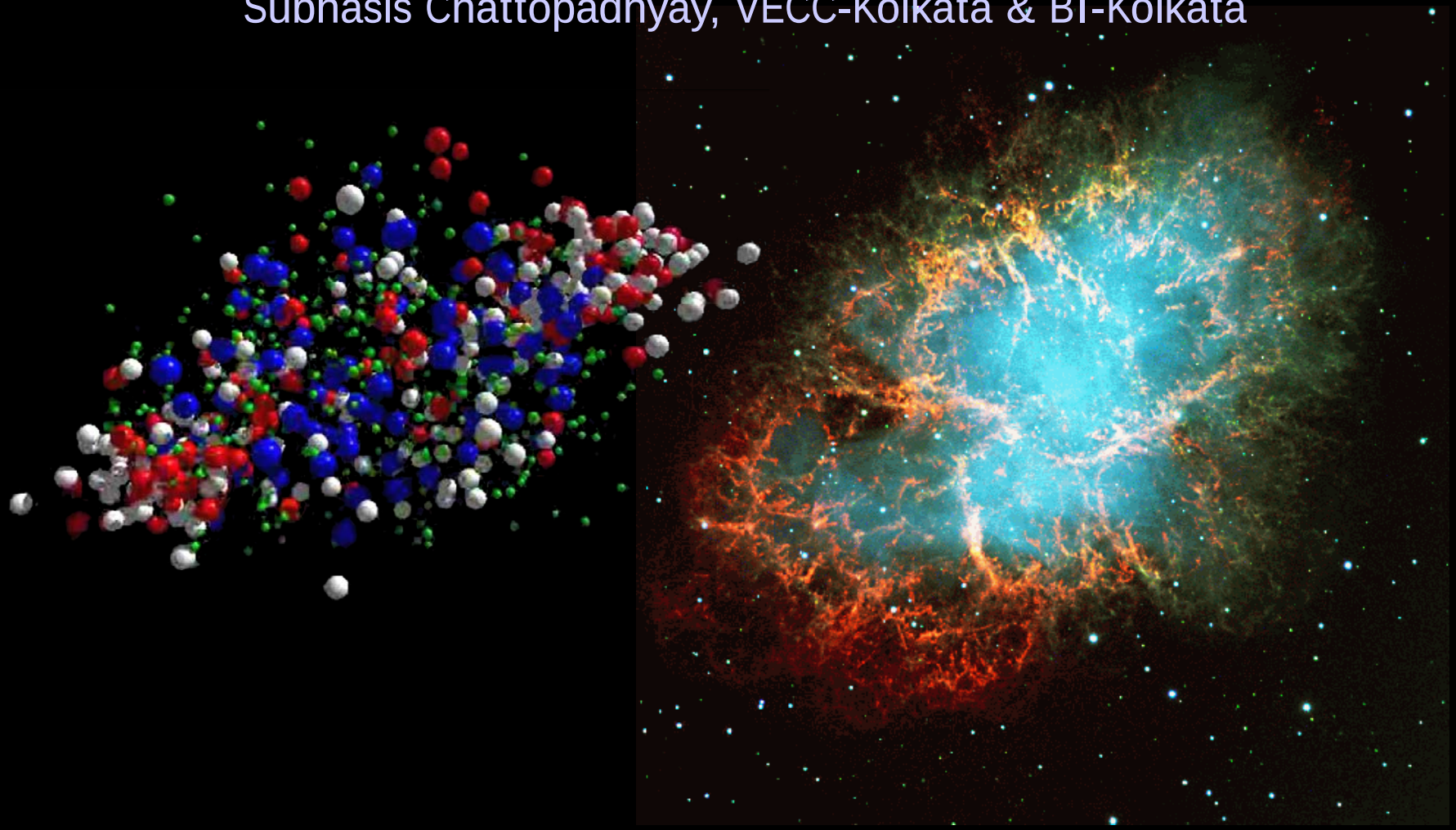
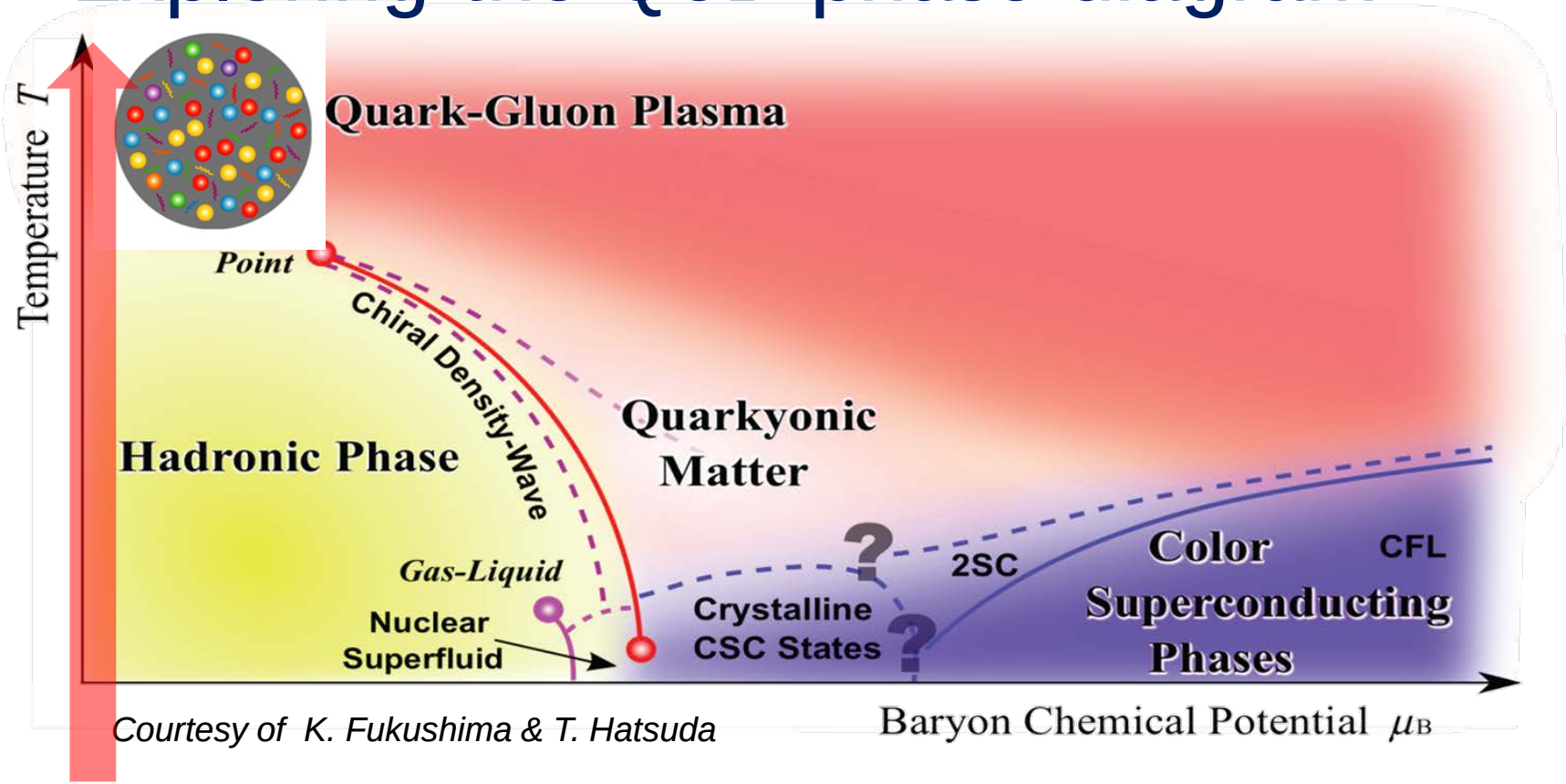
Compressed Baryonic Matter experiment at FAIR

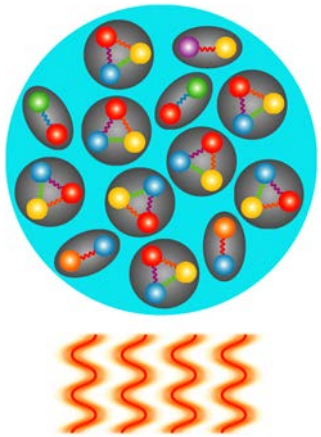
Subhasis Chattopadhyay, VECC-Kolkata & BI-Kolkata



Exploring the QCD phase diagram



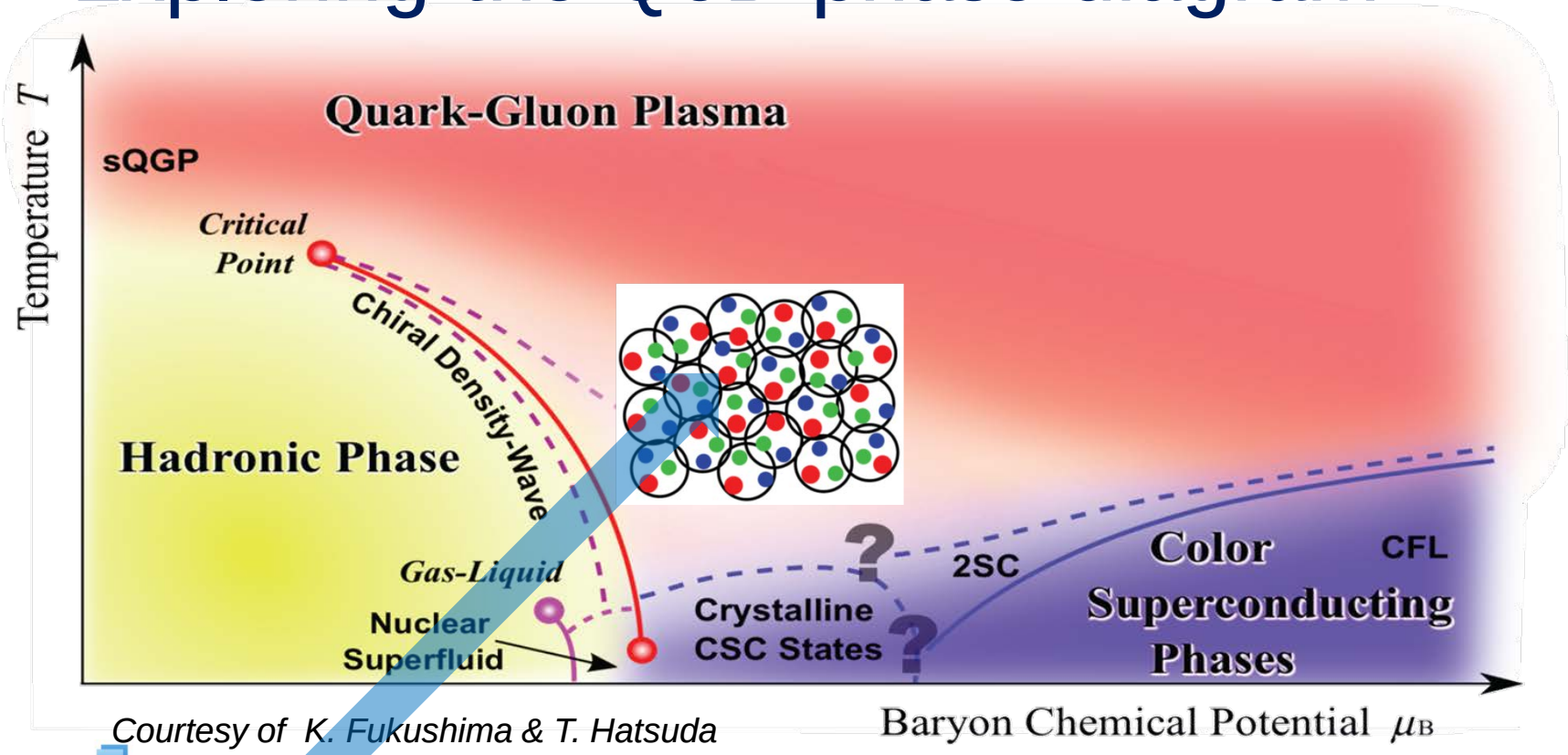
Courtesy of K. Fukushima & T. Hatsuda



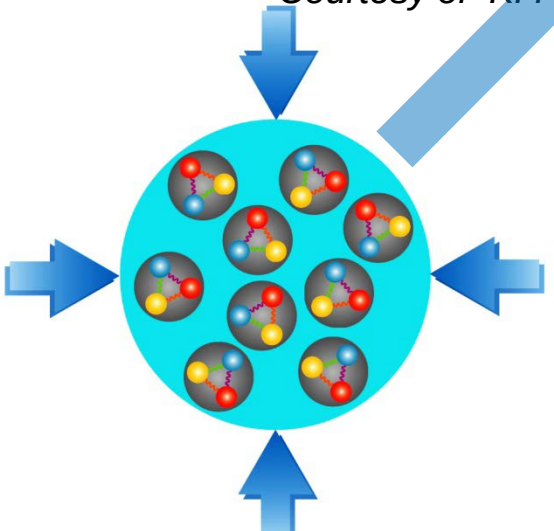
<u>At very high temperature:</u>

- N of baryons ≈ N of antibaryons
  Situation similar to early universe
- L-QCD finds crossover transition between hadronic matter and Quark-Gluon Plasma
- Experiments: ALICE, ATLAS, CMS at LHC
  STAR, PHENIX at RHIC

Exploring the QCD phase diagram



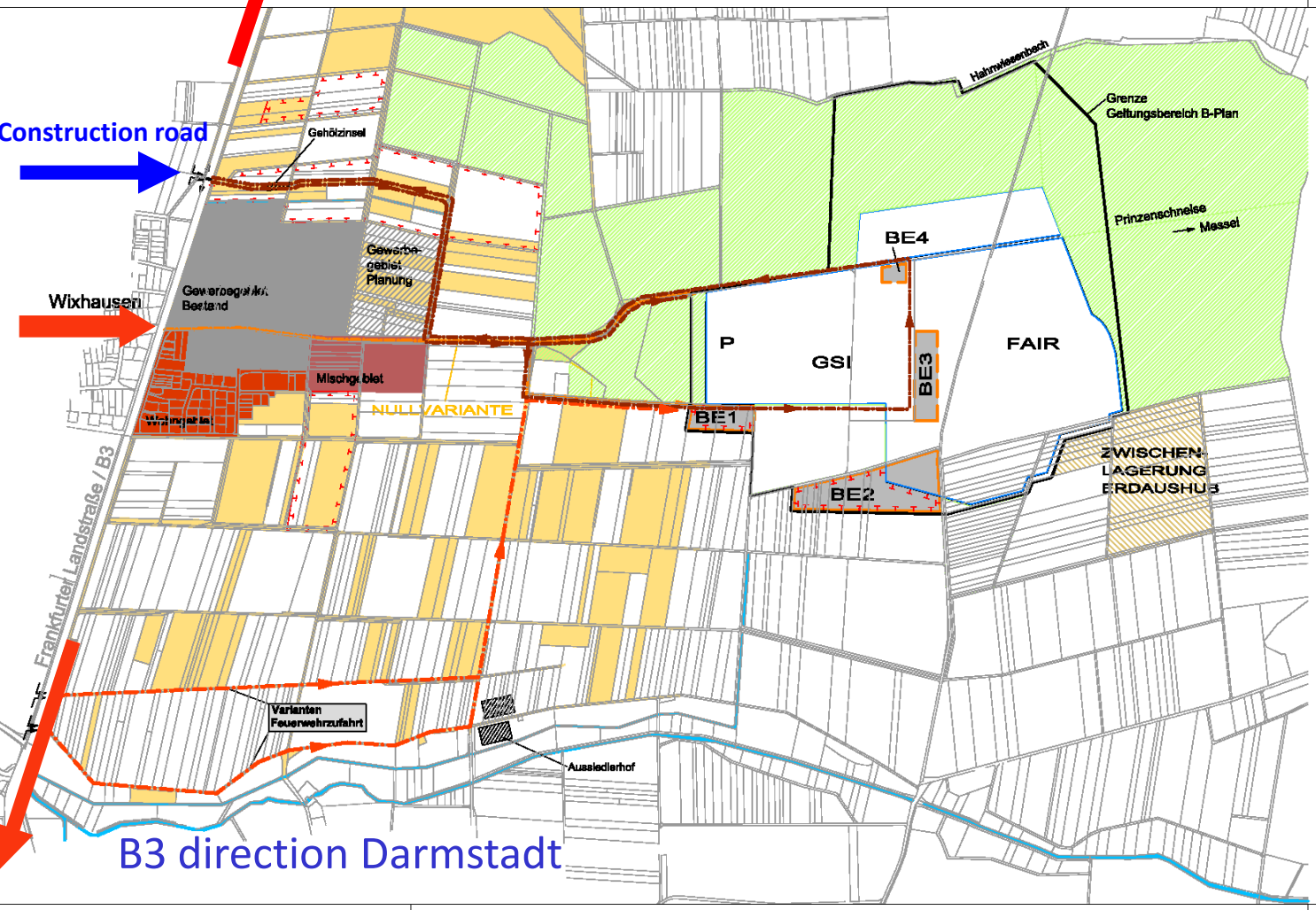
Courtesy of K. Fukushima & T. Hatsuda



At high baryon density:

- N of baryons >> N of antibaryons
  Densities like in neutron star cores
- L-QCD not (yet) applicable
- Models predict first order phase transition with mixed or exotic phases
- Experiments: BES at RHIC, NA61 at CERN SPS, **CBM at FAIR**, NICA at JINR, J-PARC

B3 Direction Frankfurt



Legende:

- Aufforstungsfläche (Ersatz)
- BE — Baustellen-Einrichtungsflächen
- Städtische Grundstücke
- Wald
- Zwischenlagerung Erdaushub
- Baustellenerschließung über Messeler-Park-Str.
- Zusätzliche Baustellenerschließungsstrasse
- Feuerwehrzufahrt

Umweltplanung Bullermann Schneible GmbH

Erweiterung GSI, Projekt FAIR
Konzept Verkehrliche Baustellenerschließung

Übersichtslageplan

063101
1:5.000

Hehn | Burger | 0625416 | Feb. 2009 | 21.02.2011

AUFTRAGGEBER
GSI
GESELLSCHAFT FÜR SCHWERIONENFORSCHUNG
PLANCKSTRASSE 1, 64291 DARMSTADT

PLANVERFASSER
UMWELTPLANUNG BULLERMANN SCHNEIBLE GmbH
HAVELSTRASSE 7A, D-64295 DARMSTADT
TELEFON:06151/9768-0 TELEFAX:06151/9768-50

Facility for Antiproton & Ion Research

Primary Beams

- 10^{12}/s; 1.5 GeV/u; $^{238}U^{28+}$
- 10^{10}/s $^{238}U^{92+}$ up to 11 (35) GeV/u
- 3x10^{13}/s 30 (90) GeV protons

Technical Challenges

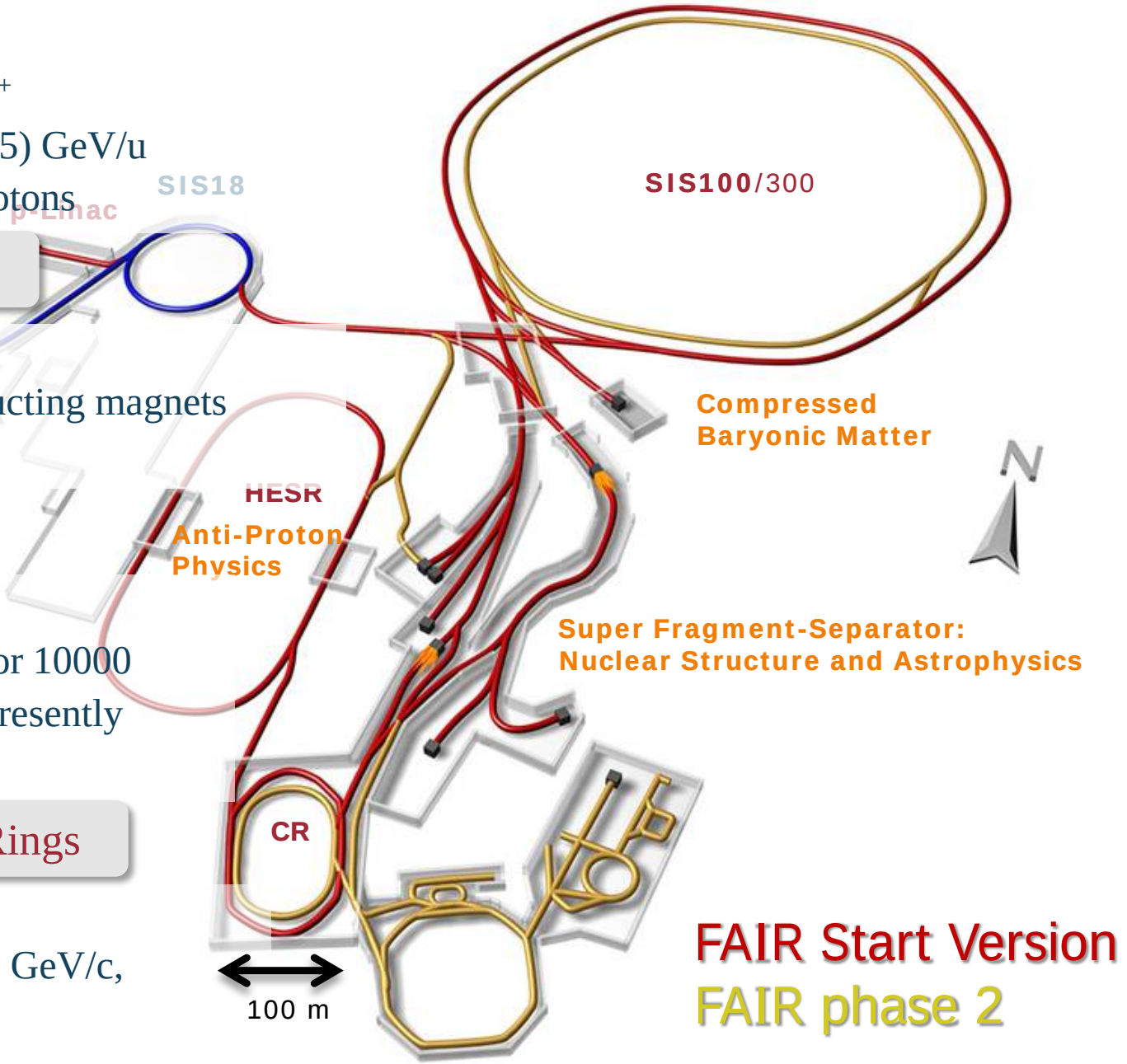
- cooled beams
- rapid cycling superconducting magnets
- dynamical vacuum

Secondary Beams

- radioactive beams up to 1.5 - 2 GeV/u; up to factor 10000 higher in intensity than presently
- antiprotons 3 - 30 GeV

Storage and Cooler Rings

- radioactive beams
- 10^{11} antiprotons 1.5 - 15 GeV/c, stored and cooled



Facility for Antiproton & Ion Research

FAIR is the largest upcoming fundamental science project worldwide this decade.

Forefront research in nuclear, hadron, atomic, plasma and applied physics.

- First beam in 2022
- 10 member states up to date
- 2500 - 3000 users
- Total cost ~1.6 Billion €

(German funds 70%, rest from international partners)

Germany	
Russia	
Finland	
France	
India	
Poland	
Romania	
Slovenia	
Sweden	
UK (associated)	

FAIR Signatory Countries

7th February’ 07: signing of ministerial agreement on FAIR

FAIR GmBH formed (convention signed) on 4th October 2010

Founder countries:

Germany
Russia
India
France
Poland
Romania
Finland
Slovania
Sweden

Bose-Institute (Kolkata) is Indian shareholder

DAE-DST mega-science project

India's contributions: 3% of the total cost of FAIR (in-kind)

Pledged Indian in-kind contributions(in Euros)

- Power converters
- SC magnets
- Beam stopper
- Vacuum chambers
- Power cables
- Detectors and electronics

= =

Indian participation (Experiments)

(41 groups, 11 from DAE labs)

India-NUSTAR collaboration

Bhabha Atomic Research Centre, Mumbai
Saha Institute of Nuclear Physics, Kolkata
Tata Institute of Fundamental Research, Mumbai
Variable Energy Cyclotron Center, Kolkata
Inter University Accelerator Center, New Delhi
Indian Institute of Technology, Bombay
Indian Institute of Technology, Kharagpur
Indian Institute of Technology, Roorkee
University of Delhi, New Delhi
University of Calcutta, Kolkata
Punjab University, Chandigarh
Aligrah Muslim University, Aligrah
Karnatak University, Dharwa
Guwahati University

Continuation of activities at VECC, IUAC and TIFR accelerator centres

India-CBM collaboration

Aligarh Muslim Univ.
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
SINP Kolkata
IOP Bhubaneswar
IIT Kharagpur
Gowhati Univ.
Bose-Institute, Kolkata
IT-Sikkim-Manipal , Sikkim

India-PANDA collaboration

BARC-Mumbai (NPD)
IIT Mumbai
SINP- Kolkata
VECC- Kolkata
IIT Indore
IIT- Gowhati
Pune university
AMU Aligarh
South Gujarat Univ.
NIT Jalandhar
MSU Vadodara
Magadh University
TIFR- Mumbai

+ Industrial participation

Motivation of our participation is to take part in advanced scientific and technological activities

Civil construction

The four most powerful drilling machines worldwide put down 1350 reinforced concrete pillars of 60 m depth and 1.2 m diameter.

An update on FAIR status

2014:

Announcement of a time delay and cost increase caused by civil construction

2015:

Evaluation by an international committee:

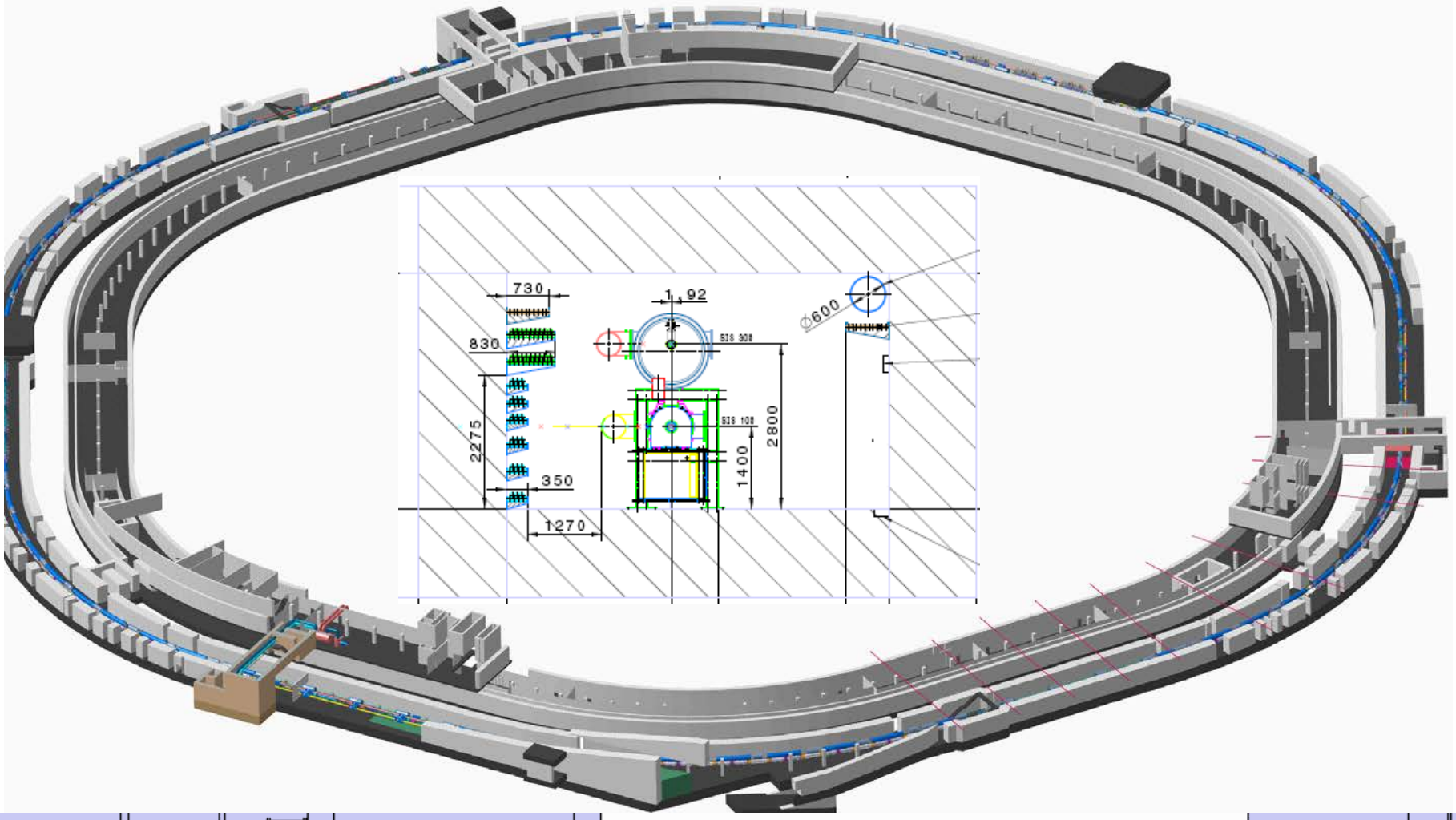
- Recommendation to restructure the FAIR management,
- Confirmation of the FAIR science program.

