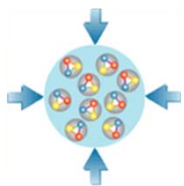


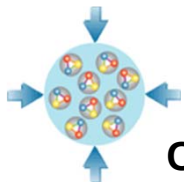
The Compressed Baryonic Matter (CBM) experiment at FAIR

Claudia Höhne, Universität Giessen



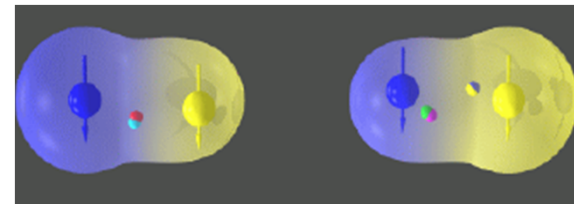
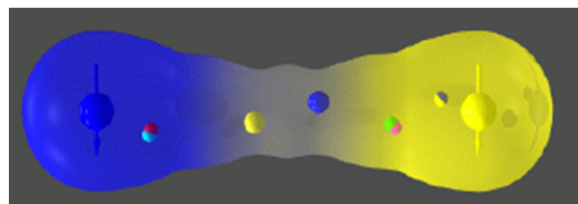
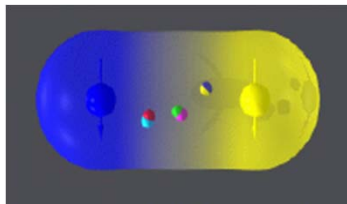
Outline

- Introduction & Motivation
 - QCD phase diagram & Heavy-ion collisions
 - Physics program and observables for CBM
- CBM experiment at SIS-100 at FAIR
 - FAIR phase 0: use CBM detector components prior to FAIR start in ongoing (starting) experiments for physics campaigns
- Summary

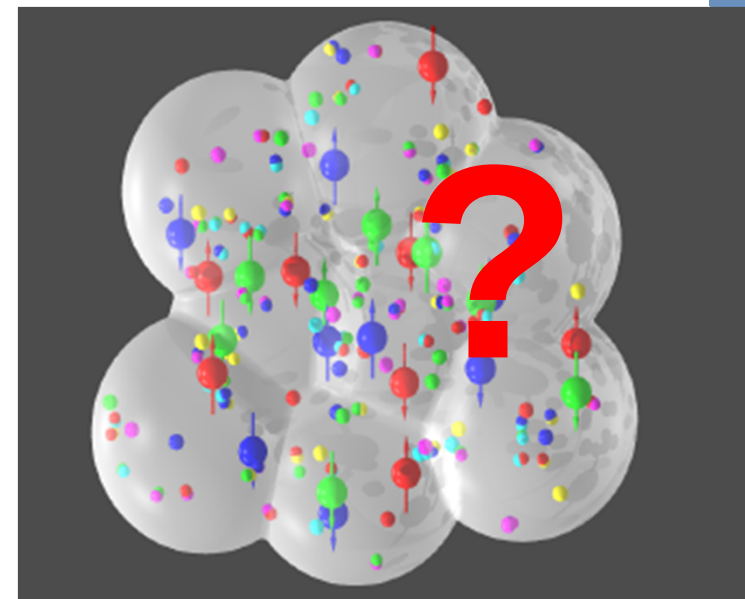
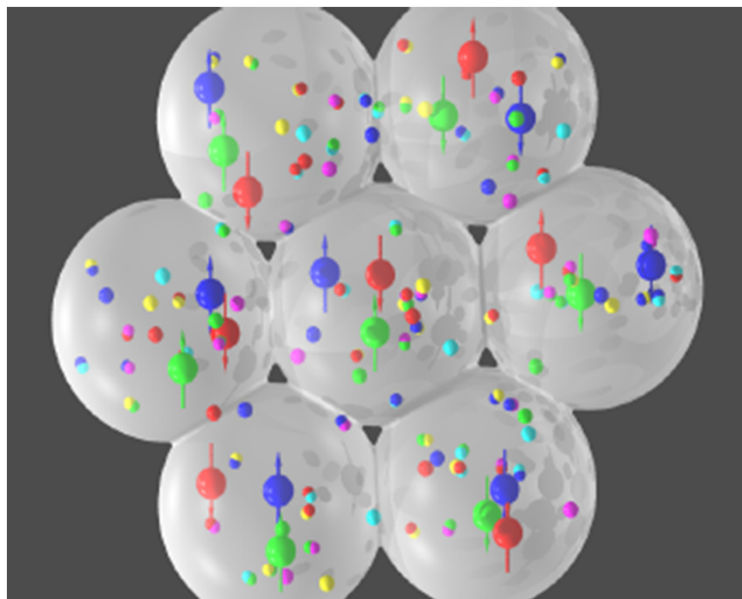
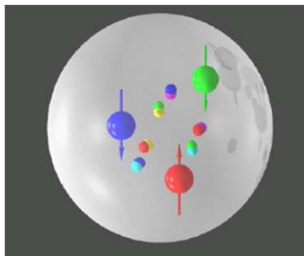


Hadronic matter

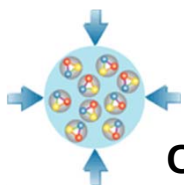
- Mesons, confinement, string break up



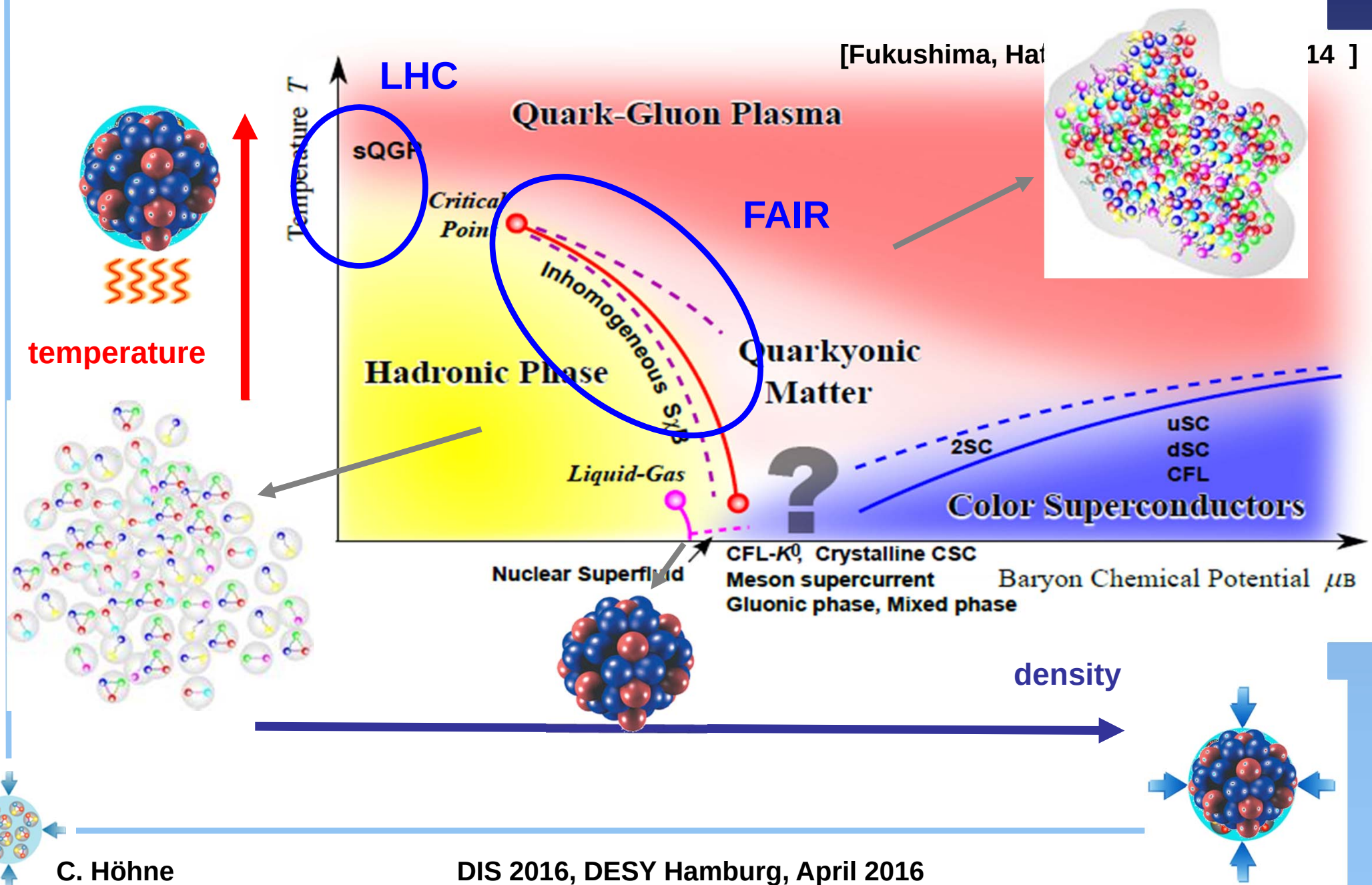
- Baryons, nuclear matter, **compressed baryonic matter?**



[pictures: Stefan Scherer, 2004]



The QCD diagram

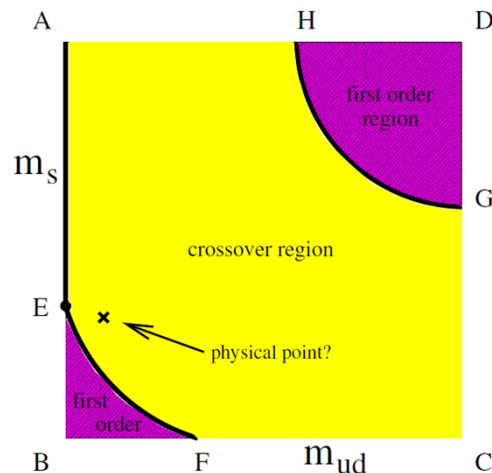


Phase diagram at $\mu_b=0$

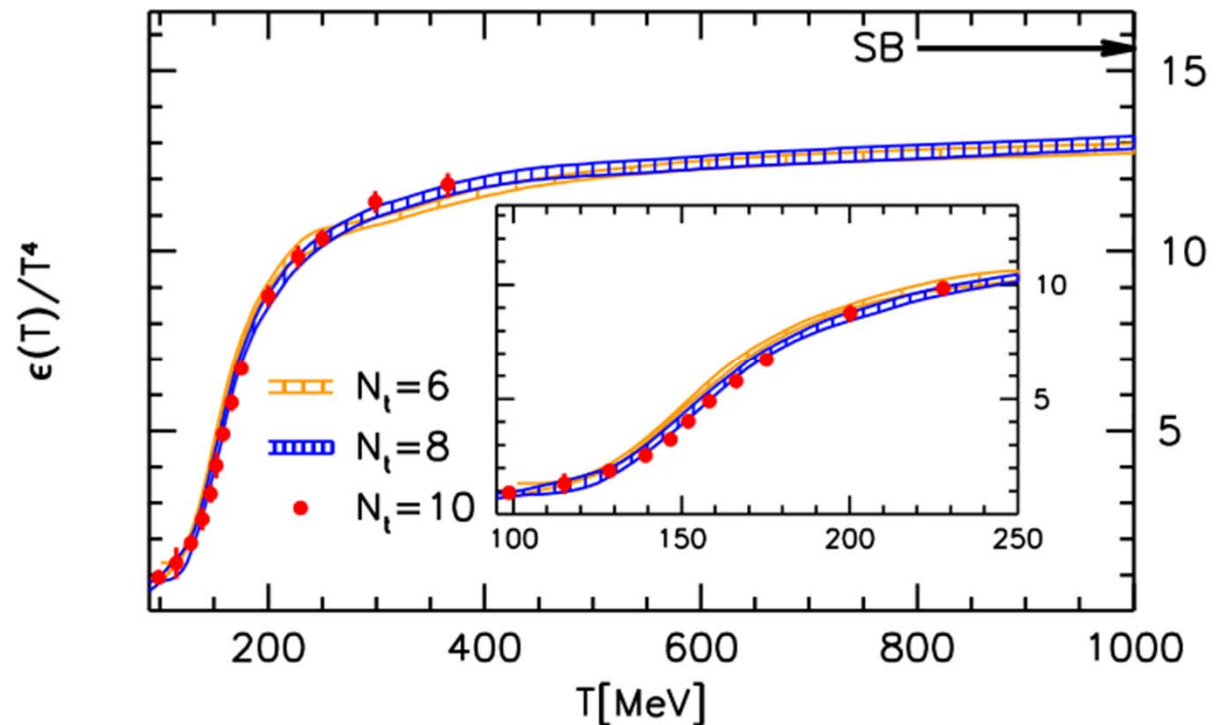
- **Lattice QCD:** phase transition at $\mu_b = 0$ for $T > T_c$, driven by energy density ε :

$$\varepsilon_{\text{crit}} \sim 1 \text{ GeV/fm}^3, T_{\text{crit}} \sim 170 \text{ MeV}$$

crossover = rapid change of properties but no clearly defined phase boundary

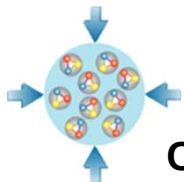


[Z. Fodor, S.D. Katz, Acta Phys.Polon. B42 (2011) 2791-2810]



- **Experiments at LHC & RHIC:**

- Crossover transition between partonic and hadronic matter
- Successfully working on characterizing matter in terms of viscosity, gluon density, ...

