Compressed Baryonic Matter experiment at FAIR

Ilya Selyuzhenkov

(GSI / EMMI / MEPhI)

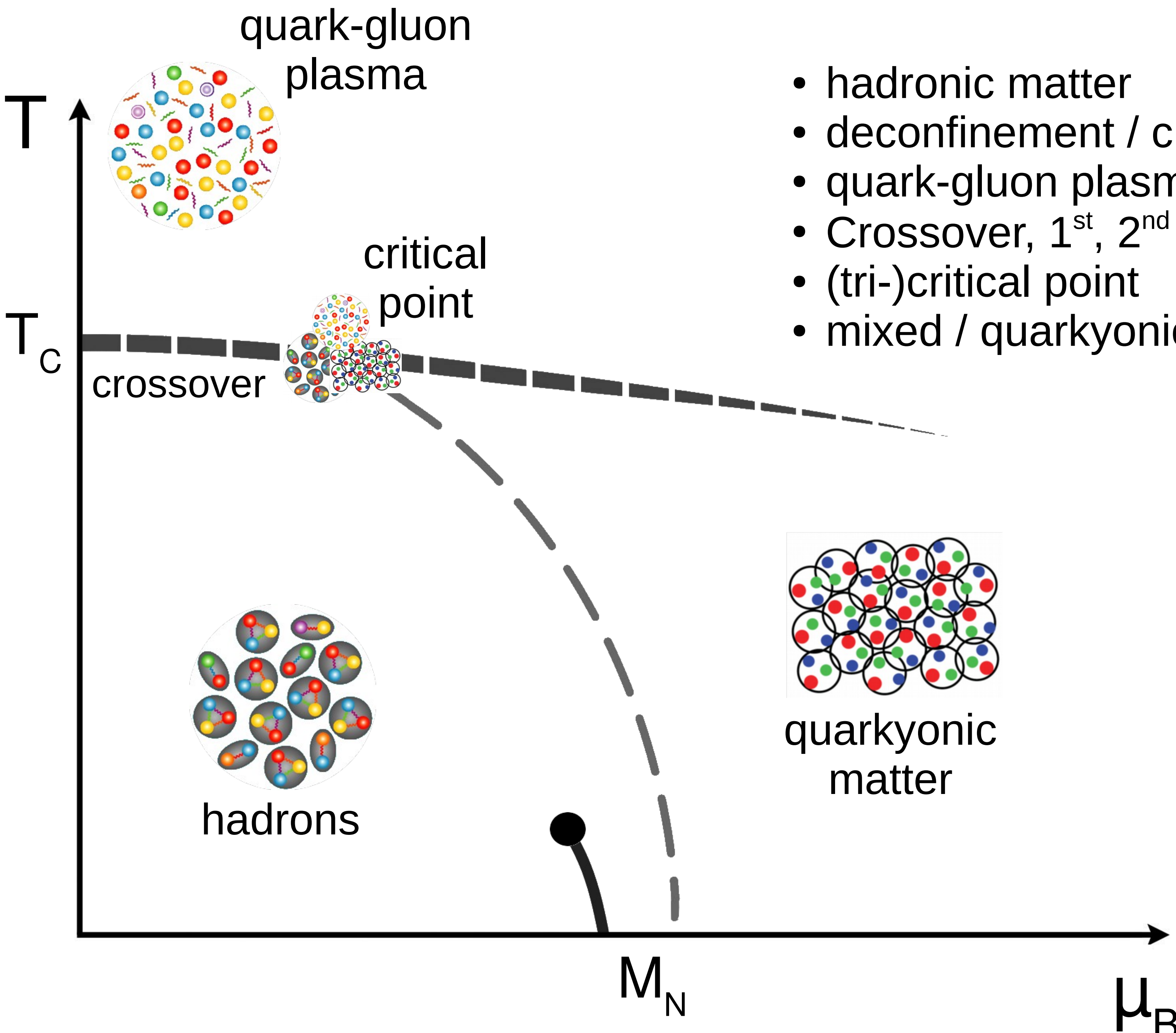
for the CBM Collaboration

FAIR next generation scientists - 5th Edition Workshop

Sitges (Spain)

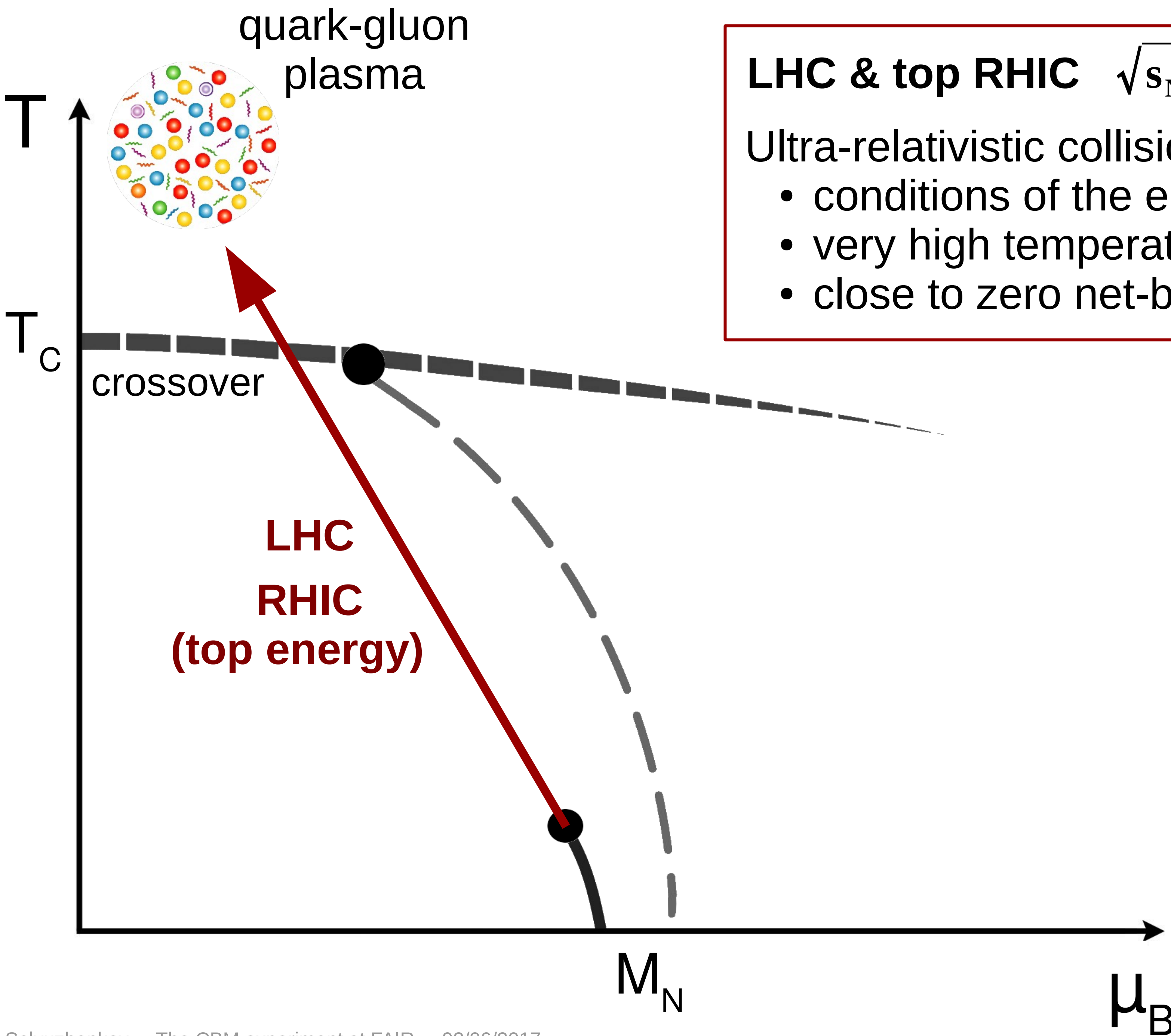
June 2, 2017

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 (?)

Experimental explorations: QGP properties

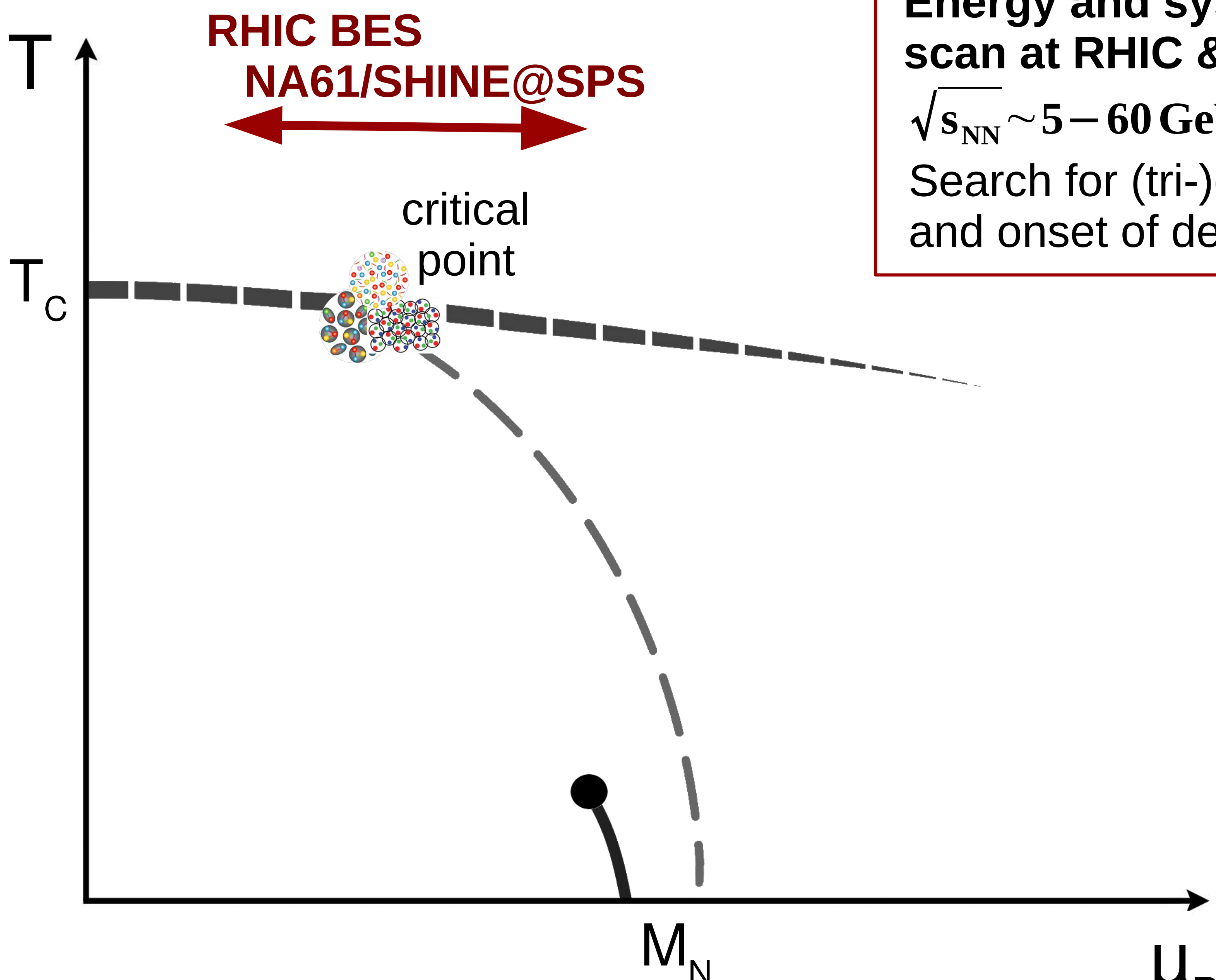


LHC & top RHIC $\sqrt{s_{NN}} \sim 0.2 - 5\,\mathrm{TeV}$

Ultra-relativistic collisions:

- conditions of the early universe
- very high temperature
- close to zero net-baryon density

Experimental explorations: critical point



Energy and system size scan at RHIC & SPS

$$\sqrt{s_{NN}} \sim 5 - 60\,\mathrm{GeV}$$

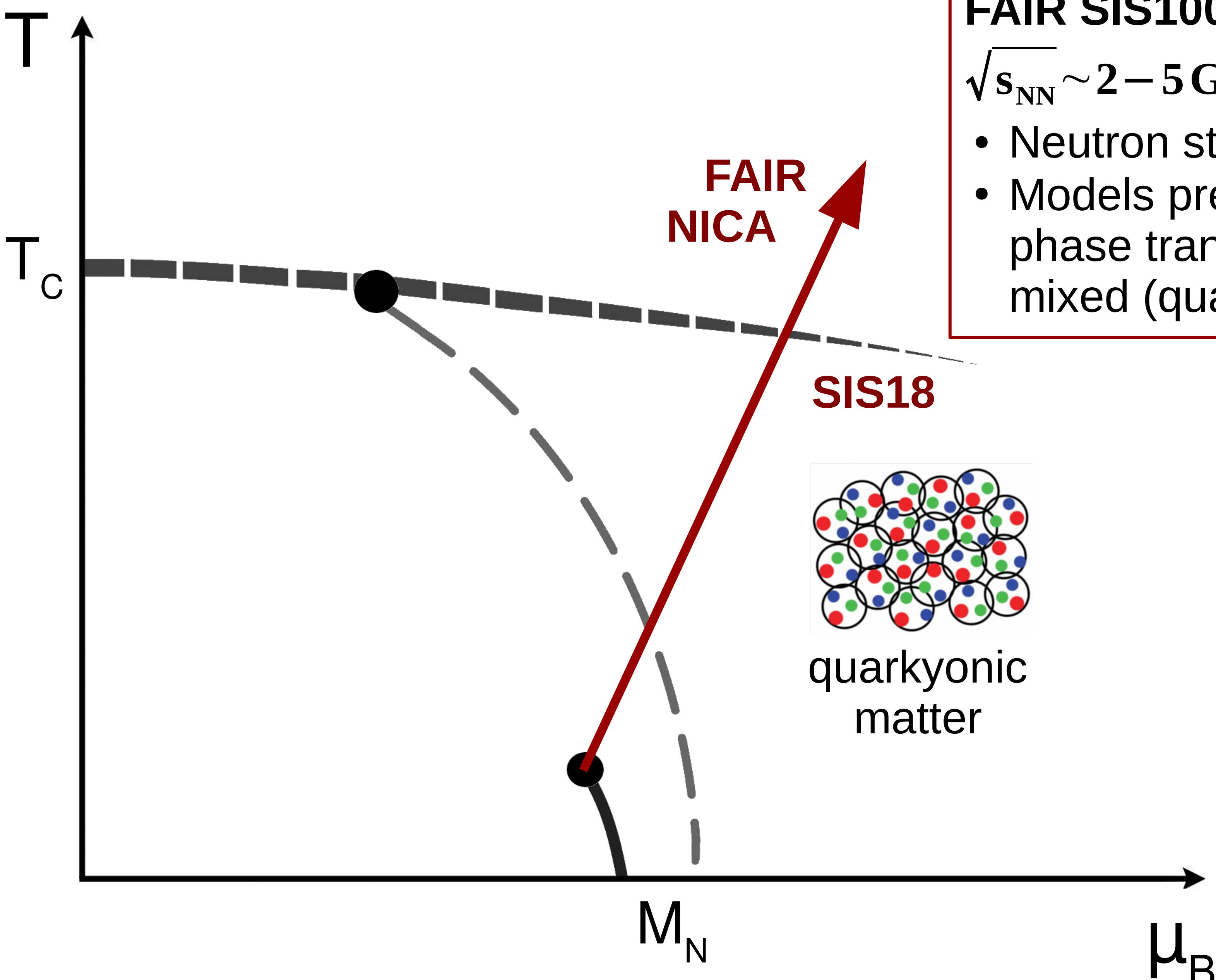
Search for (tri-)critical point and onset of deconfinement

