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Facility for Antiproton and Ion Research in Europe GmbH

CBM

GSI

CBM@FAIR

SQM 2026 | 27.03.2026 | Frédéric Julian Linz (CBM)

Outline

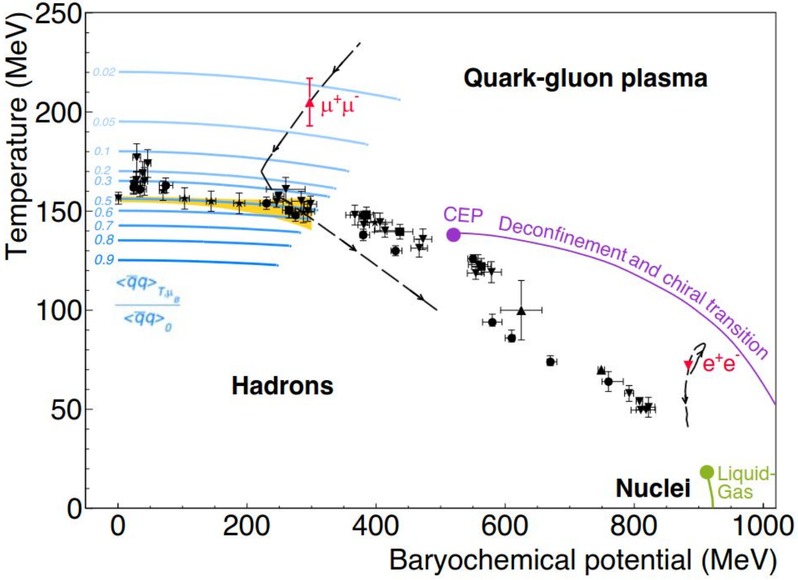
- **CBM Physics Case**
  - Motivation & Key Observables
  - Experimental Challenges

- **Towards CBM Realization**
  - Components & Purposes
  - Physics Performance Studies

- **Conclusions & Timeline**

CBM Physics Case

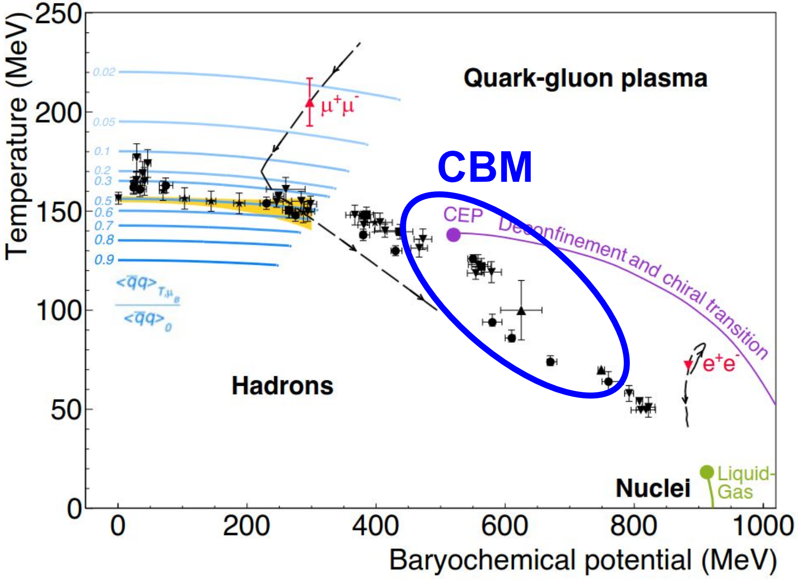
CBM Physics Case



[HADES], Nature Phys. 15 (2019) 10, 1040-1045
Andronic et al., Nature 561 (2018) no.7723

- QCD phase diagram at large μ_B and moderate T:
  - First order phase transition?
  - Critical endpoint?
  - Equation-of-state for baryon-rich matter?
- Experimental scan with relativistic collisions:
  - Nucleus charge and mass:
    - Initial baryon number relative to the total number of produced constituents ($\boldsymbol{\mu_B}$)
    - System size
  - Beam energy:
    - Initial energy available to the system (**T**, μ_B)

CBM Physics Case



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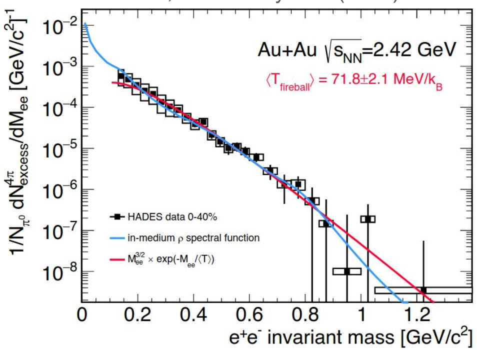
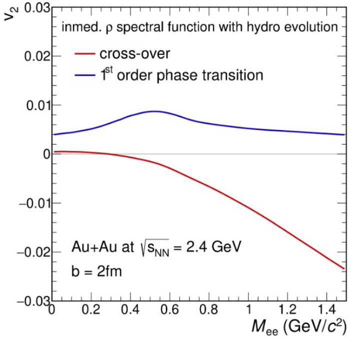
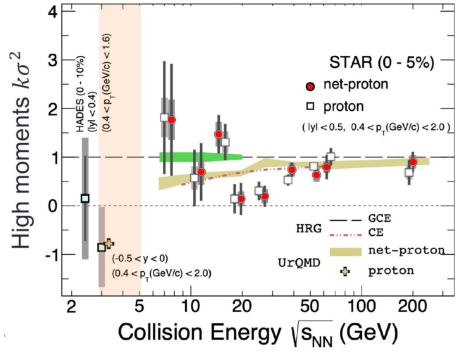
    - System size
  - Beam energy:
    - Initial energy available to the system (**T**, μ_B)
- CBM phase diagram coverage:
  - High baryo-chemical potential: $500 < \mu_B$ [MeV] < 850
  - Moderate temperatures T ~ 100 MeV

