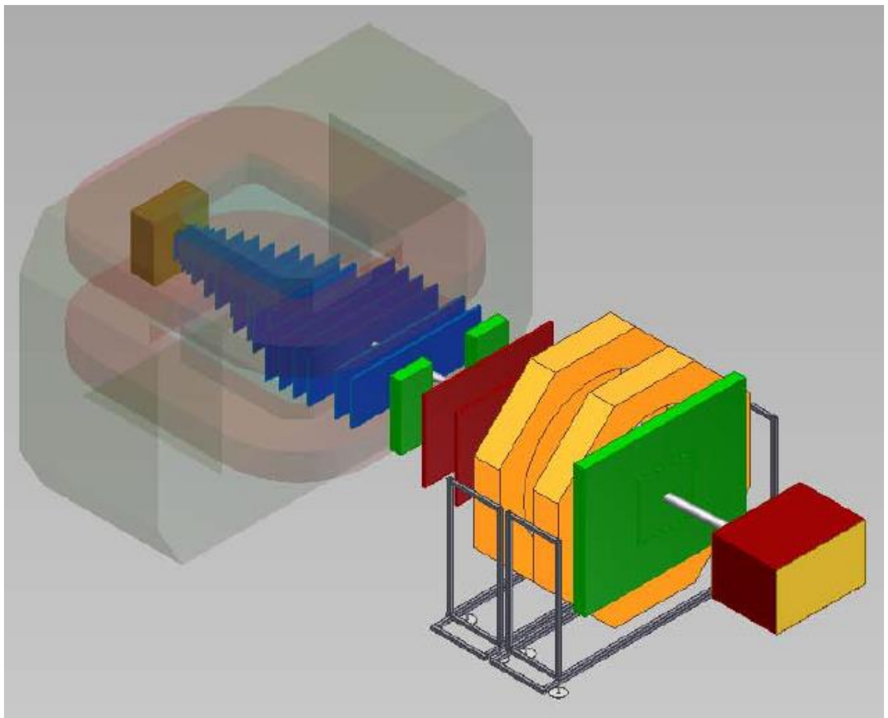
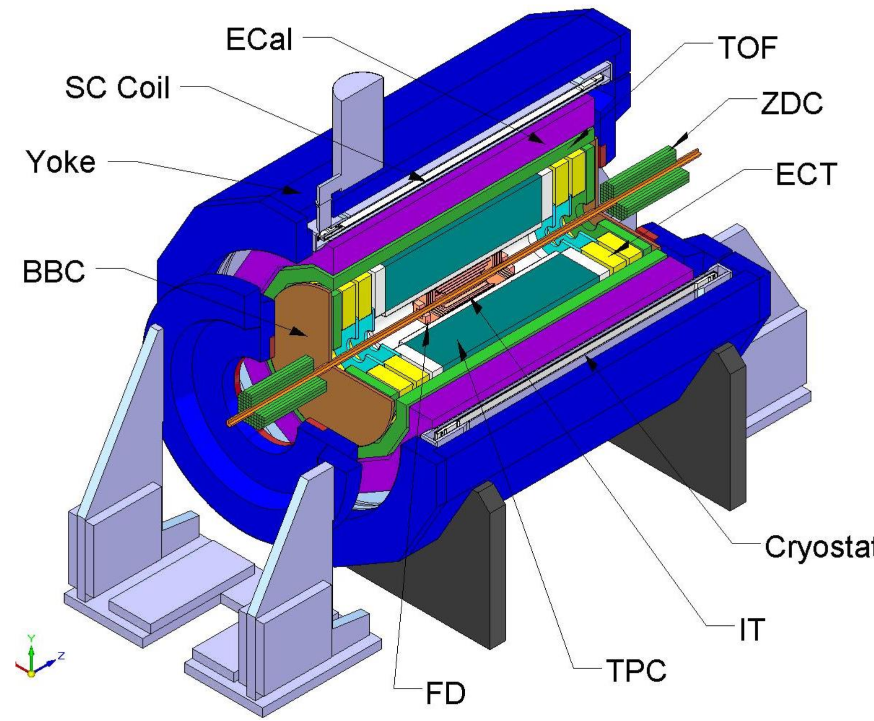
Studies of Baryonic Matter at BM@N and MPD experiments JINR

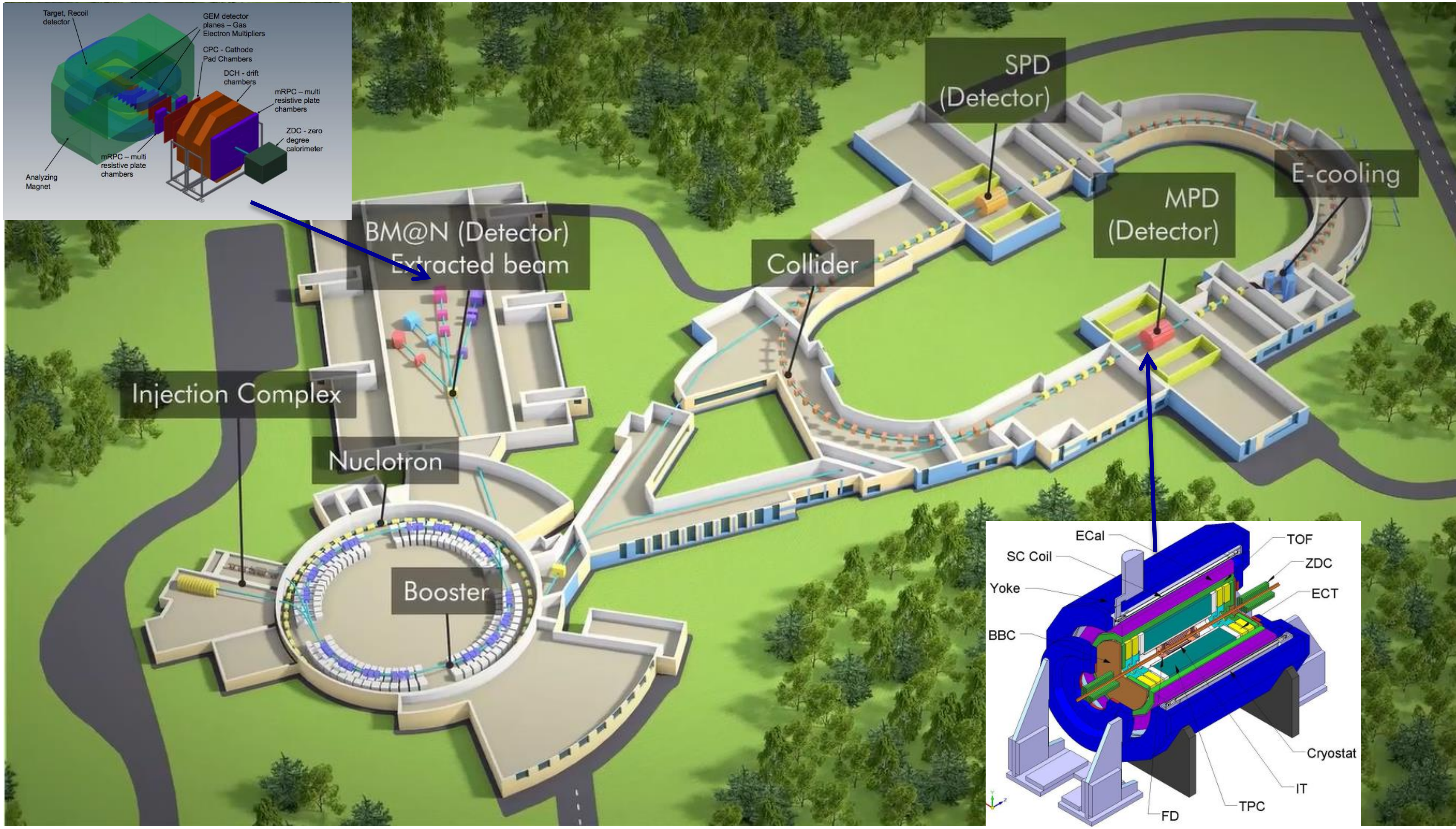
M.Kapishin





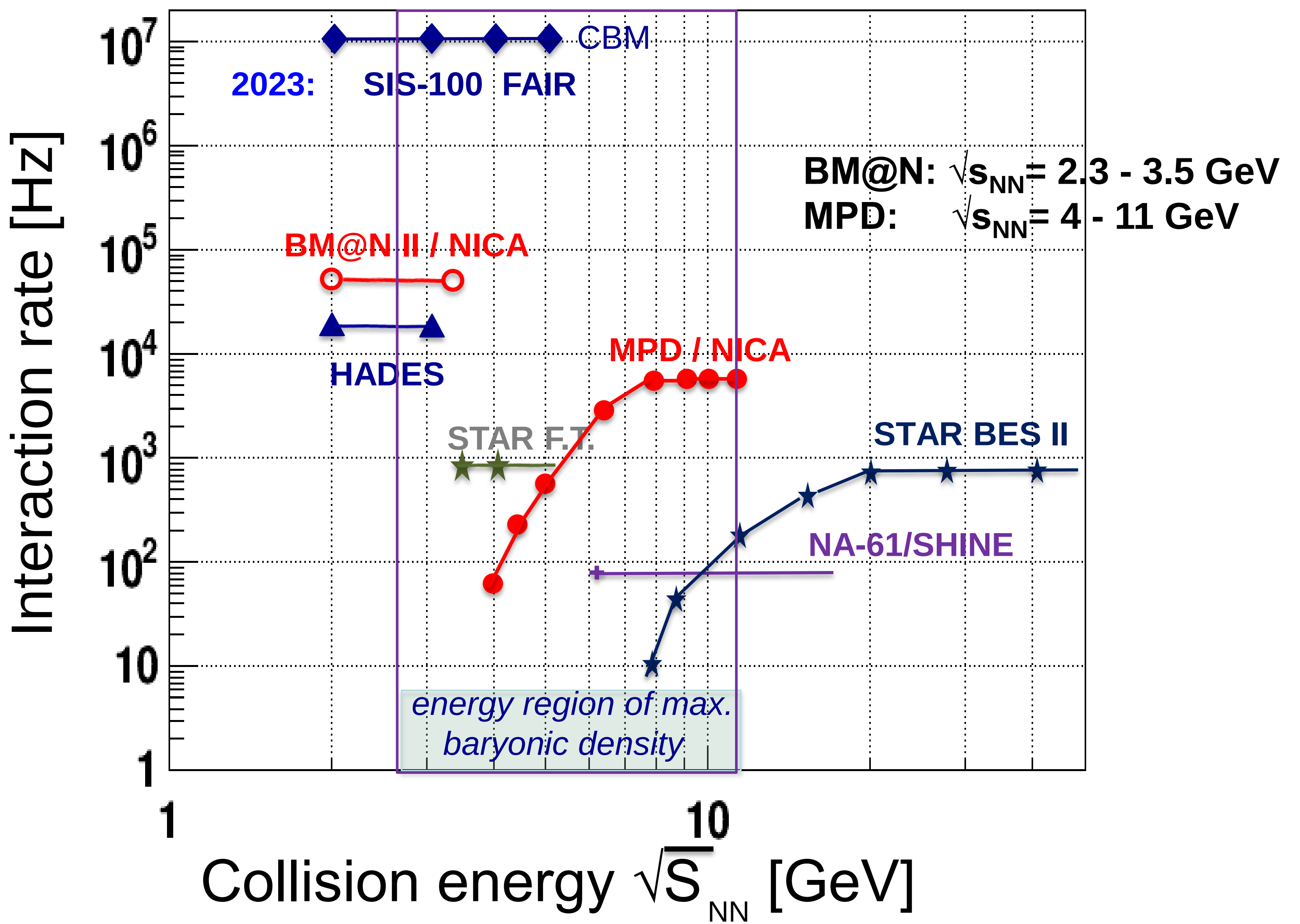
NICA Heavy Ion Complex

BM@N: heavy ion energy 1 - 4.5 GeV/n, beams: p to Au, Intensity up ~10^7 /s (Au)



MPD / NICA: Au+Au $\sqrt{s_{NN}}$ = 4 – 11 GeV, Luminosity~10^{27} /cm^2/s

Heavy Ion Collision Experiments



Physics possibilities at the Nuclotron

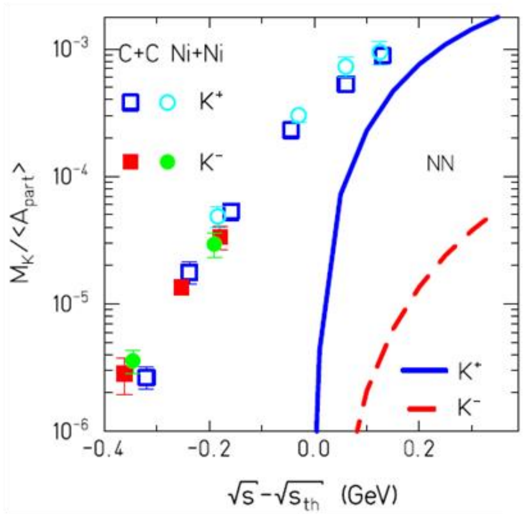
I. In A+A collisions at Nuclotron energies:

❑ Opening thresholds for strange and multi-strange hyperon production

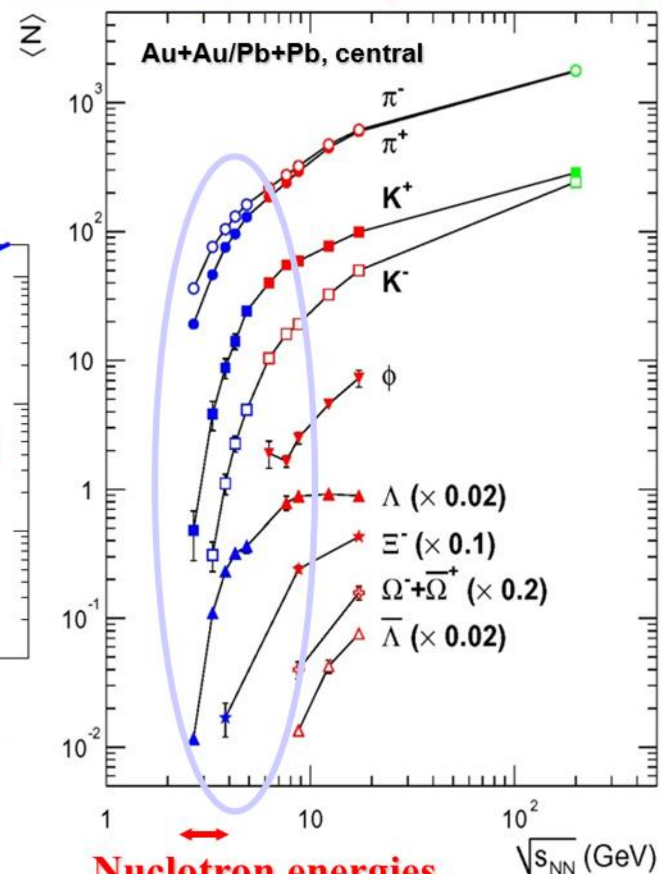
➔ strangeness at threshold

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

► Collective flows v_1, v_2



AGS NA49 BRAHMS



Nuclotron energies

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

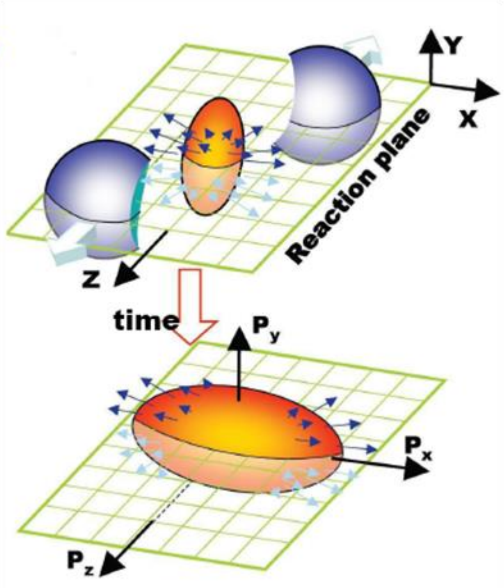
➔ hadron production in elementary reactions and ‚cold' nuclear matter as ‚reference' to pin down nuclear effects

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

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

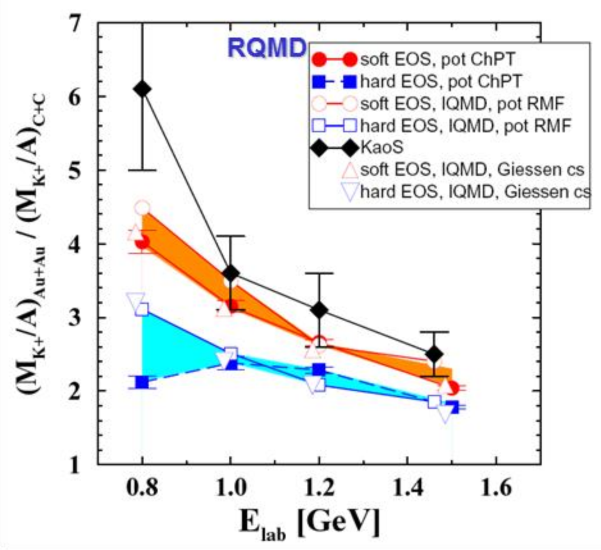
➔Observables sensitive to EoS:
collective flow (v_1,v_2,…)
particle ratios

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)

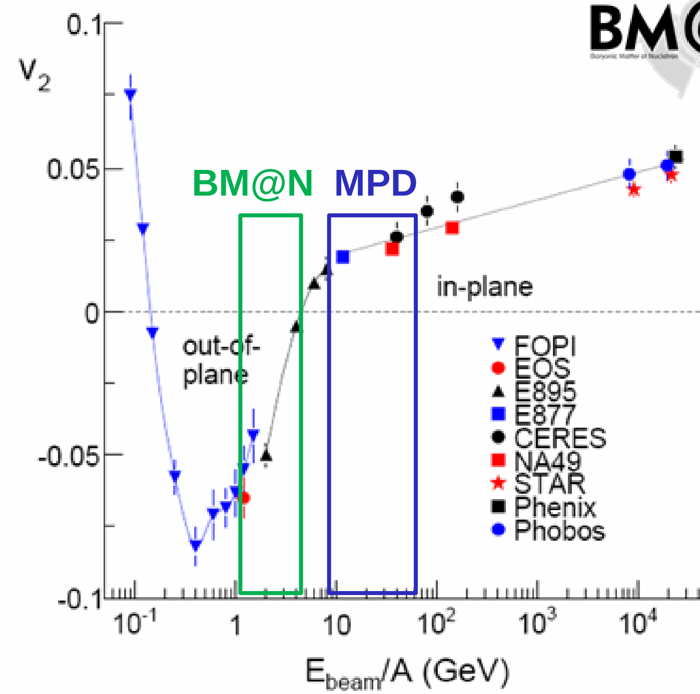
➔ Density dependence of the EoS can be studied in BM@N by a beam energy scan



Study of EoS: Collective flow of identified particles

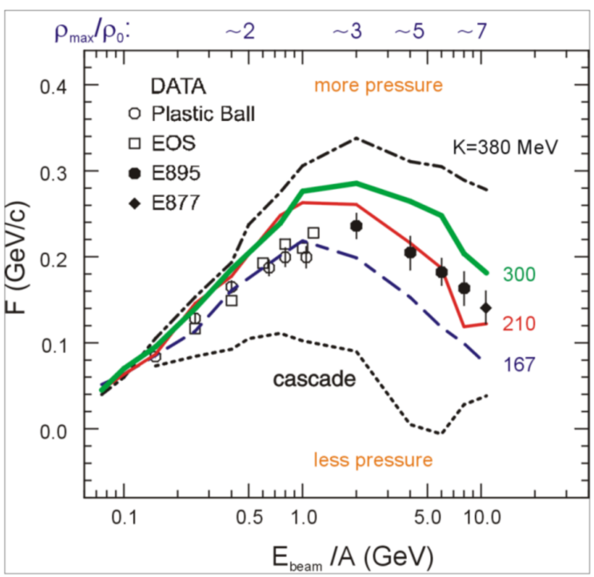
Azimuthal angle distribution:
$dN/d\varphi \propto (1 + 2v_1 \cos\varphi + 2v_2 \cos 2\varphi)$

