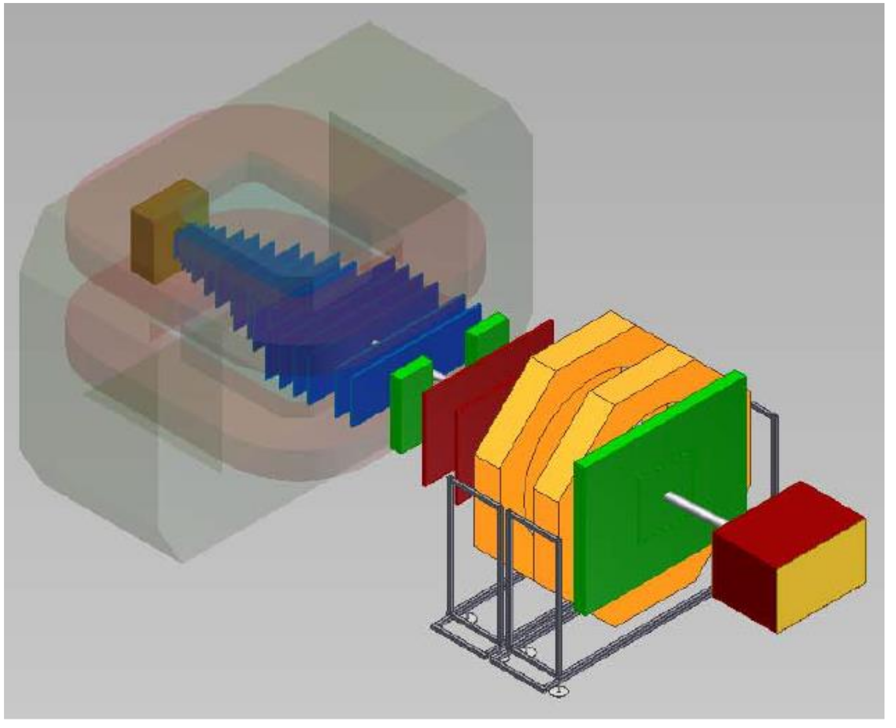
BM@N first results

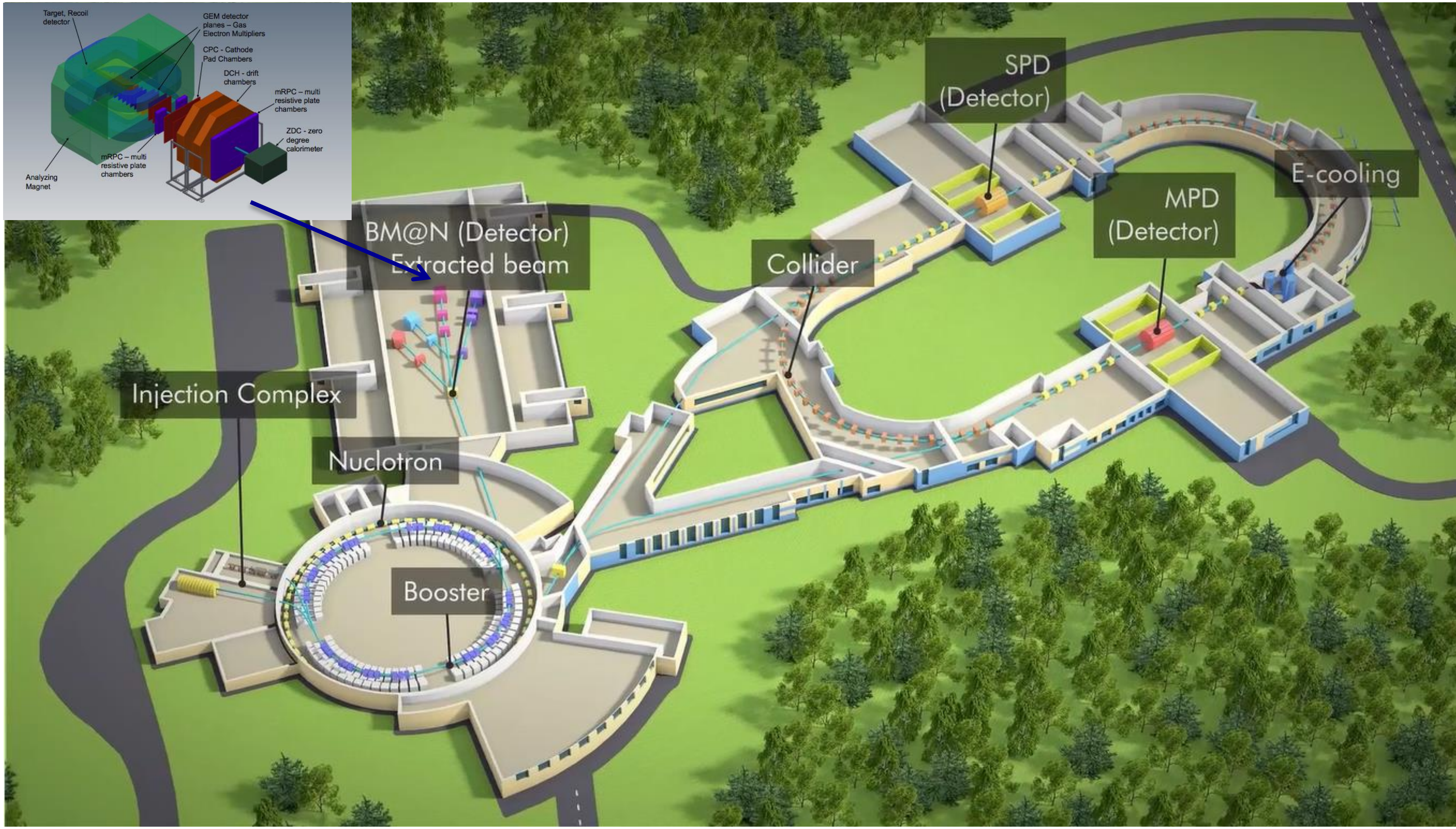
M.Kapishin

for the BM@N Collaboration



NICA Heavy Ion Complex

BM@N: heavy ion energy 1 - 4.5 GeV/n, beams: p to Au, Intensity ~few 10^6 /s (Au)



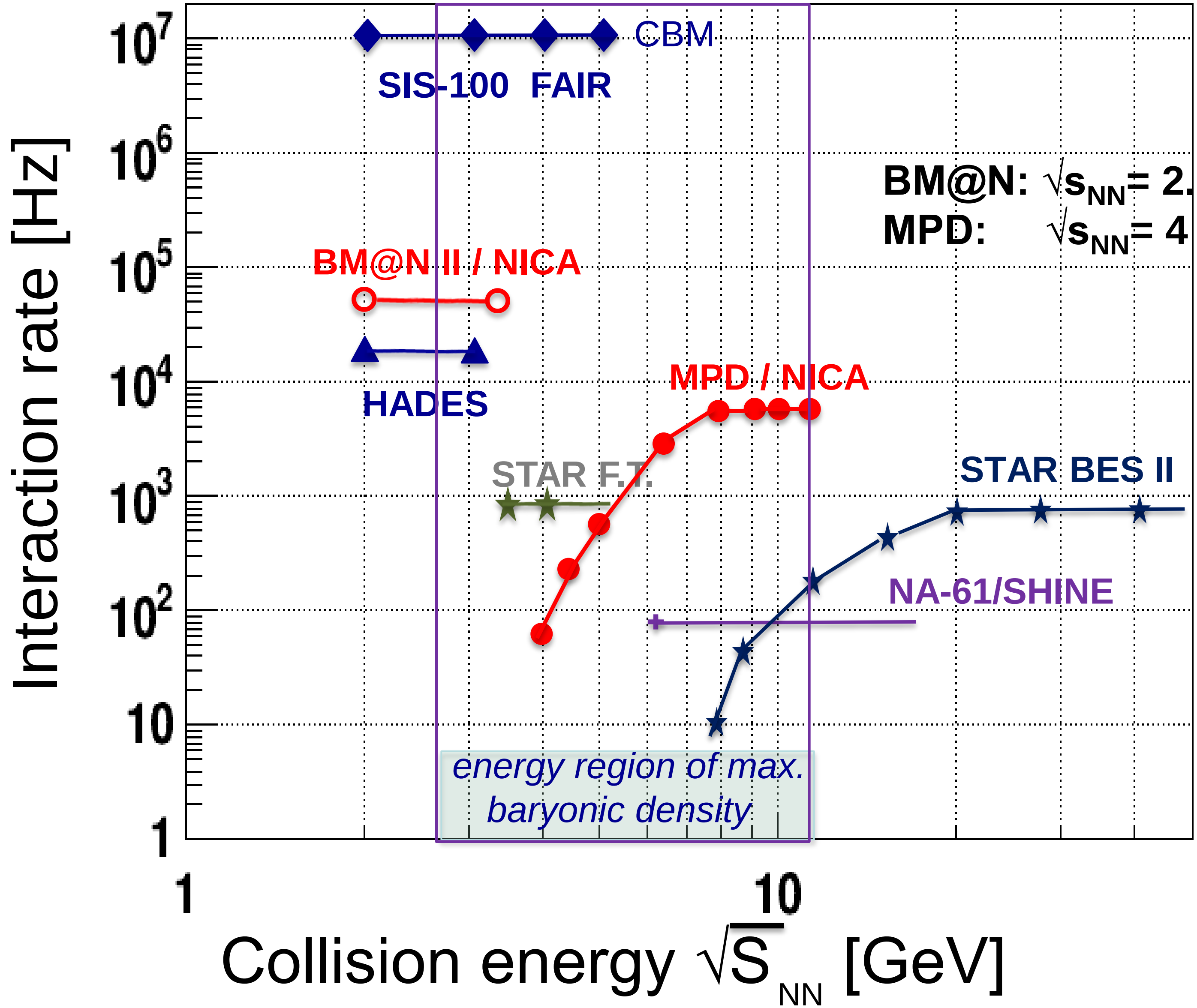
Three meetings on formation of the MPD and BM@N Collaborations

carried out in Dubna in 2018 and April 2019

Next BM@N meeting in October 2019

BM@N Collaboration: 21 Institutions from 11 countries, 230 participants

Heavy Ion Collision Experiments



BM@N: $\sqrt{s_{NN}}$= 2.3 - 3.5 GeV
MPD: $\sqrt{s_{NN}}$= 4 - 11 GeV

Physics possibilities at the Nuclotron

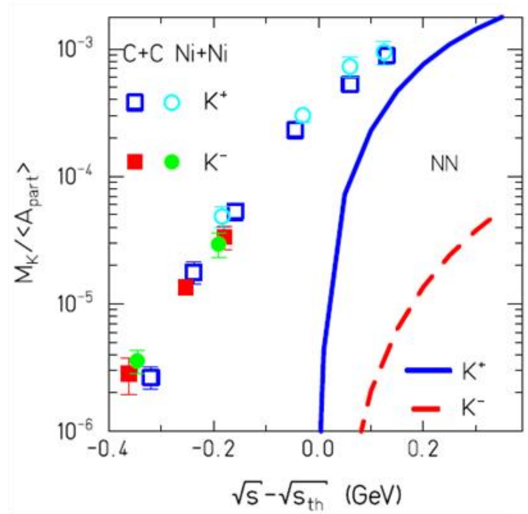
I. In A+A collisions at Nuclotron energies:

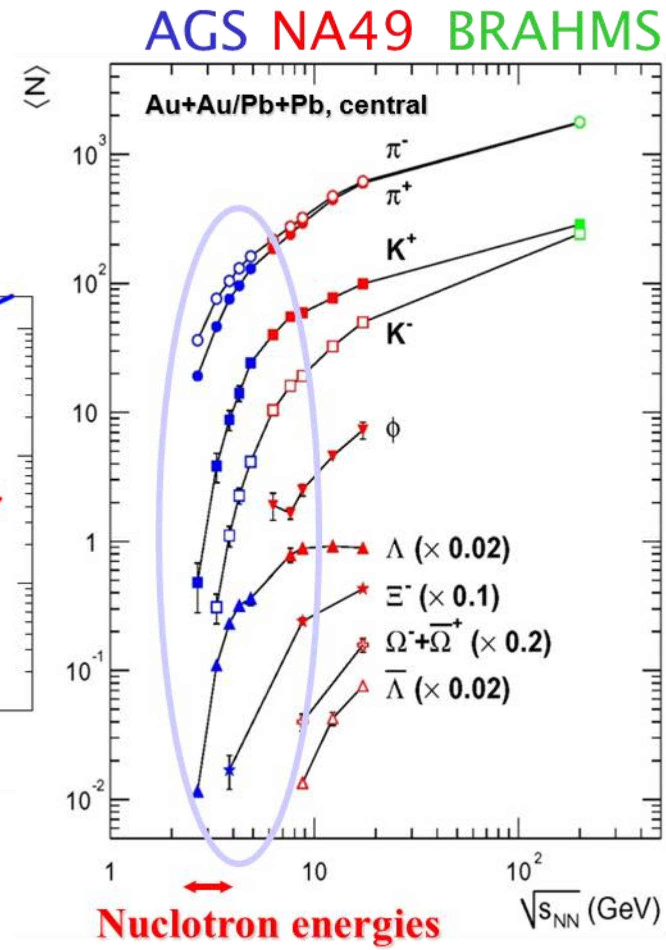
❑ **Opening thresholds for strange and multi-strange hyperon production**

