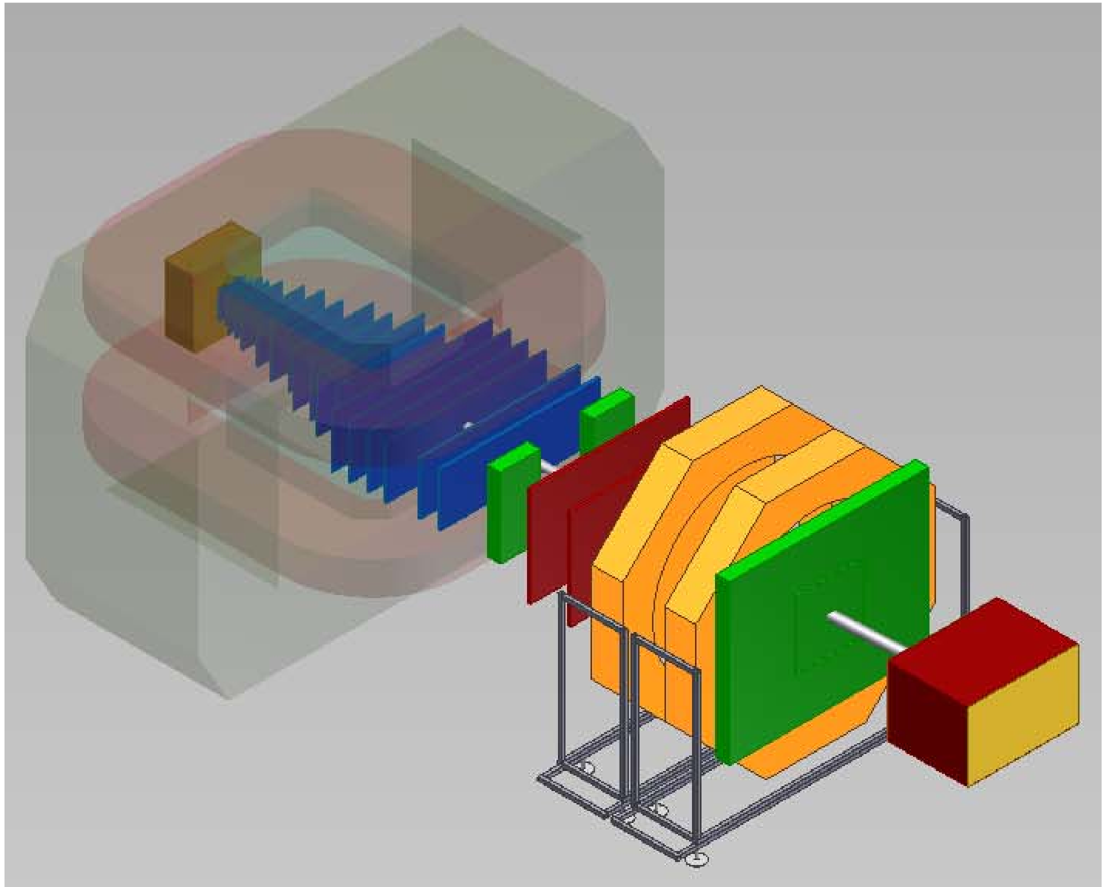
Status of Baryonic Matter at Nuclotron

Results of deuteron and carbon runs

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

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

M.Kapishin



Nuclotron and BM@N beam line

26 elements of magnetic optics:

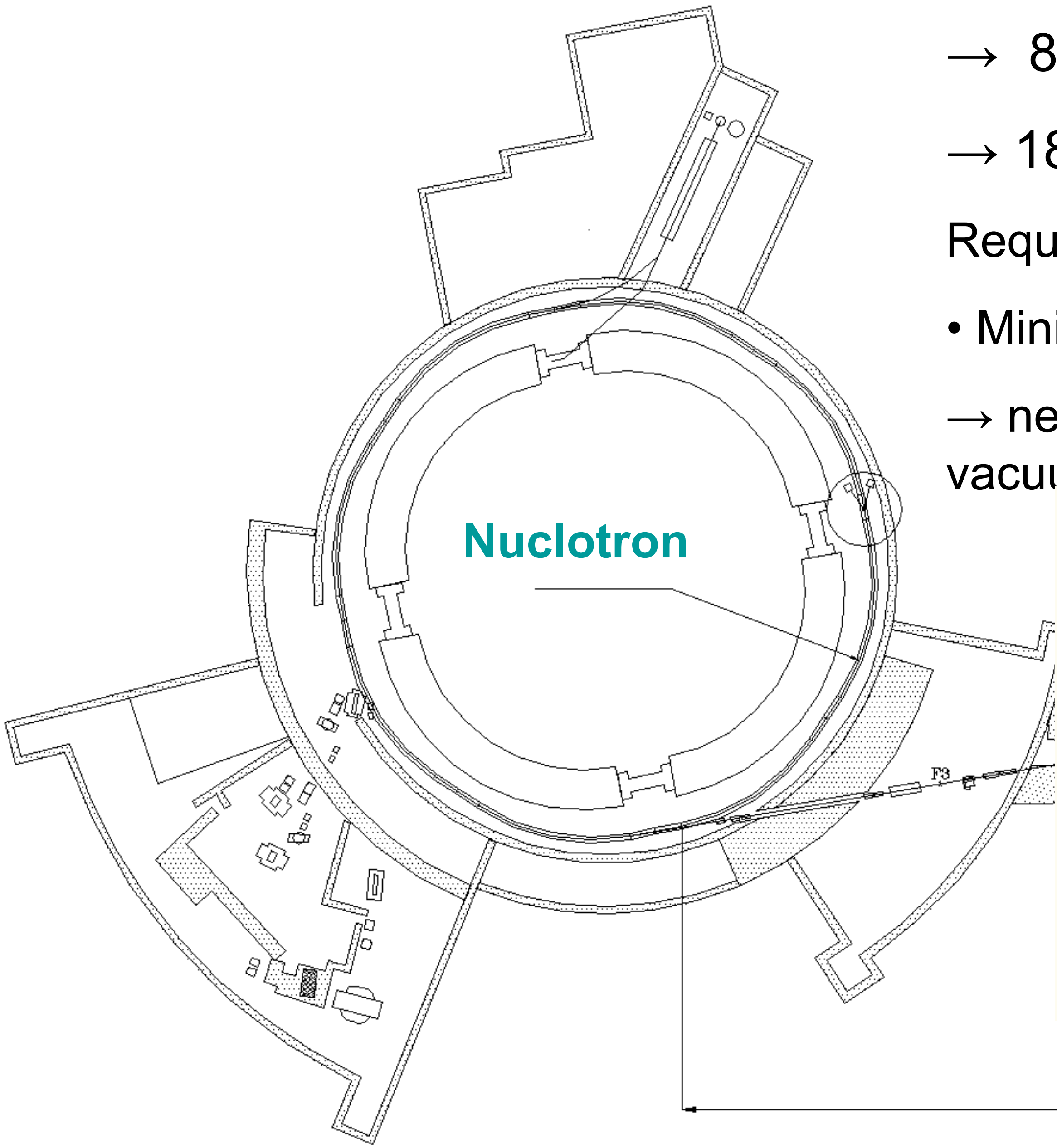
→ 8 dipole magnets

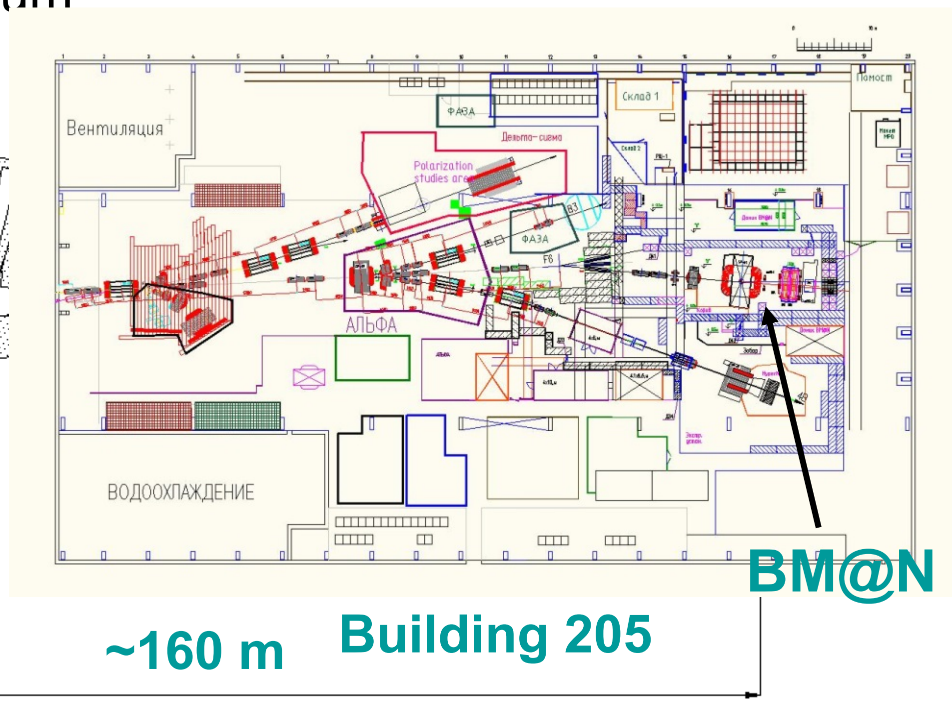
→ 18 quadruple lenses

Requirements for Au beam:

• Minimum dead material

→ need to replace air intervals / foils with vacuum

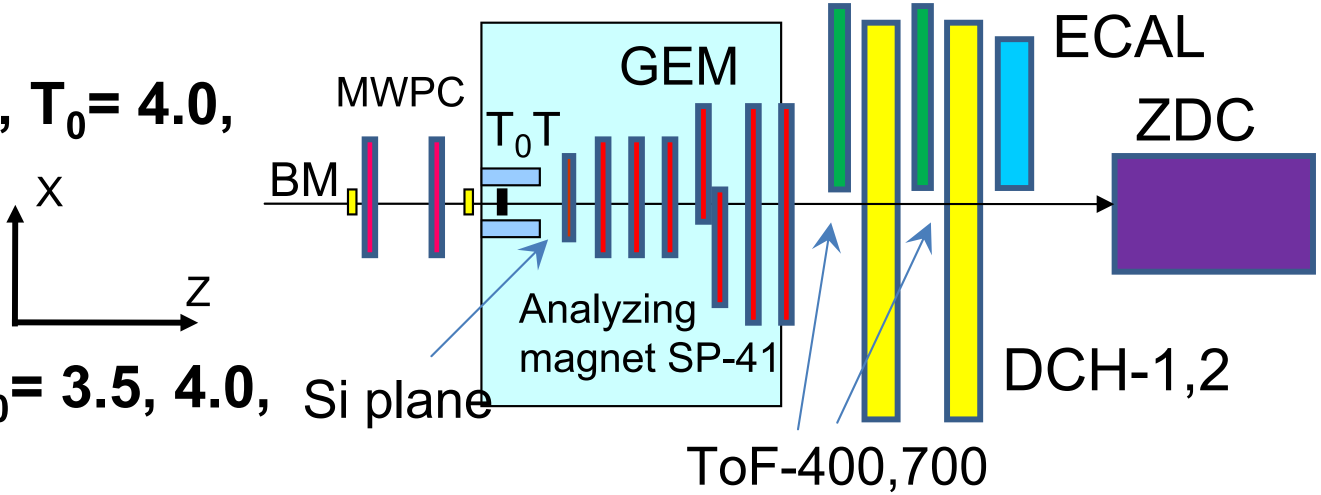




BM@N in technical runs with deuteron and carbon beams

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 41cm^2 + 2 GEM detectors 163 x 45 cm^2 and 1 plane of Si detector for tracking

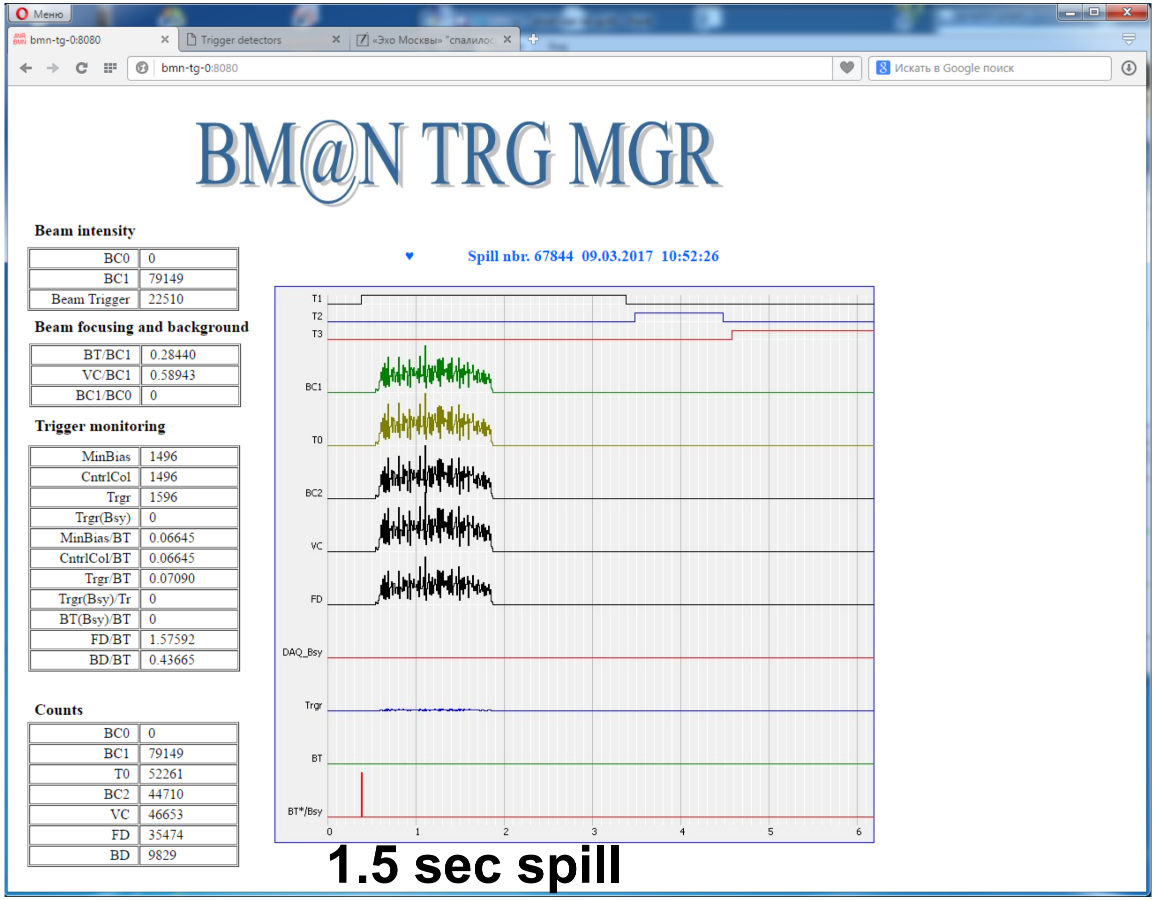
• Test / calibrate ToF, T0+Trigger barrel detector, full ZDC, part of ECAL

Program:

• Trace beam through detectors, align detectors, measure beam momentum in mag. field of 0.3 – 0.85 T

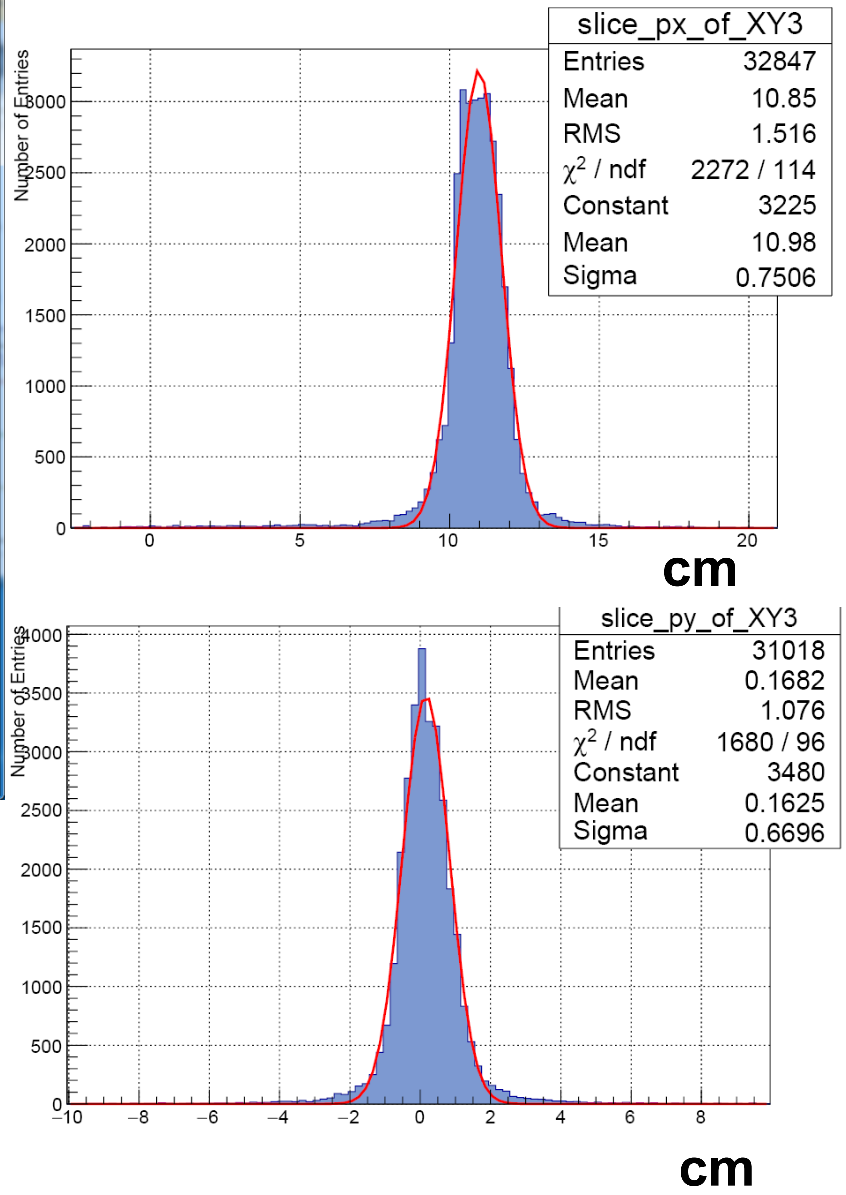
• Measure inelastic reactions d (C) + target → X with deuteron and carbon beam energies of 3.5 - 4.6 GeV/n on targets CH_2, C, Al, Cu, Pb

Deuteron / carbon beams at BM@N



1.5 sec spill

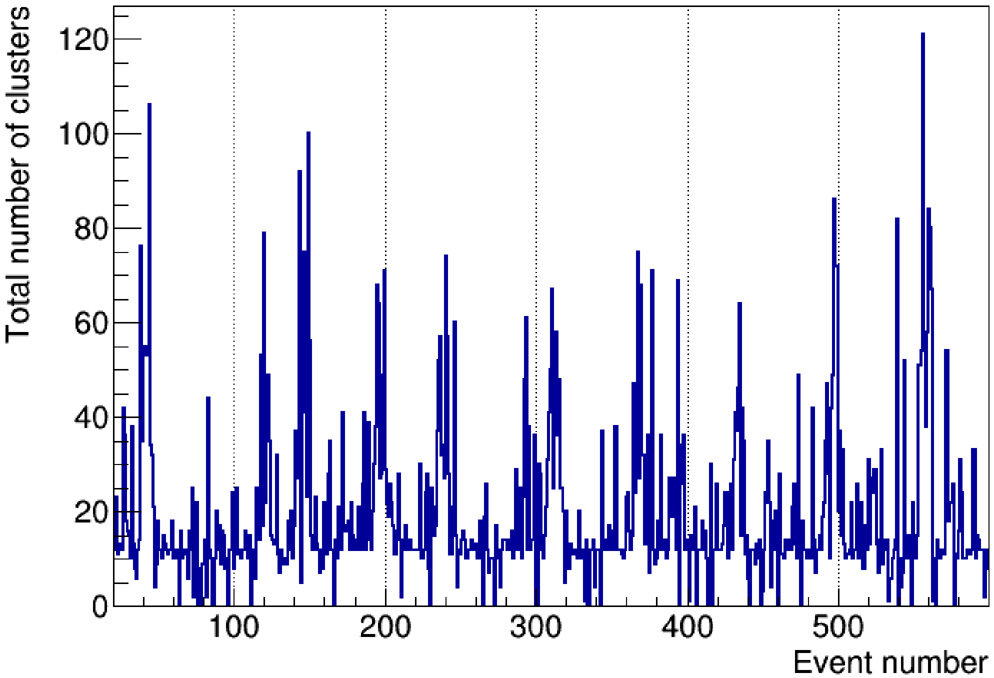
X, Y profiles of deuteron beam in 1st GEM

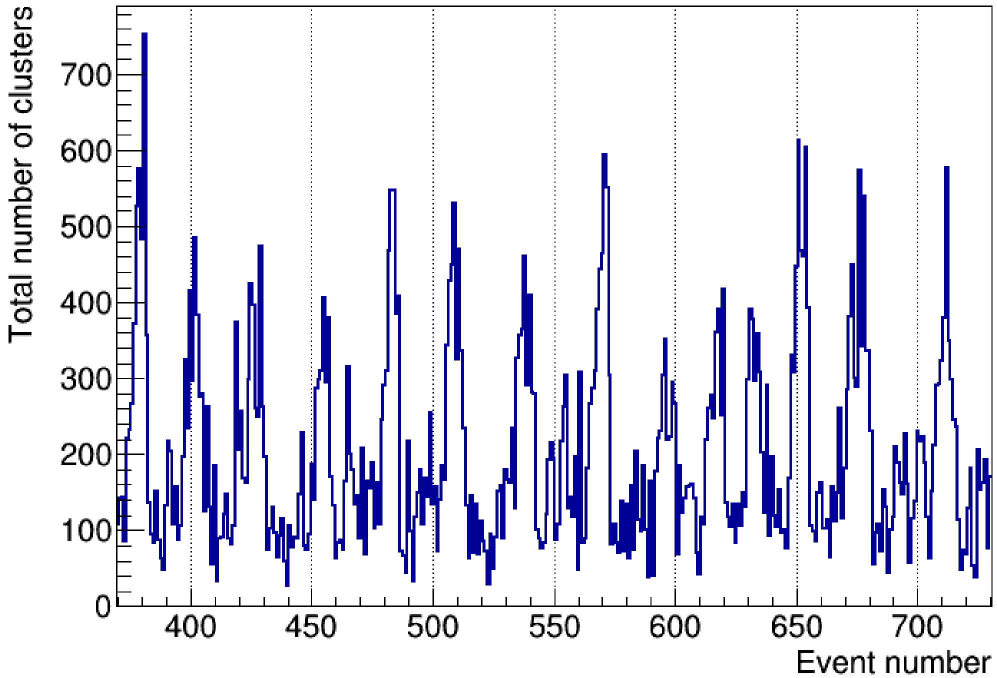


- **10^5 - $3{\cdot}10^5$ per spill, but non-uniform spiky structure**
  - ➢ **Pileup in GEM detectors**
  - ➢ **Limits DAQ rate to 4-5 kHz**