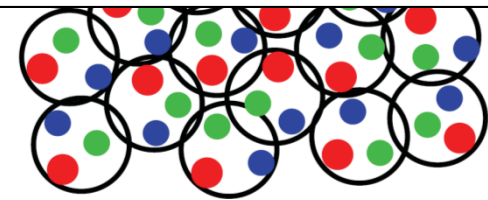


High density range of QCD phase diagram

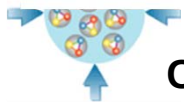
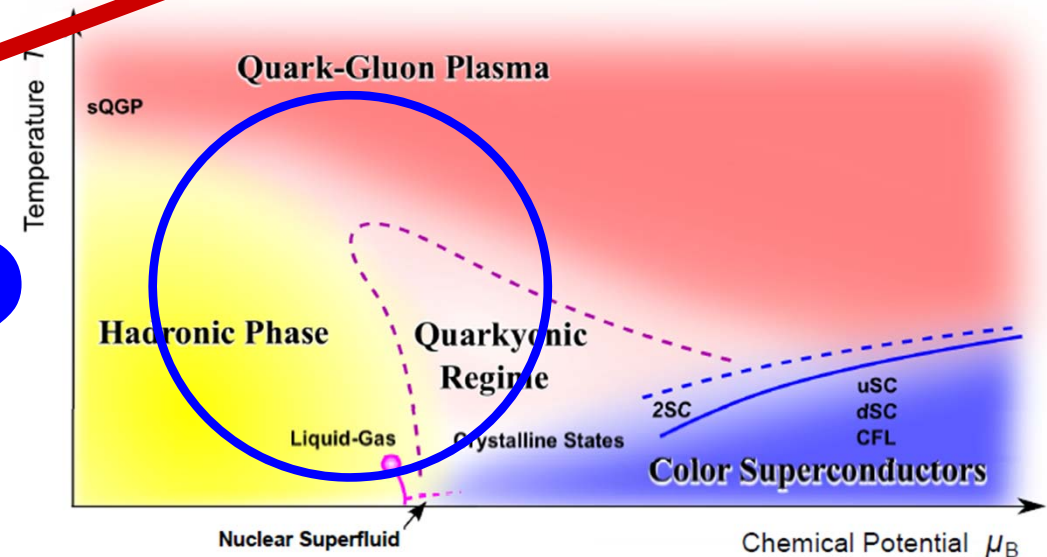
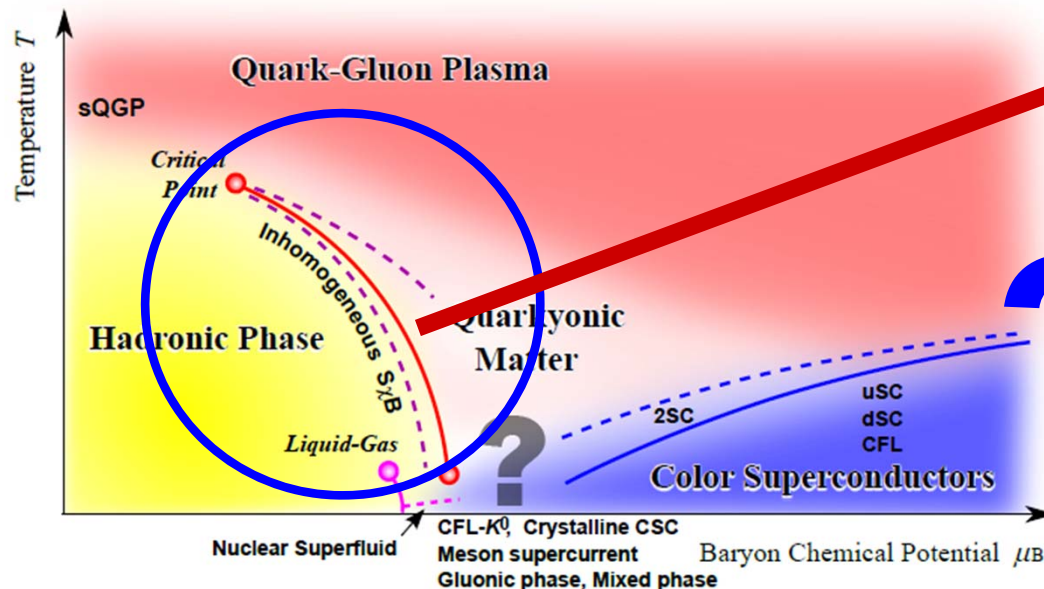
At large μ_b phase structure is uncharted territory

- deconfinement & chiral symmetry restoration at high T , large μ_b
- first order phase transition at large μ_b ?
- e.g. latent heat phase coexistence region ?
- critical point: $T_{\text{crit}} \sim 160 \text{ MeV}$ $\mu_{\text{crit}} \sim 360 \text{ MeV}$?
- different forms of matter? Quarkyonic phase?

Field driven by experimental data!
Need: $\sim 2\text{-}40 \text{ AGeV}$ beam energies

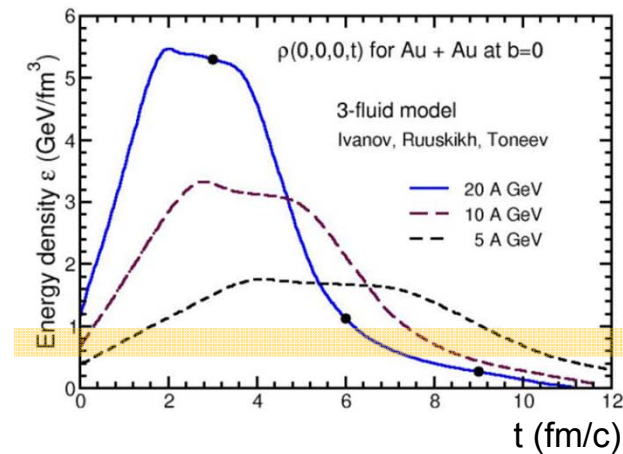
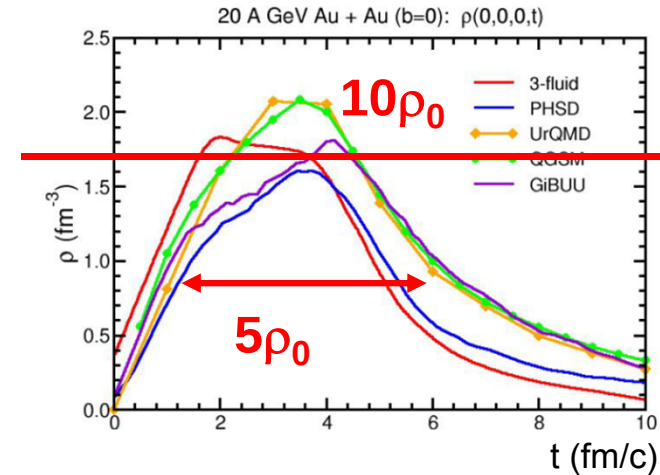
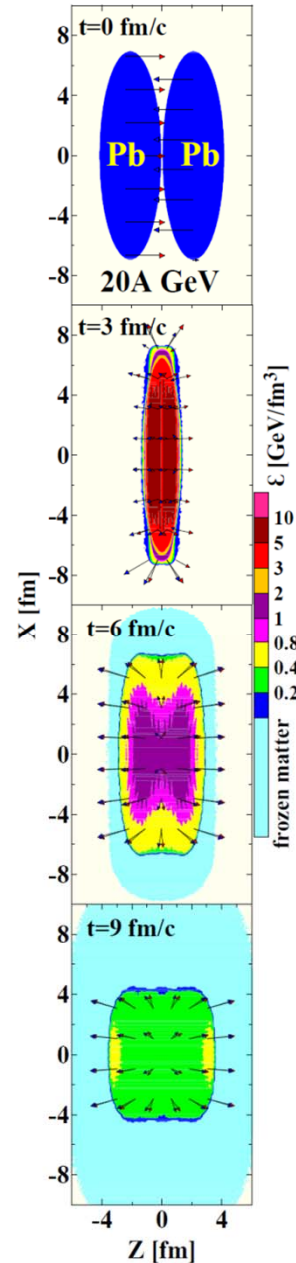
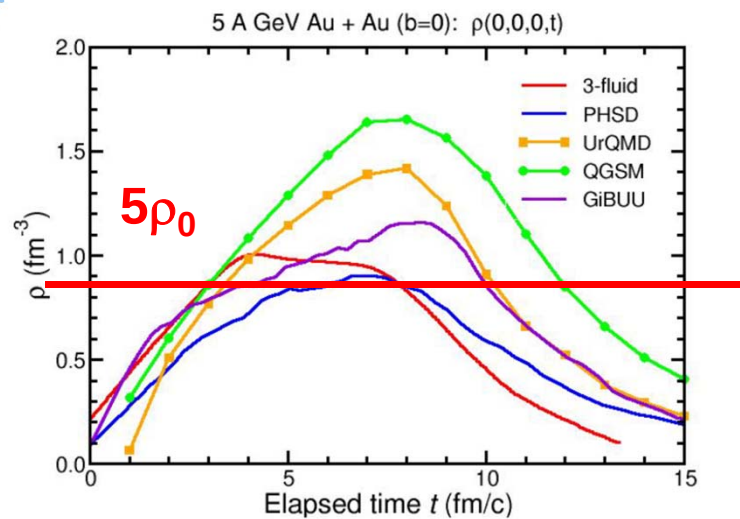


(K. Fukushima, T. Hatsuda, Rept.Prog.Phys.74:014001,2011)



