THE PHYSICS OF COMPRESSED BARYONIC MATTER
&
HOW THE CBM COLLABORATION WANTS TO CONTRIBUTE

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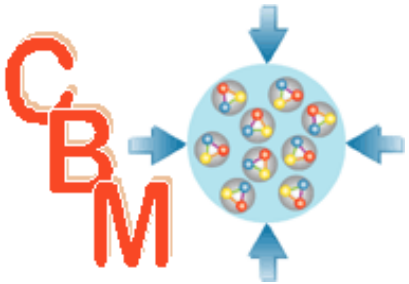
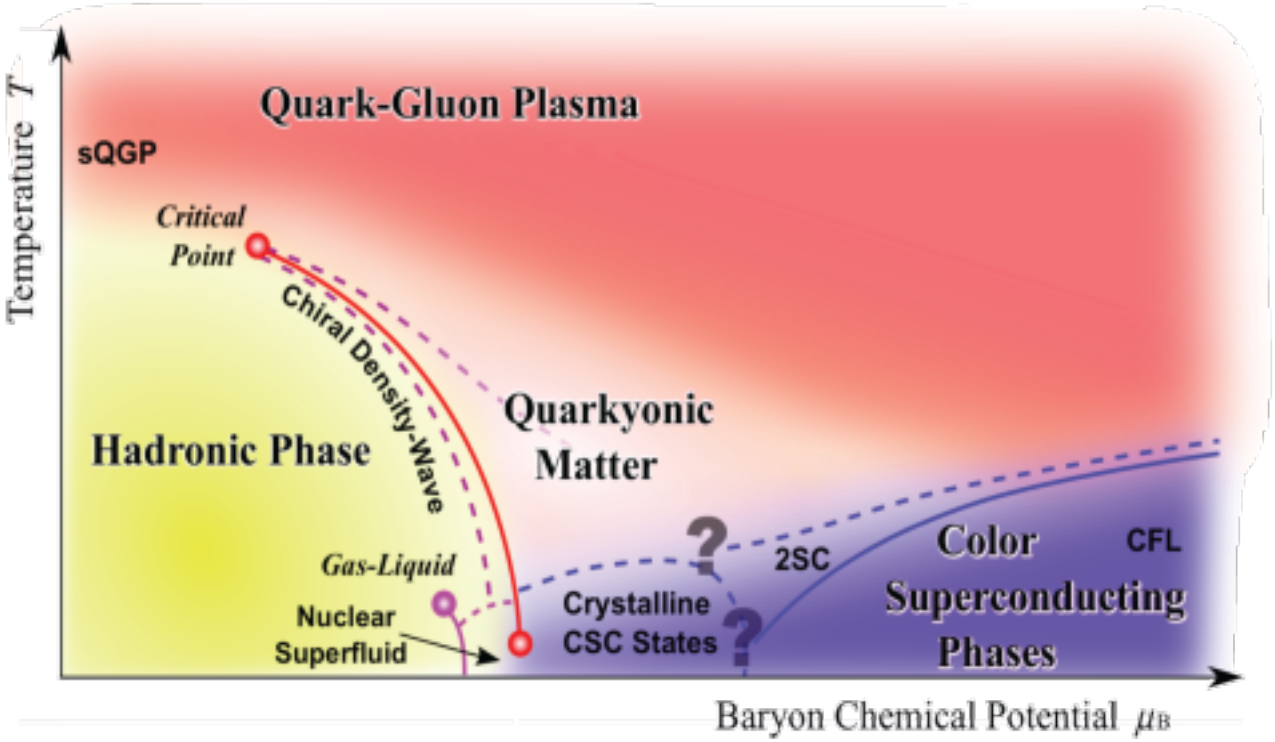
Goethe University Frankfurt / GSI
INTERNATIONAL SCHOOL OF NUCLEAR PHYSICS
ERICE, September 2016



The QCD phase diagram



Courtesy of K. Fukushima & T. Hatsuda

Open questions:

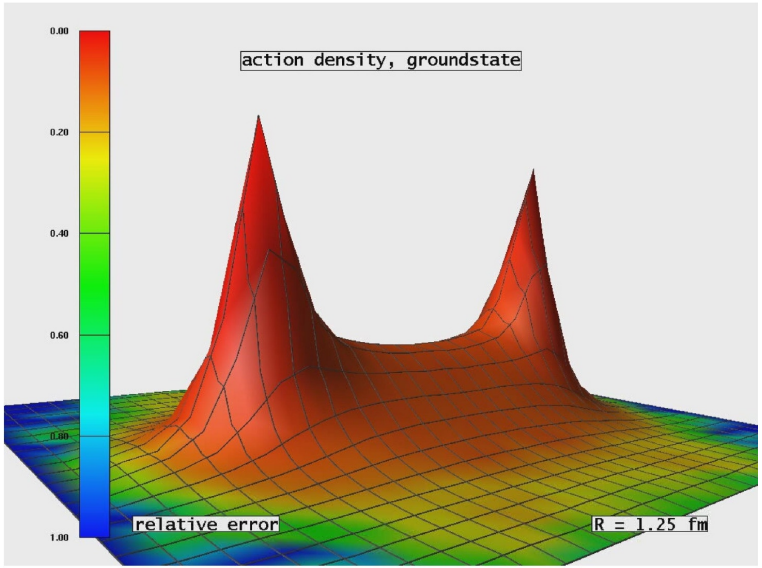
- Origin of mass?
- Nature of confinement?
- Role of condensates?

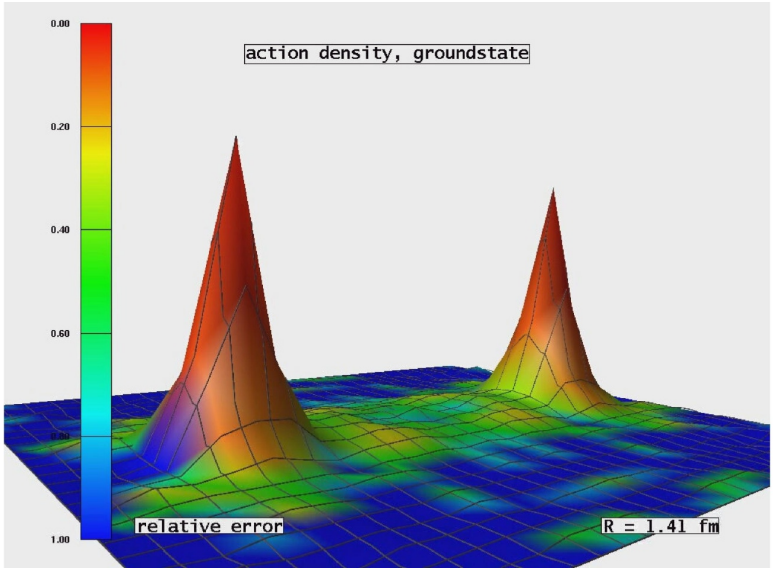
- Lattice QCD
  - sign problem
- Experiment
  - finite size and lifetime

Vacuum action around two static quarks ($q\bar{q}$)

Flux tubes present at small distance disappear due to light quark pair excitation.

DCSB provides low-lying colorless states (pion cloud). In-between is true vacuum (no condensates). *arXiv:hep-lat/0510051*





Goldstone boson: Attraction between two dynamically dressed quarks approximately cancels the mass of the (gluon-dressed) quarks.

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

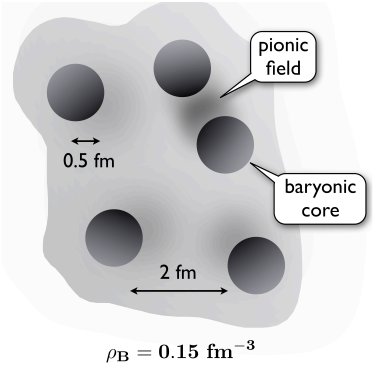
Chiral symmetry restoration

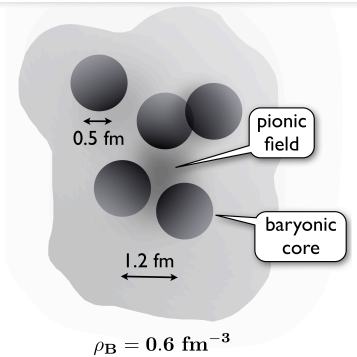
- in-medium a_1/ρ spectral functions. Trend seen like conjectured by Rapp/Hohler.

  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.

