Upgrading the BM@N experiment for high-rate Au+Au collisions

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Outline:

- BM@N physics case: EOS and hypernuclei
- Upgrade program:
  1. STS layout and design studies
  2. STS development activities
  3. Beam transport system

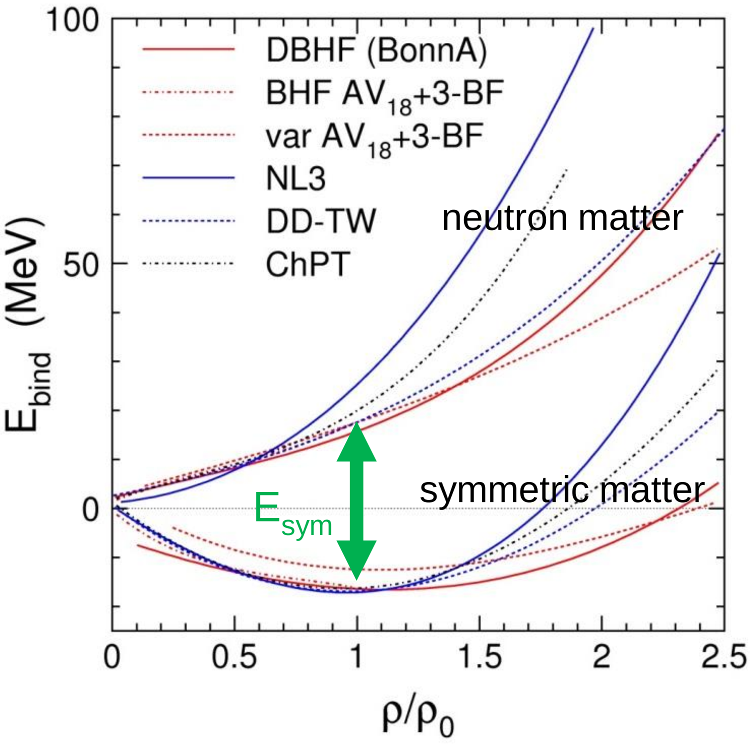
BM@N DAC Meeting, Jan. 23, 2019, JINR, Dubna

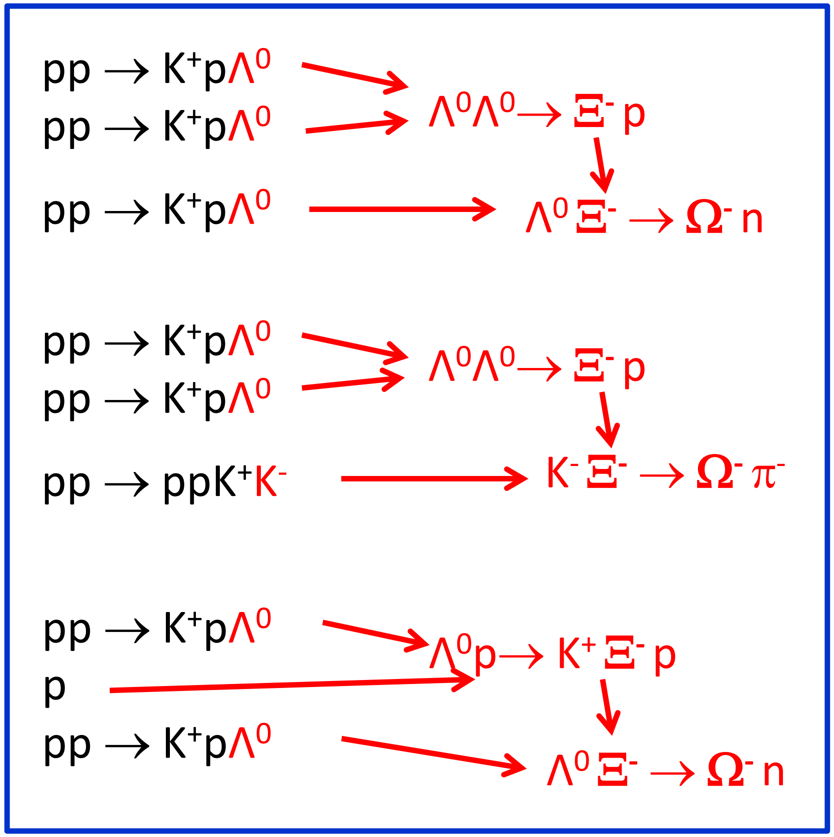
The high-density nuclear matter EOS

Observables:

- collective flow of identified particles (π,K,p,Λ,Ξ,Ω,...) driven by the pressure gradient in the early fireball
- particle production at subthreshold energies via multi-step processes (multi-strange hyperons)

At Nuclotron energies: Hyperon yield ~ multi-step collisions ~ density → EOS





$pp \to K^+p\Lambda^0$

$pp \to K^+p\Lambda^0$

$\Lambda^0\Lambda^0 \to \Xi^- p$

$pp \to K^+p\Lambda^0$

$\Lambda^0\Xi^- \to \Omega^- n$

$pp \to K^+p\Lambda^0$

$pp \to K^+p\Lambda^0$

$\Lambda^0\Lambda^0 \to \Xi^- p$

$pp \to ppK^+K^-$

$K^-\Xi^- \to \Omega^- \pi^-$

$pp \to K^+p\Lambda^0$

p

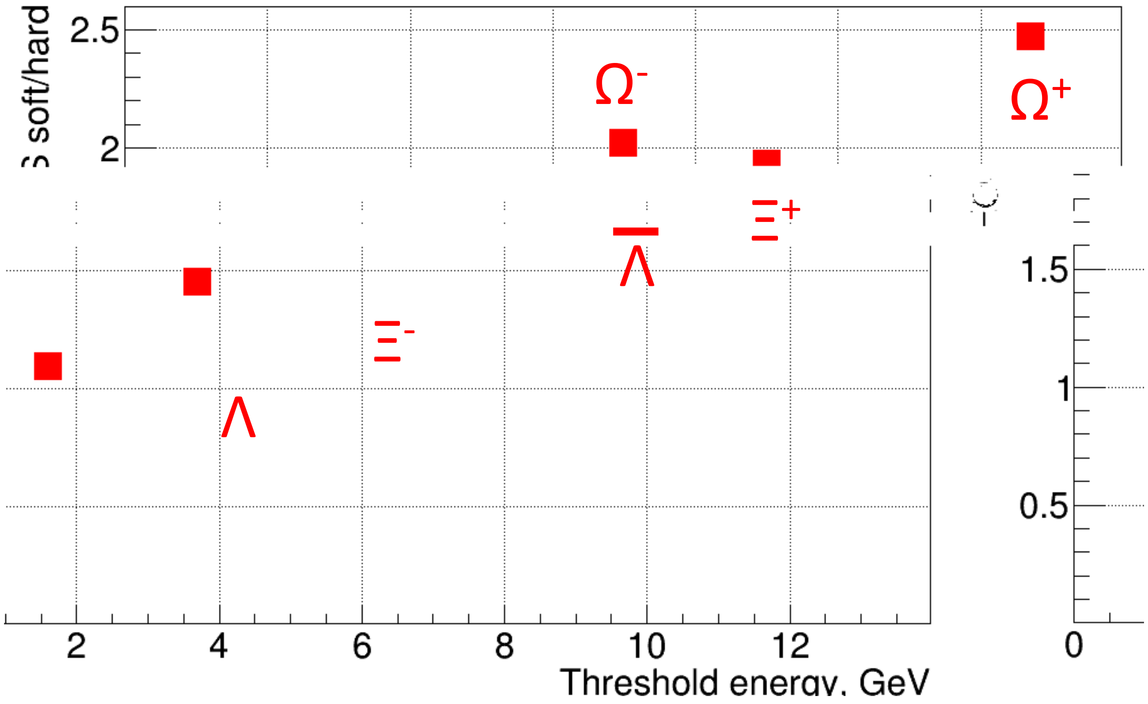
$pp \to K^+p\Lambda^0$

$\Lambda^0 p \to K^+\Xi^- p$

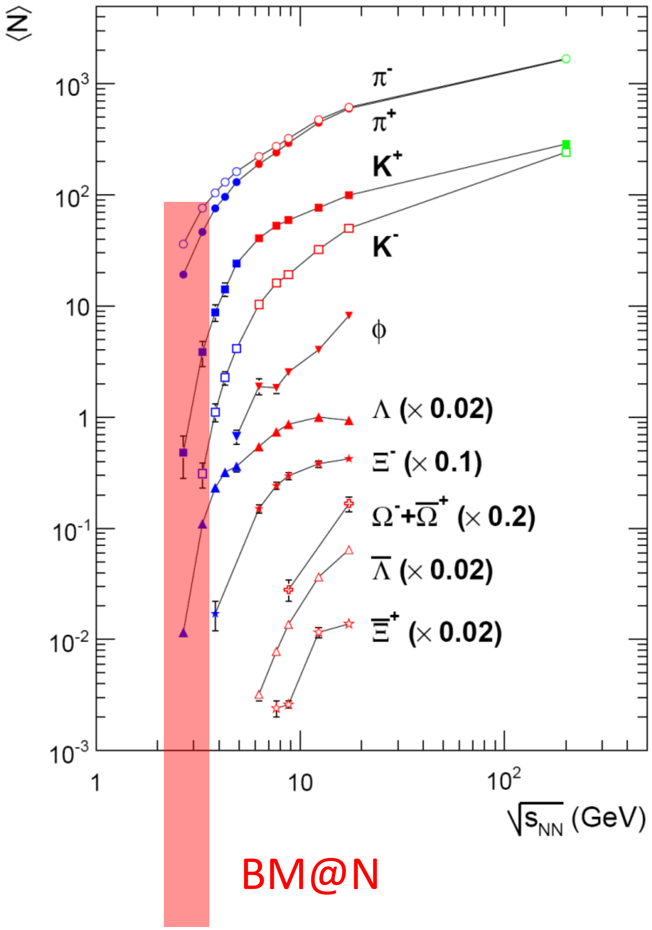
$\Lambda^0\Xi^- \to \Omega^- n$

EOS observables

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



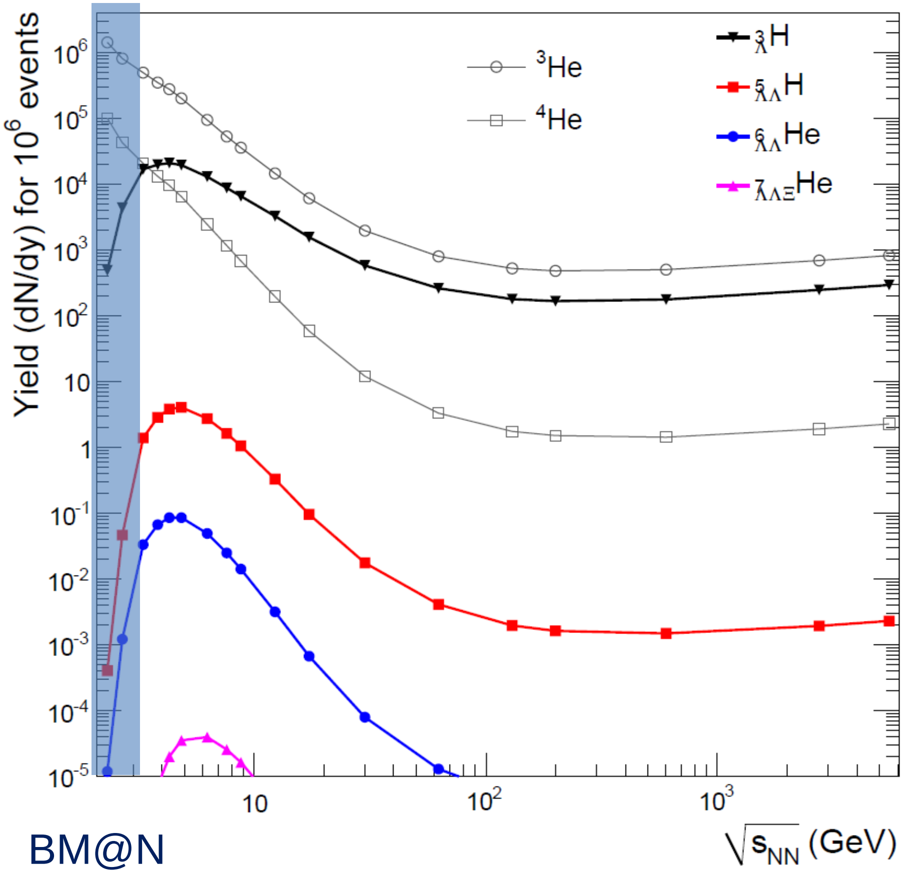
PHQMD calculations , V. Kireyeu et al., priv. comm.



Hypernuclei

N-Λ interaction

- Lambda hypernuclei



A. Andronic et al., Phys. Lett. B697 (2011) 203

Hypernuclei yields at the Nuclotron:
4 A GeV min. bias Au+Au collisions,
Reaction rate 10^4/s, Efficiency = 1%

Hyper-nucleus	Yield/week
$_\Lambda{}^3$H	$3\cdot10^5$

Measure:

$$_\Lambda{}^3\mathrm{H} \rightarrow {}^2\mathrm{H} + p + \pi^-$$

Upgrading the BM@N tracking system

1. STS layout and design studies

Mission:

Exploring (multi-strange) particle production in Au+Au collisions with kinetic beam energies of up to 4.5A GeV and beam intensities up to $2 \cdot 10^6$ ions/s.

Requirement:

Highly granulated and radiation hard tracking detector system.

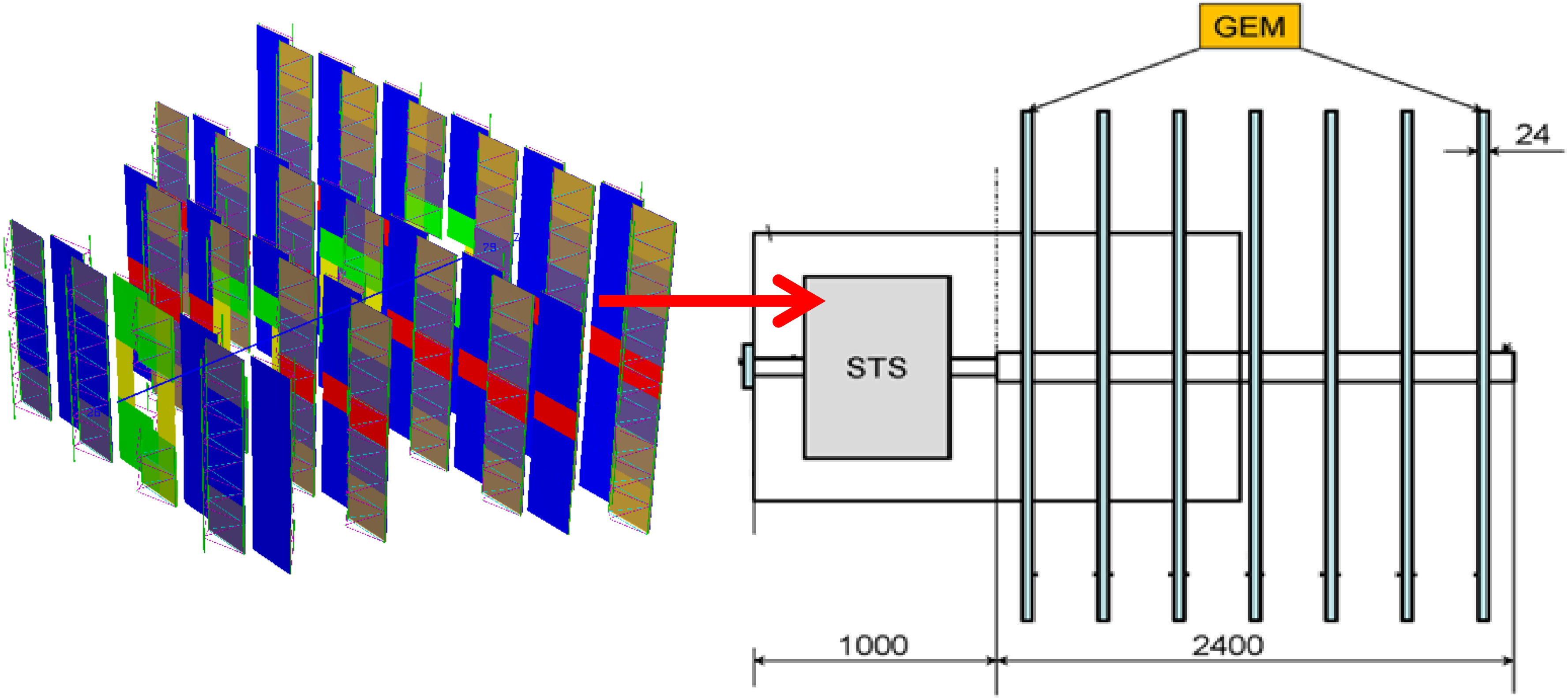
Proposal:

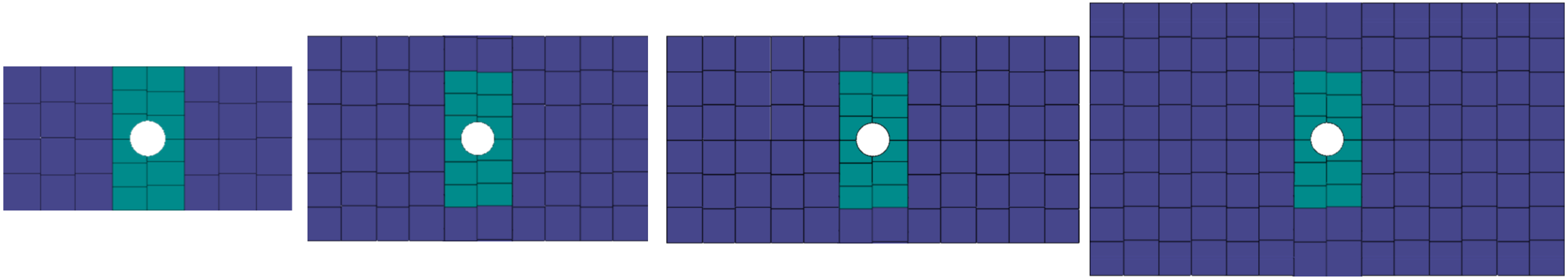
Installation of 4 detector stations based on double-sided multi-strip silicon sensors developed for the CBM experiment, including read-out electronics.

Design studies:

Simulations of min. bias Au+Au collisions with beam kinetic energies of 4A GeV using the LAQGSM transport code. The detector model comprizes sensors, read-out cables, frontend electronics, and carbon fiber support structures (E. Lavrik).

Upgrading the BM@N tracking system





Numbers and sizes of silicon sensors

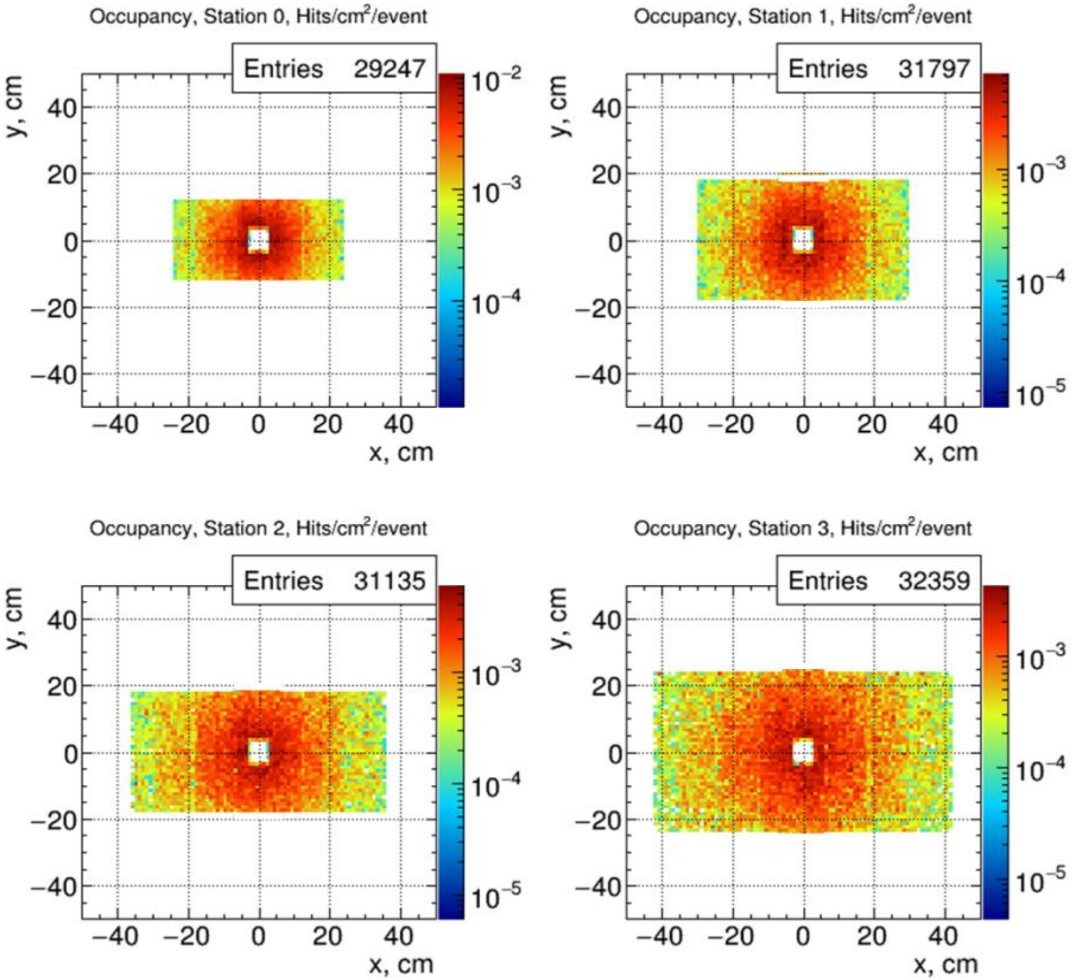
Double-sided sensors, 1024 channels each side, pitch 57 μm, stereo angle 7.5°

STS Station	Number of sensors	Size of sensors
1	24	62 x 62 mm^2
	8	42 x 62 mm^2
	4 (cut)	42 x 62 mm^2
2	52	62 x 62 mm^2
	8	42 x 62 mm^2
	4 (cut)	42 x 62 mm^2
3	64	62 x 62 mm^2
	8	42 x 62 mm^2
	4 (cut)	42 x 62 mm^2
4	104	62 x 62 mm^2
	8	42 x 62 mm^2
	4 (cut)	42 x 62 mm^2

Sum of sensors	Size of sensors
244	62 x 62 mm^2
32	42 x 62 mm^2
16 (cut)	42 x 62 mm^2
Total: 292	

Occupancies

Evgeny Lavrik (GSI)



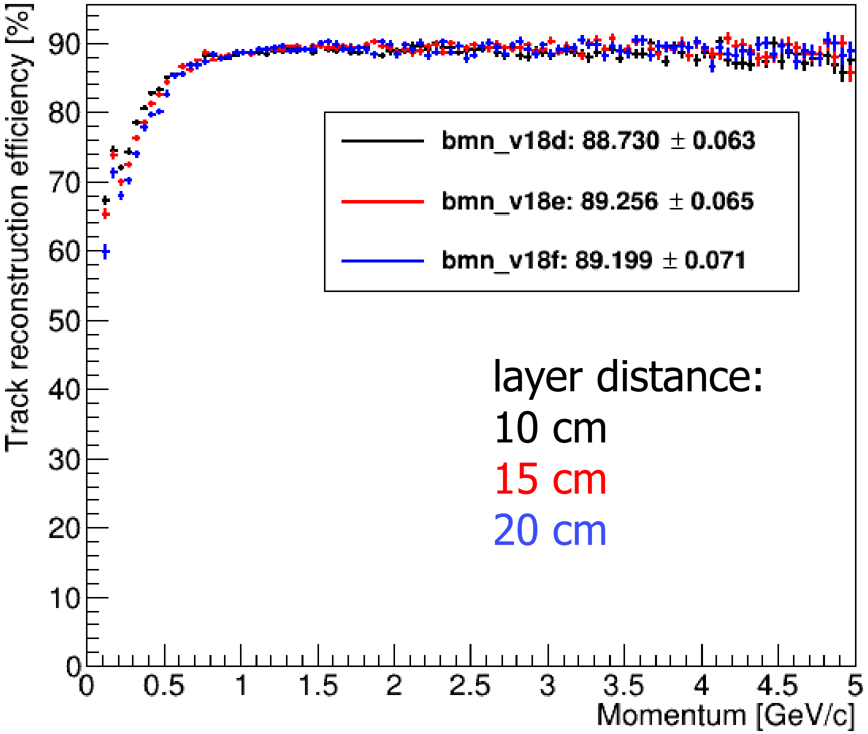
- ➢ Layer distance 15 cm
- ➢ Hit densities < 0.01 hits/cm^2/event.
- ➢ For sensor of size 42 x 62 mm^2 : strip occupancy < $5 \cdot 10^{-4}$ per event.

STS track reconstruction performance

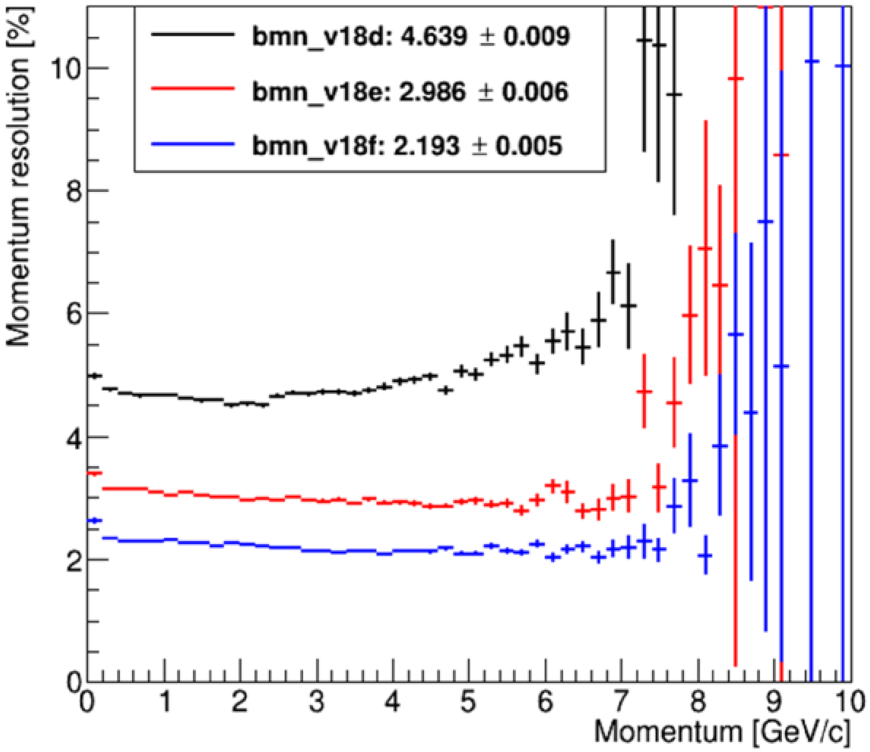
Evgeny Lavrik (GSI)

Simulations of min. bias Au+Au collisions at 4A GeV for B·L = 0.44 Tm

Track reconstruction efficiency

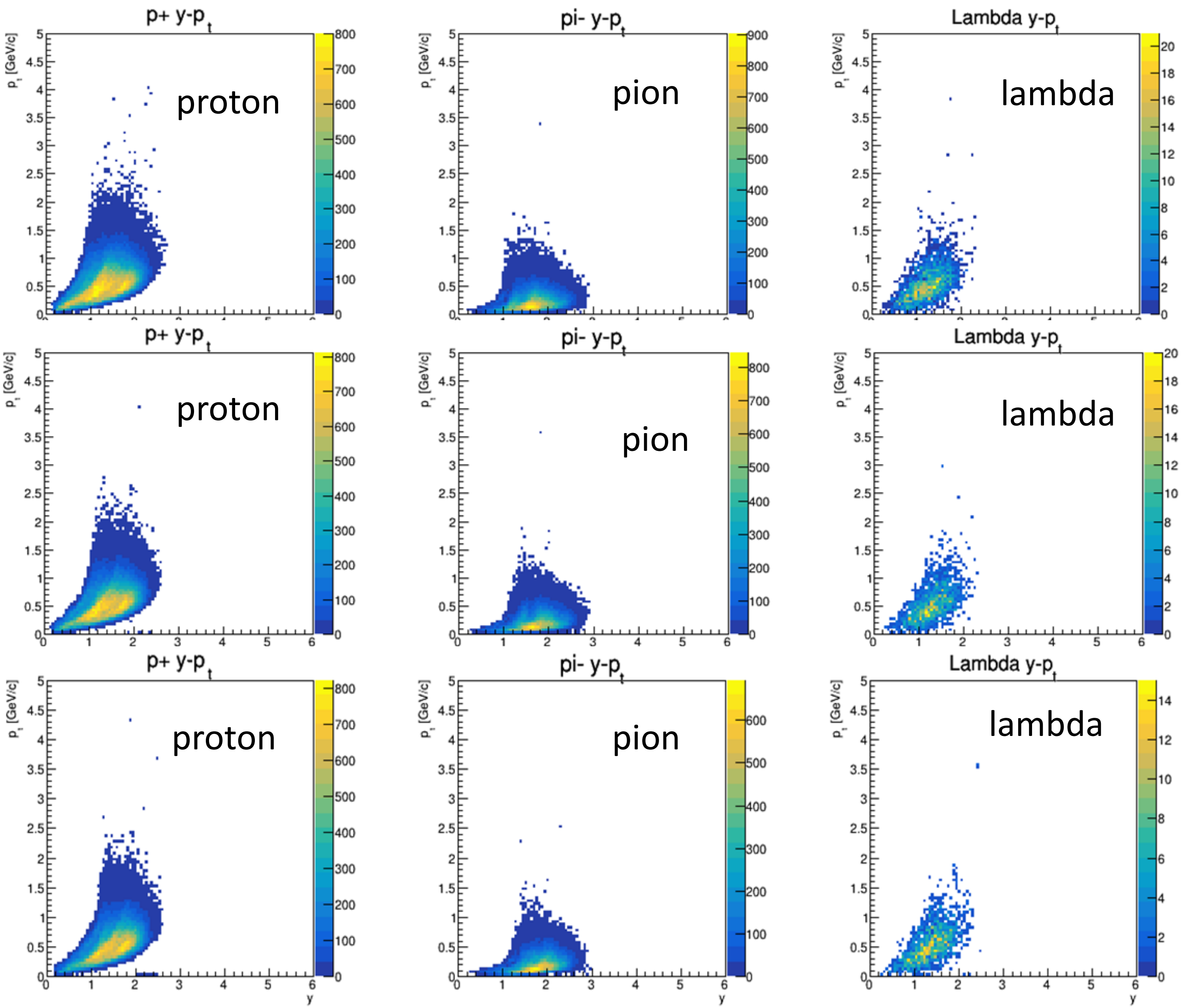


Momentum resolution



Acceptance: STS only

Evgeny Lavrik (GSI)



