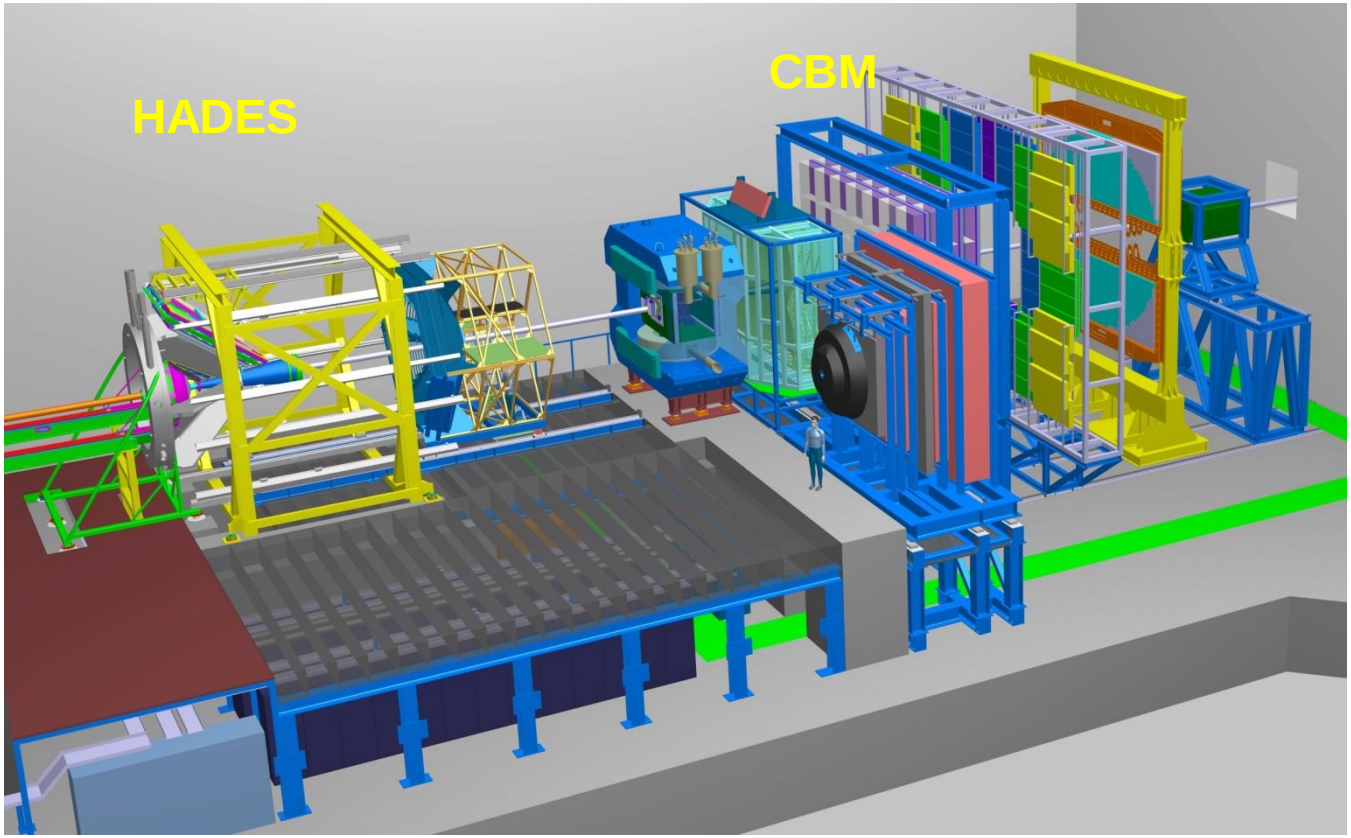
The Compressed Baryonic Matter Experiments

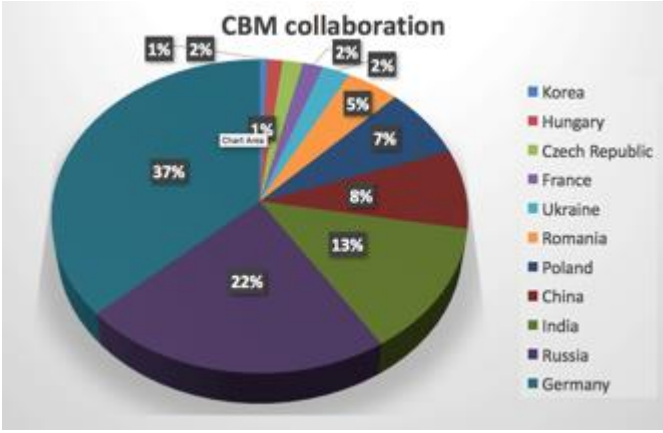


Outline:

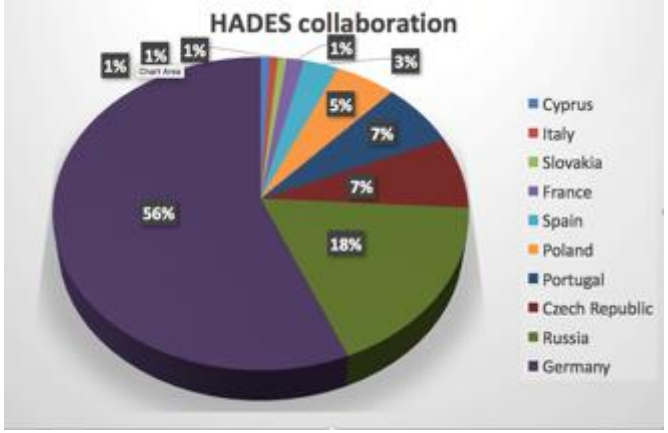
Reminder: Physics case
Status of experiments (HADES & CBM)
Day-1 Setup (> 2024)
FAIR Phase 0 program (2018 – 2024)

C.B.M. – Collaborations

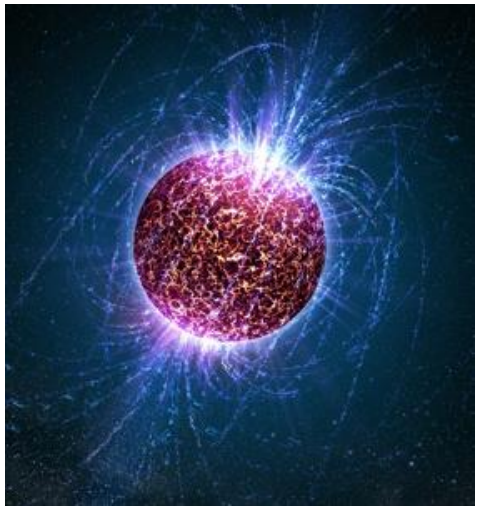
CBM Collaboration: 436 members, 11 countries



