EMMI RRTF
The physics of neutron star mergers at GSI/FAIR

Heavy-ion collisions - Discussion session III

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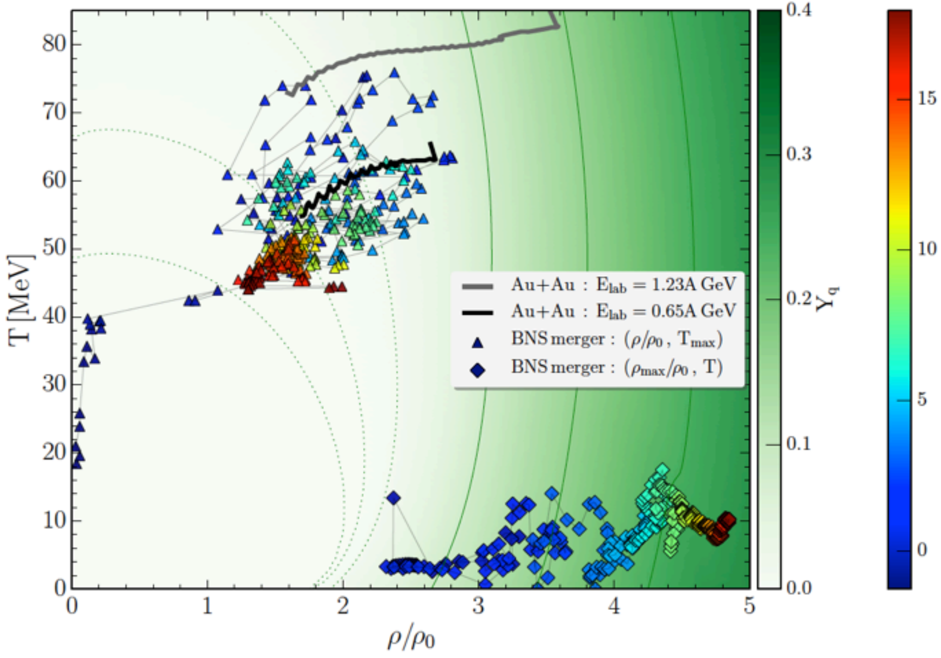
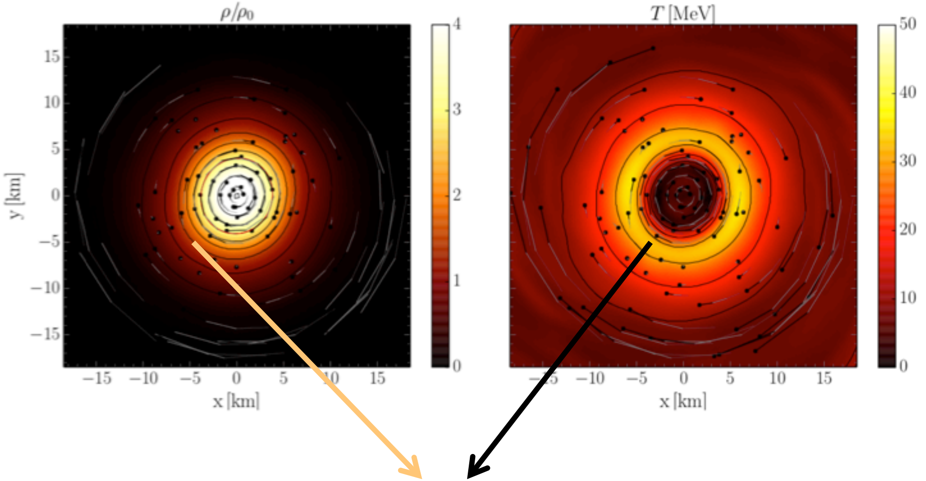
Low beam energy HIC compared to NS merger simulations

- Chiral Mean Field Model enables to treat heavy-ion collisions and NS mergers on the same footing



