THE COMPRESSED BARYONIC MATTER EXPERIMENT AT FAIR

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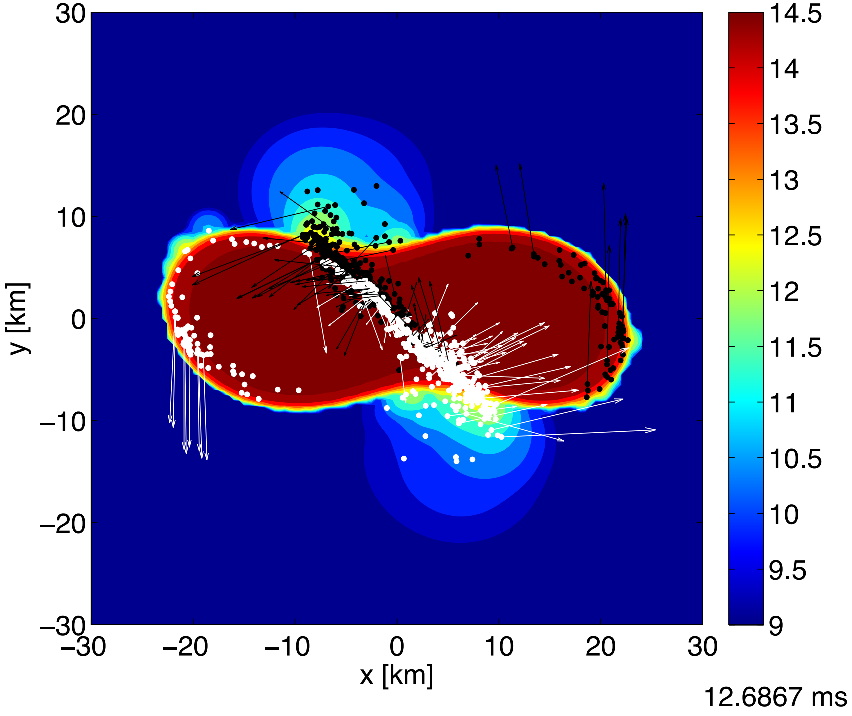
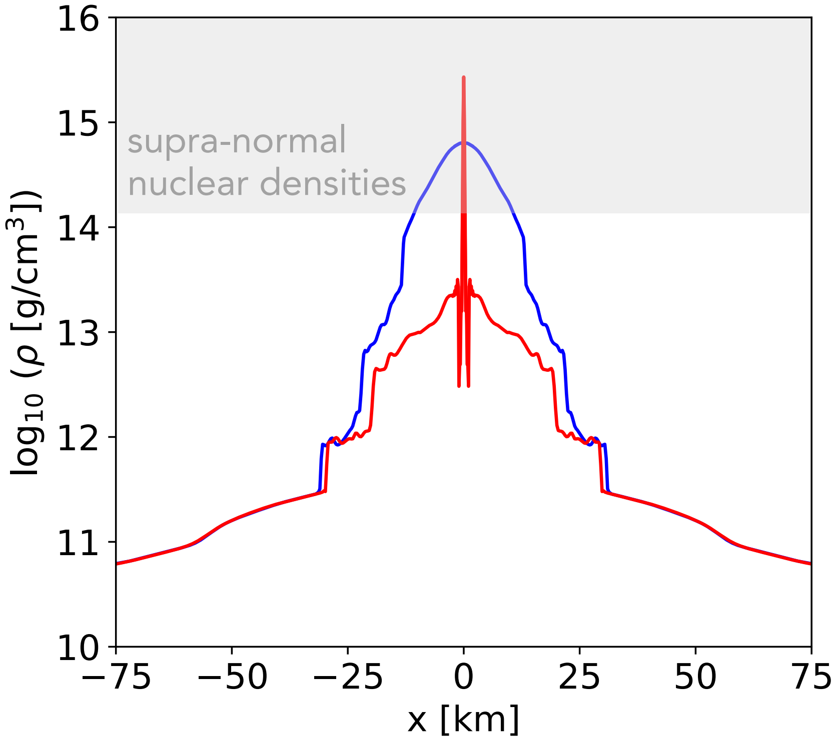
The QCD challenge

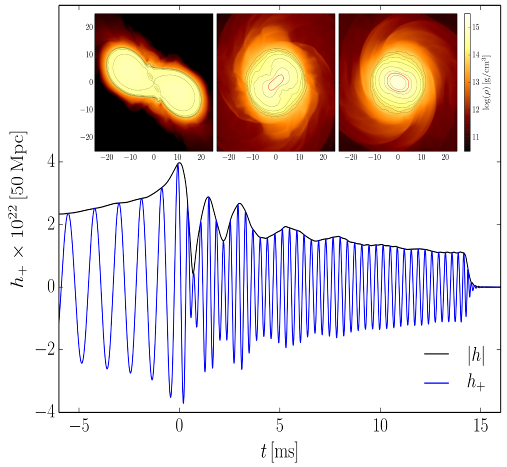
- From particles (quarks) to hadrons to nuclei and to matter (NS merger as site for r-process)
- Governed by non-perturbative QCD, ab-initio approach complicated
- Experimental approach to QCD matter: heavy-ion collisions, gravitational waves



A. Bauswein et al. [1302.6530]

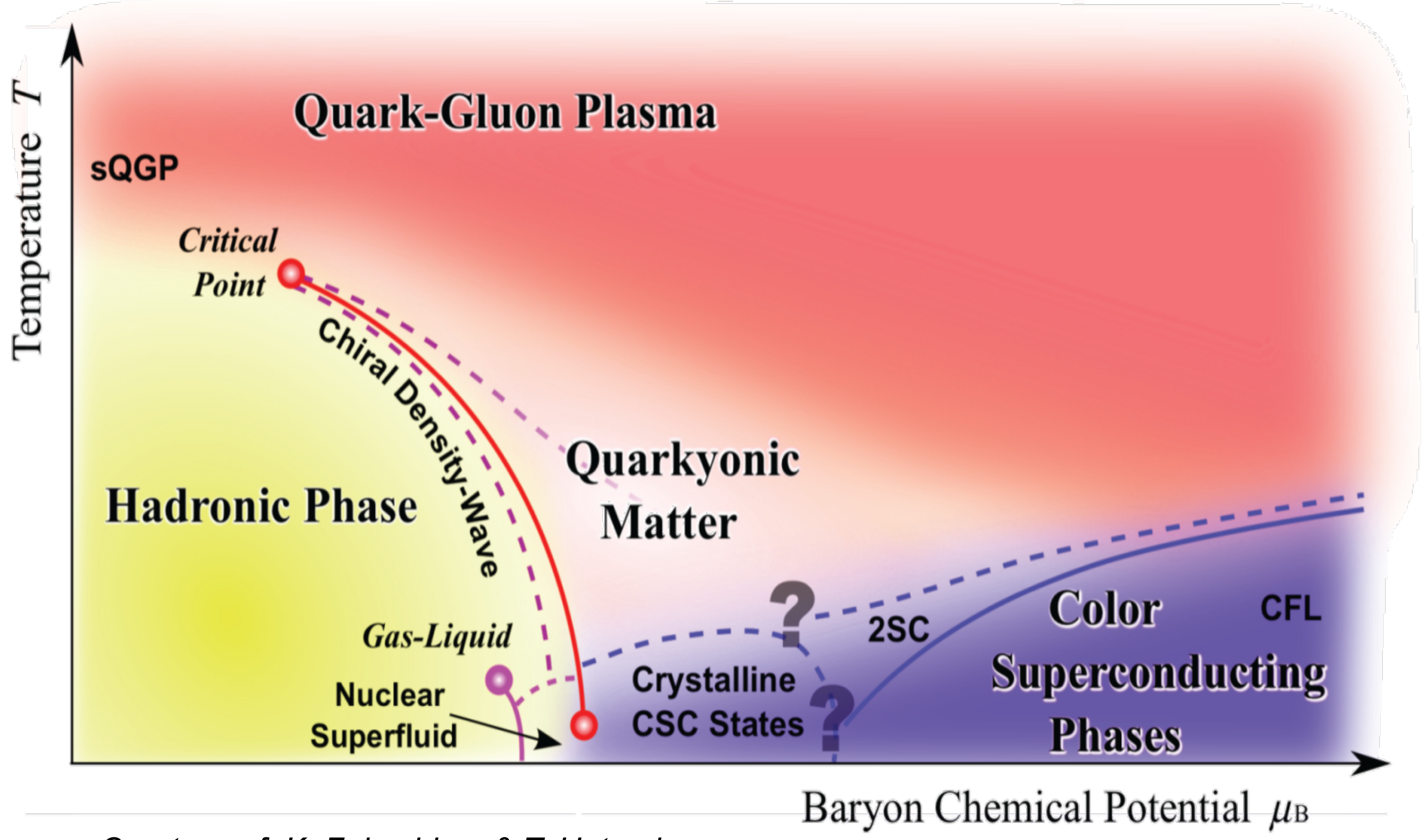


Density profile across a merging NS binary system. Taken $t = 1.4$ ms ($t = 0$ see below).



M. Hanauske, L. Rezzolla et al.   J.Phys.Conf.Ser. 878 (2017) no.1, 012031

The QCD phase diagram

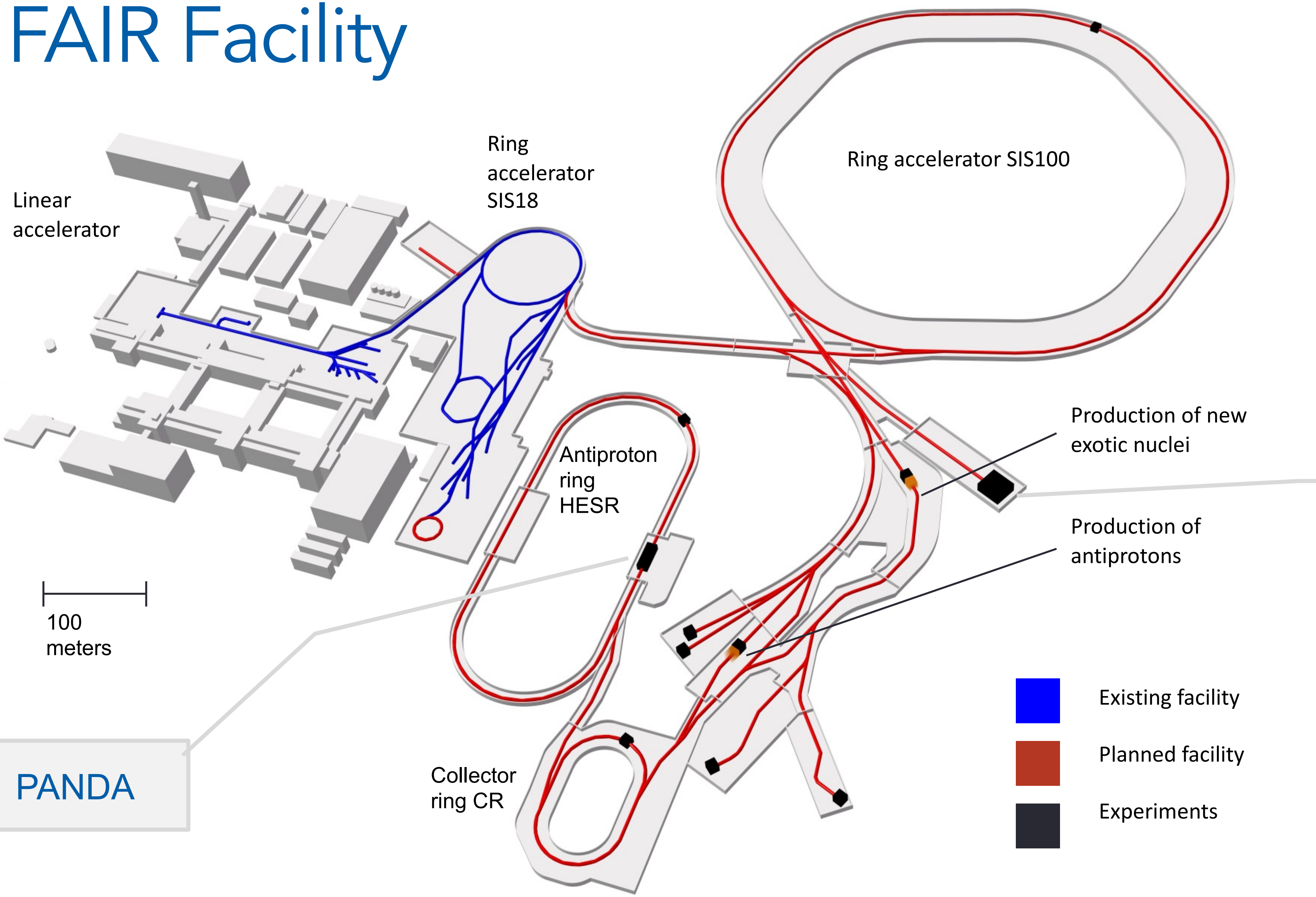


Courtesy of K. Fukushima & T. Hatsuda

Open questions:

- Origin of mass?
- Nature of confinement?
- Role of condensates?
- EOS of dense/hot matter

The FAIR Facility



CBM
HADES

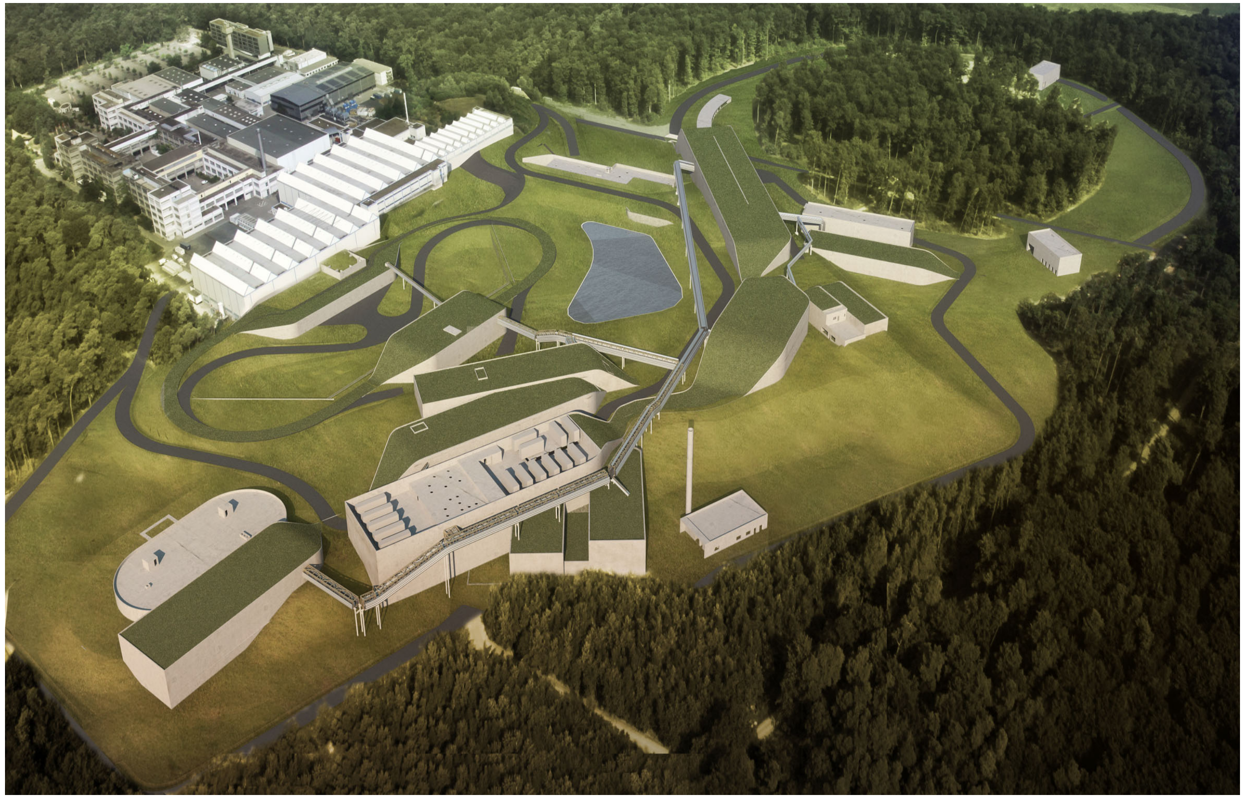
PANDA

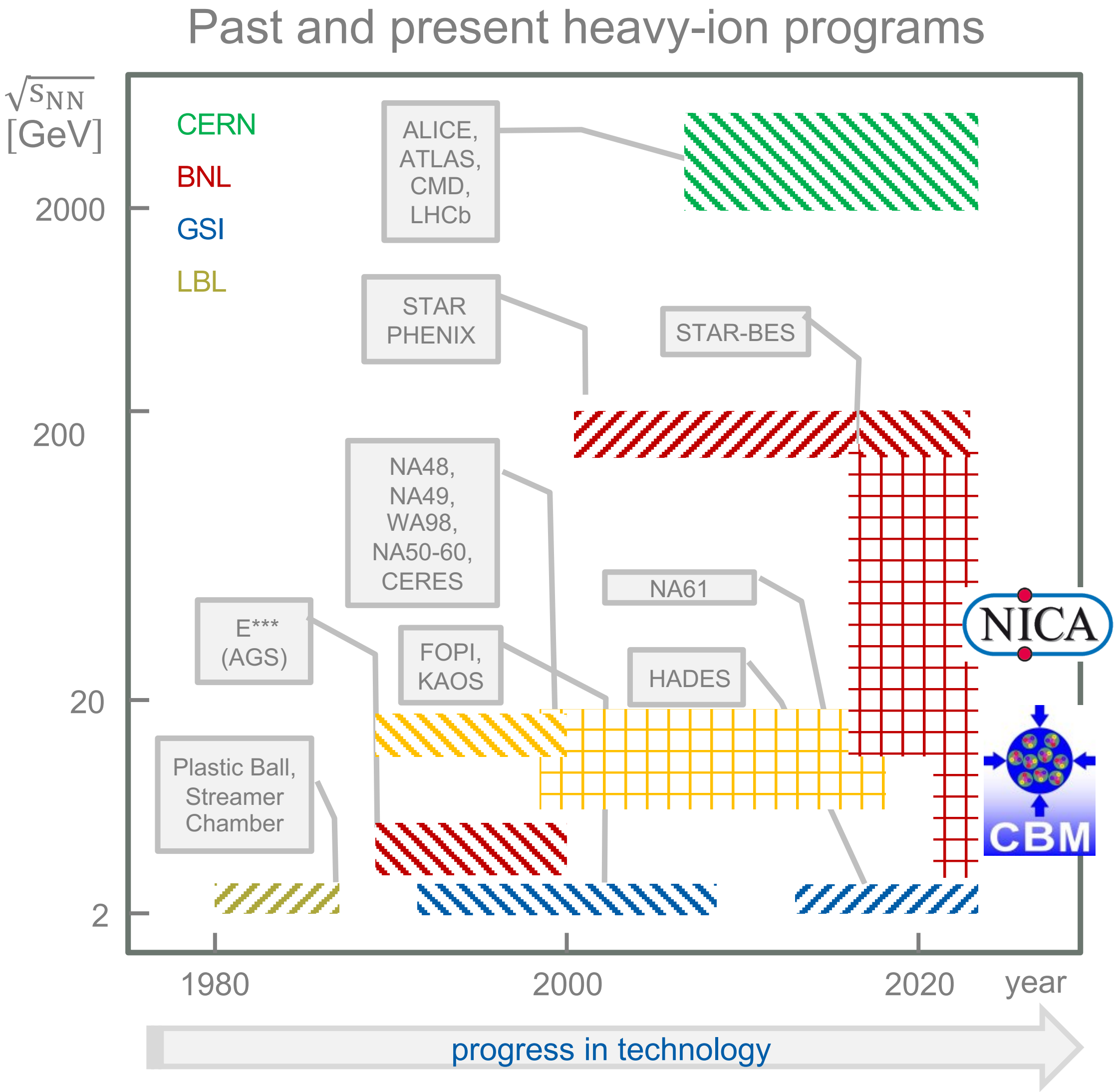
FAIR Groundbreaking Ceremony June 2017

2021 finish concrete pouring – 2023 start installation CBM/HADES –2025 full operation.

QCD physics at FAIR

- Hadron- and Quark Matter Physics (CBM/HADES)
- Hadron Spectroscopy and Structure (PANDA)
- Properties and Reactions of Rare Isotope (NUSTAR)





MOTIVATION

CBM - "nomen est omen" - Cloudy Bag Model ;)

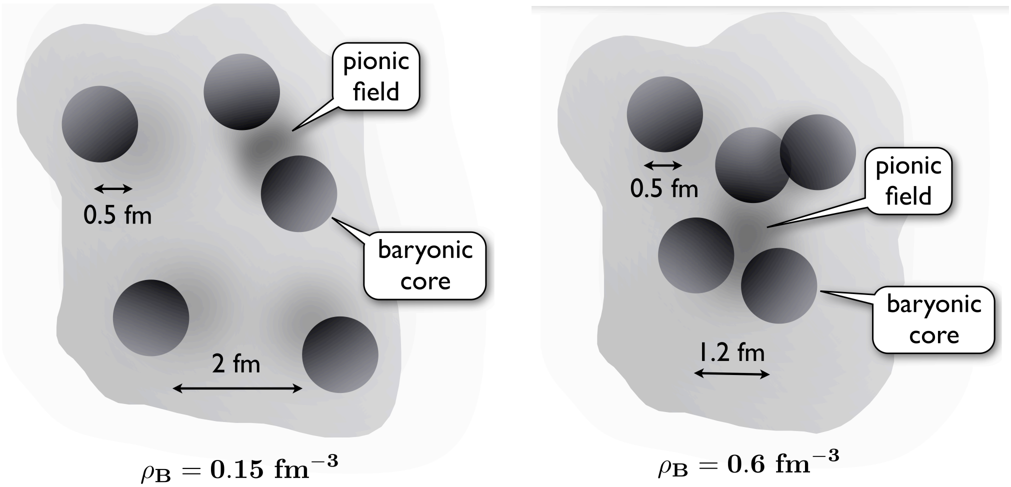
A lot already known about nucleons and their excitations from (lattice) QCD:

- Confinement of light quarks nothing to do with flux tubes. Rather appears because the condensates are suppressed between the valence quarks.
- Resonance properties substantially driven by cloud-meson core final state interaction.
  L. Karatidis et al., arXiv:1608.03051
  J. M. M. Hall et al., arXiv:1411.3402

Chiral symmetry restoration

- in-medium a_1/ρ spectral functions. Trend seen like conjectured by Rapp/Hohler.
  H. Meyer et al. arXiv: 1212.4200 & INPC2016
- Likely no generation of mass without confinement.

What does it take, to force the quarks forming a giant bubble?



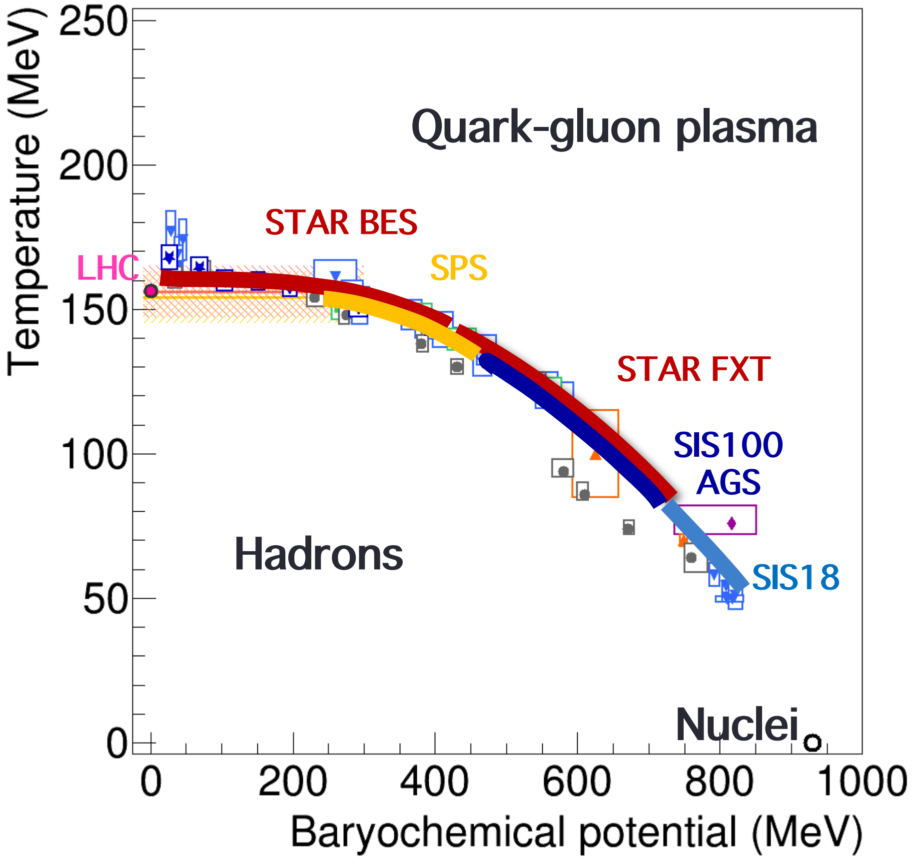
Chiral Perturbation Theory:

- Provides prediction for chiral order parameter a.f.o. baryon
- Sees strong repulsion (at low to moderate temperatures.

