Report from the NA61/SHINE experiment at the CERN SPS

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Status report to the proposal SPSC-P-330

Report from the NA61/SHINE experiment at the CERN SPS

CERN-SPSC-2017-038

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Addendum to the NA61/SHINE Proposal SPSC-P-330

Feasibility Study for the Measurement of Nuclear Fragmentation Cross Sections with NA61/SHINE at the CERN SPS

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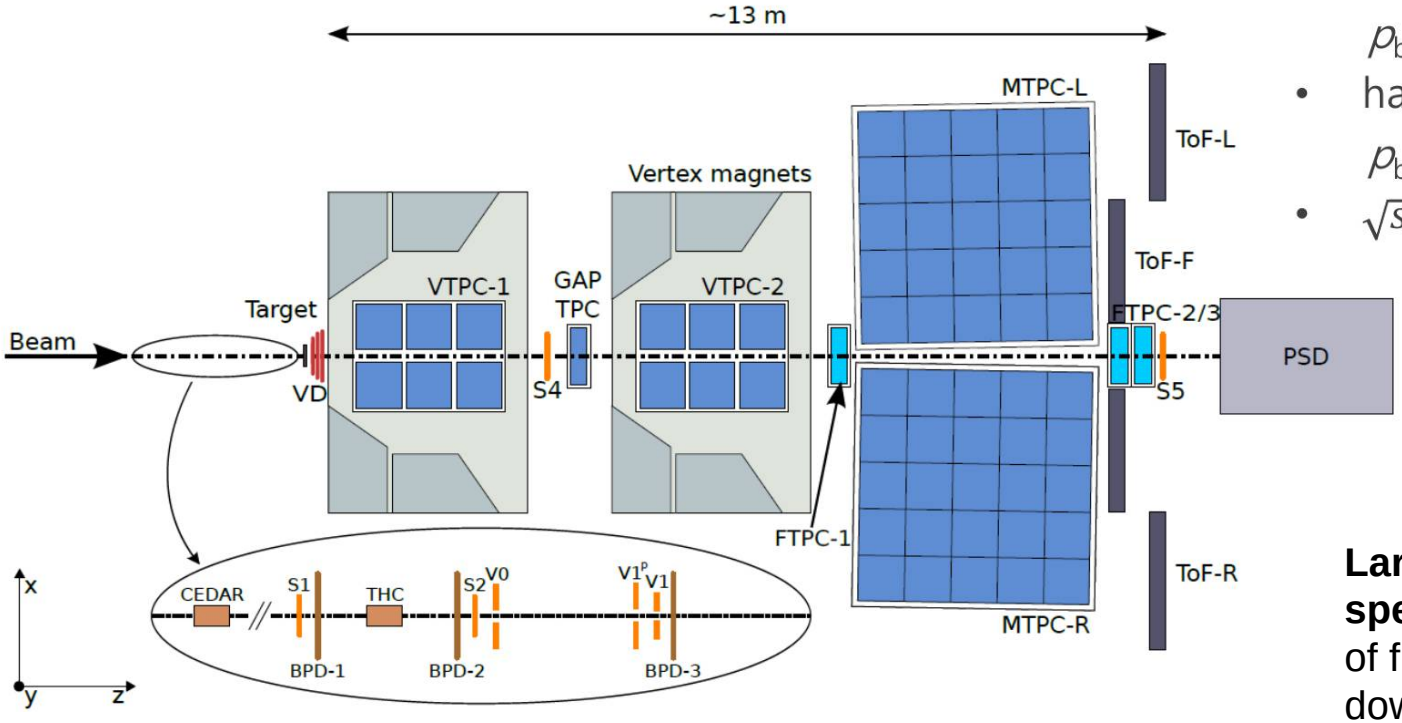
NA61/SHINE Experiment

Fixed target experiment located at SPS



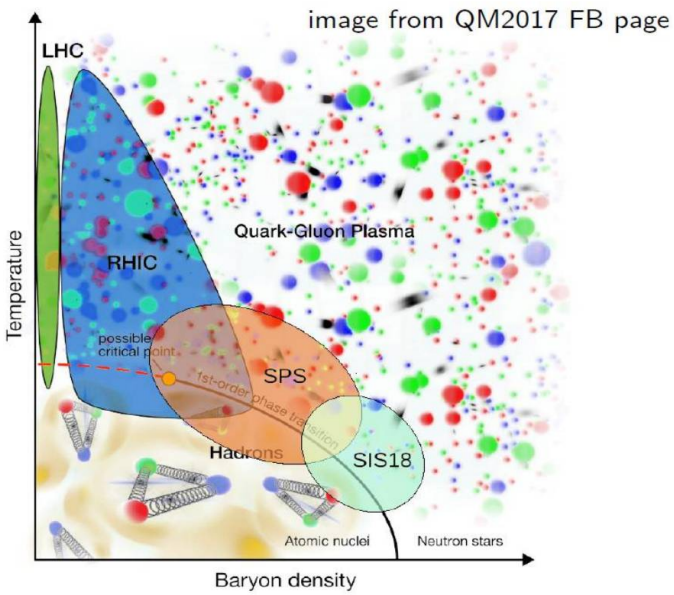
Beams:

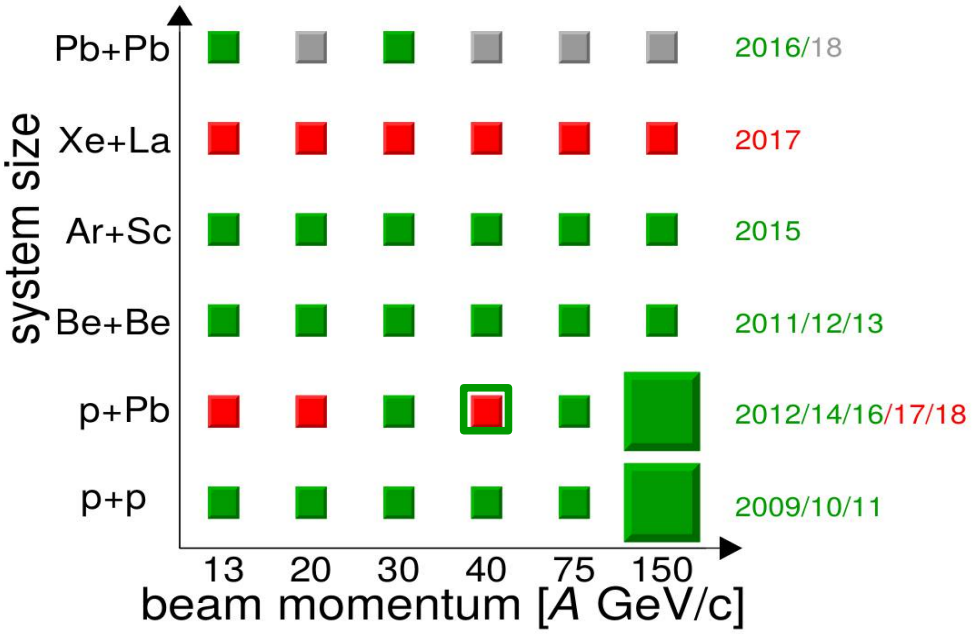
- ions (Be, Ar, Xe, Pb)
  p_{beam}=13A–150A GeV/c
- hadrons (π, K, p)
  p_{beam}=13–400 GeV/c
- $\sqrt{s_{NN}}$= 5.1–16.8 (27.4) GeV

Large acceptance hadron spectrometer – coverage of full forward hemisphere, down to p_T = 0

Research program: strong interactions

2D scan of energy and system size to study phase diagram of strongly interacting matter





→ search for the critical point of strongly interacting matter
→ study of the properties of the onset of deconfinement

New possibilities: direct measurement of open charm at SPS energies

Research program: measurements for neutrino and cosmic ray experiments

- **Hadron production measurements for neutrino experiments**
  → reference measurements for neutrino experiments for computing initial neutrino fluxes at J-PARC and FERMILAB

- **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, KASCADE) for improving air shower simulations

