MPD and BM@N experiments at NICA (Dubna) and contributions of INR RAS

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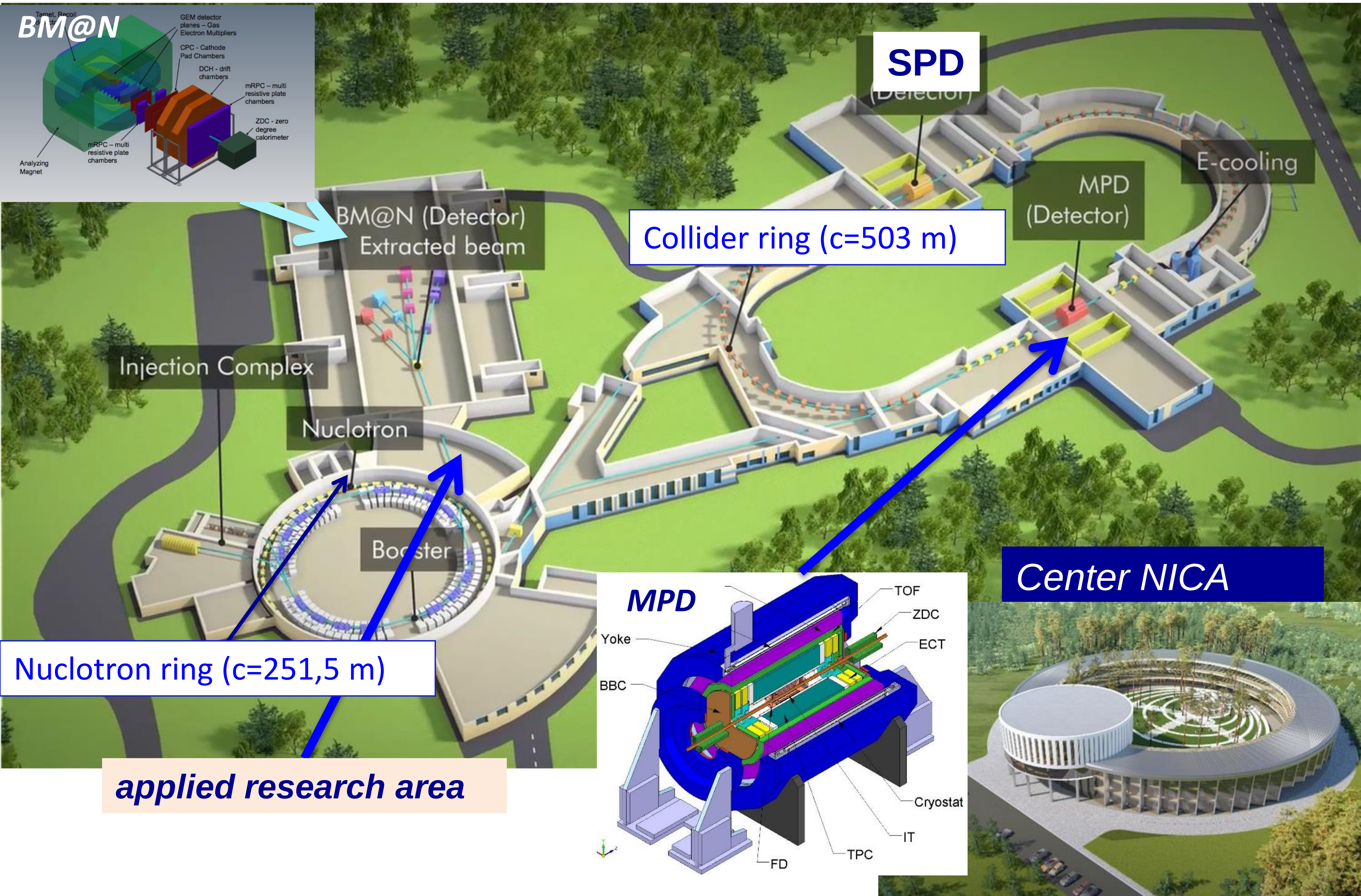
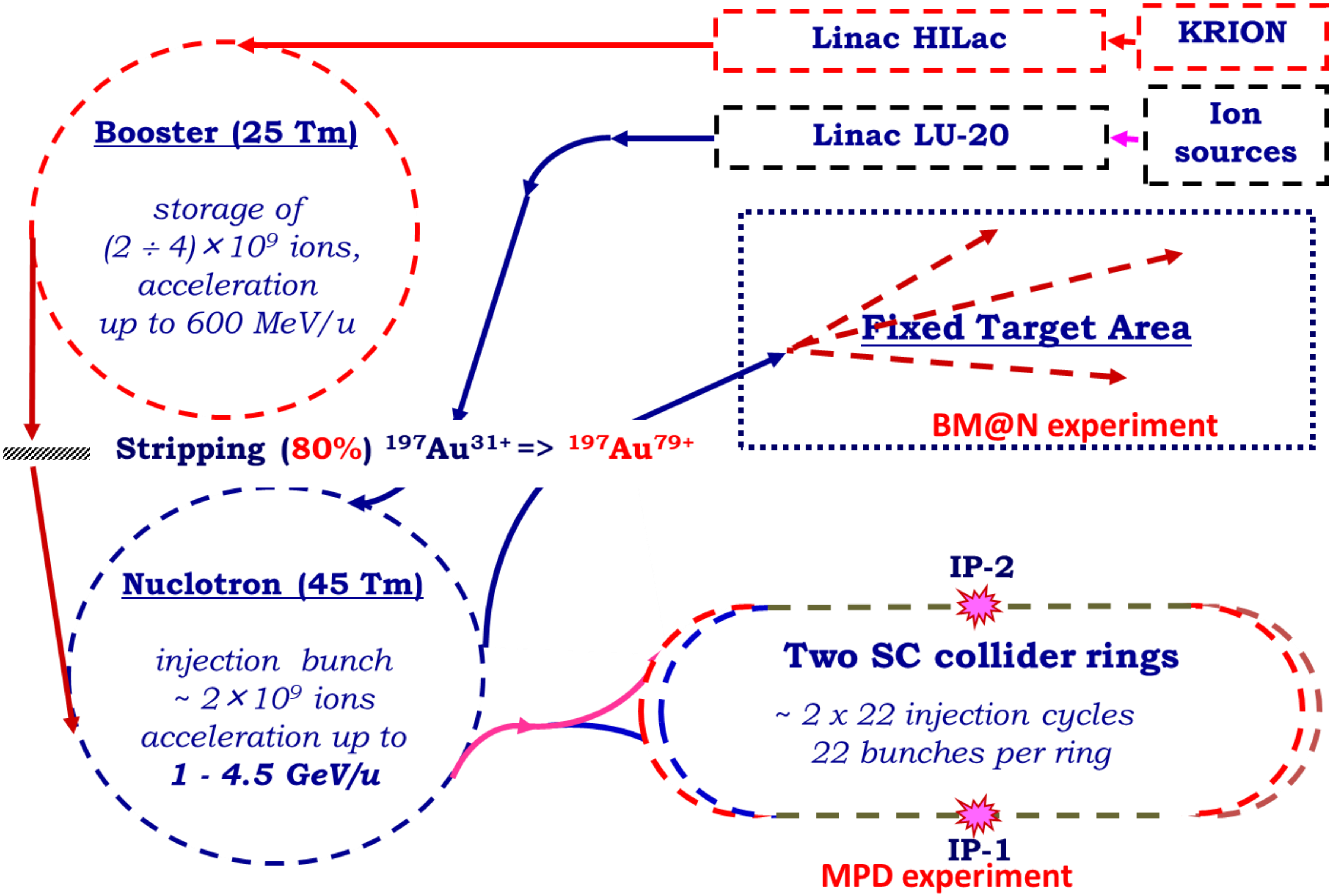
NICA (Nuclotron based Ion Colider fAcility)



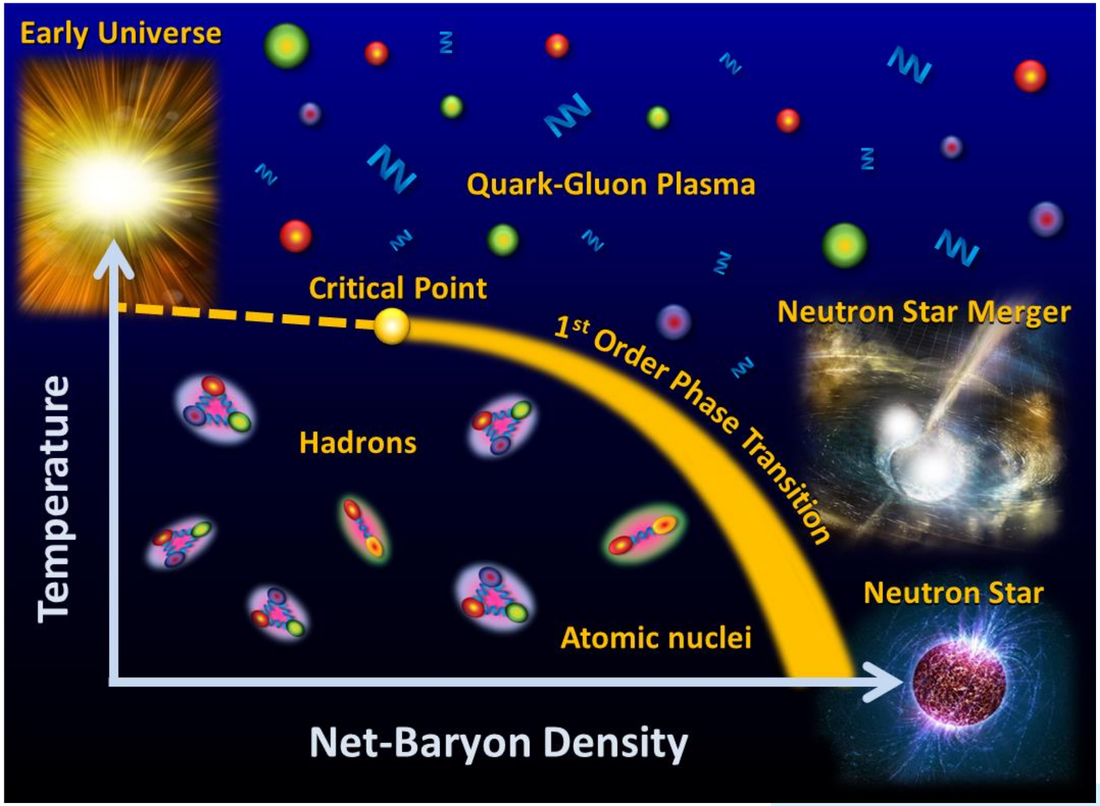
Structure and Operation Regimes



Civil construction, March 2018.

MPD Hall will be ready for equipment installation in – 2018

The discovery potential of BM@N and MPD/NICA.



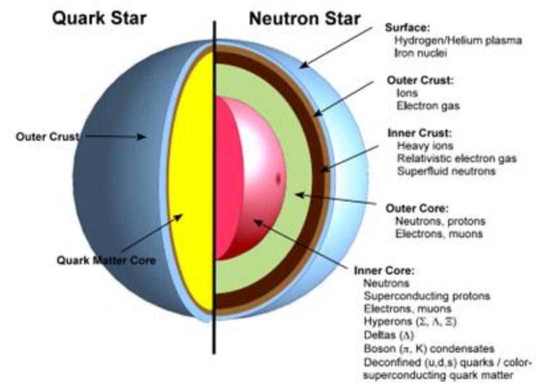
- *equation of state*
- *onset of deconfinement*
- *onset of chiral symmetry restoration*
- *first order phase transition observation*
- *search for critical end-point*
- *polarization phenomena*

Physics background.

