GSI

GOETHE UNIVERSITÄT FRANKFURT AM MAIN

STRANGE OBSERVATIONS WITH HADES

Joachim Stroth
Goethe University Frankfurt / GSI

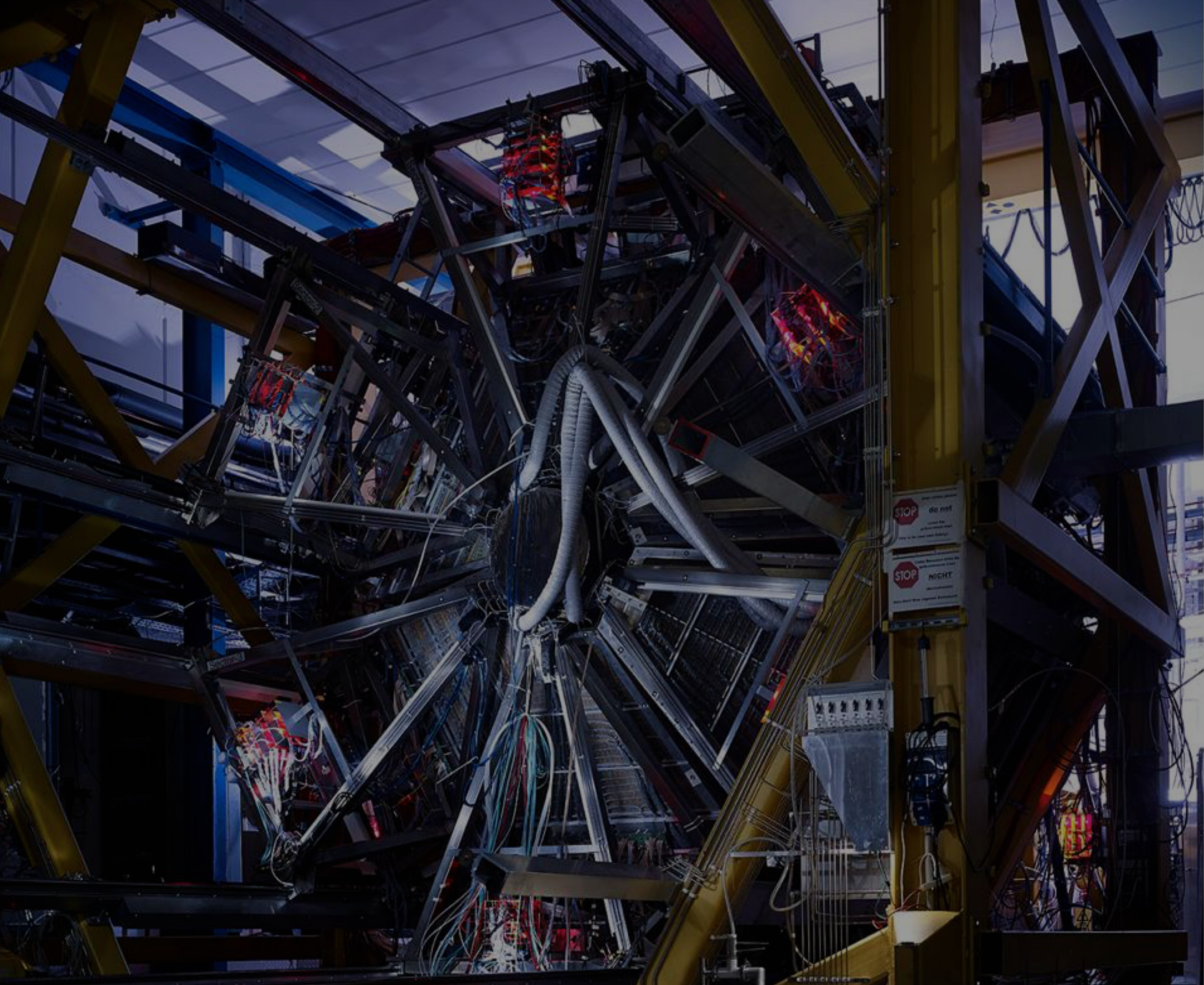
INT Workshop on Exploring the QCD phase diagram with BES
SEATTLE, October 2016

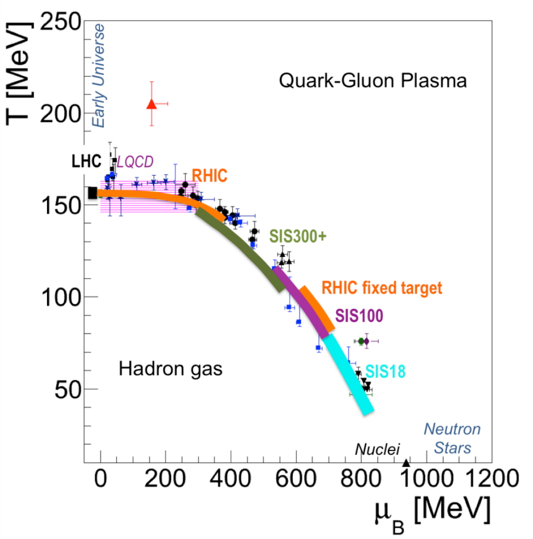
HADES

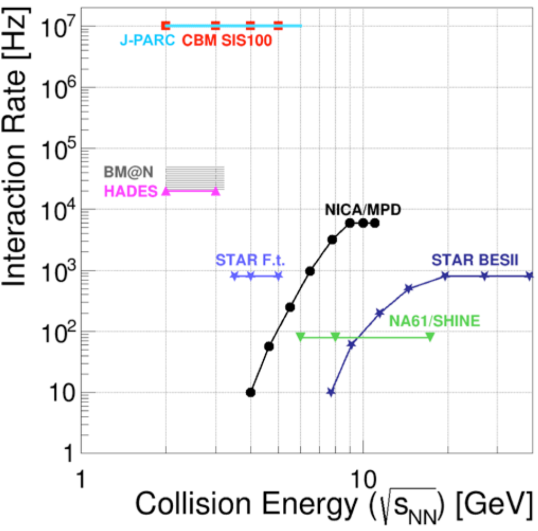
Program

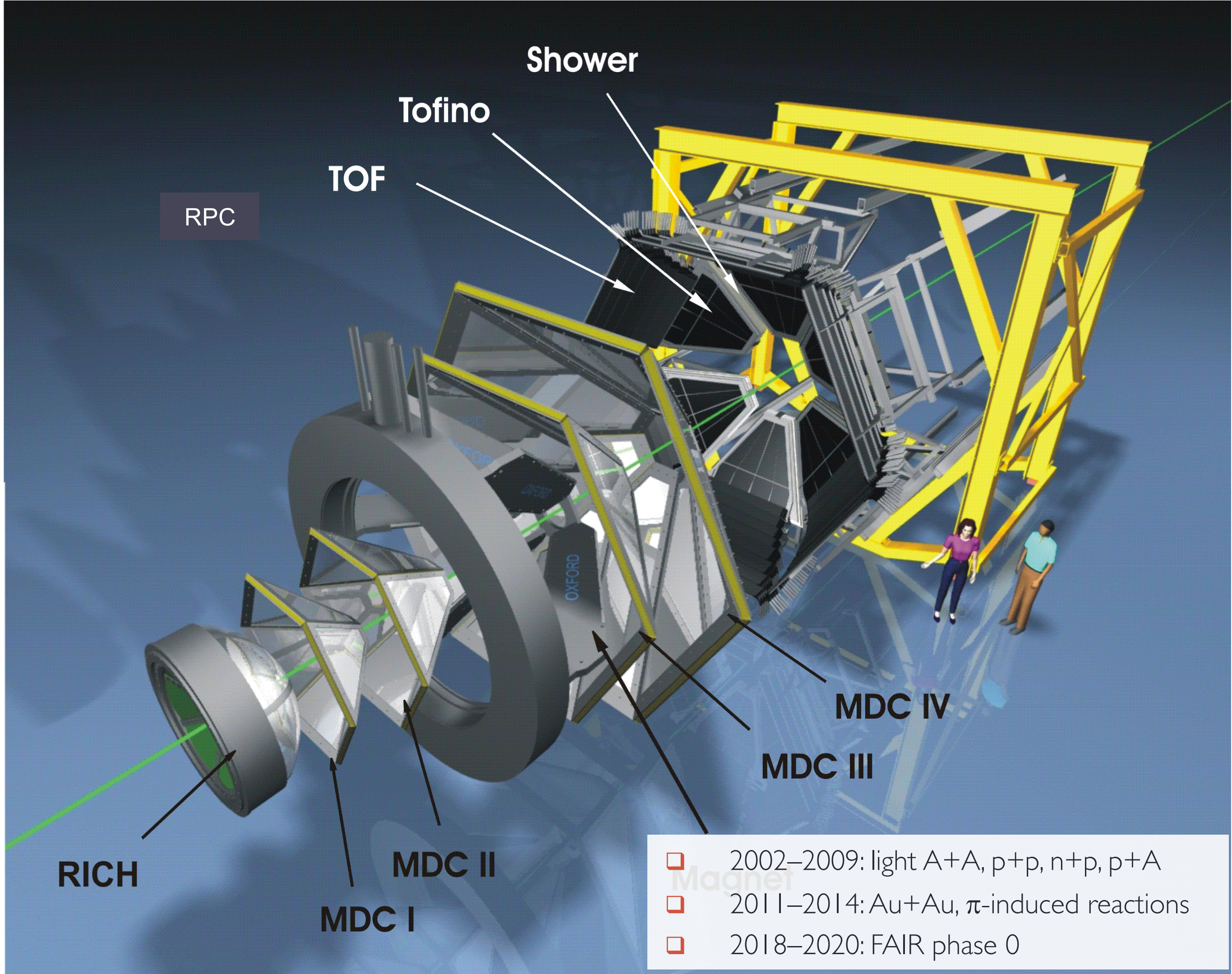
Mostly Au+Au (40% most central) collisions at 1.23A GeV

