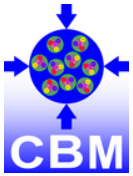
Town meeting: Relativistic Heavy Ion Physics

FAIR : CBM

Tetyana Galatyuk

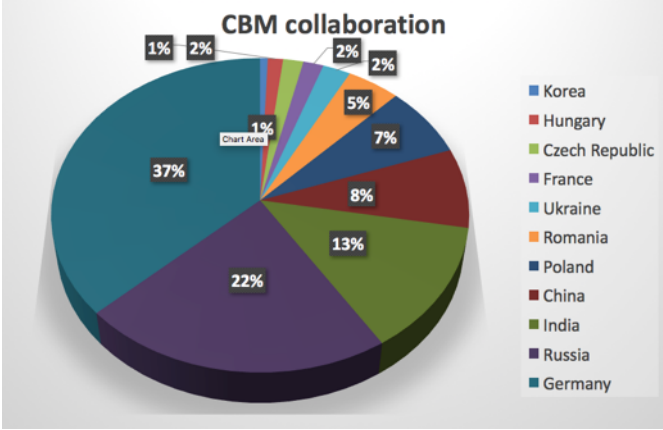
GSI and Technische Universität Darmstadt

for the HADES and CBM Collaborations



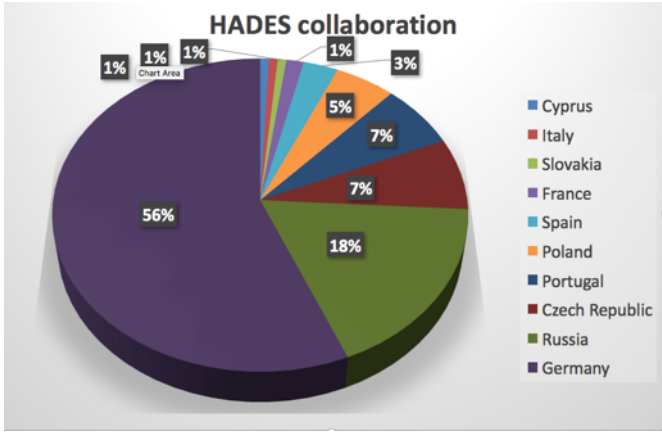
CBM Collaboration: 464 scientists, 11 countries

Spokesperson Norbert Herrmann

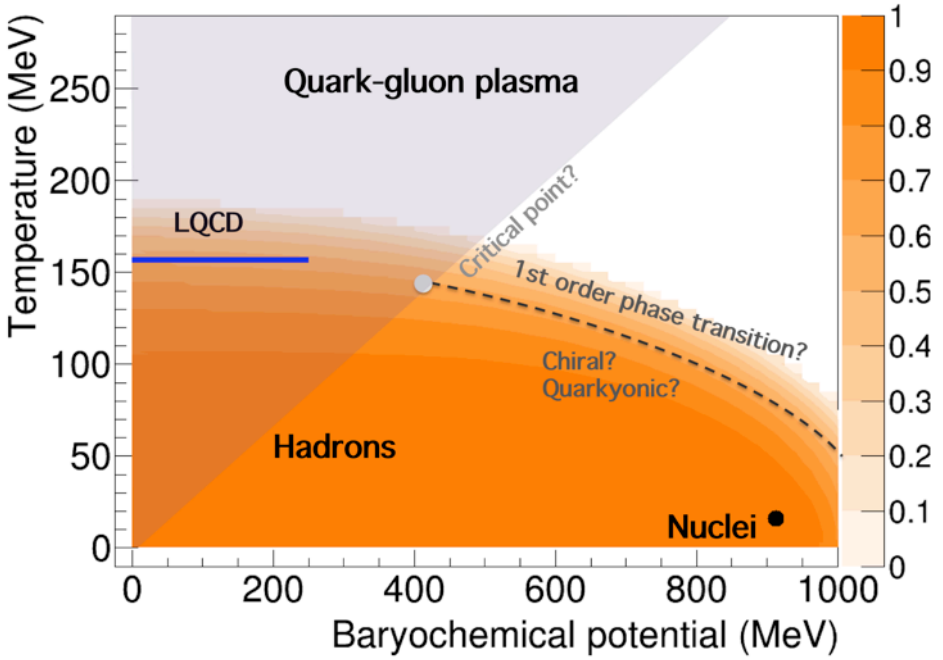


HADES Collaboration: 135 scientists, 9 countries

Spokesperson Joachim Stroth



What is the QCD phase structure?



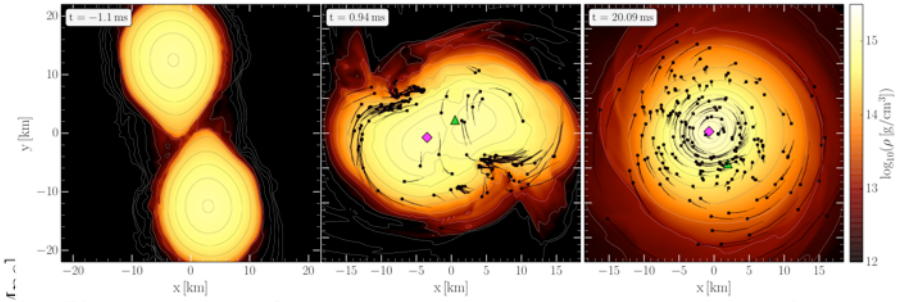
P. Steinbrecher (HotQCD), arXiv:1807.05607
Condensate: B.J. Schaefer and J. Wambach

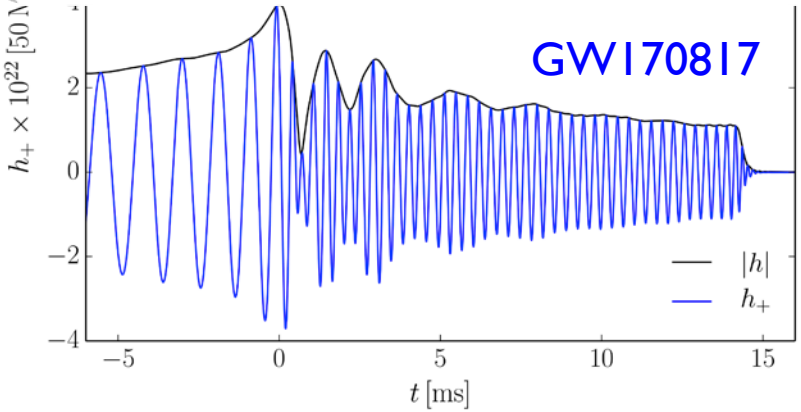
- Vanishing μ_B, high T (lattice QCD)
  - Crossover, universality
  - no CP indicated by lattice QCD at $\mu_B < 400$ MeV, $T > 140$ MeV
- Large μ_B moderate T (lQCD inspired models)
  - Thermal equilibrium?
  - 1st order transition?
  - QCD critical point?
  - Melting of the condensate?

$2 < \sqrt{s_{NN}} < 8$ GeV
Large discovery potential!

Laboratory studies of the matter properties (EoS) in compact stellar objects

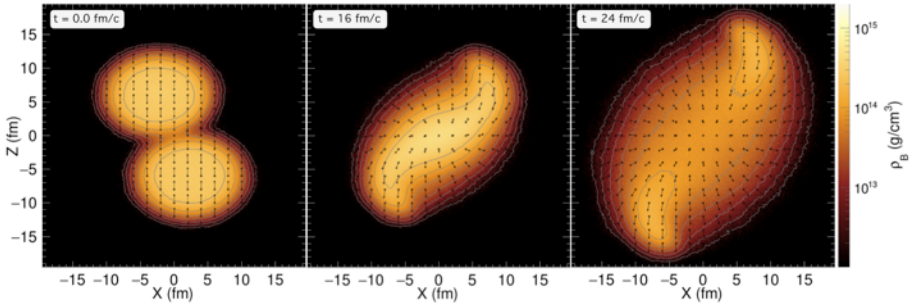
Neutron Star merger (model calculations)





M. Hanauske, Journal of Phys.: Conf. Series 878 (2017) 012031
L. Rezzolla *et al.*, arXiv:1807.03684 [astro-ph.HE]

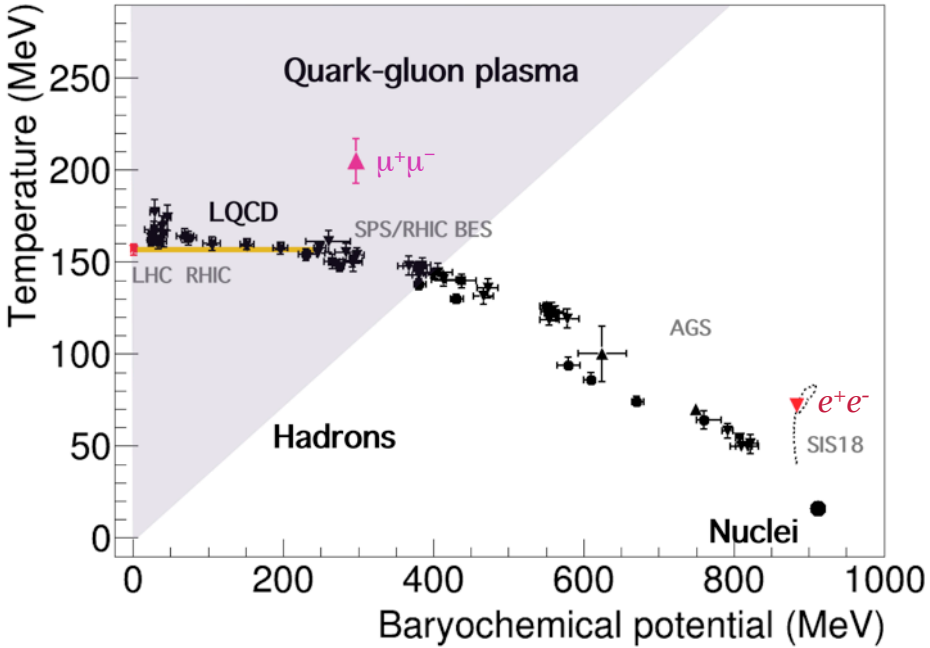
Au+Au 1.25*A* GeV (UrQMD)