layer distance: 10 cm

layer distance: 15 cm

layer distance: 20 cm

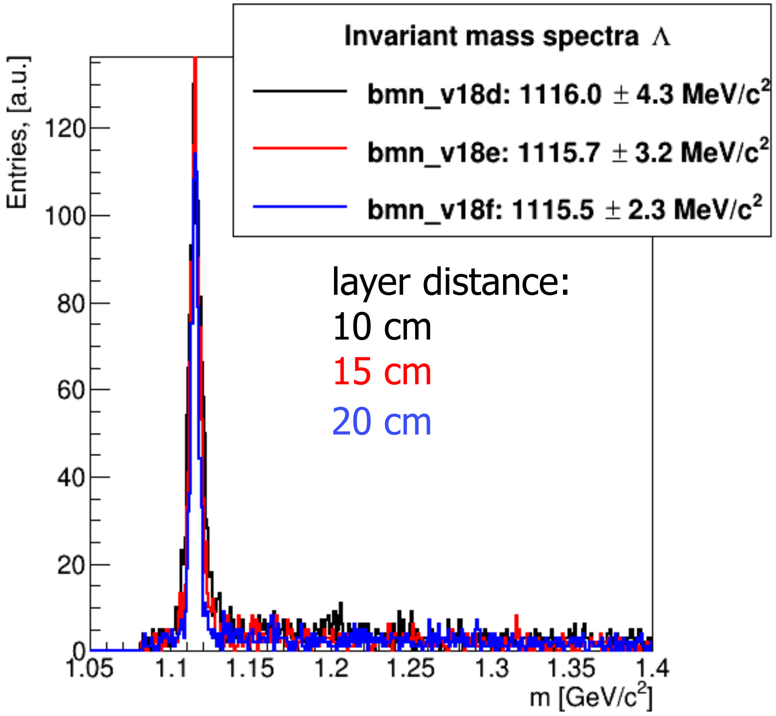
Midrapidity y_0 = 1.17

Lambda reconstruction: STS only

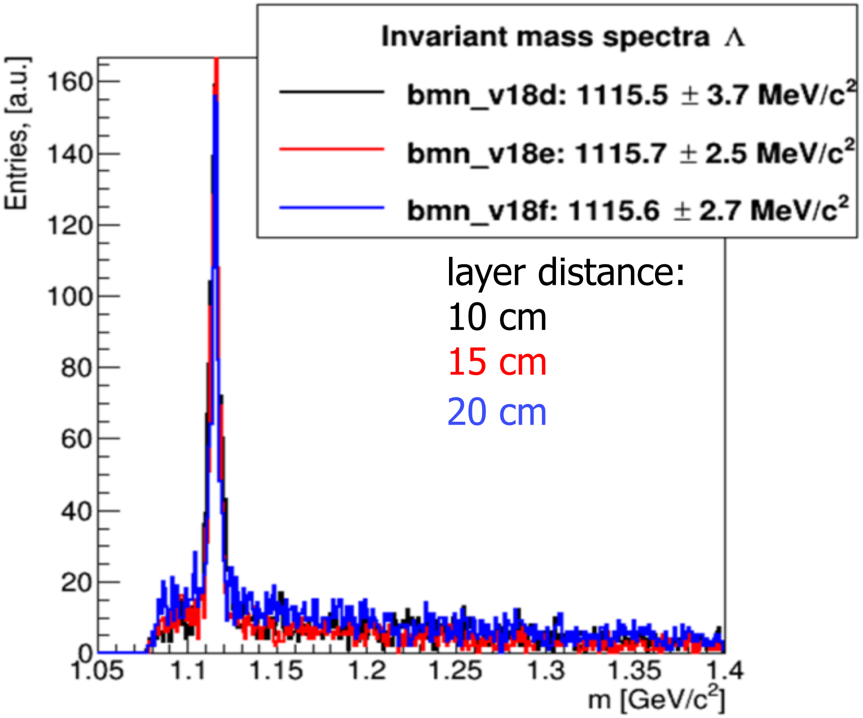
Evgeny Lavrik (GSI)

$p\ \pi^-$ invariant mass spectra

Simulations of min. bias Au+Au collisions at 4A GeV for B·L = 0.44 Tm using the LAQGSM transport code and the CBM KF particle finder



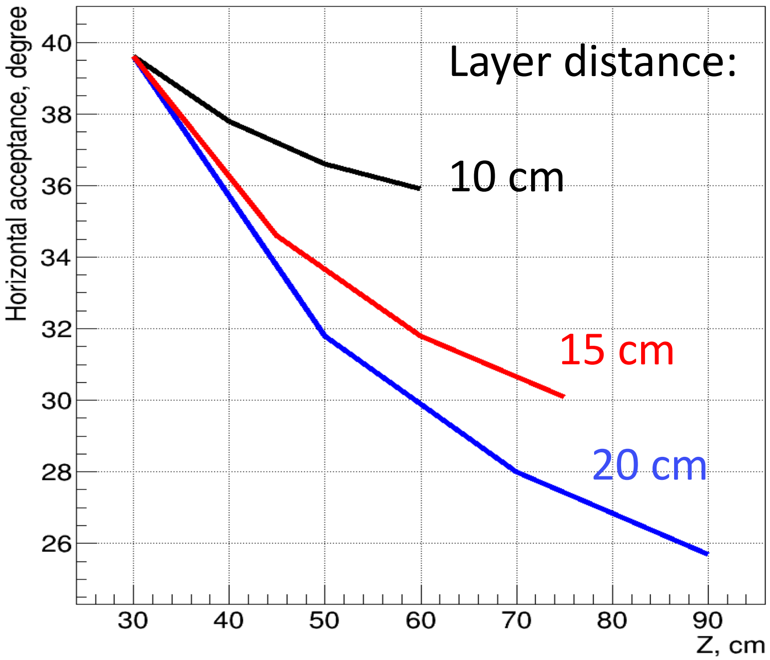
MC particle identification



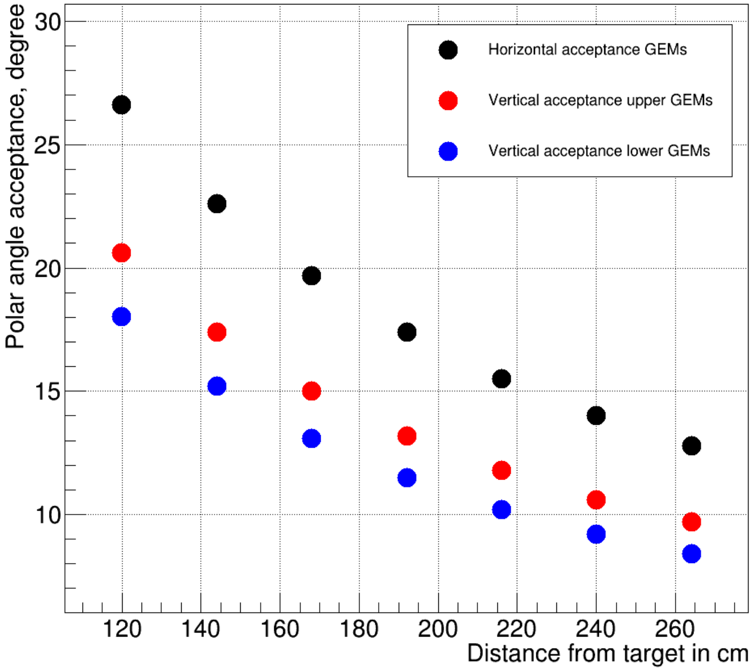
no particle identification

Geometrical angular acceptances

STS



GEMs



TOF-400: 6°< 21°

TOF-700: < 13°

Data analysis scenarios

The performance the BM@N tracking system will be improved when including the GEM tracking stations into the analysis. However, the GEM stations and the TOF detectors cover smaller polar angles, which reduces the transverse momentum acceptance and the efficiency.

Depending on the physics case, and on the signal to background situation of the various particles, it might be favorable to perform two data analyses, one with STS only, and another one with the hybrid tracker STS + 8 stations GEM.

Possible scenario: STS + 3 first GEM stations + TOF cover a horizontal angular angular acceptance of 20° (last GEM station covers only 13°).

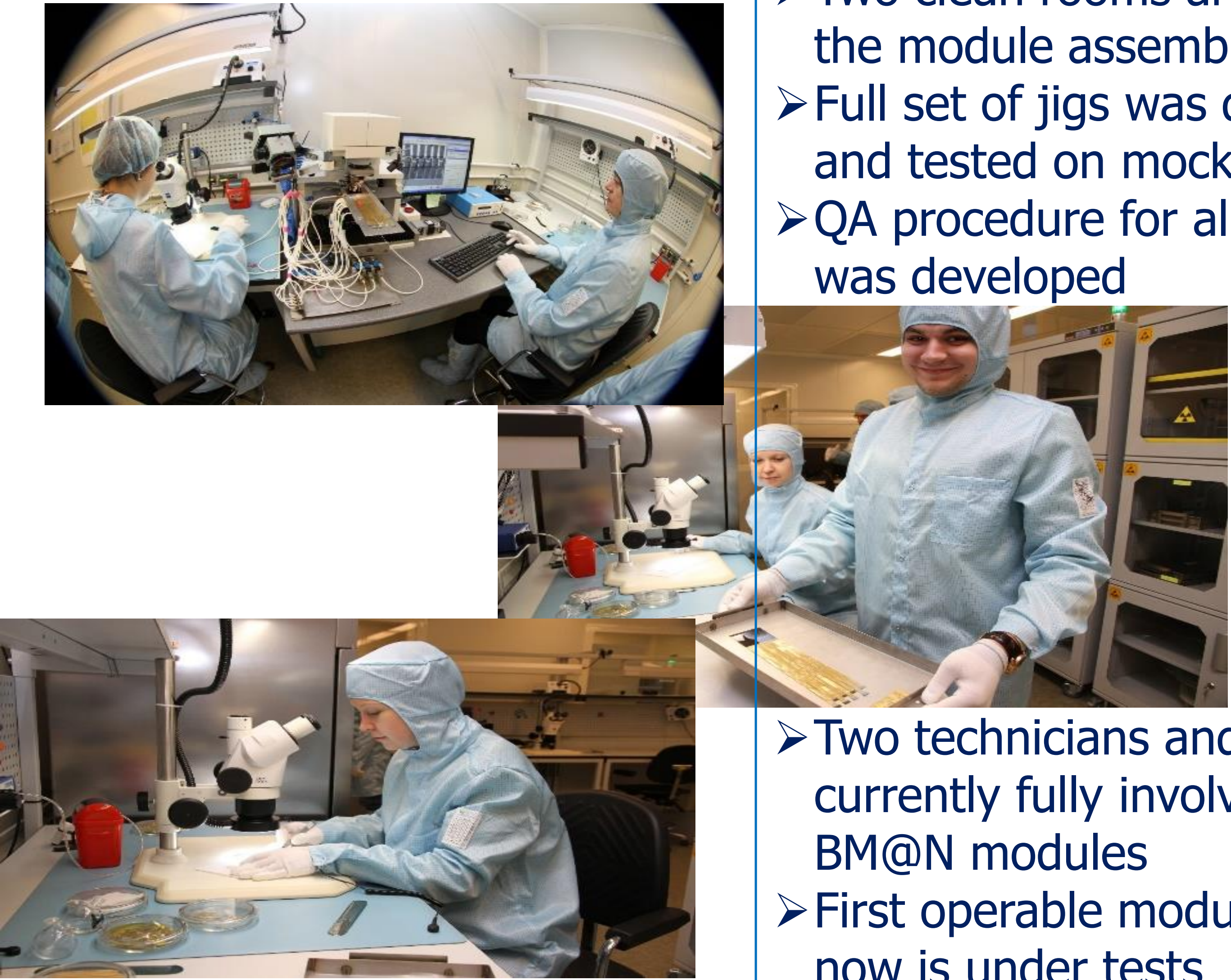
STS layout studies: Summary and conclusions

Simulations confirm performance of the STS design concerning occupancy, acceptance, track reconstruction efficiency. Lambda hyperons can be clearly identified, even without particle identification.

Required: detailed simulations on multi-strange particle production including GEM and TOF based on realistic detector geometries and material budget.

Detector development activities at JINR

- Two clean rooms are already equipped for the module assembly
- Full set of jigs was developed, produced and tested on mockups
- QA procedure for all steps of assembling was developed

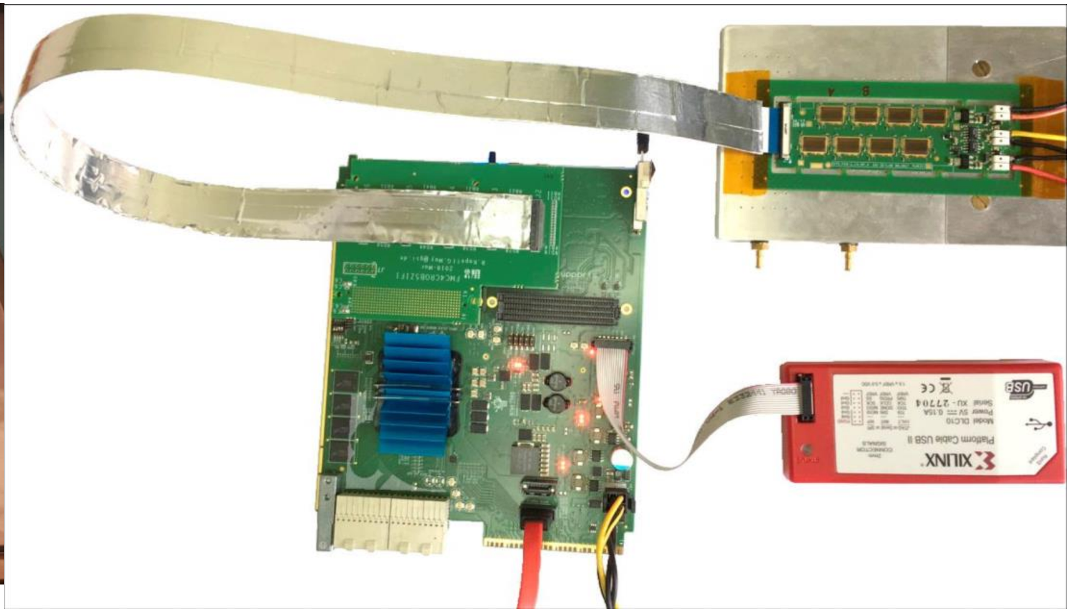


- Two technicians and two engineers are currently fully involved into assembling of BM@N modules
- First operable module was assembled and now is under tests

Detector development activities at JINR

Dmitrii Dementev (JINR STS team)

Module assembly at JINR:
Sensor + microcables + FEBs



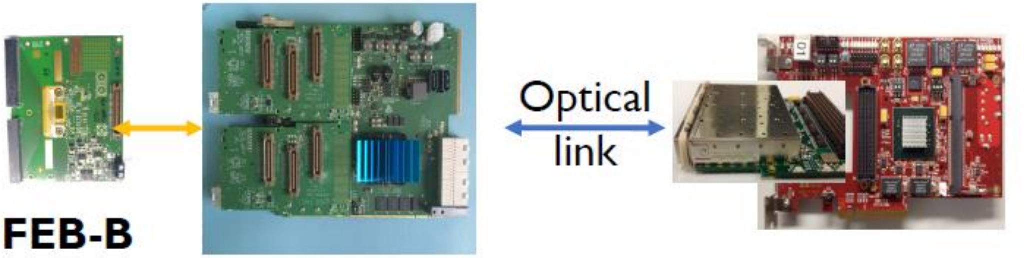
Test bench for Front-End Boards with 8 ASICS

Joint JINR-GSI workshop on Dec. 10 – 11 2018 at GSI

Beam tests at LINAK-200

Dmitrii Dementev (JINR STS team)

Scheme of the readout chain:

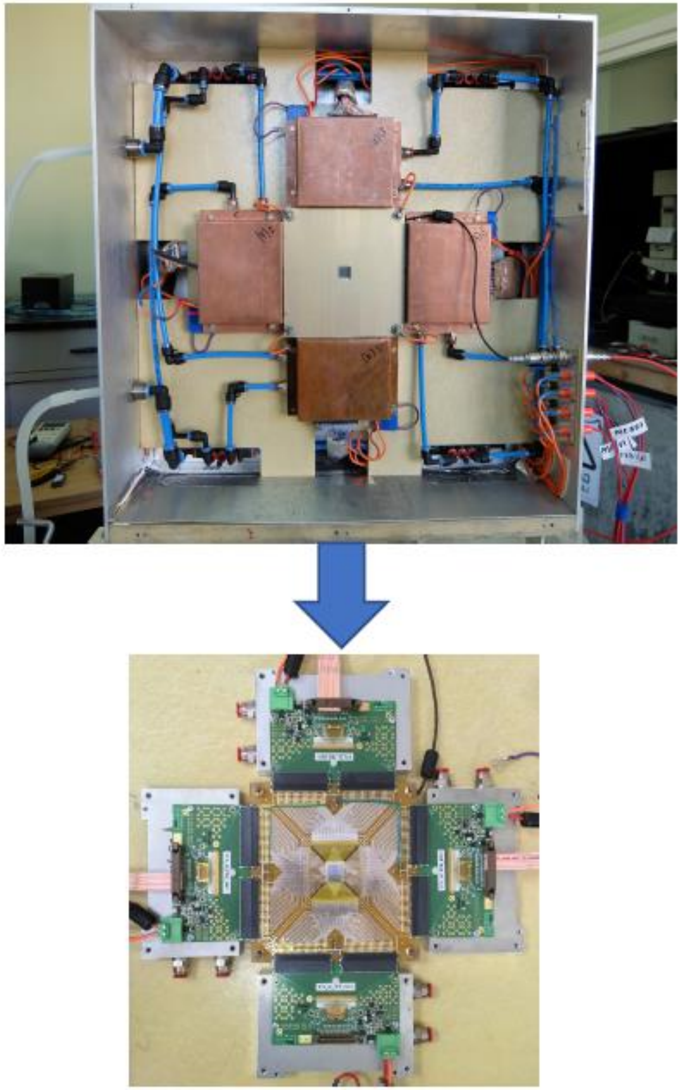


FEB-B

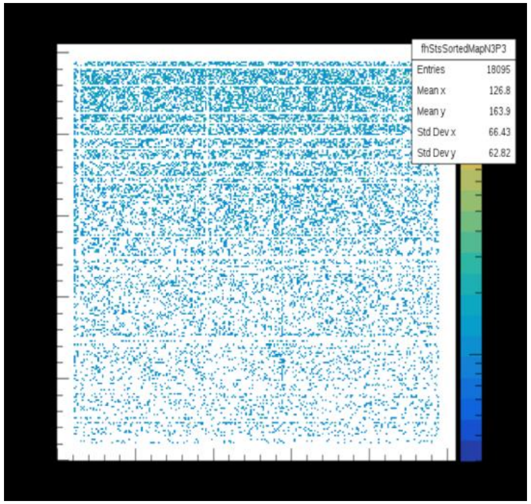
Optical link

AFCK with 2x gDPB FMC

HTG-K700 with FM-S18 FMC



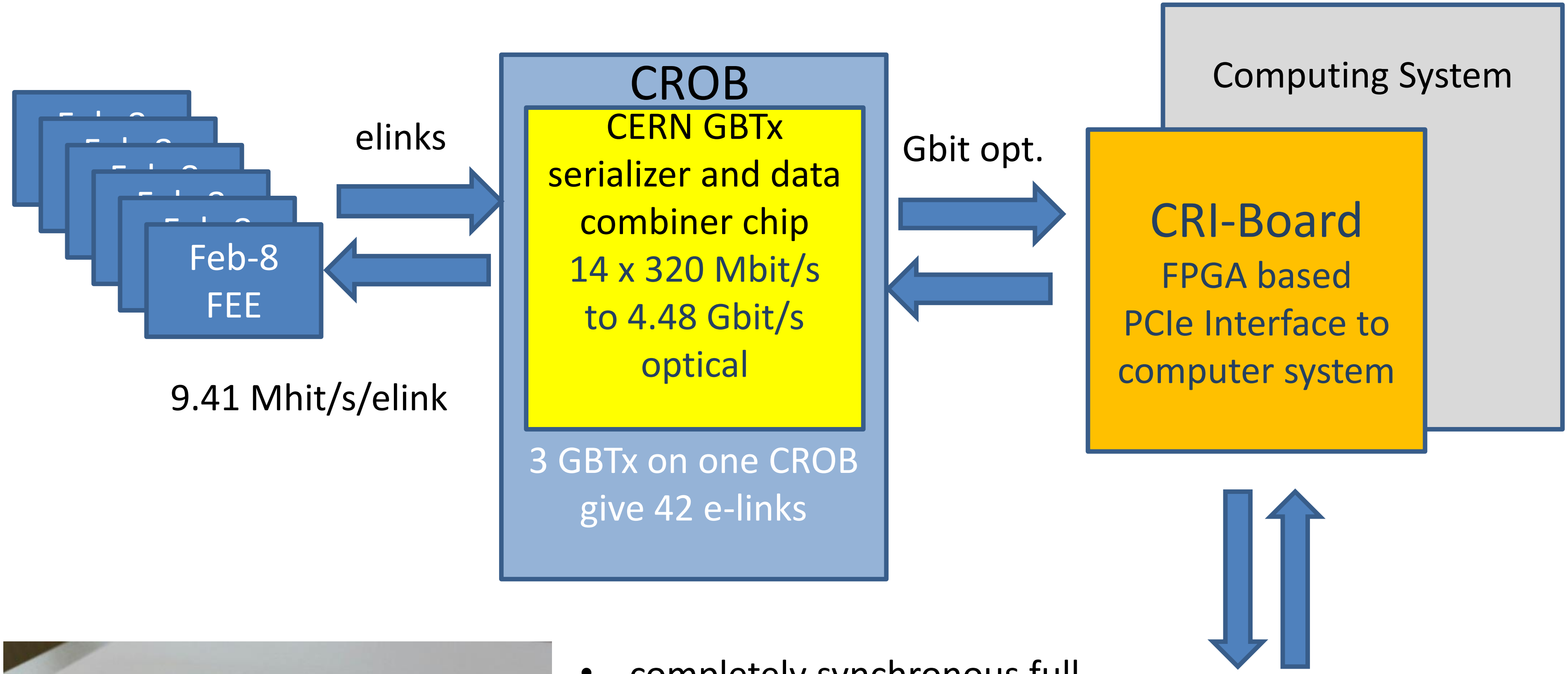
Test setup comprises two test stations with baby sensors and 8 FEBs-B



Sensors, readout system, synchronization and online monitoring of data were tested

STS data read-out chain (CBM)

Christian Schmidt (Head of GSI Det-lab)



Feb-8
FEE

elinks

9.41 Mhit/s/elink

CROB

CERN GBTx serializer and data combiner chip

14 x 320 Mbit/s to 4.48 Gbit/s optical

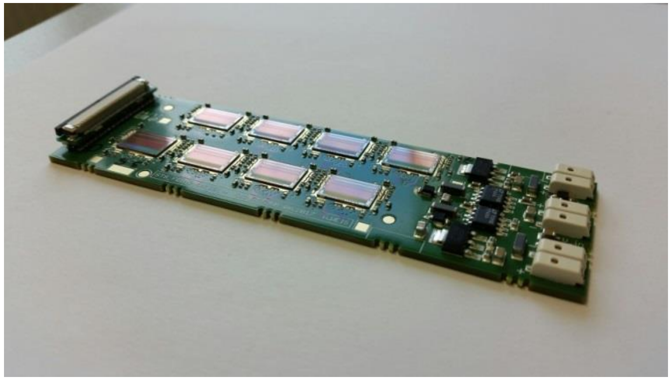
3 GBTx on one CROB give 42 e-links

Gbit opt.

Computing System

CRI-Board

FPGA based PCIe Interface to computer system



- completely synchronous full system operation,
- generating free streaming, self triggered data
- time-stamp-clocks on all chips need to be synchronous

TFC
Timing and Fast Control

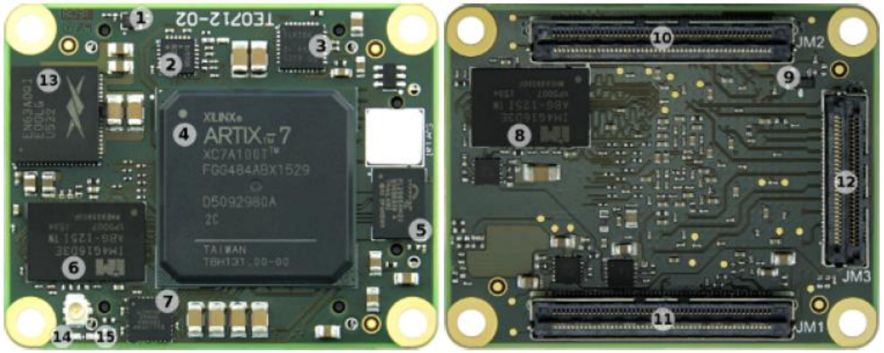
Adaption to BM@N

Christian Schmidt (Head of GSI Det-lab)

- Emulate GBTx functionality on an FPGA
- Employ all of CBM firmware and software for BM@N
- For optimized economic solution: try to scale rate capability to adequately match BM@N data rates

Visa-Card sized XYLINX Serial-7 FPGA Board

Fully functional and tested, long term availability (15 years guaranteed). No design iterations needed, directly dive into firmware adaptation and development



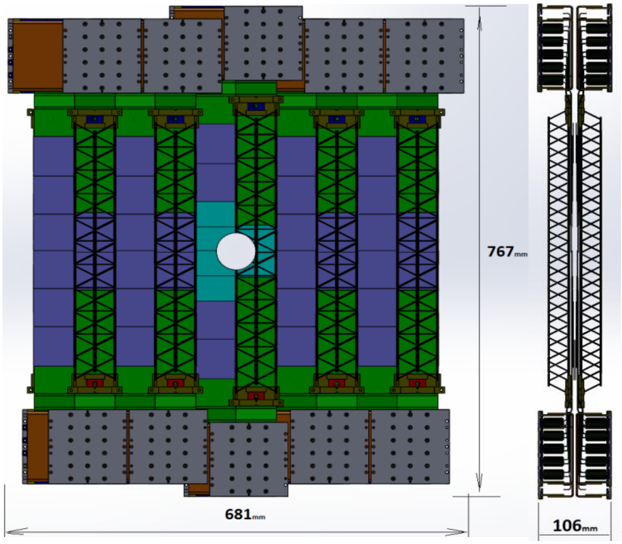
Firmware workpackages:

Firmware GBTxEMU-3Sens	WUT Warsaw, W. Zabolotny
Firmware GERI	WUT Warsaw, W. Zabolotny, Univ. Frankfurt ?
Firmware TFC-System	KIT Karlsruhe, Vladimir Sidorenko, Lukas Meder

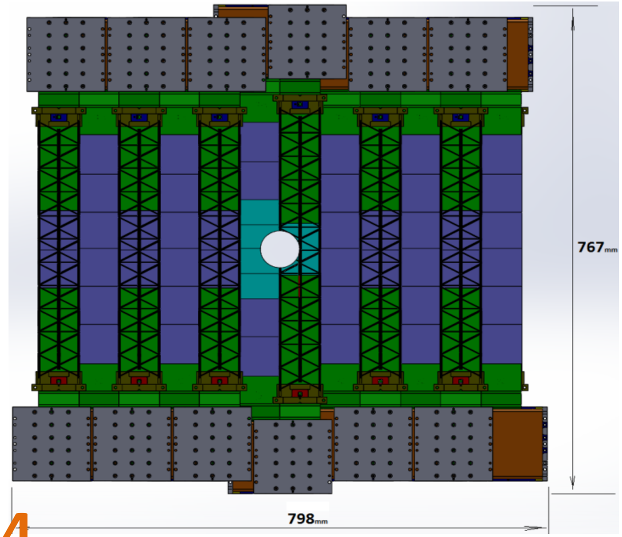
Tentative STS layout: ladders

Vladimir Elsha (LHEP JINR)

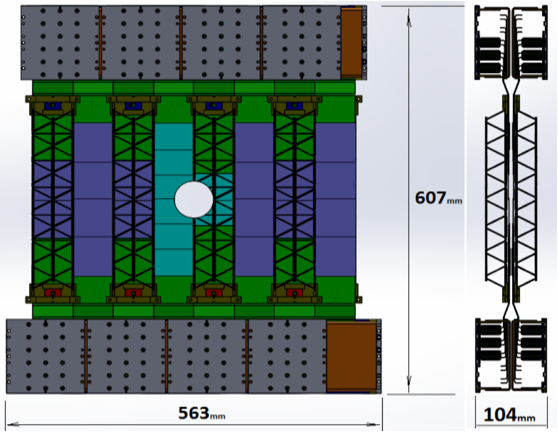
STS2



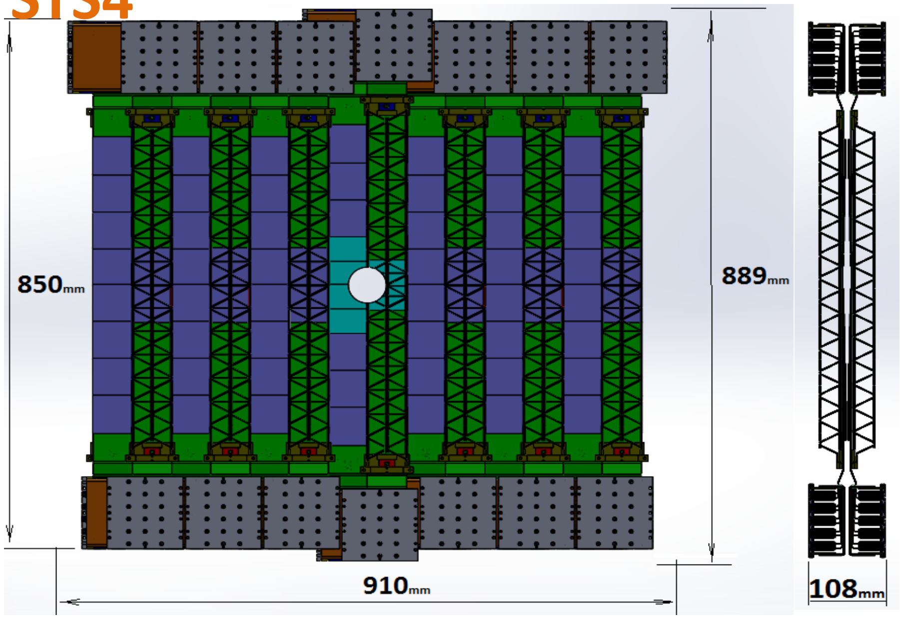
STS3



STS1

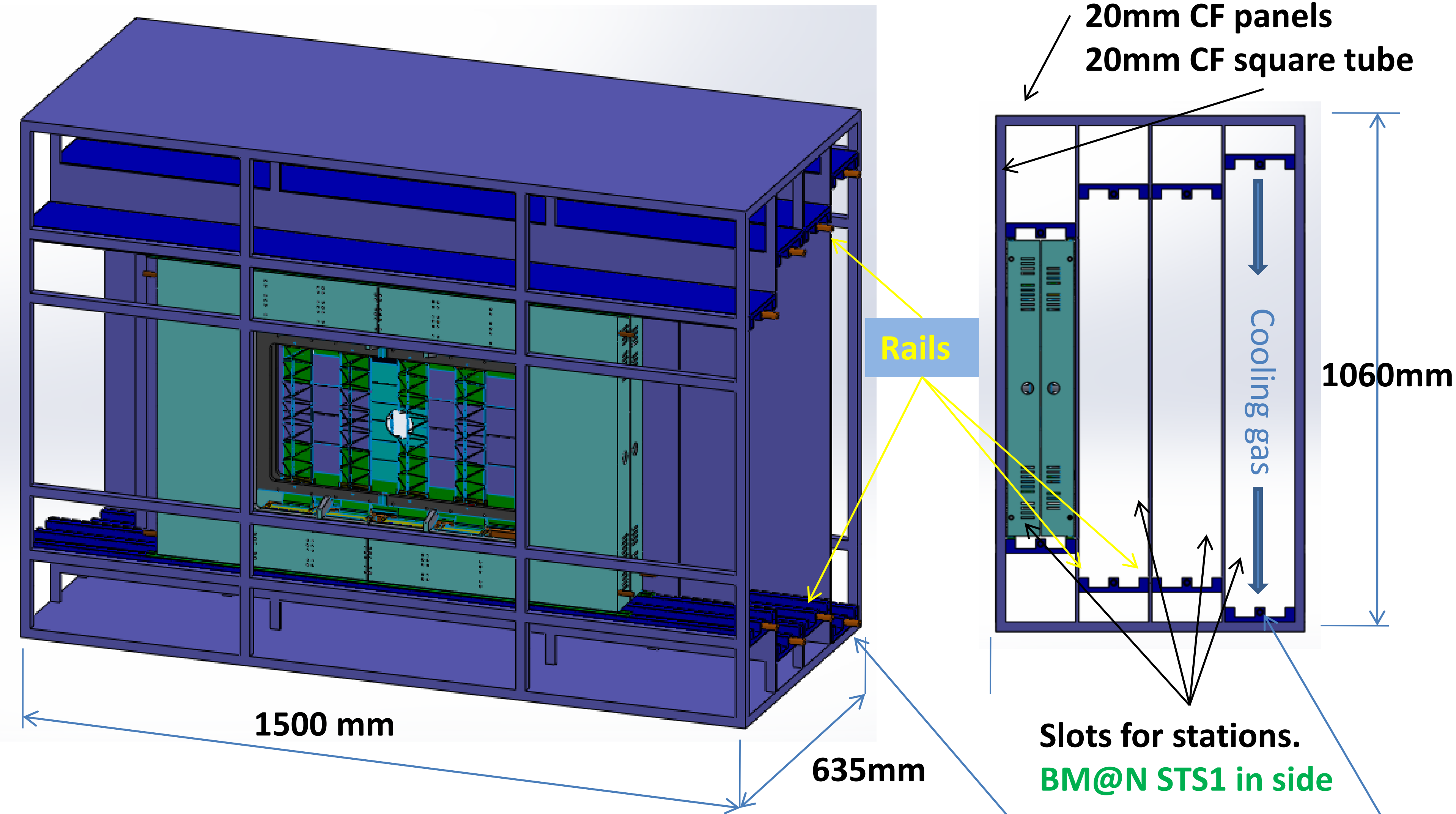


STS4



Tentative STS layout: mainframe

Vladimir Elsha (LHEP JINR)



