Recent results from NA61/SHINE

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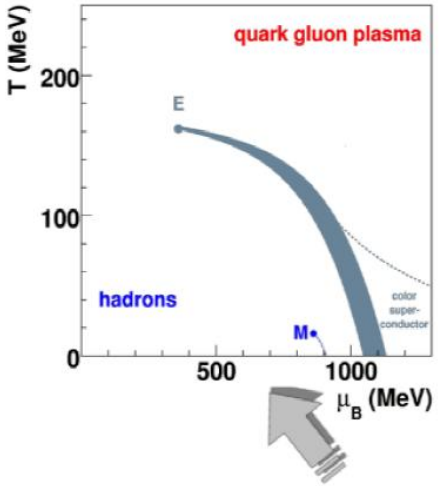
NA61/SHINE – few facts

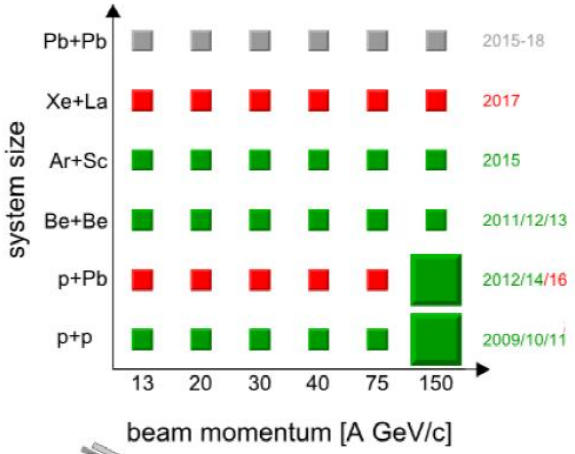
- Located at the CERN SPS
- Large acceptance spectrometer for fixed target experiment on primary (ions) and secondary (ions, hadrons) beams
- Data taking since 2009
- NA61/SHINE is the third largest non-LHC experiment at CERN

Physics program

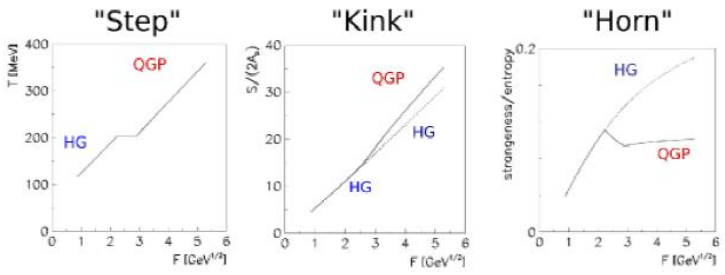
- **Strong interactions program**
  - **search for the critical point of strongly interacting matter**
  - **study of the properties of the onset of deconfinement**
  - **study high p_T particles production (energy dependence of nuclear modification factor)**
- Hadron-production measurements for neutrino 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



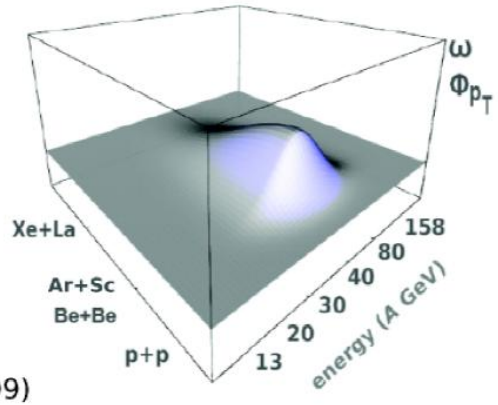


Statistical Model of the Early Stage (SMES)



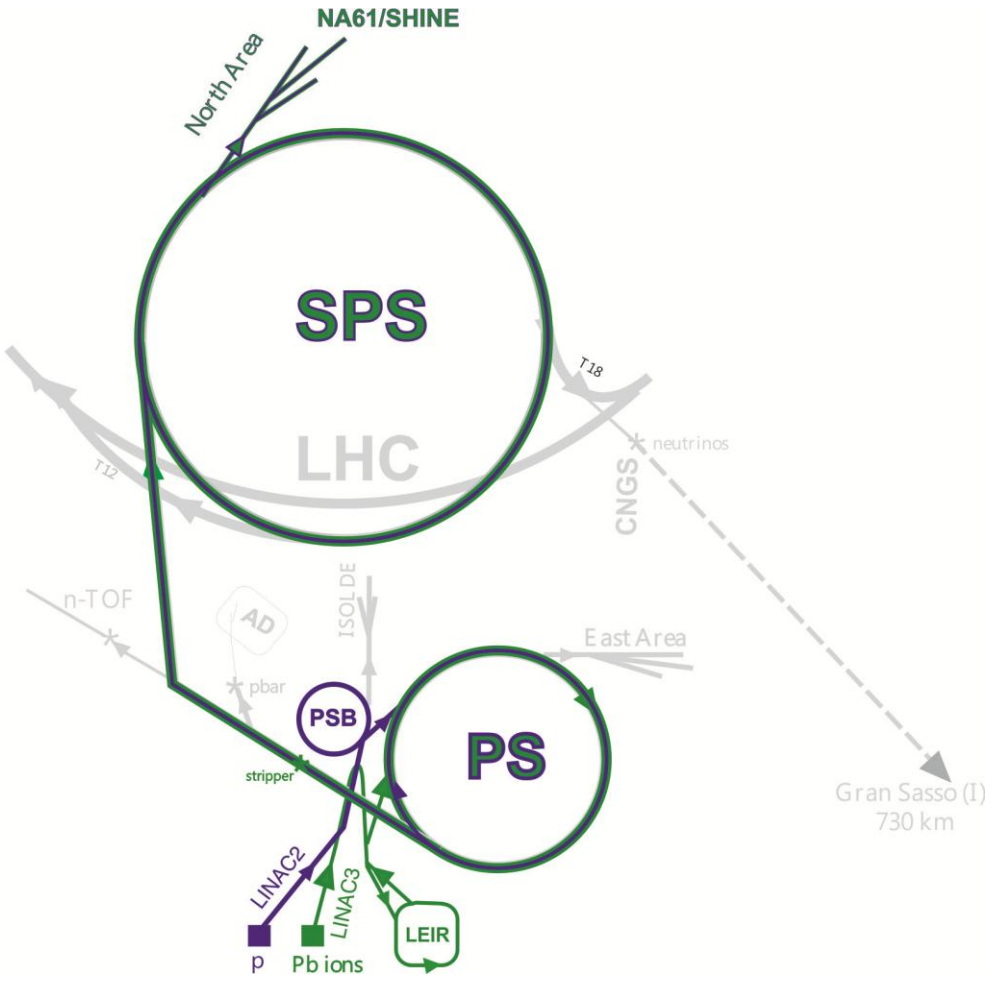
$F \approx \sqrt[4]{s_{NN}}$

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



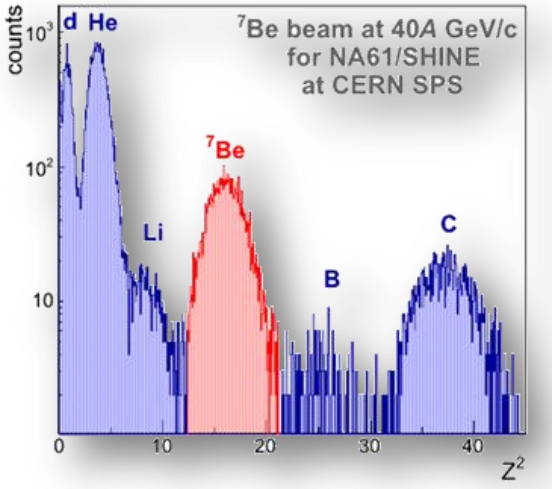
Facility

Beams for NA61/SHINE



Available beams:

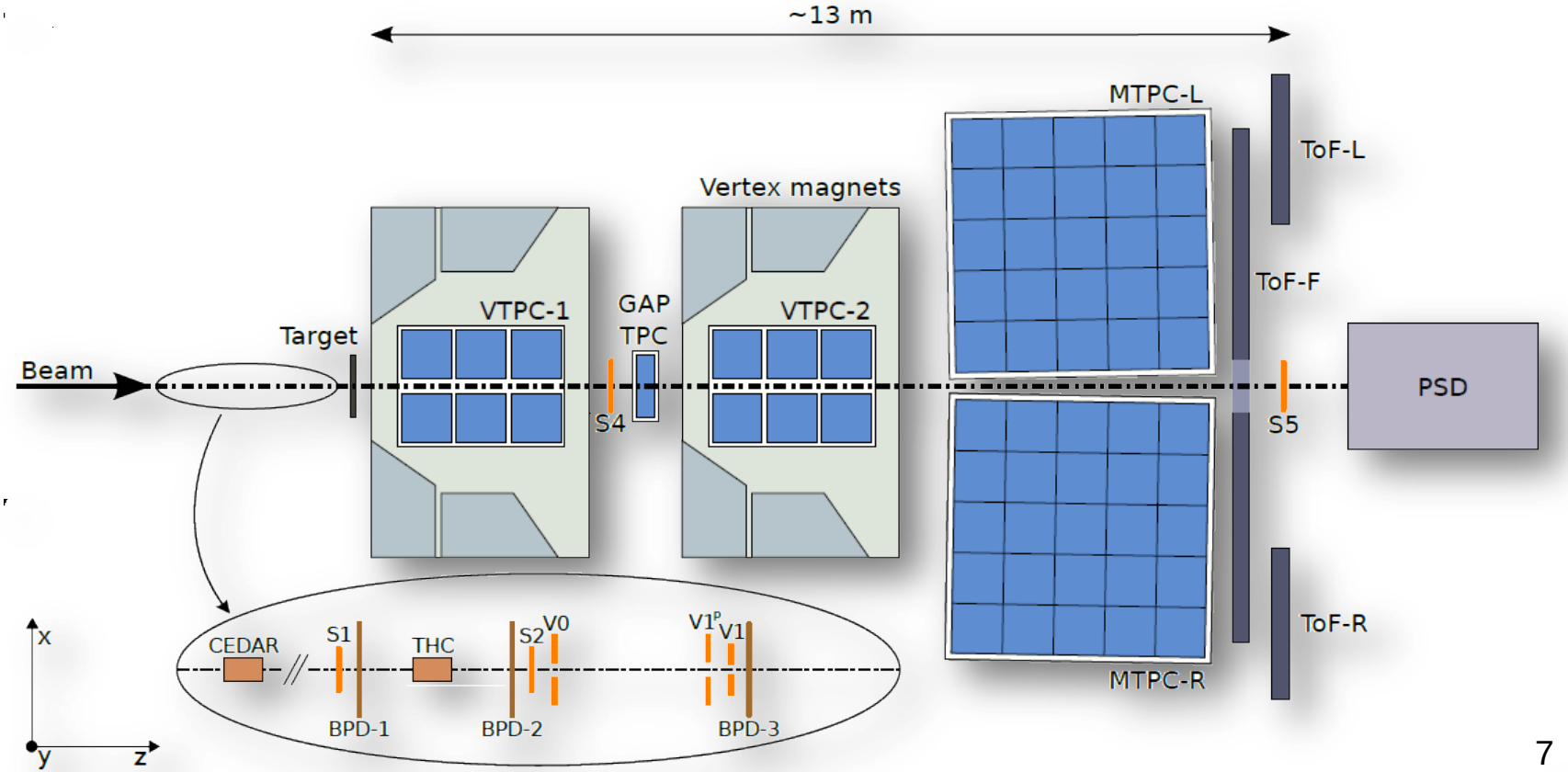
- Primary ions (13A - 158A GeV/c):
  - Argon
  - Xenon
  - Lead
- Secondary:
  - hadrons (p,$\pi^{\pm}$, $K^{\pm}$) 13 - 350 GeV/c
  - ions (Be, . . .) 13A - 150A GeV/c



Secondary ion beam composition
(Pb fragmentation on Be target)