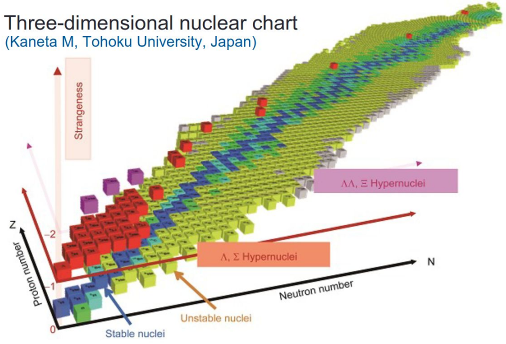
CBM Physics Case

HADES, Nature Phys. 15 (2019) 1040







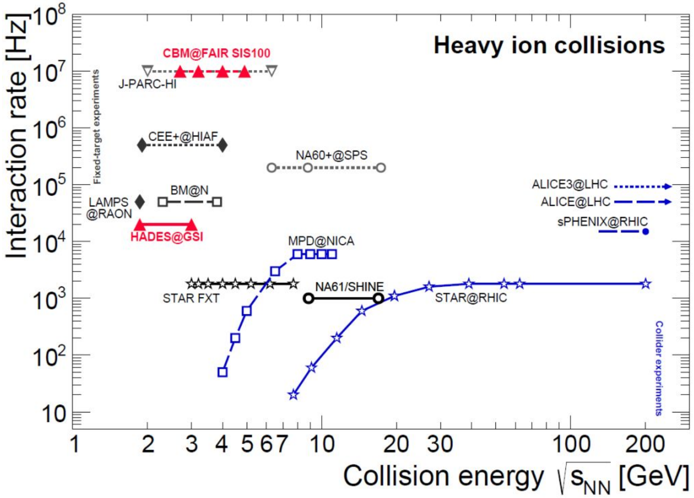


STAR, PRL 128 (2022) 20, 202303
HADES, PRC 102 (2020) 2, 024914

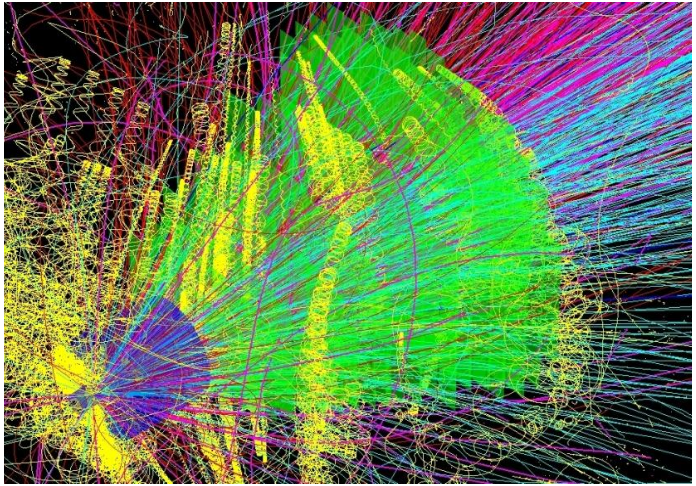
- Key observables for CBM:
  - Chemical freeze-out line T - μ_B, source size & emission
    - (Multi-strange) hadron production
    - Particle correlations (femtoscopy)
  - Equation-of-state (EoS):
    - Particle production, collective flow & vorticity
  - (Partial) chiral symmetry restoration and temperature:
    - Dilepton production
  - Critical end point:
    - High-order net-baryon cumulants
  - Hypernuclei
    - Discovery of double-strange hypernuclei?
    - YN- & YY-interaction (mass-radius relation of neutron stars, D. Lonardoni et al. PRL114 (2015) 092301)
  - Elementary reactions
    - pp- and np-reactions

Experimental challenges for CBM

T. Galatyuk, NPA 982 (2019), 2024 (CBM), EPJA 53 3 (2017) 60



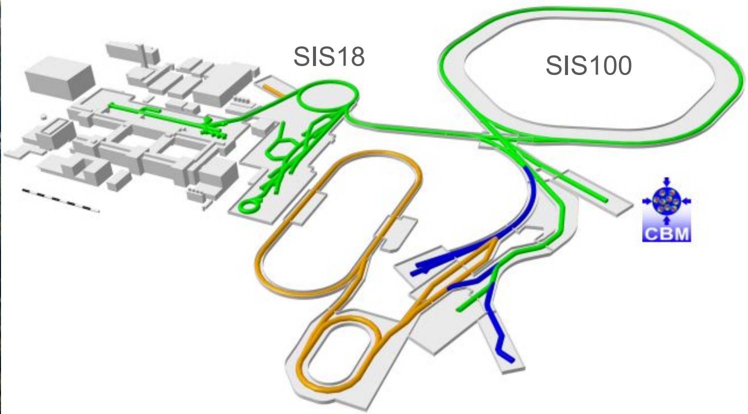
- Investigation of rare probes requires high statistics
  - High intensity beams
    - Free streaming read-out electronics
  - High performance computing
    - Online event selection, no hardware triggers
  - Capable detectors
    - High vertex resolution
    - Large acceptance and high efficiency
    - Light material budget (reduce beam background)
    - High radiation tolerance



