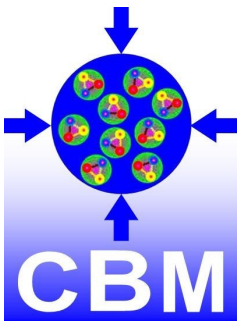
# The Compressed Baryonic Matter (CBM) Experiment at FAIR

Viktor Klochkov

(GSI, Frankfurt University)

for the CBM Collaboration




GOETHE UNIVERSITÄT FRANKFURT AM MAIN

FAIR

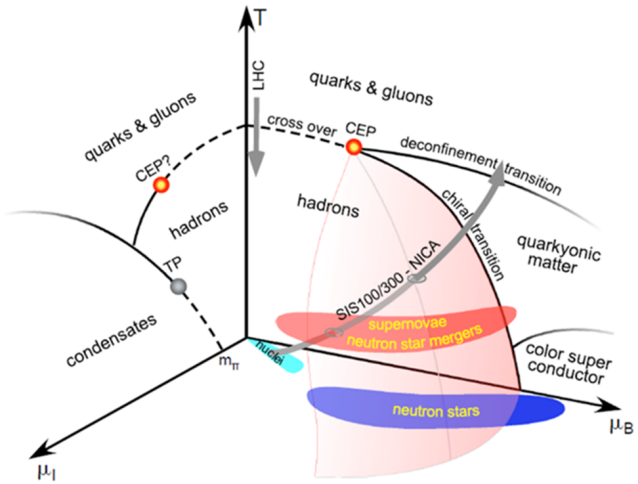
GSI

HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

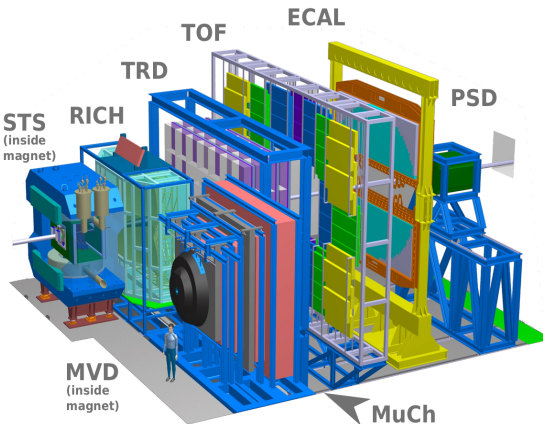
QM2019, Wuhan, 4-9 November

# Outline

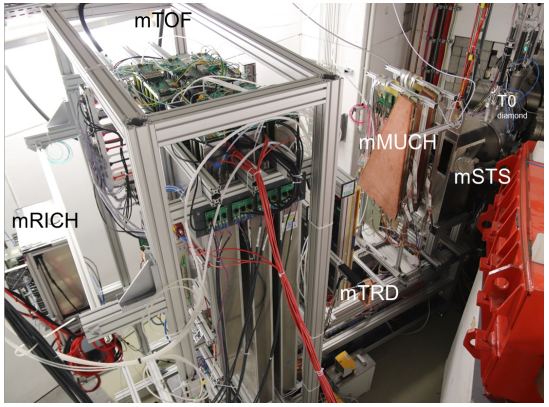
## Physics motivation



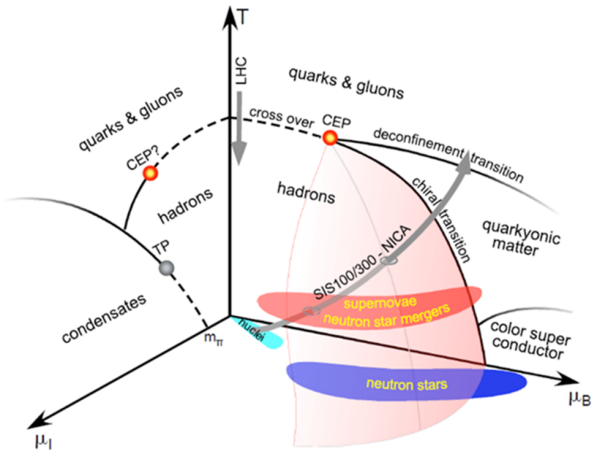

## CBM experimental setup




## Physics performance & FAIR Phase-0 activities

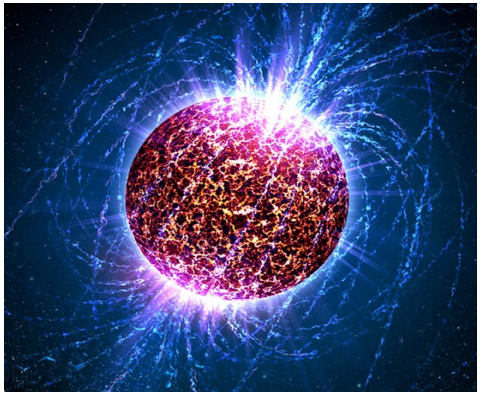


# Dense Baryonic Matter

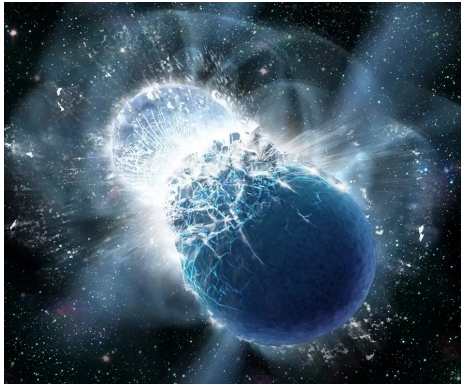



NUPECC Long Range Plan 2017

Neutron stars

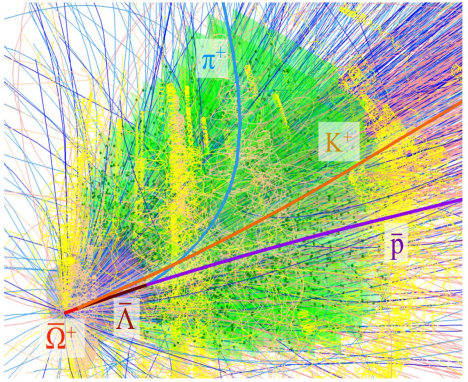


Neutron star merger



GW170817

Heavy-ion collisions



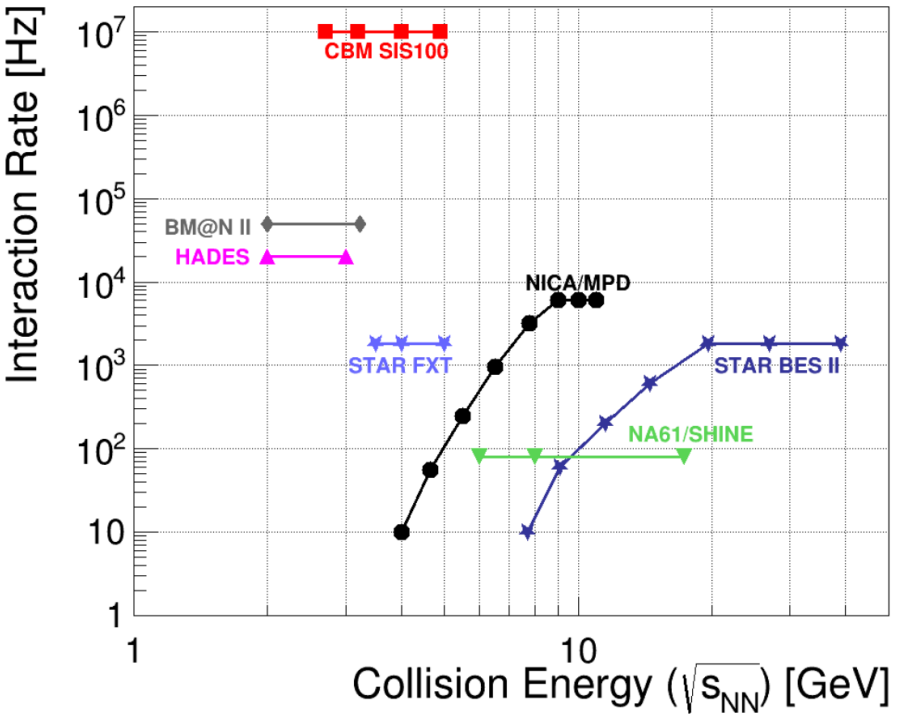

SIS100 energies

| | | | |
|---|---|---|---|
| Temperature (T) | < 10 MeV | ~10-100 MeV | < 120 MeV |
| Density (ρ) | < 10 $\rho_0$ | < 2-6 $\rho_0$ | < 5-15 $\rho_0$ |
| Lifetime / Reaction time (t) | ∞ | ~10 ms | ~$10^{-23}$ s |

