Studies of Baryonic Matter at BM@N JINR

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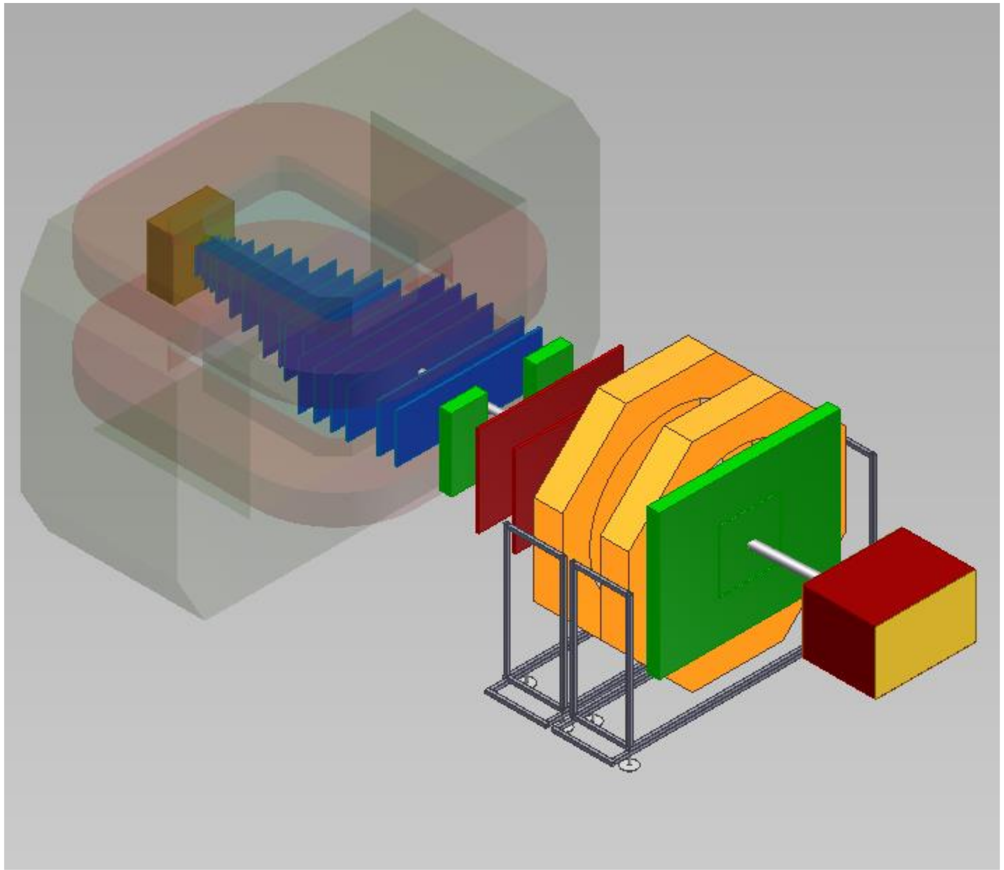
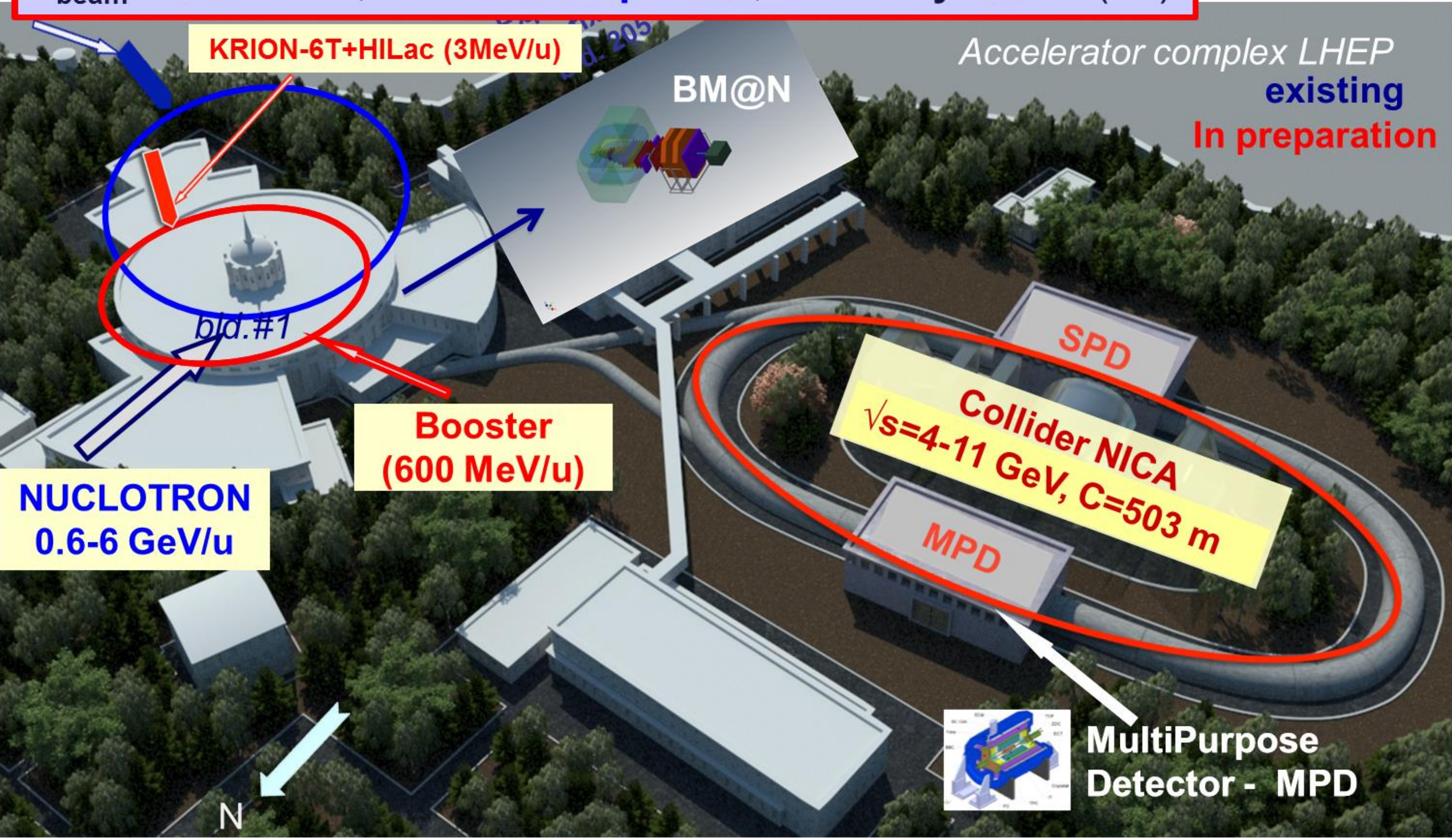
for BM@N Collaboration