➔ **strangeness at threshold**

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

► **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

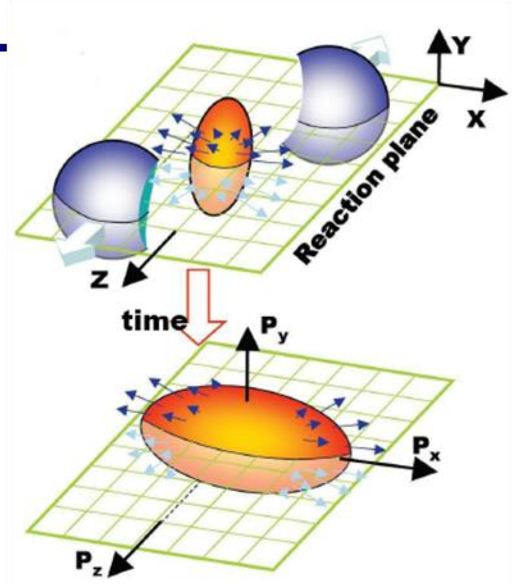
Heavy-ions A+A: Study of the EoS with strangeness

BM@N

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

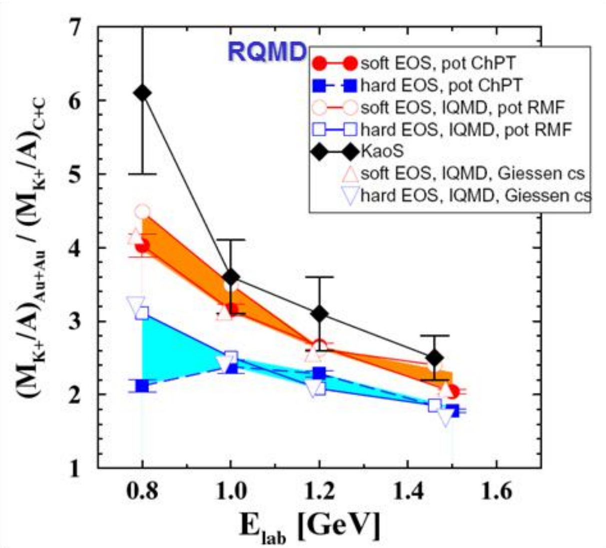
➔Observables sensitive to EoS:
collective flow (v_1,v_2,…)
particle ratios

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

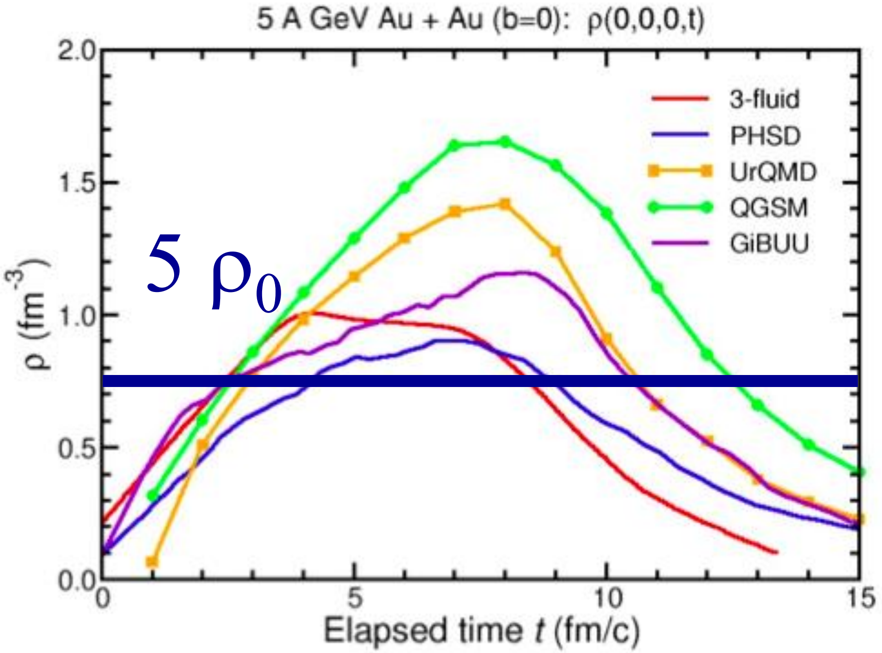


Explore high density baryonic matter

Baryonic densities in central Au+Au collisions

FAIR SIS-100 / Nuclotron

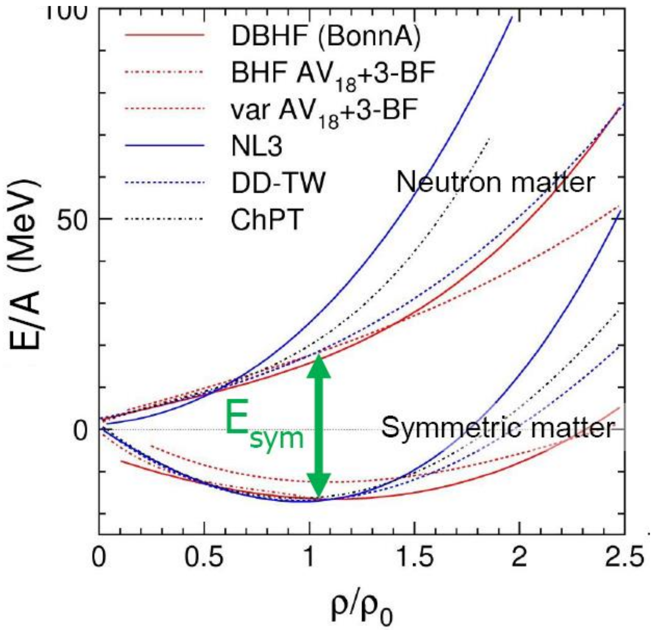
5 A GeV



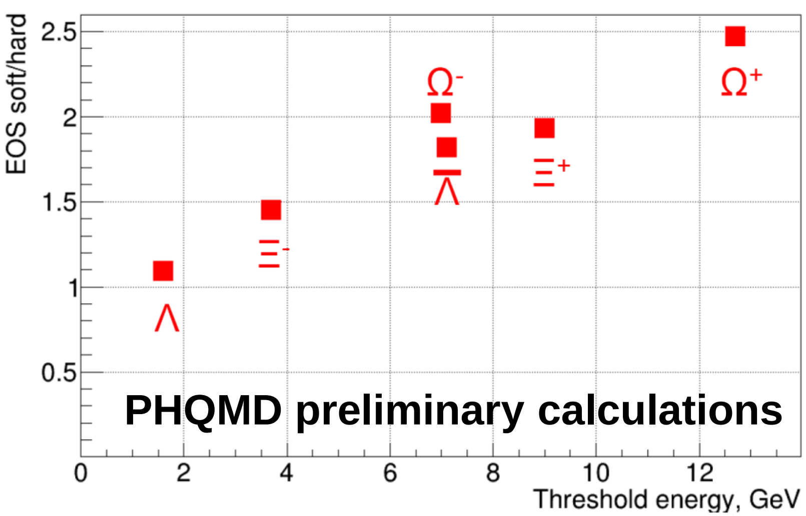
I.C. Arsene at al., Phys. Rev. C75 (2007) 34902.

EOS of symmetric and asymmetric nuclear matter

Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5



Hyperon yield in 4A GeV Au+Au:
soft EOS (K=240 MeV) / hard EOS (K=350) MeV



EOS: relation between density, pressure, temperature, energy and isospin asymmetry

$$E_A(\rho,\delta) = E_A(\rho,0)+E_{sym}(\rho)\cdot\delta^2$$

with $\delta= (\rho_n-\rho_p)/\rho$

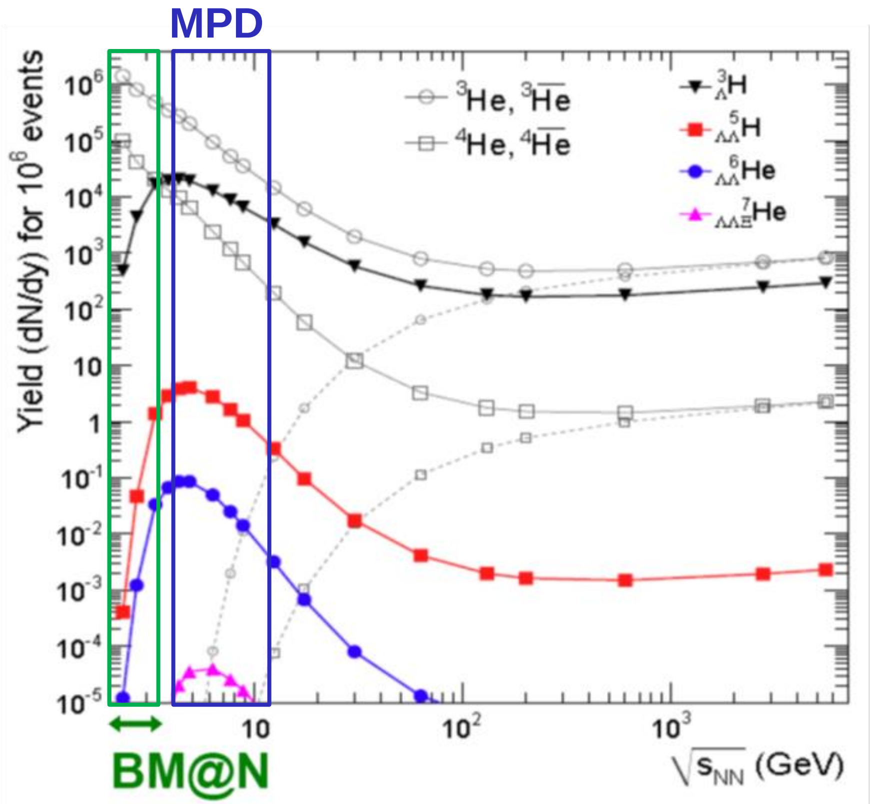
Curvature defined by nuclear incompressibility: $K = 9\rho^2\ \delta^2(E/A)/\delta\rho^2$

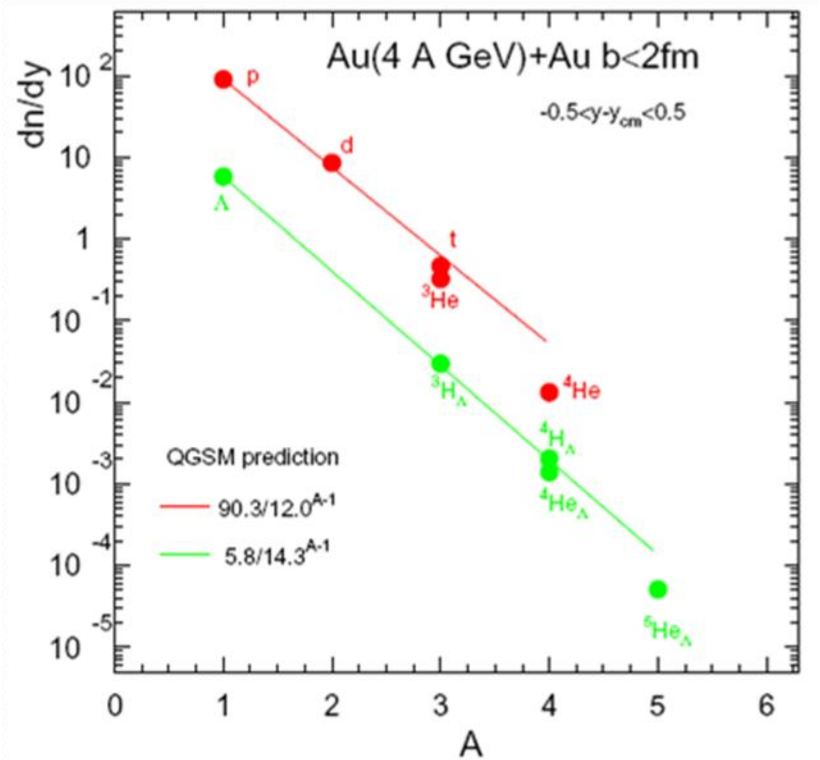
►Study symmetric matter EOS at ρ=3-5 ρ^0
→ elliptic flow of protons, mesons and hyperons
→ sub-threshold production of strange mesons and hyperons

►Constrain symmetry energy E_{sym}
→ elliptic flow of neutrons vs protons
→ sub-threshold production of particles with opposite isospin

Heavy-ions A+A: Hypernuclei production

MPD





- **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 search of hyper-nuclei

Nuclotron and BM@N beam line

26 elements of magnetic optics:

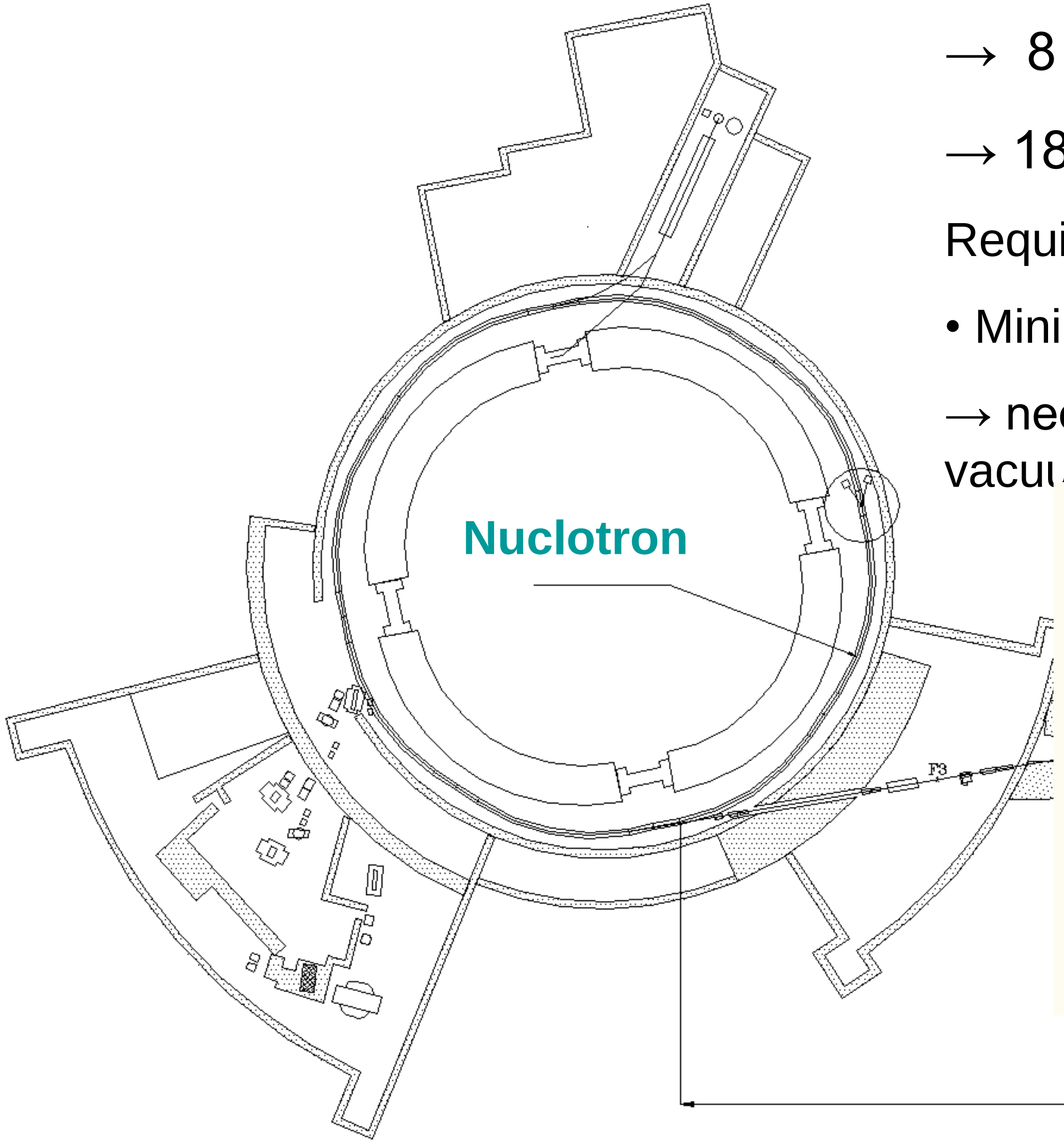
→ 8 dipole magnets

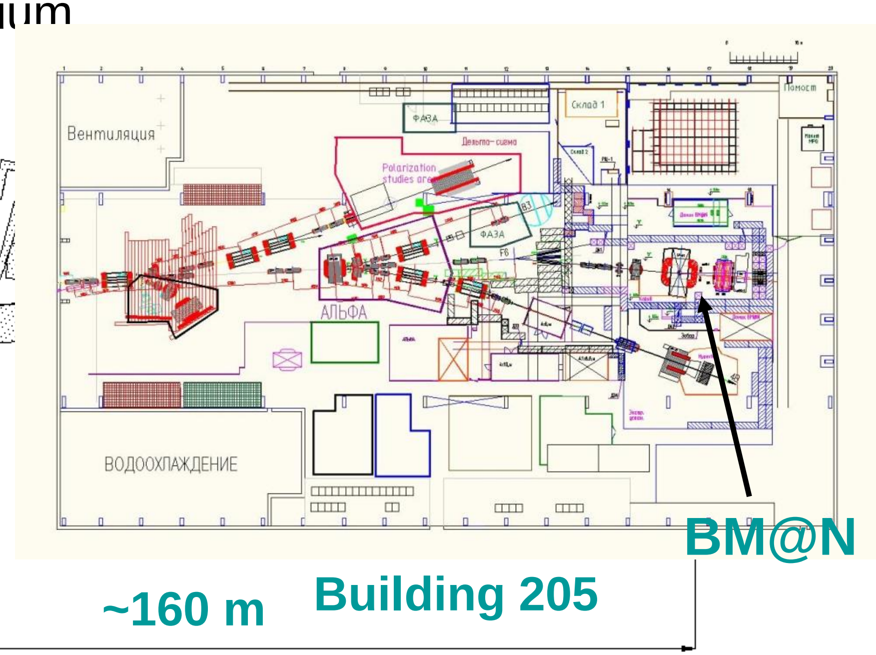
→ 18 quadruple lenses

Requirements for Au beam:

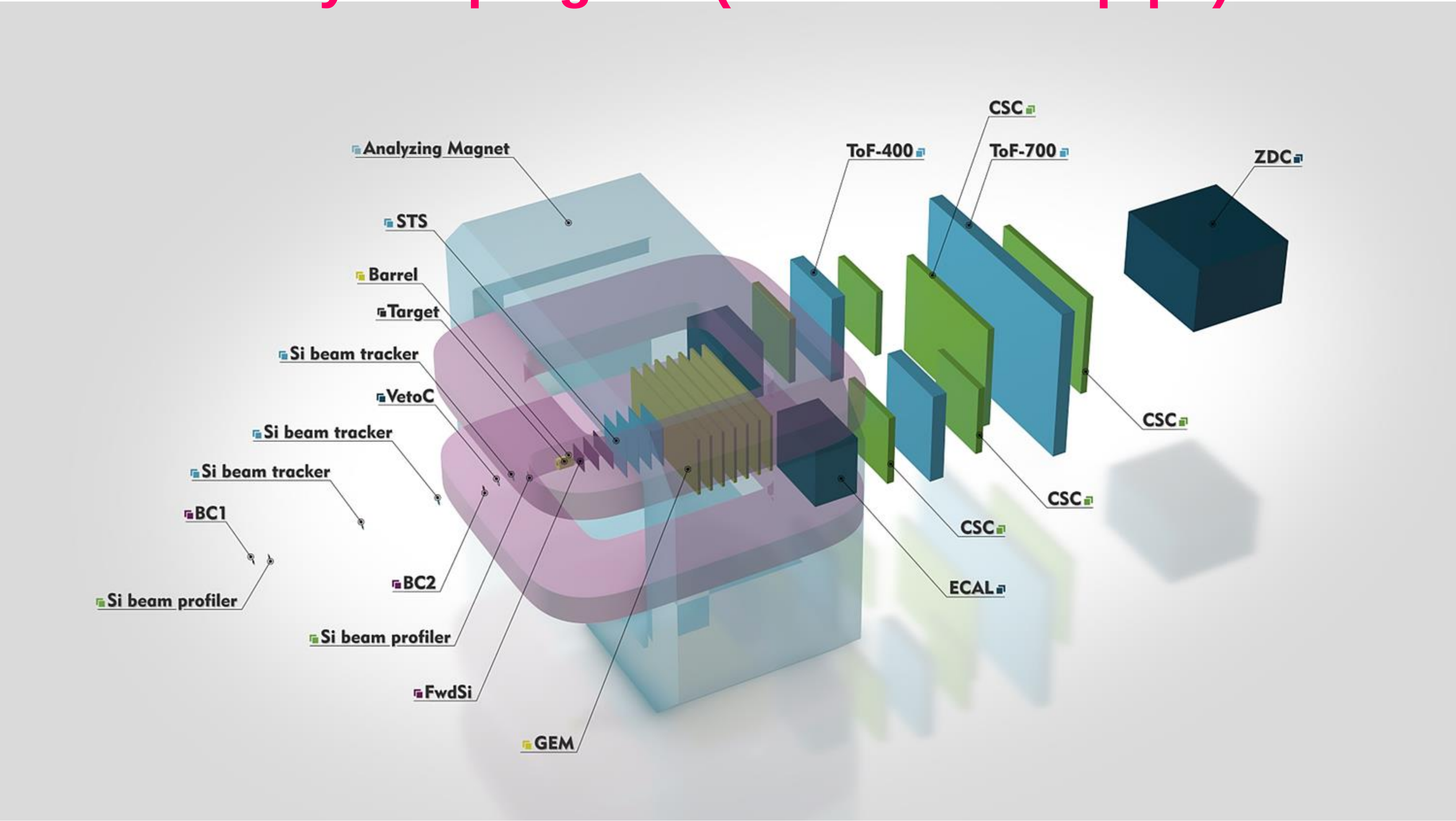
- Minimum dead material

→ need to replace air intervals / foils with vacuum





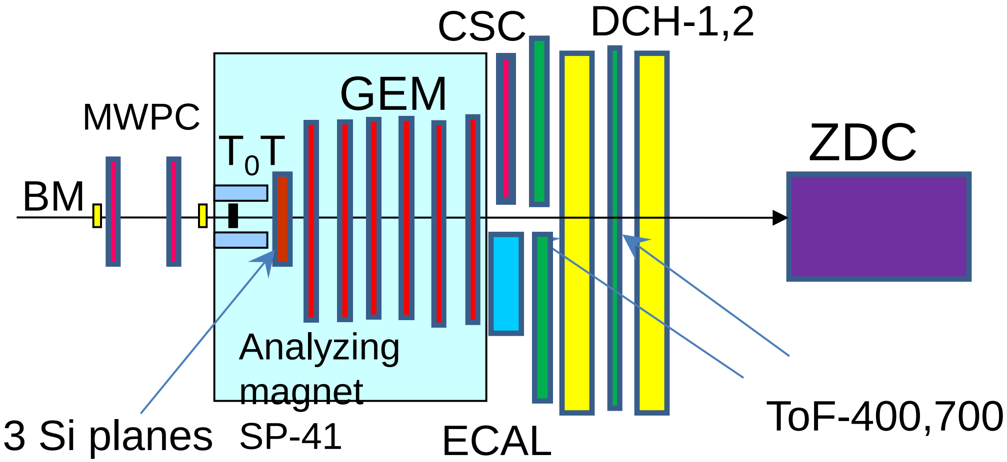
Configuration of BM@N detector for heavy ion program (without beampipe)



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

Ar beam, T_0= 3.2 GeV/n

Kr beam, T_0= 2.4 (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**
  → Partial coverage of BM@N design configuration

Program:

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

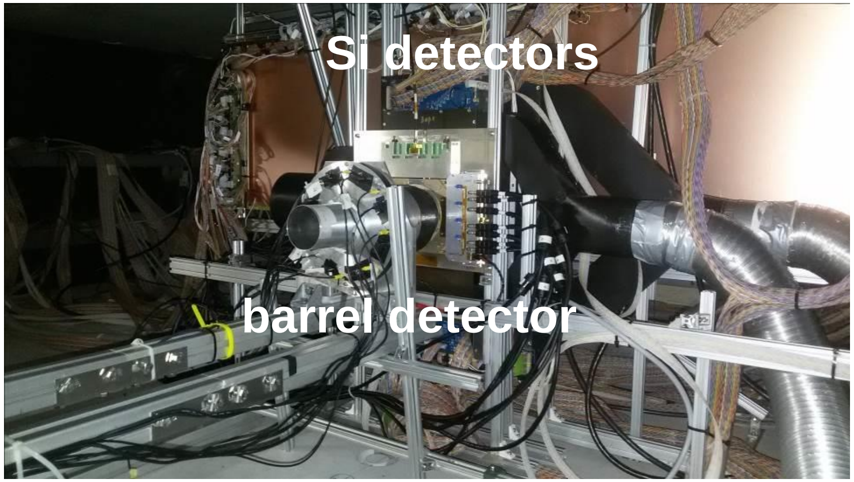
→ Hyperon production measured in central tracker (Si + GEM)

→ Charged particles and nuclear fragments identified with ToF

→ Gamma and multi-gamma states identified in ECAL

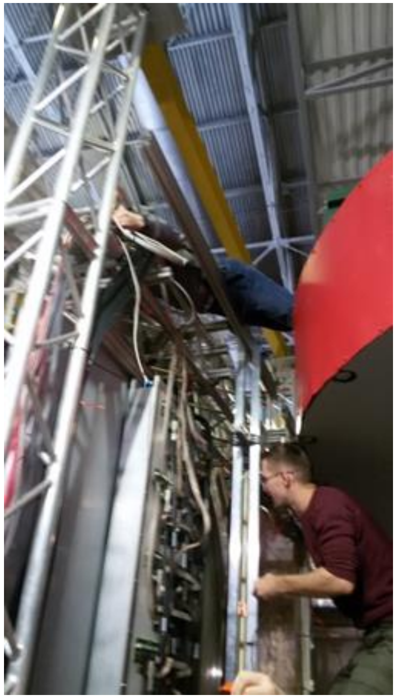
+ analyze data from previous technical run with Carbon beam of 3.5 - 4.5 GeV/n