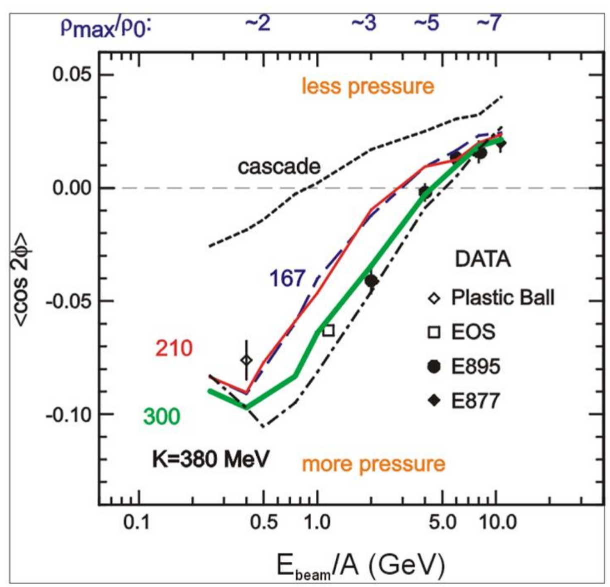
Nuclear incompressibility: $K = 9\rho^2\ \delta^2(E/A)/\delta\rho^2$



Proton flow in Au+Au collisions

in-plane flow $\sim v_1$ out-of-plane flow v_2



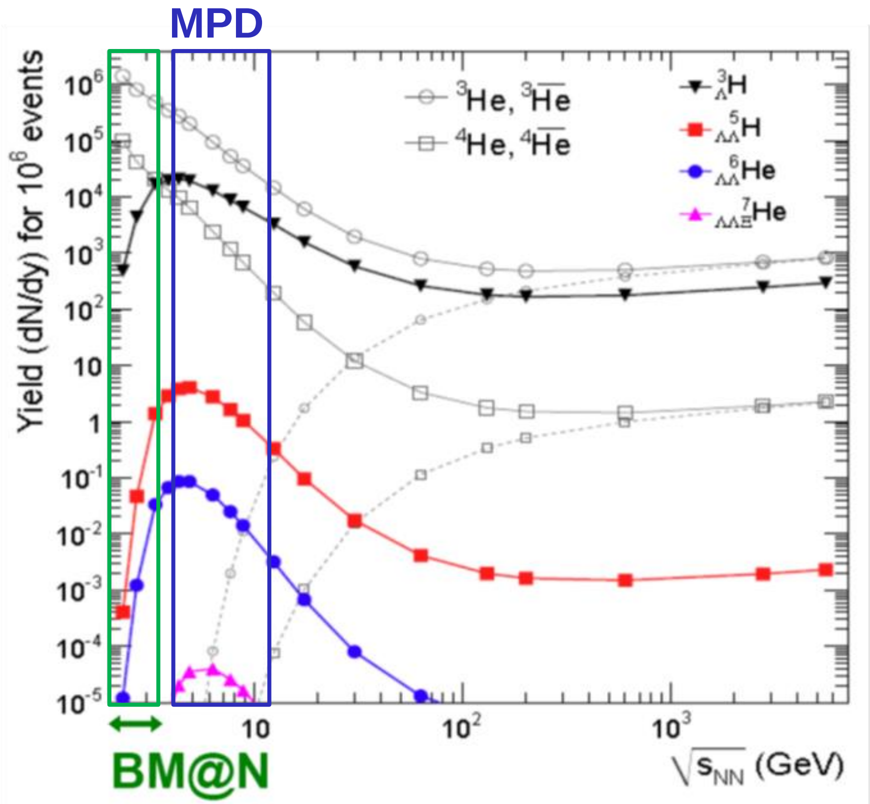


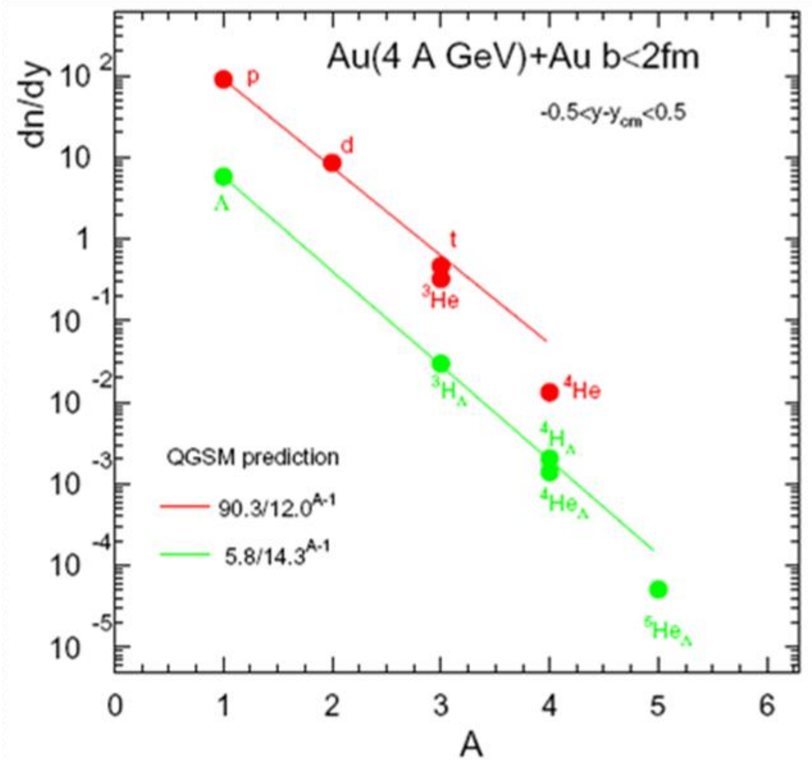
P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592

M.Kapishin

BM@N / MPD experiments

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)

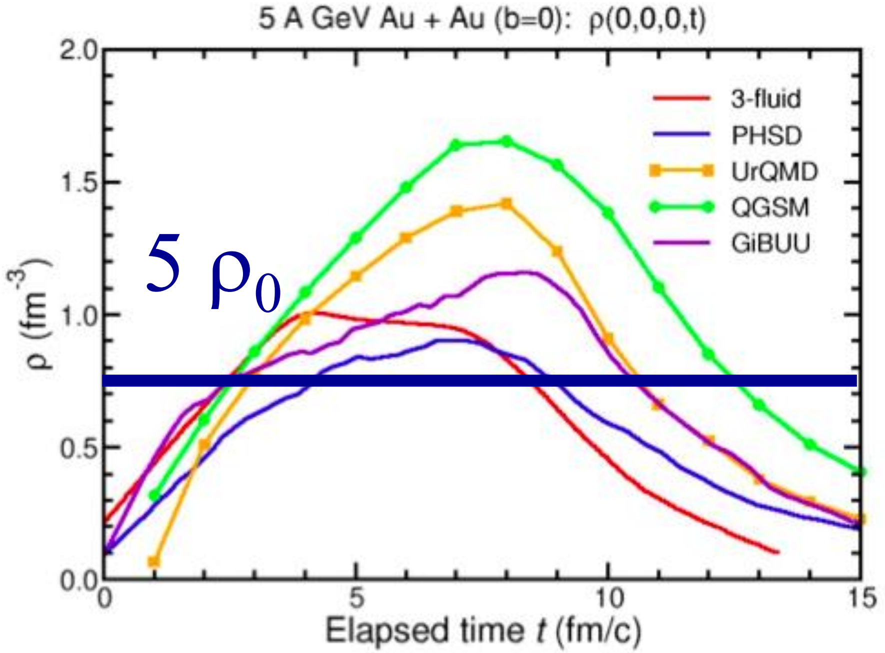
► BM@N / MPD energy range is suited for search of hyper-nuclei

Explore high density baryonic matter

Baryonic densities in central Au+Au collisions

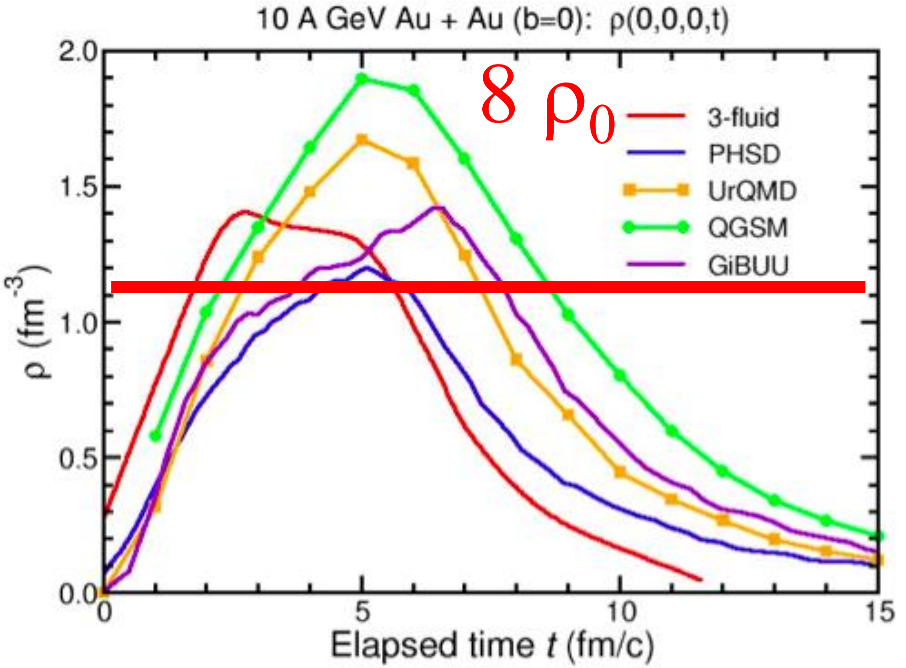
FAIR SIS-100 / Nuclotron

5 A GeV



FAIR SIS-100 / NICA

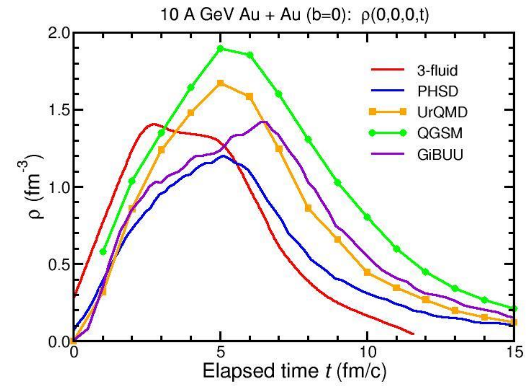
10 A GeV

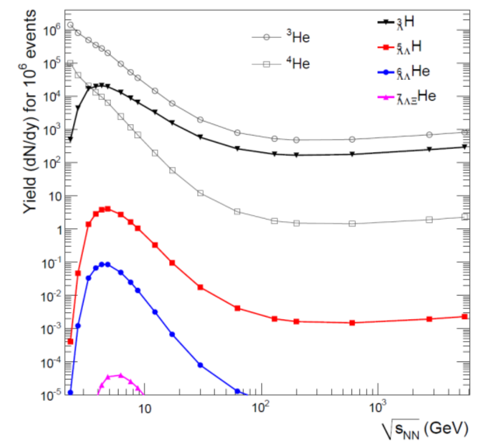


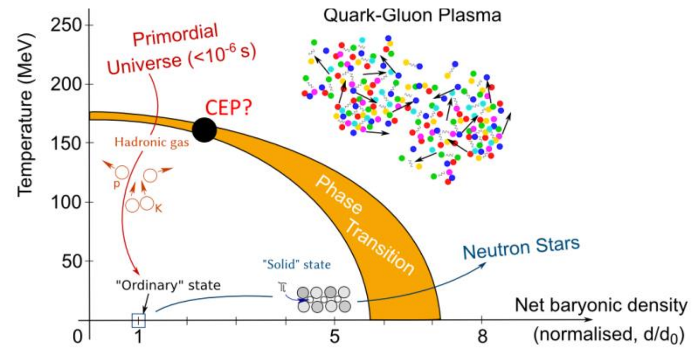
I.C. Arsene at al., Phys. Rev. C75 (2007) 34902.

QCD matter at MPD / NICA energies

- *maximum of net baryon density –*
  density frontier
- *maximum of K^+/π^+ ratio*
- *maximum of Λ/π ratio*
- *maximum yield of hyper-nuclei*
- *transition from Baryon to Meson dominated system*
- *maximum of Λ polarization*
- *1-st order transition & mixed phase creation*
- *Critical Endpoint ?*







BM@N / MPD Physics objectives

- ***EOS at high net baryon density (BM@N + MPD)***
  - collective flow of identified particles
  - excitation function of (multi)-strange hyperons and strange mesons
- ***Y-N and Y-Y interactions in dense nuclear matter (BM@N + MPD)***
  - yields of single and double Λ-hypernuclei
- ***Onset of chiral symmetry restoration at high ρ_B (MPD)***
  - in-medium modifications of hadrons: $\rho, \omega, \phi \rightarrow e^+e^-$
  - di-leptons at intermediate invariant masses: $4\pi \rightarrow \rho\text{-}a_1$ chiral mixing
- ***Phase transition from partonic to hadronic matter (MPD)***
  - excitation function of multi-strange hyperons and charm (J/ψ, D)
  - Λ polarization
- ***search for QCD Critical Point (MPD)***
  - event-by-event fluctuations & correlations

Nuclotron and BM@N beam line

26 elements of magnetic optics:

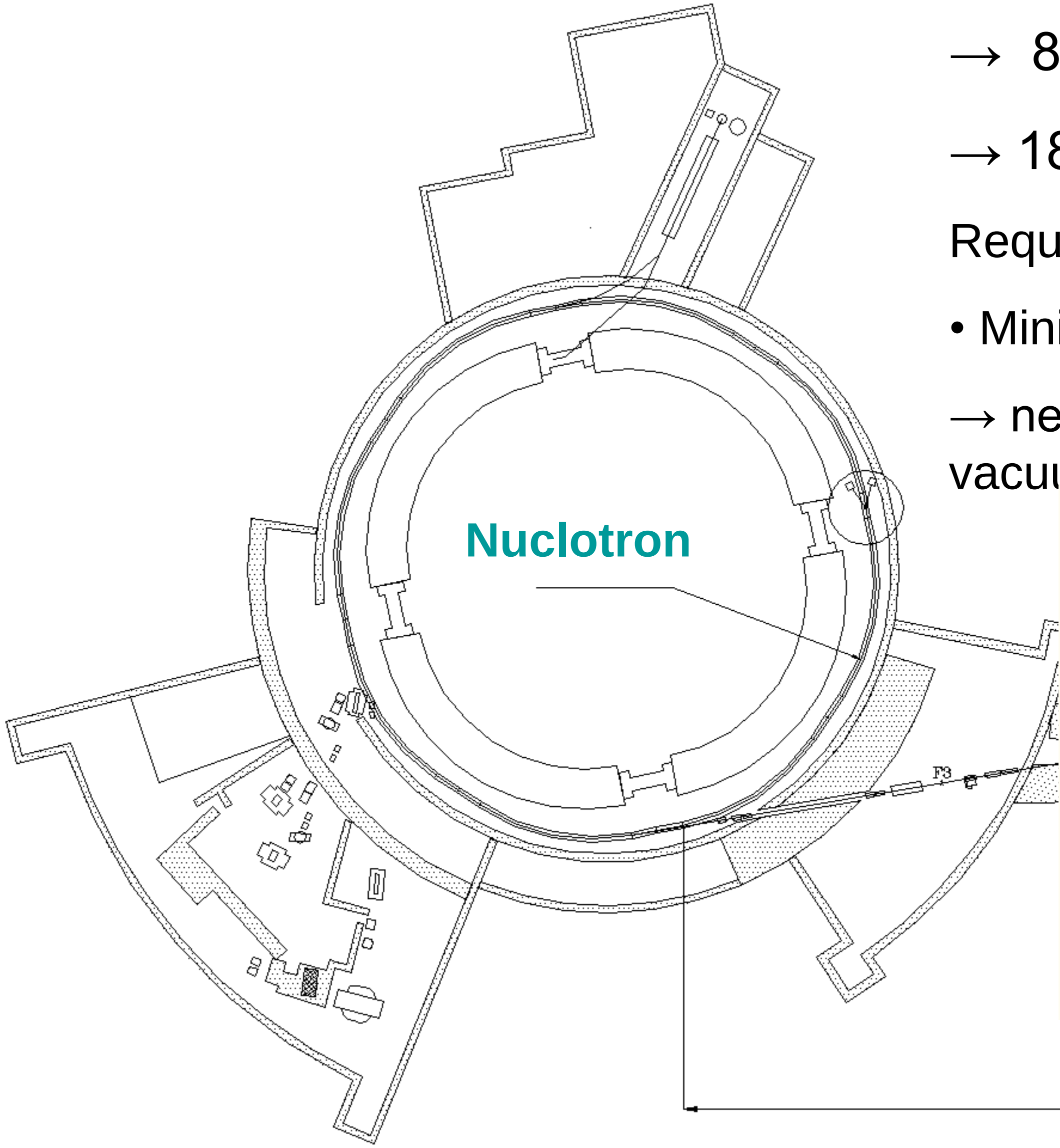
→ 8 dipole magnets

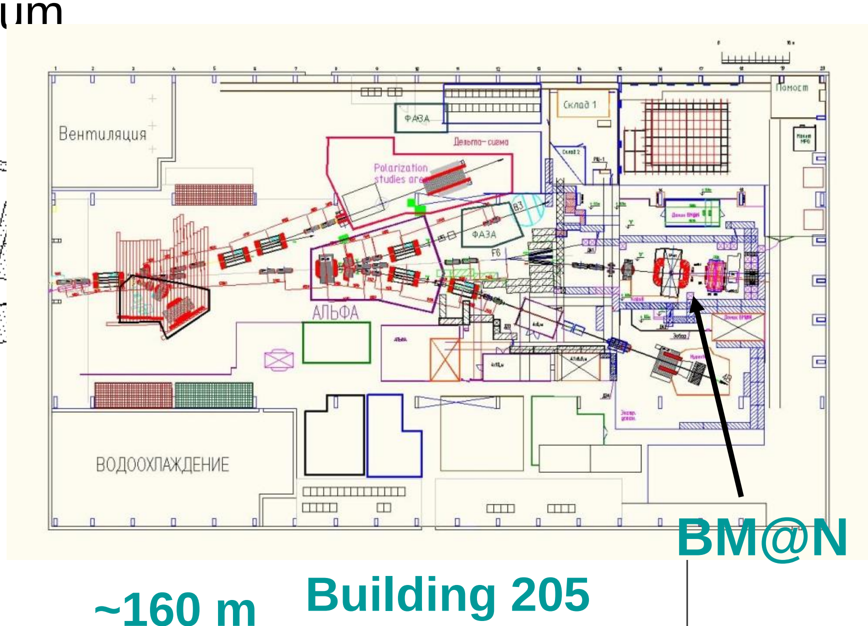
→ 18 quadruple lenses

Requirements for Au beam:

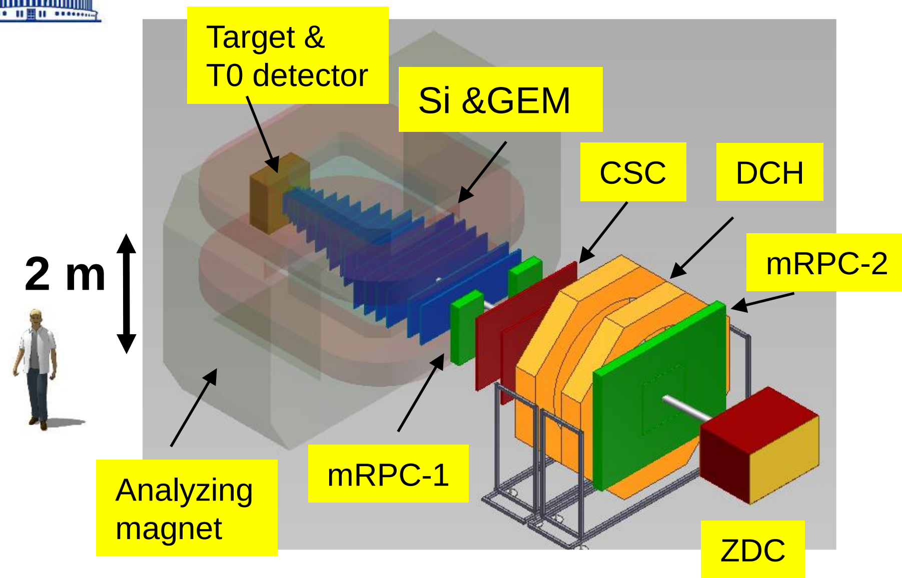
• Minimum dead material

→ need to replace air intervals / foils with vacuum





BM@N setup



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

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

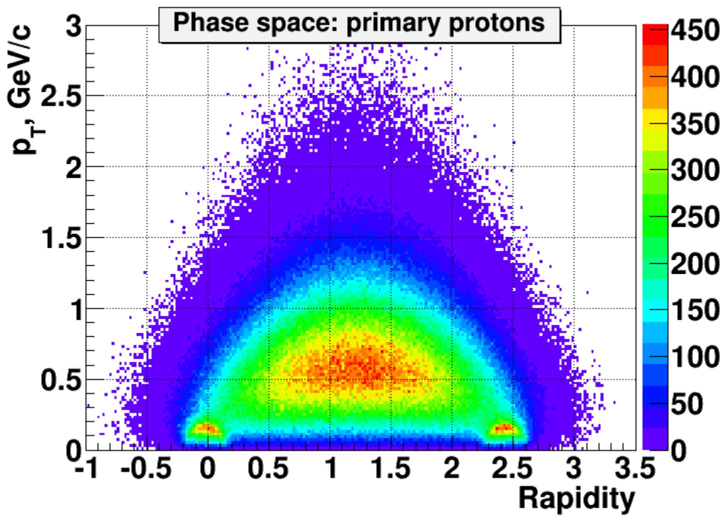
→ divide detectors for particle identification to “near to magnet” and “far from magnet” to measure particles with low as well as high momentum (p > 1-2 GeV/c)

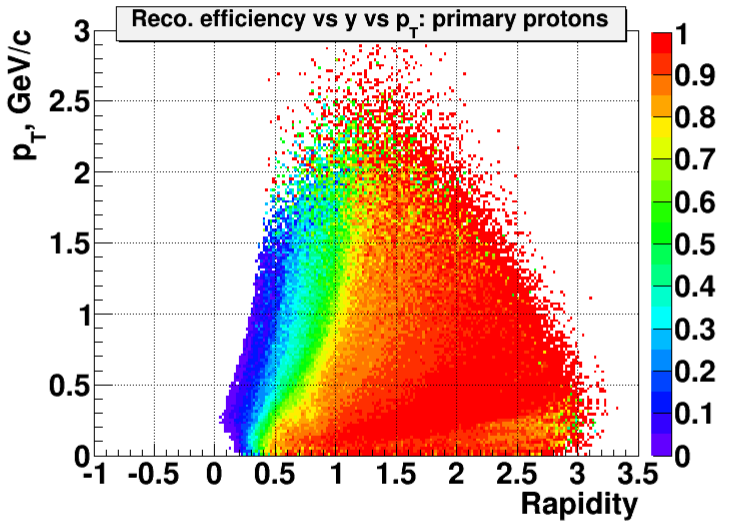
→ fill distance between magnet and “far” detectors with coordinate detectors

- 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-

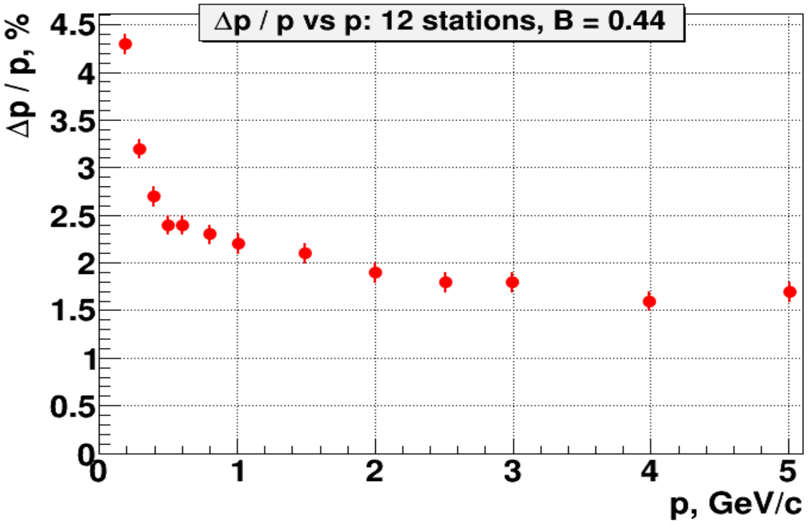
GEM tracker: acceptance / momentum resolution / detection efficiency

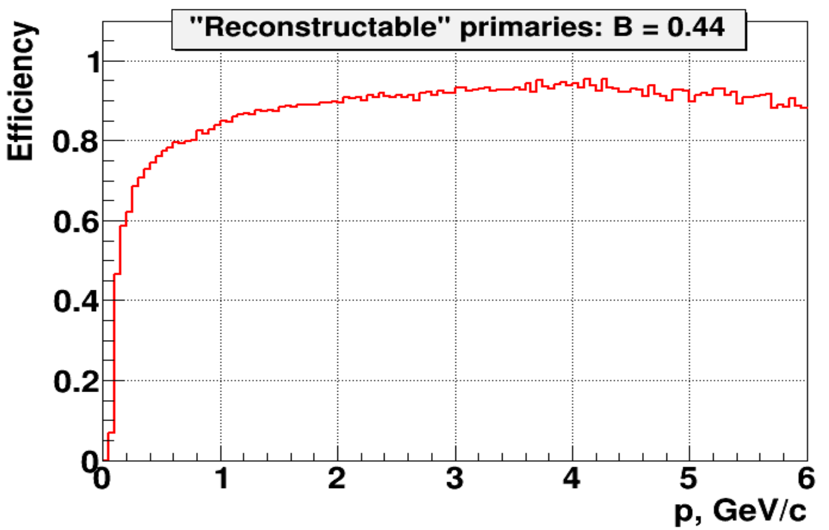
Phase space / acceptance to primary protons: Au+Au, 4.5 AGeV





Momentum resolution / detection efficiency

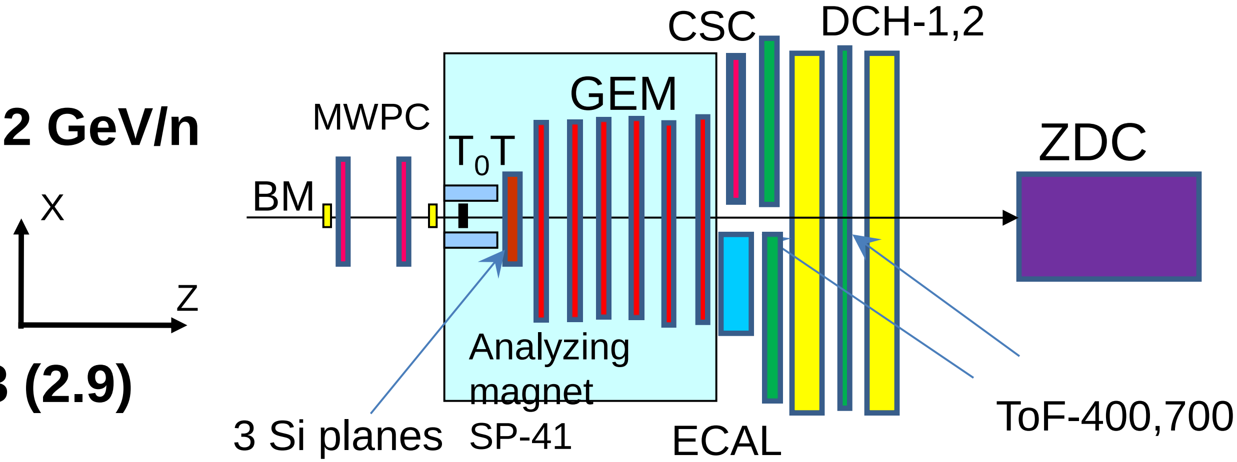




BM@N run with Ar and Kr beams in March 2018

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**

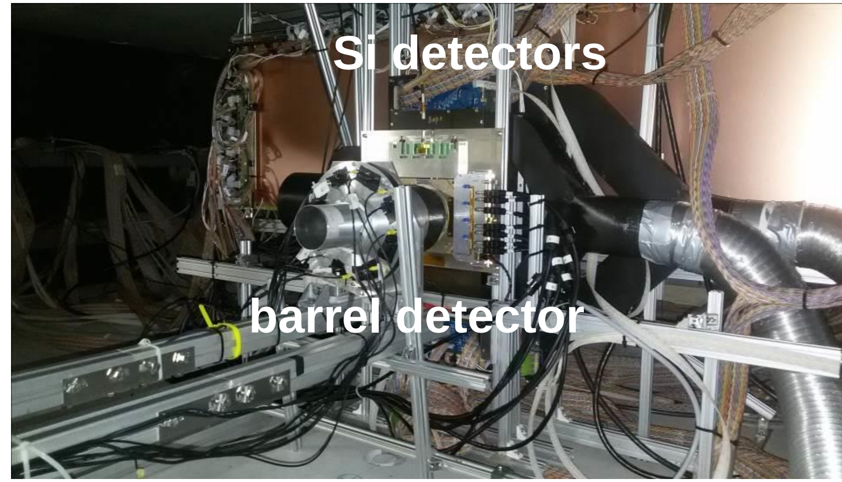
→ Hyperon production measured in central tracker (Si + GEM)

→ Charged particles and nuclear fragments identified with ToF

→ Gamma and multi-gamma states identified in ECAL

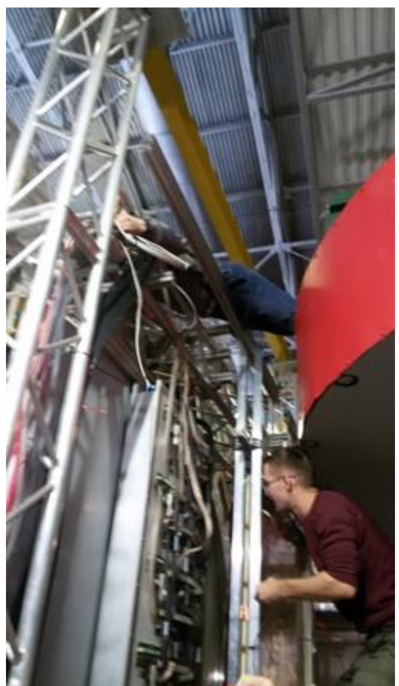
+ analyze data from previous technical runs with Deuteron and Carbon beams of 3.5 - 4.6 GeV/n

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



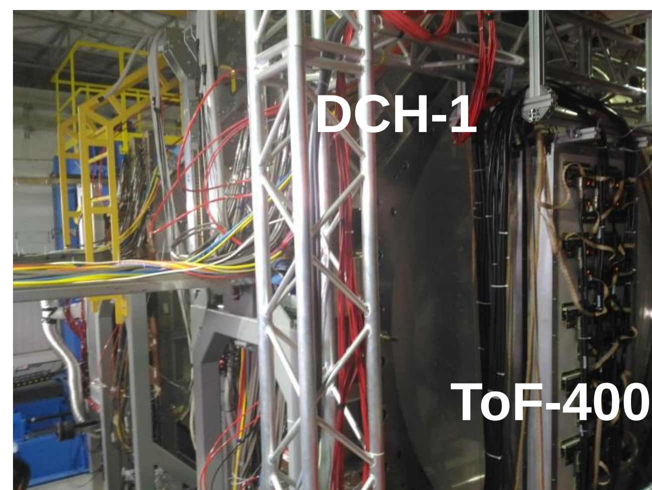
CSC chamber

ToF-400 installation

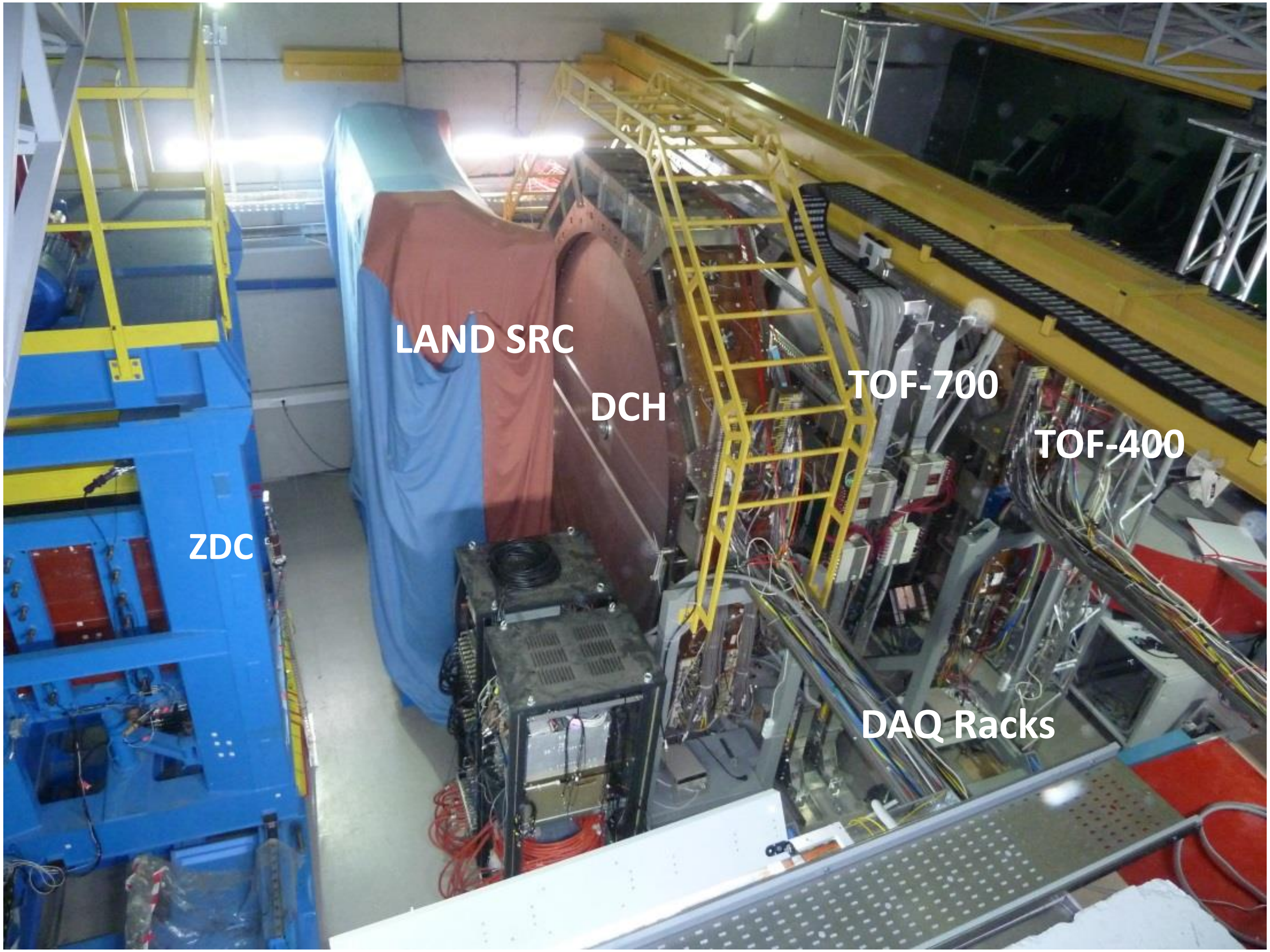


New detector components:

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

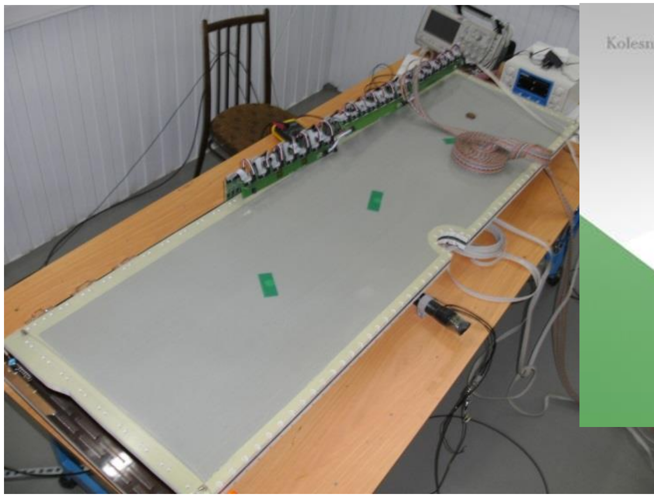


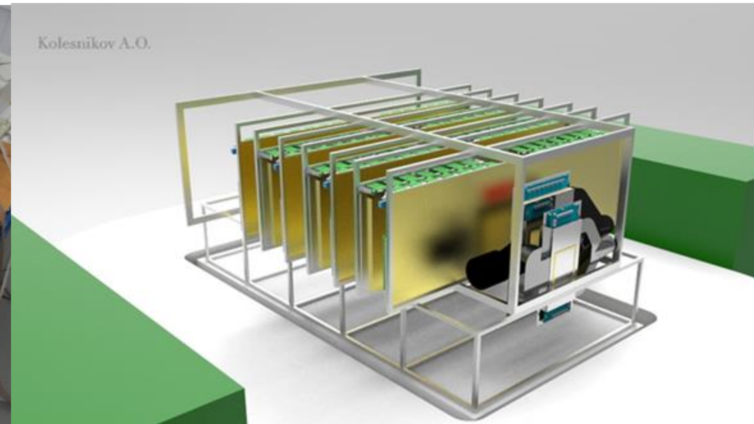
BM@N setup behind magnet, 2018

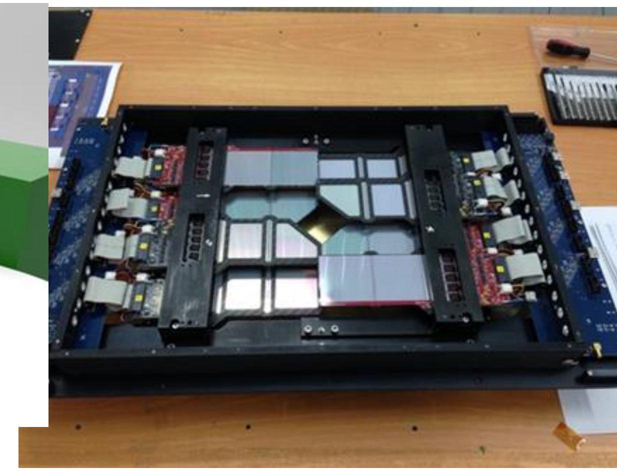


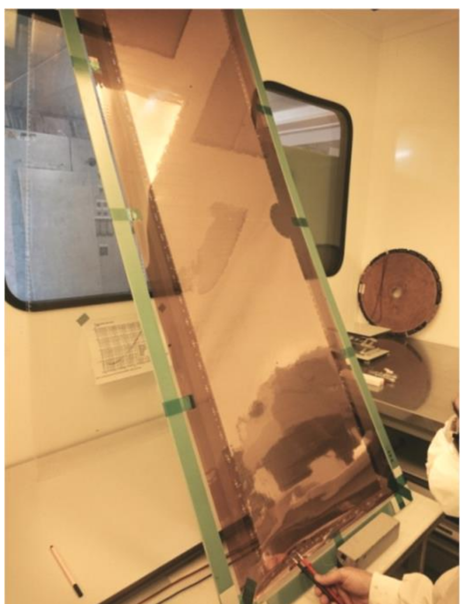
GEM and Si detectors for central tracker

