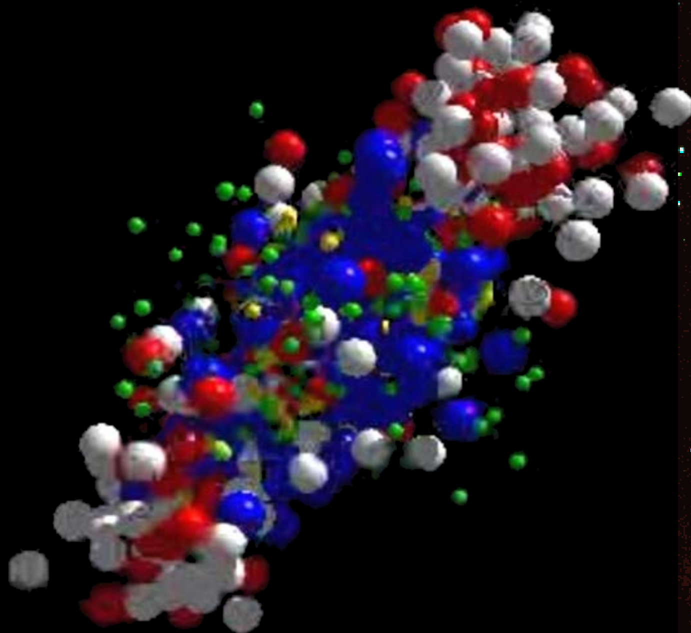
QCD matter physics at FAIR
The CBM experiment

Peter Senger GSI and Univ. Frankfurt

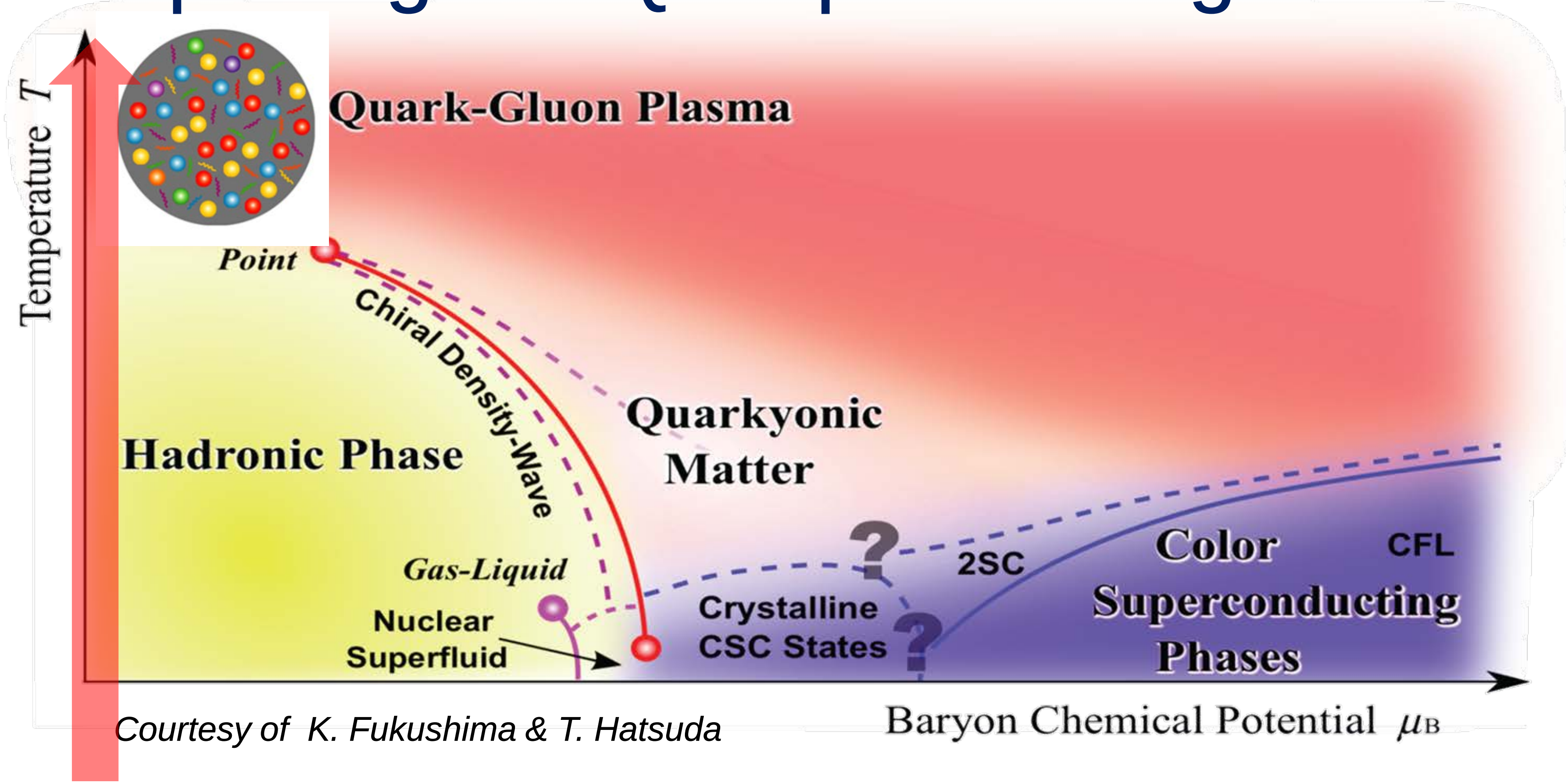


Outline:

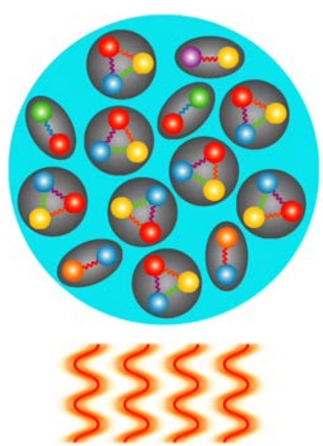
- The CBM physics case
- Status experiment preparation

International Conference on Matter under High Densities,
21 – 23 June 2016, Sikkim Manipal Institute of Technology, Rangpo, Sikkim, India

Exploring the QCD phase diagram



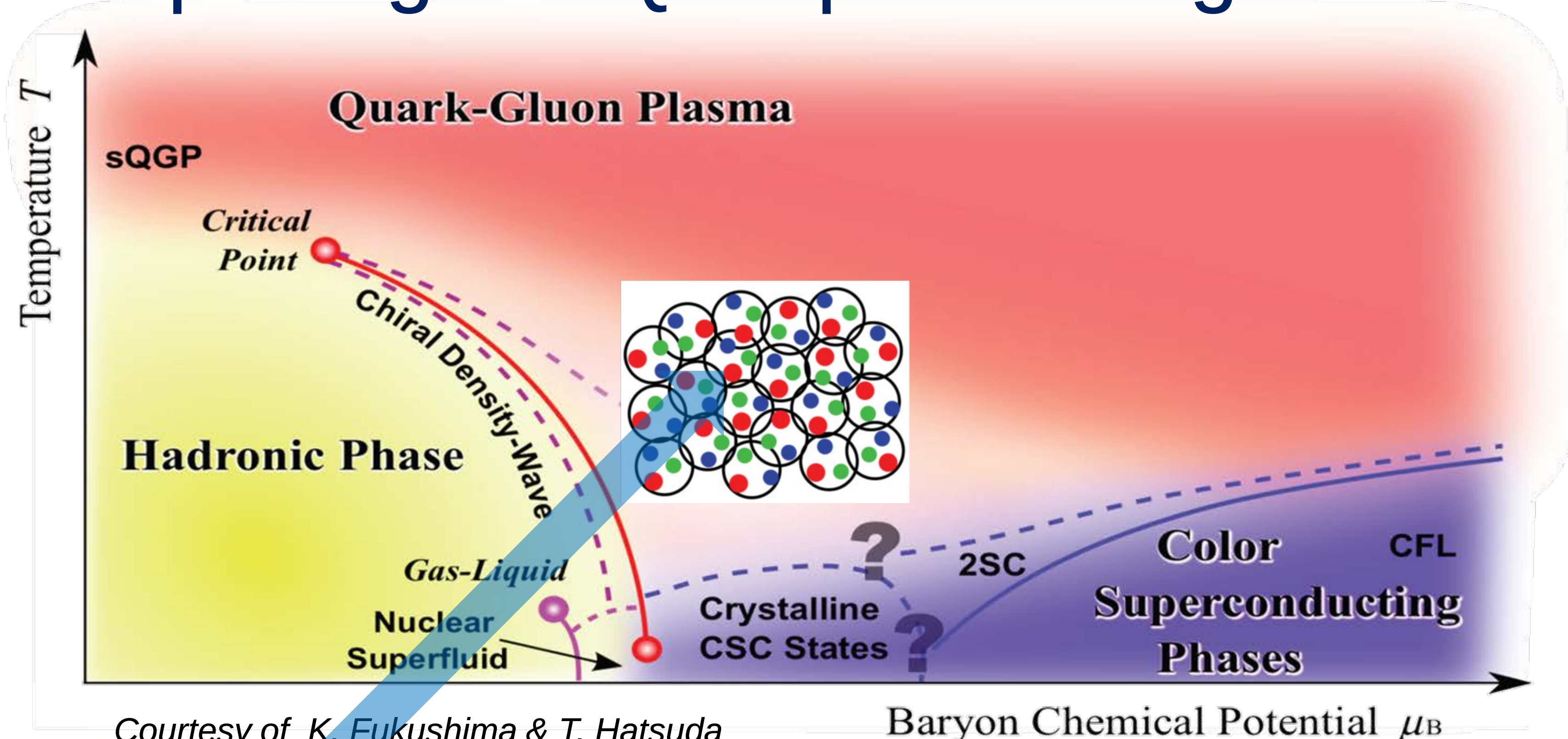
Courtesy of K. Fukushima & T. Hatsuda



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

- N of baryons ≈ N of antibaryons
  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



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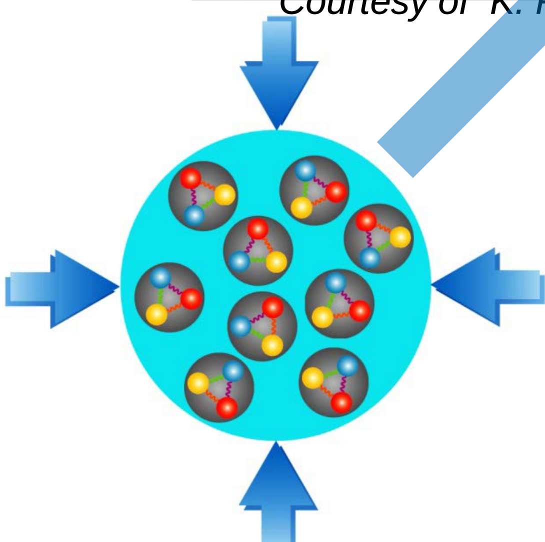


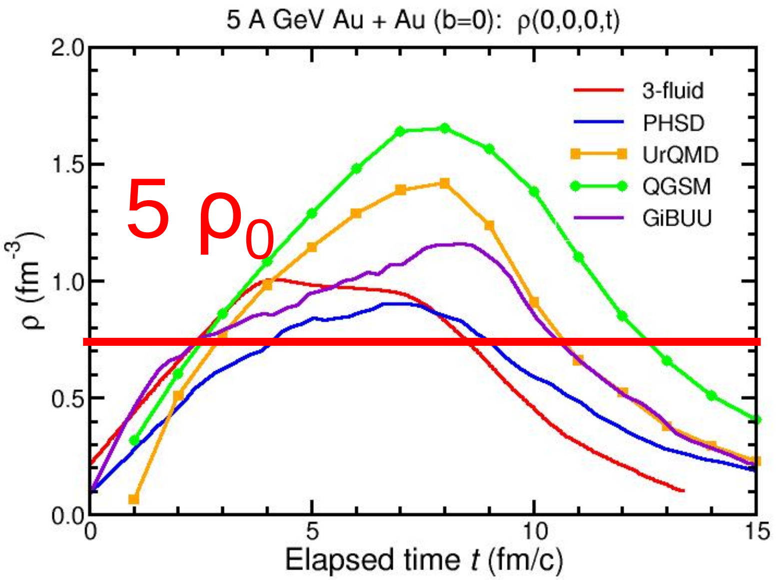
<u>At high baryon density:</u>

- N of baryons >> N of antibaryons
  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, J-PARC

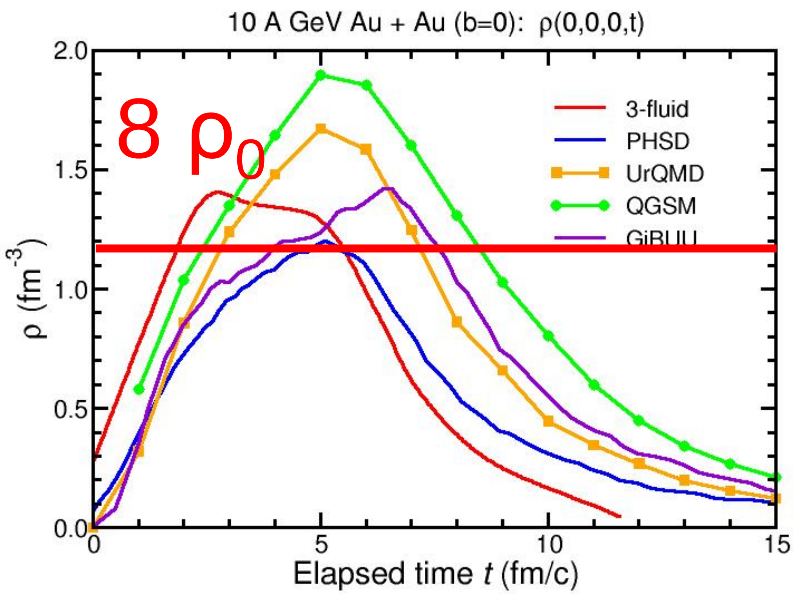
Baryon densities in central Au+Au collisions

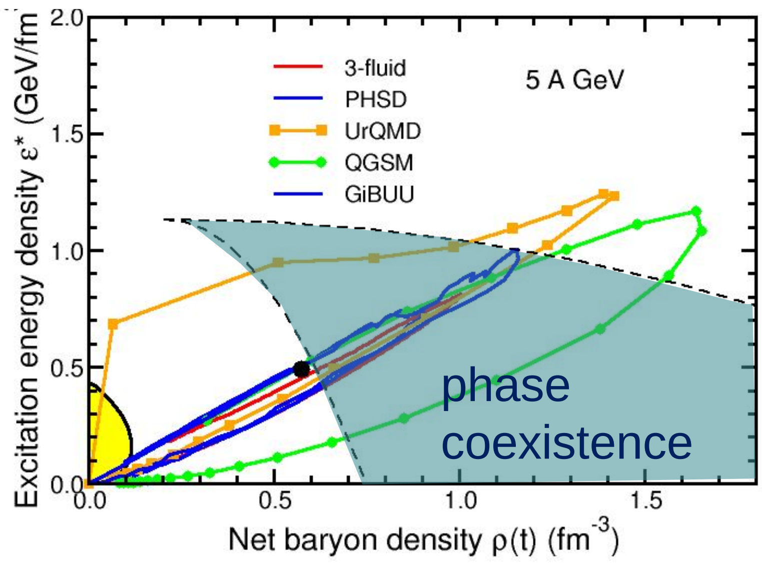
I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

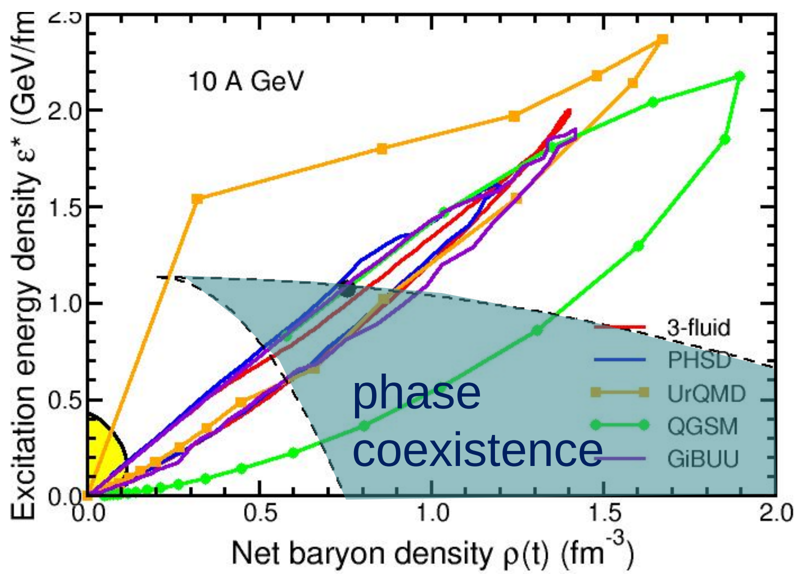
5 A GeV



10 A GeV

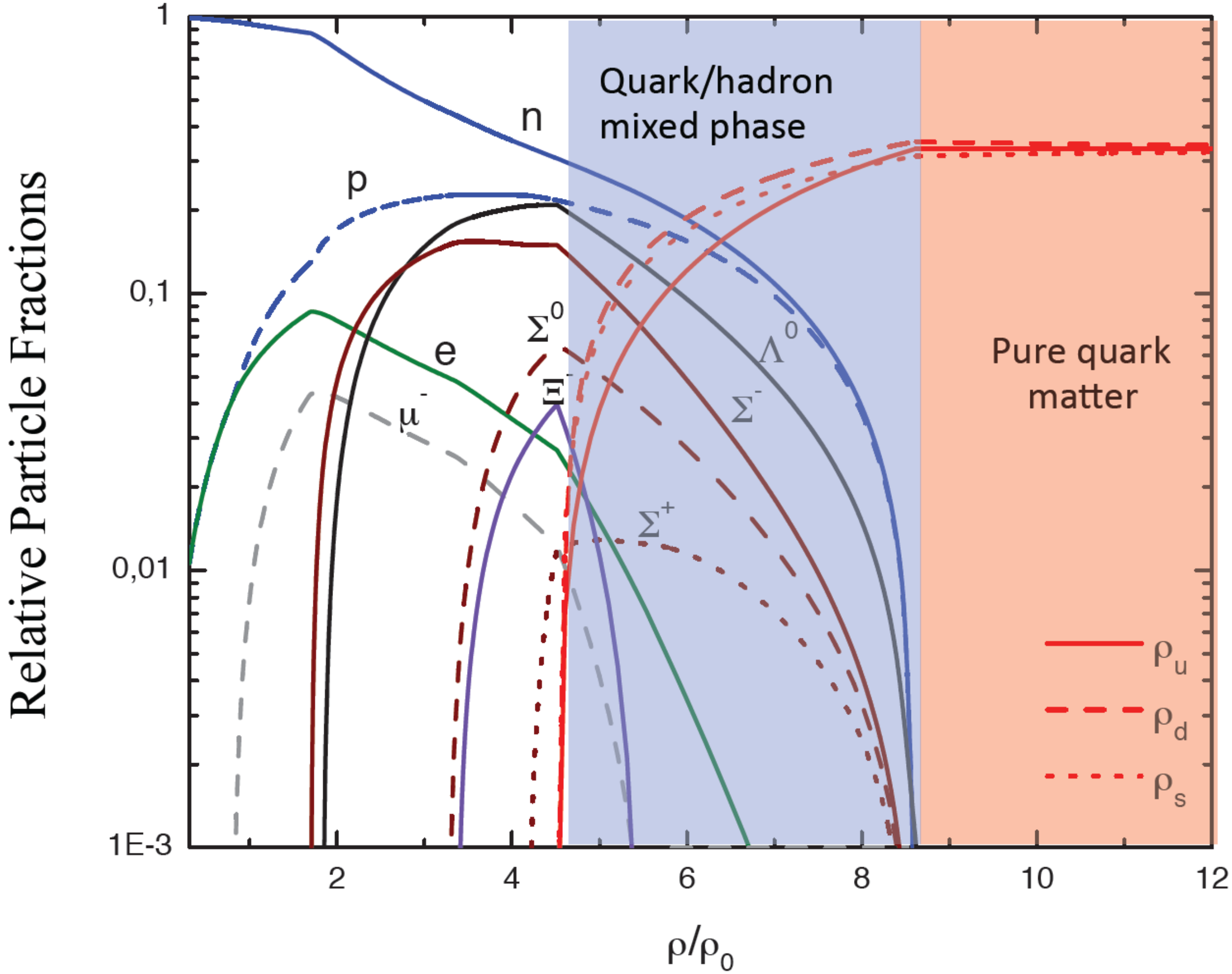






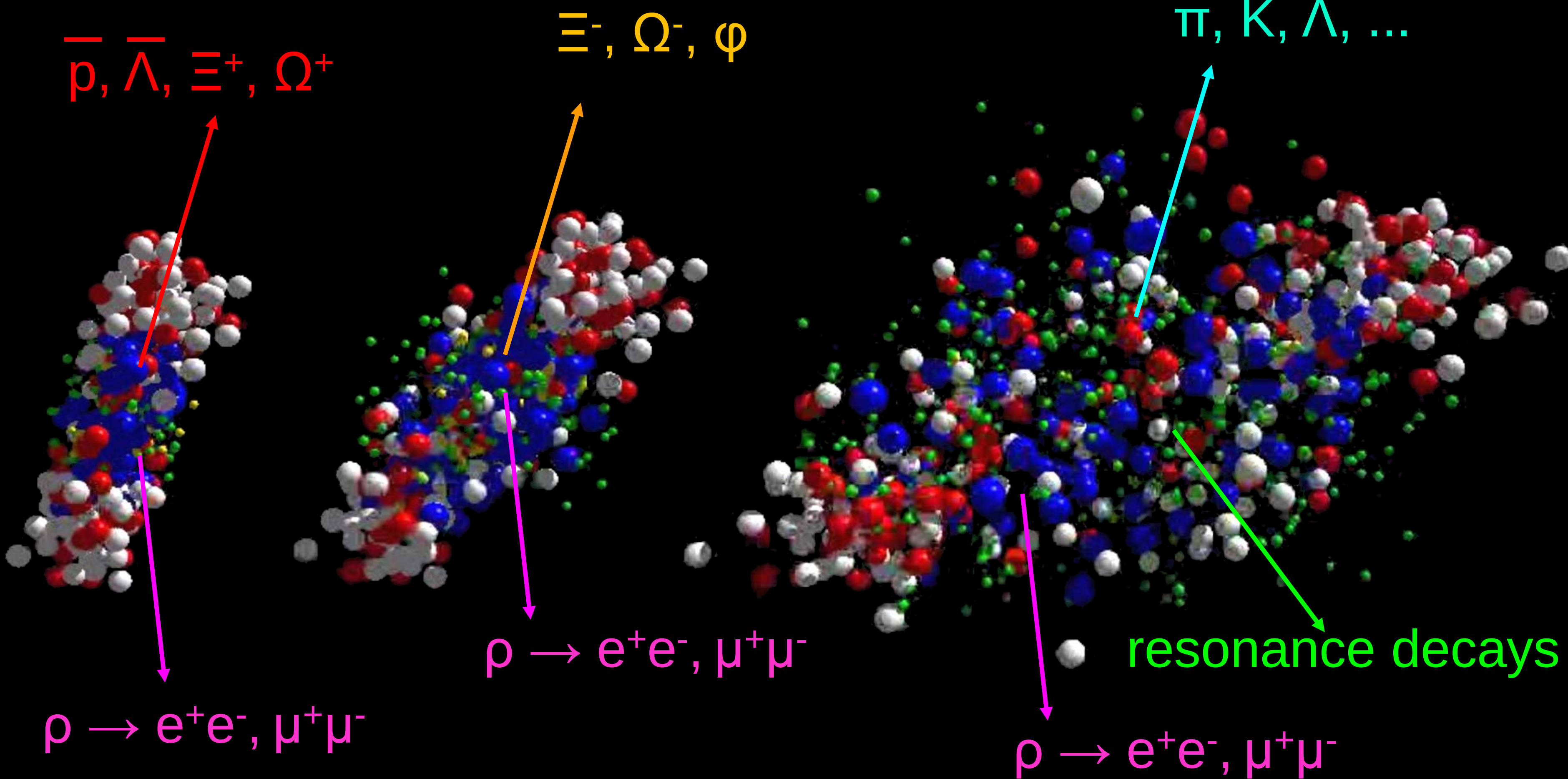
Quark matter in massive neutron stars?

