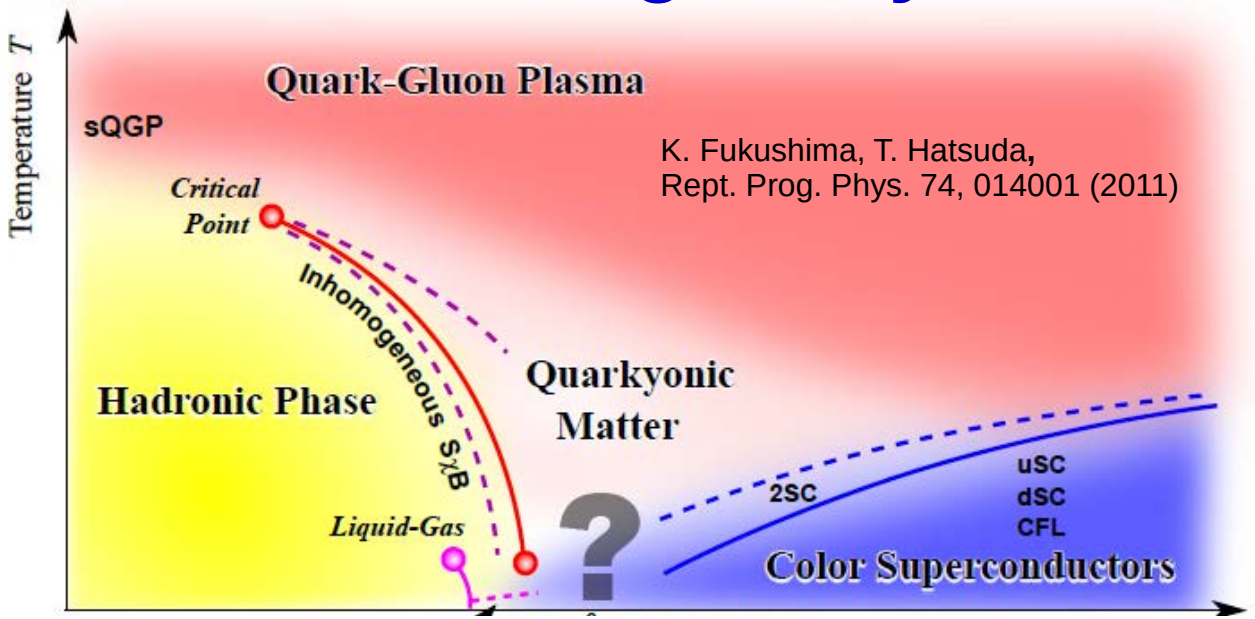
The Compressed Baryonic Matter experiment @ FAIR

N. Herrmann, Univ. Heidelberg

Workshop on Perspectives for
Joint Science and Academic Training at FAIR and NICA

Mission: QCD phase diagram at large baryon densities



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

Outline: **Experimental Strategy of CBM**

Examples of Observables

- **Strange particle yields and flow**
- **Dilepton spectra**
- **Open and hidden charm**

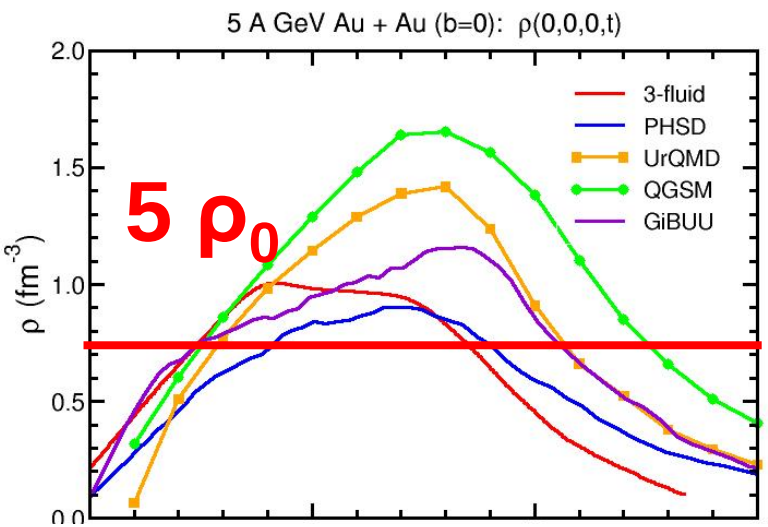
Status of CBM

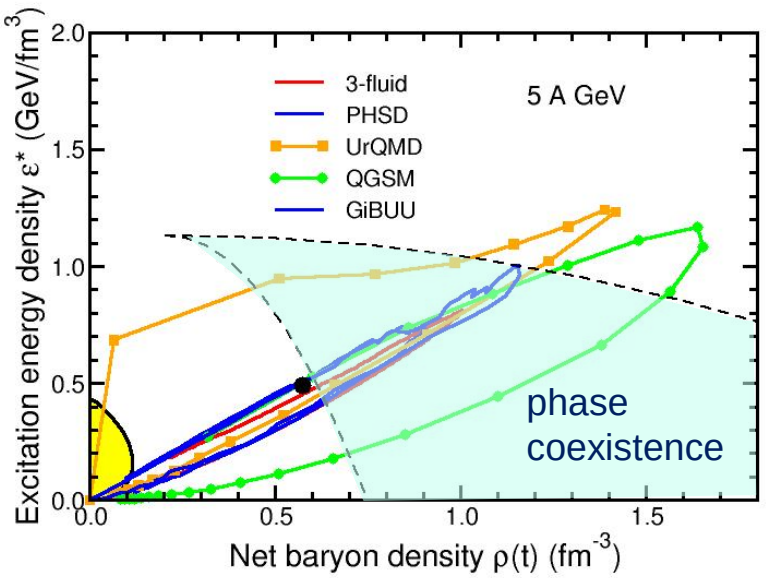
- **FAIR Phase 0 program**

Conclusion

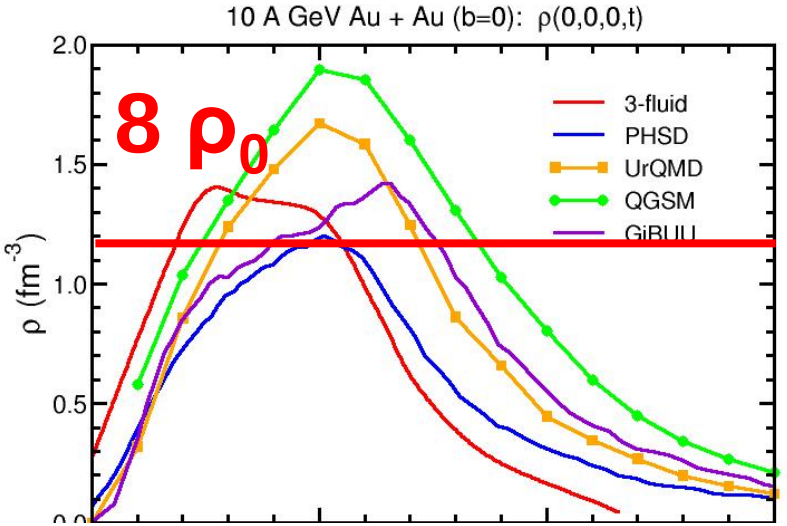
Baryon densities in central Au+Au collisions