- Strangeness production
  - Comparison to statistical hadronization model
  - Contribution of ϕ decay to K- yield
- Higher moments of e-by-e proton distributions
  - Efficiency corrections
  - Volume fluctuations
  - N-particle correlations
- Low-mass lepton pairs
  - see talk by Tetyana Galatyuk in the afternoon today









- 2002–2009: light A+A, p+p, n+p, p+A
- 2011–2014: Au+Au, π-induced reactions
- 2018–2020: FAIR phase 0

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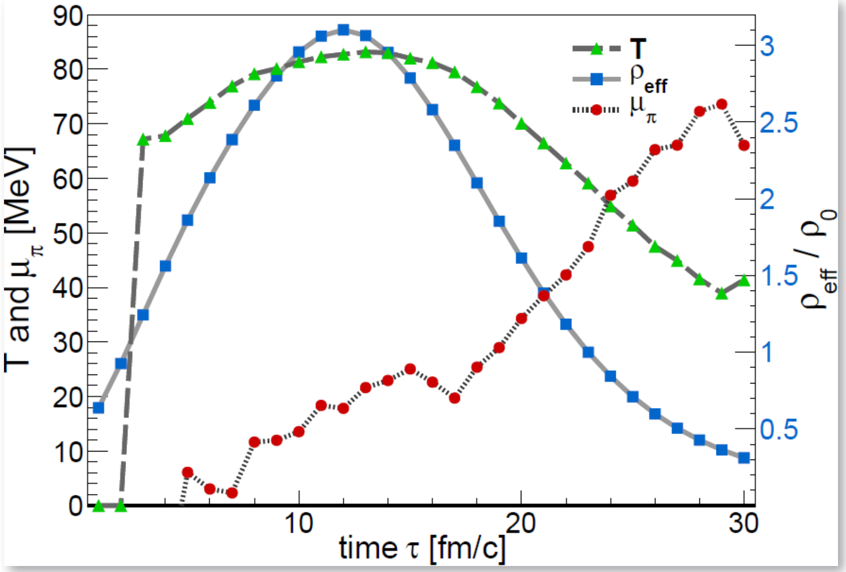
Reminder: RHICollisions at 1-2 *A* GeV

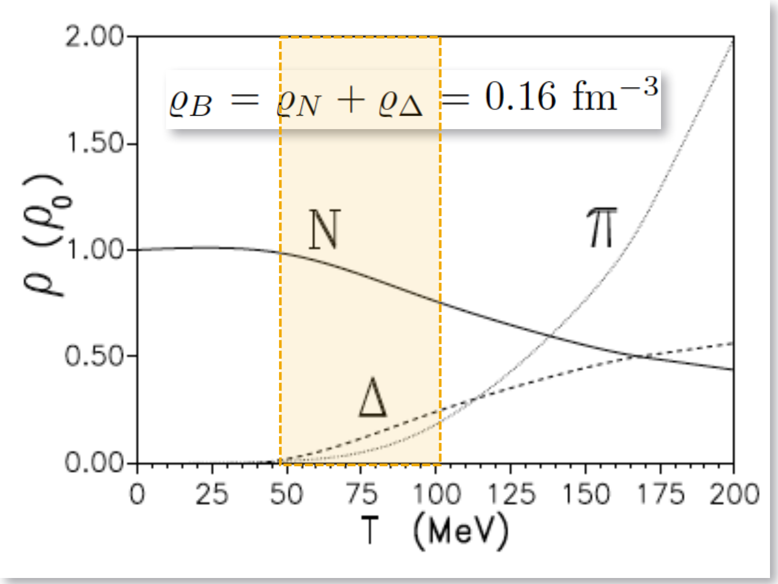
- Experiments:
  Bevalac, TAPS, KAOS, FOPI, HADES
- Evolution of the fireball (transport)
  - Coarse grained UrQMD
  - Au+Au 1.23*A* GeV central cell (b=0)



T. Galatyuk, F. Seck et al. , et al., Eur. Phys. J. A 52 (2016) 13,
S. Bass et al., Prog. Part. Nucl. Phys. 41 (1998)

"Resonance matter"

- Most of the pions in the final state from baryonic resonances
- $\rho_{max} = 3\,\rho_0$ and $T_{max} \sim 0.5\,T_c$ (Transport)
- About 10% of baryons in excited states

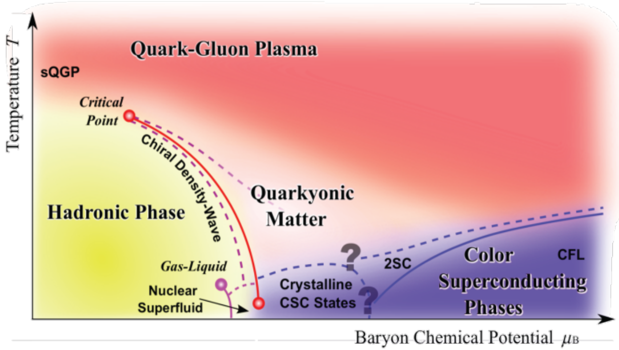


Rapp, Wambach, Adv.Nucl.Phys. 25 (2000)

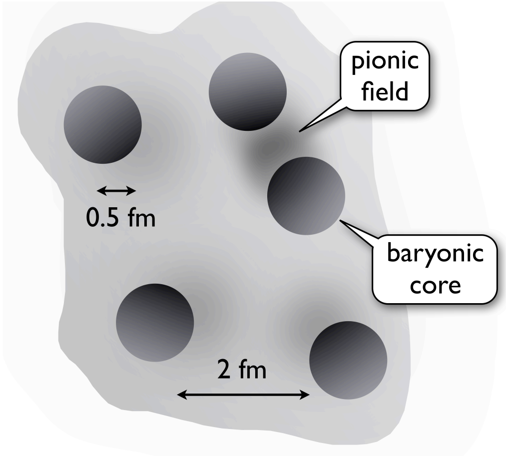
Chiral Nuclear Thermodynamics

- EOS of dense baryonic matter (at low to moderate temperatures)
- Provides prediction for chiral order parameter a.f.o. baryon density
- Sees strong repulsion.

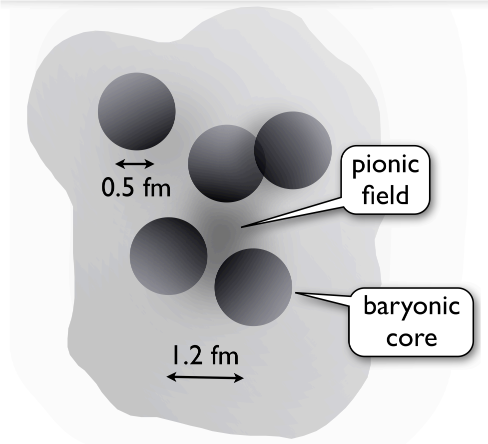
J.W. Holt, M. Rho, W. Weise arXiv1411.6681



Courtesy of K. Fukushima & T. Hatsuda



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

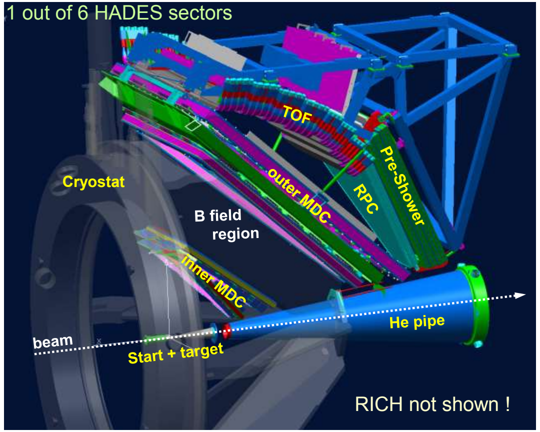


$\rho_B = 0.6\ \mathrm{fm}^{-3}$

HADES Au+Au data

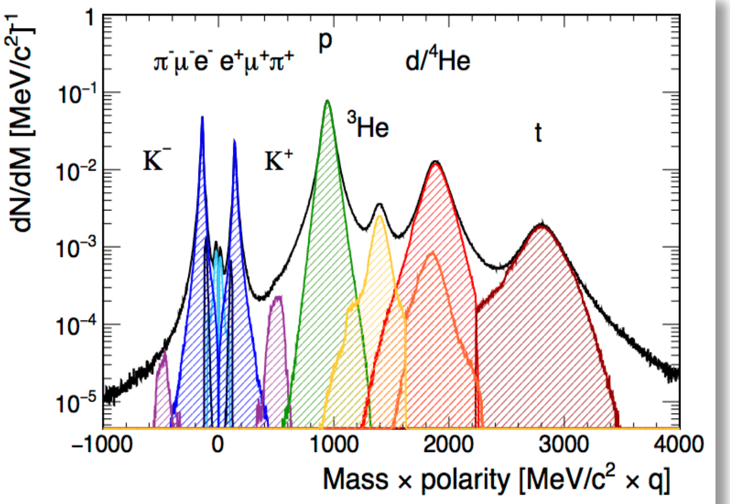
HADES

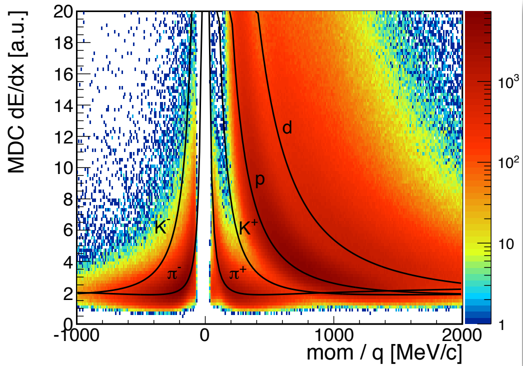
- Beam: 1.5 x 10^6 Au ions per second
- LVL1 trigger rates of up to 8 kHz
  - ➢ 7 · 10^9 events recorded
- LVL1 trigger on 40% most central coll.

