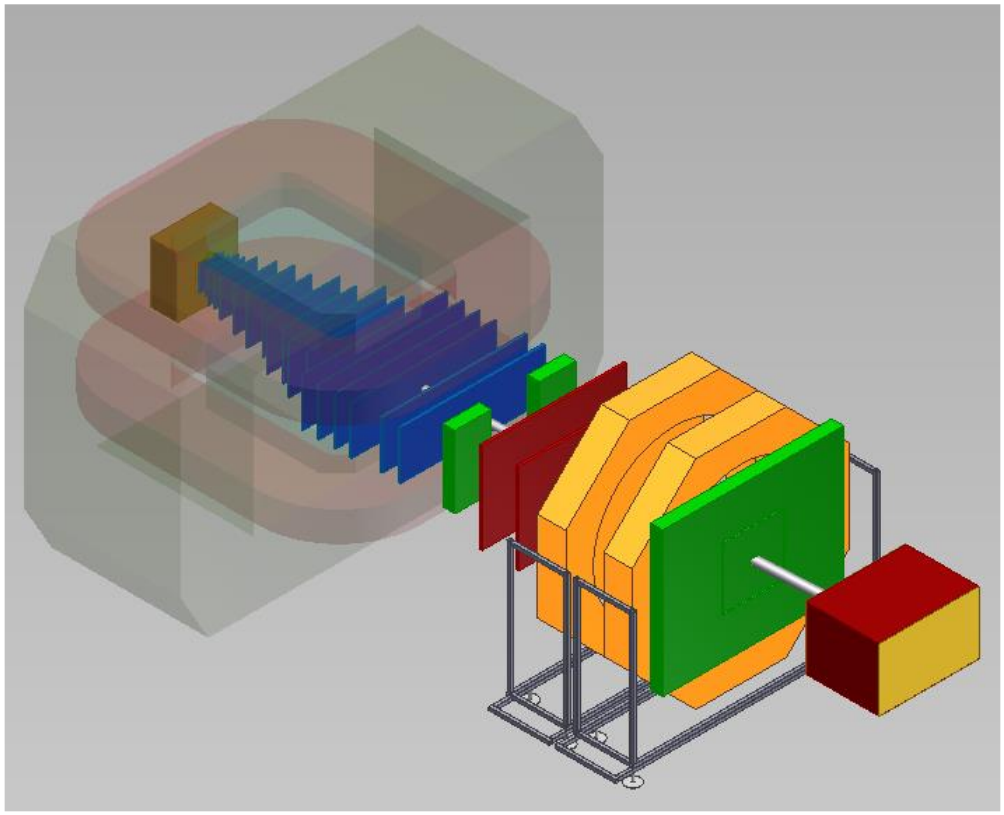
Status of Baryonic Matter at Nuclotron

BM@N Project

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

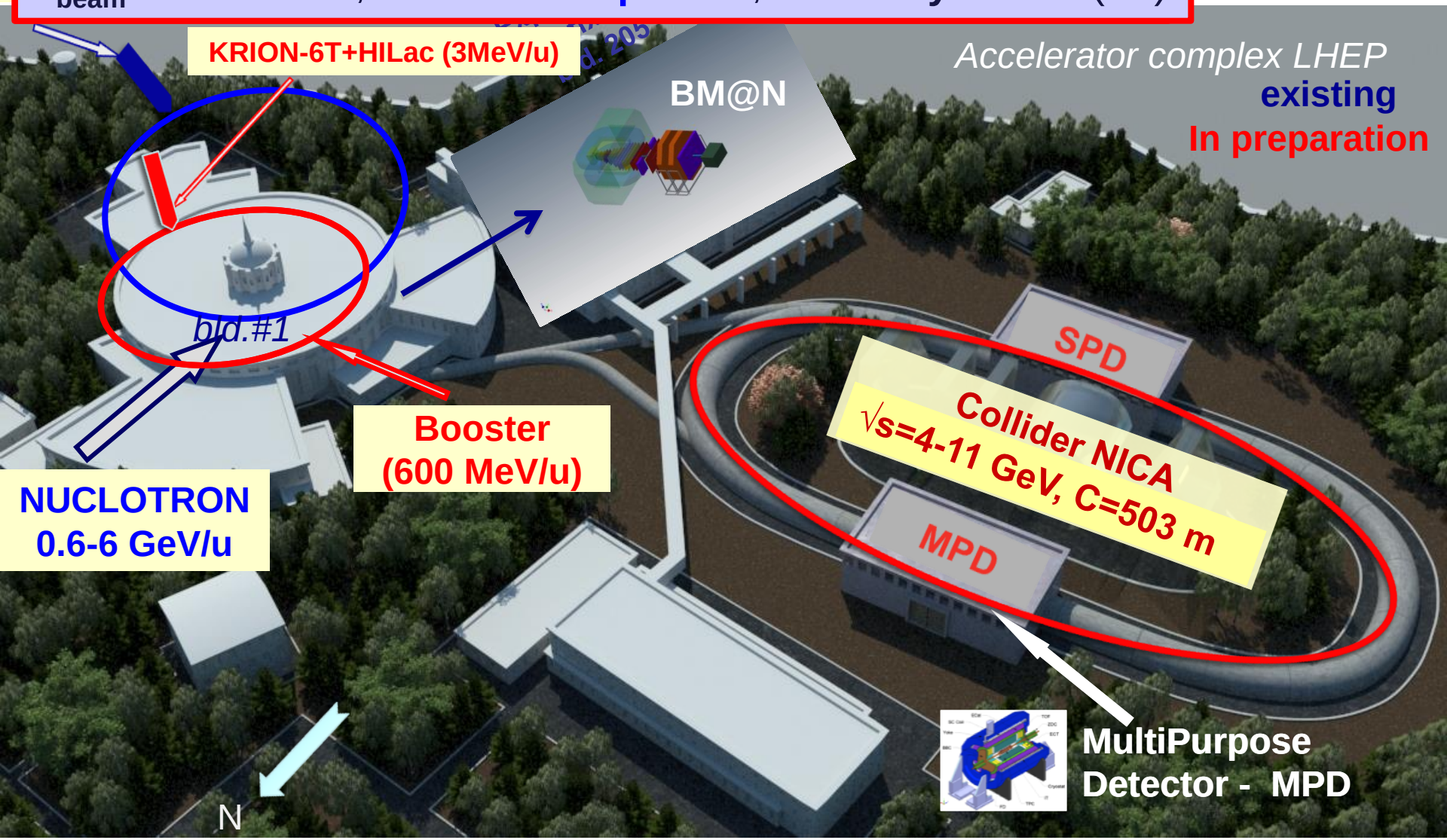
WUT (Warsaw), Goethe Uni (Frankfurt), MoU with GSI (Darmstadt) + SRC team

M.Kapishin



Complex NICA

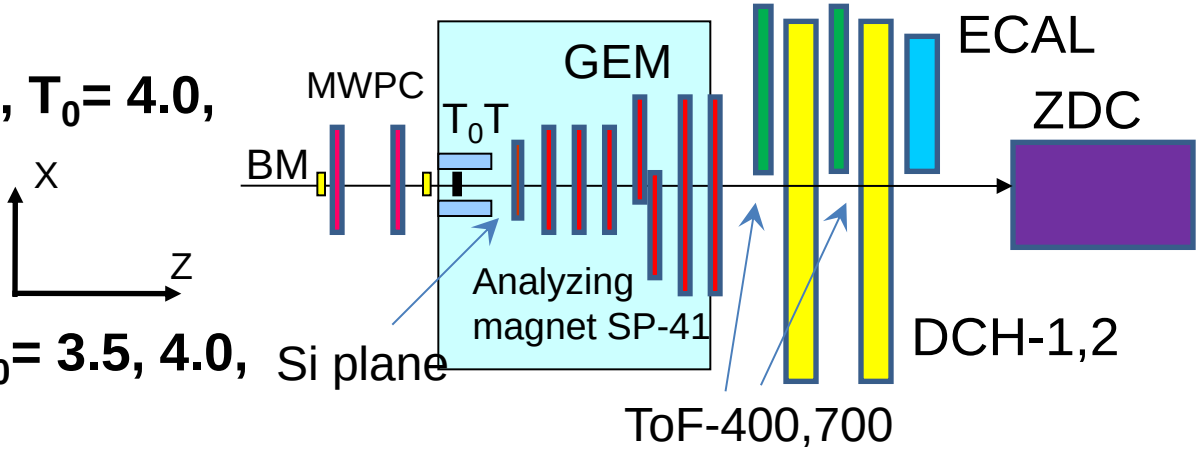
Parameters of Nuclotron for BM@N experiment:
E_{beam} = 1-6 GeV/u; *beams*: *from* p to Au; Intensity~10^7 c^{-1} (Au)



BM@N in technical runs with deuteron and carbon beams

Deuteron beam, T_0= 4.0, 4.6 GeV/n

Carbon beam, T_0= 3.5, 4.0, 4.5, (5.14) GeV/n

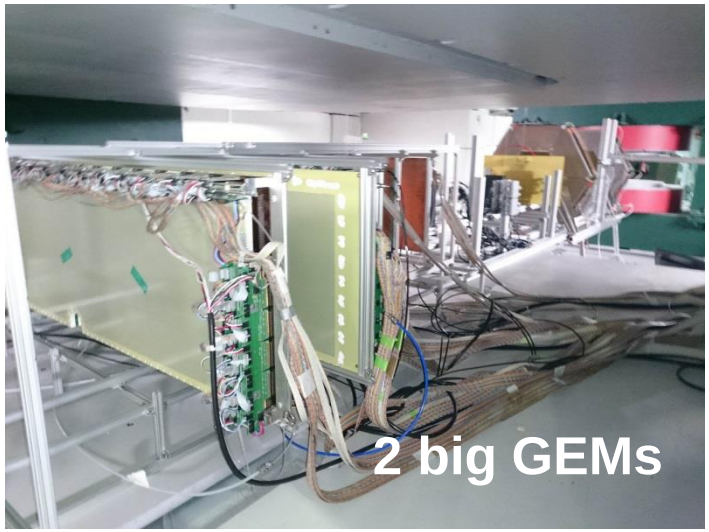


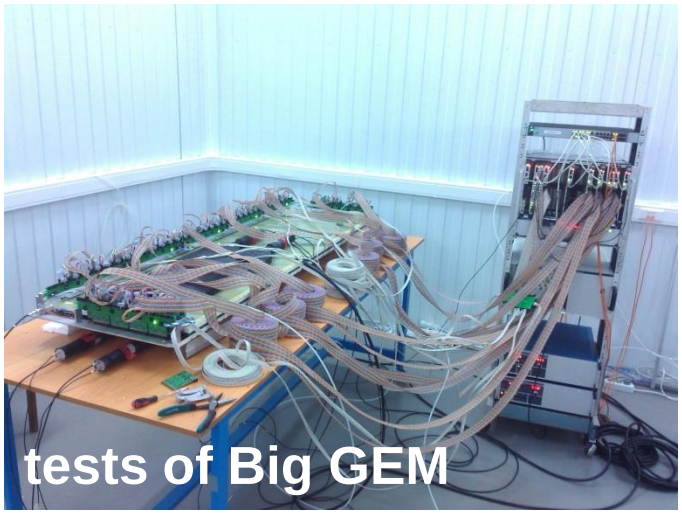
- **Focus on tests and commissioning of central tracker inside analyzing magnet → 5 GEM detectors 66 x 41cm² + 2 GEM detectors 163 x 45 cm² and 1 plane of Si detector for tracking**
- **Test / calibrate ToF, T0+Trigger barrel detector, full ZDC, part of ECAL**

Program:

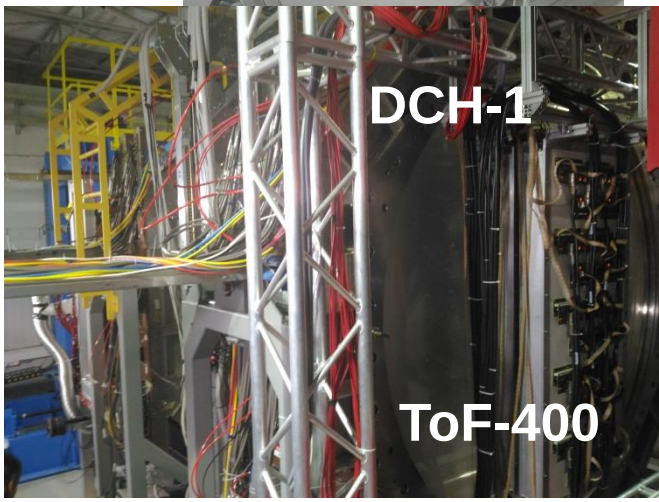
- **Trace beam through detectors, align detectors, measure beam momentum in mag. field of 0.3 – 0.85 T**
- **Measure inelastic reactions d (C) + target → X with deuteron and carbon beam energies of 3.5 - 4.6 GeV/n on targets C, Al, Cu, Pb**