HADES Collaboration: 139 members, 9 countries



Dense Baryonic Matter



Neutron stars

Temperature
T < 10 MeV

Density
$\rho < 10\ \rho_0$

Lifetime
T ~ infinity

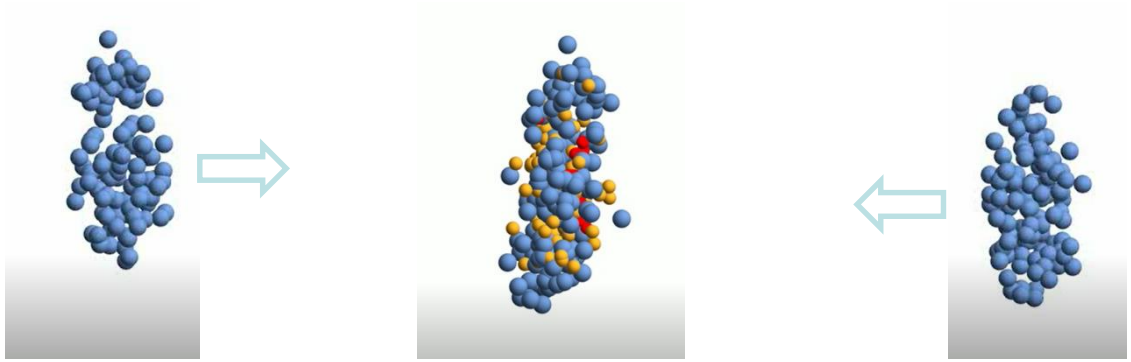
Neutron star merger

Temperature
T < 50 MeV

Density
$\rho < 2 - 6\ \rho_0$

Reaction time
(GW170817)
T ~ 10 ms

Heavy ion collisions at SIS100



Compressed Baryonic Matter

Temperature
T < 120 MeV

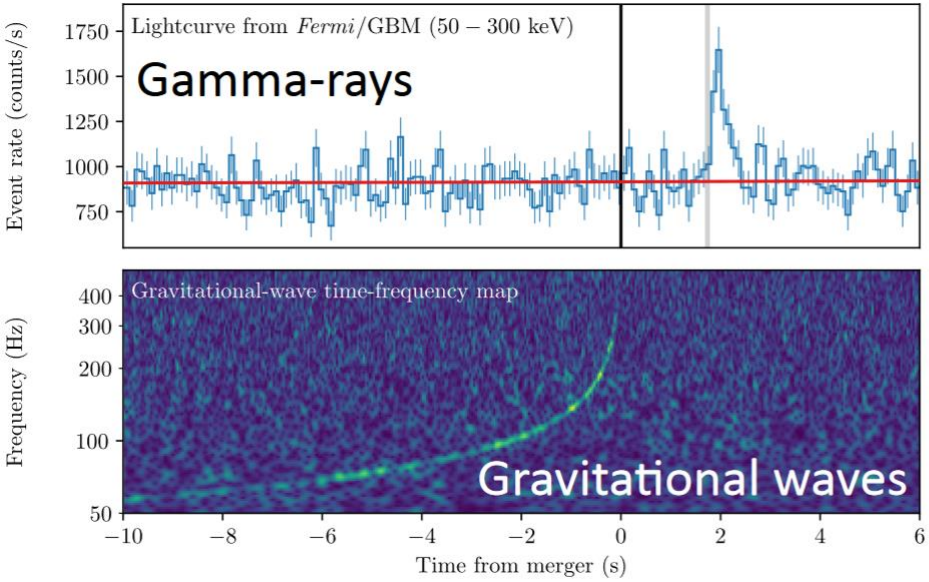
Density
$\rho < 8\rho_0$

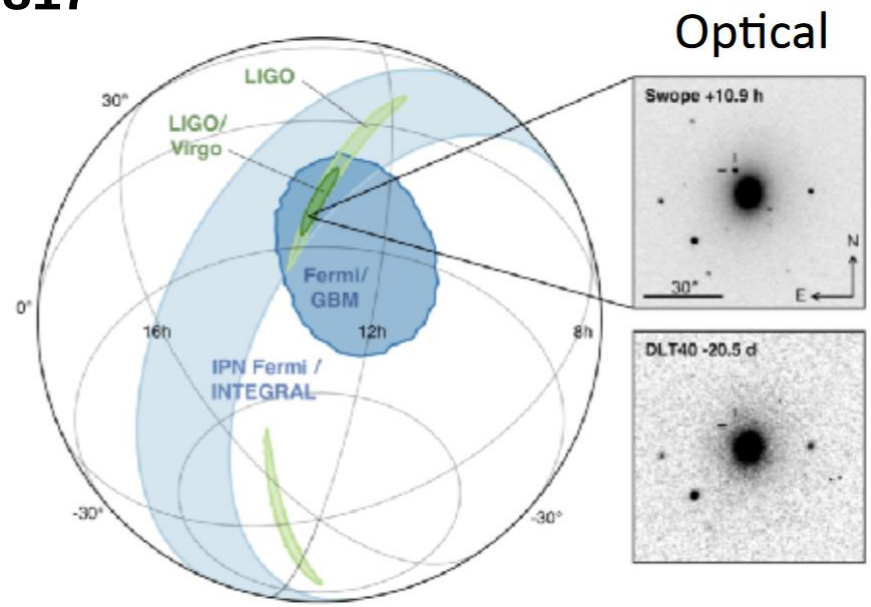
Reaction time
$t \sim 10^{-23}$ s

Isospin symmetric matter

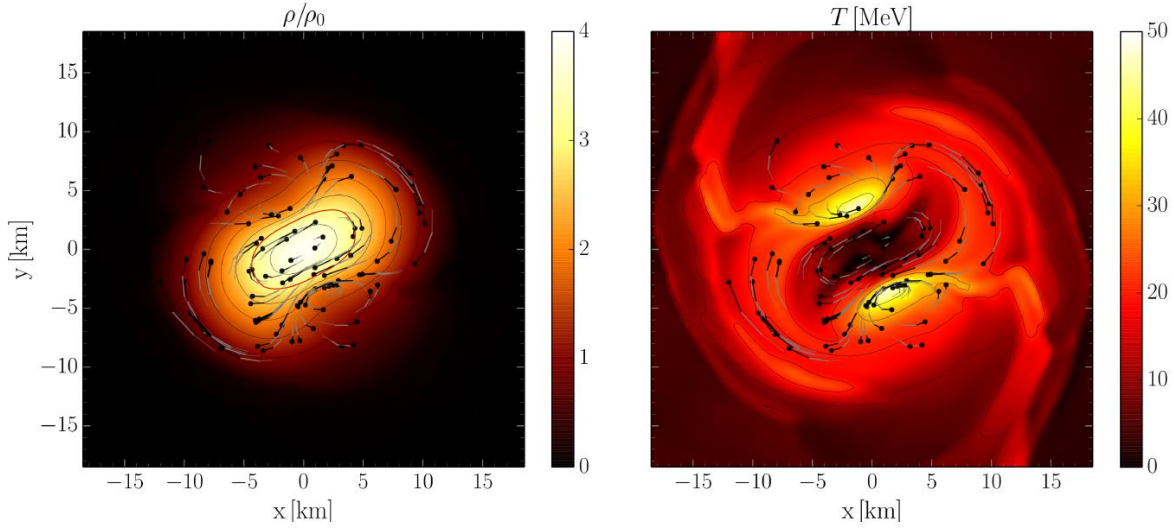
Neutron star merger

GW170817



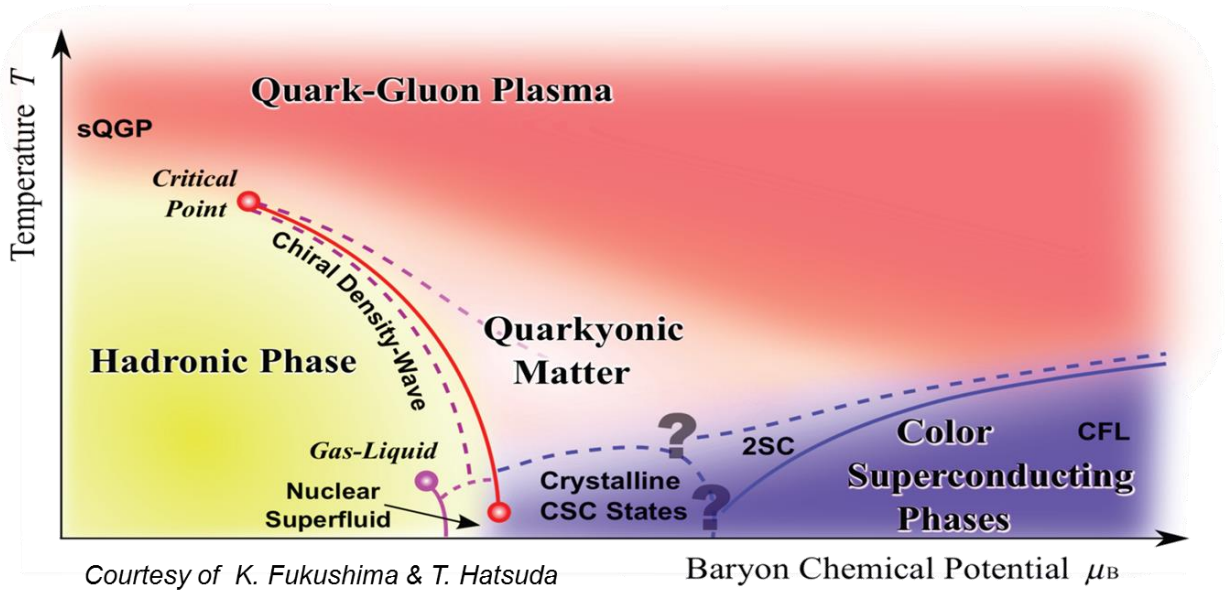


http://www.ligo.org



M. Hanauske et al.,
J. Phys.: Conf. Ser.
878 012031

CBM – Goals



Courtesy of K. Fukushima & T. Hatsuda

Mission:

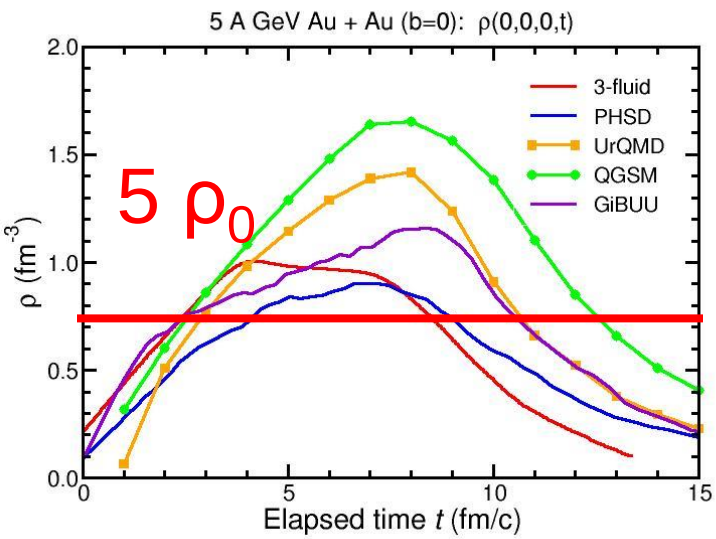
Systematically explore QCD matter at large baryon densities with high accuracy and rare probes.

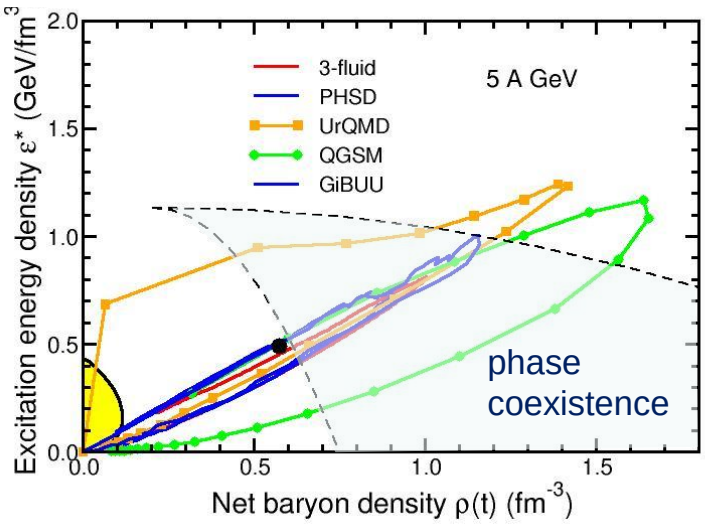
Fundamental questions:

Equation of State of QCD matter at neutron star densities
Phase structure of QCD matter
Chiral symmetry restoration at large densities
Bound states with strangeness
Charm in dense baryonic matter

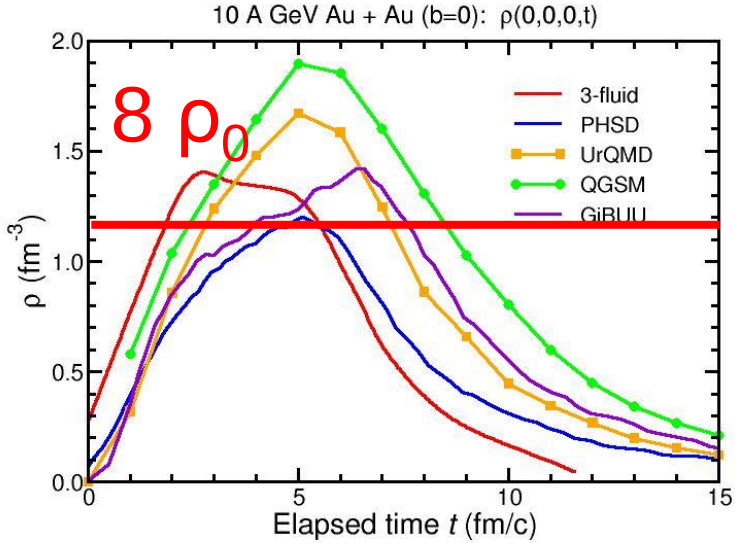
Baryon densities in central Au+Au collisions

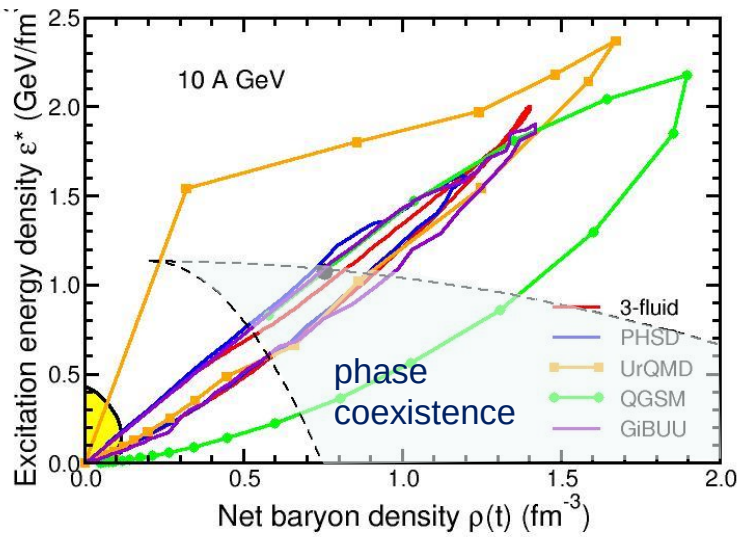
5 A GeV





10 A GeV





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

CBM physics and observables

Eur.Phys.J. A53 (2017) 60

QCD equation-of-state
- collective flow of identified particles
- particle production at threshold energies

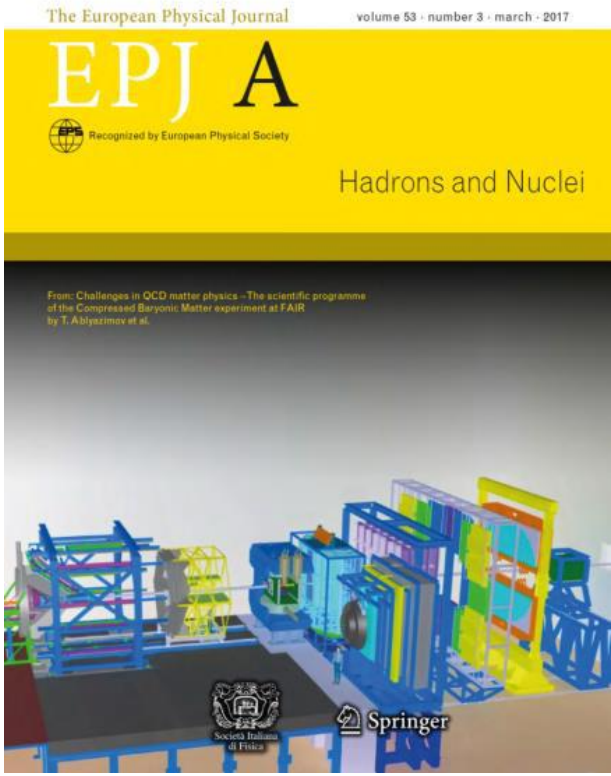
Phase transition
- excitation function of hyperons
- excitation function of LM lepton pairs

Critical point
- event-by-event fluctuations of conserved quantities

Chiral symmetry restoration at large ρ_B
- in-medium modifications of hadrons
- dileptons at intermediate invariant masses

Strange matter
- (double-) lambda hypernuclei
- Search for meta-stable objects (e.g. strange dibaryons)