M. Orsaria, H. Rodrigues, F. Weber, G.A. Contrera, arXiv:1308.1657
Phys. Rev. C 89, 015806, 2014



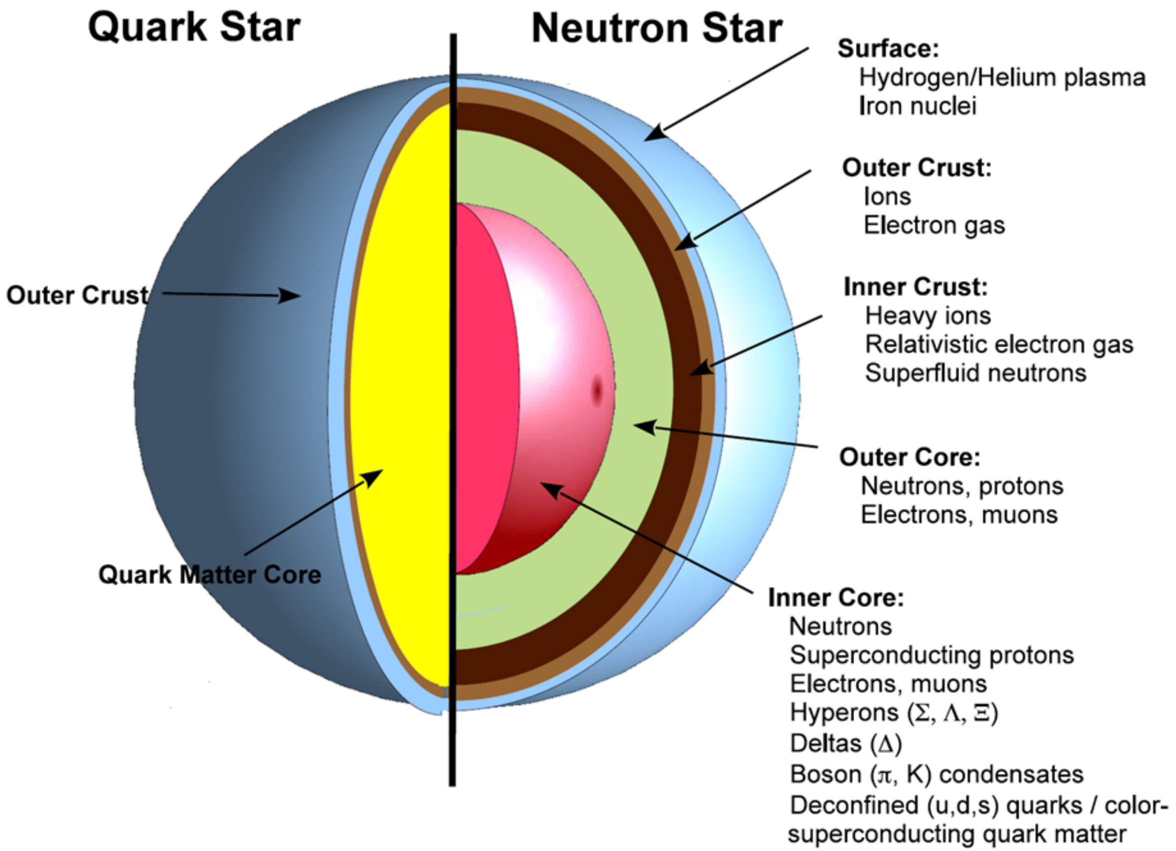
Messengers from the dense fireball: CBM at FAIR

UrQMD transport calculation Au+Au 10.7 A GeV



The physics case of CBM

- The equation-of-state of QCD matter at neutron star core densities



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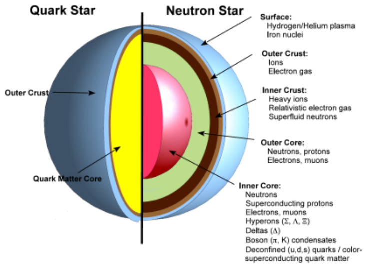
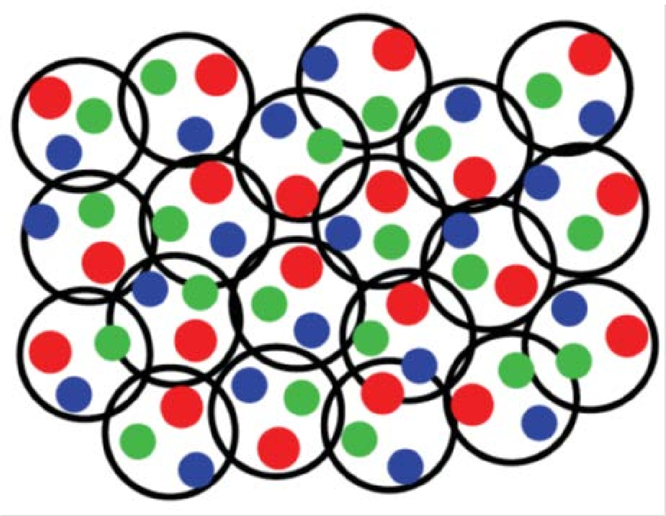
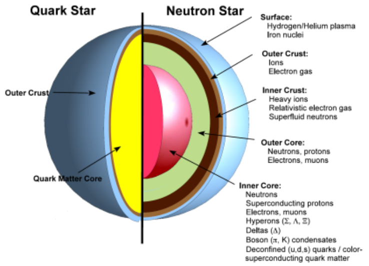


- The equation-of-state of QCD matter at neutron star core densities

- Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point



The physics case of CBM



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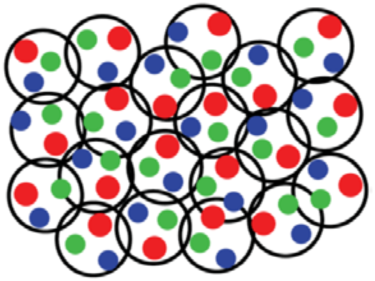
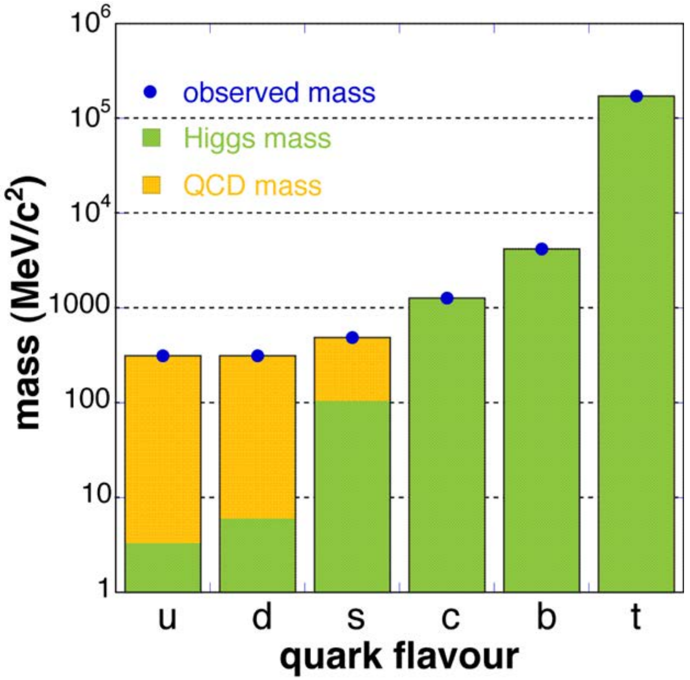
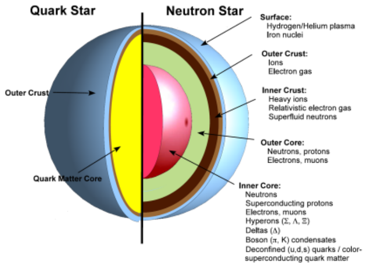


- Chiral symmetry restoration in dense baryonic matter

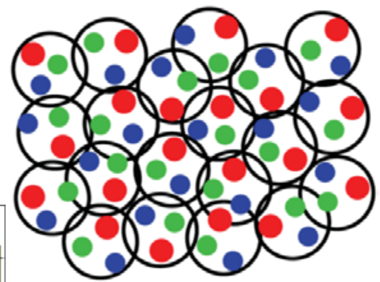


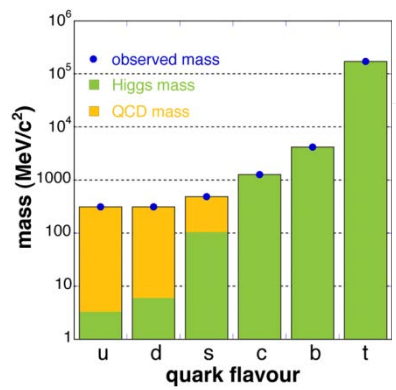
The physics case of CBM



- ➢ The equation-of-state of QCD matter at neutron star core densities

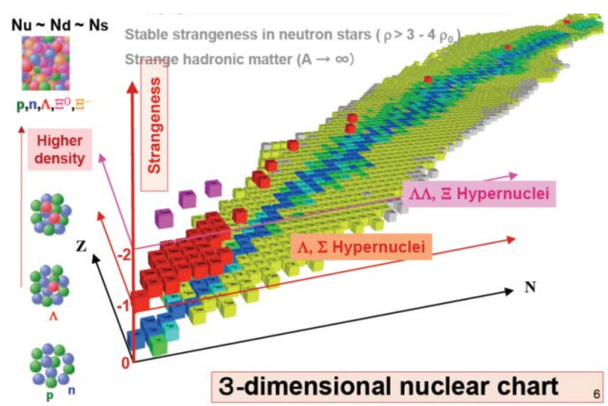
- ➢ Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point





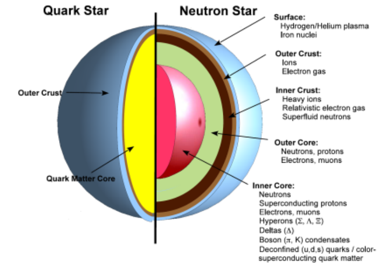
- ➢ Chiral symmetry restoration in dense baryonic matter

- ➢ Extension of the nuclear chart into the strange domain

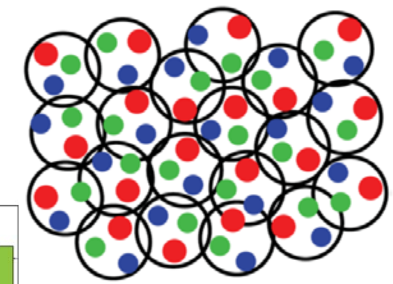


The physics case of CBM

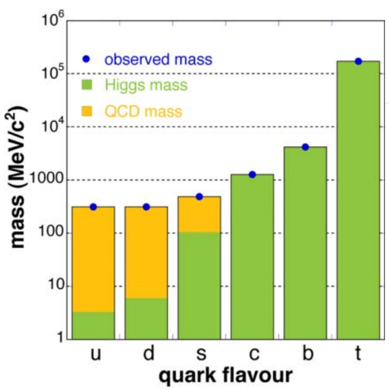
- The equation-of-state of QCD matter at neutron star core densities



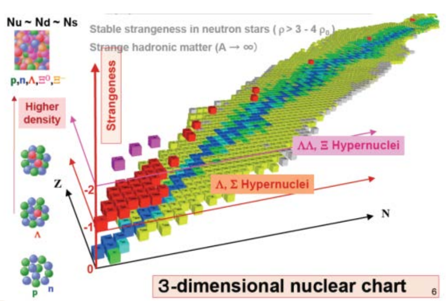
- Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point



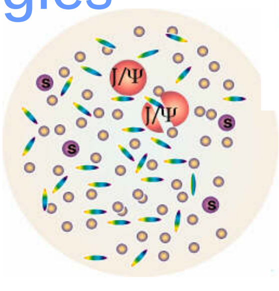
- Chiral symmetry restoration in dense baryonic matter



- Extension of the nuclear chart into the strange domain



- Charm production at threshold energies in cold and hot matter



CBM physics case I

The QCD matter equation-of-state at neutron star core densities

Equation of state:

$P = \delta E/\delta V \,|_{T=const}$

$V = A/\rho$

$\delta V/ \delta\rho = - A/\rho^2$

$P = \rho^2 \; \delta(E/A)/\delta\rho \,|_{T=const}$

T=0: $E/A = 1/\rho \int U(\rho)d\rho$

Effective NN-potential:

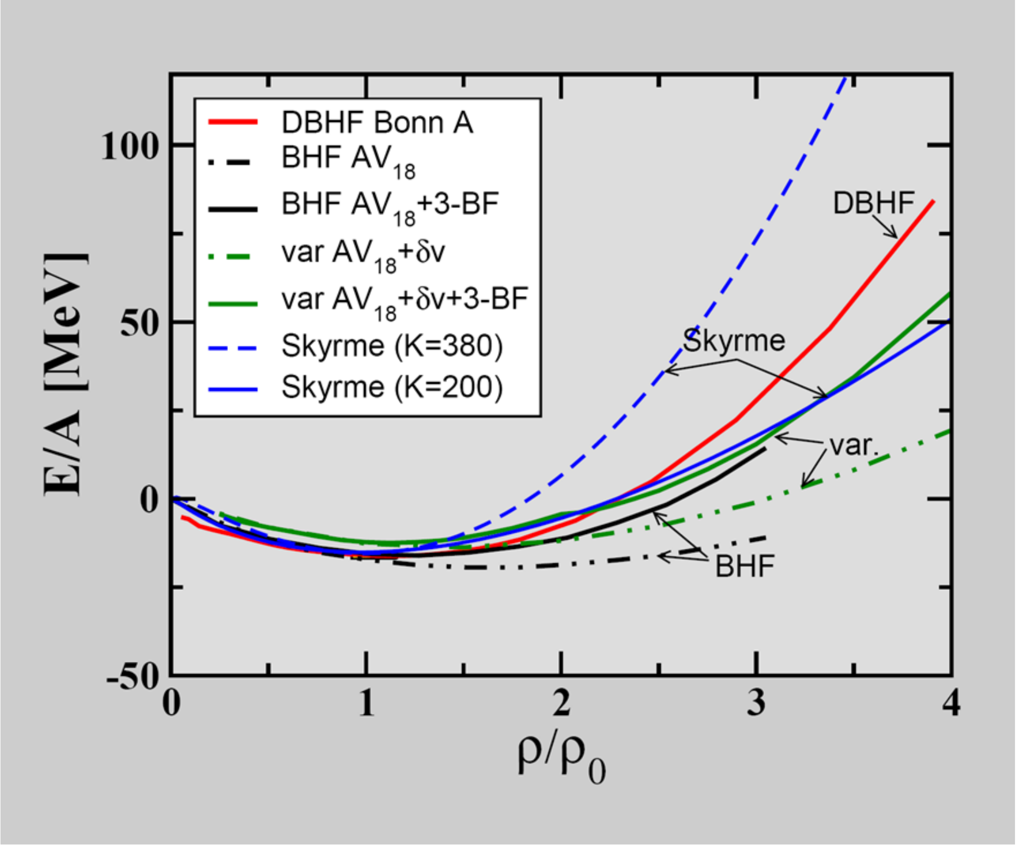
$U(\rho)=\alpha\rho+\beta\rho^\gamma$

$E/A(\rho_o) = -16$ MeV

- $\delta(E/A)(\rho_o)/\delta\rho = 0$
- Compressibility:

$\kappa = 9\rho^2 \; \delta^2 (E/A)/ \delta\rho^2$

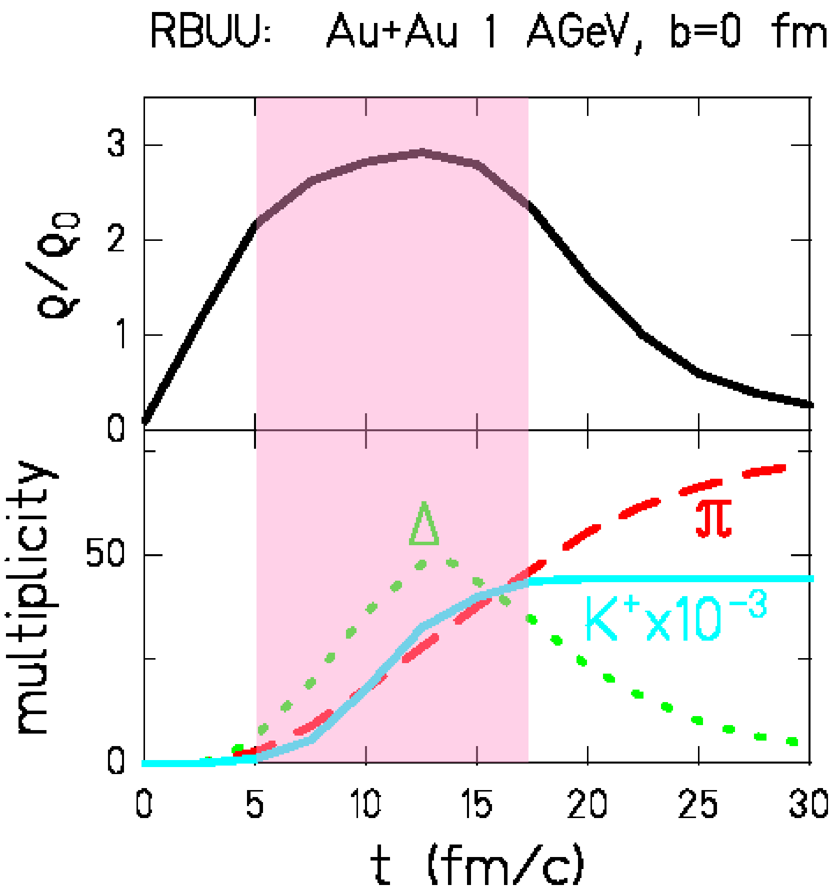
Equation of state of symmetric nuclear matter



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

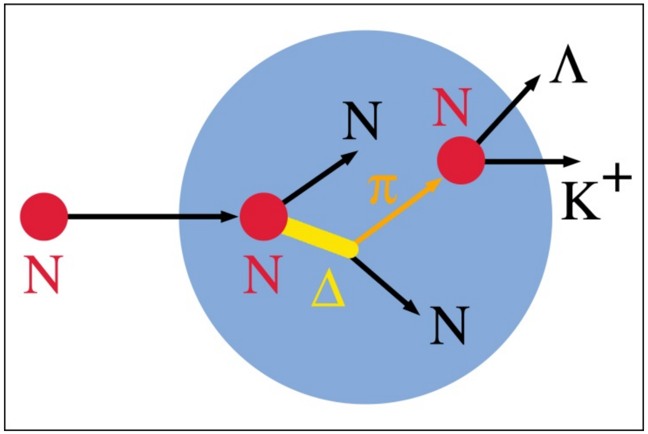
The equation-of-state of (symmetric) nuclear matter

Observable: Kaon production in Au+Au collisions at 1 AGeV



pp → $K^+\Lambda p$ (E_{thres}= 1.6 GeV)