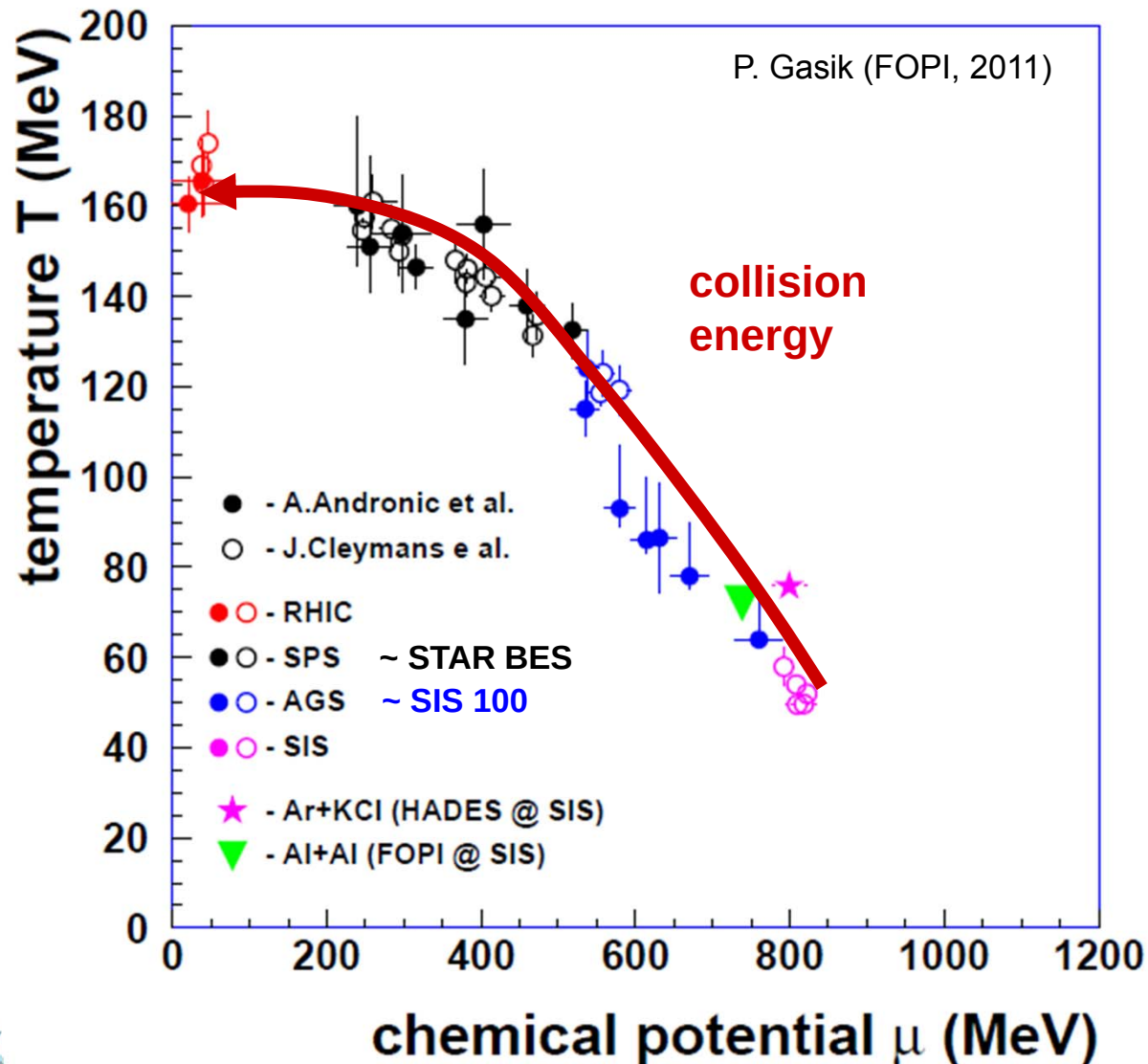
Heavy-ion collisions

- 3-fluid model [Ivanov] at 20 AGeV: High total energy density and net baryon energy density for more than 5 fm/c
- 5 AGeV: depending on the model $\sim 5\rho_0$



Critical energy density

Experimental scan of the phase diagram



High precision data at low μ_b

New measurement campaign with BES at RHIC

Exploratory measurements at high densities

Chemical equilibrium at low energies?

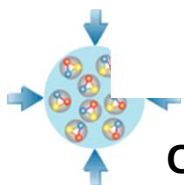
Data sources:

A. Andronic, P. Braun-Munzinger, J. Stachel, Nucl. Phys. A772 (2006) 167

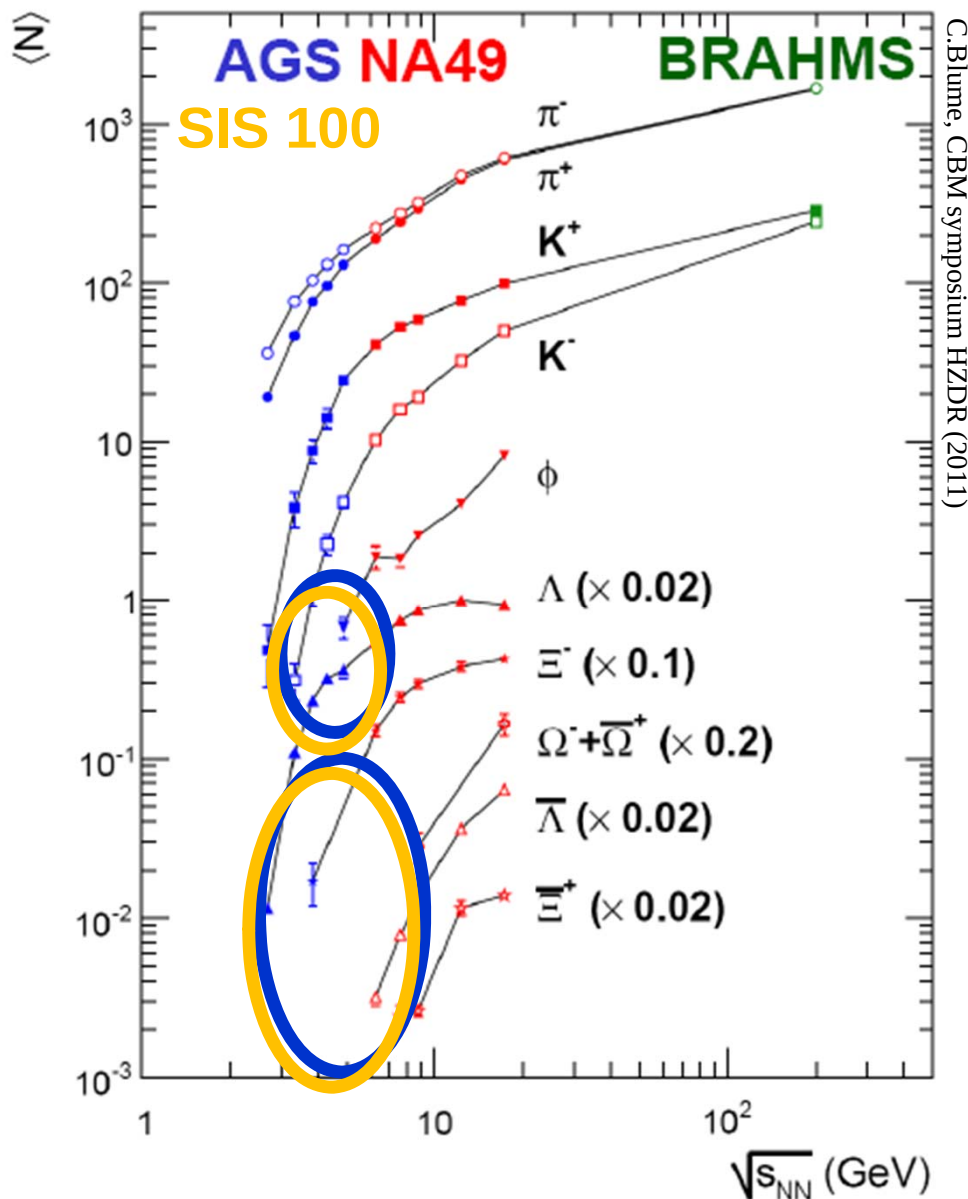
J. Cleymans, H. Oeschler, K. Redlich, S. Wheaton, Phys. Rev. C73 (2006) 034905

G. Agakishiev et al. (HADES), Eur. Phys. J. A47 (2011) 21

Errors include systematic errors (if given)



The CBM mission



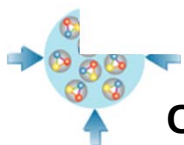
Explore and characterize high-baryon density matter in A+A collisions

- Equation of state
- New forms of matter (quarkyonic, strange matter, hypernuclei, ...)
- phase transitions?

High precision experiment!

- unprecedented interaction rates
- statistics, systematics
- rare probes

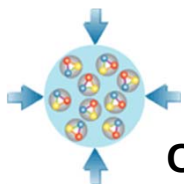
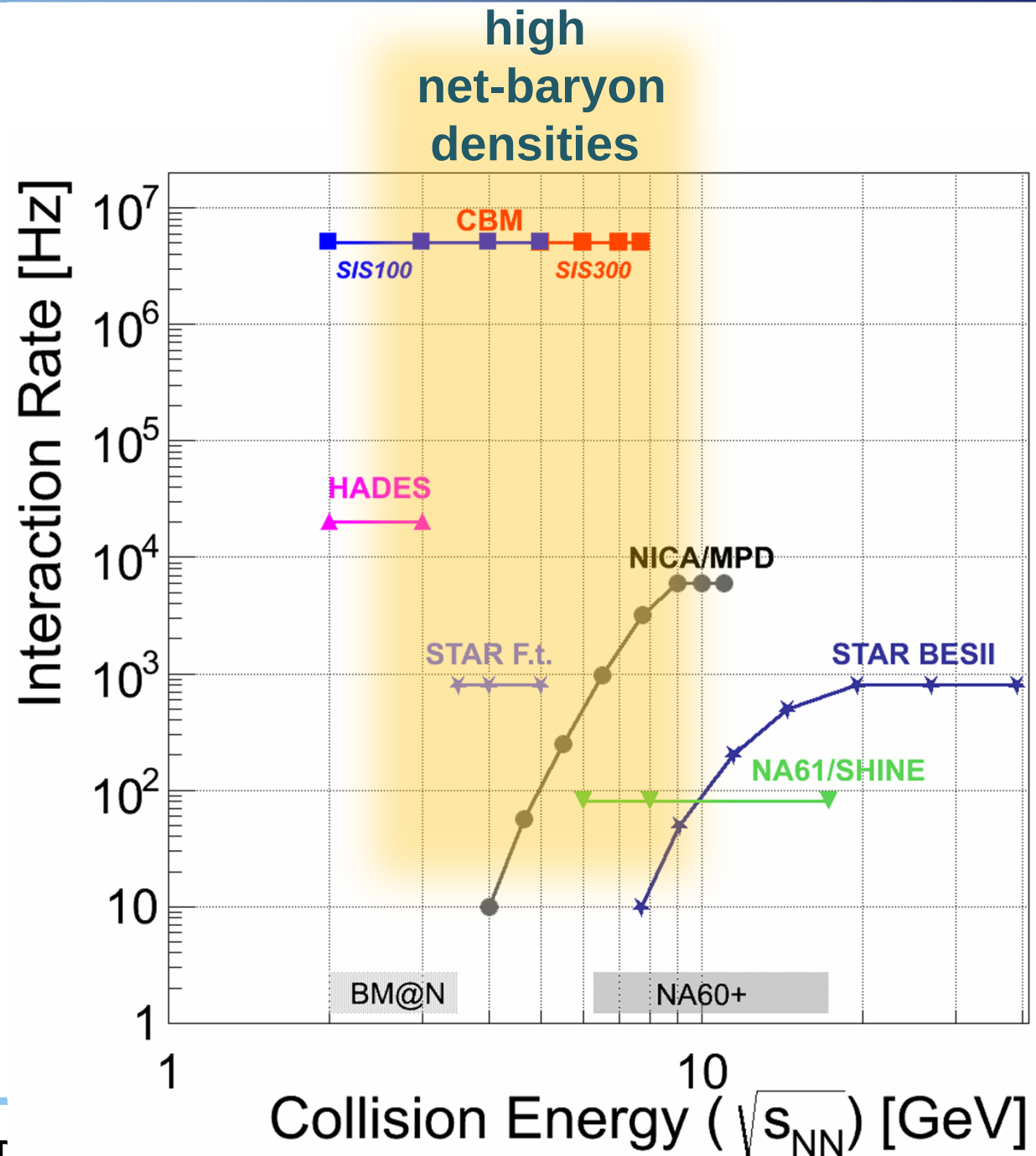
SIS 100; Au+Au at 11 AGeV beam energy max,
 $\sqrt{s_{NN}}=4.7$ GeV, $T \sim 120$ MeV, $\mu_b \sim 550$ MeV



Experiments exploring dense QCD matter

CBM:
high rate experiment!

