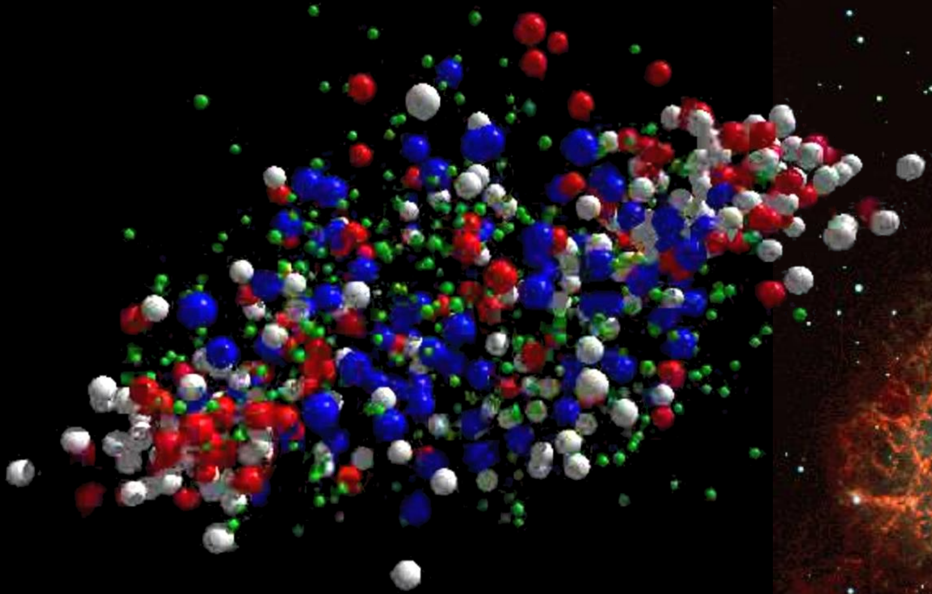
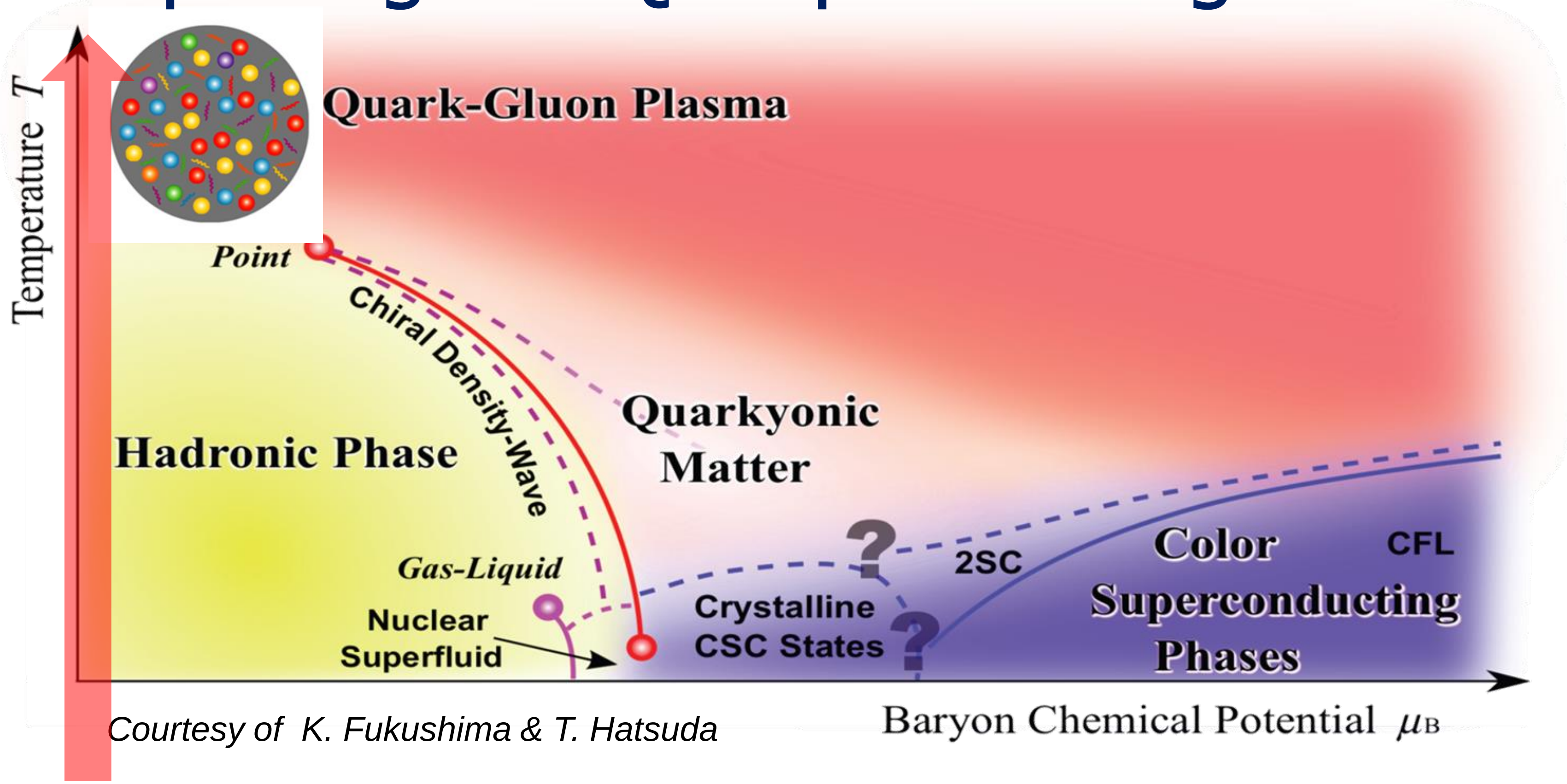
Compressed Baryonic Matter experiment at FAIR

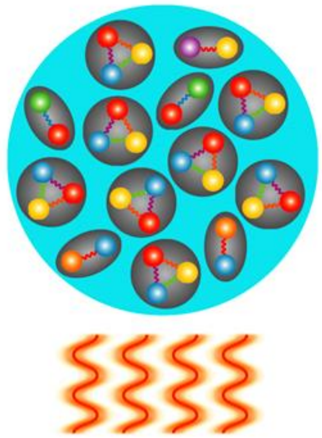
Subhasis Chattopadhyay, VECC-Kolkata & BI-Kolkata



Exploring the QCD phase diagram



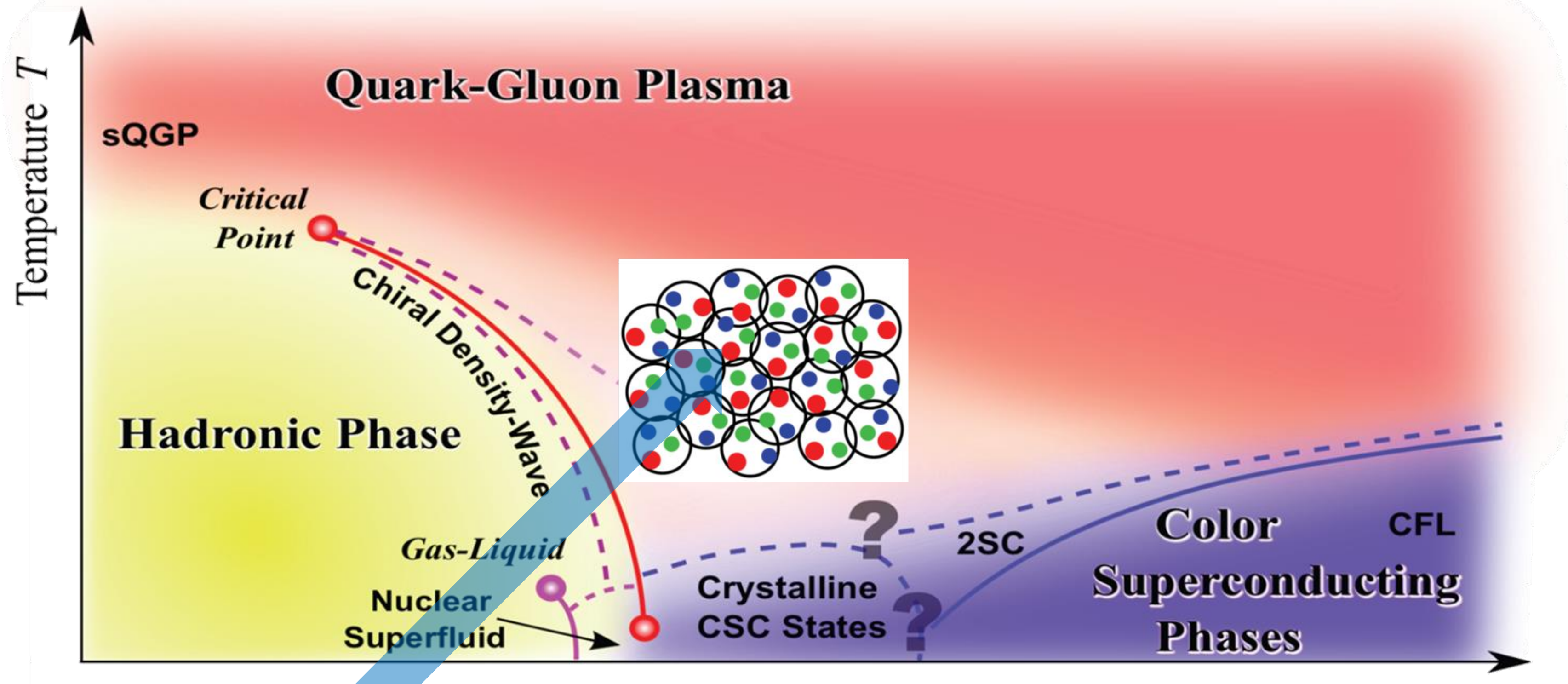
Courtesy of K. Fukushima & T. Hatsuda



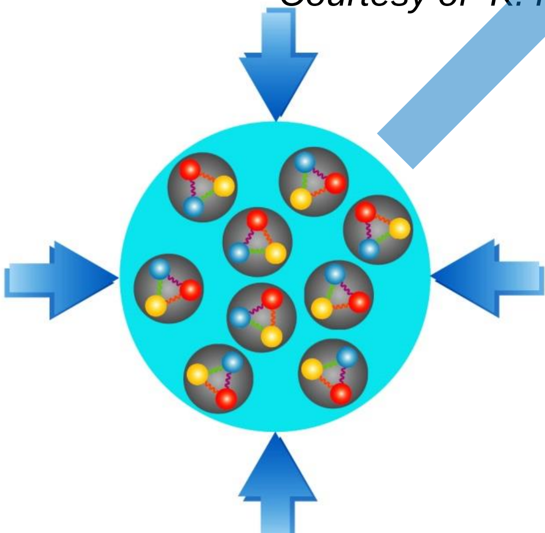
<u>At very high temperature:</u>

- 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



<u>At high baryon density:</u>

- 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

Time line

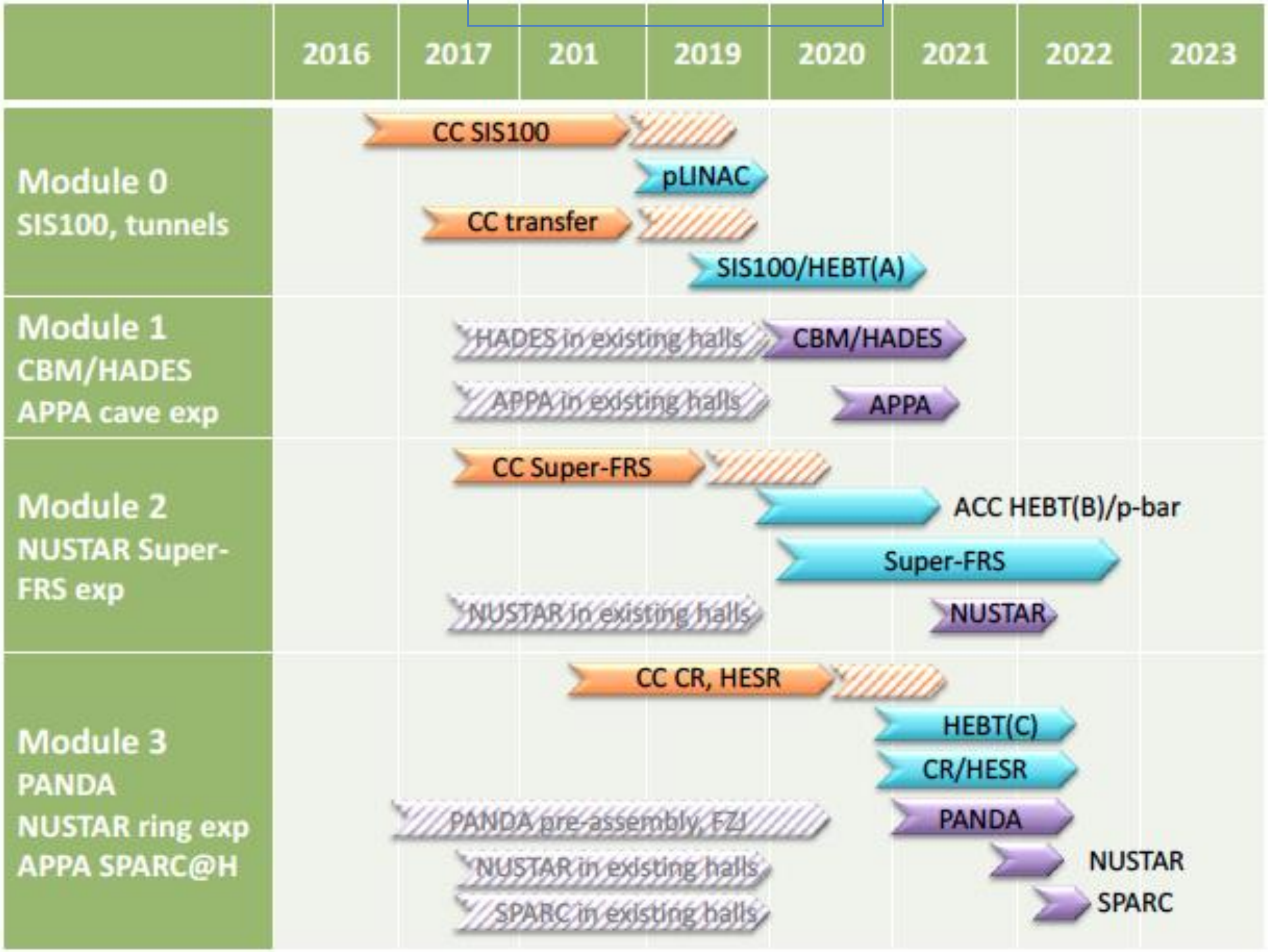
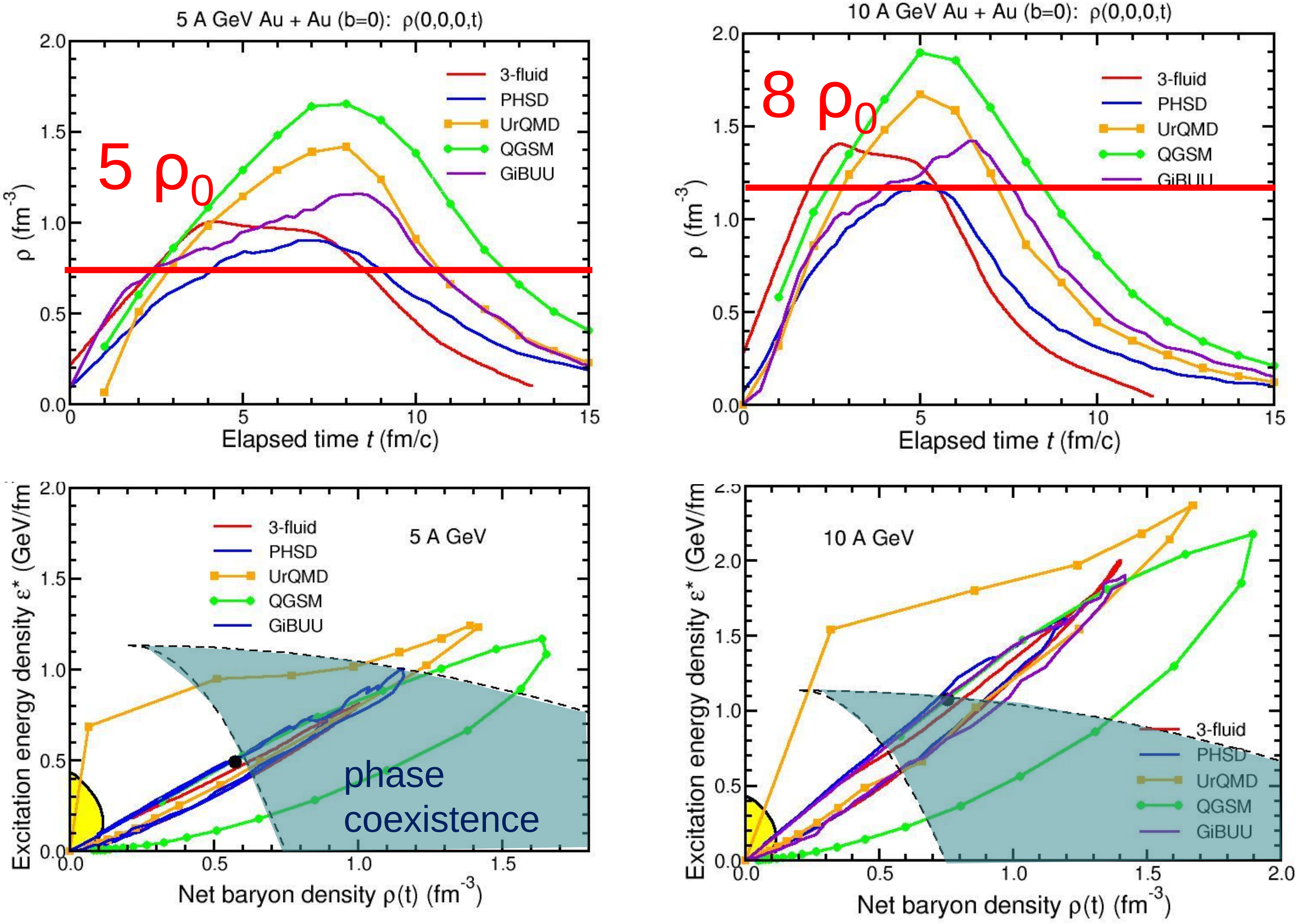


