COLD MATTER STUDIES WITH HADES AND CBM

Joachim Stroth

Physics opportunities with proton beams at SIS100

Wuppertal University

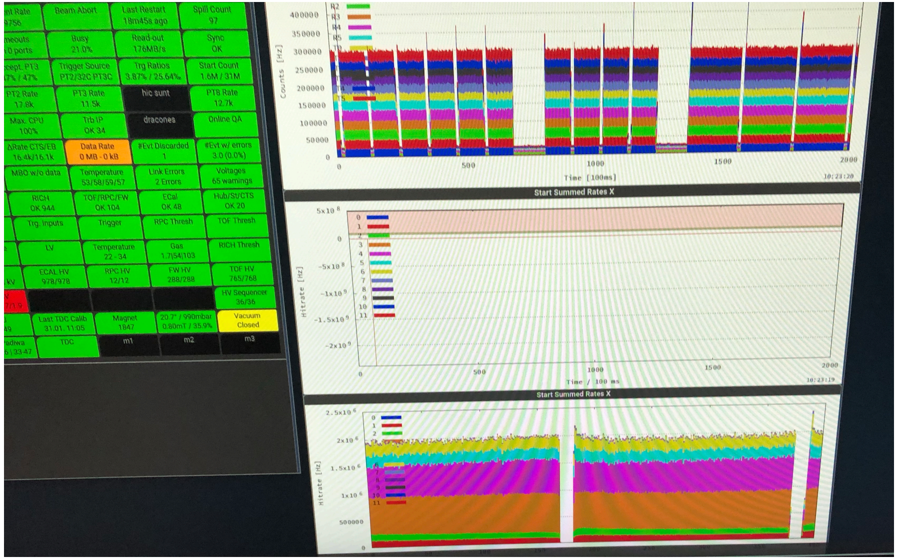
February 6–9, 2024

Breakthrough in slow extraction at SIS18

For the first time, the new regulated knock-out extraction was turned on at SIS18

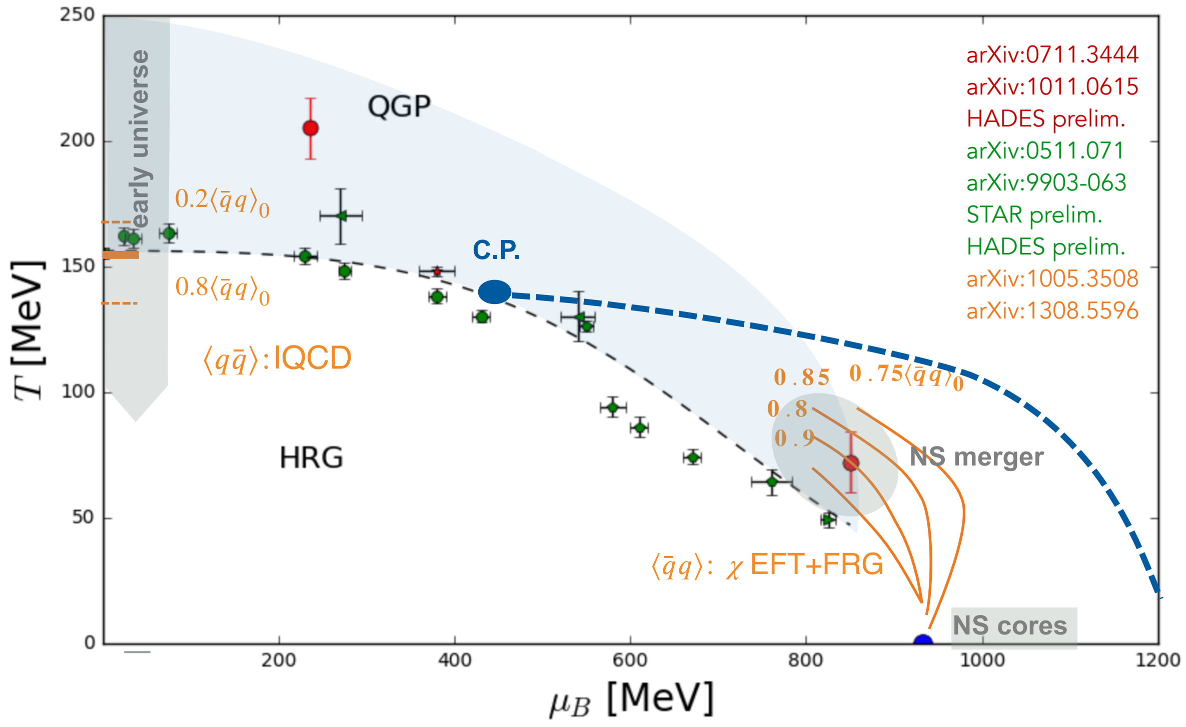
- Electrostatic septum is regulated using the actual beam intensity measured with HADES T0 detector
- Carbon beam at 0.8 A GeV (~2 10^6 Hz) directed to HADES target

Congratulations to Rahul Singh, Philipp Niedermayer, Peter Forck and the whole team (BEA)



HADES/CBM MOTIVATION

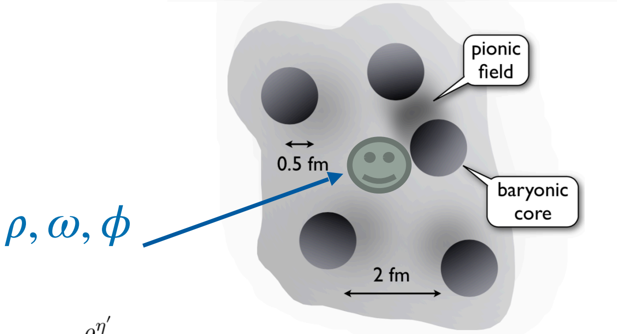
Exploring the QCD phase diagram



- Astrophysical relevance
  - Hadronization in the early universe
  - Neutron stars
  - Neutron star mergers
- lQCD / χEFT landmarks
  - Chiral cross over at $\mu_B = 0$ with pseudo critical temperature $(T_c = 154(9)\ \mathrm{MeV})$
  - Chiral condensate
- „Observations“
  - Freeze-out conditions (SHM)
  - „Mean“ fireball temperatures (“Planck” radiation)
  - Liquid gas phase transition
- Conjectures
  - 1st order chiral/deconfinement phase transitions @ high μ_B
  - Exotic phases
  - (U-)RHIC)range

Hadron spectrum and QCD condensates

- Dynamical mass generation due to spontaneous symmetry breaking:
  - Hadron mass: breaking of scale invariance (trace anomaly)
  - Parity splitting, Goldstone modes: breaking of χ symmetry