- T<70 MeV, $\rho<3\rho_0$ for both (note the different isospin)
- SIS100: T<150 MeV, $\rho<8\rho_0$
  → super dense core of neutron stars

Strong connections between the fields

Searching for landmarks of the QCD matter phase diagram



- Experimental approach:
  - Probe with highest precision different regions of the QCD matter phase diagram
- Systematic measurements (E_{beam}, A)
  → extract numbers that might be related to the QCD phase diagram
  - Chemical freeze-out (analysis in framework of SHM)
  - Fireball temperature (dilepton invariant mass)

A. Andronic *et al.*, Nature 561 (2018) no.7723
F. Becattini *et al.* , PLB 764 (2017) 241
J. Cleymans *et al.*, PRC 73 (2006) 034905; STAR Collab, PRC 96 (2017) 044904
HADES Collab., EPJA 52 (2016) 178; FOPI Collab, PRC 76 (2007) 052203
▲ H. J. Specht *et al.* (NA60 Collab.), AIP Conf. Proc. (2010) 1322
▼ HADES preliminary, Quark Matter 2018

Core Physics Motivation

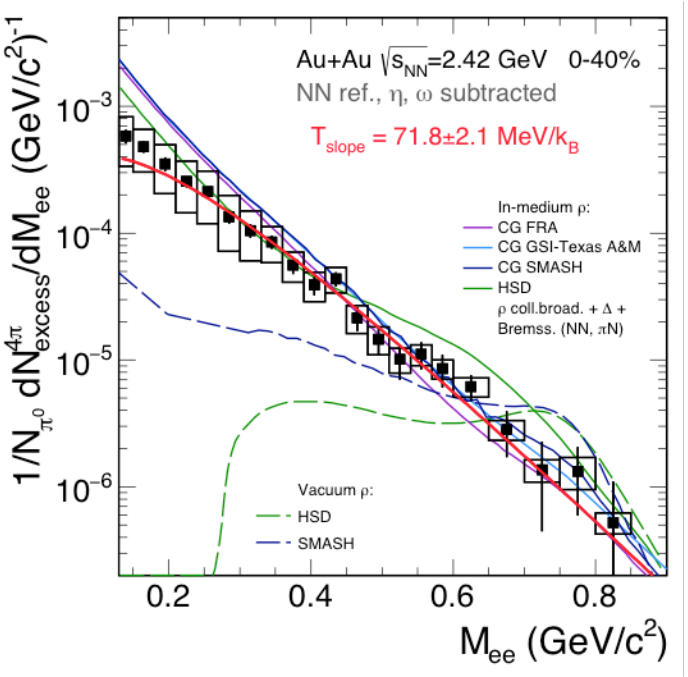
- The QCD Equation-of-State
  - → Collective behavior (flow anisotropies)
  - → Multi-strange baryons
  - → Hyperon-N, Hyperon-Hyperon interactions
- Search for exotic phases and 1st order phase transition
  - → E-b-e observables (higher moments)
  - → Dilepton production ("caloric curve")
- Is there a Critical point?
  - → Net-baryon number fluctuations
  - → Dilepton production (low-mass dilepton excess yield)
- Path to restoration of chiral symmetry
  - → High-precision dilepton invariant mass distributions at low- and intermediate masses
- Strange matter
  - → (Double-) lambda hypernuclei
  - → Meta-stable objects (e.g. strange di-baryons)
- Charm production (and propagation) at threshold
  - → pp, pA

CBM Collab., EPJA 53 (2017) 60

Strong interest internationally
- → RHIC BES, NA61 SPS, MPD NICA (BM@N)
- → *NA60+ SPS, CEE HIAF, HI injector J-PARC*

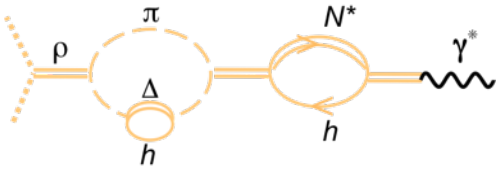
Electromagnetic radiation

Excess yield fully corrected for acceptance



HADES Collab., submitted
CG FRA Endres et al.: PRC 92 (2015) 014911
CG GSI-Texas A&M TG et al.: Eur.Phys.J.A52 (2016) no.5, 131
CG SMASH: J. Staudenmaier et al., arXiv:1711.10297v1
HSD: Phys. Rev. C 87, 064907 (2013)

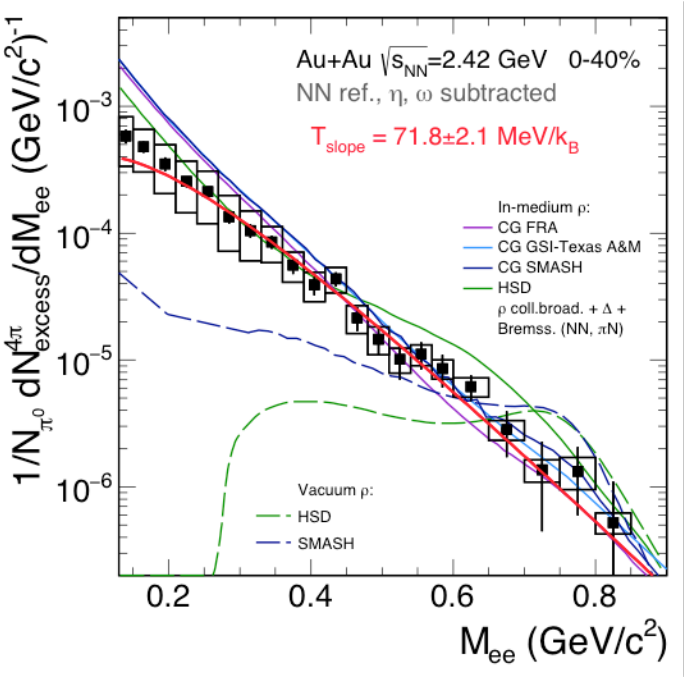
- Strong broadening of the in-medium ρ



- Supports baryon-driven medium effects at UrHIC
- ρ-baryon coupling mechanism - in accordance with strict VMD, verified by HADES in π^-+p
- Thermal origin of low-mass excess, <T> = 72 ± 2 MeV

Electromagnetic radiation

Excess yield fully corrected for acceptance



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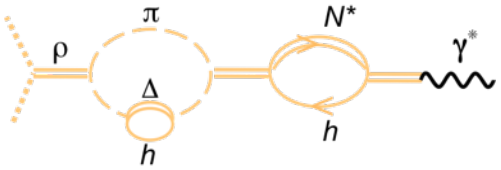

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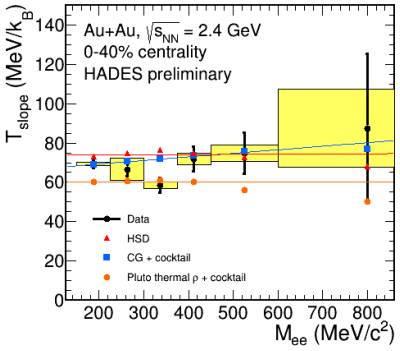