# CBM physics and observables

- QCD 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
- Chiral symmetry at large baryon densities
  - ✔ In-medium modifications of light vector mesons
  - ✔ ρ, ω, φ → $e^+$+$e^-$ ($\mu^+$+$\mu^-$) via dilepton measurements
- Hypernuclei
- Charm production and propagation at threshold energies
  - ✔ Excitation function in p+A collisions (J/ψ, $D^0$ , $D^{+-}$)
  - ✔ Charmonium suppression in cold nuclear matter

Existing and experiments under construction



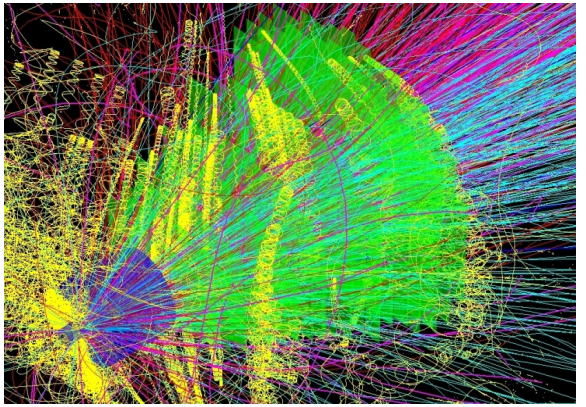

[CBM Collaboration] "Challenges in QCD matter physics"

High statistics needs high reaction rates: $10^5$ - $10^7$ Au+Au collisions/sec!

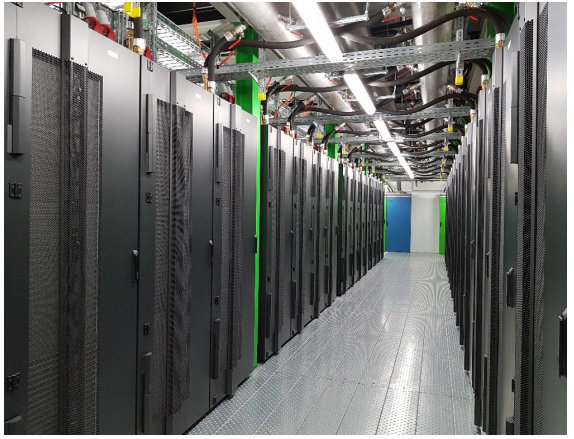
# Main experimental requirements

- High event rates: $10^5$ – $10^7$ Au+Au collisions/sec
- Fast, radiation hard detectors & front-end electronics
- Free-streaming readout & 4 dimensional (space+time) event reconstruction
- Particle identification: hadrons and leptons, displaced (~50 μm) vertex reconstruction for charm measurements
- High speed data acquisition & performance computing farm for online event selection

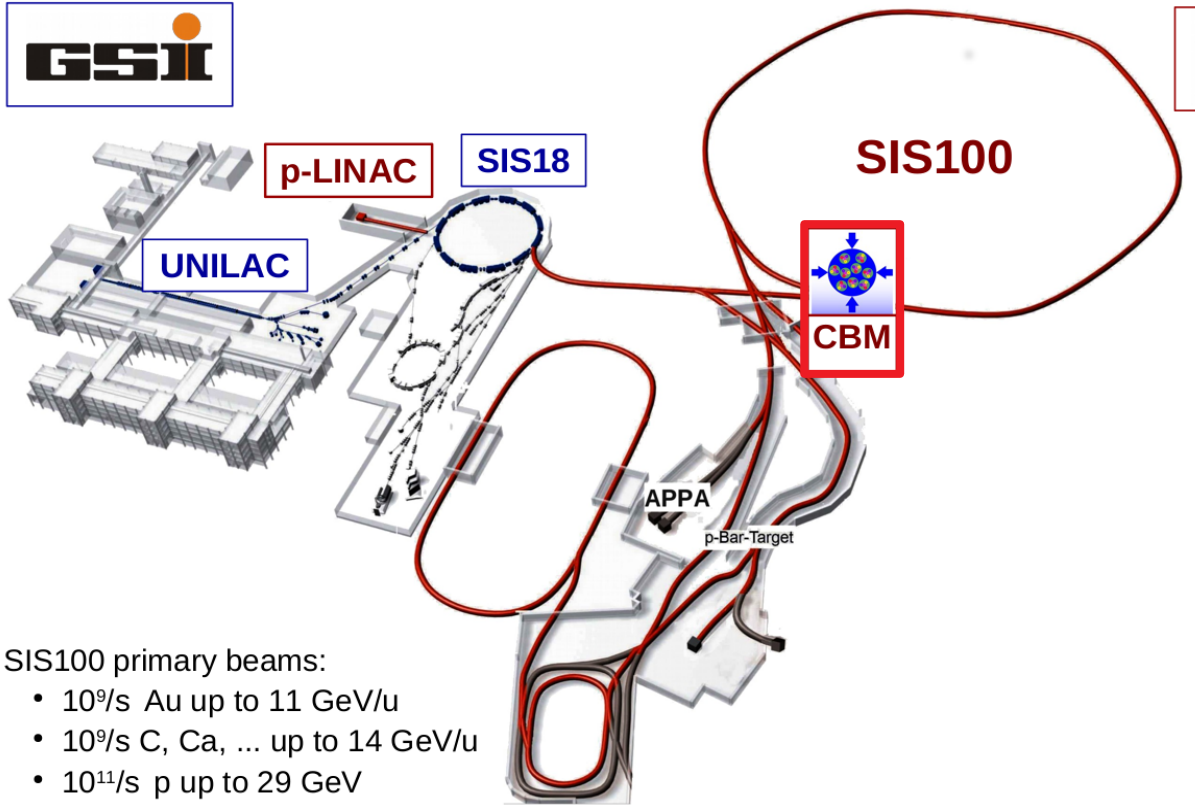
central Au+Au collision @ 10*A* GeV/*c*



GSI IT Center



# Facility for Antiproton and Ion Research (FAIR)




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

## Timeline

- July 2017: Start of excavation and trench sheeting
- January 2018: Civil construction north area awarded (SIS tunnel, CBM building)
- July 2018: Start of shell construction

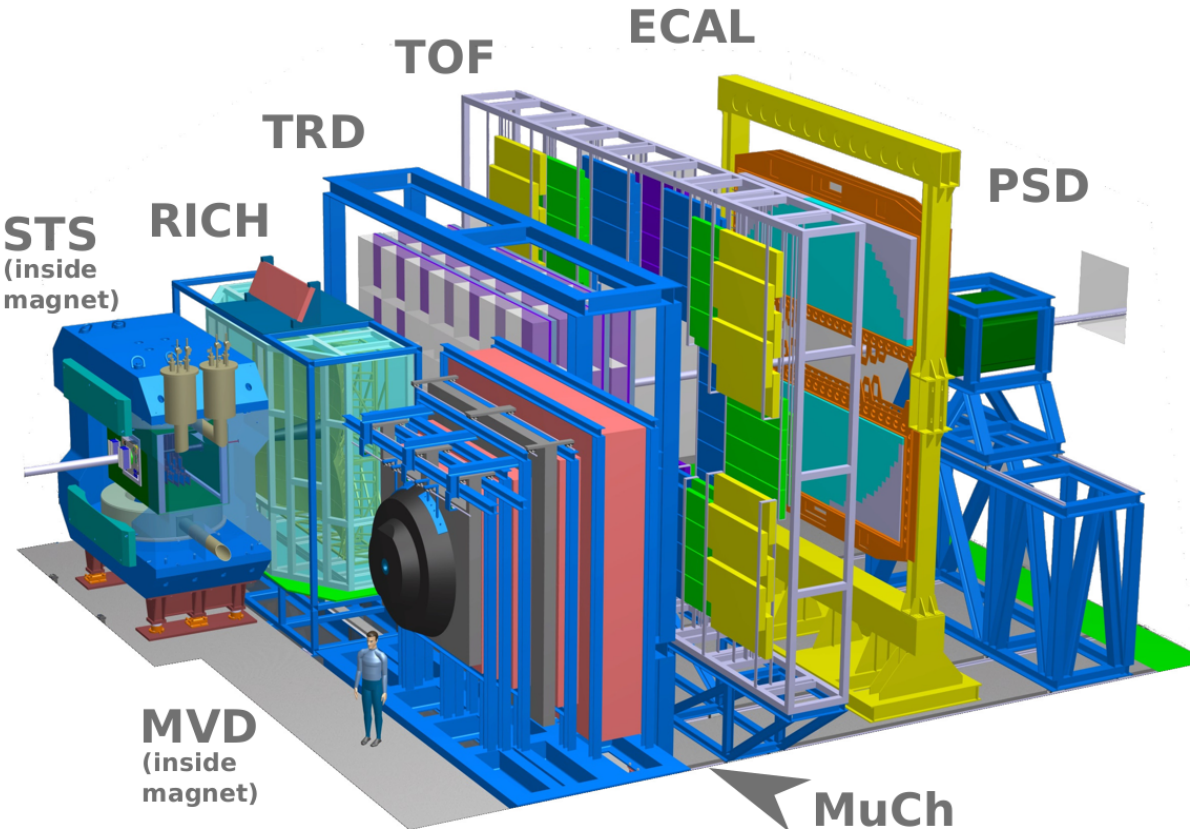
  ⇒ We are here ⇐
- 2022: Buildings completed (including CBM cave)
- 2025: Completion of full facility and start of operations