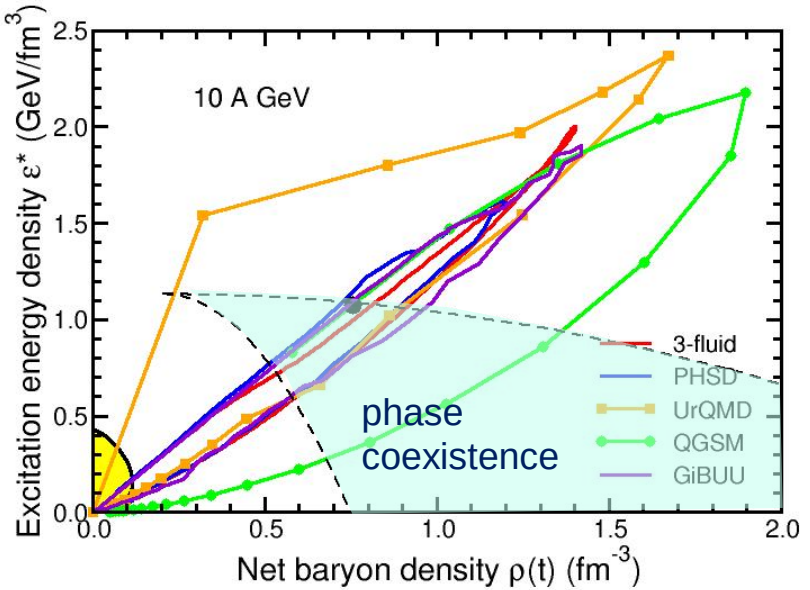
5 A GeV





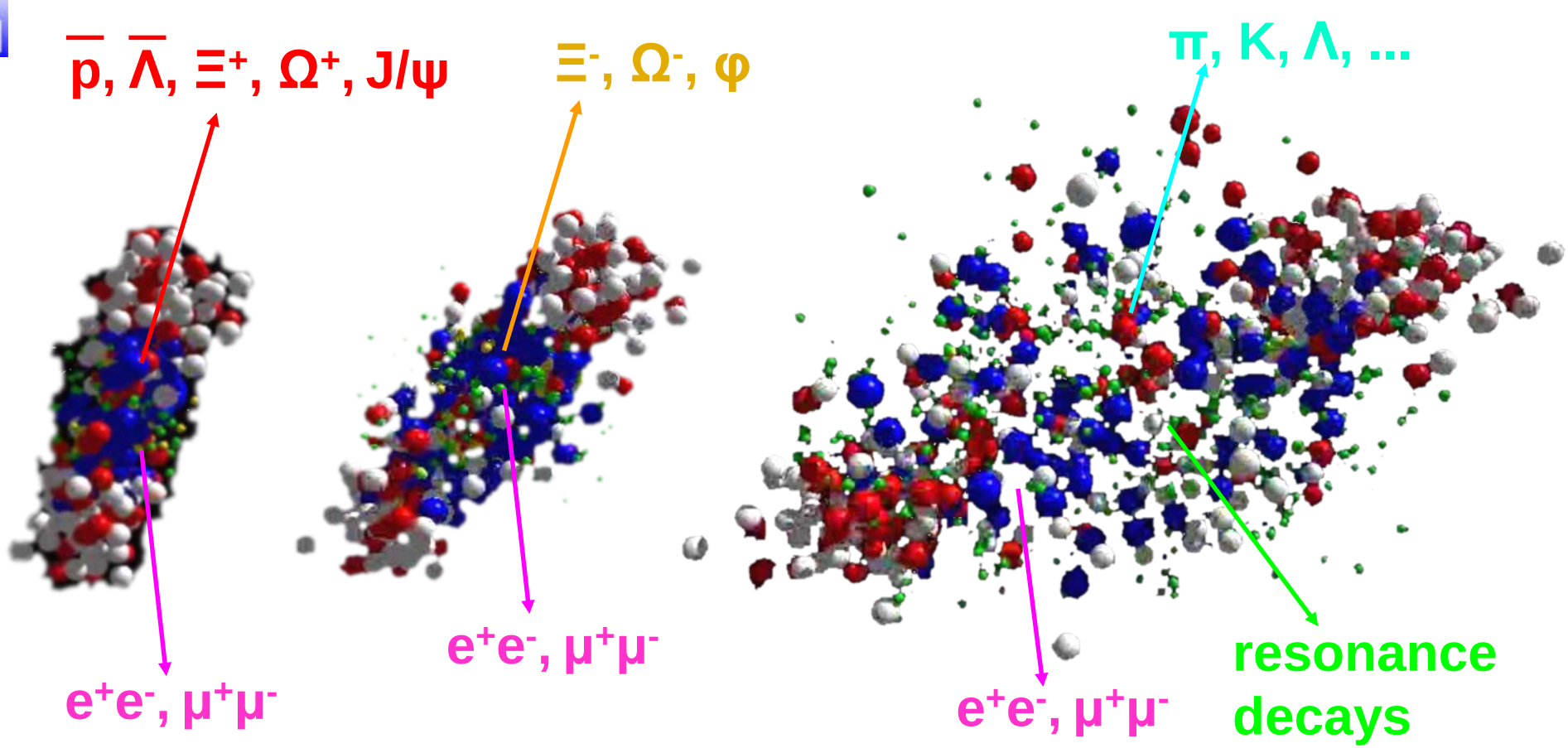
10 A GeV





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

Heavy – Ion Collisions



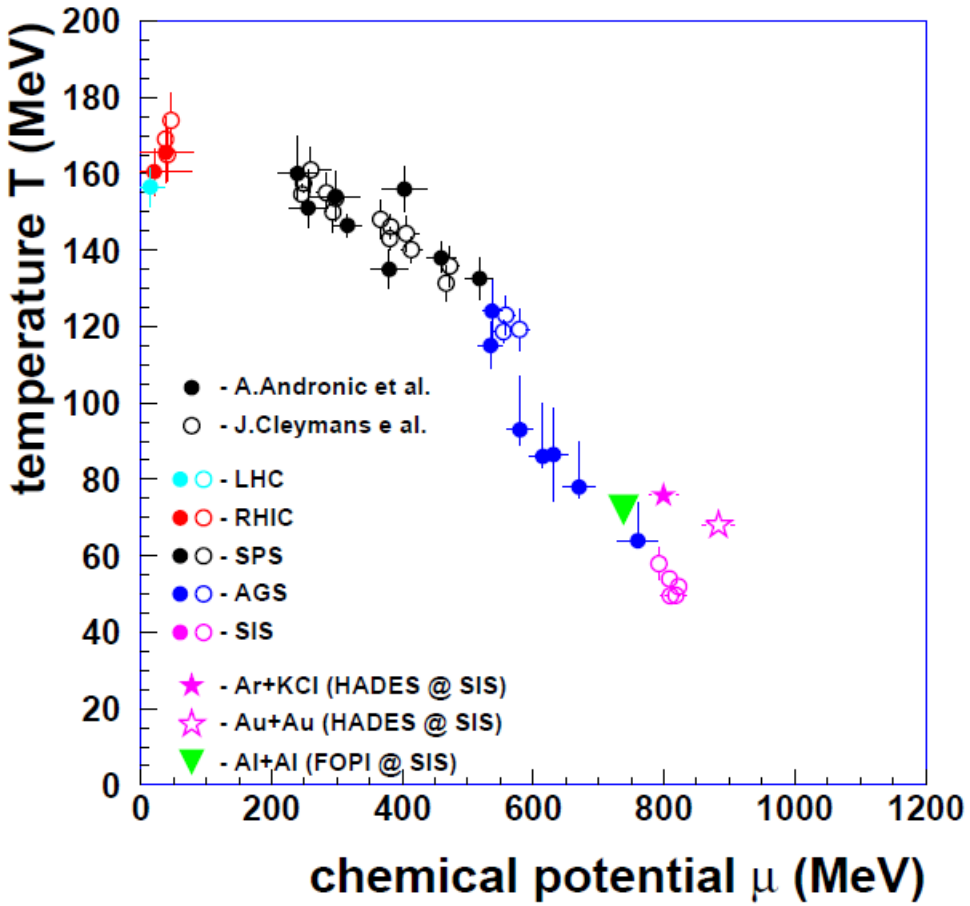
Hard probes (initial state)

Penetrating probes (integrate over collision history) Relicts (produced in dense phase)

Freeze-out (final state particles)

Thermalized (?) hadrons

Chemical Freeze-out data



Analyses of 'world data' in framework of Statistical Hadronisation Model

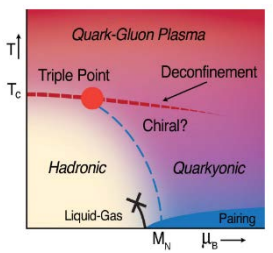
High energies: grandcanonical ensemble

Lower energies / small systems: canonical ensemble, strangeness suppression factor γ_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 ?

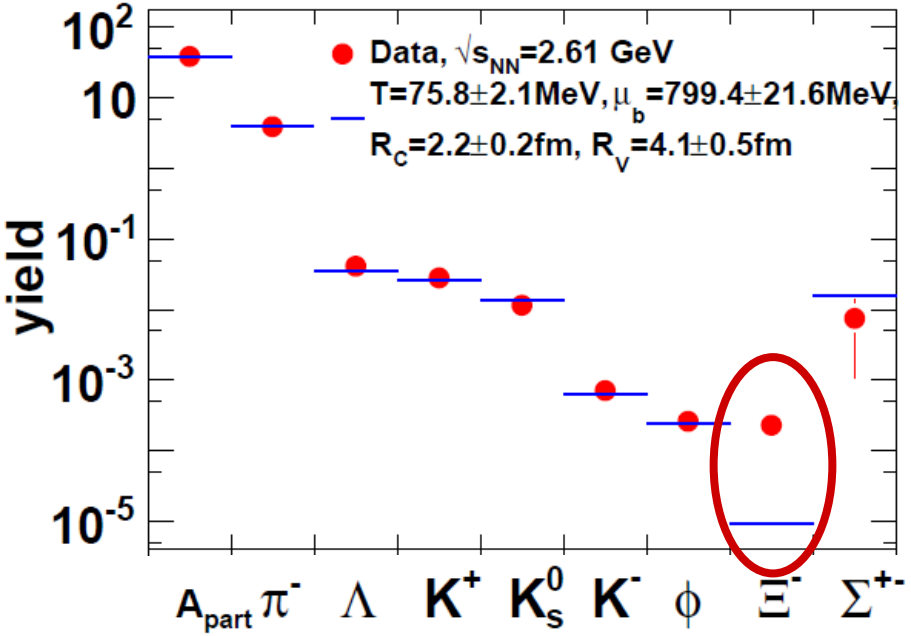


A. Andronic et al.,
Nucl. Phys. A837 (2010) 65

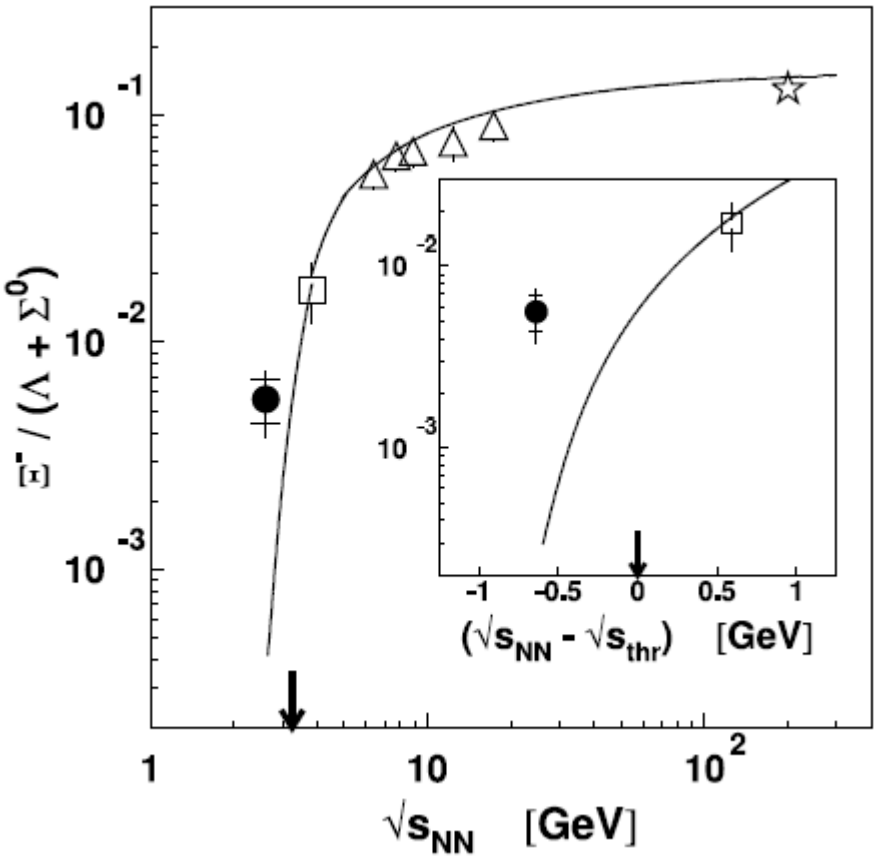
HADES: Sub-threshold Ξ^- - production

Ar+KCl reactions at 1.76A GeV

- Ξ^- yield by appr. factor 25 higher than thermal yield

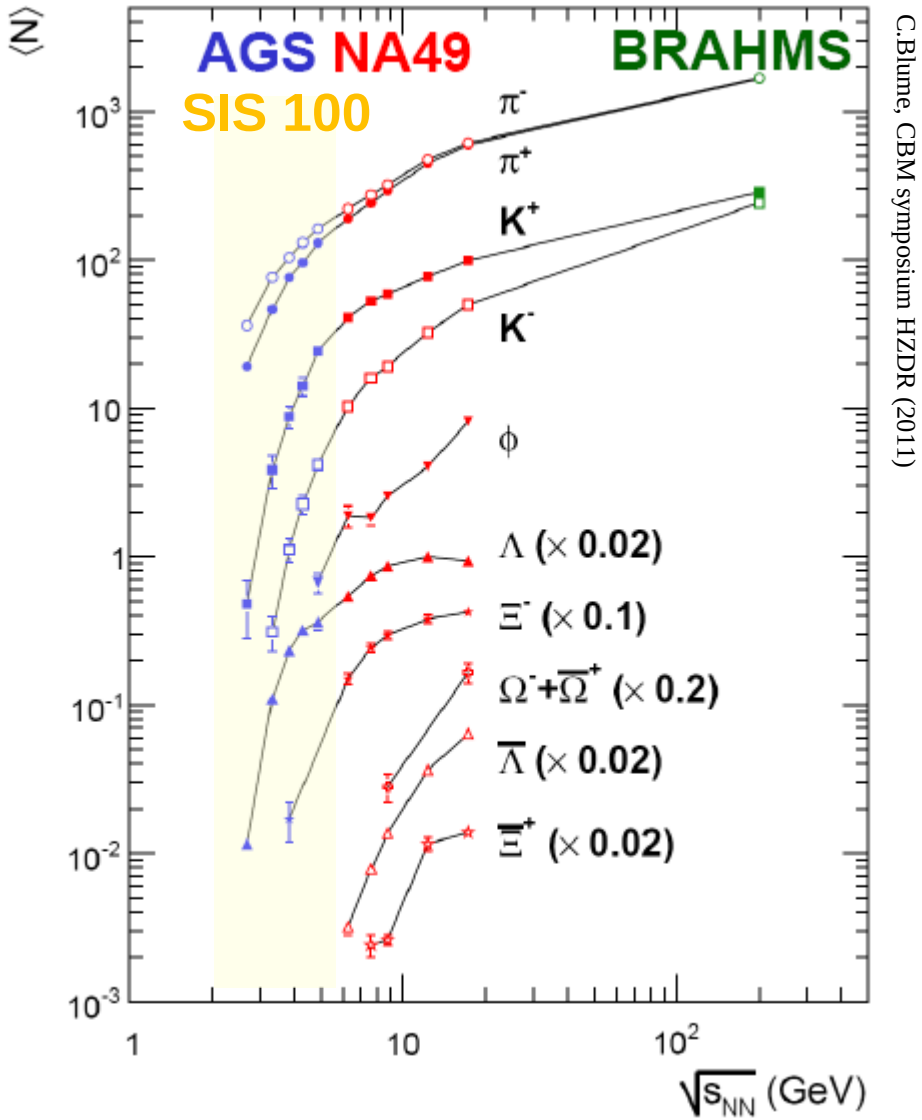


G. Agakishiev et al. (HADES), PRL103, 132301, (2009)



Final state particle abundance

Particle yield ratios from central Au + Au collisions

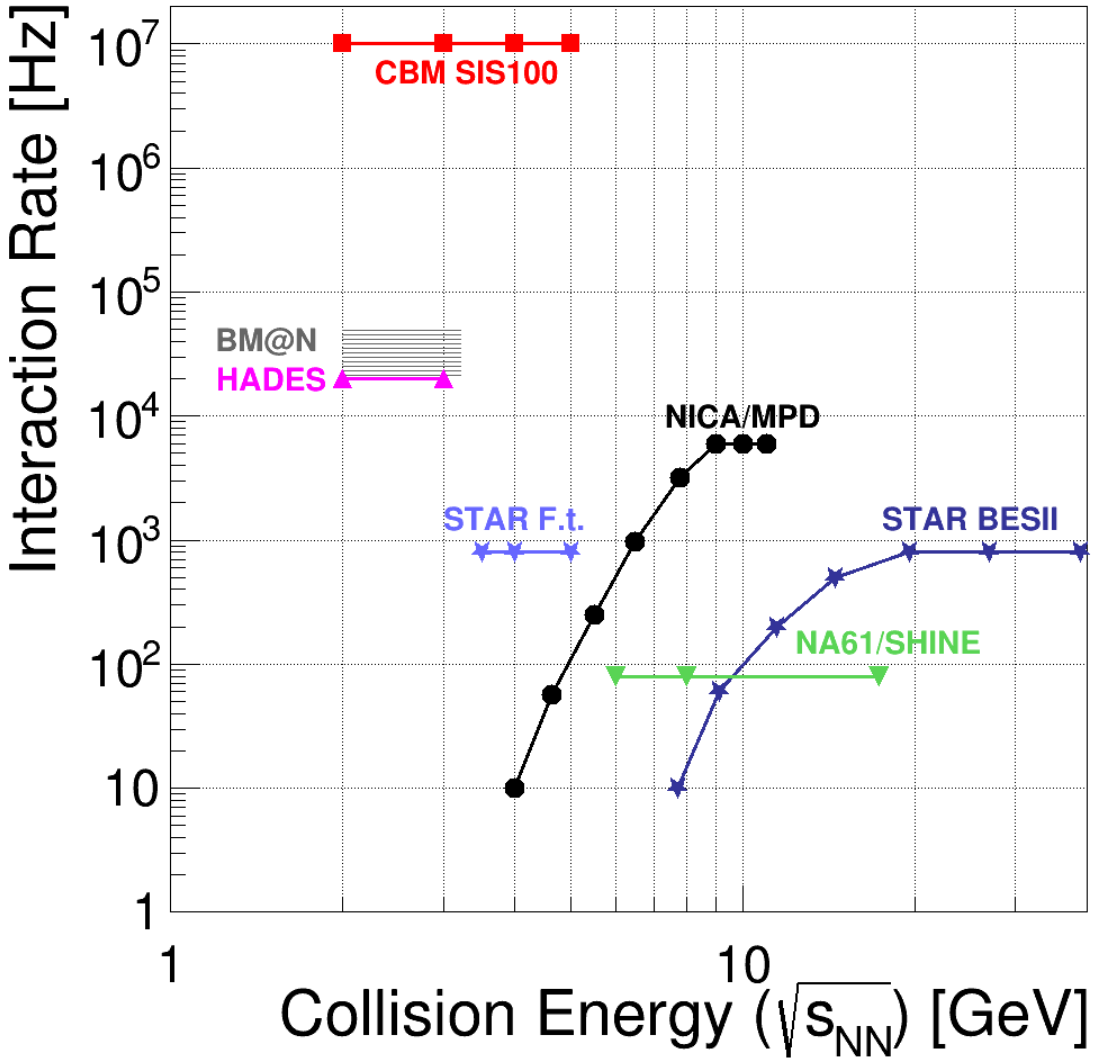


C.Blume, CBM symposium HZDR (2011)