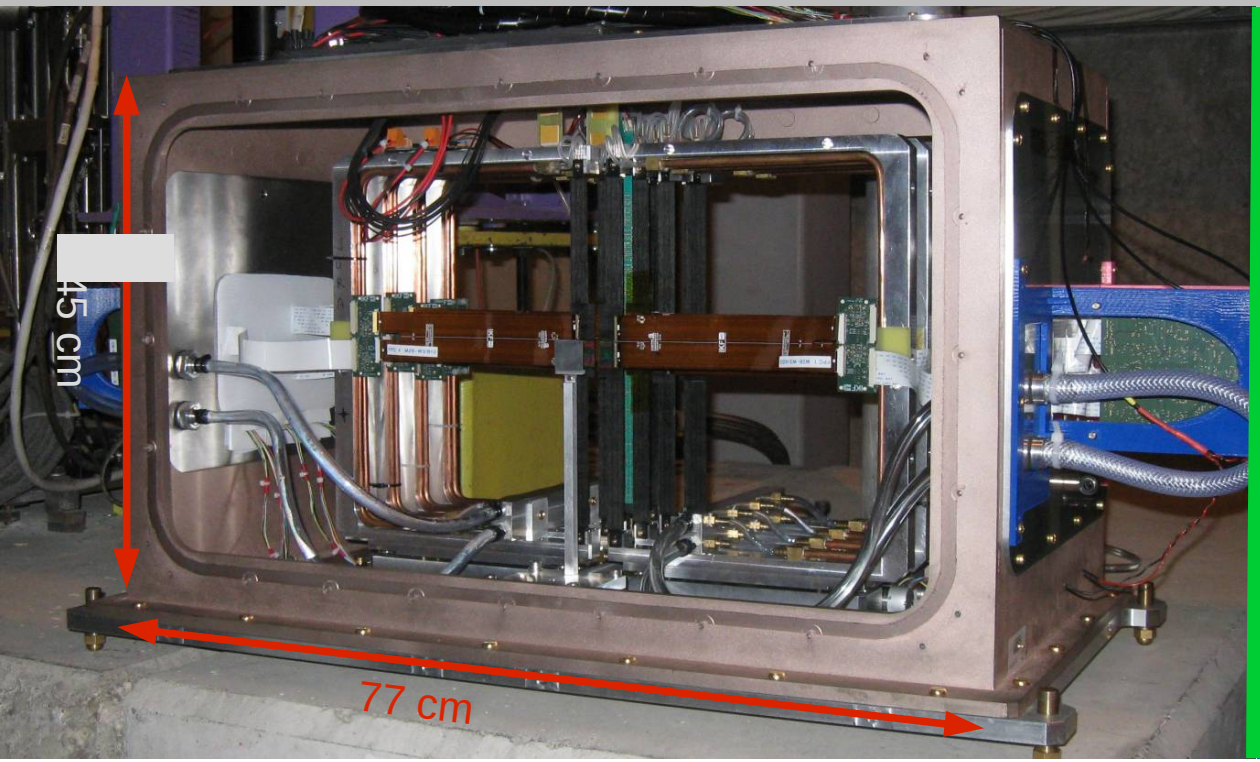
Data taking in 2016 and 2017

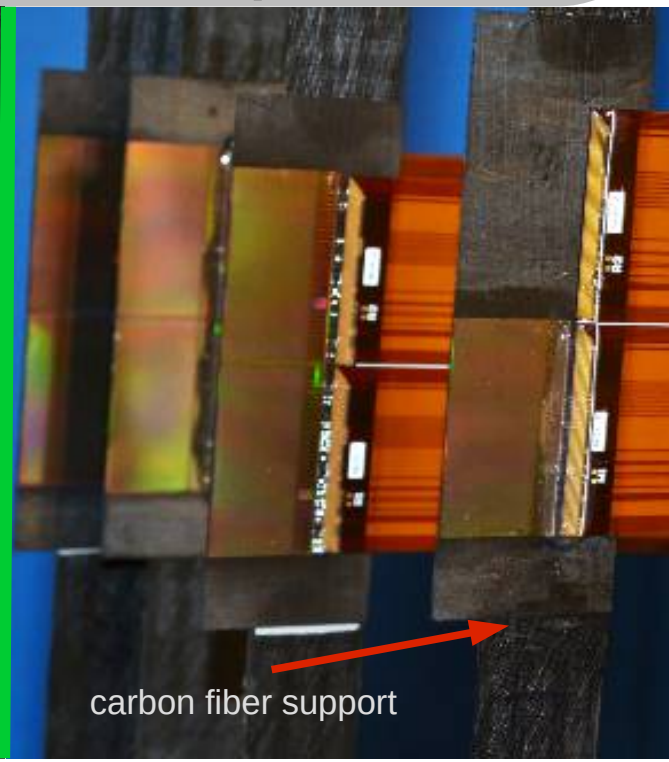
beam	target	beam momentum	number of events	
π^+	C	60 GeV/c	2.6M	
p	C	120 GeV/c	4.1M	**September/October 2016:** data taken for Fermilab neutrino beams
p	Al	60 GeV/c	3.2M	
p	Be	60 GeV/c	2.2M	
π^+	Be	60 GeV/c	2.7M	
p	Be	120 GeV/c	2.5M	
π^+	Al	60 GeV/c	2.6M	
π^+	C	30 GeV/c	2.2M	**August 2017:** data taken for Fermilab neutrino beams with newly installed FTPCs
π^-	C	60 GeV/c	3.6M	
p	C	120 GeV/c	2.6M	
p	Be	120 GeV/c	4.0M	
p	C	90 GeV/c	3.4M	
p	p	400GeV/c	9.5M	**October/November 2016:** p+p data for strong interaction program
p	Pb	30GeV/c	5.2M	**June 2017:** p+Pb at 30 GeV/c data for strong interaction program
p	Pb	40GeV/c	currently running	
Pb	Pb	13A GeV/c	2.9M	**November/December 2016:** Pb+Pb data for strong interactions
Pb	Pb	30A GeV/c	5.7M	→ collective flow (13A GeV/c, 30A GeV/c)
Pb	Pb	150A GeV/c	1.6M	→ test of Vertex Detector (150A GeV/c)

Summary of Facility modifications

- Forward TPCs installation and successful data taking in 2017
- **Small Acceptance Vertex Detector (SAVD) tests**
- Forward Time of Flight with DRS4 based readout
- Projectile Spectator Detector maintenance
- Beam Position Detector electronics upgrade
- Chiller for TPC FEE cooling

Vertex Detector tests with Pb+Pb at 150*A* GeV/*c*





SAVD:

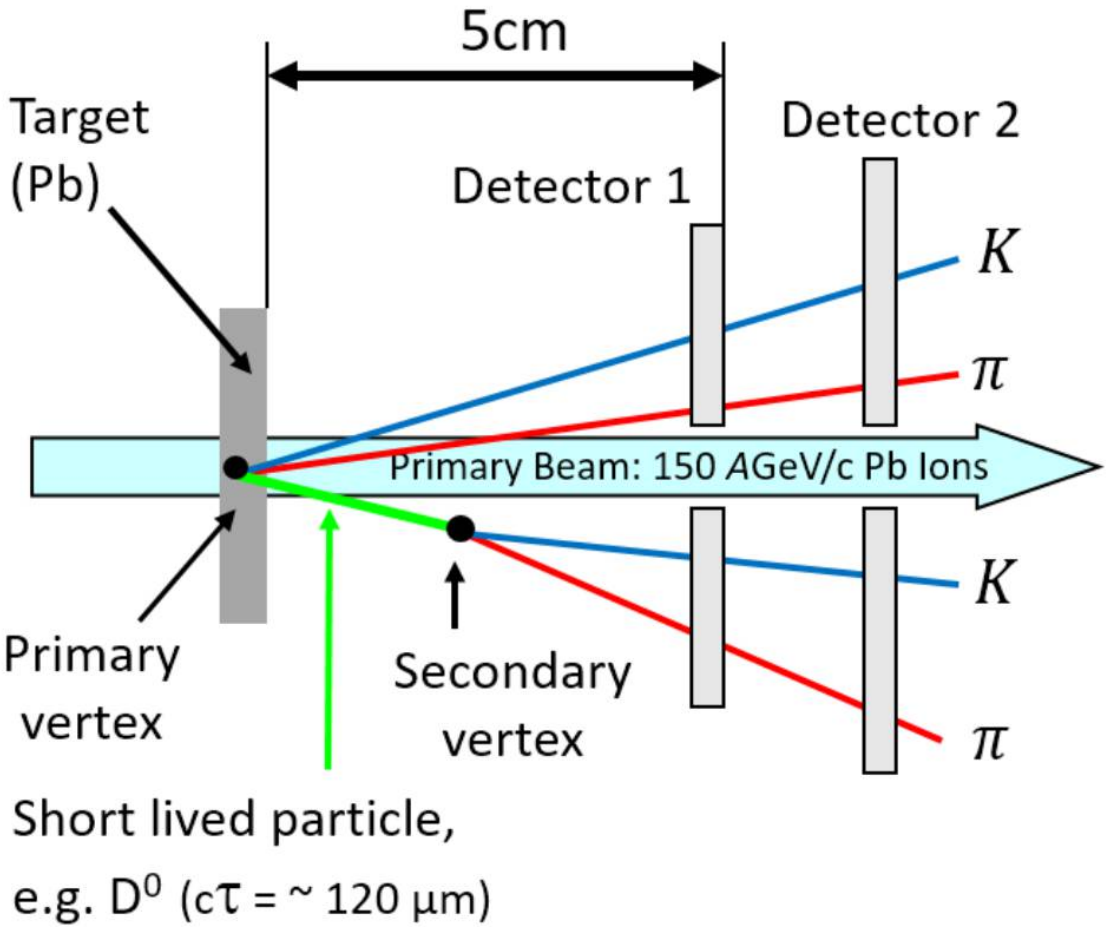
- 16 MIMOSA-26 sensors located on 2 horizontally movable arms.
- Target holder integrated with SAVD base plate

Achieved goals:

- tracking in the large track multiplicity environment
- precise Primary Vertex reconstruction
- TPC and SAVD track matching
- first search for D^0 signal

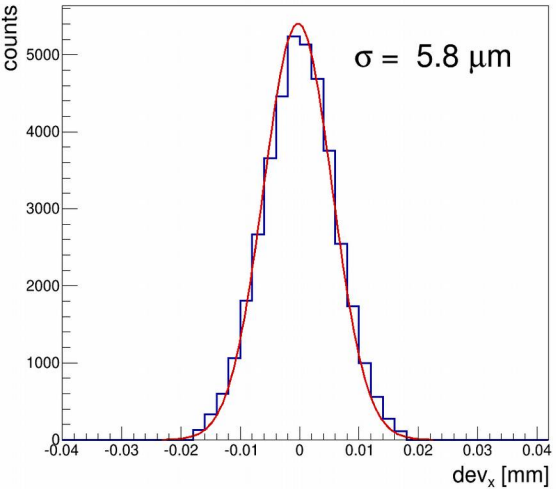
Why Vertex Detector is needed to measure open charm?

