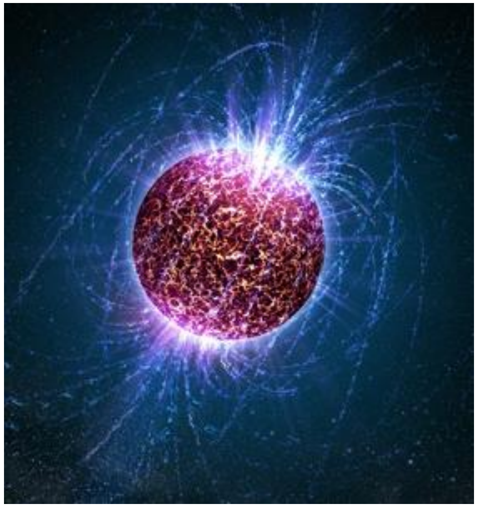
# CBM Status

**Norbert Herrmann**
**Heidelberg Univ.**

# Dense Baryonic Matter



## Neutron stars

Temperature
T < 20 MeV

Density
$\rho < 10\ \rho_0$

Lifetime
T ~ infinity

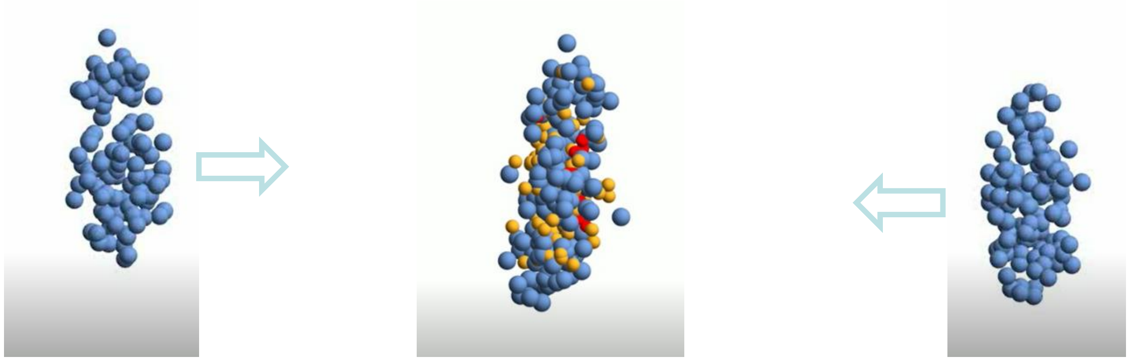
## Neutron star merger

Temperature
T < 70 MeV

Density
$\rho < 2 – 6\ \rho_0$

Reaction time
(GW170817)
T ~ 10 ms

## Heavy ion collisions at SIS100



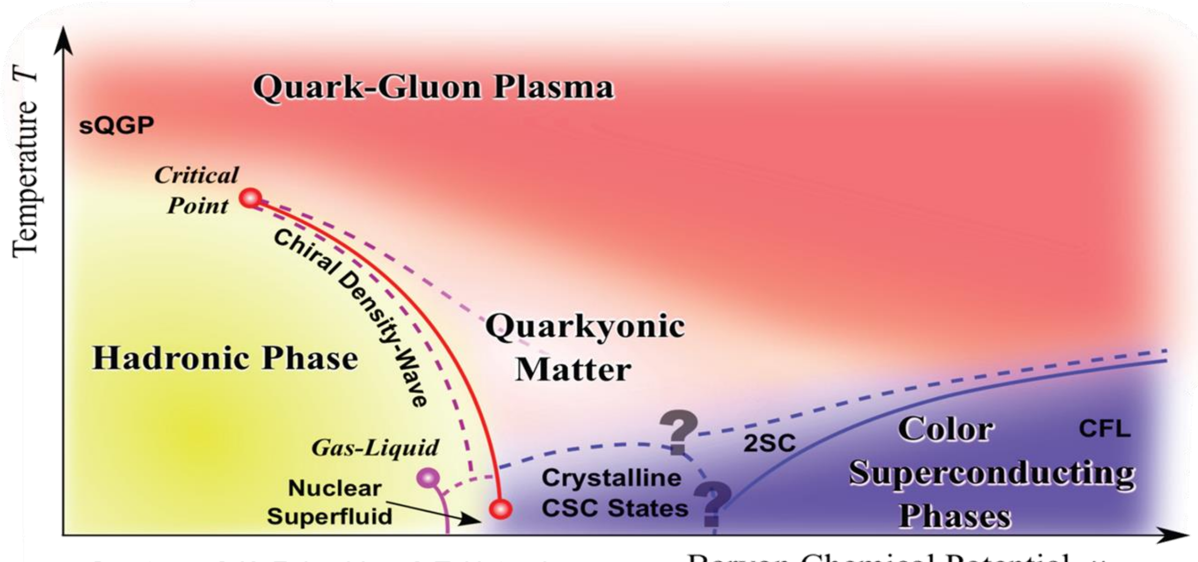
Compressed Baryonic Matter

Temperature
T < 120 MeV

Density
$\rho < 8\rho_0$

Reaction time
$t \sim 10^{-23}$ s

# CBM – Goals



Courtesy of K. Fukushima & T. Hatsuda

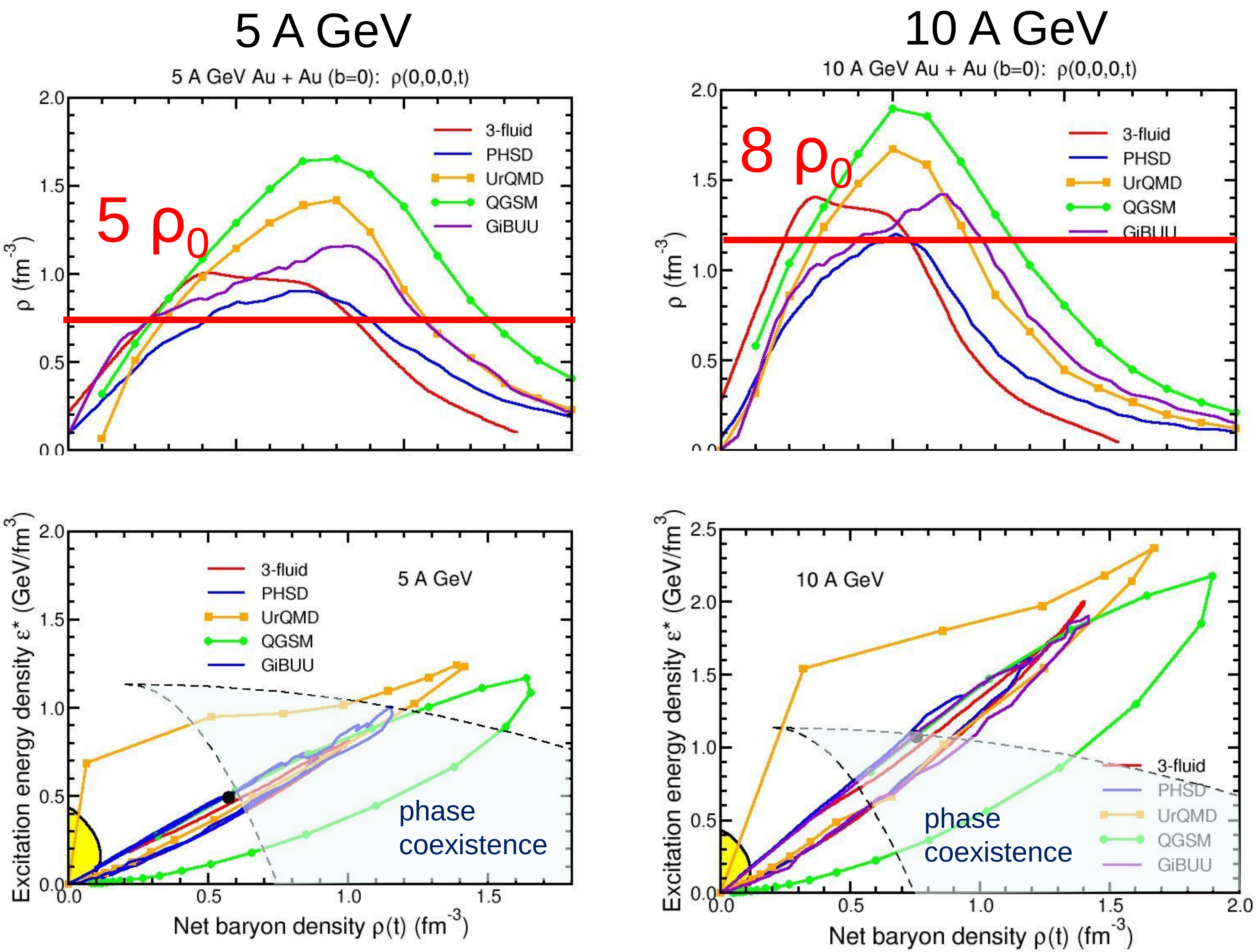
**Mission:**

Systematically explore QCD matter at large baryon densities with high accuracy and rare probes.

**Outline:**

Current experimental knowledge
Experimental and theoretical expectations / predictions
Experiment setup
Planned Fair Phase-0, Day-1 and Phase-1 measurements

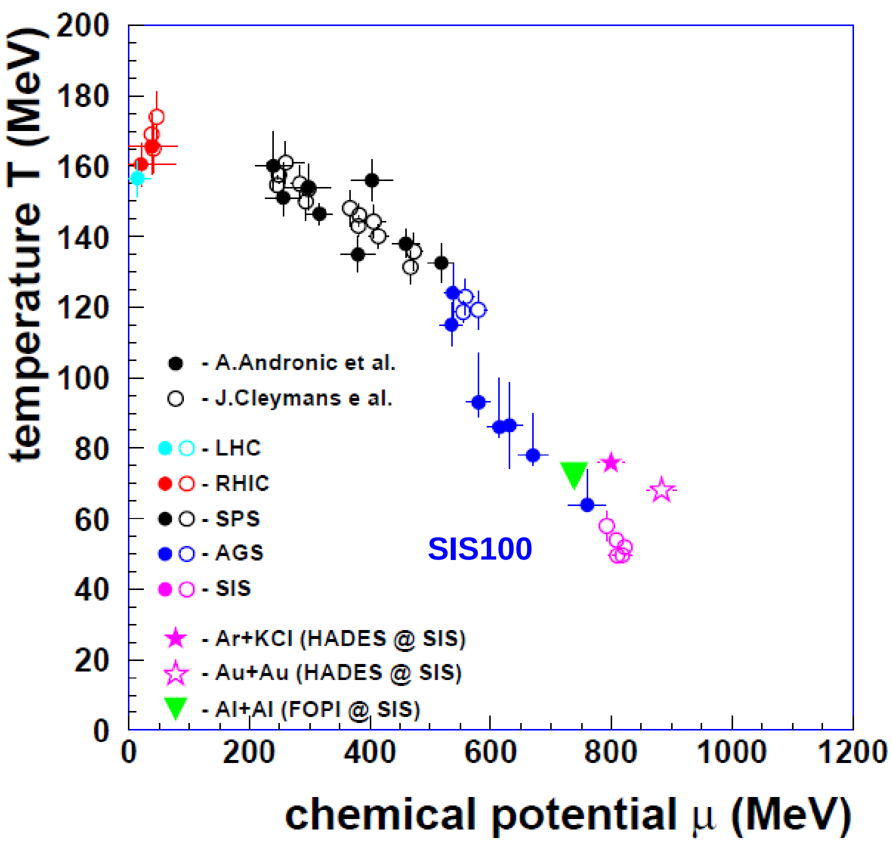
# Baryon densities in central Au+Au collisions




I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

# Chemical Freeze-out data

Analyses in framework of
Statistical Hadronisation Model




High energies:

grandcanonical ensemble

$$n_i(\mu,T) = \frac{N_i}{V} = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2}\int \frac{p^2 dp}{e^{\frac{E_i-\mu_i}{T}} \pm 1}$$

$$\mu_i = \mu_B B_i + \mu_S S_i + \mu_{I_3} I_{3,i}$$

Lower energies / small systems:

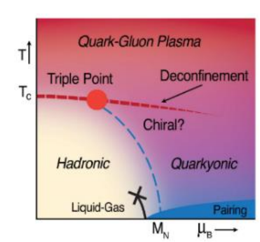
canonical ensemble,

strangeness suppression factor $\gamma_s$

Equilibrium achieved in small systems?

