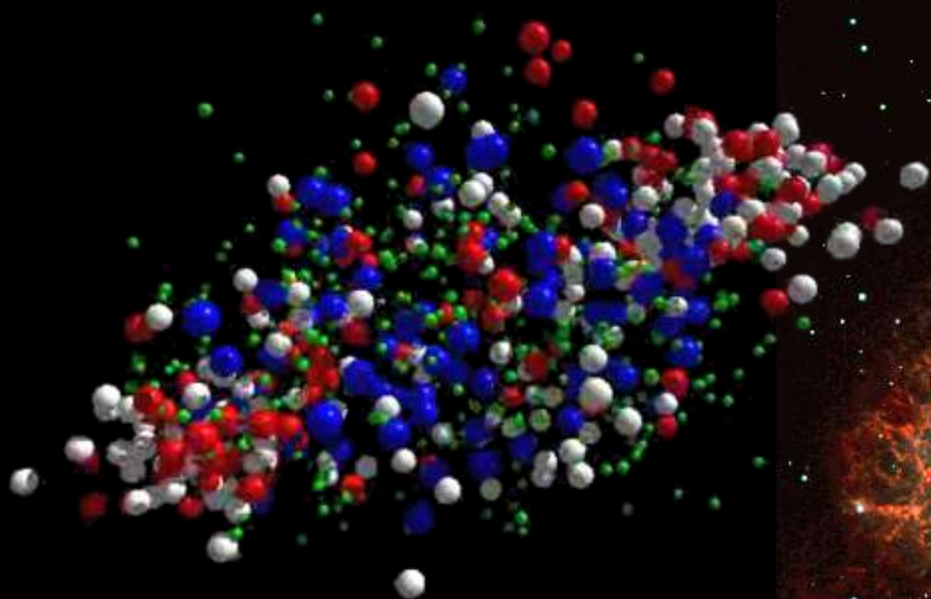
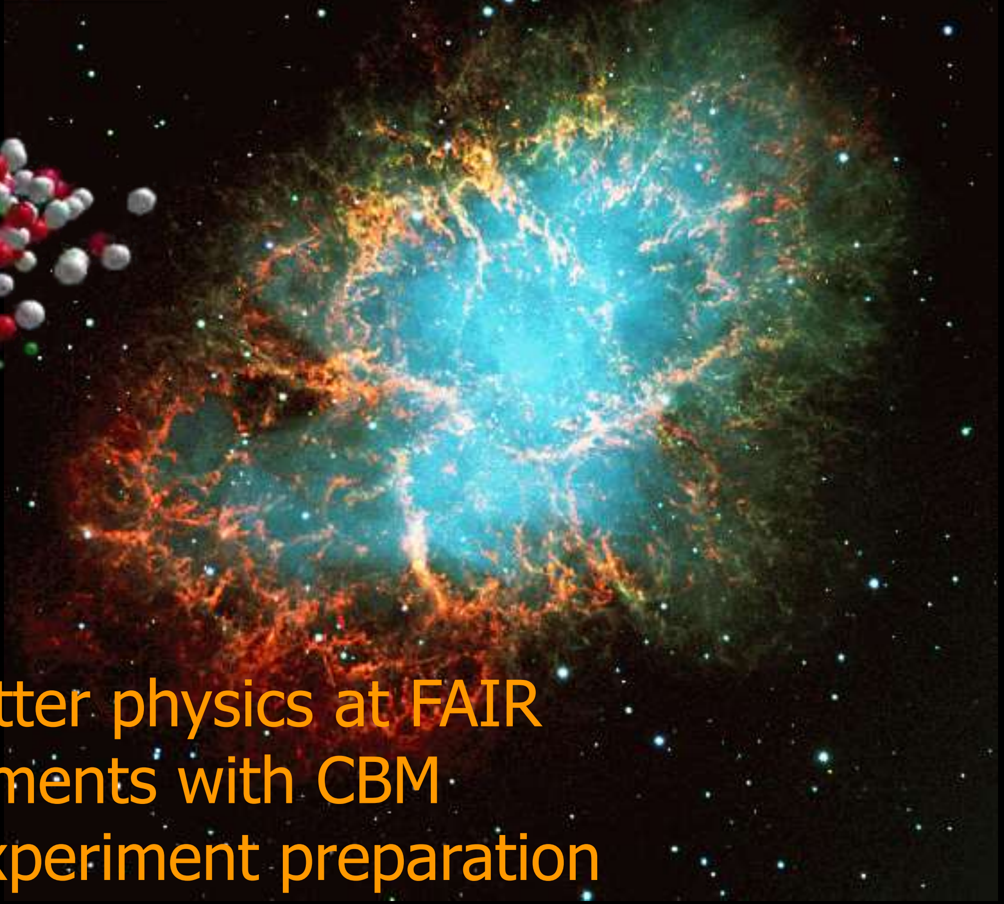
First measurements with the Compressed Baryonic Matter Experiment

Peter Senger GSI and Univ. Frankfurt

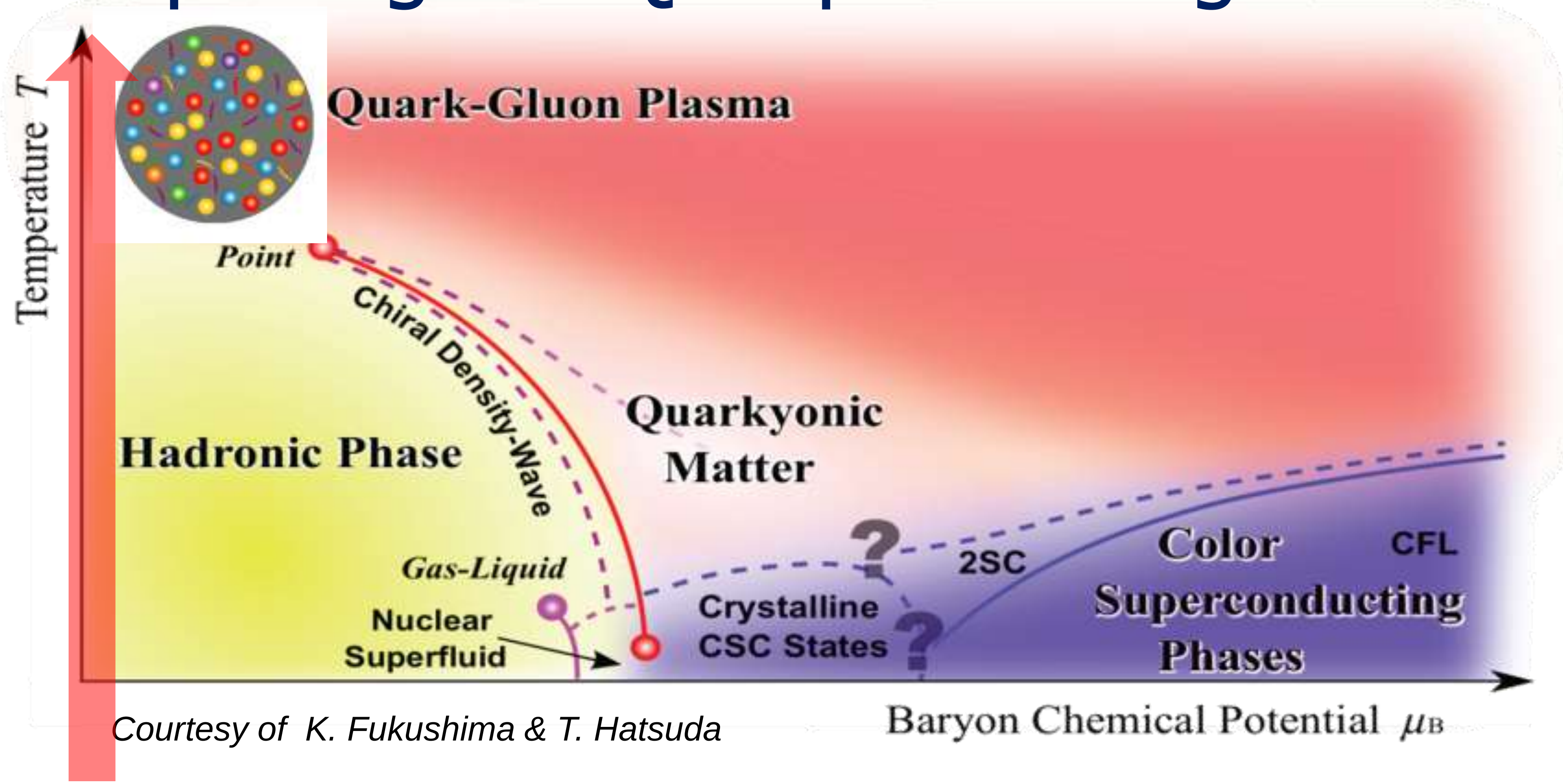




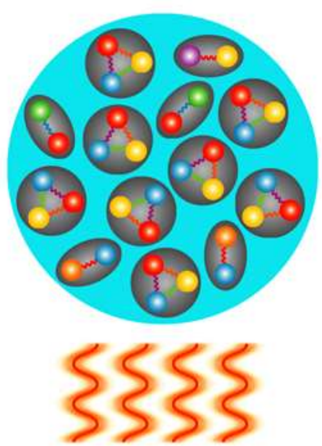
Outline:
- Nuclear matter physics at FAIR
- First experiments with CBM
- Status of experiment preparation

International Conference on Science and Technology for FAIR in Europe
Worms, Germany, 13-17 Oct 2014

Exploring the QCD phase diagram



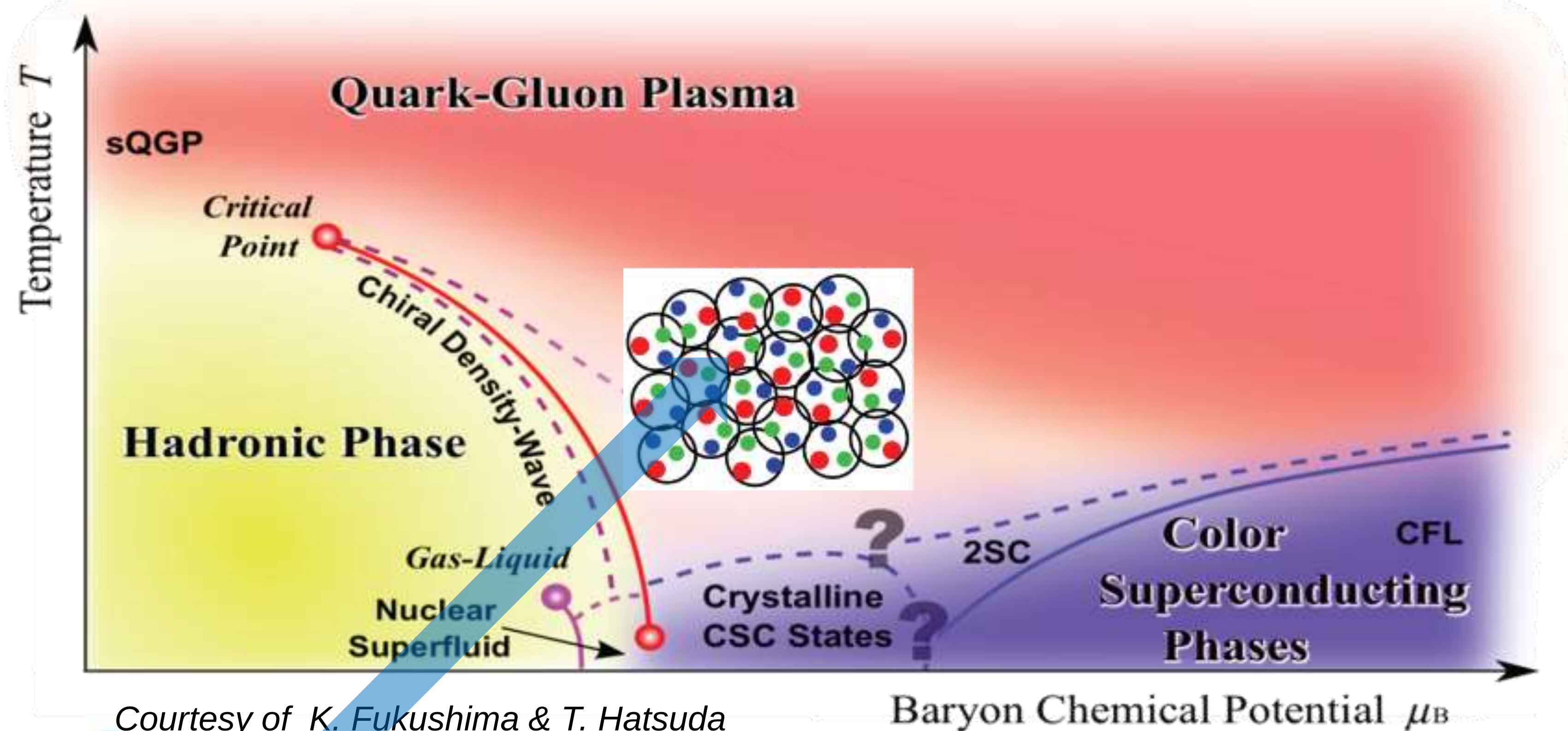
Courtesy of K. Fukushima & T. Hatsuda



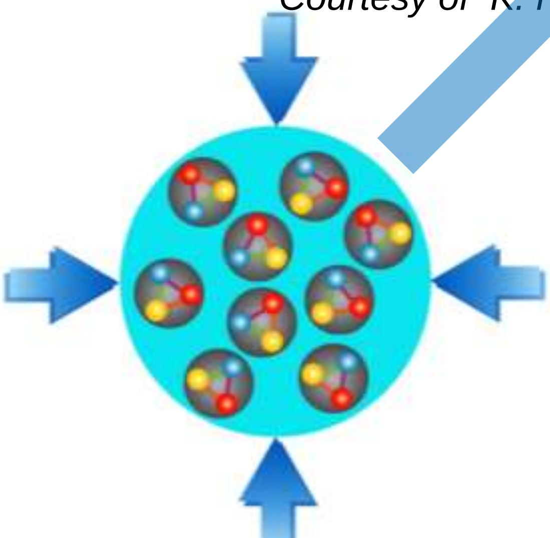
<u>At very high temperature:</u>

- ➢ N of particles ≈ N of antiparticles
  Situation similar to early universe
- ➢ L-QCD finds crossover transition between
  hadronic matter and Quark-Gluon Plasma
- ➢ Experiments: ALICE, ATLAS, CMS at LHC
  STAR, PHENIX at RHIC