A dense and cold core with a hot hadronic corona



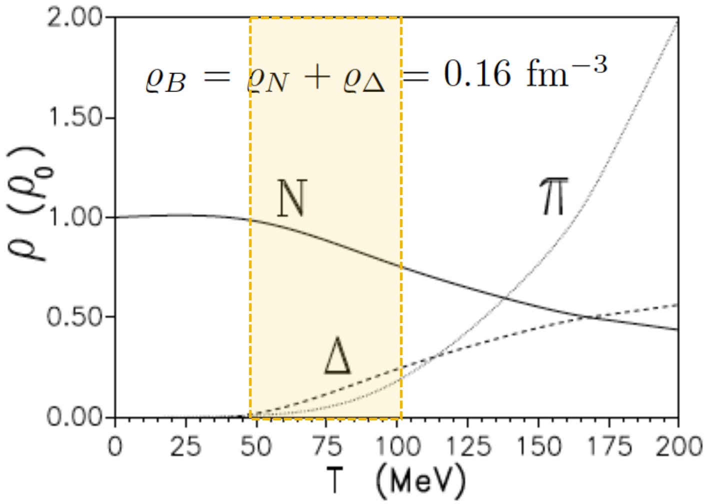
NS mergers and HIC at E_{lab} < 2*A* GeV probe the same region in the phase diagram

See J. Steinheimer, Mo 11 Jun

Can HIC help to constrain the EoS?

Baryonic matter at 1-2*A* GeV beam energy

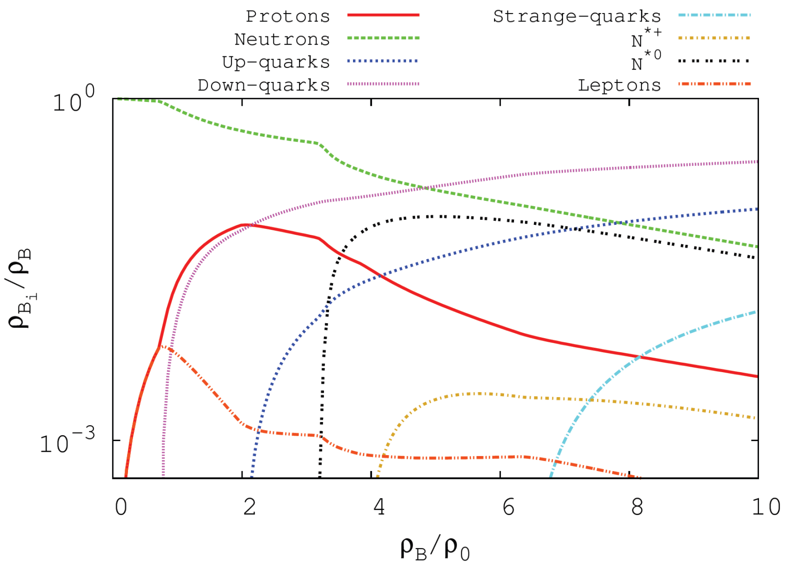
Composition of a hot πΔN gas



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

Isospin?

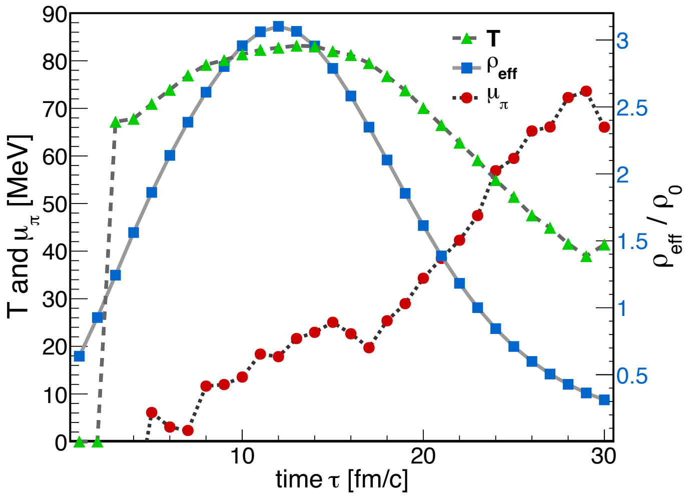
Chemical composition of neutron star matter
A smooth transition from hadrons to quarks