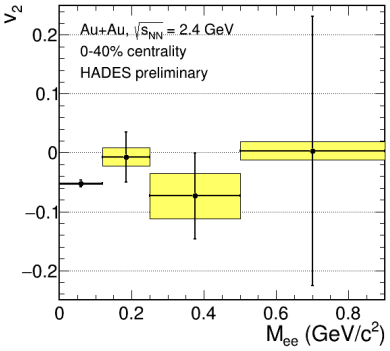

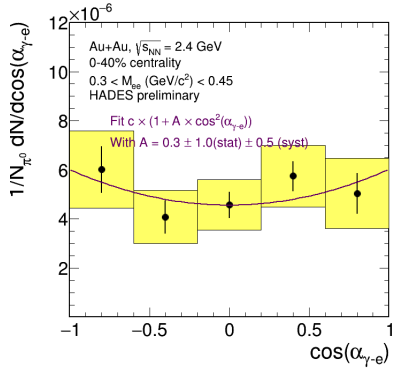

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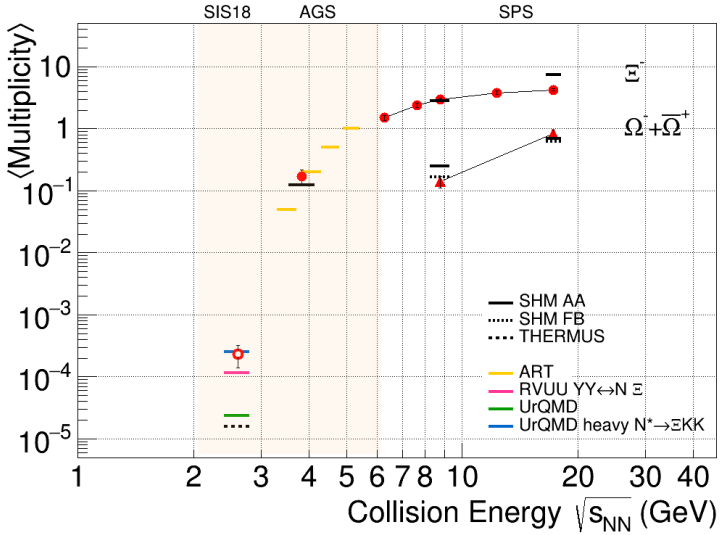
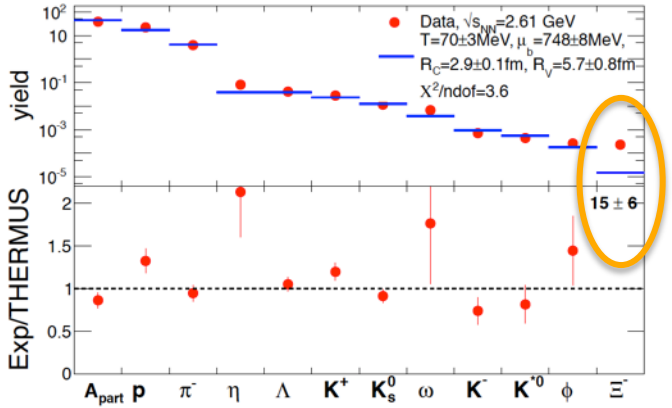
CG SMASH: J. Staudenmaier et al., arXiv:1711.10297v1
HSD: Phys. Rev. C 87, 064907 (2013)

Multi-strange baryons



HADES Coll., PRL 103 (2009) 132301

- $\sqrt{s_{NN}}$ < 6 GeV – baryon rich matter, data are missing for less abundant particles (Ξ, Ω)!
- Unexpectedly large Ξ^- yield at sub-threshold energies (HADES ArKCl, pNb)
  - Not in equilibrium?
  - Role of *YY* interaction, high mass baryonic resonances?

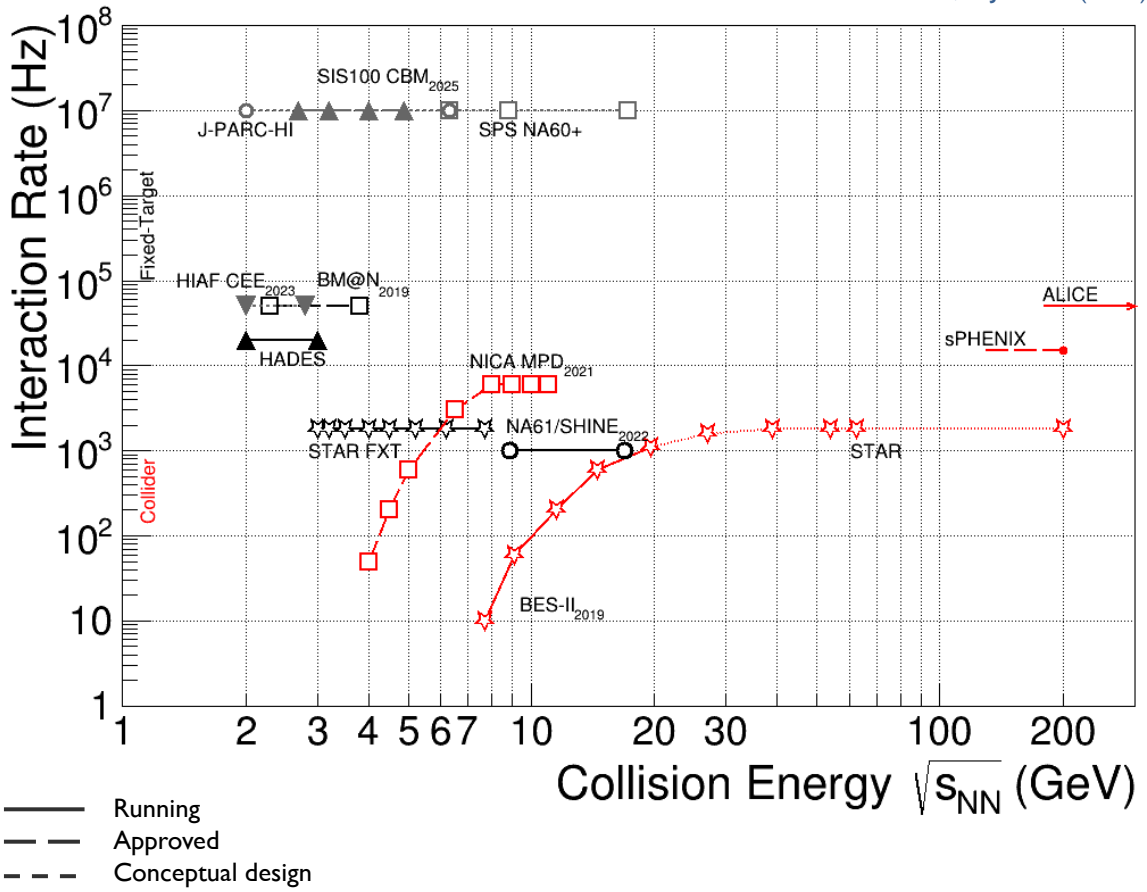


HADES Collab. Eur.Phys.J.A52 (2016) 178

Multi-differential analysis (spectra, flow) needed to increase the discrimination power with respect to models

Explore QCD phase structure through energy scan

CBM Collab., EPJA 53 3 (2017) 60



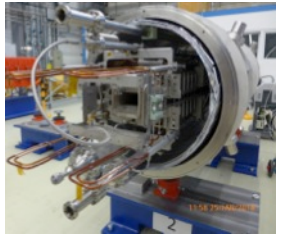
- CBM's unique feature – high statistics measurement of rare probes
- HADES marks lowest point of the excitation functions

Excavation pit for CBM

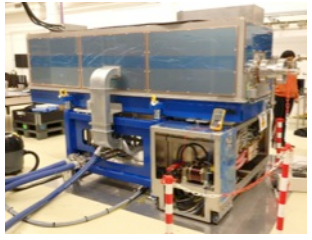
FAIR is a multi-purpose (strong interaction) facility

- SIS18 tunnel upgrade – finished
- Excavation of SIS100 tunnel progresses rapidly
- Serial production of major components for SIS100 started
- CBM cave readiness 2022
- SIS100 commissioning with beam 2025