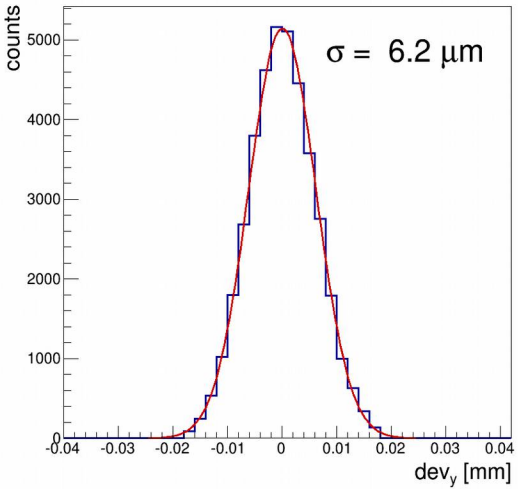
$$D^0 \rightarrow \pi^+ + K^-$$



Vertex detector is needed to reconstruct primary vertex and secondary vertexes with high precision.

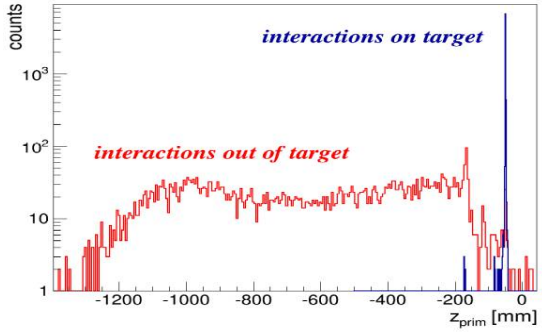
Vertex Detector performance

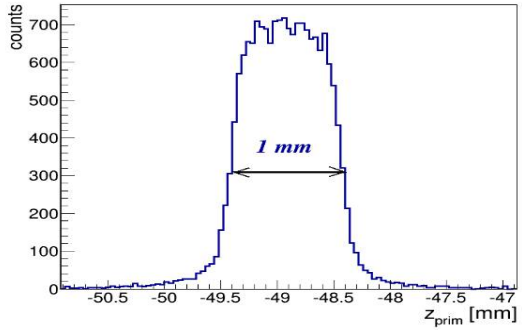




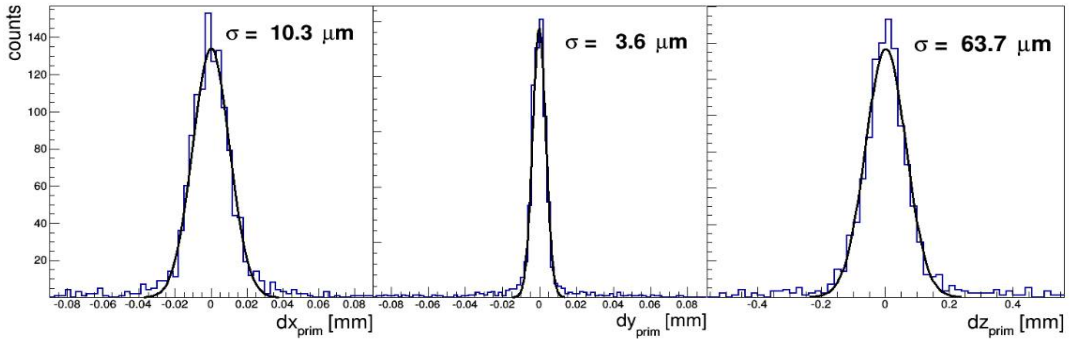
Sensor position resolution about 5 μm as expected

$$\sigma_{x/y} = \sqrt{\frac{2}{3}}\,\sigma_{dev_{x/y}}$$





Reconstruction of Primary Vertex allows to separate **in-** and **out-target** interactions



Spacial position resolution:

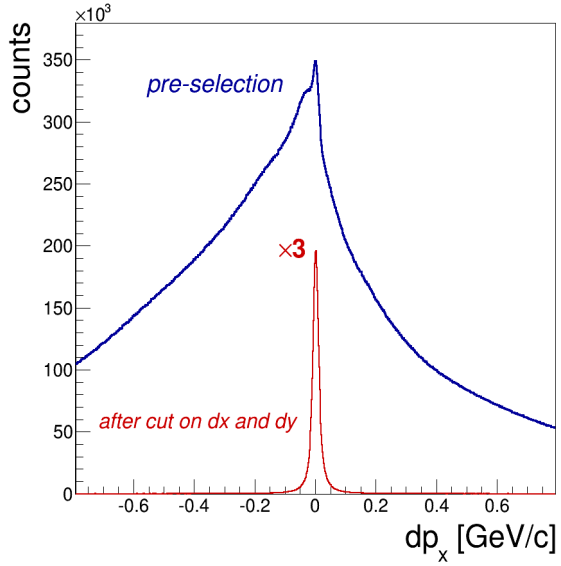
σ_x = 5 μm

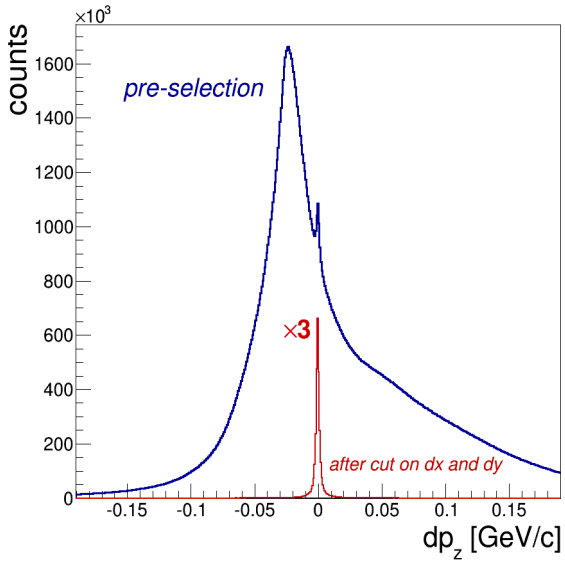
σ_y = 1.8 μm

σ_z = 30 μm

Worse resolution in x due to presence of magnetic field (B_y)

VD – TPC track matching

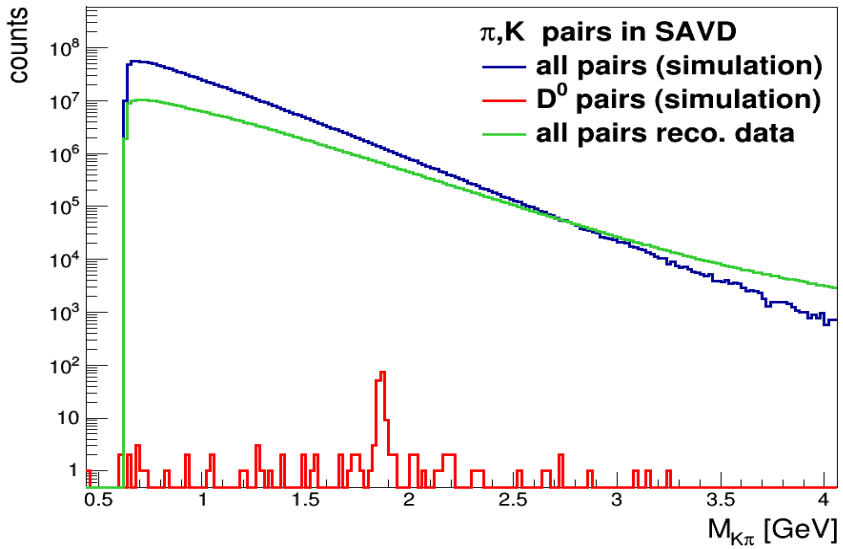




Extrapolate SAVD tracks to TPC volume.

Pre-selection: cut on y-slopes of tracks.

After cuts on dx and dy clear correlation peaks are seen in dp_x and dp_z



Matching with TPC provides:
momenta and PID to VD tracks

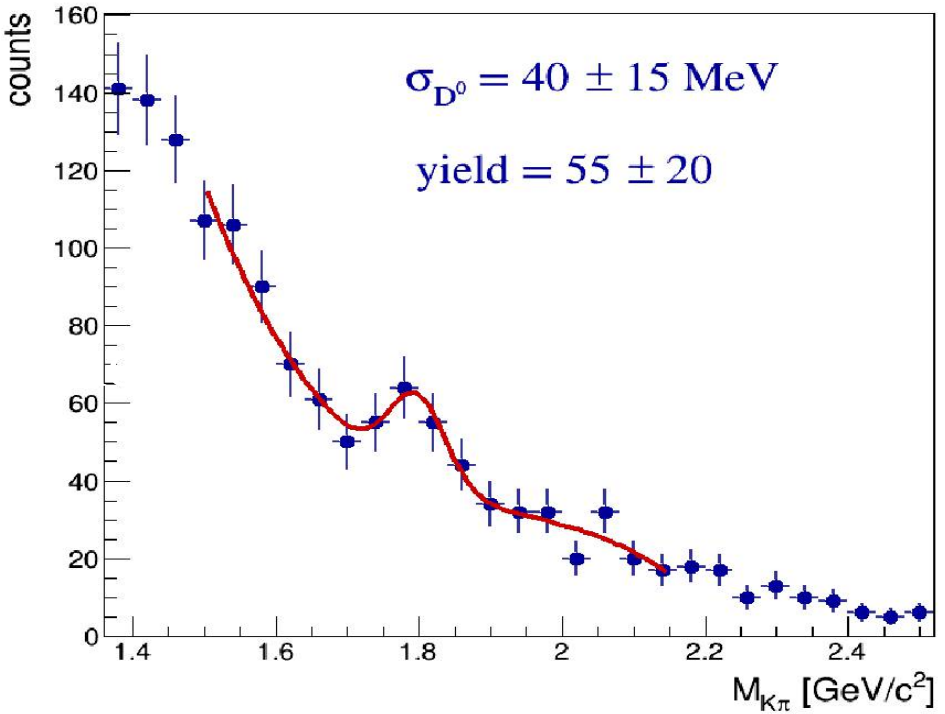
→ invariant mass distribution

VD: search for D^0 and K^0_s

First results using simplified reconstruction (200k 0-20% central Pb+Pb)