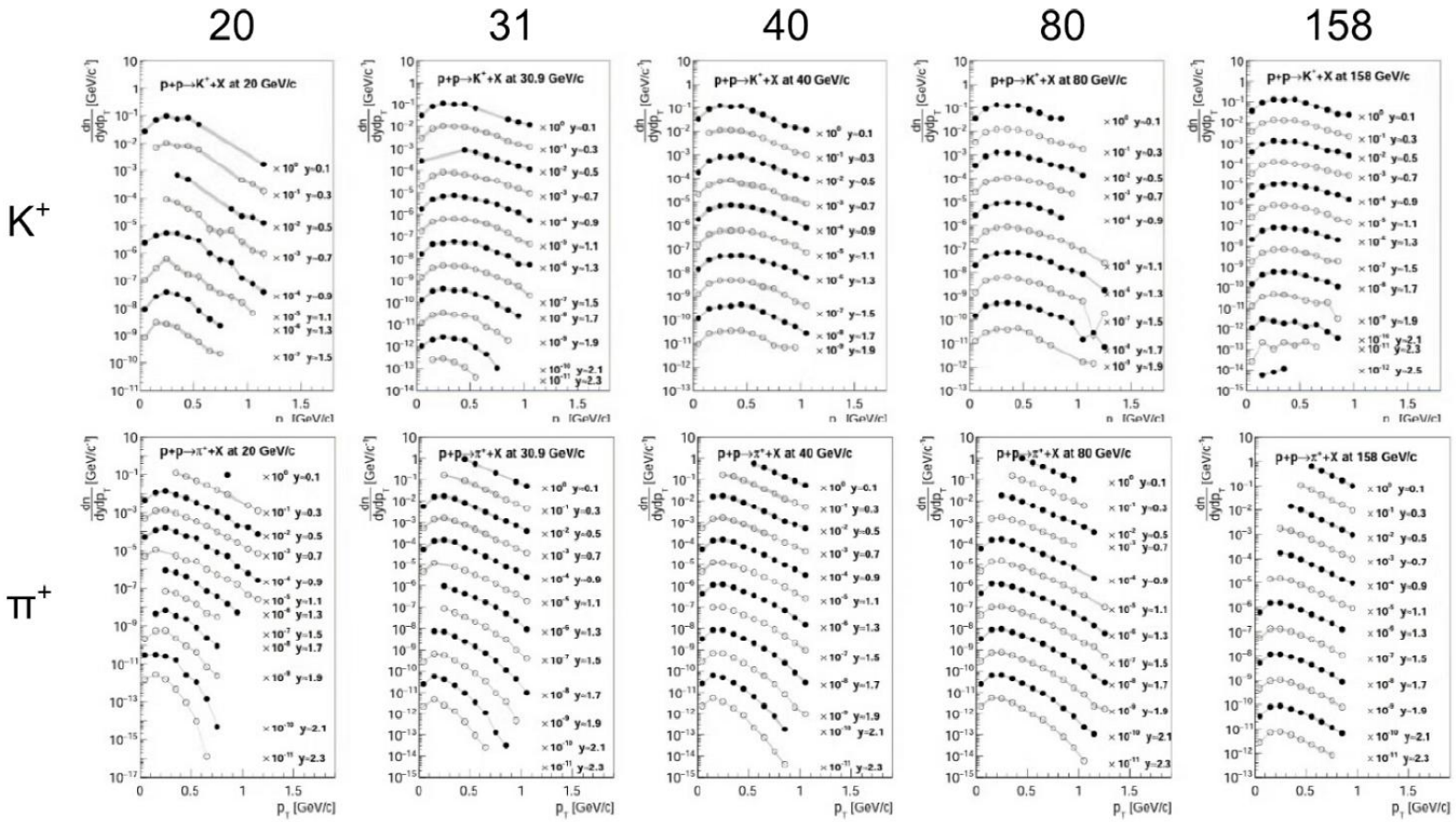
Experimental layout

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

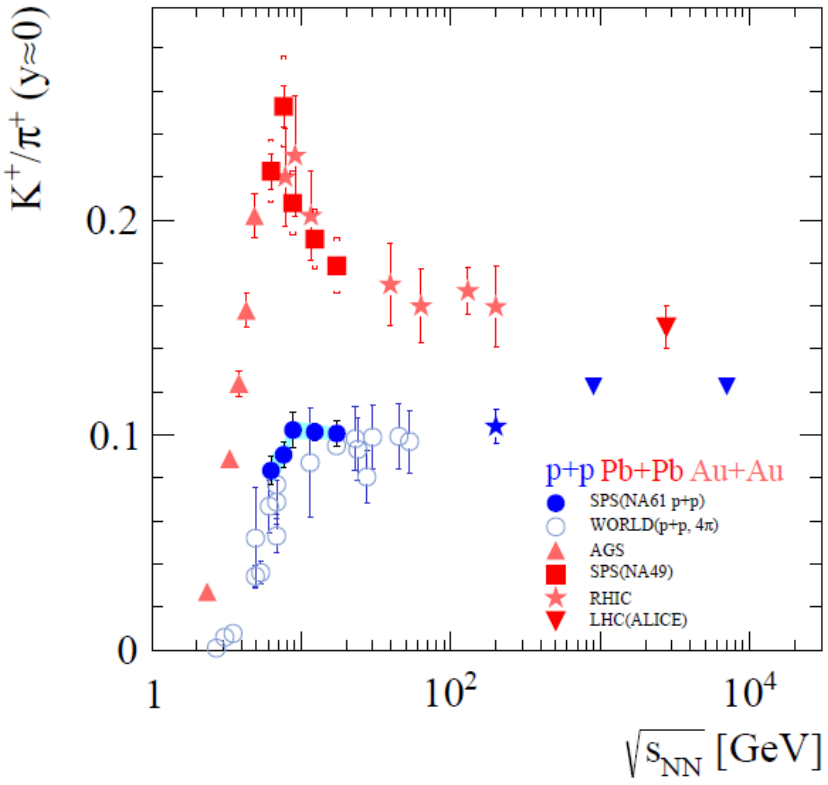


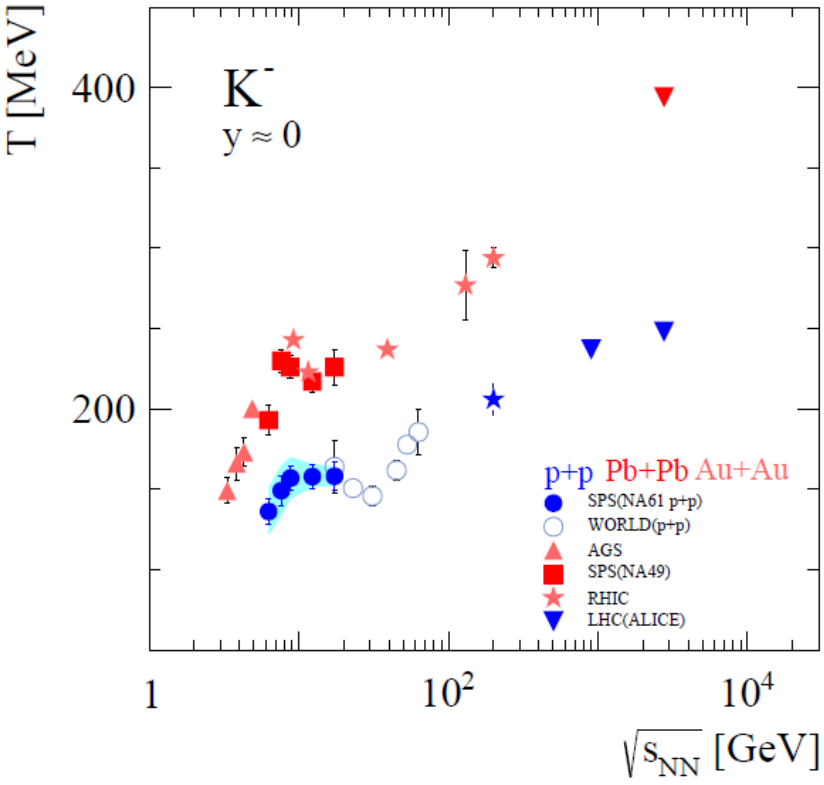
Single particle spectra in p+p

Single particle spectra from p+p interactions



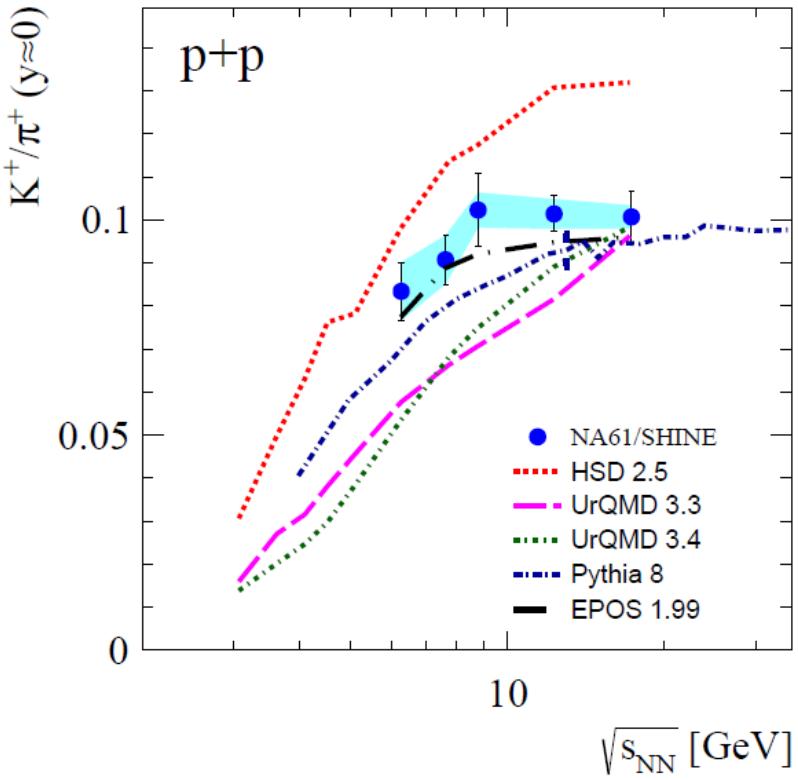
Rapid changes in p+p at SPS

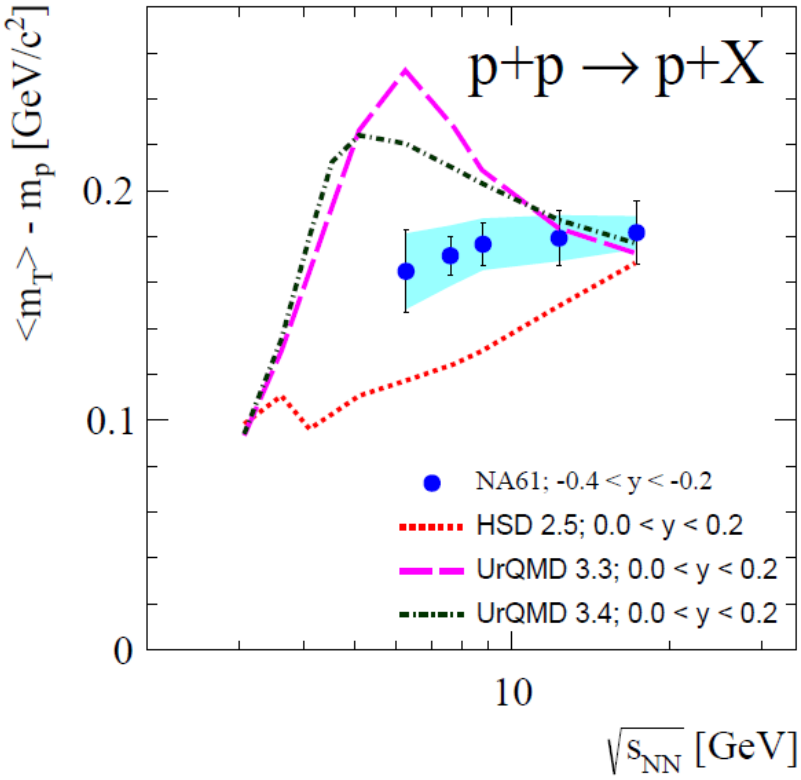




K^+/π^+ ratio and inverse slop parameter of m_T spectrum of K^- exhibits rapid changes in the SPS energy range