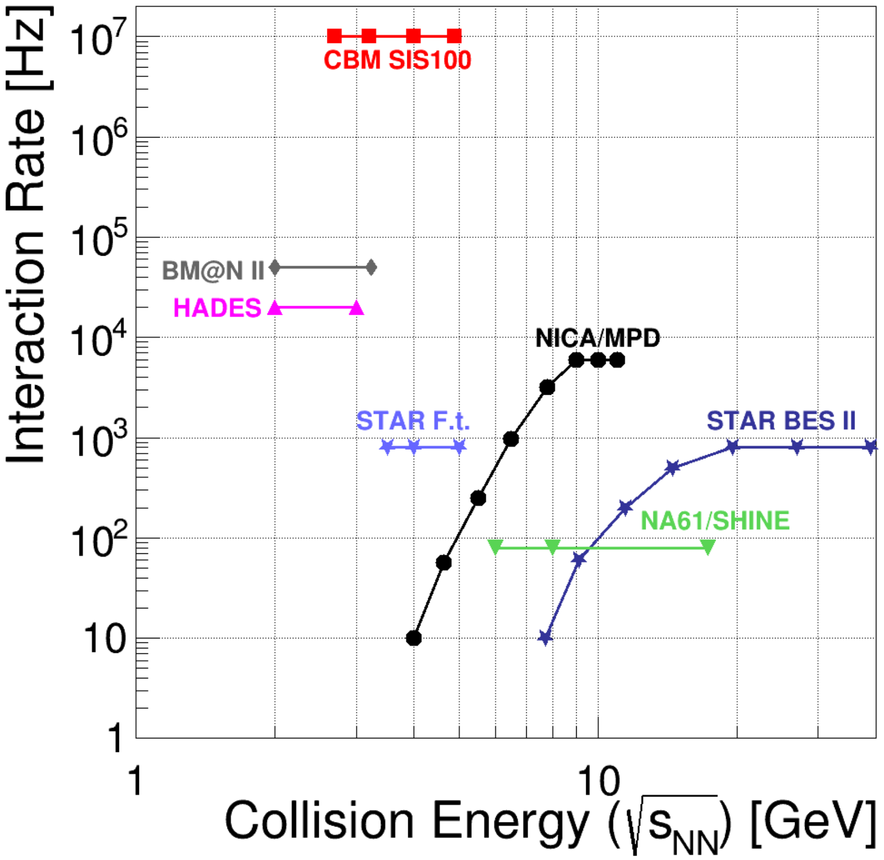
J.W. Holt, M. Rho, W. Weise arXiv1411.6681

Exploration of the High-μ_B Region

Reach:
Temperature and chemical potential extracted from particle multiplicities and assuming thermalization



Speed:
Mean event rates before event selection.
Note the luminosity drop for colliders at low beam energy.

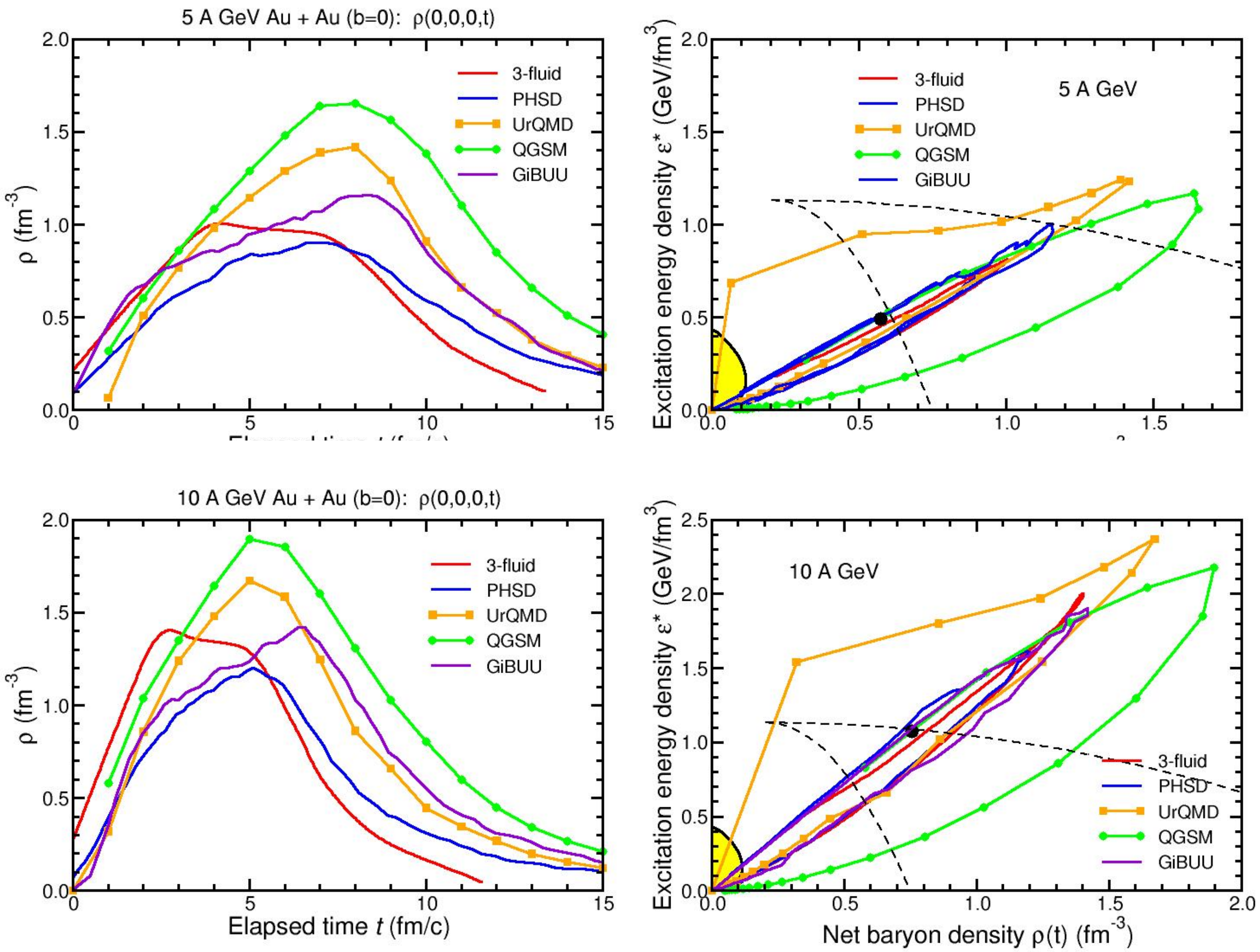


Heavy-ion collisions at SIS100 energies

- Nearly complete stopping leads to baryon-rich matter in the overlap zone.
- Generally shorter lifetime and larger densities as beam energy goes from 1 to 10 A GeV.

5 A GeV

10 A GeV



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

Physics addressed by CBM

The QCD Equation-of-State

- Collective behavior (flow)
- Multi-strange baryons

Search for novel phases and 1st order phase transition

- e-b-e observables (higher-moments)
- Excitation function of hadron multiplicities and virtual photons

Path to restoration of chiral symmetry

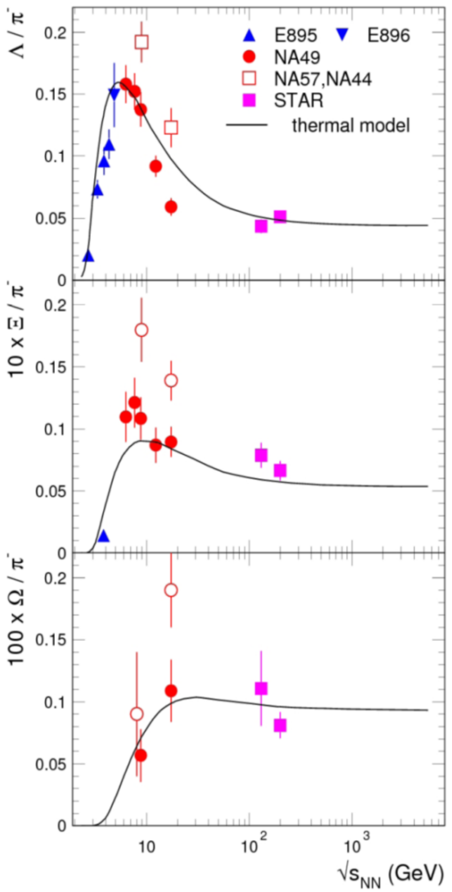
- High-precision invariant mass distributions low- and intermediate mass range

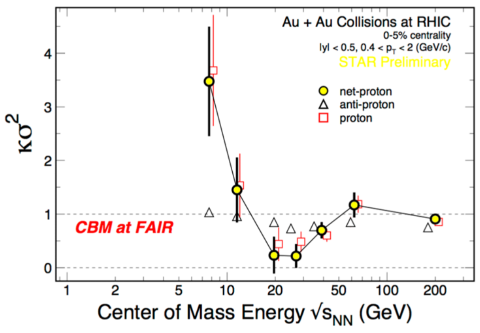
Strange matter

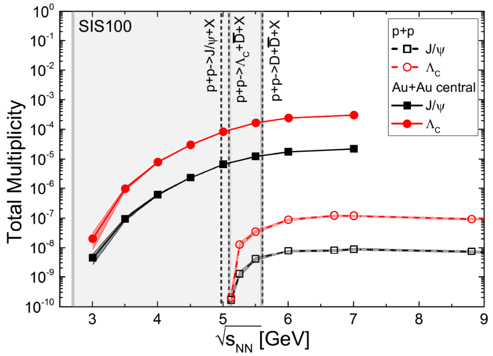
- (Double-) lambda hypernuclei
- Meta-stable objects (e.g. strange dibaryons)

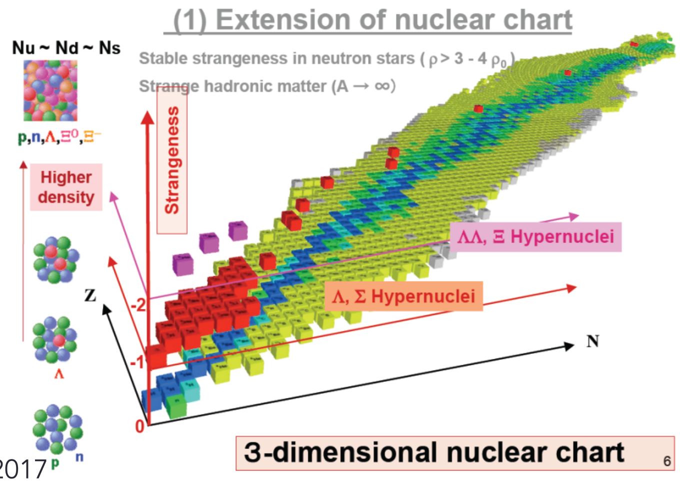
Charm production (and propagation) at threshold