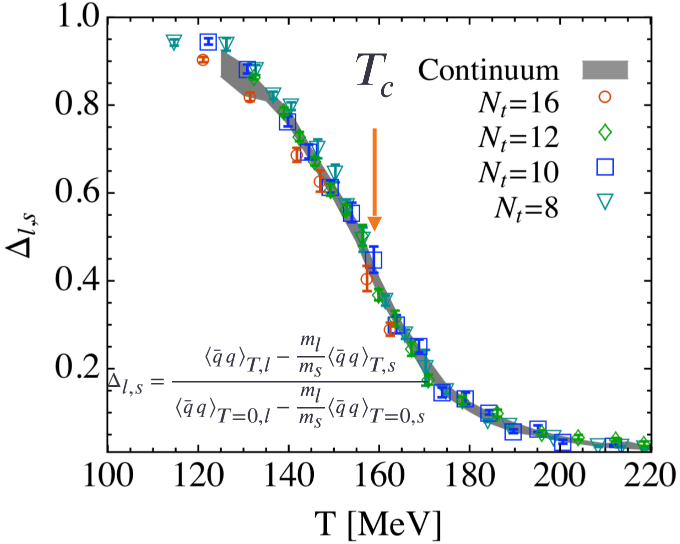


$\rho_B = 0.15\ \mathrm{fm}^{-3}$

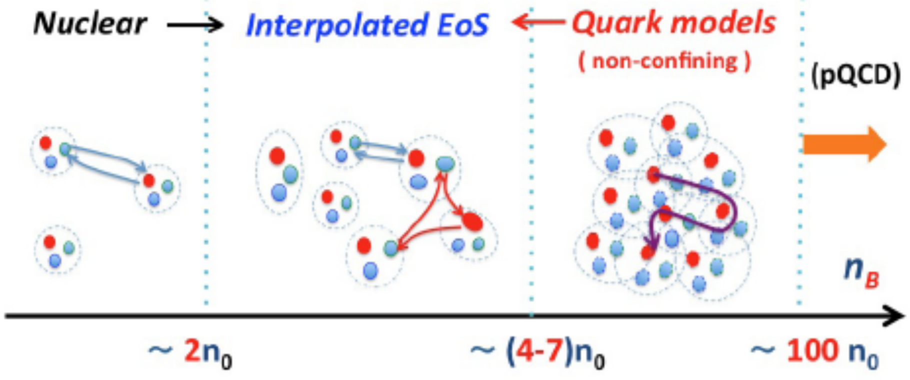
normal nuclear matter: dilute

W. Weise, QNP2018

lQCD – WB group; arXiv:1005.3508

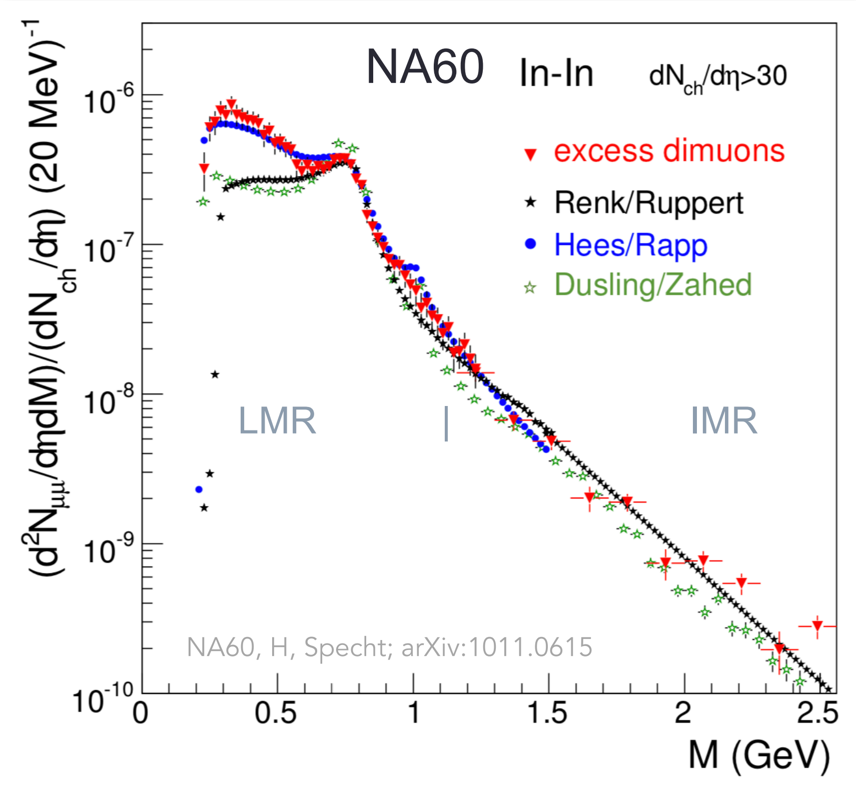


$$\frac{\langle \bar{q}q \rangle_T}{\langle \bar{q}q \rangle_0} = 1 - \frac{\varrho_s^\pi}{2m_\pi f_\pi^2} - \frac{\varrho_s^K}{4m_K f_K^2} - \frac{\varrho_s^\eta}{6m_\eta f_\eta^2} - \frac{\varrho_s^{\eta'}}{3m_{\eta'} f_{\eta'}^2}$$
$$- \sum_B \frac{\sigma_B}{f_\pi^2 m_\pi^2} \varrho_s^B - \sum_M \frac{\sigma_M}{f_\pi^2 m_\pi^2} \varrho_s^M - \alpha T^{10} .$$



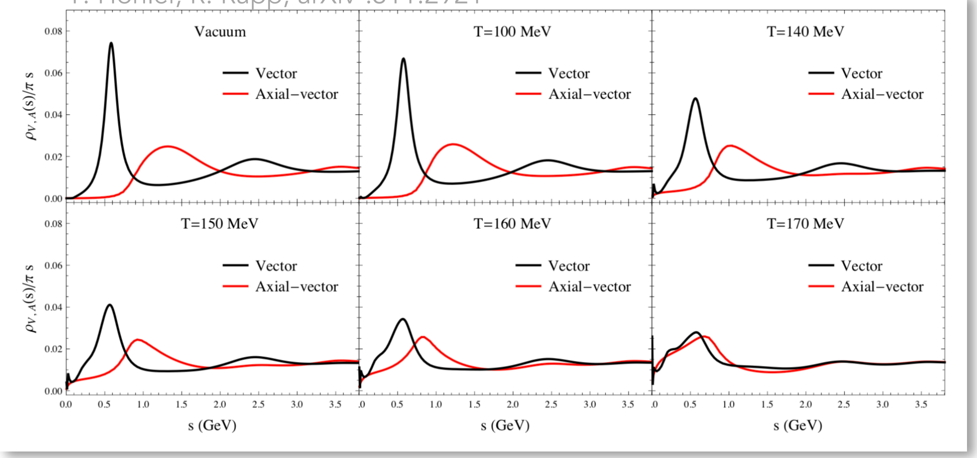
G. Baym, QNP2018

Thermal radiation and chiral symmetry restoration

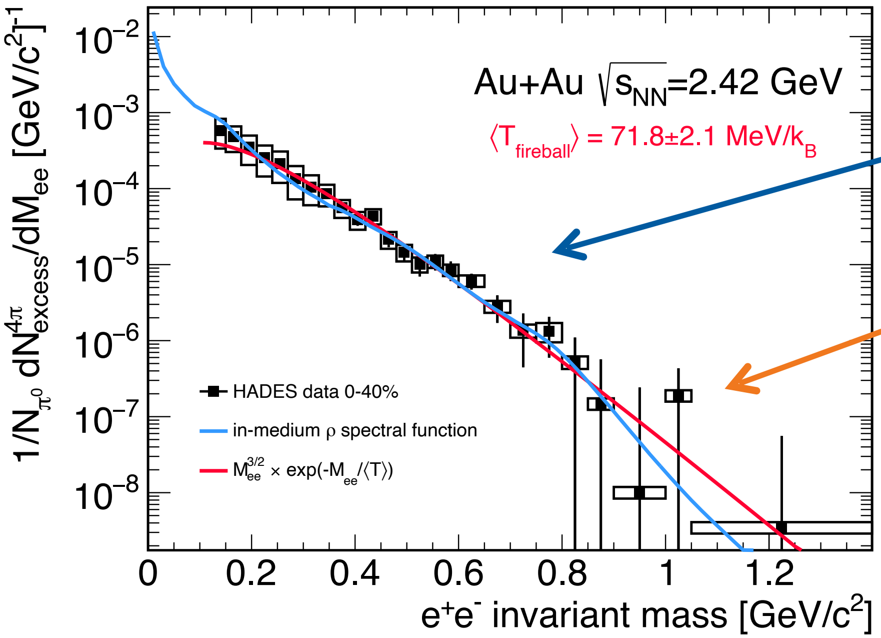


- Strong excess due to ρ baryon coupling in the LMR
- Direct measurement (no blue-shift) of the emitting temperature in the IMR (black-body radiation))
- Strong broadening of in-medium ρ spectral function – link to χ symmetry restoration?