Figure 3: High level schedule of the FAIR MSV. The arrows indicate the construction/installation periods of: buildings (orange), technical infrastructure (orange-white), accelerator systems (blue) and experiments (purple). The arrows marked in grey-white indicate the opportunities for intermediate experimental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

Baryon densities in central Au+Au collisions

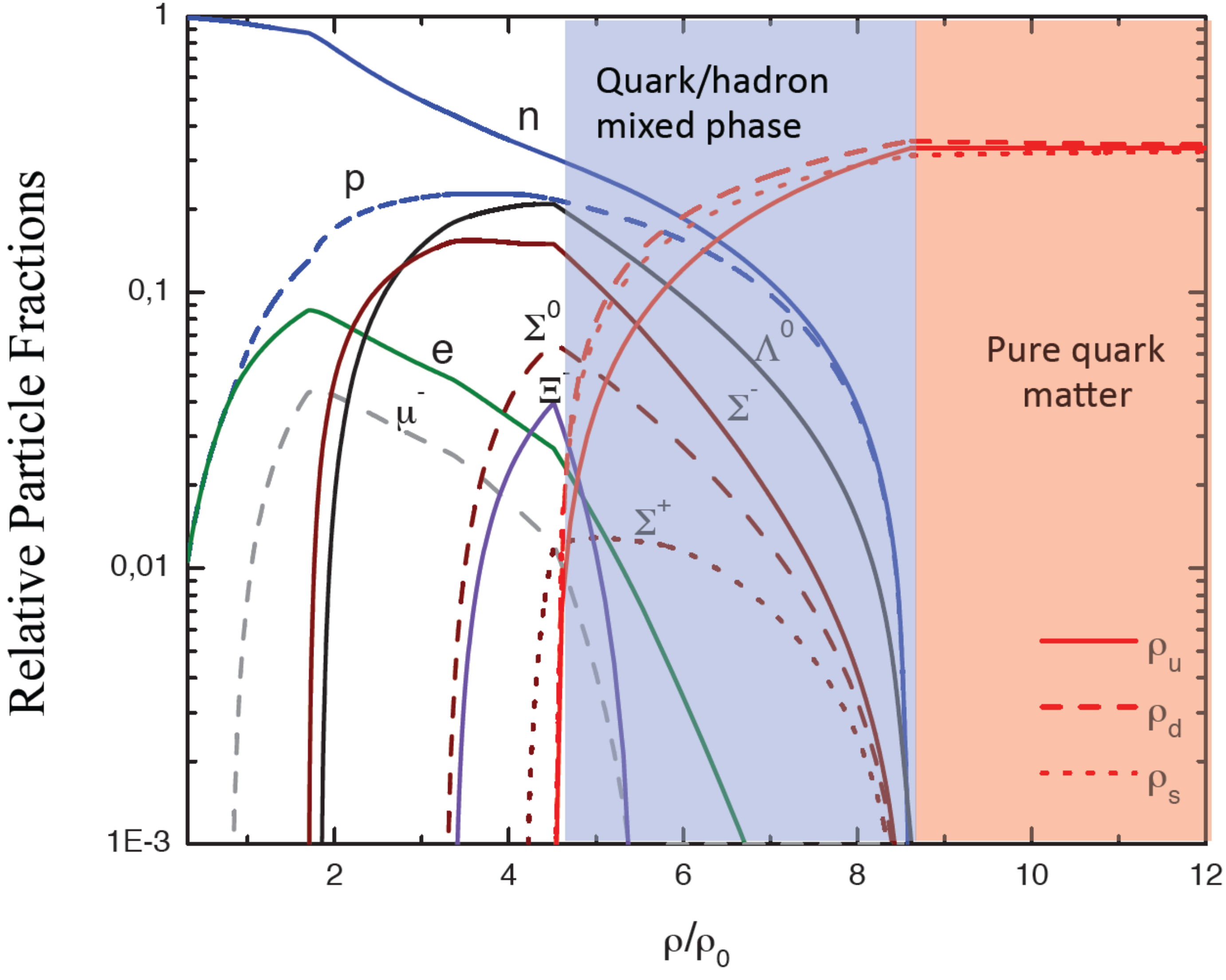
I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

5 A GeV **10 A GeV**



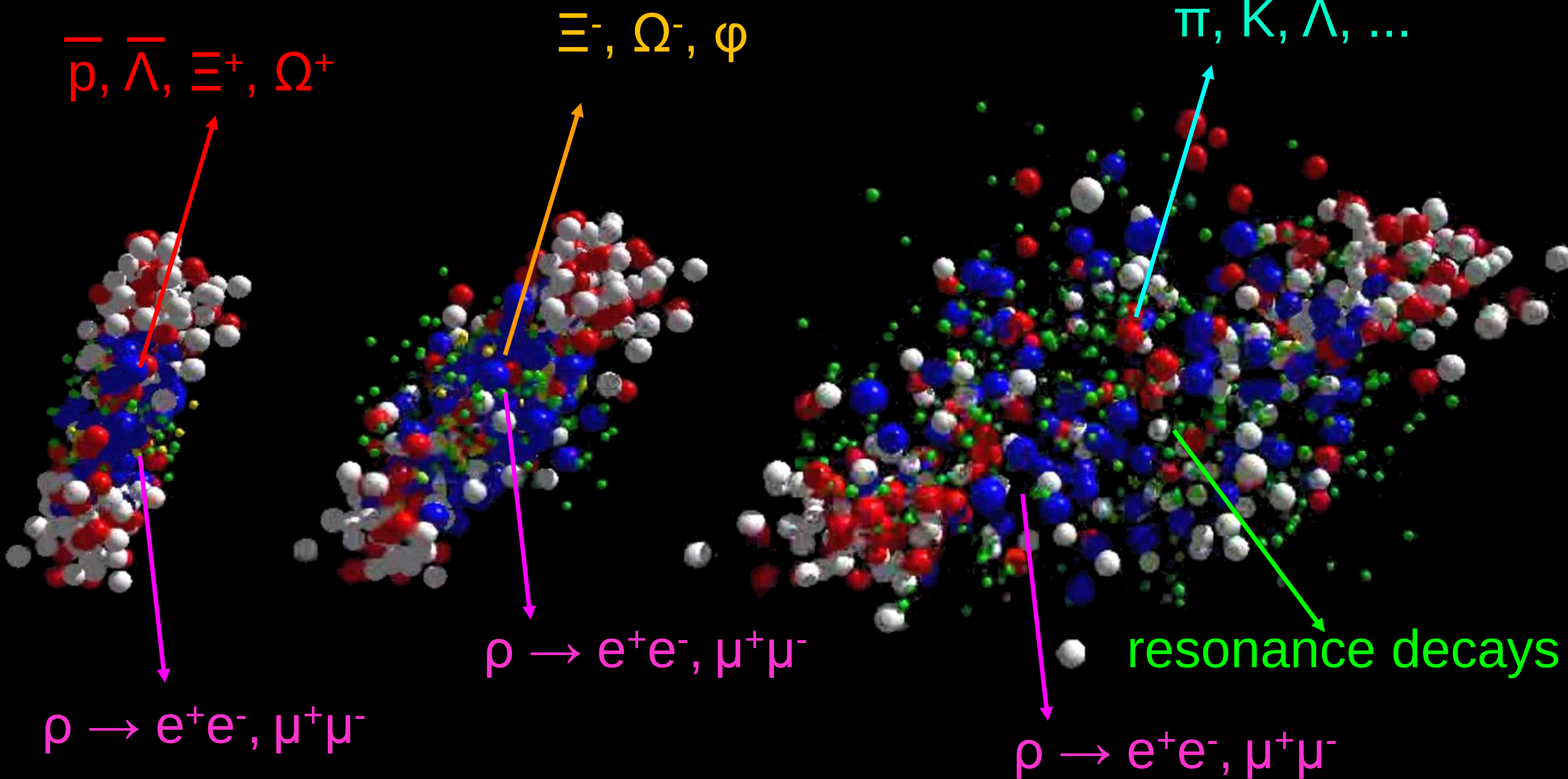
Quark matter in massive neutron stars?

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

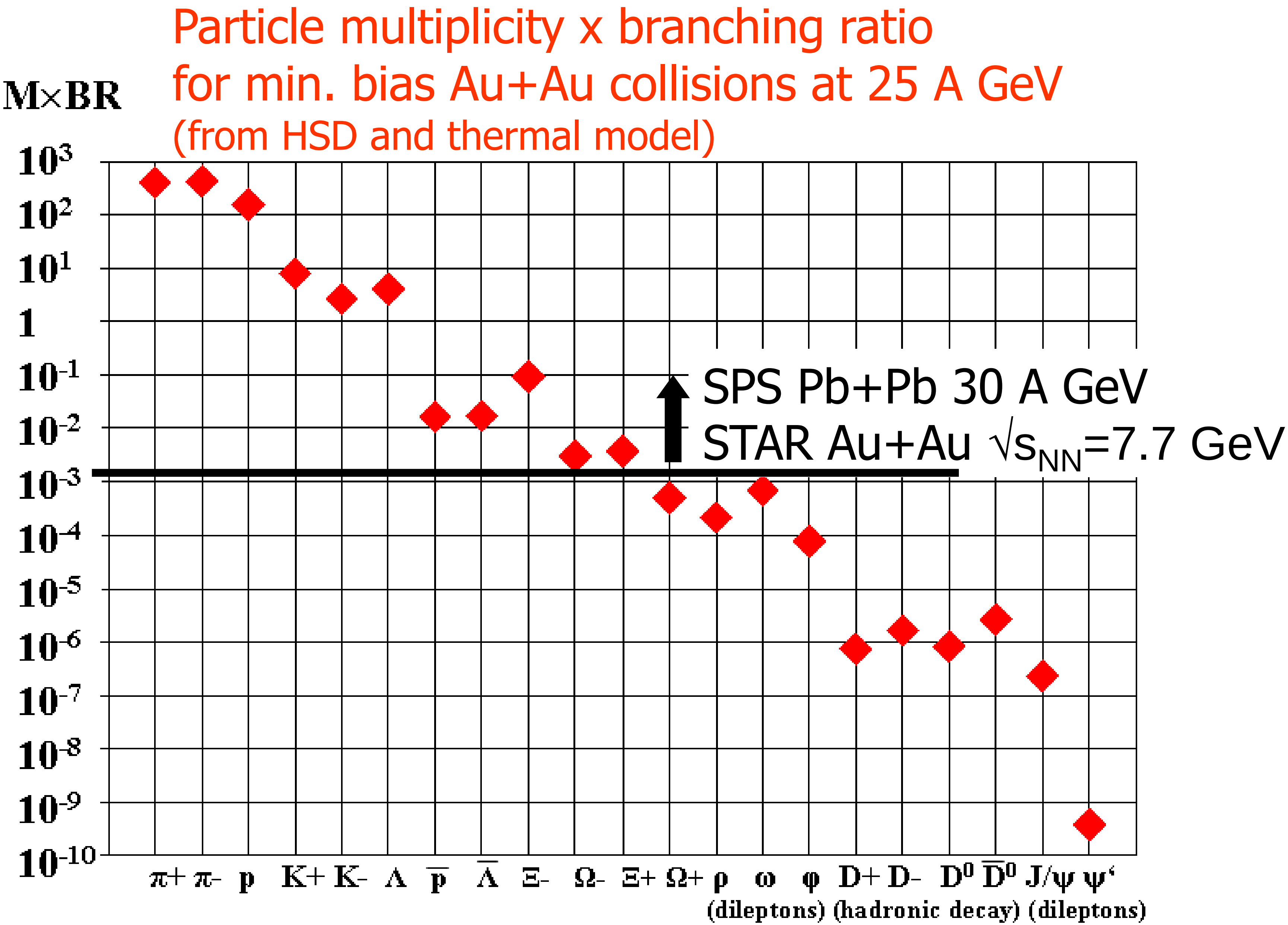


Messengers from the dense fireball: CBM at FAIR

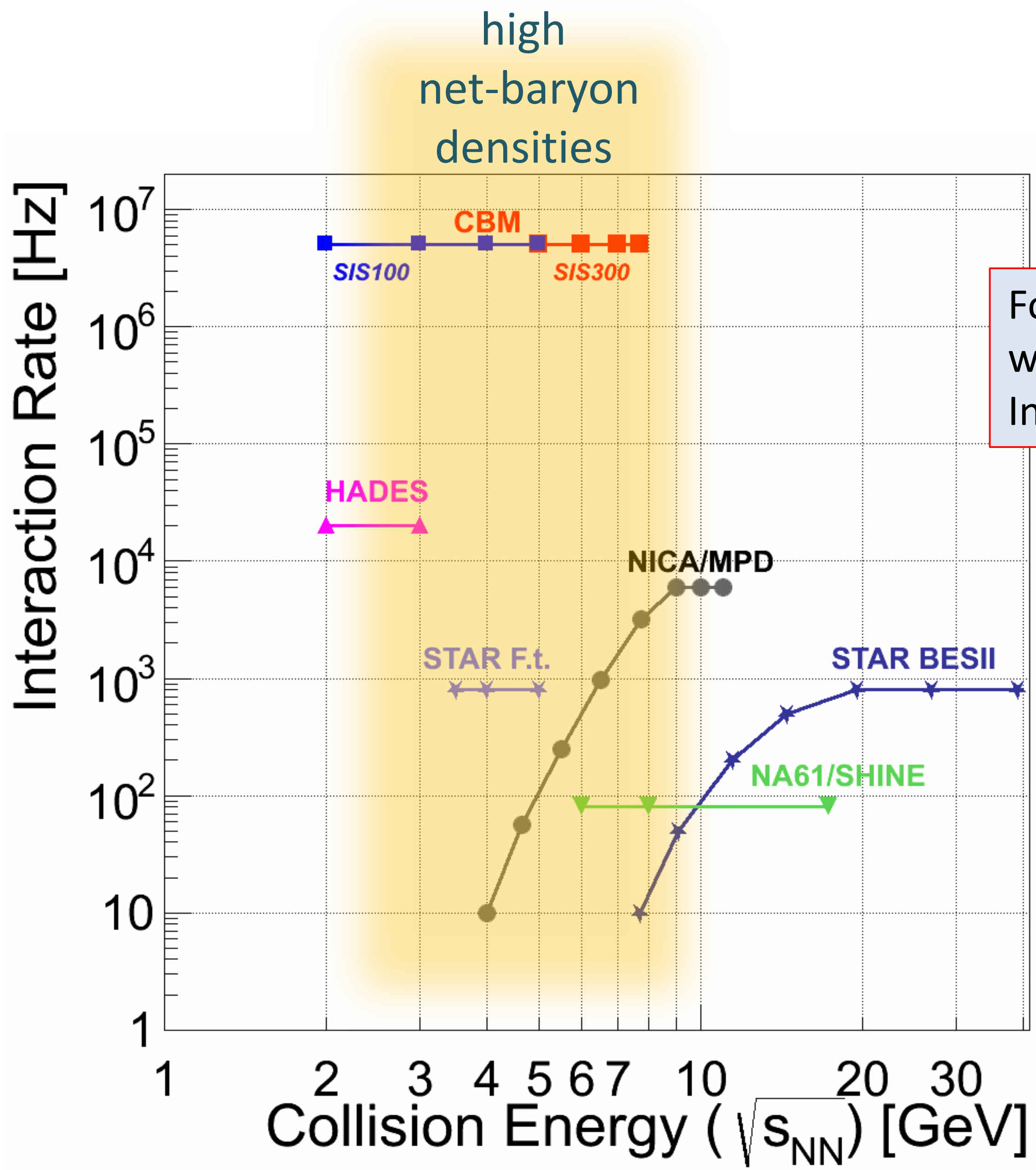
UrQMD transport calculation Au+Au 10.7 A GeV