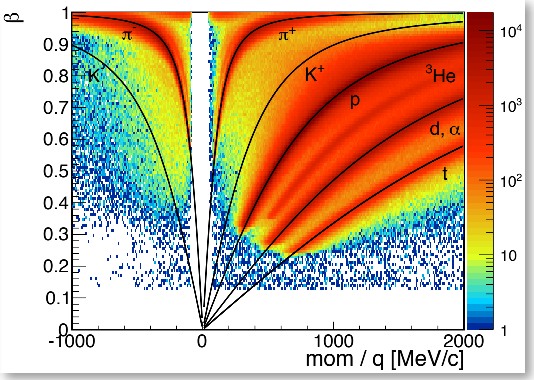


PID:

- Time-of-flight (β) from RPC and TOF
- dE/dx in MDC and TOF (not shown)



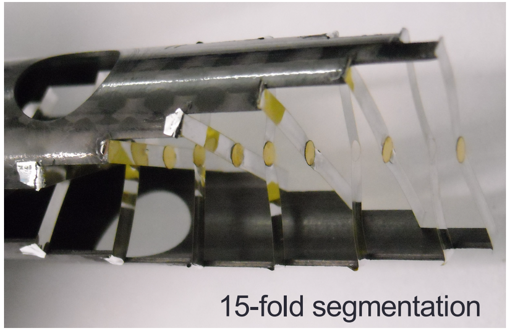


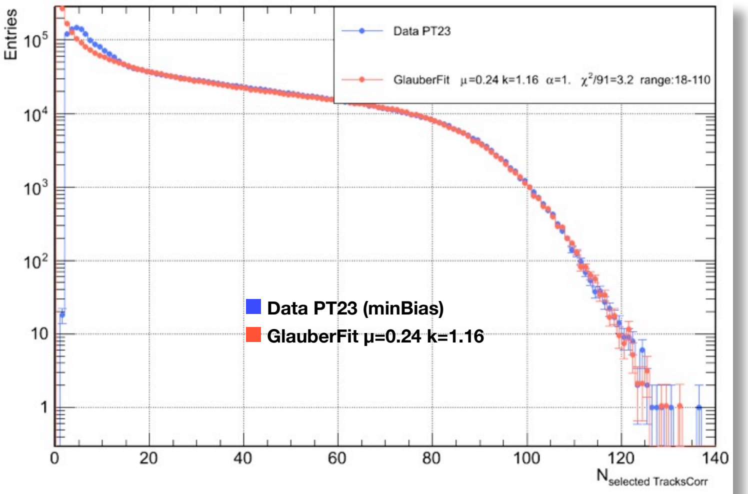


Centrality selection

- Multiplicity:
  - Correlation between multiplicity in FW and META (reduces pile-up)
  - Clean START signal (reduces pile-up and particle misidentification)
- Fit of Glauber MC to reconstructed raw track multiplicity
  - good description for track multiplicities above 20

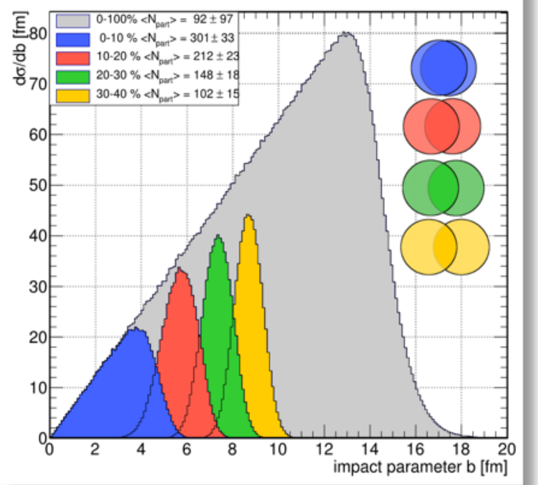
2% interaction target (Au)





Au+Au centrality classes

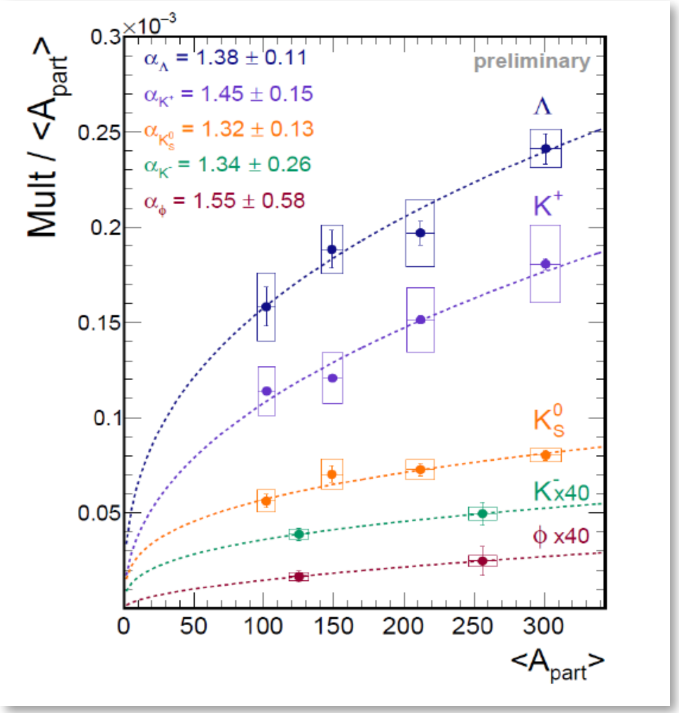
percentile	A_{part}
0 - 10	301
10 - 20	212
20 - 30	148
30 - 40	102

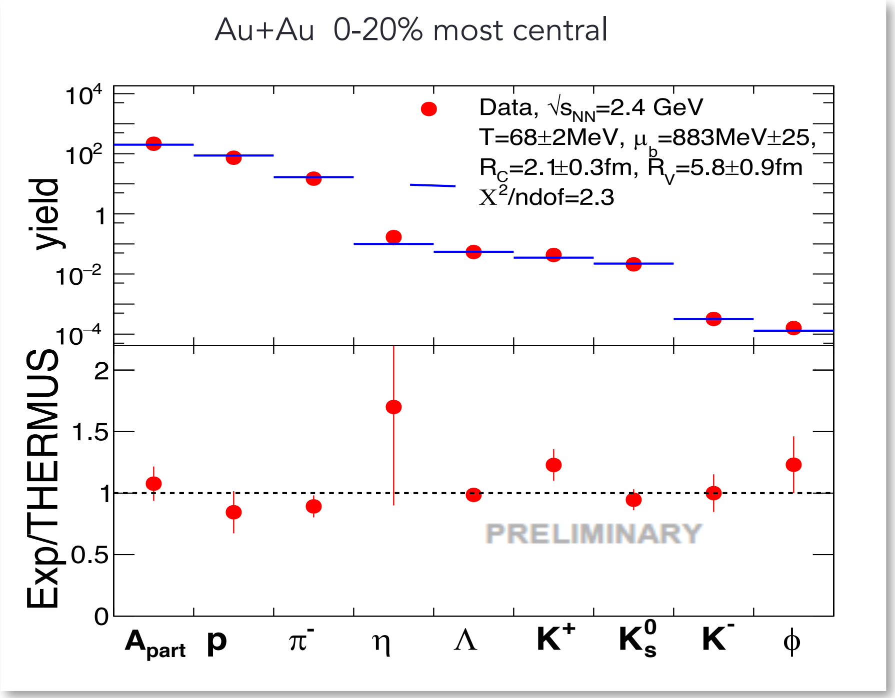


strangeness production

Particle production in accord with SHM

- All strange hadrons are produced below the free NN threshold: $K^+\Lambda\ (-160\ \mathrm{MeV}); K^+K^-\ (-470\ \mathrm{MeV})$
- Canonical suppression applied in THERMUS (R_c), ϕ not affected