Tests of GEM detector 163 x 45 cm^2







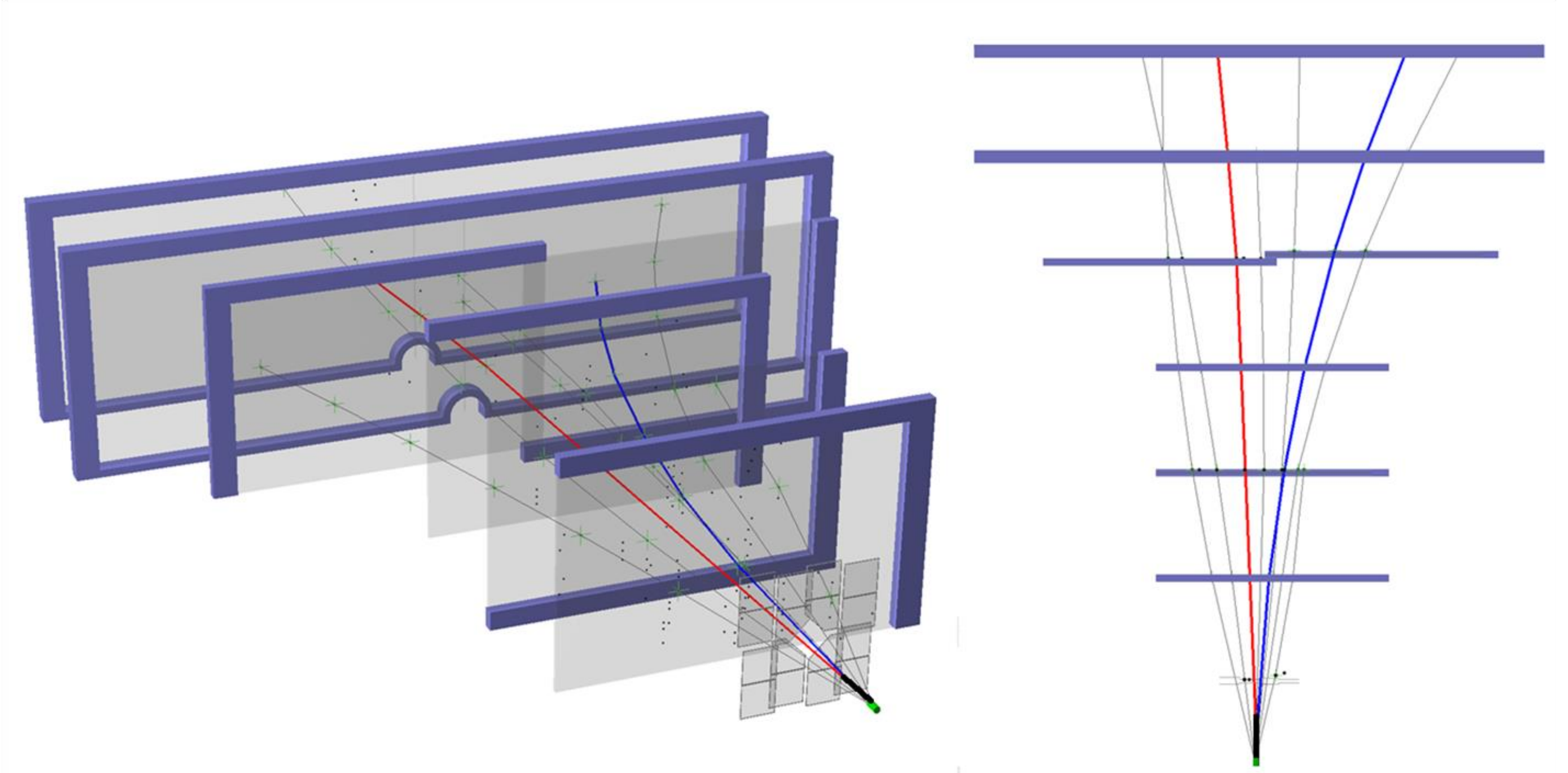


- **7 GEM detectors of 163 x 45 cm^2 are produced at CERN workshop**
- **2-coordinate Si strip detector with pitch of 95/103 µm, full size of 25 x 25 cm^2**

✓ **detector combined from 4 sub-detectors arranged around beam**

✓ **+ two smaller vertex Si strip detectors**

Event display of Λ decay in C+C collision



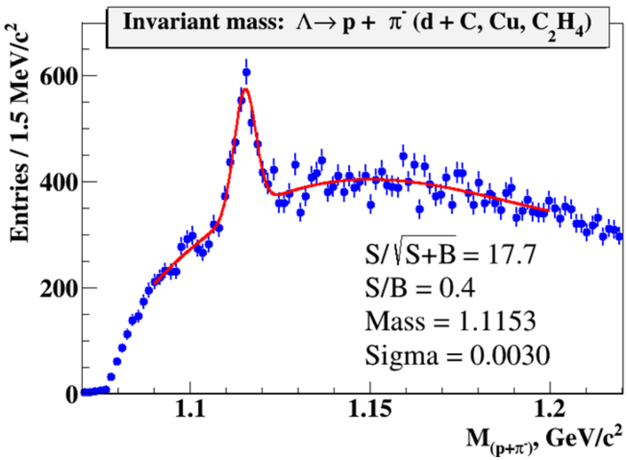
Λ→pπ⁻ decay reconstruction in GEM + Si tracker in C+C interaction, March 2017

Λ in deuteron and carbon beams

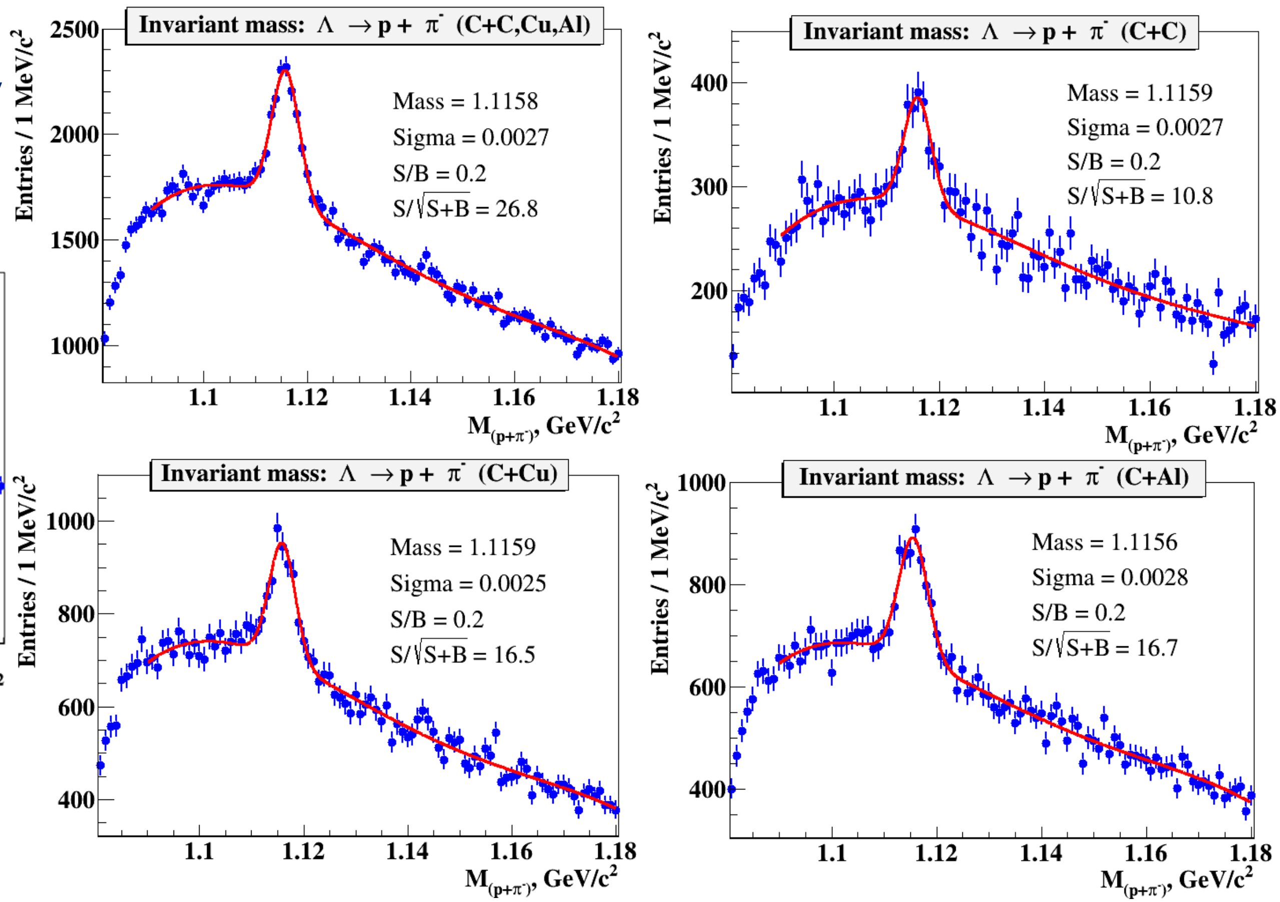
d (C) + target → X

Λ signal width ~ 2.5-3 MeV

Deuteron Data



Carbon beam run, 4 AGeV

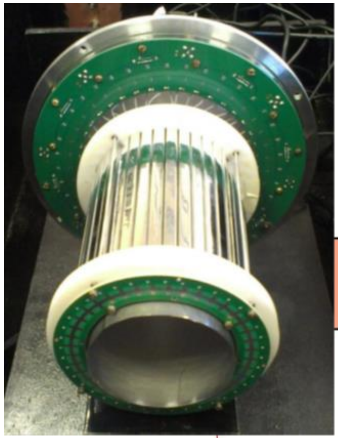


To improve vertex and momentum resolution and reduce background under Λ:

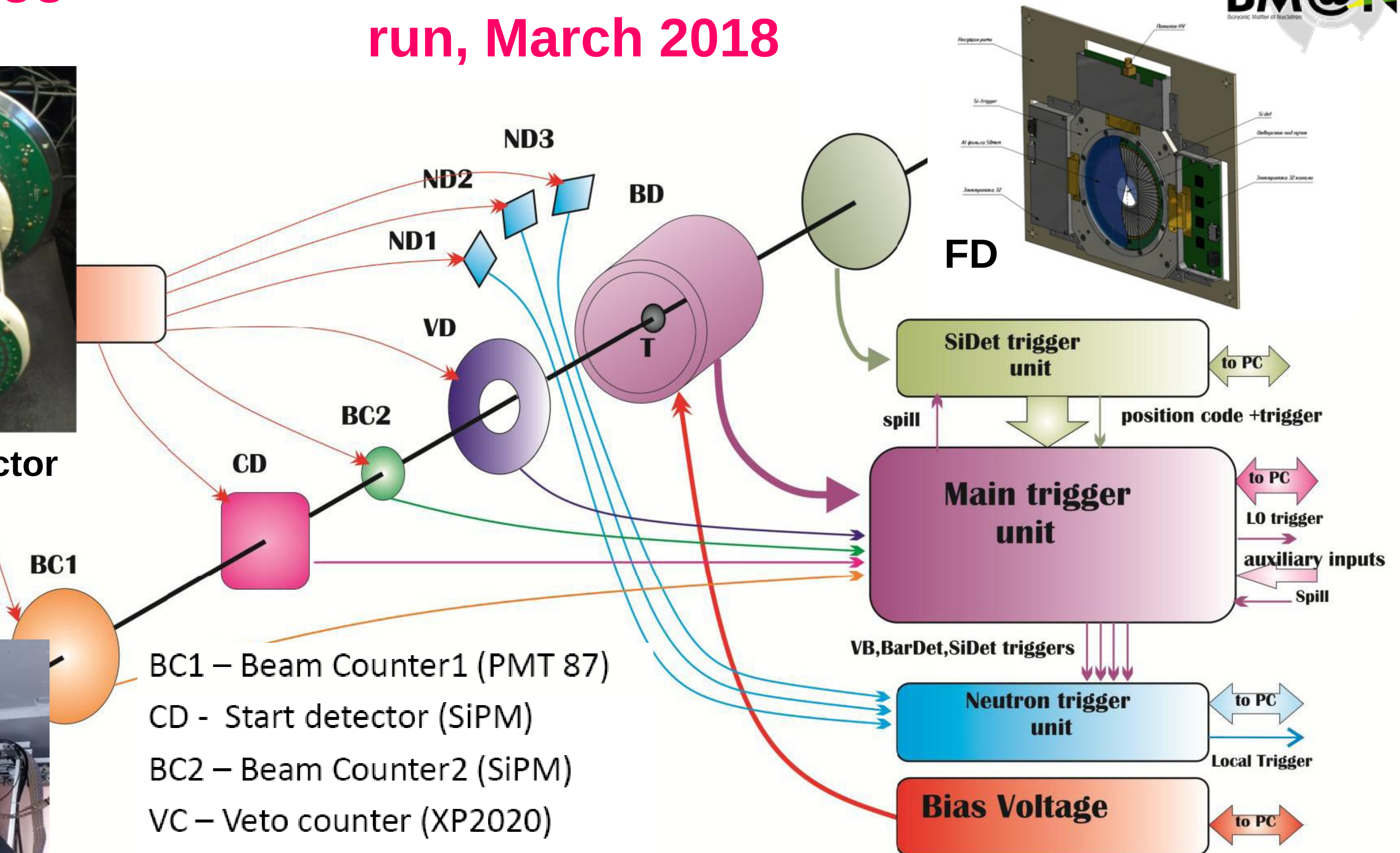
- **Need few planes of forward Silicon detectors → 3 planes used in last run**
- **Need more GEM planes to improve track momentum reconstruction**

Methodical Paper published in 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)

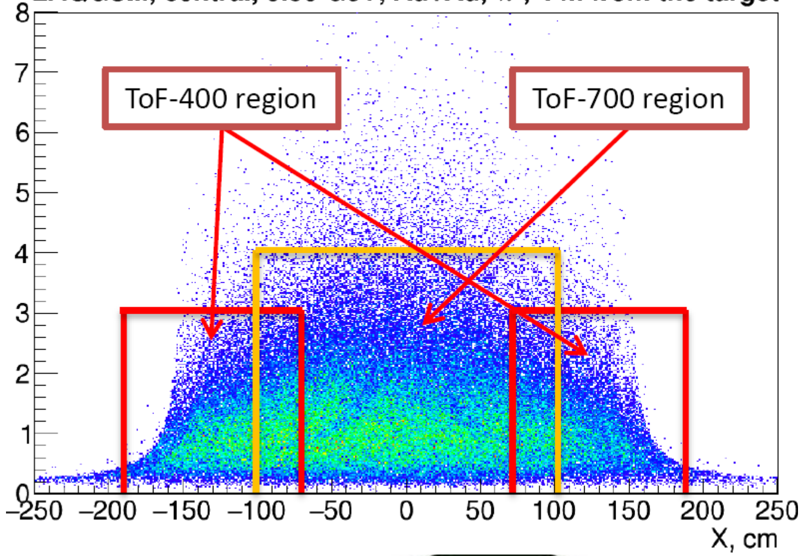
BD – Barrel Detector – 40ch. SiPM

T – target

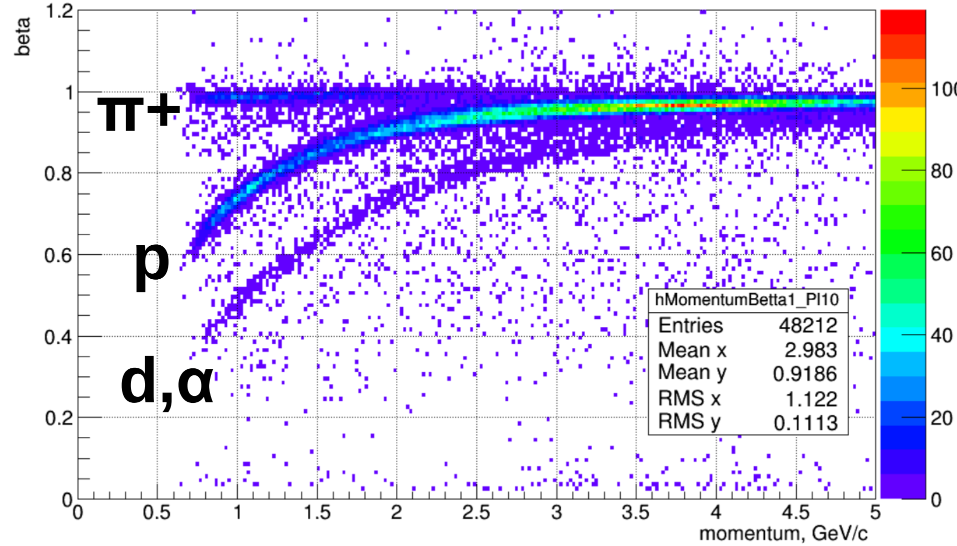
SiDet – Silicon Detector

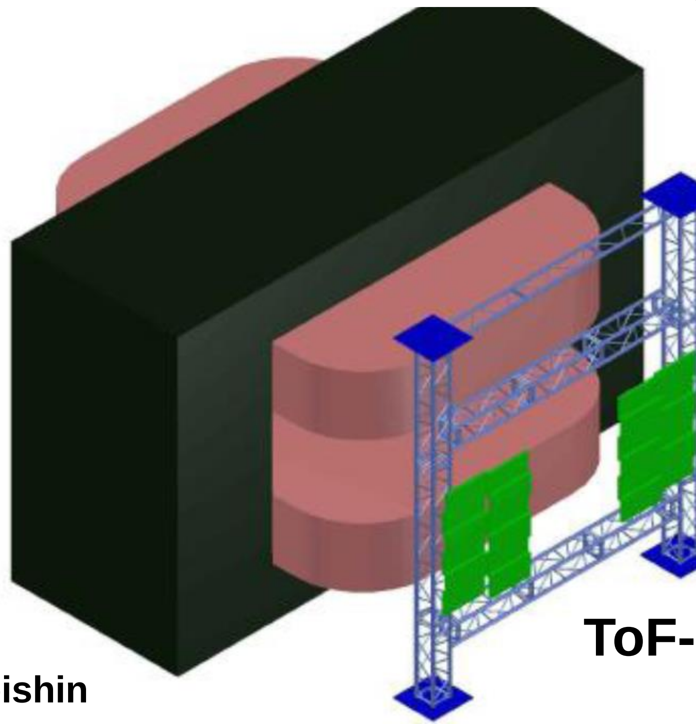
Selection of events with activity in barrel detector: BD >= N or forward Si detector: FD >= N