P. Hohler, R. Rapp; arXiv-:311.2921



Thermal dileptons Au+Au 1.23A GeV (HADES)



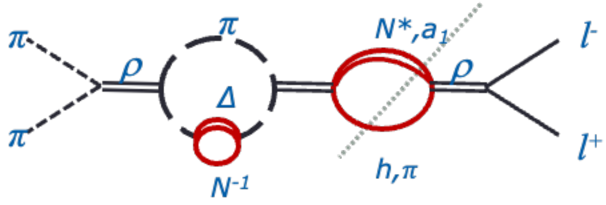
HADES; Nature Phys. 15 (2019) 10, 1040-1045

0.3 < M < 0.7 GeV:
- In-medium spect. funct.
- fireball life time
- fireball temperature(1)

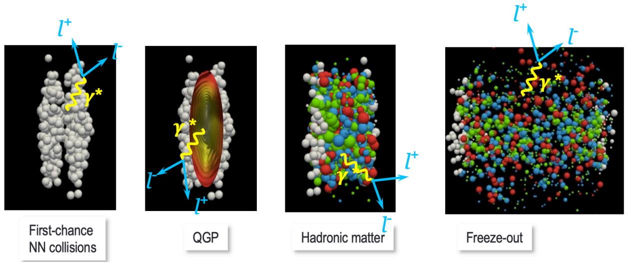
M > 1 GeV/c^2:
- ρ – a1 chiral mixing
- dominated by contribution from the hottest and densest region

Coarse-grained UrQMD & thermal emissivity with in-medium propagator

Rapp, van Hees; arXiv:1411.4612v
CG GSI-TAMU; Galatyuk, Seck, et al.; arXiv:1512.08688

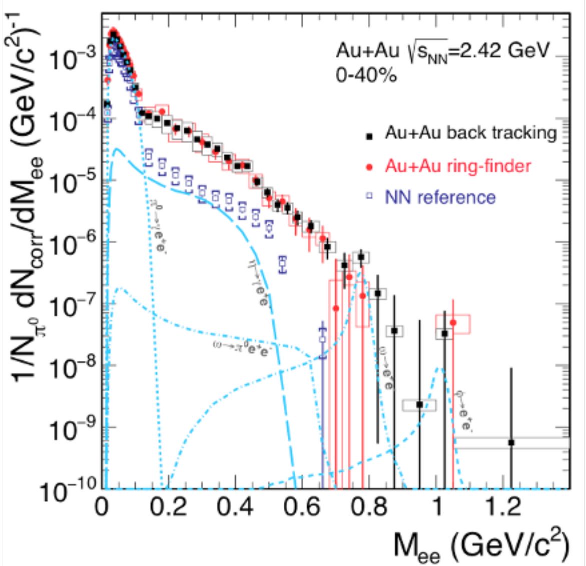


Extraction of the excess radiation

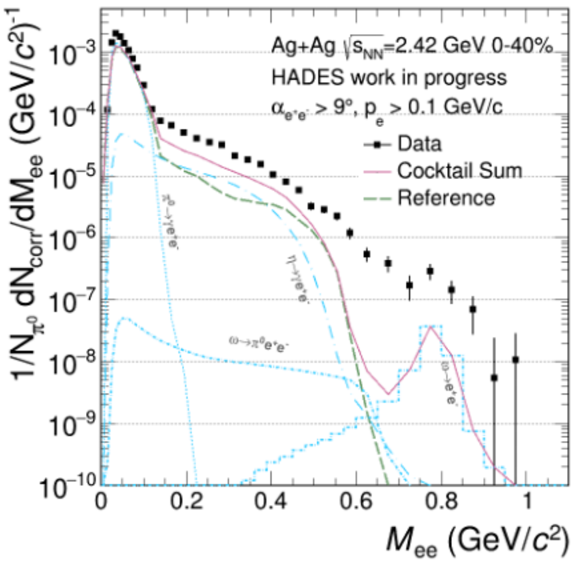


- Pre-equillibrium from reference measurements
- Hadronic cocktail from π^(-/+) or γγ measurement
- Implicit scaling to π^0 yield

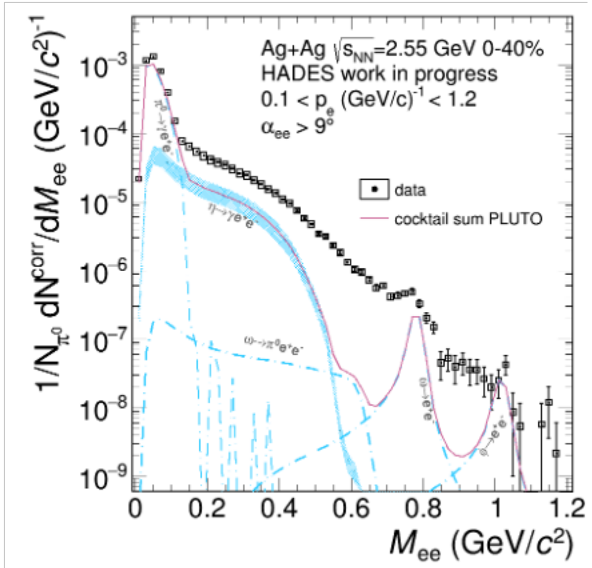
Au+Au at $\sqrt{s_{NN}} = 2.42$ GeV



Ag+Ag at $\sqrt{s_{NN}} = 2.42$ GeV



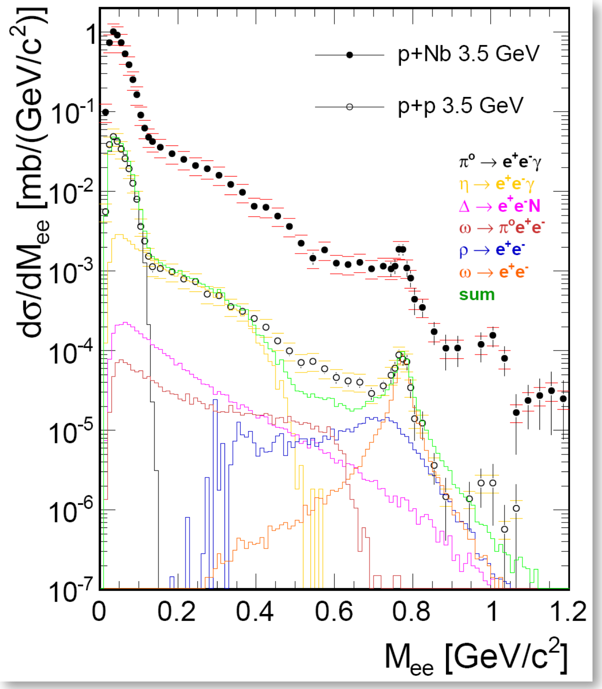
Ag+Ag at $\sqrt{s_{NN}} = 2.55$ GeV



COLD-MATTER – LIGHT QUARKS

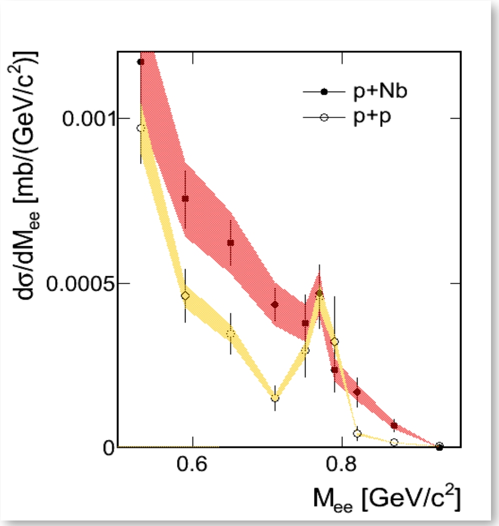
Vector mesons in cold matter

- Ideal probe to monitor possible mass shifts
- Low relative momentum to medium needed to increase sensitivity