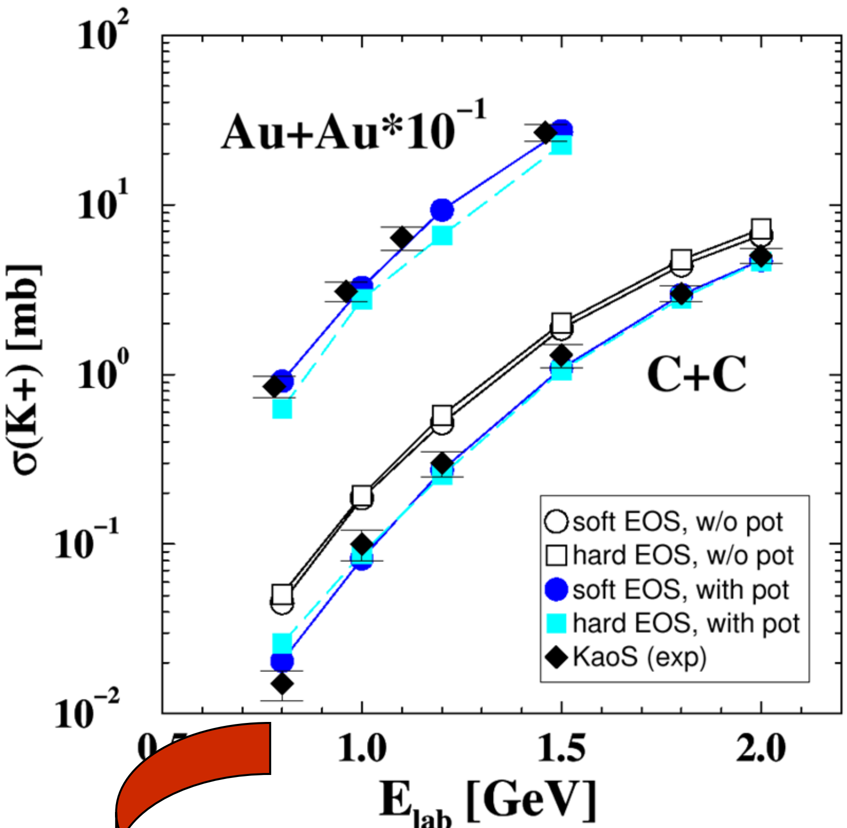
Kaon production via multiple collisions

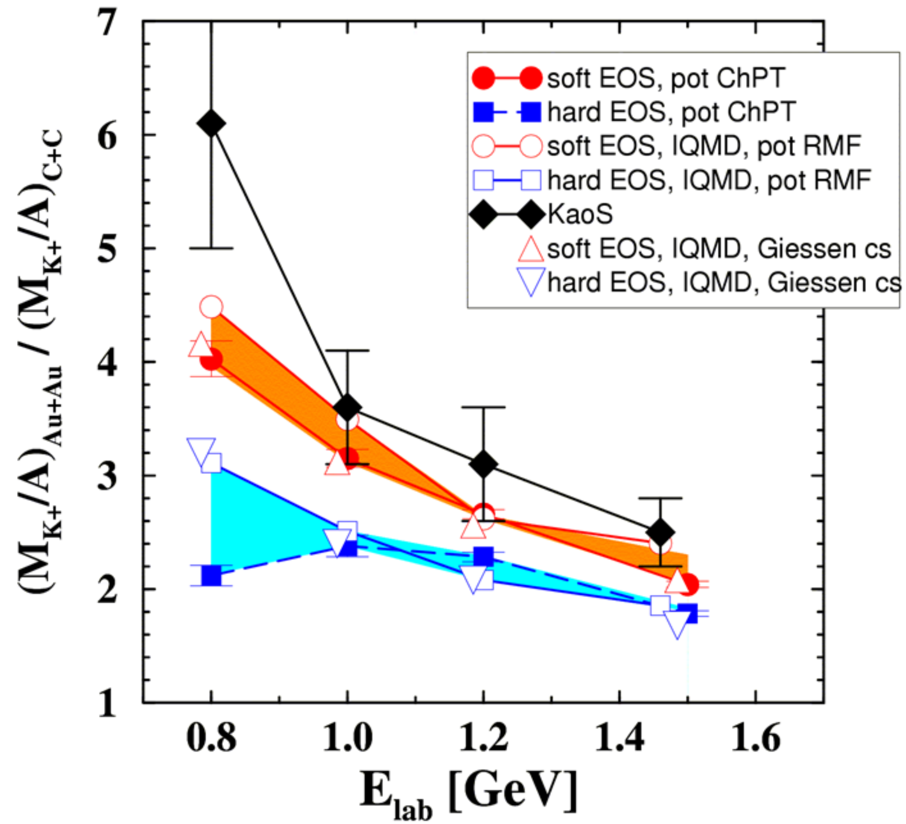


Idea: K^+ yield ∝ baryon density ρ ∝ compressibility κ

The equation-of-state of (symmetric) nuclear matter

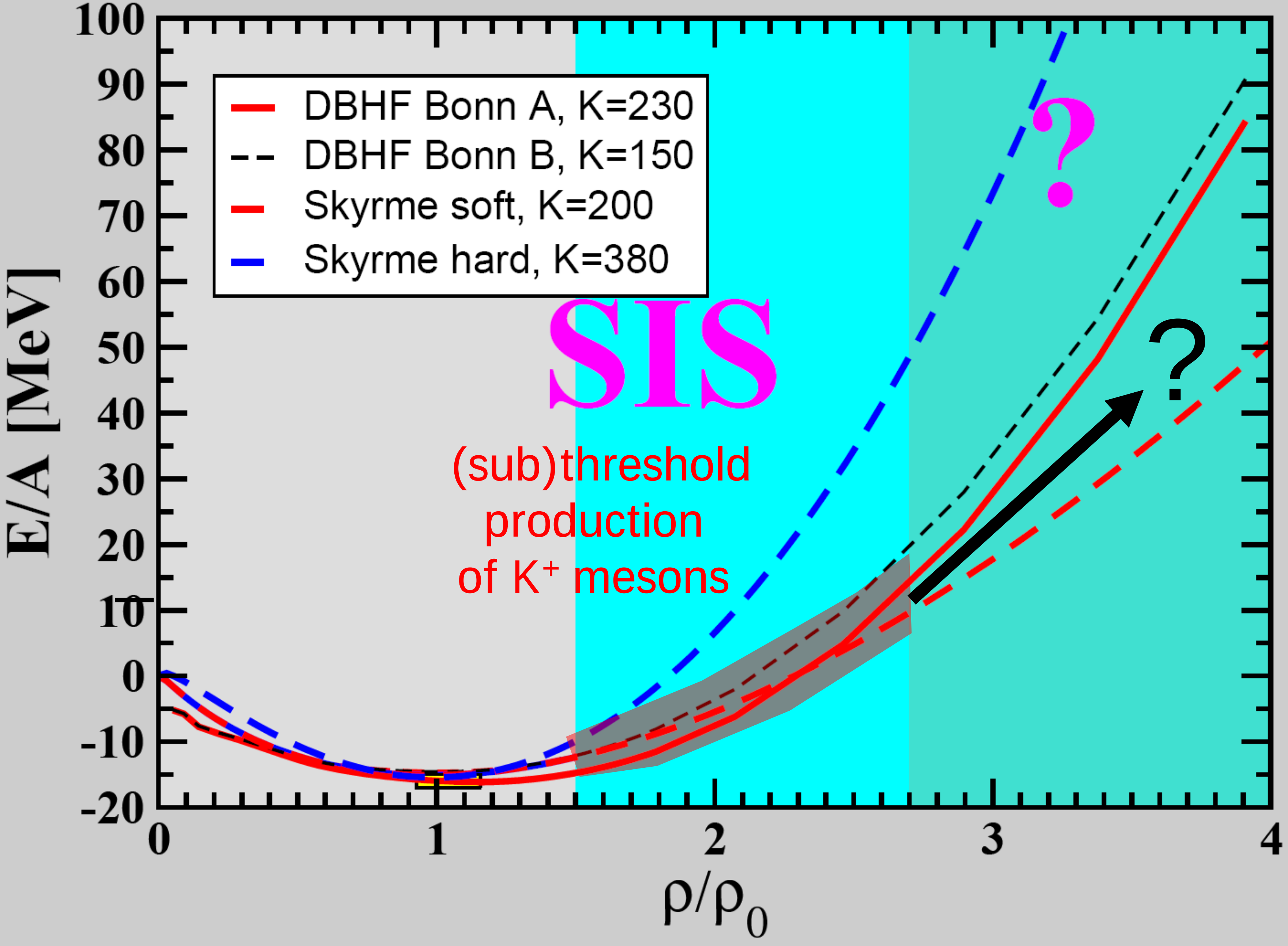
Experiment: Excitation function of K^+ production in Au+Au and C+C collisions
C. Sturm et al., (KaoS Collaboration), Phys. Rev. Lett. 86 (2001) 39
Model calculation: Ch. Fuchs et al., Phys. Rev. Lett. 86 (2001) 1974





soft equation-of-state: κ ≤ 200 MeV

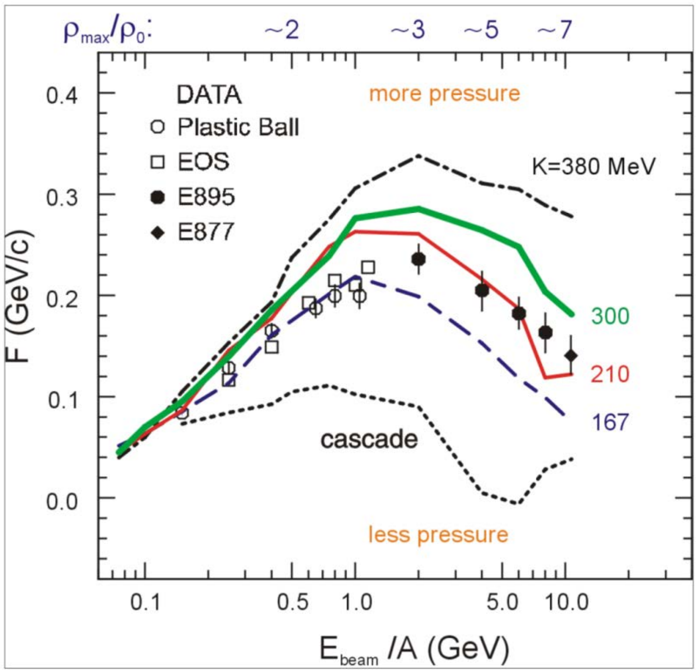
nuclear matter EOS

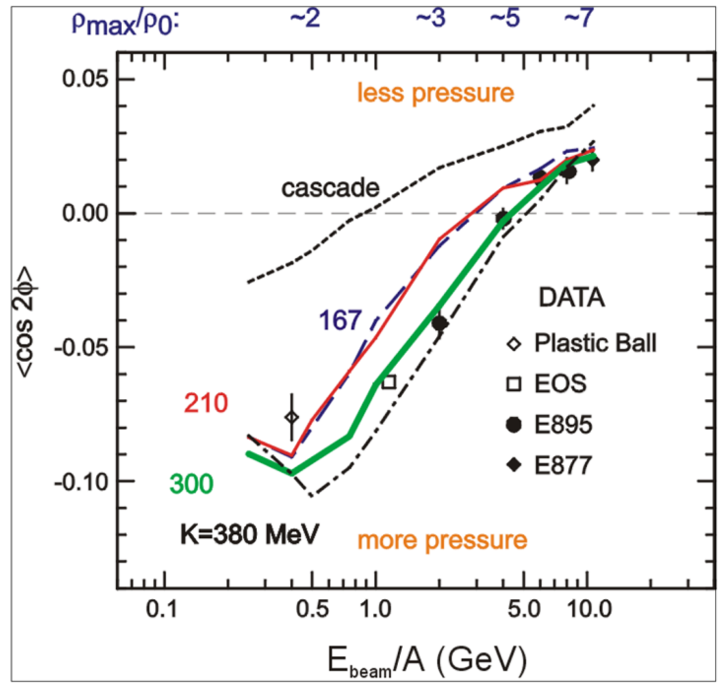


The equation-of-state of (symmetric) nuclear matter

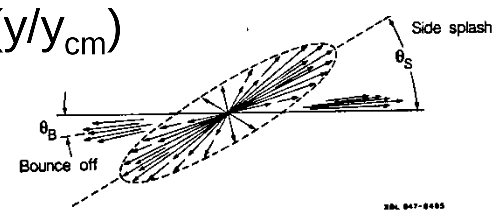
Experiments at AGS: collective flow of protons in Au+Au collisions

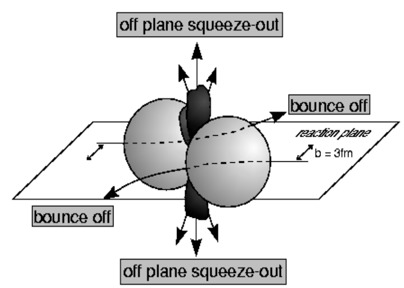
Azimuthal angle distribution: $dN/d\phi = C\,(1 + v_1 \cos(\phi) + v_2 \cos(2\phi) + \ldots)$

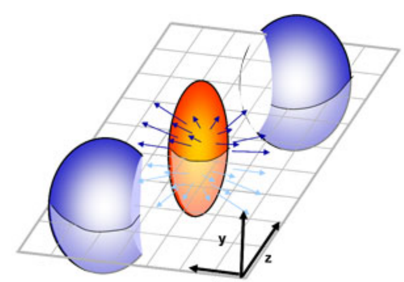




$F = d(p_x/A)/d(y/y_{cm})$







P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592

CBM physics case and observables

The QCD matter equation-of-state at neutron star core densities

- collective flow of identified particles (π,K,p,Λ,Ξ,Ω,...) driven by the pressure gradient in the early fireball
- particle production at (sub)threshold energies via multi-step processes (multi-strange hyperons, charm)

Direct multi-strange hyperon production:

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

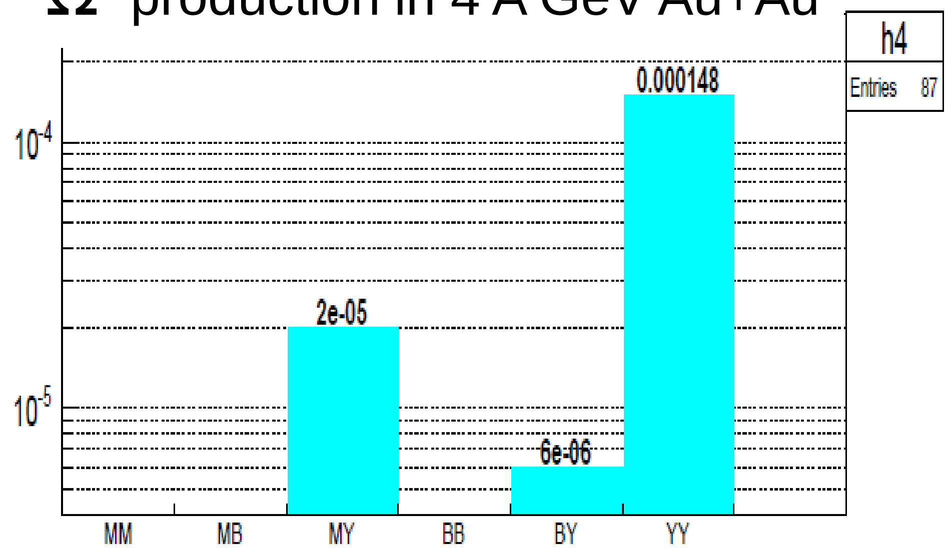
Hyperon production via multiple collisions

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

Antihyperons

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

Ω^- production in 4 A GeV Au+Au



HYPQGSM calculations , K. Gudima et al.

CBM physics case and observables

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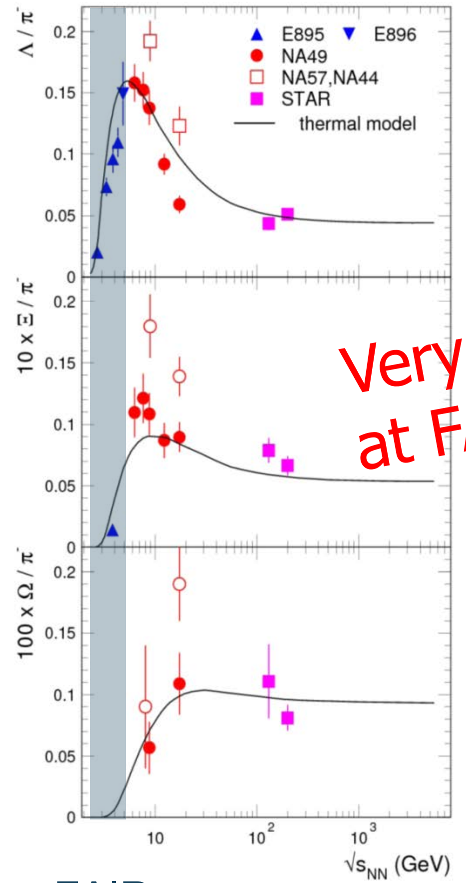


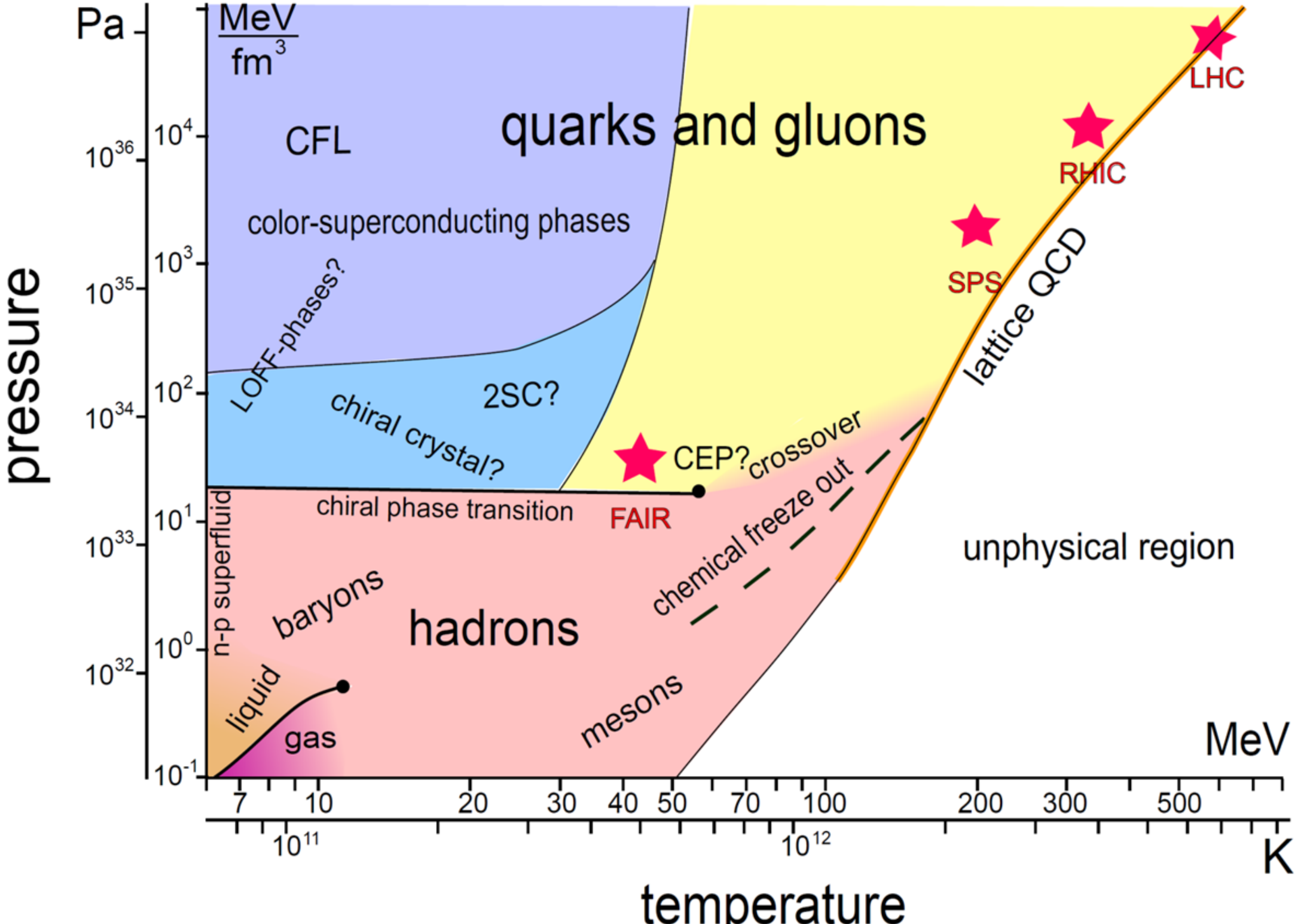
FAIR

Pb+Pb, Au+Au central collisions

Very few data at FAIR energies

CBM physics case II

Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point

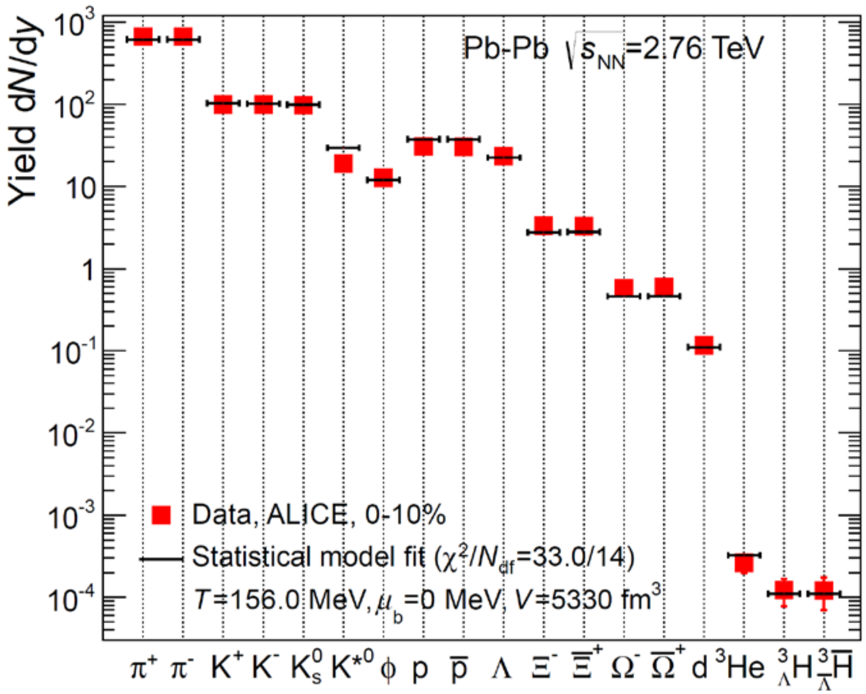


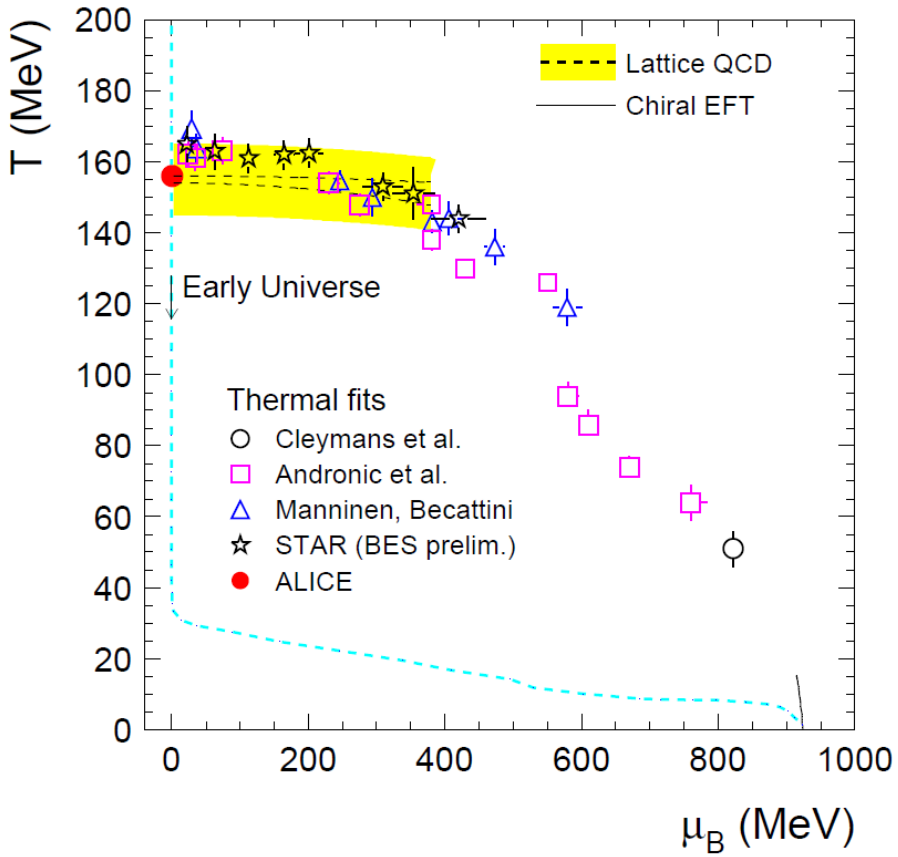
J. Wambach, K. Heckmann, M. Buballa, Act. Phys. Pol. B, Vol. 5 (2012)

Chemical freeze-out and the QCD phase boundary

Thermal model fits to measured hadron abundances suggest that all hadrons are in chemical equilibrium (including multi-strange hyperons)

$$n_i = N_i/V = -\frac{T}{V}\frac{\partial \ln Z_i}{\partial \mu} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 \mathrm{d}p}{\exp[(E_i-\mu_i)/T] \pm 1}$$