Experimental explorations: Large net-baryon densities

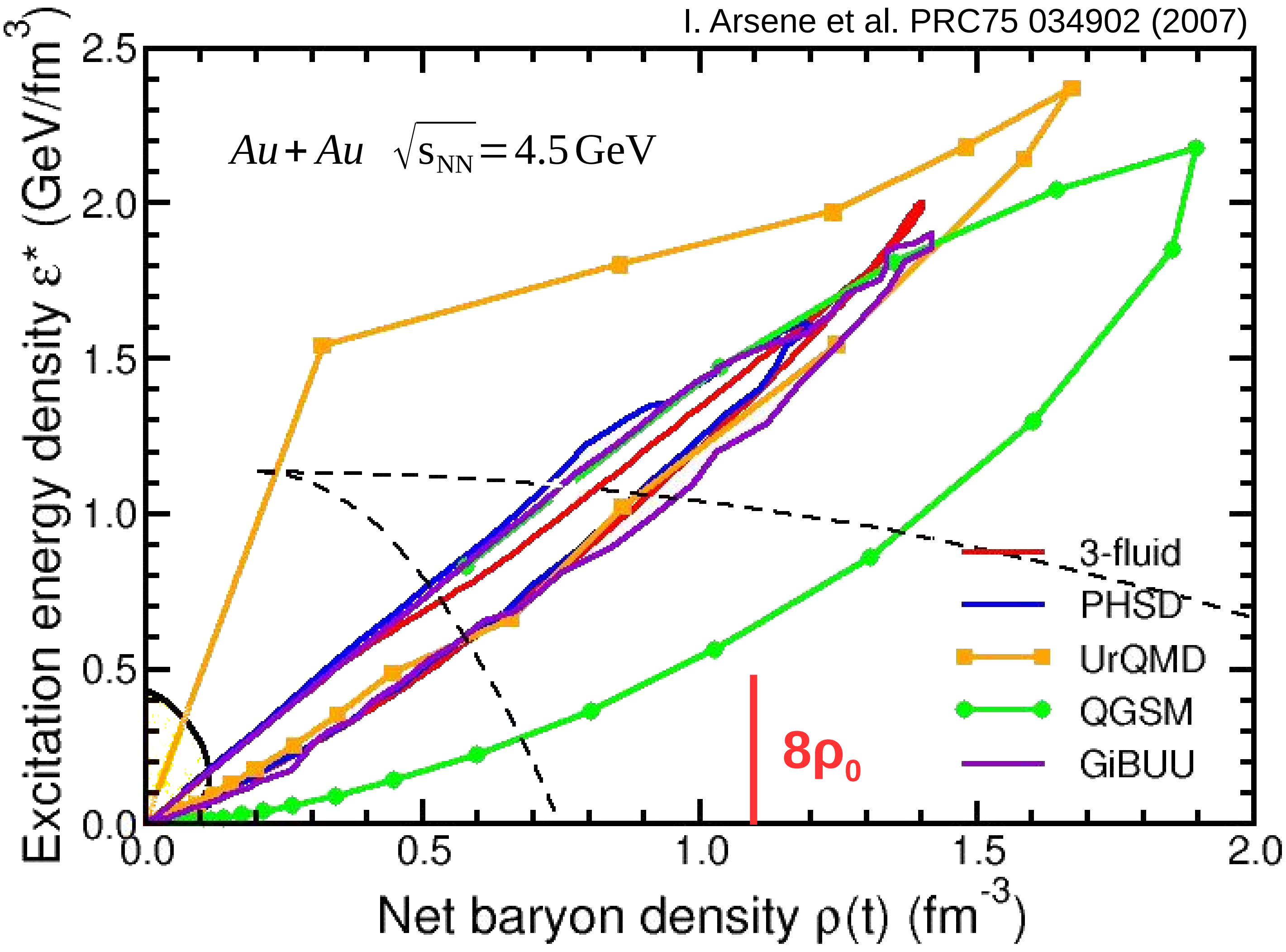
FAIR SIS100, NICA, SIS18

$\sqrt{s_{NN}} \sim 2-5\,\mathrm{GeV}$

- Neutron star densities
- Models predict 1st order phase transition with mixed (quarkyonic) phase



Net-baryon density at SIS100 FAIR energies



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

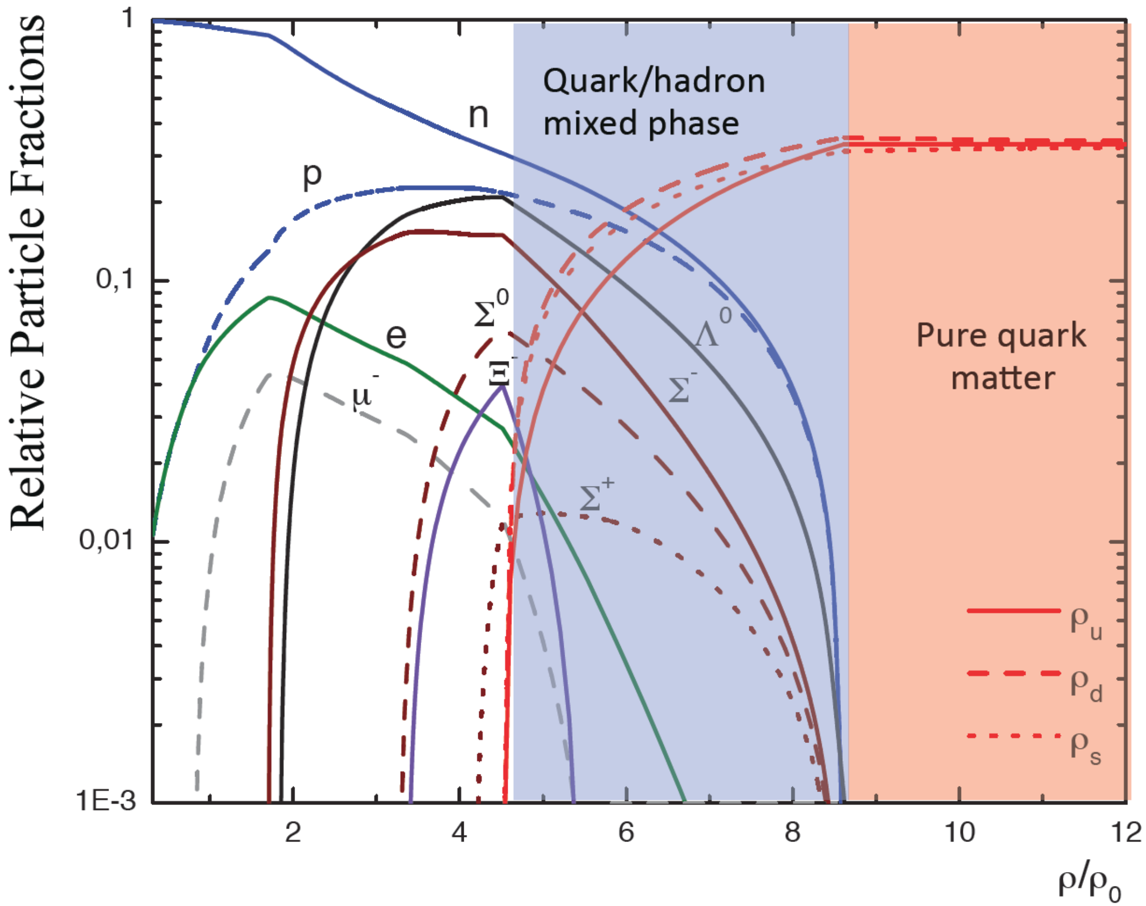
- experimentally access the region of mixed / quarkyonic phase

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)



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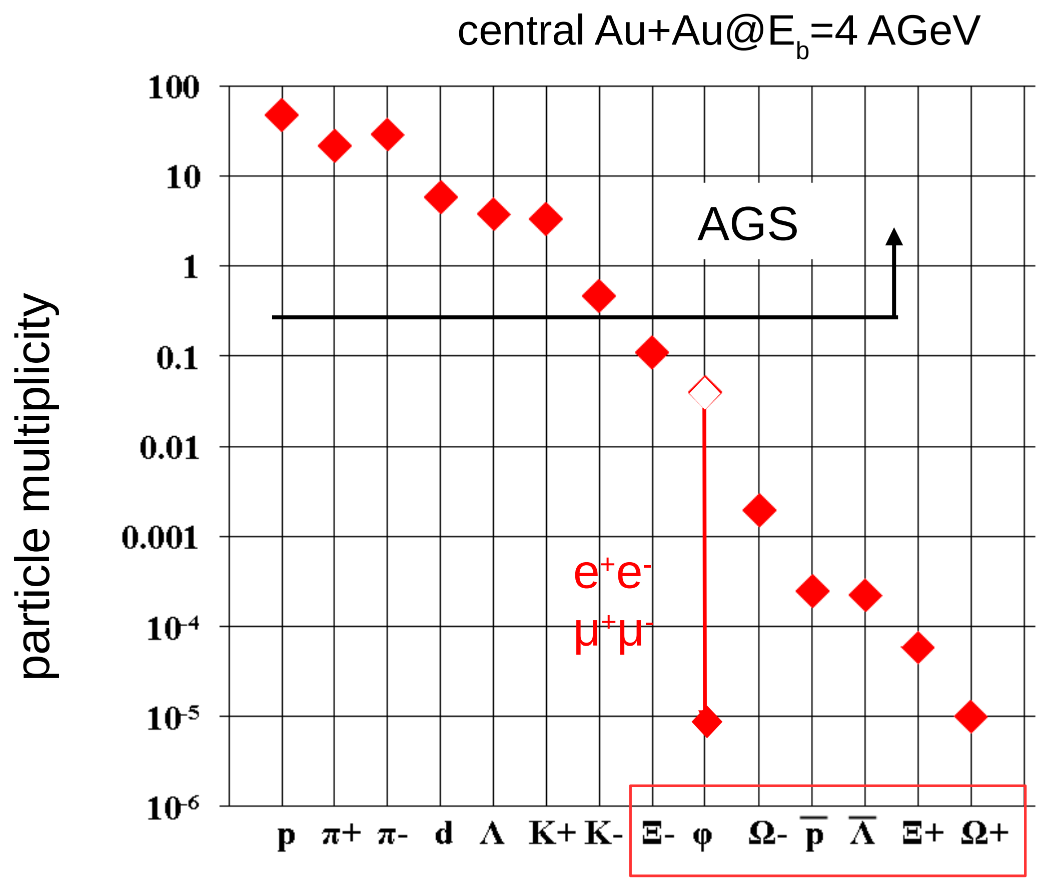


