Compressed Baryonic Matter experiment at FAIR

Ilya Selyuzhenkov

(GSI / EMMI / MEPhI)

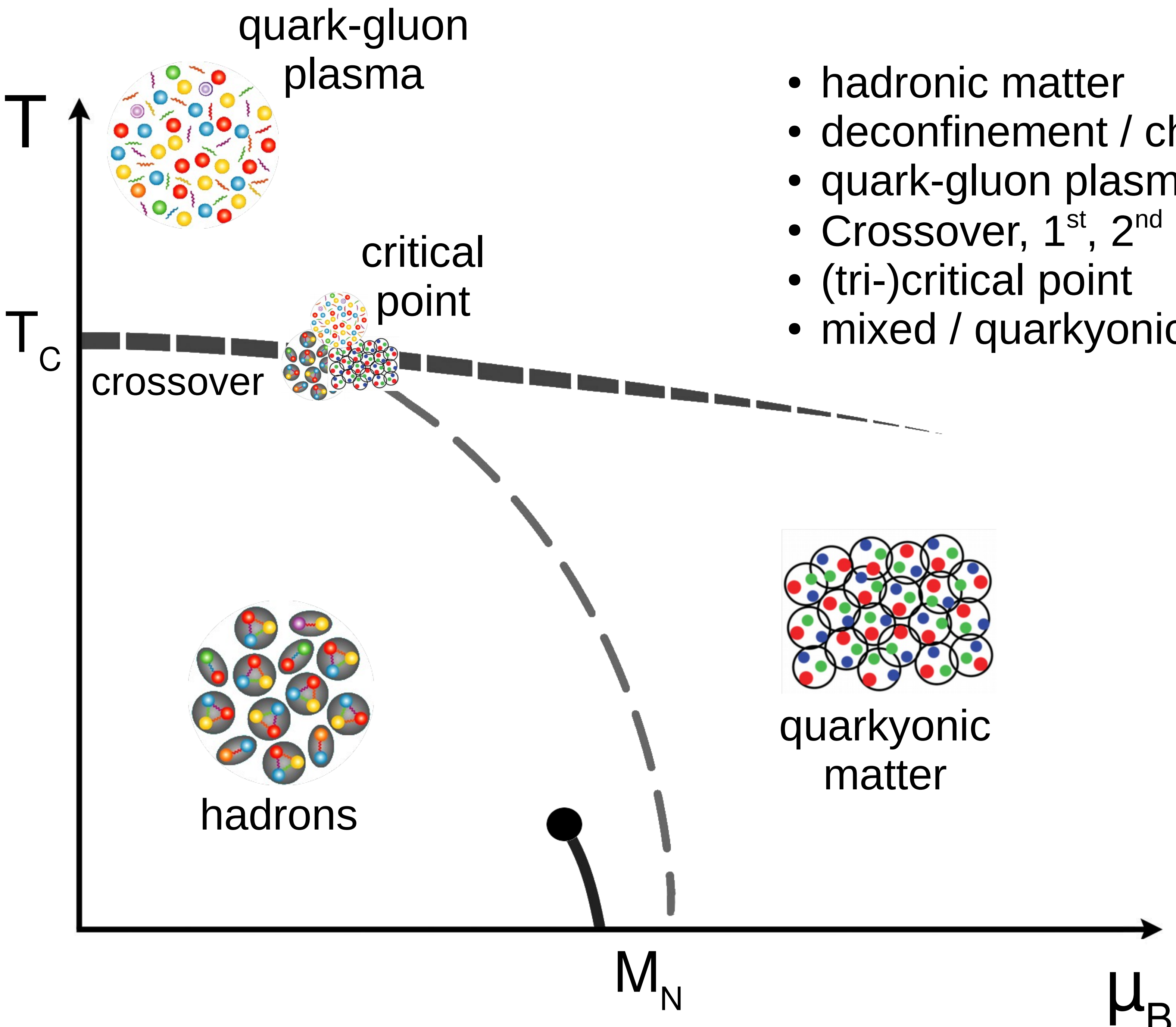
for the CBM Collaboration

The 3rd international conference on particle physics and astrophysics

Moscow, Russia

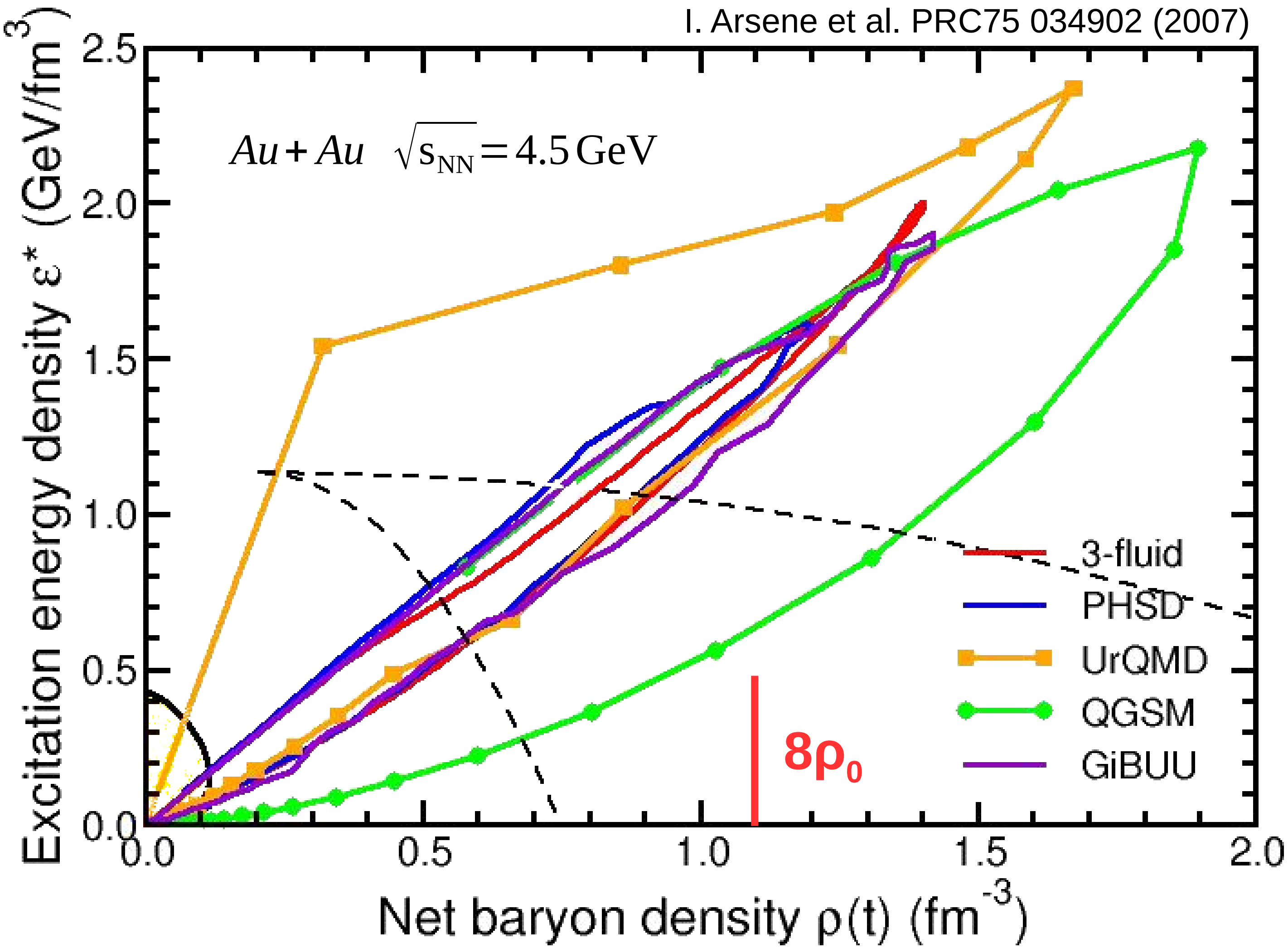
October 3, 2017

Rich structure of the QCD matter phase diagram



- hadronic matter
- deconfinement / chiral symmetry
- quark-gluon plasma
- Crossover, 1st, 2nd order transition
- (tri-)critical point
- mixed / quarkyonic phase (?)

Net-baryon density at SIS100 FAIR energies



Net-baryon density reaches a value 5-15 times of the normal matter:

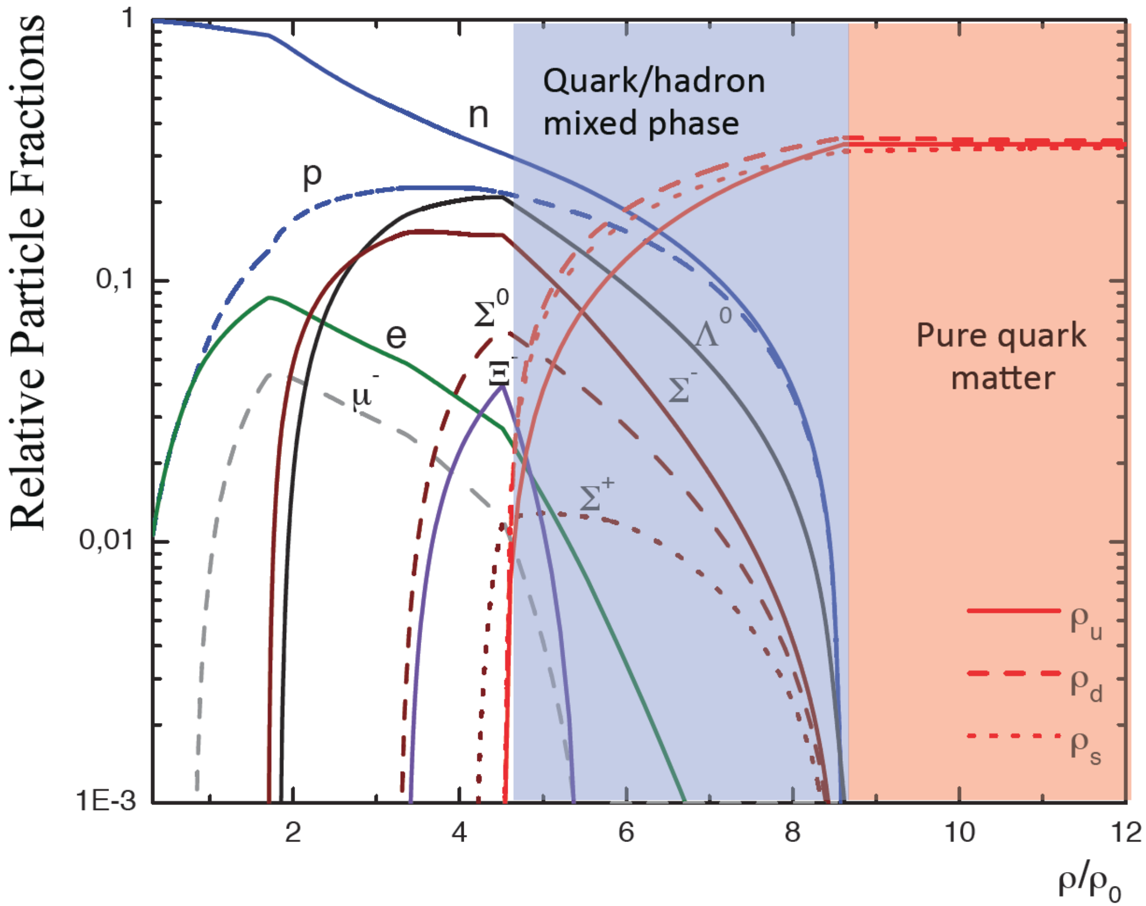
- experimentally access the region of mixed / quarkyonic phase

