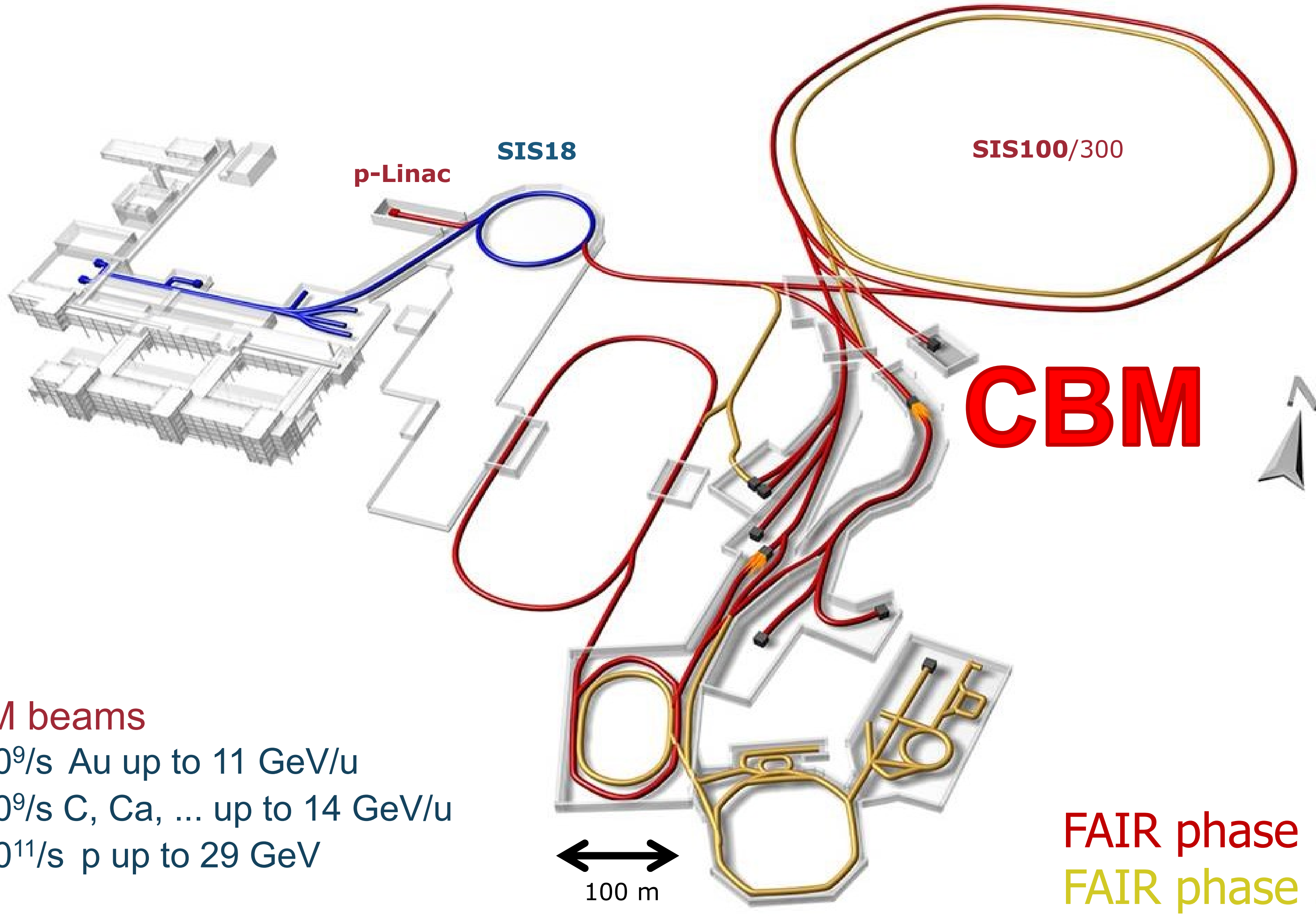
Status of the CBM experiment at FAIR

Norbert Herrmann
Heidelberg Univ.

Facility for Antiproton & Ion Research



FAIR phase 1
FAIR phase 2

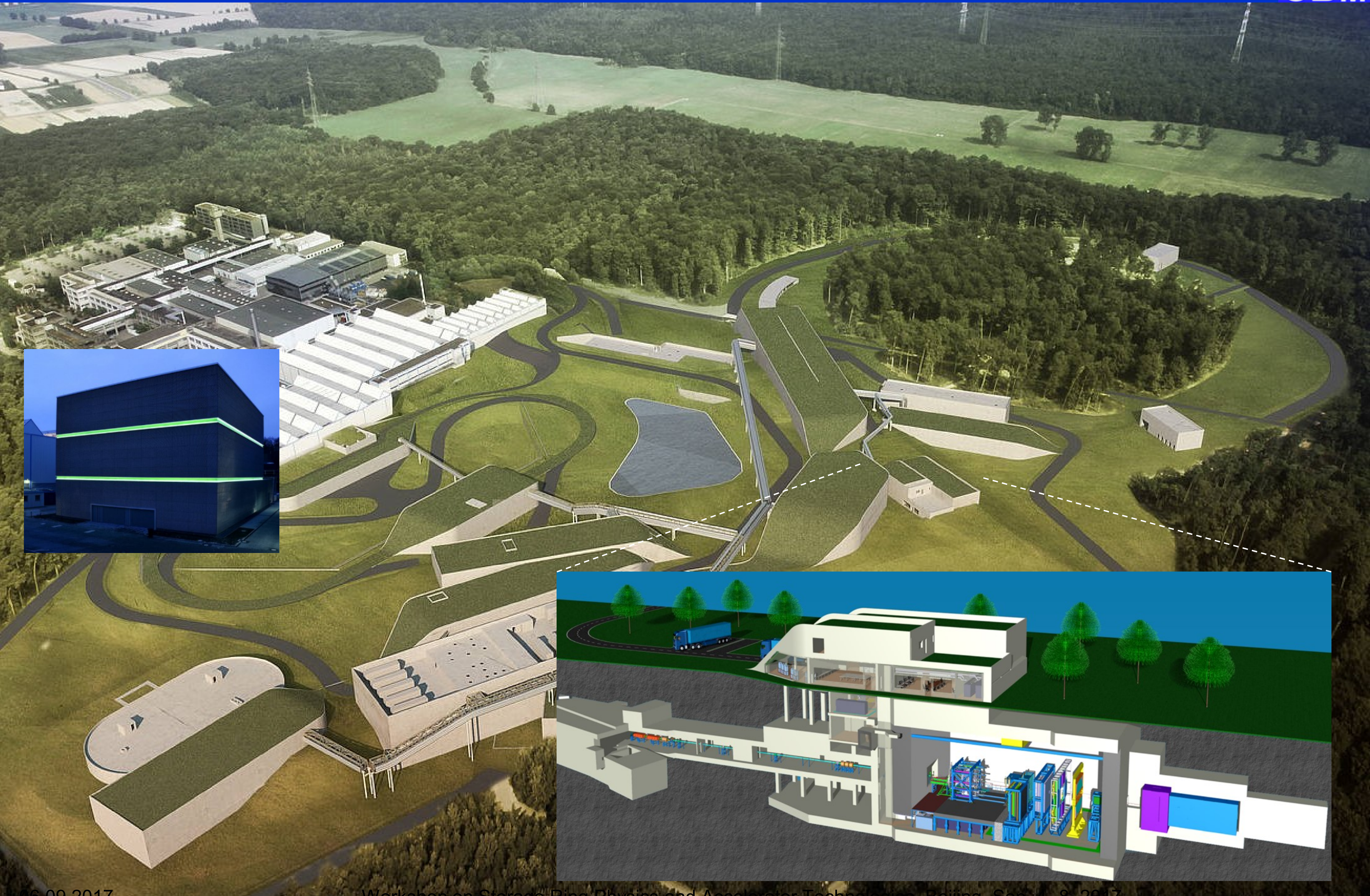
CBM beams

- 10^9/s Au up to 11 GeV/u
- 10^9/s C, Ca, ... up to 14 GeV/u
- 10^{11}/s p up to 29 GeV

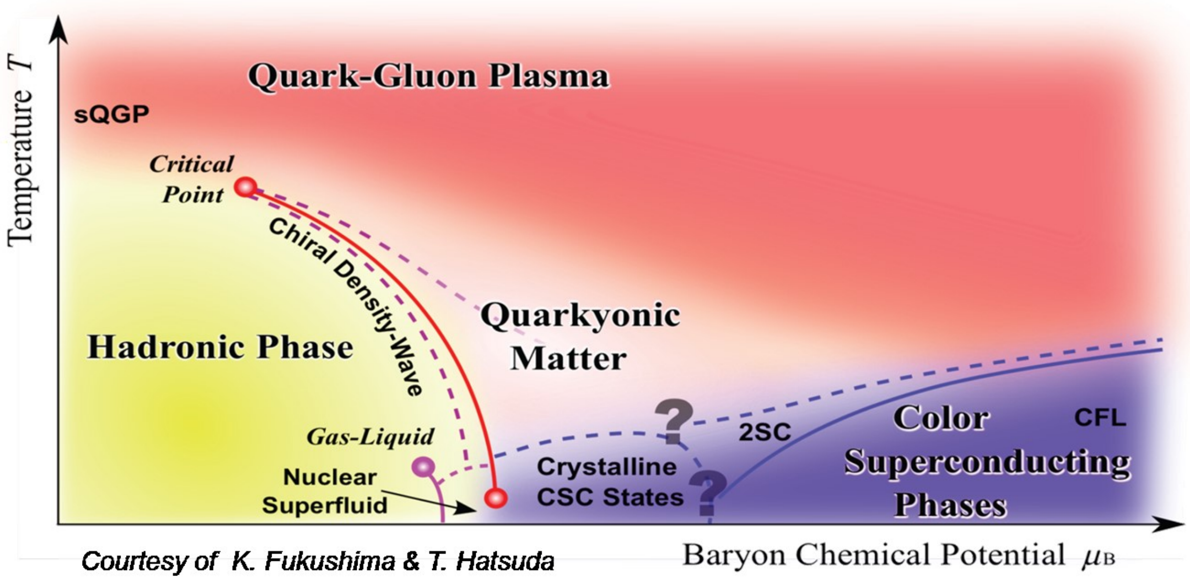
FAIR Groundbreaking ceremony July 4th, 2017

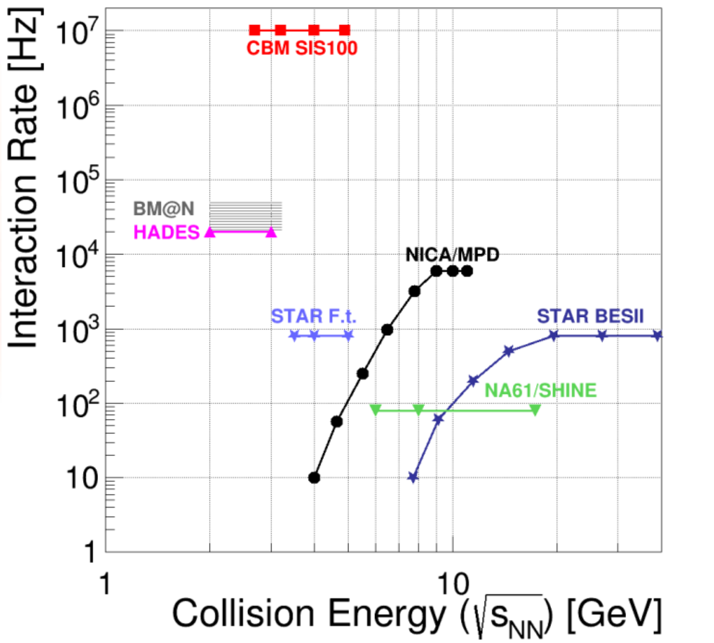
- Civil construction of SIS 100 tunnel and CBM cave started
- Detector installation/ commissioning 2021 – 2024
- FAIR MSV fully operational 2025
- CBM will get first SIS100 beams

CBM @ FAIR: ≤ 2025 !



CBM – Goals





Common CBM/HADES goal:

Systematically explore baryon-rich dense matter with rare probles.

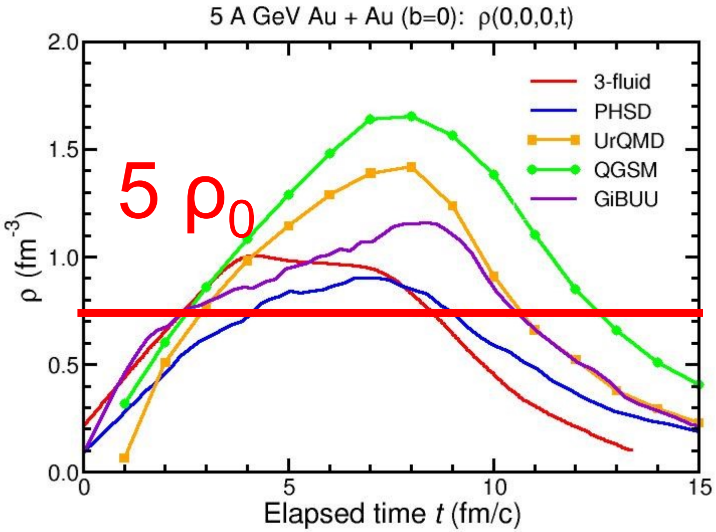
Timeline: Restart of SIS18 beams: 2018 (FAIR Phase 0)

Start of SIS100 operation: 2024 (FAIR Day 1, FAIR Phase 1)

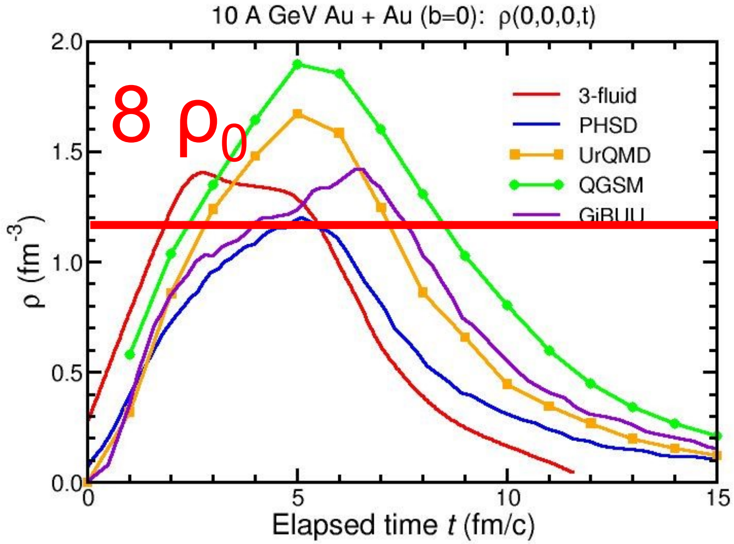
Outline: Conditions at FAIR, Observables, Detector layout, Experiment status & plans.