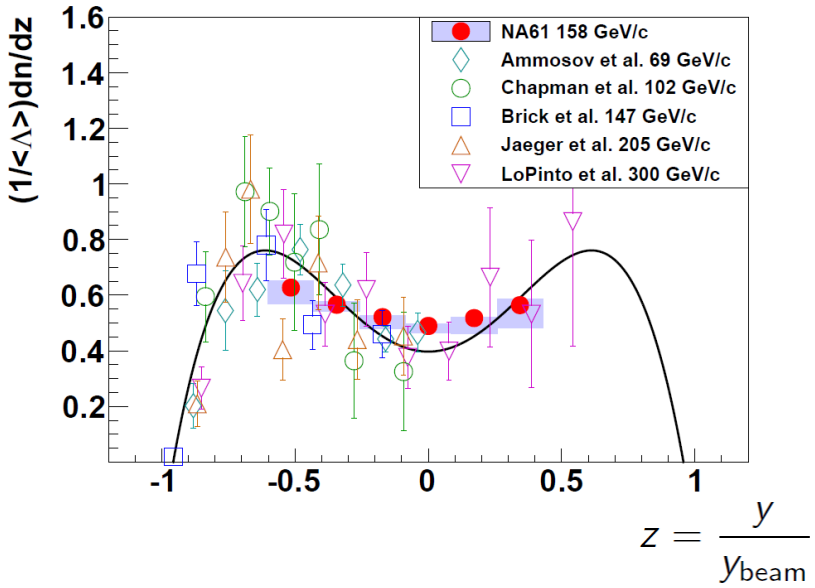
Rapid changes in p+p at SPS – comparison with models

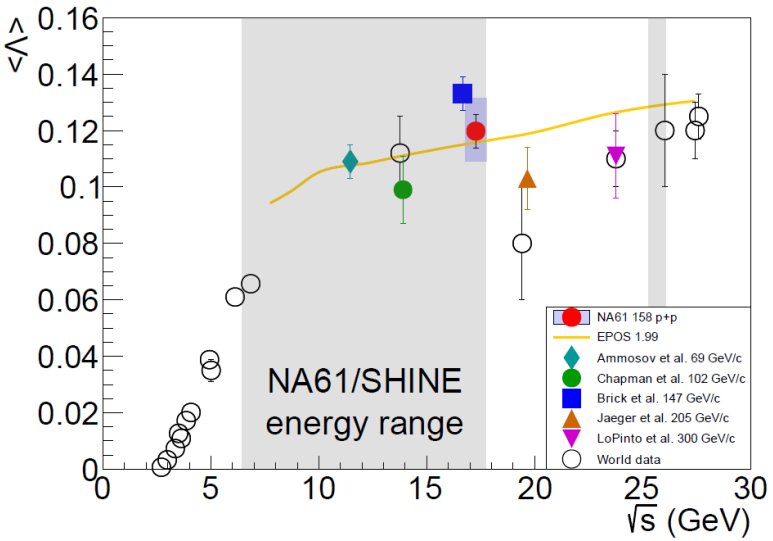




Monte-Carlo models provide poor description of data

Λ spectra in p+p at 158 GeV/c





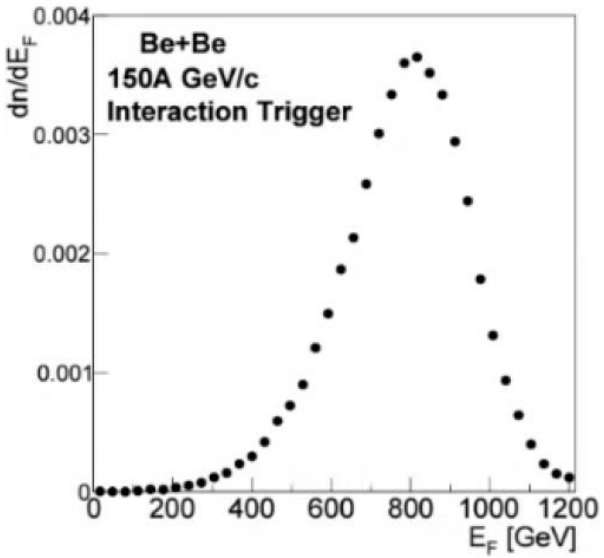
- NA61/SHINE results are consistent with world data
- Other NA61/SHINE energies – work in progress

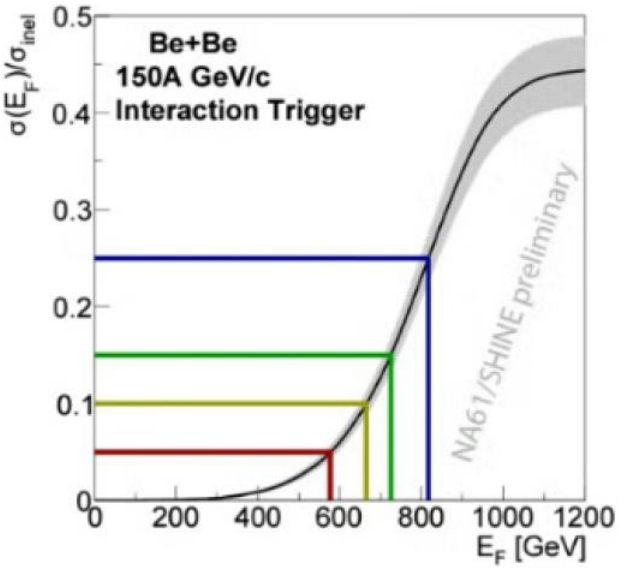
Single particle spectra in Be+Be

Centrality selection in ion collisions

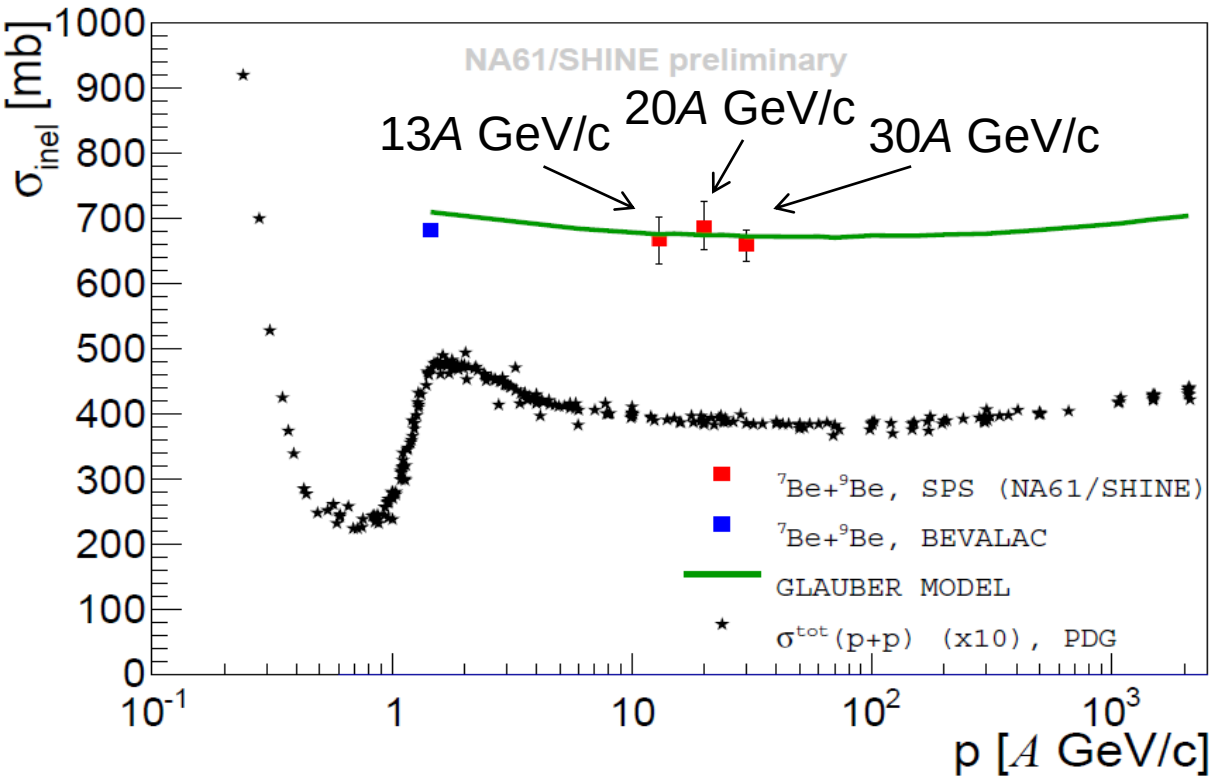
- PSD (Projectile Spectator Detector) is located on the beam axis and measures the forward energy E_F related to the non-interacting nucleons of the beam nucleus
- Cuts on E_F allows to select different centrality classes
- Four event classes

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



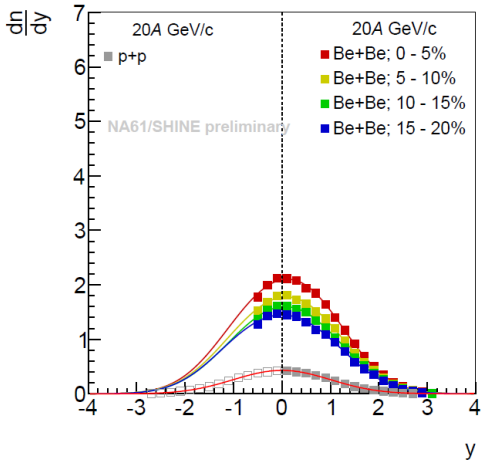


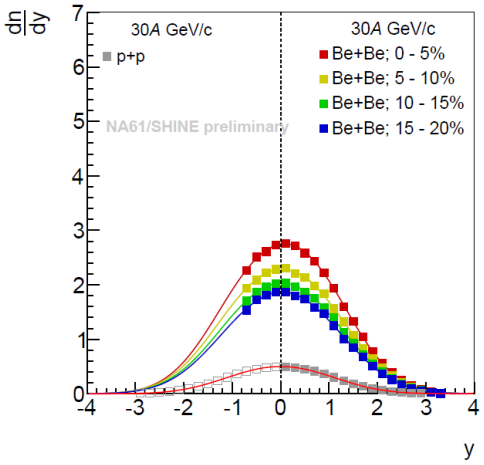
Inelastic ^{7}Be+^{9}Be cross section

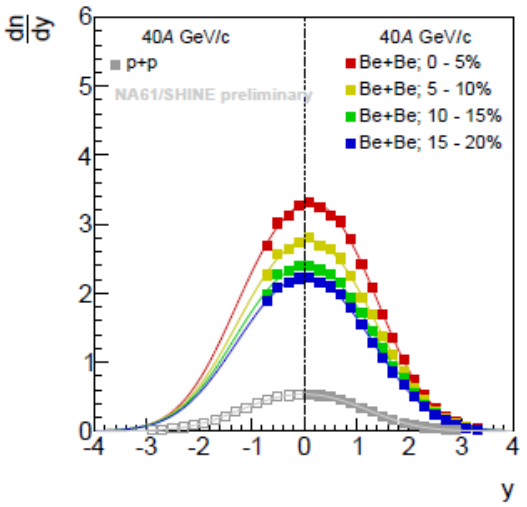


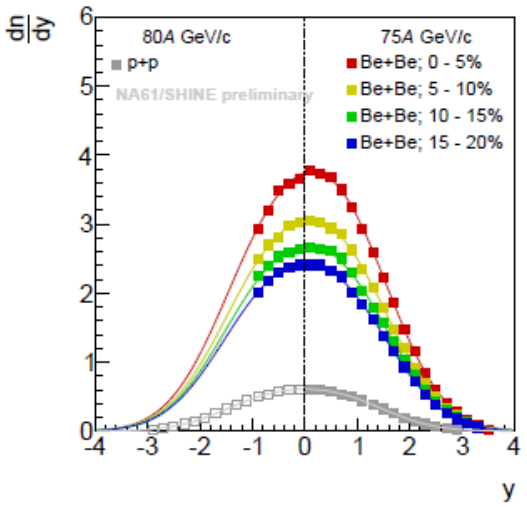
- NA61 measurements together with 1*A* GeV/c Bevalac data established energy dependence of the inelastic cross section