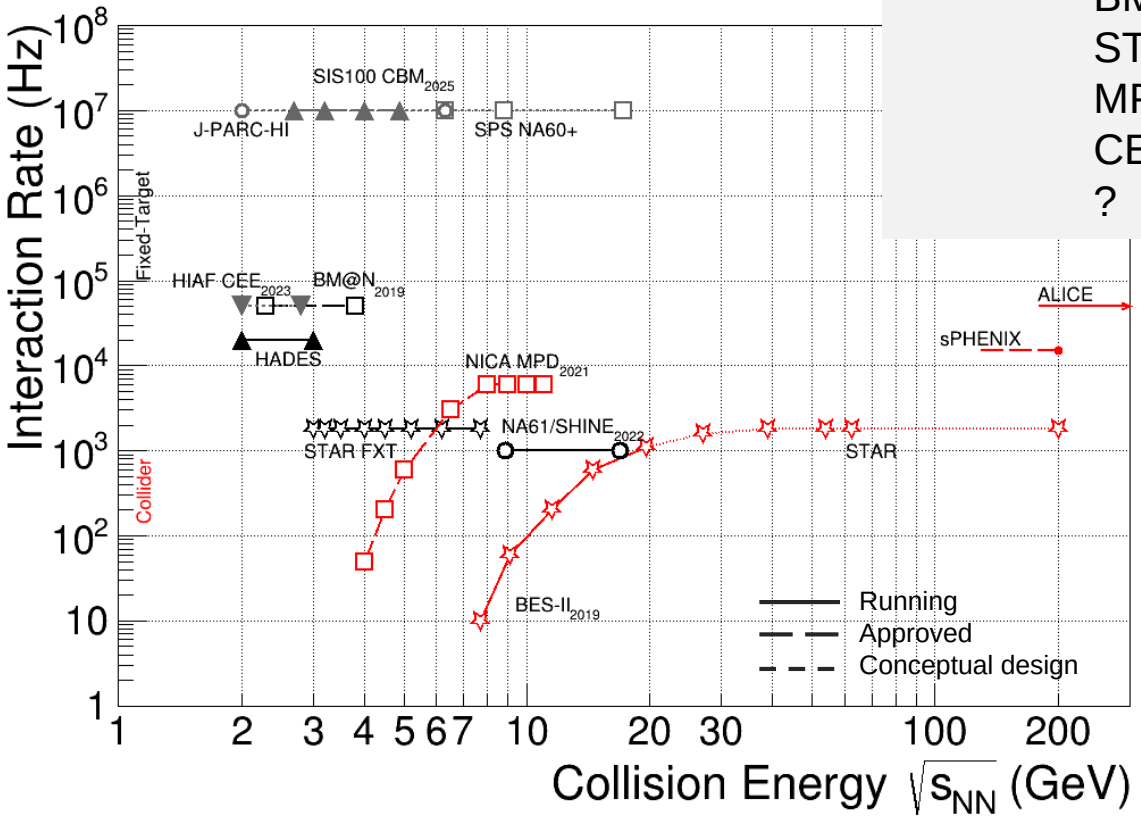
Heavy flavour in cold and dense matter
- excitation function of charm production



CBM – experimental efforts

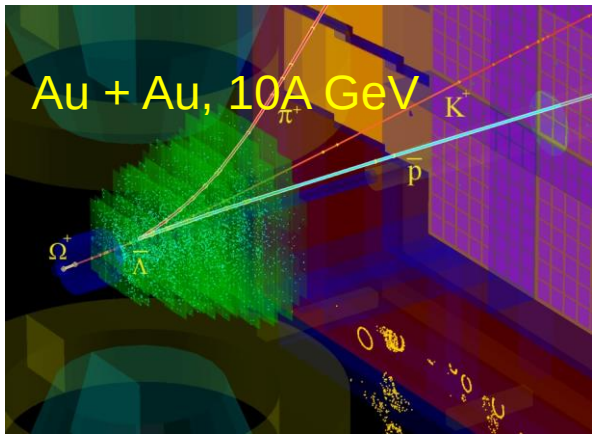
Exploration of QCD phase diagram
as international effort:

NA61	@ SPS / CERN
BM@N	@ Nuclotron/JINR
STAR (FXT)	@ RHIC/BNL
MPD	@ NICA / JINR
CEE	@ HIAF
?	@ J-PARC



CBM‘s unique feature:
Comprehensive high statistics measurement of rare probes

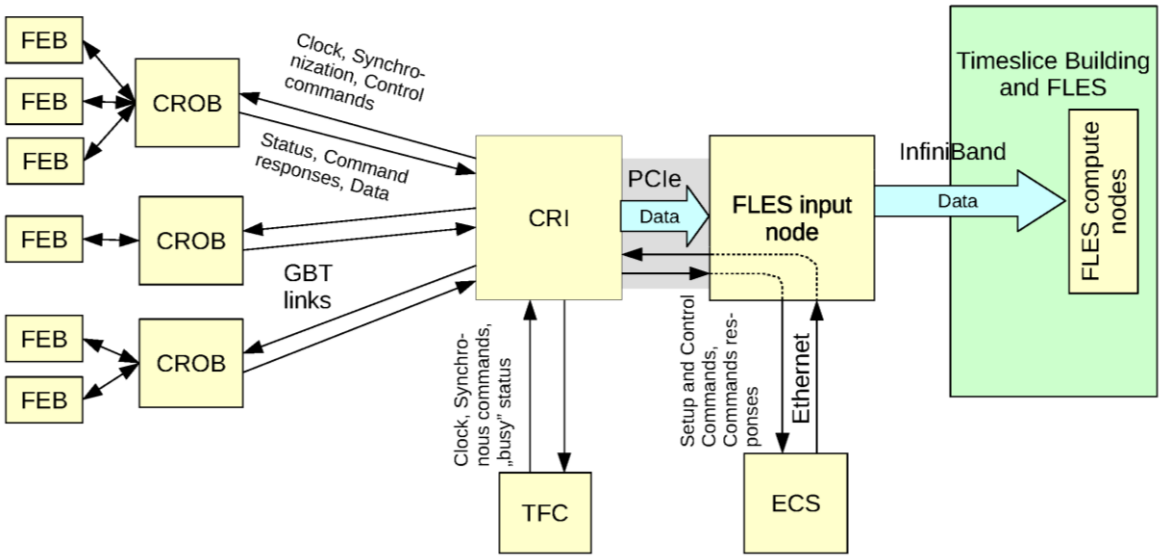
CBM data processing system



Reaction rate Au + Au:

10^7 collisions per second

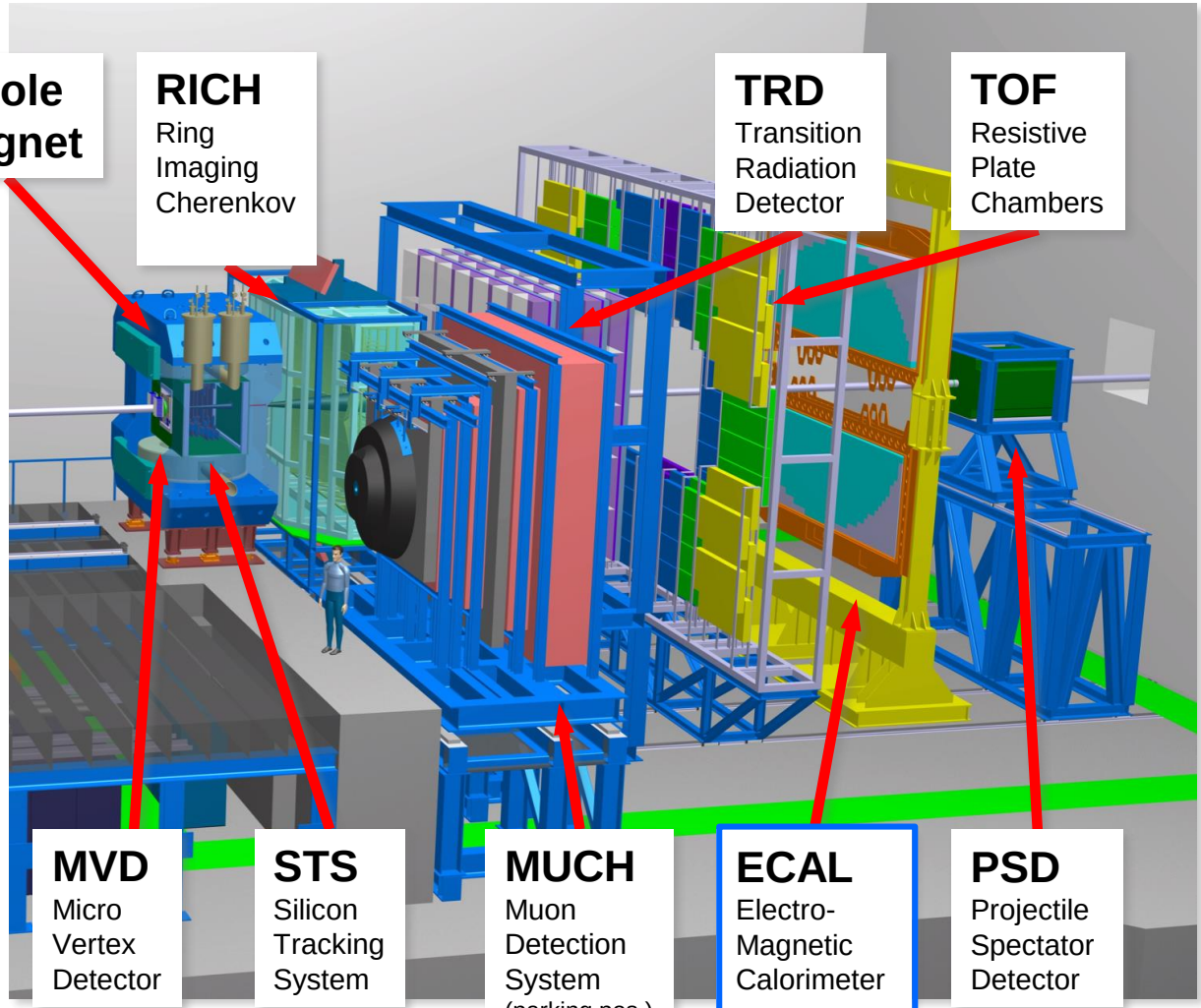
Data rate: ~ 1 TB/s



Main features:

- radiation tolerant detectors and front-end electronics
- free streaming (triggerless) data with time stamps,
- software based event selection

CBM experimental setup (day-1)



- Tracking acceptance: $2^o < \theta_{lab} < 25^o$
- Free streaming DAQ
- R_{int} = 10 MHz (Au+Au)

  $R_{int} \approx 0.5$ MHz

  full bandwith:

  Det. – Entry nodes

  reduced bandwidth

  Entry nodes – Comp. farm

  with

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

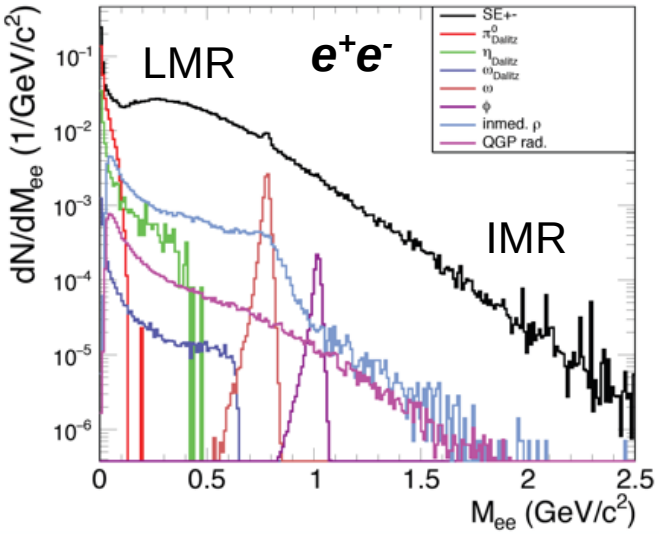
Day-1 setup
funding: ~ 90% secured

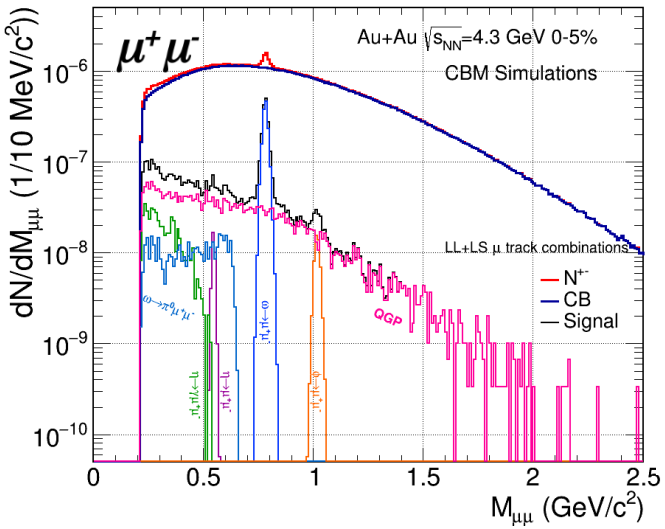
Day-1 setup = MSV (Phase-1) setup – Compute Performance - ECAL