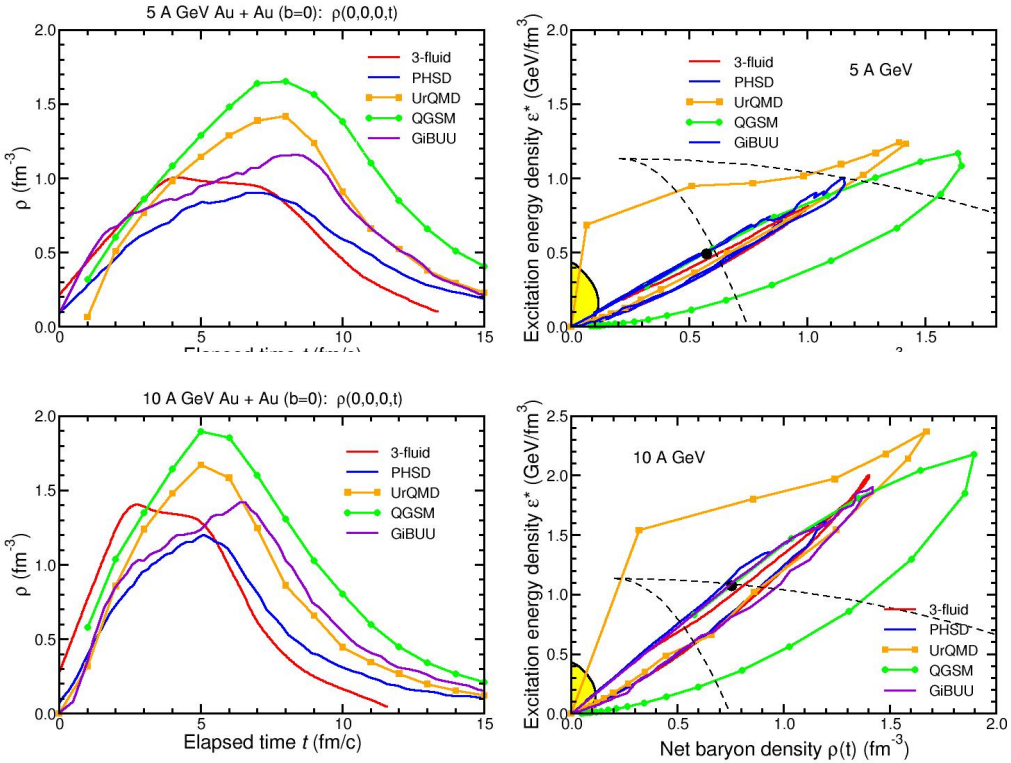
  J.W. Holt, M. Rho, W. Weise arXiv1411.6681

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.
- Substantial heating of the pion cloud.

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

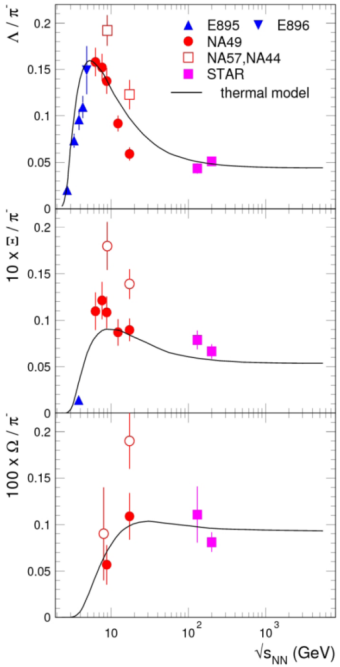
- High-precision invariant mass distributions low- and intermediate mass range

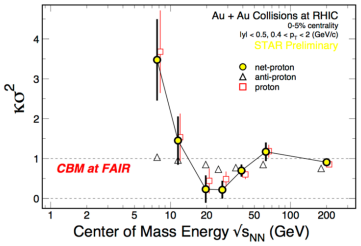
Strange matter

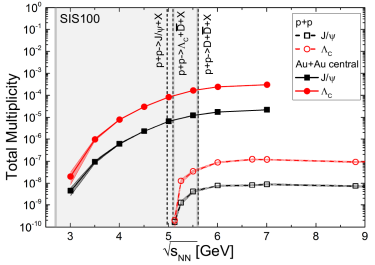
- (Double-) lambda hypernuclei
- Meta-stable objects (e.g. strange dibaryons)

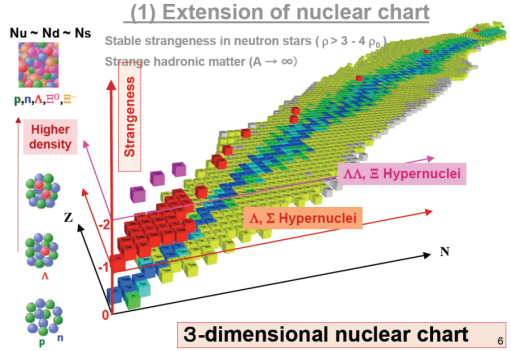
Charm production (and propagation) at threshold

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



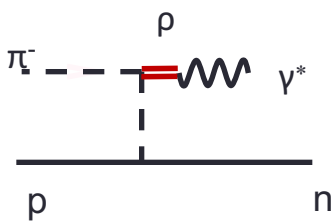


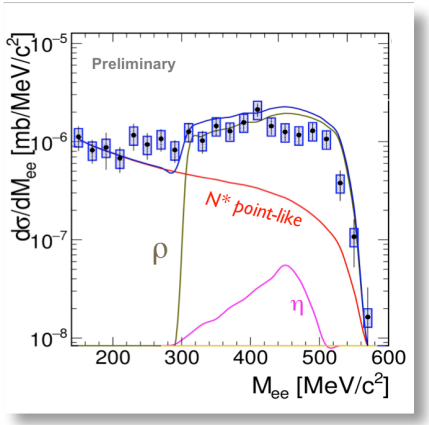




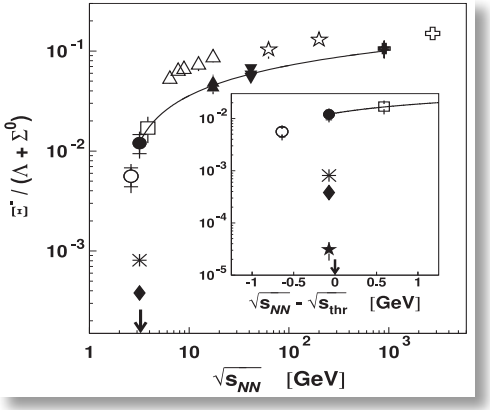
HADES contribution to the energy scan (+FAIR Phase 0)