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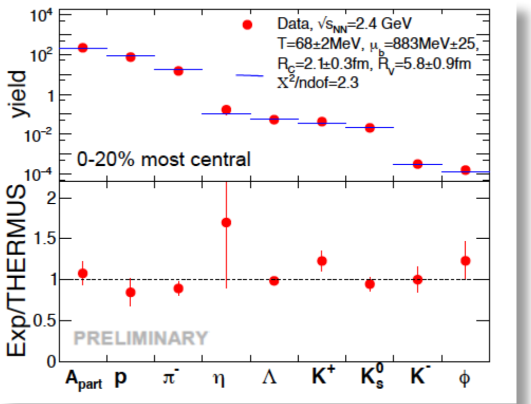
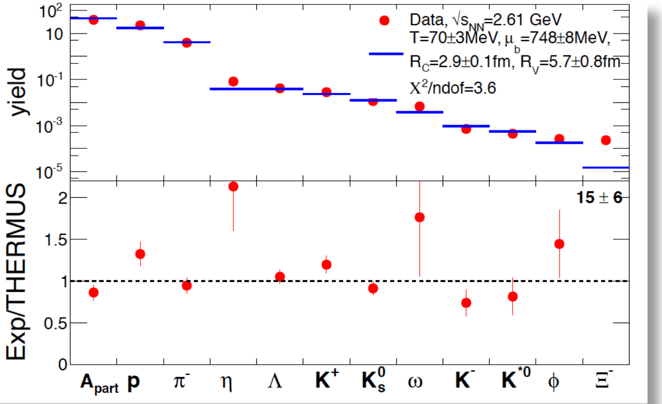
Ξ^- production

- Unexpected yield observed in two systems: Ar+KCl, p+Nb
- Au+Au 1.23 AGeV too far below threshold

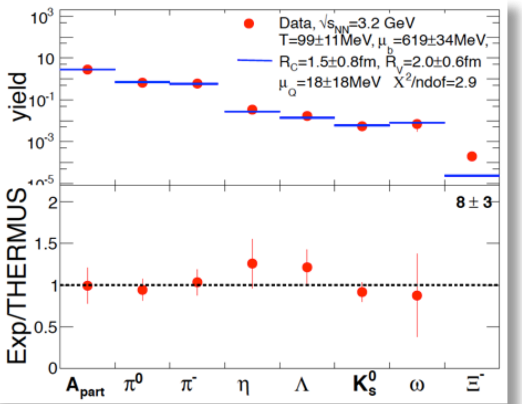
Au+Au $\sqrt{s_{NN}}$= 2.42 GeV



Ar+KCl $\sqrt{s_{NN}}$= 2.61 GeV



p+Nb $\sqrt{s_{NN}}$= 3.2 GeV



Transverse momenta spectra

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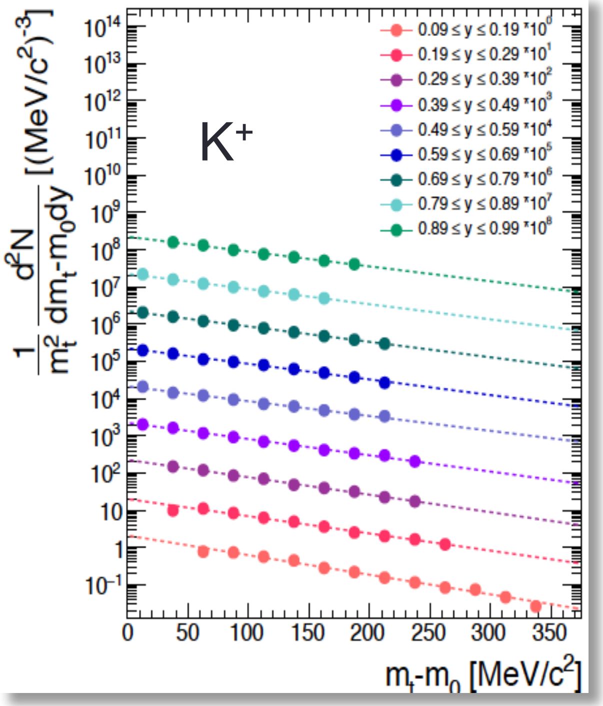
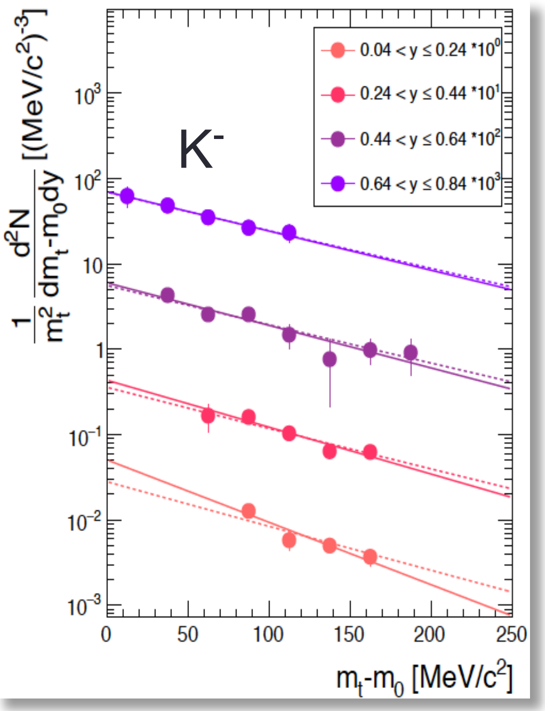
T_{eff} = 105 ± 4 MeV

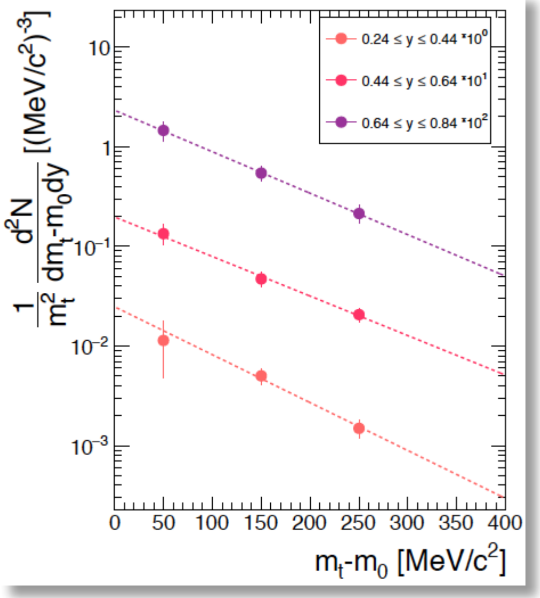


T_{eff} = 82 ± 9 MeV



→ $T_{eff}(K^+)$ >> $T_{eff}(K^-)$

T_{eff} = 103±10 MeV

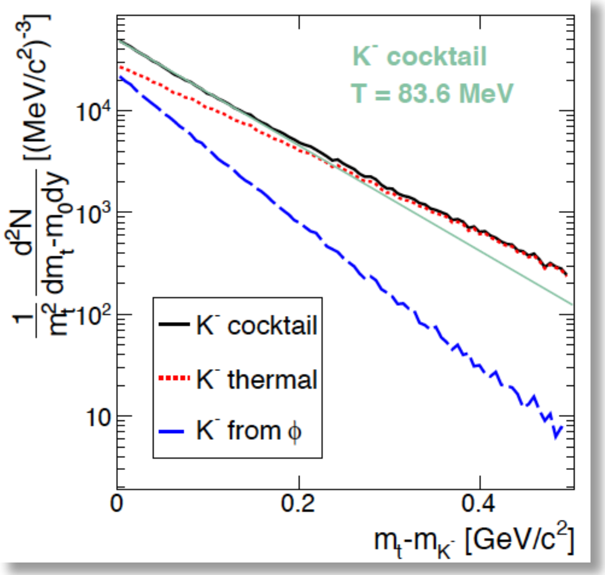


HADES Au+Au strangeness analysis: Heidi Schuldes, Tino Scheib, Manuel Lorenz

ϕ decay as source for K^- (feed-down correction)

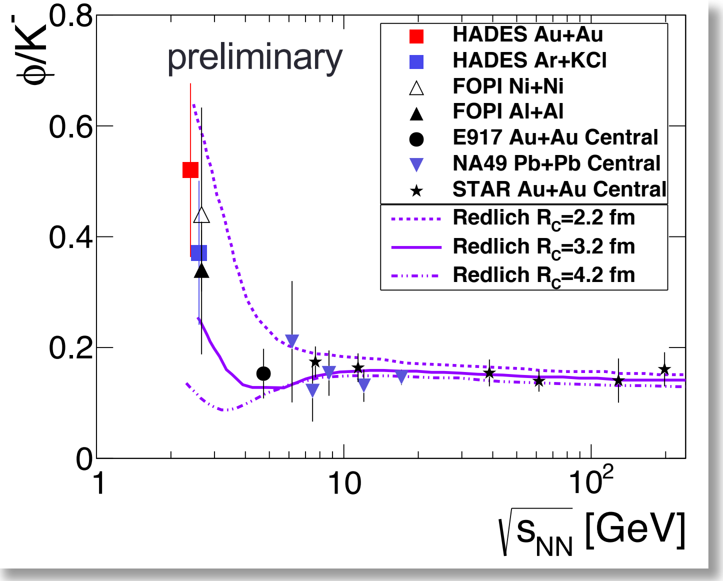
30 % of K^- from ϕ decay

- *assume* T_{K-} (thermal) = T_{K+} (measured) 105 MeV
- *derive* T_{K-} (cocktail) = 83 MeV ≈ T_{K-} (measured)