Deuteron & carbon beam structure

Total number of GEM hit clusters as function of event number

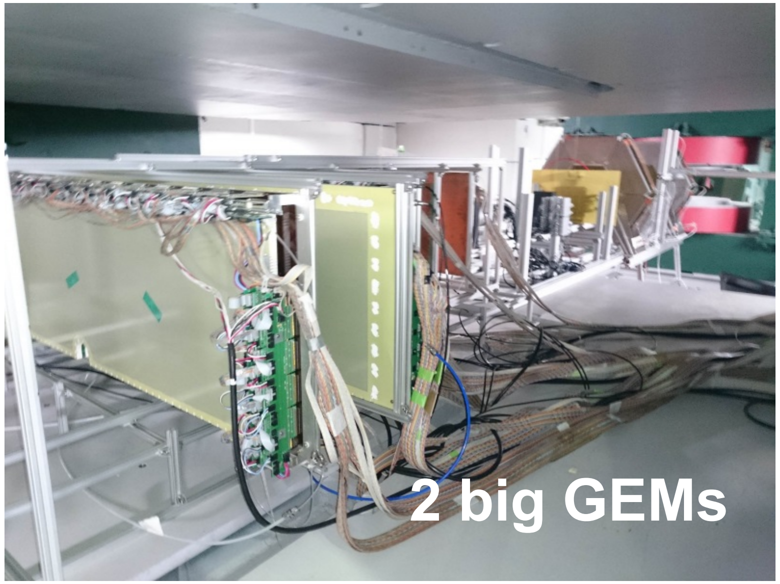


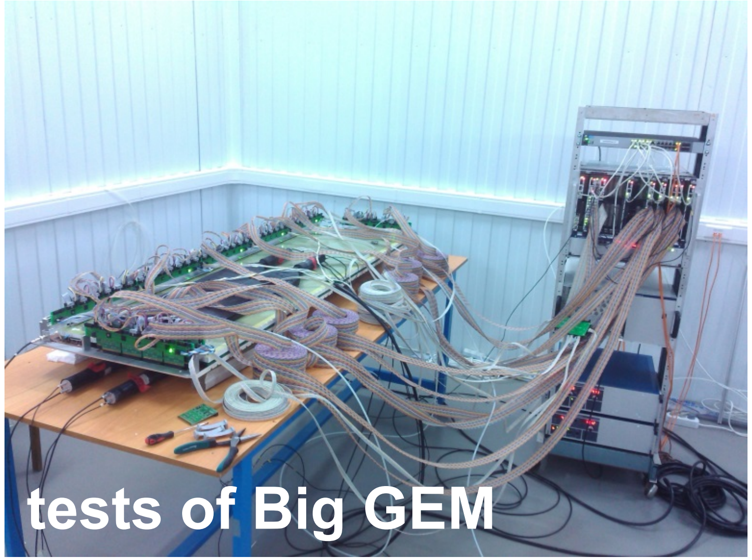


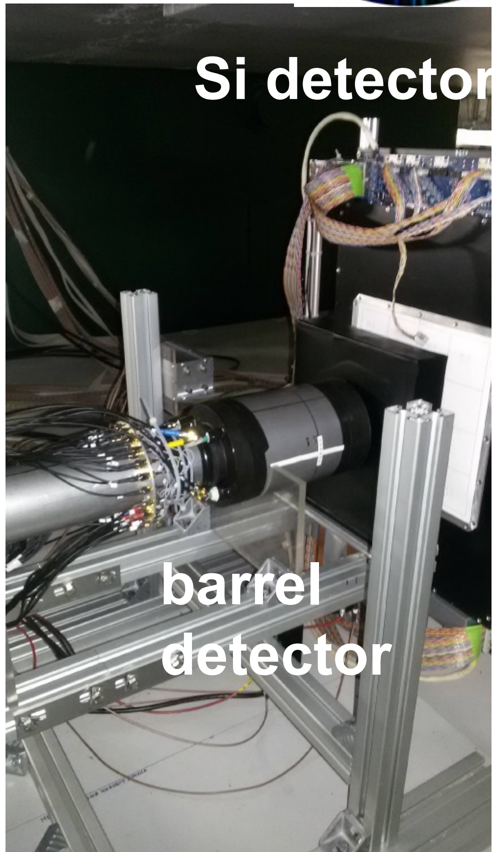
Deuteron run (December 2016)
Deuteron beam trigger, 4 AGeV

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

BM@N experiment in carbon run, March 2017

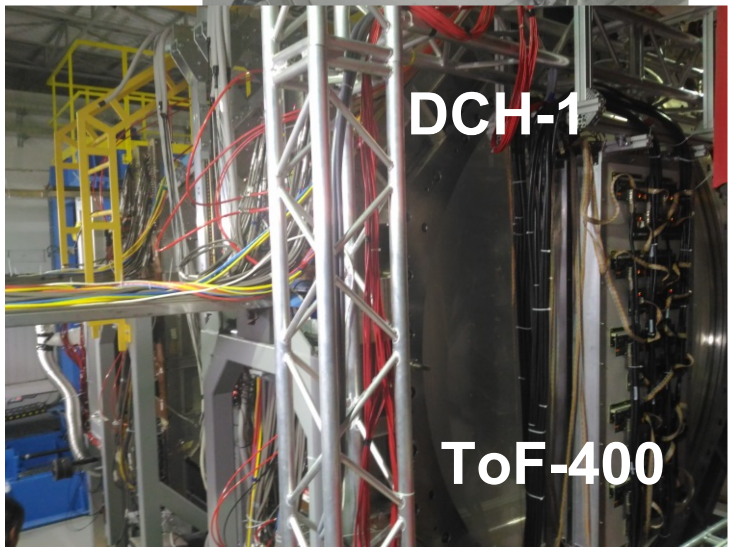






New detector components:

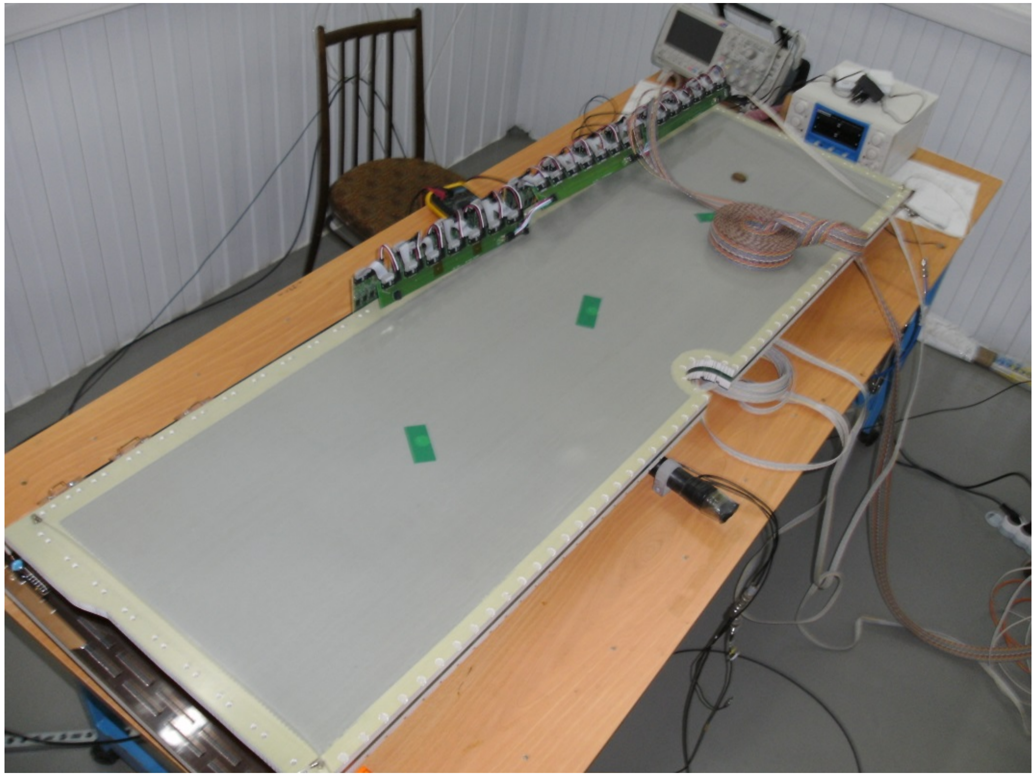
2 big GEMs, trigger barrel detector, Si detector, ECAL

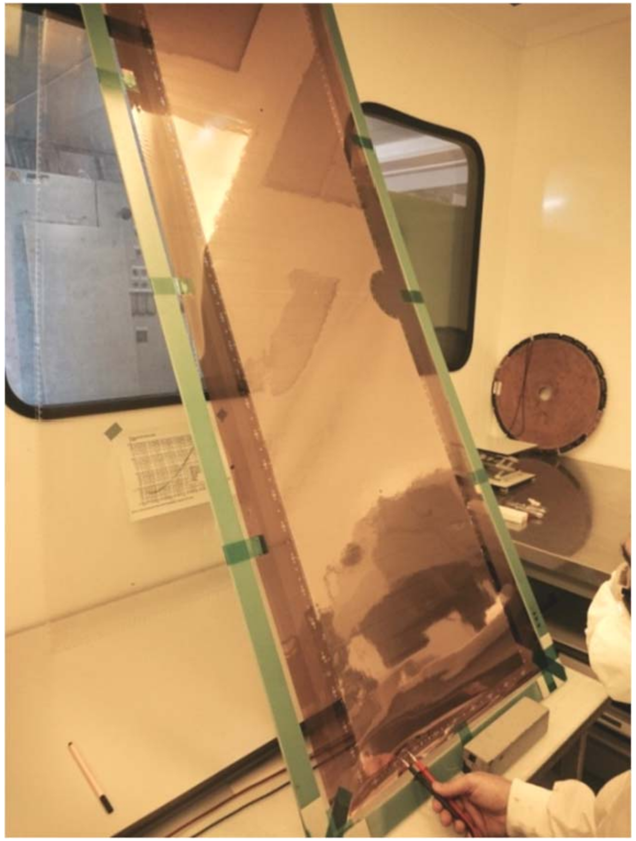


GEM detectors for central BM@N tracker

Tests of GEM detector 163 x 45 cm^2

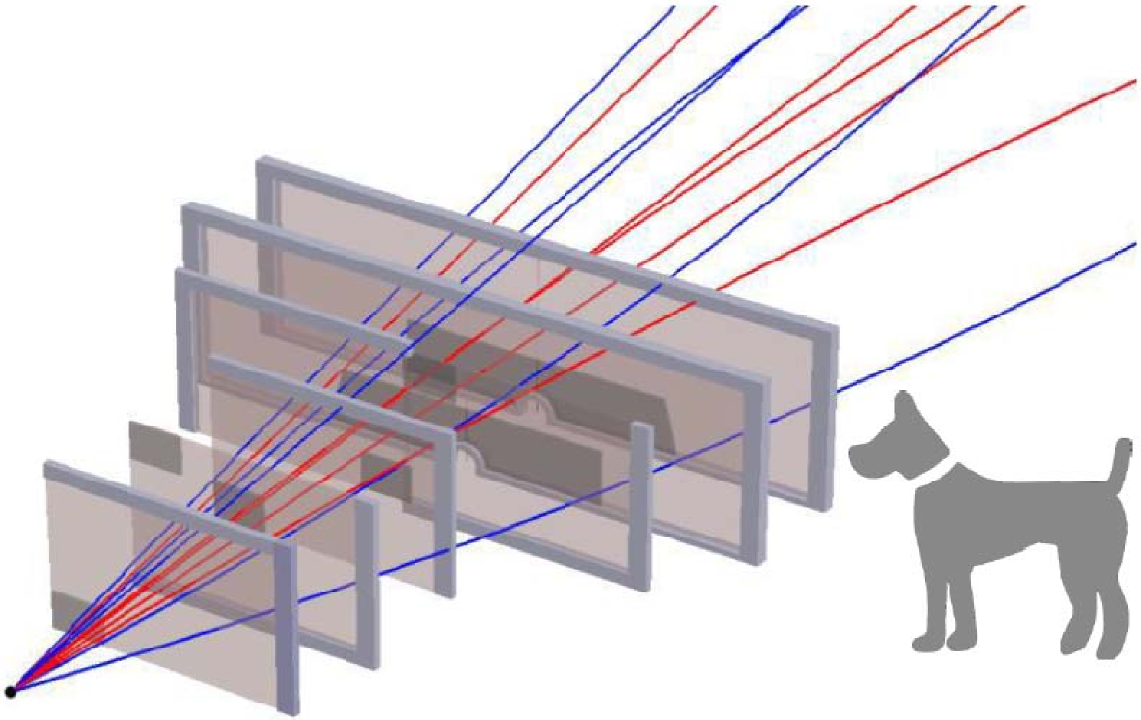
CERN workshop + GEM group



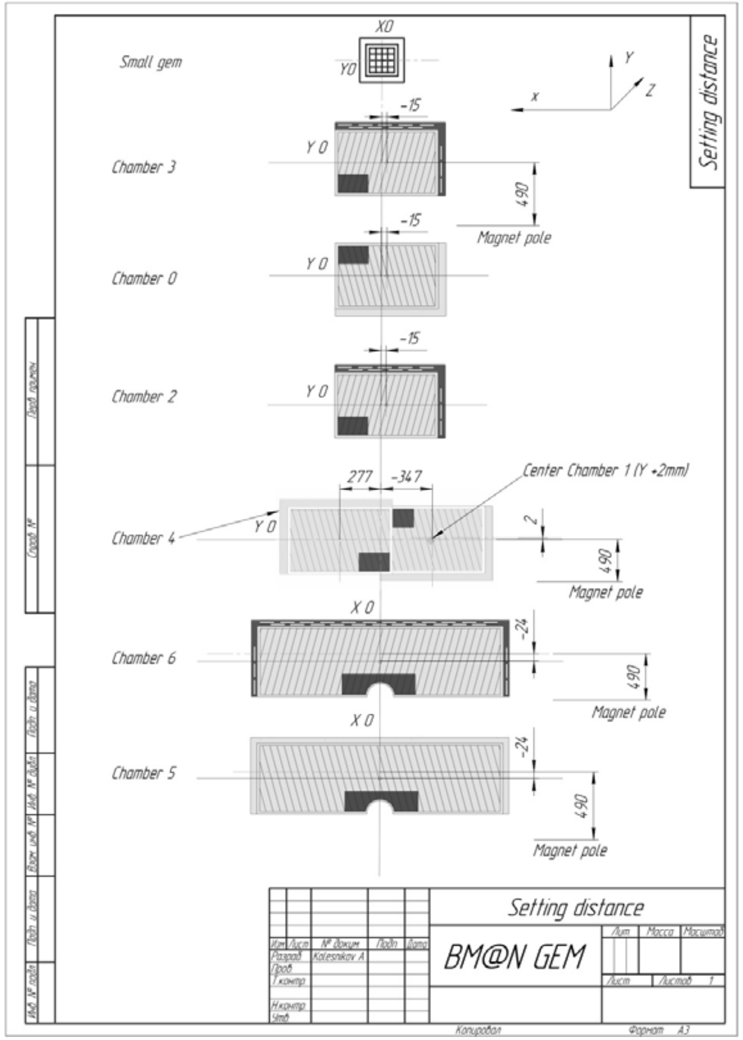


- for tracking in technical runs with deuteron and carbon beams in December 2016 and March 2017 used **5 detectors 66 x 41 cm^2 and 2 detectors 163 x 45 cm^2**
- for BM@N run in autumn 2017 produced only **1 additional detector 163 x 45 cm2** at CERN workshop

BM@N central tracker in deuteron and carbon runs

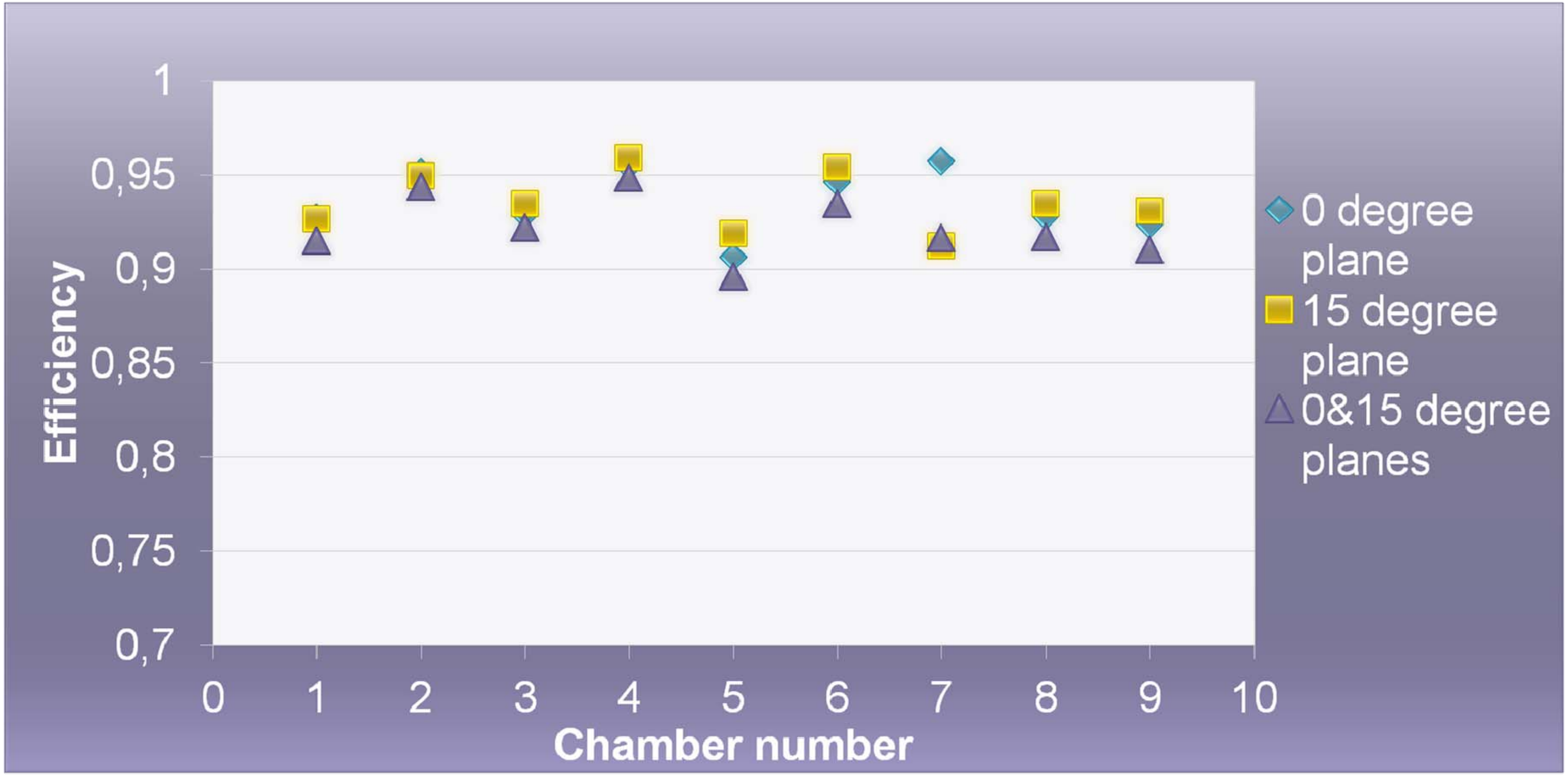


Example of an event reconstruction in the central tracker



GEM detector efficiency in deuteron run

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



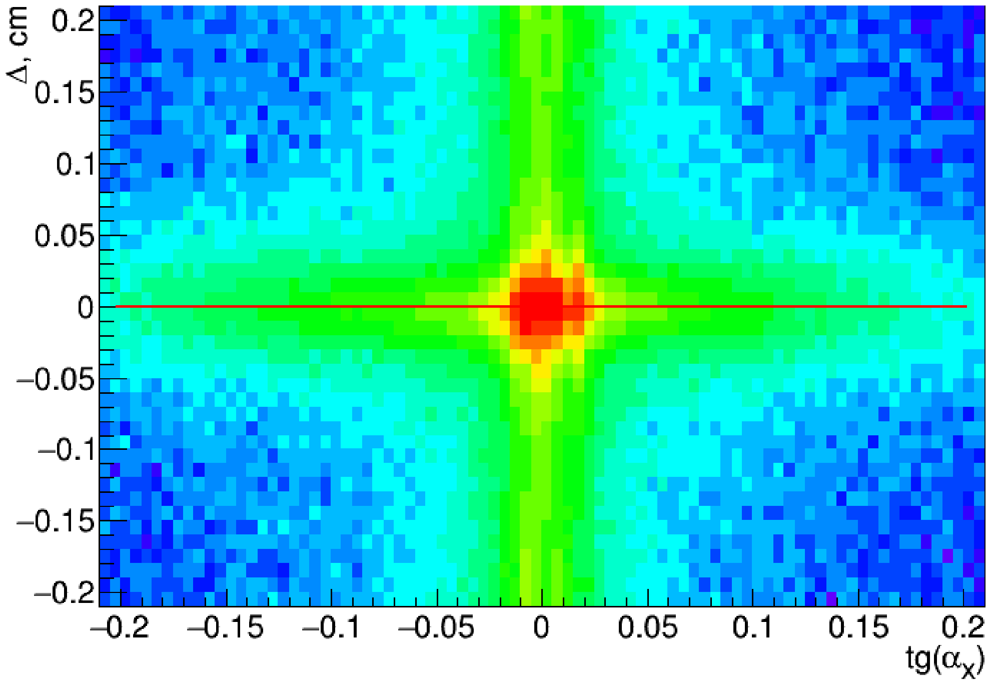
X plane

X' plane

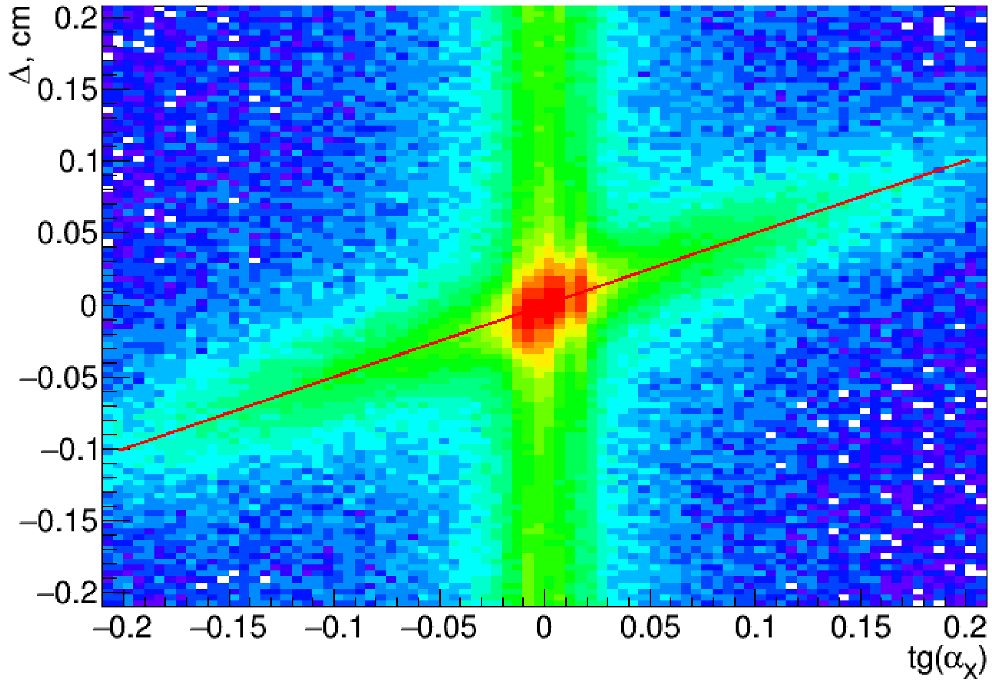
X & X' planes

Alignment of GEM Z position

Proper Z position.



5 mm Z displacement.