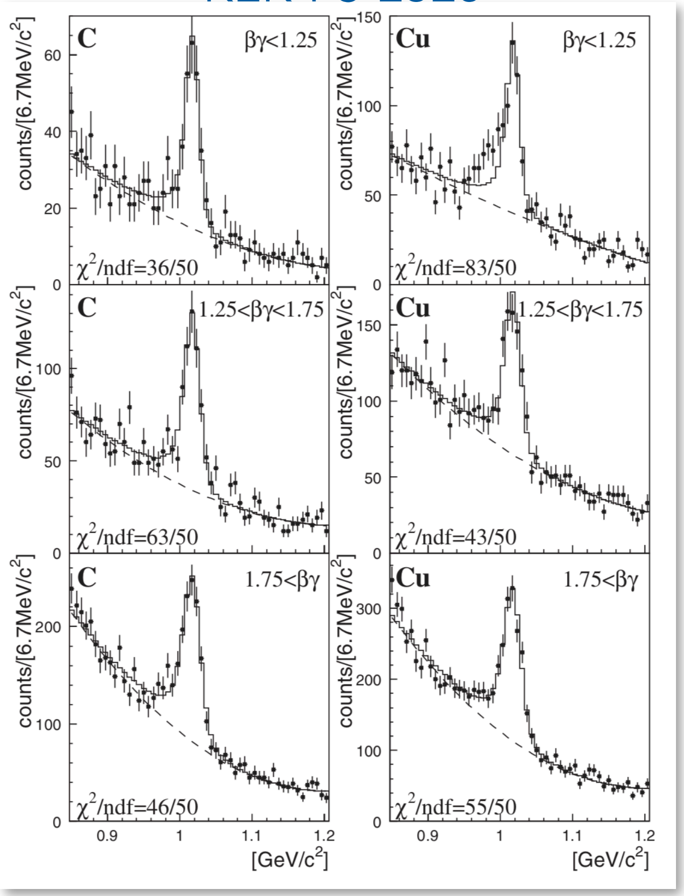


- Broadening and/or mass shift?

HADES



KEK-PS E325

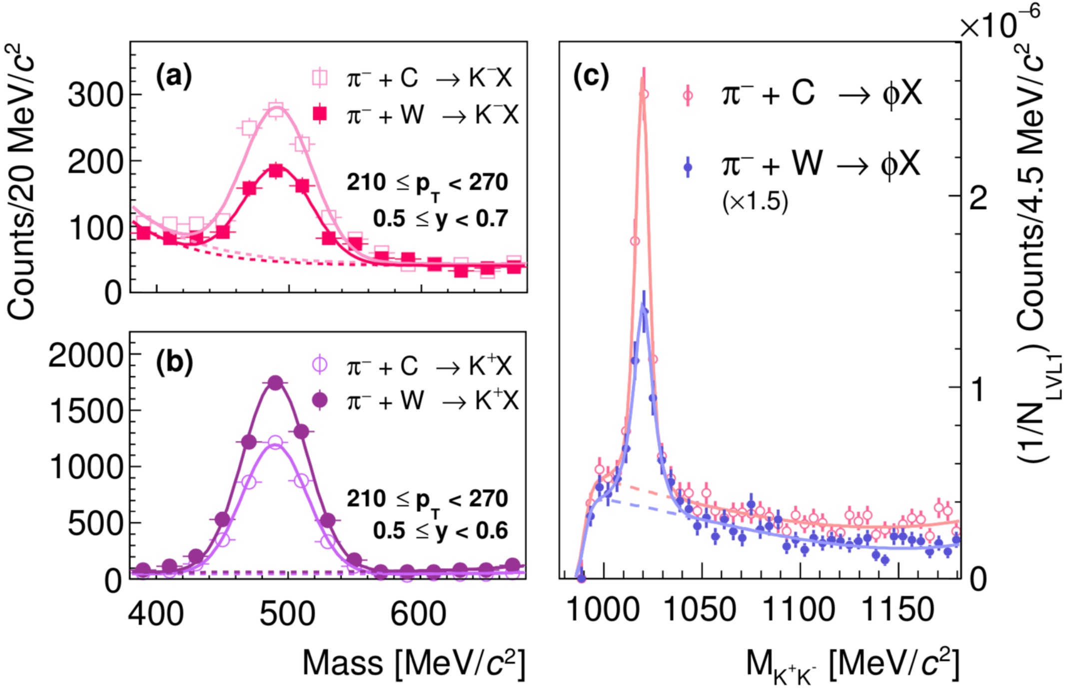


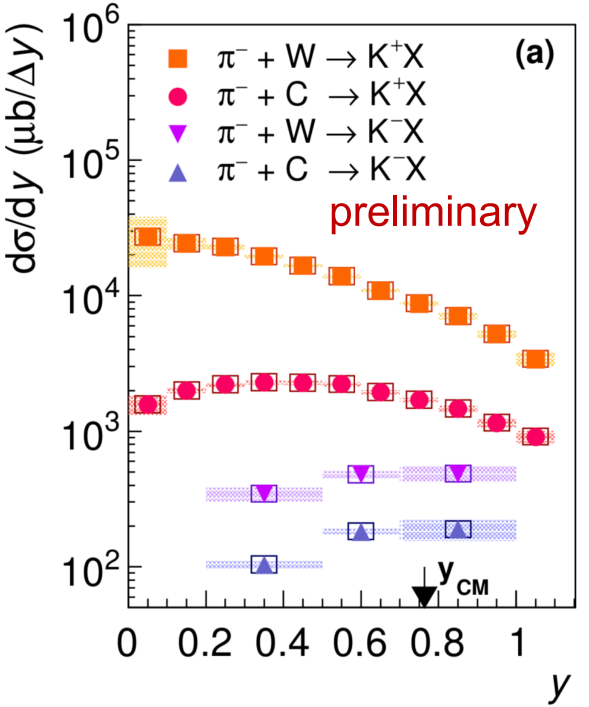
HADES, PLB 715 (2012)

KEK-PS E325, PRL 98, 042501 (2007)

ϕ production in $\pi + A$ collisions (HADES Collaboration)

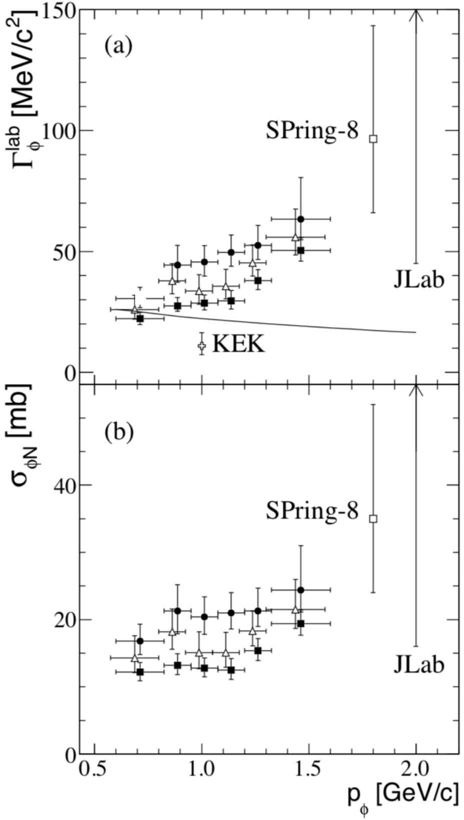
- Evidence for substantial absorption in cold matter
- Earlier decoupling in ultra-relativistic HIC!?

