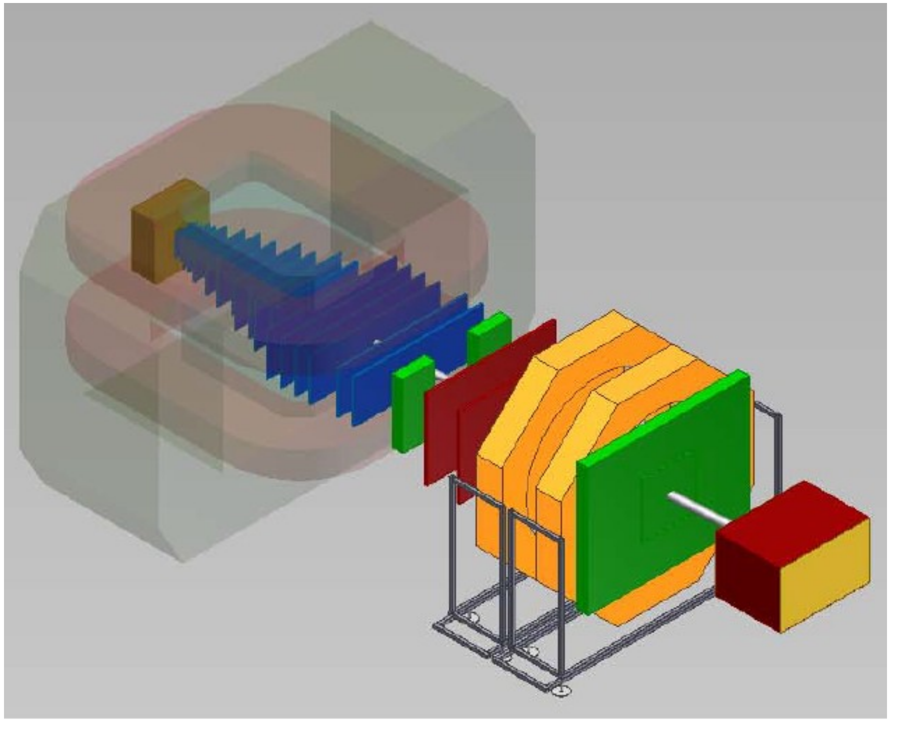
The BM@N experiment for studies of baryonic matter at the Nuclotron