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

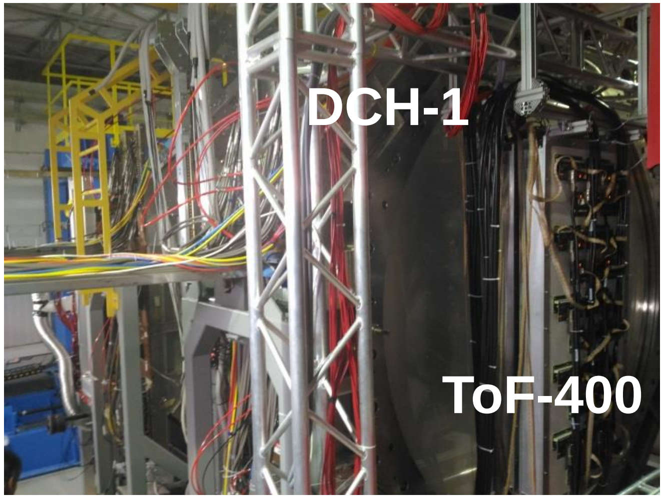


CSC chamber

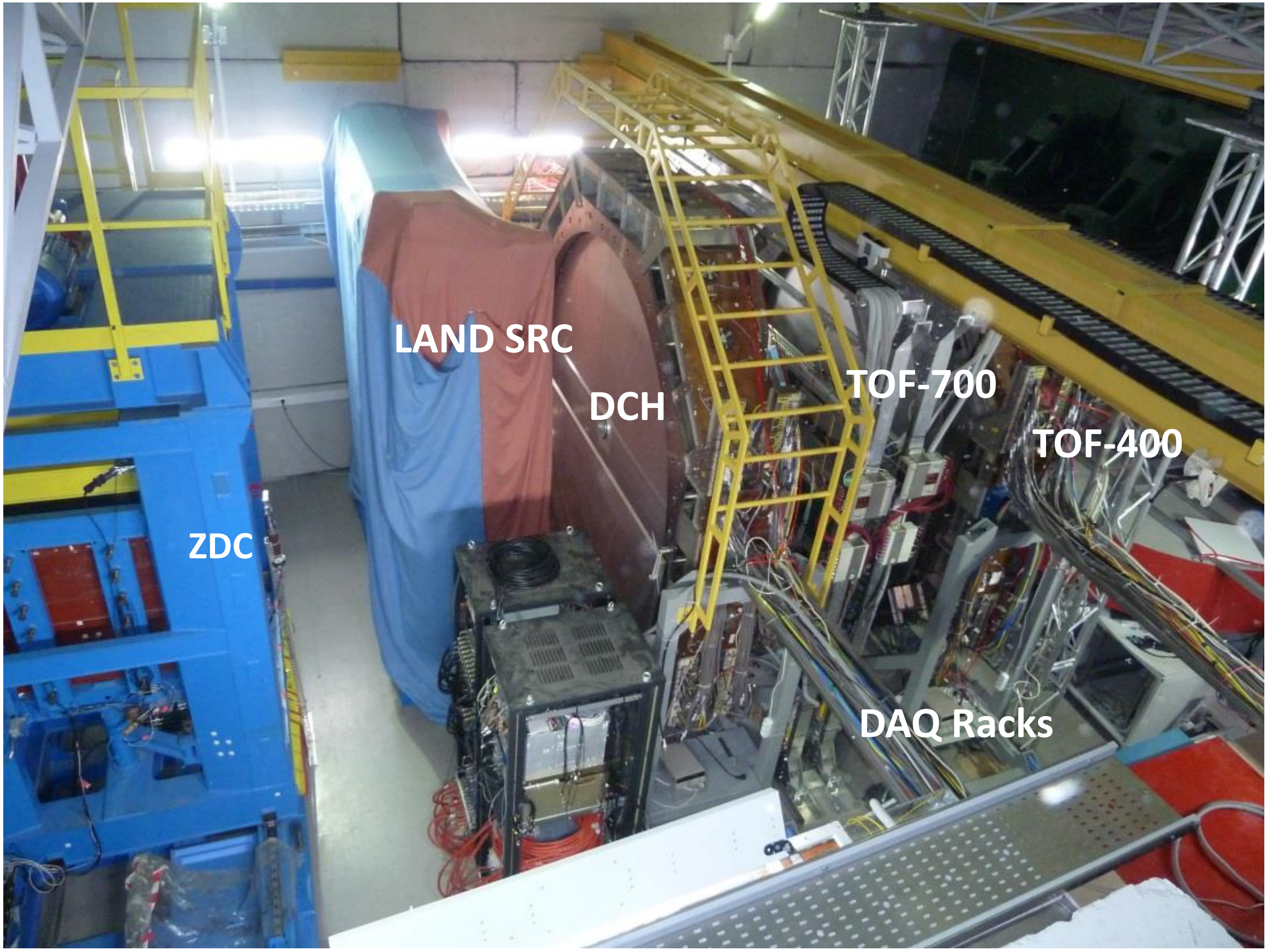
ToF-400 installation



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

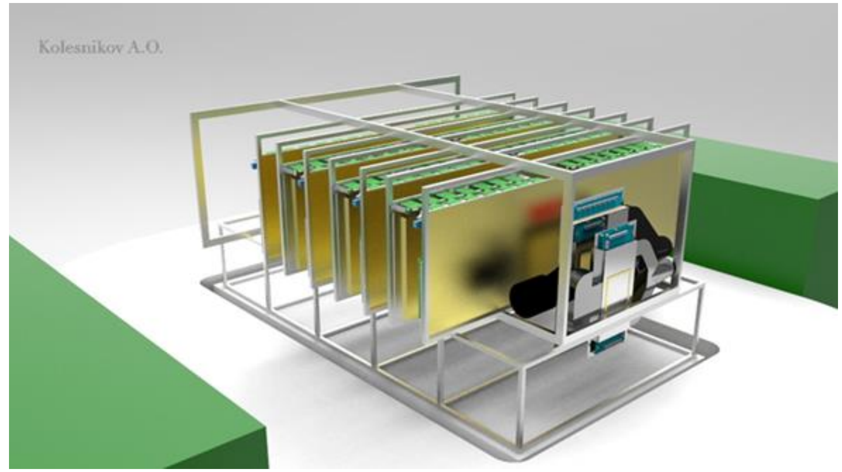


BM@N setup behind magnet, 2018

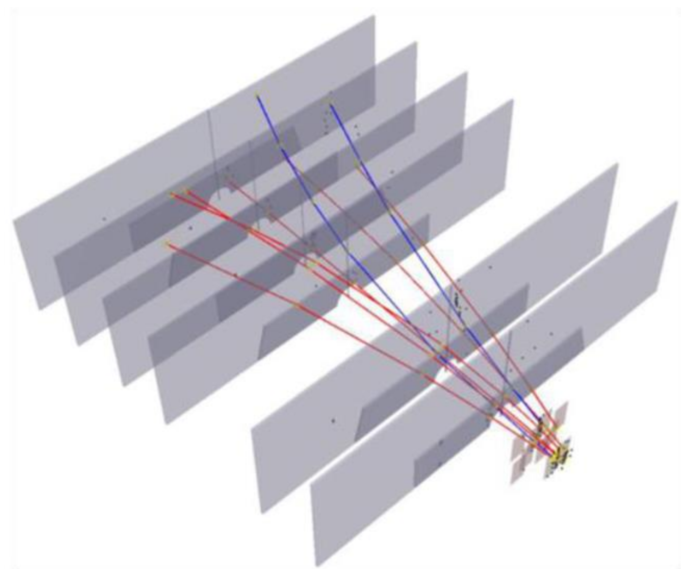


Silicon + GEM central tracker in Ar, Kr runs

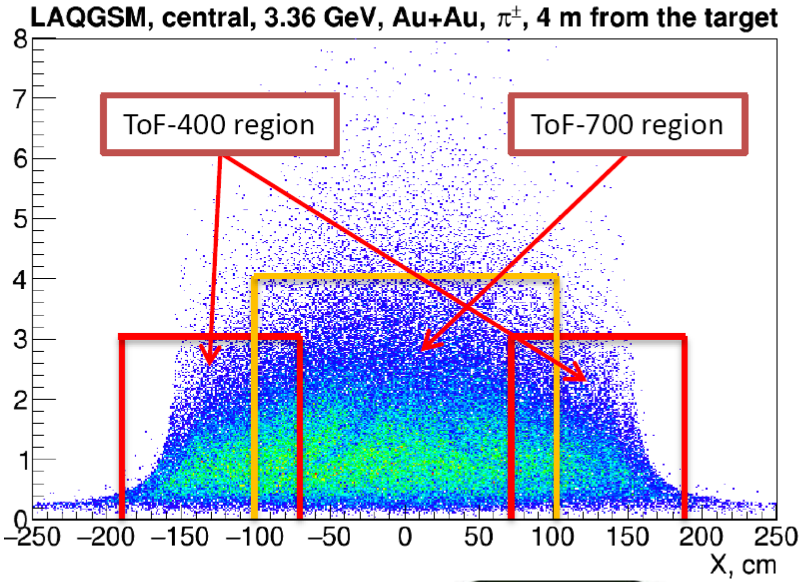
3 Forward Si detectors and 6 GEM detectors