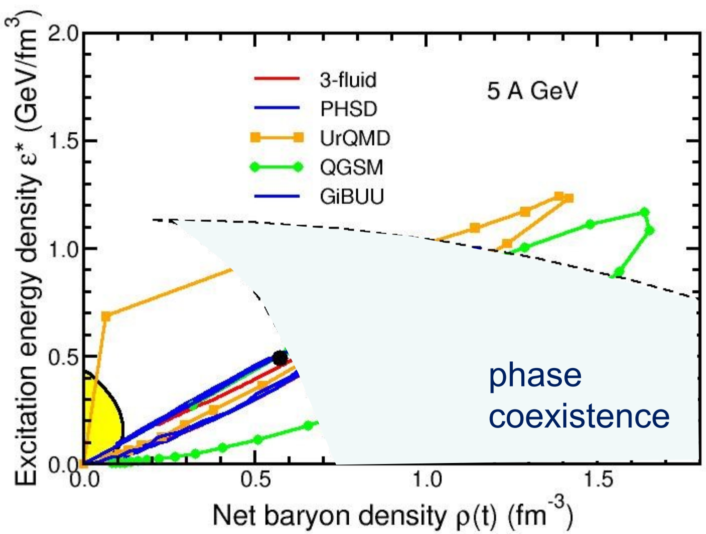
Baryon densities in central Au+Au collisions
Baryon densities in central Au+Au collisions

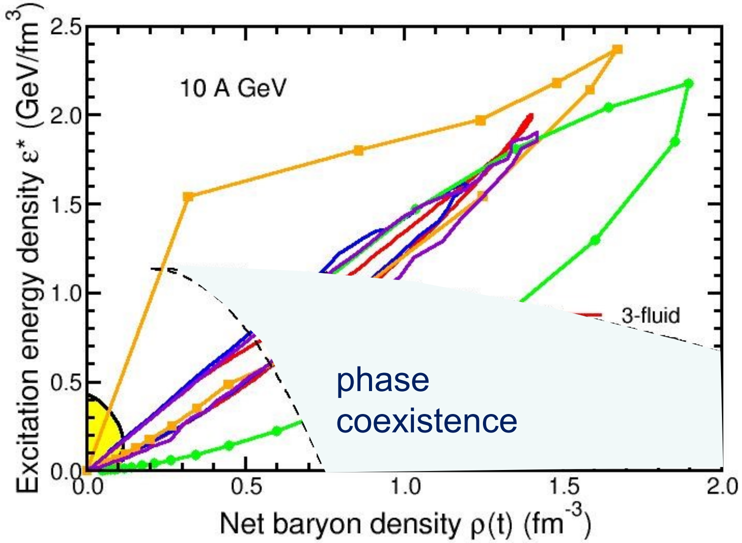
5 A GeV



10 A GeV

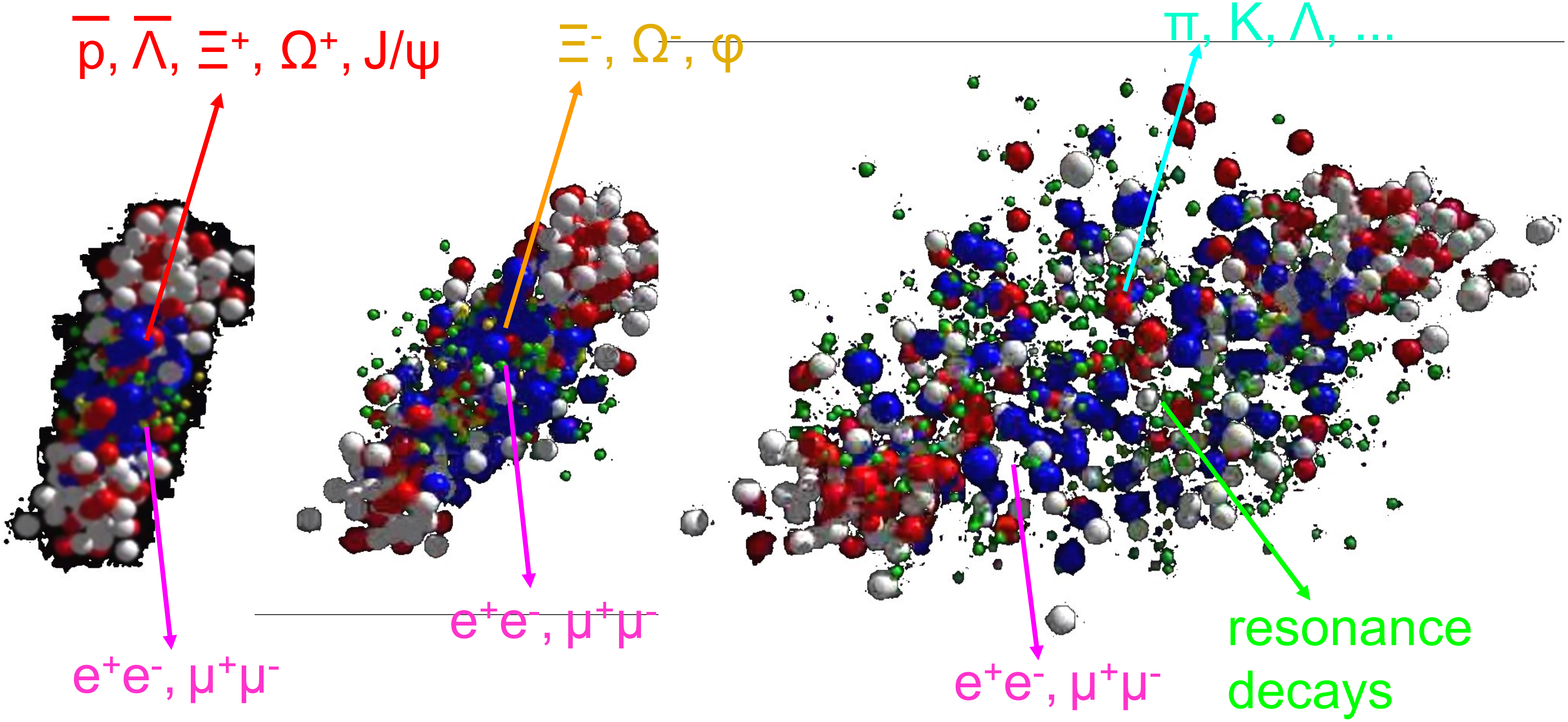






I.C. Arsene et al., Phys. Rev. C 75, 24902 (2007)

Heavy – Ion Collisions



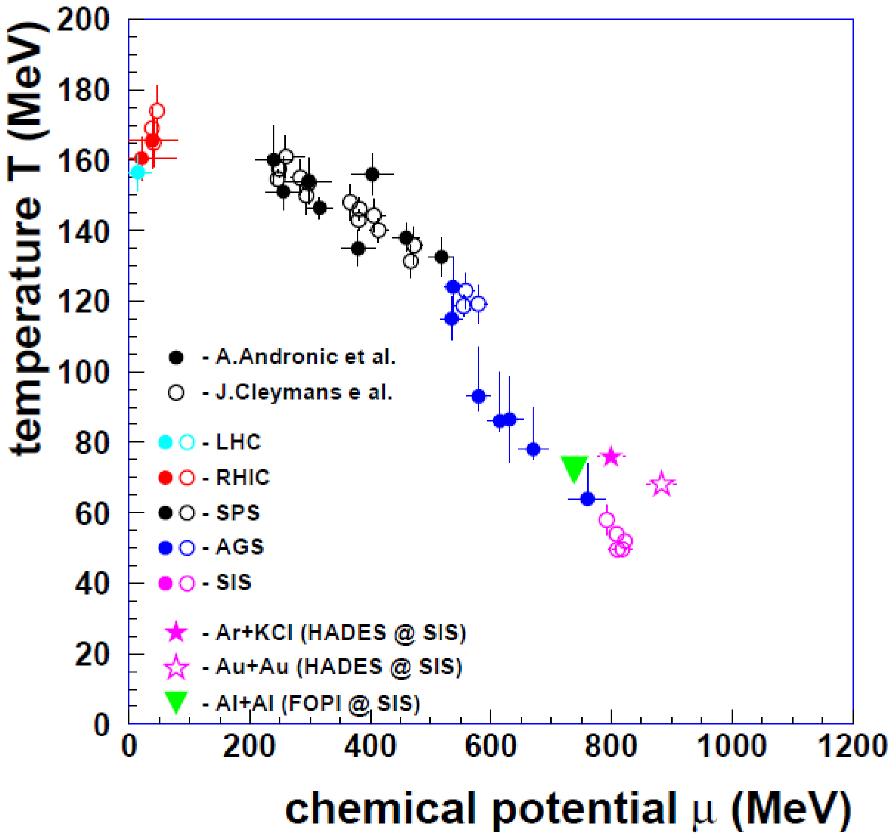
Hard probes
(initial state)

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

Freeze-out
(final state particles)

Thermalized (?) hadrons

Chemical Freeze-out data



Analyses in framework of
Statistical Hadronisation Model

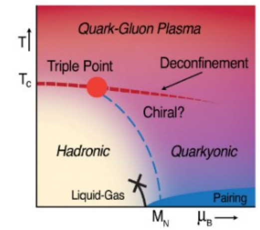
High energies:
grandcanonical ensemble

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 ?