A. Andronic, P. Braun-Munzinger, K. Redlich, J. Stachel, Jour. Phys. G38 (2011)

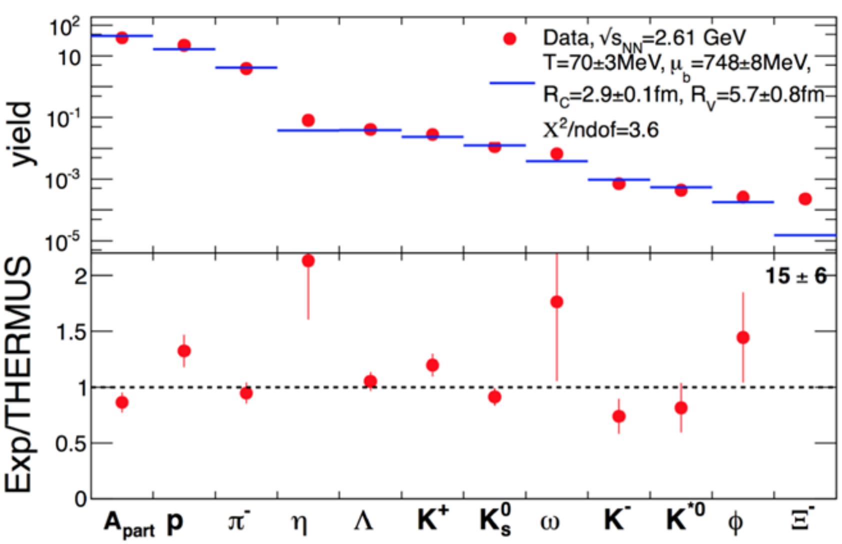
CBM physics case and observables

Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point

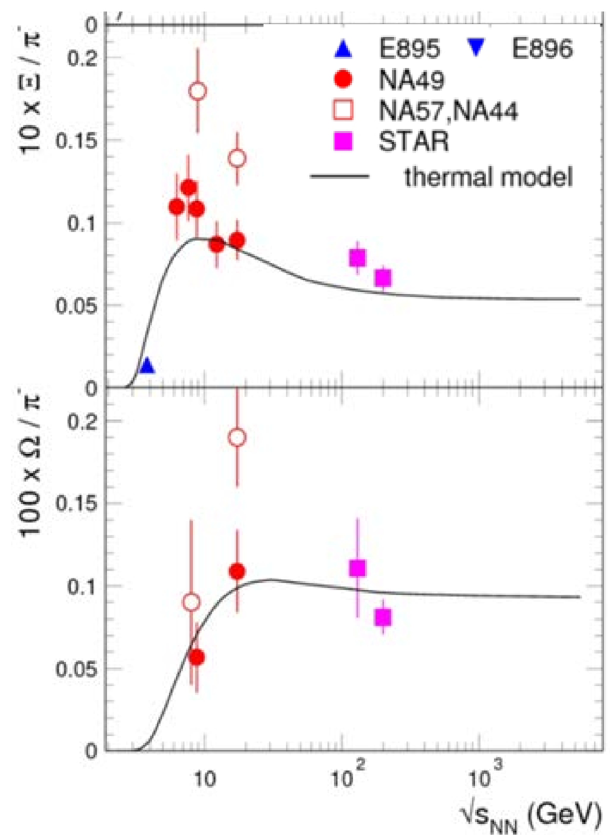
- excitation function of strangeness: Ξ^-(dss), Ξ^+($\overline{dss}$), Ω^-(sss), Ω^+($\overline{sss}$)
  $\rightarrow$ chemical equilibration at the phase boundary

Very few data at FAIR energies

Particle yields and thermal model fits



HADES: Ar + KCl 1.76 A GeV
G. Agakishiev et al., arXiv:1512.07070

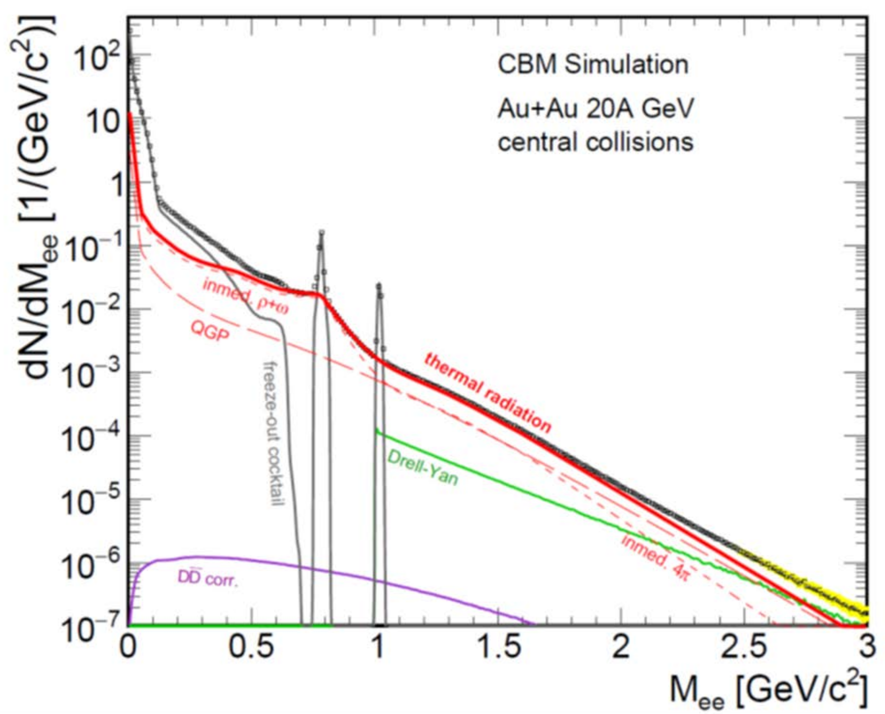


CBM physics case and observables

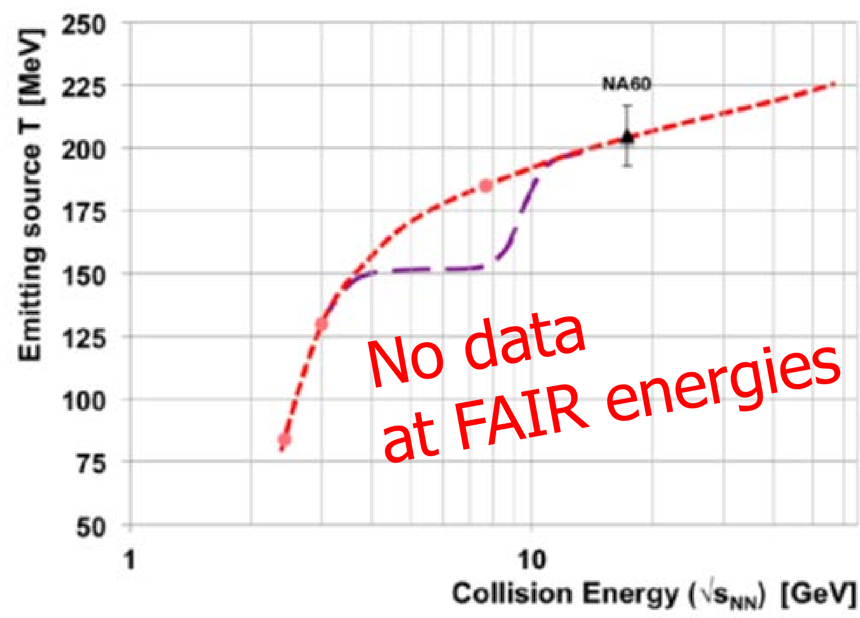
Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point

- excitation function of strangeness: $\Xi^-(dss)$, $\Xi^+(\overline{dss})$, $\Omega^-(sss)$, $\Omega^+(\overline{sss})$
  $\rightarrow$ chemical equilibration at the phase boundary
- excitation function (invariant mass) of lepton pairs:
  Thermal radiation from QGP, caloric curve

Invariant mass distribution of lepton pairs



Slope of dilepton invariant mass spectrum
1 GeV/c^2 < M_{inv} < 2.5 GeV/c^2



CBM physics case and observables

Phase transitions from hadronic matter to quarkyonic or partonic matter at high ρ_B, phase coexistence, critical point

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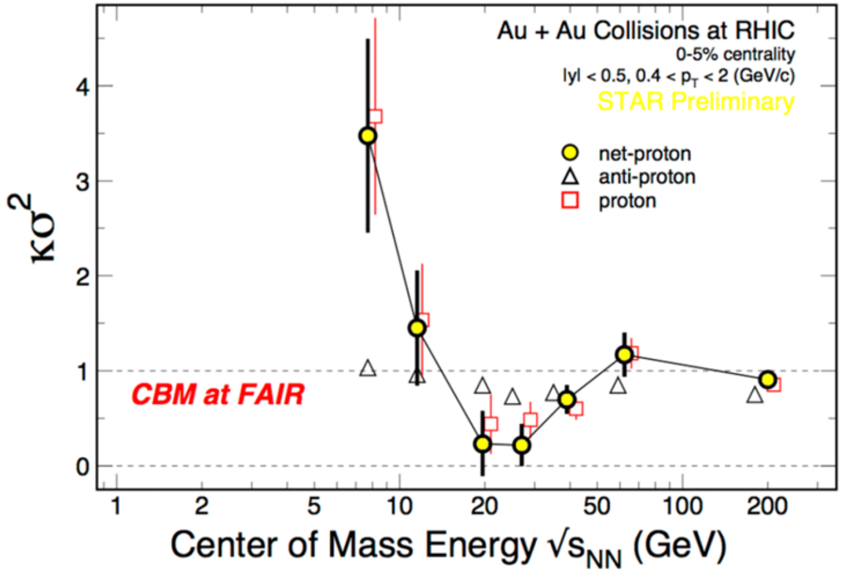
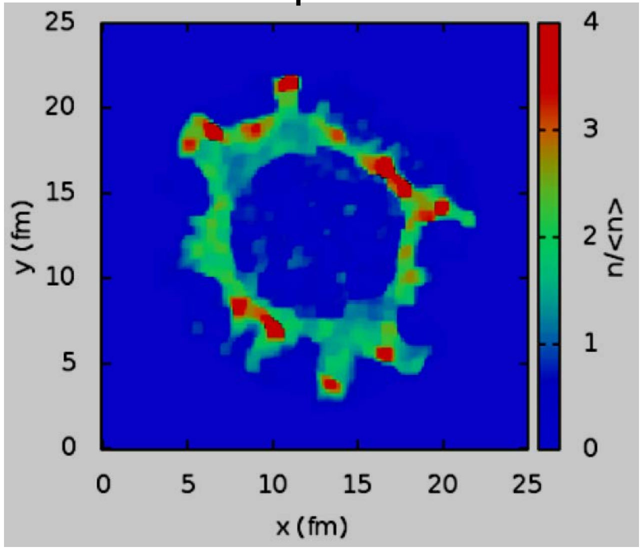
  → chemical equilibration at the phase boundary
- excitation function (invariant mass) of lepton pairs:
  Thermal radiation from QGP, caloric curve
- event-by-event fluctuations of conserved quantities (B,S,Q):
  ”critical opalescence”
- anisotropic azimuthal angle distributions: “spinodal decomposition”

No data at FAIR energies

4^{th} moment of net-proton multiplicity distribution: critical fluctuations



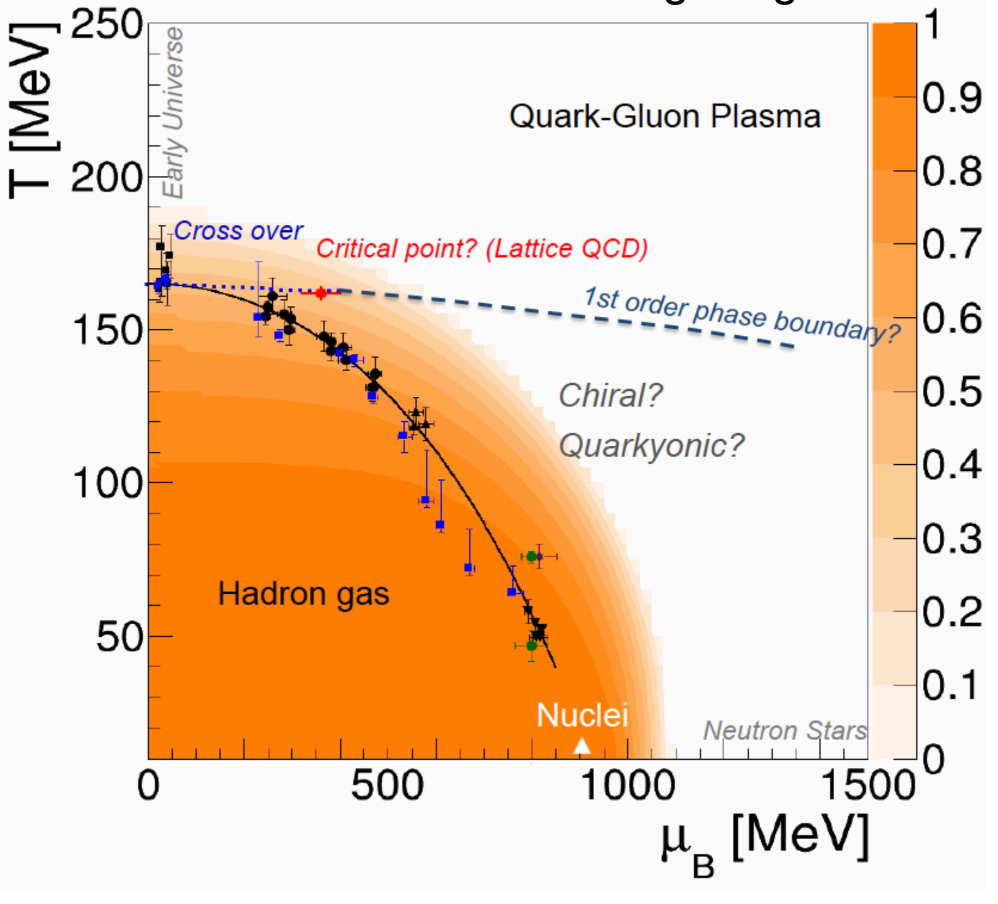
Spinodal decomposition of the mixed phase



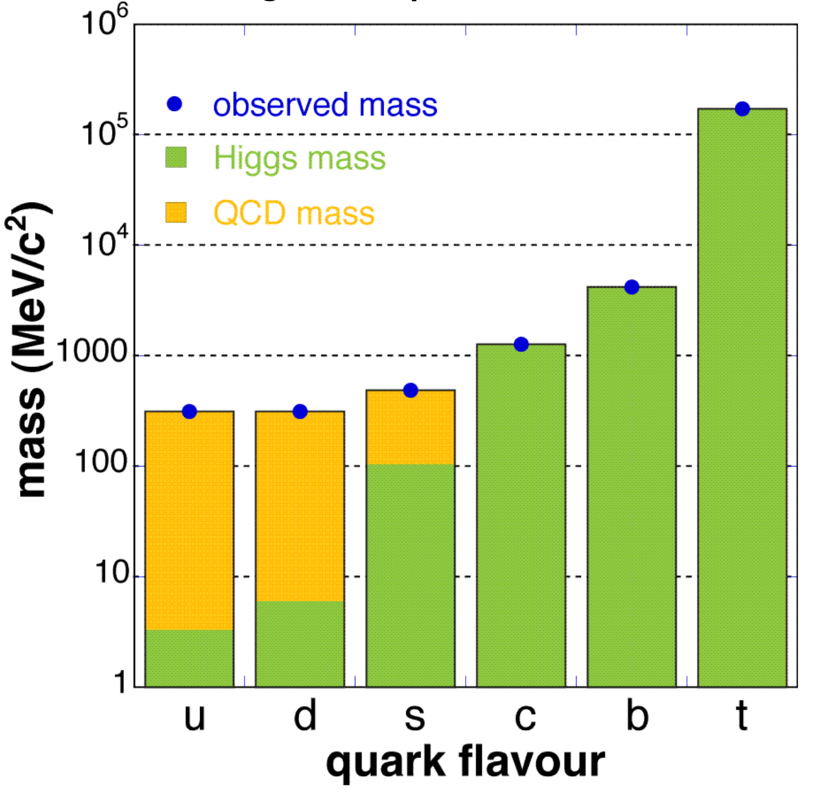
CBM physics case III

Onset of chiral symmetry restoration at high ρ_B

Chiral condensate: orange region



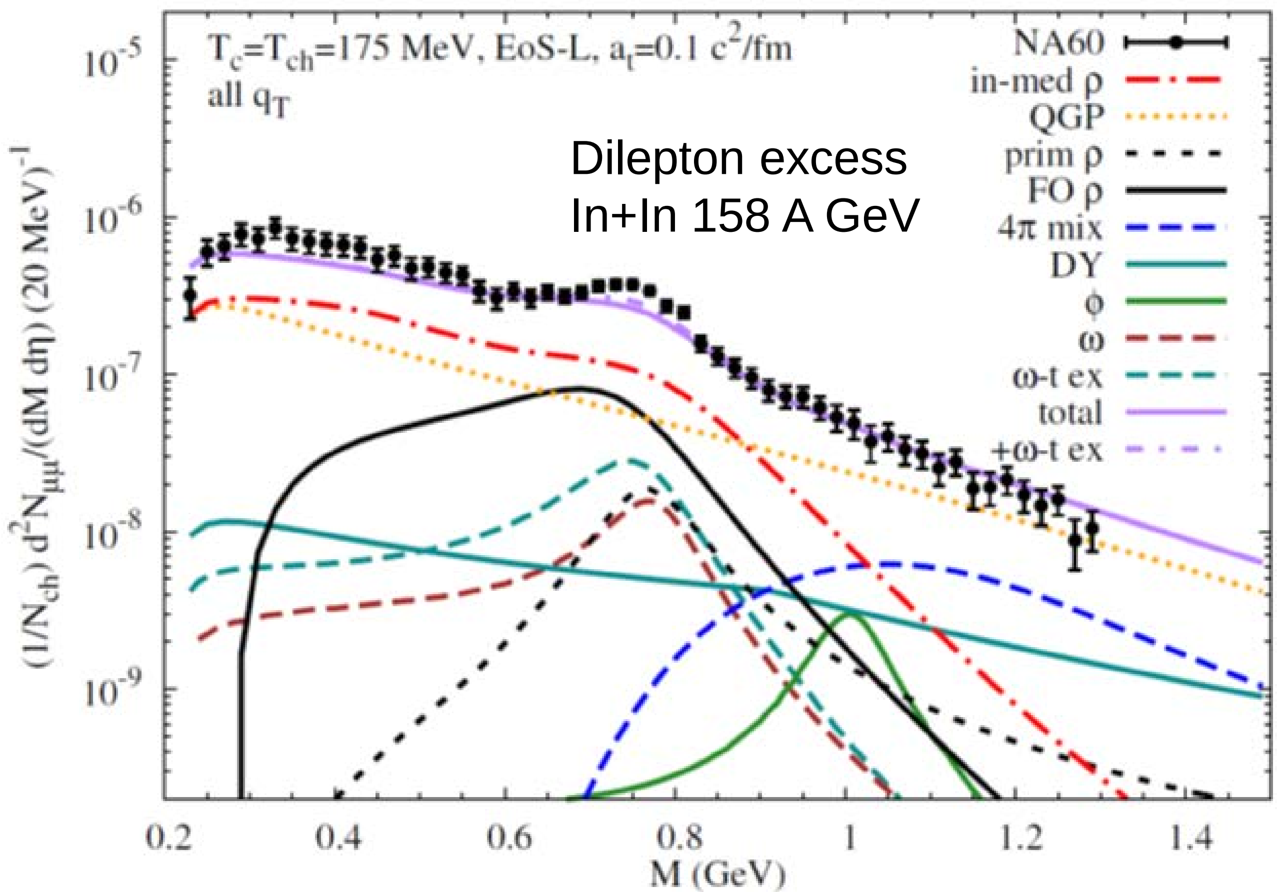
Origin of quark masses



CBM physics case and observables

Onset of chiral symmetry restoration at high ρ_B

- in-medium modifications of hadrons: $\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$
- dileptons at intermediate invariant masses: 4 π $\rightarrow$ ρ-a_1 chiral mixing



Experiment: R. Arnaldi et al. [NA60 Coll.], Phys. Rev. Lett. 96, (2006) 162302,
Theory: R. Rapp, J. Wambach and H. van Hees, in Relativistic Heavy-Ion Physics, edited by R. Stock, Landolt Börnstein (Springer), New Series I/23A (2010), arXiv:0901.3289 hep-ph

