ERuM
FSP-T06

Compressed
Baryonic
Matter

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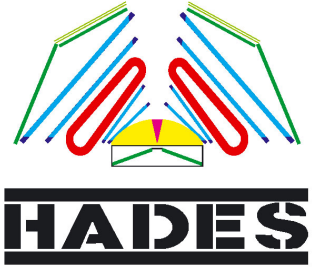
C.B.M. – STATUS UND PERSPECTIVES

Joachim Stroth

Goethe University Frankfurt / GSI

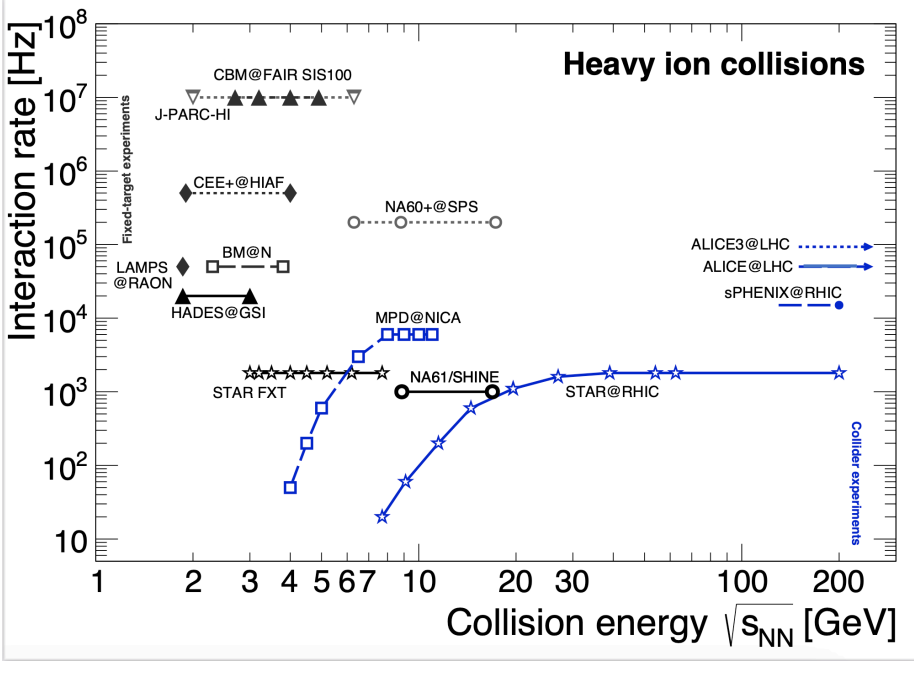
KHuK Jahrestreffen 2023 Bad Honnef



Mission Statement

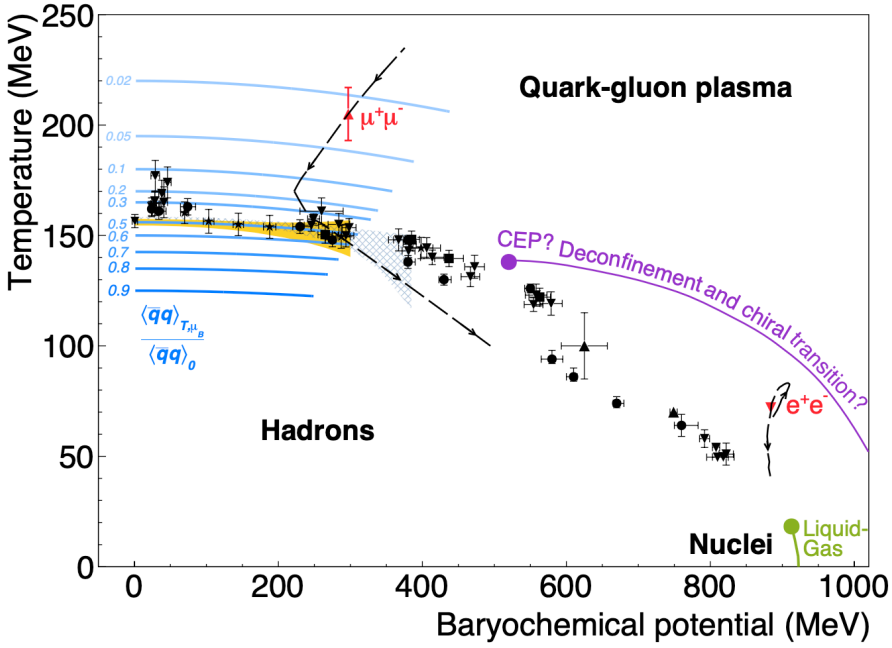
"Explore the phase properties and microscopic structure of strong-interaction matter at high(est) net-baryon densities"

- Focus on rare/penetrating probes and precision measurements
- Requires high statistics/rates and excellent understanding of detector response



Exploration of the Strong-interaction Phase Diagram

From medium-effects to novel phases of QCD matter



HADES, Nature Phys. 2019

Conjecture: after ~10 years of studies of electromagnetic probes:

- QCD matter at high μ_B exists as baryonic cores embedded in an entangled pion cloud
- State cannot be described as dilute resonance matter

Methods for **further investigations:**

- Search for signs of criticality (conjectured first-order phase transition and critical point, remnants of liquid-gas critical point)
- In-medium properties of mesons
- Strangeness production and propagation
- Study of meson-baryon/hyperon coupling and baryon/hyperon em transition form factors

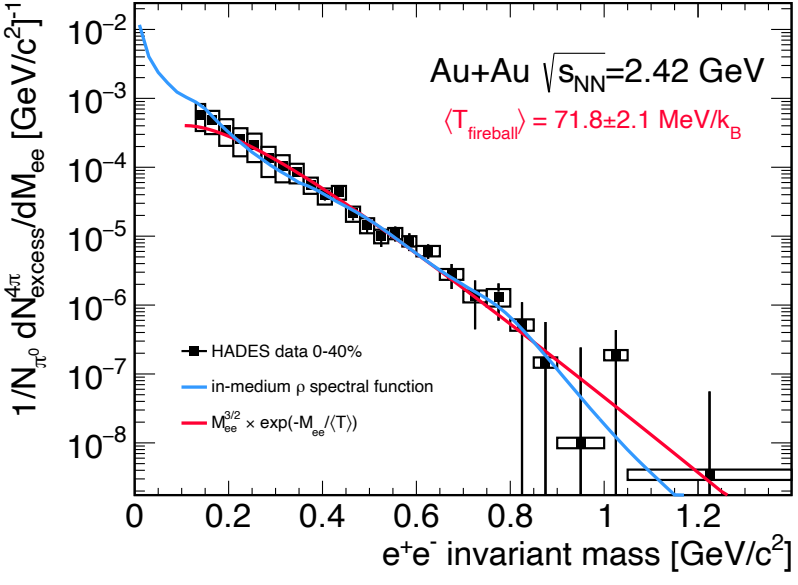
Spin-offs:

- Vector Meson Dominance, EoS, hypernuclei, em transition form factors, Short Range Correlations

