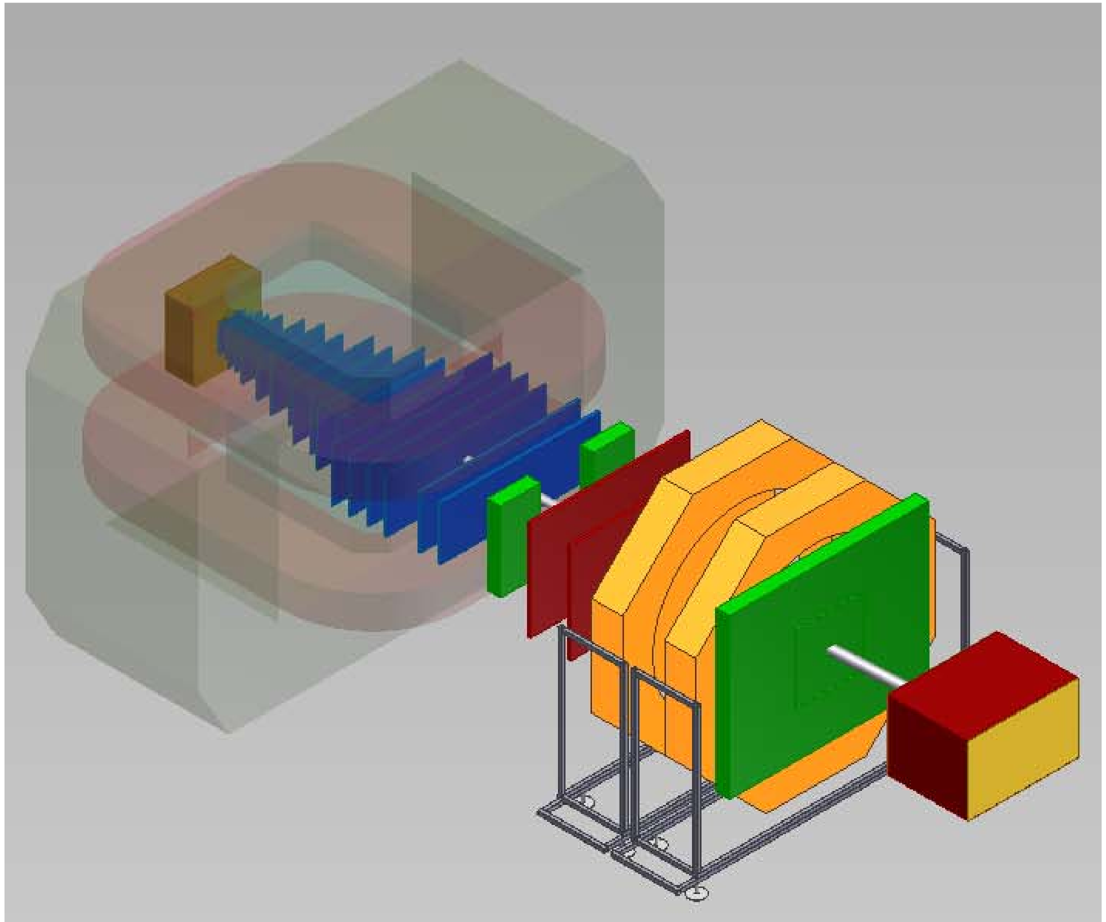
Baryonic Matter at Nuclotron: status and physics program

M.Kapishin (JINR, Dubna)

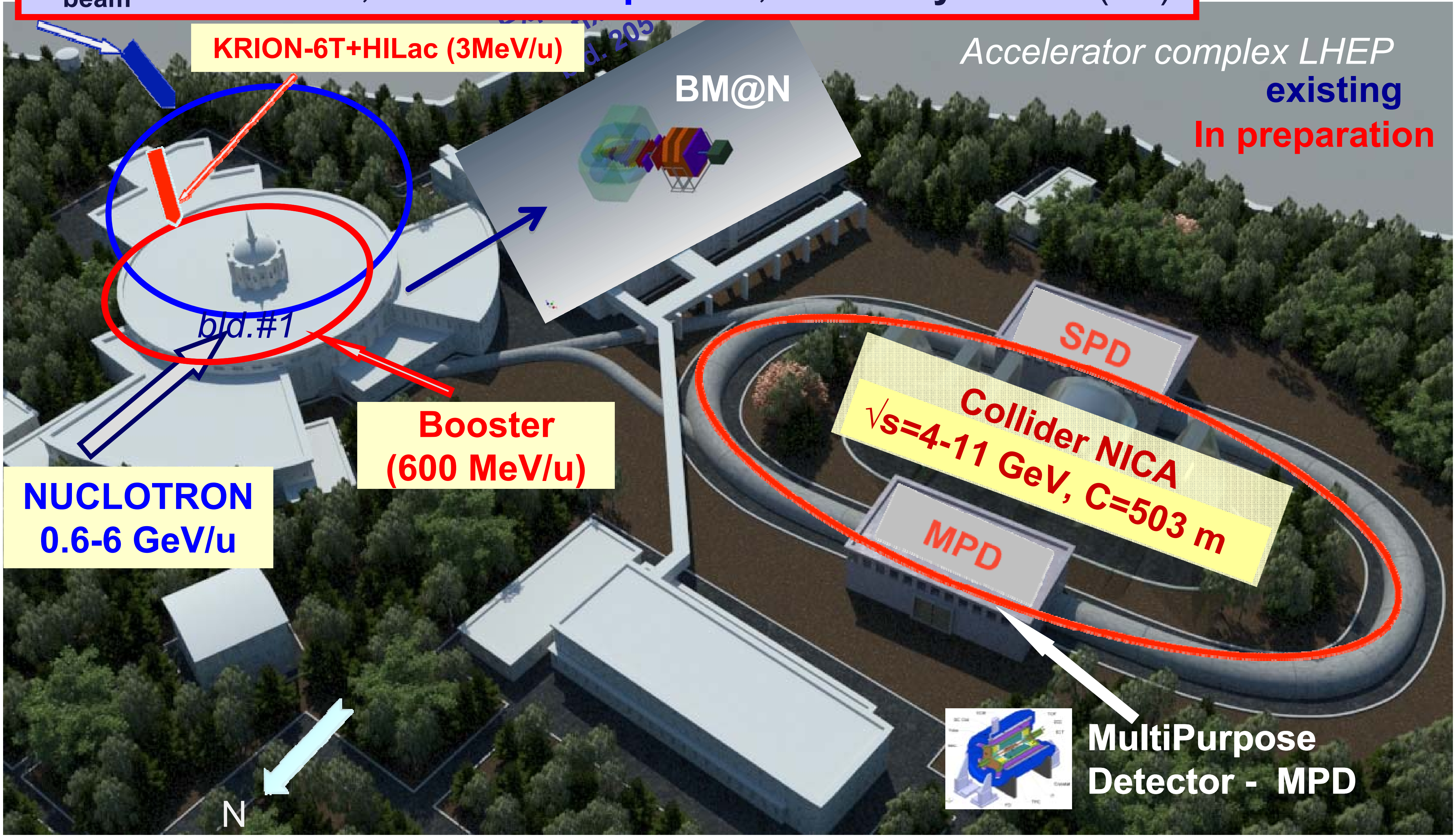
JINR (Dubna), IHEP (Protvino), INR RAS (Troitsk), ITEP (Moscow), SINR MSU

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

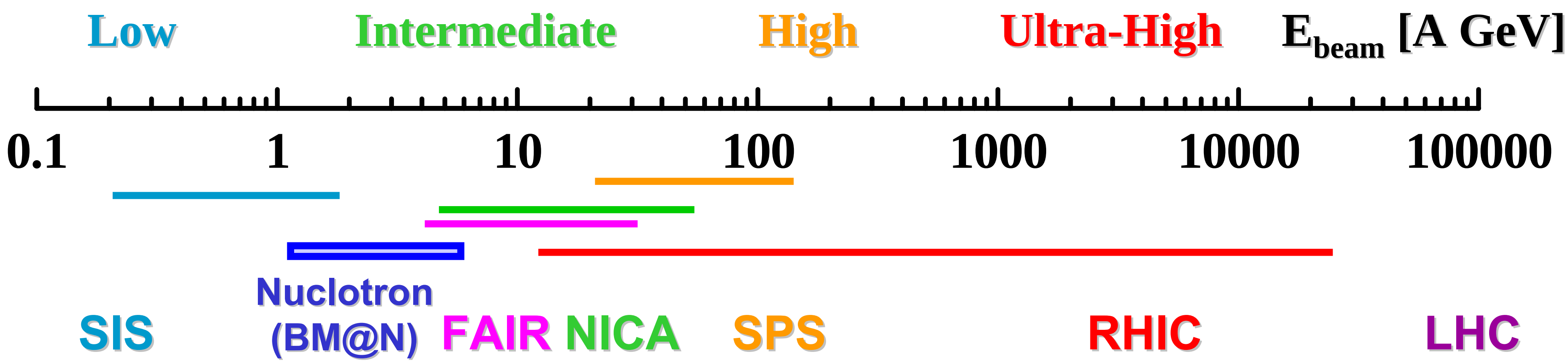


Complex NICA

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



Baryonic matter

||

Meson and baryon spectroscopy
In-medium effects
EoS

‚Mixed' phase:
hadrons (baryons, mesons) + quarks and gluons

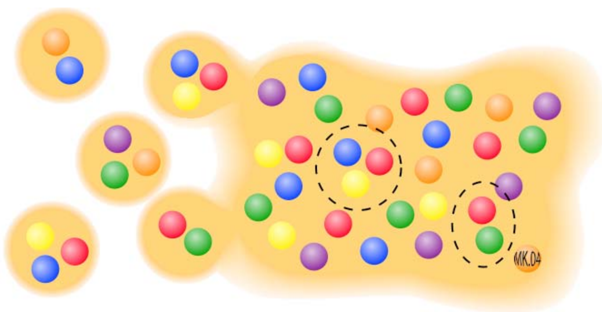
||

In-medium effects
Chiral symmetry restoration
Phase transition to sQGP
Critical point in the QCD phase diagram

QGP: quarks and gluons

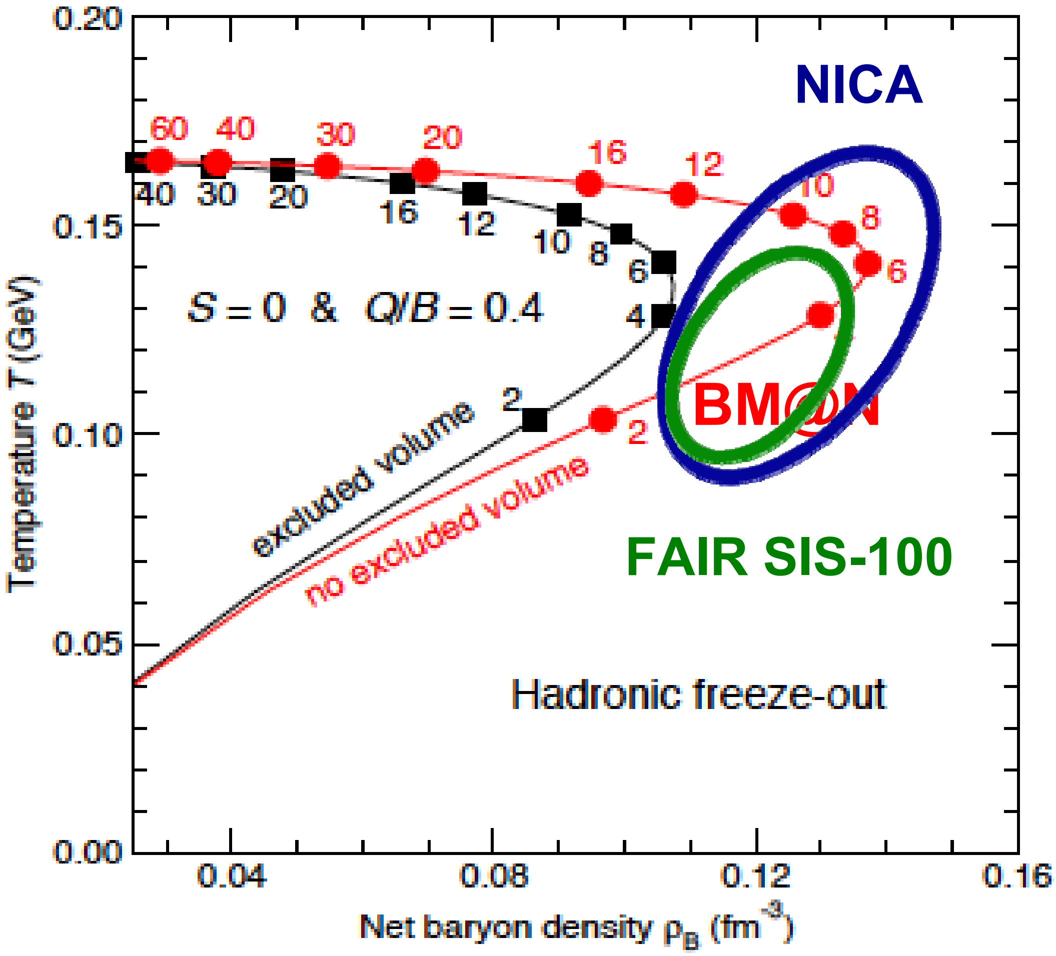
||

Properties of sQGP

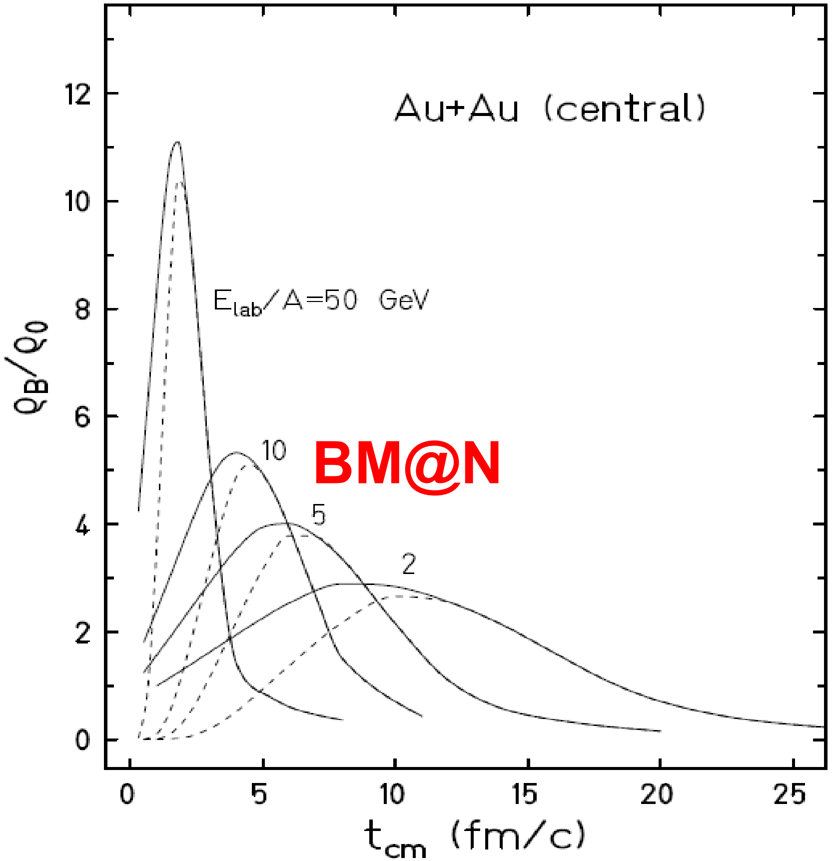


Explore high density baryonic matter

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

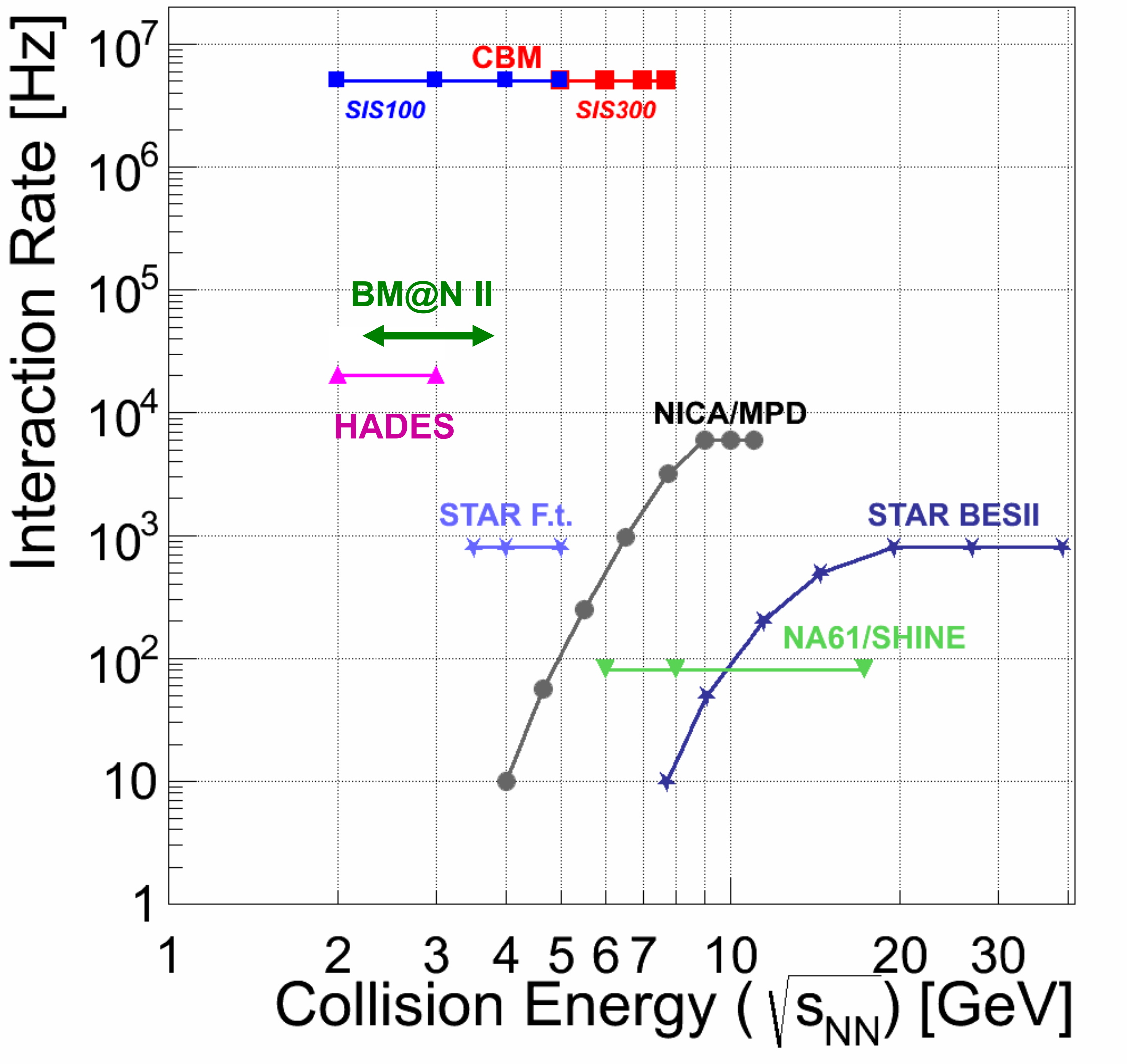


Baryon-dominated system throughout
Comparatively long lifetime



Heavy Ion Collision experiments

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



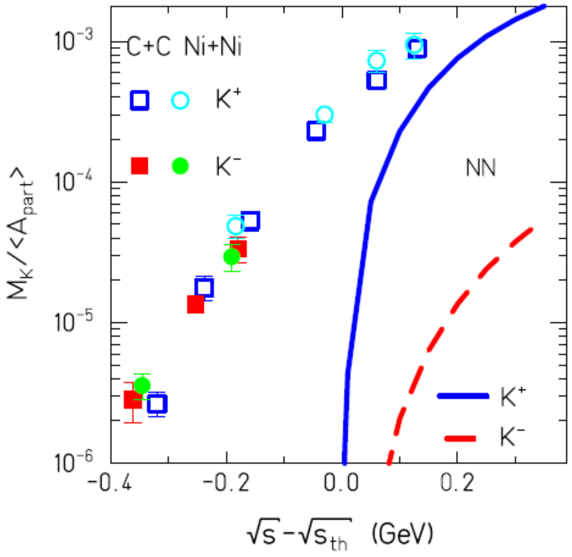
Physics possibilities at the Nuclotron

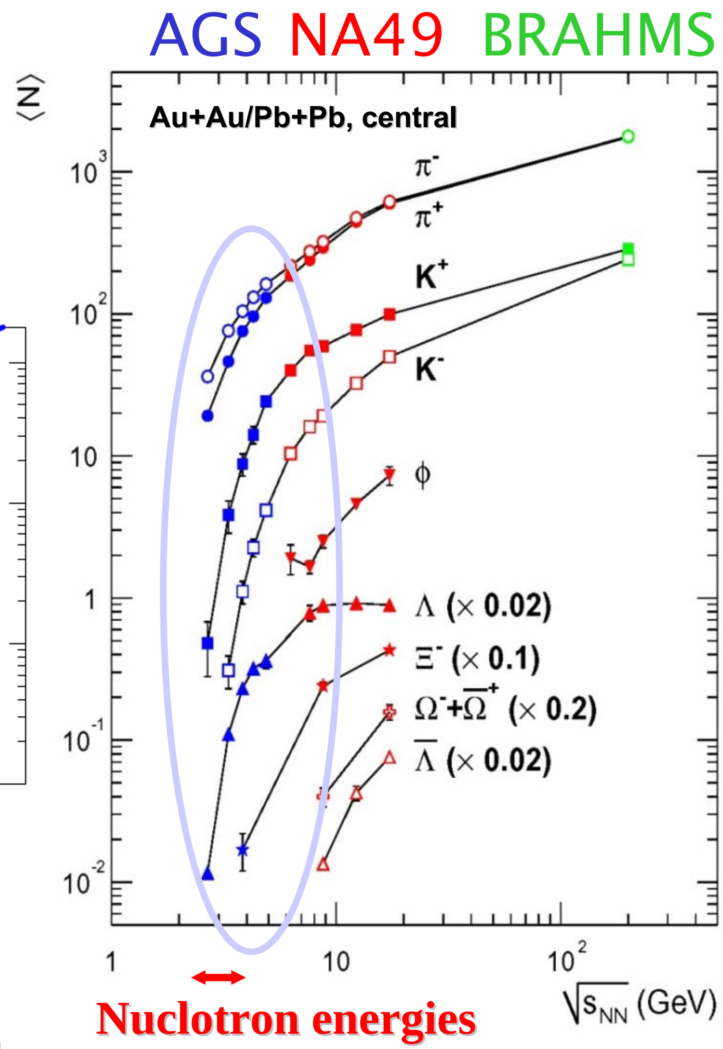
I. In A+A collisions at Nuclotron energies:

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

➔ **strangeness at threshold**

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





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

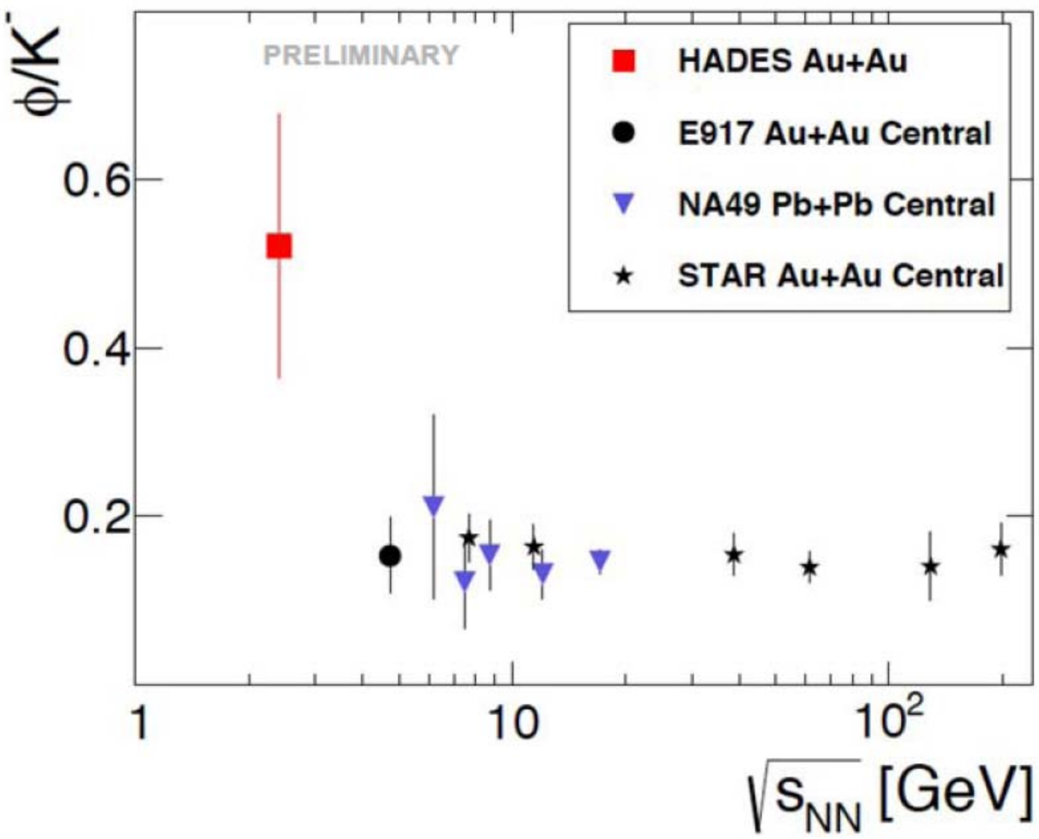
➔ **hadron production in elementary reactions and ‚cold' nuclear matter as ‚reference' to pin down nuclear effects**