Thermal insulating box

20mm CF panels

20mm CF square tube

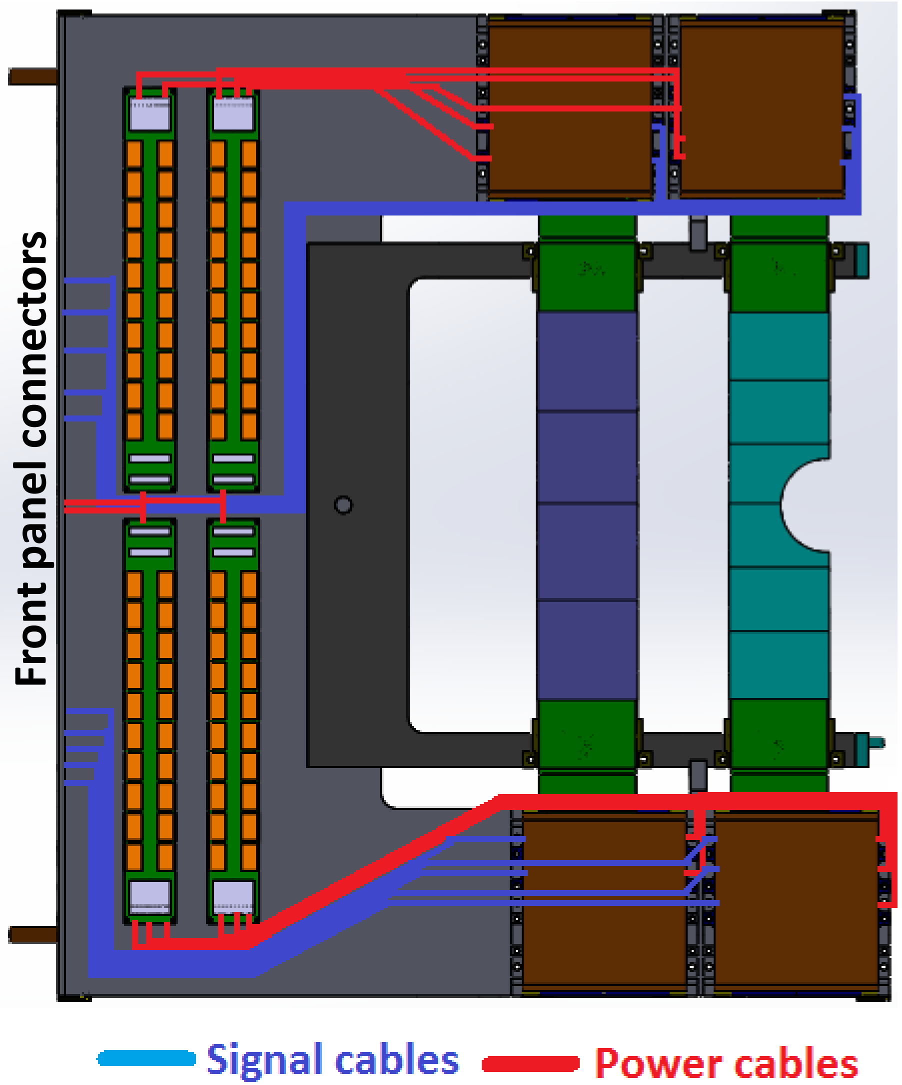
Slots for stations.

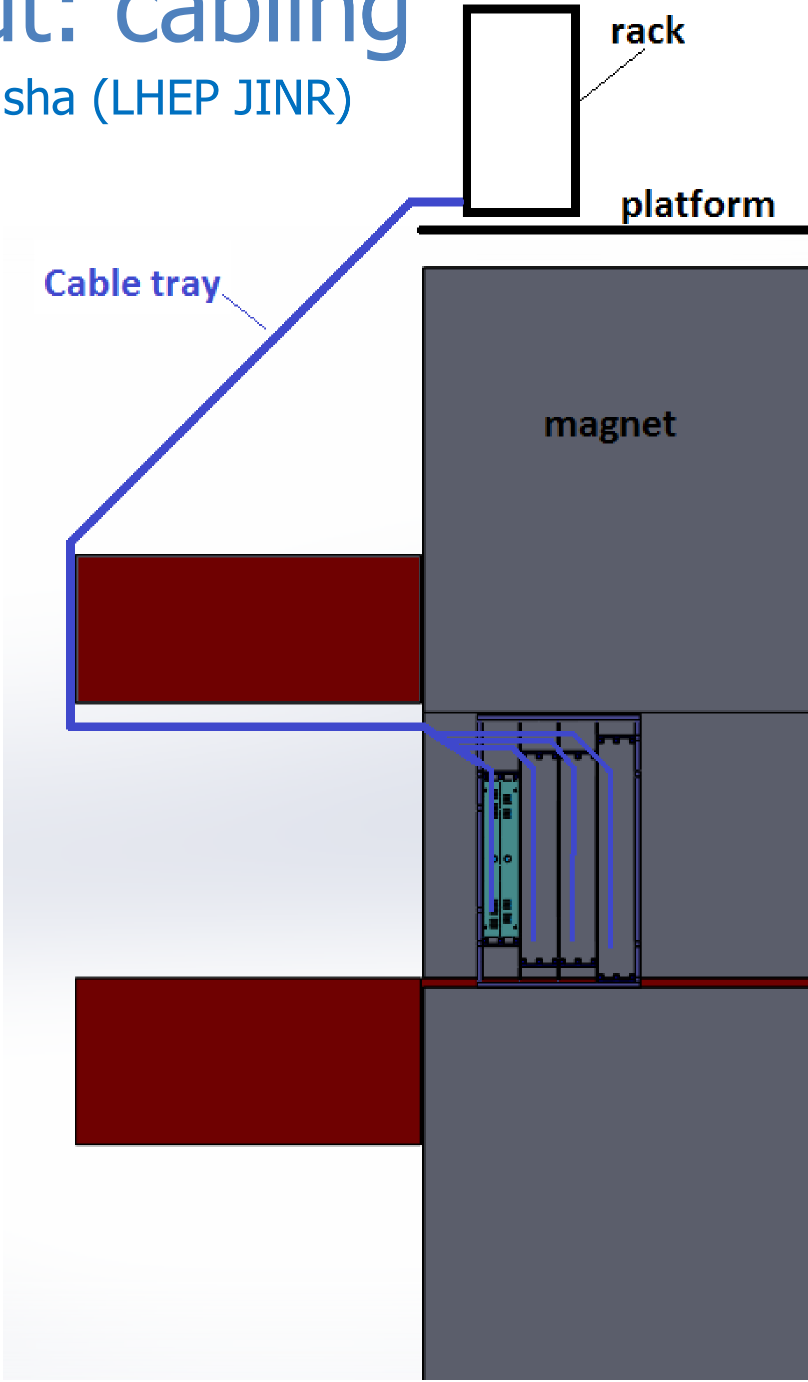
BM@N STS1 in side

Cooling gas jet system

Tentative STS layout: cabling

Vladimir Elsha (LHEP JINR)



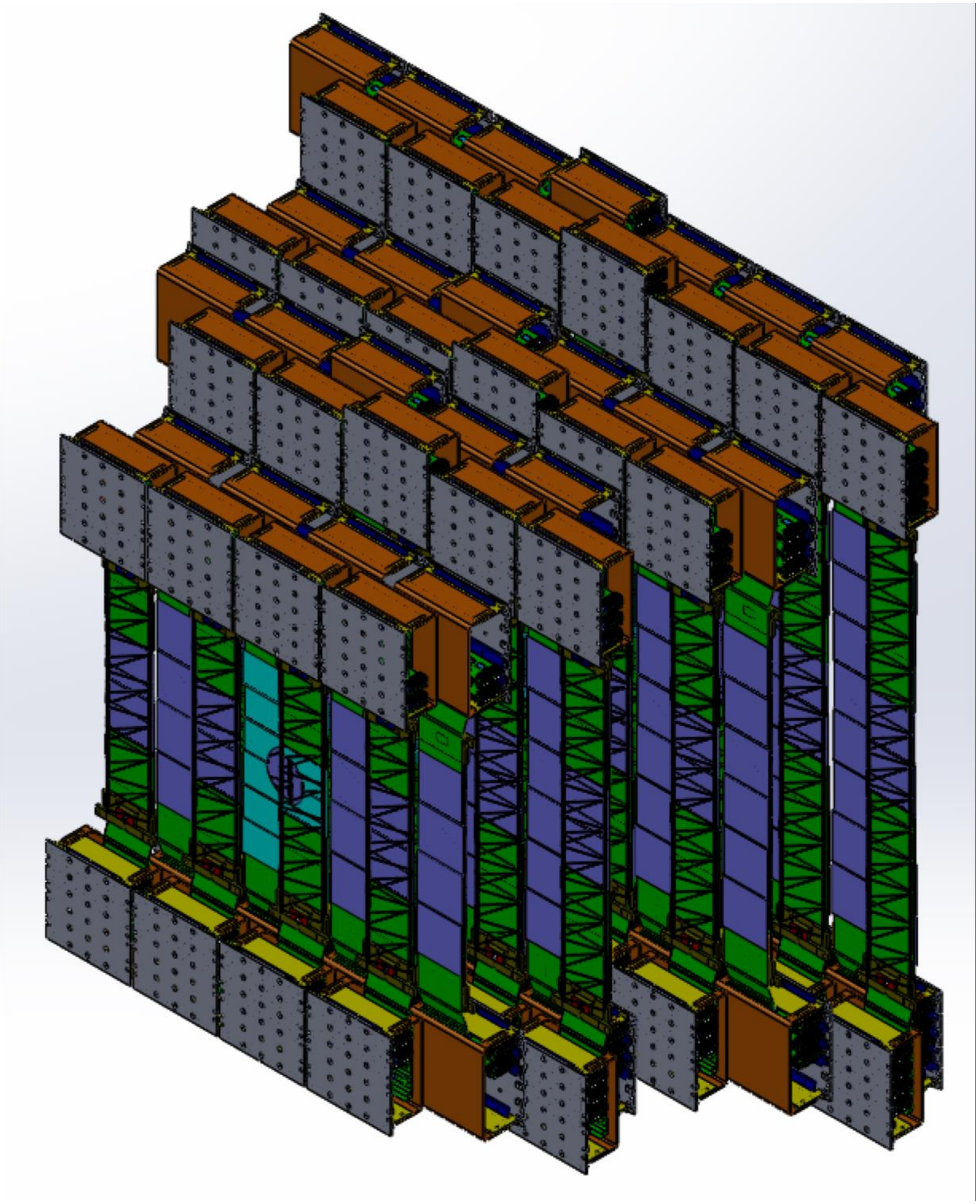


Cable tray length approximately – **6 m**

Cable and connectors type are open issues

Detector development: To-do list

Vladimir Elsha (LHEP JINR)



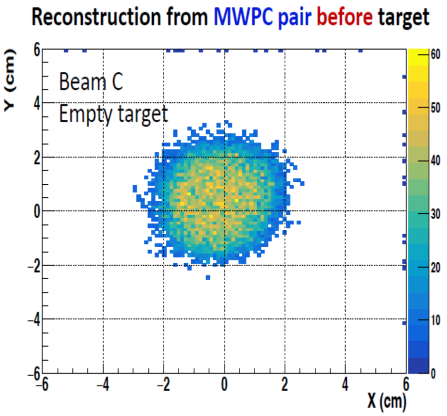
1. Design and production of innermost sensors of size 42 x 62 mm^2 with cutoff for beam pipe.
2. Design and production of CF frames.
3. Choice of cables and connectors.
4. Design and production of rail systems for the half-stations and for the mainframe.
5. Design and production of the cooling system.
6. Realization of the data readout chain.