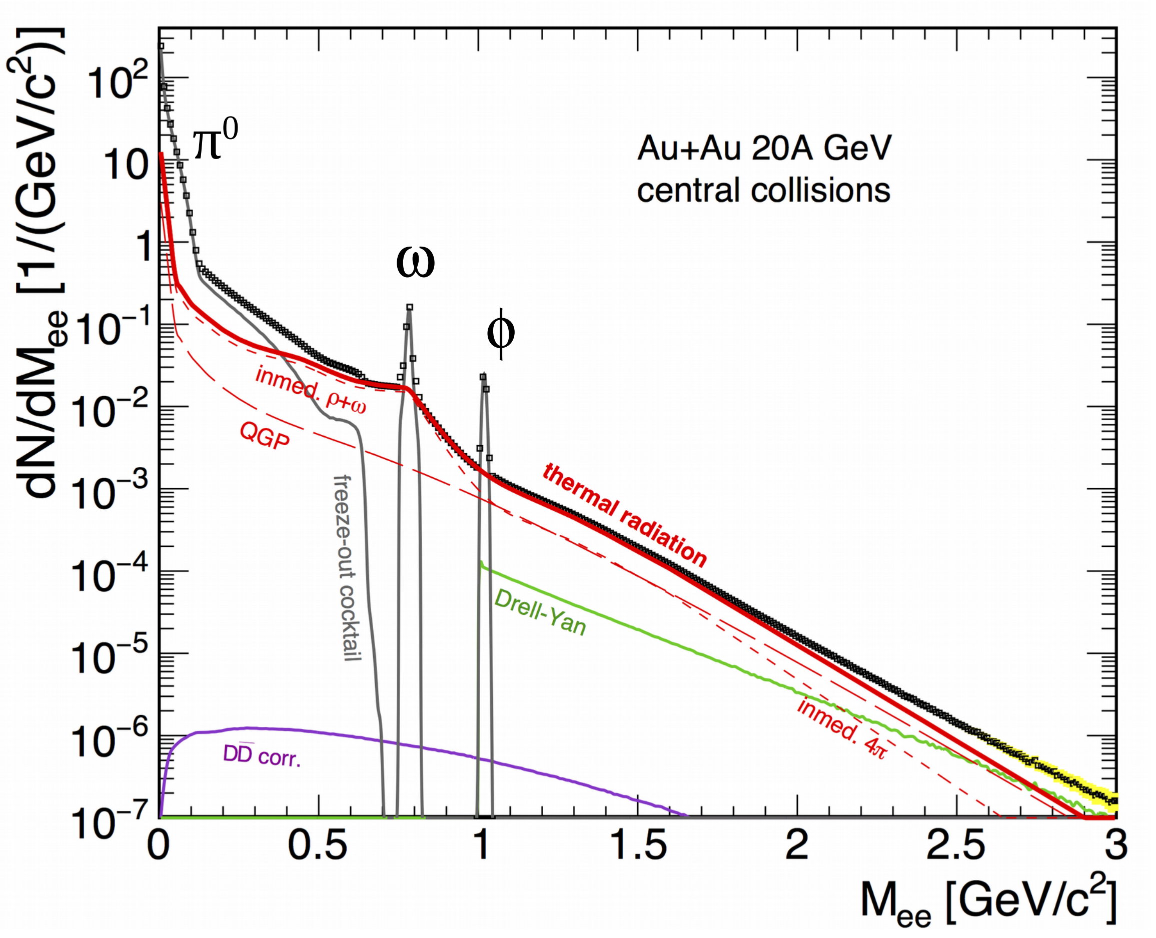
Stat.model, A. Andronic

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

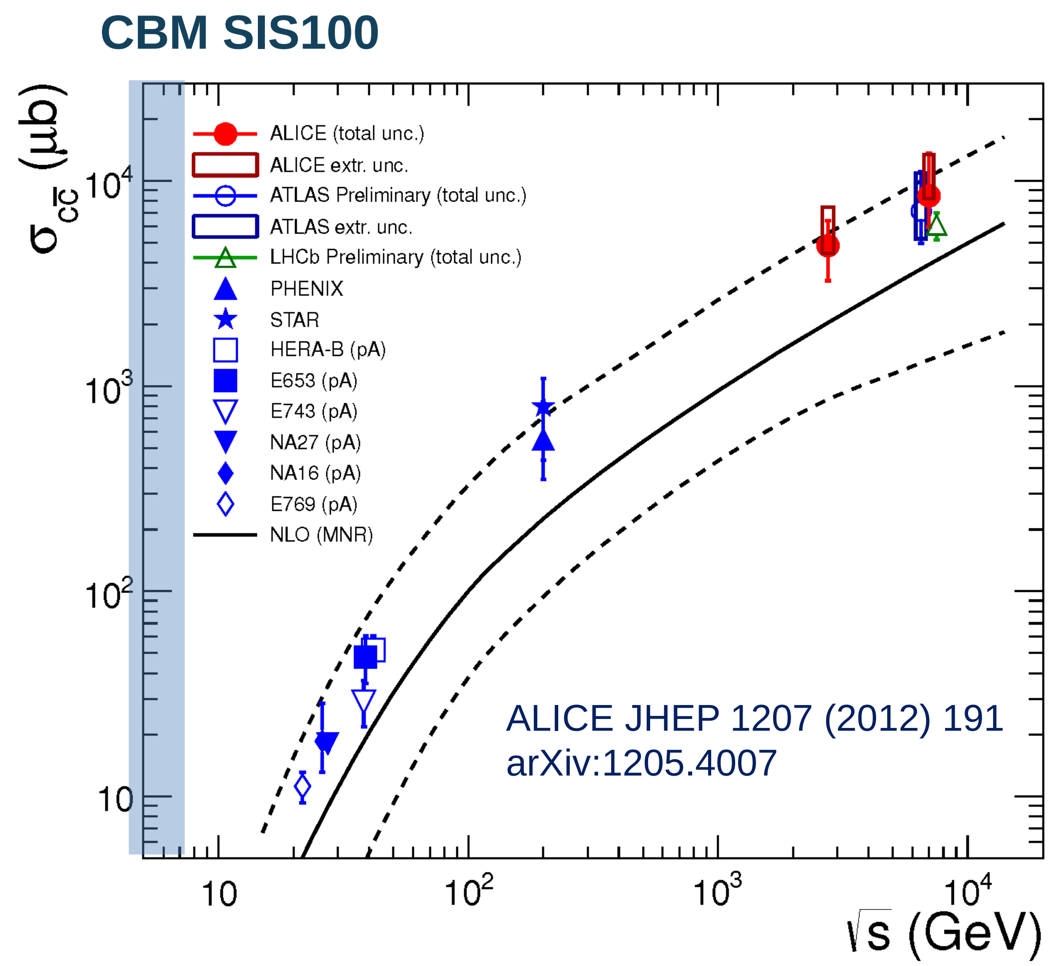
Electromagnetic radiation of produced matter



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

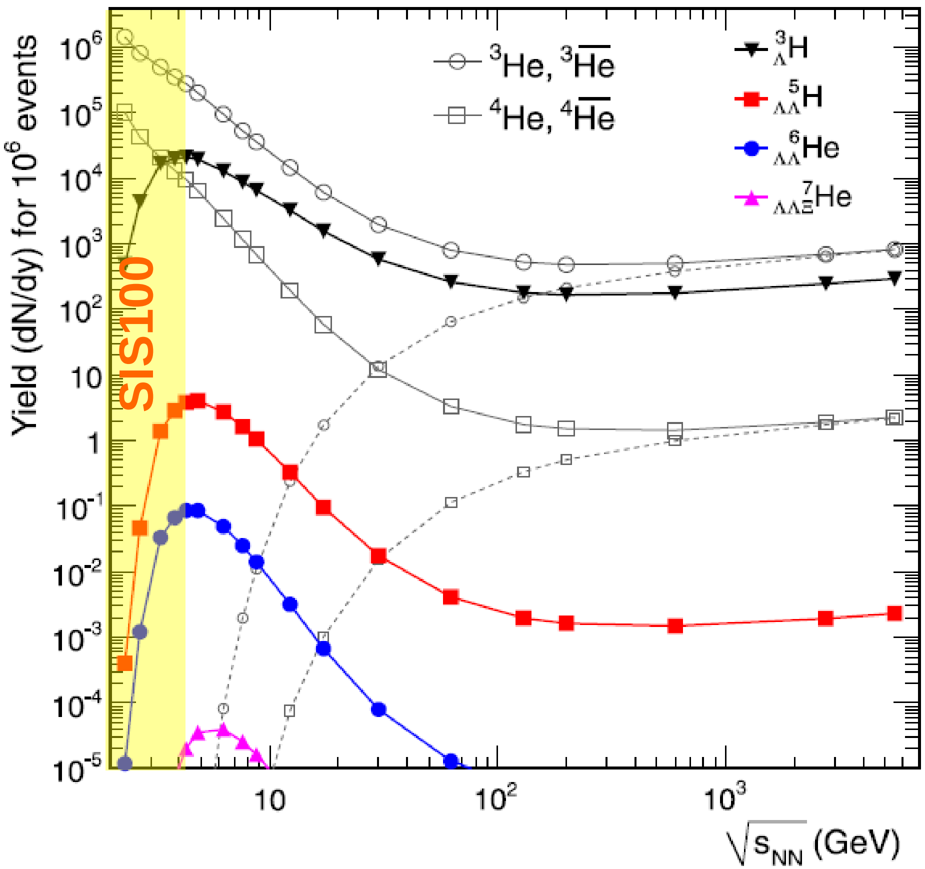


CBM physics and observables

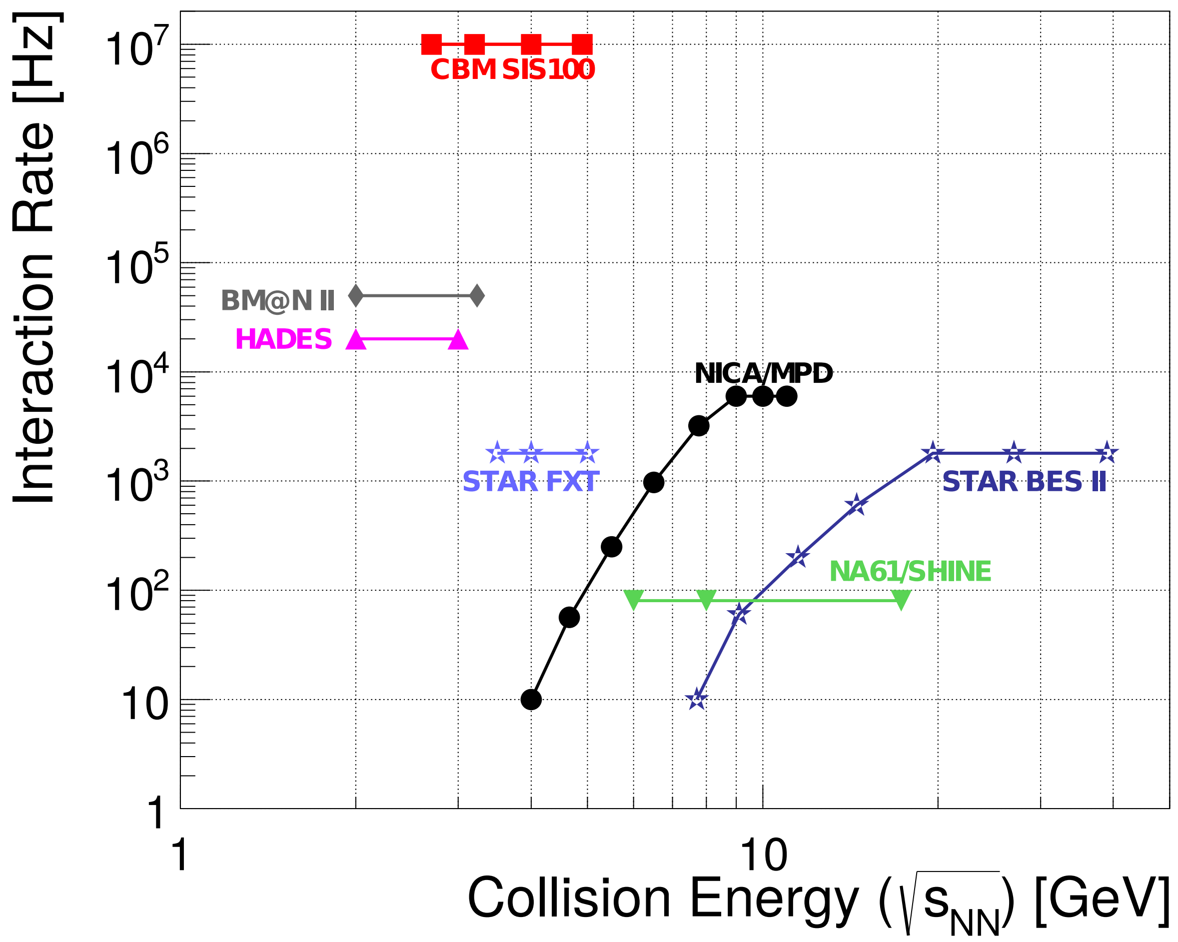
Strange nuclear matter:

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

A. Andronic, PLB697 203 (2011)



Main experimental requirements



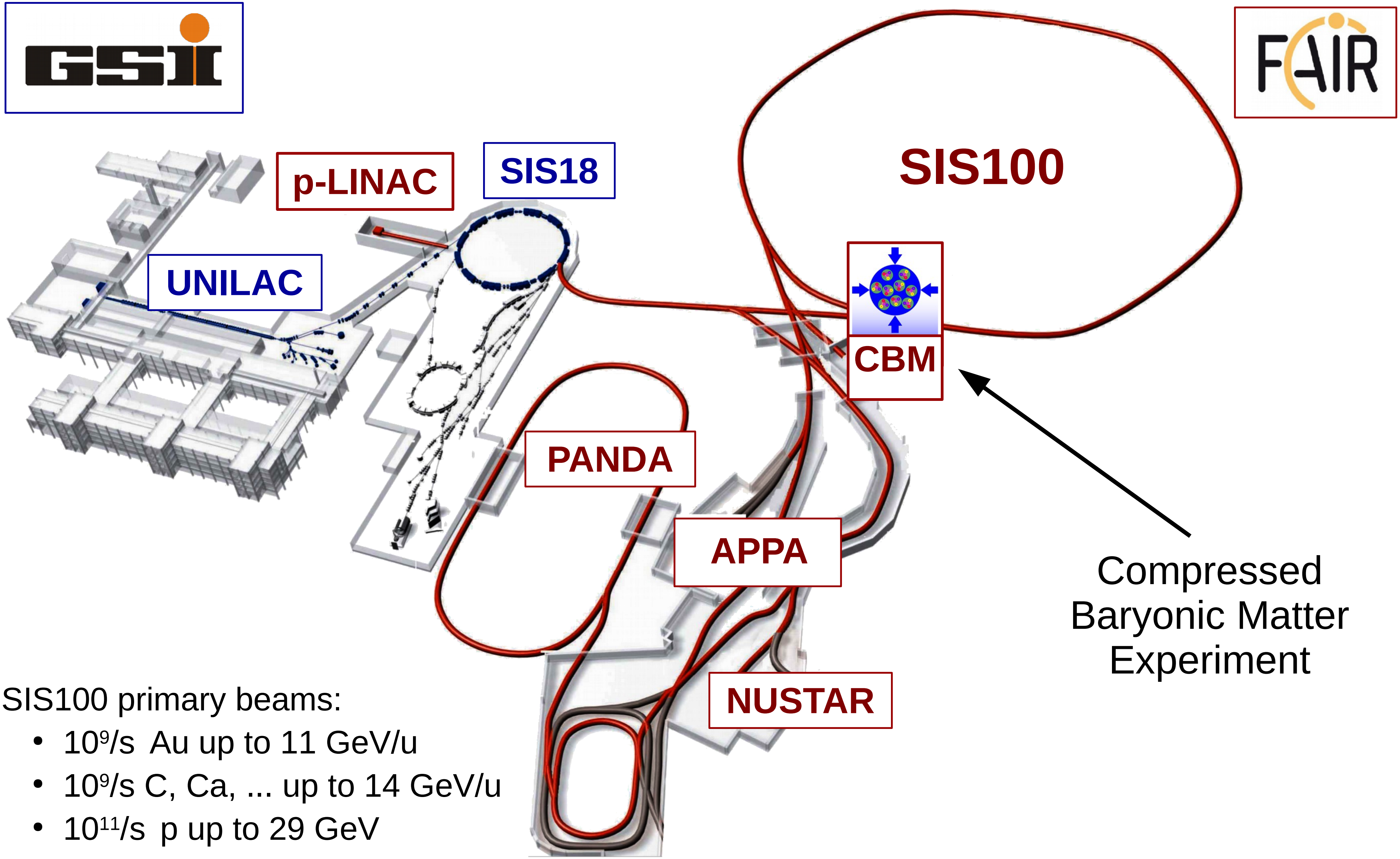
High statistics means high reaction rates:

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 ($\sigma \approx 50\ \mu m$) 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