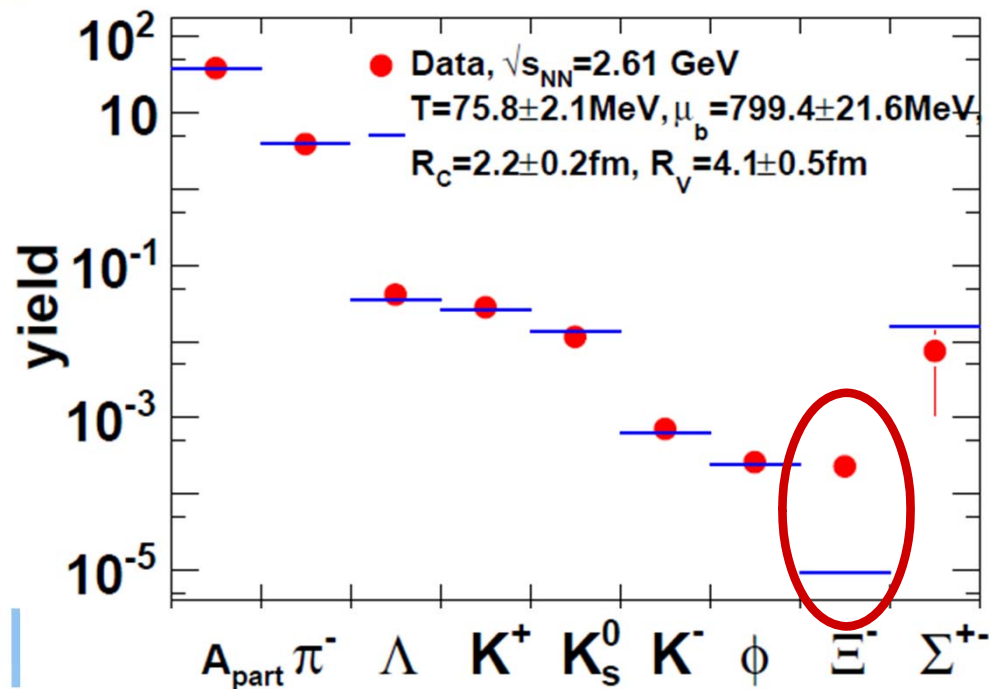
- Opens up new possibilities!
- High statistics and good systematics on **hadronic observables**:
multi-s baryons, flow, fluctuations
- **New (exotic) observables**:
kaonic clusters, hypernuclei
- **Electromagnetic probes**



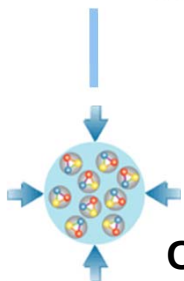
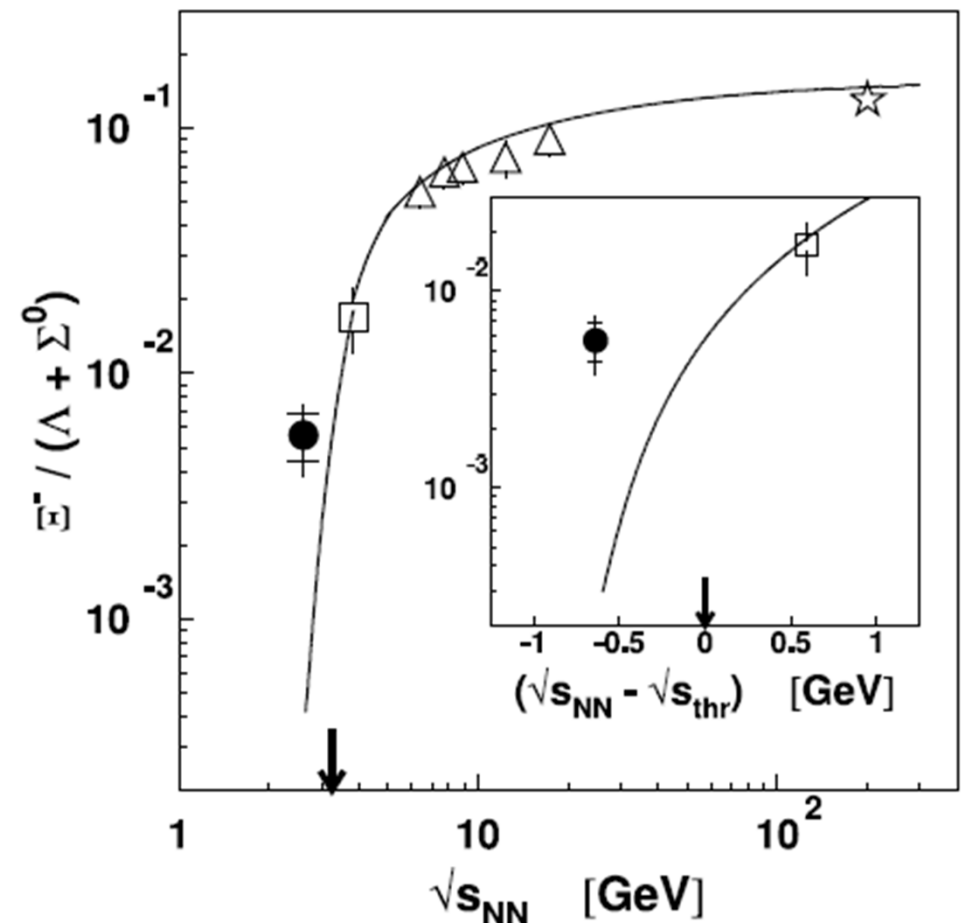
HADES: Sub-threshold Ξ^- - production

Ar+KCl reactions at 1.76A GeV

- Ξ^- yield by appr. factor 25 higher than thermal yield
- strangeness exchange reactions like



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



Fluctuations and critical point

Net-Proton Fluctuations in Beam Energy Scan (BES) from STAR

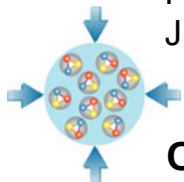
→ analyse event-by-event distributions of e.g. net-protons:
Extract also higher moments like skewness, kurtosis

→ can be related to ratios of susceptibilities in Lattice QCD: measure fluctuations that are directly connected to critical behaviour

'Low' energy data limited by statistics

Fluctuations for energies $\sqrt{s_{NN}} < 7$ GeV ?

L. Adamczyk et al. (STAR Collaboration),
Phys. Rev. Lett. 112, 032302 (2014)
J. Thaefer, QM2015



C. Höhne

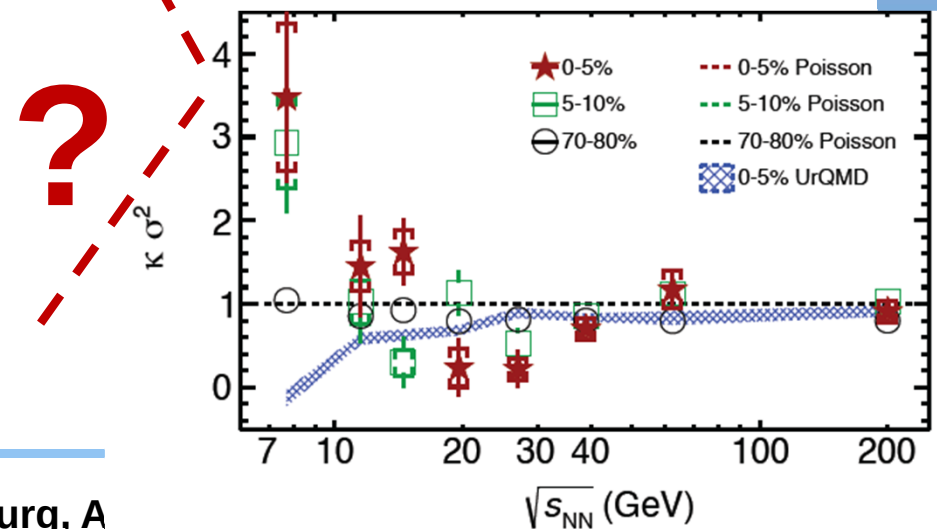
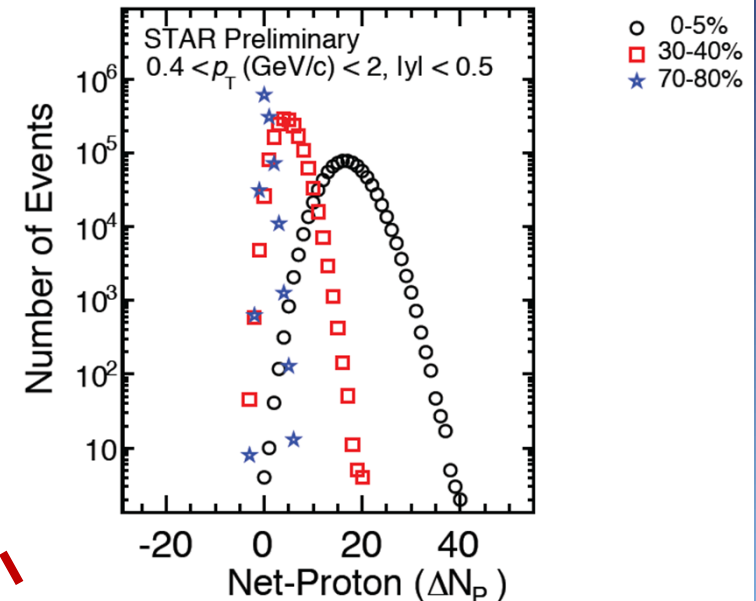
DIS 2016, DESY Hamburg, A

Net-Proton

Au+Au collisions at RHIC

$0.4 < p_T \text{ (GeV/c)} < 2.0, |y| < 0.5$

STAR preliminary



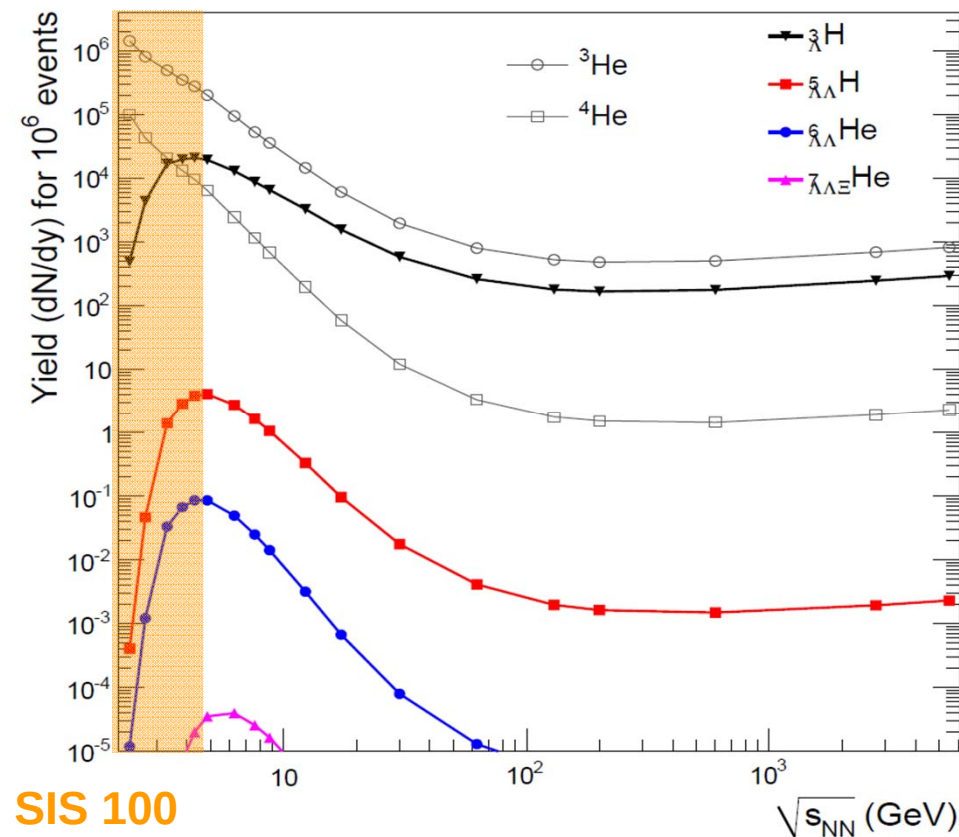
Strange baryonic bound states

Whole range of predictions/ proposals well accessible at SIS 100 energies:

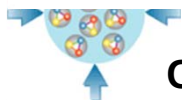
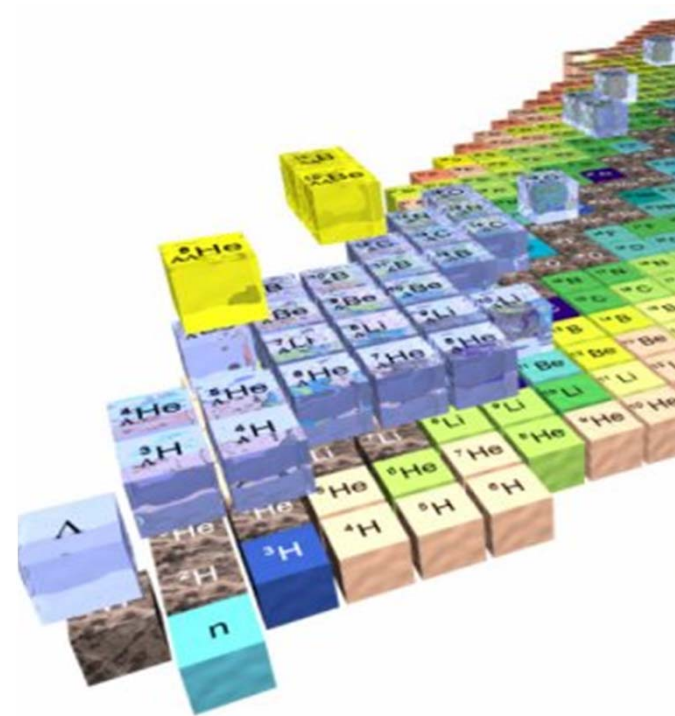
- Single and double strange hypernuclei in heavy ion collisions
- Strange matter in the form of strange dibaryons and heavy multi-strange short-lived objects.

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

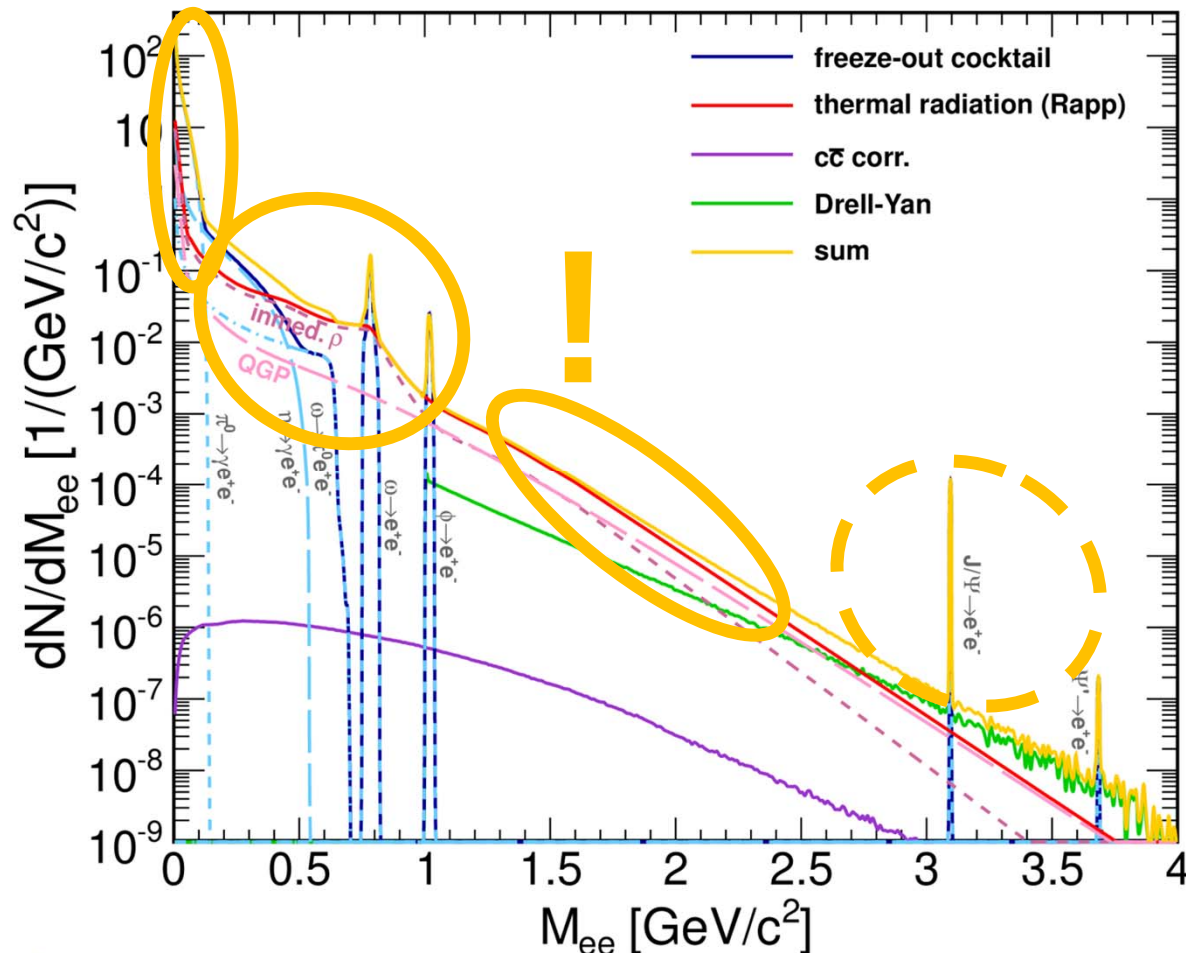
A. Andronic, P. Braun-Munzinger, J. Stachel, H. Stöcker,
Phys. Lett. B697 (2011) 203



SIS 100



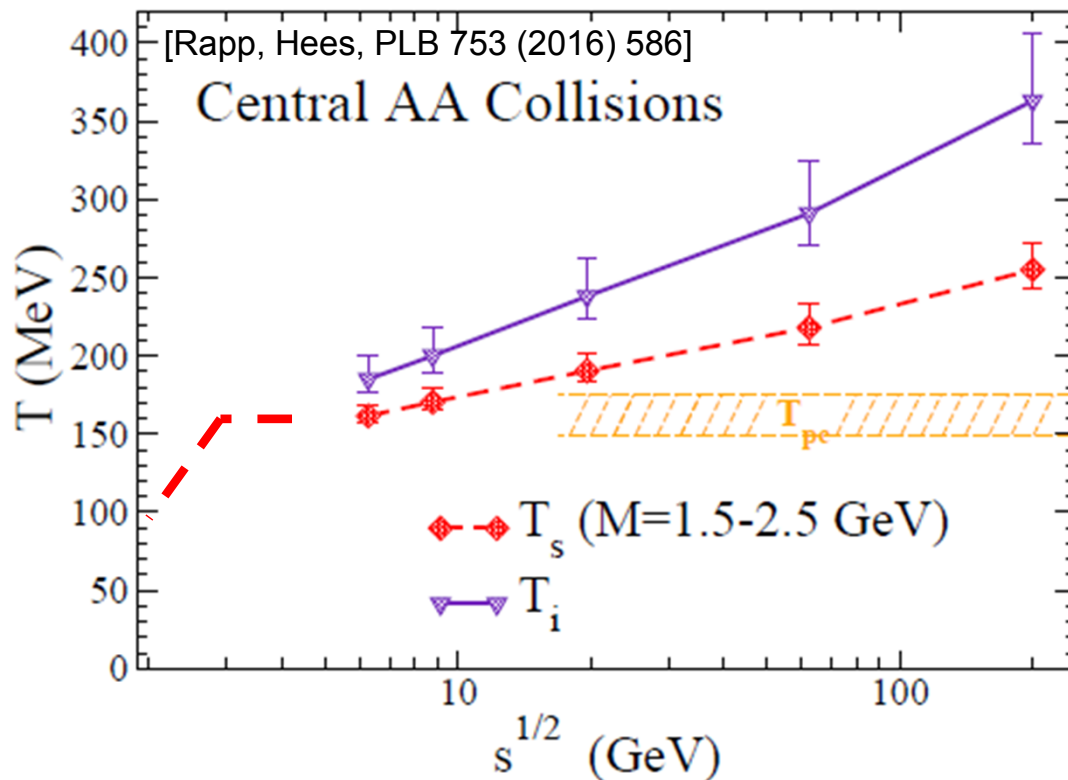
Dileptons at CBM



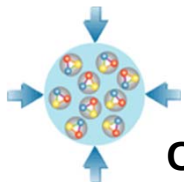
- Photons: access to early temperatures
→ **excitation function?**
- Low-mass vector mesons: in-medium properties of ρ
→ strength due to coupling to baryons (see HADES)
→ **go to real dense matter!**
- Intermediate range: access to fireball radiation:
QGP, 4π - or ρ - a_1 chiral mixing
→ **quarkyonic phase?**
- J/ψ : charm as a probe for dense baryonic / partonic matter
→ **propagation of charm?**
→ **distribution amongst hadrons?**

Central Au+Au collisions, 25 AGeV

Dileptons at CBM

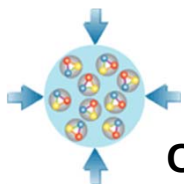
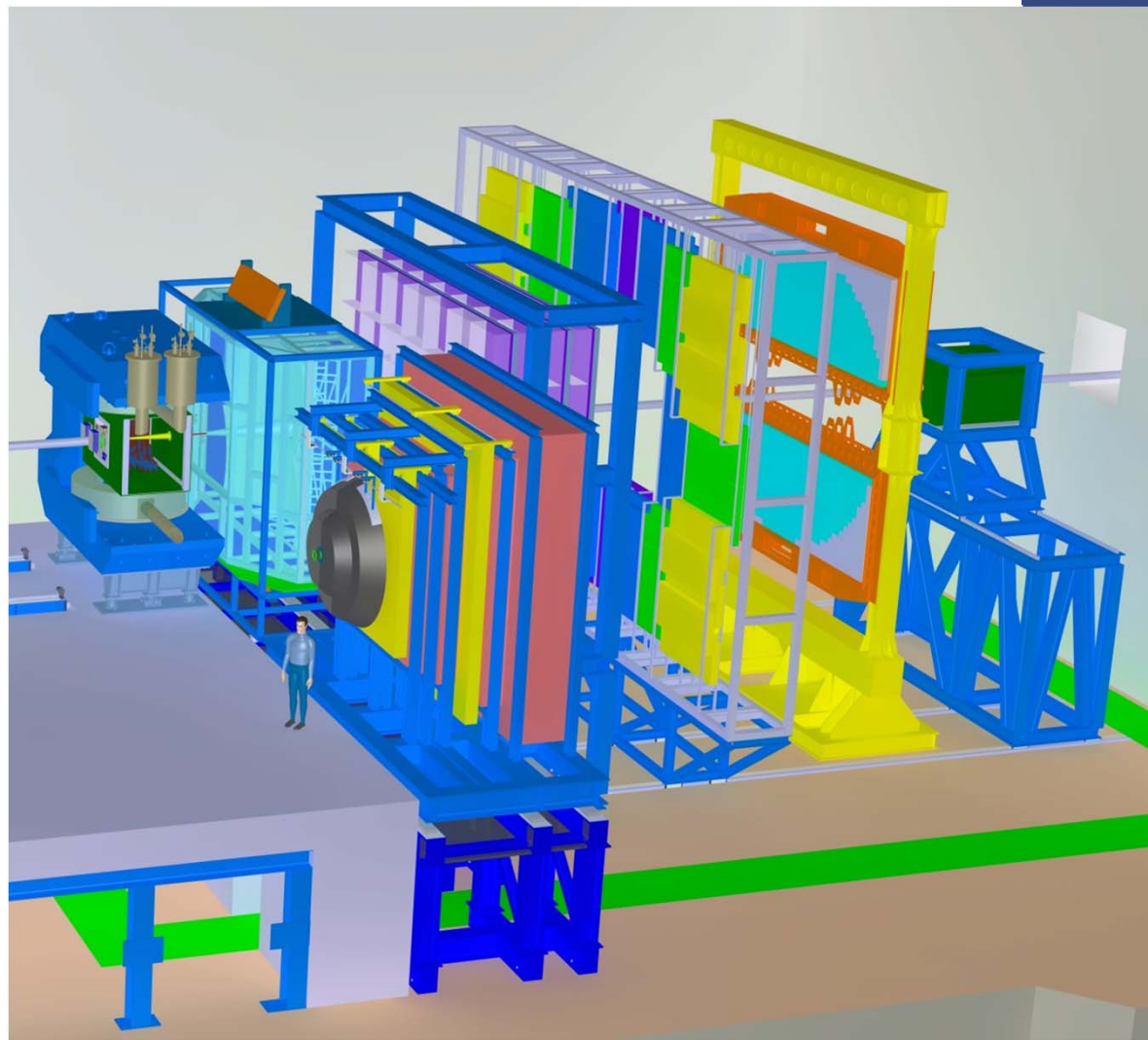


