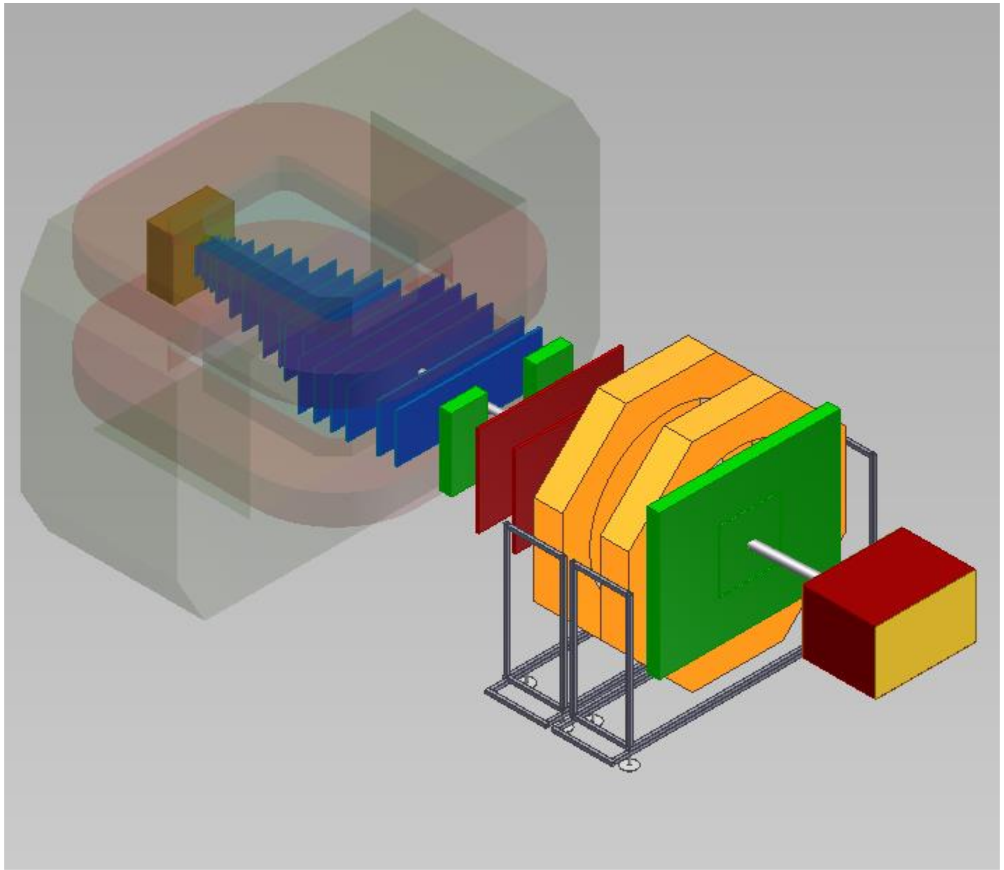
Overview of Baryonic Matter at Nuclotron (BM@N)

JINR (Dubna), IHEP (Protvino), INR RAS (Troitsk), ITEP (Moscow), SINR MSU, MEPHI

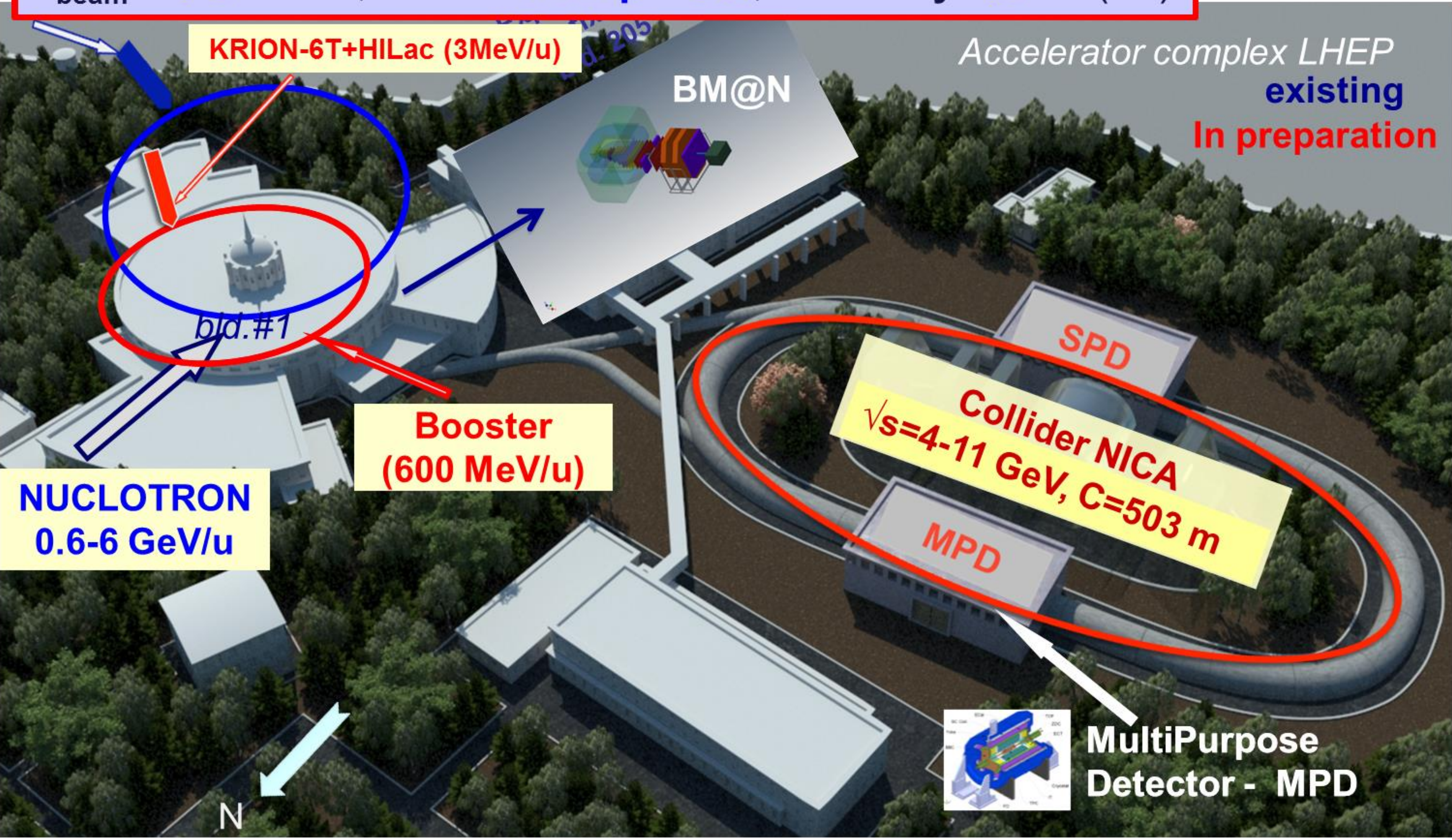
Plovdiv Uni, WUT (Warsaw), Goethe Uni (Frankfurt), MoU with GSI (Darmstadt) + SRC team

M.Kapishin



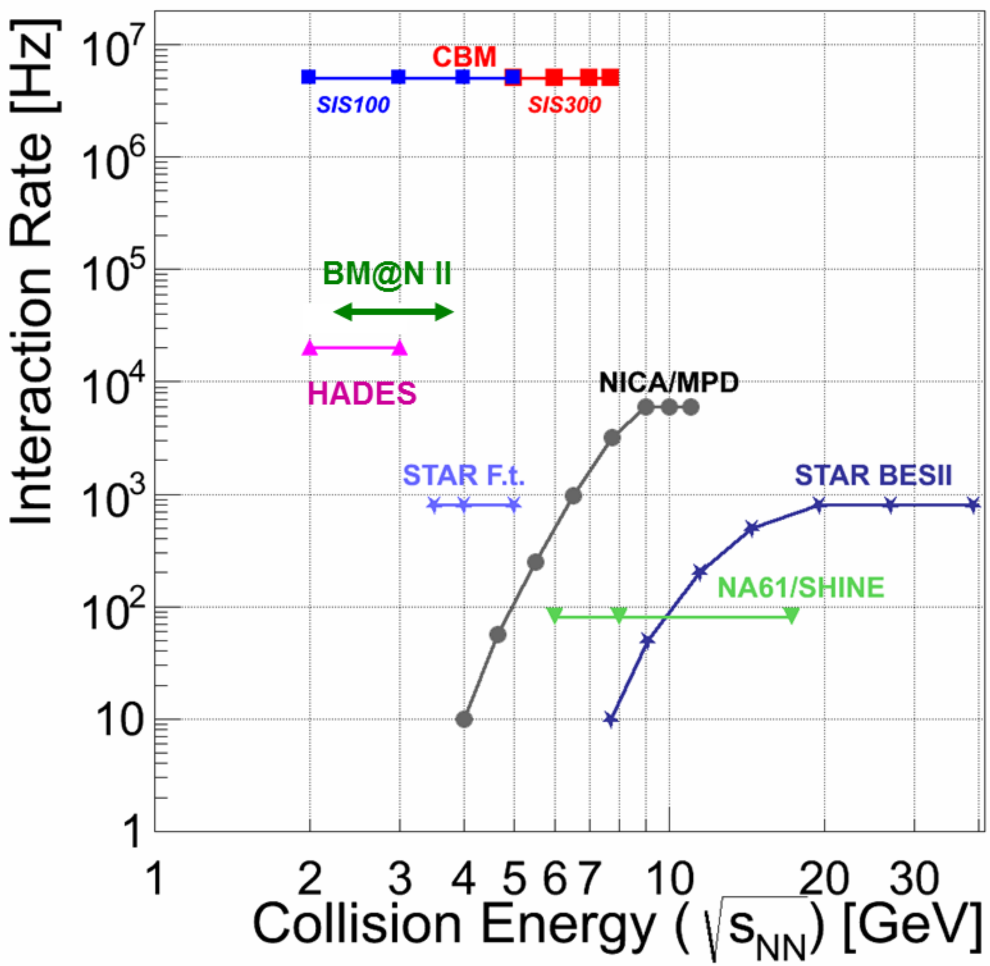
Complex NICA

Parameters of Nuclotron for BM@N experiment:
E_{beam} = **1-6** GeV/u; ***beams**: from* **p** to **Au**; **Intensity~10^7** c^{-1} (Au)



Heavy Ion Collision experiments

BM@N: $\sqrt{s_{NN}}$=2.3 - 3.5 GeV



Physics possibilities at the Nuclotron

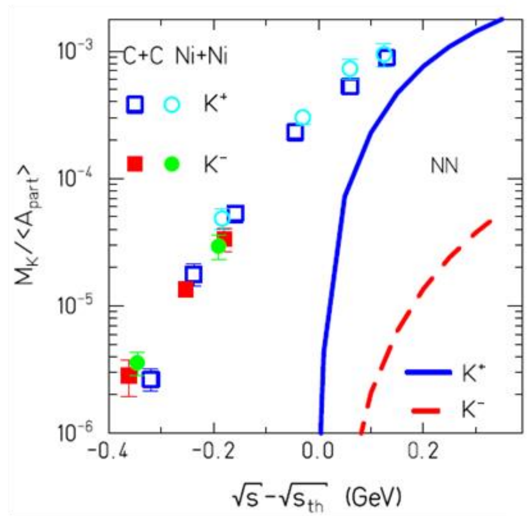
I. In A+A collisions at Nuclotron energies:

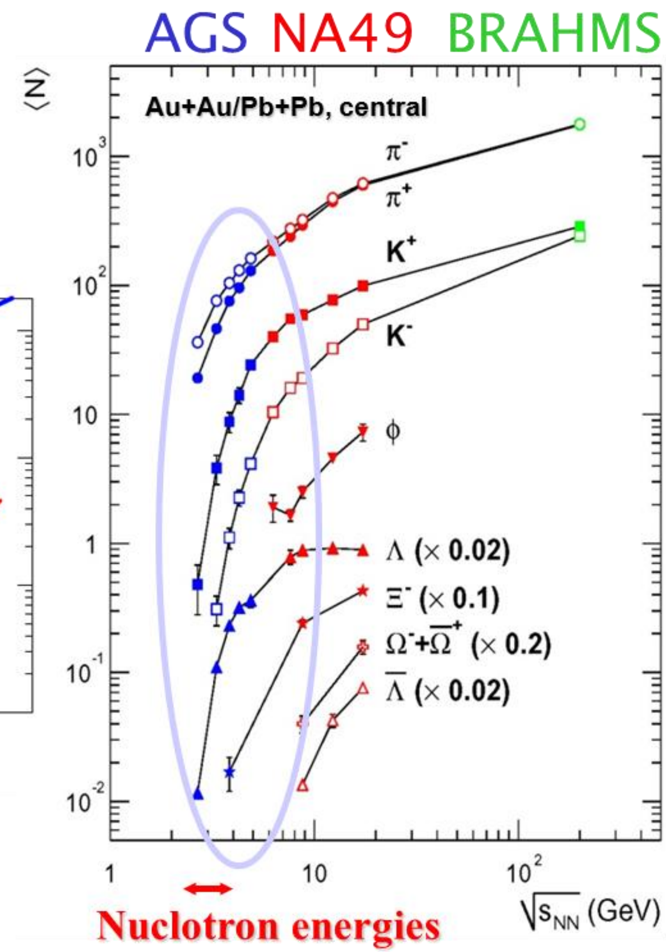
❑ **Opening thresholds for strange and multi-strange hyperon production**

➔ **strangeness at threshold**

➔ Need more precise data for strange mesons and hyperons, multi- variable distributions, unexplored energy range

► **Collective flows v_1, v_2**

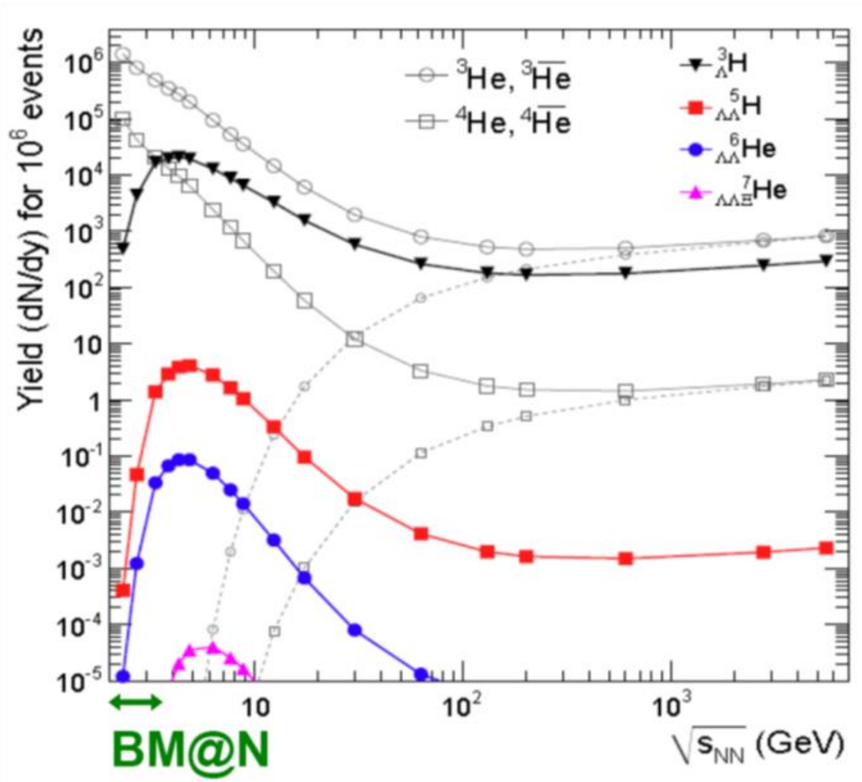


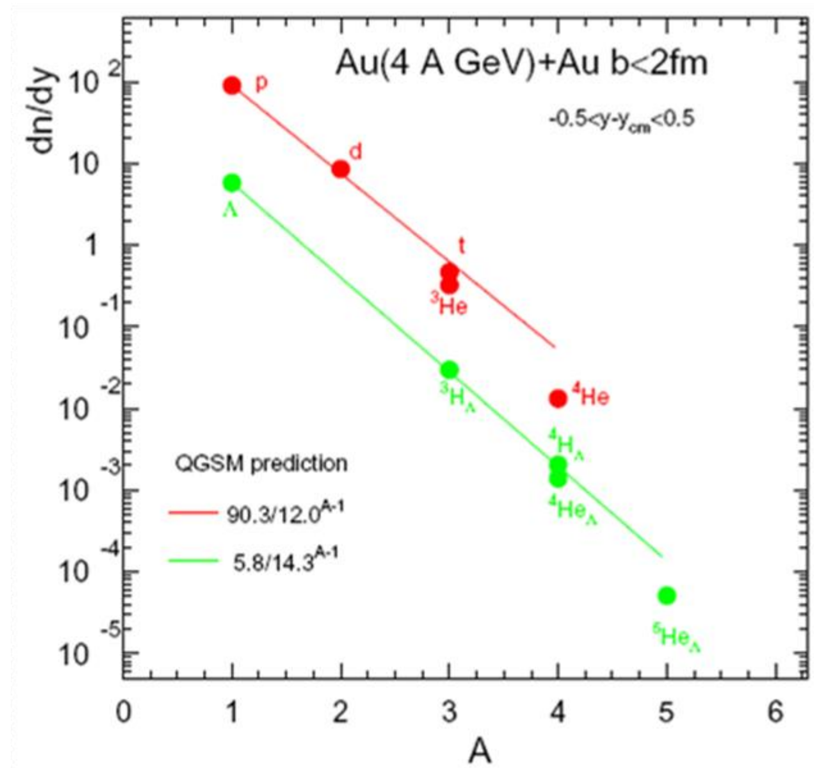


II. In *p+p, p+n, p+A* collisions:

➔ **hadron production in elementary reactions and 'cold' nuclear matter as 'reference' to pin down nuclear effects**

Heavy-ions A+A: Hypernuclei production

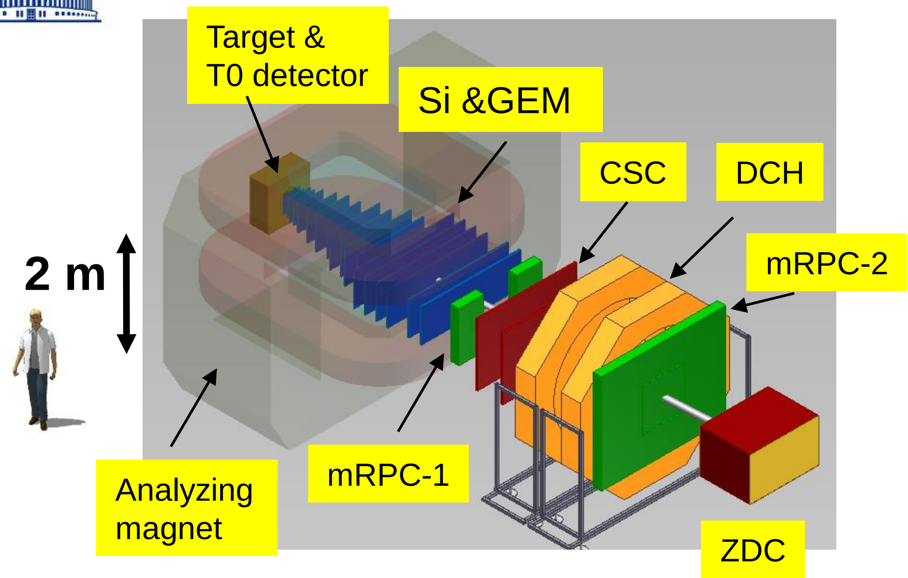




- In heavy-ion reactions: production of hypernuclei through coalescence of Λ with light fragments enhanced at high baryon densities
- Maximal yield predicted for √s=4-5A GeV (stat. model) (interplay of Λ and light nuclei excitation function)