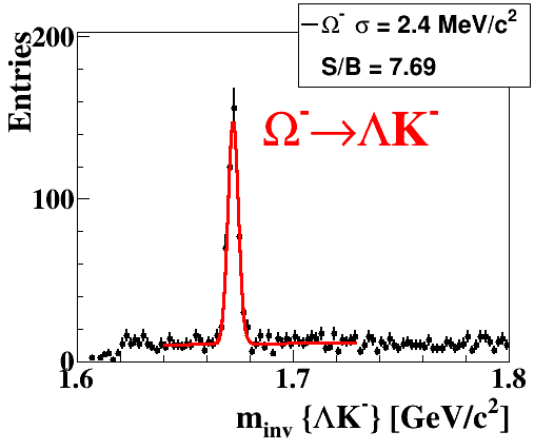
Physics potential of Day-1 configuration

Unique, unprecedented measurements in SIS100 energy range

- excitation function of dilepton yields (e^+e^-, $\mu^+\mu^-$)
- excitation function of multi strange hyperon production



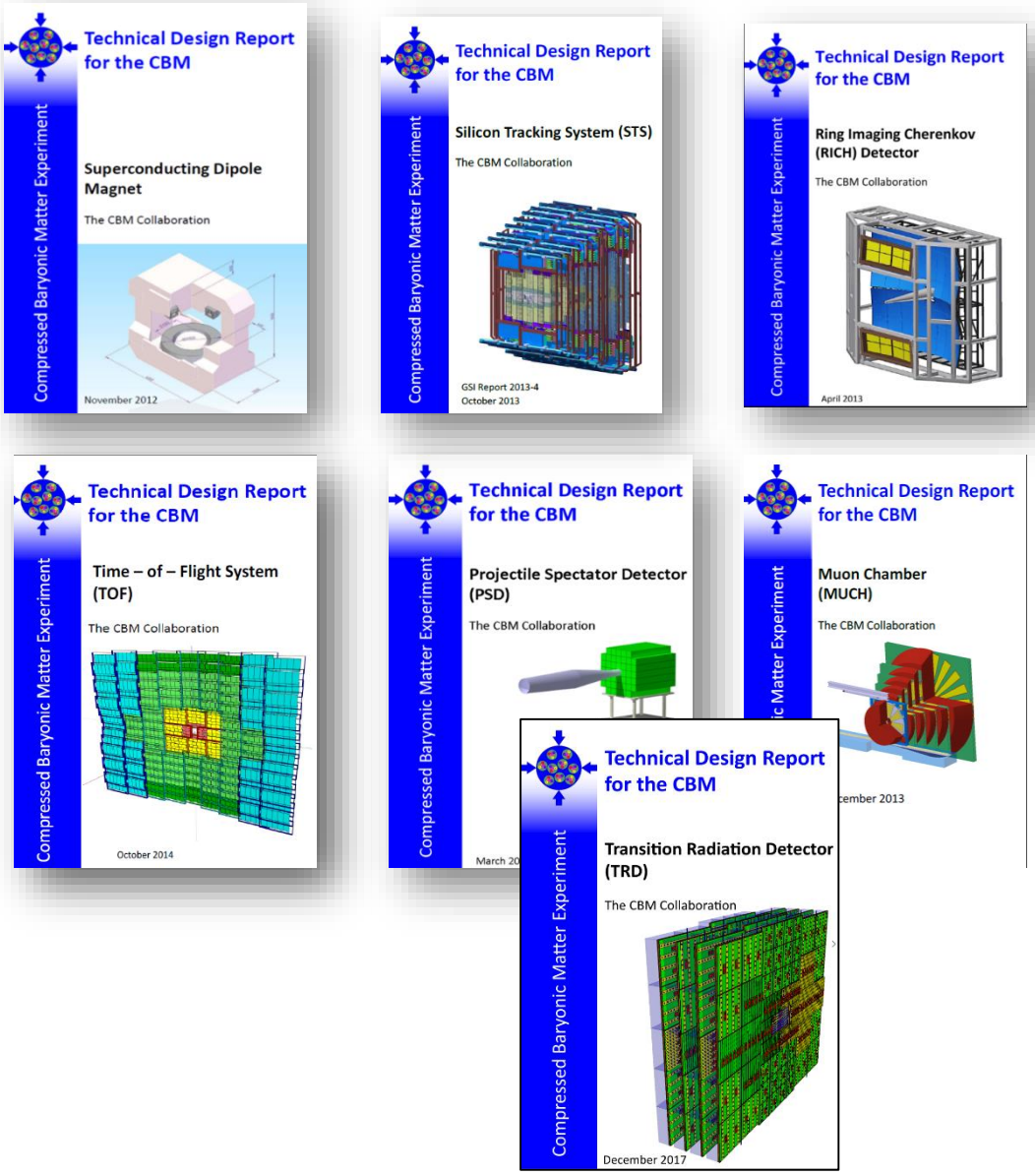




CBM & HADES physics programs are endorsed by JSC.

CBM Technical Design Reports

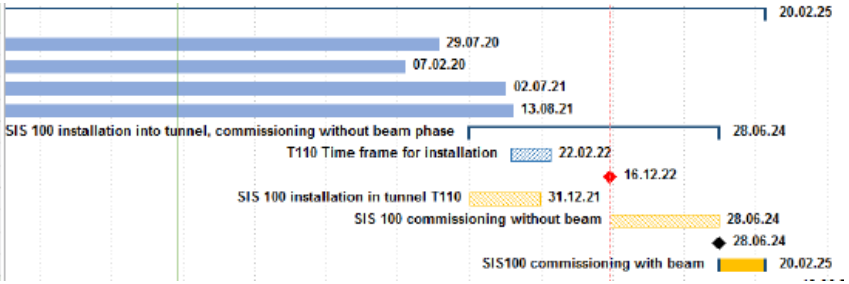
#	Project	TDR Status
1	Magnet	approved 2013
2	STS	approved 2013
3	RICH	approved 2014
4	TOF	approved 2015
5	MuCh	approved 2015
6	PSD	approved 2015
7	TRD	approved 2018
8	MVD	submission 2019
9a	Online Systems: DAQ	submission 2019
9b	Online Systems: FLES	submission 2020
10	ECAL	submission t.b.d.



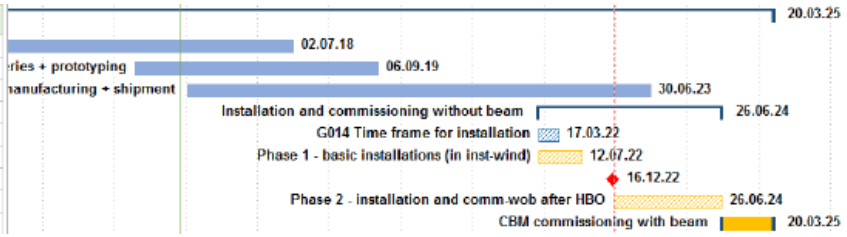
FAIR / CBM schedule

as presented in ECE 26.7.2017

120	**SIS100**	**174,17 mons**	**17.10.2011**	**20.02.2025**
121	SIS 100 planning phase	114,6 mons	17.10.2011	29.07.2020
122	SIS 100 manufacturing of pre-series phase	99,25 mons	02.07.2012	07.02.2020
123	SIS 100 manufacturing of series phase	97,2 mons	21.01.2014	02.07.2021
124	SIS 100 shipment, SAT A phase	101,1 mons	14.11.2013	13.08.2021
125	**SIS 100 installation into tunnel, commissioning without beam phase**	**45,6 mons**	**31.12.2020**	**28.06.2024**
126	T110 Time frame for installation	6,75 mons	29.07.2021	22.02.2022
127	Acceptance by HBO	0 mons	16.12.2022	16.12.2022
128	SIS 100 installation in tunnel T110	13,06 mons	31.12.2020	31.12.2021
129	SIS 100 commissioning without beam	20 mons	19.12.2022	28.06.2024
130	SIS 100 ready for beam	0 mons	28.06.2024	28.06.2024
131	**SIS100 commissioning with beam**	**8,42 mons**	**28.06.2024**	**20.02.2025**



233	**CBM**	**152,67 mons**	**08.07.2013**	**20.03.2025**
234	Phase 2: design and planning	65 mons	08.07.2013	02.07.2018
235	Phase 4: pre-series + prototyping	44,5 mons	11.04.2016	06.09.2019
236	Phase 5+6: manufacturing + shipment	84,6 mons	05.01.2017	30.06.2023
237	**Installation and commissioning without beam**	**33,55 mons**	**01.12.2021**	**26.06.2024**
238	G014 Time frame for installation	3,1 mons	02.12.2021	17.03.2022
239	Phase 1 - basic installations (in inst-wind)	160 dys	01.12.2021	12.07.2022
240	Acceptance by HBO	0 mons	16.12.2022	16.12.2022
241	Phase 2 - installation and comm-wob after HBO	398 dys	19.12.2022	26.06.2024
242	**CBM commissioning with beam**	**9,52 mons**	**26.06.2024**	**20.03.2025**

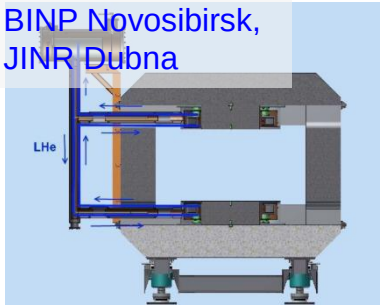


- Dec ‘21 to Jul ‘22 — 1st installation window
- Dec ‘22 — Building acceptance
- Dec ‘22 to Jun ‘24 — Installation & commissioning w/o beam
- Mar ’23 — Cryo: DB2 cold; cool down CBM Magnet
- Jun ‘24 to Mar ‘25 — Commissioning beam from SIS100

*Rebaselining of project planned for end 2018 !

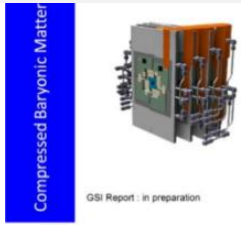
Progress in developments

Magnet
GSI Darmstadt,
BINP Novosibirsk,
JINR Dubna



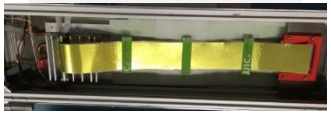
PDR in Apr. 19

MVD
IKF Frankfurt,
IPHC Strasbourg,
Pusan Nat'l Univ.



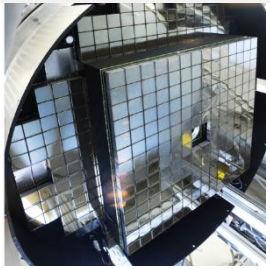
TDR in 2019

STS
GSI Darmstadt,
JINR Dubna,
KIT Karlsruhe,
JU Crakow,
AGH Crakov,
KINR Kiev,
Univ. Tübingen,
Warsaw UT



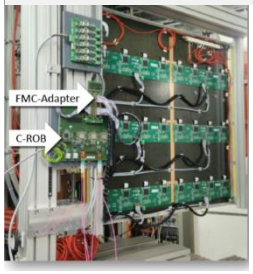
Full 2sided ro demostrated, sensor contracting started

RICH
Univ. Giessen,
Univ. Wuppertal,
PNPI Gatchina,
GSI Darmstadt



MAPMT ready for HADES beam.

TRD
NIPNE Bucharest,
Univ. Frankfurt,
Univ. Heidelberg,
Univ. Münster



2 chambers operational for mCBM beam.