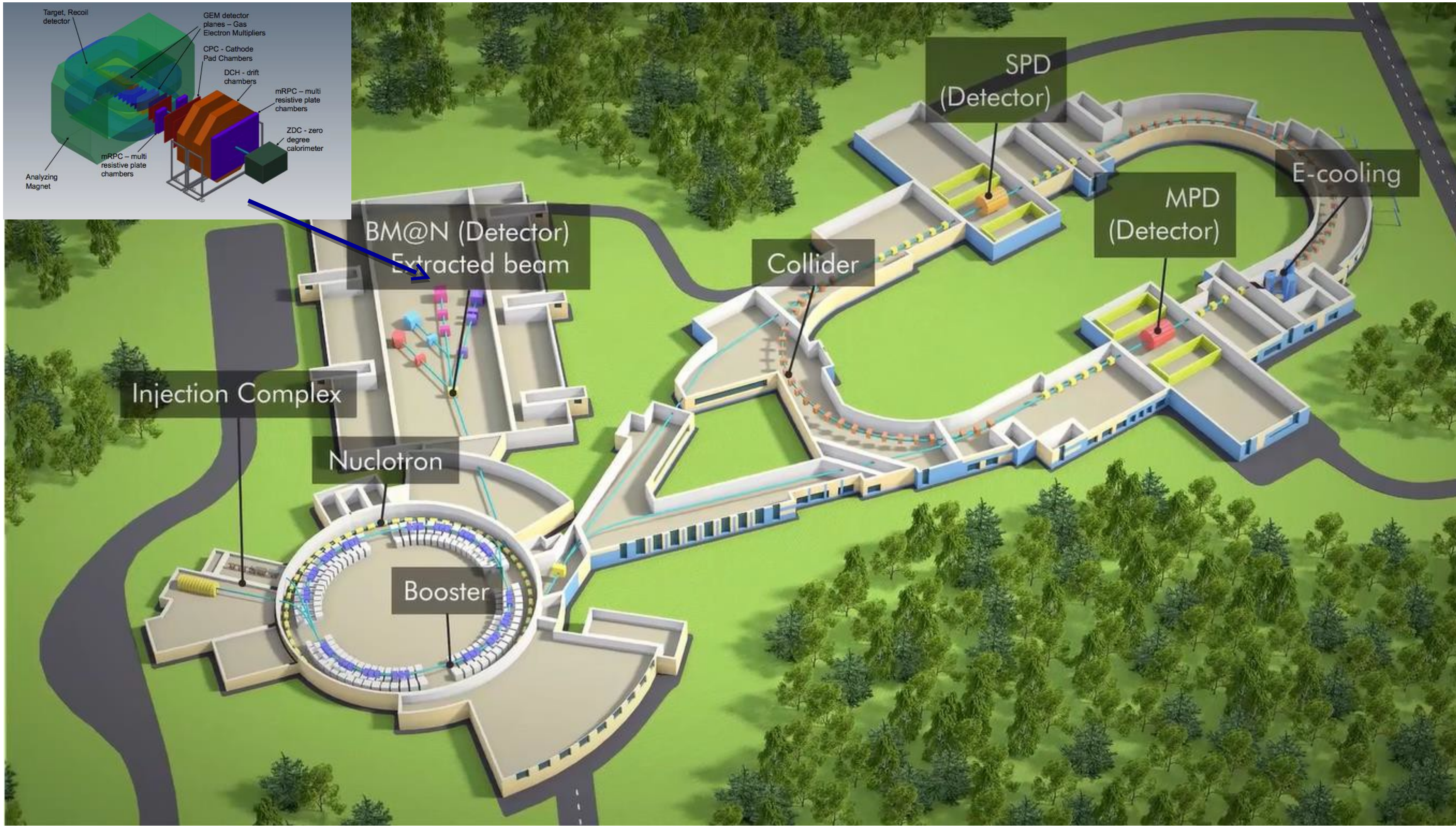
V.Plotnikov

for the BM@N Collaboration

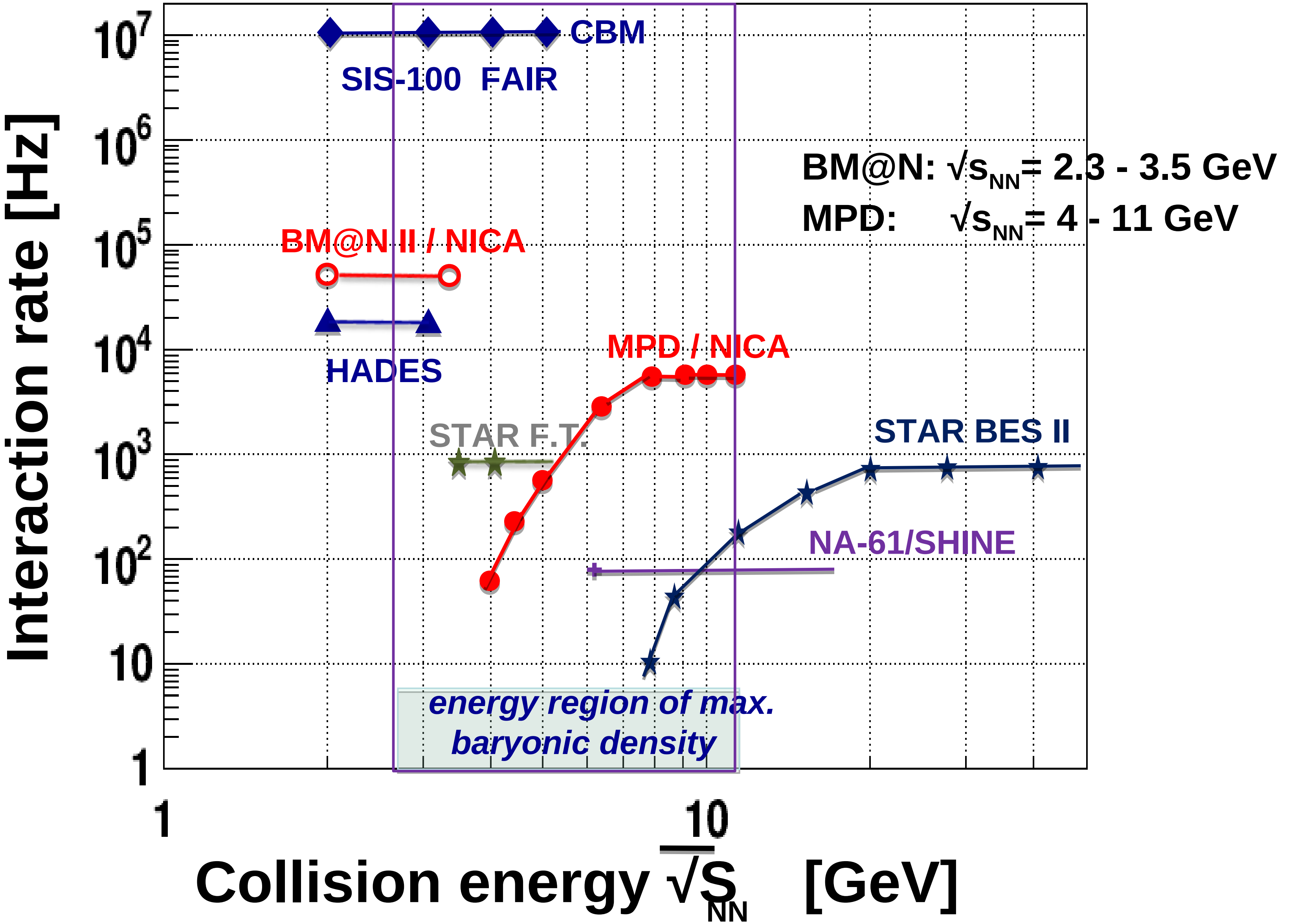


NICA Heavy Ion Complex

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



Heavy Ion Collision Experiments



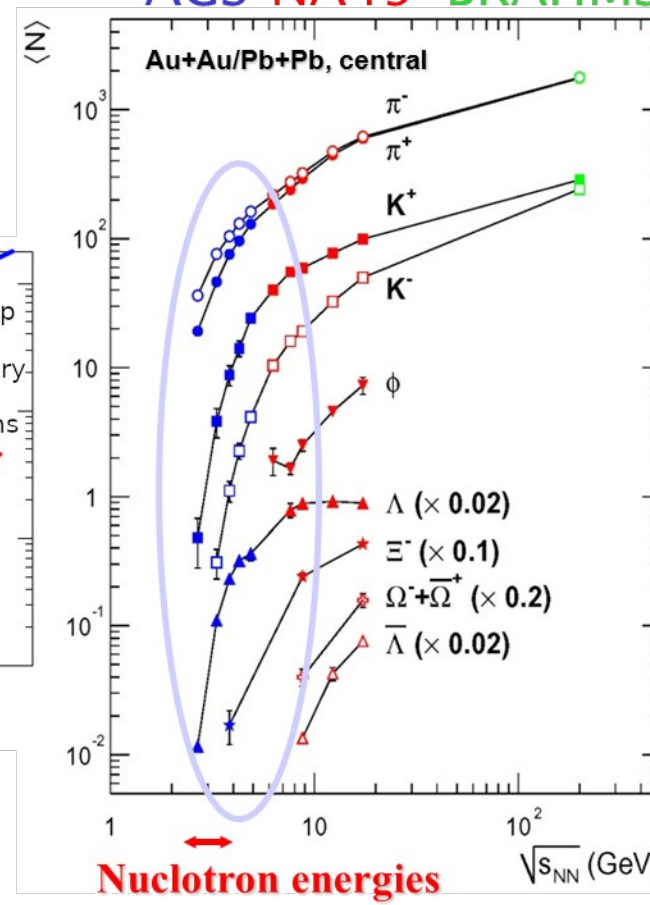
Physics possibilities at the Nuclotron

I. In A+A collisions at Nuclotron energies:

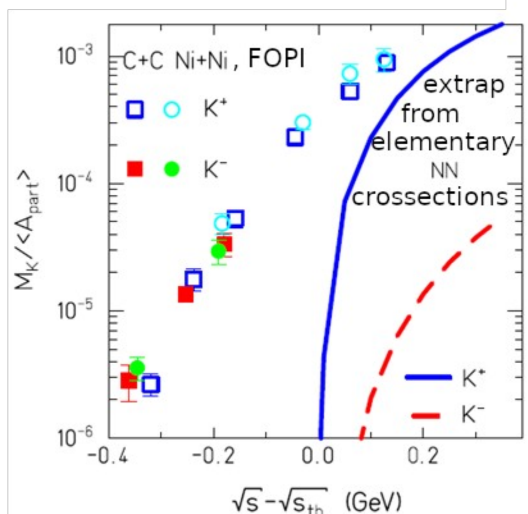
❑ **Opening thresholds for strange and multi-strange hyperon production**

➔ **strangeness at threshold**

AGS NA49 BRAHMS



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

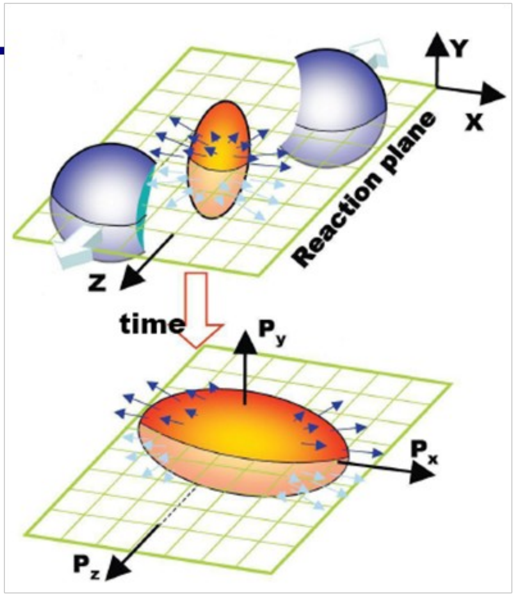


► **Collective flows v_1, v_2**

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

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

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



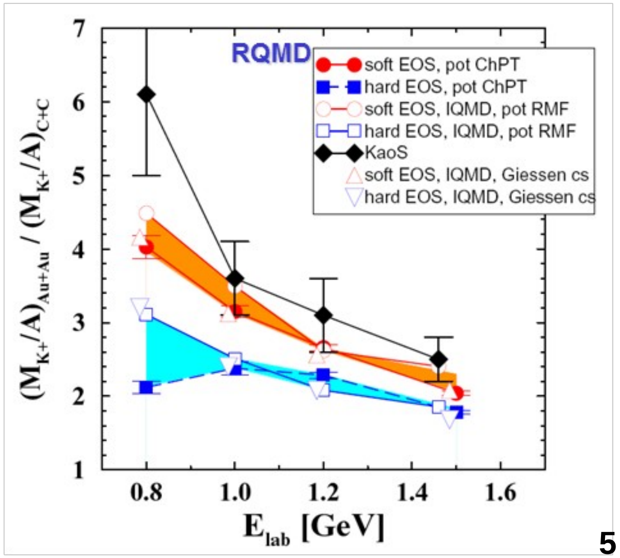
❖ The nuclear dynamics is defined by the EoS (via density dependent NN-interaction)