➔ BM@N energy range is suited for the search of hypernuclei

BM@N setup



BM@N advantage: large aperture magnet (~1 m gap between poles)

→ fill aperture with coordinate detectors which sustain high multiplicities of particles

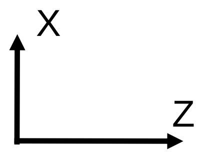
→ divide detectors for particle identification to "near to magnet" and "far from magnet" to measure particles with low as well as high momentum (p > 1-2 GeV/c)

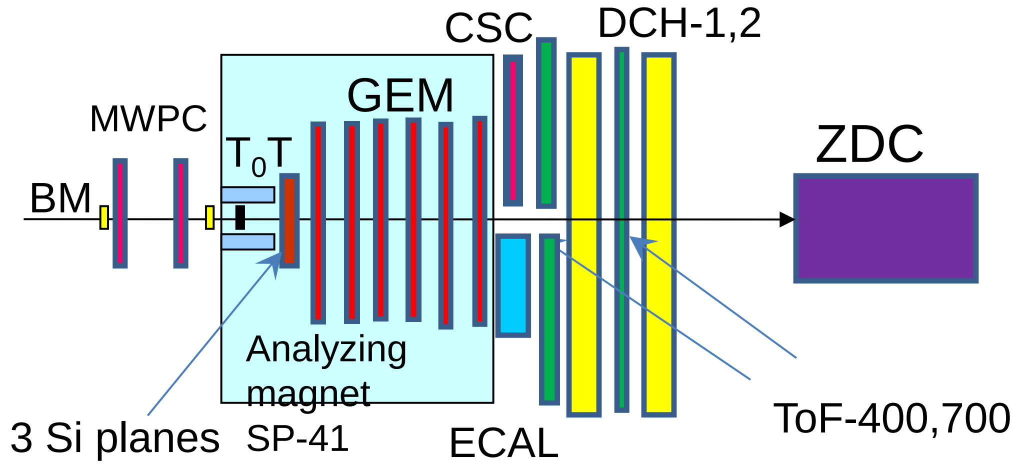
→ fill distance between magnet and "far" detectors with coordinate detectors

- Central tracker (Si + GEM) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (CSC, DCH) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions and form trigger
- Detectors to form T0, L1 centrality trigger and beam monitors
- Electromagnetic calorimeter for γ,e+e-

BM@N run with Ar and Kr beams in March 2018

Ar beam, T_0= 3.2 GeV/n





Kr beam, T_0= 2.3 (2.9) GeV/n

• Central tracker inside analyzing magnet → 6 GEM detectors 163 x 45 cm^2 and 3 forward Si strip detectors for tracking

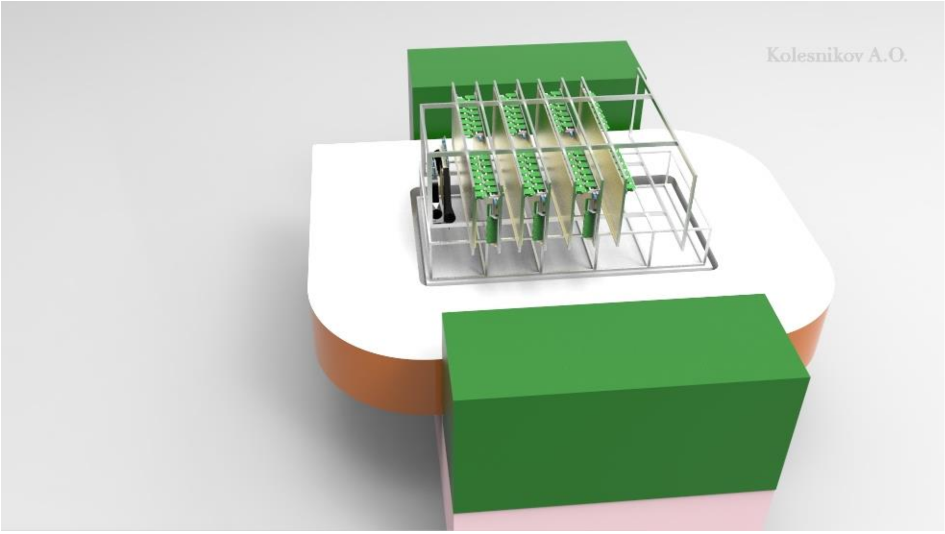
• Full ToF-400, ToF-700, T0 + Trigger barrel and Si detectors, full ZDC, part of ECAL, CSC and DCH chambers as outer tracker

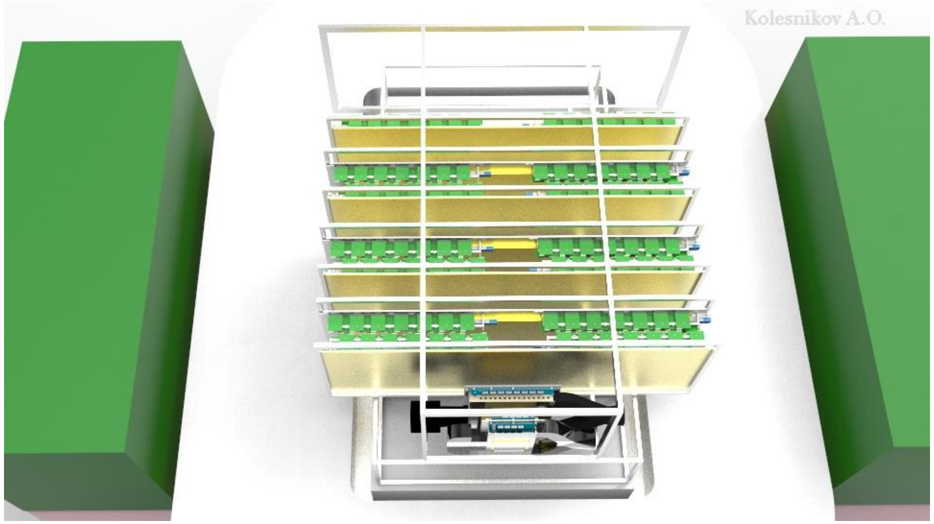
Program:

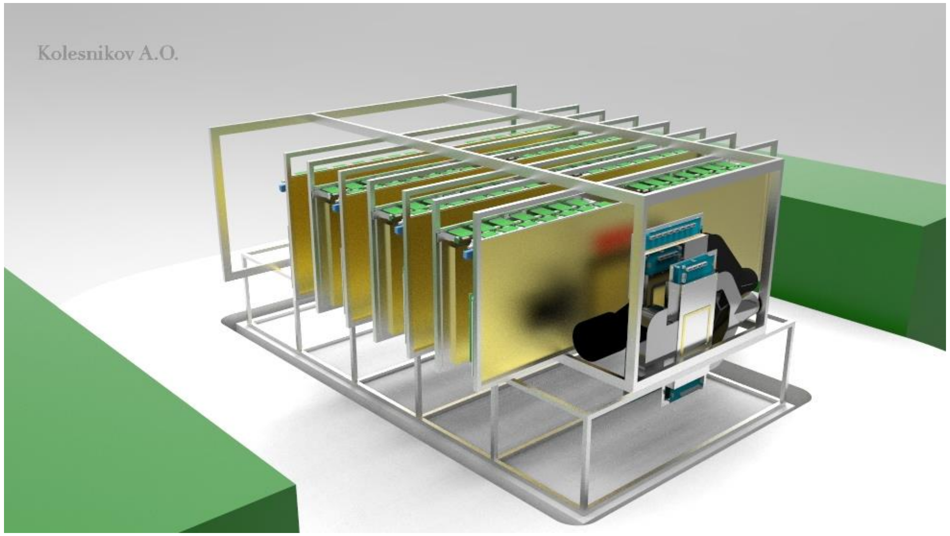
• Measure inelastic reactions Ar (Kr) + target → X on targets Al, Cu, Sn, Pb
→ Hyperon production measured in central tracker (Si + GEM)
→ Charged particles and nuclear fragments identified with ToF-400,700
→ Gamma and multi-gamma states identified in ECAL
→ 130 M events in Ar beam, 50 M events in Kr beam

+ analyze data from previous technical runs with Deuteron and Carbon beams of 3.5 - 4.6 GeV/n performed in December 2016 and March 2017

BM@N central tracker in Ar, Kr run, March 2018





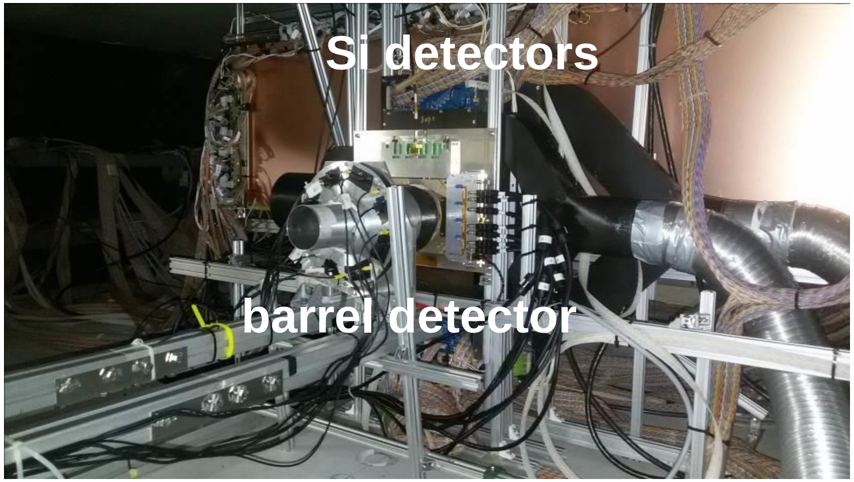


7 planes of big GEM detectors
3 planes of Si detector in front of GEMs

Beam crosses Si detectors in center, big GEMs – in beam hole
→ configuration is based on results of Λ and K^0_S simulation

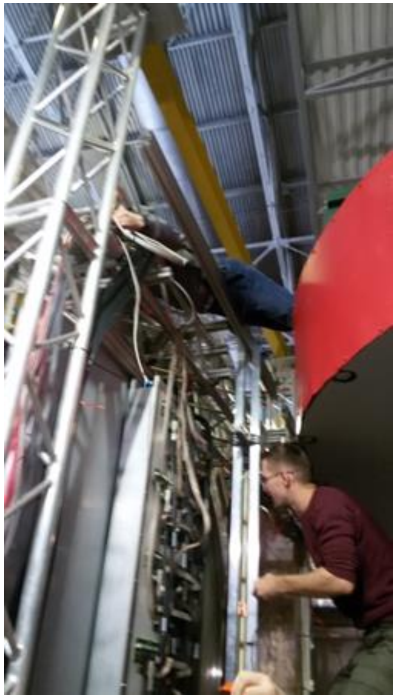
►Precise 3D measurement of all major components of BM@N setup !
(A.Kolesnikov + firm)

BM@N set-up in Ar, Kr run, March 2018



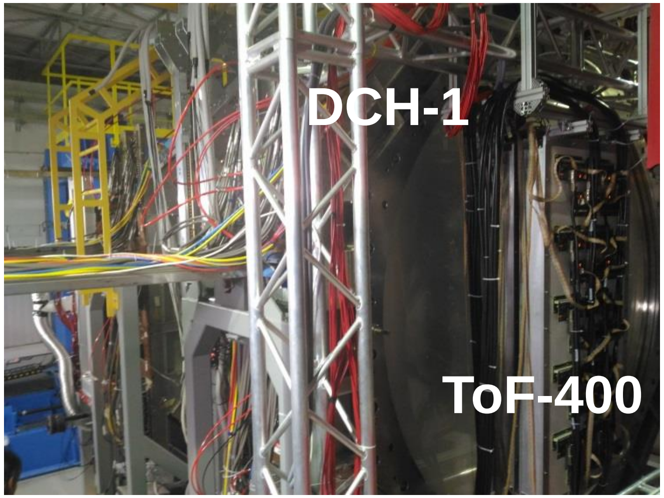
CSC chamber

ToF-400 installation

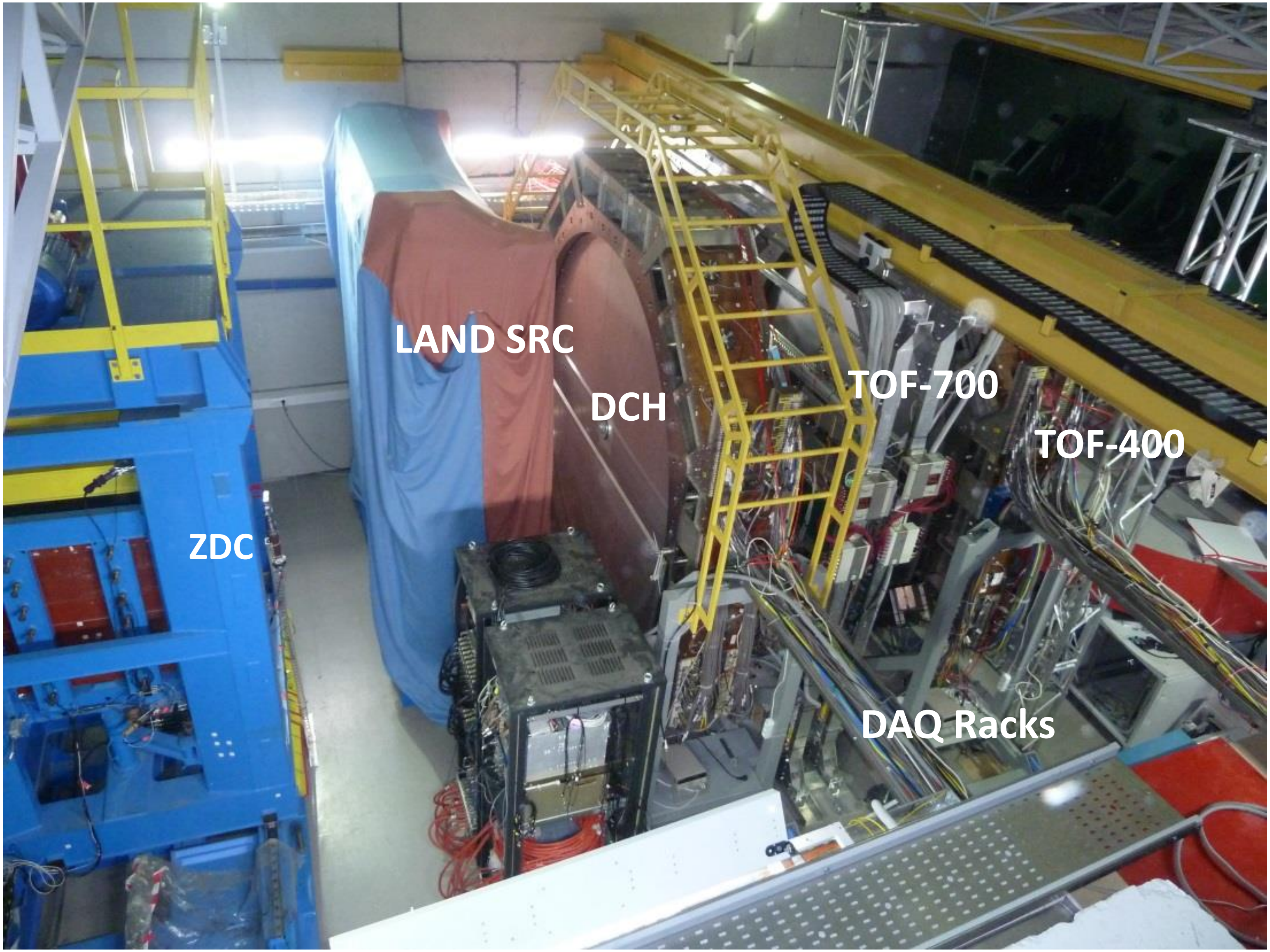


New detector components:

6 big GEMs, trigger detectors, 3 Si detectors, CSC chamber, full set of ToF detectors