P.Senger (GSI/FAIR)

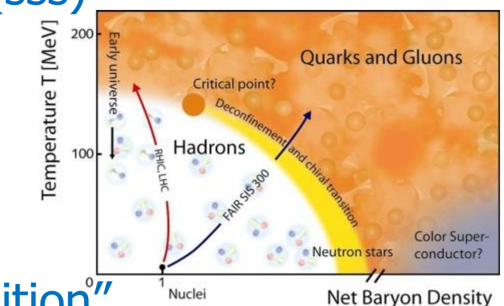
Exciting physics cases and promising observables at BM@N and MPD/NICA

- ➢ EOS at neutron star densities (BM@N + MPD)
- • Collective flow of identified particles
- • Excitation function of multi-strange hyperons



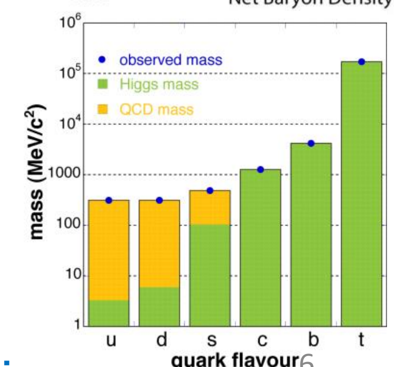
- ➢ Λ-N and Λ-N interactions (BM@N + MPD)
- • Yields and lifetime of single and double Λ-hypernuclei

- ➢ Phase transitions from partonic to hadronic matter (MPD)
- • excitation function of strangeness: Ξ^-(dss), $\Xi^+(\overline{dss})$, Ω^-(sss), $\Omega^+(\overline{sss})$
- • excitation function of charm: J/ψ, $D^{\pm}$, $\bar{D}$



- ➢ Phase coexistence (MPD)
- • excitation function (invariant mass) of lepton pairs: thermal radiation from QGP, caloric curve
- • anisotropic azimuthal angle distributions: "spinodal decomposition"

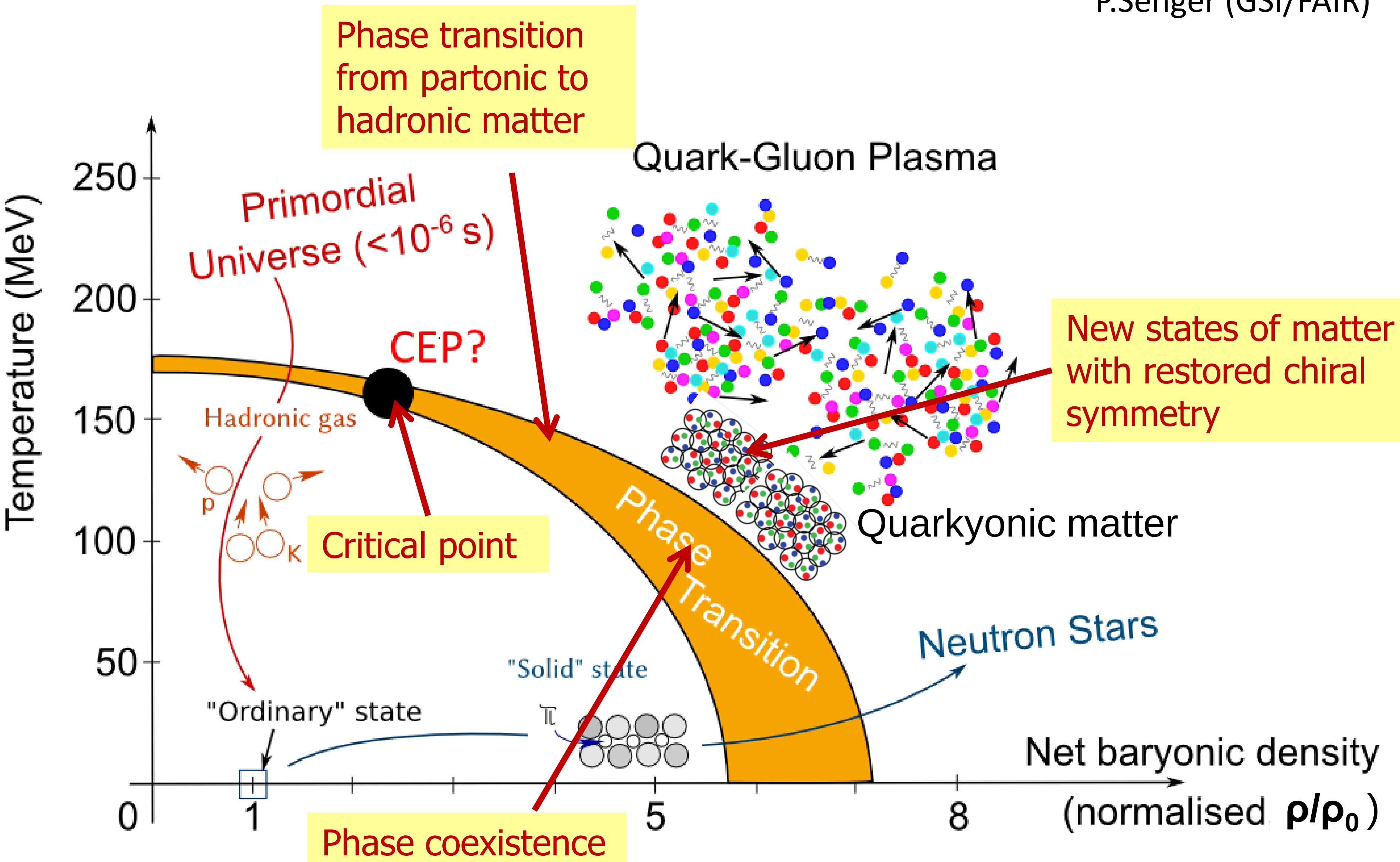
- ➢ Critical point (MPD)
- • event-by-event fluctuations of conserved quantities (B,S,Q) "critical opalescence"



- ➢ Onset of chiral symmetry restoration at high ρ_B (MPD)
- • in-medium modifications of hadrons: $\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$
- • dileptons at intermediate invariant masses: 4 π → ρ-a_1 chiral mixing

The physics cases of MPD/NICA

P.Senger (GSI/FAIR)



The equation-of-state of nuclear matter

P.Senger (GSI/FAIR)

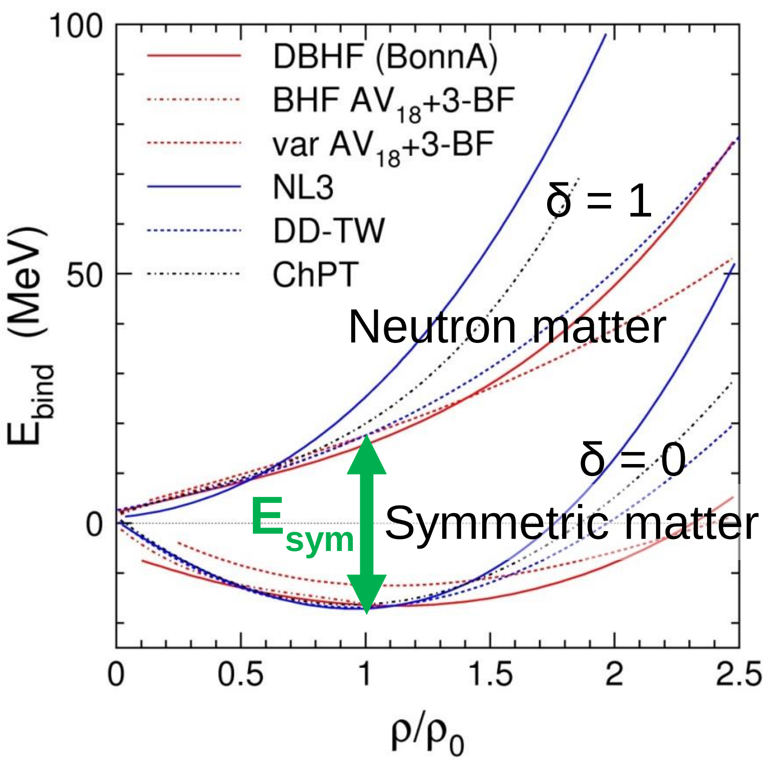
The nuclear matter equation of state (EOS) describes the relation between density, pressure, temperature, energy, and isospin asymmetry

$P = \delta E/\delta V \,|_{T=const}$
$V = A/\rho$
$\delta V/\delta\rho = -A/\rho^2$
$P = \rho^2\, \delta(E/A)/\delta\rho \,|_{T=const}$

$E_A(\rho,\delta) = E_A(\rho,0) + E_{sym}(\rho)\cdot\delta^2 + O(\delta^4)$
with asymmetry parameter $\delta = (\rho_n - \rho_p)/\rho$

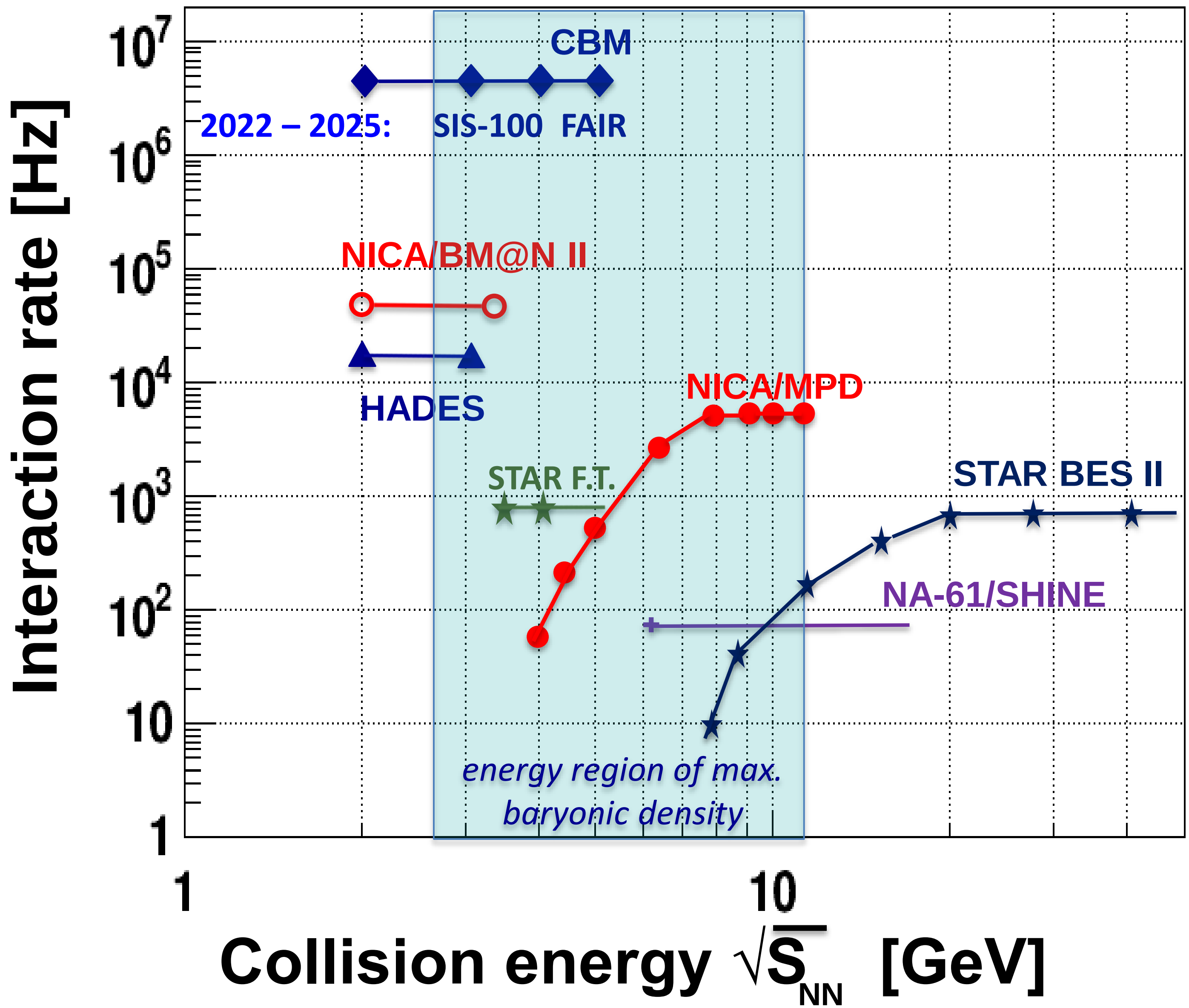
Symmetric nuclear matter:

- $E/A(\rho_o) = -16$ MeV
- $\delta(E/A)(\rho_o)/\delta\rho = 0$
- $K = 9\rho^2\, \delta^2(E/A)/\delta\rho^2$ (nuclear incompressibility)

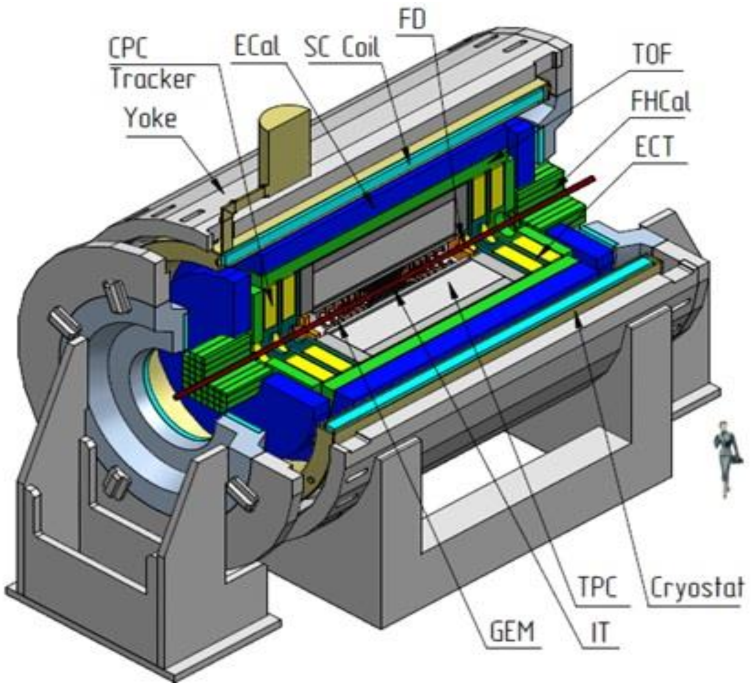


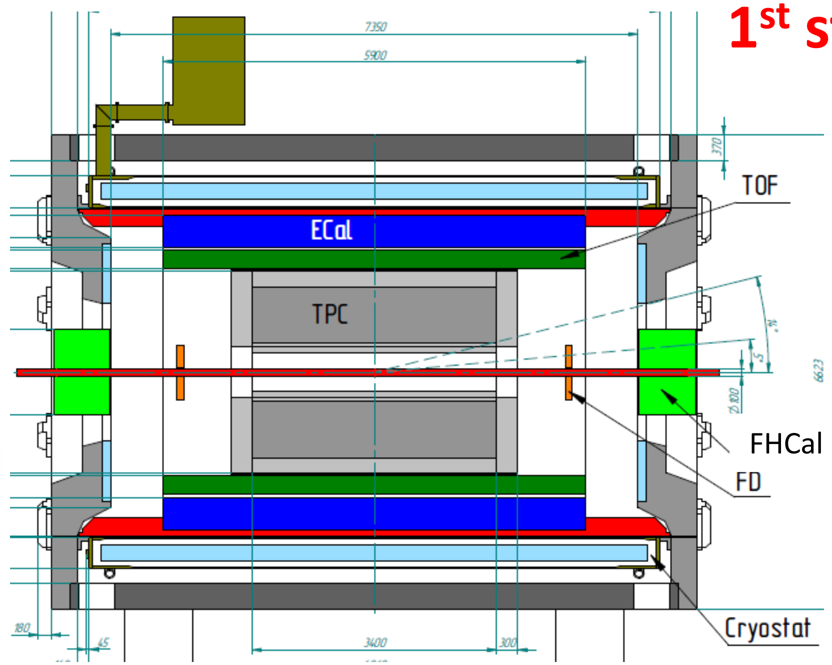
Fuchs and Wolter, EPJA 30 (2006)

Present and future HI experiments



Multi Purpose Detector (MPD).





1st stage

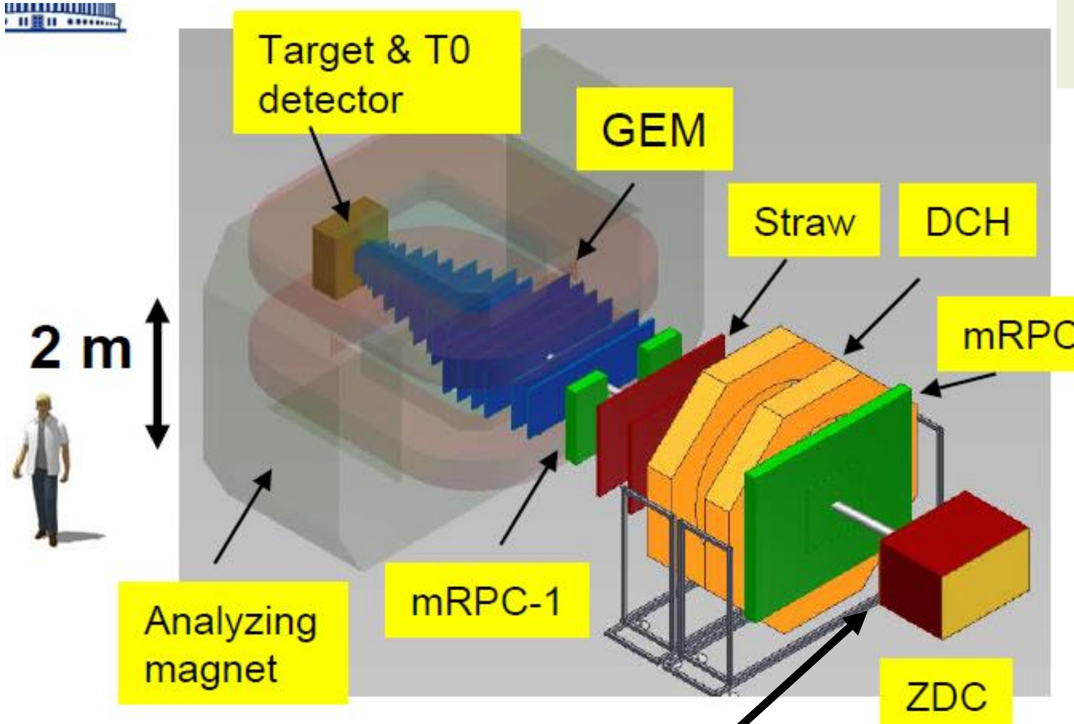
MPD participants:

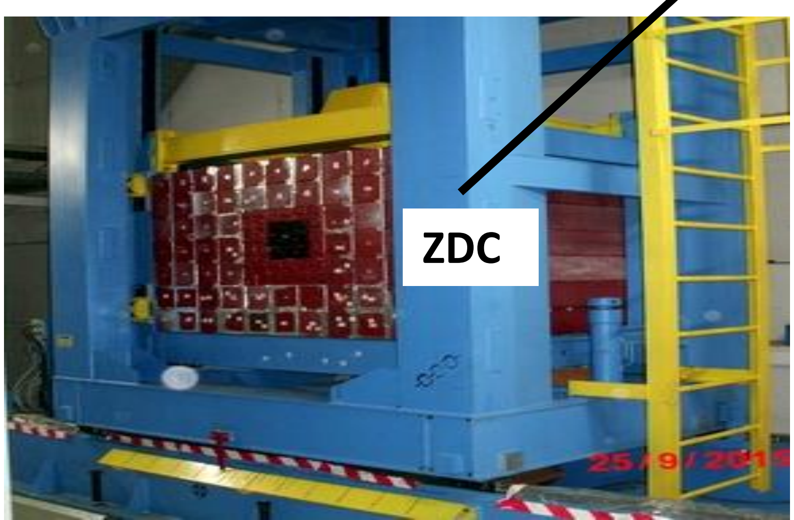
- *JINR, Dubna;*
- *Tsinghua University, Beijing, China;*
- *GSI, Germany*
- *MEPhI, Moscow, Russia.*
- *INR, RAS, Russia;*
- *PPC BSU, Minsk, Belarus;*
- *WUT, Warsaw, Poland;*

Joined recently:

- *DF, US, Mexico;*
- *ICN UNA; Mexico;*
- *DF, CIEA del I.P.N, Mexico;*
- *FCF-M UAS, Sinaloa, Mexico;*
- *FCF-MB UAP, Puebla, Mexico;*
- *PI Az.AS, Baku, Azerbaijan;*
- *ITEP, NC KI, Moscow, Russia;*
- *PNPI NC KI, Saint Petersburg, Russia;*
- *CPPT USTC, Hefei, China;*
- *SS, HU, Huzhou, Republic of South Africa.*

Barionic Matter at Nuclotron (BM@N)



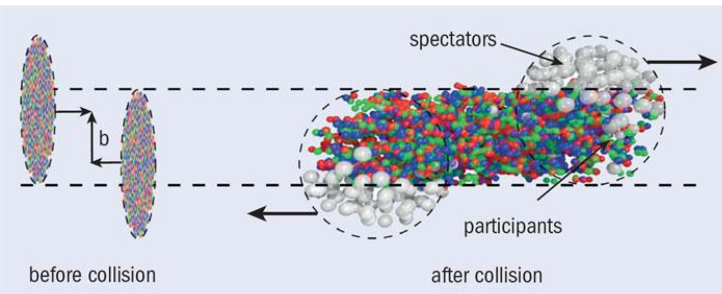


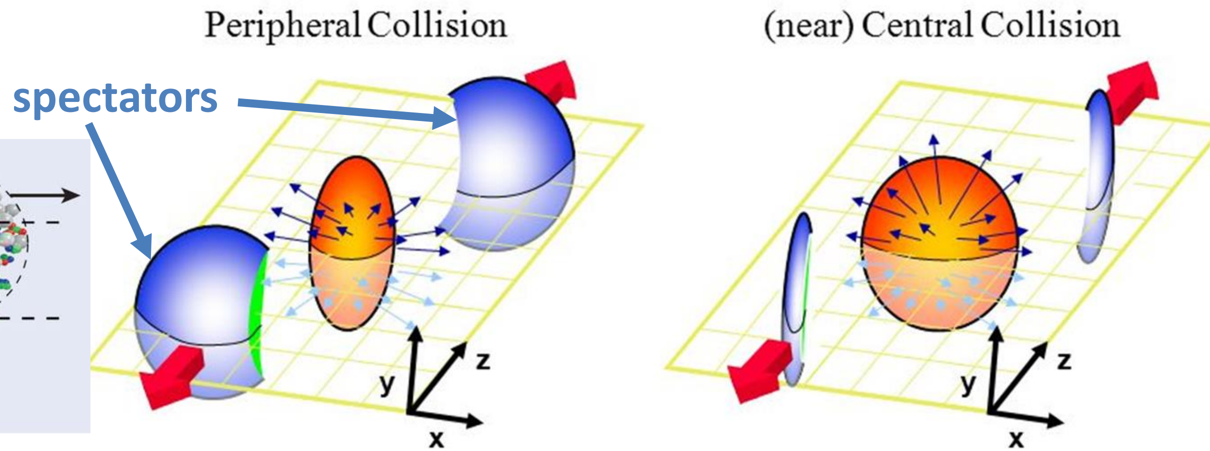
2 moths beam run already done in 2018. A lot of experimental data!