- Photons: access to early temperatures
→ **excitation function?**
- Low-mass vector mesons: in-medium properties of ρ
→ strength due to coupling to baryons (see HADES)
→ **go to real dense matter!**
- Intermediate range: access to fireball radiation:
QGP, 4π - or ρ - a_1 chiral mixing
→ **quarkyonic phase?**
- J/ψ : charm as a probe for dense baryonic / partonic matter
→ **propagation of charm?**
→ **distribution amongst hadrons?**



The CBM experiment at SIS 100

- Tracking, momentum, V^0 : MVD+STS+dipole magnet
- Event characterization: PSD
- Hadron id: TOF
- Lepton id: RICH+TRD or MUCH
- γ , π^0 : EMC
- High speed DAQ & trigger



CBM Technical Developments

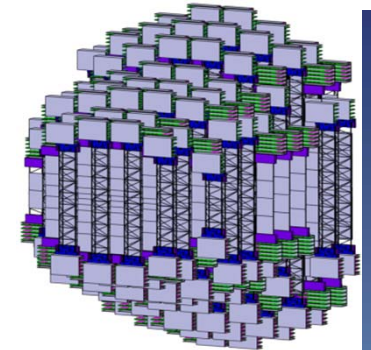
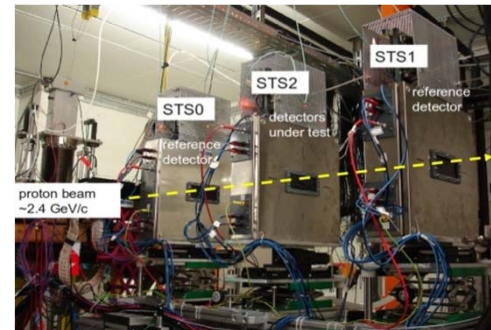
SC Magnet: JINR Dubna



Micro-Vertex Detector:
Frankfurt, Strasbourg



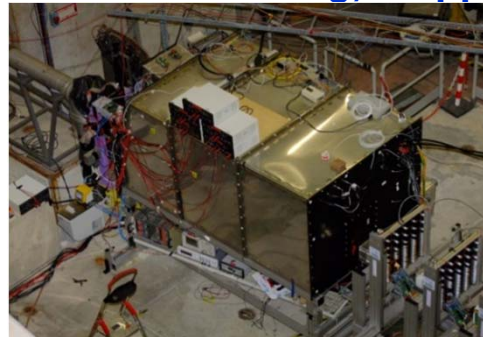
Silicon Tracking System: Darmstadt, Dubna, Krakow, Kiev, Kharkov, Moscow, St. Petersburg, Tübingen



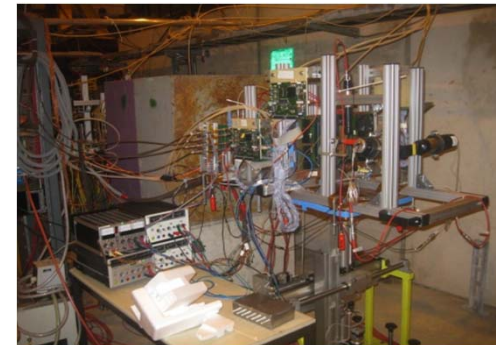
MRPC ToF Wall: Beijing, Bucharest, Darmstadt, Frankfurt, Hefei, Heidelberg, Moscow, Rossendorf, Wuhan, Zagreb



RICH Detector:
Darmstadt, Giessen, Pusan, St. Petersburg, Wuppertal



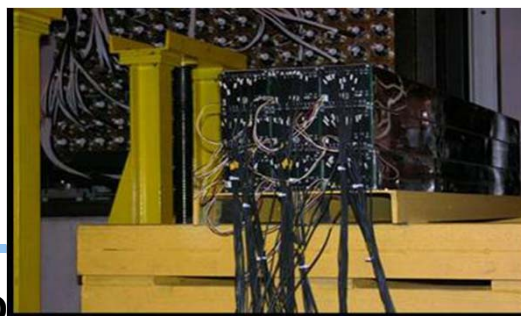
Muon detector:
Kolkata + 13 Indian Inst., Gatchina, Dubna



Transition Radiation Detector:
Bucharest, Dubna, Frankfurt, Heidelberg, Münster



Forward calorimeter:
Moscow, Prague, Rez



DAQ and online event selection:
Darmstadt, Frankfurt, Kharagpur, Warsaw



CBM readout and online systems

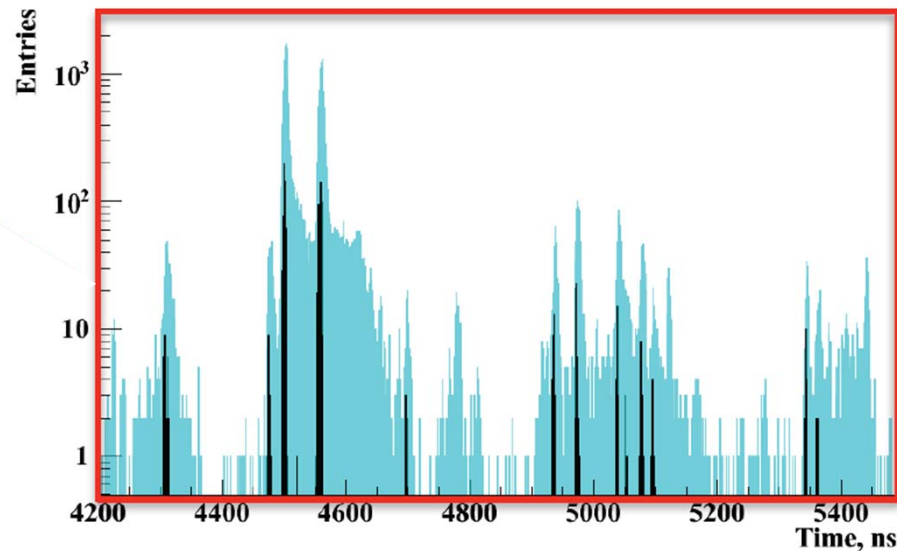
Novel readout system

- no hardware trigger on events, free streaming triggerless data
- detector hits with time stamps,
- full online 4-D track and event reconstruction
- Full analysis of 10 MHz event rate