Excitation function of ϕ/K^-

- Trend explained assuming canonical suppression in a thermalized system



Extension of the excitation function to lower energies

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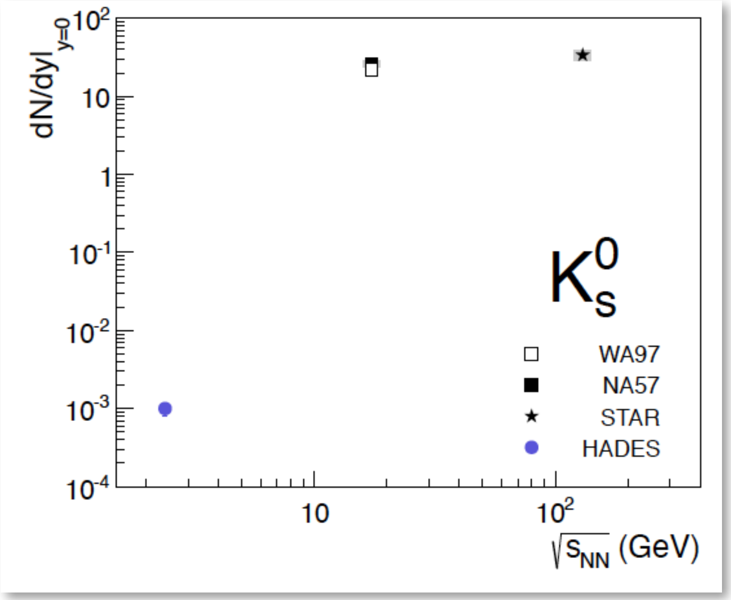
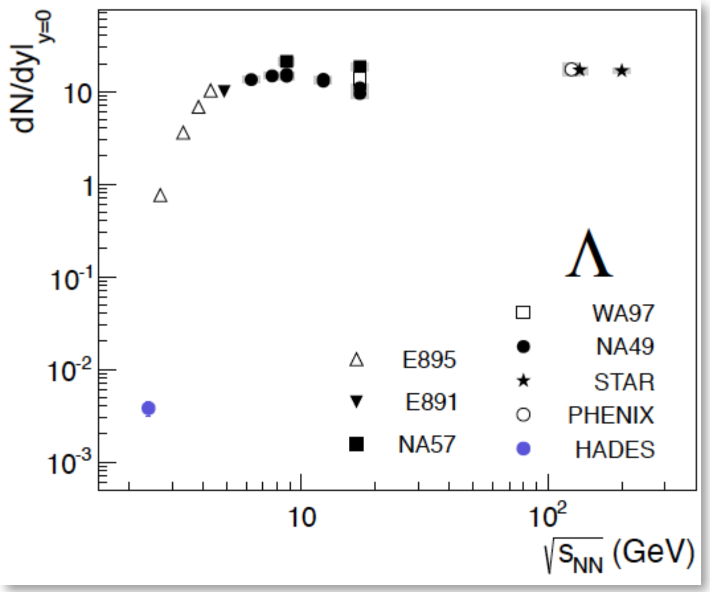
Expect large sensitivity to:
- multi-particle processes
- medium modifications





World data from: C. Blume & C. Markert, Prog. Part. Nucl. Phys. 66 (2011) 834

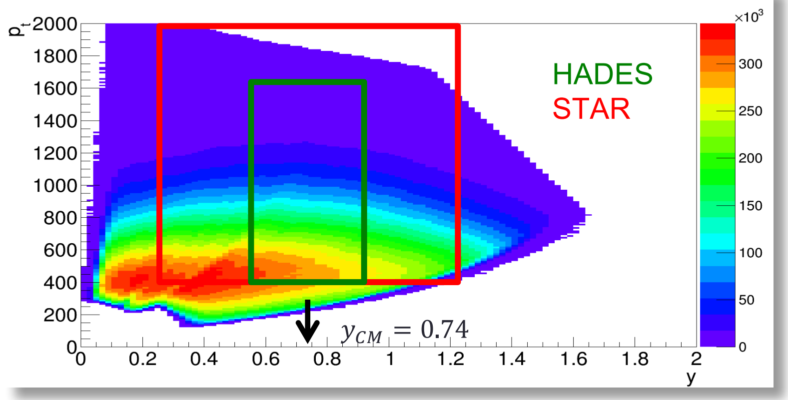
HADES

higher moments of e-by-e proton distributions

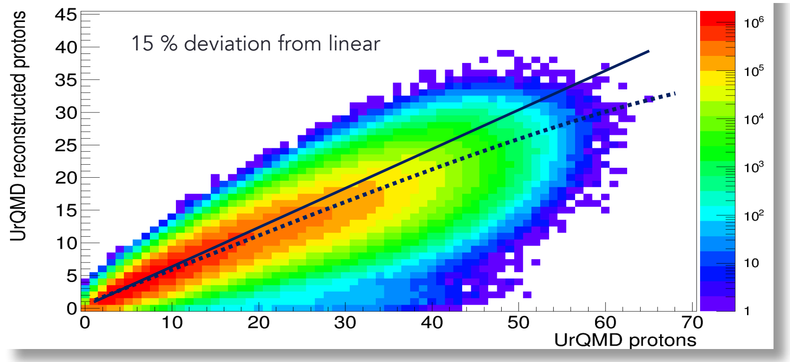
Prepare for higher-moments analysis

- HADES: large acceptance but …
  - narrow rapidity distribution
  - less p_t reach
- HADES simulation package
  - GEANT3 with complete detector geometry
  - Tuned digitizers for all detector systems
  - Embedding (for efficiency determination)
- Corrections methods:
  - Correction of moments
    AB, VK: arXiv-1206-4286, arXiv-1312-4574;
    XL: arXiv:1410.3914 (2014)
    - Multiplicity dependent treatment: $\epsilon = \epsilon(N, \text{sector})$
  - Unfolding
    G. D'Agostino, Nucl. Instr. Meth. A 362 (1995) 487
    J. Albert et al. , Nucl. Instr. Meth. A 583 (2007) 494.
    S. Schmitt, J. Instr. 7 (2012) T10003.
- still under investigation:
  - volume flucts., bound protons (deuterium etc.)

Au+Au 1.23*A* GeV, HADES data



Au+Au 1.23*A* GeV, UrQMD simulation with HADES response



The unfolding method

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Problem:

y = A · x (measured = response matrix · true)

- nowing **y** and **A**, find **x**.
- Unfortunately, **A** is often quasi-singular and can not be inverted (ill-conditioned problem!).
- Minimize via least-squares procedure the „Lagrianian" *L(x,λ)*.

Solution:

$$\mathcal{L}(x,\lambda) = \mathcal{L}_1 + \mathcal{L}_2 + \mathcal{L}_3$$

$$\mathcal{L}_1 = (\boldsymbol{y} - \mathbf{A}\boldsymbol{x})^{\mathsf{T}} \mathbf{V_{yy}}^{-1} (\boldsymbol{y} - \mathbf{A}\boldsymbol{x}),$$

$$\mathcal{L}_2 = \tau^2 (\boldsymbol{x} - f_b \boldsymbol{x_0})^{\mathsf{T}} (\mathbf{L}^{\mathsf{T}}\mathbf{L}) (\boldsymbol{x} - f_b \boldsymbol{x_0}),$$

$$\mathcal{L}_3 = \lambda (Y - \boldsymbol{e}^{\mathsf{T}} \boldsymbol{x})$$

L_1: least square minimization

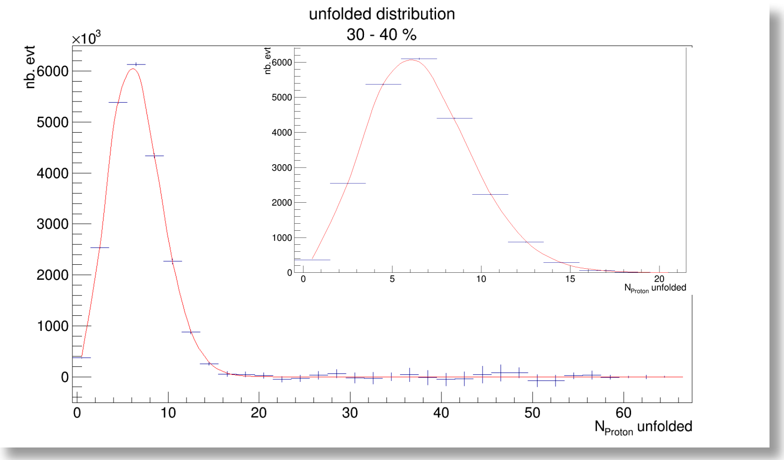
L_2: describes regularisation

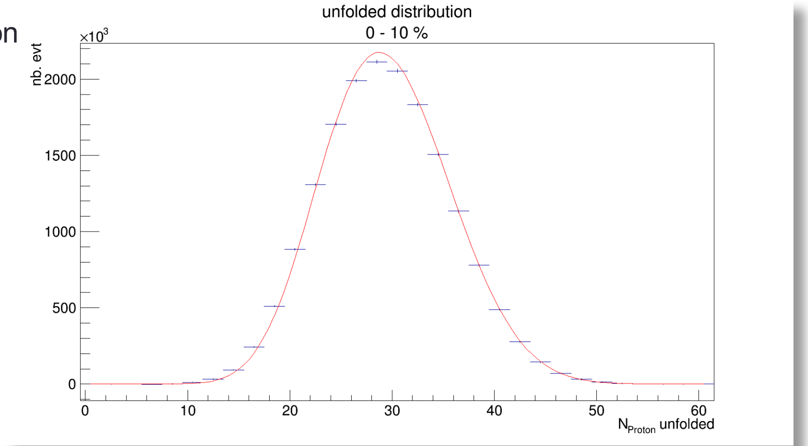
L_3: area constraint

ROOT implementation:

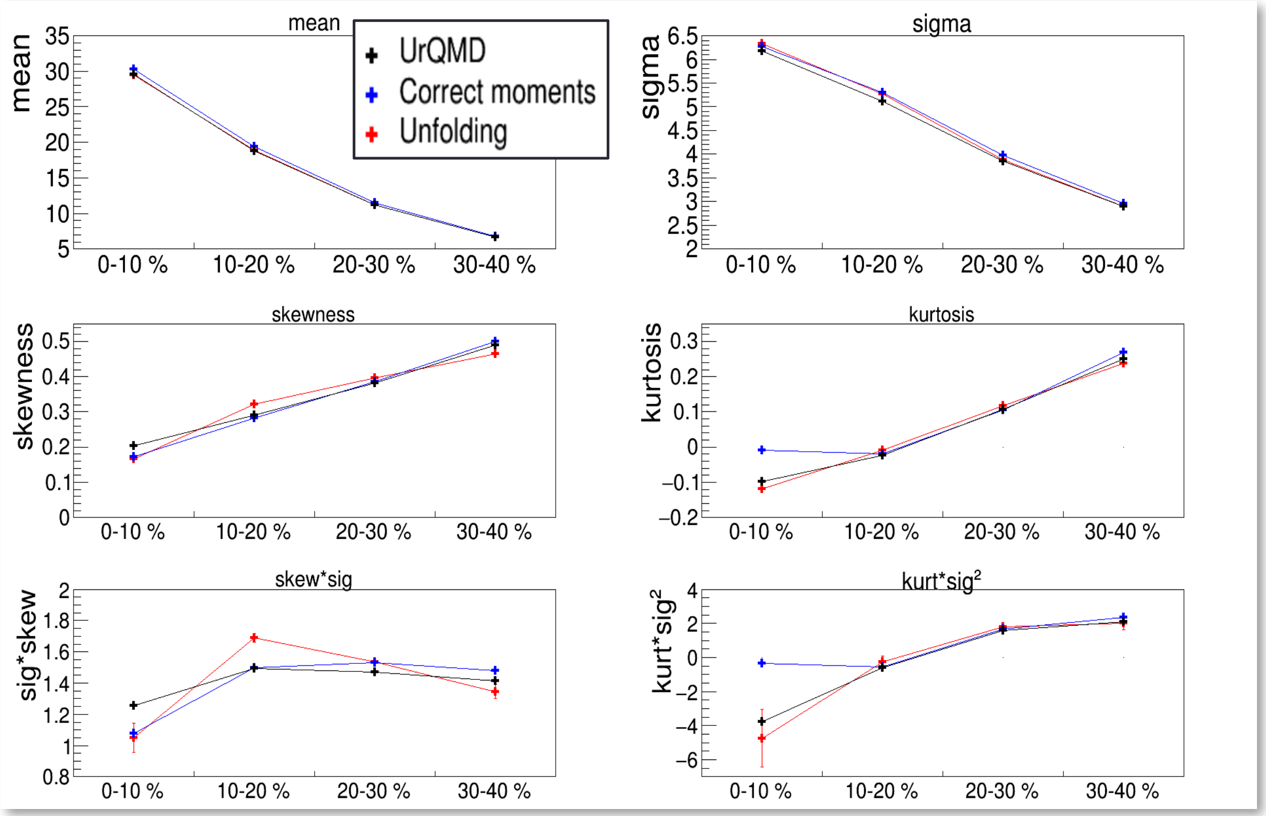
TUnfold, TUnfoldSys, TUnfoldDensity

HADES analysis: Romain Holzmann, Melanie Szala





Unfolding vs. corrected cumulants (simulation only)



UrQMD:

no detector response, MC tracks in phase-space window

Correct moments:

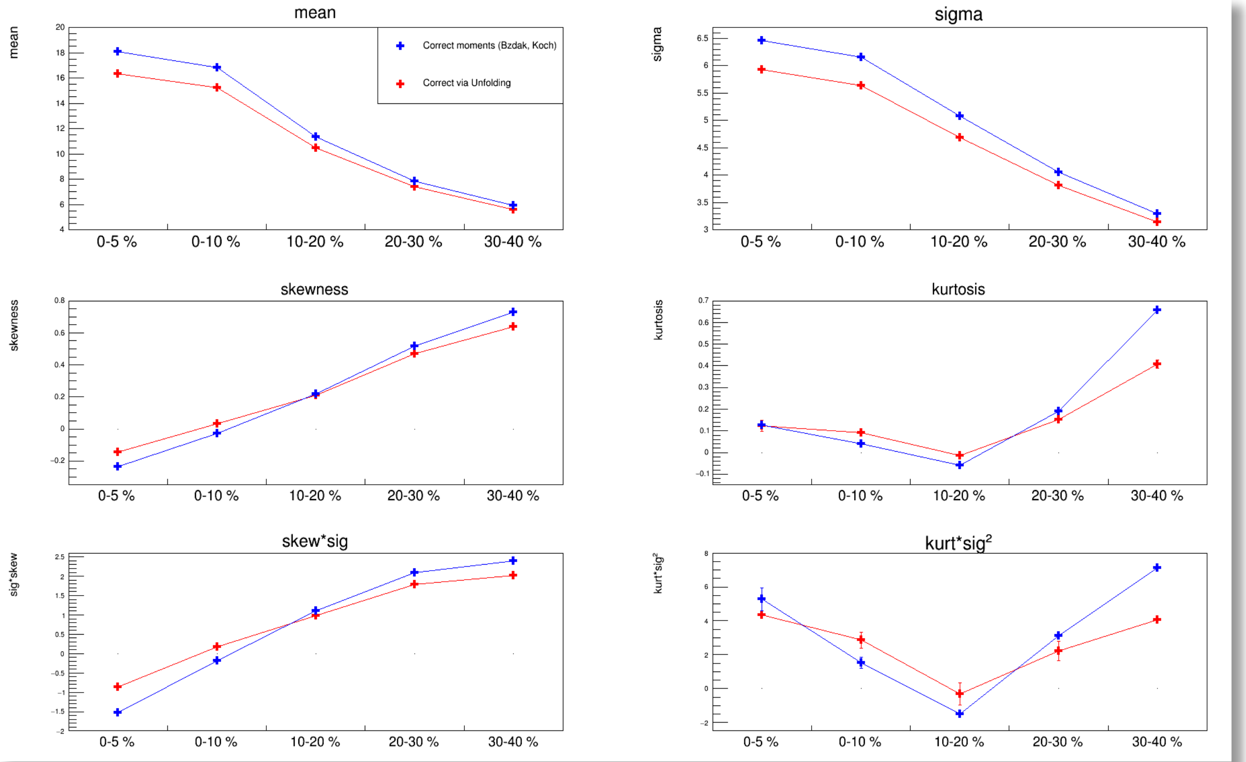
full response simulation, correction of cumulants (Bzdak, Koch)

Unfolding:

full response simulation, unfolding using root classes

Unfolding seems to perform more stable

Unfolding vs. corrected cumulants (data)



Corrected moments:

full response simulation, correction of cumulants (Bzdak, Koch)

Unfolding:

full response simulation, unfolding using root classes

Unfolding seems to perform more stable

Kurtosis behaves differently compared to UrQMD

Signal dependence on phase space window

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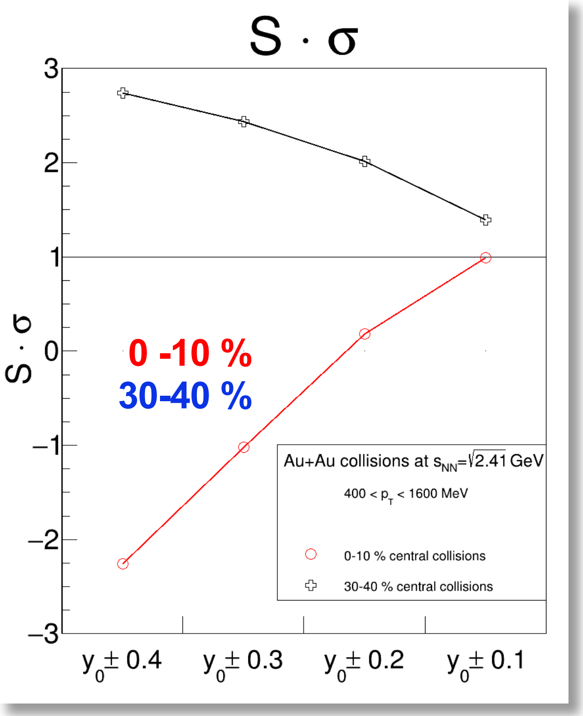
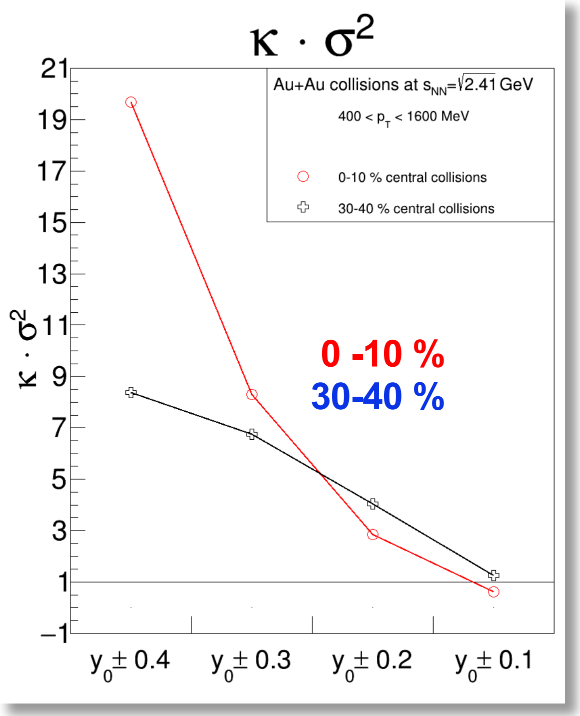
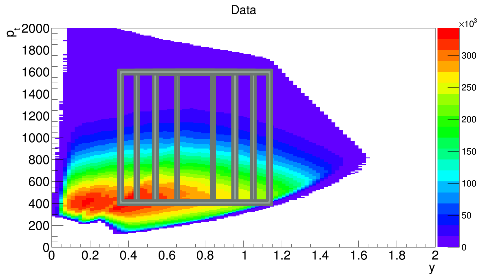