Equilibrium as signature for phase transition?

Freeze-out line at large baryon densities
as phase boundary to quarkyonic matter ?

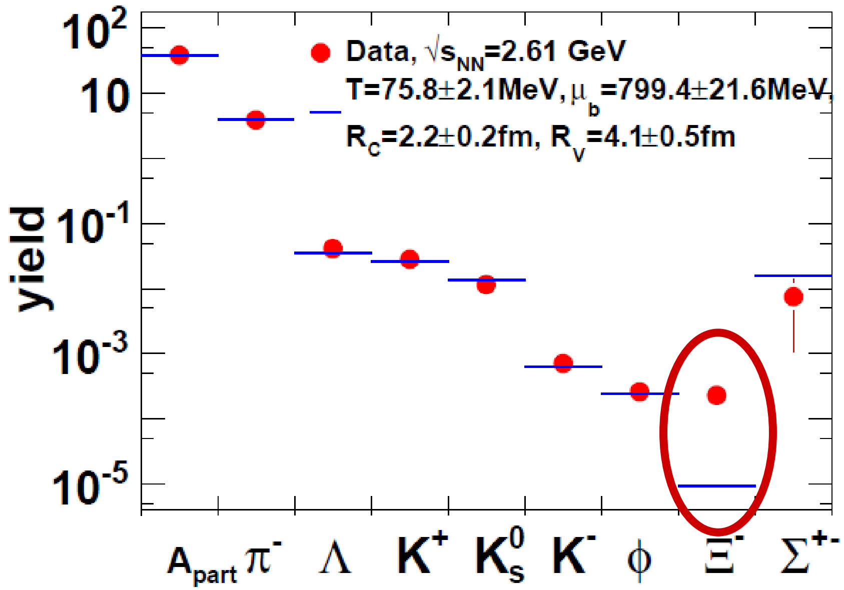



A. Andronic et al.,
Nucl. Phys. A837 (2010) 65

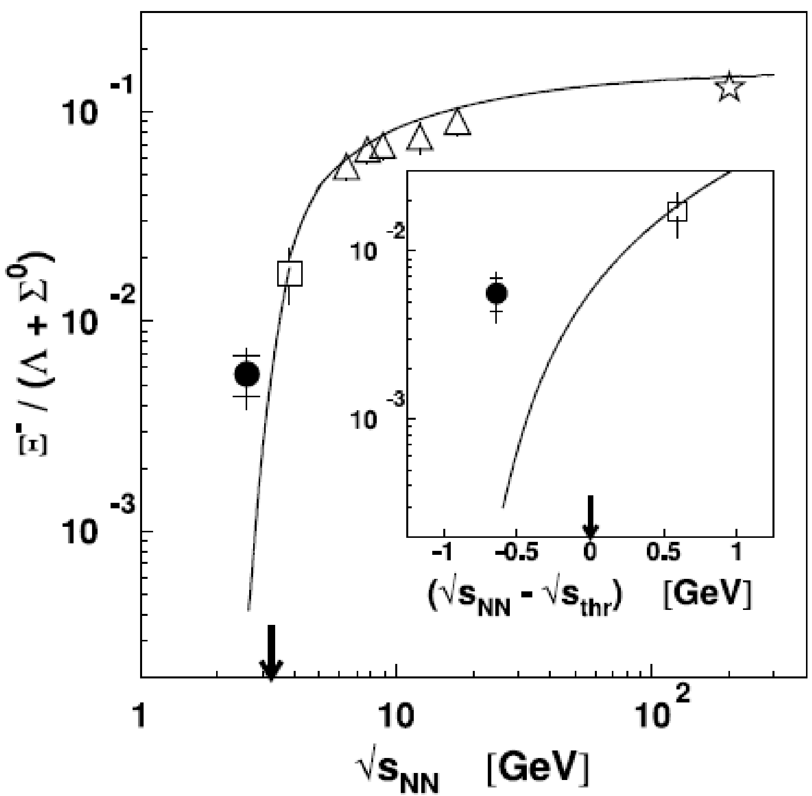
# HADES: Sub-threshold $\Xi^-$ - production

**Ar+KCl reactions at 1.76A GeV**

- $\Xi^-$ yield by appr. factor 25 higher than thermal yield

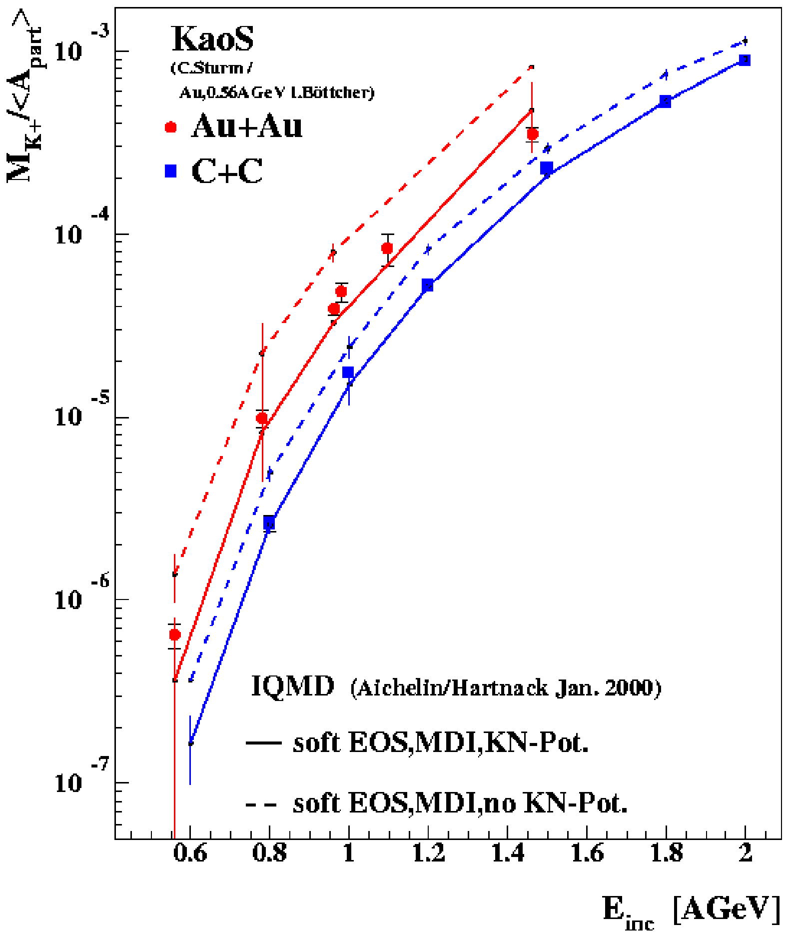



G. Agakishiev et al. (HADES), PRL103, 132301, (2009)

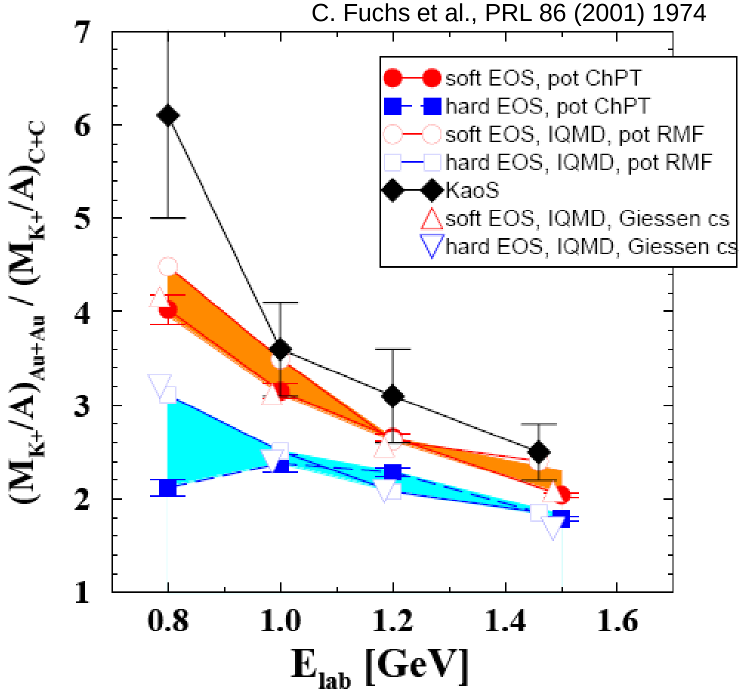


# Reminder: Subthreshold Kaon – measurements (KAOS at SIS18)

C.Sturm et al. (KaoS), PRL 86 (2001) 39



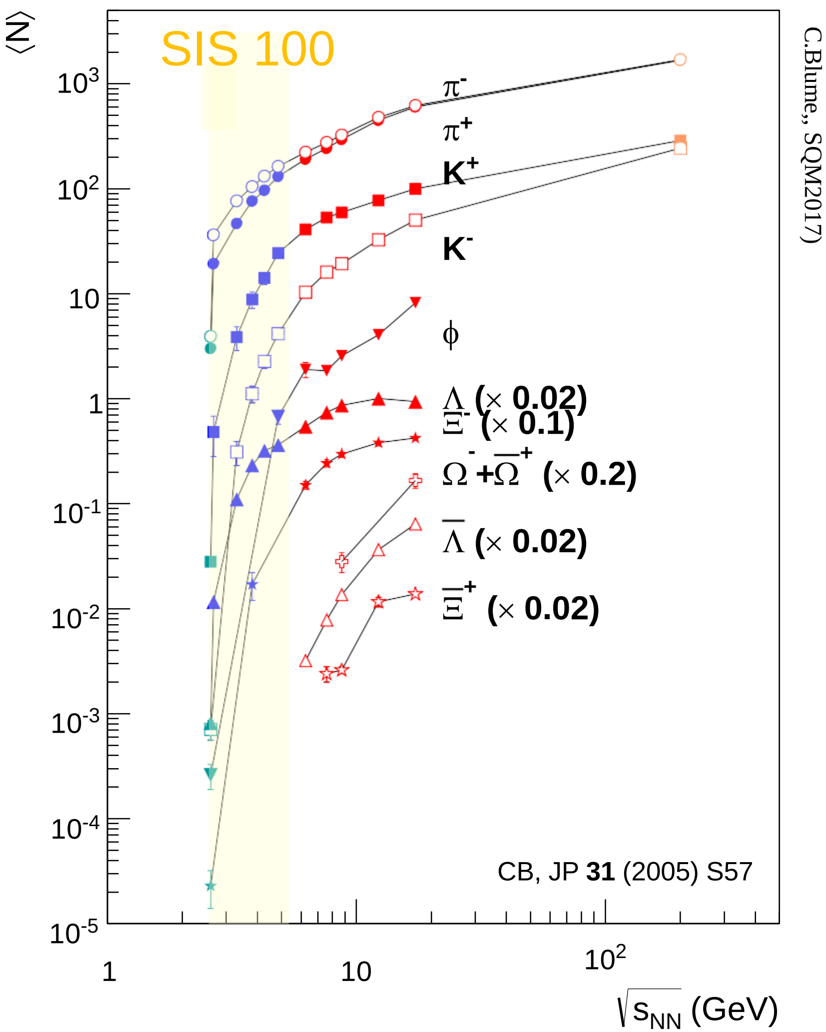

C. Fuchs et al., PRL 86 (2001) 1974




Strong sensitivity to Equation Of State
due to multistep production
(formation of nucleon resonances)
=> soft EOS (K=200 MeV)