Background suppression → cuts on:

1. track p_T
2. track impact parameter d
3. longitudinal distance V_z (pair vertex to primary vertex)
4. parent impact parameter d_P



Analysis is in progress:

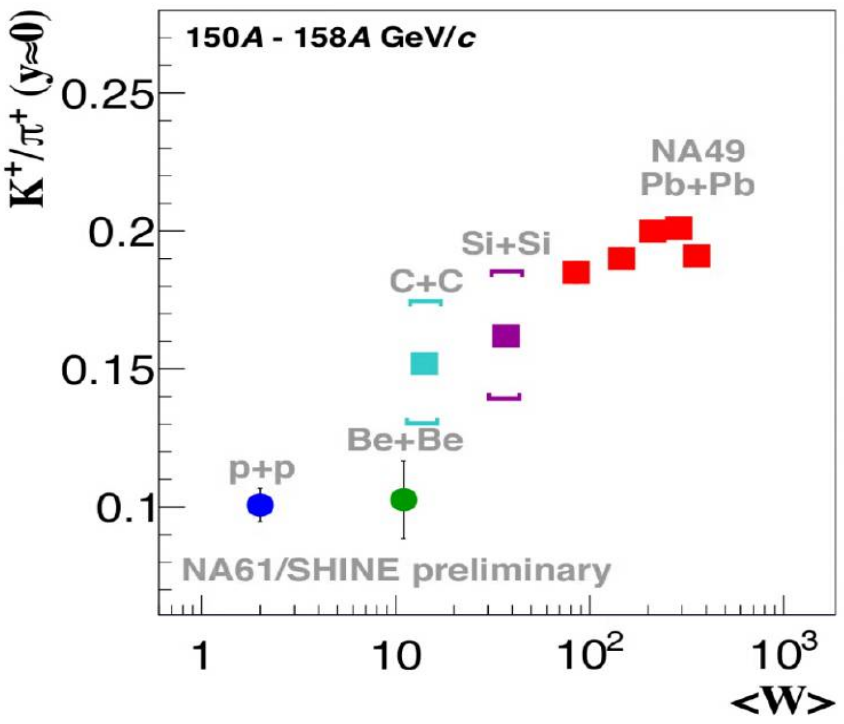
1. PID not used yet
2. improvement on matching
3. improvement on track extrapolation to primary vertex

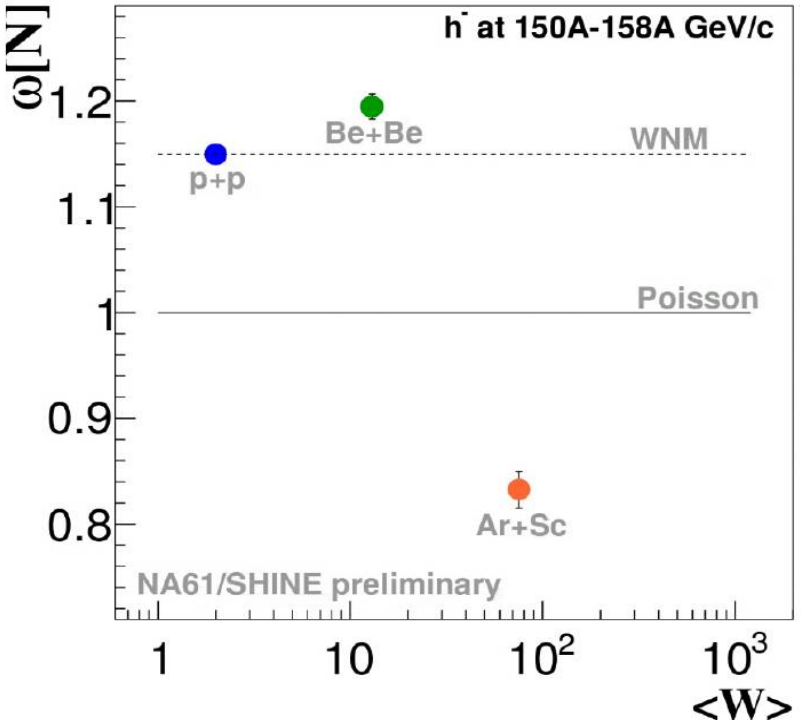
Simulation with D^0 yields based on HSD: about 100 D^0s in 200k 0-10% central Pb+Pb

Requested beam time in 2018: 8M 0-20% central Pb+Pb → 2k D^0s

New results

Particle ratios and fluctuations





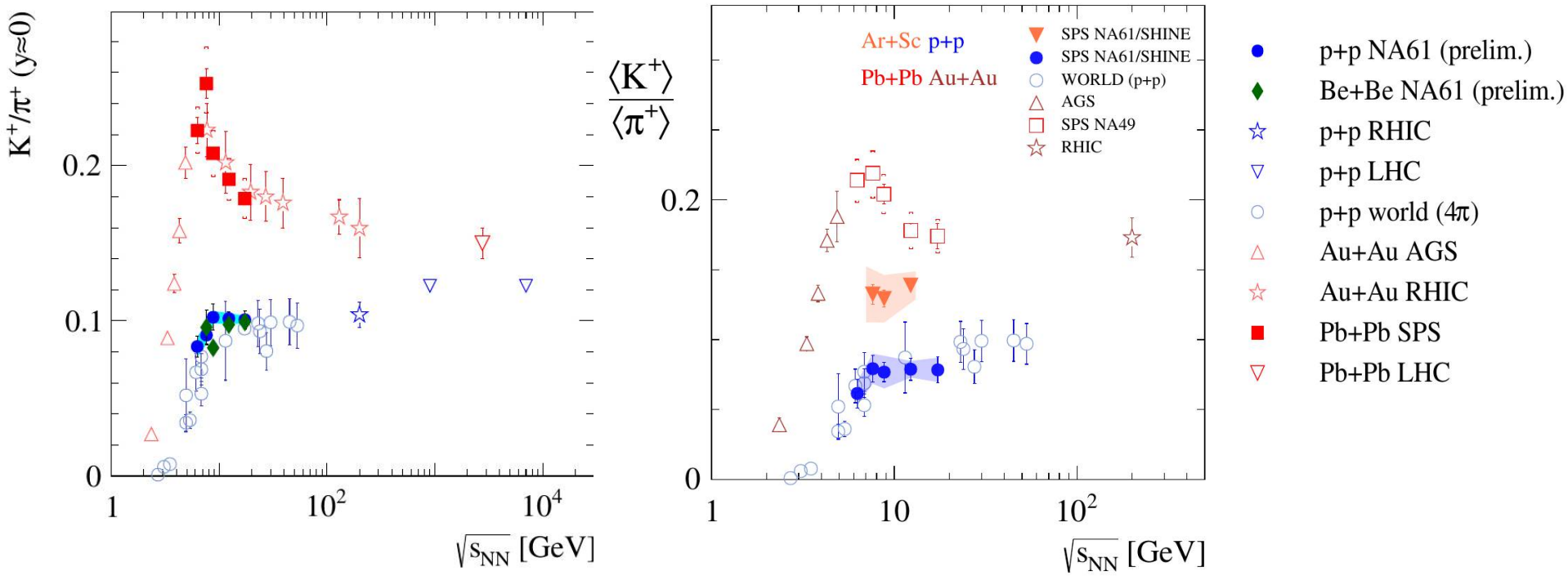
K^+/π^+ and **multiplicity fluctuations** change rapidly when moving from light (p+p, Be+Be) to intermediate/heavy systems.

For heavy systems they are closer to predictions of statistical models for large volume strongly interacting matter.

→ beginning of creation of large clusters of strongly interacting matter (**onset of fireball)**

Particle ratios and fluctuations (2)

Rapid changes in K^+/π^+ (HORN) were observed in Pb+Pb collisions. It was predicted within SMES as a signature of onset of deconfinement