MUCH
Aligarh Muslim Univ.,
Bose Inst. Kolkata,
Panjab Univ.,
Univ. of Jammu,
Univ. of Kashmir,
Univ. of Calcutta,
B.H. Univ. Varanasi,
VECC Kolkata,
IOP Bhubaneswar,
NISER Bhubaneswar,
IIT Kharagpur,
IIT Indore,
Gauhati Univ.,
PNPI Gatchina

2 modules ready for mCBM

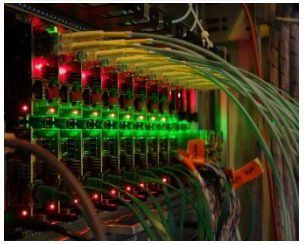
TOF
THU Beijing,
NIPNE Bucharest,
GSI Darmstadt,
TU Darmstadt,
USTC Hefei,
Univ. Heidelberg,
ITEP Moscow,
HZDR Rossendorf,
CCNU Wuhan

Preproduction and tests done for mCBM & eTOF

PSD
INR Moscow,
TU Darmstadt,
CTU Prague,
NPI Rez

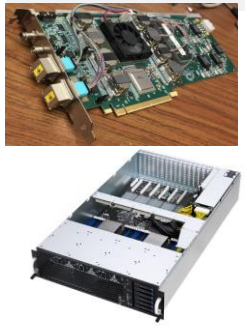
Response studies at CERN confirmed TDR performance

DAQ
GSI Darmstadt
KIT Karlsruhe
Warsaw UT
IRI Frankfurt



Data sync. within subsys. demonstrated

FLES
FIAS Frankfurt
Univ. Frankfurt

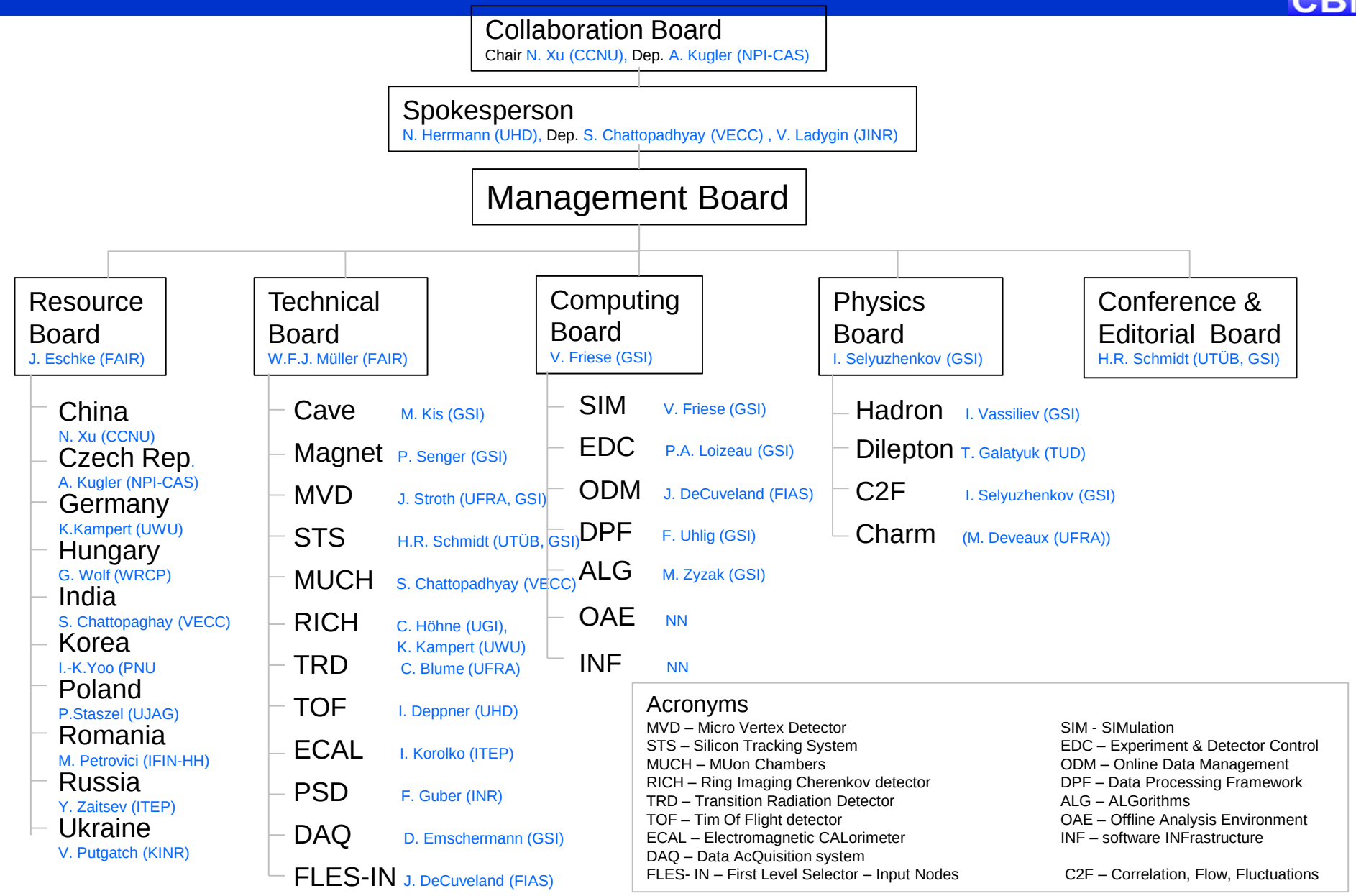


Concept. Design done, prototype FLESnet running

CBM status: score card

	Component/ Sub-System	TDR	Cost [k€ 2005]	Funding	Construction	Construction completed	Test/ Commissioning
Day-1	Micro Vertex Detector (MVD)		914			09/2023	
	Silicon Tracking System (STS)		9504			02/2024	
	Ring Image Cherenkov Detector (RICH)		3697			07/2023	
	Muon Detector (MUCH)		6138			03/2024	
	Transition Radiation Detector (TRD)		2544			01/2024	
	Time of Flight System (TOF)		5857			12/2023	
	Projectile Spectator Detector (PSD)		944			11/2021	
	Dipol Magnet		3758			09/2022	
	Online Systems (DAQ and FLES)		1896			06/2023	
	Infrastructure		2273			01/2023	
		86% *value weighted*	37525	87% *secured*	10% *value weighted*		
Phase-0 (SIS18) & Day-1 (SIS100)	HADES upgrade		2453			03/2023	

CBM organisation



Acronyms

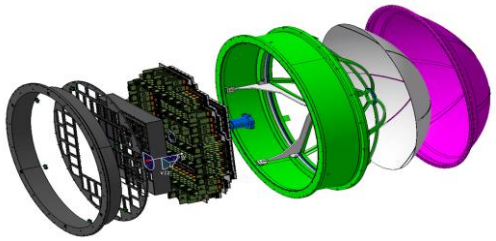
MVD – Micro Vertex Detector
STS – Silicon Tracking System
MUCH – MUon Chambers
RICH – Ring Imaging Cherenkov detector
TRD – Transition Radiation Detector
TOF – Tim Of Flight detector
ECAL – Electromagnetic CALorimeter
DAQ – Data AcQuisition system
FLES- IN – First Level Selector – Input Nodes

SIM - SIMulation
EDC – Experiment & Detector Control
ODM – Online Data Management
DPF – Data Processing Framework
ALG – ALGorithms
OAE – Offline Analysis Environment
INF – software INFrastructure

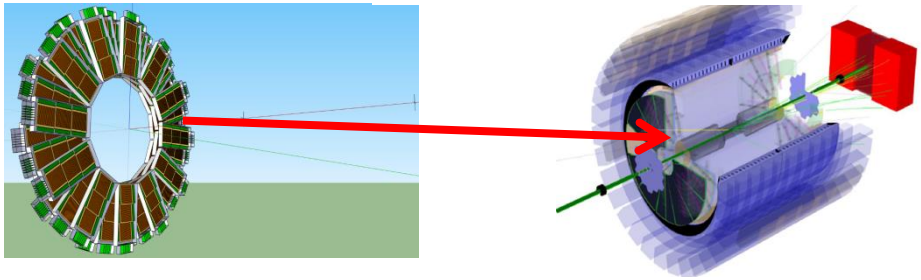
C2F – Correlation, Flow, Fluctuations

CBM – FAIR Phase 0 projects (2018 – 2024)

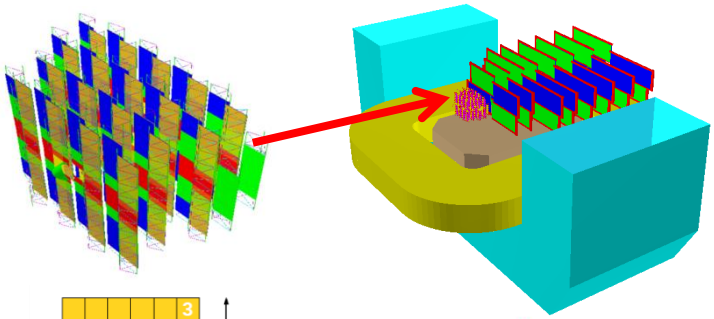
1. Install, commission and use 430 out of 1100 CBM RICH multi-anode photo-multipliers (MAPMT) including FEE in HADES RICH photon detector



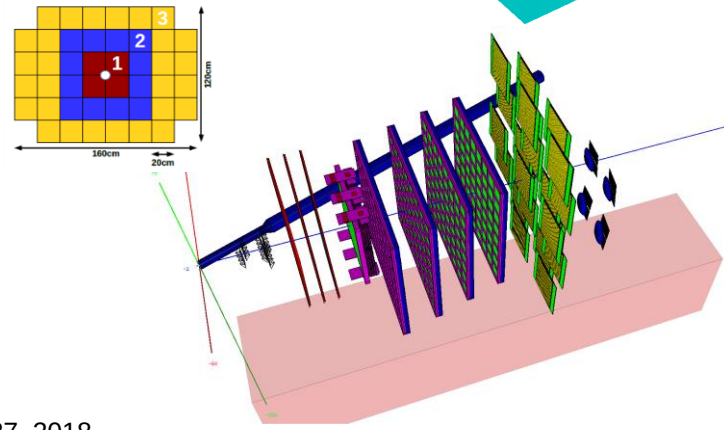
2. Install, commission and use 10% of the CBM TOF modules including read-out chain at STAR/RHIC (BES II 2019/2020)



3. Upgrade BM@N experiment with 4 Silicon stations of CBM/STS design in the BM@N experiment at the Nuclotron JINR/Dubna (Au-beams in late 2020)



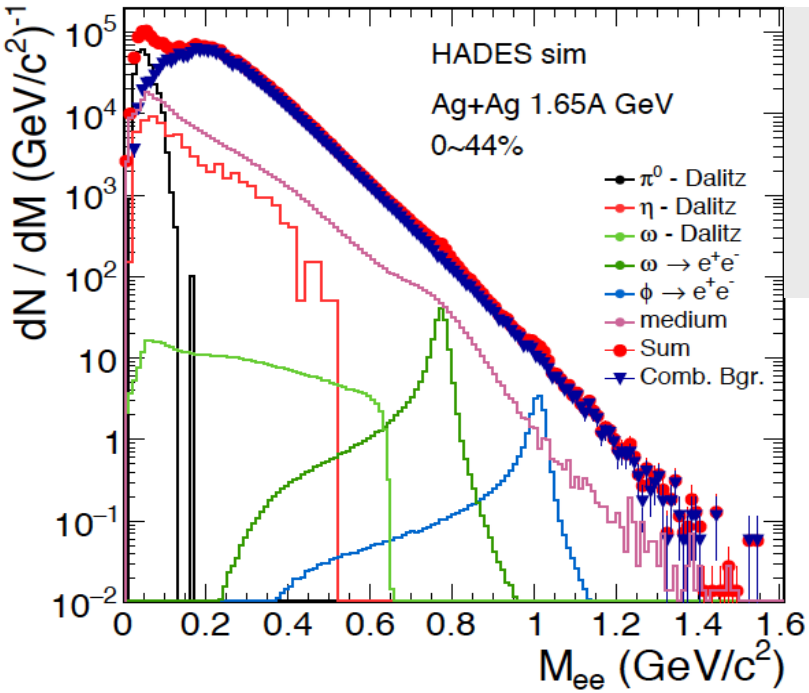
4. Install, commission and use the Project Spectator Detector at the BM@N experiment



5. mini CBM (mCBM@SIS18) demonstrator for full CBM data taking and analysis chain