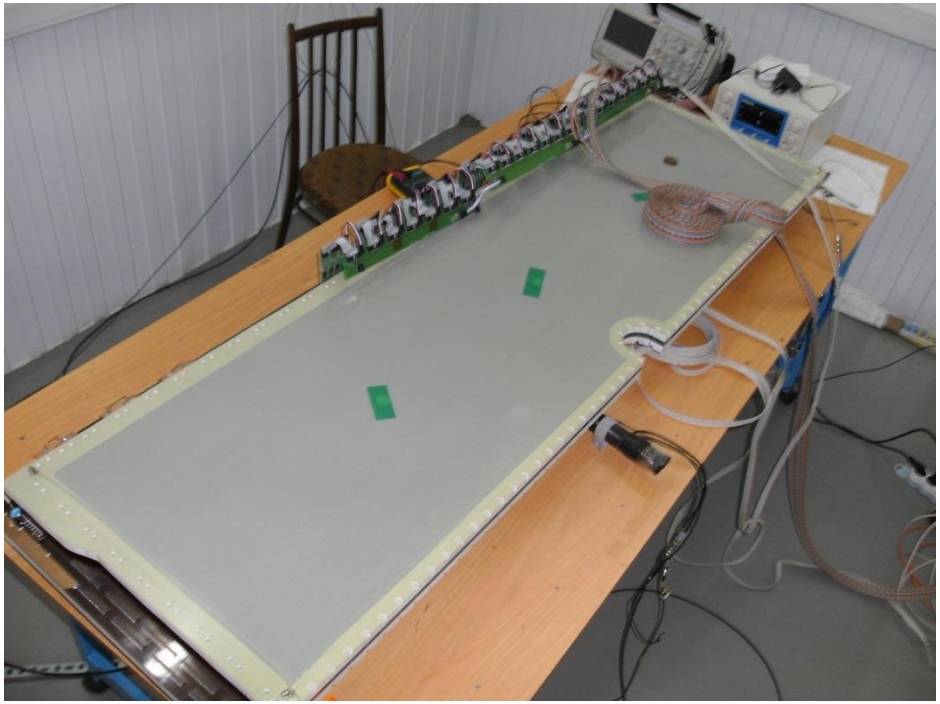
BM@N setup behind magnet, 2018

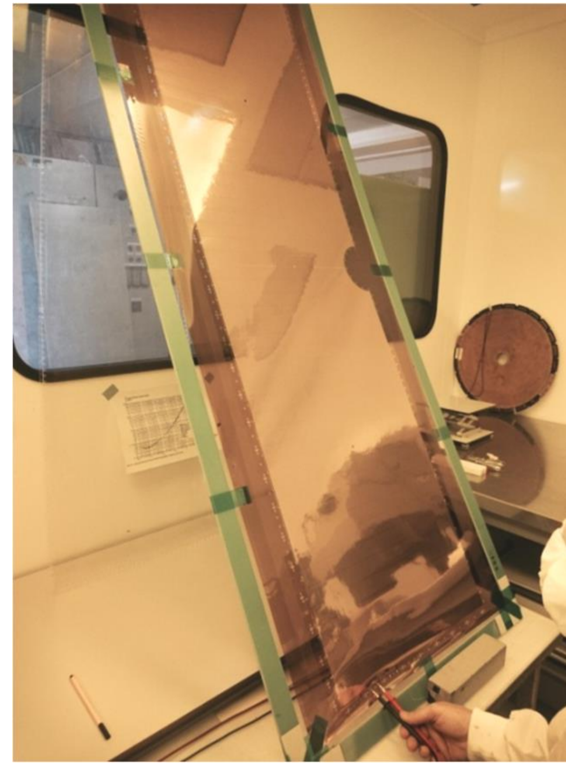


GEM detectors for central BM@N tracker

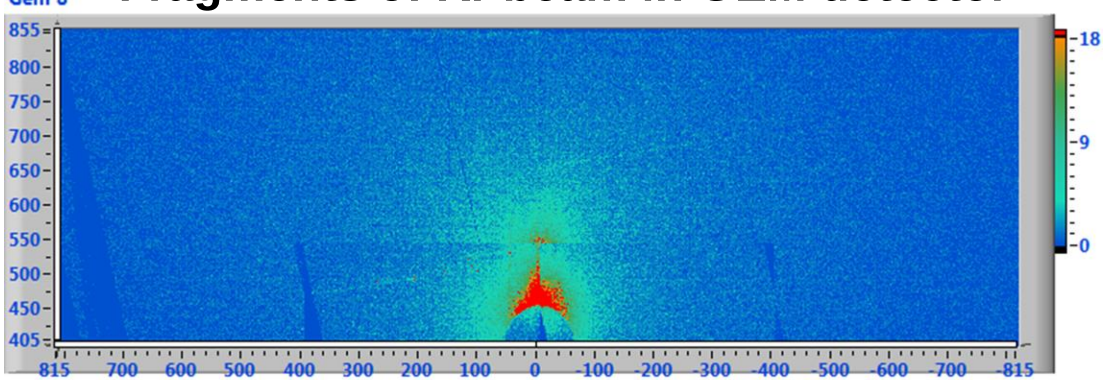
Tests of GEM detector 163 x 45 cm^2

GEM group, talk of A.Maksymchuk



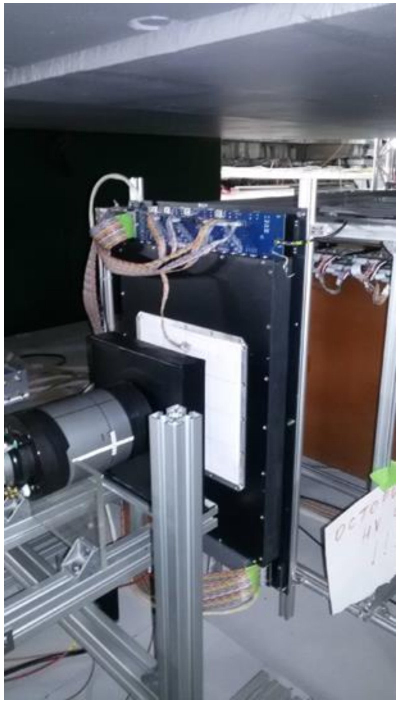


Fragments of Kr beam in GEM detector

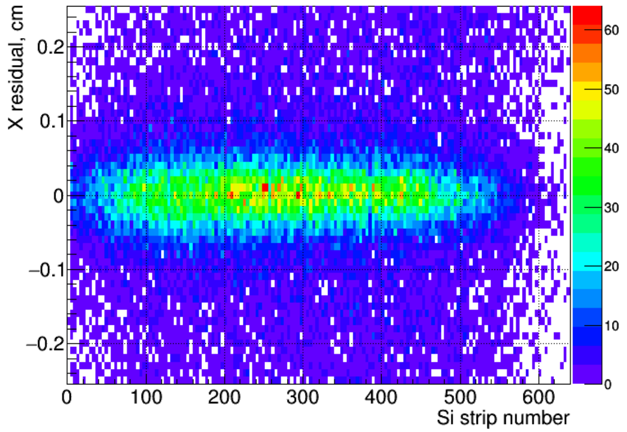


- **for BM@N run in spring 2018 7 detectors 163 x 45 cm^2 are produced at CERN workshop**

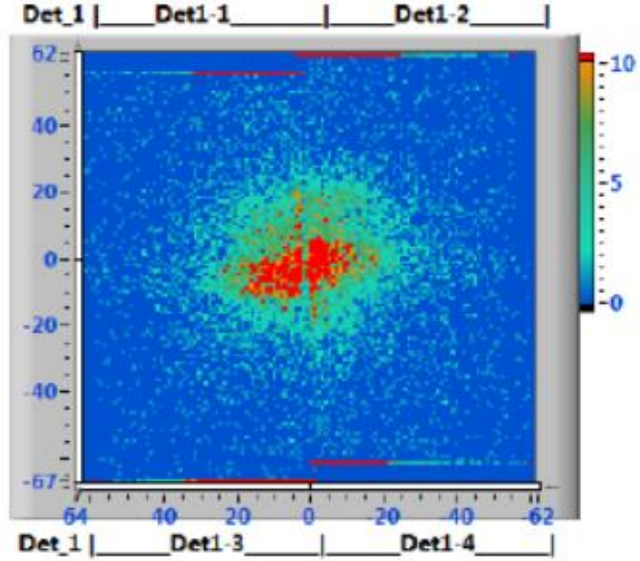
Forward silicon strip detectors



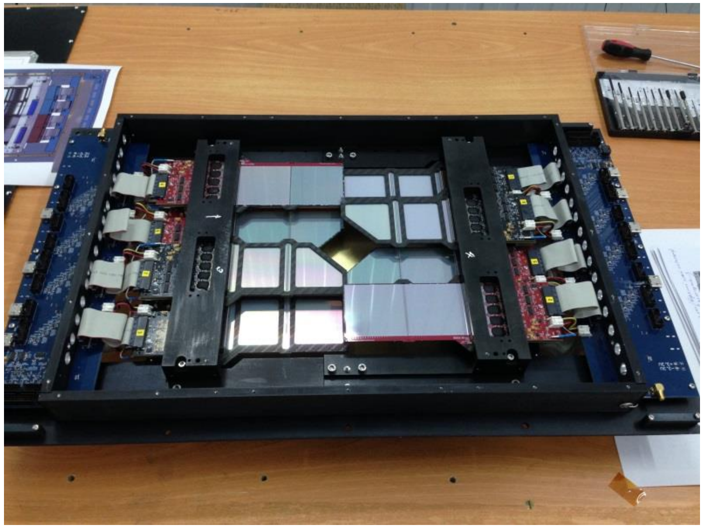
Silicon detector group, talk of N.Zamiatin



Si-GEM residuals (cm) vs strip number



Kr beam fragments in Si Vertex detector



- 2-coordinate Si detector X-X'(±2.5º) with strip pitch of 95/103 μm, full size of 25 x 25 cm^2, 10240 strips
- Detector combined from 4 sub-detectors arranged around beam, each sub-detector consists of 4 Si modules of 6.3 x 6.3 cm^2
- 1 detector installed in front of GEM tracker in March 2017, 2 vertex detectors → in March 2018

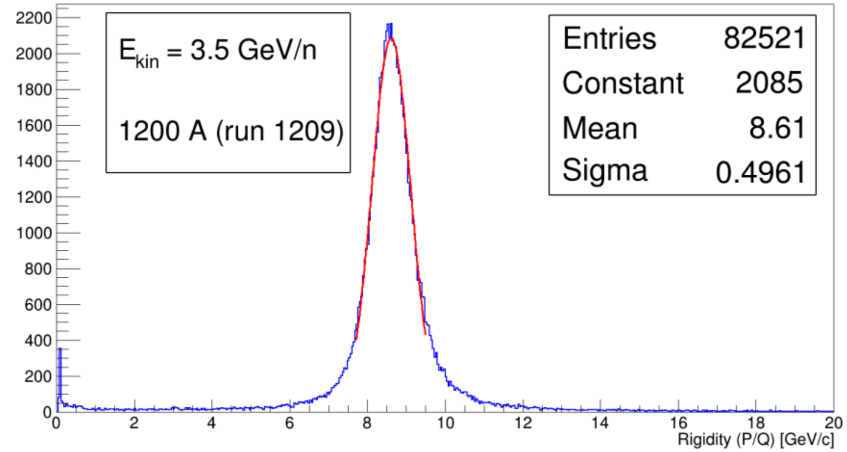
Beam momentum measured with GEM tracker

Carbon beam run, 4 AGeV

Talk of S.Merz

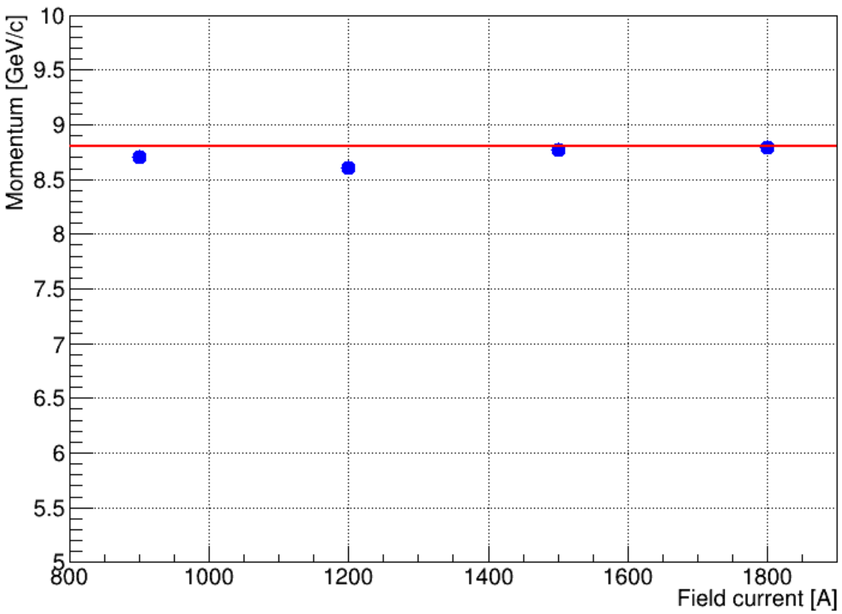
Reconstruction of carbon beam trajectory and momentum in GEM detectors at different values of magnetic field

Gas mixture: Ar + CO_2 (70:30)

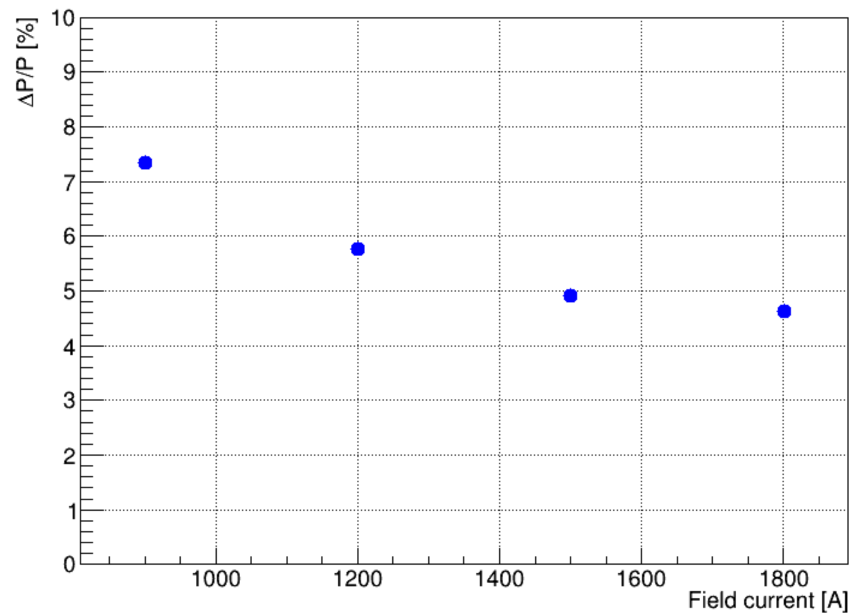


p/q

Reconstructed momentum for different magnetic fields



Momentum resolution for different magnetic fields

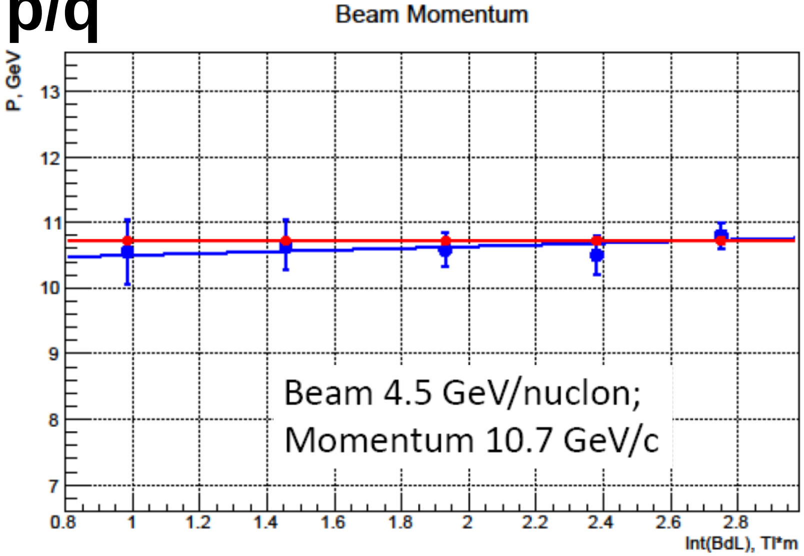


Beam Momentum measured with DCH outer tracker

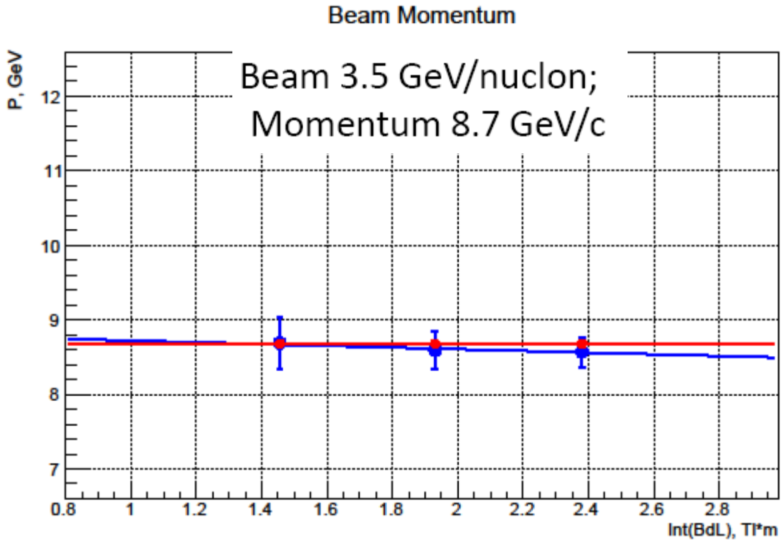
Momentum vs. Int(BdL)

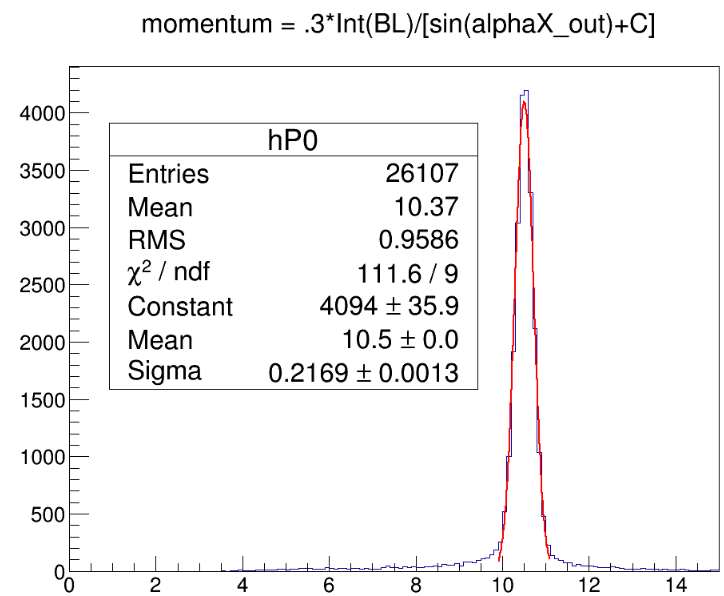
Talk of N.Voitishin

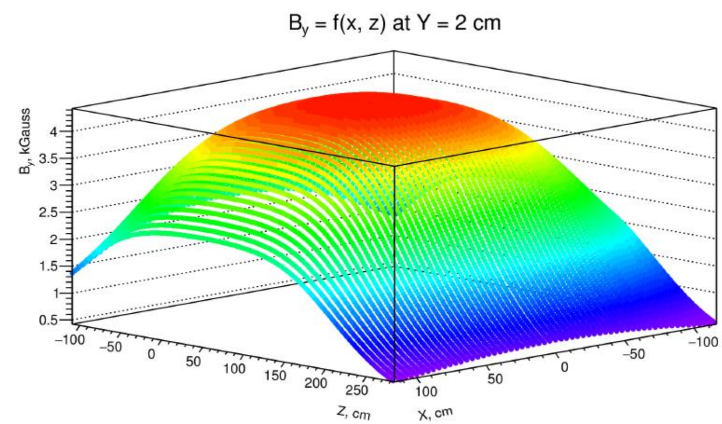
p/q



Error bars → momentum resolution







Magnetic field

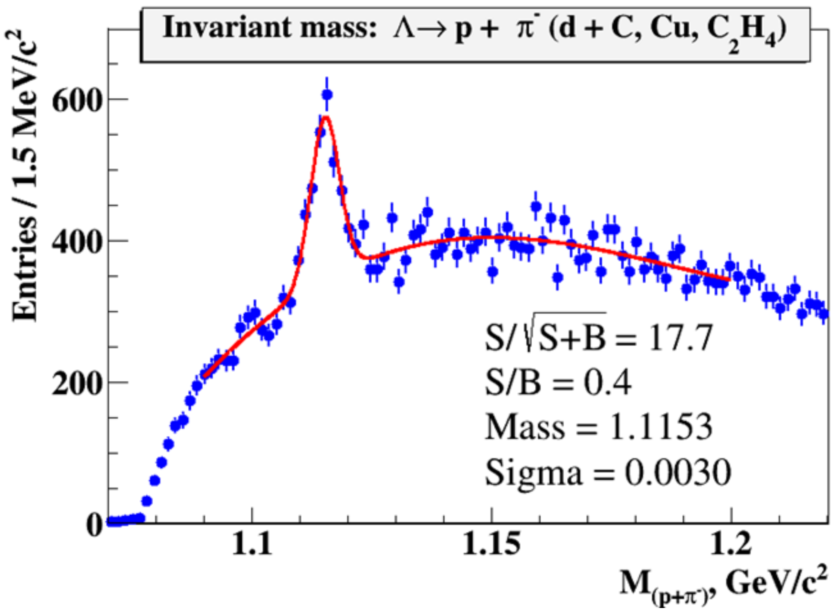
Λ in deuteron and carbon beams

d (C) + target → X

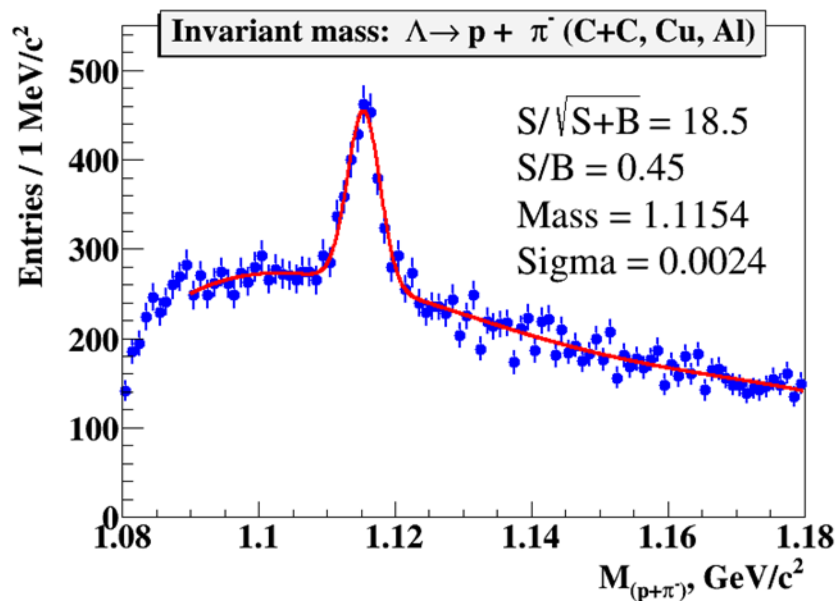
talk of A.Zinchenko

Λ signal width of 2.4 - 3 MeV

Deuteron Data



Carbon beam run, 4 AGeV

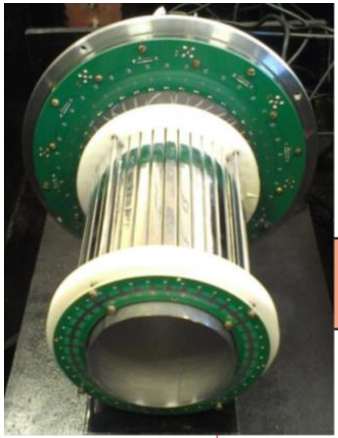


To improve vertex and momentum resolution and reduce background under Λ:

- **Need few planes of forward Silicon detectors → 3 planes used in last run**
- **Need more GEM planes to improve track momentum reconstruction**

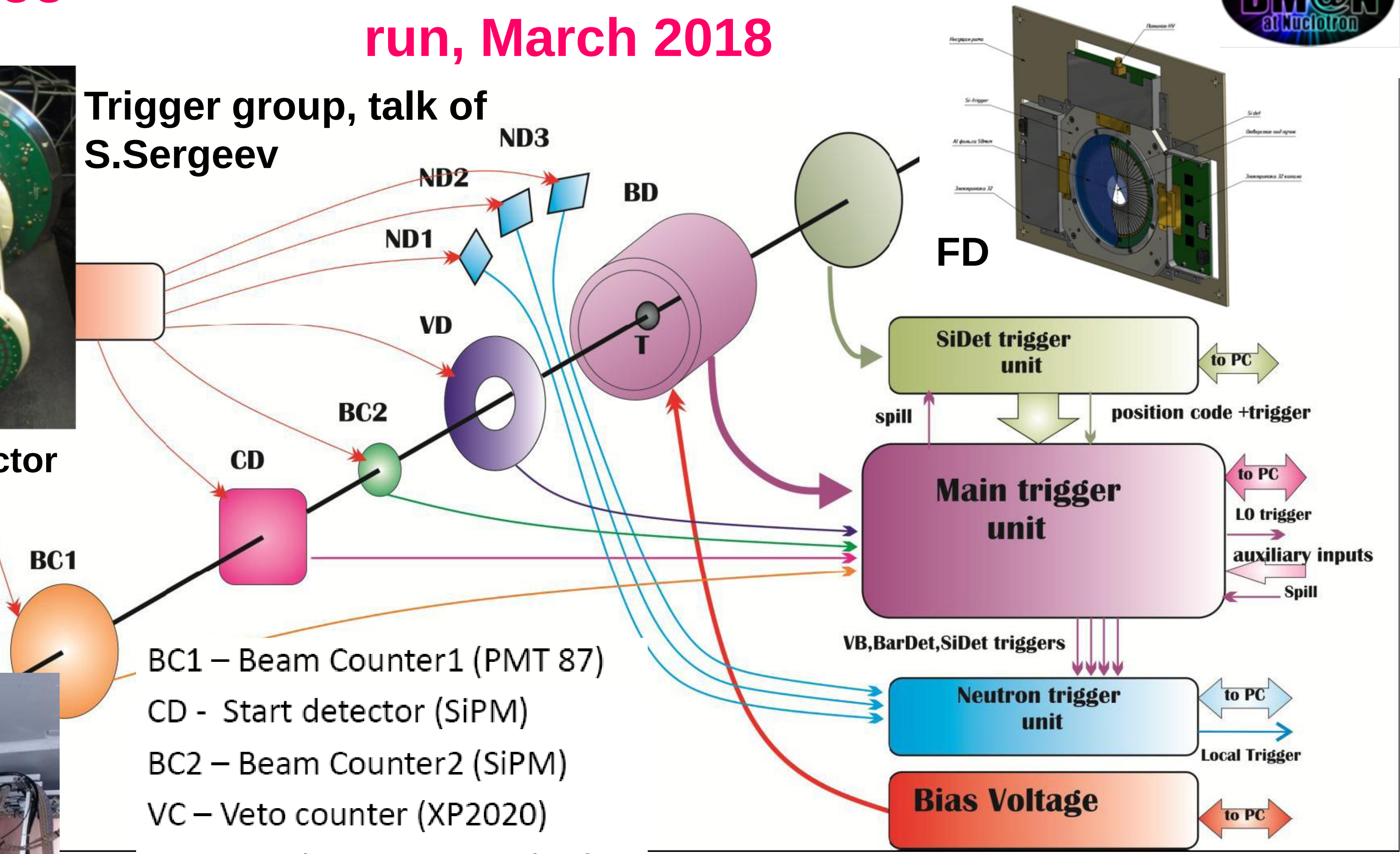
Methodical Paper published in PPNL: First results from BM@N technical run with deuteron beam

Trigger detectors and beam counters in Ar and Kr run, March 2018



Barrel detector

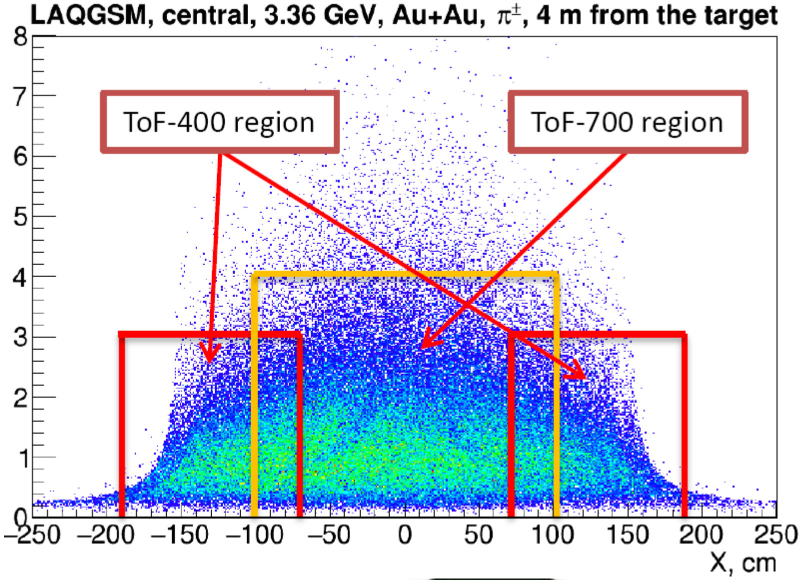
Trigger group, talk of S.Sergeev



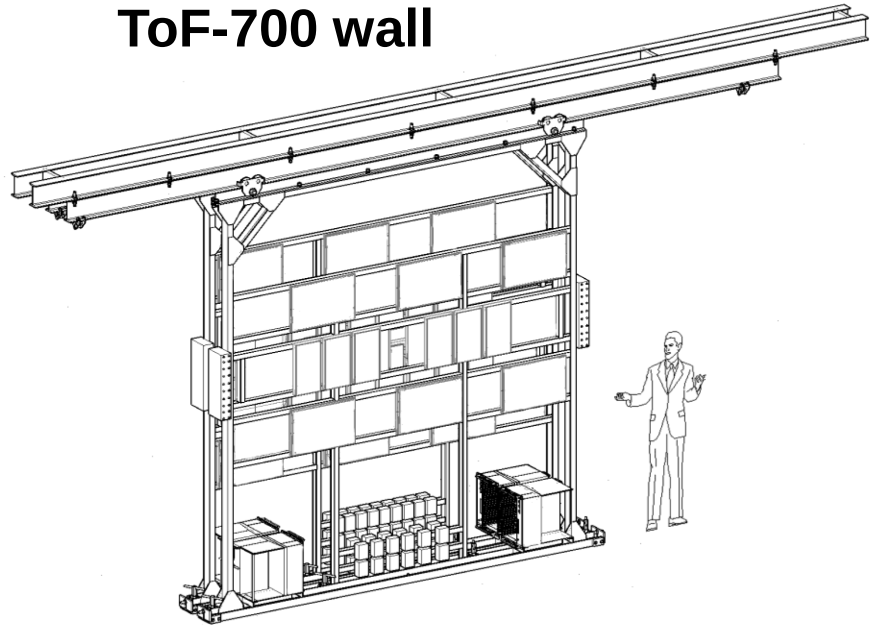
- BC1 – Beam Counter1 (PMT 87)
- CD - Start detector (SiPM)
- BC2 – Beam Counter2 (SiPM)
- VC – Veto counter (XP2020)
- BD – Barrel Detector – 40ch. SiPM
- T – target
- SiDet – Silicon Detector

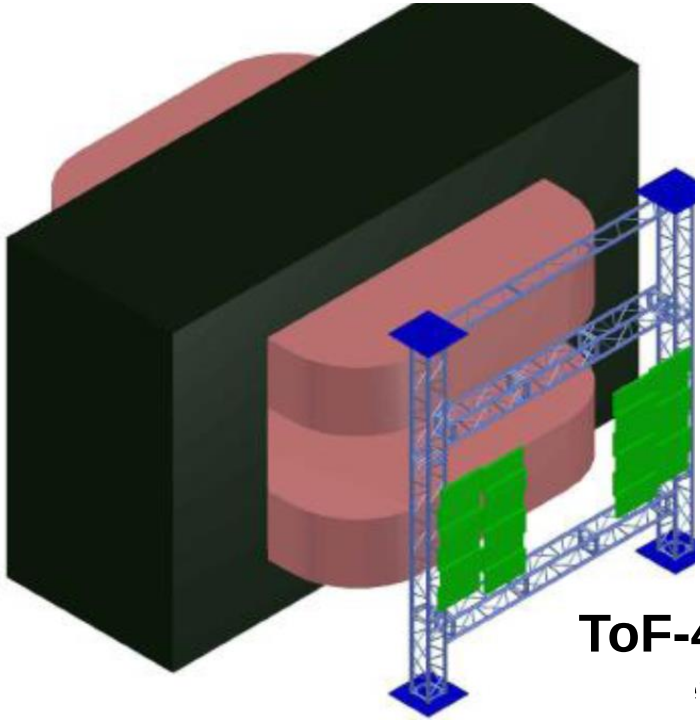
Selection of events with activity in barrel detector: BD >= N or forward Si detector: FD >= N (group of N.Zamiatin)

ToF-400 and ToF-700 based on mRPC

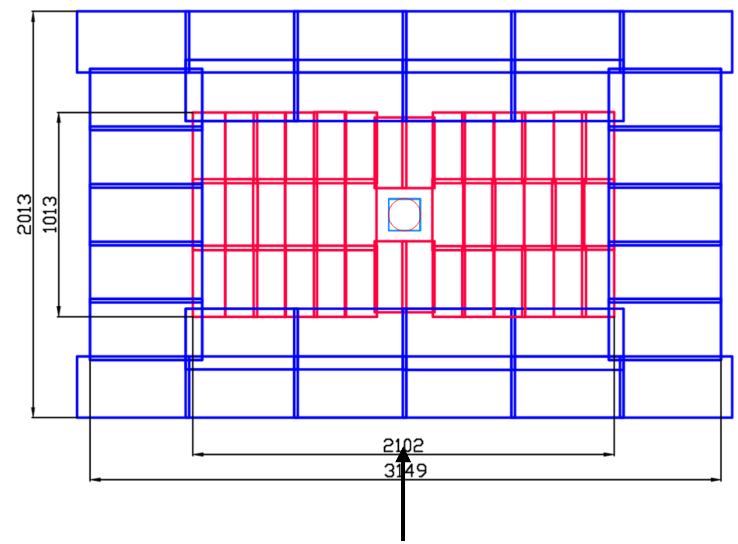


ToF-700 wall





ToF-400 wall

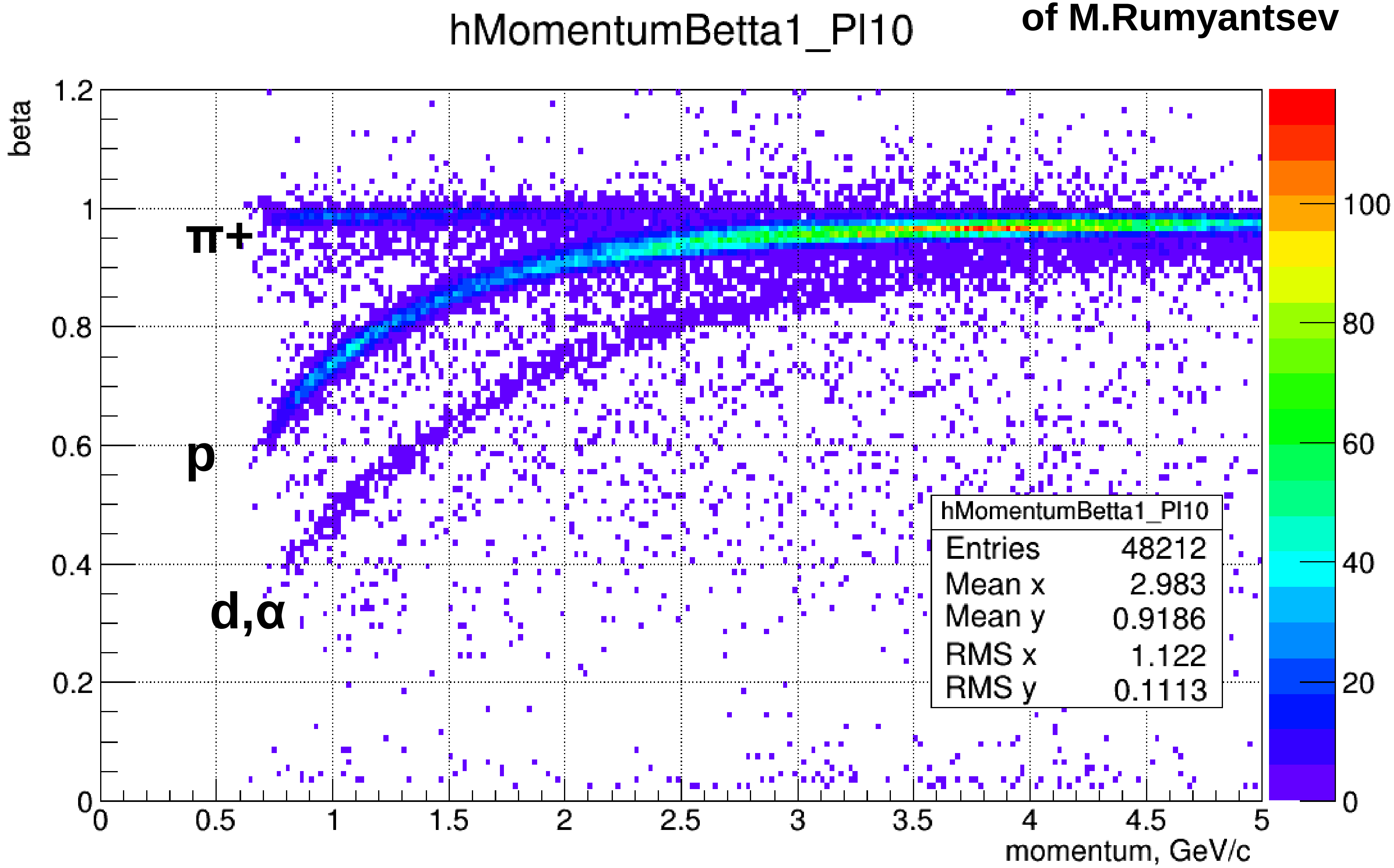


BM@N beam axis

ToF-400: status of particle identification

Carbon beam , 3.5 AGeV , C + Al → X

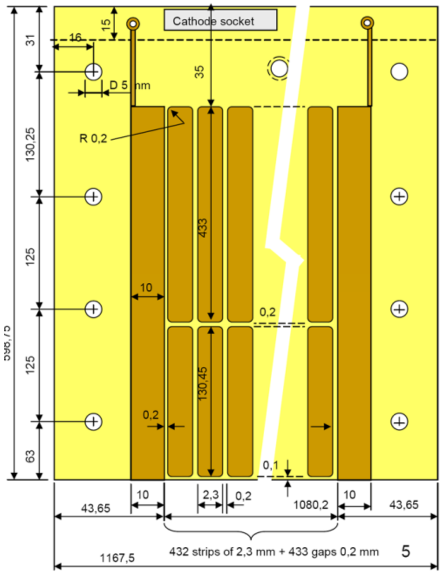
ToF-400 team, talk of M.Rumyantsev

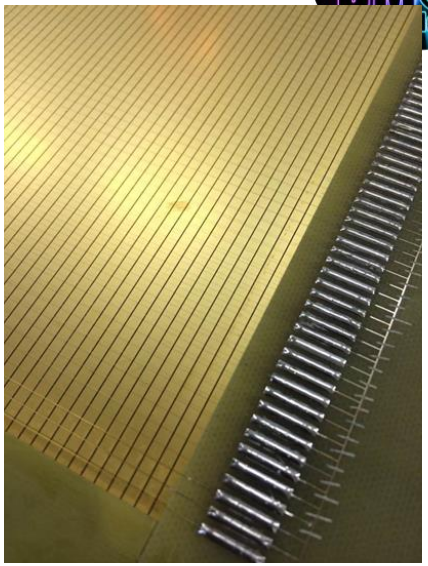


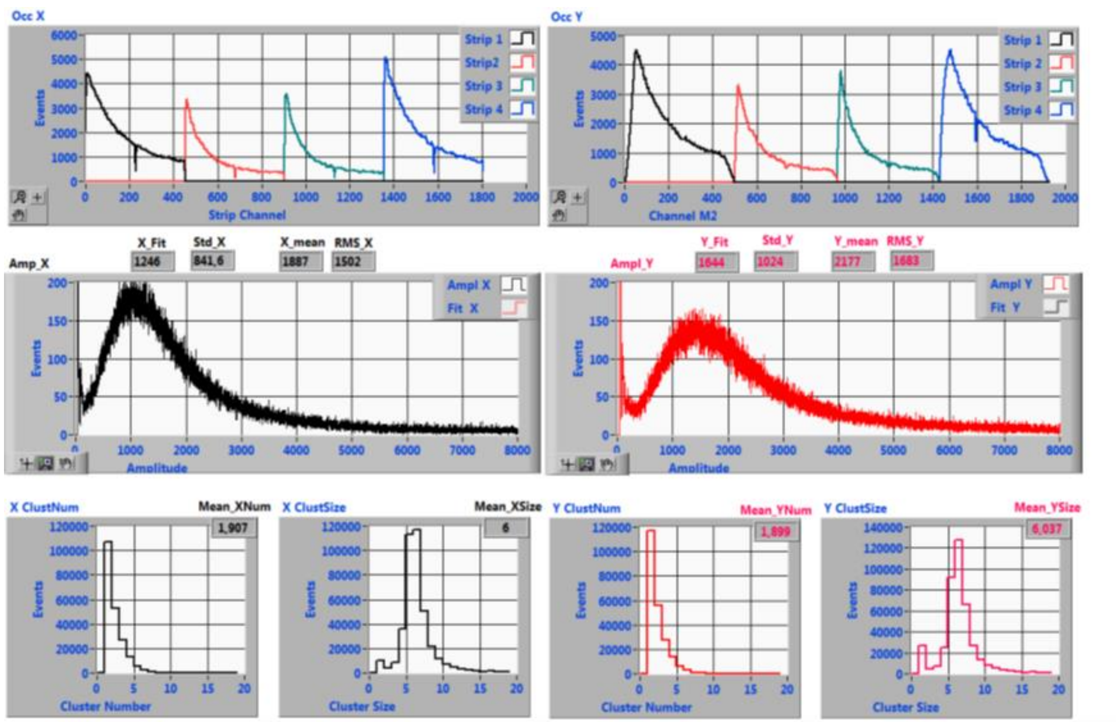
Outer Tracker: new Cathode Strip Chamber