3. Beam line from Nuclotron to BM@N

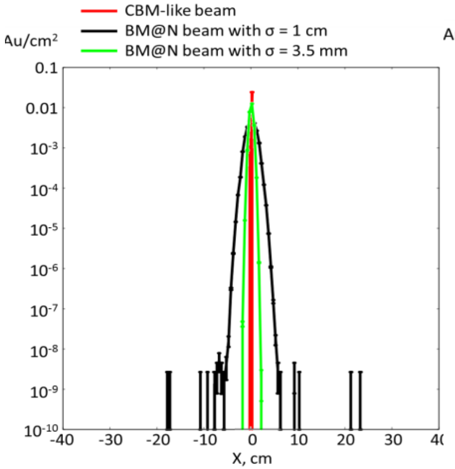
FLUKA simulations

Anna Senger (GSI)

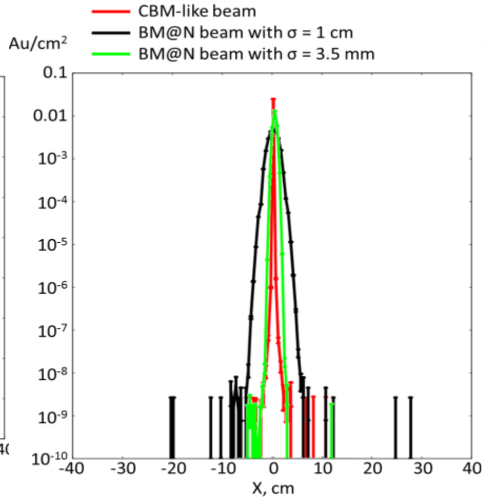
- ➢ BM@N-2 Setup with vacuum beam pipe downstream the target
- ➢ Au-beam with energy of 5A GeV, 2x10^6 Au ions/s
- ➢ Au target 250 μm (1% interaction)
- ➢ Beam parameters:
  - \- Present Nuclotron beam: Gauss with sigma 1 cm, divergence 1 mrad
  - \- Improved Nuclotron beam: Gauss with sigma 0.35 cm, divergence 1 mrad
  - \- SIS100 beam: rectangular 0.06 cm X/Y, divergence 1.7 mrad



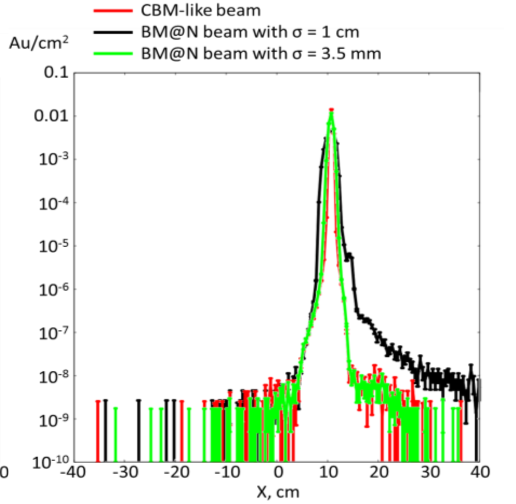
Present Nuclotron beam at target



Beam profiles at target

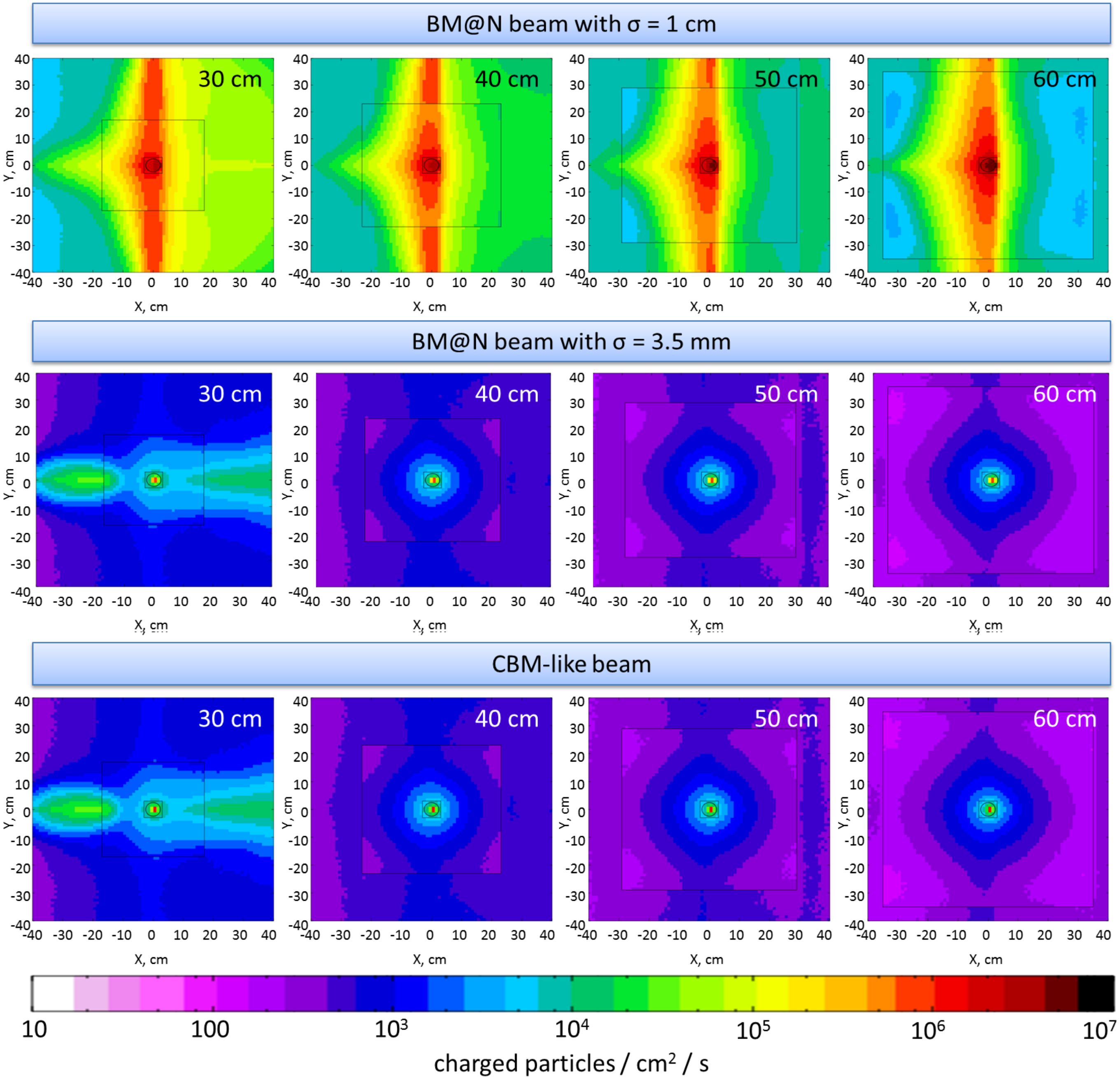


Beam profiles at 30 cm downstream target



Beam profiles at 420 cm downstream target

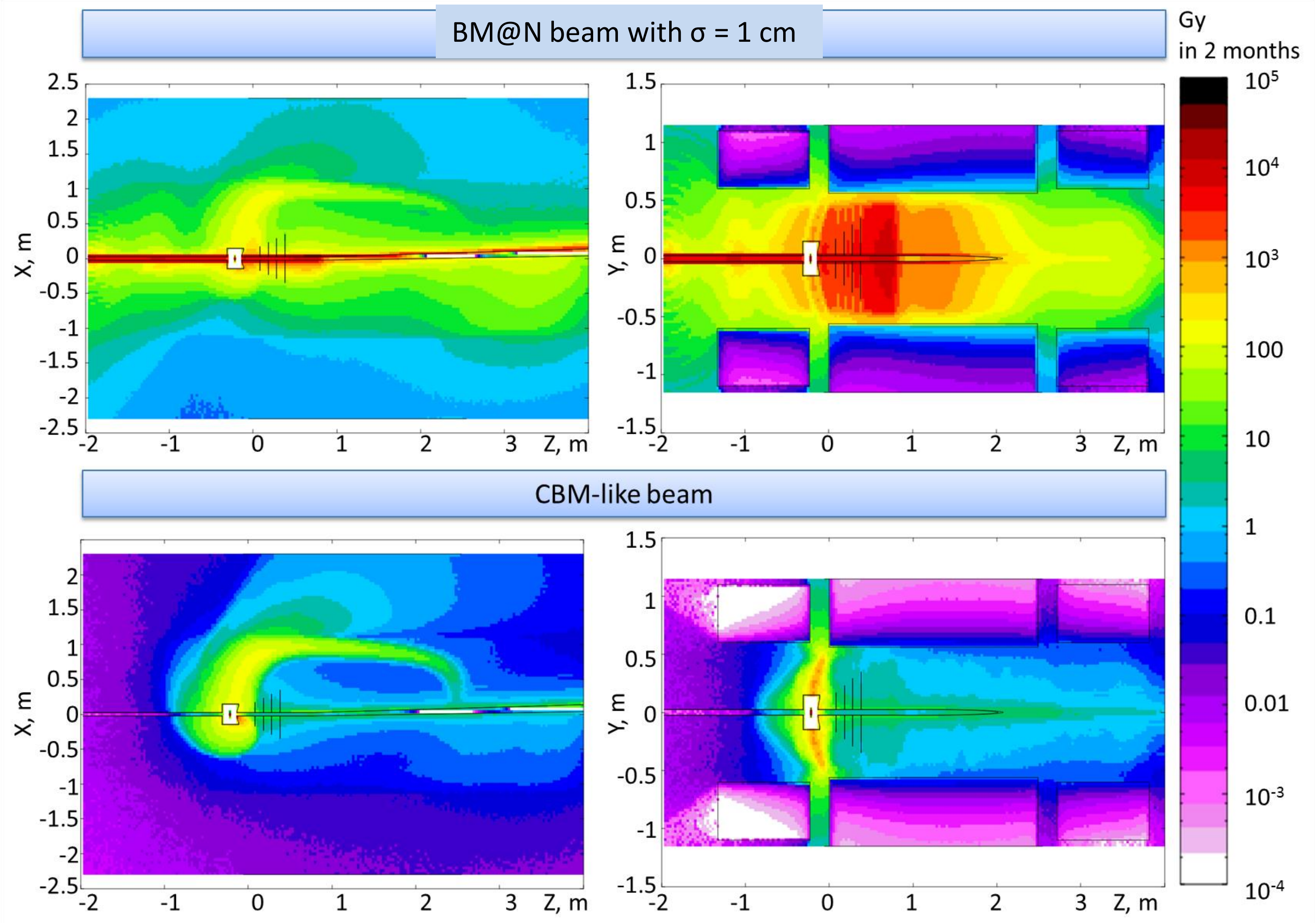
Charged particle densities in the four STS stations



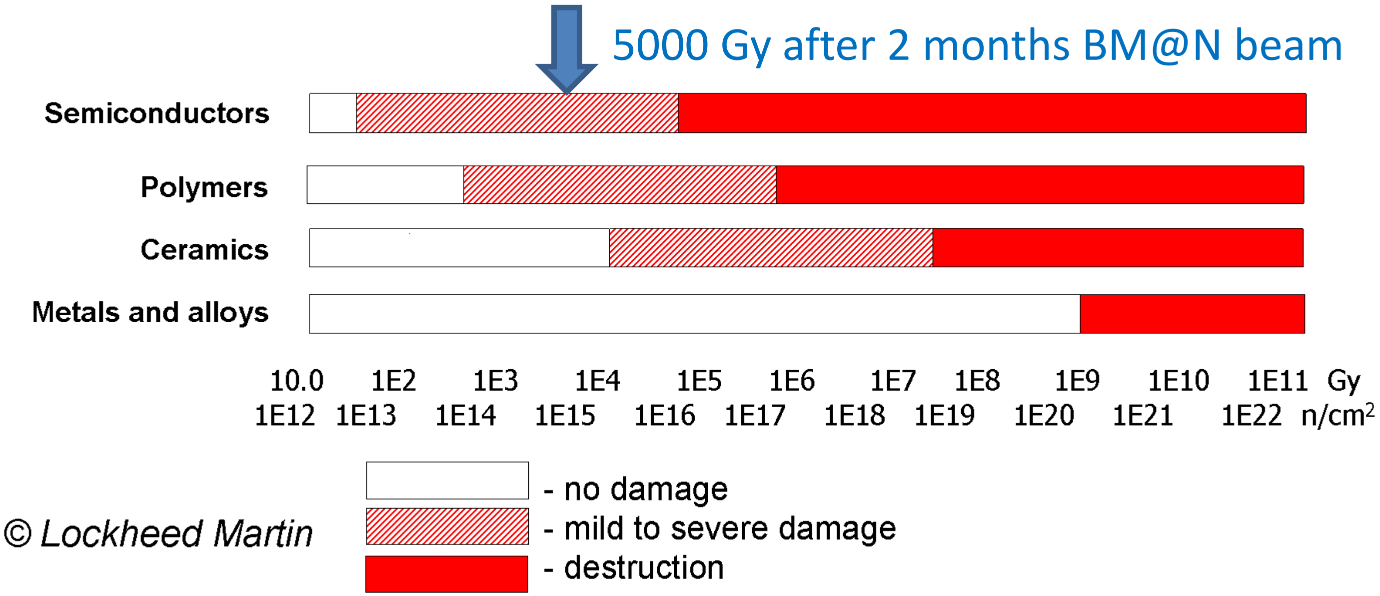
Anna
Senger
(GSI)

Ionizing dose after 2 months of $2 \cdot 10^6$ Au ions/s

Anna Senger (GSI)



Radiation damage

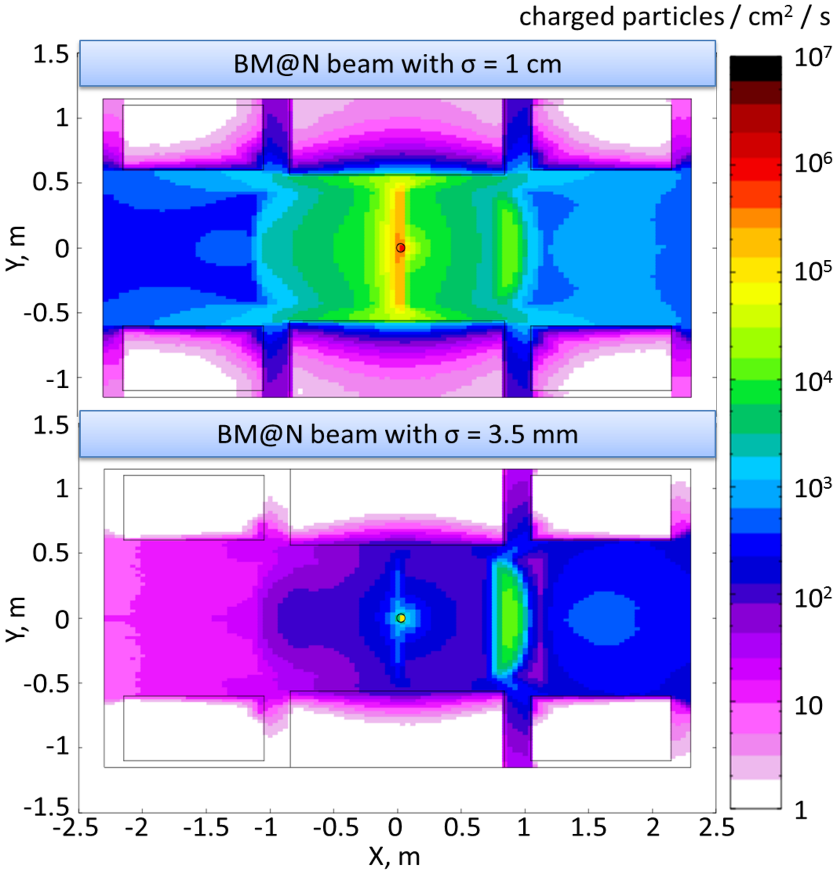


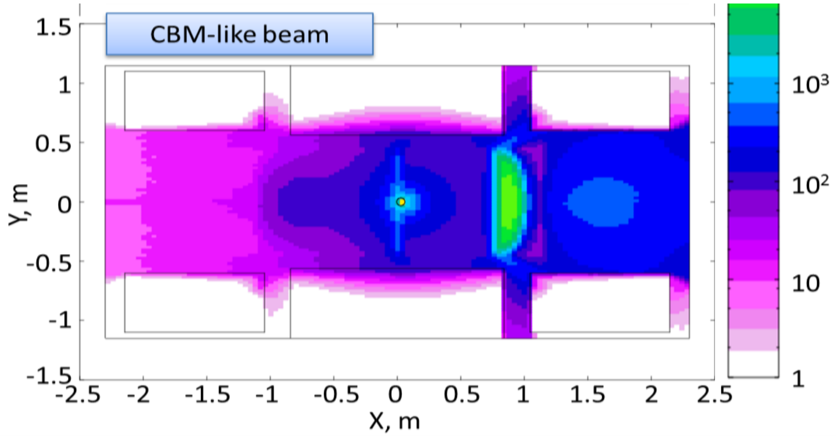
5000 Gy after 2 months BM@N beam

© *Lockheed Martin*

After 2 months BM@N beam (2x10^6 Au ions/s):
STS: severe damage
GEM: mild damage

Charged particles in GEM stations at z = 2 m





Anna Senger (GSI)

<u>BM@N beam with σ = 1 cm (2x10^6 Au ions/s):</u>
Delta electron rate: 200 kHz/cm^2

Electron rate on one strip (inner zone):
200 kHz/cm^2·1.2 cm^2 = 240 kHz
Channels busy: 240 kHz·2 μs = **48 %**

Electron rate on one strip (outer zone):
200 kHz/cm^2·2.4 cm^2 = 480 kHz
Channels busy: 480 kHz·2 μs = **96 %**