Exploring the QCD phase diagram



Courtesy of K. Fukushima & T. Hatsuda

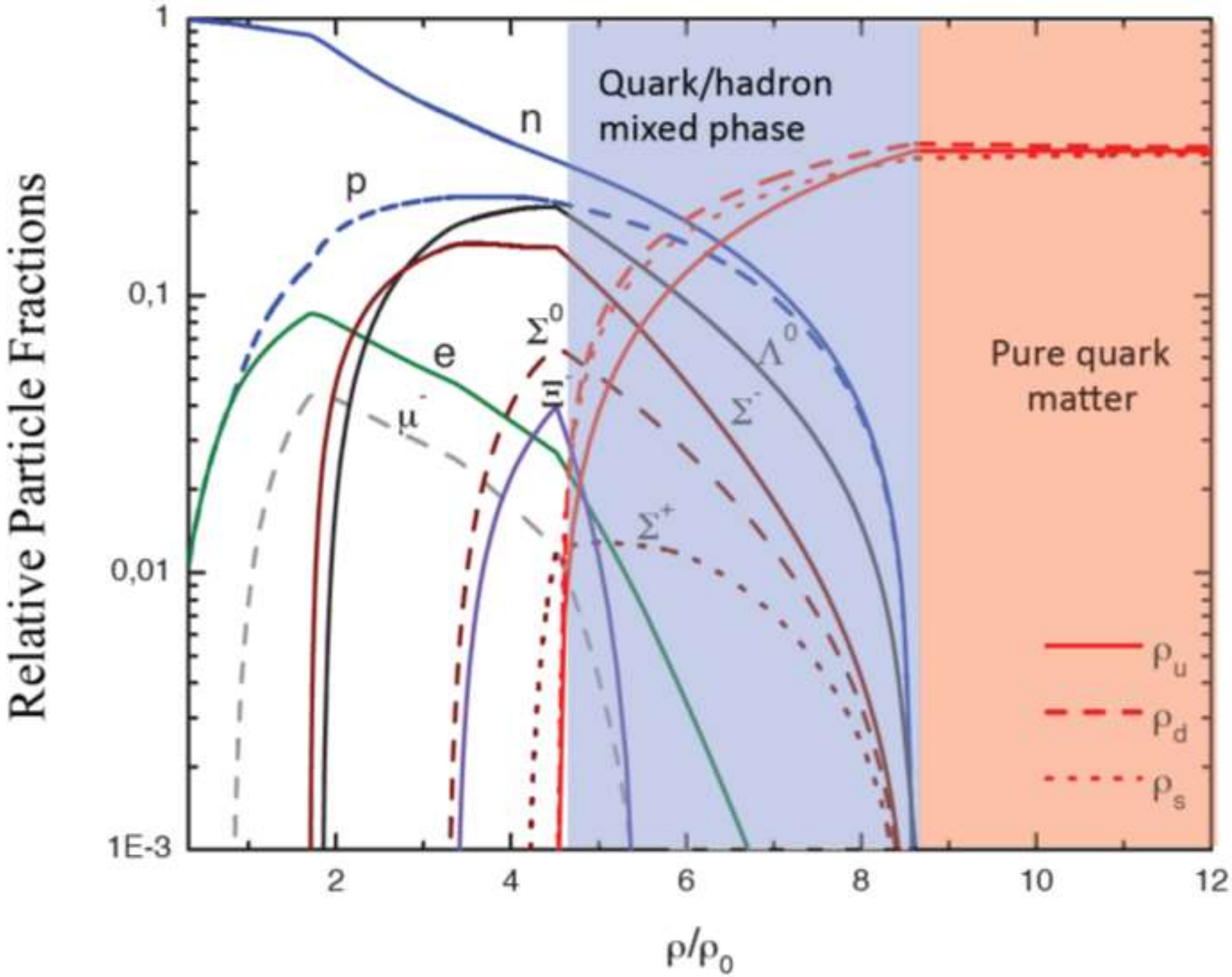


<u>At high baryon density:</u>

- N of particles >> N of antiparticles
  Densities like in neutron star cores
- L-QCD not (yet) applicable
- Models predict first order phase transition
  with mixed or exotic phases
- Experiments: BES at RHIC, NA61 at CERN SPS,
  CBM at FAIR, NICA at JINR

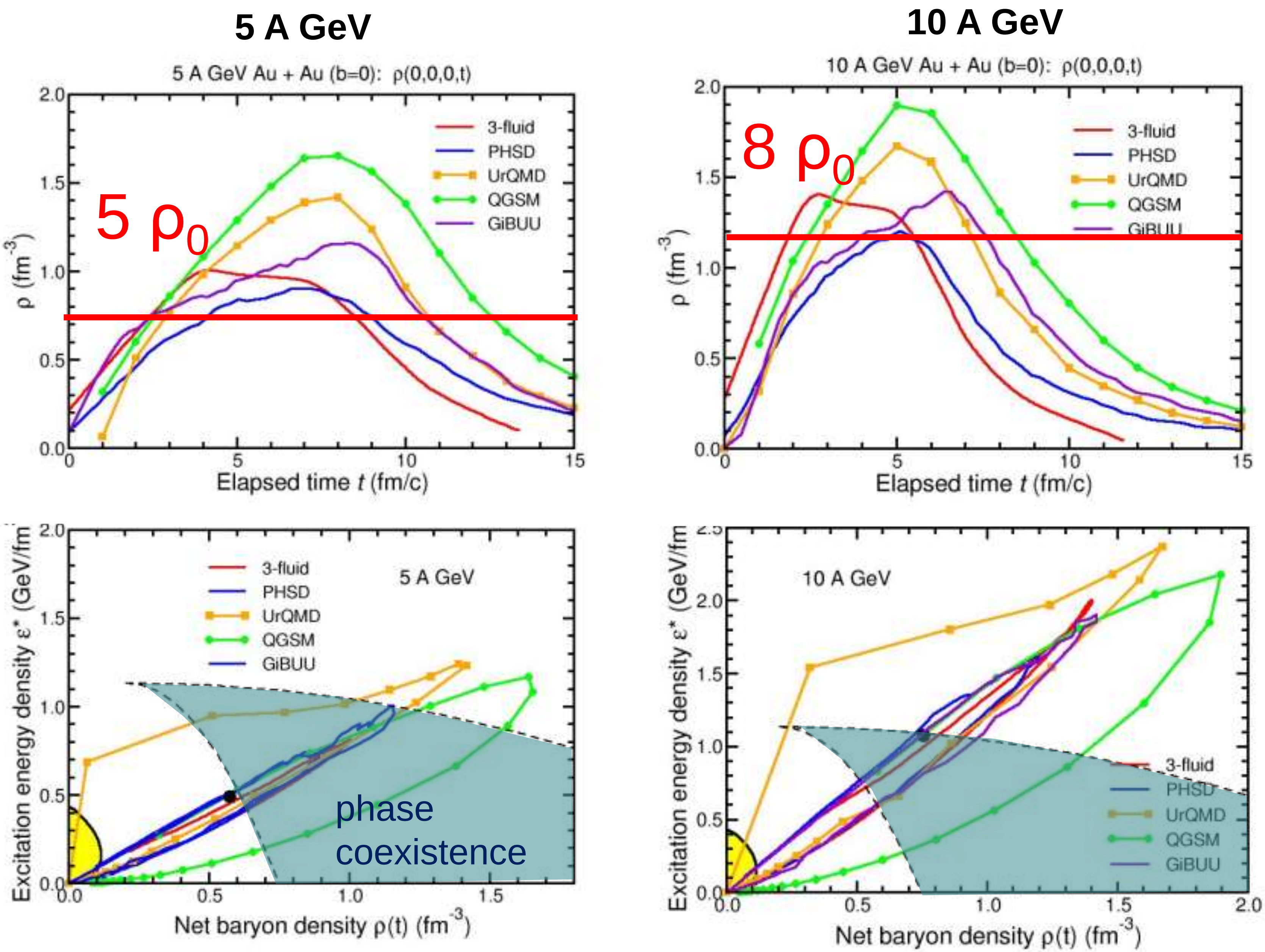
Quark matter in massive neutron stars?

Equation-of-state: Non-local SU(3) NJL with vector coupling
M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, arXiv:1308.1657



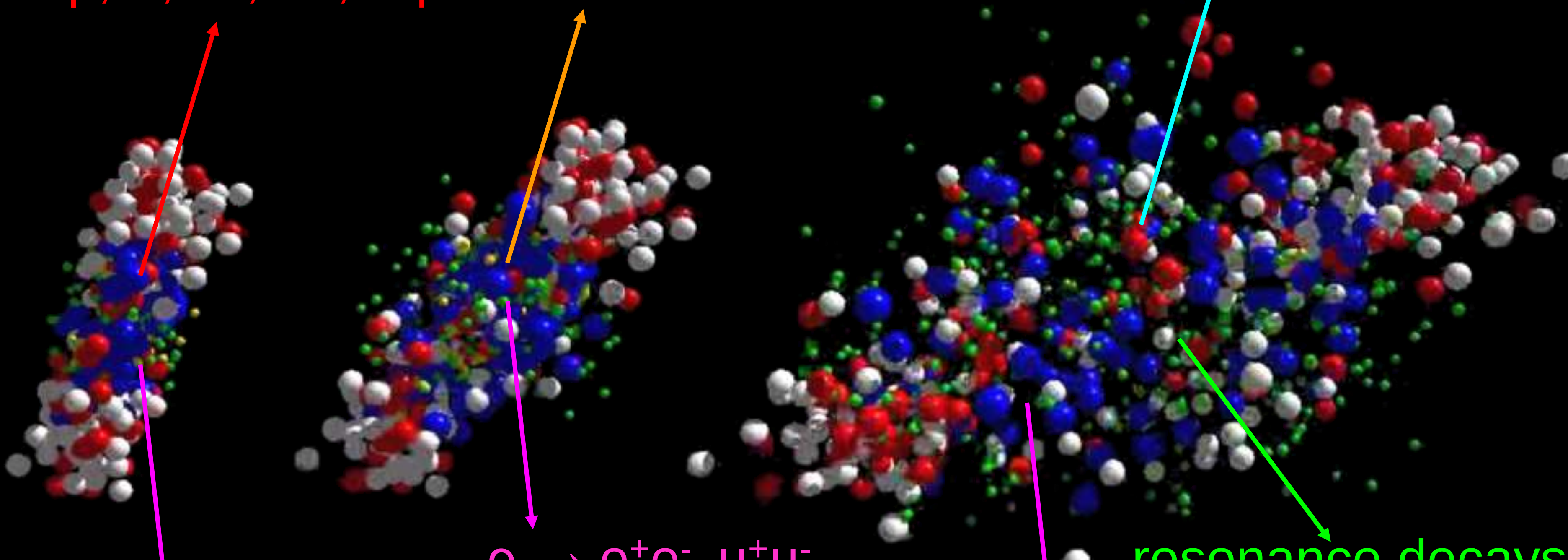
Baryon densities in central Au+Au collisions

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



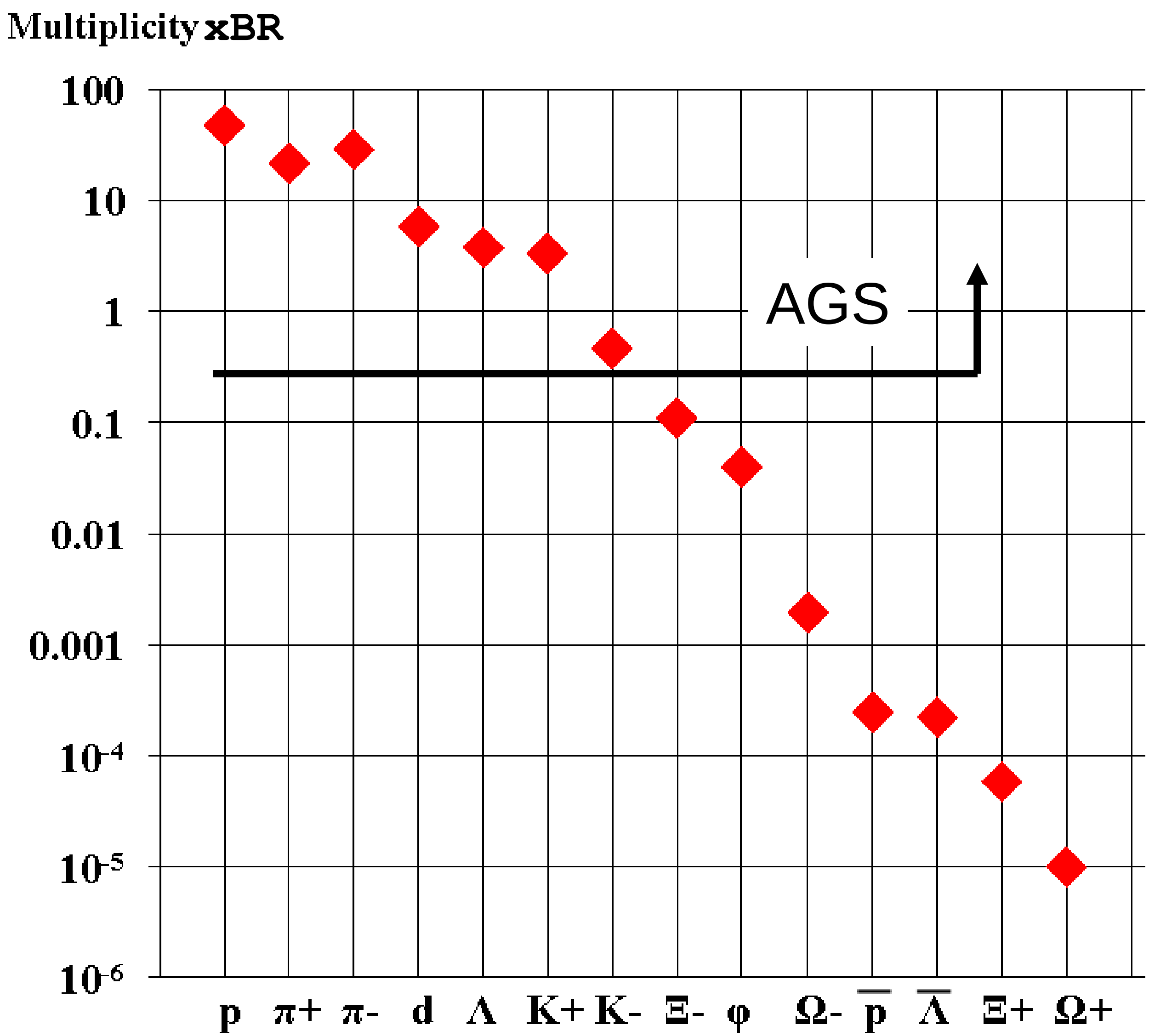
Messengers from the dense fireball: CBM at SIS100