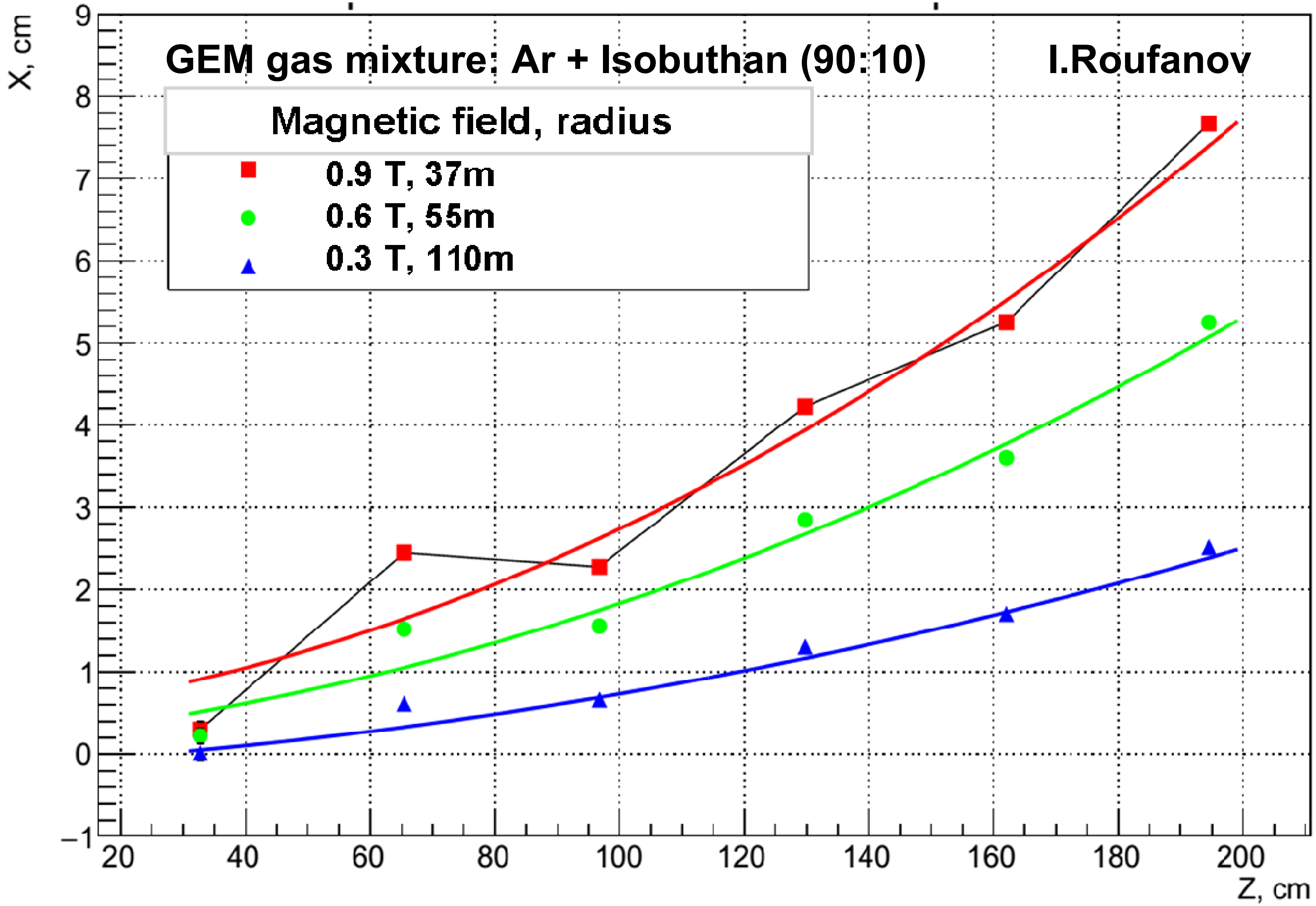
Residual distribution is horizontal along X for adjusted Z position along beam.

Residual distribution is inclined along X for shifted Z position.

- ✓ **$\Delta = \Delta_z * tg(\alpha_x)$, α_x - track angle in XoZ**
- ✓ **Precision of Z position alignment ~1 mm**
- ✓ **0.1 degree of azimuth rotation is clearly detectable**

Beam in GEM detectors in deuteron run

Averaged positions of deuteron beam with T_0= 4 GeV/nucleon reconstructed in 6 GEM planes at different values of magnetic field



Simulation of GEM response: Garfield++

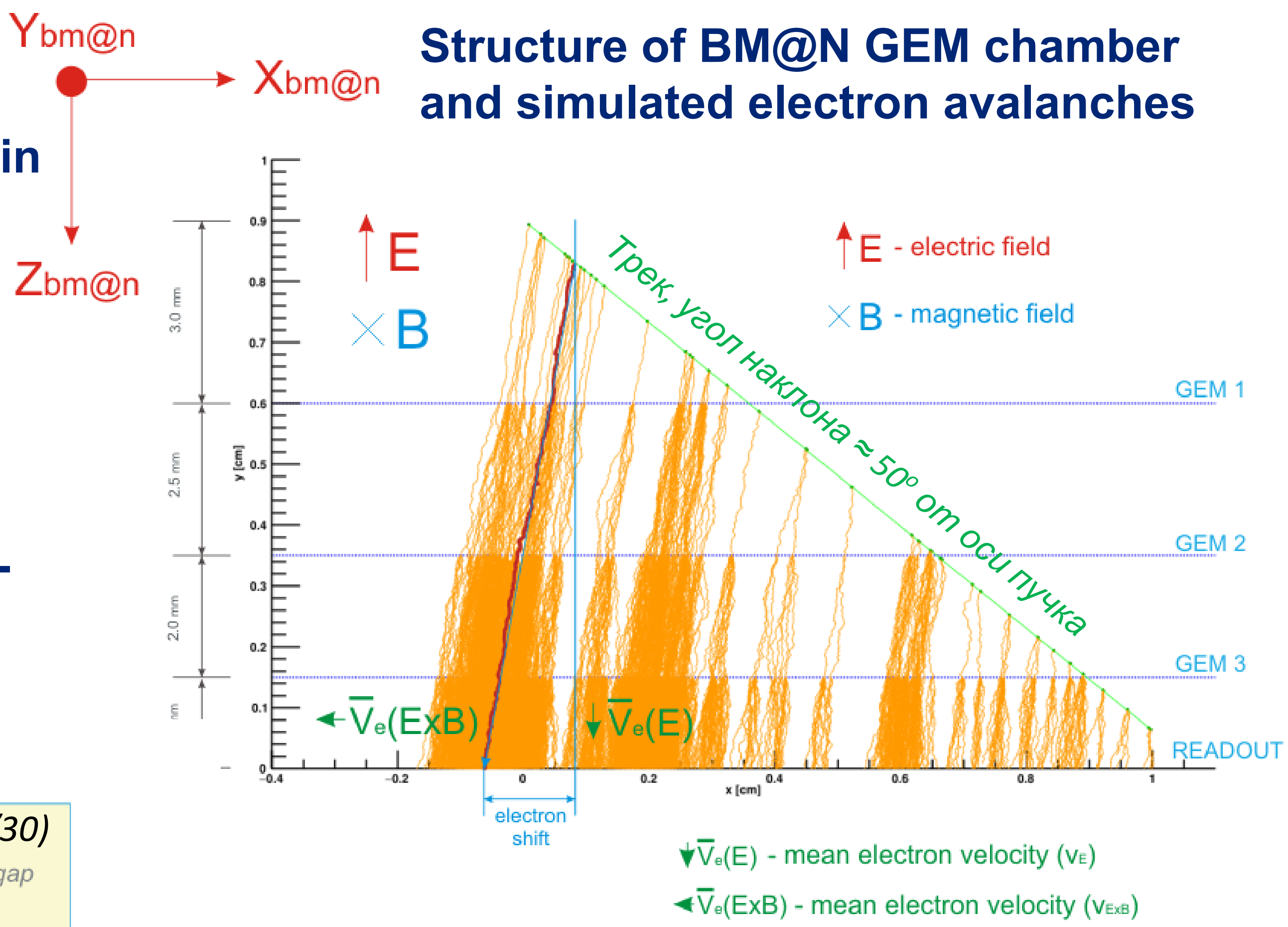
D.Baranov

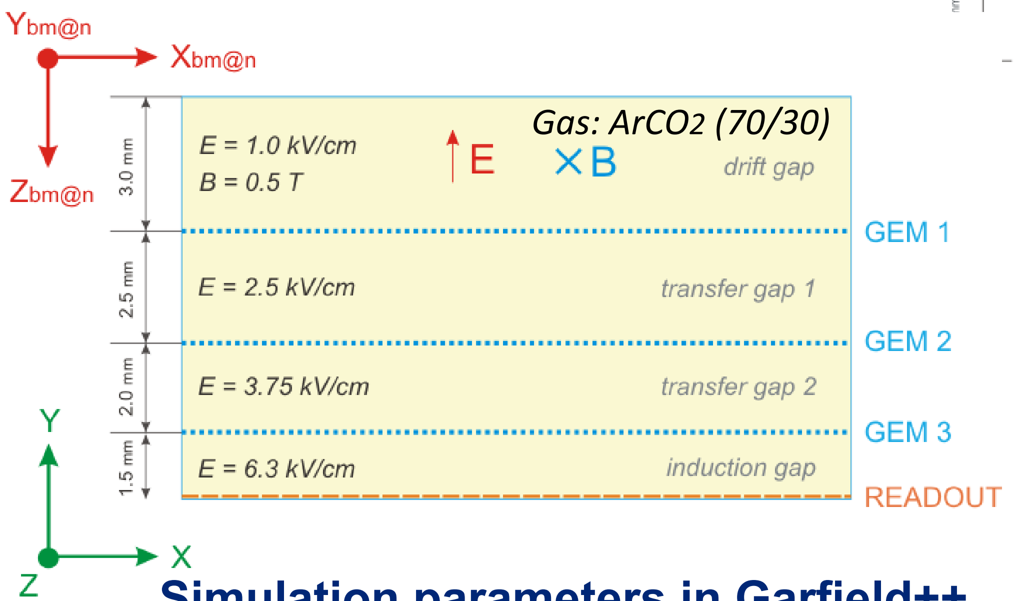
Garfield++ - framework for micro-simulation of physical processes in gas detectors

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

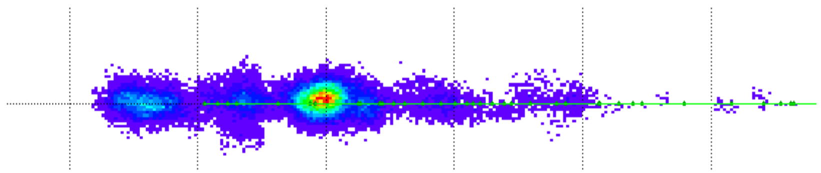
Multiplayer GEM-cascades form avalanches which drift to readout-plane and fire strips

Structure of BM@N GEM chamber and simulated electron avalanches



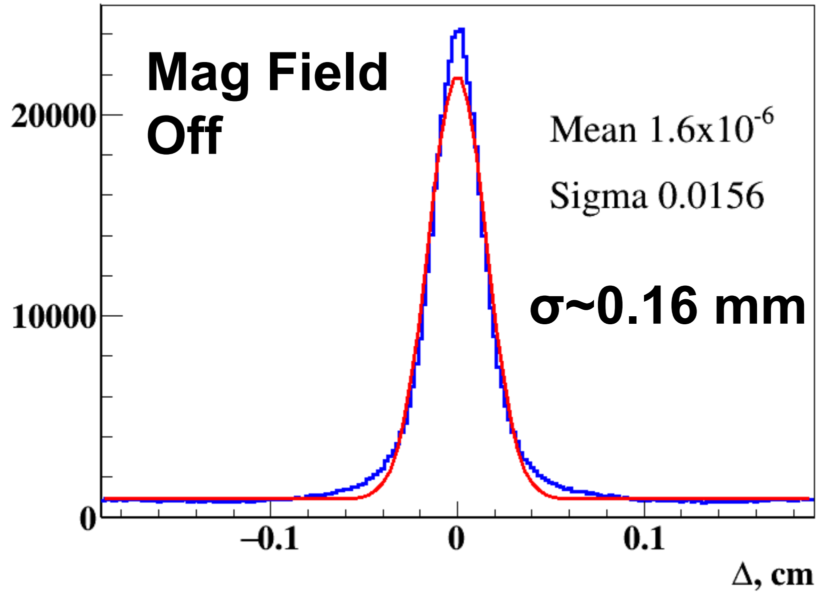


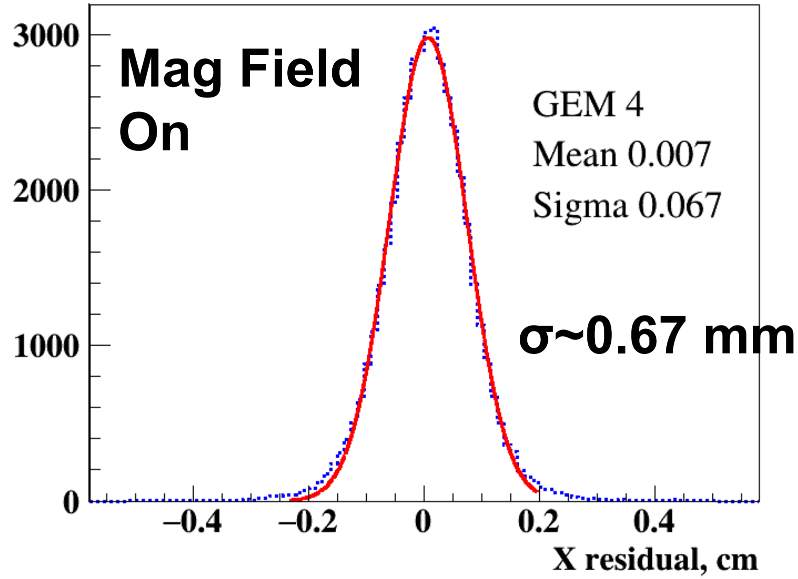
Simulation parameters in Garfield++



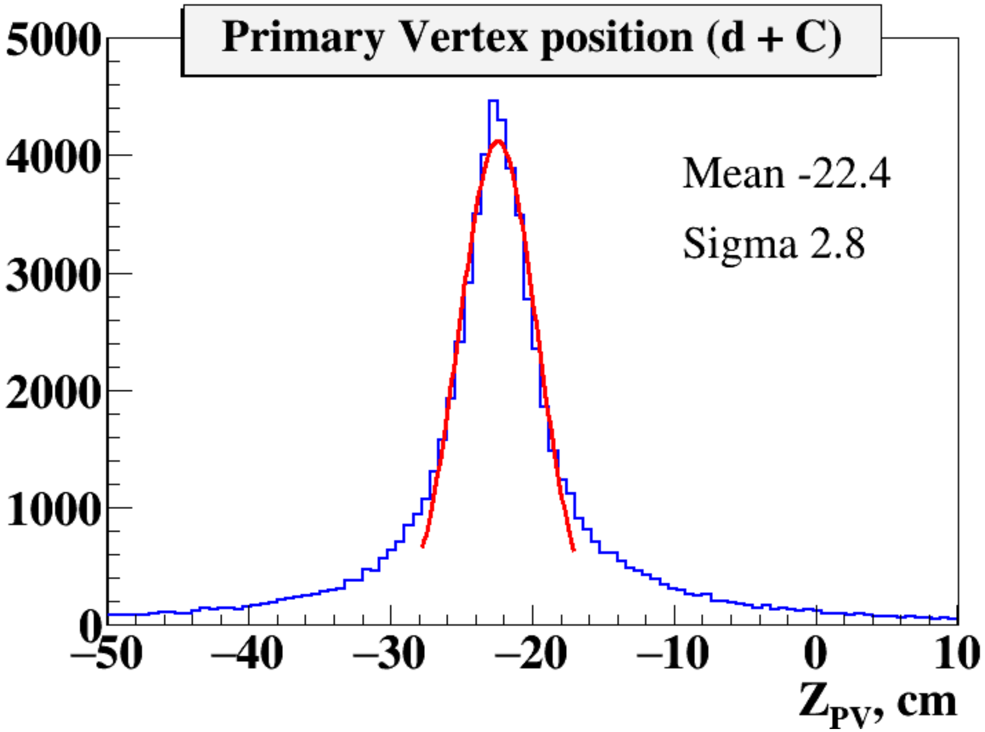
Profile of electron avalanche at the readout-plane (cluster).

Coordinate and vertex resolution of GEM detectors in deuteron run





Gas mixture: Ar + Isobuthan



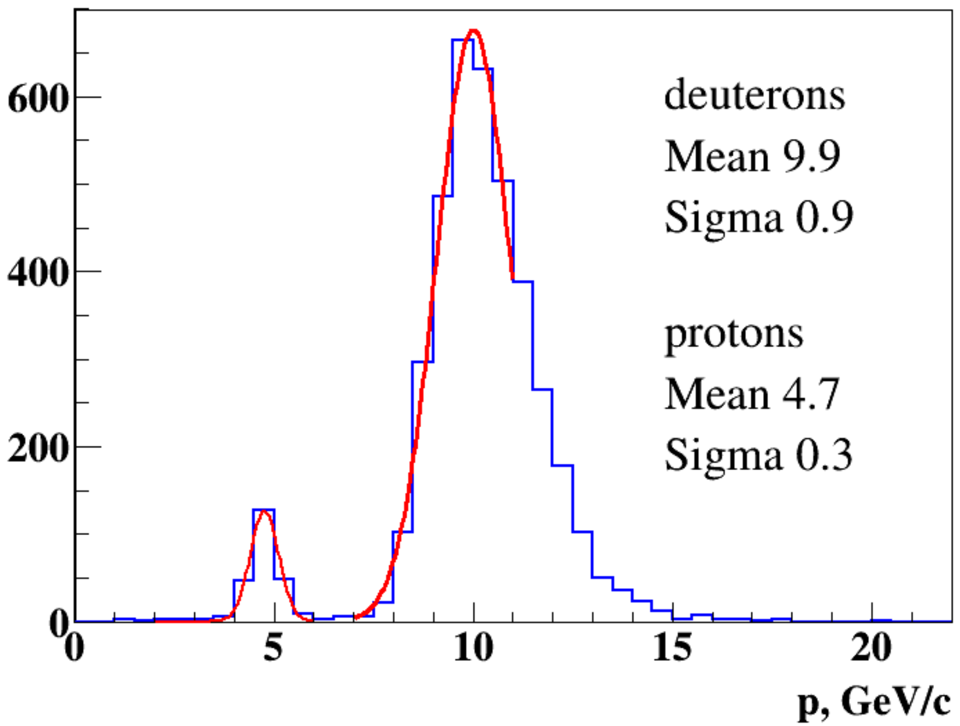
- GEM hit residuals vs reconstructed tracks after Lorentz shift corrections σ~0.67 mm
- Residuals in data are reproduced by MC simulation with Garfield
- Width of reconstructed vertex distribution along beam direction in data is reproduced in MC simulation

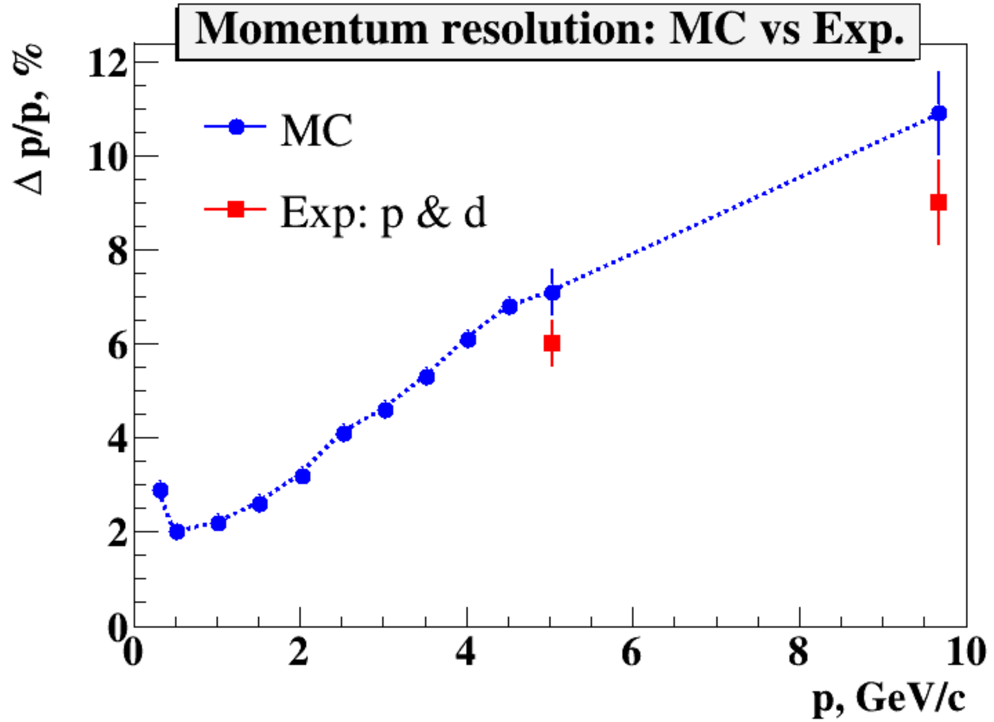
Momentum resolution: Exp. vs MC

Deuteron beam

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

GEM gas mixture: Ar + Isobuthan (90:10)



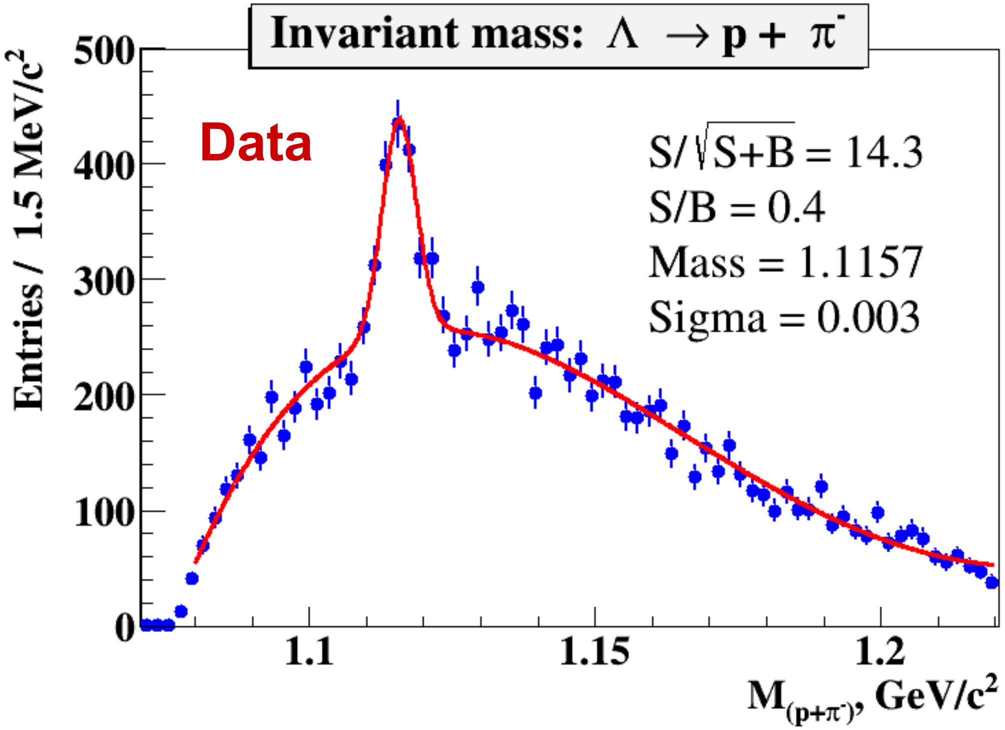


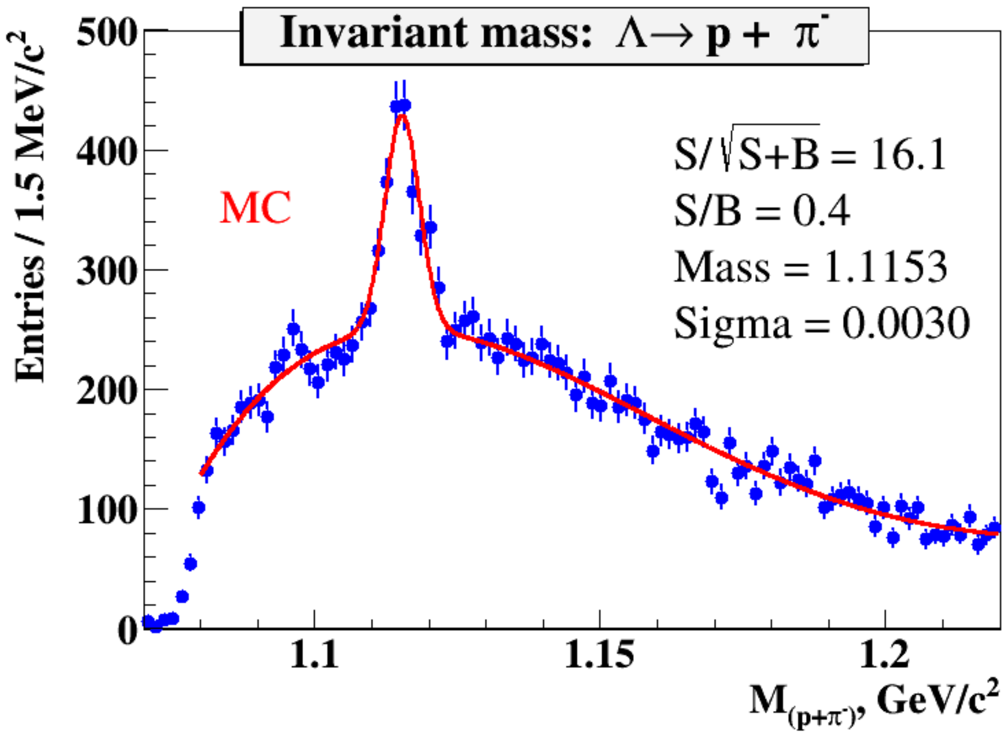
- ✓ Momentum resolution for deuteron beam of 9.7 GeV/c ~9%.
- ✓ Momentum resolution for proton spectators with momentum of 4.85 GeV ~6%.
- ✓ Momentum resolution from MC as function of particle momentum
- ✓ MC results reproduce exp. data for spectator protons and deuteron beam.