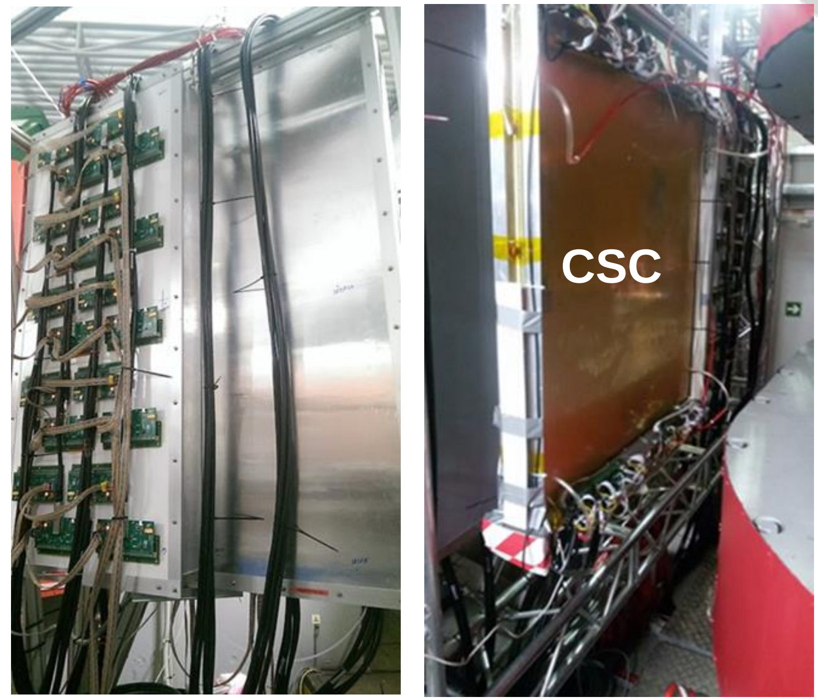


Ar+Cu interaction reconstructed in central tracker

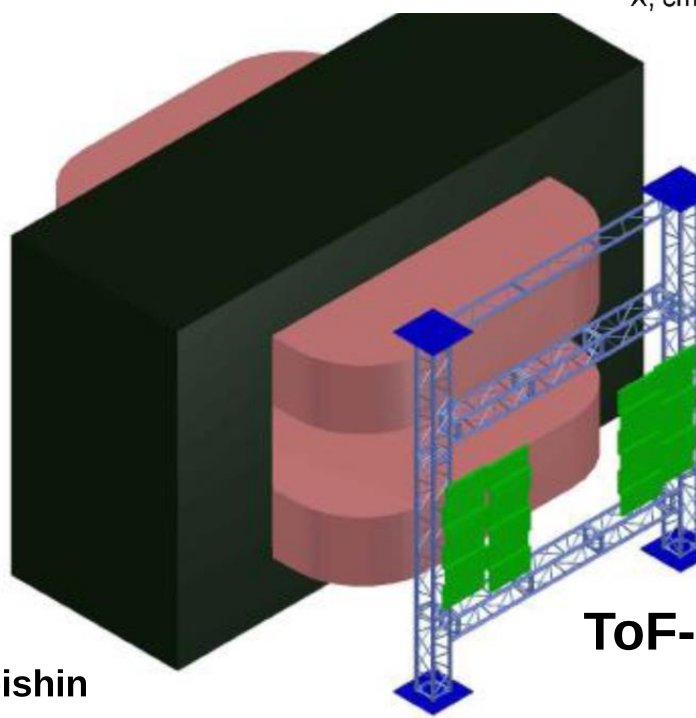


ToF-400 and ToF-700 based on mRPC

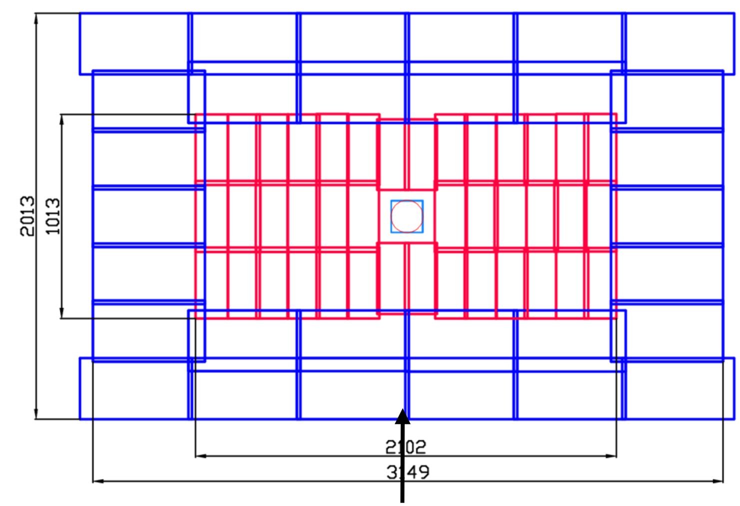




ToF-700 wall



ToF-400 wall



BM@N beam axis

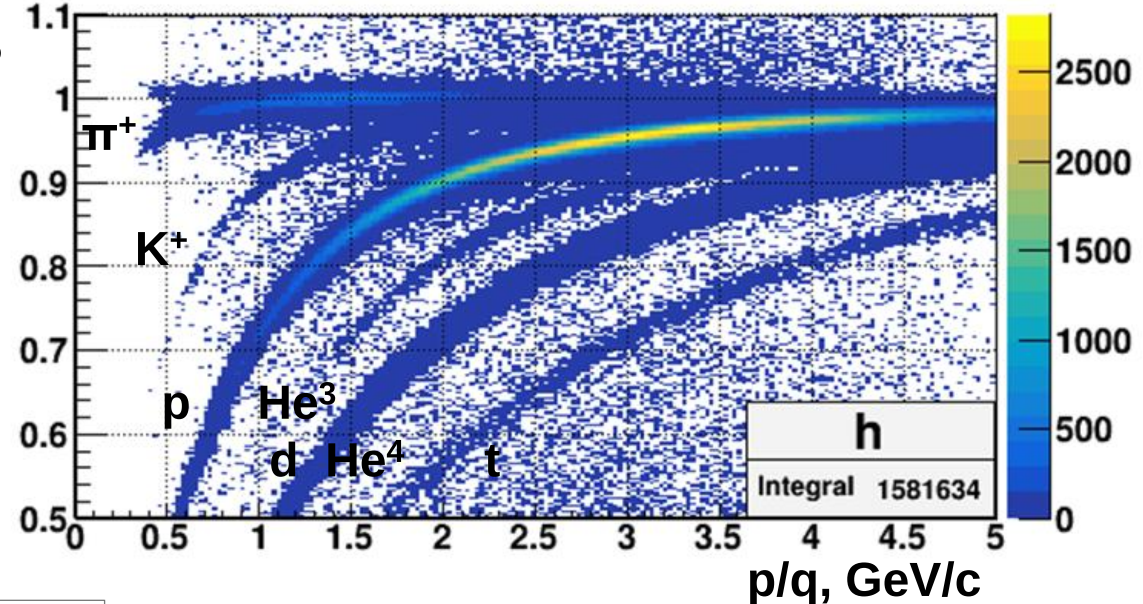
M.Kapishin

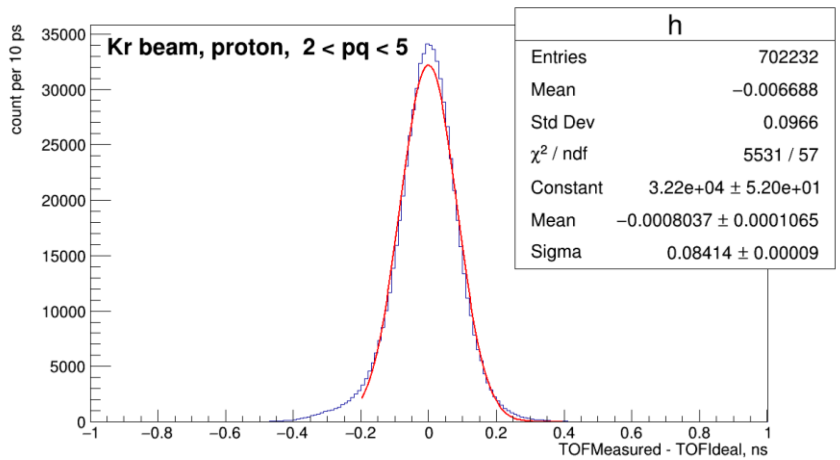
Status of TOF-400 particle identification

First expected results:

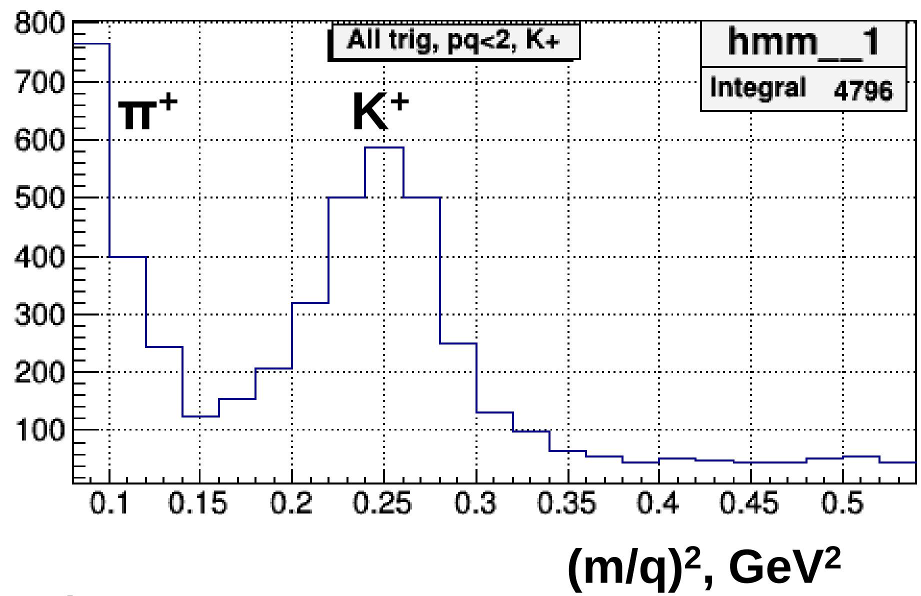
- Ratio of K^+/π^+ in Ar - nucleus interactions at beam kinetic energy of 3.2 AGeV
- Ratio of K^+/π^+ in Kr - nucleus interactions at beam kinetic energy of 2.4 AGeV

Ar beam , 3.2 AGeV , Ar + C,Al,Sn,Cu → X





Time resolution within proton band ~85 ps



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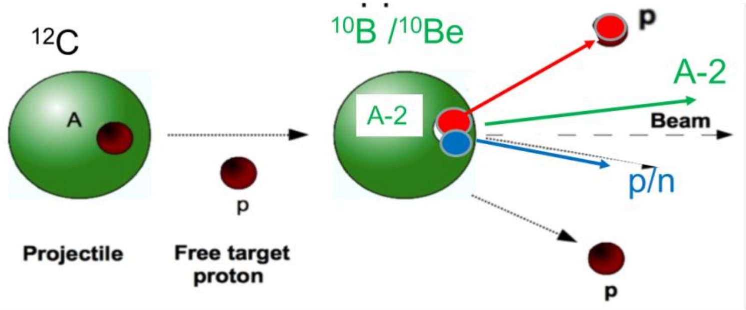
BMN & SRC program

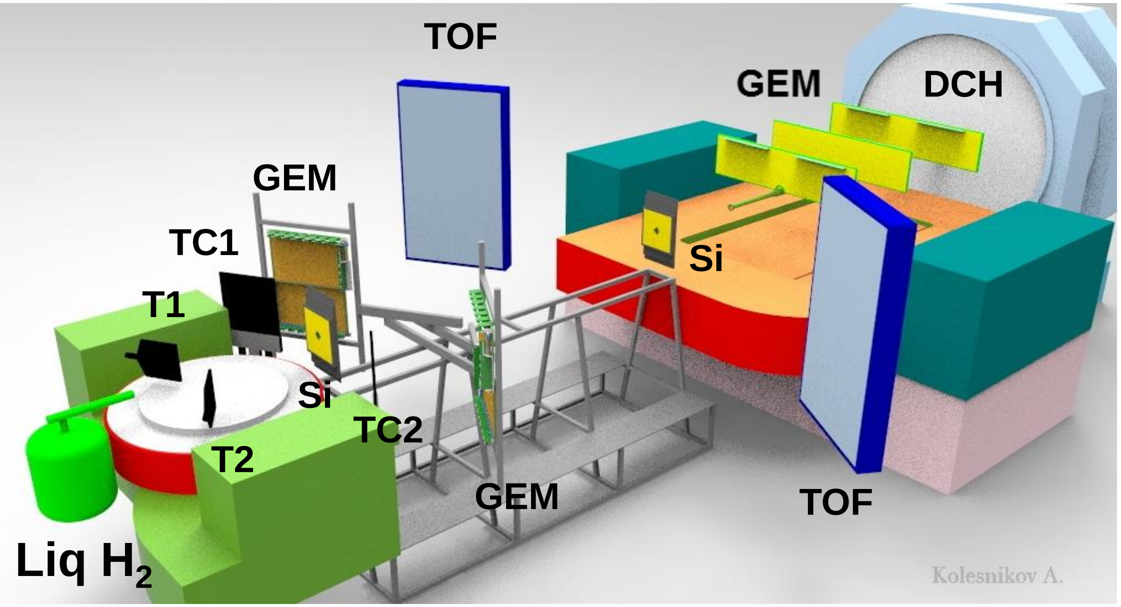
to study SRC with hard inverse kinematic reactions



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

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

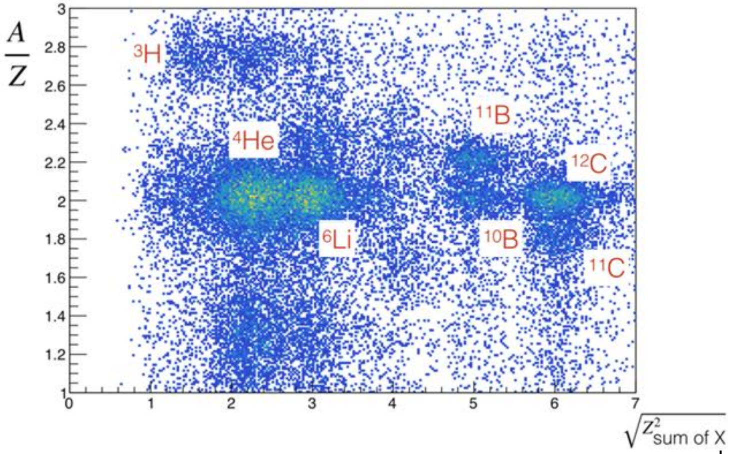
First SRC @ BMN run in March 2018



Objectives:

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

Identification of A-2 system

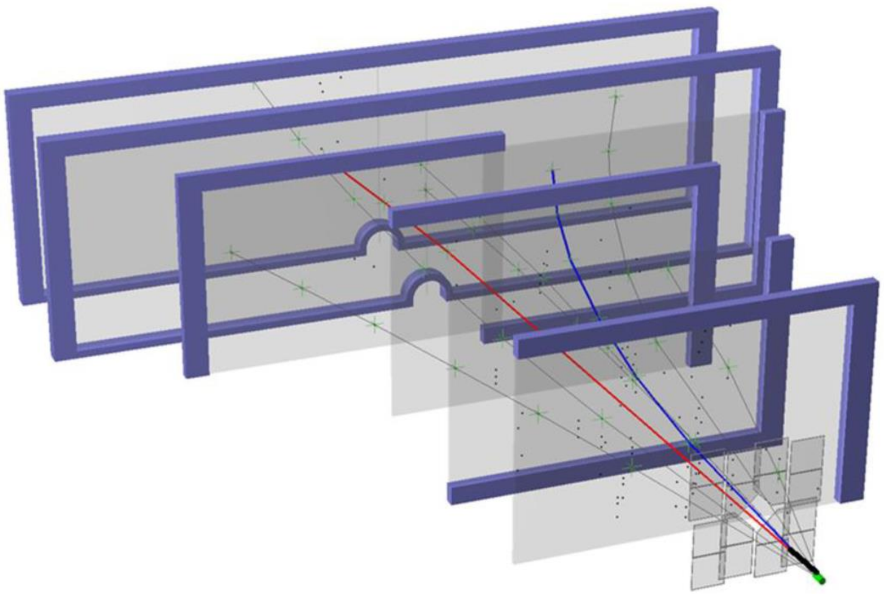


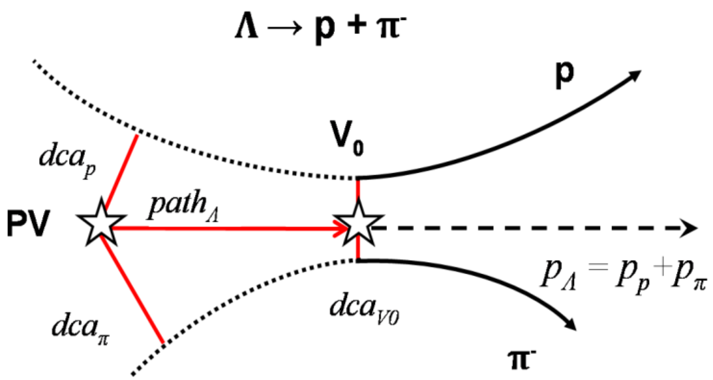
First expected result:

- Study A-2 residual system after SRC knockout

Λ hyperon production in 4A GeV Carbon-nucleus interactions

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



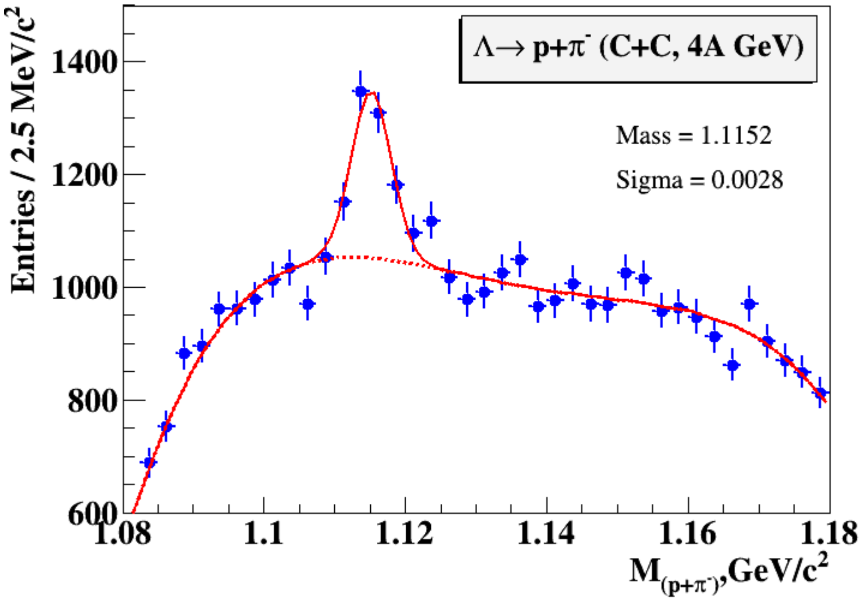


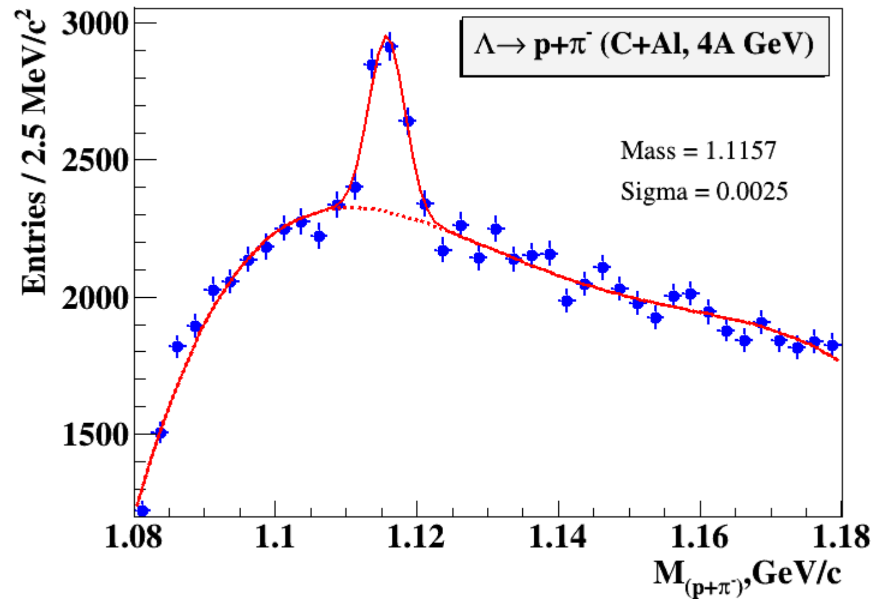
Event topology:

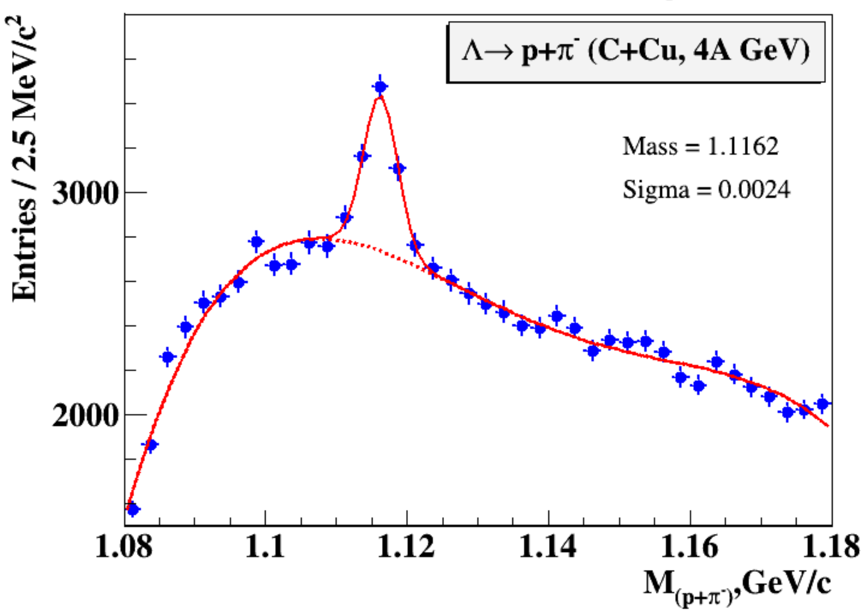
- ✓ PV – primary vertex
- ✓ V_0 – vertex of hyperon decay
- ✓ *dca* – distance of the closest approach
- ✓ *path* – decay length

Analysis without PID

Λ hyperon signals in 4A GeV Carbon-nucleus interactions





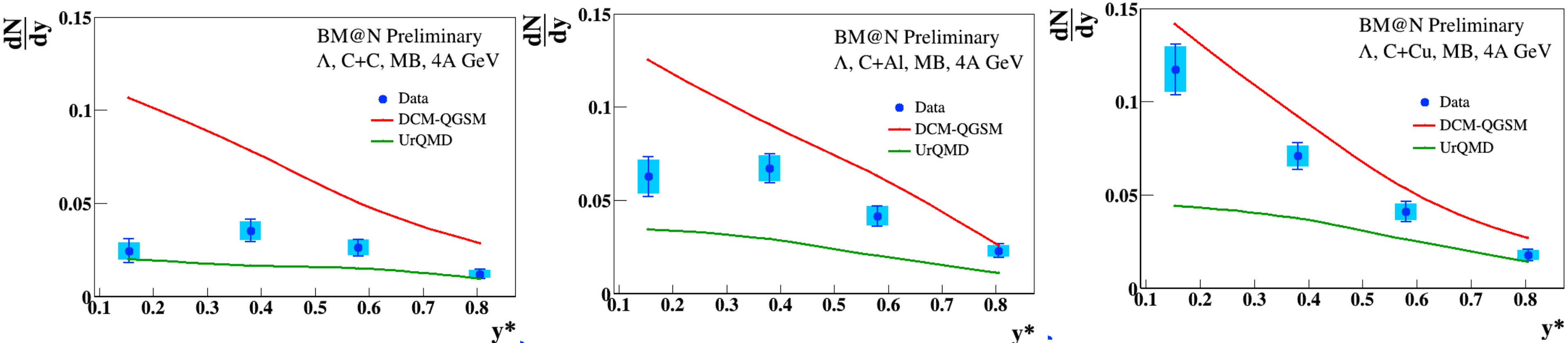


C beam 4 AGeV
C + C,Al,Cu → Λ + X minimum bias
Λ signal width 2.4 – 3 MeV

C+C: 4.6M triggers
C+Al: 5.3M triggers
C+Cu: 5.3M triggers

2.5 days of data taking

Λ hyperon yield in 4A GeV Carbon-nucleus min bias interactions



measured kinematic range $0.1<p_T<1.05$ GeV/c, $0.03<y^*<0.93$
data are corrected for acceptance and reconstruction efficiency

- **Yield of Λ in C+C, C+Al, C+ Cu minimum bias interactions in dependence on rapidity y* in c.m.s. $y^* = y_{lab}-1.17$**

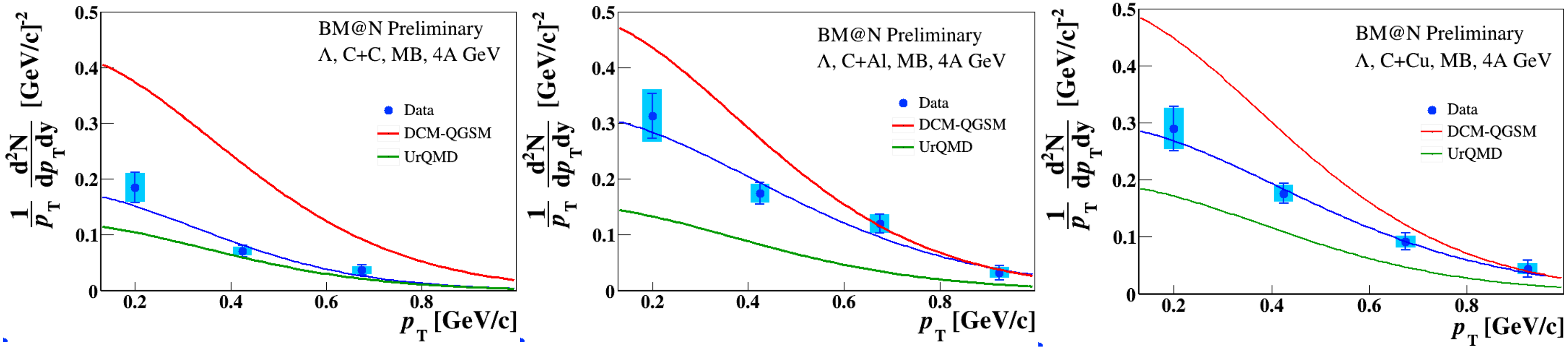
► **y* spectrum becomes softer with increase of target atomic weight**

- **Data compared with predictions of DCM-QGSM and UrQMD models**

► **DCM-QGSM overestimates data in C+C interactions, but more compatible with data measured with heavier targets (C+Cu)**

► **UrQMD predictions are below data for heavier targets, but in better agreement for C+C**

Λ hyperon invariant p_T spectra in 4A GeV Carbon-nucleus interactions



- **Fit of invariant p_T spectra of Λ yields in C+C, C+Al, C+Cu minimum bias interactions by function:**

$$1/p_T \cdot d^2N/dp_T dy = A \cdot exp(-(m_T - m_\Lambda)/T), \quad m_T = \sqrt{(m_\Lambda^2 + p_T^2)}$$

- **Inv slope *T* in comparison with predictions of DCM-QGSM and UrQMD models**

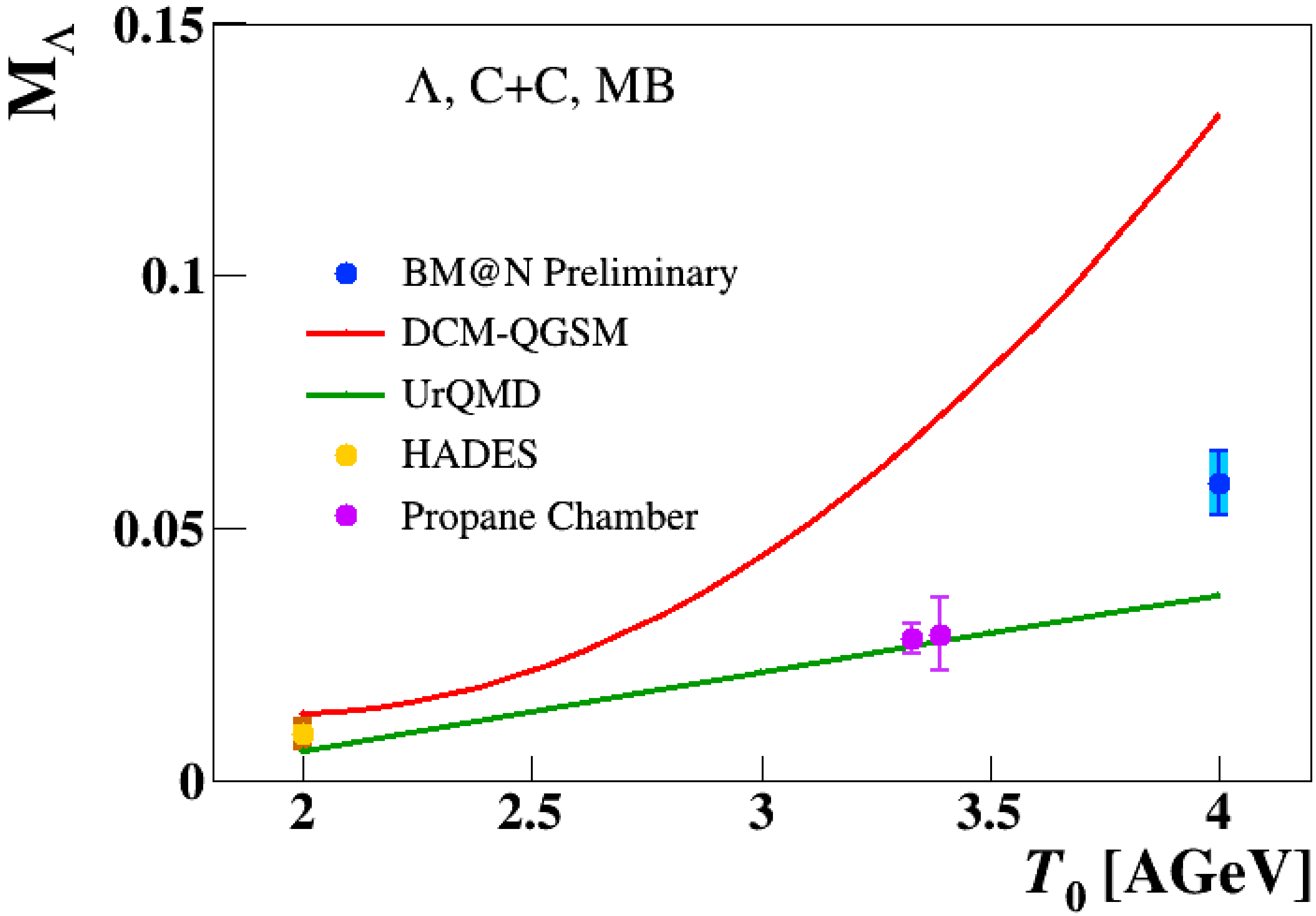
	T [MeV] *C+C*	*T* [MeV] *C+Al*	*T* [MeV] *C+Cu*
BM@N Preliminary	**98 ± 24 ± 25**	**157 ± 24 ± 12**	**160 ± 27 ± 21**
DCM-QGSM	122	129	131
UrQMD	107	127	132

Λ hyperon yield and cross section in 4 AGeV Carbon-nucleus interactions

	C+C	*C+Al*	*C+Cu*
Λ yield in the measured kinematic range $0.1<p_T<1.05$ GeV/c, $0.03<y^*<0.93$	0.0214 ± 0.0023 ± 0.0024	0.0431 ± 0.0034 ± 0.0035	0.0561 ± 0.0039 ± 0.0047
Λ yield in the full kinematic range, M_Λ [1)] N part DCM-QGSM	0.0589 ± 0.0063 ± 0.0065 9	0.133 ± 0.010 ± 0.011 13.4	0.239 ± 0.017 ± 0.020 23
Λ min bias cross section σ_Λ [2)] [mb]	48.9 ± 5.2 ± 5.1	167 ± 13 ± 13	427 ± 30 ± 29