UrQMD transport calculation Au+Au 10.7 A GeV



Experimental challenges

Particle yields in central Au+Au 4 A GeV



CBM physics program

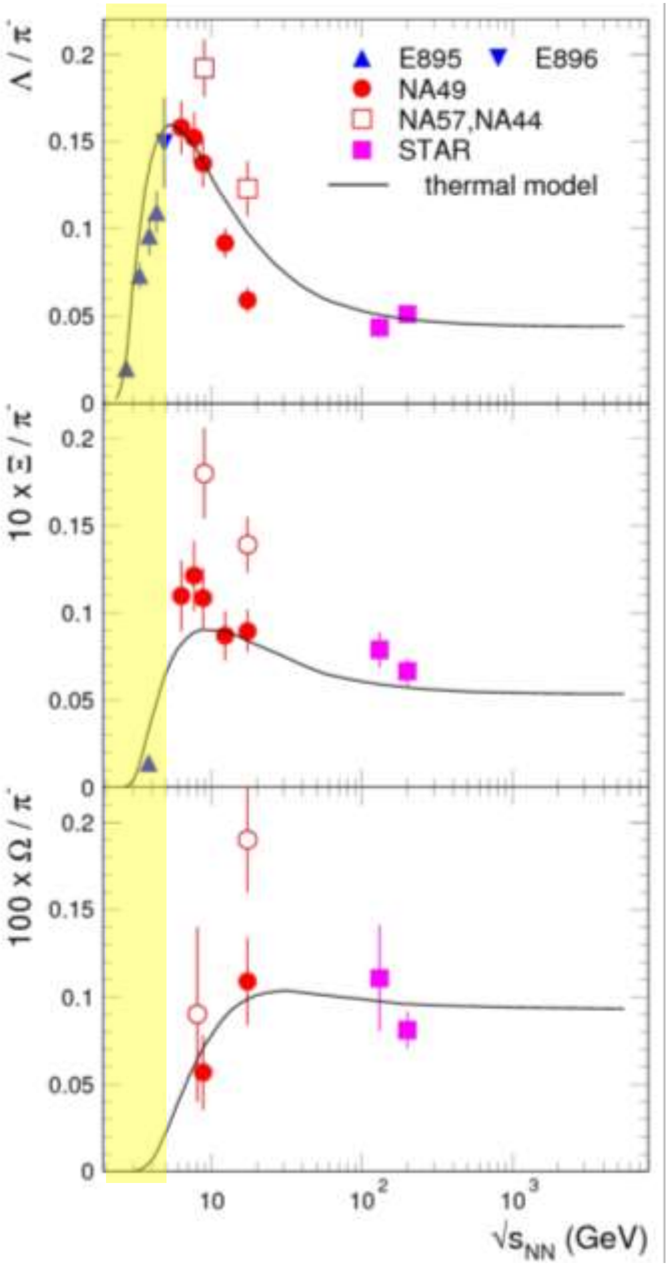
Strangeness

Excitation function of yields and phase-space distributions of multi-strange particles in heavy-ion collisions.

Physics case

- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities
- Equation-of-state of matter at neutron star core densities

very few data
at FAIR energies



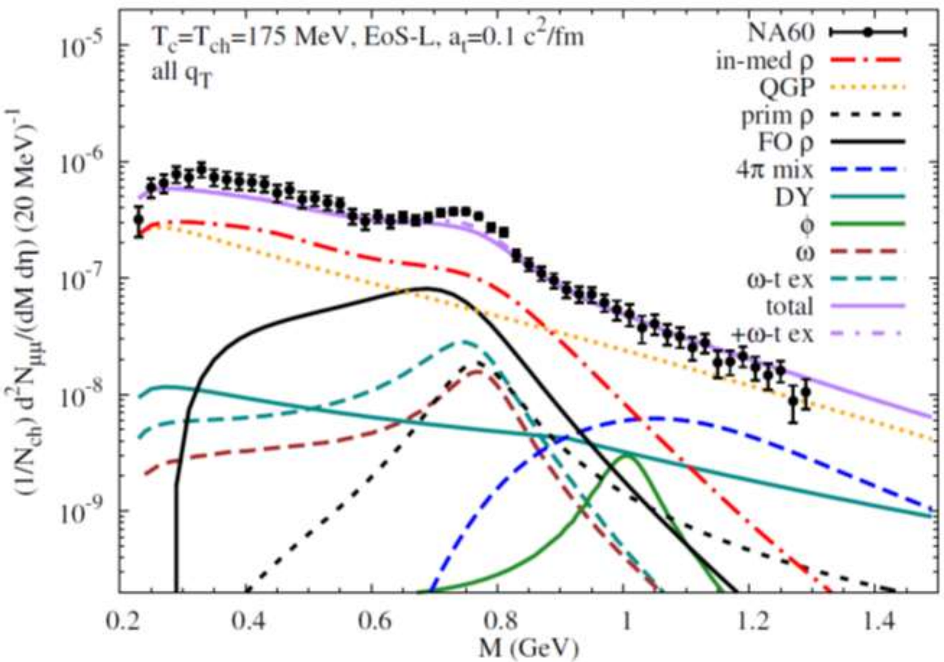
CBM physics program

Dileptons

Excitation function of yields and phase-space distributions of lepton pairs in heavy-ion collisions.

Physics case

- Electro-magnetic radiation from the dense fireball
- Chiral symmetry restoration in dense baryonic matter



In+In 158 A GeV
Exp: NA60
Theory: R. Rapp et al.

No dilepton data at FAIR energies

CBM physics program

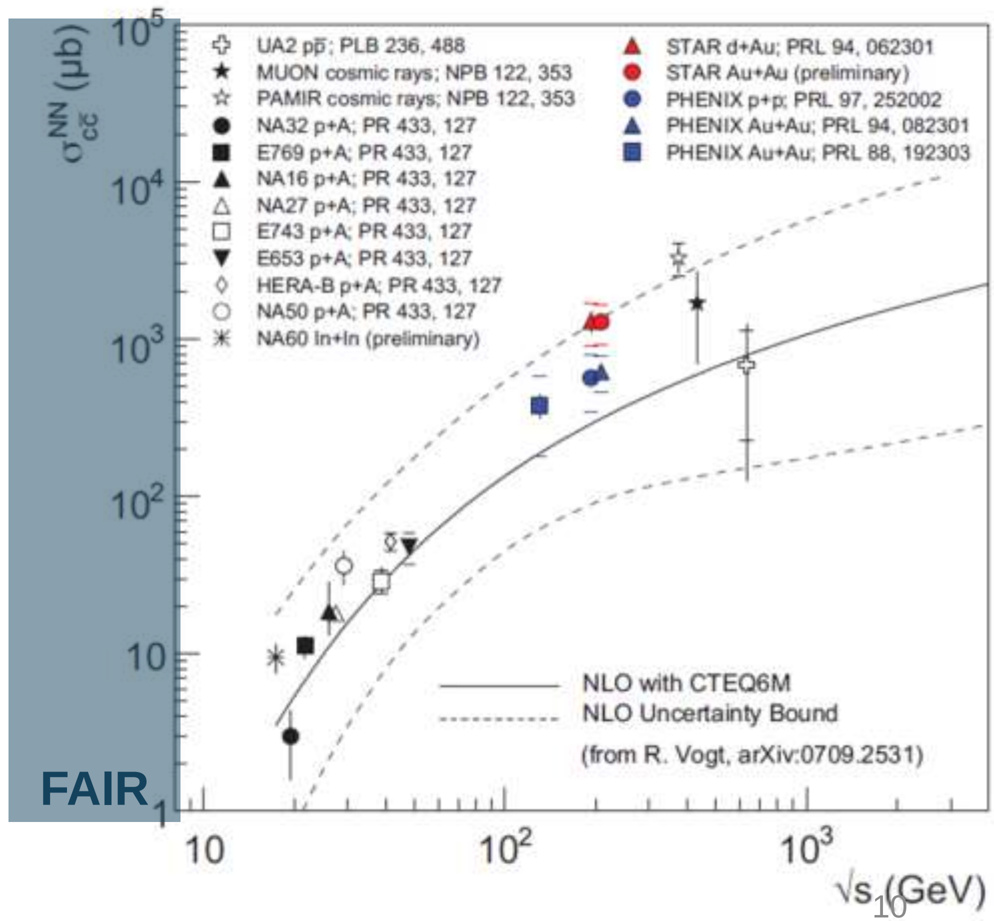
Charm

Cross sections and phase-space distributions of open and hidden charm in proton-nucleus collisions and nucleus-nucleus collisions.

Physics case

- Charm production at threshold energies
- Charm propagation in (dense) nuclear matter
- Charmonium suppression in partonic matter

No charm data at FAIR energies



A. Frawley, T. Ulrich, R. Vogt, Phys.Rept.462:125-175,2008

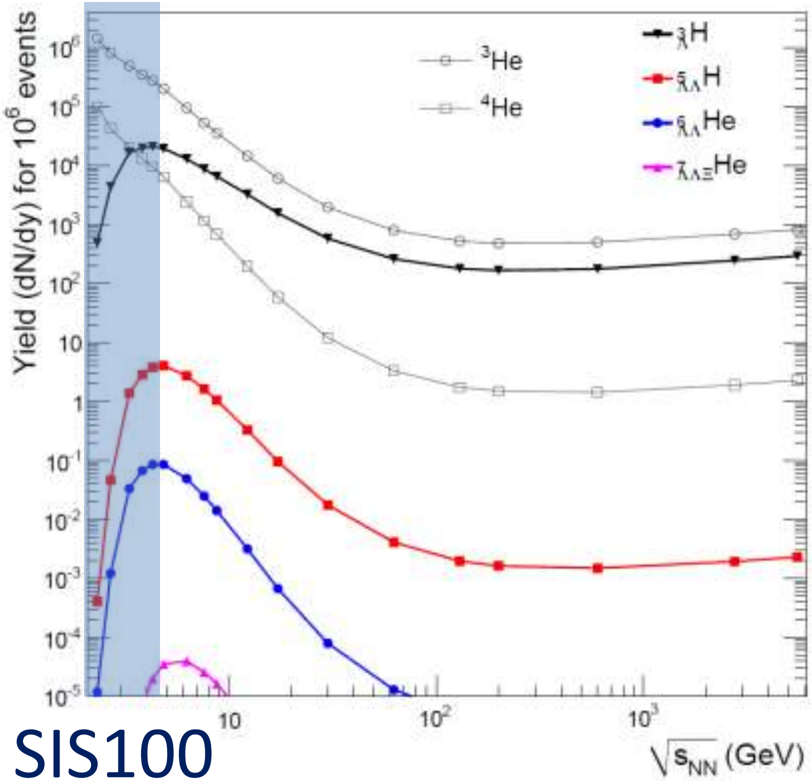
CBM physics program

No data at FAIR energies

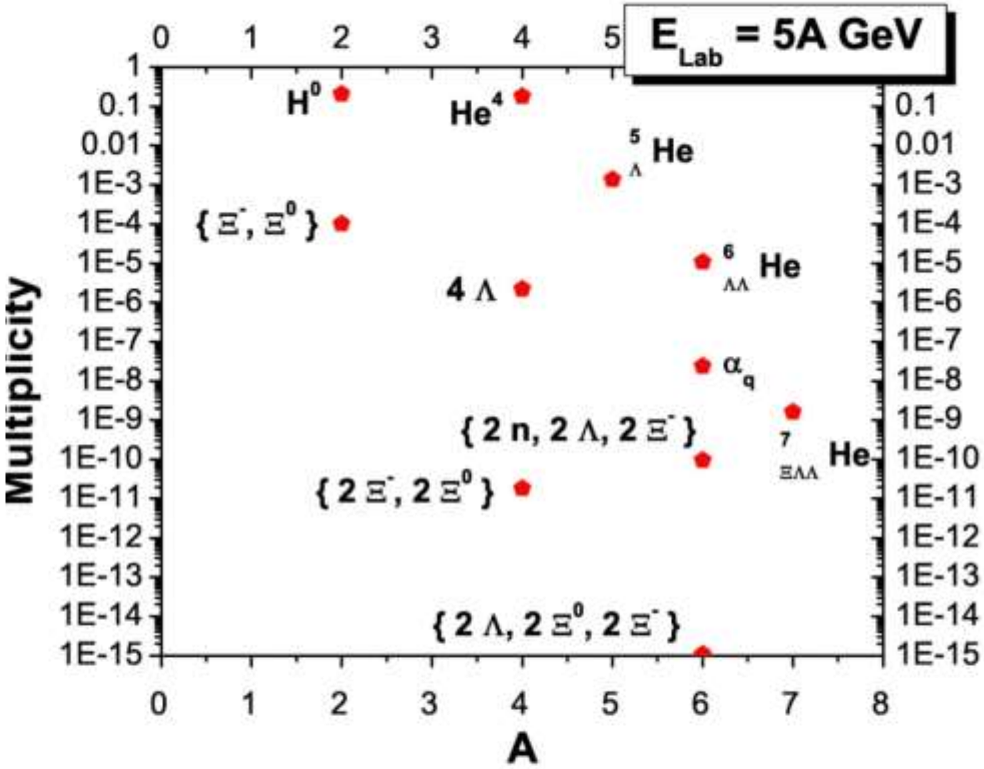
Strange matter

Hypernuclei, strange dibaryons and massive strange objects

Production of hypernuclei via coalescence of hyperons and light nuclei



SIS100



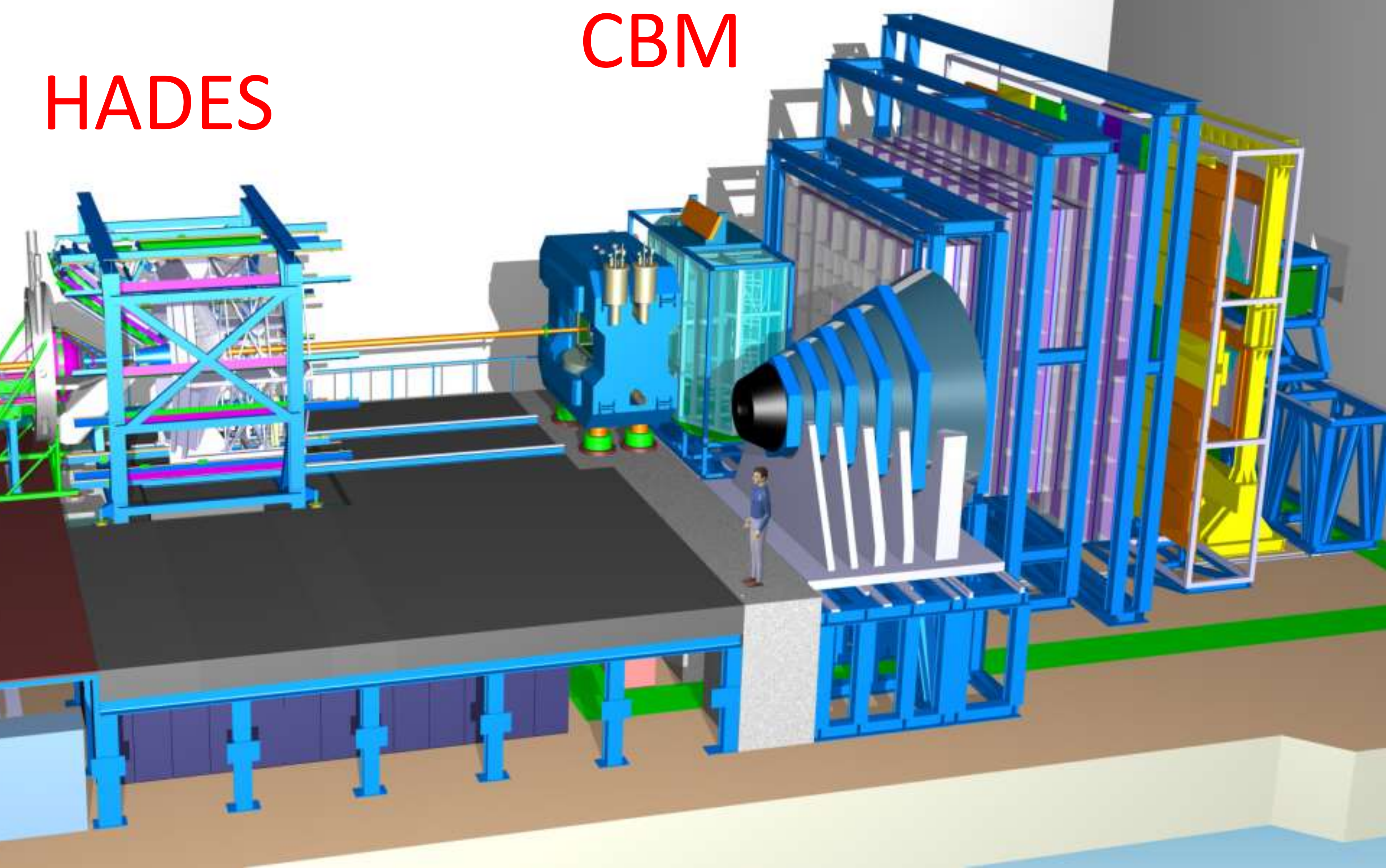
A. Andronic et al., Phys. Lett. B697 (2011) 203