CBM physics and observables

Quark matter equation-of-state at large baryon densities, coexistence (quarkyonic) & partonic phases:

- Hadron yields, collective flow, correlations, fluctuations
- (Multi-)strange hyperons (K, Λ, Σ, Ξ, Ω) production at (sub)threshold energies

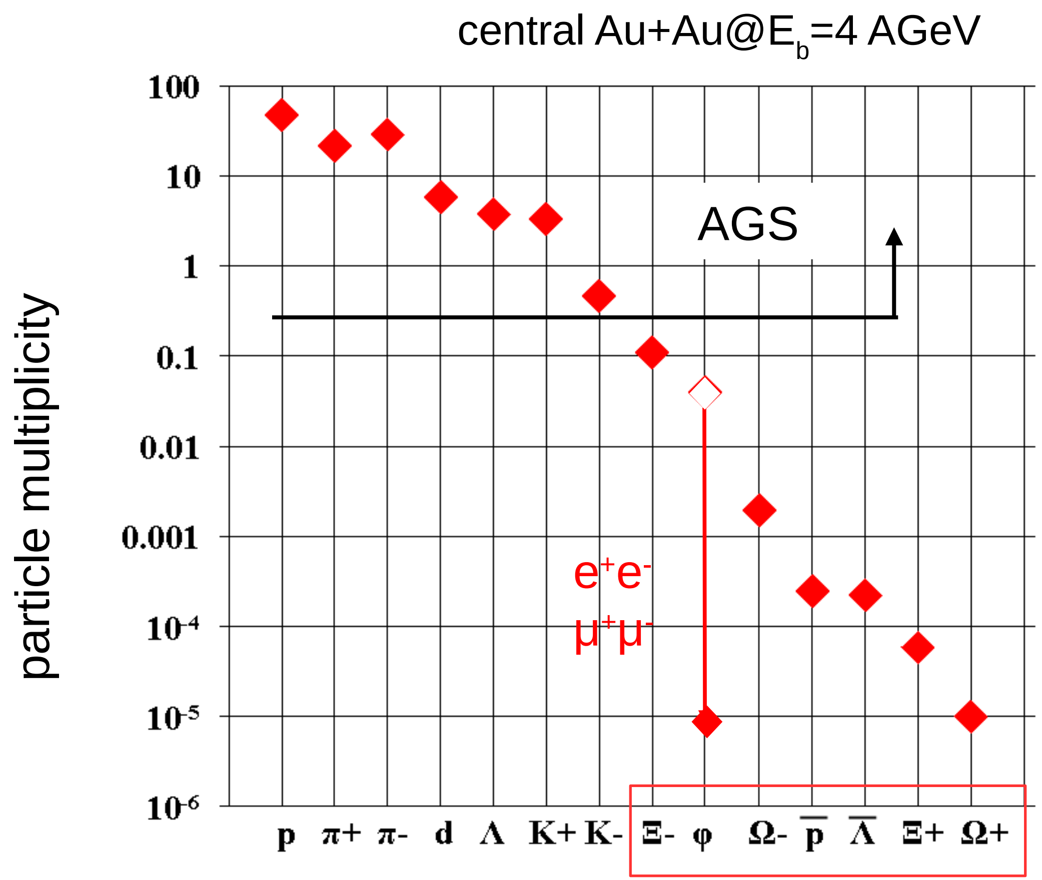
M. Orsaria et.al. PRC89 015806 (2014)



CBM physics and observables

Quark matter equation-of-state at large baryon densities, coexistence (quarkyonic) & partonic phases:

- Hadron yields, collective flow, correlations, fluctuations
- (Multi-)strange hyperons (K, Λ, Σ, Ξ, Ω) production at (sub)threshold energies



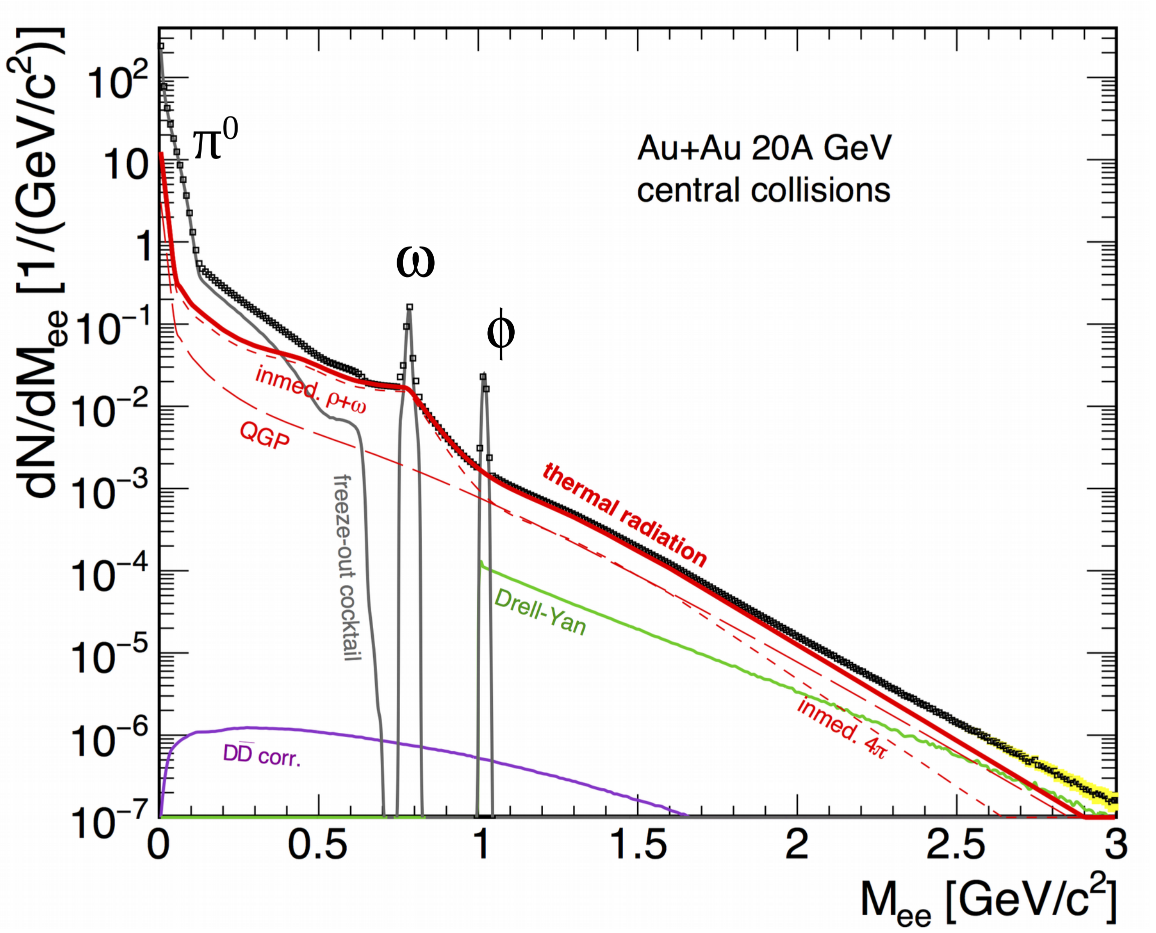
Stat.model, A. Andronic

CBM physics and observables

Chiral symmetry at large baryon densities:

- In-medium modifications of light vector mesons ρ, ω, $\phi \rightarrow e^+e^-$ ($\mu^+\mu^-$) via dilepton measurements

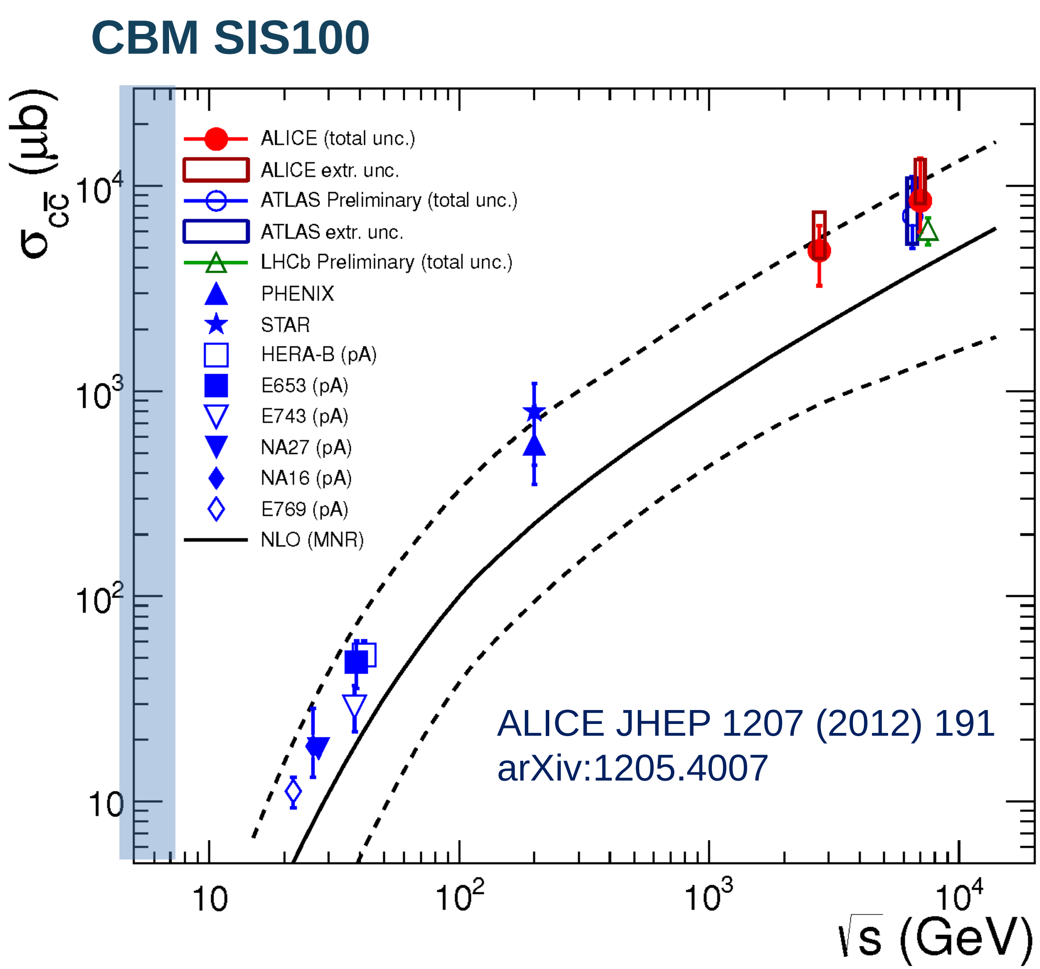
Electromagnetic radiation of produced matter