Questions from HADES experiment

Excess of φ and Ξ^- production in heavy ion collisions

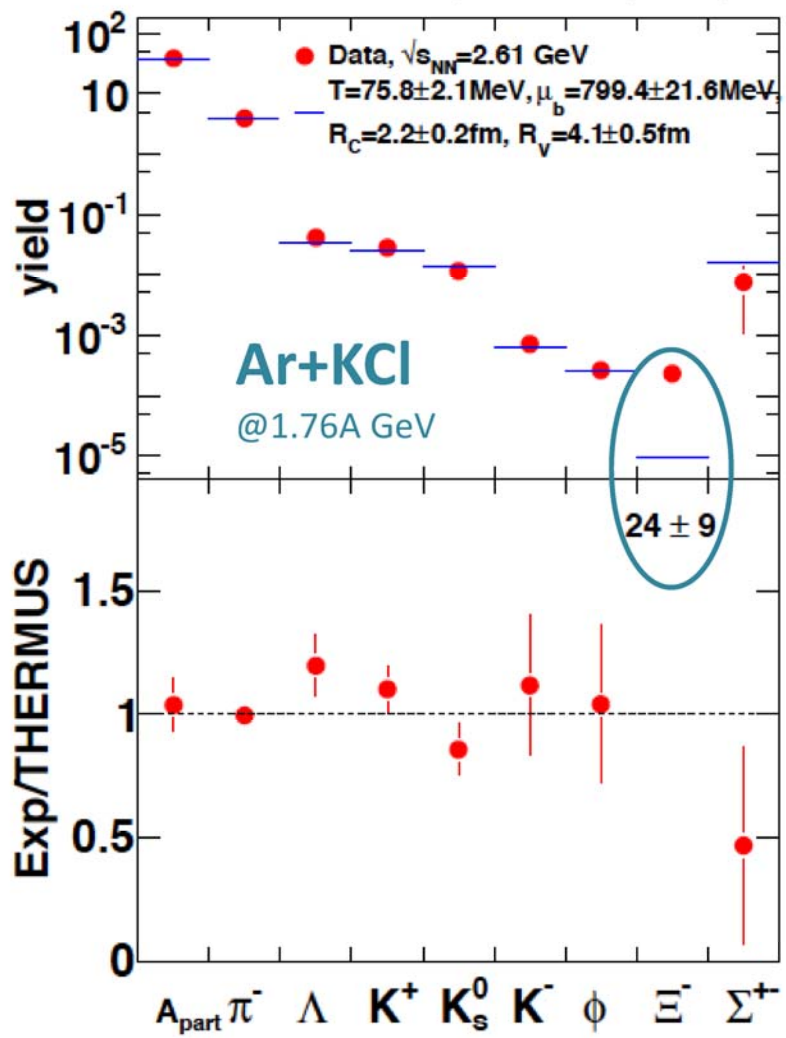
Large multiplicity of Strangeonium (ϕ)

- $\approx 25\%$ $of\ K^-$ due to ϕ decay after freeze-out

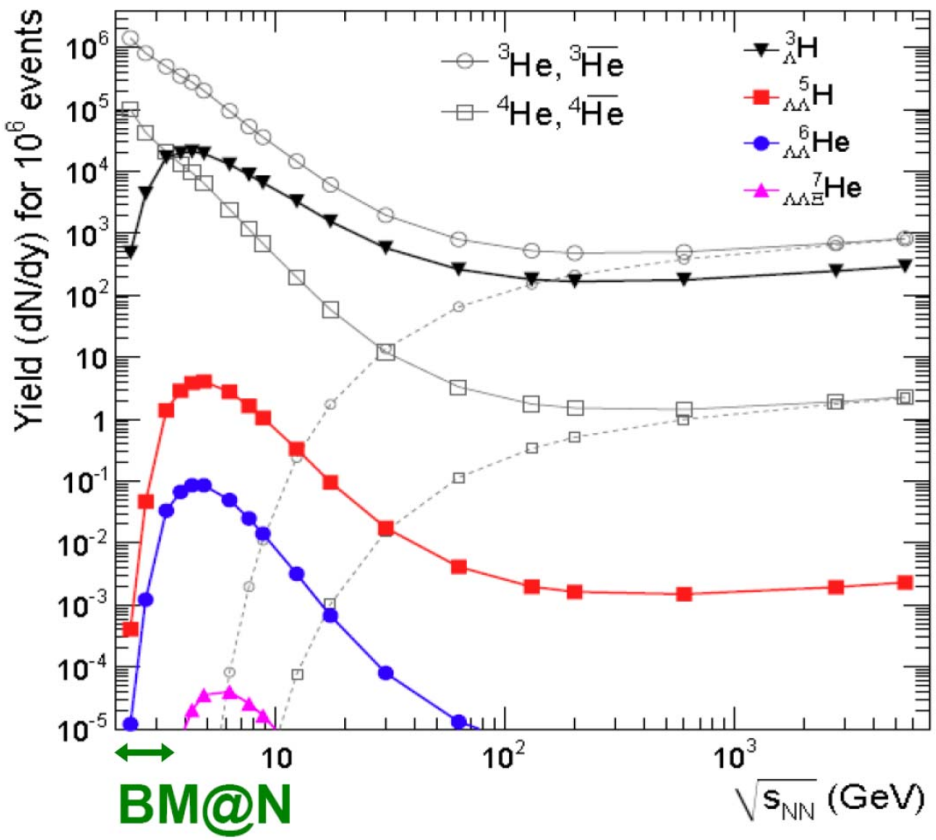


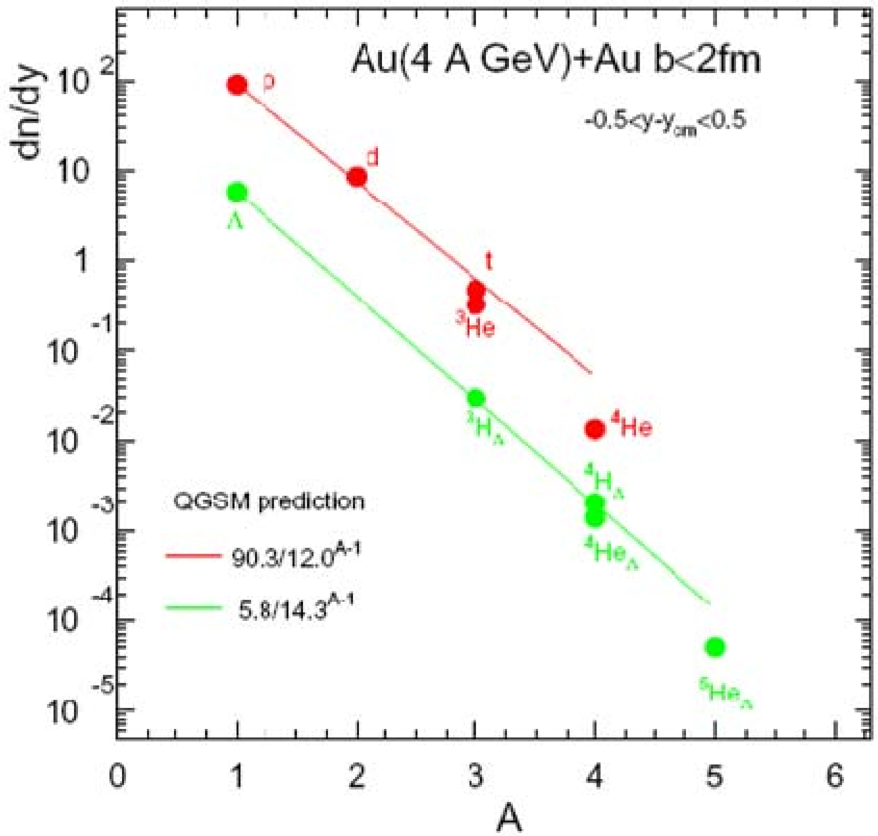
- Observed yield in Ar+KCl much above expectation from SHM

Eur.Phys.J. A47 (2011) 21



Heavy-ions A+A: Hypernuclei production



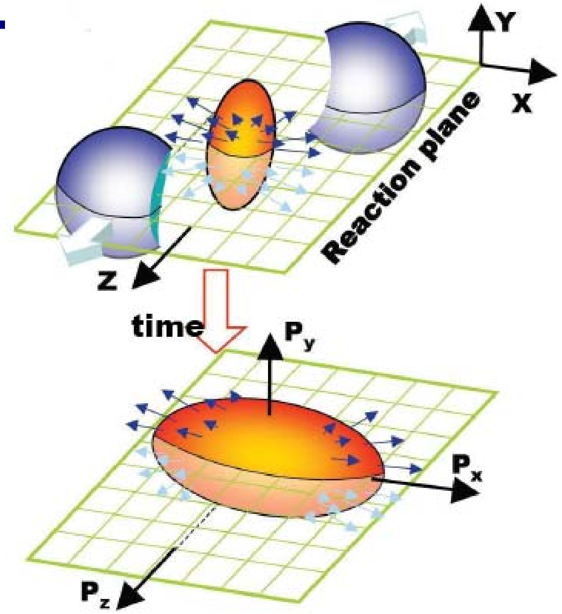


❑ **In heavy-ion reactions:** production of hypernuclei through coalescence of Λ with light fragments enhanced at high baryon densities

❑ **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

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



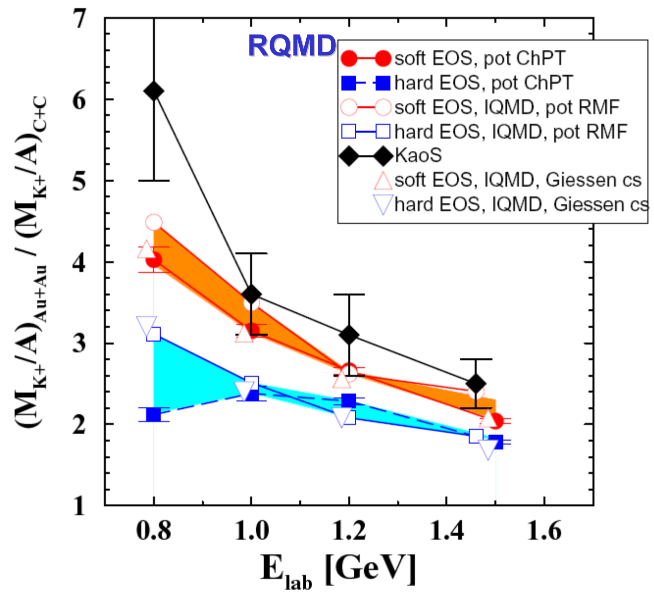
❖ The nuclear dynamics is defined by the EoS (via density dependent NN-interaction)

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

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

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

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



Nuclotron and BM@N beam line

26 elements of magnetic optics:

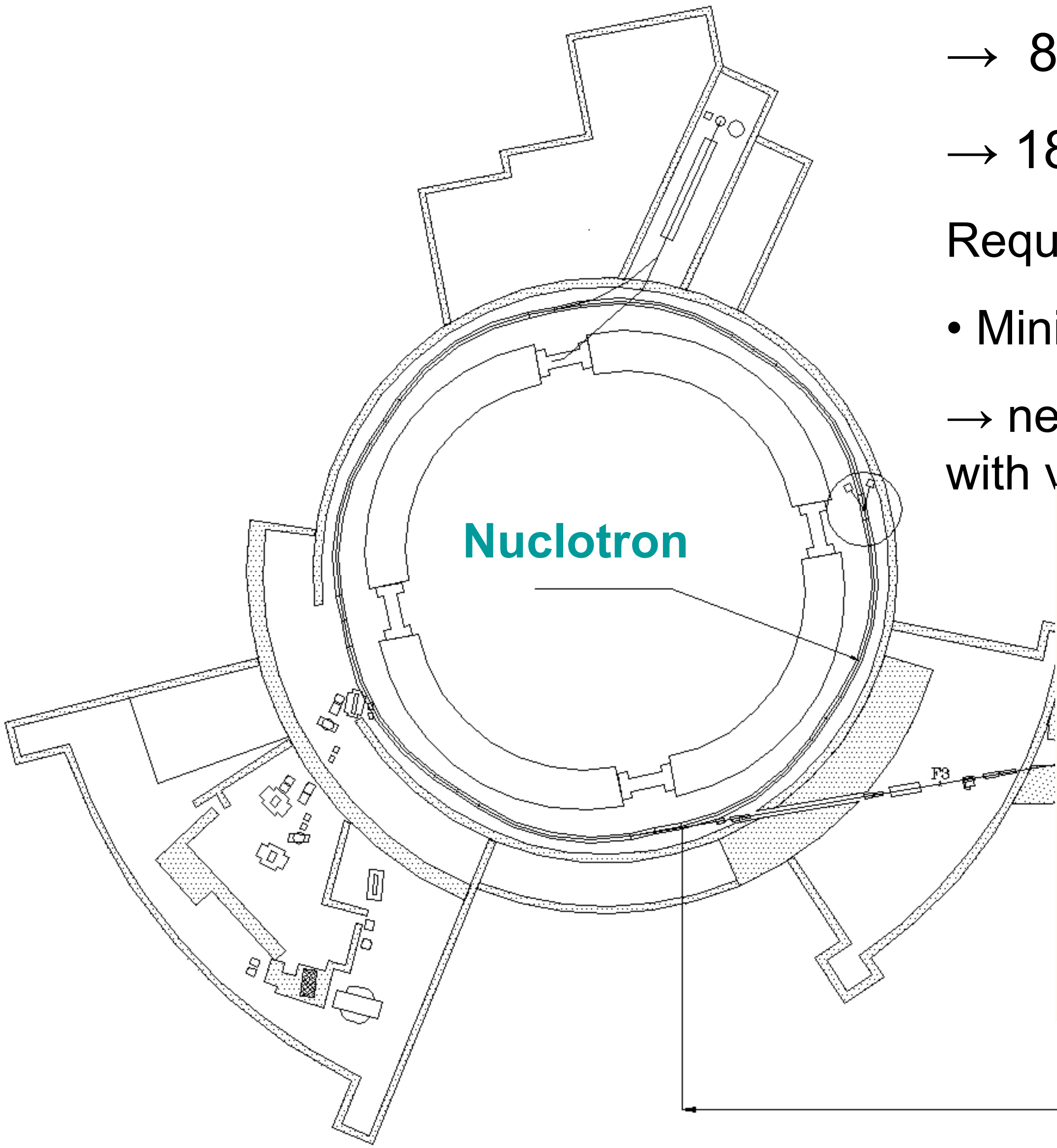
→ 8 dipole magnets

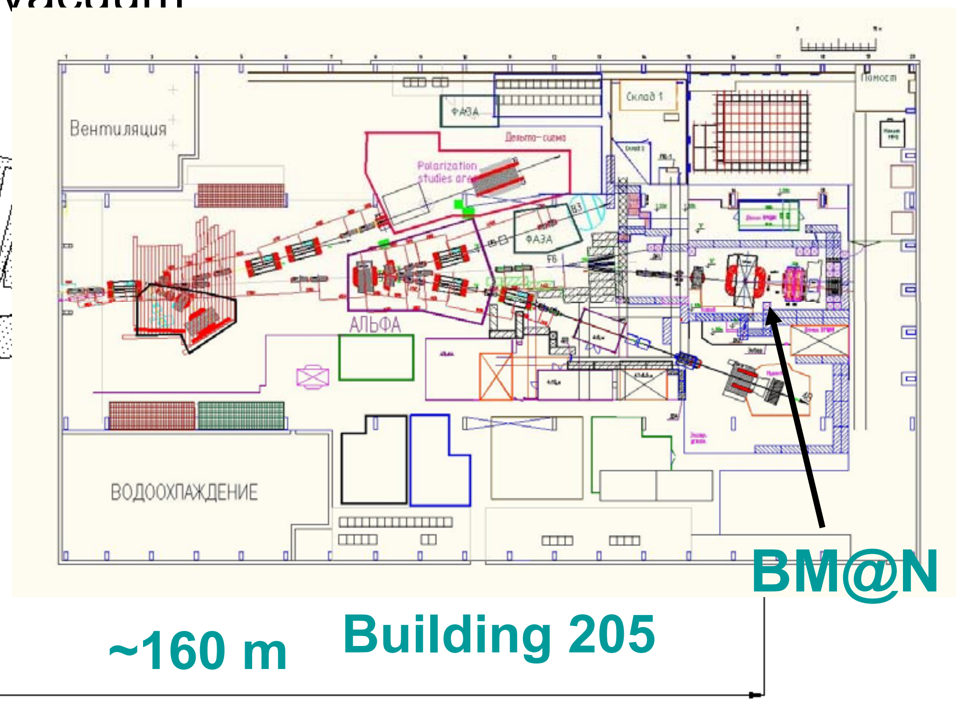
→ 18 quadruple lenses

Requirements for Au beam:

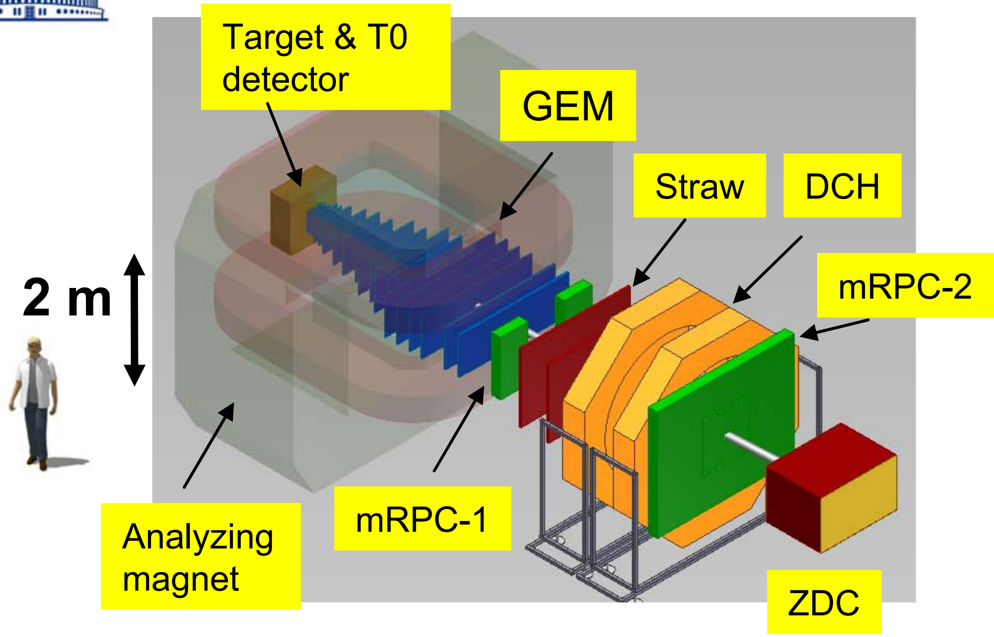
• Minimum dead material

→ need to replace 40 m 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

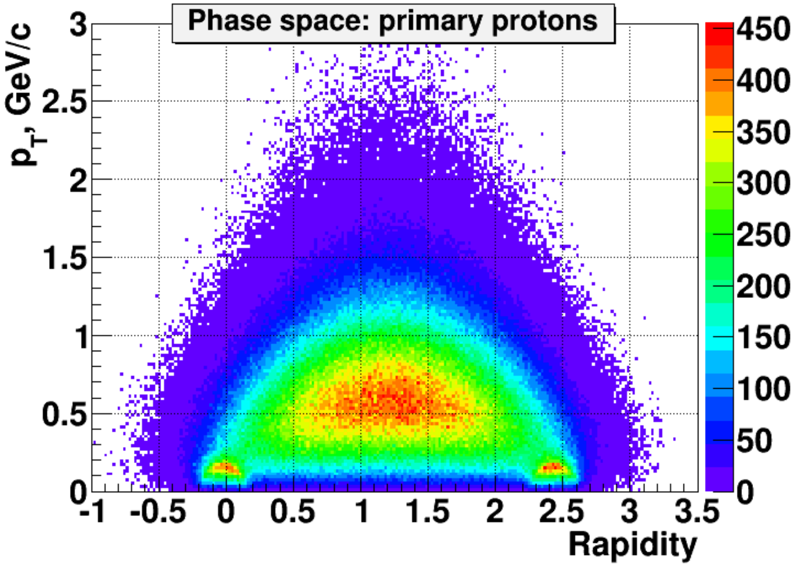
→ divide detectors for particle identification to "near to magnet" and "far from magnet" to measure particles with low as well as high momentum (p > 1-2 GeV/c)

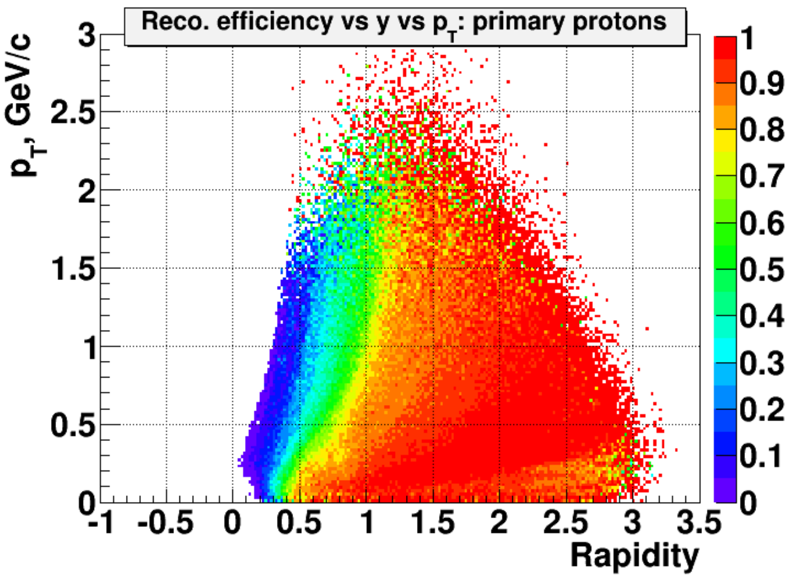
→ fill distance between magnet and "far" detectors with coordinate detectors

- Central tracker (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-

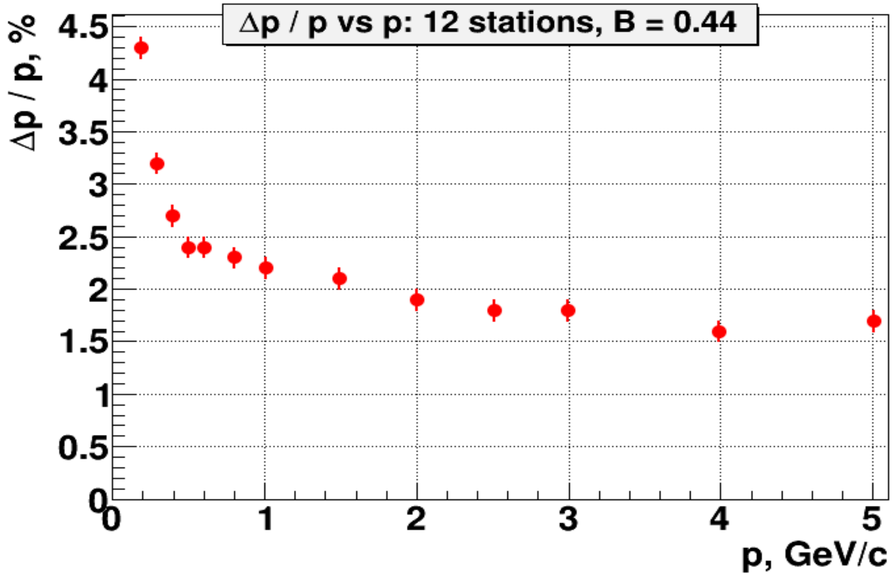
GEM tracker: acceptance / momentum resolution / detection efficiency

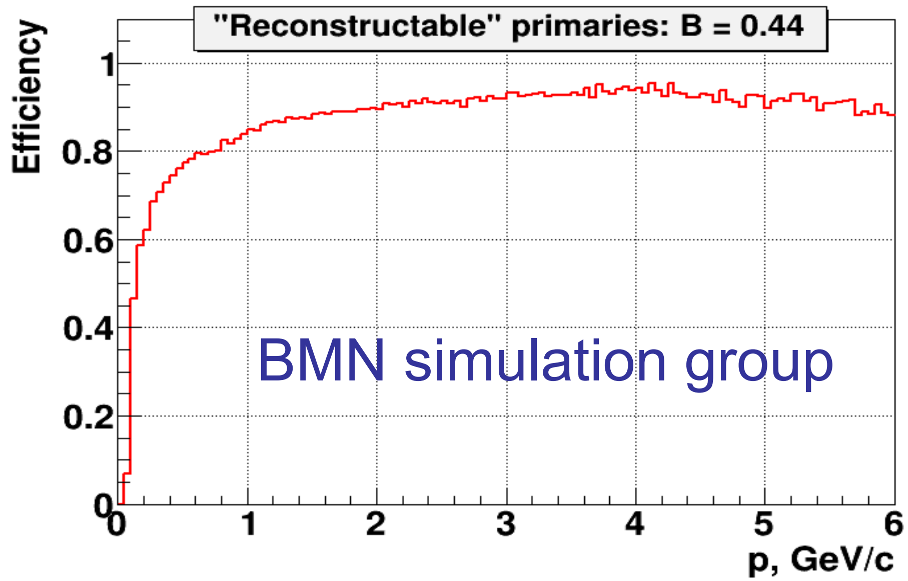
Phase space / acceptance to primary protons:





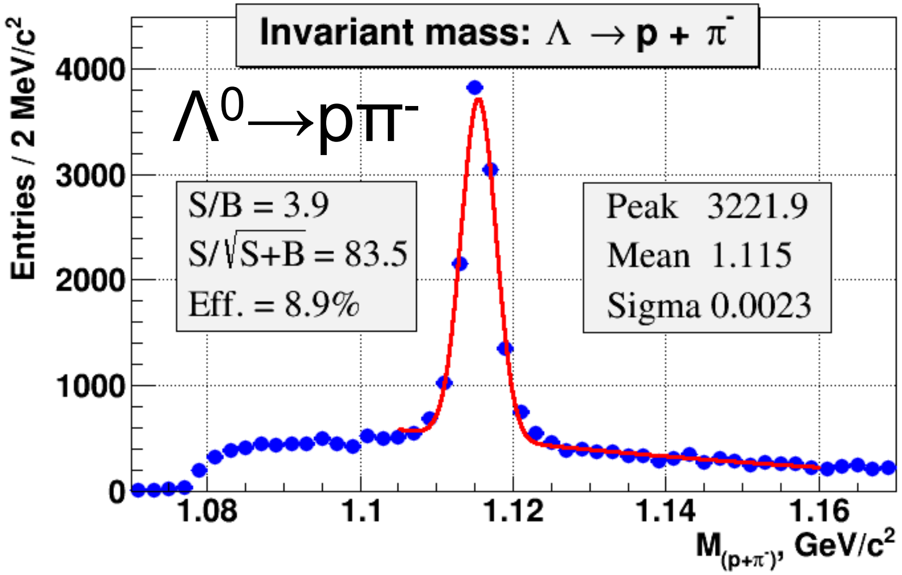
Momentum resolution / detection efficiency



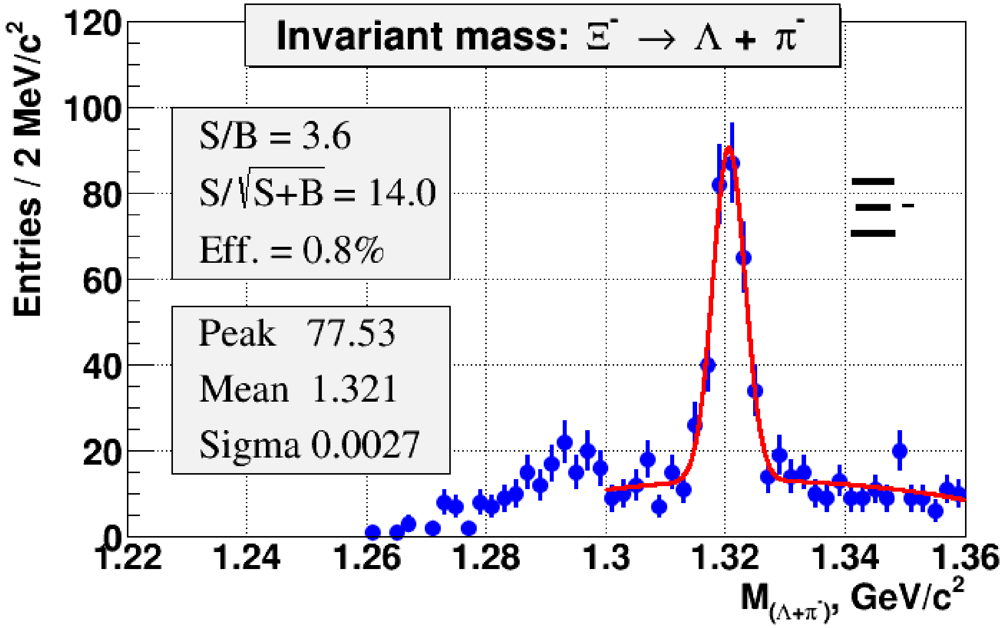


GEM tracker: Λ^0, Ξ^-, $^3H_\Lambda$ reconstruction

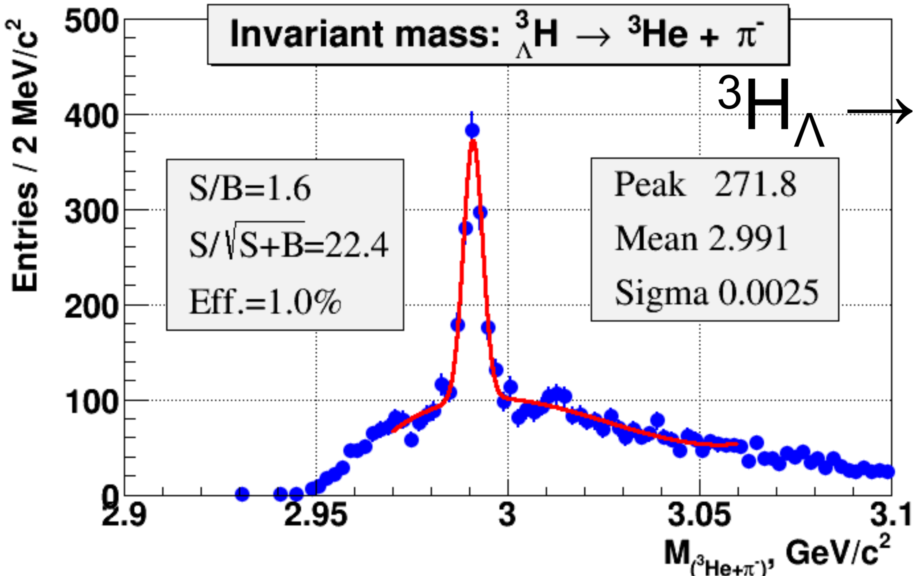
Au+Au, URQMD,10k central events



Au+Au, 4.5 AGeV, 900k central events

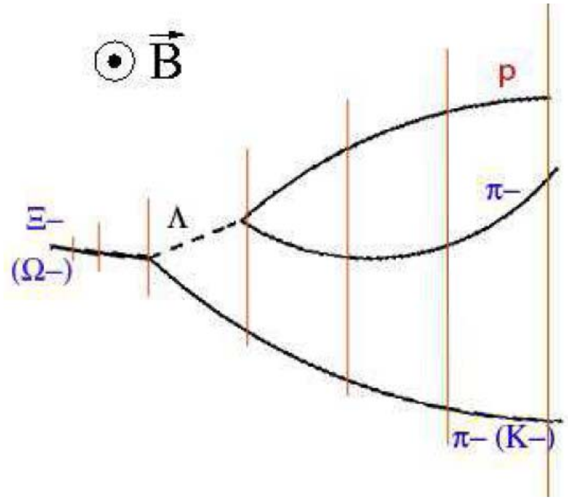


Au+Au, 4.5 AGeV, 2.6M central events



$^3H_\Lambda \longrightarrow {}^3He\ \pi^-$

$\Xi^- \rightarrow \pi^- + \Lambda^0 \rightarrow p\pi^-$

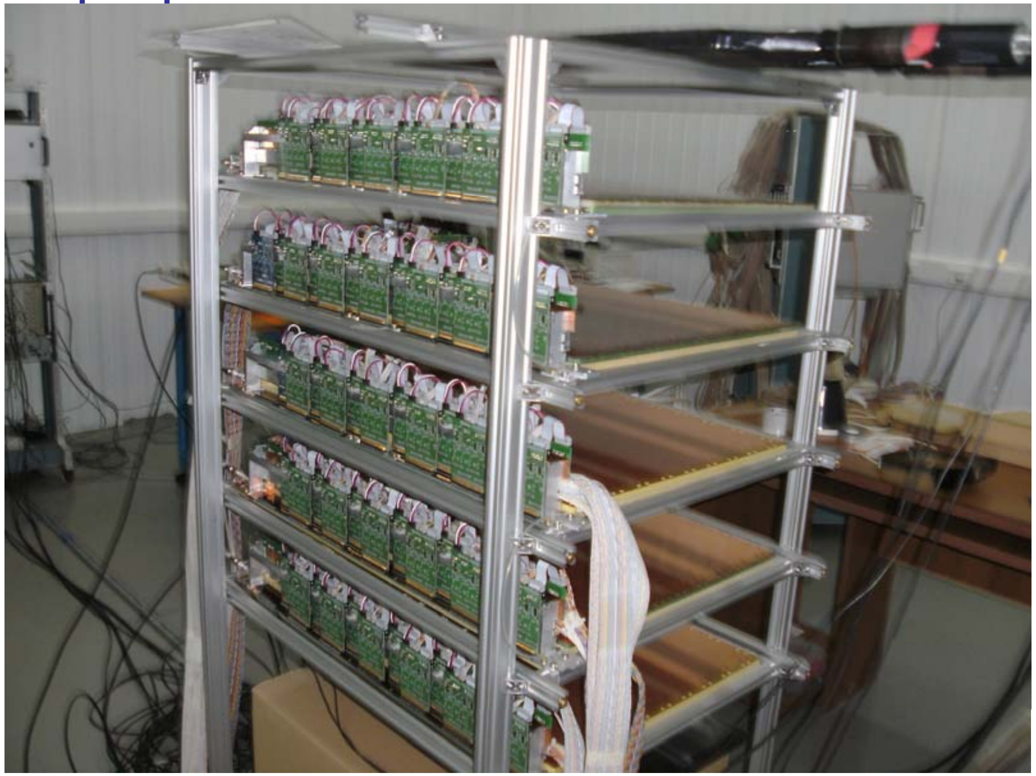


M.Kapishin BM@N experiment

GEM detectors for central BM@N tracker

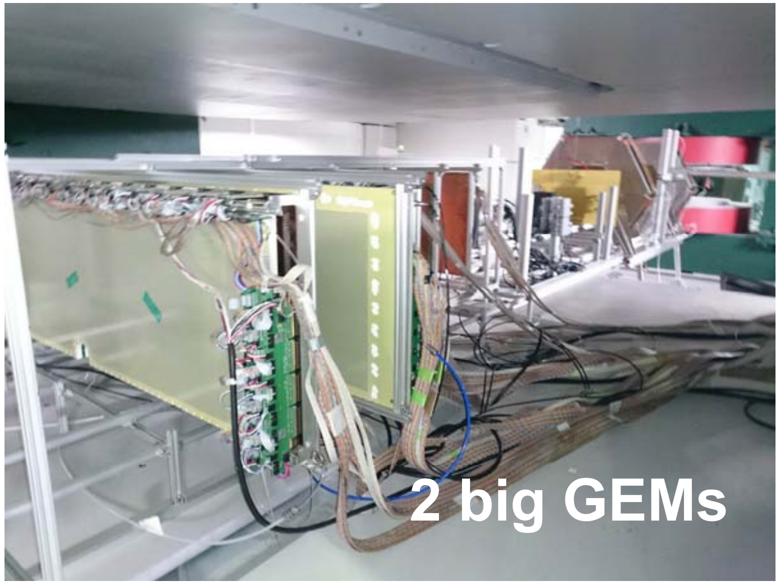
Tests of GEM detector 163 x 45 cm^2

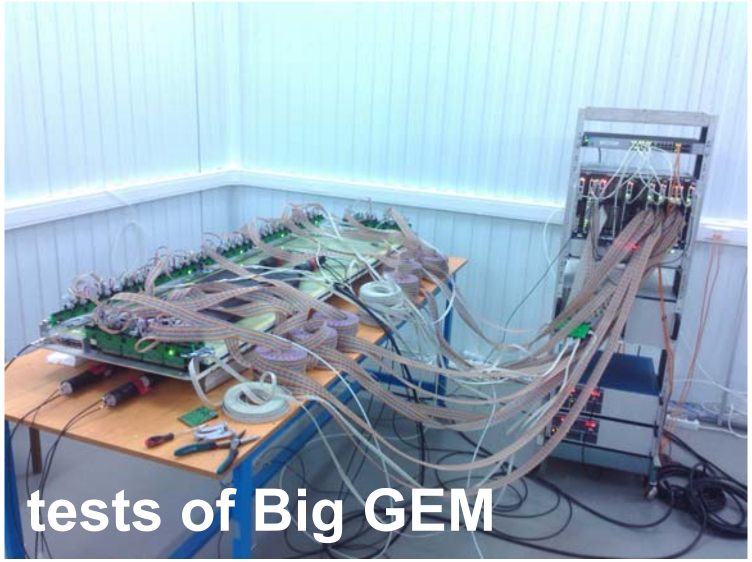
Set of 5 GEM detectors 66 x 41 cm^2 prepared for cosmic tests



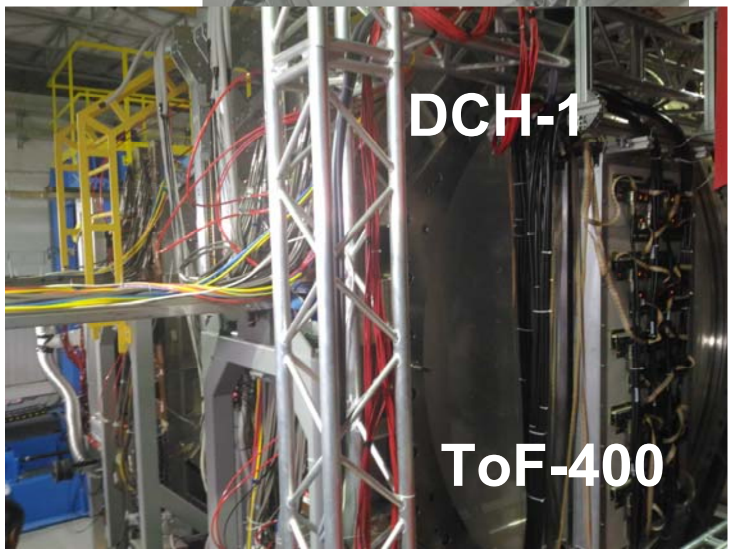
- for tracking in BM@N recent technical runs with deuteron and carbon beams used 5 detectors 66 x 41 cm^2 and 2 detectors 163 x 45 cm^2
- for BM@N run in autumn 2017 plan to produce 4 - 6 more detectors 163 x 45 cm^2

BM@N experiment in December 2016



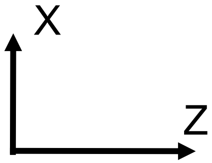


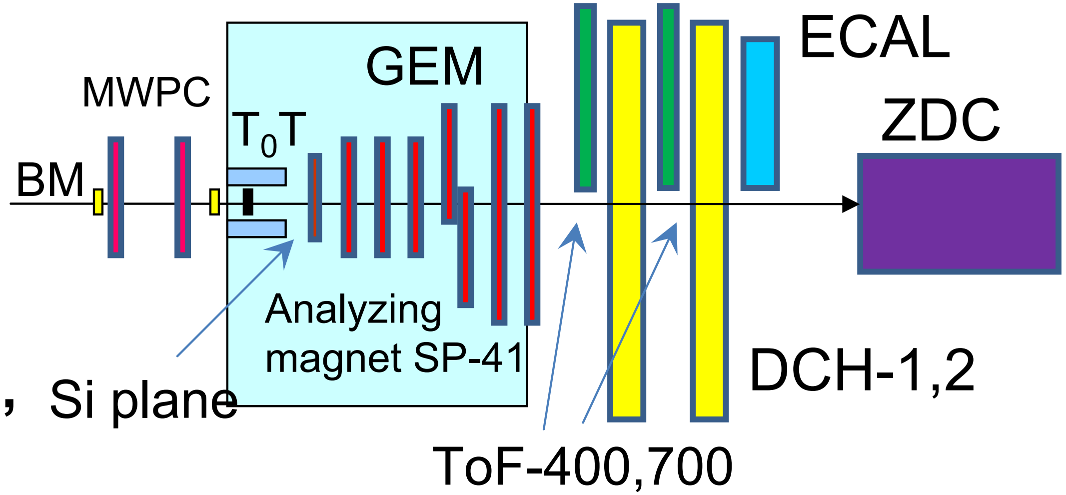
New detector components:
2 big GEMs, trigger barrel detector, Si detector, ECAL



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

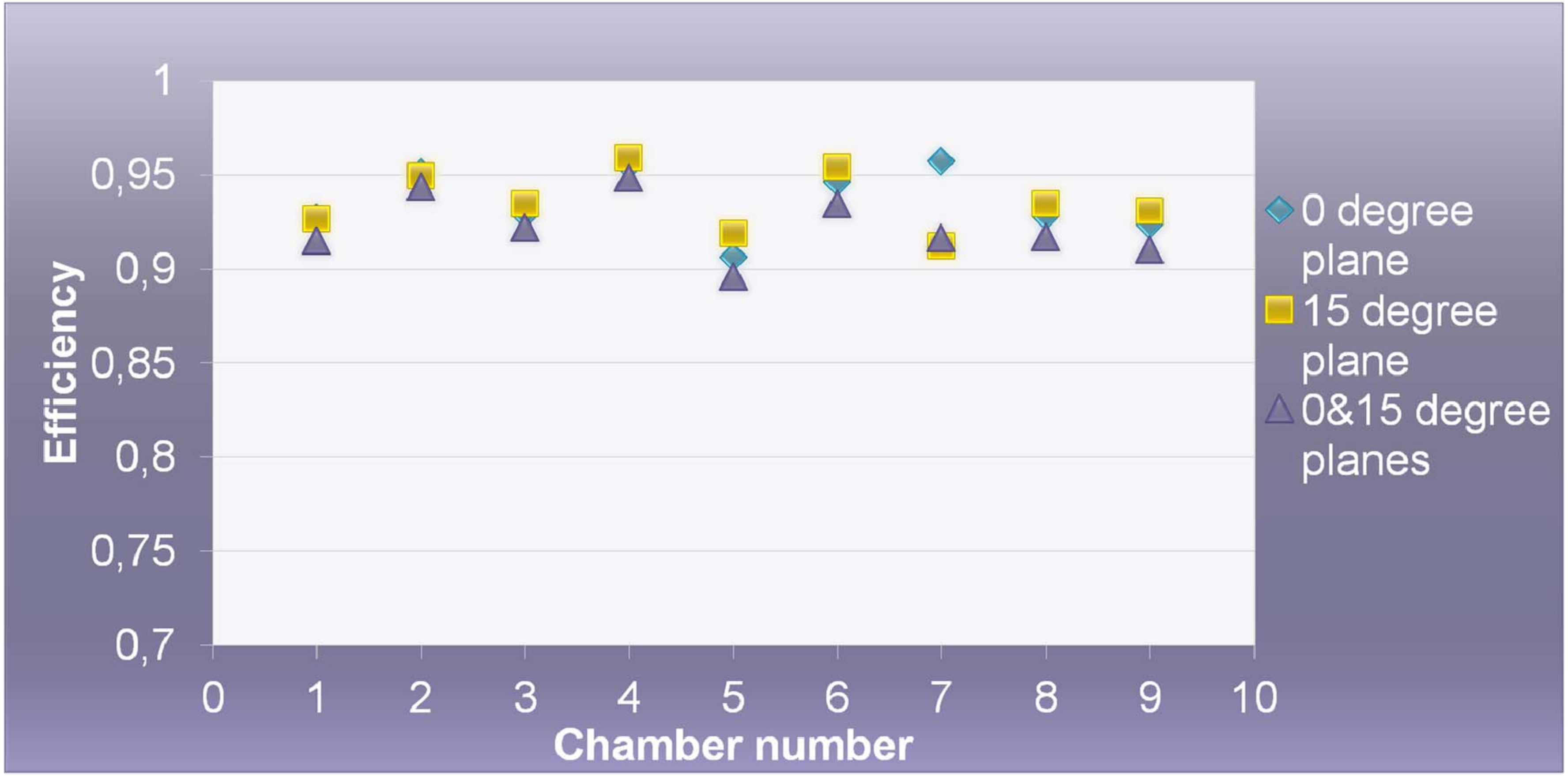
- **Focus on tests and commissioning of central tracker inside analyzing magnet → 5 GEM detectors 66 x 41cm^2 + 2 GEM detectors 163 x 45 cm^2 and 1 plane of Si detector for tracking**
- **Test / calibrate ToF, T0+Trigger barrel detector, full ZDC, part of ECAL**

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**

GEM detector efficiency in deuteron run

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



X plane

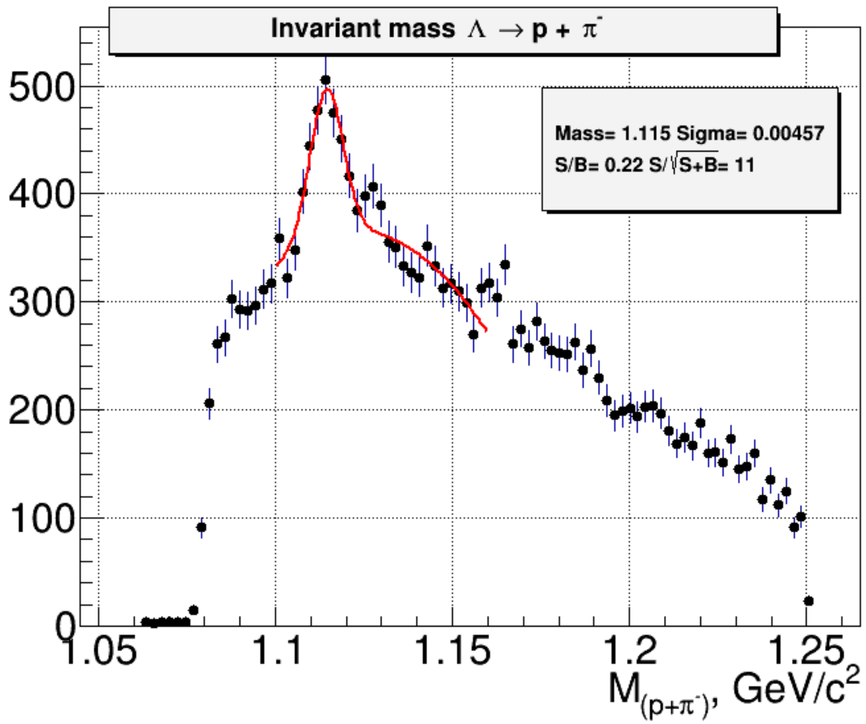
X' plane

X & X' planes

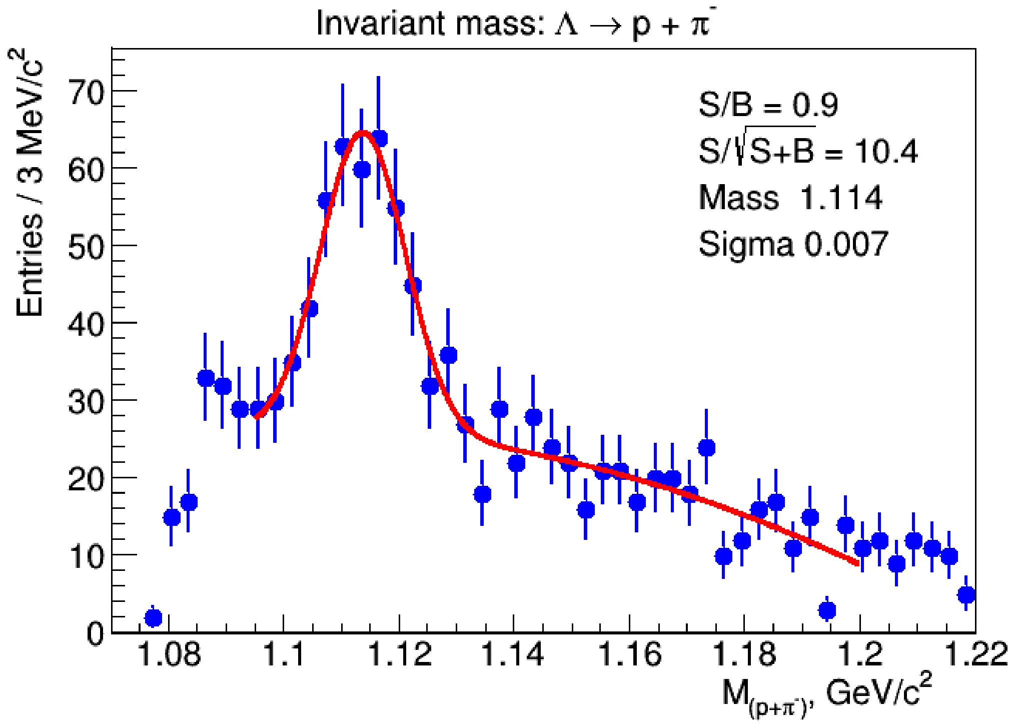
First results on Λ reconstruction with GEM detectors in deuteron beam interactions

d + target → Λ + X

Soft selection



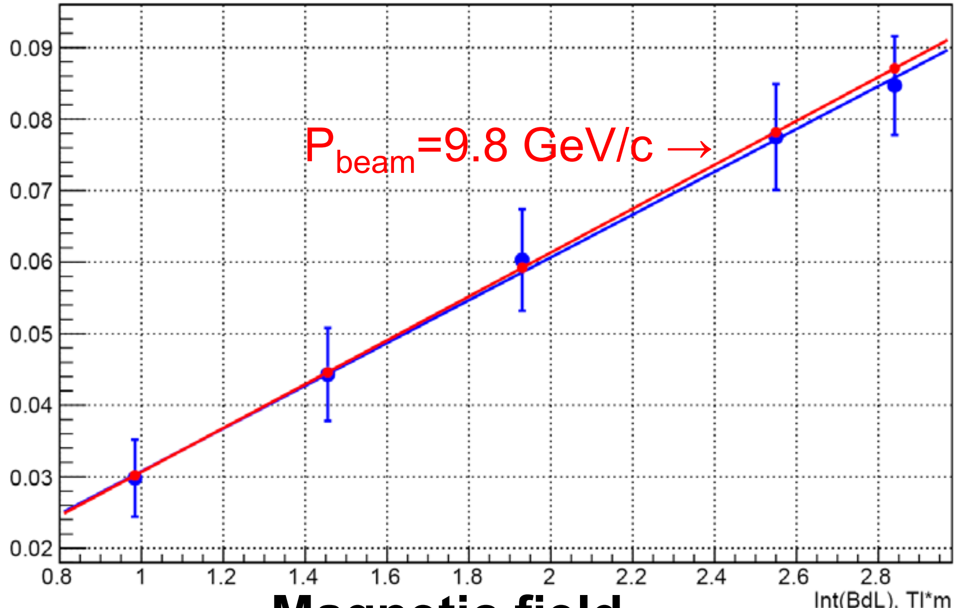
Tight selection



- **Need to improve vertex reconstruction → forward Silicon detector already implemented**
- **Need more GEM planes to improve track momentum reconstruction → plan to install 4 - 6 GEM planes in autumn 2017**