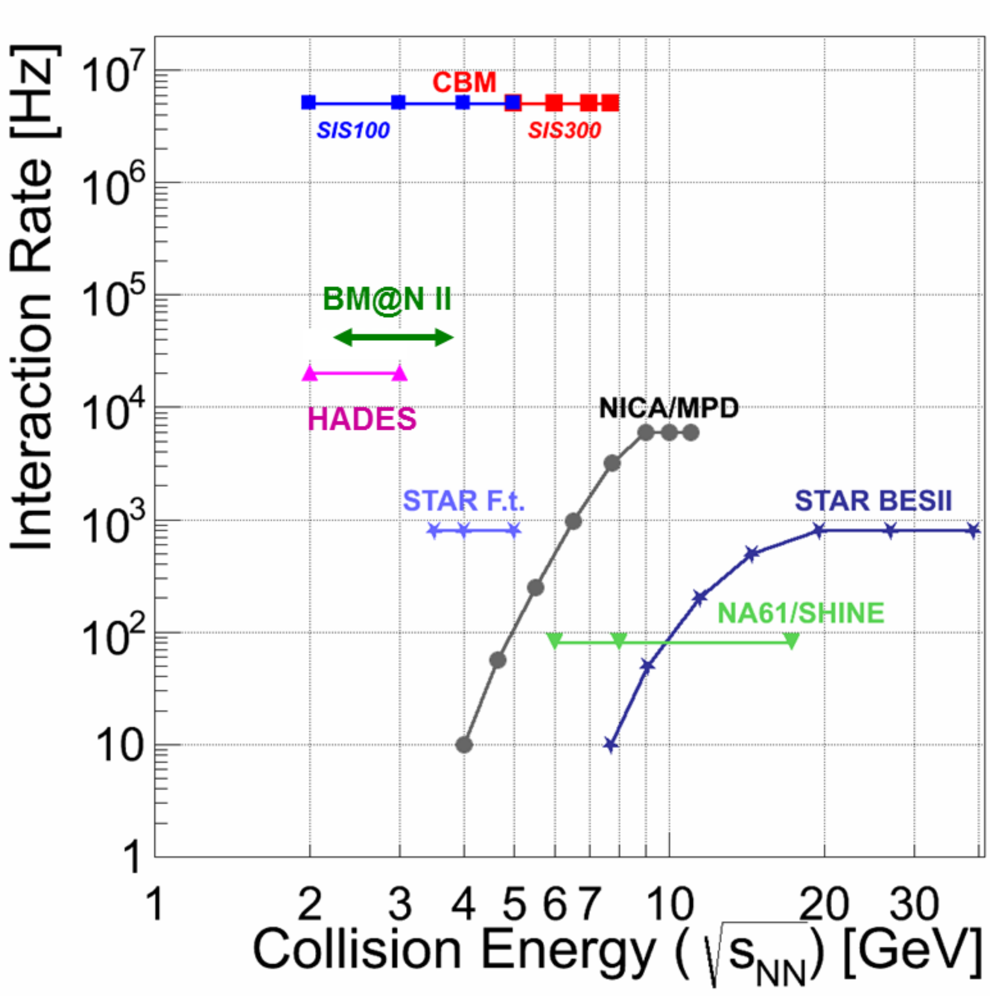
Complex NICA

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



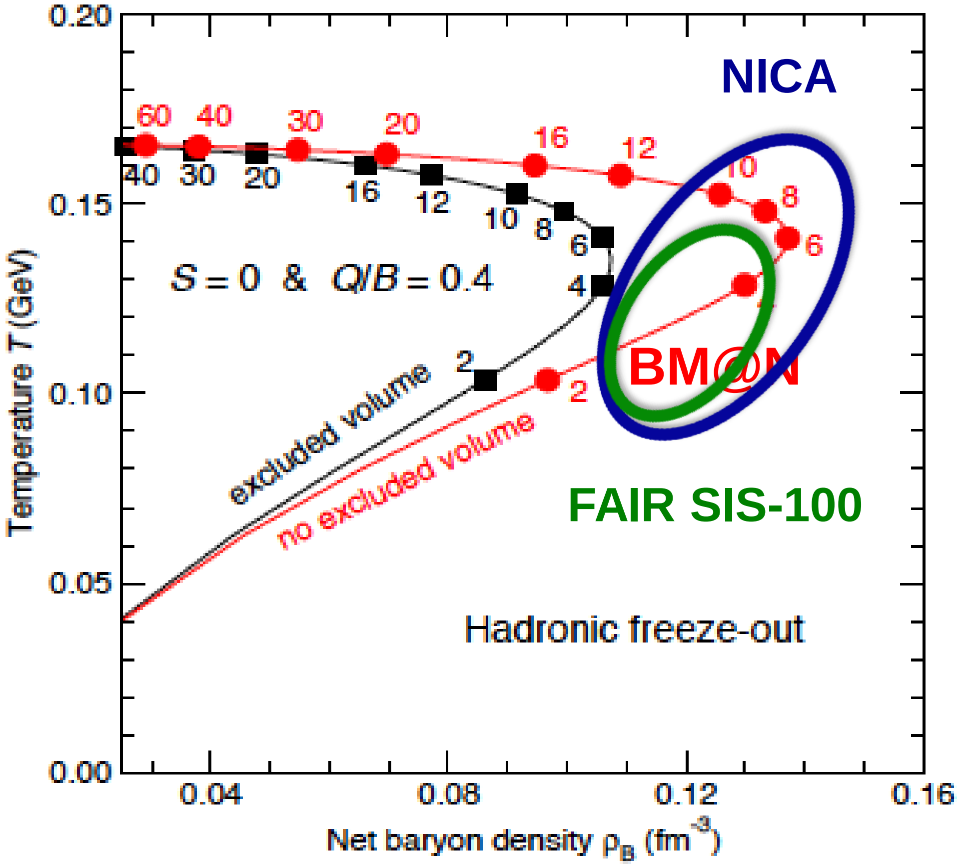
Heavy Ion Collision experiments

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

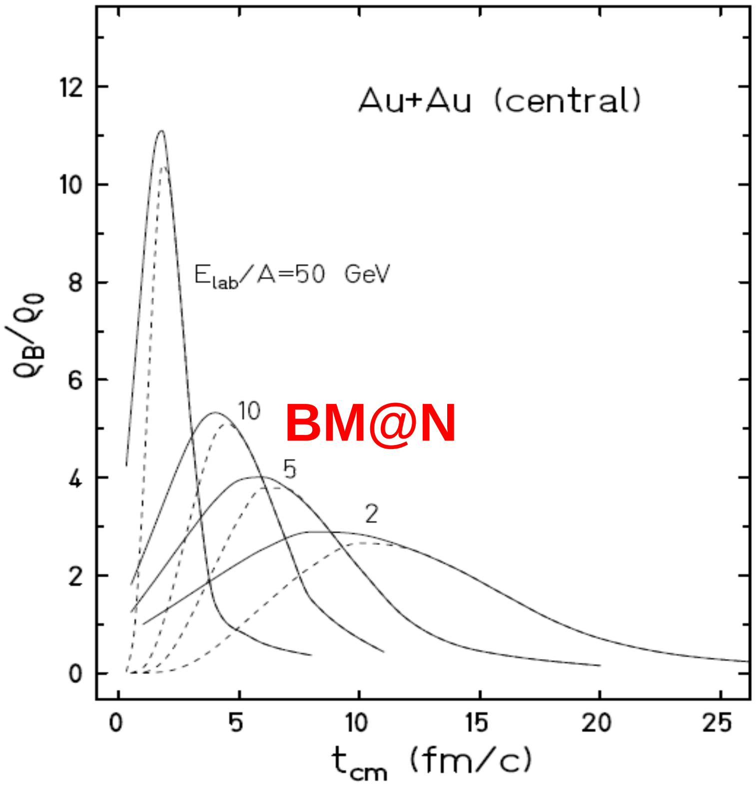


Explore high density baryonic matter

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



Baryon-dominated system throughout comparatively long lifetime



Physics possibilities at the Nuclotron

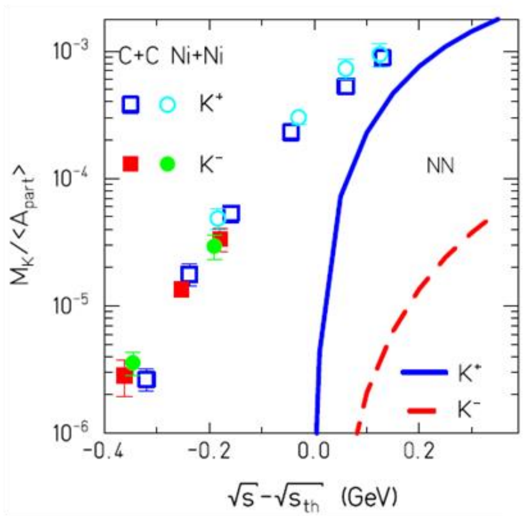
I. In A+A collisions at Nuclotron energies:

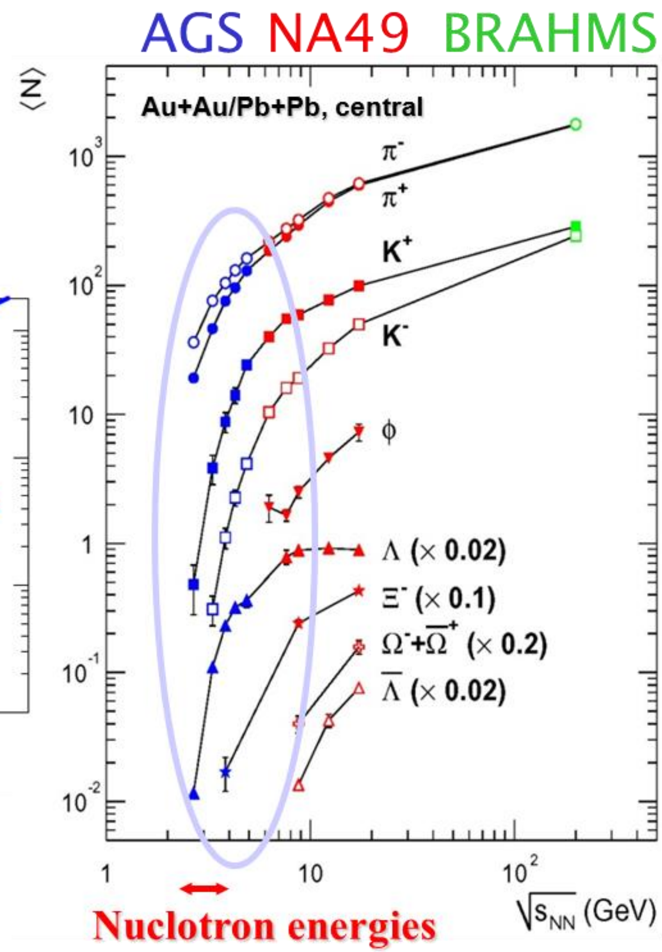
❑ Opening thresholds for strange and multi-strange hyperon production

➔ strangeness at threshold

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

► Collective flows v_1, v_2



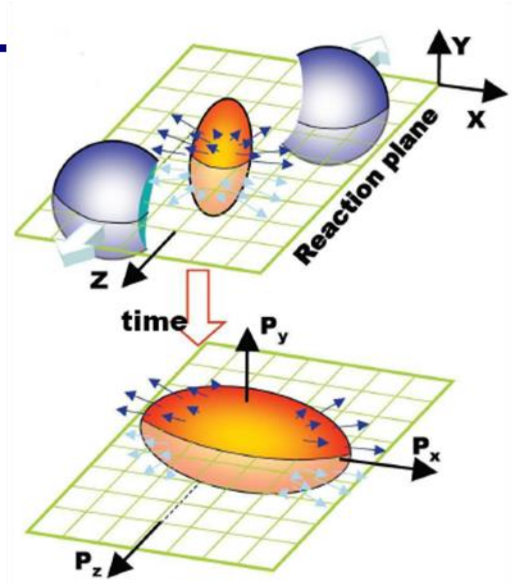


II. In *p+p, p+n, p+A* collisions:

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

Heavy-ions A+A: 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

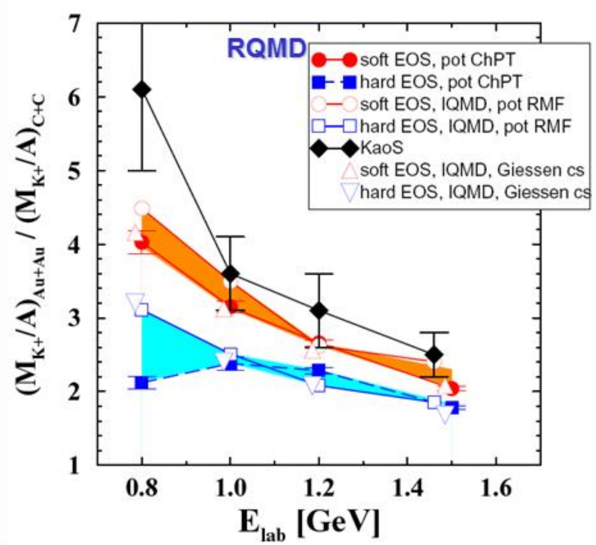
Direct information – proton v_1,v_2

Alternative information – via strangeness

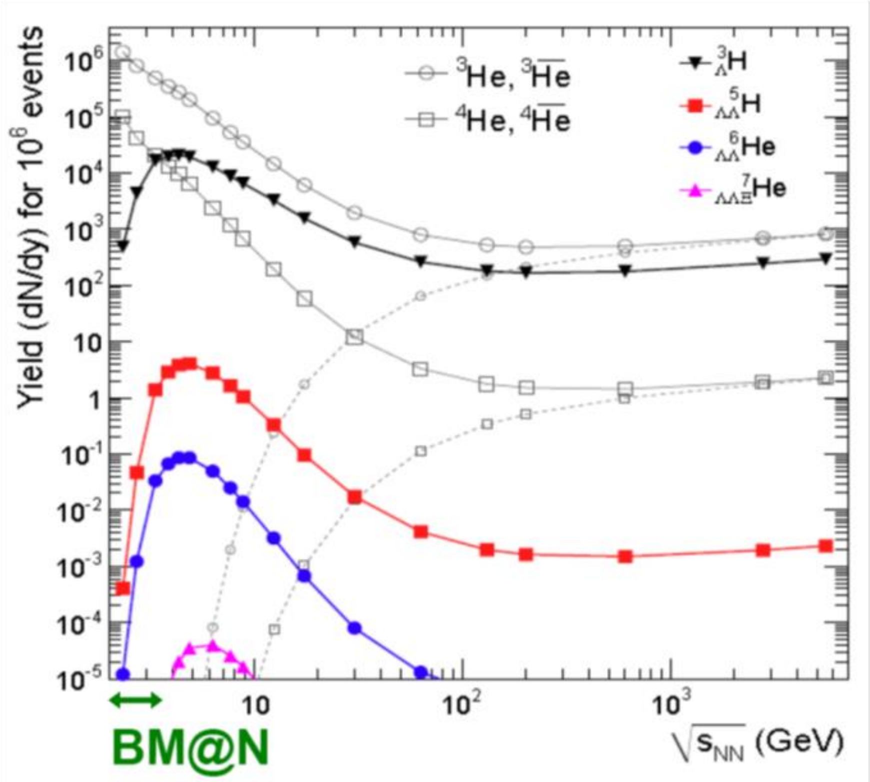
❑ Experience from SIS and AGS :

