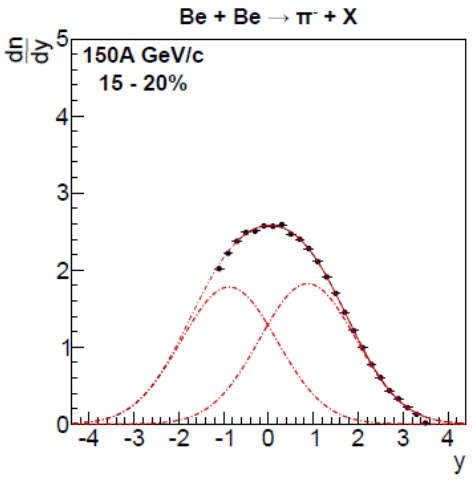
Rapidity distributions

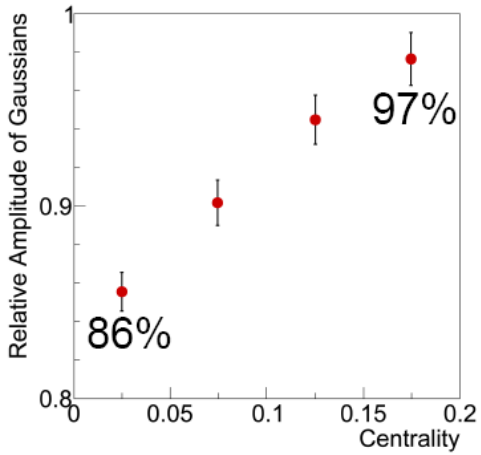




Asymmetry in π^- distributions in $^7Be+^9Be$

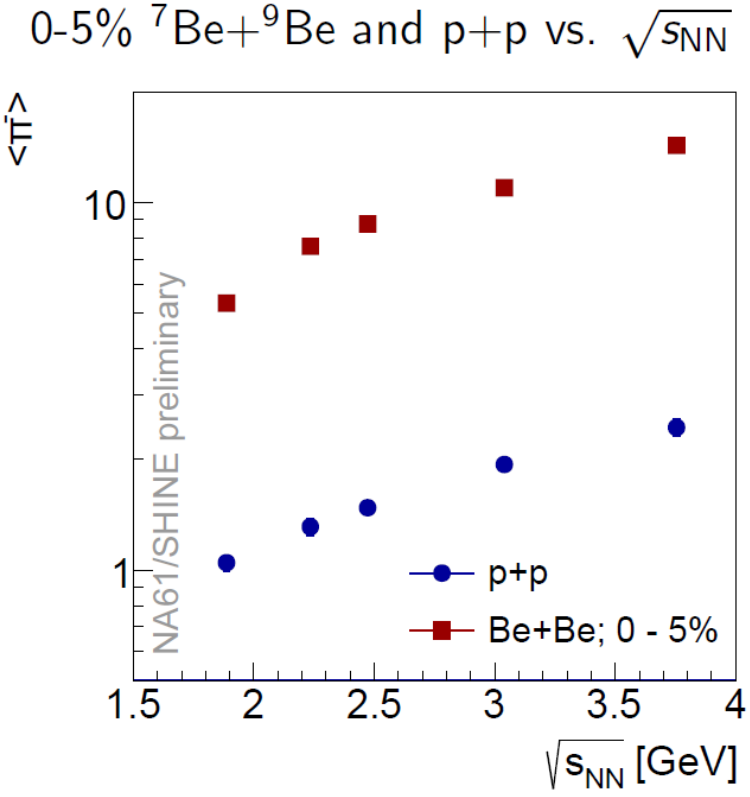


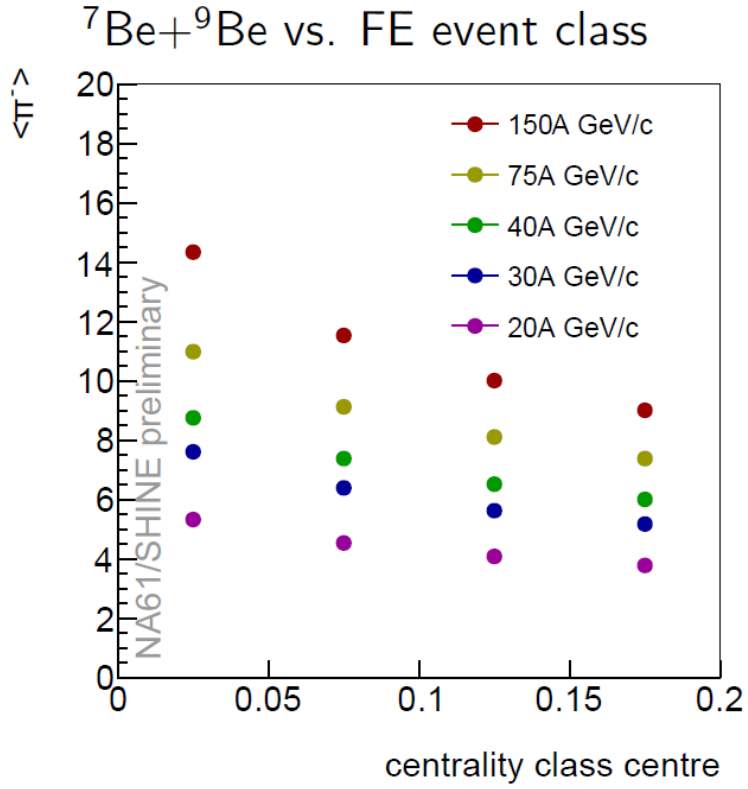




- Fitted: double Gaussian function symmetrically displaced from mid–rapidity (both Gaussians have the same width, but they differ in amplitude)
- Asymmetry decreases from 0.86 (0-5%) to 0.97 (15-20%)
- Two opposite effects influence asymmetry of the spectra:
  - asymmetric system ^7Be projectile on ^9Be target (small effect),
  - centrality selection based on projectile spectators (large effect).

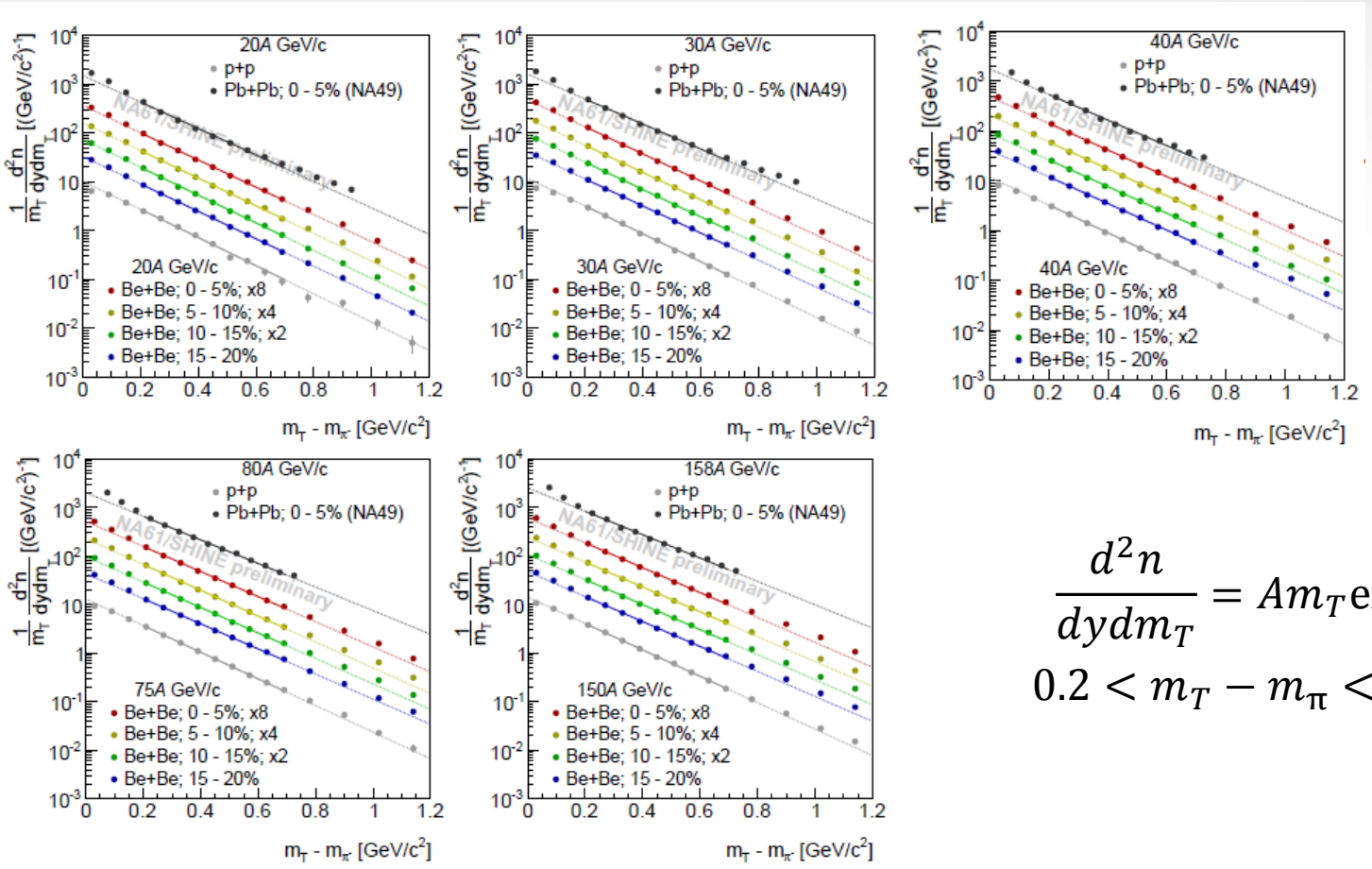
Mean multiplicities of π^- in ^{7}Be+^{9}Be