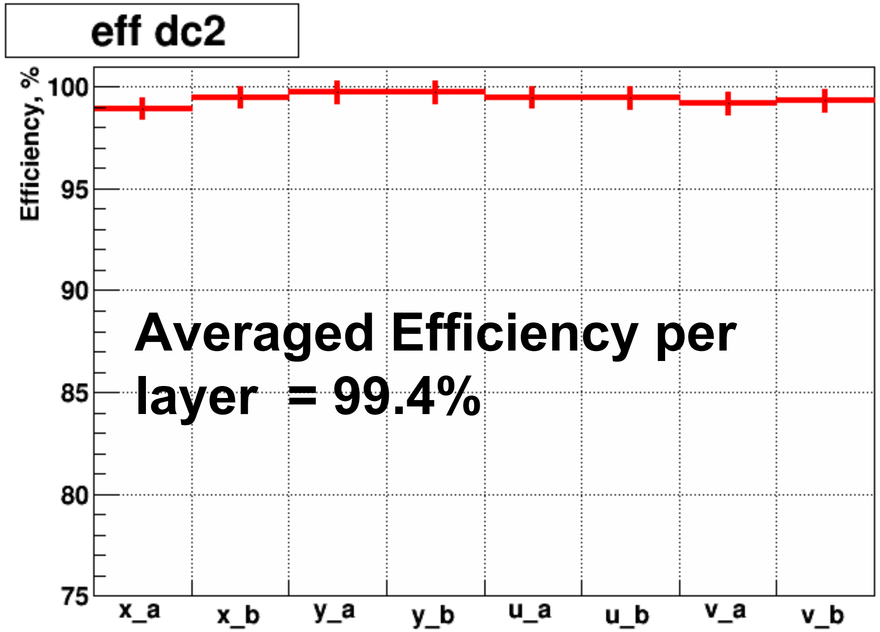
Performance of DCH outer tracker in deuteron run

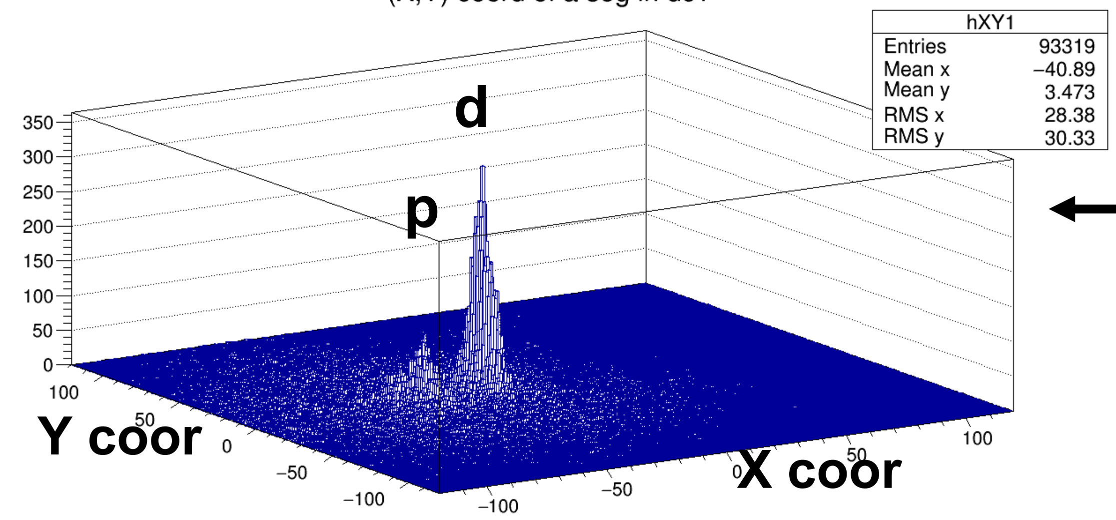
beam track angle in DCH

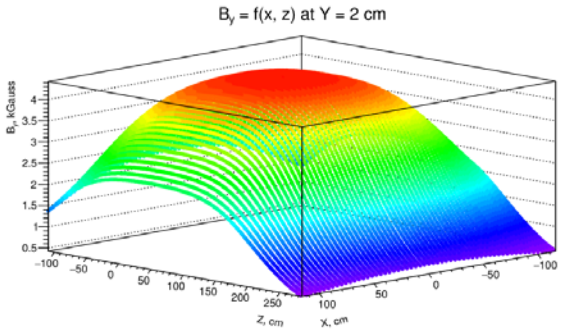


Magnetic field

Reconstructed beam tracks







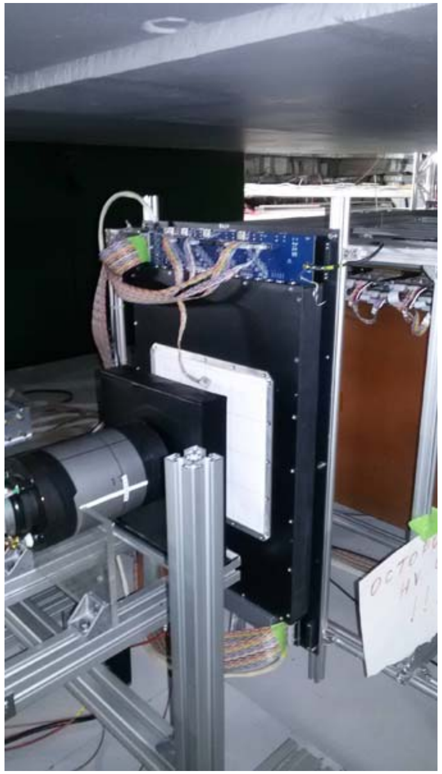
Magnetic field

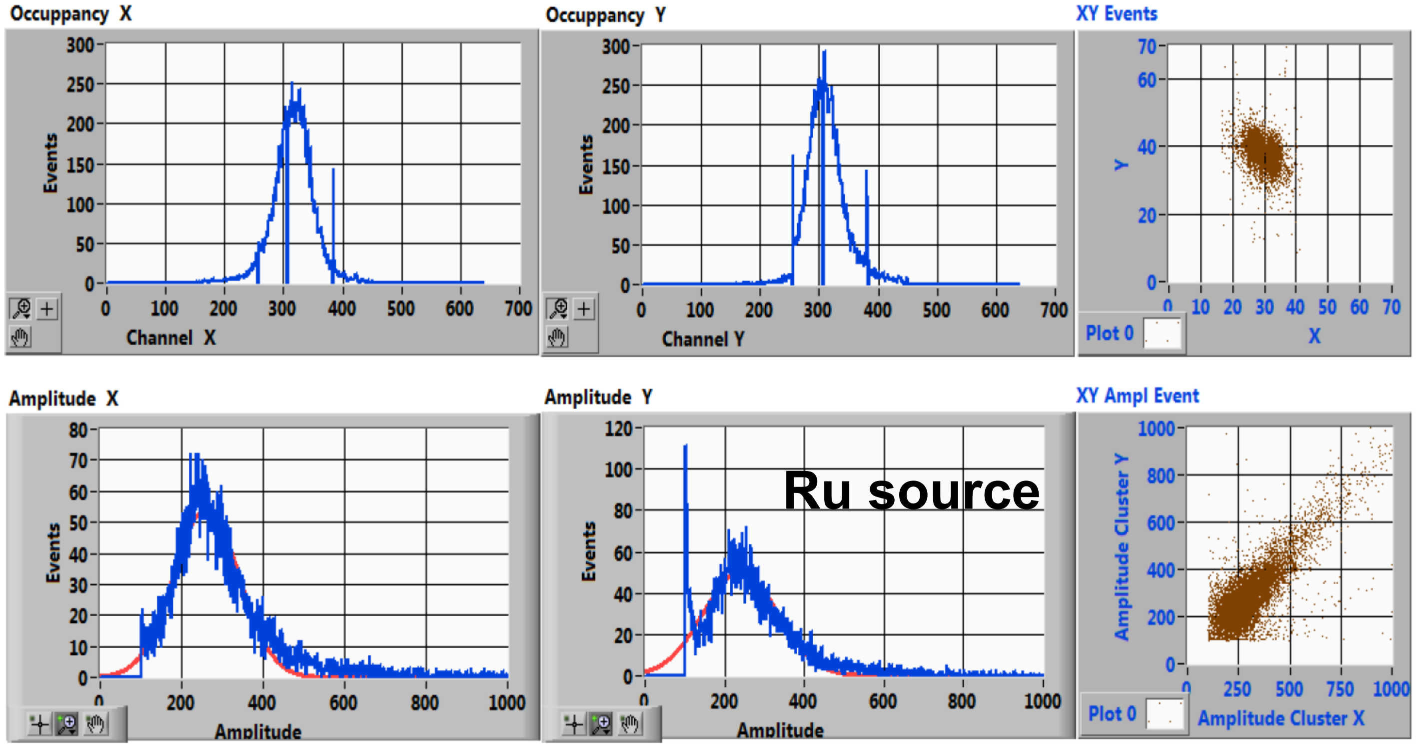
M.Kapishin

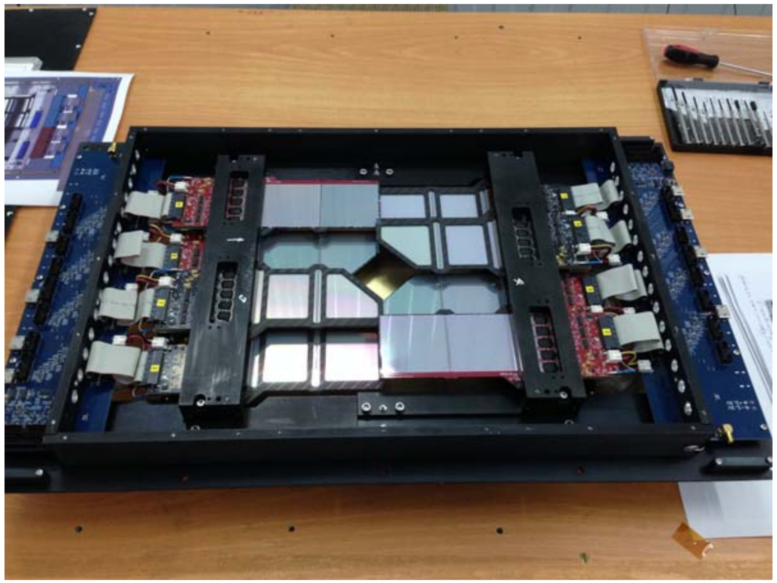
BM@N experiment

Development of silicon strip detector

Silicon detector group

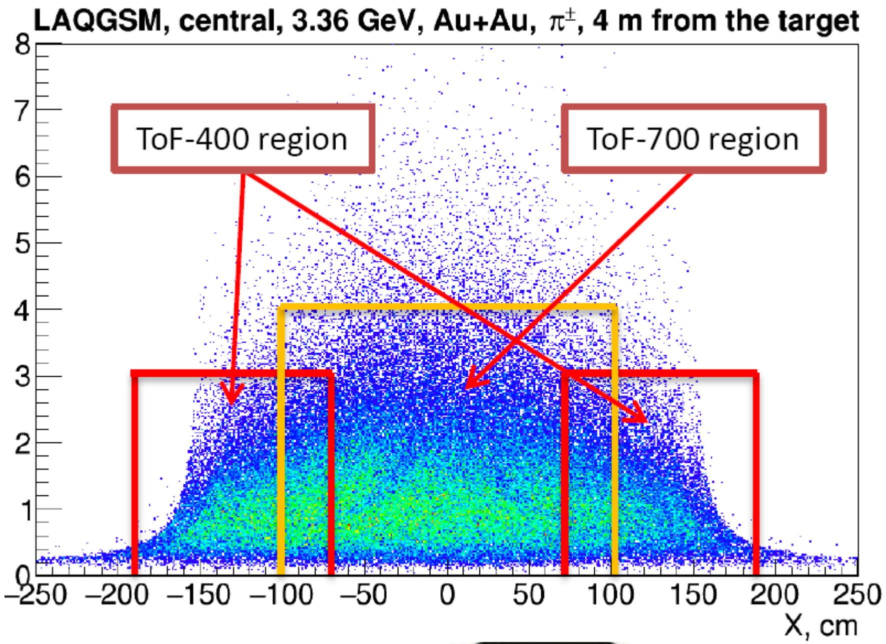


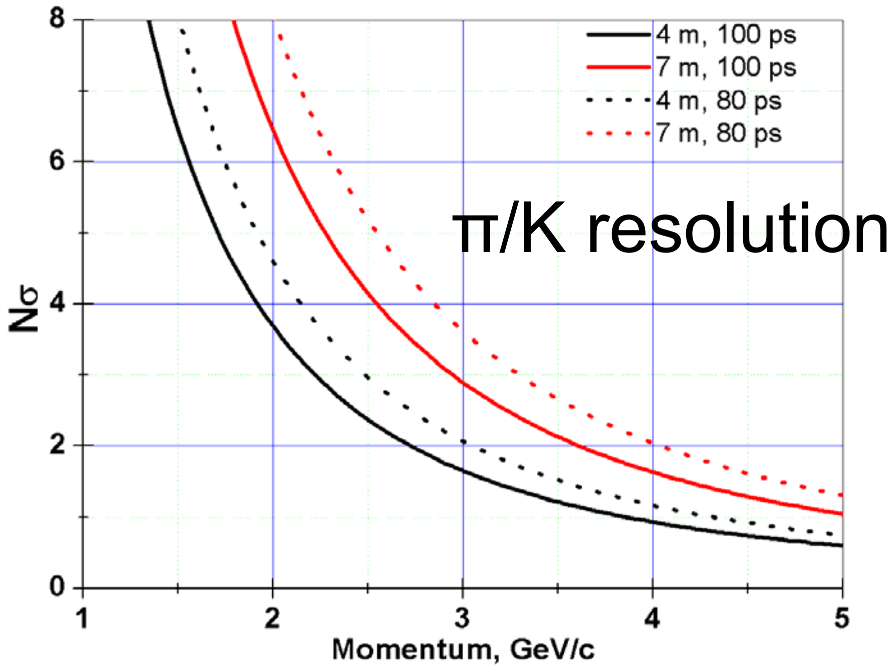




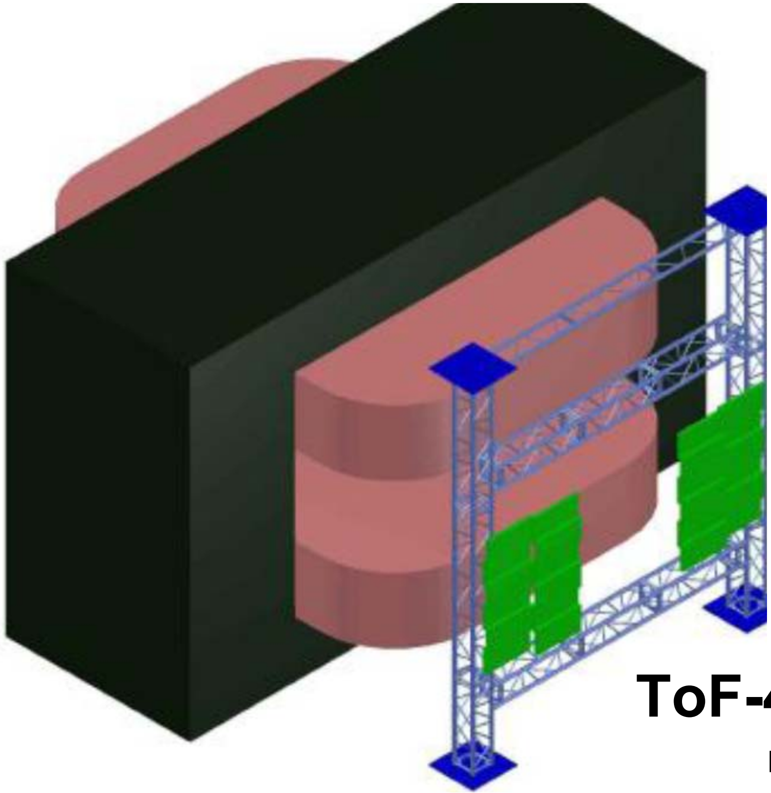
- 2-coordinate Si detector X-X'(±2.5°) with strip pitch of 95/103 μm, full size of 25 x 25 cm^2, 10240 strips
- Detector combined from 4 sub-detectors arranged around beam, each sub-detector consists of 4 Si modules of 6.3 x 6.3 cm^2
- One Si plane in front of GEM tracker was installed and operated in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

ToF-400 and ToF-700 based on mRPC

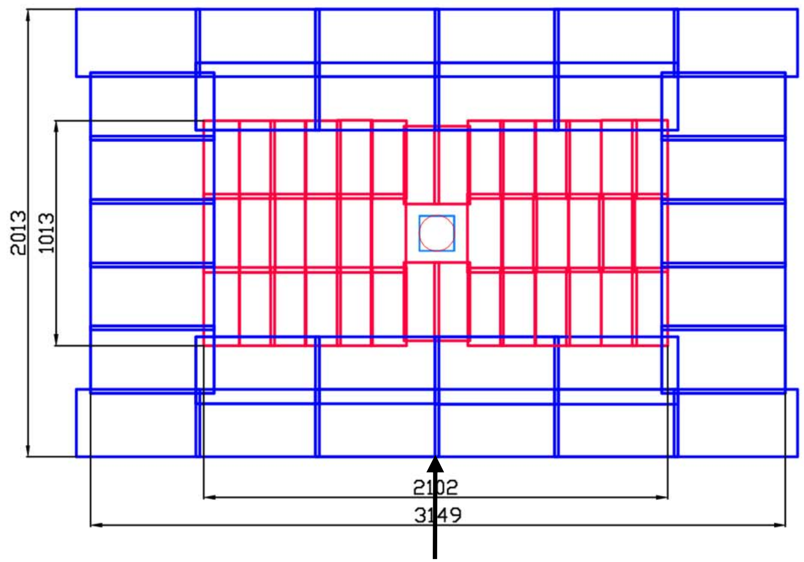




ToF-700 wall



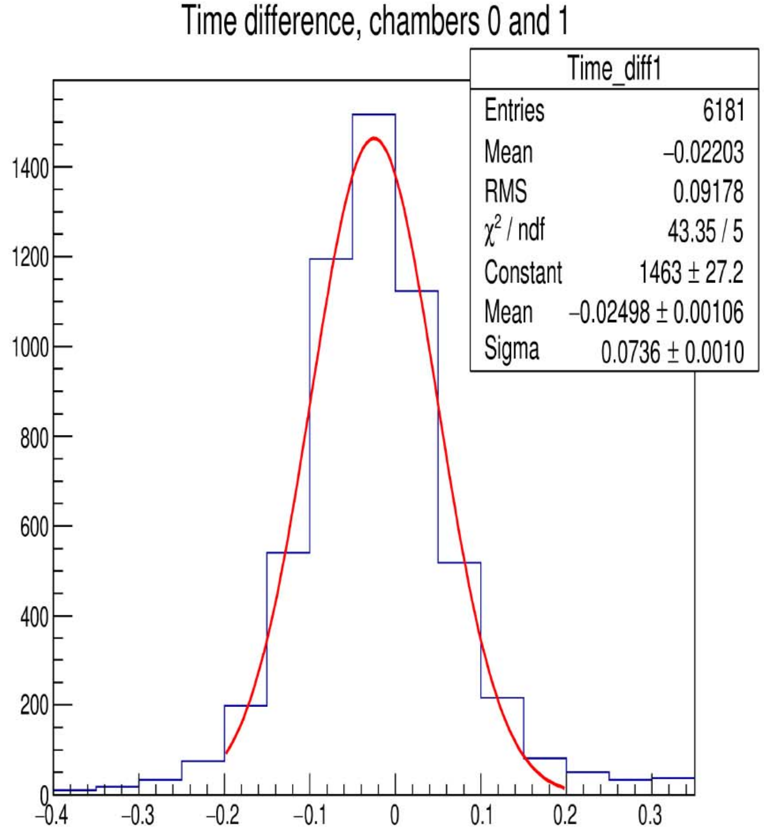
ToF-400 wall



BM@N beam axis

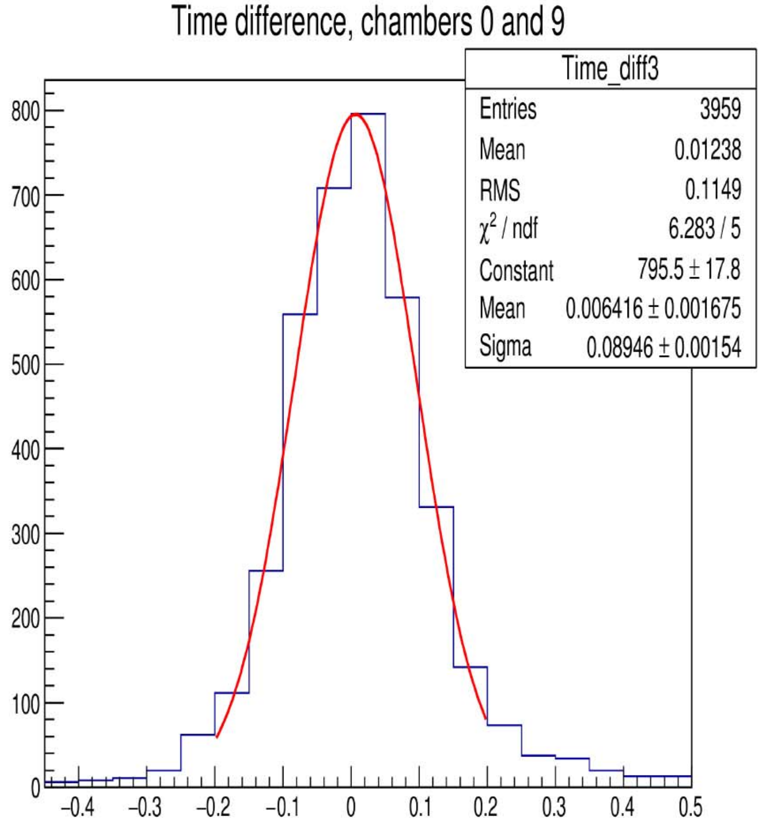
ToF system performance in deuteron run

Time resolution between two ToF-400 chambers



TOF400_1 - TOF400_2

Time resolution between ToF-700 and ToF-400 chambers

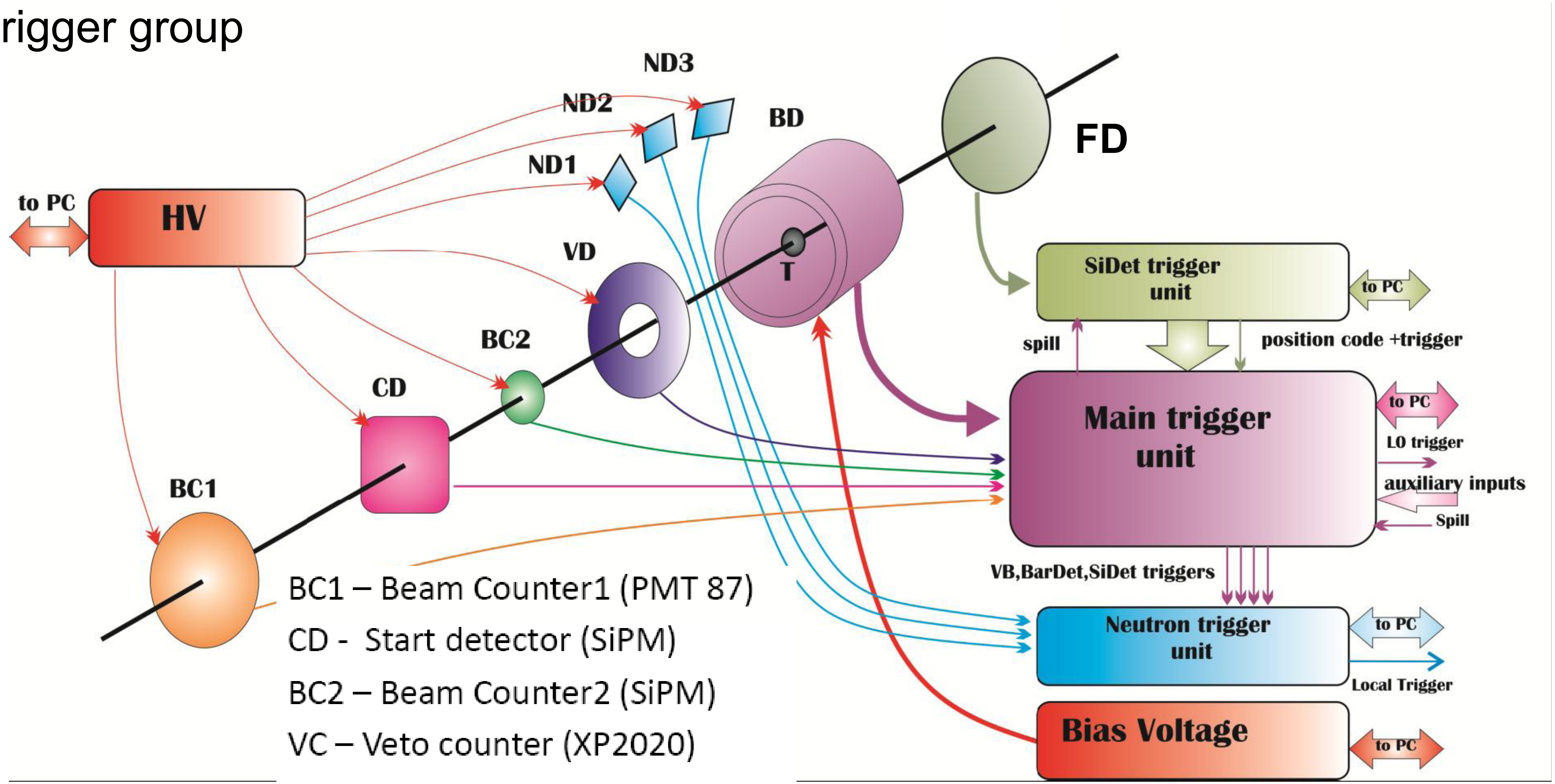


TOF700 - TOF400

- **Time resolution of ToF-700 chamber ~65 ps**
- **Time resolution of ToF-400 chamber ~53 ps**