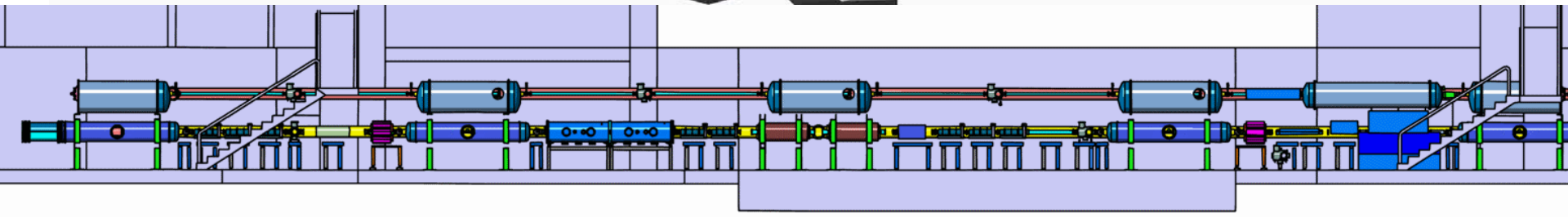
Decision of the FAIR shareholders:

- Build Start Version within staged approach and a cost cap.
- No reduction of the scientific scope.
- Commitment for 2/3 of missing funding in June 2016
- Status review in 2019
- Commitment for 1/3 of missing funding 2019

Application for the construction permit for the SIS100/300 tunnel submitted end of 2015. Goal: first beams in 2022.

Tunnel for SIS100/300





Time line

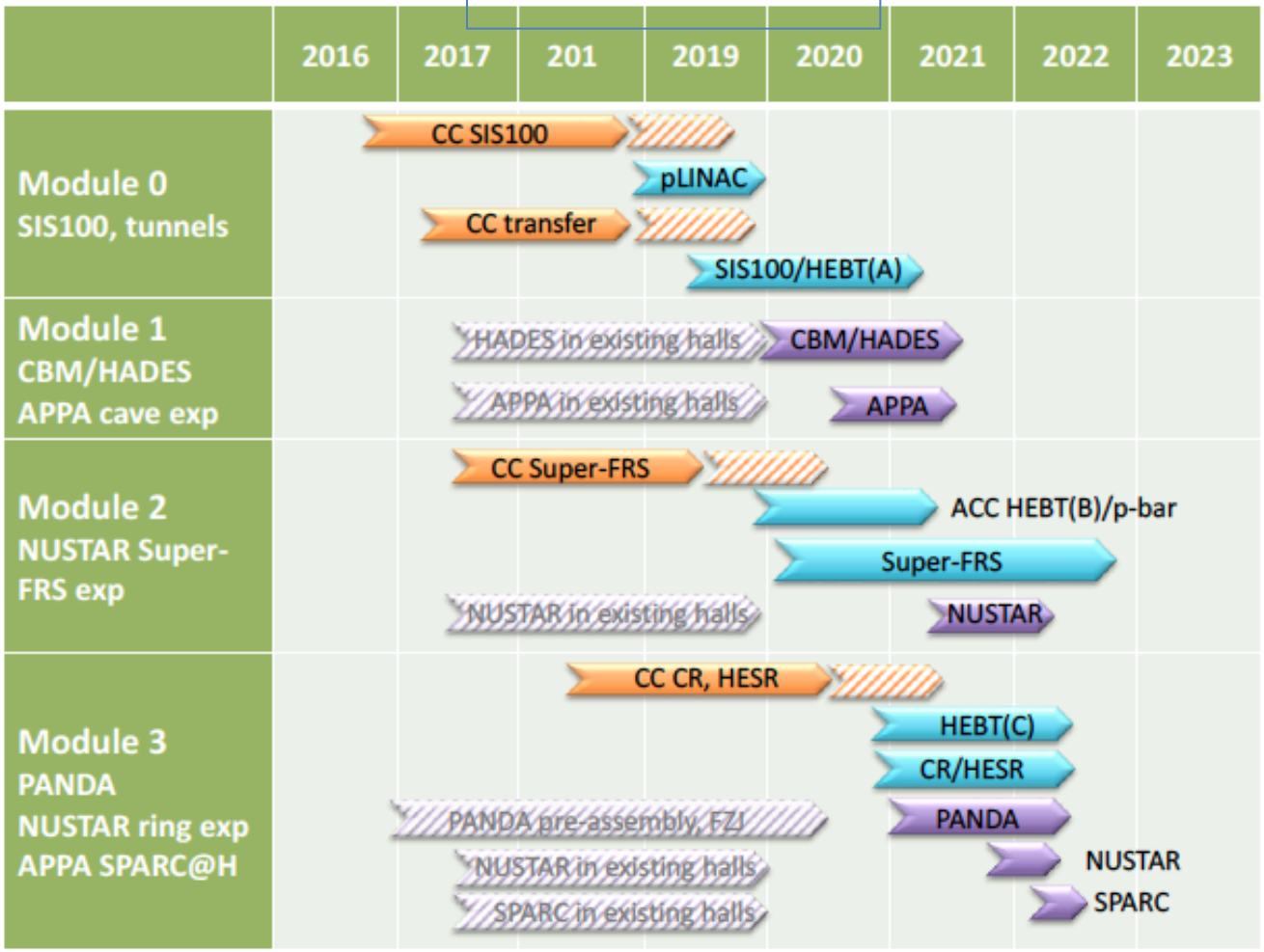
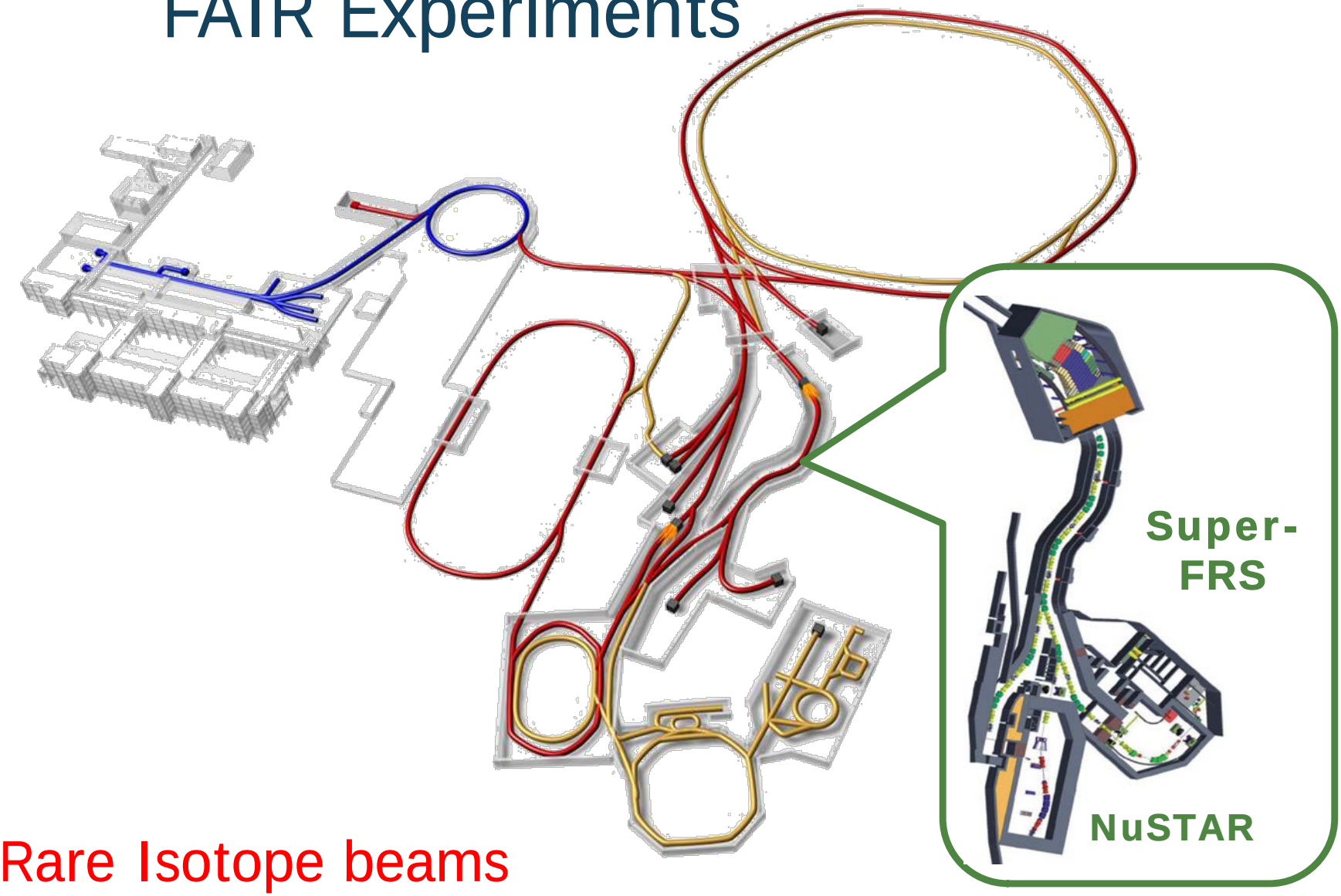


Figure 3: High level schedule of the FAIR MSV. The arrows indicate the construction/installation periods of: buildings (orange), technical infrastructure (orange-white), accelerator systems (blue) and experiments (purple). The arrows marked in grey-white indicate the opportunities for intermediate experimental programs exploiting FAIR detector components at the GSI accelerators.

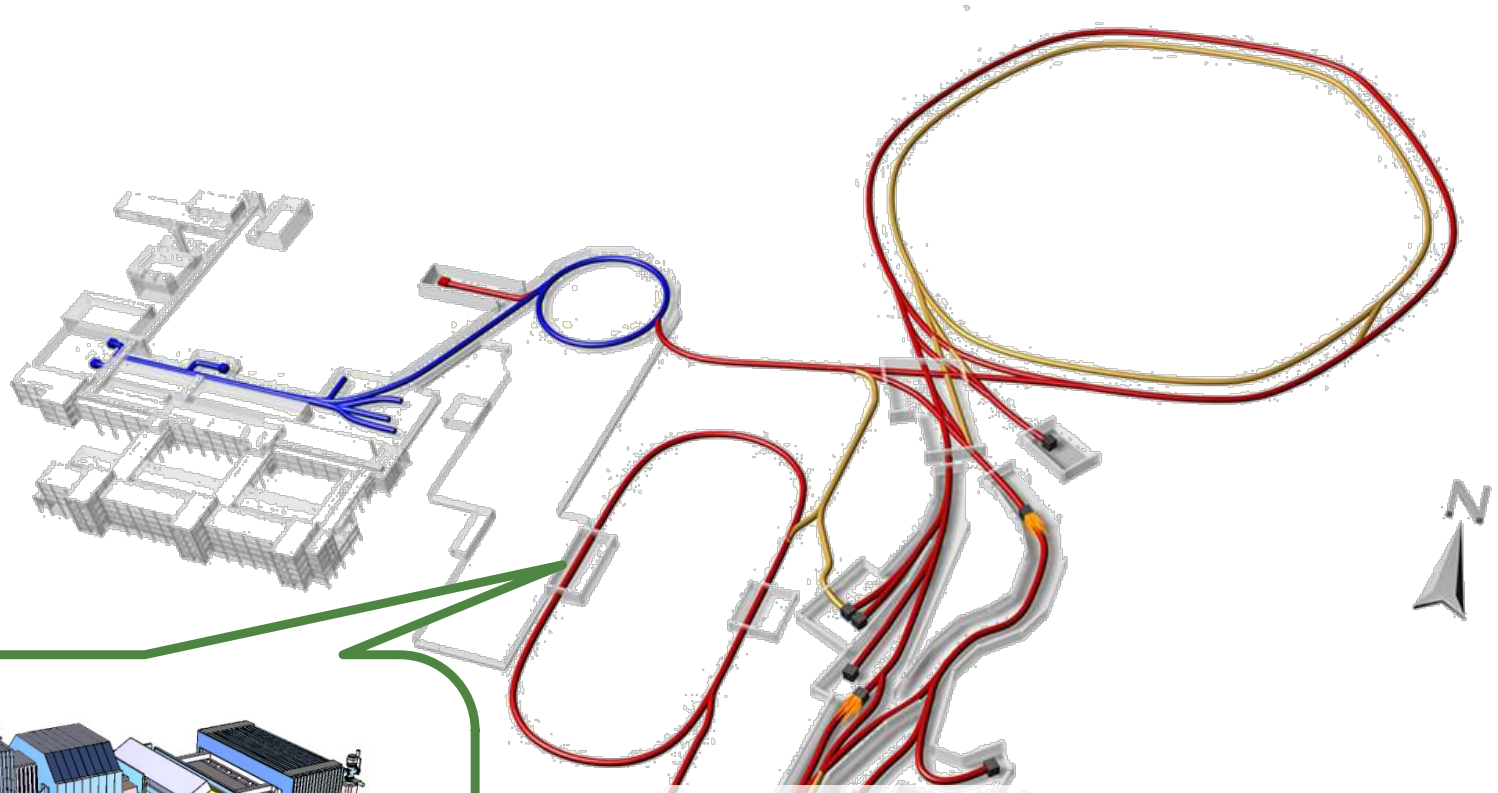
FAIR Experiments

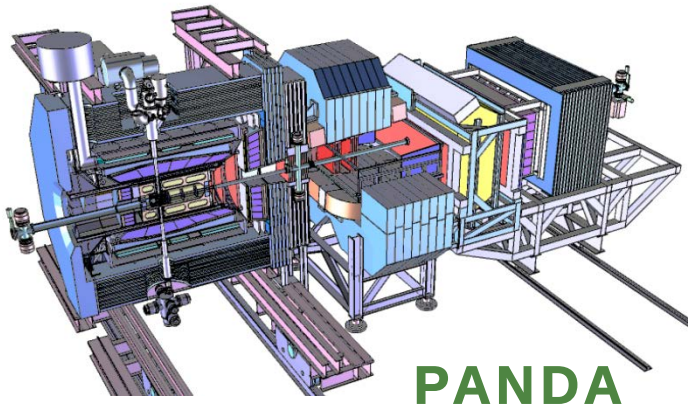


Rare Isotope beams

- Nuclear structure far off stability
- Nucleosynthesis in stars and supernovae

FAIR Experiments

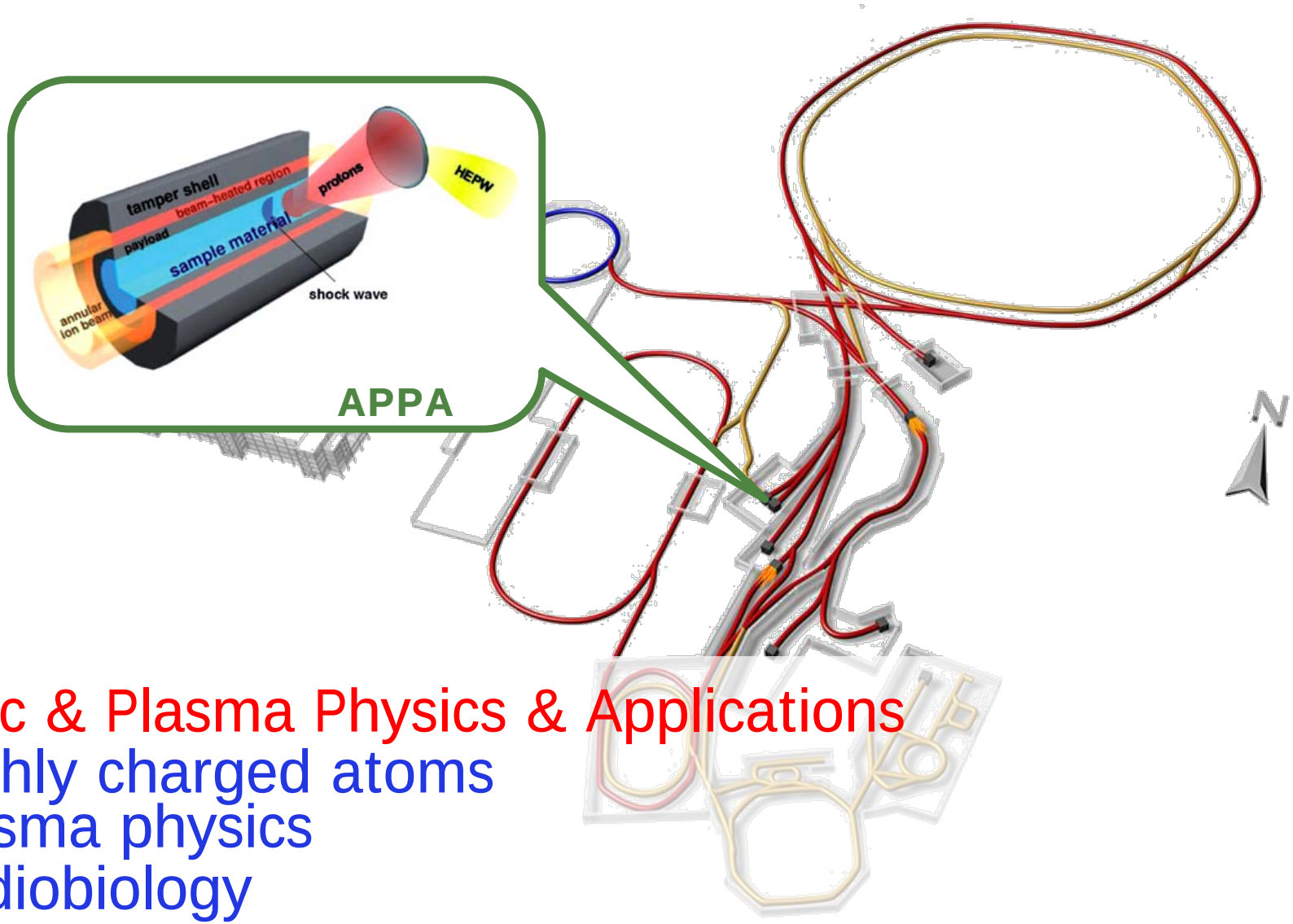




Antiproton-proton collisions:

- Charmed hadrons (XYZ)
- Gluonic matter and hybrids
- Hadron structure
- Double Lambda hypernuclei

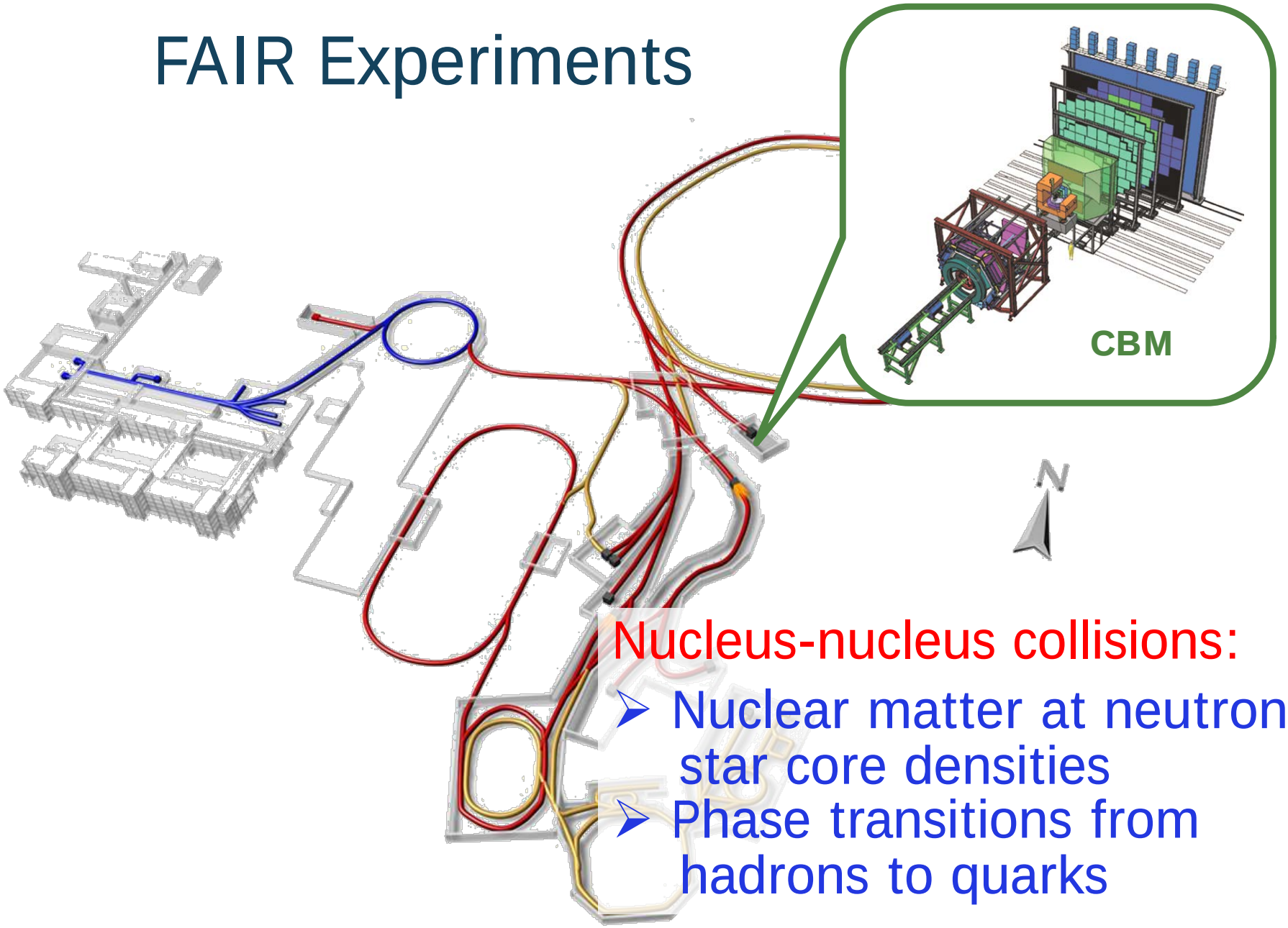
FAIR Experiments



Atomic & Plasma Physics & Applications

- Highly charged atoms
- Plasma physics
- Radiobiology
- Material science

FAIR Experiments



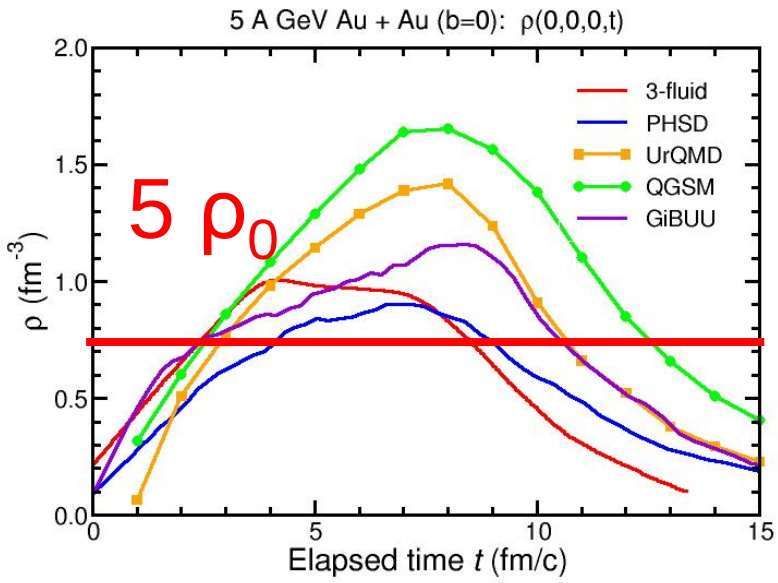
Nucleus-nucleus collisions:

- Nuclear matter at neutron star core densities
- Phase transitions from hadrons to quarks

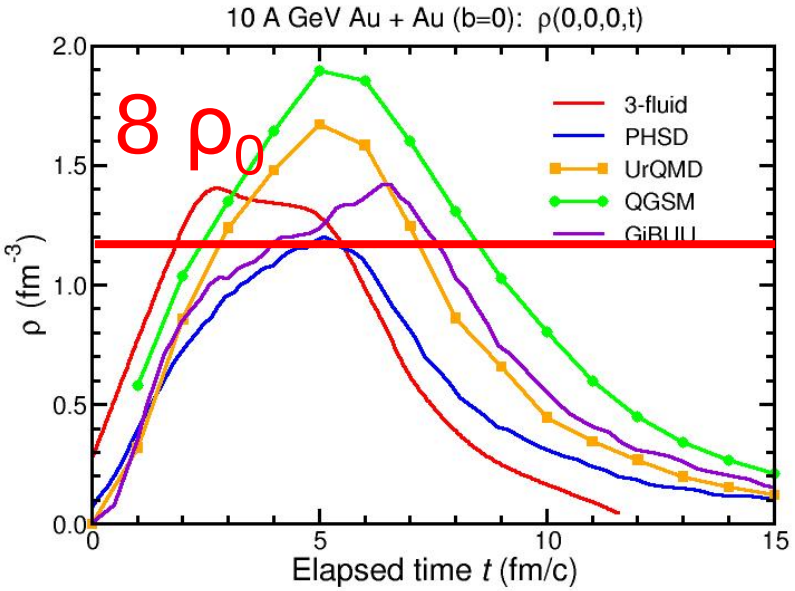
Baryon densities in central Au+Au collisions

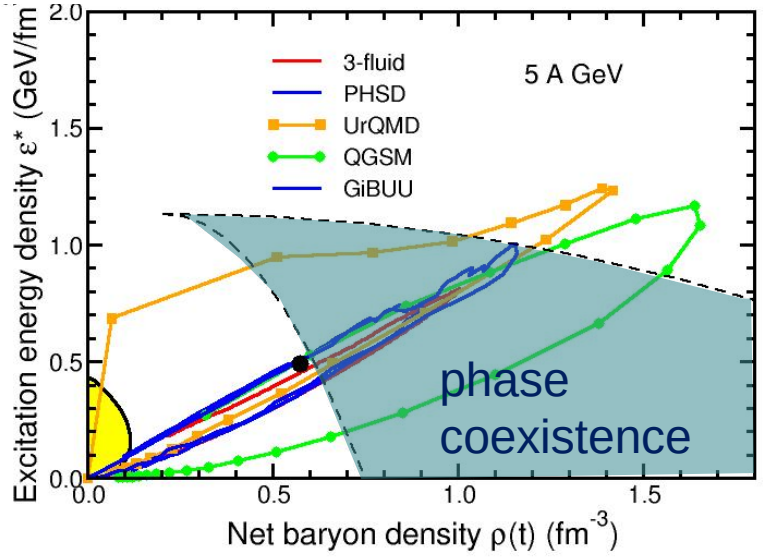
I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

