Results and prospects of the NA61/SHINE experiment at the CERN-SPS

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ZWS-2012

6 December 2012

Outline

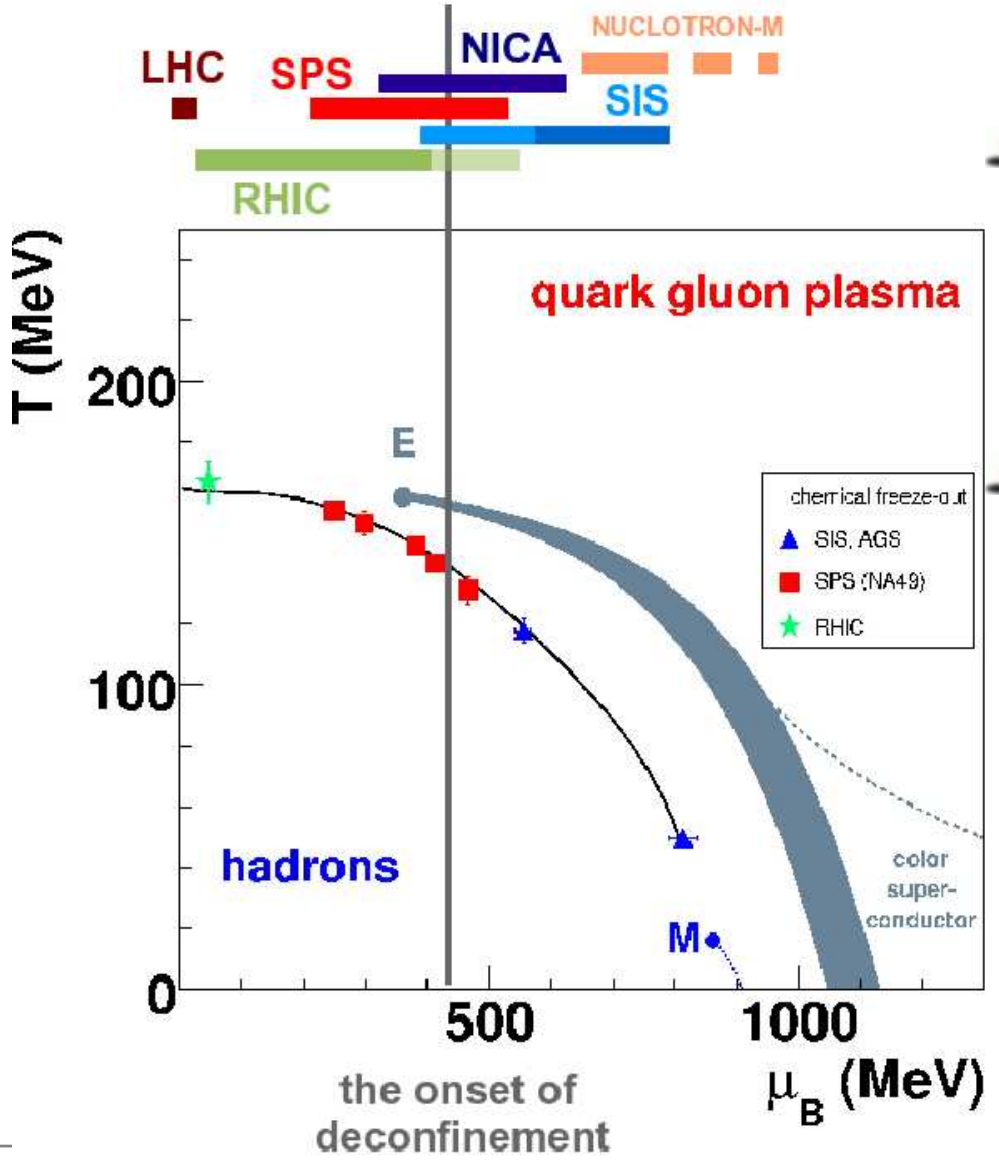
NA61/SHINE is a fixed target experiment at the CERN SPS.

- Physics goals: hadron production in h+A, A+A at SPS.
  - Search for the critical point of strongly interacting matter and study the onset of deconfinement.
  - High p_T hadron spectra to study in-medium modification.
  - Hadron spectra for T2K ν experiment.
  - Hadron spectra for Pierre Auger CR observatory.
- The NA61/SHINE experiment.
- Recent results.
- Data taking plans.
- Summary.

NA61: North Area 61 / SHINE: SPS Heavy Ion and Neutrino Experiment

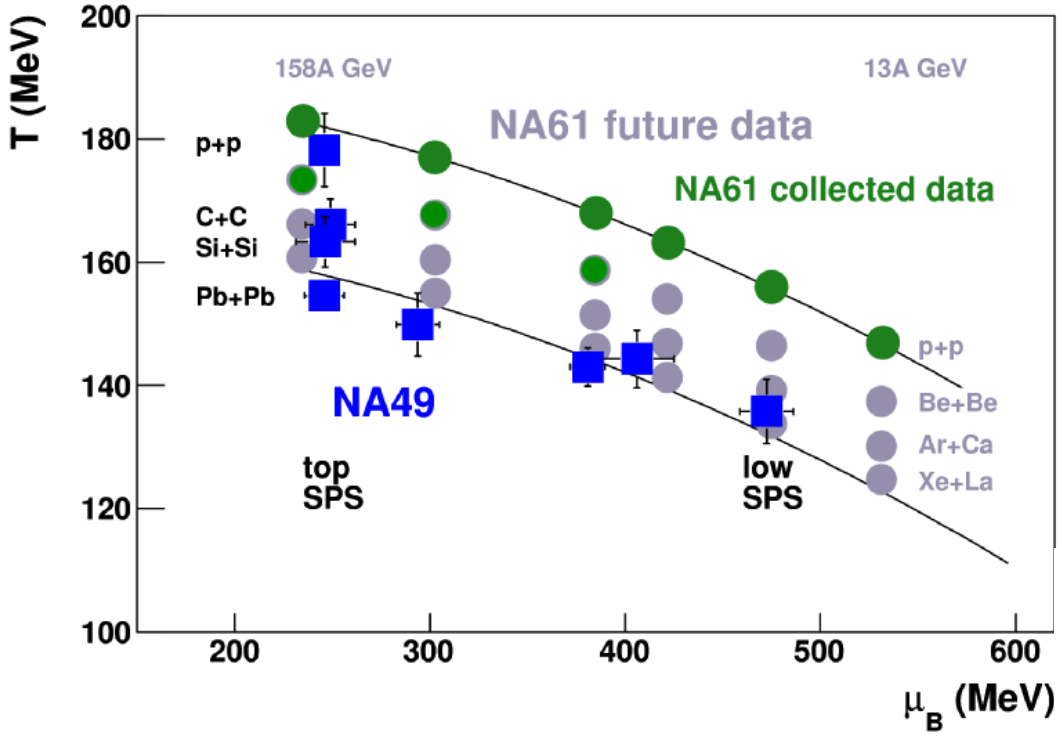
Physics goals

Search for the critical point of strongly interacting matter:

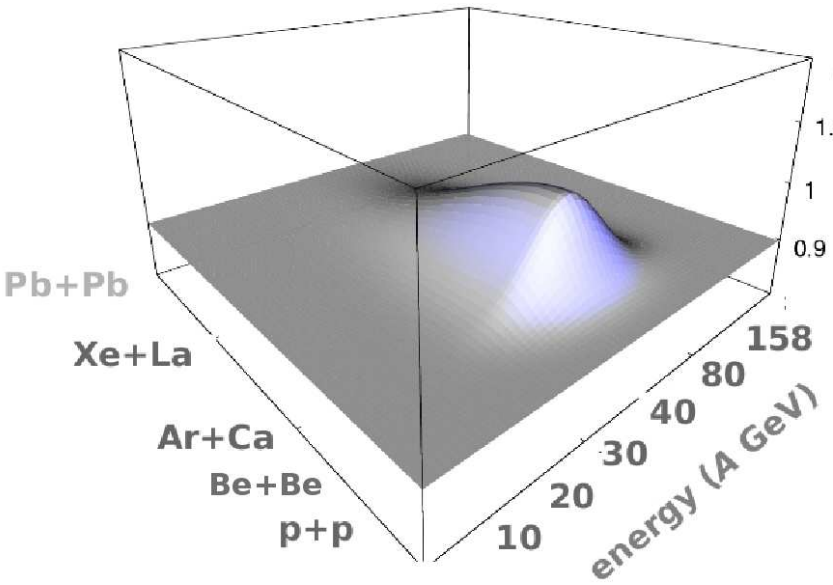


- Phase diagram of Strongly Interacting Matter according to lattice QCD calculations:
  first order phase boundary, ending in a critical point.
- At CERN SPS fixed target experiments: access to the relevant region.

Freezeout points at SPS fix target expected to be close to critical point.

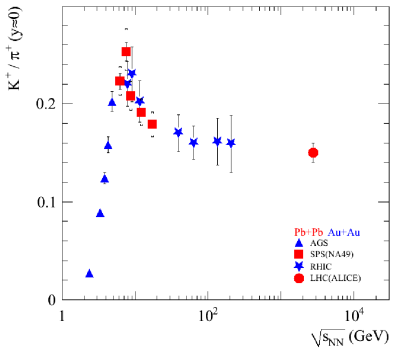


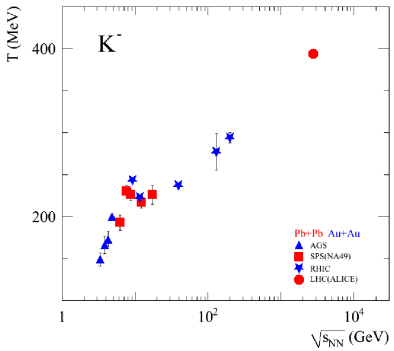
- Beccatini, Manninen, Gazdzicki: PRC **74** (2006) 044905.
- T, μ_B is related to the energy and system size of the collision.