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

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

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

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

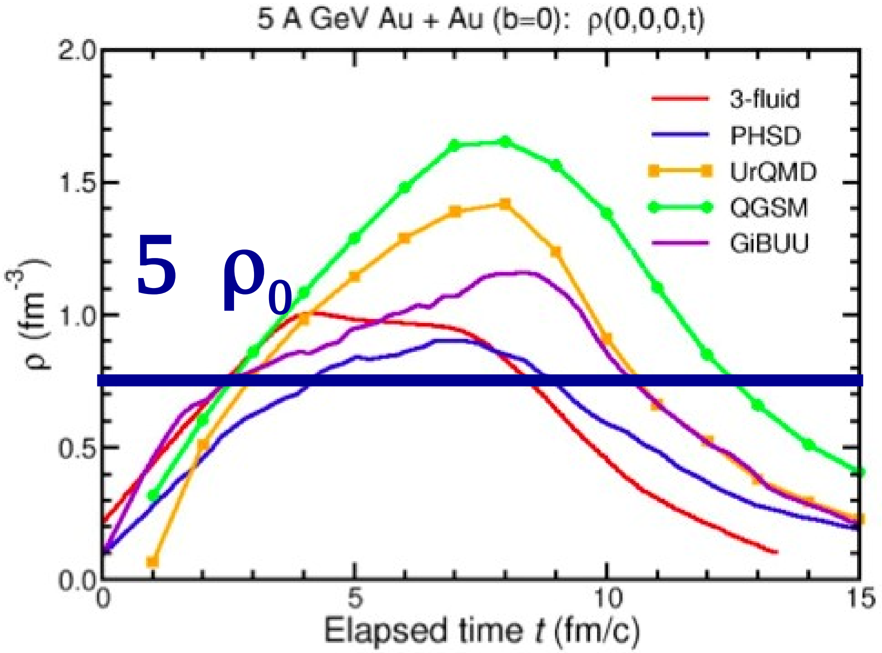


Explore high density baryonic matter

Baryonic densities in central Au+Au collisions

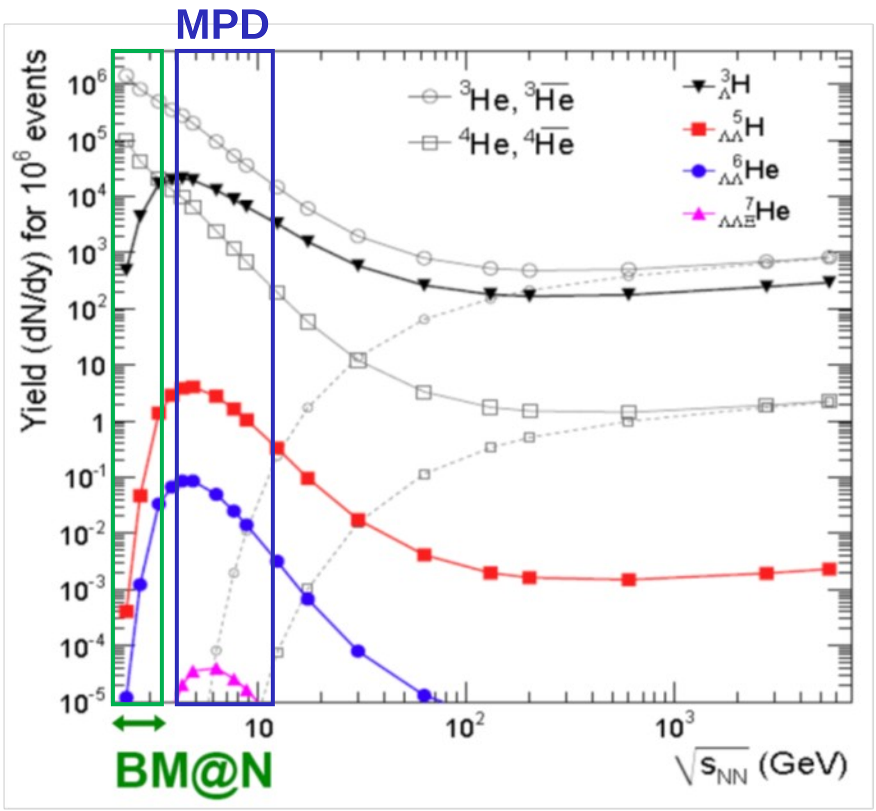
FAIR SIS-100 / Nuclotron

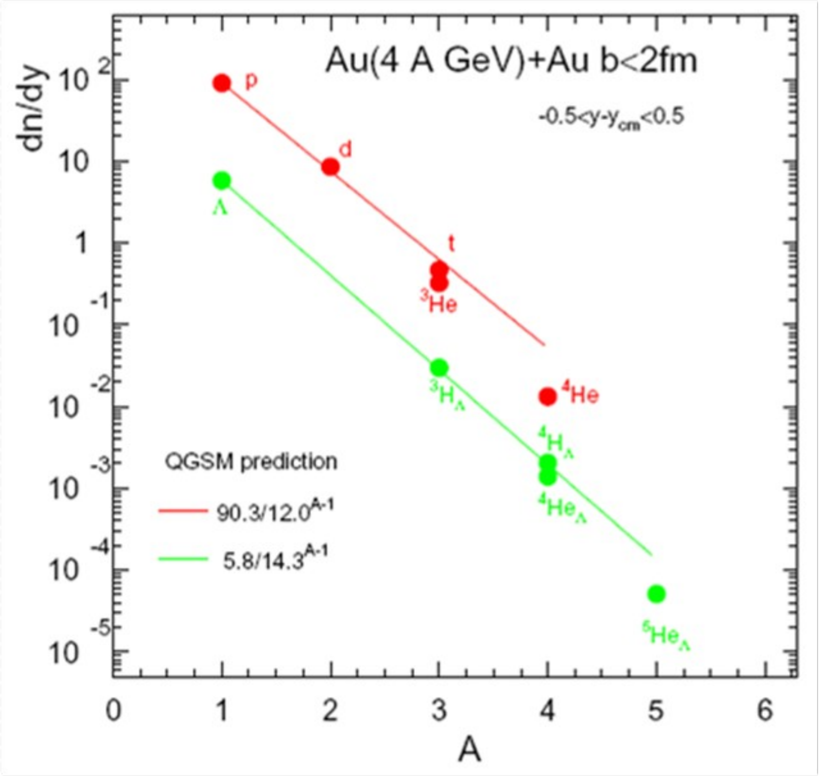
5 A GeV



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

Heavy-ions A+A: Hypernuclei production

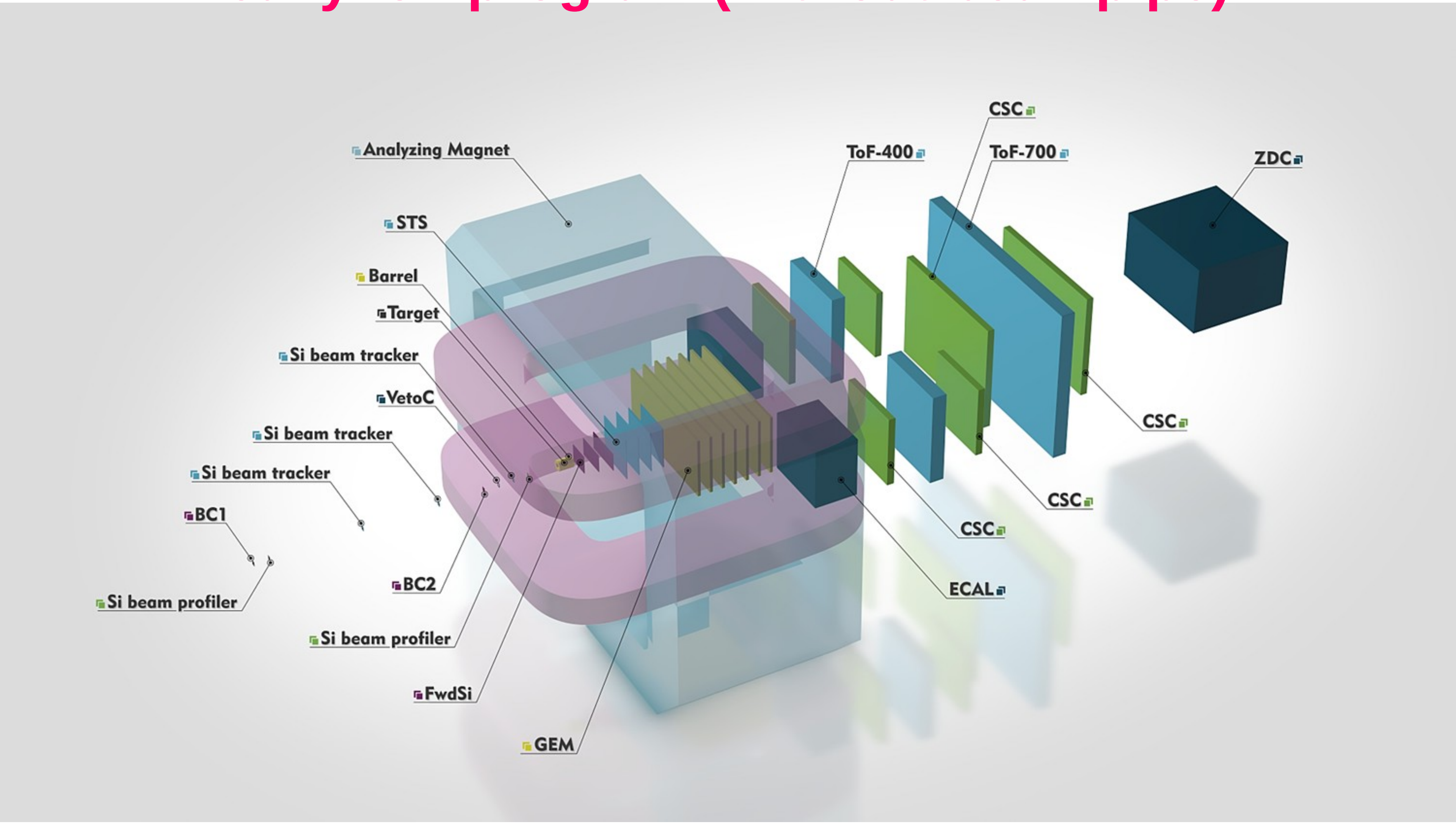




- **In heavy-ion reactions:** production of hypernuclei through coalescence of Λ with light fragments enhanced at high baryon densities
- **Maximal yield** predicted for √s=4-5A GeV (stat. model) (interplay of Λ and light nuclei excitation function)

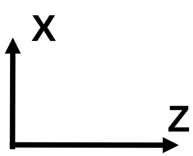
► BM@N energy range is suited for search of hyper-nuclei

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

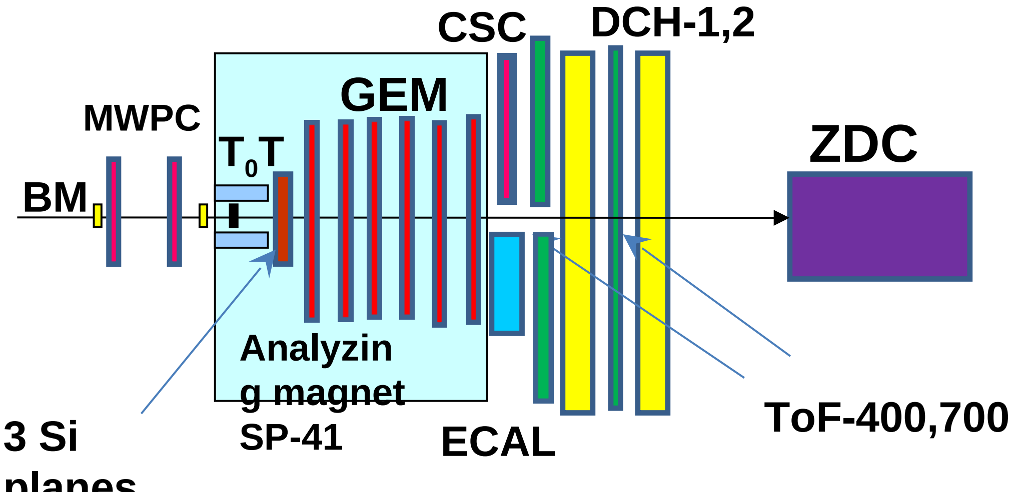


BM@N run with Ar and Kr beams in March 2018

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

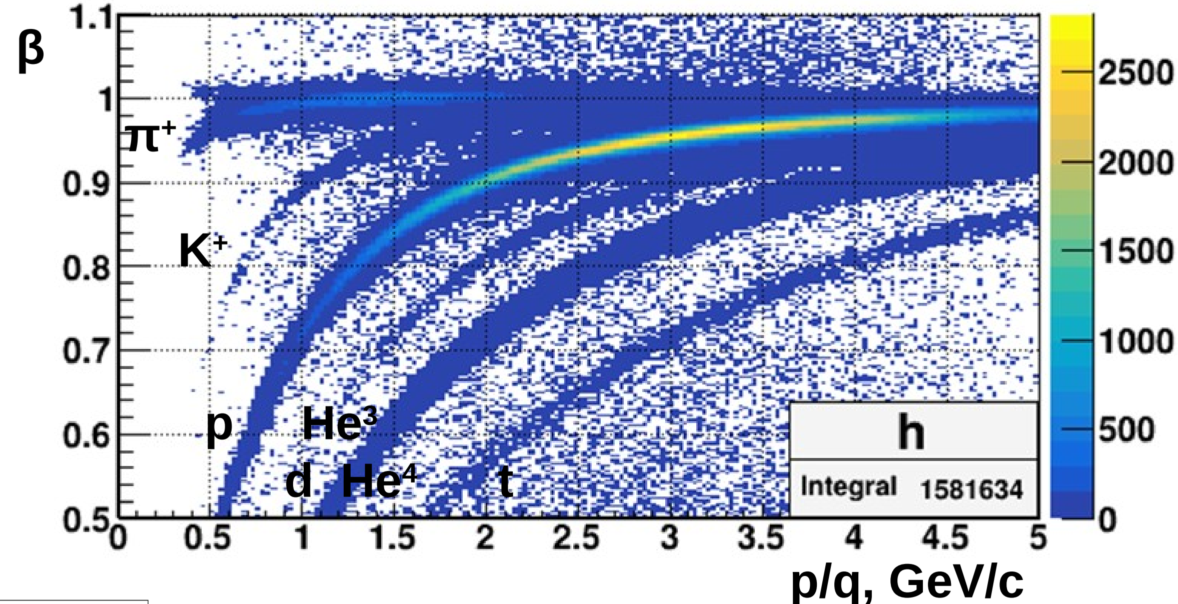
+ analyze data from previous technical run with Carbon beam of 3.5 - 4.5 GeV/n

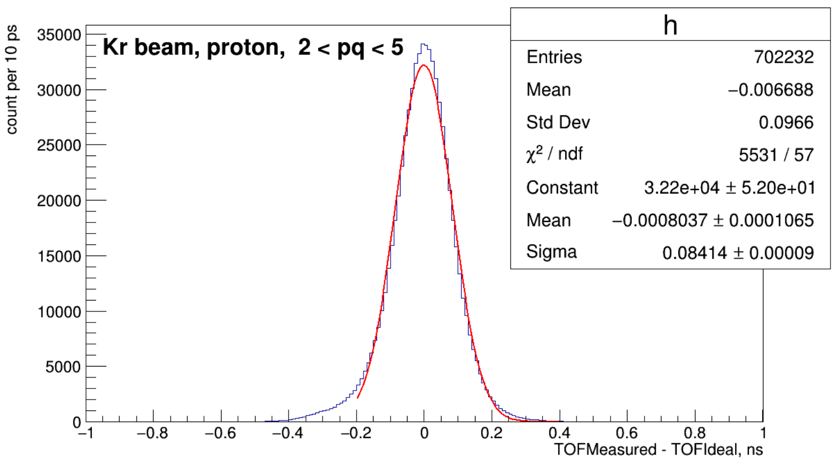
Status of TOF-400 particle identification

First expected results:

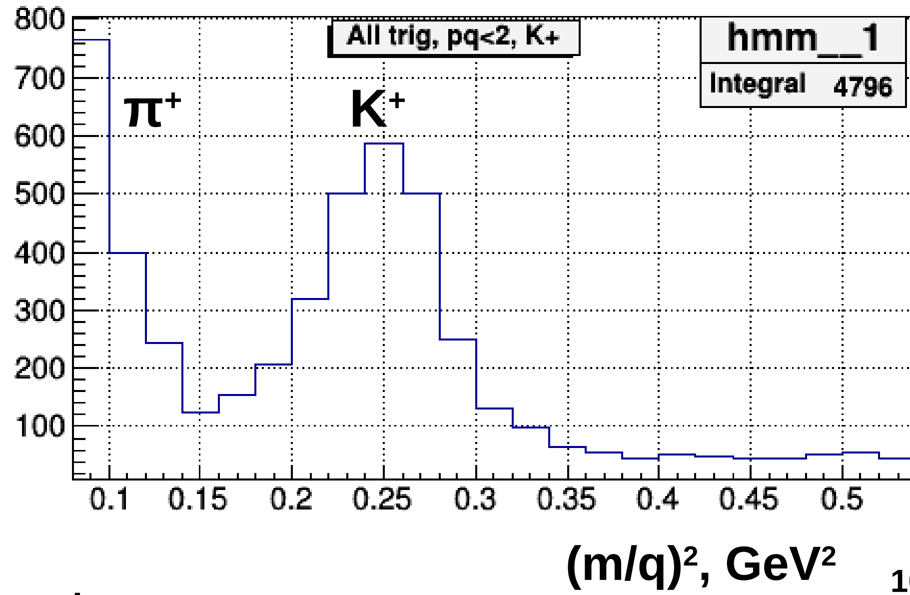
- Ratio of K^+/π^+ in Ar - nucleus interactions at beam kinetic energy of 3.2 AGeV
- Ratio of K^+/π^+ in Kr - nucleus interactions at beam kinetic energy of 2.4 AGeV