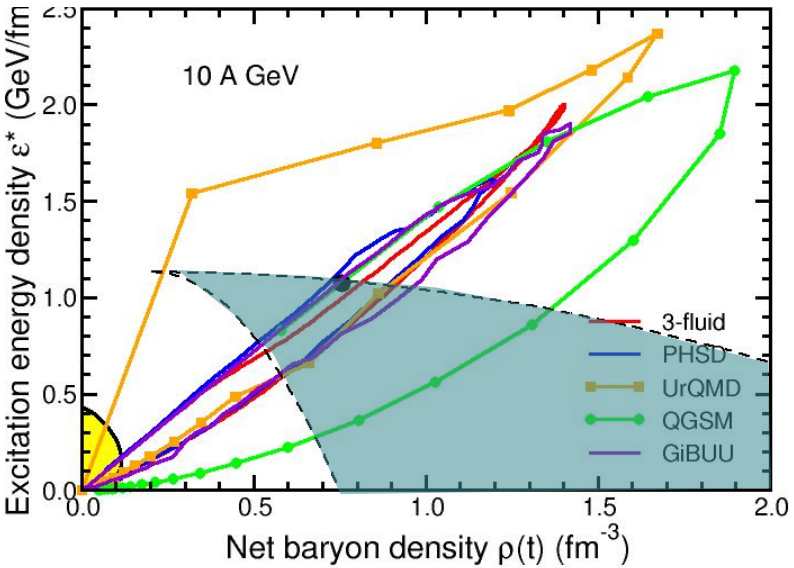
5 A GeV



10 A GeV

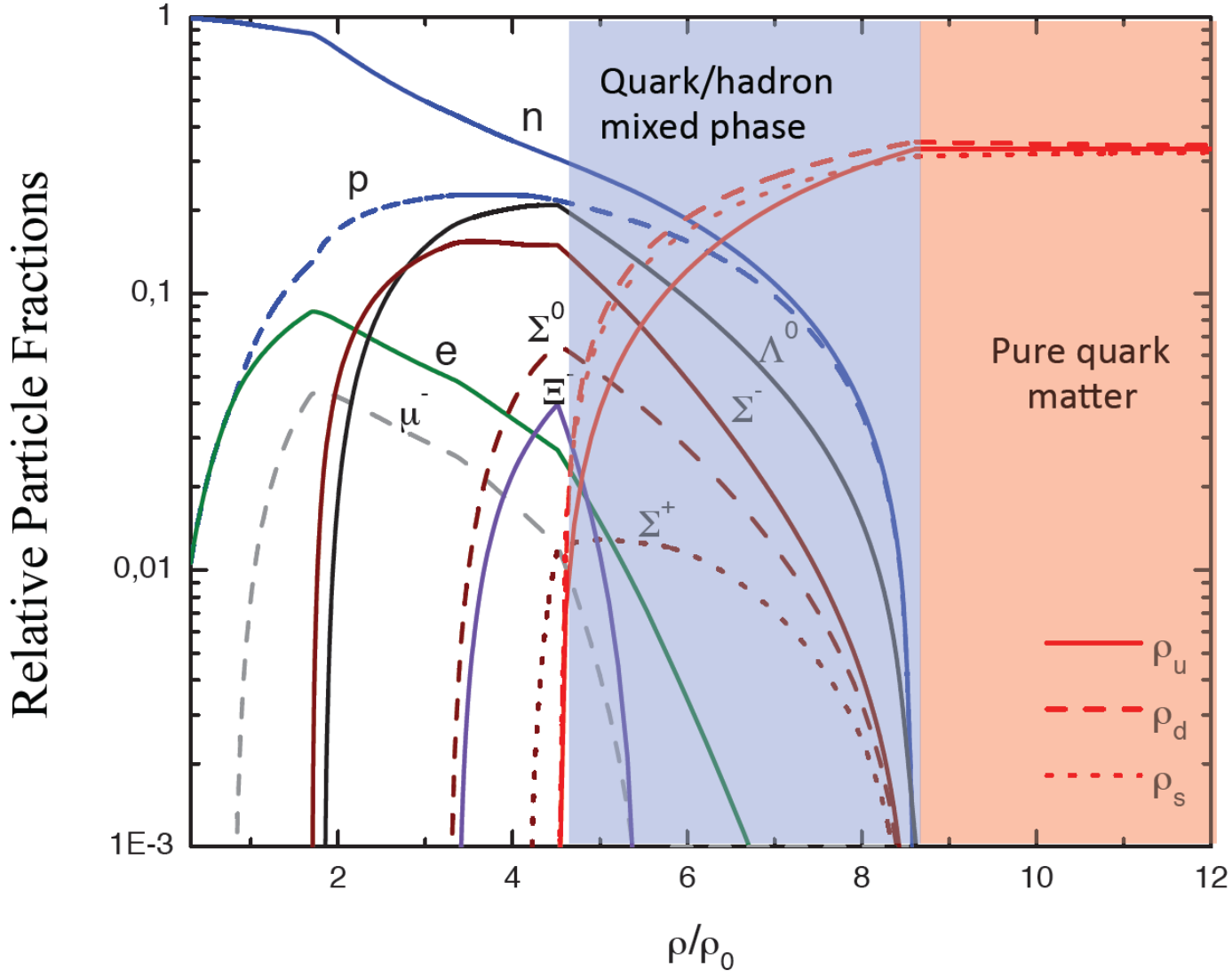




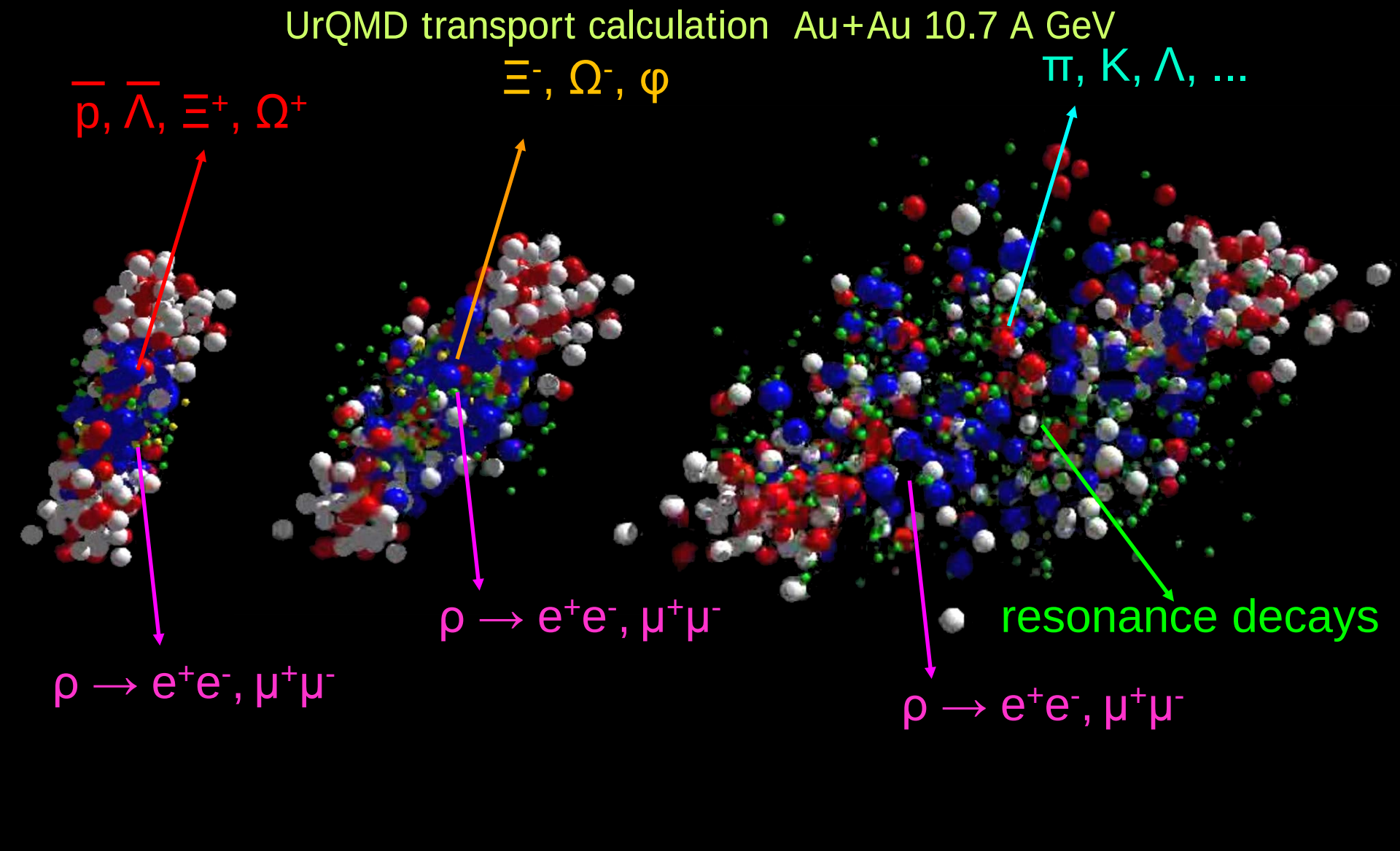


Quark matter in massive neutron stars?

M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, arXiv:1308.1657
Phys. Rev. C 89, 015806, 2014



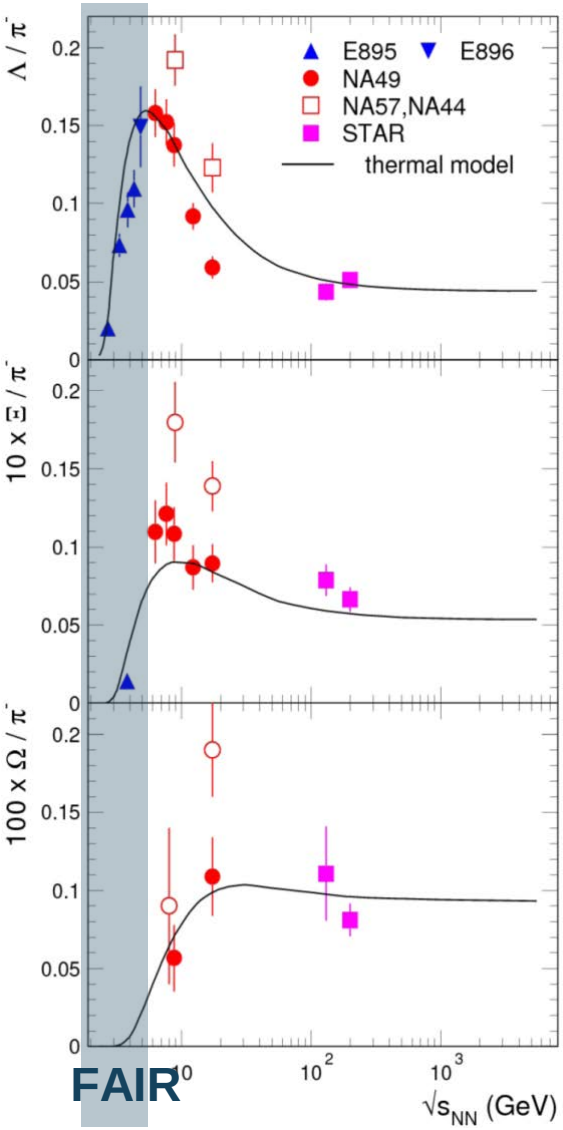
Messengers from the dense fireball: CBM at FAIR



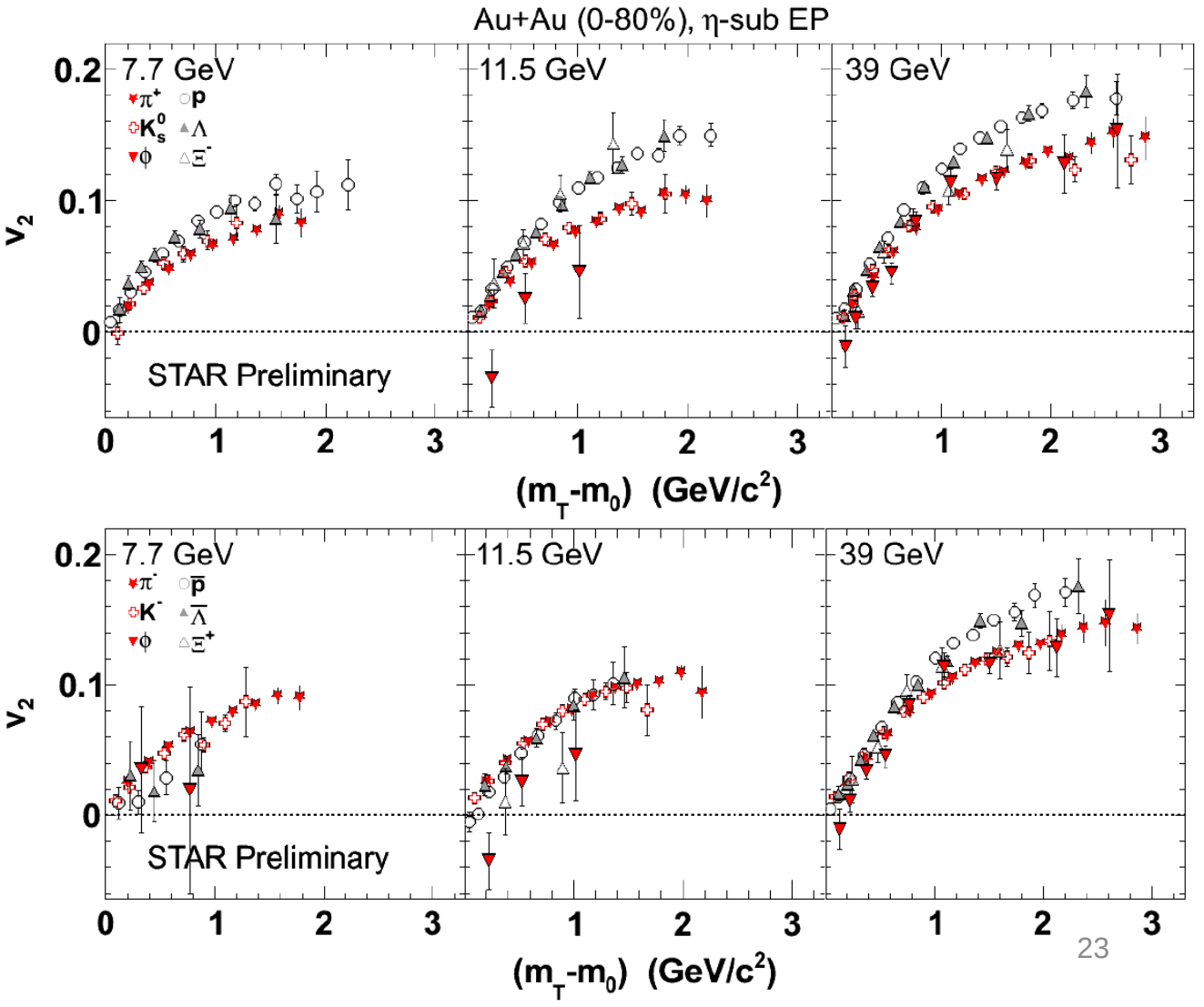
Strangeness
Data situation

very few data at FAIR energies

Pb+Pb, Au+Au (central)



RHIC beam energy scan

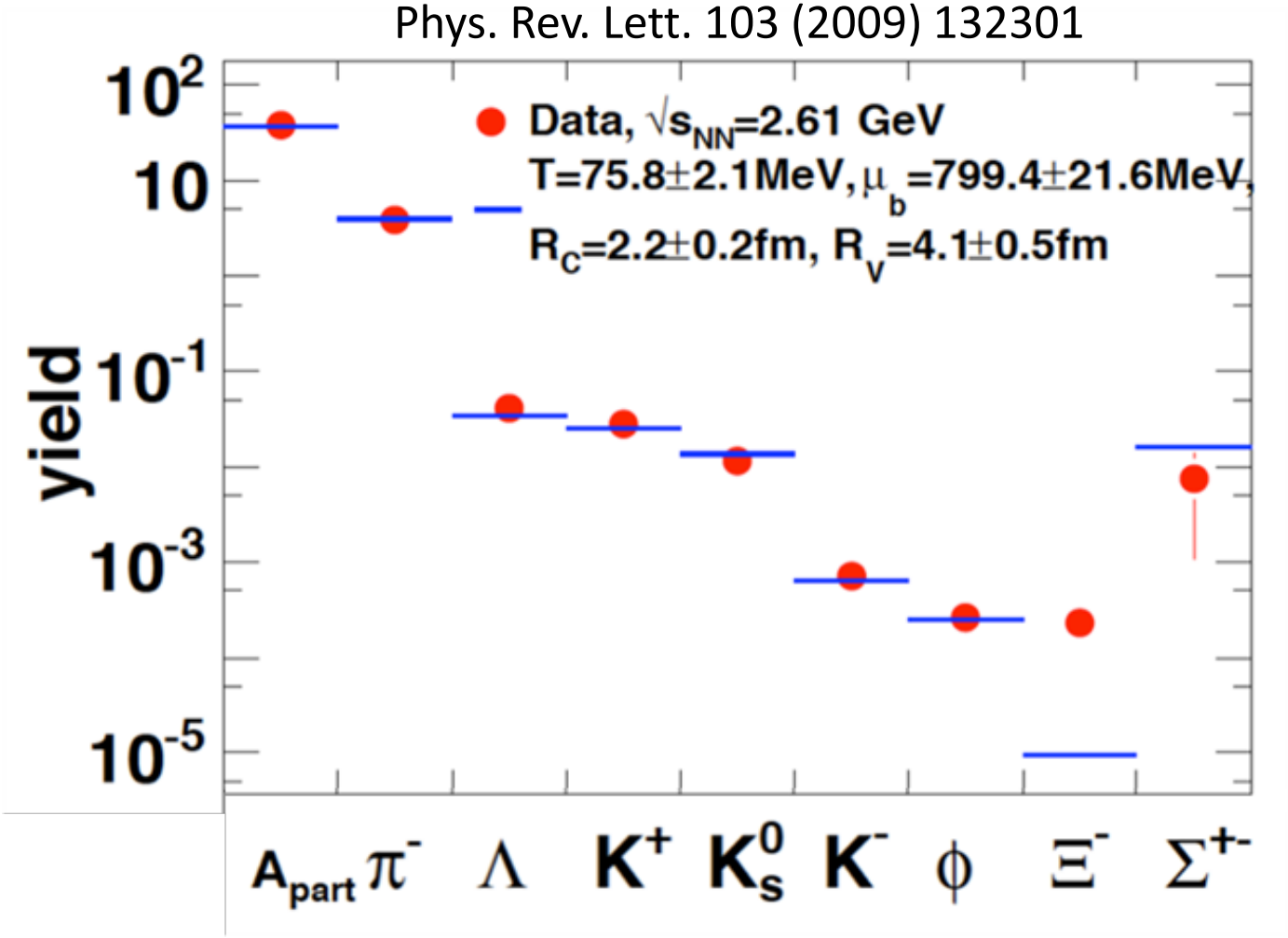


Strangeness

Data situation

HADES: Ar + KCl 1.76 A GeV

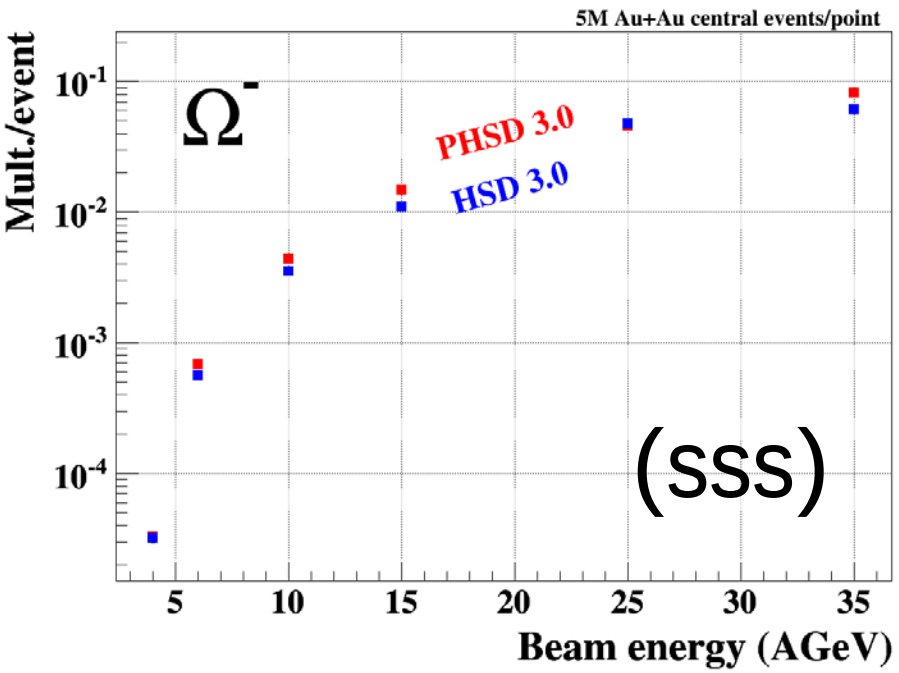
Phys. Rev. Lett. 103 (2009) 132301

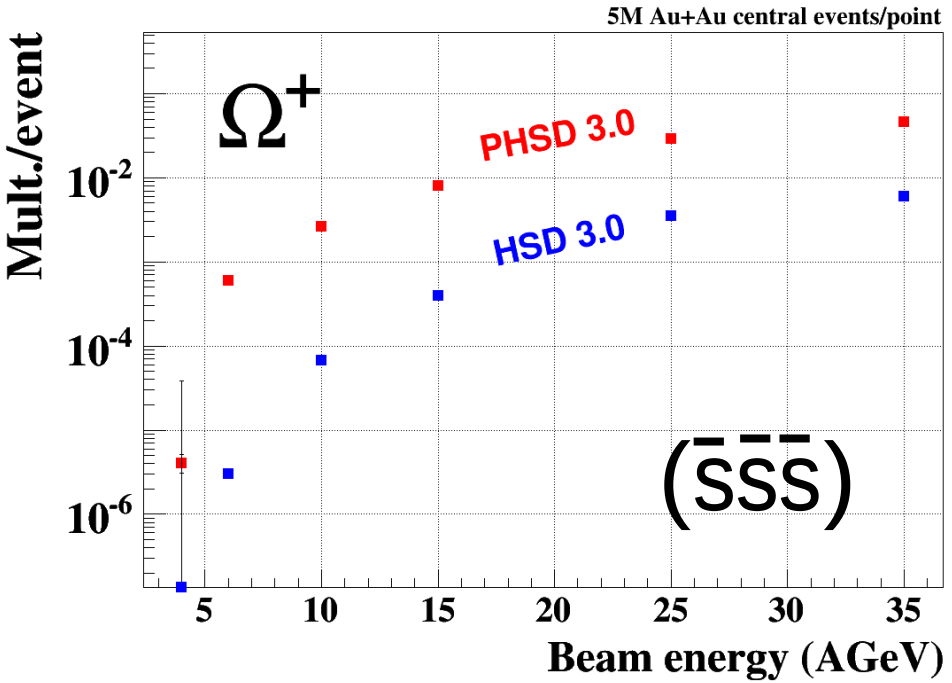


Strangeness and anti-strangeness

Multistrange (anti-)hyperon production in HSD and PHSD transport codes at FAIR energies

I. Vassiliev, E. Bratkovskaya, preliminary results





HSD: Hadronic transport code

PHSD:Hadronic transport code with partonic phase ($\varepsilon > 1$ GeV/fm^3)

Dileptons

Observables

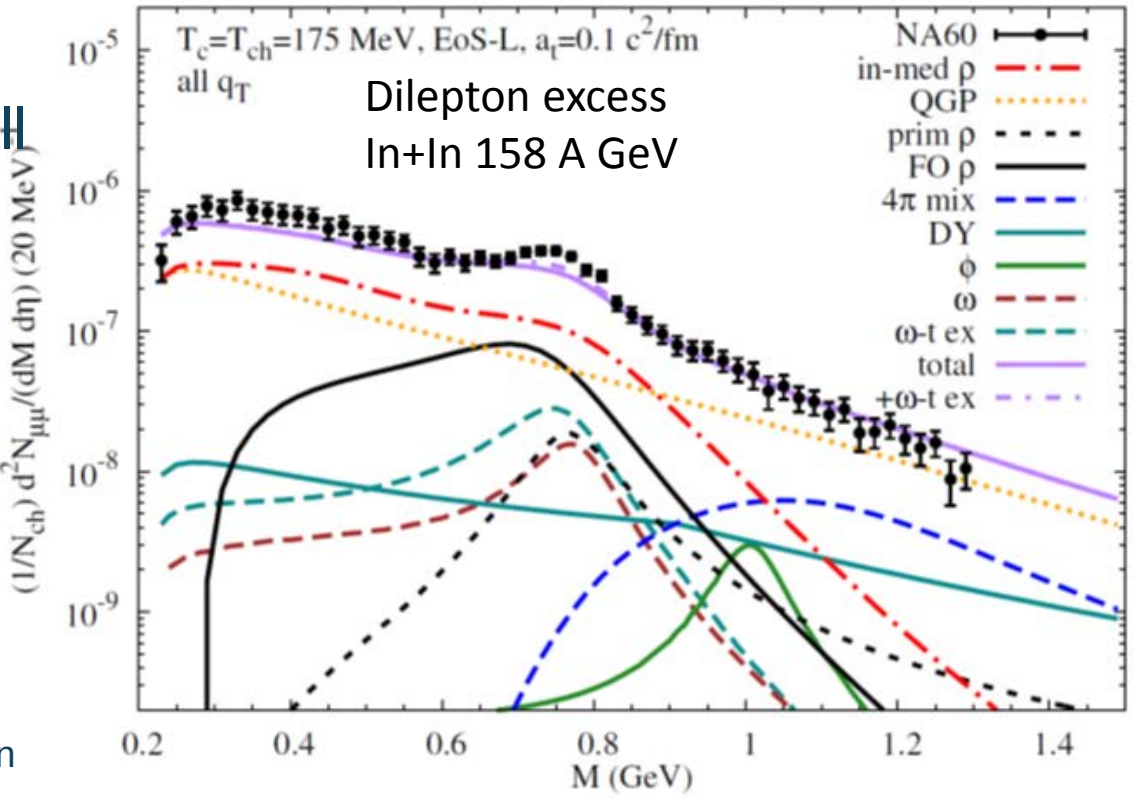
Excitation function of yields, emitting source temperature and phase-space distributions of lepton pairs in heavy-ion collisions

Physics case

- In-medium modifications of hadrons

No dilepton data at FAIR energies

- $1 < M_{inv} < 2.5$ GeV/c^2 :
  - Temperature of the fireball
  - Onset of QGP radiation



Experiment:
R. Arnaldi et al. [NA60 Coll.],
Phys. Rev. Lett. 96, (2006) 162302,
Theory:
R. Rapp, J. Wambach and H. van Hees, in
arXiv:0901.3289 hep-ph