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

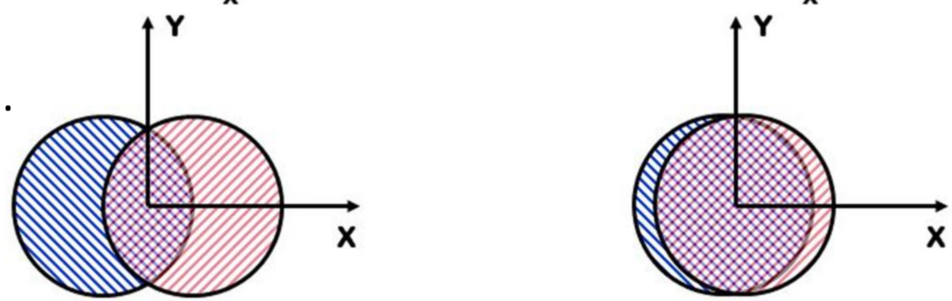
Centrality and reaction plane of collision.

Centrality – impact parameter (***b [fm])-*** distance between the centers of nuclei.

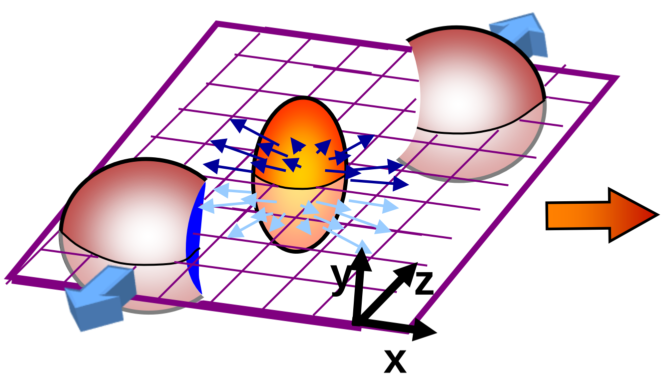


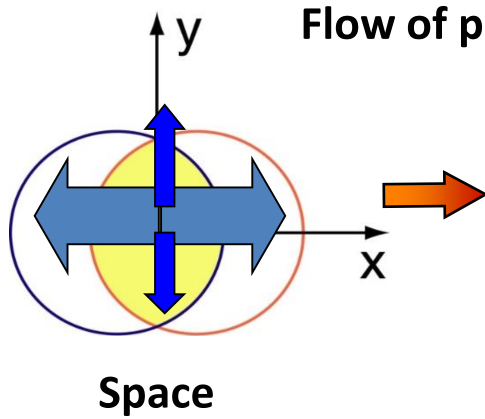


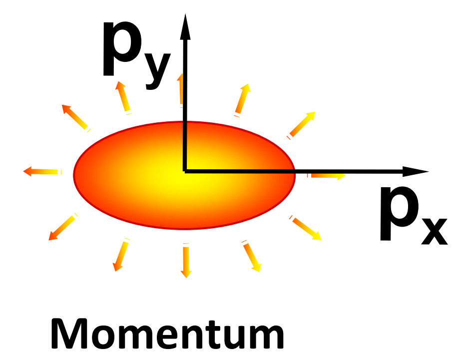
Reaction plane – plane of ***b*** and ***Z*** (beam).



Flow of particles.



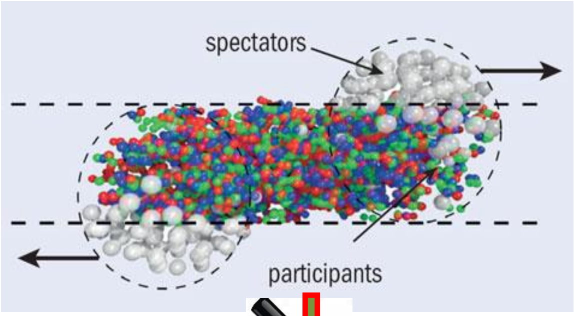




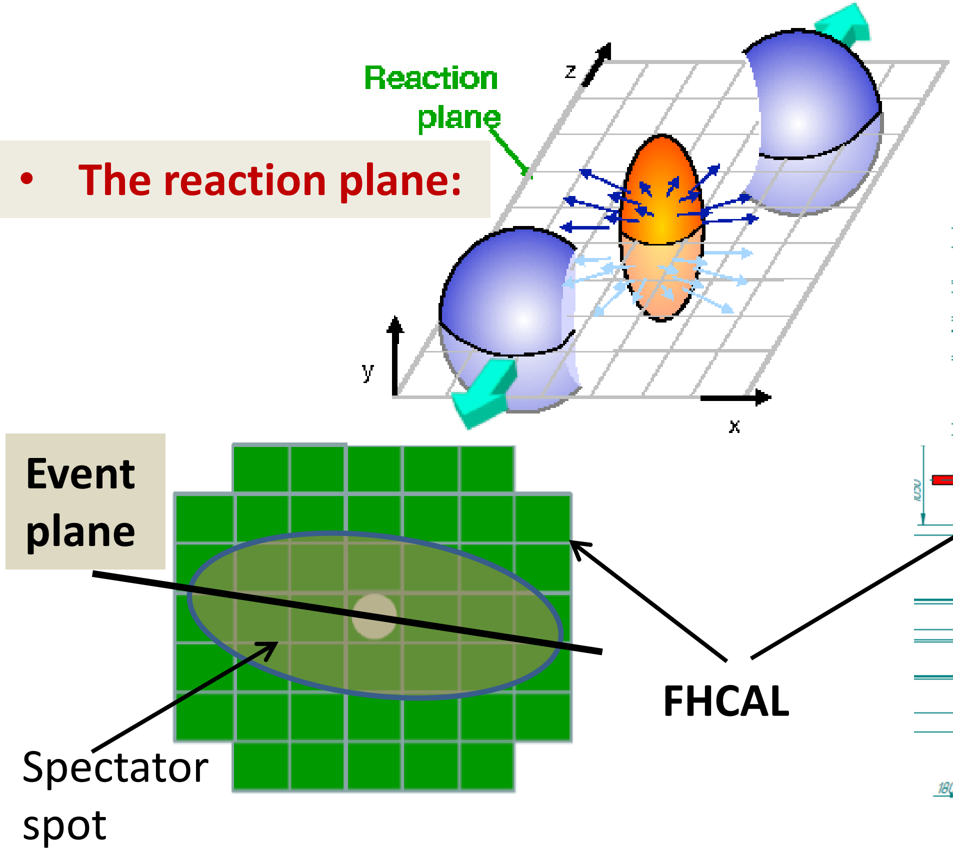
The Forward Hadron Calorimeter in MPD setup.

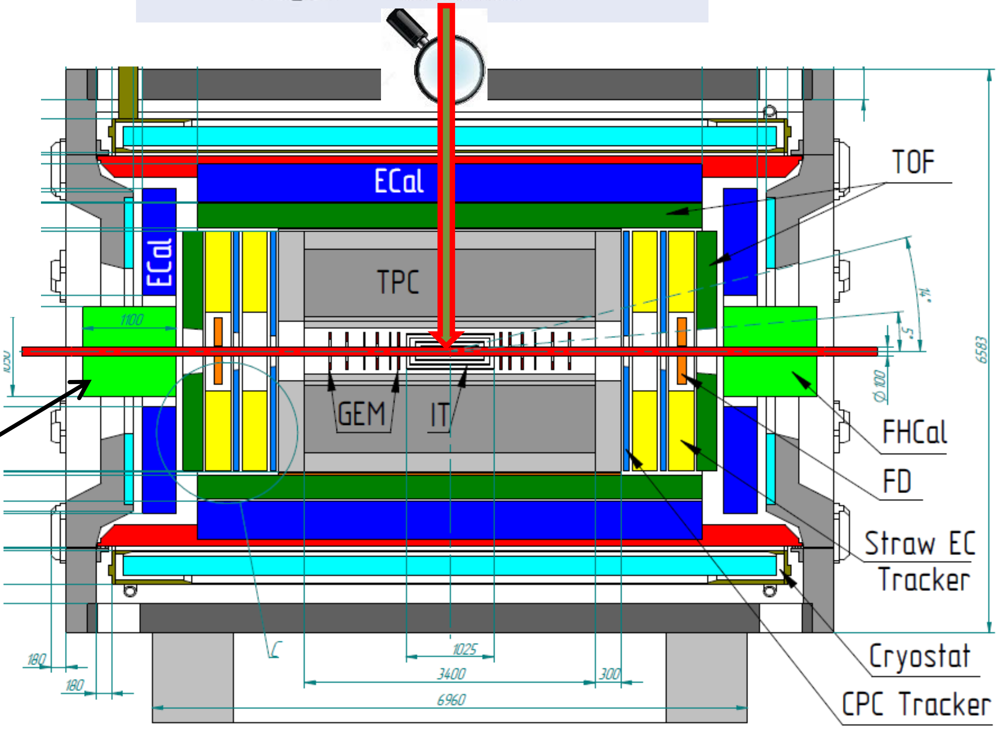
FHCal will detect the spectators to measure the geometry of ion collisions.

- **The centrality of the collisions:**



- **The reaction plane:**

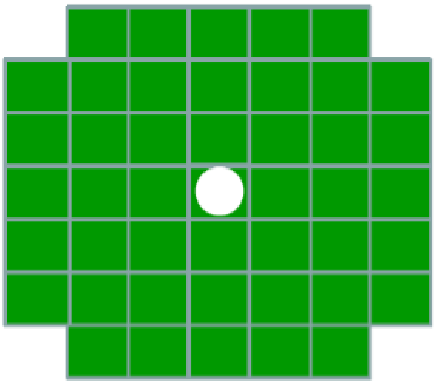




- <u>Two arms of hadron calorimeters</u> at opposite sides in forward regions.
- At the distance 3.2 meters from the interaction point.
- Acceptance corresponds to pseudorapidity $2.0 < \eta < 5.0$

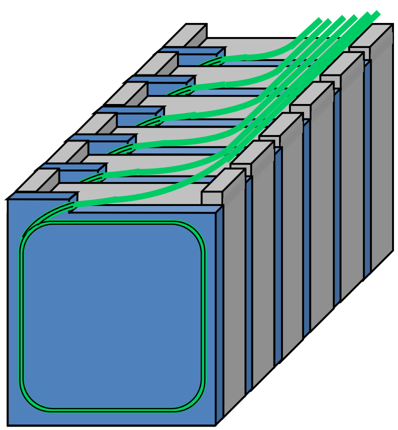
Structure of FHCal – two left/right arms.

Modular Lead/Scintillator sandwich compensating calorimeter.
Sampling ratio Pb:Scint=4:1.



Each arm:

- 45 modules;
- Beam hole;
- Weight – 9 tons.

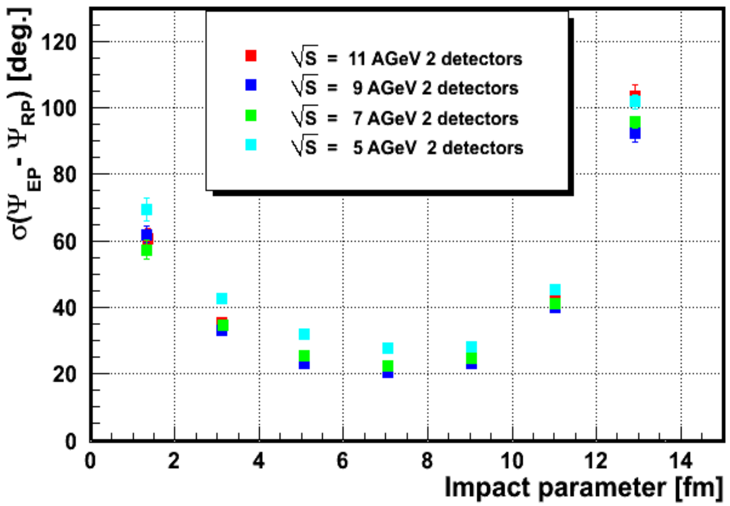


Light from scintillator tiles is captured by WLS-fibers and transported to SiPM.