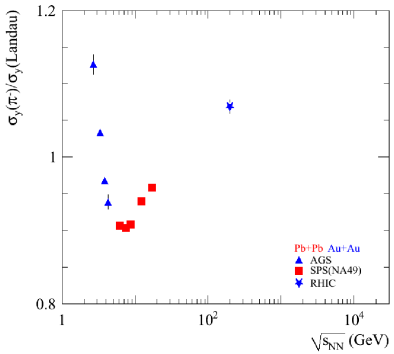


- Expectation: increase of critical point signal (e.g. multiplicity, p_T fluctuations) for system freezing out near the critical point.
- Search for "hill of fluctuations" with $E - A$ scan.

Study onset of deconfinement in strongly interacting matter:

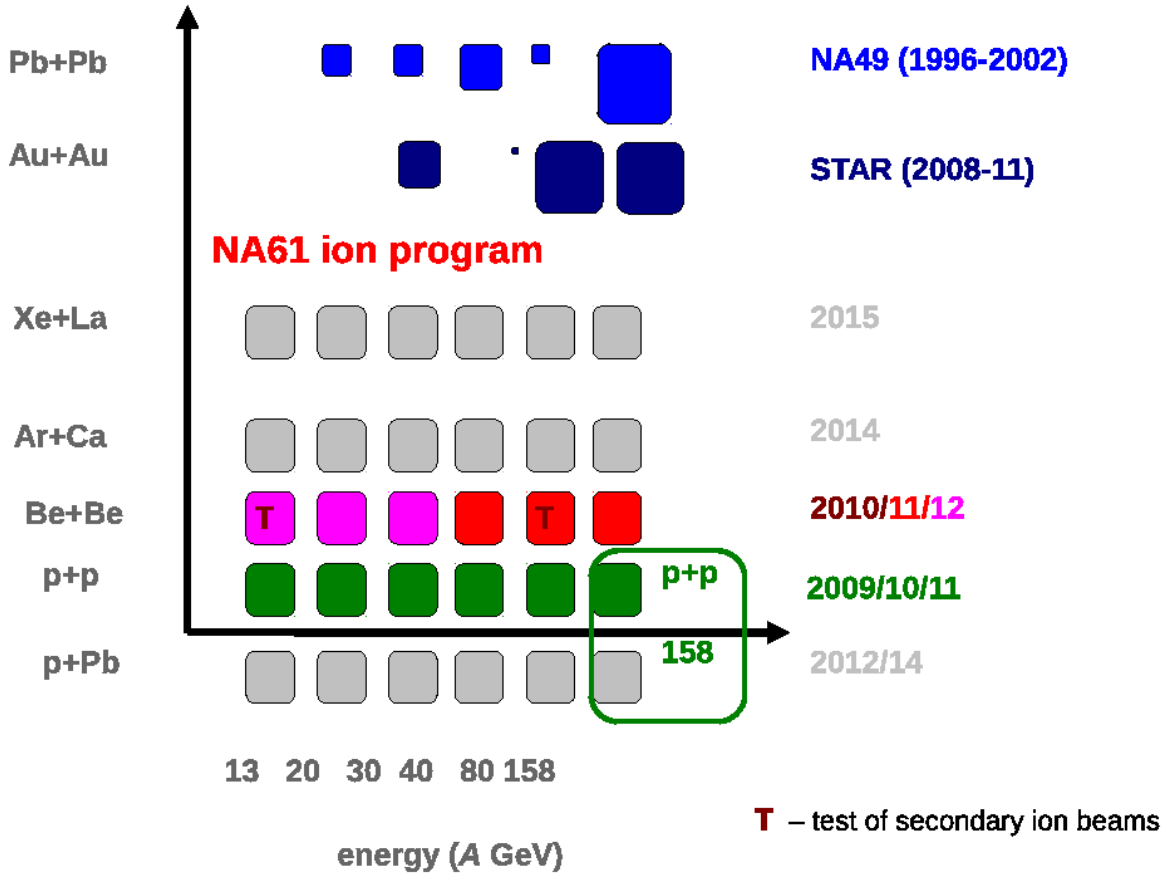






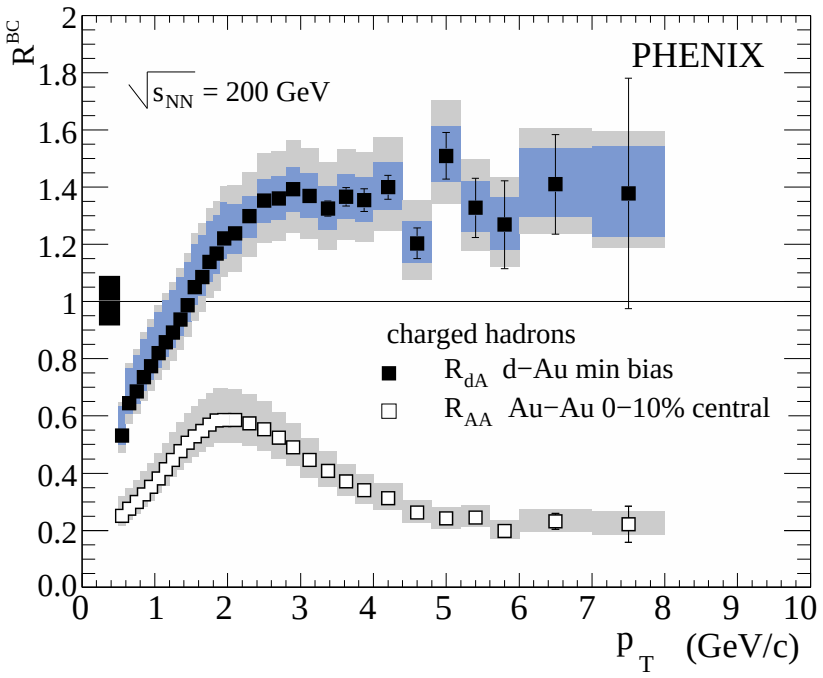
- AGS – SPS – RHIC – LHC data in A+A collisions: indication for deconfinement near 30A GeV [PRC **77** (2008) 024903].
- Observed phenomena: "horn" (in strangeness production), "step" (in temperature), "dale" (in longitudinal expansion).
- Hard to explain in statistical and dynamical models that do not include HG – QGP phase transition.
  - Horn: decrease of strangeness carrier masses.
  - Step, dale: constant T and p in mixed phase.
- Effect not seen to be present in light systems (p+p). What happens with intermediate systems?

Search for critical point and study of onset of deconfinement motivates:
an experimental program for $E - A$ scan in SPS fixed target energy range.



Existing data (NA49, STAR) are also shown.

High p_T hadron spectra to study in-medium modification:

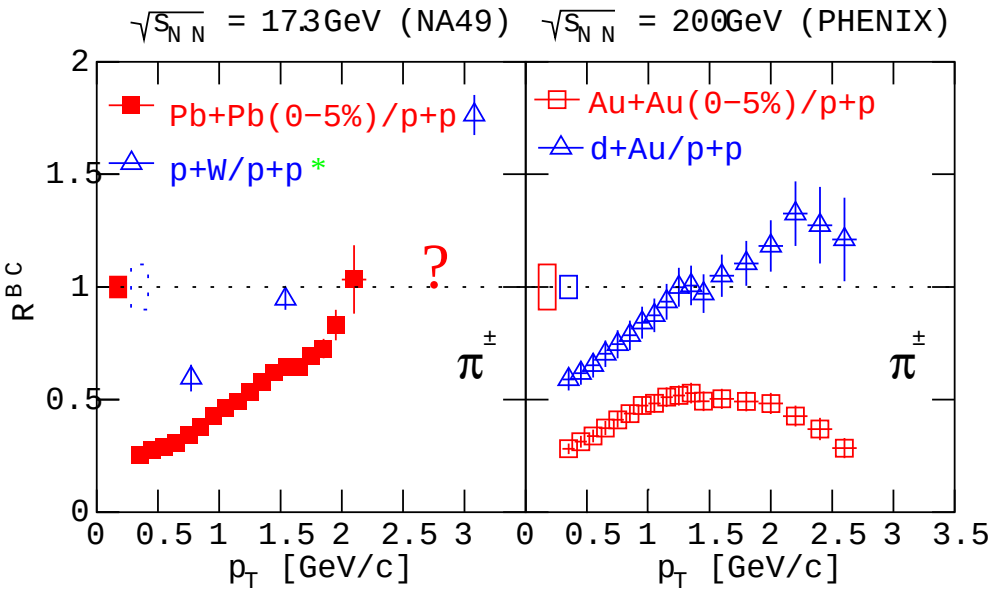


$$R^{BC}_{A+B} = \frac{1}{\langle N_{BC} \rangle (A+B)} \cdot \frac{\text{Yield}(A+B)}{\text{Yield}(p+p)}$$

PRL **91** (2003) 072303.

Suppression of high p_T hadrons in A+A.

E dependence?