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



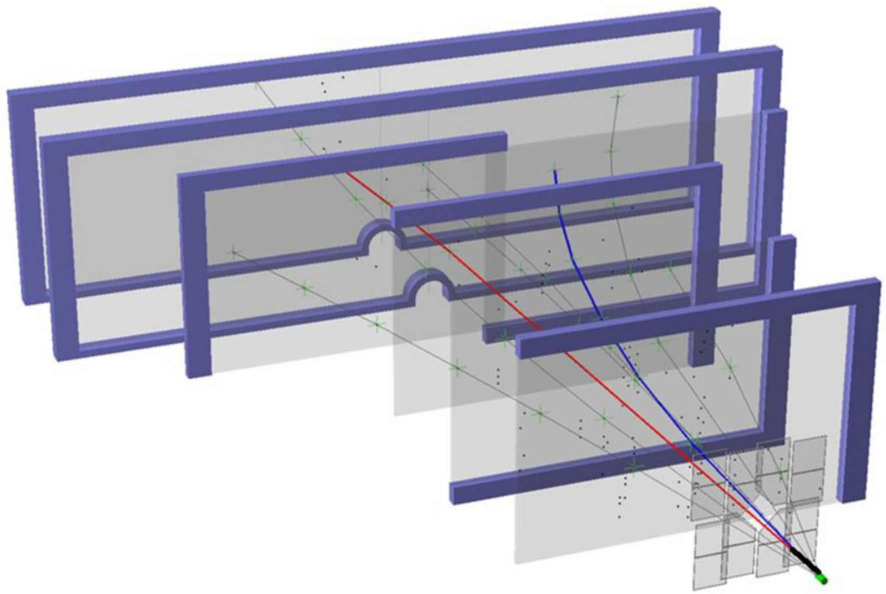


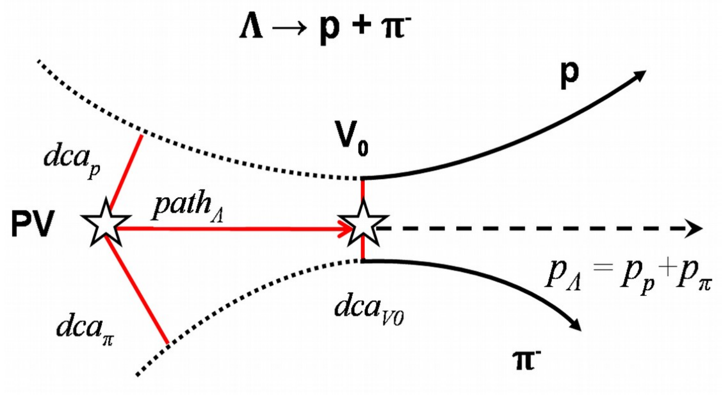
Time resolution within proton band ~85 ps



Λ hyperon production in 4A GeV Carbon-nucleus interactions

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



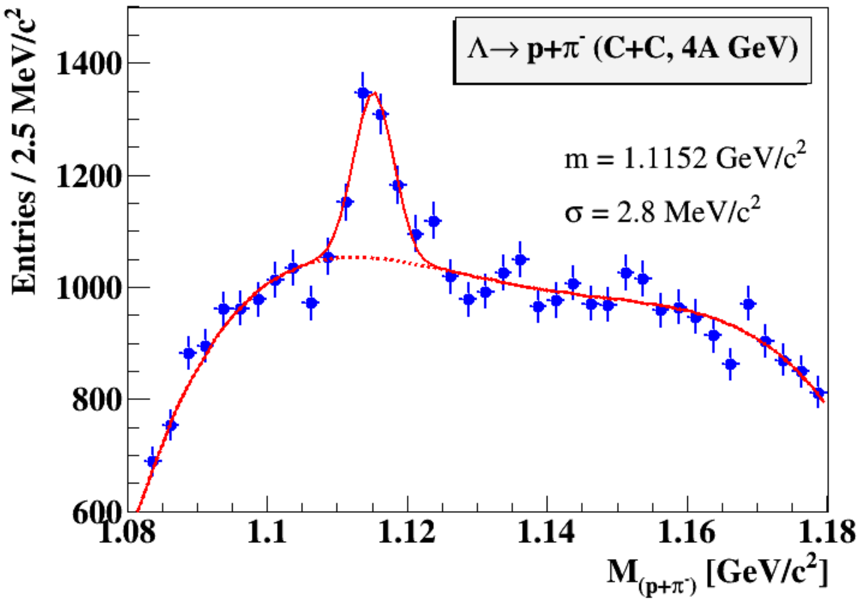


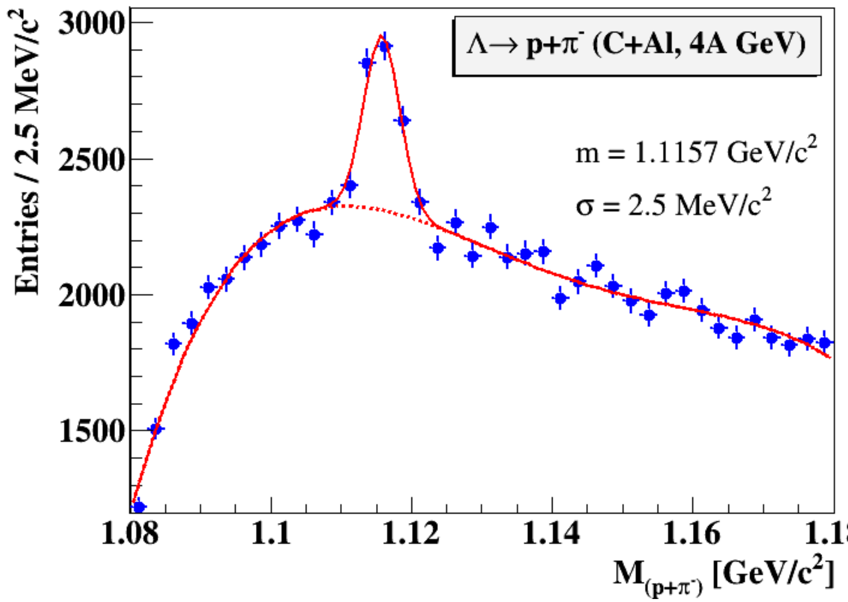
Event topology:

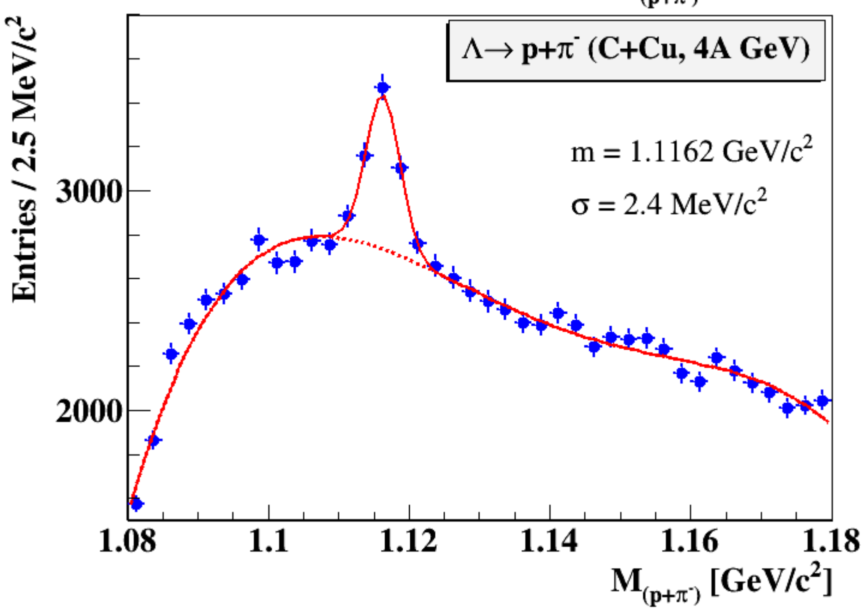
- ✓ **PV** – primary vertex
- ✓ **V_0** – vertex of hyperon decay
- ✓ ***dca*** – distance of the closest approac
- ✓ ***path*** – decay length