- Open-charm in pp, pA
- Backward production in pA (R_{pA})



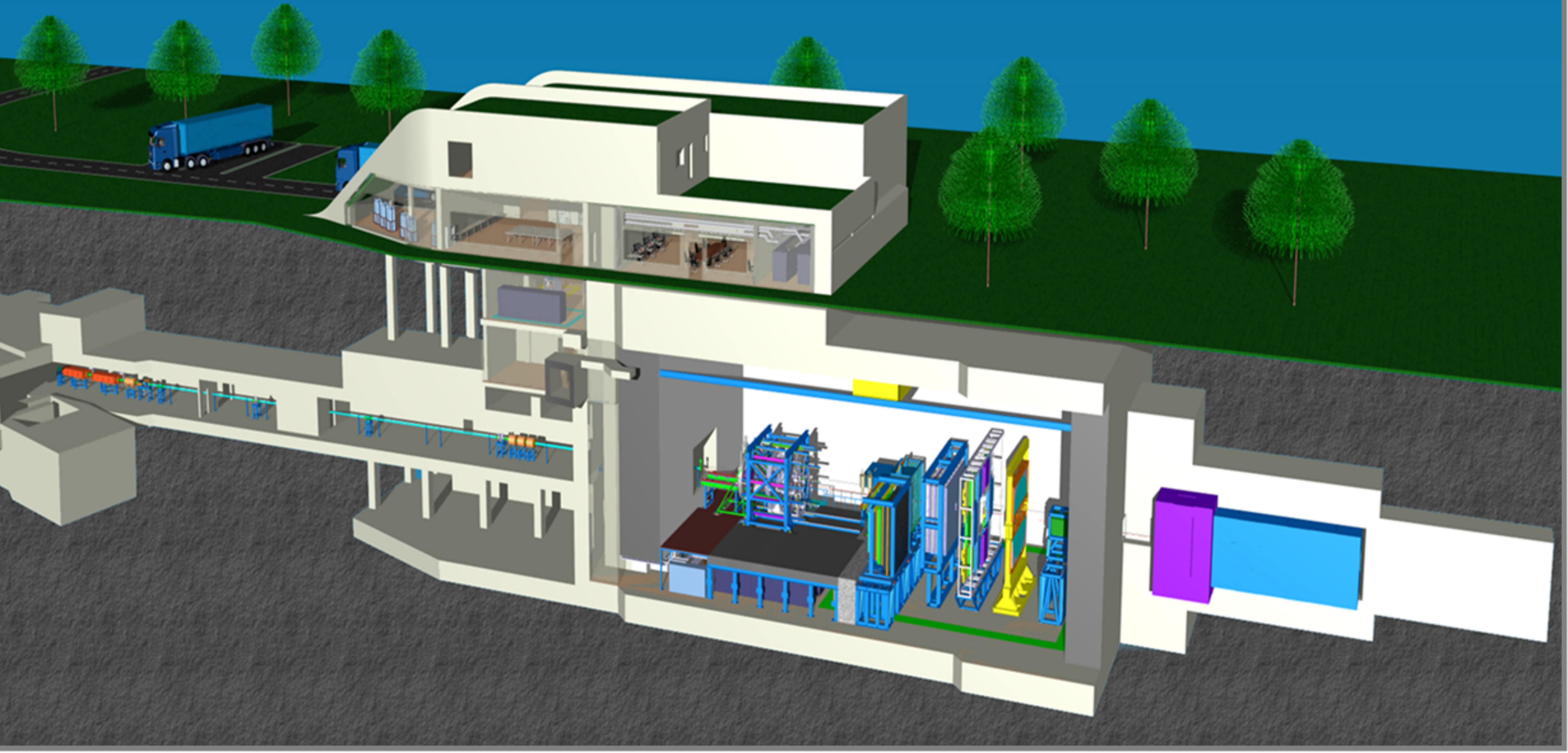






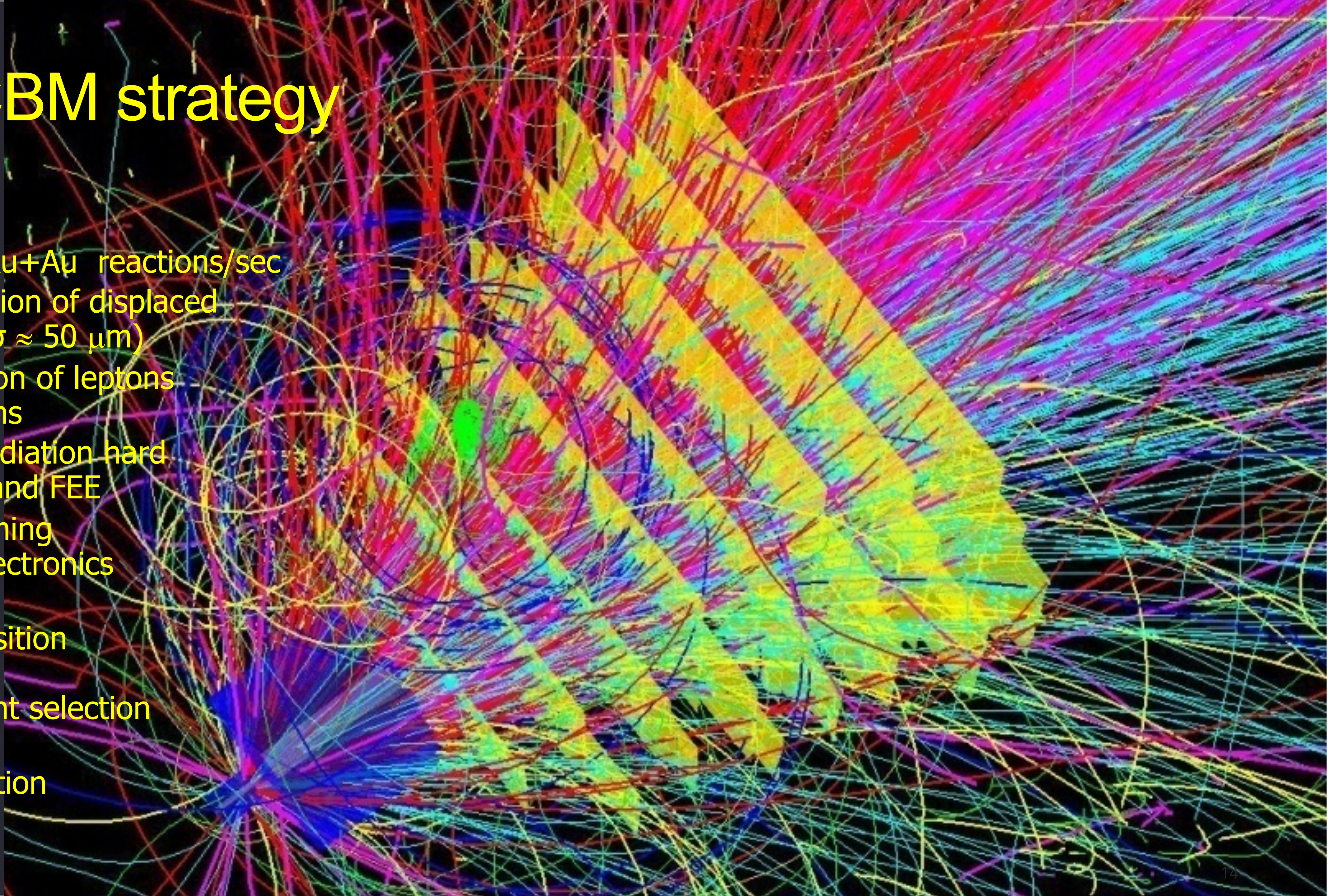
THE DETECTOR SYSTEM

The CBM cave

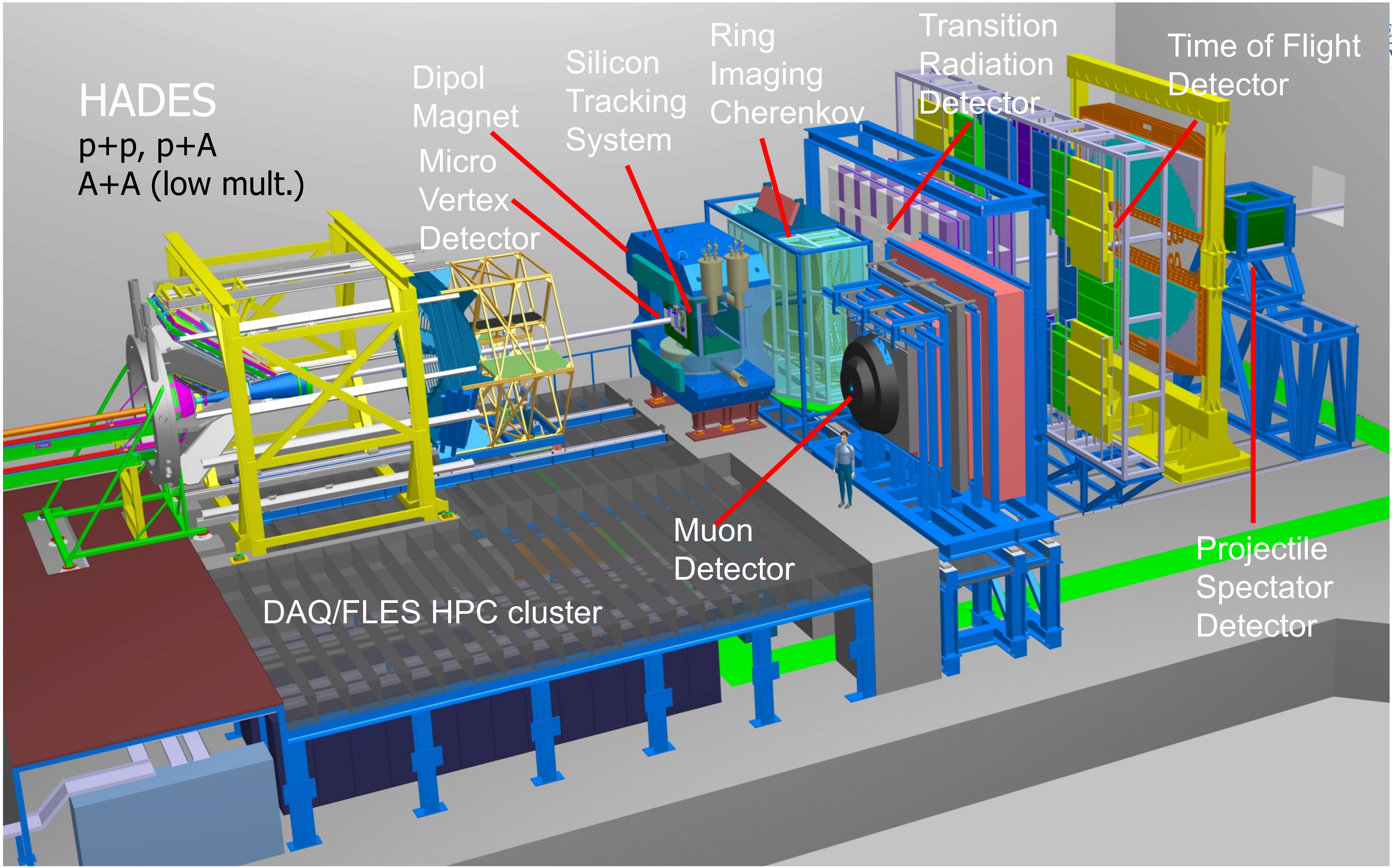


The CBM strategy

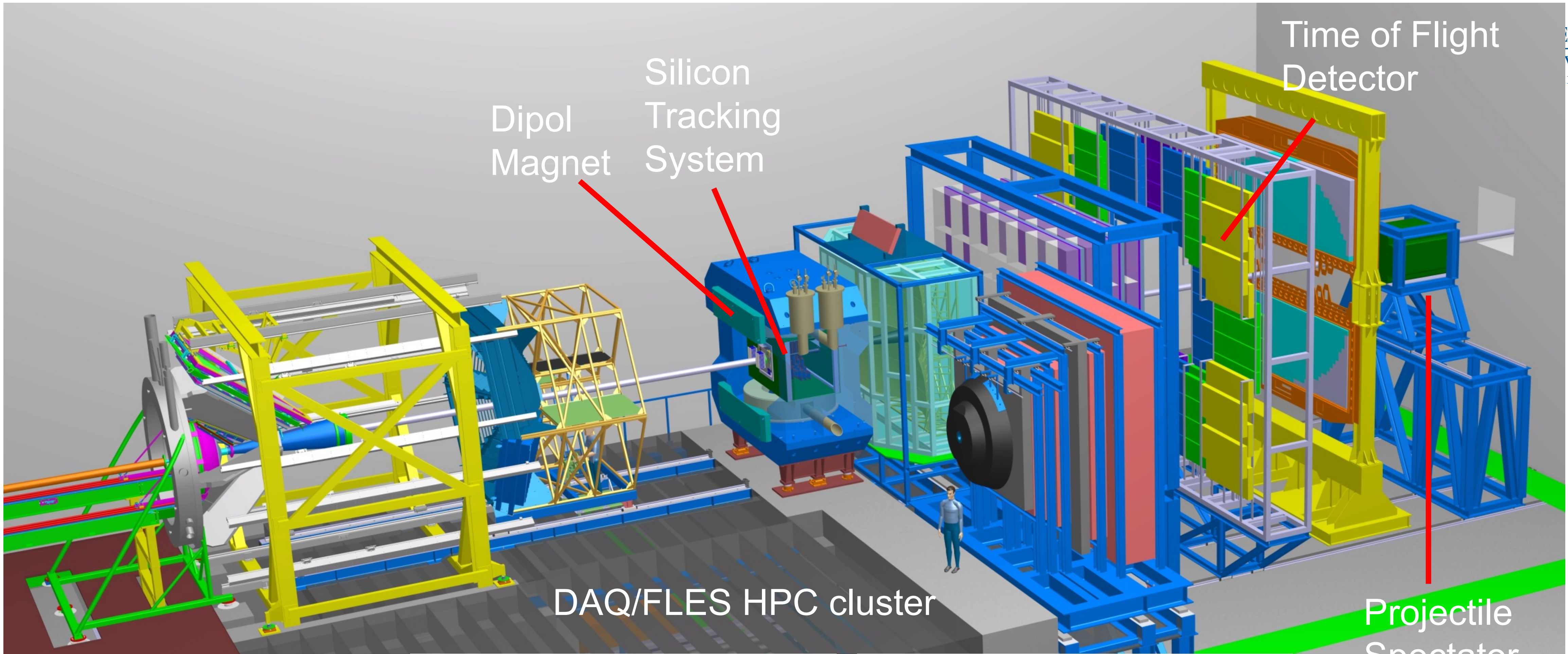
- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50\ \mu m$)
- identification of leptons and hadrons
- fast and radiation hard detectors and FEE
- free-streaming readout electronics
- high speed data acquisition and online event selection
- 4-D event reconstruction