ToF-400 and ToF-700 based on mRPC



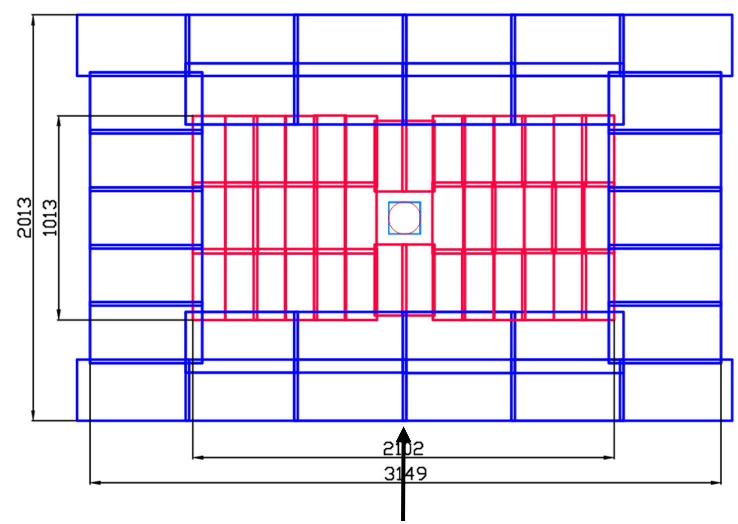
Carbon beam , 3.5 AGeV , C + Al → X





ToF-400 wall

ToF-700 wall

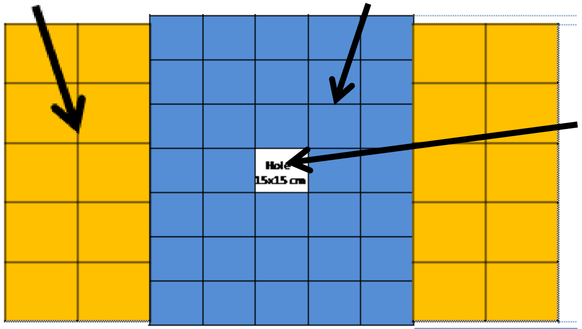


BM@N beam axis

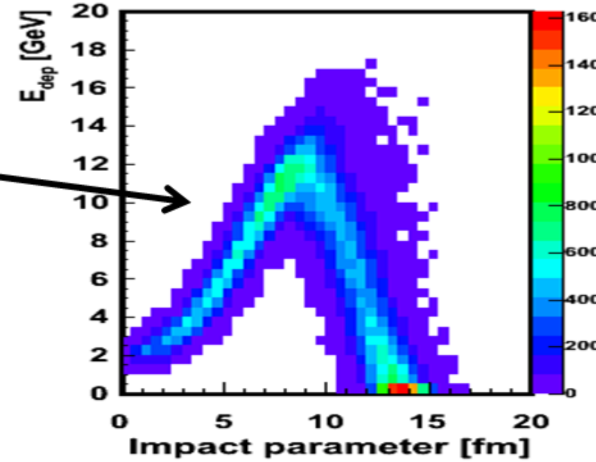
M.Kapishin

MPD / CBM hadron ZDC calorimeter

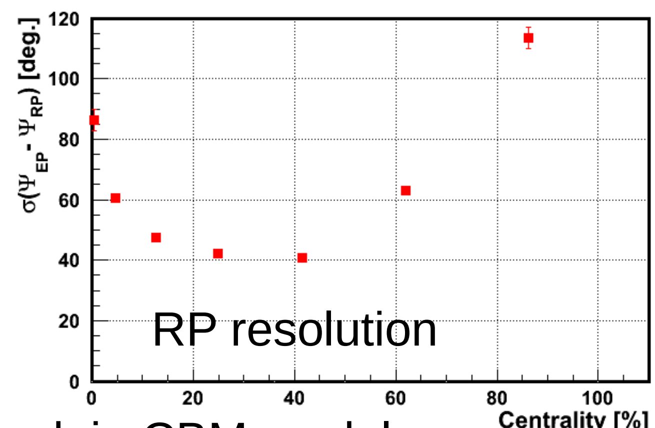
CBM modules MPD modules



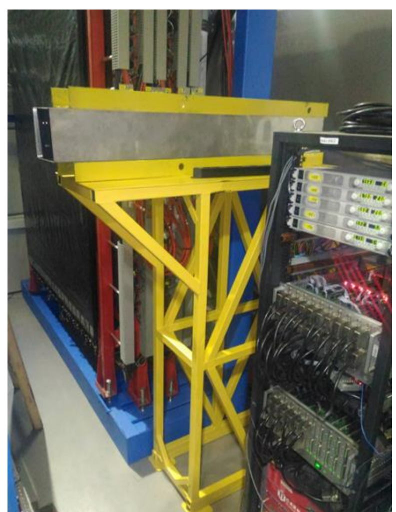
dE/dx scintillator to resolve central / peritheral interactions



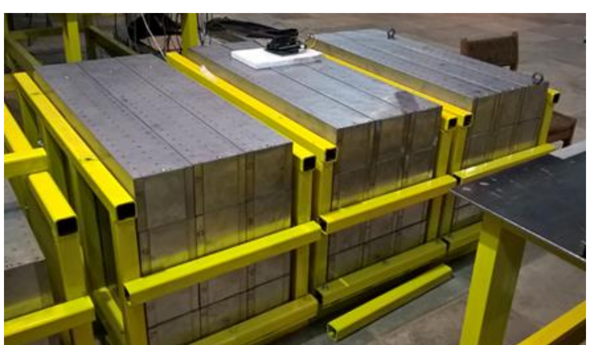
- **Modern technics;**
- **Light yield ~x10 higher;**
- **Detection of low energies;**
- **Stable operation at high count rates;**
- **Experience in operation for later MPD/CBM experiments**
- **Motivated team**



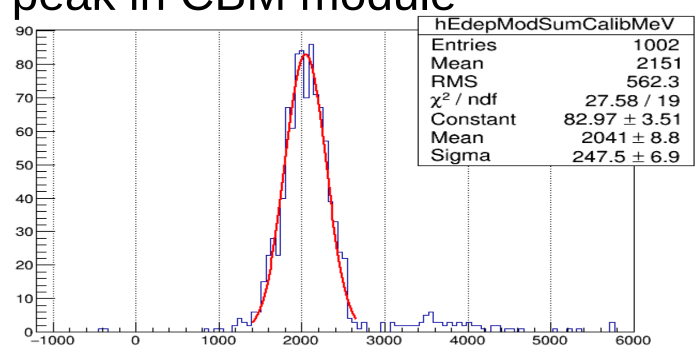
CBM module in BM@N



MPD FHCAL modules

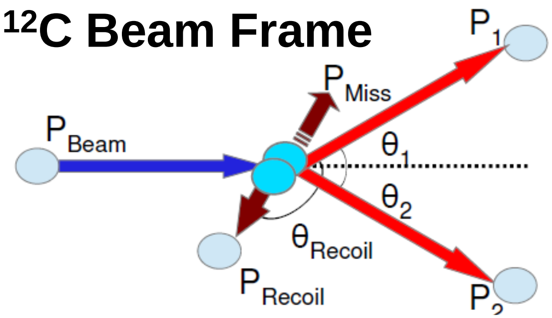


Ar peak in CBM module

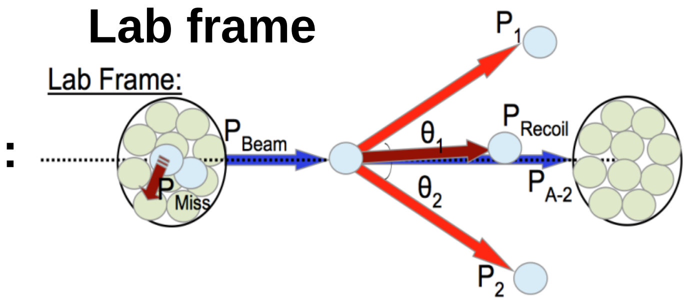


A proposal for BM@N experiment to study SRC with hard inverse kinematic reactions

^{12}C Beam Frame



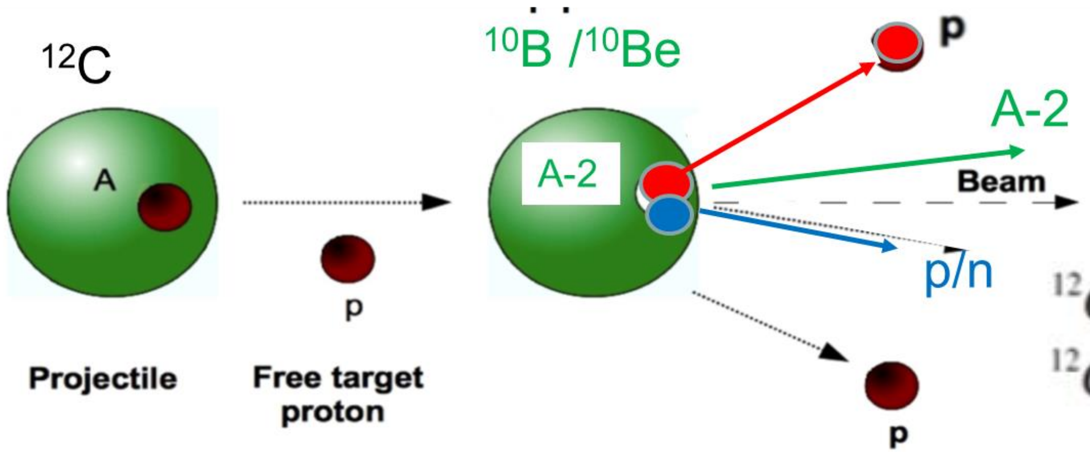
Lab frame



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

Objectives:

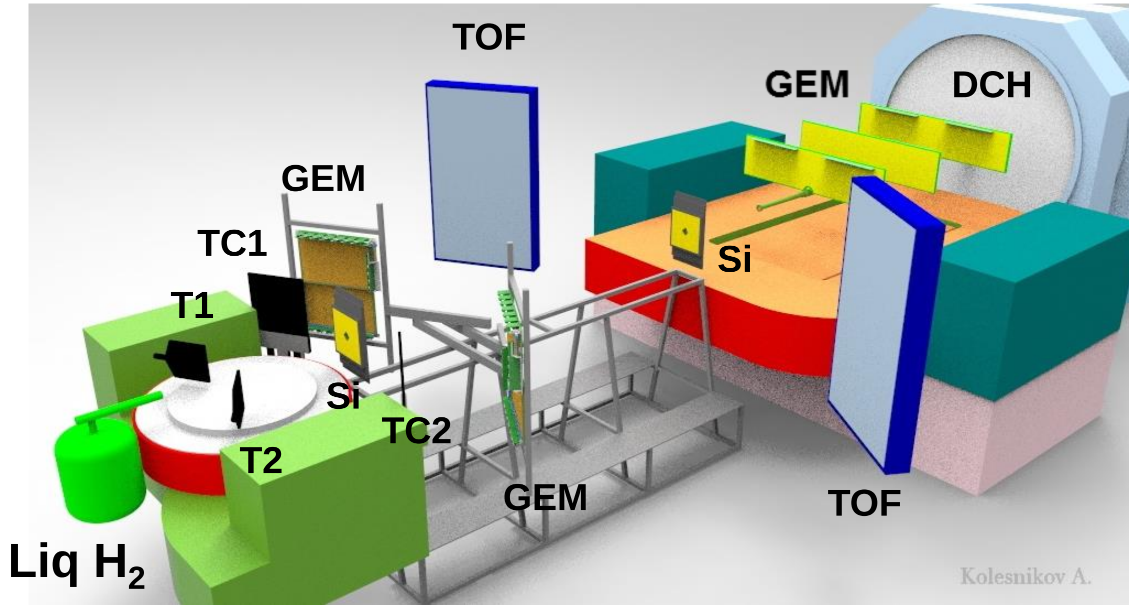
- identify 2N-SRC events with inverse kinematics
- study isospin decomposition of 2N-SRC
- study A-2 spectator nuclear system



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

BMN & SRC set-up

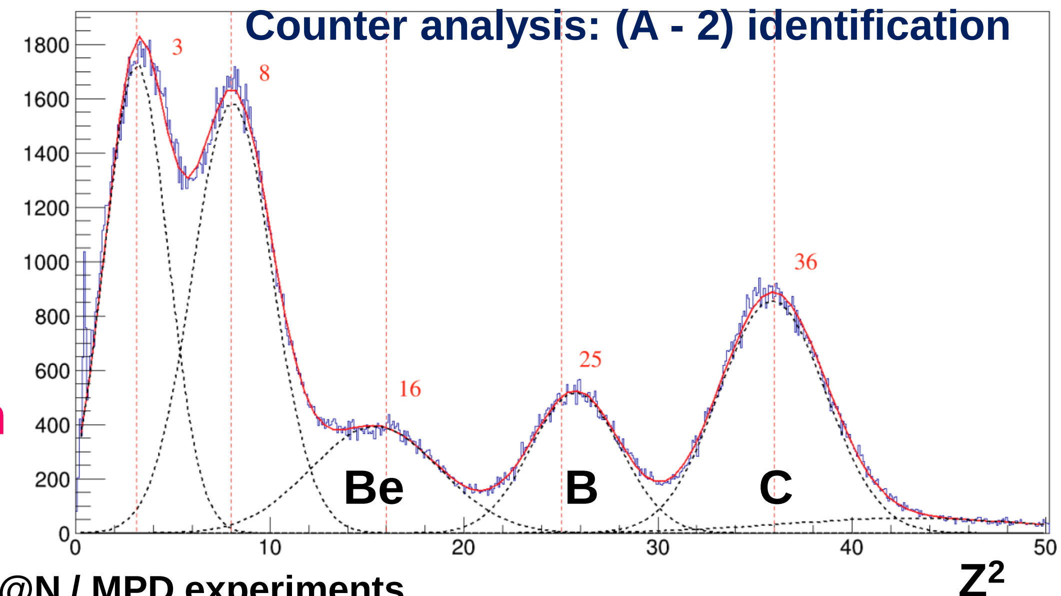
Cuts
$\|\theta_{1,2}-30^o\|<6.5^o$
$\|\Delta\varphi_{1,2}\|<7.5^o$
$\|s,t,u\|>2\ (GeV/c)^2$
$P_{miss}>0.275$ GeV/c



Trigger:
T0 · T1 · T2 · TC1 · TC2

Signal rates for 14 days of data taking

Within LAND acceptance



First SRC @ BMN run in March 2018

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	2-5M
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

BM@N present status and next plans

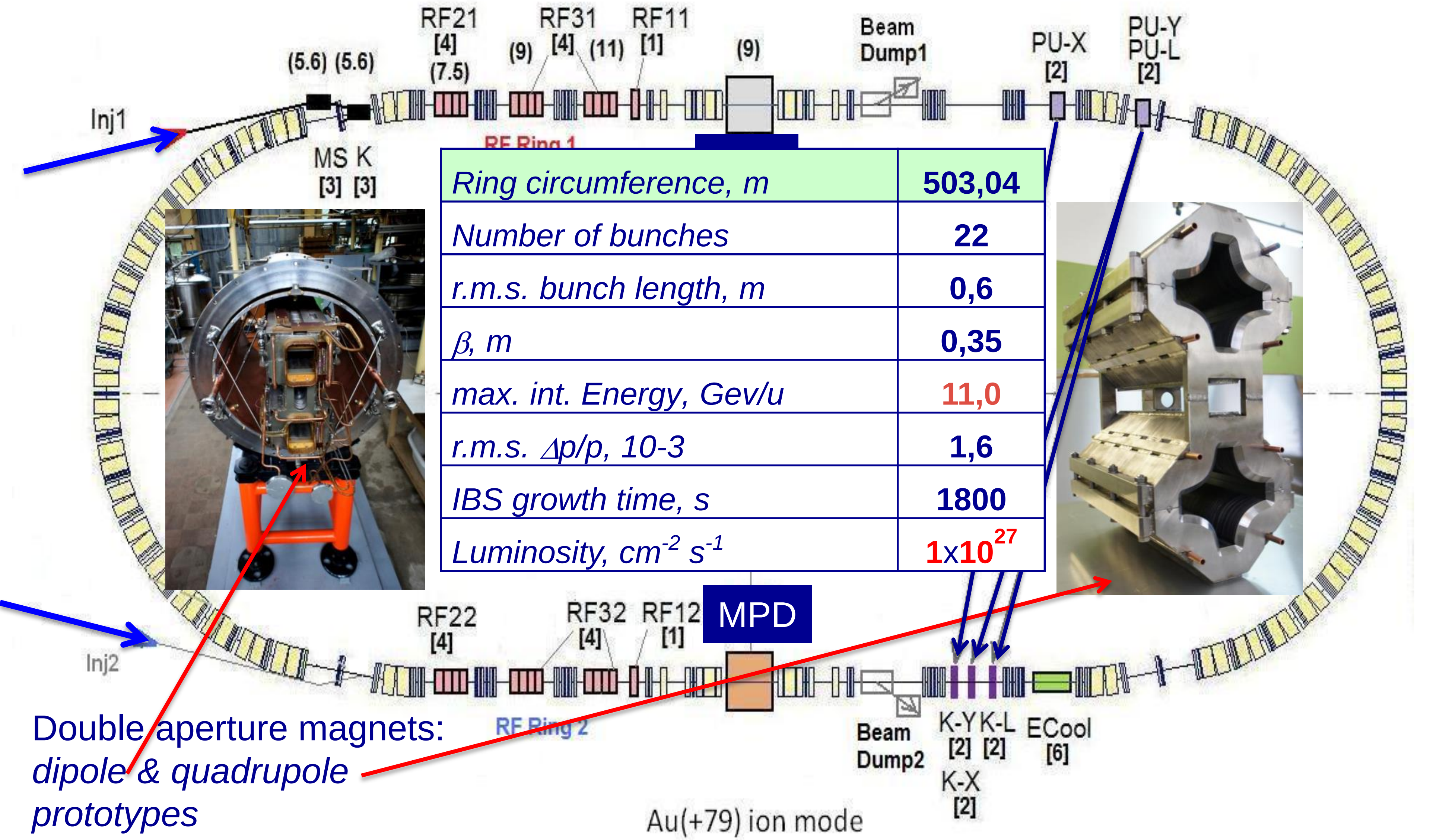
- BM@N scientific program comprises studies of nuclear matter in intermediate range between SIS and NICA/FAIR
- BM@N technical runs performed with deuteron and carbon beams at energies T_0 = 3.5 - 4.6 AGeV and recently with Ar beam of 3.2 AGeV and Kr beam of 2.3 AGeV
- Measurement of Short Range Correlations 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 run 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
- Install MPD / CBM type of hadron ZDC calorimeter
- Implement vacuum beam pipe through BM@N setup