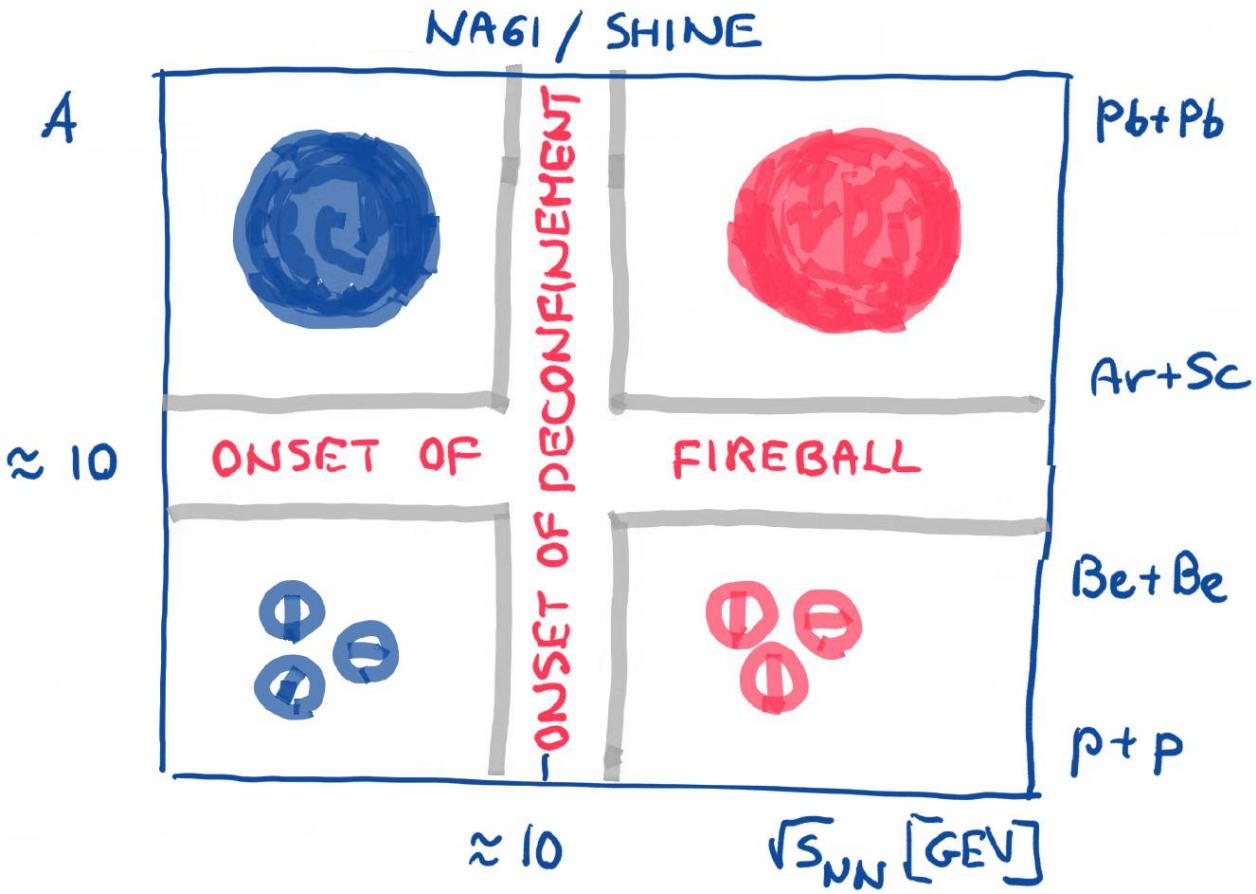


NEW RESULTS:

- plateau like structure visible in p+p
- Be+Be consistent with p+p

- $\langle K^+\rangle/\langle\pi^+\rangle$ in Ar+Sc in between p+p, Be+Be and Pb+Pb

Tentative conclusions from 2D scan



Data on particle ratios and fluctuations indicate four domains of hadron production separated by two thresholds:

onset of deconfinement

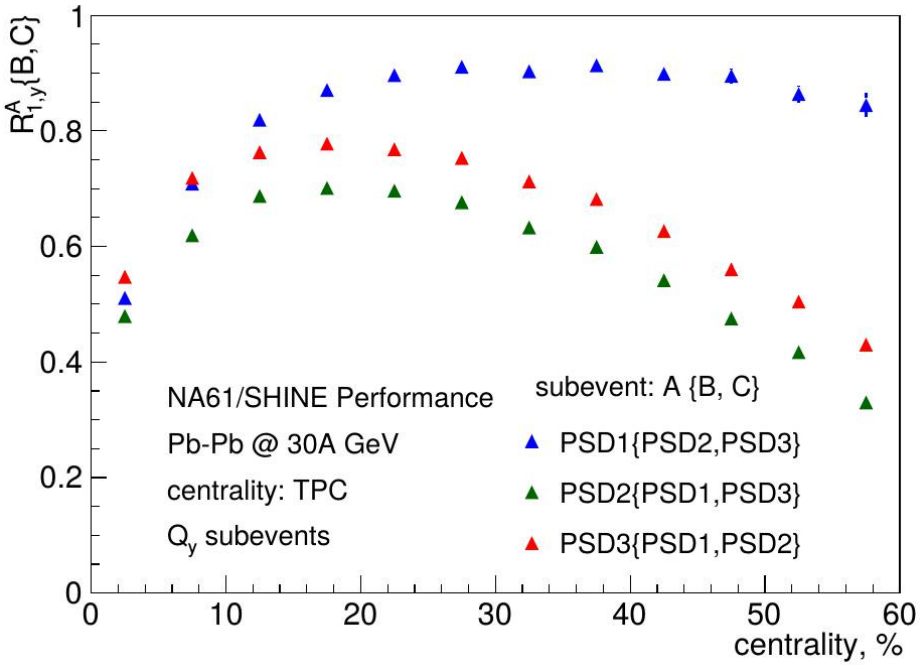
and

onset of fireball

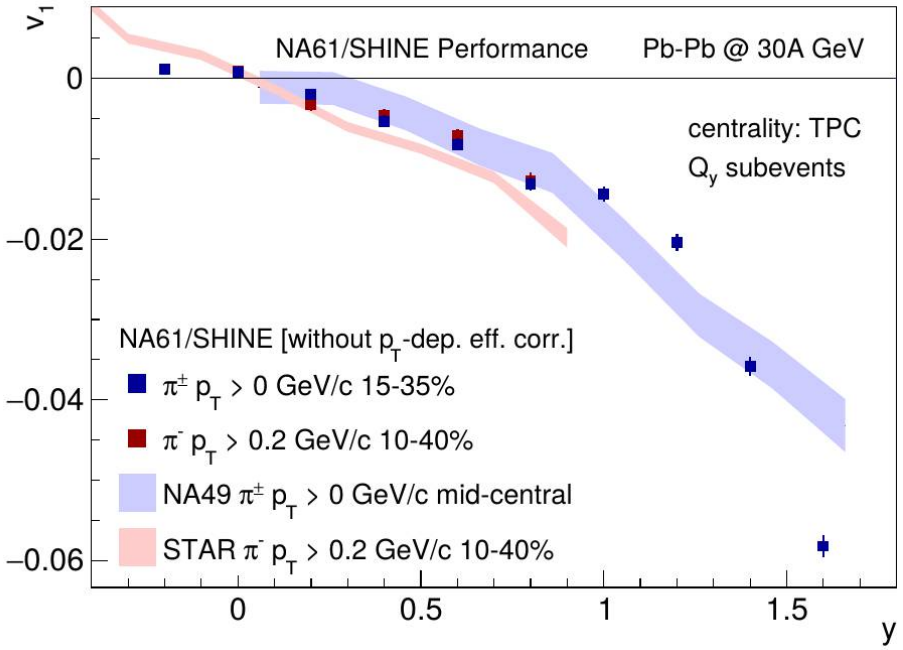
Completion of Ar+Sc analysis and new data for Xe+La awaited to verify this picture

Performance of anisotropic flow measurements in Pb+Pb

Resolution correction form PSD

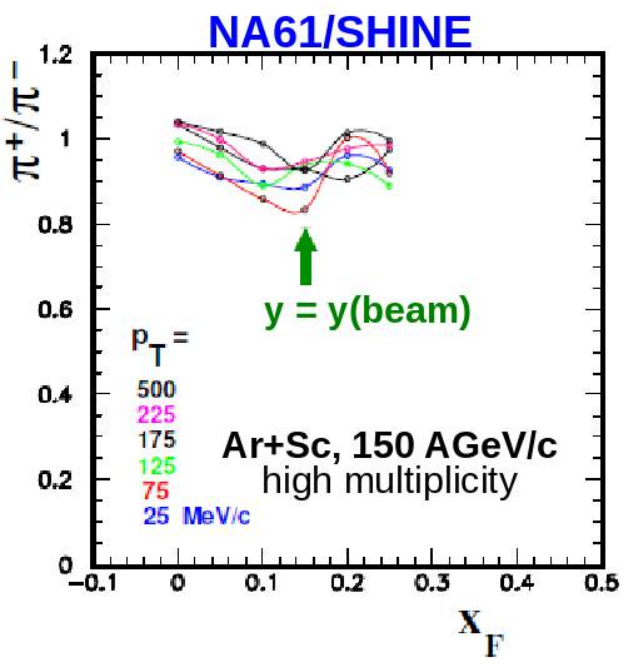


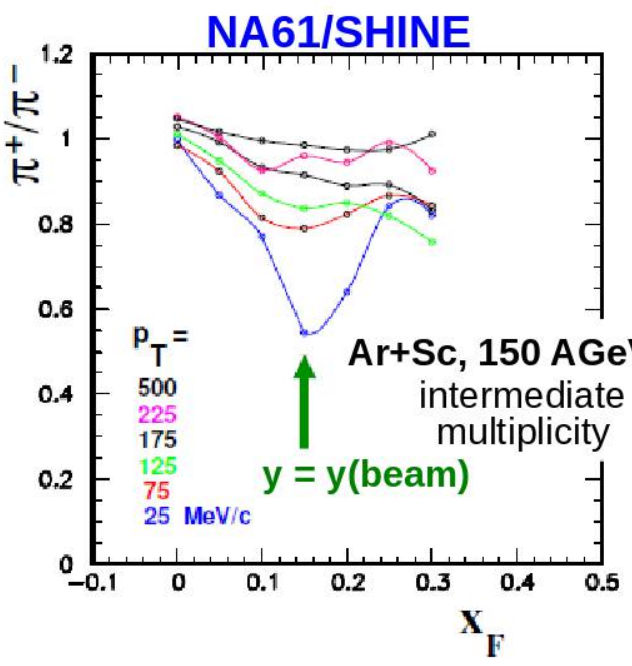
Anisotropic flow of π^+ and π^-

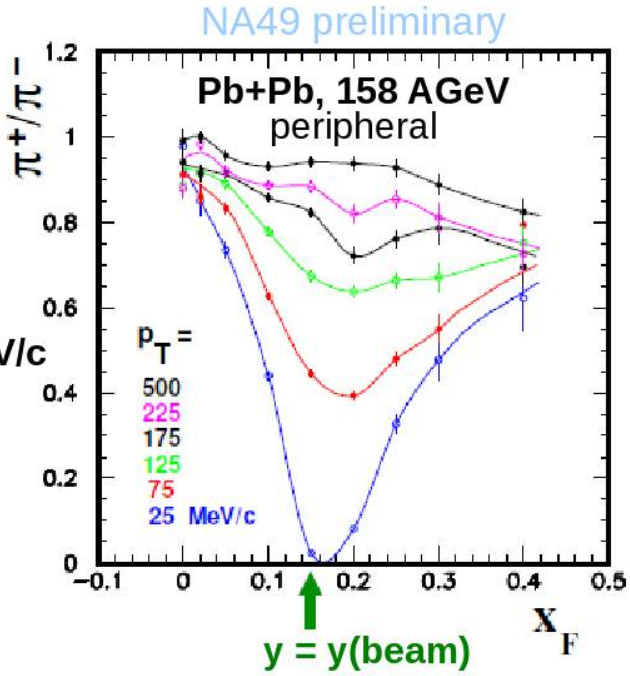


- The results promise an extended rapidity coverage for flow measurements in comparison to the RHIC BES program,
- improvements in respect to NA49 results due to reaction plane orientation measurement with the PSD