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

Experiments exploring dense QCD matter



CBM physics program

QCD equation-of-state

- collective flow of identified particles (π,K,p,Λ,Ξ,Ω,...)
- particle production at threshold energies (multi-strange hyperons, charm)

Phase transitions, phase coexistence, critical point

excitation function of strangeness: Ξ^-(dss),Ξ^+(dss),Ω^-(sss),Ω^+(sss)

$\rightarrow$ chemical equilibration at the phase boundary

excitation function (invariant mass) of lepton pairs: thermal radiation,

"caloric curve"

event-by-event fluctuations of conserved quantities: "critical opalescence"

Chiral symmetry restoration at high ρ_B

in-medium modifications of vector mesons: $\rho,\omega,\phi \rightarrow e^+e^-(\mu^+\mu^-)$

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

Charm production at threshold energies

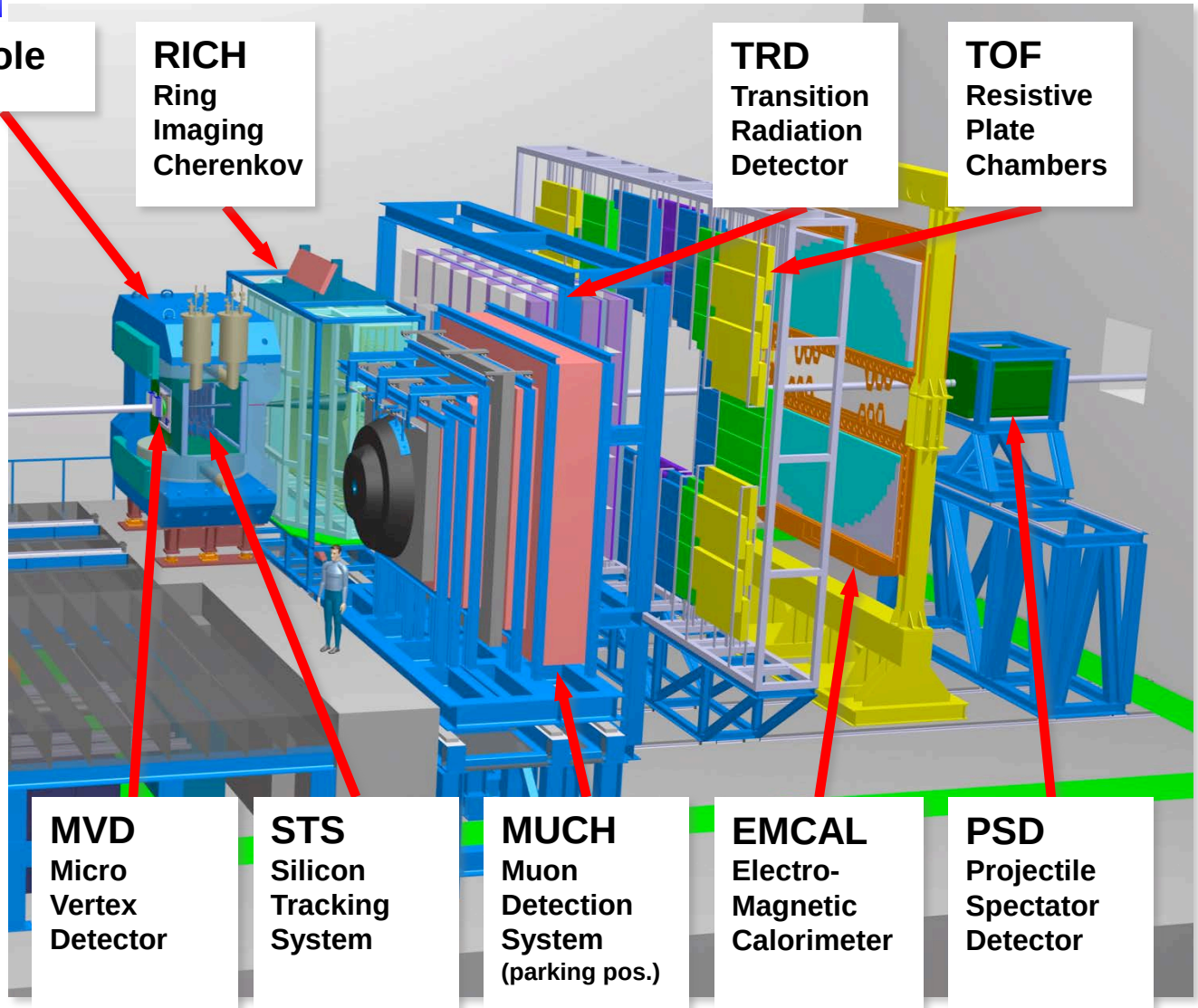
excitation function of (J/ψ, D^0, $D^{\pm}$) production in p+A and A+A

Strange matter

measurement (double-) lambda hypernuclei

search for meta-stable objects, e.g. strange dibaryons

CBM Experimental Setup

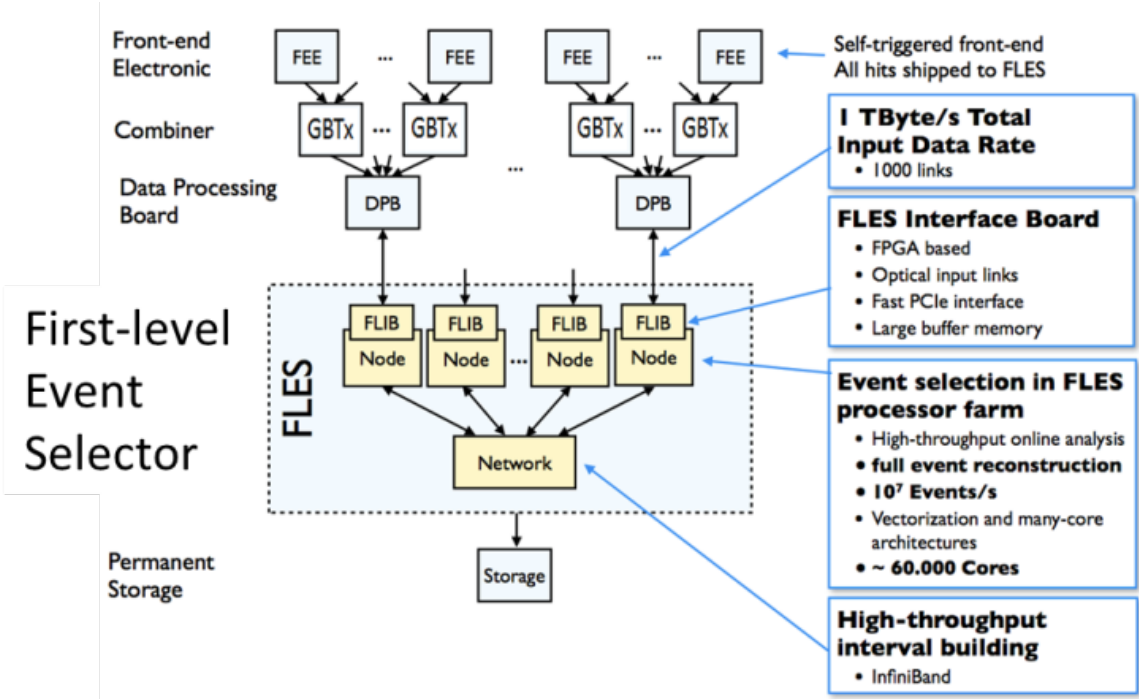


- **Tracking acceptance:** $2^o < \theta_{lab} < 25^o$
- **Free streaming DAQ**

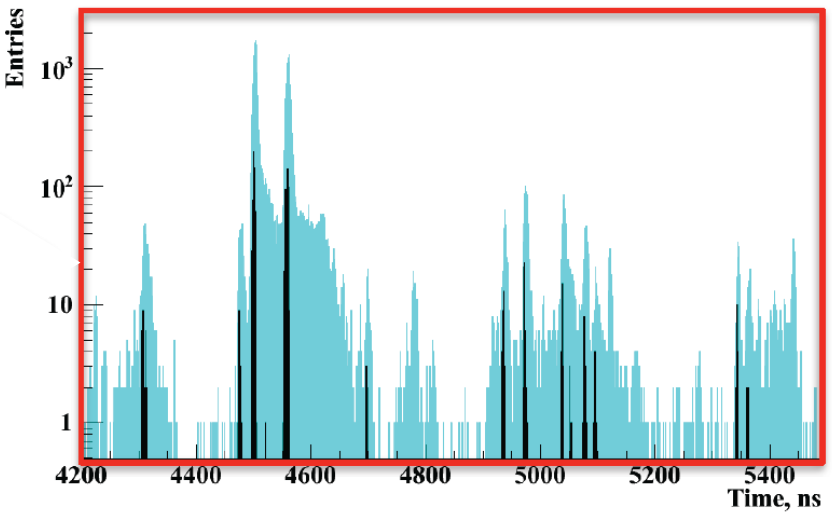
  R_{int} = 10 MHz (Au+Au)

  except:
  R_{int} (MVD)=0.1 MHz
- **Software based event selection**

CBM readout and online systems



- no hardware trigger of events,
- free streaming triggerless data,
- all detector hits with time stamps