CBM physics and observables

Charm production and propagation at threshold energies

- Excitation function in p+A collisions (J/ψ, ψ', D^0, $D^{\pm}$)
- Charmonium suppression in cold nuclear matter

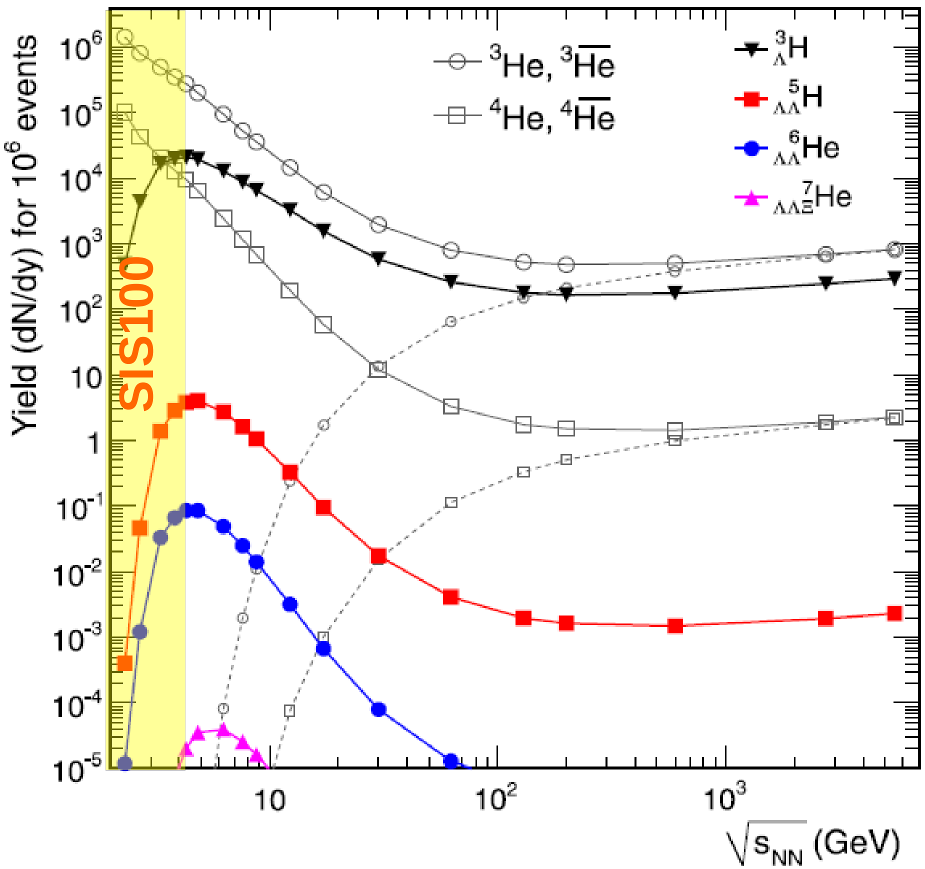


CBM physics and observables

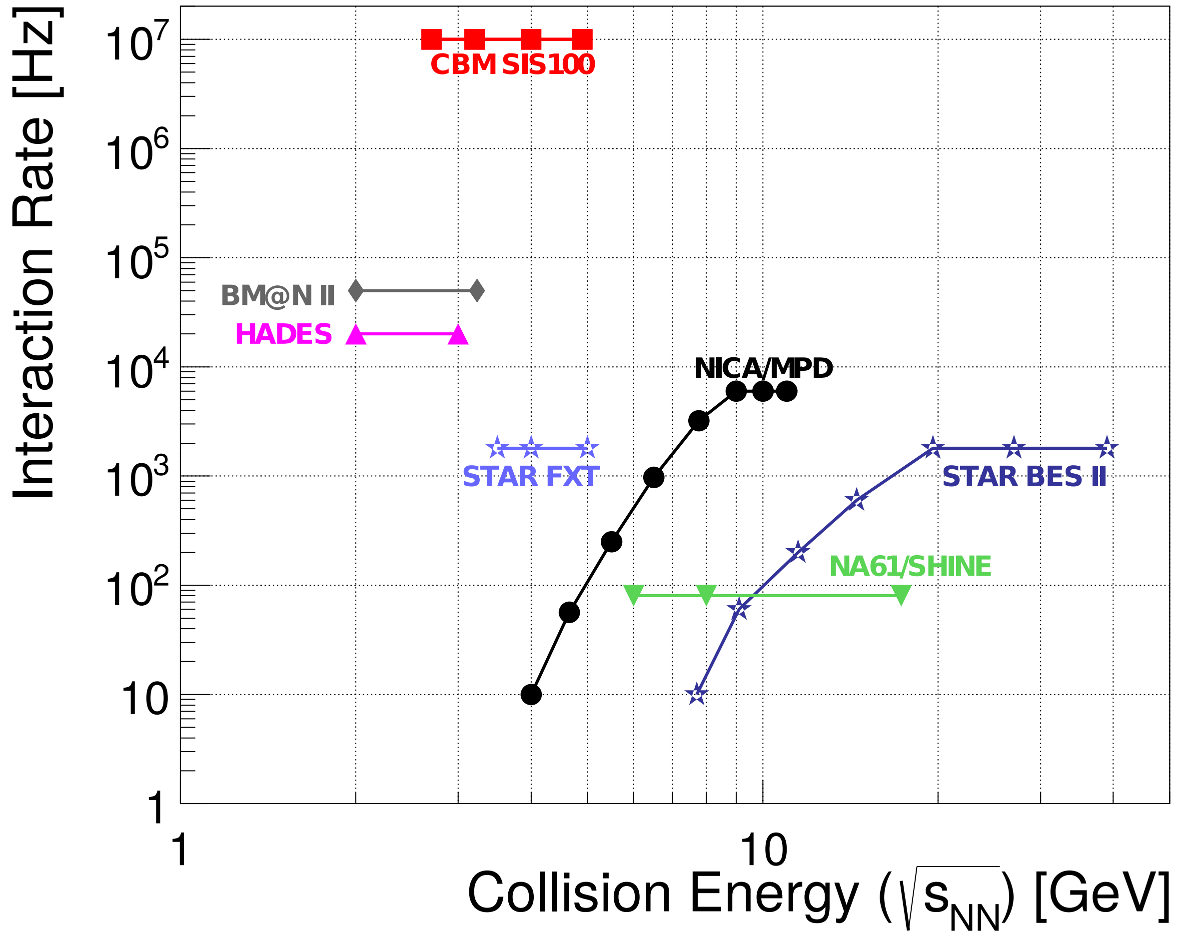
Strange nuclear matter:

- Λ-N, Λ-Λ interaction
- (Double-)lambda hypernuclei
- Meta-stable strange states

A. Andronic, PLB697 203 (2011)



Main experimental requirements



High statistics means high reaction rates:

10^5 - 10^7 Au+Au reactions/sec

Main experimental requirements

- High statistics needs high event rates:
  10^5 - 10^7 Au+Au reactions/sec

- Particle identification: hadrons and leptons, displaced ($\sigma \approx 50$ μm) vertex reconstruction for charm measurements

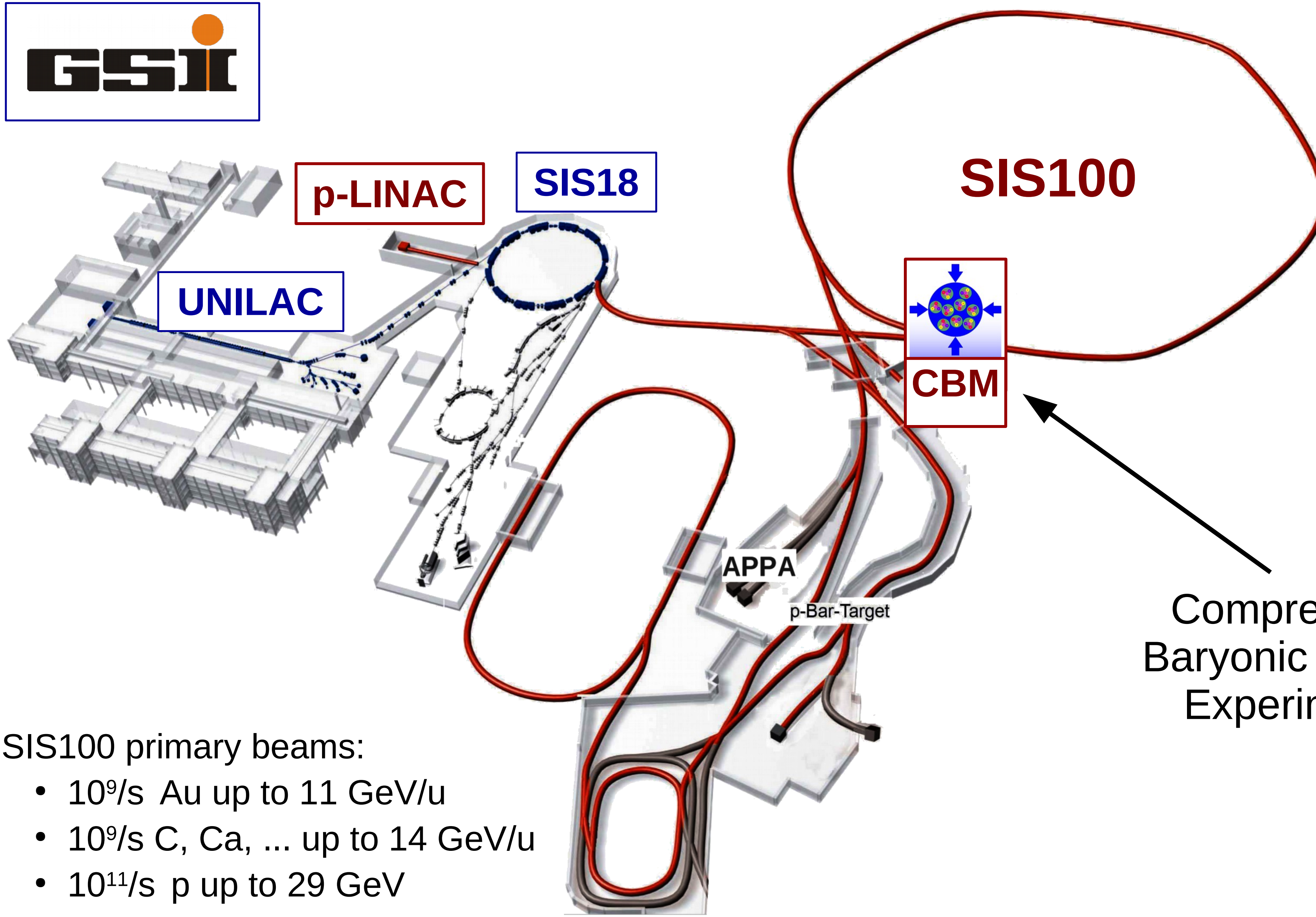
- Fast, radiation hard detectors & front-end electronics