EM effects in Ar+Sc collisions





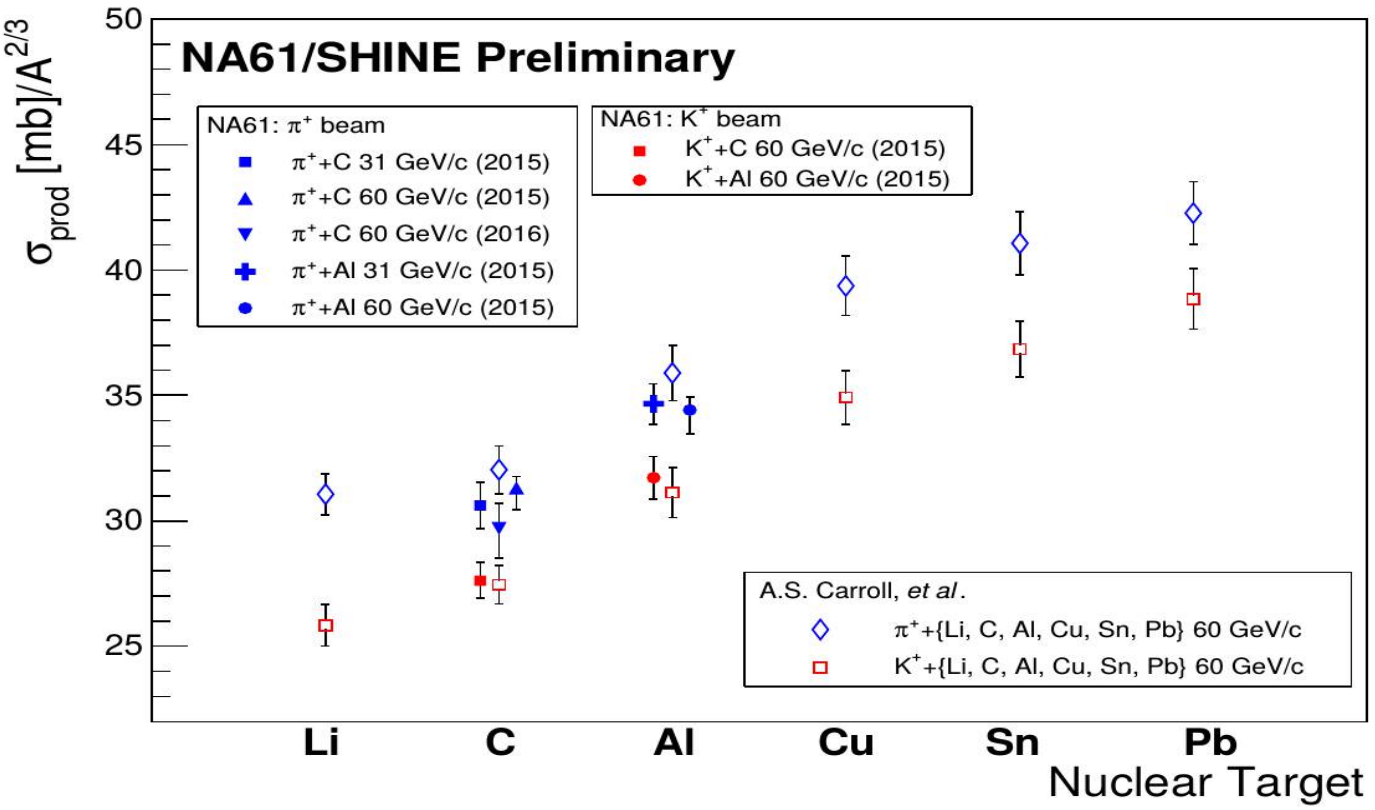


stat. uncertainties
4 – 7 %

Strong depletion of π^+/π^- ratio at beam rapidity

- first observation of spectator-induced EM effects in Ar+Sc reactions at the SPS,
- brings information on the space-time evolution of the system.

Measurements for Fermilab neutrino beams



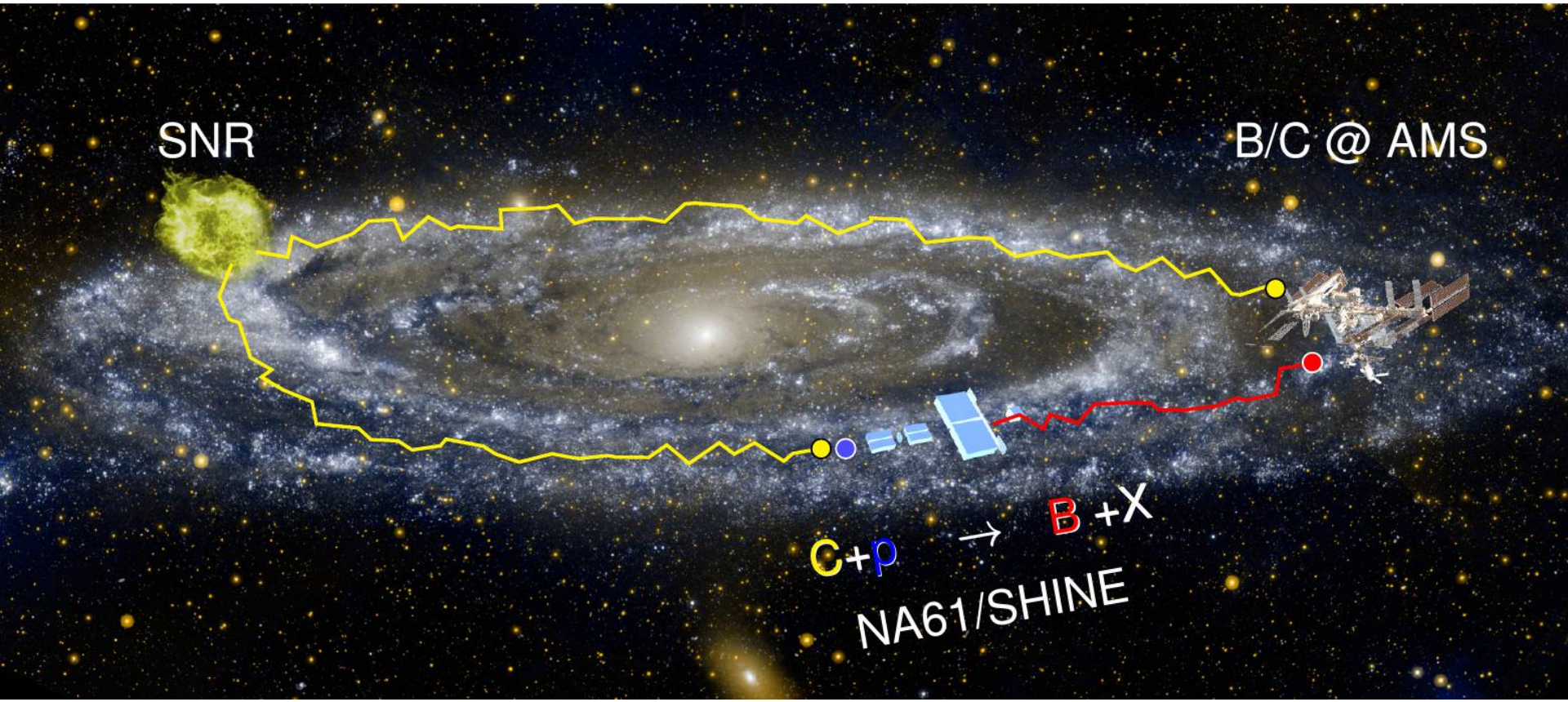
Preliminary cross sections from data taken in 2015 and 2016.

Data taken in 2016 and 2017 (with magnetic field) are under calibrations and analysis with the aim to obtain particle spectra.

Proposal of measurement of Nuclear Fragmentation Cross Sections (NFCS)

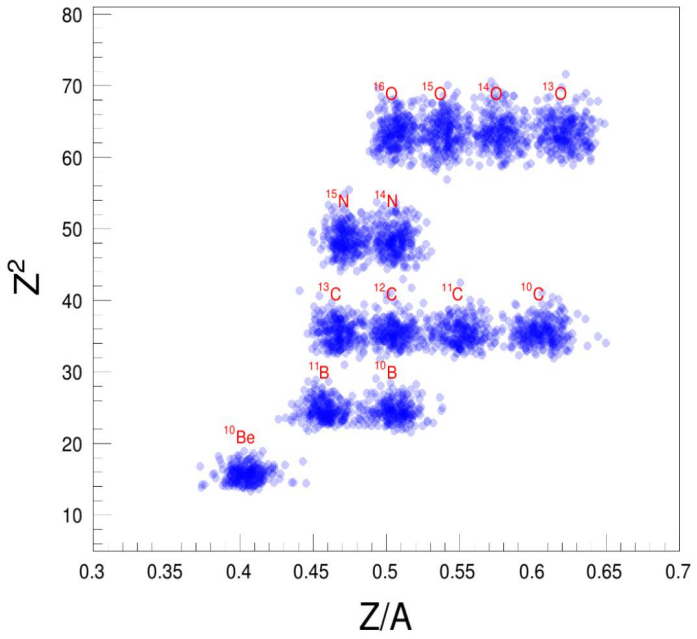
Motivation: NFCS of intermediate mass nuclei are needed to understand the propagation of cosmic rays in our Galaxy

→ background for dark matter searches with space-based experiments as AMS.