# CBM area excavation


https://www.youtube.com/watch?v=MlFbsYZrQck

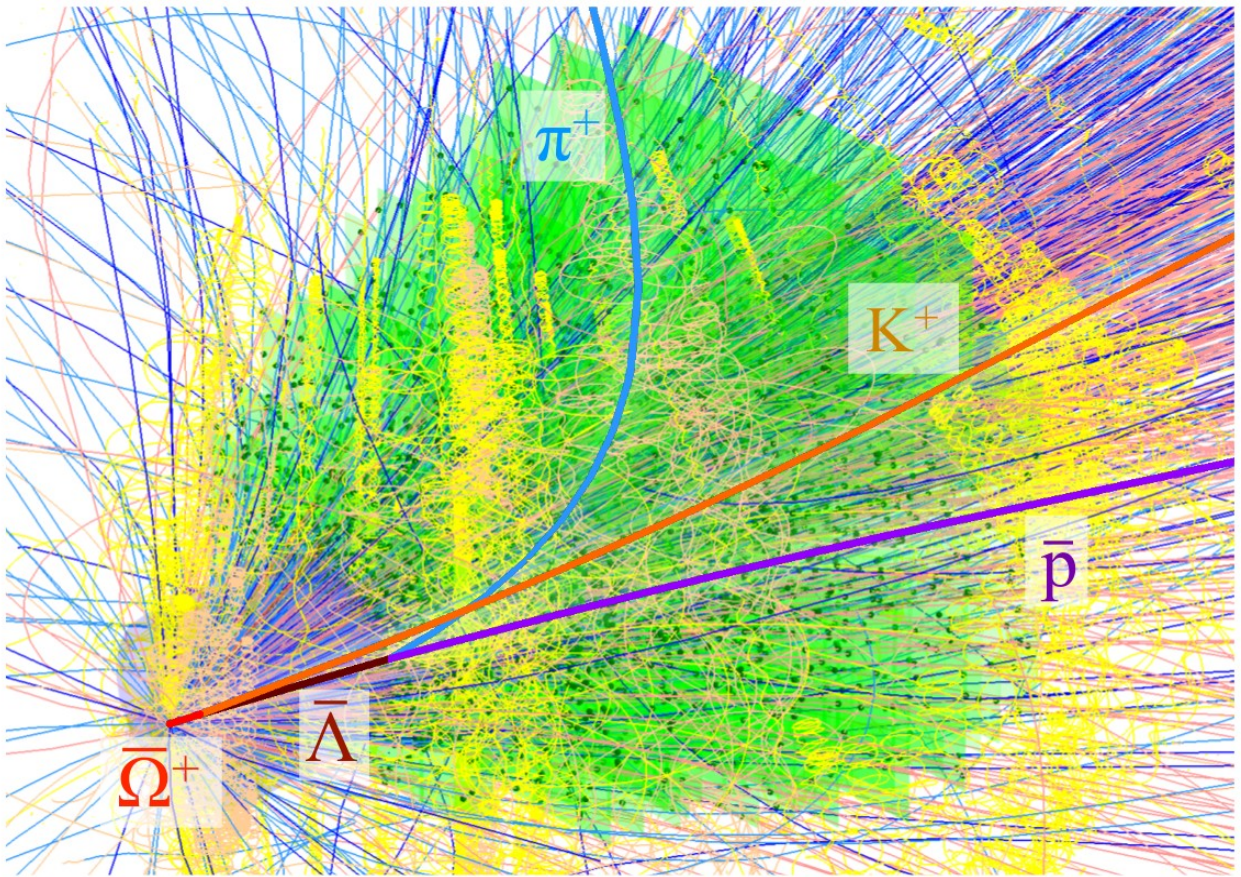
# CBM detector subsystems

| | QM-posters # |
|---|---|
| **MVD**<br>Micro Vertex Detector* | |
| **STS**<br>Silicon Tracking System* | 310, 408,<br>648, 764 |
| * inside magnetic field | |
| **MuCh or RICH**<br>Muon Chamber System /<br>Ring Imaging Cherenkov<br>Detector | 405 |
| **TRD**<br>Transition Radiation Detector | |
| **ToF**<br>Time-of-Flight Detector | 722 |
| **ECal**<br>Electromagnetic Calorimeter | |
| **PSD**<br>Projectile Spectator Detector | 451 |



# Challenges of event and track reconstruction in CBM

CBM simulation, central Au+Au collision @ 10*A* GeV/*c*



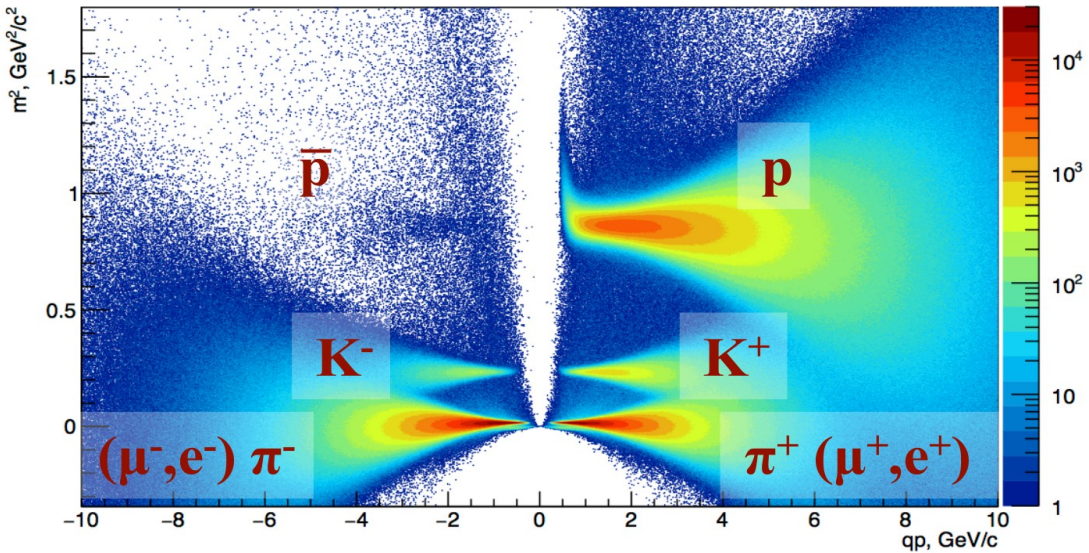

High multiplicity collisions ⇒
almost 1000 particles

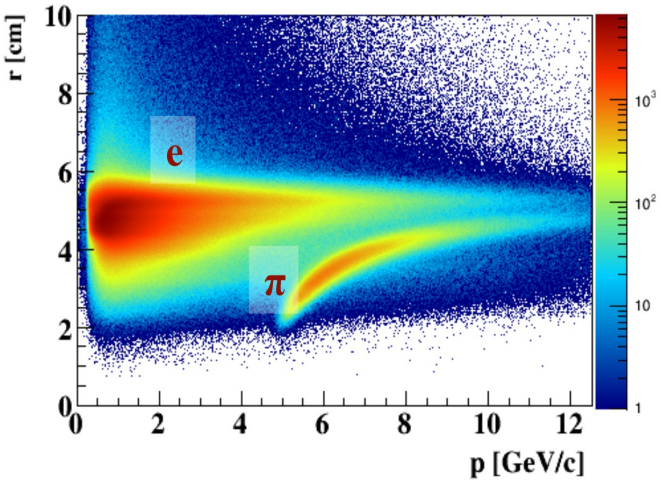
High interaction rate implies:

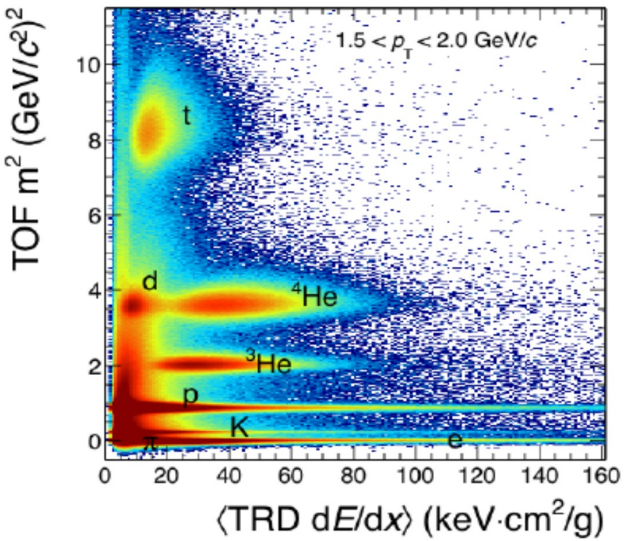
- Events in the selected time window (time slice) will overlap in time
- reconstruction in 4D (space, time)
- Decay topology reconstruction

# Particle identification

CBM simulation
central Au+Au collisions @ 10*A* GeV/*c*



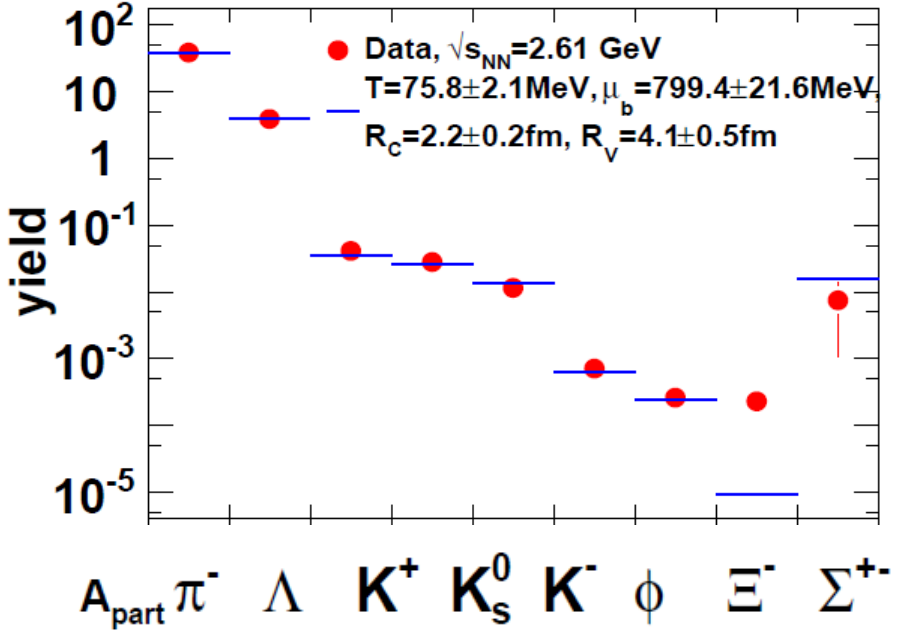




High purity identification of
charged protons, pions and kaons

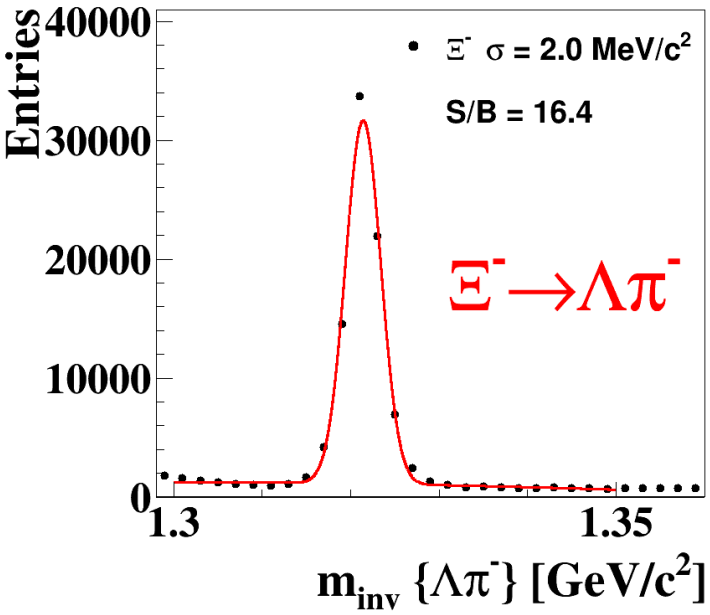
pions, electrons, and light nuclei

# Multi-strange reconstruction

HADES data:
Eur.Phys.J. A47 (2011) 21



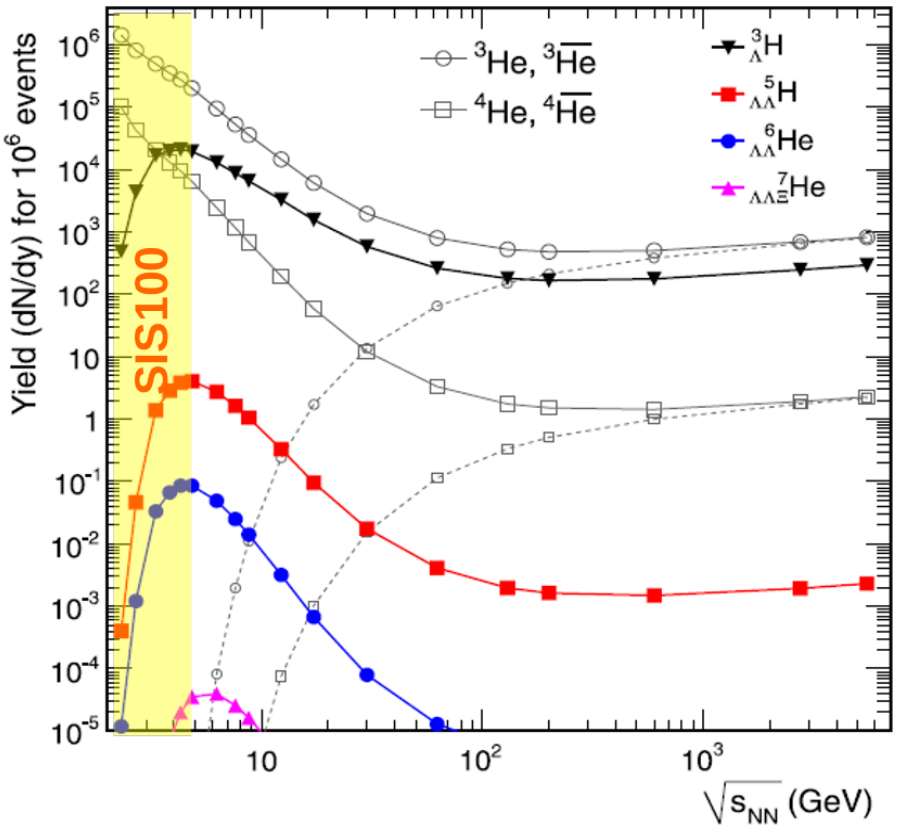

CBM simulation
UrQMD, Au+Au @ 10*A* GeV/*c*, central, 5M events



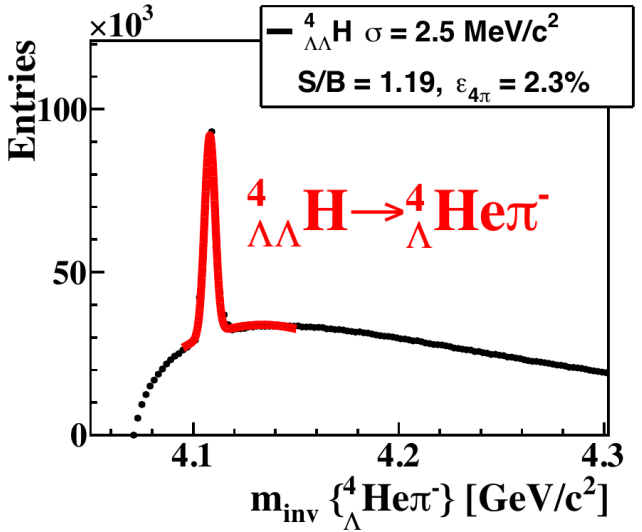

Multistrange hyperons will be accessible at SIS-100 energies
Reconstruction is based on the dedicated KFParticleFinder package