CBM physics case and observables

Onset of chiral symmetry restoration at high ρ_B

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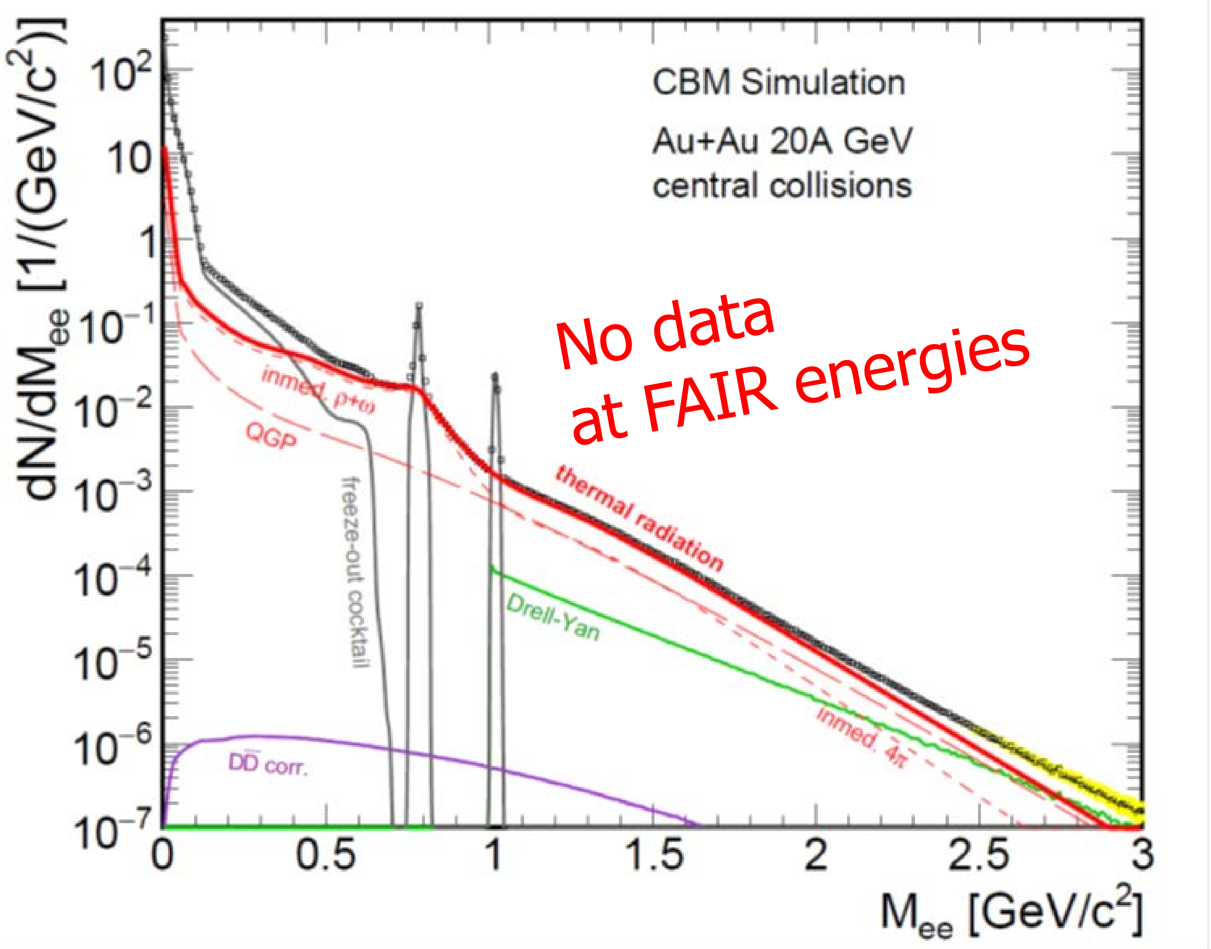
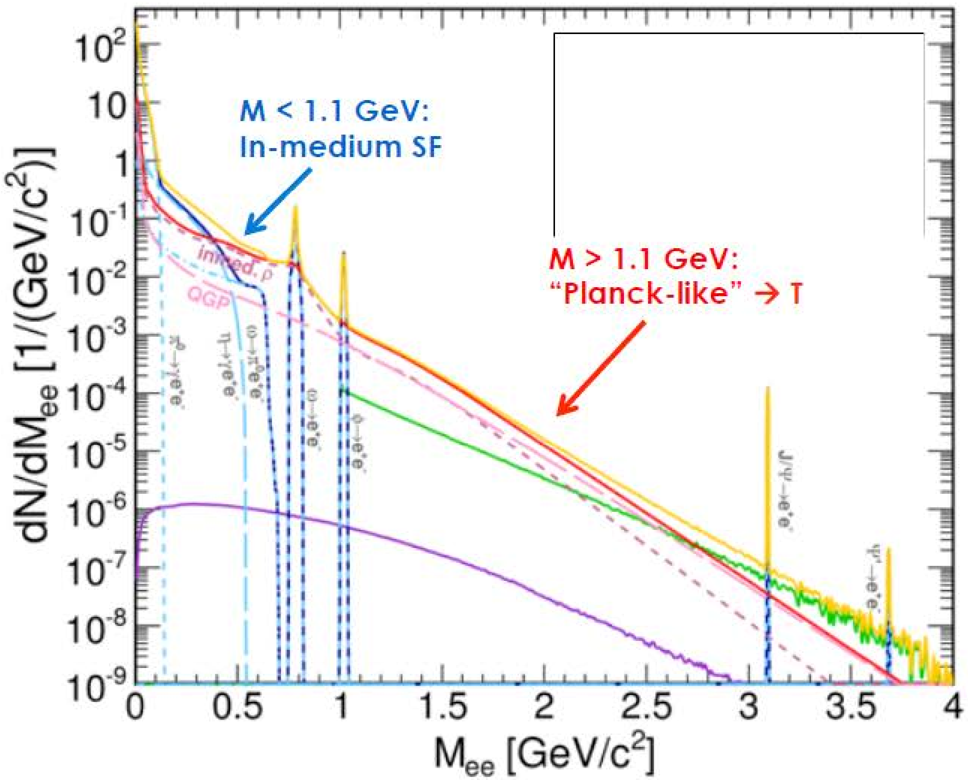
- dileptons at intermediate invariant masses: $4\pi \rightarrow \rho\text{-}a_1$ chiral mixing



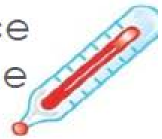
Summary Dileptons

Dileptons carry invaluable information in terms of their four-momentum



- **Chronometer**
  - LMR dilepton yield → fireball lifetime

- **Thermometer**
  - IMR slope → emitting source temperature (true T, no blue shift)



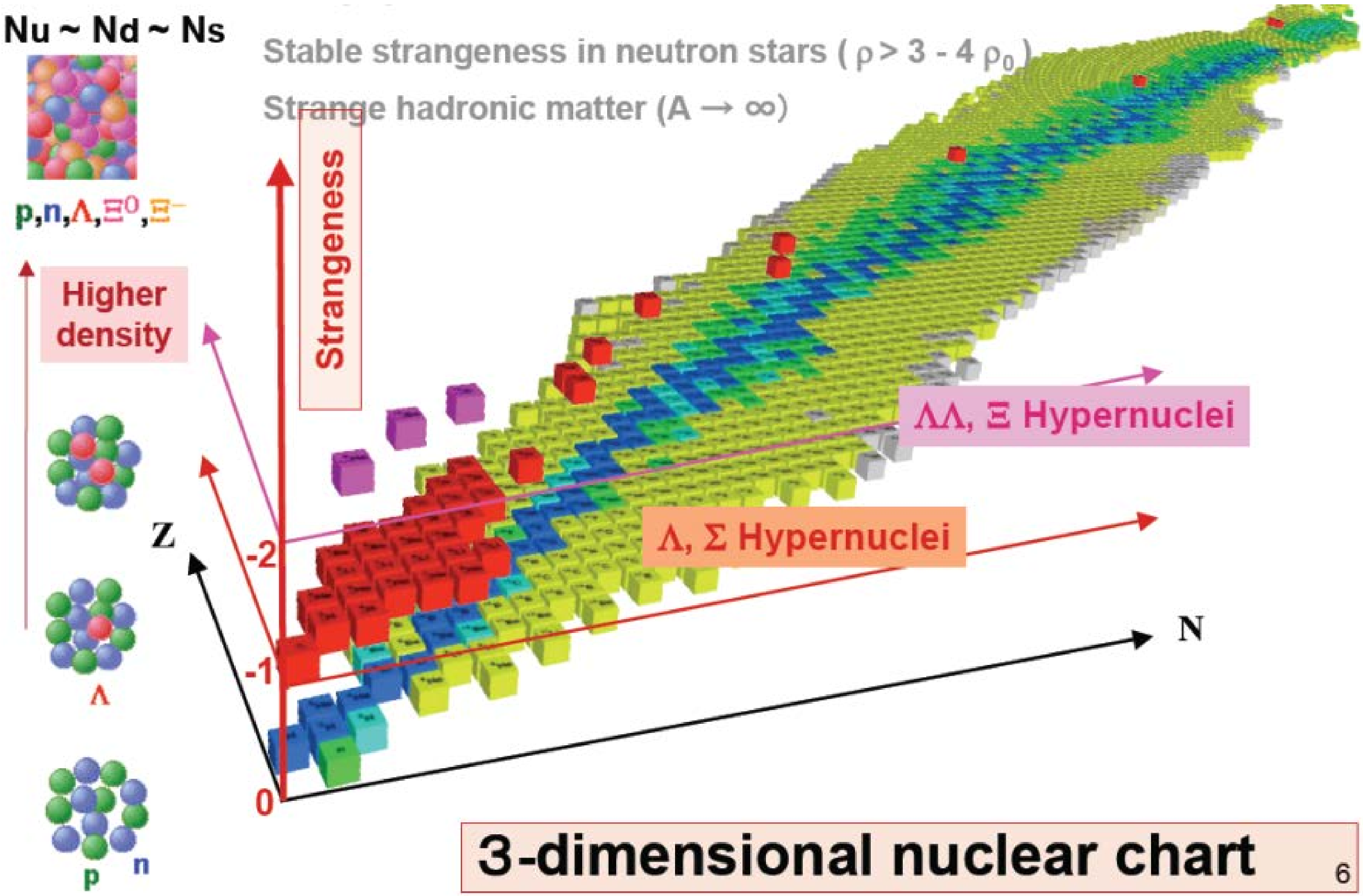
- **Barometer**
  - LMR+IMR inverse-slope analysis → fireball acceleration

- **Spectrometer**
  - IMR shape and yield → Restoration of chiral symmetry

courtesy Tetyana Galatyuk

CBM physics case IV

Extensions of the nuclear chart to the strange domain

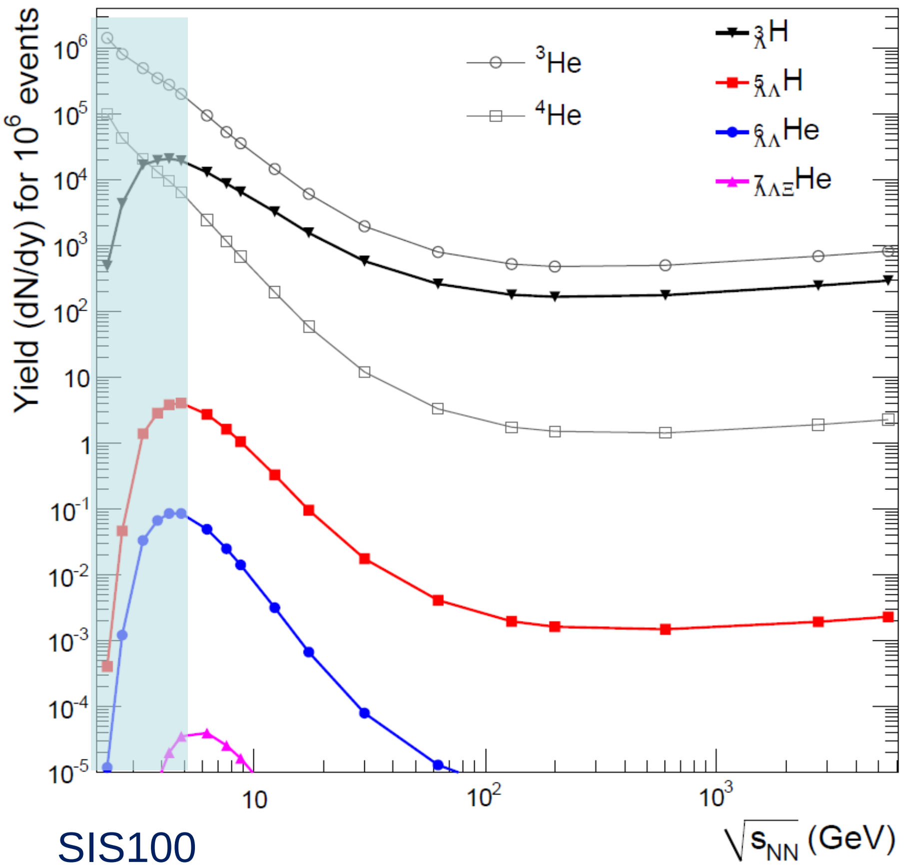


3-dimensional nuclear chart

CBM physics case and observables

N-Λ, Λ-Λ interaction, strange matter?

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



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

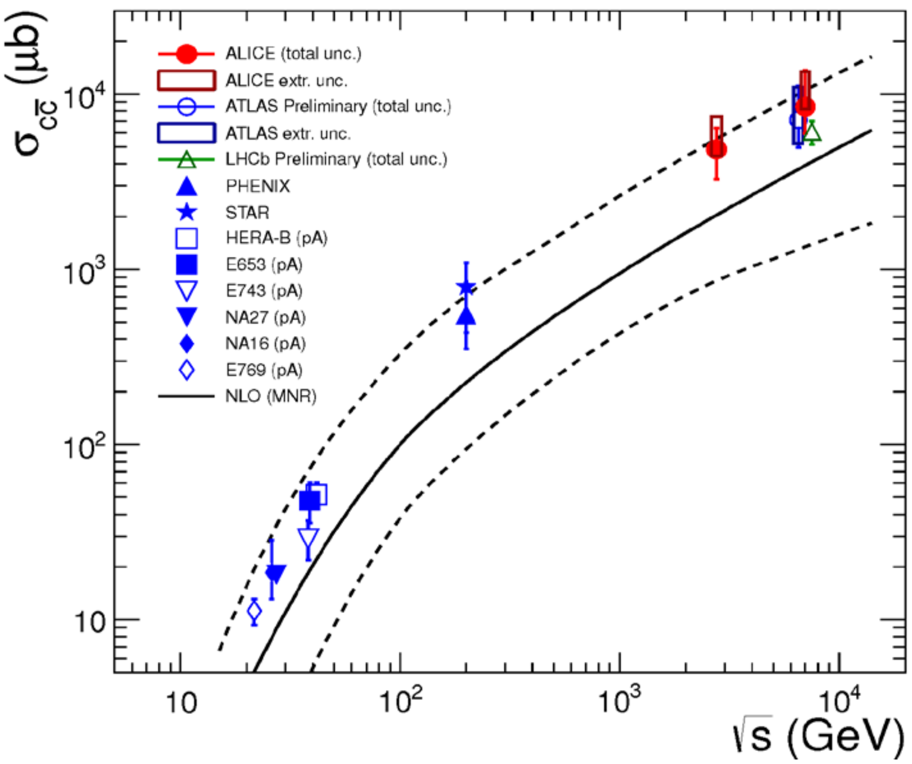
Double lambda hypernuclei production in central Au+Au collisions at 10 A GeV:

	Multiplicity	Yield in 1 week
$^5_{\Lambda\Lambda}$H	$5 \cdot 10^{-6}$	3000
$^6_{\Lambda\Lambda}$He	$1 \cdot 10^{-7}$	60

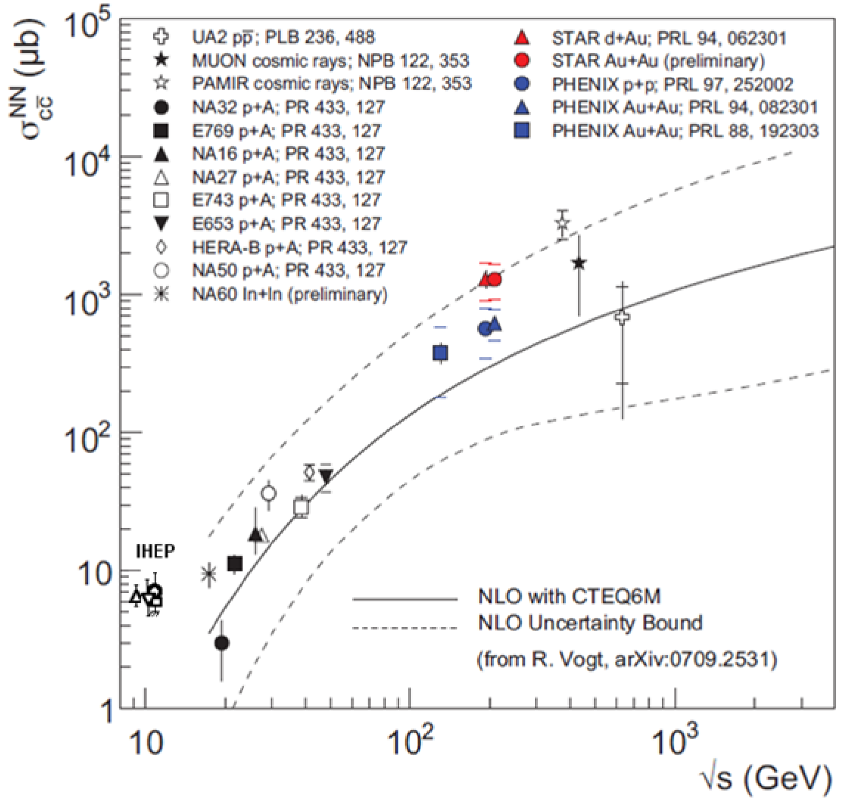
Assumption for yield calculation:
Reaction Rate 1 MHz
BR 10% (2 sequential weak decays)
Efficiency 1%

CBM physics case V

Charm production at threshold energies in cold and dense matter



ALICE JHEP 1207 (2012) 191, arXiv:1205.4007

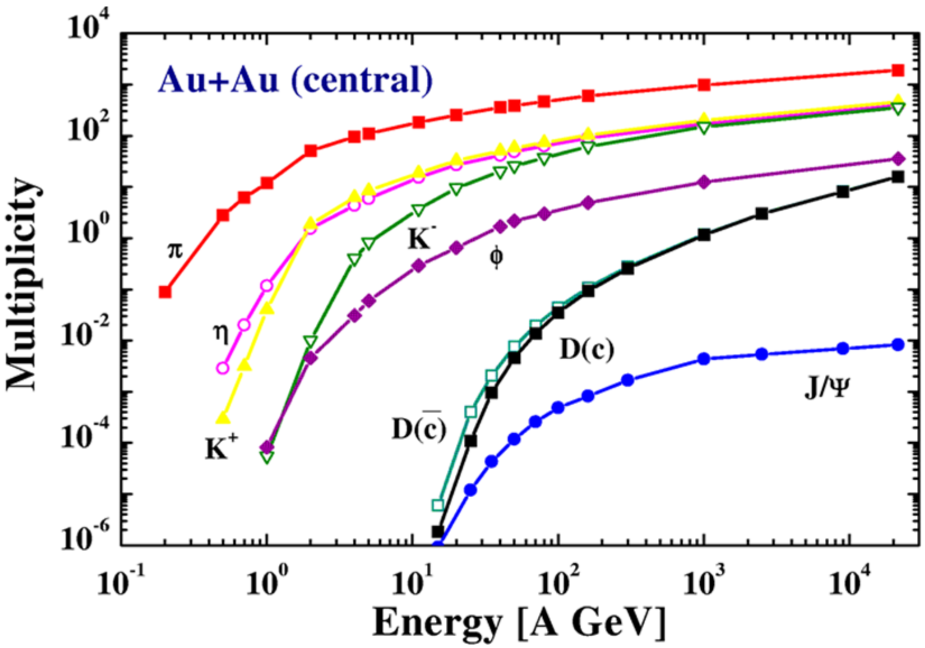


A. Frawley, T. Ulrich, R. Vogt, Phys.Rept.462:125-175,2008

CBM physics case and observables

Charm production at threshold energies in cold and dense matter

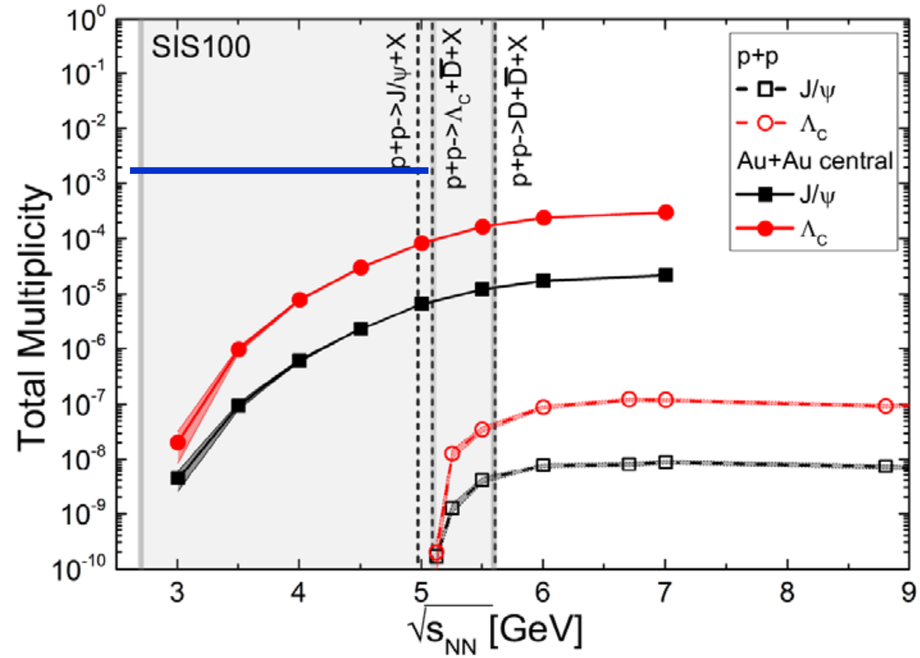
- excitation function of charm production in p+A and A+A (J/ψ, D^0, $D^\pm$)



HSD calculation

Central coll. Au+Au 10 A GeV :
$M_{J/\psi} = 1.7 \cdot 10^{-7}$

W. Cassing, E. Bratkovskaya, A. Sibirtsev, Nucl. Phys. A 691 (2001) 753



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

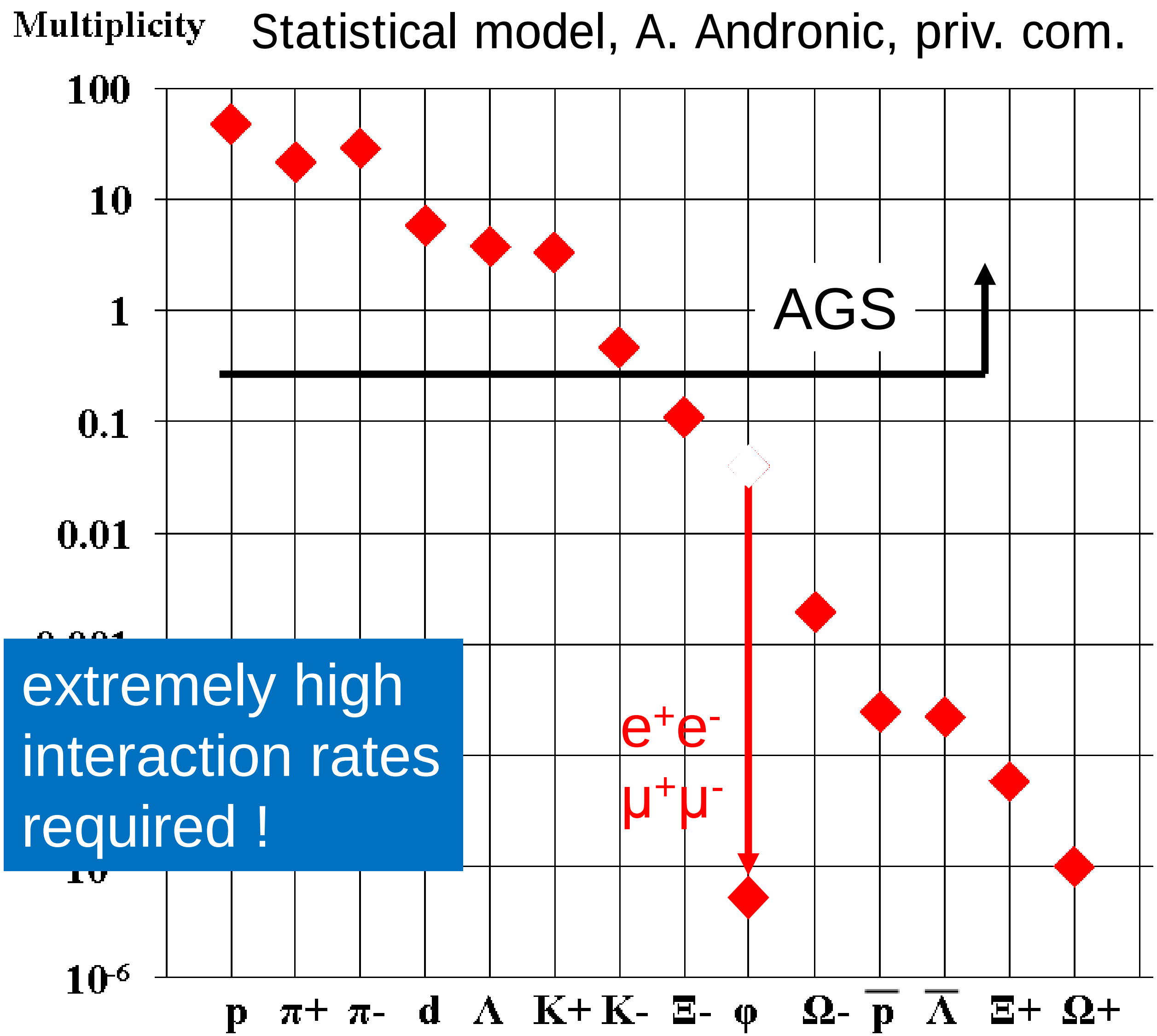
Central Au+Au collisions 10 A GeV:
$M_{J/\psi} = 5 \cdot 10^{-6}$