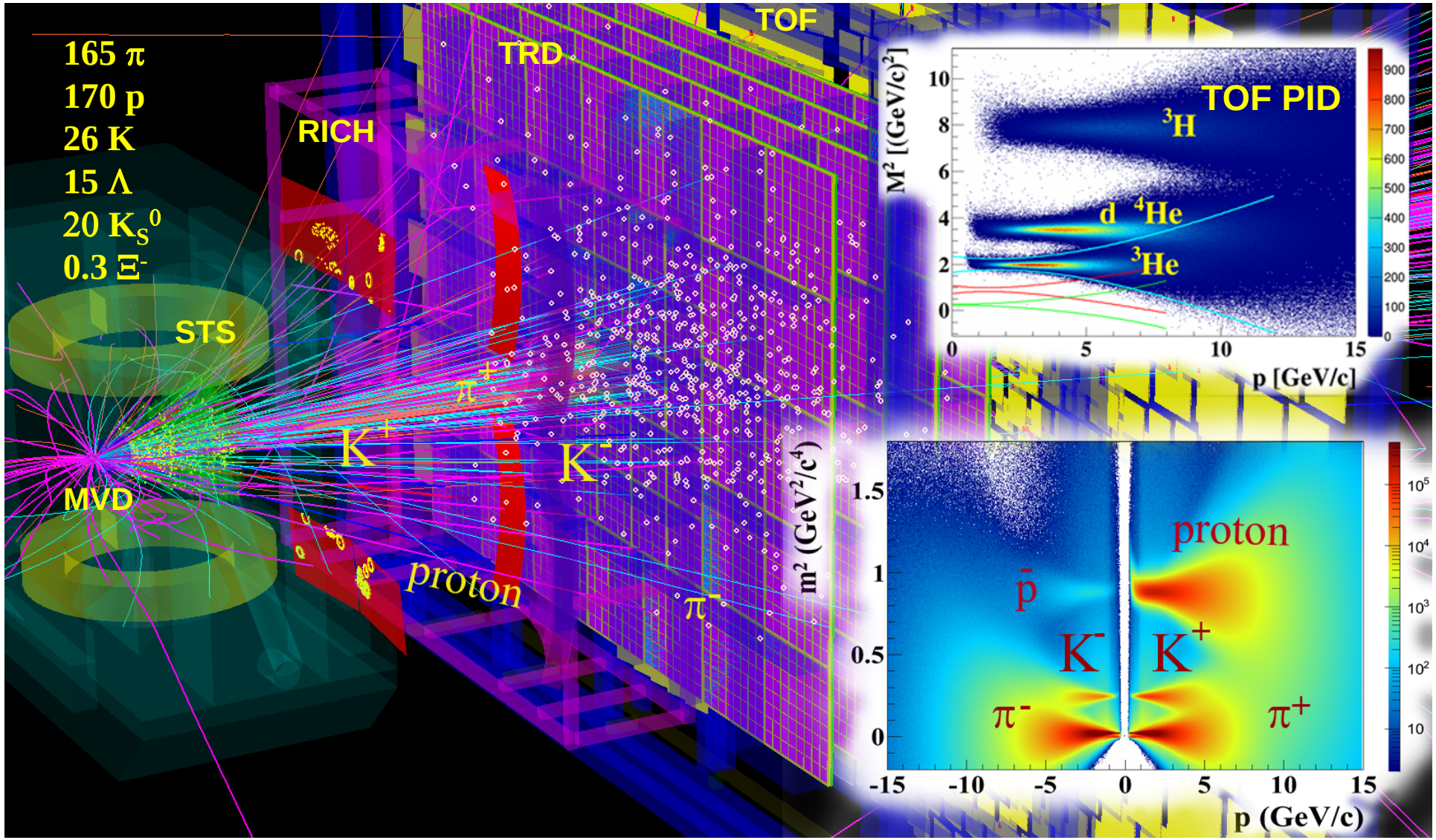


full online 4-D track and event reconstruction

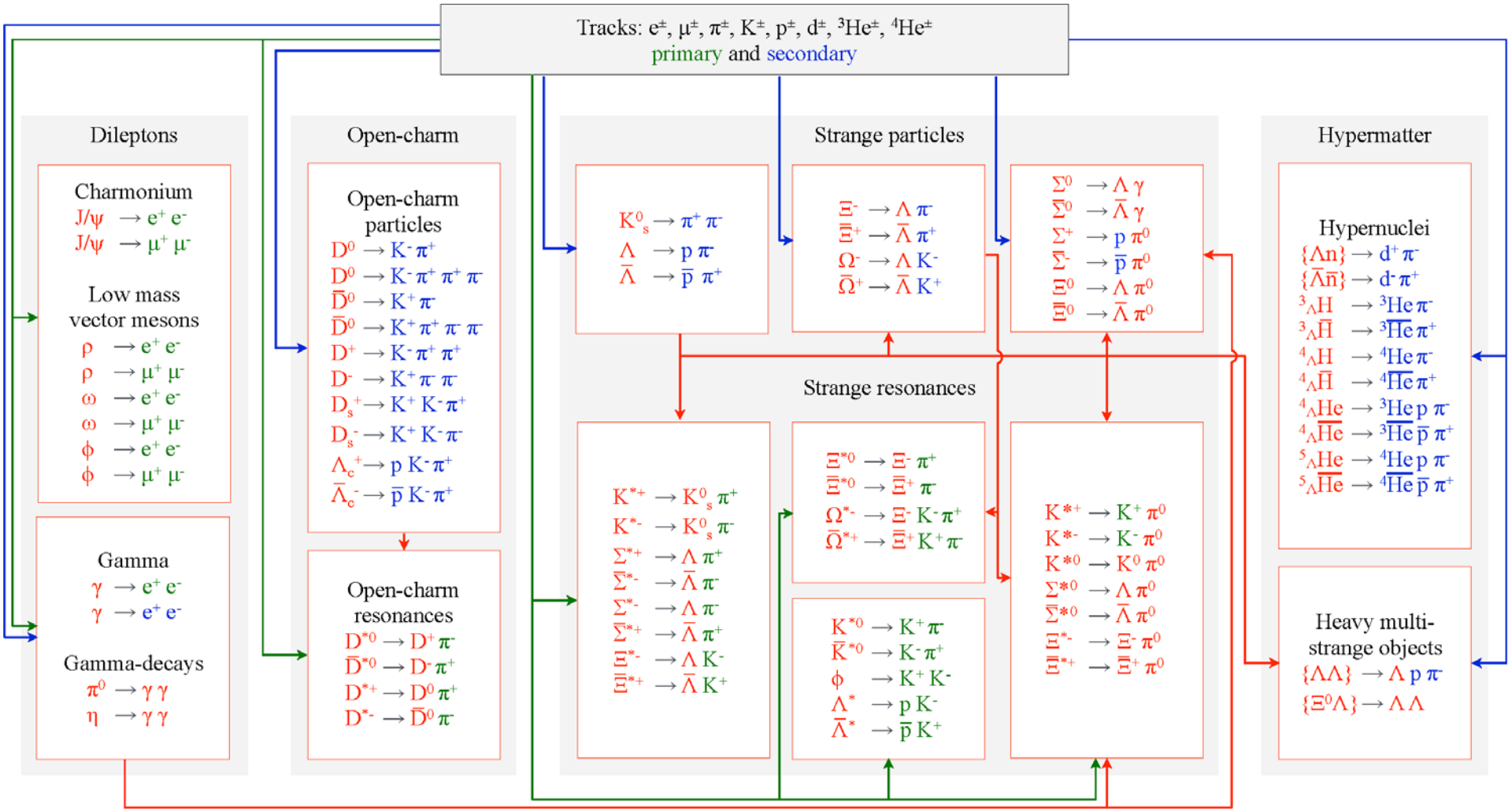
Requirement: online calibration

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

Y.Vasiliev (GSI)

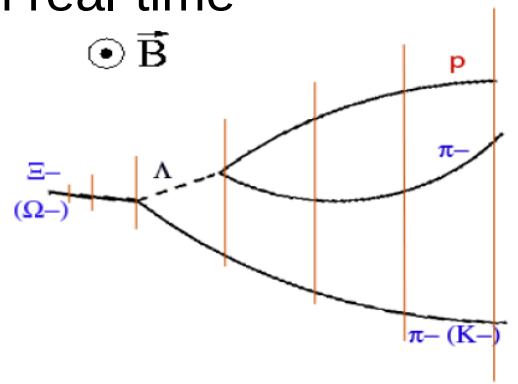


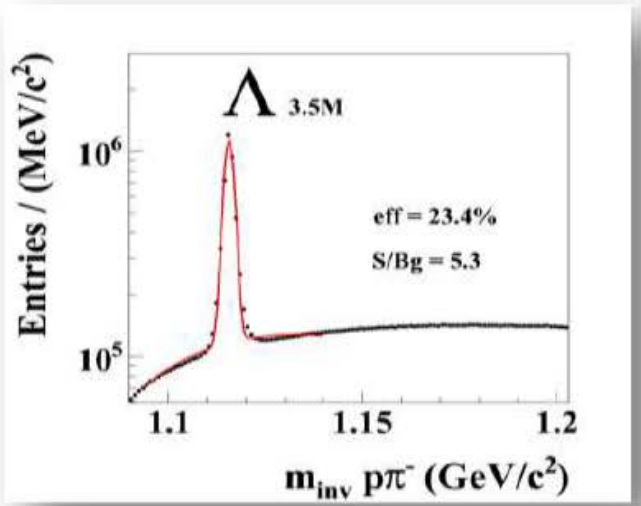
Online particle identification in CBM: The KF Particle Finder

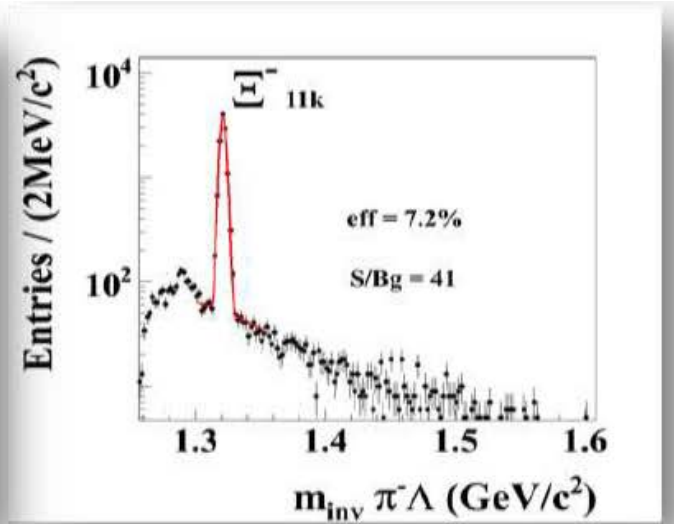


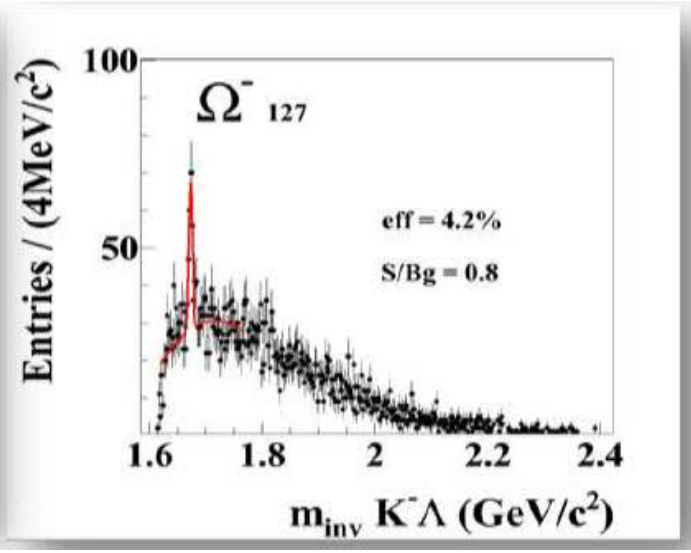
SIS 100- Hyperons

- central (b=0fm) 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?