A. Mukherjee, S. Schramm, J. Steinheimer and V. Dexheimer, Astron. Astrophys. 608, A110 (2017)

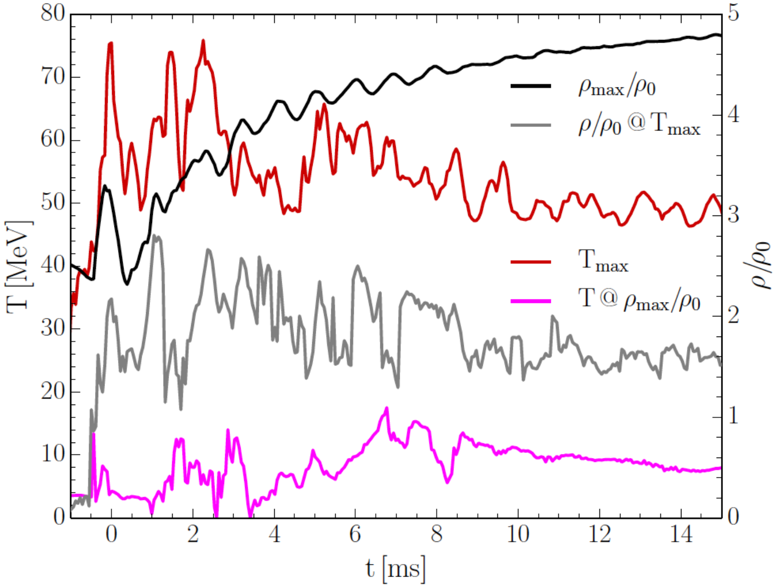
Evolution of HIC and NS merger

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



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

Evolution of the central region in a binary NS merger for CMF equation-of-state (see s.1)



Thermalization?

M. G. Alford, L. Bovard, M. Hanauske, L. Rezzolla, K. Schwenzer., Phys. Rev. Lett. 120, 041101 and Phys. Rev. D 96, 124005, M. Hanauske (priv. com.)

Observables

- Elliptic flow of p, d, t from 0.25 to 1.5*A* GeV
  - Compressibility (model dependent way) → "soft" EoS
  - UrQMD3.4 P. Hillmann, J. Steinheimer, M. Bleicher, arXiv:1802.01951 → "hard" EoS
- Differential elliptic flow v_2 of n/p
  - Symmetry energy at supra-normal densities (towards model invariance: tested stability with different models)
- Particle production (below NN production threshold), i.e. K^+ (Au/C), K^0_s/K^+
  - Compressibility (model dependent way) → "soft" EoS
- Particle spectra
  - Transverse momentum distribution of i.e. K^0_s → support in-medium repulsive vector K^0 potential ~40 MeV
- YN, YNN interactions (Y = Λ, Ξ)
  - Femtoscopy (ΛN correlation function, HADES collab., PRC 94 (2016) no.2, 025201)
- In-medium characteristics of particles
  - effective masses, spectral functions, decay widths

⇒ Measurable in pp, pA, AA

- Compare updated and new models against all available sets
- Apply machine learning methods to determine parameters in the model(s) consistently?

Electromagnetic correlator in vacuum

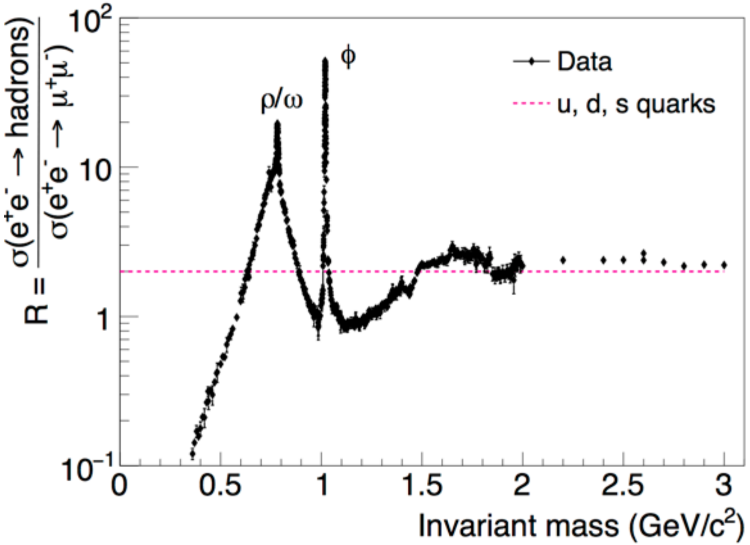
McLerran-Toimela formula

$$\frac{dN_{ll}}{d^4x d^4q} = \frac{-\alpha_{EM}^2}{\pi^3 M^2} f^B(q\cdot u;T) Im\Pi_{EM}^{\mu\nu}(M,q;\mu_B,T)$$

$$R = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)} \propto \frac{\text{Im}\Pi_{\text{EM}}^{\text{vac}}}{M^2}$$