J. Steinheimer, A. Botvina, M. Bleicher, arXiv:1605.03439v1

Experimental challenges

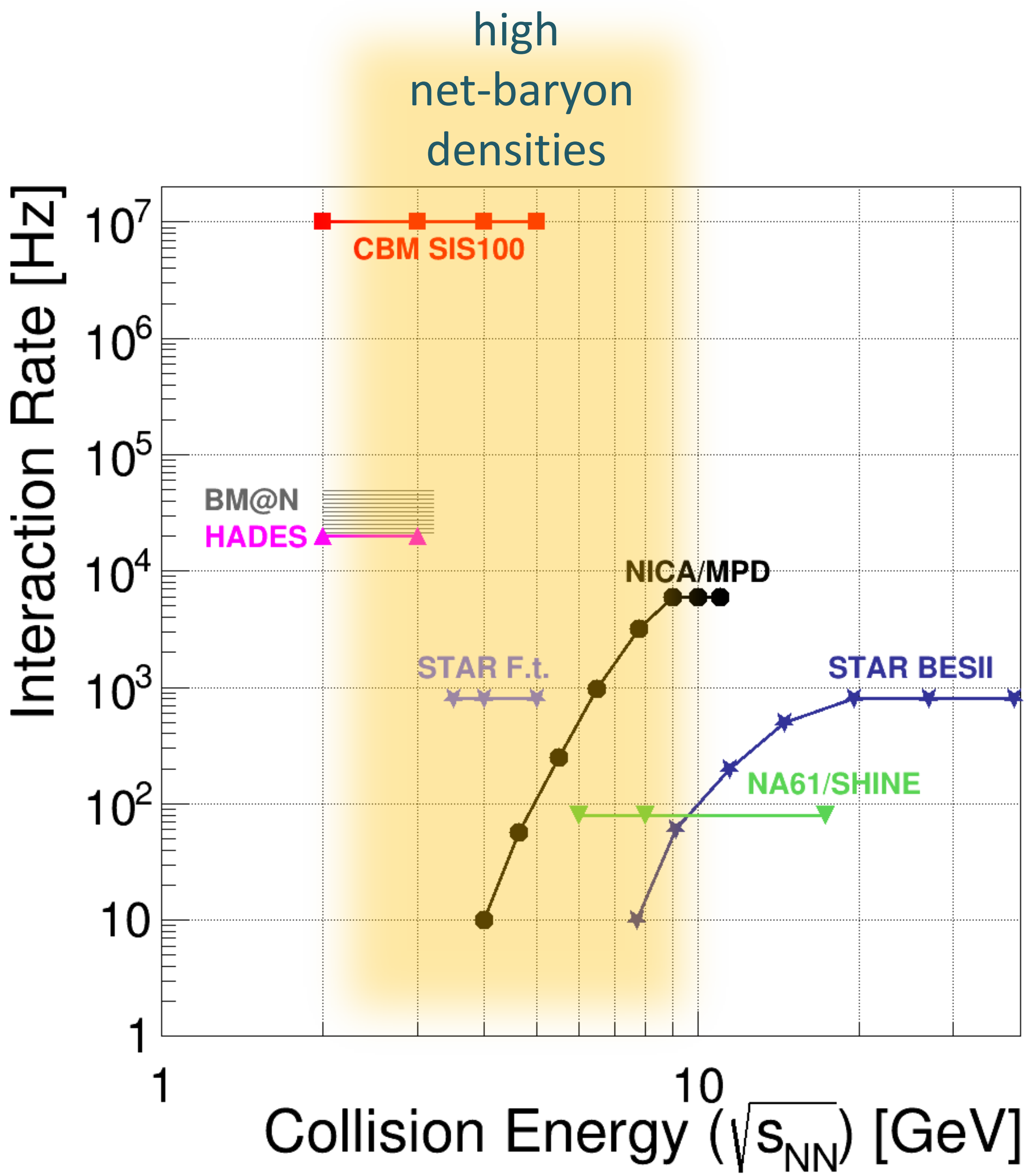
Particle yields in central Au+Au 4 A GeV

Statistical model, A. Andronic, priv. com.



extremely high interaction rates required !

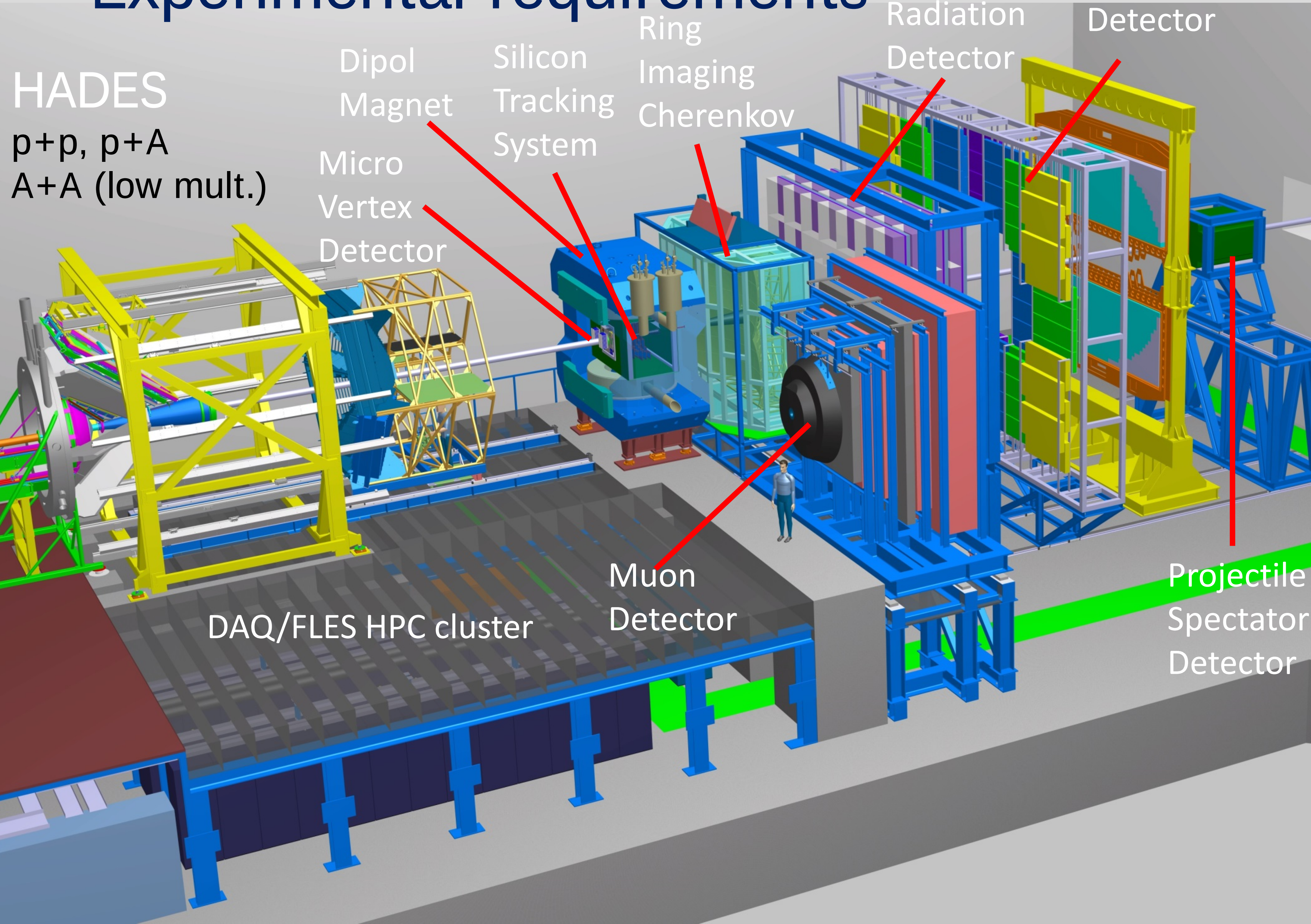
Experiments exploring dense QCD matter



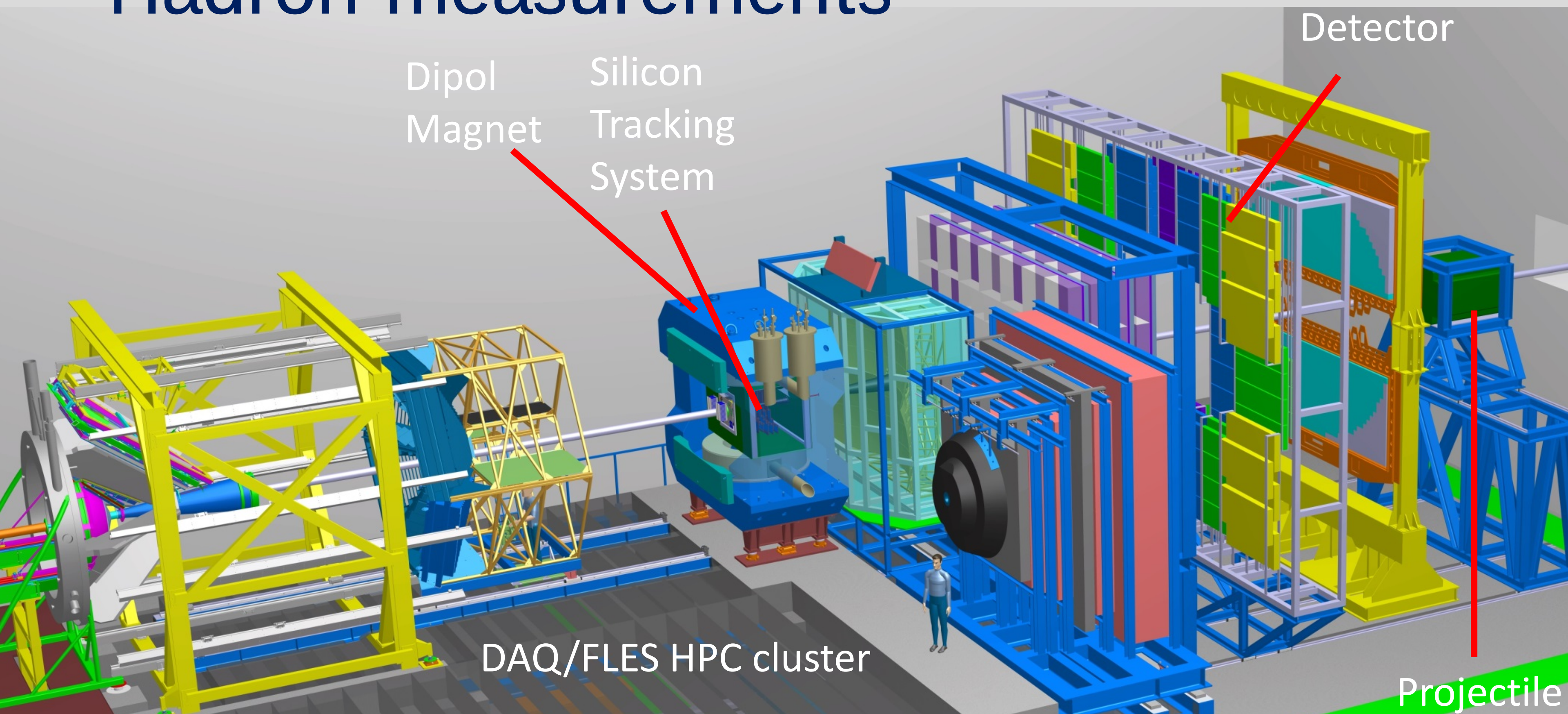
Experimental requirements

- 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 and FEE
- free-streaming readout electronics
- high speed data acquisition and high performance computer farm for online event selection
- 4-D event reconstruction