BM@N experiment in carbon run, March 2017

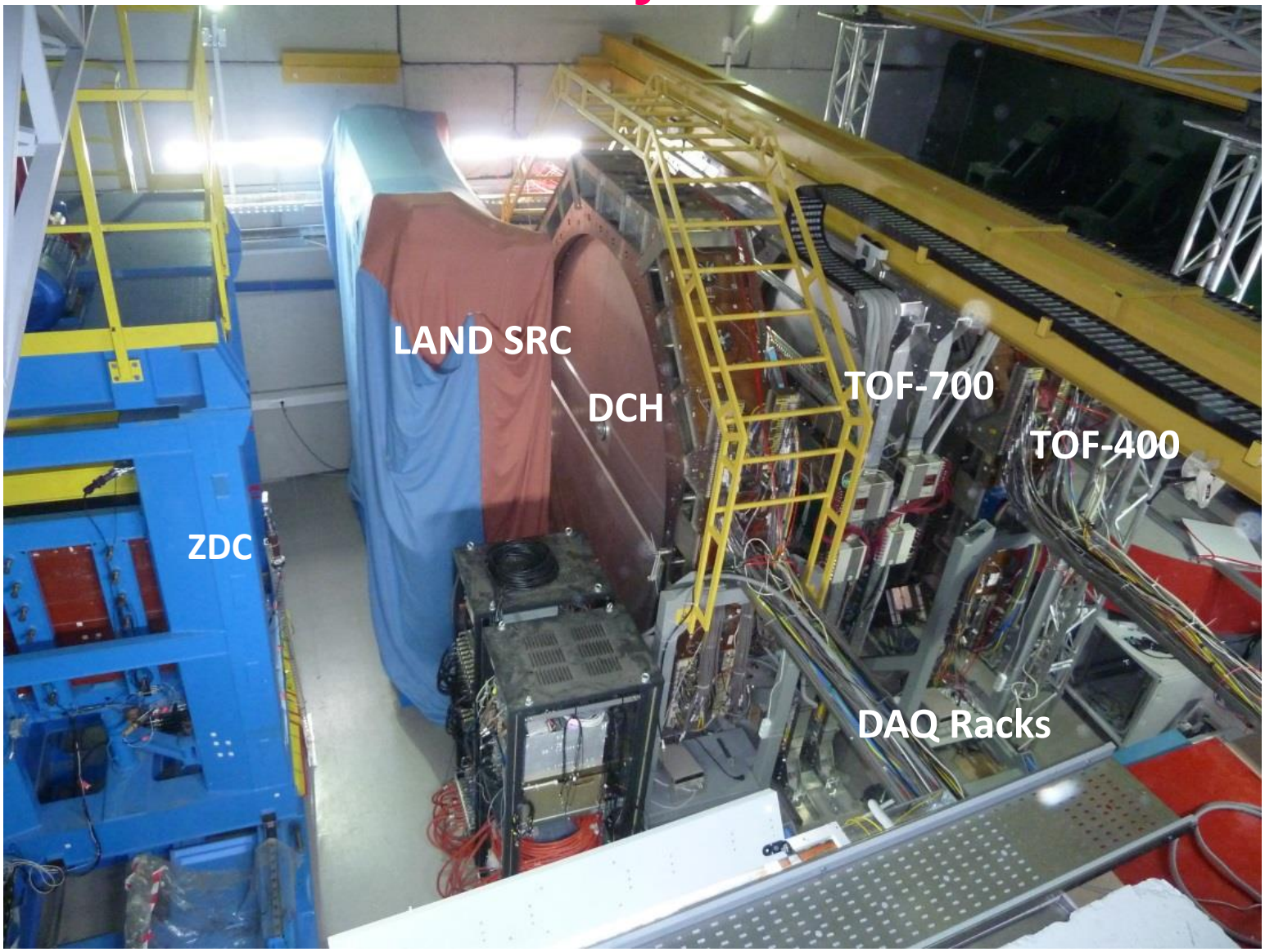




New detector components:
2 big GEMs, trigger barrel detector, Si detector, ECAL



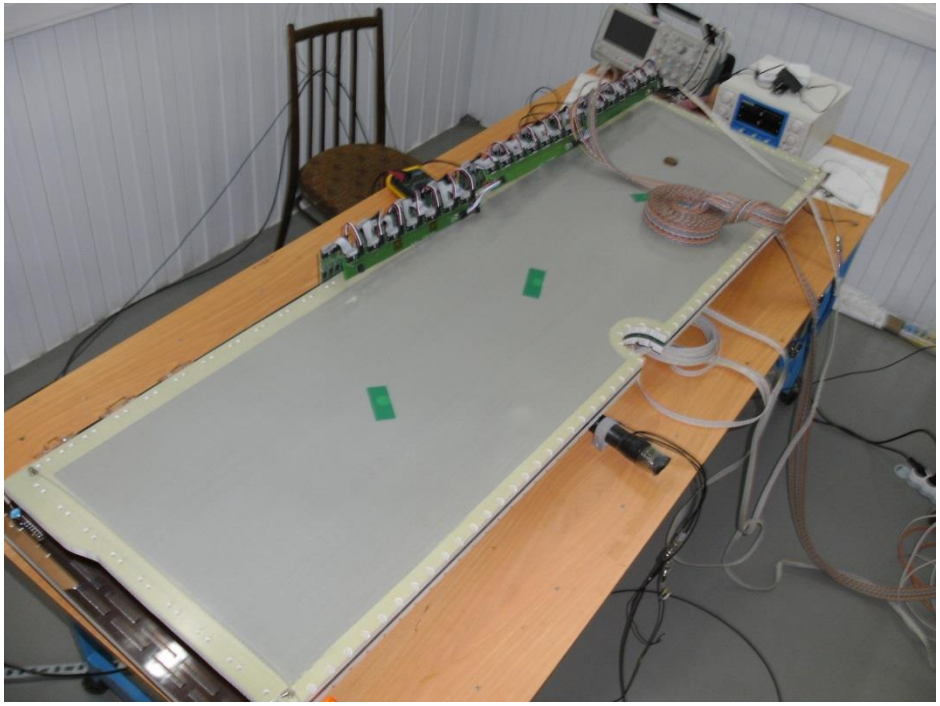
BM@N setup behind magnet January 2018



GEM detectors for central BM@N tracker

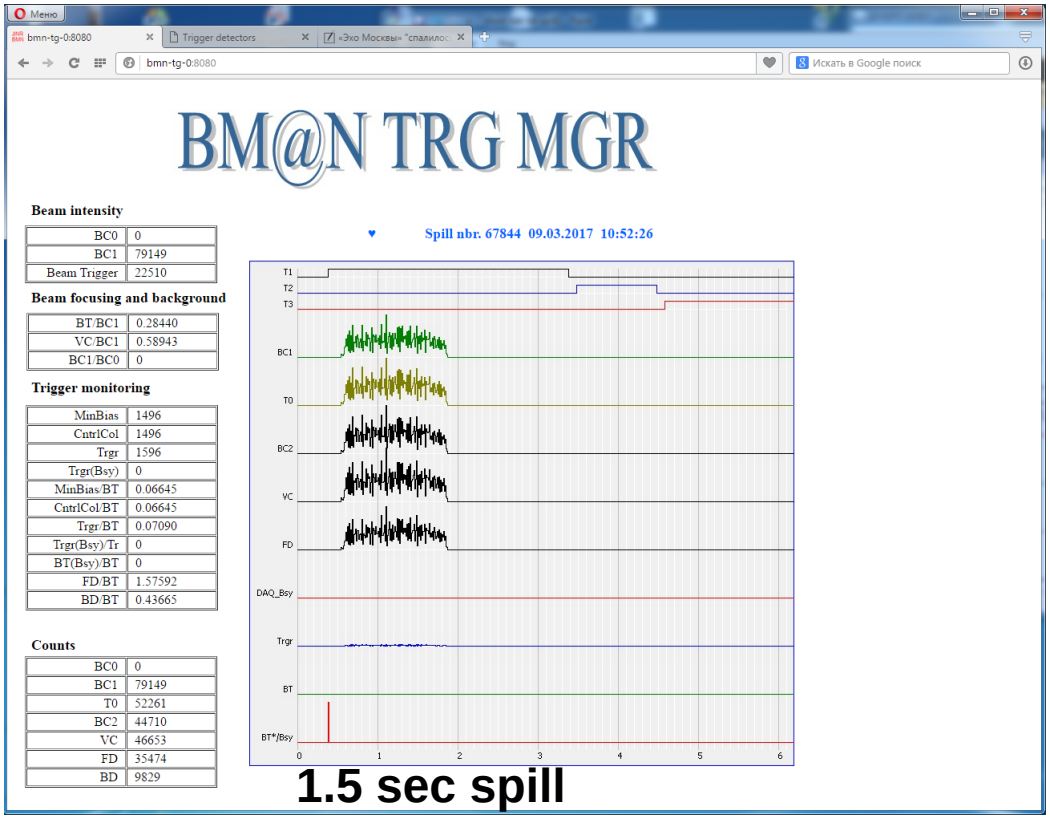
Tests of GEM detector 163 x 45 cm^2

CERN workshop + GEM group



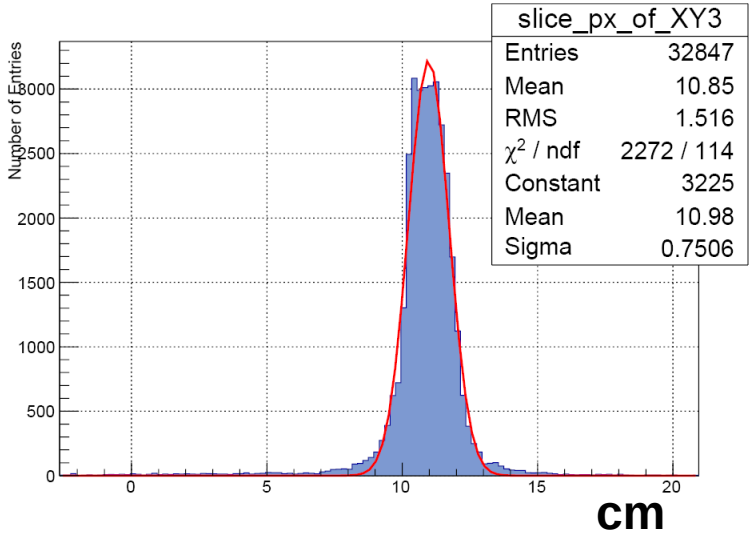
- for tracking in technical runs with deuteron and carbon beams in December 2016 and March 2017 used 5 detectors 66 x 41 cm^2 and 2 detectors 163 x 45 cm^2
- for BM@N run in spring 2018 produced 5 additional detectors 163 x 45 cm^2 at CERN workshop

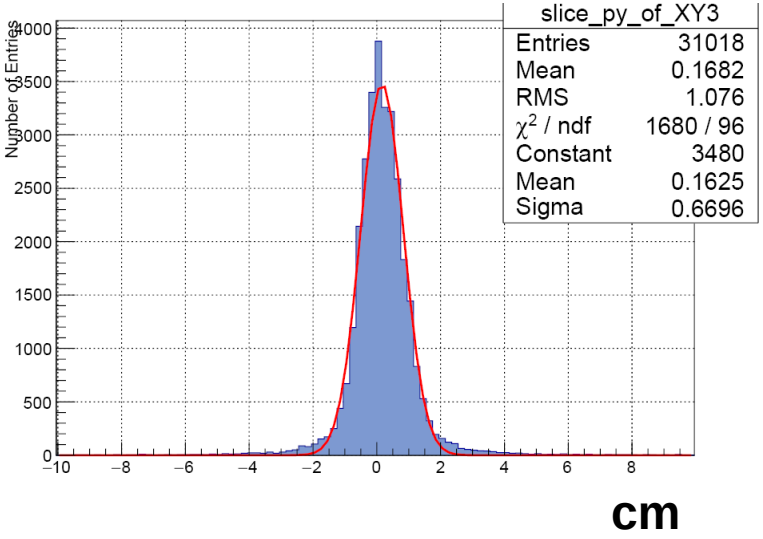
Deuteron / carbon beams at BM@N



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

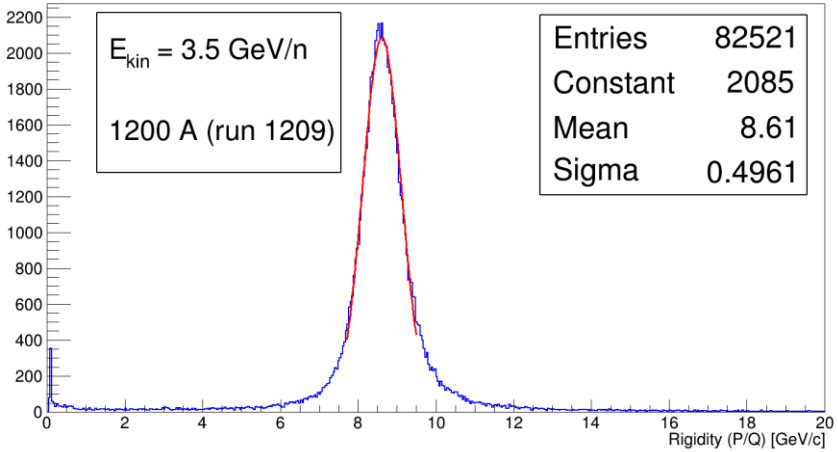
Beam momentum measured with GEM tracker

Carbon beam run, 4 AGeV

S.Merz

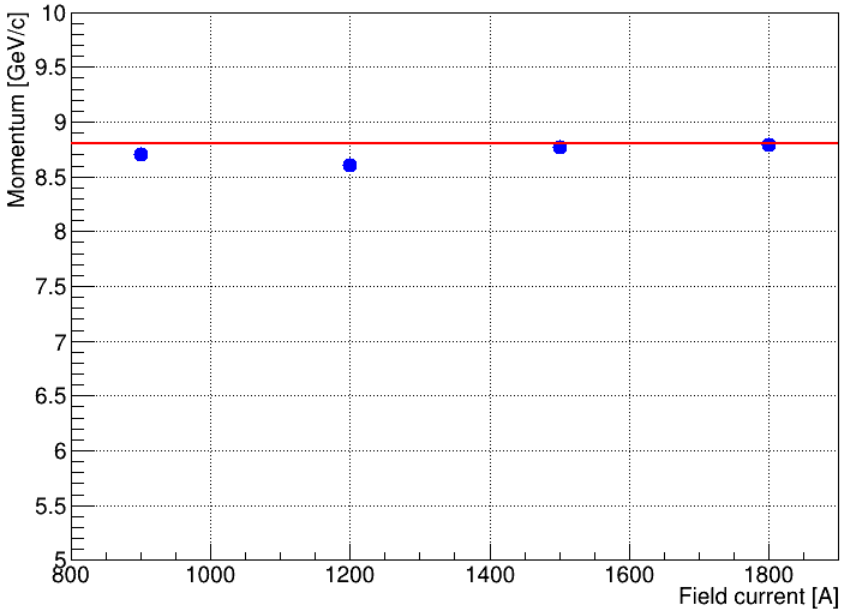
Reconstruction of carbon beam trajectory and momentum in GEM detectors at different values of magnetic field

Gas mixture: Ar + CO_2 (70:30)

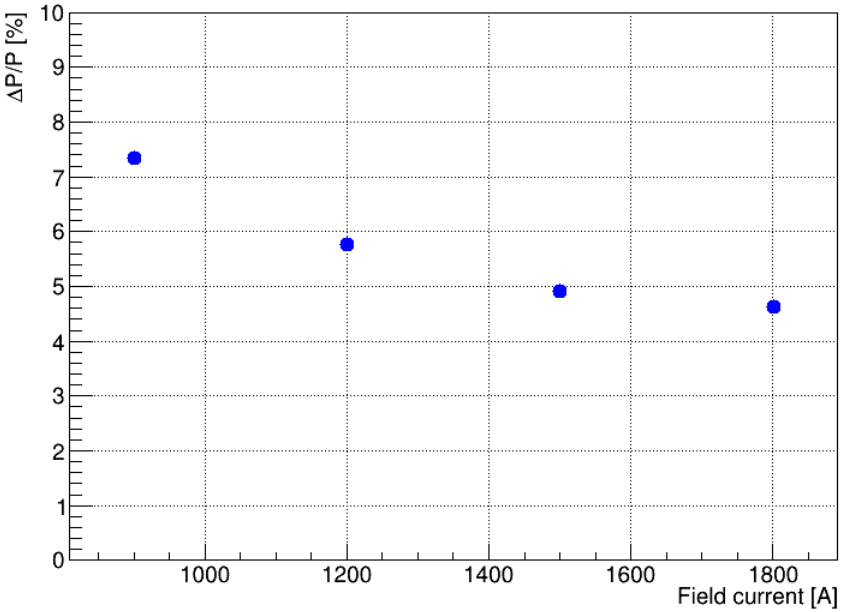


p/q

Reconstructed momentum for different magnetic fields

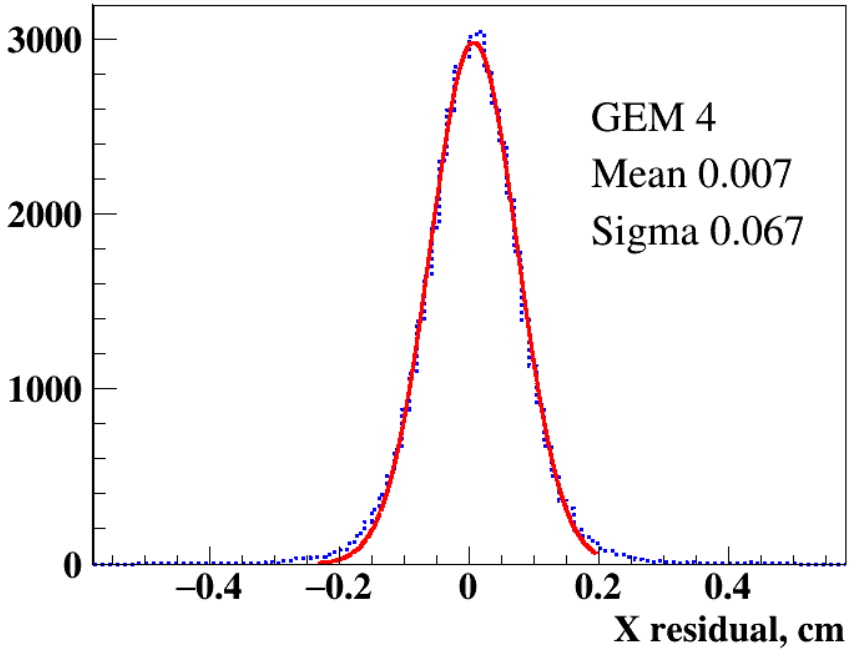


Momentum resolution for different magnetic fields

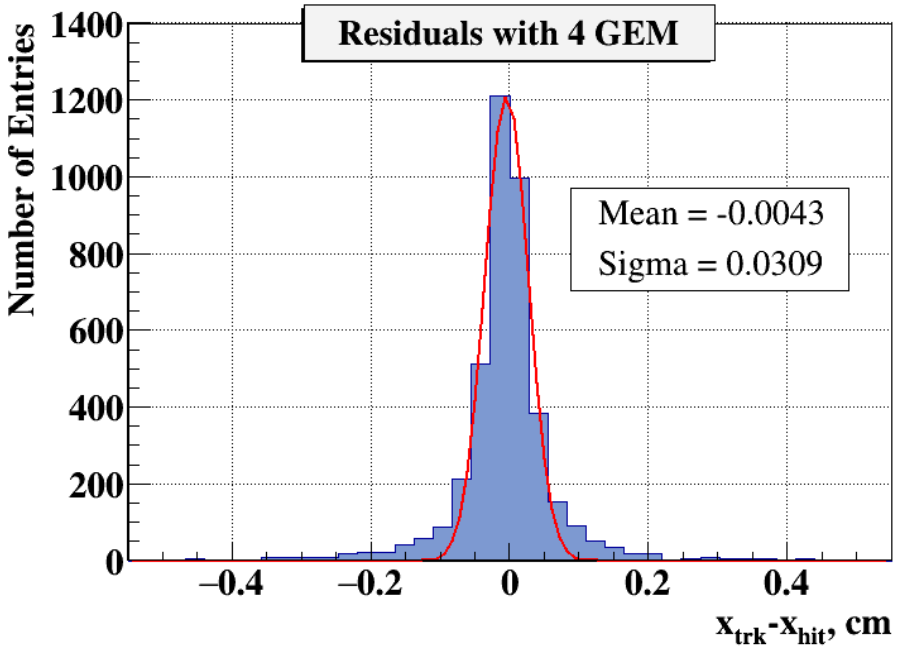


GEM residuals after Lorentz alignment

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



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



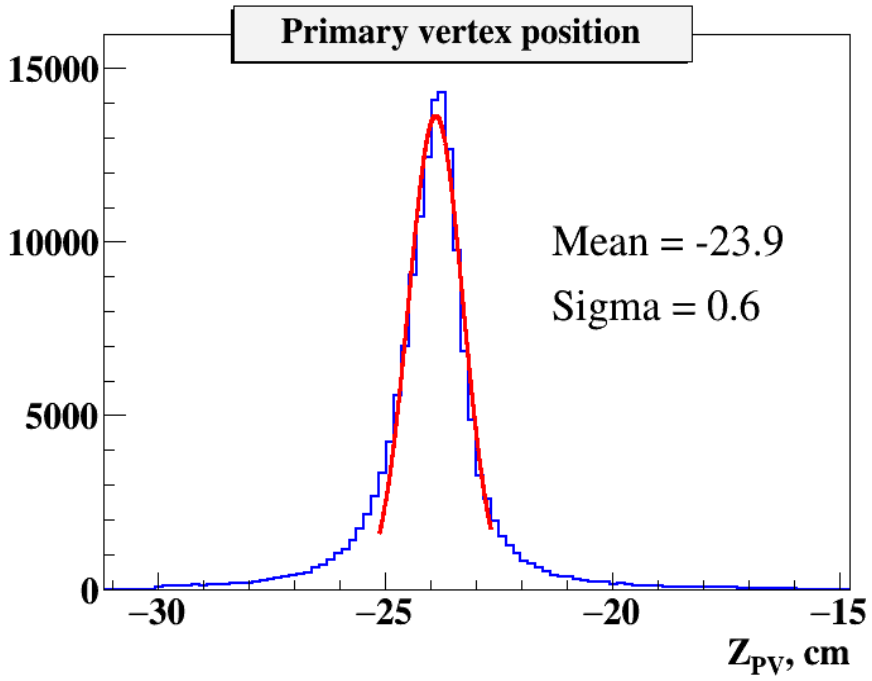
- **Fast gas mixture → reduced Lorentz shifts, better coordinate resolution**

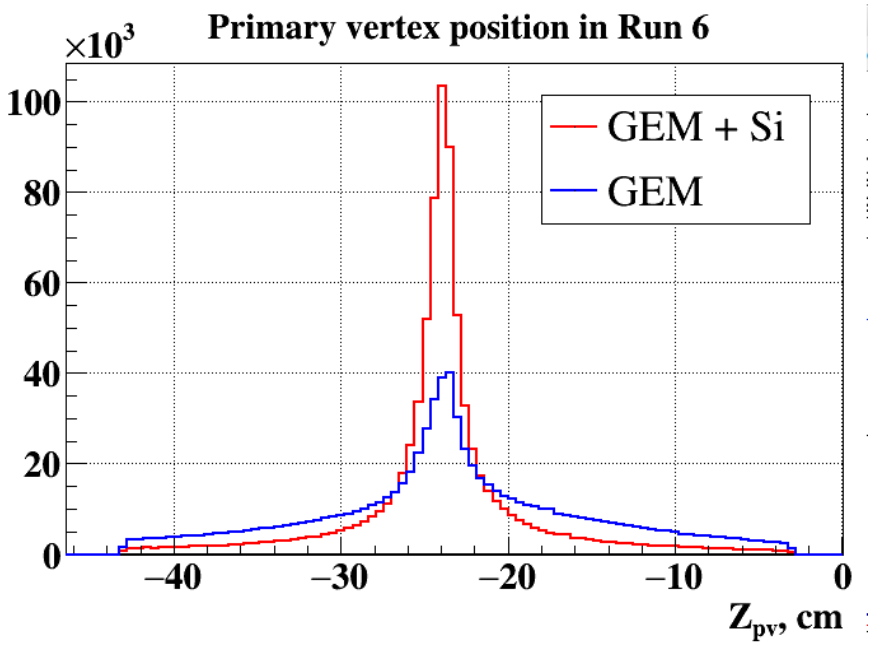
- **GEM hit residuals to reconstructed tracks in data are reproduced by MC simulation with Garfield parametrization**