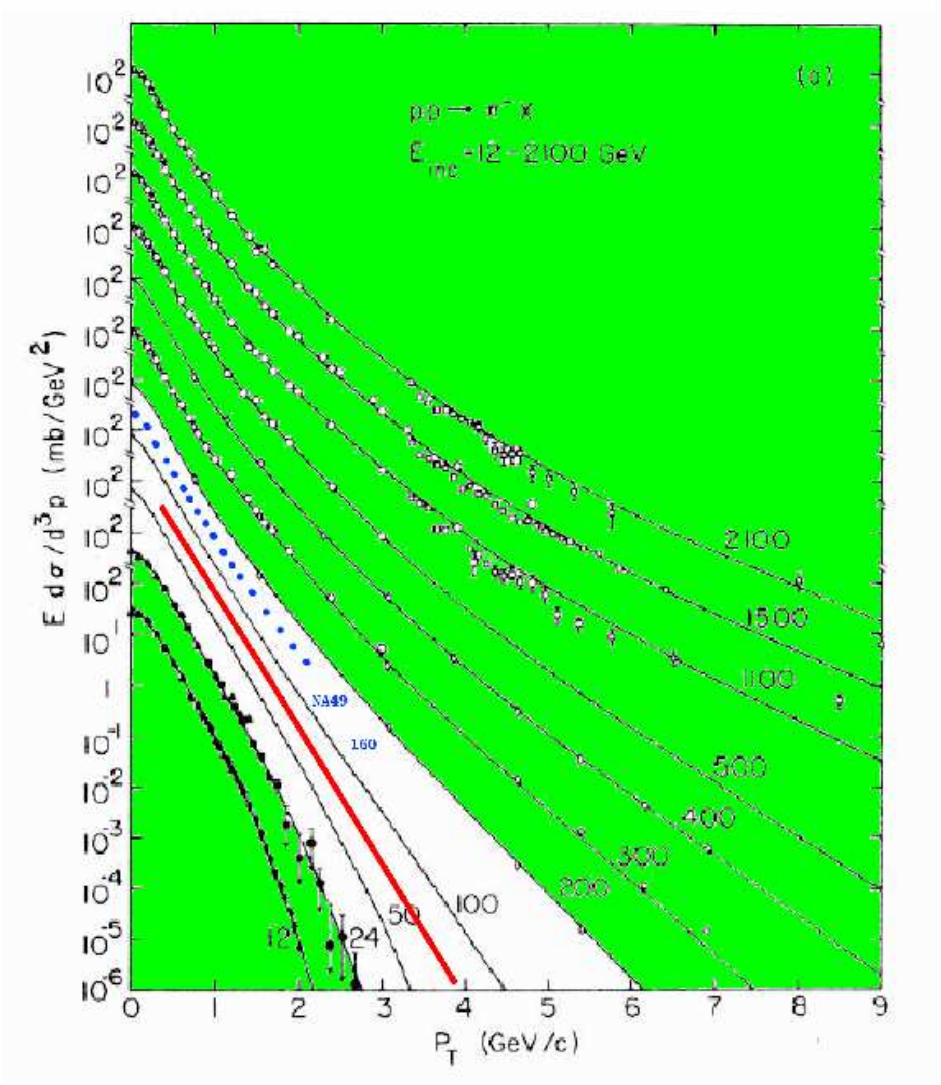
$\sqrt{s_{NN}} = 200\,\text{GeV}$
PRC **69** (2004) 034910,
PRC **74** (2006) 024904.

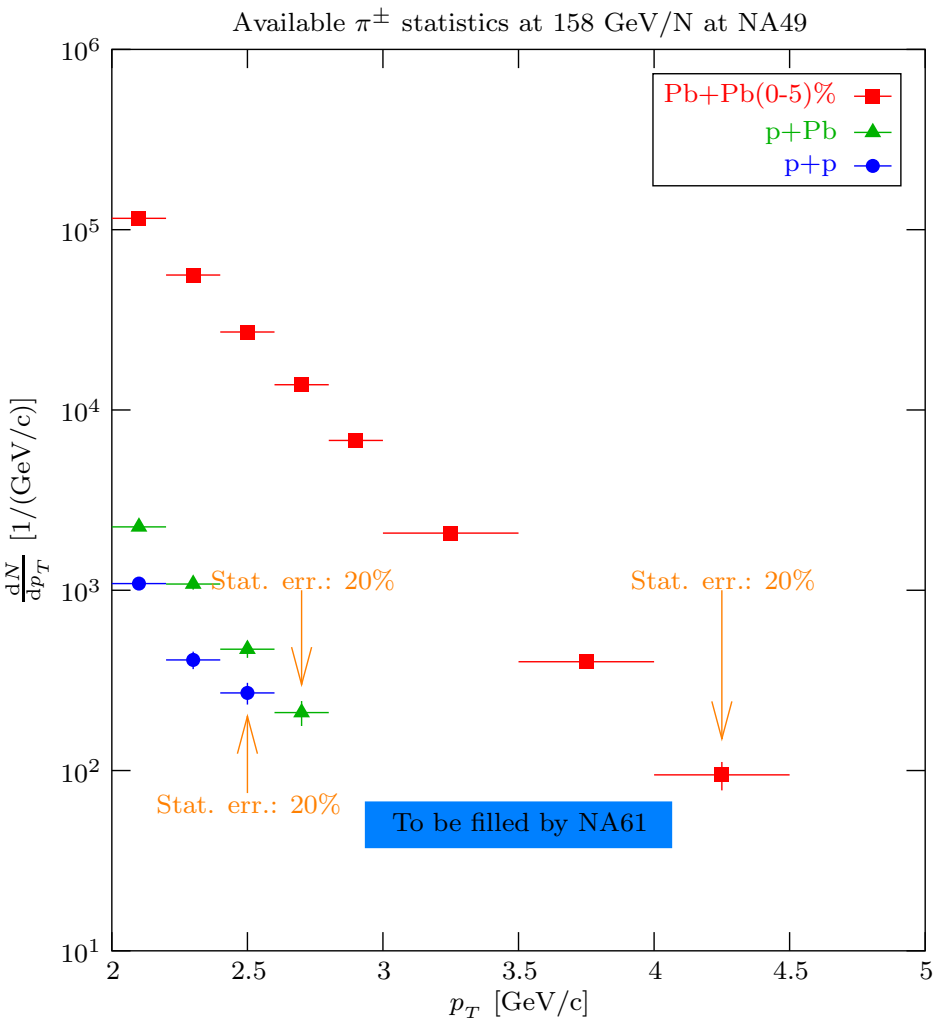
$\sqrt{s_{NN}} = 17.3\,\text{GeV}$
PRC **77** (2008) 034906.

*: $\sqrt{s_{NN}} = 19.4\,\text{GeV}$
PRD **19** (1979) 764.

No p+p data in the $\sqrt{s_{NN}}$ range in literature.

No enough p+p statistics at NA49.

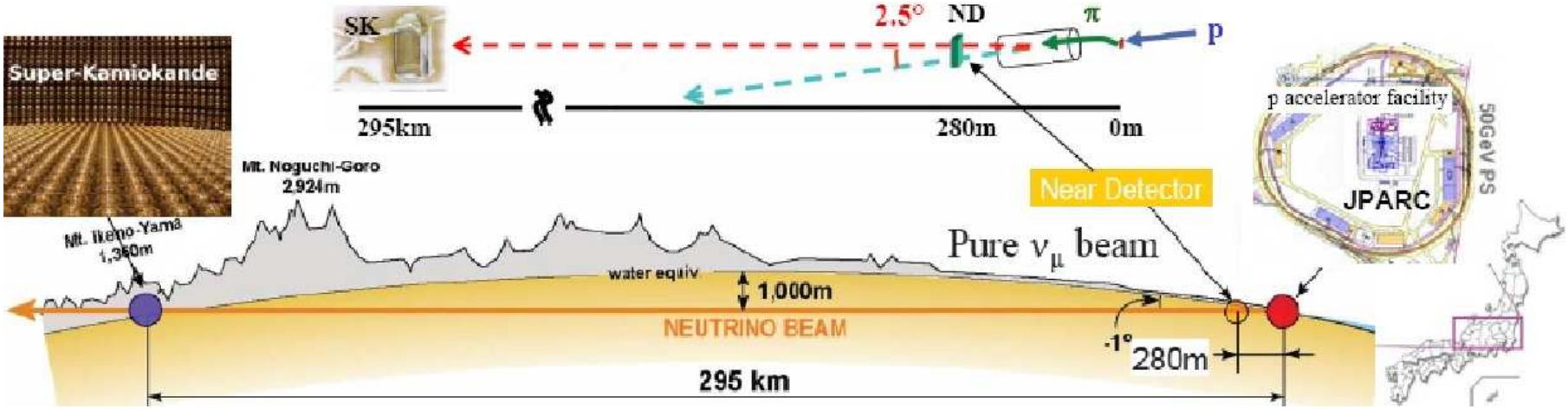




Rapid change of spectrum shape: unsafe extrapolation. Have to be measured.

Hadron spectra for ν experiments:

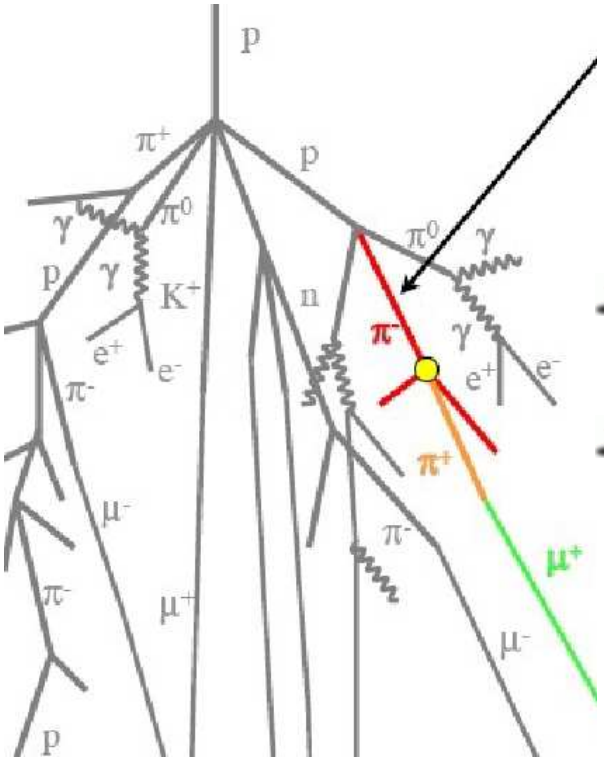
- T2K (Tokai to Kamiokande) is a ν beam experiment.
- ν_μ beam is generated by decays of $\pi^\pm, K^\pm$ produced in $p + C$ collisions at JPARC.
- ν_μ beam is projected onto SuperKamiokande, in 300km distance.
- ν oscillation is characterized by far-to-near flux ratios.