# Final state particle abundance

Particle yields from central Au + Au collisions

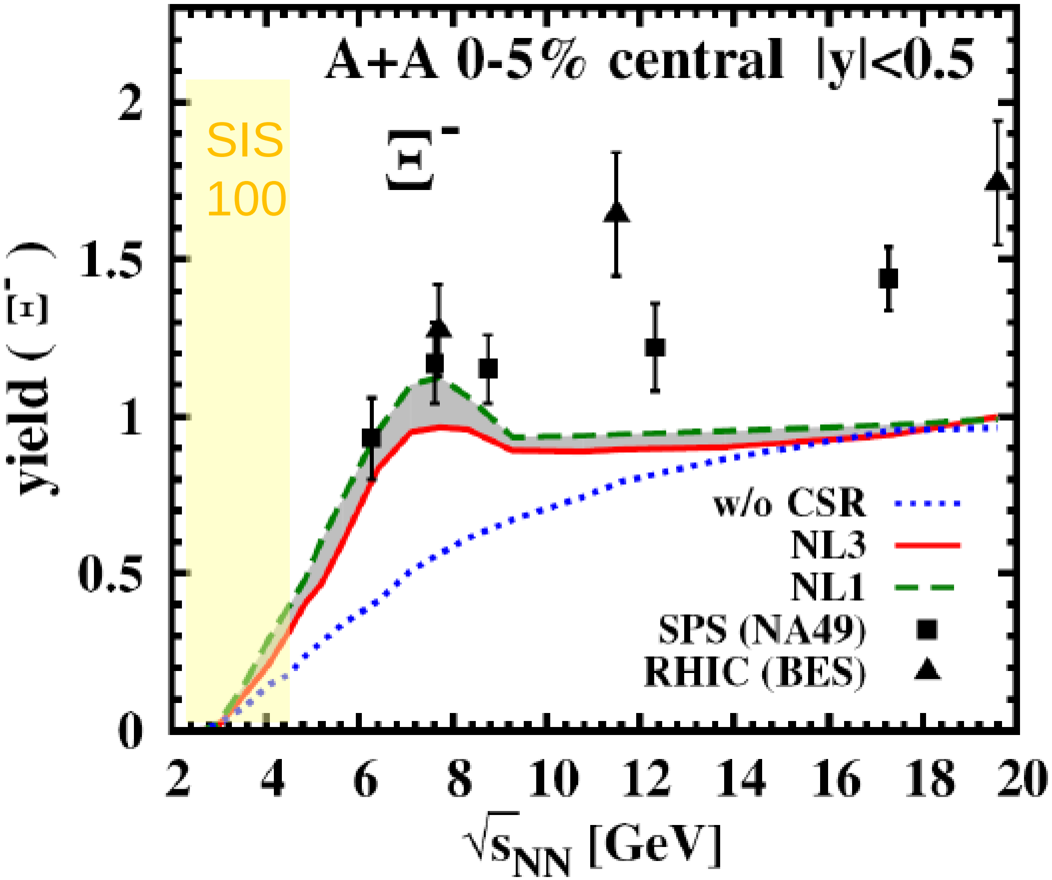



Strange and charmed particle production thresholds in pp - collisions

| reaction | $\sqrt{s}$ (GeV) | $T_{lab}$(GeV) |
|---|---|---|
| $pp \rightarrow K^+\Lambda p$ | 2.548 | 1.6 |
| $pp \rightarrow K^+K^-pp$ | 2.864 | 2.5 |
| $pp \rightarrow K^+K^+\Xi^-p$ | 3.247 | 3.7 |
| $pp \rightarrow K^+K^+K^+\Omega^-n$ | 4.092 | 7.0 |
| $pp \rightarrow \Lambda\bar{\Lambda}pp$ | 4.108 | 7.1 |
| $pp \rightarrow \Xi^-\bar{\Xi}^+pp$ | 4.520 | 9.0 |
| $pp \rightarrow \Omega^-\bar{\Omega}^+pp$ | 5.222 | 12.7 |
| $pp \rightarrow J/\Psi\, pp$ | 4.973 | 12.2 |

## PHSD interpretation of Ξ⁻ - production

A. Palmese et al. Phys.Rev. C94 (2016) no.4, 044912




Predicted sensitivities of production yields:

strong dependence on Chiral Symmetry Restoration (CSR)

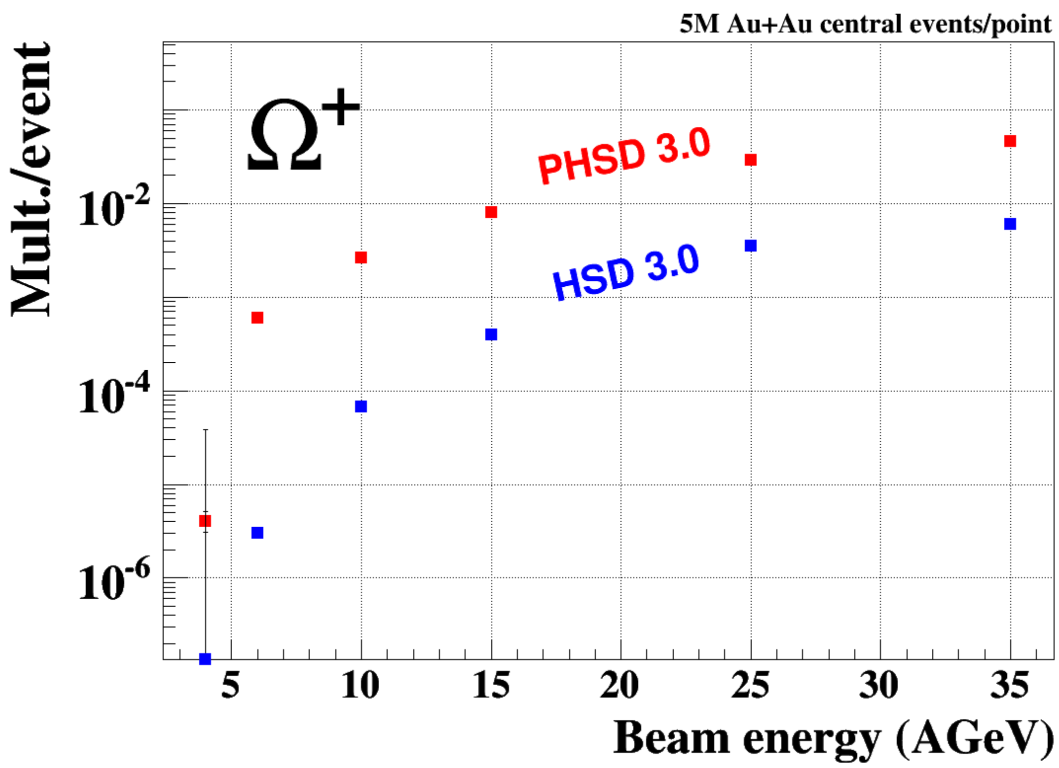
Measurable dependence on Equation of State (NL1, NL3)

Alternative explanation (URQMD): Tuned resonance parameter
J. Steinheimer, M. Bleicher, J.Phys. G43 (2016), 015104

# Antihyperon – production

**Prediction of PHSD transport model**
(E. Bratkovskaya, W. Cassing)

I. Vassiliev, CBM, private communication

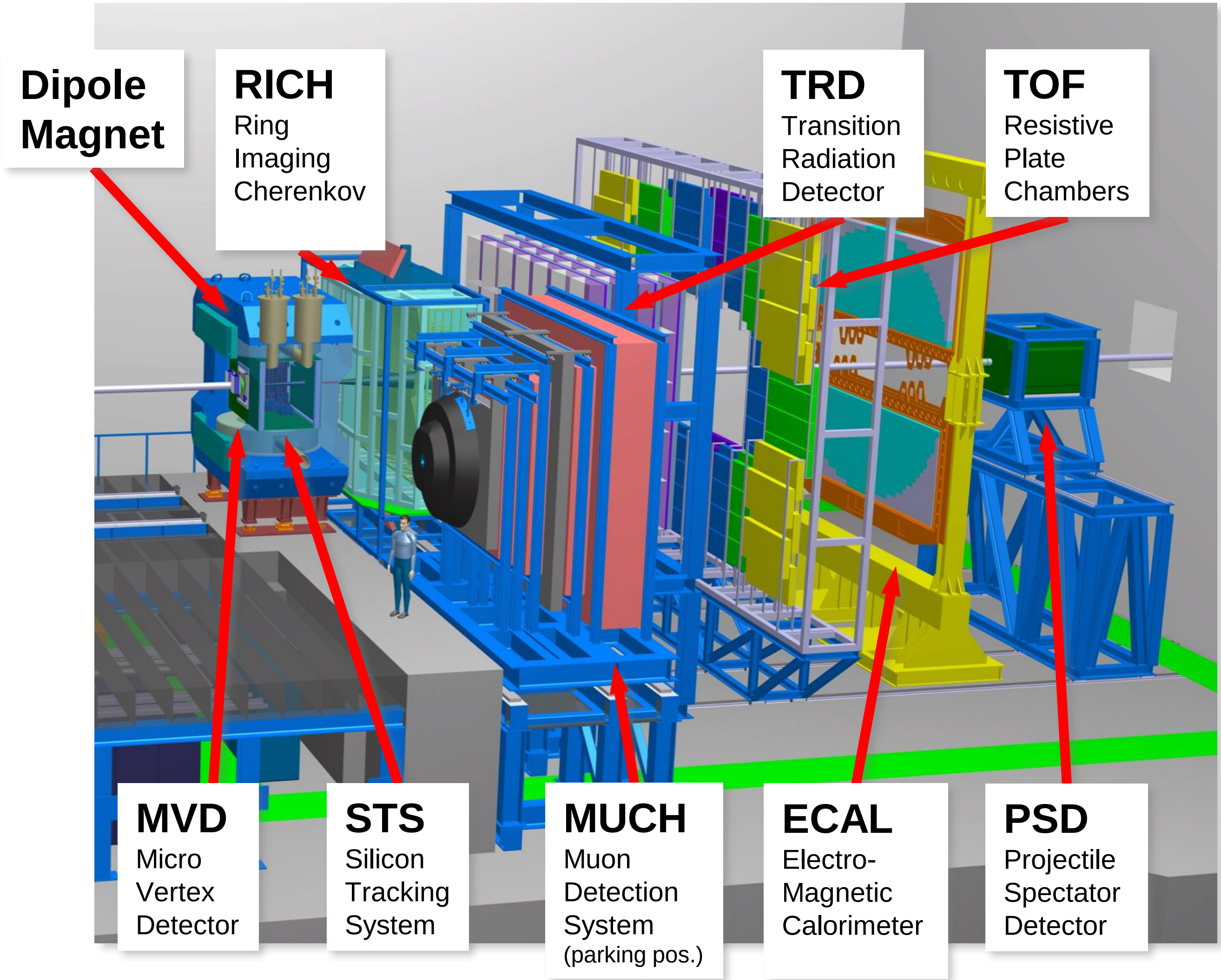



Large sensitivity to

partonic degrees of freedom
in SIS100 energy range
(deconfinement phase transition)

Mapping out the phase structure
requires systematic measurements.