CBM - GEANT simulation of a central Au+Au collision at $\sqrt{s_{NN}}$ = 4.9 GeV

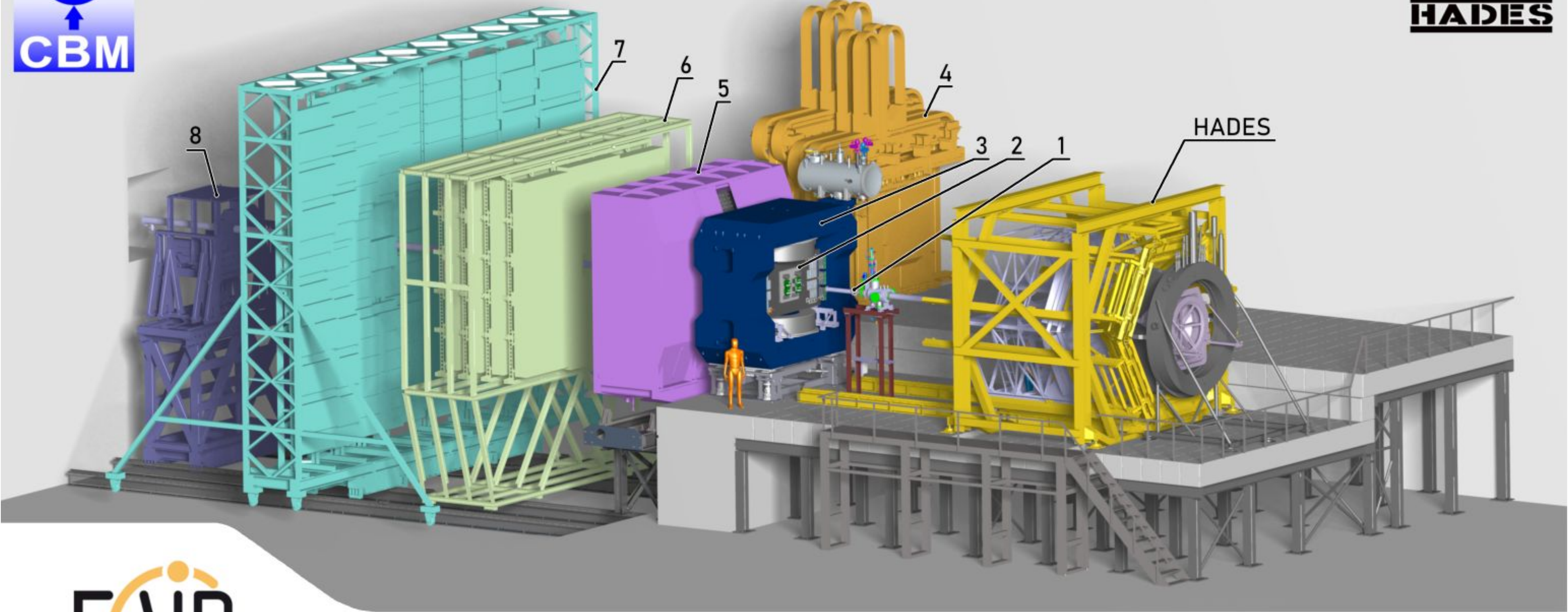
Towards CBM Realization

GSI/FAIR facilities



- SIS100 (start version):
  - $\sqrt{s_{NN}} \leq 7.6$ GeV (protons)
  - $\sqrt{s_{NN}} \leq 4.9$ GeV (Au ions)
  - Excellent quality beams with 10^{11} (10^{9}) protons (Au ions) / s

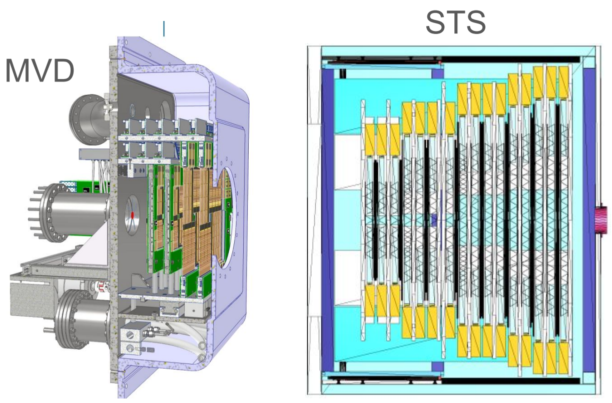
Compressed Baryonic Matter



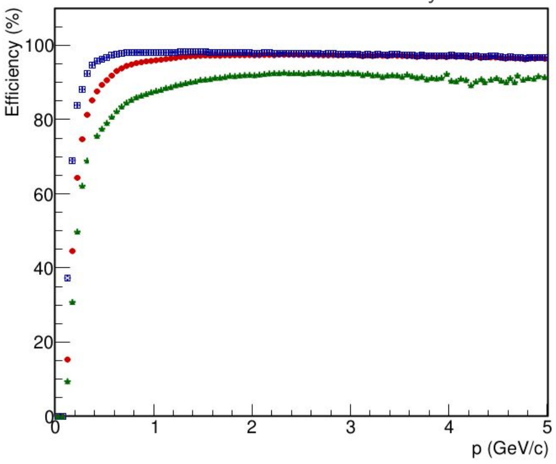
1: Time-Zero Detector & Beam Diagnostics
2: Silicon Tracking System / Micro Vertex Detector
3: Superconducting Dipole Magnet
4: Muon Chambers
5: Ring Imaging Cherenkov Detector
6: Transition Radiation Detector
7: Time of Flight Detector
8: Forward Spectator Detector

Tracking performance

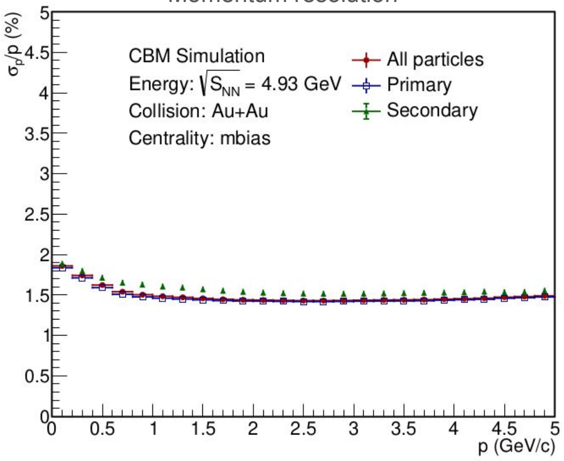
- Micro Vertex Detector (MVD):
  - Pixel sensors (27x30 μm²) for excellent vertex resolution with σ_z = 70 - 100 μm
  - Improving the reconstruction of low momentum tracks and short track segments (only 8 cm from the target)