Primary Vertex reconstruction

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

C + A → X interactions

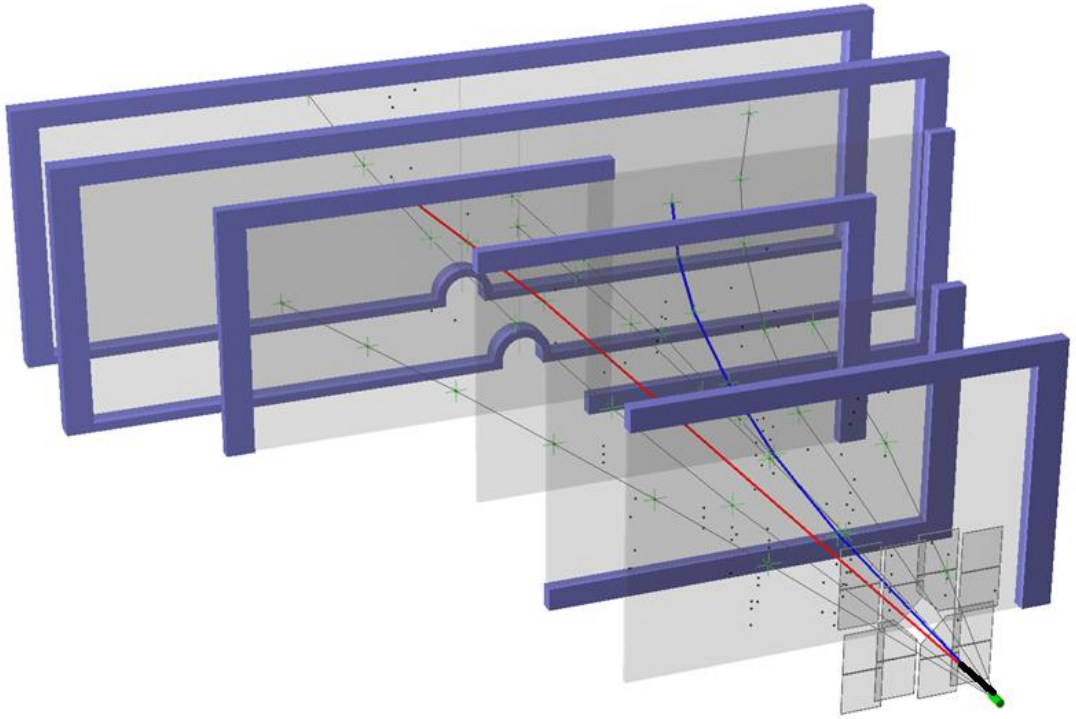


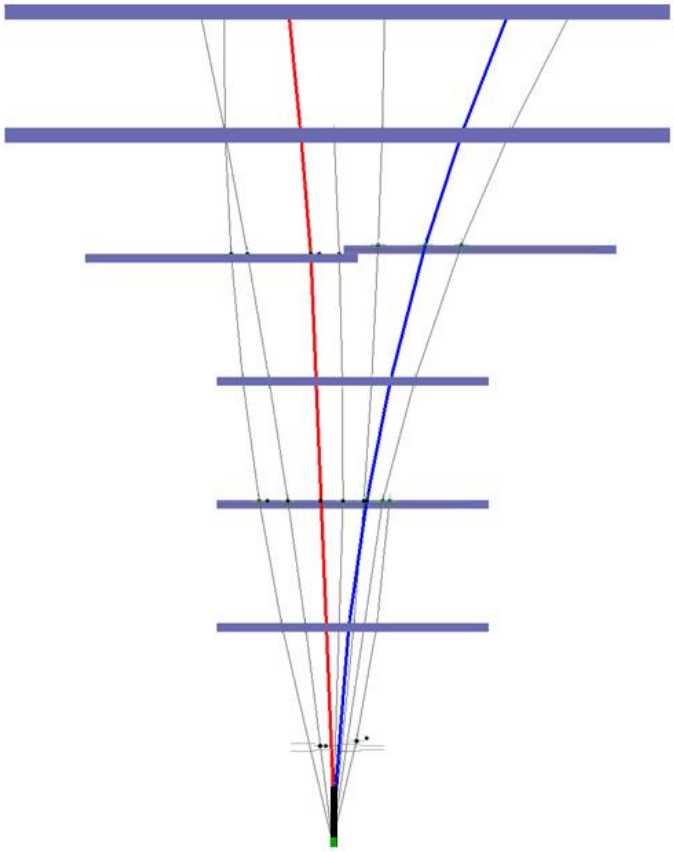


Primary Vertex reconstructed with GEM+Si detectors & Pile-up suppression

Effect of Si detector for Primary Vertex reconstruction

Event display of Λ decay in C+C collision





Λ→pπ⁻ decay reconstruction in GEM + Si tracker in C+C interaction, March 2017

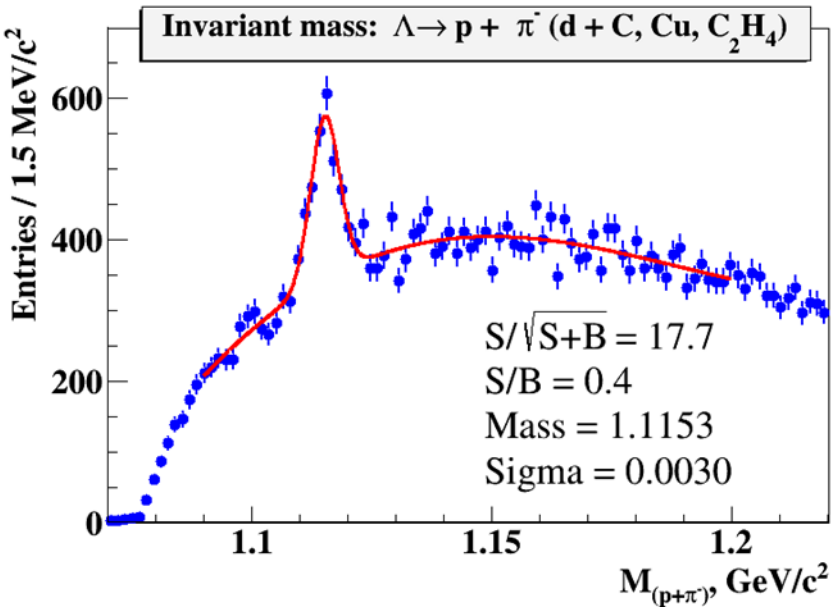
Λ in deuteron and carbon beams

d (C) + A → X

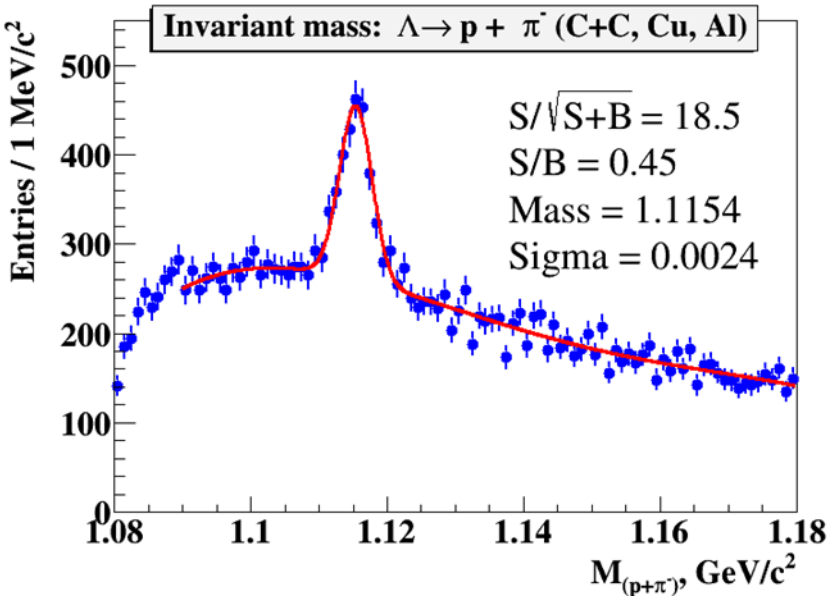
G.Pokatashkin, I.Rufanov, V.Vasendina and A.Zinchenko

Λ signal width of 2.4 - 3 MeV

Deuteron Data



Carbon beam run, 4 AGeV



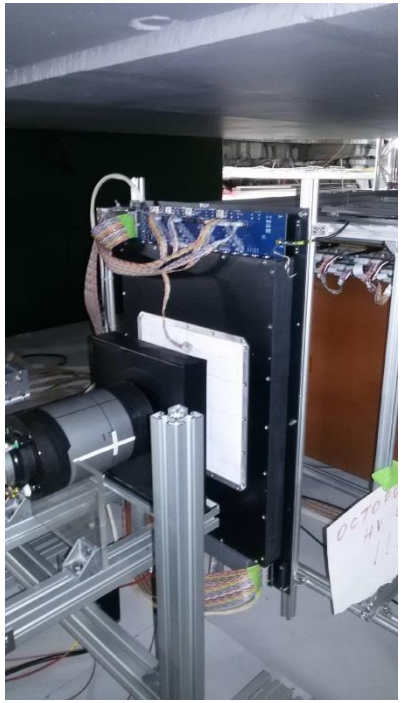
To improve vertex and momentum resolution and reduce background under Λ:

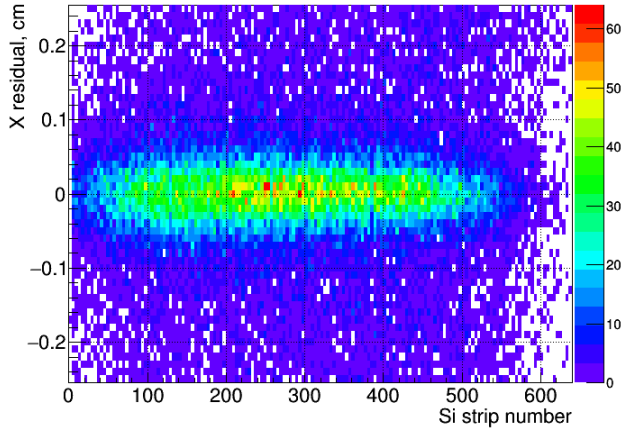
- **Need few planes of forward Silicon detectors → 3 planes in next run**
- **Need more GEM planes to improve track momentum reconstruction**

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

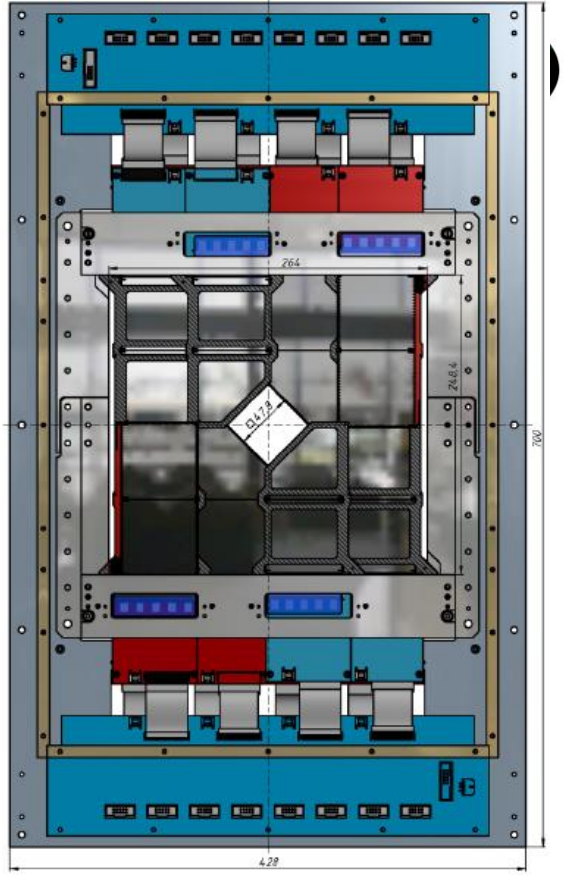
Forward silicon strip detector

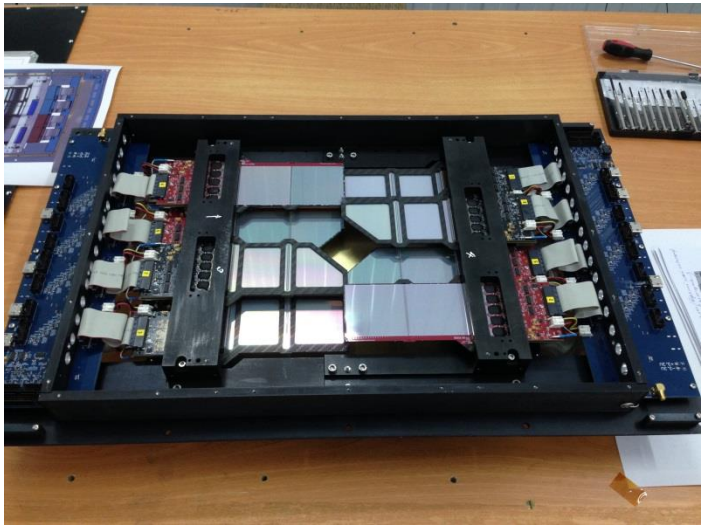
Silicon detector group, N.Zamiatin





Si-GEM residuals (cm) vs strip number

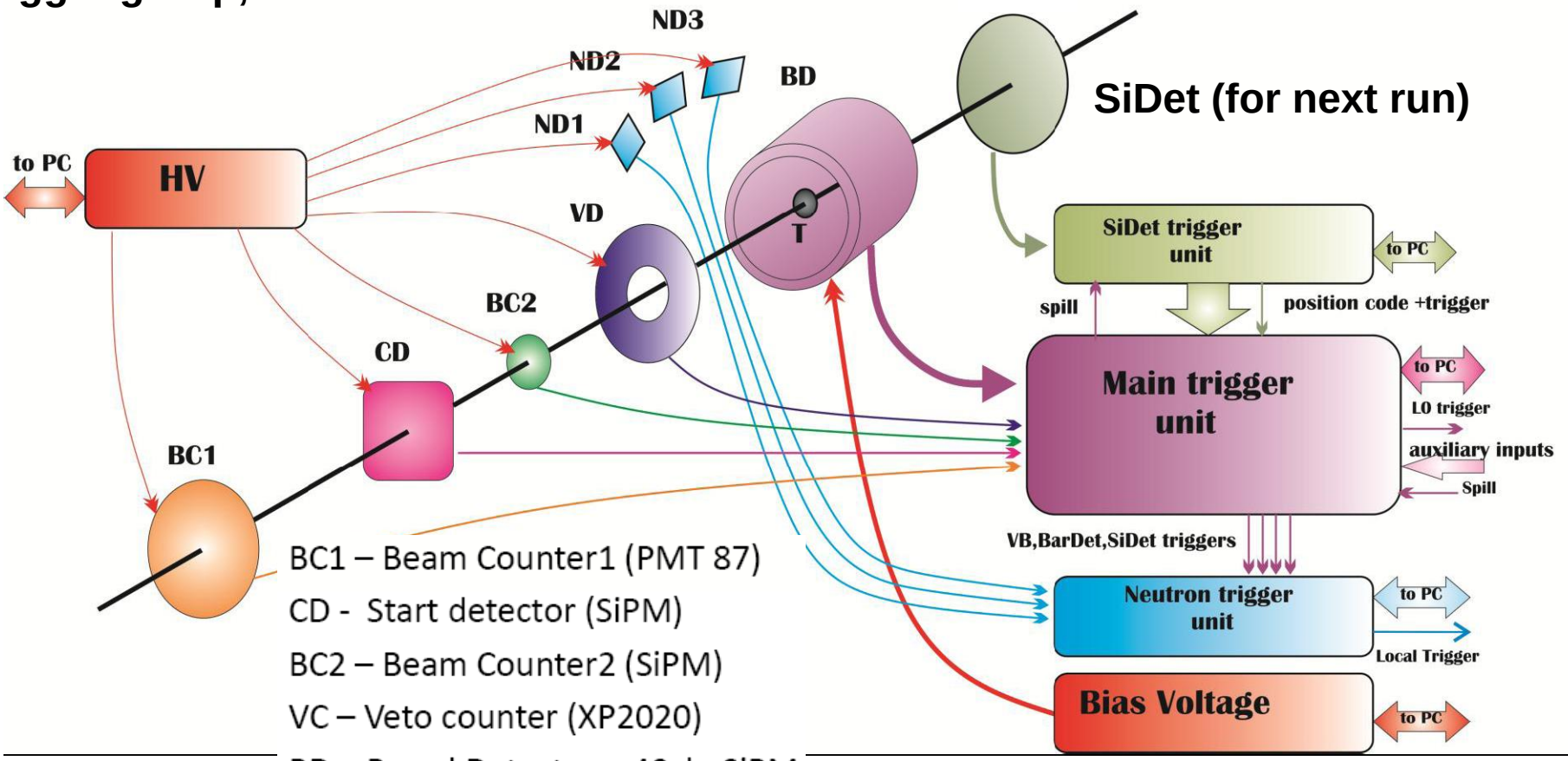




- **2-coordinate Si detector X-X'(±2.5º) with strip pitch of 95/103 μm, full size of 25 x 25 cm^2 , 10240 strips**
- **Detector combined from 4 sub-detectors arranged around beam, each sub-detector consists of 4 Si modules of 6.3 x 6.3 cm^2**
- **One plane installed in front of GEM tracker and operated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

Trigger detectors: beam counters and barrel detector in last carbon beam run (March 2017)