Each module:

- Transverse size - $15x15cm^2$;
- Total length - 106 cm.
- Interaction length ~4 λ_{int};
- Longitudinal segmentation – 7 sections;
- 1 section ~ $0.56\lambda_{int}$;
- 7 photodetectors/module;
- Photodetectors – silicon photomultipliers (SiPM).

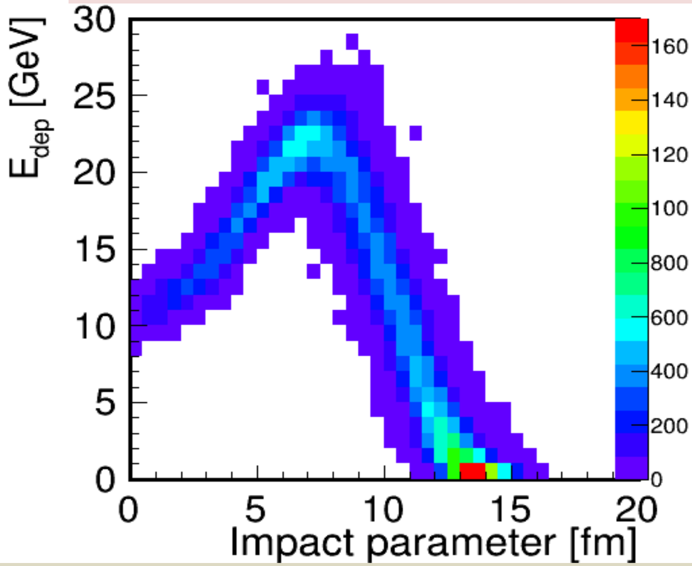
Event plane and centrality resolution.

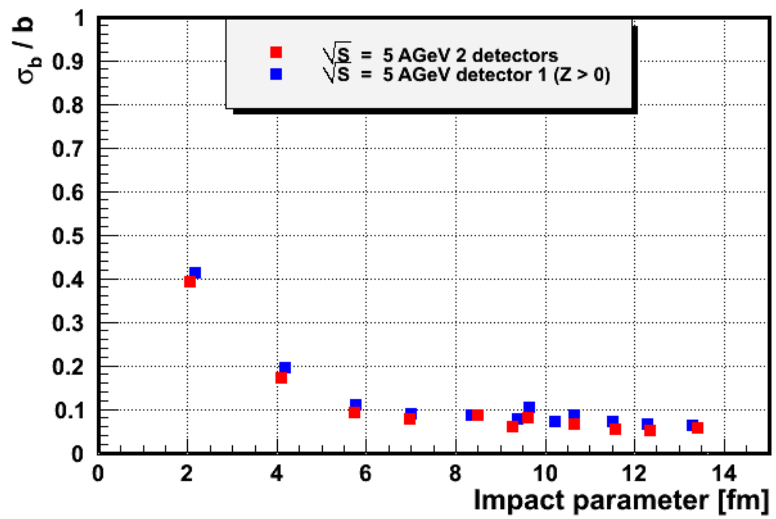


Modules 15x15 cm^2 are optimum choice and fit the transverse size of hadron showers (interaction length of lead+scint. λ_I~20 cm).

The event plane resolution of 20^0-25^0: two arms of FHCal (maximum spectator multiplicity) and no influence of magnet field.

Energy deposition in FHCal isn't monotonic due to beam hole and can't resolve the central and peripheral events.

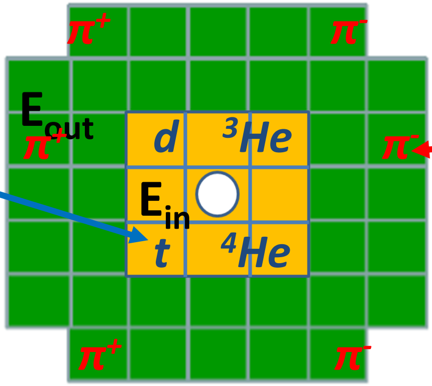




The ambiguity in centrality determination can be resolved by taking track multiplicity in TPC. Or by using other observables in FHCal.

Other FHCal observable for the centrality measurement.

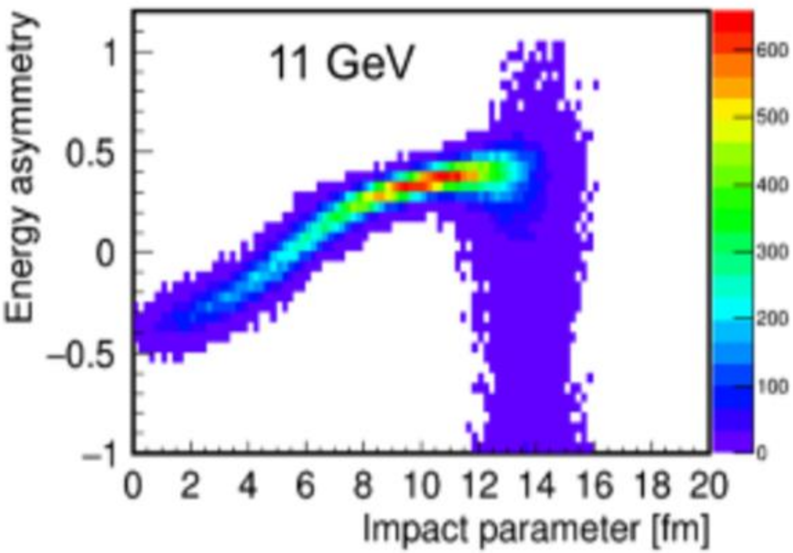
Mainly, **fragments** are produced in peripheral collisions and located near beam hole.

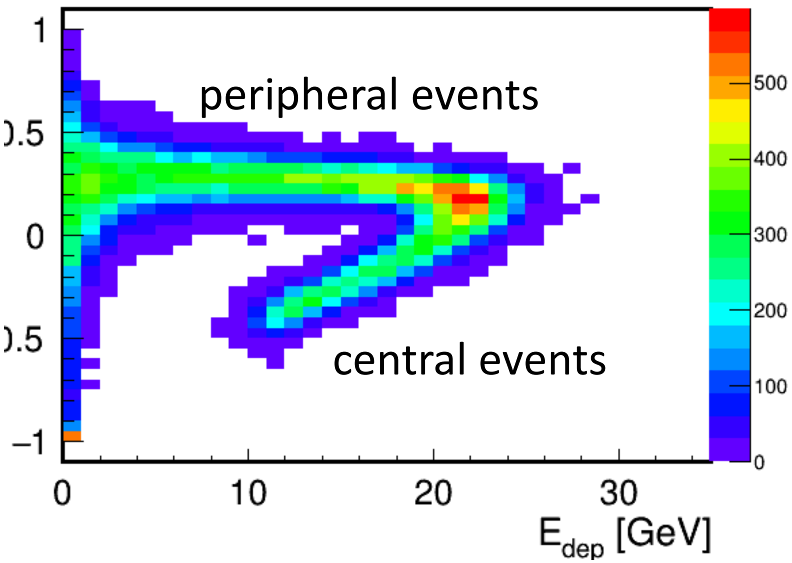


while **pions** are produced in central collisions.

Depending on centrality there must be difference in the energy depositions in inner and outer parts of calorimeter.

Let's construct *energy asymmetry:* $A_E = \frac{E_{in} - E_{out}}{E_{in} + E_{out}}$

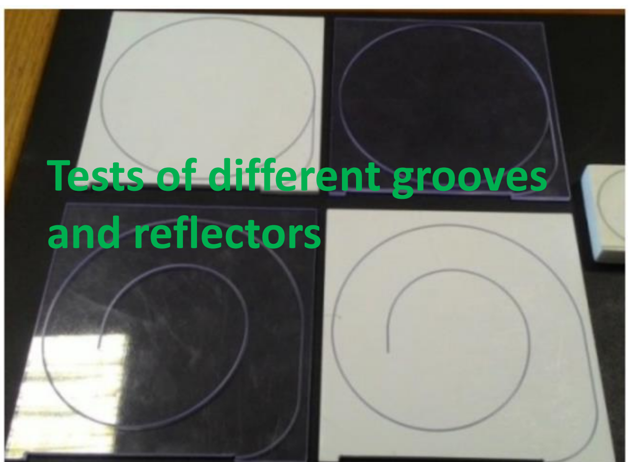


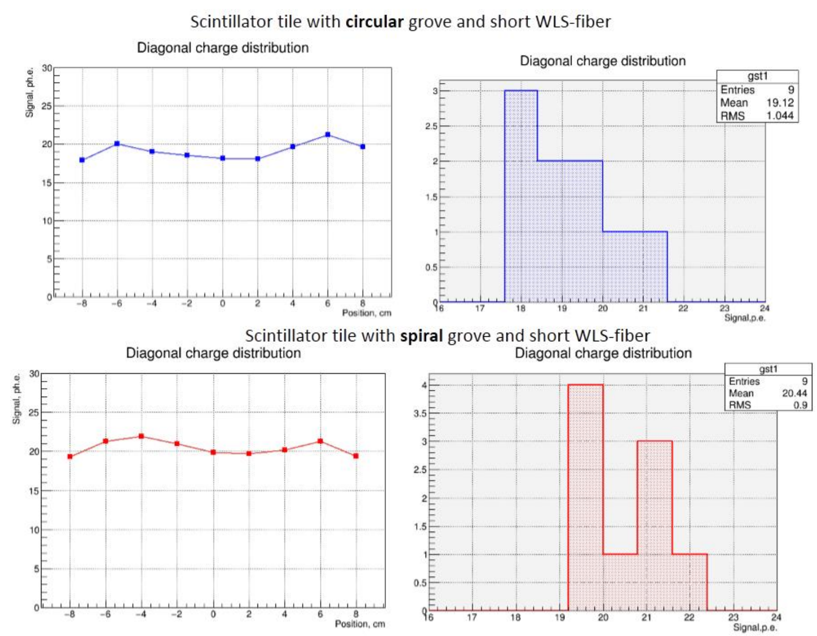


FHCal can resolve central and peripheral collisions!

Stages of FHCal production: scintillators.

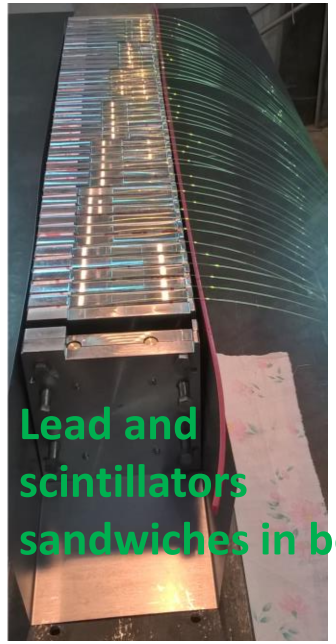
FHCal scintillator tiles and modules are assembled in workshop of INR, Moscow.