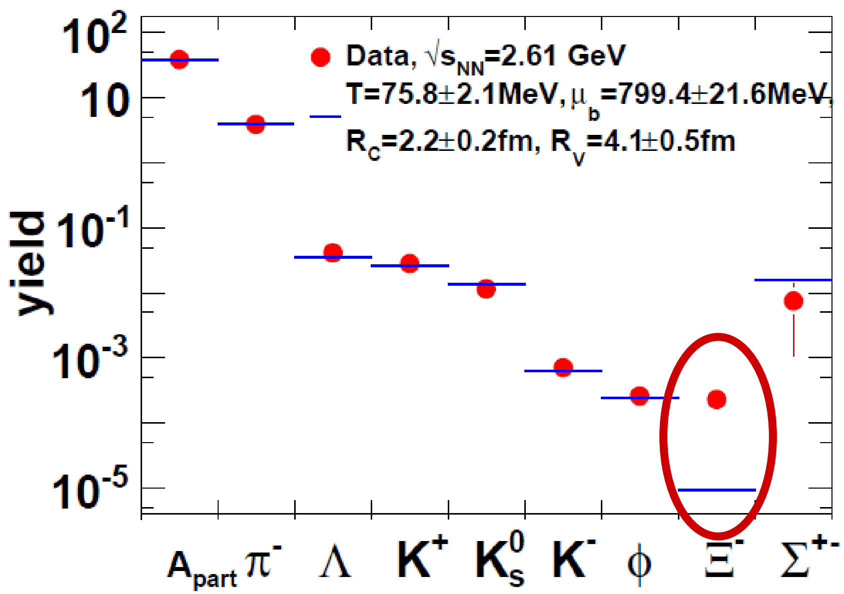


A. Andronic et al.,
Nucl. Phys. A837 (2010) 65

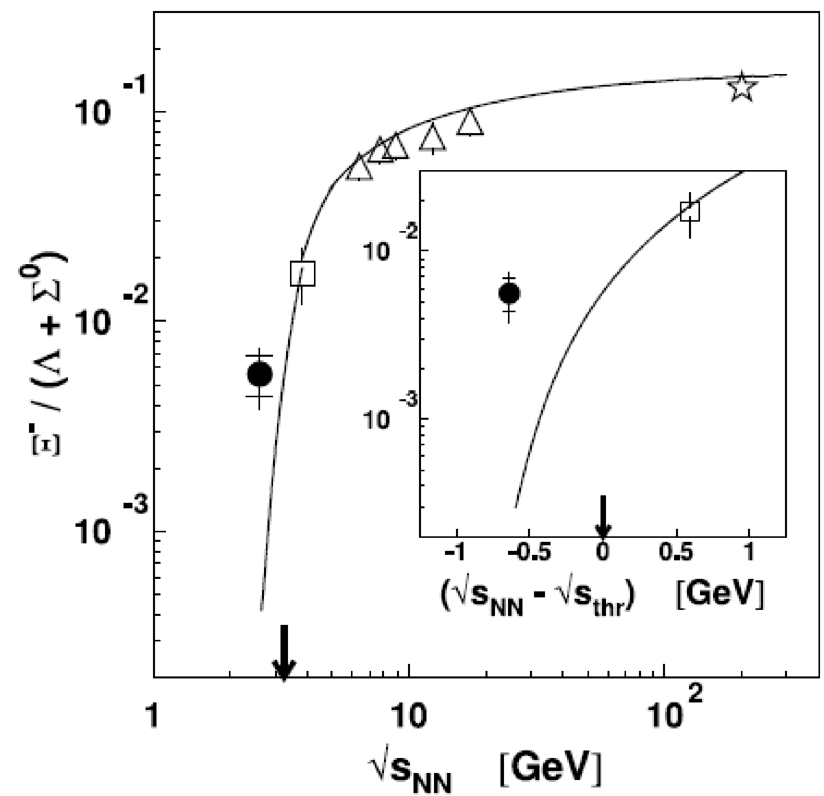
HADES: Sub-threshold Ξ^- - production

Ar+KCl reactions at 1.76A GeV

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

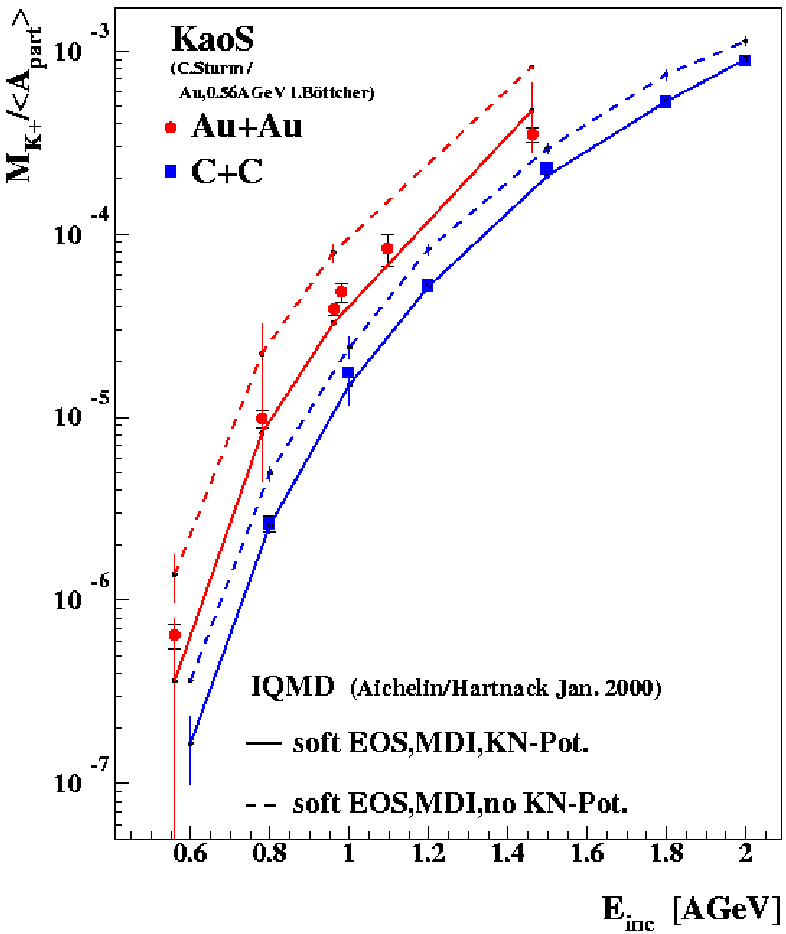


G. Agakishiev et al. (HADES), PRL103, 132301, (2009)

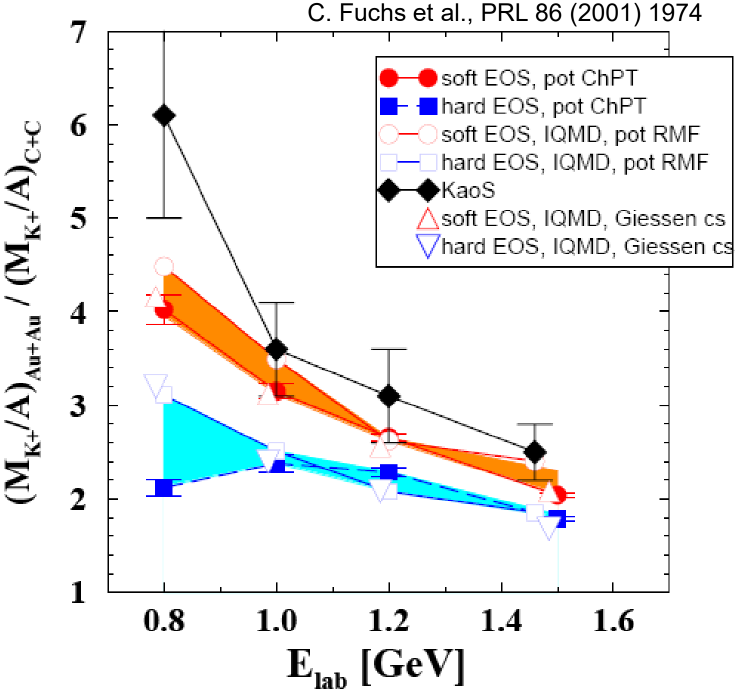


Reminder: Subthreshold Kaon – measurements (KAOS at SIS18)

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



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

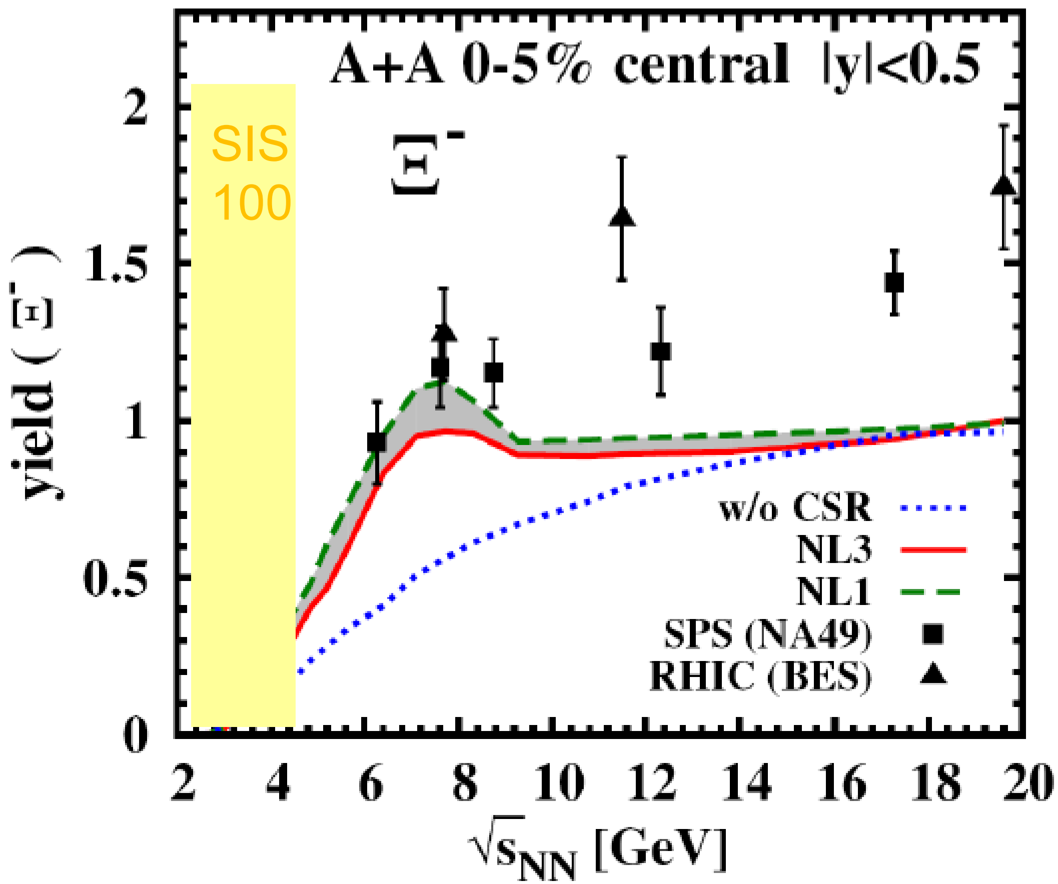


Strong sensitivity to Equation Of State
due to multistep production
(formation of nucleon resonances)
=> soft EOS (K=200 MeV)

Hyperons as probes of dense matter

PHSD interpretation of Ξ^- -production

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



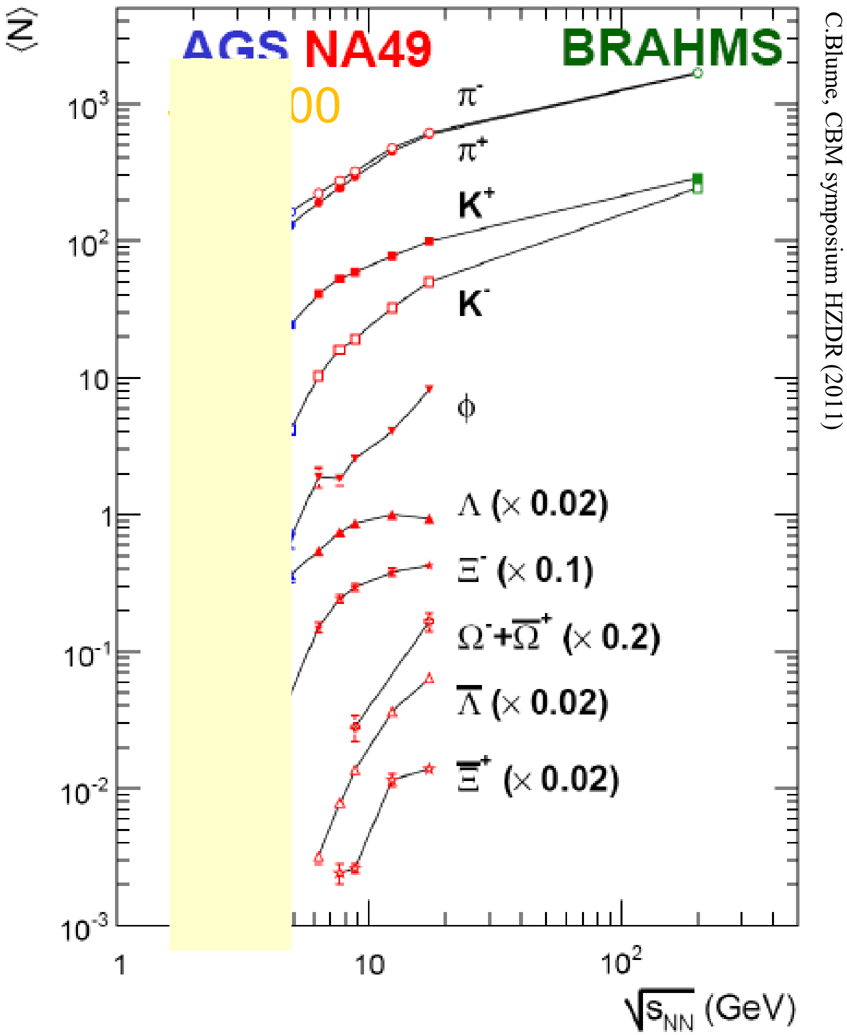
Predicted sensitivities of production yields:

strong dependence on Chiral Symmetry Restoration (CSR)

Measurable dependence on Equation of State (NL1, NL3)

Final state particle abundance

Particle yields from central Au + Au collisions



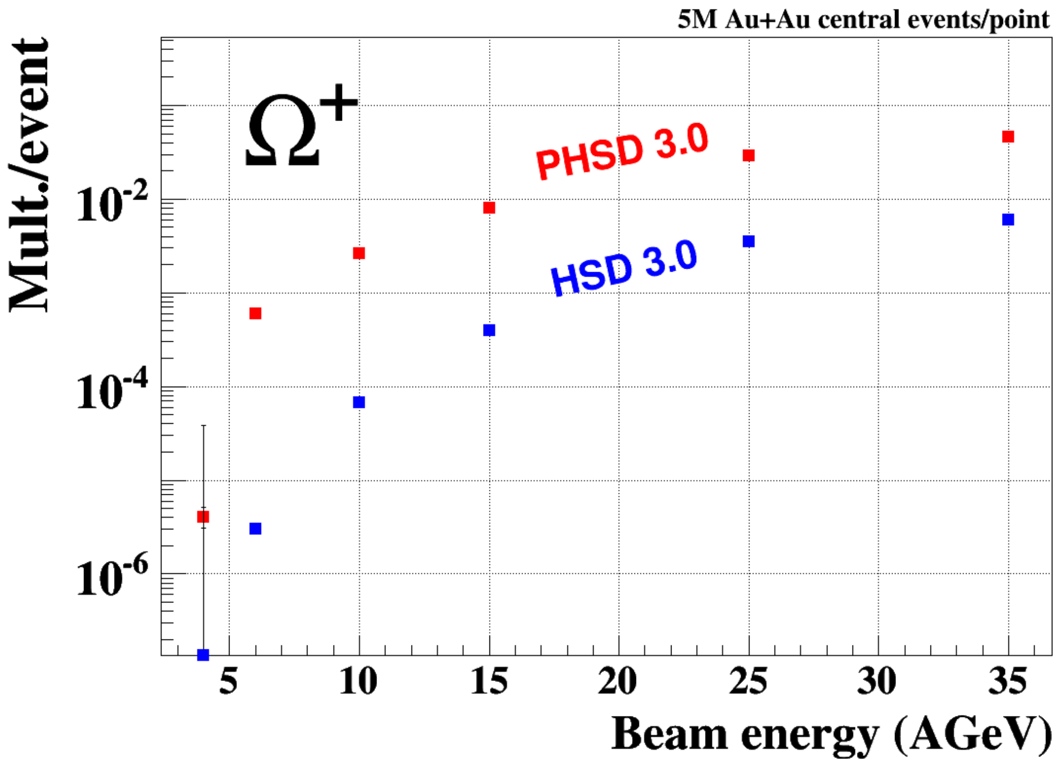
Strange and charmed particle production thresholds in pp - collisions

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

Antihyperon – producttion

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

I. Vassiliev, CBM, private communication



Large sensitivity to

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

Mapping out the phase structure
requires systematic measurements.

Directed and elliptic flow

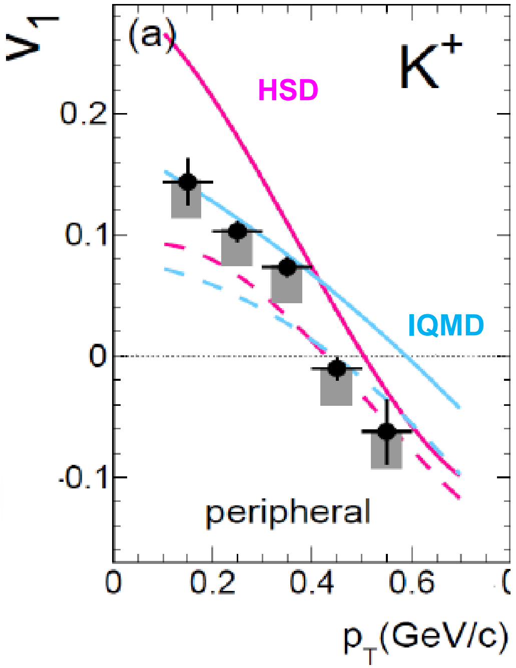
Measurement of differential flow offers additional information on

Equation – of – State (EOS)

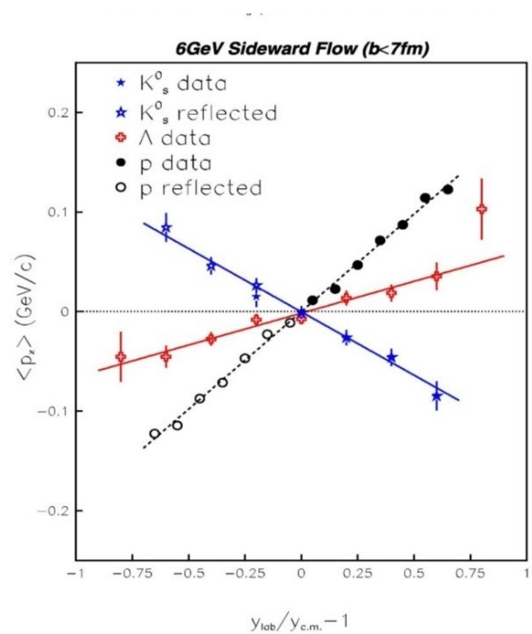
In – medium modifications of hadron masses (CSR)

Large data samples required for rare probes.