Analysis without PID

Λ hyperon signals in 4A GeV Carbon-nucleus interactions





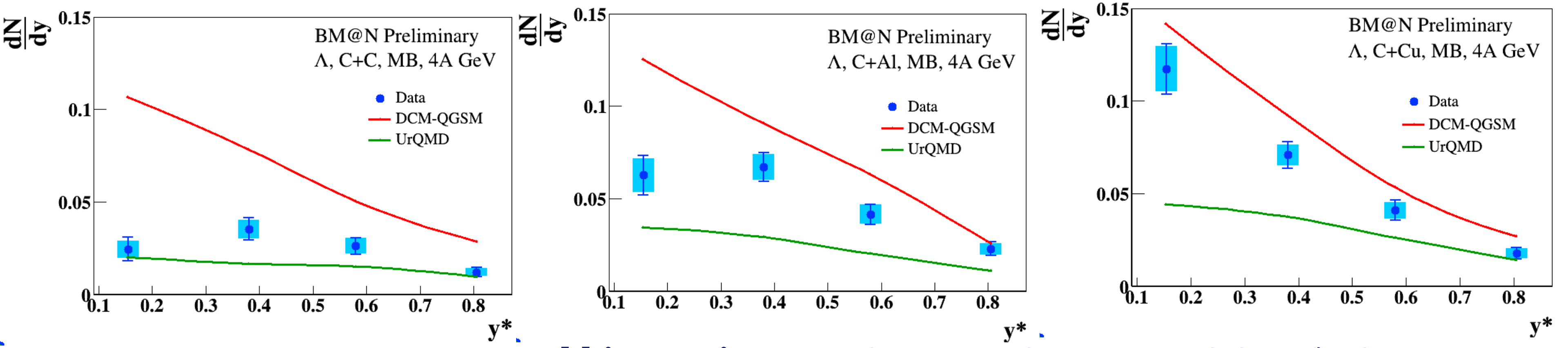


C beam 4 AGeV
C + C,Al,Cu → Λ + X minimum bias
Λ signal width 2.4 – 3 MeV

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. $y^* = y_{lab}-1.17$**

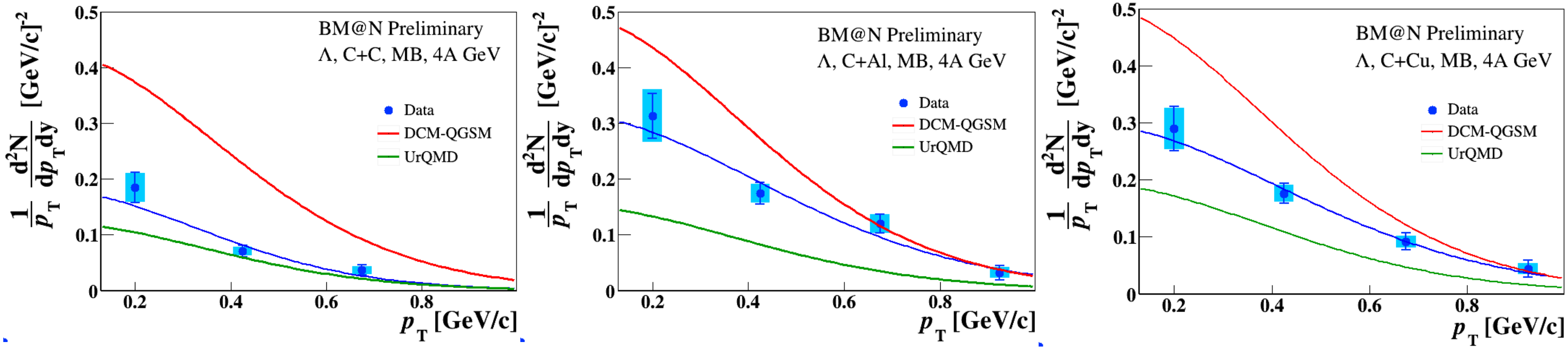
► **y* spectrum becomes softer with increase of target atomic weight**

- **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



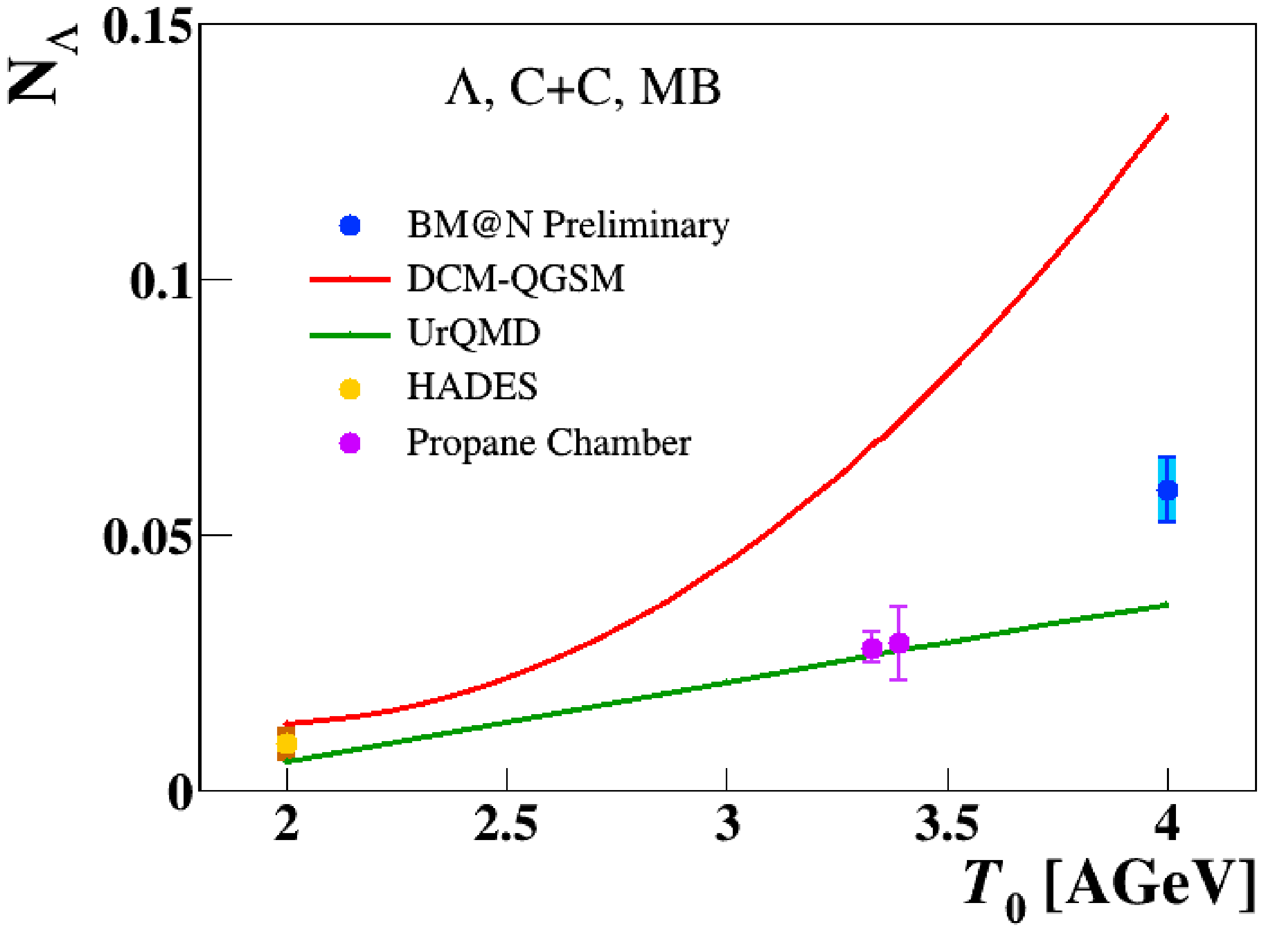
- **Fit of invariant p_T spectra of Λ yields in C+C, C+Al, C+Cu minimum bias interactions by function:**

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

- **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

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



BM@N yield extrapolated to full kinematic range

Next plans:

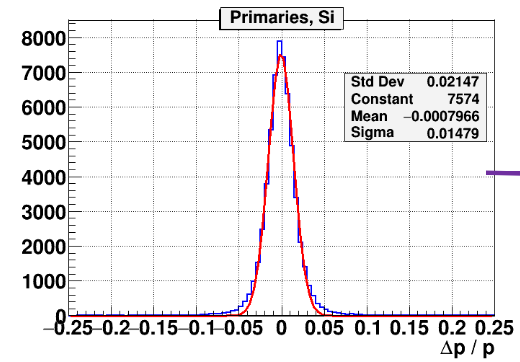
→ **add results for semi-central C+A interactions**

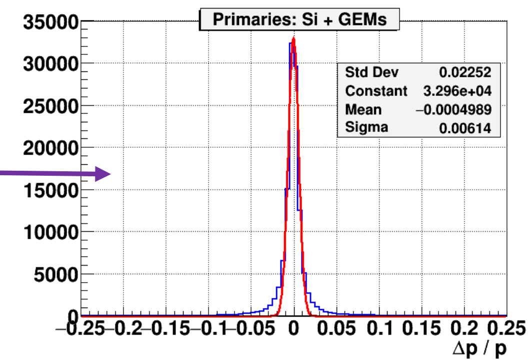
→ **add results for 3.5 and 4.5 AGeV Carbon beam data**

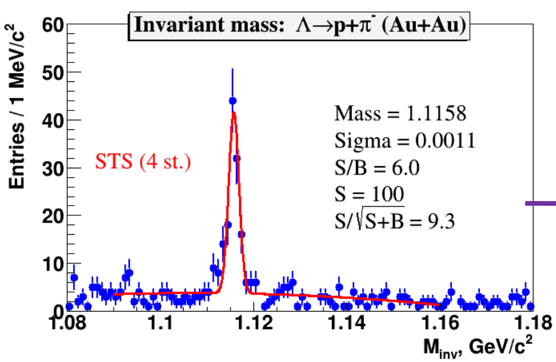
Forward Si, STS and GEM detectors

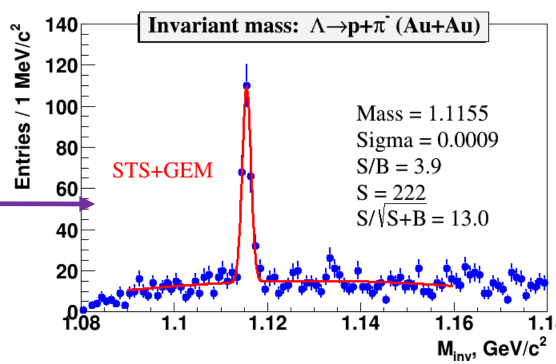
4 STS

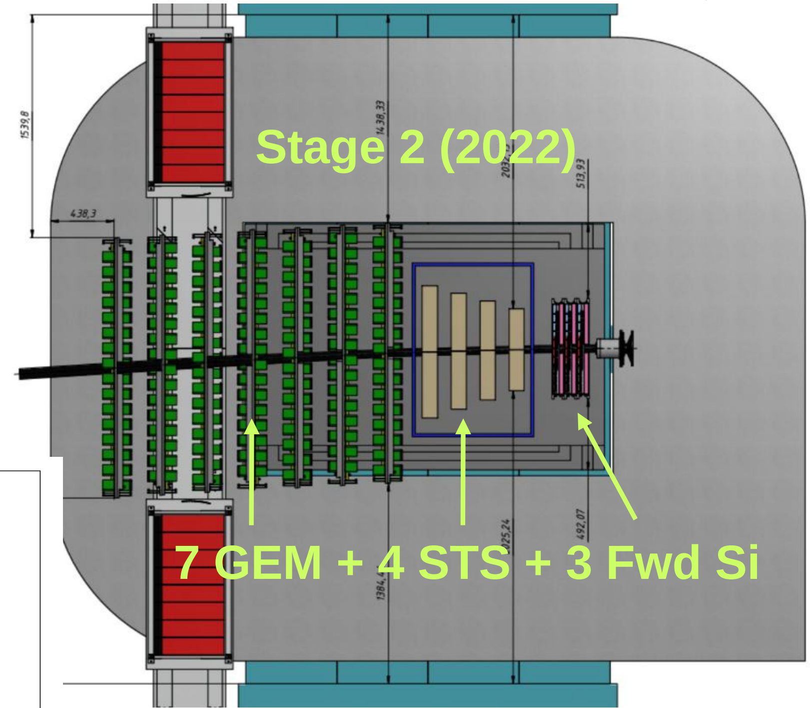
4 STS + 7 GEM

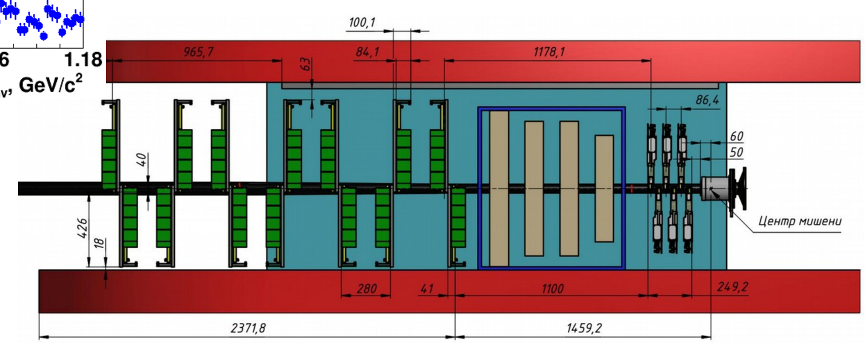












Hybrid STS + GEM tracker vs STS:

► 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

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**
- **First physics results obtained on Λ yields in C + C, Al, Cu interactions**
- **Reconstruction and analysis of interactions of Ar, Kr beams with targets 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!