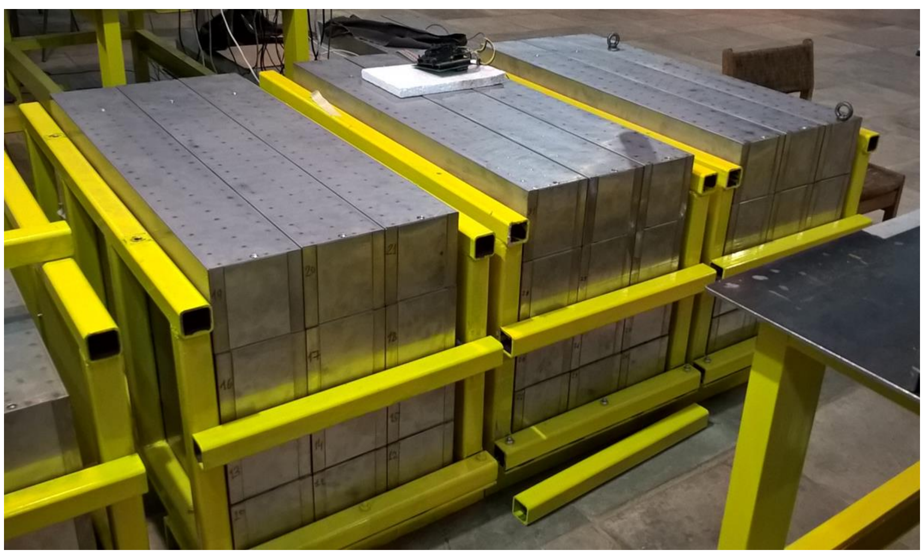




Permanent quality control of scintillator tiles, WLS-fibers and gluing is performing with ^{90}Sr β-source.

Stages of FHCal production: modules.





At present, about 1/3 of FHCal modules are ready for the tests.
All FHCal modules will be ready in 2019.

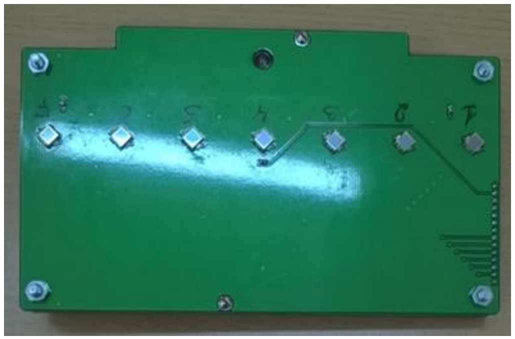
Tests of modules with cosmic muons are done in parallel with the development of Front-End-Electronics and readout.

Photodiodes, FEE and readout electronics.

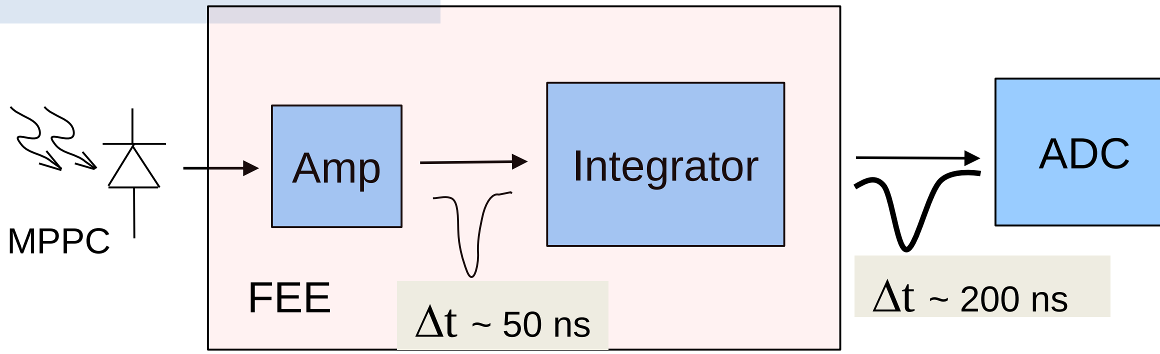
A first samples of FEE with MPPC photodetectors were developed and produced.

Photodetectors: **Hamamatsu MPPC: size – 3x3 mm^2;**
pixel -10x10 μm^2;
PDE~12%.

Front-End-Electronics:



7 channels:
two-stage amplifiers;
HV channels;
LED calibration source.



The readout electronics:
FPGA based 64 channel ADC64 board, 62.5MS/s (AFI Electronics, JINR, Dubna).

Full readout chain was tested with cosmic muons and at beam!

Test of calorimeter supermodule at CERN T9 line.

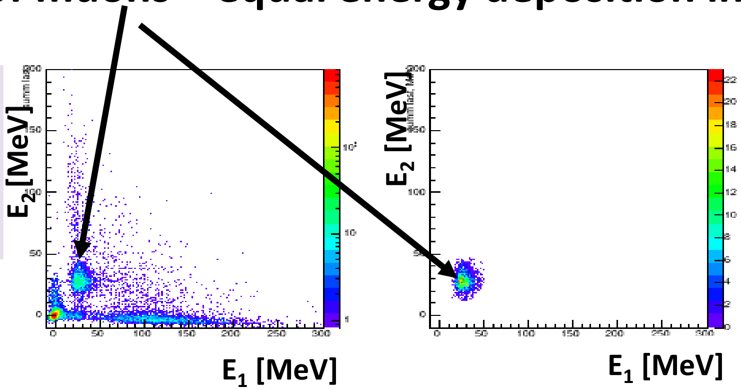
Proton momentum range: 3-10 GeV/c

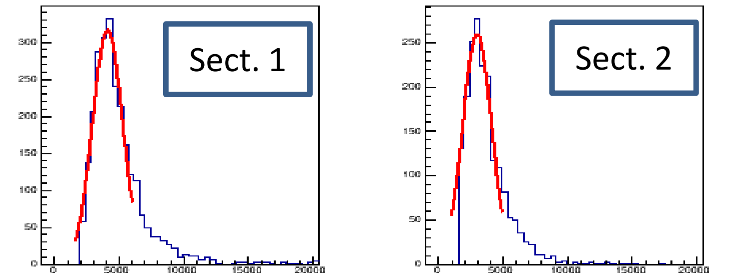
- **Supermodule consists of 9 (3x3) CBM modules.**
- **The FEE and readout are designed for MPD (BM@N) experiment.**
- **Each module has 10 longitudinal sections with 10 SiPMs at the end.**
- **Full size 60x60x160 cm^3.**
- **Weight ~ 4.5 tons.**

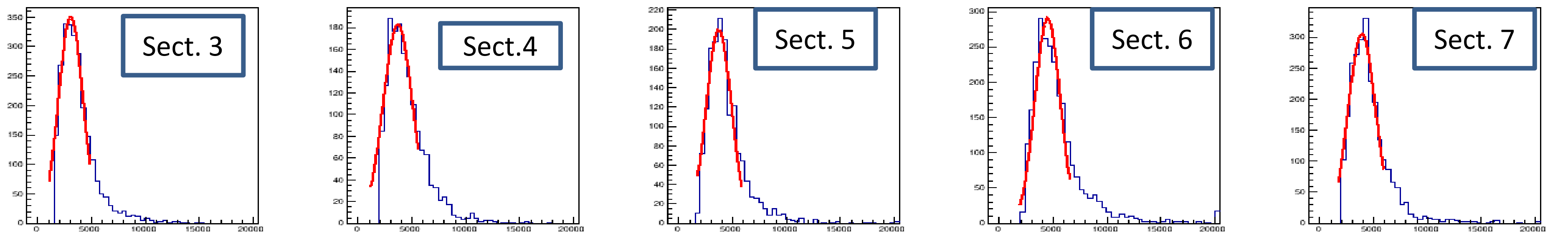
Calibration of longitudinal sections with beam muons, 6 GeV/c

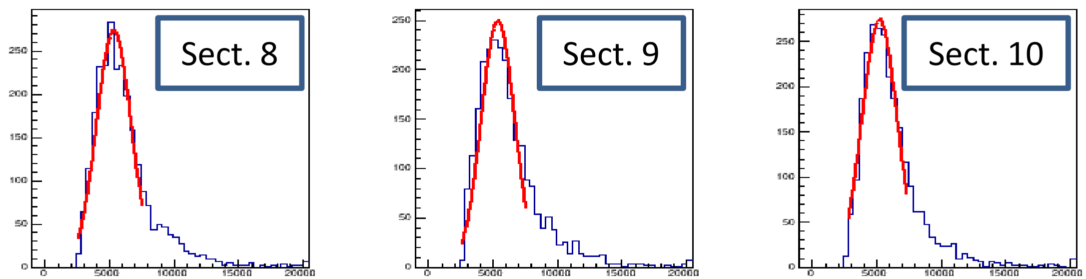
Identification of muons – equal energy deposition in first and last half of modules.

Muons deposit ~5 MeV in one section





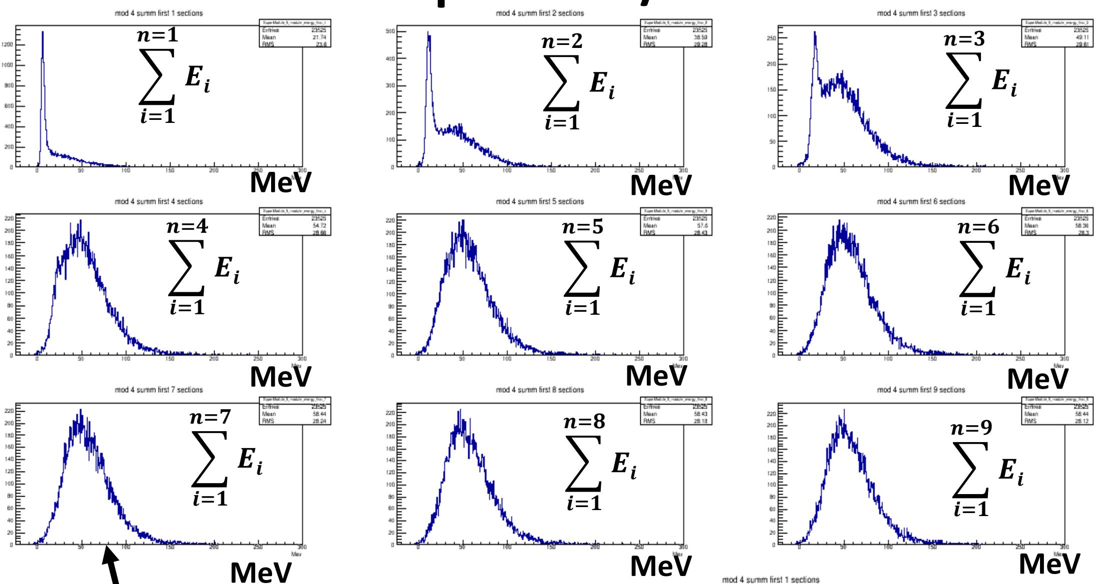




Muons energy deposition spectra in 10 sections of central module.