# Hypernuclei

A. Andronic, PLB697 203 (2011)




CBM simulation
Au+Au 10*A* GeV/*c*
mbias, $10^{12}$ events




CBM physics cases

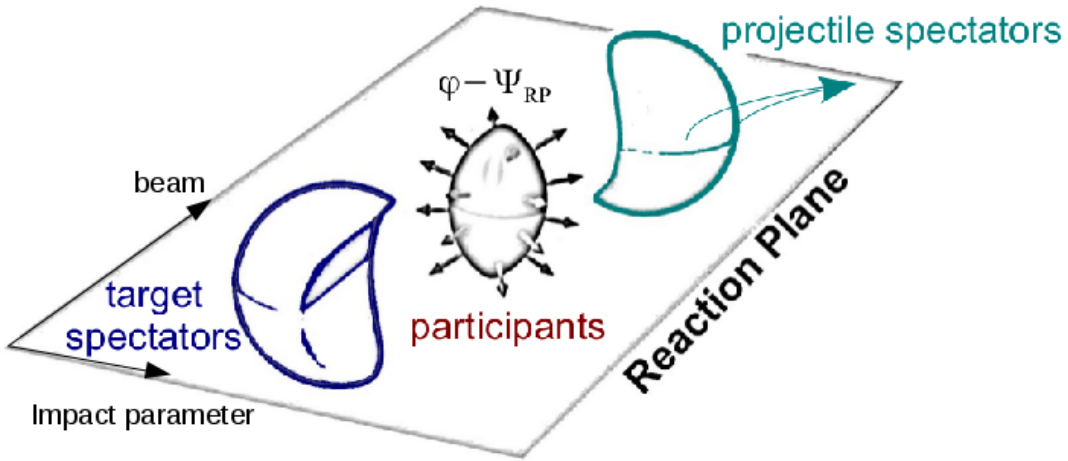
- Λ-N, Λ-Λ interaction
- (Double-)lambda hypernuclei
- Meta-stable strange states

Anton Lymanets, Poster #185

# Anisotropic flow

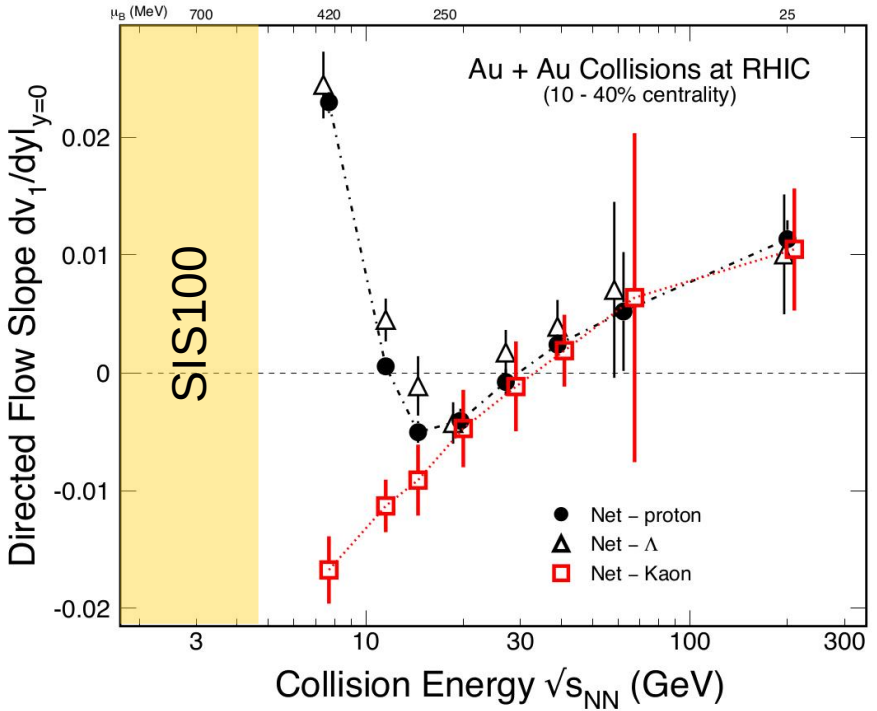
Asymmetry in coordinate space converts due to interaction into

momentum asymmetry with respect to the symmetry plane (reaction plane - RP)

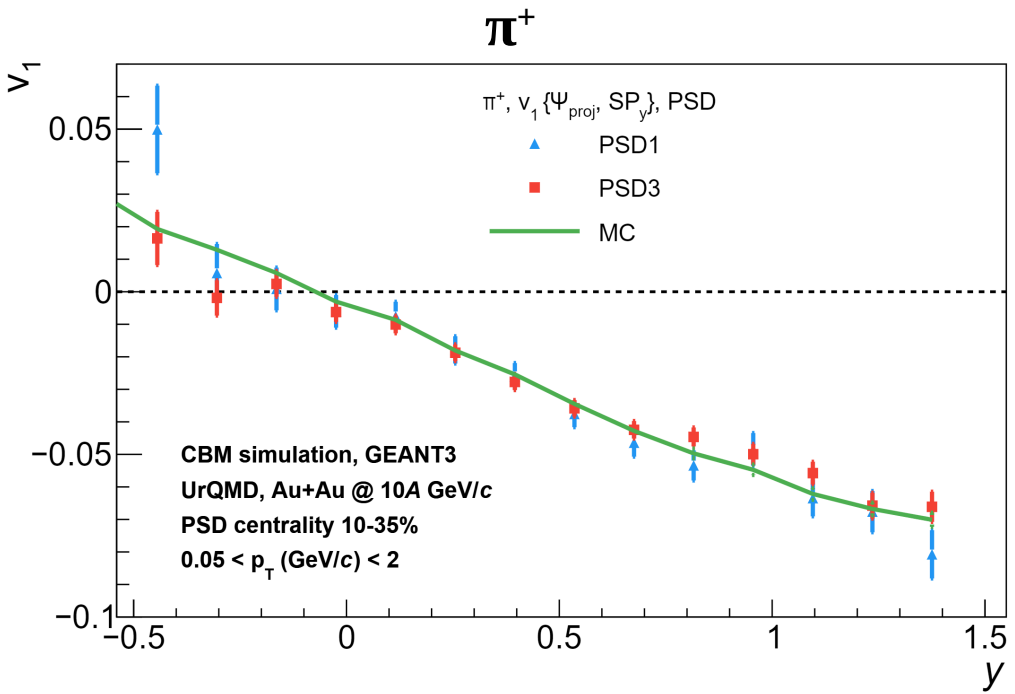


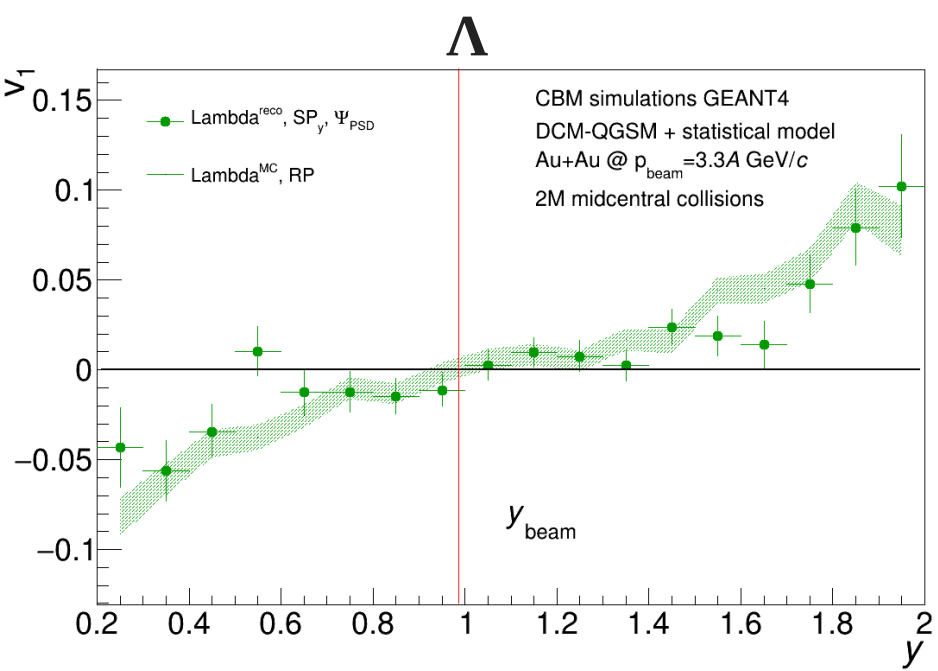

STAR Collaboration:

Phys.Rev.Lett. 120 (2018) no.6, 062301



# Performance for directed flow ($v_1$)



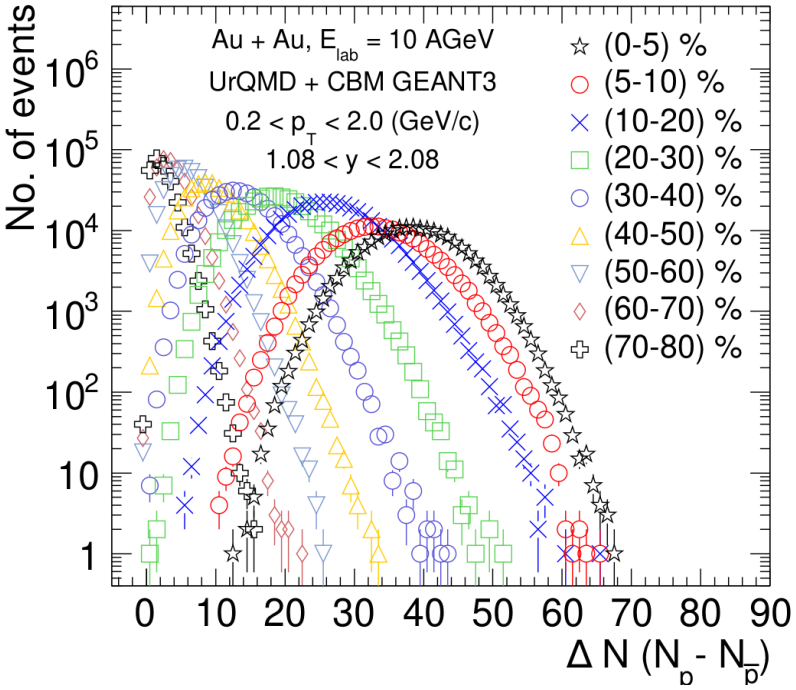

"input" model $v_1$ is recovered using "data-driven" methods with projectile spectators

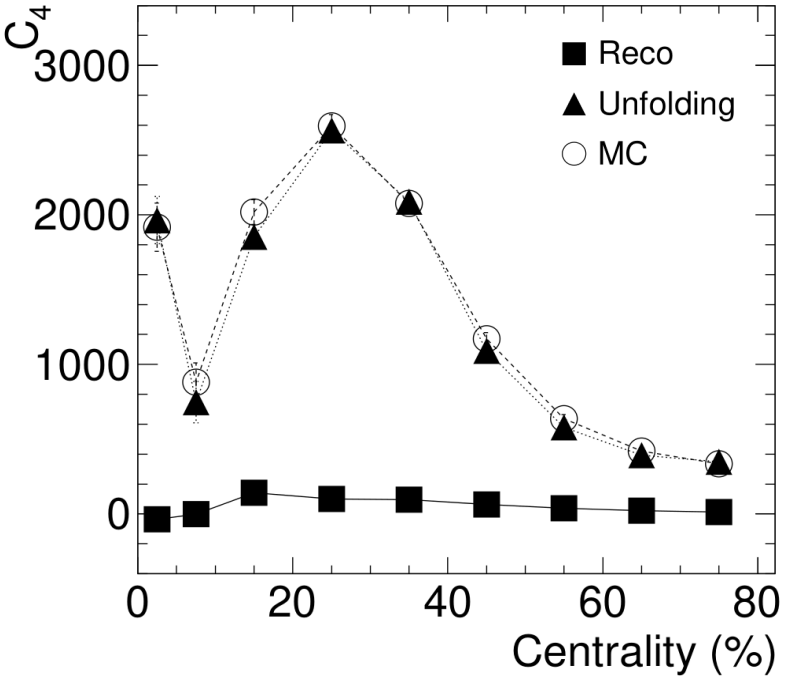
Oleg Golosov, Poster #415

# Net-proton cumulants: $C_4$

Talk by Subhasis Samanta

Uncorrected for efficiency and acceptance



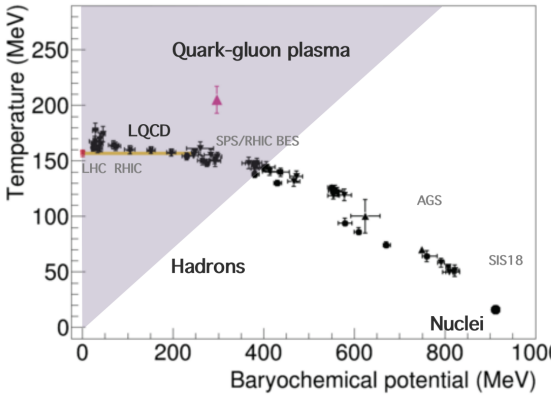




Fluctuations of conserved charges are sensitive to phase transition and critical point

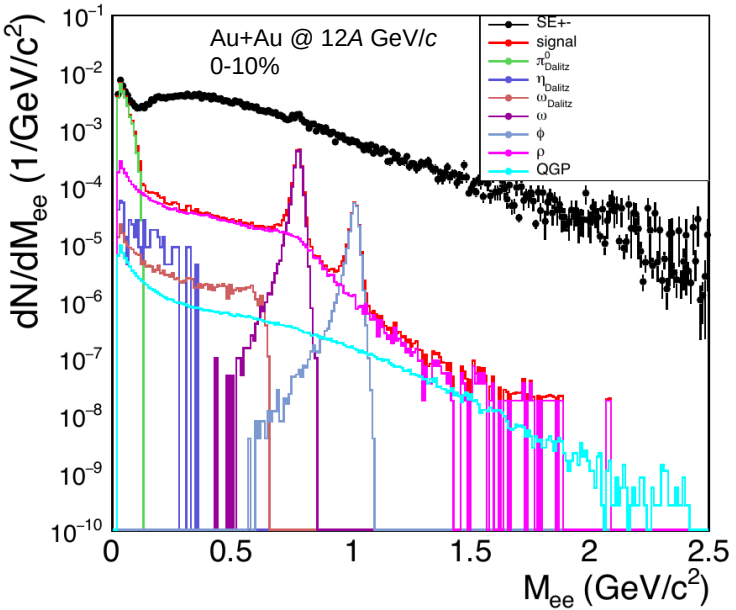
Corrections applied: centrality bin width correction, efficiency correction with unfolding ⇒ we are able to get back cumulants of MC