Λ reconstruction in d + Target → X

Λ signal width of 3 MeV and background level is reproduced by MC simulation.

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



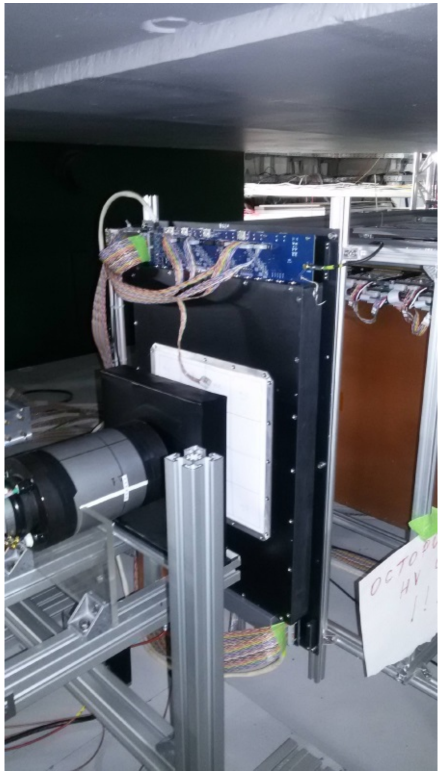


To improve vertex and momentum resolution and reduce background under Λ:

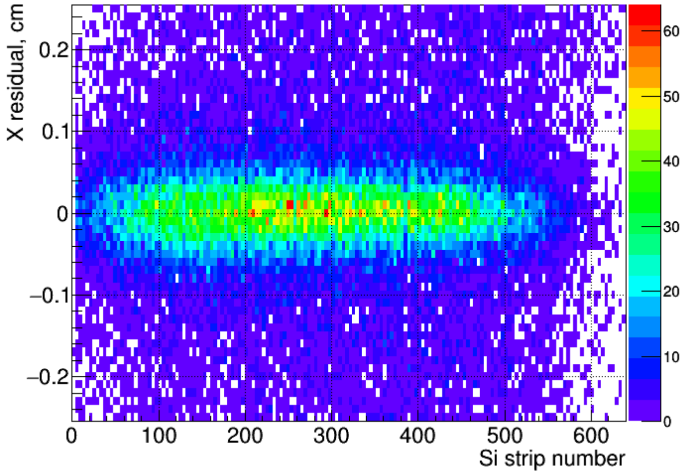
- **Need few planes of forward Silicon detectors → 1 plane already implemented**
- **Need more GEM planes to improve track momentum reconstruction**

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

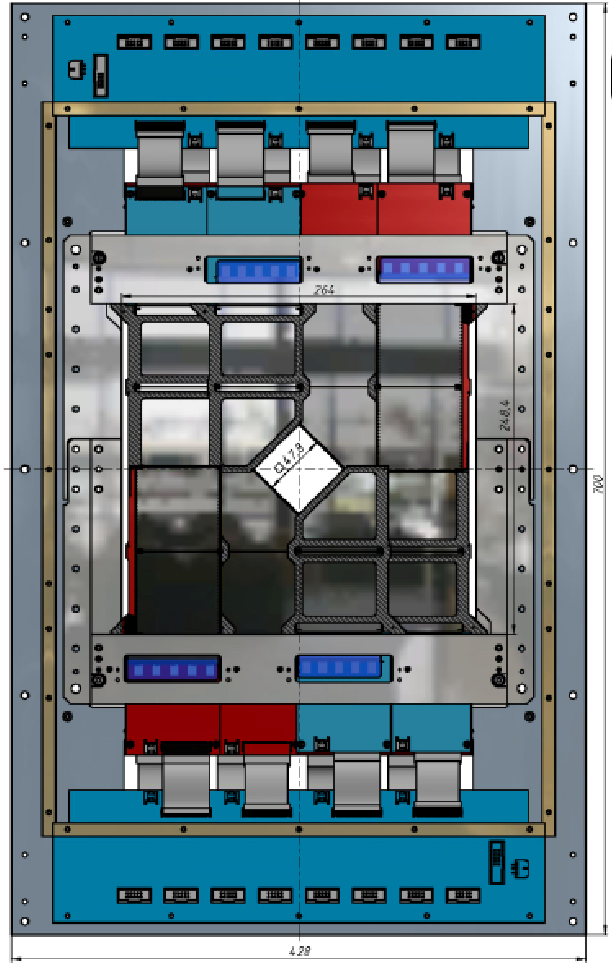
Forward silicon strip detector

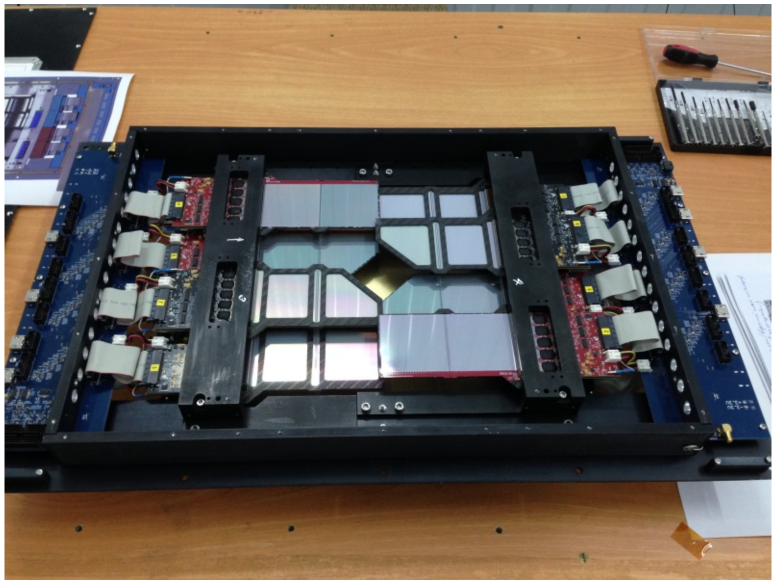


Silicon detector group, N.Zamiatin



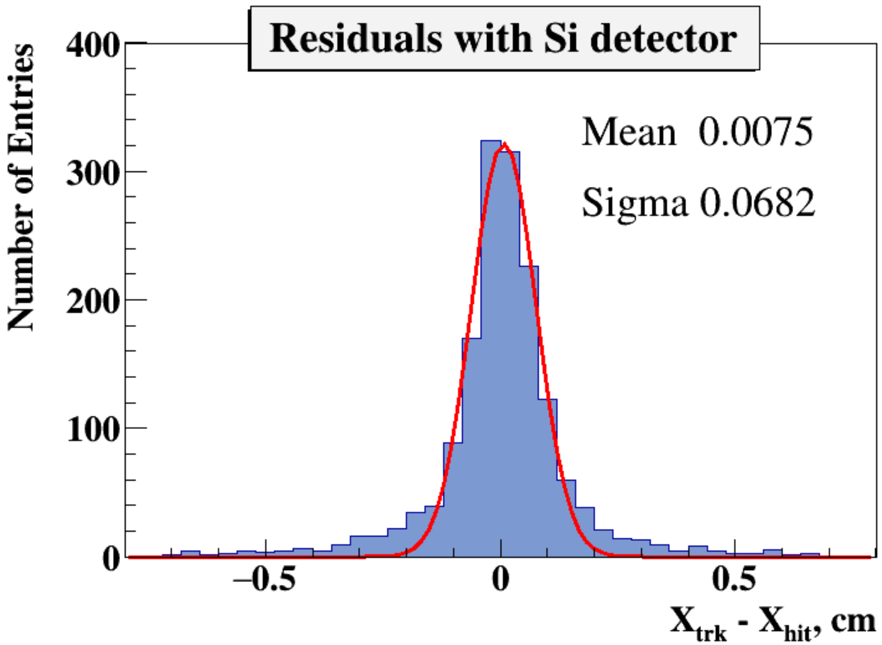
Si-GEM residuals (cm) vs strip number

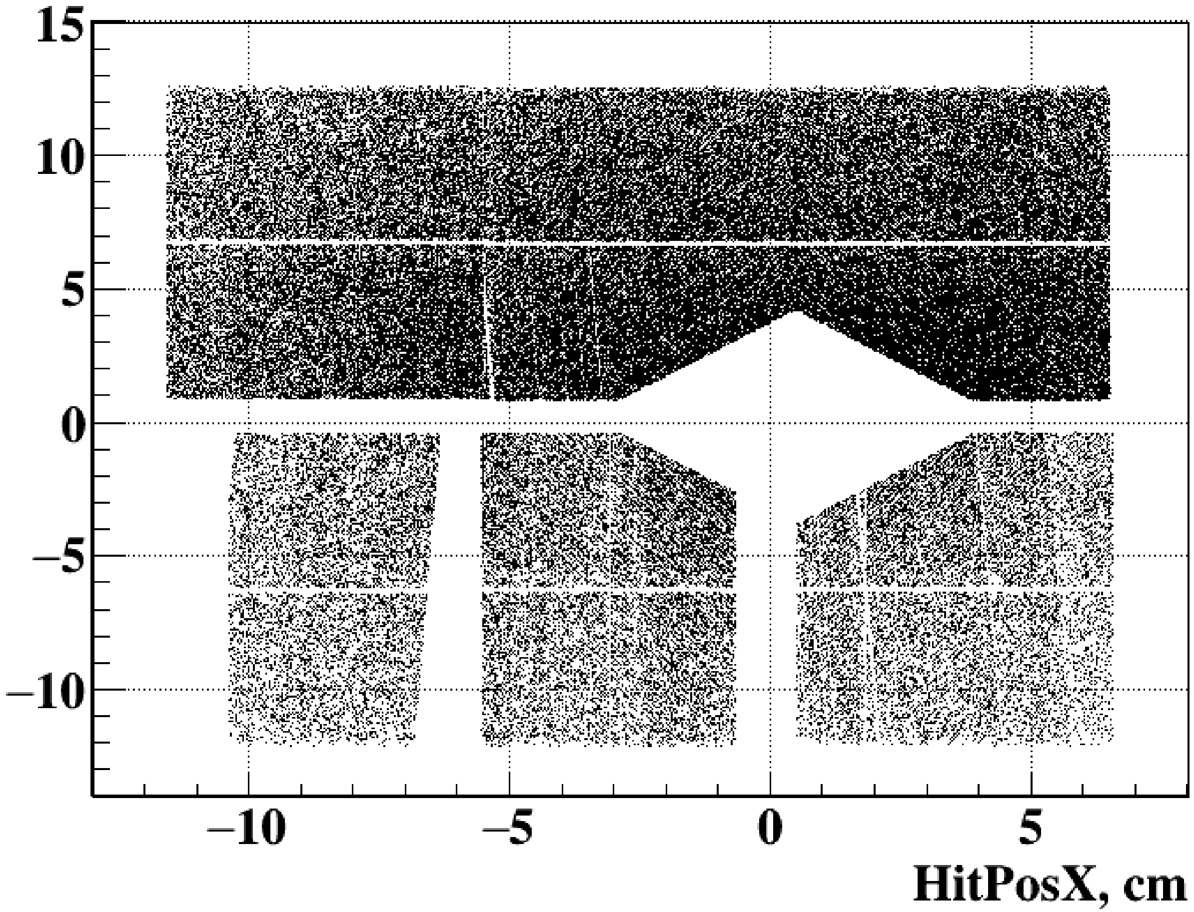




- **2-coordinate Si detector X-X'(±2.5°) with strip pitch of 95/103 µm, full size of 25 x 25 cm², 10240 strips**
- **Detector combined from 4 sub-detectors arranged around beam, each sub-detector consists of 4 Si modules of 6.3 x 6.3 cm²**
- **One plane installed in front of GEM tracker and operated in March 2017**

Hits and residuals in silicon detector

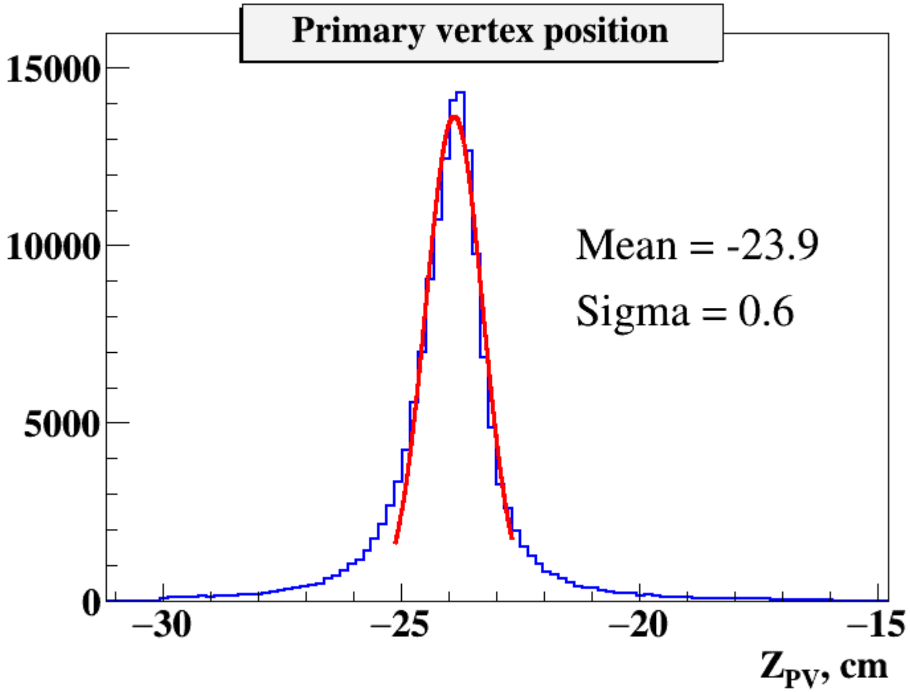




Λ reconstruction in C + Target → X

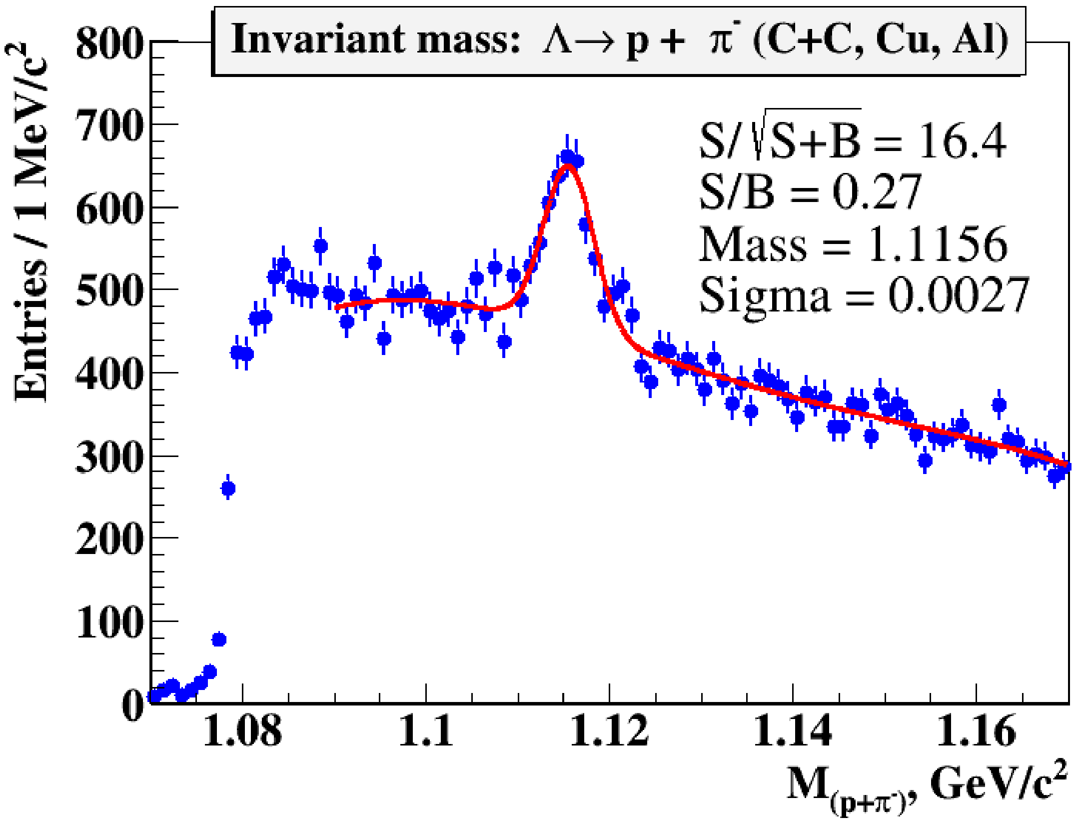
Primary vertex along beam direction in high multiplicity events

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



Carbon beam run, 4 AGeV

Λ signal width of 2.7 MeV



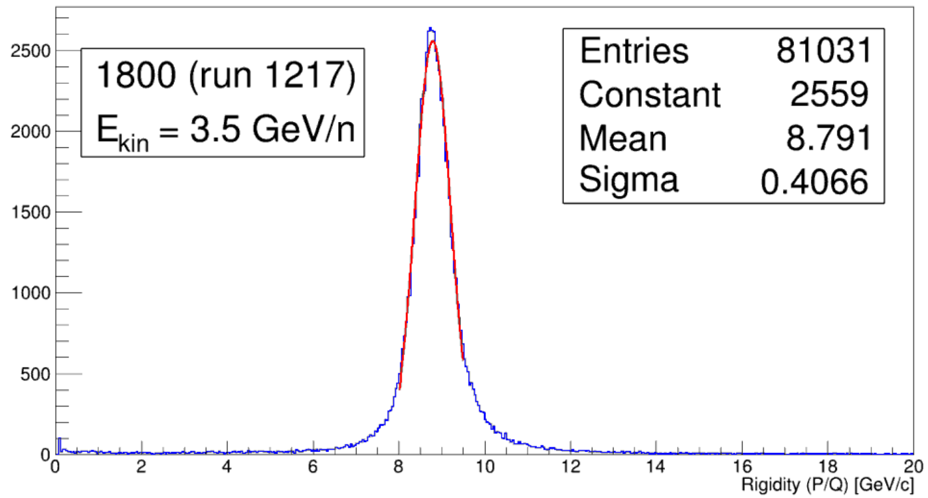
Beam momentum measured with GEM tracker

Carbon beam run, 4 AGeV

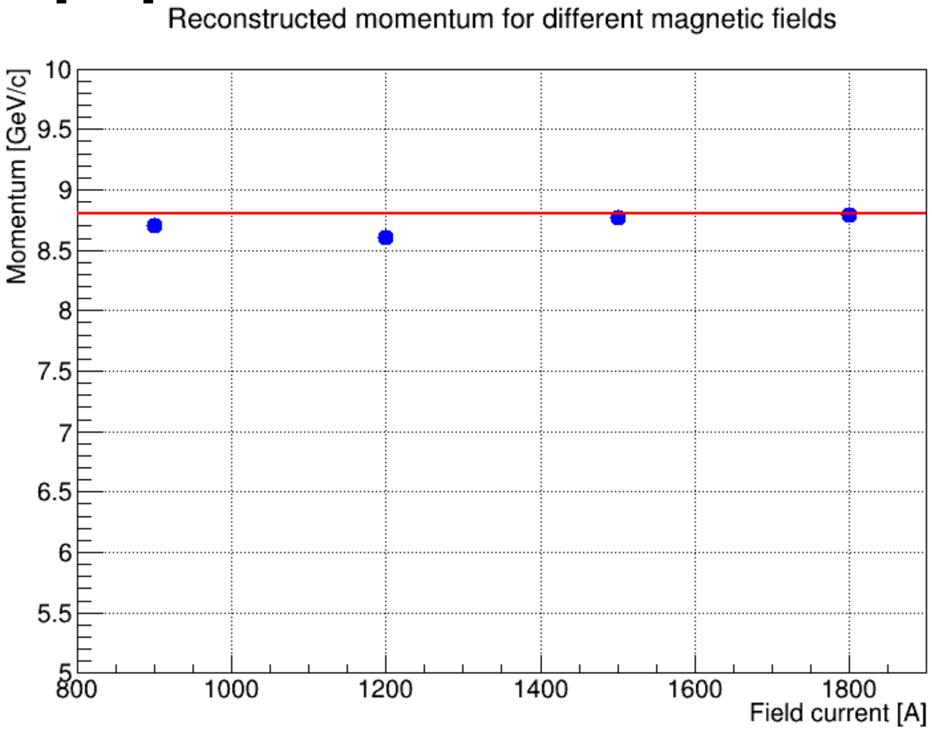
S.Merz

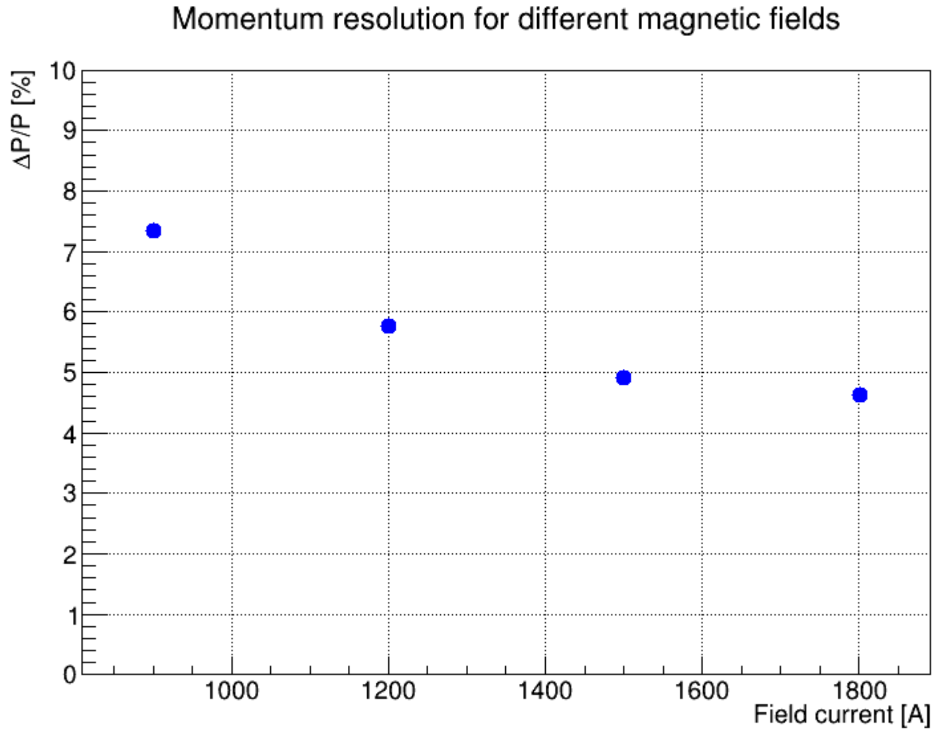
Reconstruction of carbon beam trajectory and momentum in GEM detectors at different values of magnetic field