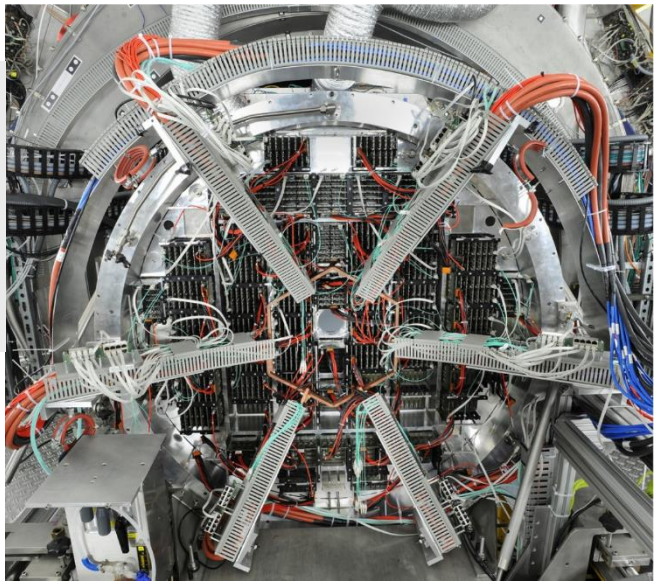
Phase-0: Ag+Ag, 1.65*A* GeV @ SIS18

Expected **dielectron** invariant mass spectrum



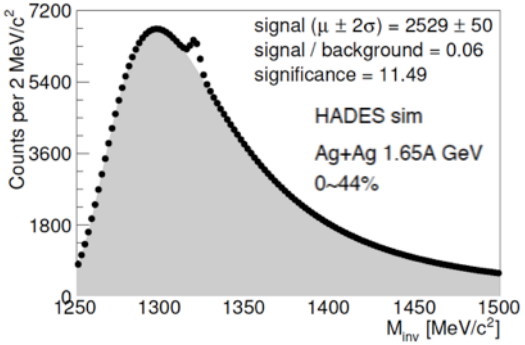
4.5×10^9 events
10 kHz trigger rate
4 wks beam on target

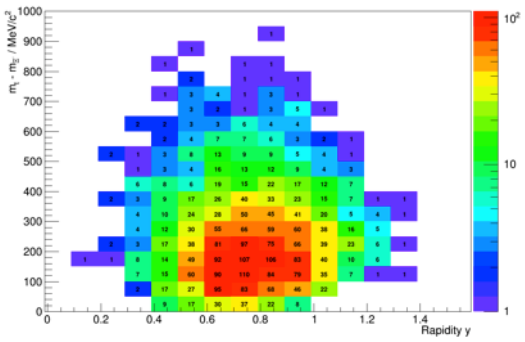
Physics run scheduled
for Feb/Mar 2019



- Access for the first time at this collision energies intermediate mass range

(Multi)-Strangeness in Ag+Ag.
Understanding of the Ξ^- excess.

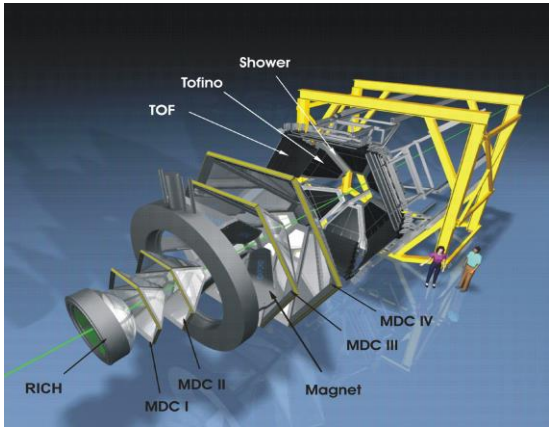




Participating CBM groups:
- Univ. Wuppertal
- Univ. Giessen
- GSI Darmstadt
- Univ. Frankfurt
- TU Darmstadt

HADES upgrades

HADES Spectrometer



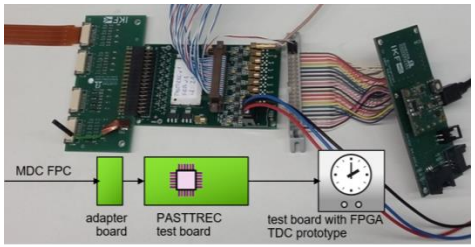
RICH Upgrade

HADES Calorimeter

- ✓ **RICH (HADES/CBM phase 0 project) – finished, ready for beam**
  - Gain in lepton pair detection efficiency (x 3)
  - Improved background/noise rejection:
    - Better conversion pair rejection
    - Precise time information (down to 300ps precision)
  - Joint (CBM/PANDA/HADES) development of read-out system based on TRB3 platform.
- ✓ **Electromagnetic Calorimeter – 4 sectors ready for beam in 2019**
  - π0 and η decays into γγ channel
  - Electromagnetic decays of baryonic resonances
  - Improved e/π separation: important for di-electron spectroscopy
  - Proven technology: lead glass modules read out with Hamamatsu PMTs
- ✓ **MDC readout upgrade – Installation in 2020**
  - Multi-hit TDC (TRB based) – essential for high rate experiments
  - Read-out trigger rate increase from 50 kHz to 200 kHz
- ✓ **Forward Detector (HADES/PANDA phase 0 project) – installation in 2019**
  - Enhance HADES capabilities for exclusive channels – forward region
  - Hyperon production and EM decays
  - PID via TOF, dE/dx(straw tube) – no magnetic field

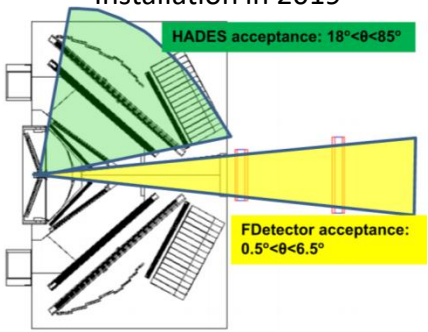
MDC readout upgrade

Installation in 2020

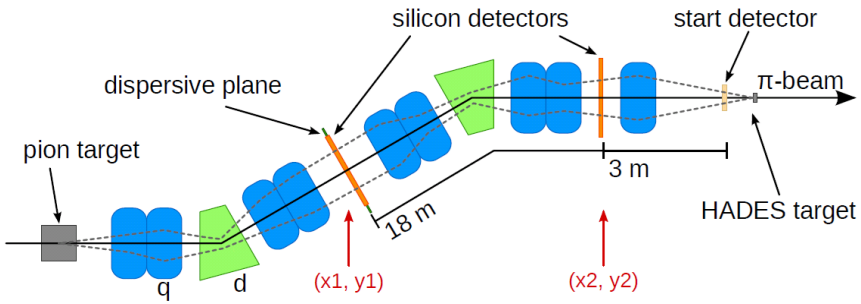


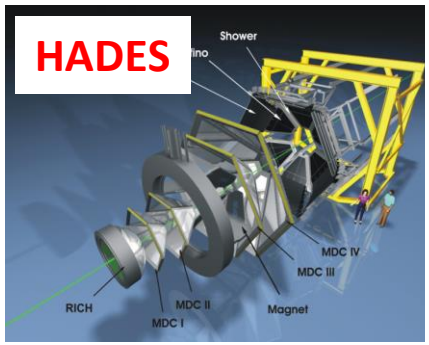
Forward Detector –

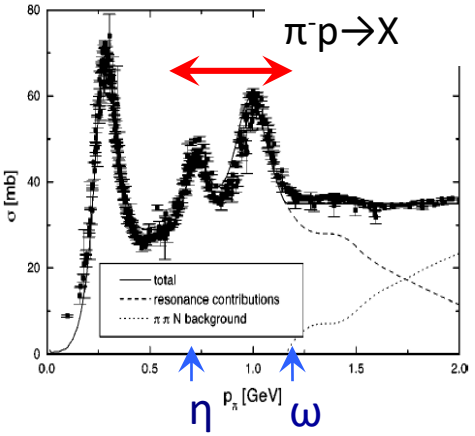
Installation in 2019



π Beam experiments with HADES at GSI

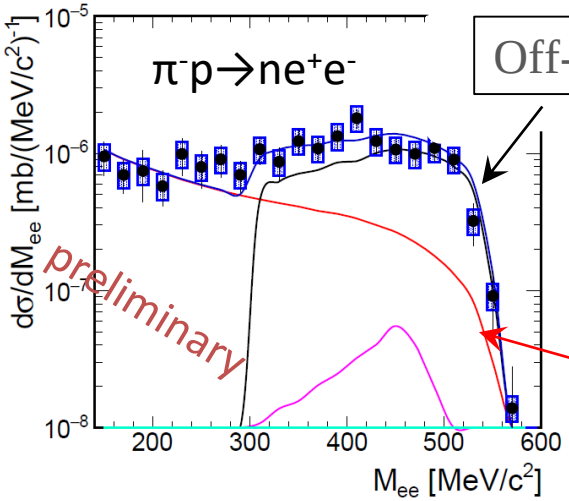




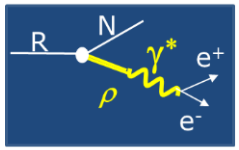


Ideal tool (and unique in world) for baryon resonance studies
→ invaluable source of information on QCD

Successful pioneering experiment in 2014
in the N(1520) region



Off-shell ρ



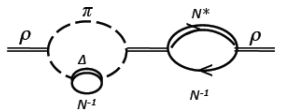
Point-like baryons

π⁻p:

Hadronic channels: ππN (**ρn**), ηn, ωn, ΛK
Partial Wave Analysis for baryon spectroscopy
(together with γ beam data)
e^+e^- : time-like baryon transitions
(cf electron scattering)

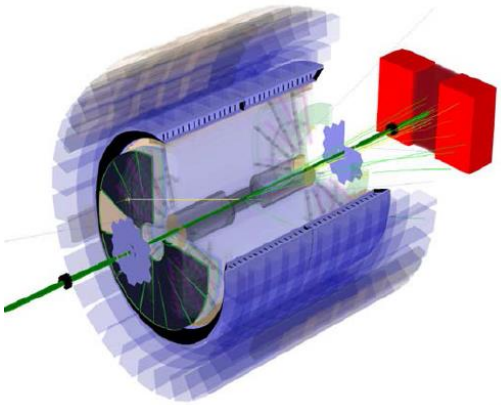
π⁻A:

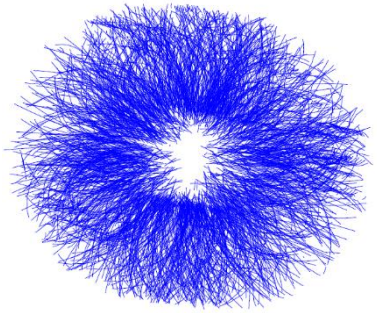
cold matter studies, collective ρ-induced
baryon-hole excitations