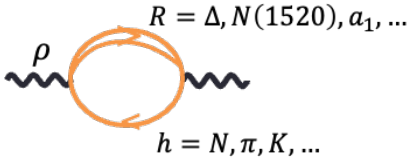
Key observable – dilepton excess radiation

Emissivity of compressed baryonic matter:

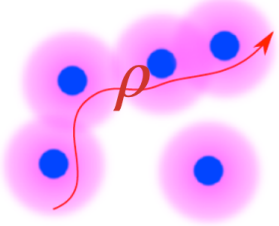
Radiation explained by decays of **medium-modified vector mesons** (VMD, "radiation of the cloud")



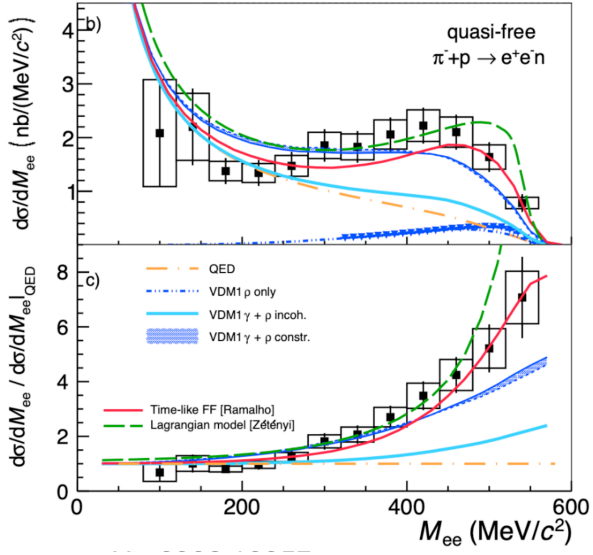
Nature Phys. 15 (2019) 10, 1040-1045



Rapp, van Hees; arXiv:1411.4612v



K. Fukushima, T. Kojo, W. Weise; arXiv:2008.08436v2
(also G. Baym, QNP2018)

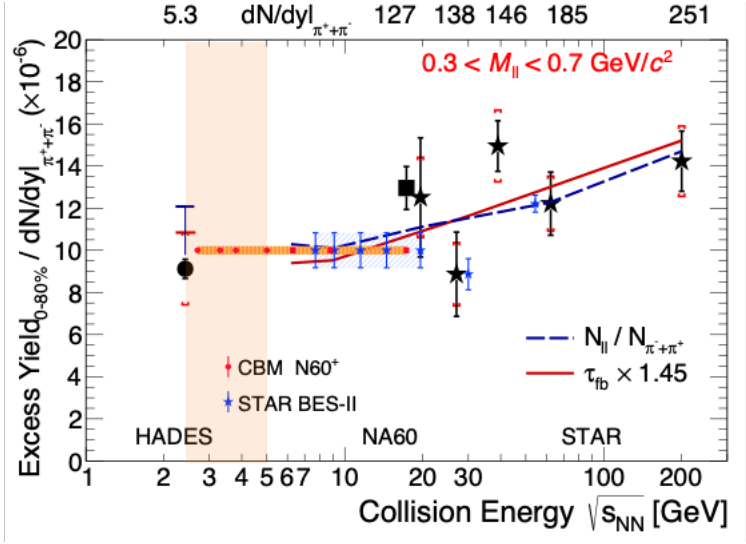


arXiv.2309.13357, arXiv.2205.15914

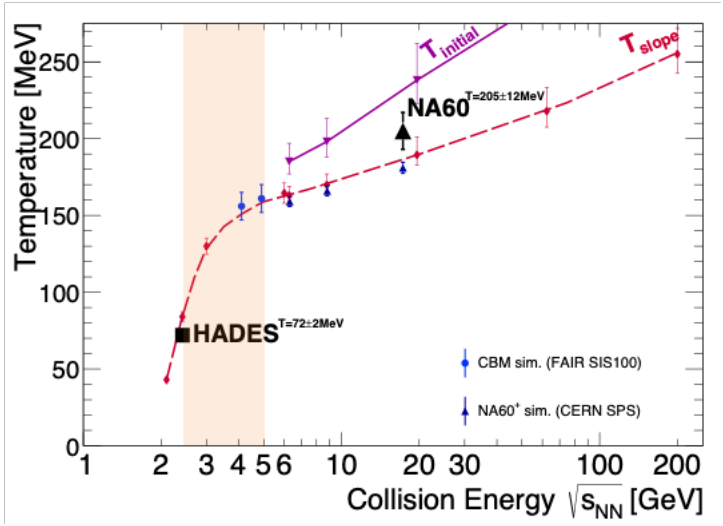
Excitation function of dilepton excess radiation

Virtual photons provide rich information about the properties of radiating medium and the dynamics of the fireball evolution:

Yield (LMR):	space-time integral → **phase transition**	Salabura, Stroth Prog.Part.Nucl.Phys. 120 (2021)
Spectral distrib. (LMR):	$\rho - a_1$ mixing → **chiral symmetry** restoration	Seck, Galatyuk et al. Phys.Rev.C 106 (2022
Spectral distrib. (IMR):	temperature → **caloric curve**	Hohler and Rapp, Phys. Lett. B 731 (2014)
Polarization:	discriminate **partonic** from **hadronic** sources	Seck, Friman, Galatyuk et al. 2309.03189 [nucl-th]



Galatyuk, JPS Conf.Proc. 32 (2020) 010079



https://github.com/tgalatyuk/QCD_caloric_curve

E-b-E fluctuations of protons

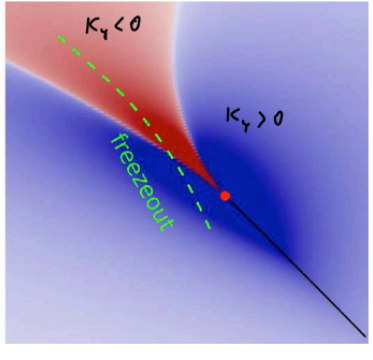
Promising observable for critical behaviour

- B: baryon number (conserved)
- μ_B: respective chemical potential
- $\hat{\chi}_n^B$: susceptibilities from derivatives of the pressure
- Z: partition function (from theory, e.g. lQCD)
- κ_n: cumulants (from experiment via proxies)

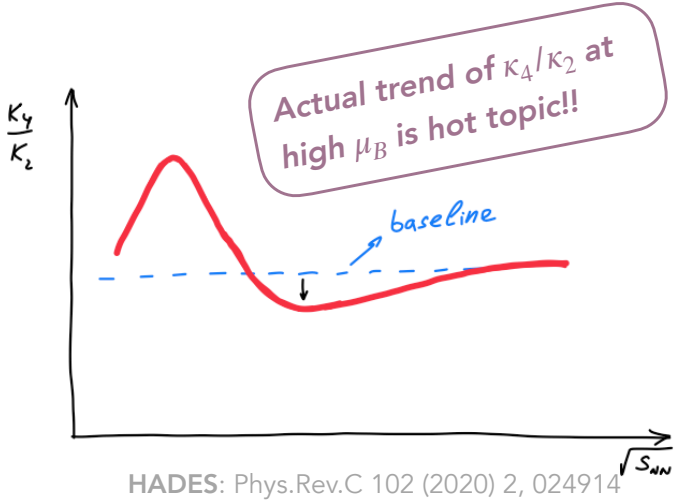
➡ Experimental challenges:
- Proxi for baryon number
- Event purity
- Volume fluctuations (centrality)