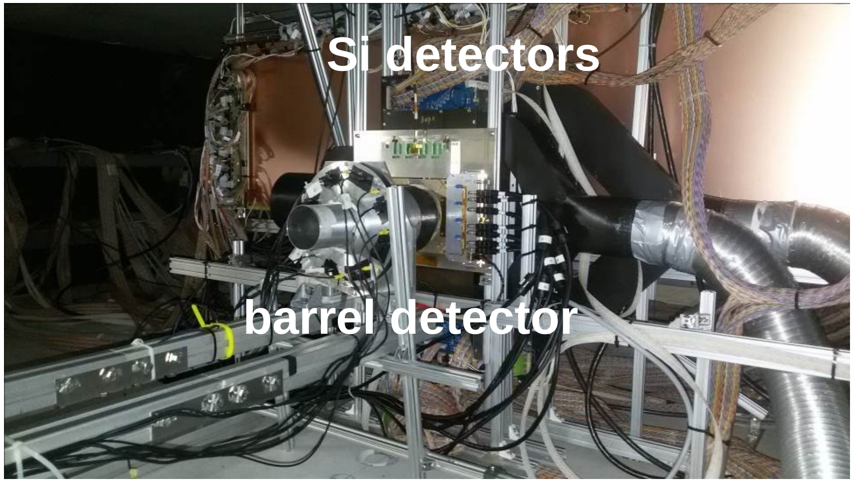
Three meetings on formation of the MPD and BM@N Collaborations

carried out in Dubna in 2018 and April 2019

Next BM@N meeting in October 2019

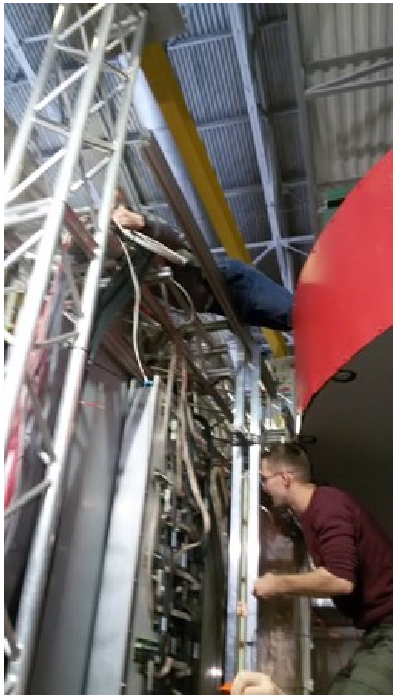
BM@N Collaboration: 21 Institutions from 11 countries, 230 participants

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

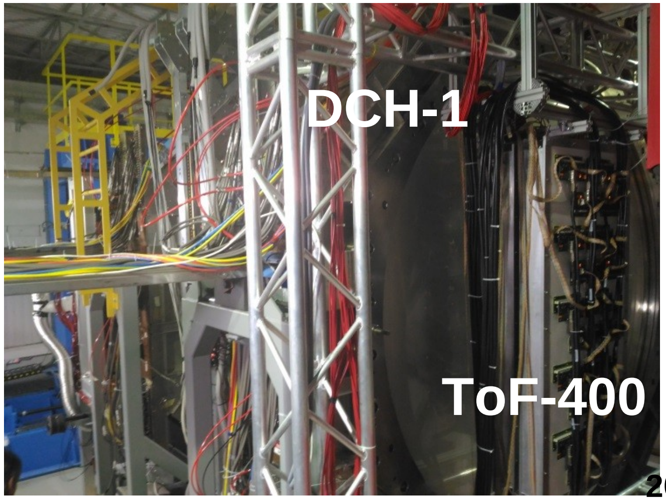


CSC chamber

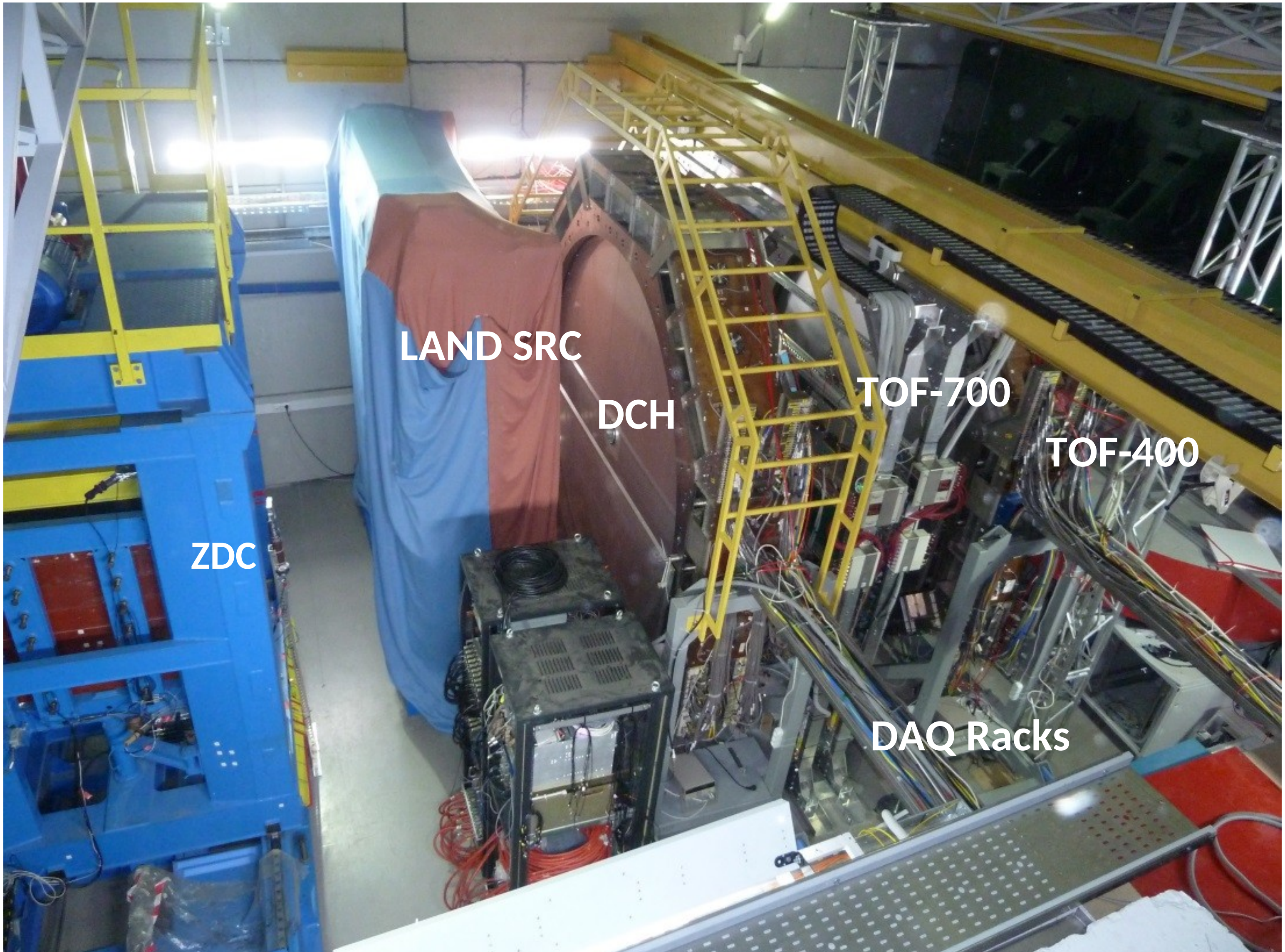
ToF-400 installation



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

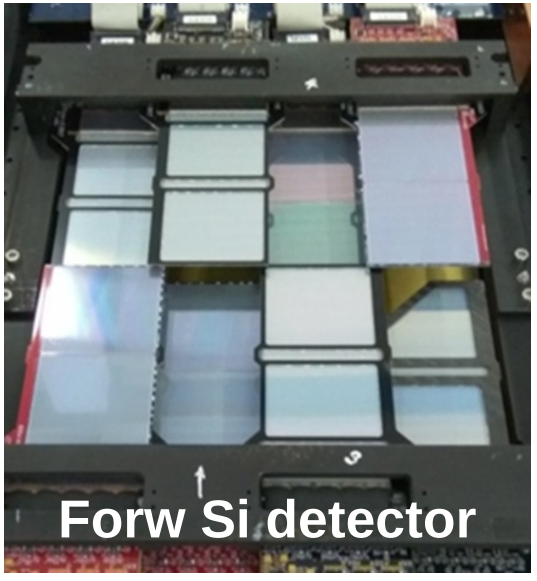


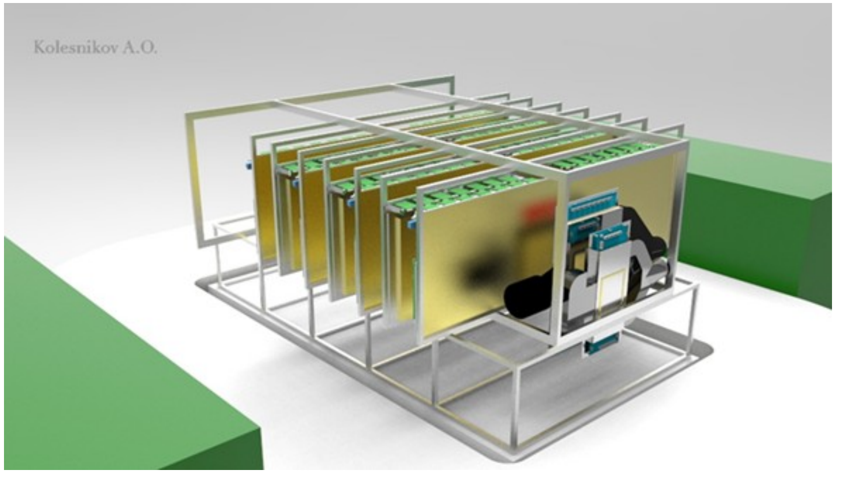
BM@N setup behind magnet, 2018



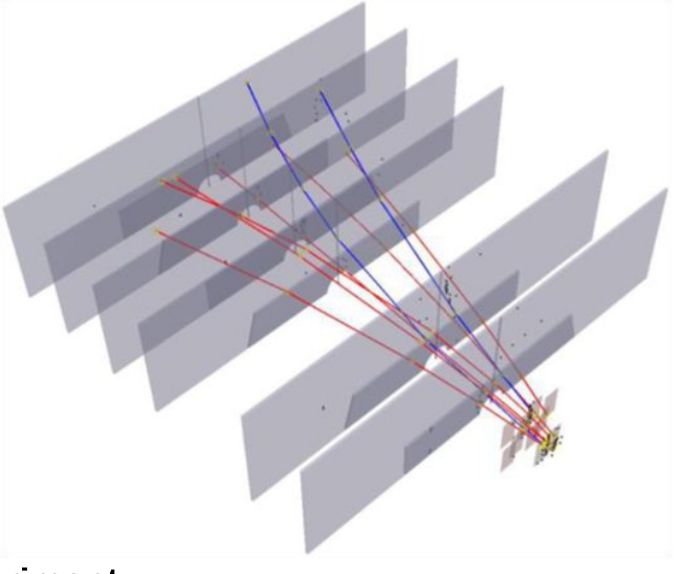
Silicon + GEM central tracker in Ar, Kr runs