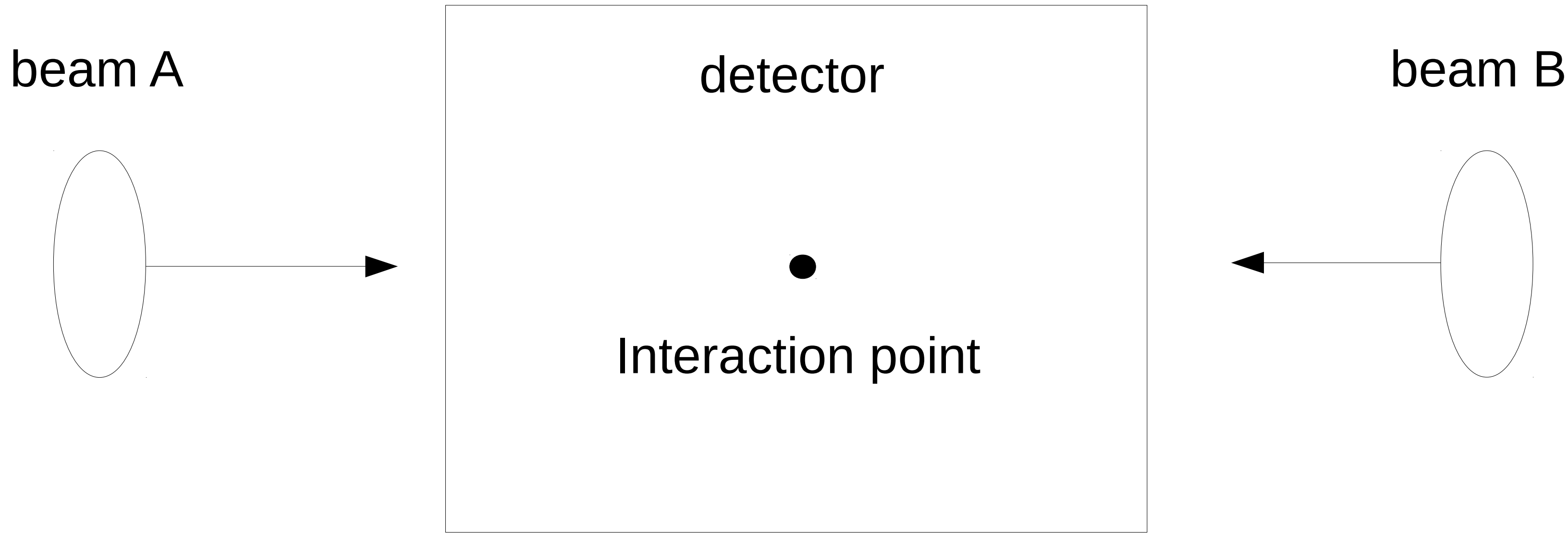
CBM at FAIR, Darmstadt



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

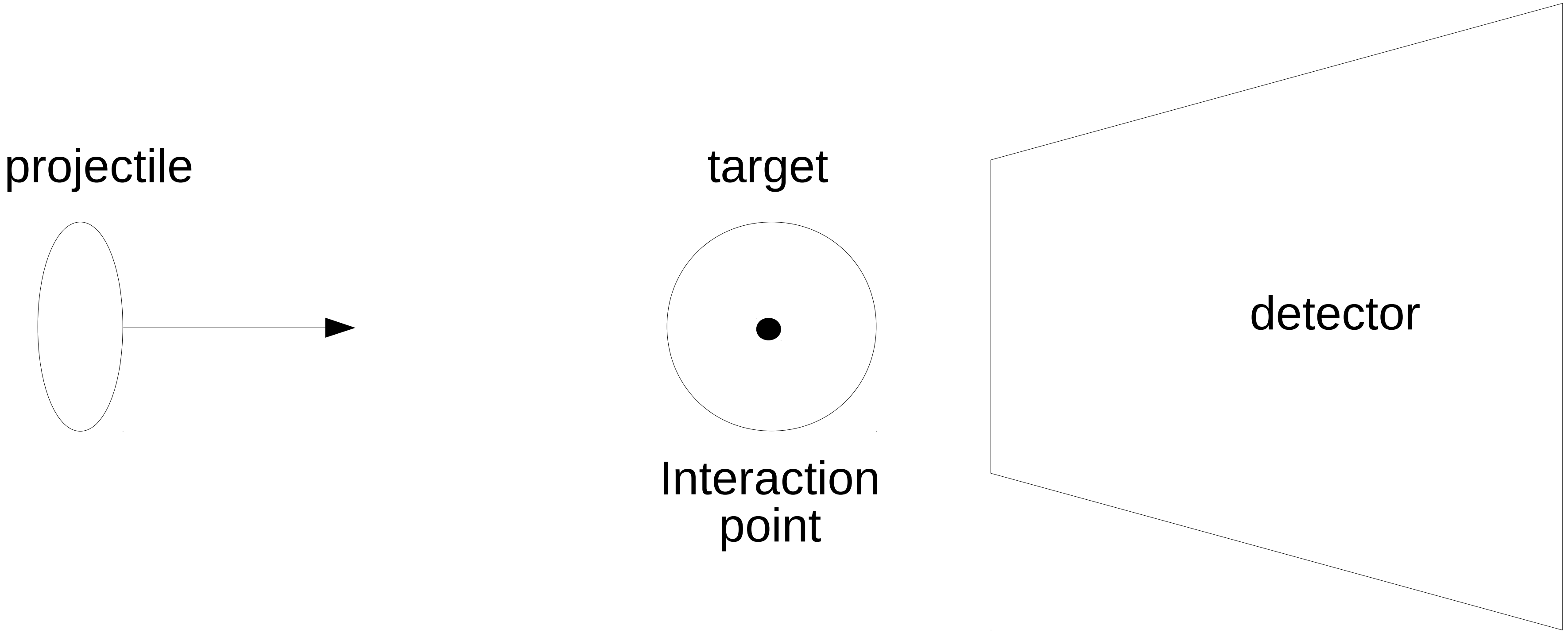
Fixed target vs. collider experiments



Pros: symmetry acceptance: forward – backward
Acceptance (in the collision center-of-mass)
do not changes with beam energy

Cons: hard to reach high luminosity

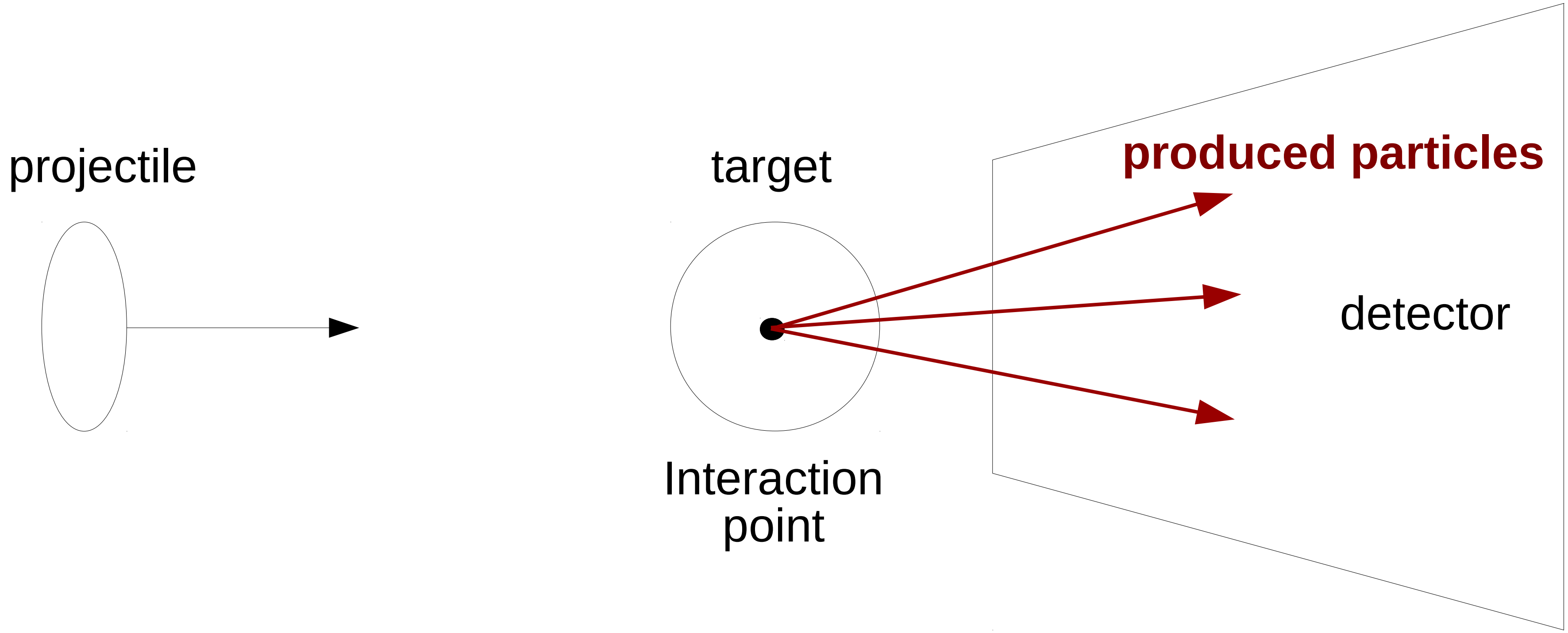
Fixed target vs. collider experiments



Cons: Asymmetric acceptance: only forward hemisphere
Acceptance (in the collision center-of-mass) changes with beam energy

Pros: Easy to reach high luminosity → thicker target

CBM is a fixed target experiment



Need to measure as many particles as possible and

particles kinematics (energy/momentum)

type of the particles (mass, charge)

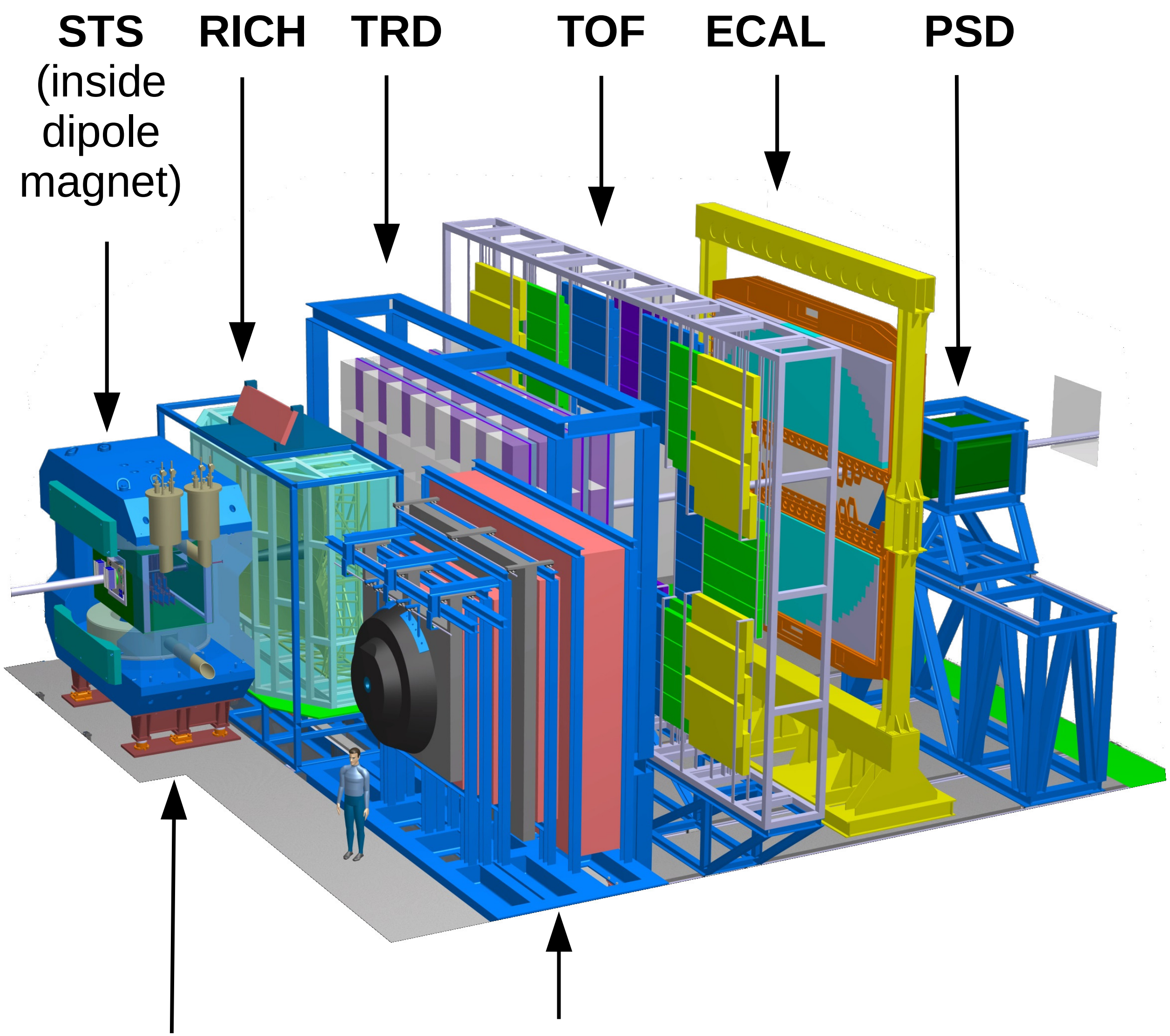
CBM building layout

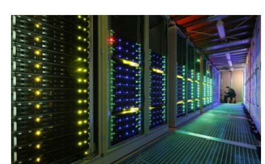
HADES: p+p, p+A, A+A
limited to low multiplicity A+A
optimized for dileptons

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)

TRD (Transition Radiation Detector)
electron identification

TOF (Time of Flight detector)
hadron identification

MUCH (MUon CHambers)
muon identification

ECAL (Electromagnetic Calorimeter)
electron/photon identification

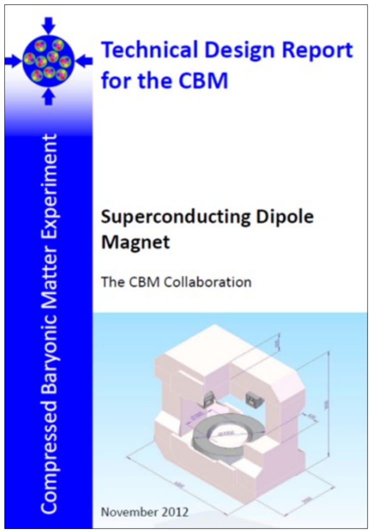
PSD (Projectile Spectator Detector)
collision centrality and
reaction plane determination