Trigger detectors: beam counters and barrel detector

Trigger group



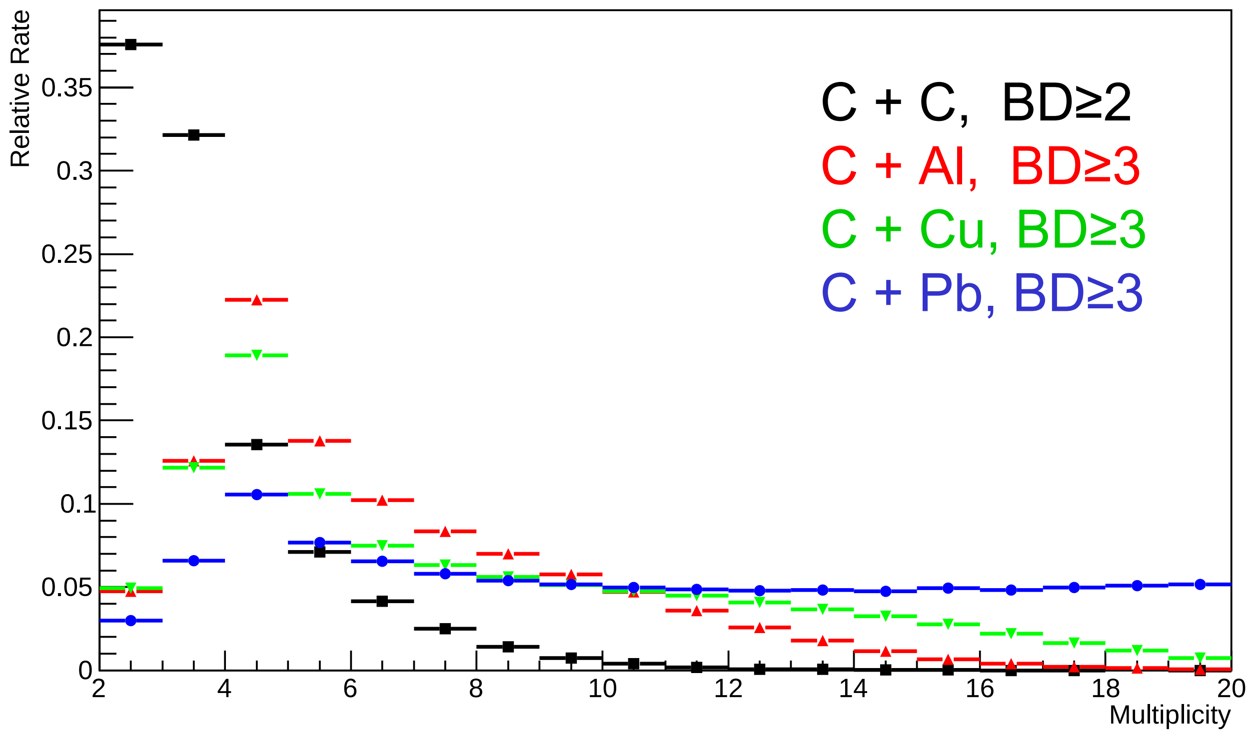
BC1 – Beam Counter1 (PMT 87)
CD - Start detector (SiPM)
BC2 – Beam Counter2 (SiPM)
VC – Veto counter (XP2020)
BD – Barrel Detector – 40ch. SiPM
T – target
SiDet – Silicon Detector

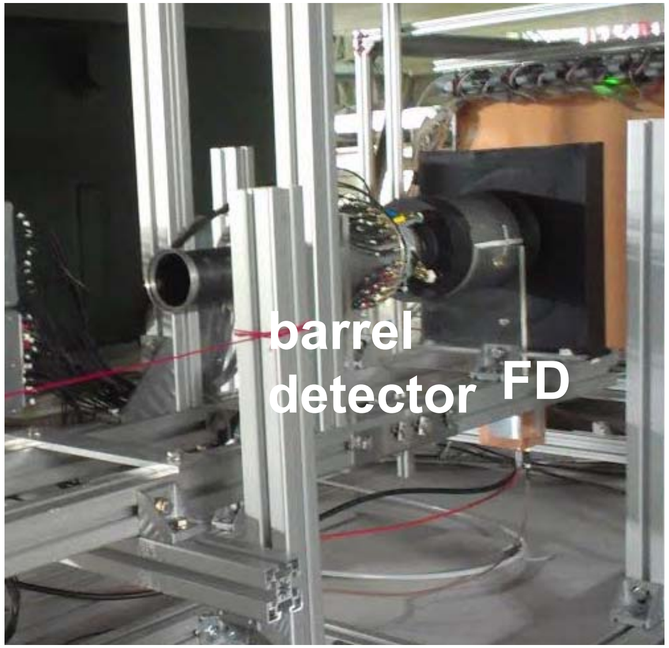
Selection of events with activity in barrel detector: BD ≥ 2, ≥ 3 or forward detector (with beam hole) FD

Trigger barrel detector in BM@N setup

Trigger group

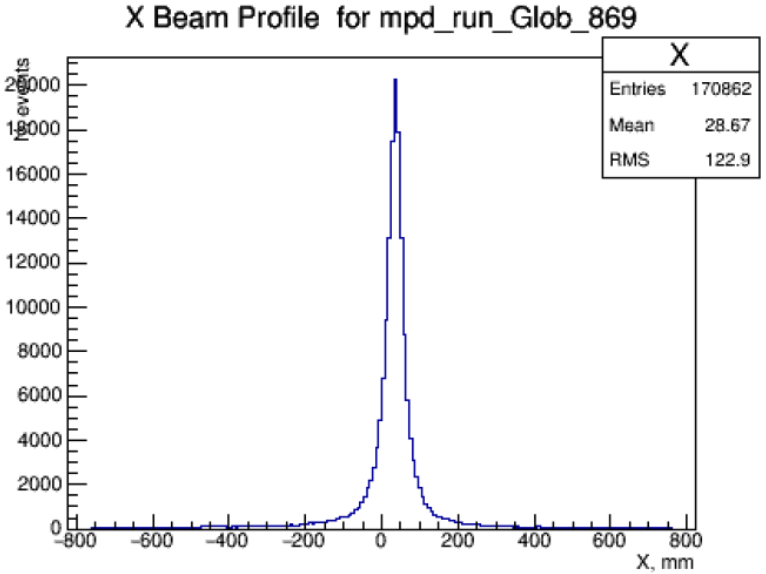
BD multiplicity in carbon beam interactions



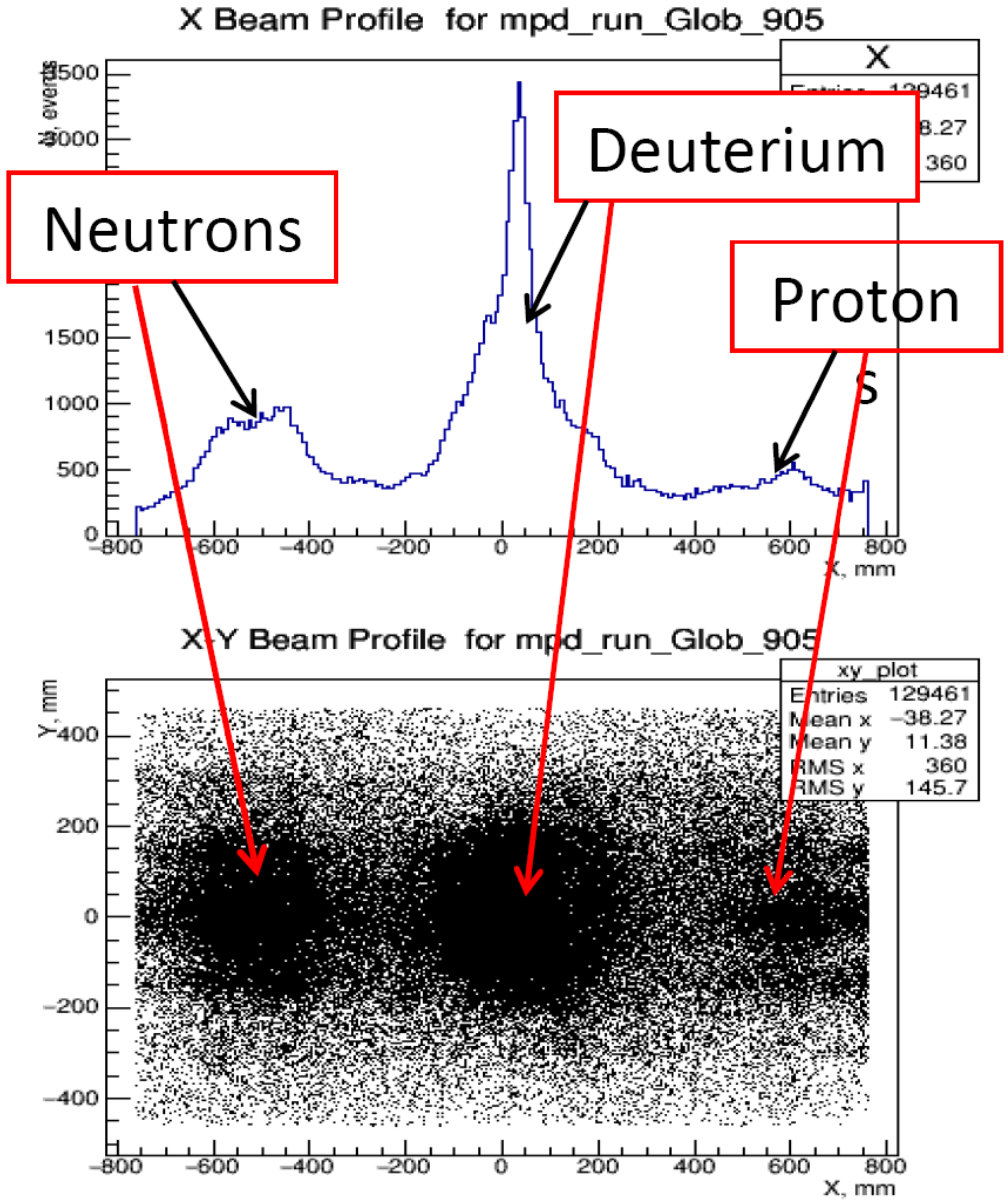


ZDC performance in deuteron beam

Profile of deuteron beam in ZDC

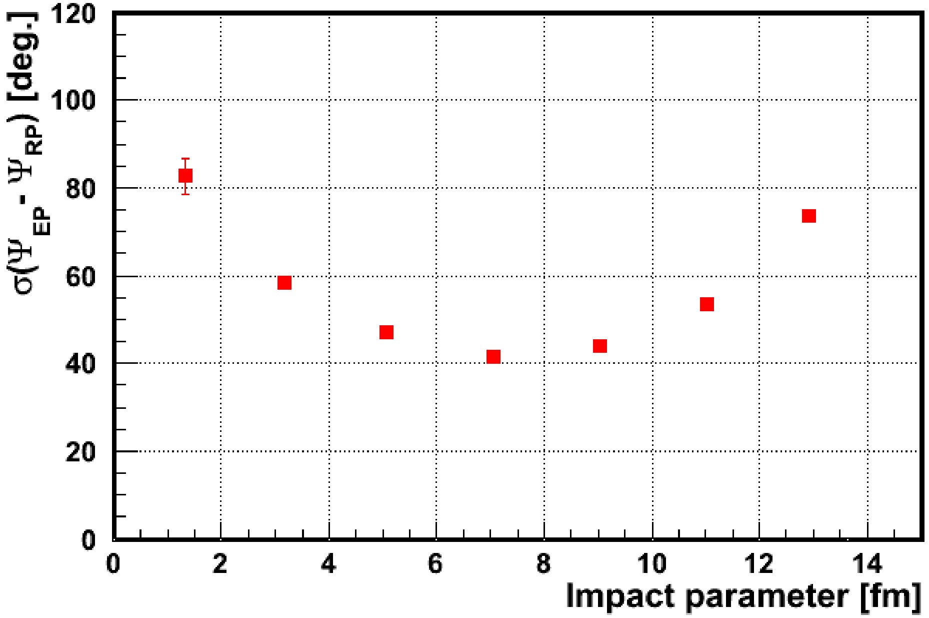


ZDC response to deuterons and products of d+CH_2 interactions



New ZDC calorimeter for Au+Au

RP resolution Au+Au

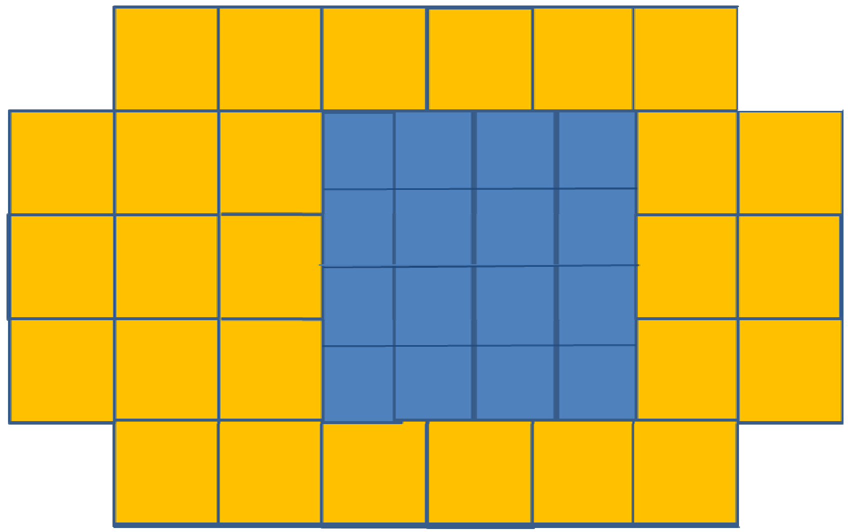


LAQGSM GEANT4 simulation

New BM@N ZDC for Au+Au: 43 modules

Yellow – CBM modules – 20x20 cm, 27 modules

– NICA MPD modules – 15x15 cm, 16 modules



INR RAS, Troitsk

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.	10 GEM half pl.	8 GEM full pl.	10 GEMs + 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: T0 = 3.5 - 4.6 AGeV
- Finally 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

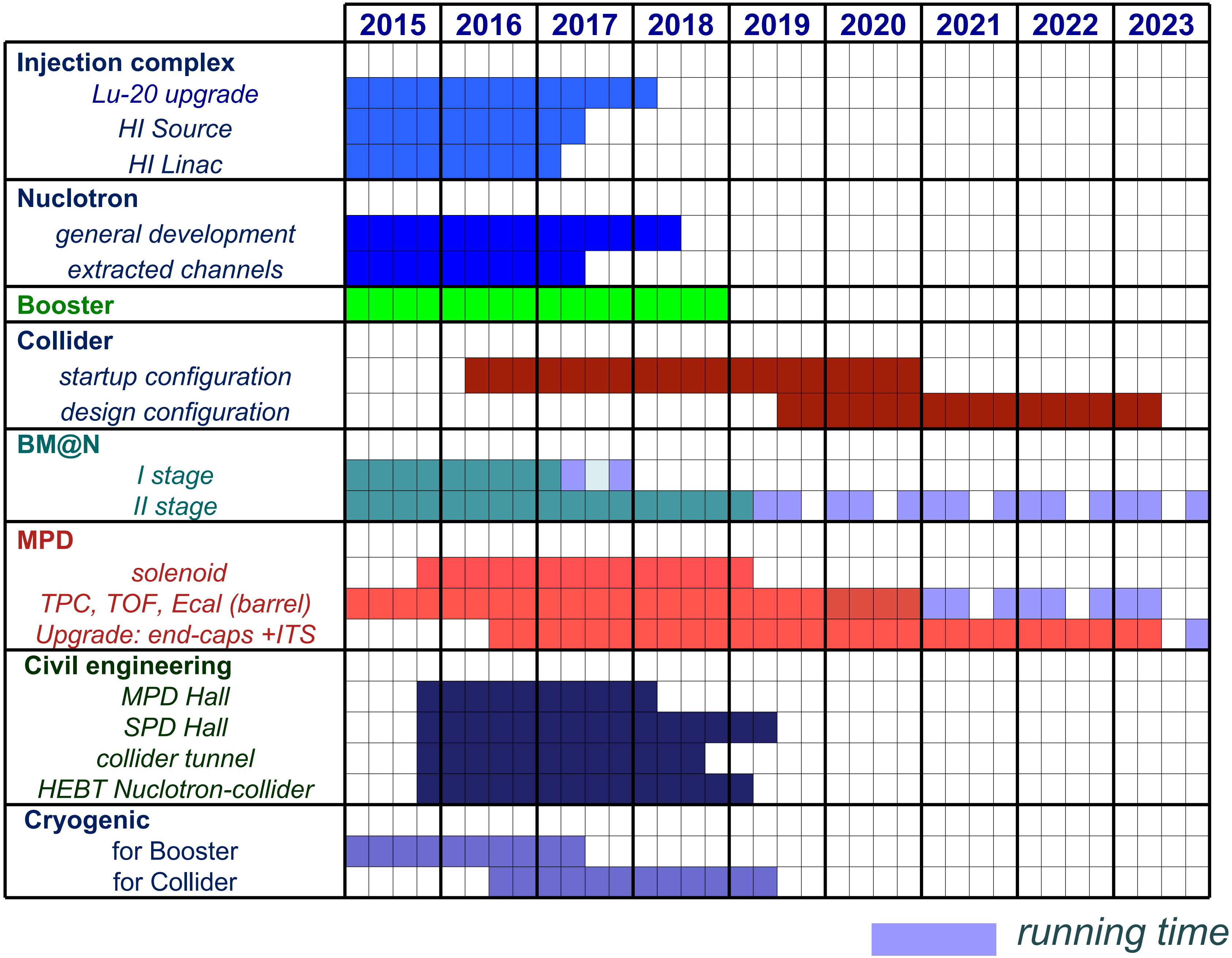
BM@N plans for run in November- December 2017:

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

BM@N setup: extended GEM tracker (+ 4-6 detectors) , forward Silicon detector (+2 planes), extended trigger system, ToF, DAQ configurations, extended Outer tracker (2 new CPC chambers)

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

NICA schedule

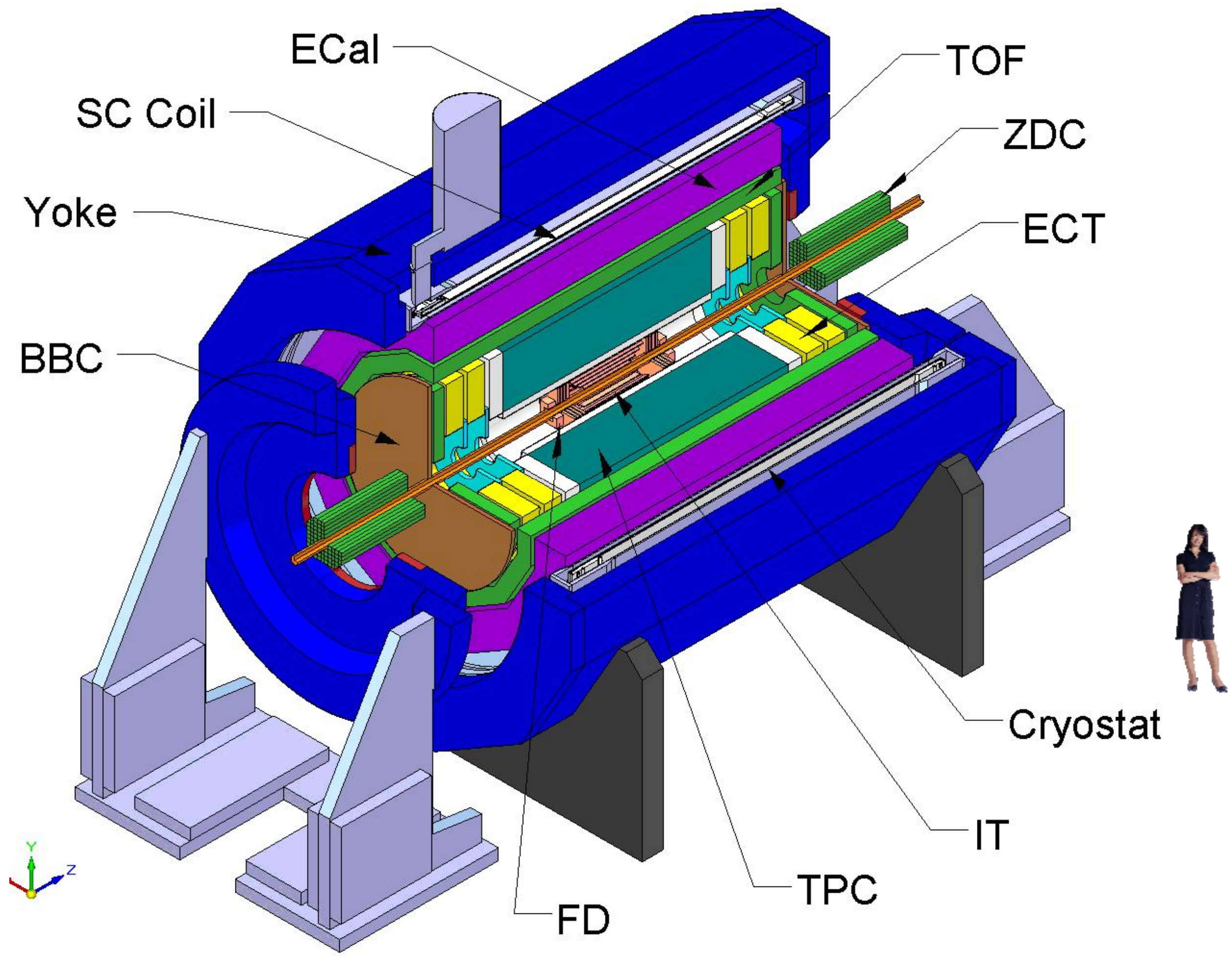


NICA collider major parameters

Ring circumference, m	**503.04**
heavy ions	
β, m	**0.35**
energy range for ***Au^{79+}****: $\sqrt{S_{NN}}$, GeV*	**4 - 11**
r.m.s. $\Delta p/p$, 10^{-3}	**1.6**
peak Luminosity for ***Au^{79+}****, $cm^{-2}\ s^{-1}$*	**$1x10^{27}$**
polarized particles	
max. energy for polarized ***p****, Gev*	**26**
peak Luminosity for ***p****, $cm^{-2}\ s^{-1}$*	**$1x10^{32}$**

MultiPurpose Detector (MPD)

Main target: - *study of hot and dense baryonic matter at the energy range of max net baryonic density*