➡ Instrumental challenges
- Acceptance fluctuations
- PID purity

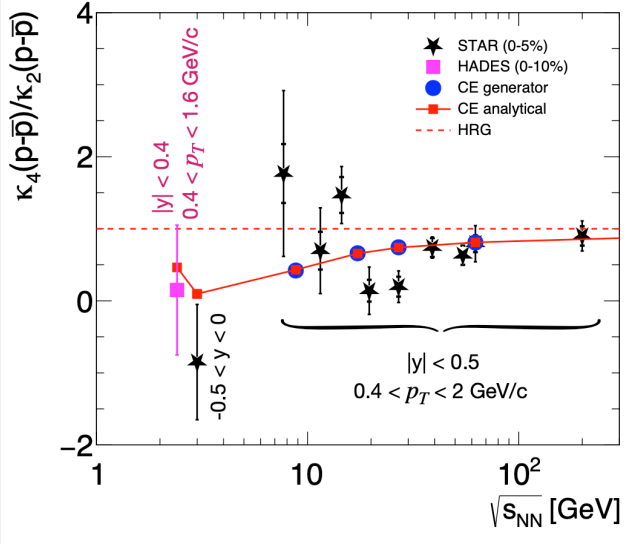
$$\hat{\chi}_n^B \equiv \frac{\partial^n \hat{P}}{\partial(\mu_B/T)^n} = \frac{1}{VT^3}\frac{\partial^n \ln Z(V,T,\mu_b)}{\partial(\mu_B/T)^n} = \frac{\kappa_n(N_B - \bar{N}_B)}{VT^3}$$



M. Stephanov, PRL102.032301(2009)
Depictions courtesy of A. Rustamov

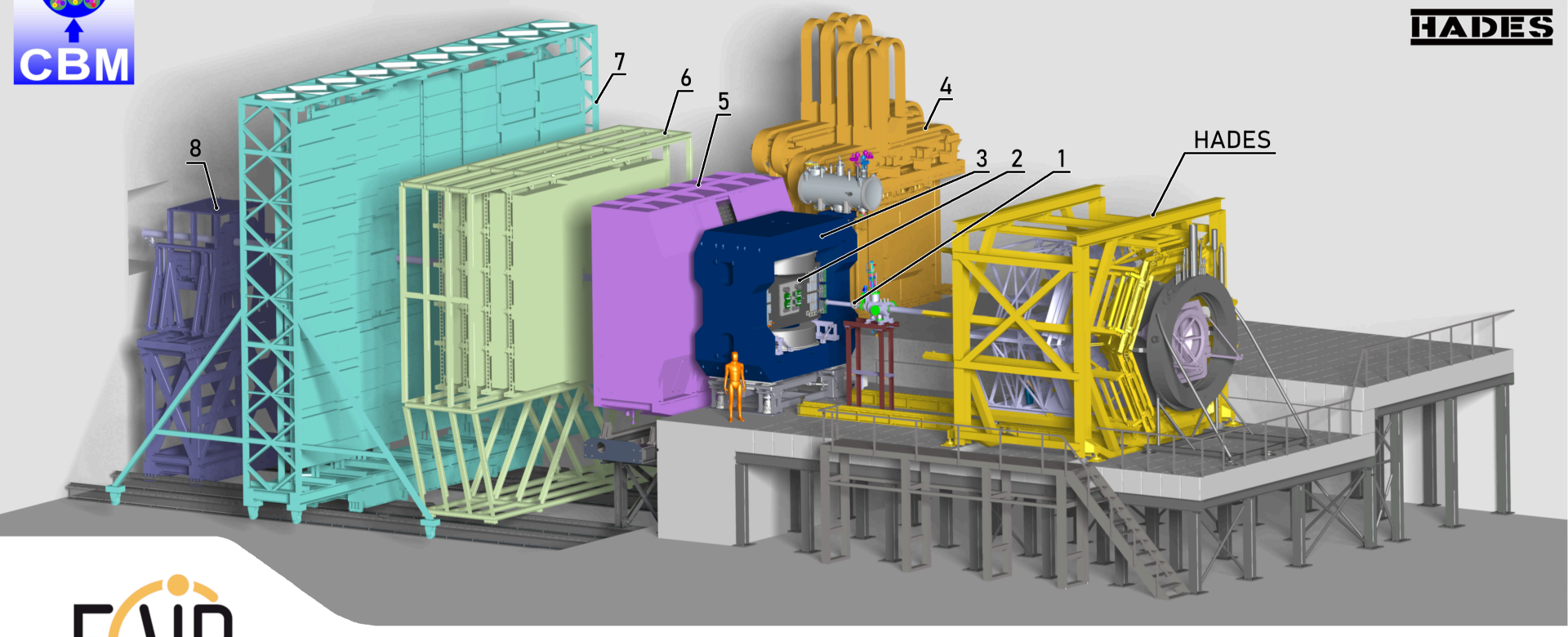


HADES: Phys.Rev.C 102 (2020) 2, 024914
STAR: Phys.Rev.Lett. 126 (2021) 9, 092301



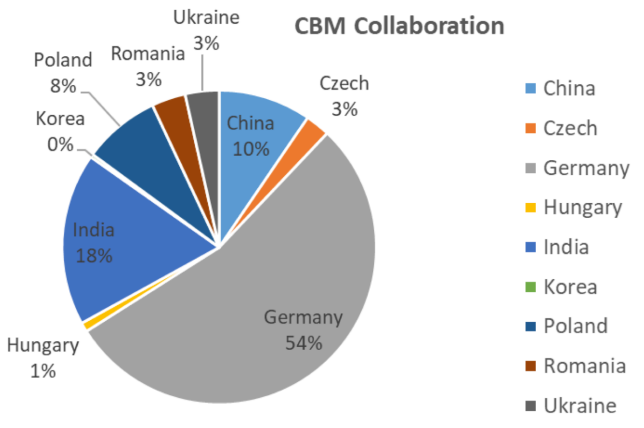
THE CBM EXPERIMENT

Compressed Baryonic Matter



1: Time-Zero Detector & Beam Diagnostics
2: Silicon Tracking System / Micro Vertex Detector
3: Superconducting Dipole Magnet
4: Muon Chambers
5: Ring Imaging Cherenkov Detector
6: Transition Radiation Detector
7: Time of Flight Detector
8: Forward Spectator Detector

CBM Collaboration and Project Status (w/o Russian Institutions)