SIS100 Dipole



RF Cavity System

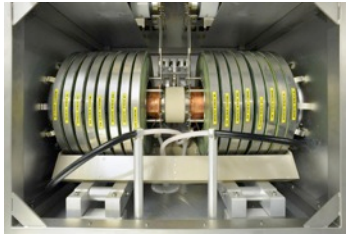


Cryo catcher

Dipole, quadrupole units

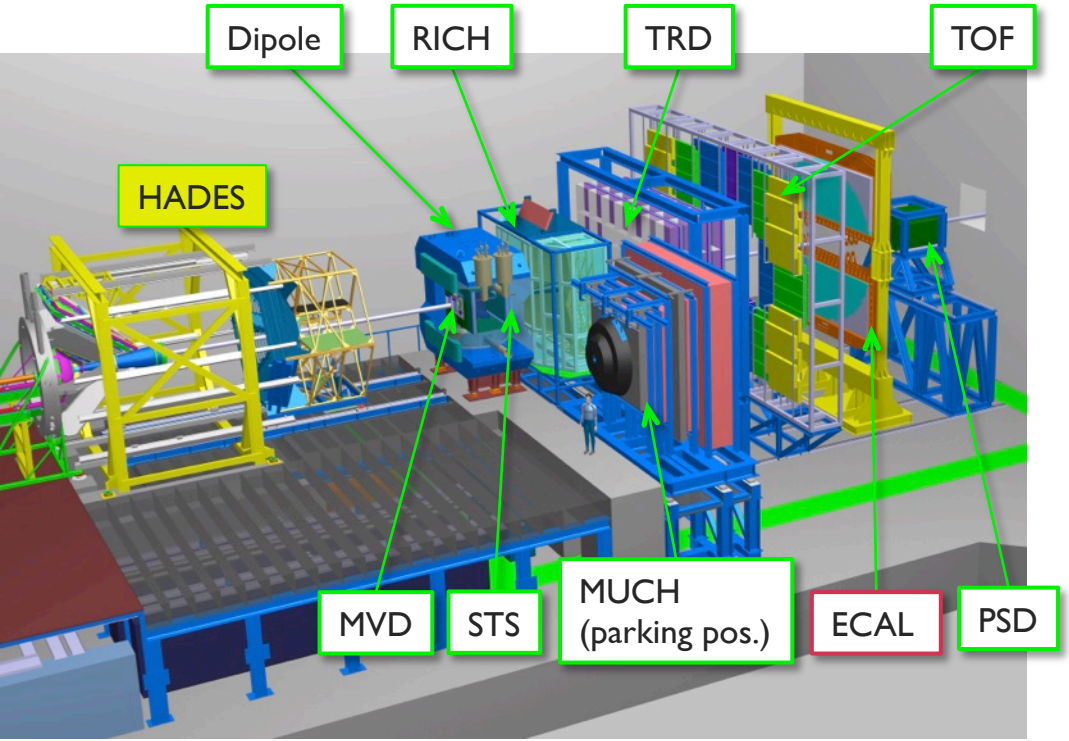
Cryo bypas line

Bunch compressor



The CBM strategy

~20 years progress in technology since AGS

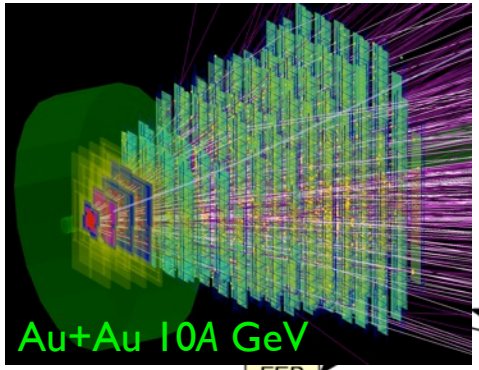


- Fixed target experiments
  → obtain highest luminosities
- Versatile detector systems
  → optimal setup for given observable
- Tracking based entirely on silicon
  → fast and precise track reconstruction
- Free-streaming FEE
  → nearly dead-time free data taking
- On-line event selection
  → high-selective data reduction

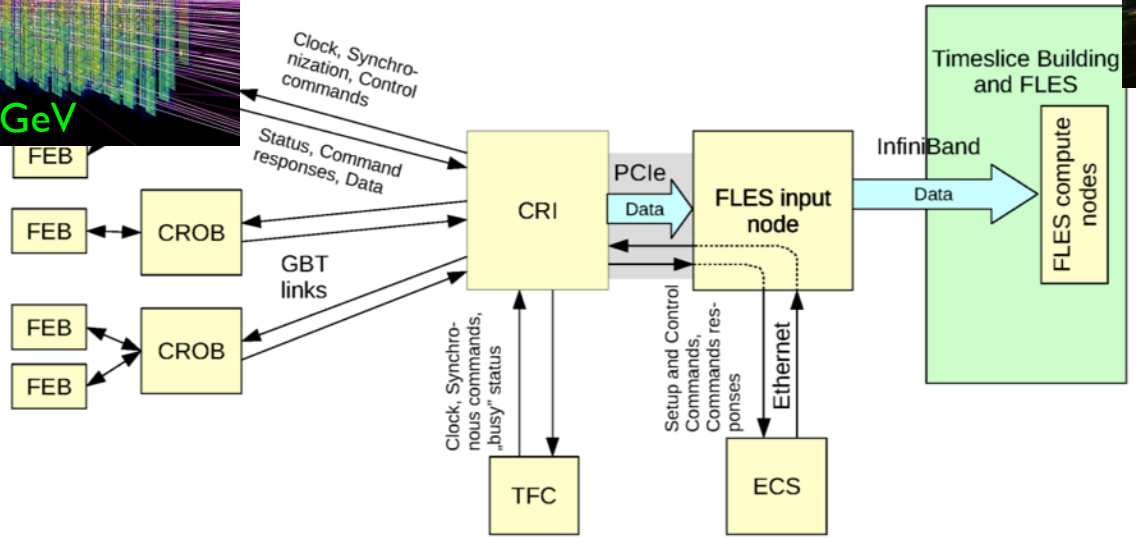
Day-1 setup: R_{int} = 0.5 MHz (0.1 MHz with MVD)
Phase-1 setup: Day-1+ECAL+Compute Performance → R_{int} = 10 MHz

Day-1 funding ~90% secured

CBM data processing system



- Reaction rate Au+Au: 10^7 collisions / s
- Data rate: ~1 TB / s
- Archived data volume 10 - 20 PB/year



- Radiation tolerant detectors and front-end electronics
- Software based event selection, 4D tracking

ALFA - a common framework for ALICE and FAIR experiments

The Anticipated Physics Performance (selected cases)

https://fair-center.eu/for-users/experiments/cbm-and-hades/cbm/collaboration.html

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Spokesperson
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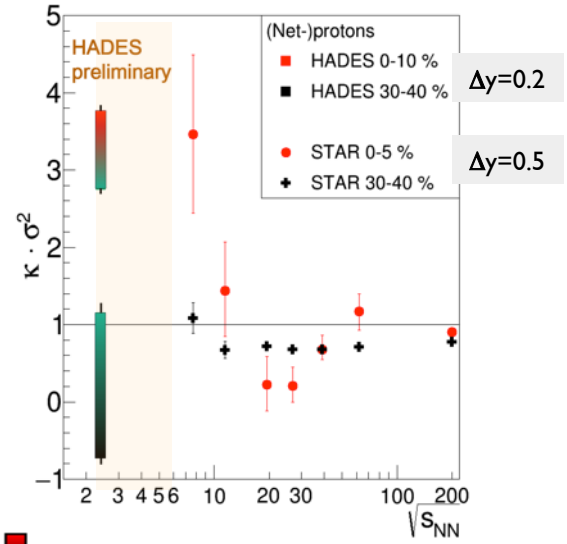
Physics Coordinator: Ilya Selyuzhenkov

Critical fluctuations

- Probe the structure of strongly interacting matter
  - Need detailed systematic study of experimental and instrumental effects
    - E-b-e changes of efficiency
    - Corrections for volume fluctuations

V. Skokov et al., PRC 88 (2013) 034911
PBM, A. Rustamov, J. Stachel, NPA 960 (2017) 114
Bzdak et al., Phys.Rev. C94 (2016) 064907
M. Kitasawa, PRC 93 (2016)

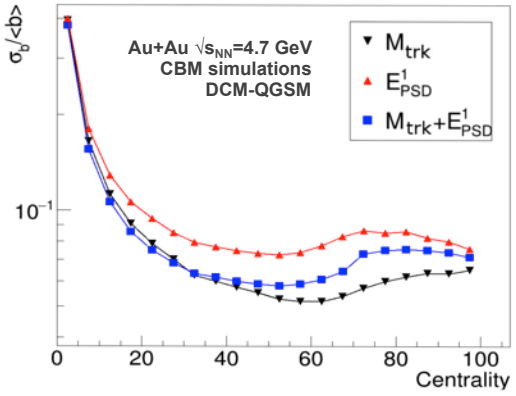


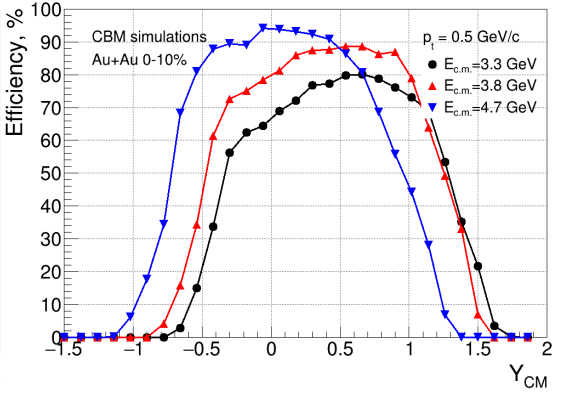
Unfolding + vol. flucs. corr.