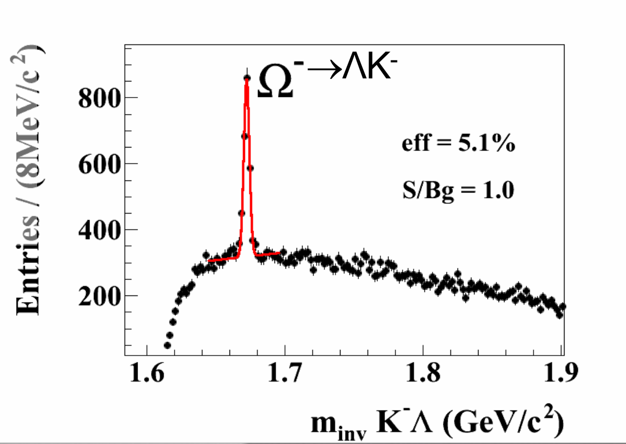
Experimental requirements

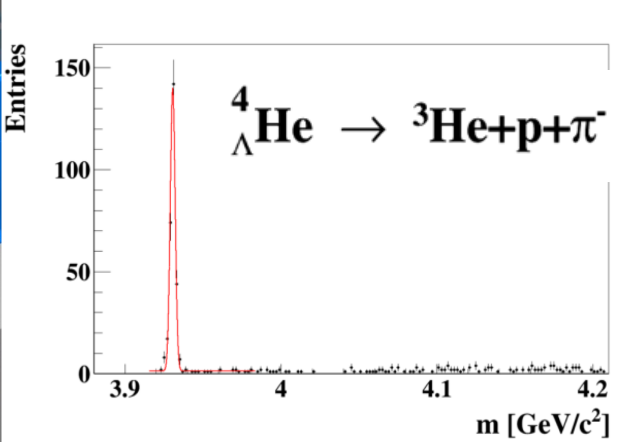


Hadron measurements

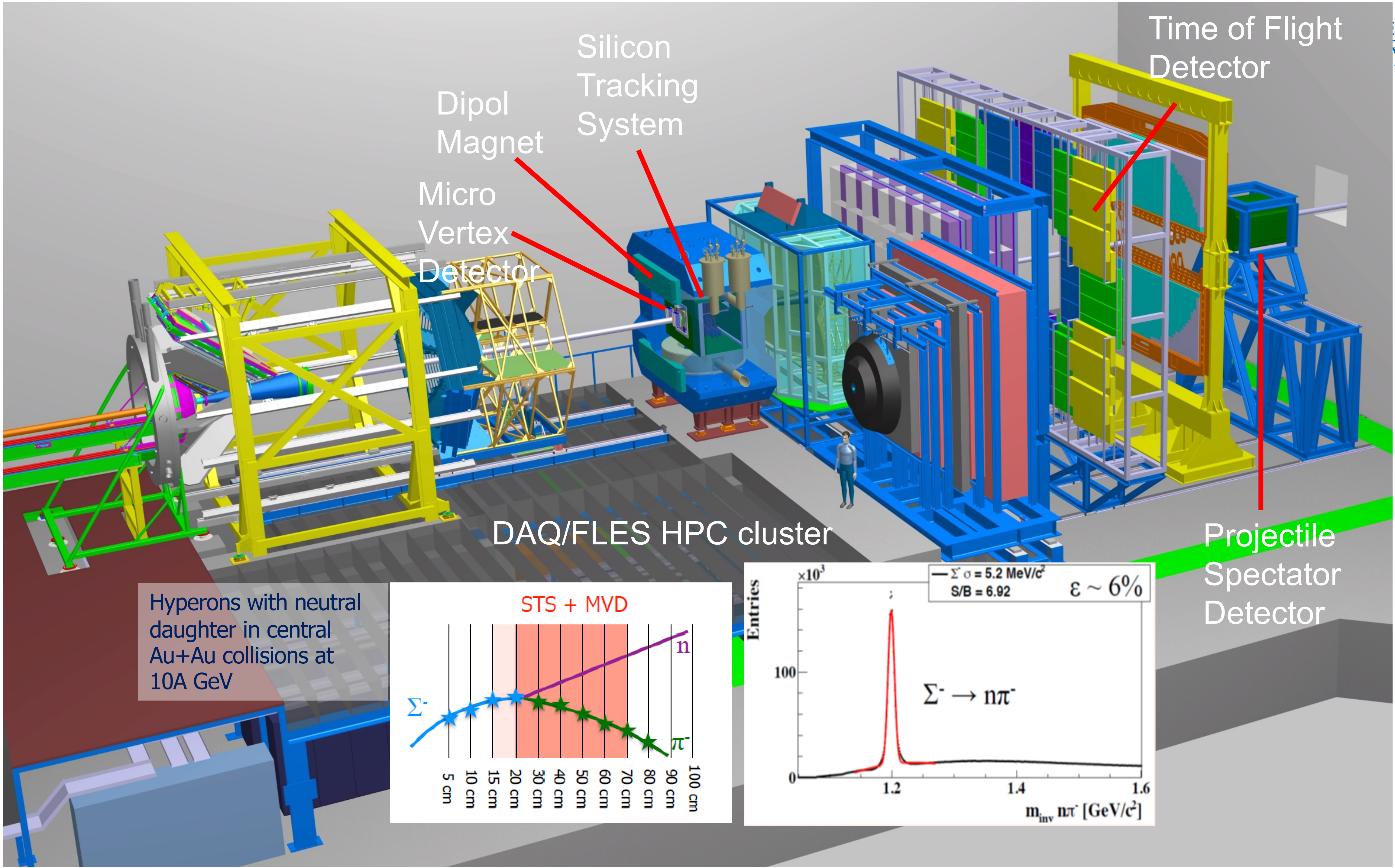


Hyperons and hypernuclei in central Au+Au collisions at 10A GeV

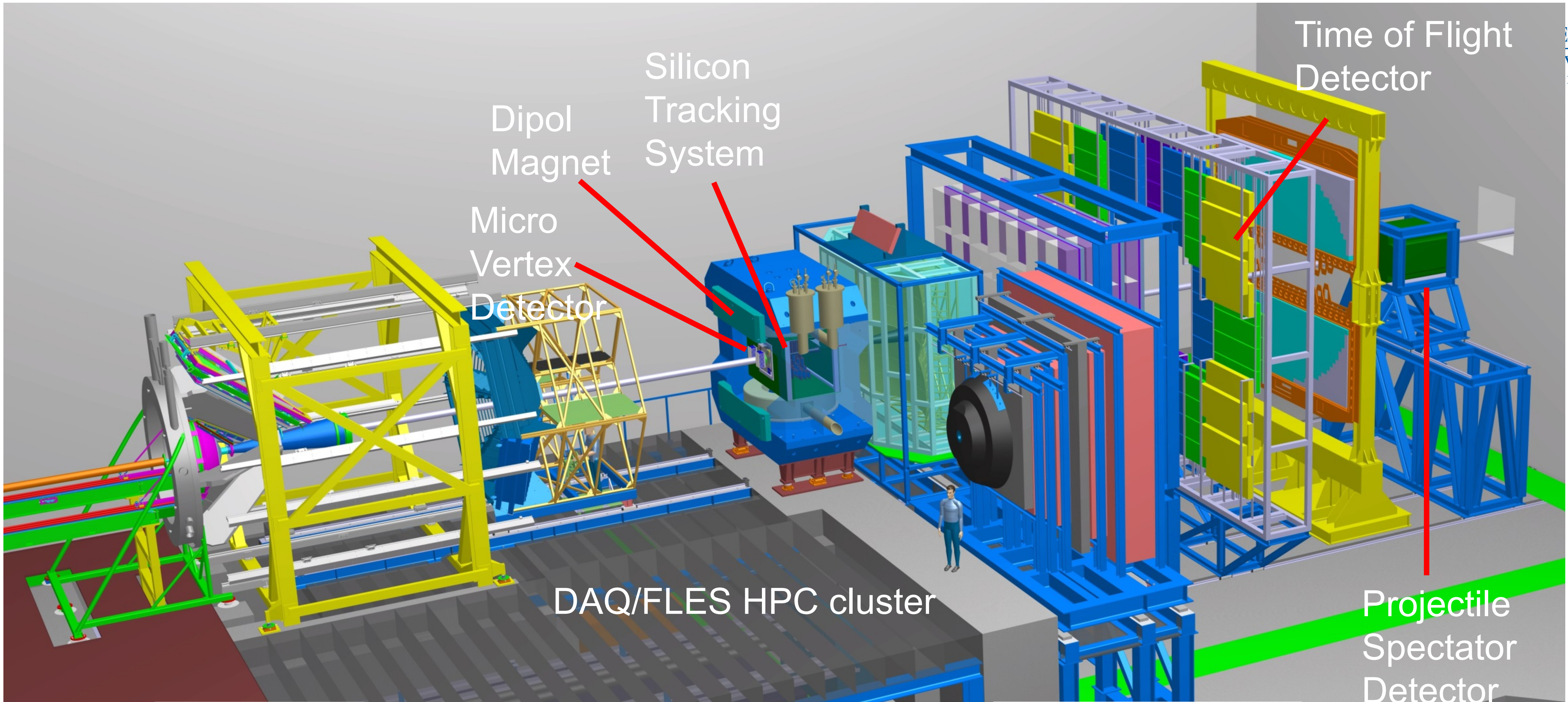




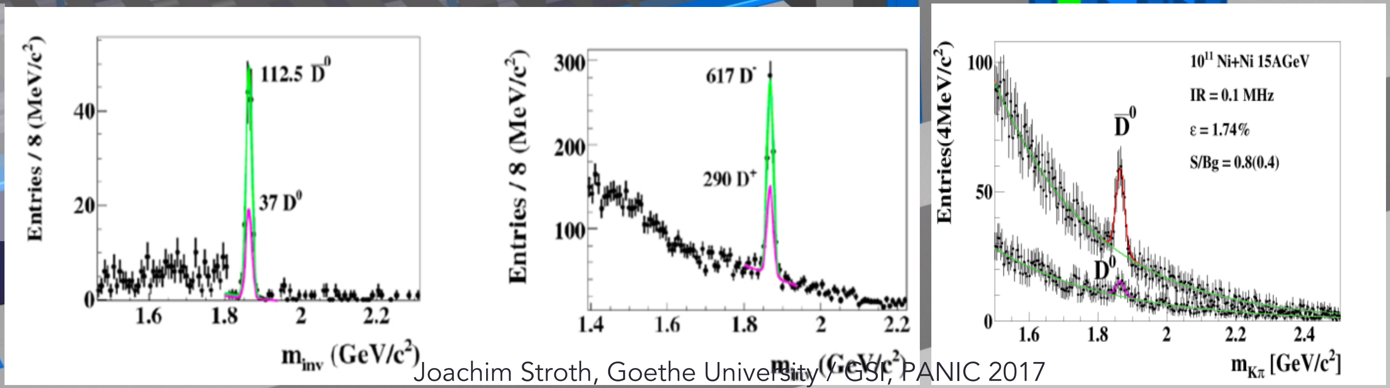
Hadron measurements



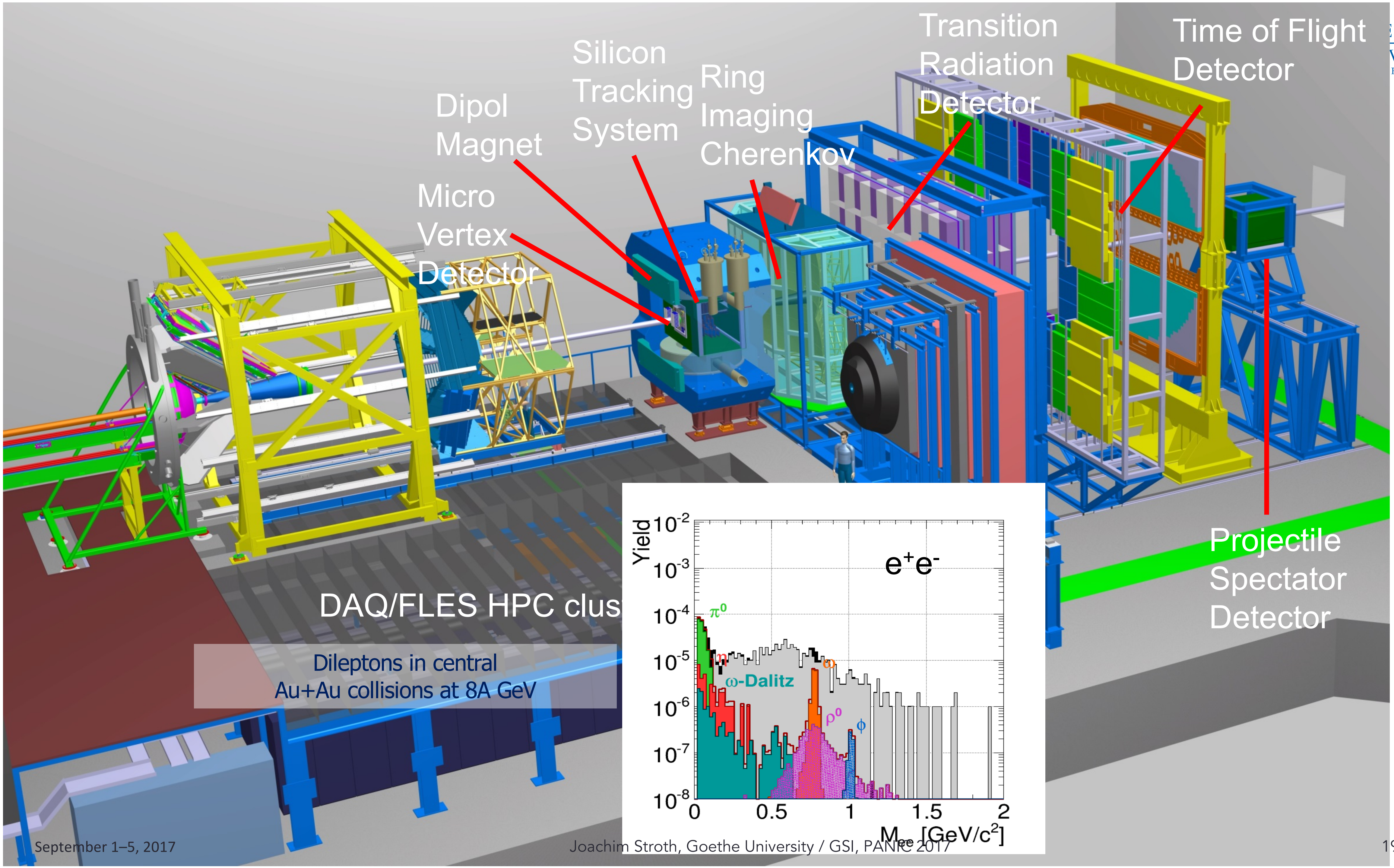
Open charm measurements



Open Charm in
p+A
30 GeV and
Ni+Ni
15A GeV

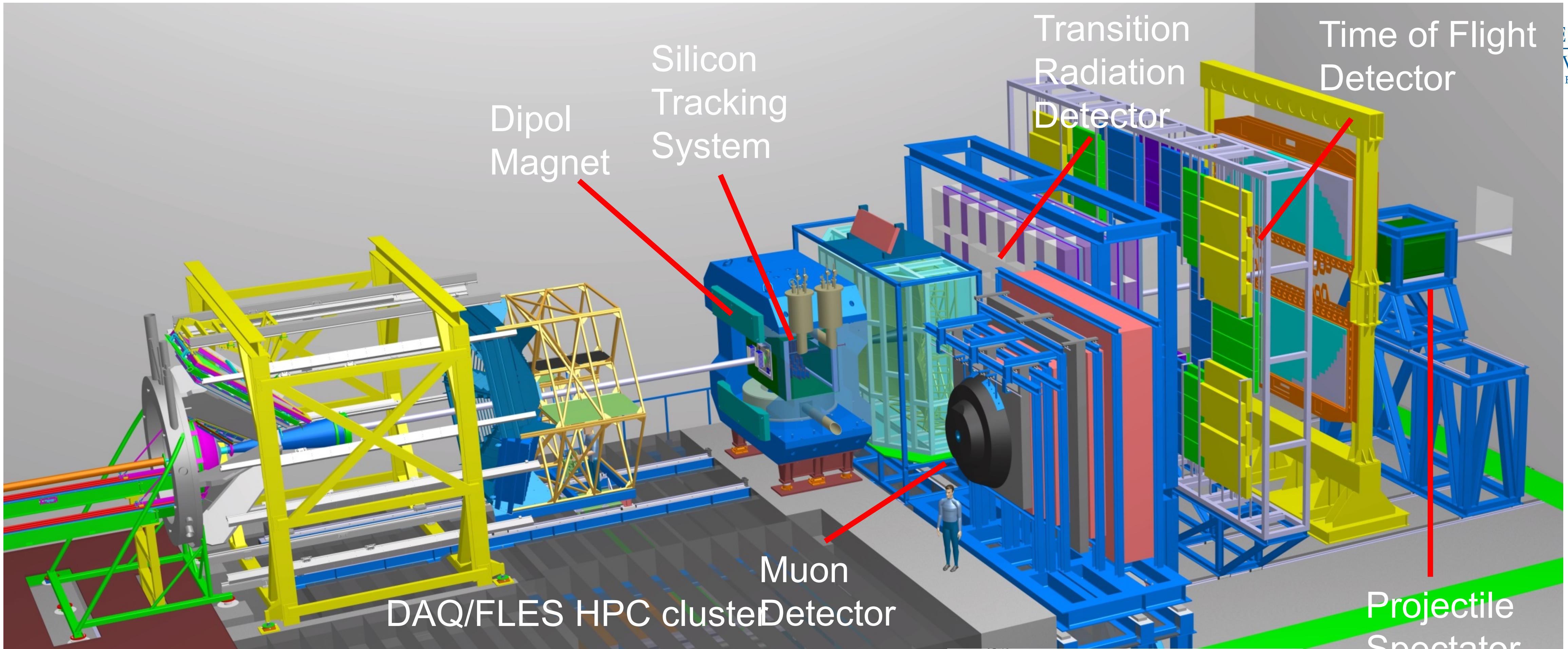