- Free-streaming readout & 4 dimensional (space+time) event reconstruction

- High speed data acquisition & performance computing farm for online event selection

Compressed Baryonic Matter (CBM) experiment at FAIR

CBM at FAIR, Darmstadt



Compressed Baryonic Matter Experiment

SIS100 primary beams:

- 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

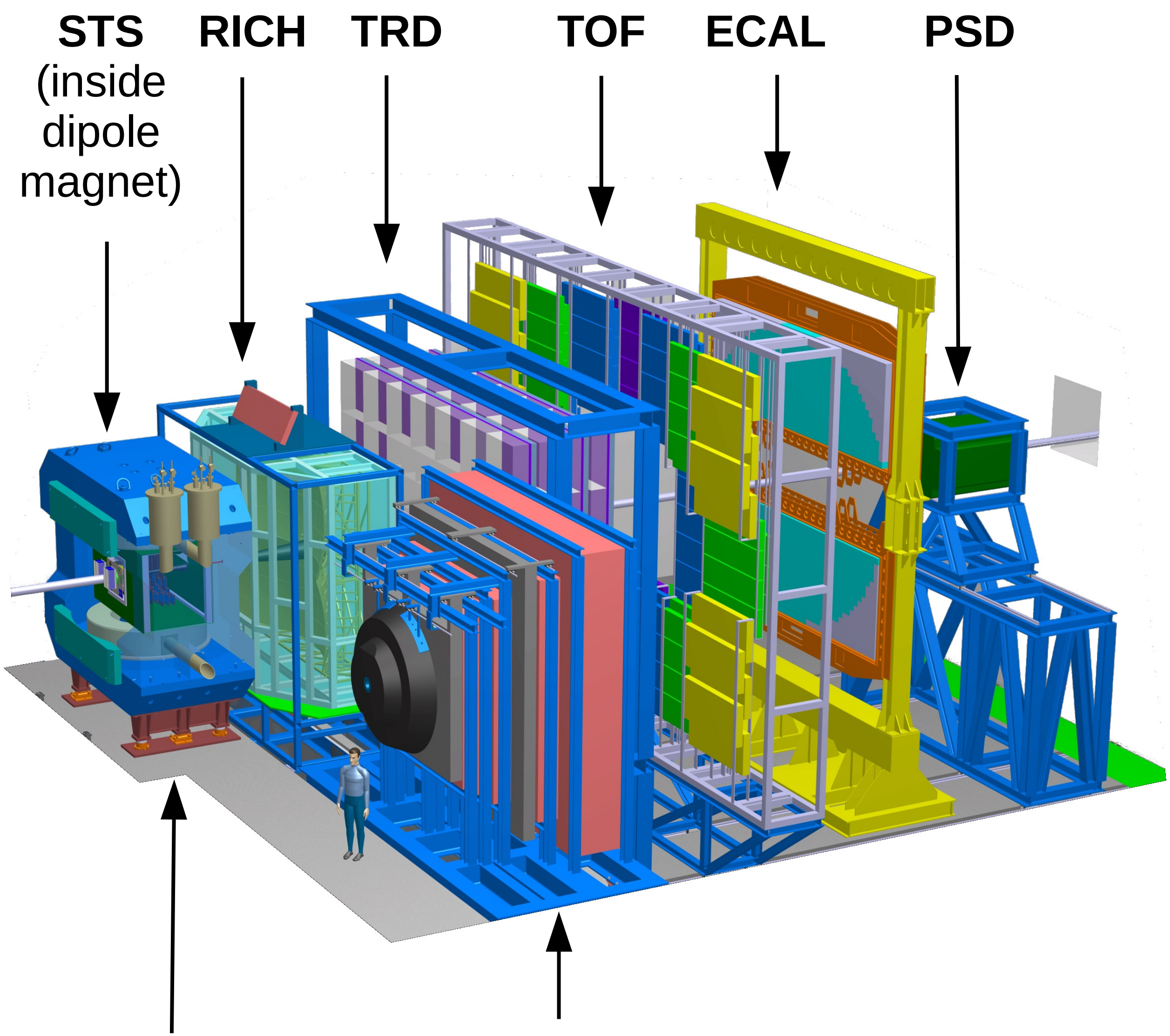
CBM building layout

HADES: p+p, p+A, A+A
limited to low multiplicity A+A
optimized for dileptons

CBM: p+p, p+A, A+A
designed for high multiplicity
general purpose detector

Complementary operation of HADES and CBM at FAIR

CBM detector subsystems



Dipole Magnet
bends charged particle's trajectories

STS (Silicon Tracking System)
charged particle tracking

MVD (Micro-Vertex Detector)
secondary vertex reconstruction

RICH (Ring Imaging Cherenkov)
electron identification

TRD (Transition Radiation Detector)
electron identification

TOF (Time of Flight detector)
hadron identification

MUCH (MUon CHambers)
muon identification

ECAL (Electromagnetic Calorimeter)
electron/photon identification

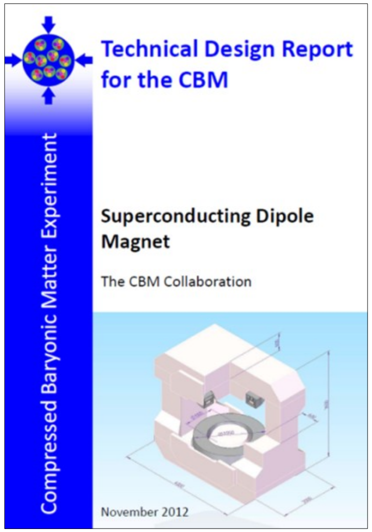
PSD (Projectile Spectator Detector)
collision centrality and
reaction plane determination