Track reconstruction efficiency



Momentum resolution

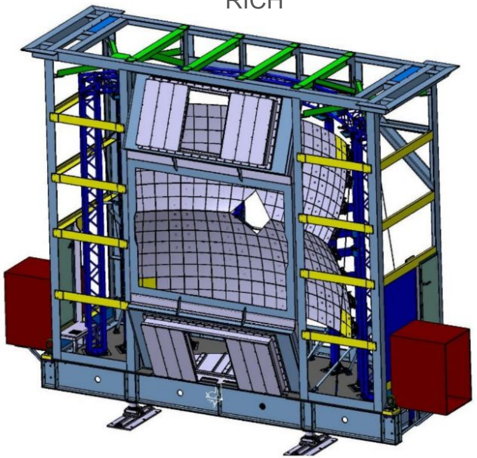


- Silicon Tracking System (STS):
  - Core tracking device of double-sided silicon mircostrip sensors
  - Track finding using Cellular Automaton (CA) algorithm (at least 3 hits in MVD+STS)
  - Spatial hit resolution $\sigma_{X,Y,Z} \lesssim$ 15 μm
  - Time resolution $\sigma_t \lesssim$ 5 ns
  - High efficient track reconstruction
  - Precise momentum resolution $\lesssim$ 2%

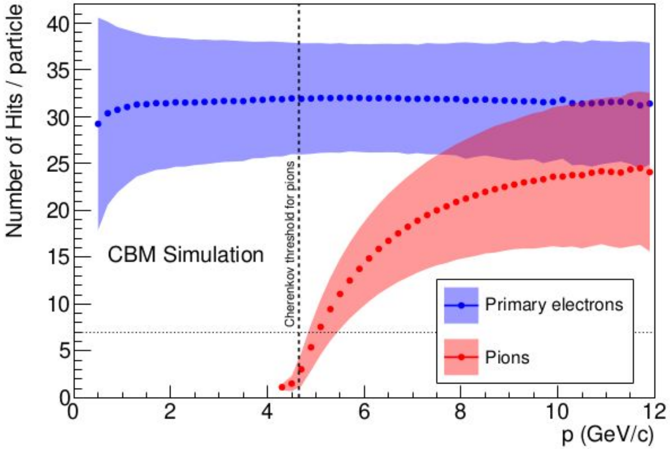
Particle Identification

- Ring Imaging Cherenkov detector (RICH)
  - Enough hits/particle for robust ring reconstruction
  - Electron identification up to p ~ 8 GeV/c
  - Pion suppression factor > 100

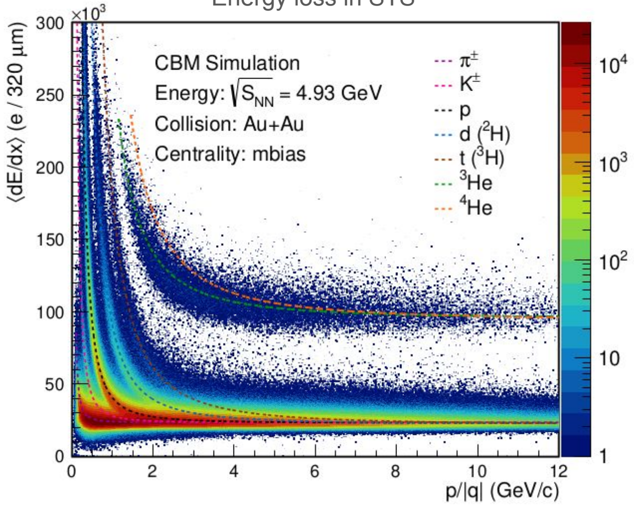
RICH



Measured hits per particle emitting Cherenkov light



Energy loss in STS

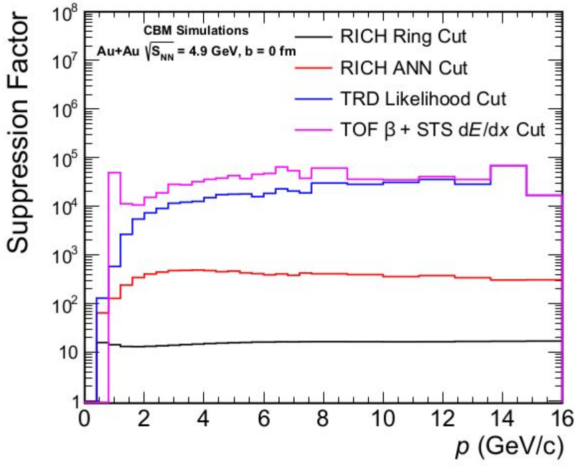


- STS:
  - Momentum reconstruction in the dipole field
  - Energy loss via layer-averaged cluster charge

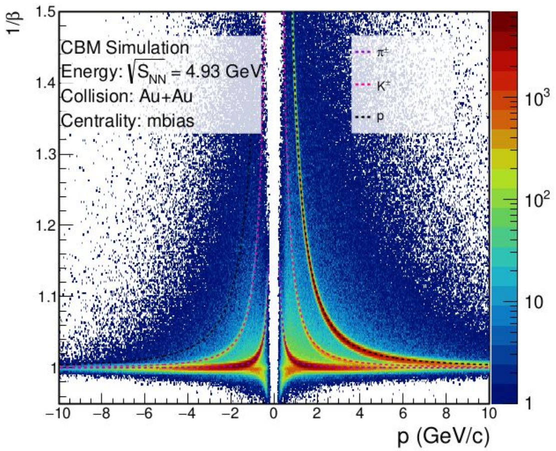
Particle Identification

- Transition Radiation Detector (TRD):
  - Additional electron-hadron discrimination
  - 4 layers of multi-wire proportional chambers allow for tracking
  - Specific energy loss to distinguish d from ^{4}He