NFCS measurements: goals and performance

- One week test run in 2018 is proposed:
  → establish capability of NA61/SHINE to measure NFCS.
- No major modifications to the experimental setup are needed.
- The comprehensive measurement program (beyond 2020) will be formulated based on experience gained in 2018.
- The test data on carbon-proton and oxygen-proton at 13*A* GeV/*c* should already improve the current cross section uncertainties.



Simulation of fragments reconstruction in the NA61/SHINE detector

Data-taking plan for 2018

20 days of Pb beam at 150*A* GeV/*c*
20 days of Pb beam at 75*A* GeV/*c*
} primary beams dedicated to open charm, collective effects and fluctuations

8 days of Pb beam at 40*A* GeV/*c*
8 days of Pb beam at 20*A* GeV/*c*
} primary beams dedicated to collective effects and fluctuations

7 days of Pb primary beam at 14*A* GeV/*c* to produce **C and O beams** needed for the test of fragmentation cross section measurements by cosmic-ray community.

Hadron beams for PSD calibration, mRPC test and for neutrino experiment are listed in the table:

Beam		Target	Momentum	Year	Days	Physics
Primary	Secondary		(*A* GeV/*c*)			
p			400			
	h	Pb	13-400	2018	14 days	PSD calibration
p			400			
	p	Pb	400	2018	7 days	mRPC test
p			400			
	K^+	C	30 or 60	2018	7 days	ν
p			400			
	p	T2K RT	120	2018	28 days	ν

NA61/SHINE

We would like to thank the CERN EP, BE, EN and IT Departments for the strong support of NA61/SHINE

The NA61/SHINE Collaboration

A. Aduszkiewicz[16], Y. Ali[13], E.V. Andronov[22], T. Antićić[3], B. Baatar[20], M. Baszczyk[14], S. Bhosale[11], A. Blondel[25], M. Bogomilov[2], A. Brandin[21], A. Bravar[25], W. Bryliński[18], J. Brzychczyk[13], S.A. Bunyatov[20], O. Busygina[19], A. Bzdak[14], H. Cherif[7], M. Ćirković[23], T. Czopowicz[18], A. Damyanova[25], N. Davis[11], M. Deveaux[7], P. von Doetinchem[30], W. Dominik[16], P. Dorosz[14], J. Dumarchez[4], A. Datta[30], R. Engel[5], A. Ereditato[24], G.A. Feofilov[22], Z. Fodor[8,17], C. Francois[24], A. Garibov[1], M. Gaździcki[7,10], M. Golubeva[19], K. Grebieszkow[18], F. Guber[19], A. Haesler[25], A.E. Hervé[5], J. Hylen[26], S.N. Igolkin[22], A. Ivashkin[19], S.R. Johnson[28], K. Kadija[3], E. Kaptur[15], M. Kiełbowicz[11], V.A. Kireyeu[20], V. Klochkov[7], V.I. Kolesnikov[20], D. Kolev[2], A. Korzenev[25], V.N. Kovalenko[22], K. Kowalik[12], S. Kowalski[15], M. Koziel[7], A. Krasnoperov[20], W. Kucewicz[14], M. Kuich[16], A. Kurepin[19], D. Larsen[13], A. László[8], T.V. Lazareva[22], M. Lewicki[17], B. Lundberg[26], B. Łysakowski[15], V.V. Lyubushkin[20], M. Maćkowiak-Pawłowska[18], B. Maksiak[18], A.I. Malakhov[20], D. Manić[23], A. Marchionni[26], A. Marcinek[11], A.D. Marino[28], K. Marton[8], H.-J. Mathes[5], T. Matulewicz[16], V. Matveev[20], G.L. Melkumov[20], A.O. Merzlaya[22], B. Messerly[29], Ł. Mik[14], G.B. Mills[27], S. Morozov[19,21], S. Mrówczyński[10], Y. Nagai[28], M. Naskręt[17], V. Ozvenchuk[11], V. Paolone[29], M. Pavin[4,3], O. Petukhov[19,21], C. Pistillo[24], R. Płaneta[13], P. Podlaski[16], B.A. Popov[20,4], M. Posiadała[16], R.R. Prado[5], S. Puławski[15], J. Puzović[23], R. Rameika[26], W. Rauch[6], M. Ravonel[25], R. Renfordt[7], E. Richter-Wąs[13], D. Röhrich[9], E. Rondio[12], M. Roth[5], B.T. Rumberger[28], A. Rustamov[1,7], M. Rybczynski[10], A. Rybicki[11], A. Sadovsky[19], K. Schmidt[15], I. Selyuzhenkov[21], A.Yu. Seryakov[22], P. Seyboth[10], M. Słodkowski[18], A. Snoch[7], P. Staszel[13], G. Stefanek[10], J. Stepaniak[12], M. Strikhanov[21], H. Ströbele[7], A. Shukla[30], T. Šuša[3], A. Taranenko[21], A. Tefelska[18], D. Tefelski[18], V. Tereshchenko[20], A. Toia[7], R. Tsenov[2], L. Turko[17], R. Ulrich[5], M. Unger[5], F.F. Valiev[22], D. Veberič[5], V.V. Vechernin[22], M. Walewski[16], A. Wickremasinghe[29], C. Wilkinson[24], Z. Włodarczyk[10], A. Wojtaszek-Szwarc[10], O. Wyszyński[13], L. Zambelli[4], E.D. Zimmerman[28], and R. Zwaska[26]

Addendum on the NA61/SHINE program beyond 2020 is under preparation

Backup slides

Published papers

11.1. Published papers

1. Results on transverse momentum and multiplicity fluctuations of non-identified hadrons in p+p at 20–158 GeV/c [20]
2. Results on two-particle correlations of non-identified hadrons in azimuthal angle and pseudo-rapidity in p+p at 20–158 GeV/c [41]
3. Results on $\pi^{\pm}$ differential yields from the surface of the T2K replica target for incoming 31 GeV/c protons [56]
4. Results on ρ^0, K^{*0} ω production in π^-+C interactions at 158 and 350 GeV/c [68]

11.2. Submitted papers

Already published

1. Results on $\pi^{\pm}$, $K^{\pm}$, (anti-)proton production in p+p at 20–158 GeV/c; based on information from dE/dx and *tof*-dE/dx [78]; submitted to EPJC

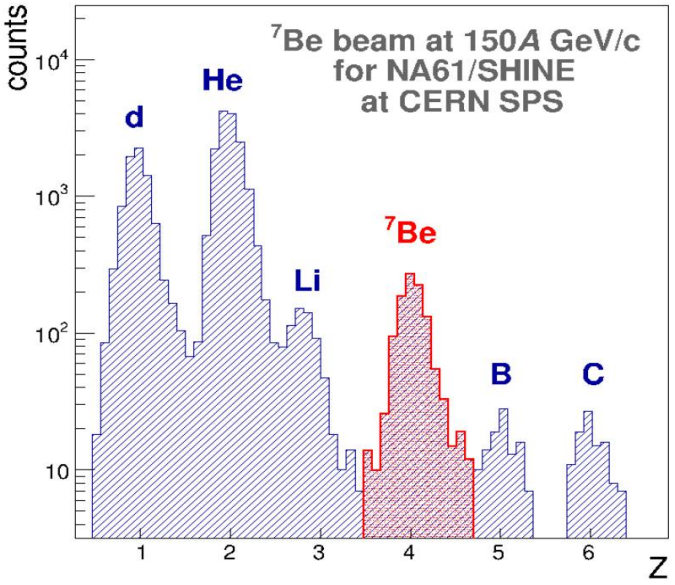
Preliminary results

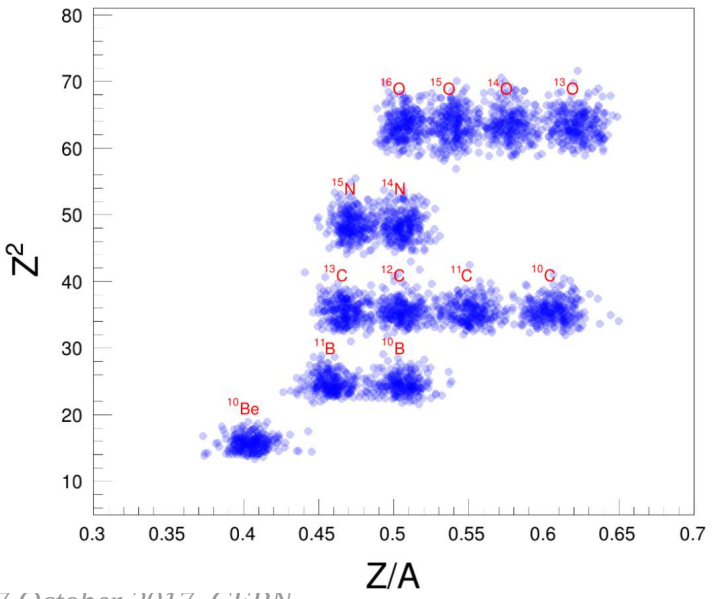
11.3. New preliminary results

1. p+p collisions at 13, 20, 31, 40, 80, and 158 GeV/c
   a) ϕ meson spectra and yields in p+p at 40–158 GeV/c [8, 11, 12]
2. Be+Be collisions at 13A, 19A, 30A, 40A, 75A, and 150A GeV/c
   a) Charged kaon spectra in Be+Be at 30A–150A GeV/c; based on information from *tof*-dE/dx [7, 8, 9, 10, 11, 12]
   b) Multiplicity and forward energy fluctuations of negatively charged hadrons in Be+Be at 19A–150A GeV/c [15, 16, 17, 11]
   c) Pseudorapidity dependence of fluctuations of non-identified hadrons in Be+Be at 150A GeV/c [32]
   d) Protons intermittency in Be+Be at 150A GeV/c [34]
   e) Two-particle correlations of non-identified hadrons in azimuthal angle and pseudo-rapidity in Be+Be at 19A–150A GeV/c [40]
3. Ar+Sc collisions at 13A, 19A, 30A, 40A, 75A, and 150A GeV/c
   a) Charged kaon spectra and yields in Ar+Sc at 30A, 40A and 75A GeV/c; based on information from dE/dx [14, 12]
4. p+C collisions at 31 GeV/c (thin target and T2K replica target)