FLES (First-level Event Selector)
online reconstruction / event selection

Subsystems preparation status

TDRs approved by FAIR

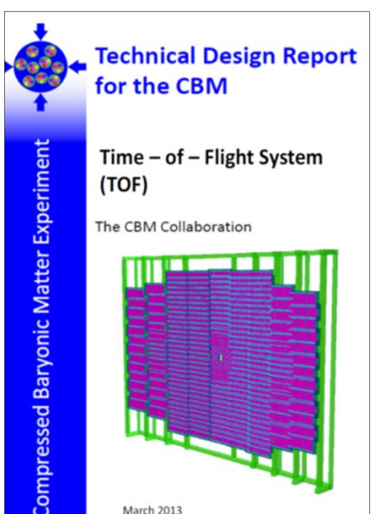
Dipole Magnet



STS

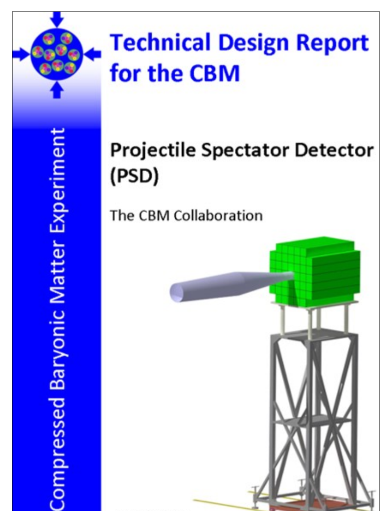
RICH

TOF



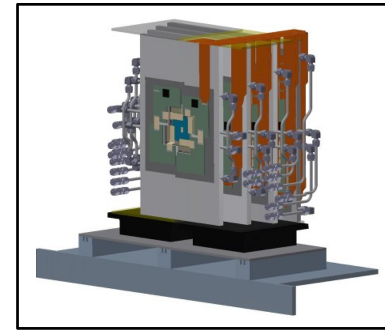
MUCH

PSD

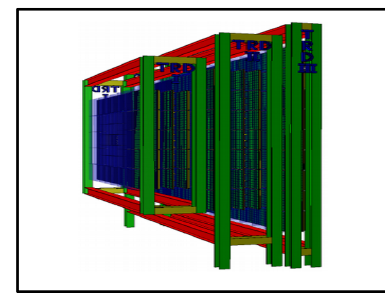


TDR in preparation

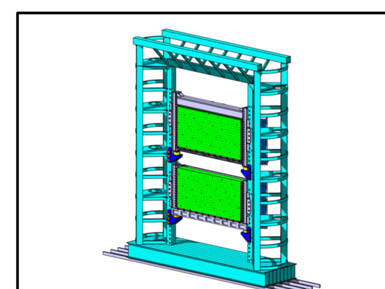
MVD



TRD



ECAL

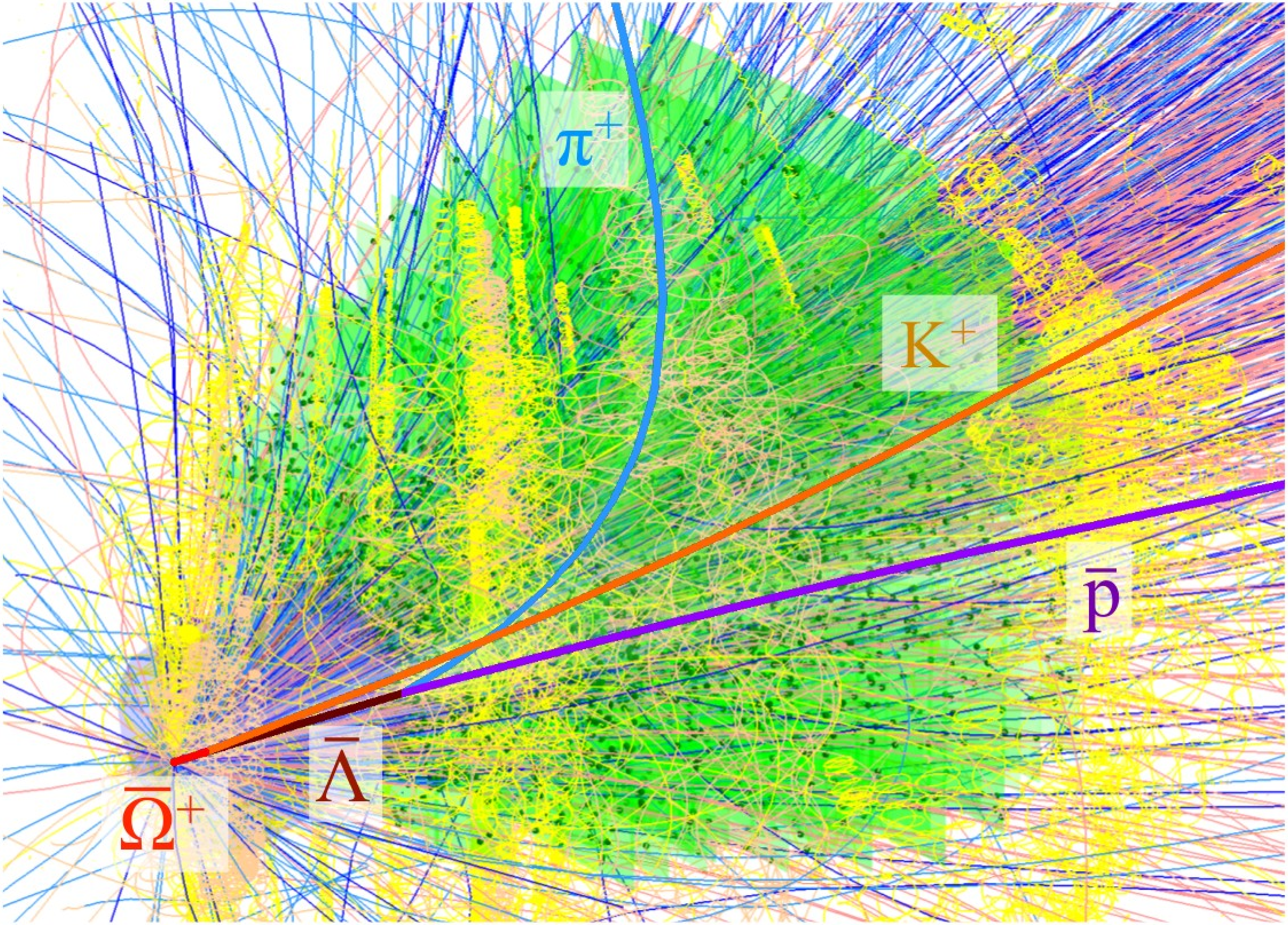


FLES

Physics performance

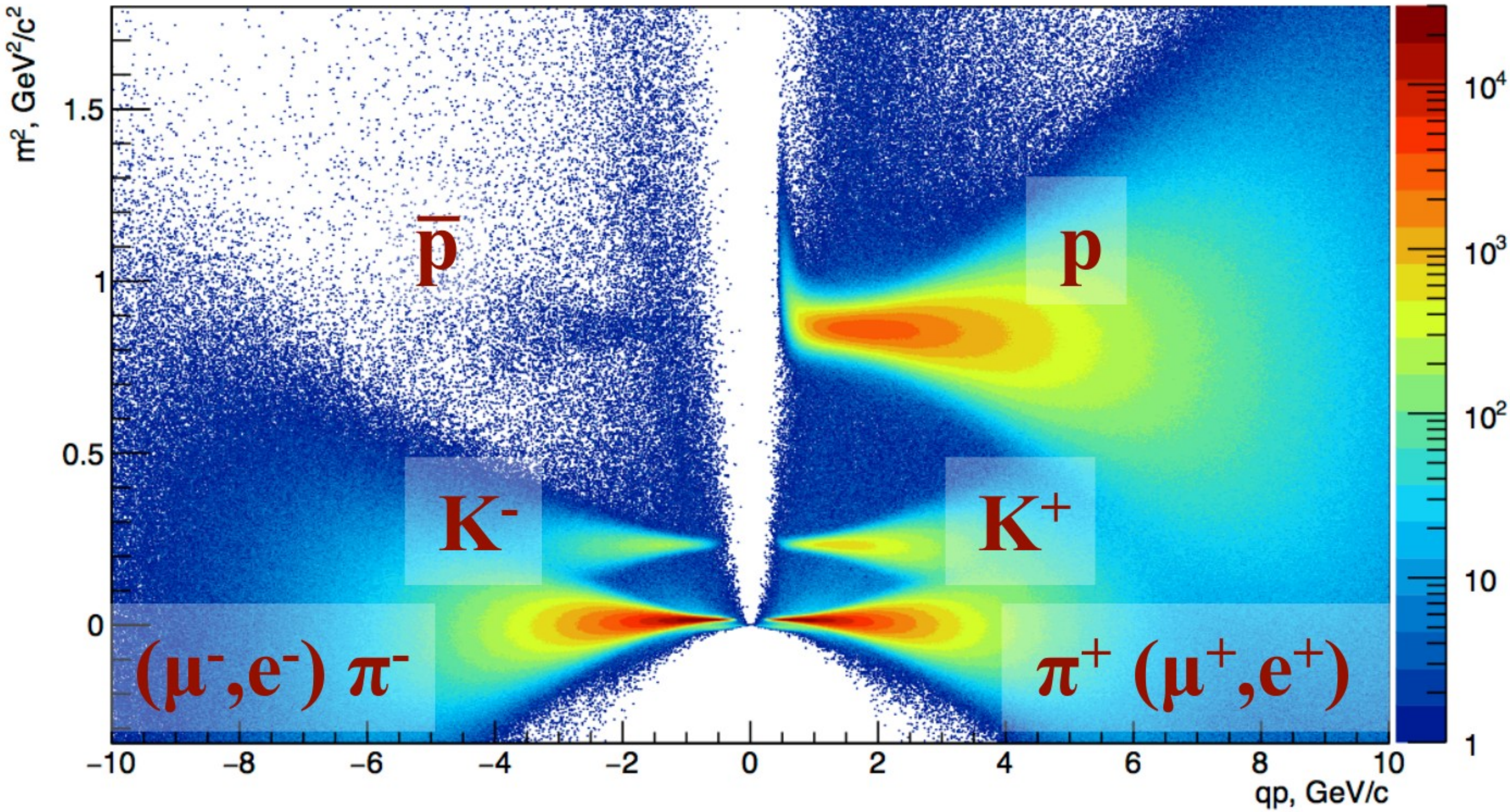
CBM event and track reconstruction

central AuAu@10AGeV



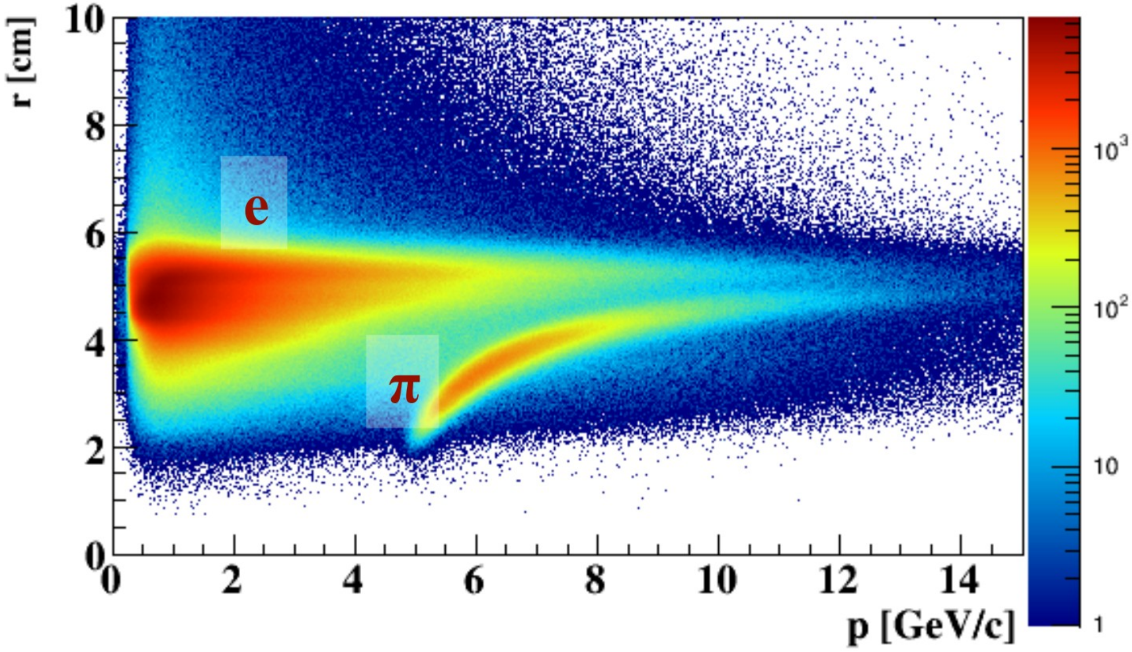
Particle identification: light hadrons

Beta (TOF detector) vs. charge*momentum (STS detector)

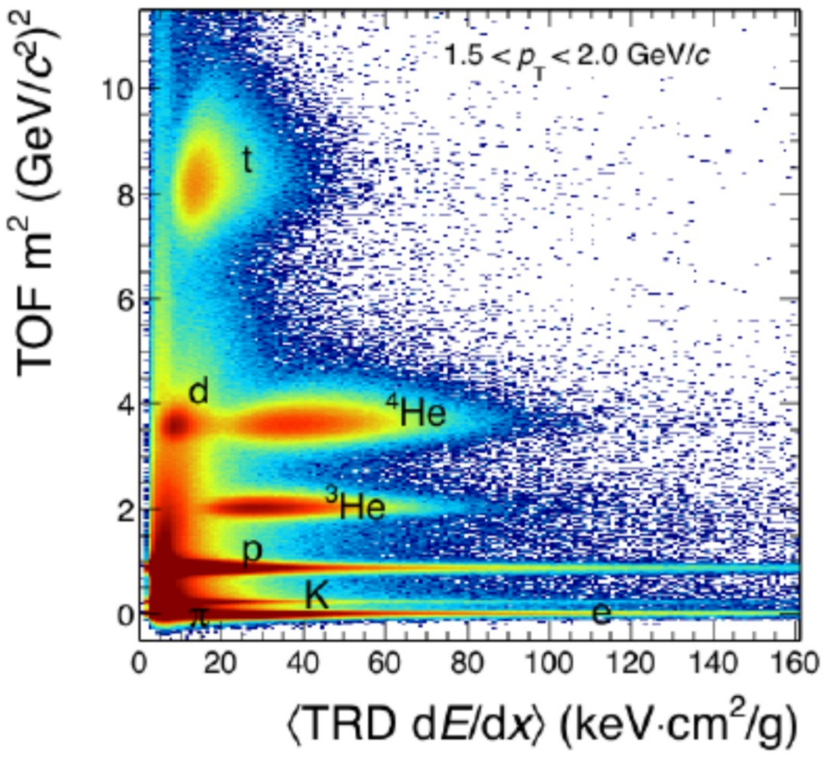


Particle identification: electrons and light nuclei

RICH (electrons)