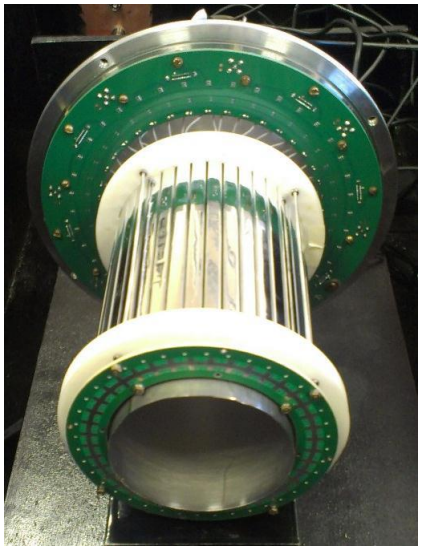
Trigger group, V.Yurevich

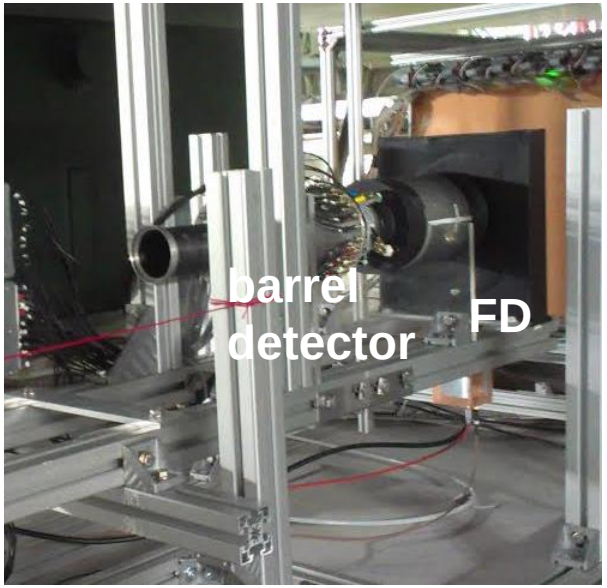


Selection of events with activity in barrel detector: BD >= N
+ forward Si detector in next run

Trigger barrel and Si detectors in BM@N setup

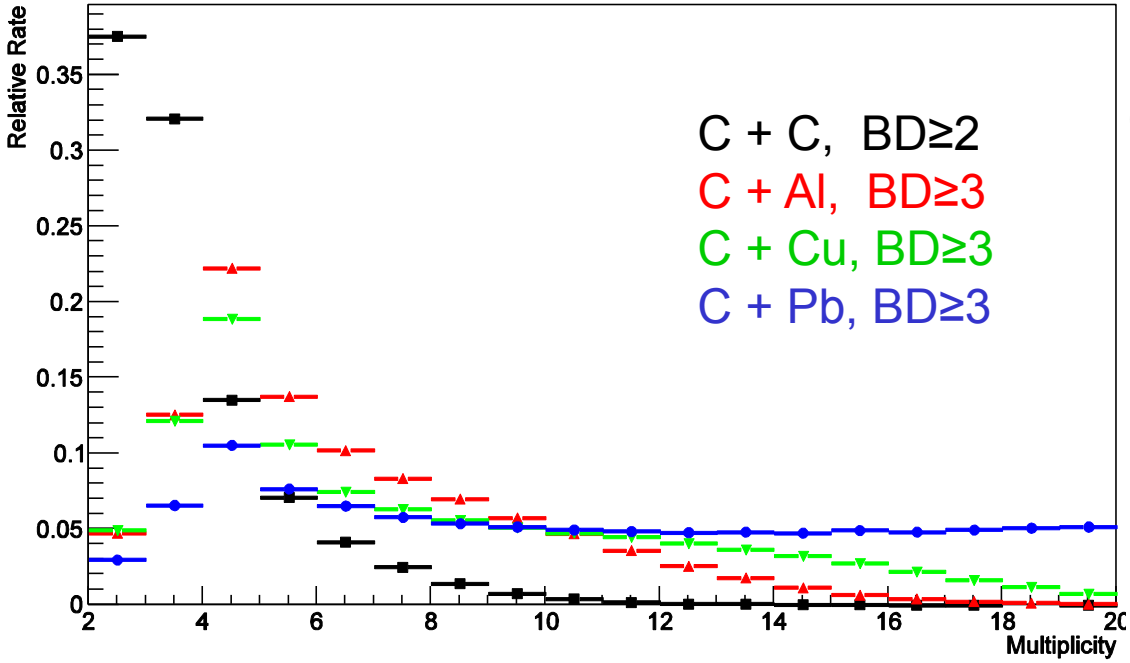
Trigger group, V.Yurevich



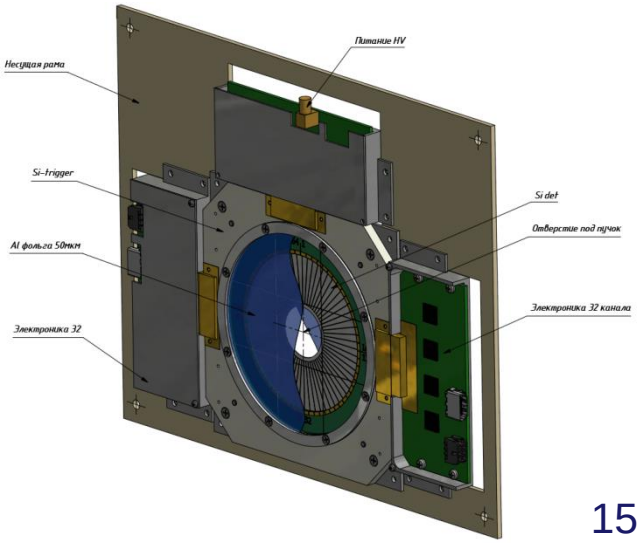


Barrel Detector multiplicity in carbon beam interactions with different targets

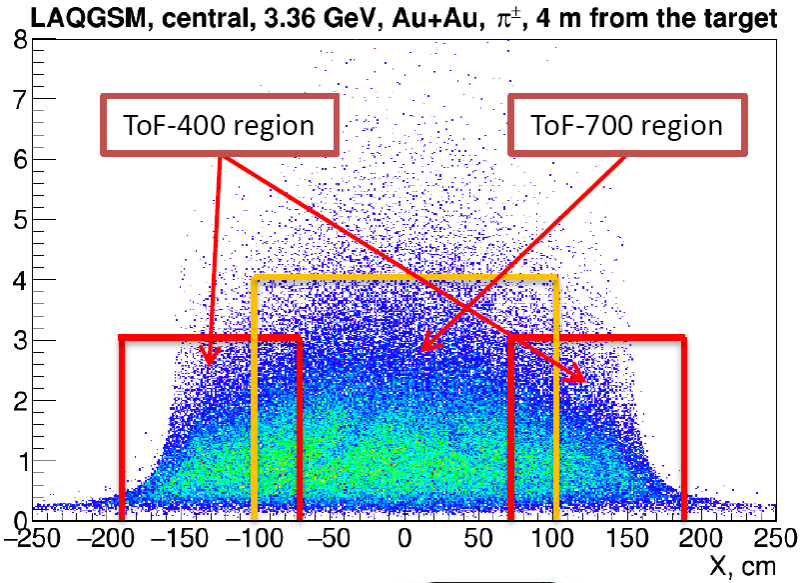
NBD1



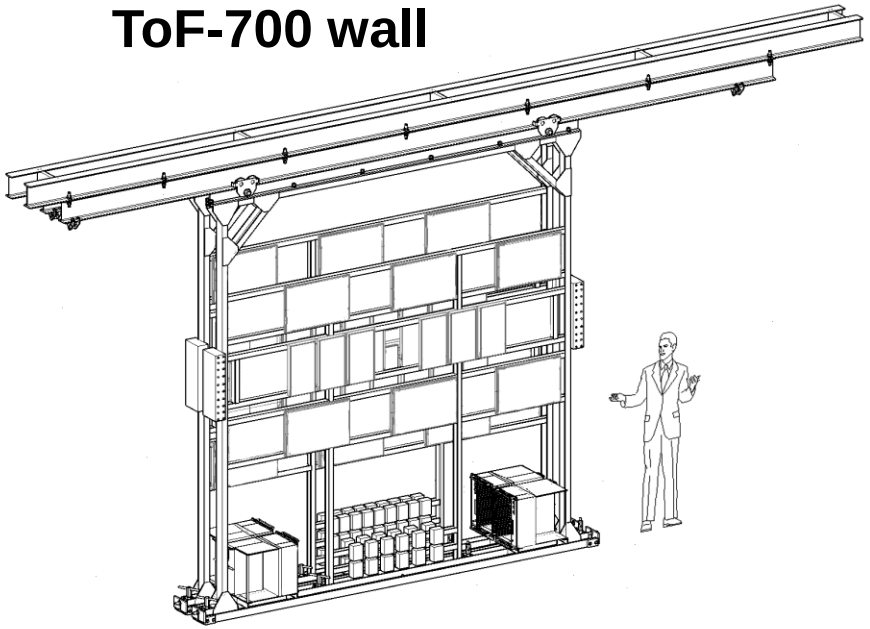
Forward Si trigger detector development, N.Zamiatin group

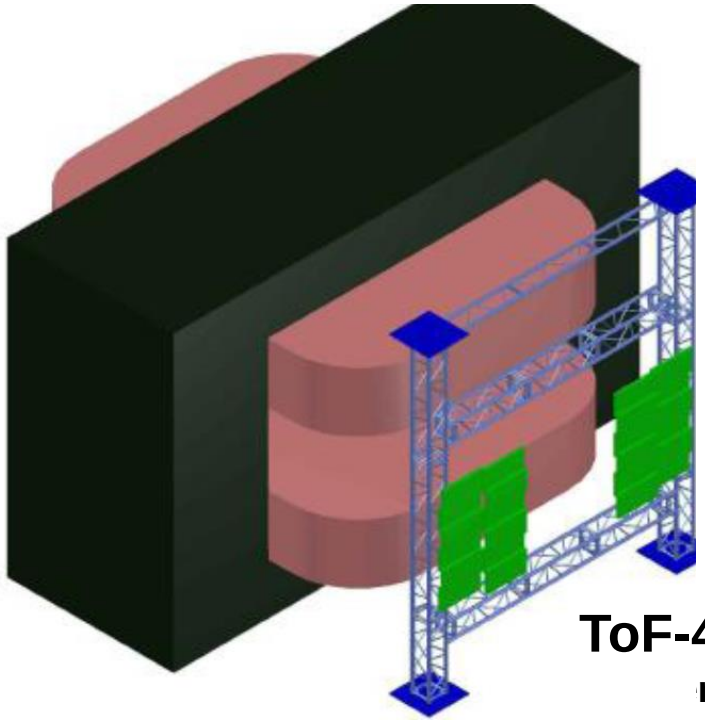


ToF-400 and ToF-700 based on mRPC

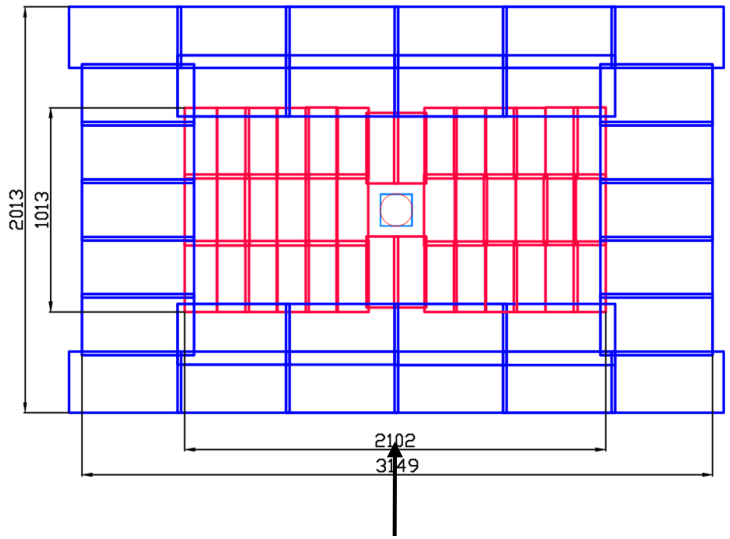


ToF-700 wall





ToF-400 wall

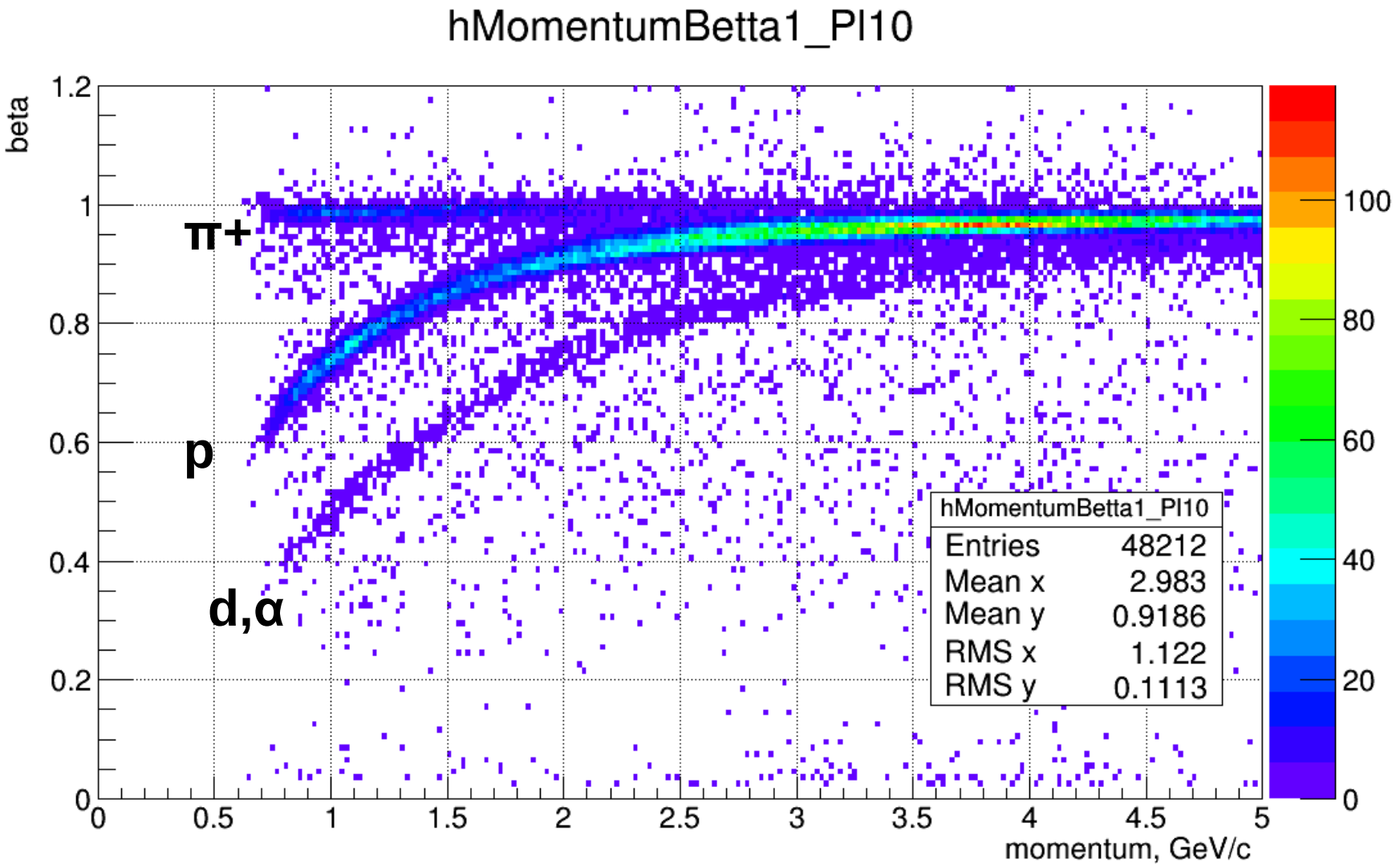


BM@N beam axis

ToF-400: status of particle identification

Carbon beam , 3.5 AGeV , C + Al → X

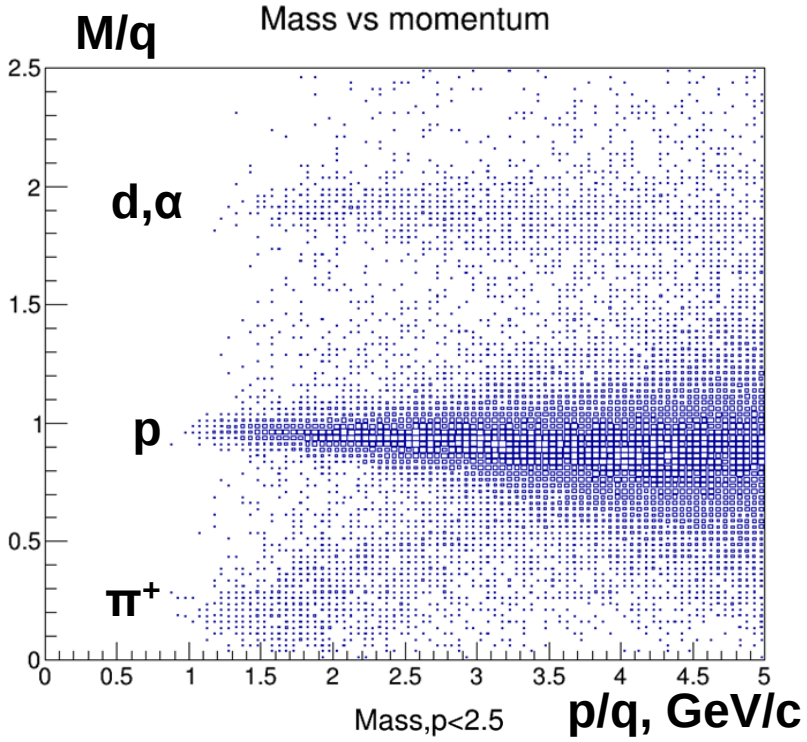
ToF-400 team

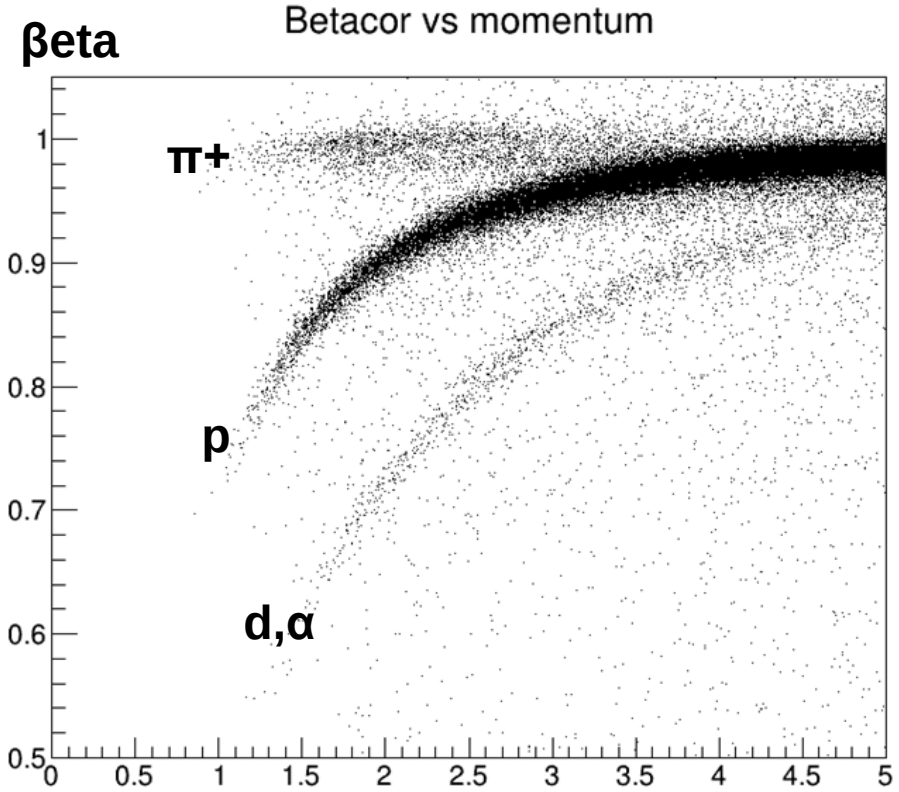


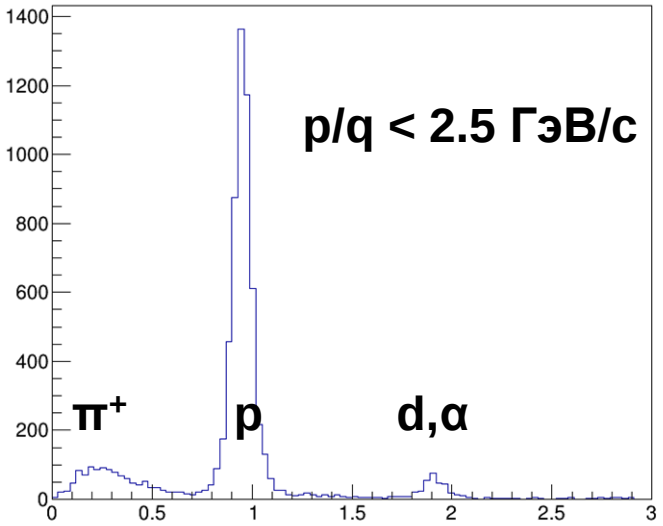
ToF-700: status of particle identification