MPD Physics objectives

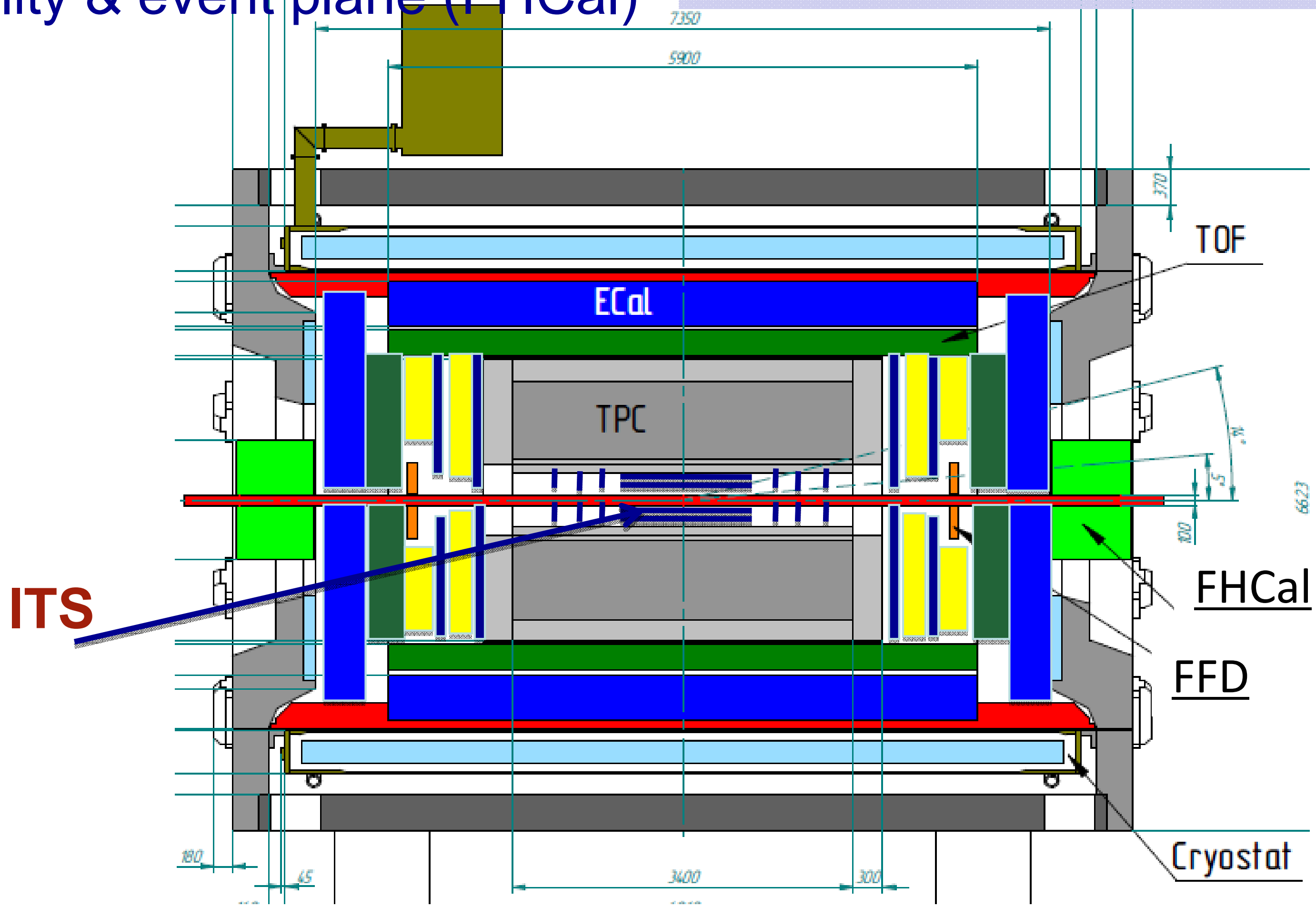
- *Bulk properties, EOS*
  - particle yields & spectra, ratios, femtoscopy, flow
- *In-Medium modification of hadron properties*
  - onset of low-mass dilepton enhancement
- *Deconfinement (chiral) phase transition at high* ρ_B
  - enhanced strangeness production
  - Chiral Magnetic (Vortical) effect, Λ *polarization*
- *QCD Critical Point*
  - event-by-event fluctuations & correlations
- *Y-N interactions in dense nuclear matter*
  - hypernuclei

MPD

Tracking: up to |η|<1.8 (TPC)
PID: hadrons, e, γ (TOF, TPC, ECAL)
Event characterization:
centrality & event plane (FHCal)

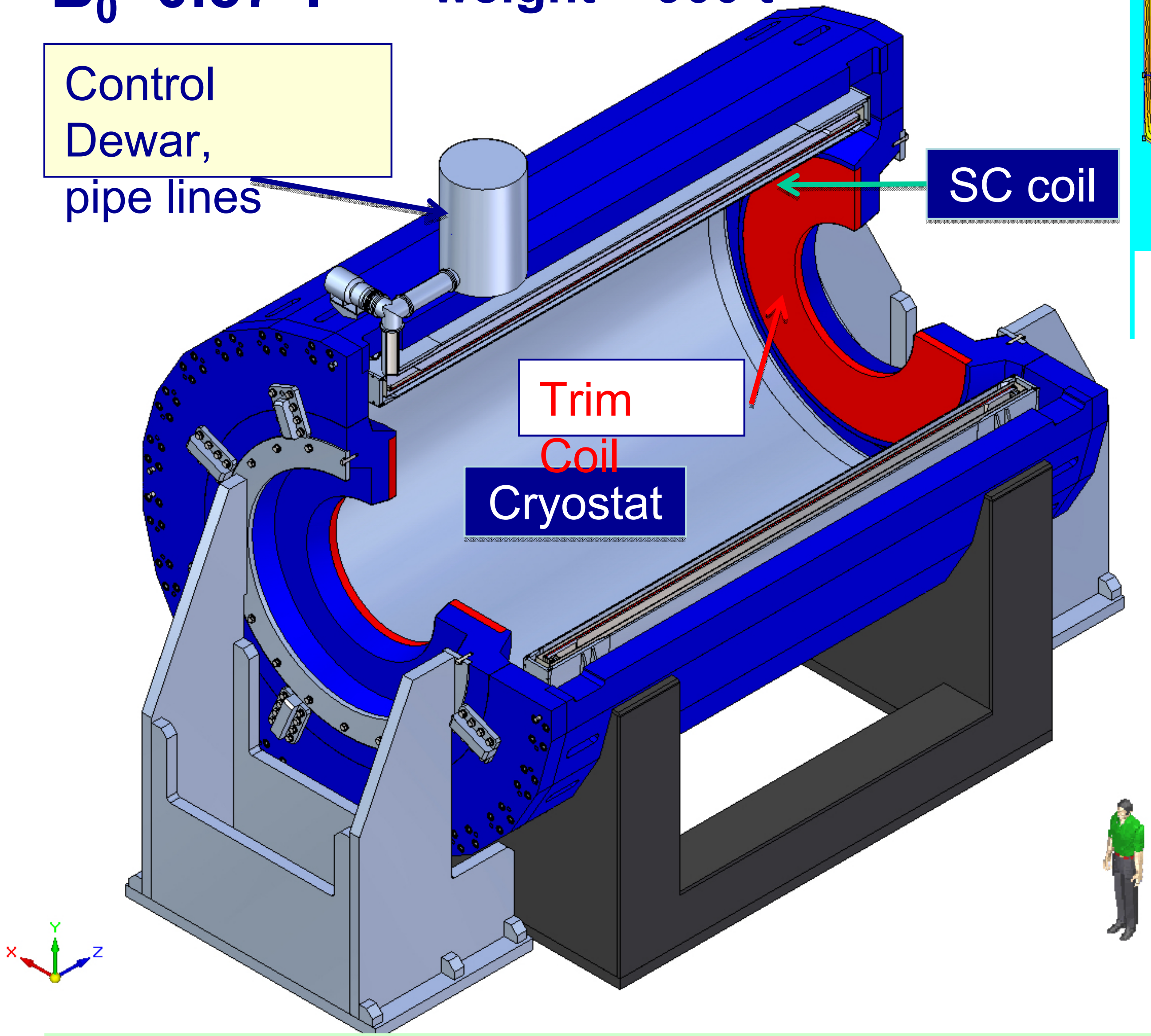
Stage 1 *(2020)*: **TPC**, **FHCal, FFD, Barrel** (TOF, Ecal)

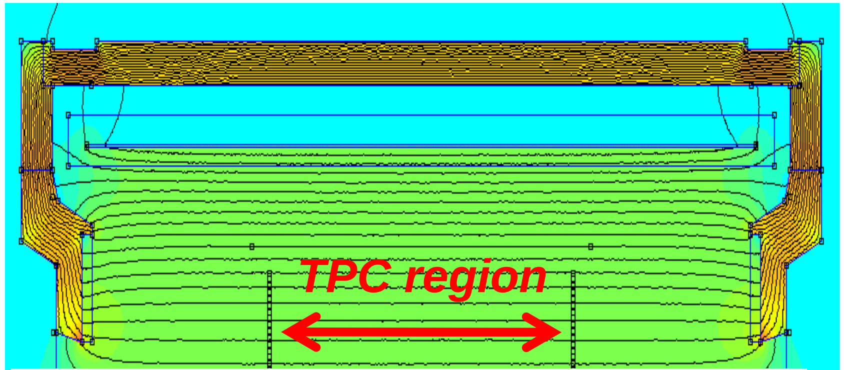
Stage 2 *(2023)*: **ITS** (JINR+ **CERN**), **EndCaps** (tracker, TOF, Ecal)



MPD superconducting Solenoid

B_0=0.57 T **weight ~ 900 t**





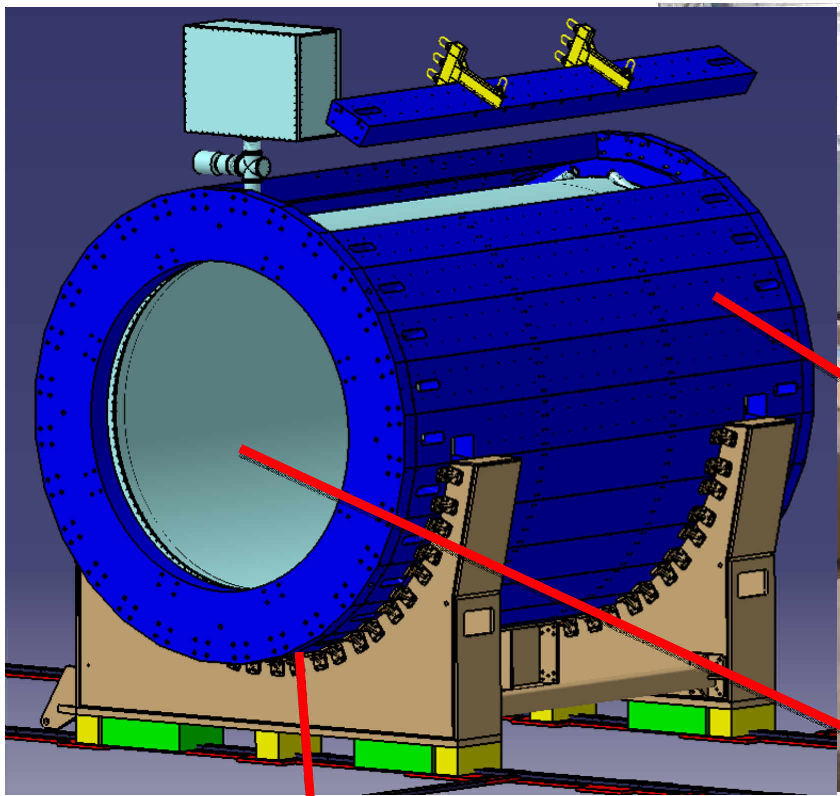
high level (~ 3x10^{-4}) of magnetic field homogeneity

Contract with
ASG Superconductor
(Genova, Italy)**:**

- *Cold Mass + Cryostat*
- *Vacuum System*
- *Trim Coils*
- *Control System*
- *PS*
- ***General responsibility***

+ ***contracts for:*** *yoke; kryo suppl.; movement system; mag. measurement*

Yoke production: *all packages are at Vitkovice HM*



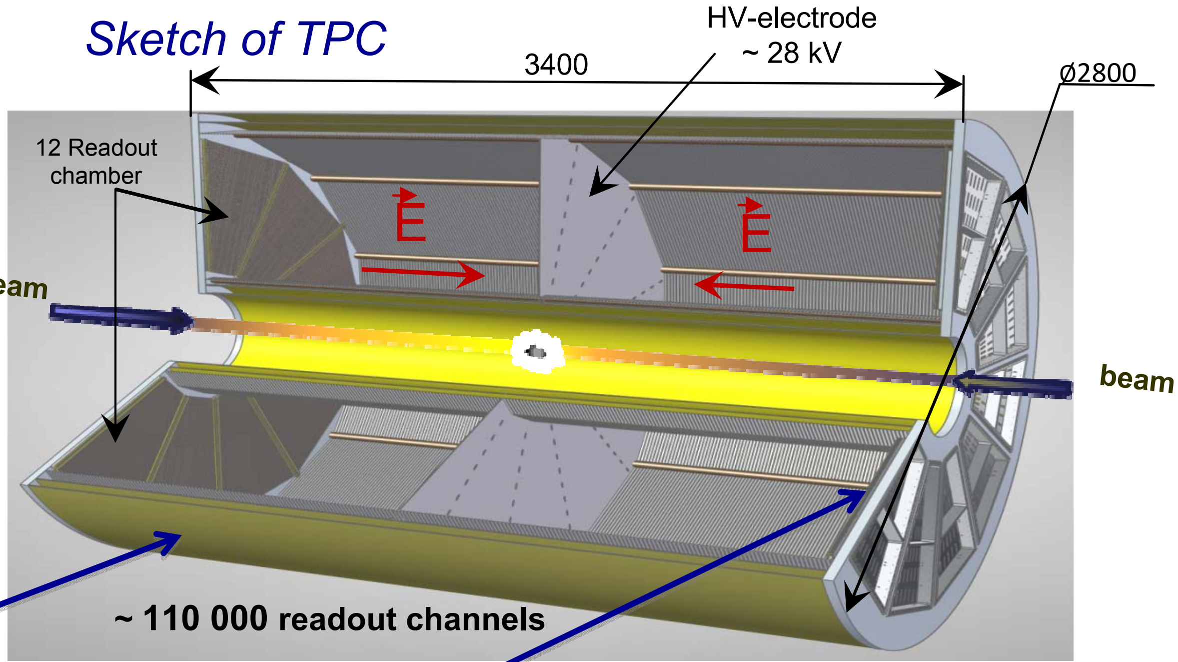
VITKOVICE Heavy Machinery, Sept. 5, 2016

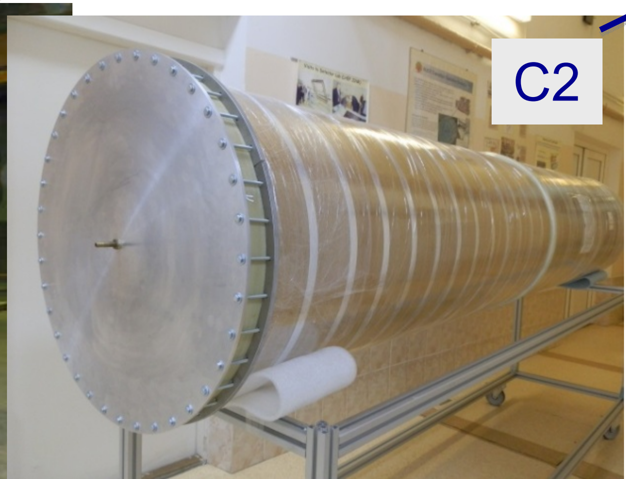
Time Projection Chamber

Leader: *S. Movchan*

gas system:
delivery to JINR in 2017

Sketch of TPC





Project status:

- ***TDR***
- *assembly workshop (clean room) is ready*
- *R&D for alternative ROCh is in progress;*

Works are going in accordance with the schedule

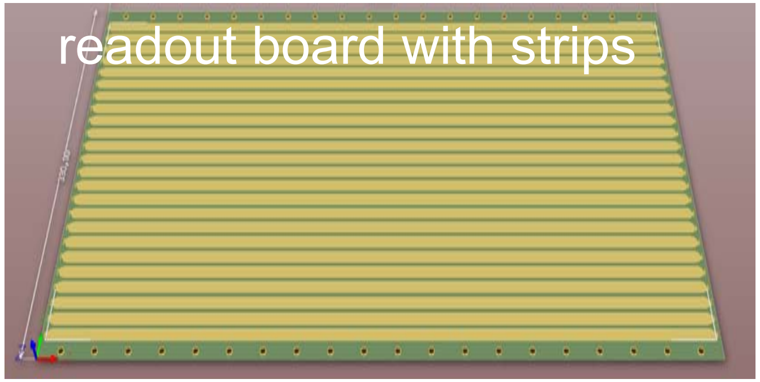
TOF Barrel

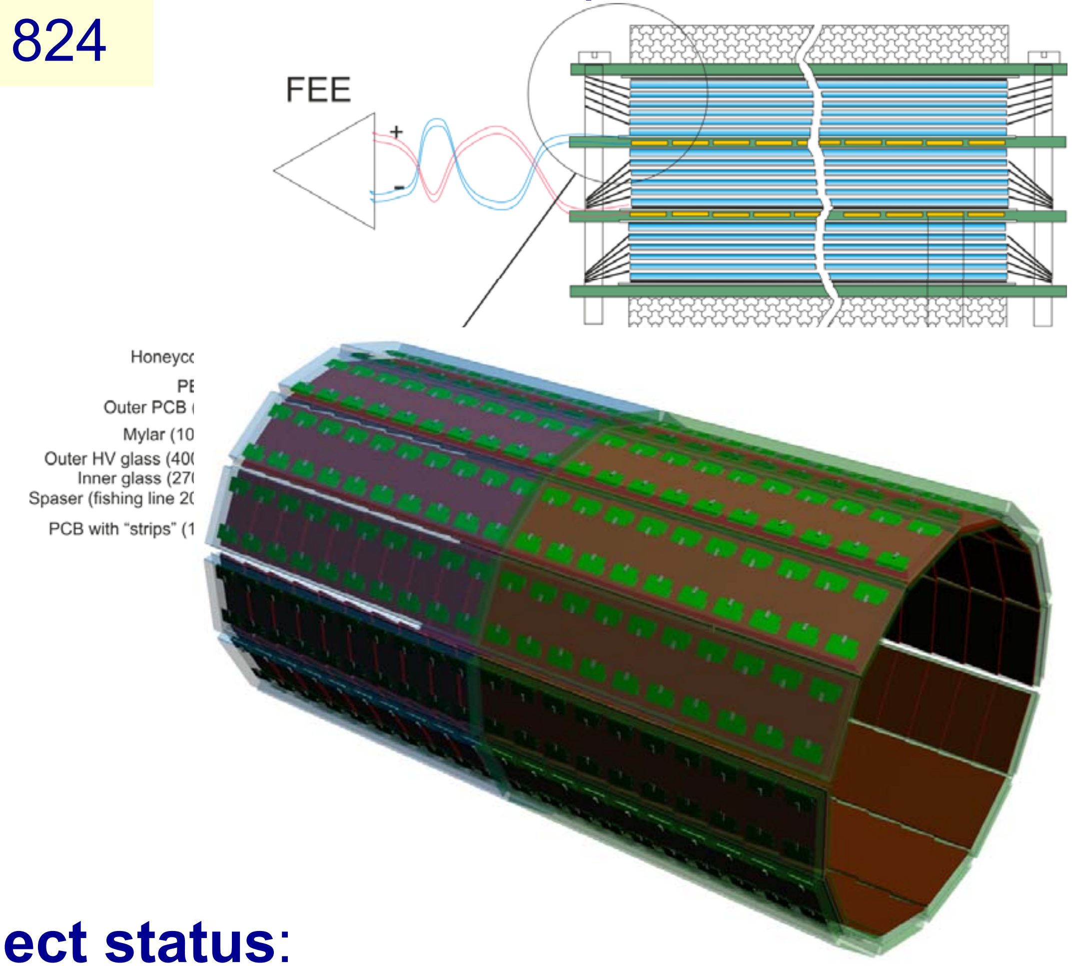
Leader: *V. Golovatyuk*

The barrel consist of 12 super-modules (*two modules connected together*)

active area of TOF barrel	~56 m^2
number of channels	13 824

triple-stack MRPC

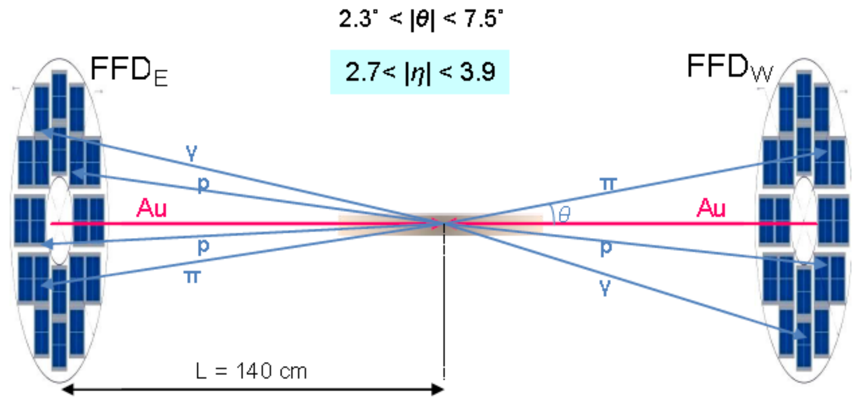


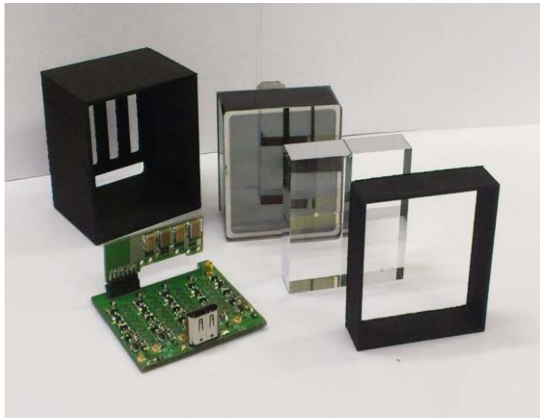


Project status:

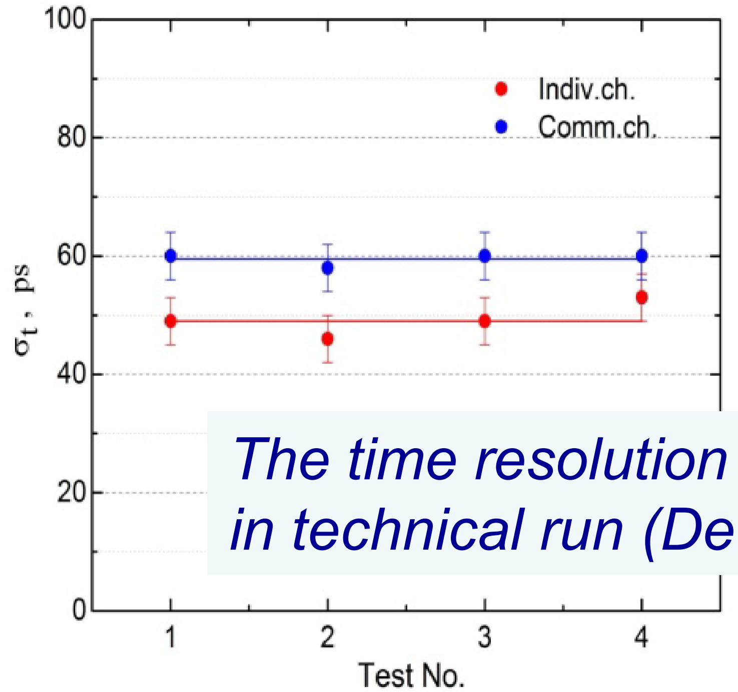
ready for mass production

MPD FFD : progress in 2016



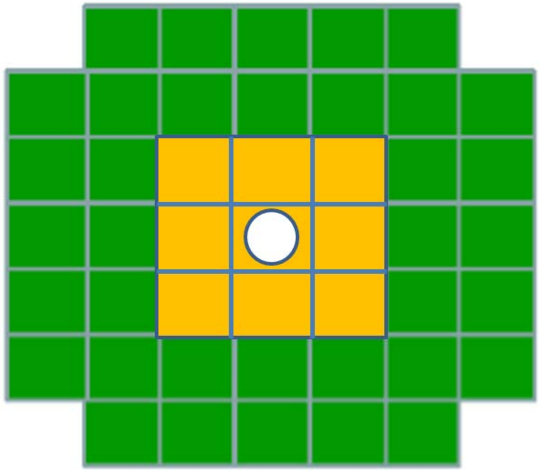


- *TDR – OK! Production close to completion*
- *Tests of the trigger electronics & software at BM@N*
- *Progress in FE electronics and LV system for FFD*



The time resolution < 50 ps was obtained in technical run (Dec. 2016)

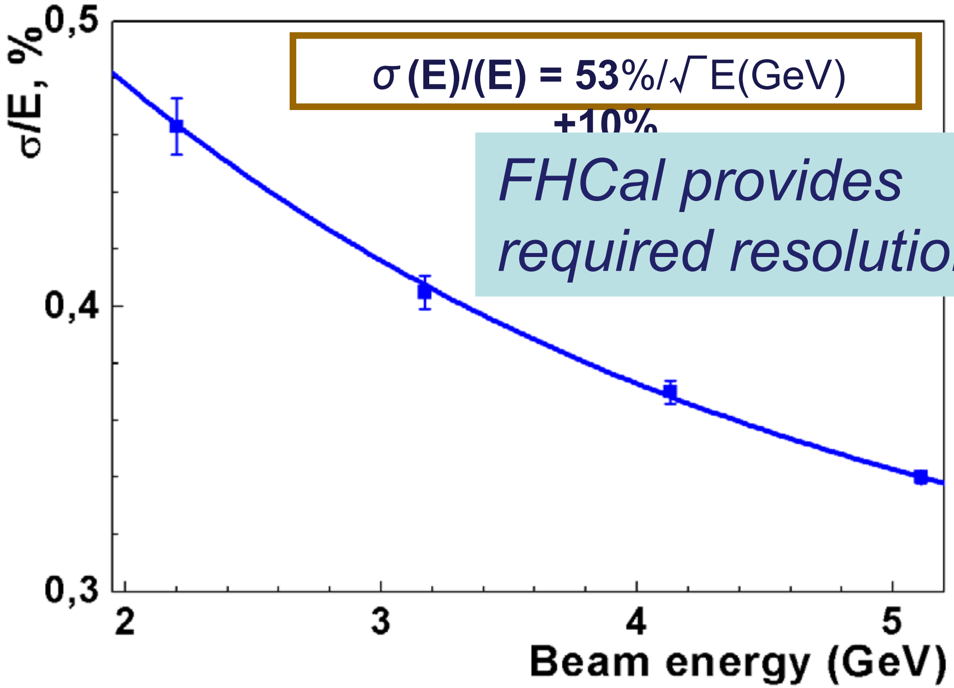
FHCAL: for determination of reaction plane and centrality



- 2-arm (left/right) calorimeter (at ~3.2 m from the IP)
- each arm consists of 45 modules (15x15 cm^2).