NA61/SHINE p+p results published in Eur.Phys.J. C74 (2014) 2794

Transverse mass spectra of π^-



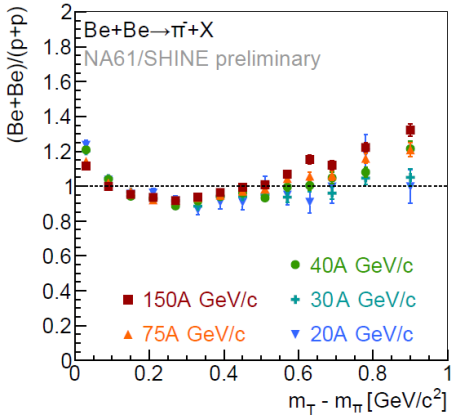
$$\frac{d^2n}{dydm_T} = Am_T \exp\left(\frac{-m_T}{T}\right)$$

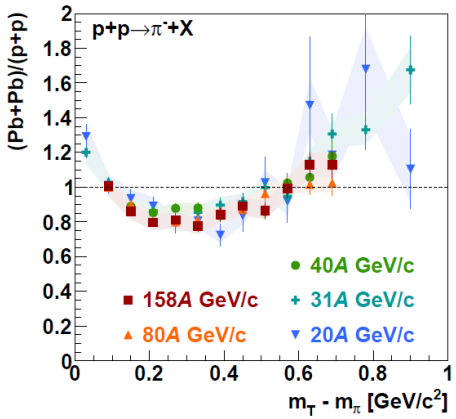
$$0.2 < m_T - m_\pi < 0.7\, GeV/c^2$$

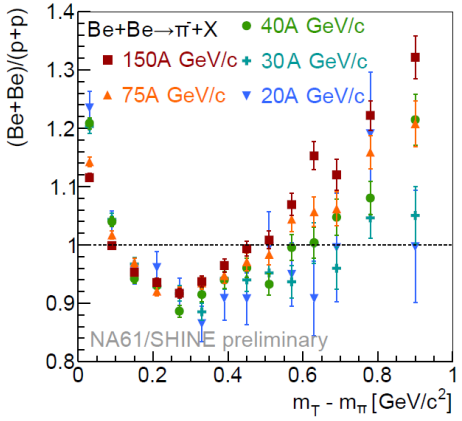
Comparison of π^- transverse mass spectra

- Ratio of normalized m_T spectra at different energies allows to compare shape of the spectra

- From $m_T - m_{\pi^-} > 0.3$ GeV/c^2 the ratio increases with beam momentum
- Up to $m_T - m_{\pi^-} < 0.3$ GeV/c^2
- the ratio decreases with beam momentum
- The beam momentum dependence of the ratio observed in ^{7}Be+^{9}Be is not visible in Pb+Pb collisions
- The shape of the ratio indicates the presence of radial collective fow in ^{7}Be+^{9}Be
- The energy dependence of the ratio suggests that the radial ow increases with the collision energy

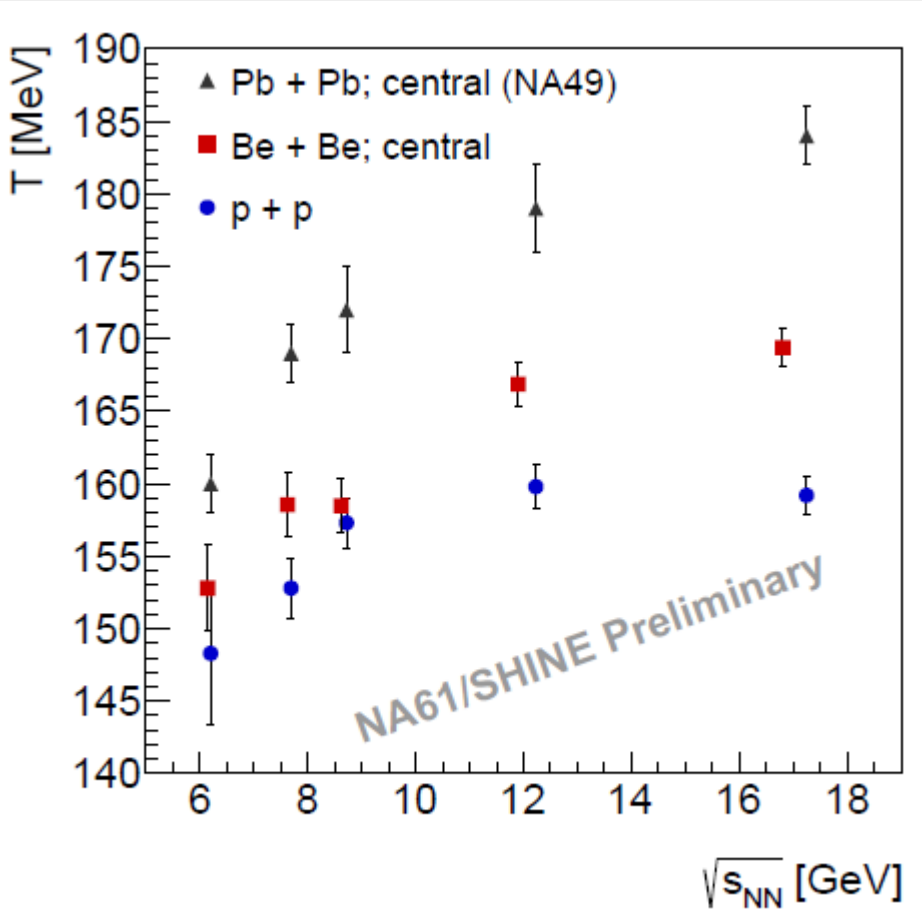






^{7}Be+^{9}Be data for 0-15% FE event class
Pb+Pb data for 5% or 7.5% most central interactions

Collective effects

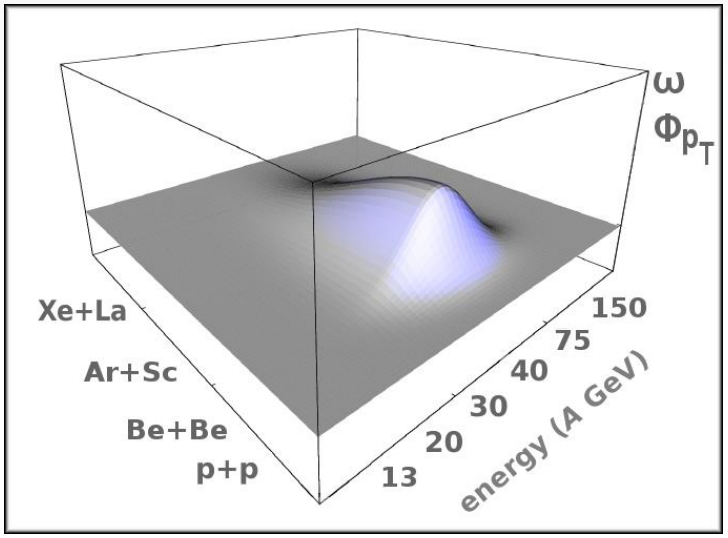


- Effect of radial flow for Pb+Pb at all energies
- Inverse slop parameter T larger in ^{7}Be+^{9}Be than in p+p → possible evidence of transverse collective flow in ^{7}Be+^{9}Be