NICA Collider

45 T*m, *4.5 GeV/u for* ***Au**$^{79+}$*

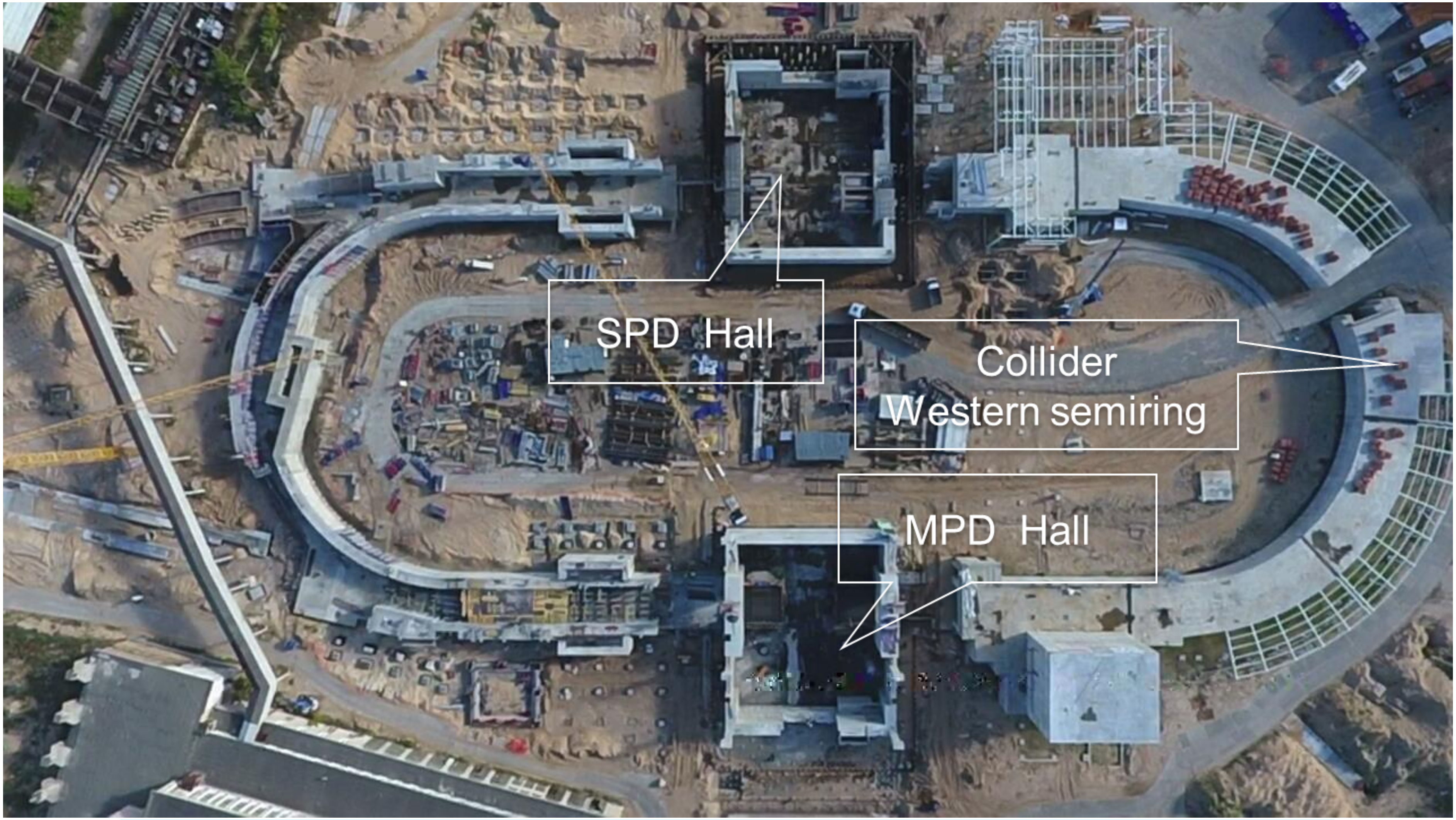


Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
max. int. Energy, Gev/u	**11,0**
r.m.s. Δp/p, 10-3	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**1x10^{27}**

Double aperture magnets:
dipole & quadrupole prototypes

NICA Civil Construction

September 2018



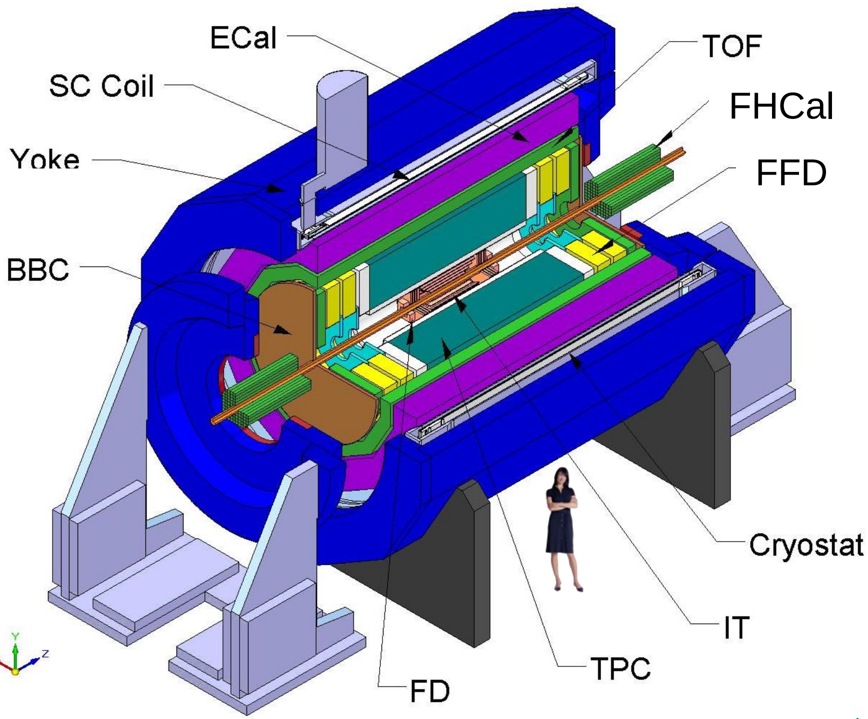
readiness for equipment installation in the MPD Hall - 2019

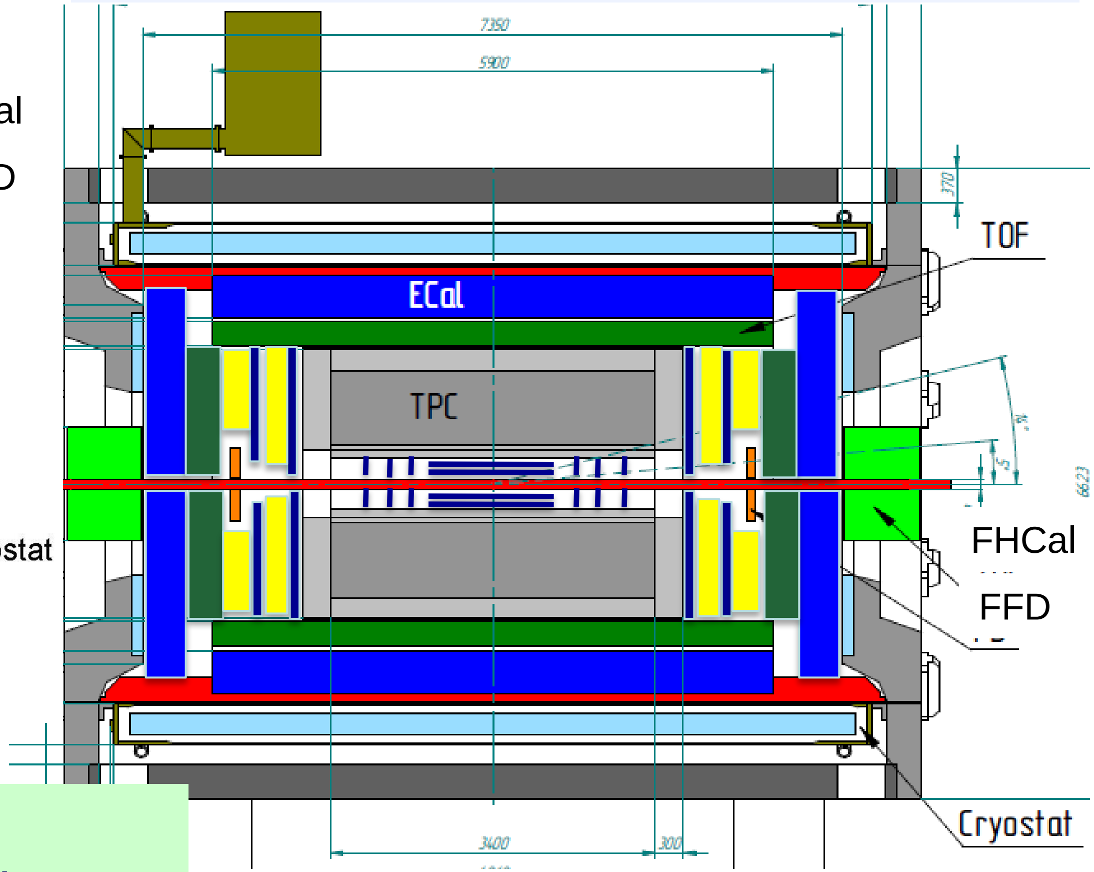
Multi-Purpose Detector (MPD)

tracking: *up to |η|<1.8* (**TPC**)
PID: *had., e, γ* (**TOF**, **TPC**, **ECAL**)
Reaction: *centrality & plane determination* (**FHCal**)

Stage 1 (2020): TPC, TOF(barrel), ECAL(barrel), FHCAL, FFD

Stage 2 (2023): ITS + EndCap (tracker, TOF, ECAL)

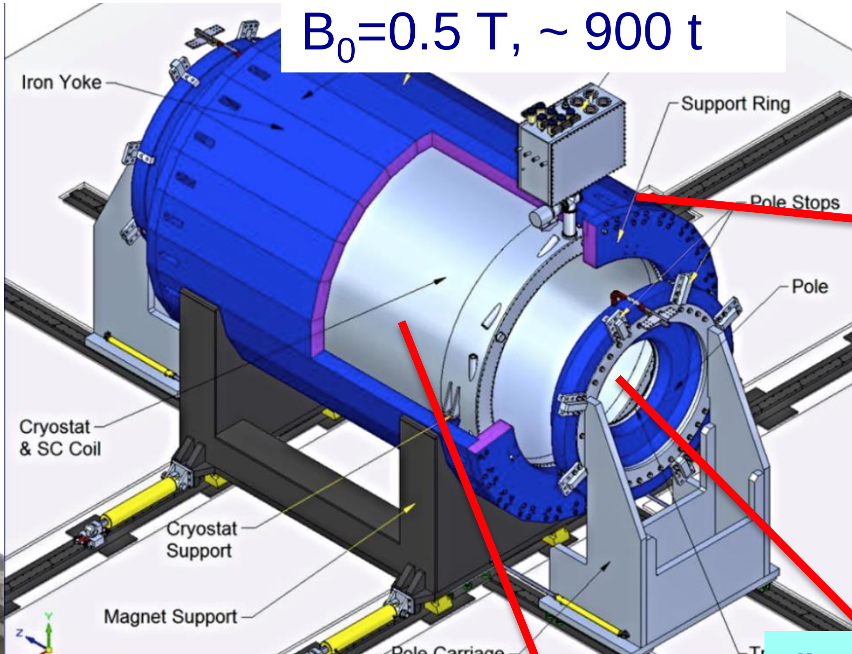




Plan: *overall commissioning starts in 2020*

Magnet production: *ASG (Genova) & Vitkovice HM*

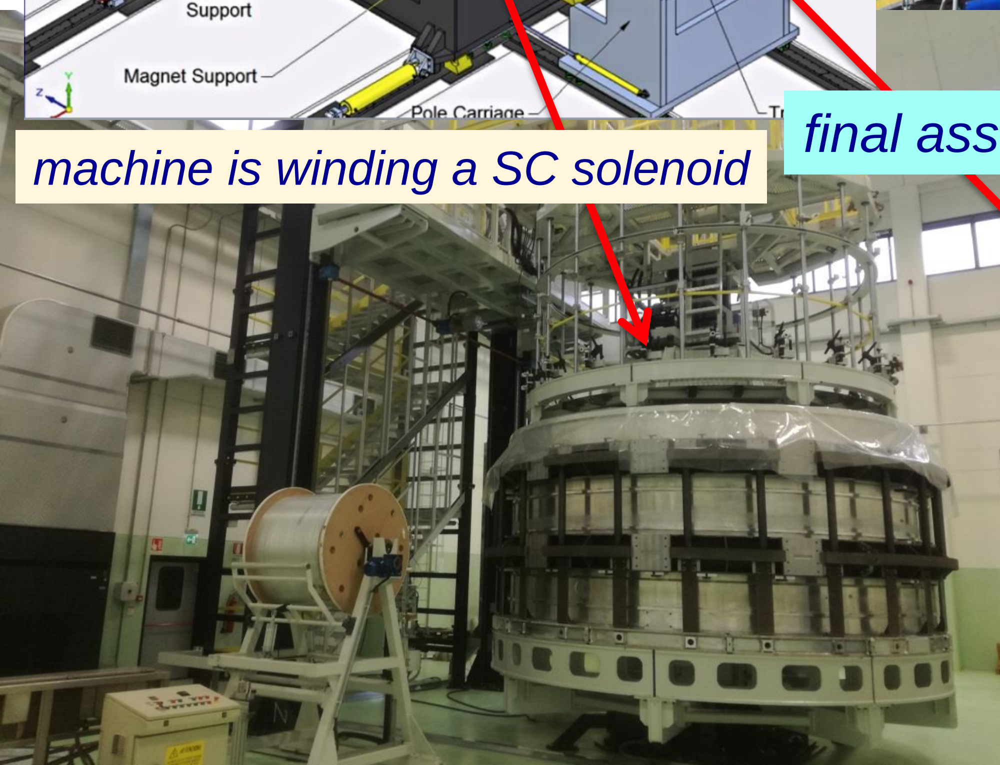
B_0=0.5 T, ~ 900 t



yoke control assembly at HM Vitkovice

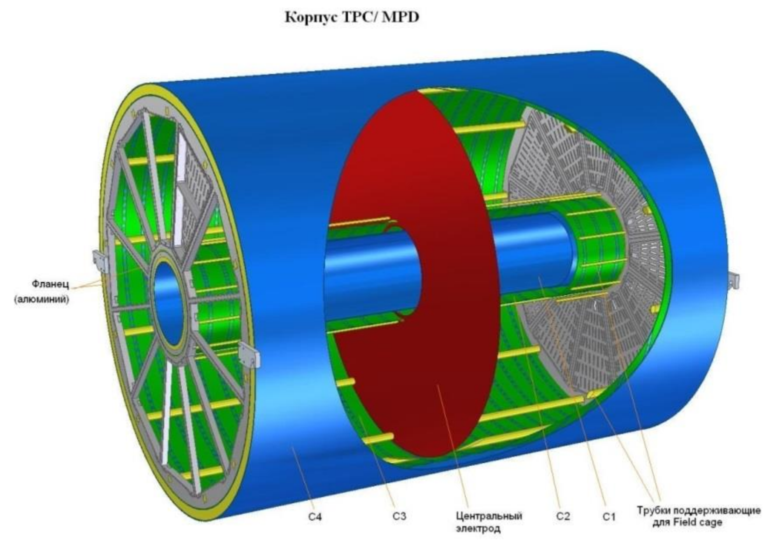
*final assembly in the MPD hall - **June 2019***

machine is winding a SC solenoid

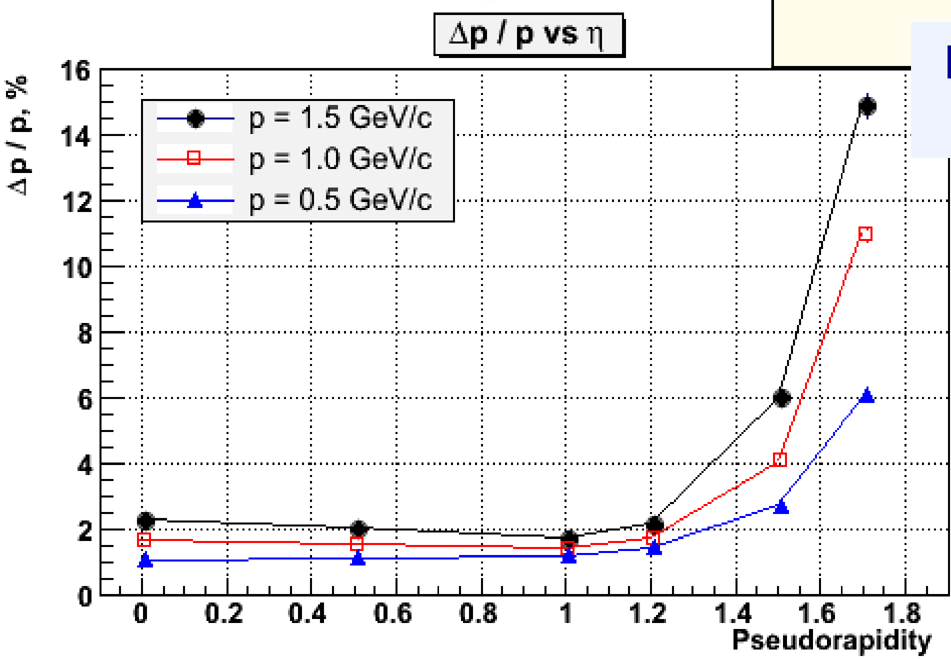


trim coil

Time Projection Chamber (TPC) – basic tracker

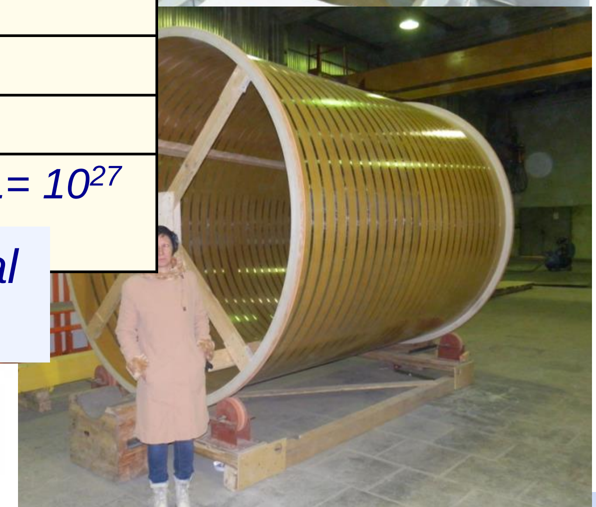


length	*340 см*
out Radii	*140 см*
in Radii	*27 см*
gas	*90% Ar+10% CH_4*
drift velocity	*5.45 см / mcs;*
velocity time	*< 30 mcs;*
N R-O Chamb.	*12 + 12*
N pads / chan.	*95232*
max event rate	*< 7 kGz (L= 10^{27}*