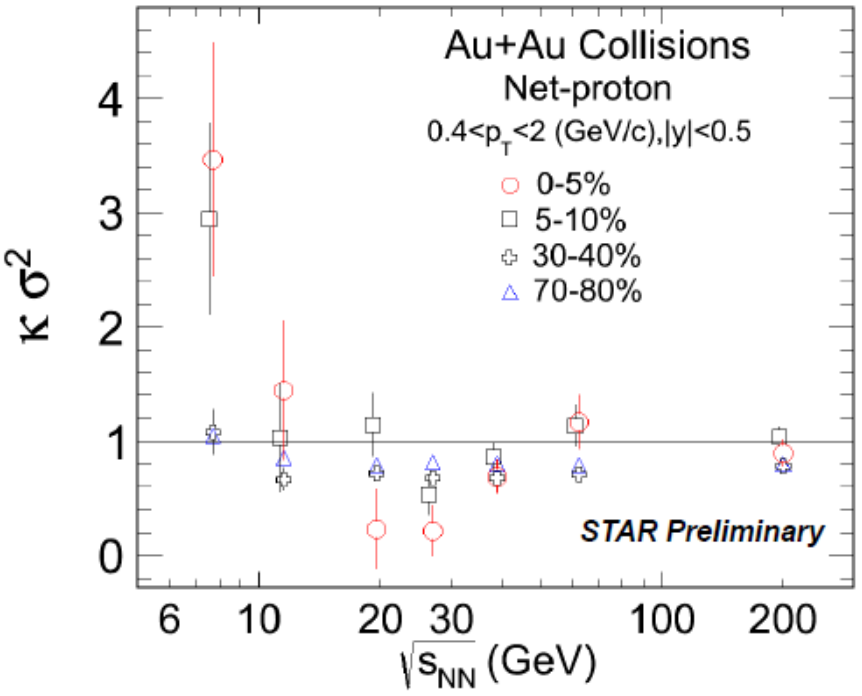
Collective flow, correlations, fluctuations

Observables

- Excitation function of flow of identified particles
- Enhanced production of composite particles, multi-particle correlations
- Higher moments of net-baryon and net-charge distributions

Physics case

- Equation of state
- Phase coexistence
- Phase transition
- Critical endpoint



Few data at FAIR energies

Charm at CBM (SIS100)

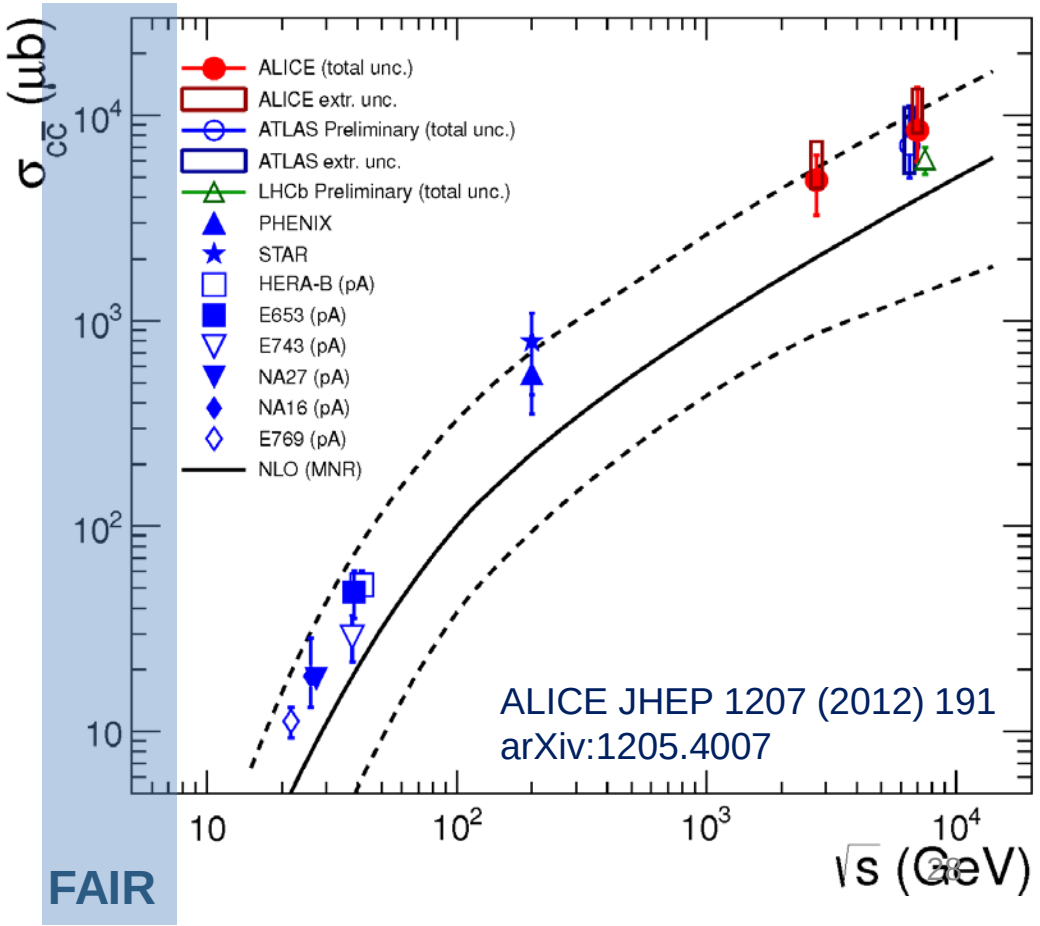
Observables

Cross sections and phase-space distributions of open and hidden charm in proton-nucleus collisions (p+A up to 30 GeV) and nucleus-nucleus collisions (Ni+Ni up to 15 A GeV).

Physics case

- Charm production at threshold energies
- Charm production in cold nuclear matter
- Charm propagation in dense QCD matter

No charm data at FAIR energies

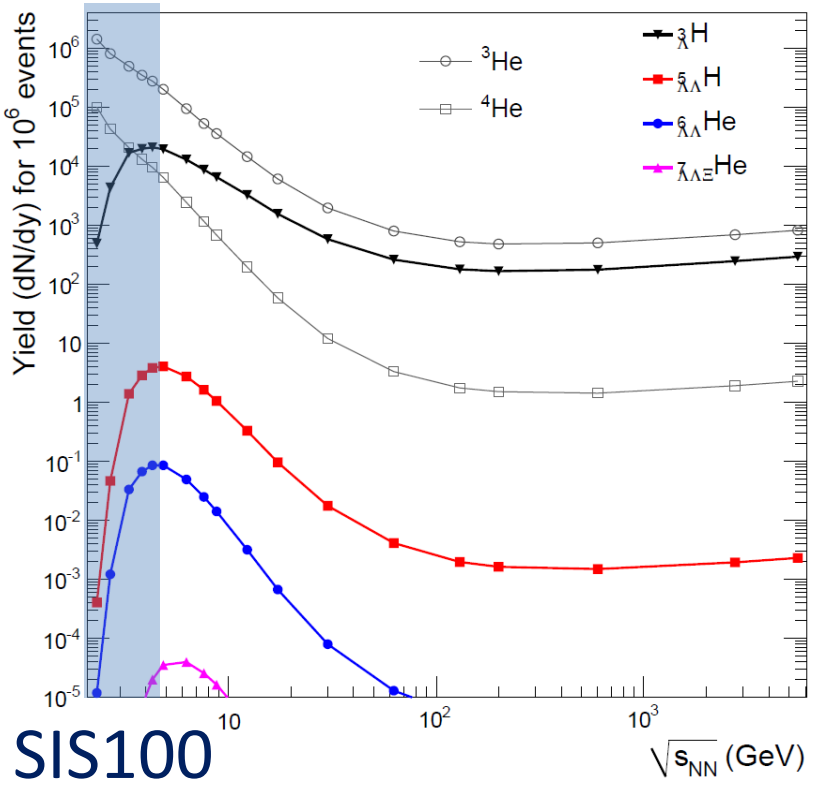


Strange Matter

Observables

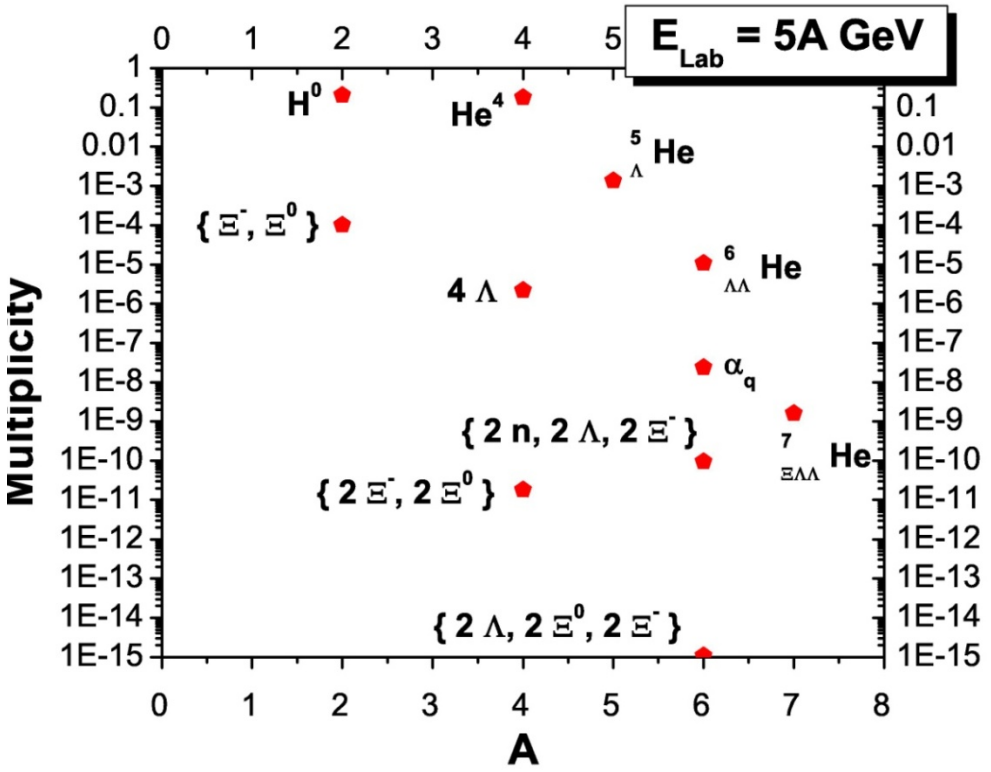
No data at FAIR energies

Hypernuclei, strange dibaryons and massive strange objects



SIS100

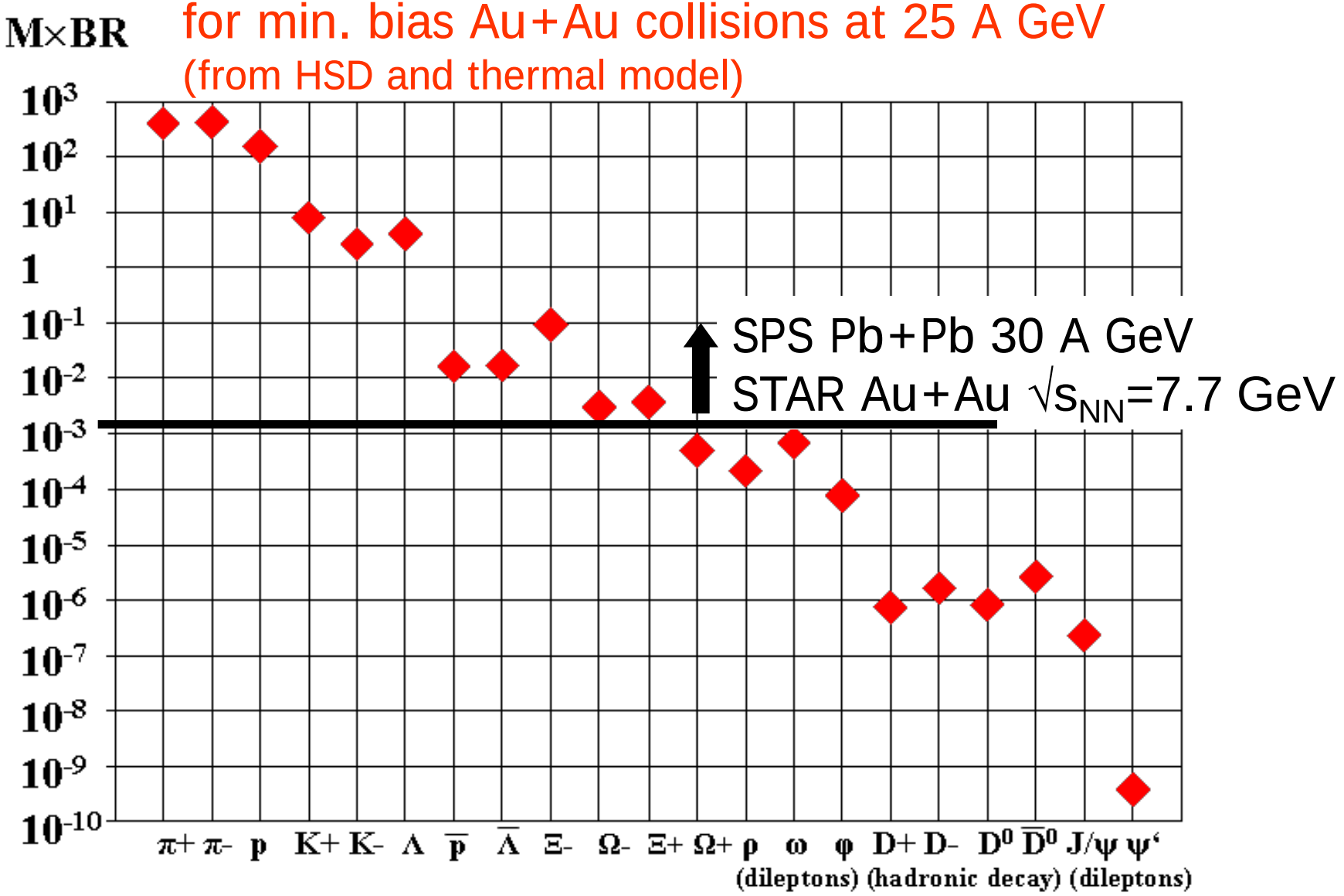
A. Andronic et al., Phys. Lett. B697 (2011) 203



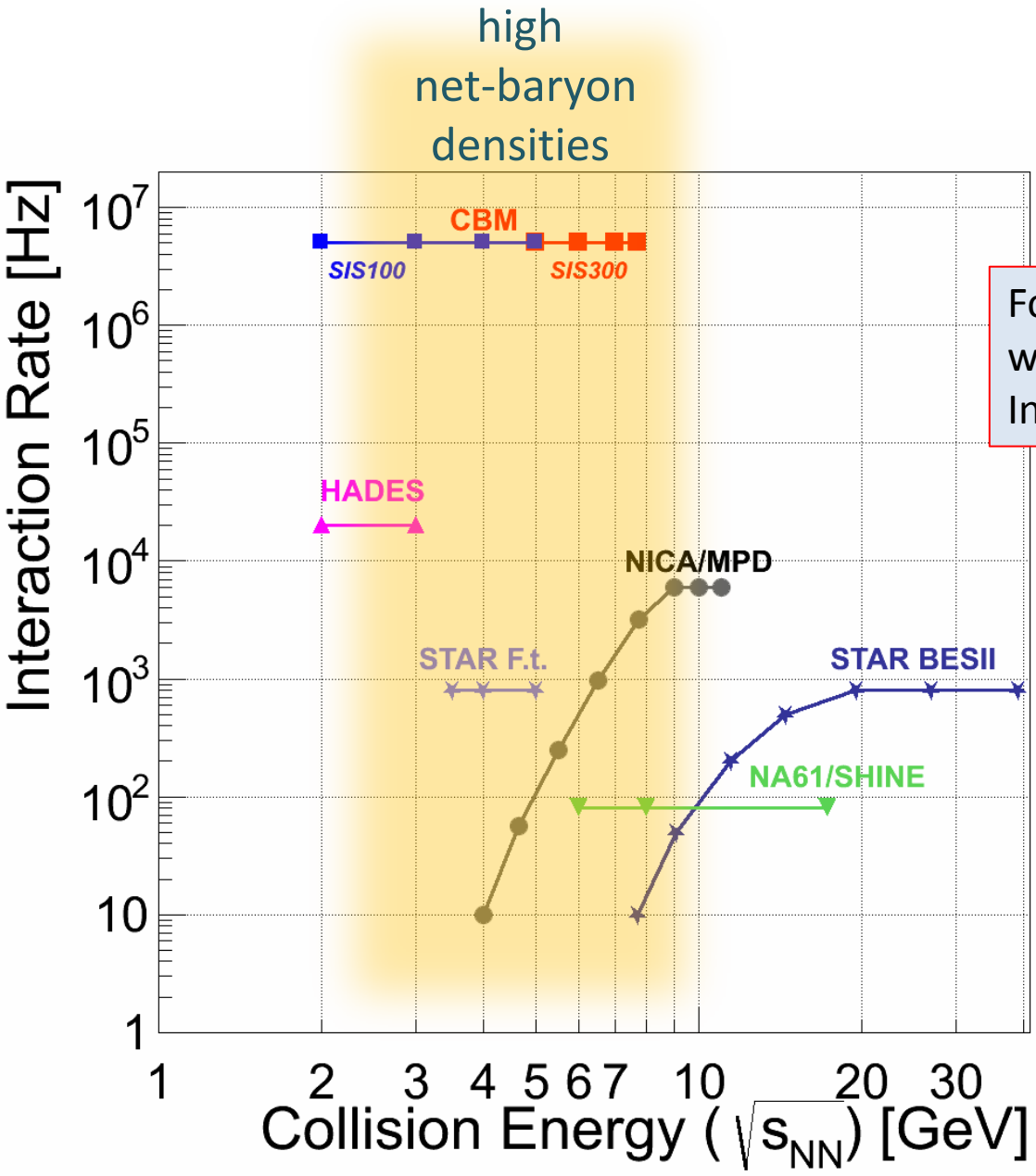
H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c

Experimental challenges

Particle multiplicity x branching ratio
for min. bias Au+Au collisions at 25 A GeV
(from HSD and thermal model)



Experiments exploring dense QCD matter

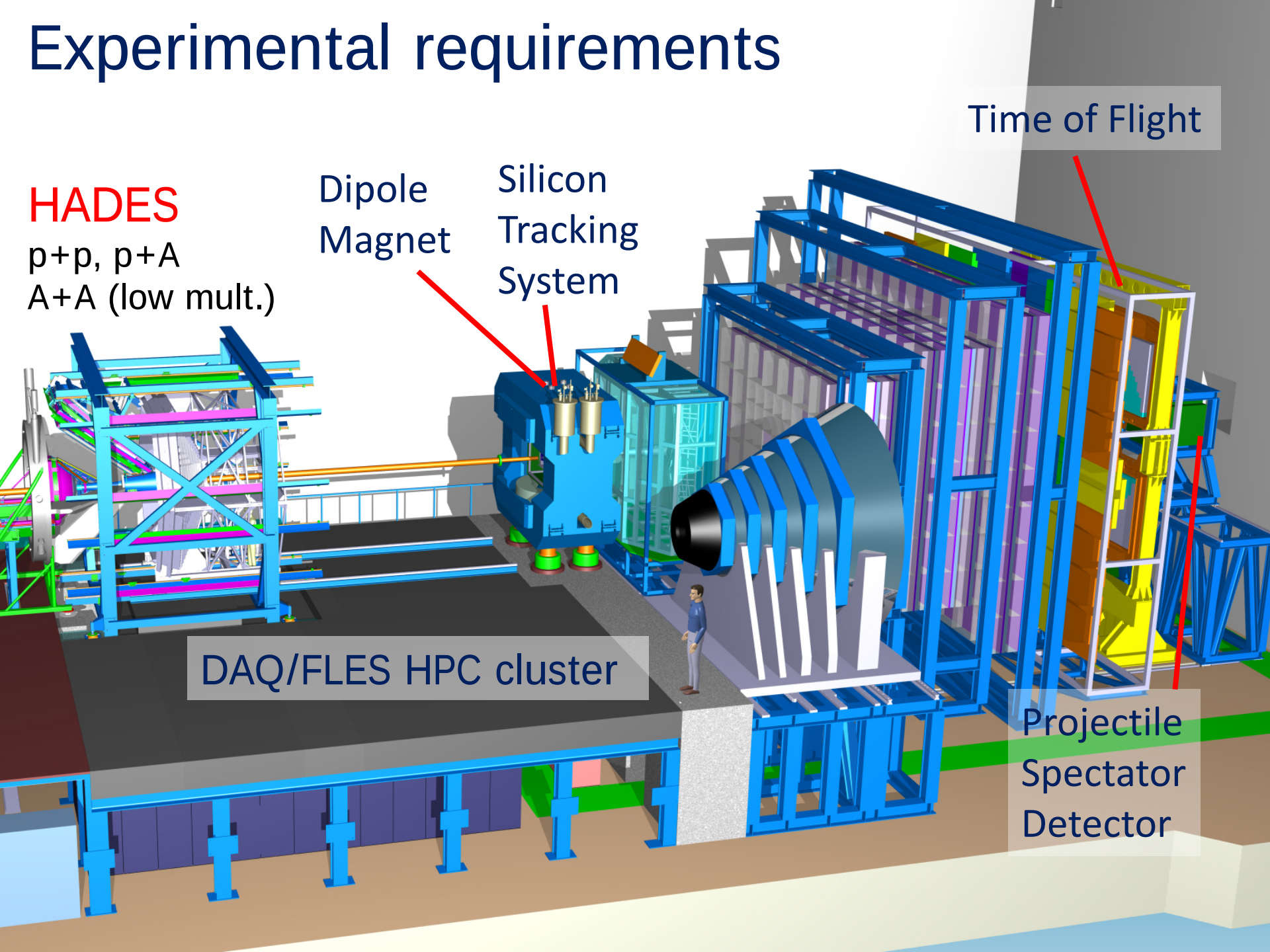


Focus on rare probes with high Interaction rates

Experimental requirements

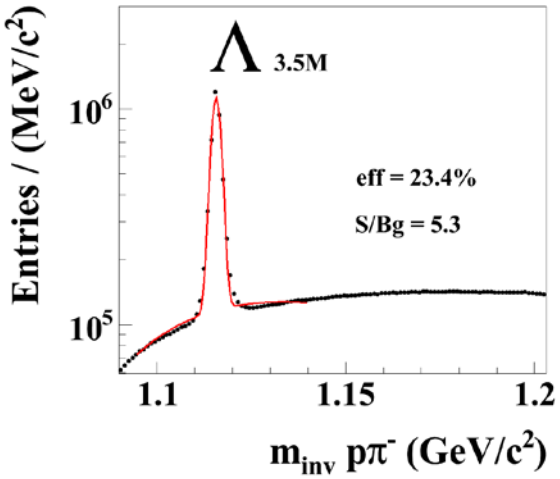
- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors and FEE
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

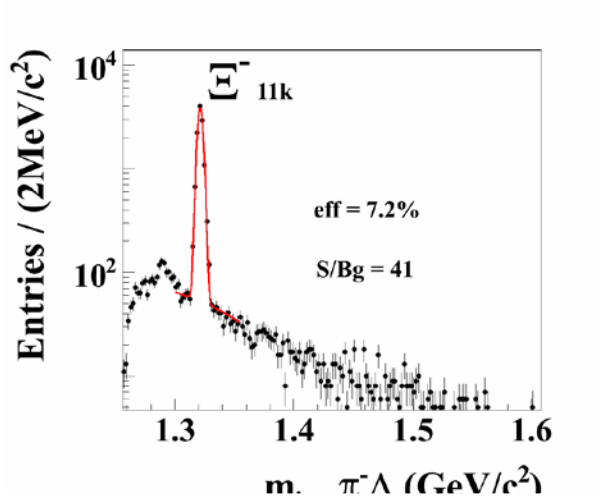
Experimental requirements

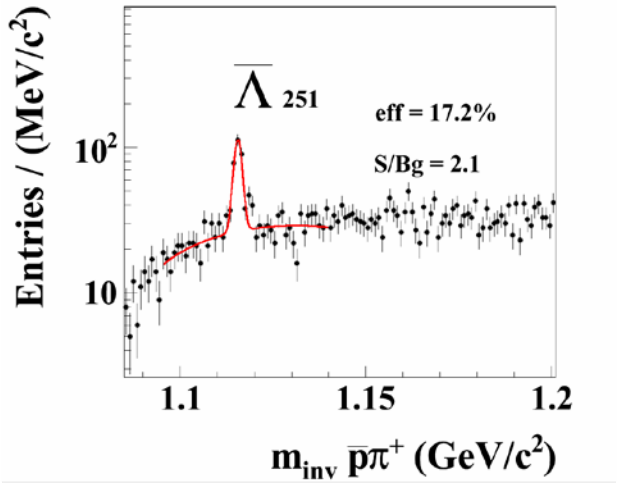


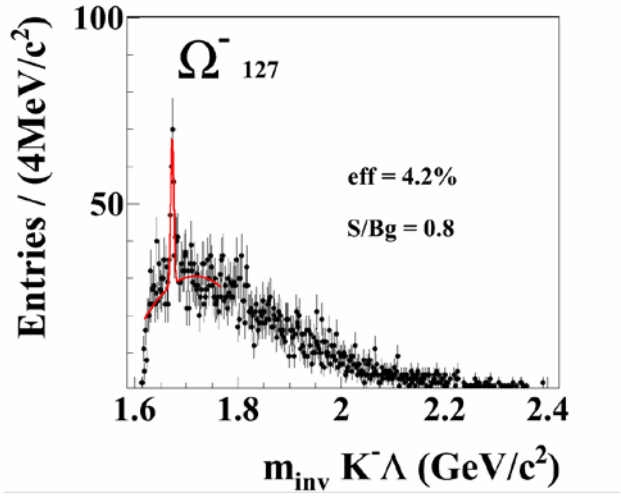
Hyperons in CBM at SIS100

Example: Au+Au at 8 A GeV, 10^6 central collisions (UrQMD)