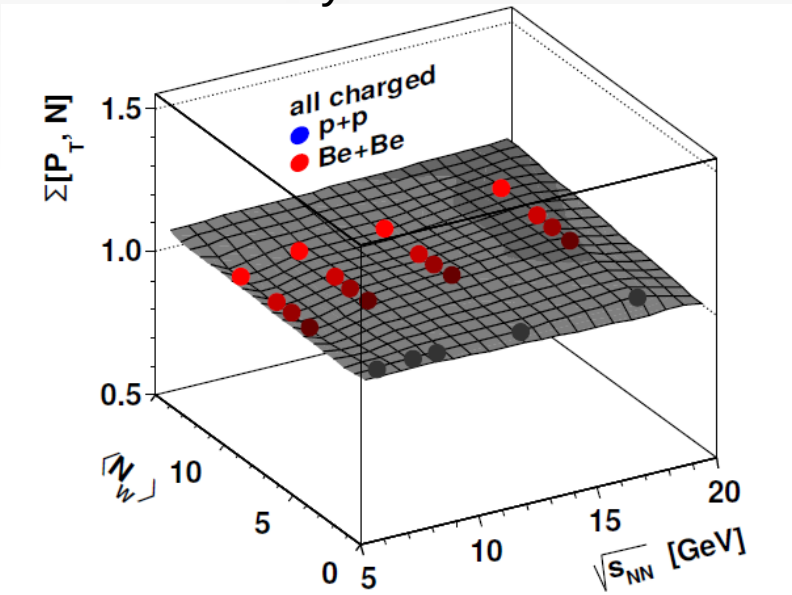
Fluctuations and correlations

Fluctuations

Theoretical fluctuations in presence of critical point

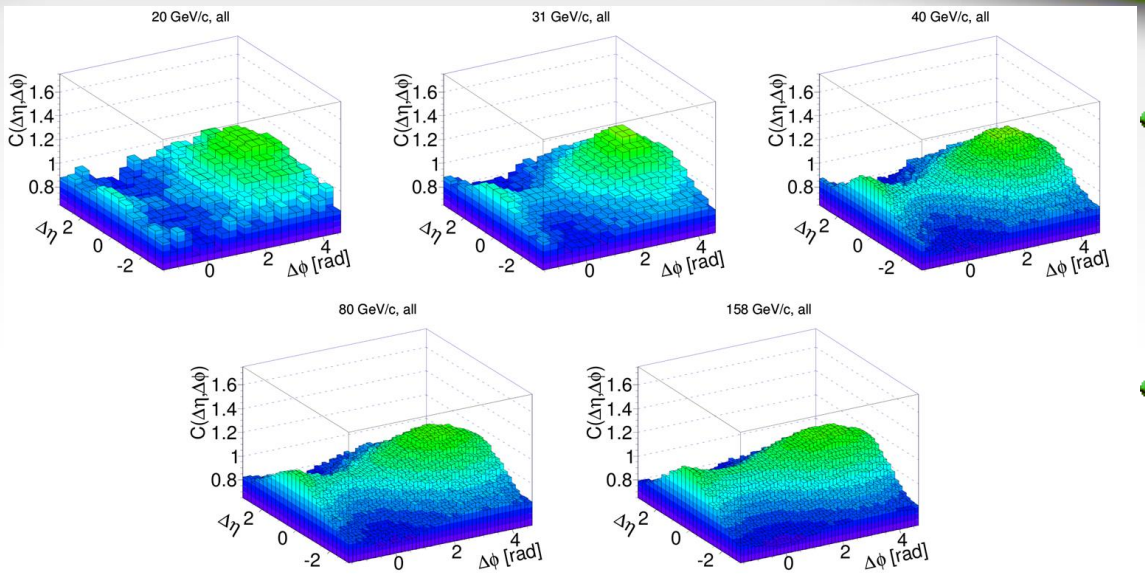


N-p_T fluctuations in p+p and centrality selected Be+Be

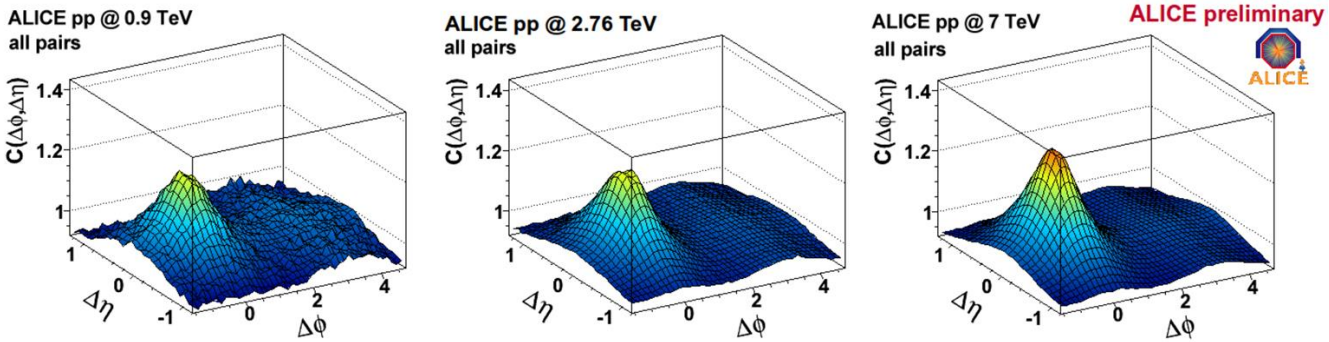


- No sign of any anomaly that can be attributed to the critical point (neither in p+p nor Be+Be)

Two-particle correlations in $\Delta\eta$, $\Delta\phi$ in p+p



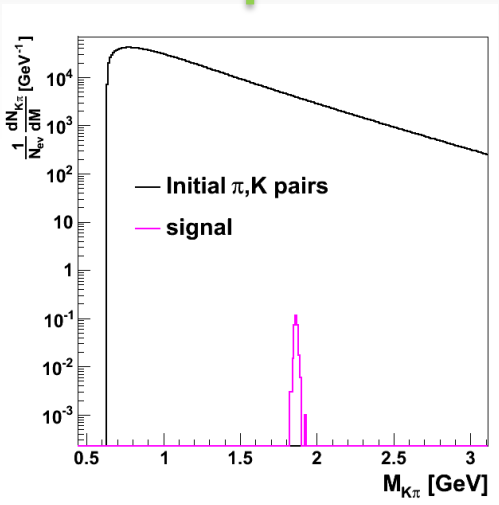
- NA61/SHINE: maximum at $(\Delta\eta,\Delta\phi) = (0,\pi)$ probably due to resonance decays and momentum conservation
- NA61 results show stronger enhancement in $\Delta\phi \approx \pi$ and no "jet peak" at $\Delta\phi \approx 0$ (in comparison with ALICE)