# CBM experimental setup (MSV)

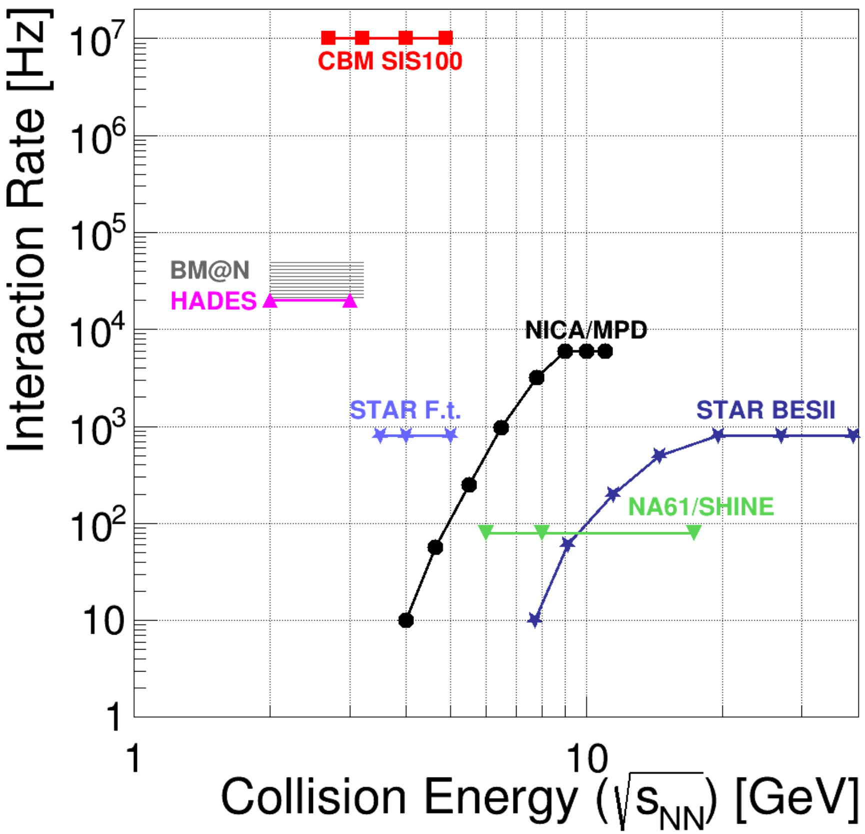



- Tracking acceptance: $2^o < \theta_{lab} < 25^o$
- Free streaming DAQ

  $R_{int}$ = 10 MHz (Au+Au)

  with
  $R_{int}$ (MVD) = 0.1 MHz
- Software based event selection

# CBM – Strategy

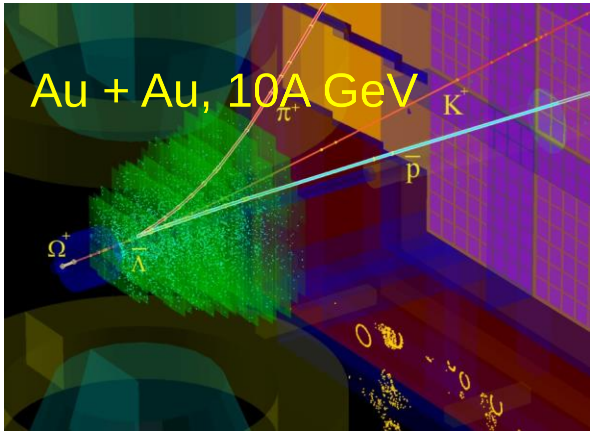



Exploration of QCD phase diagram as international effort:

| | |
|---|---|
| NA61 | @ SPS / CERN |
| BM@N | @ Nuclotron/JINR |
| STAR (F.t.) | @ RHIC/BNL |
| MPD | @ NICA / JINR |

CBM's unique feature
High statistics measurement of rare probes

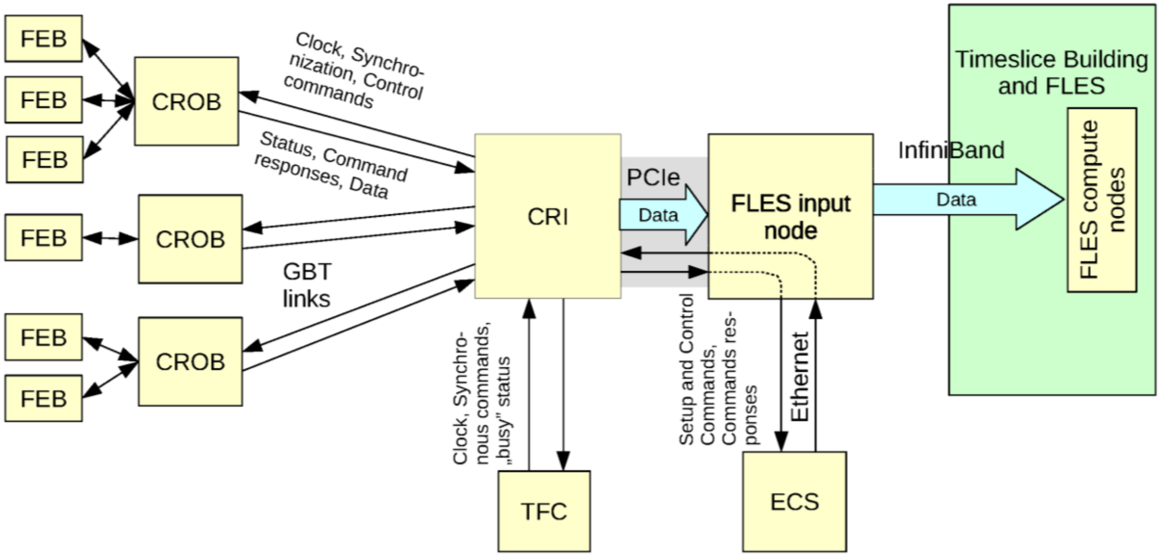
# CBM data processing system




Reaction rate Au + Au:

$10^7$ collisions per second

Data rate: ~ 1 TB/s


Main features:

- radiation tolerant detectors and front-end electronics
- free streaming (triggerless) data with time stamps,
- software based event selection

# CBM physics and observables

Eur.Phys.J. A53 (2017) 60

## QCD equation-of-state

- collective flow of identified particles
- particle production at threshold energies

## Phase transition

- excitation function of hyperons
- excitation function of LM lepton pairs

## Critical point

- event-by-event fluctuations of conserved quantities

## Chiral symmetry restoration at large $\rho_B$

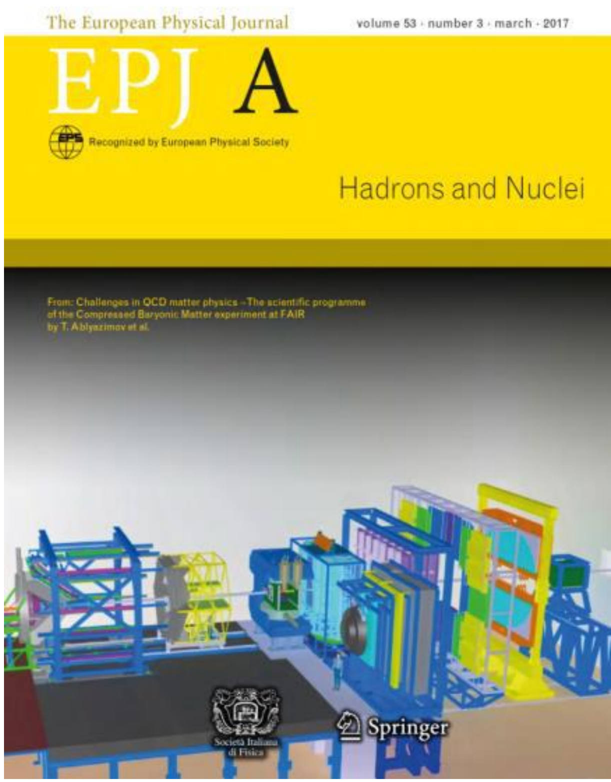
- in-medium modifications of hadrons
- dileptons at intermediate invariant masses