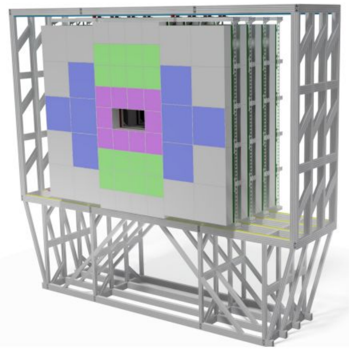
Proton suppression factors



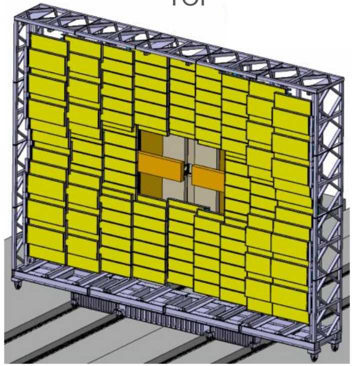
Inverse velocity (TOF) vs. momentum (STS)



TRD



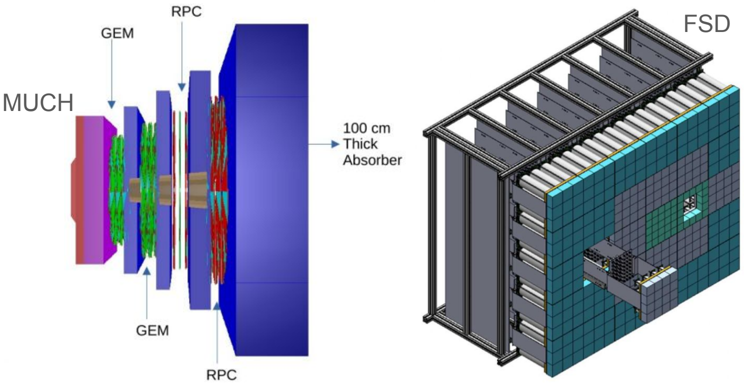
TOF



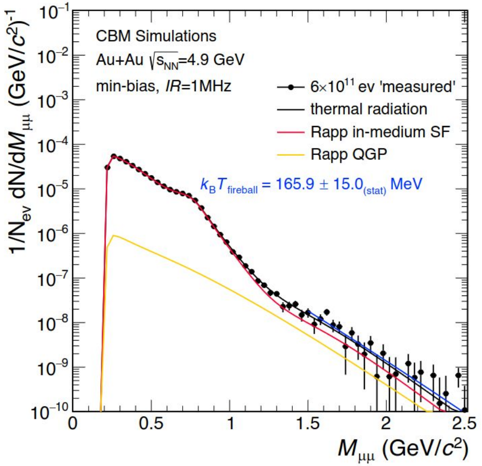
- Time-Of-Flight wall (TOF)
  - Large active area of 120m²
  - Time resolution $\sigma_T \lesssim 60$ ps
  - Hit reconstruction efficiency $\varepsilon \gtrsim 95$ %
  - Varying granularity to guarantee occupancy $\lesssim 5\%$

Muon Identification and Event Characterization

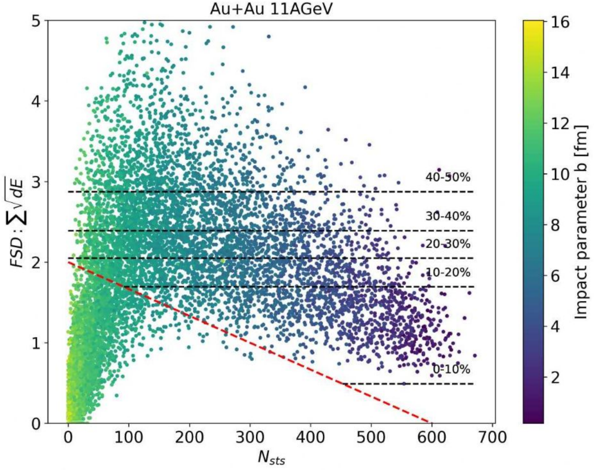
- MUon CHamber system (MUCH):
  - Interchangeable with RICH (electron/muon mode)
  - Combination of absorbers and tracking stations
  - High purity muon identification in the environment of high particle multiplicities



Dimuon invariant mass slope

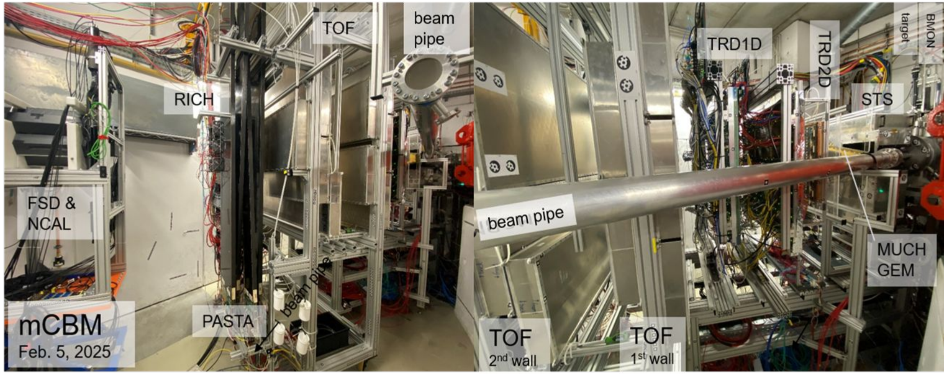


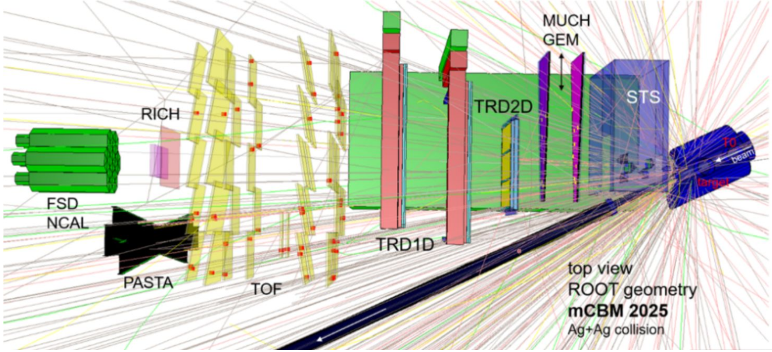
FSD energy deposit vs. track multiplicity