Al. Vishnevsky + GEM team

C, Ar and Kr runs in March 2018: CSC chamber installed in front of ToF-400 to check its performance as Outer tracker for heavy ion beams

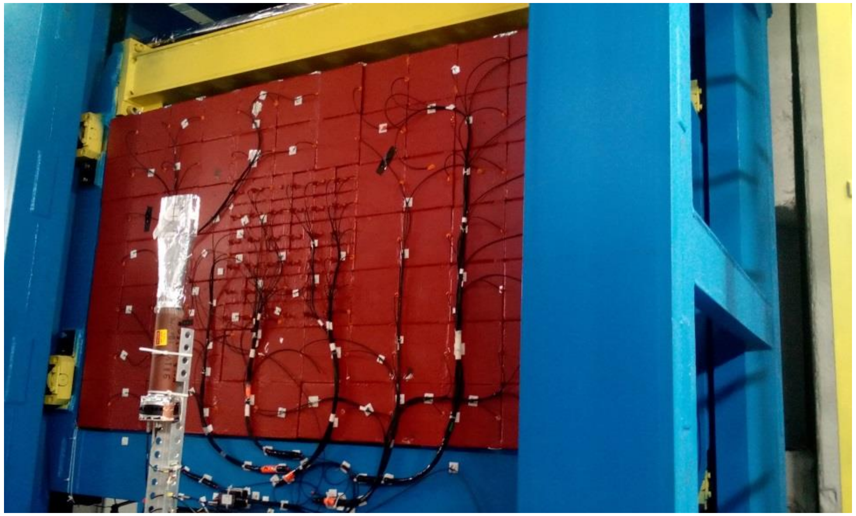




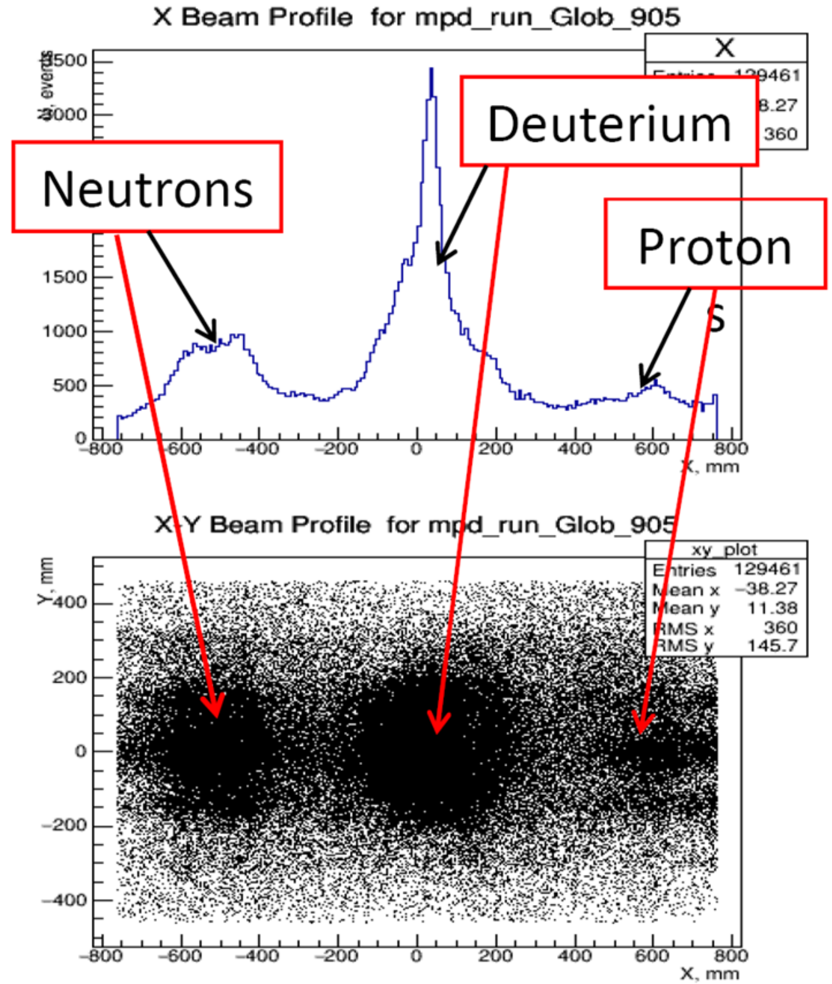


ZDC hadron calorimeter

Talk of O.Gavrischuk

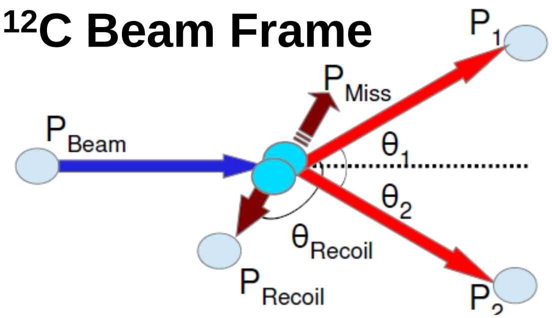


Talk of A.Ivashkin: MPD / CBM type of calorimeter

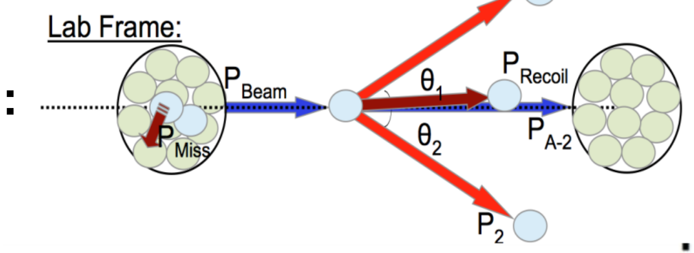


- **Collect deuteron, carbon beam data with ZDC at different positions**
- **Calibration of cell amplitudes to get beam energy in cluster**
- **Spread of energies reconstructed at different ZDC positions ~3%**

A proposal for BM@N experiment to study SRC with hard inverse kinematic reactions

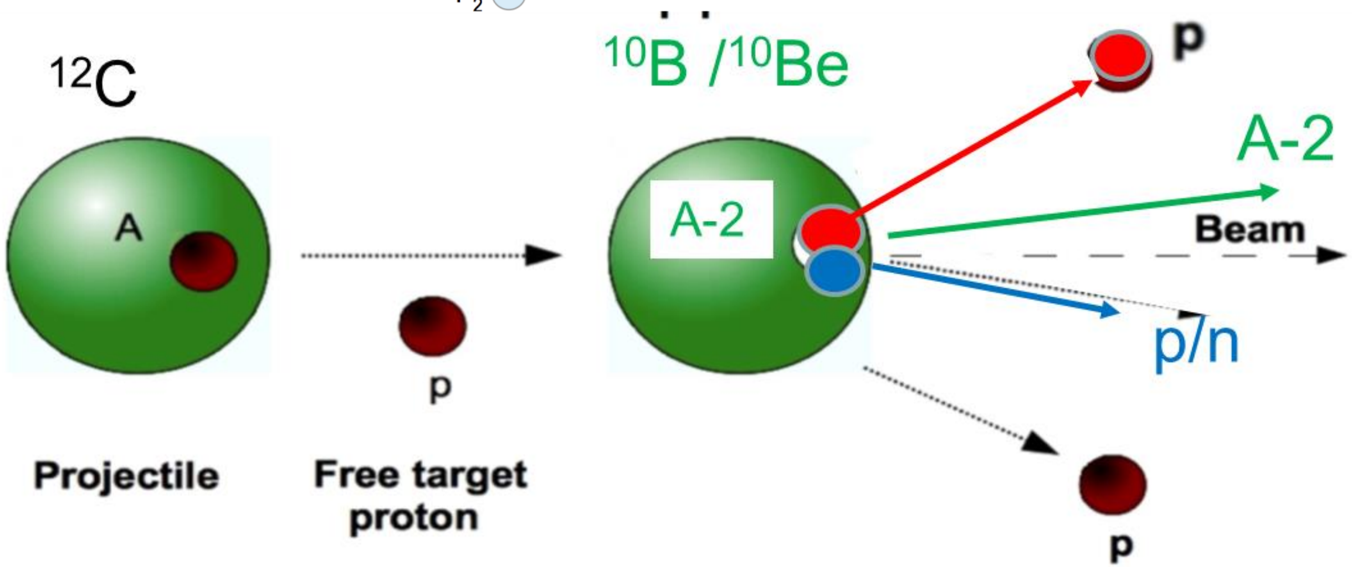


JINR (Dubna): BM@N
Israel: Tel Aviv University
Germany: TUD and GSI
USA: MIT
FRANCE: CEA



Objectives:

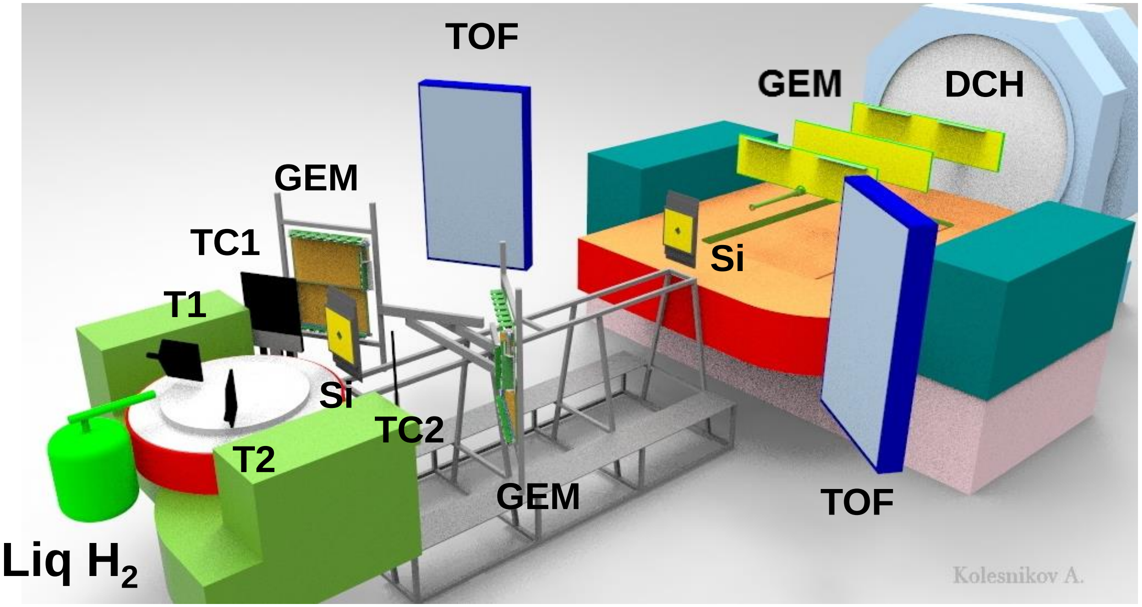
- identify 2N-SRC events with inverse kinematics
- study isospin decomposition of 2N-SRC
- study A-2 spectator nuclear system



BMN & SRC set-up

Talk of E.Piasetzky

Cuts
$\lvert\theta_{1,2}-30^o\rvert<6.5^o$
$\lvert\Delta\varphi_{1,2}\rvert<7.5^o$
$\lvert s,t,u\rvert>2\ (GeV/c)^2$
$P_{miss}>0.275$ GeV/c



Liq H_2

Trigger:
T0 · T1 · T2 · TC1 · TC2

T0 +Target + T1

Signal rates for 14 days of data taking

Within LAND acceptance

$$^{12}C+p\rightarrow\ ^{10}B+pp$$ np SRC

$$^{12}C+p\rightarrow\ ^{10}Be+pp$$ pp SRC

$$^{12}C+p\rightarrow 2p+\ ^{10}_{5}B+n$$ np SRC

$$^{12}C+p\rightarrow 2p+\ ^{10}_{4}Be+p$$ pp SRC

→ First SRC @ BMN run in March 2018: collected 8 M events

Table 1. Beam parameters and setup at different stages of the experiment

year	2016	2017 spring	**2018 spring**	**2020**	**2021 and later**
beam	d(↑)	C	Kr, Ar **C**(SRC)	Au	Au, p
max.intensity, Hz	0.5M	0.5M	0.5M	1M	10M
trigger rate, Hz	5k	5k	10k	10k	20k→50k
central tracker status	6 GEM half pl.	6 GEM half pl.	6 GEM half pl. **3 small Si planes**	7 GEM full pl. **small + 4 large Si planes**	7 GEMs **small + 4 large Si planes**
experim. status	techn. run	techn. run	techn. run	stage 1 physics	stage 2 physics

Present status and next plans

- BM@N technical runs performed with deuteron and carbon beams at energies T_0 = 3.5 - 4.6 AGeV and recently with Ar beam of 3.2 AGeV and Kr beam of 2.3 AGeV
- Measurement of Short Range Correlations with inverse kinematics: C beam + H_2 target
- Major sub-systems are operational, but are still in limited configurations: GEMs, forward Silicon detectors, Outer tracker, ToF, ZDC, ECAL, trigger, DAQ, slow control, online monitoring
- Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed

Major BM@N plans for Au+Au:

- Collaborate with CBM to produce and install large aperture STS silicon detectors in front of GEM setup
- Extend GEM central tracker and CSC outer tracker to full configuration
- Implement beam detectors into vacuum beam pipe, implement vacuum / helium beam pipe through BM@N setup

Actual tasks and Needed contributions

Software and data analysis:

► Need man power for calibration, alignment and MC simulations of sub-detectors: GEM+CSC, forward Silicon detectors, ToF-700, ECAL, ZDC to analyze already collected data

► Urgent task for algorithms of track and event reconstruction in central tracker and data analysis, but very limited qualified man power

►Charged particle identification based on ToF-400,700 data combined with outer tracks and momentum from central tracker

►Reconstruction of e-m clusters and multi-gamma states in ECAL data

► Simulation of large area silicon detectors for STS setup optimization

Detectors and hardware for heavy ion beams:

►construction of large area silicon tracking stations (4 STS stations)

►construction of beam and T0 detectors in vacuum inserts

►construction of vacuum (helium) beam pipe inside BM@N

►production of CSC chambers for outer tracker

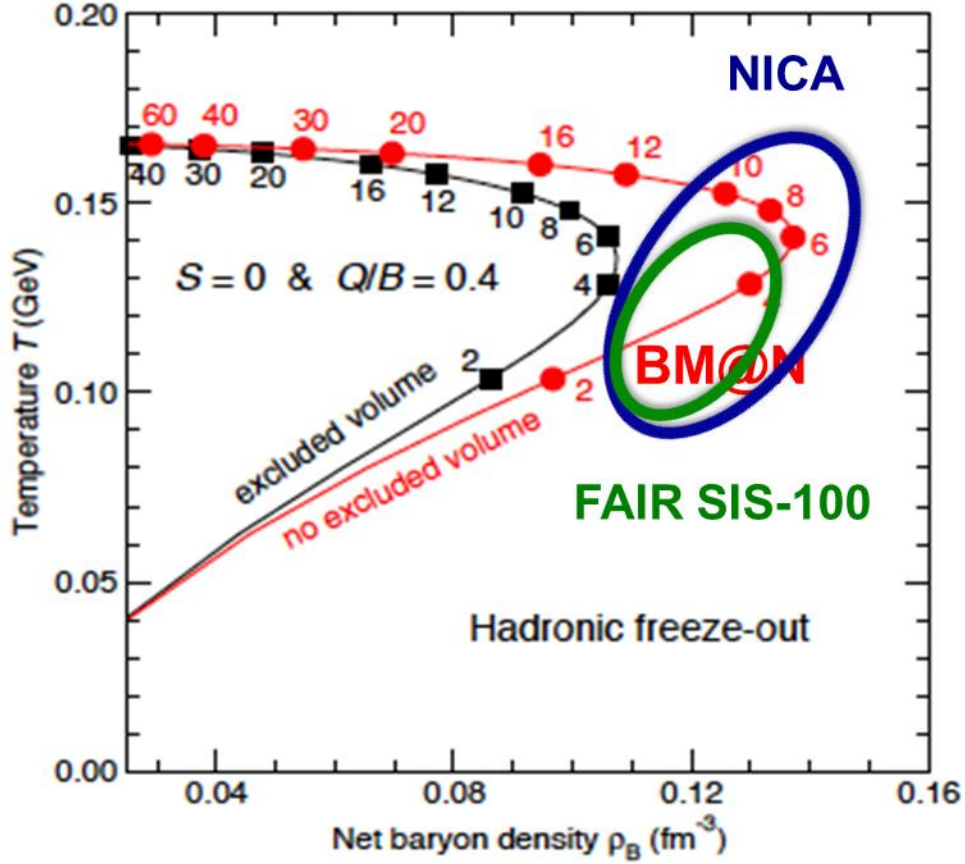
►development of fast & compact FEE electronics for GEM and CSC

Thank you for attention!