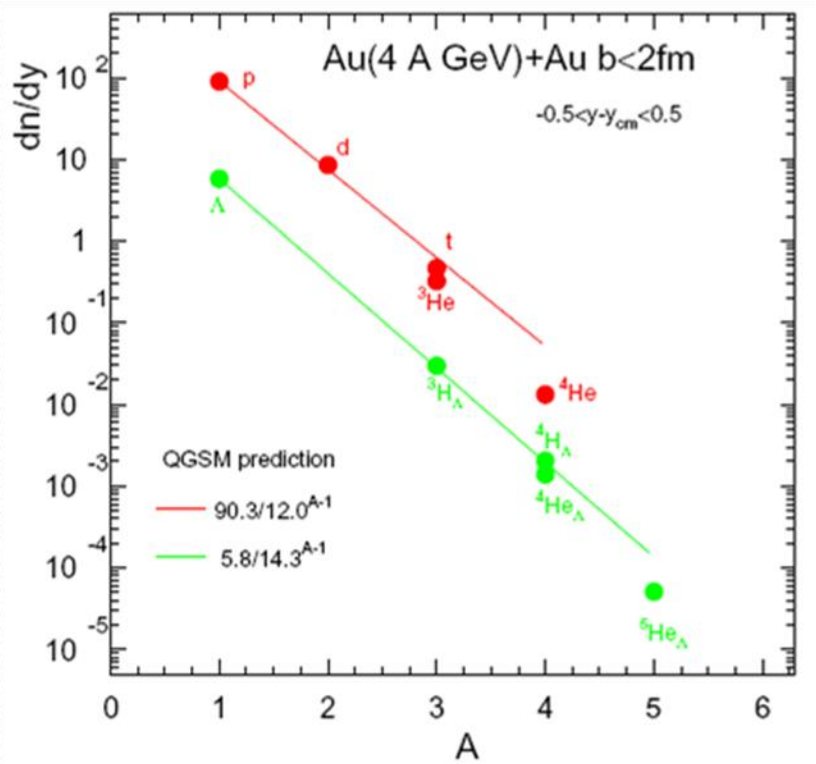
ratio of K^+ yield Au+Au/C+C at SIS energies and proton v_1,v_2 favor a soft EoS (somewhat sensitive to the details of models)

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



Heavy-ions A+A: Hypernuclei production

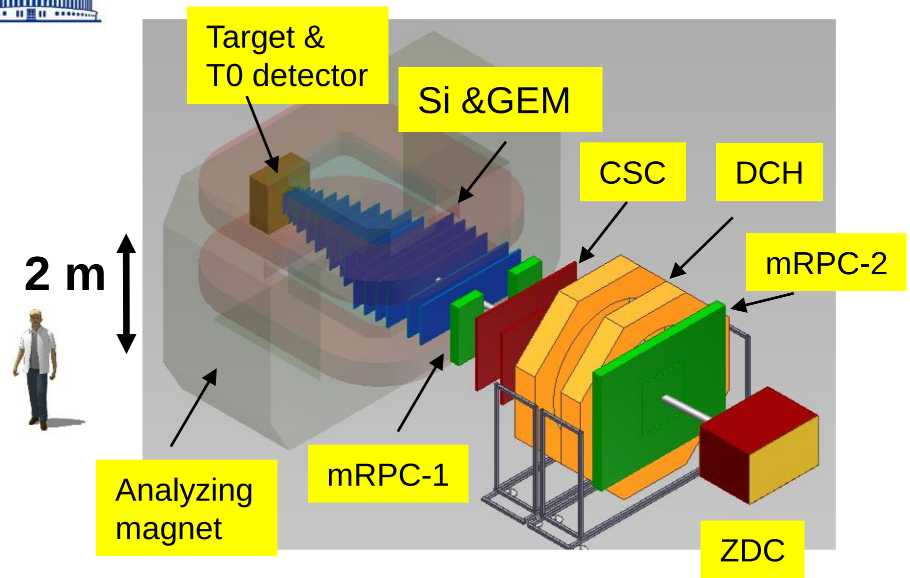




- In heavy-ion reactions: production of hypernuclei through coalescence of Λ with light fragments enhanced at high baryon densities
- Maximal yield predicted for √s=4-5A GeV (stat. model) (interplay of Λ and light nuclei excitation function)

➔ 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

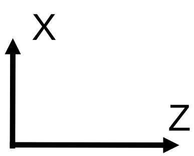
→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

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

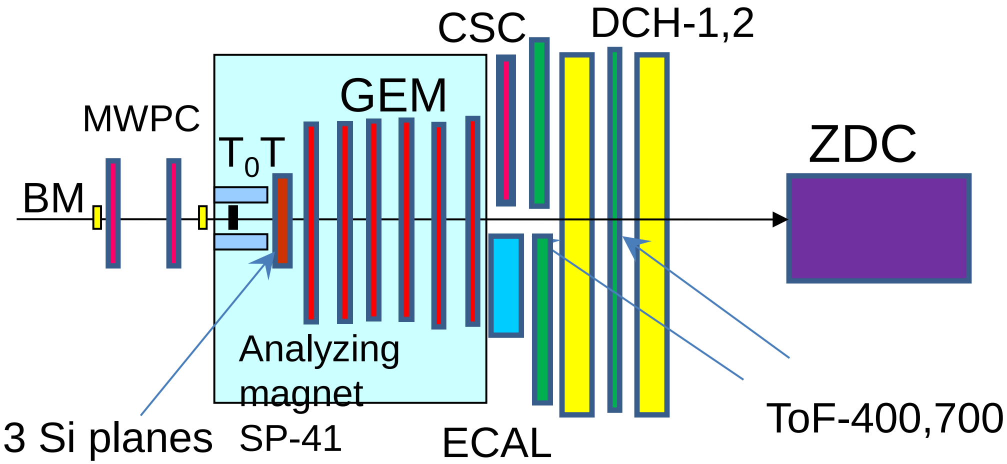
- Central tracker (Si + GEM) inside analyzing magnet to reconstruct AA interactions
- Outer tracker (CSC, DCH) behind magnet to link central tracks to ToF detectors
- ToF system based on mRPC and T0 detectors to identify hadrons and light nucleus
- ZDC calorimeter to measure centrality of AA collisions 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 forward Si strip detectors for tracking**
- **ToF system, trigger detectors, hadron and EM calorimeters, outer tracker**

Program:

- **Measure inelastic reactions Ar (Kr) + target → X on targets Al, Cu, Sn, Pb**

→ Hyperon production measured in central tracker (Si + GEM)

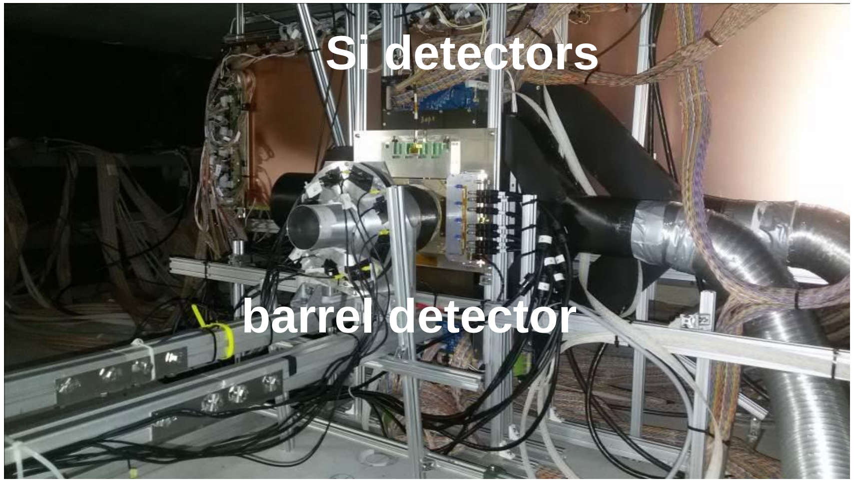
→ Charged particles and nuclear fragments identified with ToF

→ Gamma and multi-gamma states identified in ECAL

→ 130 M events in Ar beam, 50 M events in Kr beam

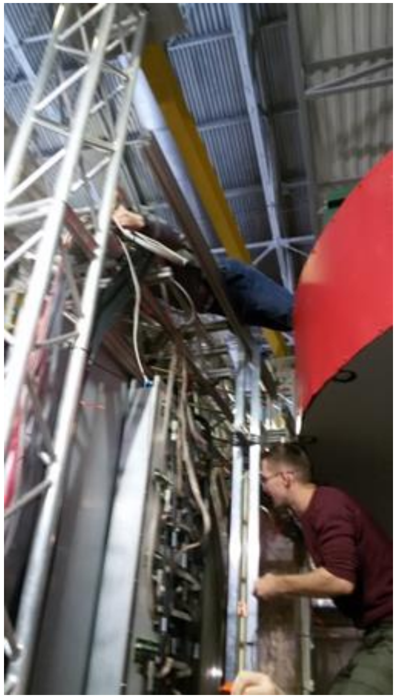
+ analyze data from previous technical runs with Deuteron and Carbon beams of 3.5 - 4.6 GeV/n