Gas mixture: Ar + CO_2 (70:30)



p/q





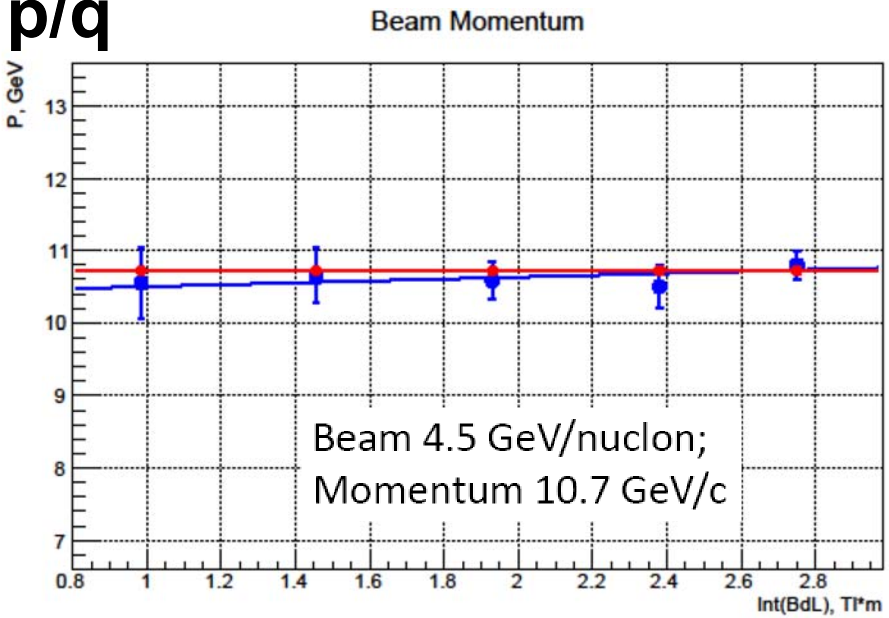
Beam Momentum measured with DCH outer tracker

Momentum vs. Int(BdL)

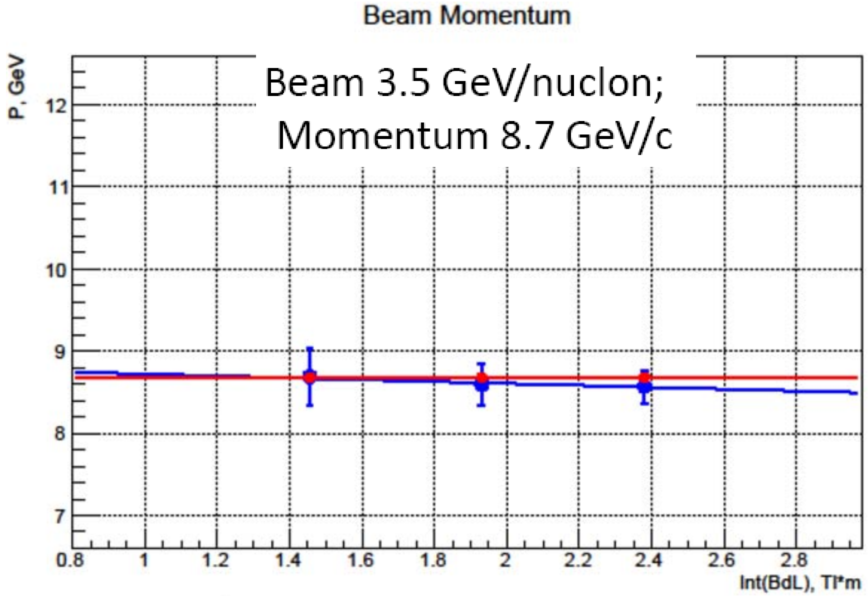
LIT: V.Pal'chik, N.Voitishin

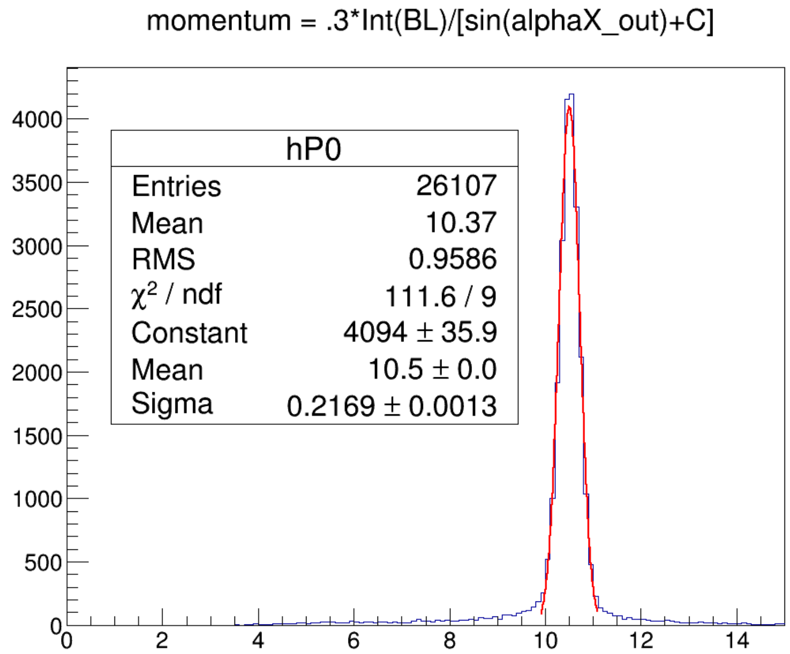
V.Lenivenko

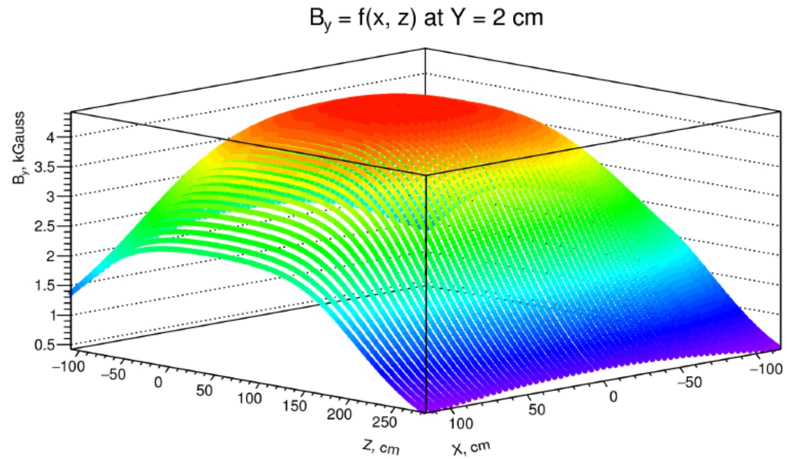
p/q



Errors → momentum resolution



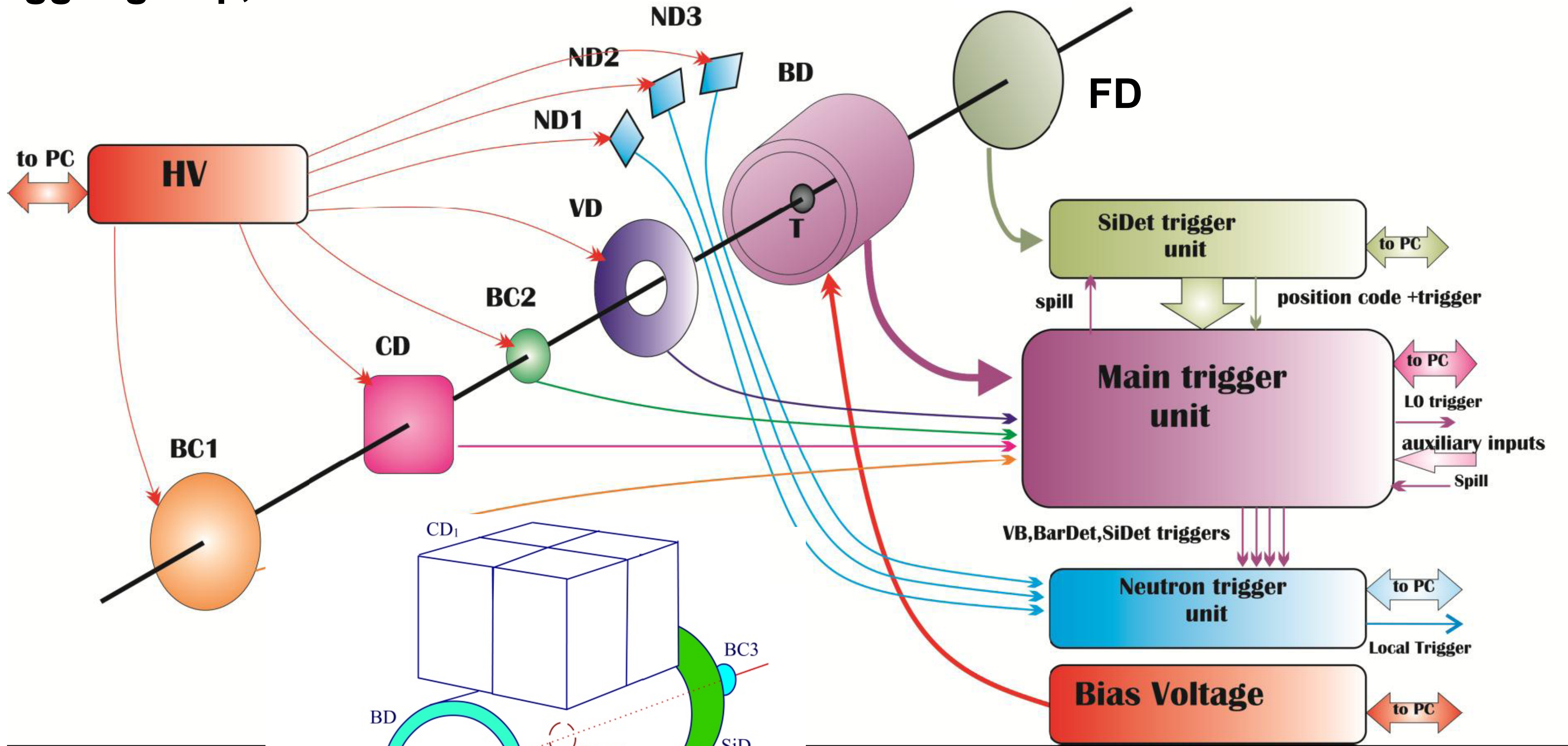




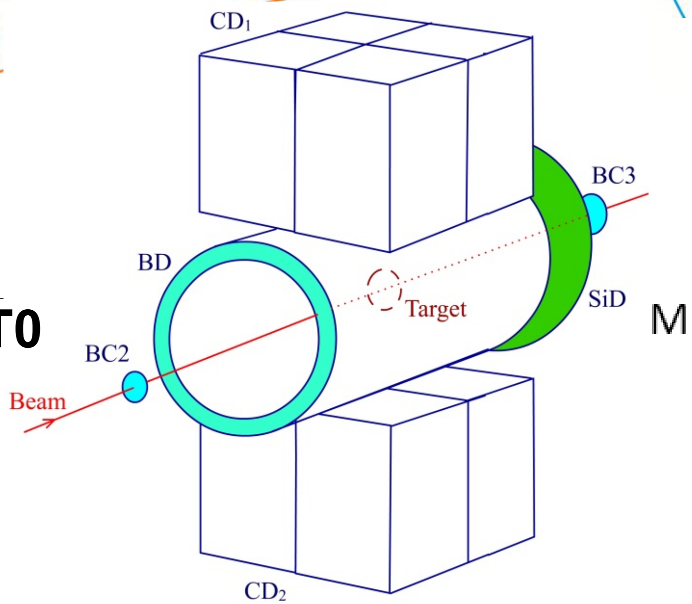
Magnetic field

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

Trigger group, V.Yurevich



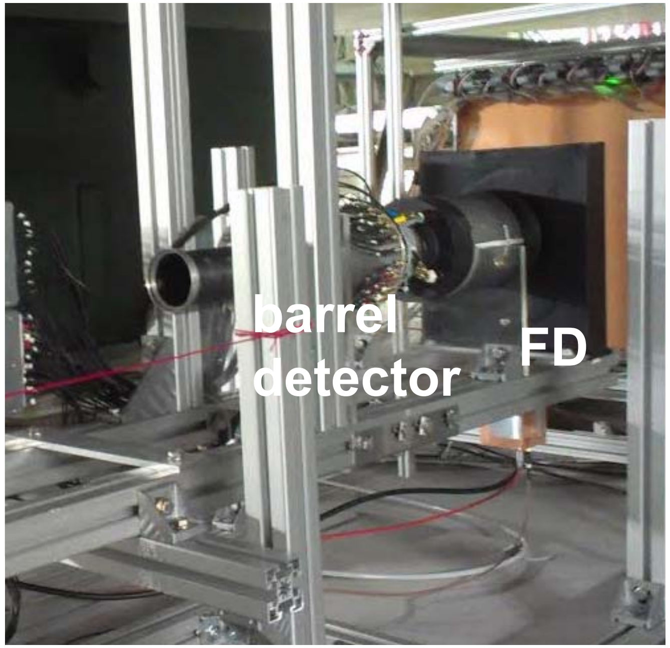
Trigger and T0 detectors for heavy ions



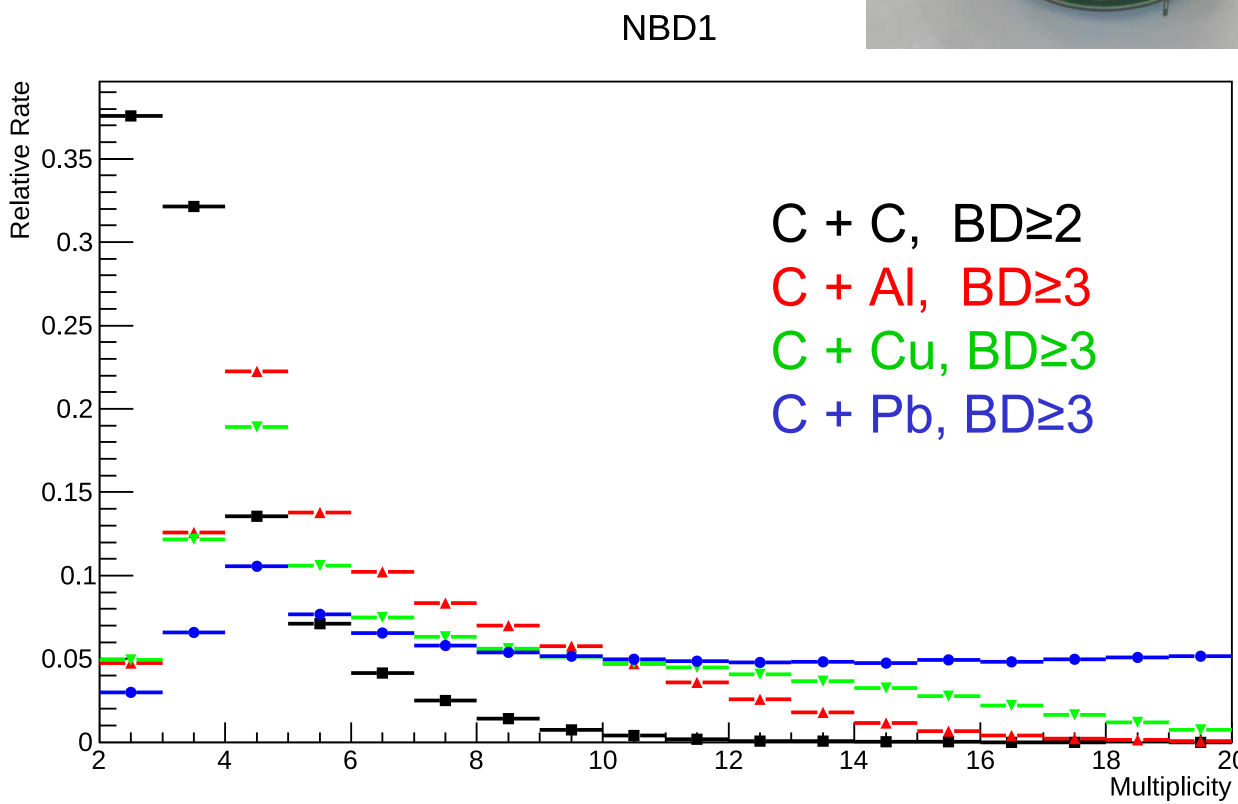
Selection of events with activity in barrel detector: BD >= 2, >= 3

Trigger barrel and Si detectors in BM@N setup

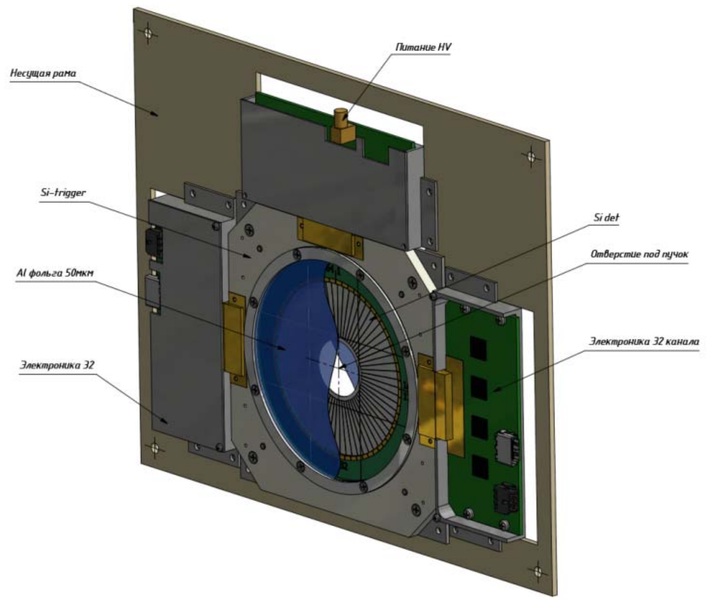
Trigger group, V.Yurevich



Barrel Detector multiplicity in carbon beam interactions with different targets



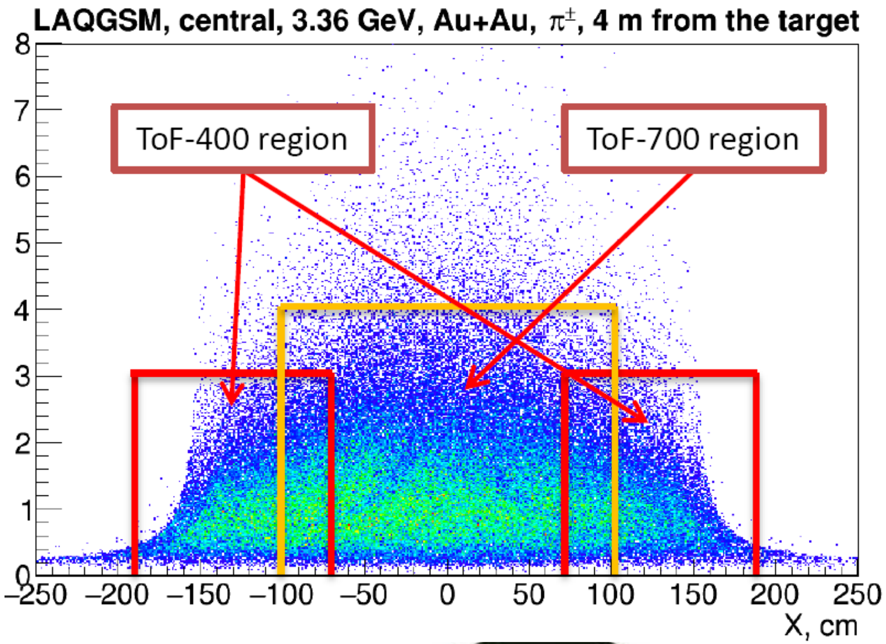
Forward Si trigger detector development, N.Zamiatin group