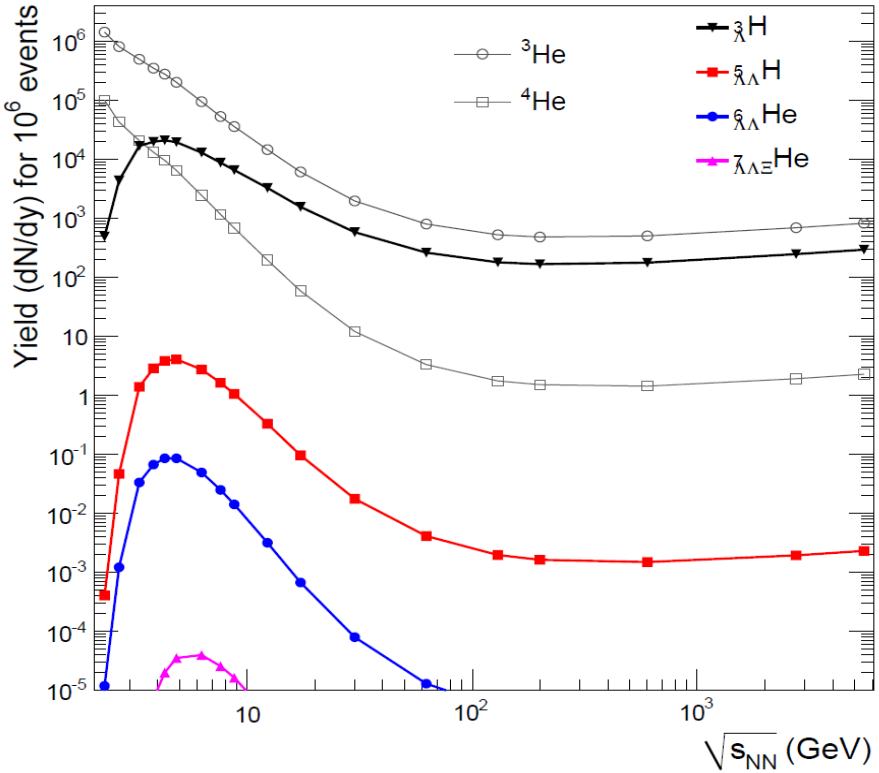




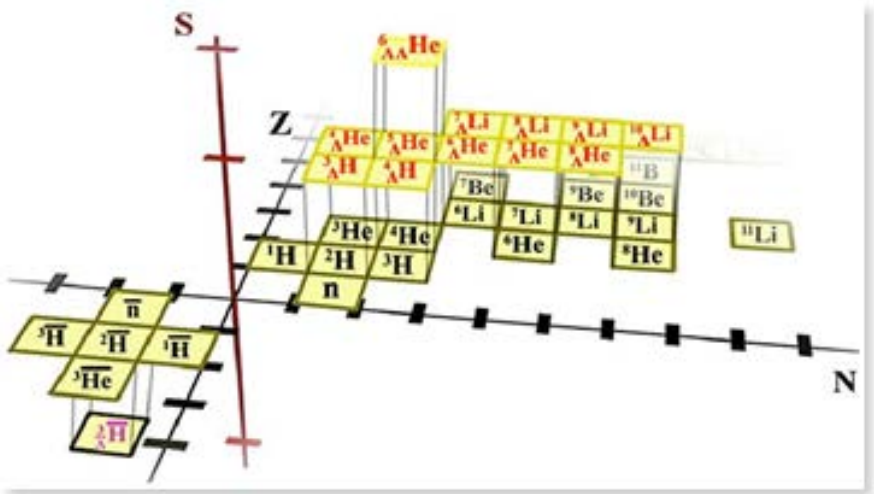


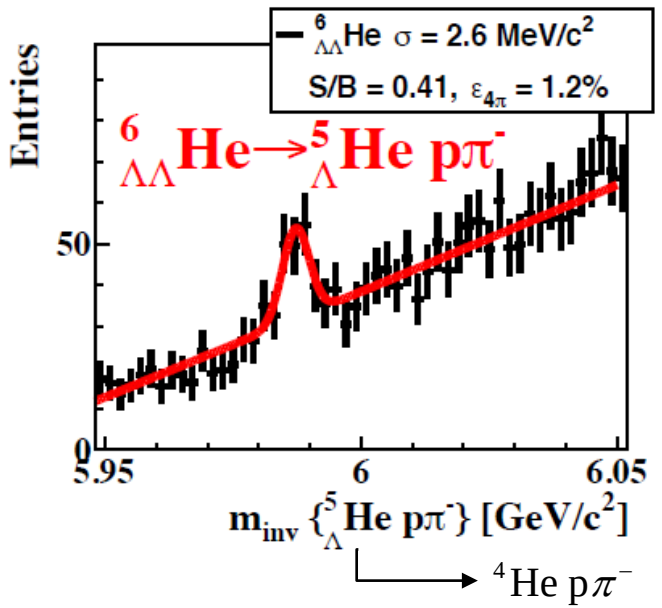
SIS 100- Hypernuclei

Thermal model prediction



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



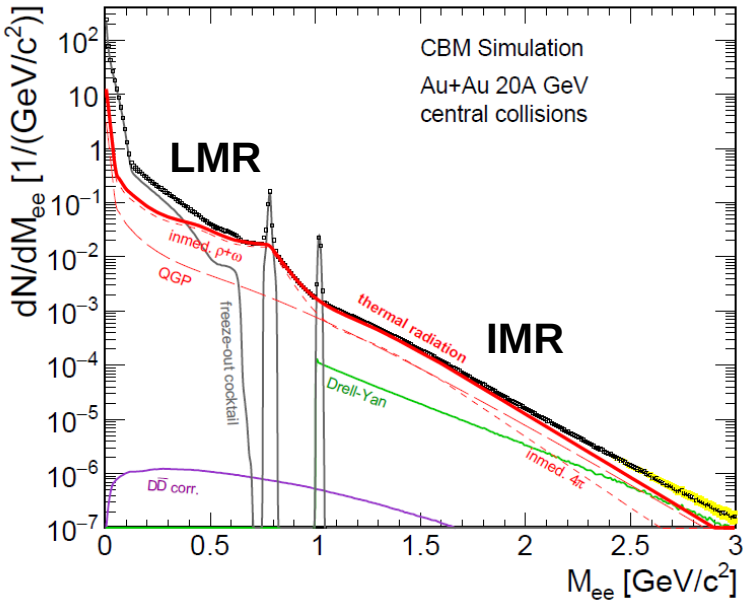


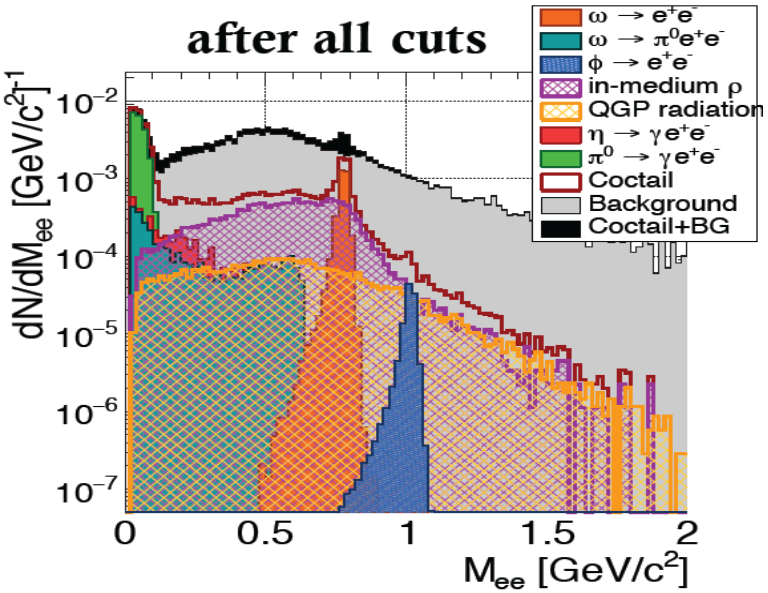
Simulation:
Au+Au collisions at 10 AGeV,
Background scaled to 10^{12} central events,
TOF PID

~ 7 days of running at max. luminosity

Dileptons as probes for dense matter

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



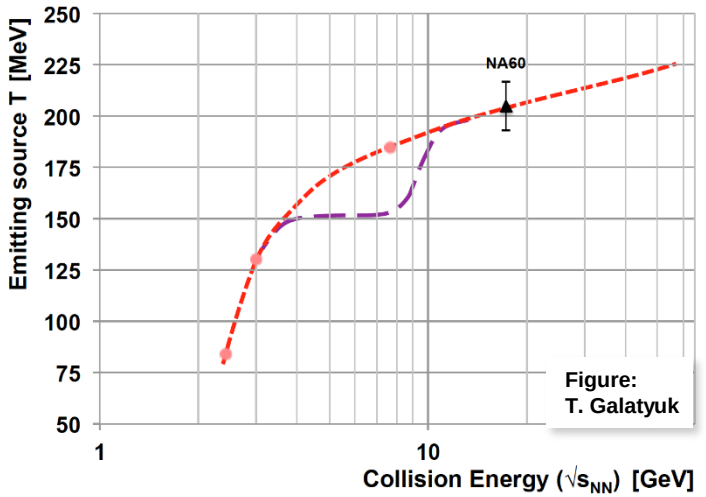


- 1M Au+Au (b=0 fm), 8 AGeV
- IMR: S/B > 1/100
- Statistical accuracy of 10% requires ~1 week of beamtime

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



Di-muon measurements

Dipol Magnet

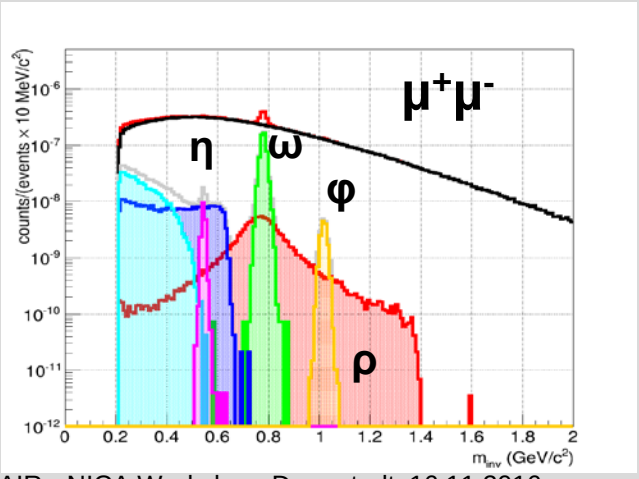
Silicon Tracking System

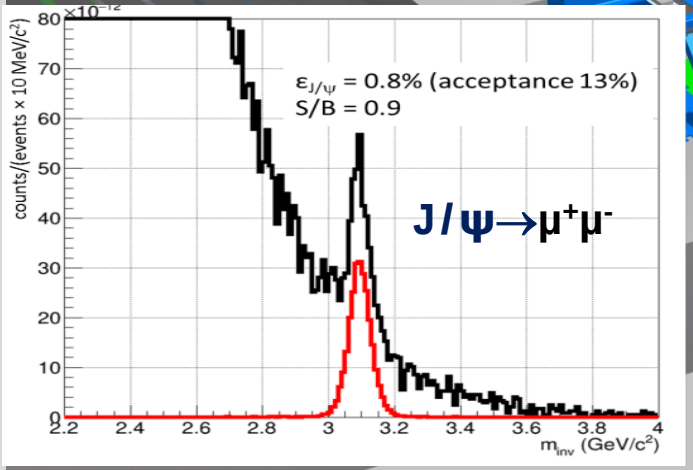
Transition Radiation Detector

Time of Flight Detector

+ DAQ/FLES HPC cluster

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





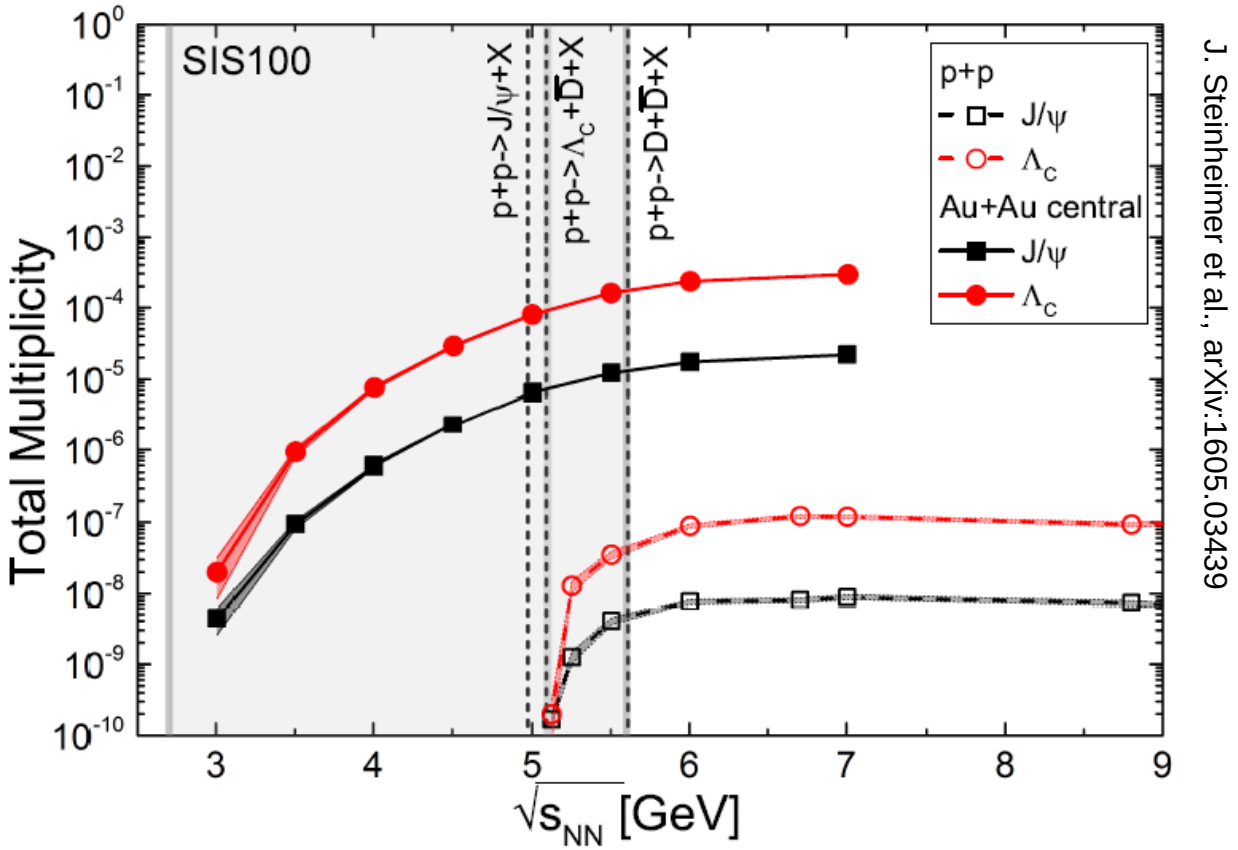
Muon Detector

Projectile Spectator Detector

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

Charm production at threshold

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



Yields are an order of magnitude larger than in HSD.