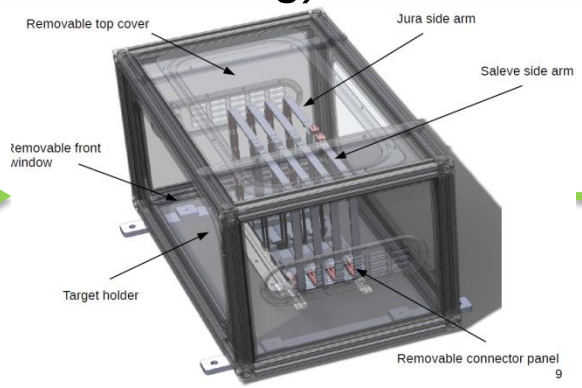
Future of NA61/SHINE

Open charm measurements

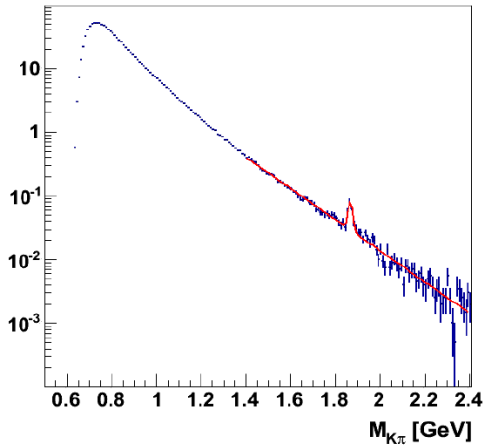
D^0 candidates selected by TPCs only



- Feasibility of the D^0 meson measurements in two body decay channel: $D^0 \rightarrow K^+ + \pi^-$, in central Pb+Pb collisions at the top SPS energy
- Simulation for 200k events (0.5 day of data taking)



D^0 candidates selected by TPCs and vertex detector



- Vertex detector:
  - four pixel detection stations
  - MIMOSA-26AHR sensor

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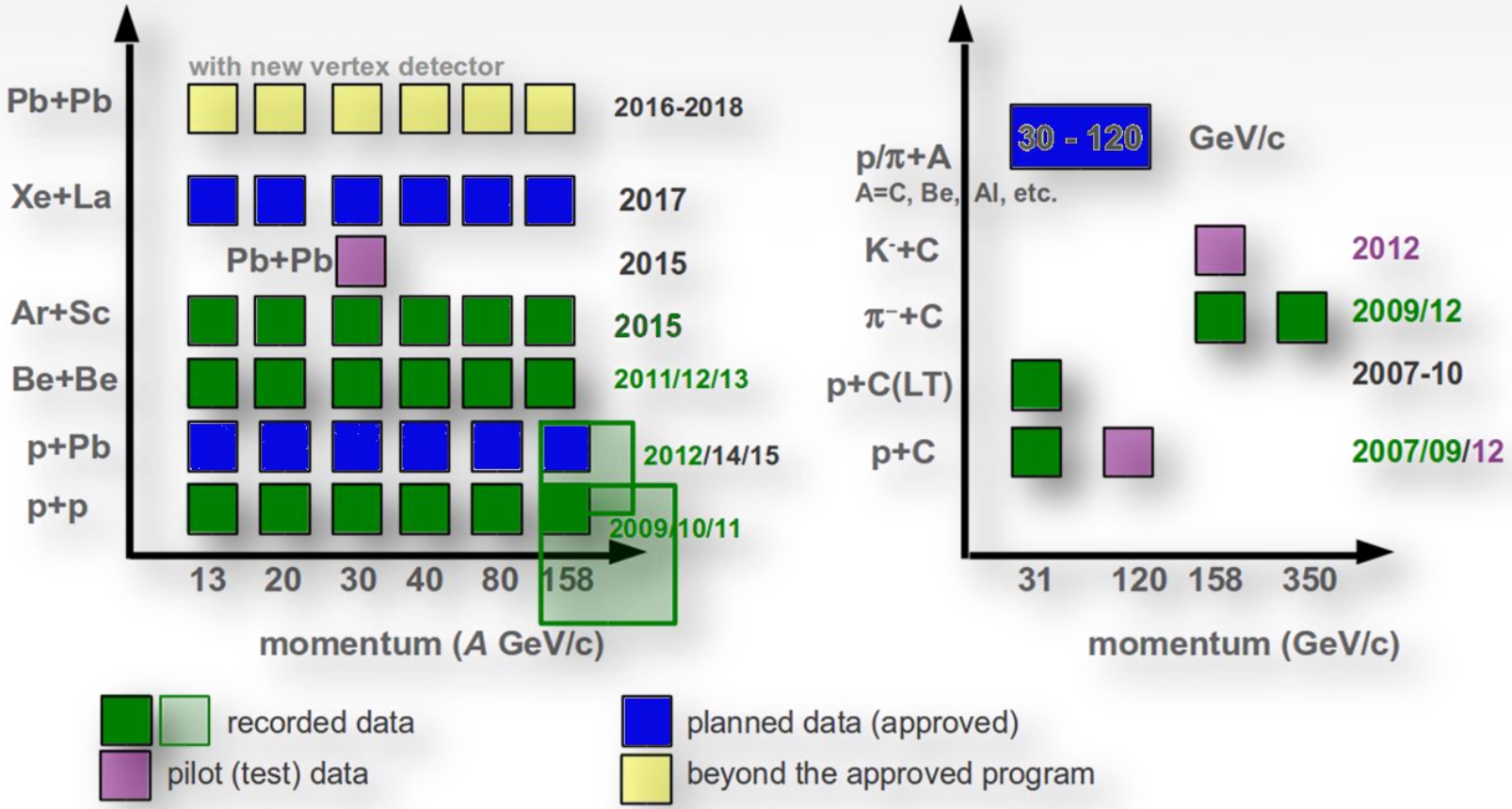
Extension of the data taking plan



Summary

- NA61/SHINE measures collisions of hadrons and ions for three physics programs: strong interactions, neutrions and cosmic ray studies in SPS energy range
- High precision double – differential pion spectra were measured in p+p and ^{7}Be+^{9}Be collisions at 5 different energies
- Rapid changes in particle production observed in p+p interactions at mid-SPS energy
- Collective effects are observed in ^{7}Be+^{9}Be reactions
- No sign of any anomaly that can be attributed to critical point in p+p and ^{7}Be+^{9}Be interactions

The Collaboration

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Joint Institute for Nuclear Research, Russia
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LPNHE-Universites Paris, France
Institute of Physics, University of Silesia, Poland
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National Center for Nuclear Research, Poland
St. Petersburg State University, Russia
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Institute of Physics, Jan Kochanowski University, Poland
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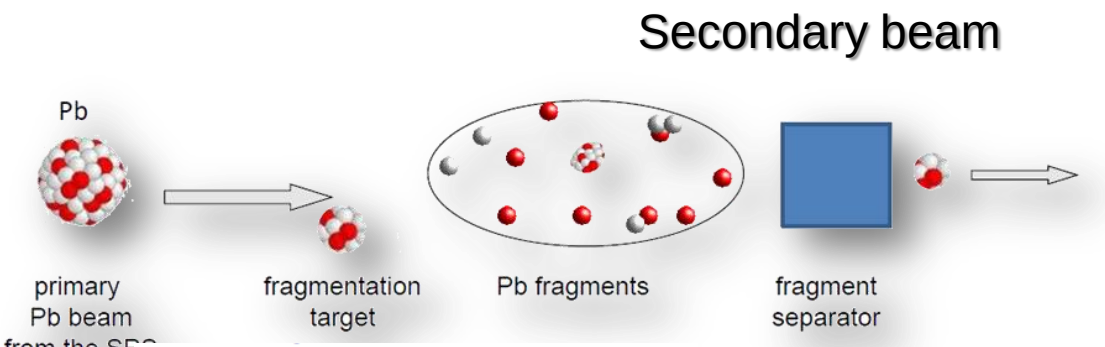
THANK YOU

BACKUP SLIDES

Secondary beryllium beam

- Fragmentation target length optimized to maximize the production of the desired fragment
- Double magnetic spectrometer separates fragments according to the selected magnetic rigidity
- Possible to use degrader, Cu plate where ions lose energy according to the charge