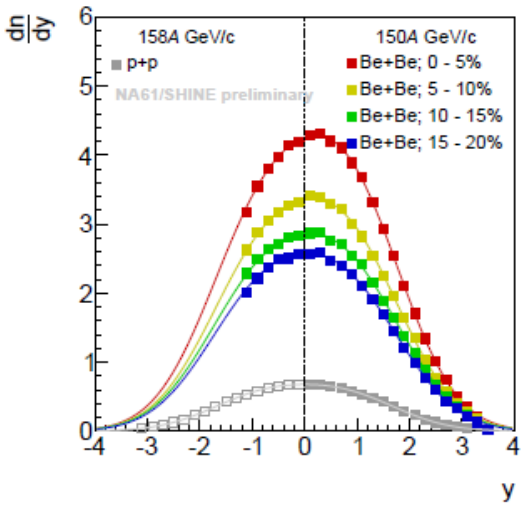
Rapidity distributions



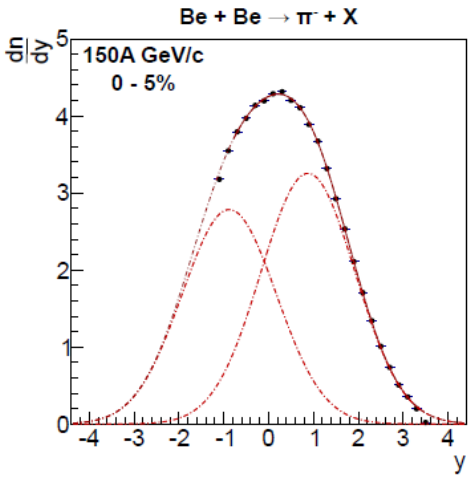


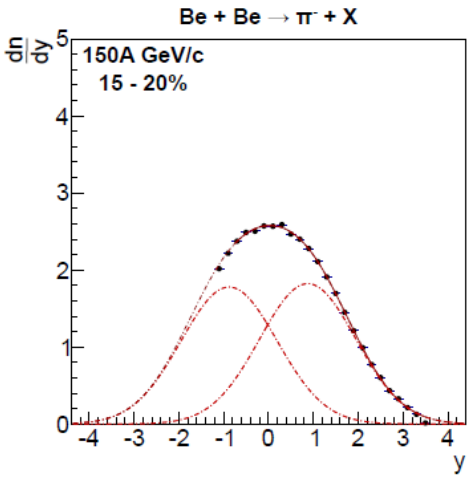


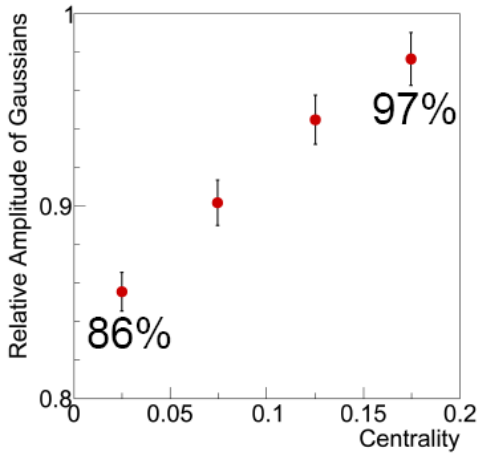




Asymmetry in π^- distributions in $^7Be+^9Be$

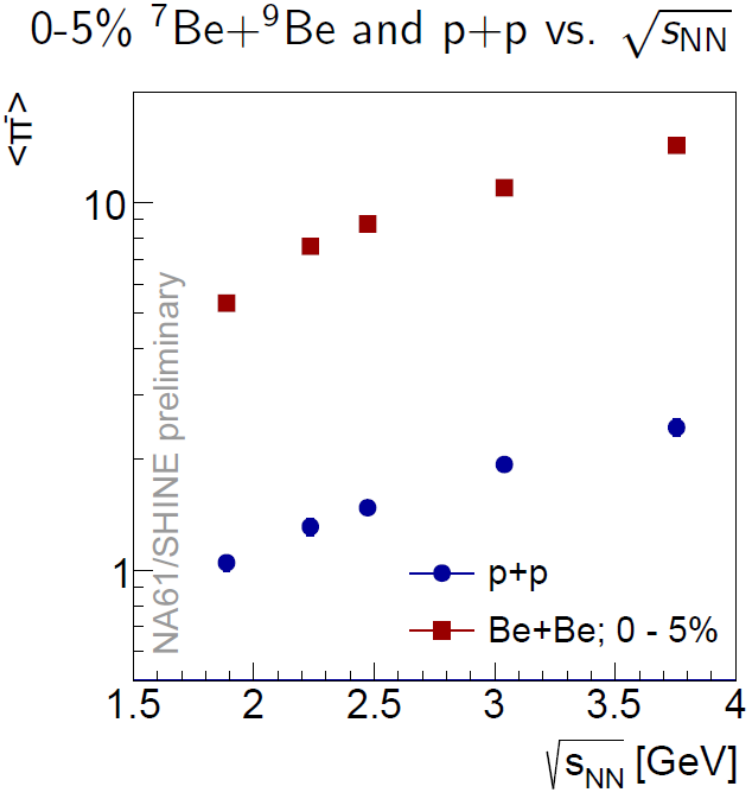


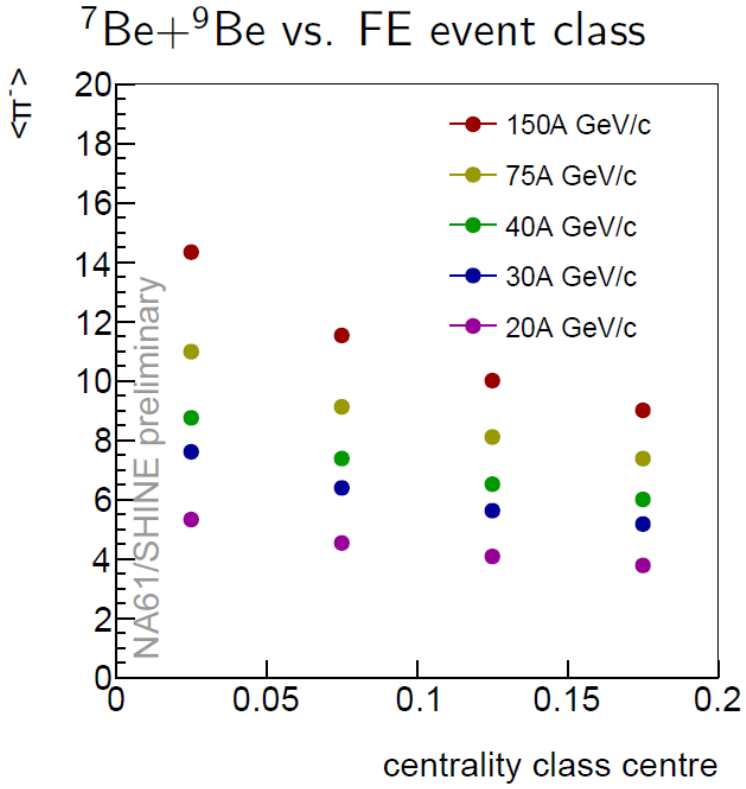




- Fitted: double Gaussian function symmetrically displaced from mid–rapidity (both Gaussians have the same width, but they differ in amplitude)
- Asymmetry decreases from 0.86 (0-5%) to 0.97 (15-20%)
- Two opposite effects influence asymmetry of the spectra:
  - asymmetric system ^7Be projectile on ^9Be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

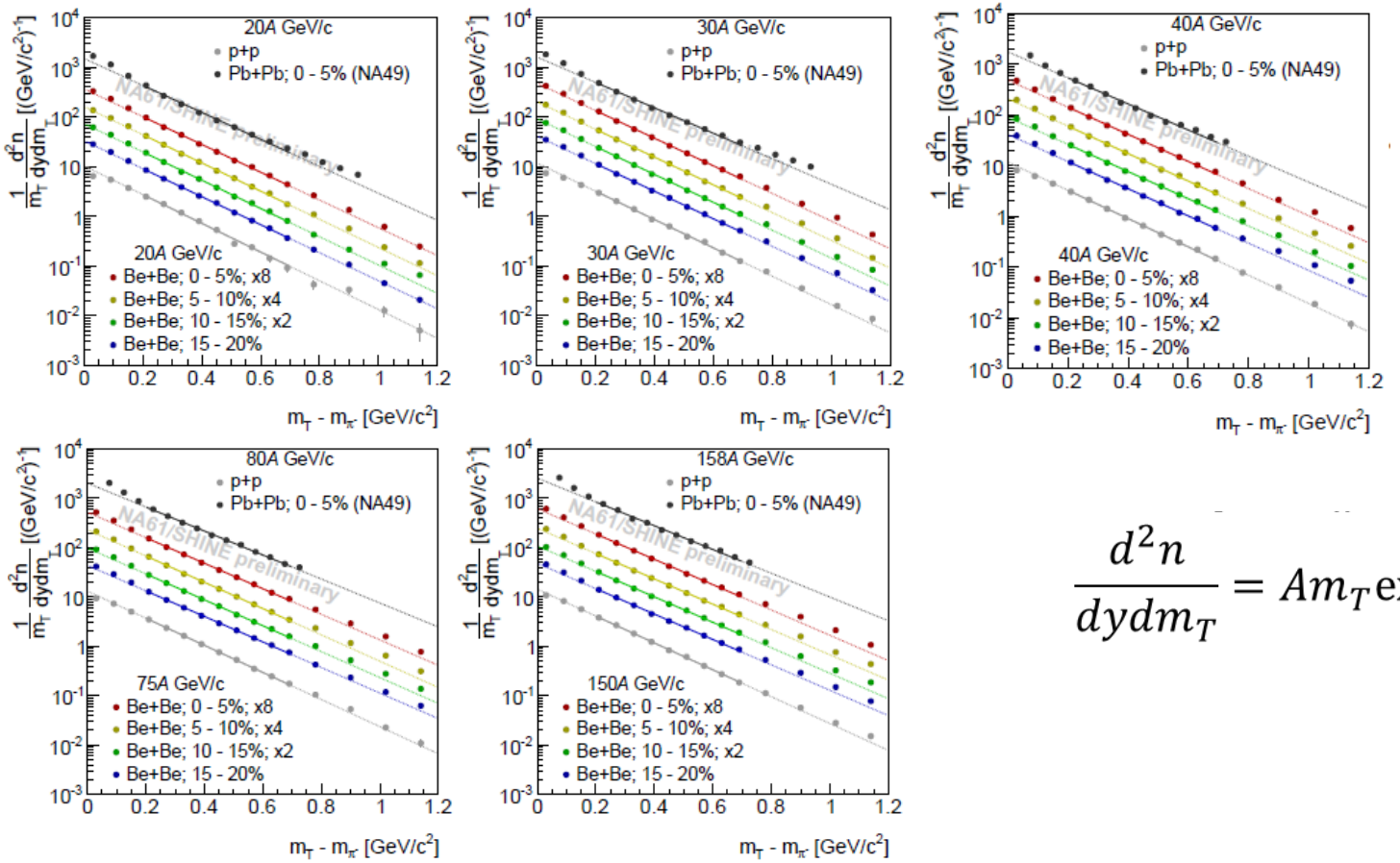
Mean multiplicities of π^- in ^{7}Be+^{9}Be





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

Transverse mass spectra of π^-

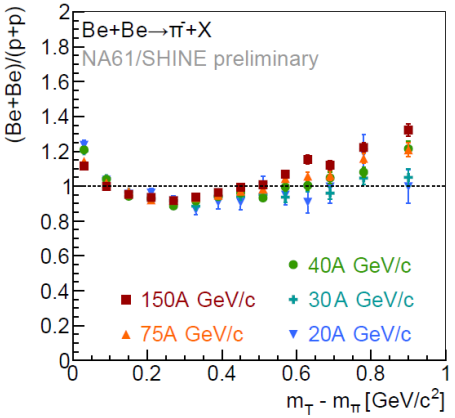


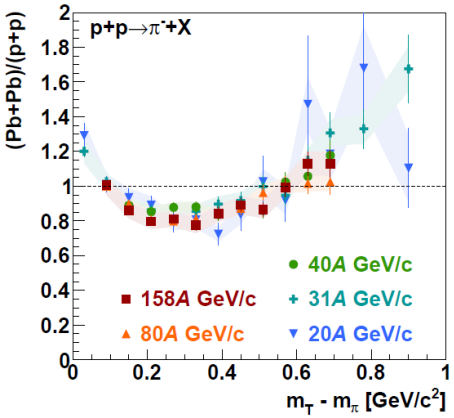
$$\frac{d^2n}{dydm_T} = Am_T \mathrm{ex}$$