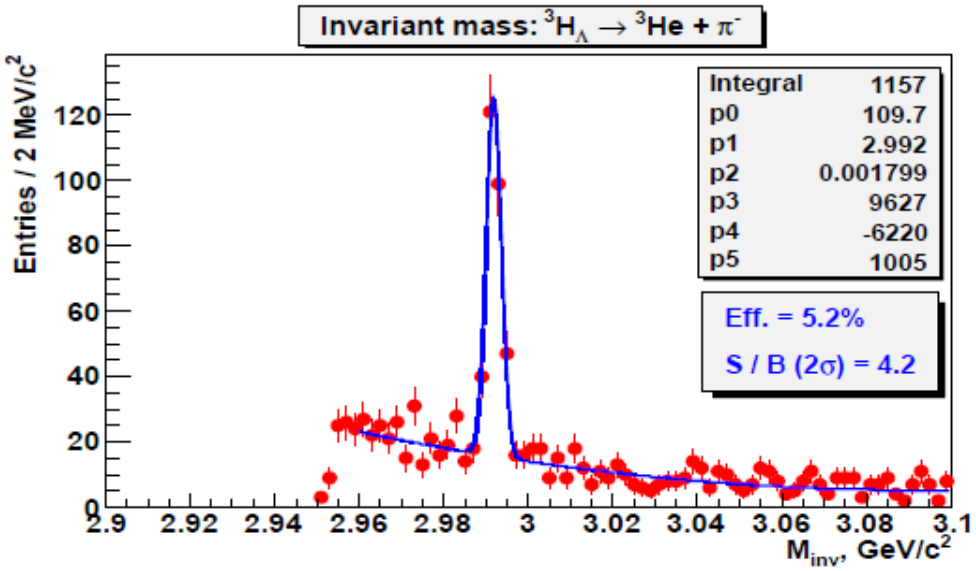


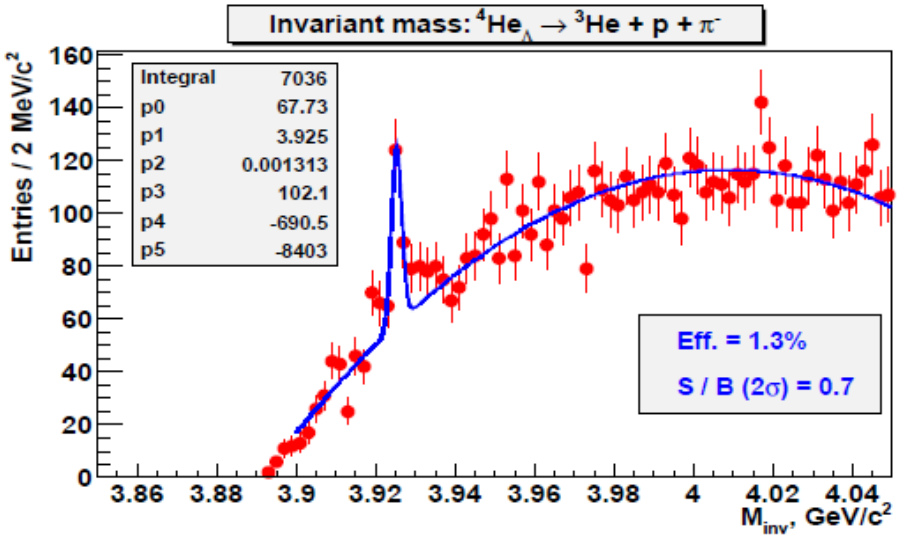


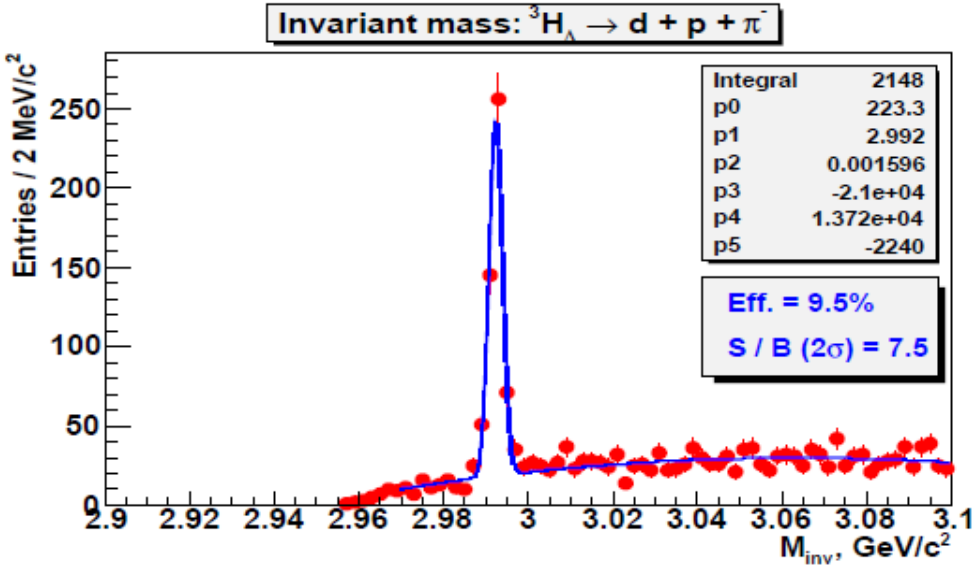
- In addition:
  K*,Λ*,Σ*,Ξ*,Ω*
- Event rate:
  100 kHz to 1 MHz

Hypernuclei in CBM at SIS100

Au+Au at 10 A GeV







Hyper nuclei	M central	BR	ε %	Yield/week central
$_\Lambda{}^3H$	$2\cdot10^{-2}$	0.6	7	$4.6\cdot10^{7}$
$_{\Lambda\Lambda}{}^5H$	$6\cdot10^{-6}$	0.36	1	1300

central collision rate 100 kHz

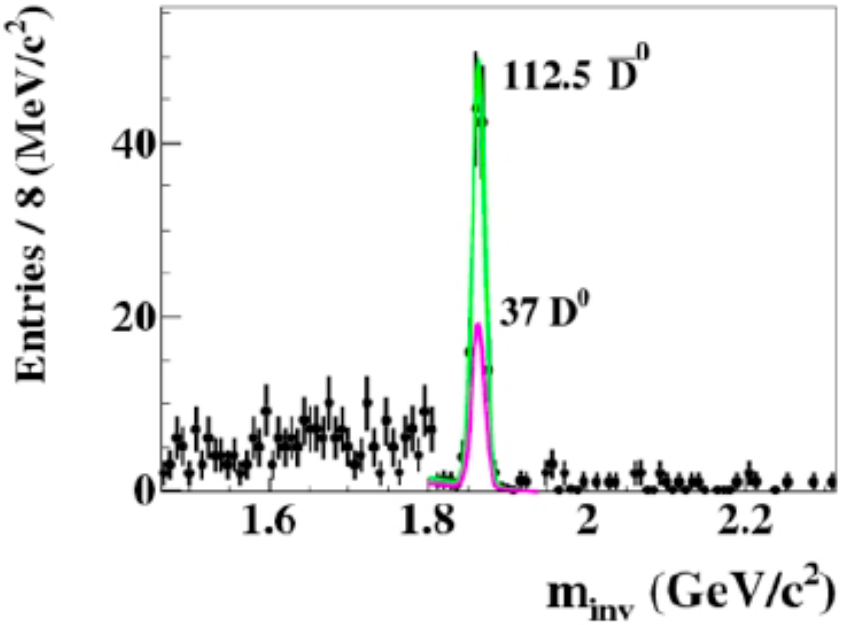
BR = 36% for double lambda hypernuclei is a guess

Open charm in CBM at SIS100

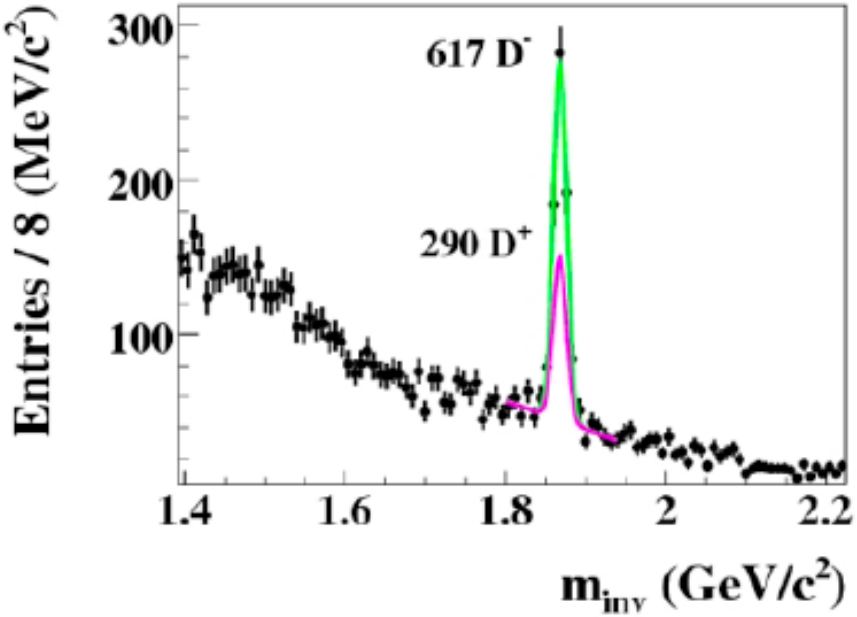
- Charm production cross sections at threshold energies
- Charm propagation in cold nuclear matter

30 GeV p + C

$D^0 \rightarrow K\pi\pi\pi$

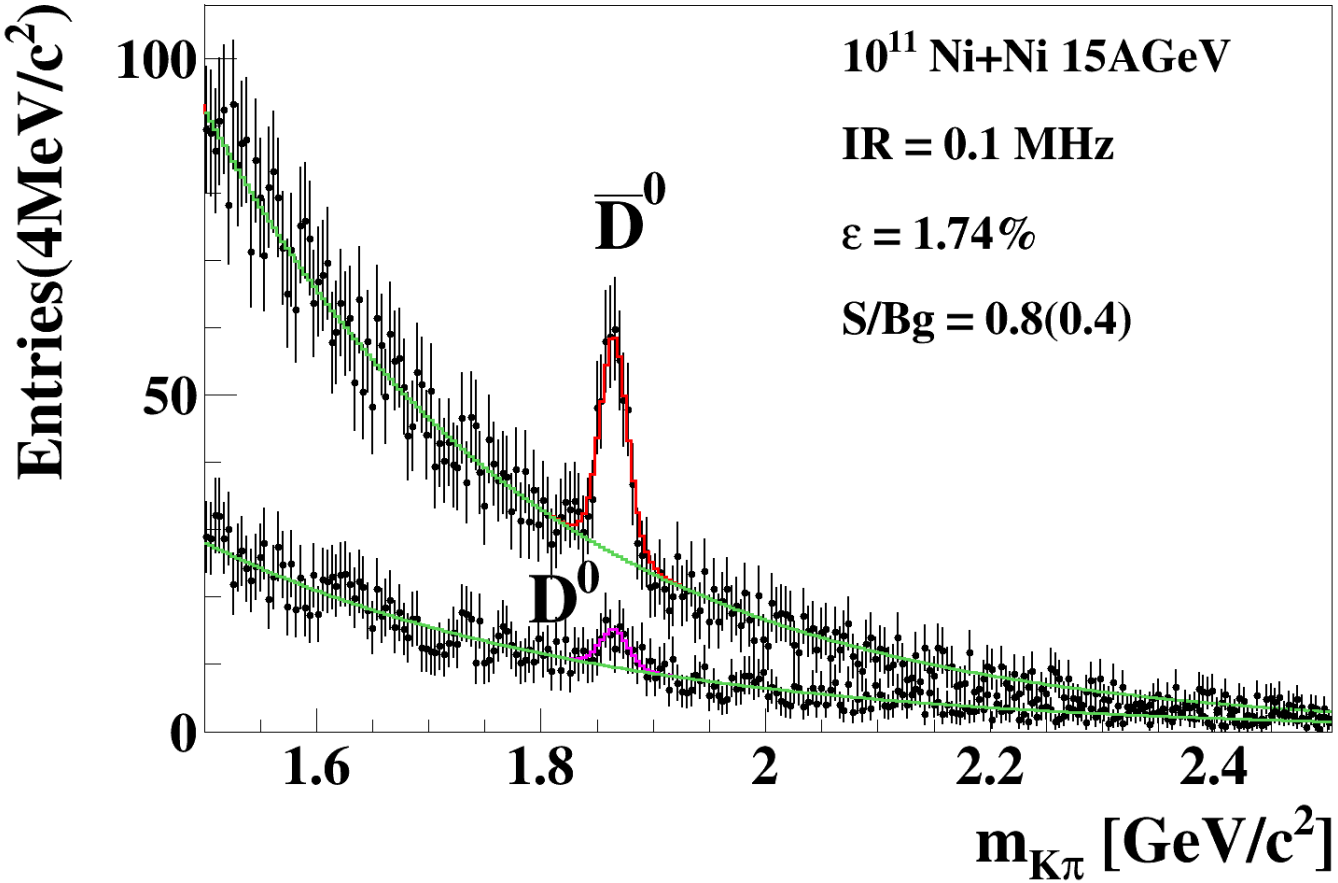


$D^{\pm} \rightarrow K\pi\pi$

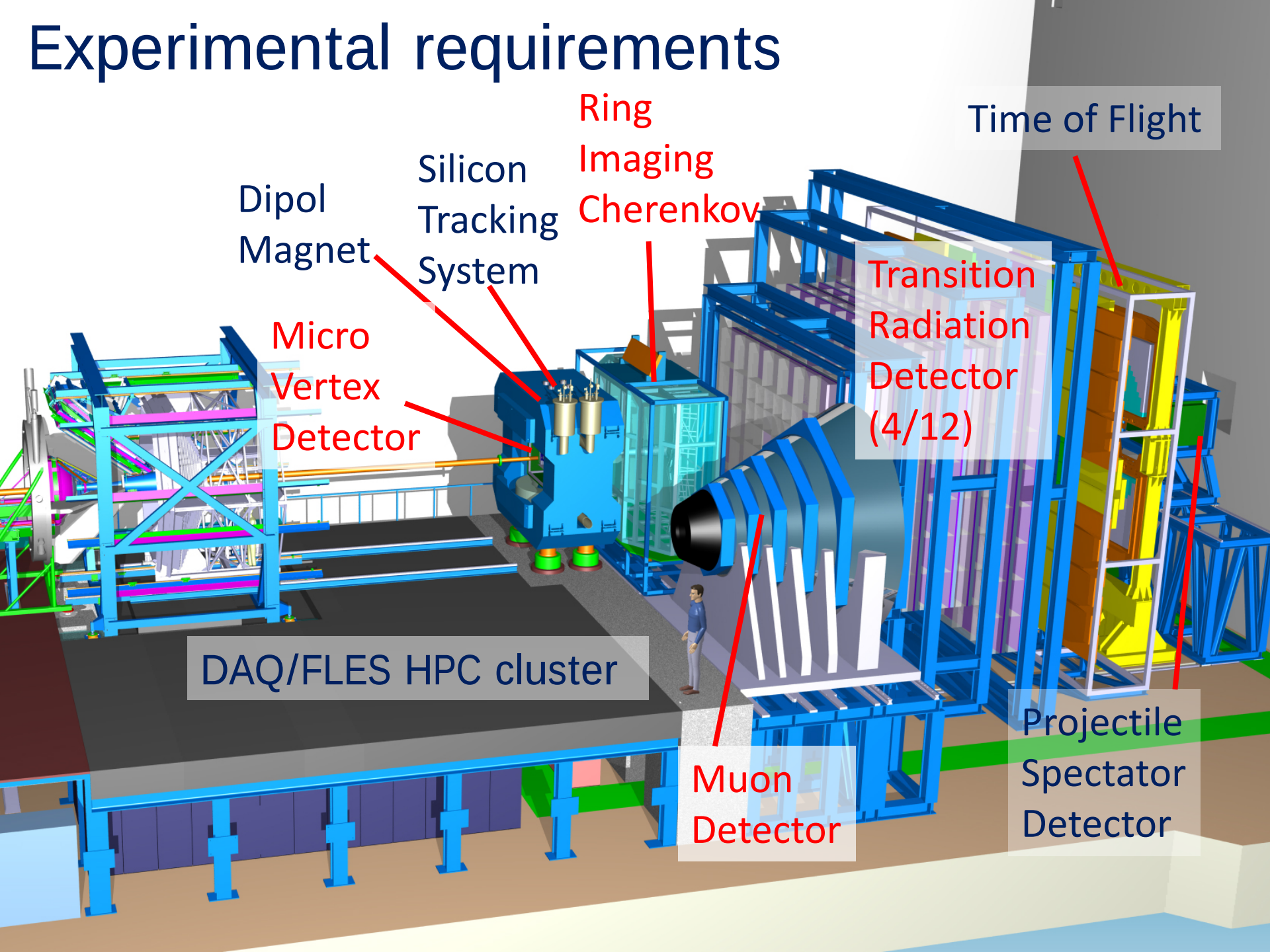


Open charm in CBM at SIS100

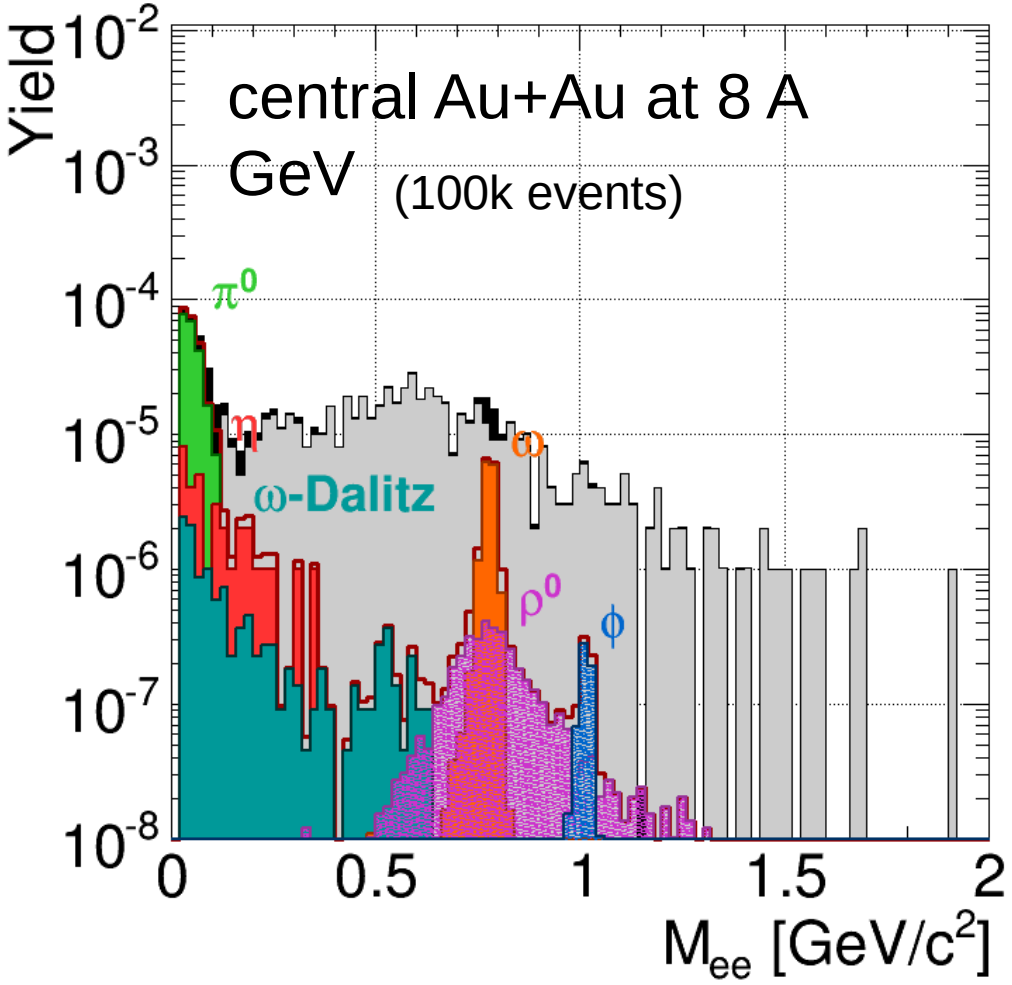
- Charm production and propagation in hot nuclear matter
- D multiplicities from thermal model (V. Vovchenko)
- 2 weeks Ni + Ni at 15 A GeV: 260 $\overline{D}^0$, 45 D^0



Experimental requirements



Electrons in CBM at SIS100



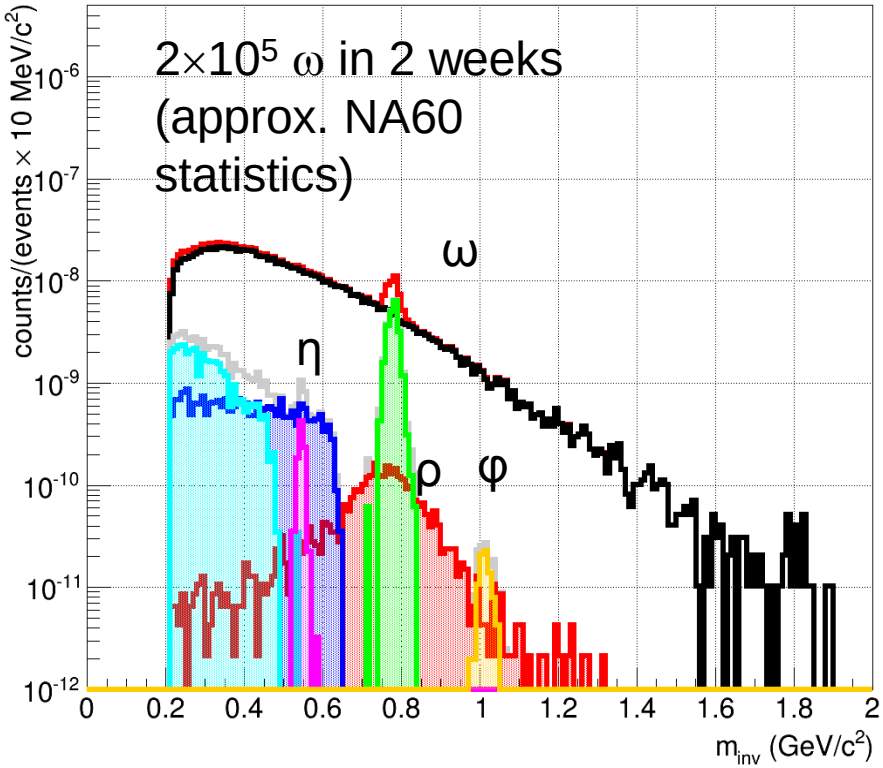
8 A GeV:
2×10^6 ω in 2 weeks

Simulation:
Signal yields from HSD
Background from UrQMD

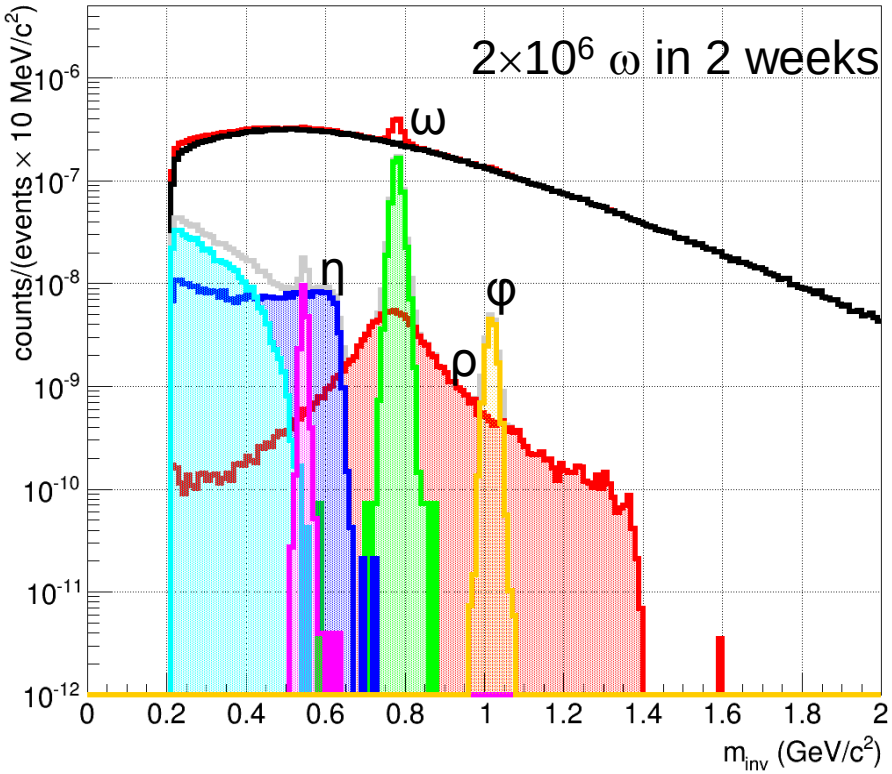
Muons in CBM at SIS100

Simulation: Signal yields from HSD, Background from UrQMD

central Au+Au at 4 A GeV

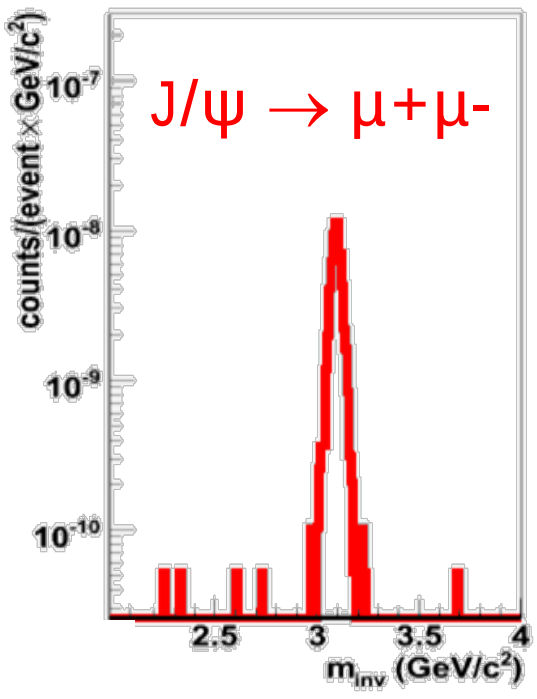


central Au+Au at 8 A GeV



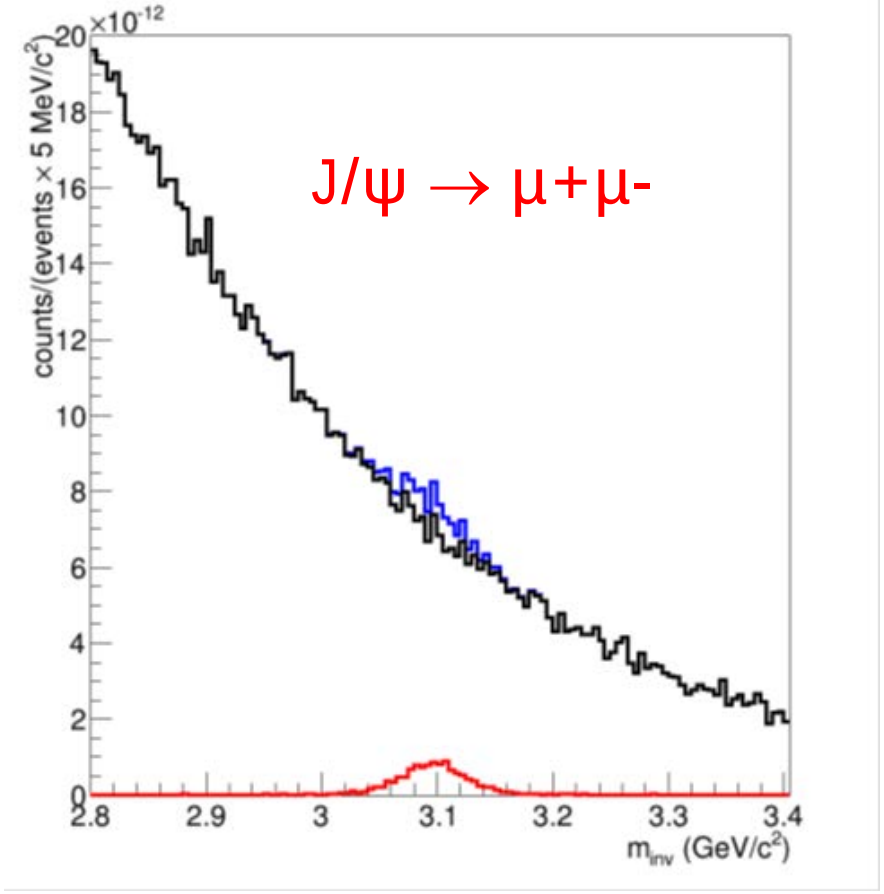
Hidden charm in CBM at SIS100

30 GeV p + Au



1000 J/ψ in 10^{12} events (1 day)
(multiplicity from HSD)

central Au+Au at 10 A GeV



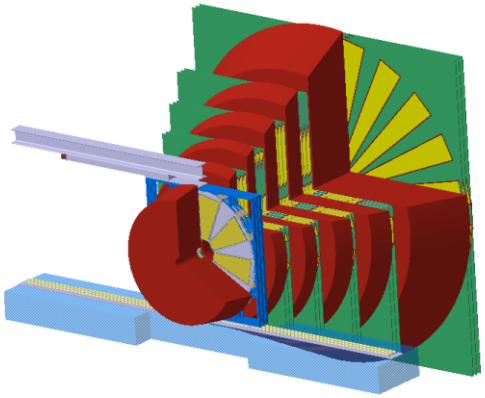
1000 J/ψ in 10^{13} events (10 days)
(multiplicity from HSD)

Compressed Baryonic Matter Experiment

Technical Design Report for the CBM

Muon Chamber (MUCH)