ToF-700 team

Carbon beam , 4.0 AGeV , C + Cu → X

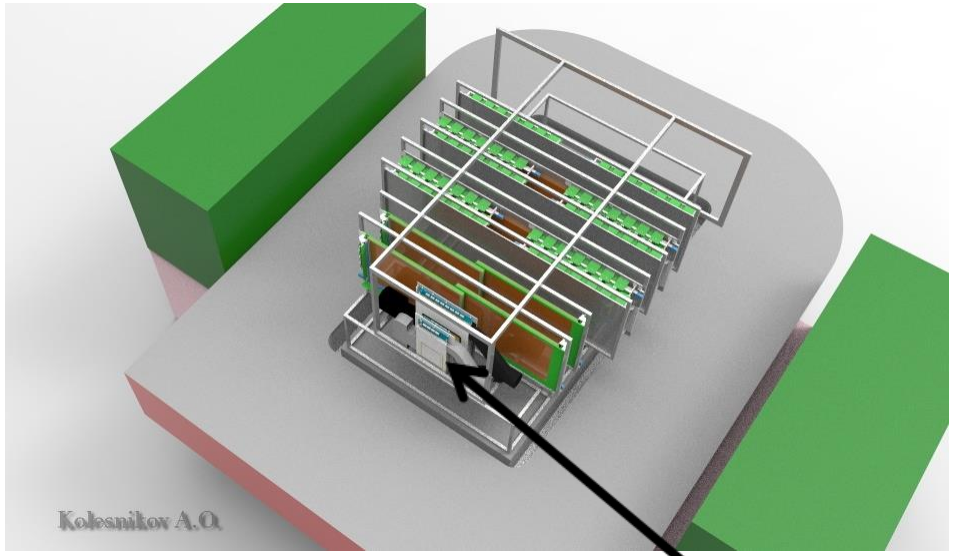


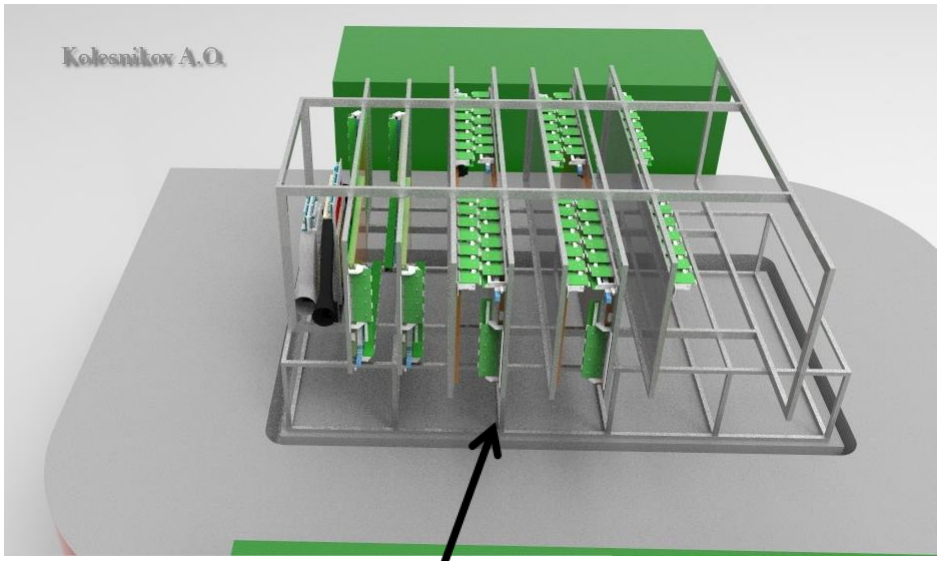


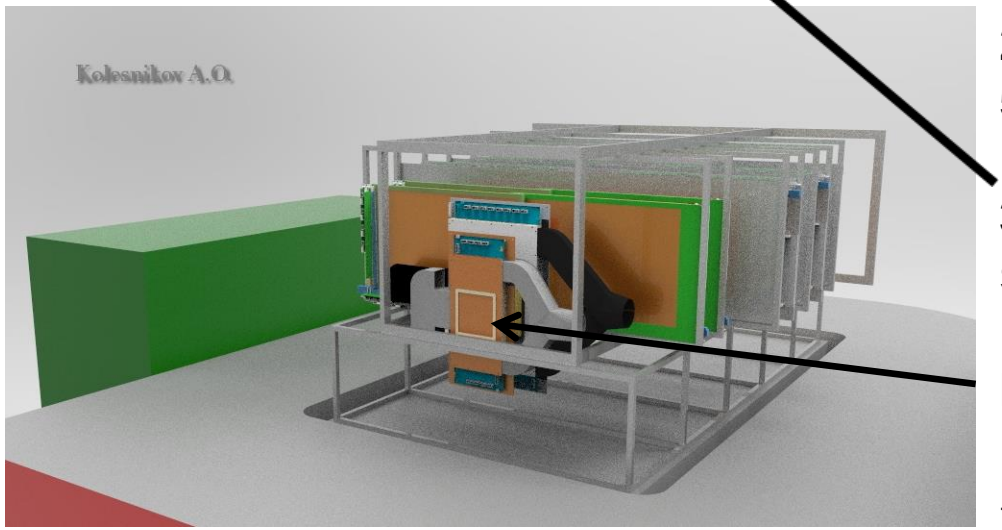


- ✓ To get π / K separation need better calibration of ToF chambers and better momentum resolution of central tracker

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







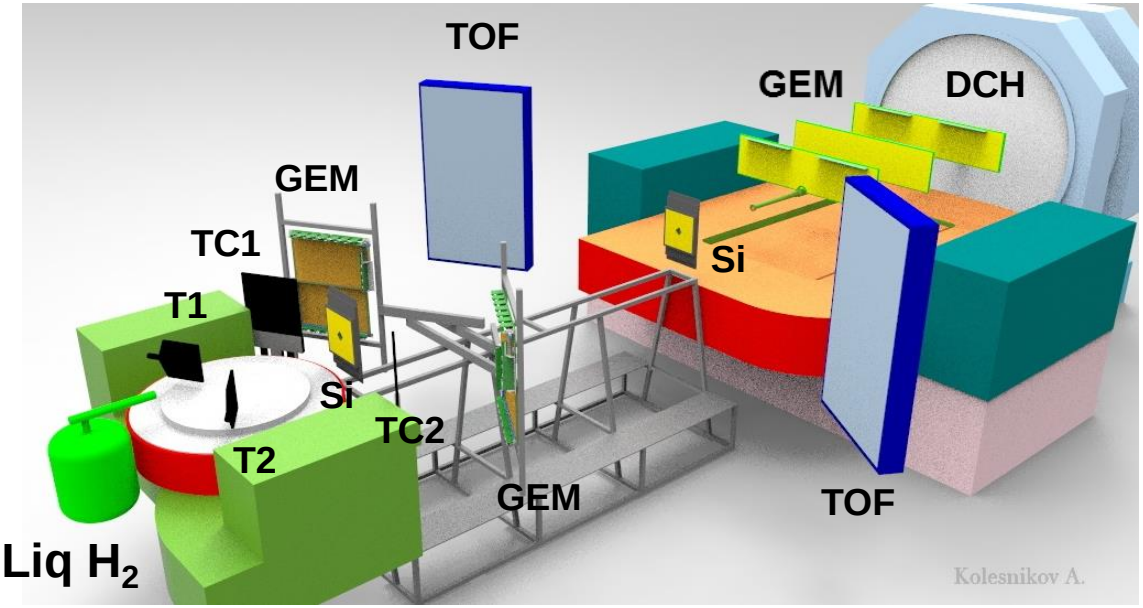
7 planes of GEM detectors:
2 combined planes of middle size GEM
5 big GEM detectors

3 planes of Si detector in front of GEM set-up

Beam crosses middle GEMs in short 'hot' zone, big GEMs – in beam hole → configuration is based on results of Λ and K^0_S simulation

BMN & SRC set-up

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



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	4000	Events
$^{12}C+p\rightarrow{}^{10}Be+pp$	pp SRC	200	
$^{12}C+p\rightarrow 2p+{}^{10}_{5}B+n$	np SRC	350	
$^{12}C+p\rightarrow 2p+{}^{10}_{4}Be+p$	pp SRC	100	

→ **First SRC @ BMN run in February 2018**

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	Au	Au, p
max.intensity, Hz	0.5M	0.5M	0.5M	1M	10M
trigger rate, Hz	5k	5k	5k	10k	20k→50k
central tracker status	6 GEM half pl.	6 GEM half pl.	7 GEM half pl. + **3 small Si planes**	7 GEM full pl. + **4 large Si planes**	7 GEMs + **4 large Si planes**
experim. status	techn. run	techn. run	techn. run	stage 1 physics	stage 2 physics

Concluding remarks and next plans

- **BM@N technical runs performed** in December 2016 and March 2017 with deuteron and carbon beams at energies: T_0 = 3.5 - 4.6 AGeV

- Major sub-systems are operational, but are still in limited configurations: GEMs, forward Silicon detector, Outer tracker, ToF, ZDC, trigger, DAQ, slow control, online monitoring

- Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed

BM@N plans for next run in February-March 2018:

- Beams provided by heavy ion source: C, Ar, Kr, extracted to BM@N setup

BM@N setup: GEM tracker (+ 5 detectors) , forward Silicon detector (+ 2 planes), extended trigger system, ToF, DAQ configurations

- Program for studies of Short Range Correlations with inverse kinematics: C beam + H_2 target

BM@N future plans for Au+Au: collaborate with CBM to produce and install large aperture STS silicon detectors in front of GEM setup

Thank you
for attention!

Backup slides

Nuclotron and BM@N beam line

26 elements of magnetic optics:

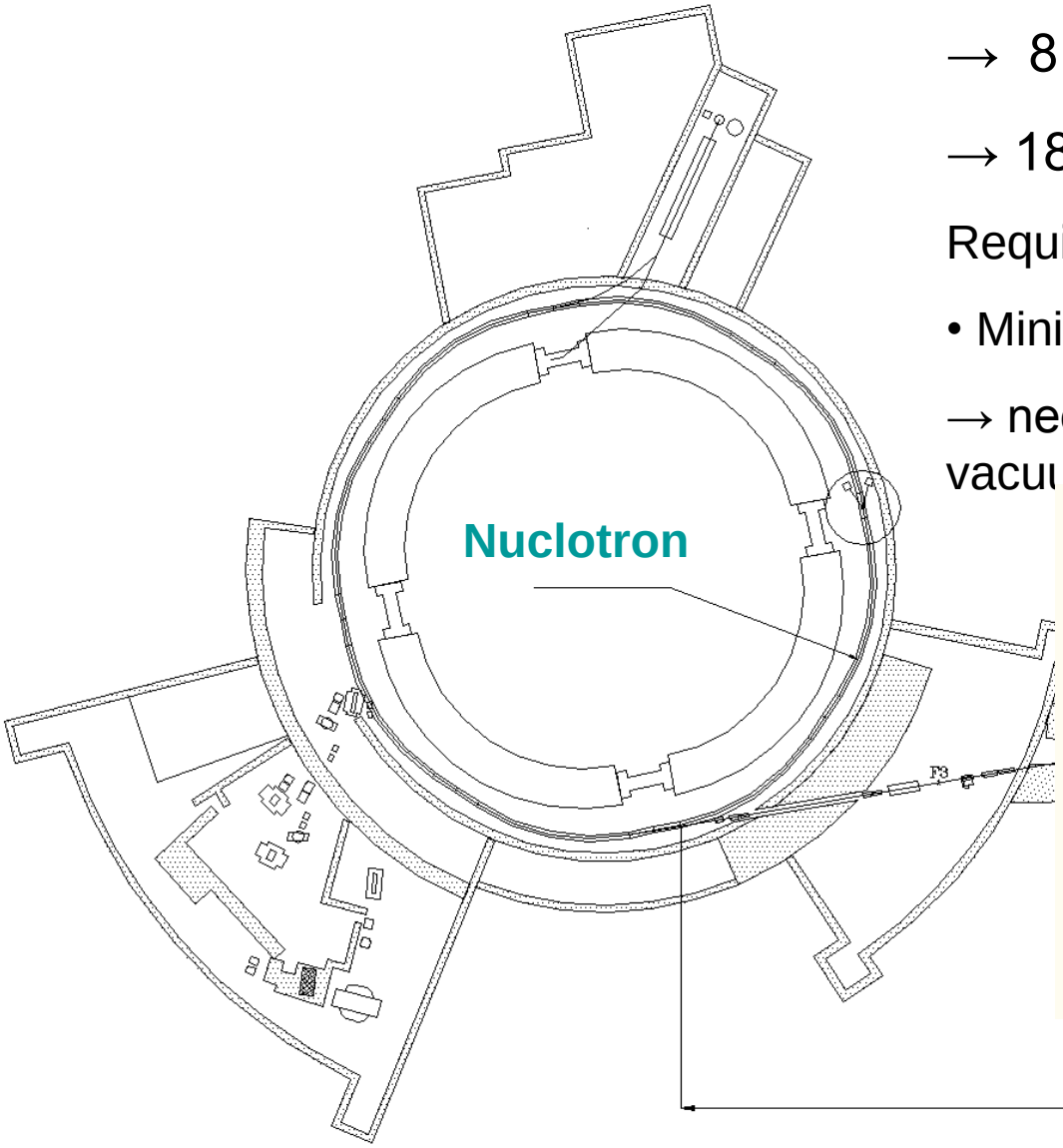
→ 8 dipole magnets

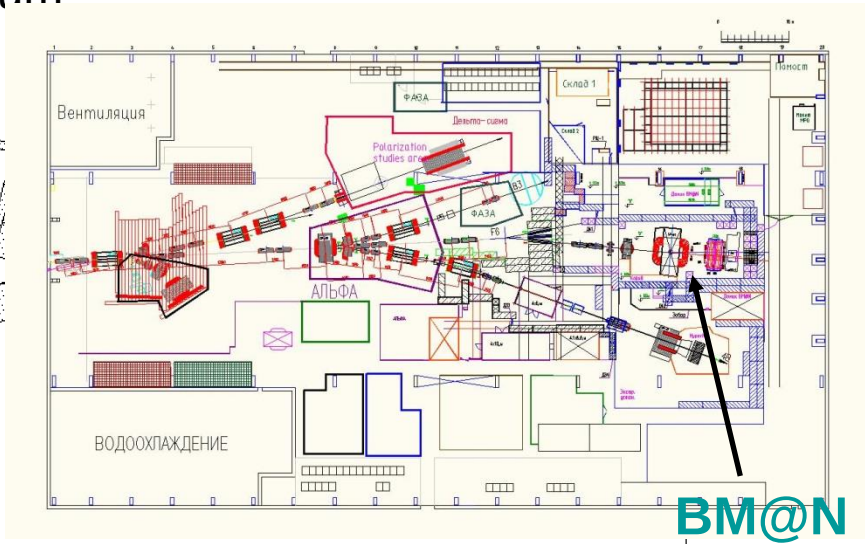
→ 18 quadruple lenses

Requirements for Au beam:

• Minimum dead material

→ need to replace air intervals / foils with vacuum

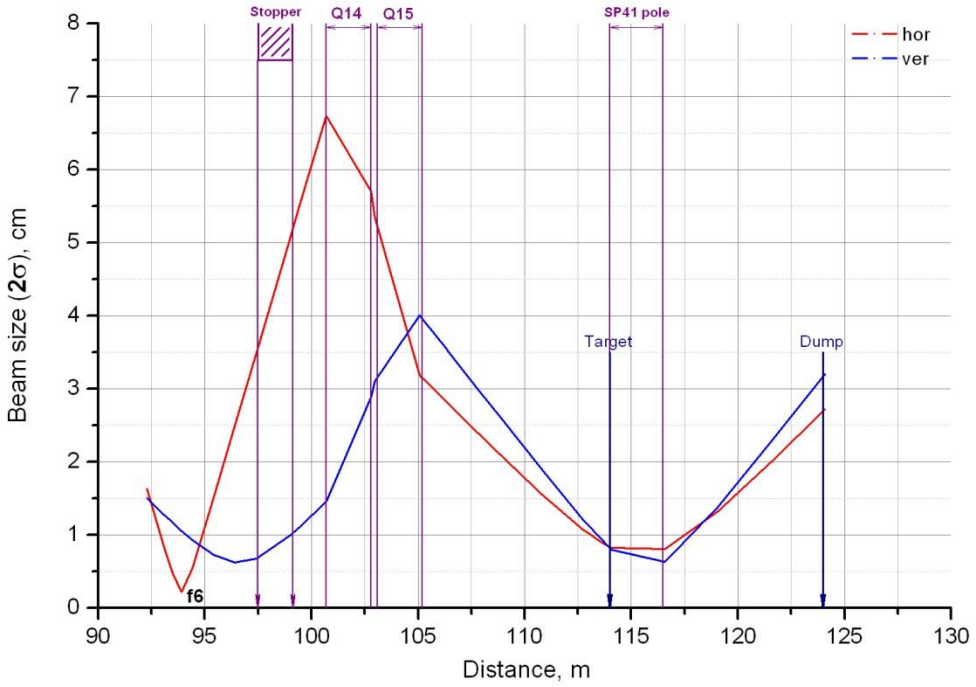




~160 m Building 205

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	$2 \cdot 10^{11}$
^{131}Xe	10^7 at BM@N
^{197}Au	10^7 at BM@N