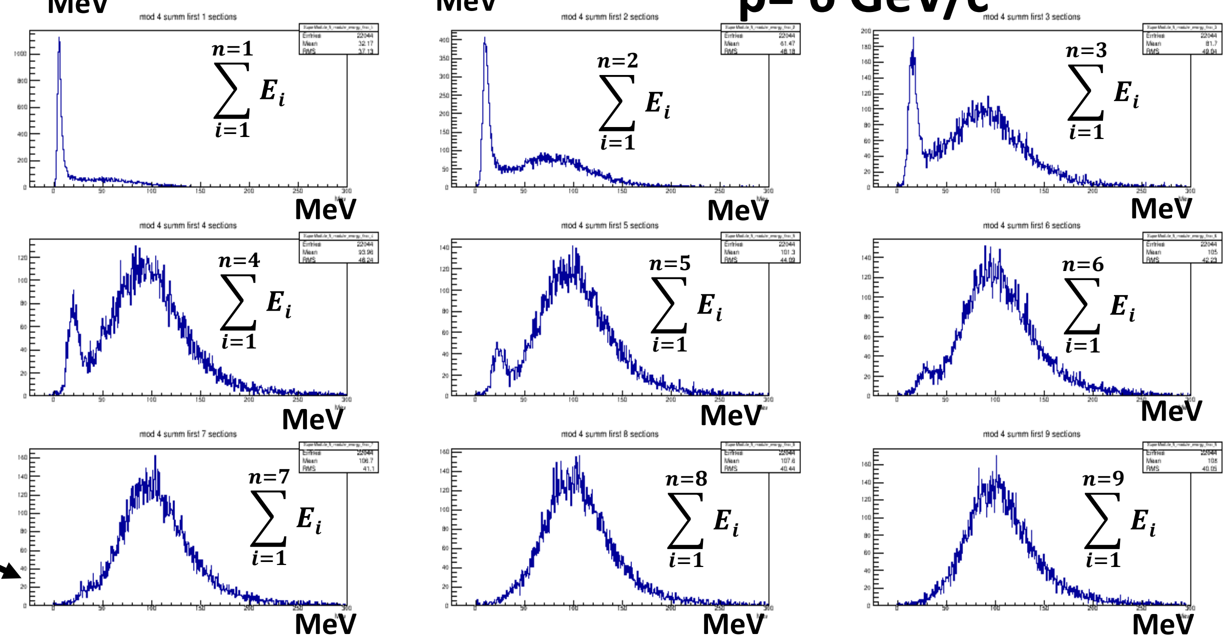
Spectra of energy sum in first *n* sections in central module, protons 3 and 6 GeV/c.

p= 3 GeV/c



Some part of protons has only ionizing energy loss without hadron shower in first sections.

p= 6 GeV/c

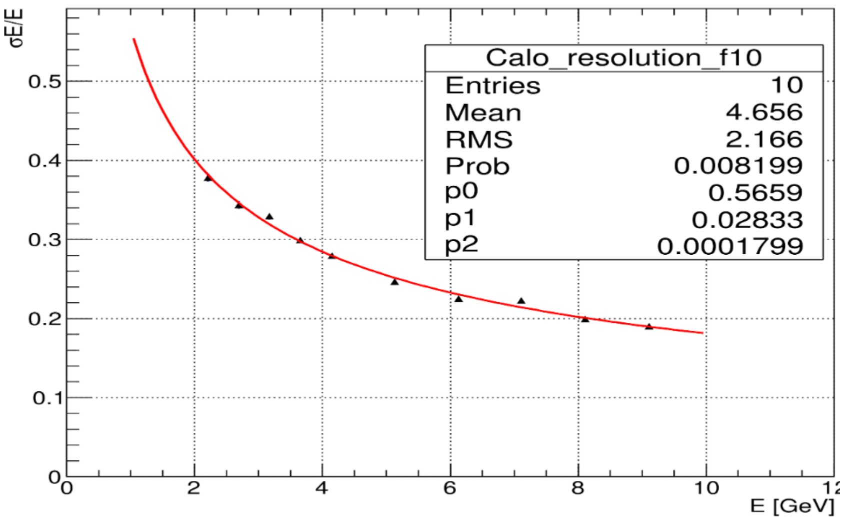


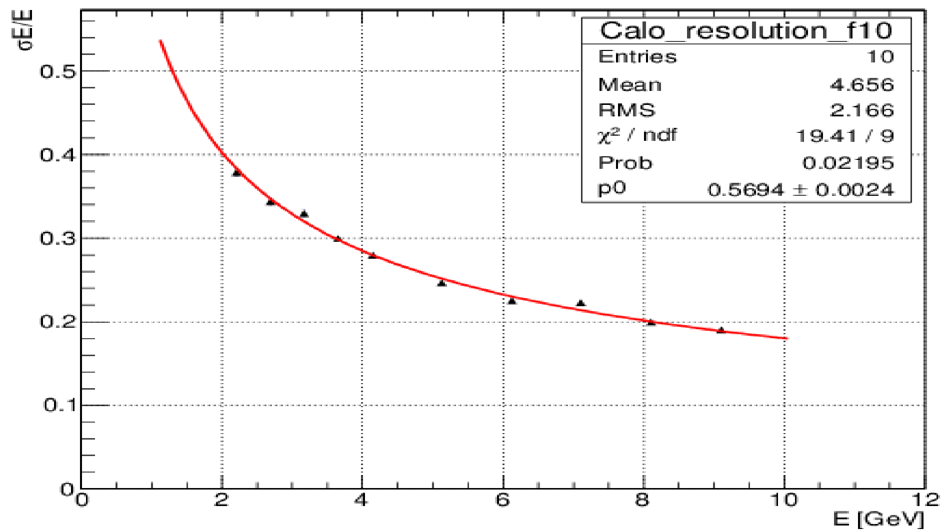
In 7th section the low energy ionizing peak is disappeared. Energy spectrum has Gaussian shape.

Energy resolution for full supermodule.

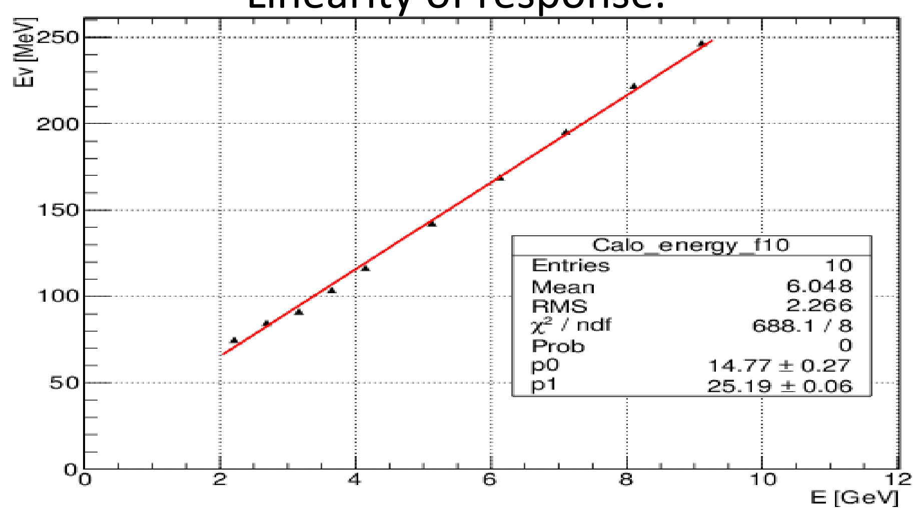
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}}$$



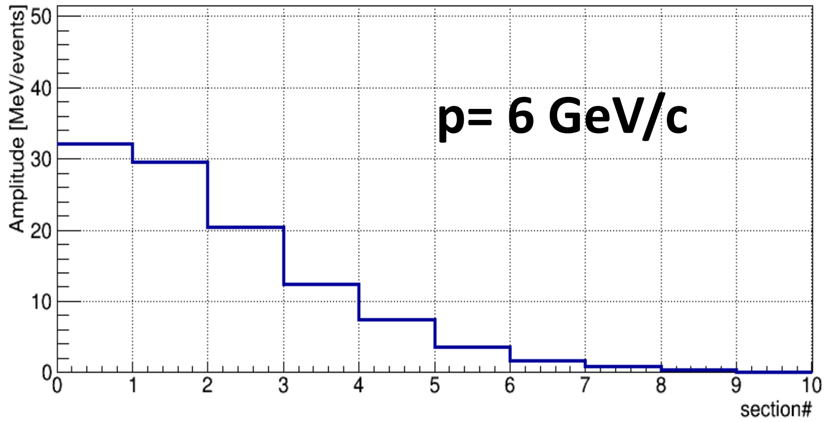


Linearity of response.



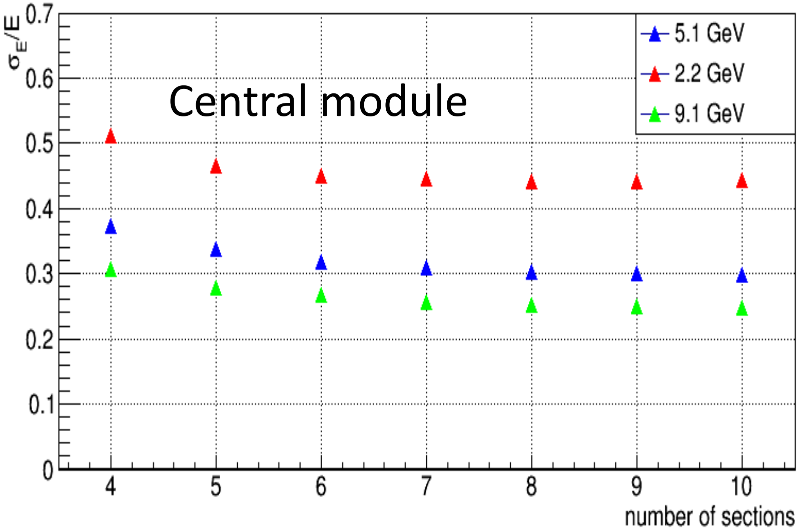
The stochastic term of ~56% practically doesn't depend on the fitting function.
Good agreement with MC results.
The noise term is almost zero.

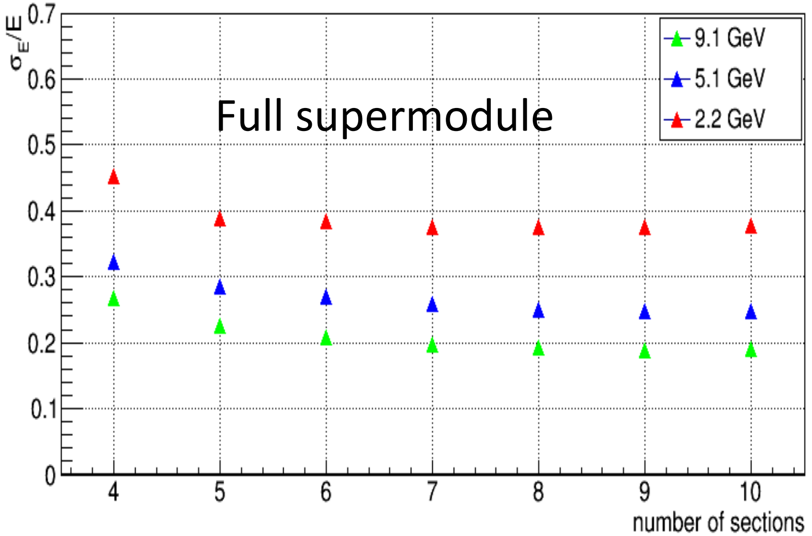
Dependence of energy resolution on supermodule length.



Longitudinal profile of hadron shower in central module.

The energy resolution for central module and for full supermodule is practically constant starting from the 7 longitudinal sections.

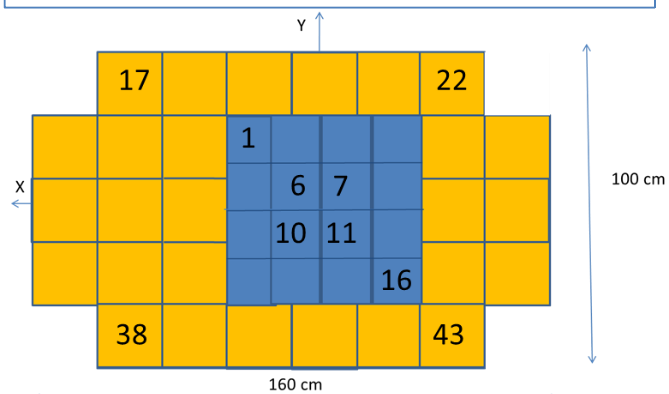




Length of $4\lambda_I$ or 7 longitudinal sections is optimum for momentum range 3-6 GeV/c

Upgrade of ZDC for BM@N.

MPD modules + CBM modules



Present ZDC at BM@N

- No beam hole.
- central part consist of 36 modules with sizes 7.5×7.5 cm^2,
- peripheral part contains 68 modules of 15×15 cm^2.
- Total number of modules - 104.