3 Forward Si detectors and 6 GEM detectors



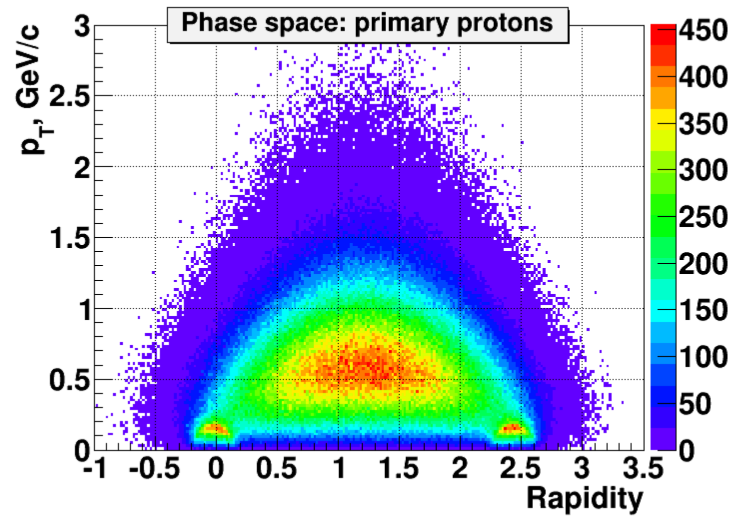


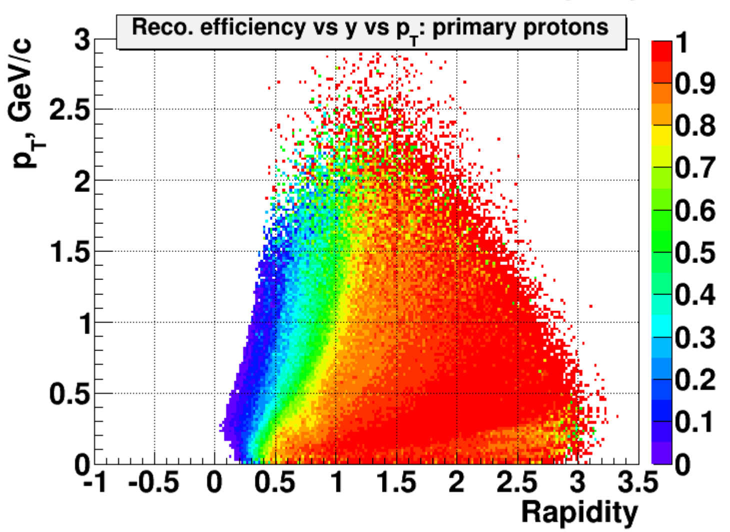
Ar+Cu interaction reconstructed in central tracker



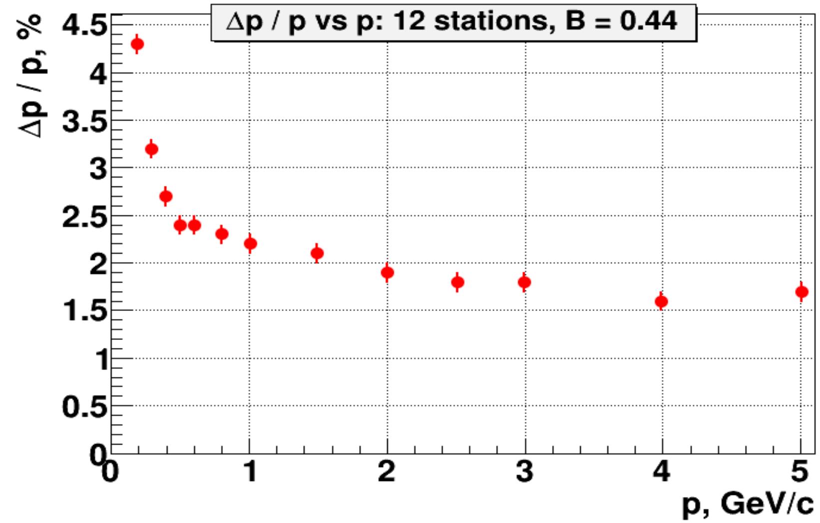
GEM tracker: acceptance / momentum resolution / detection efficiency

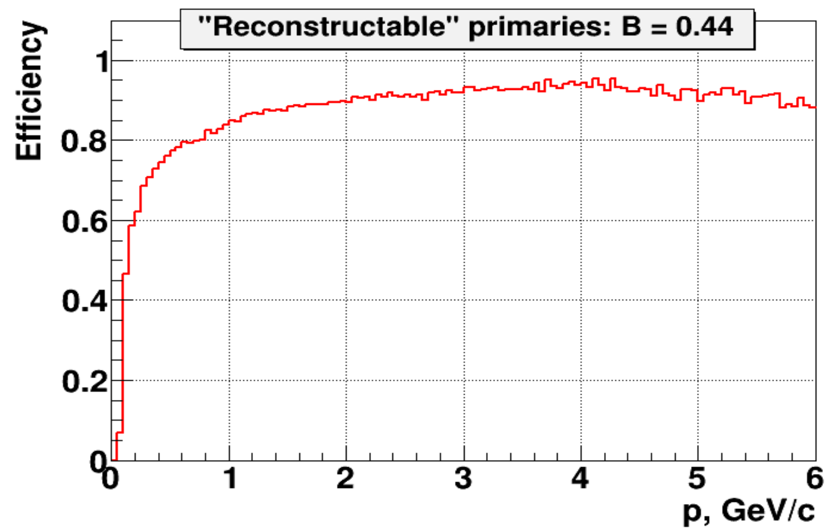
Phase space / acceptance to primary protons: Au+Au, 4.5 AGeV



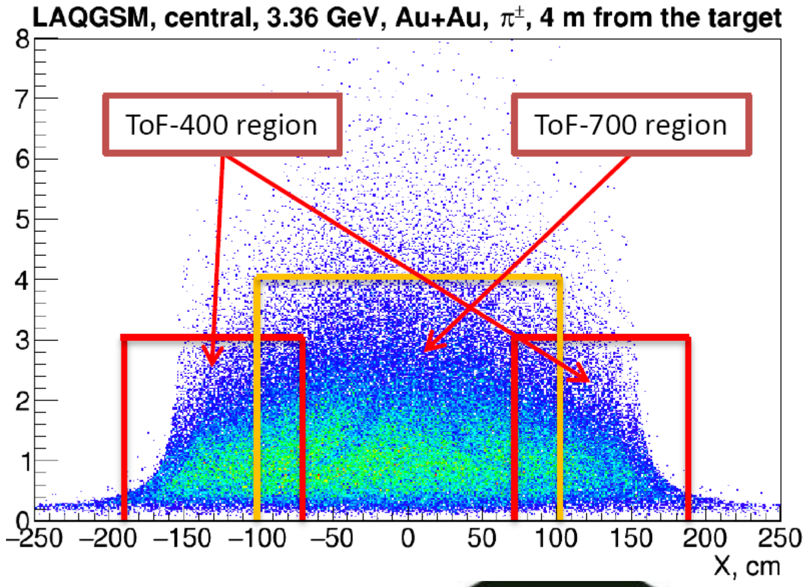


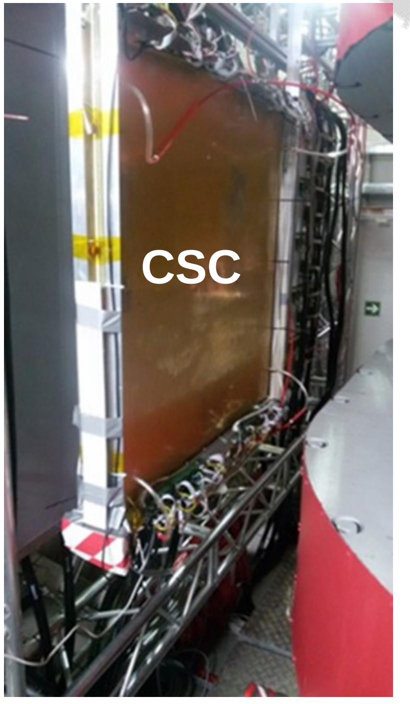
Momentum resolution / detection efficiency