H. Stöcker et al., Nucl. Phys. A 827 (2009) 624c

Experimental requirements

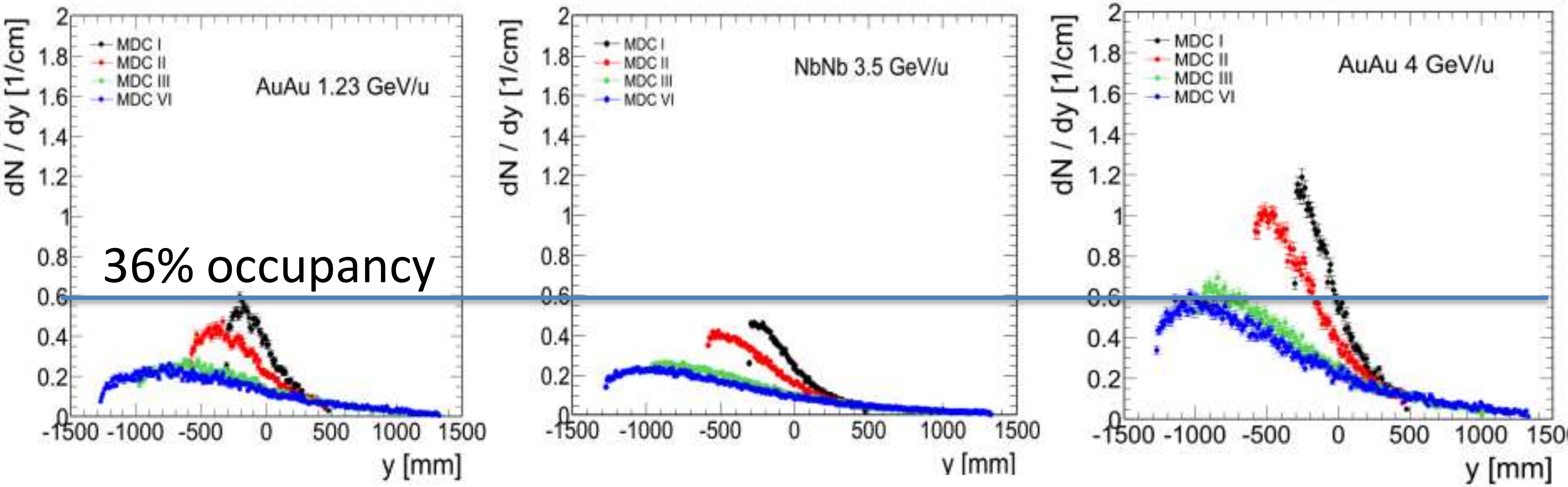
- 10^5 - 10^7 Au+Au reactions/sec
- determination of displaced vertices ($\sigma \approx 50$ μm)
- identification of leptons and hadrons
- fast and radiation hard detectors
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

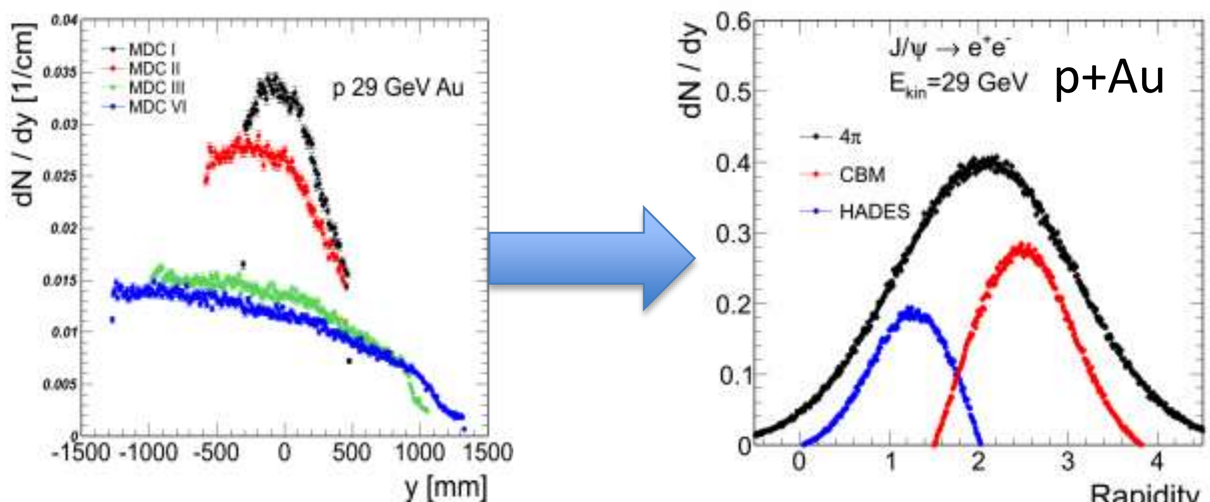
Experimental setups



HADES at SIS100

Occupancy in tracking chambers (b_{max} = 1 fm)





HADES:

Θ = 18° - 85°

Rate 20 kHz

Complementary to CBM for:

- p+A collisions
- A+A with low multiplicities

First measurements with CBM

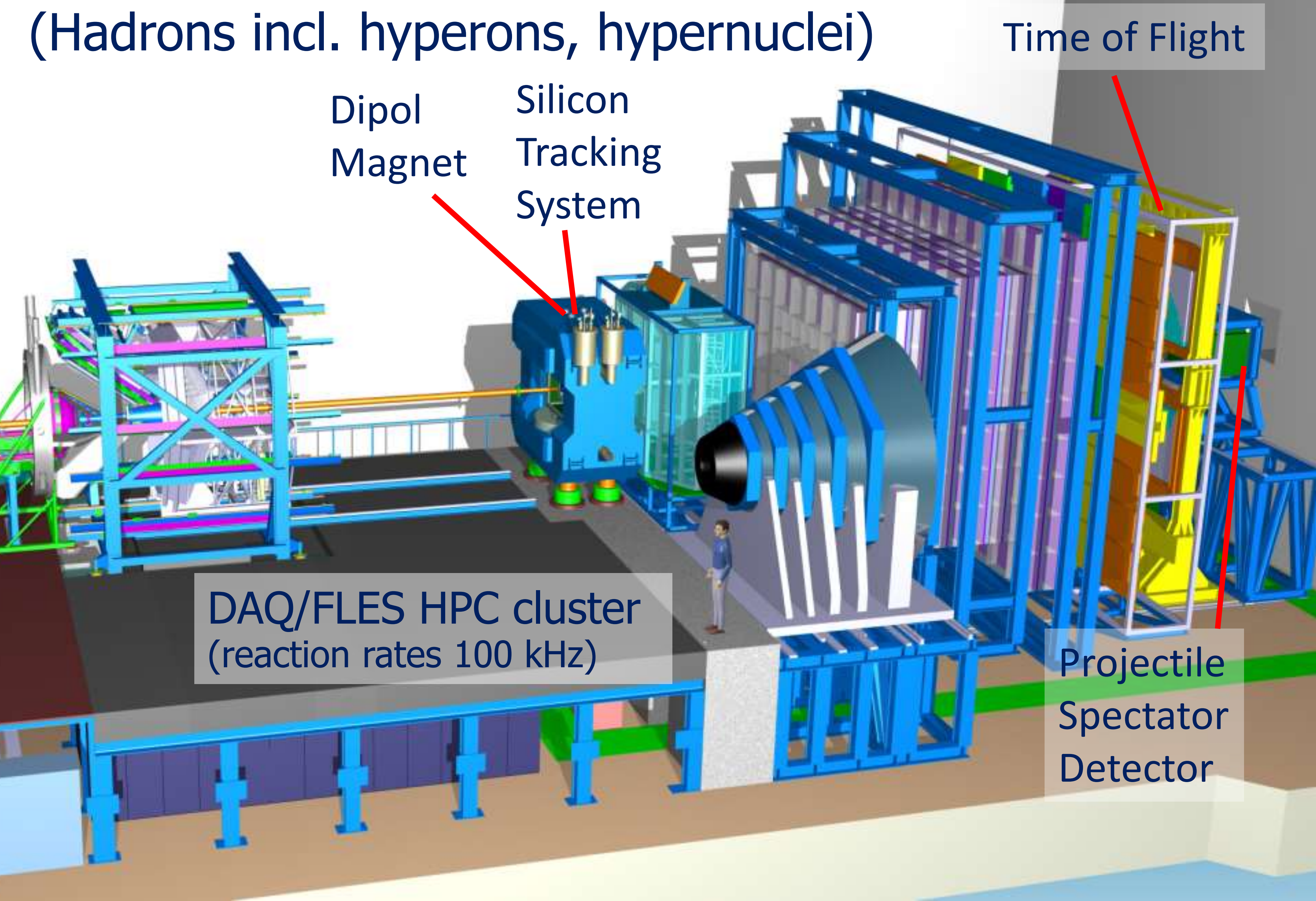
Phase 1: Hadrons incl. Hyperons, Hypernuclei
Phase 2: Dileptons

Excitation function of yields and phase-space distributions of multi-strange hyperons and lepton pairs in Au+Au and C+C collisions from 2-11 A GeV (no data available in this energy range). Included: pions, protons, light fragments, fluctuations, correlations, centrality, reaction plane.

Physics cases

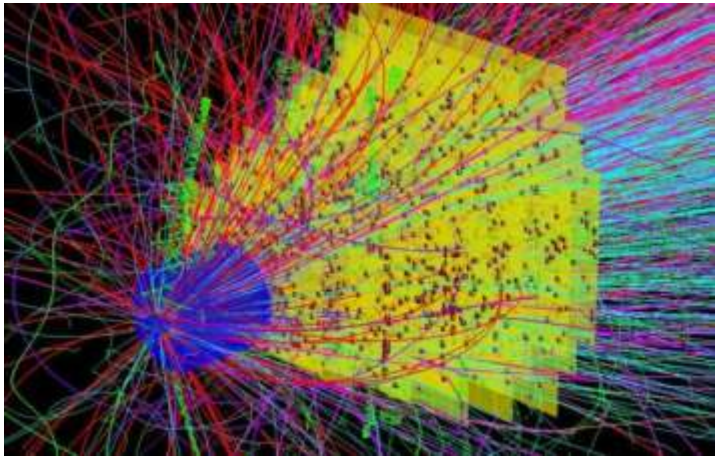
- Equation-of-state of matter at neutron star core densities (1)
- Hypernuclei: Λ-N, Λ-Λ interaction (1)
- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities (1+2)
- Electro-magnetic radiation from the dense fireball (2)
- Chiral symmetry restoration in dense baryonic matter (2)

Experimental requirements phase 1
(Hadrons incl. hyperons, hypernuclei)

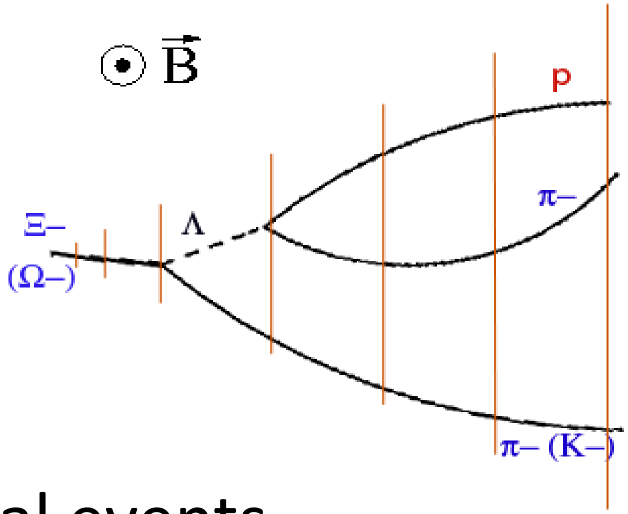


Feasibility Studies: Silicon Tracker and TOF

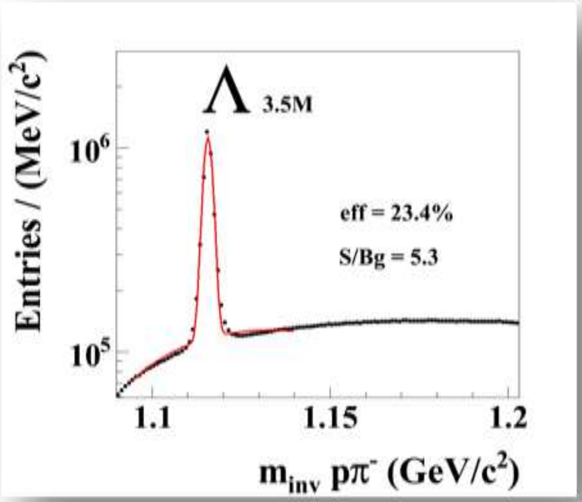
Event generators UrQMD 3.2
Transport code GEANT3, FLUKA
Realistic detector geometries, material budget and detector response