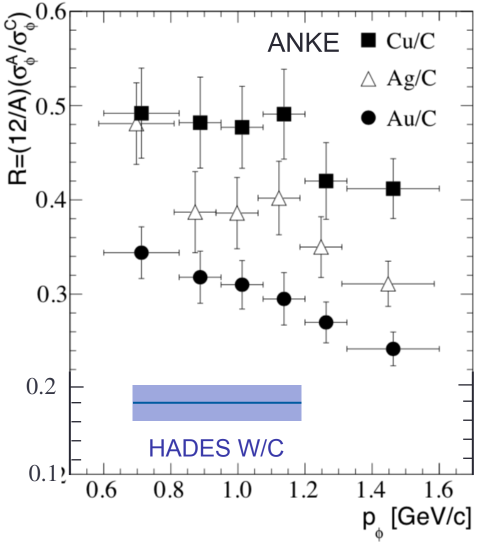




ϕ transparency in p+A collisions (ANKE Collaboration)

- Momentum depended production cross section off targets with different size
- Interpretation in terms of absorption needs models:
  - In-medium spectral function and
    $pN \rightarrow \phi pN \qquad \Delta N \rightarrow \phi pN$
    Phys. Rev. C 71, 065202 (2005)
  - In-medium spectral function and
    $pN \rightarrow \phi pN \qquad \pi N \rightarrow \phi N$
    J. Phys. G 36, 015103 (2009)
  - Adjustable in-medium cross section and transport (GiBUU)

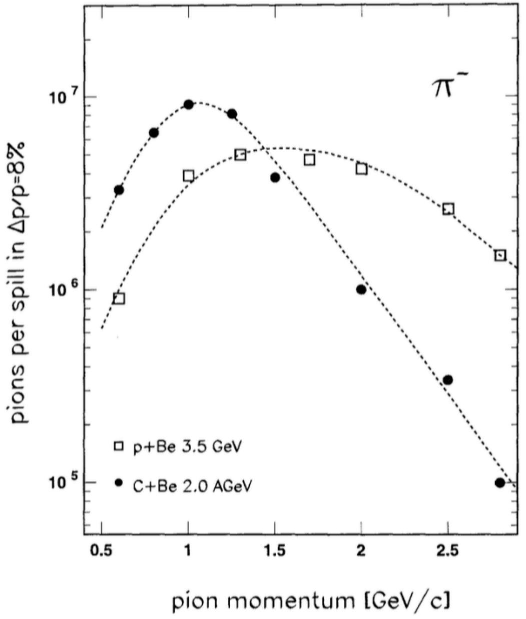


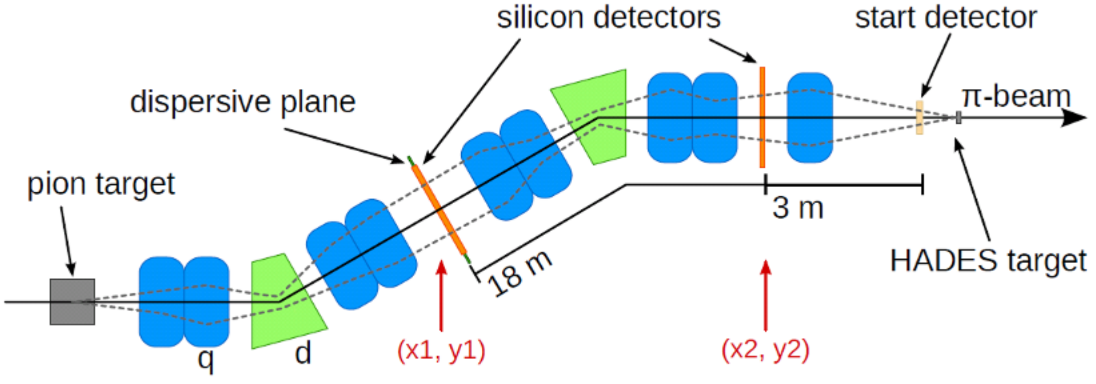


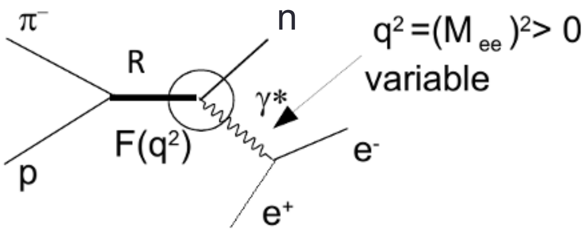
ANKE
arXiv:1201.3517
HADES W/C
arXiv:1812.03728

The GSI pion beam facility

- So far, only one longer run at reduced intensity due to radiation safety issues (2014)
- Accelerator department implemented five different measures to mitigate the radiation level
- December 2023 successful test of pion production with 8×10^{10} N ions per spill → **expect intensities as shown on the plot**