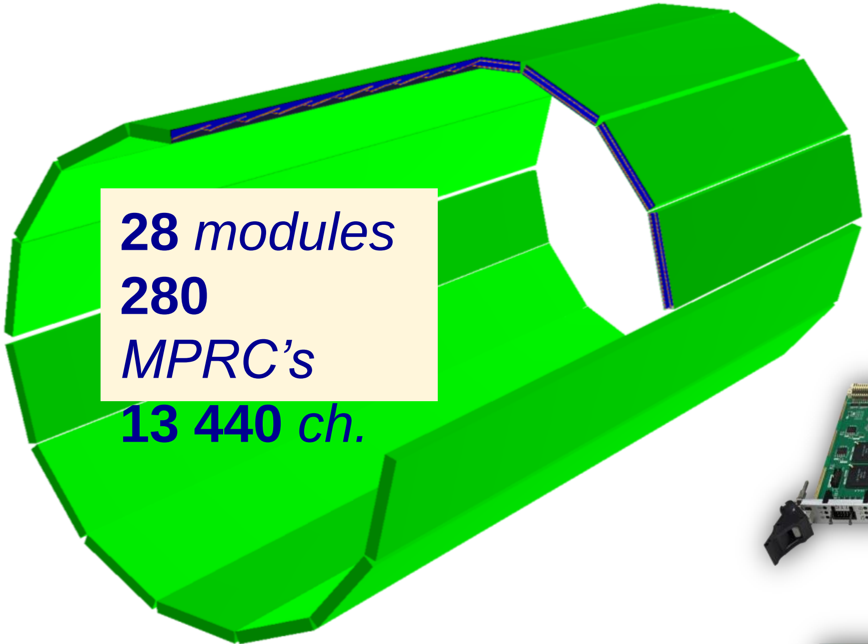


FEC64SAM - *dual SAMPA card*

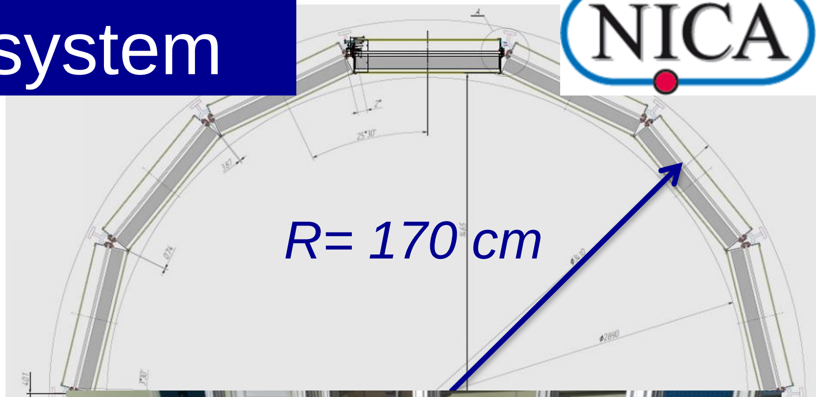
TPC/MPD Front-end card

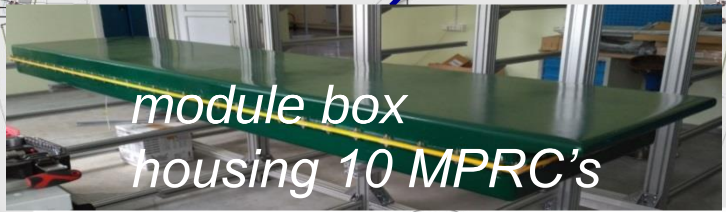


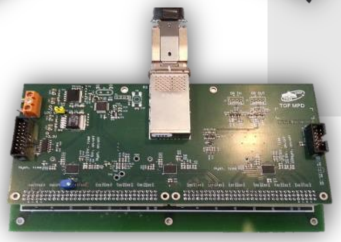
Time of Flight (TOF) system

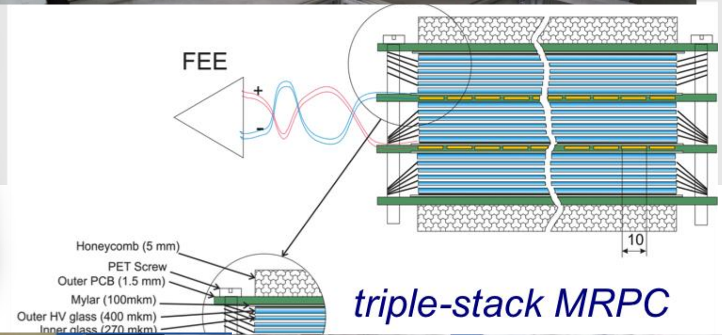


28 *modules*
280 *MPRC's*
13 440 *ch.*



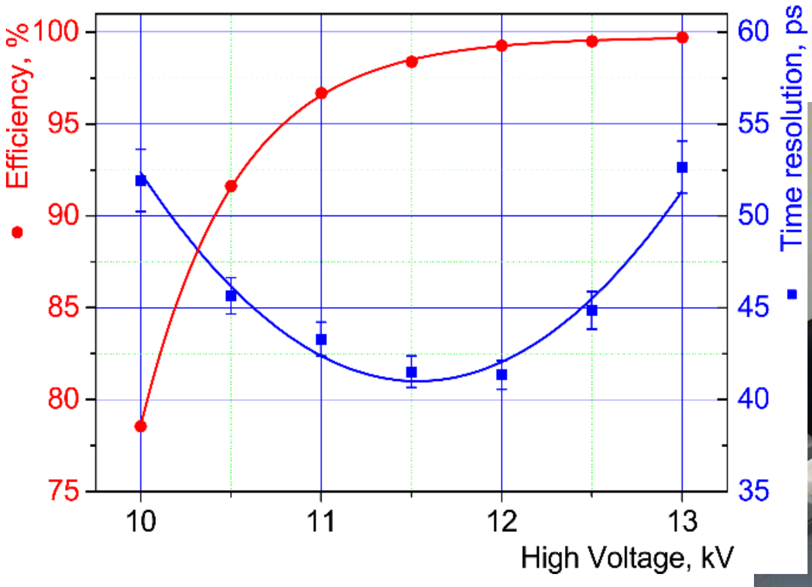


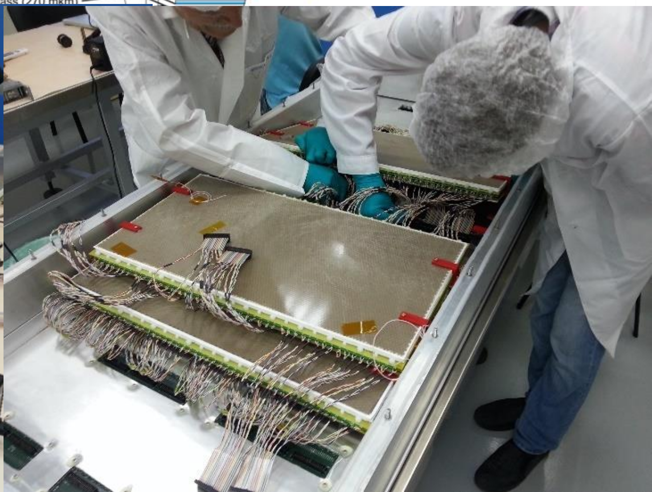




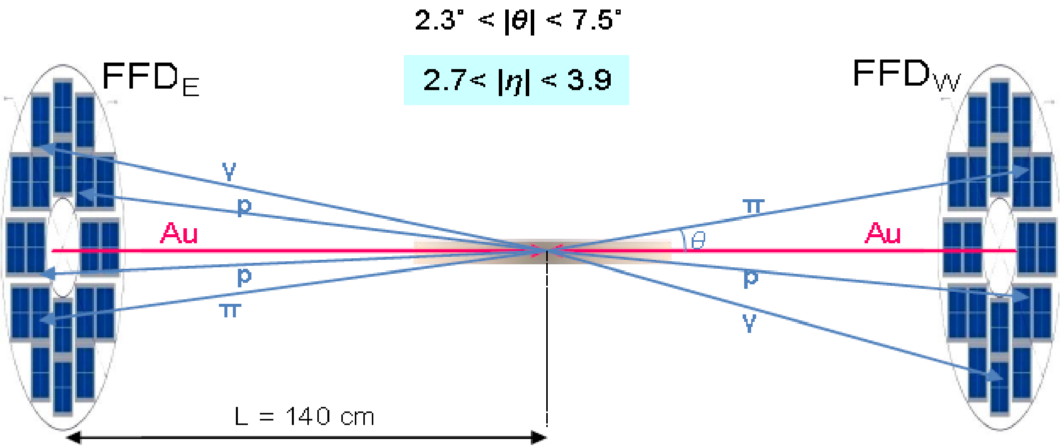
triple-stack MRPC

efficiency and time resolution

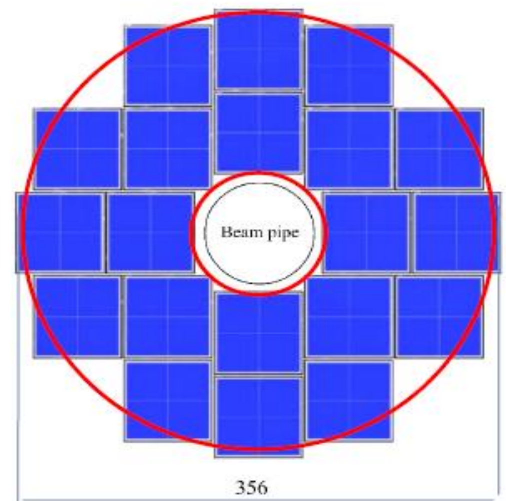




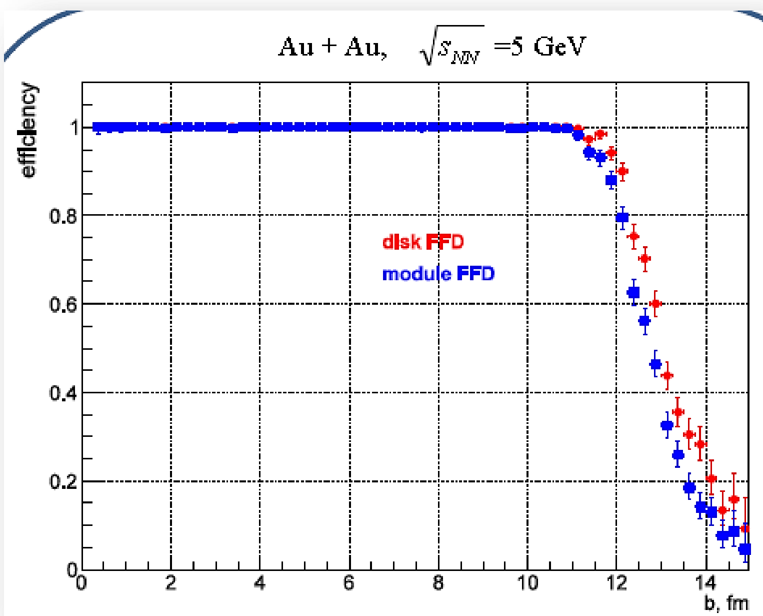
Fast Forward Detector – (FFD)

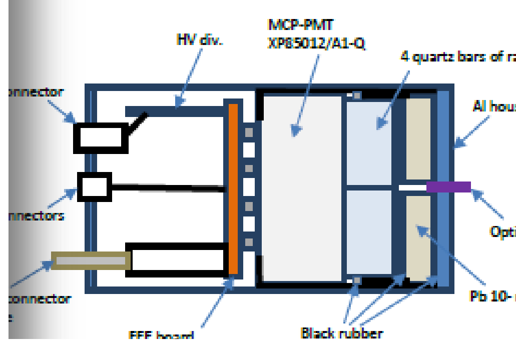


array of 20 modules
Planacon MCP-PMTs
80 +20 channels

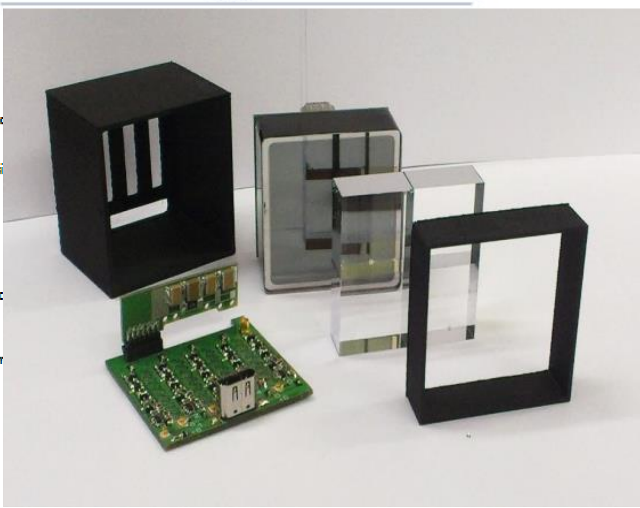


time resolution < 50 ps

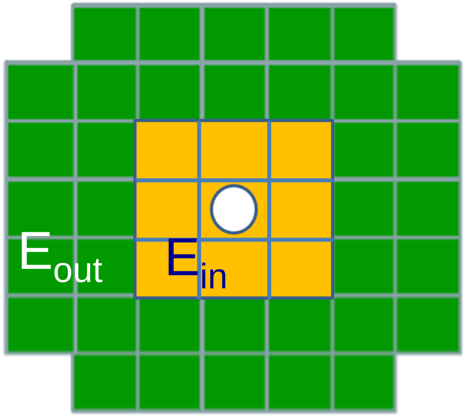


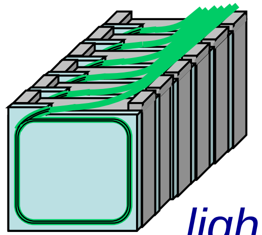


15 mm quartz radiator
10 mm lead converter



FHCAL: determination of reaction plane and centrality





light collection
WLS-fibers & SiPM

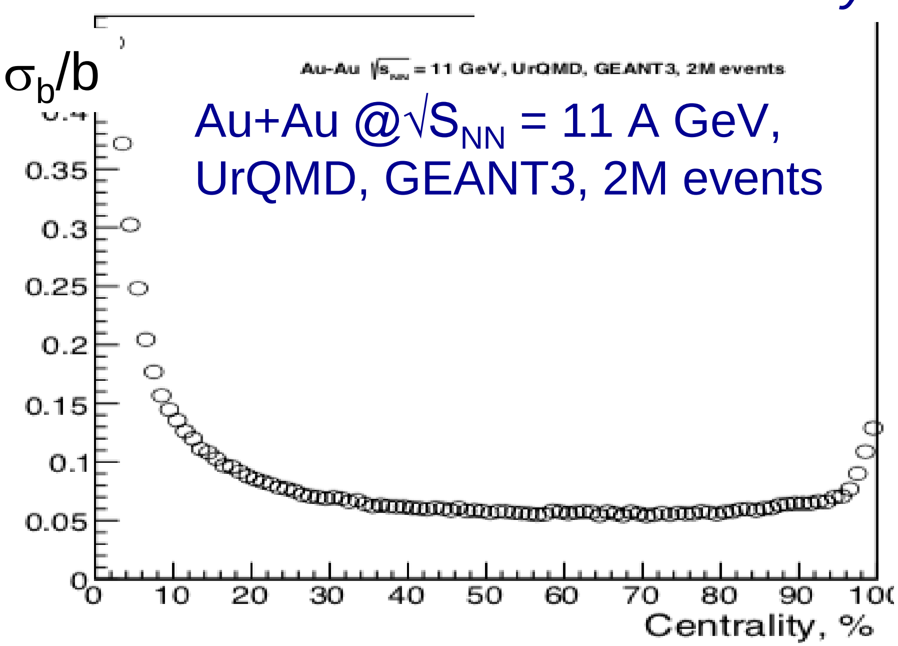
2 x 45 modules (15 x 15 cm^2 each)
located left and right at ~3.2 m from the IP)

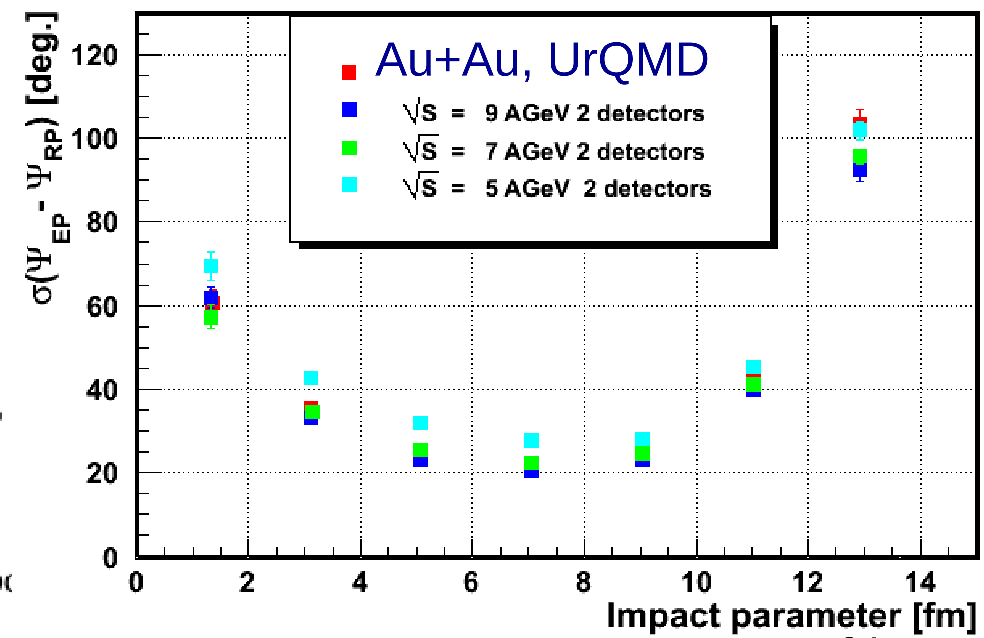
acceptance: 2.2<|η|< 4.8

$\sigma(E)/(E) = 53\%/\sqrt{E(GeV)} + 10\%$

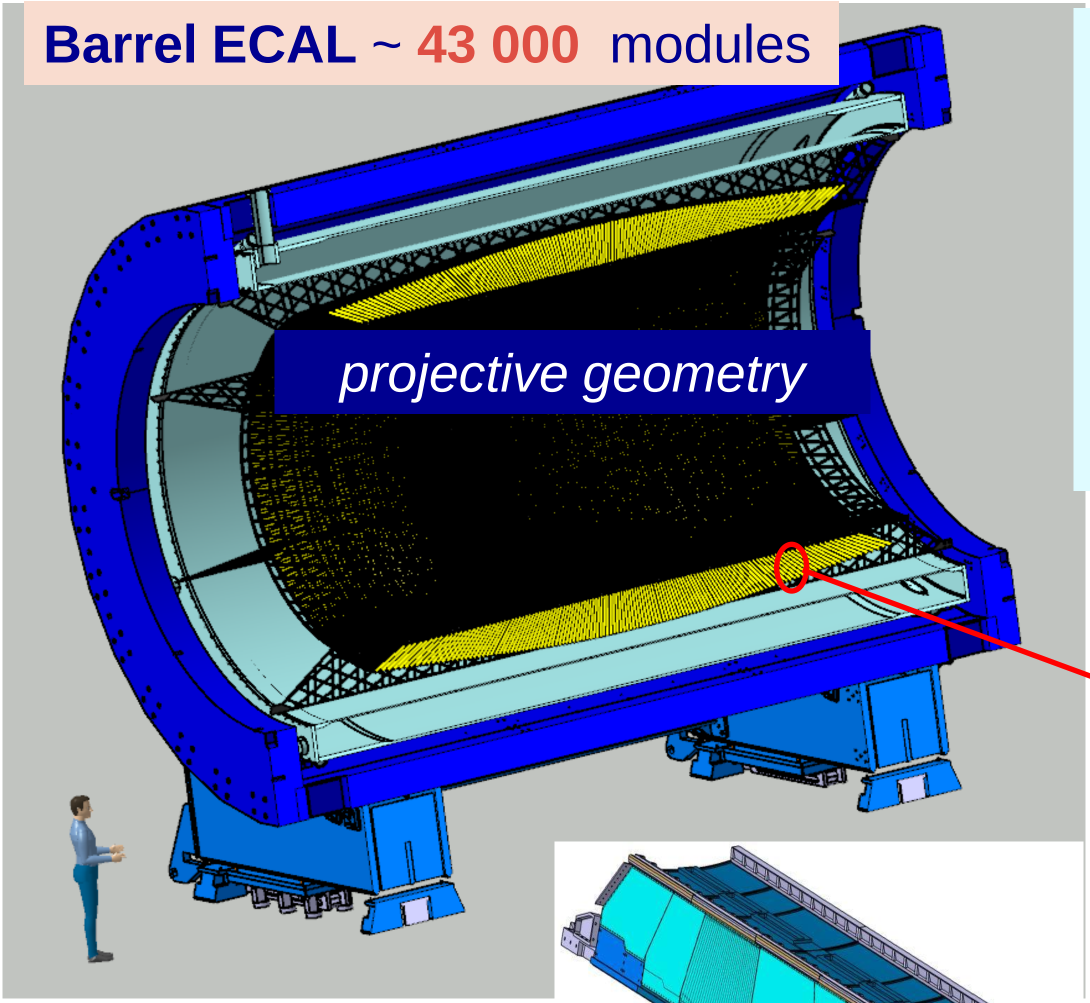
transverse granularity allows to measure:

- *the reaction plane with accuracy ~* 20^0-30^0
- *the centrality with accuracy below* 10%.