E-b-e eff corr. of factorial moments + vol. flucs. cor

Centrality detector independent in acceptance from main detector – avoid autocorrelations

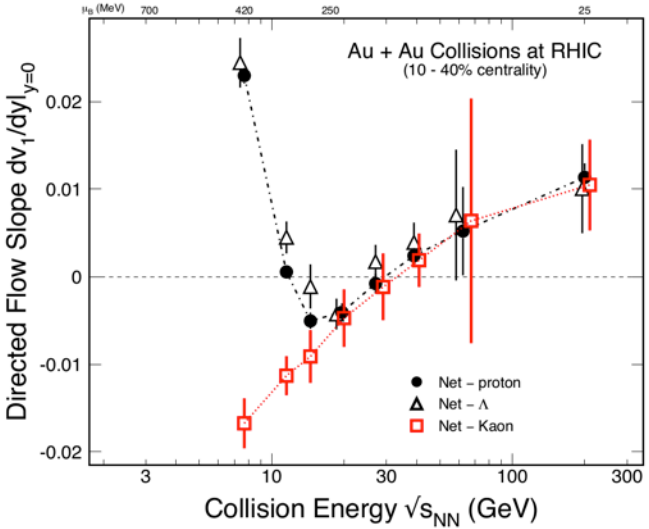
Sufficient proton coverage at mid-rapidity





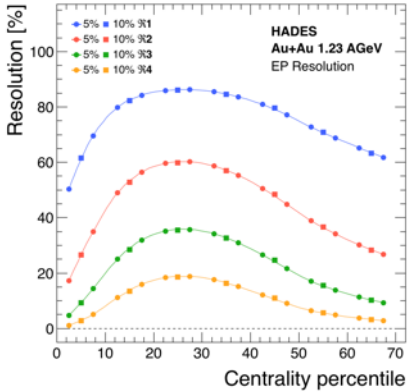
Anisotropic flow

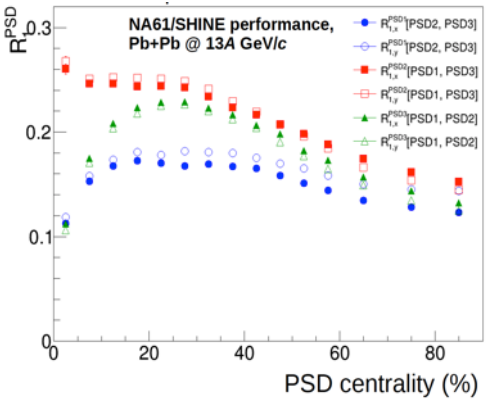
- Probe the EoS of matter
- Exploiting many synergies between CBM, MPD, HADES, NA61, ALICE
  - Similar type detector, same techniques, analysis of real data

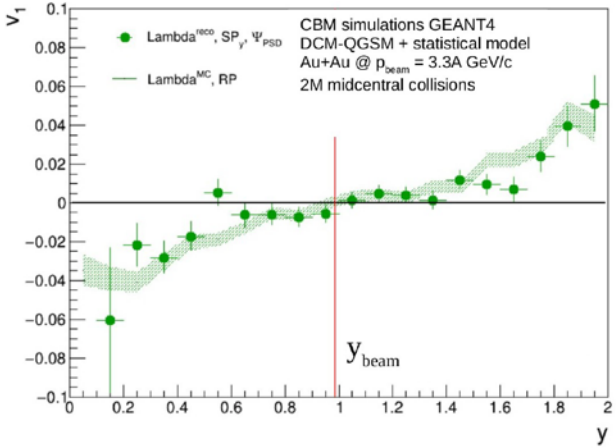


STAR Collab., PRL120 (2018) 062301

Precise *n* order event plane resolution (using spectators)







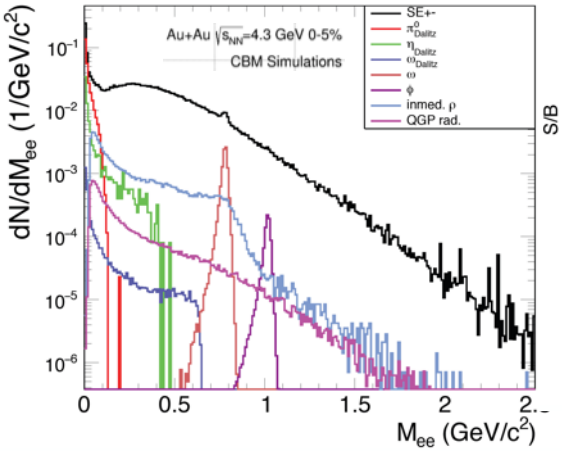
Directed flow of Λ
(full scale MC simulations)

"Input" model v_1 is recovered using "data-driven" method

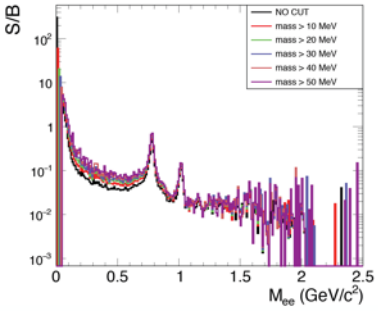
Thermal dileptons

- Phase transition (and CP)
  - Measurement of excitation function of low-mass excess yield
  - Measurement of "caloric curve" with an accuracy of T at MeV level
- Chiral symmetry restoration
  - Isolation of dilepton spectrum from ρ-a_1 chiral mixing
    - Negligible correlated charm contribution
    - Significant reduction of $\mathcal{D}$rell-$\mathcal{Y}$an (pA measurements!)
    - Decrease of QGP

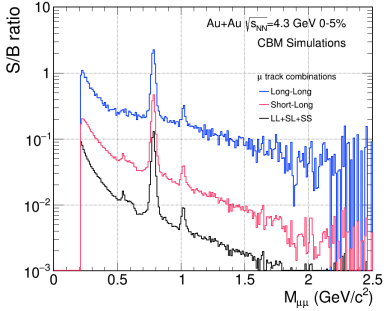
Hohler and Rapp, Phys.Lett. B731 (2014)
Jung, Tripolt, et al., Phys.Rev. D95, 036020 (2017)

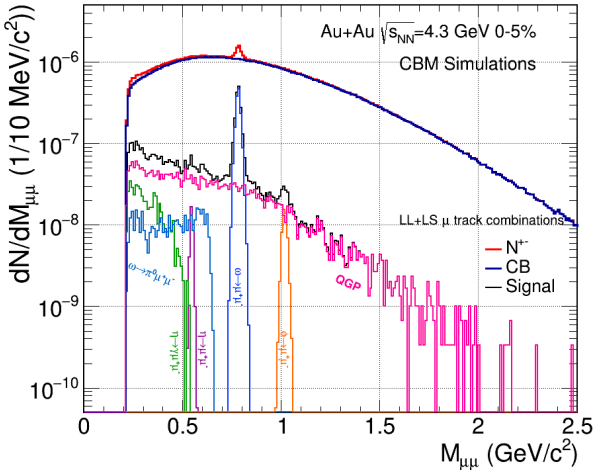


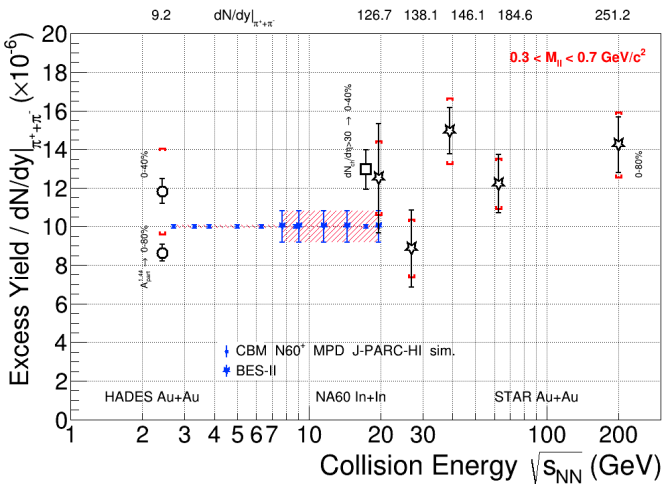
e^+e^-

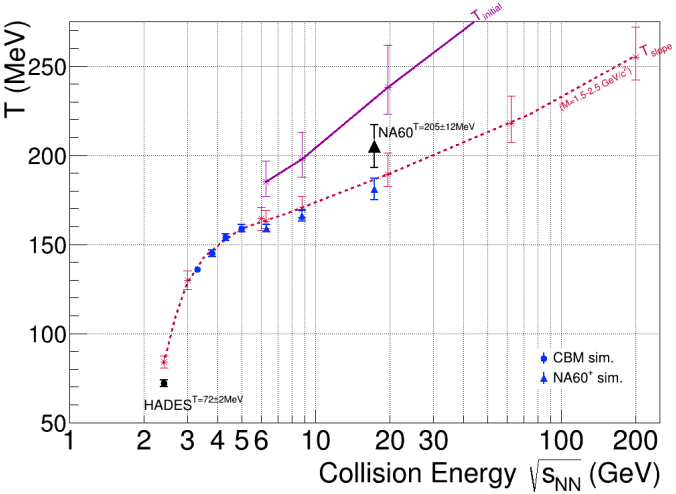


$\mu^+\mu^-$









Thermal dileptons excitation functions

- M_{ll}<1 GeV/c^2
  - ρ dominates, 'melts' close to T_c
  - Yield in low-mass window tracks fireball lifetime

→ Search for "extra radiation" around phase transition (& critical point?)

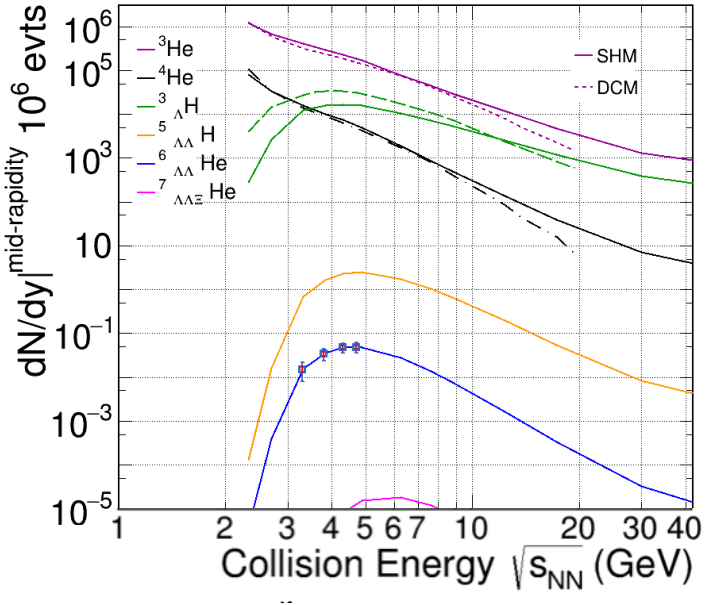
NA60: Chiral 2010, AIP Conf.Proc. (2010) 1322
STAR: PLB 750 (2015), arXiv:1612.05484 [nucl-ex]
HADES: S. Harabasz QM2018

- M_{ll}>1 GeV/c^2
  - Measures true T (no blue shift) of emitting source from fit of acceptance corrected thermal spectra with $M^{3/2}\exp(-M/T_s)$

→ Plateau around onset of deconfinement?