Experimental challenges



Experiments exploring dense QCD matter

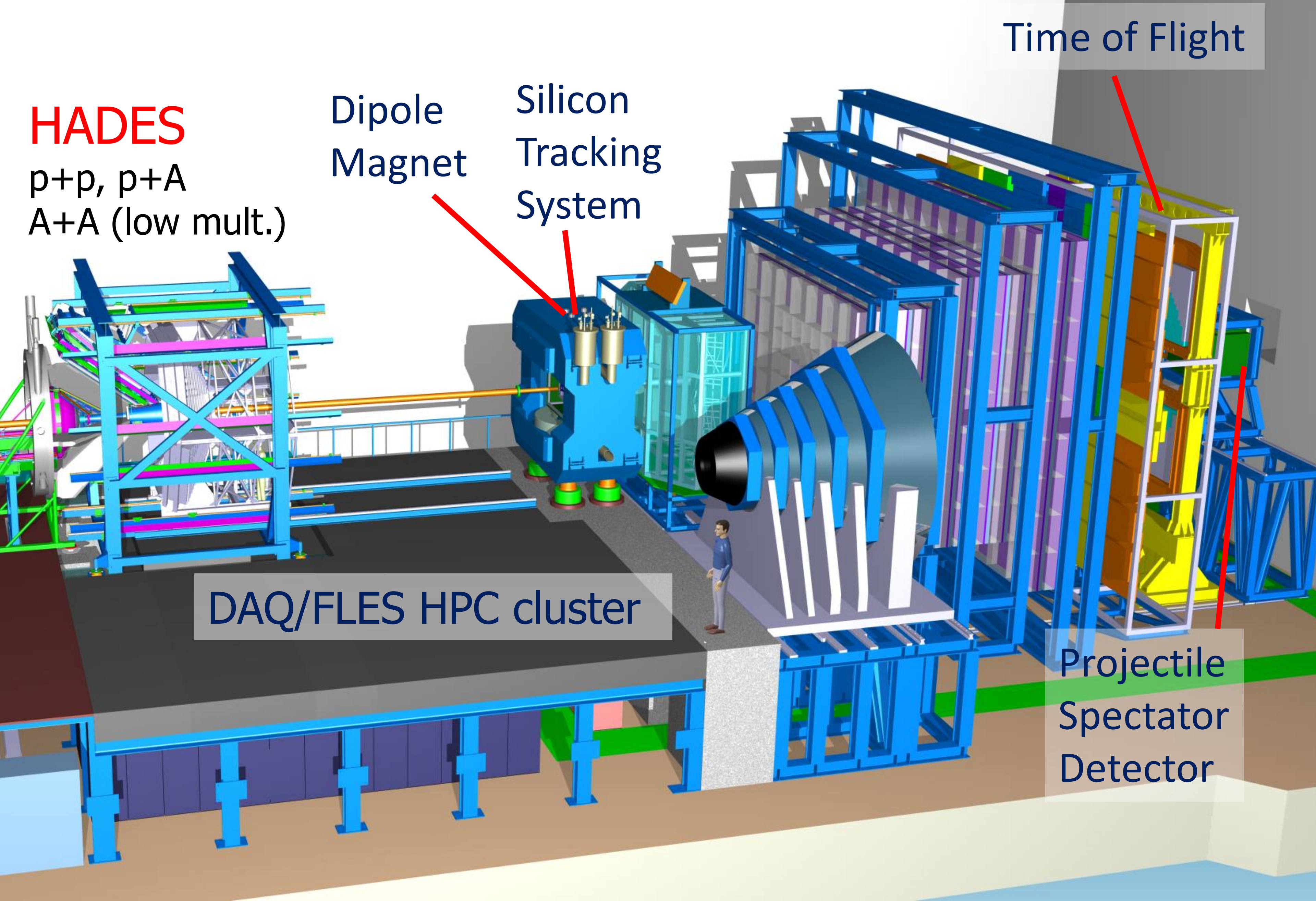


Focus on rare probes with high Interaction rates

Experimental requirements

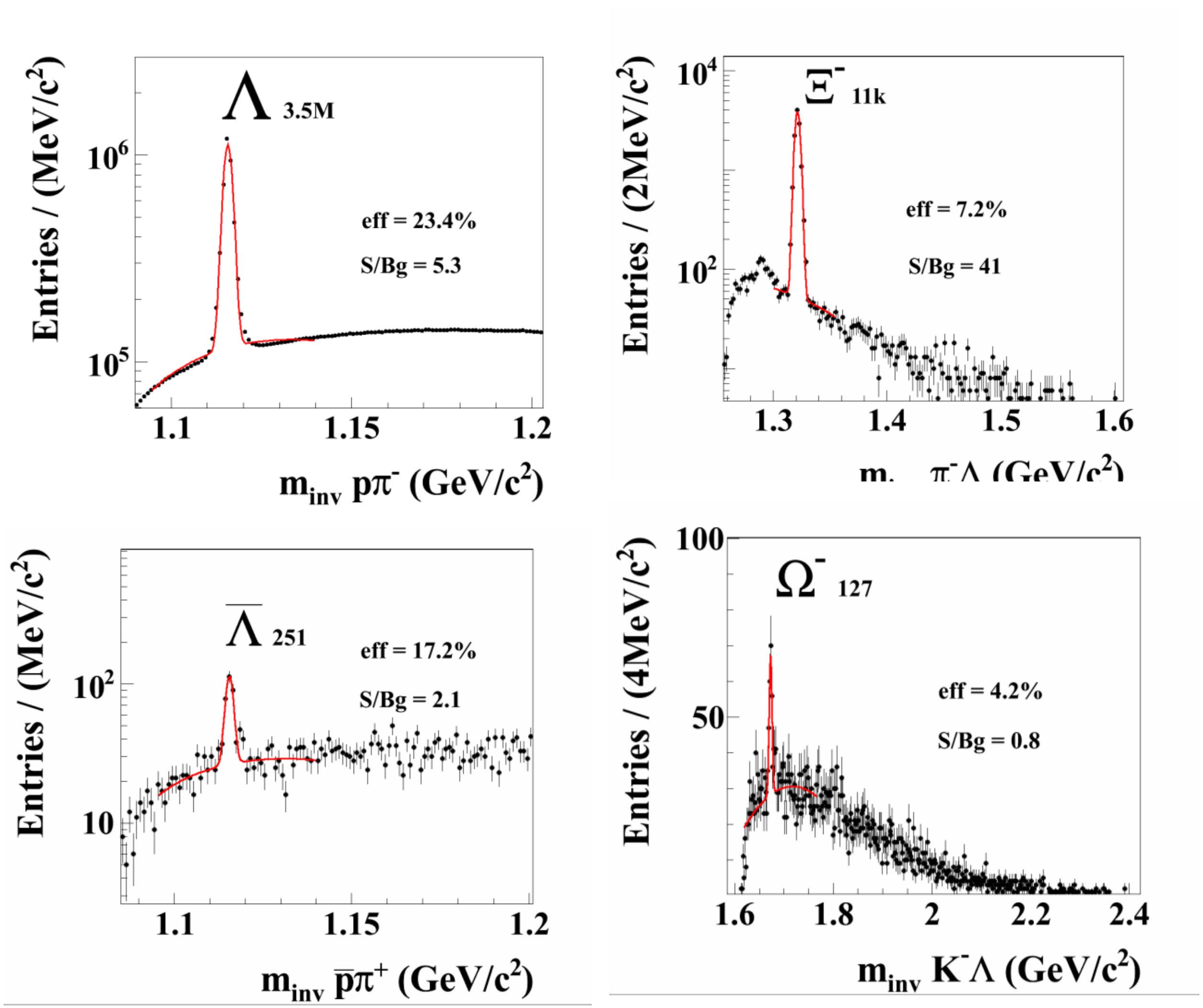
- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors and FEE
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection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

Experimental requirements



Hyperons in CBM at SIS100

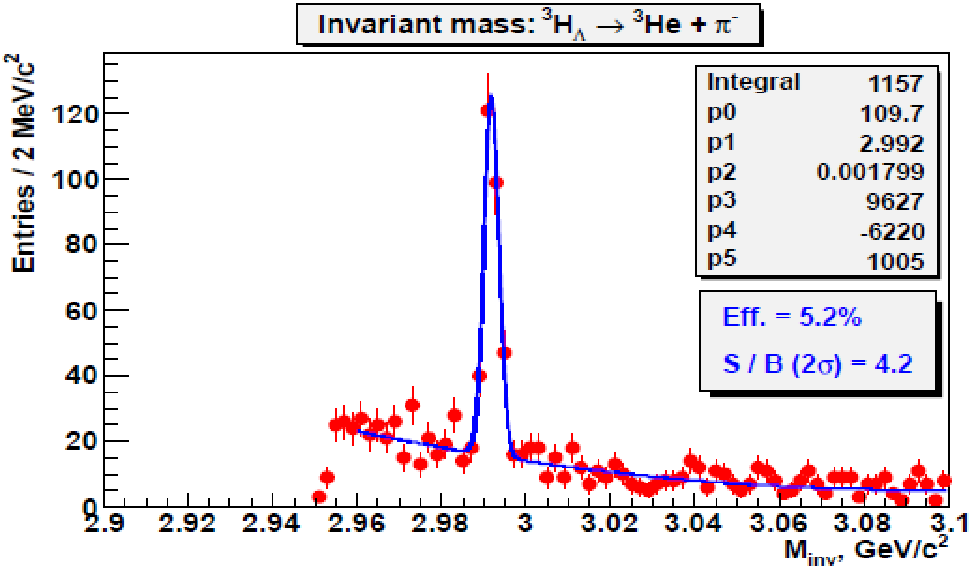
Example: Au+Au at 8 A GeV, 10^6 central collisions (UrQMD)

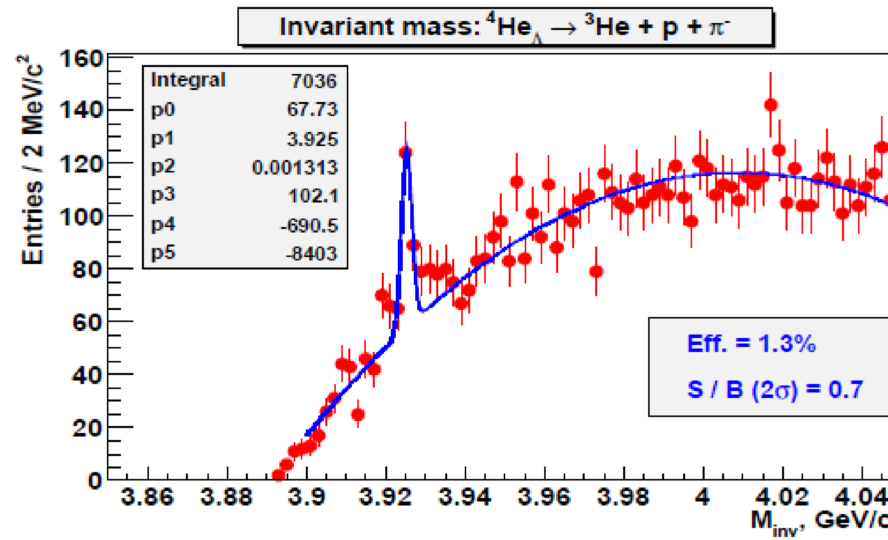


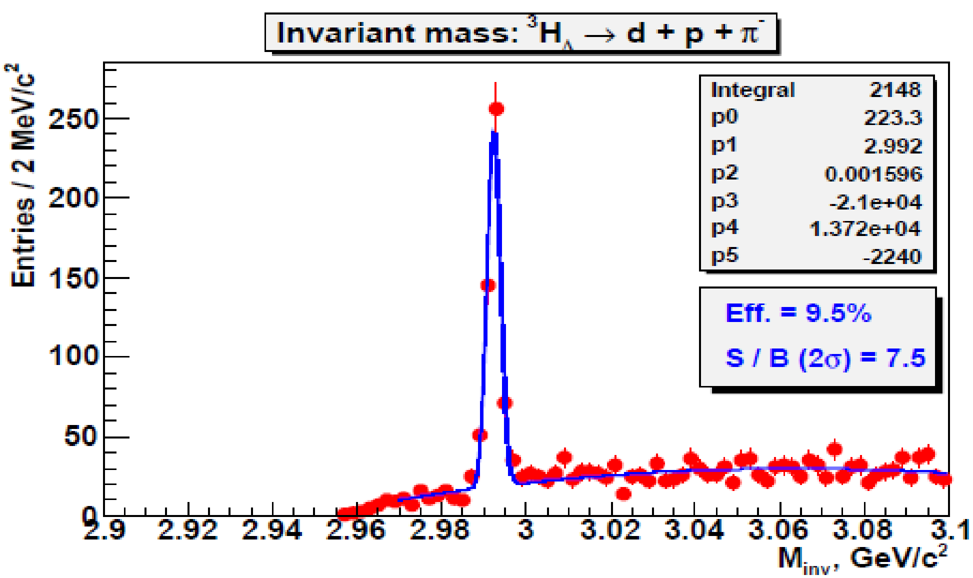
- In addition:
  K*,Λ*,Σ*,Ξ*,Ω*
- Event rate:
  100 kHz to 1 MHz

Hypernuclei in CBM at SIS100

Au+Au at 10 A GeV







Hyper nuclei	M central	BR	ε %	Yield/week central
${}_{\Lambda}{}^{3}H$	$2 \cdot 10^{-2}$	0.6	7	$4.6 \cdot 10^{7}$
${}_{\Lambda\Lambda}{}^{5}H$	$6 \cdot 10^{-6}$	0.36	1	1300

central collision rate 100 kHz

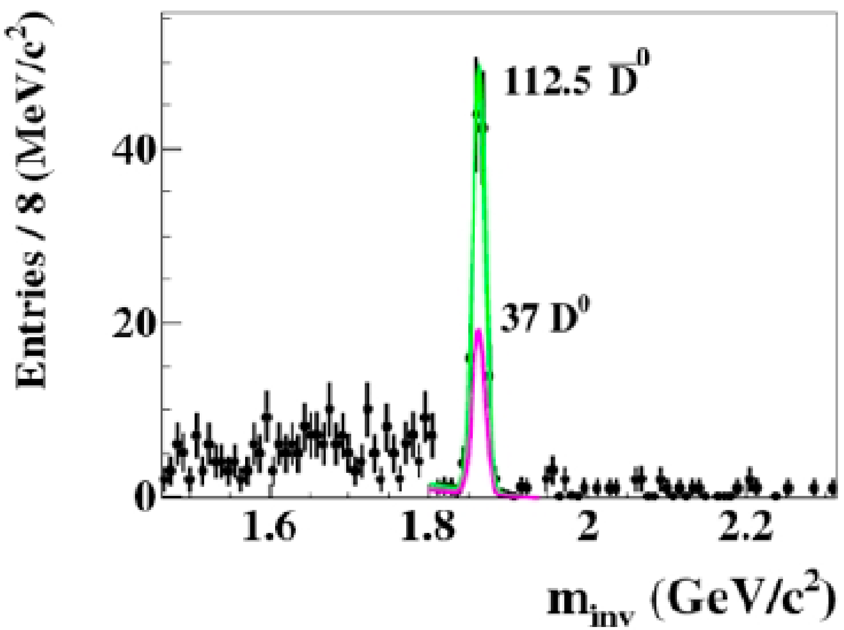
BR = 36% for double lambda hypernuclei is a guess