Charm production close to threshold energies new probe of cold and dense matter: measure excitation function of charm production in p+A and A+A (J/ψ, D^0, $D^{\pm}$)

CBM Technical Design Reports

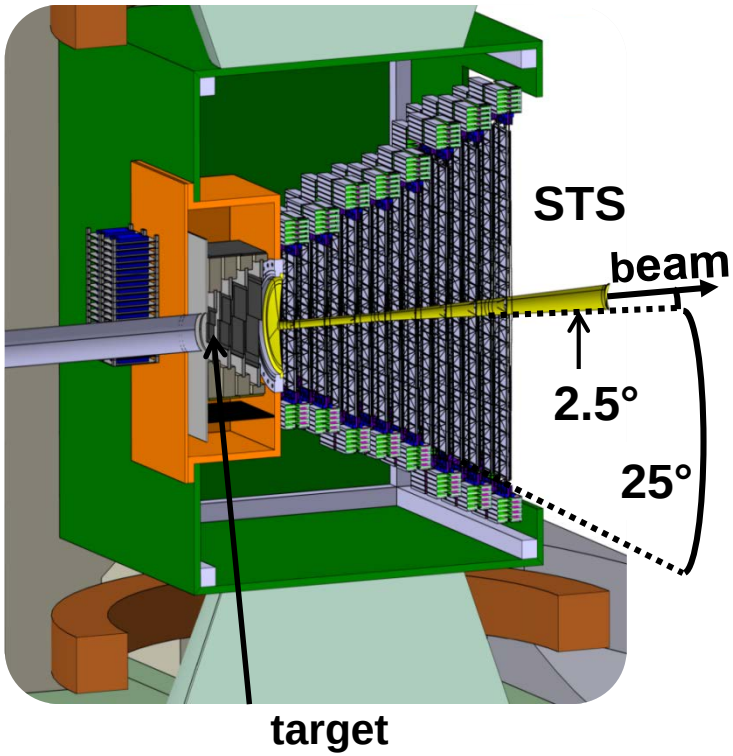
http://www.fair-center.eu/en/for-users/experiments/cbm/documents.html

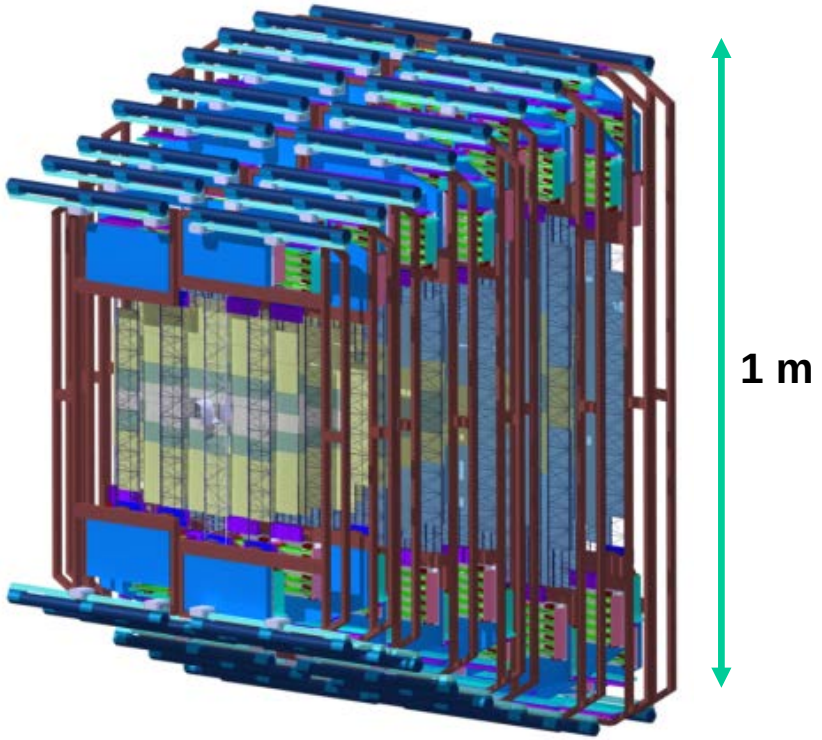
#	Project	TDR Status
1	Magnet	approved
2	STS	approved
3	RICH	approved
4	TOF	approved
5	MuCh	approved
6	HADES ECAL	approved
7	PSD	approved
8	MVD	submission 2017
9	DAQ/FLES	submission 2017
10	TRD	submission 2017
11	ECAL	submission 2017

CBM Silicon Tracking System

central detector of the CBM experiment:

- **measures tracks of charged particles, determines their momenta, in pA and AA collisions**
- **detects particle decay topologies**
- **challenge: large aperture, fine segmentation, low-mass, radiation hard , 0.1- 10 MHz r/o**

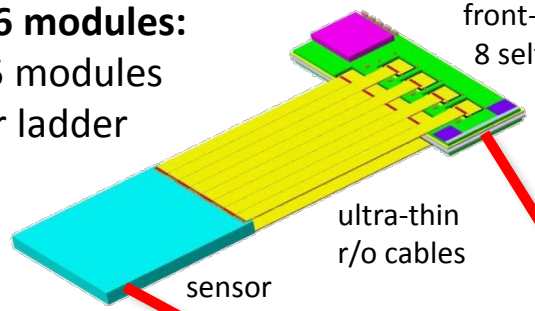




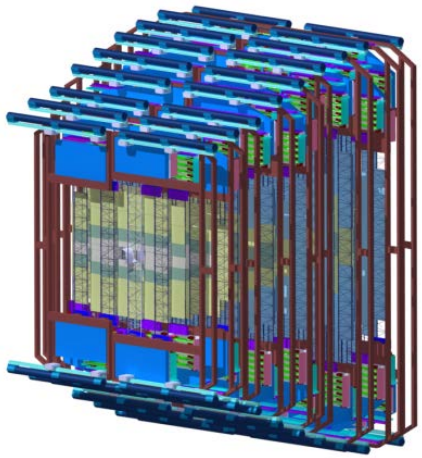
STS integration

- 8 stations, volume 2 m^3, area 4 m^2
- 896 detector modules
  - 1220 double-sided microstrip sensors
  - ~ 1.8 million read-out channels
  - ~ 14 400 r/o STS-XYTER ASICs
  - ~ 14 400 ultra-thin r/o cable stacks
- 106 detector ladders with 4-5 modules
- power dissipation: 42 kW (CO_2 cooling)

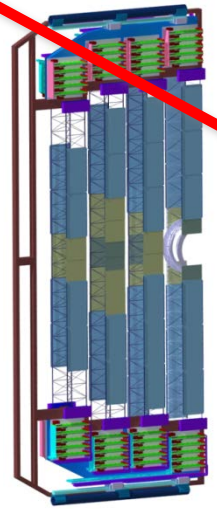
896 modules:
4-5 modules
per ladder



C-frame

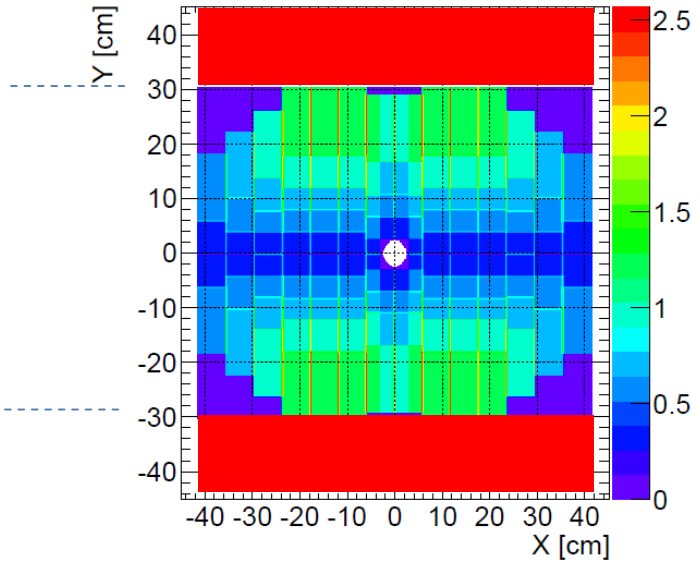


8 tracking stations



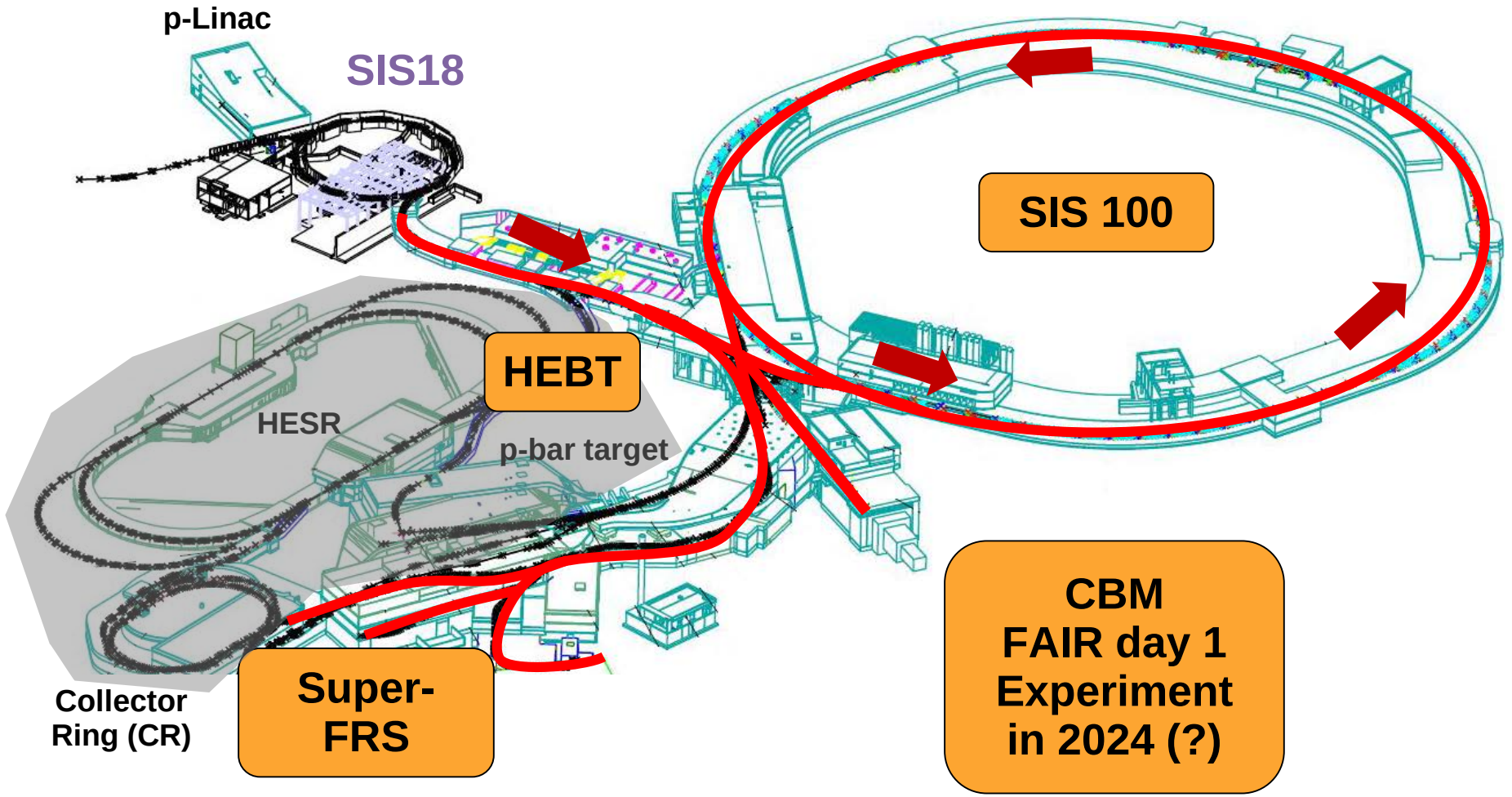
18 half-units

106 ladders



material budget of one tracking station [%X_0]