R. Rapp, H. van Hees, PLB 753 (2016) 586
TG et al.: EPJA 52 (2016) 131

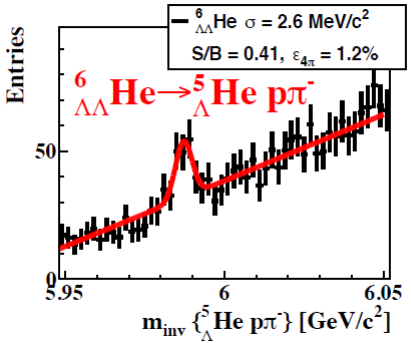
SHM: A. Andronic et al., Phys.Lett. B697 (2011)
DCM: J. Steinheimer et al., Phys.Lett. B714 (2012)



Nuclei and hyper-nuclei production

- How do nuclei and hyper-nuclei form?
  - Compact multi-quark states at the phase boundary?
  - Coalescence?
- What are their properties?
- Do *YY* bound states exist?
- How do *YN, YY* interact?

ALICE Collab., Phys. Lett. B 754 (2016) 360
STAR Collab., arXiv:1710.00436 [nucl-ex]
HAL CD Coll., arXiv:1709.00654 [hep-lat]



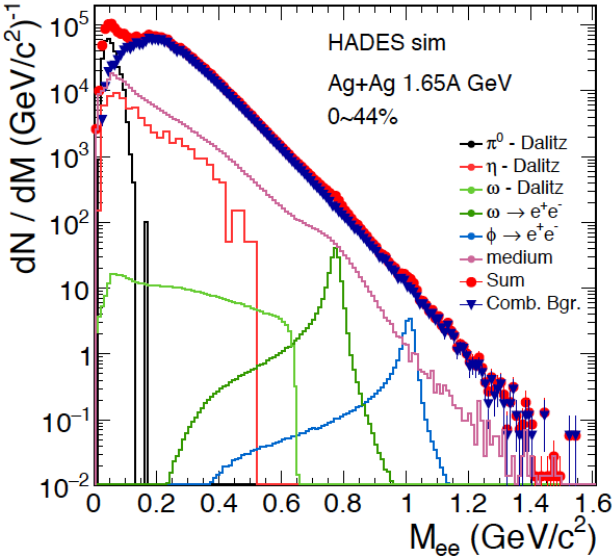
Precision measurement of spectra, life-time and flow pattern

	Mult	BR	$\sqrt{s_{NN}}$	Run time	ε %	R_{int}	*Duty F*	Yield
$^{3}_{\Lambda}$H	3.8×10^{-2}	0.25	4.7 GeV	1 wks	19	10 MHz	0.5	1.4×10^{9}
$^{4}_{\Lambda}$He	2×10^{-3}	0.32	4.7 GeV	1 wks	15	10 MHz	0.5	7×10^{7}
$^{6}_{\Lambda\Lambda}$He	6×10^{-8}	0.01	4.7 GeV	10 wks	1.3	10 MHz	0.5	600

Near future : CBM at FAIR Phase-0

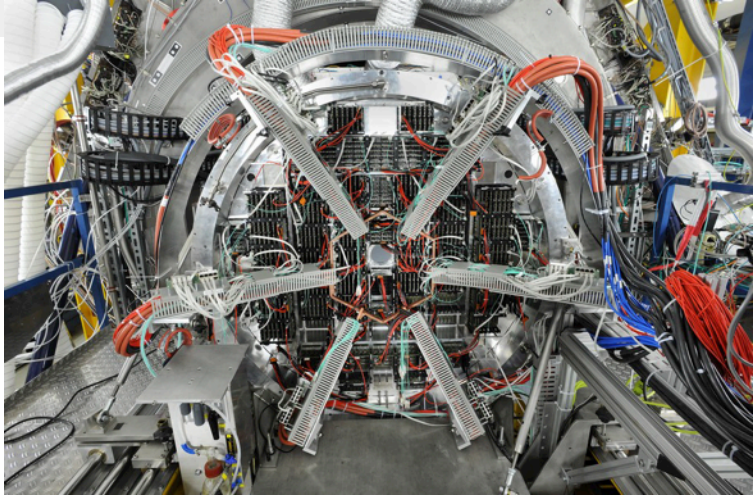
HADES at SIS18/GSI

Expected e^+e^- invariant mass spectra (full scale MC simulation)



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

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

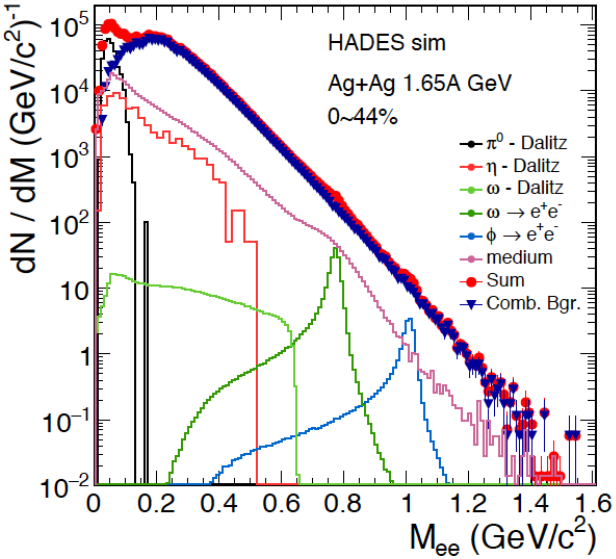


This is already ½ of the CBM RICH photon detector

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

HADES at SIS18/GSI

Expected e^+e^- invariant mass spectra (full scale MC simulation)



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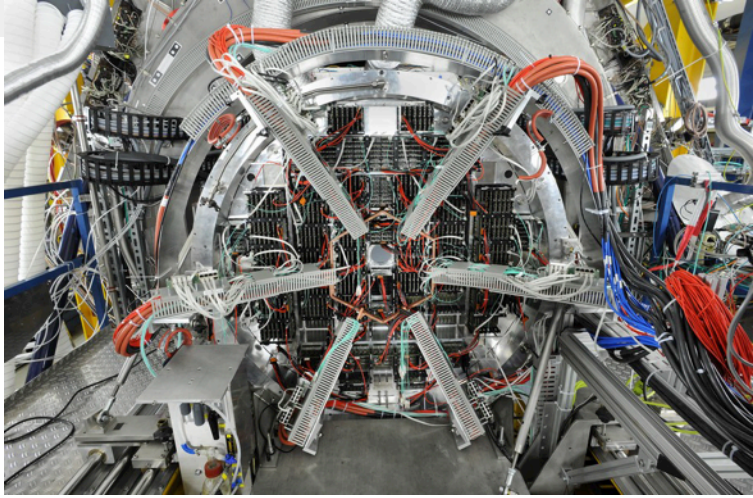
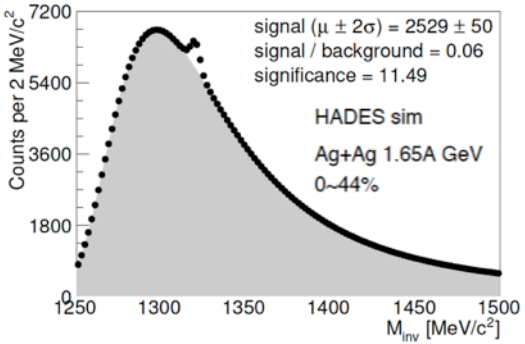
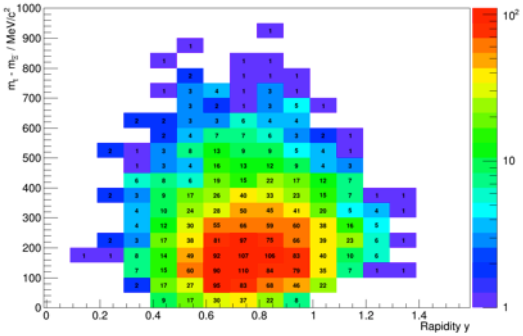


This is already ½ of the CBM RICH photon detector

- Access for the first time at this collision energies intermediate mass range
- Identify the mechanism responsible for the unexpectedly large Ξ^- yield