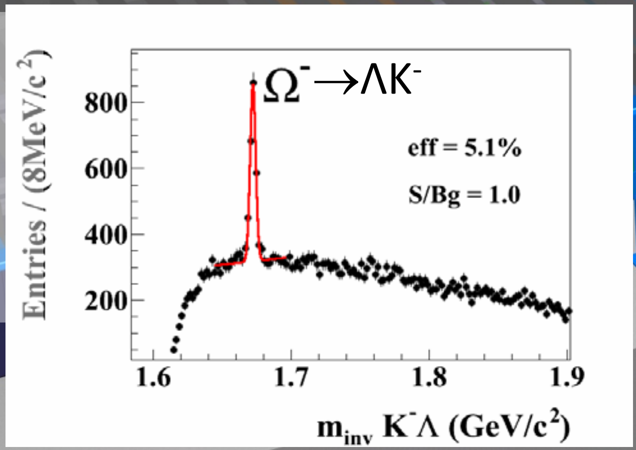
Experimental requirements

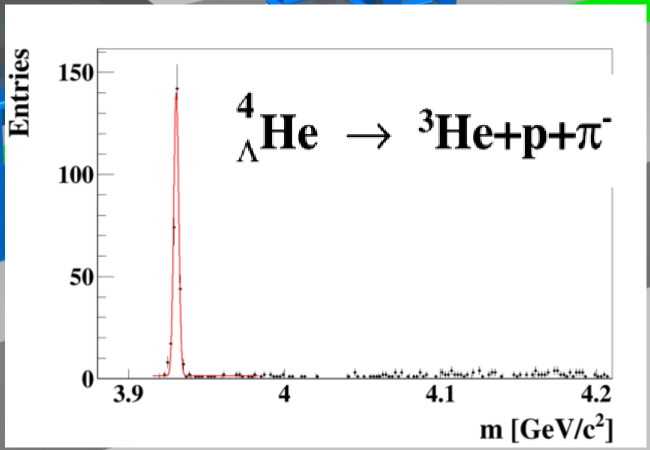


Hadron measurements

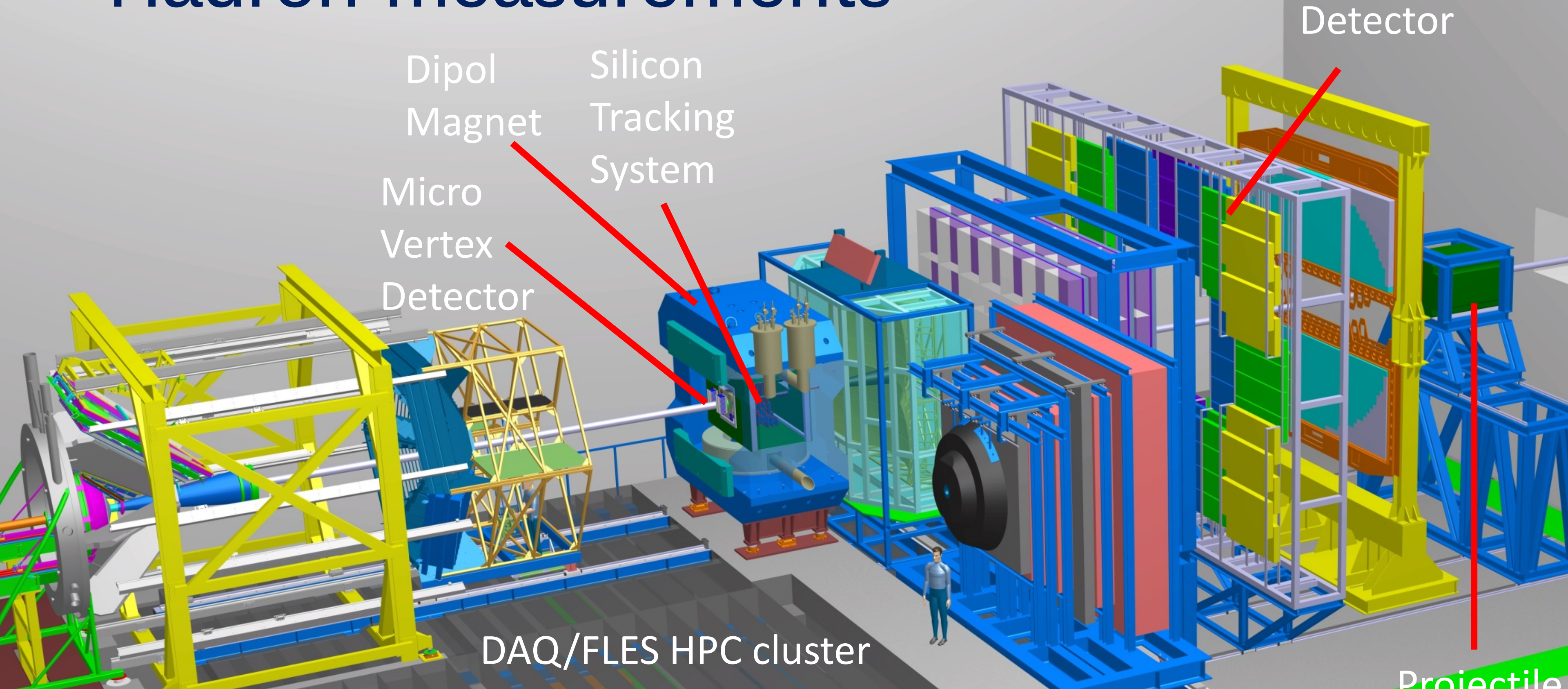


Hyperons and hypernuclei in central Au+Au collisions at 10A GeV

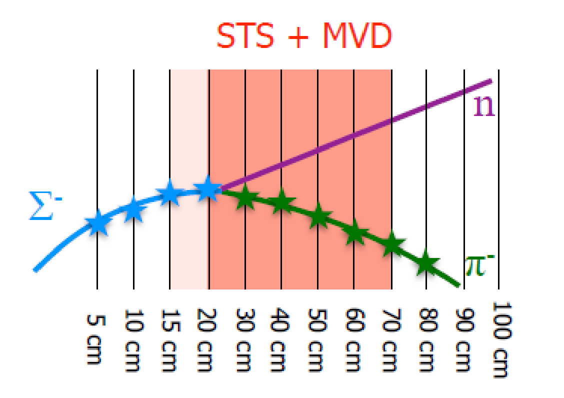


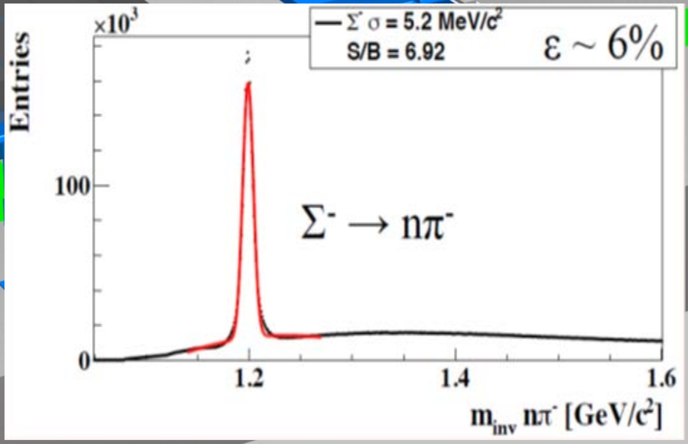


Hadron measurements

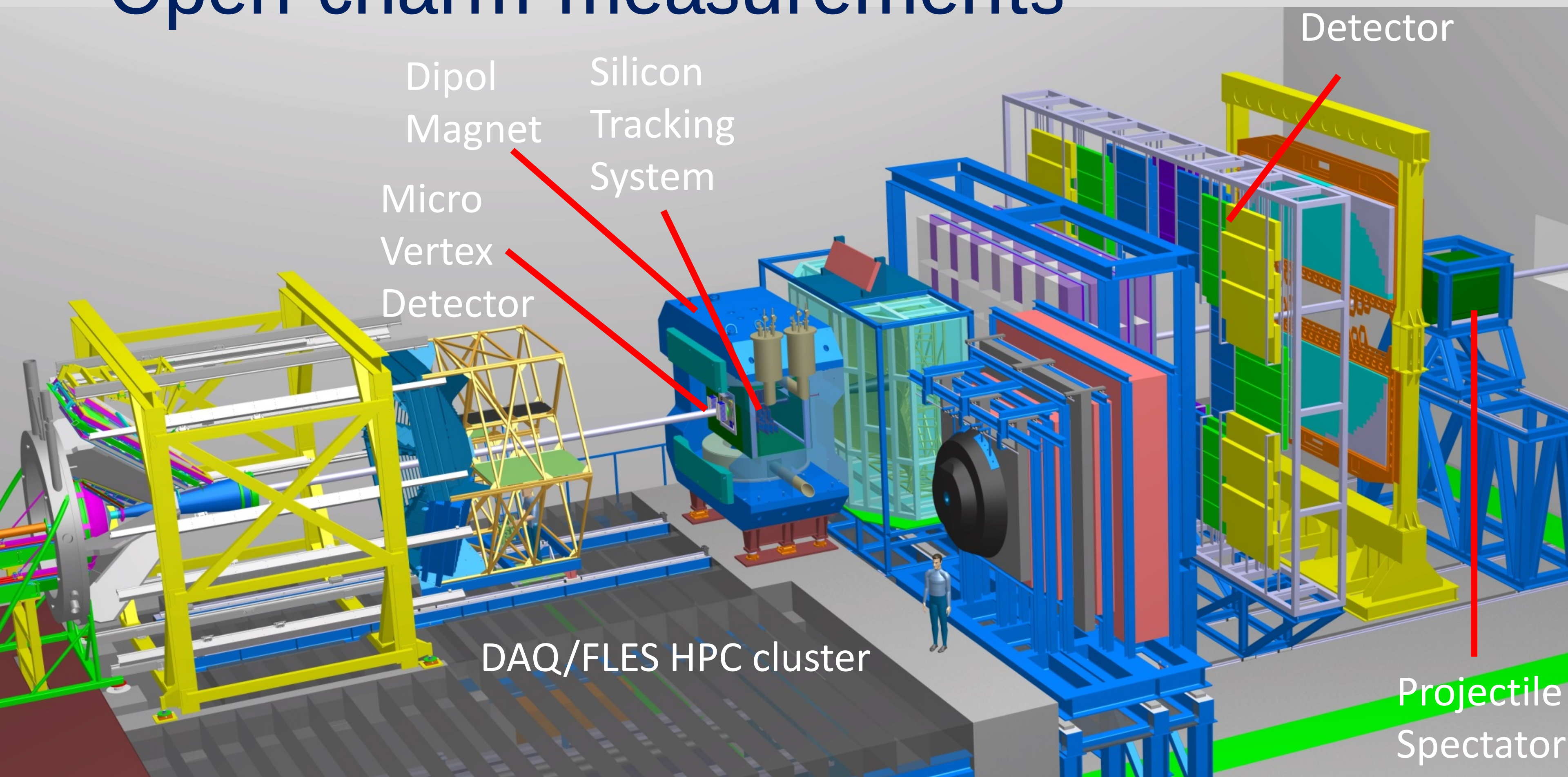


Hyperons with neutral daughter in central Au+Au collisions at 10A GeV

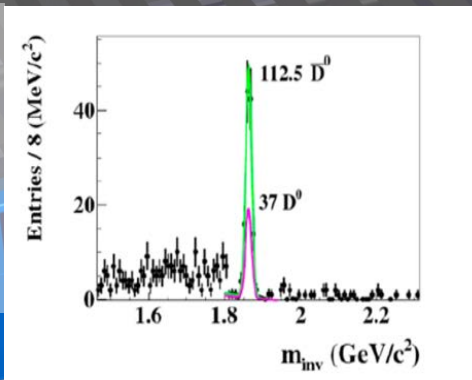


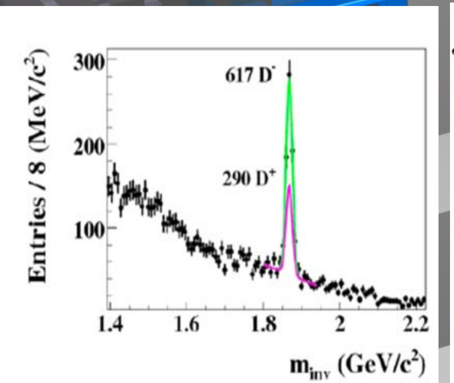


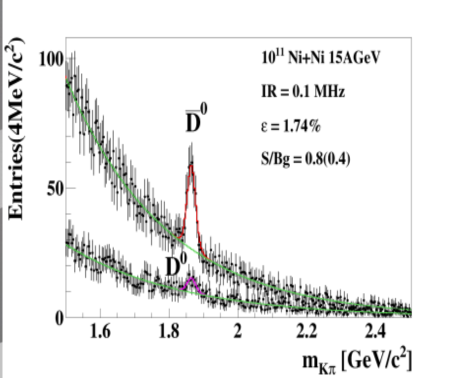
Open charm measurements



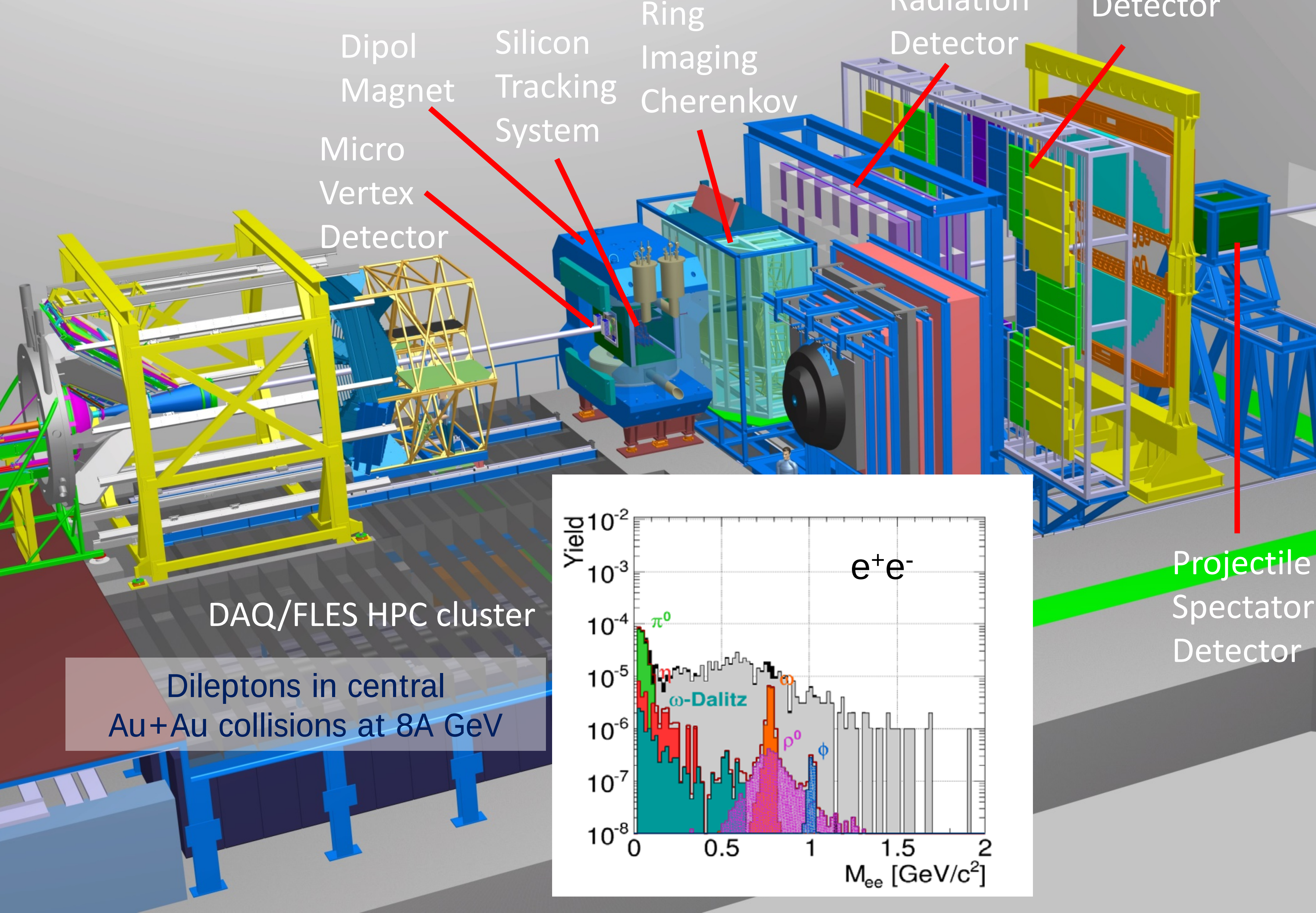
Open Charm
in p+A
30 GeV and
Ni+Ni
15A GeV



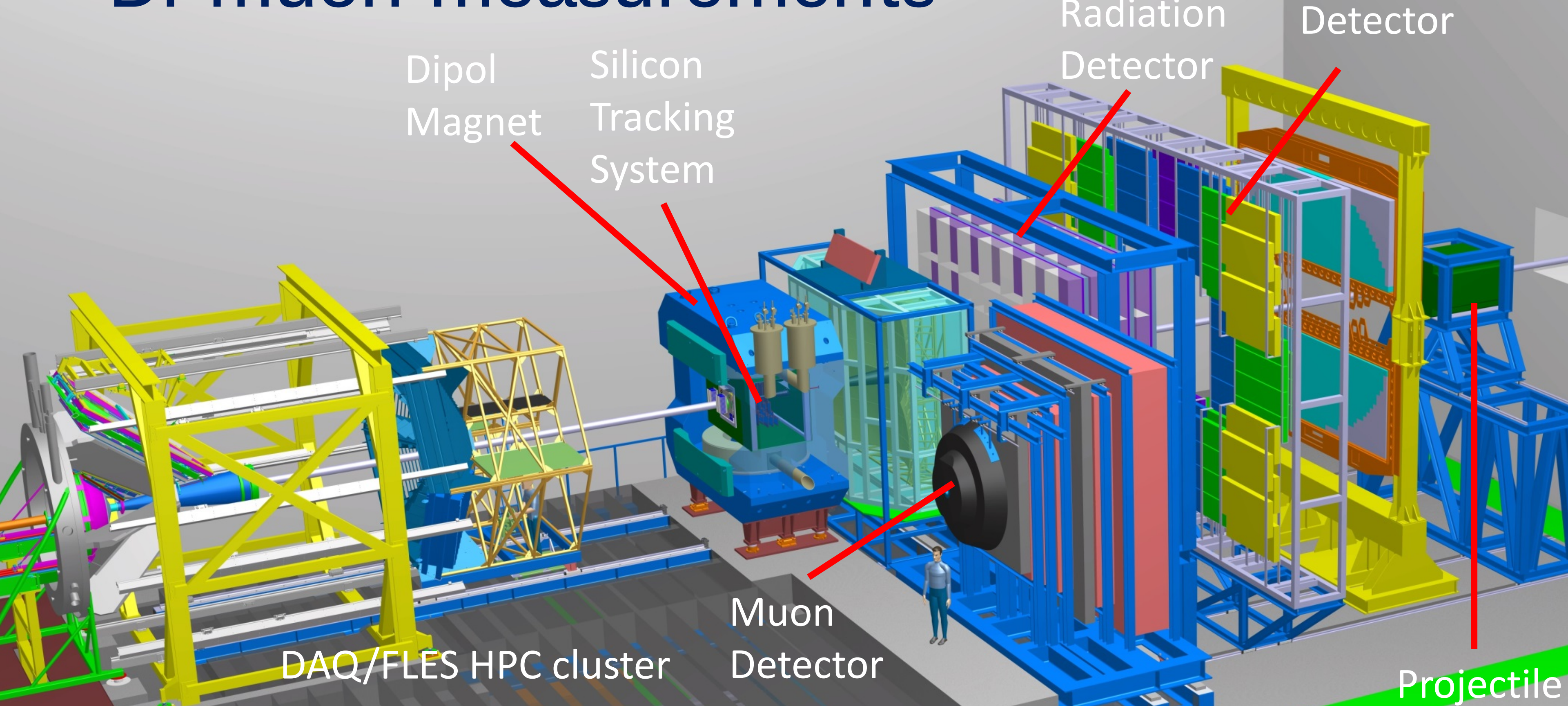




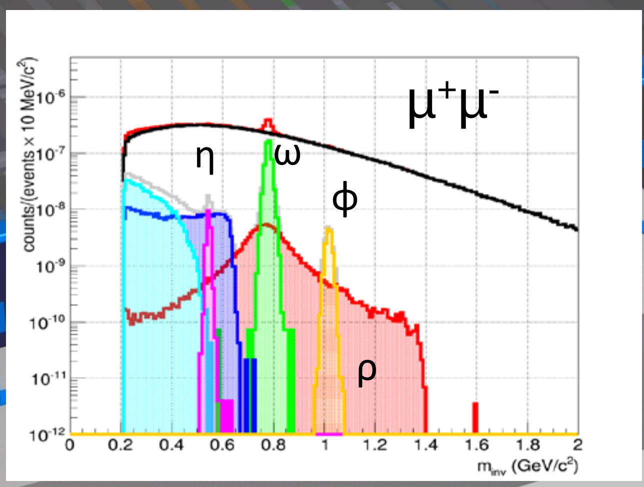
Di-electron measurements

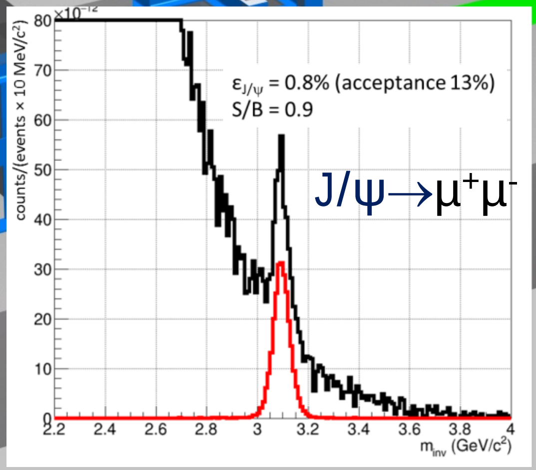


Di-muon measurements

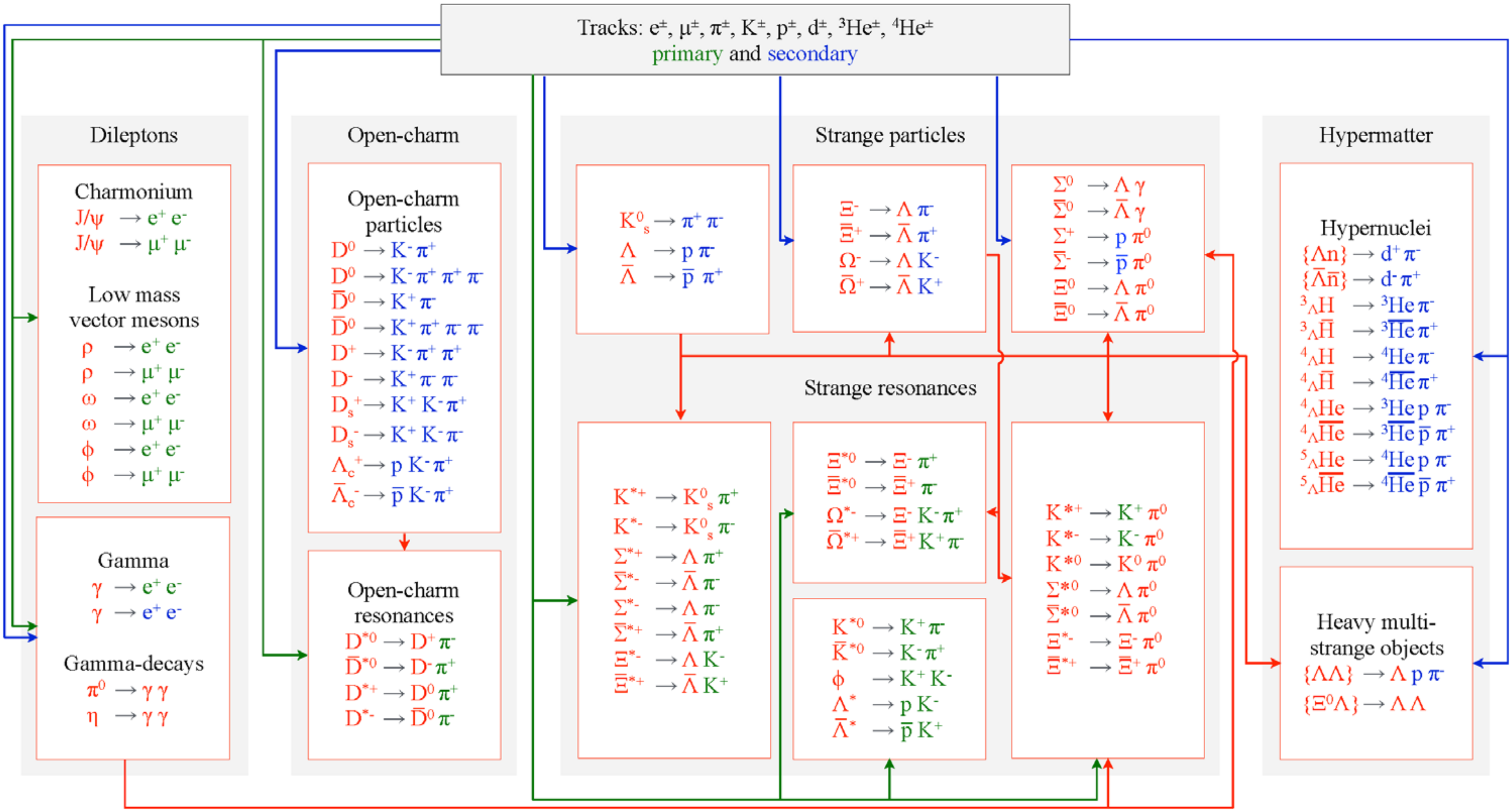


Di-muons in central Au+Au collisions at 8A GeV and 10A GeV (J/ψ)





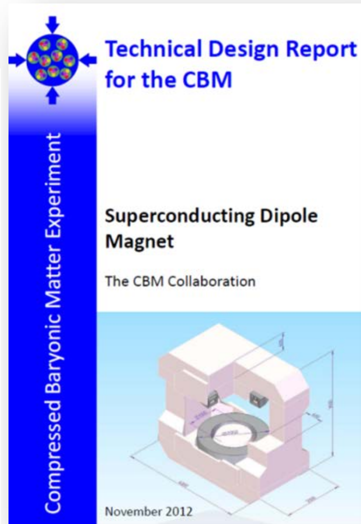
Online particle identification in CBM: The KF Particle Finder

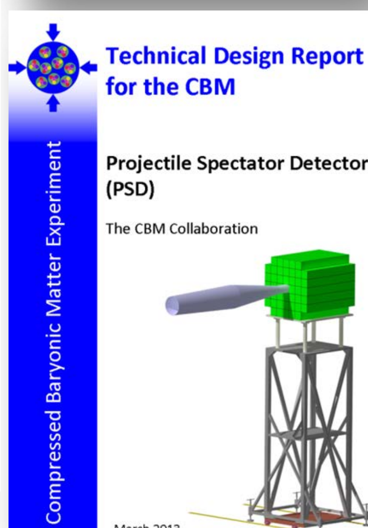


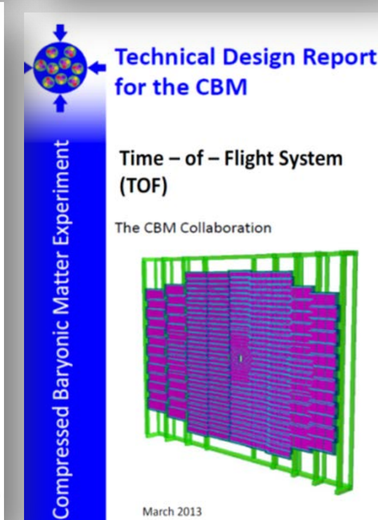
successfully used online in the STAR experiment

CBM Technical Design Reports

#	Project	TDR Status
1	**Magnet**	approved
2	**STS**	approved
3	**RICH**	approved
4	**TOF**	approved
5	**MuCh**	approved
6	**HADES ECAL**	approved
7	**PSD**	approved
8	**MVD**	submission 2016
9	**DAQ/FLES**	submission 2017
10	**TRD**	submission 2016
11	**ECAL**	submission 2016







CBM mile stones

CBM components	TDR approved	Start production	Ready for installation	Ready for beam
Micro Vertex Detector (MVD)	01.04.17	30.04.18	31.12.19	30.06.20
Silicon Tracking System (STS)	05.07.13	31.03.17	31.03.20	31.12.20
Ring Imaging Cherenkov Detector (RICH)	07.01.14	31.12.16	31.12.19	31.12.20
Muon Detector (MUCH)	28.02.15	31.12.16	31.12.19	31.12.20
Transition Radiation Detector (TRD)	01.04.17	31.12.17	31.12.20	31.12.21
Time of Flight System (TOF)	30.04.15	31.06.16	31.12.19	31.12.20
Electromagnetic Calorimeter (ECAL)	31.12.16	30.06.18	31.12.19	31.12.20
Projectile Spectator Detector (PSD)	28.02.15	31.12.15	31.12.18	31.12.19
Dipol Magnet	01.10.13	30.06.17	31.12.19	30.06.20
Online Systems (DAQ and FLES)	31.12.17	30.06.18	30.06.19	31.12.19

CBM detectors will be in place
to take the first beams from SIS100

The CBM cave

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.

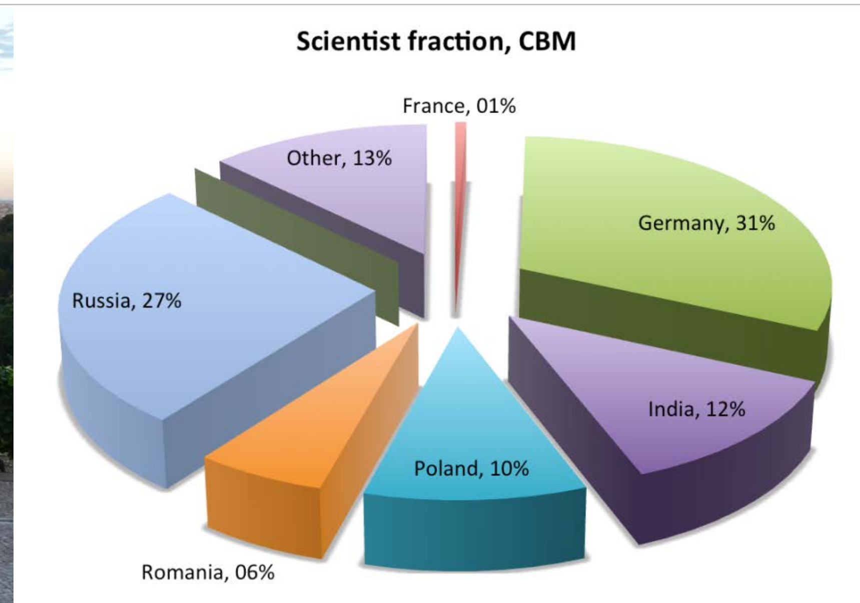
Poland:
AGH Krakow
Jag. Univ. Krakow
Silesia Univ. Katowice
Warsaw Univ.
Warsaw TU

Romania:
NIPNE Bucharest
Univ. Bucharest

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

26th CBM Collaboration meeting in Prague, CZ
14 -18 Sept. 2015



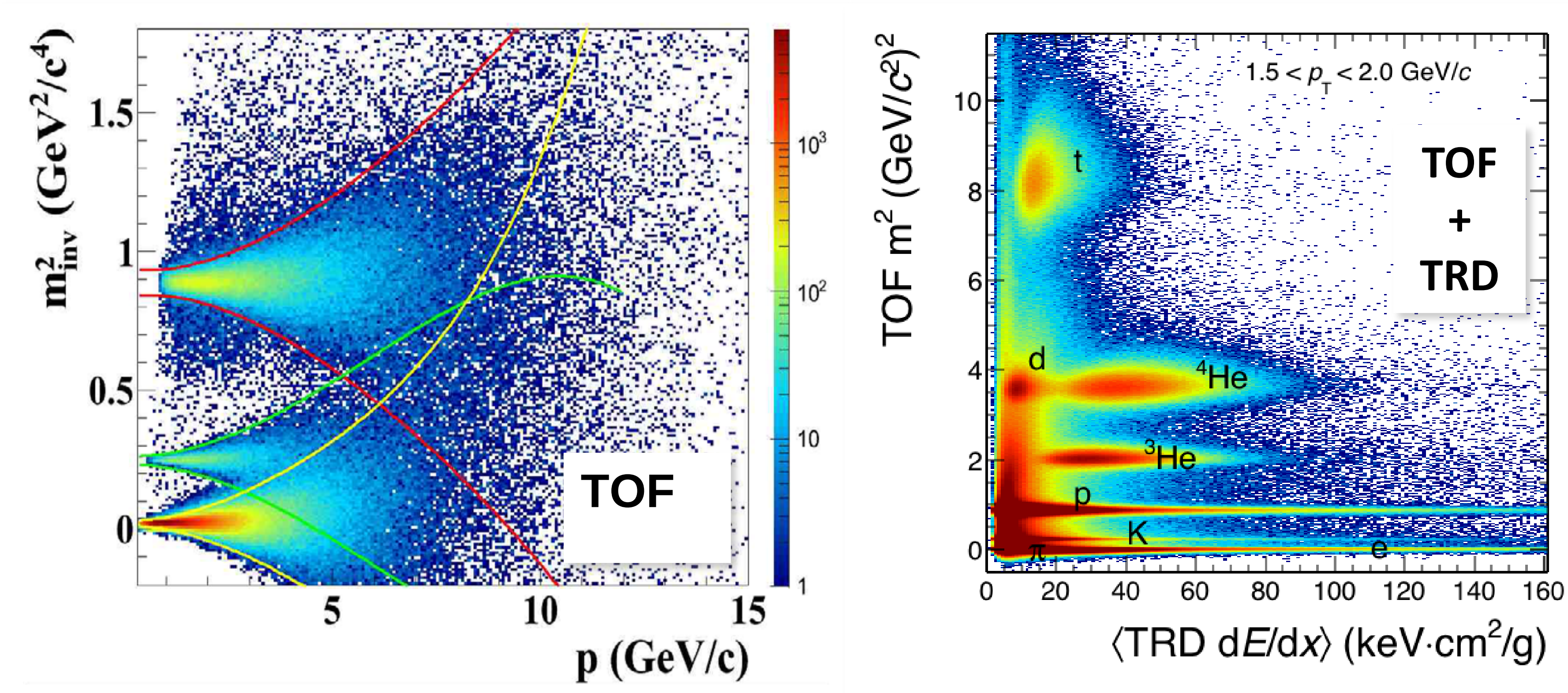
Summary

- CBM scientific program at SIS100:
  Exploration of the QCD phase diagram in the region of neutron star core densities $\rightarrow$ 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.
  7 TDRs approved, 4 TDRs in preparation.
- Funding:
  Substantial part of the CBM start version is financed (+ EoI).
- FAIR Phase 0:
  HADES with CBM RICH photon detector,
  use CBM detectors at STAR/BNL, BM@N/JINR, NA61/SPS.
  mCBM@SIS18 including DAQ and FLES for full system test