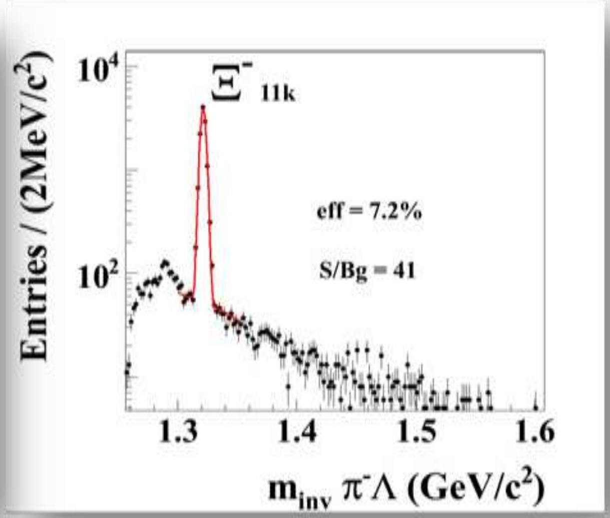


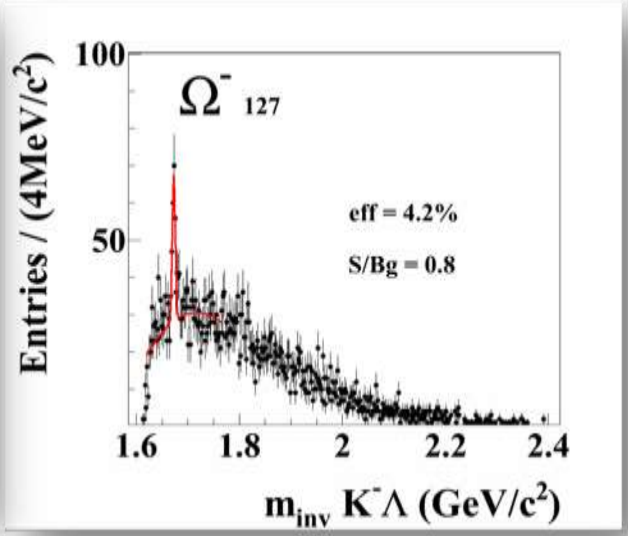
reconstruction



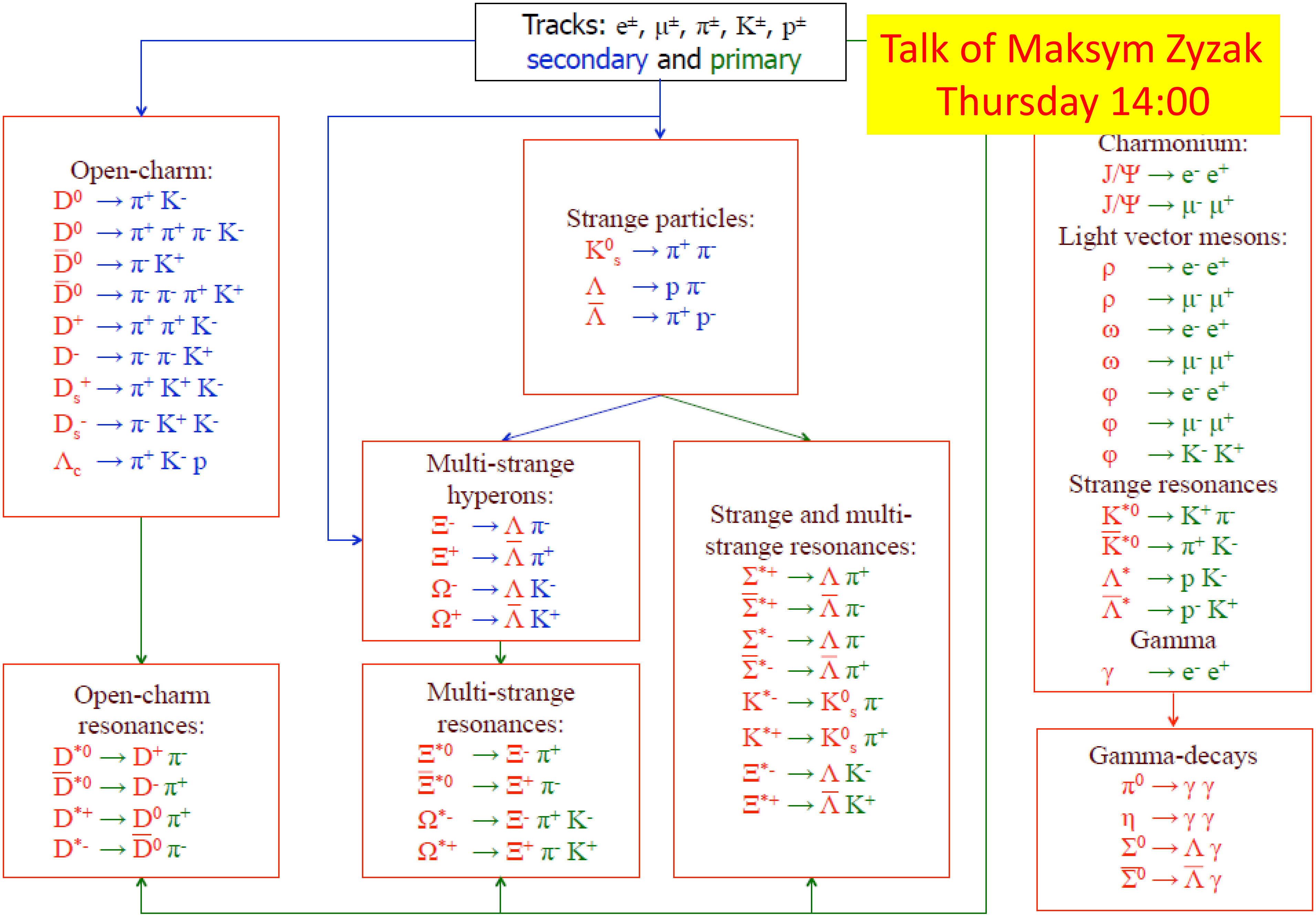
Au+Au 8 A GeV: 10^6 central events







KF Particle Finder for On-line Event Selection



Running scenario phase 1

- 4 month per year:

  Au+Au, C+C at 4 energies (4, 6, 8, 10 A GeV)

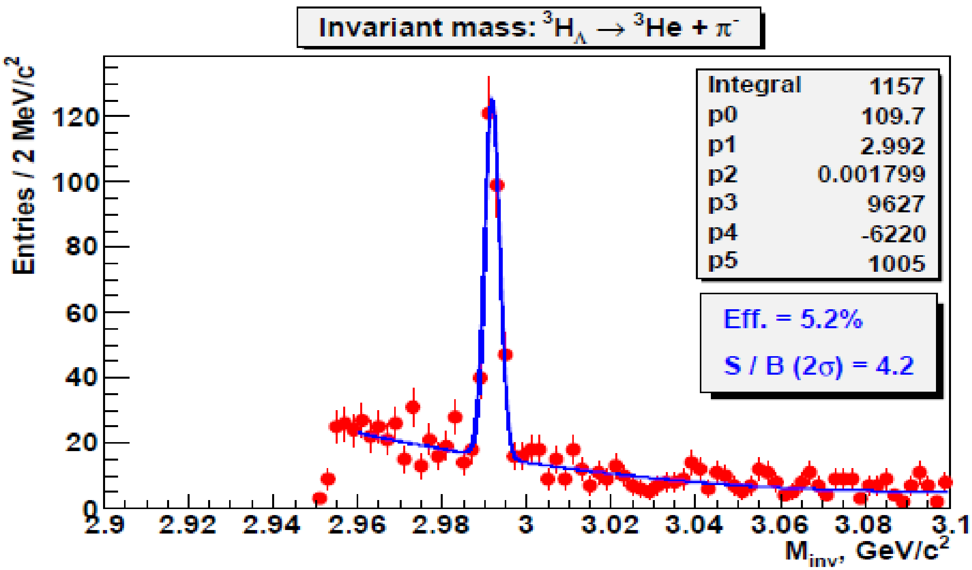
- Expected reconstructed yields for 4 weeks Au+Au with 10^7 beam ions/s (100 kHz events/s):

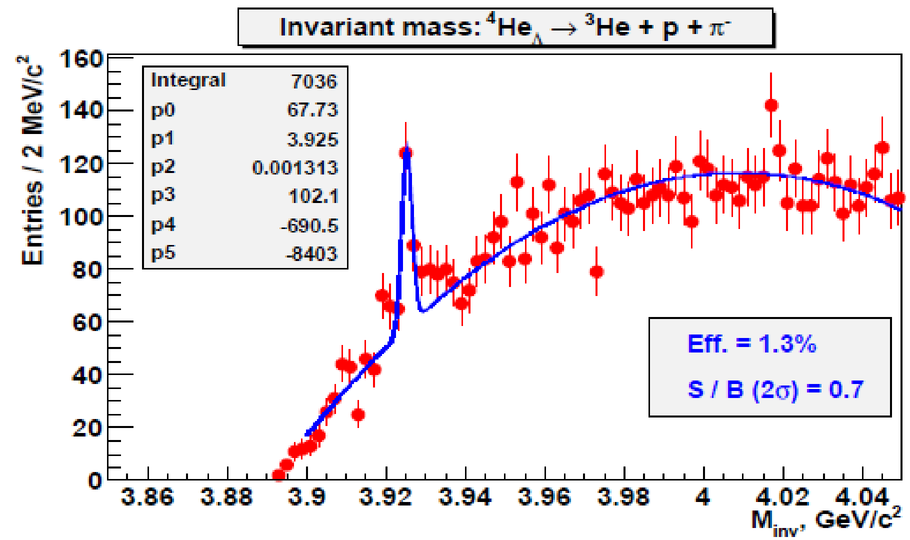
A GeV	Λ	$\bar{\Lambda}$	Ξ^-	Ξ^+	Ω^-	Ω^+
4	$8.1\cdot10^{10}$	$3.0\cdot10^{5}$	$6.6\cdot10^{7}$	$6.0\cdot10^{4}$	$3.6\cdot10^{5}$	$1.2\cdot10^{3}$
6	$1.6\cdot10^{11}$	$5.0\cdot10^{6}$	$3.4\cdot10^{8}$	$1.8\cdot10^{5}$	$2.4\cdot10^{6}$	$1.2\cdot10^{4}$
8	$2.1\cdot10^{11}$	$1.5\cdot10^{7}$	$6.6\cdot10^{8}$	$3.0\cdot10^{5}$	$7.6\cdot10^{6}$	$6.0\cdot10^{4}$
10	$2.4\cdot10^{11}$	$3.8\cdot10^{7}$	$9.6\cdot10^{8}$	$2.0\cdot10^{6}$	$1.3\cdot10^{7}$	$1.5\cdot10^{5}$

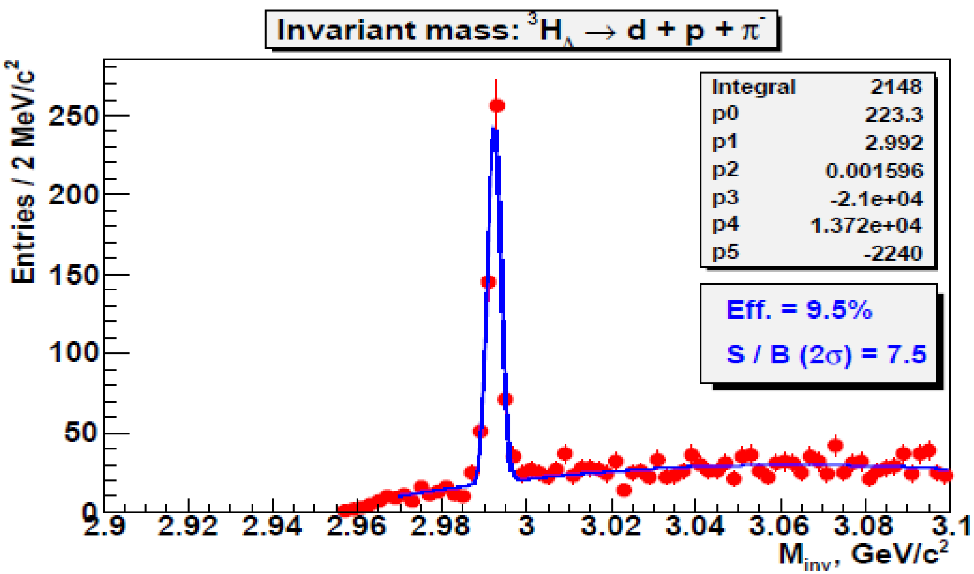
- In addition kaons and resonances (K^*,Λ^*,Σ^*,Ξ^*,Ω^*)

Hypernuclei production in Au+Au collisions at 10 A GeV

A.I. Zinchenko[†1], *K.K. Gudima*[2], *E.I. Litvinenko*[1], *Yu.A. Murin*[1], *and V.A. Vasendina*[1]
[1]JINR, Dubna, Russia; [2]Institute of Applied Physics, AS, Chisinau, Moldova