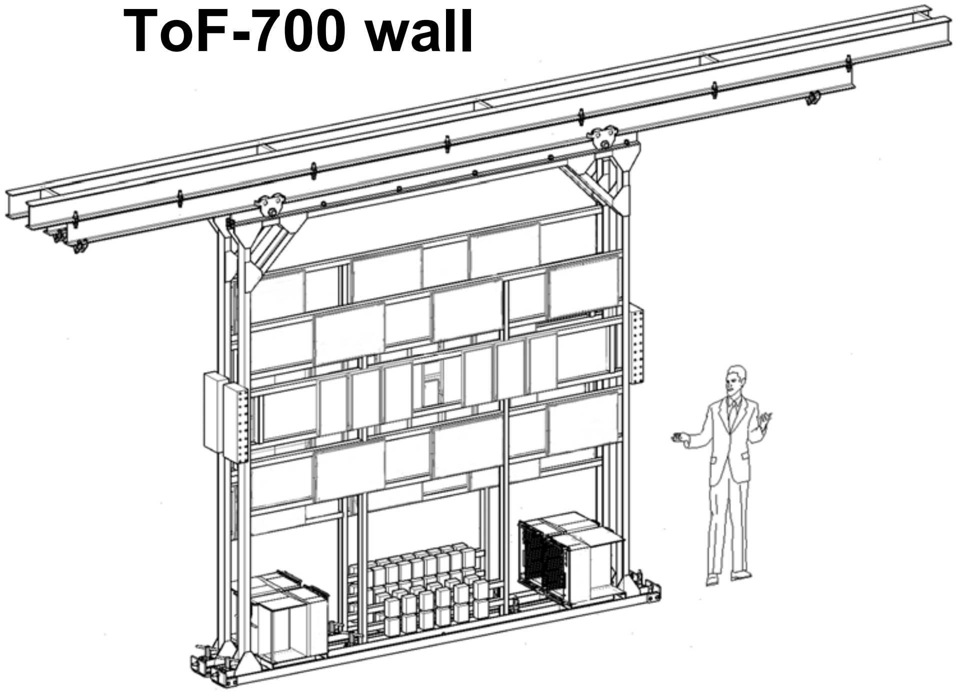
M.Kapishin

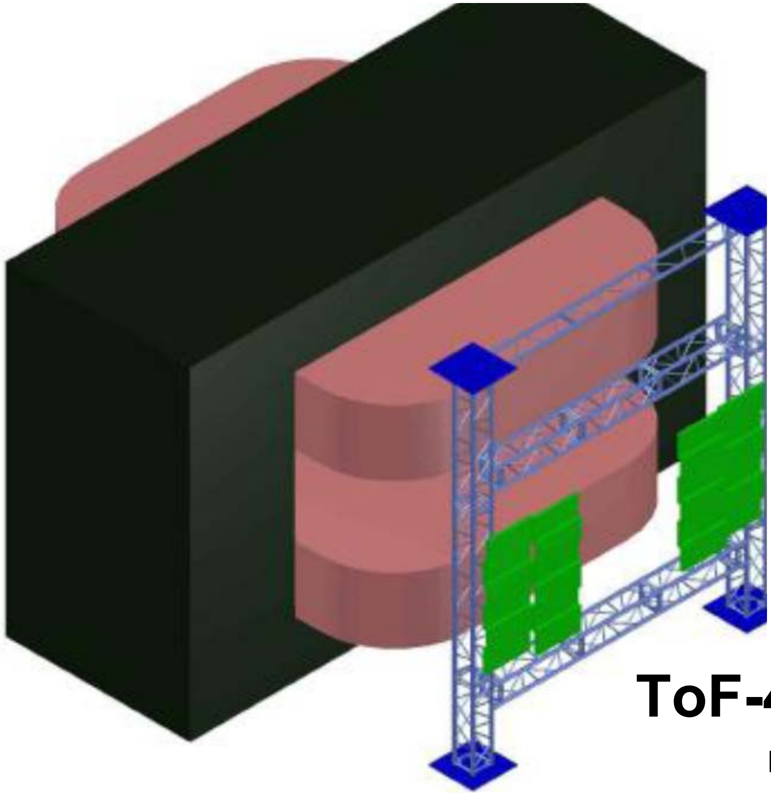
BM@N experiment

ToF-400 and ToF-700 based on mRPC

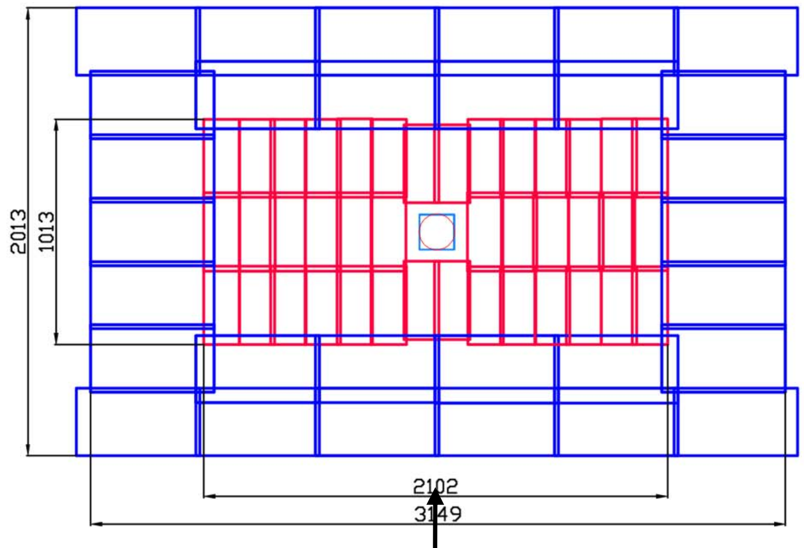


ToF-700 wall





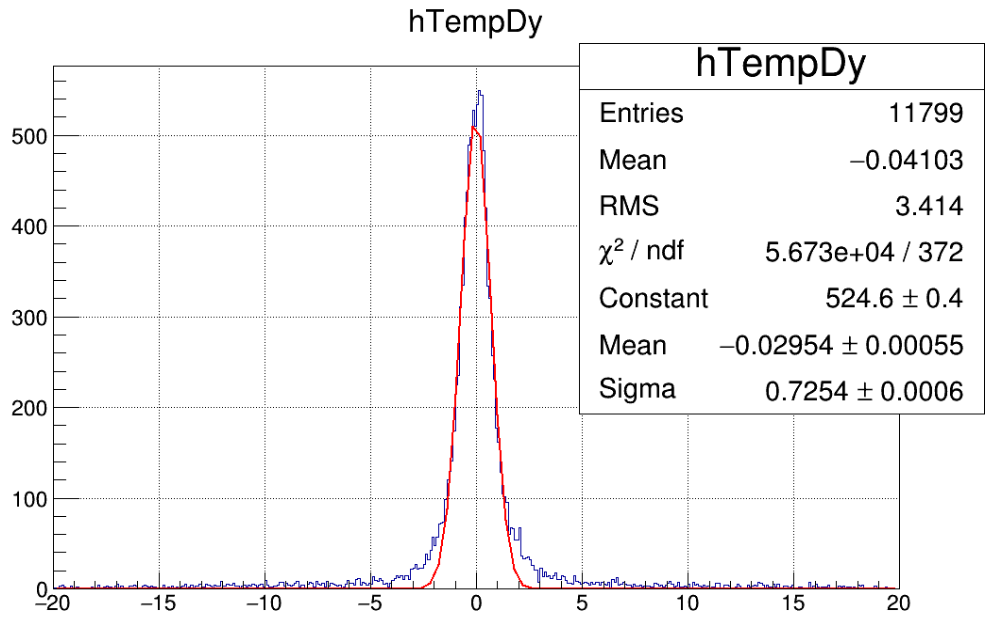
ToF-400 wall



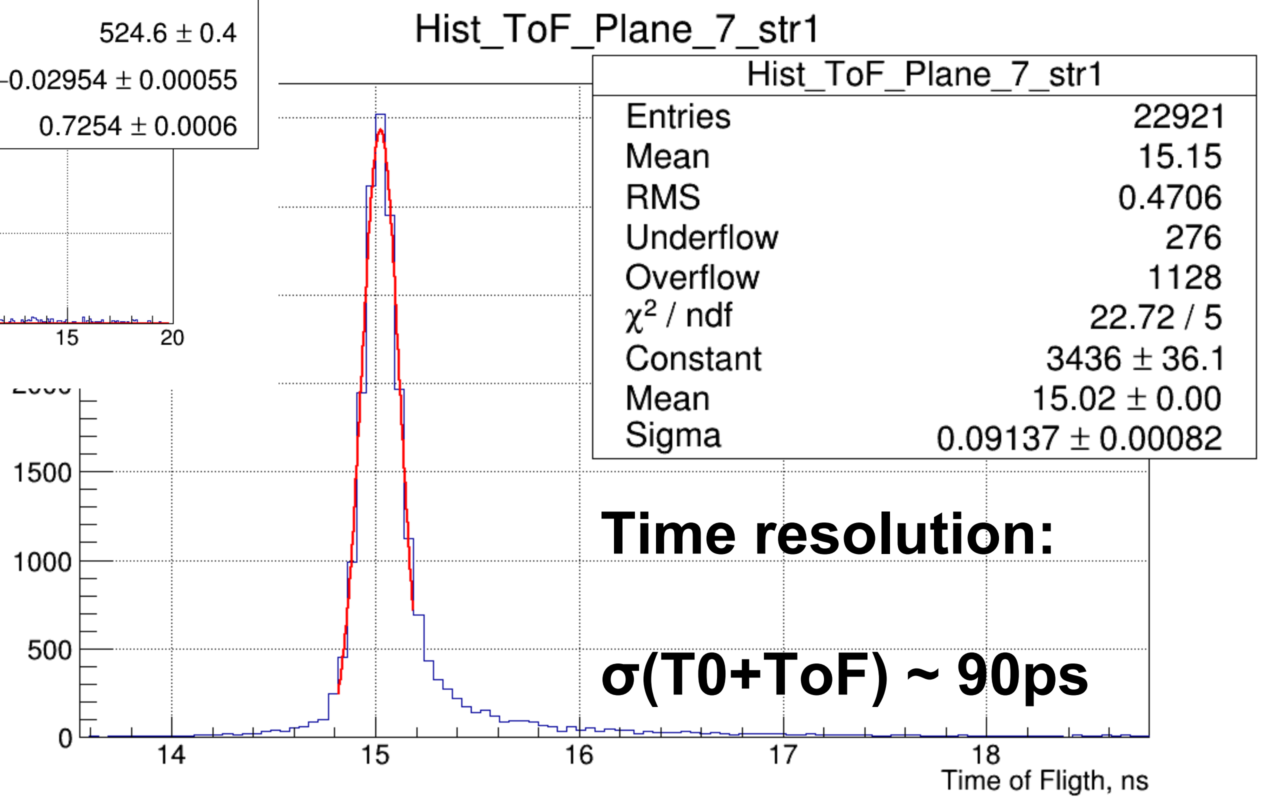
BM@N beam axis

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

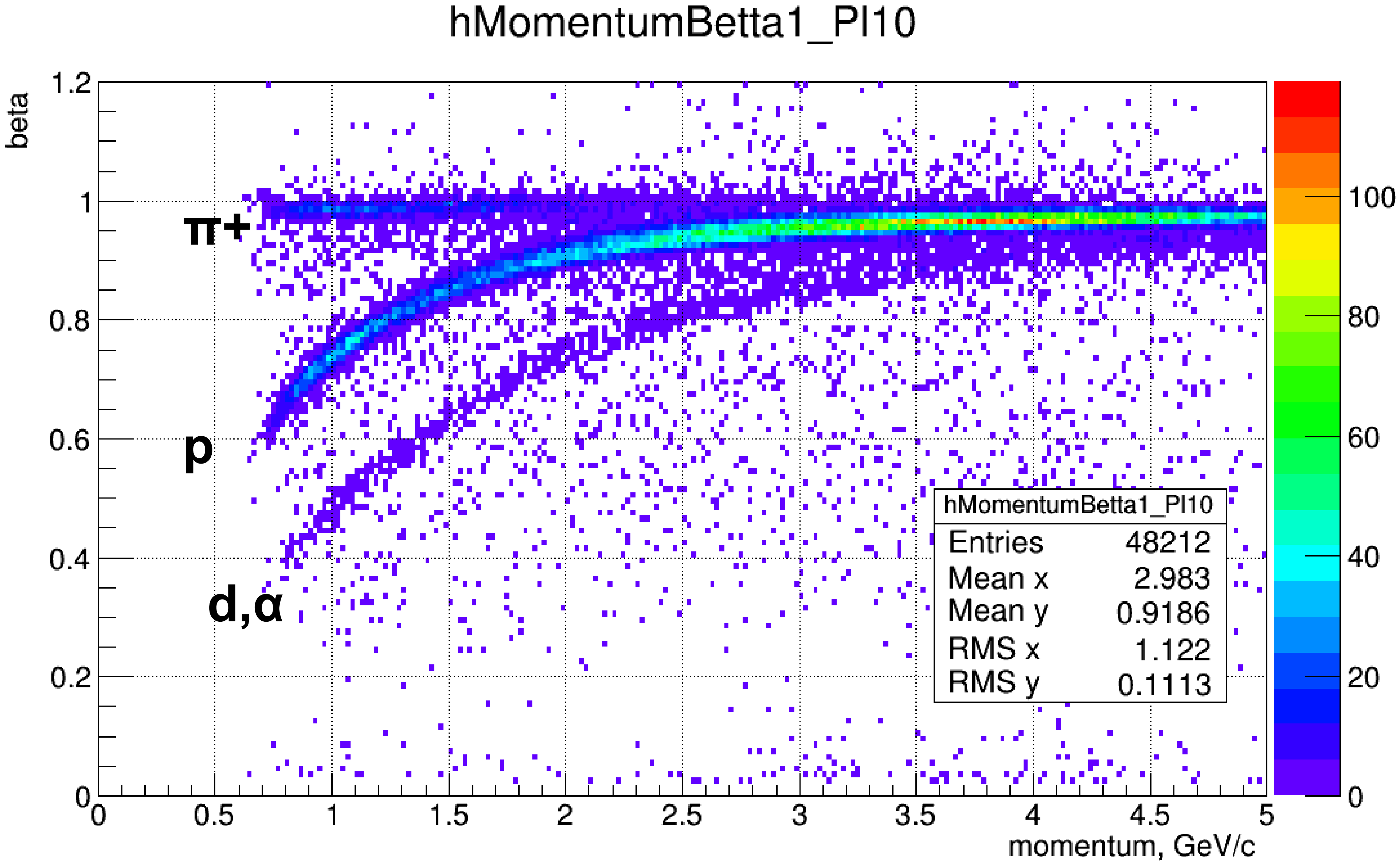
Time resolution:

$\sigma(T0+ToF)$ ~ 90ps

ToF-400: status of particle identification

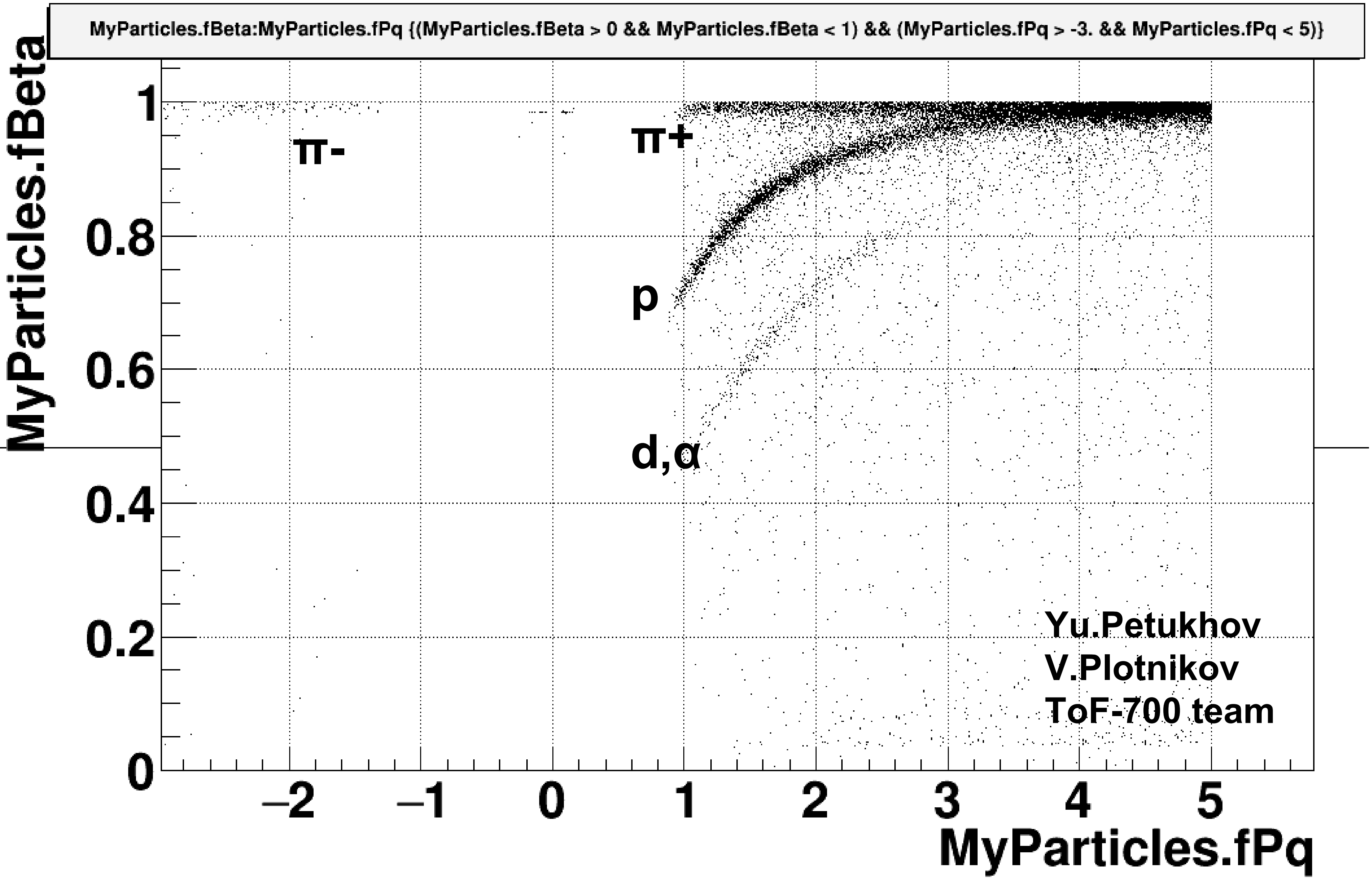
Carbon beam , 3.5 AGeV , C + Al → X

ToF-400 team



ToF-700: status of particle identification

Carbon beam , 4.5 AGeV , C + Cu → X

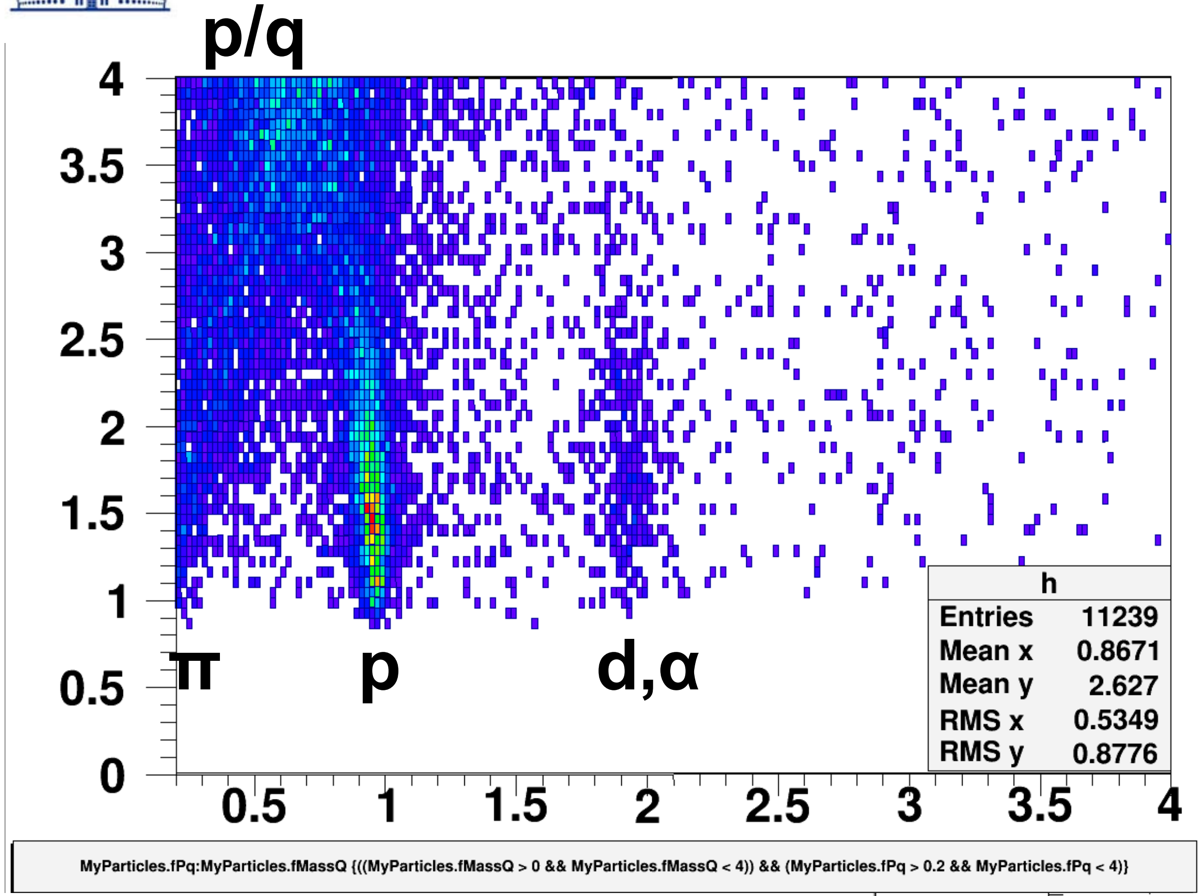


ToF-700: status of particle identification

Yu.Petukhov

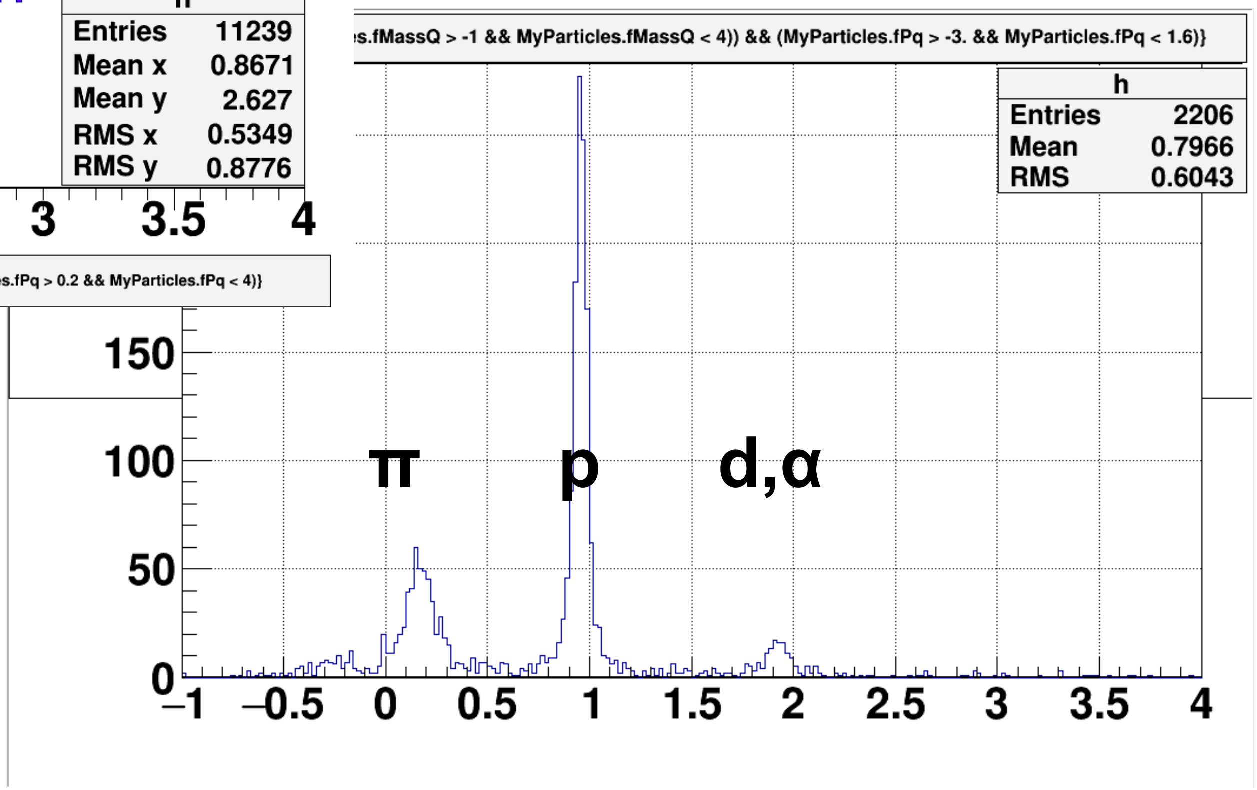
V.Plotnikov

ToF-700 team



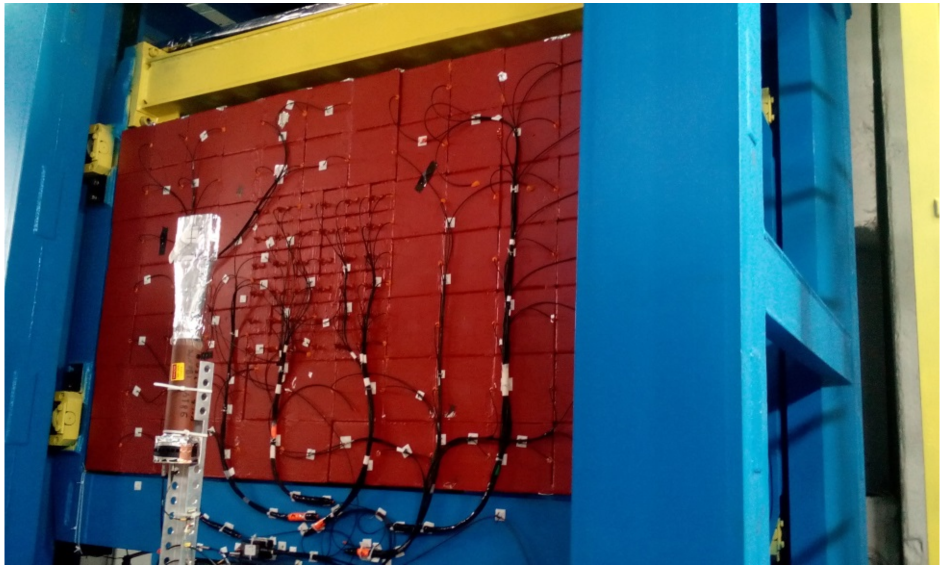
M/q

M/q, p/q < 1.6 ГэВ/с

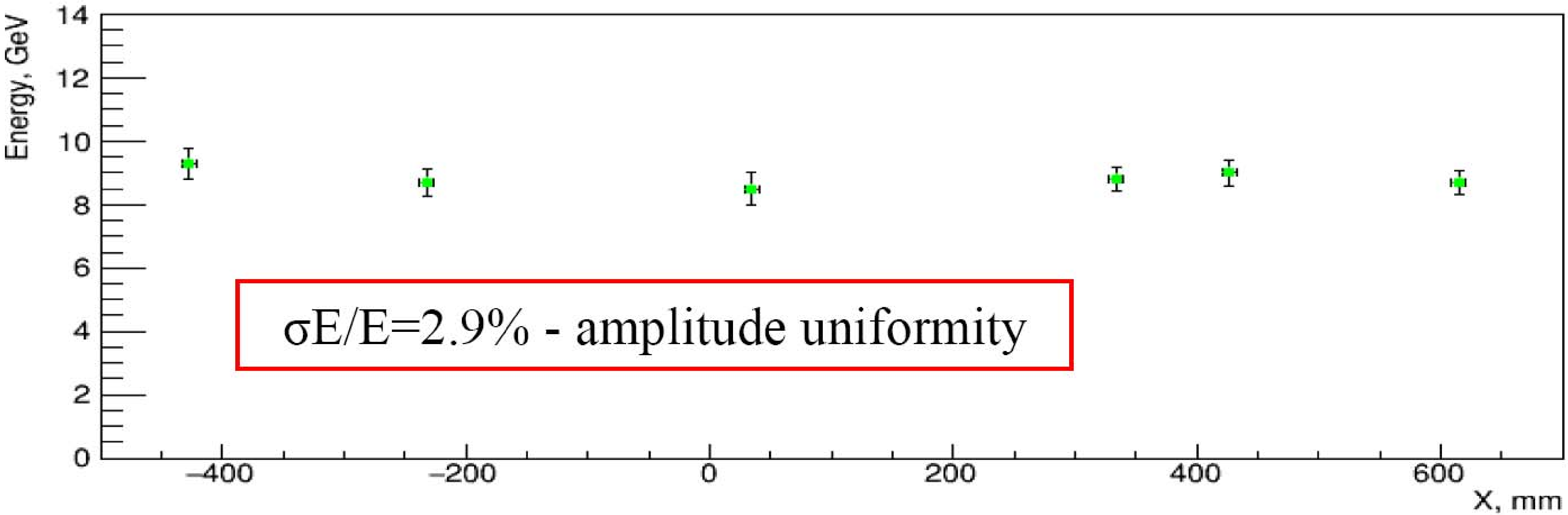


Calibration of ZDC calorimeter

O.Gavrischuk, SNEO



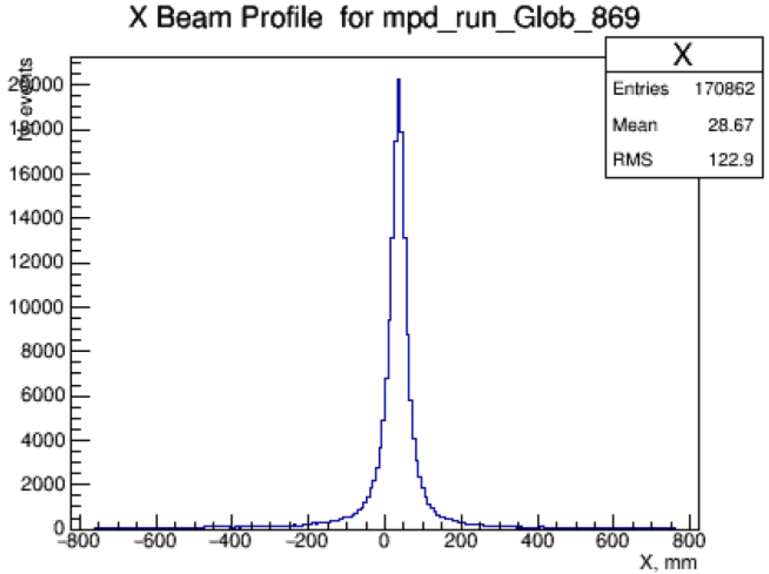
- Collect deuteron and carbon beam data with ZDC at different positions
- Calibration of cell amplitudes to get beam energy in cluster
- Spread of energies reconstructed at different ZDC positions ~3%