- Corrections and systematic error estimation depends on $p + C \to \pi^\pm, K^\pm + X$ production.
- NA61 measured and published $p + C \to \pi^\pm, K^+ + X$ results at $31\,\mathrm{GeV/c}$ beam mom., specialy for T2K community: PRC **84** (2011) 034604, also `arXiv:1112.0150`.

Hadron spectra for cosmic ray observatories:

- Pierre Auger Observatory is a large area cosmic ray detector.
- Cosmic rays are detected via products of air-shower induced by them
  $\Rightarrow$ strong dependence on modelling of shower evolution.
- Shower evolution strongly depends on the $\pi^{\pm}$+air-nucleus$\rightarrow \pi^{\pm} + X$ production in the vicinity of the SPS fixed target energies. (Air-nucleus $\approx$ carbon.)

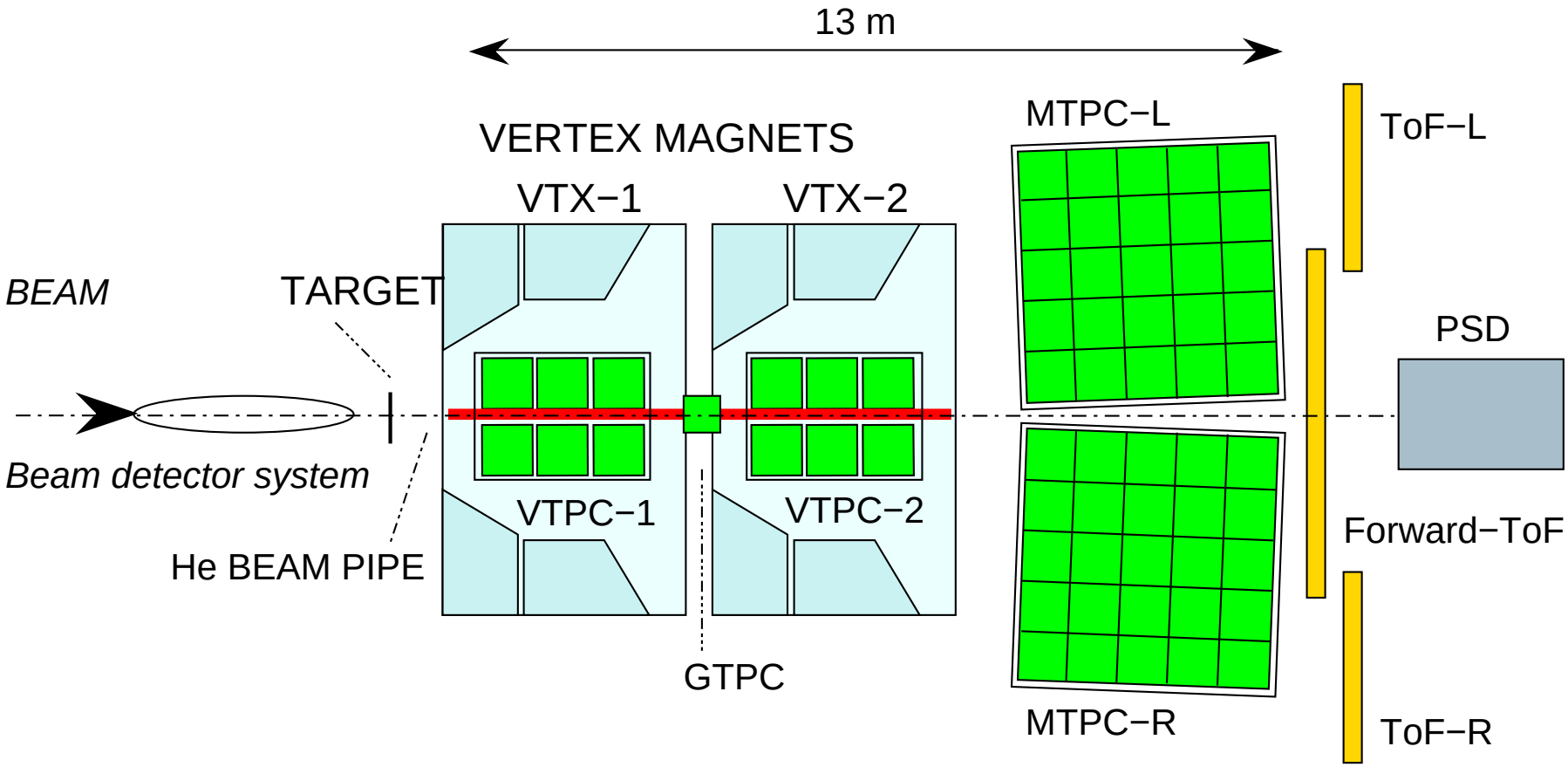


- NA61 recorded data on $\pi^- + C$ interactions at 158 and $350\,\mathrm{GeV/c}$.
- Also useful: $p + C$ at $31\,\mathrm{GeV/c}$ and $p + p$ at $13, \ldots, 158\,\mathrm{GeV/c}$ recorded for the other experimental programs.

The NA61/SHINE experiment

Detector setup:

- NA61/SHINE is a fixed target hadron spectrometer experiment at the CERN SPS.
- Its tracking system is inherited from the former NA49 experiment.
- Several upgrades are done motivated by the requirements of the physics goals.



Large variety of reactions:

- Target material is variable (Pb, C, Be, liquid-H etc).
- Large variety of primary and secondary SPS beams.
  - Secondary hadron beams (p, $\pi^{\pm}$) at $10 - 350\,\mathrm{GeV/c}$.
  - Secondary lepton beams ($\mu^{\pm}$, $e^{\pm}$) at $10 - 350\,\mathrm{GeV/c}$.
  - Secondary (fragmented) light-ion beams (^7Be) at $10 - 160\,\mathrm{GeV/c}$ per nucleon.
  - Primary heavy-ion beams (Pb, Ar, Xe) at $10 - 160\,\mathrm{GeV/c}$ per nucleon, when compatible with LHC.
  - Beam particle identification with Cerenkov triggers for purity.

Main detector parameters:

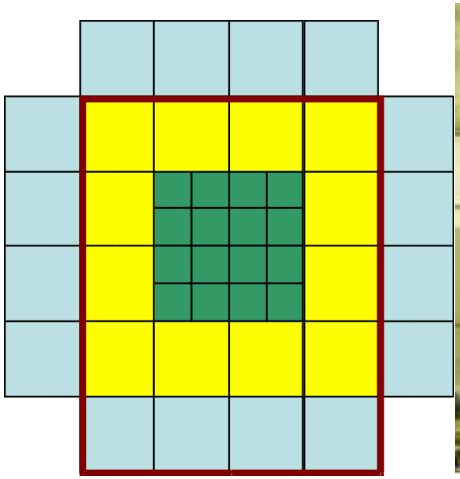
- Large acceptance ($\approx 50\%$ at $p_T \leq 2.5\,\mathrm{GeV/c}$).
- Good momentum resolution ($\sigma(p)/p^2 \approx 10^{-4}\,(\mathrm{GeV/c})^{-1}$ at the full magnetic field).
- Good tracking efficiency ($\geq 95\%$).
- Good particle identification capabilities.
  - Good ToF time resolution ($\sigma(t) \approx 60\,\mathrm{ps}$).
  - Good $\frac{\mathrm{d}E}{\mathrm{d}x}$ resolution ($4 - 6\%$).
  - Good V^0 mass resolution ($\sigma(m) \approx 5\,\mathrm{MeV}$).

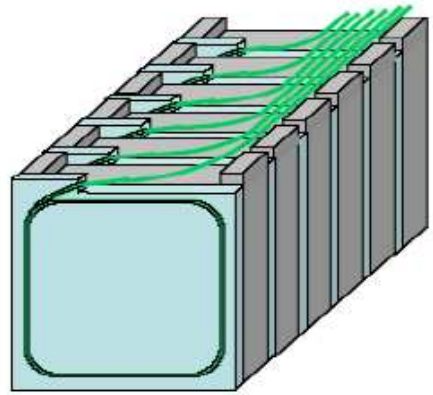
Main detector upgrades:

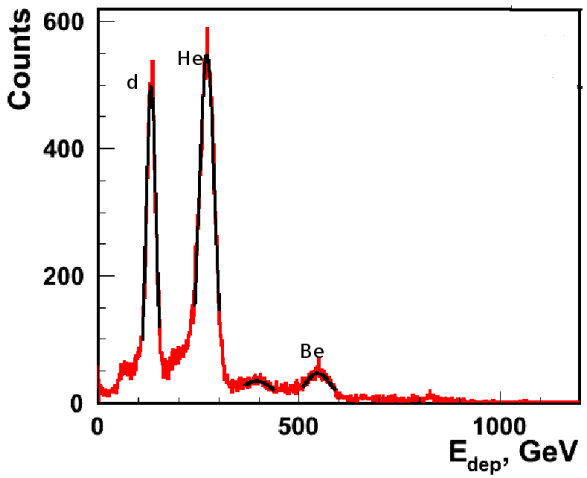
- 2007: Construction of the forward ToF wall to identify $p < 3\,\mathrm{GeV/c}$, $\theta < 400\,\mathrm{mrad}$ particles (down to $p \approx 1\,\mathrm{GeV/c}$).
- 2008: Replacement of the TPC readout and central DAQ to increase event rate to $\approx 80\,\mathrm{Hz}$ (factor 10 increase).
- 2010: Improvement of beamline for production of fragmented ion beams for light ion program.
- 2011: Replecement of the old calorimeter (VCAL) used for event centrality measurement in A+A by spectator energy by the new Projectile Spectator Detector (PSD) to get 1 nulceon precision (factor 5 improvement).
- 2011: Insertion of He beam pipes to VTPCs to eliminate δ-electrons.
- 2011: Z-detectors (Cerenkov) to measure beam charge of secondary beam ions.
- 2011: A-detector (time-of-flight) to measure isotope composition of secondary ion beams.
- 2011: Construction of Low Momentum Particle Detector (LMPD) for centrality measurement in p+A by counting gray protons.
- 2011: Started software upgrade to assure long-term maintainability.