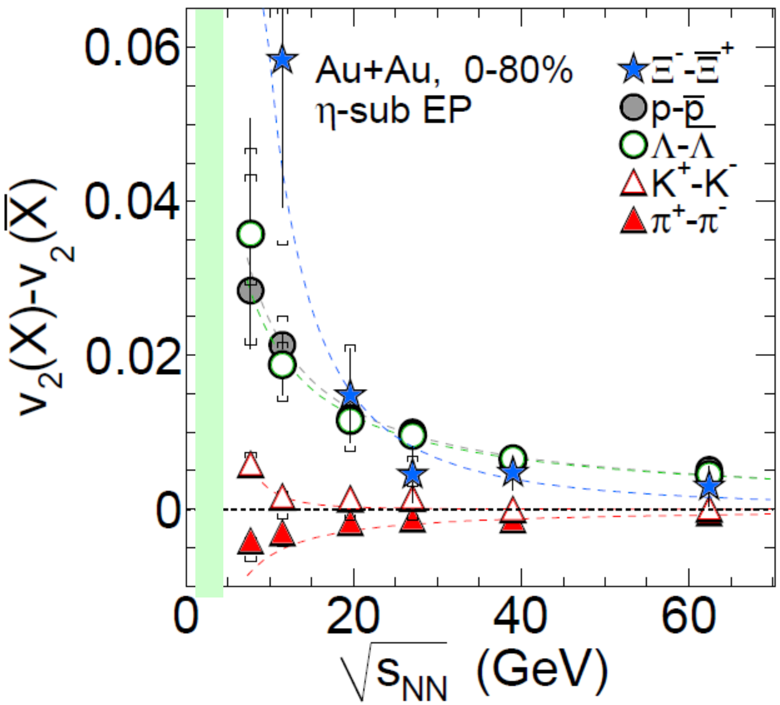
V.Zinyuk et al. (FOPI)
PRC 90 (2014) 025210



P. Chung et al. (E895),
PRL85, 940 (2000)



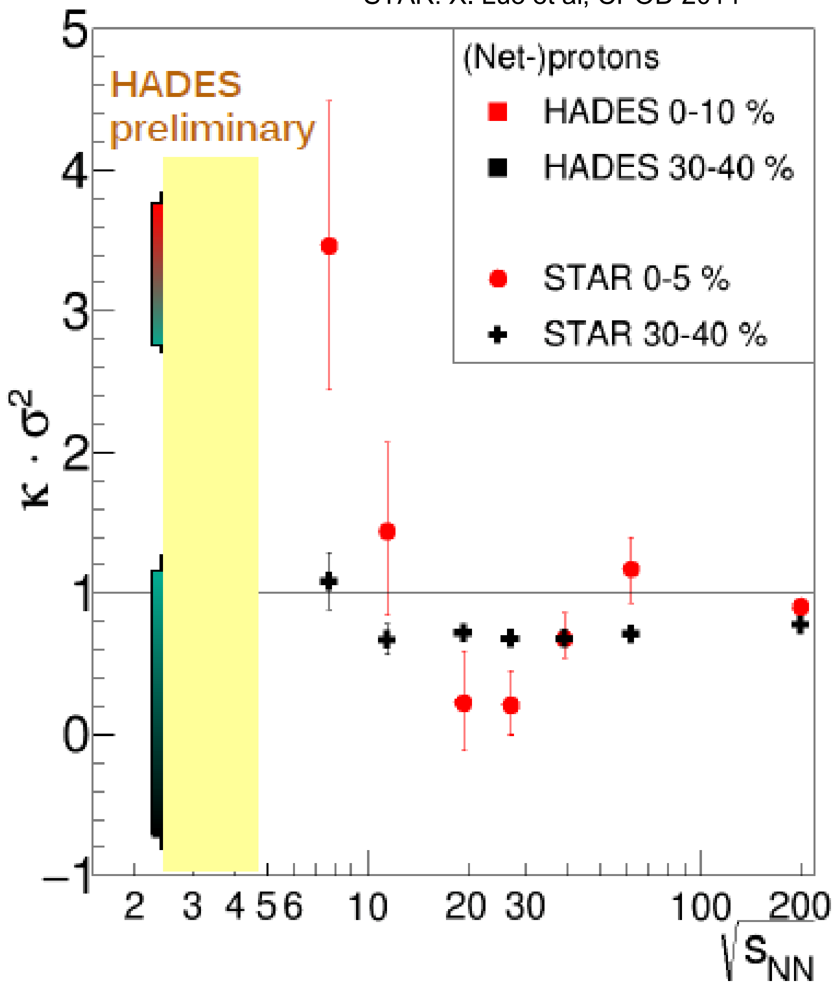
[STAR, PRL 110 (2013) 142301]



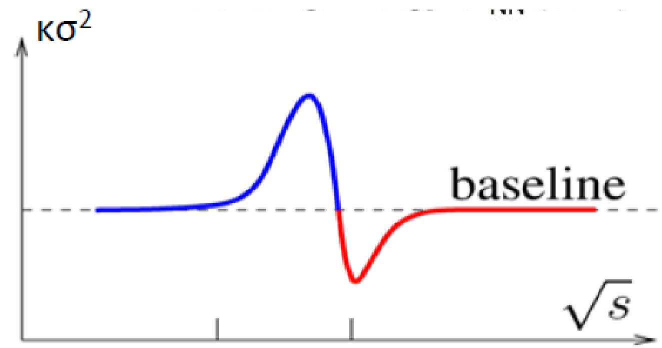
Fluctuations as probe for critical point

Current status

HADES: M. Lorenz, QM 2017
STAR: X. Luo et al, CPOD 2014



Theoretical expectation



M. Stephanov. J. Physics G.: Nucl. Part. Phys. ***38*** (2011) 124147

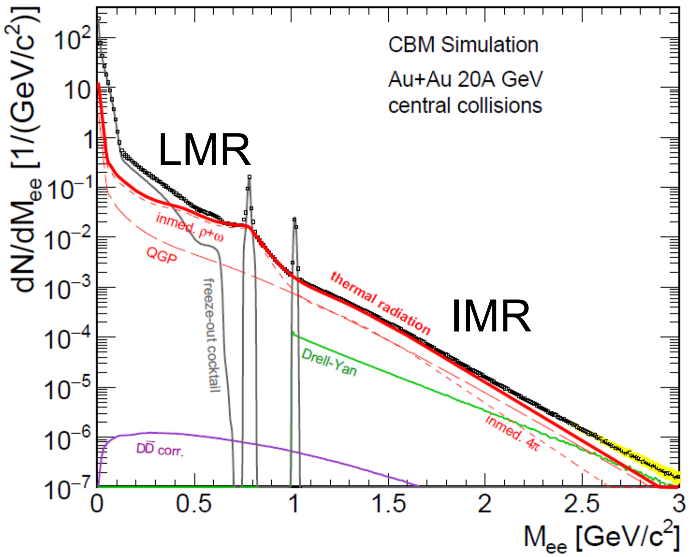
Event-by-event fluctuations of conserved quantities (strangeness, baryon, net-charge) are related to susceptibilities χ and correlation length ξ

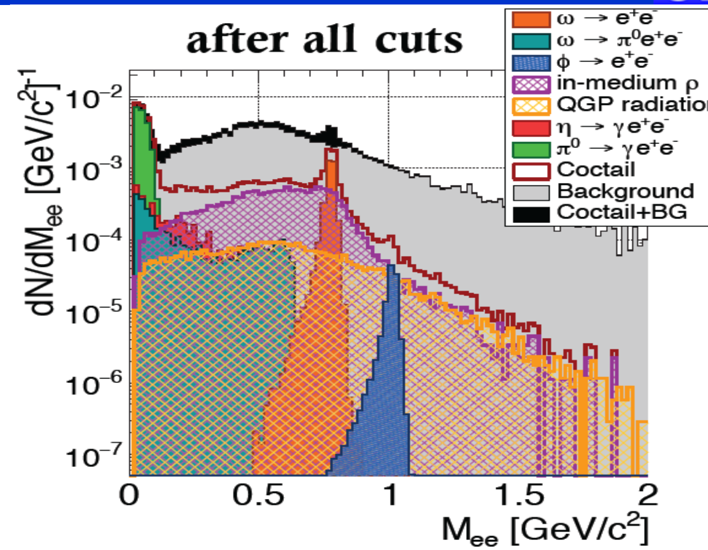
$$\kappa = \overline{\left(\frac{N-\bar{N}}{\sigma}\right)^4}$$

$$\kappa\sigma^2 \approx \frac{\chi^{(4)}}{\chi^{(2)}} \propto \xi^3$$

Dileptons as probes for dense matter

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



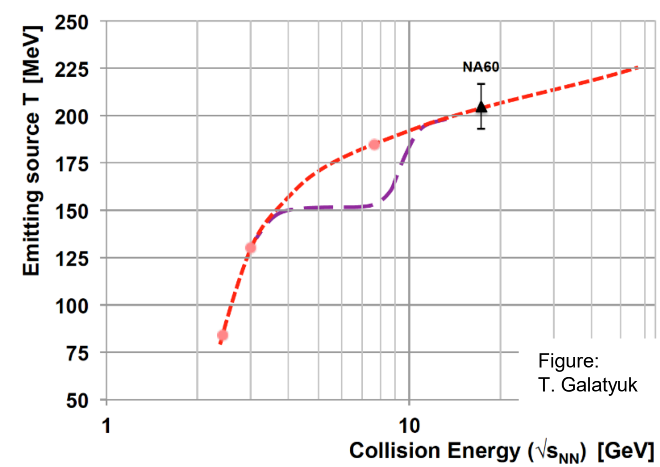


- 1M Au+Au (b=0 fm), 8 AGeV
- IMR: S/B > 1/100
- Statistical accuracy of 10% requires ~1 week of beamtime

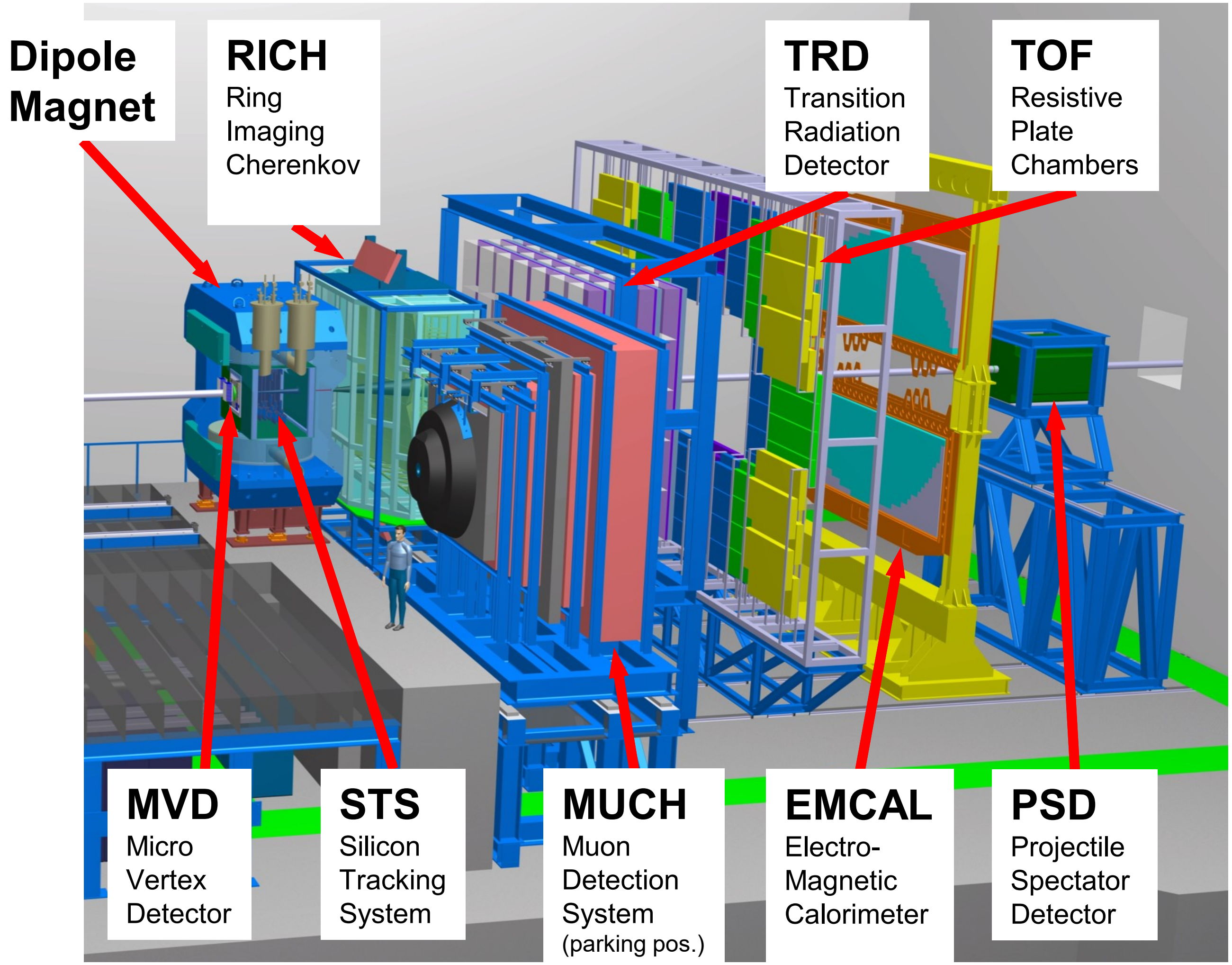
LMR: ρ – chiral symmetry restoration
fireball space – time extension