1) Used averaged extrapolation factor from DCM-QGSM and UrQMD models
2) $\sigma_\Lambda = M_\Lambda \cdot \sigma_{inel}$

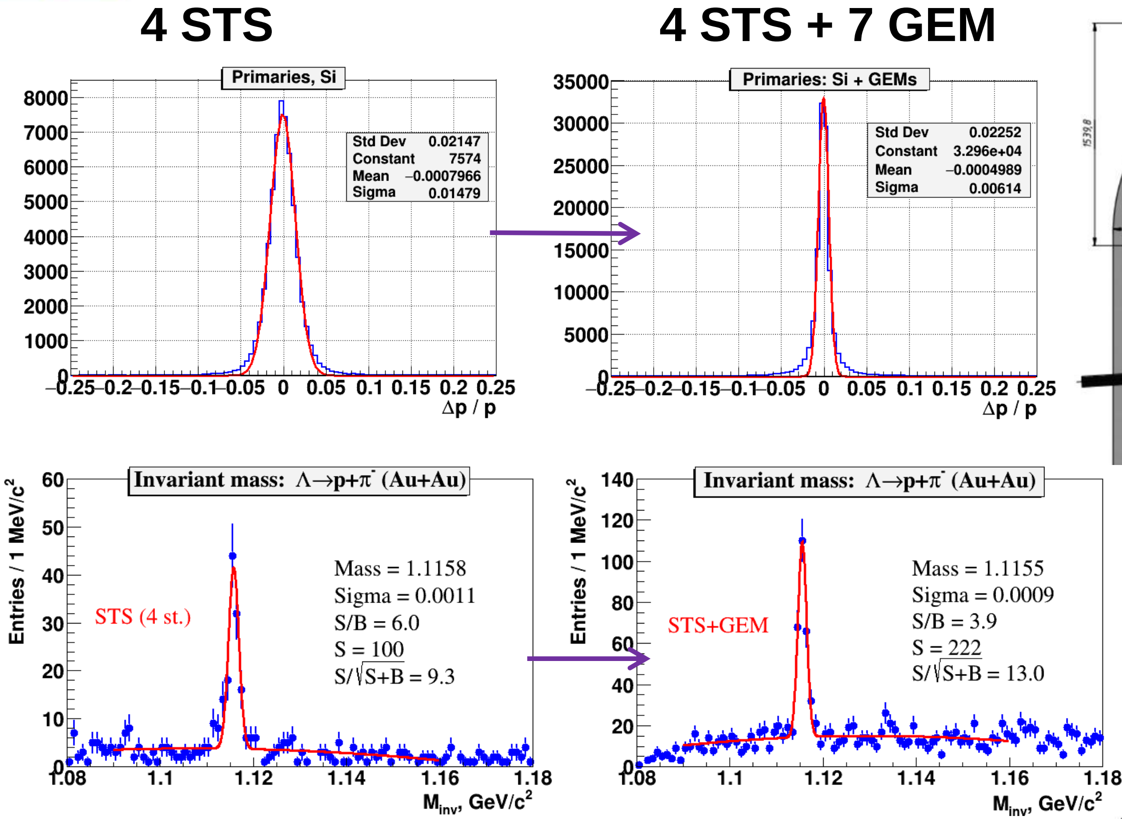
Energy dependence of Λ hyperon yields in minimum bias C+C interactions

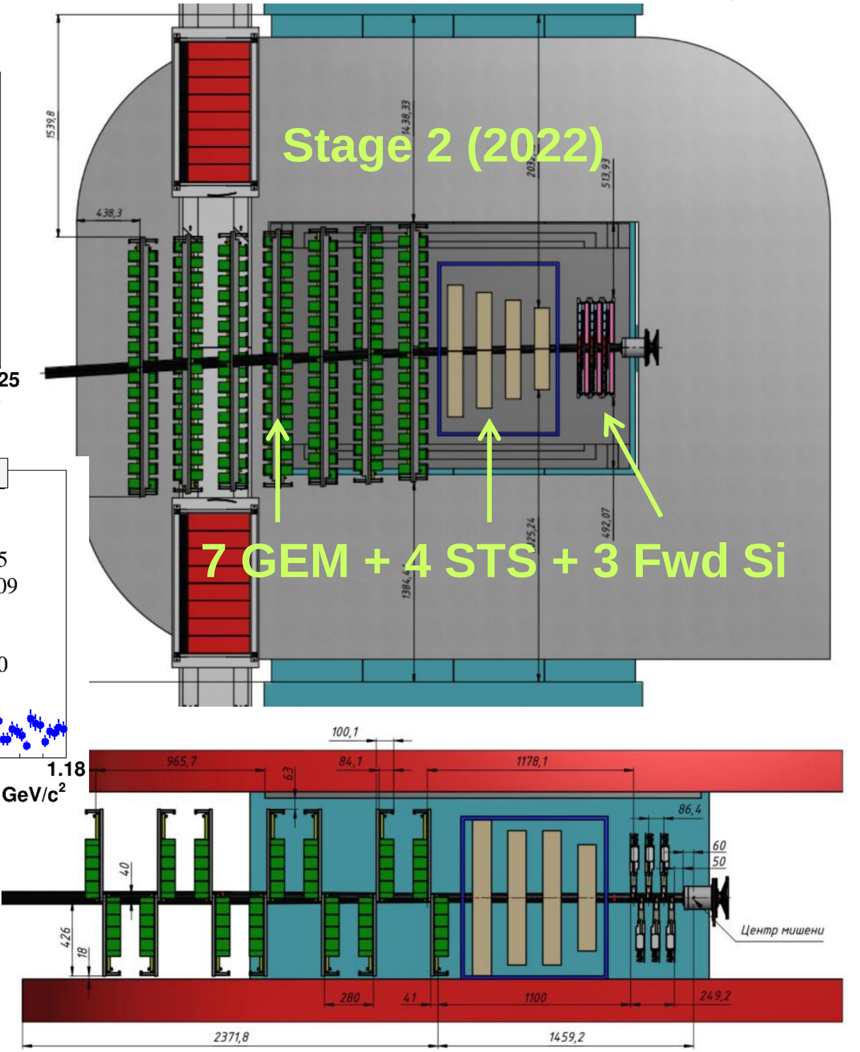


→ **add results for semi-central C+A interactions**

→ **add results for 3.5 and 4.5 AGeV Carbon beam data**

Forward Si, STS and GEM detectors





Hybrid STS + GEM tracker vs STS:
► 2 times increase in number of reconstructed tracks and Λ hyperons
►2 times better momentum resolution

For heavy ion beam intensities few 10^6 Hz
→ keep 4 STS + 7 GEM
→ fast FEE and readout electronics

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

Year	2016	2017 spring	2018 spring	fall 2020-2021	2022 and later
Beam	d(↑)	C	Ar,Kr, C(SRC)	C,Kr,Xe	up to Au
Max.intensity, Hz	0.5M	0.5M	0.5M	0.5M	2M
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 forward Si planes	7 GEM full planes + forward Si planes	7 GEM full planes + forward Si + large STS 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-18 and NICA/FAIR
- **BM@N technical runs performed** with carbon beam of T_0 = 3.5 - 4.5 AGeV, Ar beam of 3.2 AGeV and Kr beam of 2.4 (2.9) AGeV on fixed targets
- Measurement of **Short Range Correlations** performed with inverse kinematics: C beam + H_2 target
- First physics results obtained on Λ yields in C + C, Al, Cu interactions
- Reconstruction and analysis of interactions of Ar, Kr beams with targets and SRC data are progressing

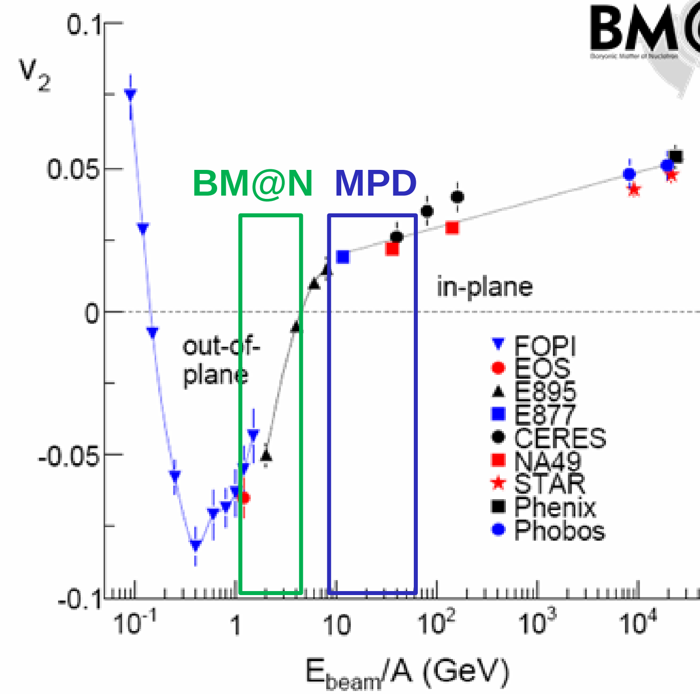
- **BM@N is on the way for heavy ion high intensity runs in 2020 and later:**
- Extend central tracker with large aperture STS silicon detectors in front of GEM setup (in collaboration with CBM)

Thank you
for attention!

Study of EoS: Collective flow of identified particles

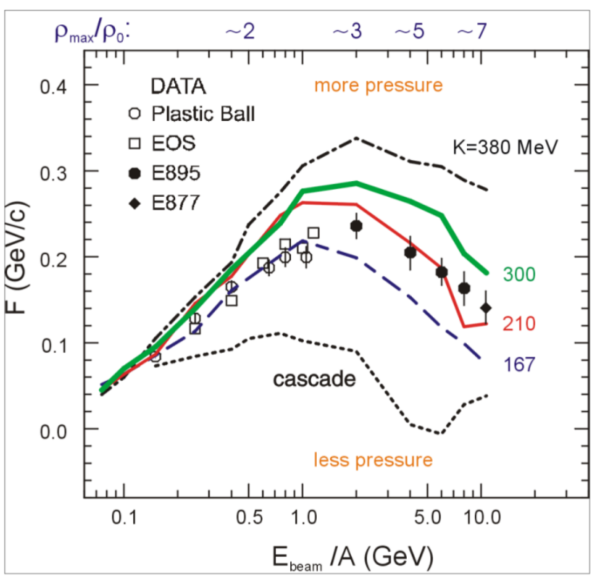
Azimuthal angle distribution:
$dN/d\varphi \propto (1 + 2v_1 \cos\varphi + 2v_2 \cos 2\varphi)$

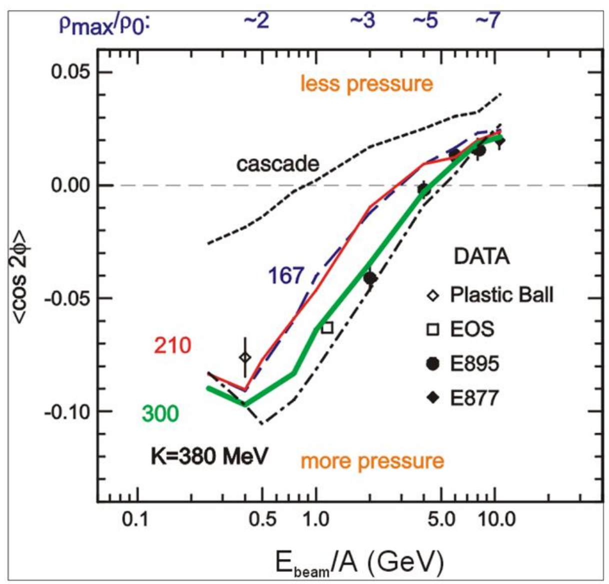
Nuclear incompressibility: $K = 9\rho^2\, \delta^2(E/A)/\delta\rho^2$



Proton flow in Au+Au collisions

in-plane flow ~ v_1 out-of-plane flow v_2





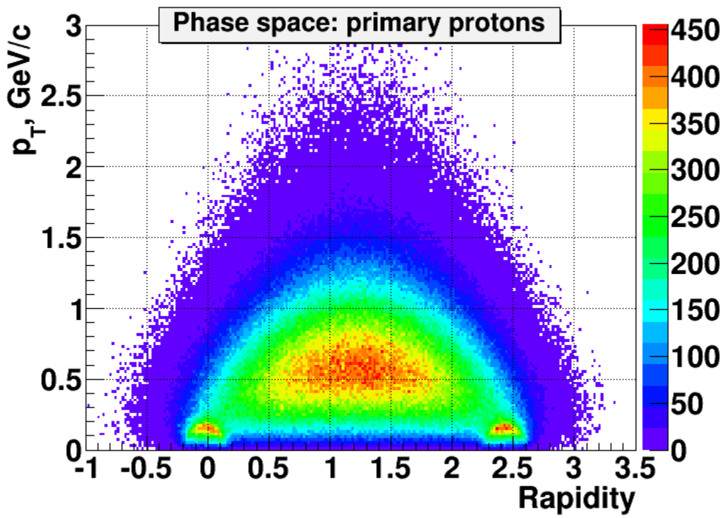
P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592