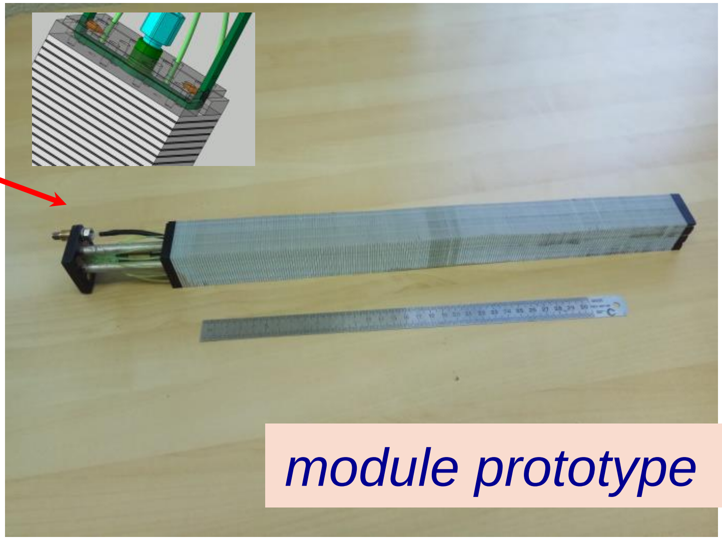




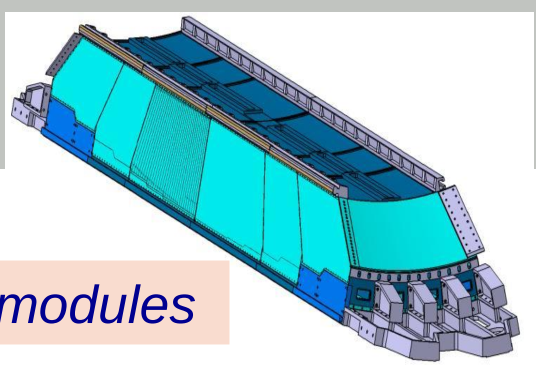
Electromagnetic calorimeter: ECAL



- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2),*
- *σ(E) better than 5% @ 1 GeV;*
- *time resolution ~500 ps*



module prototype

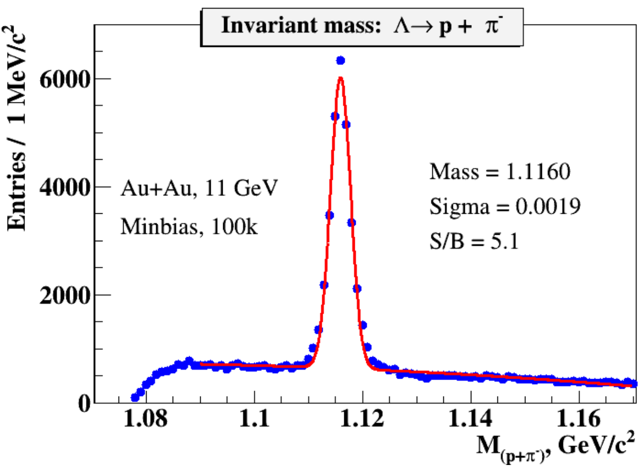


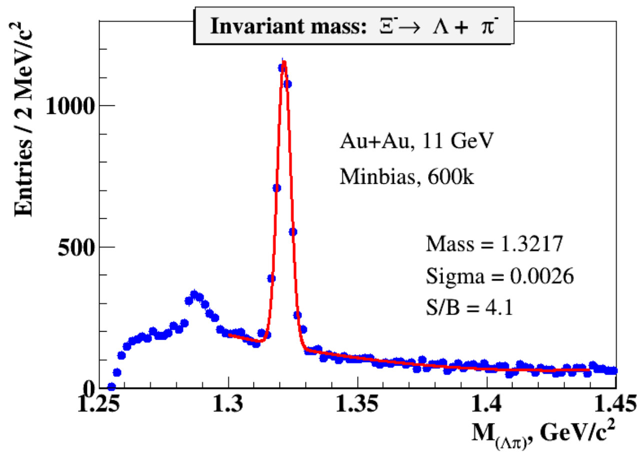
block of modules

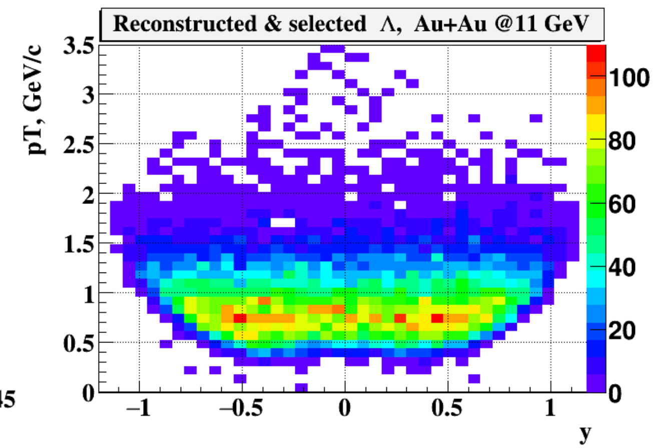
MPD: Strange and multi-strange baryons

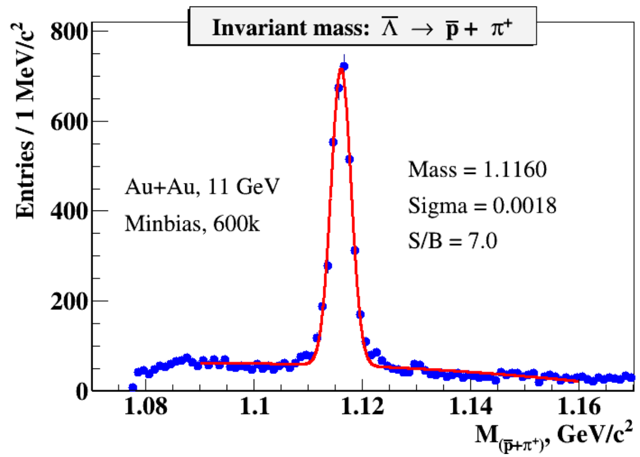
Stage'1 (TPC+TOF): Au+Au @ 11 GeV, UrQMD

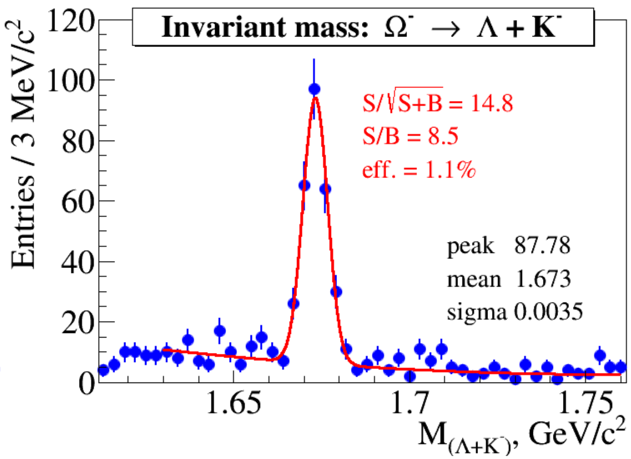
phase-space

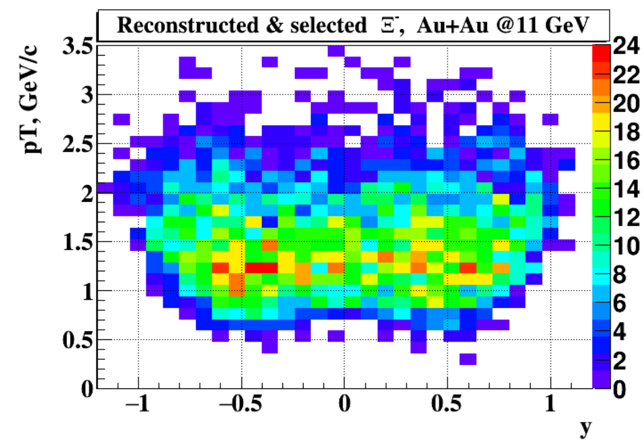








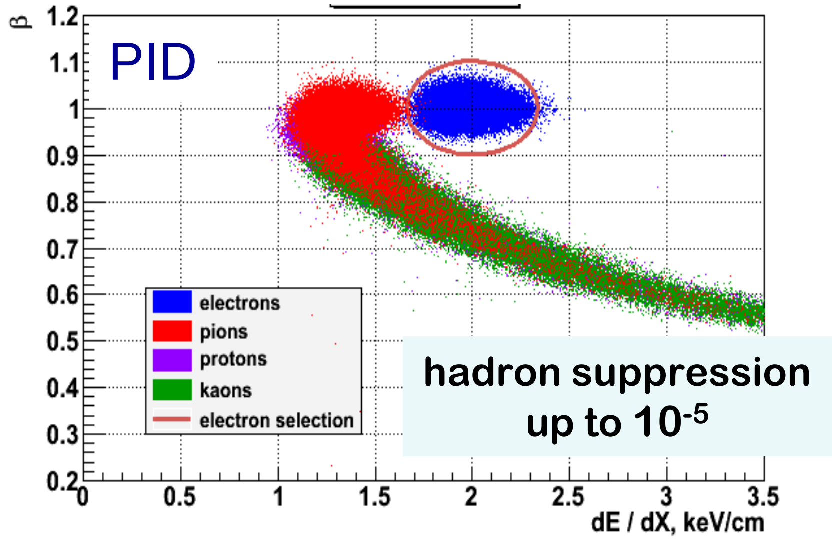


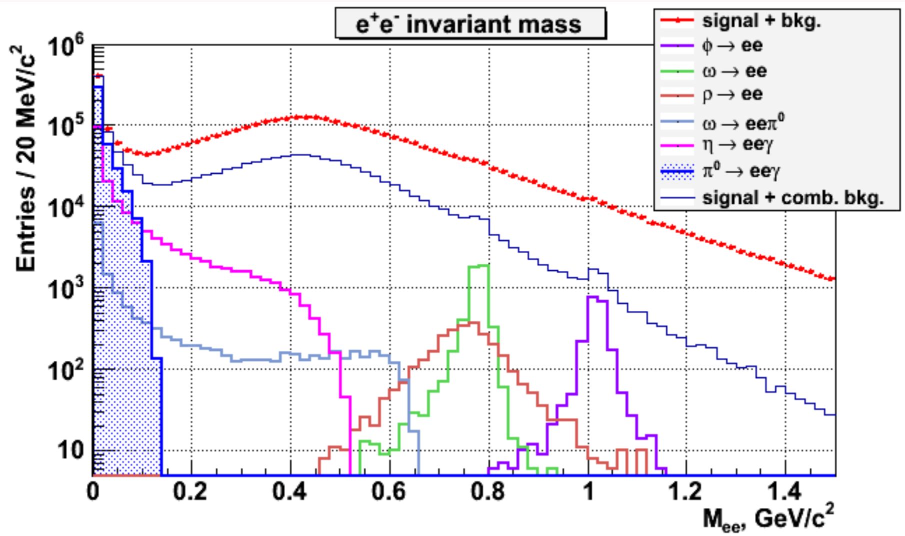


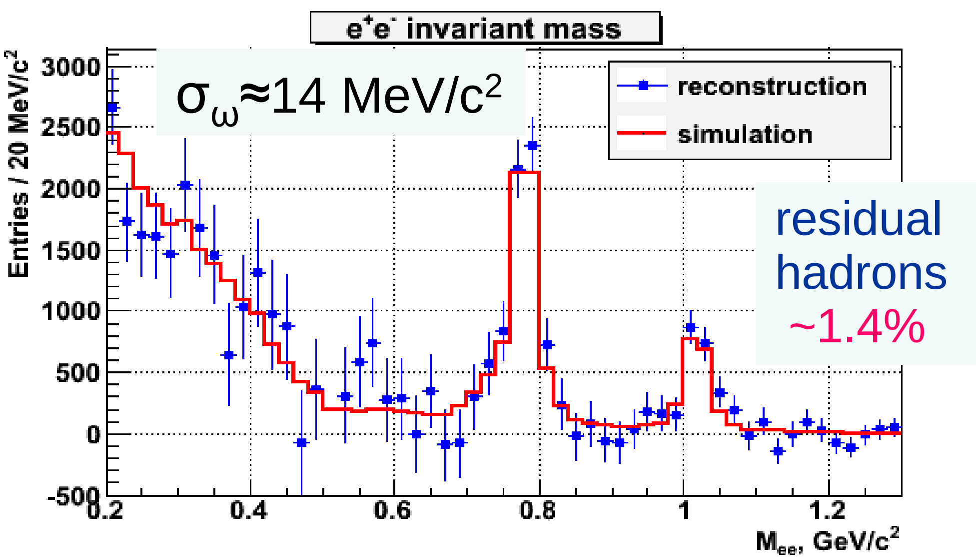
particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
yield in 10week	$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

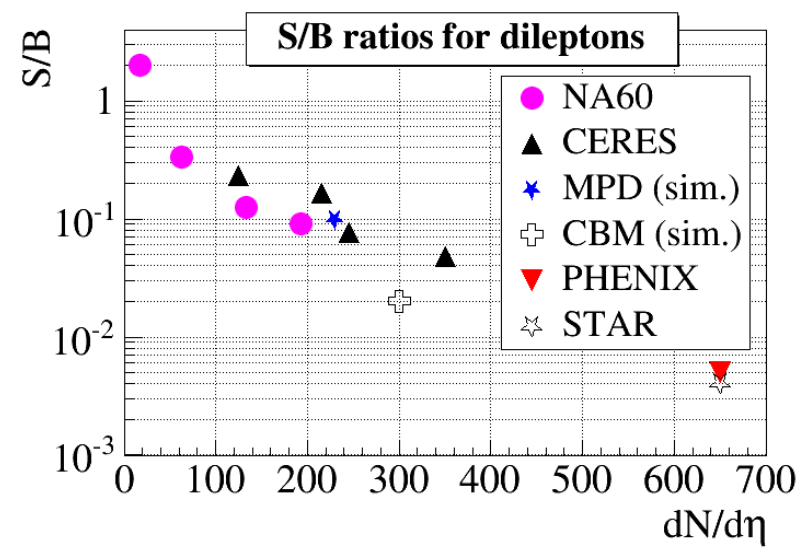
MPD: Prospects for study of di-leptons

- **Event generator:** *UrQMD+Pluto (for the cocktail) central Au+Au @ 8 GeV*
- **PID**: *dE/dx (from TPC) + TOF (s ~100 ps) + ECAL*

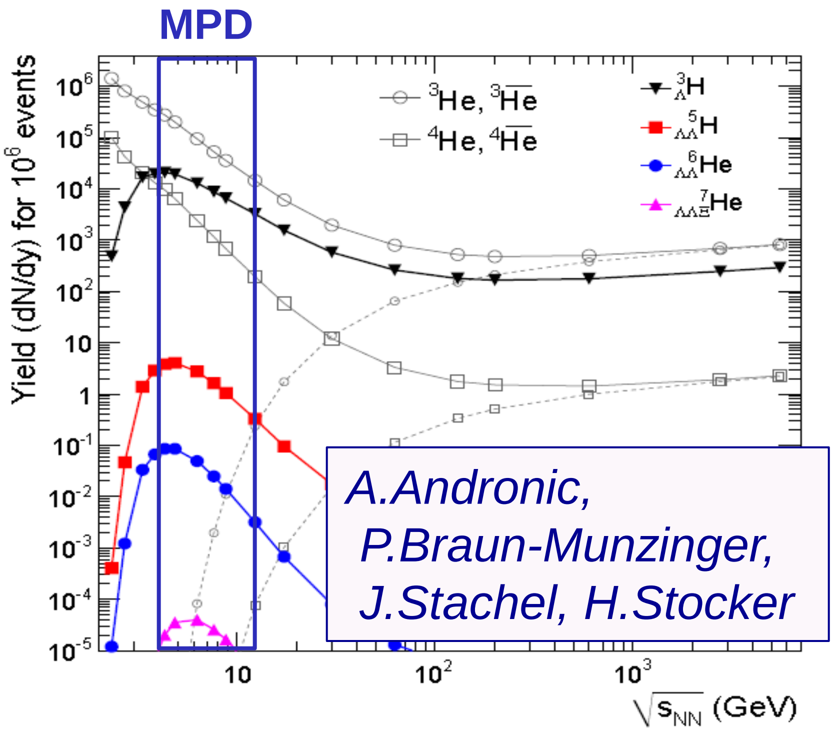






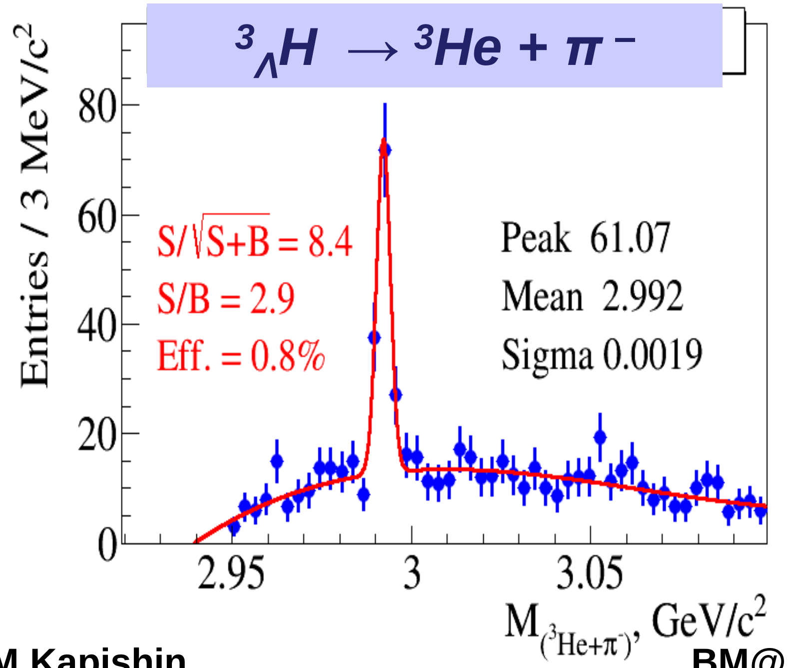


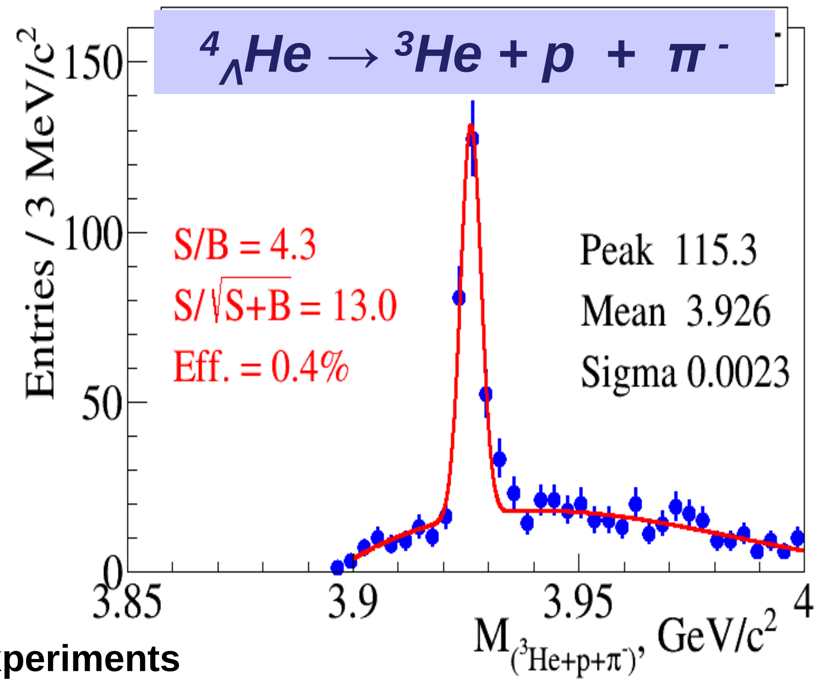
MPD: Hyper nuclei



Stage 2: ***central Au+Au @ 5 AGeV; DCM-QGSM***

hyper nucleus	yield in 10 weeks
$^{3}_{\Lambda}$H	$9 \cdot 10^{5}$
$^{4}_{\Lambda}$He	$1 \cdot 10^{5}$





kick-off meeting on formation of the MPD and BM@N Collaborations

carried out in Dubna on 11-13 April, 2018

https://indico.jinr.ru/conferenceDisplay.py?ovw=True&confId=385

The second meeting will take place on 29-31 October, 2018

Concluding remarks

- **NICA complex with two experiments BM@N and MPD has a potential for competitive research *in the field of baryon rich matter***

- **The BM@N experiment (*stage 0*) *has already started data taking***

- **Preparations of MPD experiment *is going close to the schedule***

- **Collaborations of both experiments BM@N and MPD *are permanently growing***

Thank you
for attention!