Recent important upgrades – first physics data with the PSD (2011)

- Calorimeter for measuring energy of projectile spectator nucleons for event centrality.
- Design resolution: $\sigma(E)/E = 56\%/\sqrt{E/\mathrm{GeV}} + 2\%$ to see ± 1 nucleon.
- High transverse granularity, good uniformity, modular design, flexible geometry.
- 60 lead/scintillator sandwich layers, read out with MAPDs.



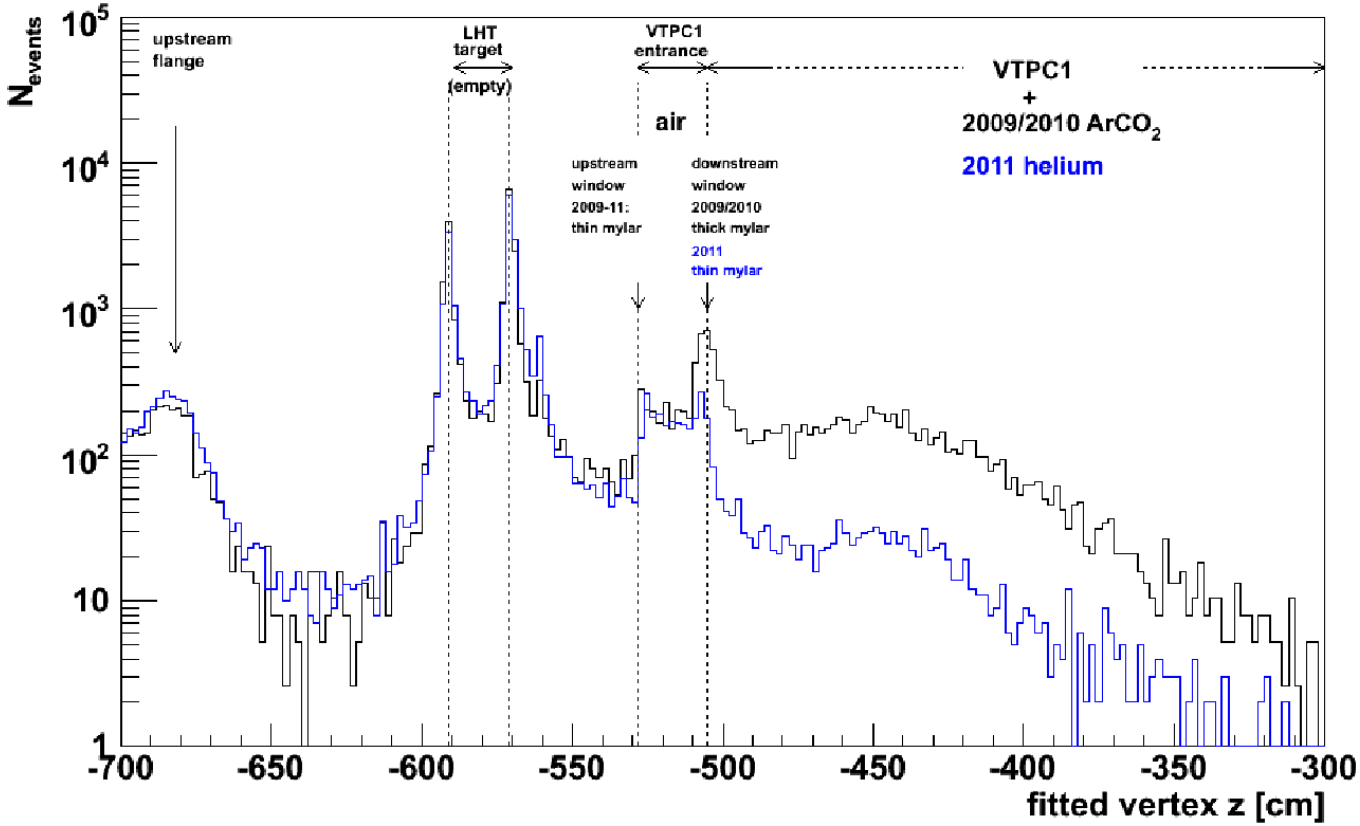




- Valparaiso group contribution: MAPDs and testing of them.
- Resolution: about factor $1.5\times$ desing resolution with preliminary calibration.

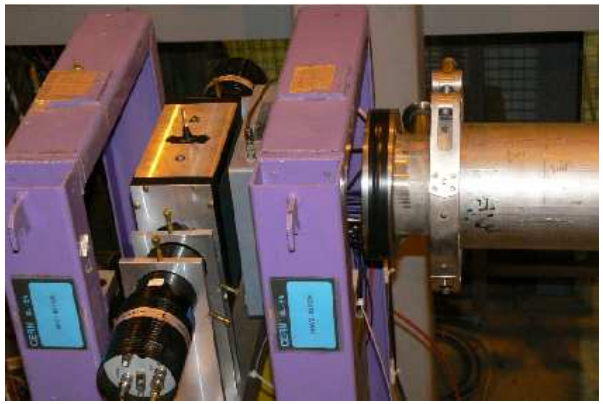
Recent important upgrades – He beam pipes in VTPCs (2011)

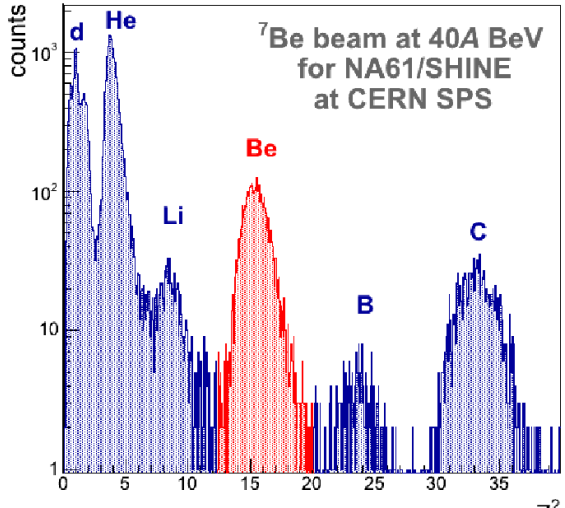
- Considerable background for fluctuation measures in search for the critical point of strongly interacting matter: δ-electrons along beamline.
- To reduce this, double-wall He beam pipes were inserted to VTPCs. Difficult surgery.
- Significant background reduction observed.



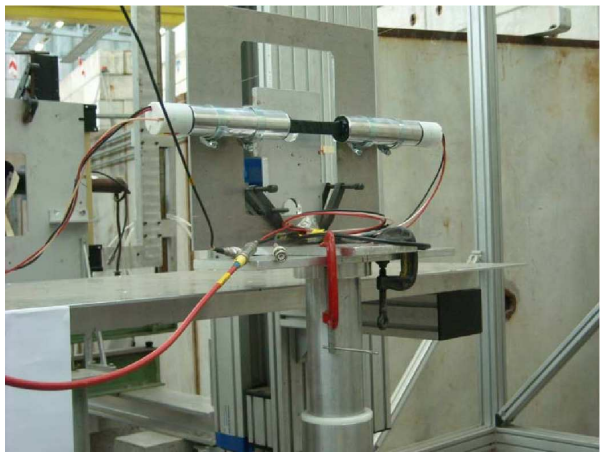
Recent important upgrades – Z and A detectors (2011)

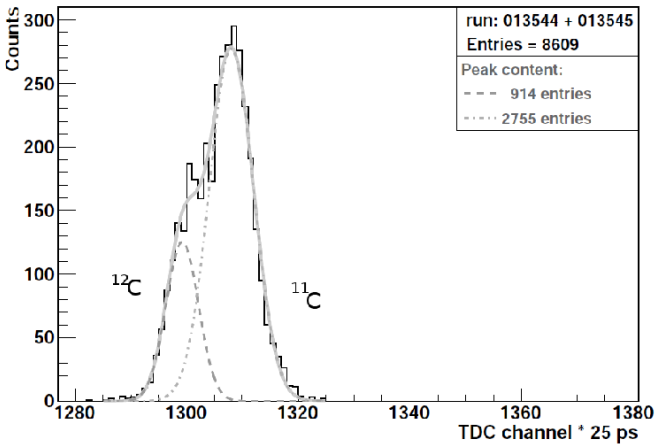
- For secondary ion beams, triggering on charge of beam nucleus is necessary.
- Constructed Z-detectors (gas and quartz Cerenkov, sensitive to Z^2):





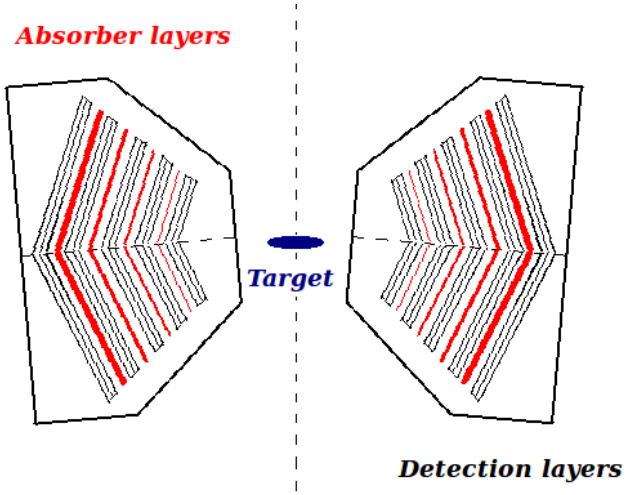
- For secondary ion beams, monitoring isotope composition is necessary (given the Z).
- Constructed diagnostic A-detector (ToF on 140m) to monitor purity:

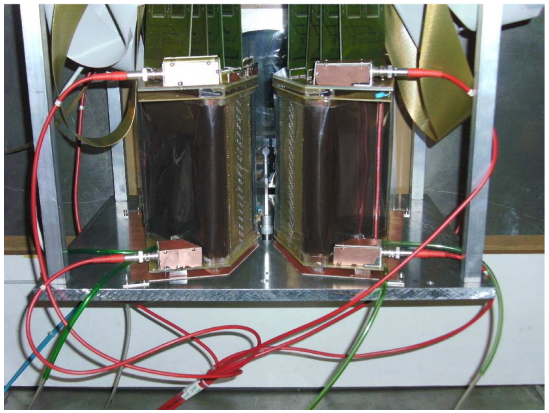


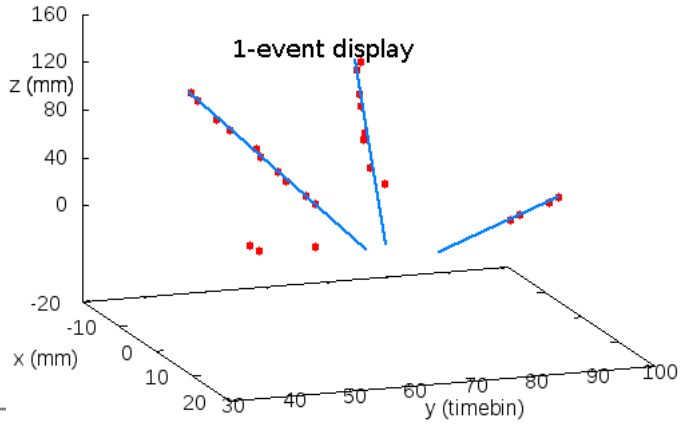


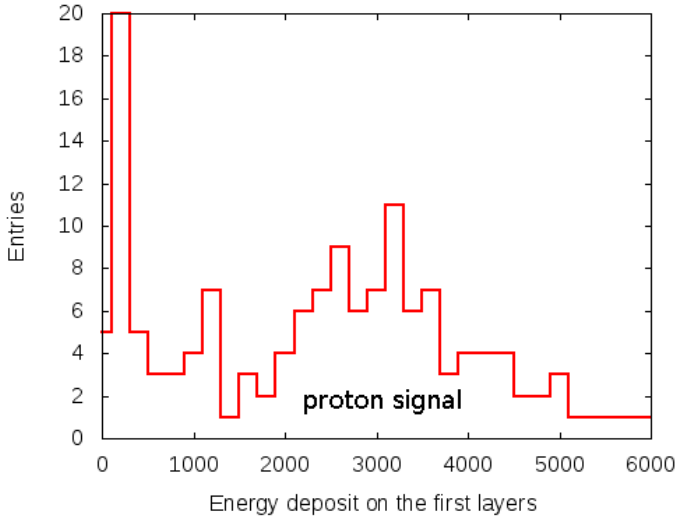
Recent important upgrades – Low Momentum Particle Detector (2011)

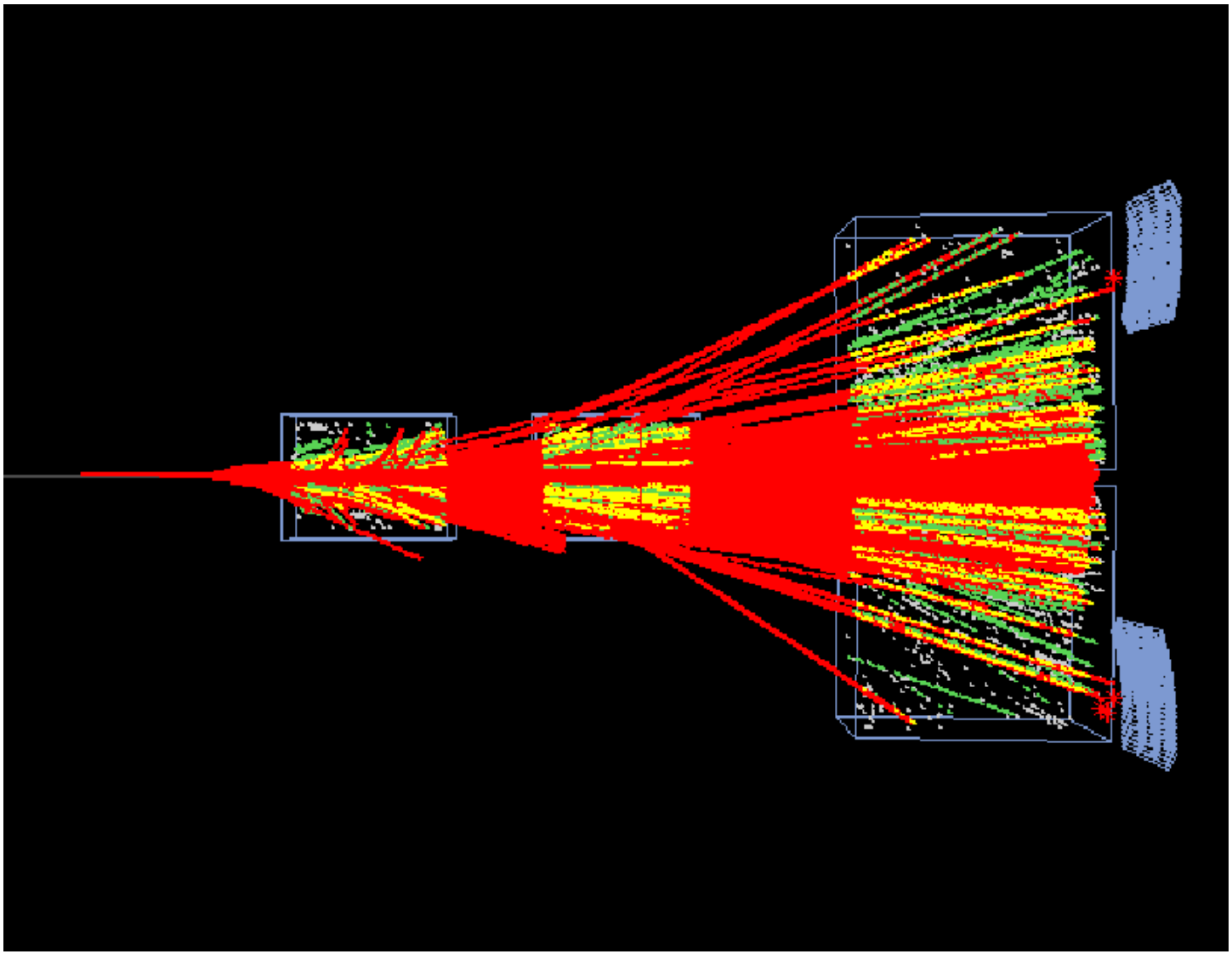
- Counts number of low momentum protons in h+A collisions for centrality determination ("target spectator detector").
- Two small size TPCs with 4 absorber layers. PID + momentum determination by $\mathrm{d}E/\mathrm{d}x$ + range measurement.









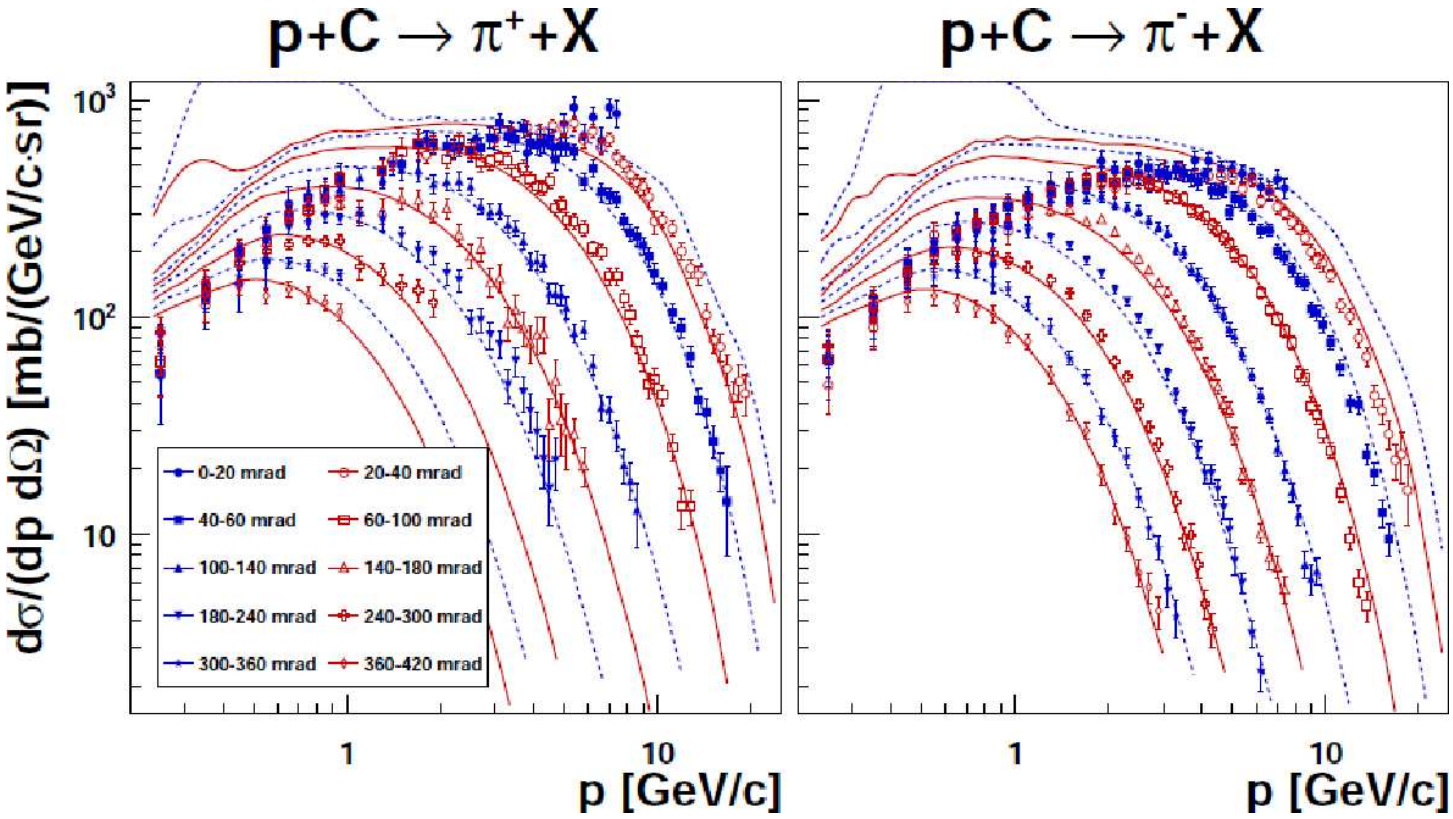


(Event display: $Pb + Pb$ @ $80\,\mathrm{GeV/c}$ per nucleon coll. from the 2011 test.)