GSI/FAIR strategy: staged realization along the beam towards MSV

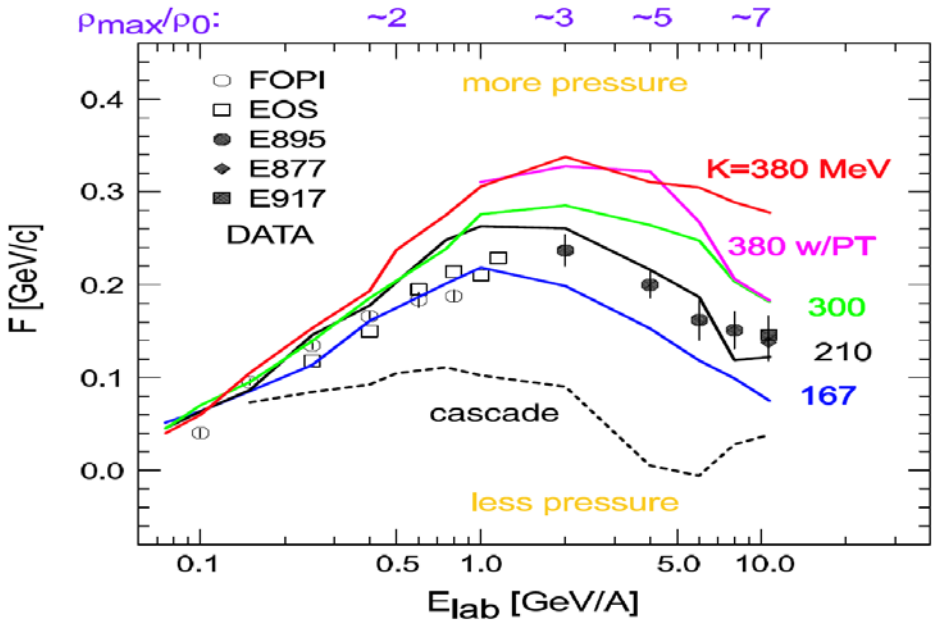


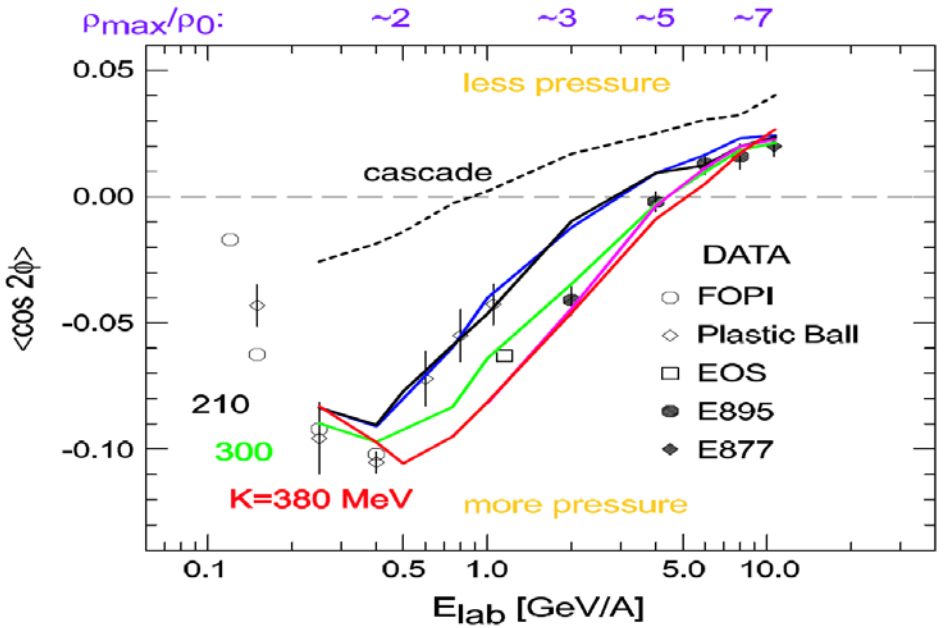
Excitation function of flow variables

$$F = \frac{d\langle p_x / A \rangle}{d(y / y_{cm})}$$

Proton flow

P. Danielewicz et al.
nucl-th/0112006 (2001),
Science 298, 1592 (2002)

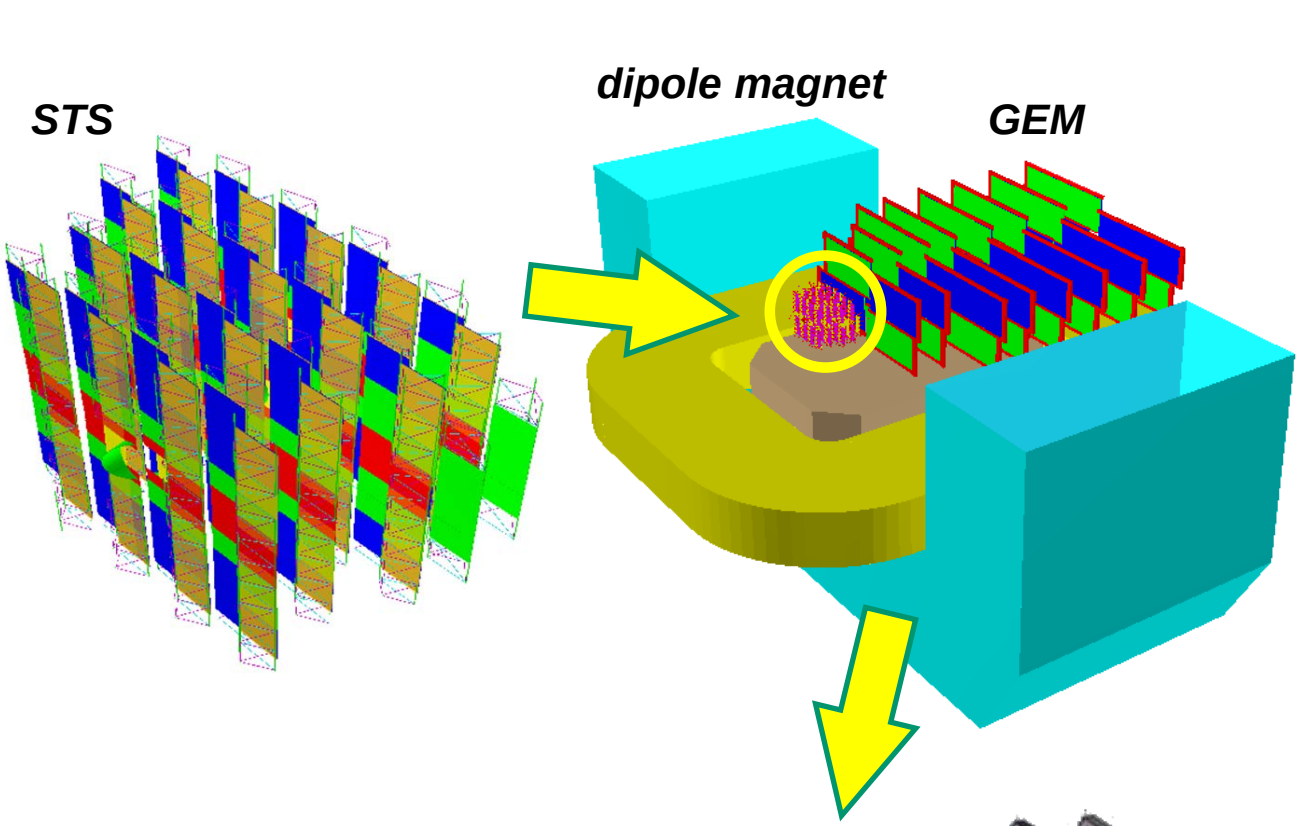


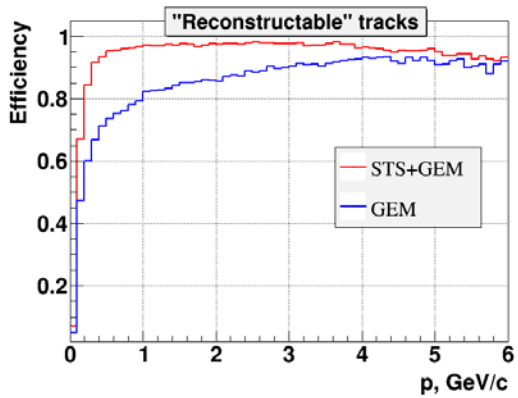


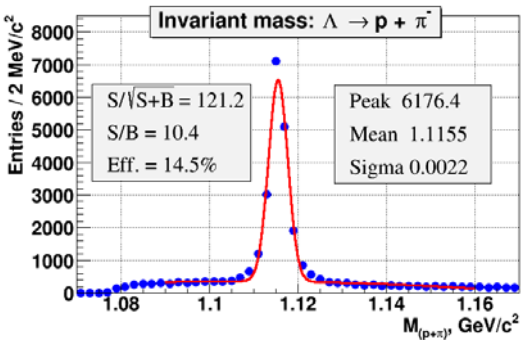
- **Sensitivity to Equation – of – State**
- **Largest sensitivity to model parameters in energy range 2 – 5 AGeV.**
- **Improvements possible with moderate detector requirements.**

FAIR Phase 0: CBM – BM@N

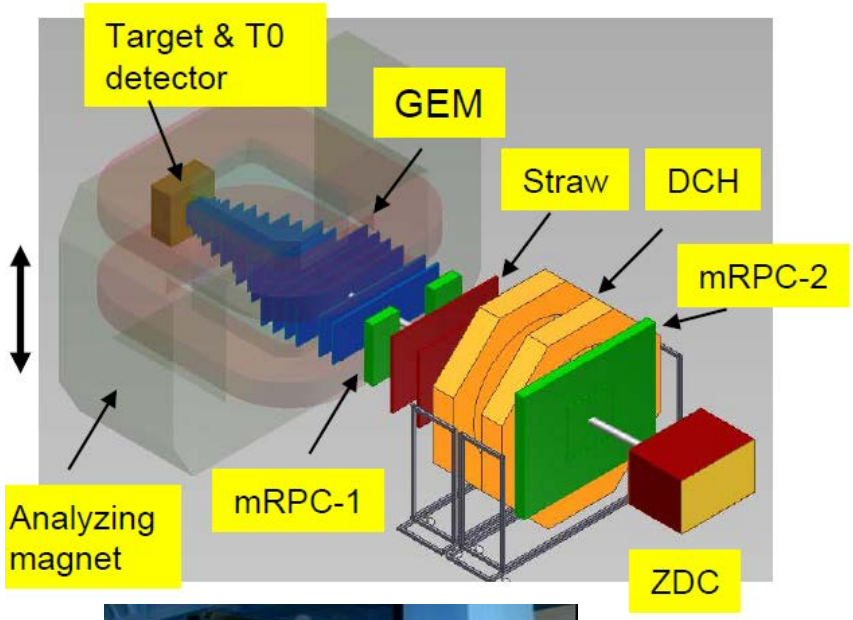
Install, commission and use 4 STS layers and the PSD at the BM@N experiment at the Nuclotron in JINR/Dubna (Au-beams up to 4.5 A GeV in 2018/19)







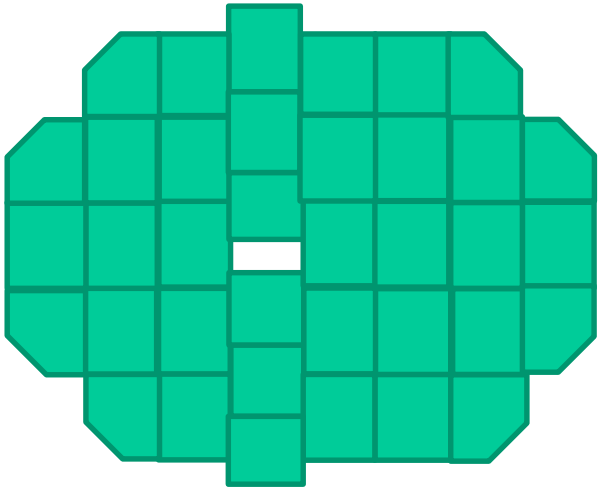
CBM Projectile Spectator Detector for BM&N

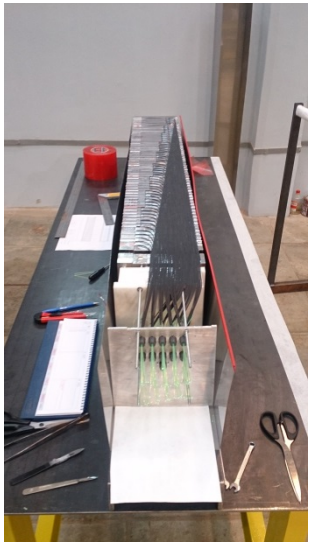


Projectile Spectator Detector (PSD) provides:

- **Centrality of the collision**
- **Orientation of the reaction plane**

BM&N already has ZDC, but old technology of light collection and detection is used ➡ problems with calibration, long term stability etc .





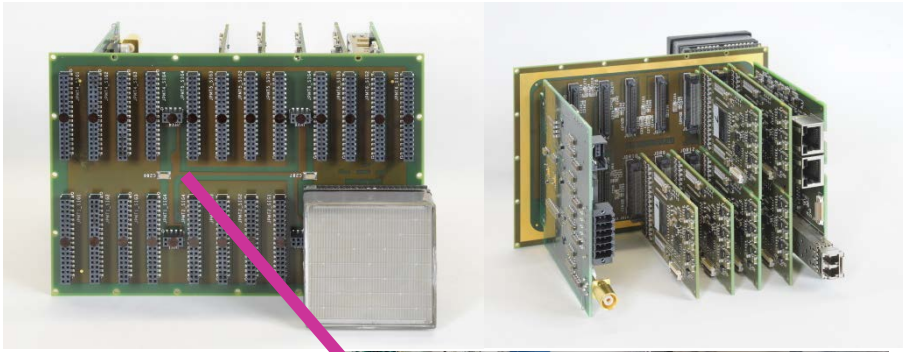
New ZDC with the hole in the center assembled from 36 PSD modules with use of modern technologies has been proposed.

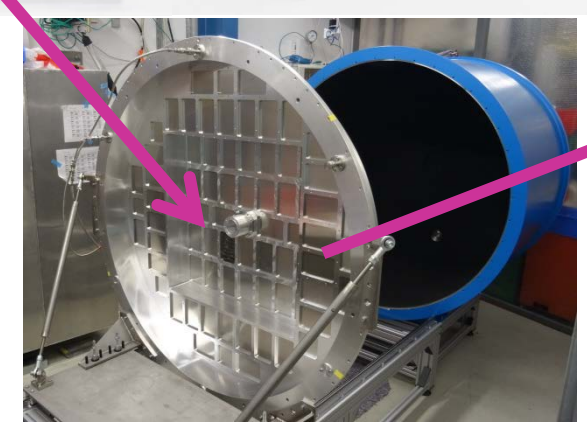
FAIR Phase 0: CBM – HADES (SIS18)

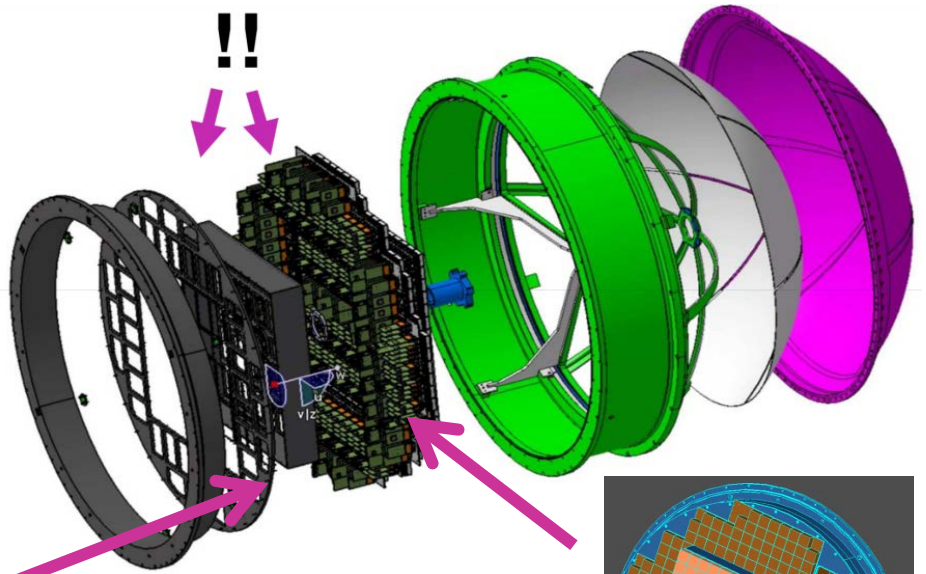
Install, commission and use 430 out of 1100 CBM RICH multi-anode photomultipliers (MAPMT) in HADES RICH photon detector,
Develop readout electronics,