- Forward Spectator Detector (FSD)
  - Collision centrality and event plane reconstruction
  - Measures multiplicity, spatial distribution and energy deposition of protons and nuclear fragments
  - No correlation to mid-rapidity observables

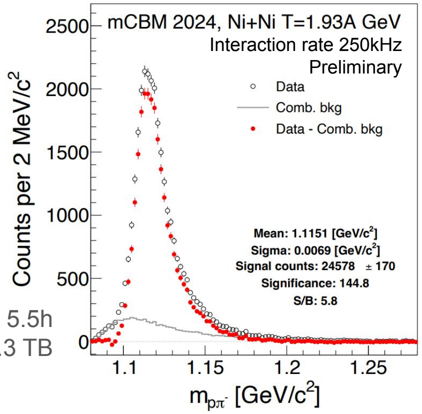
Data Acquisition Validation with mCBM





- mini-CBM demonstrator (mCBM) for testing detector components at high interaction rates up to 10^7 events/s
  - Enormous data stream of ~500 GB/s
  - Real time data reduction of factor 100 required before storage
    - Online identification of rare probes (e.g. hyperon decays)
    - Free-streaming data acquisition, online event builder, reconstruction and trigger
- Concept has been validated with mCBM (benchmark Λ reconstruction)

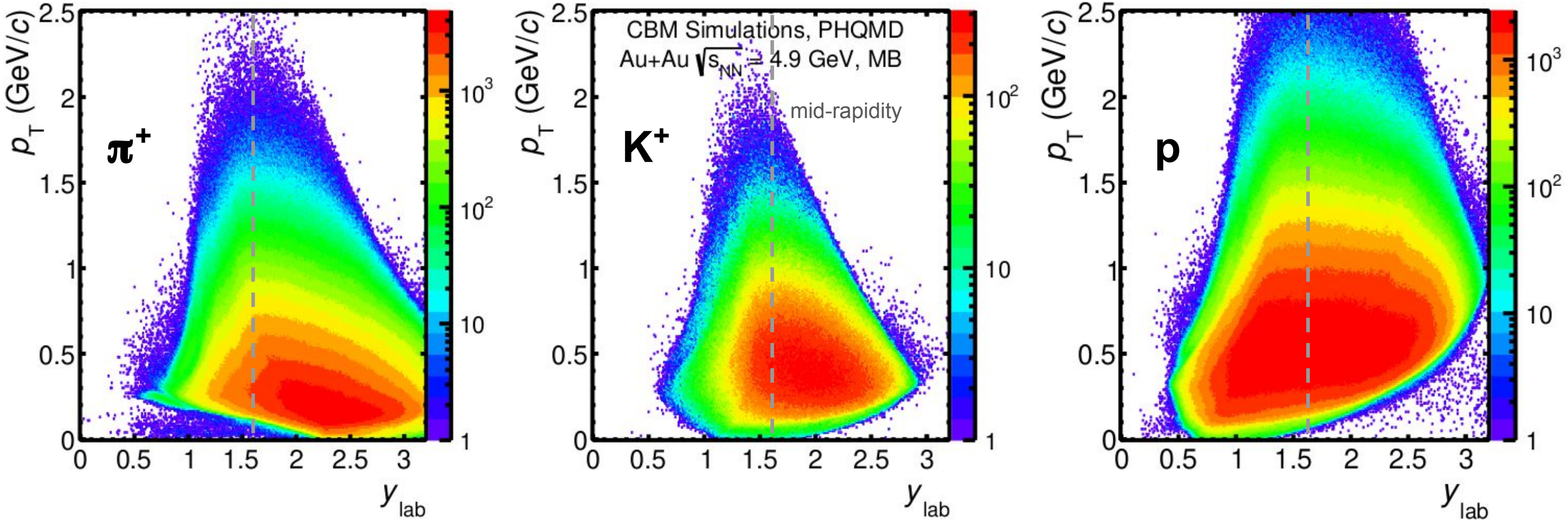
Λ invariant mass distribution



Recording time: 5.5h
Disk space: 7.3 TB

Physics Performance Studies

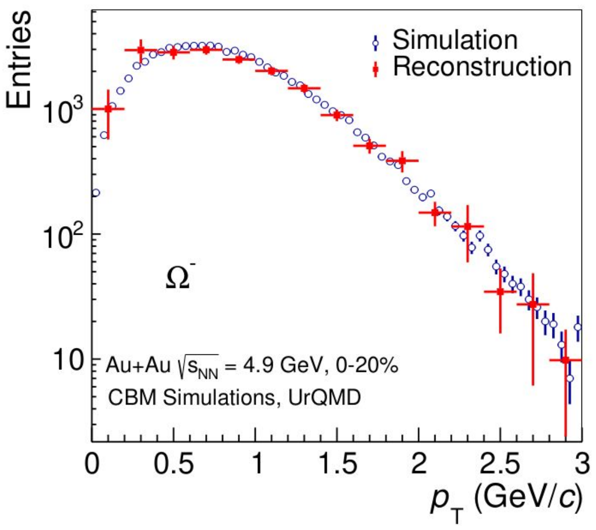
- PHQMD / UrQMD simulations at the top energy of $\sqrt{s_{NN}}$ = 4.9 GeV
- Large phase space coverage of CBM allows the study of various observables