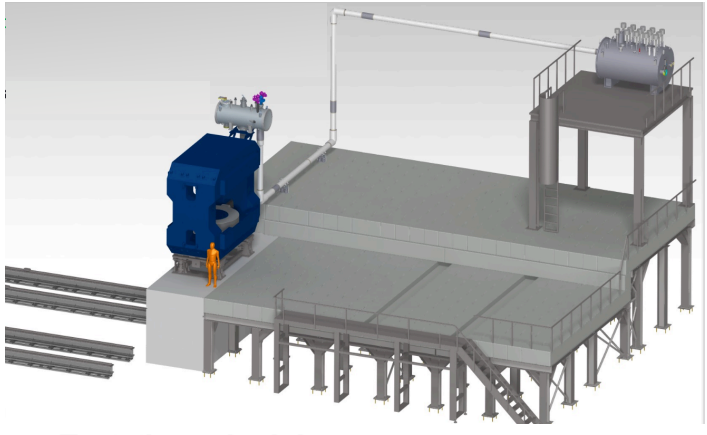
Major **Russian in-kind** – **not realized** – and mitigation measures:

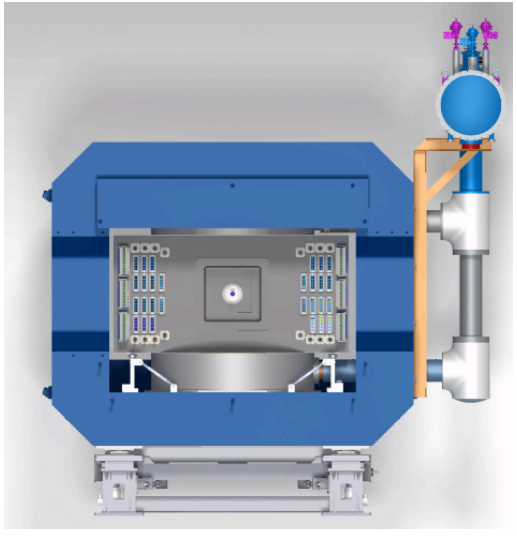
- Superconducting **Dipole** Magnet → now covered by FAIR funds, see next slide
- **PSD** → New detector concept, designed and constructed with fresh funds in Czech Republic (now FSD)
- **STS** assembly line → Revised assembly plan with productions sites at GSI and KIT
- **RICH** mechanics incl. box and mirror support → New designs (U Gießen, U Wuppertal) and realization with financial support from FAIR

Superconducting Dipole Magnet

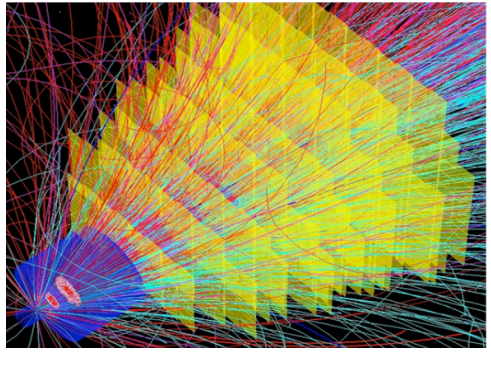
Decision: re-procurement from commercial companies

- Tendering procedure started after decision of FAIR Council to include this item in the urgent re-procurement list
- Procurement through FAIR funds decided by FAIR Council in July 2023
- Order has been awarded in November and contract is signed





Tracking in compact dipole based on silicon sensors.



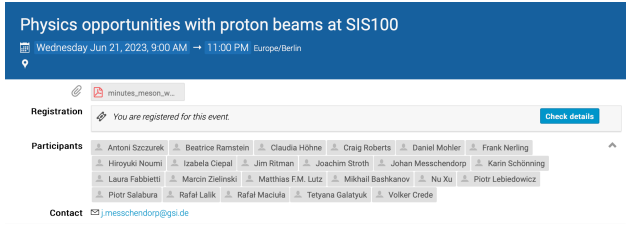
Tentative schedule

Milestone	Estimated Date
Award of contract	12/23
Preliminary Design Review (PDR)	03/24
Conceptional Design Review (CDR)	09/24
Final Design Review (FDR)	03/25
Final Acceptance Test FAT	09/26
Shipment incl. documentation	12/26
Site Acceptance Test (SAT)	03/27
Final Acceptance	06/27
Magnetic field mapping	09/27

Preparing for FS(+) decision

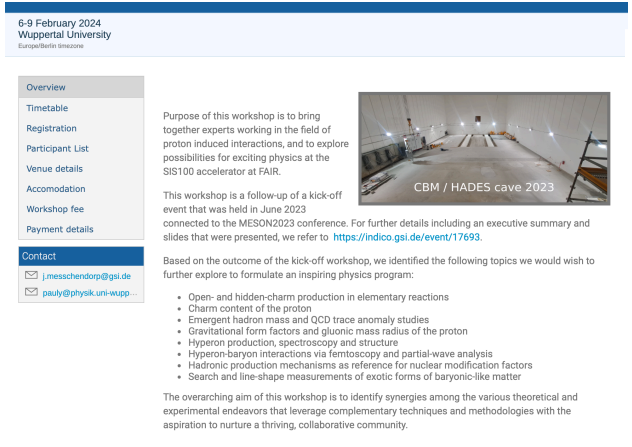
- **Shell construction finished** in summer 2023
- First cave installations already done
- **TBI halted** (awaiting positive decision of Council in 6/2024)
- In case of timely start, TBI expected to finish in 2026
- Formal cave access after HBO currently expected for Q1/2027, **but installation expected (needs) to start earlier**

Initiative started to widen the physics scope of the CBM setup by ncluding measurements of exclusive production channels using proton beam

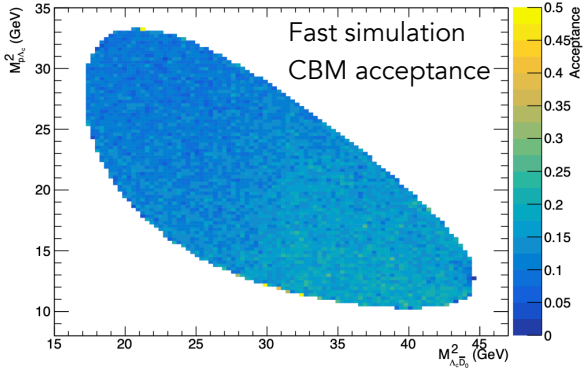


One-day Symposium ▲
(before MESON 2023)