## Strange matter

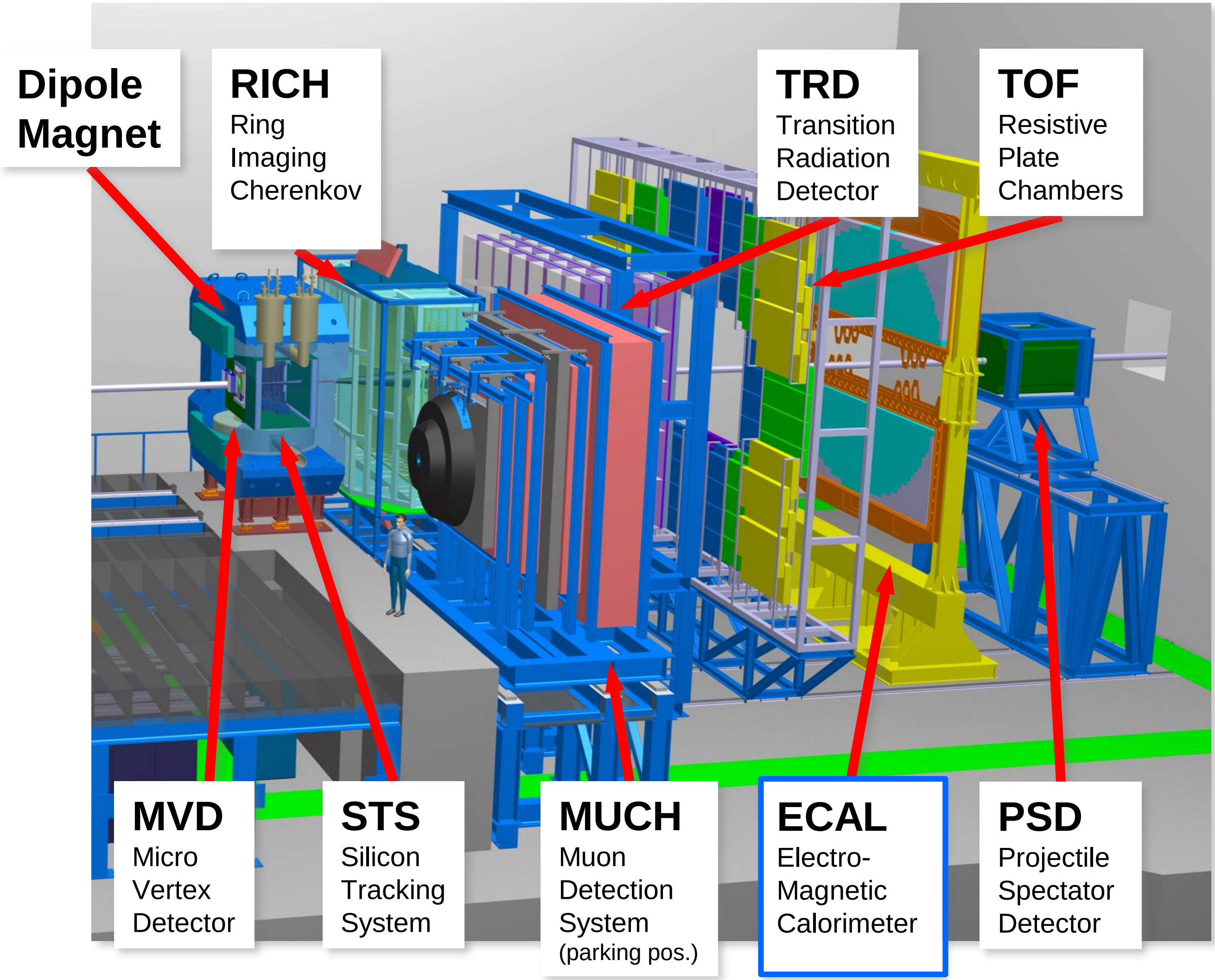
- (double-) lambda hypernuclei
- Search for meta-stable objects (e.g. strange dibaryons)

## Heavy flavour in cold and dense matter

- excitation function of charm production



# CBM experimental setup (day-1)




- Tracking acceptance: $2^o < \theta_{lab} < 25^o$
- Free streaming DAQ
- $R_{int}$ = 10 MHz (Au+Au)

  $R_{int} \approx 0.5$ MHz
  full bandwith:
  Det. – Entry nodes
  reduced bandwidth
  Entry nodes – Comp. farm

  with
  $R_{int}$ (MVD)=0.1 MHz
- Software based event selection

Day-1 setup = MSV setup – Compute Performance - ECAL
Phase-1 = Day1 with full Compute Performance + ECAL

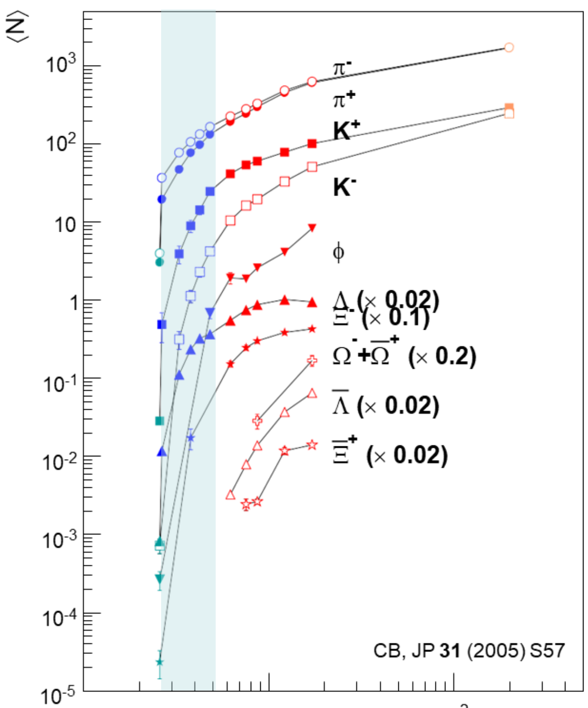
Day-1 funding:
~ 90% secured

# CBM day-1 – program

## Observables: Strangeness and Dileptons

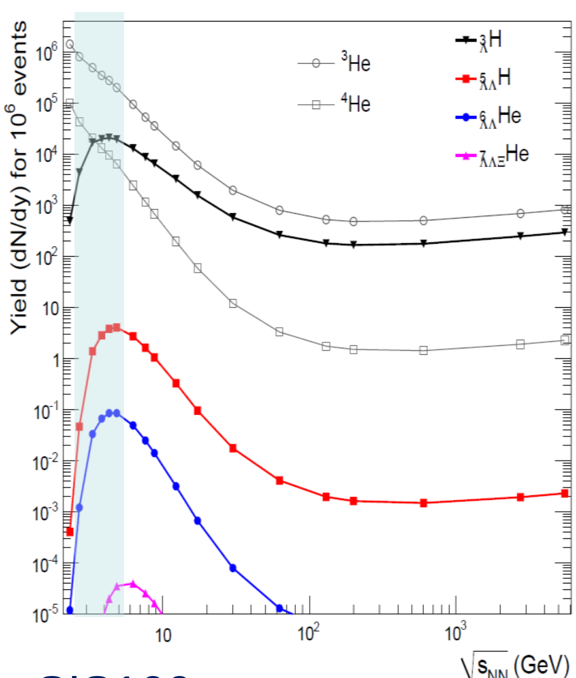
Excitation function of yields and phase-space distributions of
multi-strange hyperons and
lepton pairs in AA (C+C, Au+Au) collisions from 2-11 A GeV.
Search for hypernuclei (no data available in this energy range).

multi-strange hyperons



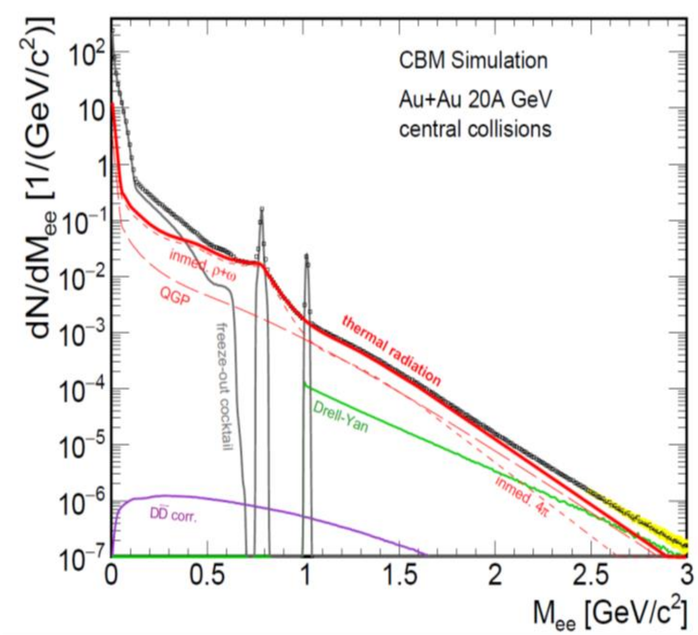

SIS100

hypernuclei




SIS100

dilepton invariant mass



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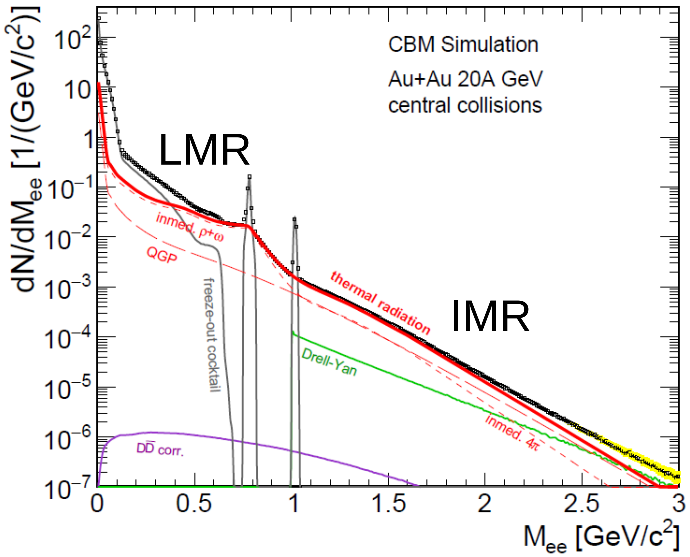
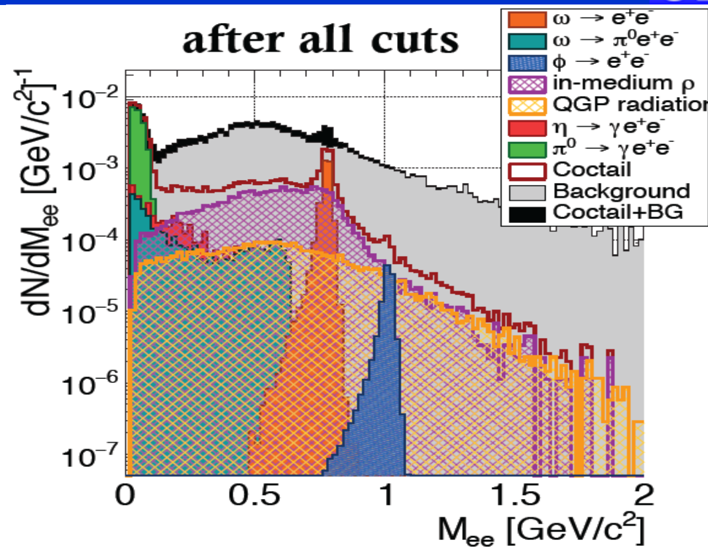
# Dileptons as probes for dense matter (Day 1)

[R. Rapp, H. v.Hees, PLB 753 (2016) 586]



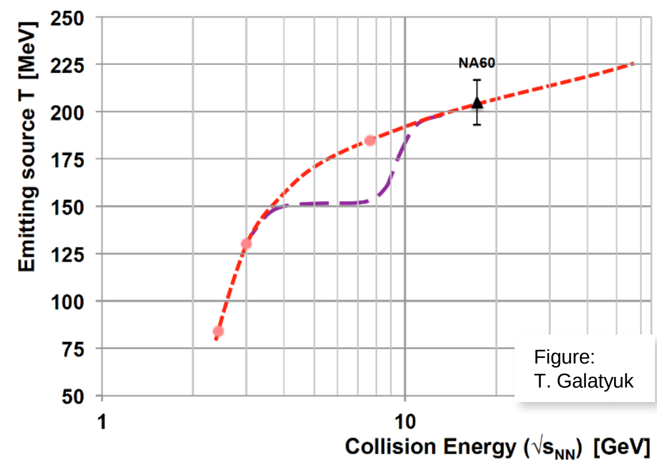




- 1M Au+Au (b=0 fm), 8A GeV
- IMR: S/B > 1/100
- Statistical accuracy of 10% requires ~1 week of beamtime