Physics Performance Studies

- High-statistics data will allow for multi-differential measurements
  - Multi-strange hyperons: yield, collective flow, global polarization, etc.
  - Hypernuclei: YN & YY interactions to constrain nuclear EoS, discovery of double-strange hypernuclei?
- Very important to keep systematic effects under control

Channel: $\Omega^{-} \rightarrow \Lambda + K^{-}$



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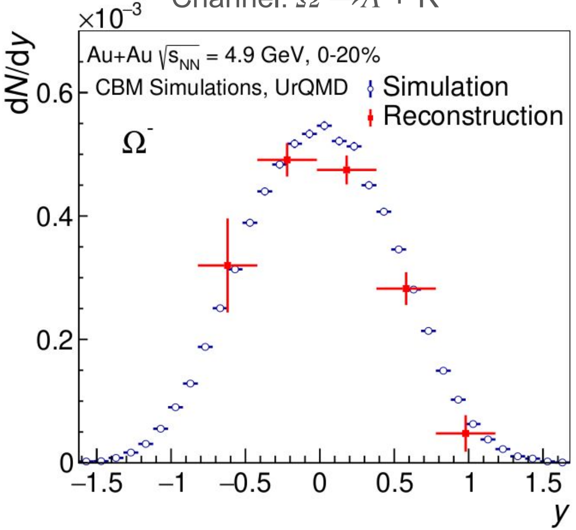
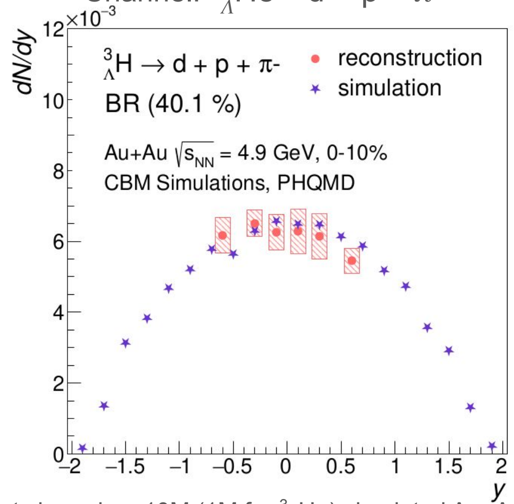
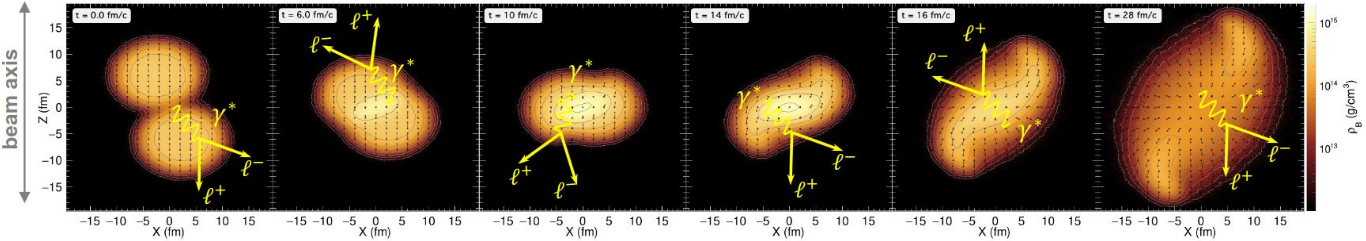


Channel: ${}^{3}_{\Lambda}He \rightarrow d + p + \pi^{-}$



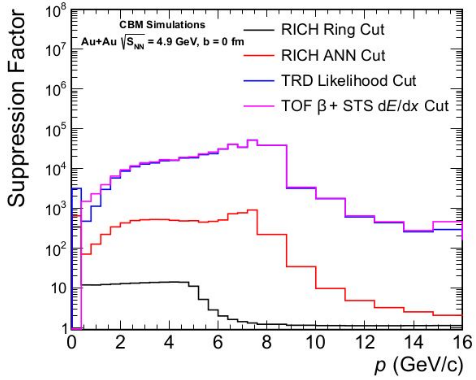
Plots based on 10M (1M for ${}^{3}_{\Lambda}He$) simulated Au+Au collisions
→orders of magnitudes more experimental signal