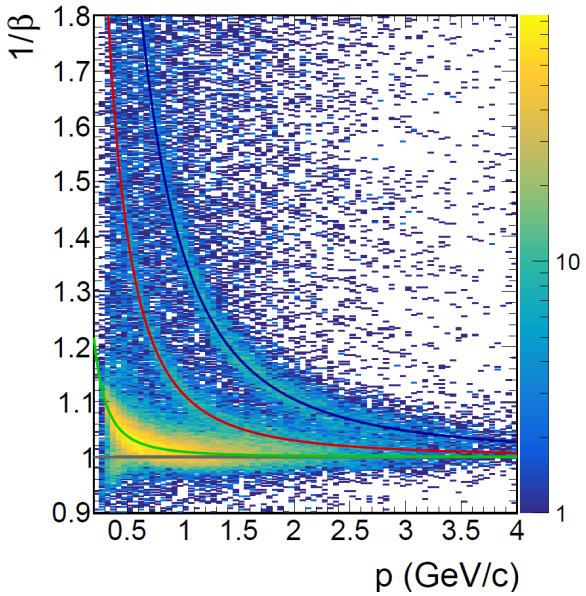
~2500 Ξ^- → Multi-differential analysis feasible



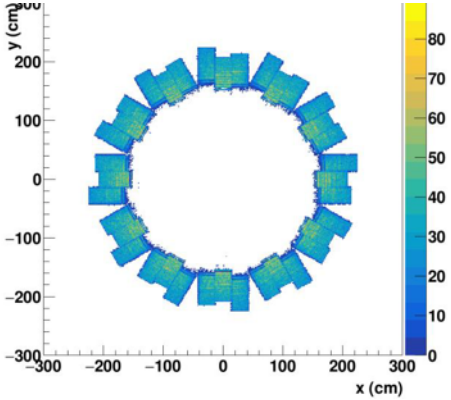


STAR at RHIC/BNL

Matched tracks Run18
CBM eTof – STAR TPC



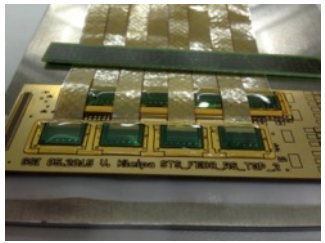
10% CBM ToF



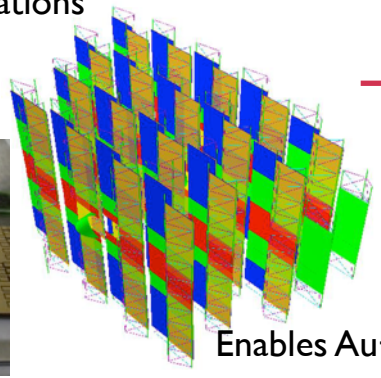
eToF wheel installation	2018
Physics Run	2019 – 2020
Transfer of modules to FAIR	2022 – 2023

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

BM@N at Nuclotron/JINR

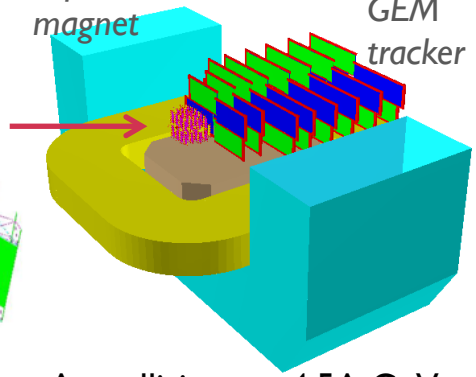


Silicon Tracking Stations



Dipole magnet

GEM tracker



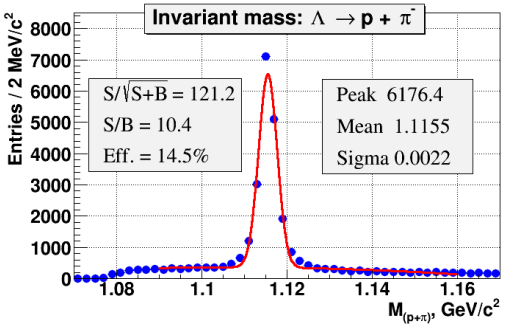
Enables Au+Au collisions at 4.5A GeV

PSD module

Synergy with NA61/SHINE

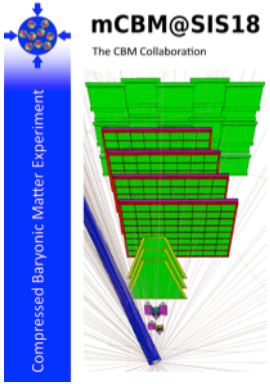
- PSD detector
- Flow analysis

CBM groups:
GSI Darmstadt, Univ. Tübingen, JINR Dubna



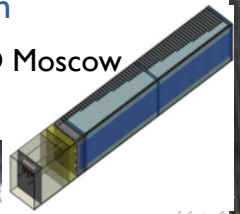
2018 Installation of PSD detector (MoU signed)
2019 Au beams from Nuclotron
2020 Installation of 4 Si Tracking Stations (MoU signed)

mCBM at SIS18/GSI

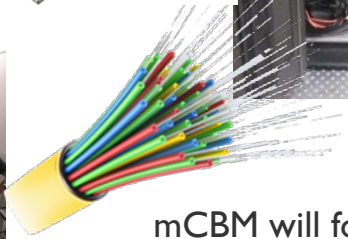


Demonstrator for full CBMdata taking and analysis chain under full load (Au-Au, 10^7 interactions/s)

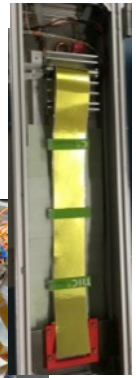
mPSD Moscow



mTOF Heidelberg



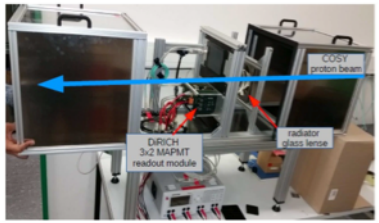
mTRD Münster, Frankfurt



mSTS GSI

mMVD$_{2020}$ Frankfurt

mMUCH VECC



mRICH Giessen, Wuppertal

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

Towards FAIR Phase-1

Time line

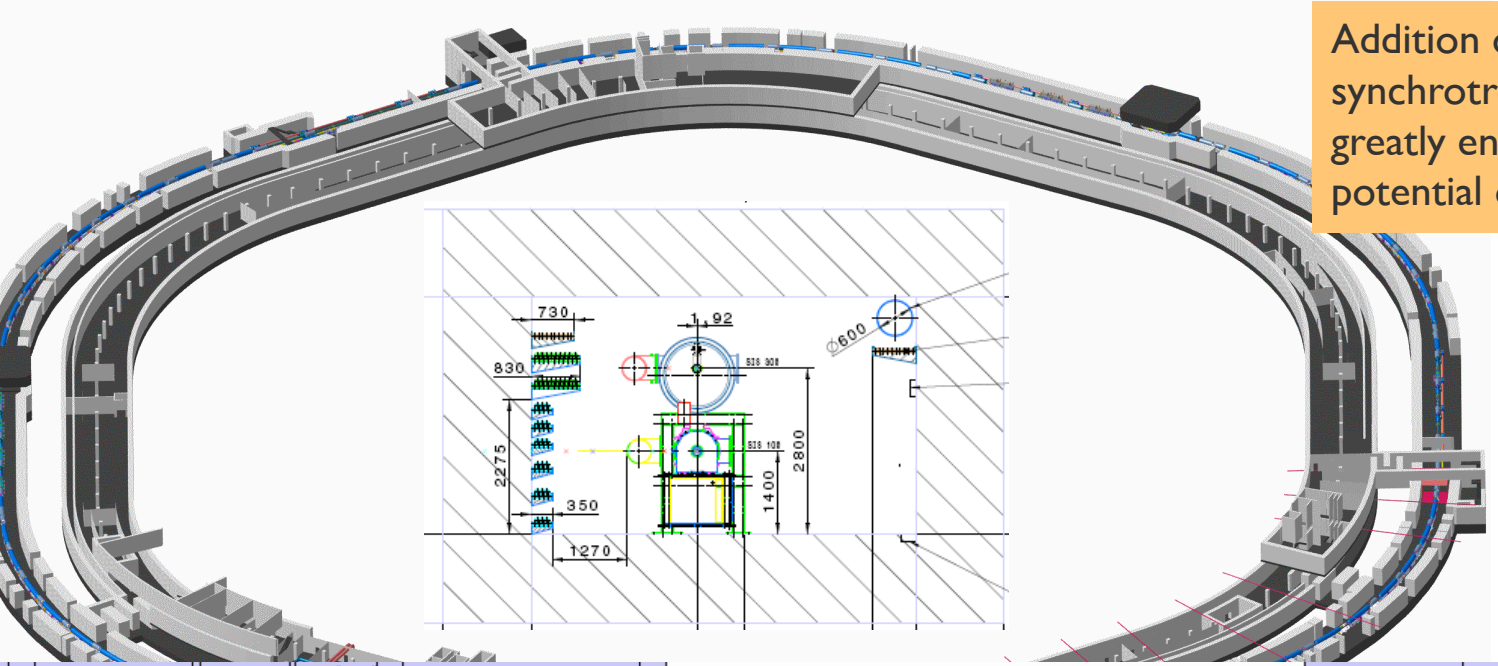
2017	2018	2019	2020	2021	2022	2023	2024	2025	…	2030++
		HADES@SIS18						Day-1		
		mCBM								
		TOF@STAR BESII								
		BM@N								
		Phase-0						Phase-I		SIS 500?