Di-electron measurements

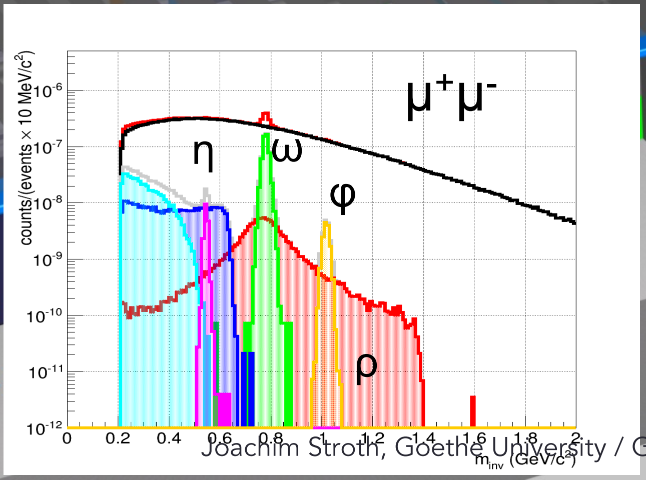


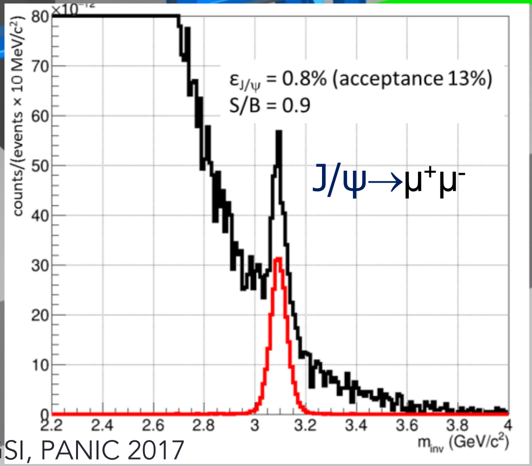
Dileptons in central Au+Au collisions at 8A GeV

Di-muon measurements



Di-muons in central Au+Au collisions at 8A GeV and 10A GeV (J/ψ)





R&D

CBM Technical Developments

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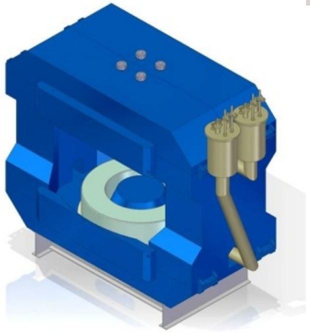
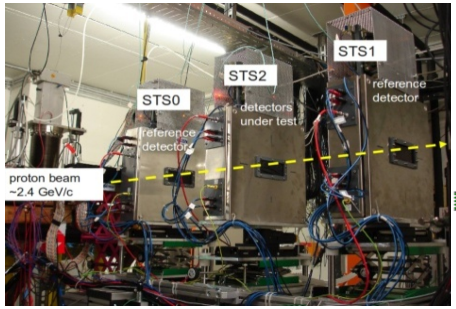
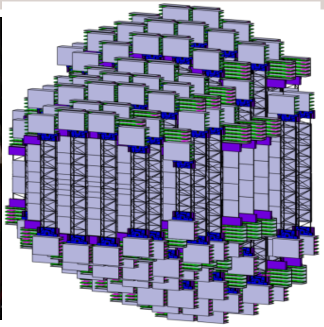
SC Magnet: JINR Dubna