Open charm in CBM at SIS100

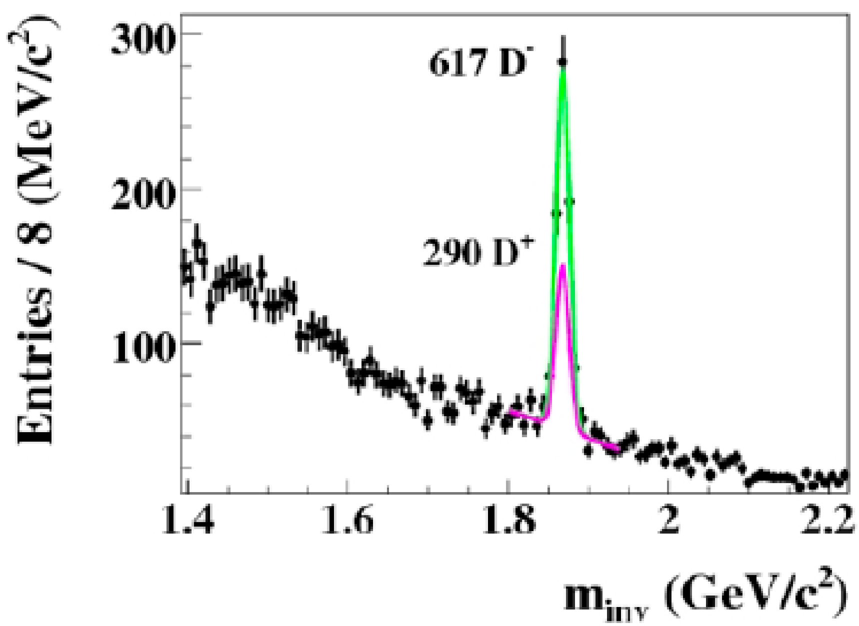
- Charm production cross sections at threshold energies
- Charm propagation in cold nuclear matter

30 GeV p + C

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

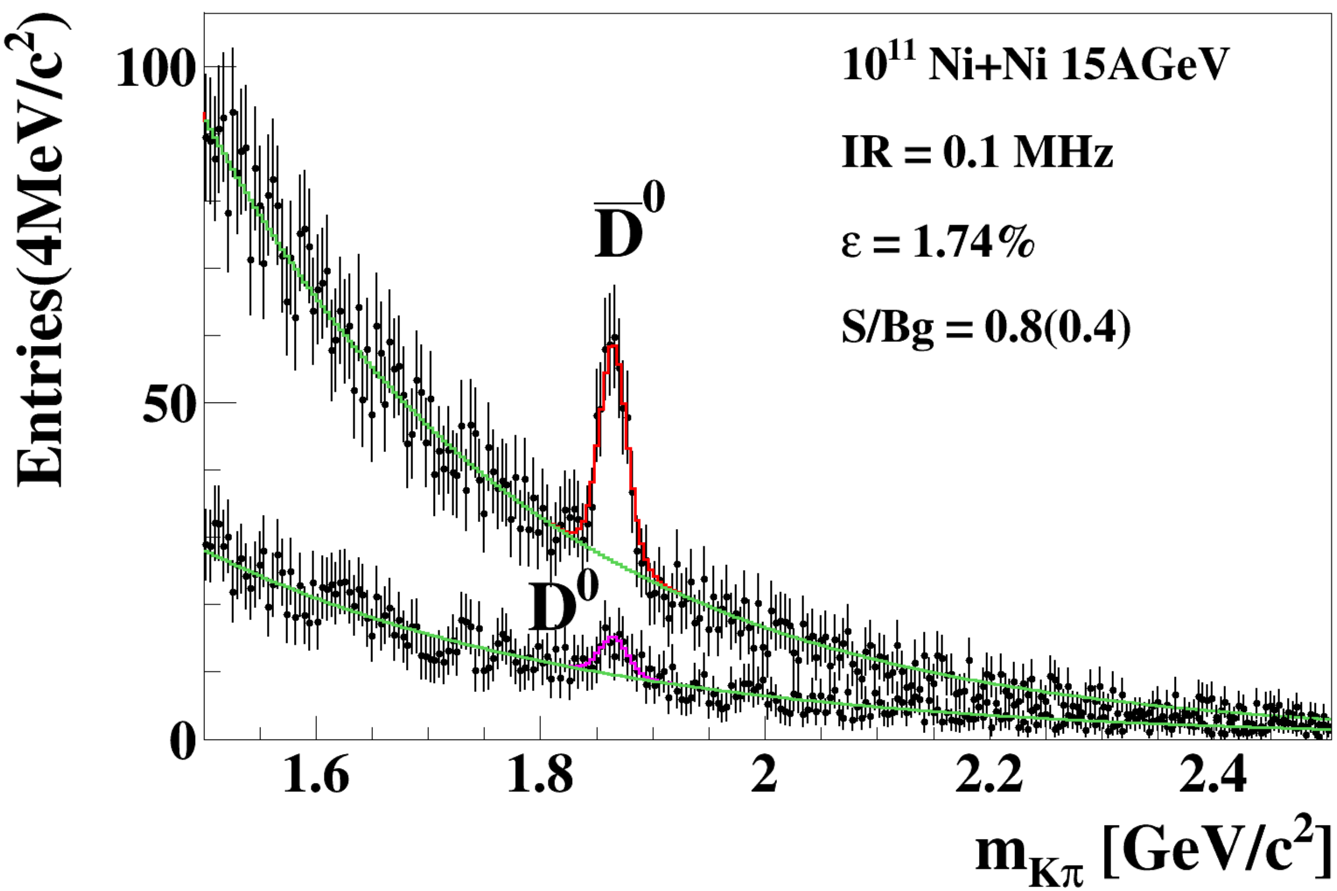


$D^{\pm} \rightarrow K\pi\pi$

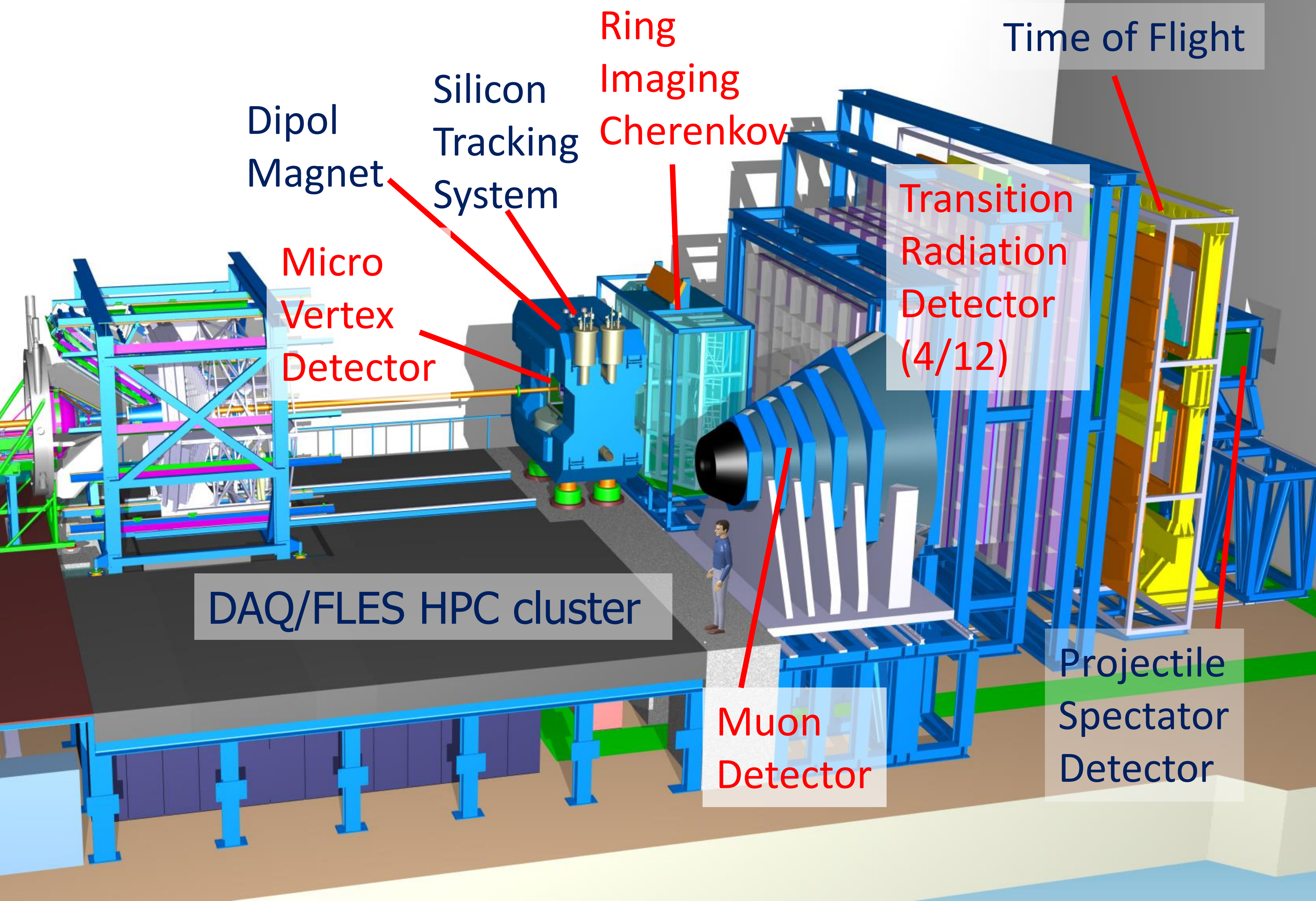


Open charm in CBM at SIS100

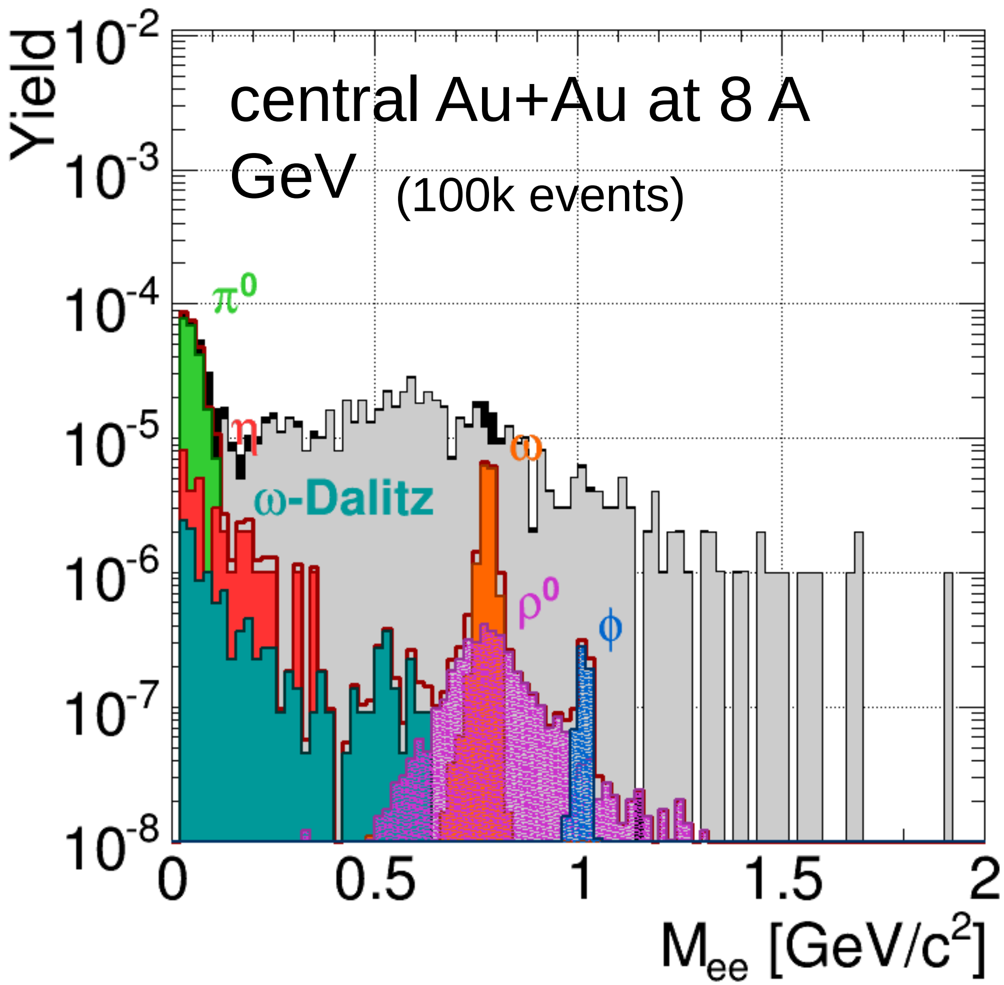
- Charm production and propagation in hot nuclear matter
- D multiplicities from thermal model (V. Vovchenko)
- 2 weeks Ni + Ni at 15 A GeV: 260 $\overline{D}^0$, 45 D^0



Experimental requirements



Electrons in CBM at SIS100



8 A GeV:

$2{\times}10^6$ ω in 2 weeks

Simulation:

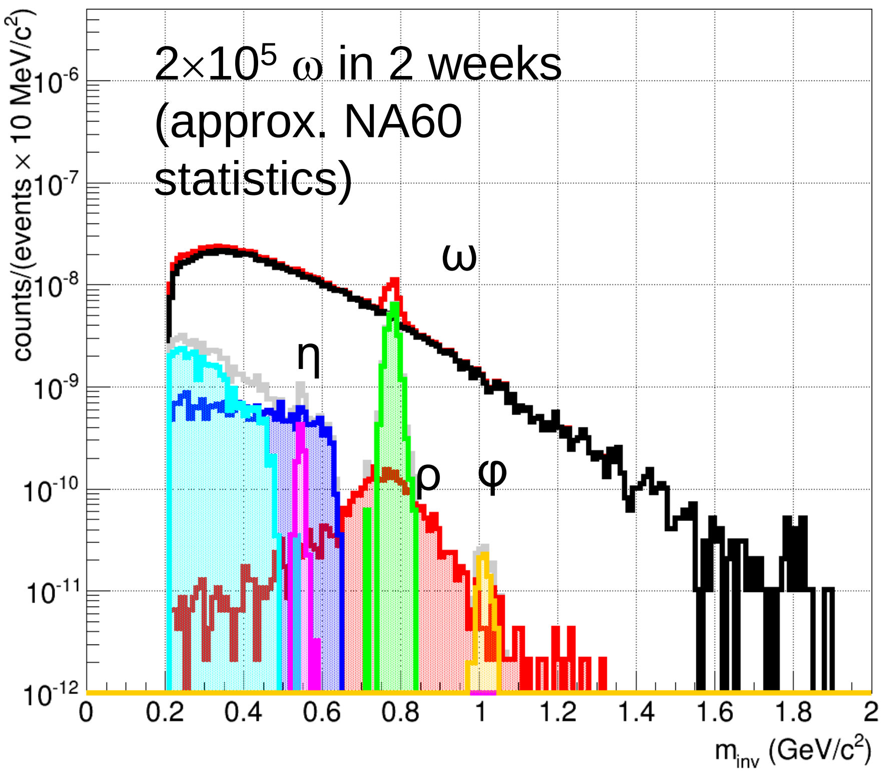
Signal yields from HSD

Background from UrQMD

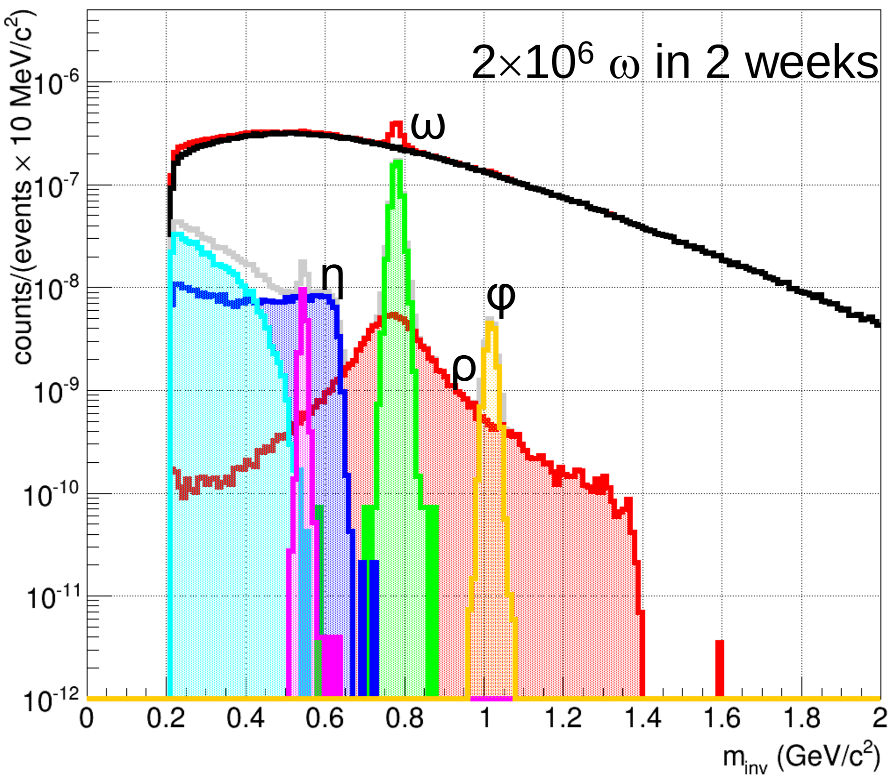
Muons in CBM at SIS100

Simulation: Signal yields from HSD, Background from UrQMD

central Au+Au at 4 A GeV

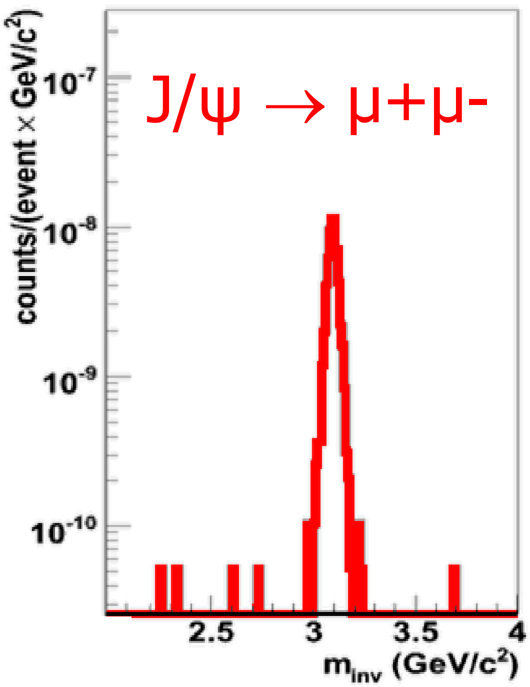


central Au+Au at 8 A GeV



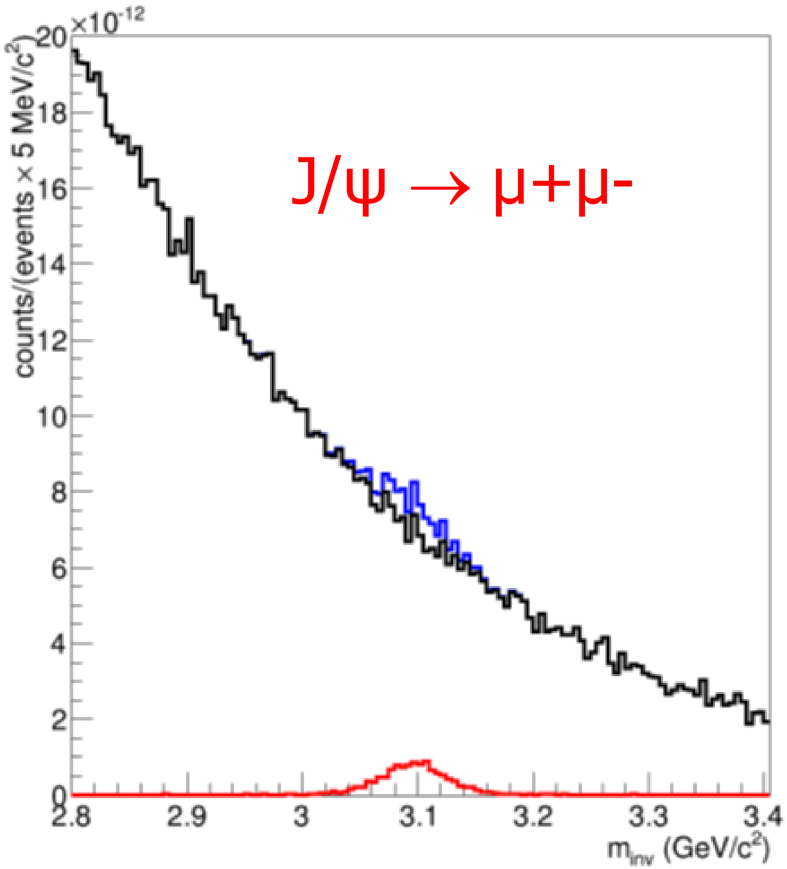
Hidden charm in CBM at SIS100

30 GeV p + Au



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

central Au+Au at 10 A GeV

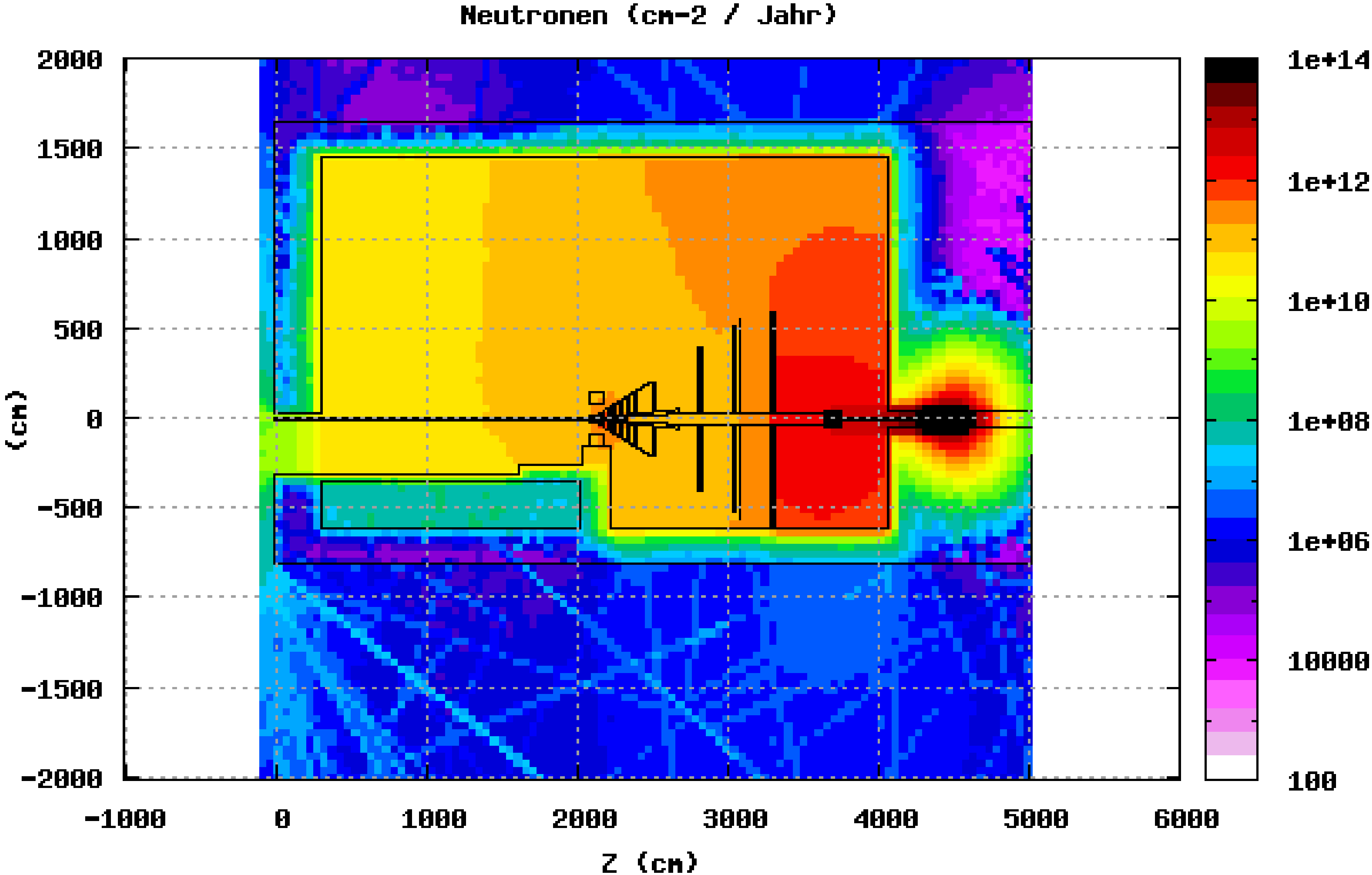


1000 J/ψ in 10^{13} events (10 days)
(multiplicity from HSD)

CBM Technical Design Reports

#	Project	TDR Status
1	Magnet	approved
2	STS	approved
3	RICH	approved
4	TOF	approved
5	MuCh	approved
6	HADES ECAL	approved
7	PSD	approved
8	MVD	submission 2016
9	DAQ/FLES	submission 2016
10	TRD	submission 2016
11	ECAL	submission 2016

Neutronflux in the CBM cave: 2 month of 10^9 Au ions at 25 A GeV, 1% interaction Au target

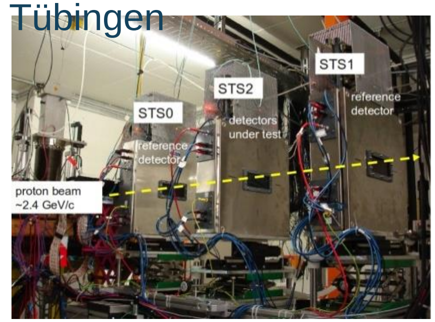


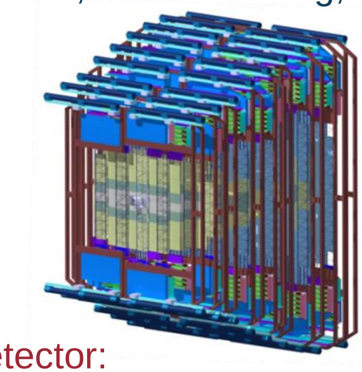
CBM Technical Developments

SC Magnet: JINR Dubna

Micro-Vertex Detector: Frankfurt, Strasbourg

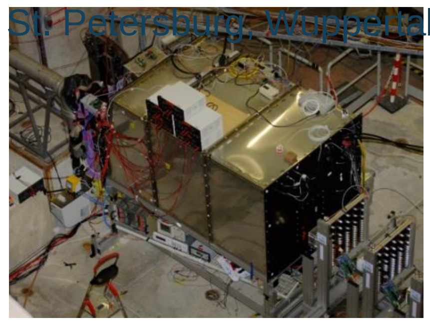
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



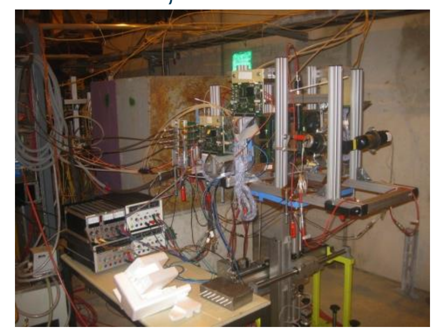


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan

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

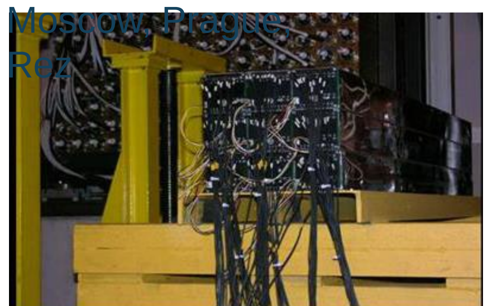


Muon detector: Kolkata + 13 Indian Inst., Gatchina, Dubna



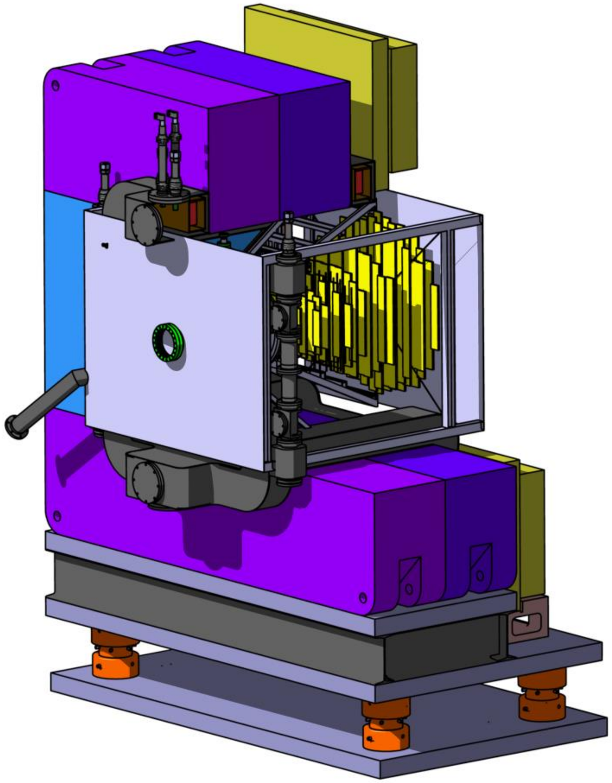
Transition Radiation Detector: Bucharest, Dubna, Frankfurt, Heidelberg, Münster

Forward calorimeter: Moscow, Prague, Rez

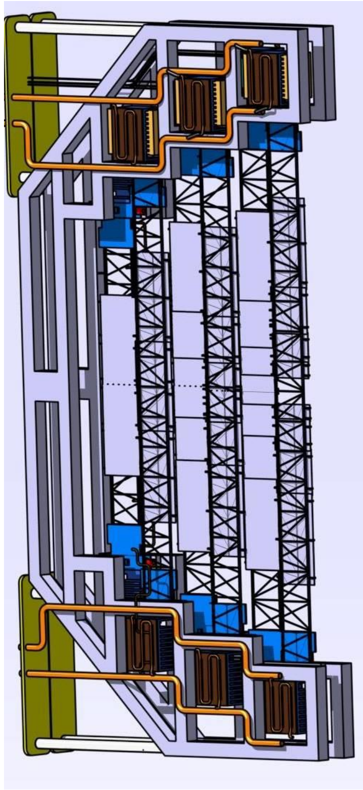


DAQ and online event selection: Darmstadt, Frankfurt, Heidelberg, Kharagpur, Warsaw

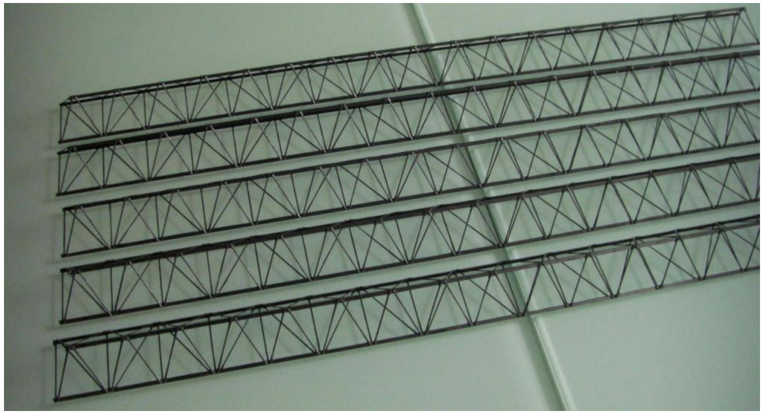
Development of the Silicon Tracking System for CBM



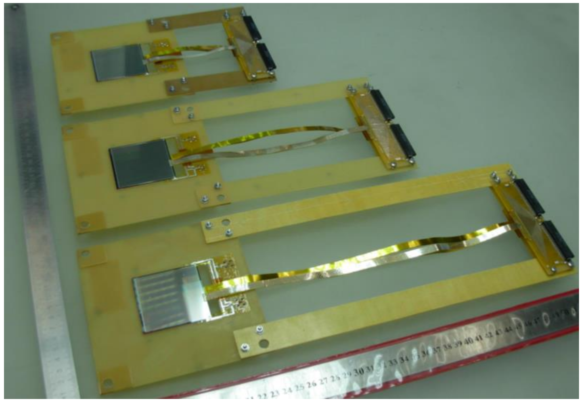
STS in thermal enclosure (-10^{o}C)