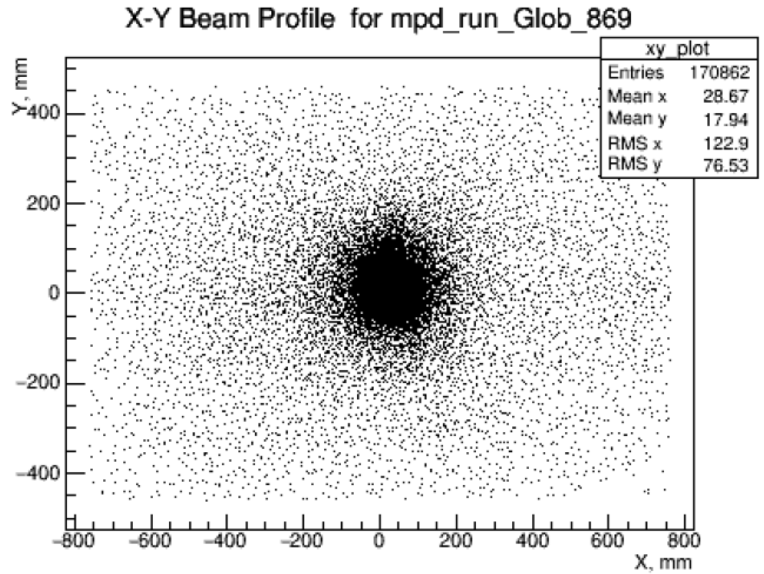


ZDC performance in deuteron run

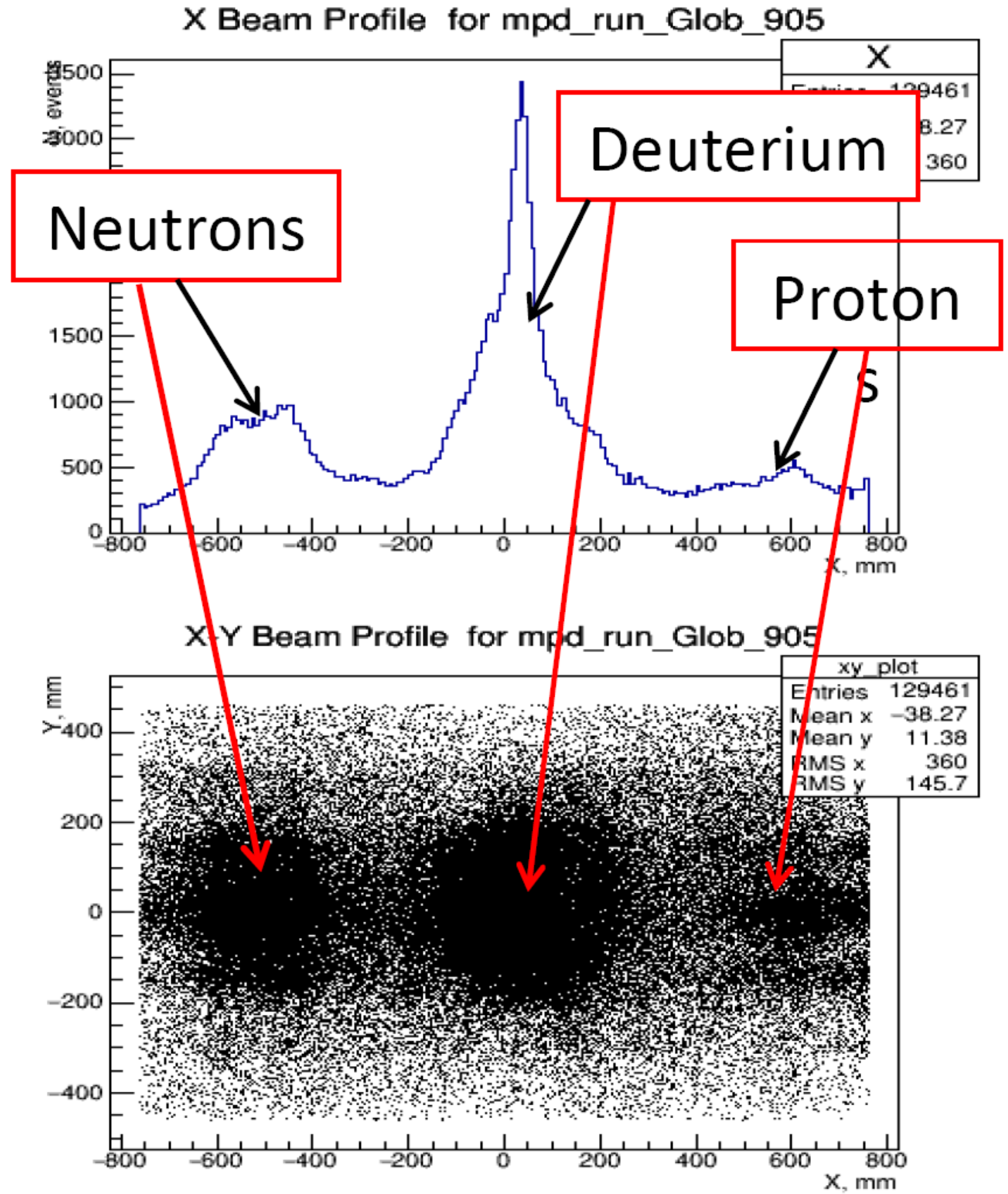
O.Gavrischuk, SNEO

Profile of deuteron beam in ZDC

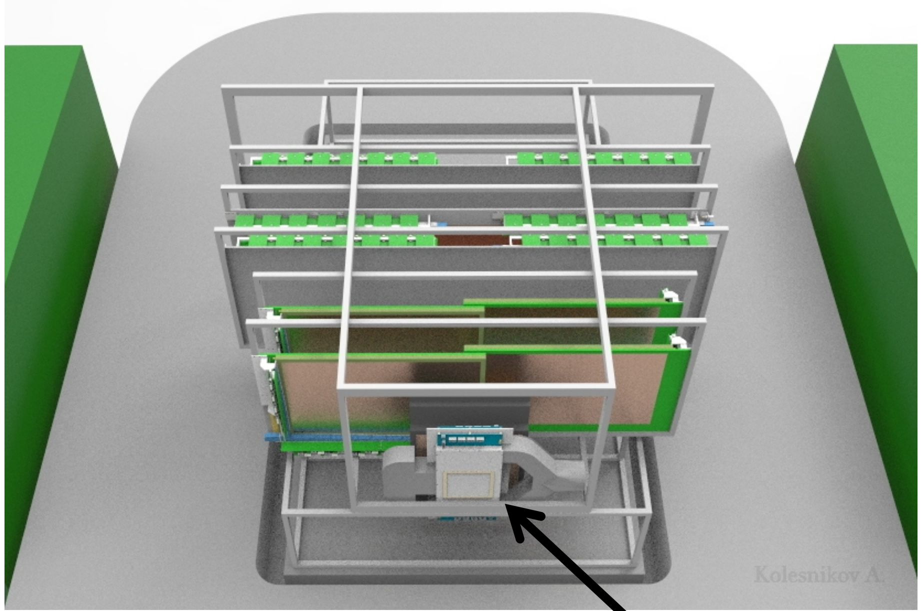


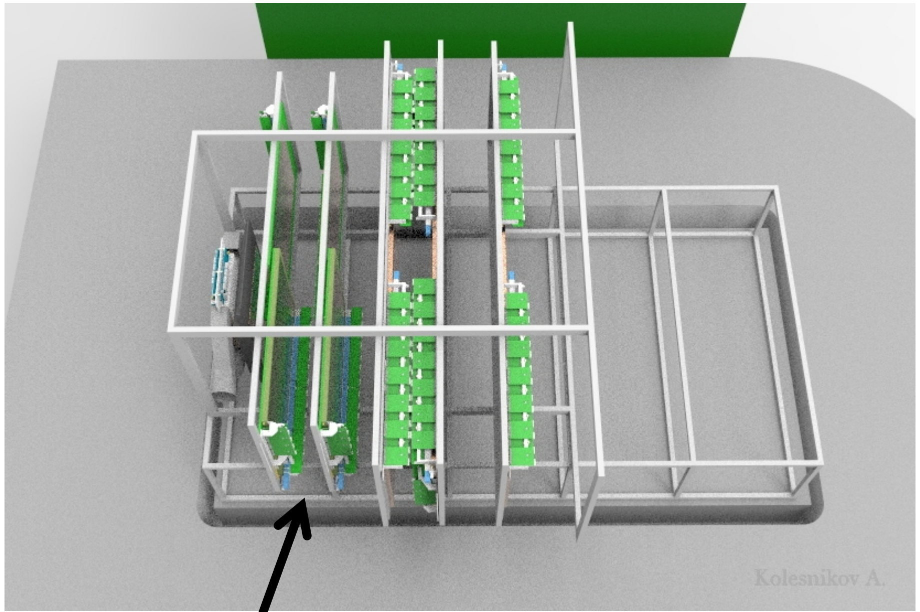


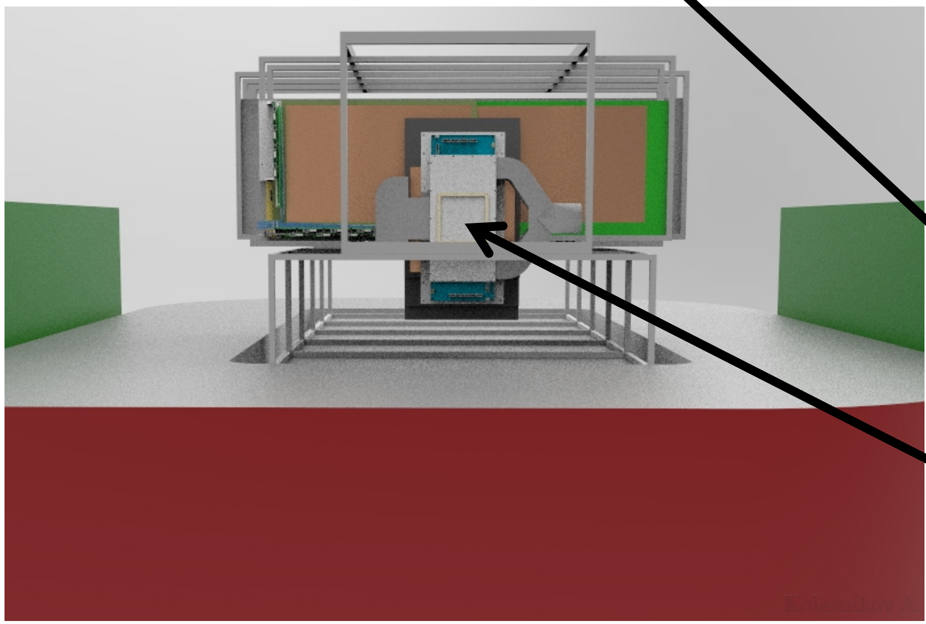
ZDC response to deuterons and products of d+CH_2 interactions



BM@N central tracker in run 55







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

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

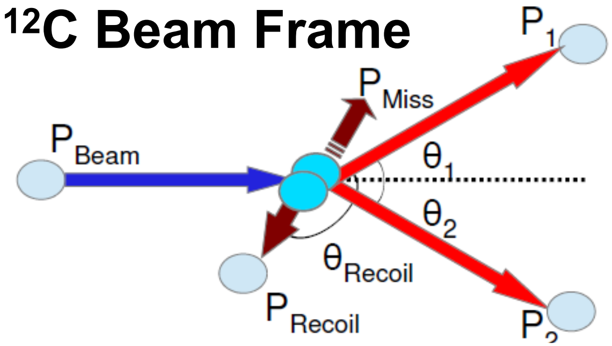
Beam crosses middle GEMs in short ‘hot’ zone, big GEMs – in beam hole → configuration is based on results of Λ and K^0_S simulation

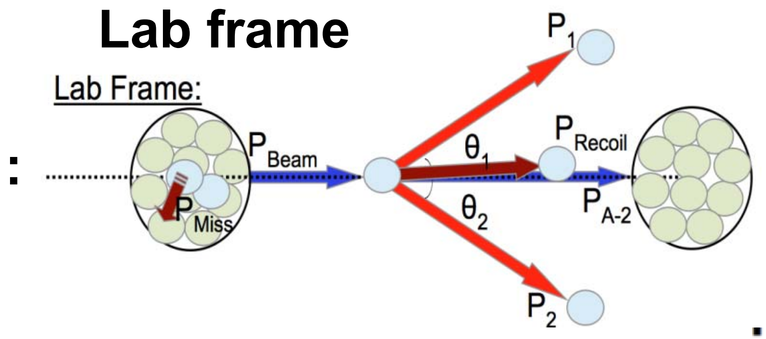
Table 1. Beam parameters and setup at different stages of the experiment

year	2016	2017 spring	2017 autumn	2019	2020 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.	5 GEM half pl. + **Si planes**	8 GEM full pl. + **Si planes**	10 GEMs + Si planes
experim. status	techn. run	techn. run	techn. run	stage 1 physics	stage 2 physics

A proposal for BM@N experiment

to study SRC with hard inverse kinematic reactions

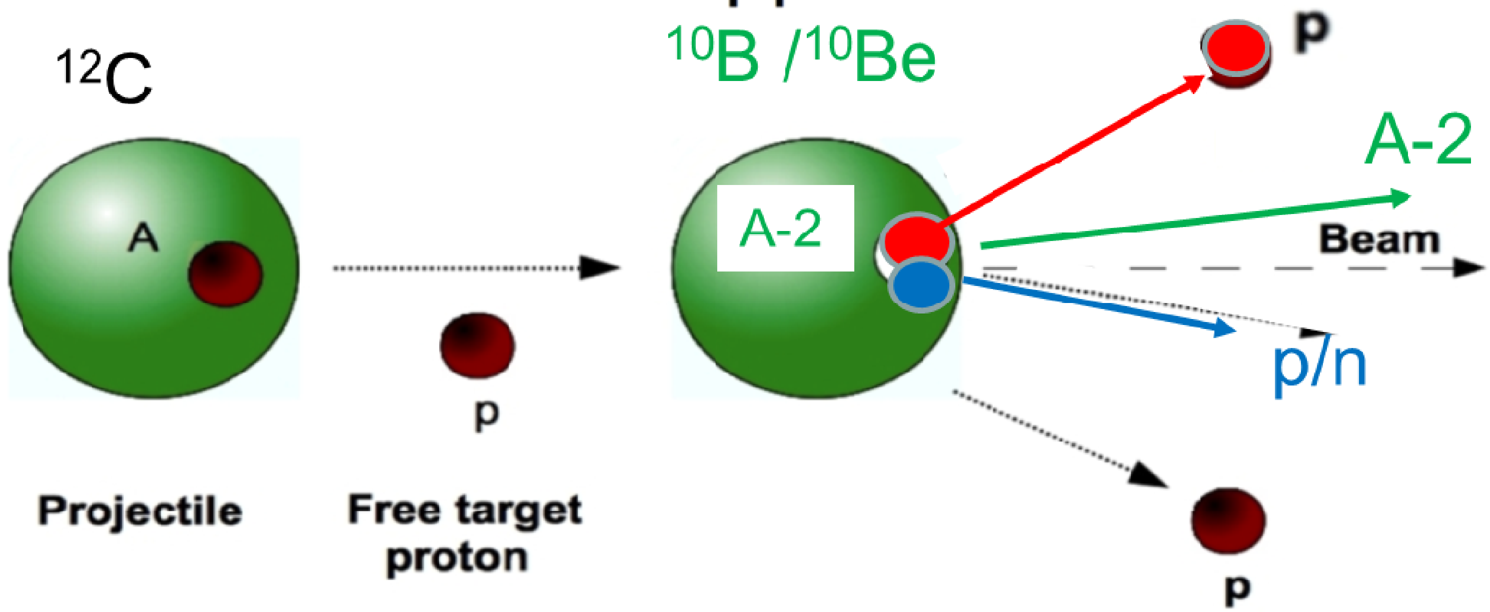




JINR (Dubna): BM@N
Israel: Tel Aviv University
Germany: TUD and GSI
USA: FIU, MIT, ODU, PSU
FRANCE: CEA

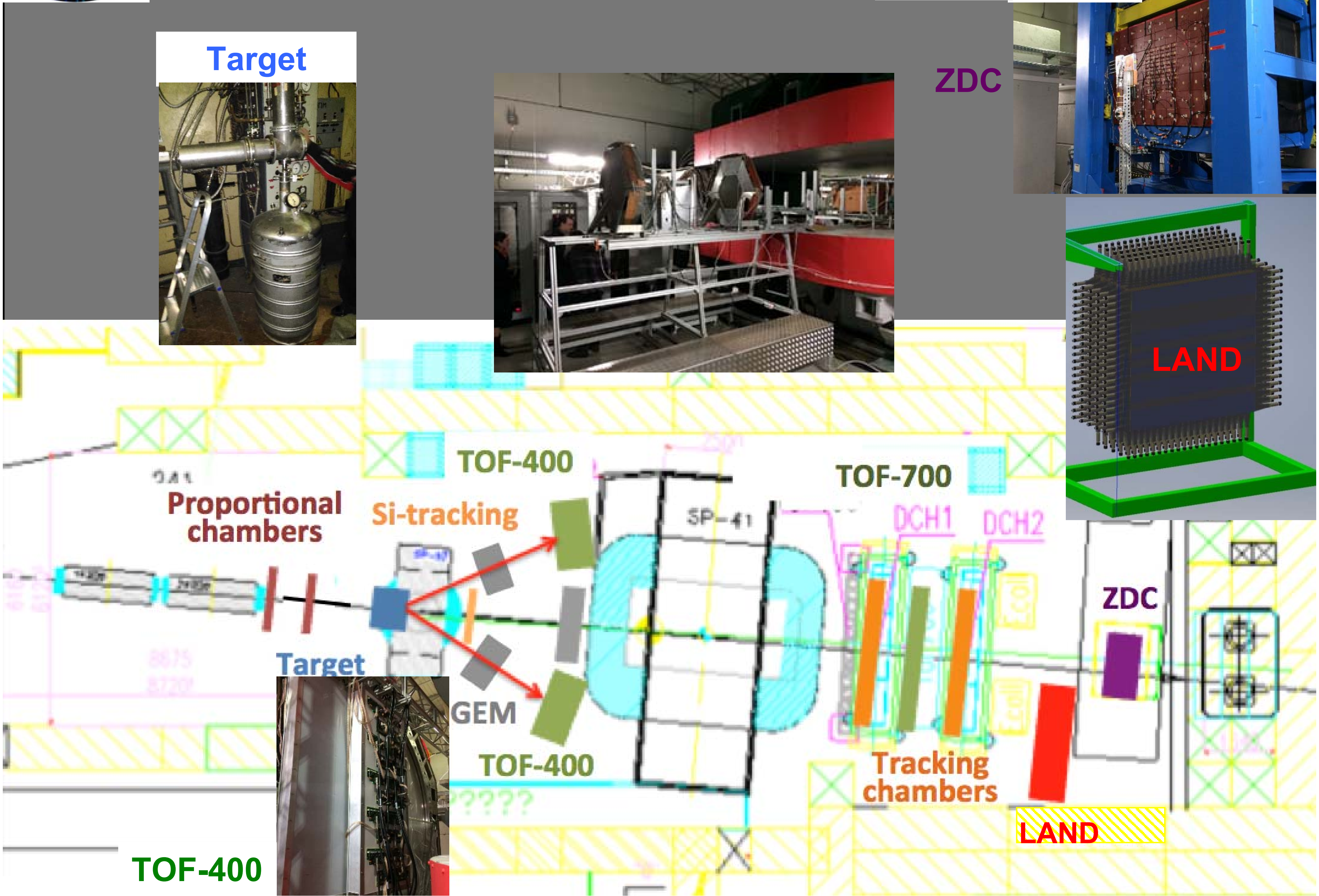
Objectives:

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



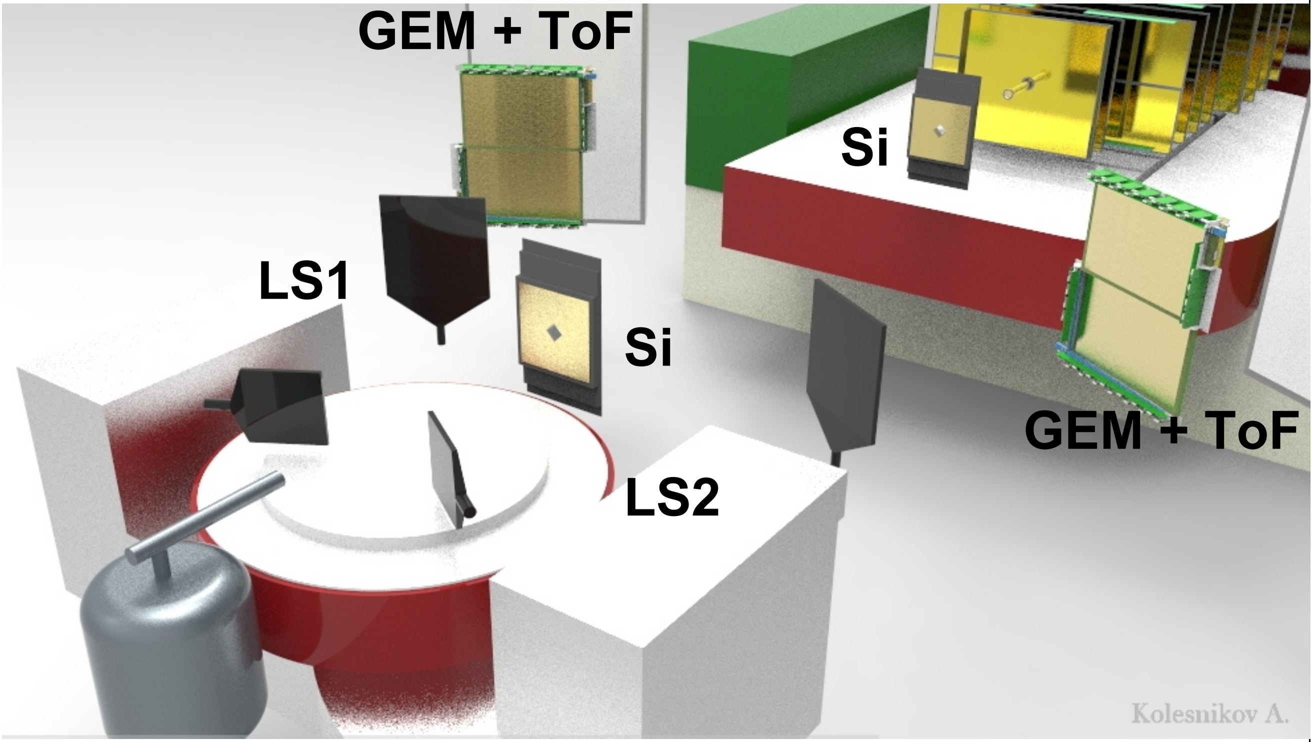
A dedicated talk of E.Piasetzky: Probing short range correlations at BM@N