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

Subsystems preparation status

TDRs approved by FAIR

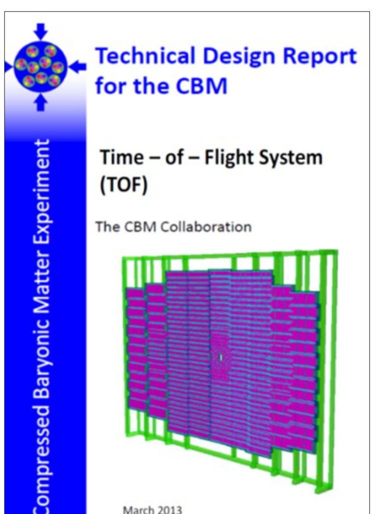
Dipole Magnet



STS

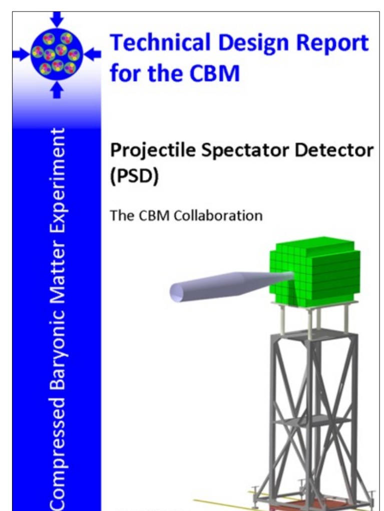
RICH

TOF



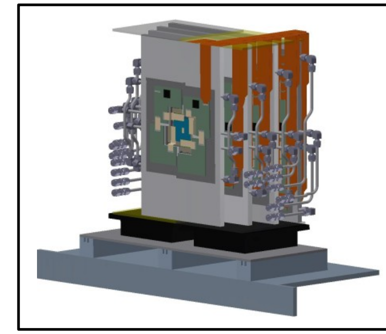
MUCH

PSD

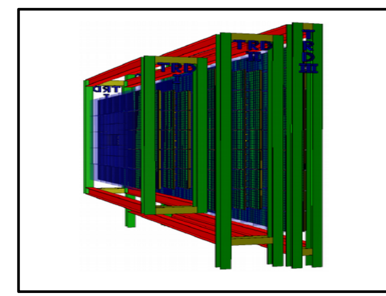


TDR in preparation

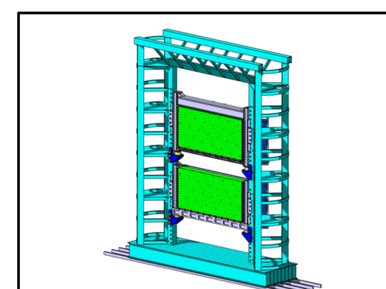
MVD



TRD



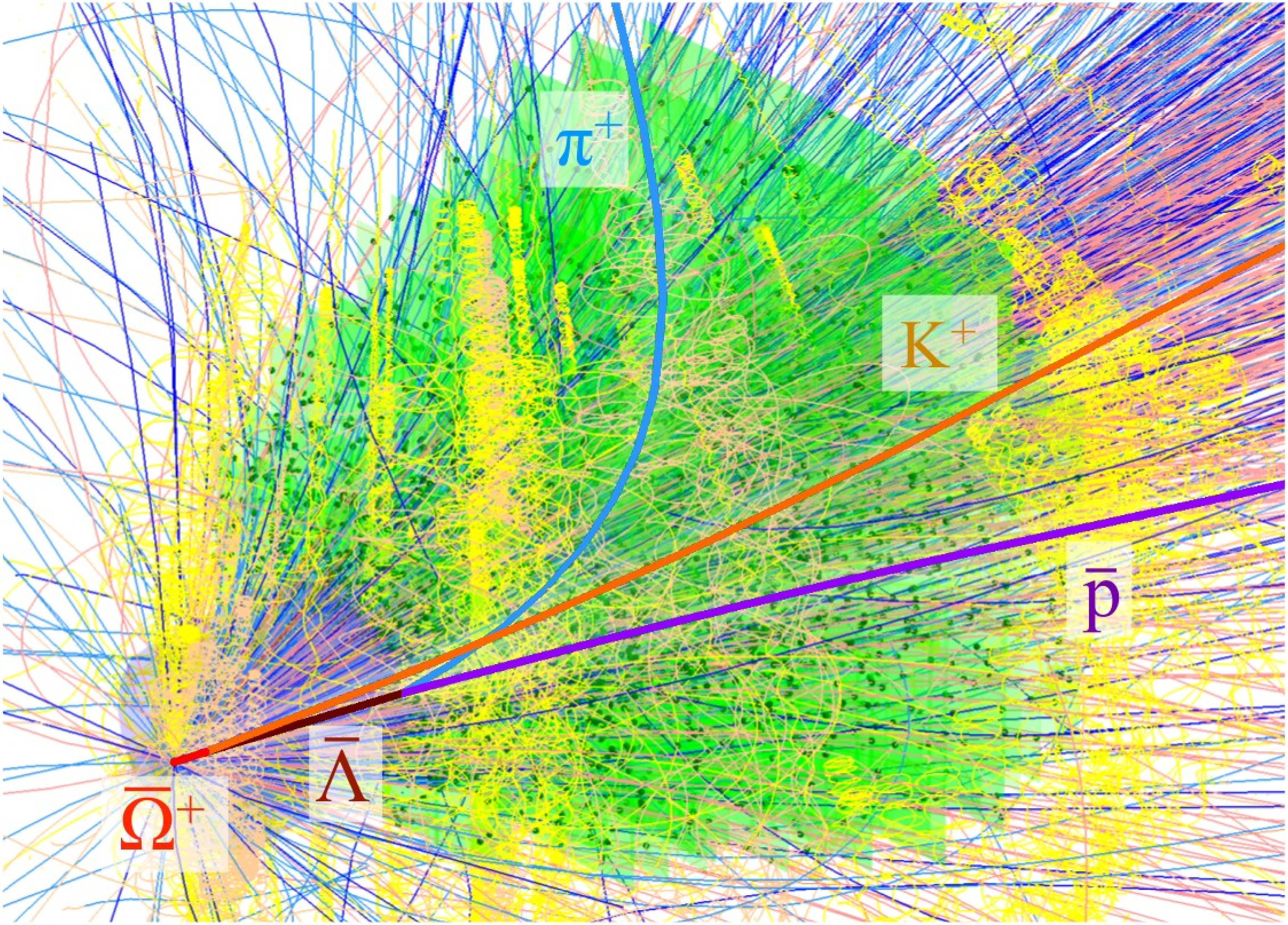
ECAL



FLES

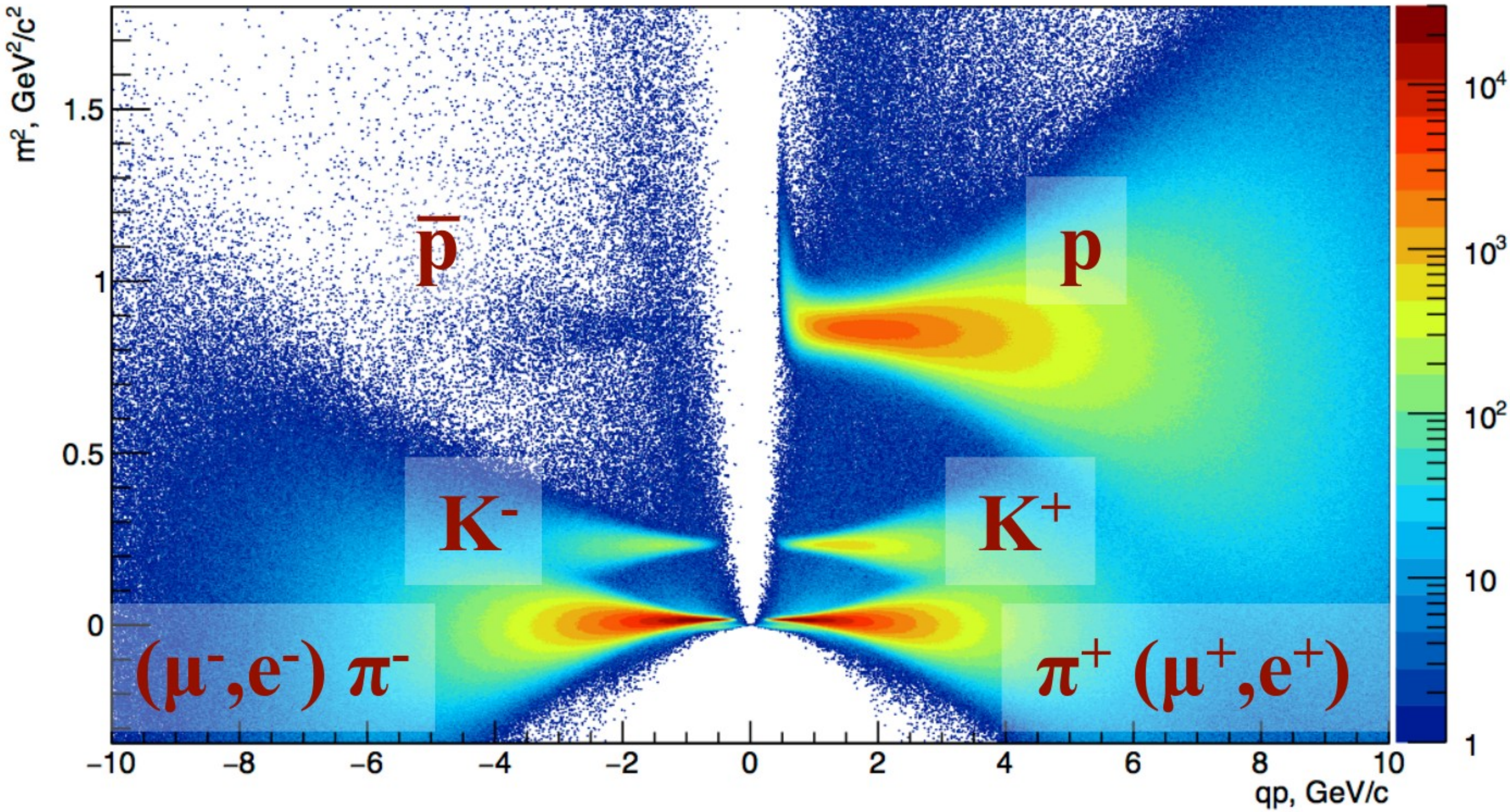
CBM event and track reconstruction

central AuAu@10AGeV



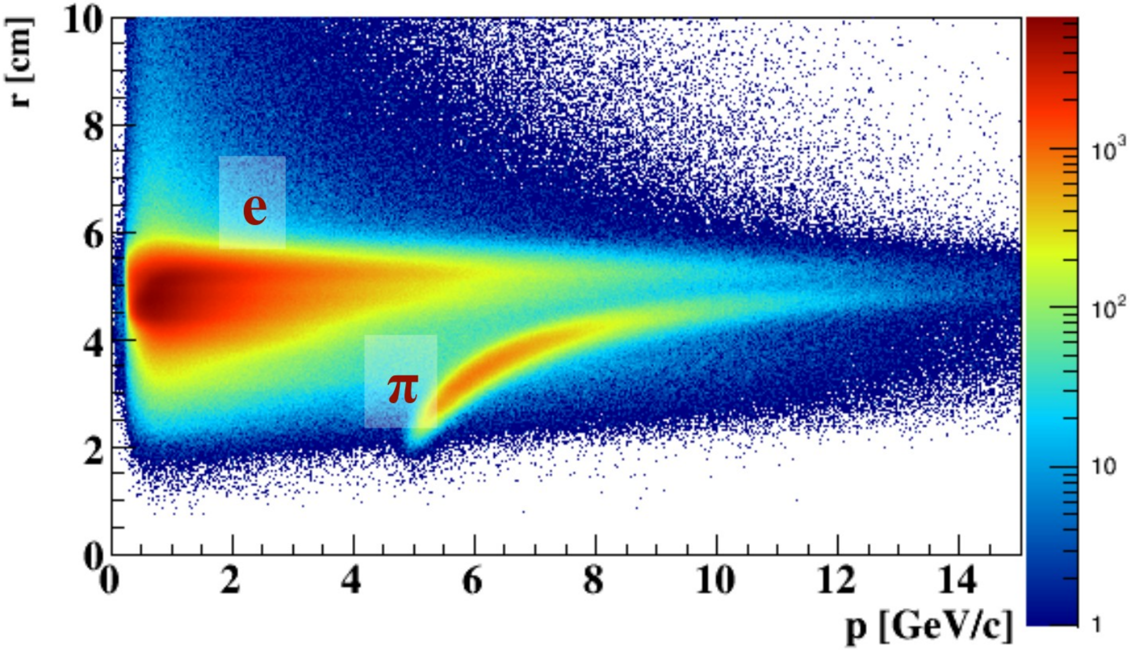
Particle identification: light hadrons

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

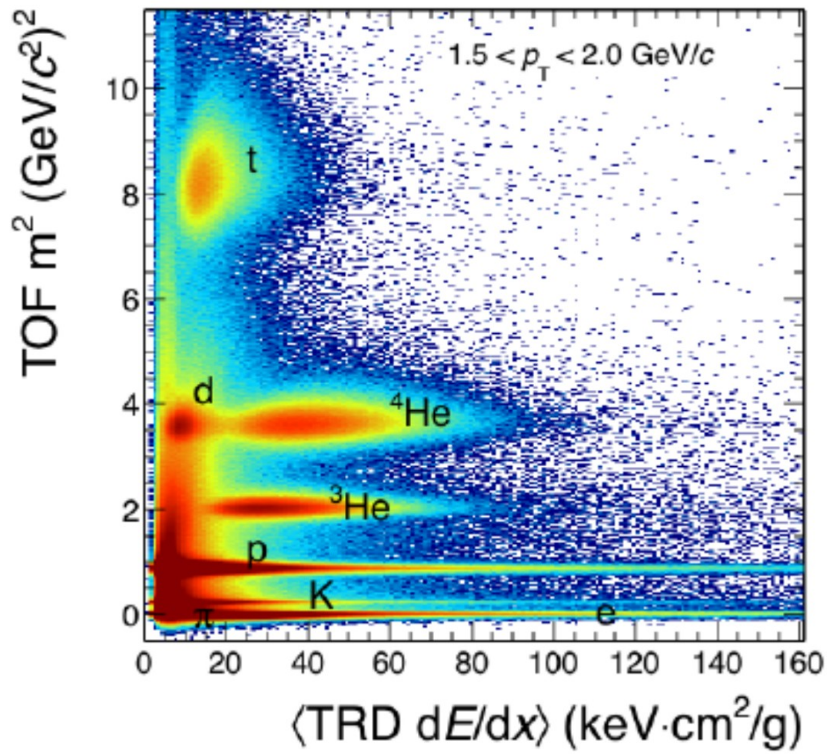


Particle identification: electrons and light nuclei

RICH (electrons)



TRD+TOF

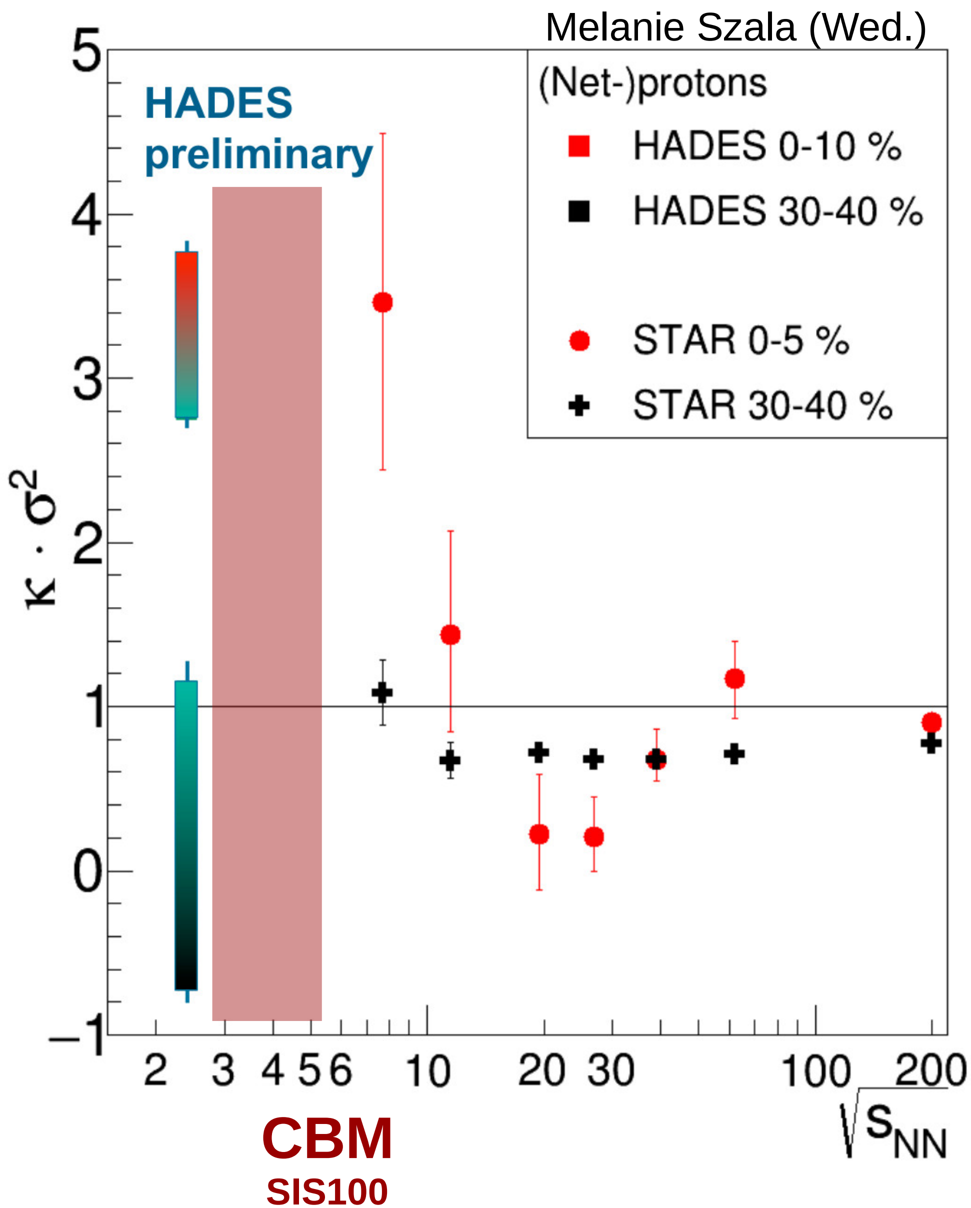


Physics performance study

Fluctuations of conserved quantities

Moments of (net-)proton distribution:

1st - mean, 2nd - variance (σ), 3rd - skewness (s), 4th - kurtosis (κ)

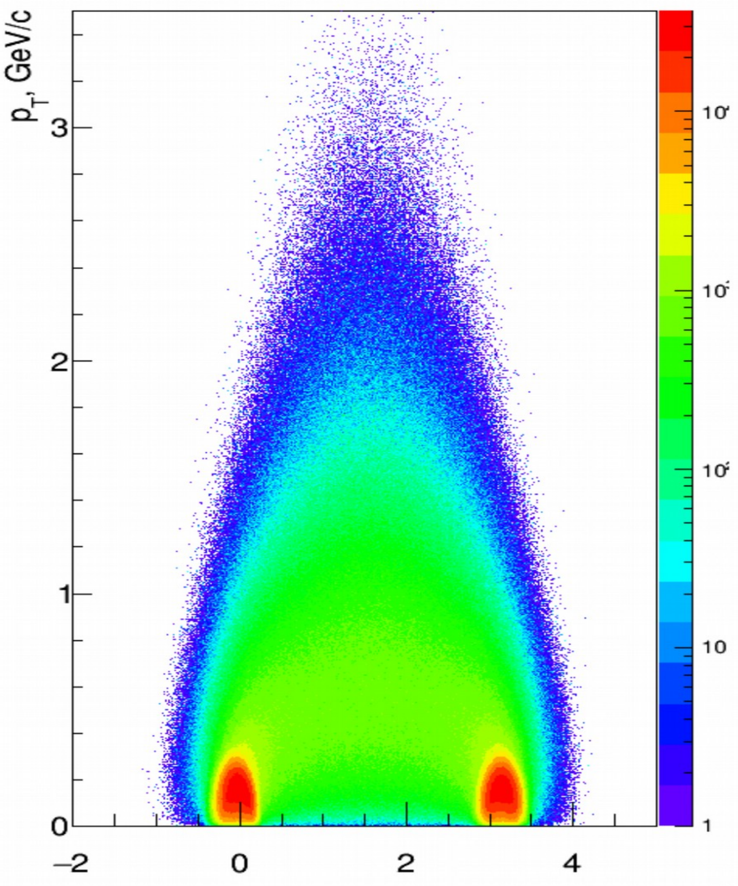


- Moments are connected to susceptibilities, e.g $k\,\sigma^2 = \chi^{(4)}/\chi^{(2)}$
- Sensitive to the correlation length of the system (phase transition/critical region)

Proton identification and acceptance

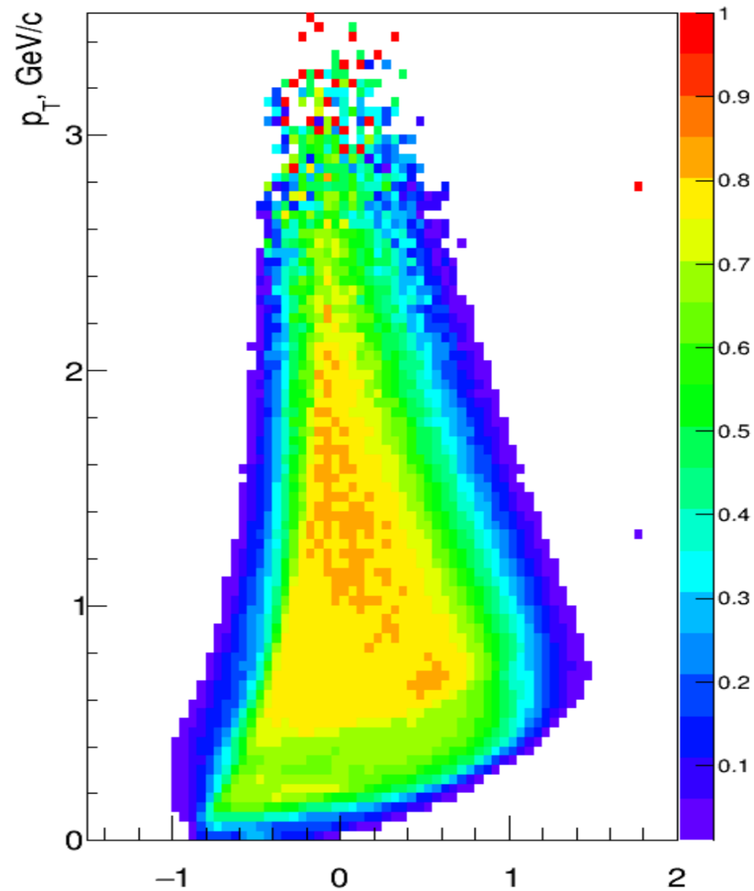
All simulated protons

Au+Au, 10AGeV UrQMD



Lab rapidity

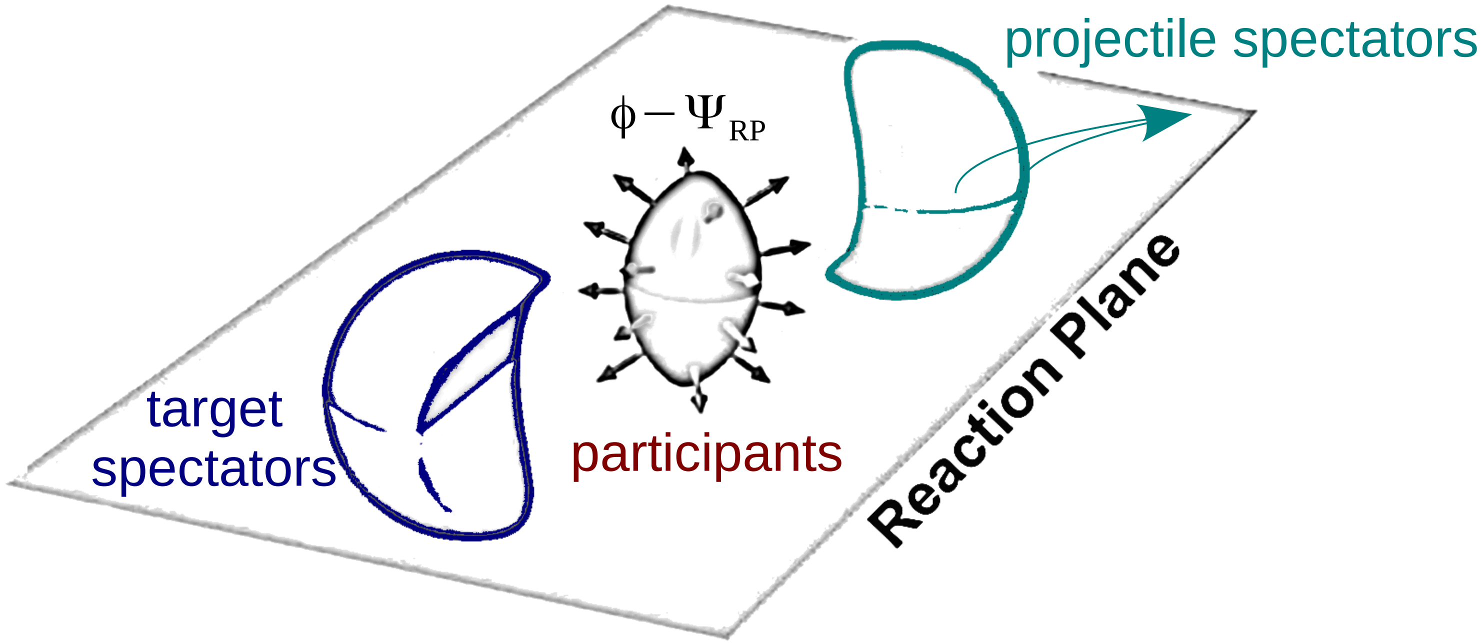
Proton reconstruction efficiency



Center-of-mass rapidity

sufficient proton coverage at midrapidity

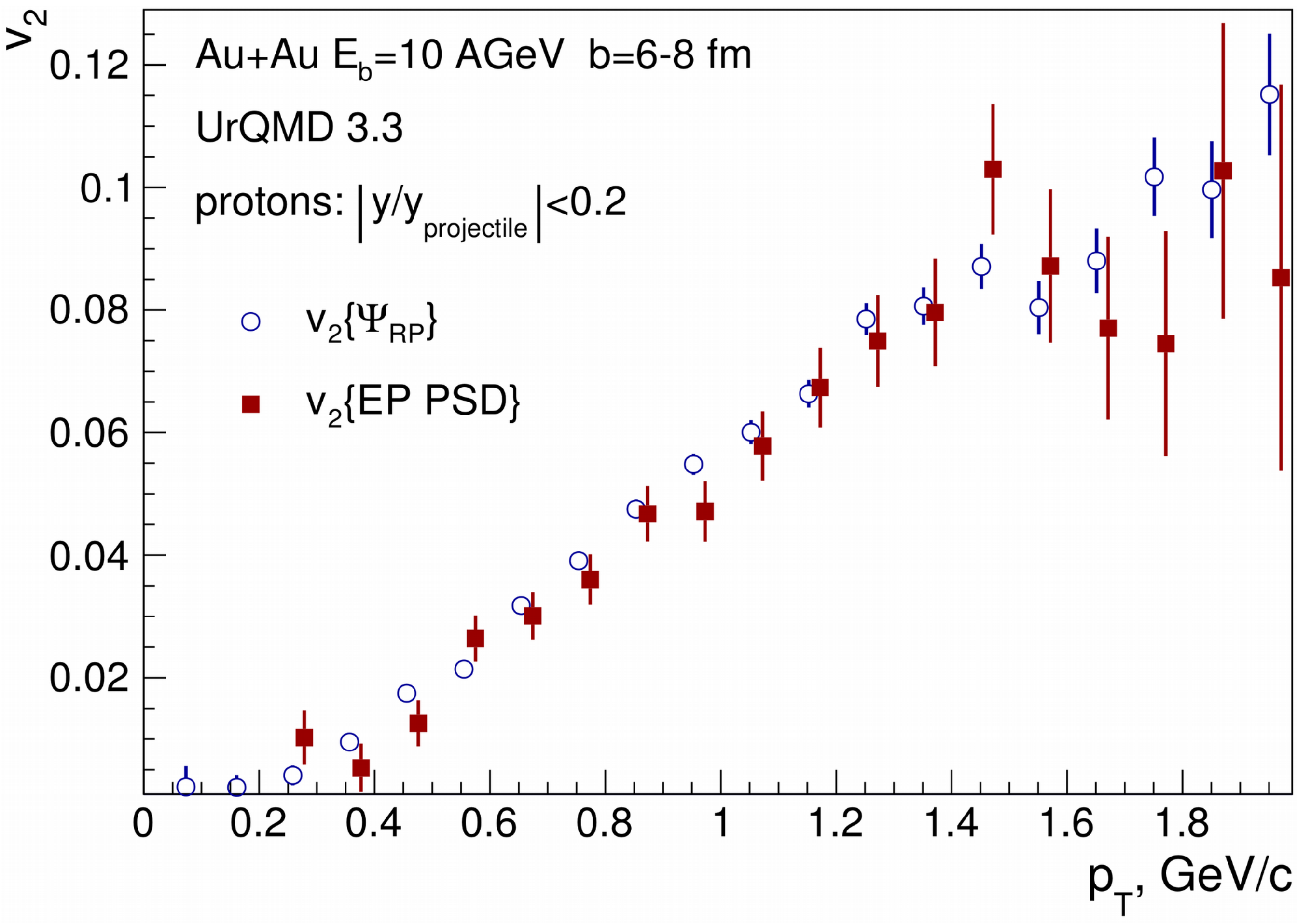
Anisotropic flow & reaction plane determination



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

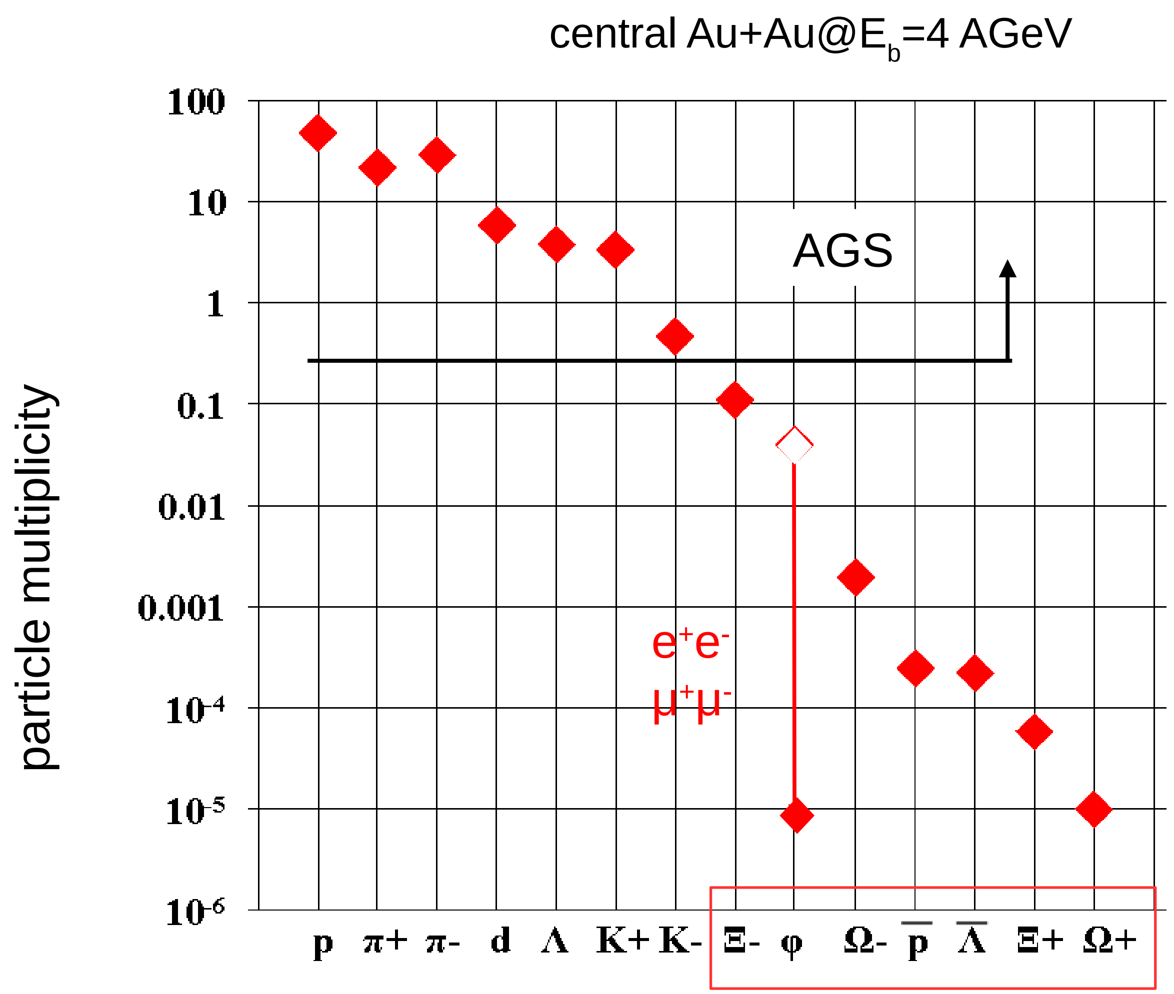
$$v_n\{\Psi_{RP}\} = \langle \cos[n(\phi - \Psi_{RP})] \rangle$$