- If $\frac{\text{Im}\Pi_{EM}^{\mu\nu}}{M^2} \sim const.$ thermal dilepton emission will follow a Bose distribution

→ Dileptons as thermometer



$$\text{Im}\Pi_{EM}^{vac}(M \le 1.5\text{GeV}) = \sum_{v=\rho,\omega,\phi} \left(\frac{m_v^2}{g_v}\right)^2 \text{Im}D_v^{vac}(M)$$

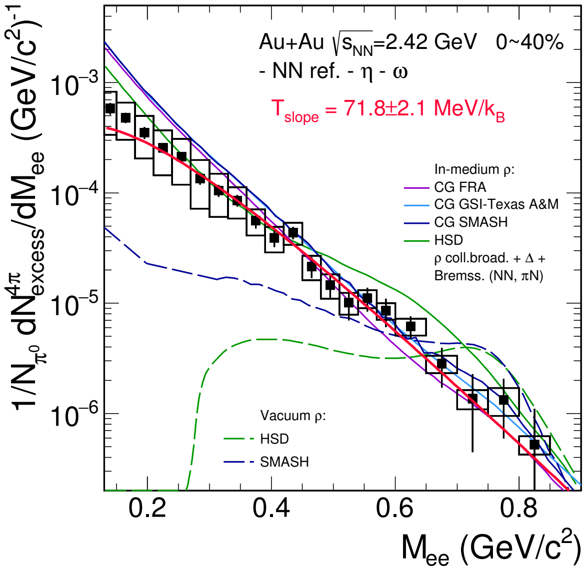
Vector Meson Dominance: $J^P = 1^-$ for both γ^* and VM (with ρ playing a dominant role)

$$\text{Im}\Pi_{EM}^{vac}(M > 1.5\text{GeV}) = -\frac{M^2}{12\pi}\left(1 + \frac{\alpha_s(M)}{\pi} + \ldots\right) N_c \sum_{q=u,d,s} (e_q)^2$$