# Dilepton measurements: $e^+$+$e^-$ and $\mu^+$+$\mu^-$

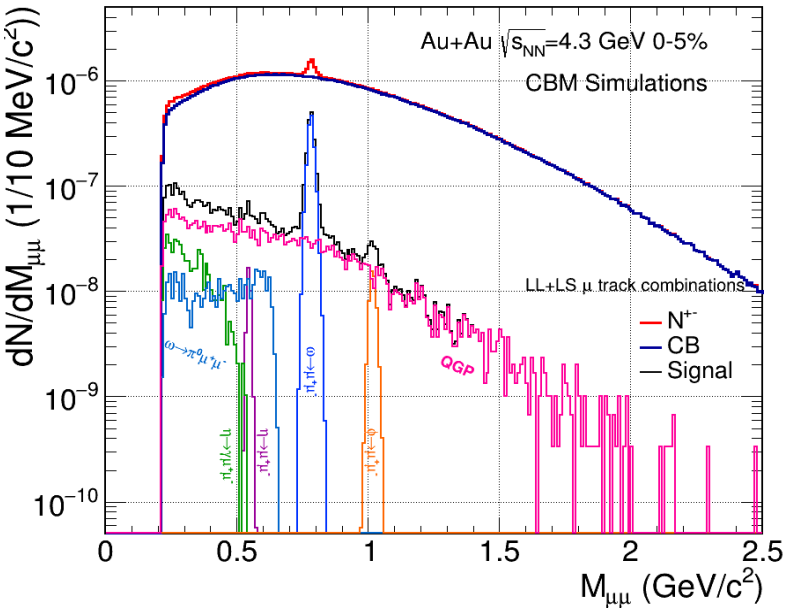
Nuclear Physics A 982 (2019) 163–169




$e^+$+$e^-$




$\mu^+$+$\mu^-$



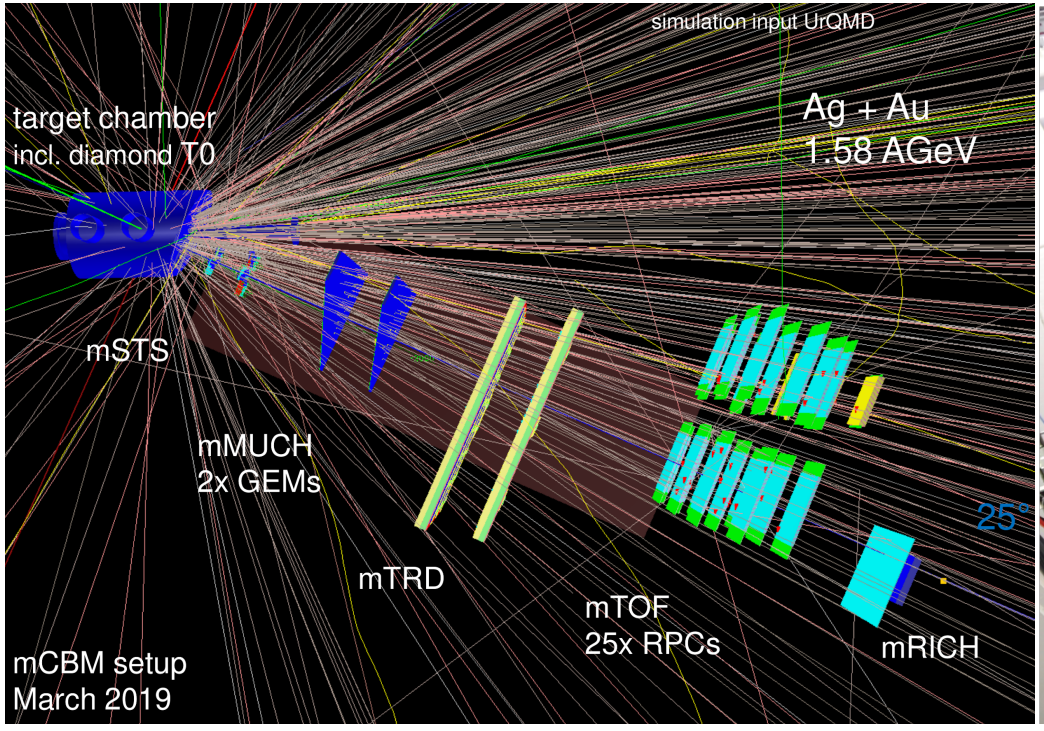

- ➔ Dileptons can be used as thermometer, chronometer and barometer of the emitting source
- ➔ Carry information about the early phases of the fireball

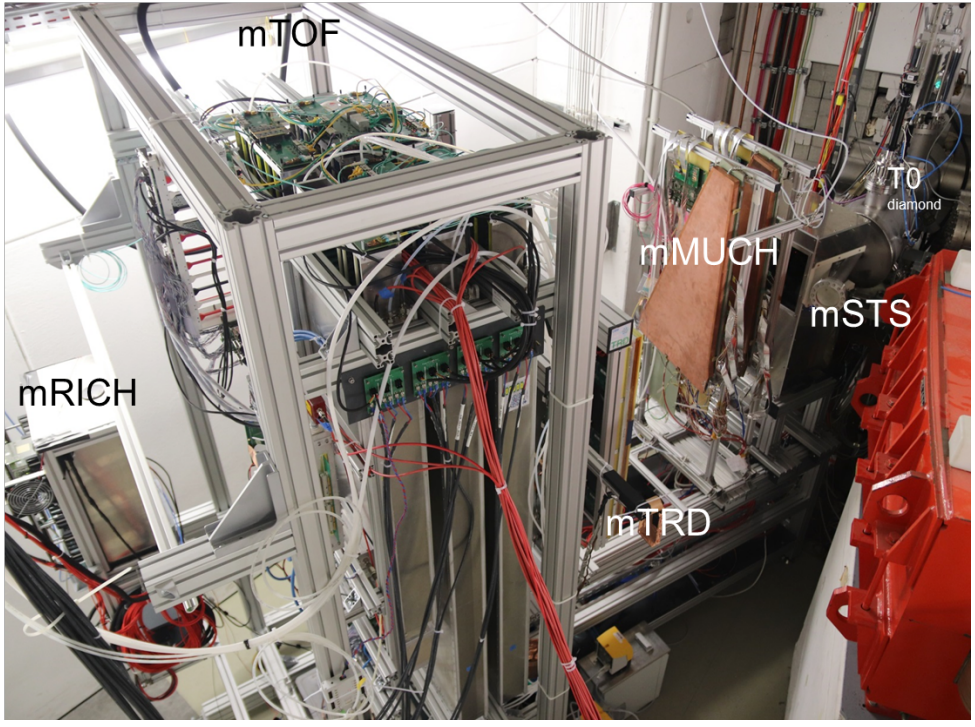
- Clear peaks for the low mass vector mesons
- Access to thermal signal is very feasible with good background description

Jan-Hendrik Otto, Poster #775

Etienne Bechtel, Poster #532

# mCBM @ GSI/SIS18 program



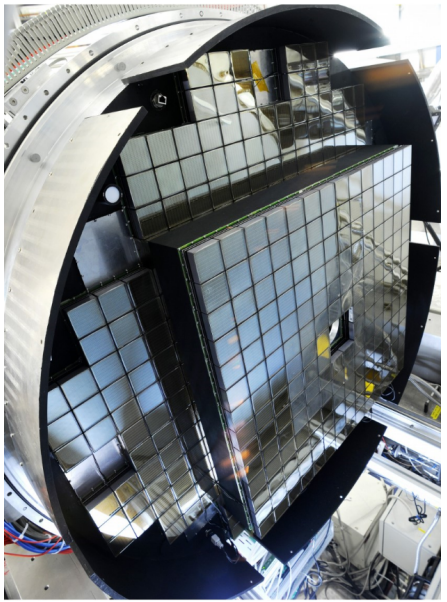




- CBM full-system test for high-rate nucleus-nucleus collisions at the SIS18 facility
- 1st data taking 12/2018 & 03/2019, data analysis ongoing
  - data transport of all subsystems in a common, synchronized data stream
  - beam intensities up to $10^8$ Ag ions/sec with collision rate up to 10 MHz
  - peak data rate > 2.5 GByte/s
- 2nd data campaign: 11/2019 & 05/2020

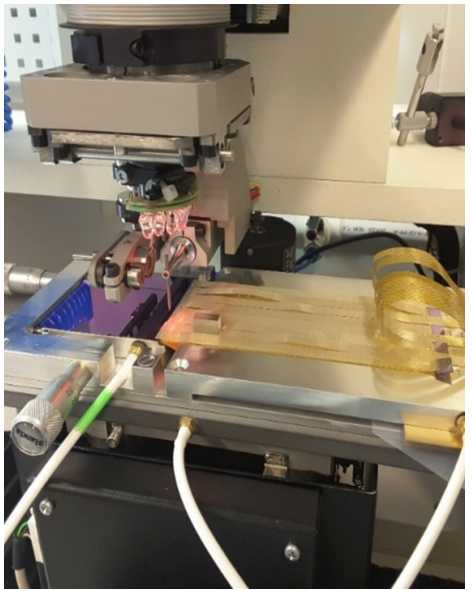
# CBM FAIR Phase-0 program (before operation in 2025)