VDM in radiative baryon-resonance decays

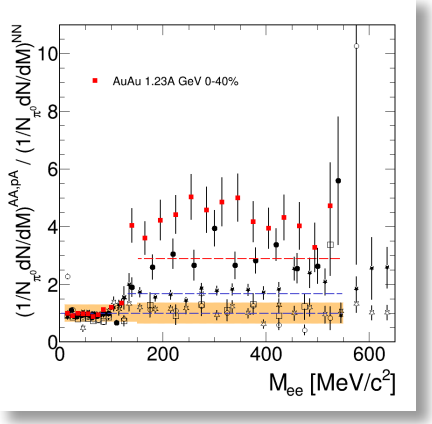




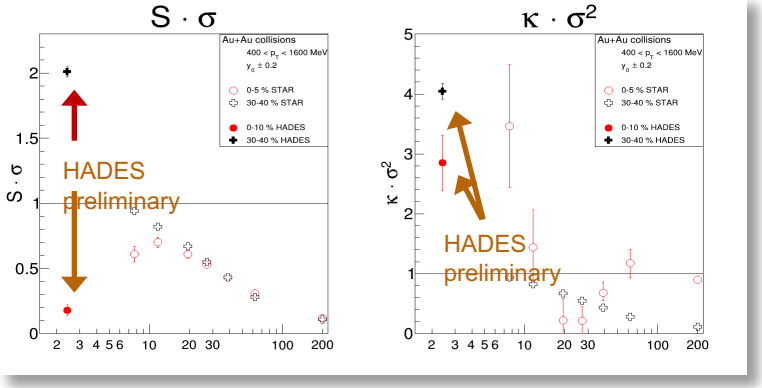
Ξ⁻ multiplicity above SHM prediction



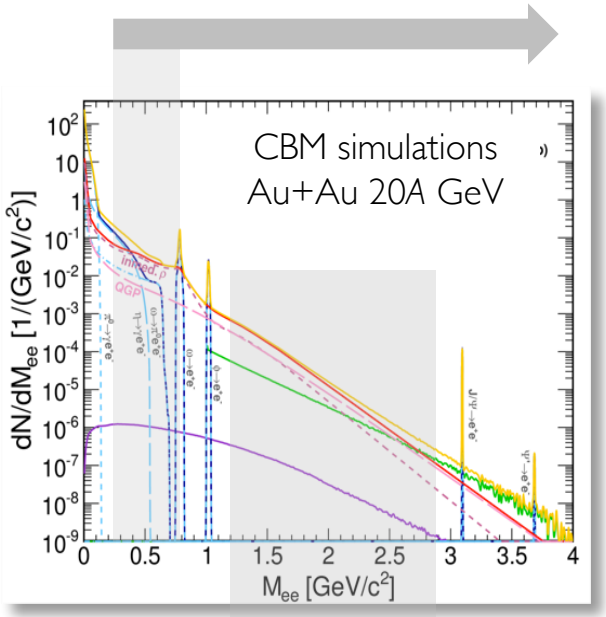
Regeneration of resonances

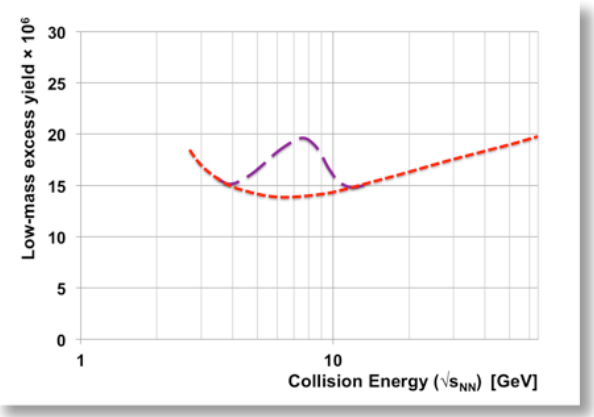


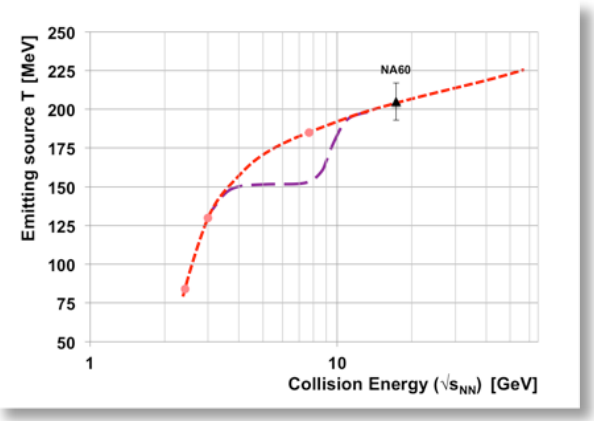
Higher moments of (net-)proton e-b-e multiplicity



Virtual photons as diagnostic tool for the phase diagram







Yield in low-mass window tracks fireball lifetime:

- Measure excitation function of ρ spectral function.
- Search for anomalous fireball lifetime around phase transition & CP.

Intermediate mass slope:

- Measure T_{slope} (note, $T_{slope} < T_{initia}$) "caloric curve"
- Plateau around onset of deconfinement?
  (see e.g. M. D'Agostino et al. NPA 749 (2005) 5533)

– – – : If nature was kind!

The CBM strategy …

Modern CMOS camera …

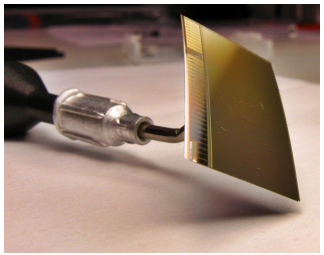
Galileo Telescope …

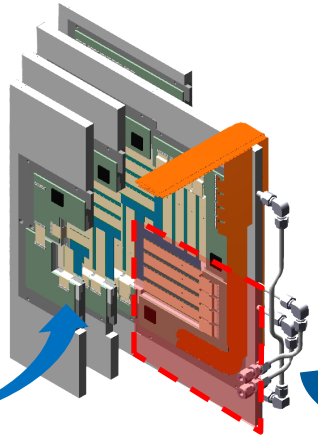
… and his drawing of the moon.

… and a picture you can take on any clear night's sky.

…. [CMOS in CBM] ….

- CBM micro vertex detector (MVD) will use MAPS.
- More than 10 years of joint R&D activity (ILC, STAR, ALICE, CBM).

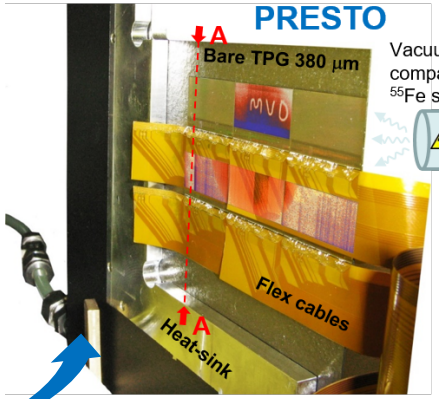


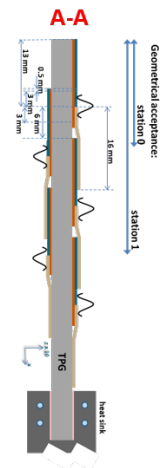


GOETHE UNIVERSITÄT FRANKFURT AM MAIN

MVD

IPHC Institut Pluridisciplinaire Hubert Curien STRASBOURG

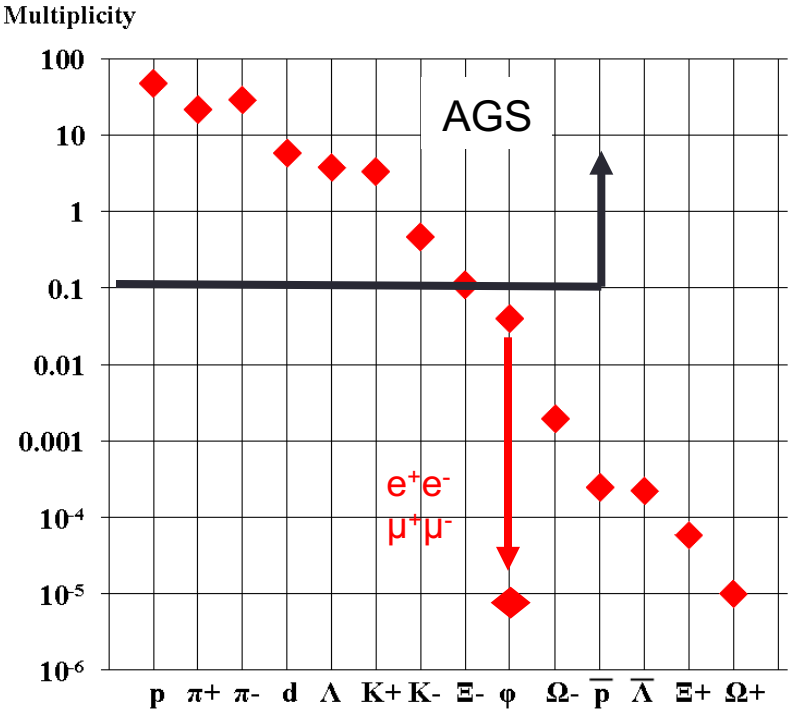


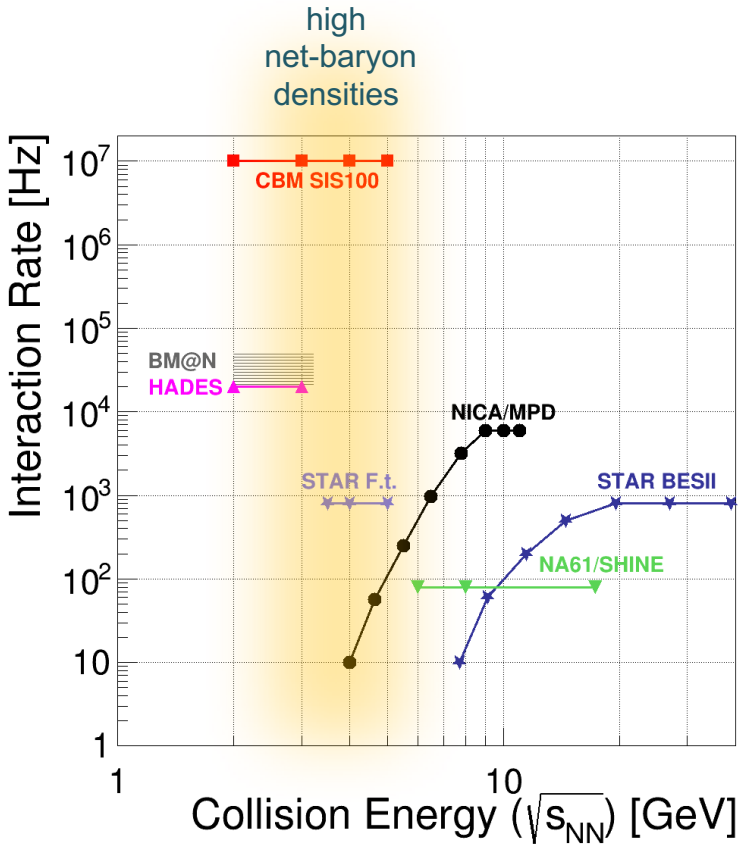


- Background suppression for di-electron measurements
- Determination of secondary vertices of open charm decays ($\tau = 10^{-12}$-10^{-13} s)
- Improved tracking for hyperon-ID