FHCal coverage: 2.2<|η|< 4.8

Transverse granularity allows to measure:
-the reaction plane with the accuracy **~ 20^0-30^0**
-the centrality with accuracy below **10%.**

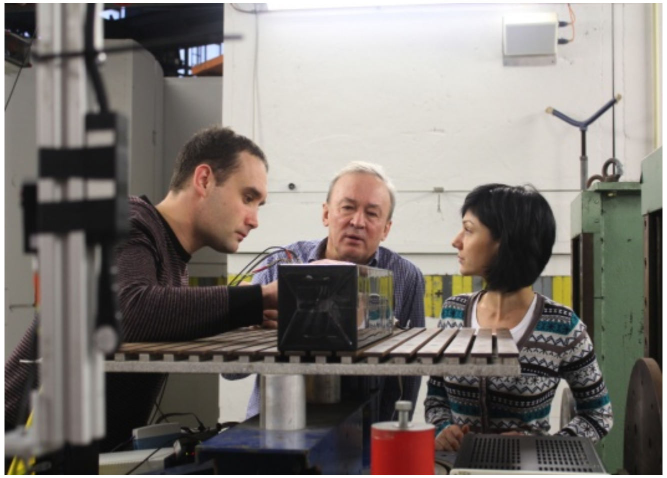


FHCal provides required resolution

modules production – in progress

ECAL: TDR - in preparation

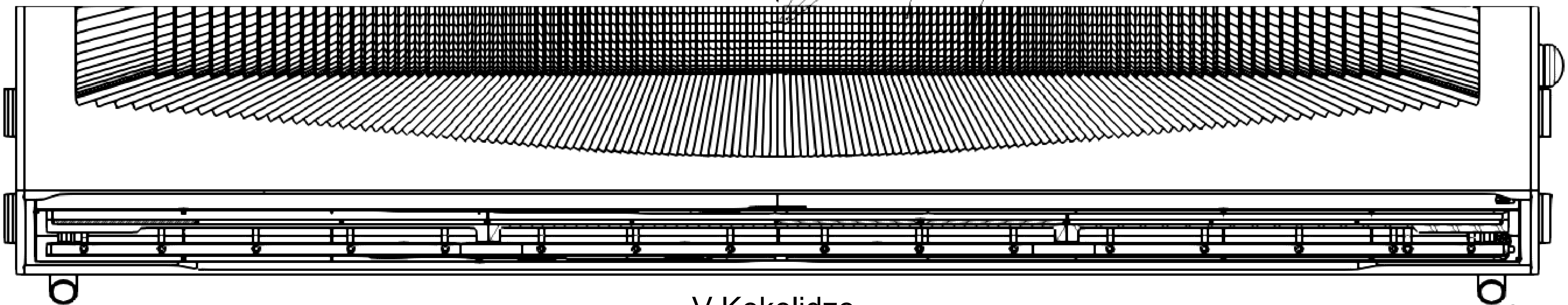
- *Pb+Sc "Shashlyk"*
- *read-out: WLS fibers + MAPD*
- *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2), full azimuthal coverage;*
- *E resolution better than 5% @ 1 GeV;*
- *time resolution ~500 ps*



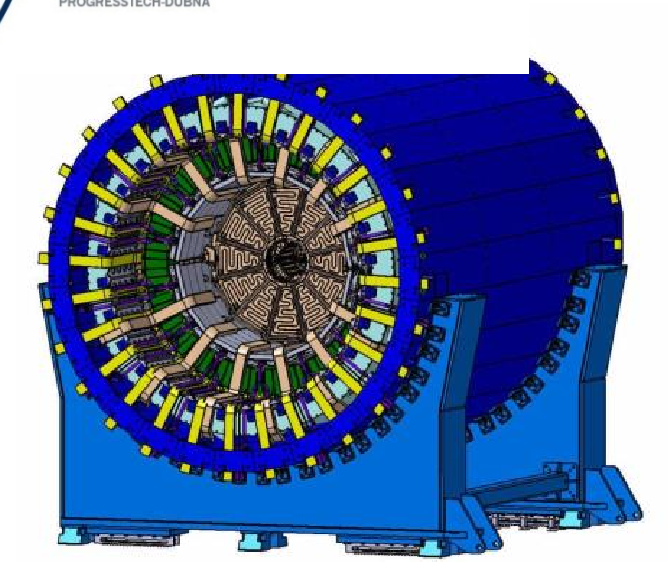
Agreement between **JINR** and **Tsinghua University** has been signed on:

- *participation in the MPD experiment;*
- *preparation for mass production of Ecal*

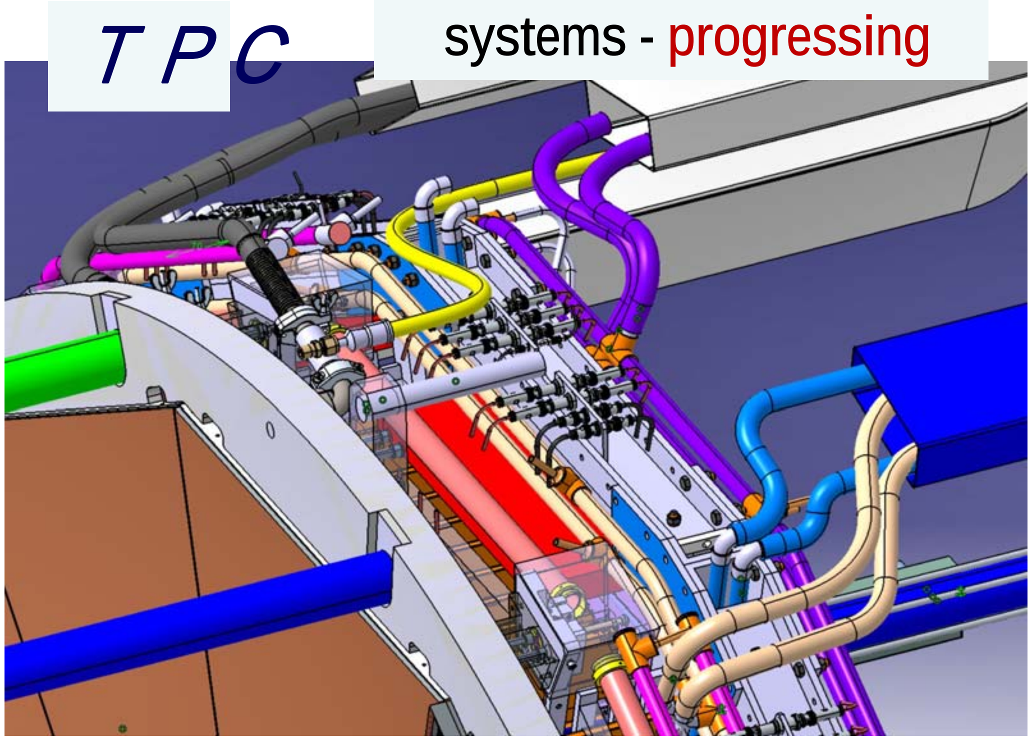
projective geometry

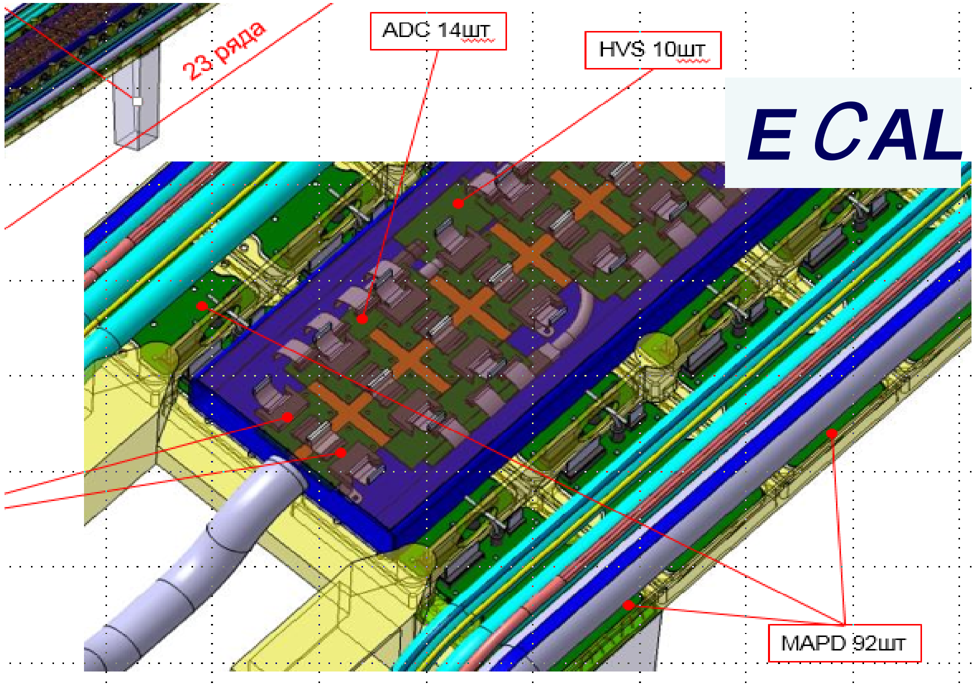


MPD Integration : service, cabling



Integration of TPC service systems - progressing





- Final design of internal support structures
- Finalizing TPC, TOF & ECAL assembling plans
- Integration of service systems, cabling, etc..
- Drawing of tooling for (dis)assembling MPD elements and MPD integration

MPD Concluding remarks

- MPD experiment has a potential for competitive research *in the field of baryon rich matter*

- The construction of MPD *is progressing close to the schedule*

- MPD collaboration is growing

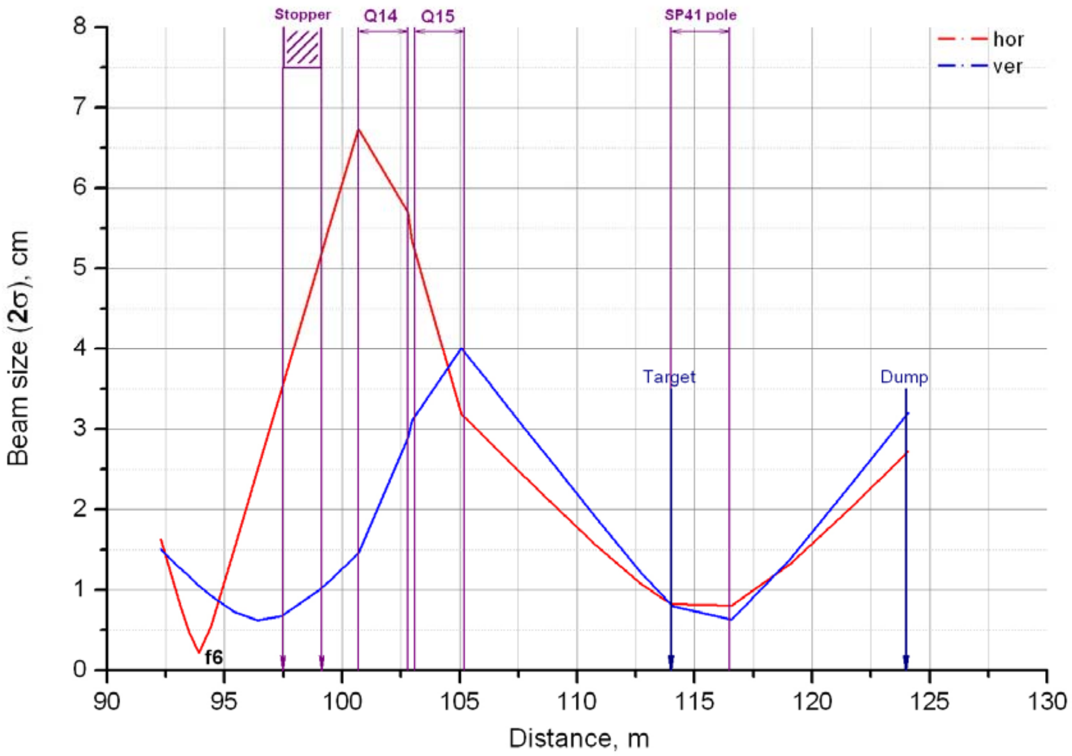
- Welcome to join the MPD collaboration

Thank you
for attention!

BM@N Backup slides

BM@N beam line

Beam envelopes at the BM@N area



Beam	Planned intensity of Nuclotron + booster (per cycle)
p , d	10^7 at BM@N
^{12}C	10^7 at BM@N
^{40}Ar	10^7 at BM@N
^{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

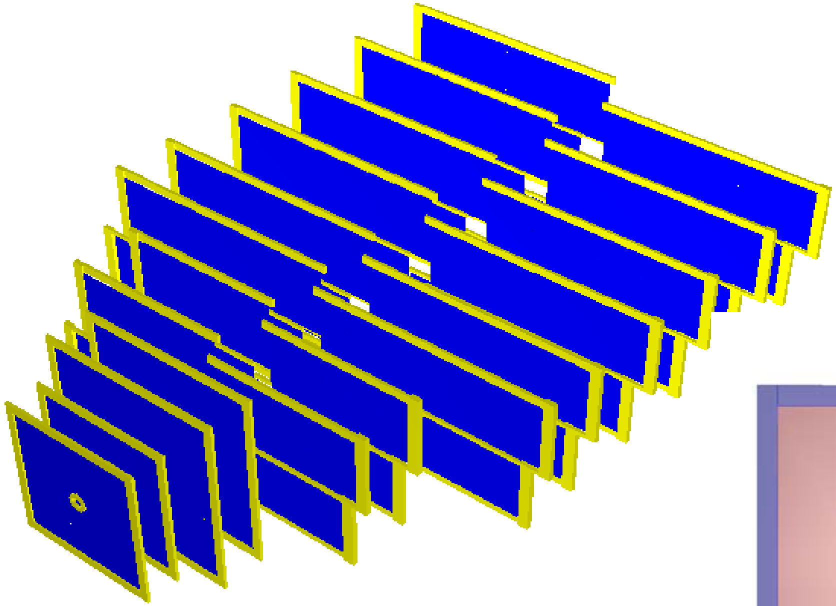
→ stabilization circuits for existing power supplies for quadruples and dipoles

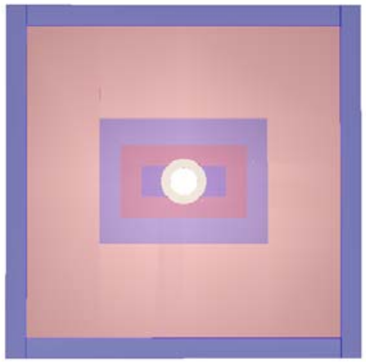
→ non destructive beam position monitoring on movable vacuum inserts

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

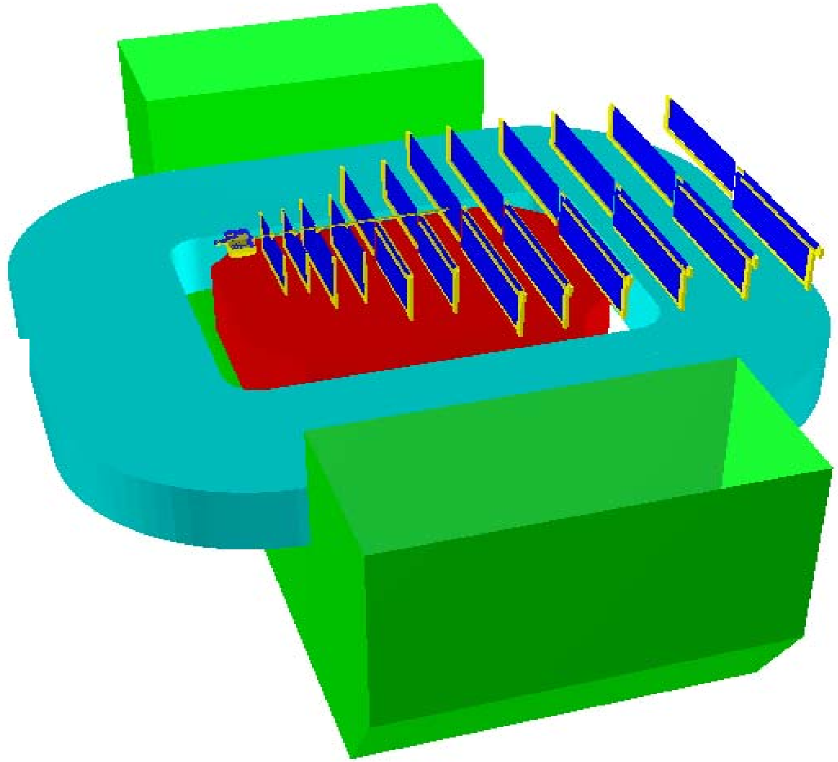
Optimized GEM detector configuration

BMN simulation group



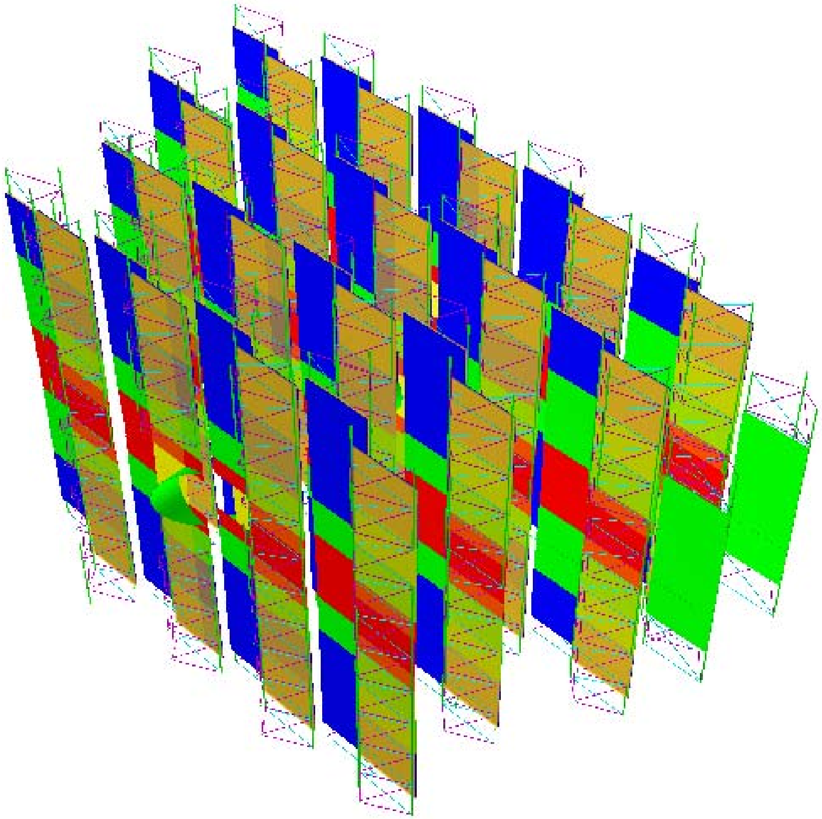


Stations 1 - 4

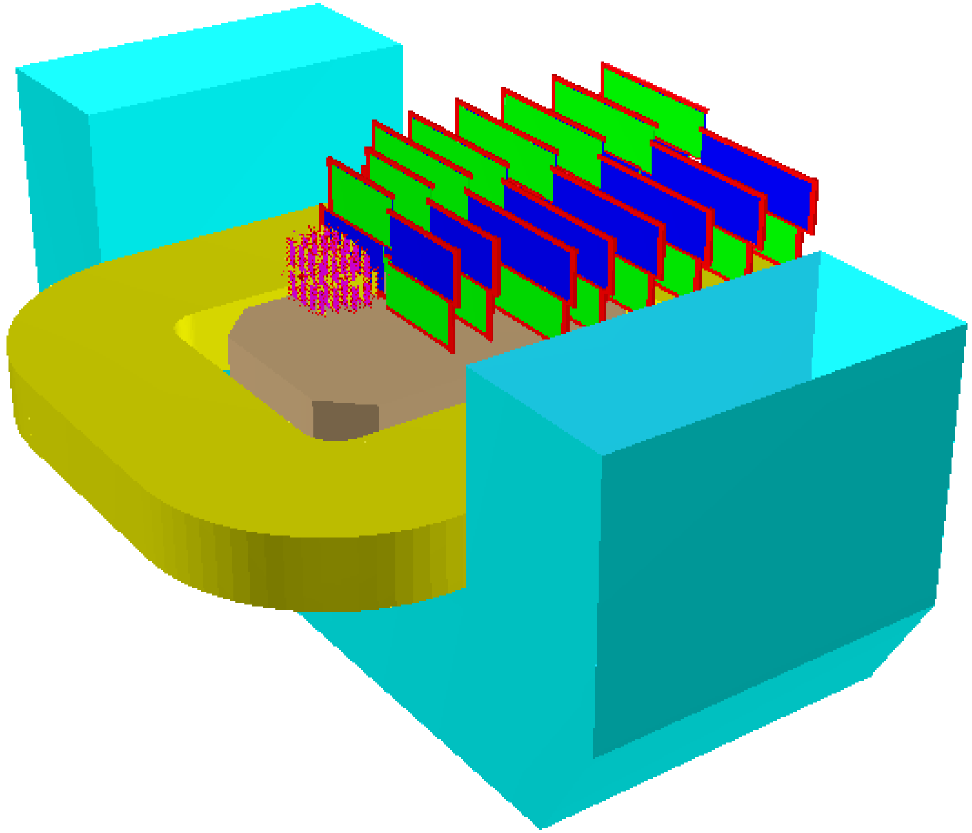


12 stations: Z = 30 – 45 – 60 – 80 – 100 – 130 – 160 – 190 – 230 – 270 – 315 – 360
Stereo angles: 0 – 7.5 deg in stat. 1-4; 0 – 15 deg in stat. 5 - 12
Pitch: 400 um in stat. 1-4, 800 um in stat. 5-12