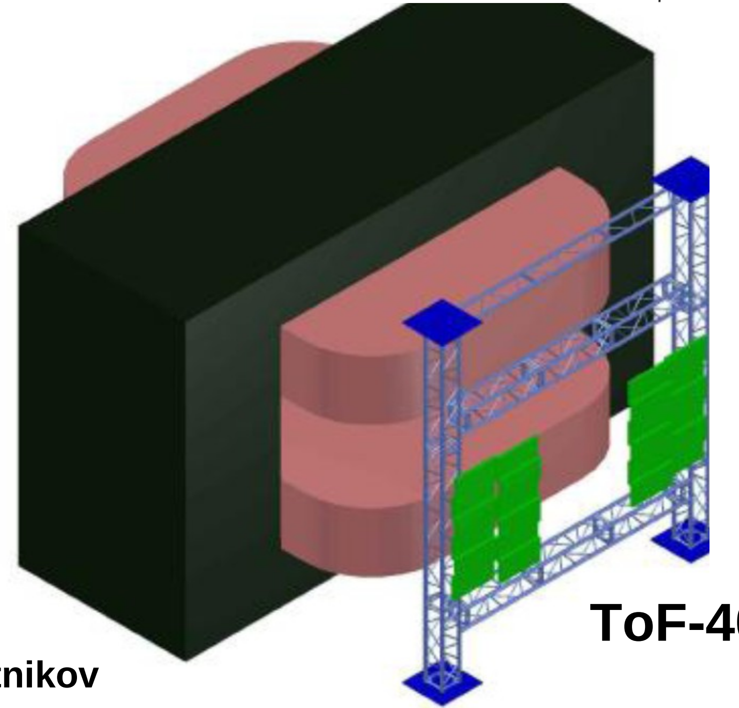


ToF-400 and ToF-700 based on mRPC

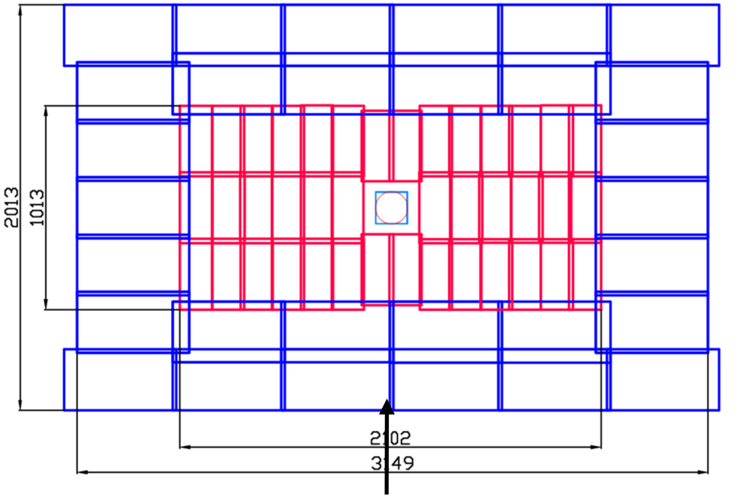




ToF-700 wall



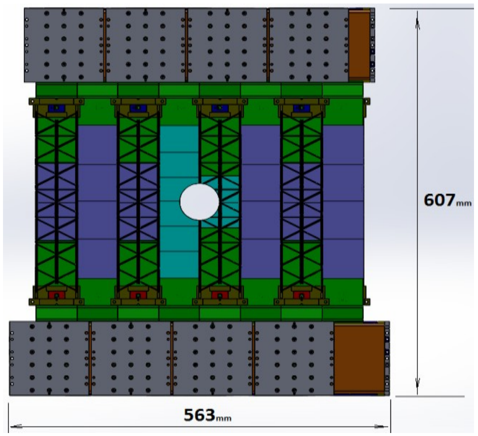
ToF-400 wall



BM@N beam axis

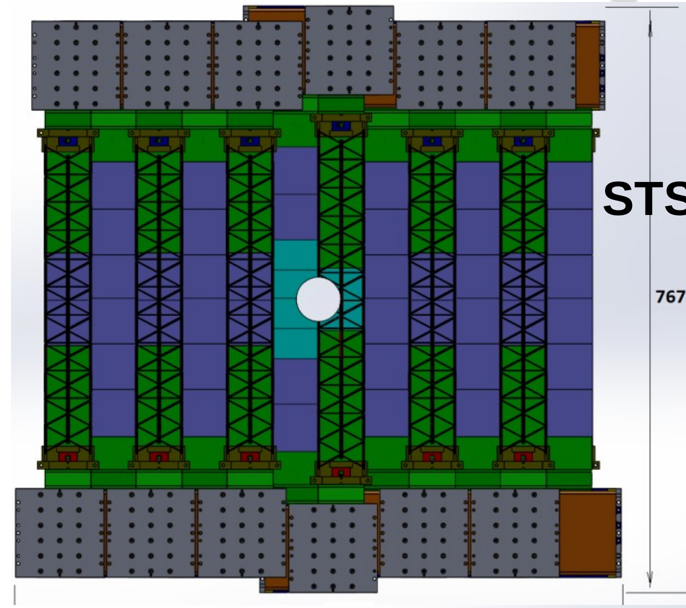
Upgrade of central tracker with CBM STS

STS-1

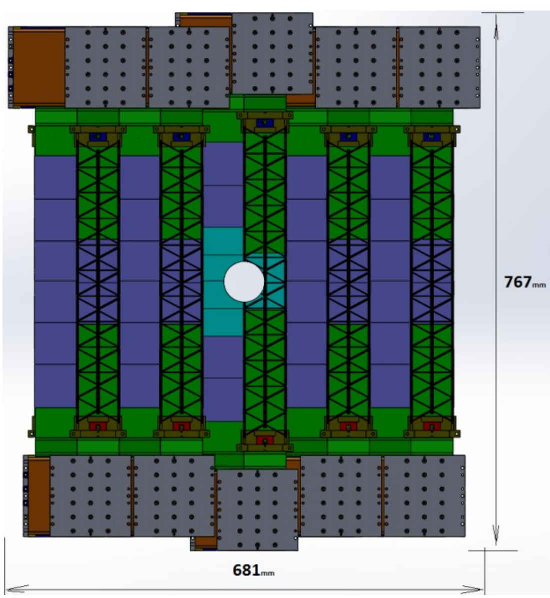


Team: LHEP JINR, MSU, GSI, Tübingen University

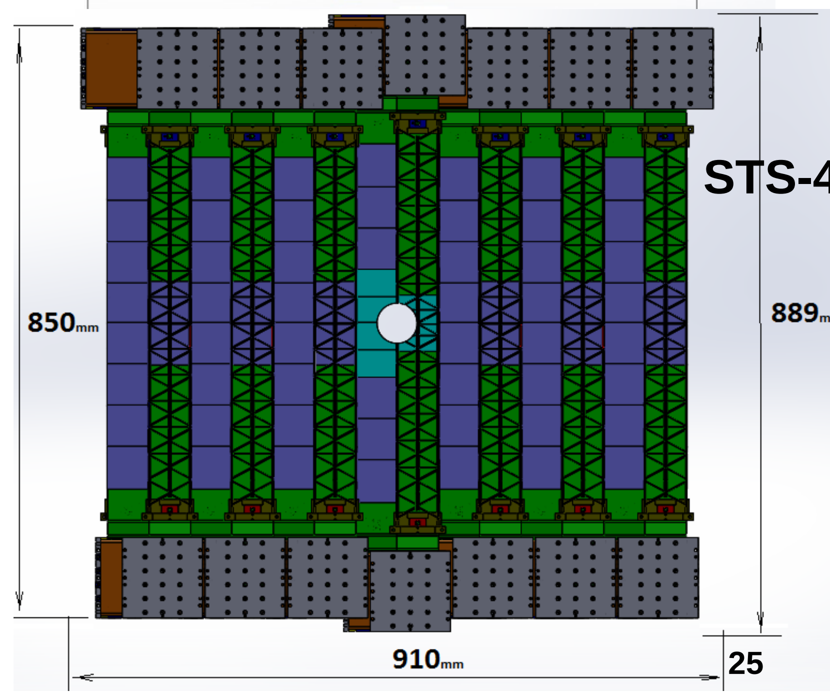
STS-3



STS-2

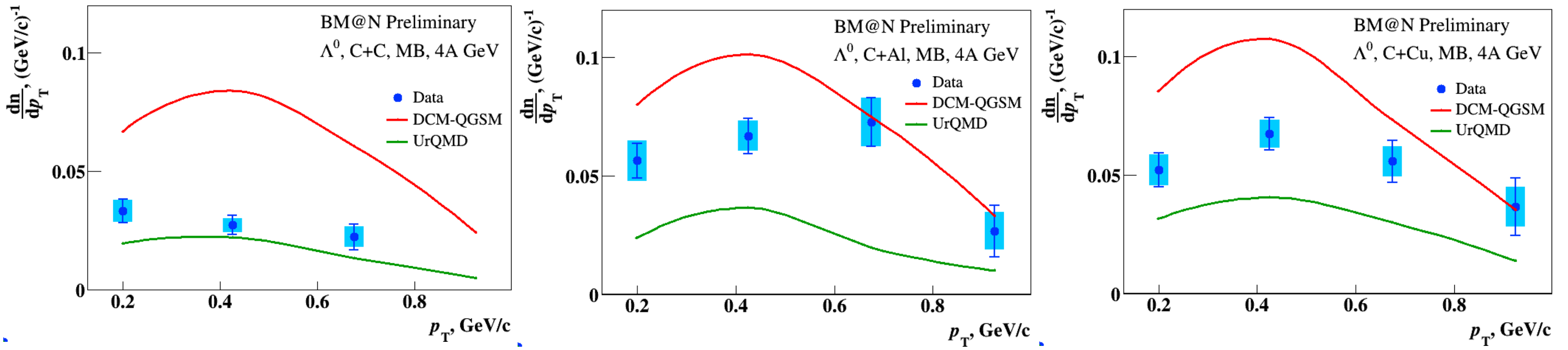


STS-4



Total: 292 modules, ~600k channels

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



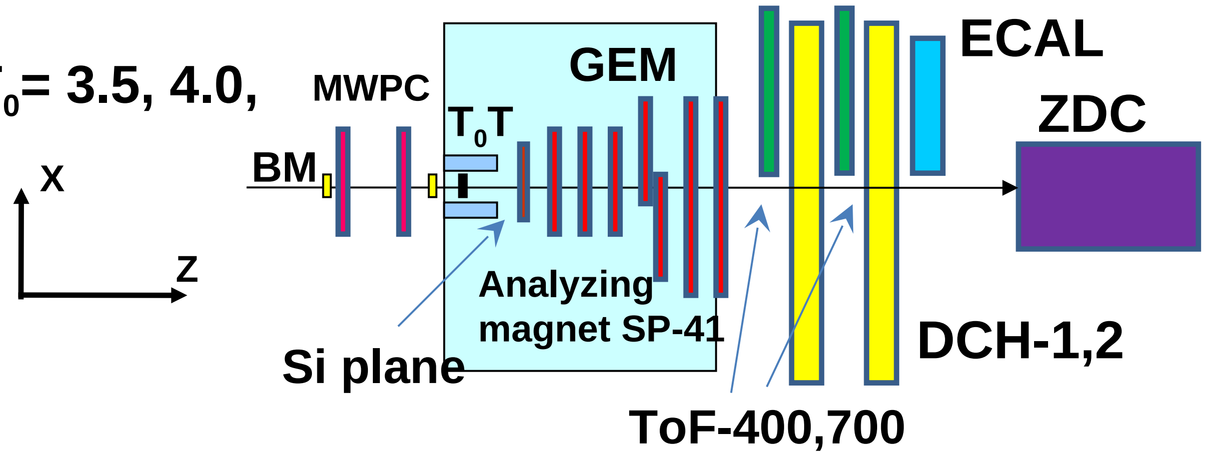
measured kinematic range 0.1< p_T <1.05 GeV/c, 0.03< y^* < 0.93

- **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 41cm² + 2 GEM detectors 163 x 45 cm² 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

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, N_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) $\sigma_\Lambda = N_\Lambda \cdot \sigma_{inel}$

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