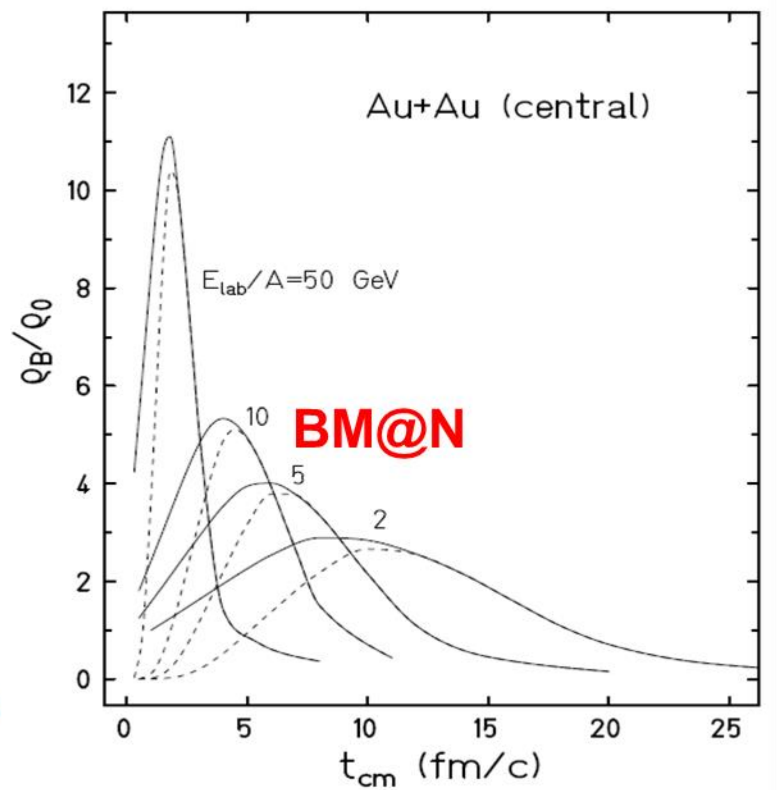
Backup slides

Explore high density baryonic matter

Nuclotron is well suited to study in high density (dominantly baryonic) matter



Baryon-dominated system throughout
Comparatively long lifetime

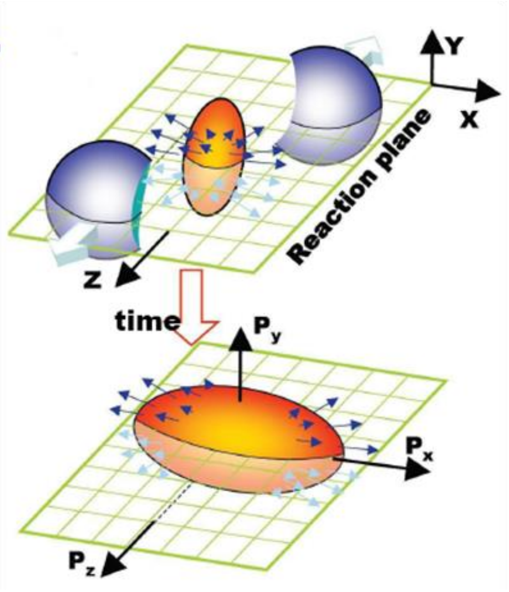


Heavy-ions A+A: Study of the EoS with strangeness

❖ The nuclear dynamics is defined by the EoS (via density dependent NN-interaction)

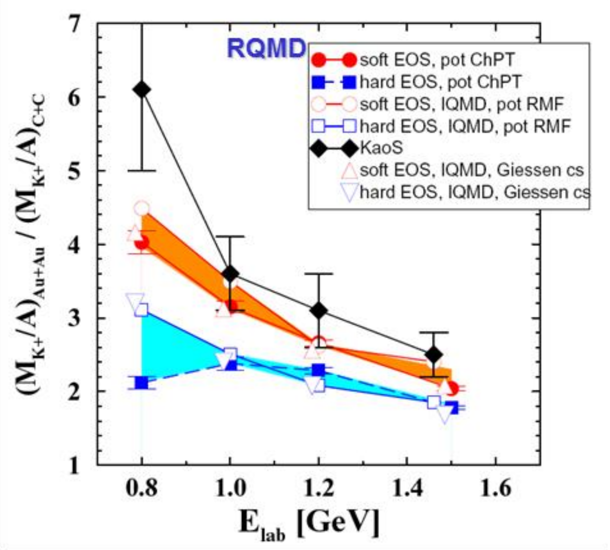
➔Observables sensitive to EoS:
collective flow (v_1,v_2,…)
particle ratios

Direct information – proton v_1,v_2
Alternative information – via strangeness



❑ Experience from SIS and AGS :
ratio of K^+ yield Au+Au/C+C at SIS energies and proton v_1,v_2 favor a soft EoS (somewhat sensitive to the details of models)

➔ Density dependence of the EoS can be studied in BM@N by a beam energy scan



Nuclotron and BM@N beam line

26 elements of magnetic optics:

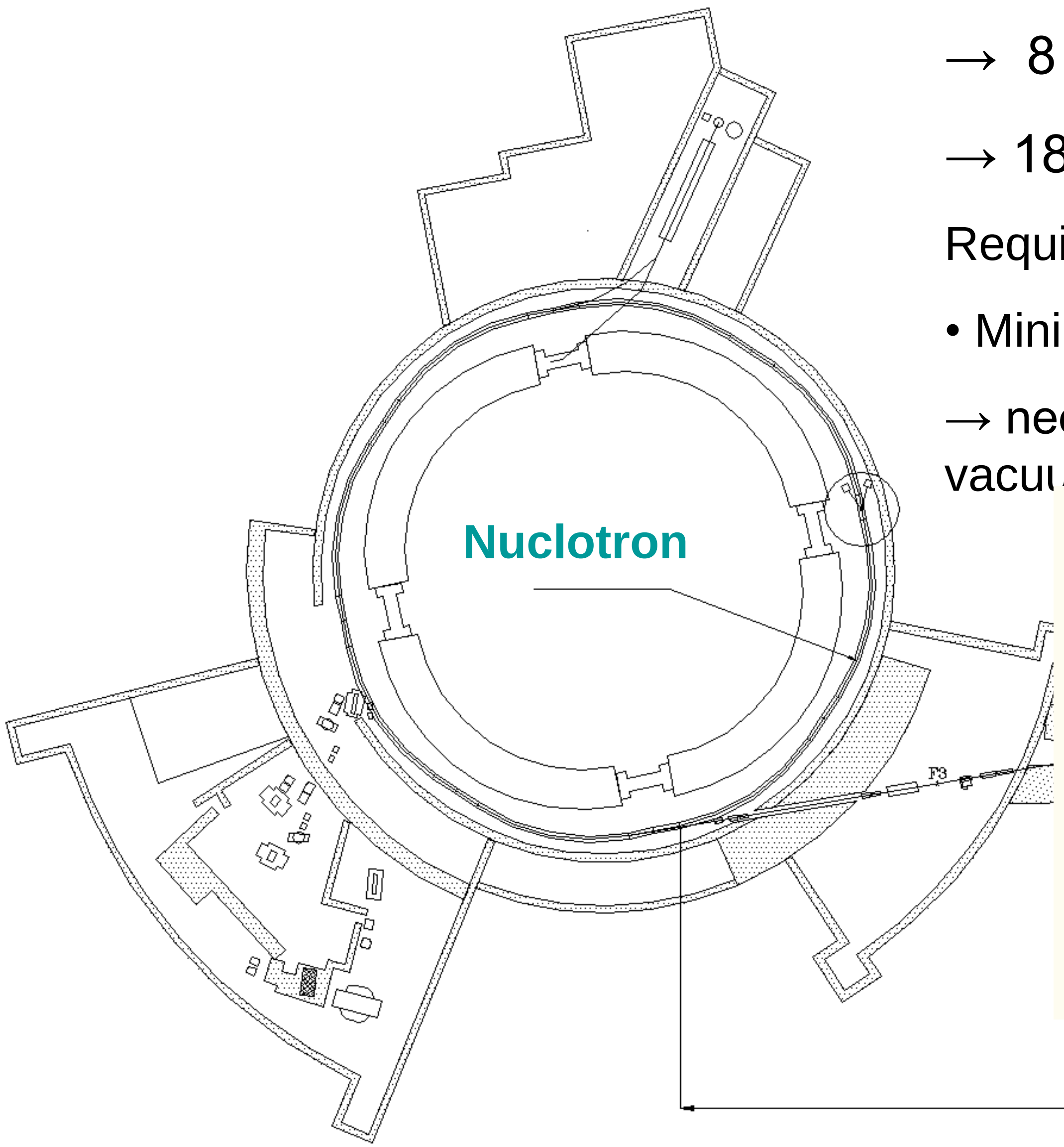
→ 8 dipole magnets

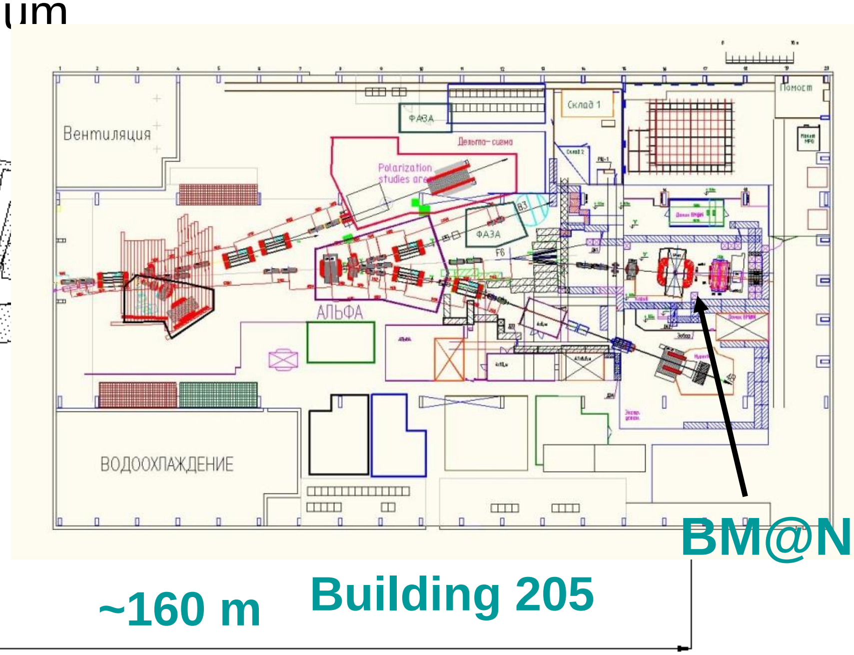
→ 18 quadruple lenses

Requirements for Au beam:

• Minimum dead material

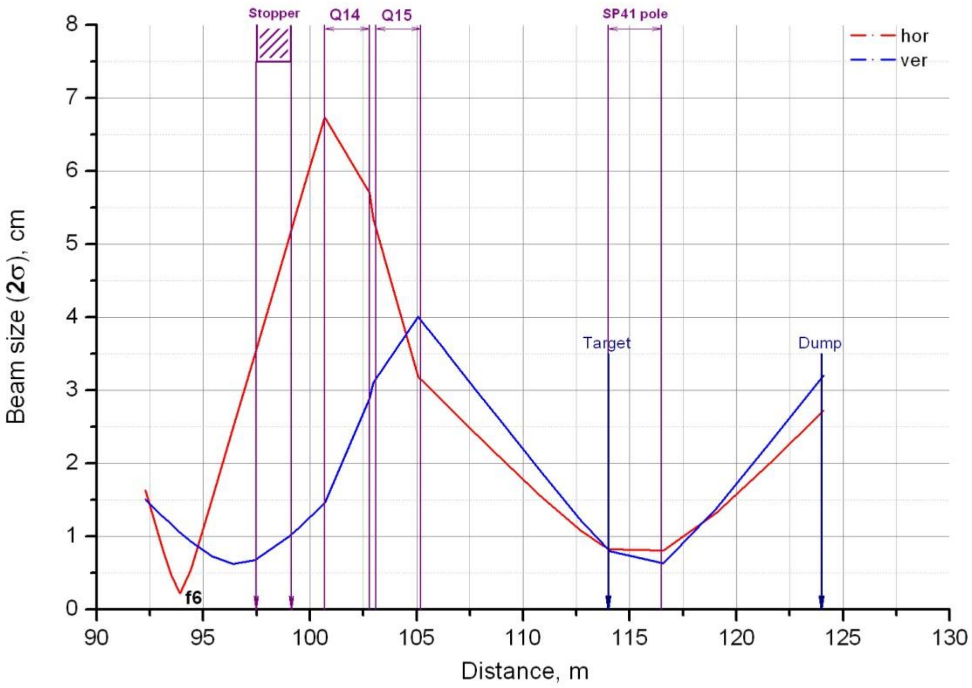
→ need to replace air intervals / foils with vacuum





BM@N beam line

Beam envelopes at the BM@N area



Beam	Planned intensity of Nuclotron + booster (per cycle)
p , d	$5 \cdot 10^{12}$
^{12}C	$2 \cdot 10^{11}$
^{40}Ar	10^{7} at BM@N
^{131}Xe	10^{6} at BM@N
^{197}Au	10^{6} at BM@N

Targets: ^{12}C, ^{64}Cu, ^{197}Au, liquid H_2, $^{2}H_2$

Plans for extensive upgrade of BM@N beam line:

→ new stable power supplies for dipole magnets

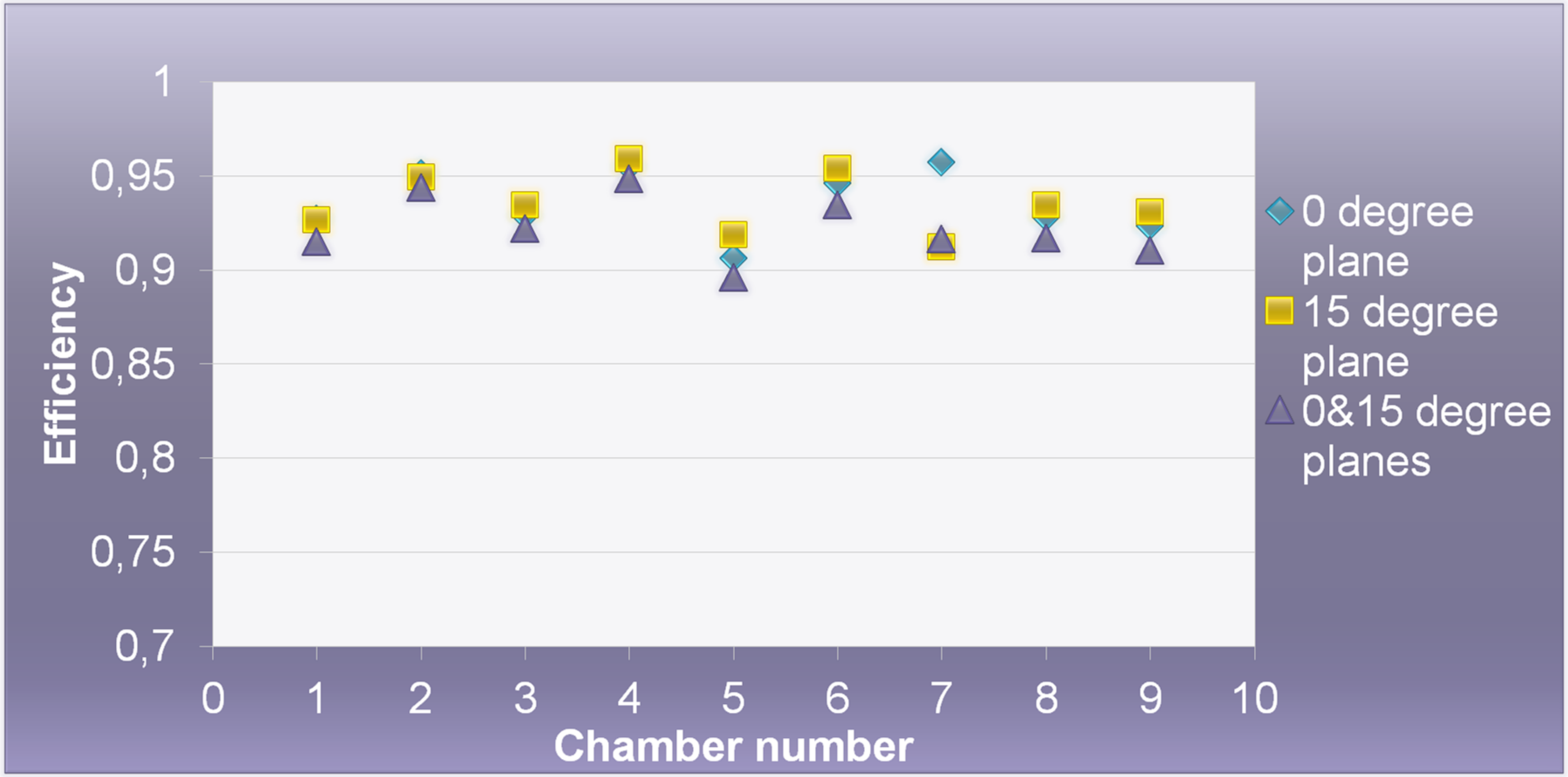
→ stabilization circuits for existing power supplies for quadruples and dipoles

→ non destructive beam position monitoring on movable vacuum inserts

→ carbon fiber vacuum beam pipe inside BM@N from the target to the end

GEM detector efficiency in deuteron run

Plane efficiency calculated using reconstructed tracks of beam inclined at different angles



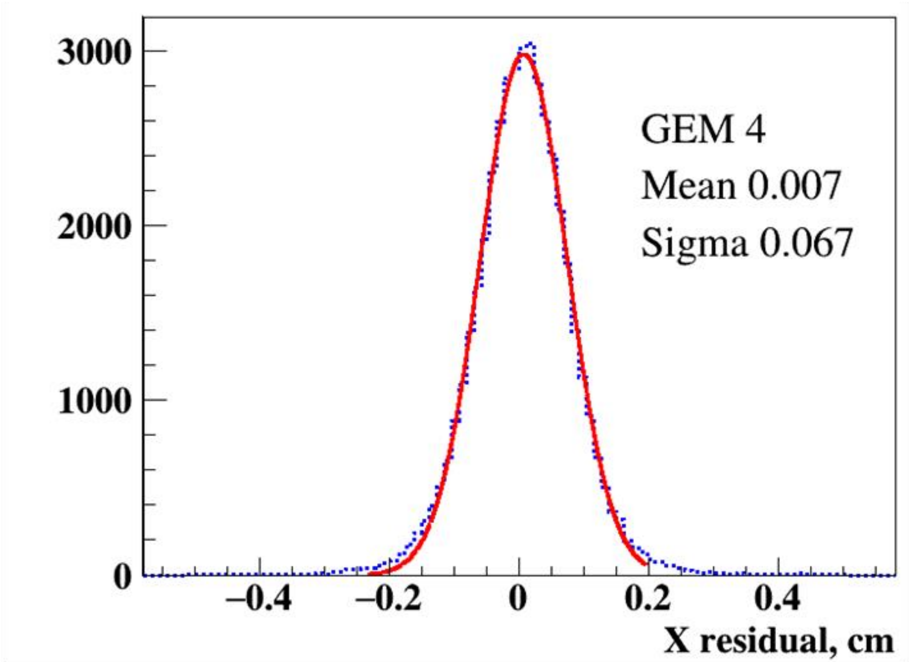
X plane

X‘ plane

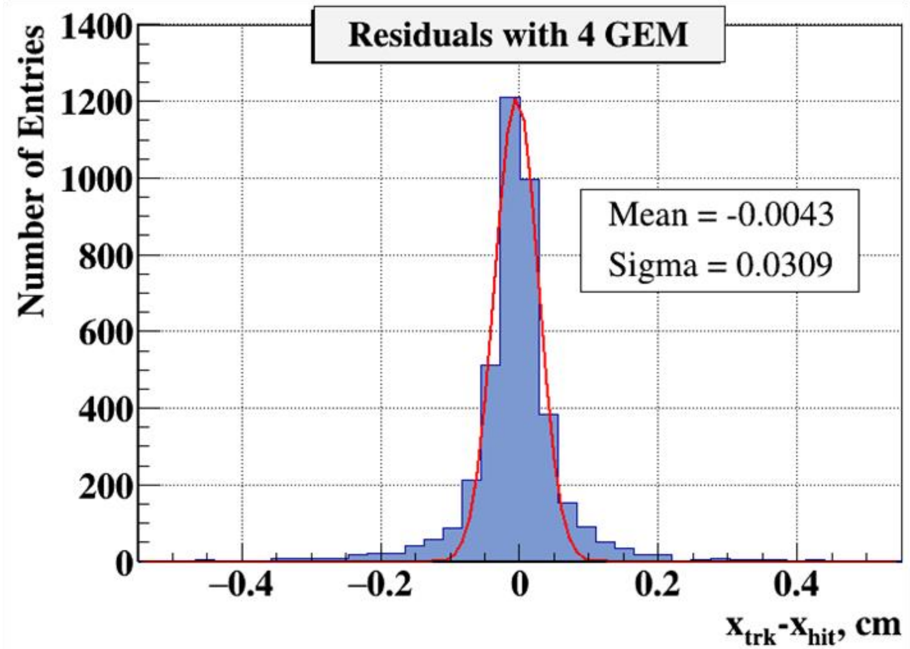
X & X‘ planes

GEM residuals after Lorentz alignment

Deuteron beam data
Gas mixture: Ar / Isobuthan (90:10)