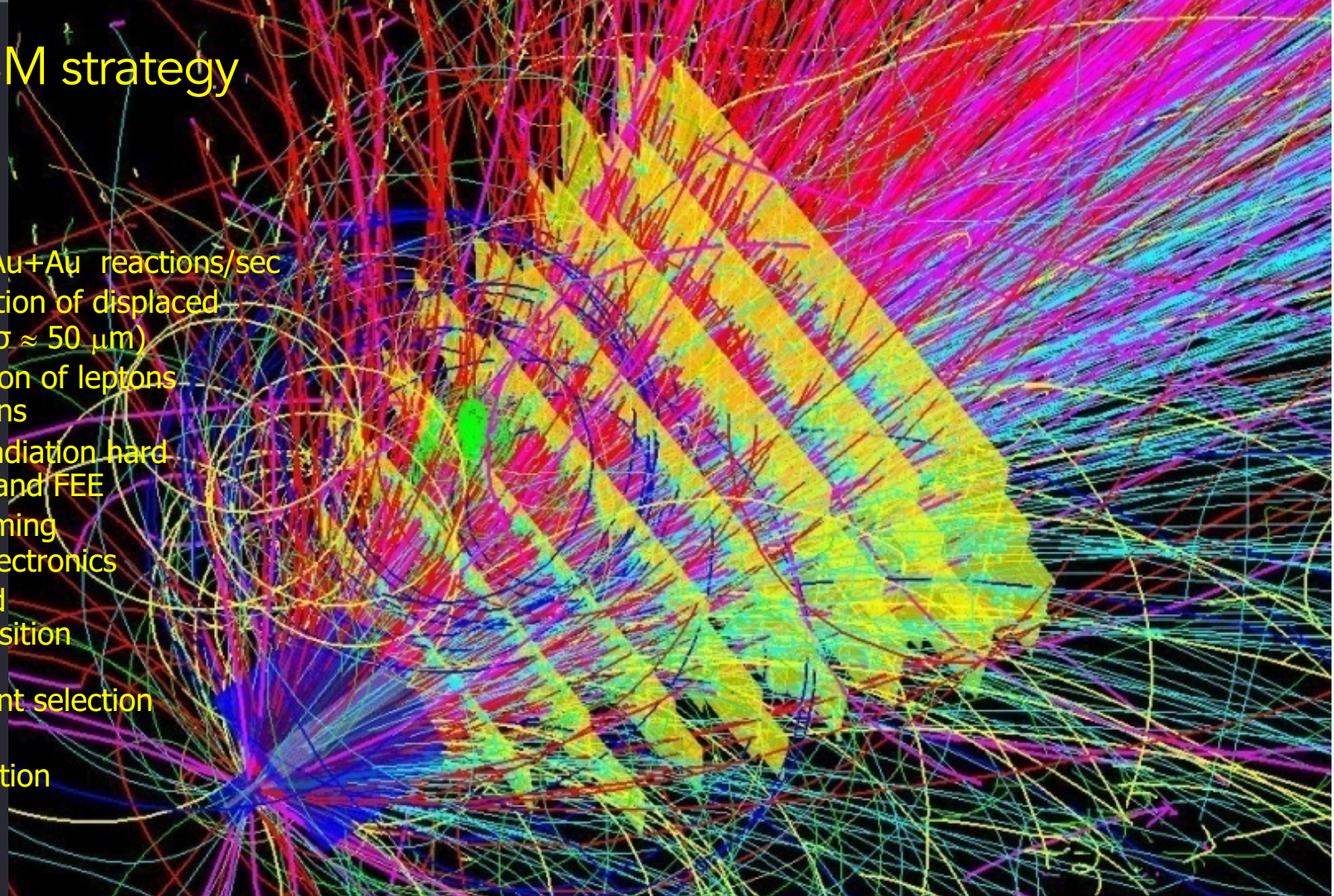
… and the challenges.

- needs extremely high rates **and precision**!