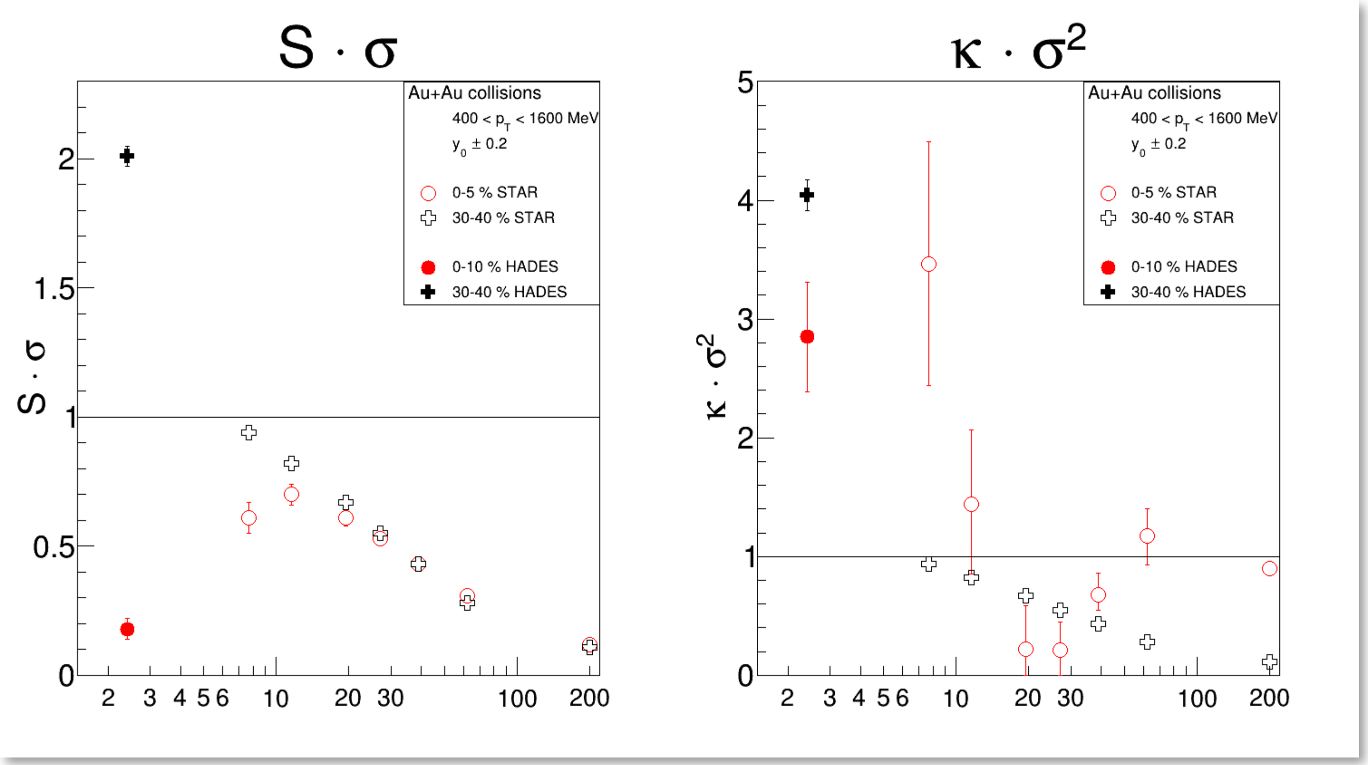
"Poissonizer" (VK)

- Data corrected with unfolding method.
- Both observables approach the expected unity



Comparison to STAR

- HADES data from unfolding method



Particle Correlations

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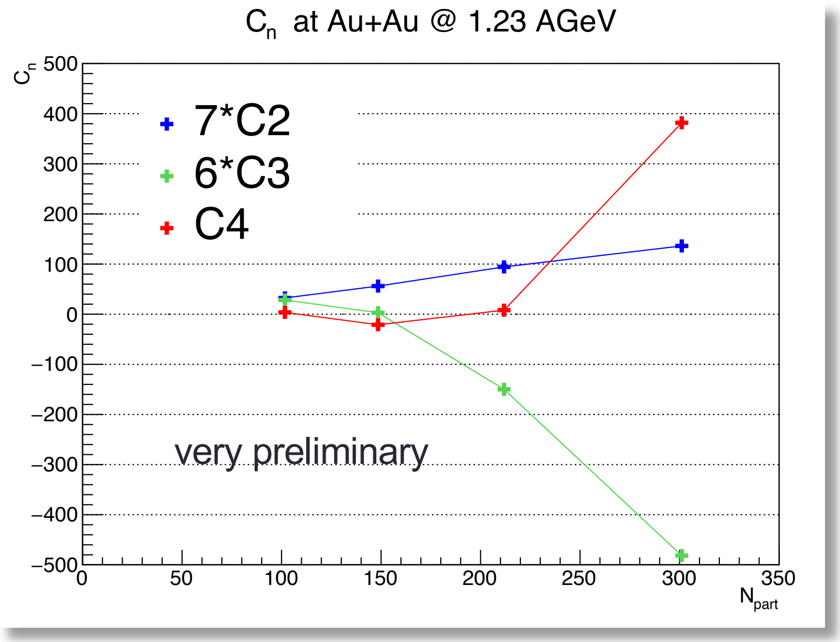
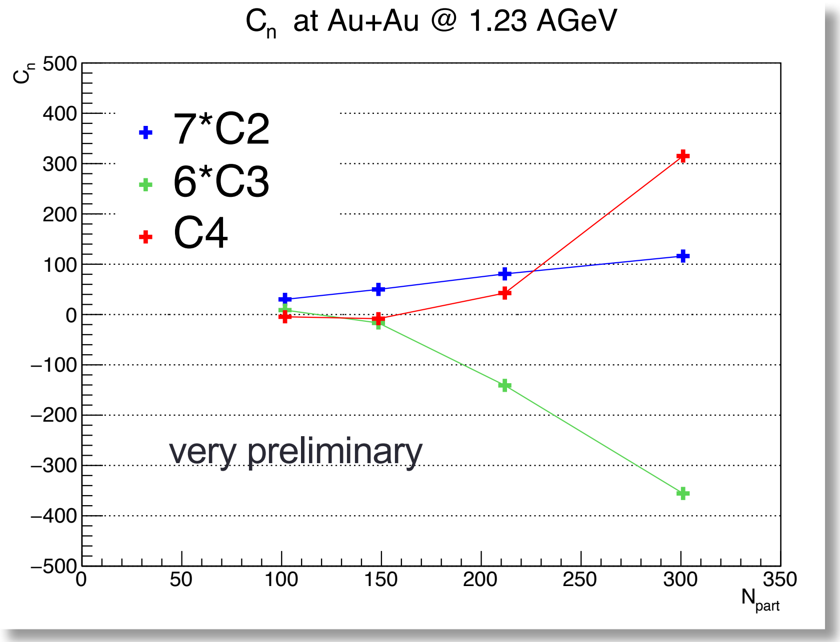
$$C_2 = -\langle N\rangle + K_2,$$
$$C_3 = 2\langle N\rangle - 3K_2 + K_3,$$
$$C_4 = -6\langle N\rangle + 11K_2 - 6K_3 + K_4.$$

- CUMULANT

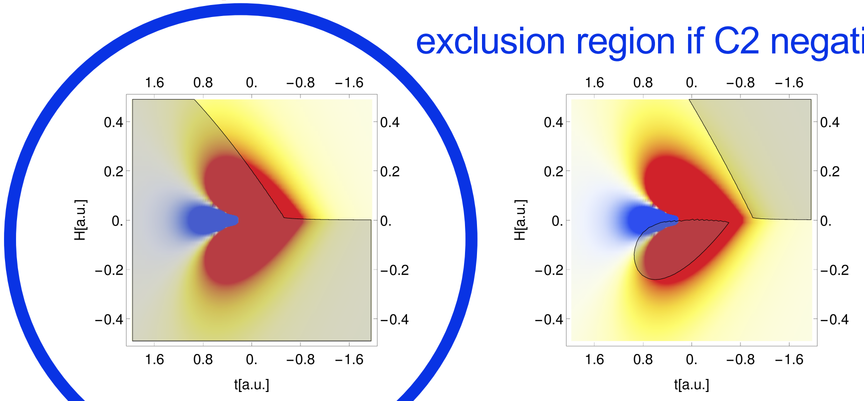


- UNFOLDNG



"Comparison" to STAR and 3D Ising → 0716.07375

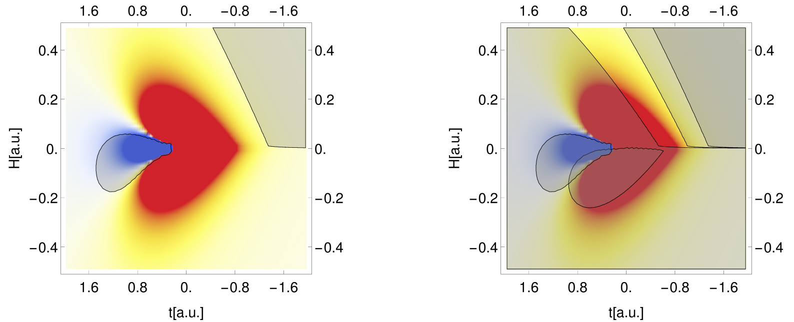
exclusion region if C2 negative



(a) The shaded area is excluded by requiring $C_2 < 0$

(b) The shaded area is excluded by requiring $C_3 < 0$.