Carbon beam data
Gas mixture: Ar / CO_2 (70:30)



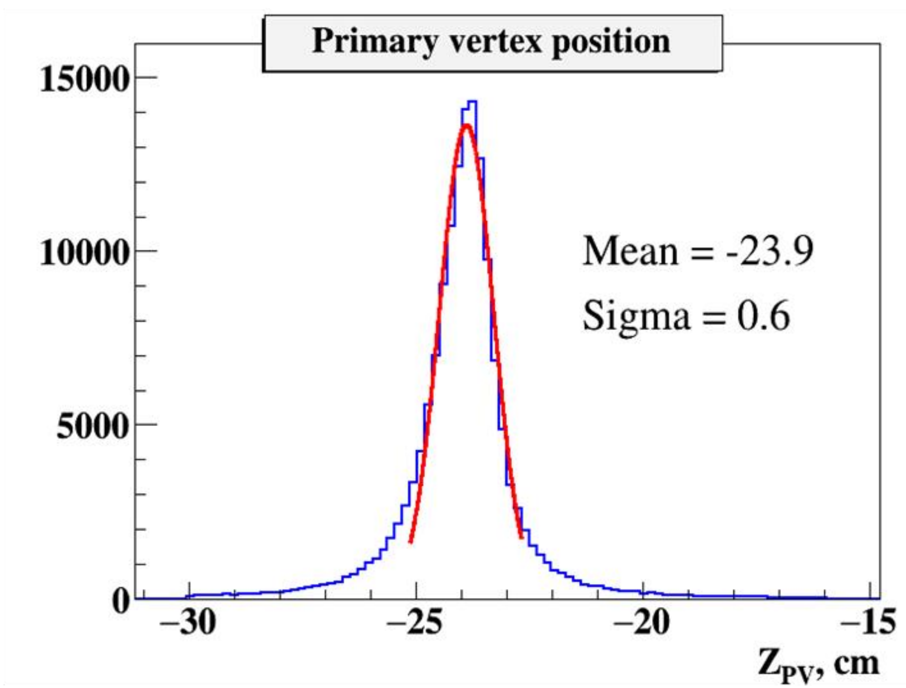
- Fast gas mixture → reduced Lorentz shifts, better coordinate resolution

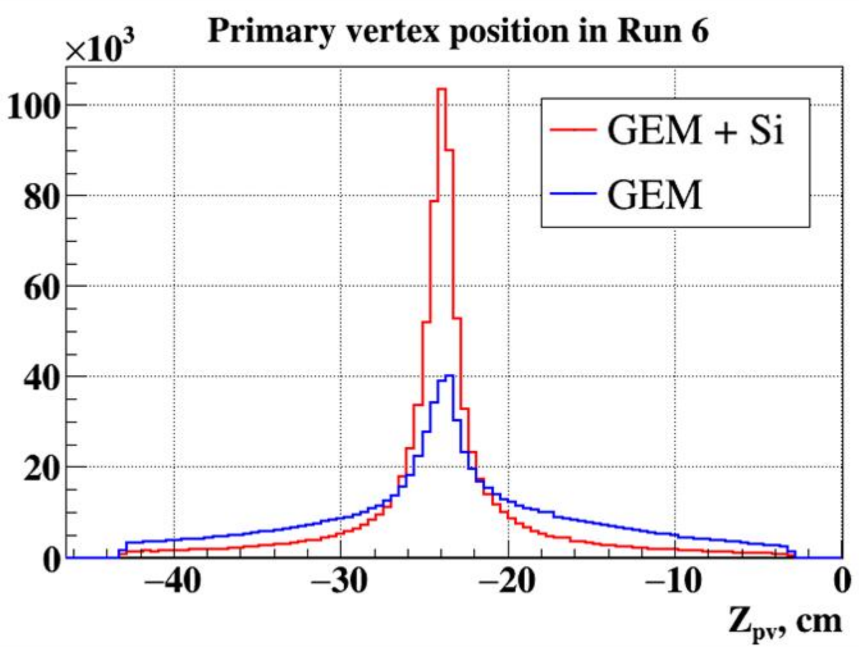
- GEM hit residuals to reconstructed tracks in data are reproduced by MC simulation with Garfield parametrization

Primary Vertex reconstruction

G.Pokatashkin, I.Rufanov, V.Vasendina and A.Zinchenko

C + A → X interactions

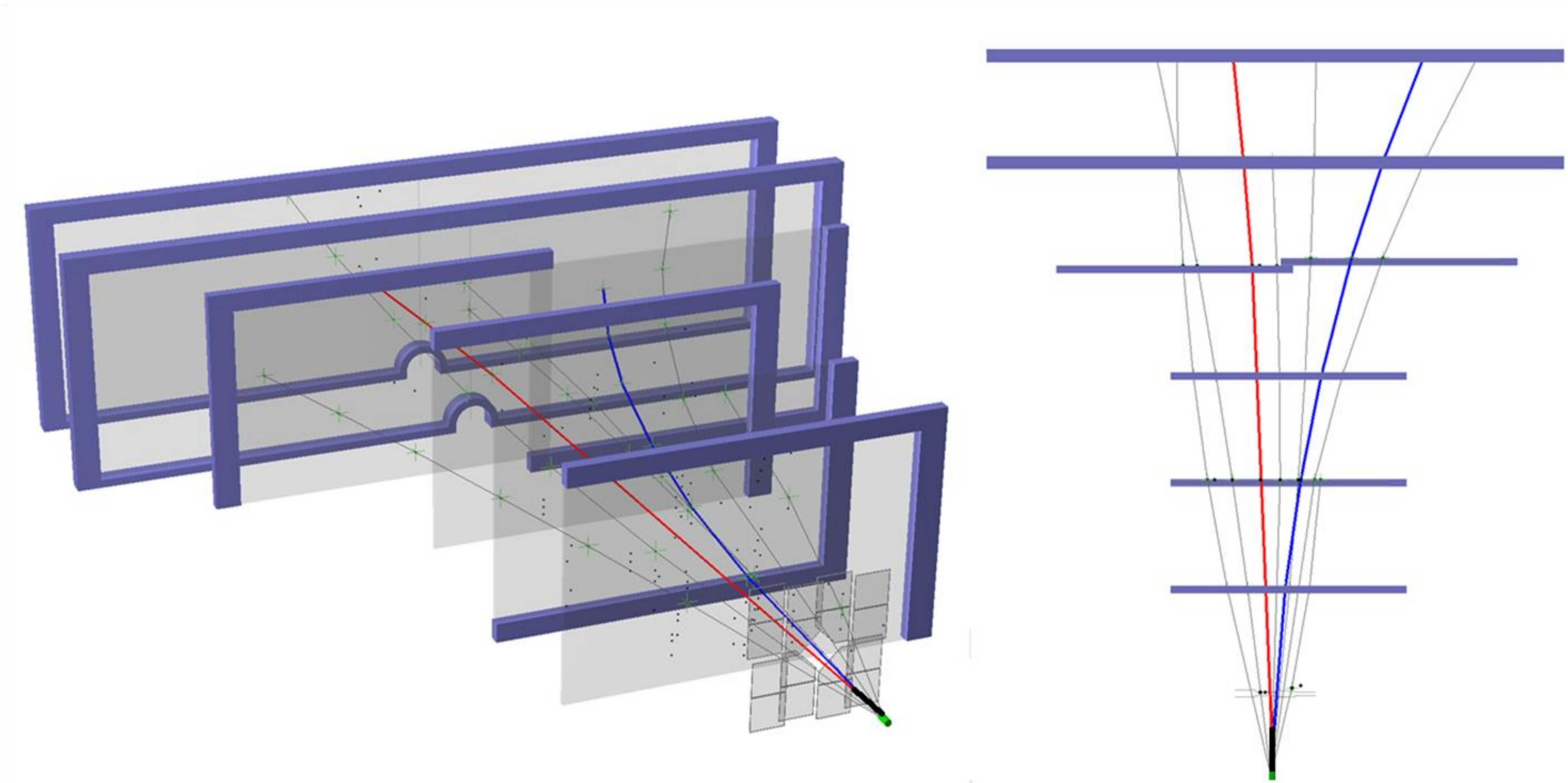




Primary Vertex reconstructed with GEM+Si detectors & Pile-up suppression

Effect of Si detector for Primary Vertex reconstruction

Event display of Λ decay in C+C collision

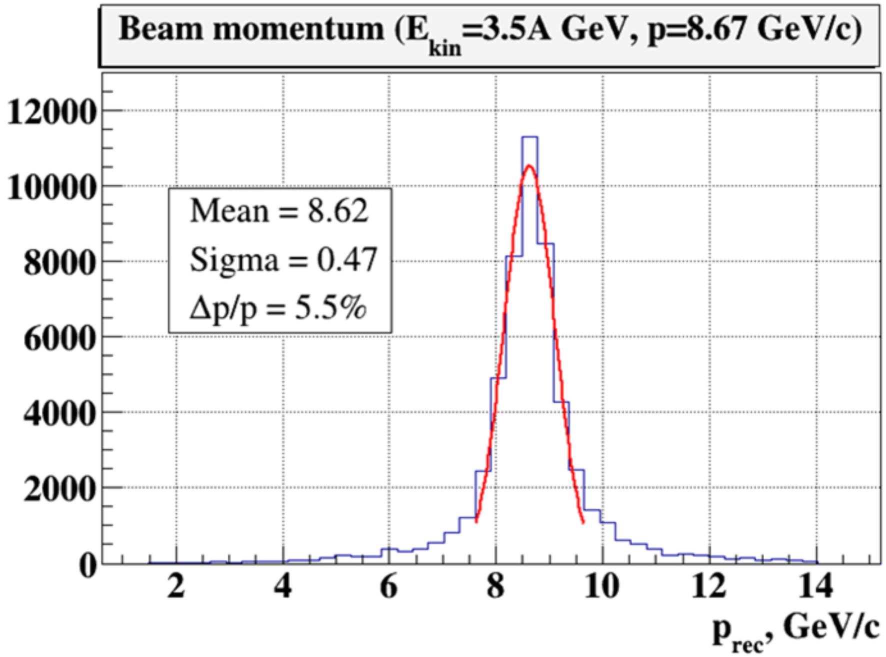


$\Lambda \rightarrow p\pi^-$ decay reconstruction in GEM + Si tracker in C+C interaction, March 2017

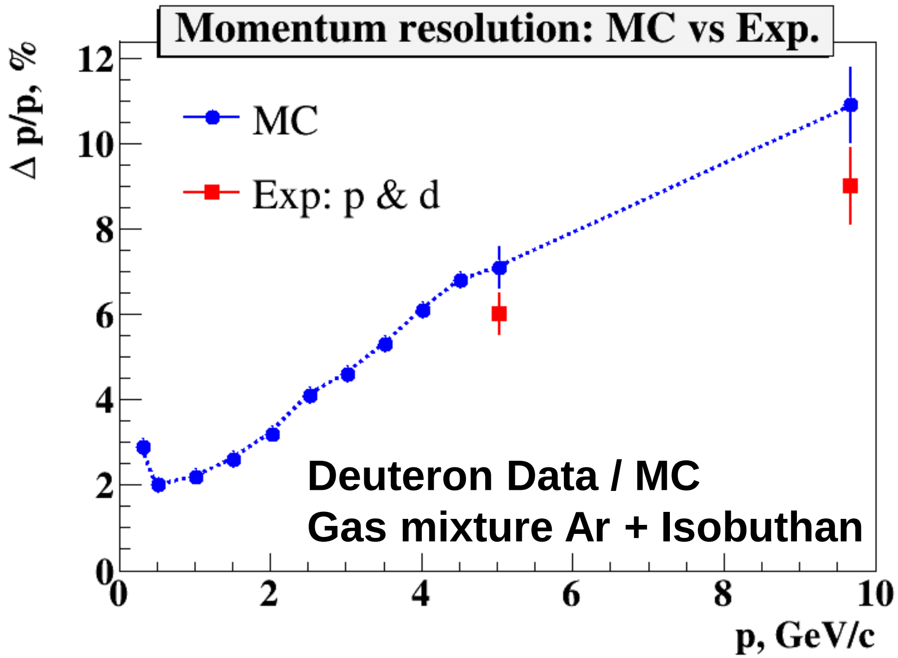
Momentum resolution: Exp. vs MC

G.Pokatashkin, I.Rufanov, V.Vasendina and A.Zinchenko + D.Baranov (Garfield)

Carbon beam



GEM gas mixture: Ar + CO_2 (70:30)

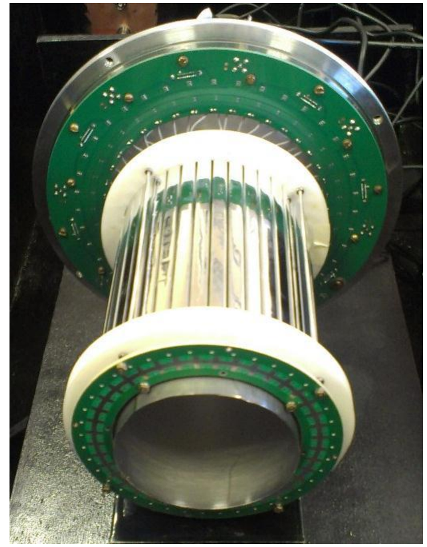


- ✓ Momentum resolution for carbon beam of 8.6 GeV/c ~5.5%.

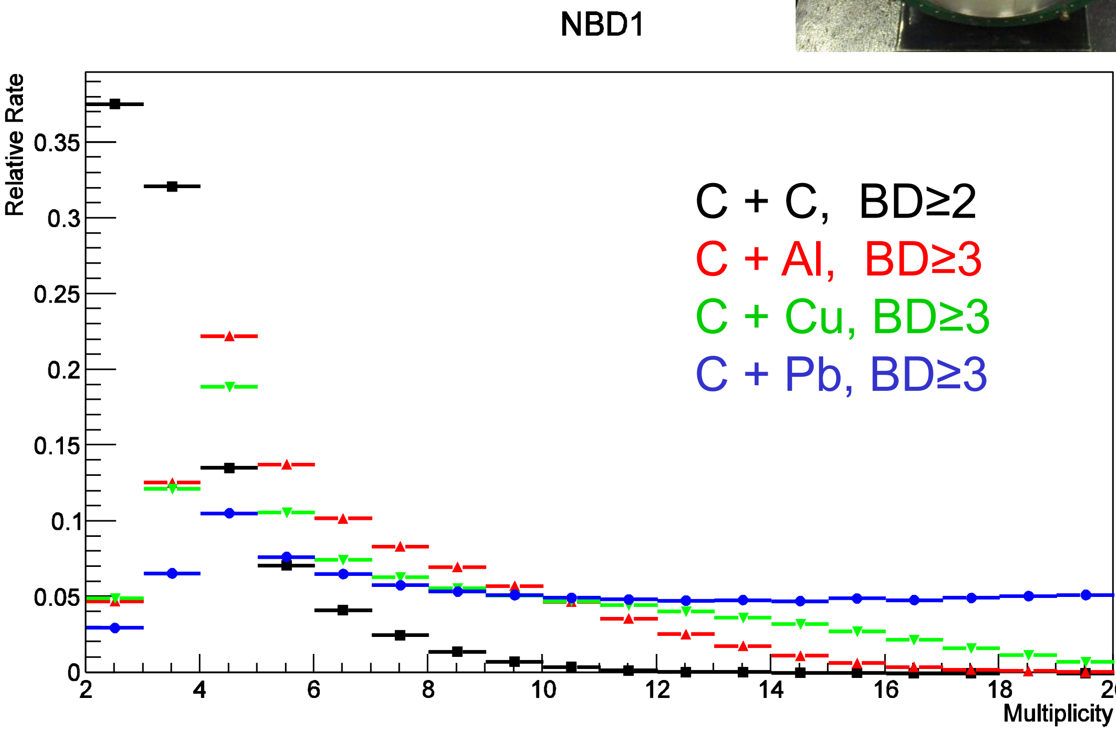
- ✓ Momentum resolution from MC as function of particle momentum
- ✓ MC results reproduce exp. data for spectator protons and deuteron beam

Trigger barrel and Si detectors in BM@N setup

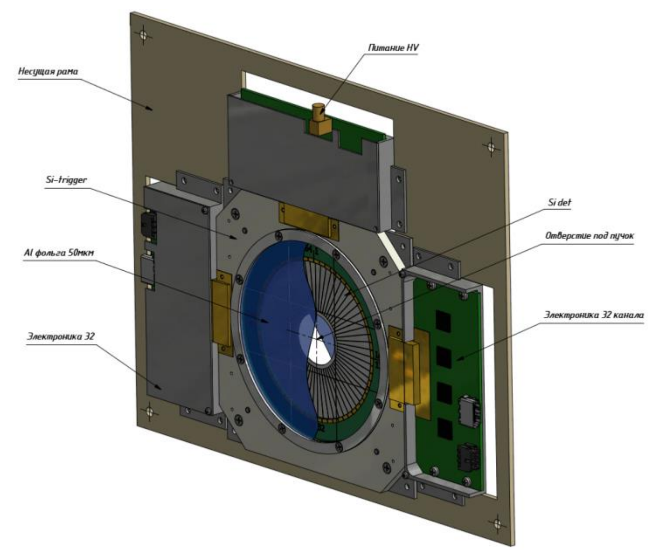
Trigger group, V.Yurevich



Barrel Detector multiplicity in carbon beam interactions with different targets



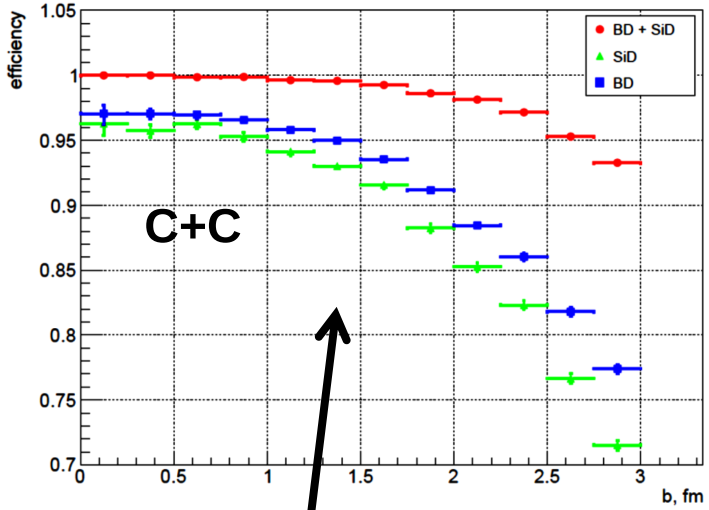
Forward Si trigger detector, group of N.Zamiatin