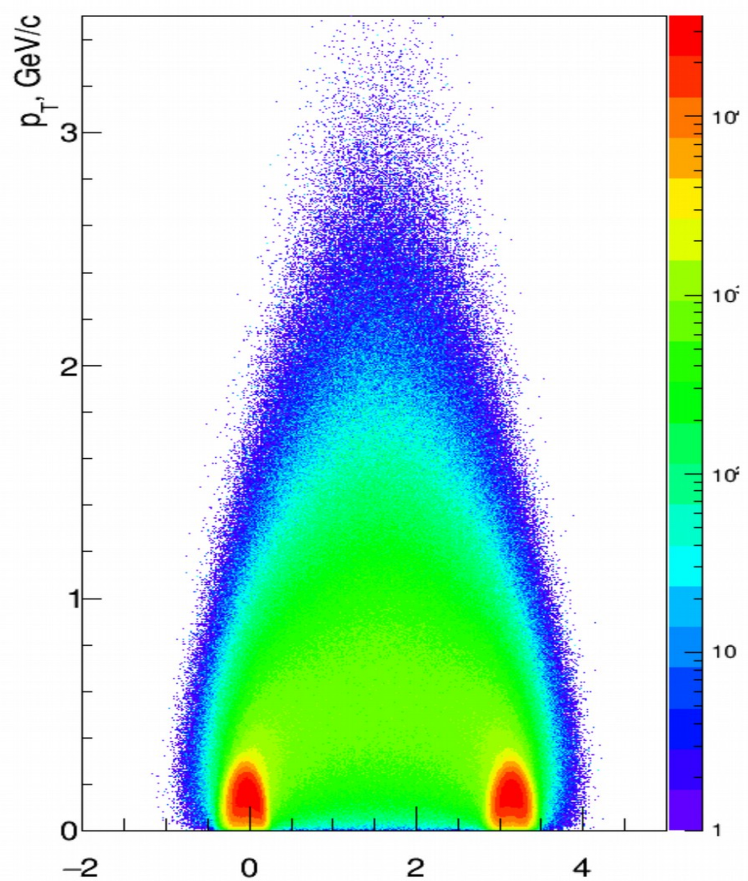
TRD+TOF



Proton identification and acceptance

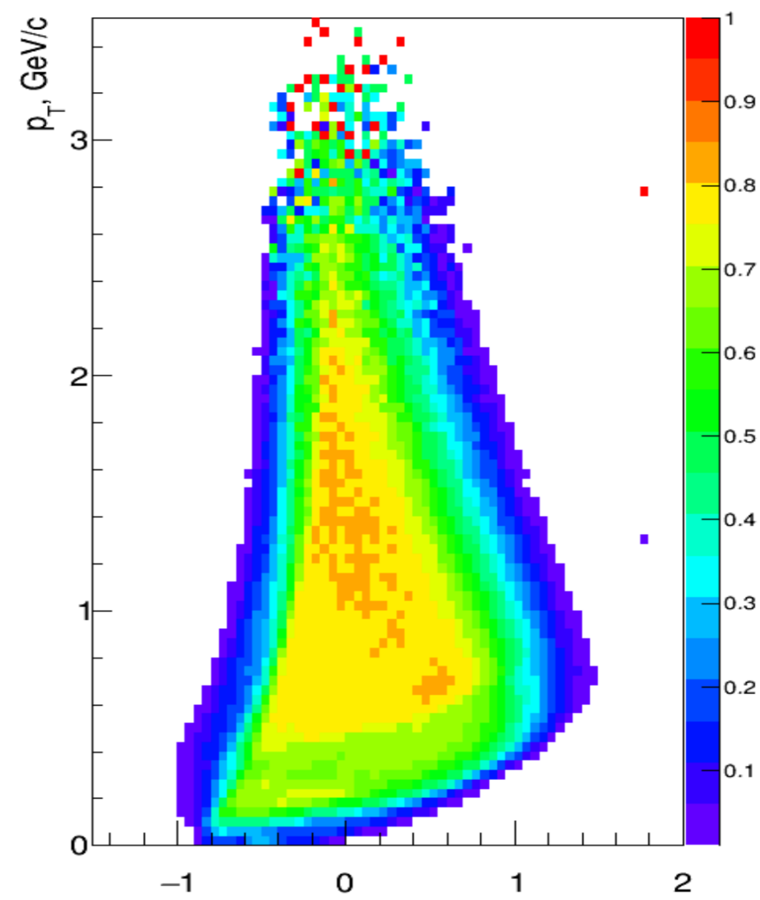
All simulated protons

Au+Au, 10AGeV UrQMD



Lab rapidity

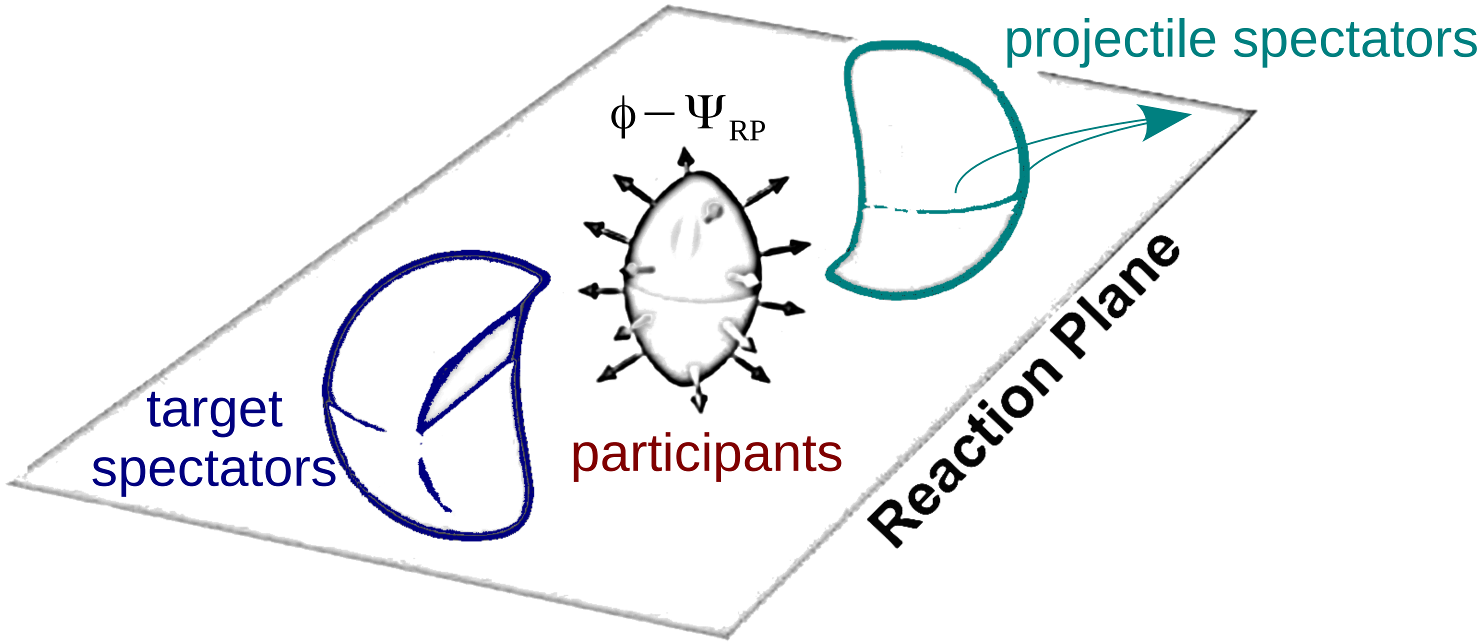
Proton reconstruction efficiency



Center-of-mass rapidity

sufficient proton coverage at midrapidity

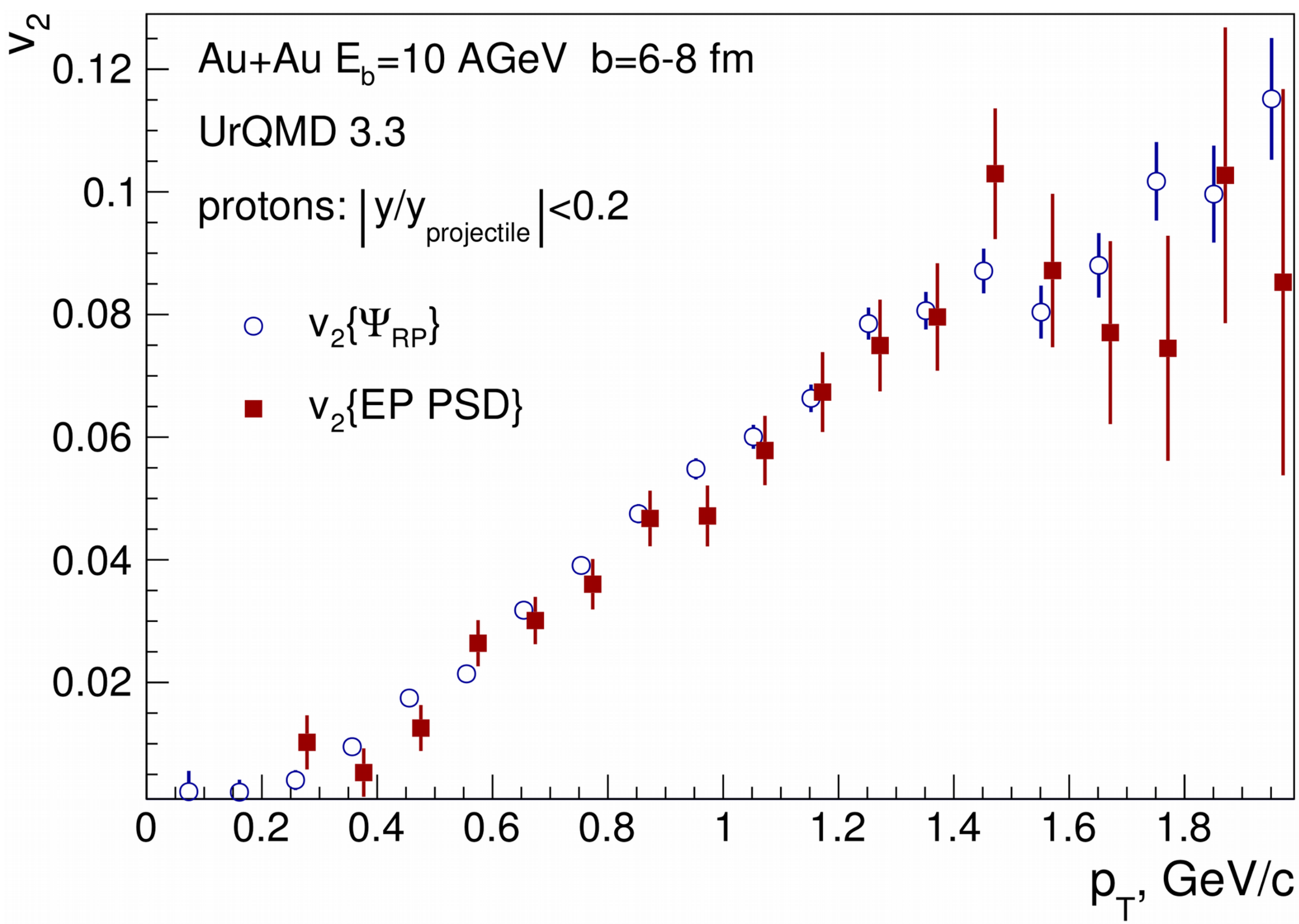
Anisotropic flow & reaction plane determination