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

Plans for extensive upgrade of BM@N beam line:

→ new stable power supplies for dipole magnets

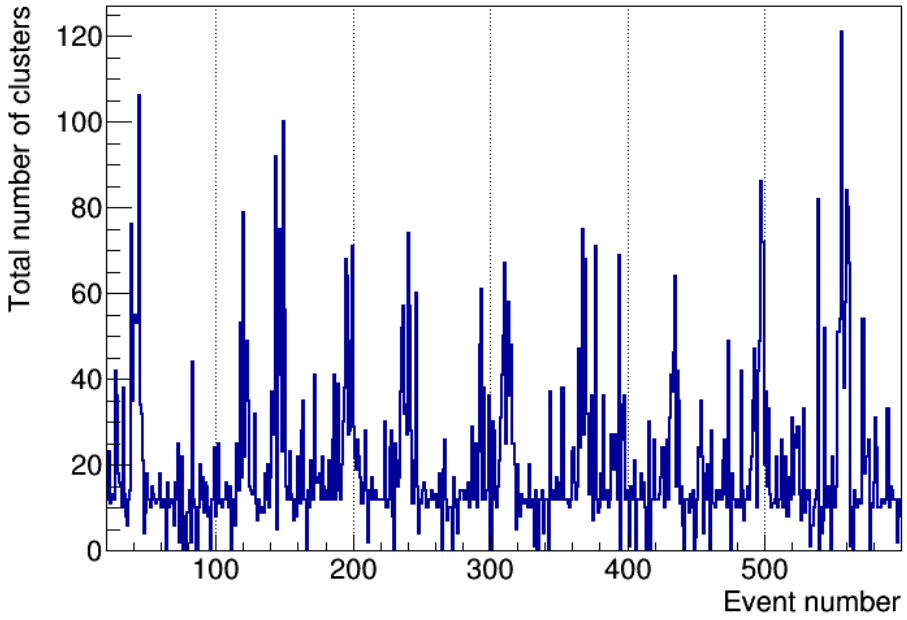
→ stabilization circuits for existing power supplies for quadruples and dipoles

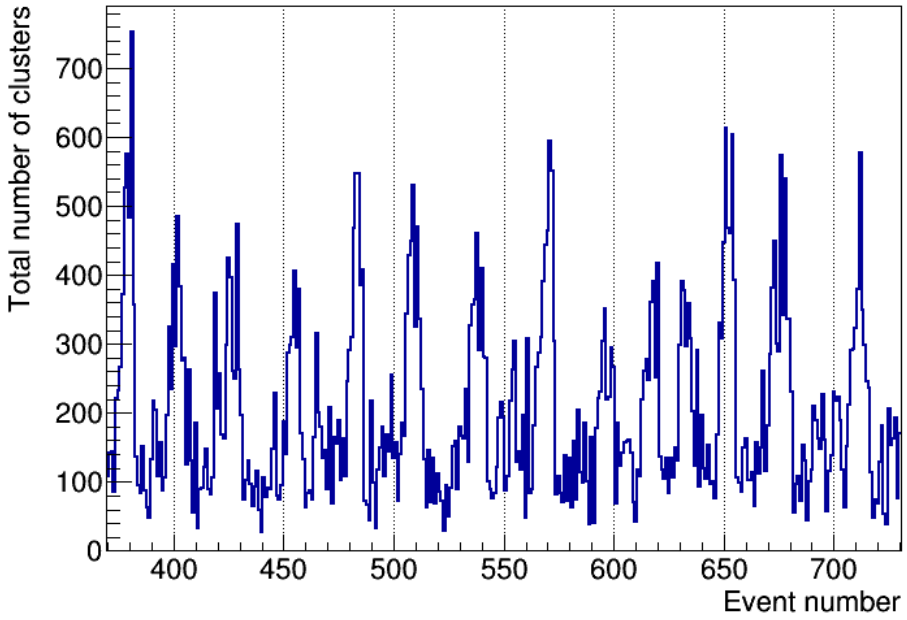
→ non destructive beam position monitoring on movable vacuum inserts

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

Deuteron & carbon beam structure

Total number of GEM hit clusters as function of event number

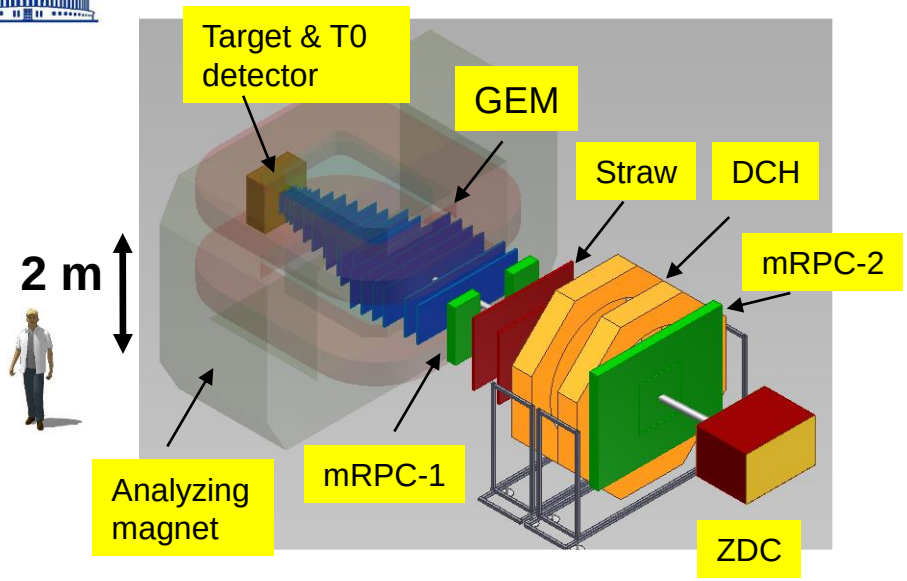




Deuteron run (December 2016)
Deuteron beam trigger, 4 AGeV

Carbon beam Run (March 2017)
C+A collisions , 4.5 AGeV

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 (GEM+Si) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (DCH, Straw / CPC) 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-

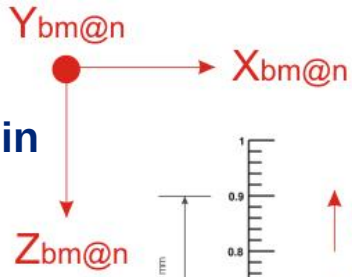
Simulation of GEM response: Garfield++

D.Baranov

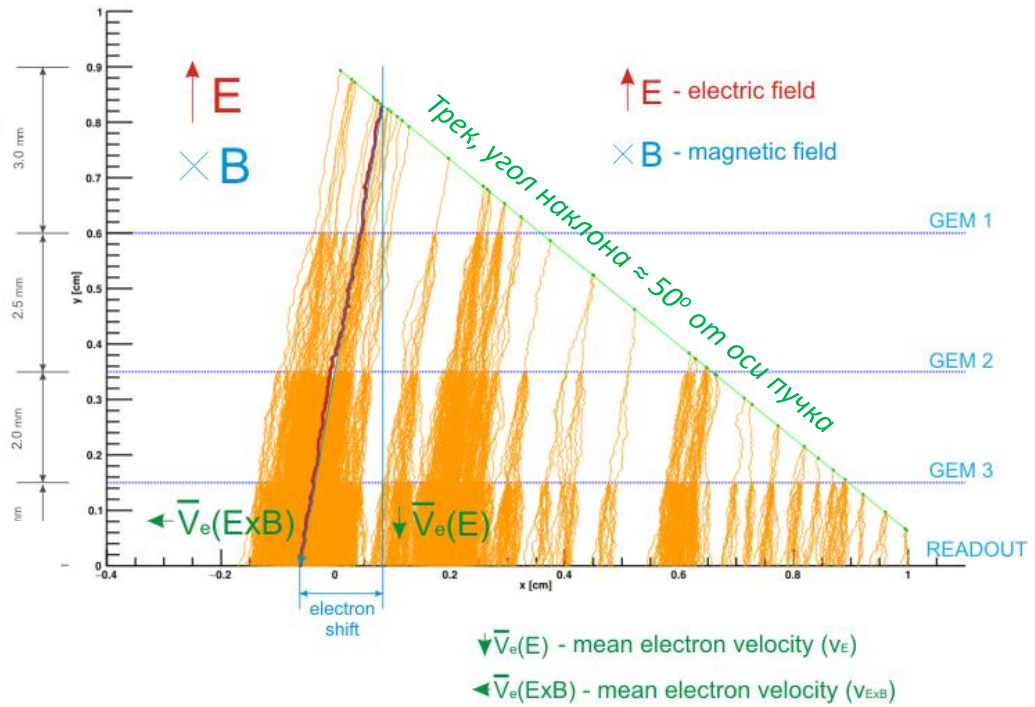
Garfield++ - framework for micro-simulation of physical processes in gas detectors

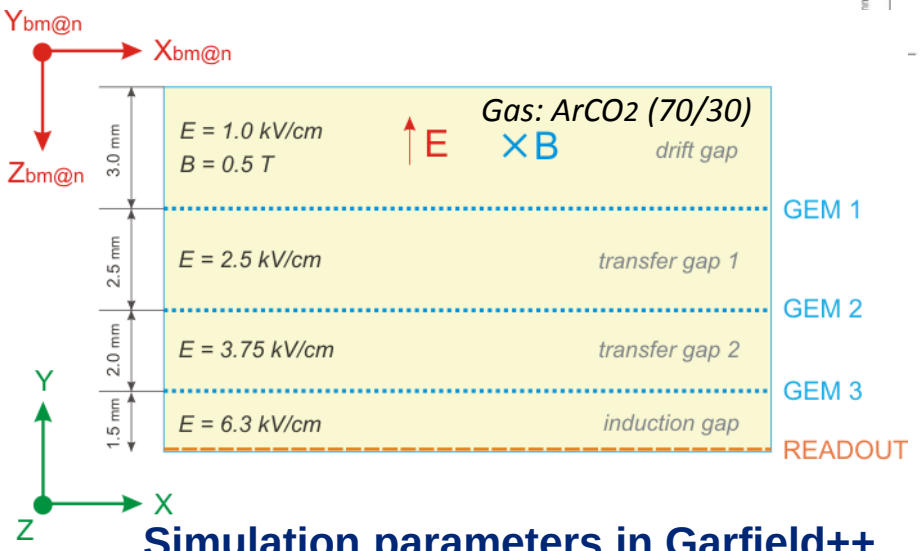
Charge particle passing through GEM chamber detecting volume ionizes electrons in gas

Multiplayer GEM-cascades form avalanches which drift to readout-plane and fire strips

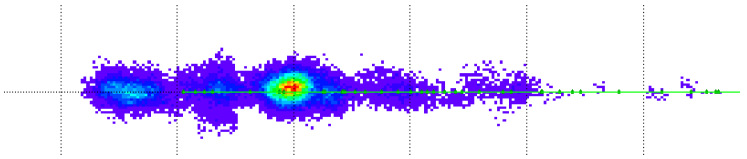


Structure of BM@N GEM chamber and simulated electron avalanches





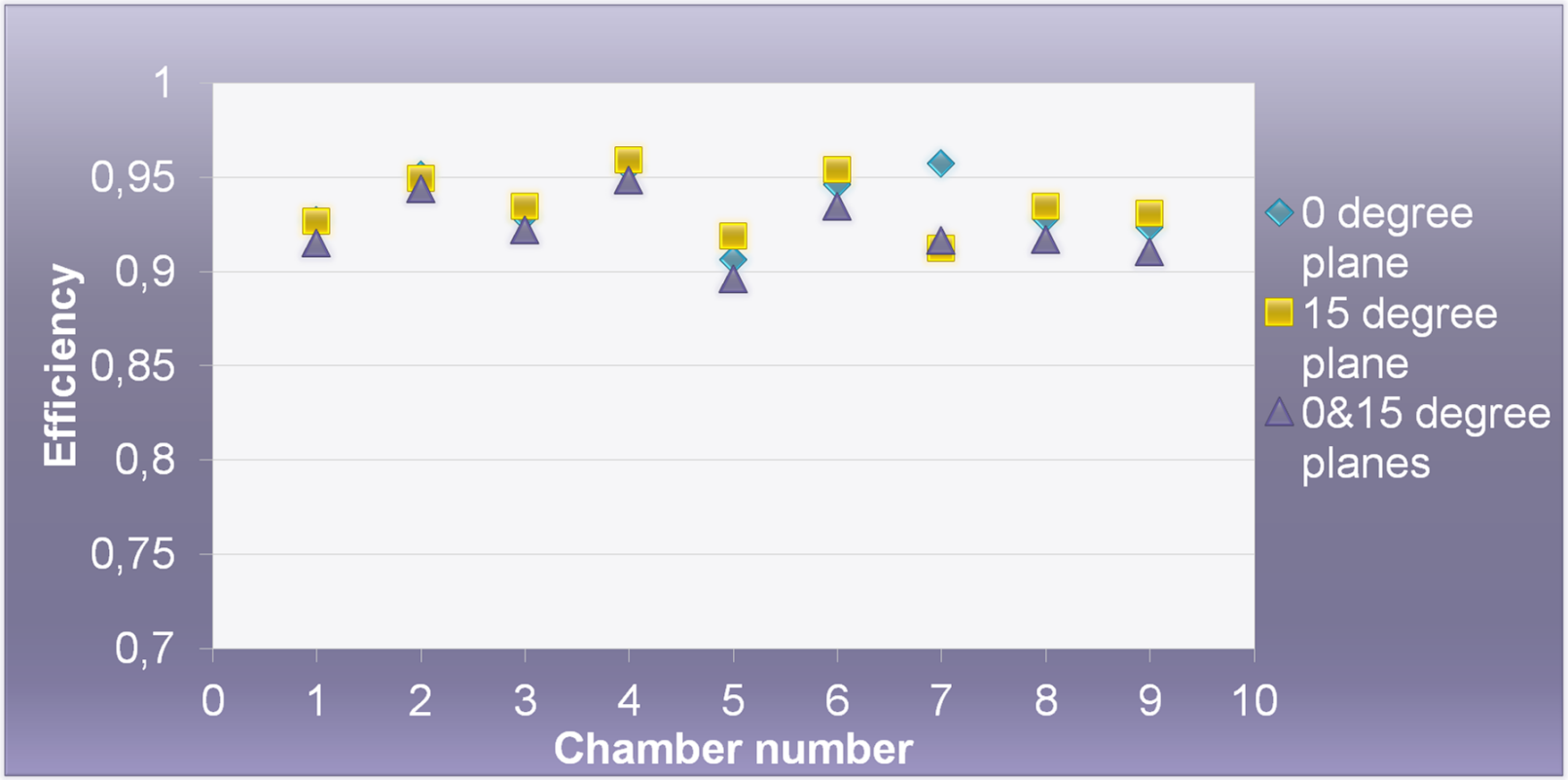
Simulation parameters in Garfield++



Profile of electron avalanche at the readout-plane (cluster).

GEM detector efficiency in deuteron run

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



X plane

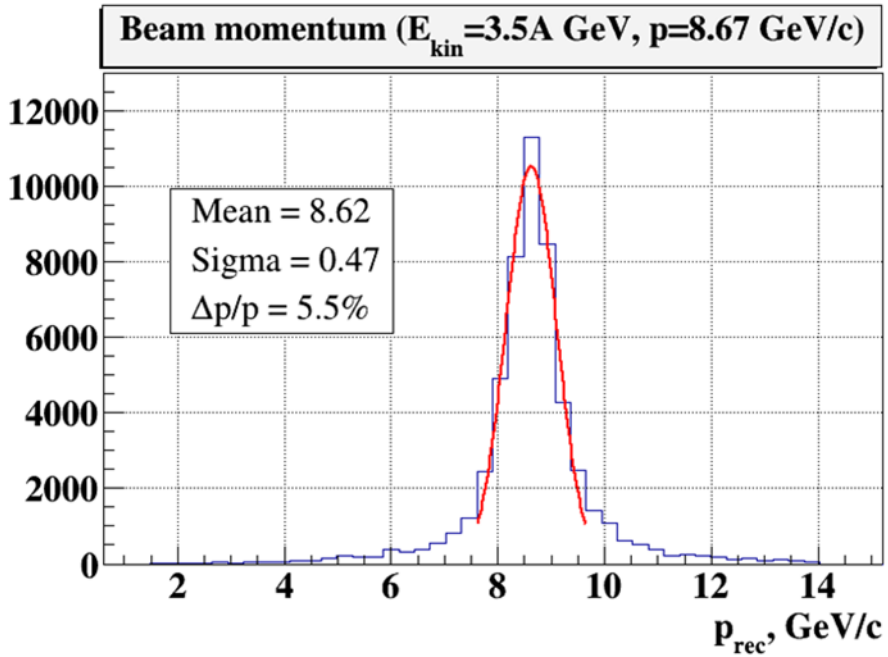
X‘ plane

X & X‘ planes

Momentum resolution: Exp. vs MC

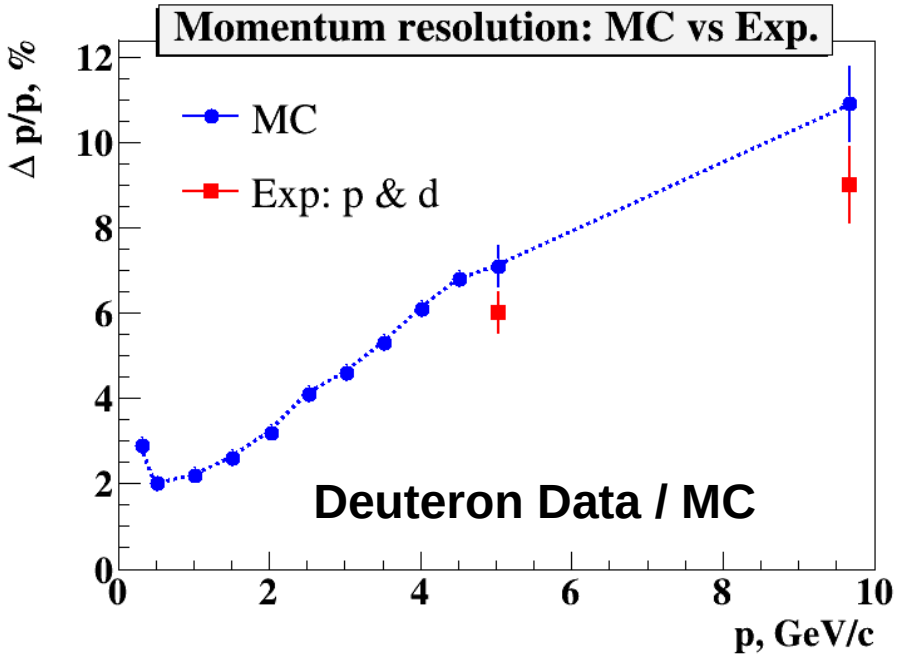
G.Pokatashkin, I.Rufanov, V.Vasendina and A.Zinchenko + D.Baranov (Garfield)