Upcoming 3-day workshop in Wuppertal ▶

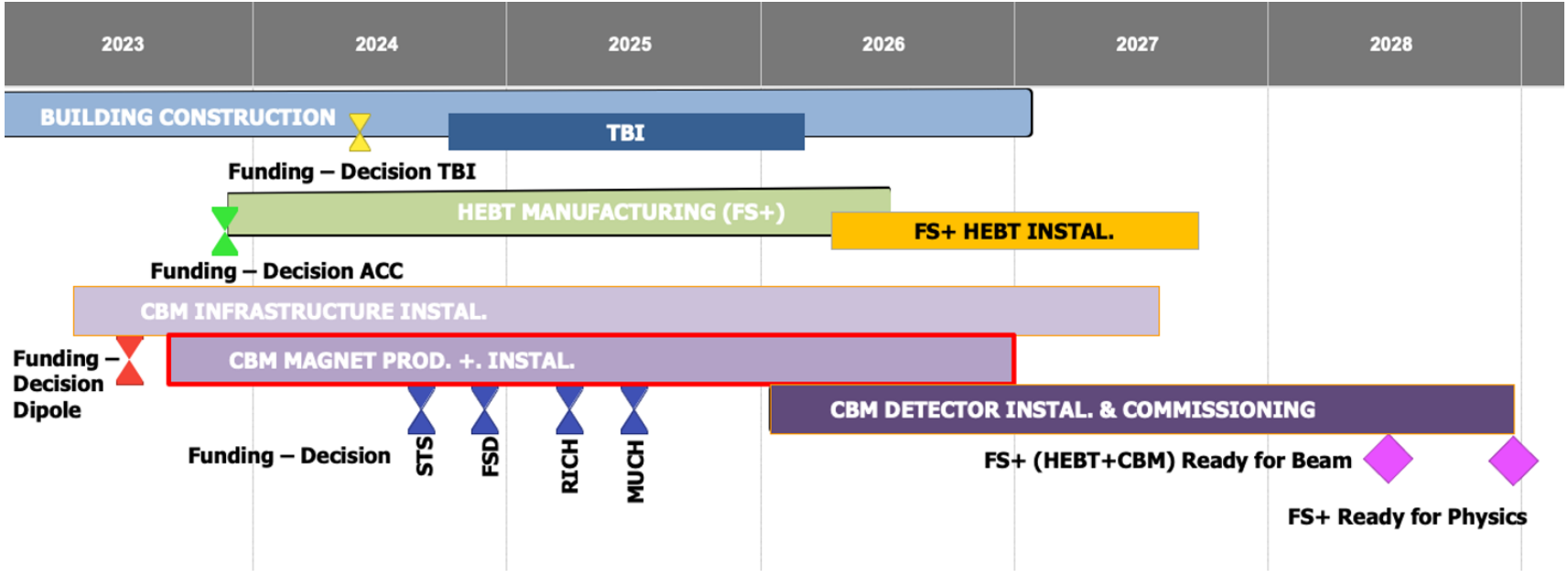


$$pp \to p\Lambda_c(\to pK^-\pi^+)\bar{D}_0(\to K^+\pi^-)$$



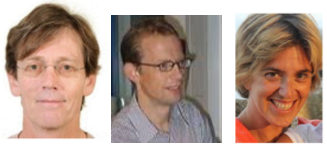
The CBM timeline to FS+

- Timely completion of CBM for First Physics (+) in 2028 in reach!
- However, critical funding decisions ahead of us which we must not miss:
  - Dipole (FAIR) ✓; Beam line elements (FAIR) !, Technical Building Infrastructure (FAIR) !, various for detectors including **remaining Core Invest from BMBF ErUM Pro !**.



DAQ, First Level Event Selection
Prof. V. Lindenstruth, Prof. U. Kebschull,
Prof. A. Toia, U. Frankfurt,
Dr. F. Schintke, ZIB Berlin

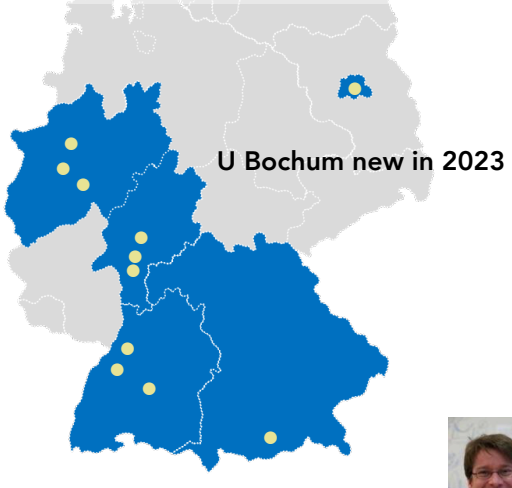
– 7 – MRPC Time-of-Flight Wall (RPC)
Prof. N. Herrmann, Dr. I. Deppner, U. Heidelberg
Phase-0@STAR

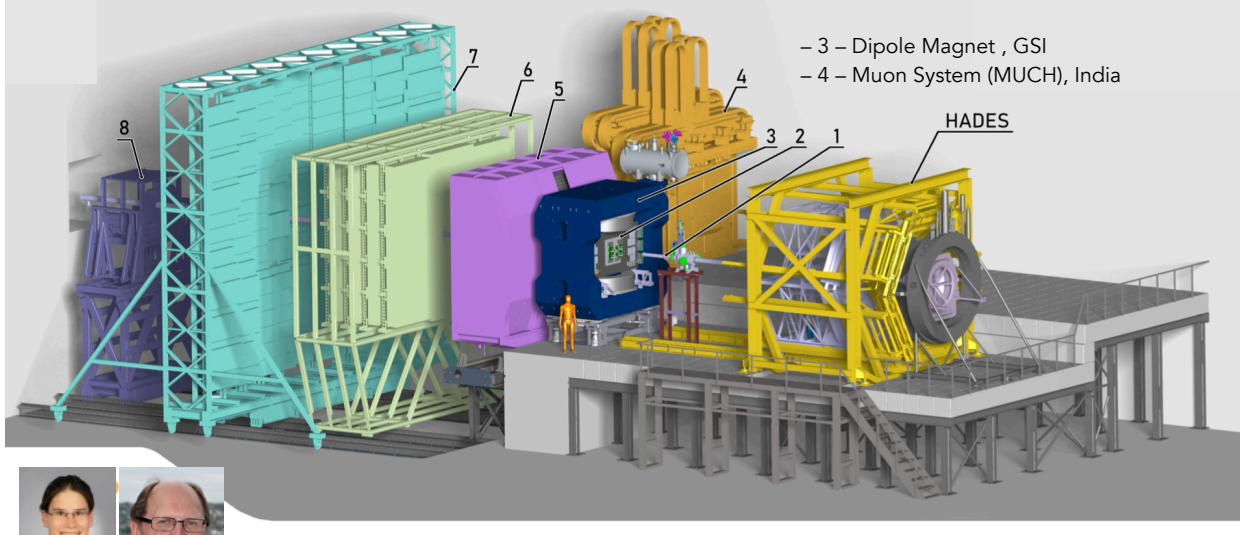


– 2 – Silicon Strip Detector (STS)
Prof. R. Schmidt U. Tübingen, C. Schmidt
Prof., A. Toia GSI

– 6 – Transition Radiation-Detektor (TRD)
Prof. A. Andronic U. Münster,
Prof. C. Blume, Prof. U., Kebschull U. Frankfurt,
Prof. P. Fischer U. Heidelberg
Prof J. Ritman U. Bochum

German university groups in ERuM FSP T06





– 3 – Dipole Magnet , GSI
– 4 – Muon System (MUCH), India

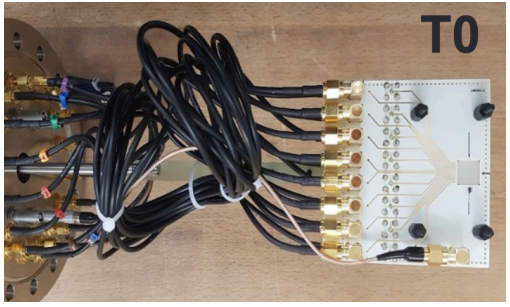
– 5 – Ring Imaging Cherenkov-Detektor (RICH)
Prof. C. Höhne, U. Gießen,
Prof. K.H. Kampert, U. Wuppertal
Phase-0@HADES