IMR: access to fireball temperature
ρ-a_1 chiral mixing

Measurement program:
e.g. excitation function of IMR - slope



CBM Experimental Setup



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

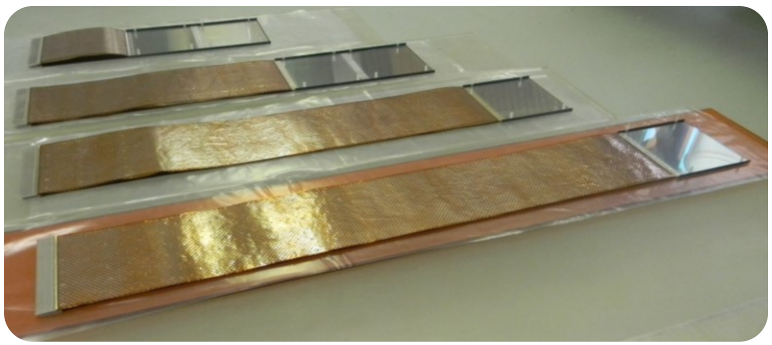
  R_{int} = 10 MHz (Au+Au)

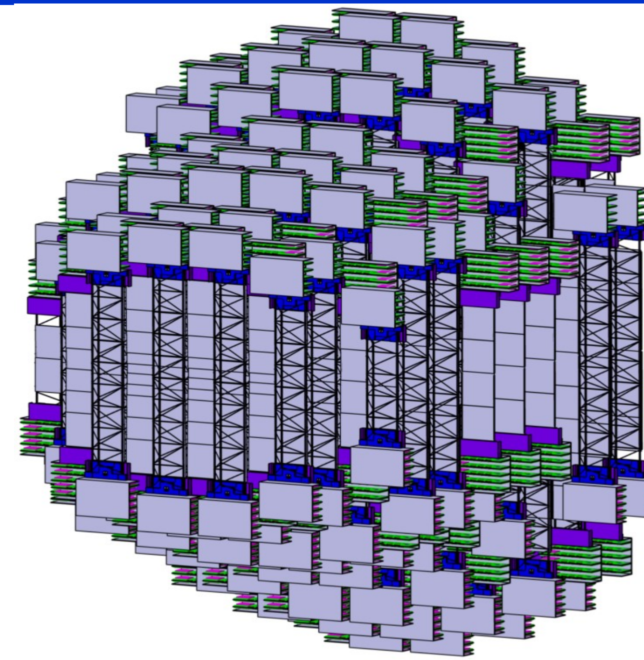
  except:
  R_{int} (MVD)=0.1 MHz
- Software based event selection

CBM Silicon Tracking System (STS)

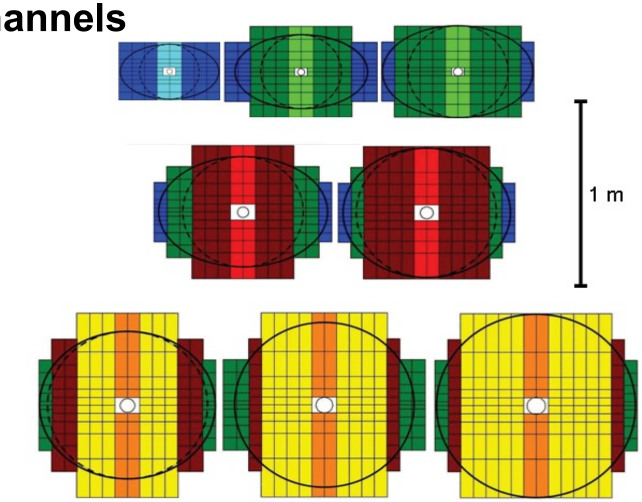
Silicon sensors:
double-sided micro-strips,
1024 strips on each side,
58 μm pitch, stereo angle 0°, 7.5°
width 60 mm, height 20, 40, 60 mm

Micro cables from sensors to FEBs

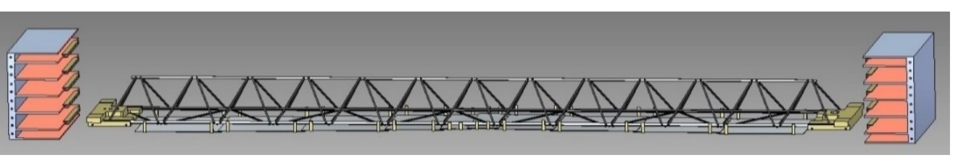




8 STS stations, distance from target 30–100 cm
2.133 M channels



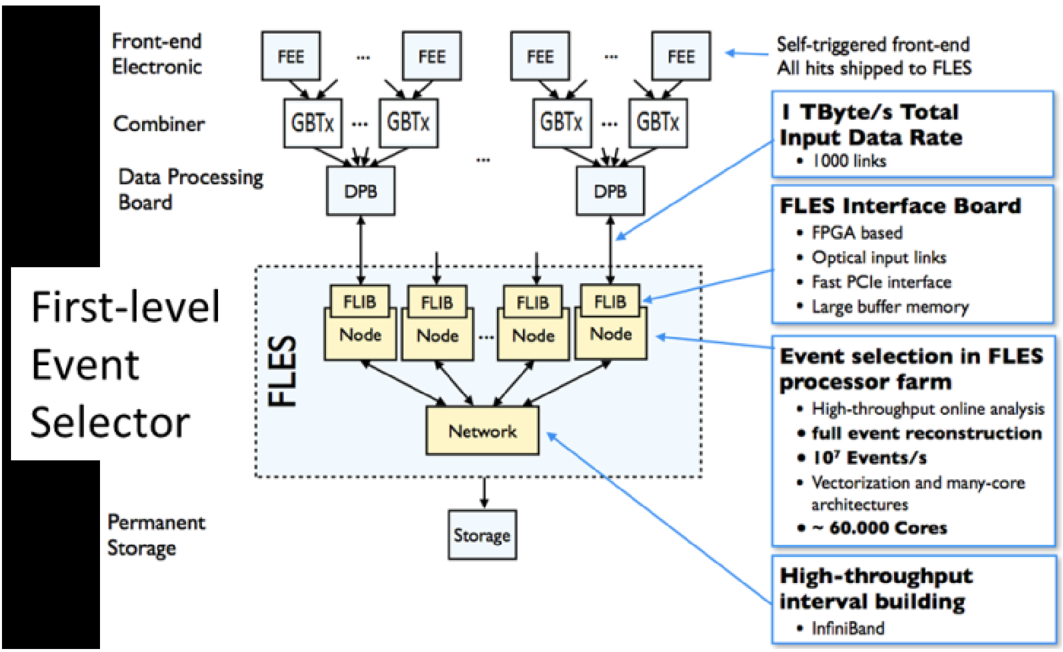
Light weight carbon fibre ladders

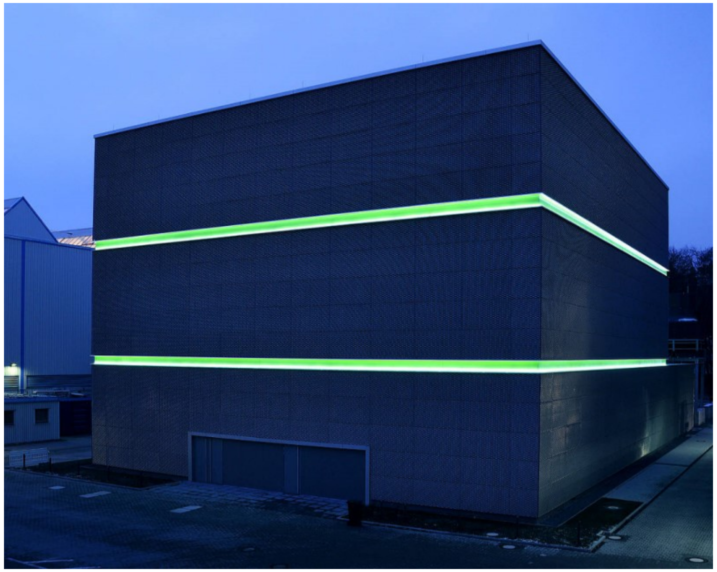


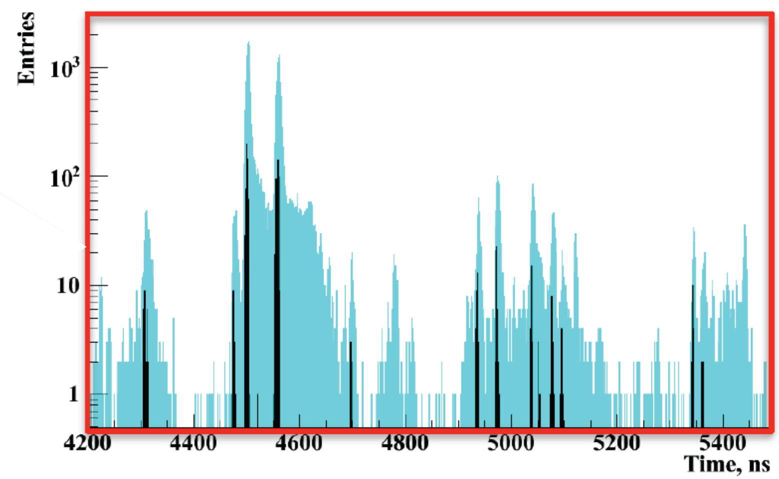
ASIC:
free streaming, hits with time stamp

FEB cooling: CO_2

CBM readout and online systems







Novel readout scheme

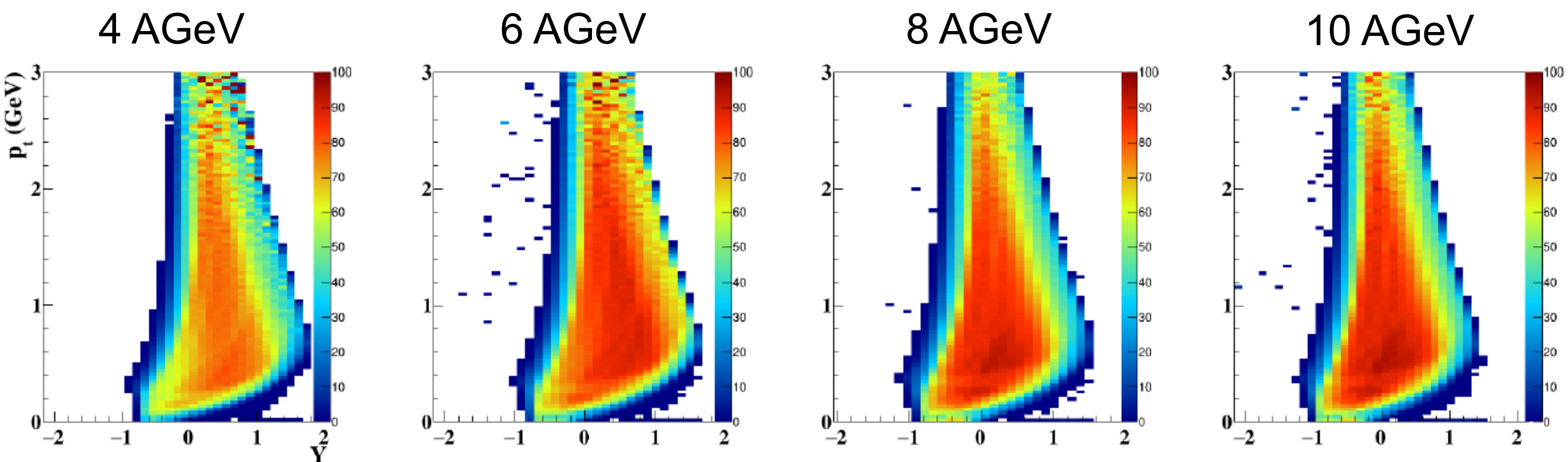
- no hardware trigger of events,
- free streaming triggerless data,
- all detector hits with time stamps

full online 4-D track and event reconstruction

Requirement: online calibration

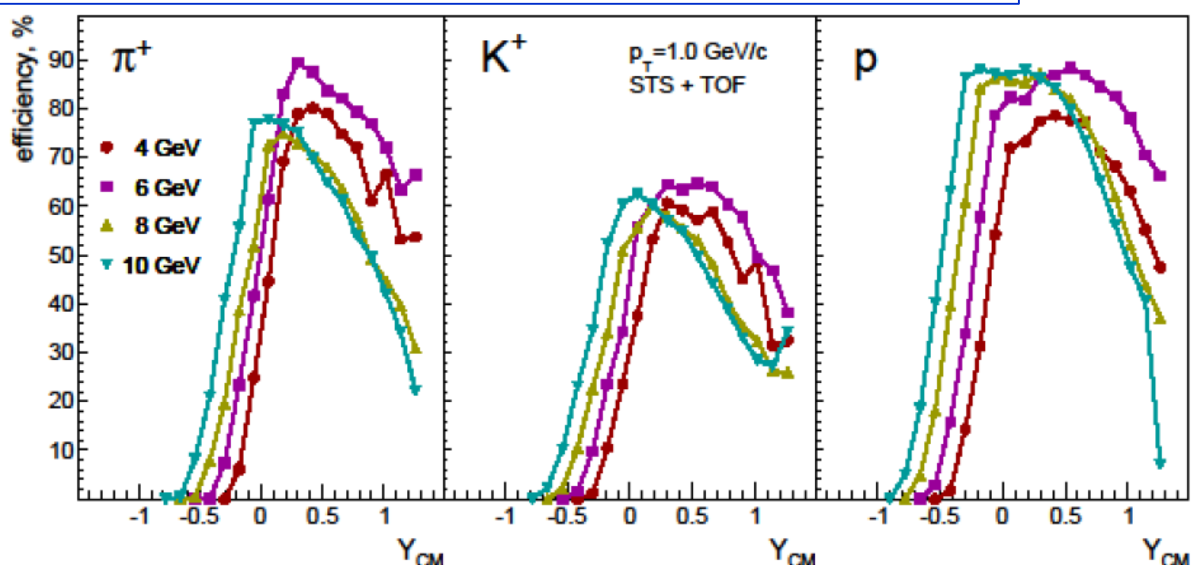
Hadron acceptance (STS + TOF)

Acceptance for protons (STS + TOF)

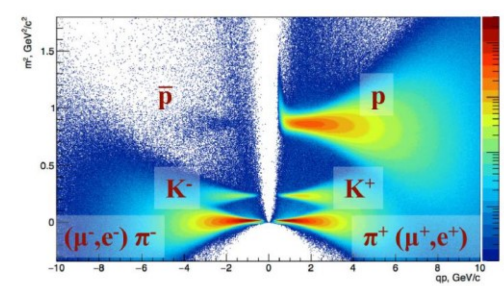


rapidity in CMS

Reconstruction efficiency for π, K, p (STS + TOF)