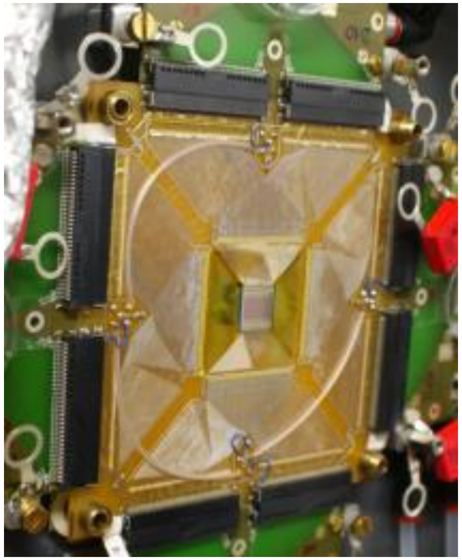


Detector layers:
Low-weight carbon structures



Sensor development:
Double-sided microstrips
60 μm pitch, 300 μm thick, read-out via ultra-thin micro-cables

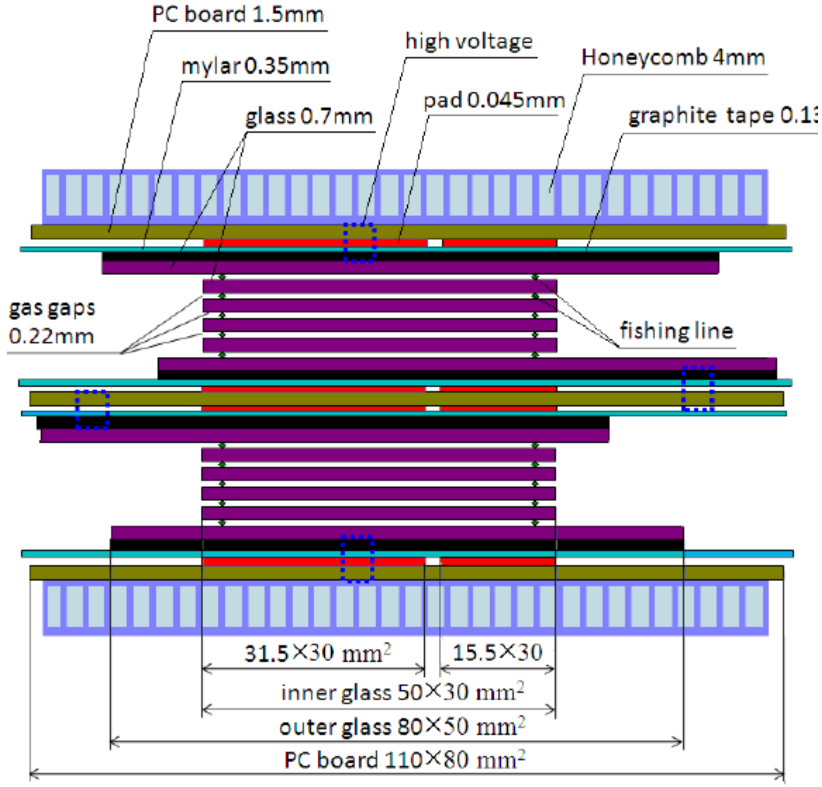


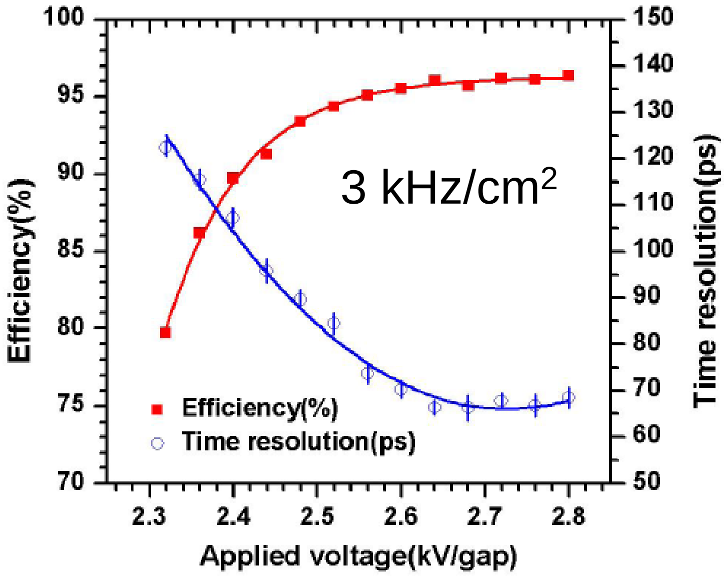


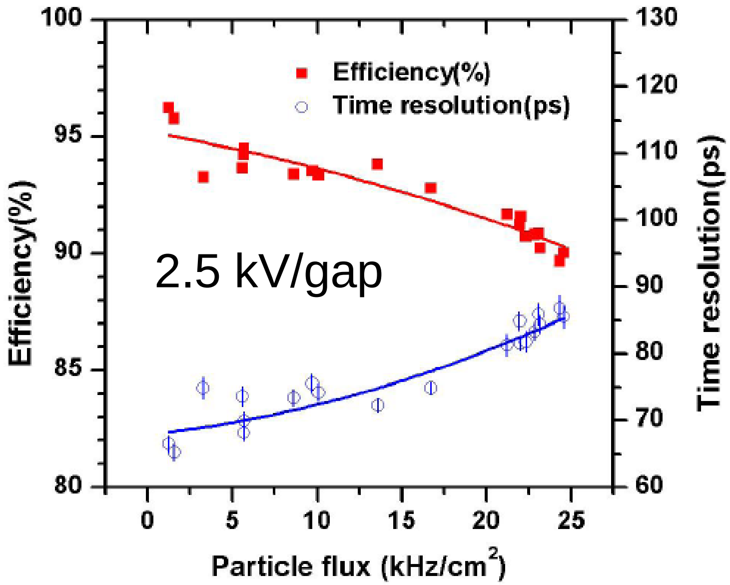
High-rate MRPCs for the CBM TOF detector

Requirements:
- rate capability up to 20 kHz/cm²
- time resolution 80 ps
- active area ~100 m²

Prototype detector:
10-gap RPC with low-resistivity glass



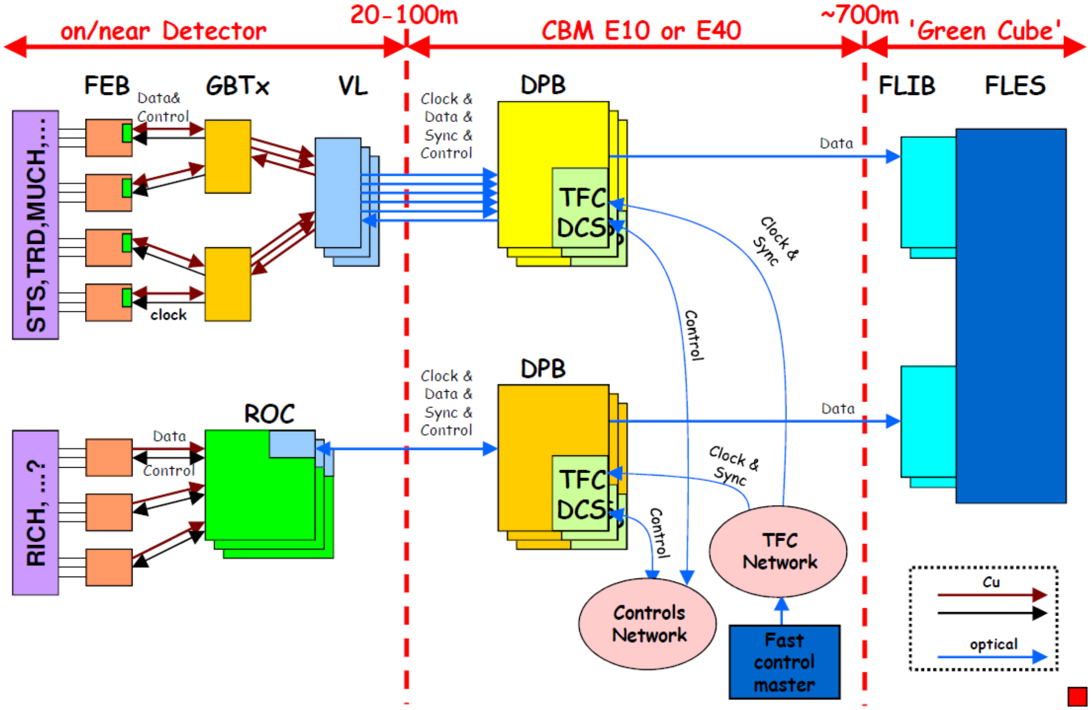




Status experiment preparation

DAQ, First Level Event Selection

- Funding: German and Polish contributions
- Prototype built and tested, final HPC cluster: GreenIT cube
- Participating institutes: Univ. Frankfurt, FIAS, GSI, KIT Karlsruhe, IIT Kharagpur, Warsaw UT, ZIB Berlin

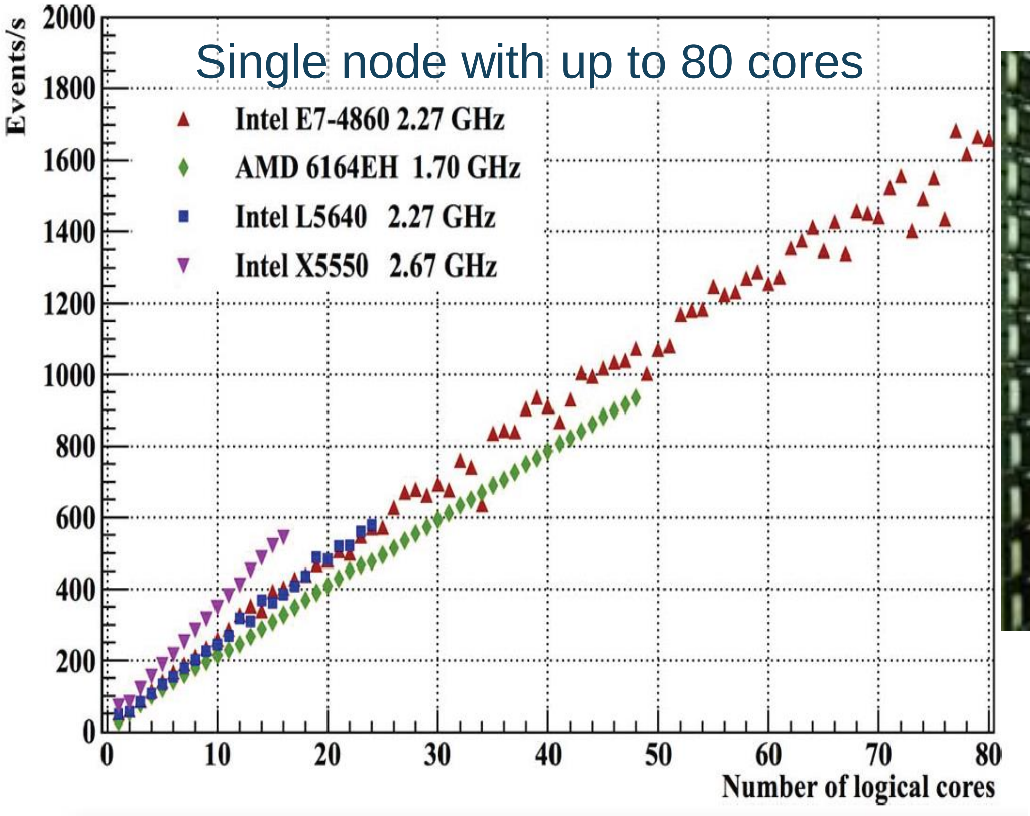


GreenIT cube at GSI

CBM First Level Event Selection (FLES)

The FLES package is vectorized, parallelized, portable and scalable

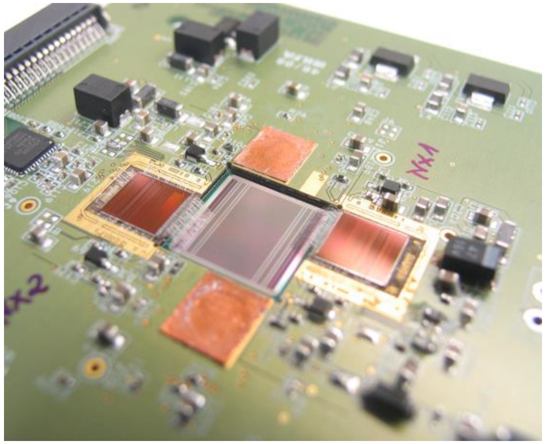
<u>Example:</u>
Full track reconstruction including KF particle analysis of multi-strange (anti) hyperons for min. bias Au+Au collisions at 25 A GeV.



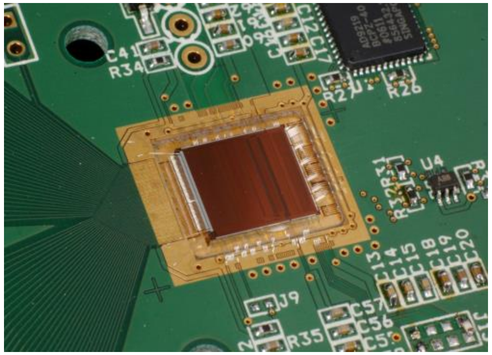
GSI „Minicube“ with 10.000 cores

CBM Front-End Electronic development

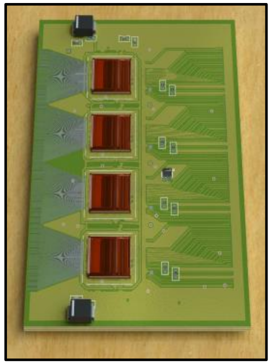
Double sided silicon strip readout:
Prototype FEB with 4 n-XYTER



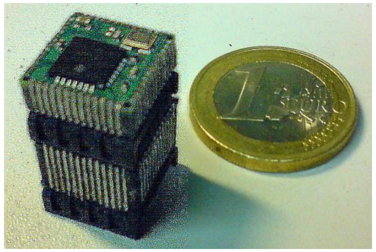
n-XYTER FEB for
gas det. prototyping

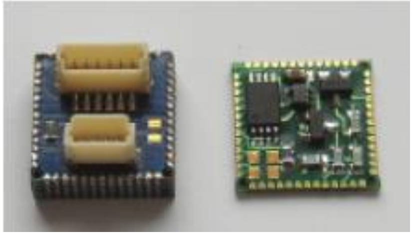


evaluative
STS FEB



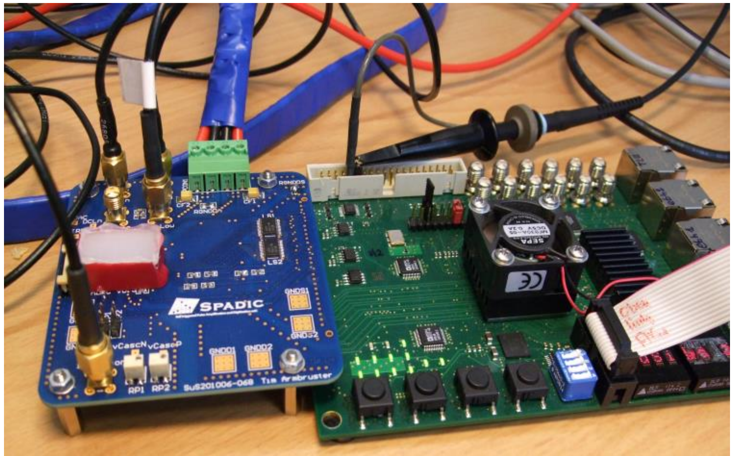
Future FEBs:
3-d assembly



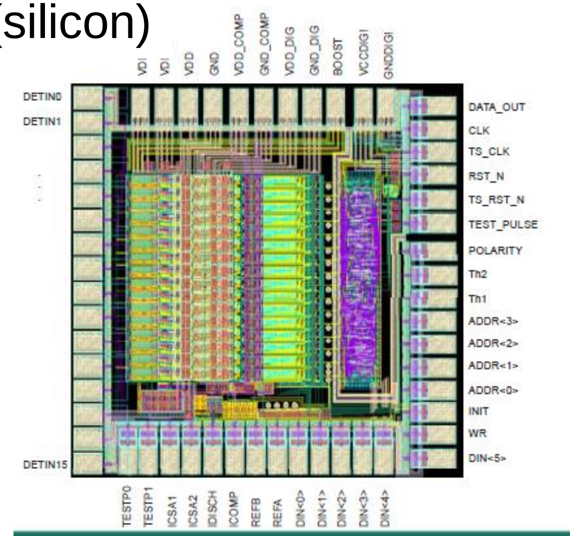


Next generation ASICs

SPADIC (TRD)



TOT2 (silicon)