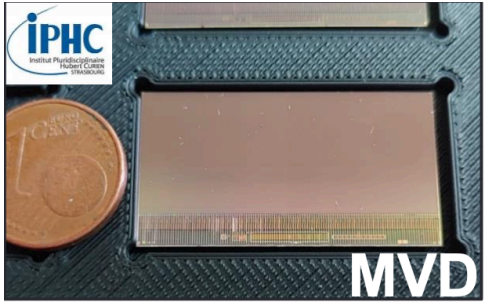
– 2 – Micro Vertex Detektor (MVD)
Prof. J. Stroth, U. Frankfurt

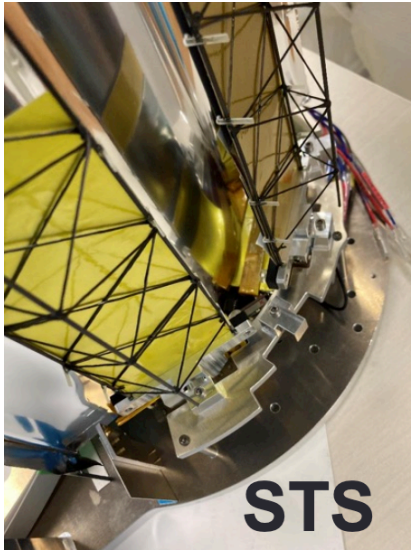
– 1– T0 and Beam Abort System (BMON)
Prof. T. Galatyuk, TU Darmstadt,
Dr. J. Pietraszko, GSI
Phase-0@HADES

– 8 –Forward Spectator Detector
Prof. J. Ritman U Bochum

CBM Detector Construction Progress







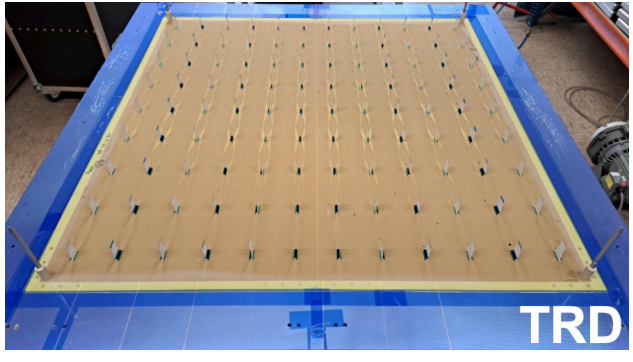
CVD T0 Detector for mCBM ▶ MIMOSIS-2 TOWER produced

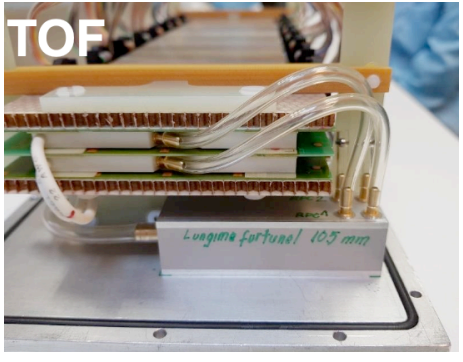
▲ ▼

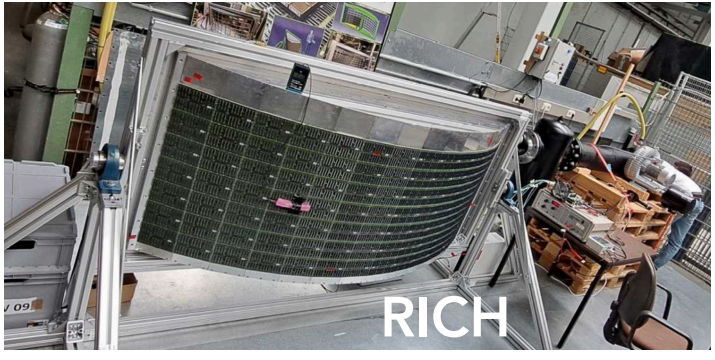
TDR for Online System approve STS ladders for JPARC

▲ ▼

TRD back plane ◀ New RPC gas distribution ◀ RICH camera







FAIR PHASE-0

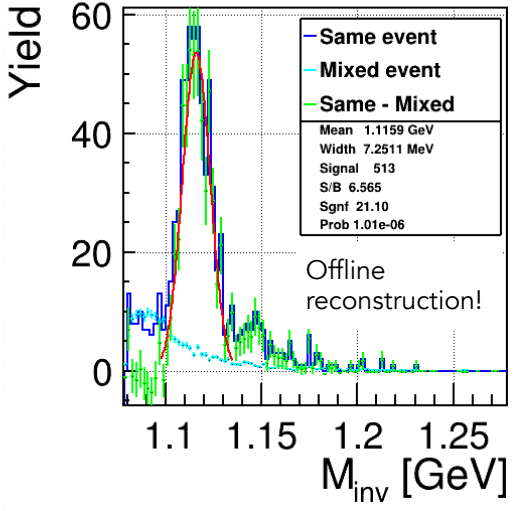
HADES, mCBM, STAR

C.B.M. FAIR Phase-0 – mCBM as commissioning platform

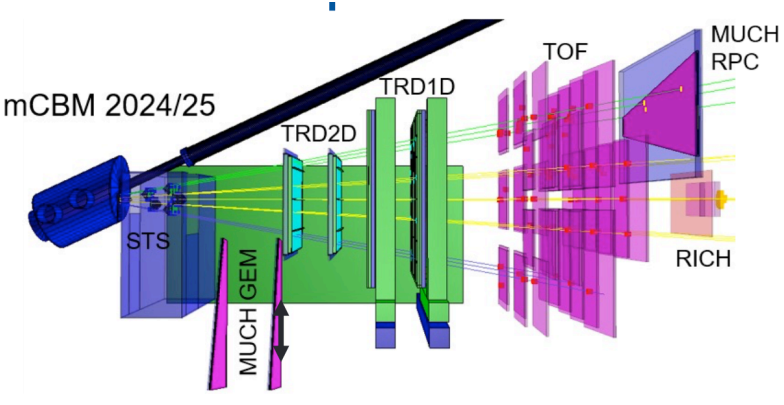
Single-arm arrangement of **prototype/FOS detectors** including **full free-streaming read-out chain**. Several days of beam time every year. Placed in a dedicated high-intensity cave near R3B cave at SIS18.