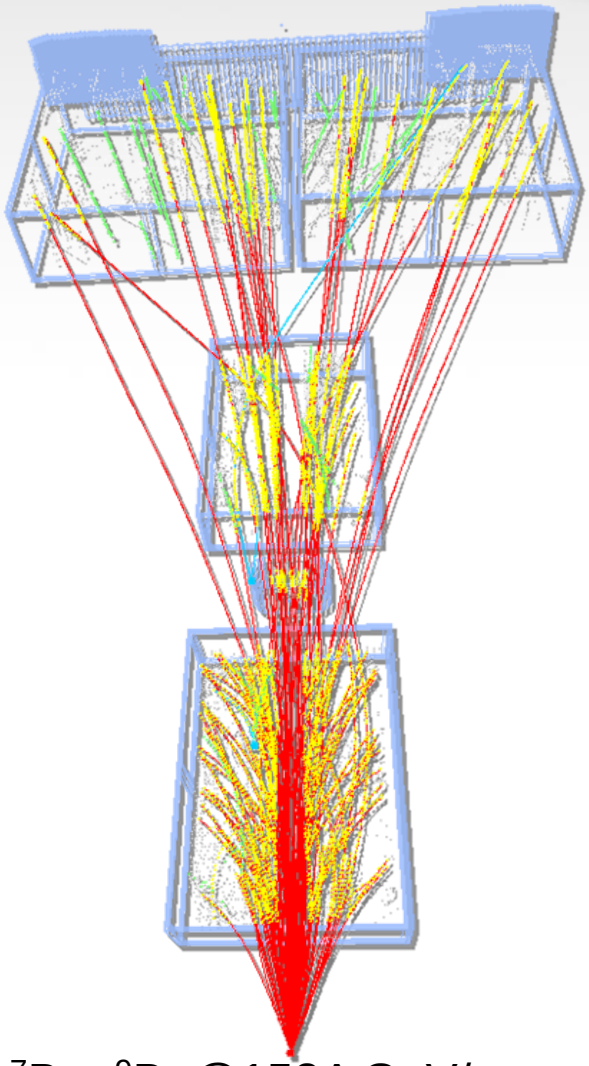
CERN COURIER

Apr 27, 2012

Light work with heavy ions

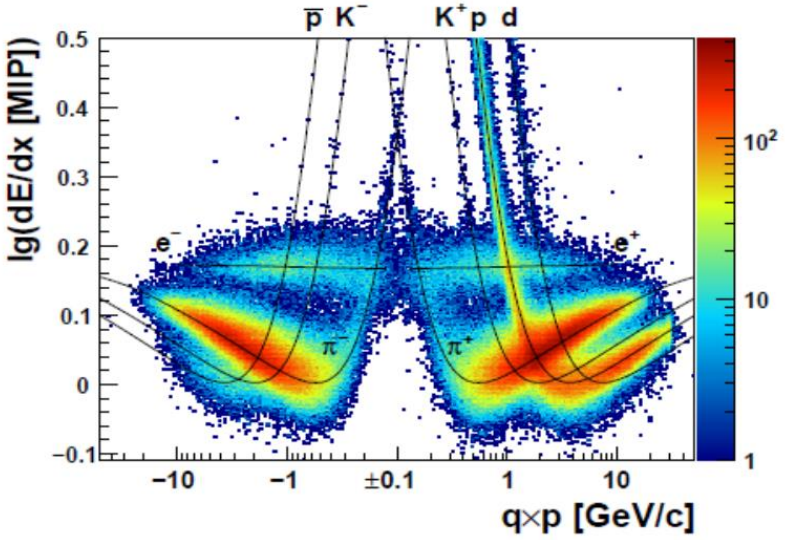
H. Stroebele & I. Efthymiopoulos

NA61/SHINE Detector

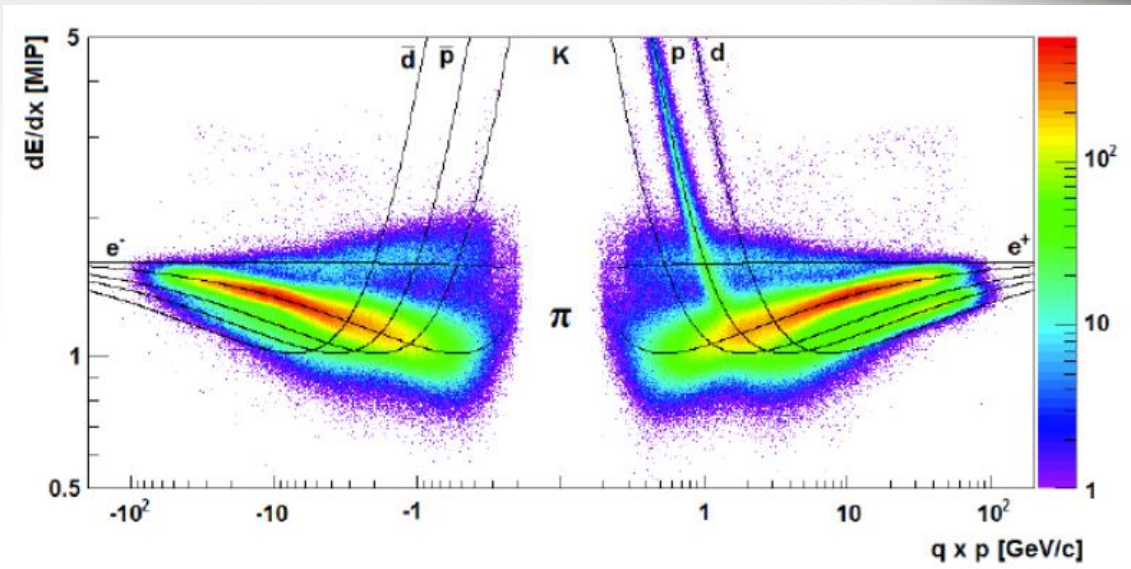


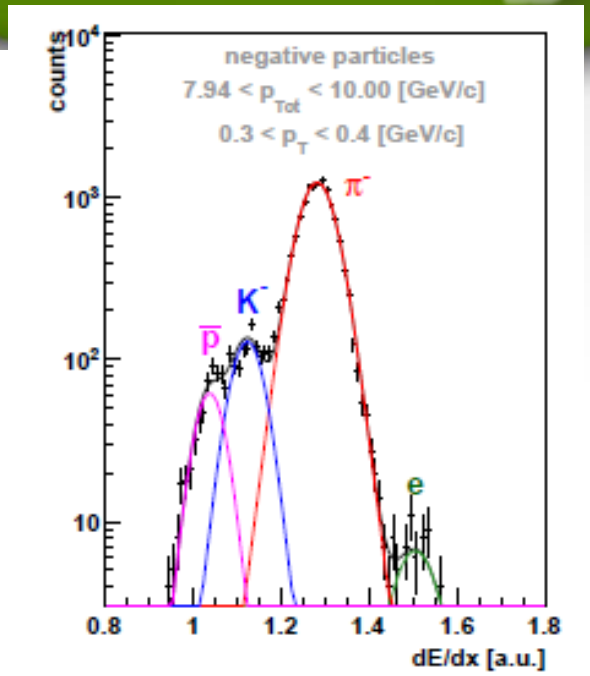
^{7}Be+^{9}Be@158A GeV/c

- Large acceptance: 50%
- High momentum resolution:
  - $\sigma(p)/p^2 \approx 10^{-4}$ (GeV /c)$^{-1}$ (at full B=9 T m)
- ToF walls resolution:
  - ToF-L/R: $\sigma(t) \approx 60$ps; ToF-F: $\sigma(t) \approx 120$ps
- Good particle identification:
  - $\sigma(dE/dx)/ < dE/dx > \approx 0.04$; $\sigma(m_{inv}) \approx 5$MeV
- High detector efficiency: 95%
- Event recording rate: 70 events/sec