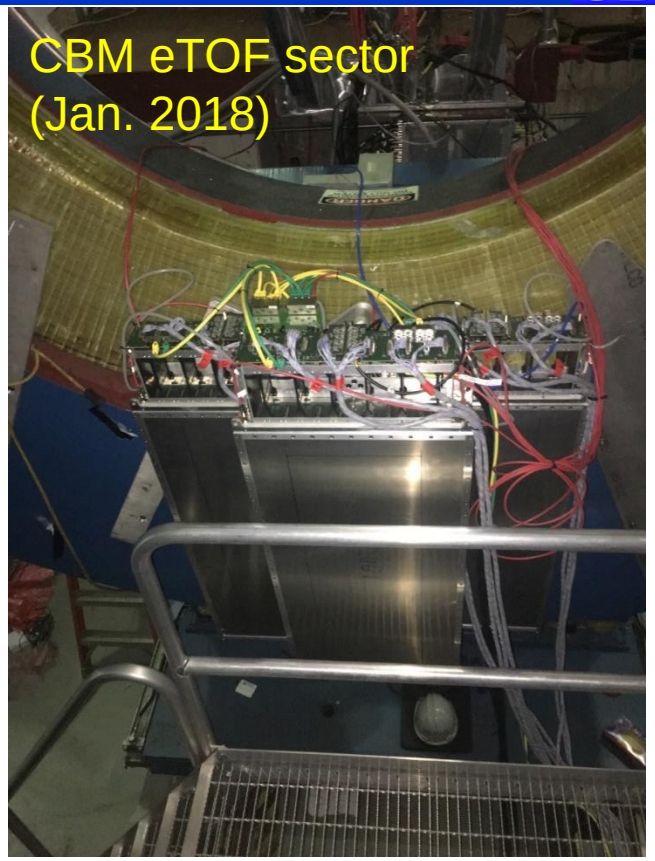


Beam request for investigation of the N(1720) region

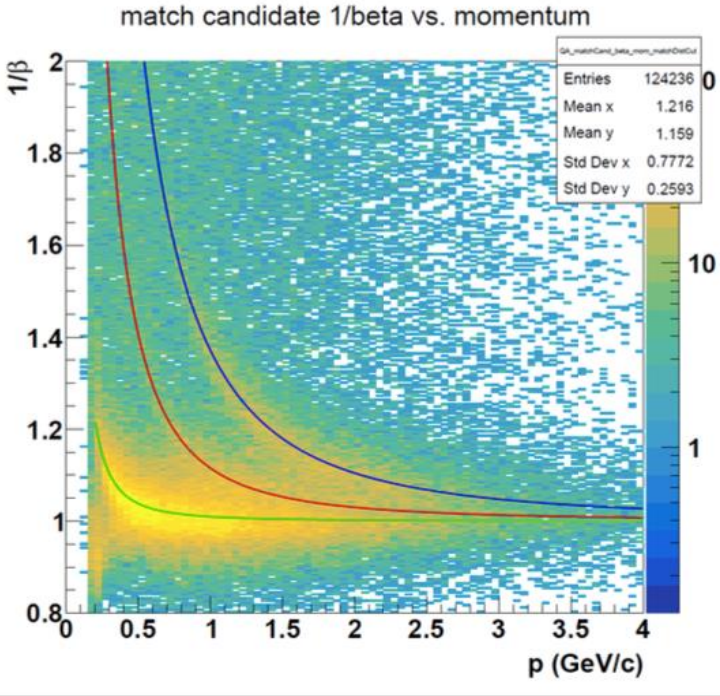
eTOF & HPC software in STAR at RHIC (BNL)







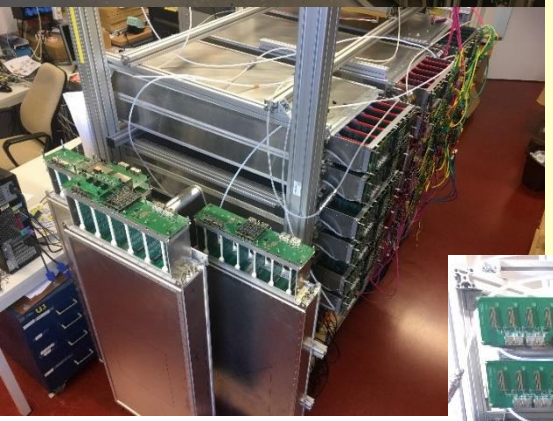
Correlation:
CBM-eTOF
with STAR TPC
from Run18

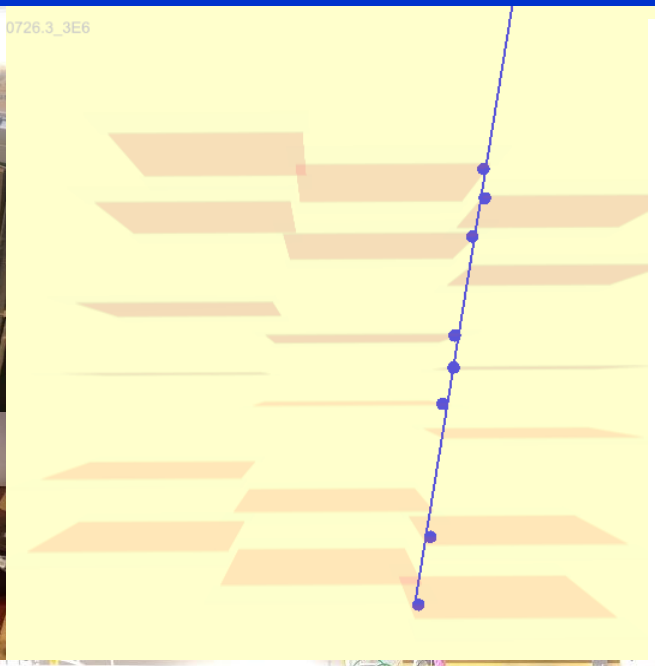


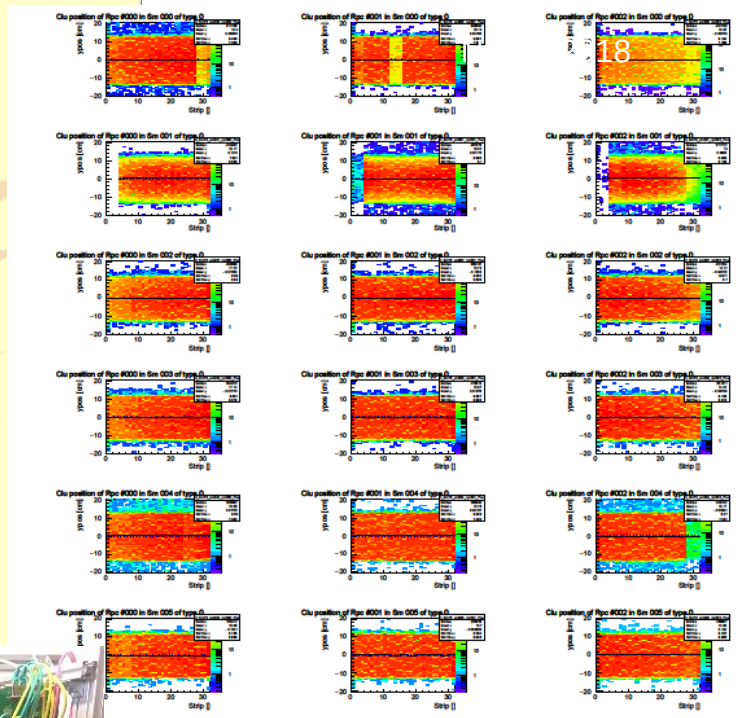
CBM groups:
- Tsinghua Univ. Beijing
- GSI Darmstadt
- TU Darmstadt
- Univ. Frankfurt
- Univ. Heidelberg
- USTC Hefei
- CCNU Wuhan

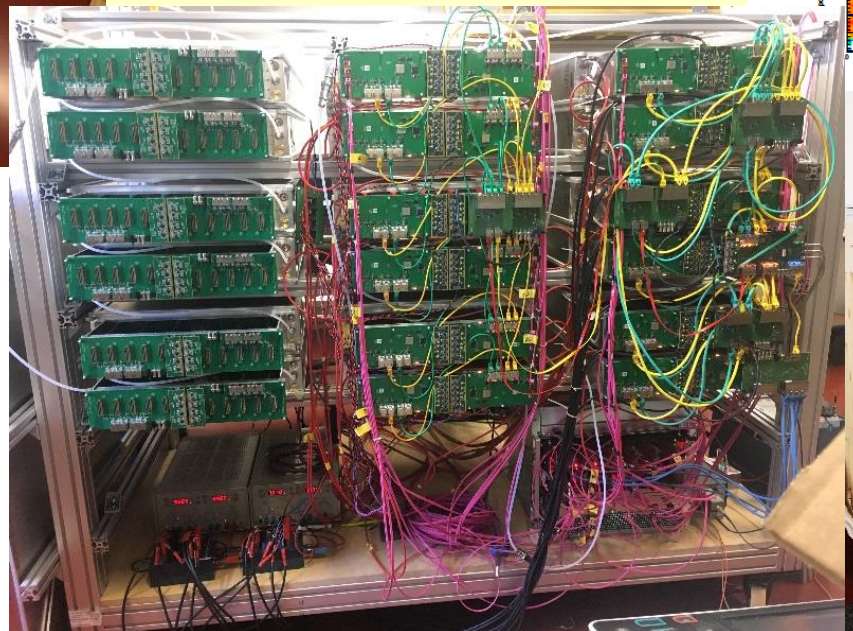
Test module operational	(Oct. 2016)
STAR DAQ interface	(Jan. 2017)
Full sector test	(Spring 2018)
Wheel installation	(Fall 2018)
BES II data taking	(2019/2021)
Transfer of modules to FAIR	(2022/23)

CBM-STAR eTOF: module production & test in HD



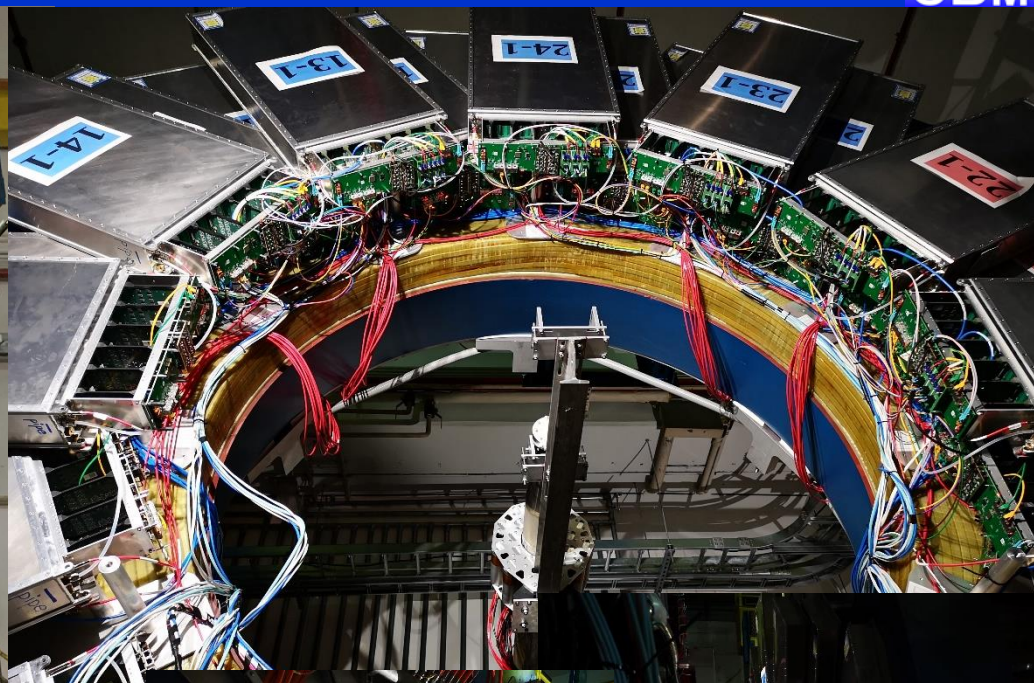


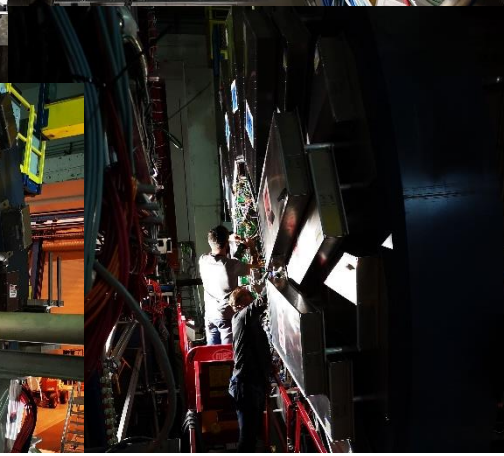




36 modules
108 MRPCs
72 GBTX PCBs
216 GET4 PCBs
216 PADI PCBs
6912 channels
DAQ/FLES HW/SW

CBM-STAR eTOF: status

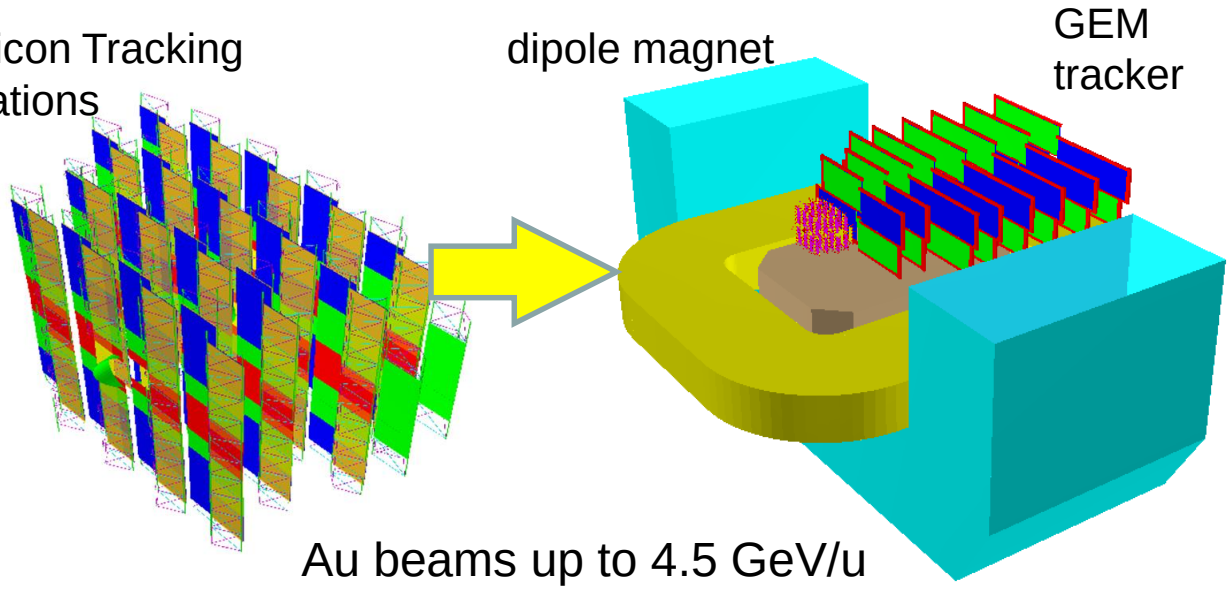




Nov. 23, 2018:
all eTOF modules installed and functional,
SW integration ongoing.