Anisotropic flow v_n is defined via Fourier decomposition of azimuthal (φ) distribution of produced particles relative to the reaction plane Ψ_{RP}:

$$v_n\{\Psi_{RP}\} = \langle \cos[n(\phi-\Psi_{RP})] \rangle$$

Performance for elliptic flow (v_2) of protons

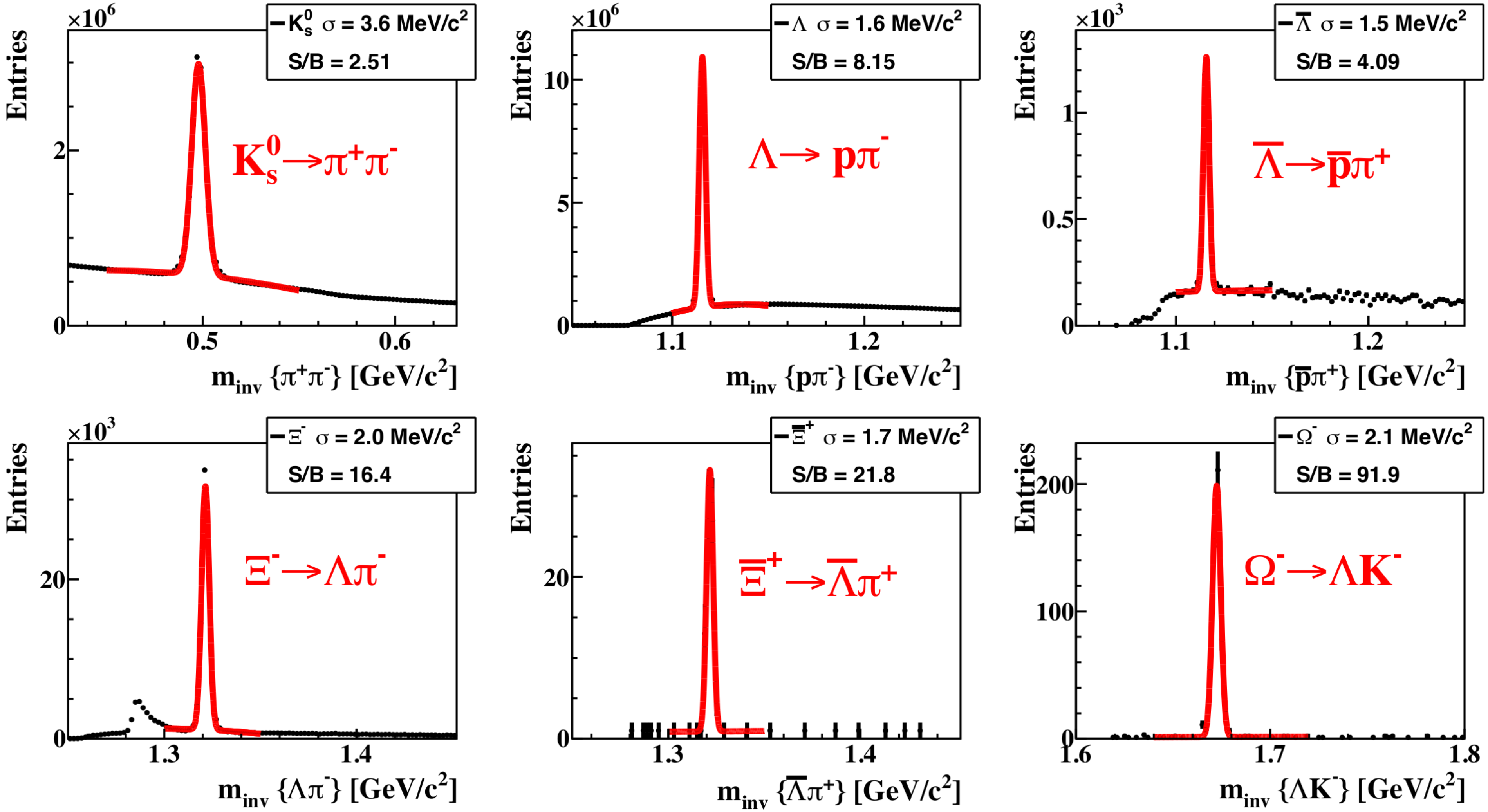


- “input” model v_2 is recovered using “data-driven” method
- Statistical error projections promises high precision measurements of (strange-)baryons v_2 in a wide p_T range between 0.3 - 2.0 GeV/c at mid-rapidity already after 2 months of CBM experiment operation

Reconstred hyperon yields in central collisions

UrQMD central Au+Au E_b=10 AGeV

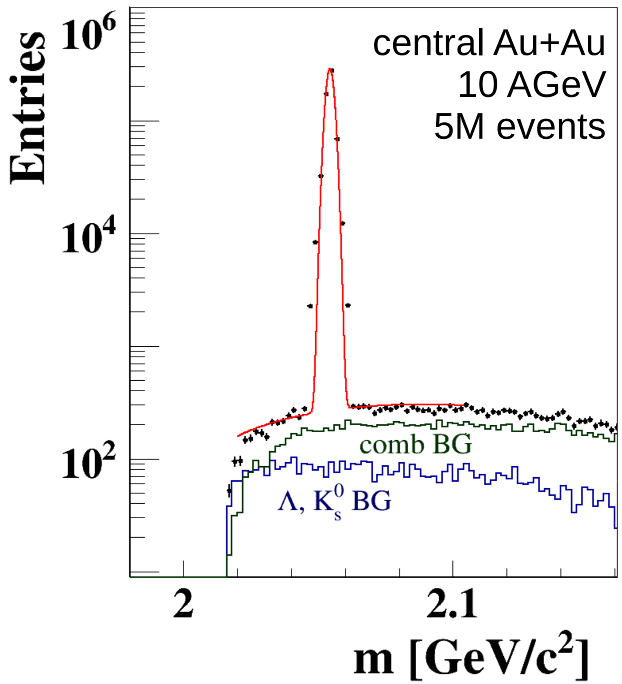
Decay topology reconstruction using the KFParticleFinder



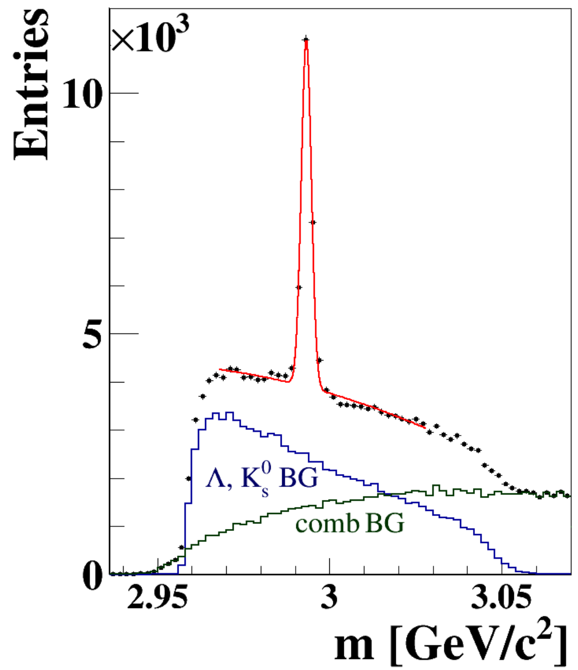
Feasibility of hypernuclei measurements

Branching Ratios: H. Kamada et al., PRC57 1595 (1998)
Background: UrQMD

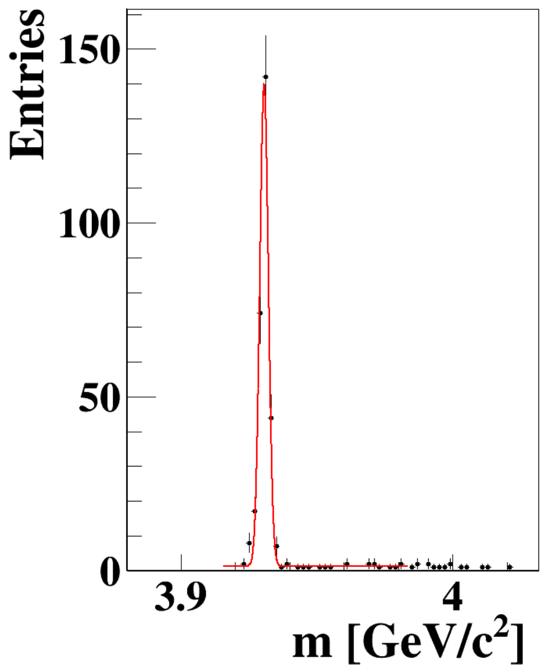
$(\Lambda, N)_{\text{bound}} \rightarrow d + \pi^-$