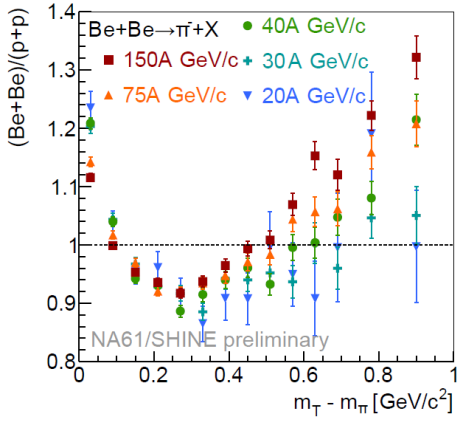
Comparison of π^- transverse mass spectra

- 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 flow increases with the collision energy

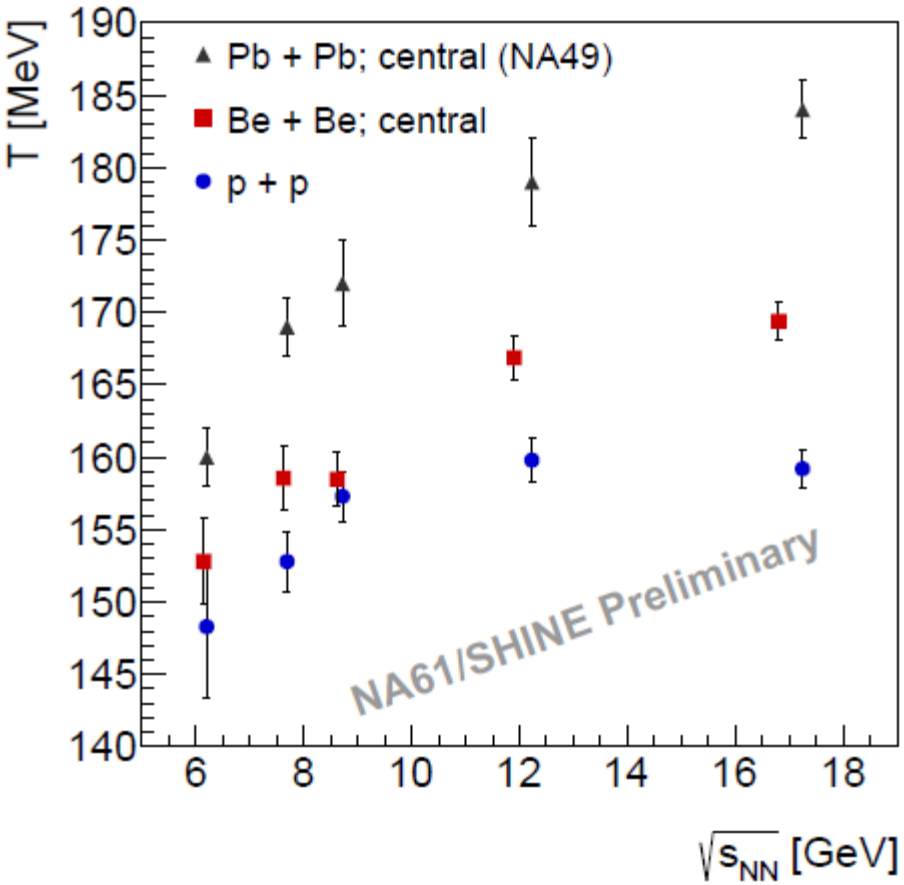






^{7}Be+^{9}Be data for 0-15% FE event class
Pb+Pb data for 5% or 7.5% most central interactions

Collective effects

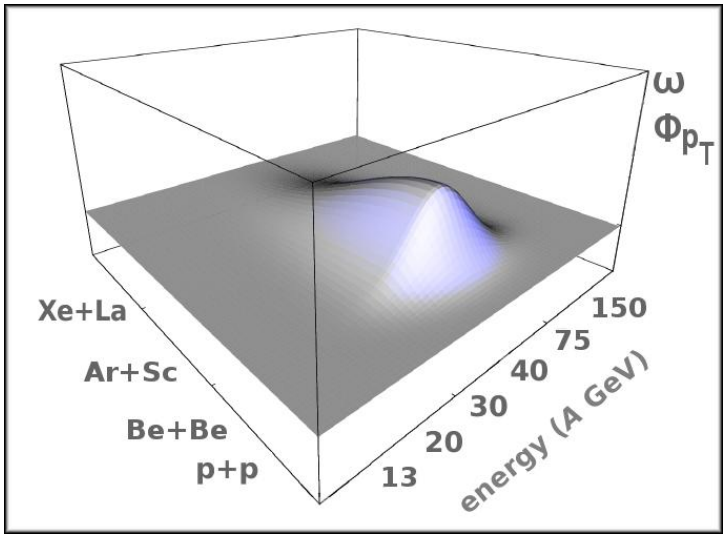


- Effect of radial flow for Pb+Pb at all energies
- Inverse slop parameter T larger in ^{7}Be+^{9}Be than in p+p → possible evidence of transverse collective flow in ^{7}Be+^{9}Be

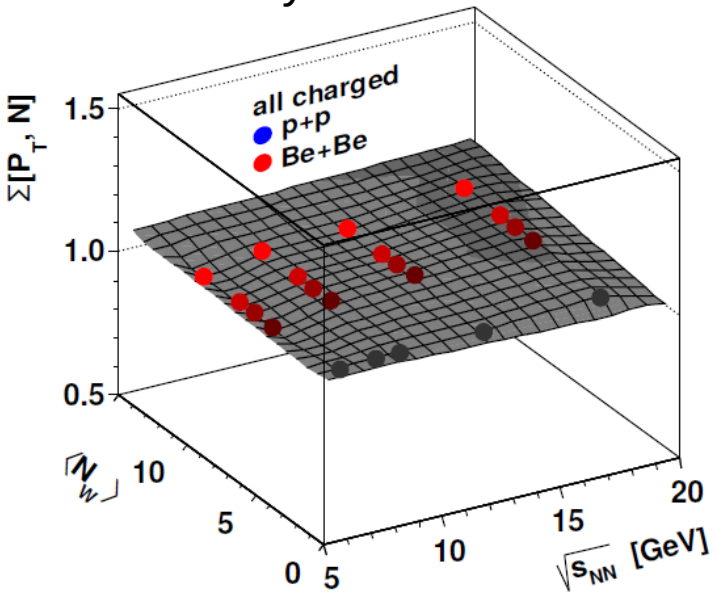
Fluctuations and correlations

Fluctuations

Theoretical fluctuations in presence of critical point

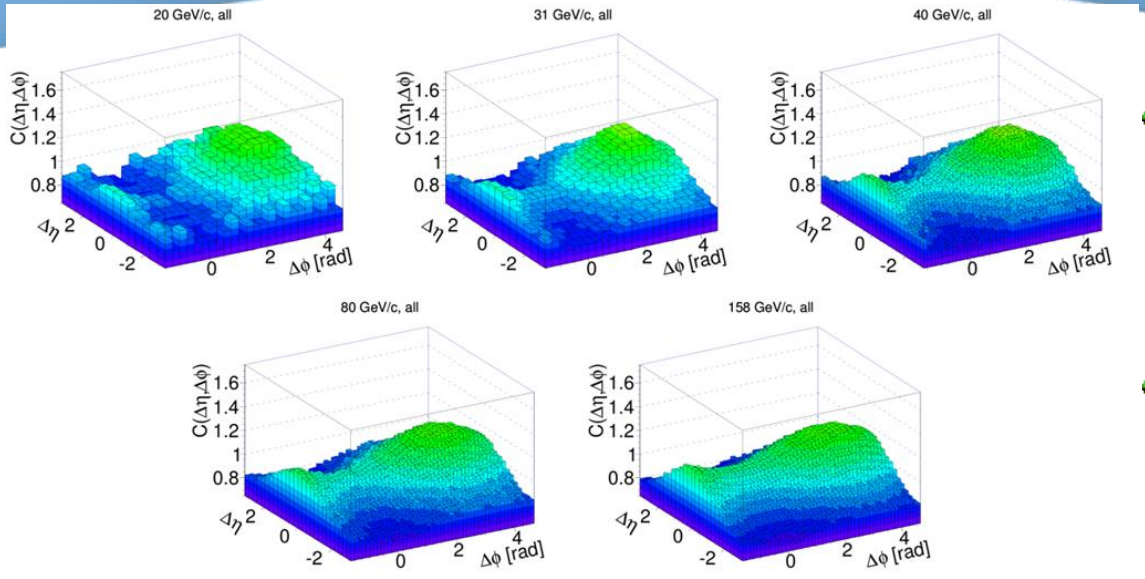


N-p_T fluctuations in p+p and centrality selected Be+Be

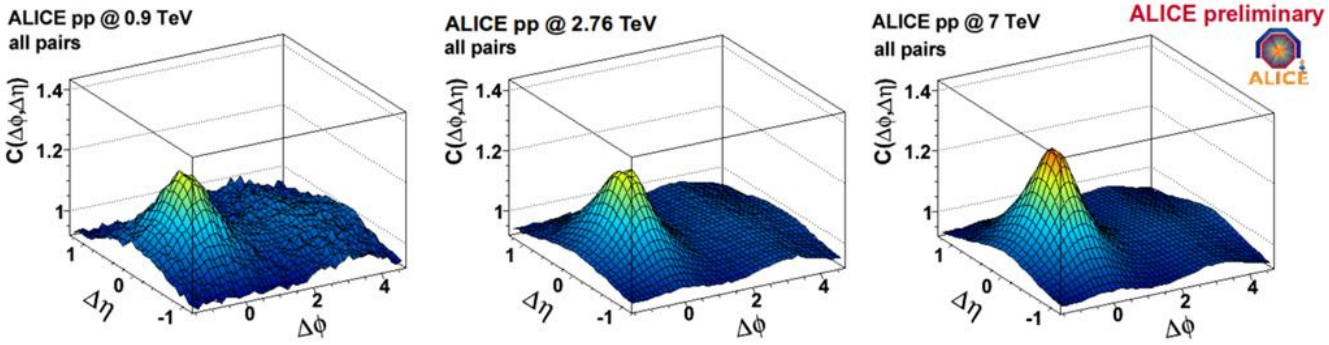


- No sign of any anomaly that can be attributed to the critical point (neither in p+p nor Be+Be)

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



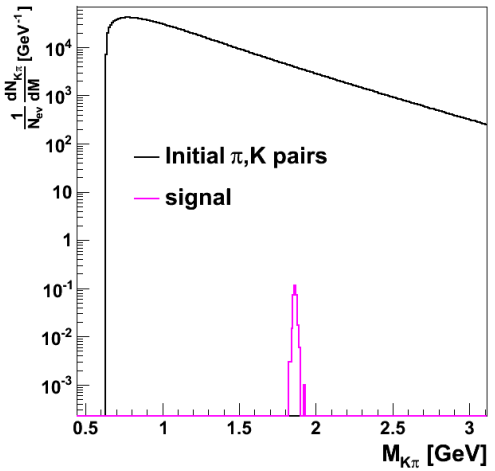
- NA61/SHINE: maximum at $(\Delta\eta,\Delta\phi) = (0,\pi)$ probably due to resonance decays and momentum conservation
- NA61 results show stronger enhancement in $\Delta\phi \approx \pi$ and no "jet peak" at $\Delta\phi \approx 0$ (in comparison with ALICE)



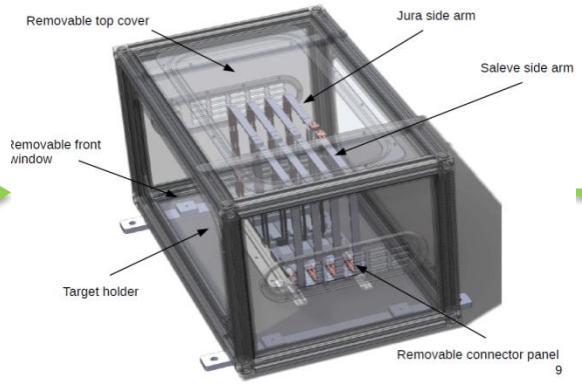
Future of NA61/SHINE

Open charm measurements

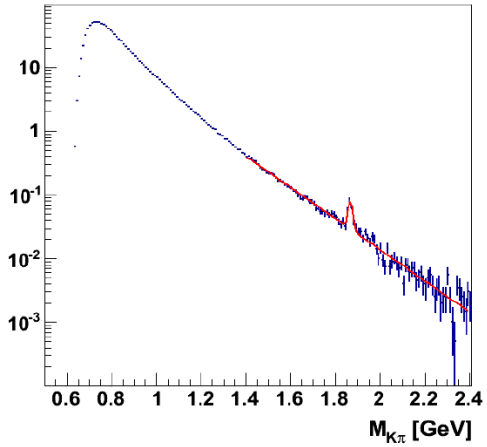
D^0 candidates selected by TPCs only



- 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)