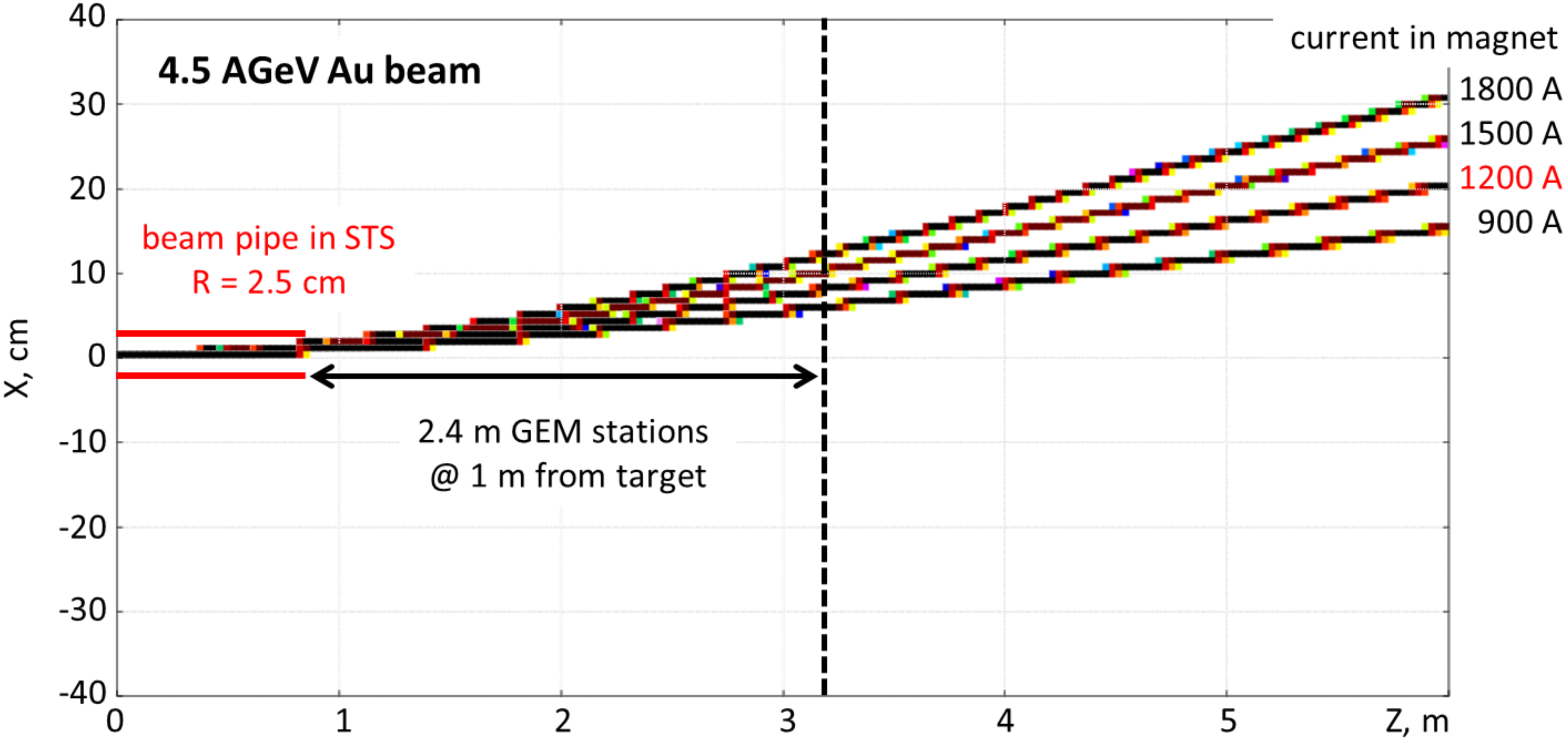
<u>BM@N beam with σ = 0.35 cm (2x10^6 Au ions/s):</u>
Delta electron rate: 2 kHz/cm^2

Electron rate on one strip (inner zone):
2 kHz/cm^2·1.2 cm^2 = 2.4 kHz
Channels busy: 2.4 kHz·2 μs = **0.48 %**

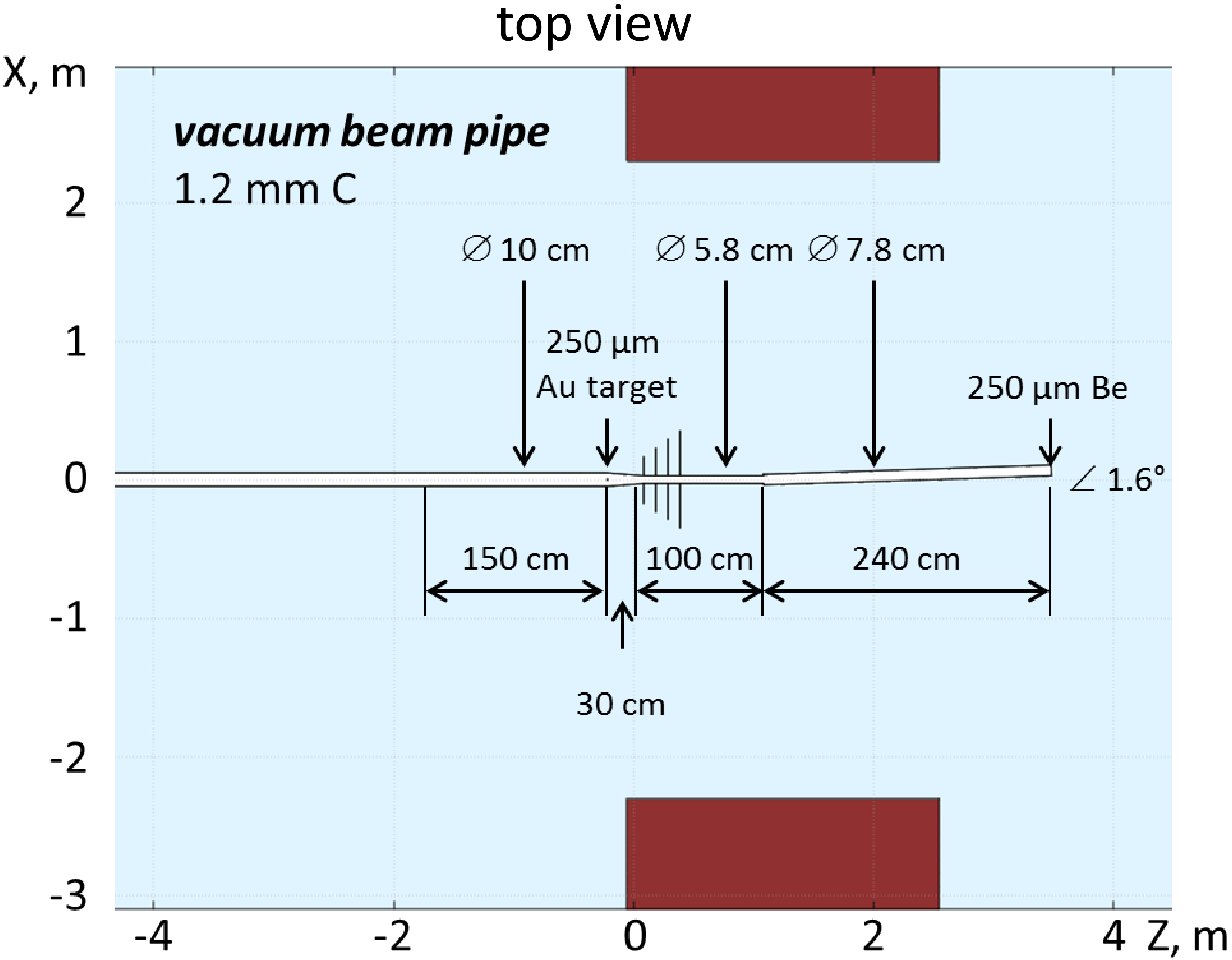
Electron rate on one strip (inner zone):
2 kHz/cm^2·2.4 cm^2 = 4.8 kHz
Channels busy: 4.8 kHz·2 μs = **0.96 %**

4. Beam pipe downsteam BM@N target

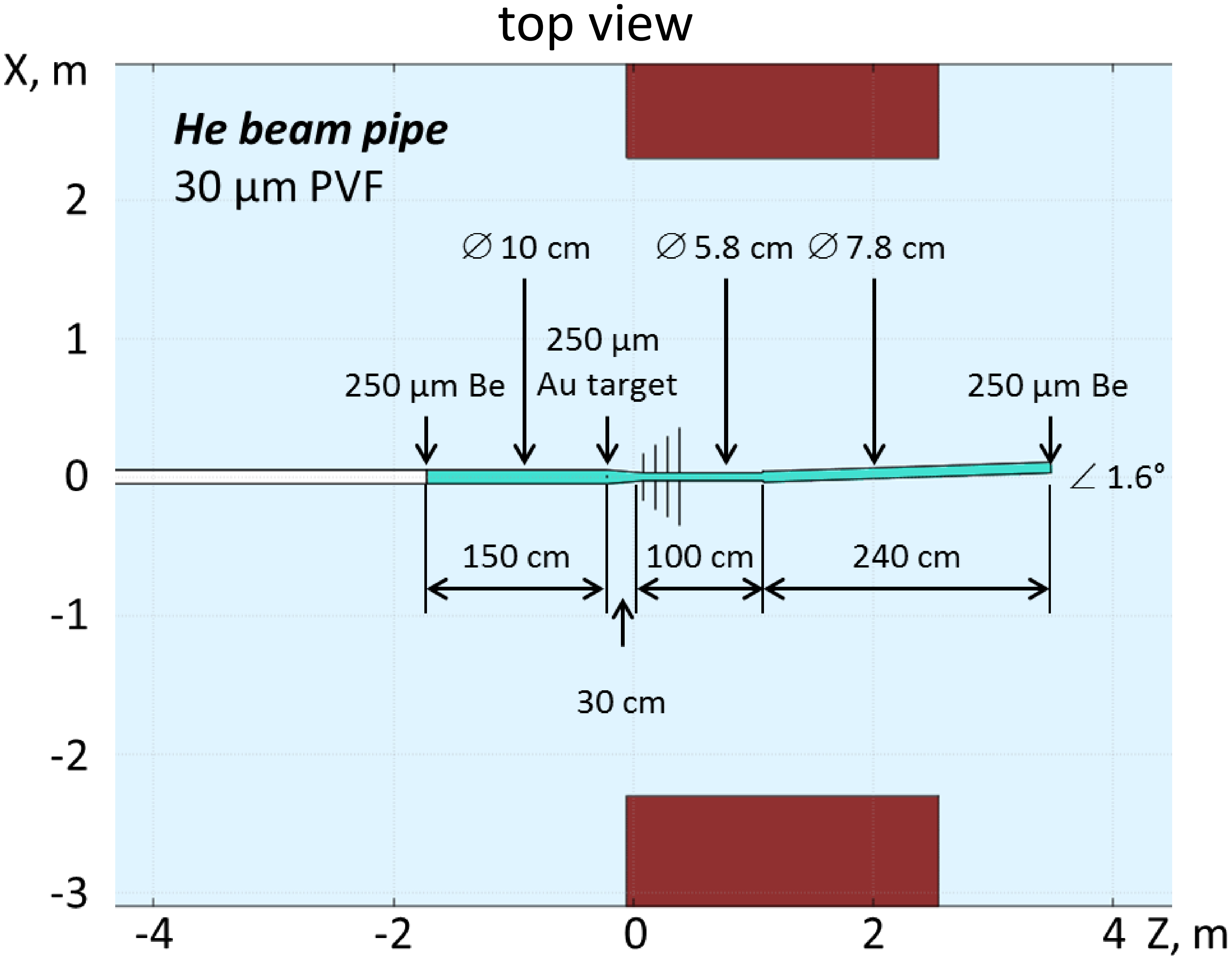
- BM@N-2 Setup with vacuum beam line upstream the experiment
- Au-beam with energy of 5A GeV, $1\text{x}10^6$ Au ions/s
- Au target 250 μm (1% interaction)
- CBM-like beam: rectangular 0.06 cm X/Y, divergence 1.7 mrad
- Beam pipe downstream target: Helium or vacuum