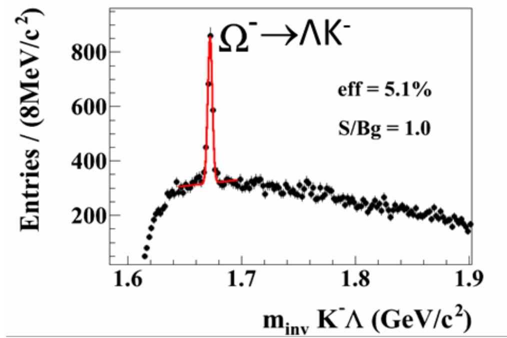
PID



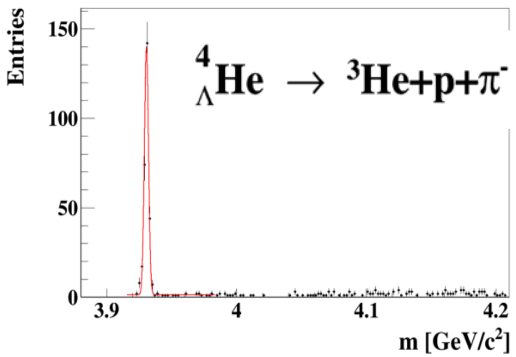
CBM day one experiment

Strategy: Start measurement program under „favorable“ conditions

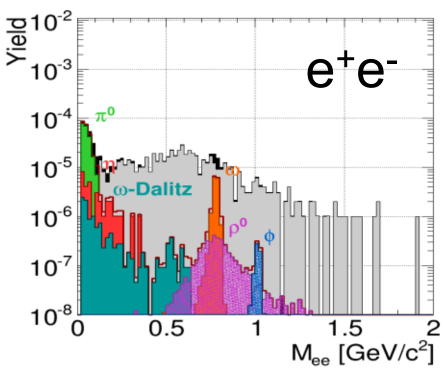
Hyperons at 10 A GeV

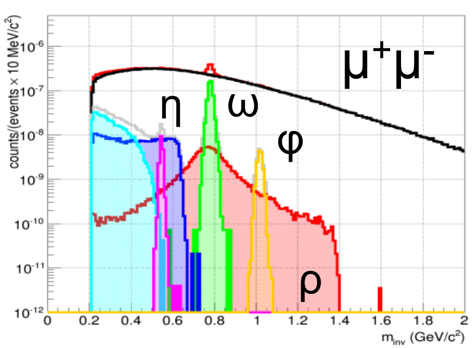


Hypernuclei at 10 A GeV



Dileptons 8A GeV





CBM – Day one experiment (~2024)

Observables: Strangeness and Dileptons

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

Physics program

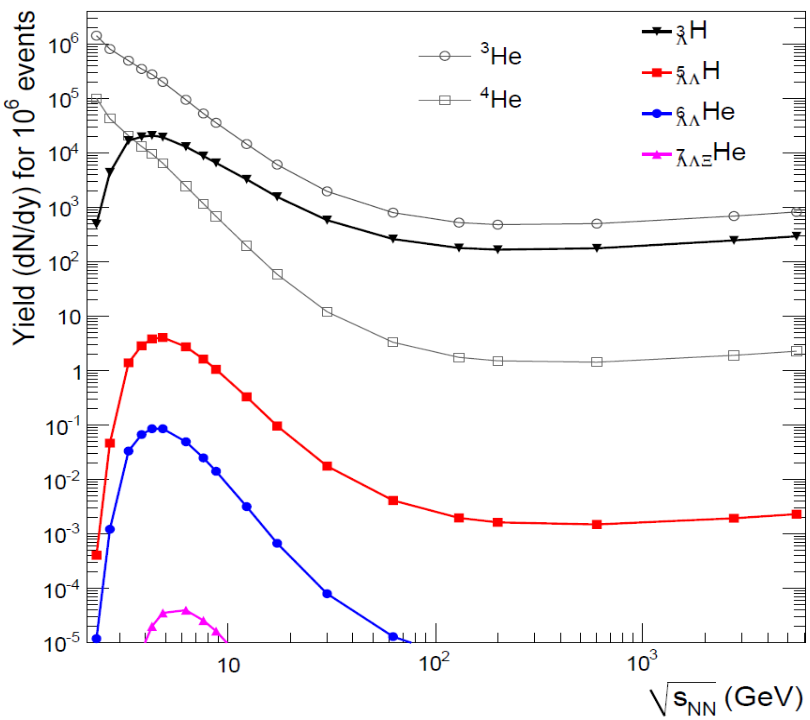
- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities
- Equation-of-state of matter at neutron star core densities
- Electro-magnetic radiation from the dense fireball (caloric curve)
- Chiral symmetry restoration in dense baryonic matter

Required setup

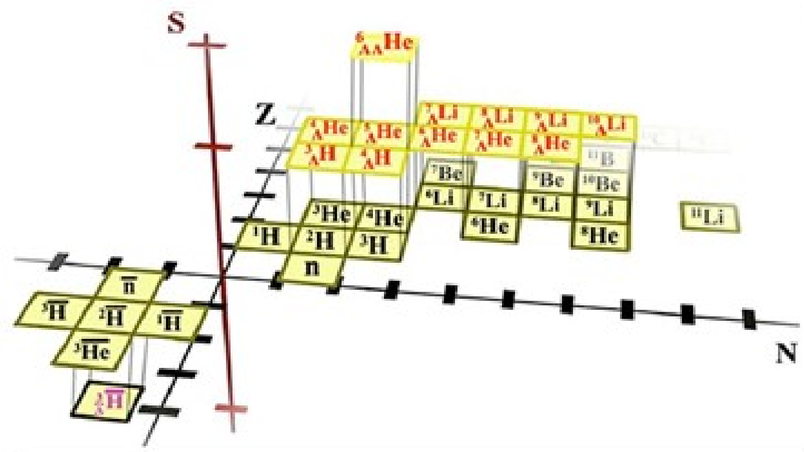
Dipole Magnet, Micro-Vertex Detector, Silicon Tracking System, RICH Detector, 4 layers TRD, TOF-Detector, MUCH Detector, Projectile Spectator Detector, DAQ/HPC cluster for First Level event Selection.
Reaction rates 100 kHz for ~ 2 month

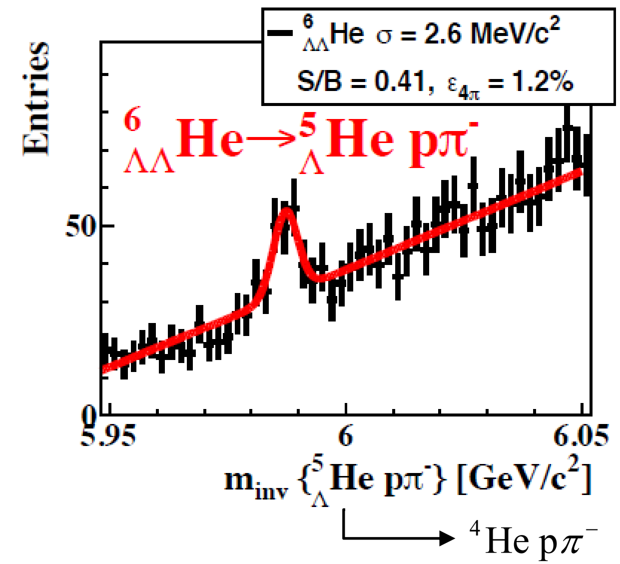
SIS 100- Hypernuclei

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

Expected particle yields

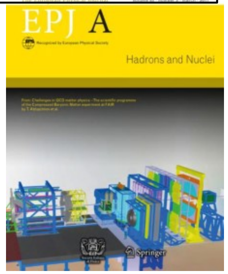
Event generator: URQMD + thermal source for hypernuclei

Particle (mass MeV/c^2)	Multi-plicity 6 AGeV	Multi-plicity 10 AGeV	decay mode	BR	ε (%)	yield (s^{-1}) 6AGeV	yield (s^{-1}) 10AGeV	yield in 10 weeks 6AGeV	yield in 10 weeks 10 AGeV	IR MHz
Λ (1115)	$4.6 \cdot 10^{-4}$	0.034	$p\pi^+$	0.64	11	1.1	81.3	$6.6 \cdot 10^{6}$	$2.2 \cdot 10^{8}$	**10**
Ξ^- (1321)	0.054	0.222	$\Lambda\pi^-$	1	6	$3.2 \cdot 10^{3}$	$1.3 \cdot 10^{4}$	$1.9 \cdot 10^{10}$	$7.8 \cdot 10^{10}$	**10**
Ξ^+ (1321)	$3.0 \cdot 10^{-5}$	$5.4 \cdot 10^{-4}$	$\Lambda\pi^+$	1	3.3	$9.9 \cdot 10^{-1}$	17.8	$5.9 \cdot 10^{6}$	$1.1 \cdot 10^{8}$	**10**
Ω^- (1672)	$5.8 \cdot 10^{-4}$	$5.6 \cdot 10^{-3}$	ΛK^-	0.68	5	17	164	$1.0 \cdot 10^{8}$	$9.6 \cdot 10^{8}$	**10**
Ω^+ (1672)	-	$7 \cdot 10^{-5}$	ΛK^+	0.68	3	-	0.86	0	$5.2 \cdot 10^{6}$	**10**
${}^{3}_{\Lambda}H$ (2993)	$4.2 \cdot 10^{-2}$	$3.8 \cdot 10^{-2}$	${}^{3}He\pi^-$	0.25	19.2	$2 \cdot 10^{3}$	$1.8 \cdot 10^{3}$	$1.2 \cdot 10^{10}$	$1.1 \cdot 10^{10}$	**10**
${}^{4}_{\Lambda}He$ (3930)	$2.4 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$	${}^{3}Hep\pi^-$	0.32	14.7	110	87	$6.6 \cdot 10^{8}$	$5.2 \cdot 10^{8}$	**10**

4D (time based) simulation
Particle yields allow for differential analysis

CBM - Phase 1 Physics Potential

Eur.Phys.J. A53 (2017) 60

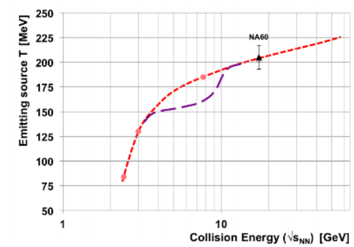


The QCD equation-of-state at neutron star core densities

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

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

- excitation function of strangeness: $\Xi^{-/+}, \Omega^{-/+} \rightarrow$ chemical equilibration at the phase boundary
- excitation function (invariant mass) of lepton pairs: Thermal radiation from fireball, "caloric curve"
- anisotropic azimuthal angle distributions: "spinodal decomposition"
- event-by-event fluctuations of conserved quantities: "critical opalescence"

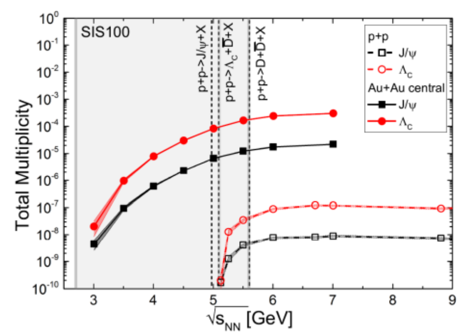


Onset of chiral symmetry restoration at high ρ_B

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

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, $D^\pm$)

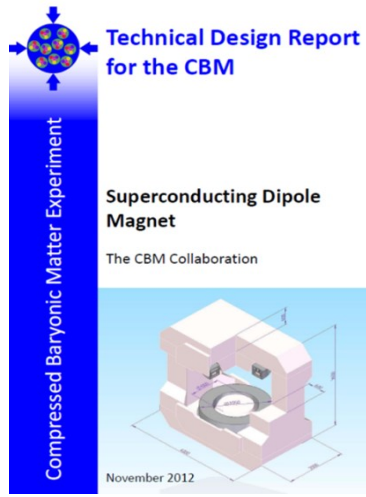


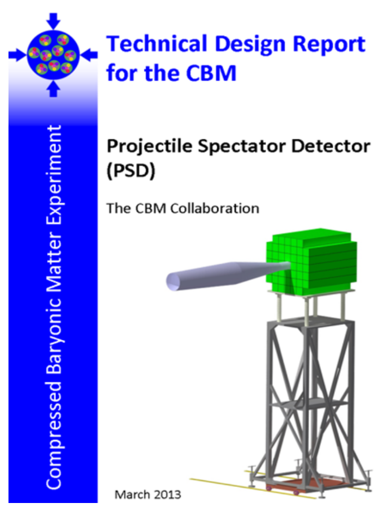
N-Λ, Λ-Λ interaction, strange matter

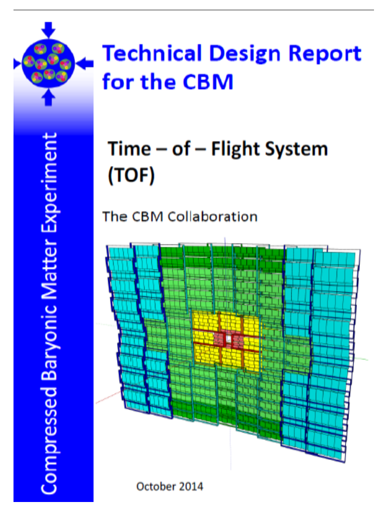
- (double-) lambda hypernuclei
- meta-stable objects (e.g. strange dibaryons)

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	TRD	submission 2017
9	MVD	submission 2018
10	Online I	submission 2018
11	Online II	submission 2019
12	ECAL	submission t.b.d

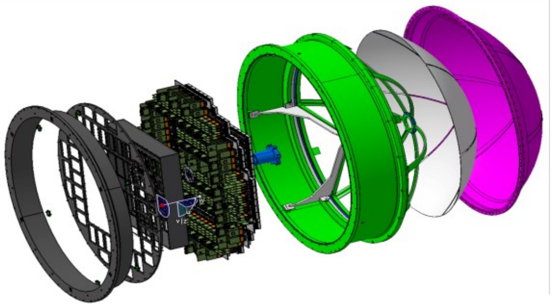




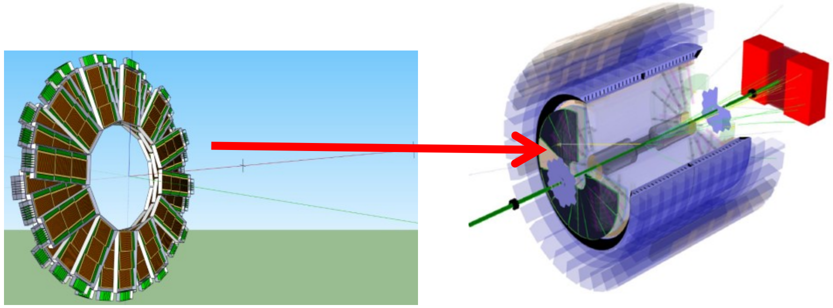


CBM – FAIR Phase 0 projects (2018 – 2022)