Physics Performance Studies

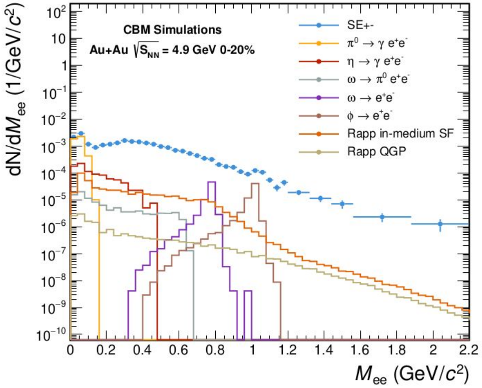


HADES, Nature Phys. 15 (2019) 1040

Pion suppression



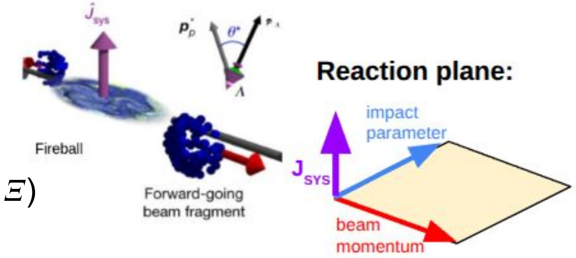
Reconstructed dielectron spectra



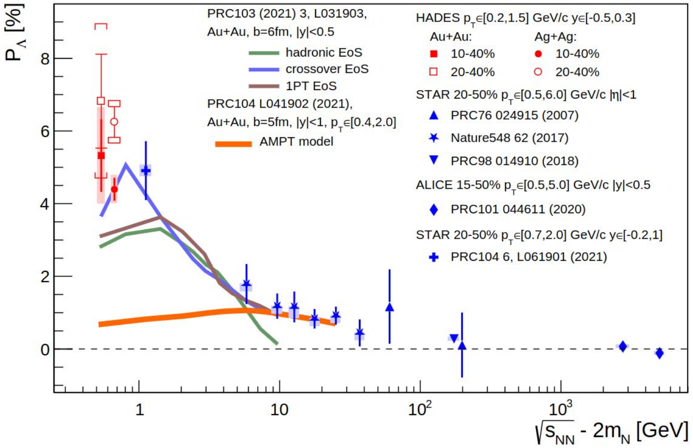
- (Virtual-)Photons sensitive to all stages of the collision
  - Mean fireball temperature from m_{inv} > 1.5 GeV/c²
  - Access also lifetime of the fireball, in-medium modifications of vector mesons, chiral symmetry restoration, etc.
  - Sign of elliptic flow sensitive to phase transition (?)
- Importance of background reduction to access rare dilepton probes with S/B ~ 10^{-2}
- No dilepton measurements in the range $\sqrt{s_{NN}}$ = 3 - 10 GeV
- Multi-differential measurements for both dielectrons and dimuons

Physics Performance Studies

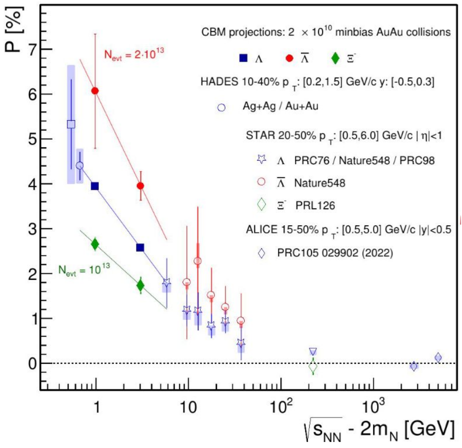
- Vortical structure of the QCD matter?
  - Large orbital angular momenta ~ 10^3 - 10^7 ħ in non-central heavy-ion collisions
  - Vorticity coupled to the spin degrees of freedom
  - Experimentally accessible via parity violating weak decays (e.g. Λ, Ω, Ξ)



HADES, Phys .Lett. B 835 (2022) 137506



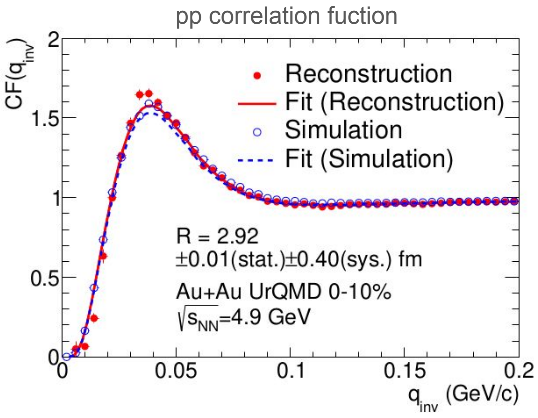
Global polarization



- Global polarization vs. directed flow
  - Both sensitive to the initial velocity field
  - Different behavior in peripheral events
    - Polarization mechanism?
    - Simultaneous description of v_1 and P_H?
- Elliptic flow measurements with $v_2 < 0.02$ can be established

Physics Performance Studies

- Probing the space-time structure of the fireball using femtoscopy
  - Analysis of two-particle correlations close in momentum space
  - Extraction of source sizes & emission durations (accuracy of fm)
  - Comparison of reconstructed correlations with model output allow to quantify momentum resolution, finite acceptance & reconstruction efficiency effects on final observables



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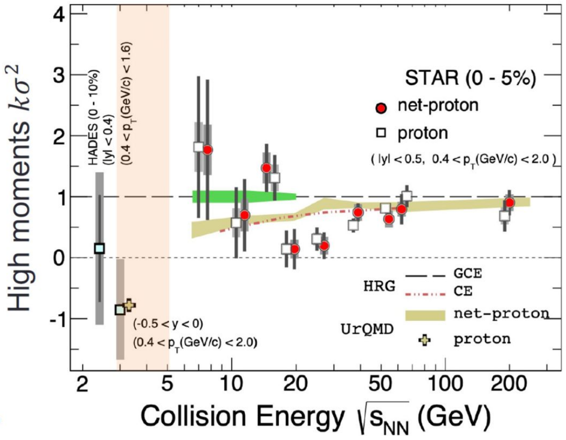

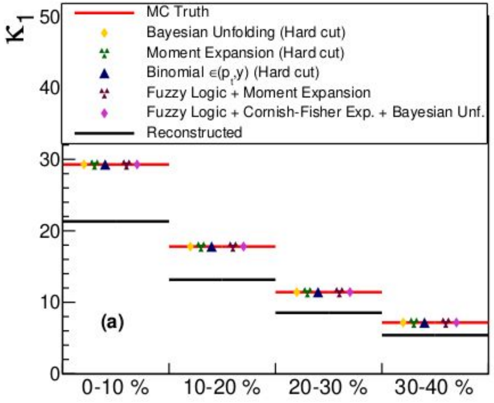

- Event-by-event fluctuations
  - Clean proton identification
  - Well capable to reproduce the simulated input for κ_1, …, κ_4
- 1st order phase transition
  - Non-monotonous behavior of higher order moments of particle number distributions

Conclusions & Timeline

Conclusions & Timeline

- **Physics performance studies show high potential of CBM**
  - High acceptance, measurement accuracy & reconstruction efficiency
  - Free-streaming read-out to run at high interaction rates & collect large data samples
  - Important to have systematics under control - studies are ongoing

- **CBM prototype mCBM**
  - Testing detector components
  - Establish online event builder and triggering for data reduction before storage (Λ benchmark)
  - Validation of free-streaming read-out, calibration & alignment

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- **CBM realization timeline:**
  - 2023-2027: installation of CBM infrastructure
  - 2026-2028: installation of CBM detectors & commissioning
  - End of 2028: start of CBM operations