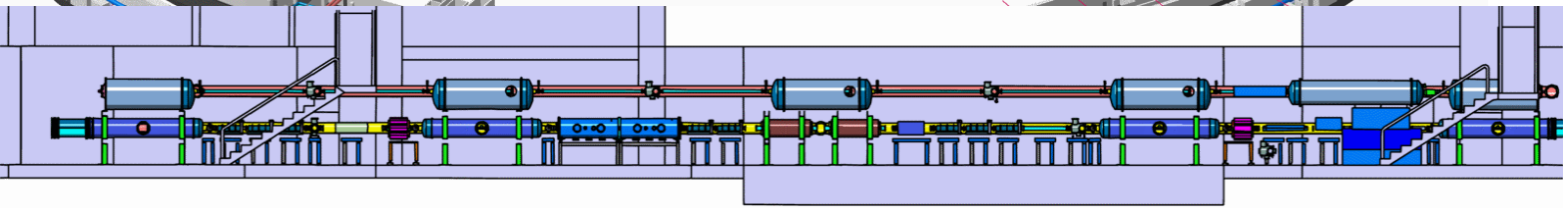
HADES upgrade 2019-2020:
DAQ upgrade - 200 kHz
interaction rate (p+p, p+A)

CBM:
Au+Au program
Cold matter physics (p+A)

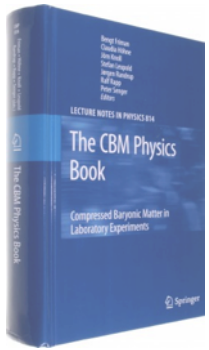
HADES:
Cold matter physics (p+A)
Exclusive measurements (p+p)
(Ag+Ag 4.5*A* GeV for comparison)

Tunnel for SIS100 / SIS500





Addition of a higher rigidity synchrotron (500 Tm) would greatly enhance the physics potential of CBM (and FAIR)



Priority endorsed by

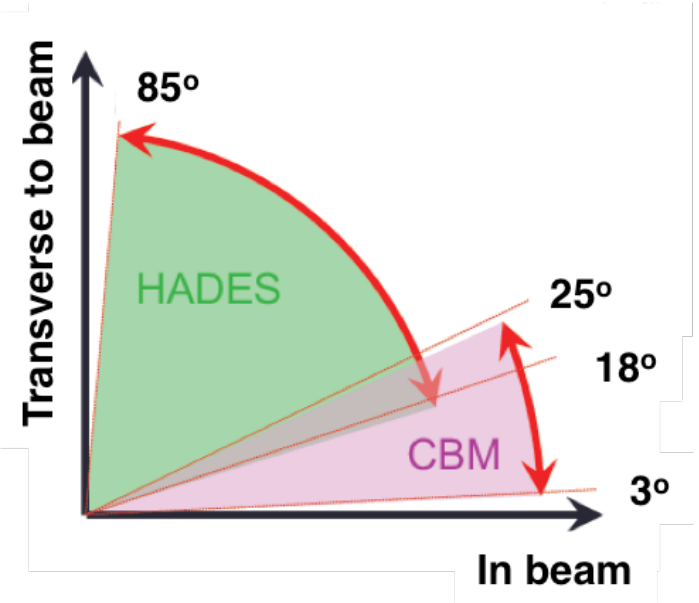
- NuPECC Long Range Plane
  - Strategic planning until 2030

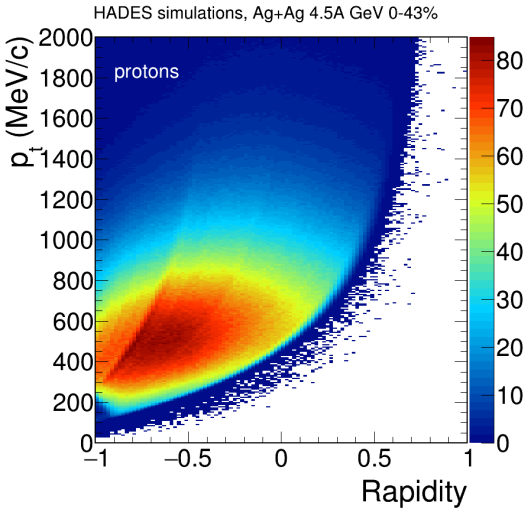
- Recommendations

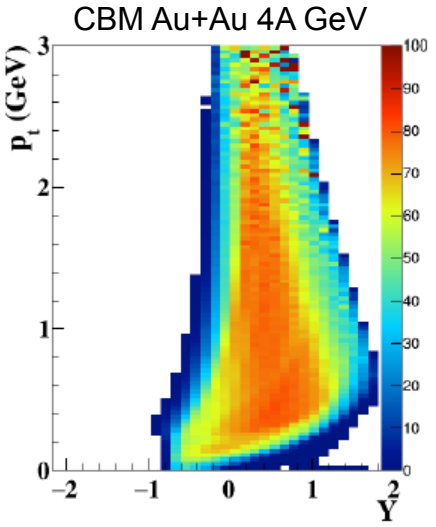
  - At intermediate energies, we recommend the continuation of the on-going programmes: HADES at SIS-18, NA61 at the SPS.
  - In order to investigate nuclear matter at high baryonic density, the timely construction of SIS-100 at FAIR and the realization of the CBM experiment are of utmost importance.
  - In parallel, efforts should continue in order to support developments for a future SIS-300 upgrade.

Thank you for your attention!

HADES – CBM complementarity

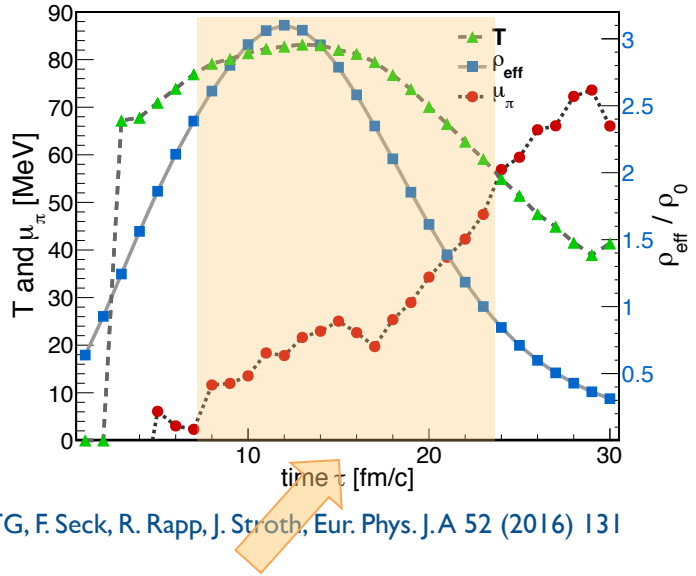






Evolution of HIC and NS merger

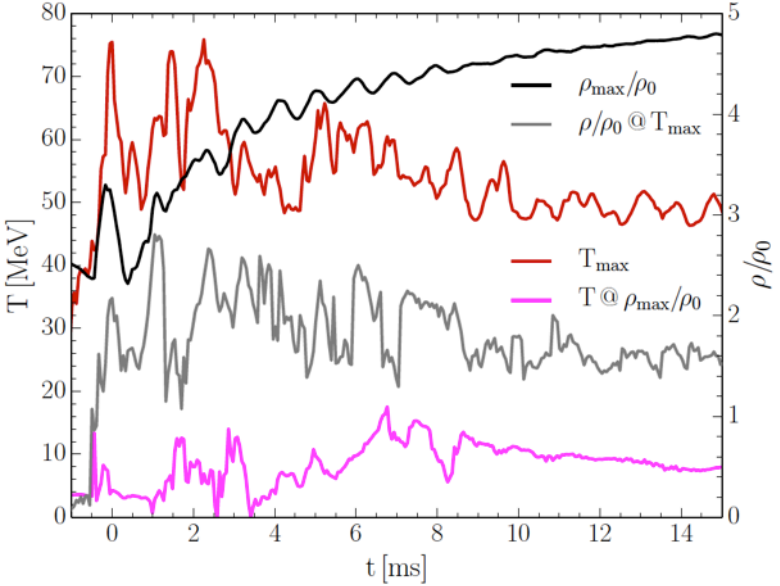
Central cell (3x3x3 fm3) thermodynamic properties from coarse graining UrQMD



TG, F. Seck, R. Rapp, J. Stroth, Eur. Phys. J. A 52 (2016) 131

Active thermal e^+e^- radiation window ~13 fm/c
Dileptons sensitive to dense phase

Evolution of the central region in a binary NS merger



M. G. Alford *et al.*, Phys. Rev. Lett. 120, 041101
M. G. Alford, *et al.*, Phys. Rev. D 96, 124005,
A. Bauswein *et. al.*, Astrophys. J. 773, 78 (2013)
M. Hanauske (priv. com.)