LMR: ρ – chiral symmetry restoration
fireball space – time extension

IMR: access to fireball temperature
ρ-$a_1$ chiral mixing

Measurement program:
e.g. excitation function of IMR – slope
full performance, uses MVD (100 kHz)

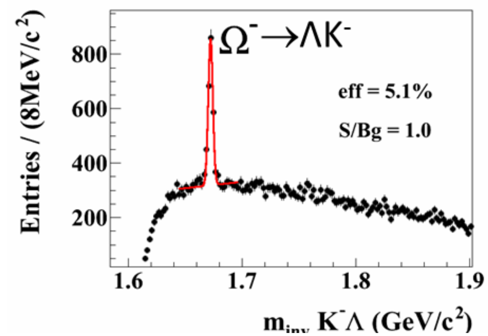


# CBM Day 1 – further unique measurements

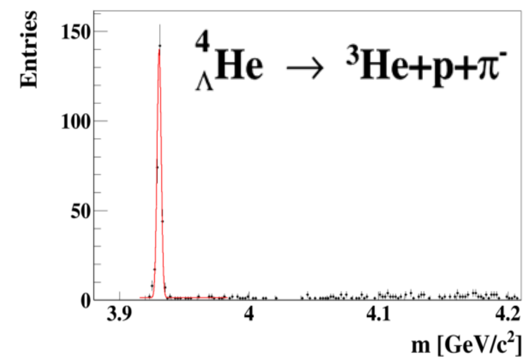
Hyperon measurements:

Au+Au at 10A GeV, $\varepsilon_{duty}$ = 50%, R=100kHz

| Particle | Multi-plicity | BR | ε (%) | yield ($s^{-1}$) | yield in 1 week |
|---|---|---|---|---|---|
| $\Omega^-$ (1672) | $5.6\cdot10^{-3}$ | 0.68 | 5 | 1.64 | $5\cdot10^5$ |
| $^4_\Lambda$He (3930) | $1.9\cdot10^{-3}$ | 0.32 | 14.7 | 0.87 | $3\cdot10^5$ |



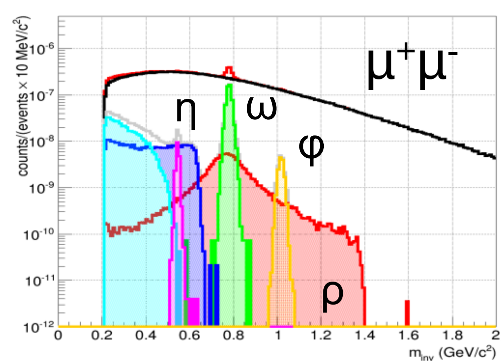

Hypernuclei measurement:




Di-Muon

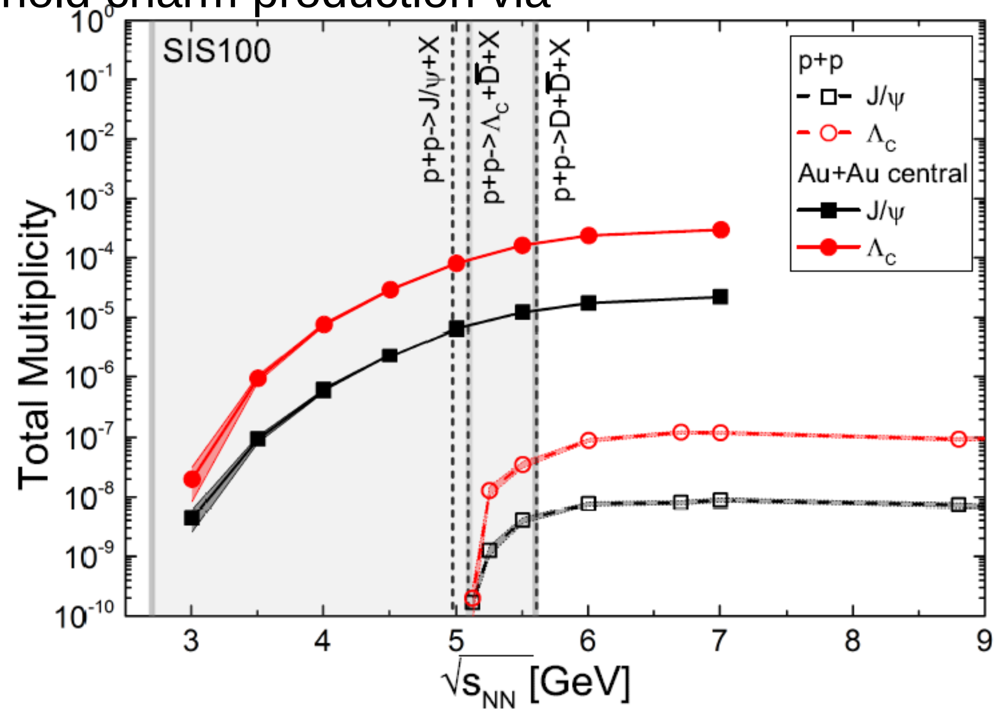
LM measurement at 8A GeV

complementary measurement to $e^+e^-$ with different systematic errors



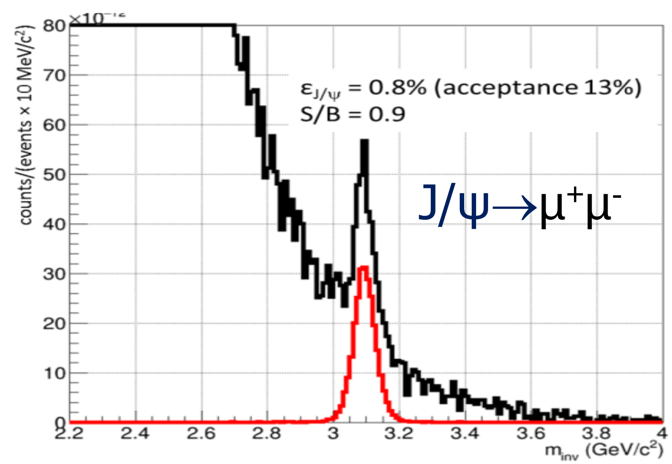
# Indian contribution: Muon Detector and Physics

UrQMD calculation including subthreshold charm production via
$N^* \rightarrow \Lambda_c + D$ and $N^* \rightarrow N + J/\psi$



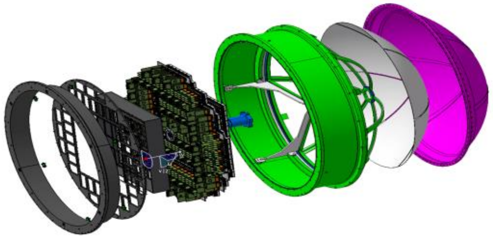

Di-muons in central Au+Au collisions at 10A GeV (J/ψ)

HSD prediction:
300 J/Ψ per week
at 10 MHz

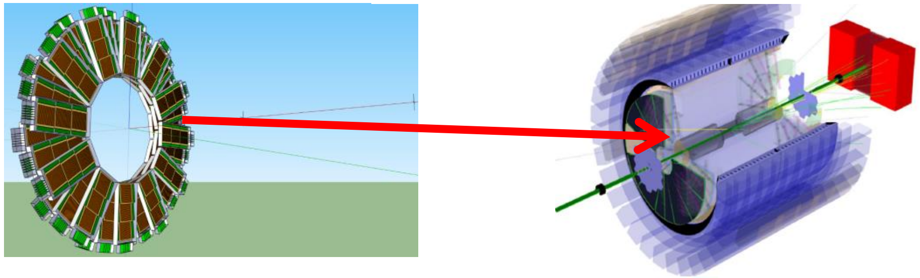


# CBM – FAIR Phase 0 projects (2018 – 2022)

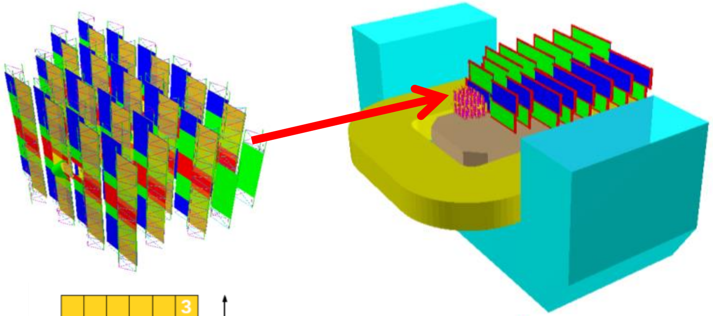
1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) including FEE in HADES RICH photon detector



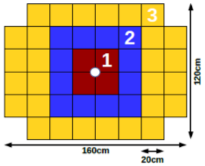
2. Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)



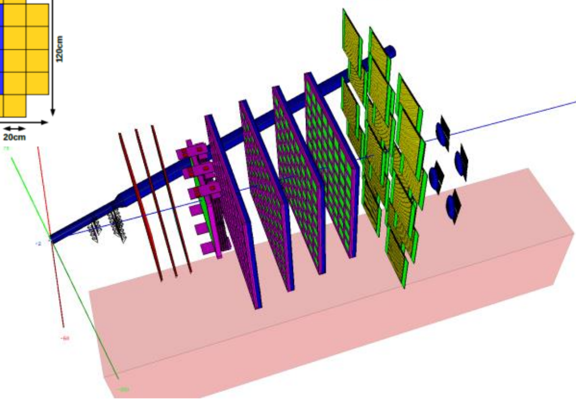
3. Upgrade BM@N experiment with 4 Silicon stations of CBM/STS design in the BM@N experiment at the Nuclotron JINR/Dubna (Au-beams in late 2020)



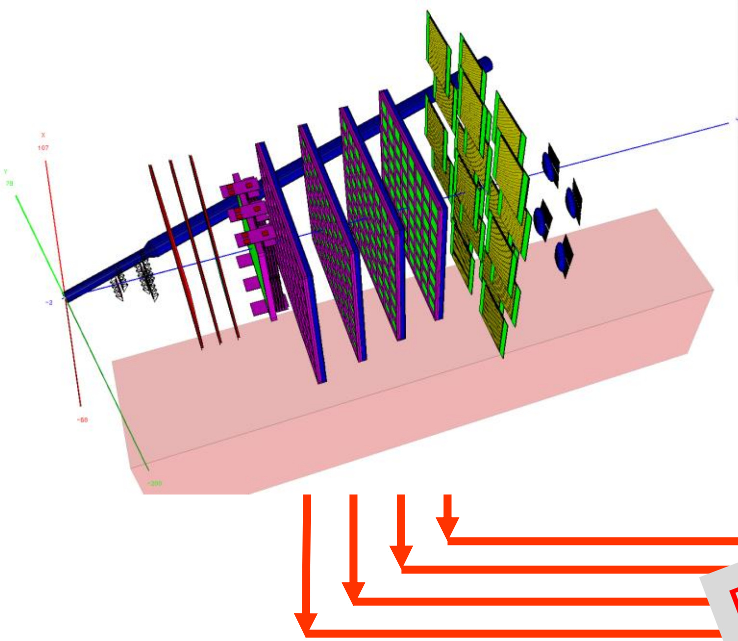
4. Install, commission and use the Project Spectator Detector at the BM@N experiment