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

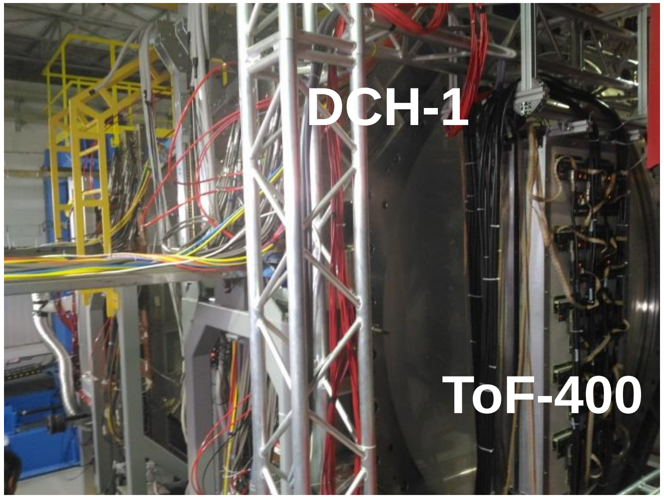


CSC chamber

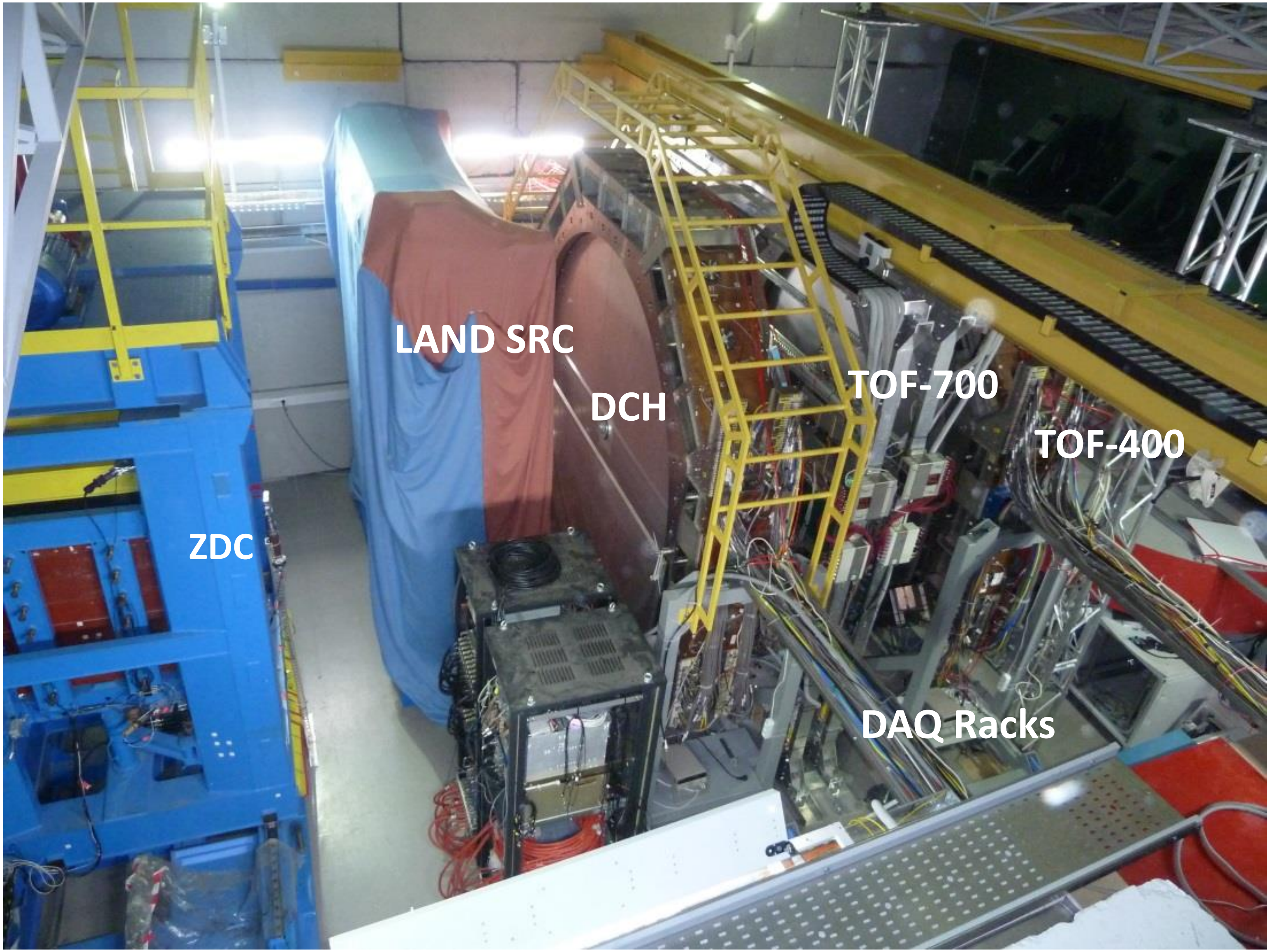
ToF-400 installation



New detector components:
6 big GEMs, trigger detectors, 3 Si detectors, CSC chamber, full set of ToF detectors

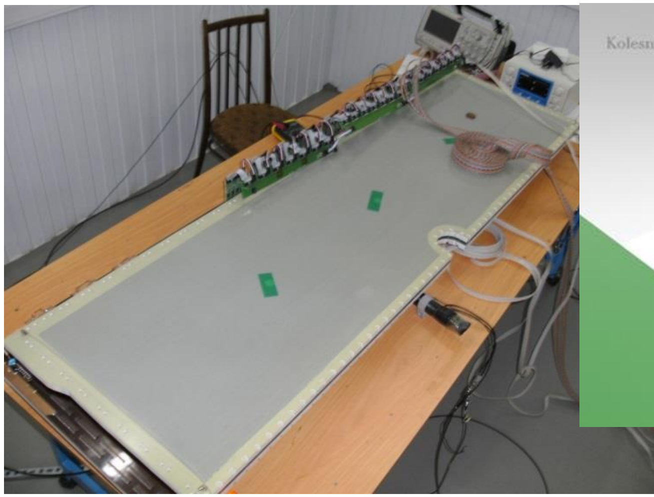


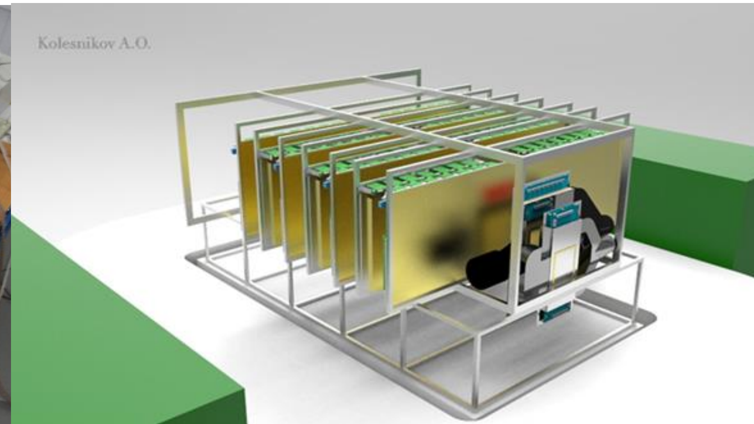
BM@N setup behind magnet, 2018

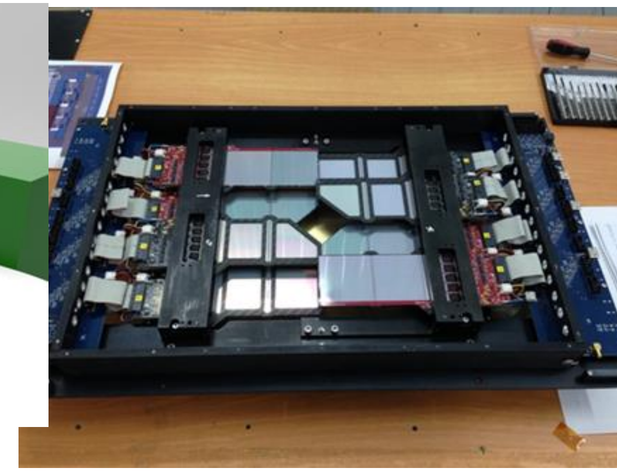


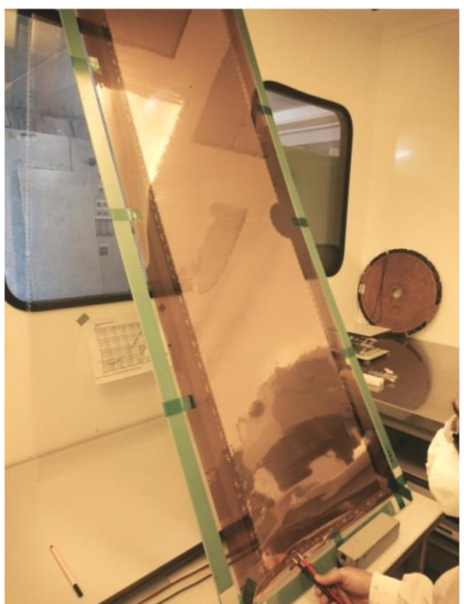
GEM and Si detectors for central tracker

Tests of GEM detector 163 x 45 cm^2









- 7 GEM detectors of 163 x 45 cm^2 are produced at CERN workshop
- 2-coordinate Si strip detector with pitch of 95/103 μm, full size of 25 x 25 cm^2

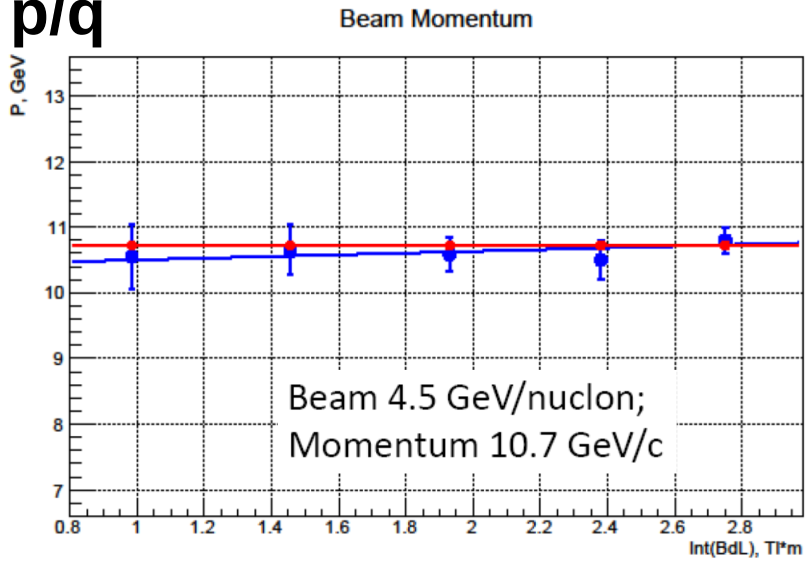
✓ detector combined from 4 sub-detectors arranged around beam