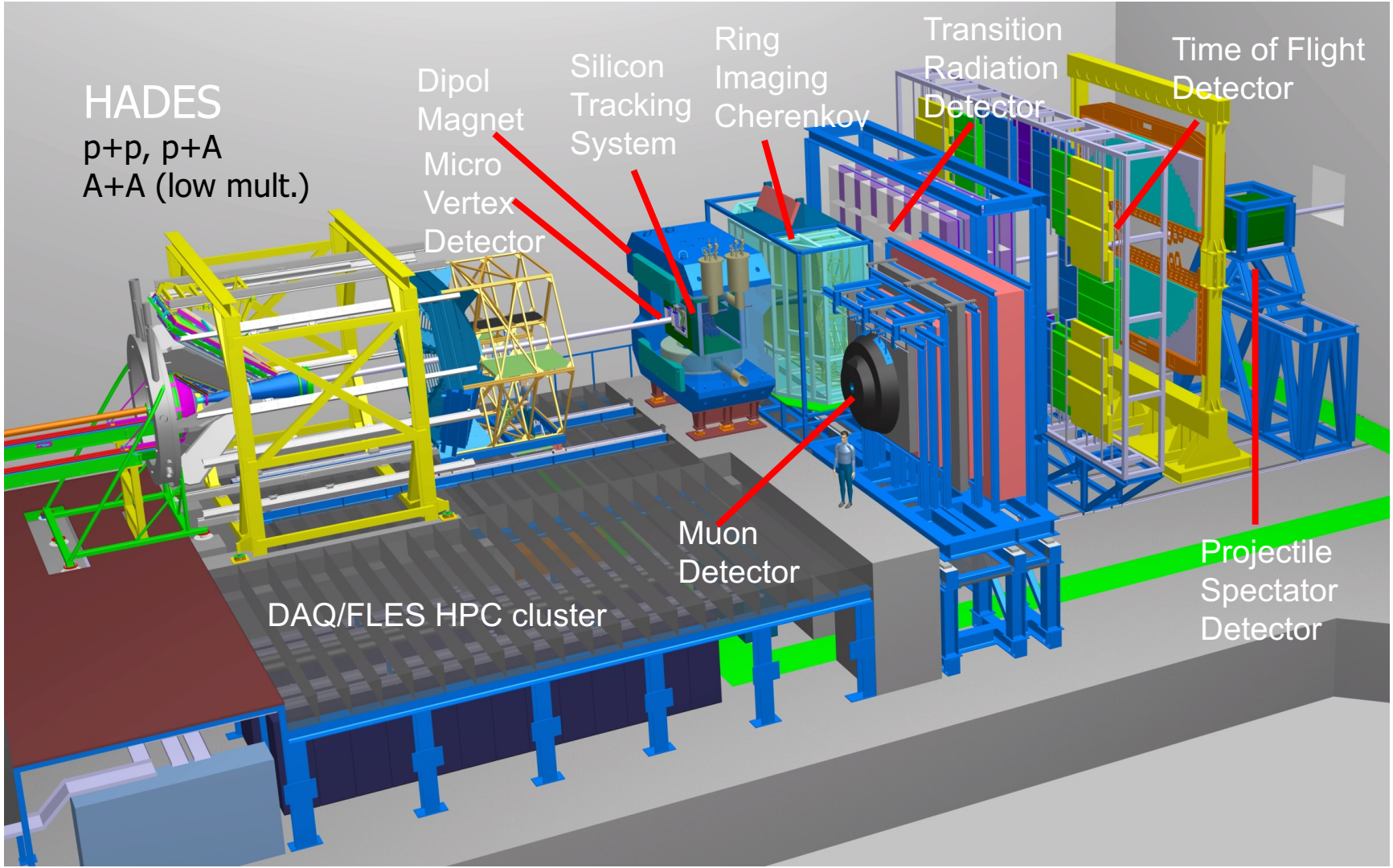


The CBM strategy

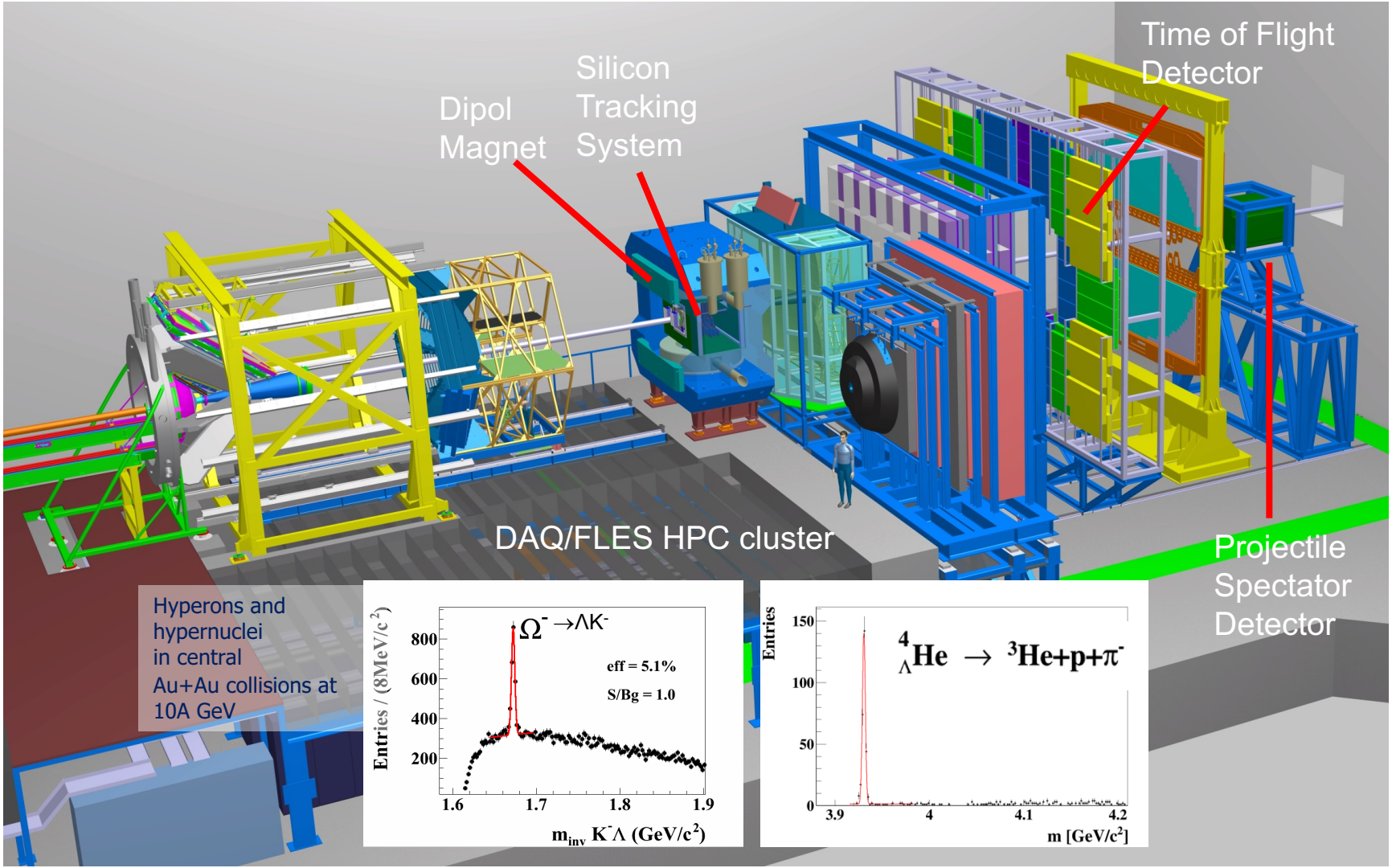


- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors and FEE
- free-streaming readout electronics
- high speed data acquisition and online event selection
- 4-D event reconstruction