5. mini CBM (mCBM@SIS18) demonstrator for full CBM data taking and analysis chain

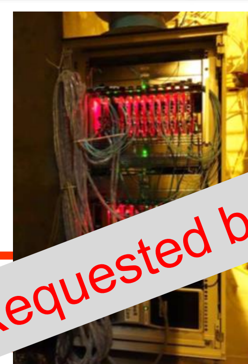


# mCBM schedule

**Schedule**

| | |
|---|---|
| 10/2017 | cave & beam line: reconstruction started, procurement started |
| 11/2017 | μDAQ test stand @ Heidelberg operational |
| 12/2017 | beam dump mounted |
| 03/2018 | cave reconstruction completed |
| 04/2018 | mFLES cluster @ Green IT Cube installed |
| 05/2018 | beam line installed and commissioned |
| 05/2018 | installation of detector stations |
| 06/2018 | start commissioning w/o beam |
| 08/2018 | start commissioning with beam |
| Q3/2019 | first system high rate test |

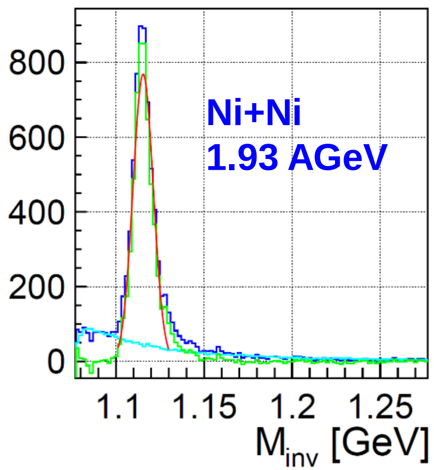


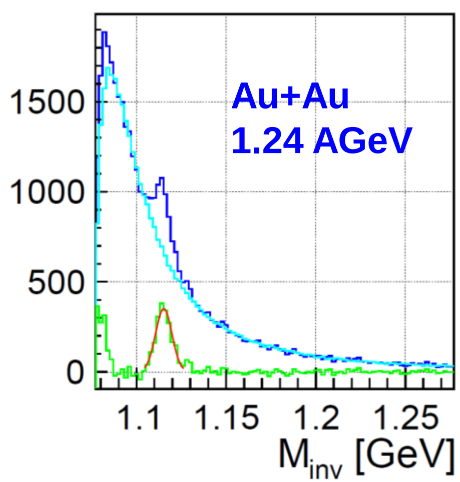

Requested beamtime was fully granted by G-PAC

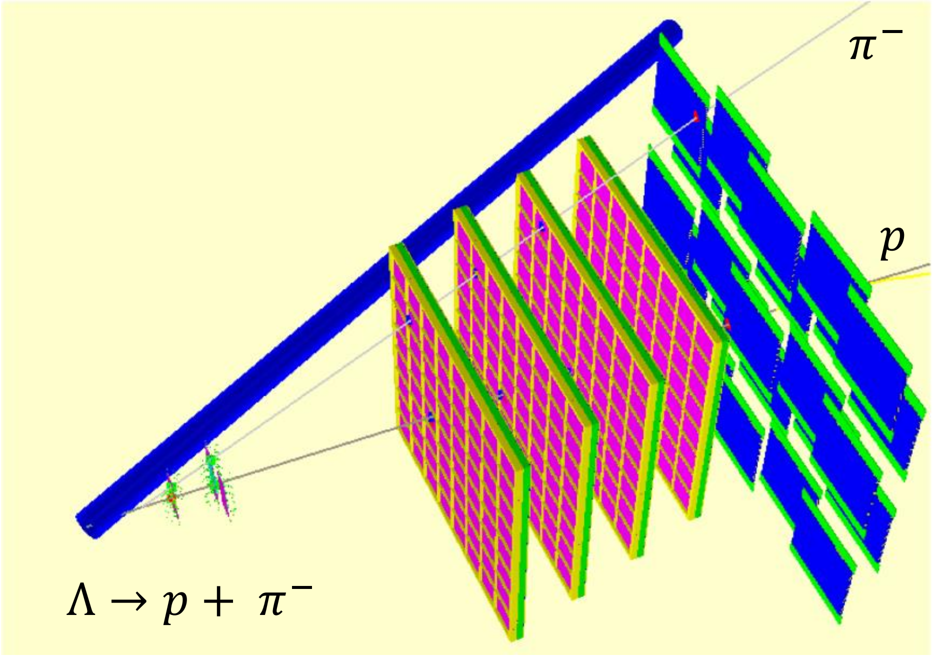
# mCBM performance benchmark

(Sub)threshold Λ – baryon reconstruction.

Event based MC simulation of $10^8$ events
(measurement time: 10 s)



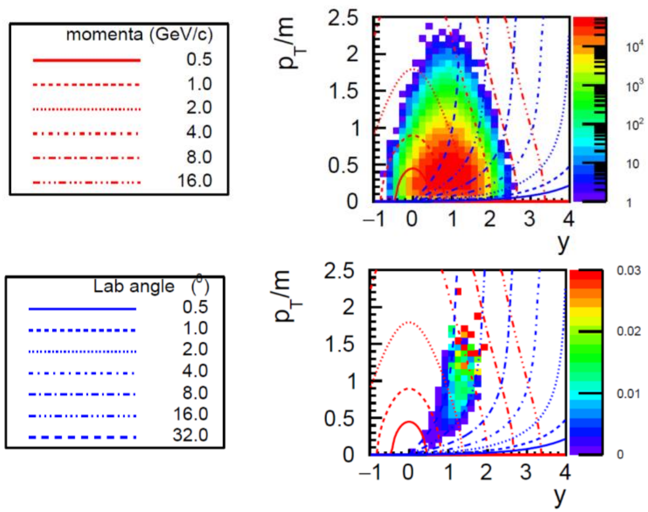




Acceptance

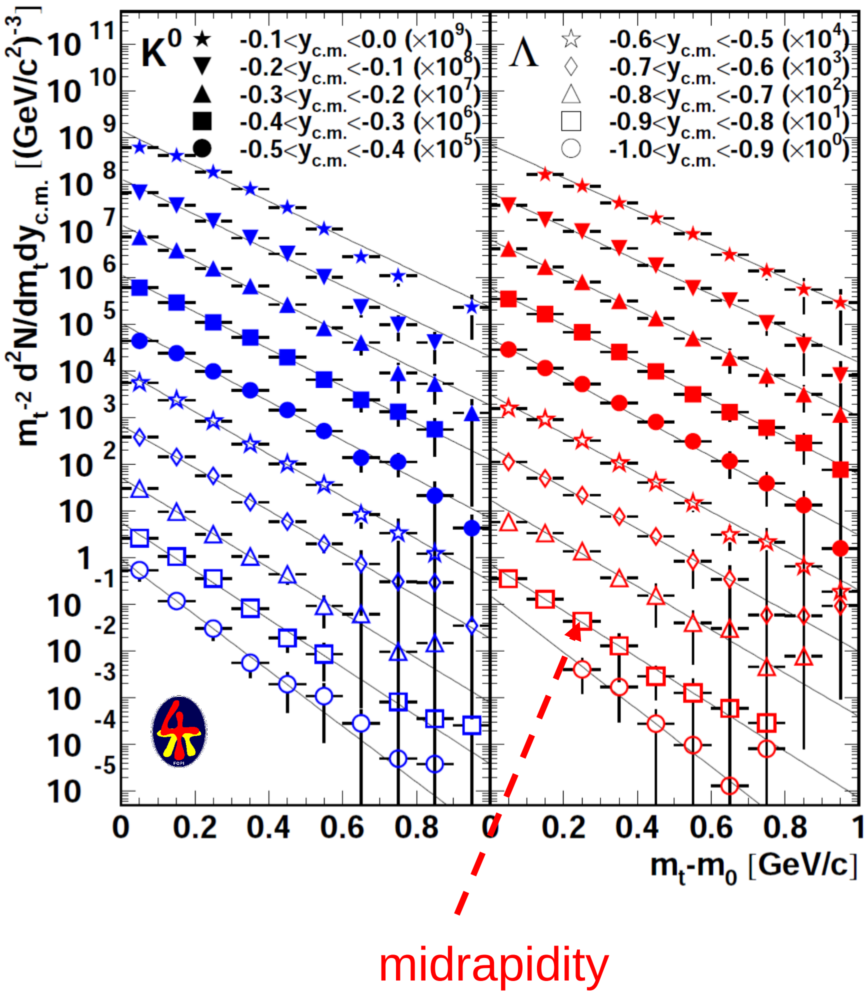
&

Efficiency



# Reference data for Λ – production

M. Merschmeyer et al. (FOPI), PRC 76, 024906 (2007)




Reaction:

$^{58}Ni + ^{58}Ni$ at 1.93 AGeV

Centrality:

350 mb (most central)

$\frac{\sigma_{cen}}{\sigma_{geo}} \leq 0.13$

Data taking period:

17.1.2003 – 3.2.2003

Statistics:

~ 60.000 reconstructed Λ

Derived quantities:

slope parameter

integrated yield

# CBM – Collaboration: 55 institutions, 470 members

**China:**
CCNU Wuhan
Tsinghua Univ.
USTC Hefei
CTGU Yichang
Chongqing Univ.

**Czech Republic:**
CAS, Rez
Techn. Univ. Prague

**France:**
IPHC Strasbourg

**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.

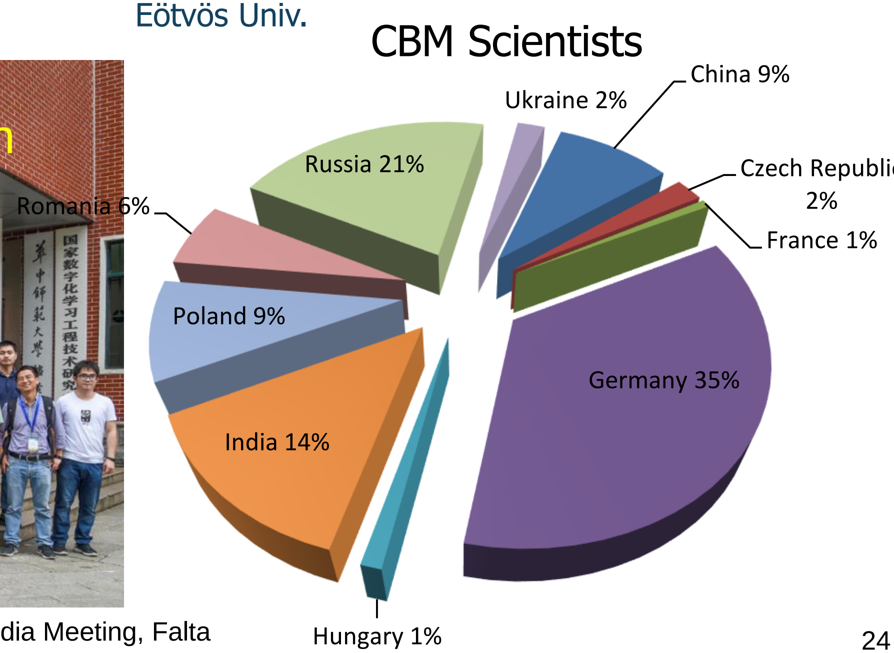
**Poland:**
AGH Krakow
Jag. Univ. Krakow
Warsaw Univ.
Warsaw TU

**Romania:**
NIPNE Bucharest
Univ. Bucharest

**Hungary:**
KFKI Budapest
Eötvös Univ.

**Russia:**
IHEP Protvino
INR Troitzk
ITEP Moscow
Kurchatov Inst., Moscow
VBLHEP, JINR Dubna
LIT, JINR Dubna
MEPHI Moscow
PNPI Gatchina
SINP MSU, Moscow

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

# Task list for Indian groups

1. **Detector**
   - install and operate full scale GEM prototypes in μCBM and/or mCBM
   - install and operate RPC prototypes in μCBM and/or mCBM
   - verify resolutions (position & time), rate capability and aging
   - prepare PRRs

2. **Software**
   - Time based MUCH digitizer
   - Time based MUCH hit finder for MC & Data (mCBM)
   - MUCH Tracklet finder
   - General contributions to Computing Projects ?