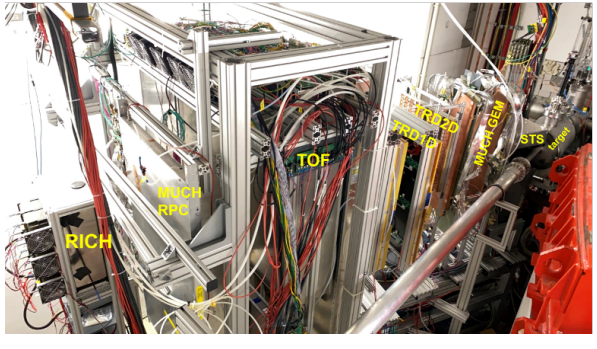
Goals:

- Gain indispensable insights into the functioning of the detectors,
- develop close-to-final firmware and software for the DAQ chain,
- implement a prototype system for detector controls,
- establish and benchmark the **online event reconstruction** machinery for **rare probes**, including quality assessment.



Ni+Ni 1.93 AGeV (May '22):
10^9 collisions in 1:57 h at
400 kHz average collision rate.





FAIR Phase-0: eTOF @ STAR

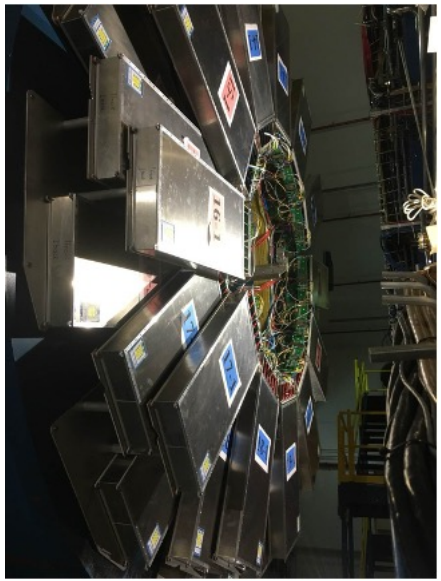
36 modules, 108 MRPCs, ~7000 FEE channels. Integrated as end-cap TOF in STAR experiment

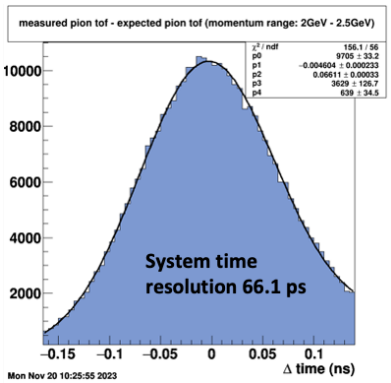
- BESII campaign finished
- eTOF system **time precision better 70 ps**
- Important information obtained about stable operation
- **Excellent PID** for STAR FXT (BES-II)
- Physics analysis ongoing (e.g. anti proton measurements)

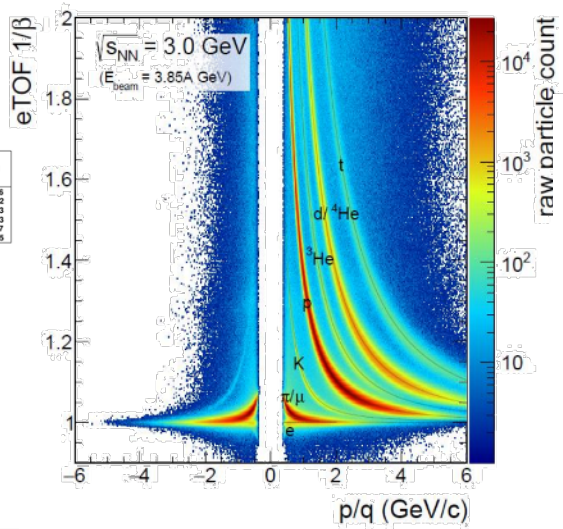
$\sqrt{s_{NN}}$ / GeV	# coll. Event	Year
7.7	100 M	2021
9.1	150 M	2020
11.5	230 M	2020
14.6	320 M	2019
19.6	580 M	2019

Collider mode ▲
Fixed-target mode ▶

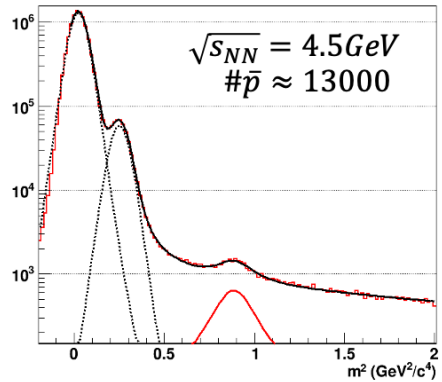
$\sqrt{s_{NN}}$ / GeV	# coll. Events	Year
3.0	2 B	2021
3.5	100 M	2020
3.9	50 M	2020
4.5	100 M	2020
5.2	100 M	2020
6.2	100 M	2020
7.7	50 M	2020
9.2	50 M	2021
11.5	50 M	2021
13.7	50 M	2021