Recent results

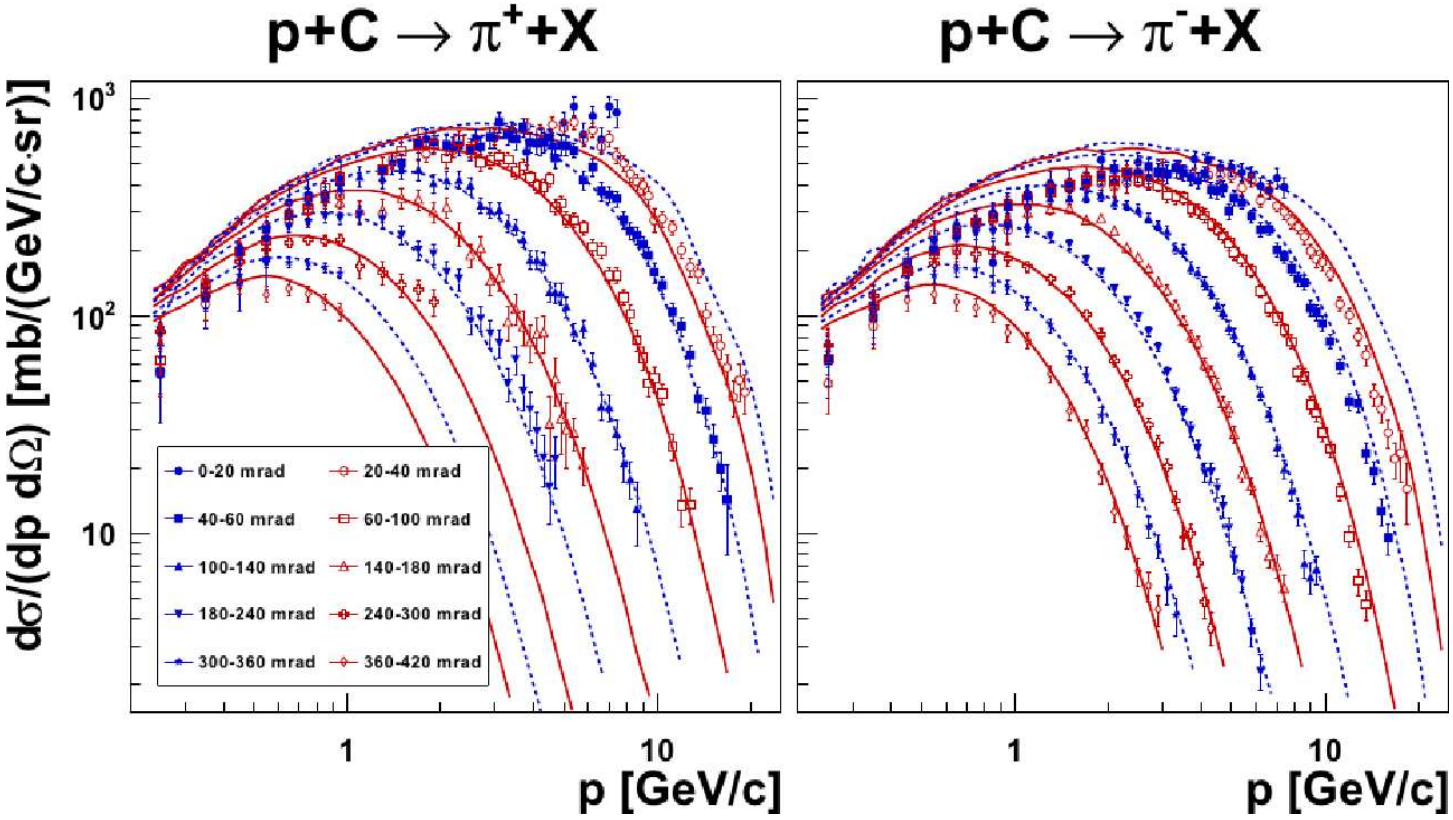
Charged pion spectra in $p + C$:

- Publication of $p + C \rightarrow \pi^{\pm} + X$ production cross-sections at $31\,\mathrm{GeV/c}$ beam momentum, PRC **84** (2011) 034604.



(Shown together with corresponding UrQMD 1.3.1 simulated data.)

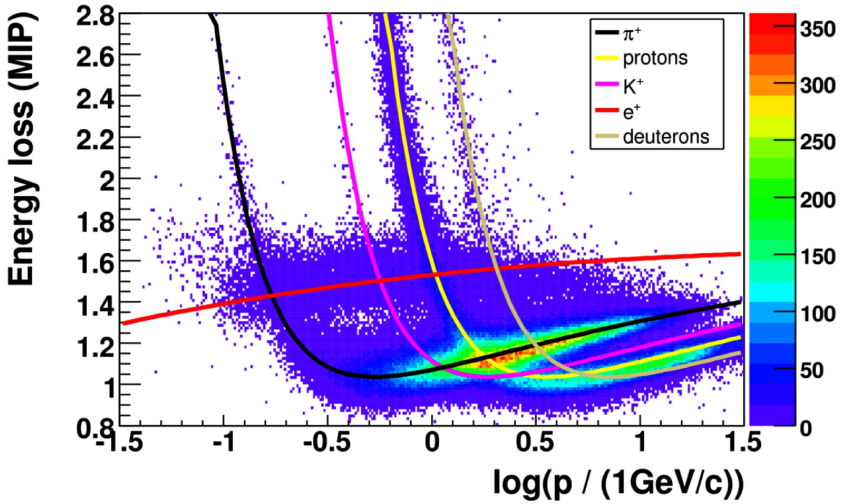
- Measured spectra were used to improve MC generators (UrQMD – `arXiv:1107.0374`, Fritiof – `arXiv:1109.6768`).
- Measured spectra were used by T2K to improve systematic error estimates.

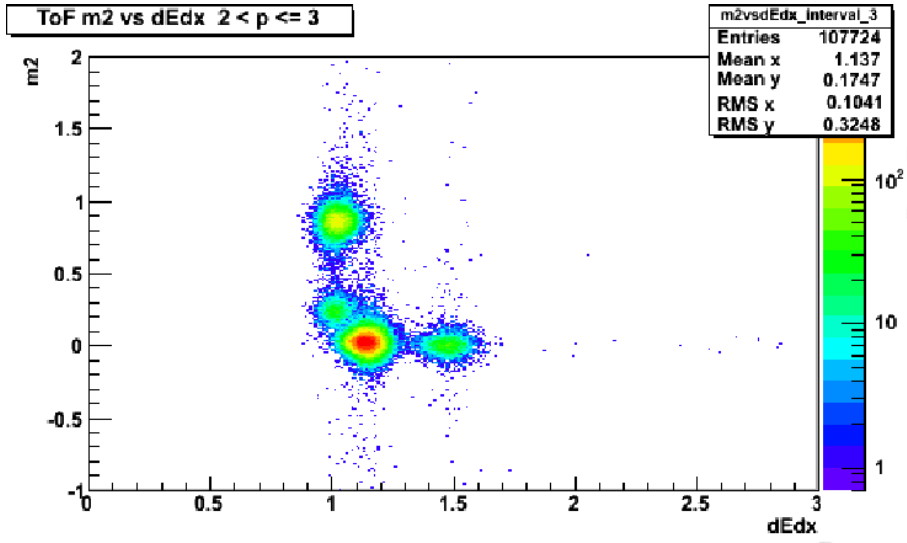


(Shown together with corresponding patched UrQMD 1.3.1 simulated data.)

Analysis was based on $\frac{\mathrm{d}E}{\mathrm{d}x}$ and ToF + $\frac{\mathrm{d}E}{\mathrm{d}x}$ inclusive analysis.

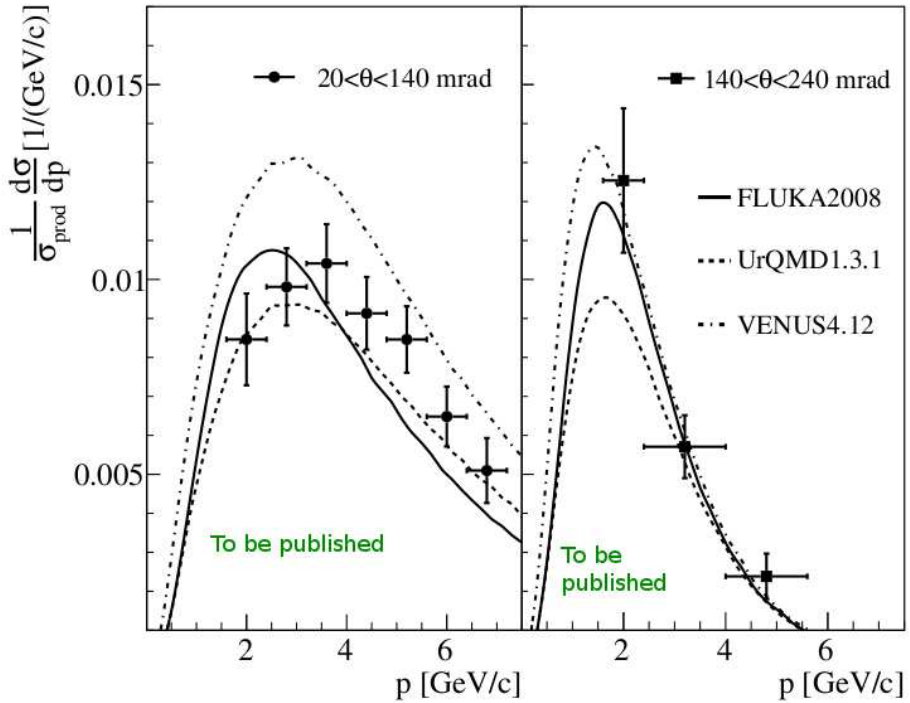
Positive particles





Charged Kaon spectra in p+C:

- Release of $p + C \rightarrow K^+ + X$ production cross-sections at $31\,\mathrm{GeV/c}$ beam momentum, `arXiv:1112.0150` (similar analysis to that of $\pi^{\pm}$).