3. **Analysis**

   Internal reports on

   MUCH software
   - muon identification algorithm

   MUCH physics performance (finally to be published)
   - LMVM at SIS100
   - J/Ψ measurements at SIS100

   Fluctuation and Correlation Signatures at SIS100 within PWG C2F

# Summary / Conclusion

CBM scientific program at SIS100 is unique

- explore QCD matter at neutron star core densities
- employ high statistics capibility
  - to achieve high-precision of multi-differential observables
  - to enable rare processes as sensitive probes

CBM day-1 setup allows start of program with significant discovery potential

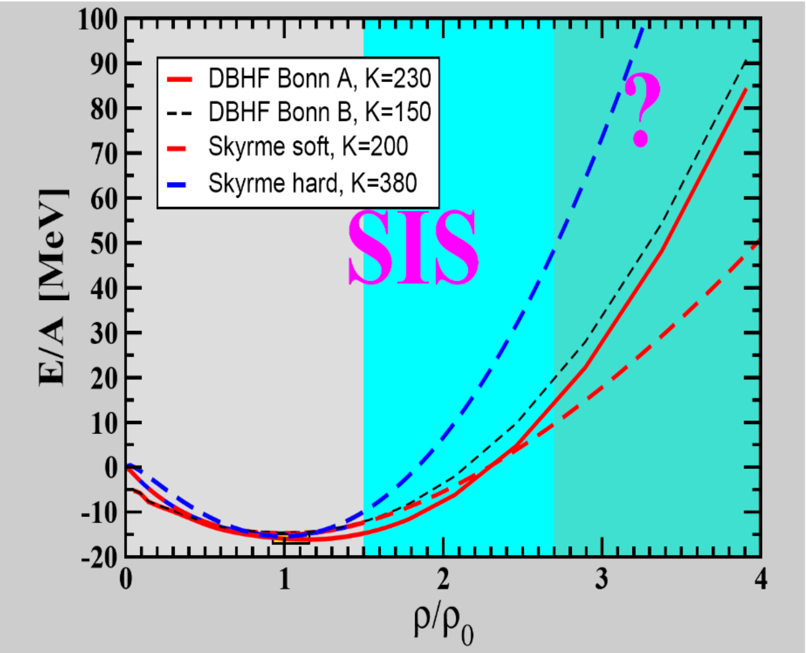
- excitation function of hyperons production
- excitation function of di-lepton production
- study of hypernuclei

CBM Phase 0 activities targeted towards usage and understanding of major components & production of visible physics results with CBM devices

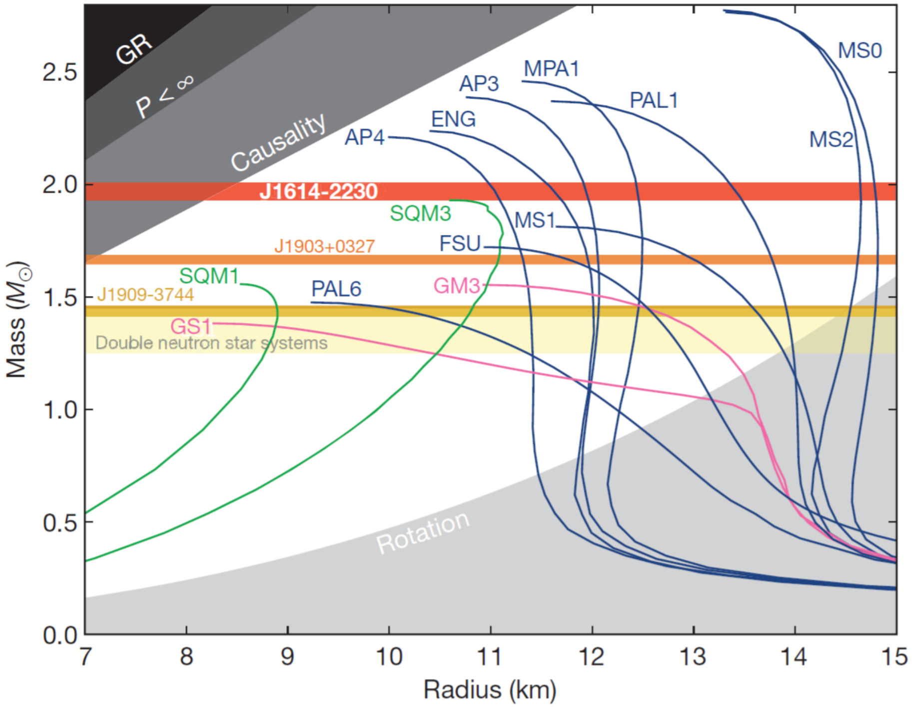
| | |
|---|---|
| CBM – RICH sensors & readout | in HADES at SIS18 |
| CBM – TOF and HPC software | in STAR at RHIC/BNL |
| CBM – PSD and CBM - STS | in BM@N at Nuclotron/JINR |
| Integration of all subsystems & FLES | in mCBM at SIS18 |

# Equation of State & Neutron stars

C. Fuchs,
Prog. Part. Nucl. Phys. 56 (2006) 1




P.B. Demorest (2010)
doi:10.1038/nature09466

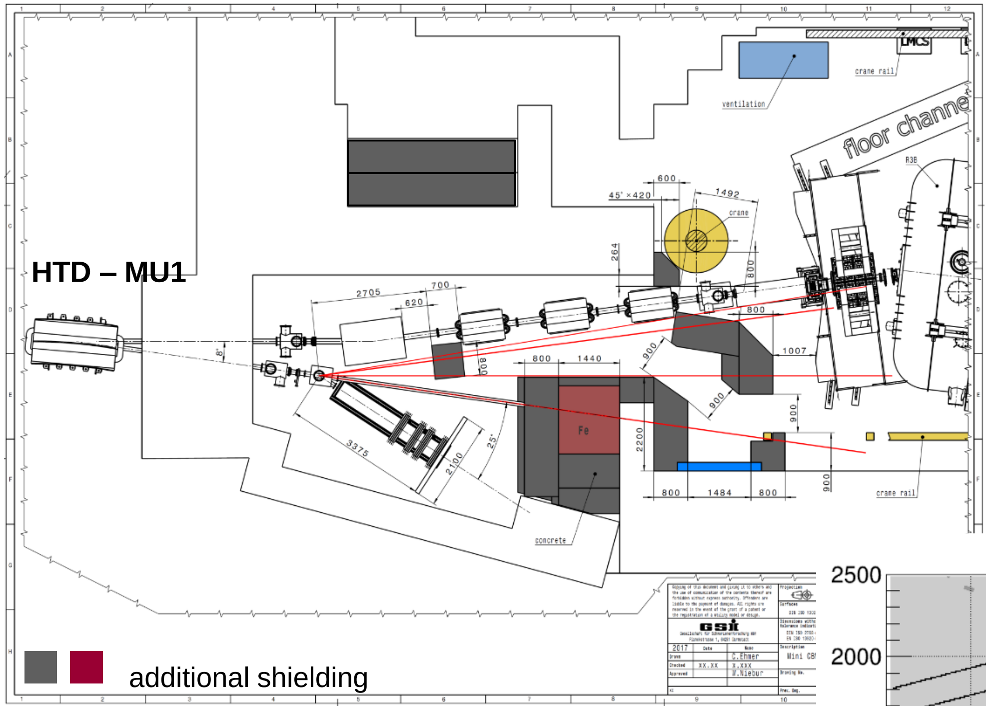



Soft EOS (Skyrme, K = 200 MeV) is not repulsive enough to allow for a neutron star with 2 solar masses.

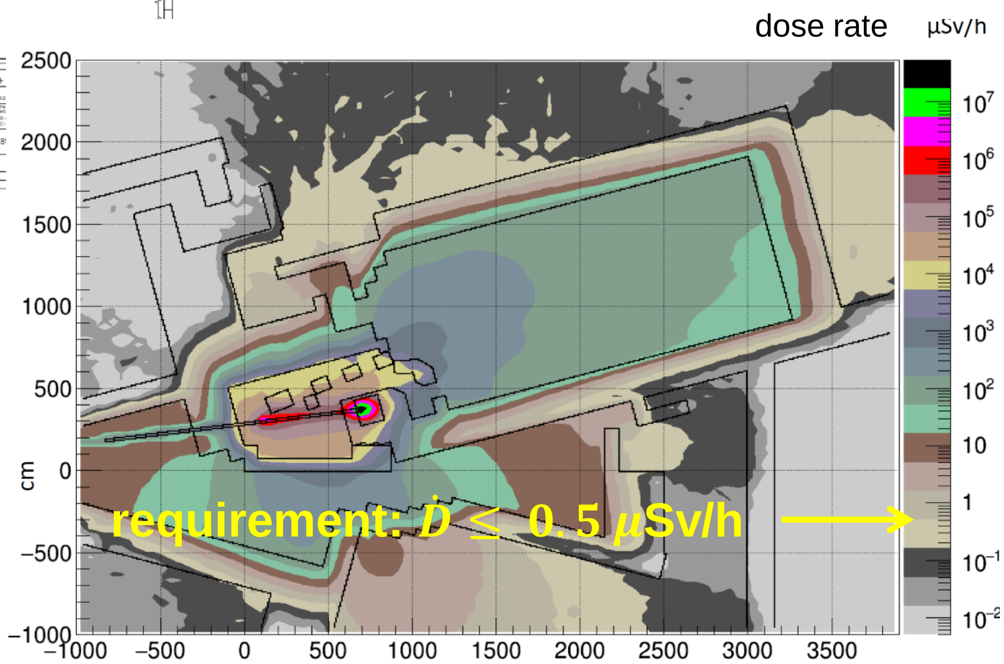
DBHF BONN A corresponds to AP4, however, does not contain strange baryons.

Stiffening of EOS must occur in the range of densities up to 4 $\rho_0$ (SIS100 energy range).

# mCBM Cave (HTD)




- Modified switching magnet (HTD – MU1)
- New beam dump
- Additional shielding




FLUKA calculations:
$10^8$ Au ions $s^{-1}$, 1.24 AGeV,
2.5 mm Au target ($P_{int}$ = 10%)
vertical section: **beam level**