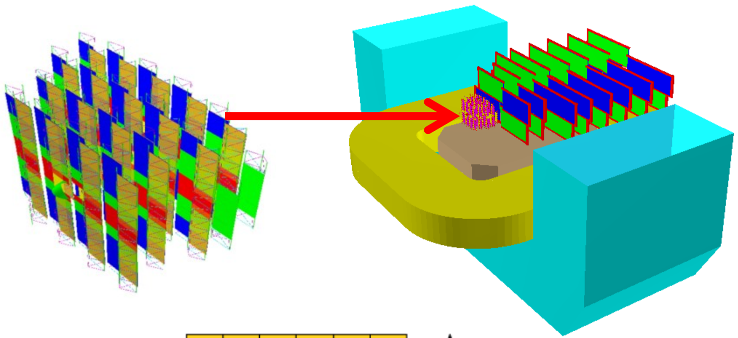
1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) in HADES RICH photon detector



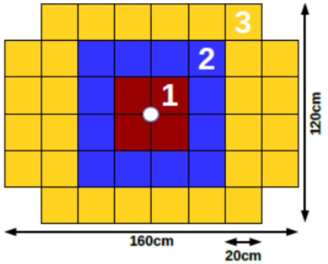
2. Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)



3. Install, commission and use 4 Silicon Tracking Stations in the BM@N experiment at the Nuclotron in JINR/Dubna (Au-beams up to 4.5 A GeV in 2018/19)

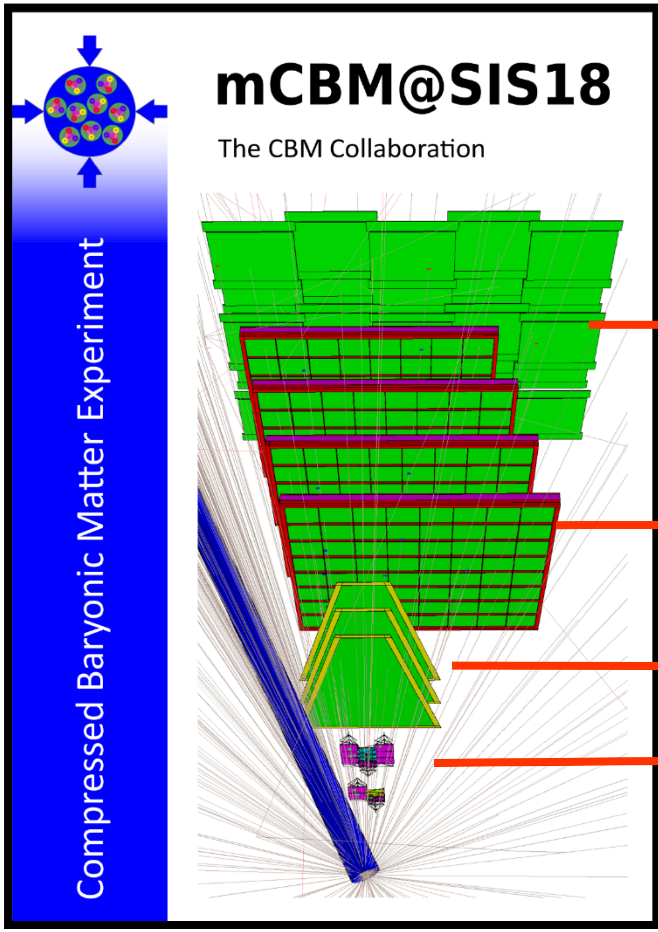


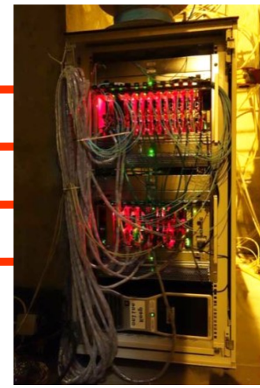
4. Install, commission and use the Project Spectator Detector at the BM@N experiment

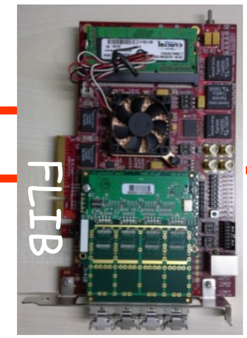


CBM Phase 0 project at SIS18: mCBM

Demonstrator for full CBM data taking and analysis chain







https://cbm-wiki.gsi.de/foswiki/pub/Public/Documents/
mcbm-proposal2GPAC-fullVersion.pdf

the mCBM test-setup (“mini-CBM”) will focus on

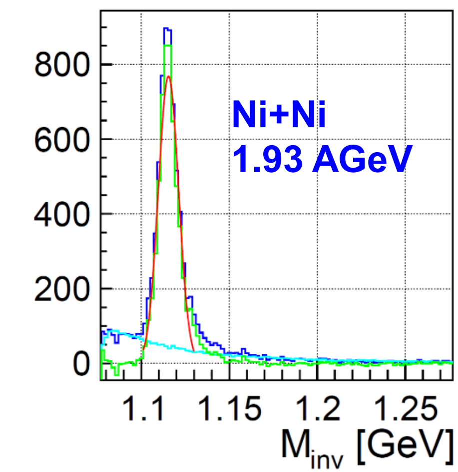
- test of final detector prototypes
- free streaming data transport to a computer farm
- online reconstruction and event selection
- offline data analysis

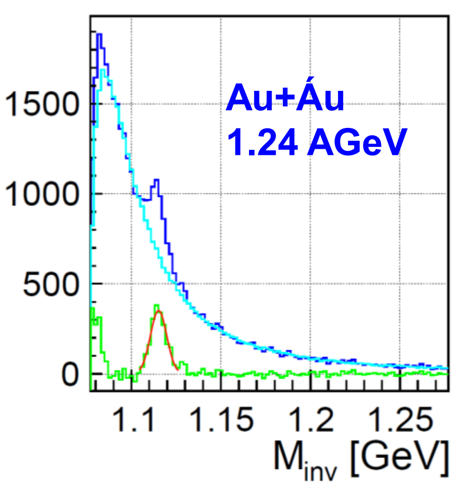
under full load conditions (Au + Au, 10^7 interactions/s)

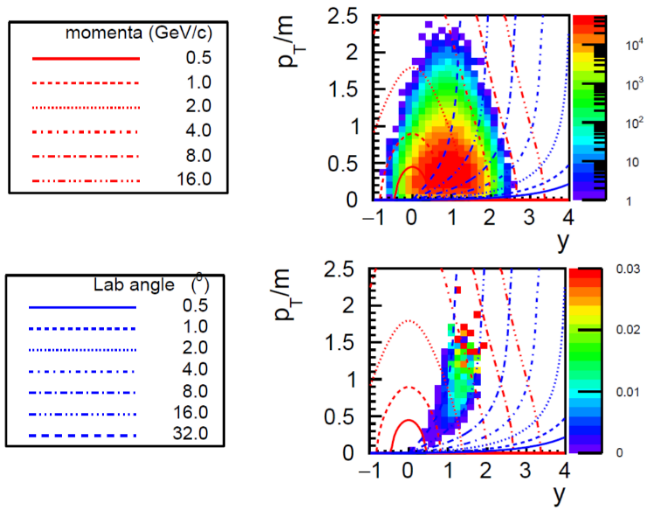
mCBM performance benchmark

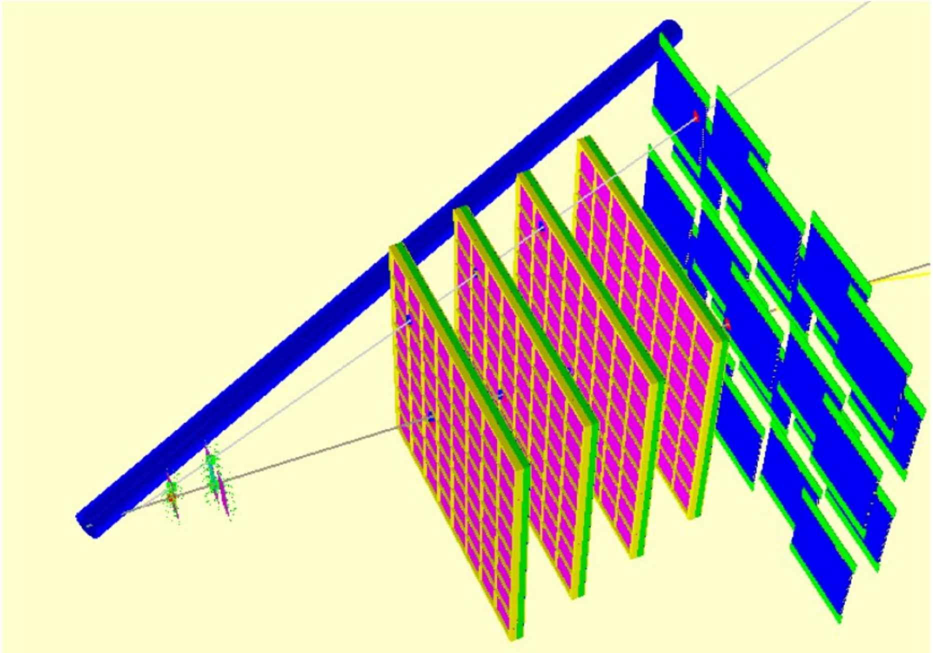
(Sub)threshold Λ – baryon reconstruction.

Event based MC simulation of 10^8 events





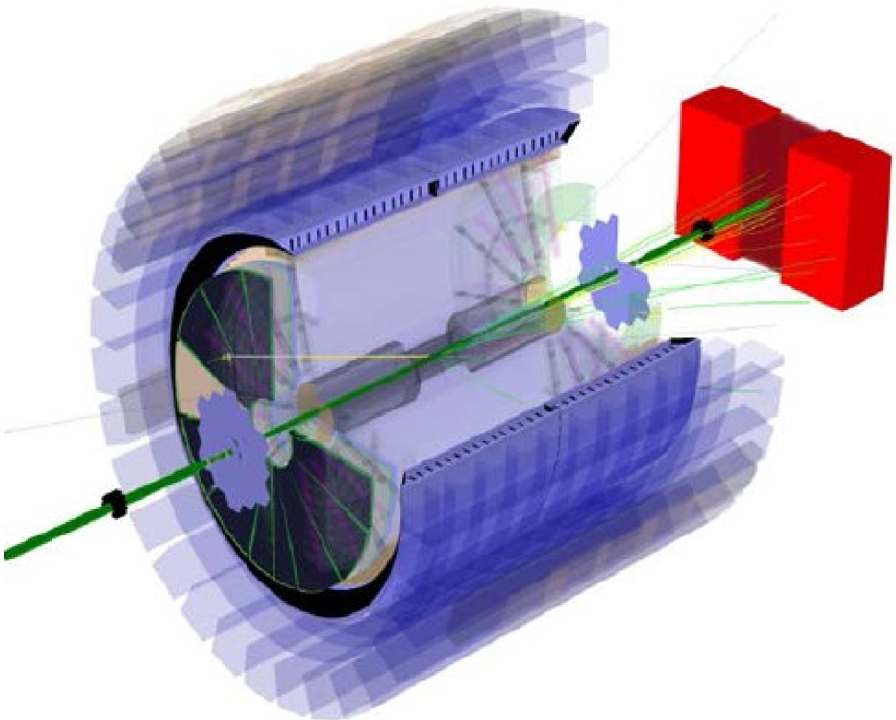


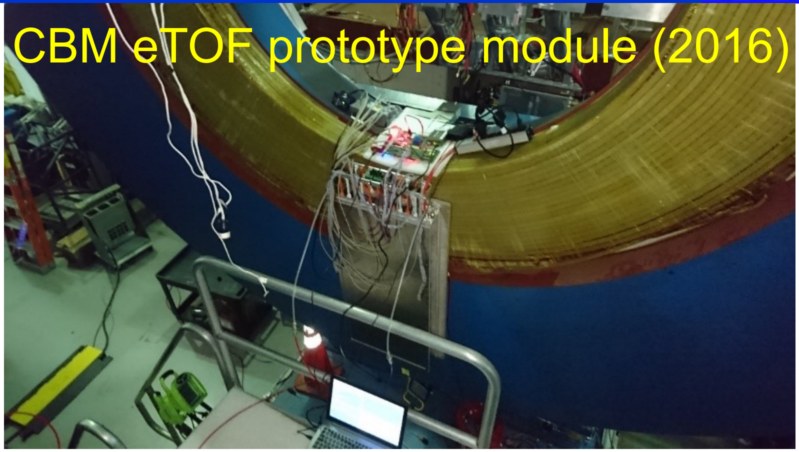


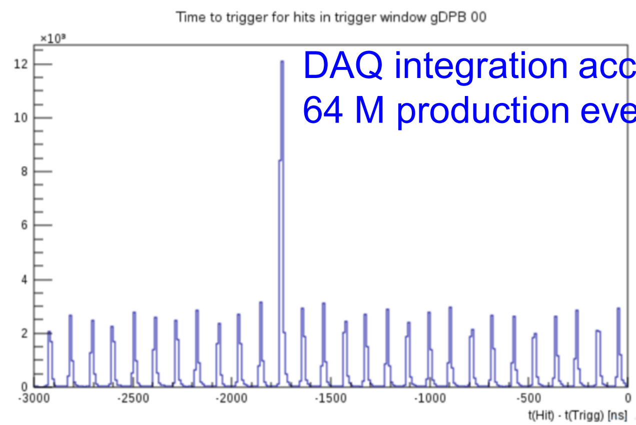
mCBM timeline

year	Goal
2017	Preparation of exp. area
2018	Installation / detector tests
2019	Commissioning for full rate
2020	1. benchmark run
2021	Λ excitation function

eTOF & HPC software in STAR at RHIC (BNL)







Participating CBM – TOF groups:

- Tsinghua Univ. Beijing
- GSI Darmstadt
- TU Darmstadt
- Univ. Frankfurt
- Univ. Heidelberg
- USTC Hefei
- CCNU Wuhan

Test module installed	(Oct. 2016),
Module is operational	(Oct. 2016),
STAR DAQ interface	(Jan. 2017),
Full sector test	(Spring 2018),
Wheel installation	(Summer 2018),
BES II data taking	(2019/2020),
Transfer of modules to FAIR	(2021/22).