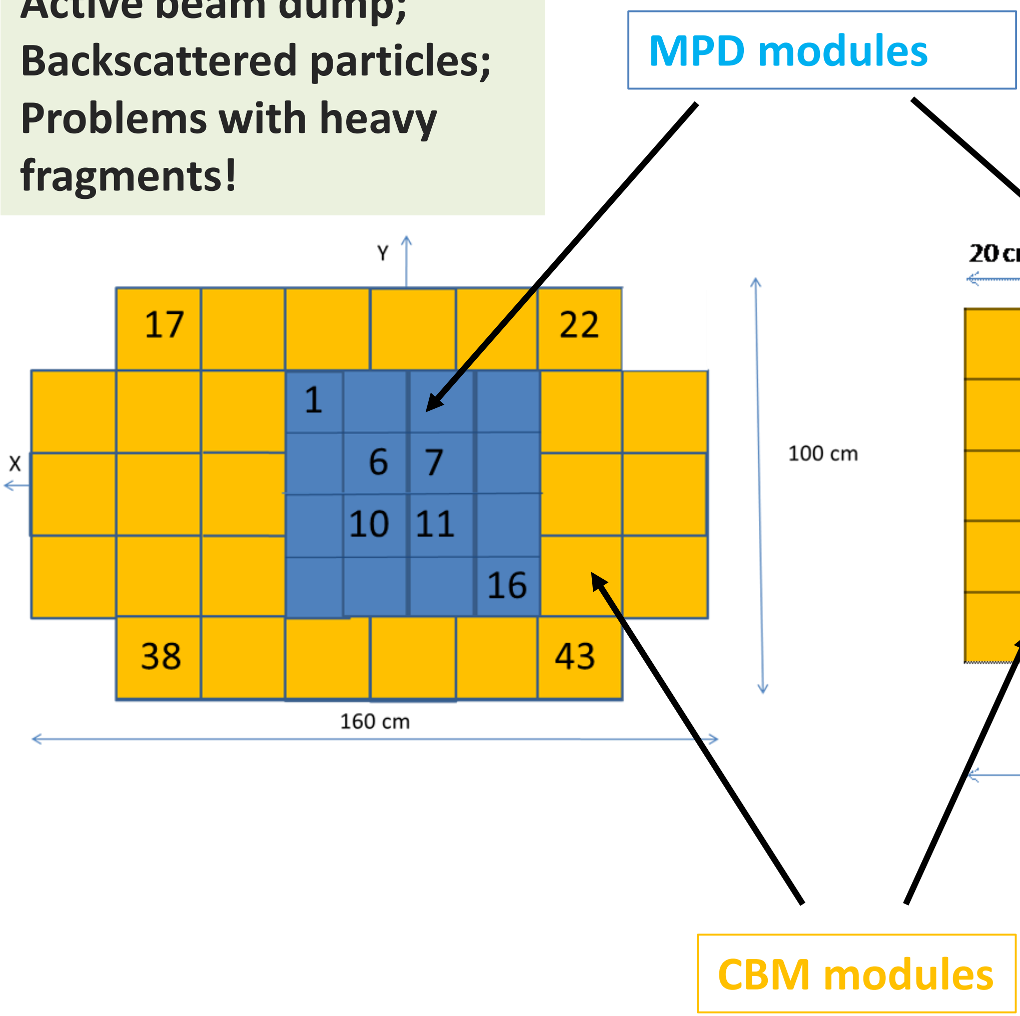
MPD/CBM synergy for BM@N: Why?

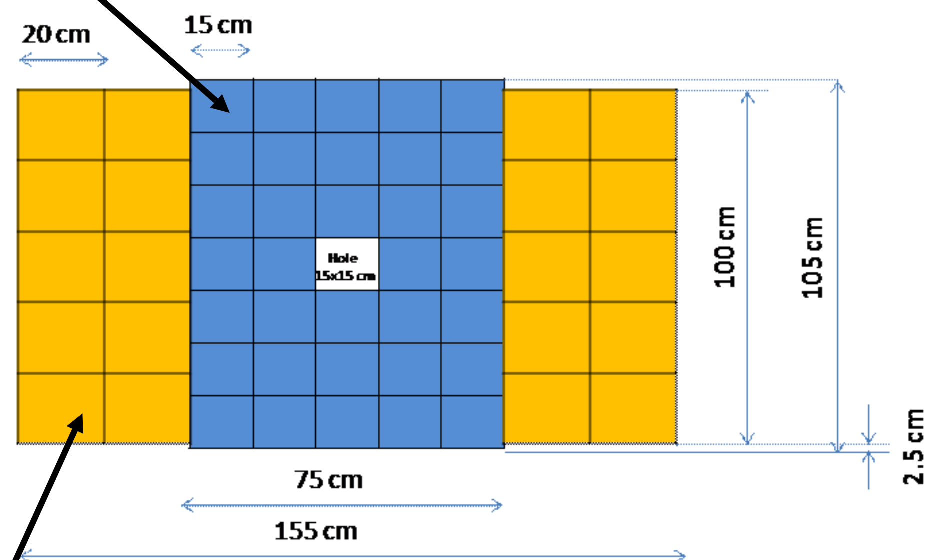
- Modern technics;
- Light yield ~x10 higher;
- Detection of low energies;
- Stable operation at high count rates;
- Unification of approaches;
- Experience in operation for later MPD/CBM experiments.

Variants of ZDC for BM@N.

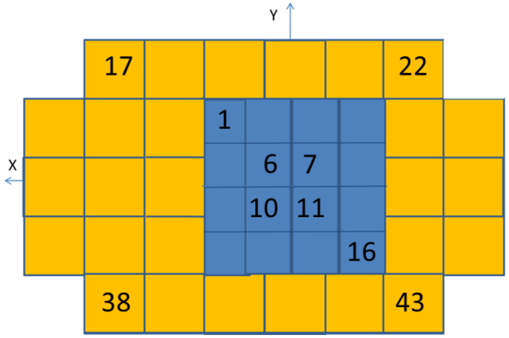
Active beam dump;
Backscattered particles;
Problems with heavy fragments!

No active beam dump;
No backscattered particles;
No heavy fragments!



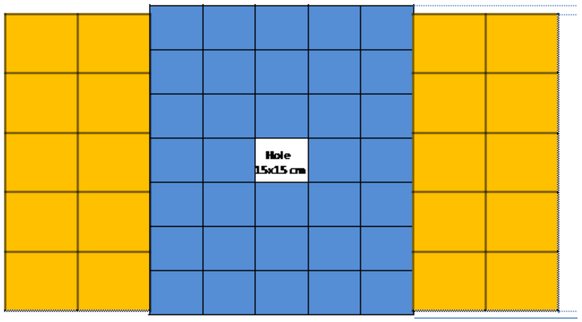


Problems with centrality measurement at BM@N.

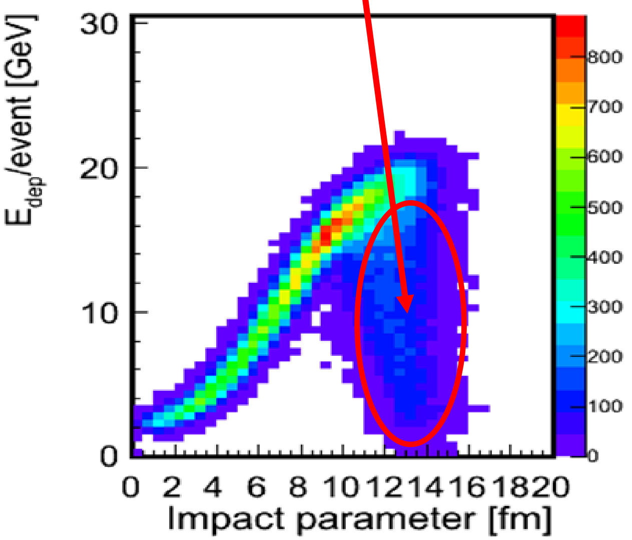


Energy deposition is not monotonic in both cases even without beam hole!

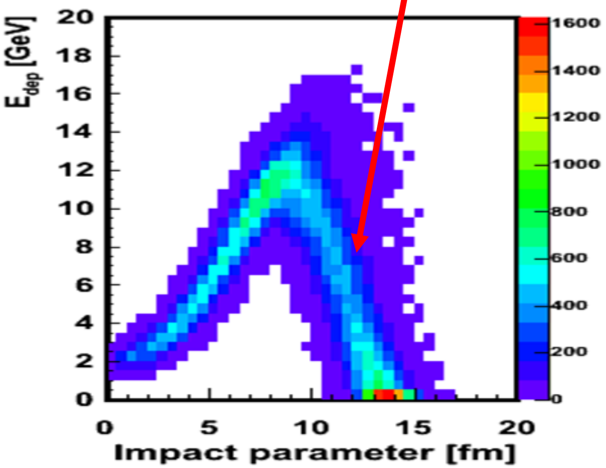
Simulations: LA-QGSM Au+Au@4.5 AGeV



Some heavy ions with A>100 deposit energy through e.-m. ionizing loss without hadron cascade.



Leak of heavy ions in beam hole.



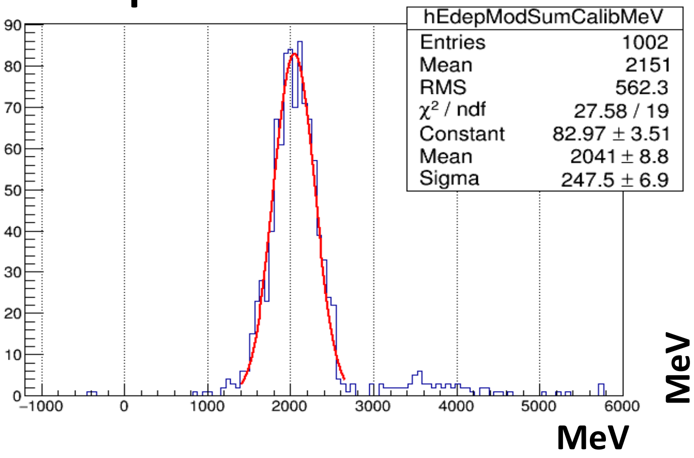
Centrality measurements are not simple in both geometries!

Current status.

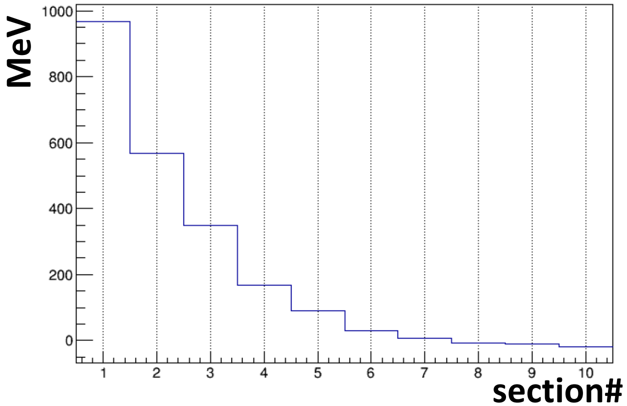
- **The FHCal project is well developed.**
- **But there are many open questions.**
- **New manpower for both hardware and software is desired!**

First CBM module is already installed at BM@N.

Ar-peak in CBM module.



Shower profile



Tasks to be solved (software).

BM@N experiment

- Optimization of ZDC geometry,
- Methods of centrality measurements,
- Reconstruction of reaction plane,
- Collective flow analysis,
- Analysis of the existing experimental data.

MPD experiment

- Methods of centrality measurements,
- Reconstruction of reaction plane,
- Collective flow analysis,
- Simulation of FHCal sensitivity to beam quality.

Tasks to be solved (hardware).

BM@N experiment

- Assembling of ZDC modules,
- Tests of module parameters with cosmic muons,
- Development of FEE and readout electronics,
- Development of Slow Control,
- Installation in experimental area,
- Integration to BM@N Data Acquisition system.

MPD experiment

- Assembling of FHCal modules,
- Tests of module parameters with cosmic muons,
- Development of FEE and readout electronics,
- Development of Slow Control,
- Installation in experimental area,
- Integration to MPD Data Acquisition system.

Thank you!