Experimental set up



Expected SRC event rate

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



T0 +Target + T1

Trigger:
T0 · T1 · LS1 · LS2

Signal rates for 14 days of data taking

$^{12}C + p \rightarrow {}^{10}B + pp$	np SRC	4000	Events
$^{12}C + p \rightarrow {}^{10}Be + pp$	pp SRC	200	

Within LAND acceptance

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

→ First SRC @ BMN run in December 2017

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
- BM@N collected data to check efficiencies of sub-detectors and develop algorithms for event reconstruction and analysis
- 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

BM@N plans for run in November- December 2017:

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

BM@N setup: GEM tracker (+ 1 detector) , 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

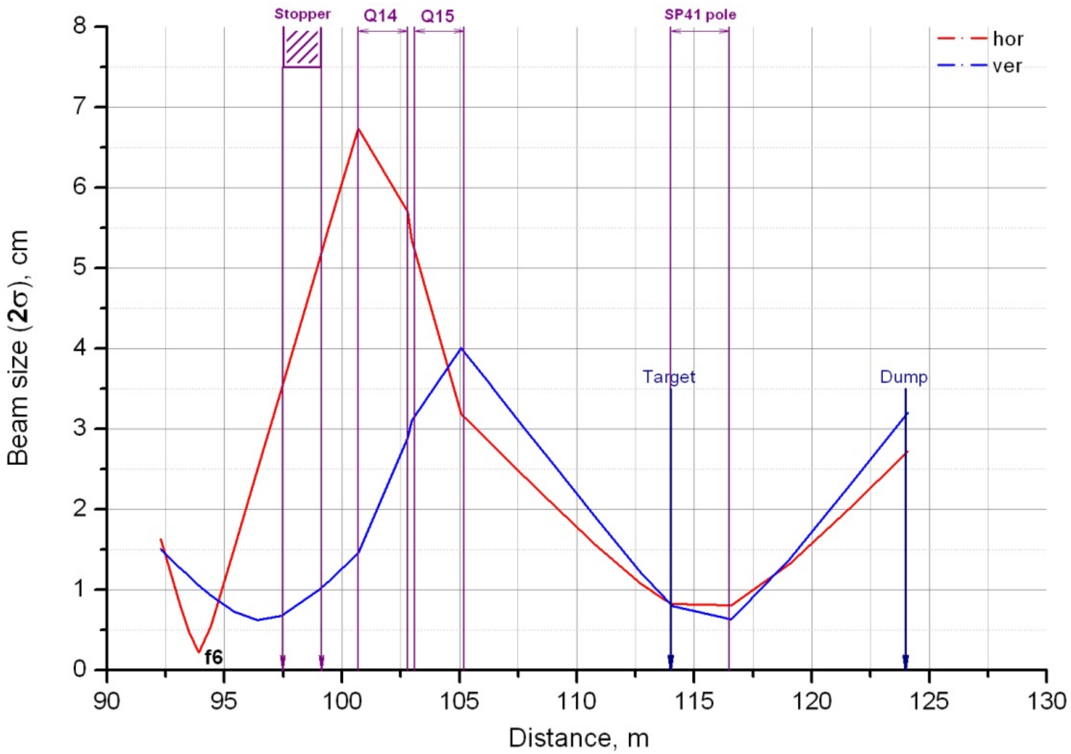
BM@N future plans for Au+Au: collaborate with CBM to produce and install large aperture STS silicon detectors in front of GEM setup

Thank you for attention!

Backup slides

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:

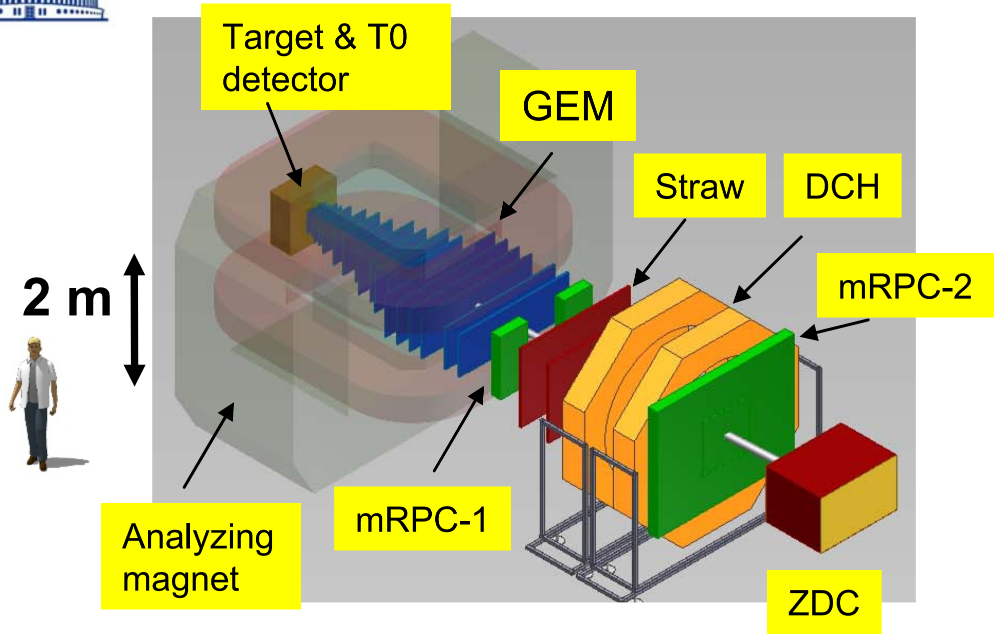
→ new stable power supplies for dipole magnets

→ 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

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

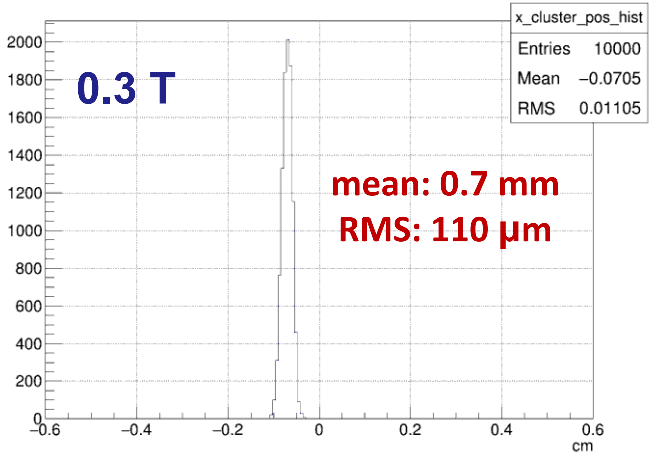
→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

→ fill distance between magnet and “far” detectors with coordinate detectors

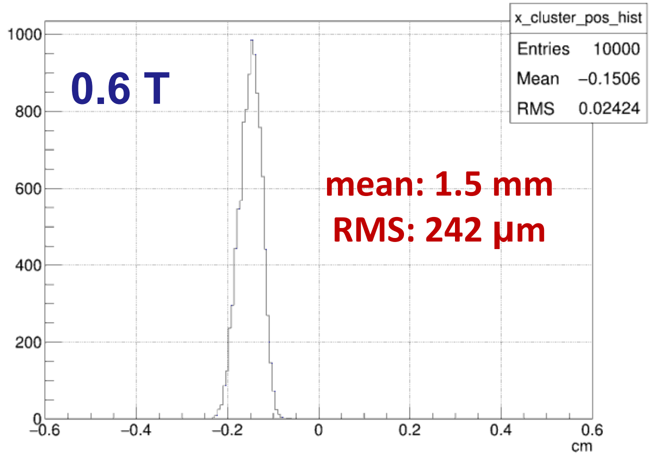
- Central tracker (GEM+Si) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (DCH, Straw / CPC) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions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

Simulations of GEM response: Garfield++

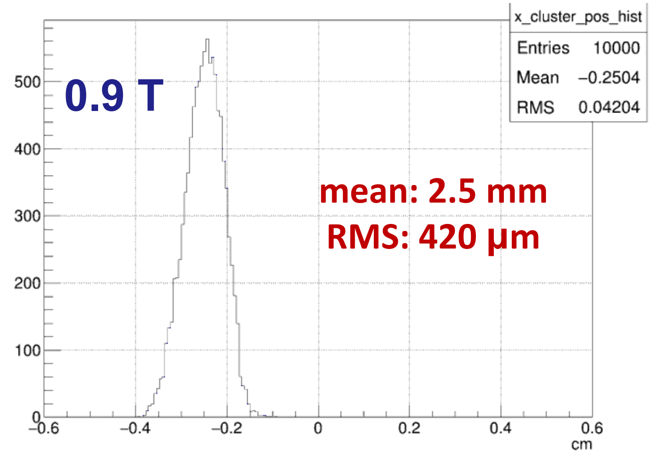
D.Baranov



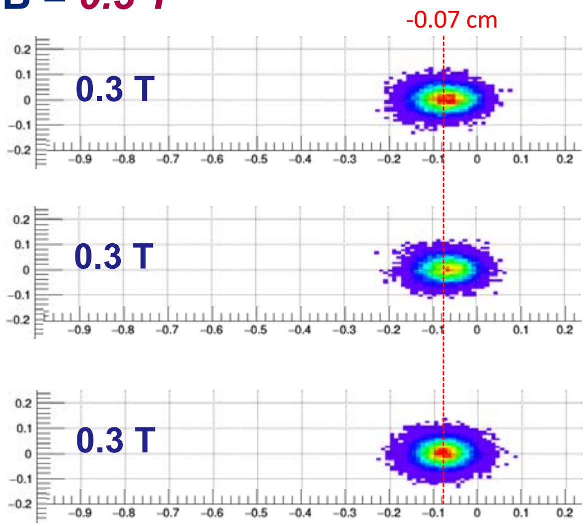
X distribution of avalanche centers at read-out plane
B = *0.3 T*

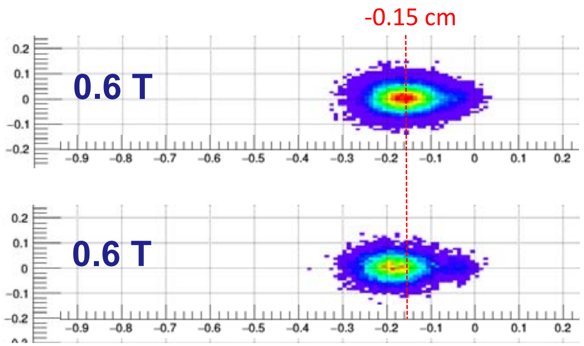


X distribution of avalanche centers at read-out plane
B = *0.6 T*

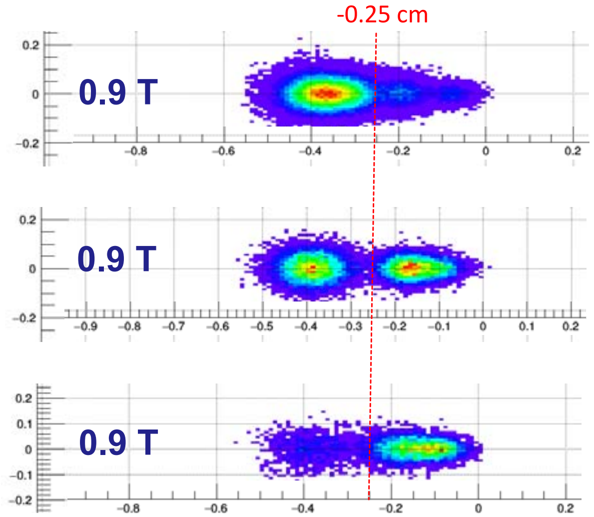


X distribution of avalanche centers at read-out plane
B = *0.9 T*





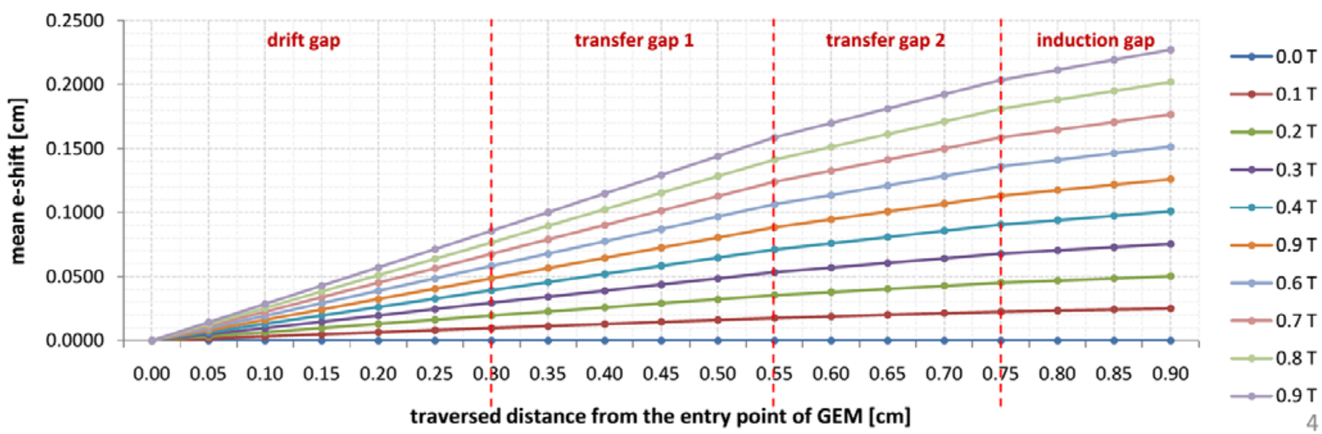
Examples of the avalanche profile of single track at the read-out plane.



Results are presented for gas mixture: Ar + Isobuthan = 90:10.

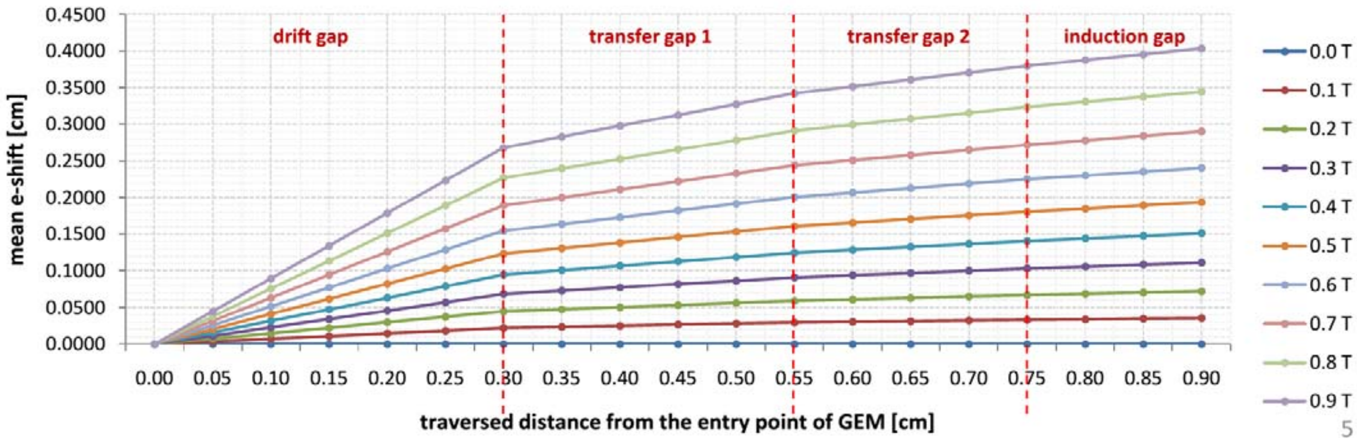
GEM Garfield simulation

Ar+ CO_2 (70:30)

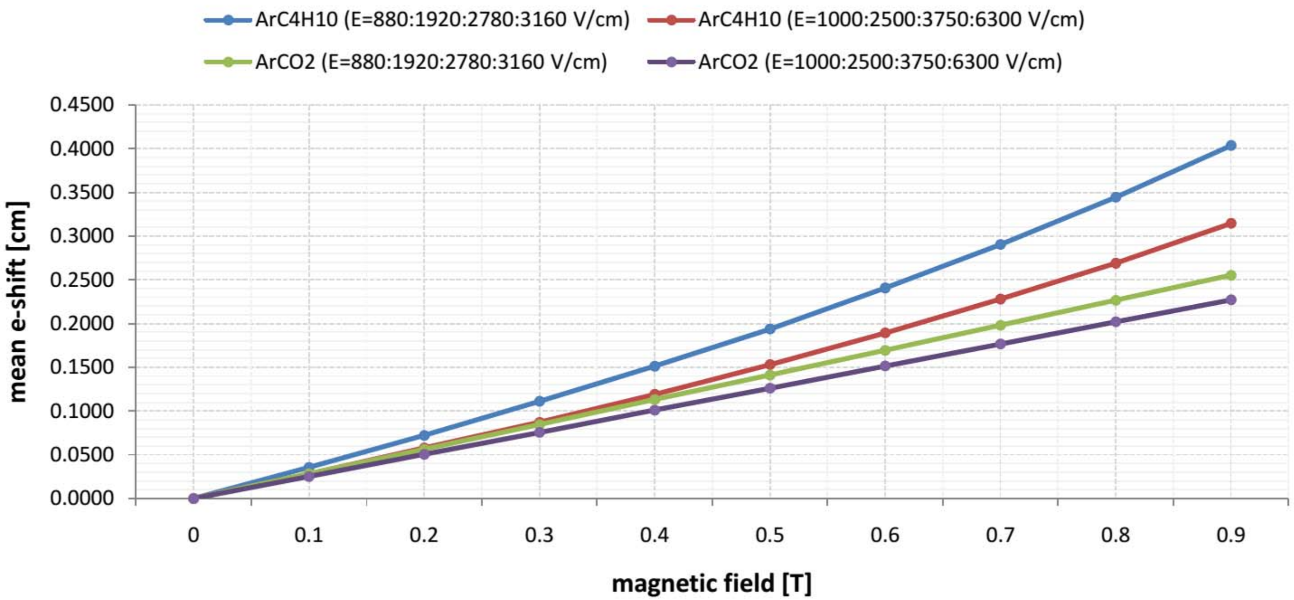


D.Baranov

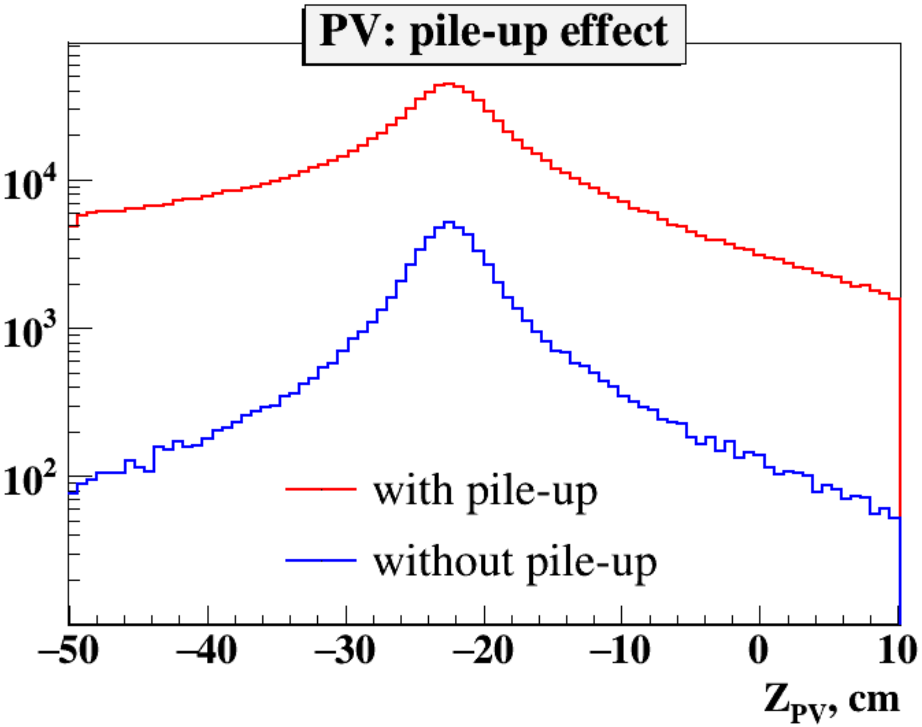
Ar + Isobuthan (90:10)

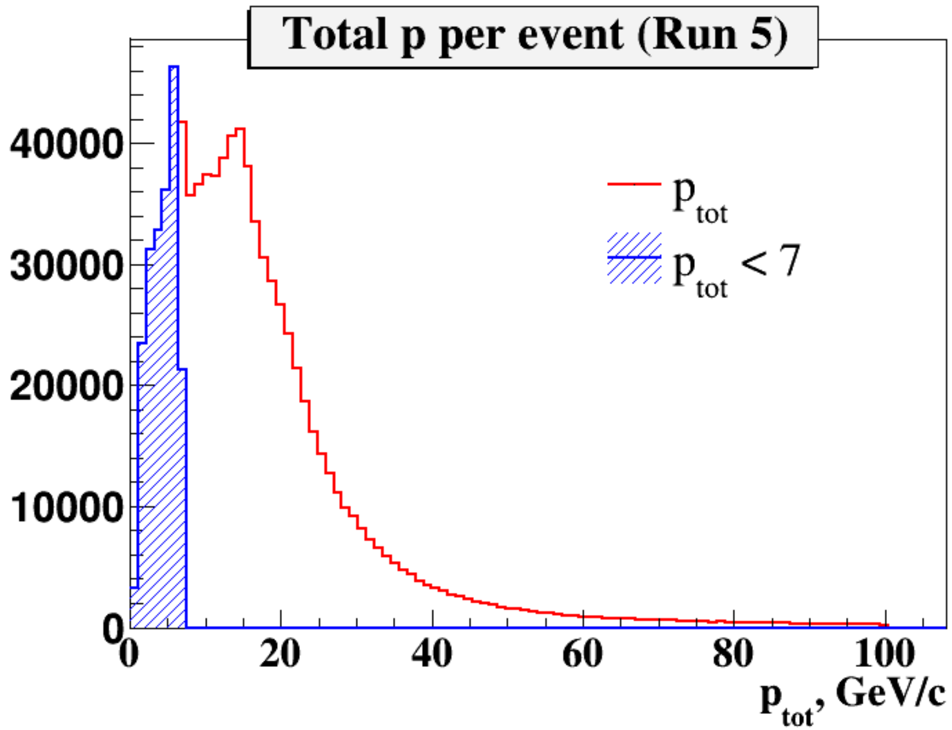


Lorenz shift vs magnetuc field



Pile-up effect in Deuteron Run





- ✓ Event pile-up due to non-uniform time structure of deutron beam.
- ✓ Cut on total momentum of particles in event < 7 GeV/c reduces pile-up significantly.

CPC chamber design

Al. Vishnevsky

Plan to produce in LHEP and install in autumn 2017 one CPC chamber in front of ToF-400 to check its performance as Outer tracker for heavy ion beams

Cathode printed board #1