✓ + two smaller vertex Si strip detectors

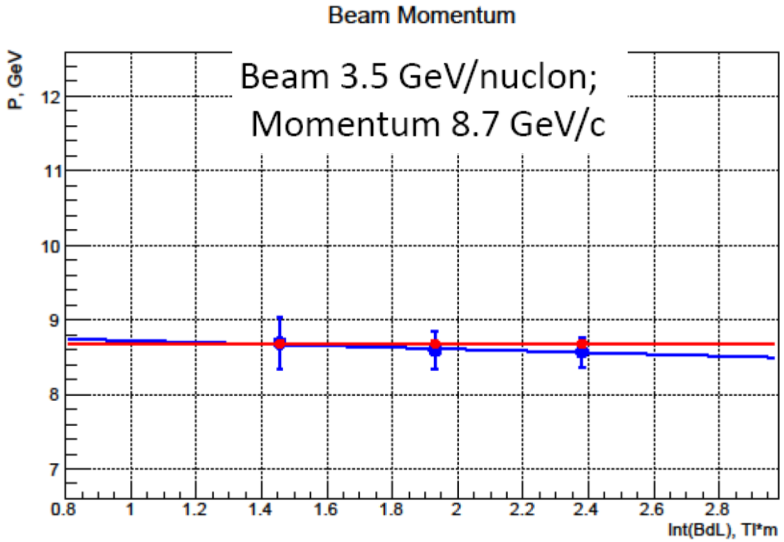
Beam Momentum measured with DCH outer tracker

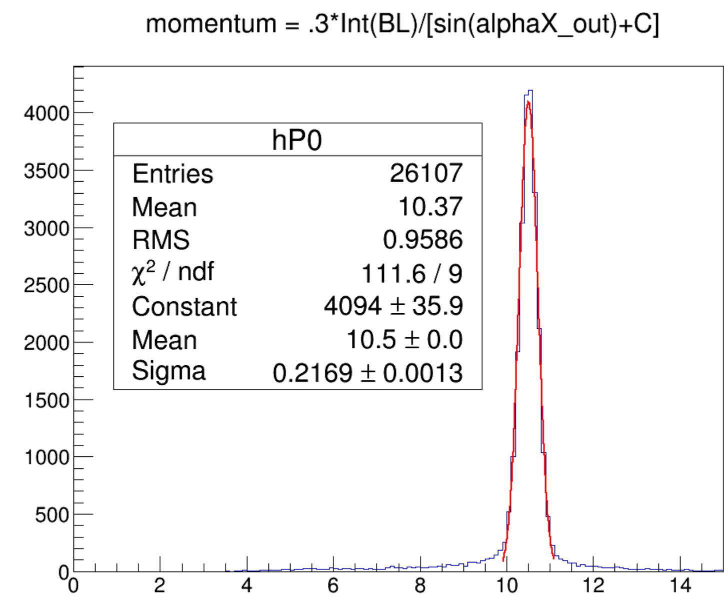
Momentum vs. Int(BdL)