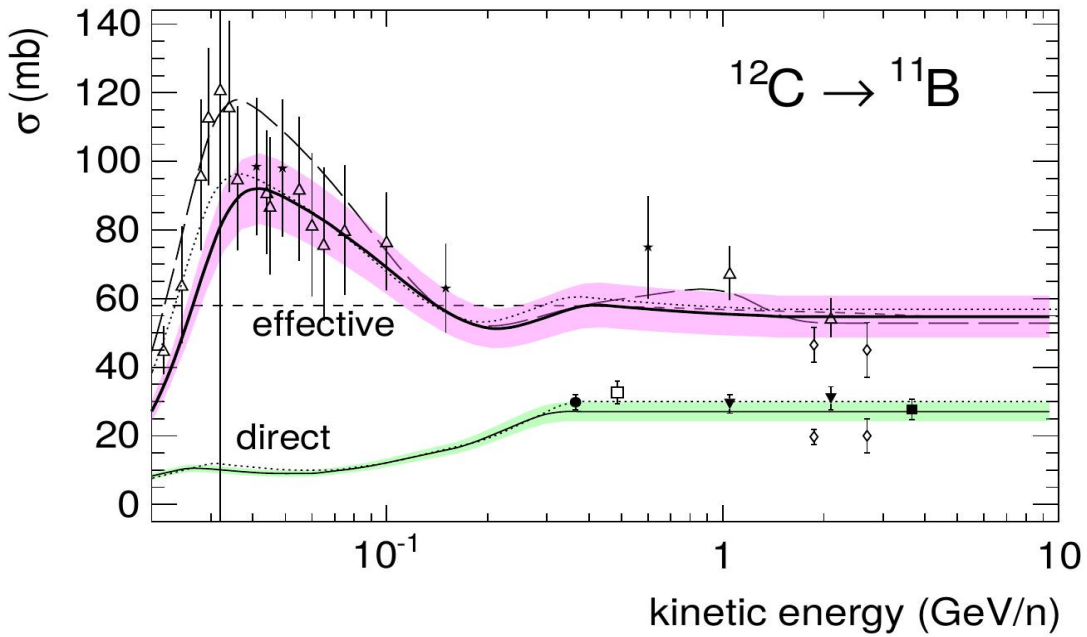
NFCS: performance of test

- **Secondary ion beam**: nuclear fragments from SPS, Pb ions on primary Be target, selection of *A/Z* = 2 and p = 13*A* GeV/*c,*
- **target:** thin polyethylene foil and carbon targets,
- **beam PID:** *A* from Time of Flight at 140 m, *Z* from Cherenkov quartz plate based detector (see figure below),
- **fragment PID:** *Z* from scintilator downstream of the target and energy deposited in TPCs. *A/Z* from from the bending in the NA61 superconductiong magnets (9 Tm).



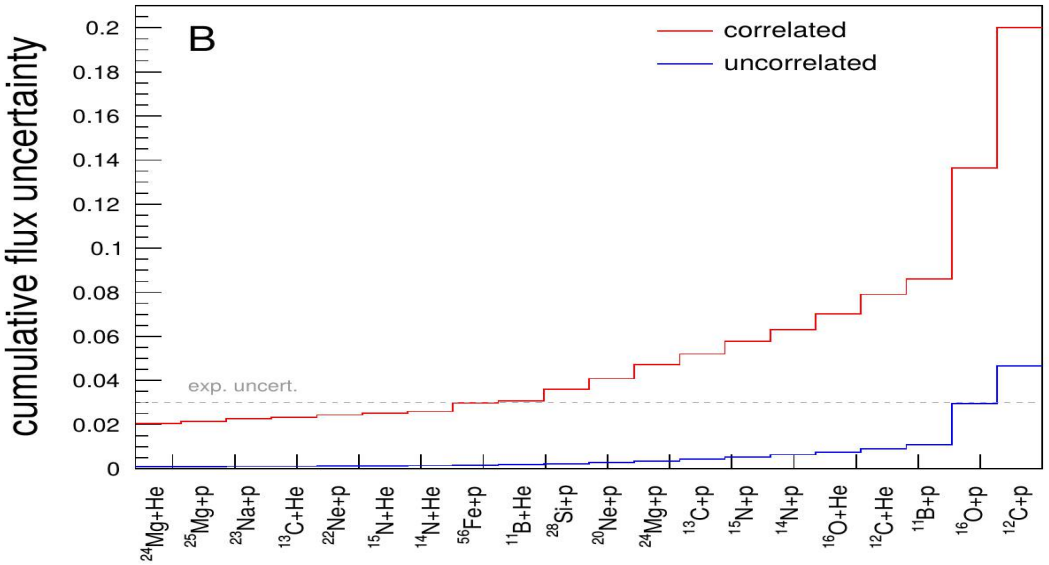


NFCS: current situation



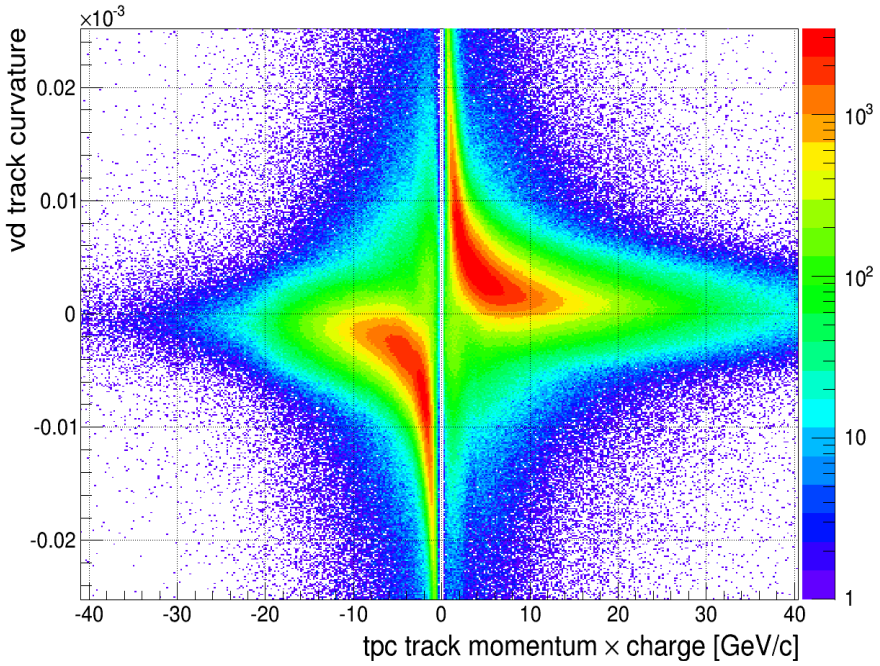
Precise measurement of the cross sections at around 13 *A* GeV/*c* can improve situation dramatically.

Similar situation is for $^{16}O + p \rightarrow {}^{11}B$



Main uncertainties to the cumulative flux are related to uncertainty on NFCS for C+p and O+p

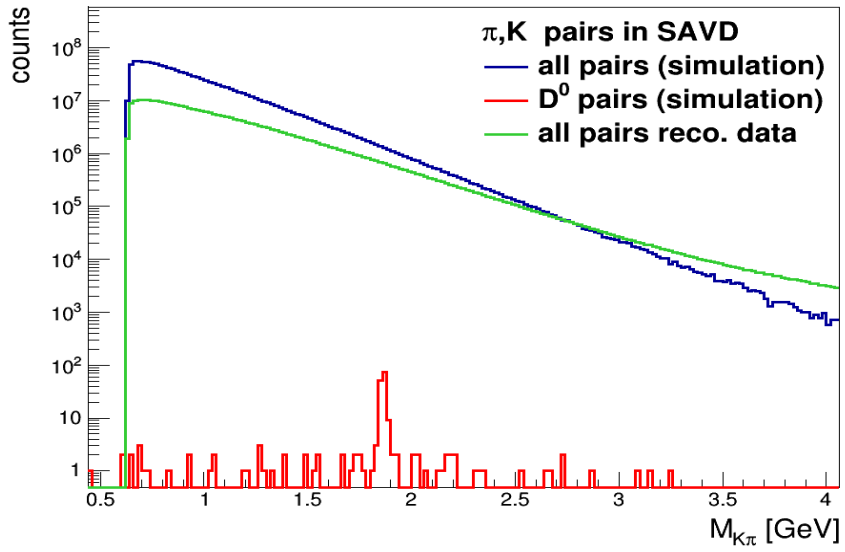
VD – TPC track matching



Clear correlation between SAVD track curvature and TPC track momentum.

The correlation is broad due to low magnetic field in the SAVD volume:

$$\int Bdl \approx 0.04 \text{ Tm}$$



Matching with TPC provides:
momenta and PID to VD tracks

→ invariant mass distribution