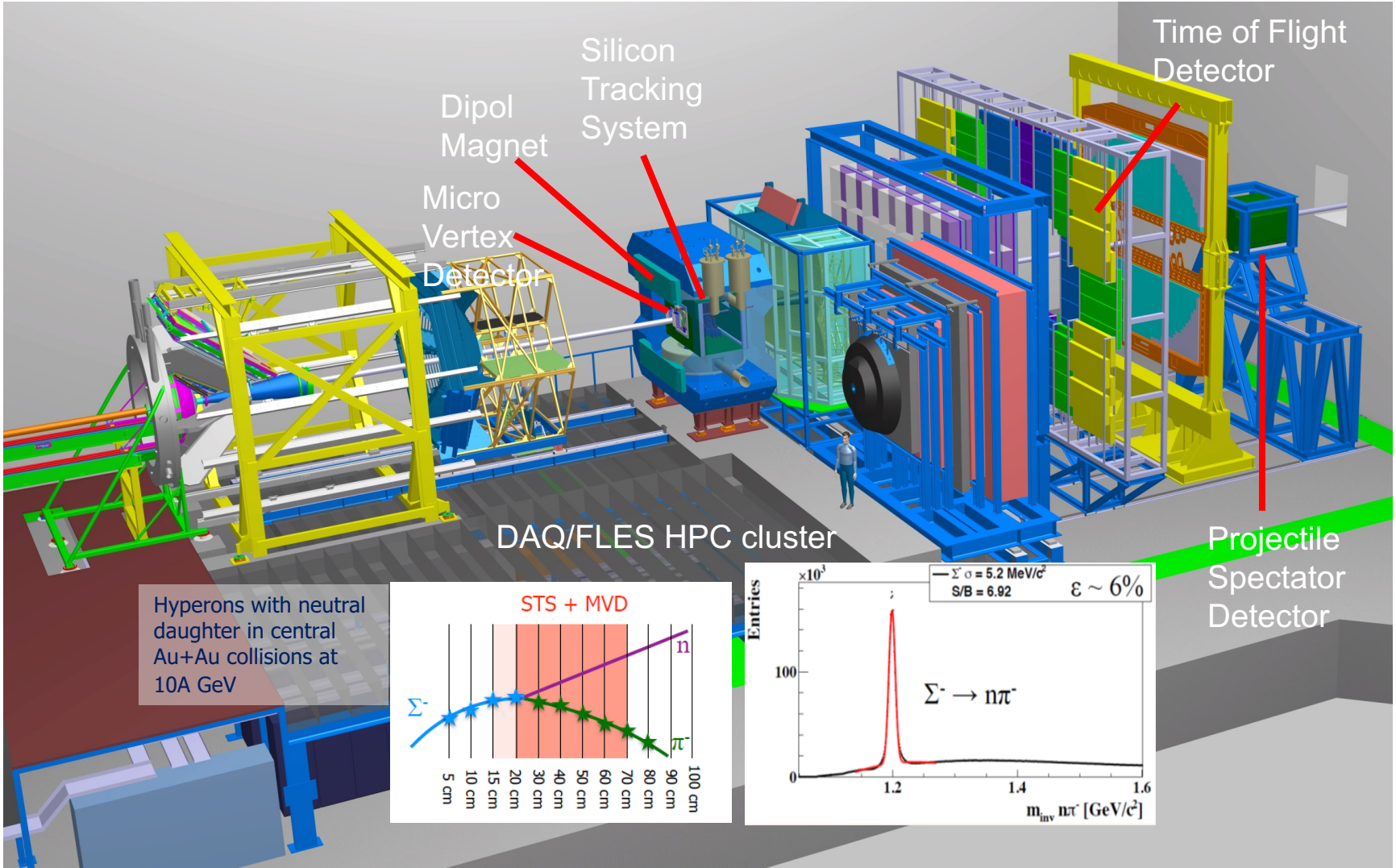
Experimental requirements



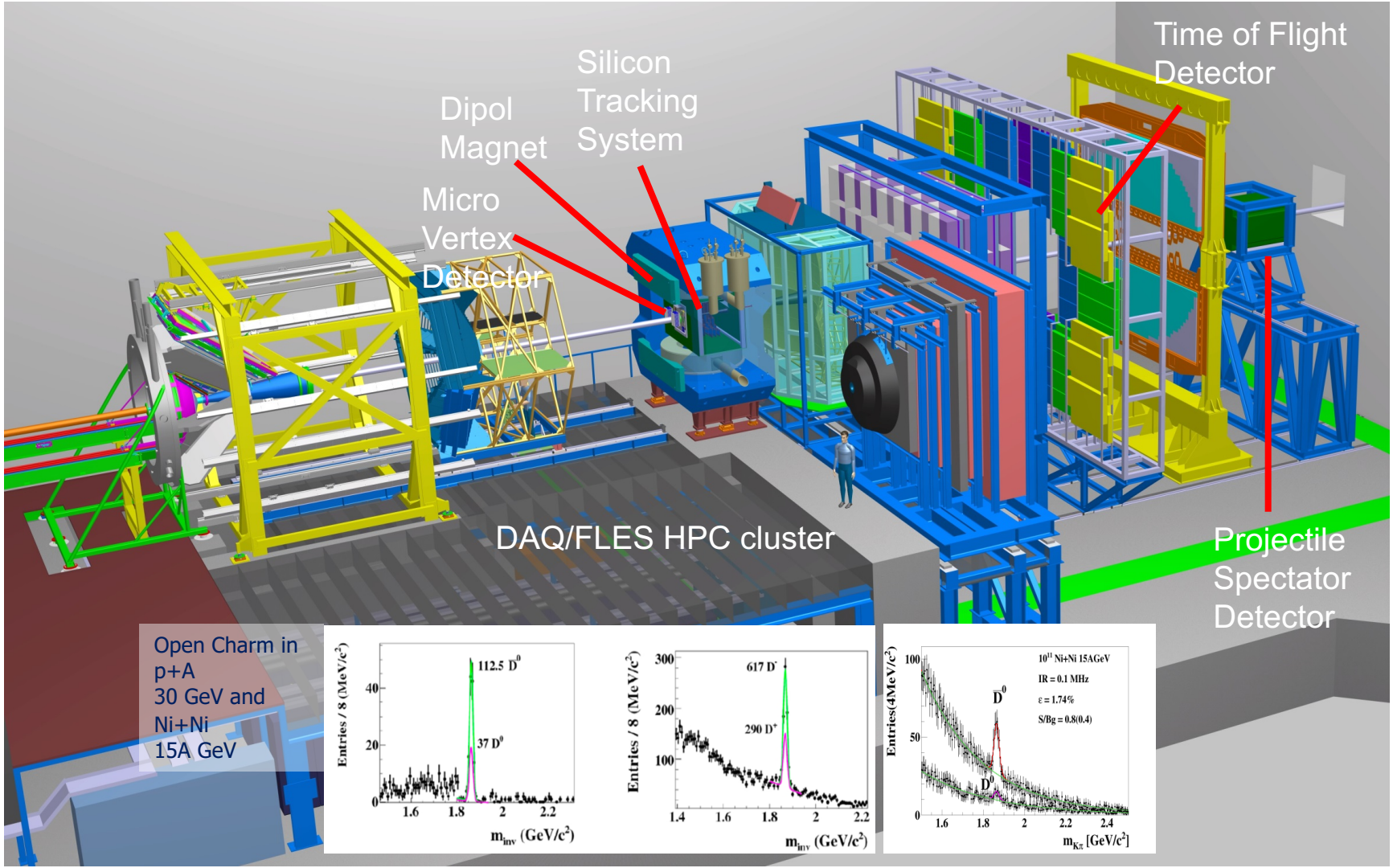
Hadron measurements



Hadron measurements

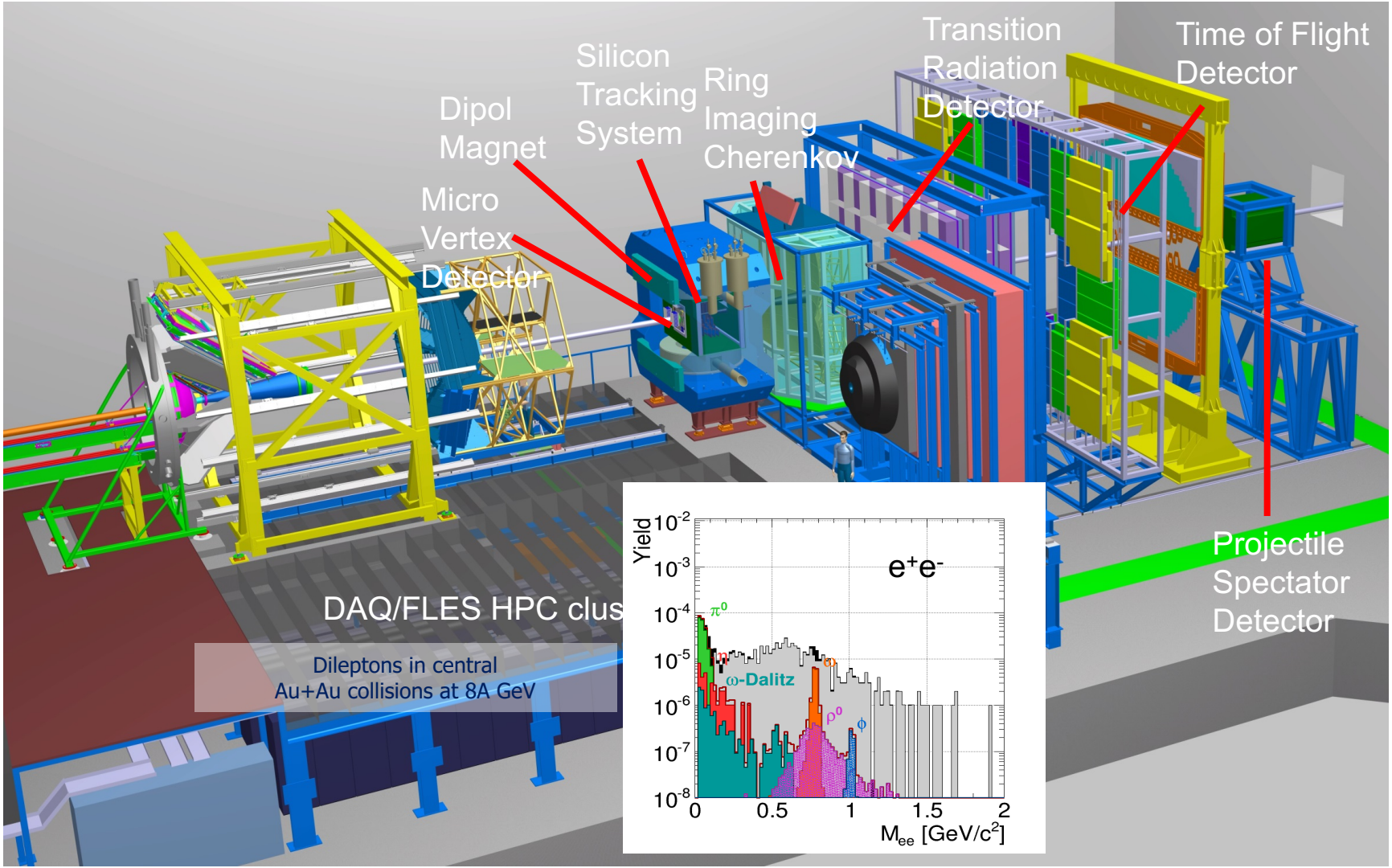


Open charm measurements

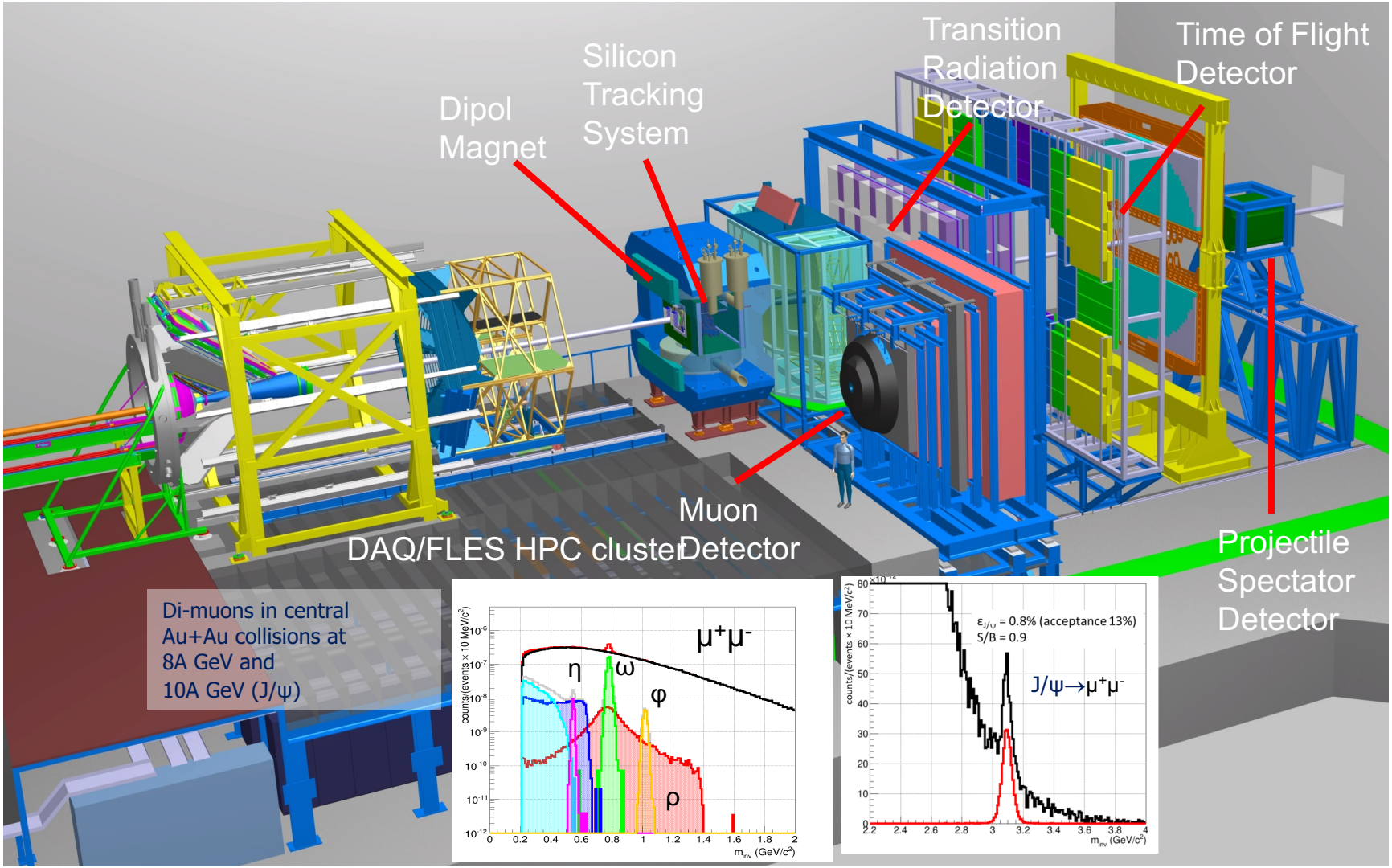


Open Charm in
p+A
30 GeV and
Ni+Ni
15A GeV

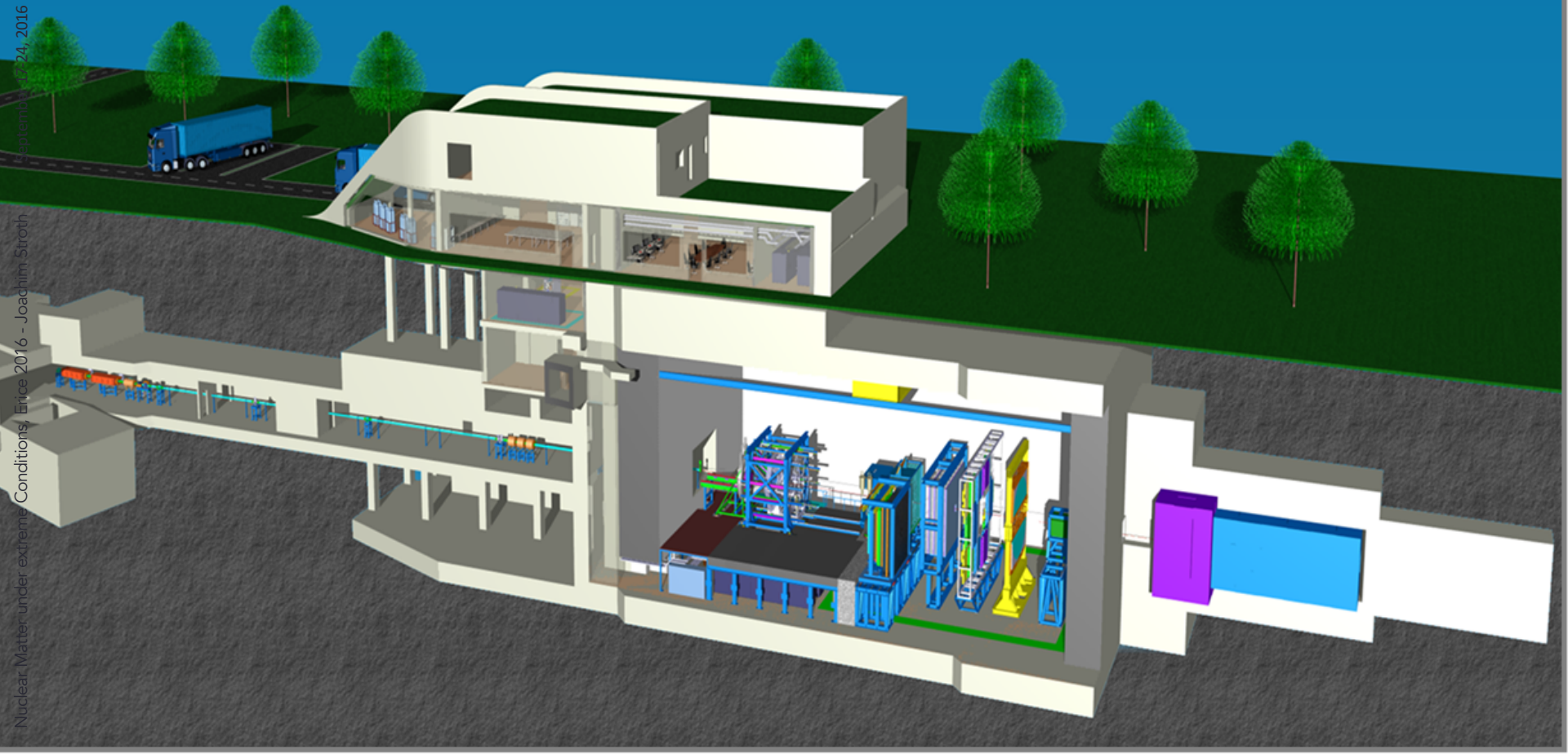
Di-electron measurements



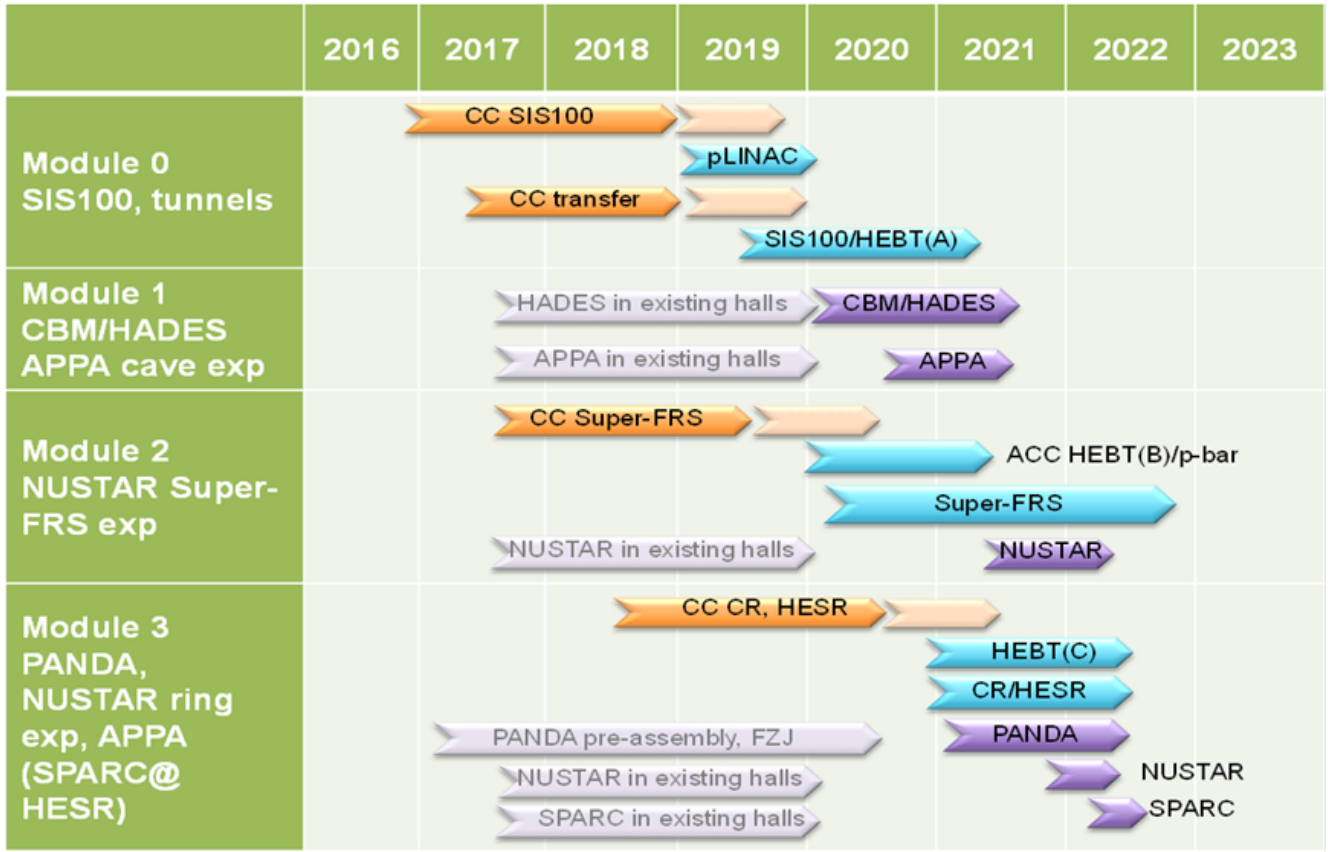
Di-muon measurements



The CBM cave



FAIR time line



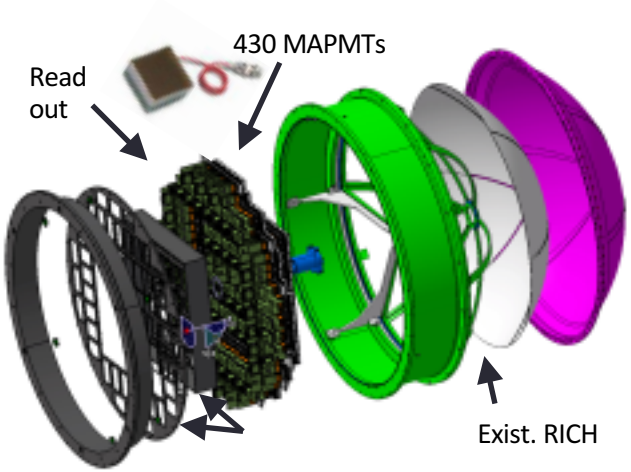
- Status FAIR as of 2015. Updated version will be presented in November to the FAIR council.

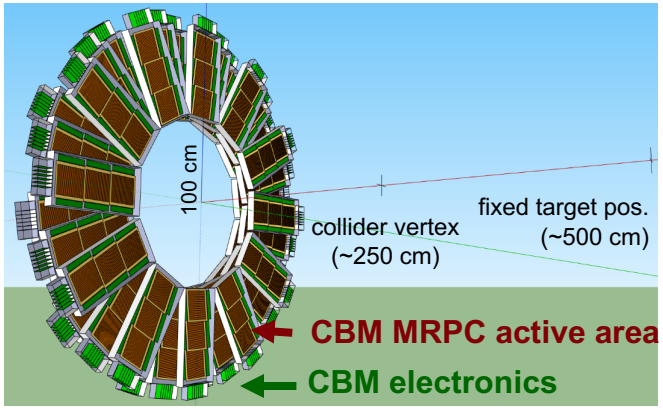