The CBM Collaboration



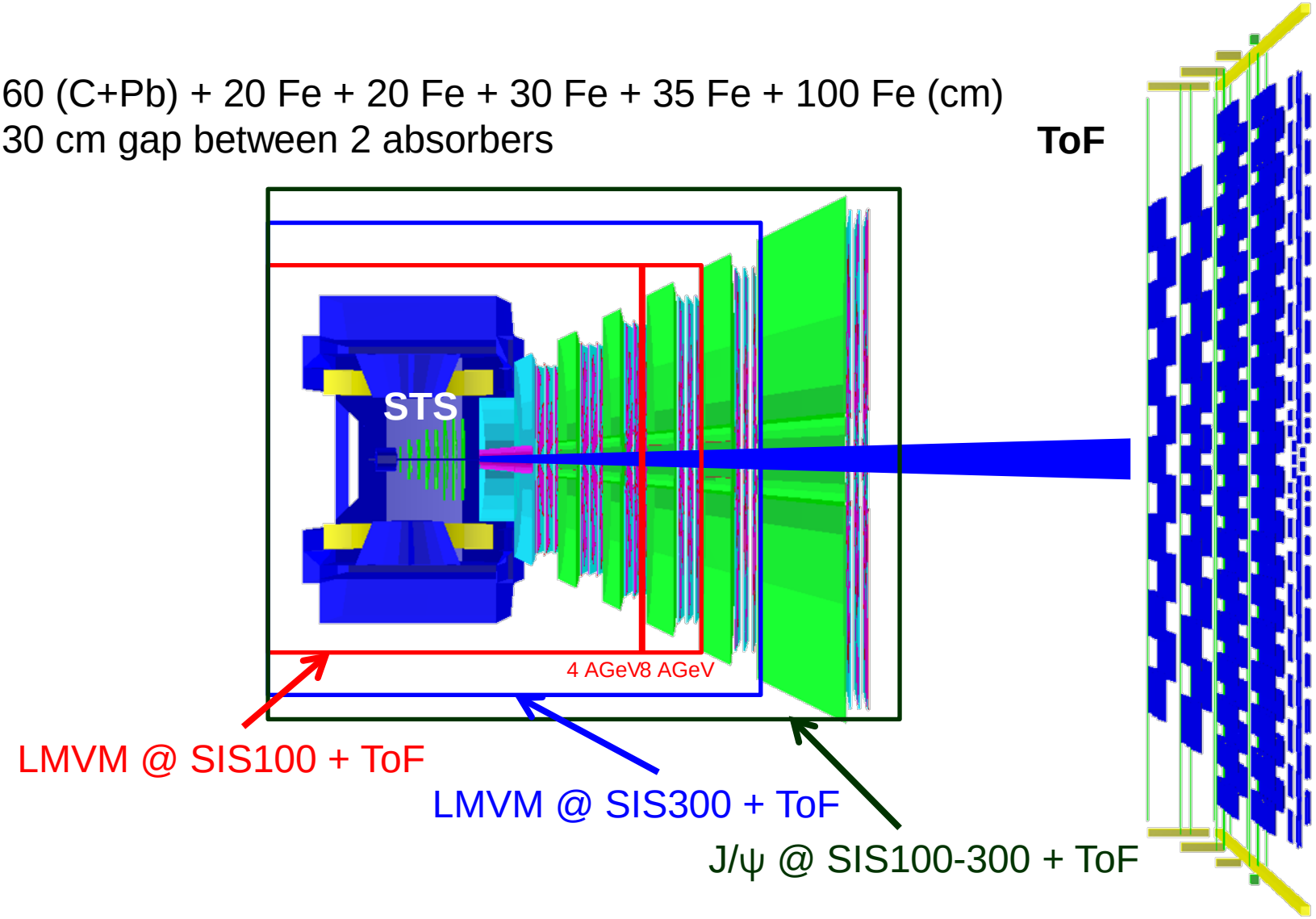
December 2013

Technical Design Report
Submission for review: 21/10/13
Approved: 26th January 2015

Theses:
Arun Prakash, BHU
Partha Bhaduri, VECC
Husnud, AMU
Shabir, KU
Kalyan Dey, GU
Jogender Saini, VECC
Swagata Mondal, VECC

Much setup (SIS100/300)

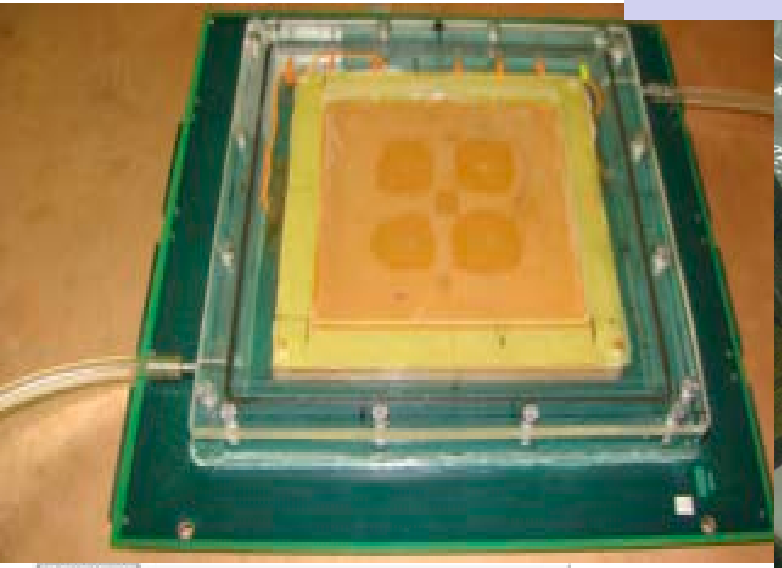
60 (C+Pb) + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers

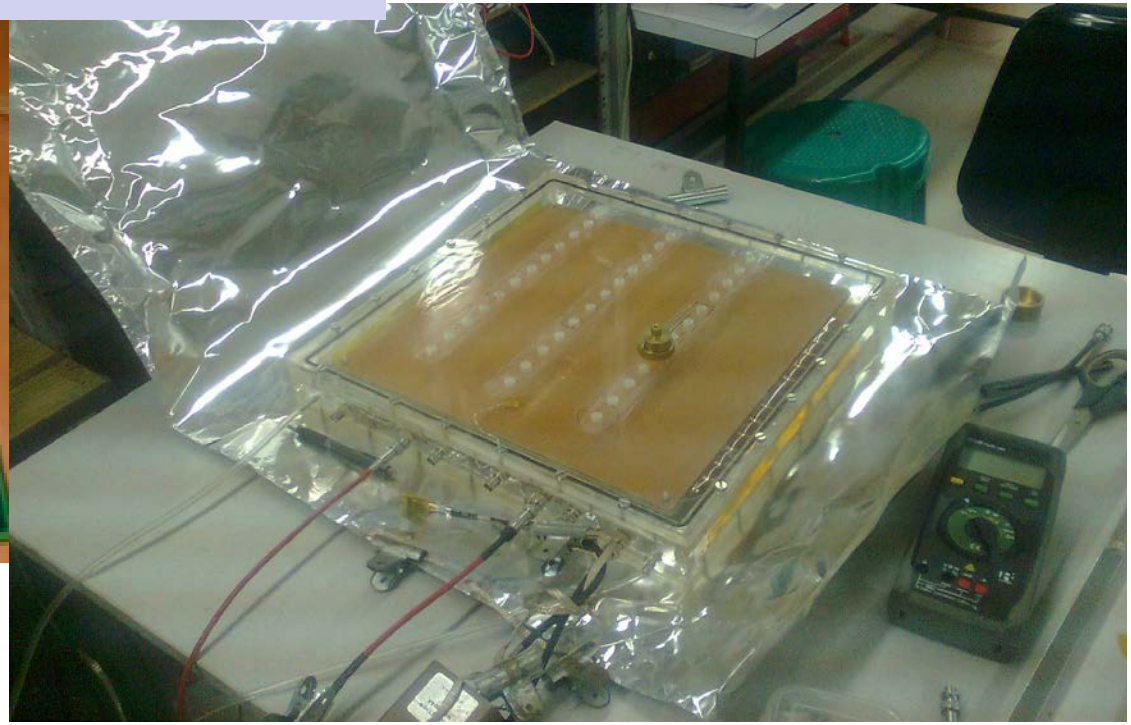


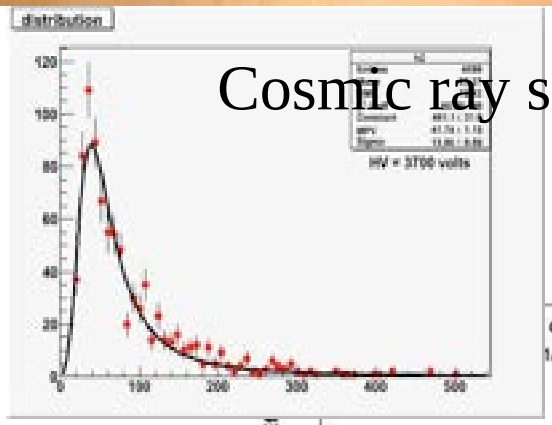
MUCH version	Carbon absorber	No. of iron absorber slices	total thickness of iron absorber	No. of tracking chamber triplets	Type of Chambers	Physics case
SIS100-A	60 cm	2	40 cm	3	2 GEM, 1 Straw tube	LMVM A + A 4-6 AGeV
SIS100-B	60 cm	3	70 cm	4	2 GEM, 2 Straw tubes	LMVM A + A 8-10 AGeV
SIS100-C	60 cm	4	170 cm	5	2 GEM 2 Straw tubes 1 TRD	p + A (J/ψ) 29 GeV
SIS300-A	60 cm	5	105 cm	5	2 GEM, 2 Straw tubes, 1 TRD	LMVM (A + A) 15-25 AGeV
SIS300-B	60 cm	6	205 cm	6	2 GEM, 2 Straw tubes 1 Hybrid GEM, 1 TRD	J/ψ (A + A) 10-35 AGeV

Table 2.1: Various MUCH configurations in SIS100 and SIS300

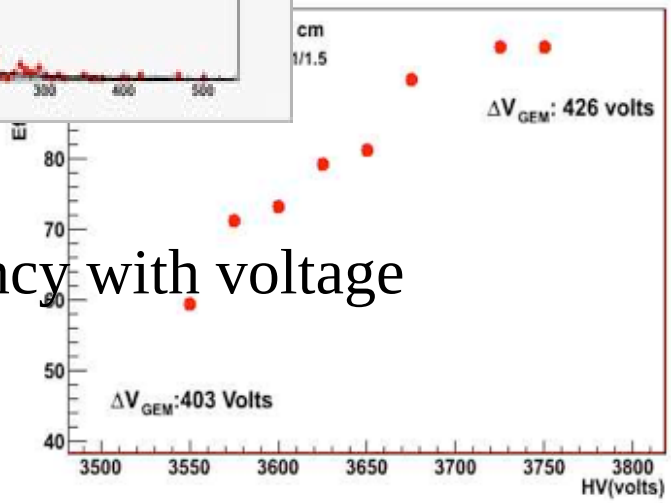
GEM R&D at VECC



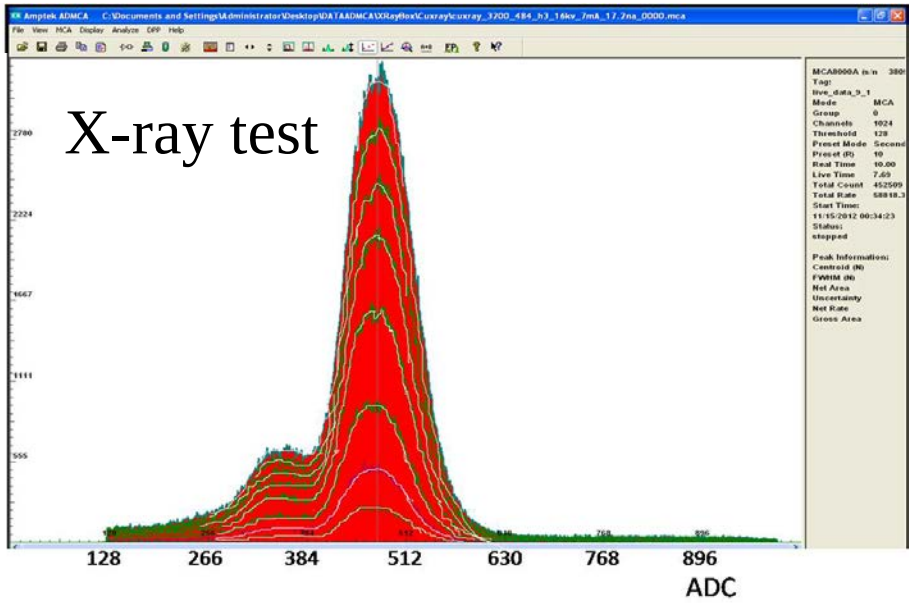




Cosmic ray spectra

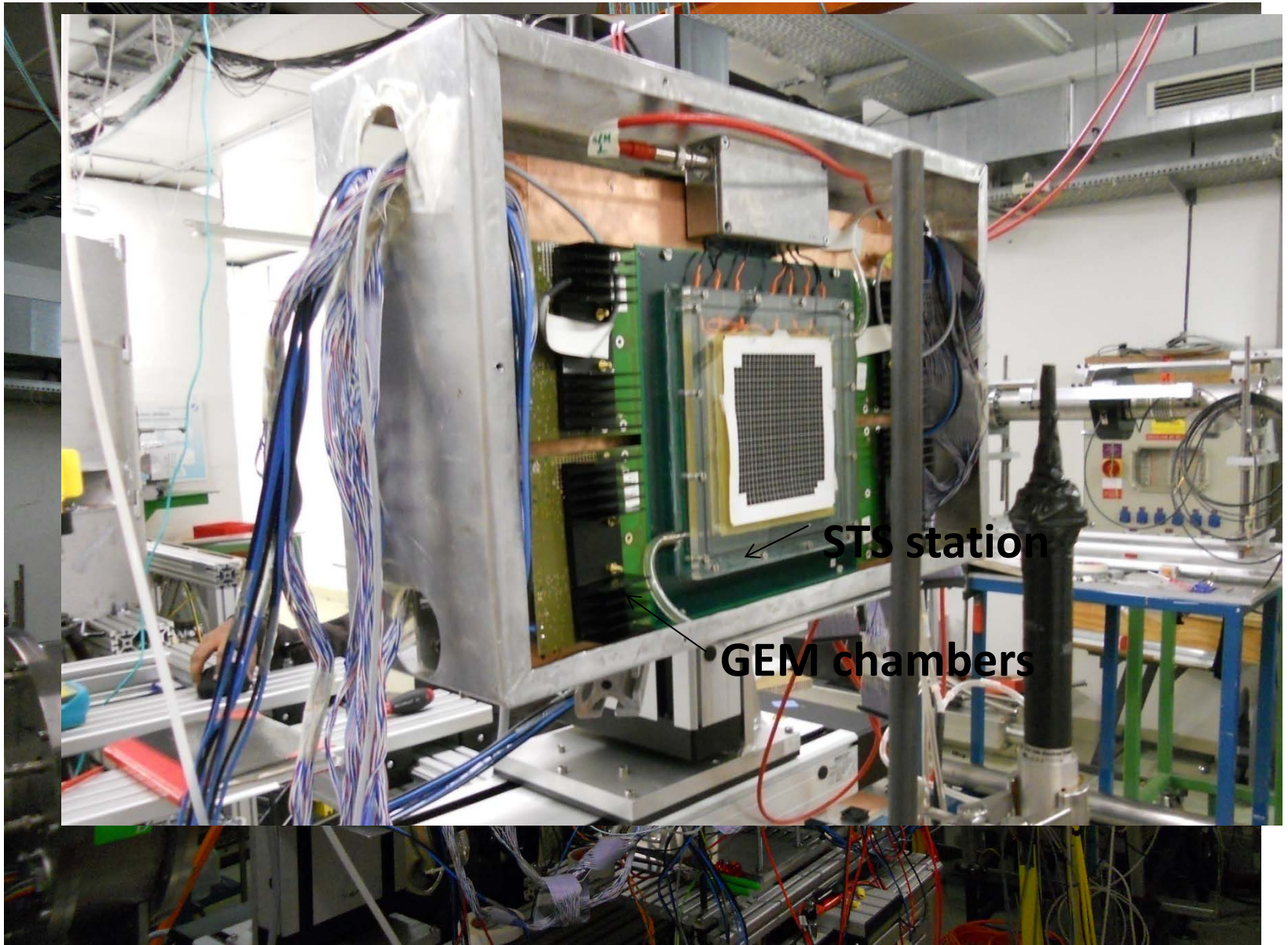


Efficiency with voltage

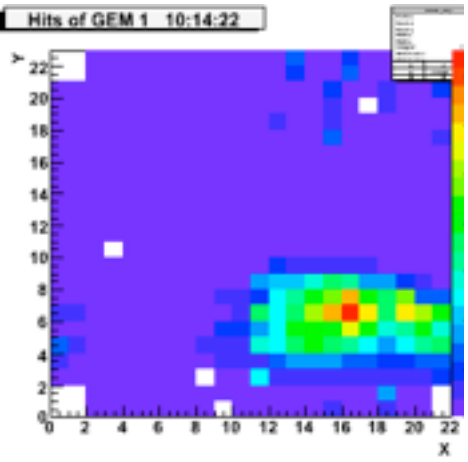


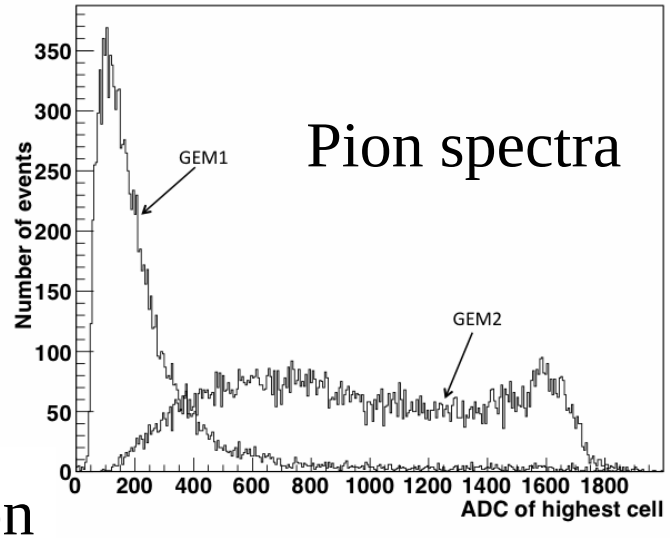
X-ray test

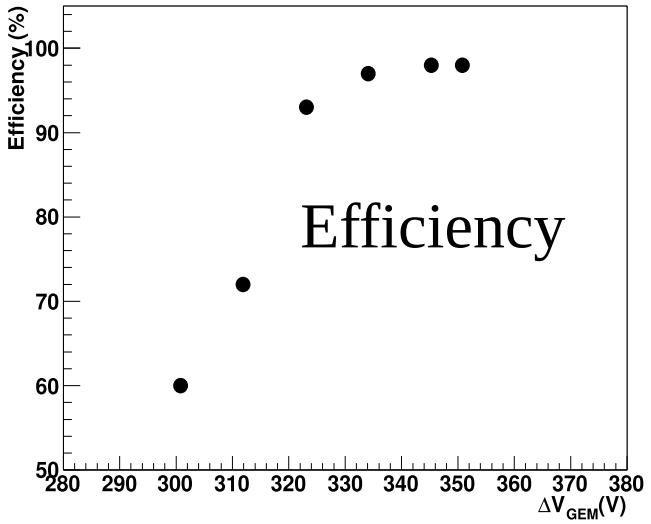
Test setup at Jessica beamline at COSY (Julich), Dec'10

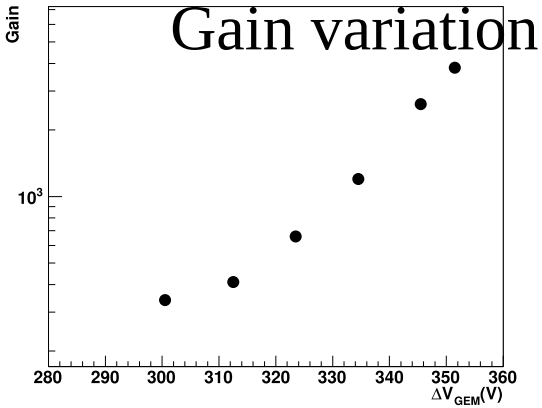


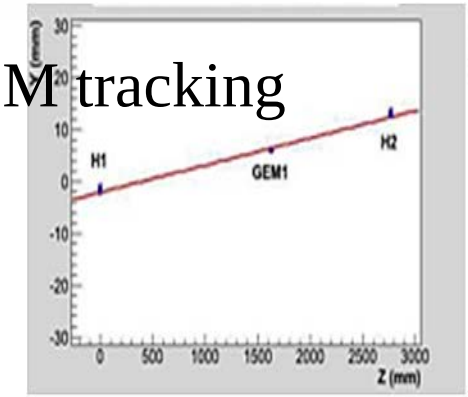
P beam

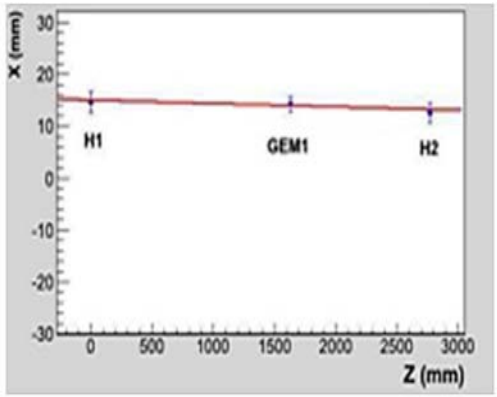


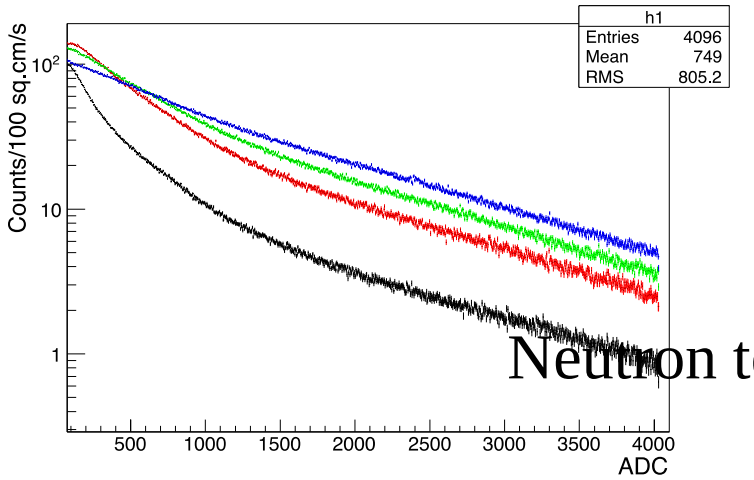


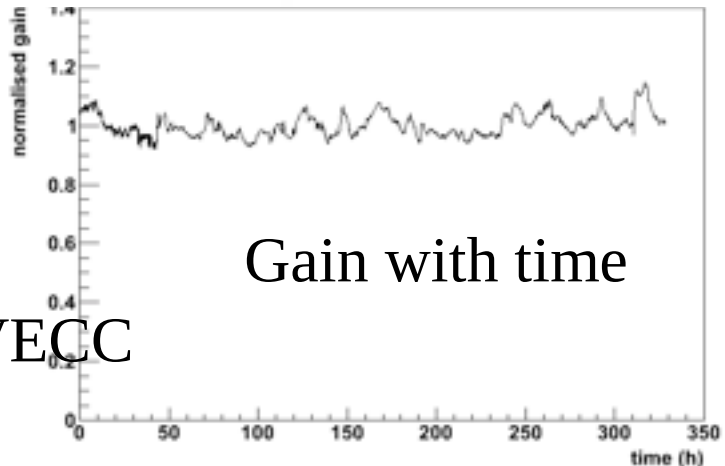




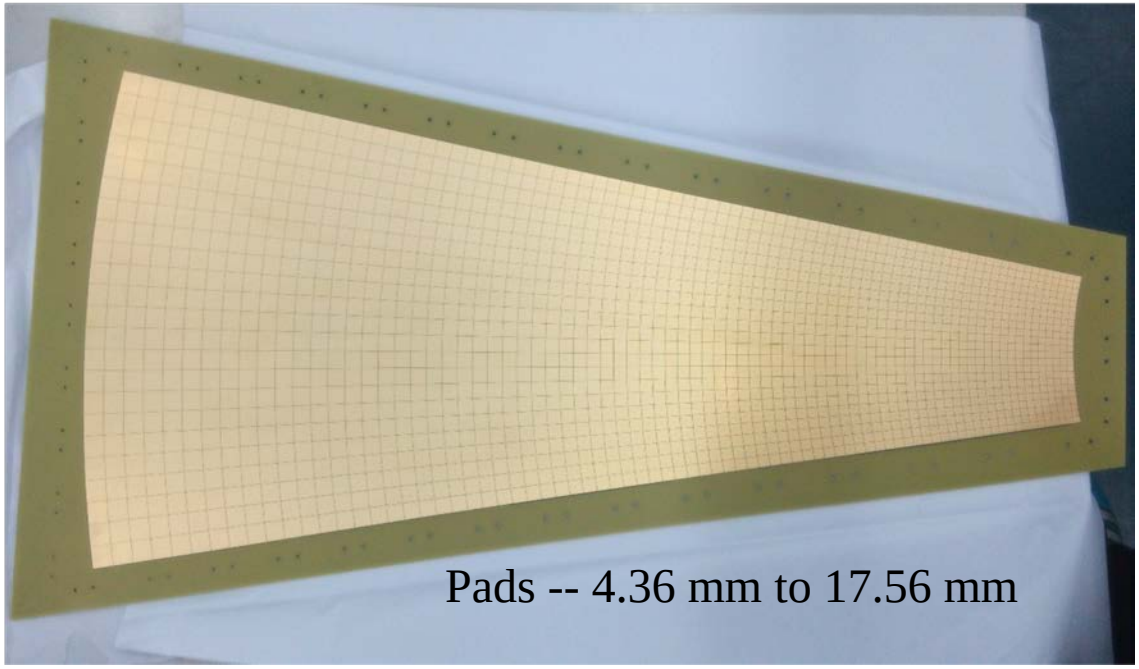








Neutron test at VECC



Readout PCB
inner side

~1920 pads with
Projective geometry
From 4.36 mm to
17.56 mm

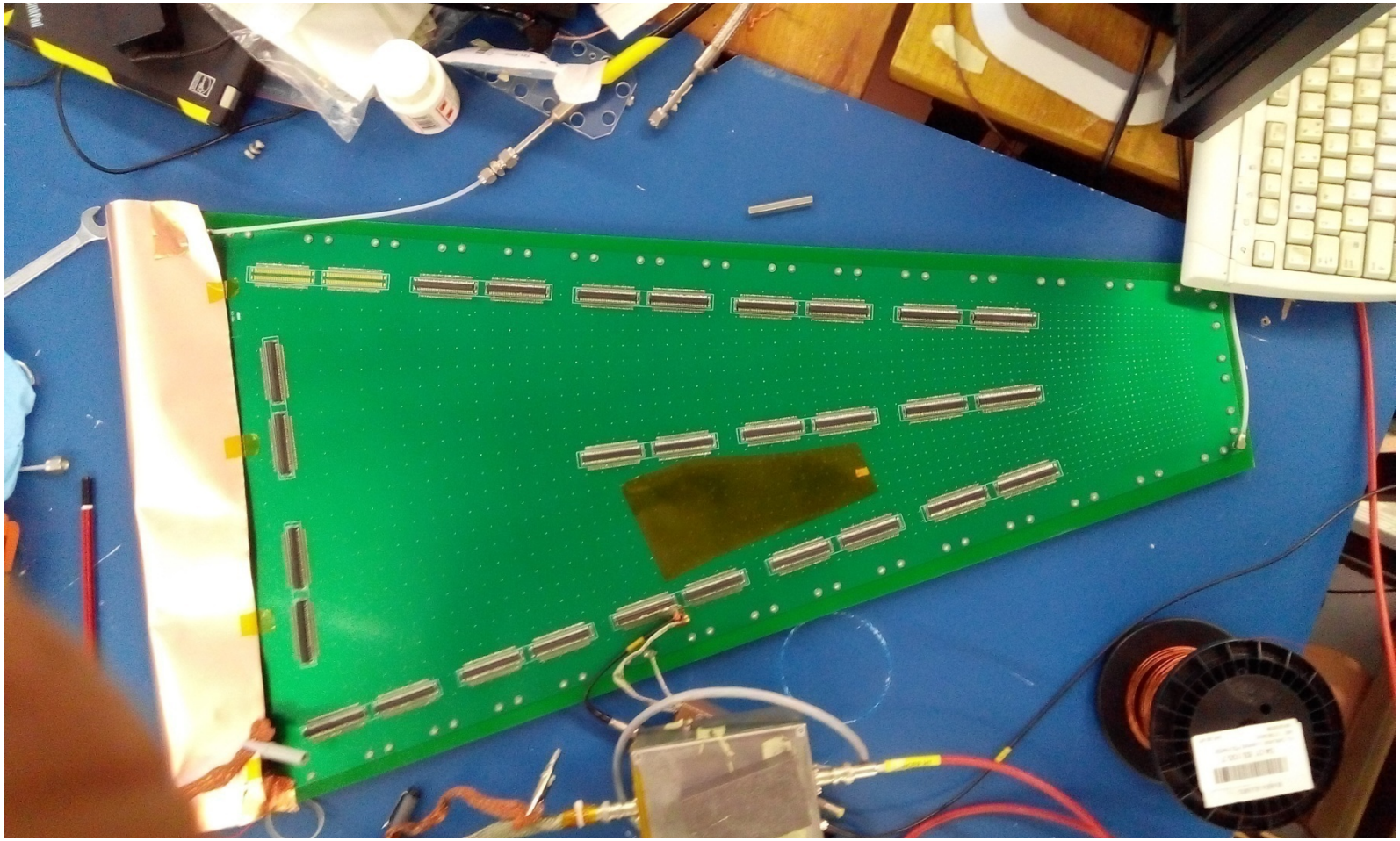
Readout PCB
(8-layer)
outer side
with 15 FEB
connections
(nXYTER)