Carbon beam



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

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



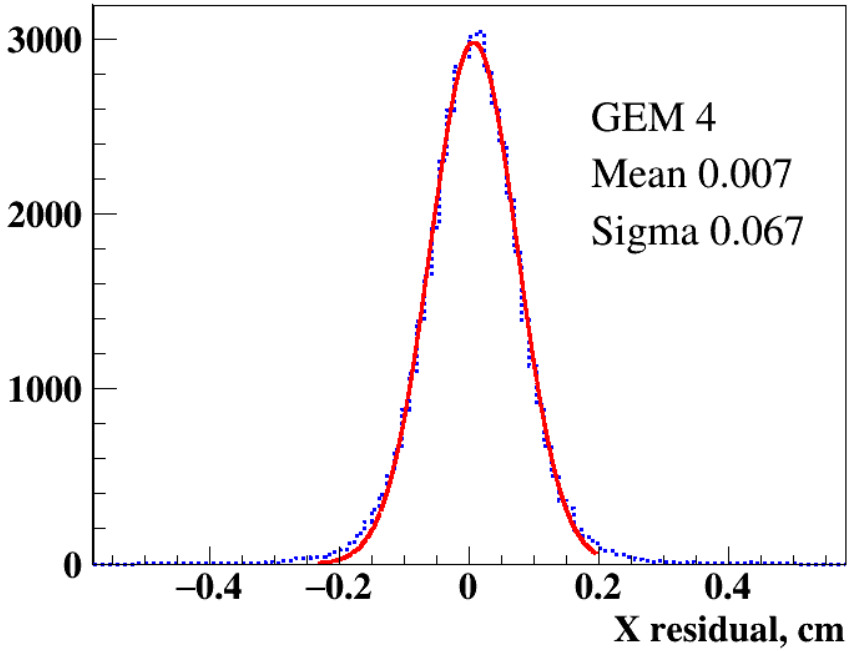
Gas mixture: Ar + Isobuthan (90:10)

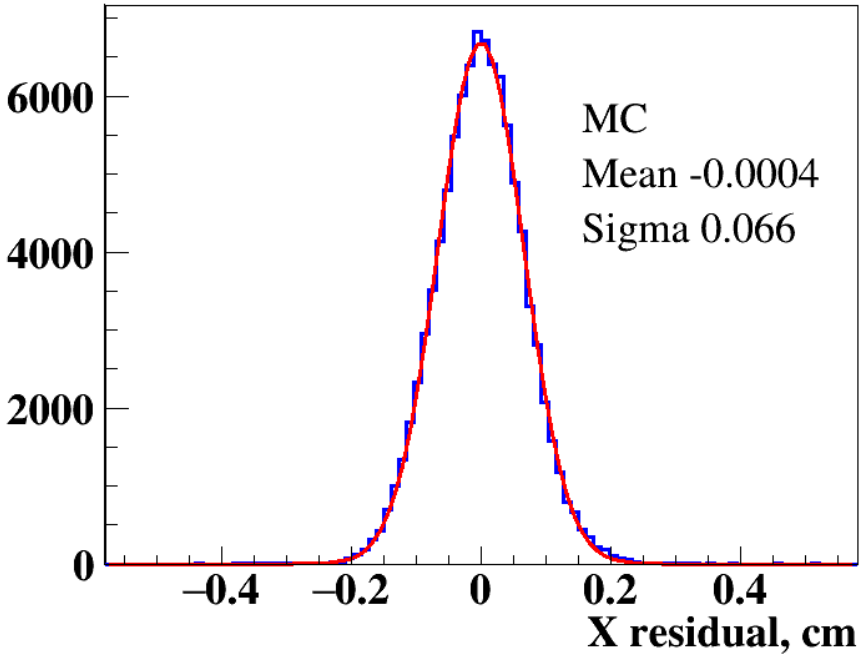
✓ Momentum resolution from MC as function of particle momentum

✓ MC results reproduce exp. data for spectator protons and deuteron beam

GEM Hit residuals: Exp. vs MC

Gas mixture Ar + Isobuthan (90:10)





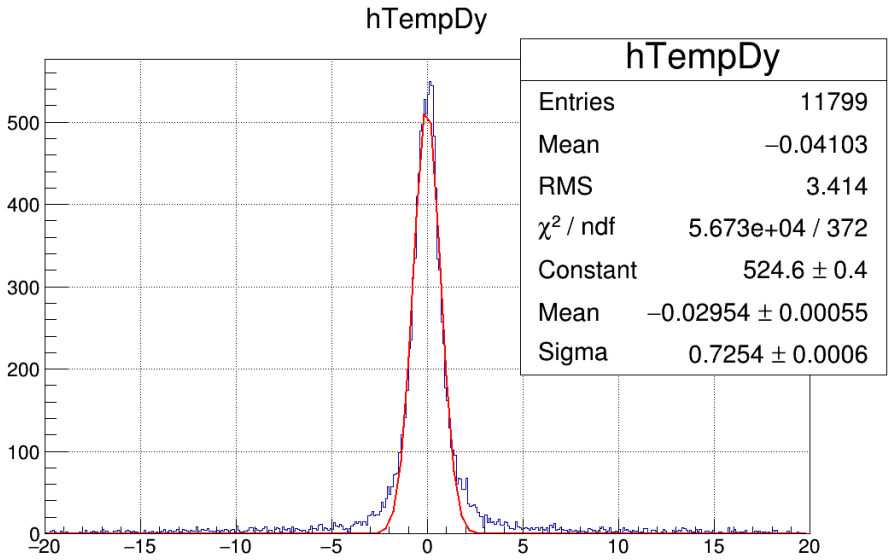
GEM hit residuals vs reconstructed tracks in horizontal plane after Lorentz shift corrections σ~0.67 mm.

Mag. field 0.79 T

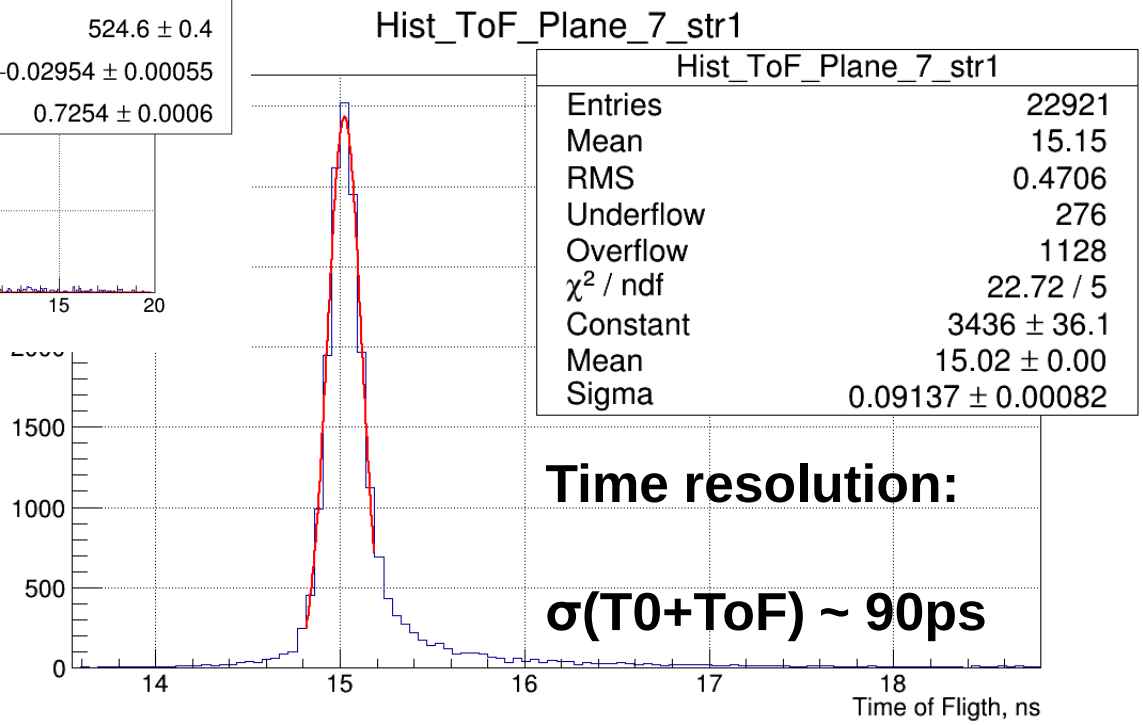
MC simulation with Garfield ++ parametrization reproduces exp. data.

ToF-400 in carbon beam interactions

ToF-400 group



Time of Flight T0 - ToF400



Coordinate resolution:

σ_Y = 7.2/√2 ~5 mm

σ_X = 12.5/√12 ~3.6 mm

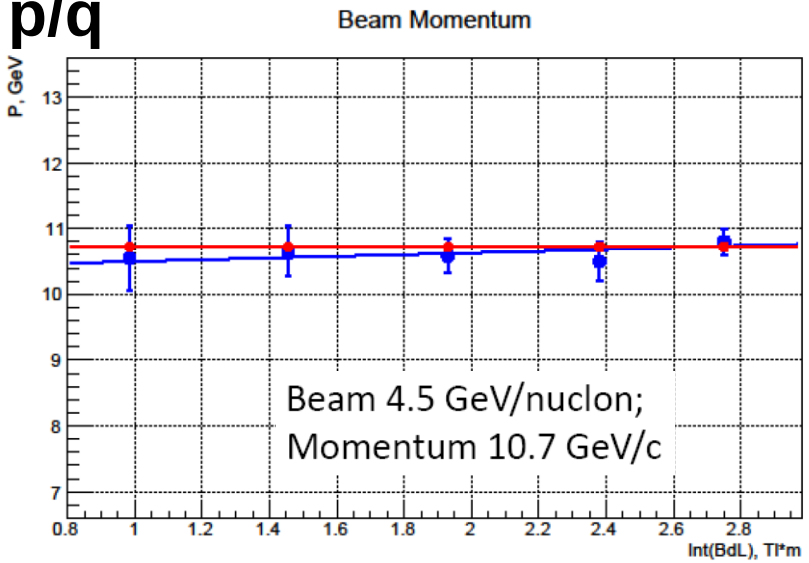
Time resolution:

σ(T0+ToF) ~ 90ps

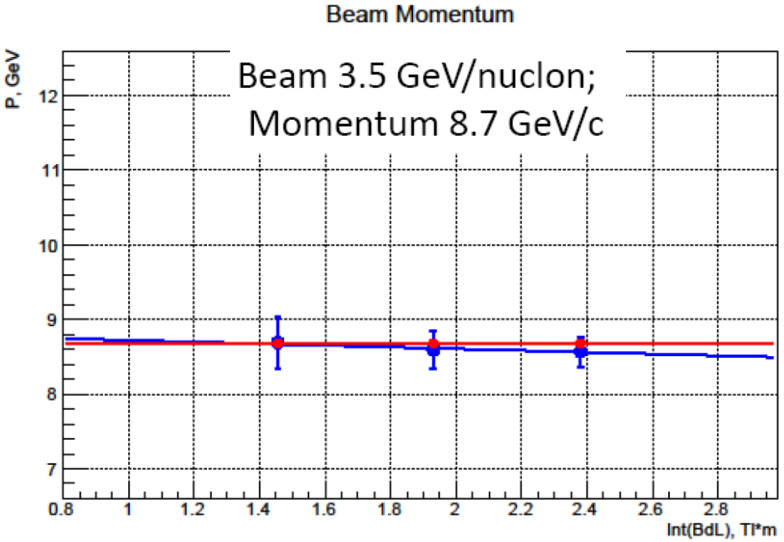
Beam Momentum measured with DCH outer tracker

Momentum vs. Int(BdL)

p/q



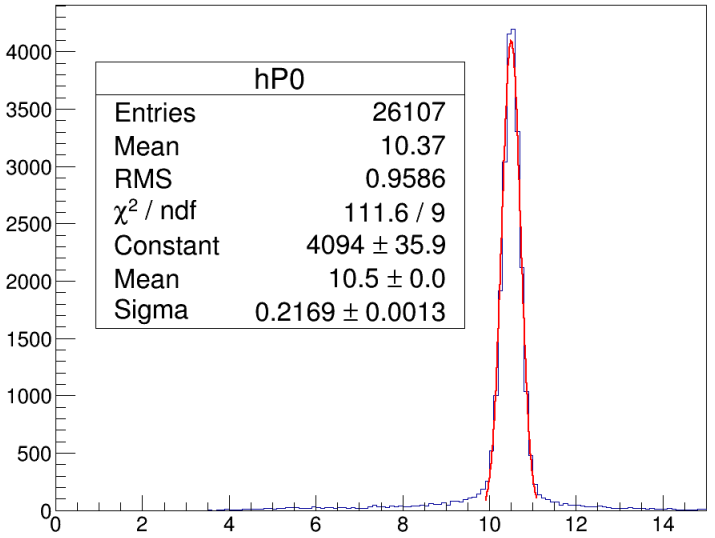
Errors → momentum resolution

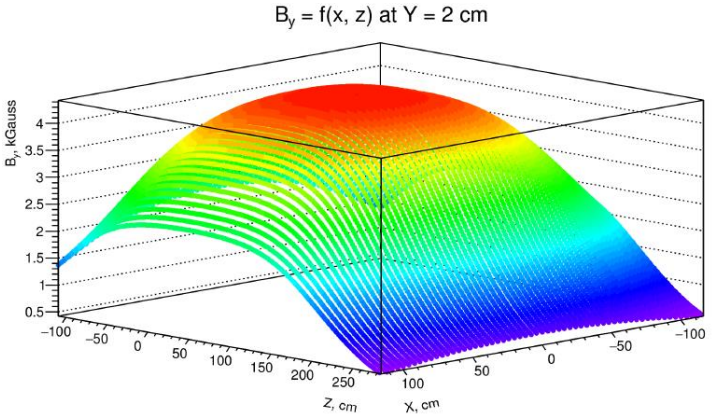


LIT: V.Pal'chik, N.Voitishin

V.Lenivenko

momentum = .3*Int(BL)/[sin(alphaX_out)+C]