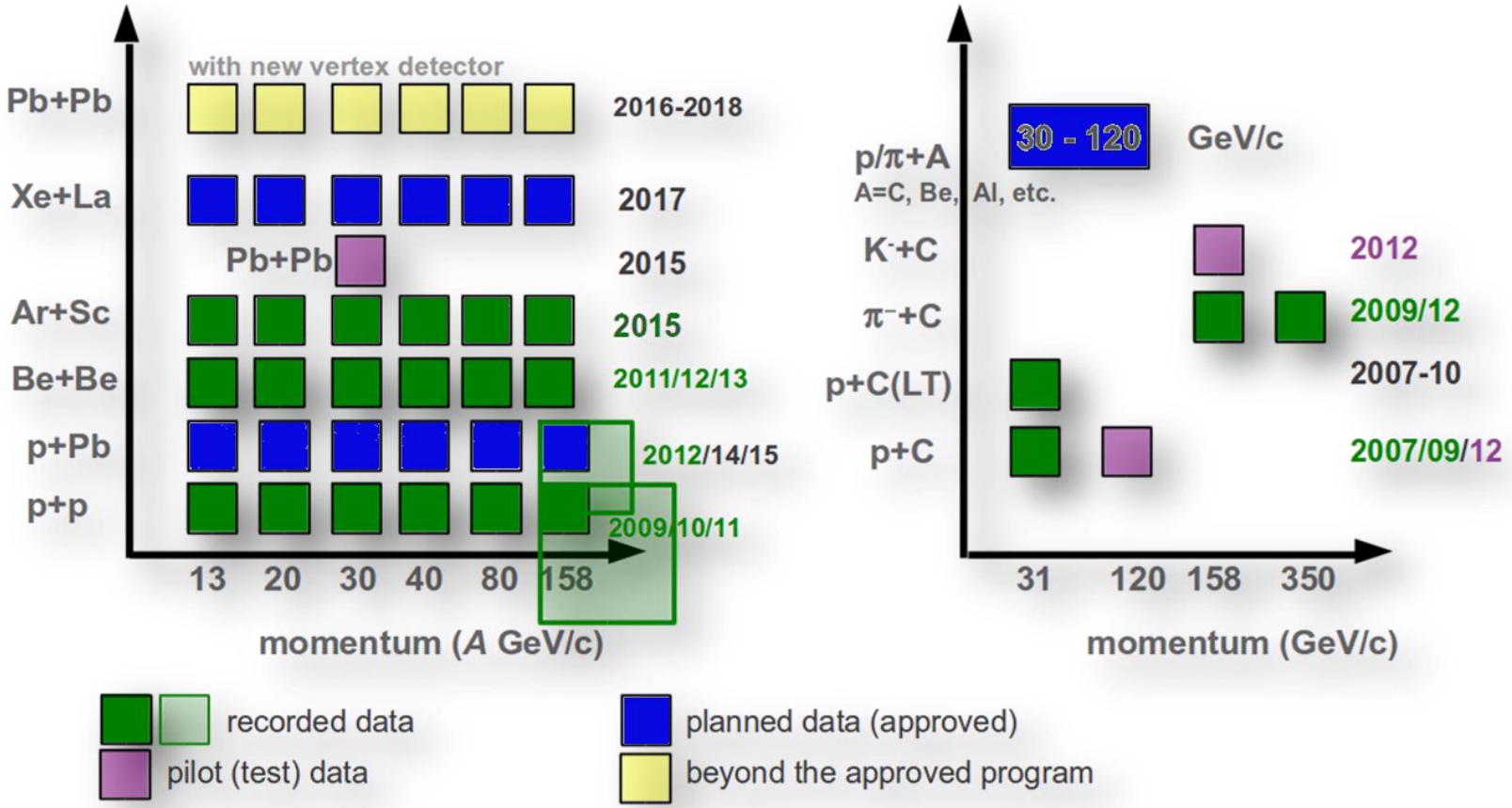


D^0 candidates selected by TPCs and vertex detector



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

Extension of the data taking plan



Summary

- NA61/SHINE measures collisions of hadrons and ions for three physics programs: strong interactions, neutrinos 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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Institute for Particle and Nuclear Studies, High Energy Accelerator Research Organization, Japan
Institute of Physics, Jagiellonian University, Poland
Joint Institute for Nuclear Research, Russia
Wigner Research Centre for Physics of the Hungarian Academy of Sciences, Hungary
LPNHE-Universites Paris, France
Institute of Physics, University of Silesia, Poland
Ruđer Bošković Institute, Croatia
National Center for Nuclear Research, Poland
St. Petersburg State University, Russia
Laboratory of Astroparticle Physics, University Nova Gorica, Slovenia
Institute of Physics, Jan Kochanowski University, Poland
Nuclear and Particle Physics Division, University of Athens, Greece
National Research Nuclear University, Russia
Department of Physics and Technology, University of Bergen, Norway
Albert Einstein Center for Fundamental Physics, Laboratory for High Energy Physics, University of Bern, Switzerland
Institut für Kernphysik, Goethe-Universität, Germany
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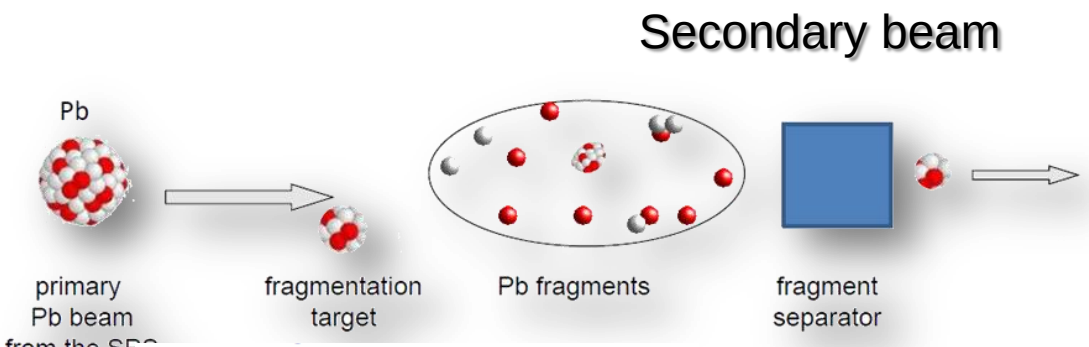
THANK YOU