Micro-Vertex Detector: Frankfurt, Strasbourg

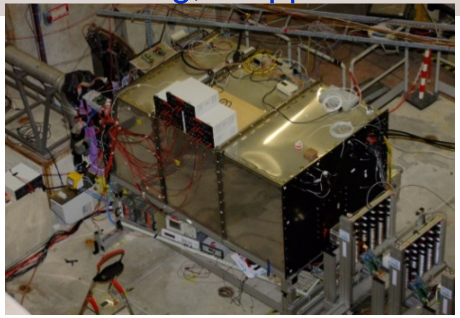
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



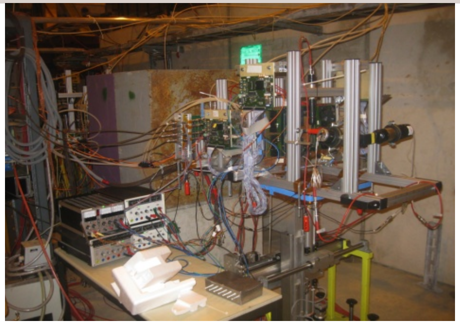


MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan, Zagreb

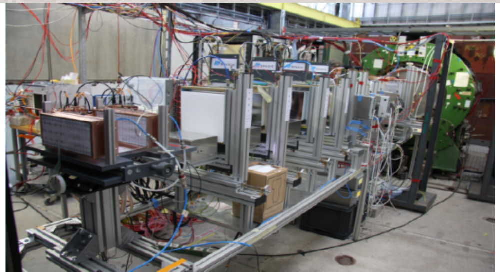
RICH Detector: Darmstadt, Giessen, St. Petersburg, Wuppertal



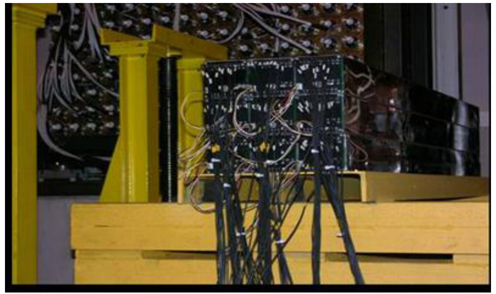
Muon detector: Kolkata + 13 Indian Inst., Gatchina, Dubna



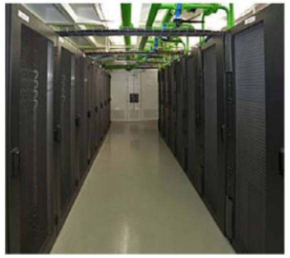
Transition Radiation Detector: Bucharest, Frankfurt, Heidelberg, Münster



Forward calorimeter: Moscow, Prague, Rez



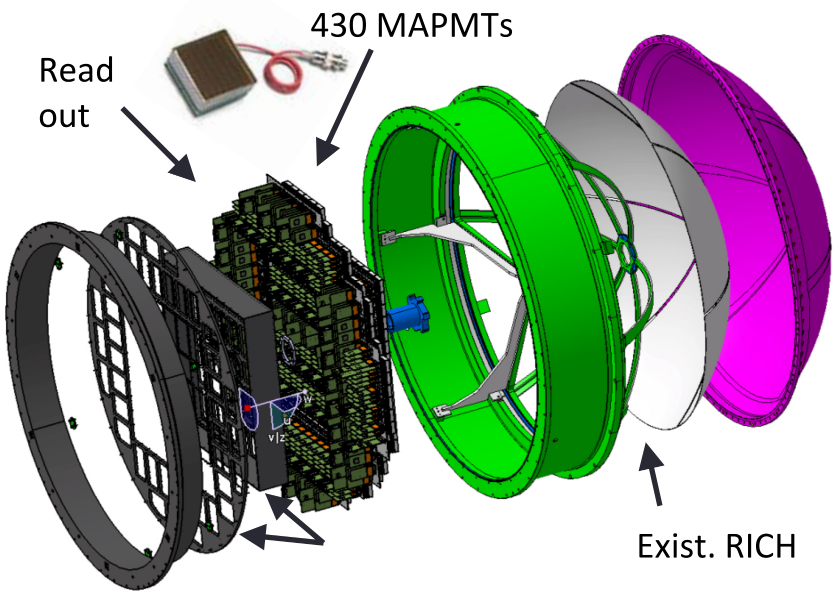
DAQ and online event selection: Darmstadt, Frankfurt, Kharagpur, Warsaw

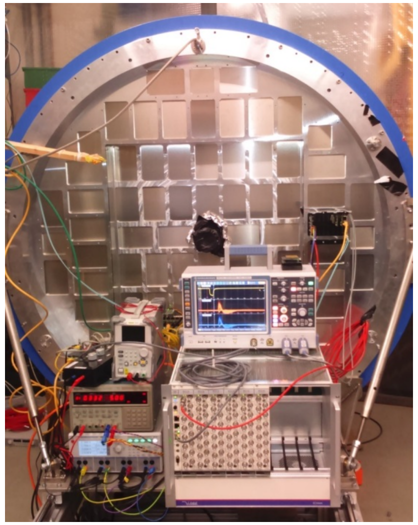


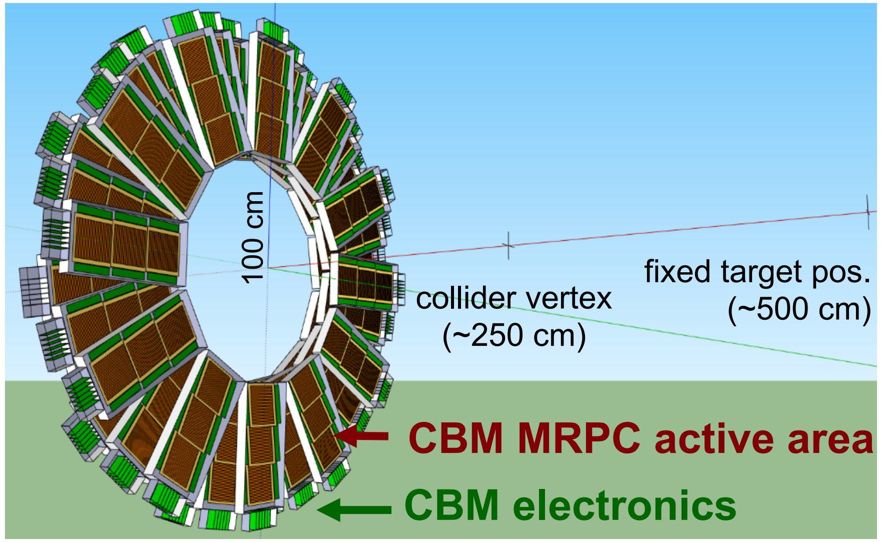
CBM FAIR Phase 0 experiments

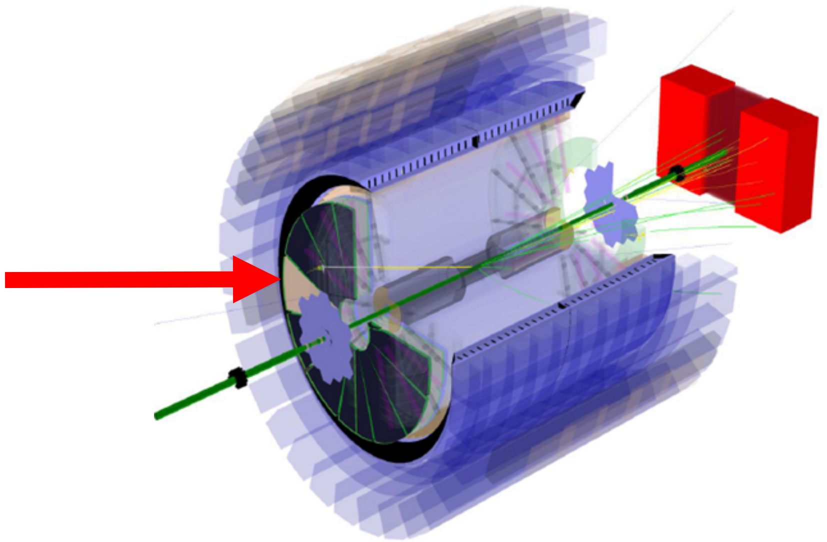
1. Install, commission and use 430 out of 1100
   - CBM RICH multi-anode photo-multipliers (MAPMT) in HADES RICH photon detector

2. Install, commission and use
   - 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)



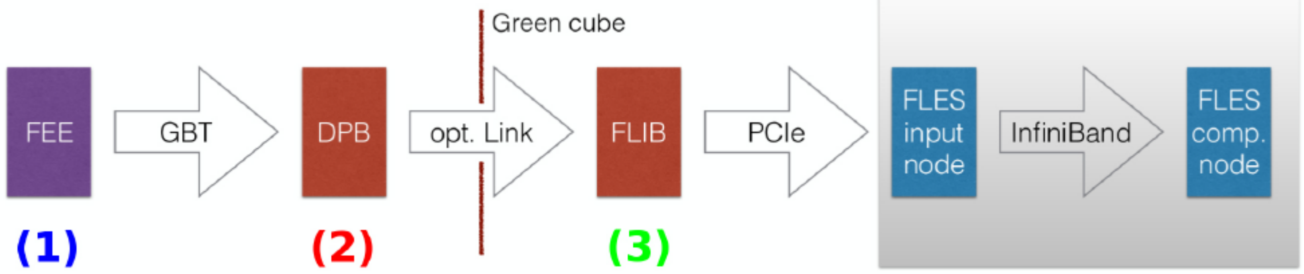


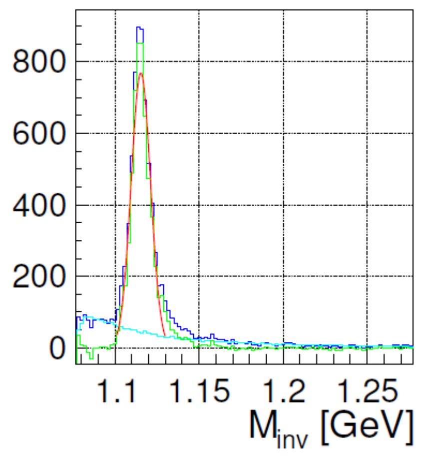




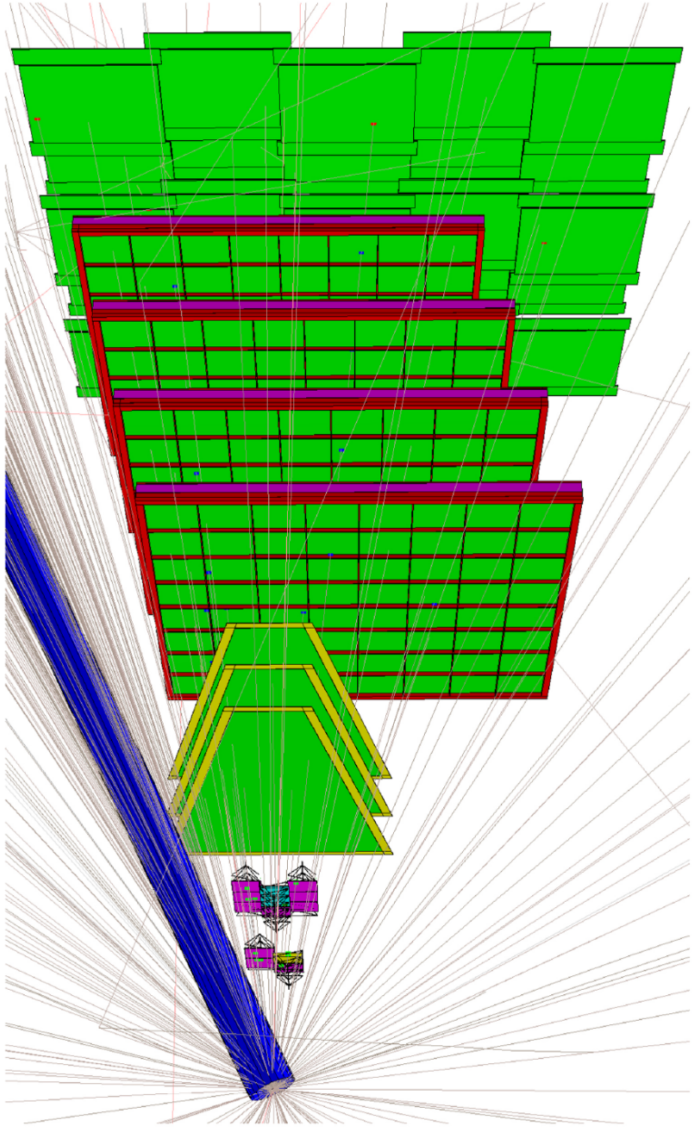
mCBM

- Pre-series detector modules will be arranged to track charged particles v
- Test full read-out chain with free streaming front-ends
- Operate starting from 2019 on at SIS18
- On-line select Lambda decays by track topology only