N.Herrmann

Phase-0: STS & PSD in BM@N (JINR)



Au beams up to 4.5 GeV/u

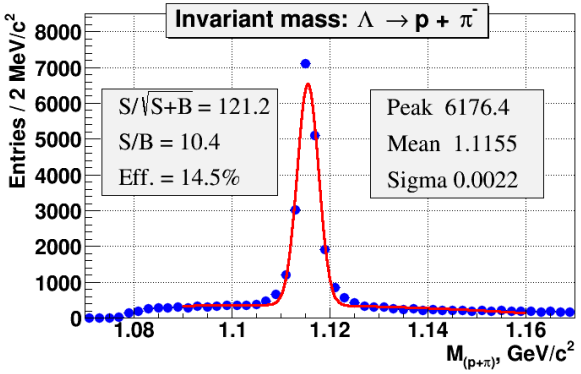
PSD calorimeter (synergies with usage in NA61/shine)

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

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

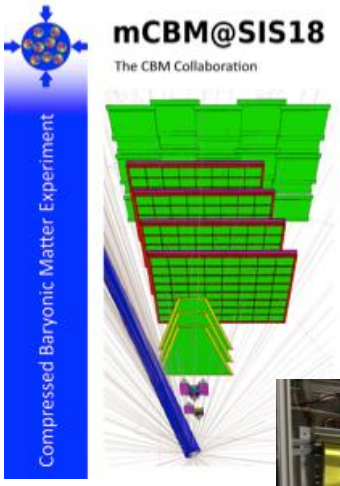
Participating CBM groups:
GSI Darmstadt,
Univ. Tübingen,
JINR Dubna,
INR Moscow

Improvement in efficiency & signal / backrgound

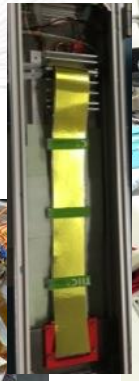


CBM Phase-0: mCBM

Demonstrator for full CBM data taking and analysis chain under full load (Au-Au, 10^7 interactions/s)



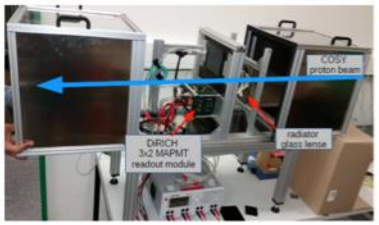

mMVD


mSTS

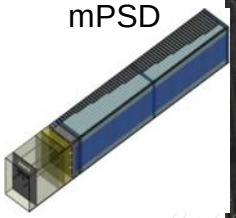

mMUCH


mTRD

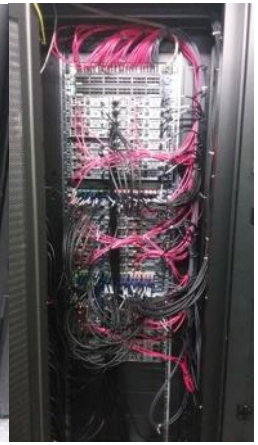

mTOF

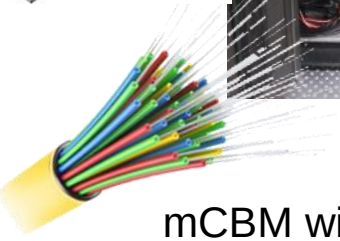


mRICH


mPSD

mFLES racks @ Green IT Cube





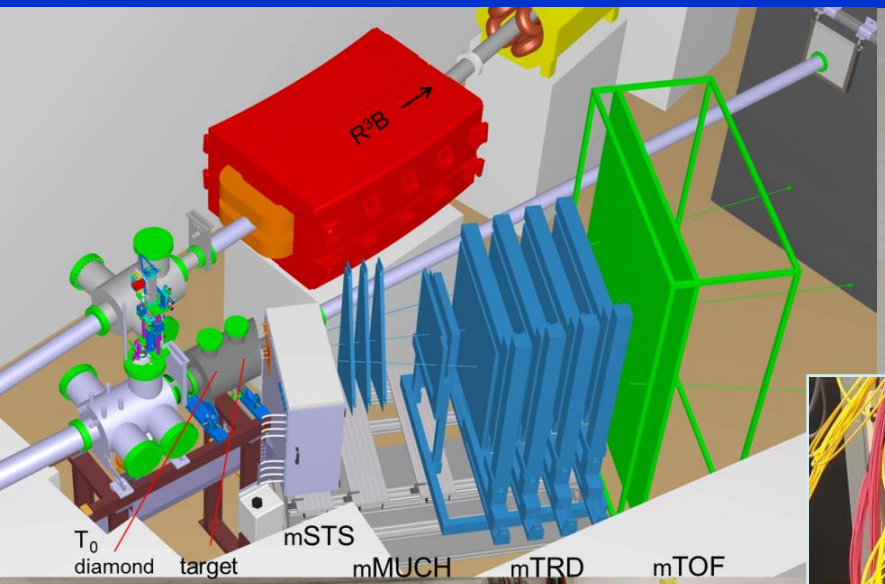
mCBM will focus on:

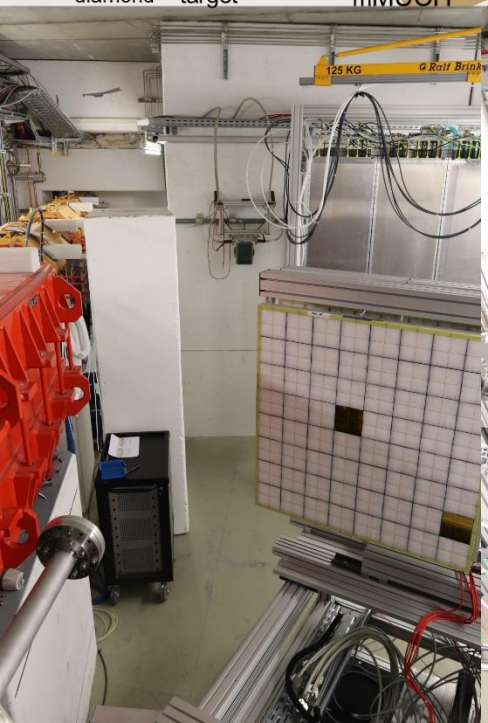
- Free streaming data transport to a computer farm
- Online reconstruction and event selection
- Offline data analysis

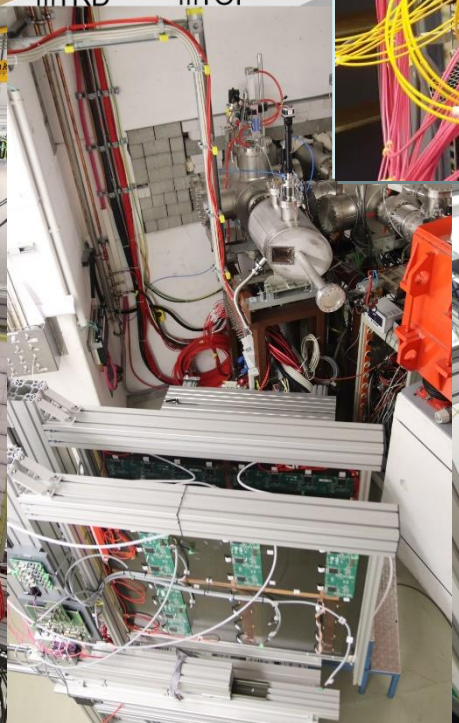
Requested beam time was fully granted by G-PAC

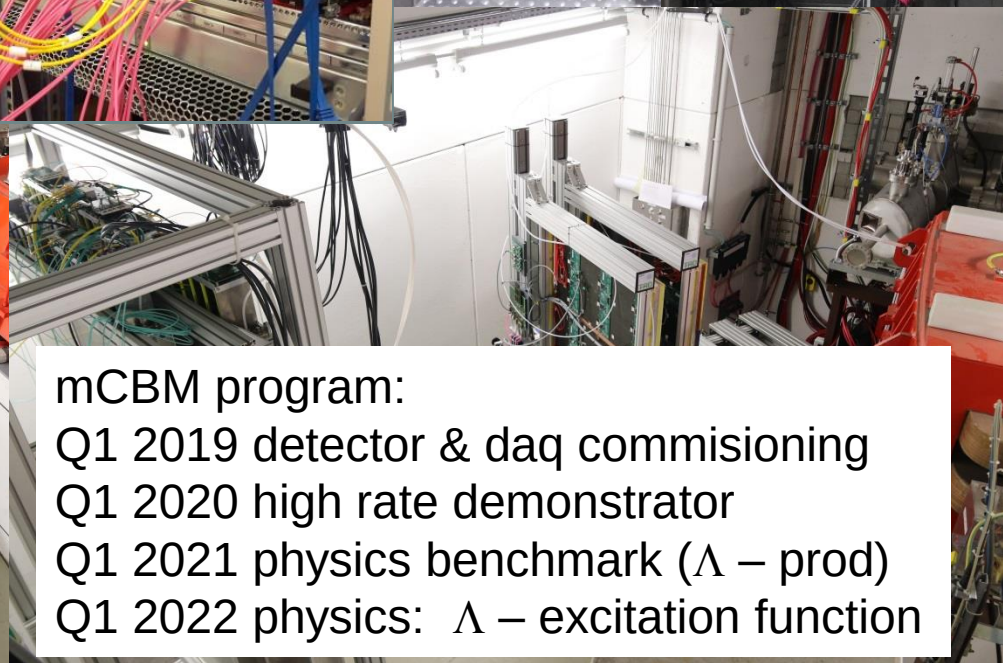
Common effort of all CBM groups!

mCBM (Nov. 2018)









mCBM program:
Q1 2019 detector & daq commisioning
Q1 2020 high rate demonstrator
Q1 2021 physics benchmark (Λ – prod)
Q1 2022 physics: Λ – excitation function

Summary / Conclusion

CBM scientific program at SIS100 is unique

- explore QCD matter at neutron star core densities
- employ high statistics capibility
  - to achieve high-precision of multi-differential observables
  - to enable rare processes as sensitive probes

CBM day-1 setup allows start of program with significant discovery potential

- excitation function of hyperons production
- excitation function of di-lepton production
- study of light hypernuclei

CBM Phase 0 activities targeted towards usage and understanding of major components & production of physics results with CBM devices

CBM – RICH sensors & readout	in HADES at SIS18
CBM – TOF and HPC software	in STAR at RHIC/BNL
CBM – PSD and CBM - STS	in BM@N at Nuclotron/JINR
Integration of all subsystems & FLES	in mCBM at SIS18

CBM collaboration is open for contributions from additional groups.

CBM needs the sustained support of all funding agencies for HW and SW projects.