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



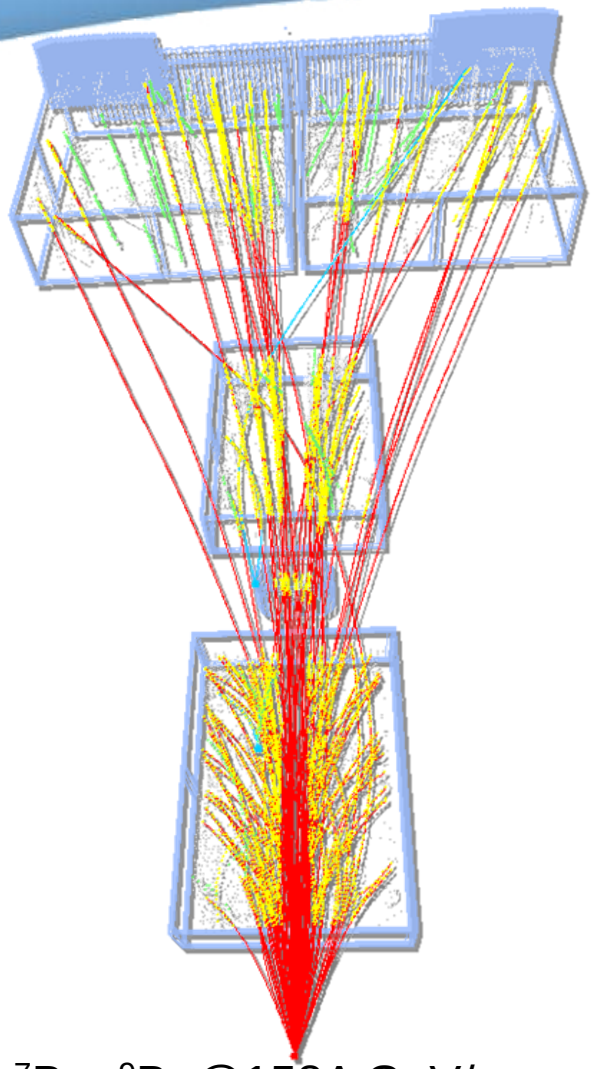
CERN COURIER

Apr 27, 2012

Light work with heavy ions

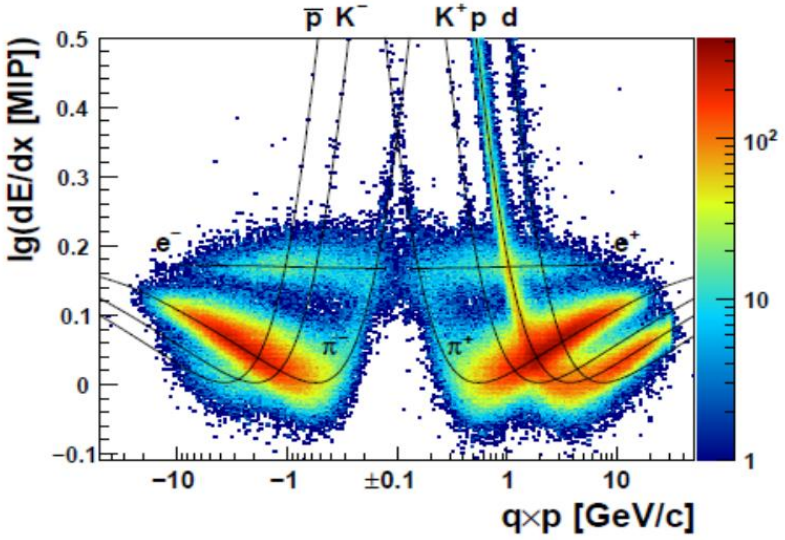
H. Stroebele & I. Efthymiopoulos

NA61/SHINE Detector

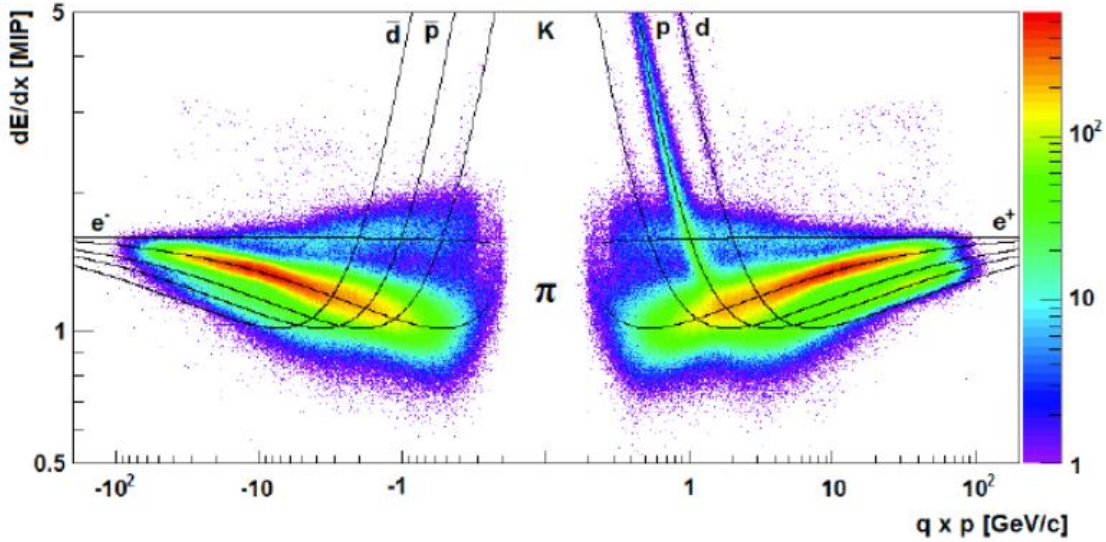


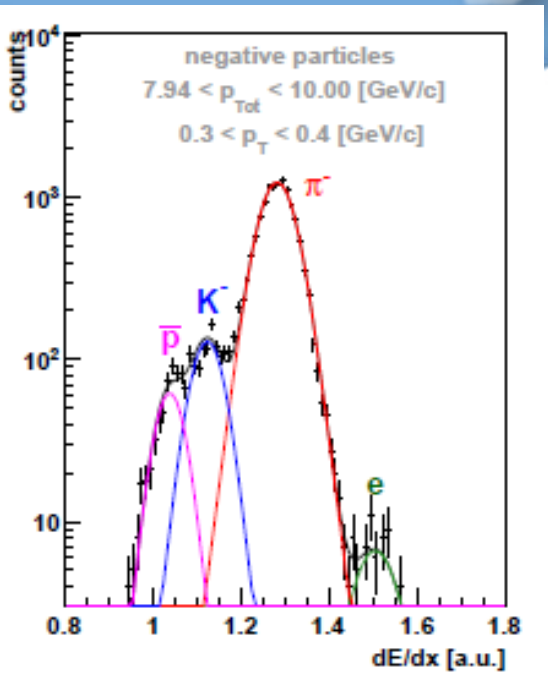
^{7}Be+^{9}Be@158A GeV/c

- 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



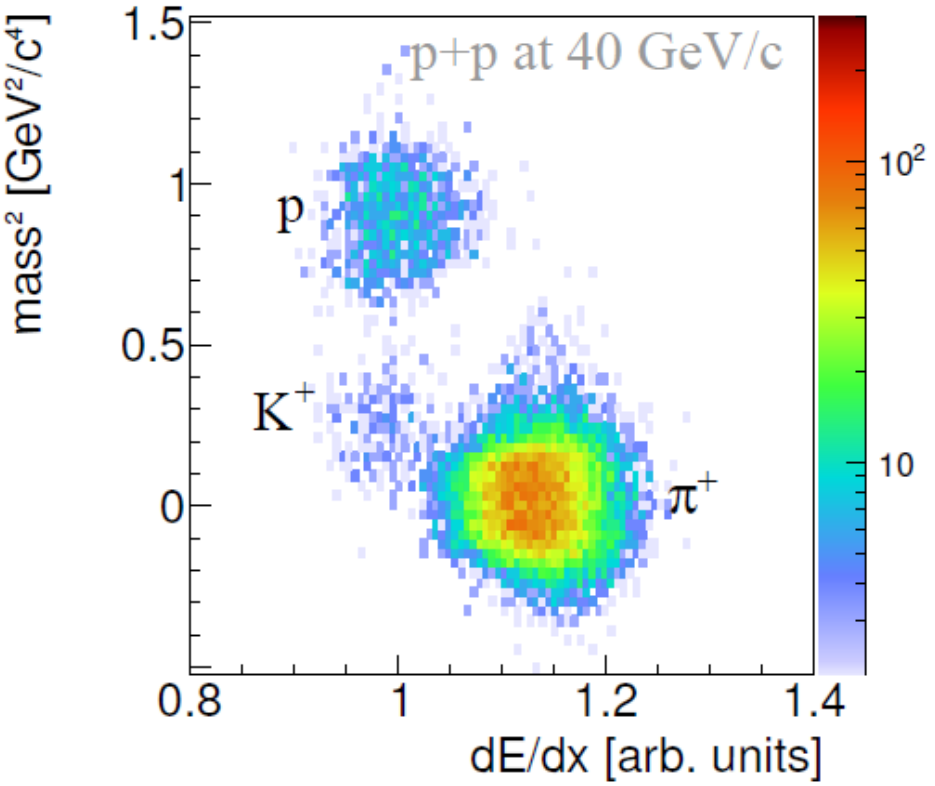
Energy loss (dE/dx) method





- 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

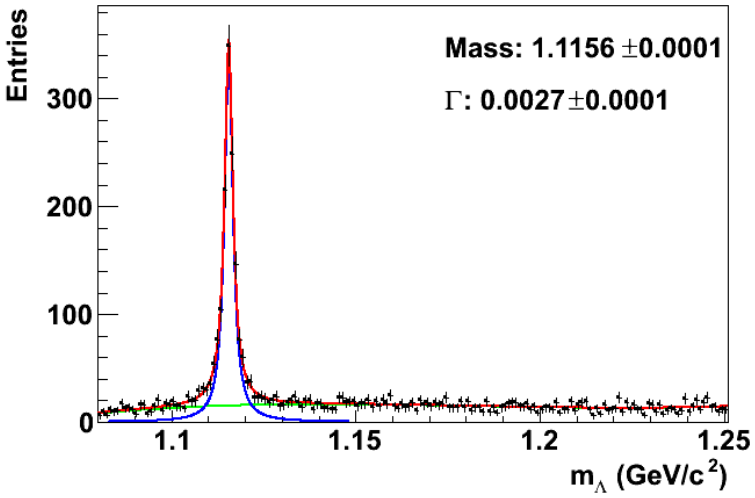
Energy loss (dE/dx) vs time of flight (tof) method



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

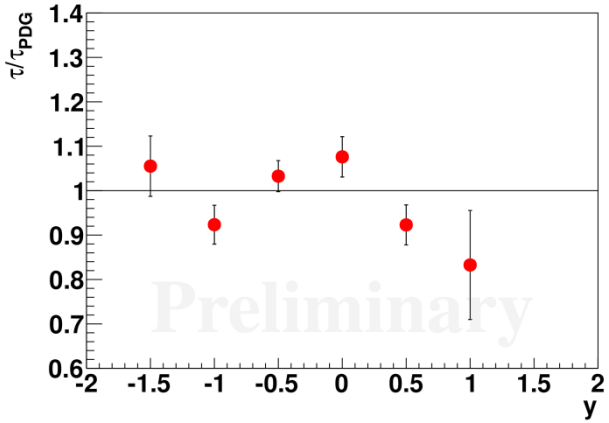
V^0 – method

- 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

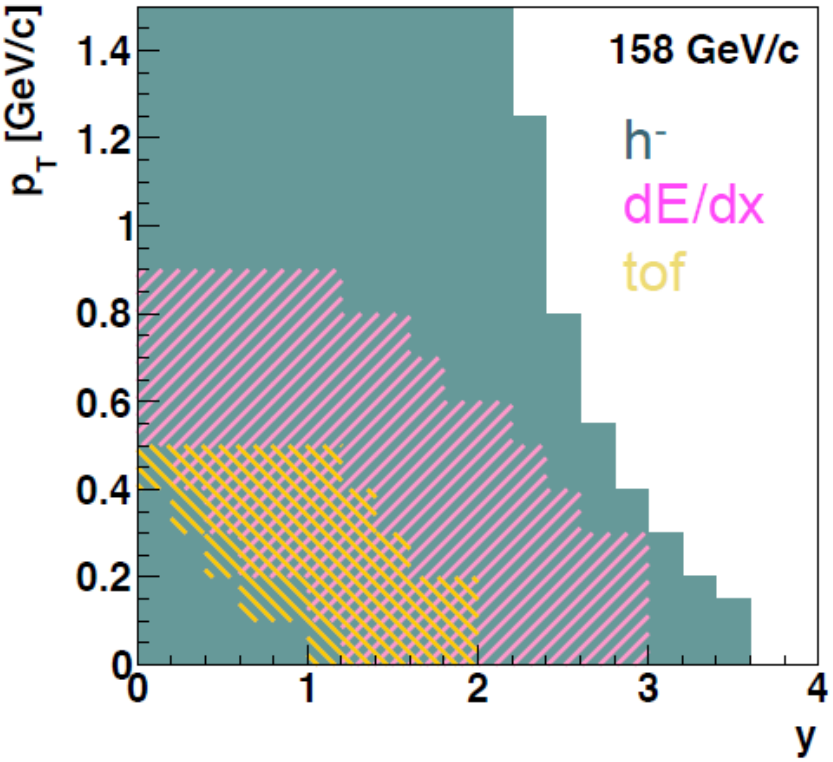
Lifetime is calculated based on the difference between position of the main and the decay vertex



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

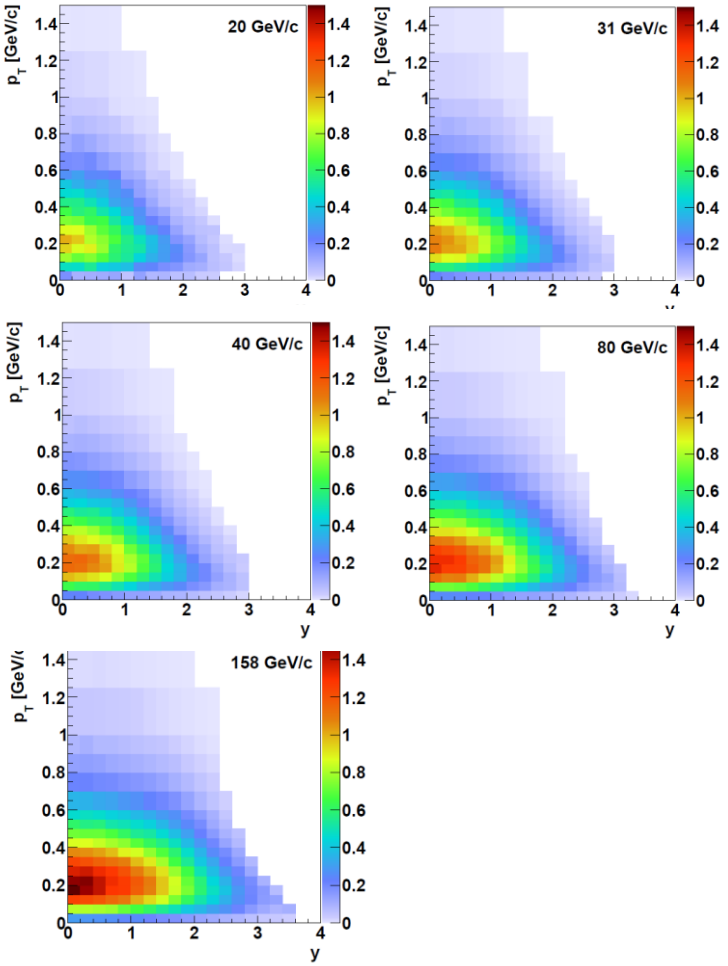
h^- analysis method

- 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

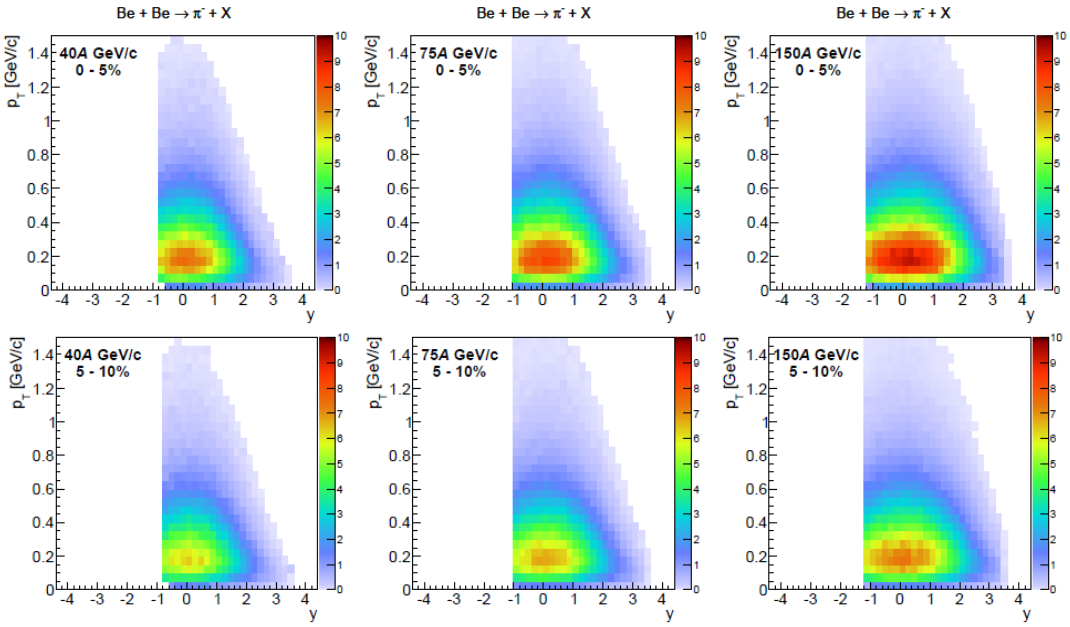


Precise measurements (π^- meson)