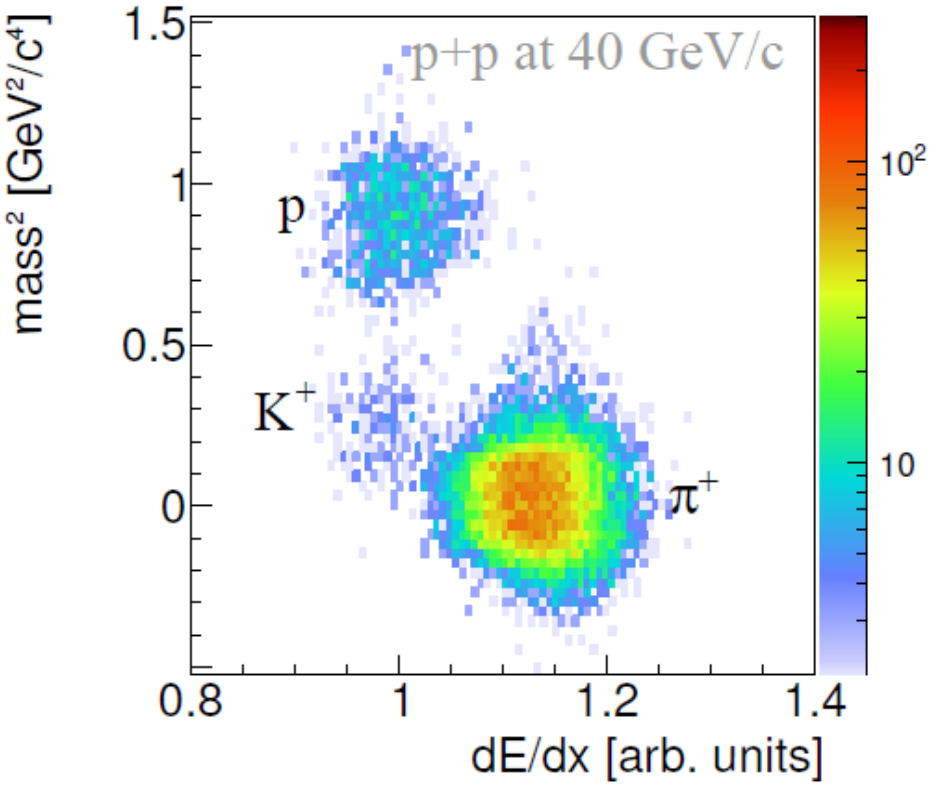
Energy loss (dE/dx) method





- In each p, p_T bin sum of Gauss functions is fitted to the dE/dx spectrum
- For each track the probability for being a hadron of specific type is calculated based on the fitted dE/dx distribution
- Sum of these probabilities gives the mean multiplicity of the identified hadrons

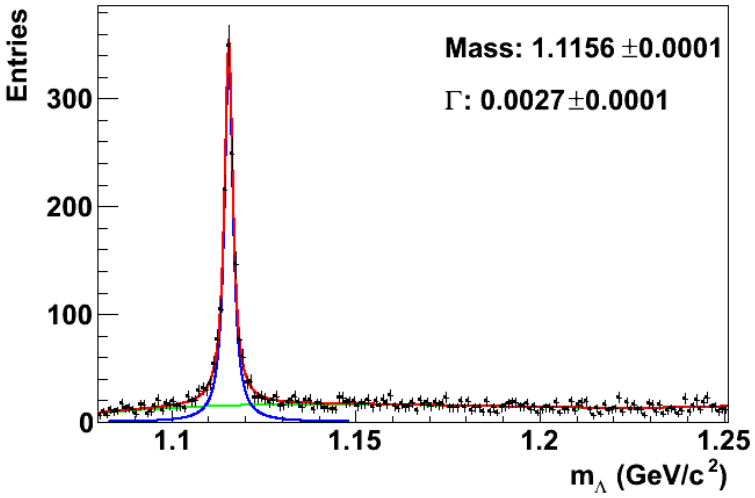
Energy loss (dE/dx) vs time of flight (tof) method



- Fit a two-dimensional weighted Gaussian function in the mass^2 vs dE/dx plane

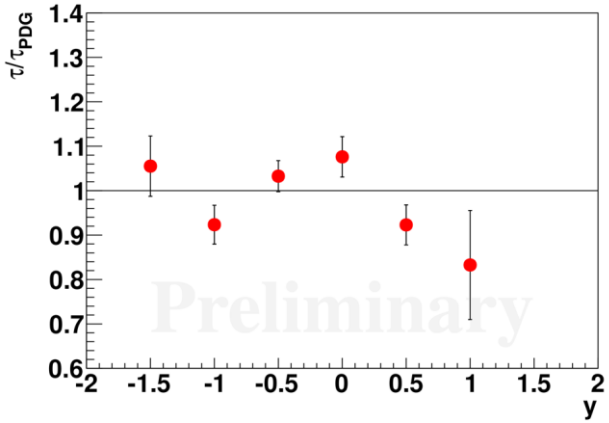
V^0 – method

- Method example
  - Decay channel: $\Lambda \rightarrow p + \pi^-$
  - Invariant mass histograms in p_T and y bins
  - In each p, p_T bin sum of signal (i.e. Lorentzian) and background functions is fitted to the invariant mass spectrum



Λ mass from PDG 1115.678±0.006±0.006 GeV/c^2

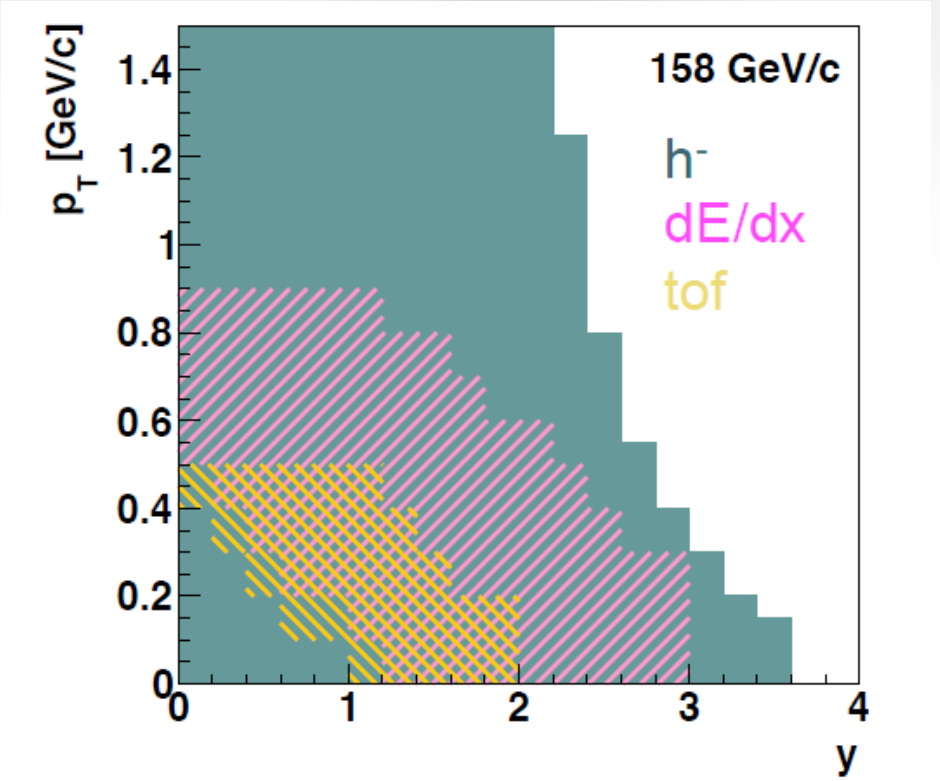
Lifetime is calculated based on the difference between position of the main and the decay vertex



Results are consistent with PDG value ($c\tau_\Lambda$ = 7.89 cm)

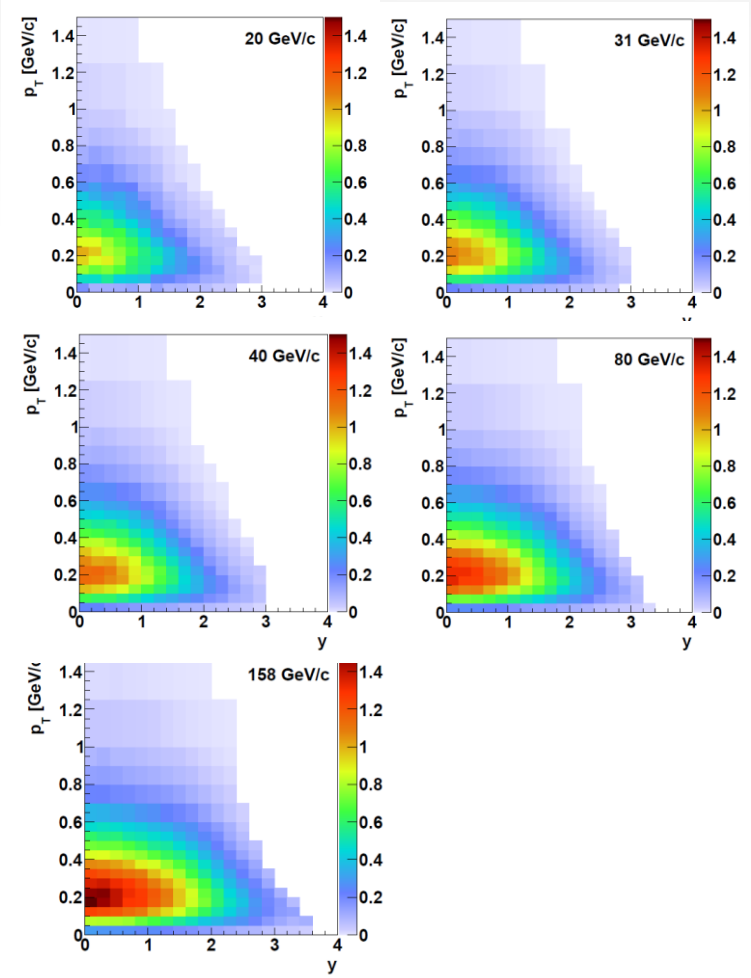
h^- analysis method

- Majority (more than 90%) of negatively charged particles are π^- mesons
- The small contribution of other particles (K^-, $\bar{p}$, and decays from Λ and K^0_S) is subtracted based on data and model predictions