- Reconstruction performance based on 10^8 simulated UrQMD collisions of Ni-Ni at 1,93 AGeV
- Technical goal: reach respective statistics in less than a minute data taking

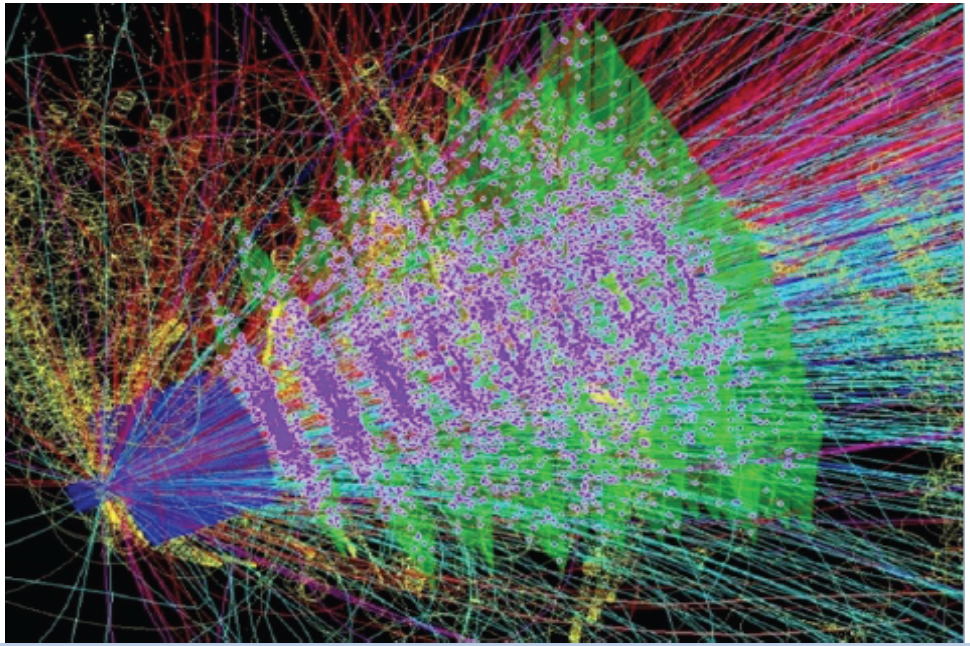


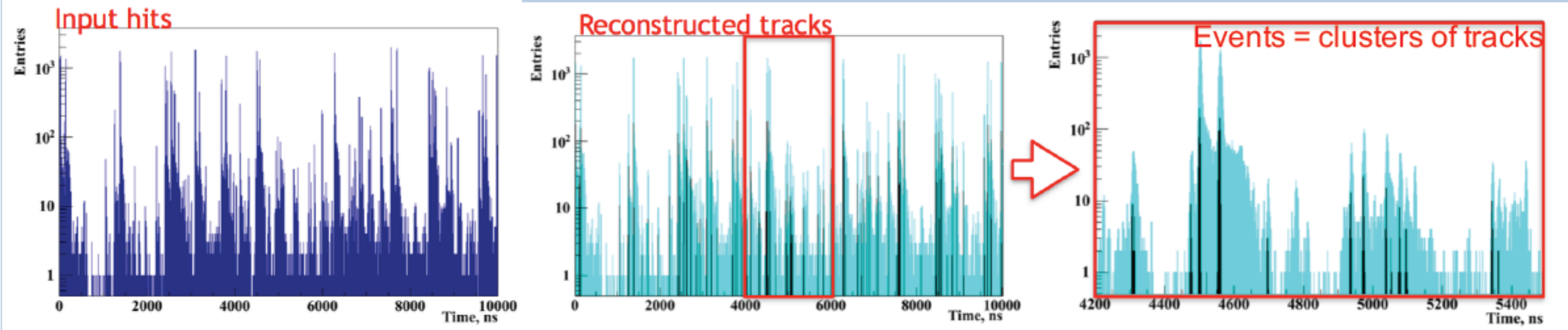
PERFORMANCE EXAMPLES

CBM readout and online systems

Novel readout system

- no hardware trigger on events, free streaming triggerless data
- detector hits with time stamps,
- full online 4-D track and event reconstruction
- analysis of 10 MHz event rate implemented, only very moderate losses in efficiency





Strange particle production: Σ^+ & Σ^-

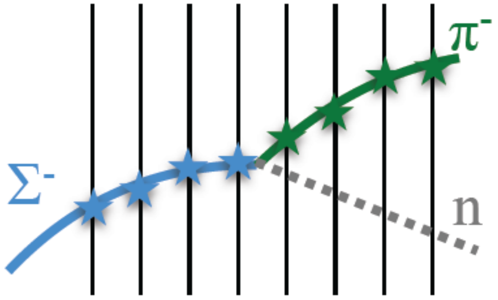
NEW: Identification of Σ^+ and Σ^- via their decay topology

$\Sigma^+ \to p\pi^0$	$\bar{\Sigma}^+ \to \bar{p}\pi^0$	BR = 51.6%
$\Sigma^+ \to n\pi^+$	$\bar{\Sigma}^+ \to \bar{n}\pi^-$	BR = 48.3%
$\Sigma^- \to n\pi^-$	$\bar{\Sigma}^- \to \bar{n}\pi^-$	BR = 99.8%

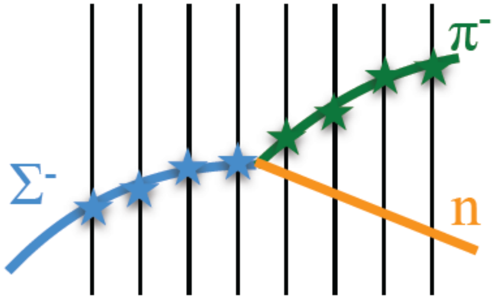
Method:

- Find all primary and secondary tracks, use TOF PID for secondary track
- Search whether two would fit together with a kink
- From momentum conservation get momentum of neutral particle
- Assume e.g. Σ^- decay, calculate (missing) mass of neutral particle
- Select neutron candidates, recalculate Σ mass

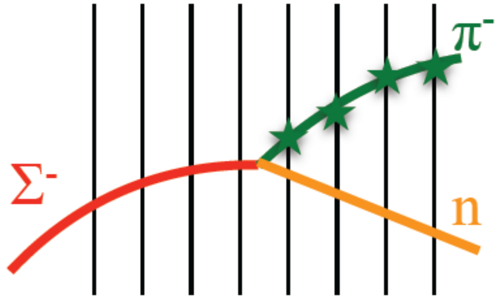
Find tracks of Σ and its charged daughter in STS and MVD



Reconstruct a neutral daughter from the mother and the charged daughter



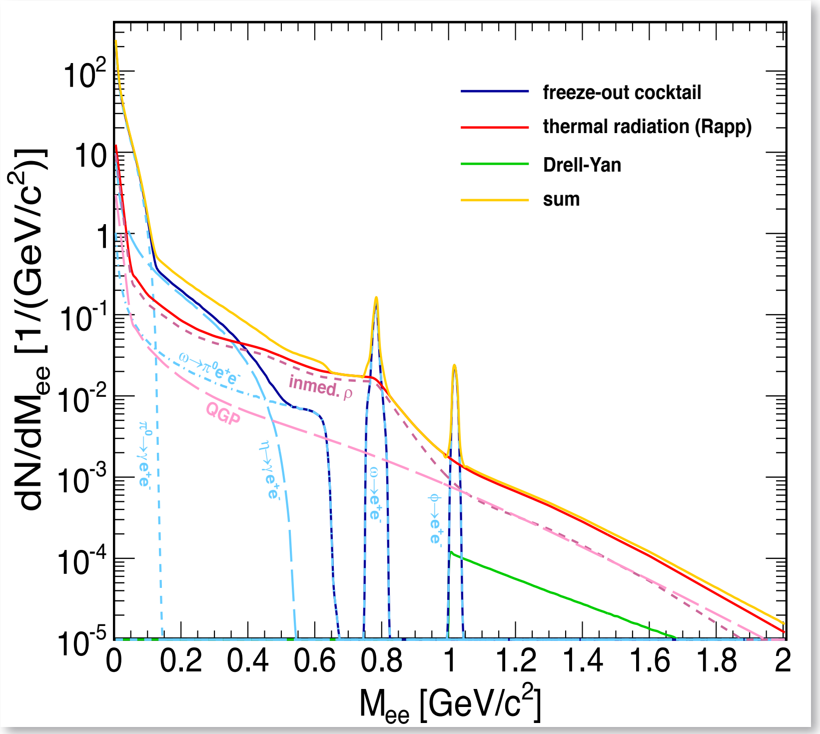
Reconstruct Σ mass spectrum from the charged and obtained neutral daughters



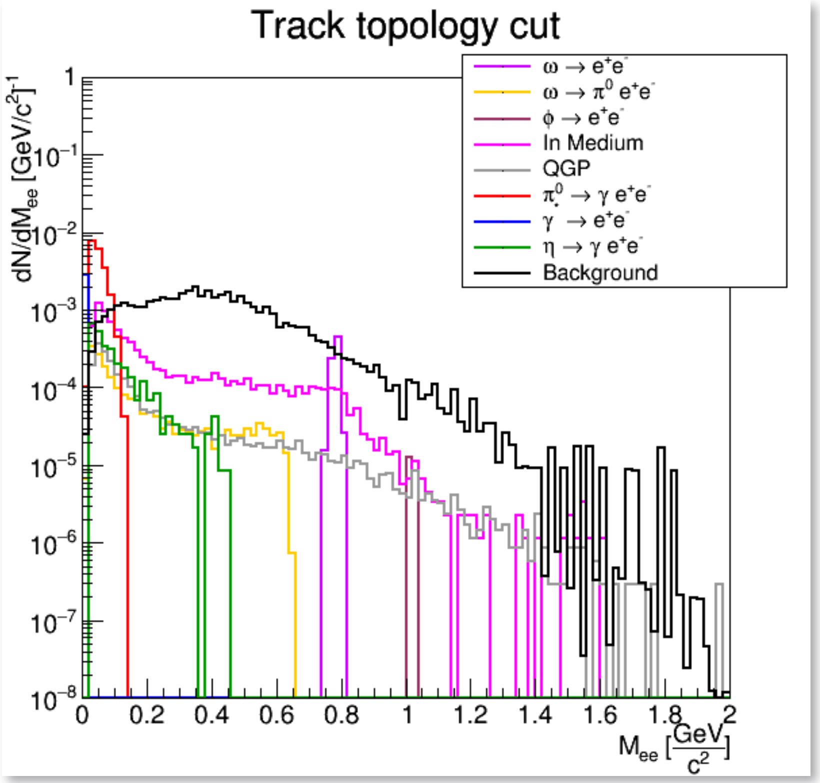
Di-electron measurements with CBM

Au-Au collisions at 8 *A* GeV, full Monte-Carlo.

Input cocktail



Reconstructed in acceptance



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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:
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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

The CBM Collaboration

60 institutions, 530 members

Summary

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.

Status of experiment preparation:

- Prototype detector performances fulfill CBM requirements.
- 7 TDRs approved, 4 TDRs in preparation.

FAIR Phase 0:

- HADES with CBM RICH photon detector, use CBM detectors at STAR/BNL, BM@N/JINR, NA61/SPS.
- mCBM@SIS18 including DAQ and FLES for full system test