Readout PCB fabricated at Bangalore, India

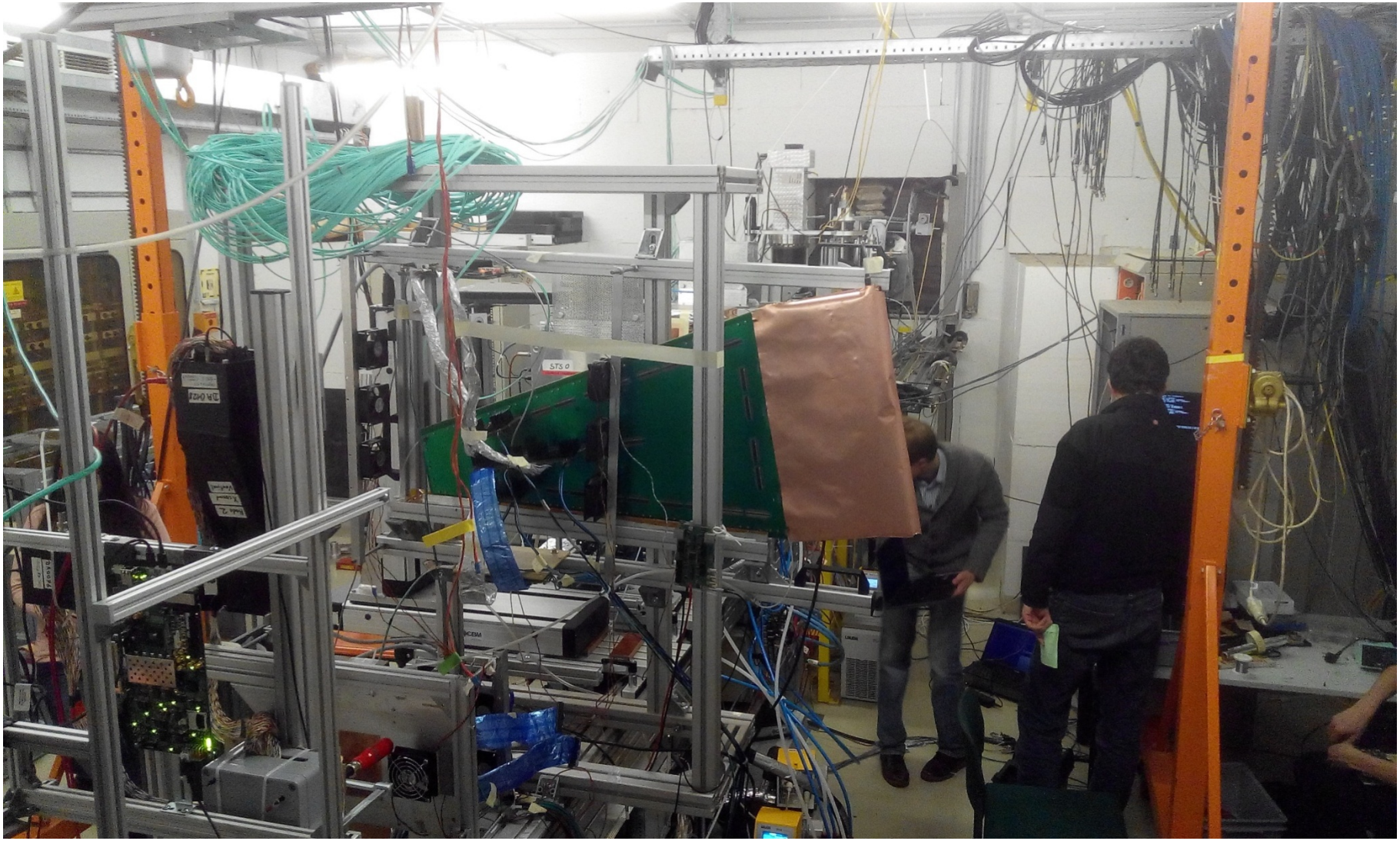
The GEM assembly with inner frames being placed on the Drift plane

Stretching the GEMs

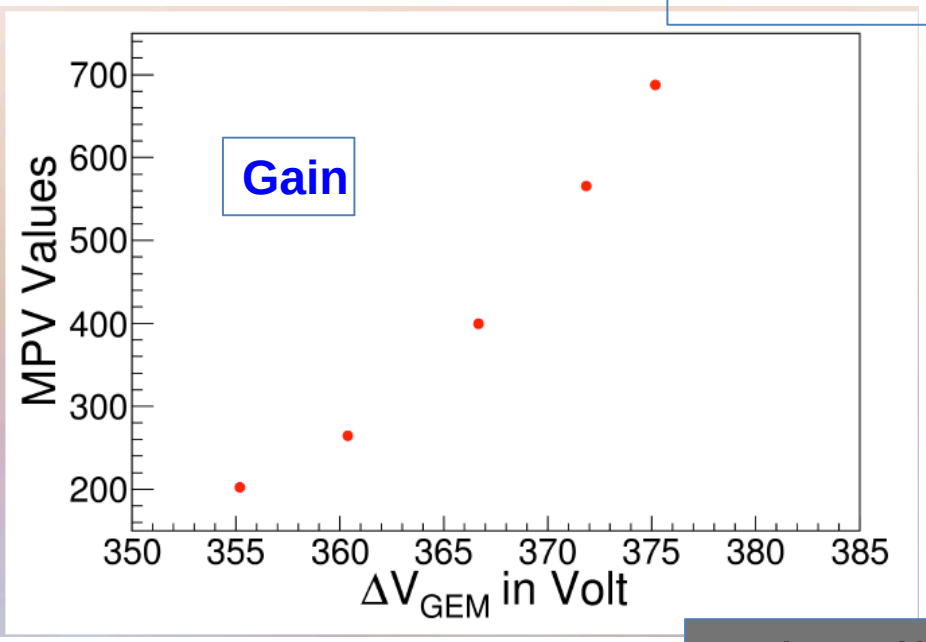
Testing in RD51 lab

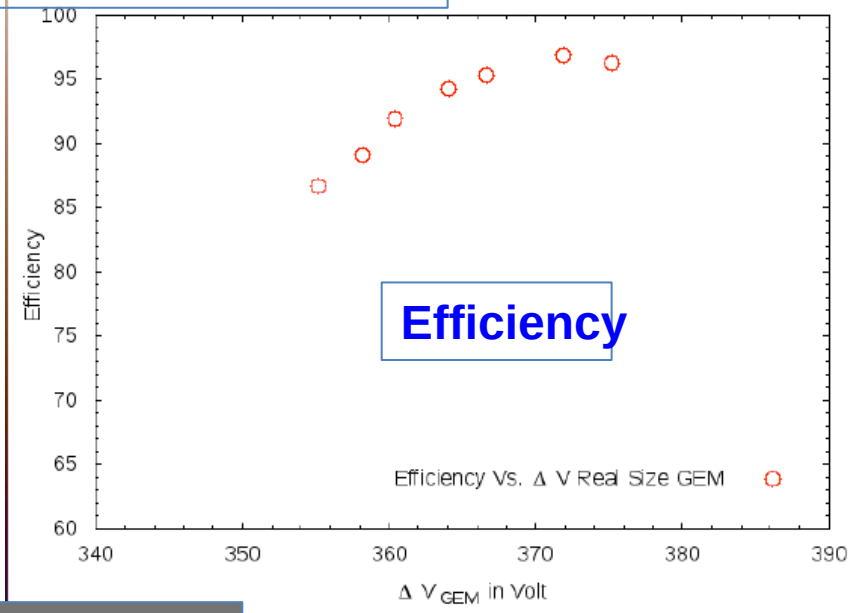


Beamtest of real size prototype at JESSICA@COSY, Juelich

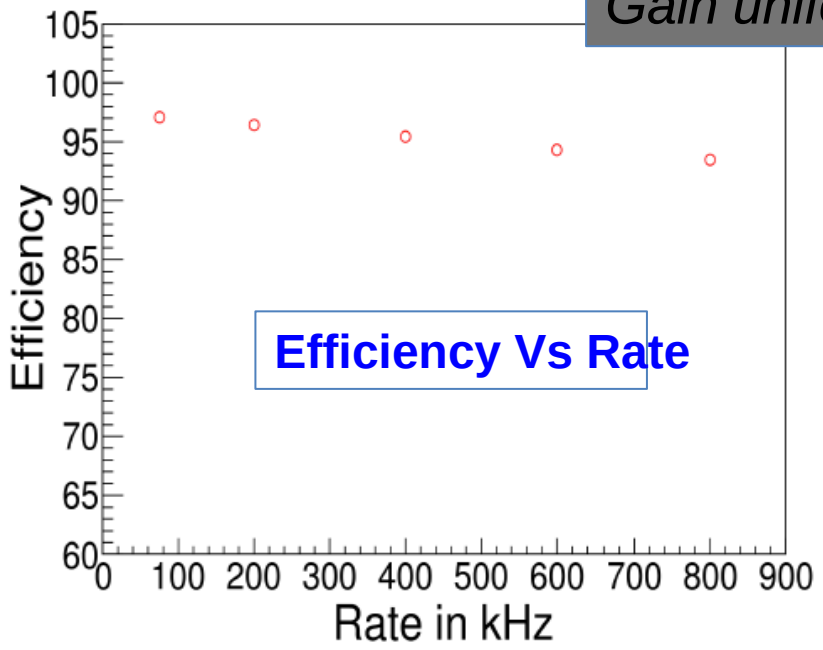


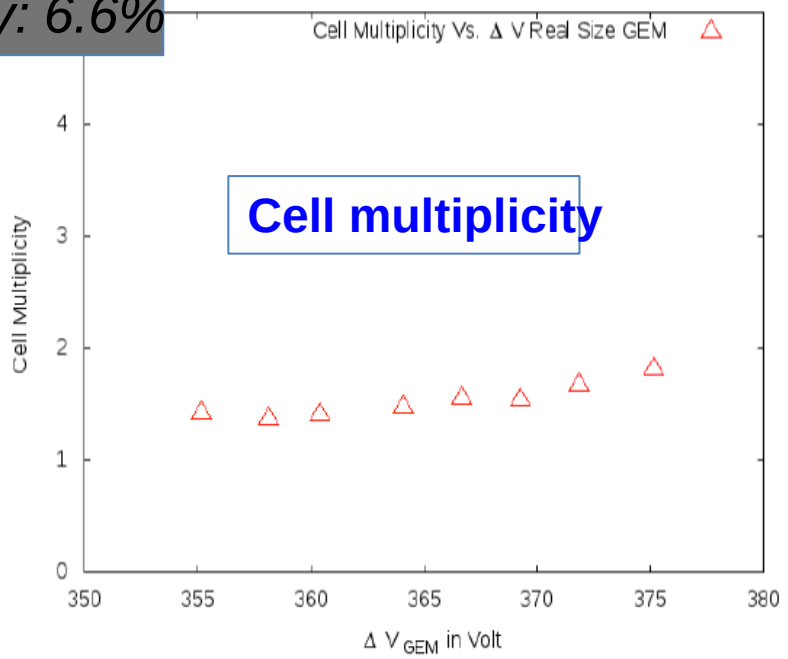
Test beam results

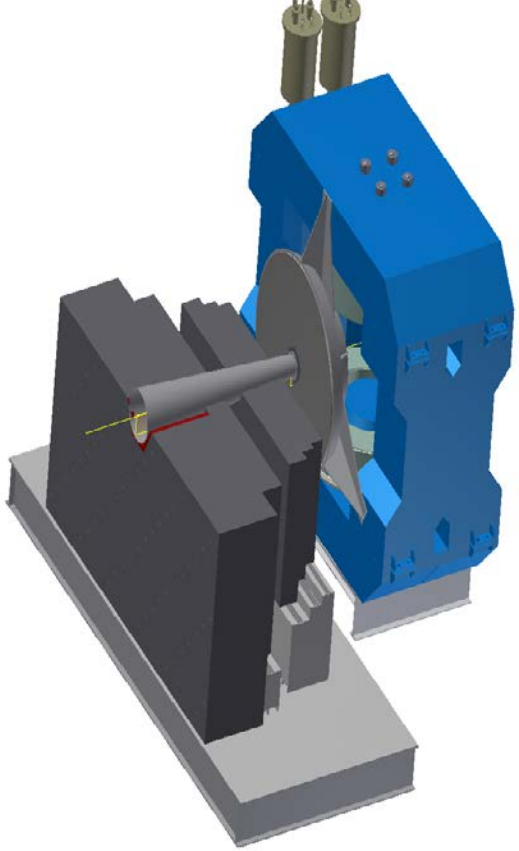


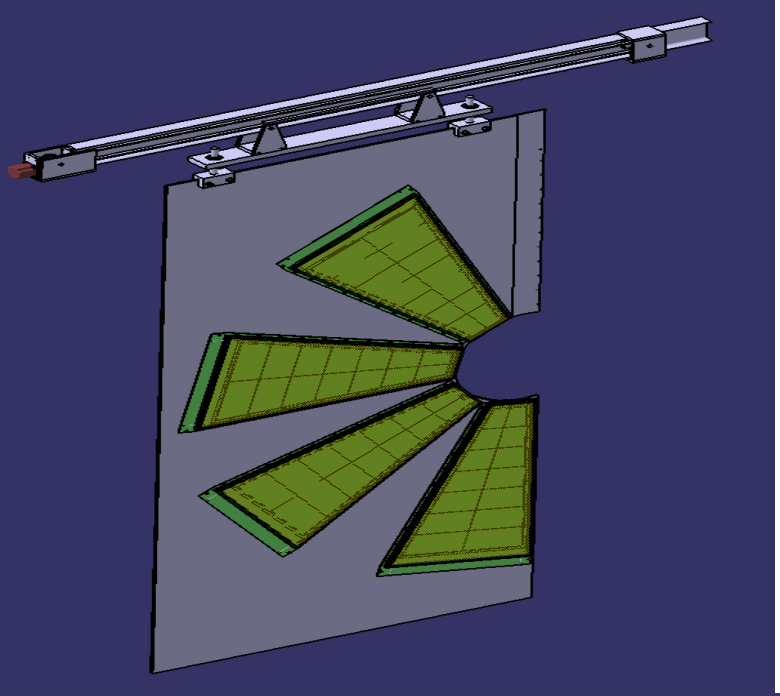


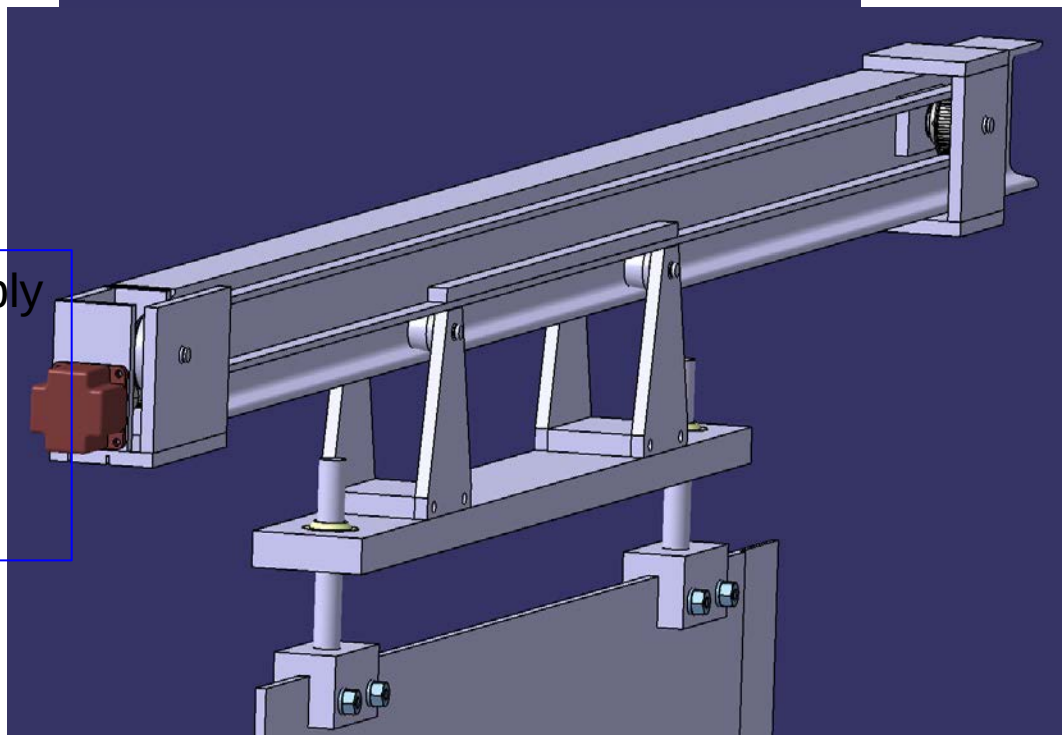
Gain uniformity: 6.6%







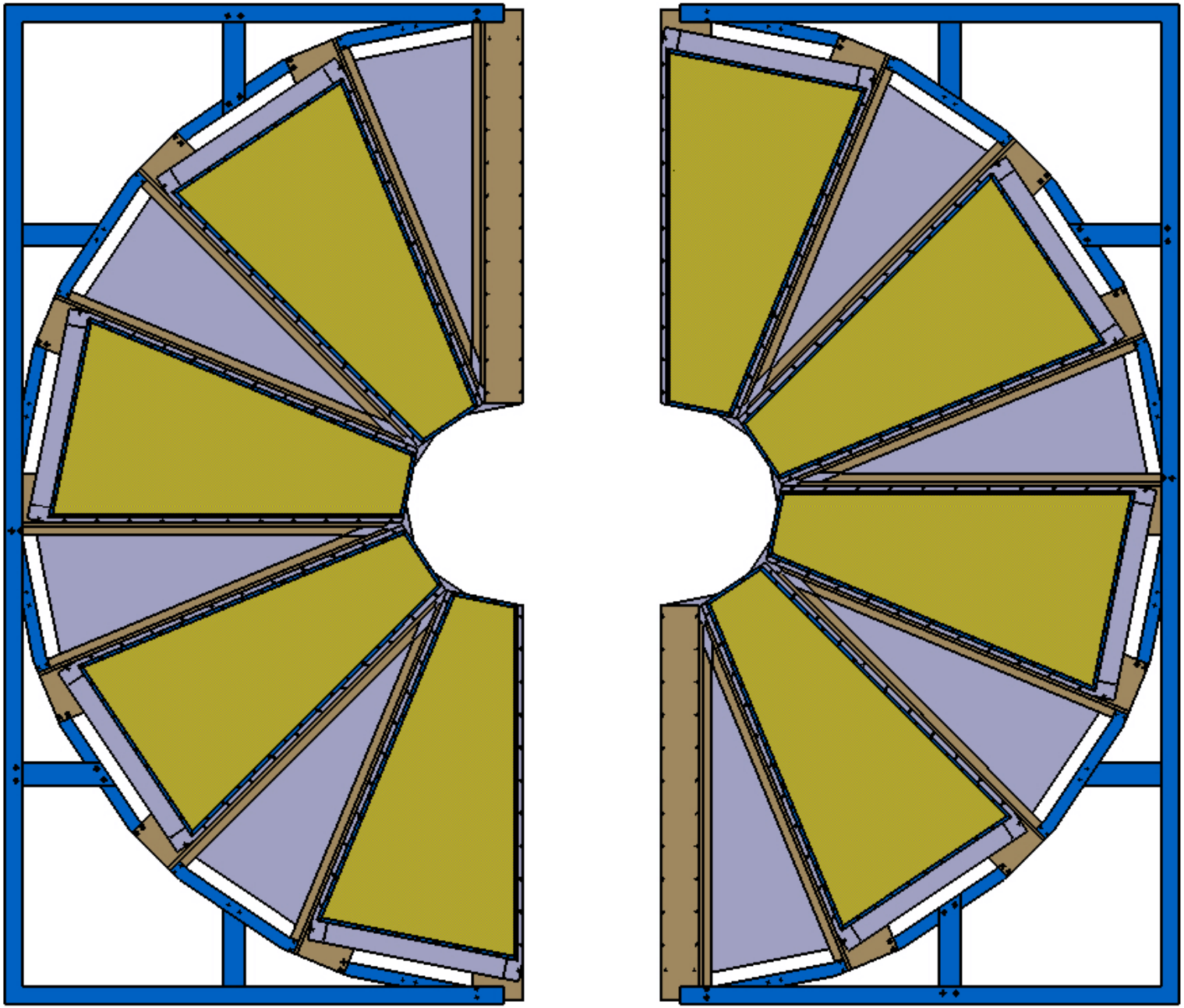




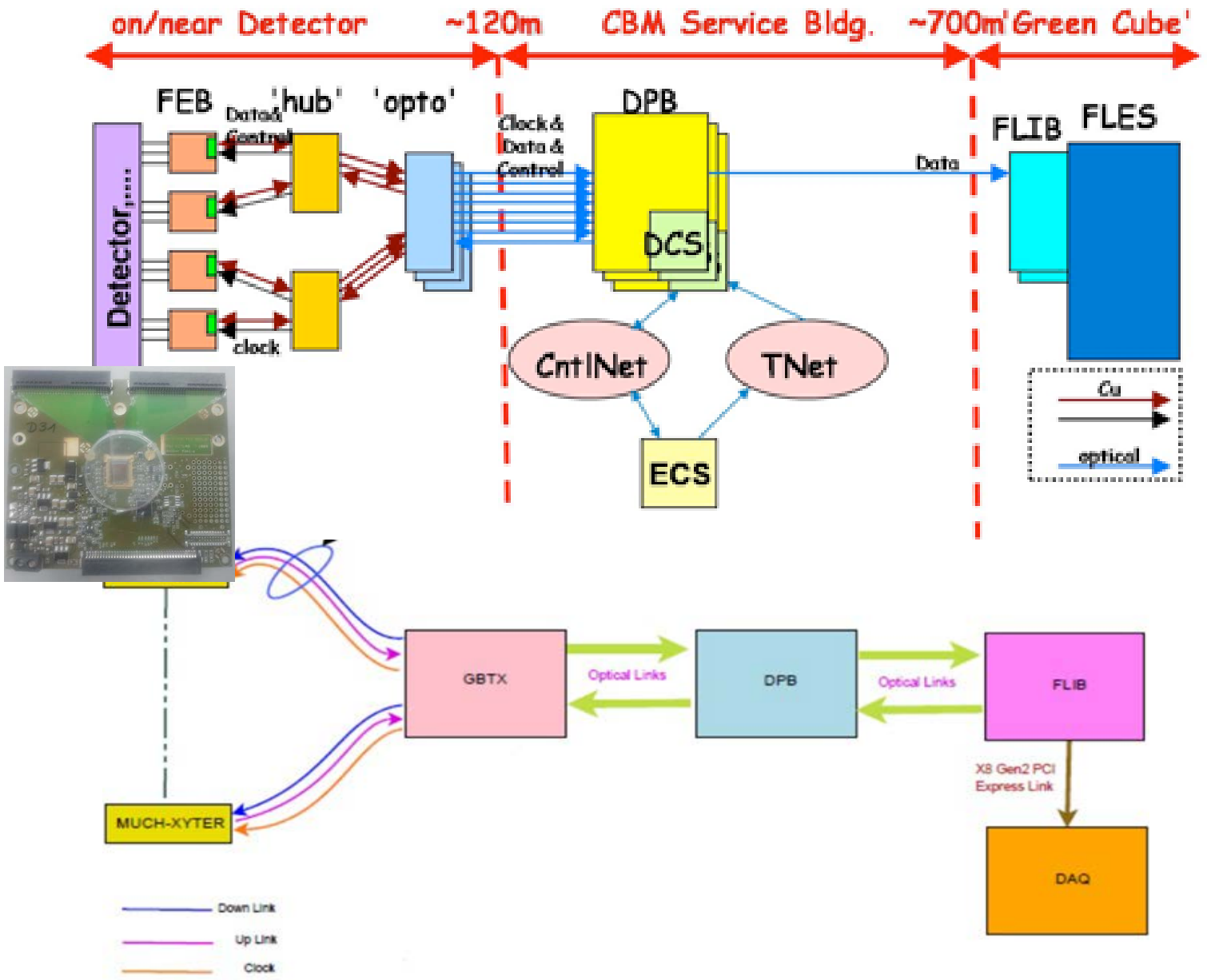
- Superstructure + absorber assembly
- Mounting of chambers
- Integration to CBM systems

PNPI-Russia

MUCH station 1, Layer 1



CBM readout scheme



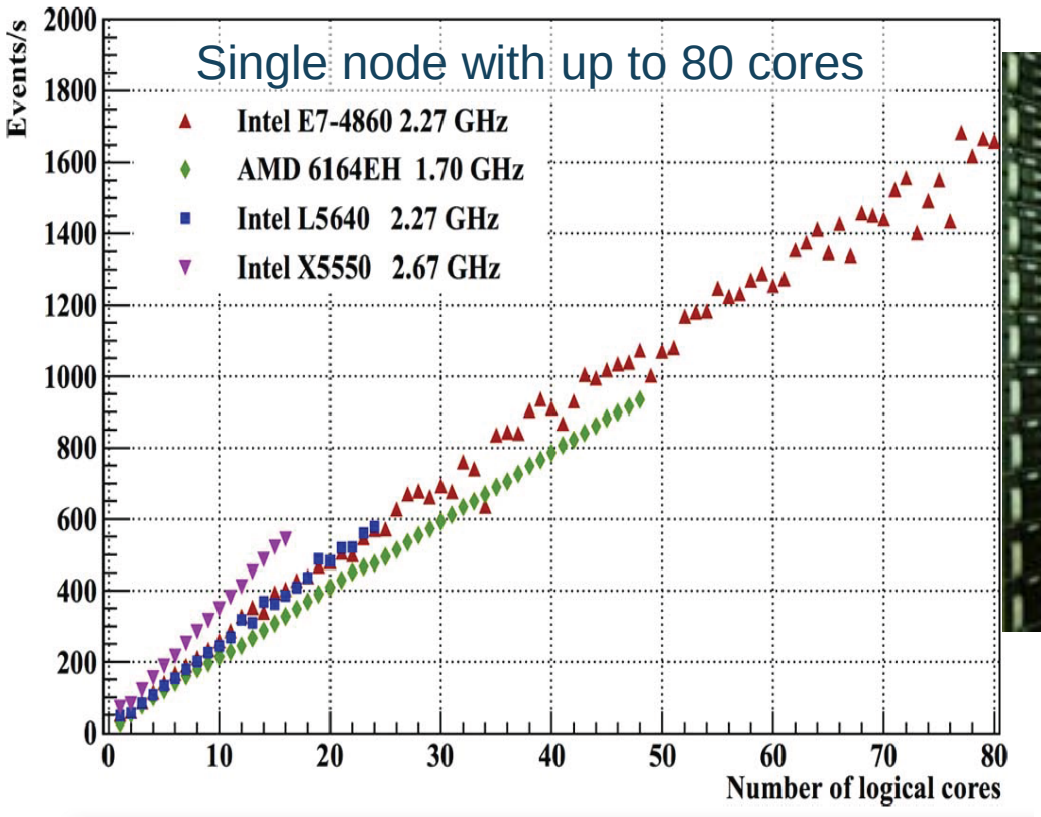
View'12

View'14

CBM First Level Event Selection (FLES)

The FLES package is vectorized, parallelized, portable and scalable

Example:
Full track reconstruction including KF particle analysis of multi-strange (anti) hyperons for min. bias Au+Au collisions at 25 A GeV.