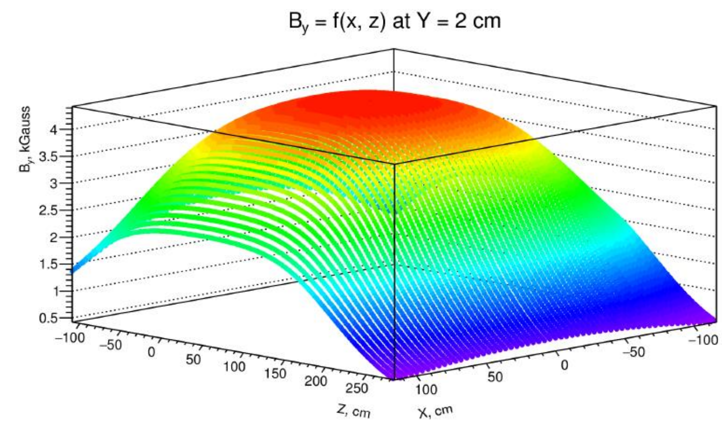
p/q



Error bars → momentum resolution

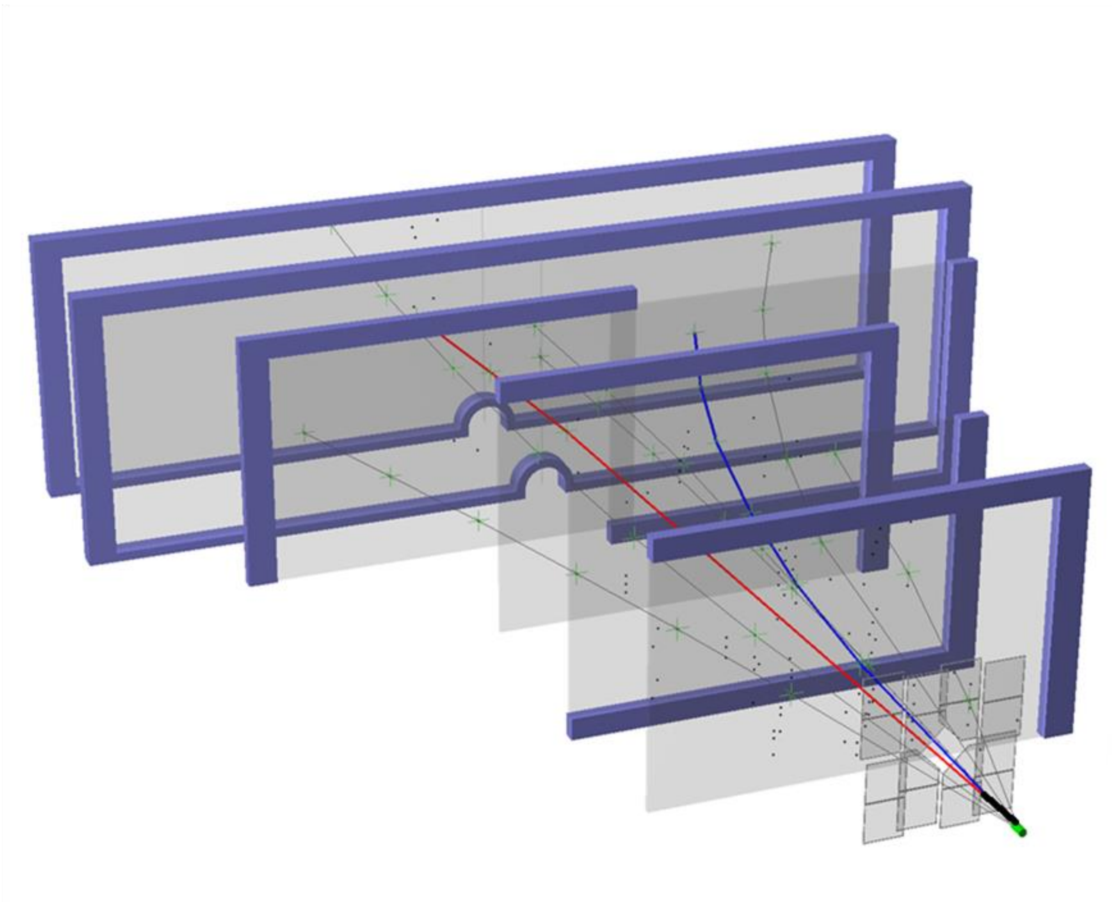


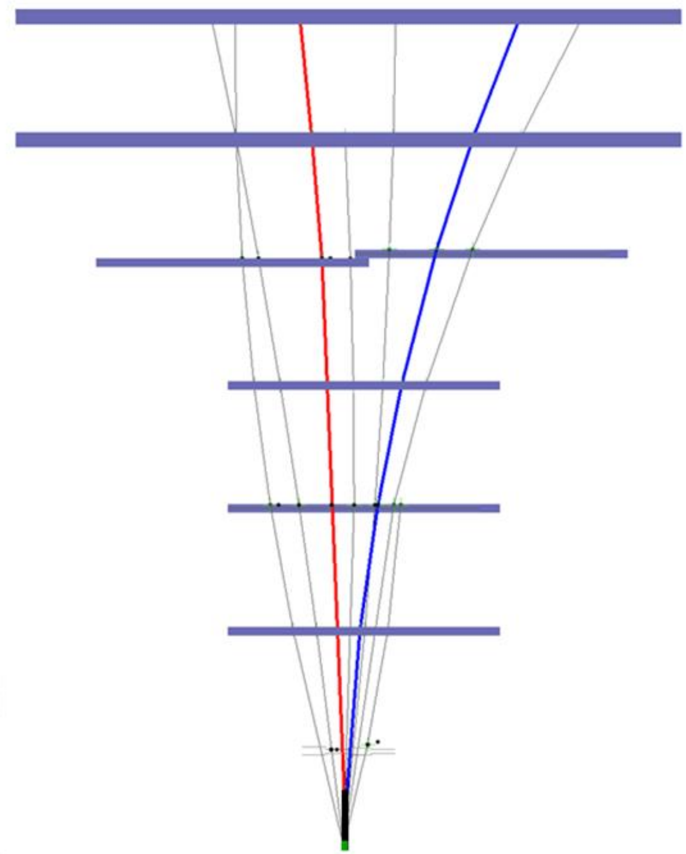




Magnetic field

Event display of Λ decay in C+C collision





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

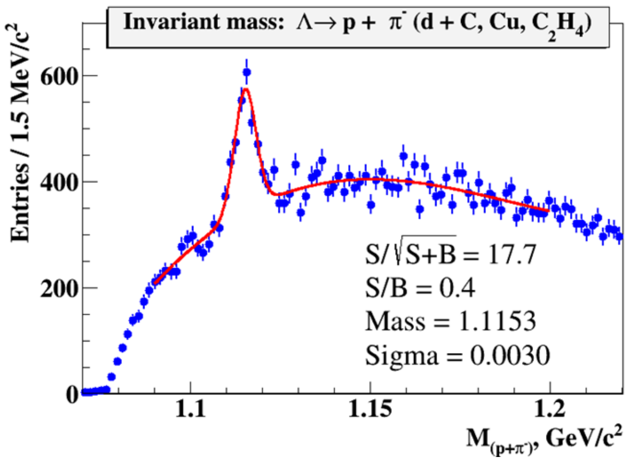
Λ in deuteron and carbon beams

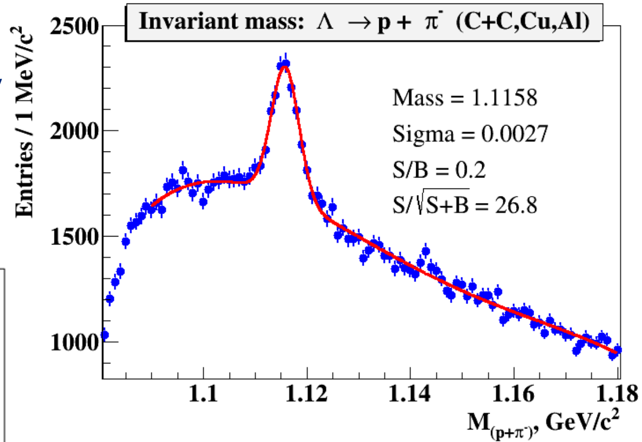
Carbon beam run, 4 AGeV

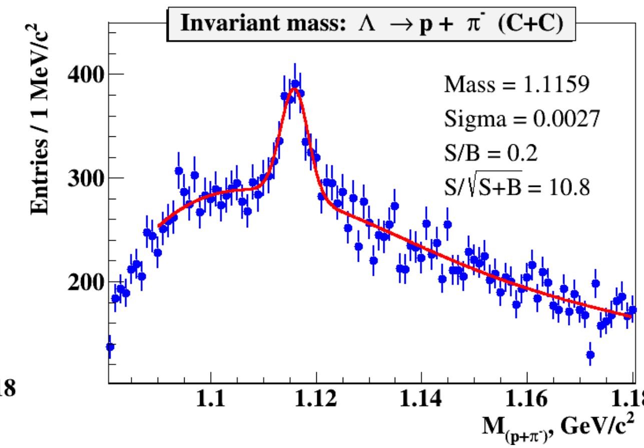
d (C) + target → X

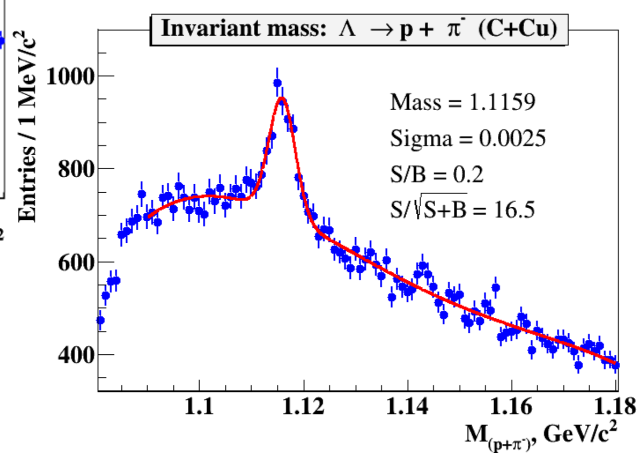
Λ signal width ~ 2.5-3 MeV

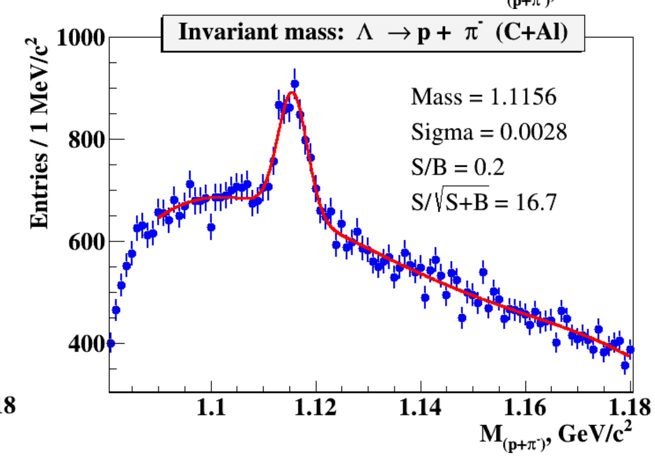
Deuteron Data









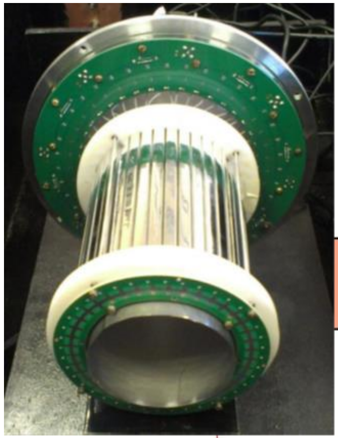


To improve vertex and momentum resolution and reduce background under Λ:

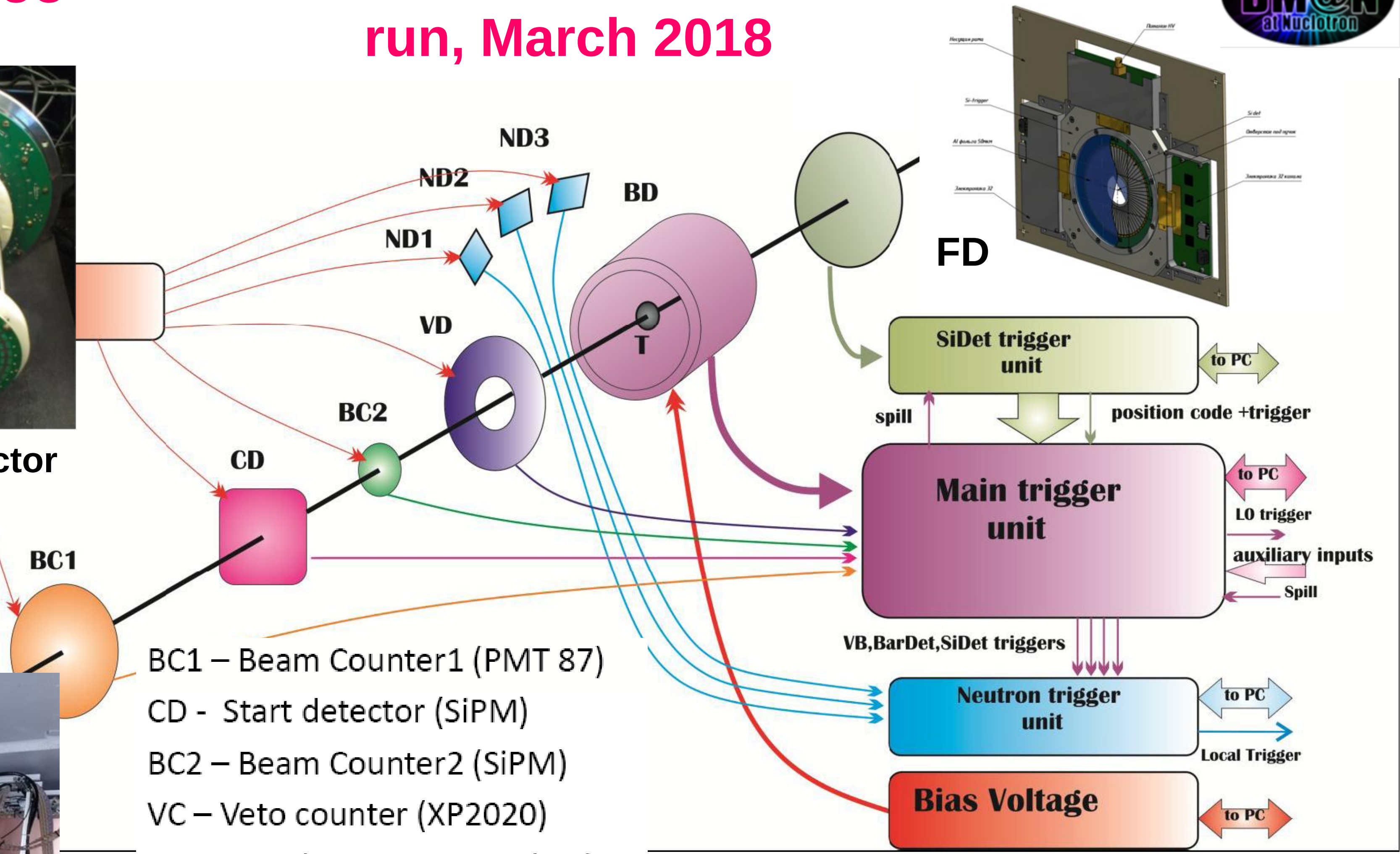
- **Need few planes of forward Silicon detectors → 3 planes used in last run**
- **Need more GEM planes to improve track momentum reconstruction**

Methodical Paper published in PEPAN Letters, v.15, p.136, 2018(2): First results from BM@N technical run with deuteron beam