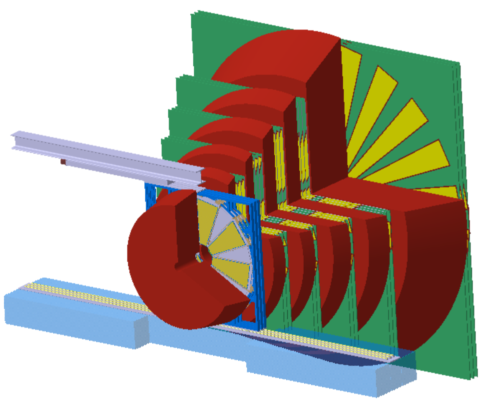


Compressed Baryonic Matter Experiment

Technical Design Report for the CBM

Muon Chamber (MUCH)

The CBM Collaboration



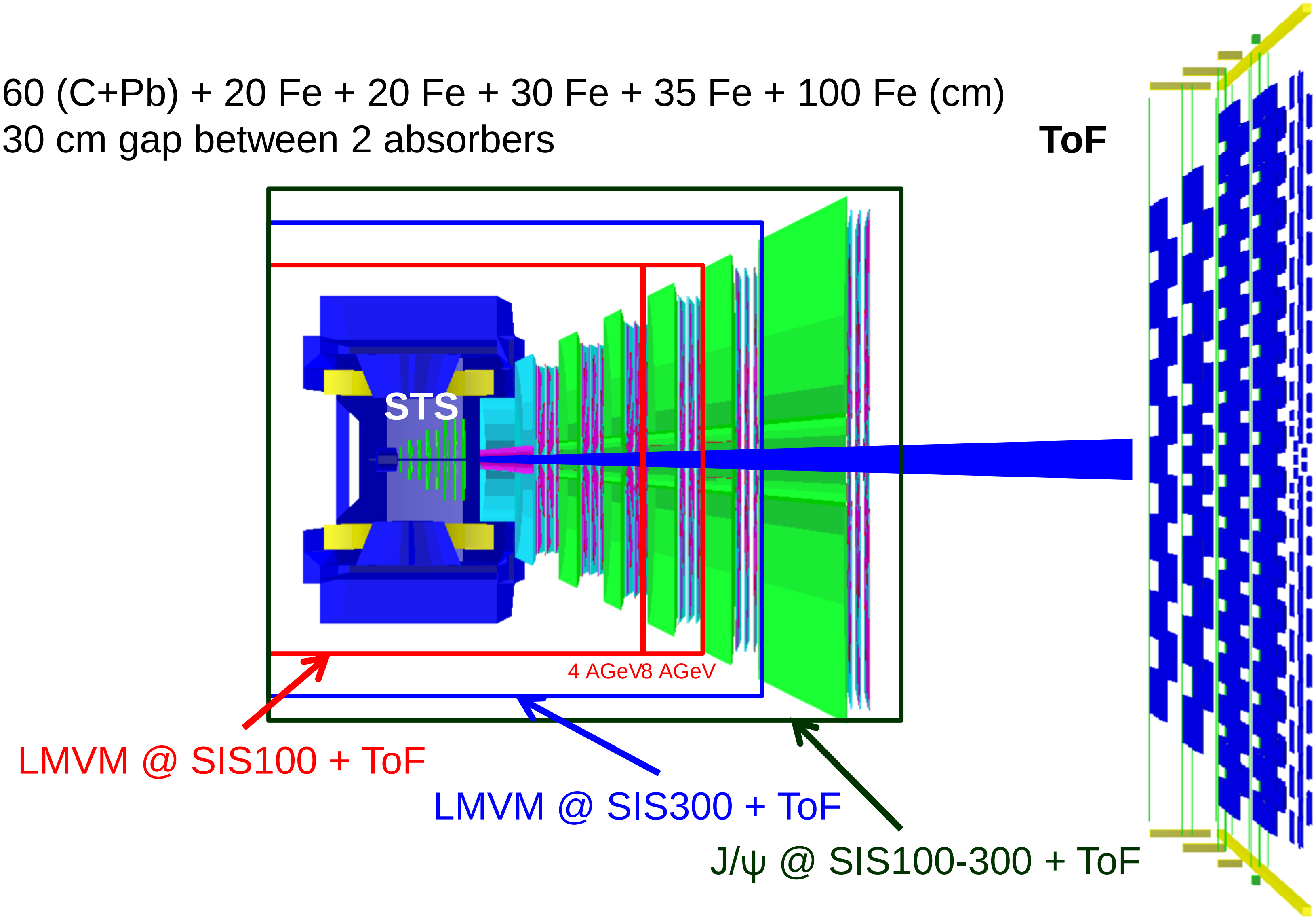
December 2013

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)

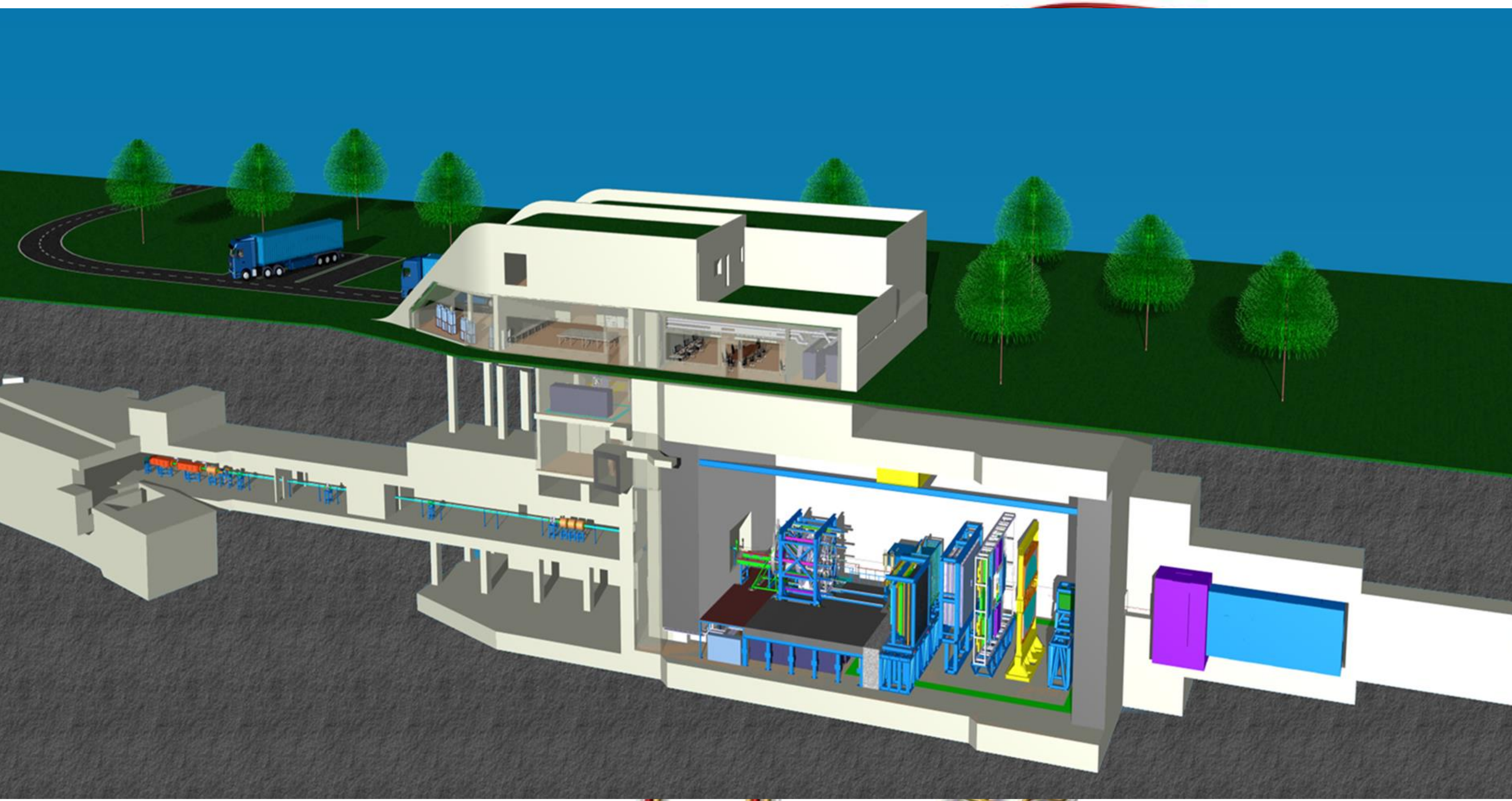
60 (C+Pb) + 20 Fe + 20 Fe + 30 Fe + 35 Fe + 100 Fe (cm)
30 cm gap between 2 absorbers



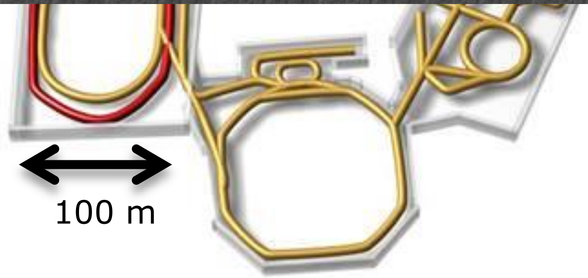
MUCH version	Carbon absorber	No. of iron absorber slices	total thickness of iron absorber	No. of tracking chamber triplets	Type of Chambers	Physics case
SIS100-A	60 cm	2	40 cm	3	2 GEM, 1 Straw tube	LMVM A + A 4-6 AGeV
SIS100-B	60 cm	3	70 cm	4	2 GEM, 2 Straw tubes	LMVM A + A 8-10 AGeV
SIS100-C	60 cm	4	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

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.

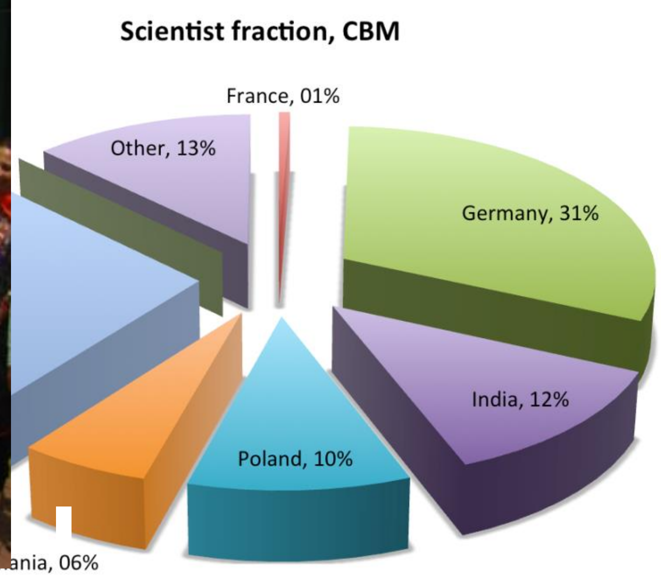
Korea:
Pusan Nat. Univ.

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

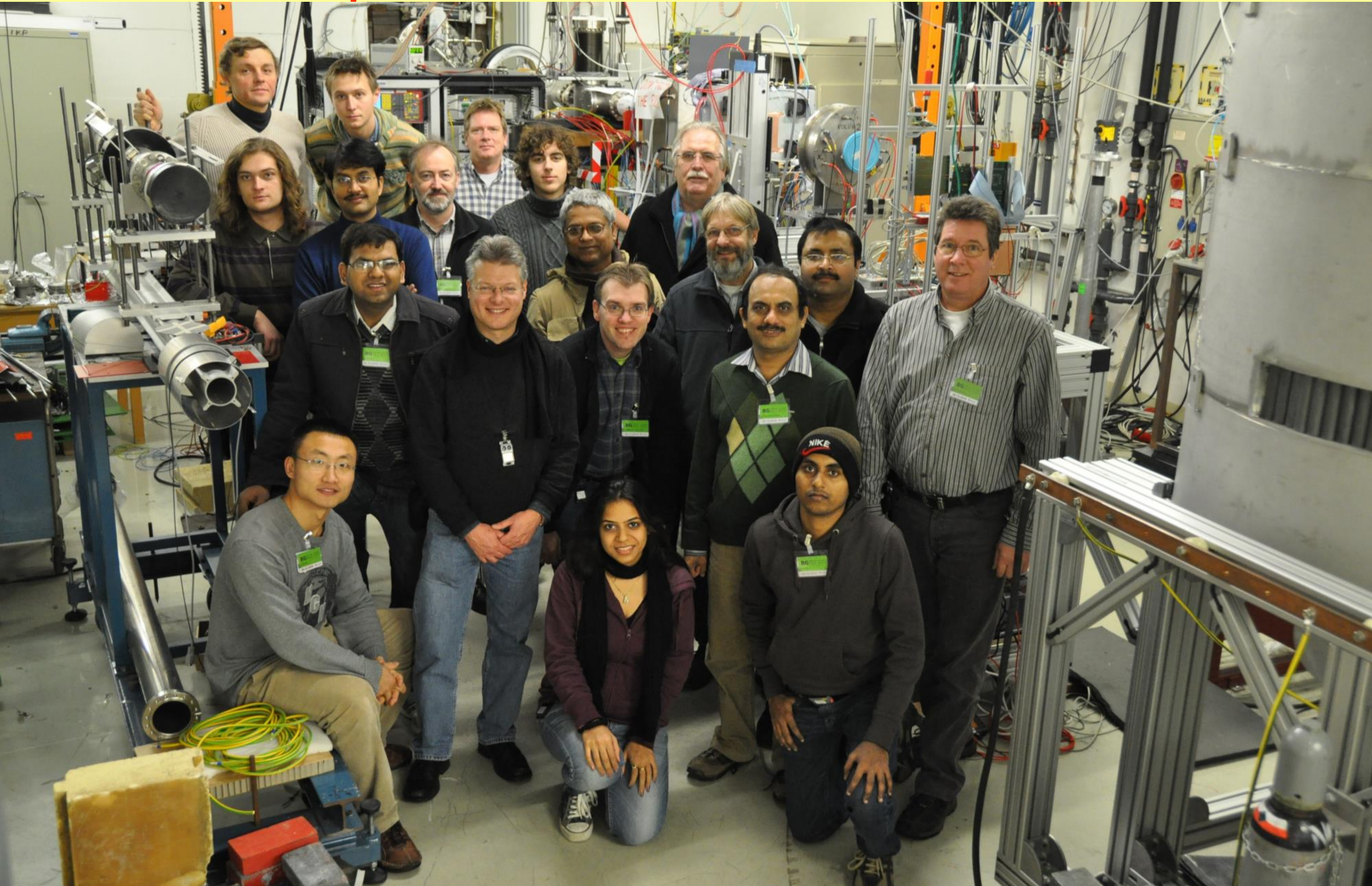
Romania:
NIPNE Bucharest
Univ. Bucharest

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



Tests of silicon micro-strip and GEM detectors with 3 GeV protons at COSY Dec. 2011



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

A few general comments:

- Strong mandate is to build things within the country
- We have a fixed amount in FAIR-India fund for experiments
- The amount is STRICTLY for production of detectors and not for R&D
- If you can manage production and R&D it is upto the project co-ordinator

Immediate steps towards funding:

1. PC has to give total scope of the project within the approved funding
2. Breakup of collaborators and their fund share
3. Funding profile (phases, different heads etc)
4. BI-IFCC has prepared an MoU (some of you have seen that), that will be sent to collaborating institutions.
5. To be reviewed once by the ECE and then funds will be released
6. There will be strict monitoring on utilization
7. Student is not under the scope of project, this is from BI-IFCC student pool

What I will expect from this meeting?