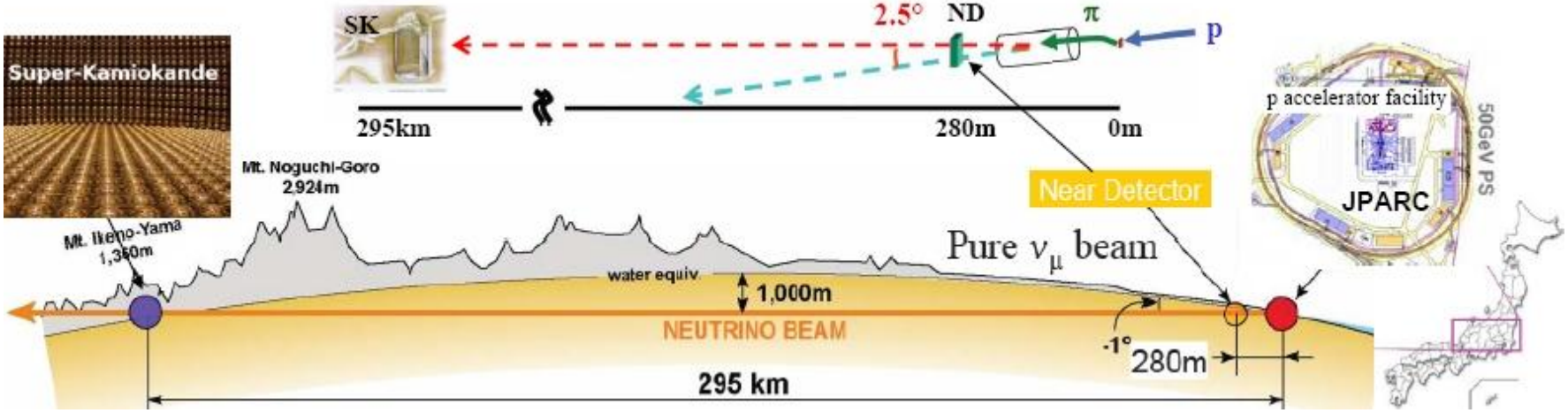
p+p collisions



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



Hadron-production measurements for neutrino experiments

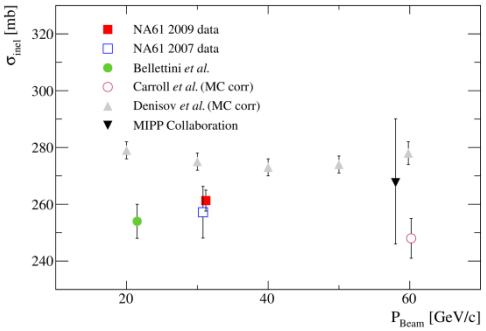


The T2K experiment published a measurement of θ_{13} angle in the neutrino mixing matrix (PRL 107, 041801 (2011))

Systematic error estimate was based on the NA61/SHINE results

39

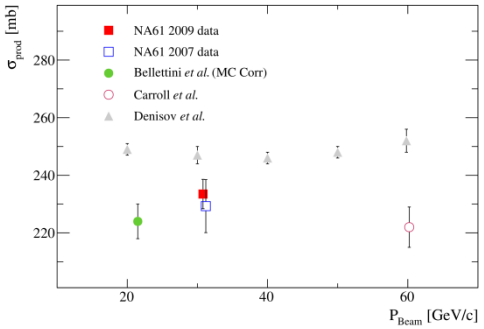
Hadron-production measurements for neutrino experiments

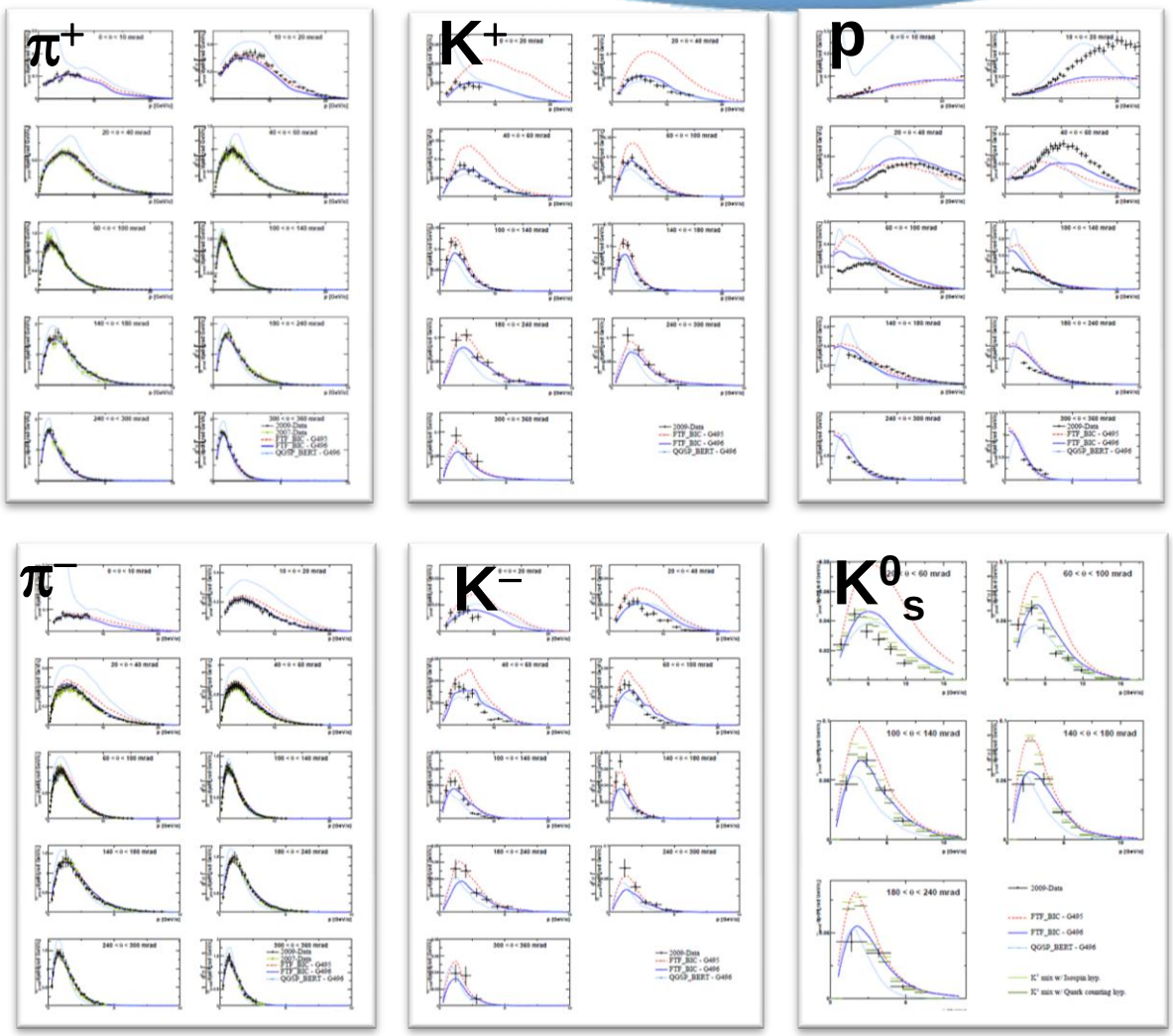


High statistics 2009 p+C at 31GeV/c "thin-target" dataset

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

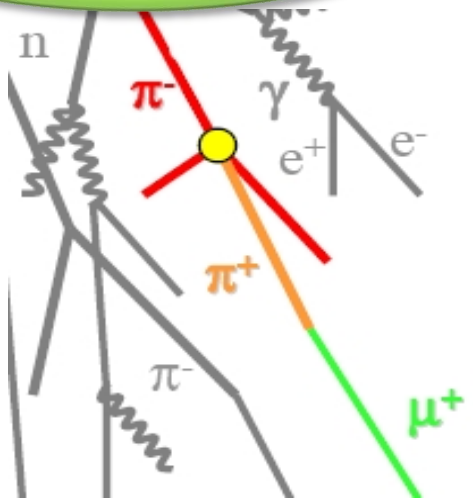
Cosmic ray composition of central importance for understanding sources, kink, ankle...

Modern detector installations: high statistics/quality data

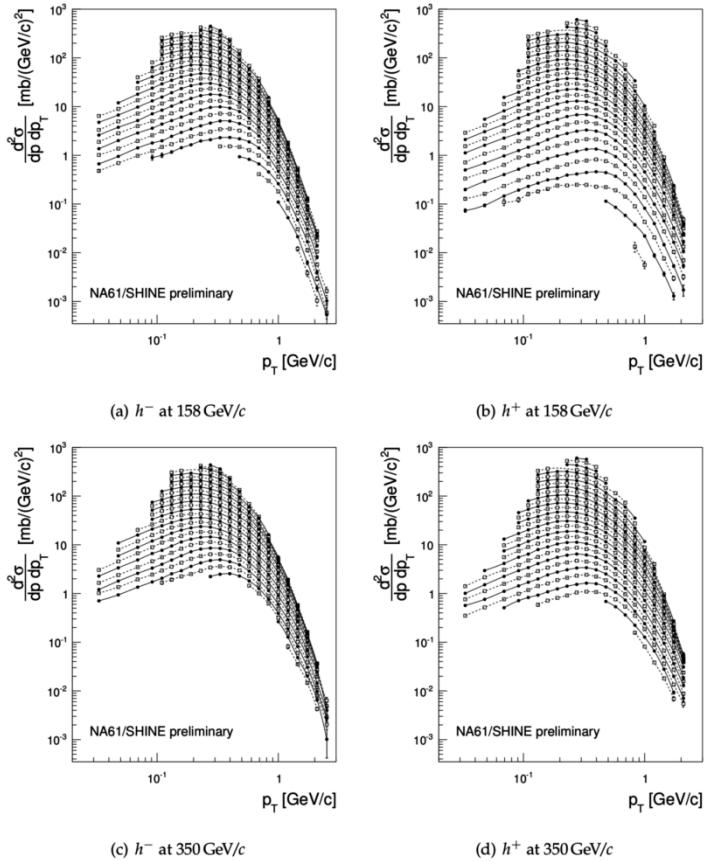
Indirect measurement (extensive air showers): simulations needed

Strong model dependence: due mainly to simulation of m production

m production related to hadronic interactions at fixed-target energies



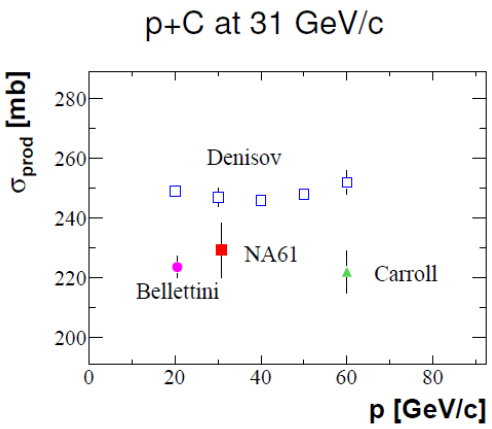
Hadron-production measurements for cosmic ray experiments

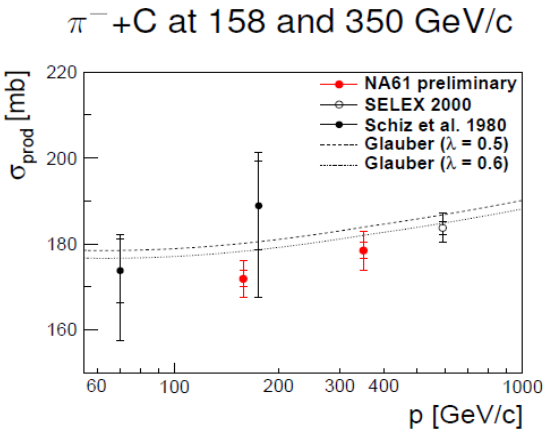


(a) h^- at 158 GeV/c (b) h^+ at 158 GeV/c

(c) h^- at 350 GeV/c (d) h^+ at 350 GeV/c

Cross sections measurements





Input for validation/tuning of Monte Carlo generators