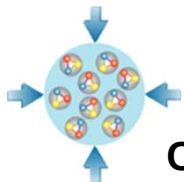
Input hits from STS

Reconstructed tracks

→ tracks clustered in groups representing events

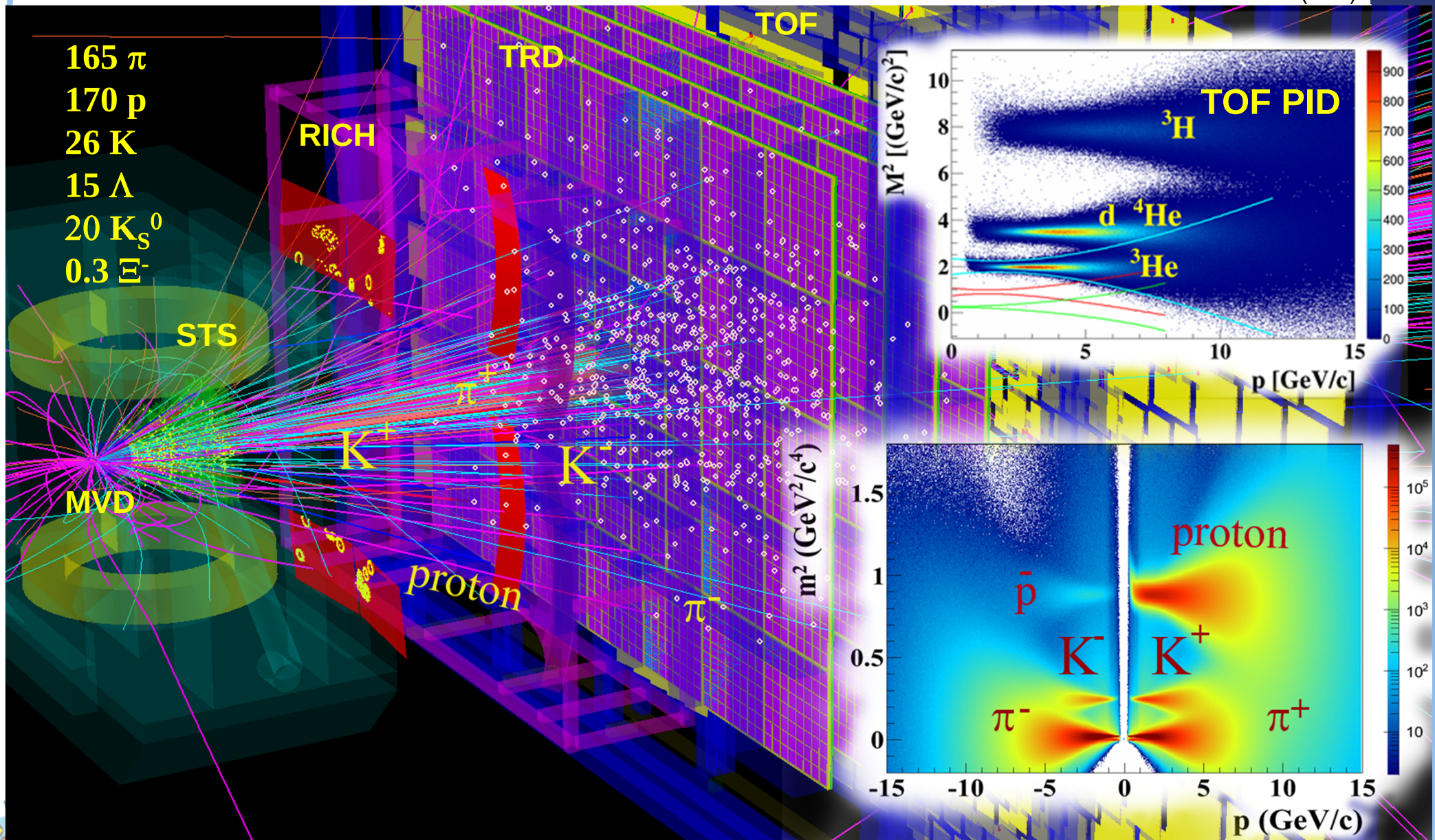


GSI Green IT Cube



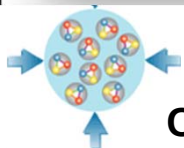
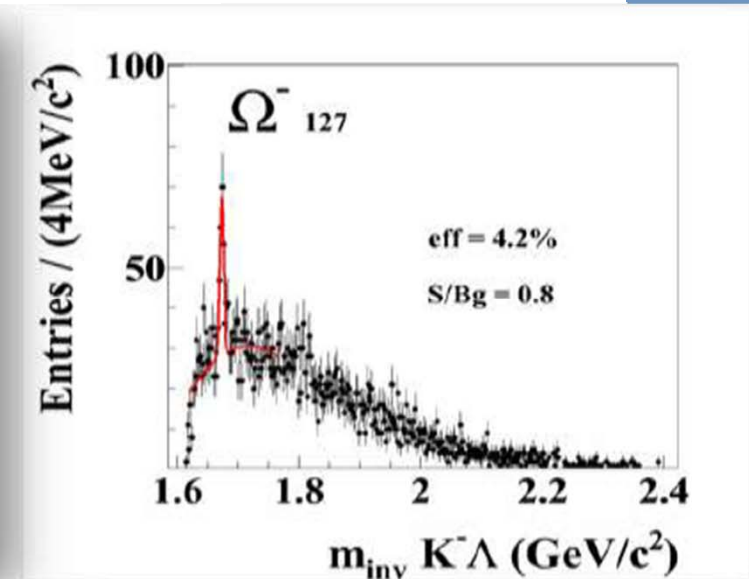
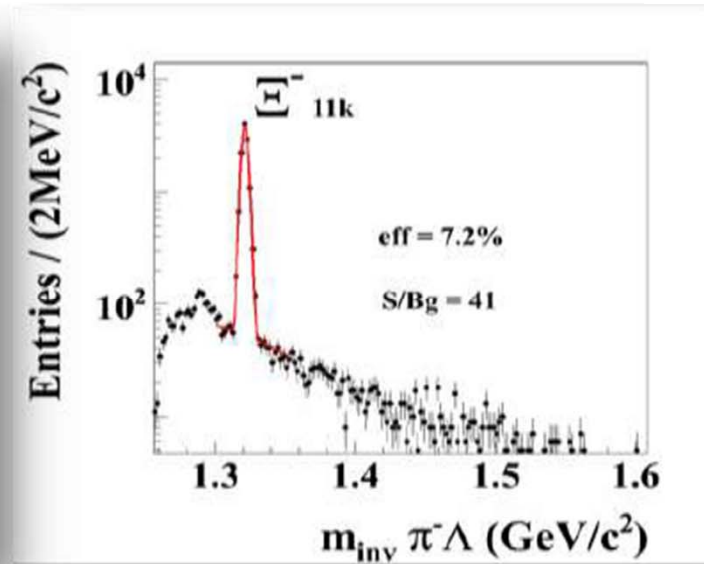
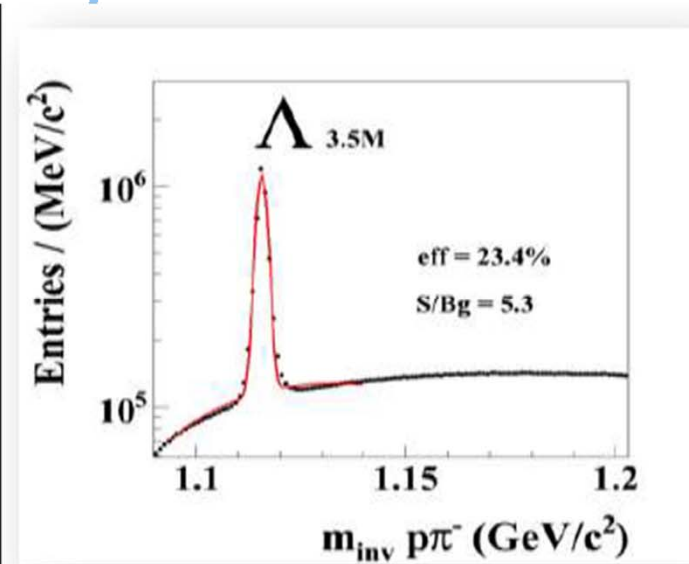
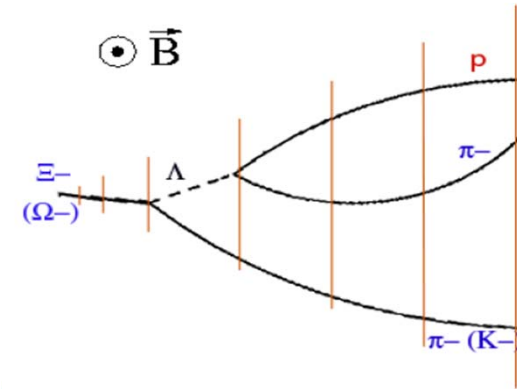
PID with ToF particle ID: Au+Au @ 10AGeV

Y.Vasiliev (GSI)



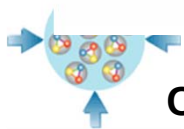
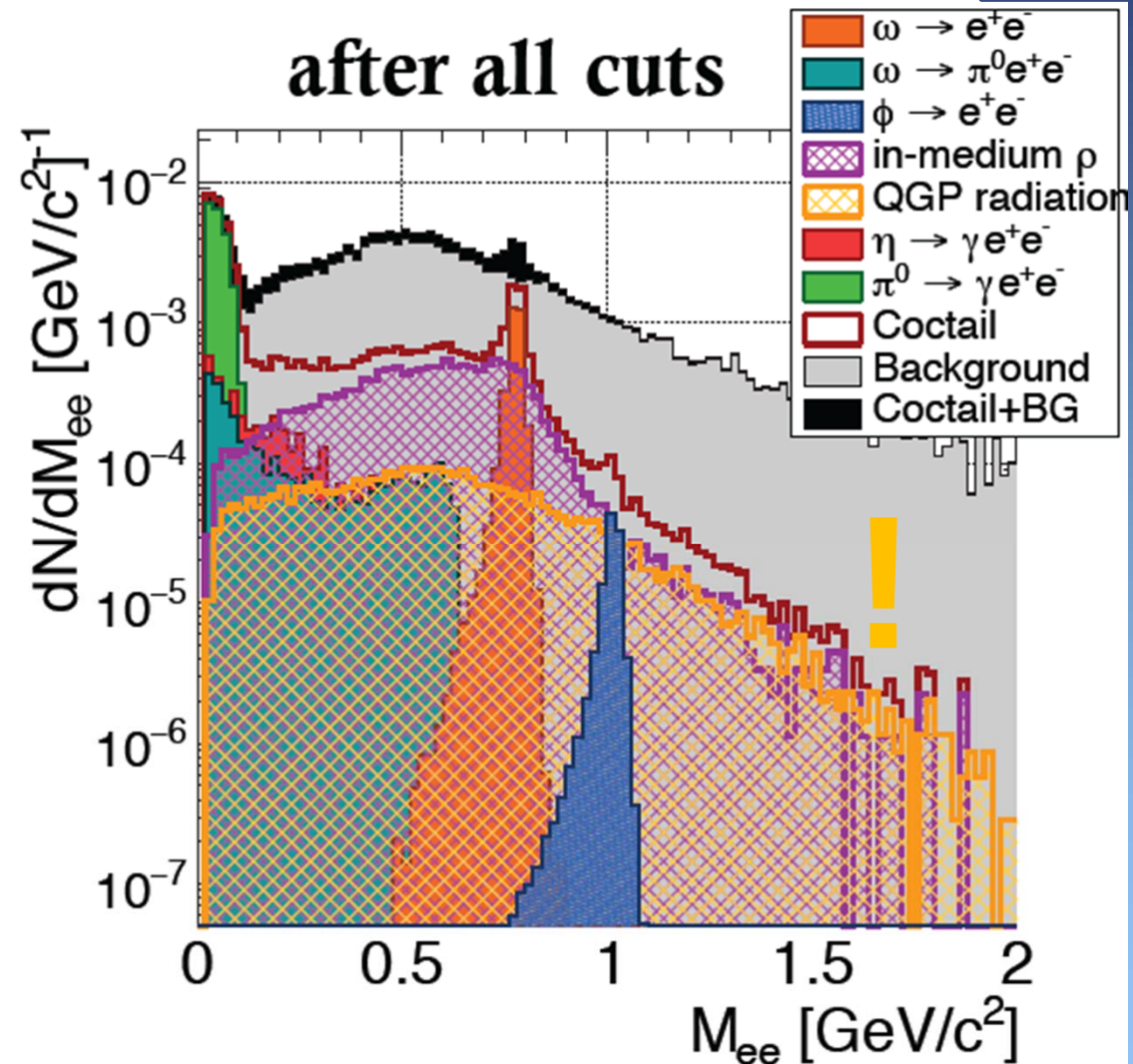
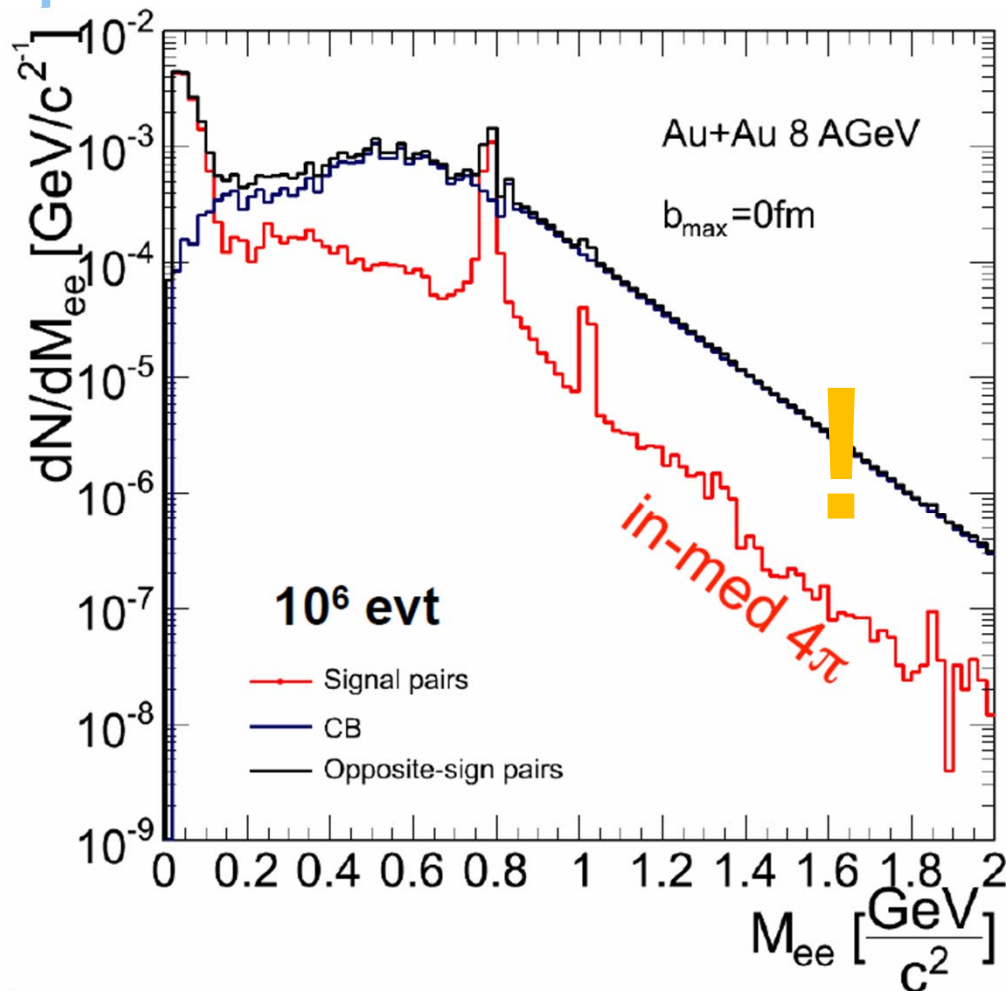
SIS 100- Hyperons

- central ($b=0\text{fm}$) Au+Au collisions at 8 AGeV, 1M events
- Massively parallel data reconstruction and selection in real-time
- 100 kHz archival rate:
 - 500k Ω^- /week
 - flow, correlations, ...
 - strange hypernuclei?