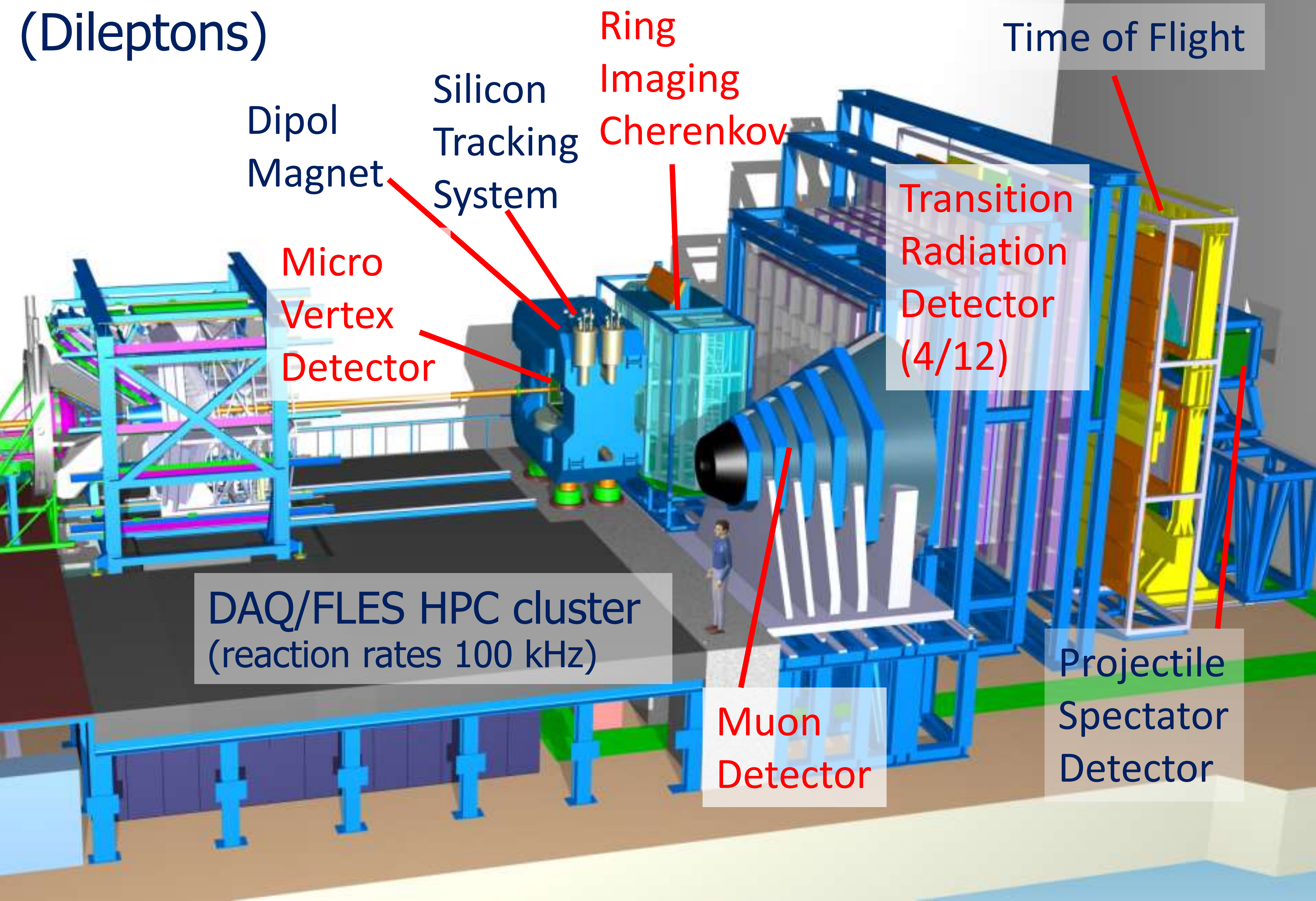


Hyper nuclei	M central	BR	ε %	Yield/week central
${}_{\Lambda}^{3}H$	$2\cdot10^{-2}$	0.6	7	$4.6\cdot10^{6}$
${}_{\Lambda\Lambda}^{5}H$	$6\cdot10^{-6}$	0.36	1	130

central collision rate 10 kHz

BR = 36% for double lambda hypernuclei is a guess

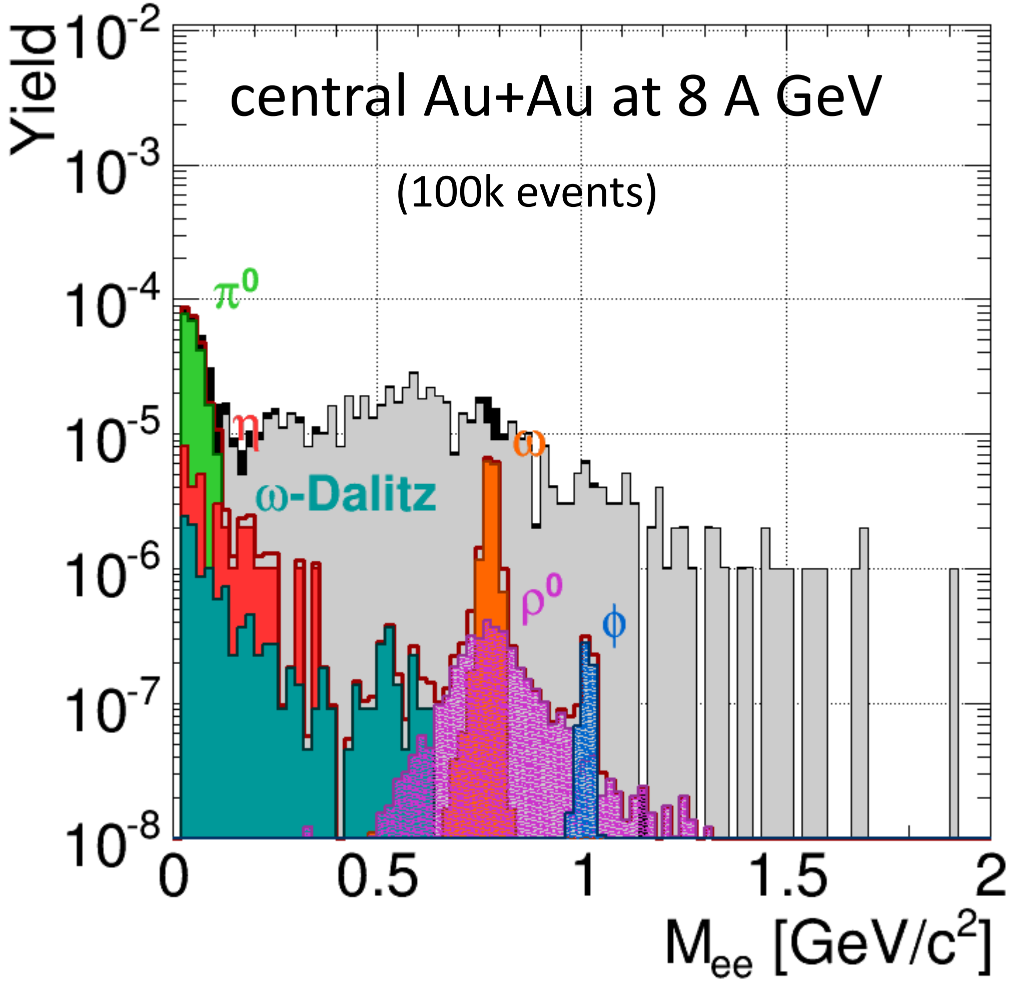
Experimental requirements phase 2
(Dileptons)



Running scenario phase 2 (electrons)

- 2 month per year:

Au+Au at 4 energies (4, 6, 8, 10 A GeV) at 100 kHz



8 A GeV:

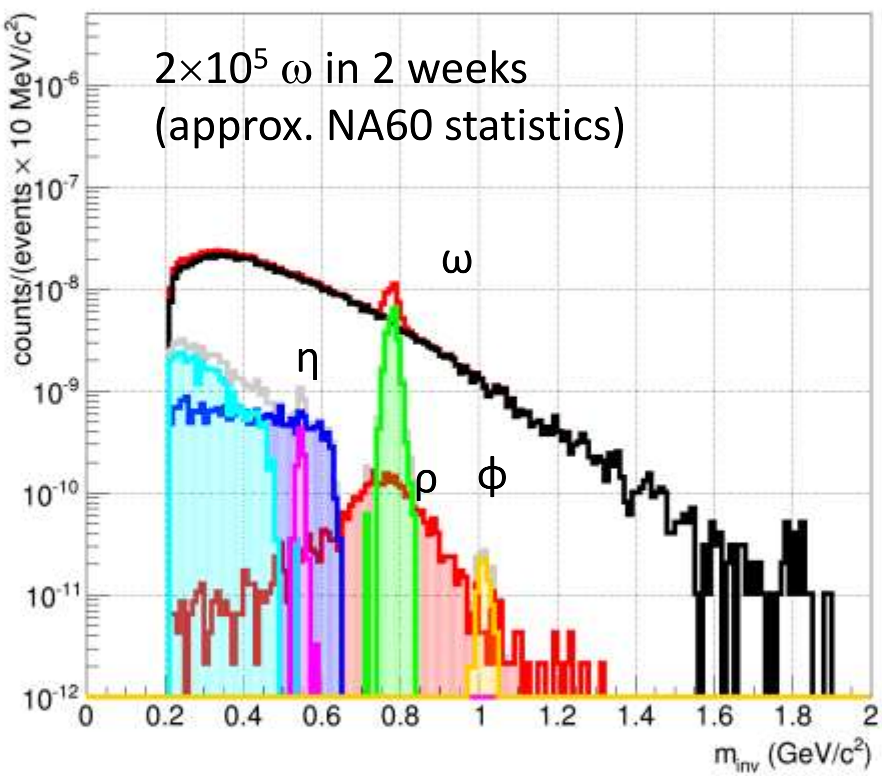
2×10^6 ω in 2 weeks

Running scenario phase 2 (muons)

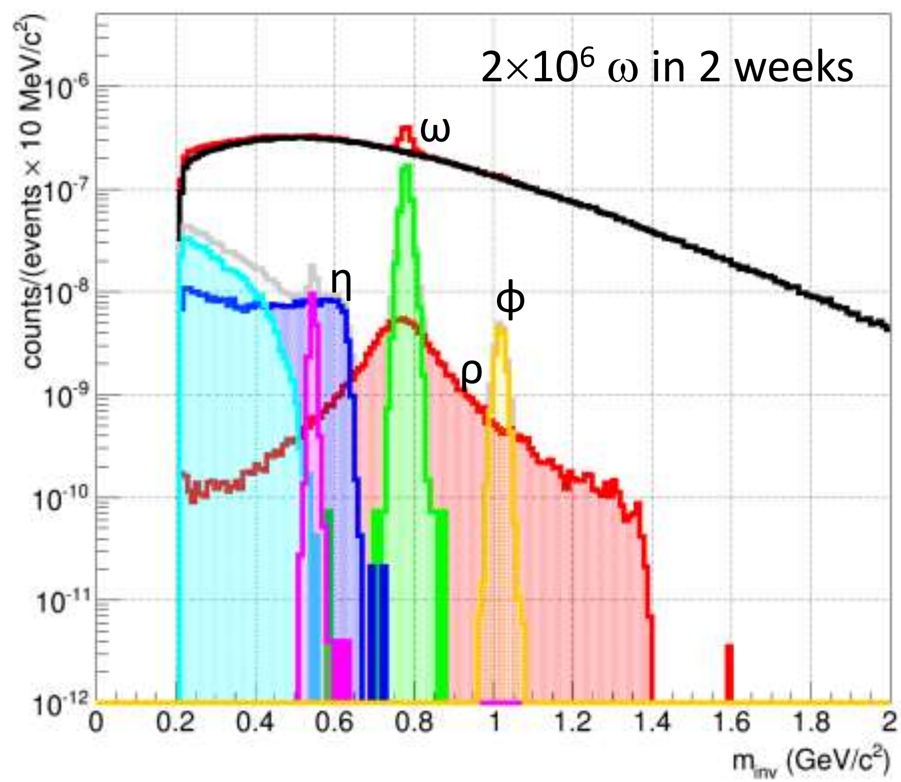
- 2 month per year:

Au+Au at 4 energies (4, 6, 8, 10 A GeV) at 100 kHz

central Au+Au at 4 A GeV



central Au+Au at 8 A GeV



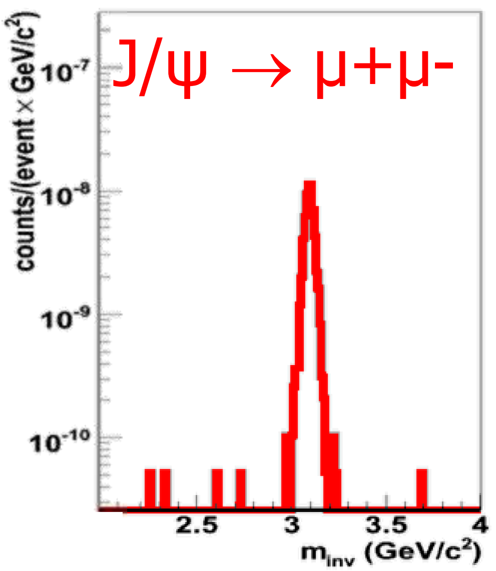
(Measurements require start version of muon detector system)

Running scenario phase 2 (muons)

- Commissioning of high rate data taking (10 MHz)
- Exploratory measurement: Charmonium production