- Detailed discussions on each detector project, critical review, modifications

(There should be critical review by othe collaborations, like Nustar for CBM and vice versa)

- Explore and identify the scope of intra-experiment collaboration (in India)
- Can we have items common and go to the industry?
- A regular mailing list for discussions
- Collaboration in simulation (Fairroot)
- Collaboration in Electronics (FPGA?)
- We should have ONE FAIR collaboration

Let's have a summary discussion at the end

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

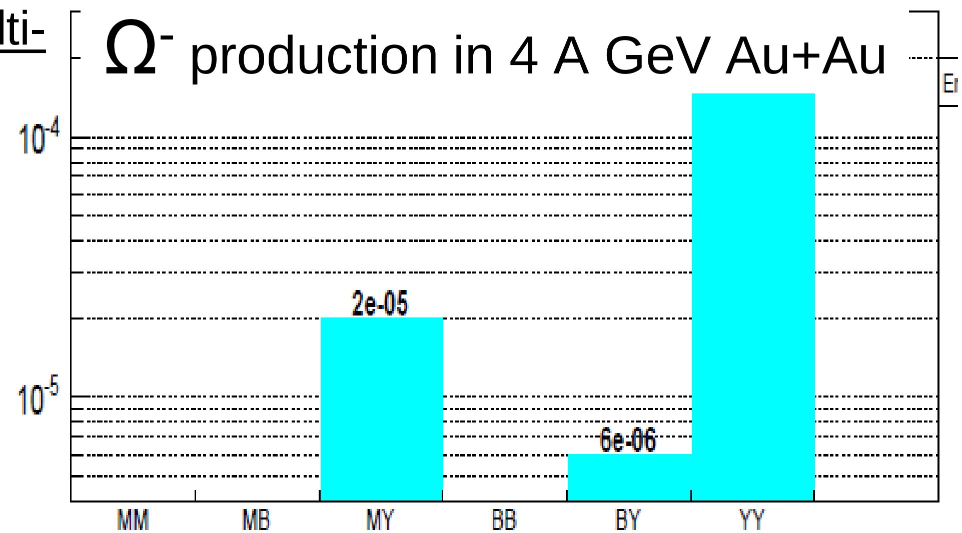
Transport codes:
Multi-strange hyperon production via multi-step strangeness exchange reactions:

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. $\Lambda^0 \Xi^- \rightarrow \Omega^- n$, $\Xi^- K^- \rightarrow \Omega^- \pi^-$

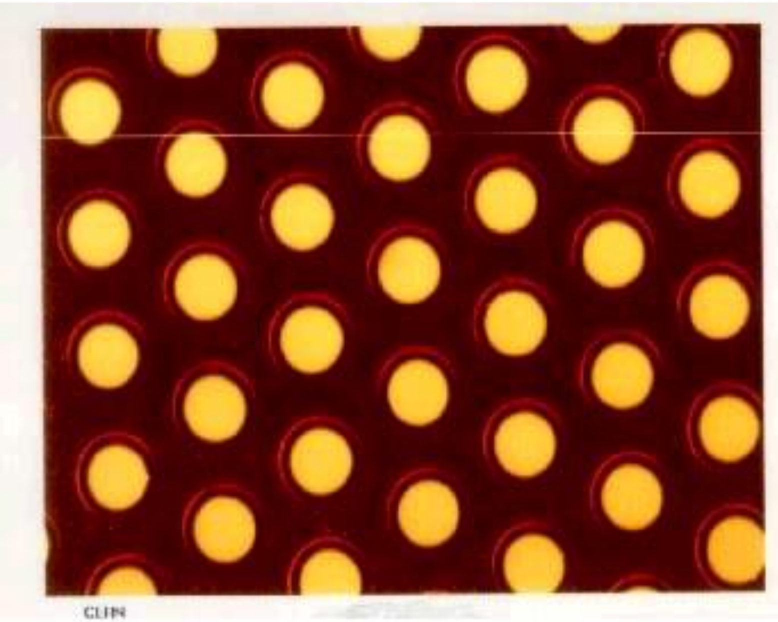
Antihyperons (anti-s quarks):

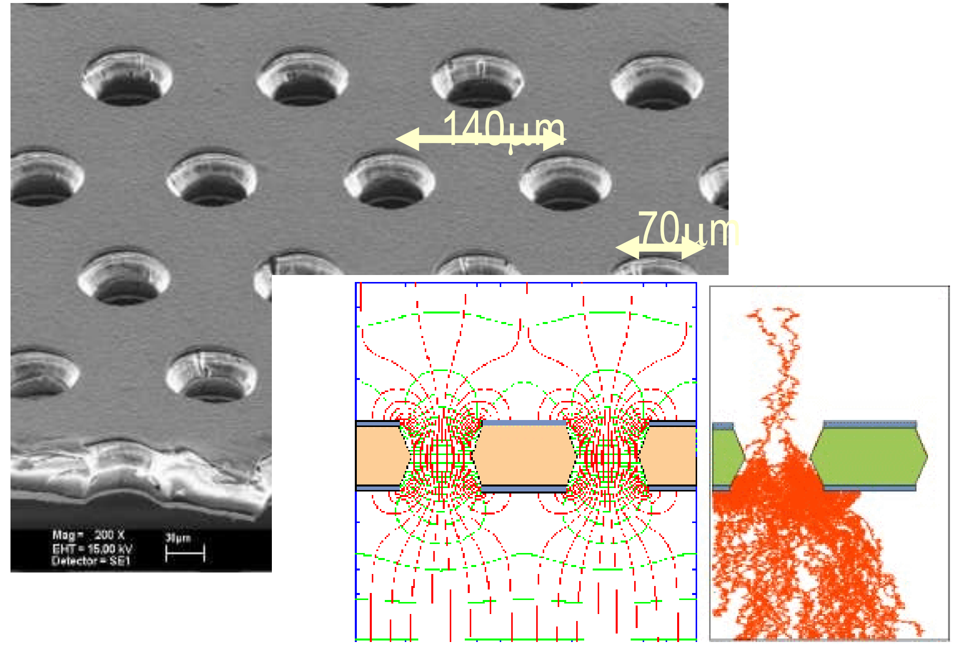
1. $\bar{\Lambda}^0 K^+ \rightarrow \Xi^+ \pi^0$,
2. $\Xi^+ K^+ \rightarrow \Omega^+ \pi^+$.



HYPQGSM calculations , K. Gudima et al.

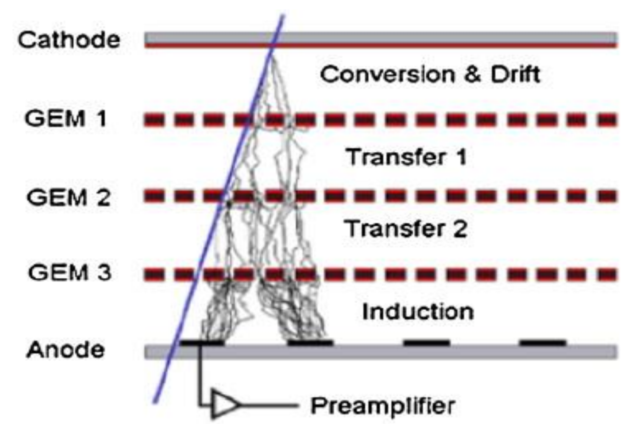
Gas Electron Multiplier (GEM) and its working principle





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

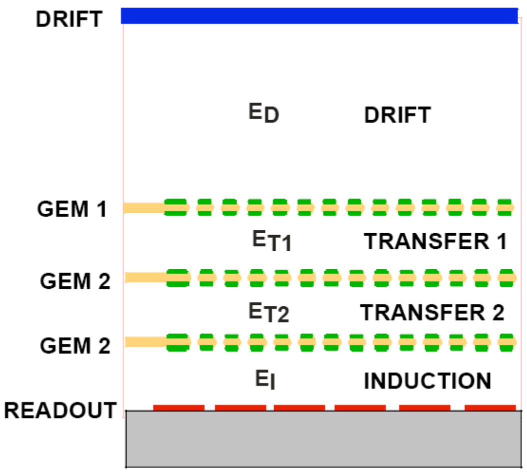
- Active medium is a gas mixture.
- electron multiplication takes place in holes of two copper foils separated by kapton
- Amplification may use 2 or 3 stages.



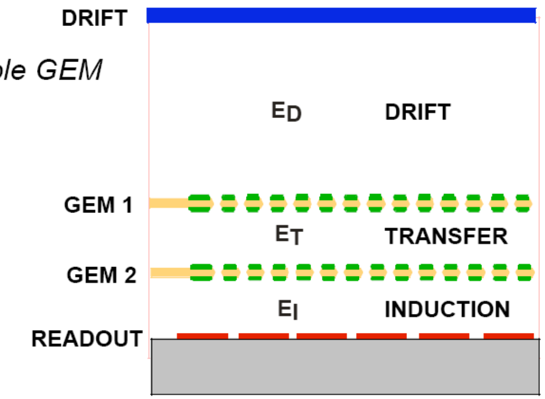
Multi GEM configurations..

Cascaded GEMs achieve larger gains and safer operation in harsh environments

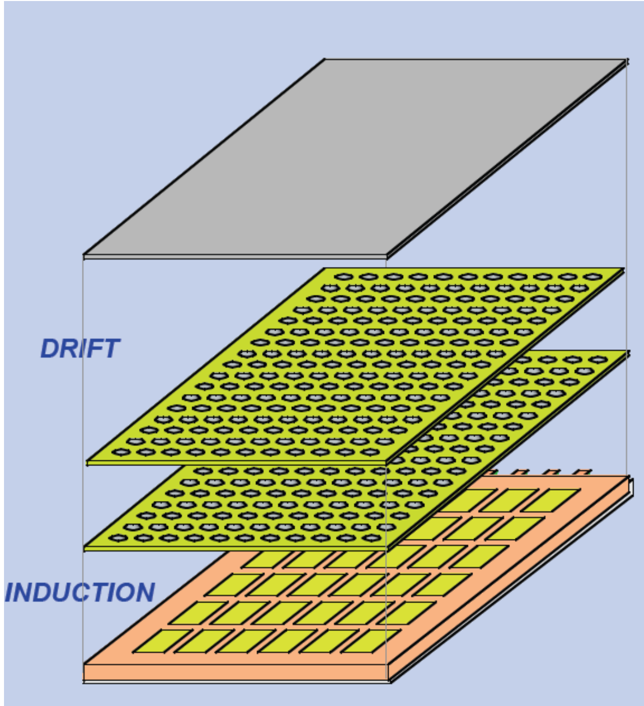
Triple GEM



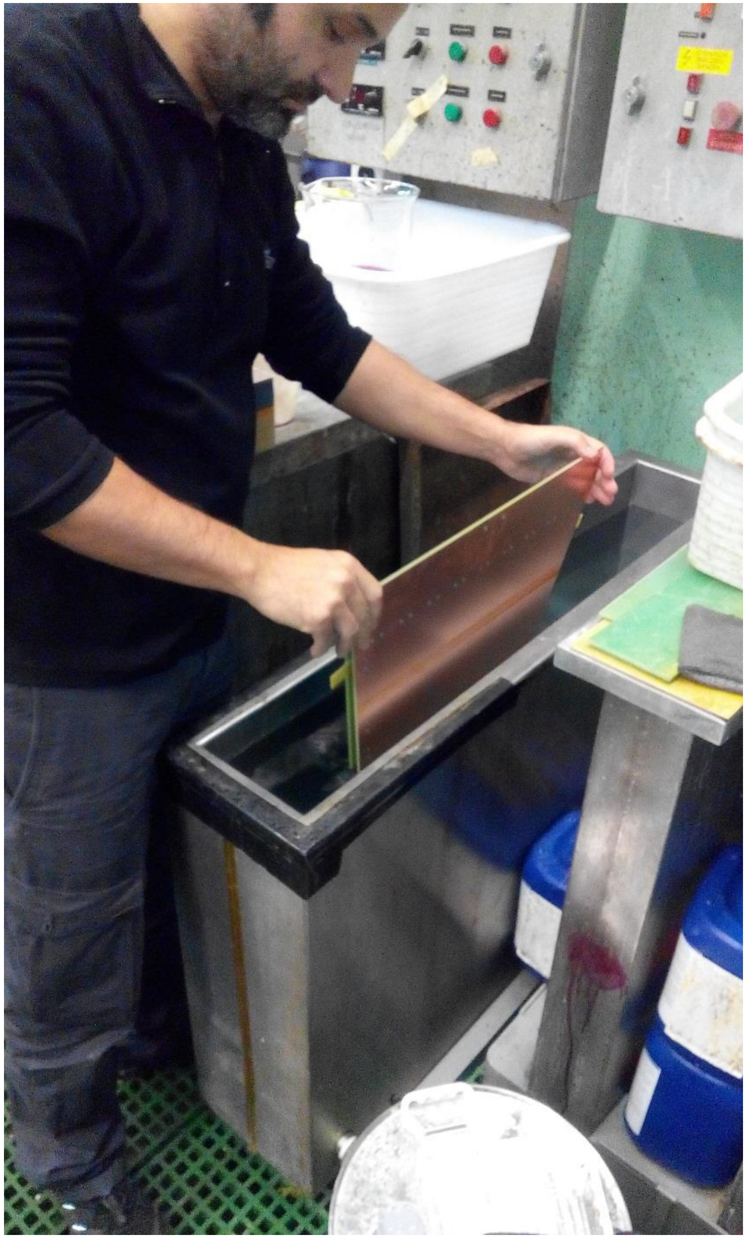
Double GEM



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

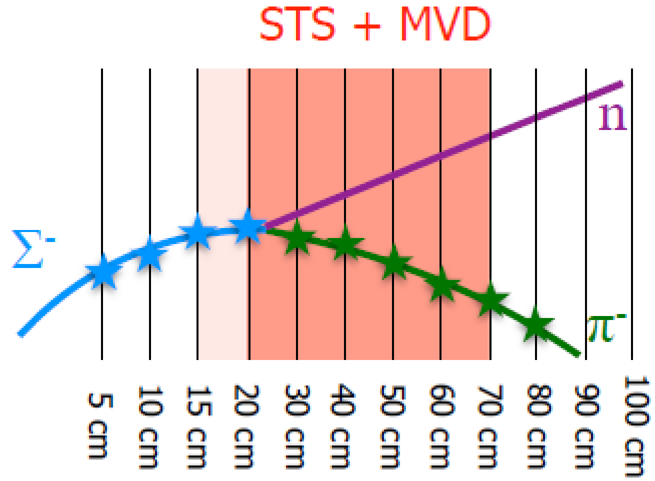


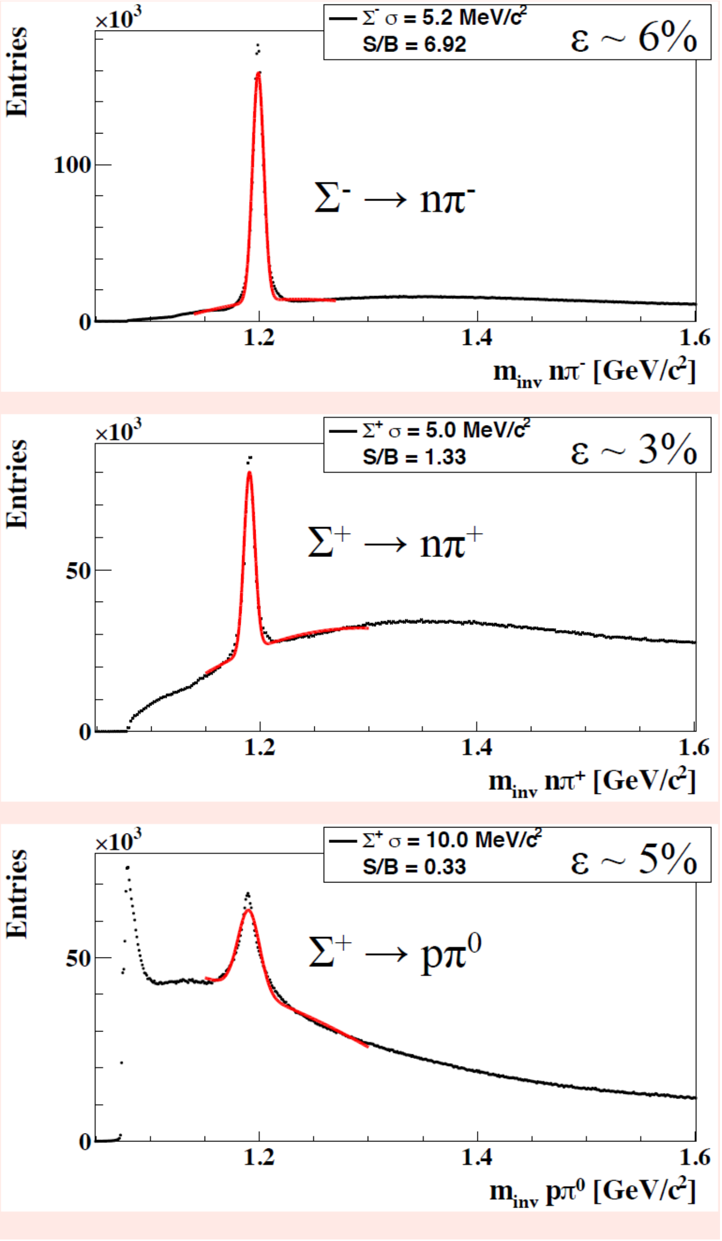
The Final cleaning
--- ultra-sonic bath

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