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



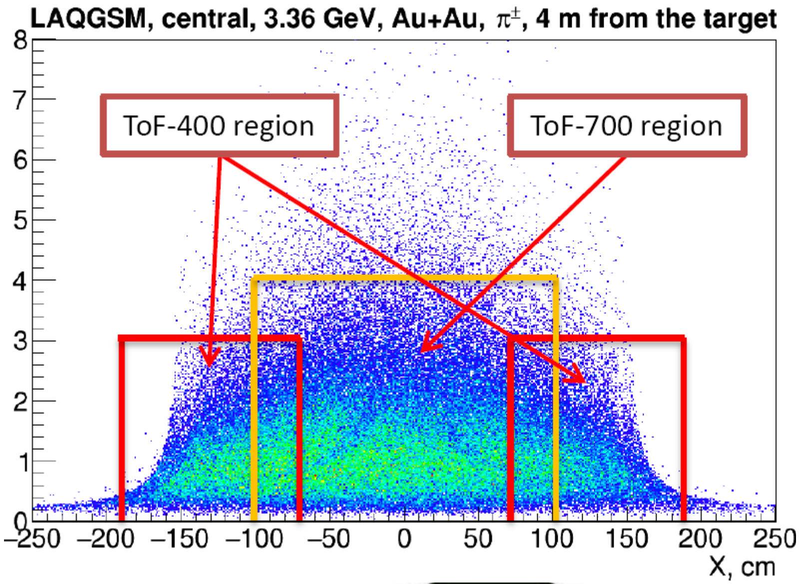
Barrel detector



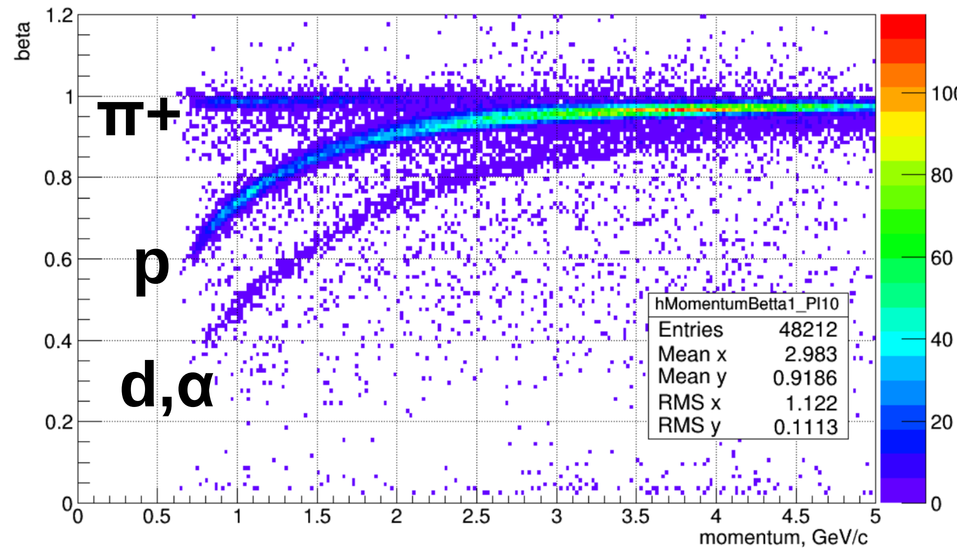
BC1 – Beam Counter1 (PMT 87)
CD - Start detector (SiPM)
BC2 – Beam Counter2 (SiPM)
VC – Veto counter (XP2020)
BD – Barrel Detector – 40ch. SiPM
T – target
SiDet – Silicon Detector

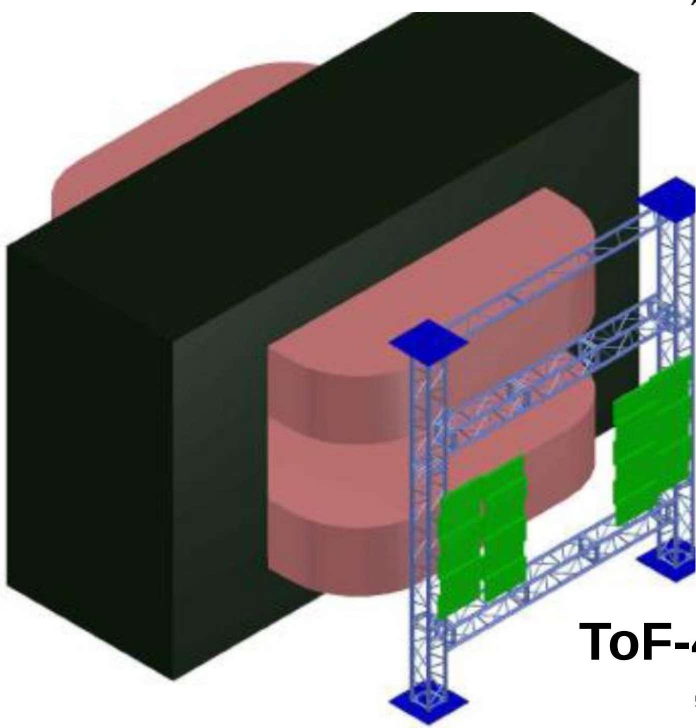
Selection of events with activity in barrel detector: BD >= N or forward Si detector: FD >= N

ToF-400 and ToF-700 based on mRPC



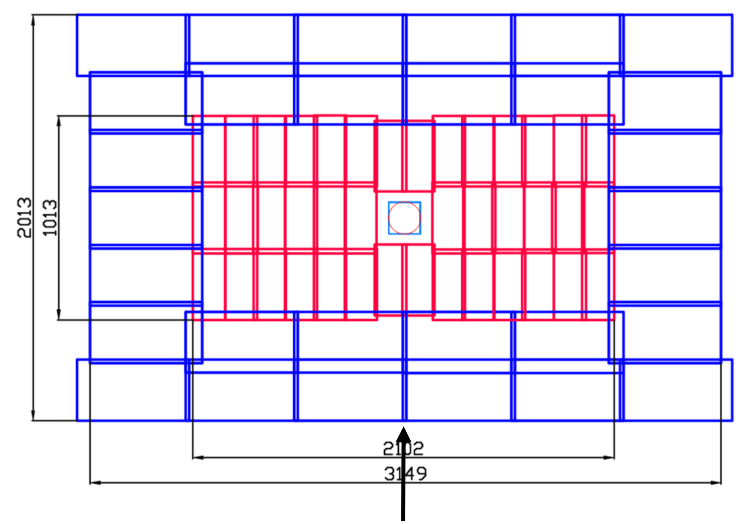
Carbon beam , 3.5 AGeV , C + Al → X





ToF-400 wall

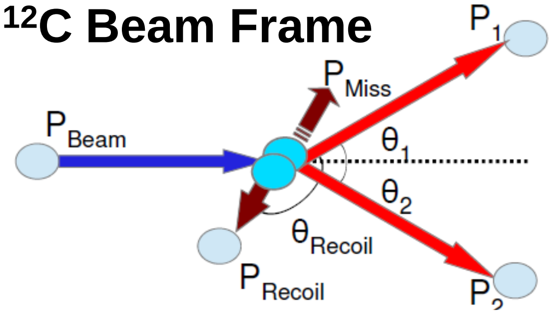
ToF-700 wall



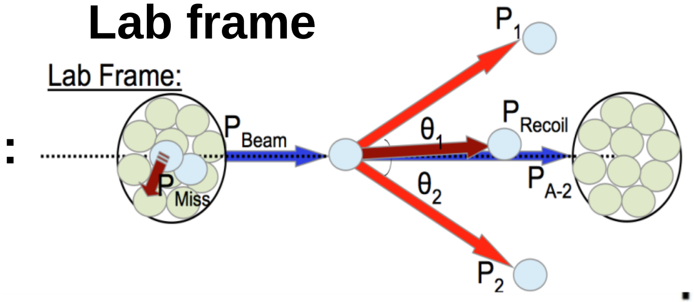
BM@N beam axis

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

^{12}C Beam Frame



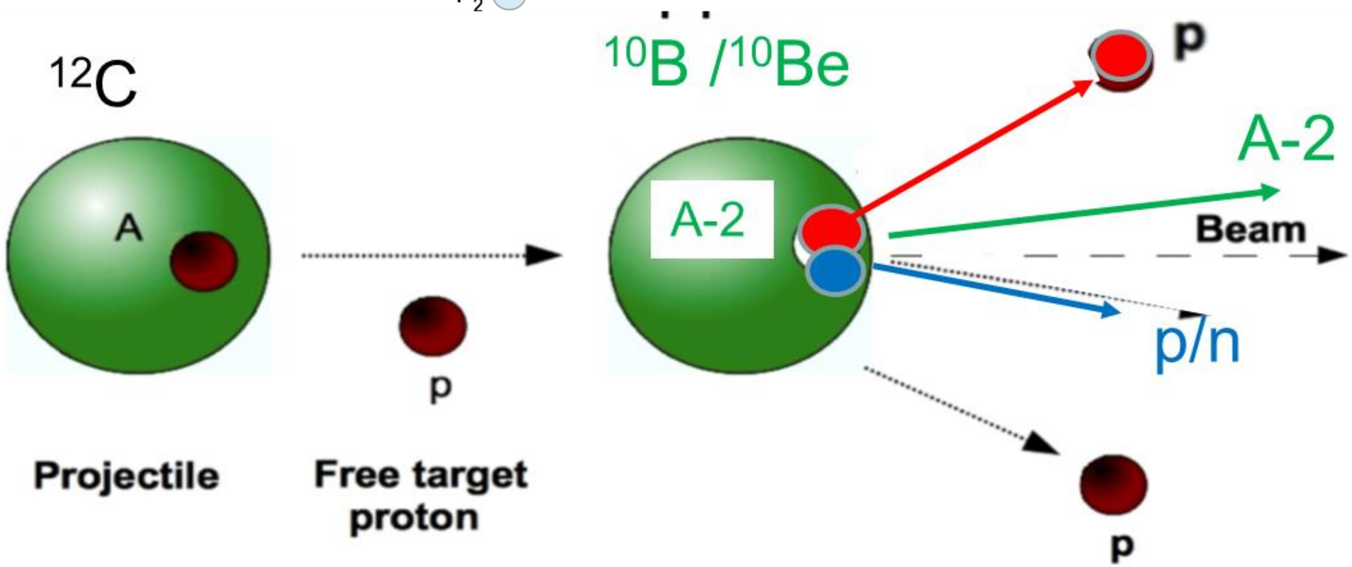
Lab frame



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

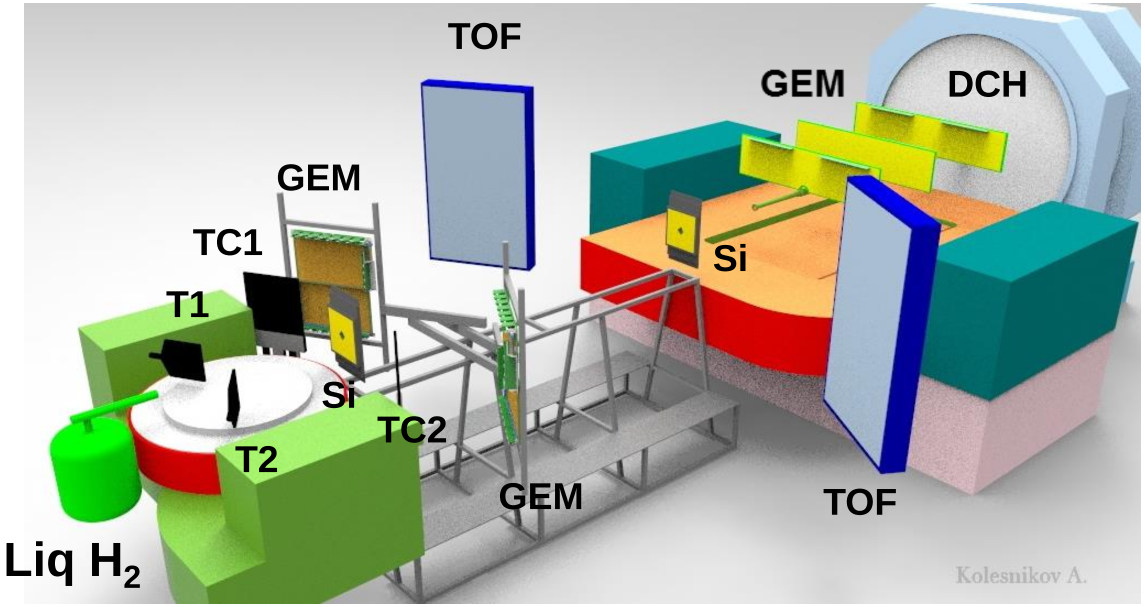
Objectives:

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



BMN & SRC set-up

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



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

Beam parameters and setup at different stages of BM@N experiment

Year	2016	2017 spring	2018 spring	2020	2021 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	Au	Au,p
Max.intensity, Hz	0.5M	0.5M	0.5M	1M	5M
Trigger rate, Hz	5k	5k	10k	10k	20k→50k
Central tracker status	6 GEM half planes	6 GEM half planes	6 GEM half planes + 3 small Si planes	7 GEM full planes + small + large Si planes	7 GEM full planes + small + large Si planes
Experimental status	technical run	technical run	technical run+physics	stage1 physics	stage2 physics

Present status and next plans

- BM@N scientific program comprises studies of nuclear matter in intermediate range between SIS and NICA/FAIR
- First meeting of BM@N / MPD experiments to form Collaborations
- 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 performed with inverse kinematics: C beam + H_2 target
- Major sub-systems are operational, but are still in limited configurations
- Algorithms for event reconstruction and analysis are being developed, signals of Λ hyperon decays are reconstructed

Major BM@N plans for Au+Au to start in 2020:

- 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 vacuum / helium beam pipe through BM@N setup

Thank you
for attention!

Backup slides

Nuclotron and BM@N beam line

26 elements of magnetic optics:

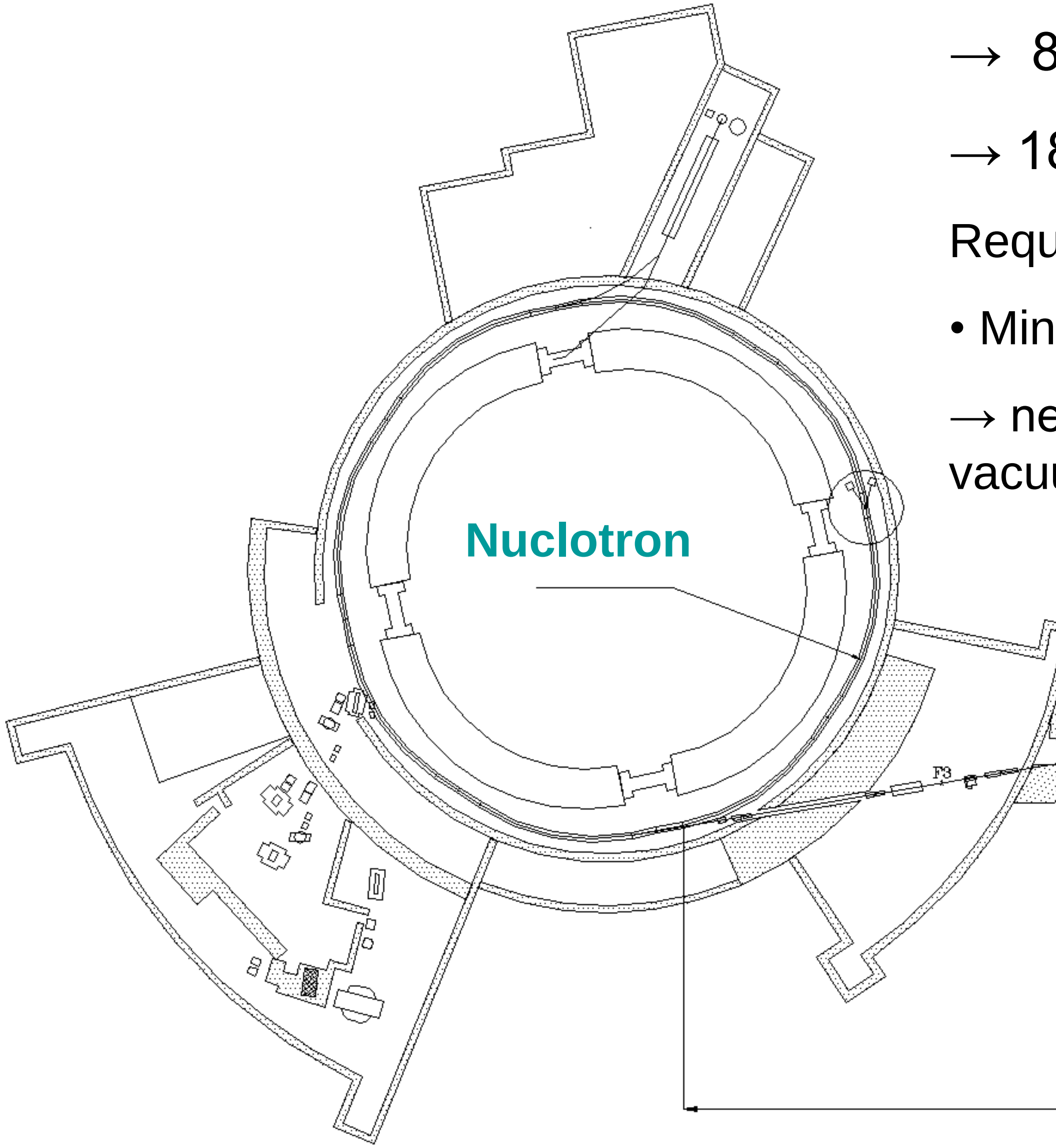
→ 8 dipole magnets

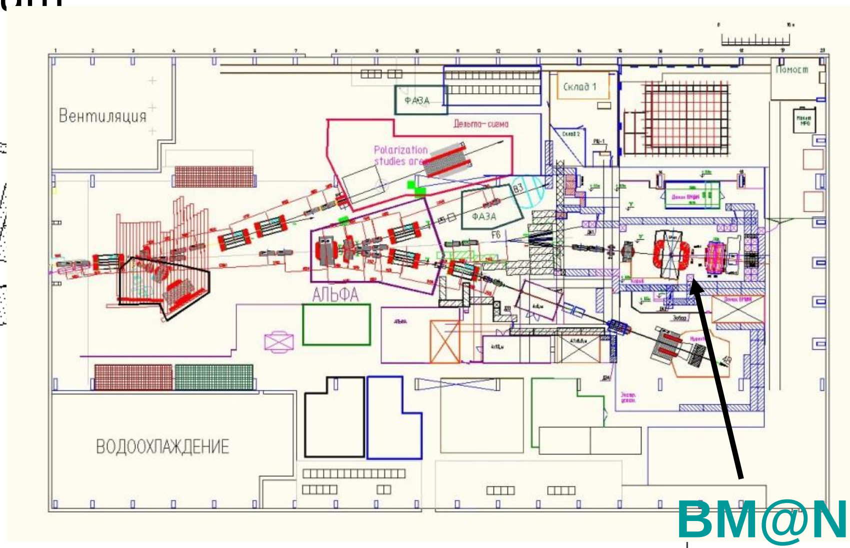
→ 18 quadruple lenses

Requirements for Au beam:

• Minimum dead material

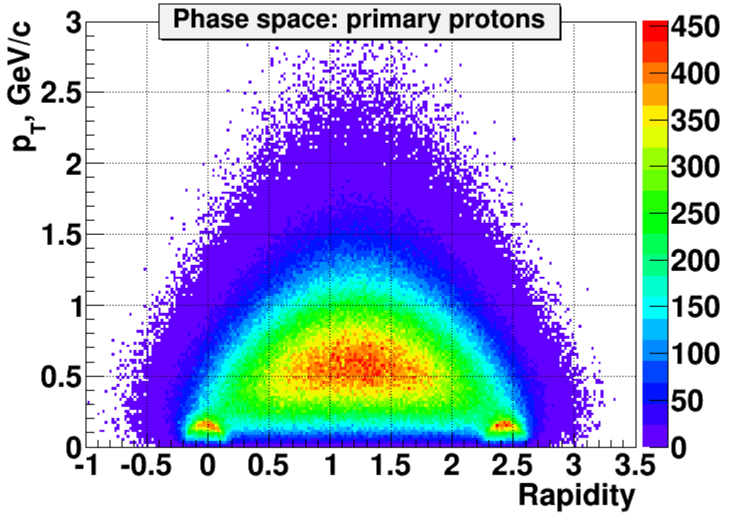
→ need to replace air intervals / foils with vacuum

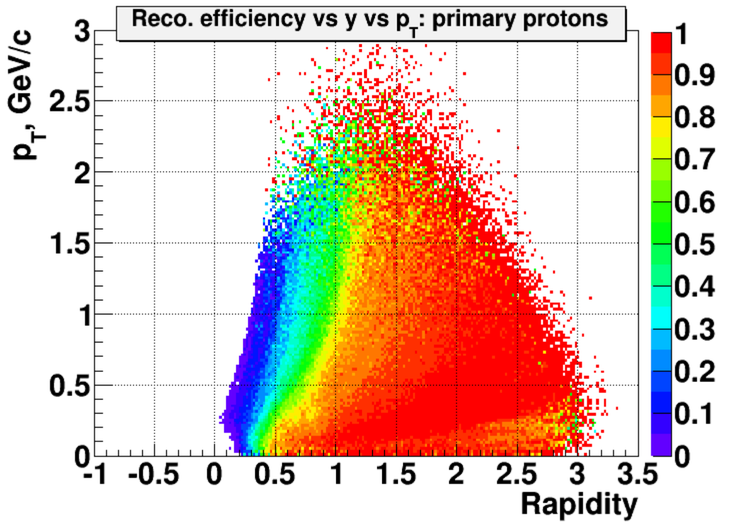




GEM tracker: acceptance / momentum resolution / detection efficiency

Phase space / acceptance to primary protons: Au+Au, 4.5 AGeV





Momentum resolution / detection efficiency