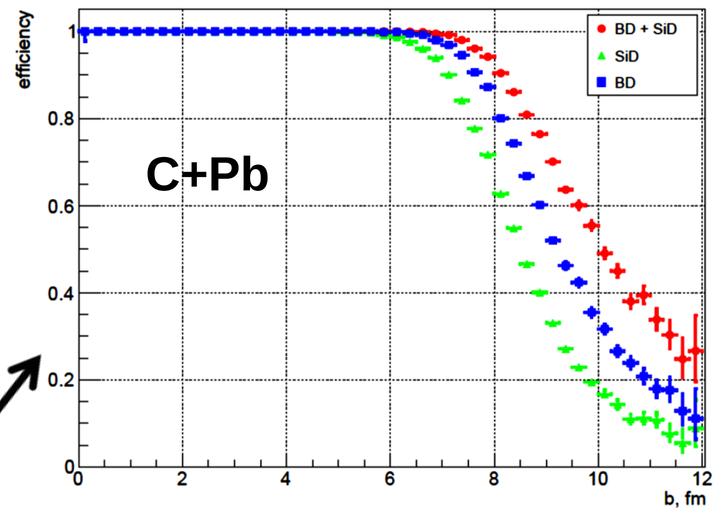


M.Kapishin **BM@N experiment**

Simulation of Trigger Barrel and Si detectors

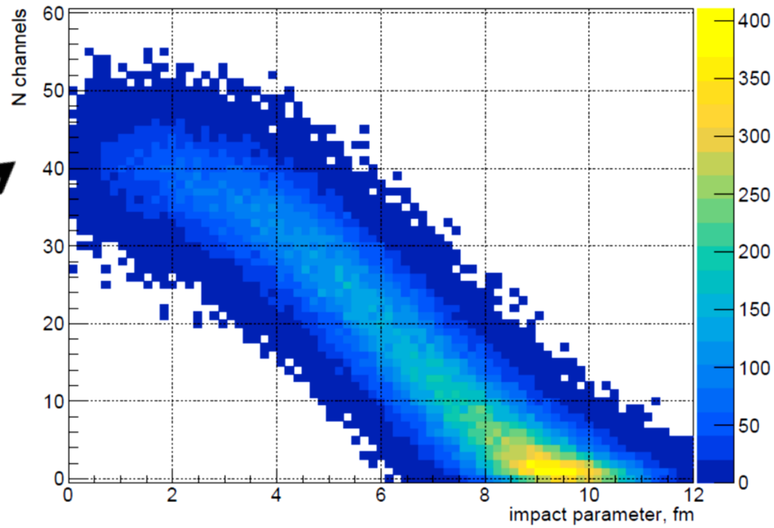
S.Lobastov





Trigger efficiency for C + C and C + Pb collisions at energy of 4 AGeV

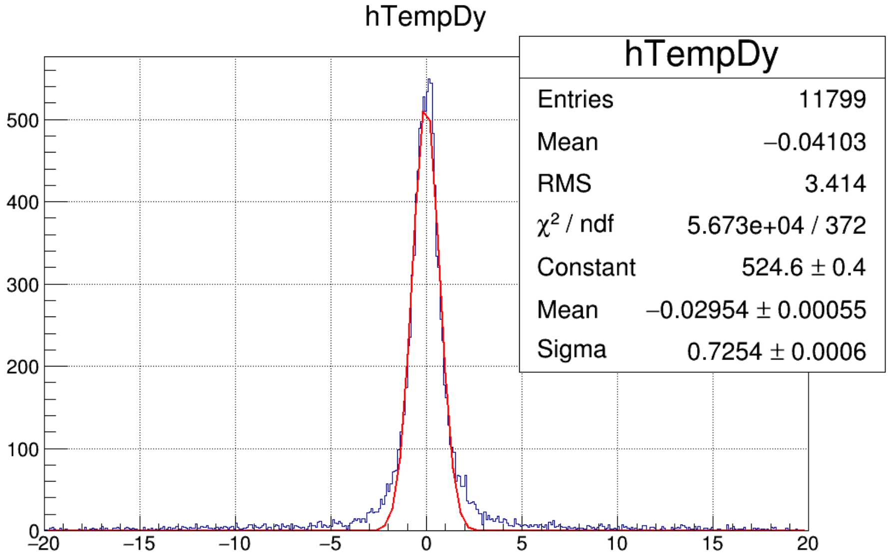
- **Barrel Detector**
- **Si Trigger Detector**
- **BD + SiD**



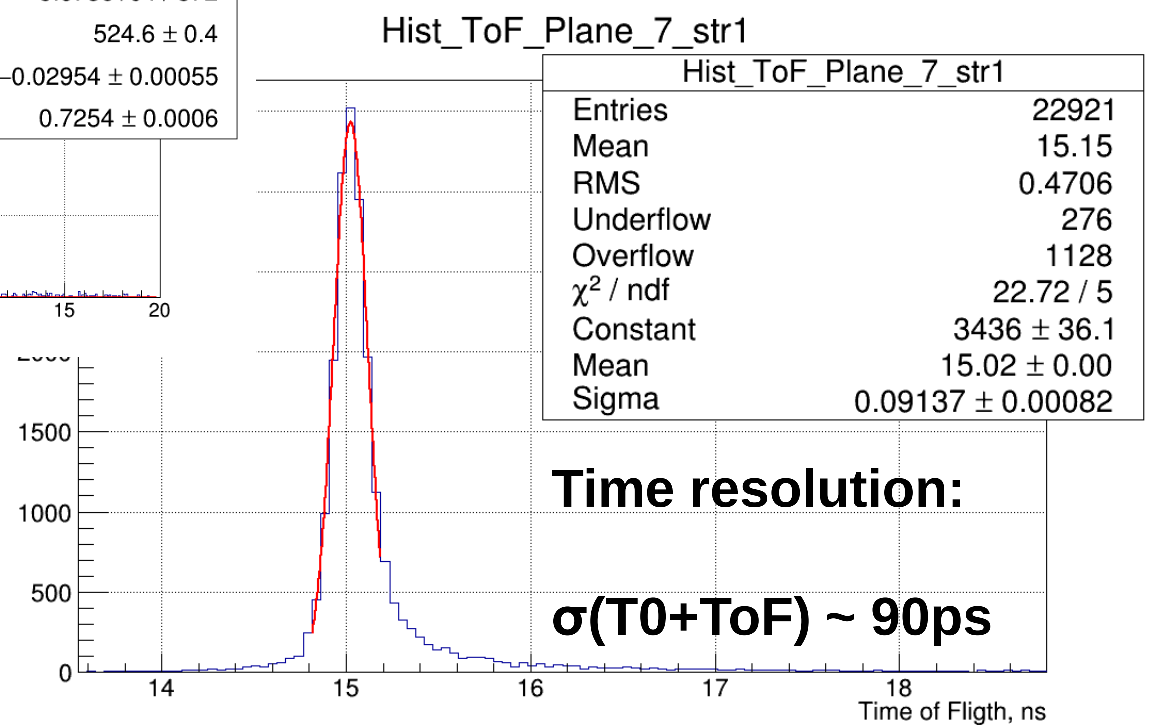
Number of fired channels BD + SiD as a function of impact parameter in C + Pb

ToF-400 in carbon beam interactions

ToF-400 group



Time of Flight T0 - ToF400



Coordinate resolution:

$\sigma_Y = 7.2/\sqrt{2}$ ~5 mm

$\sigma_X = 12.5/\sqrt{12}$ ~3.6 mm

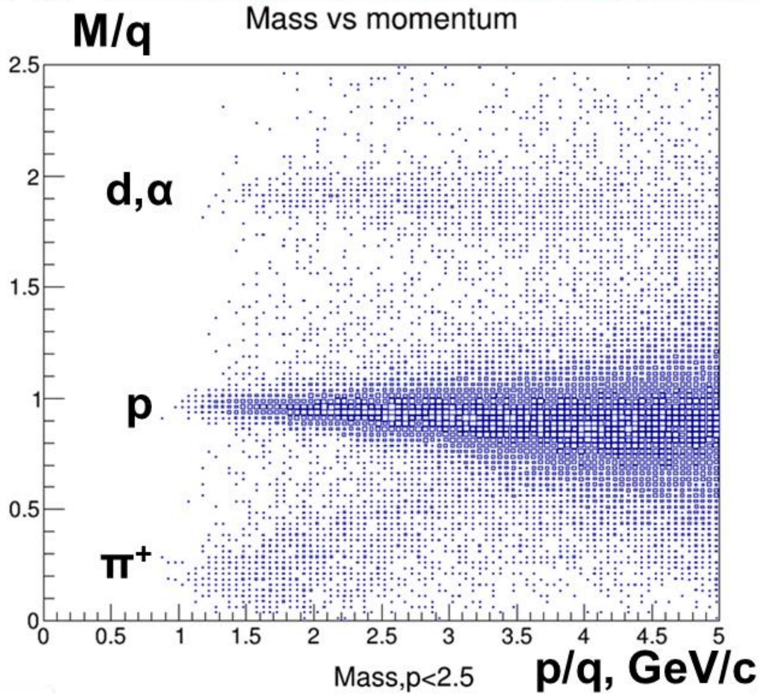
Time resolution:

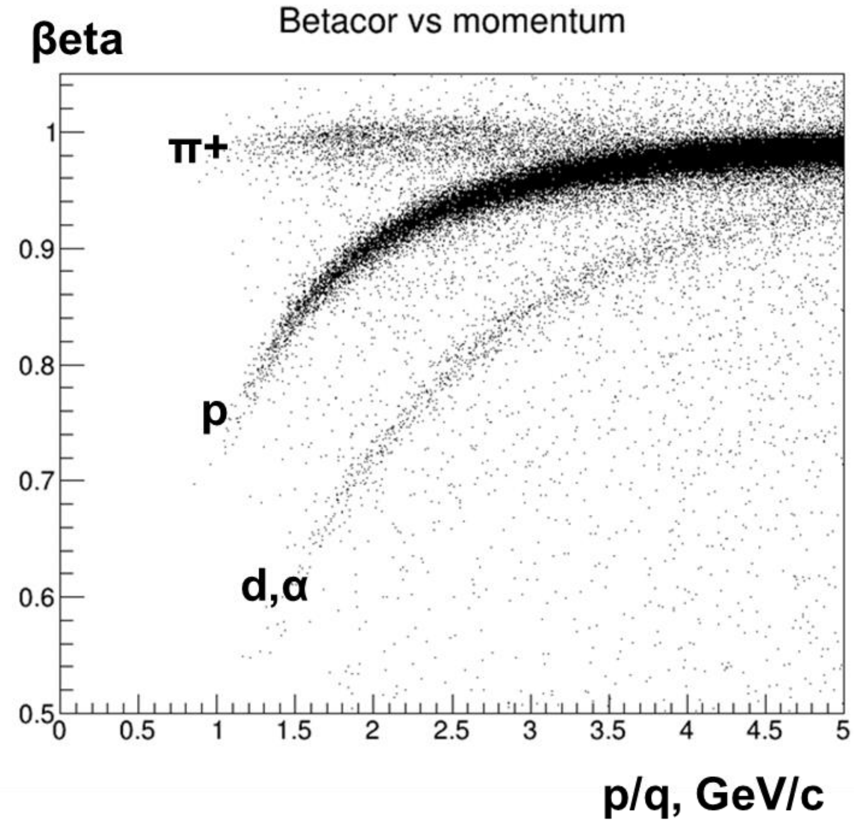
σ(T0+ToF) ~ 90ps

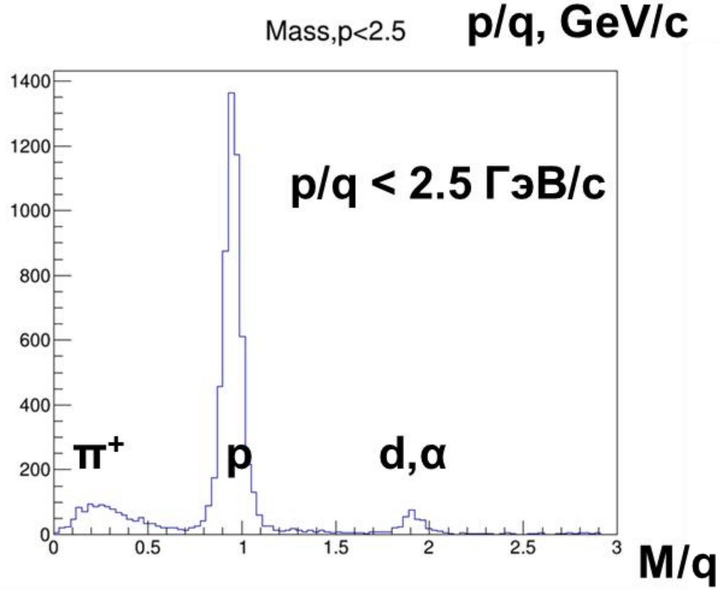
ToF-700: status of particle identification

ToF-700 team

Carbon beam , 4.0 AGeV , C + Cu → X

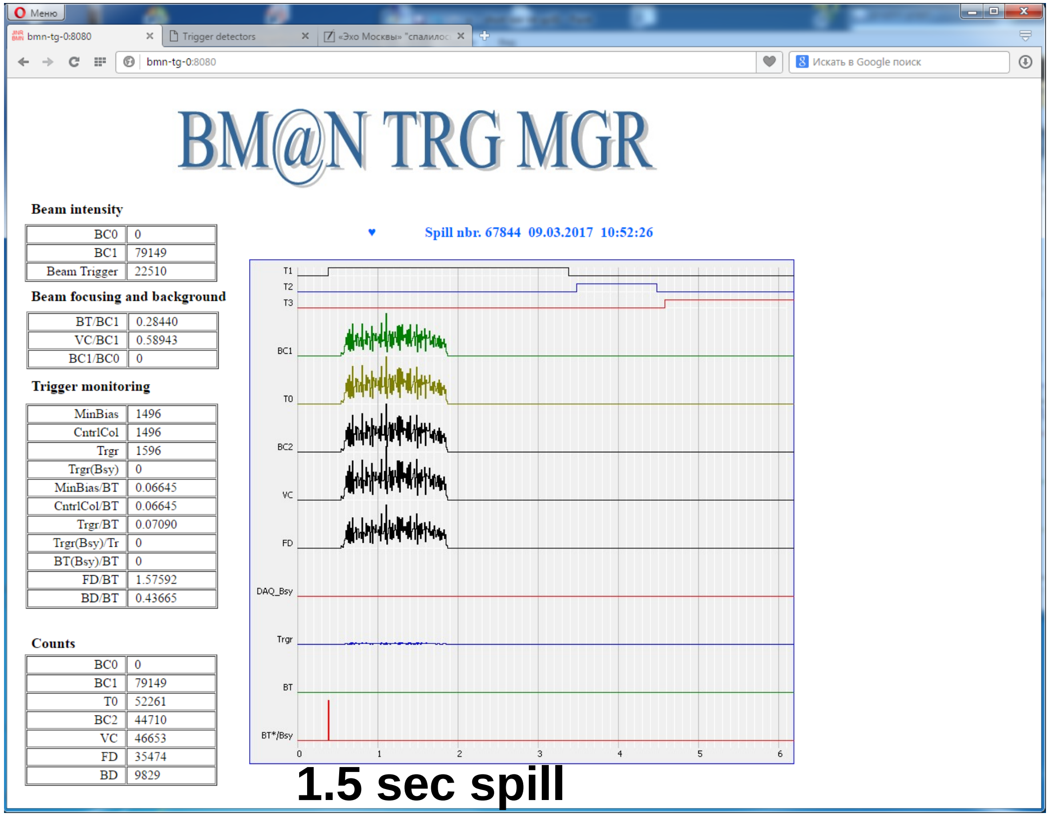






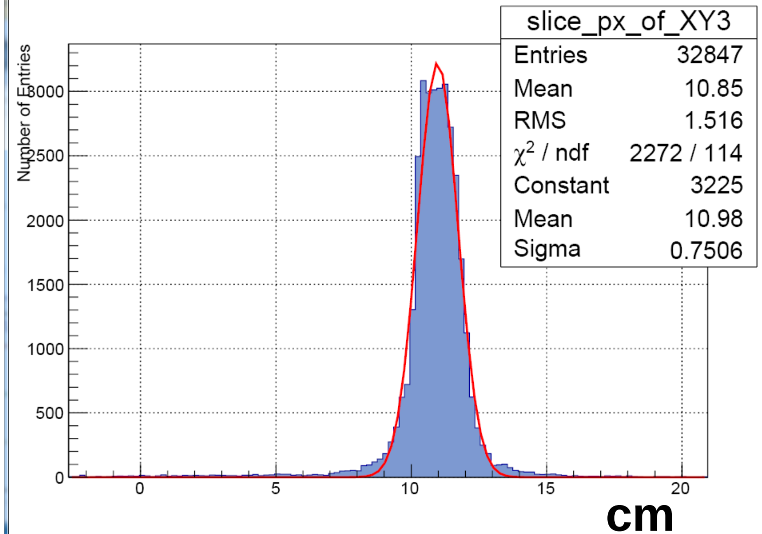
- ✓ To get π / K separation need better calibration of ToF chambers and better momentum resolution of central tracker

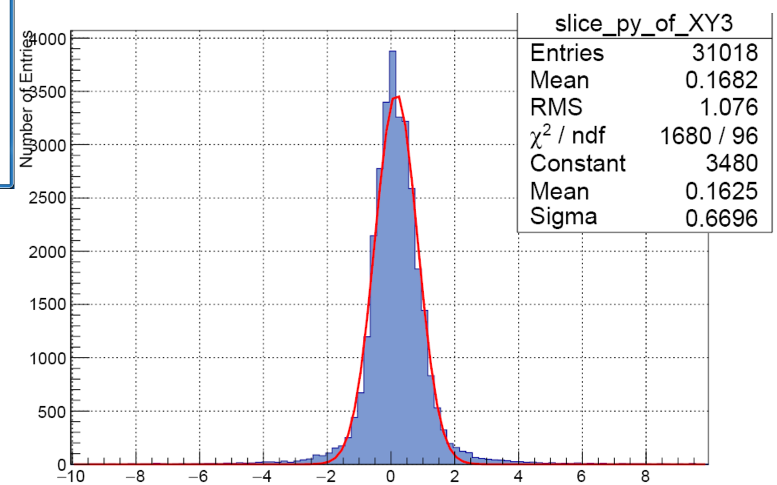
Deuteron / carbon beams at BM@N



1.5 sec spill

X, Y profiles of deuteron beam in 1st GEM





- 10^5 - $3 \cdot 10^5$ per spill, but non-uniform spiky structure

➢ Pileup in GEM detectors

➢ Limits DAQ rate to 4-5 kHz