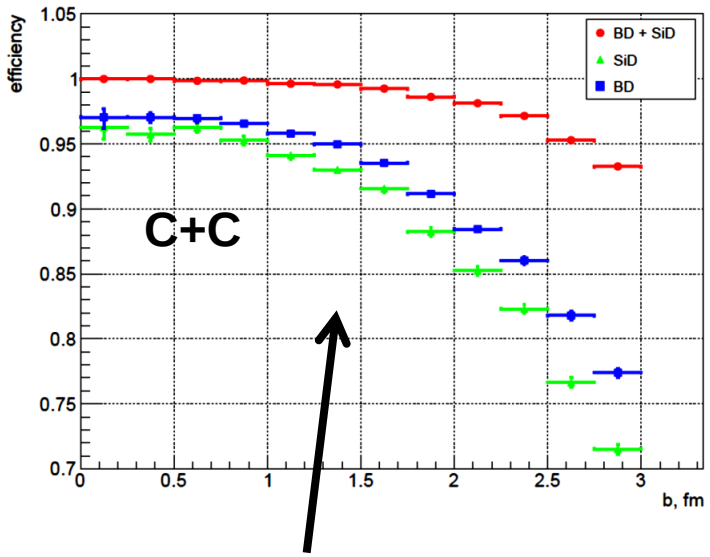


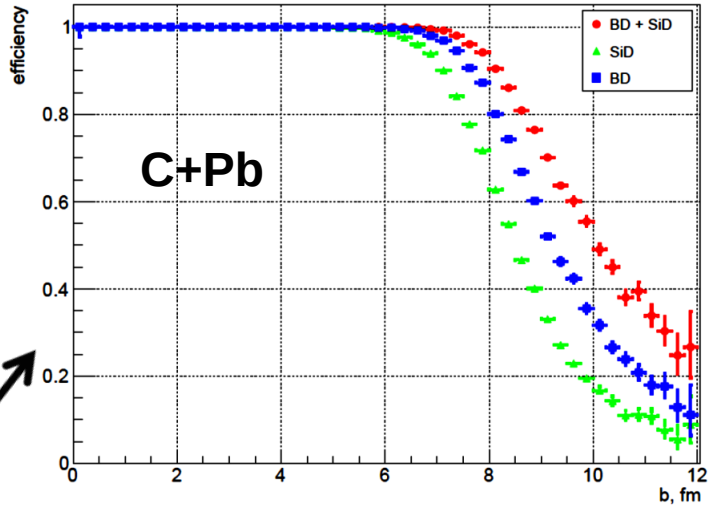


Magnetic field

Simulation of Trigger Barrel and Si detectors

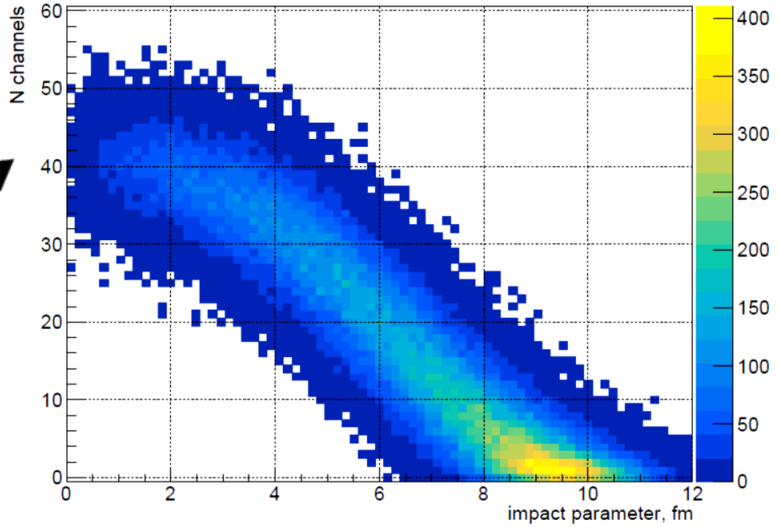
S.Lobastov





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

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

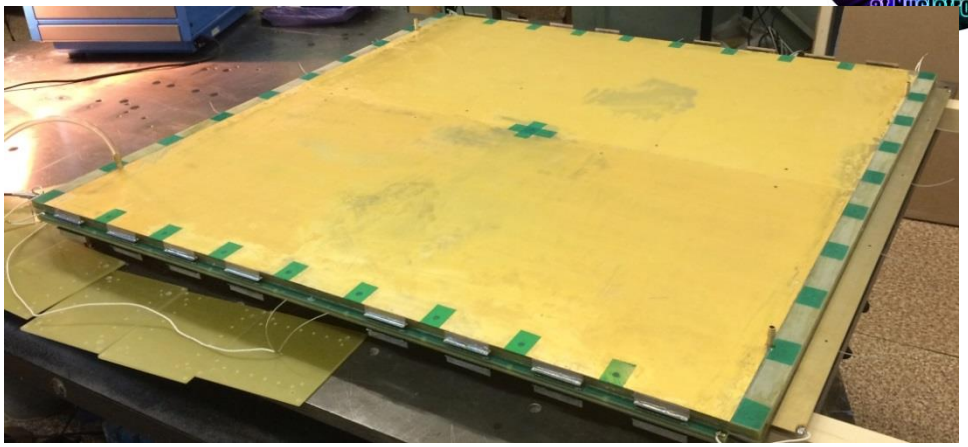


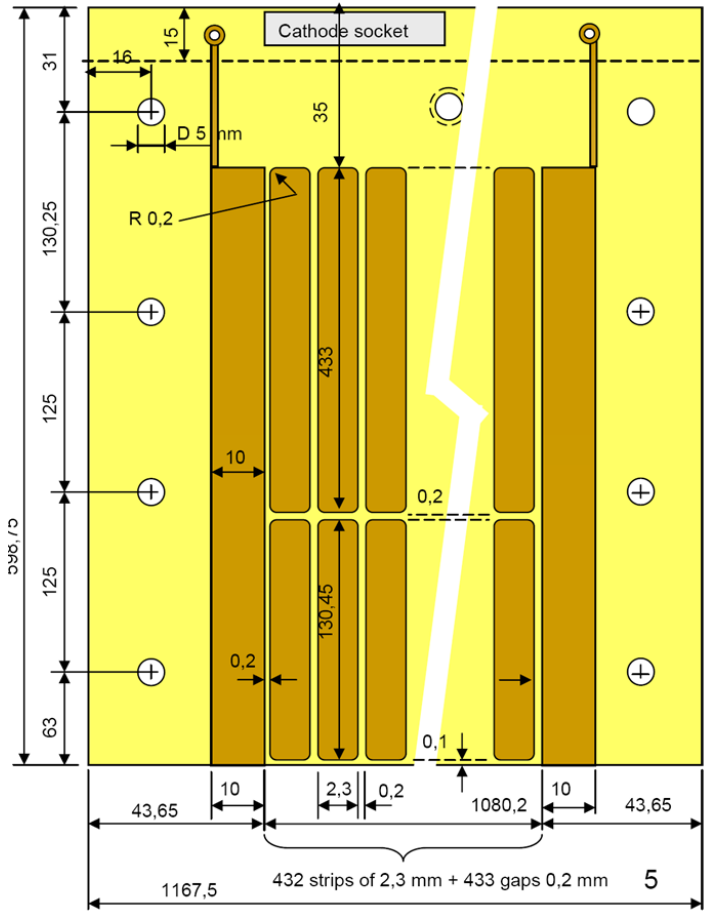
Number of fired channels BD + SiD as a function of impact parameter in C + Pb

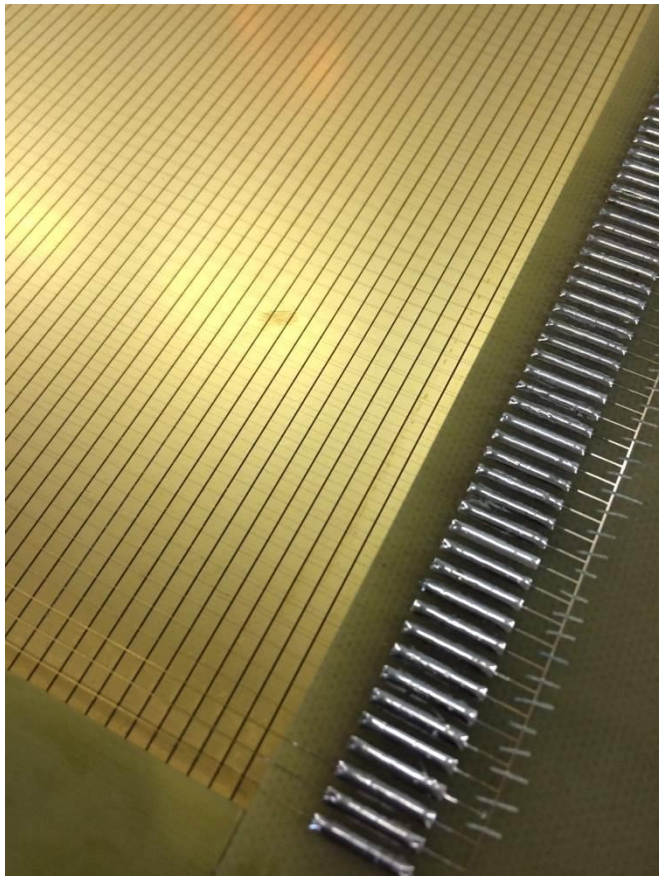
Outer Tracker: new CSC chamber

Al. Vishnevsky

Plan to install in February 2018 one CSC chamber in front of ToF-400 to check its performance as Outer tracker for heavy ion beams

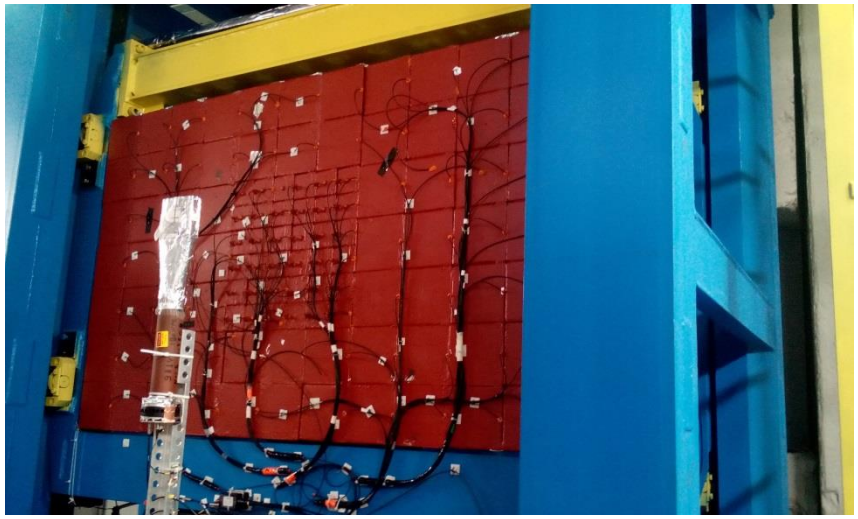




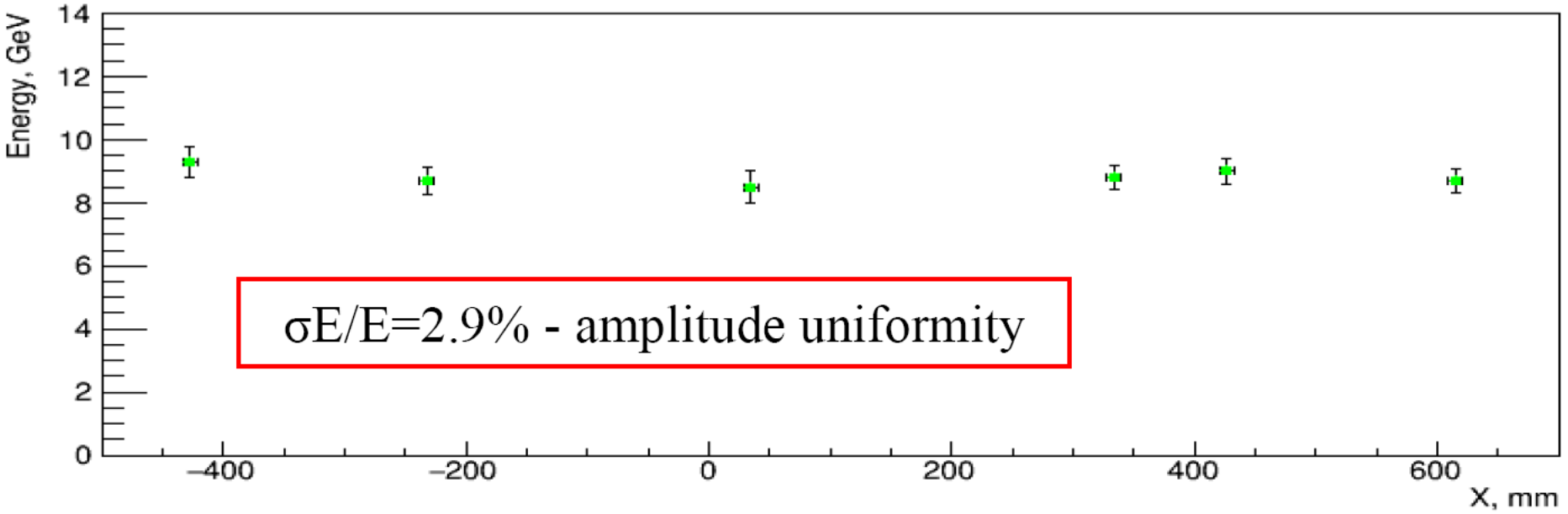


Calibration of ZDC calorimeter

O.Gavrischuk, SNEO

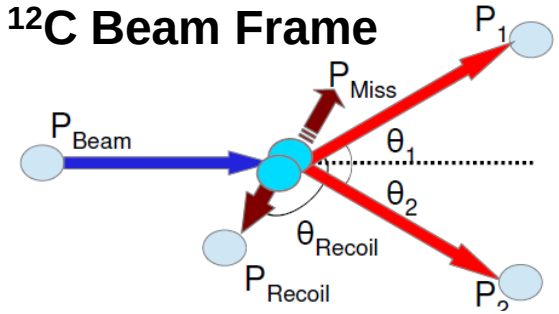


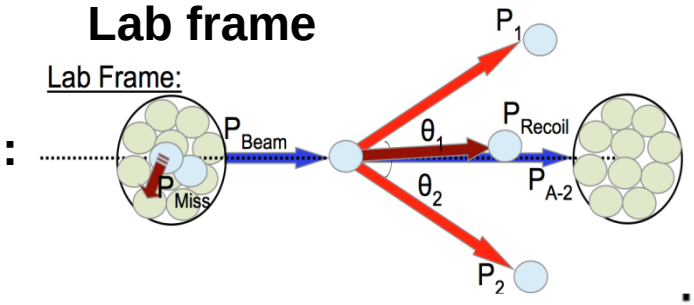
- Collect deuteron and carbon beam data with ZDC at different positions
- Calibration of cell amplitudes to get beam energy in cluster
- Spread of energies reconstructed at different ZDC positions ~3%



A proposal for BM@N experiment

to study SRC with hard inverse kinematic reactions

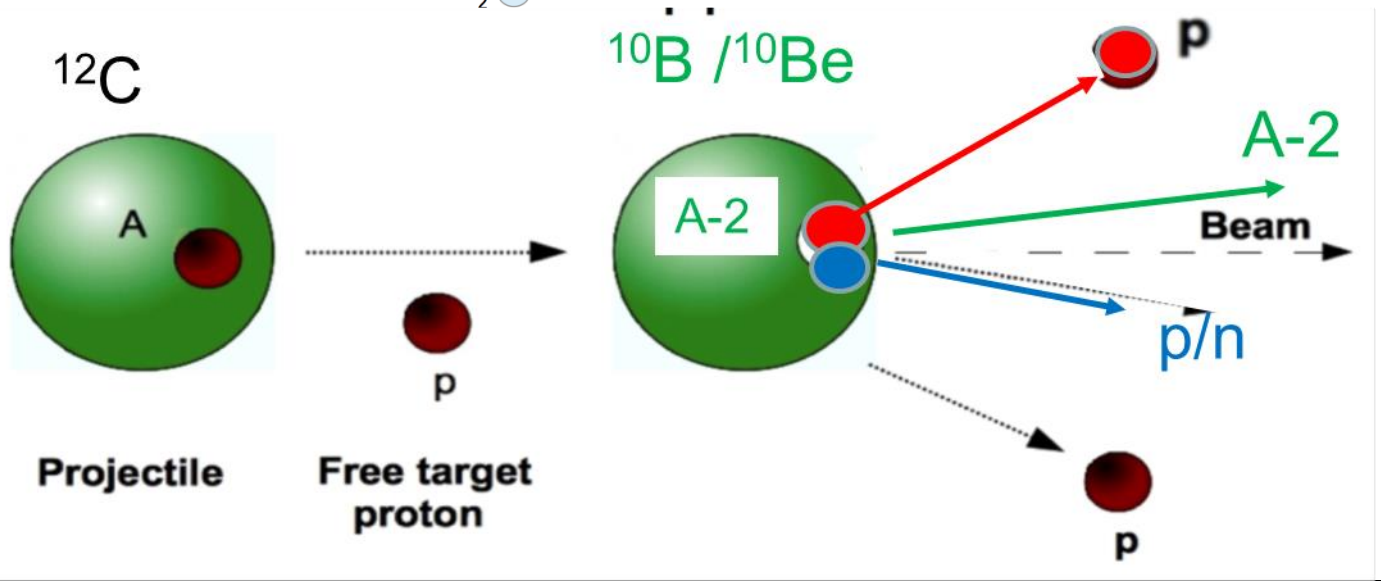




JINR (Dubna): BM@N
Israel: Tel Aviv University
Germany: TUD and GSI
USA: MIT
FRANCE: CEA

Objectives:

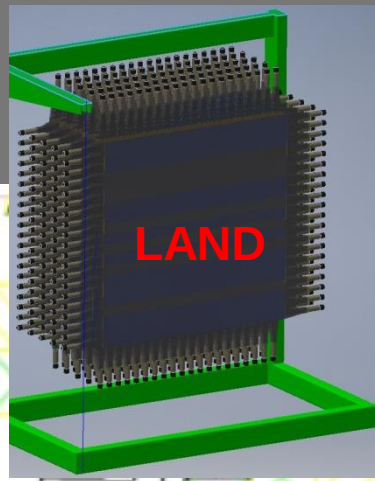
- identify 2N-SRC events with inverse kinematics
- study isospin decomposition of 2N-SRC
- study A-2 spectator nuclear system

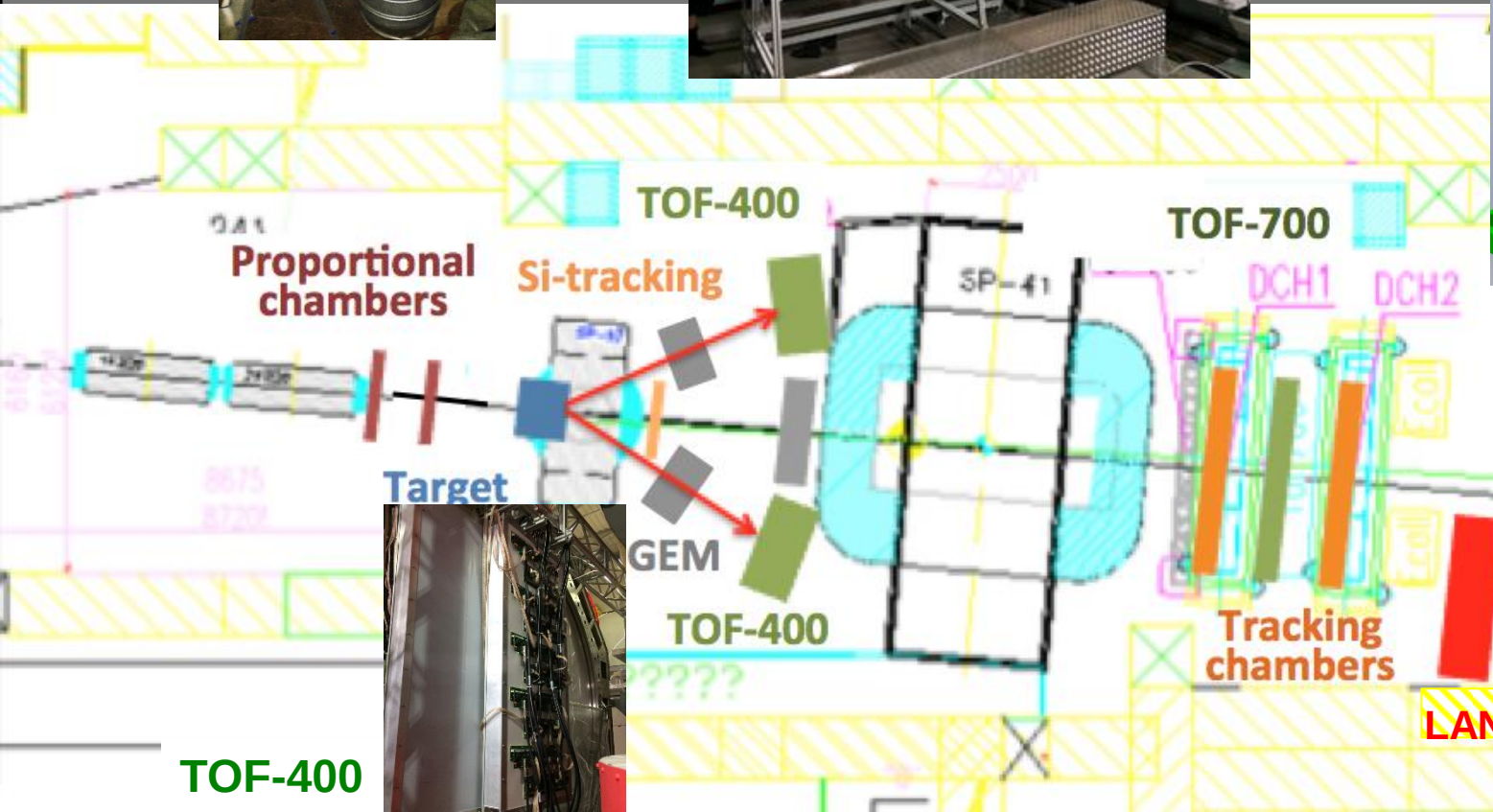


Experimental set up

Target

ZDC





TOF-400