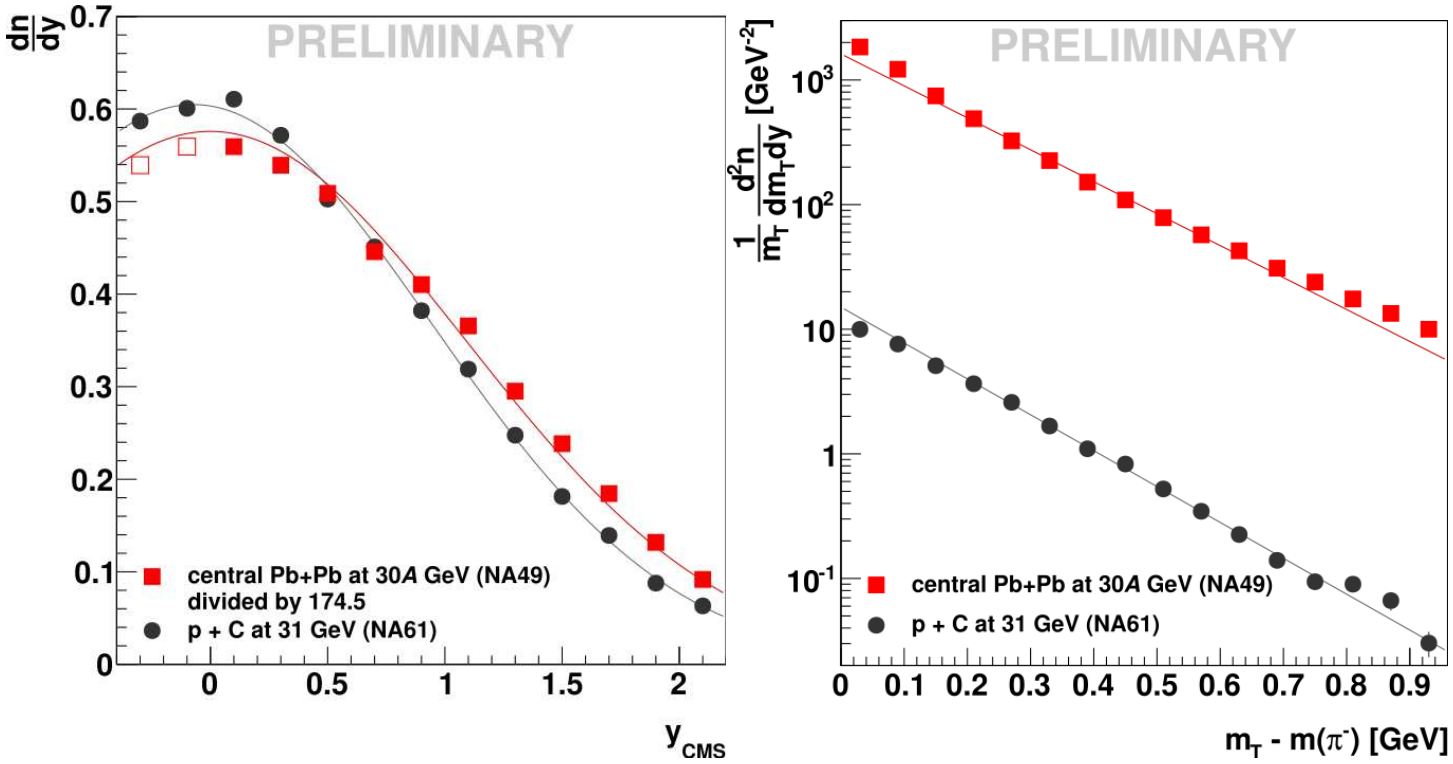


(Shown together with corresponding model predictions.)

- Used by T2K for precise prediction of high energy tail and ν_e content of ν beam.

Charged pion spectra in p+C vs Pb+Pb:

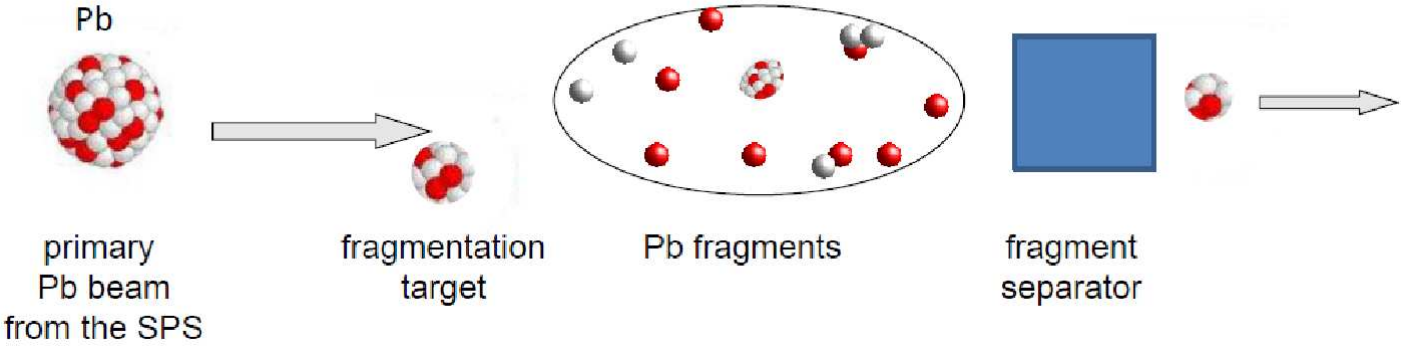
- Spectra based on h^- analysis, `arXiv:1107.2345`.



- π^- multiplicty in forward hemisphere in $Pb+Pb$ approximately proportional to the mean number of projectile wounded nucleons. y spectra in $p+C$ shifts toward target rapidity.
- In $Pb+Pb$, transverse mass spectra becomes concave, with slightly larger temperature.

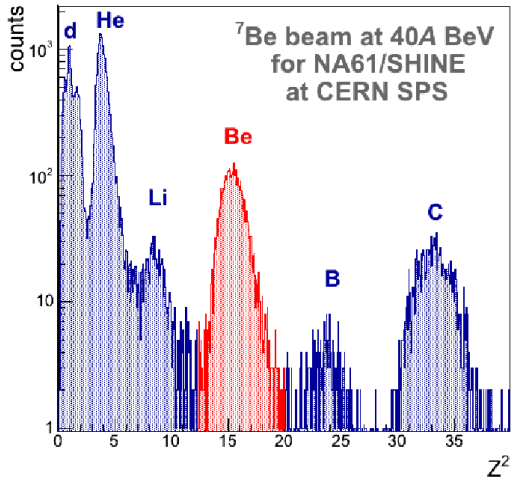
Successful data taking with secondary Be beams at 40, 75, 150A GeV/c:

In order to assure a compatibility with the LHC Pb program NA61 have recorded data on Be+Be interactions using secondary Be beams from the fragmentation of primary Pb beam.



Quite complex . . .

- Successful fragmentation / separation using the H2 beam line of the SPS North Area, tagging with Cerenkov Z-detector.



- Recorded about 3x3M $Be+Be$ physics events for ion program at $150\,\mathrm{GeV/c}$, $75\,\mathrm{GeV/c}$ and $40\,\mathrm{GeV/c}$ per nucleon beam momentum.

Data taking plans

Beam Primary	Beam Secondary	Target	Energy (A GeV)	Year	Days	Physics
	^{7}Be	Be	13, 20, 30	2012	3×12 days	CP, OD
p			400			
	p	Pb	158	2012	60 days	High p_T
Ar		Ca	13, 20, 30, 40, 80, 158	2014	6×8 days	CP, OD
p			400			
	p	Pb	13, 20, 30, 40, 80, 158	2014	6×7 days	CP, OD
Xe		La	13, 20, 30, 40, 80, 158	2015	6×8 days	CP, OD

Summary

- Publication of first physics results: inclusive $p + C \rightarrow \pi^{\pm} + X$ production cross-sections at $31\,\mathrm{GeV/c}$ beam momentum — PRC **84** (2011) 034604.
- These spectra were used to:
  - Improve MC generators.
  - Input for T2K experiment for estimate of systematics.
- Successful light-ion beams at SPS with fragmentation of Pb beam.
- Being completed: $Be + Be$ physics data with fragmented beam.
- Recorded 10M $p + Pb$ at $158\,\mathrm{GeV/c}$ partial success in high p_T data taking.
- Looking forward to record primary Ar and Xe beam data to complete ion program.

Thank you!

ETH, Zurich, Switzerland
Fachhochschule Frankfurt, Frankfurt, Germany
Faculty of Physics, University of Sofia, Sofia, Bulgaria
Karlsruhe Institute of Technology, Karlsruhe, Germany
Institute for Nuclear Research, Moscow, Russia
Institute for Particle and Nuclear Studies, KEK, Tsukuba, Japan
Jagiellonian University, Cracow, Poland
Joint Institute for Nuclear Research, Dubna, Russia
Wigner Research Centre for Physics of the Hungarian Academy of Sciences, Budapest, Hungary
LPNHE, University of Paris VI and VII, Paris, France
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