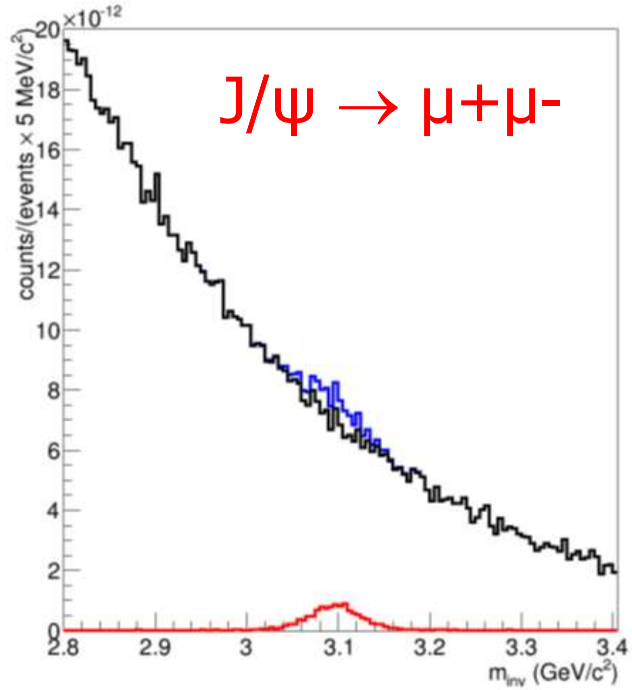
30 GeV p + Au

1000 J/ψ in 10^{12} events (1 day)
(multiplicity from HSD)



central Au+Au at 10 A GeV

1000 J/ψ in 10^{13} events (10 days)
(multiplicity from HSD)

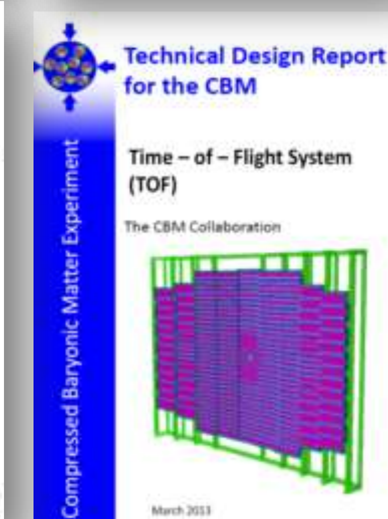


New results after 3 years CBM running

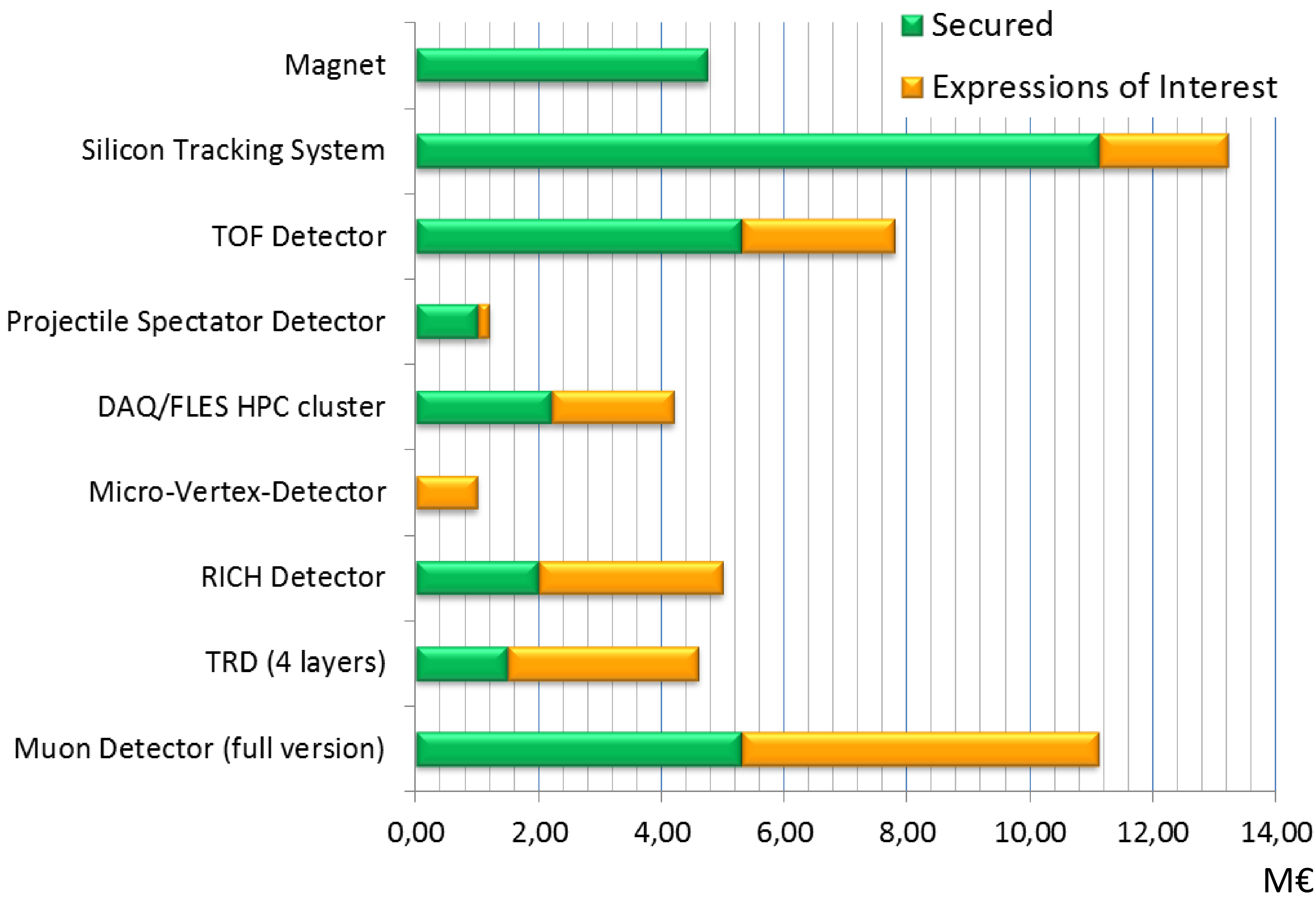
- Strangeness production and flow excitation function in Au+Au collisions from 4 – 10 A GeV
- Excitation function of e-by-e fluctuations of hadron multiplicities
- Variety of hypernuclei produced/discovered
- Heavy strange objects discovered or excluded
- In-medium properties of light vector mesons at different fireball densities and temperatures
- Excitation function of the fireball temperature
- Radial flow of dileptons as function of m_{inv}
- Charmonium production at threshold energies

CBM Technical Design Reports

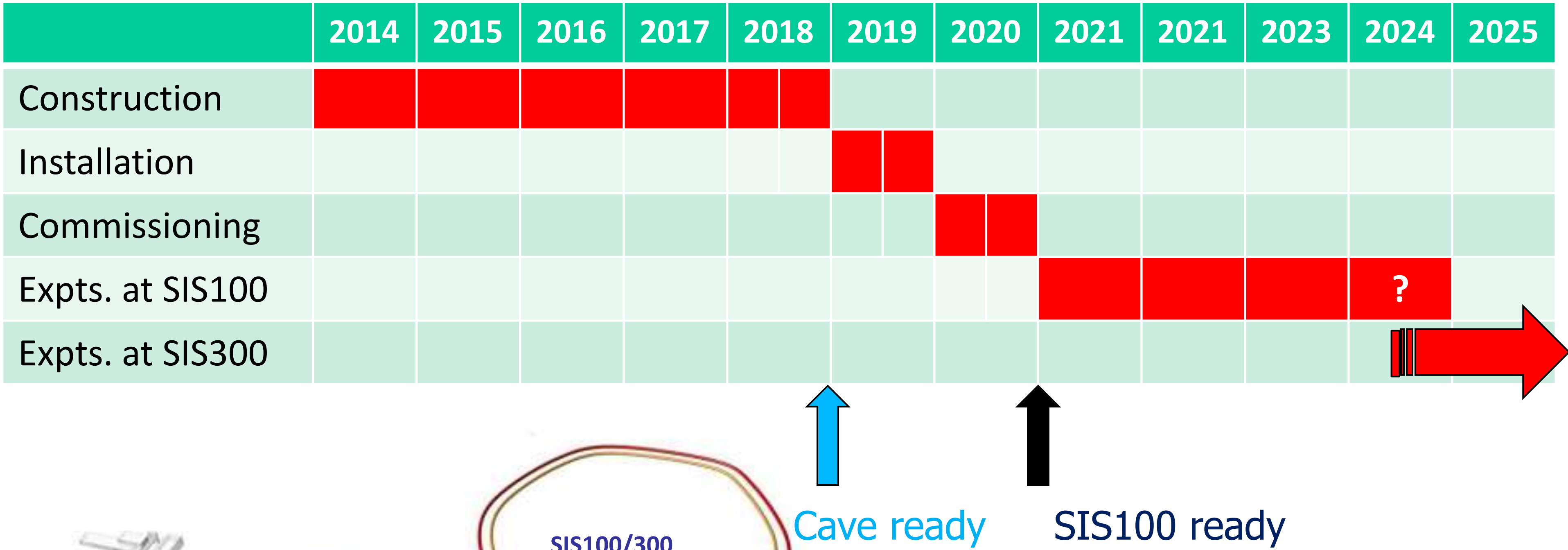
#	Project	TDR Status
1	**Magnet**	approved
2	**STS**	approved
3	**RICH**	approved
4	**TOF**	evaluation
5	**MuCh**	evaluation
6	**PSD**	evaluation
7	**MVD**	submission 2015
8	**DAQ/FLES**	submission 2015
9	**TRD**	submission 2015

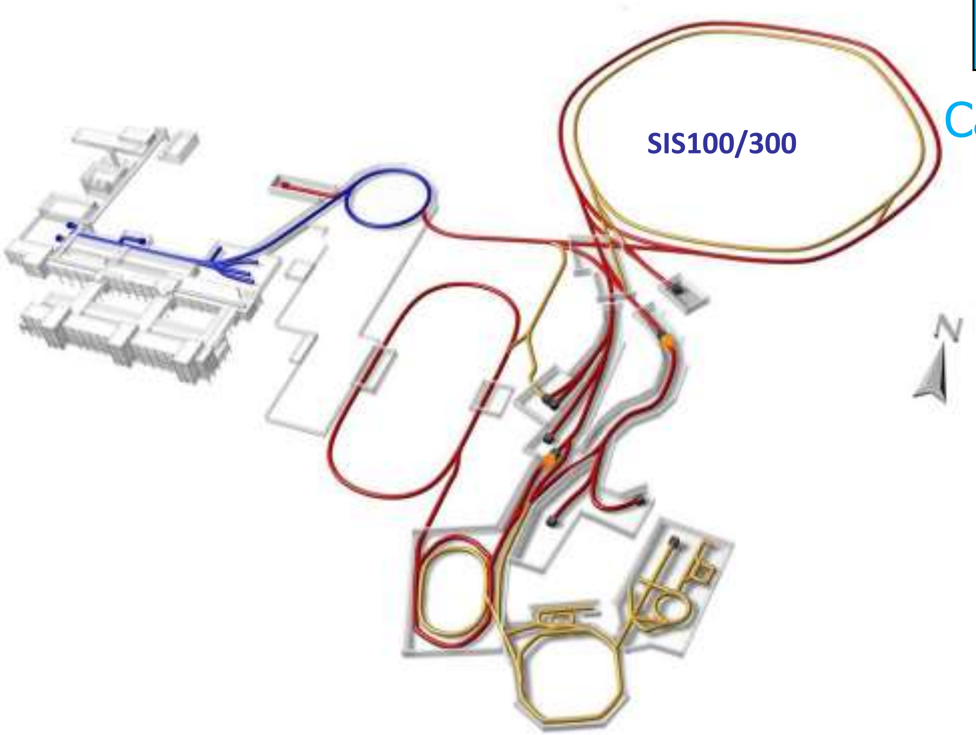


Costs and funding CBM Start version



CBM time line





CBM building

The CBM Collaboration: 56 institutions, 500 members

Croatia:
Split Univ.

China:
CCNU Wuhan
Tsinghua Univ.
USTC Hefei

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
GSI Darmstadt
Giessen Univ.
Heidelberg Univ. P.I.
Heidelberg Univ. ZITI
HZ Dresden-Rossendorf
KIT Karlsruhe
Münster Univ.
Tübingen Univ.
Wuppertal Univ.

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
SAHA Kolkata
IOP Bhubaneswar
IIT Kharagpur
Gauhati Univ.

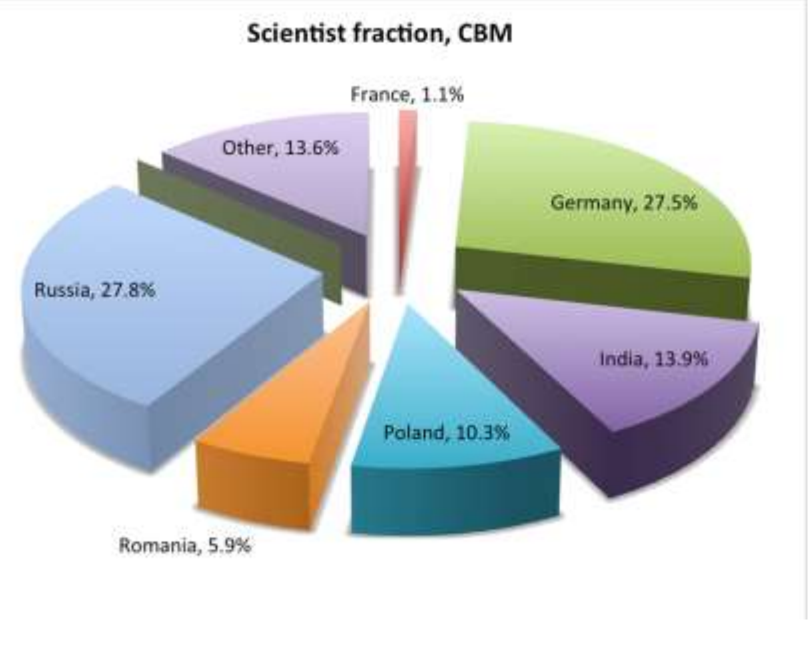
Korea:
Pusan Nat. Univ.

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
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.

Ukraine:
T. Shevchenko Univ. Kiev
Kiev Inst. Nucl. Research
LTU, Kharkiv



Summary

- CBM scientific program at SIS100:
  Exploration of the QCD phase diagram in the region of neutron star core densities $\rightarrow$ large discovery potential.

- First measurements with CBM:
  High-precision multi-differential measurements of hadrons incl. multistrange hyperons, hypernuclei and dileptons for different beam energies and collision systems $\rightarrow$ terra incognita.

- Status of experiment preparation:
  Prototype detector performances fulfill CBM requirements.
  3 TDRs approved, 3 TDRs in evaluation, 3 TDRs in preparation.

- Funding:
  Substantial part of the CBM start version is financed (+ EoI).

backup

Staging of Muon Chamber system

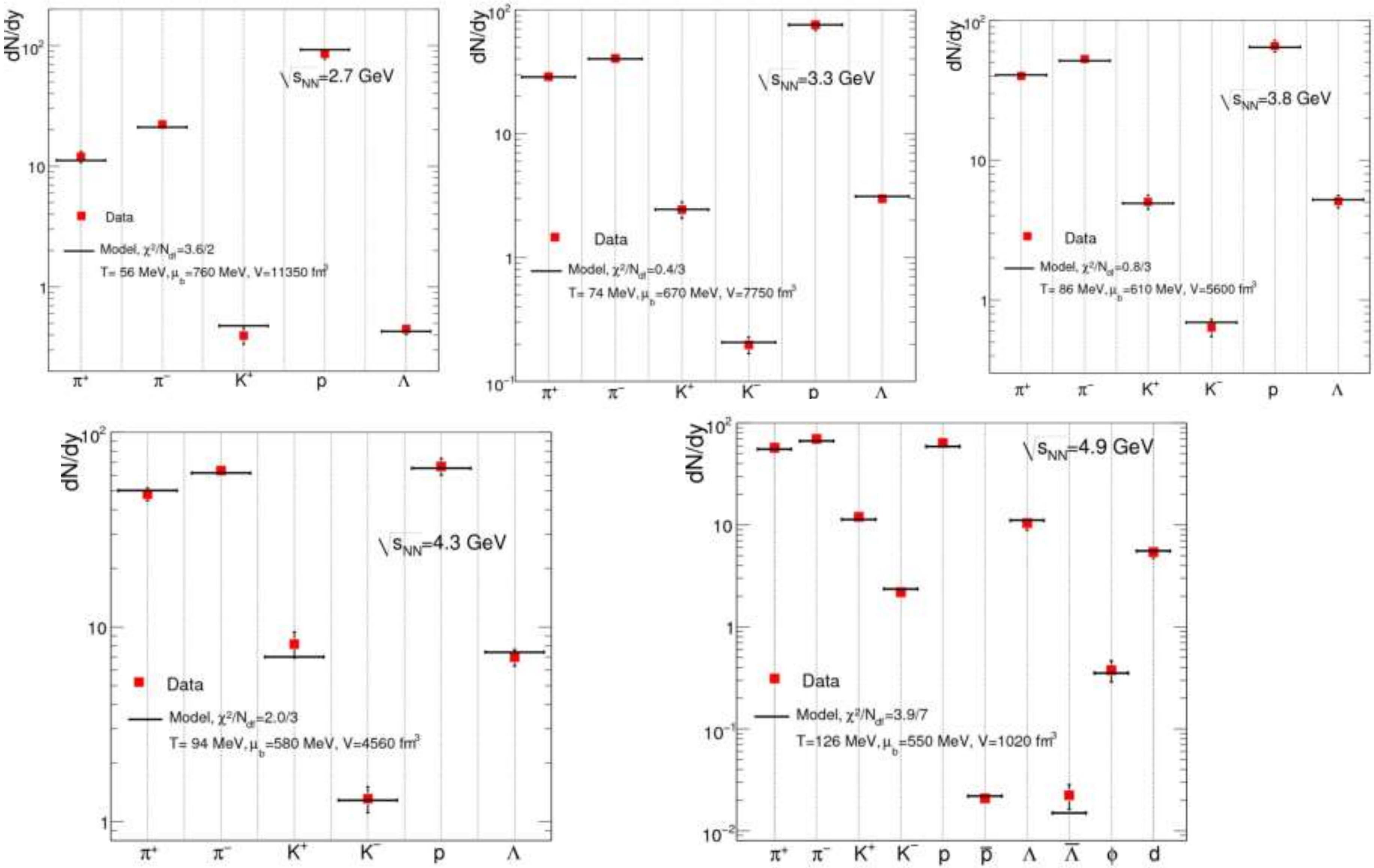
MuCh version	Carbon absorber	# of iron absorbers	total thickness of iron absorber	# of tracking chamber triplets	Type of chambers	Physics case
SIS100-A	60 cm	2	40	3	2 GEM 1 straw tube	LMVM in A+A 4-6 A GeV
SIS100-B	60 cm	3	70	4	2 GEM 2 straw tube	LMVM in A+A 8-10 A GeV
SIS100-C	60 cm	4	205	5	2 GEM 2 straw tube 1 TRD	$p+A \rightarrow J/\psi$
SIS300-A	60 cm	5	105	5	2 GEM 2 straw tube 1 TRD	LMVM in A+A 15-35 A GeV
SIS300-B	60 cm	6	205	6	2 GEM 1 hybrid GEM 2 straw tube 1 TRD	J/ψ in A+A 10-35 A GeV