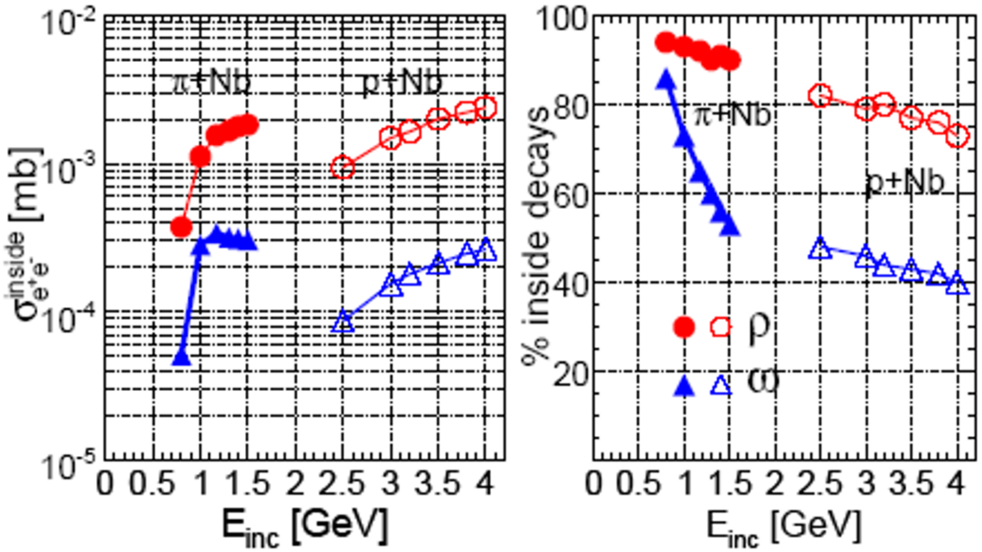


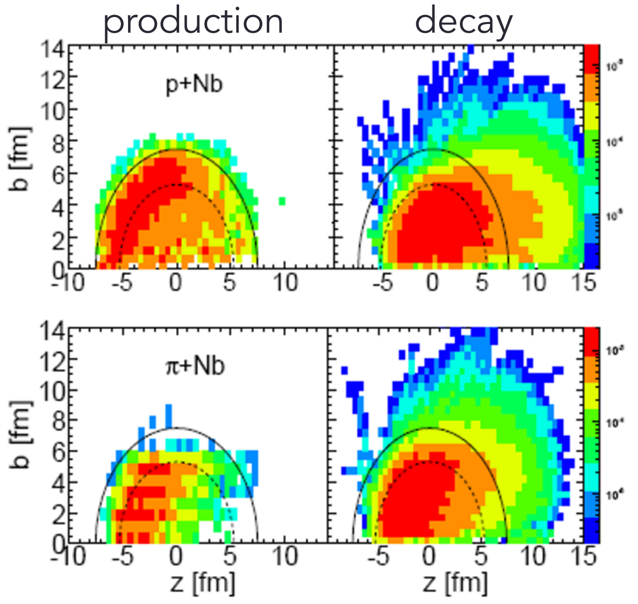
“Recoil-less” vector meson production

- Second motivation for HADES
- Motivated pion-beam facility at GSI

HSD: E. Bratkovskaya, W. Cassing Phys.Rep. 308 (1999) 65

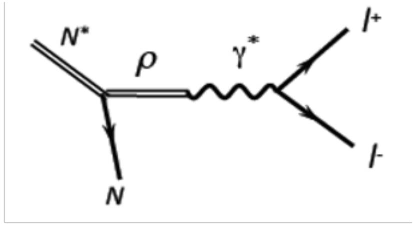
HADES Collaboration et al. (1996) Published in: Acta Phys. Polon. B 27 (1996) 2959-2963; Contribution to: MESON 96



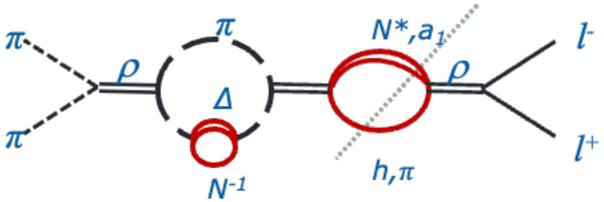


$\pi^- + p \rightarrow n + e^+e^-$ ($\sqrt{s}$=1.49 GeV)

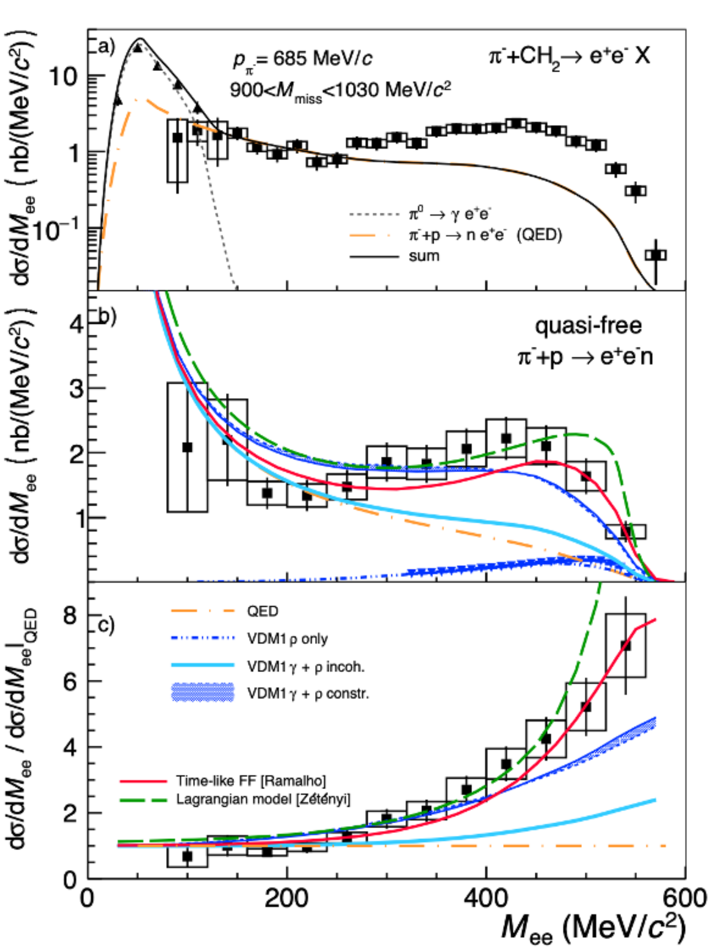
Resonance-Dalitz decay (a la VMD) …



… is analogous to baryonic contribution to in-medium ρ self energy (**emissivity**)



Effective **transition form factor** (time-like) extracted by subtracting QED expectation from exclusive invariant mass distribution.



COLD MATTER – HEAVY QUARKS

Charmonium and open charm as probe for strong-interaction matter

Key observable → charmonium / open charm (ratio of multiplicities)

[e.g. A. Andronic, Eur. Phys. J. C 76 (2016) 3]

- Uncertainties in modelling multiplicities in URHIC:
  - quasi-bound states in QGP / regeneration [e.g. X. Du and R. Rapp, *Phys. Lett. B* 834 (2022)]
  - dissociation by co-movers
  - nuclear partition functions

- Cold nuclear matter (CNM) effects
  - production mechanism in the non-perturbative regime (also pp)
  - propagation in cold matter
  - formation time effects

$$R_{\mathrm{pA}} = \frac{\sigma_{\mathrm{pA}}}{A\,\sigma_{\mathrm{pp}}}$$

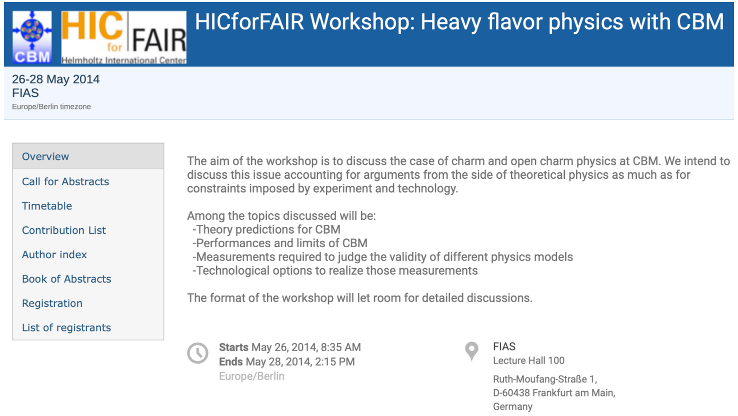
Conclusion slide from Helmut Satz

CBM can provide unique opportunity for pioneering studies of

- charm production
- charmonium formation

in normal and compressed nuclear matter

In all cases, need p-p as reference, and all reactions should be studied at the sam collision energy



HICforFAIR Workshop: Heavy flavor physics with CBM

26-28 May 2014
FIAS
Europe/Berlin timezone

- Overview
- Call for Abstracts
- Timetable
- Contribution List
- Author index
- Book of Abstracts
- Registration
- List of registrants

The aim of the workshop is to discuss the case of charm and open charm physics at CBM. We intend to discuss this issue accounting for arguments from the side of theoretical physics as much as for constraints imposed by experiment and technology.