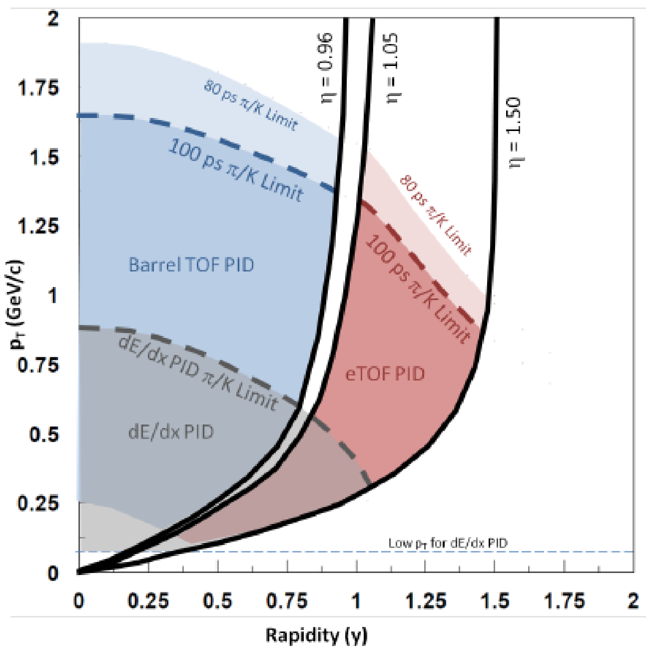
BES II physics program

Physics Program for the STAR/CBM eTOF Upgrade

The STAR Collaboration
The CBM Collaboration eTOF Group
(Dated: September 19, 2016)

arXiv:1609.05102v1 [nucl-ex]

Example: kaon acceptance

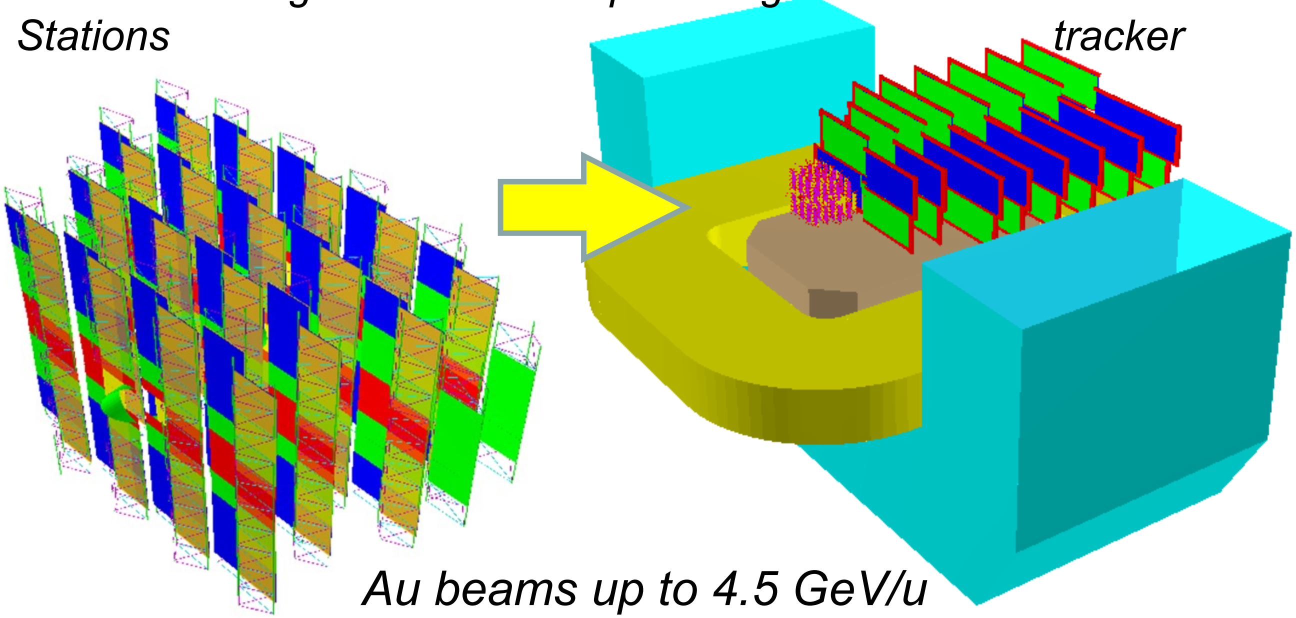


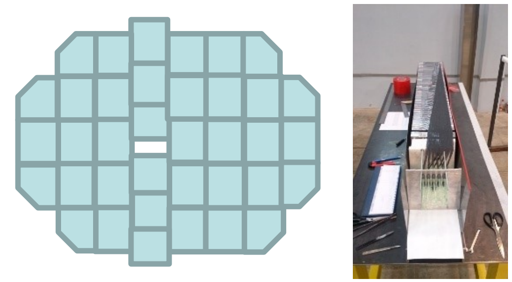
Topics to be studied with extended acceptance in energy range $\sqrt{s_{NN}} = 3 – 62$ GeV:

- Excitation function and phase-space distributions of hyperons, hypernuclei, anti-protons, ...
  → Equilibration, phase transitions
- Collective Flow (v1, v2)
  → Equation-of-State, phase transitions
- Fluctuations of conserved quantum numbers (baryon, charge, strangeness)
  → Critical point
- Dilepton yields
  → Chiral symmetry restoration

STS & PSD in BM@N (JINR)

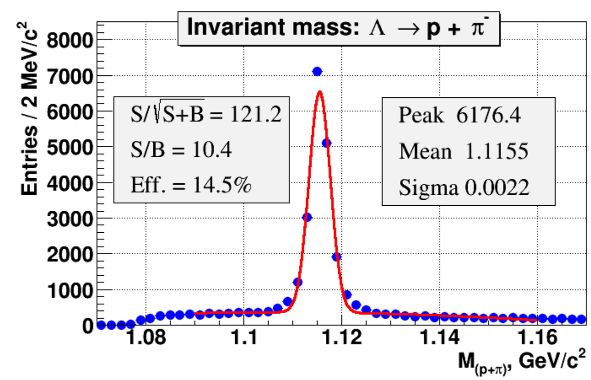
Silicon Tracking Stations





PSD calorimeter

Improvement in efficiency & signal / backrgound

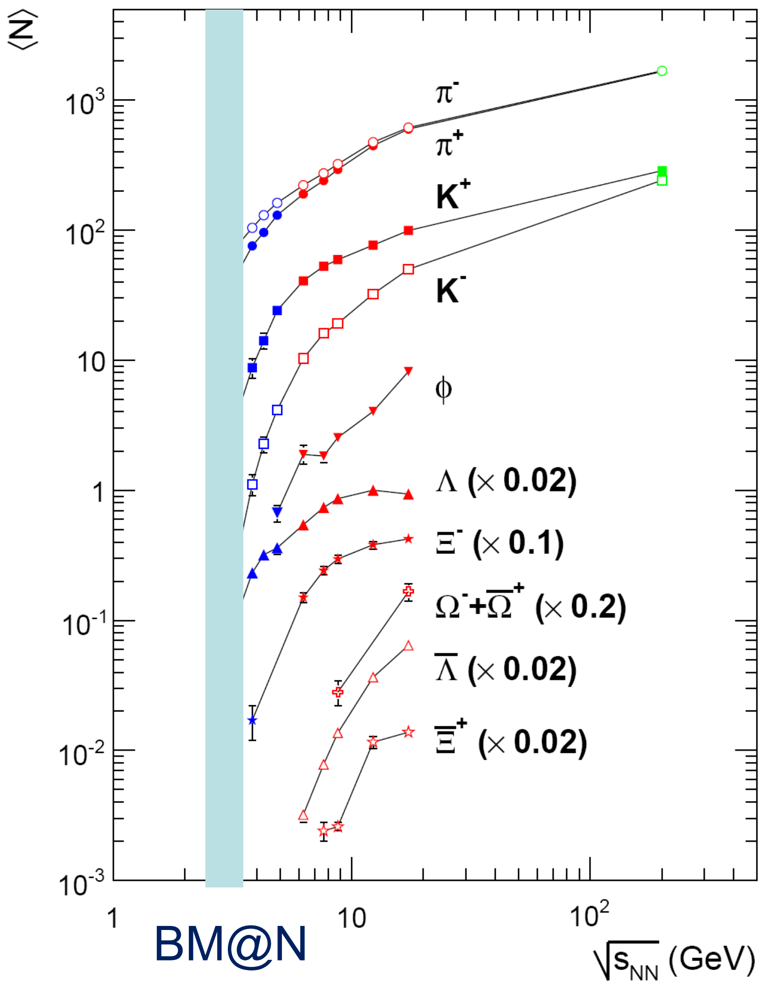


BM@N timeline: NICA white paper (Eur. Phys. J. A (2016) 213

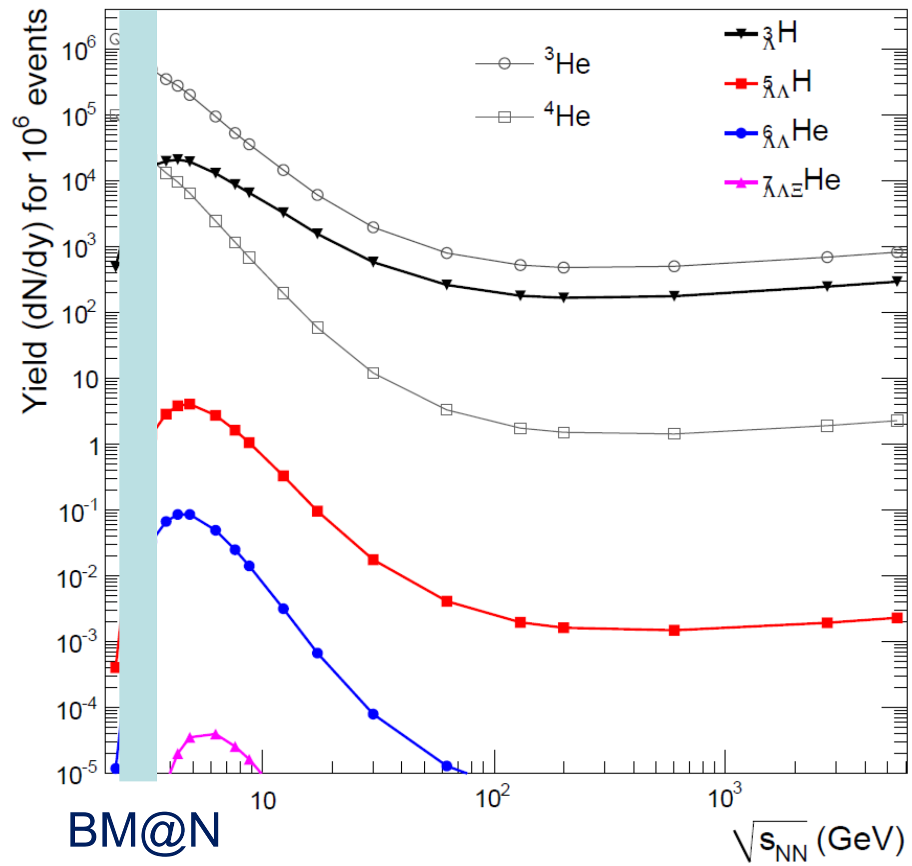
2018 Installation of PSD detector (MoU signed)
2019 Au beams from Nuclotron
2020 Installation of 4 Si Tracking Stations (MoU signed)

BM@N physics program

Hyperon production



Hypernuclei production



CBM – Collaboration: 55 institutions, 460 members

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.

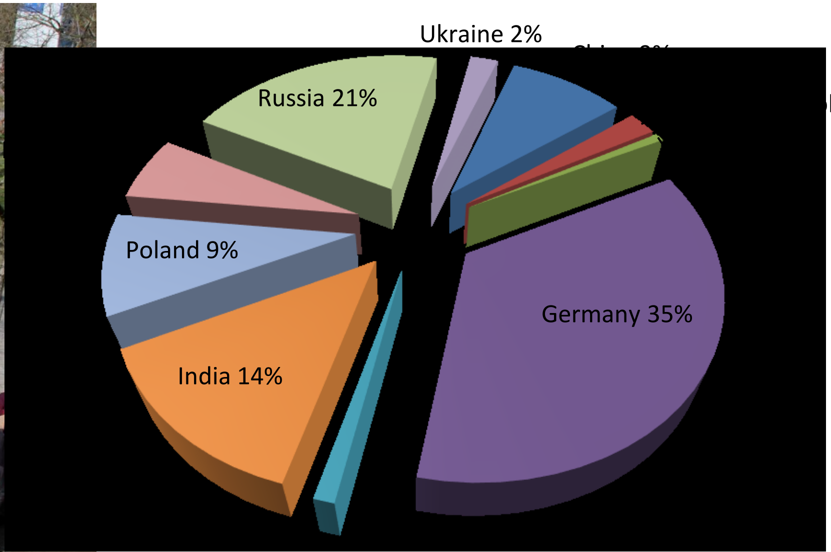
Poland:
AGH Krakow
Jag. Univ. Krakow
Warsaw Univ.
Warsaw TU

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

CBM Scientists



Conclusion

- HADES and CBM have well defined FAIR phase 0 programs preparing the operation at SIS100 with large physics potential:
  - HADES with CBM – RICH photon detector
  - CBM – TOF, CBM – HPC software in BES II campaigne of STAR @ RHIC
  - CBM – STS, CBM – PSD in BM@N
  - mCBM at SIS18
- CBM Day 1 experiment offers start of unique measurements at SIS100:
  - Multiple strange hyperon measurements at higher SIS100 energies
  - Single Λ - hypernuclei search
  - Dilepton excitation function measurements with initial focus on LMR
- CBM FAIR phase 1 addresses the complete set of physics observables to map out the phase structure of QCD in the SIS100 energy range.
- CBM physics program is starting now !