CBM + BM@N geometry

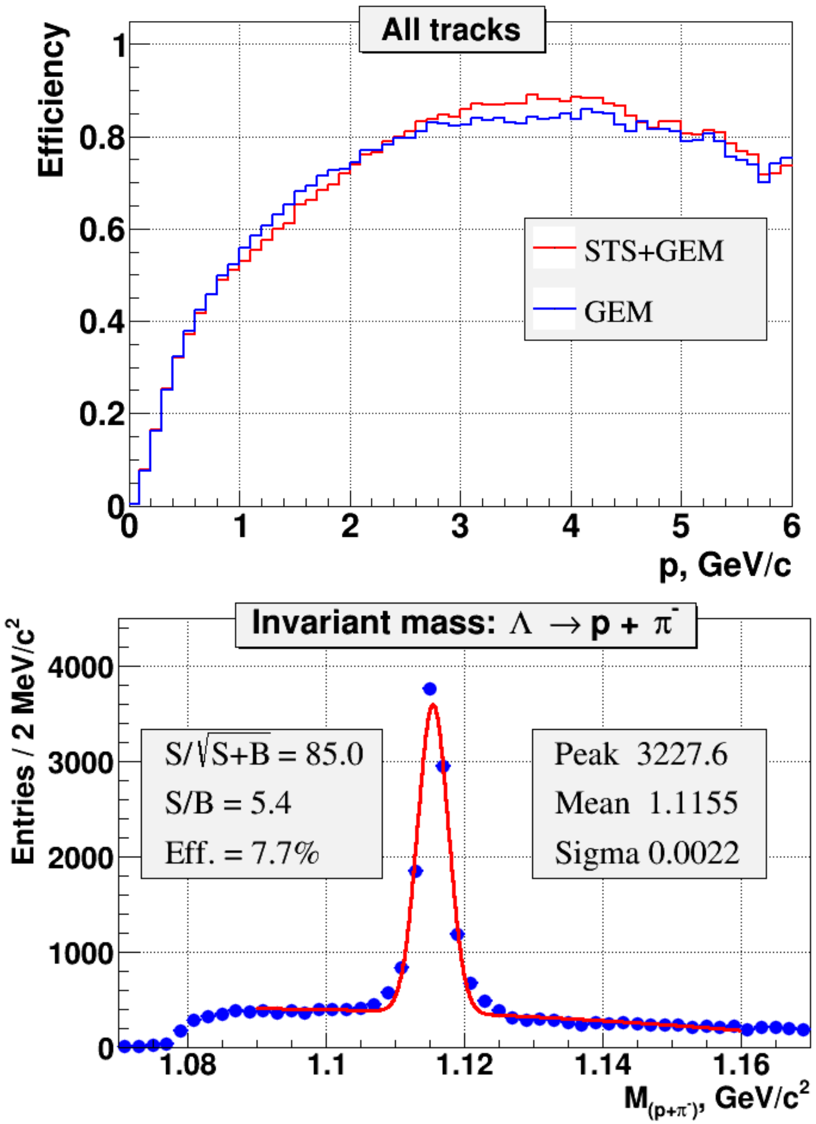


CBM STS stations: 1+1+2+2

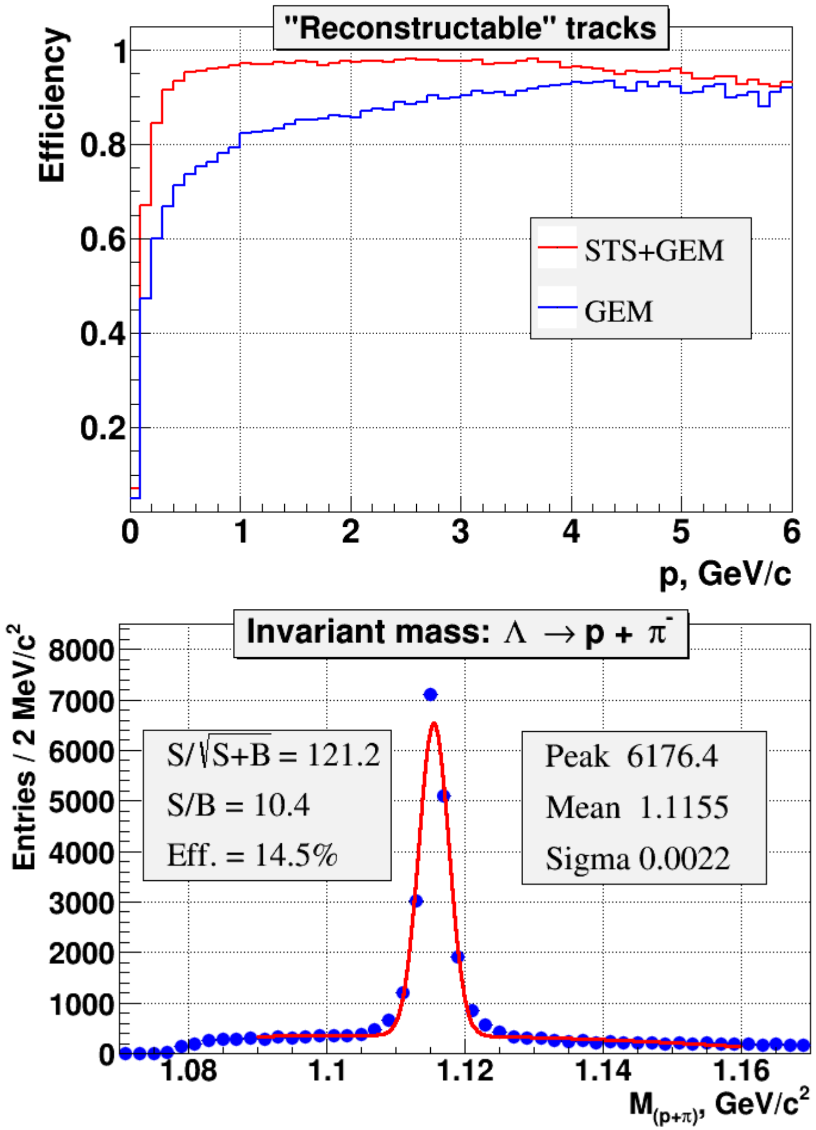


BM@N: STS + GEM

CBM + BM@N: Track and Λ reconstruction



GEM (12 stations)

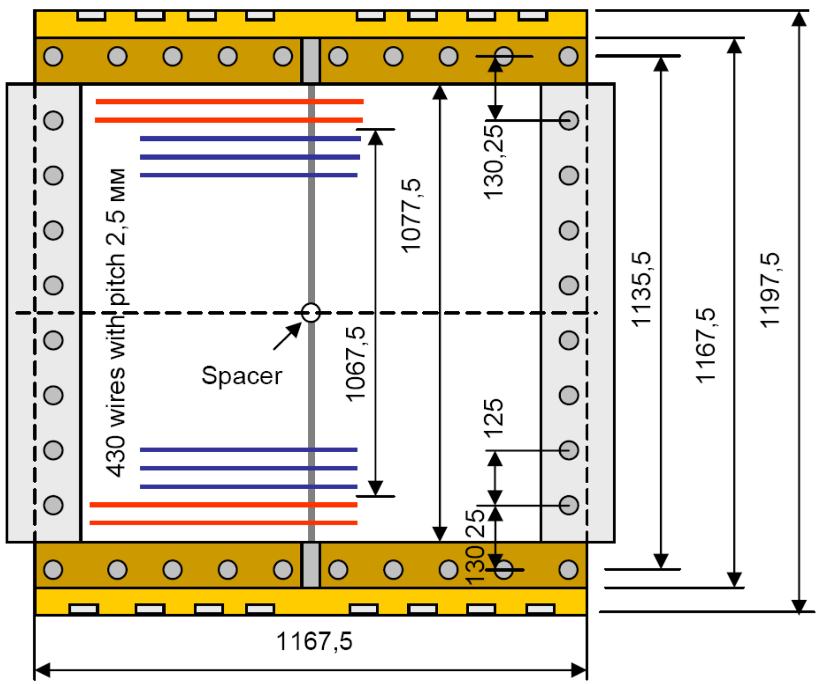


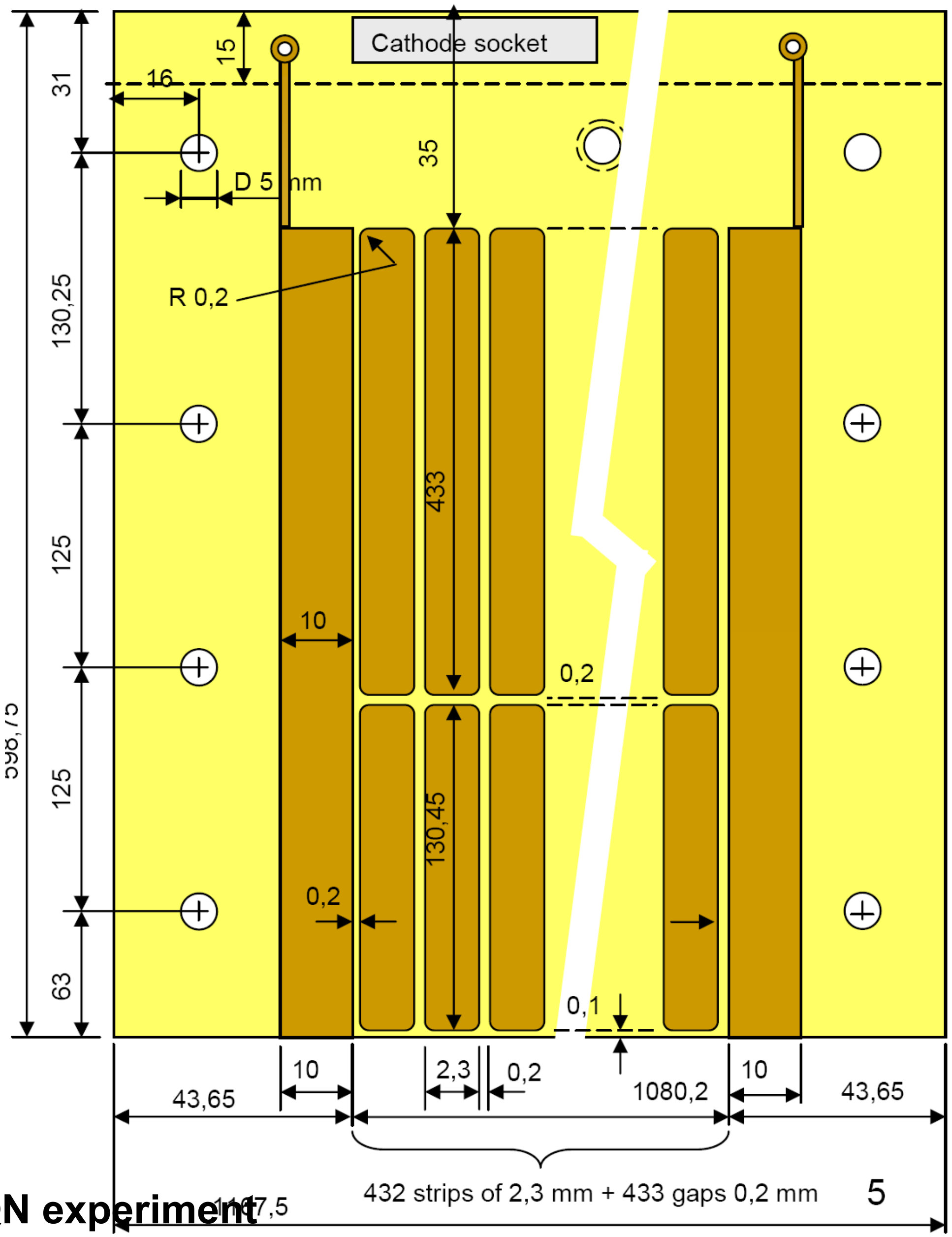
STS (4 station) +GEM (8 stations)

CPC chamber design

Plan to produce and install in autumn 2017 two CPC chambers in front and behind ToF-400 as part of Outer tracker for heavy ion beams

Cathode printed board #1



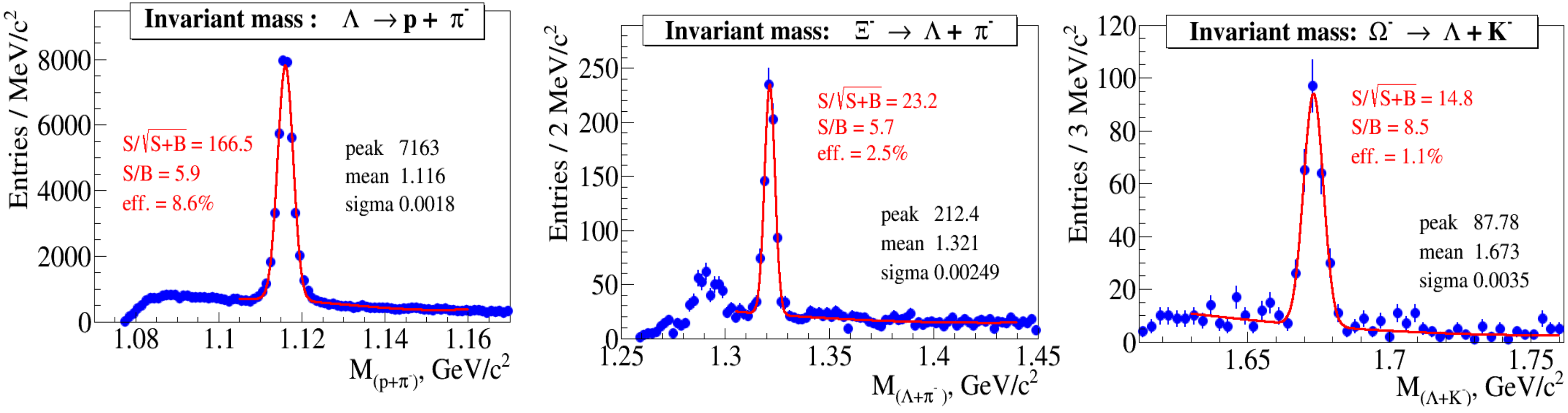


MPD backup slides

MPD performance: hyperons

Production of multi-strange hyperons to study the properties of the strongly interacting system and signal for QGP

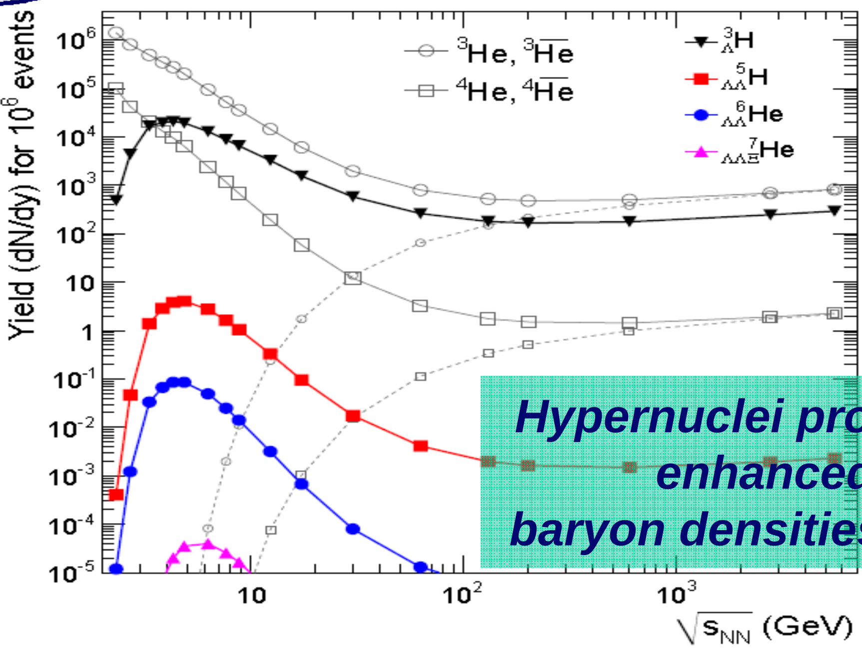
- Central Au+Au @ 9A GeV (UrQMD) , TPC+TOF barrel
- Realistic tracking and PID, secondary vertex reconstruction



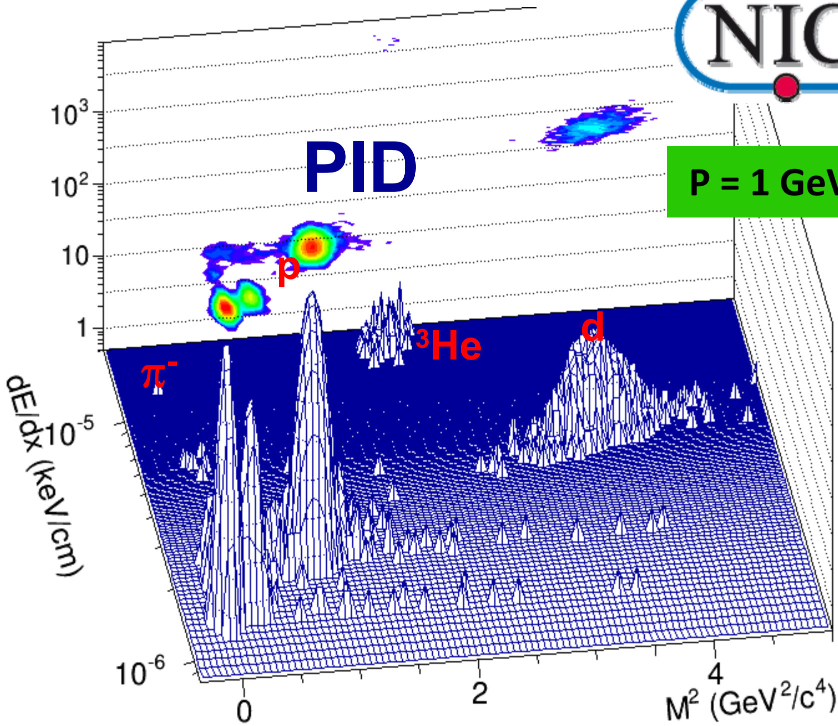
Yields for 10 weeks of running

Particle	Λ	$\bar{\Lambda}$	Ξ^-	$\bar{\Xi}^+$	Ω^-	$\bar{\Omega}^+$
Expected yield	$5.8\cdot10^9$	$7.3\cdot10^7$	$2.9\cdot10^7$	$1.6\cdot10^6$	$1.4\cdot10^6$	$2.9\cdot10^5$

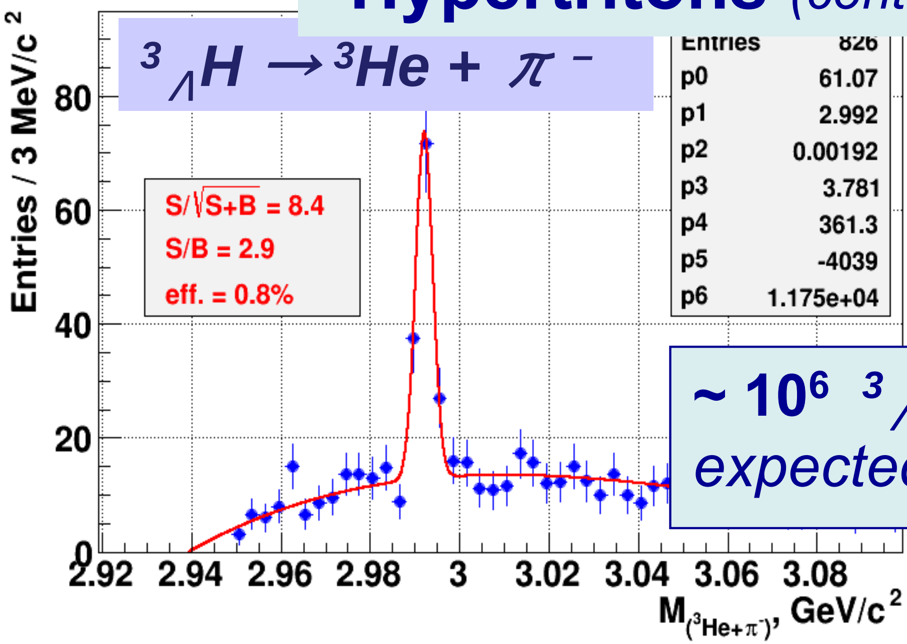
Hypernuclei @ MPD

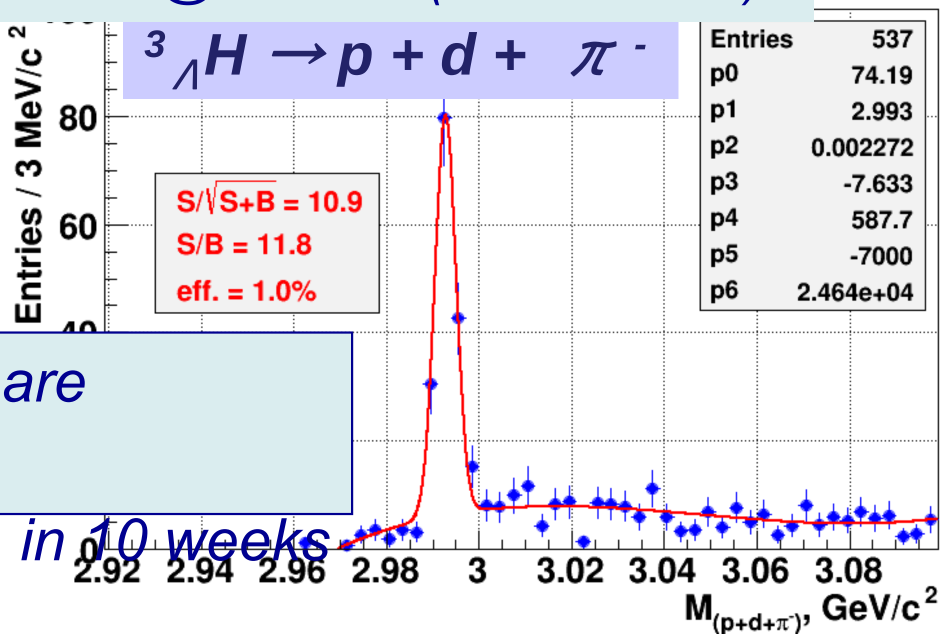


Hypernuclei production enhanced at high baryon densities (NICA)



Hypertritons *(central Au+Au @ 5A GeV (DCM-QGSM)*

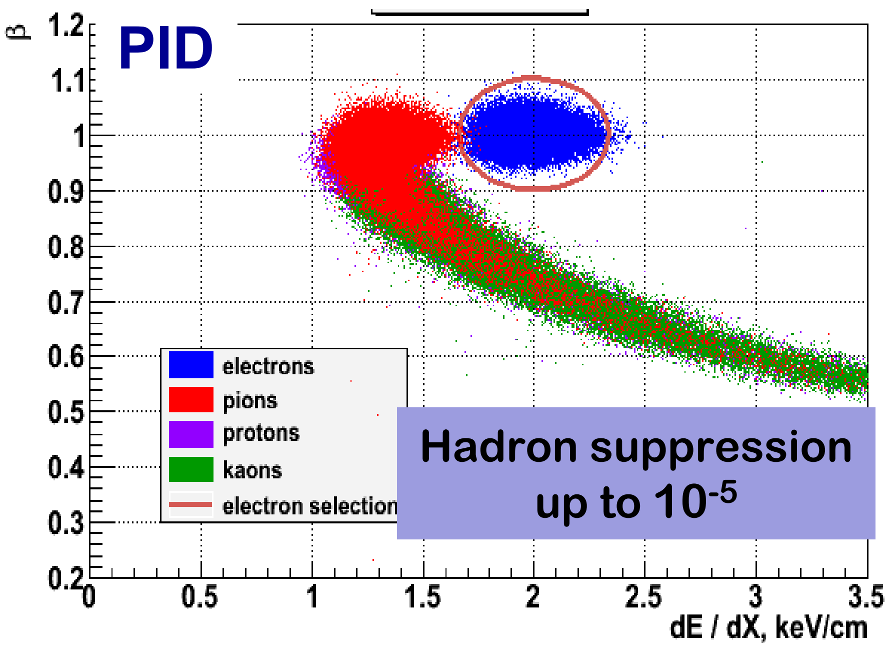


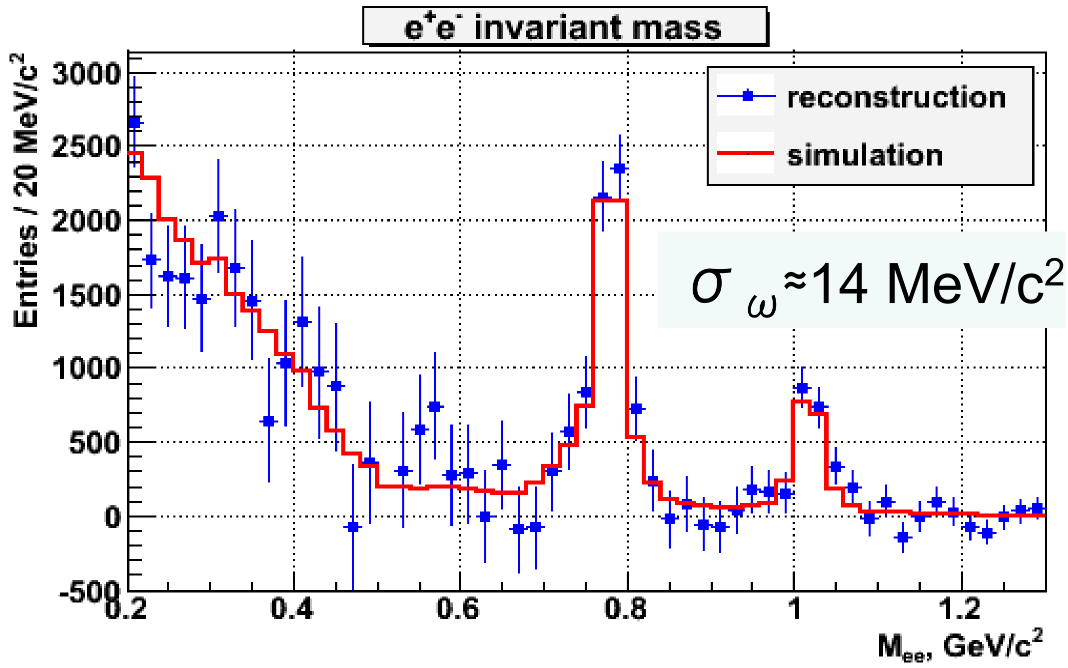


~ 10^6 $^3{}_\Lambda H$ are expected in 10 weeks

MPD performance for dileptons

Good probes to indicate medium modifications of spectral functions due to chiral symmetry restoration in A+A collisions; effect is proportional to baryon density





Yields, central Au+Au st $\sqrt{s_{NN}}$ = 8.8 GeV/u

meson	Yields		Yield / 1 w
	4π	y=0	
ρ	31	17	$7 \cdot 10^4$
ω	20	11	$7 \cdot 10^4$
φ	2.6	1.2	$1.7 \cdot 10^4$