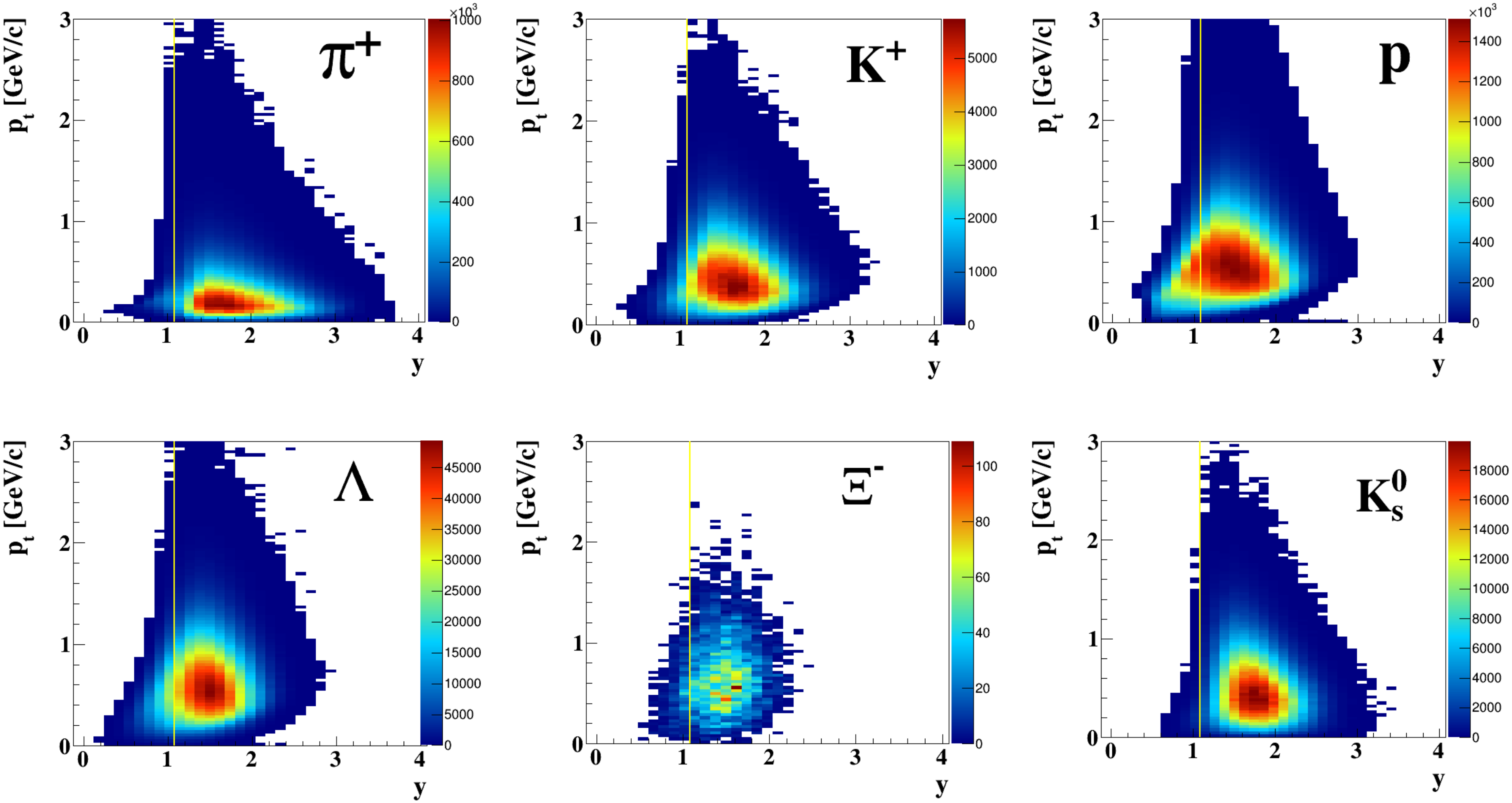
Backup

Particle Identification

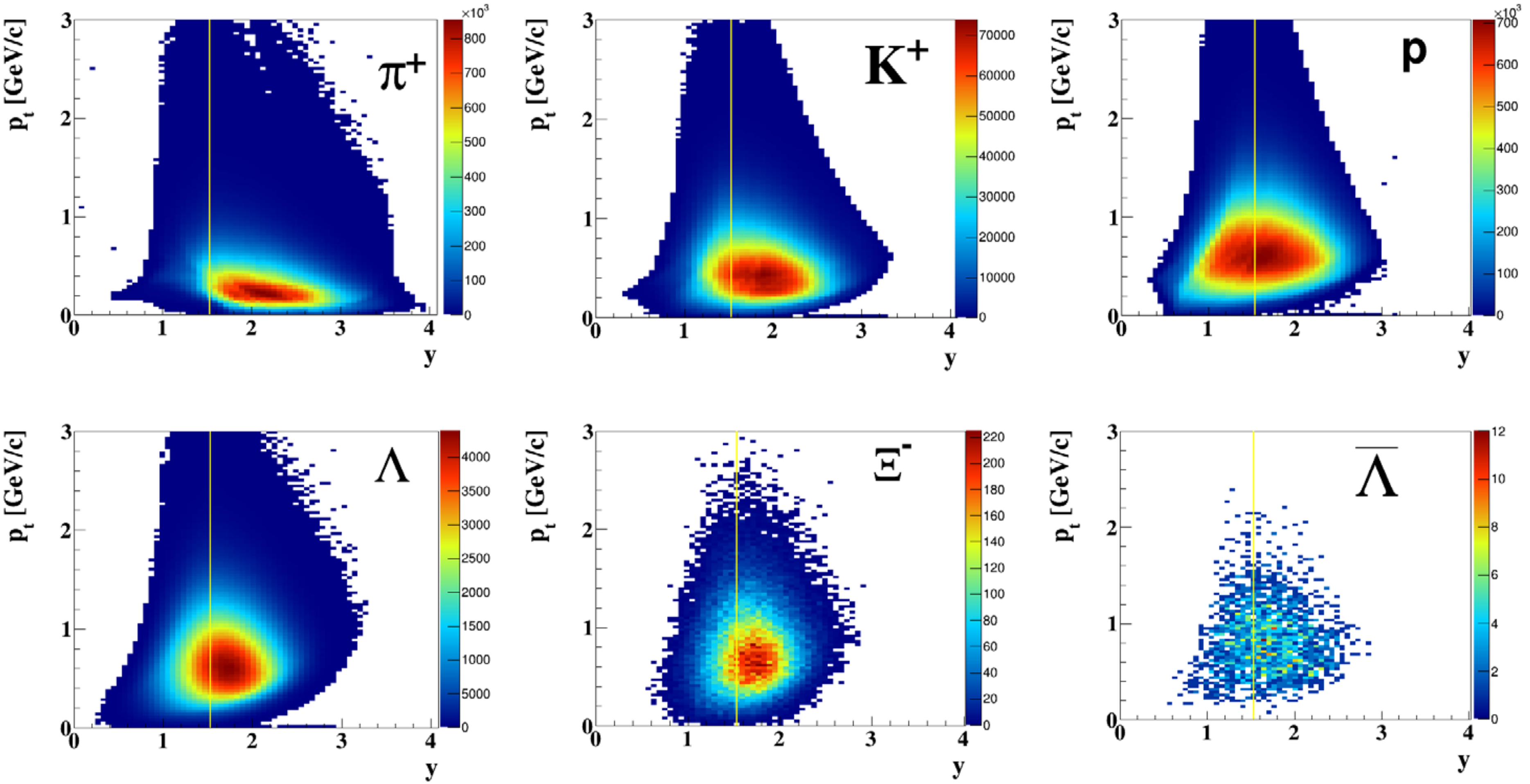
Detectors used: STS, TOF, TRD



Particle acceptance
central Au+Au collisions at 4 A GeV

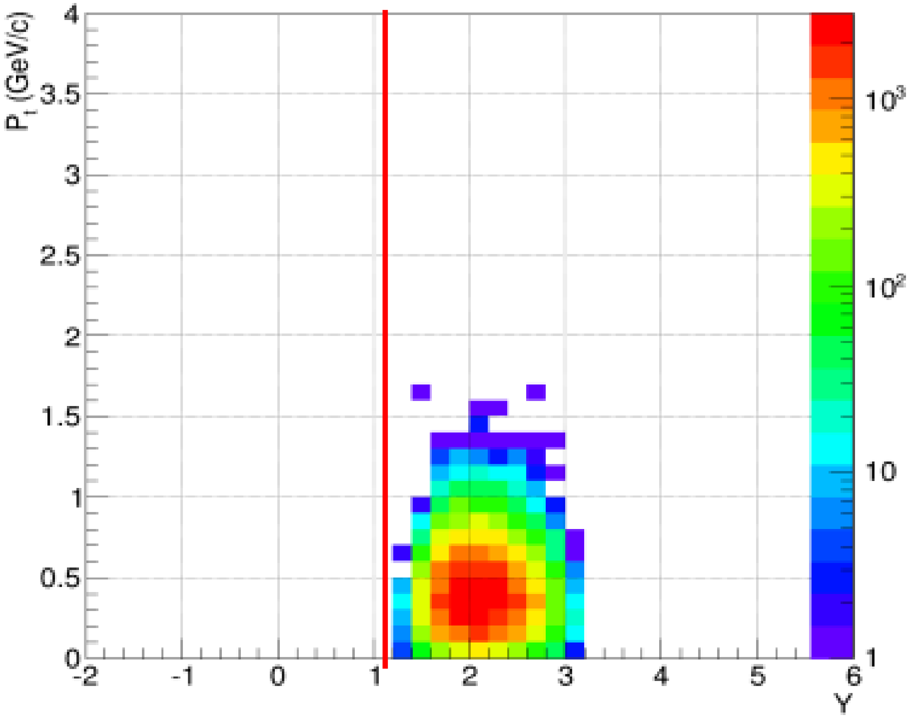


Particle acceptance
central Au+Au collisions at 10 A GeV

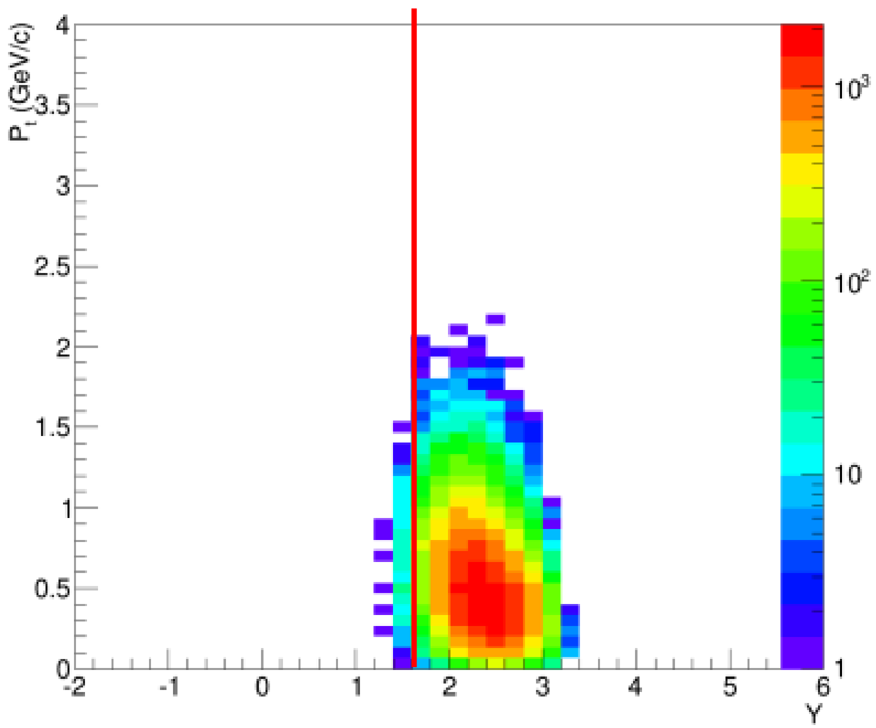


Di-muon acceptance in central Au+Au collisions

at 4 A GeV



at 8 A GeV



Particle yields based on HSD calculations

10% most central Au+Au collisions at 6 and 10 A GeV

Particle (mass MeV/c^2)	Multi-plicity 6 A GeV	Multi-plicity 10 A GeV	decay mode	BR	ε (%)	yield (s^{-1}) 6 A GeV	yield (s^{-1}) 10 A GeV	yield in 10 weeks 6 A GeV	yield in 10 weeks 10 A GeV	IR MHz
K^+ (494)	12.5	20	-	-	31	$3.9\cdot10^{5}$	$6.2\cdot10^{5}$	$2.4\cdot10^{12}$	$3.7\cdot10^{12}$	1
K^- (494)	1.4	3	-	-	27	$3.8\cdot10^{4}$	$8.1\cdot10^{4}$	$2.3\cdot10^{11}$	$4.8\cdot10^{11}$	1
ρ (770)	5	9	L^+L^-	$4.7\cdot10^{-5}$	4.6	1.1	2.0	$6.5\cdot10^{6}$	$1.2\cdot10^{7}$	1
ω (782)	3.3	6	L^+L^-	$7.1\cdot10^{-5}$	5.2	1.2	2.2	$7.4\cdot10^{6}$	$1.3\cdot10^{7}$	1
φ (1020)	0.07	0.12	L^+L^-	$3\cdot10^{-4}$	6.0	$1.3\cdot10^{-1}$	$2.2\cdot10^{-1}$	$7.6\cdot10^{5}$	$1.3\cdot10^{6}$	1
Λ (1115)	10.4	17.4	$p\pi^-$	0.64	18	$1.2\cdot10^{5}$	$2.0\cdot10^{5}$	$7.2\cdot10^{11}$	$1.2\cdot10^{12}$	1
$\bar{\Lambda}$ (1115)	$4.6\cdot10^{-4}$	0.034	$\bar{p}\pi^+$	0.64	11	1.1	81.3	$6.6\cdot10^{6}$	$2.2\cdot10^{8}$	10
Ξ^- (1321)	0.054	0.222	$\Lambda\pi^-$	1	6	$3.2\cdot10^{3}$	$1.3\cdot10^{4}$	$1.9\cdot10^{10}$	$7.8\cdot10^{10}$	10
Ξ^+ (1321)	$3.0\cdot10^{-5}$	$5.4\cdot10^{-4}$	$\Lambda\pi^+$	1	3.3	$9.9\cdot10^{-1}$	17.8	$5.9\cdot10^{6}$	$1.1\cdot10^{8}$	10
Ω^- (1672)	$5.8\cdot10^{-4}$	$5.6\cdot10^{-3}$	ΛK^-	0.68	5	17	164	$1.0\cdot10^{8}$	$9.6\cdot10^{8}$	10
Ω^+ (1672)	-	$7\cdot10^{-5}$	ΛK^+	0.68	3	-	0.86	-	$5.2\cdot10^{6}$	10
J/ψ (3097)	-	$1.74\cdot10^{-7}$	L^+L^-	0.06	5	-	$5.2\cdot10^{-4}$	-	3100	10
${}^3_\Lambda H$ (2993)	$4.2\cdot10^{-2}$	$3.8\cdot10^{-2}$	${}^3He\pi^-$	0.25	19.2	$2\cdot10^{3}$	$1.8\cdot10^{3}$	$1.2\cdot10^{10}$	$1.1\cdot10^{10}$	10
${}^4_\Lambda He$ (3930)	$2.4\cdot10^{-3}$	$1.9\cdot10^{-3}$	${}^3Hep\pi^-$	0.32	14.7	110	87	$6.6\cdot10^{8}$	$5.2\cdot10^{8}$	10

p + A collisions at 20 and 30 GeV

Particle (mass MeV/c^2)	Multi-plicity 20 GeV	Multi-plicity 30 GeV	decay mode	BR	ε (%)	yield (s^{-1}) 20 GeV	yield (s^{-1}) 30 GeV	yield in 10 weeks 20 GeV	yield in 10 weeks 30 GeV	IR MHz
$D^\pm$ (1869)	$3.4\cdot10^{-7}$	$1.3\cdot10^{-6}$	$K^+\pi^-\pi^-$	0.09	13	$4.0\cdot10^{-2}$	$1.5\cdot10^{-1}$	$2.4\cdot10^{5}$	$9.2\cdot10^{5}$	10
D^0 (1865)	$5.1\cdot10^{-7}$	$2.0\cdot10^{-6}$	$K^+\pi^-\pi^-\pi^+$	0.08	2	$8.2\cdot10^{-3}$	$3.2\cdot10^{-2}$	$4.9\cdot10^{4}$	$1.9\cdot10^{5}$	10
J/ψ (3097)	$7.5\cdot10^{-8}$	$2.9\cdot10^{-6}$	L^+L^-	0.06	5	$2.3\cdot10^{-3}$	$8.7\cdot10^{-2}$	$1.4\cdot10^{4}$	$5.2\cdot10^{5}$	10

Status CBM collaboration contracts (Russia)

Project	Partner in Russia	Task	Costs (€ 2005)	Fraction of total costs	Council Decision	Status
SC dipole magnet	JINR BINP	Design and Construction	3.758 Mio	100%	9.07.2014	In preparation
STS	JINR Dubna	Construction of detector ladders for first 4 stations	2.115 Mio	23%	10.12.2013	signed
PSD	INR Troitzk	Design and Construction	0.778 Mio	81%	30.06.2015	signed
RICH	PNPI Gatchina	Construction of mechanical structures, gas system	1.45 Mio	28%	9.07.2014	Ready for signature
MUCH	PNPI Gatchina	Construction of absorbers, mechanical structures, gas system	3.022 Mio	39%	30.06.2015	In preparation
MUCH	JINR Dubna	Straw tube chambers	0.49 Mio	6%	30.06.2015	In preparation
TOF	ITEP	Inner zone	0.468 Mio	7 %	----	In discussion

Status CBM in-kind contracts

Project	Partner Institution	Task	Costs k€ 2005	Council decision	Status In-Kind contract
STS	AGH, Crakow, Poland	Design and Construction of STS-XYTER chip	572	30.06.2015	Ready to be signed
STS	JU, Crakow, Poland	Sensors, test procedures for STS-XYTER chip and FEE	707	June 2016	In preparation
STS	AGH, Crakow, Poland	STS-XYTER Front-End Board	261	June 2016	In preparation
HADES	JU, Crakow, Poland	HADES ECAL Mechanical frame	200	30.06.2015	signed
STS	WUT, Warsaw, Poland	Development of Data Processing Boards (DPBs)	260	30.06.2015	In preparation
TOF	IFIN-HH, Bukarest, Romania	RPC chambers and FEE	748	30.06.2015	In preparation
MUCH	VECC, Kolkata + 12 Indian Institutes	GEM chambers and FEE	3022	10.12.2015	In preparation

Status CBM purchase

Nr.	contracts	Value M€	partner	Status
1	Purchase RICH MAPMT HAMAMATSU	1.65	GSI	Ordered
2	STS module assembly contract	1.1	KIT Karlsruhe	Signed
3	Purchase iron for beam dump	0.25	KIT Karlsruhe	Signed
4	Purchase ASIC GBTx	1.245	CERN	Ordered

Agreement with China

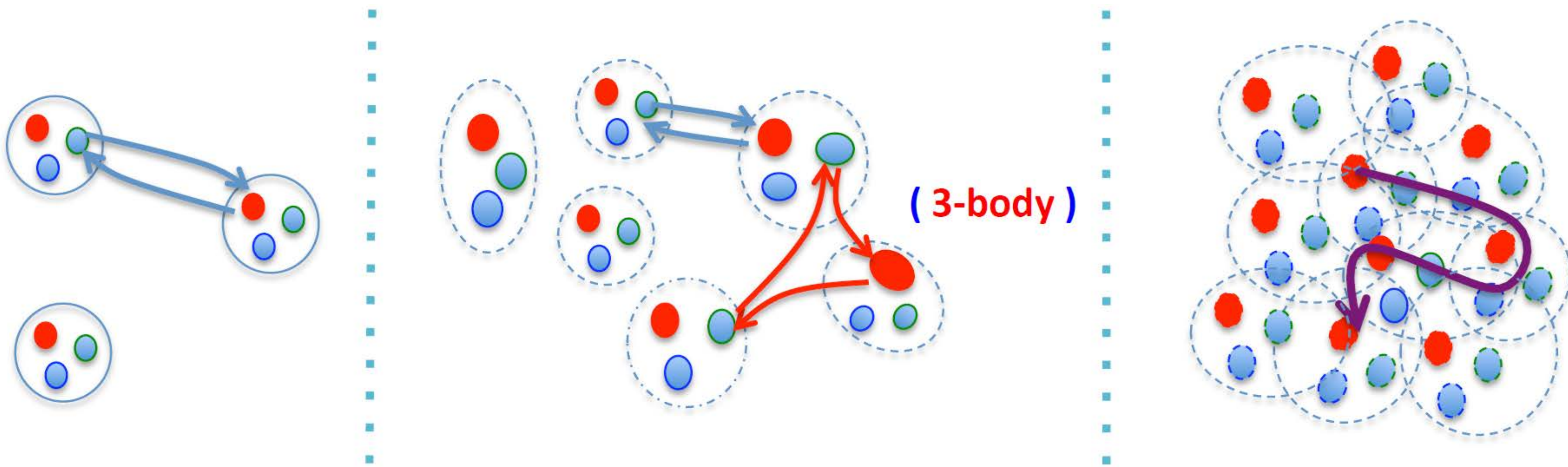
Nr.	contracts	Value M€	Partner	Status
1	MRPC Time-of flight detector	4.0	CCNU Wuhan	Signed
2	TOF read-out electronics	0.8	CCNU Wuhan	Signed

Nuclear matter at high baryon density

- exchange of few mesons
- nucleons only

- exchange of many mesons
- structural change of hadrons

- Baryons overlap
- Quark Fermi sea



$\sim 2\ \rho_0$ $\sim 5\ \rho_0$

courtesy Toru Kojo (CCNU)