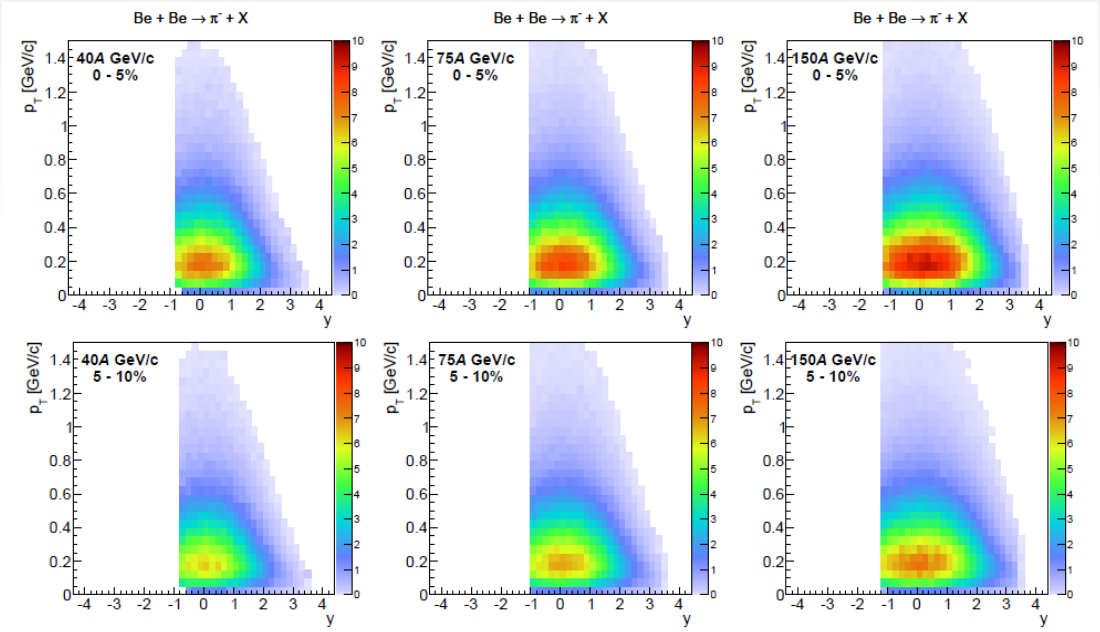


Precise measurements (π^- meson)

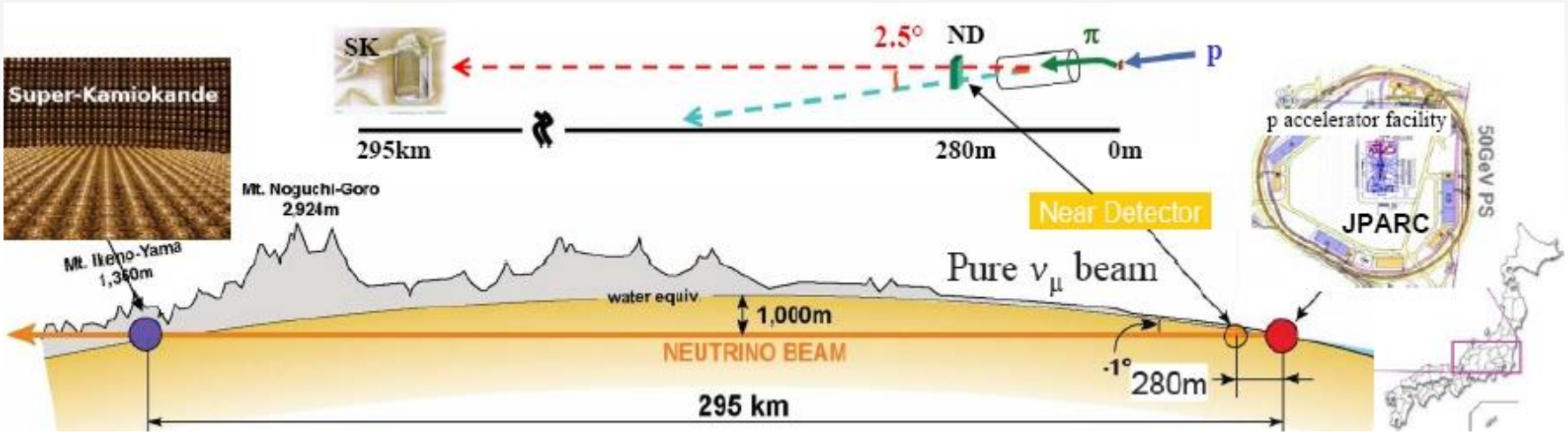
p+p collisions



^{7}Be+^{9}Be collisions



Hadron-production measurements for neutrino experiments



The T2K experiment published a measurement of θ_{13} angle in the neutrino mixing matrix (PRL 107, 041801 (2011))

Systematic error estimate was based on the NA61/SHINE results

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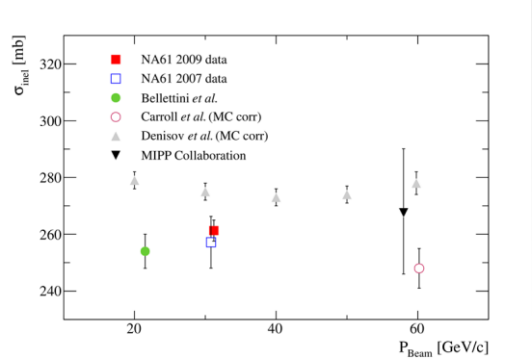
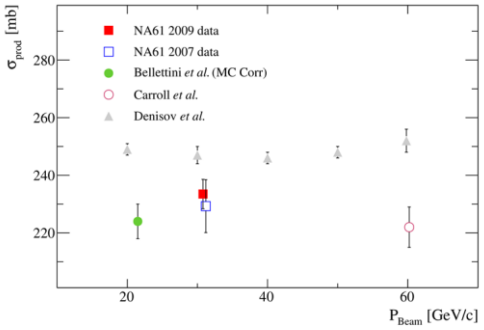
Hadron-production measurements for neutrino experiments