TOF @ STAR

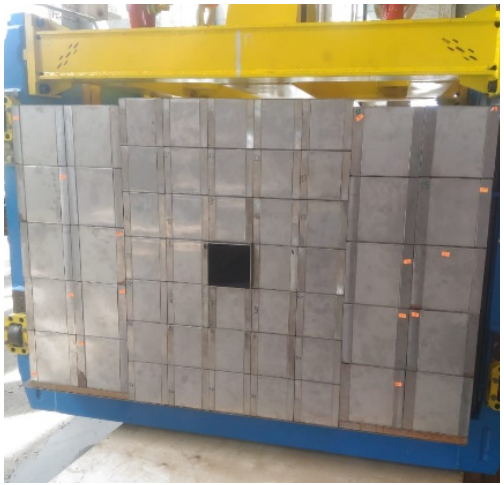

RICH @ HADES



STS @ BM@N



PSD @ BM@N / NA61/SHINE



Nikolay Karpushkin, Poster #451

- eTOF @ STAR is installed, commissioned and running
- Use 430 out of 1100 CBM RICH multi-anode photo-multipliers in HADES — Adrian Weber, Poster #405
- 4 Silicon Tracking Stations in the BM@N in JINR (start 2020 with Au-beams up to 4.5*A* GeV)
- Use PSD modules @ BM@N & NA61/SHINE
- Tests and performance studies at the NA61/SHINE experiment @ CERN SPS — Evgeny Kashirin, Poster #356

# CBM contributions at the QM2019

- ✔ Feasibility studies of conserved charge fluctuations in Au+Au collisions with CBM, Subhasis Samanta, (Talk #278)
- ✔ Challenges and prospects for the Silicon Tracking System of CBM in the first tests with heavy ions collisions, Adrian Rodriguez Rodriguez (Poster #310)
- ✔ Characterization and operation of the front-end electronics of the CBM Silicon Tracking System, Osnan Maragoto Rodriguez (Poster #648)
- ✔ Module and ladder assembly techniques for the Silicon Tracking System of the CBM experiment at FAIR, Shaifali Mehta (Poster #408)
- ✔ Development and characterization of high-density interconnection technologies for the CBM Silicon Tracking System at FAIR, Patrick Pfistner (Poster #764)
- ✔ Status and Performance of the CBM-TOF systems, Ingo Deppner (Poster #722)
- ✔ Energy calibration and signal waveform analysis of the CBM Projectile Spectator Detector, Nikolay Karpushkin (Poster #451)
- ✔ The HADES RICH upgrade within the FAIR Phase-0 program, Adrian Weber (Poster #405)
- ✔ Hypernuclei Production in CBM at FAIR - A Feasibility Study, Anton Lymanets (Poster #185)
- ✔ Physics performance studies for anisotropic flow measurements with the CBM experiment at FAIR, Oleg Golosov (Poster #415)
- ✔ Di-Electron Studies with the HADES and CBM experiments at GSI/FAIR, Jan-Hendrik Otto (Poster #775)
- ✔ Reconstruction of neutral mesons in heavy ion collisions using the conversion method with HADES and CBM, Ievgenii Kres (Poster #760)
- ✔ Simulations of thermal dielectrons for the CBM experiment, Etienne Bechtel (Poster #532)

# Summary

- CBM physics program at SIS100:
  - Precision study of the QCD phase diagram in the region of extremely high net-baryon densities
- Key experimental requirements:
  - high-rate capability of detectors and DAQ
  - online event reconstruction and selection
- Unique measurements of bulk & rare probes with CBM:
  - collective effects
  - event-by-event fluctuations
  - strangeness
  - lepton pairs
  - charm
  - hypernuclei and strange objects
- Testing CBM components and analysis methods within FAIR Phase-0

# The CBM Collaboration: 56 institutions, ~500 members

**China**
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang
IMP Lanzhou

**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.
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
Warsaw Univ.
Warsaw TU

**Russia**
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
MEPHI Moscow
PNPI Gatchina
SINP MSU, Moscow

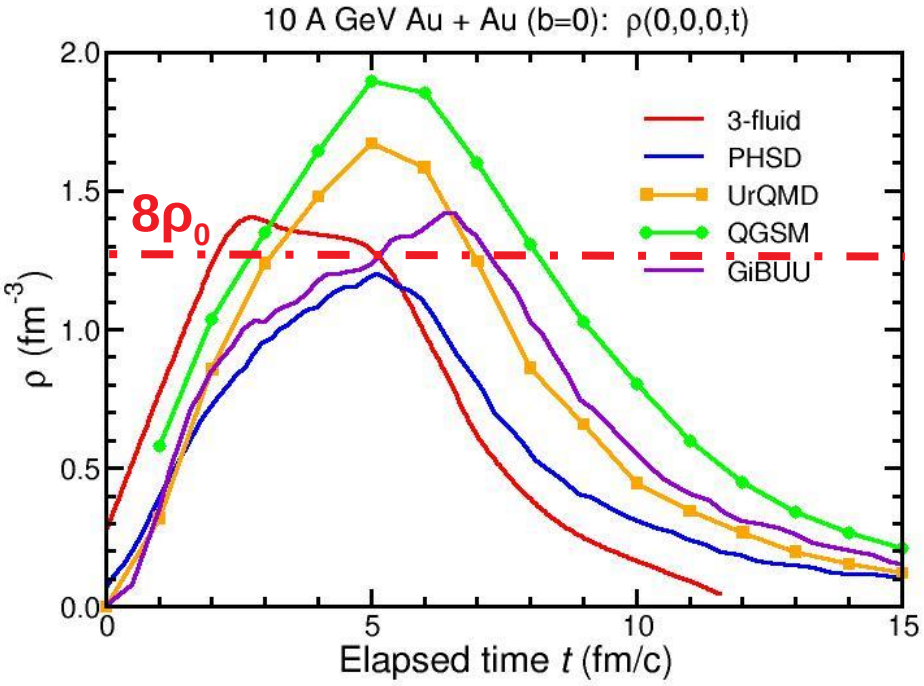
**Ukraine**
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research

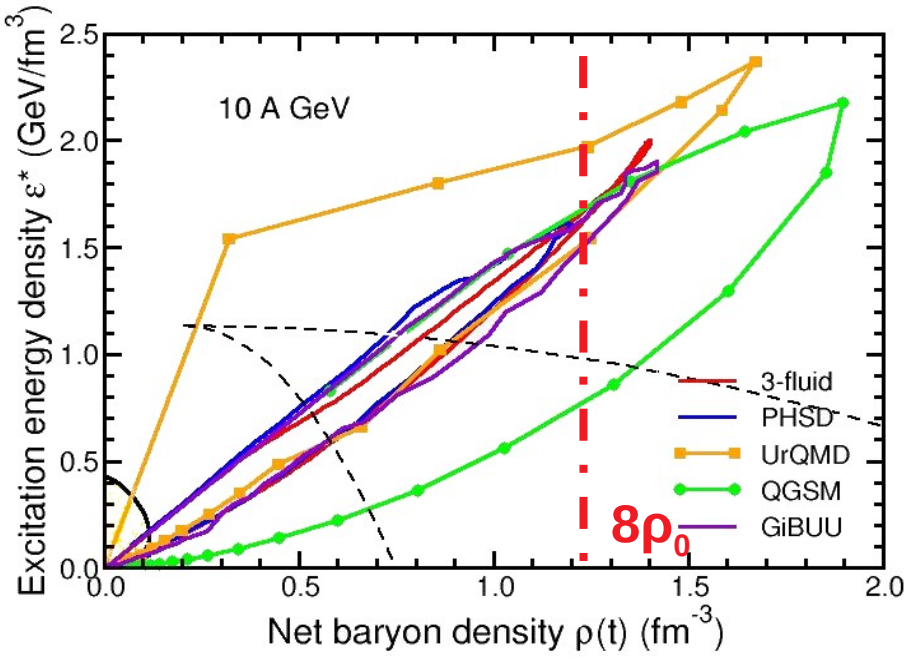
**JINR**
VBLHEP, Dubna
LIT, Dubna

# BACKUP

# Net-baryon density at SIS100 FAIR energies

I. Arsene et al. PRC75 034902 (2007)




High baryon densities during system evolution!