$^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^-$



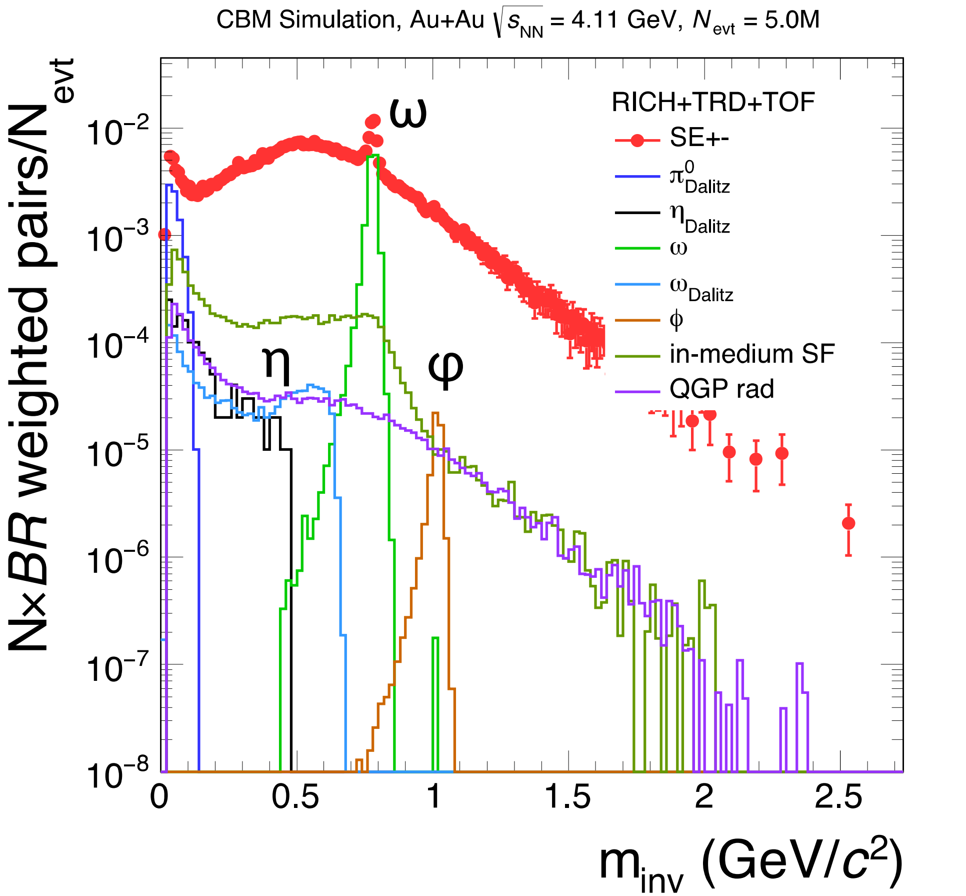
$^{4}_{\Lambda}H \rightarrow {}^{3}He + p + \pi^-$



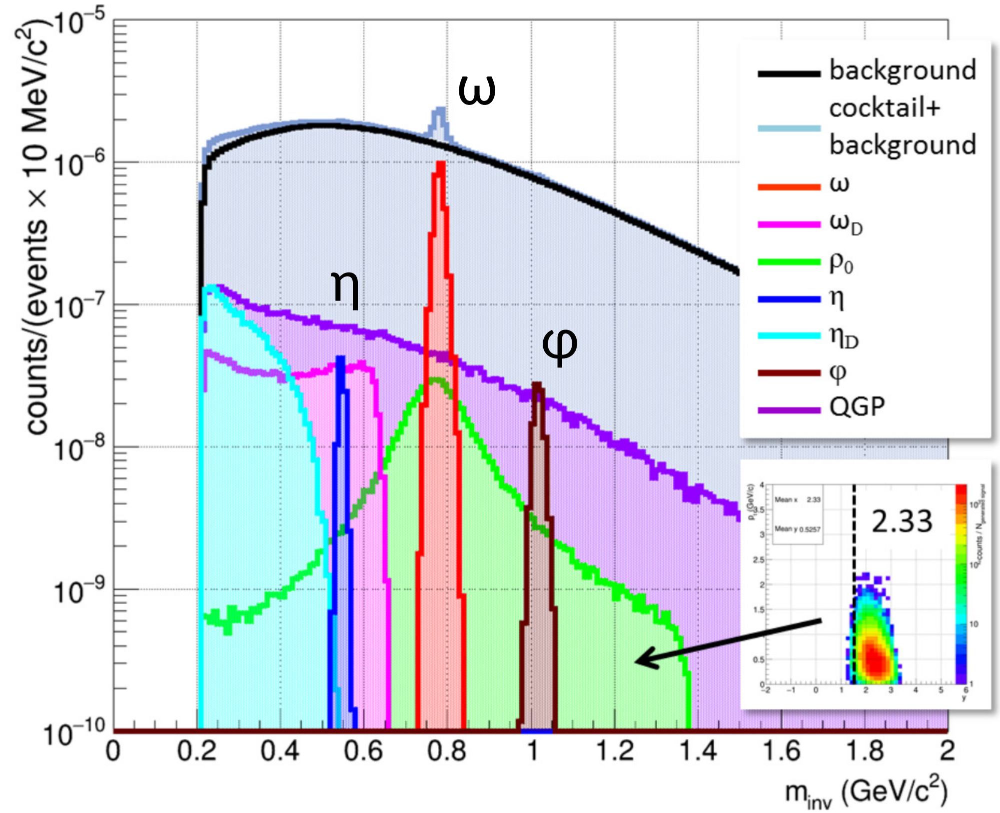
Expected significant statistics to study different hypernuclei

Simulation results for central Au+Au at E_b=8 A GeV

di-electrons

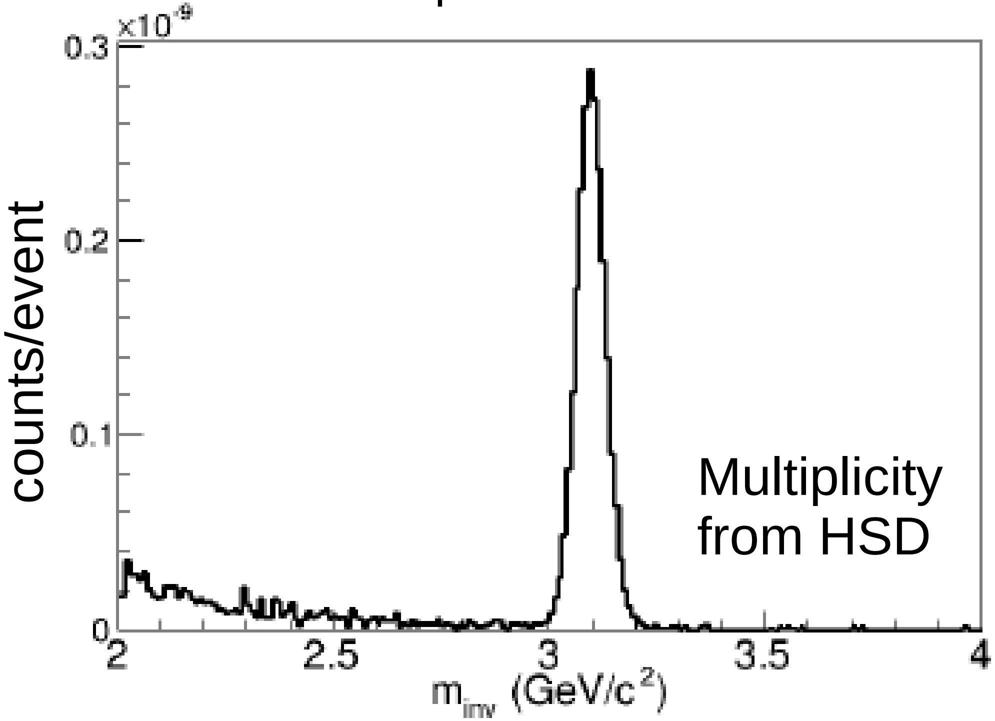


di-muons

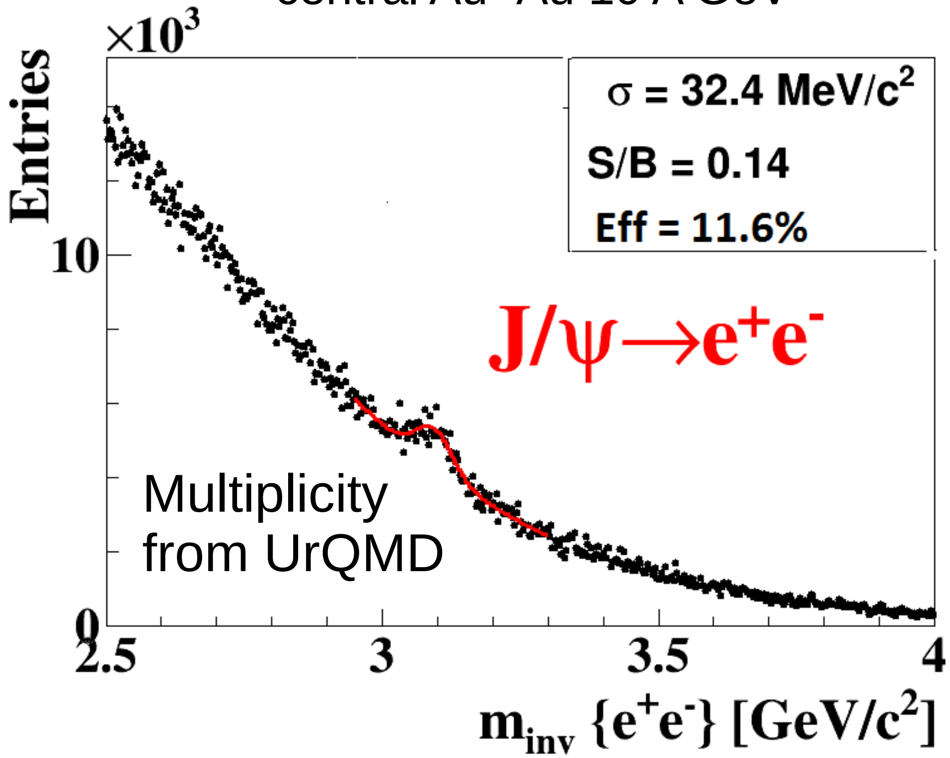


J/ψ → μ⁺μ⁻ / e⁺e⁻ reconstruction

p+Au 30GeV



central Au+Au 10 A GeV



CBM FAIR phase-0 program (before the start of operation in 2024-25)

- Use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) in HADES RICH photon detector (2018)
- Use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)
- 4 Silicon Tracking Stations
  in the BM@N in JINR/Dubna
  (start 2019 with Au-beams up to 4.5 A GeV)
- Project Spectator Detector at the BM@N experiment.
  Tests and performance studies at the NA61/SHINE SPS experiment.
- mini CBM at GSI/SIS18
  full system test with high-rate A-A collisions (2018-2021)

Summary

CBM physics program at SIS100:

- Precision study of the QCD phase diagram in the region of extreme high net-baryon densities. Discovery potential

Unique measurements of rare diagnostic probes with CBM:

- High-precision multi-differential measurements of hadrons incl. multistrange hyperons and dileptons for different beam energies and collision systems.

Key experimental requirements:

- high-rate capability of detectors and DAQ
- online event reconstruction and selection

Status of CBM experiment preparation:

- Technical Design Reports: 6 approved, 3 in preparation
- Extensive performance studies for many physics observables
- Intermediate FAIR phase-0 program