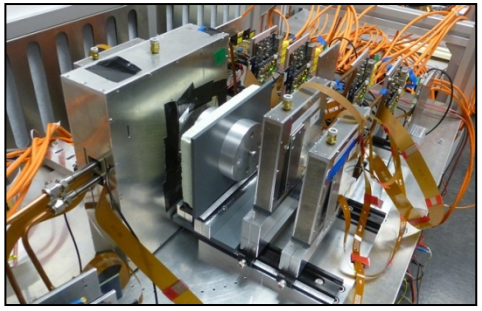


GSI „Minicube“ with 10.000 cores

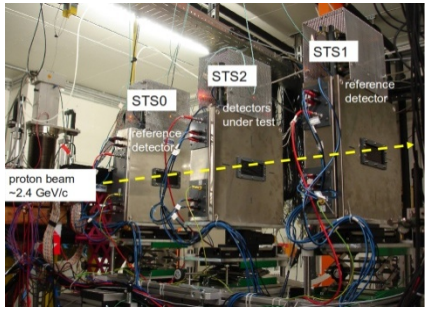
CBM Technical Developments

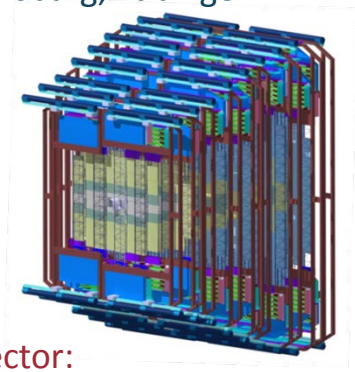
SC Magnet: JINR Dubna

Micro-Vertex Detector:
Frankfurt, Strasbourg



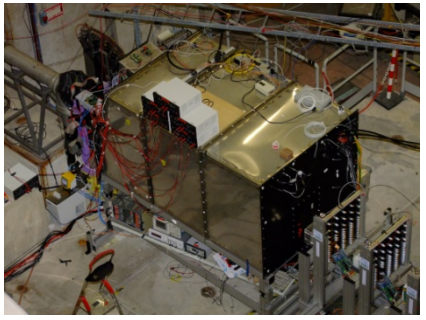
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



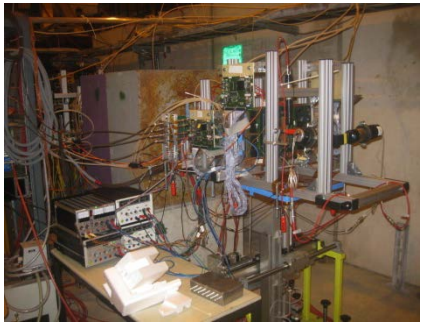


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan

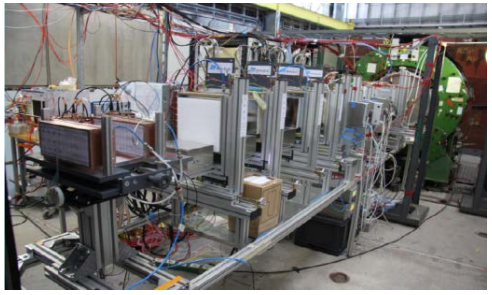
RICH Detector:
Darmstadt, Giessen, Pusan, St. Petersburg, Wuppertal



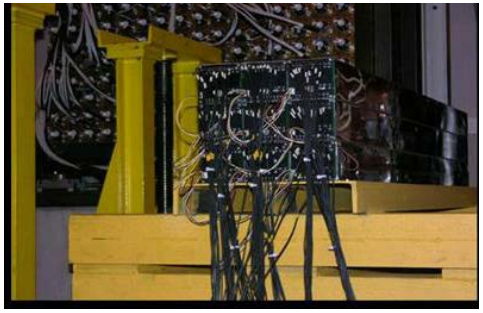
Muon detector:
Kolkata + 13 Indian Inst., Gatchina, Dubna



Transition Radiation Detector:
Bucharest, Dubna, Frankfurt, Heidelberg, Münster



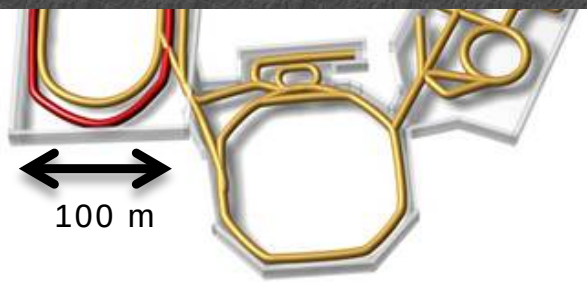
Forward calorimeter:
Moscow, Prague, Rez



DAQ and online event selection:
Darmstadt, Frankfurt, Heidelberg, Kharagpur, Warsaw

Facility for Antiproton & Ion Research

- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV



FAIR phase 1

FAIR phase 2

The CBM Collaboration: 60 institutions, 530 members

Croatia:
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang

Czech Republic:
CAS, Rez
Techn. Univ.Prague

France:
IPHC Strasbourg

Hungary:
KFKI Budapest
Budapest Univ.

Germany:
Darmstadt TU
FAIR
Frankfurt Univ. IKF
Frankfurt Univ. FIAS
Frankfurt Univ. ICS
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.
ZIB Berlin

India:
Aligarh Muslim Univ.
Bose Inst. Kolkata
Panjab Univ.
Rajasthan Univ.
Univ. of Jammu
Univ. of Kashmir
Univ. of Calcutta
B.H. Univ. Varanasi
VECC Kolkata
IOP Bhubaneswar
IIT Kharagpur
IIT Indore
Gauhati Univ.

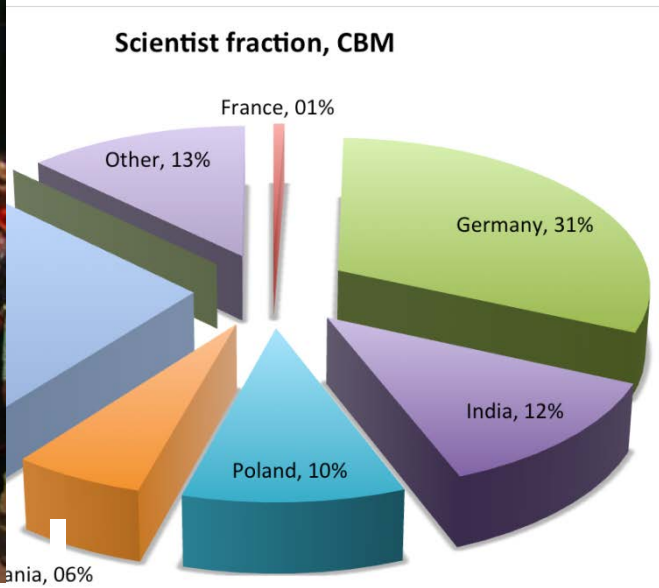
Korea:
Pusan Nat. Univ.

Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.
Warsaw TU

Romania:
NIPNE Bucharest
Univ. Bucharest

Russia:
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
LHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
Obninsk Univ.
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research



Summary

- The experiments at FAIR address fundamental questions in hadron, nuclear, atomic and plasma physics, and explore new frontiers in material and bio physics.
- The unique features of the FAIR accelerators are high-intensity primary and secondary beams.
- CBM scientific program at SIS100:
  Exploration of the QCD phase diagram in the region of neutron star core densities $\rightarrow$ large discovery potential.
- First measurements with CBM:
  High-precision multi-differential measurements of hadrons incl. multistrange hyperons, hypernuclei and dileptons for different beam energies and collision systems $\rightarrow$ terra incognita.
- Significant involvement of Indian researchers

Strangeness at CBM

Observables

Excitation function of yields, spectra, and collective flow of (multi-) strange baryons in heavy-ion collisions

Physics case

- Nuclear matter equation-of-state at extremely high net-baryon densities
- Search for quarkyonic matter or for phase coexistence

Transport codes:

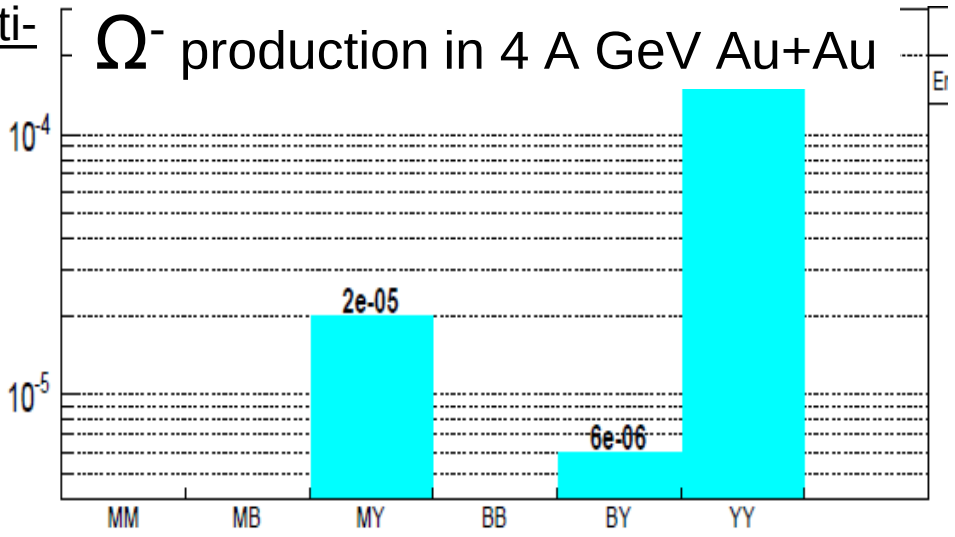
Multi-strange hyperon production via multi-step strangeness exchange reactions:

Hyperons (s quarks):

1. $pp \rightarrow K^+\Lambda^0 p$, $pp \rightarrow K^+K^-pp$,
2. $p\Lambda^0 \rightarrow K^+ \Xi^- p$, $\pi\Lambda^0 \rightarrow K^+ \Xi^- \pi$,
3. $\Lambda^0\Lambda^0 \rightarrow \Xi^- p$, $\Lambda^0 K^- \rightarrow \Xi^- \pi^0$
4. $\Lambda^0 \Xi^- \rightarrow \Omega^- n$, $\Xi^- K^- \rightarrow \Omega^- \pi^-$

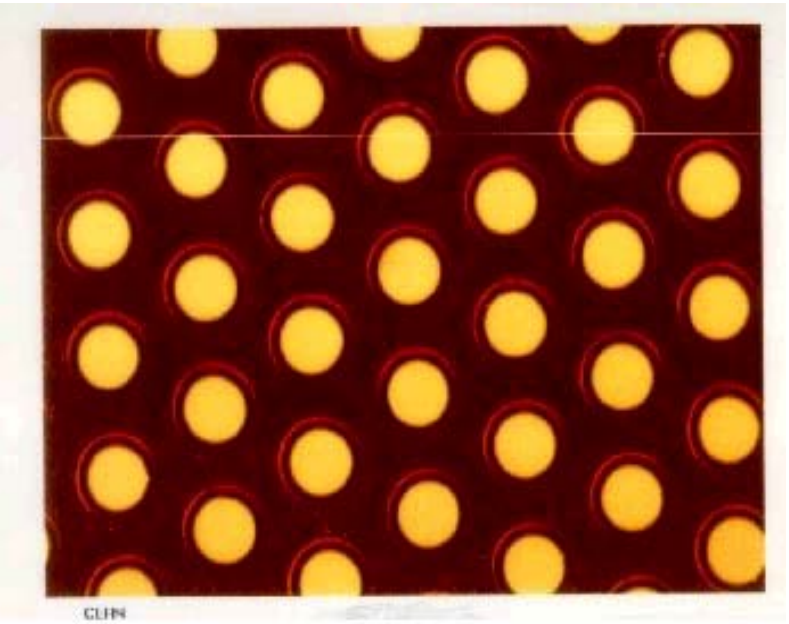
Antihyperons (anti-s quarks):

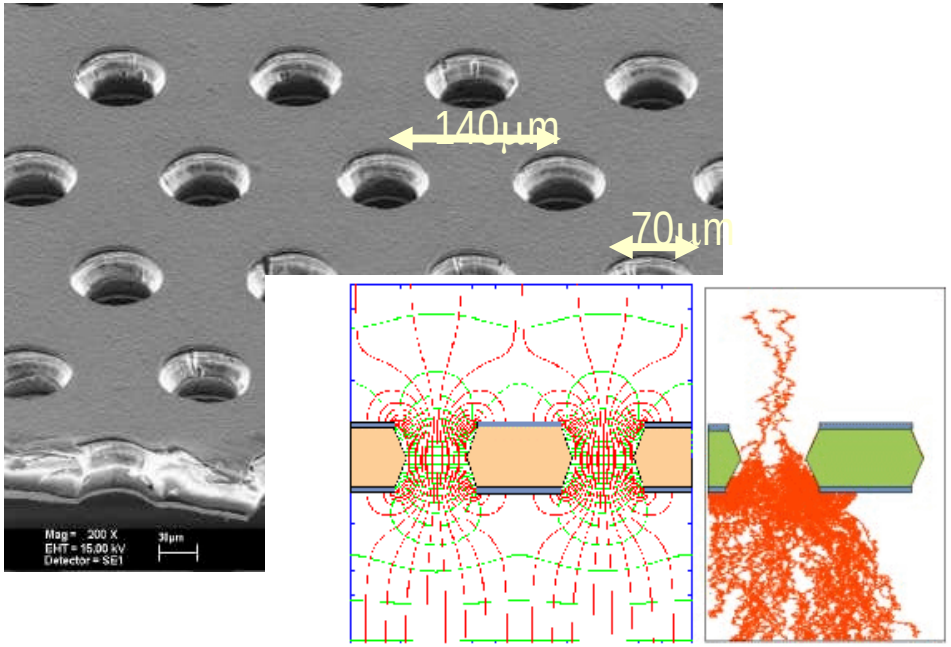
1. $\bar{\Lambda}^0 K^+ \rightarrow \bar{\Xi}^+ \pi^0$,
2. $\bar{\Xi}^+ K^+ \rightarrow \bar{\Omega}^+ \pi^+$.



HYPQGSM calculations , K. Gudima et al.

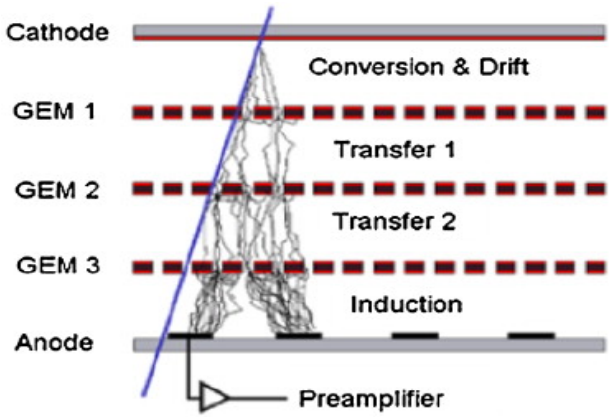
Gas Electron Multiplier (GEM) and its working principle





--- a 50 micron polyimide foil with a 5 micron Cu layer deposited on both sides of polyimide

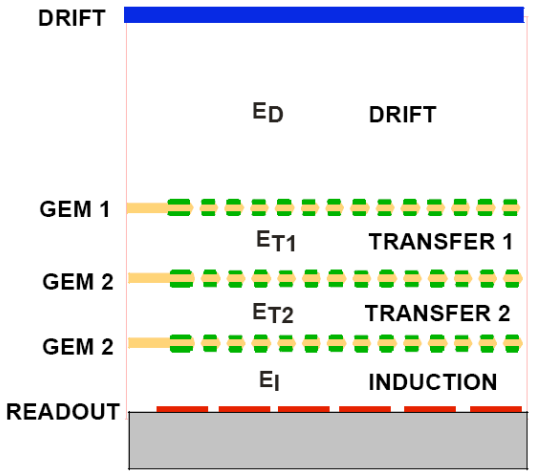
- Active medium is a gas mixture.
- electron multiplication takes place in holes of two copper foils separated by kapton
- Amplification may use 2 or 3 stages.



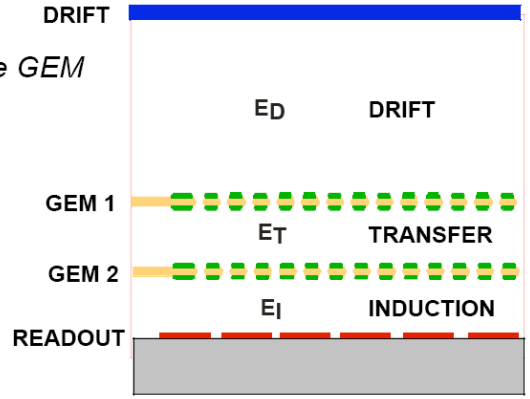
Multi GEM configurations..

Cascaded GEMs achieve larger gains and safer operation in harsh environments

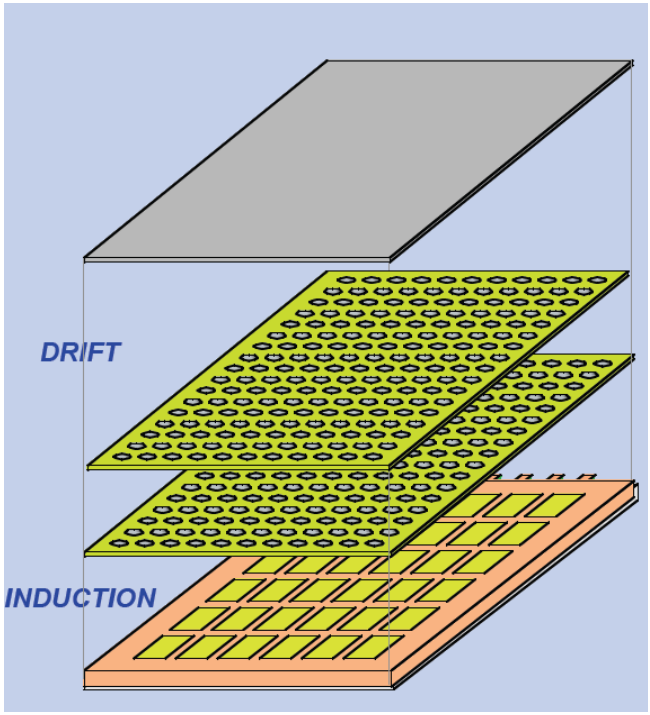
Triple GEM



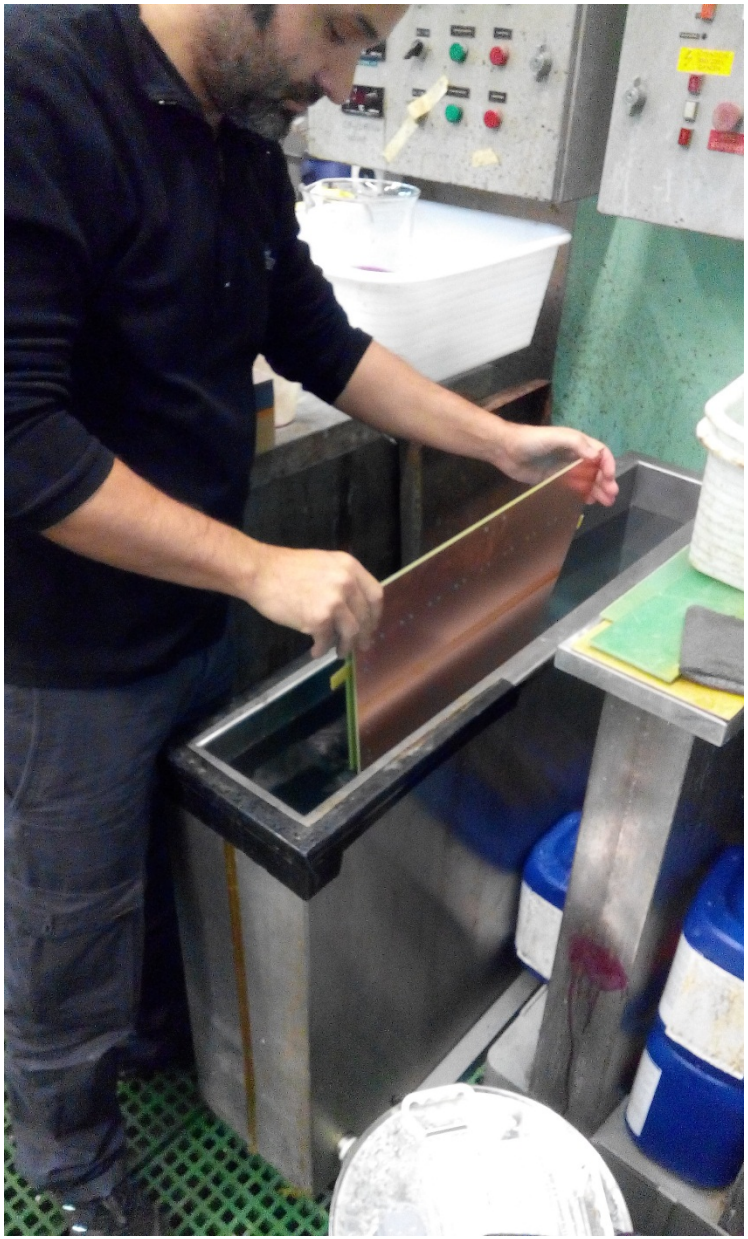
Double GEM



C. Buttner et al, Nucl. Instr. and Meth. A 409(1998)79
S. Bachmann et al, Nucl. Instr. and Meth. A 443(1999)464



-- reduced spark probability in a multiGEM configuration

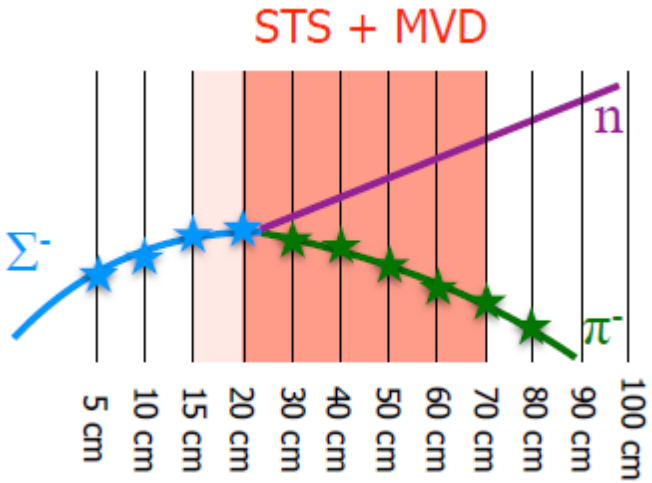


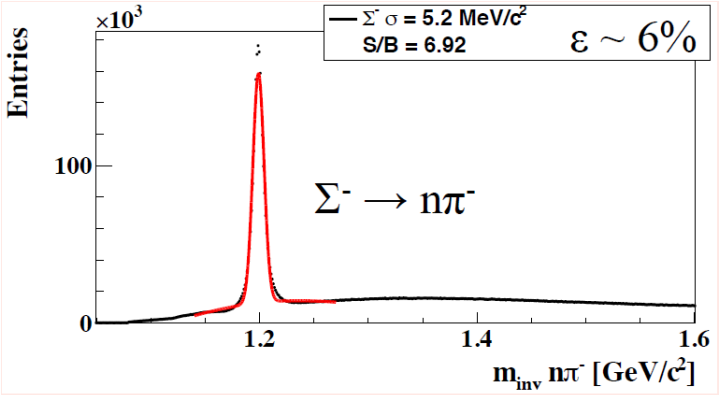
The Final cleaning
--- ultra-sonic bath

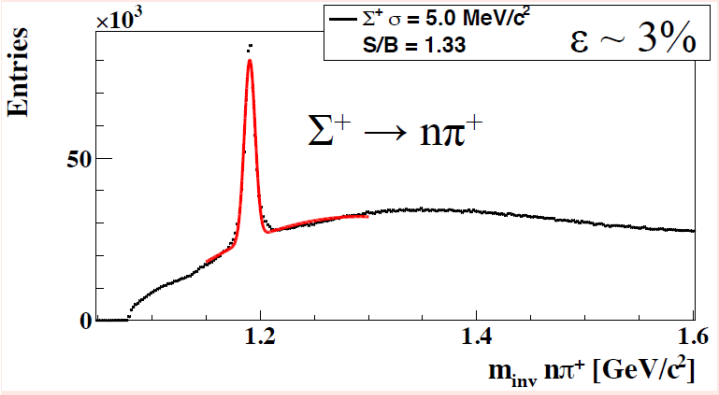
Hyperons in CBM at SIS100

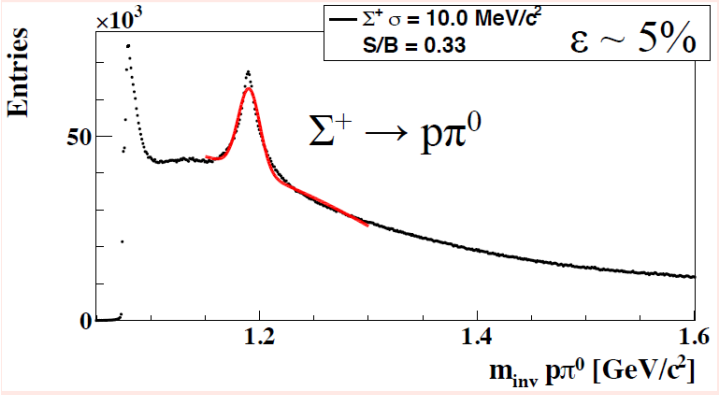
Au+Au at 10 A GeV
$5 \cdot 10^6$ central collisions (UrQMD)

missing mass analysis:









Reconstruction of a multistrange di-baryon

Signal: strange dibaryon

$(\Xi^0\Lambda)_b \rightarrow \Lambda\Lambda$ (cτ=3cm)

M= 10^{-6}, BR = 5%

Background:

central Au+Au collision

32 Λ per central event

11 Λ reconstructable