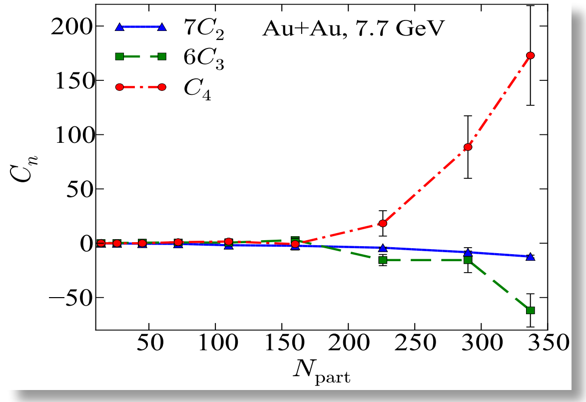
Figure 7. Density plot of K_4/K_2 where red(blue) denotes positive(negative) values with excluded areas by imposing conditions on C_2 or C_3. The critical point is located at $H = t = 0$.



(a) The shaded area is excluded by requiring $C_4 > 0$

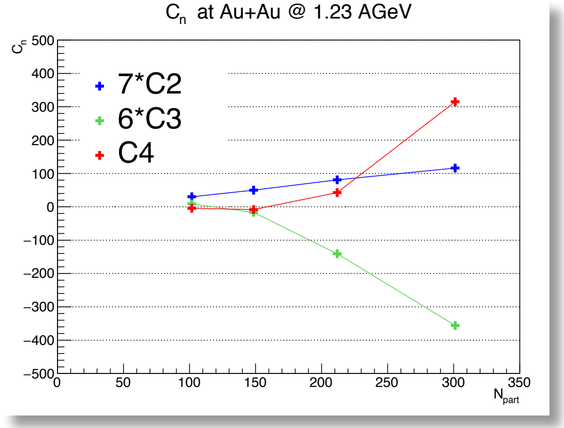
(b) The shaded area is excluded by requiring $C_2 < 0$ and $C_3 < 0$ and $C_4 > 0$.

Figure 8. Density plot of K_4/K_2 where red(blue) denotes positive(negative) values with excluded areas by imposing conditions on C_4 and C_2,C_3,C_4 simultaneously. The critical point is located at $H = t = 0$.



STAR

C2 negative



HADES

C2 positive,

scale (x10) ?!?!

future

HADES FAIR Phase-0 Preparation

HADES

Detector upgrades

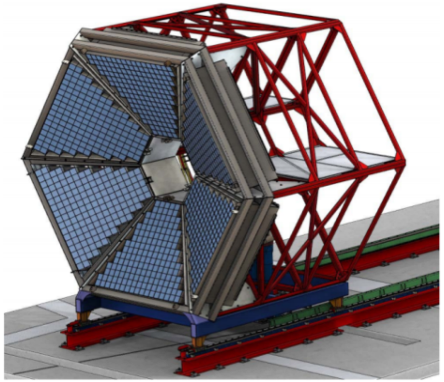
- ECAL (PSP 1.1.2.4)
- RICH-700 (synergy with CBM – UV detector)
- FW-Tracker (synergy with PANDA – straws)
- FW-RPC (detector elements mostly existing)
- MDC-FEE (PSP 1.1.2.4, 1.1.2.5)
- FW-Wall (synergy with CBM – PSD)
- START (synergy with CBM – t_0 detector)

Up to 50 kHz interaction rate, improved electron-id, detection of photons, large acceptance for exclusive processes.

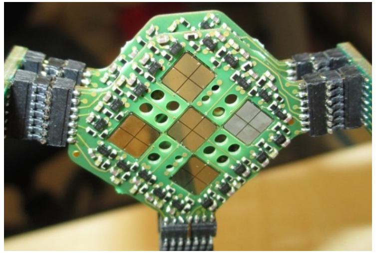
Planned physics runs (2018-2021)

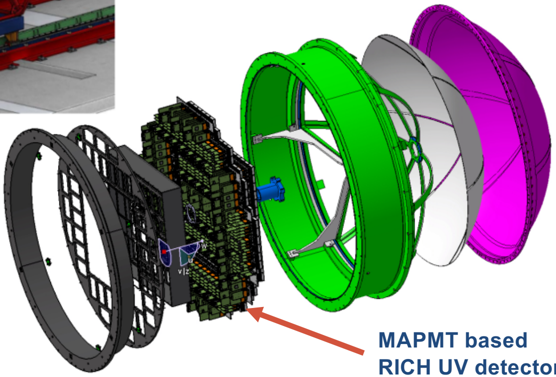
- we anticipate three long runs, i.e.:
  - $\pi+(CH_2)_n/LH_2$: baryon electromagnetic transition form factors, baryonic resonances with strangeness.
  - p+A/p+p: strangeness/vector mesons in medium.
  - A+A: medium system size at maximal energy, multi-strange baryons, dileptons.

ECAL based on OPAL lead glass



sc-CVD diamond start detector





MAPMT based RICH UV detector

Secondary pion beam in combination with dilepton spectrometer is world-wide unique!

The HADES collaboration

HADES

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Institut für Strahlenphysik, Forschungszentrum Dresden-Rossendorf, 01314 Dresden, Germany
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Summary

- HADES has collected high-statistics data on A+A and elementary collisions, including exclusive channels.
- Data mark the "lowest-energy" point of the beam-energy scan to explore the QCD phase diagram
- Interesting observations in sub-threshold strangeness production.
  - particle production in agreement with SHM
- Fluctuation signal
  - Strong effects from detector response - still under study
  - Unfolding seems tobe more stable than correction method
- Next at FAIR Phase-0 @ SIS18:
  - heavy collision systems and pion induced reactions.
- Bright future for the investigation of Compressed Baryonic Matter with CBM (and HADES) at FAIR.

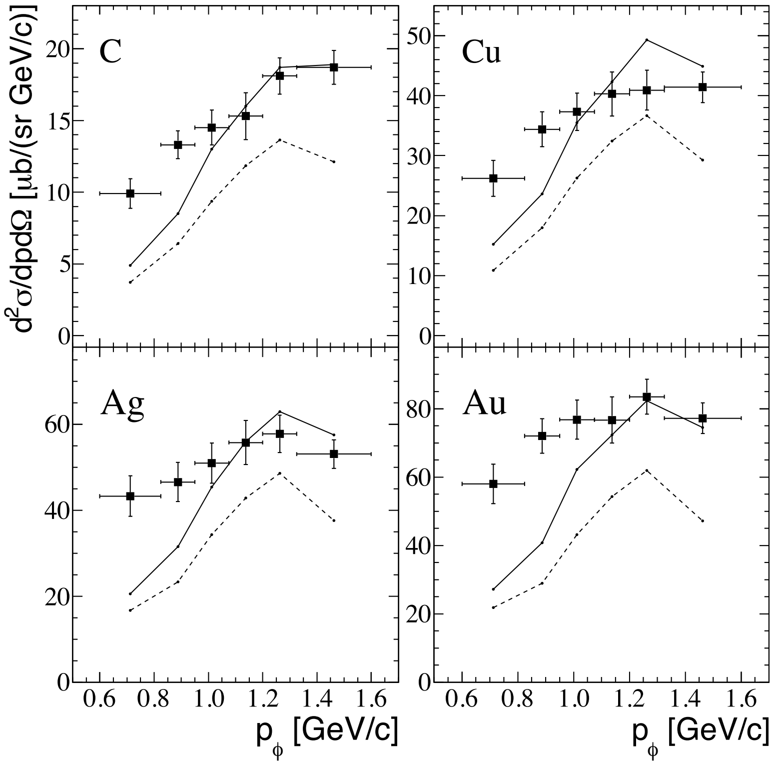
In-medium ϕ Propagation (ANKE)

ANKE reports an in-medium (cold matter) cross section for phi of 14 - 21 mb.

Proton (2.83 GeV) induced production under forward angles (θ<9°).

The curves show:

- Model 1 (not shown)
  - Eikonal approx. by Valencia group using in-medium phi spectral function
- Model 2 (dashed)
  - As 1 but with different in-medium function
- Model 3 (solid)
  - BUU from Rossendorf
  - Has also an in-medium mass shift included



ANKE, arXiv:1201.3517v1