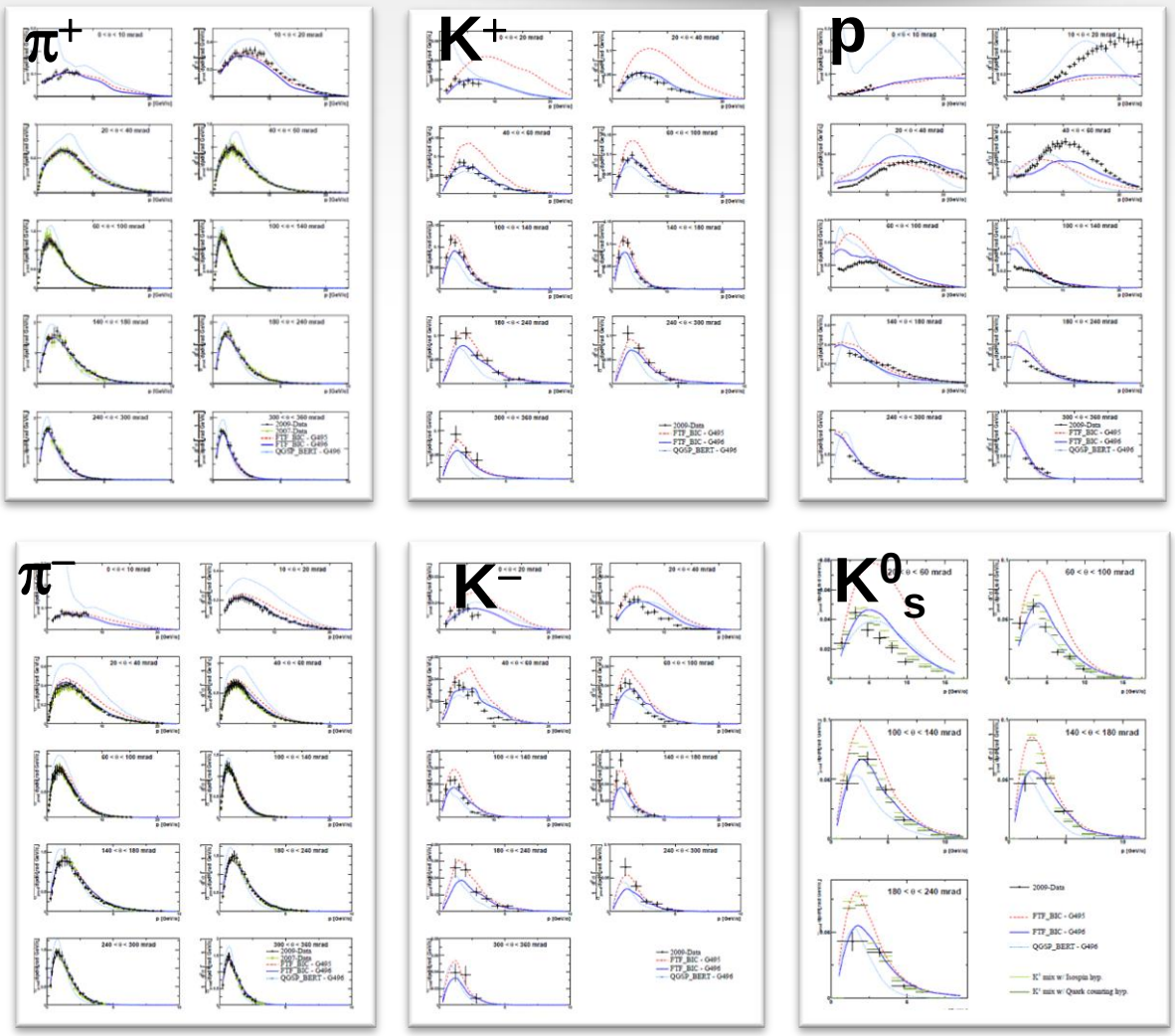


High statistics 2009 p+C at 31GeV/c "thin-target" dataset

s_{inel} = 261.3 ± 2.8(stat) ± 2.4(det) ± 0.3(mod) mb

s_{prod} = 233.5 ± 2.8(stat) ± 2.4(det) ± 3.6(mod) mb





Extension of the neutrino program by measurements for FERMILAB experiments

- Six US-NA61
- Measurements with NuMi and LBNE replica target

proton+pion event totals	**Incident proton/pion beam momentum**		
Target	120 GeV/c	60 GeV/c	30 GeV/c
NuMI (spare) replica	(*future*)		
LBNE replica	(*future*)		
thin graphite ($< 0.05\lambda_I$)	(*future*)	3M	(T2K data)
thin aluminum ($< 0.05\lambda_I$)		3M	3M
thin iron ($< 0.05\lambda_I$)	(*future*)	(*future*)	(*future*)
thin beryllium ($< 0.05\lambda_I$)	(*future*)	3M	3M

Hadron-production measurements for cosmic ray experiments

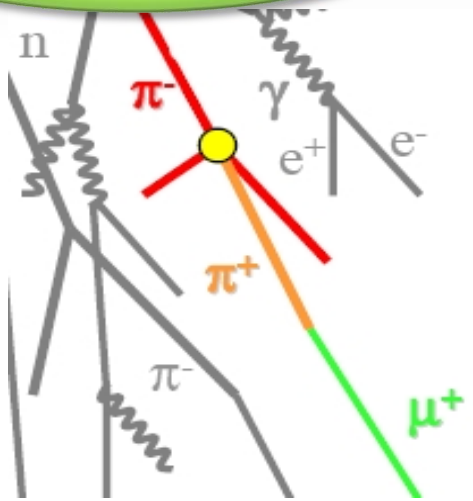
Cosmic ray composition of central importance for understanding sources, kink, ankle...

Modern detector installations: high statistics/quality data

Indirect measurement (extensive air showers): simulations needed

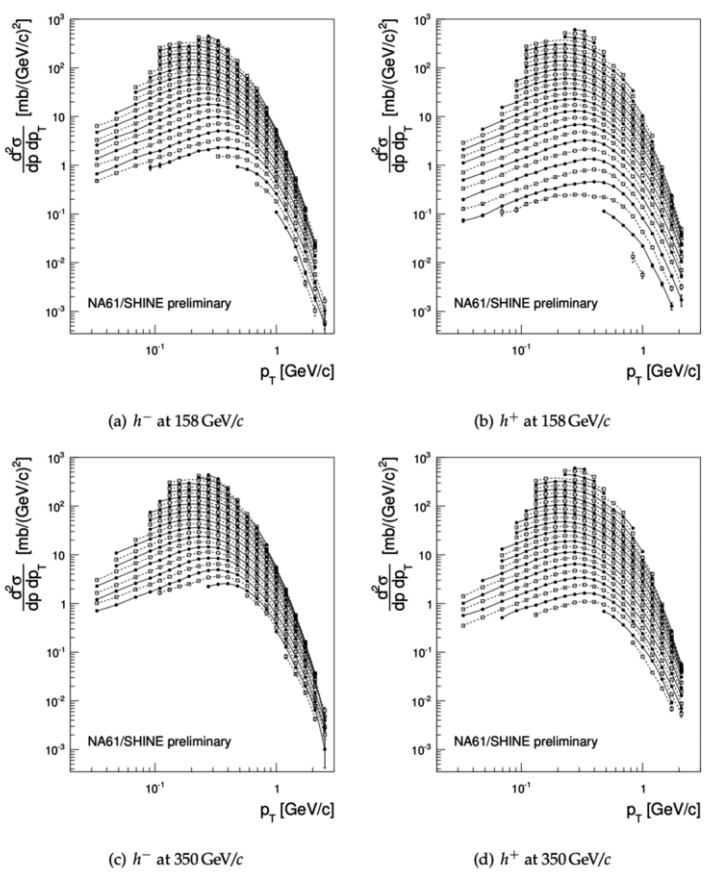
Strong model dependence: due mainly to simulation of m production

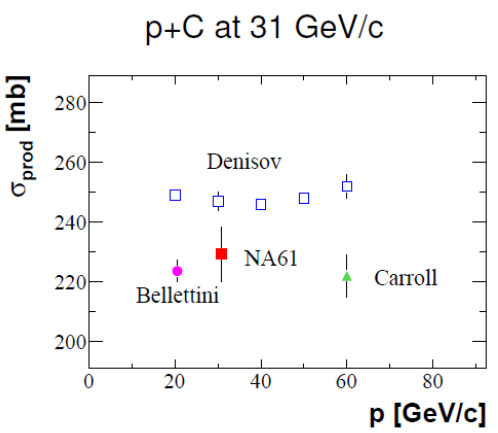
m production related to hadronic interactions at fixed-target energies

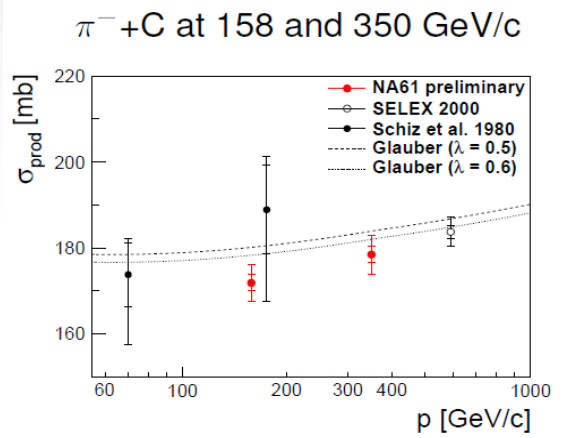


Hadron-production measurements for cosmic ray experiments

Cross sections measurements







Input for validation/tuning of Monte Carlo generators