Experiments exploring dense nuclear matter

Experiment	Energy $\sqrt{s_{NN}}$ (Au/Pb beams)	Observables	Reaction rates Hz
STAR@RHIC BNL	7 – 200 GeV	p, π, strangeness charm, e, μ	1 – 800 (limitation by luminosity)
NA61@SPS CERN	6.4 – 17.4 GeV	p, π, strangeness	80 (limitation by detector)
HADES@SIS18 GSI	< 2.4 GeV	e, p, π, strangeness	$2\cdot10^4$
Planned Experiments:			
CBM@SIS FAIR	2.7 – 4.9 GeV 2.7 – 8.3 GeV	p, π, strangeness charm, e, μ	$10^5 – 10^7$ (limitation by detector)
MPD@NICA Dubna	4.0 – 11.0 GeV	p, π, strangeness, e	~1000 (design luminosity of 10^{27} $cm^{-2}s^{-1}$ for heavy ions)
HI-Expt@ J-PARC	2.3 – 4.9 GeV	p, π, strangeness	10^5

Particles measured at AGS

AGS: central Au+Au collisions at 2, 4, 6, 8, 10.7 A GeV

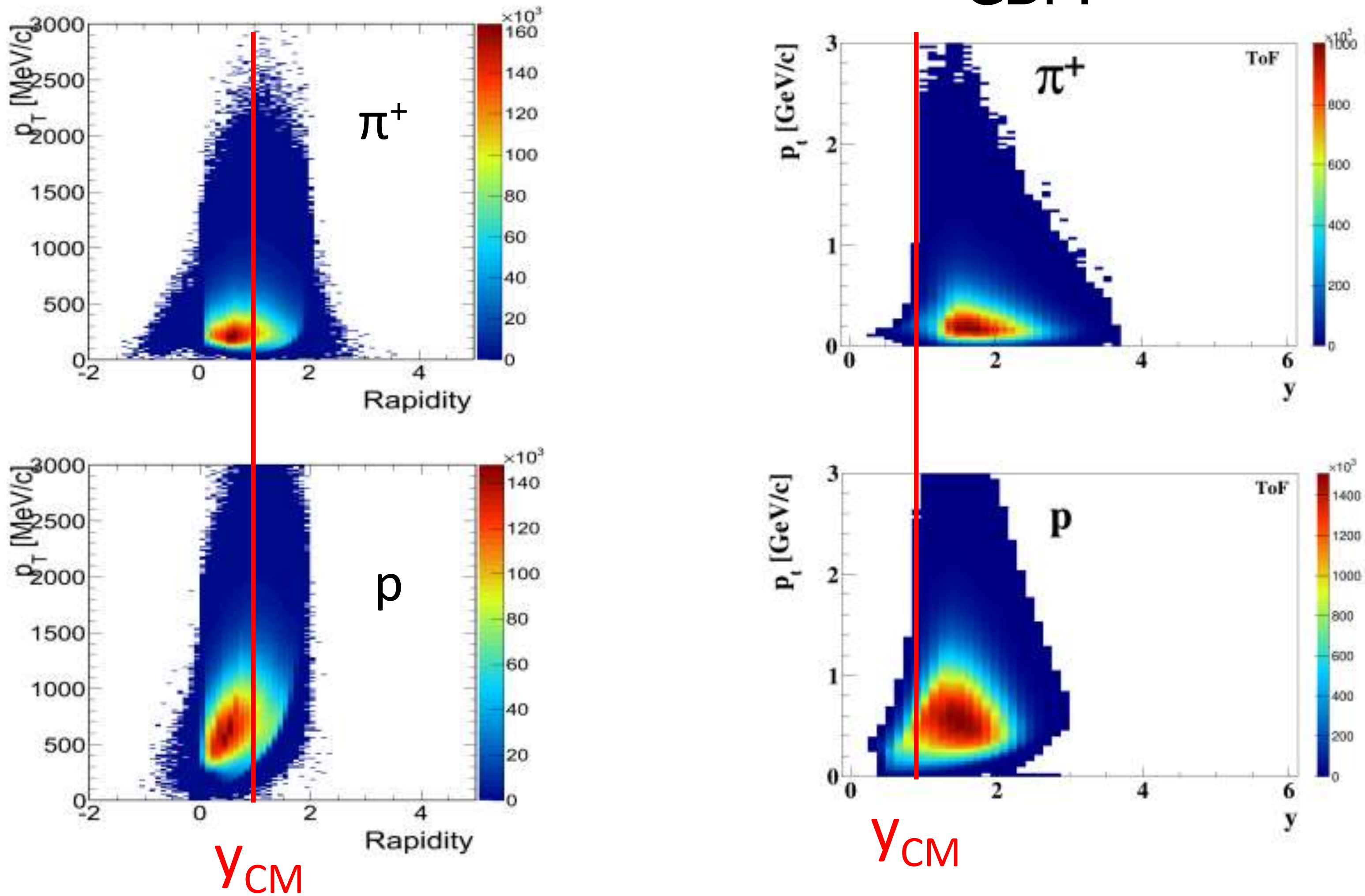


HADES and CBM at SIS100

Acceptance for A+A collisions 4 A GeV

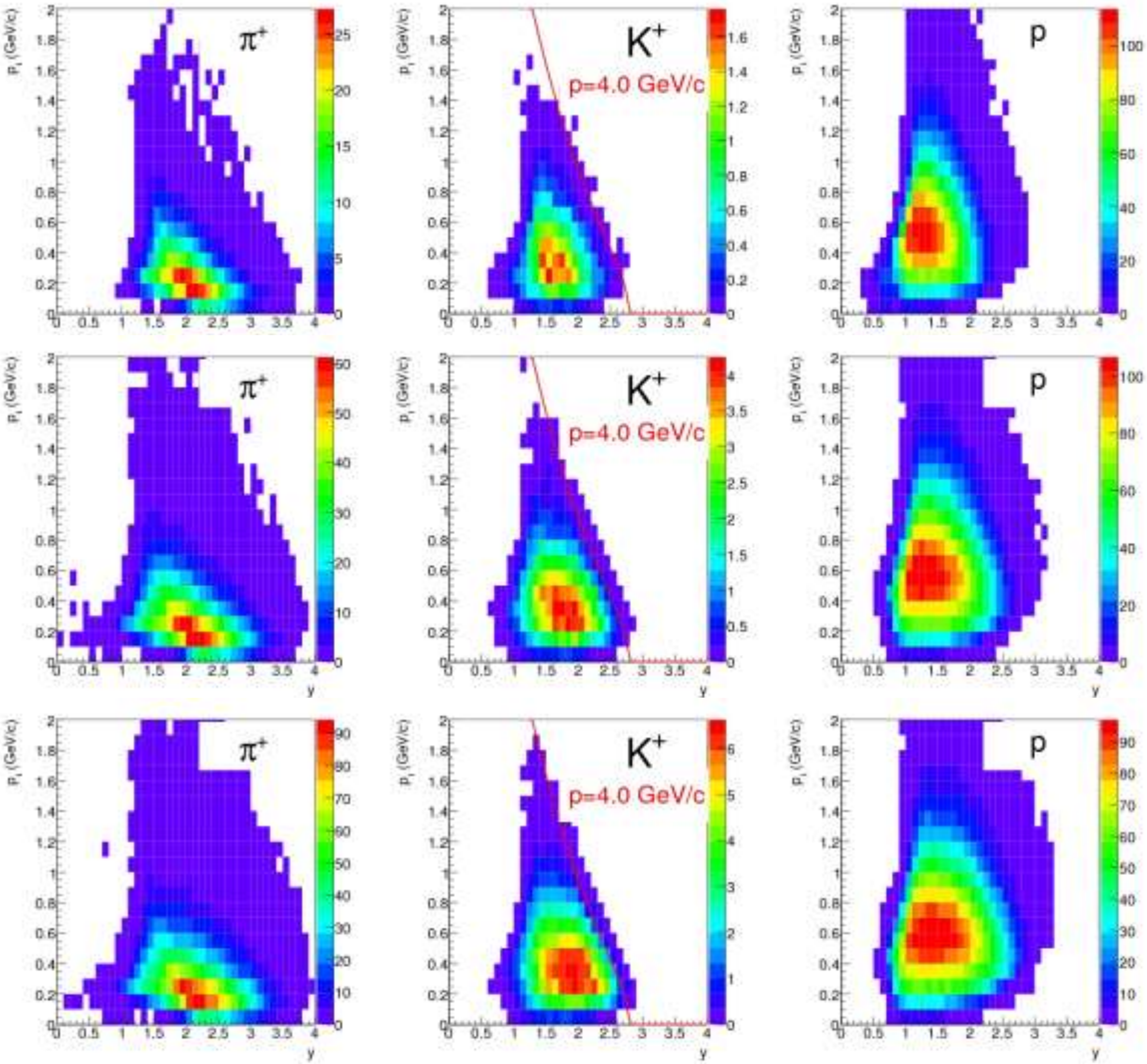
HADES

CBM



Acceptance of the CBM setup for central Au+Au collisions

TOF wall 10 m downstream of the target



4 A GeV

6 A GeV

8 A GeV

The equation-of-state of symmetric nuclear matter at neutron star core densities

Observable: multistrange hyperon production at (sub)threshold energies

<u>Direct multi-strange hyperon production:</u>

$pp \rightarrow \Xi^- K^+K^+p$ $(E_{thr} = 3.7$ GeV)
$pp \rightarrow \Omega^- K^+K^+K^0p$ $(E_{thr} = 7.0$ GeV)
$pp \rightarrow \bar{\Lambda}^0\Lambda^0 pp$ $(E_{thr} = 7.1$ GeV)
$pp \rightarrow \Xi^+ \Xi^- pp$ $(E_{thr} = 9.0$ GeV)
$pp \rightarrow \Omega^+ \Omega^- pp$ $(E_{thr} = 12.7$ GeV

<u>Hyperon production via multiple strangeness exchange reactions:</u>

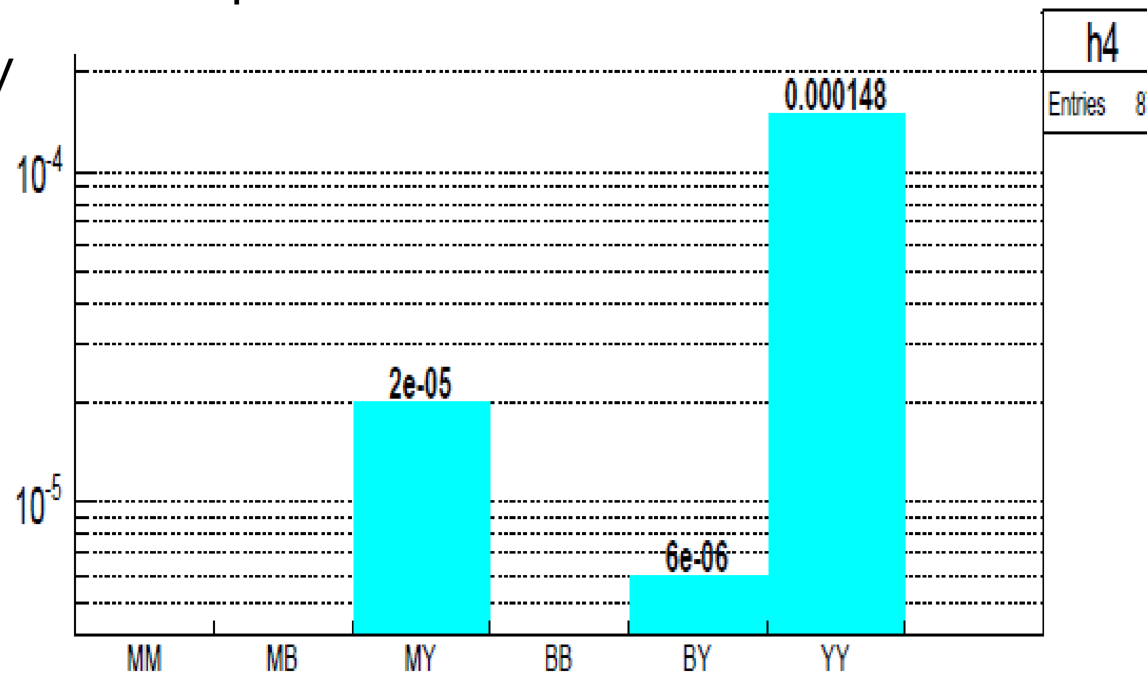
Hyperons (s quarks):

1. $pp \rightarrow K^+\Lambda^0p$, $pp \rightarrow K^+K^-pp$,
2. $p\Lambda^0 \rightarrow K^+ \Xi^- p$, $\pi\Lambda^0 \rightarrow K^+ \Xi^- \pi$,
3. $\Lambda^0\Lambda^0 \rightarrow \Xi^- p$, $\Lambda^0K^- \rightarrow \Xi^- \pi^0$
4. $\Lambda^0 \Xi^- \rightarrow \Omega^- n$, $\Xi^-K^- \rightarrow \Omega^- \pi^-$

Antihyperons (anti-s quarks):

1. $\bar{\Lambda}^0 K^+ \rightarrow \Xi^+\pi^0$,
2. $\Xi^+ K^+ \rightarrow \Omega^+ \pi^+$.

Ω^- production in 4 A GeV Au+Au



HYPQGSM calculations , K. Gudima et al.