- Good news: BMBF has approved start of first section of civil construction (SIS100 building, northern part).

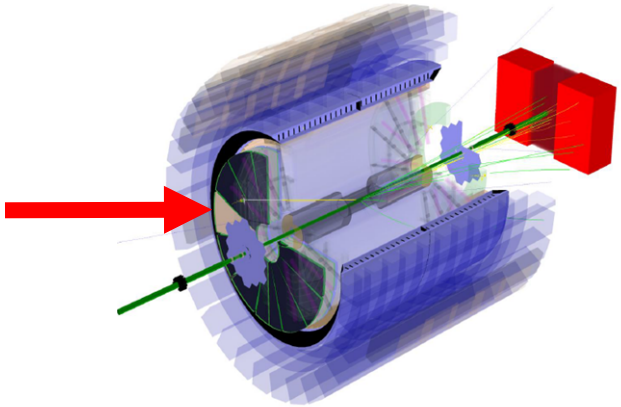
CBM FAIR Phase 0 experiments

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)





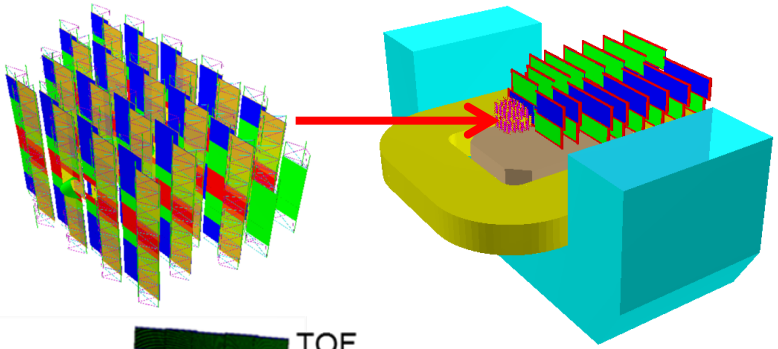


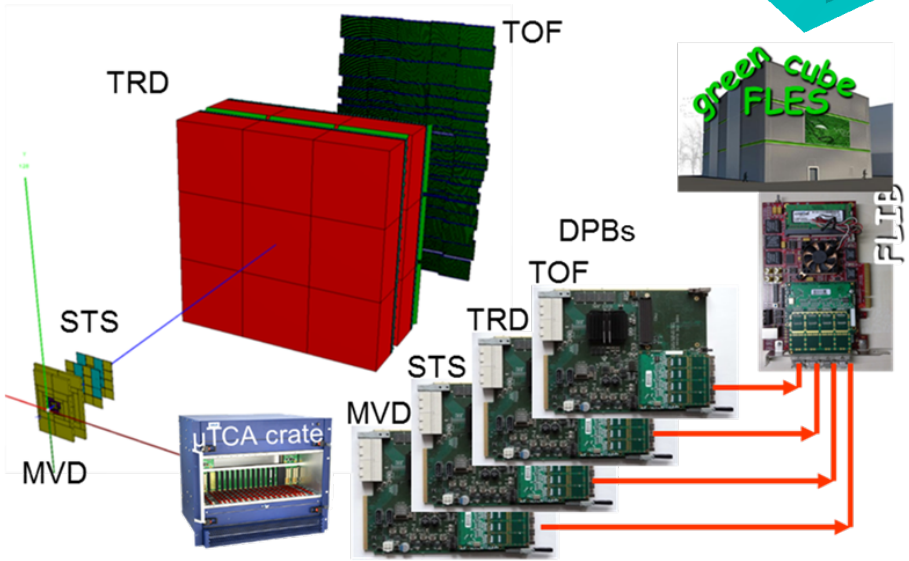
CBM FAIR Phase 0 experiments

3. CBM AT JINR (BM@N)
   - Install, commission and use 4 Silicon tracking layers and the
   - Project Spectator as forward detector
   - Nuclotron in JINR/Dubna (Au-beams up to 4.5 A GeV in 2018/19)

4. mCBM at SIS18
   - full system test with high-rate nucleus-nucleus collisions from 2017 – 2020
   - no magnetic field, system test only

5. SPS/NA61
   - MAPS
   - PSD





Next steps

2018-2021 FAIR Phase-0

- Continuation of measurements with HADES
- Contribution to the STAR BES-II (Emphasis on fixed target program)

2021 FAIR Start of Operartion

- First SIS100 beam on CBM Target
- HADES at SIS for reference measurements (mainly pA)

2025 Design Operation of FAIR

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

26th CBM Collaboration meeting in Prague, CZ
14 -18 Sept. 2015

Summary

CBM scientific program at SIS100:

- Exploration of the QCD phase diagram in the region of neutron star core densities
  → 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
  → 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