Simulation geometry vacuum beam pipe

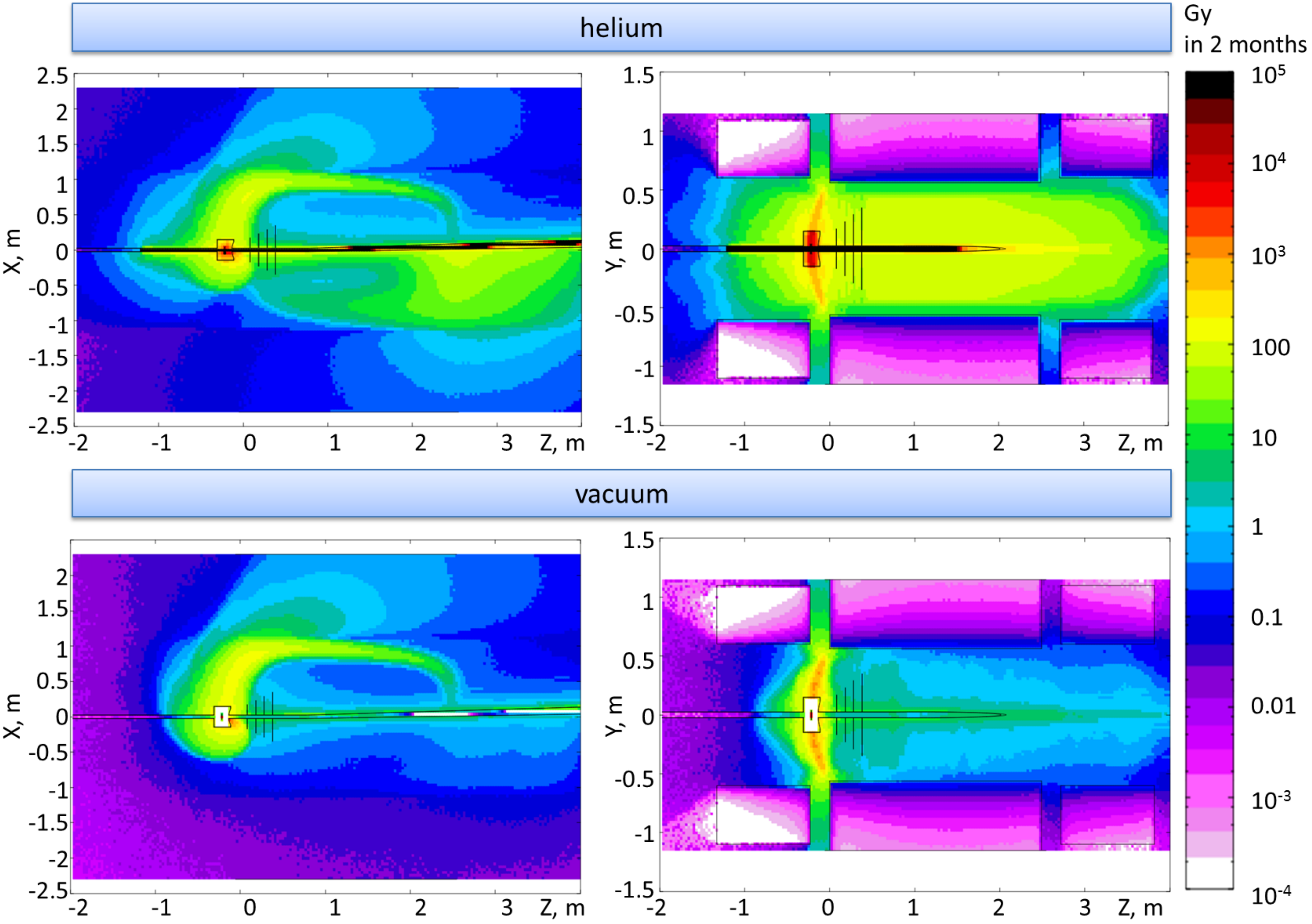


Simulation geometry He filled beam pipe

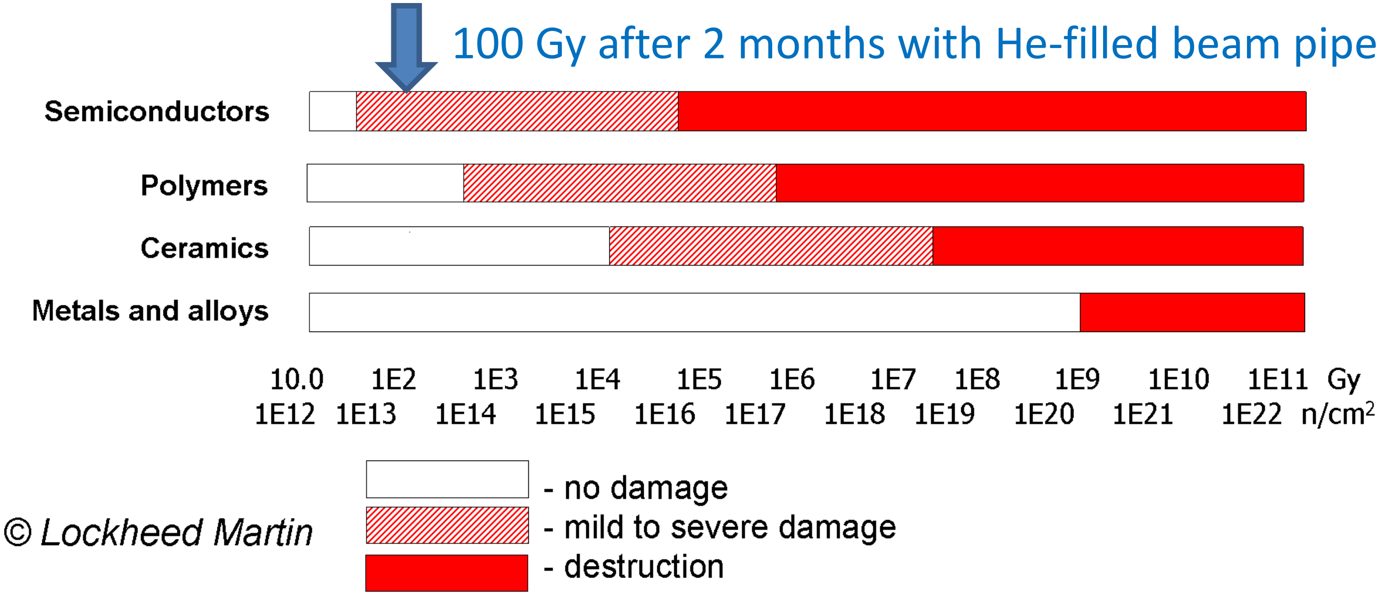


Ionizing dose along the z-axis

Anna Senger (GSI)



Radiation damage



100 Gy after 2 months with He-filled beam pipe

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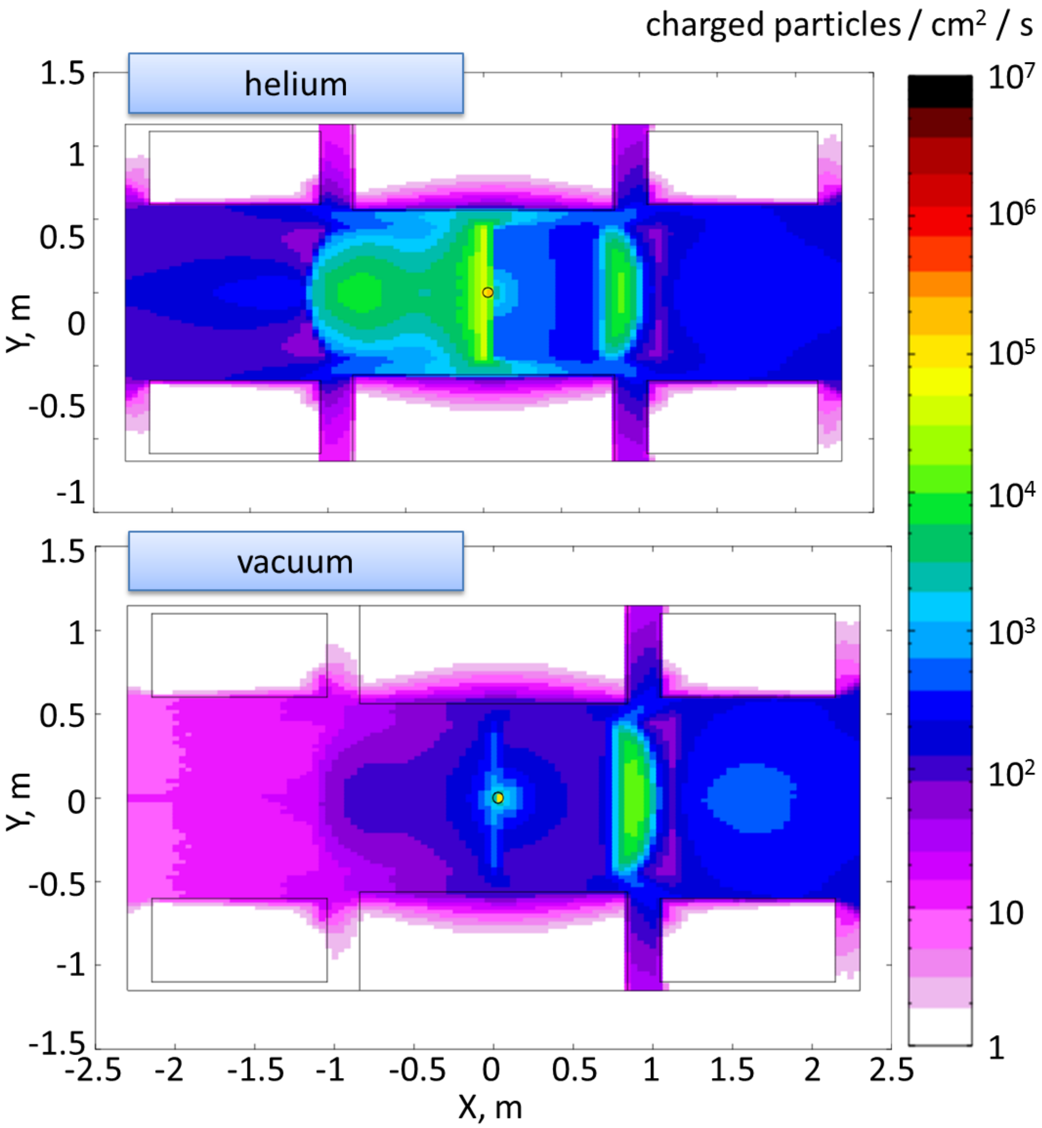
Charged particles in GEM stations at z = 2 m

Anna Senger (GSI)



Helium beam pipe:

Delta electron rate: 100 kHz/cm^2

Electron rate on one strip (inner zone):
100 kHz/cm^2·1.2 cm^2 = 120 kHz
Channels busy: 120 kHz·2 μs = **24 %**

Electron rate on one strip (outer zone):
100 kHz/cm^2·2.4 cm^2 = 240 kHz
Channels busy: 240 kHz·2 μs = **48 %**

(1x10^6 Au ions/s !)

Vacuum beam pipe:

Delta electron rate: 3 kHz/cm^2

Electron rate on one strip (inner zone):
3 kHz/cm^2·1.2 cm^2 = 3.6 kHz
Channels: 3.6 kHz·2 μs = **0.72 %**

Electron rate on one strip (outer zone):
3 kHz/cm^2·2.4 cm^2 = 7.2 kHz

Channels busy: 7.2 kHz·2 μs = **1.42 %**

Conclusions FLUKA calculations

Nuclotron beam $2x10^6$ Au ions/s	STS radiation damage (2 months)	GEMs radiation damage (2 months)	STS channel inefficiency	GEMs Channel Inefficiency
Gauss σ = 1 cm	severe	mild	$3{\cdot}10^{-3}$	48 -96 %
Gauss σ = 0.35 cm	no	no	$1.5{\cdot}10^{-4}$	0.5 – 1 %

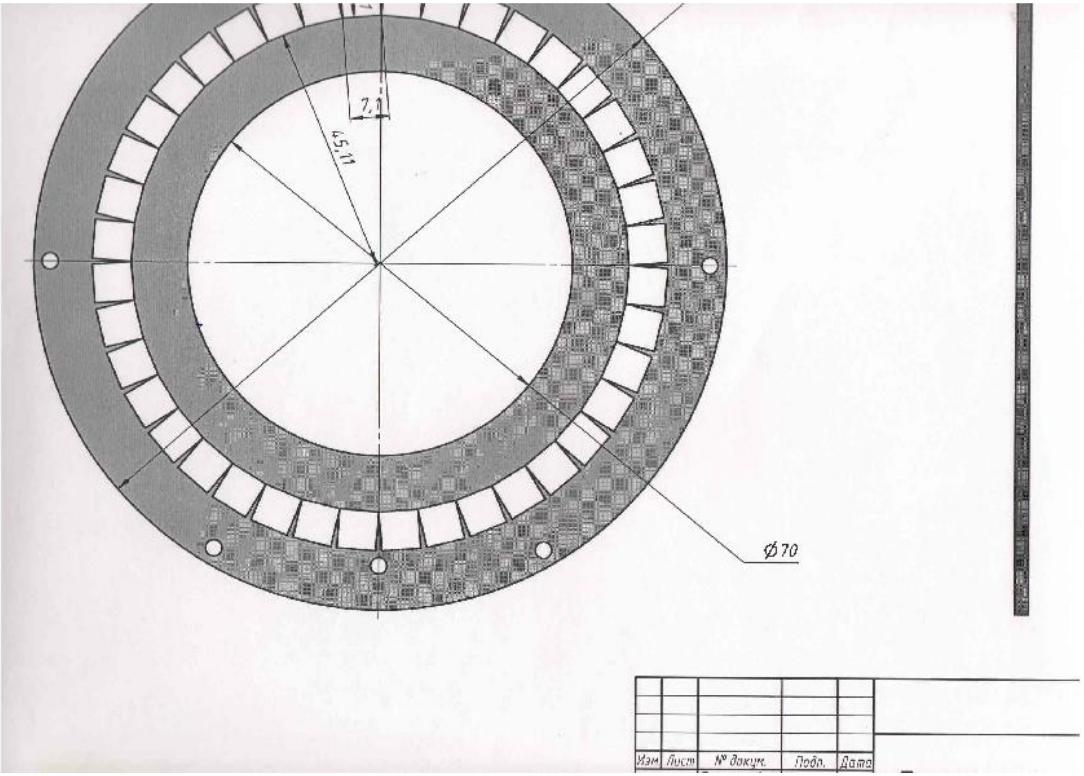
Beam line between Nuclotron and BM@N has to be improved !

BM@N beam pipe $1x10^6$ Au ions/s	STS radiation damage (2 months)	GEMs radiation damage (2 months)	STS channel inefficiency	GEMs Channel inefficiency
He filled	mild	no	$1.5{\cdot}10^{-3}$	24 – 48 %
Vacuum	no	no	$1.5{\cdot}10^{-4}$	0.8 – 1.4 %

Installation of a vacuum beam pipe required !

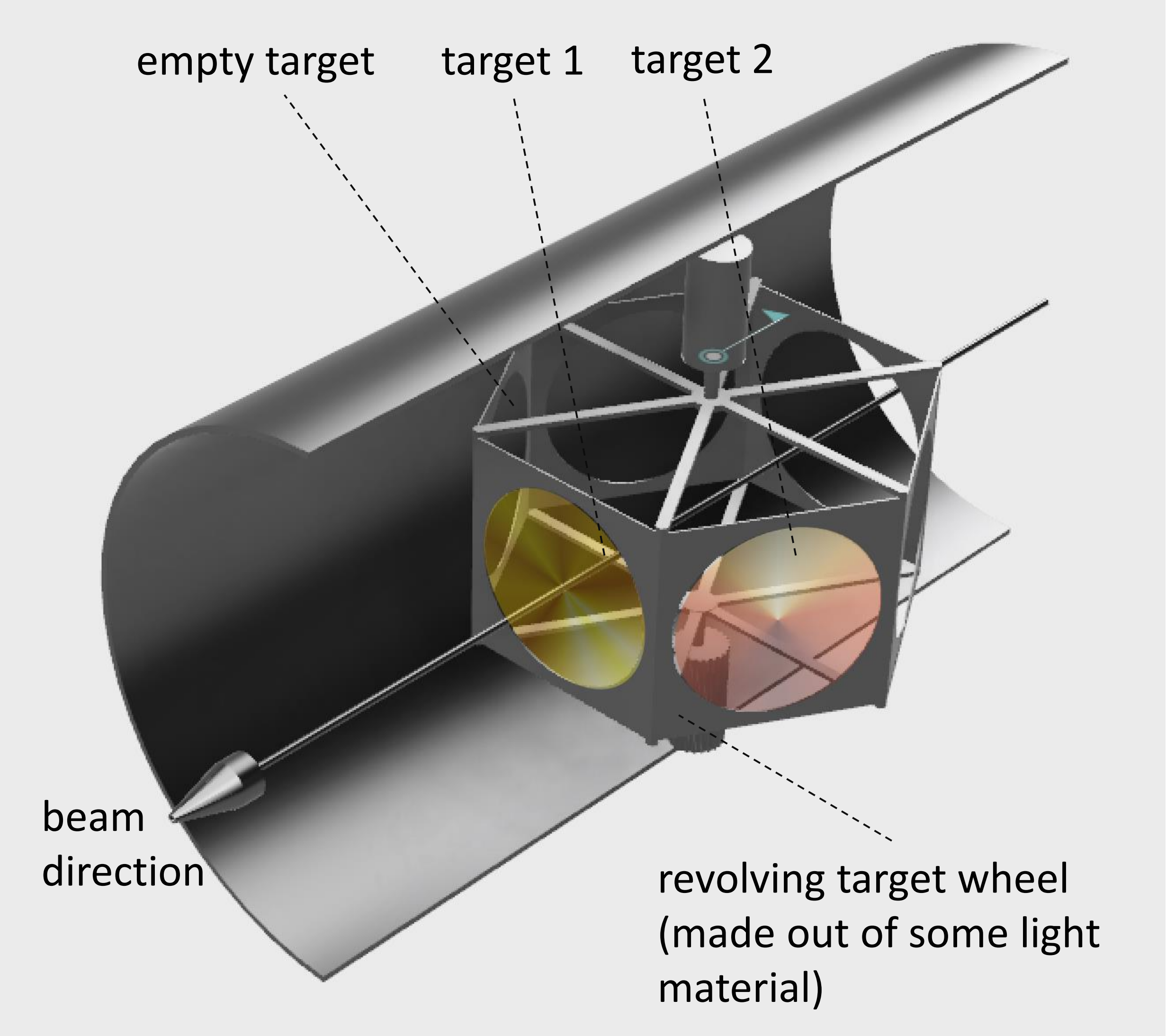
Proposal for a BM@N Target Wheel I

Goal: target in vacuum to minimize secondary interactions in air
Requirement I: has it fit into existing beam pipe surrounded by multiplicity detector
Requirement II: target change w/o breaking vacuum



cross section of BM@N beam pipe with multiplicity detector

Proposal for a BM@N Target Wheel II



empty target

target 1

target 2

beam direction

revolving target wheel (made out of some light material)

Proposal for a BM@N Target Wheel III

various (more or less) simple mechanisms are conceivable to rotate the target wheel, e.g., via:

geared belt drive + rotary vacuum feed through

Outlook

Next steps:

1. Performance simulations of the STS-GEM hybrid tracking system based on realistic detector responses, geometries and materials until next BM@N collaboration meeting.
2. Detector development: see to-do list
3. Substantial improvement of the Nuclotron beam parameters
4. Design of a vacuum beam pipe downstream the BM@N target
5. Design of a target chamber including target wheel

Additional sources of manpower and technology/equipment (to start end of 2019):

1. GSI in-kind contributions to BM@N and MPD funded by the German BMBF
2. EU CREMLIN+ funding of joint detector developments for FAIR/CBM and NICA/MPD