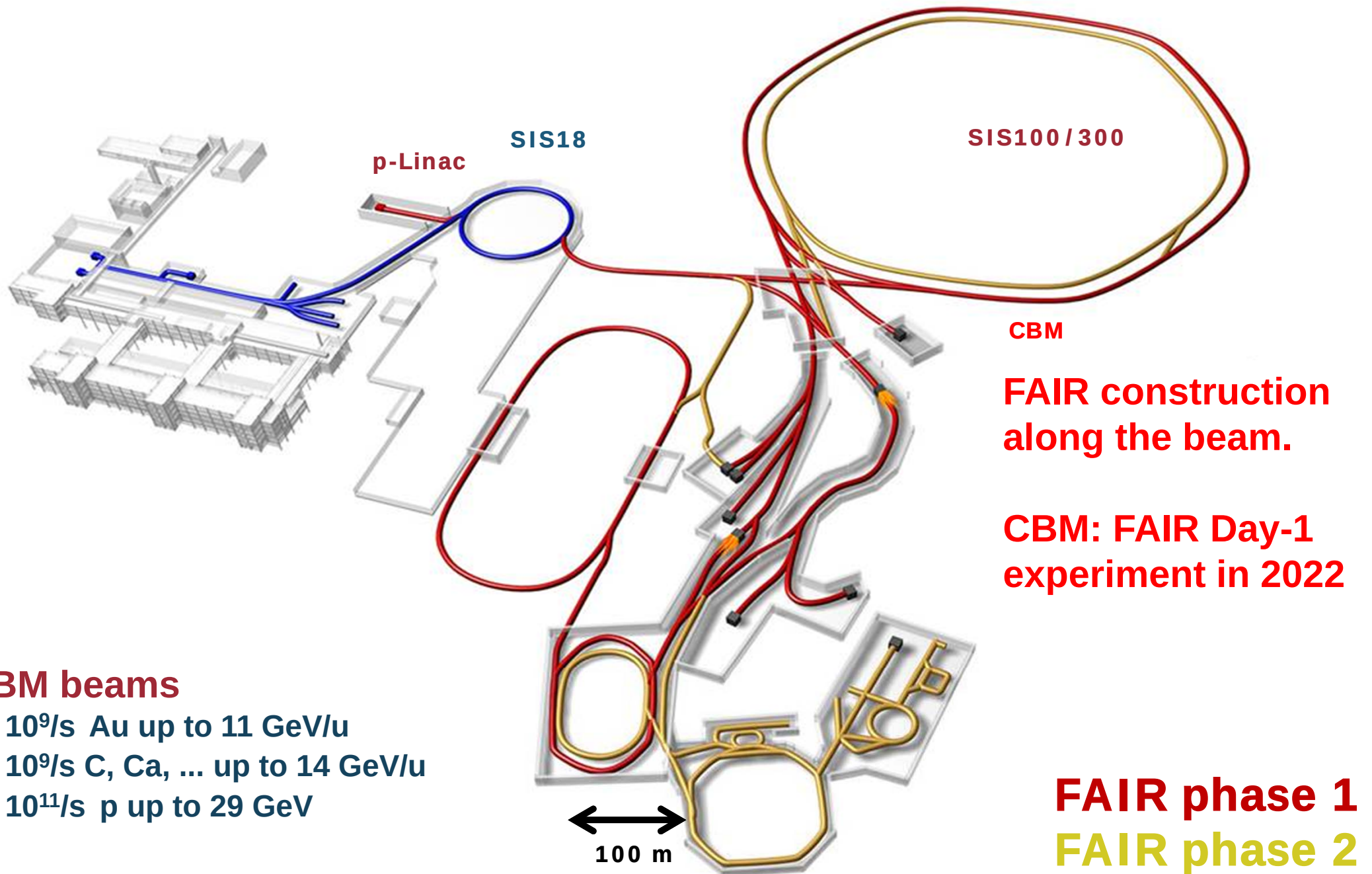


SIS 100 – Di-electrons

- 1M central ($b=0$ fm) Au+Au collisions at 8 AGeV beam energy
- Mass resolution: 13.6 MeV (ω)
- LMVM: about 10^6 ω per week



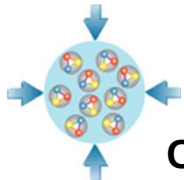
Facility for Antiproton & Ion research



Aerial view April 2015



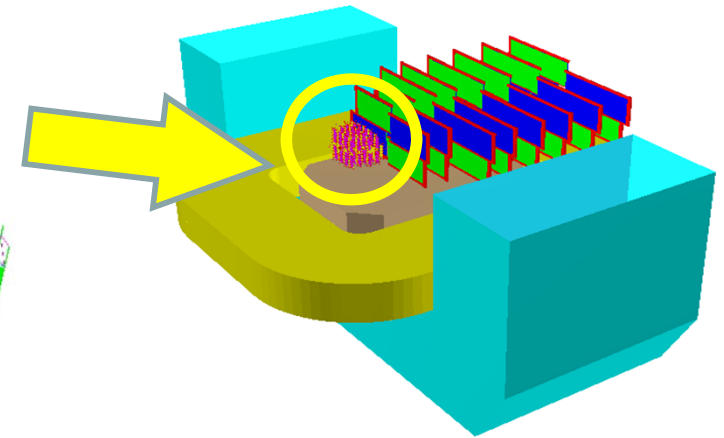
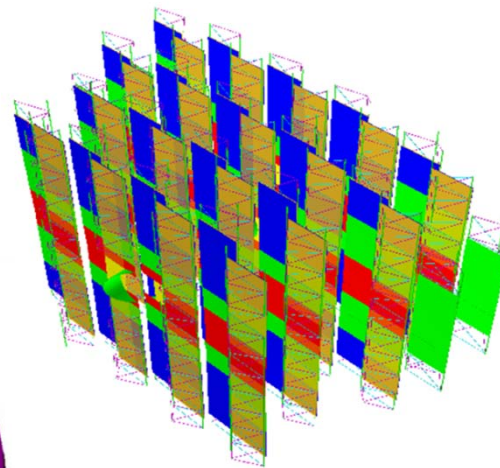
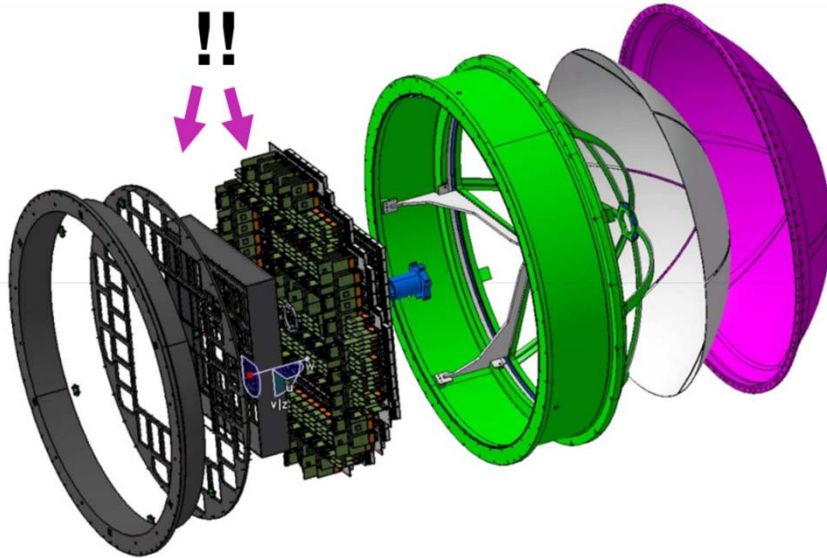
Luftbild des Baufeldes vom 22.04.2015 (Foto: Till Middelhaue für FAIR)



FAIR phase 0 experiments

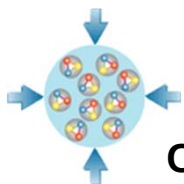
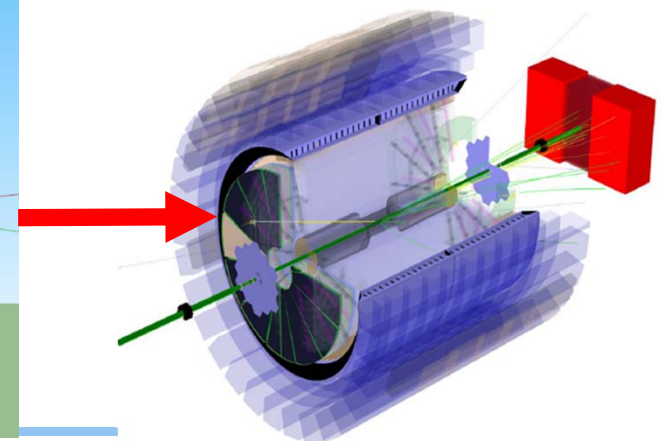
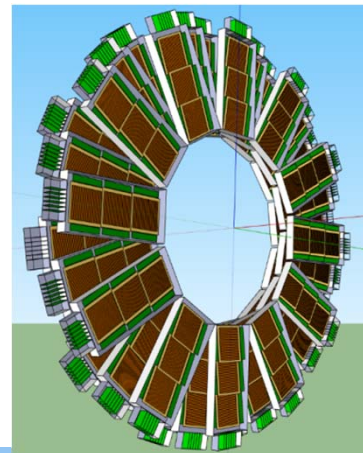
Install, commission and use CBM detector components in ongoing (starting) physics campaigns

- 4 STS stations in BM@N experiment at Dubna



- 40% of the RICH MAPMTs and electronics in HADES RICH for SIS 18

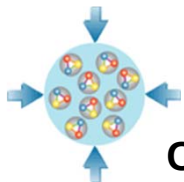
- 10% of the TOF detector modules including readout in STAR at RHIC for BESII



Summary

Mission of CBM & HADES at FAIR/SIS100 (& possibly at future SIS300)

- Exploring the QCD phase diagram at high baryon densities by systematic high-precision measurements of new observables (multistrange particles, dileptons, charm)
- The CBM physics program addresses fundamental physics questions:
 - Nuclear matter equation of state
 - Phase transitions, new phases
 - In-medium modifications of hadrons
 - Substantial discovery potential!
- CBM detector development well advanced



The CBM collaboration

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
PNPI Gatchina
SINP MSU, Moscow
St. Petersburg P. Univ.
Ioffe Phys.-Tech. Inst. St. Pb.

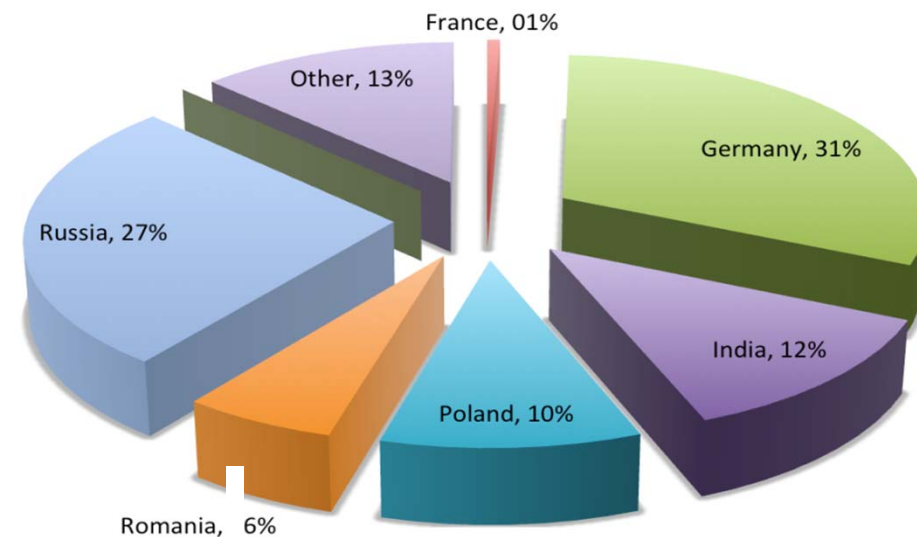
Ukraine:

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

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



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