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

Hadrons and multi-strange hyperon

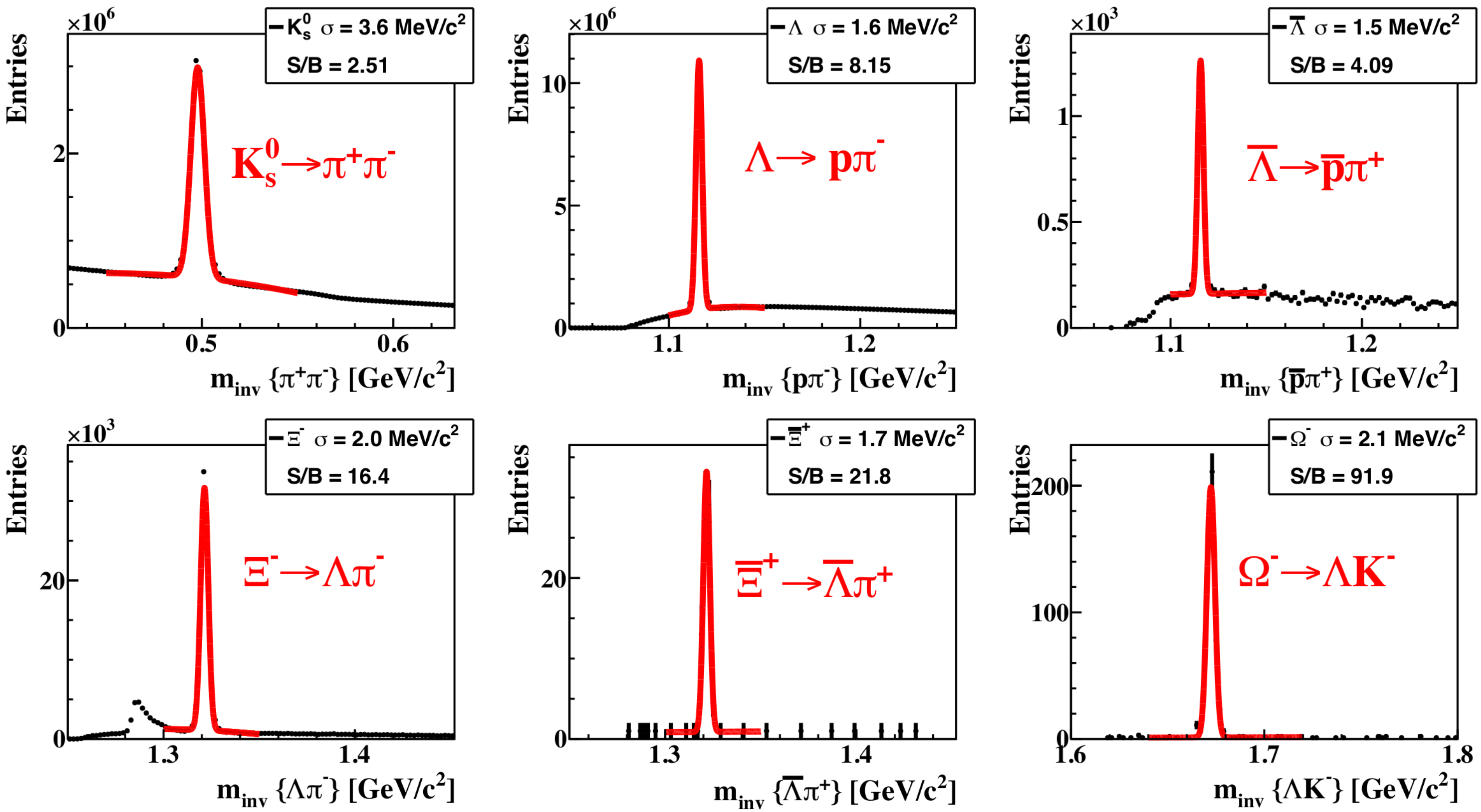


Stat.model, A. Andronic

Reconstred hyperon yields in central collisions

UrQMD central Au+Au E_b=10 AGeV

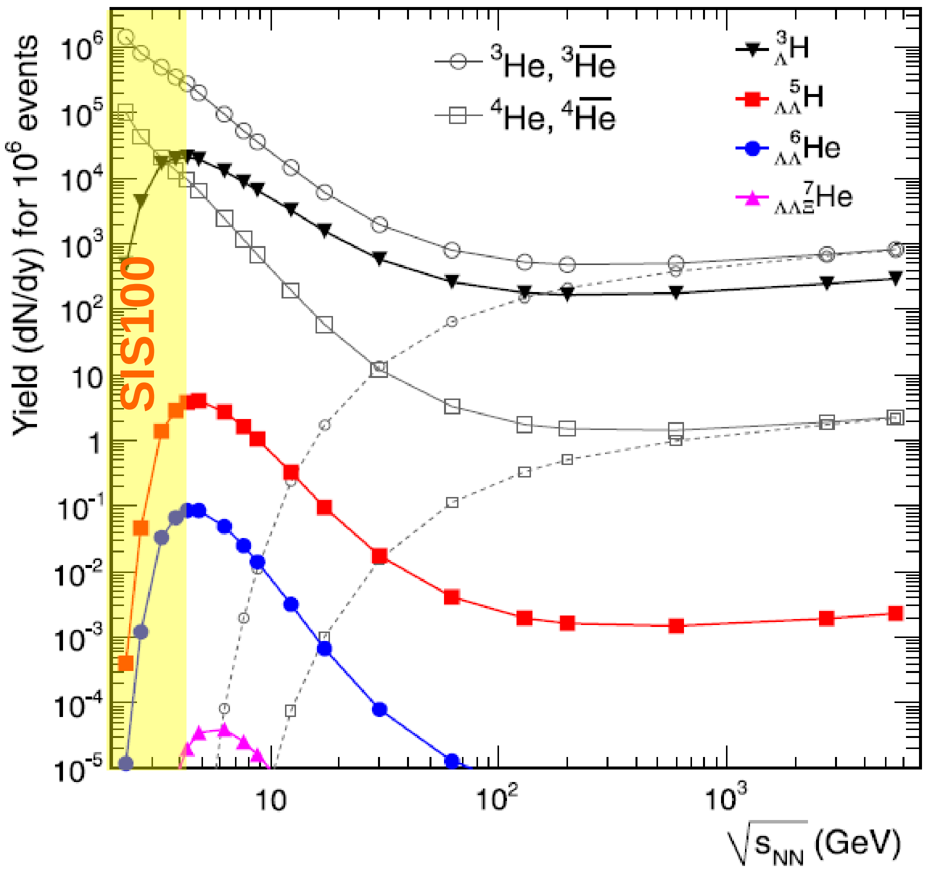
Decay topology reconstruction using the KFParticleFinder



Strange nuclear matter

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

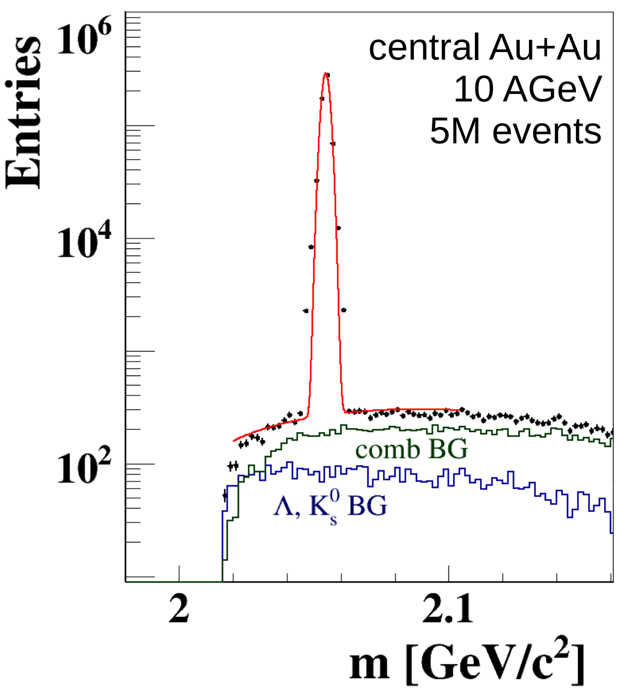
A. Andronic, PLB697 203 (2011)



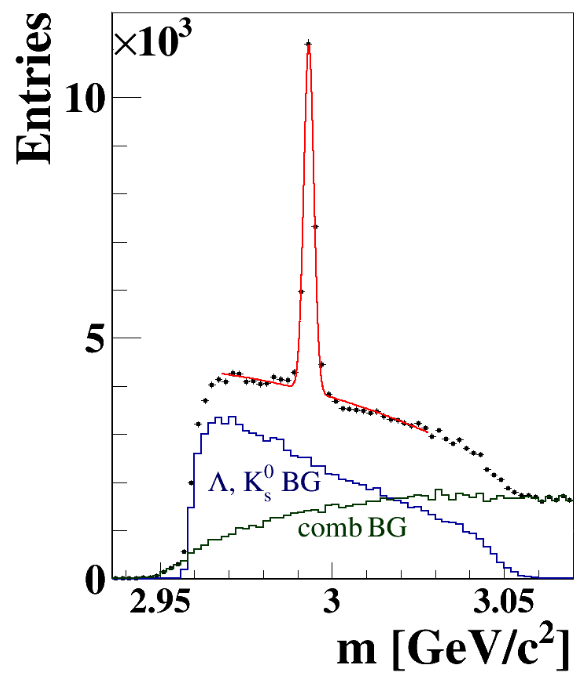
Feasibility of hypernuclei measurements

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

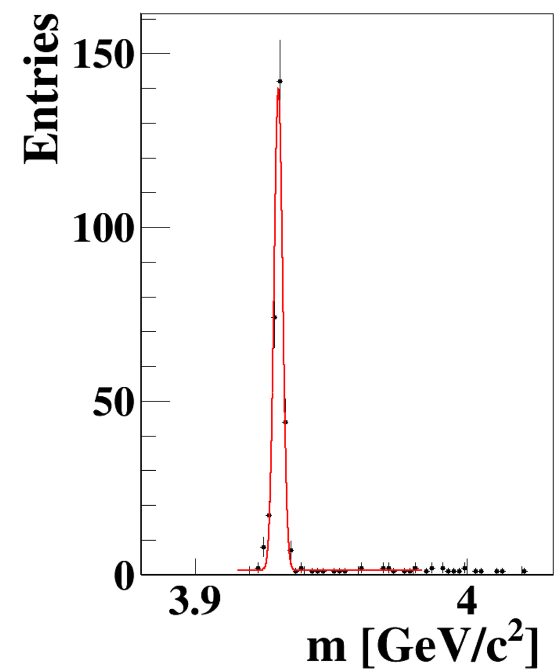
$(\Lambda, N)_{bound} \rightarrow d + \pi^-$



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



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



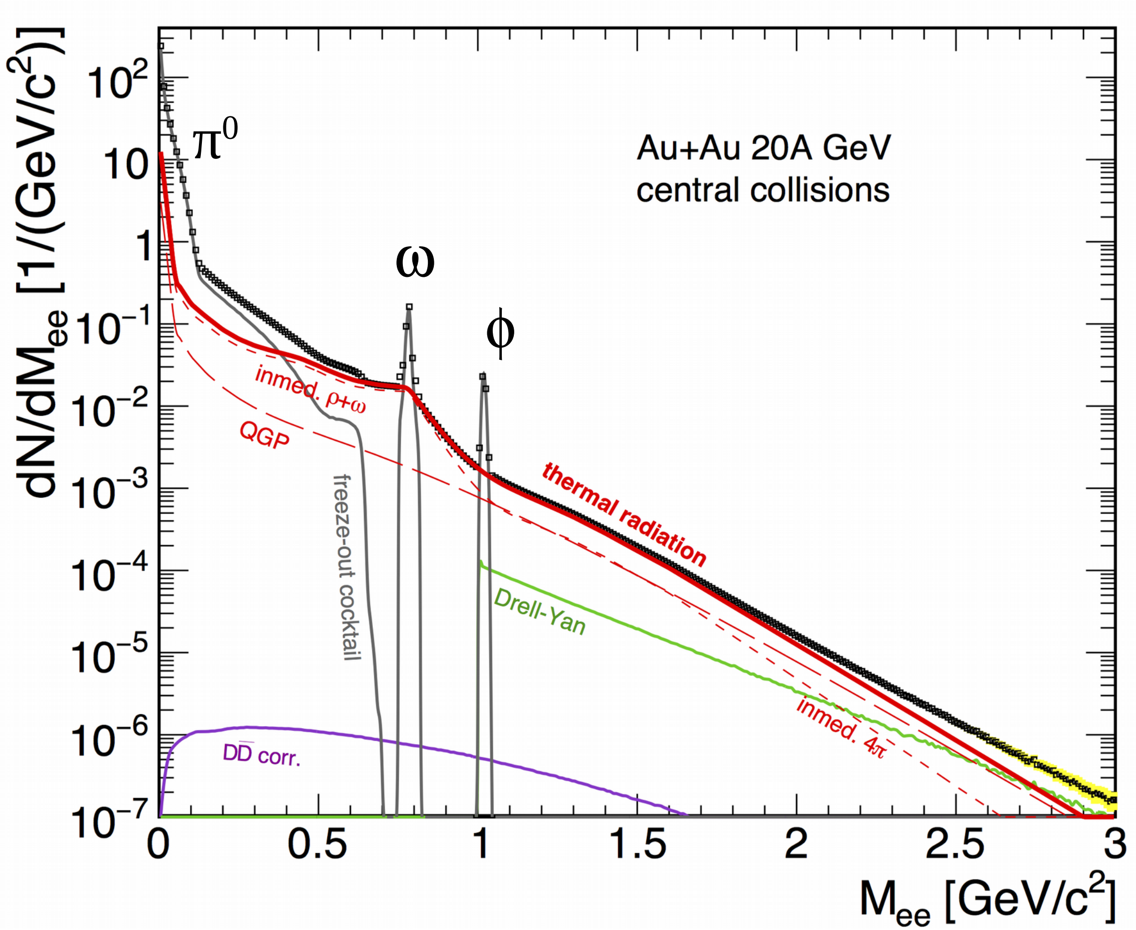
Expected significant statistics to study different hypernuclei

Dilepton measurements

Chiral symmetry at large baryon densities:

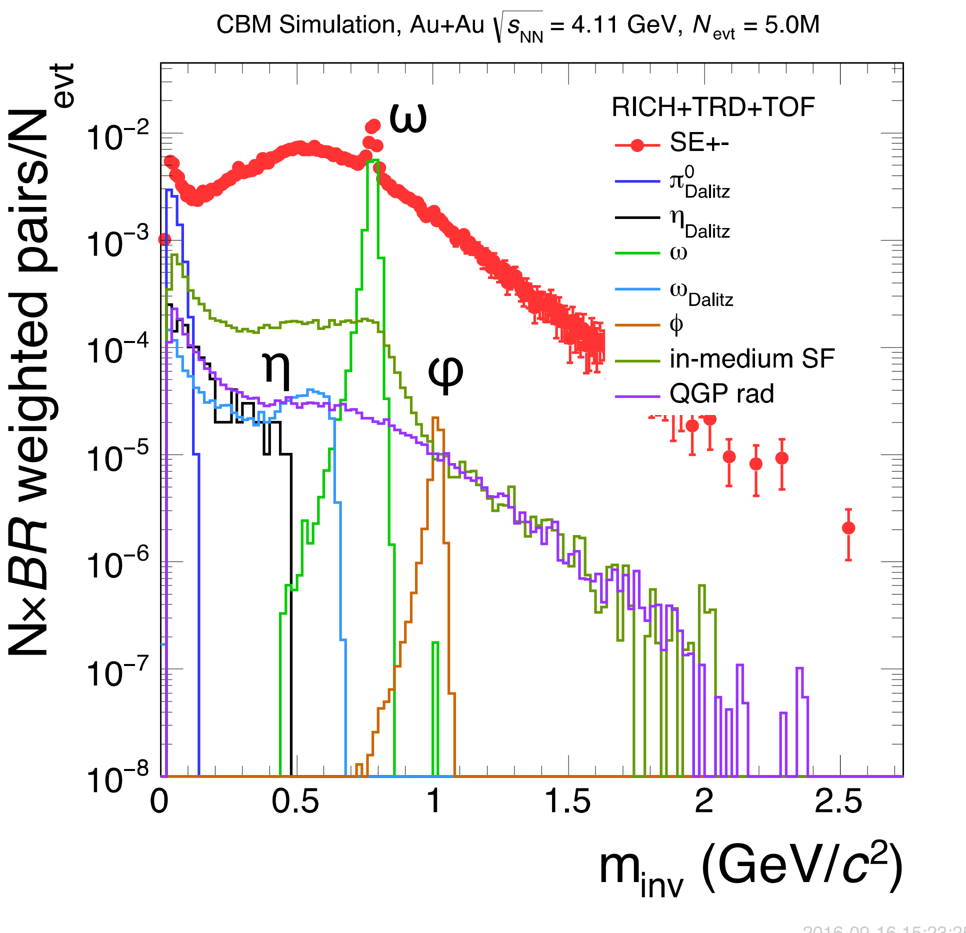
- In-medium modifications of light vector mesons
  ρ, ω, $\phi \rightarrow e^+e^-$ ($\mu^+\mu^-$) via dilepton measurements

Electromagnetic radiation of produced matter

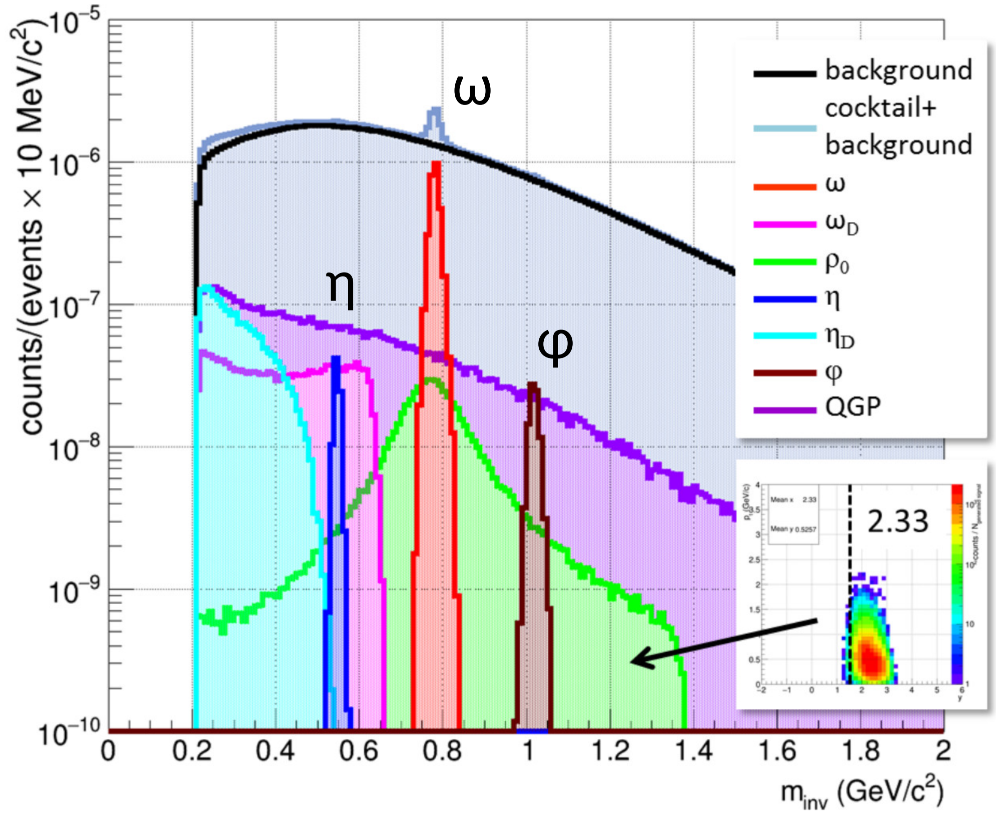


Simulation results for central Au+Au at E_b=8 A GeV

di-electrons

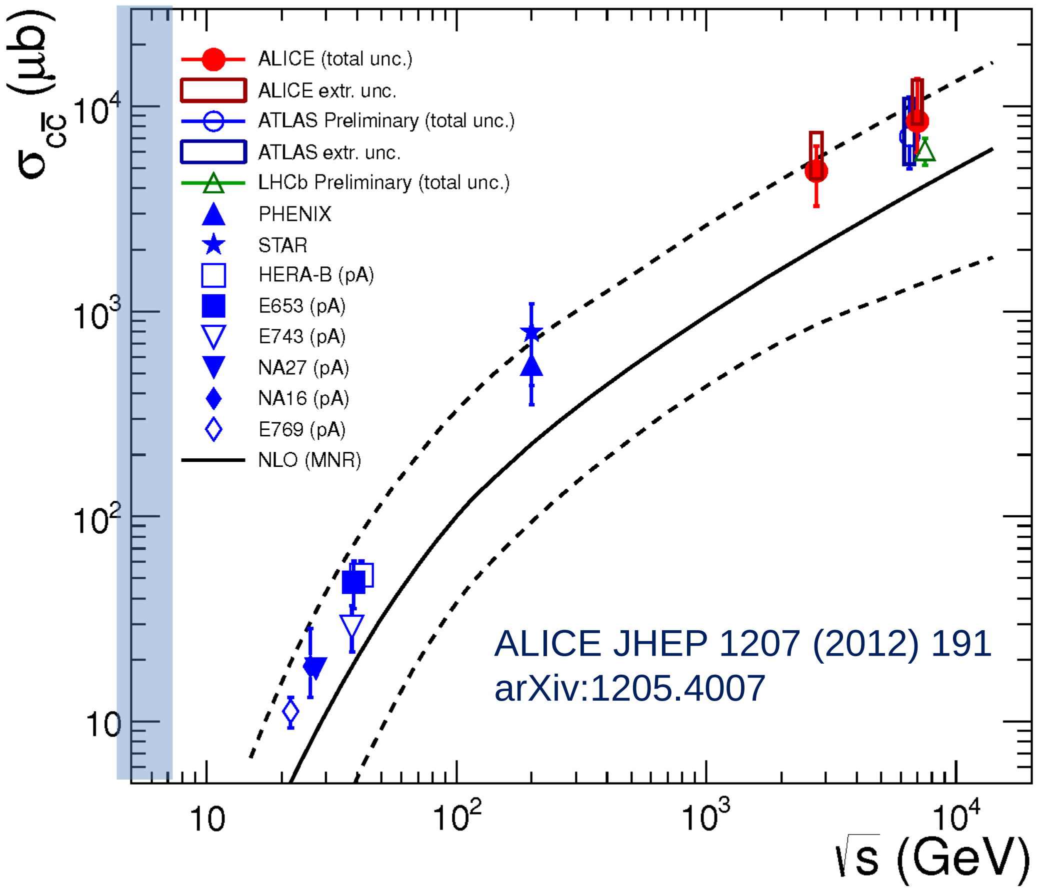


di-muons



Charm production at threshold

CBM SIS100



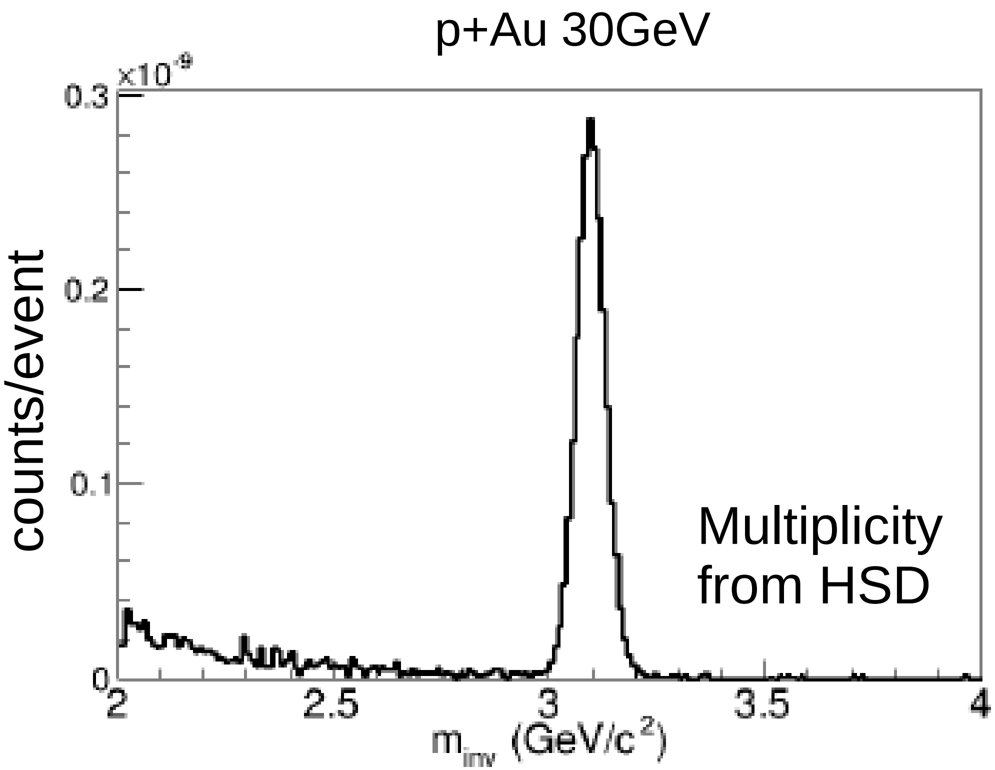
Study:

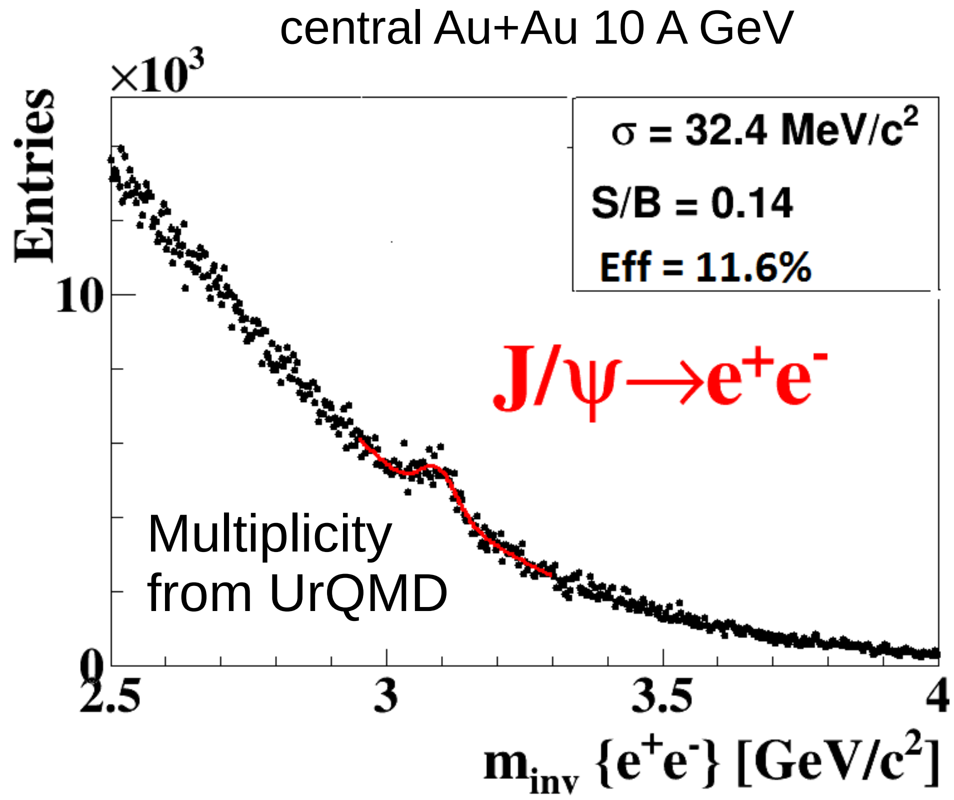
- Production at threshold
- Production in cold nuclear matter
- Propagation in dense QCD matter

Measure:
Cross section &
phase-space distributions
of open and hidden charm
in p+A and A+A collisions

No charm data at FAIR energies

J/ψ → μ⁺μ⁻ reconstruction





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, 4 in preparation
- Extensive performance studies for many physics observables
- Intermediate FAIR phase-0 program

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.

Romania
NIPNE Bucharest
Univ. Bucharest

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

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

29th CBM Collaboration Meeting, 20-24 March 2017, GSI

Information | References (67) | Citations (11) | Files | Plots

Challenges in QCD matter physics --The scientific programme of the Compressed Baryonic Matter experiment at FAIR

CBM Collaboration (T. Ablyazimov (Dubna, JINR) *et al.*) Show all 587 authors

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(2017-03-23)
DOI: 10.1140/epja/i2017-12248-y
e-Print: arXiv:1607.01487 [nucl-ex] | PDF
Experiment: GSI-FAIR-CBM

Abstract (Springer)
Substantial experimental and theoretical efforts worldwide are devoted to explore the phase diagram of strongly interacting matter. At LHC and top RHIC energies, QCD matter is studied at very high temperatures and nearly vanishing net-baryon densities. There is evidence that a Quark-Gluon-Plasma (QGP) was created at experiments at RHIC and LHC. The transition from the QGP back to the hadron gas is found to be a smooth cross over. For larger net-baryon densities and lower temperatures, it is expected that the QCD phase diagram exhibits a rich structure, such as a first-order phase transition between hadronic and partonic matter which terminates in a critical point, or exotic phases like quarkyonic matter. The discovery of these landmarks would be a breakthrough in our understanding of the strong interaction and is therefore in the focus of various high-energy heavy-ion research programs. The Compressed Baryonic Matter (CBM) experiment at FAIR will play a unique role in the exploration of the QCD phase diagram in the region of high net-baryon densities, because it is designed to run at unprecedented interaction rates. High-rate operation is the key prerequisite for high-precision measurements of multi-differential observables and of rare diagnostic probes which are sensitive to the dense phase of the nuclear fireball. The goal of the CBM experiment at SIS100 ($\sqrt{s_{NN}} =$ 2.7--4.9 GeV) is to discover fundamental properties of QCD matter: the phase structure at large baryon-chemical potentials ($\mu_B > 500$ MeV), effects of chiral symmetry, and the equation of state at high density as it is expected to occur in the core of neutron stars. In this article, we review the motivation for and the physics programme of CBM, including activities before the start of data taking in 2024, in the context of the worldwide efforts to explore high-density QCD matter.
Abstract (arXiv)

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