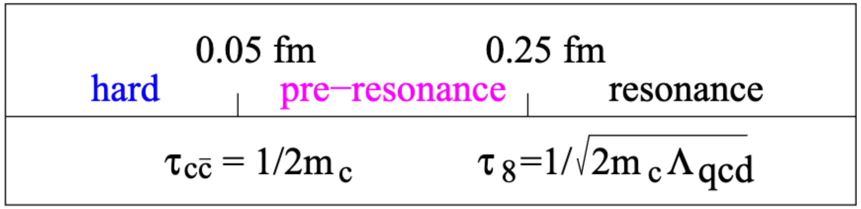
Among the topics discussed will be:
-Theory predictions for CBM
-Performances and limits of CBM
-Measurements required to judge the validity of different physics models
-Technological options to realize those measurements

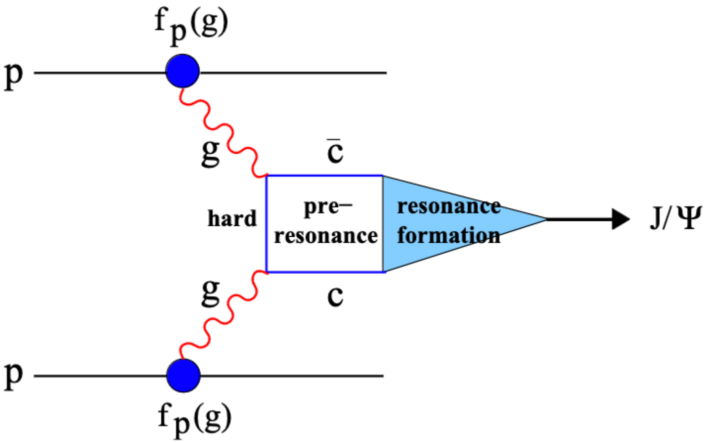
The format of the workshop will let room for detailed discussions.

Starts May 26, 2014, 8:35 AM
Ends May 28, 2014, 2:15 PM
Europe/Berlin

FIAS
Lecture Hall 100
Ruth-Moufang-Straße 1,
D-60438 Frankfurt am Main,
Germany

time evolution of J/ψ formation





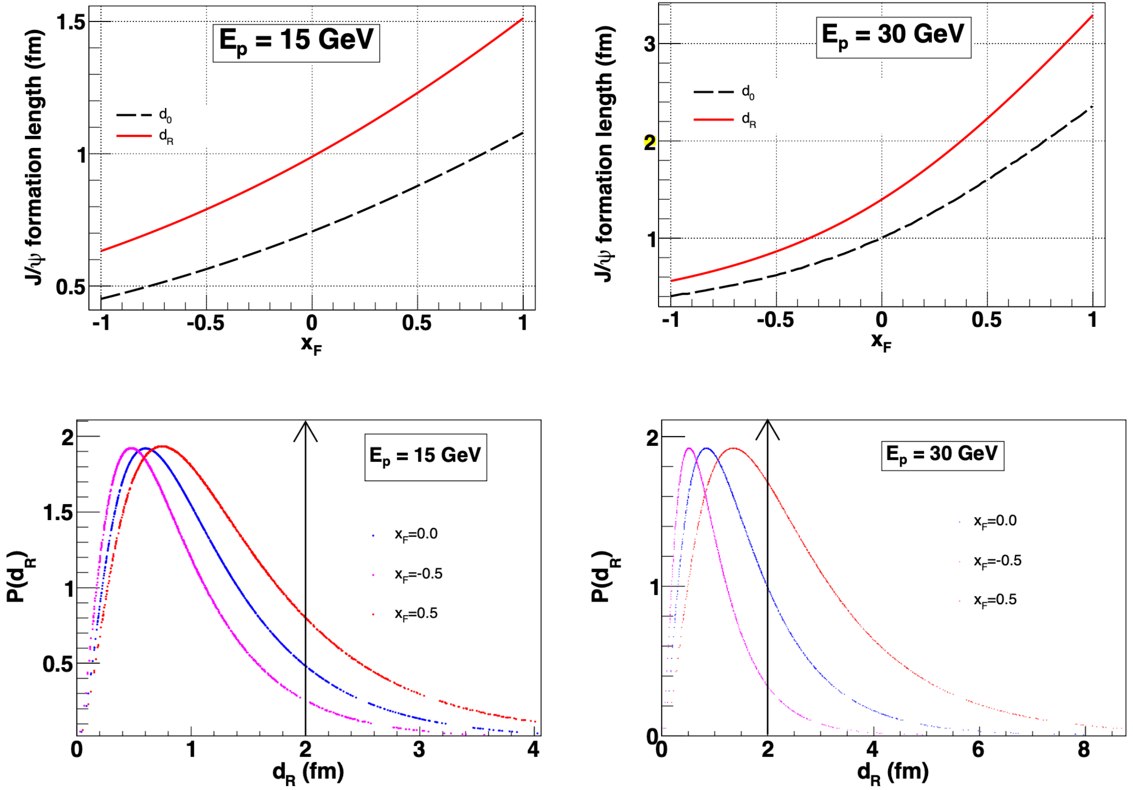
Simulation of charmonium production at FAIR energies

Simulation studies by:

P. P. Bhaduri, M. Deveaux and A. Toia

Simulation assumes perturbative cross sections and other “simplifications” → proof of principle

[J.Phys.G 45 (2018) 5, 055103]



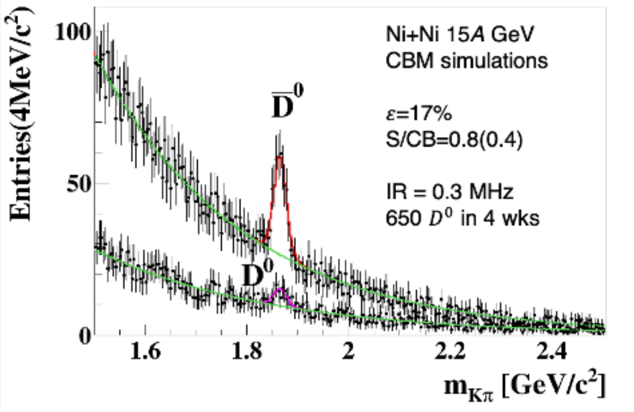
Open-charm measurements

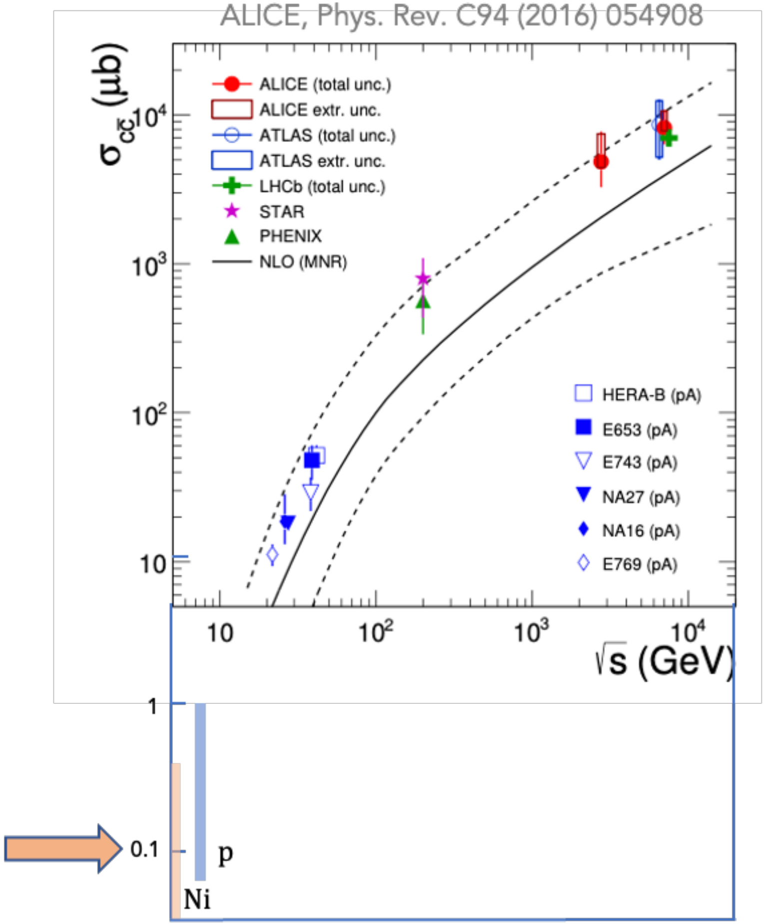
Cross section unknown at SIS100 energies,