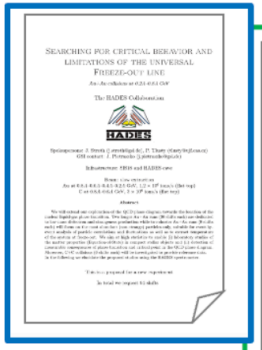


Antiproton reconstruction



C.B.M. FAIR Phase-0 – HADES proposed runs

Au+Au BES < 1 A GeV



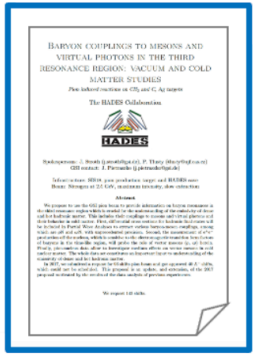
Scheduled for Februray 2024

EM transition form factors of hyperons

Successfully conducted in Feb./March 2022

Cold matter effects including line shapes and SRC

Baryon resonances, meson baryon coupling in the 3rd resonance region

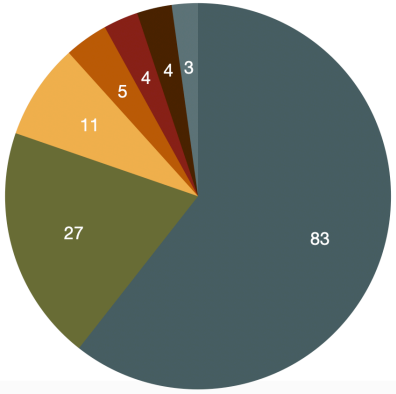


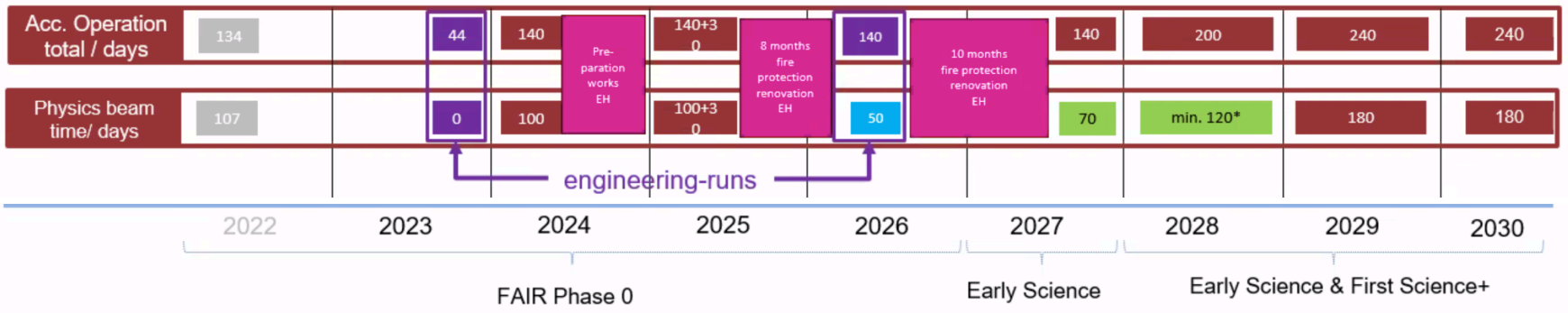
On hold otherwise A

Iso-spin effects in dilepton production

HADES collaboration members

Germany, Poland, Czech Republic, Sweden, Cyprus, Portugal, France



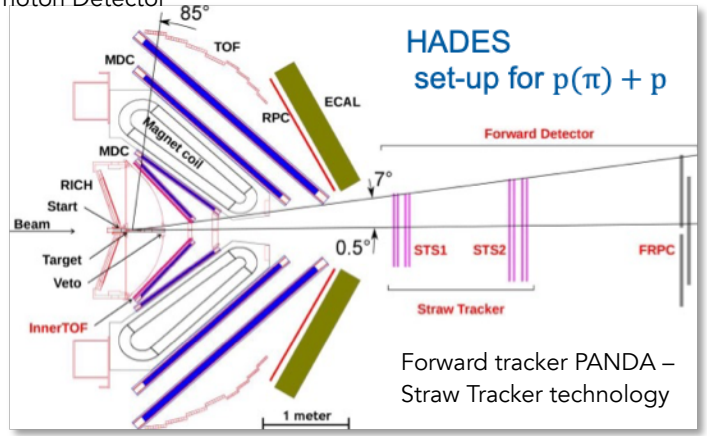


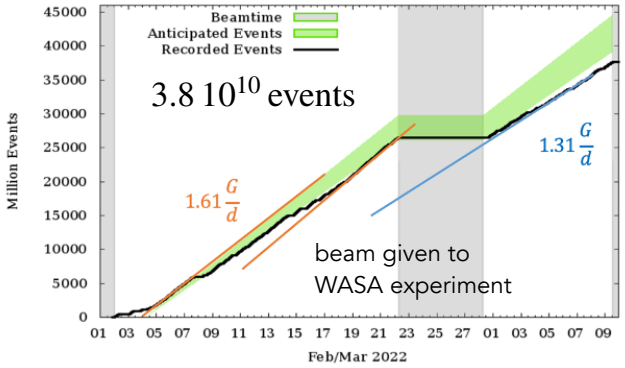
C.B.M. FAIR Phase-0 – HADES p+p run Feb 2022

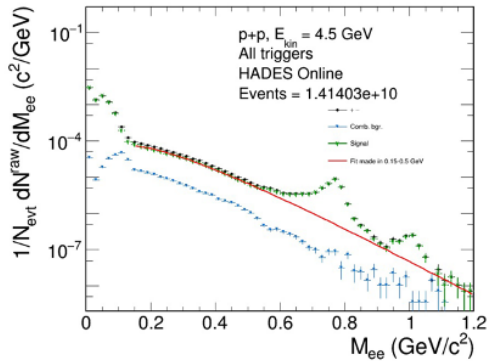
- Jointly proposed by HADES and PANDA members (HADES-PANDA MoU)
- **Uppsala (2023)** and **Bochum/FFH** group **joined HADES in full**
- First explorative measurement of Hyperon electromagnetic Dalitz decays 2022

$$pp \rightarrow p\,Y^0(\rightarrow \Lambda\, e^+e^-)\,K^+$$

RICH with HADES/CBM Photon Detector







C.B.M. FAIR Phase-0 – HADES planned physics runs

Remaining physics runs at SIS18 depends on availability and performance of SIS18 beam

- Smooth micro spill-structure to minimize dead time and pile-up
- Efficient extraction of high-intensity beam at maximum rigidity to maximize secondary pion beam intensity

o Scheduled next: Au+Au beam energy scan 0.2 to 0.8 A GeV
o Pion beam experiment to study third resonance region not scheduled yet

★ Preliminary results from **Engineering Run**:

- Successful commissioning of 81 MHz cavity installed in SIS18. **Strong improvement of micro spill structure** observed
- **Efficient extraction of** 8×10^{10} ^{14}N **ions** and transported to pion production target (minor issues with beam losses)

Engineering Run 2023

November	Mo 6.	Di 7.	Mi 8.	Do 9.	Fr 10.	Sa 11.	So 12.	Mo 13.	Di 14.	Mi 15.	Do 16.	Fr 17.	Sa 18.	So 19.	Mo 20.	Di 21.	Mi 22.	Do 23.	Fr 24.	Sa 25.	So 26.	Mo 27.	Di 28.	Mi 29.	Do 30.
EZR	Ar for HELIAC (CW)				*He4 und C*						He4 und C						54Cr						Ar for HELIAC (CW)		
Nord	C				p+			CH3		Ar		N	N	N			N						N		U
Süd								Au		Fe				Au			Au								
UNILAC HF								installation gas stripper		parallel RF conditioning				installation jet stripper		parallel RF conditioning						parallel RF conditioning			RF-conditioning
UNILAC	Pion-PE				HCC					Dual-IB		BP-HEST	OP			MEXP	54Cr X8		MEXP			Pion-PE			
SIS	Pion-PE				HCC					Dual-IB		BP-HEST	OP			MEXP			MEXP			Pion-PE			
FRS					HCC											MEXP			MEXP						
ESR																MEXP			MEXP						
HEST	Pion-PE				HHD					HTM		HTP	HHD			HHD / HTP			HHD / HTP			Pion-PE			
Cryring	MEXP									MEXP			OP Training			MEXP						GPAC-Exp.			

C.B.M. – ERUM FSP T06

FSP Coordination and Outreach

Retreats in funding period 21-24

- 24./25.10.2022, Bold Campus, Königstein
- Next planned retreat: week 9/2024

Future plans (funding period 24-27)

- Continuation of yearly retreats (accompanied by small workshops, including participation of young scientists)
  - Each retreat will cover one cross-collaborative specific topic (tracking, analysis, DAQ, ...)
- Development of easy tools which require little training time (masterclass) to perform simulations and (in the case of HADES) to display real data
  - Accompanied by tutorials each taking about 45 minutes, and each with a specific learning objective (e.g. detector resolution, statistics, phase space, etc.). -> focus is on broad audience
- Enhancement of the web page with didactic materials (e.g. 3d-models, PoV-Videos)
  - All activities are embedded in the JOO framework to enhance visibility

FSP T06 web site – roll out in January 2024

Hub page for all C.B.M. FSP groups

- Main focus on didactic presentation of the physics, detector and components
- Targeted to funding agencies
- **Embedded into the JOO framework**

THANK YOU FOR YOUR ATTENTION