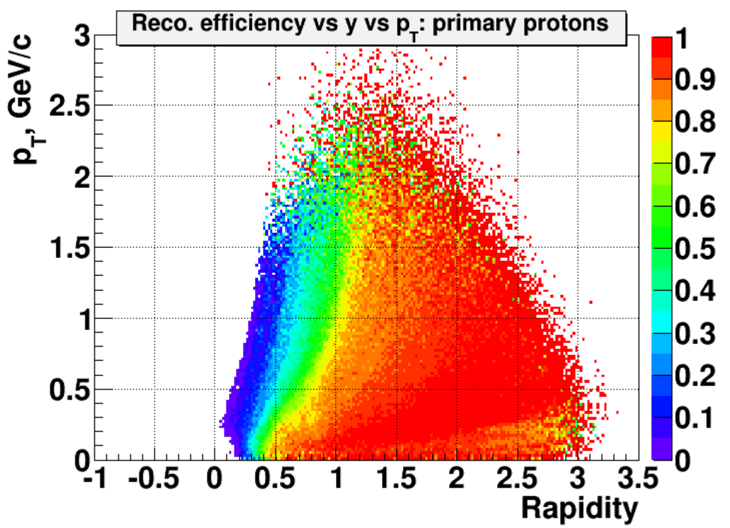
M.Kapishin

BM@N experiment

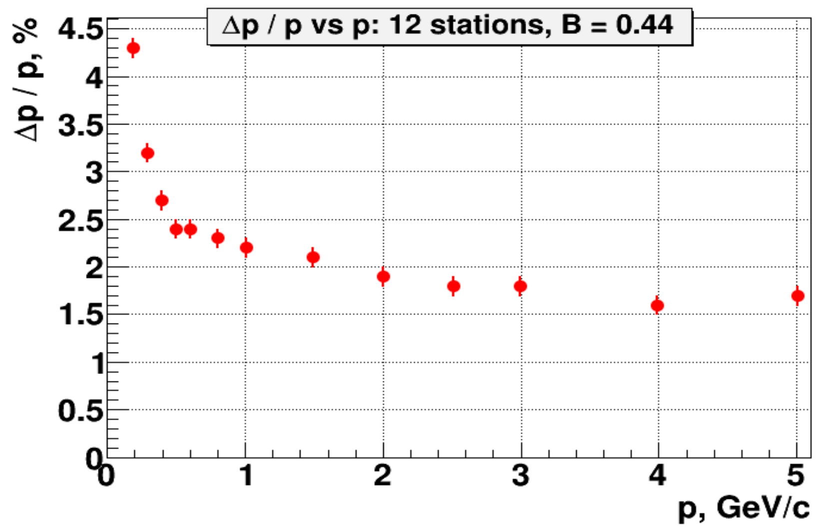
GEM tracker: acceptance / momentum resolution / detection efficiency

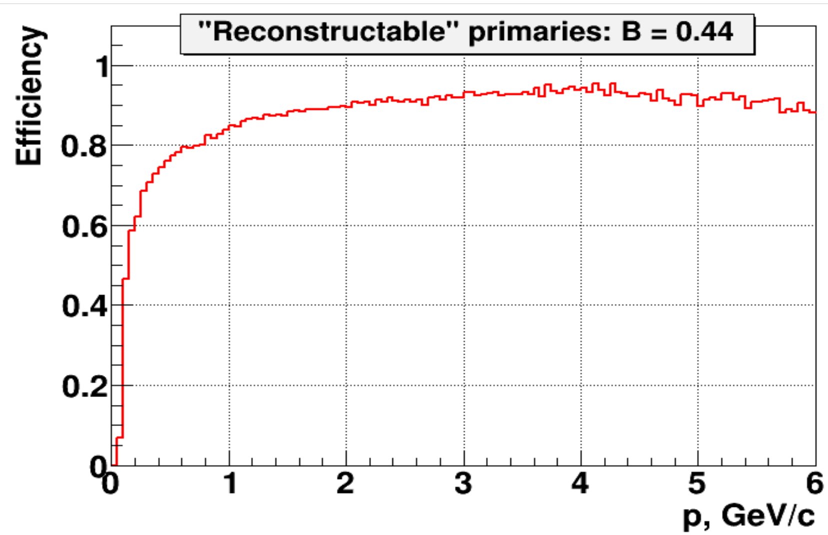
Phase space / acceptance to primary protons: Au+Au, 4.5 AGeV





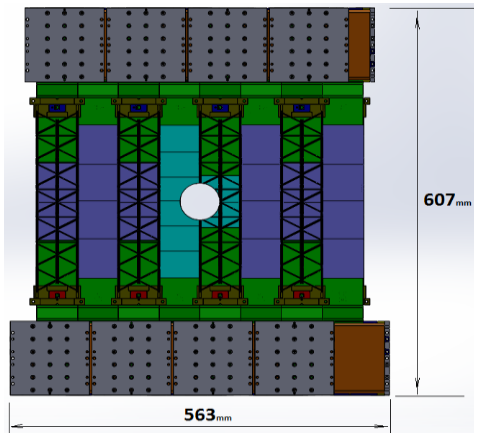
Momentum resolution / detection efficiency





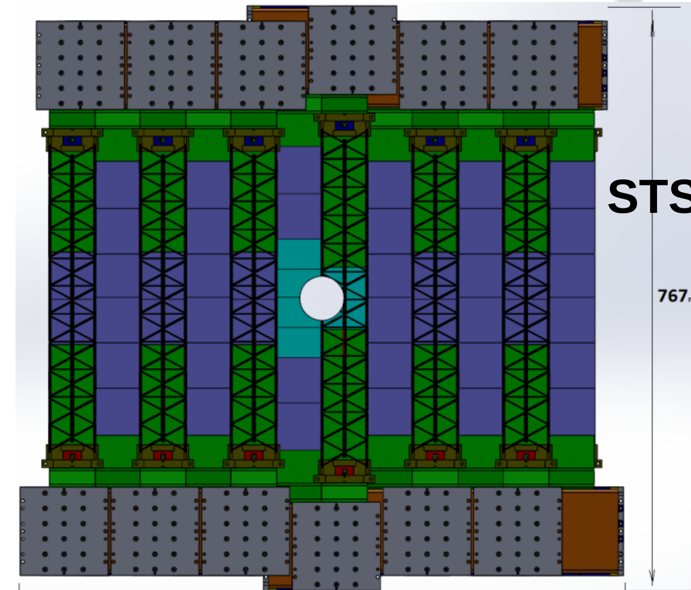
Upgrade of central tracker with CBM STS

STS-1

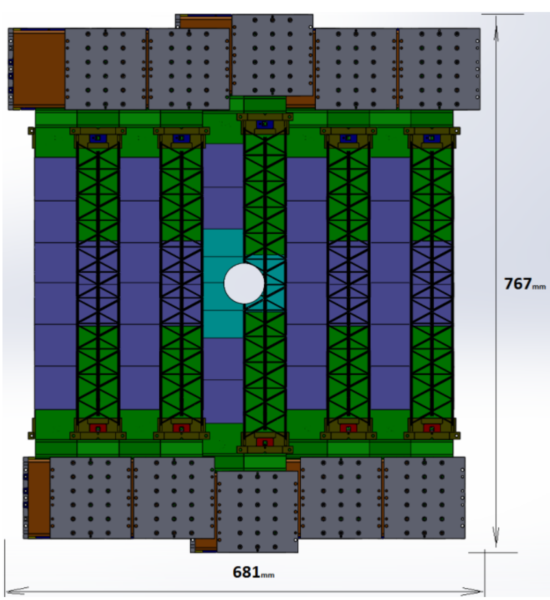


Team: LHEP JINR, MSU, GSI, Tübingen University

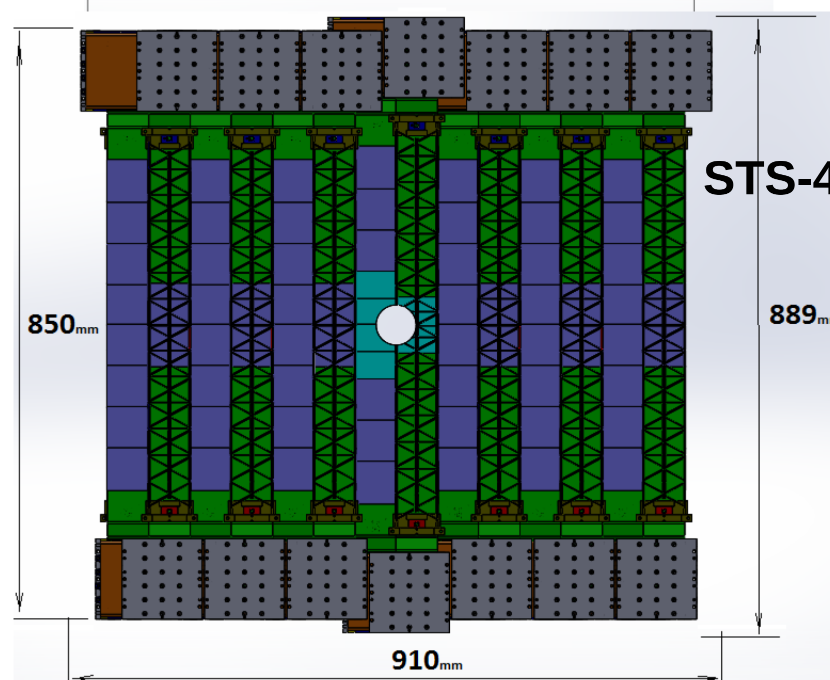
STS-3



STS-2

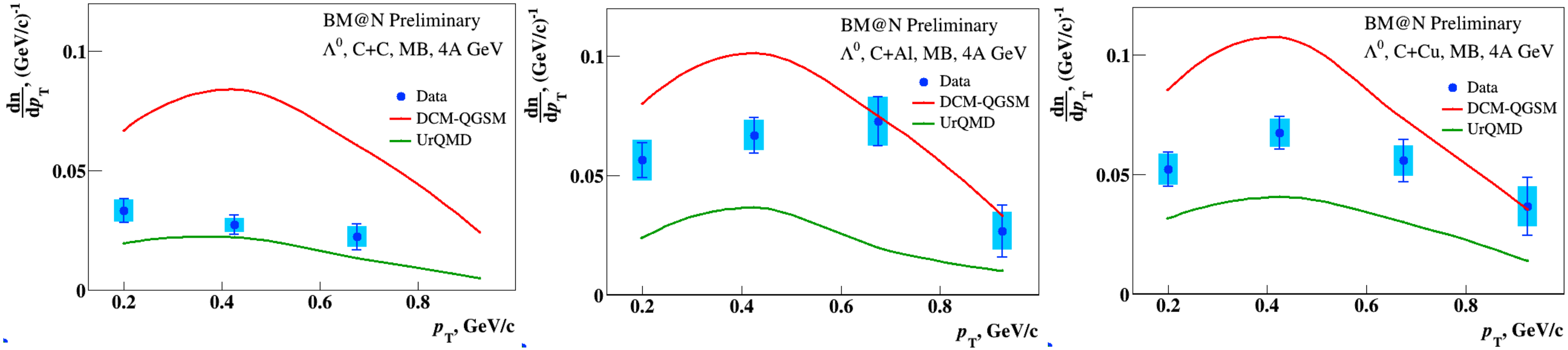


STS-4



Total: 292 modules, ~600k channels

Λ hyperon yield in 4A GeV carbon nucleus min bias interactions



measured kinematic range $0.1 < p_T < 1.05$ GeV/c, $0.03 < y^* < 0.93$

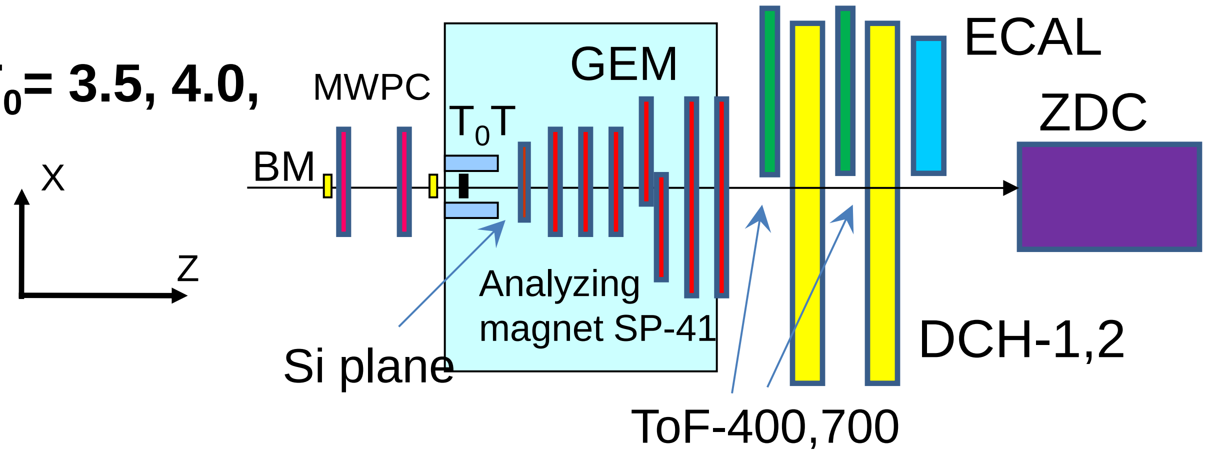
- **Yield of Λ in C+C, C+Al, C+ Cu minimum bias interactions in dependence on transverse momentum p_T**

- **Data compared with predictions of DCM-QGSM and UrQMD models**

► **shapes of p_T spectra are compatible with models**

BM@N in technical run with carbon beam

Carbon beam, T_0= 3.5, 4.0, 4.5 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 C + target → X with 3.5 - 4.5 AGeV carbon beam on targets C, Al, Cu, Pb**