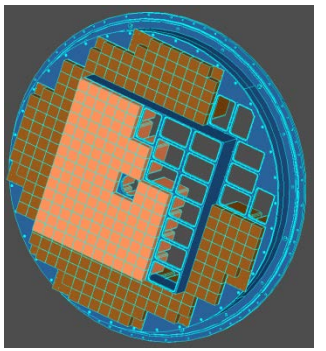
Physics questions:	**π – beam**	**– role of VMD in resonance decays**
(2018-2021)	**p+A,p+p**	**– in medium modification of hadrons**
	Ag + Ag	**– chiral symmetry restoration**

Photo of front and back side of backplane with electronics and MAPMT





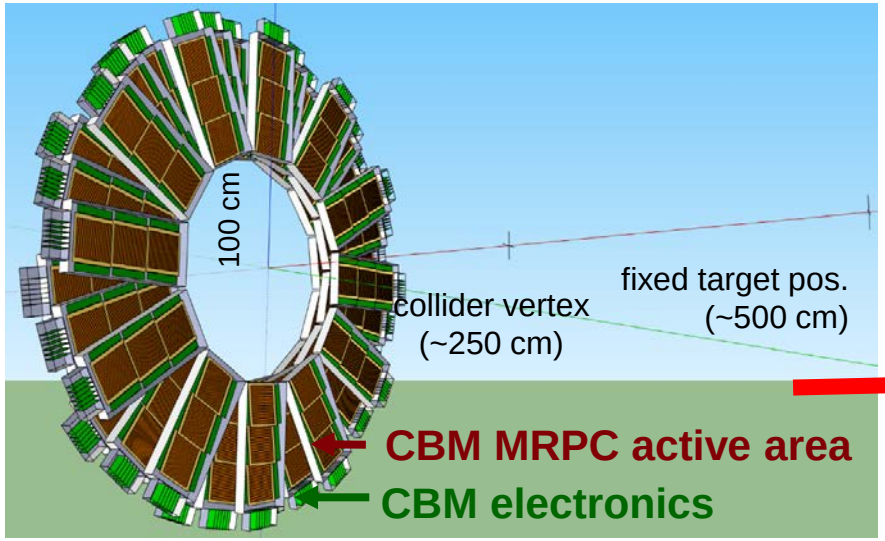


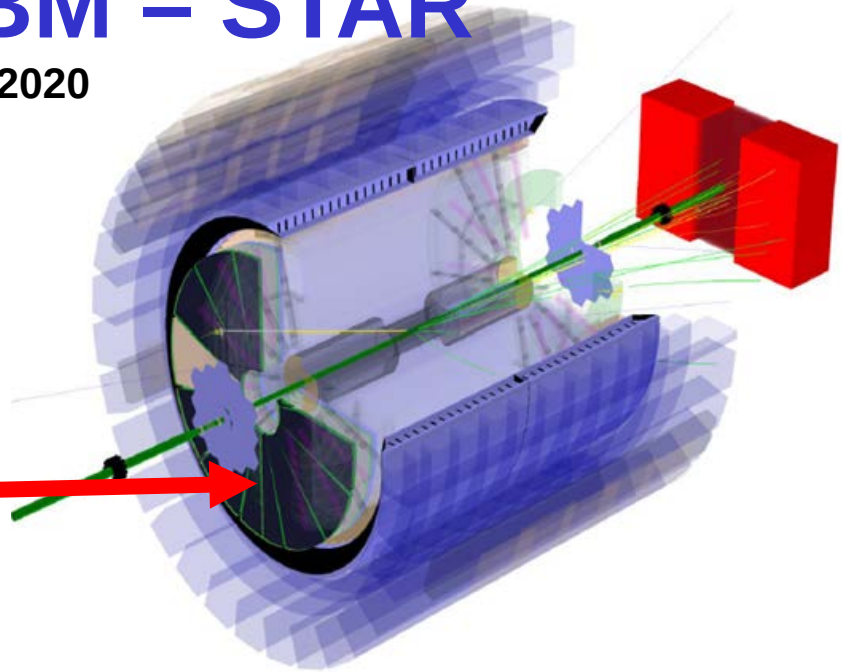


Sketch and photo of flange for HADES RICH (for 430 MAPMTs)

FAIR Phase 0: CBM – STAR

BES II data taking: 2019/2020



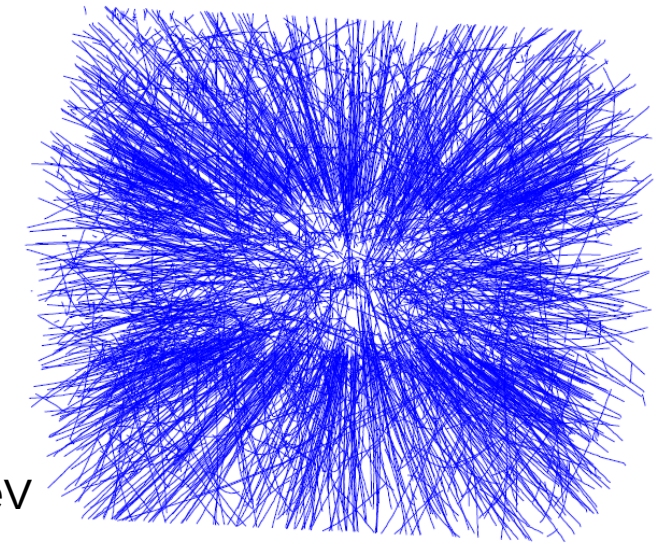


Install and operate ~ 10% of CBM TOF wall at STAR in Beam Energy Scan II campaign:

- 36 modules in wheel configuration
- 108 MRPC counters
- 6712 readout channels
- streaming DAQ system

Exercise tracking and PID with STAR data

Participate in physics analysis in energy range $\sqrt{s_{NN}}$ = 3 – 62 GeV
arXiv:1609.05102v1 [nucl-ex]

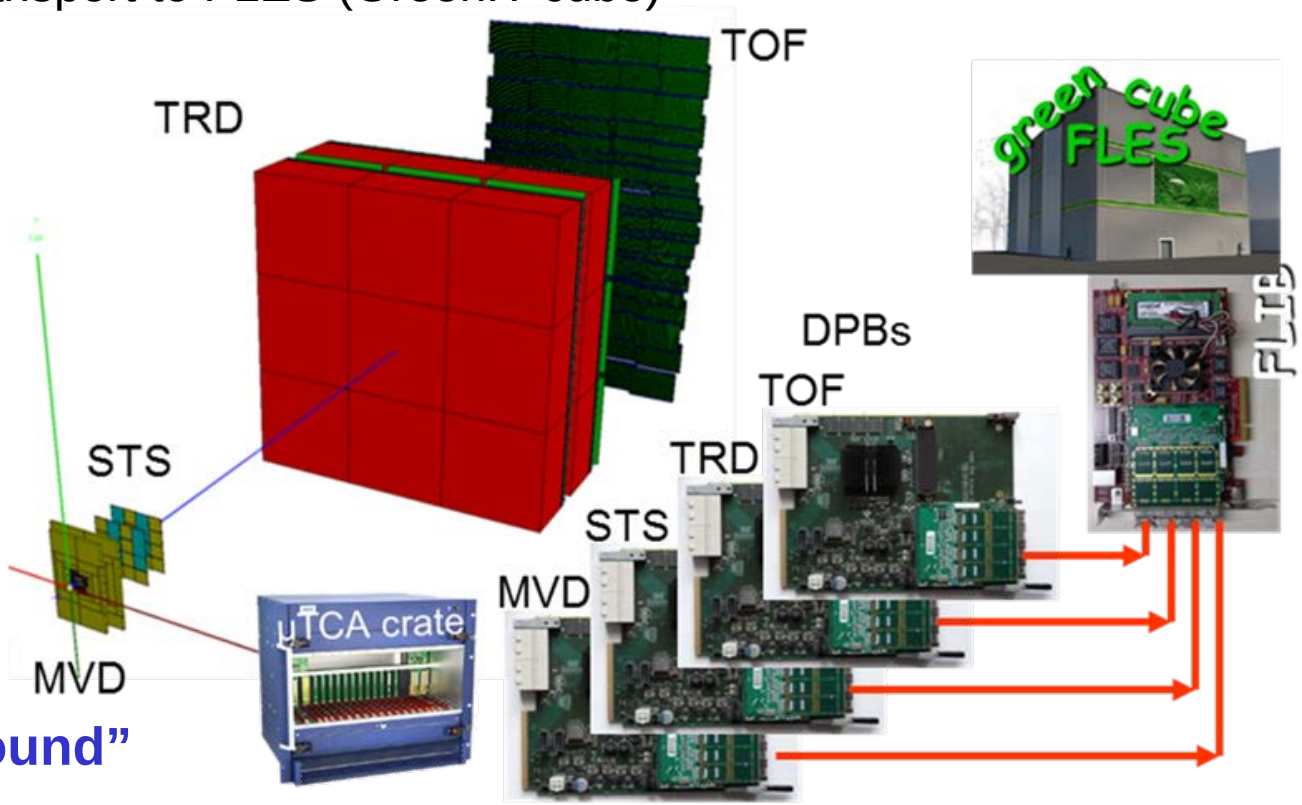


Cellular Automaton tracking

FAIR Phase 0: mCBM @ SIS18

Build mCBM at GSI/SIS18 for a full system test with high-rate nucleus-nucleus collisions from 2017 - 2020

- Set-up with full size detector modules and read-out chain
- Test and optimization of
  - performance of the detectors under experiment conditions
  - free streaming data transport to FLES (GreenIT cube)
  - online reconstruction
  - data analysis (offline)



“Technology Training Ground”

CBM Collaboration: 55 institutions, ~460 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
Eötvös 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.

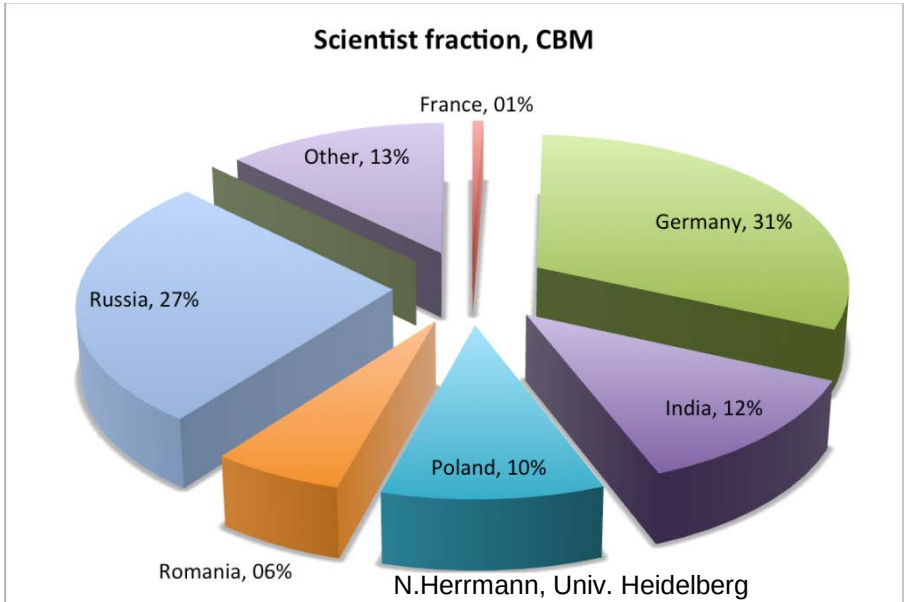
Poland:
AGH Krakow
Jag. Univ. Krakow
Warsaw Univ.
Warsaw TU

Romania:
NIPNE Bucharest
Univ. Bucharest

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

28th CBM Collaboration meeting in Tübingen
26-30 September 2016



N.Herrmann, Univ. Heidelberg

Summary / Conclusion

- **Phase structure of QCD will not be revealed by a single measurement.**

- **QCD matter physics needs facilities for systematic studies and 3. generation experiments -> CBM.**

  CBM rate capability: 10 MHz interaction rate!

- **CBM physics program**

  many open physics questions

  Equation – of – State of QCD matter
  in-medium modifications of hadrons
  phase transition to quarkyonic matter (?)
  hypernuclei and exotica

  substantial discovery potential at SIS100.

- **CBM strategy**

  systematic measurement of multi-dimensional observables of (rare) probes,
  use detector components as tool kit,
  build up experience by usage of components in running experiments,
  offer attractive opportunities for young scientists.