proton beam $\sqrt{s_{\mathrm{NN}}} < 8$ GeV

p+A runs

- Establish excitation function for charm production at these energies
- System size dependence to add to the question of transition from partonic to hadronic picture
- Additional data address formation time





MVD and charm

Radiation dose (assume CBM year 5×10^6 s)

Au+Au (1 % target) with 10 A GeV at 10^7 ions/s

- Include δ electrons
- Dominated by ionization damage. Up to → 5 Mrad
- Lower energies with reduced magnetic field lead to less radiation damage

p+Au (1 % target) at with 30 A GeV at 10^9 ions/s

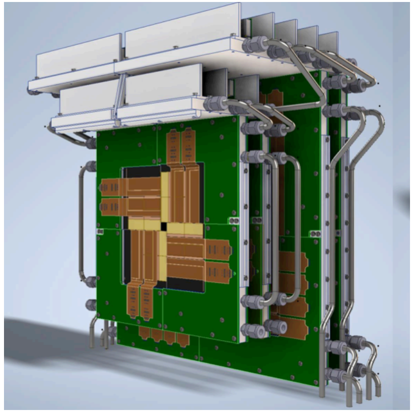
- Main damage by small angle scattering of beam protons
- Dominated by bulk damage: Up to → $7 \times 10^{13}\ n_{eq}/cm^2$

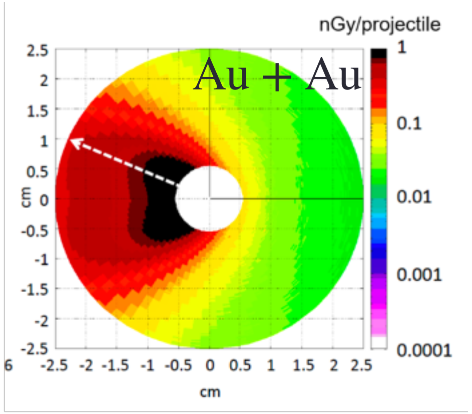
Beam halo events

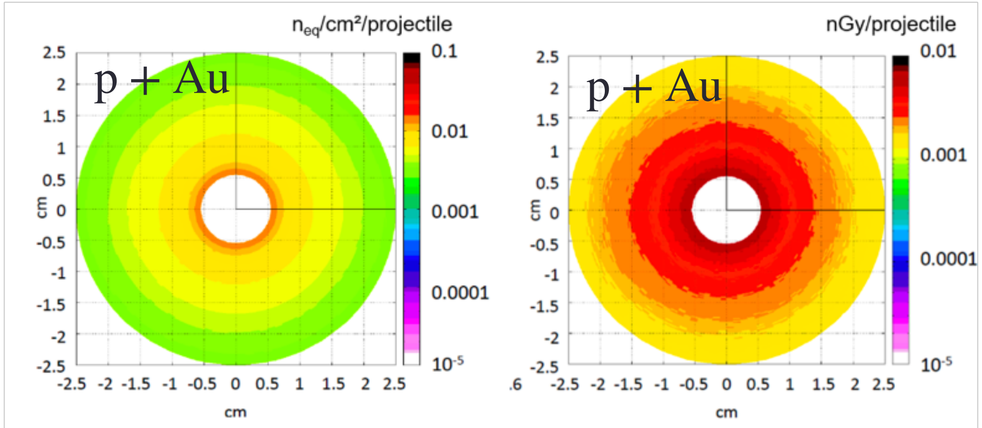
- Will dependent on beam quality (request)
- Detectors can be moved in stand-by position (5 cm away perpendicularly to the beam)

SEU / Latch-up

- Currently under investigation in mCBM
- Triple-redundancy logic in digital part
- Fast reconfiguration in spill breaks



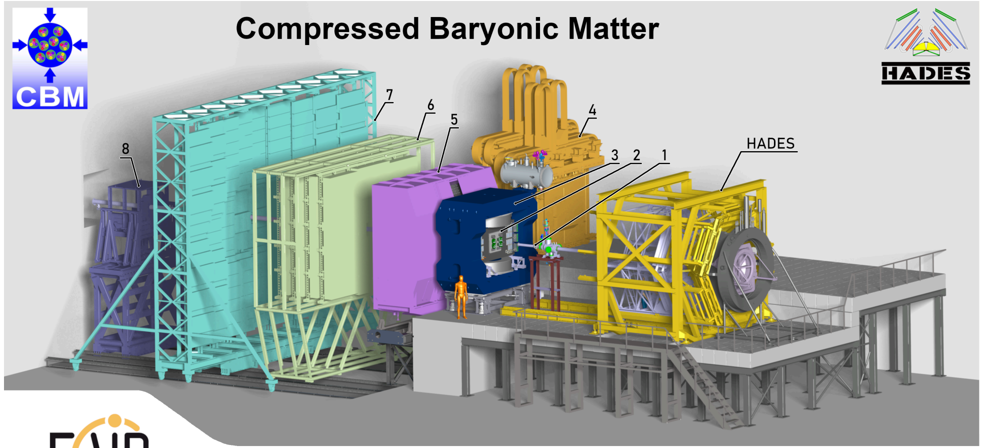




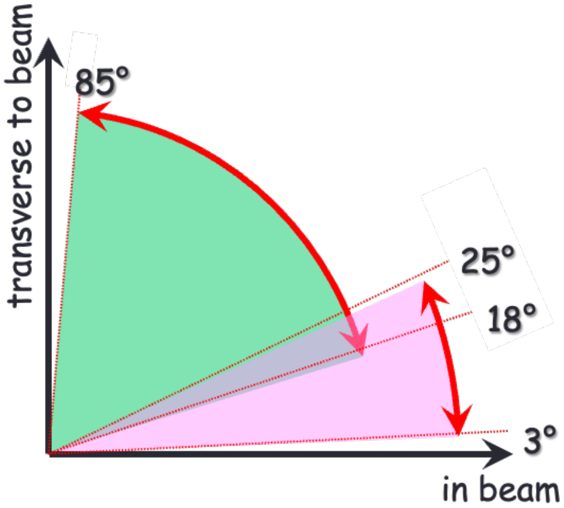
Summary

Two main topics for cold matter studies:

- Reference measurements for heavy-ion / hot and dense matter observables
- Vector mesons in-medium & charm/strangeness production and propagation
- Not discussed: Short Range Correlations ($p_{\mathrm{p}} < 5\ \mathrm{GeV}/c$) (SIS18 ok)



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



THANK YOU