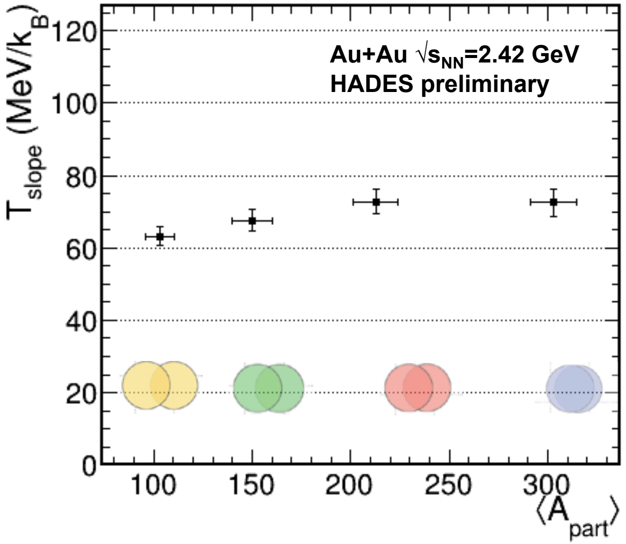
pQCD continuum

Results from HADES at SIS18, GSI

Emissivity of matter created in Au+Au collisions at 1.23*A* GeV

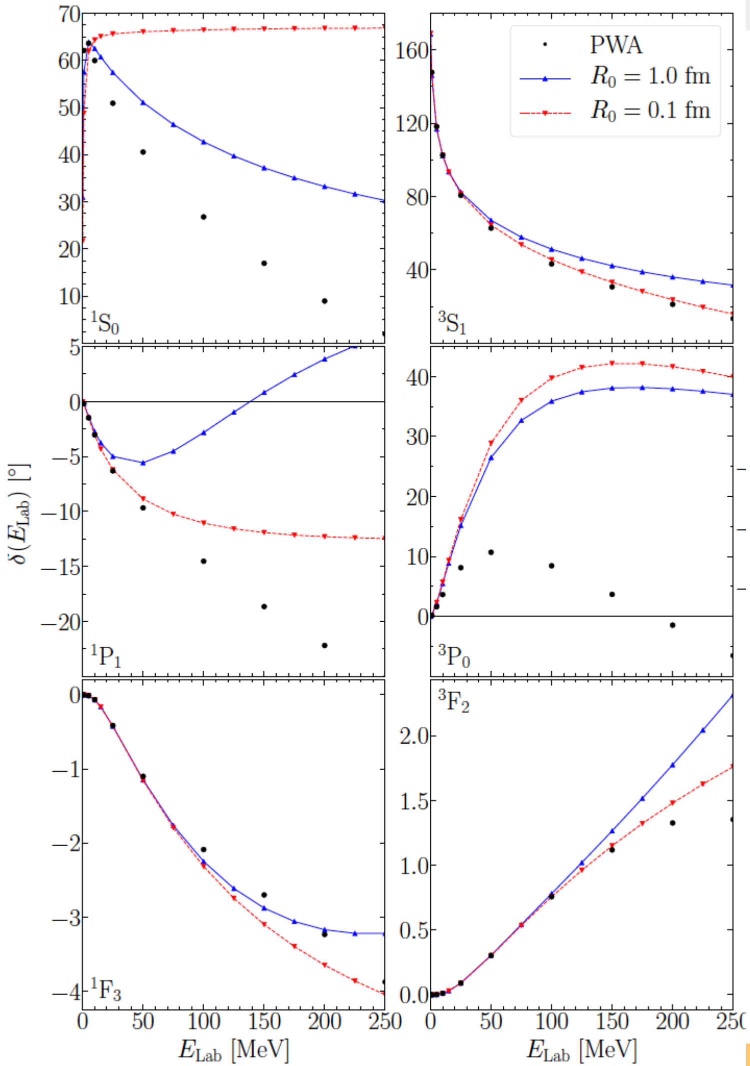


- Mass spectrum falling exponentially → "Planck-like" → T = 72 ± 2 MeV
- Agreement with coarse-grained approach $\rho/\rho_0 = 2 - 3$



- Control T, density and pressure by varying centrality, system size, energy
- Measure γ^* radiation in Au+Au collisions at 0.6 – 0.8*A* GeV

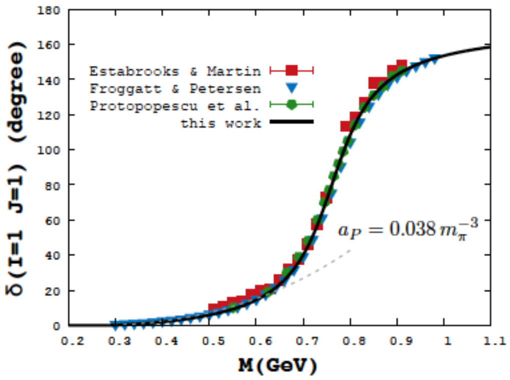
→ Start from comparing spectral distributions (i.e. @ T=40 MeV, ρ/ρ_0 = 1.5-2)
→ go for EoS

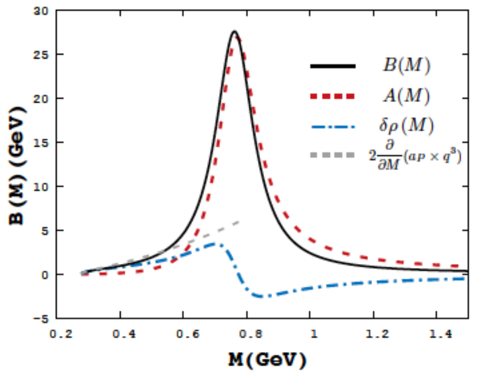


Phase shifts as function of the laboratory energy

I. Tews et al.,
arXiv: 1806.00233v1 [nucl-th]

S-matrix approach to thermodynamics





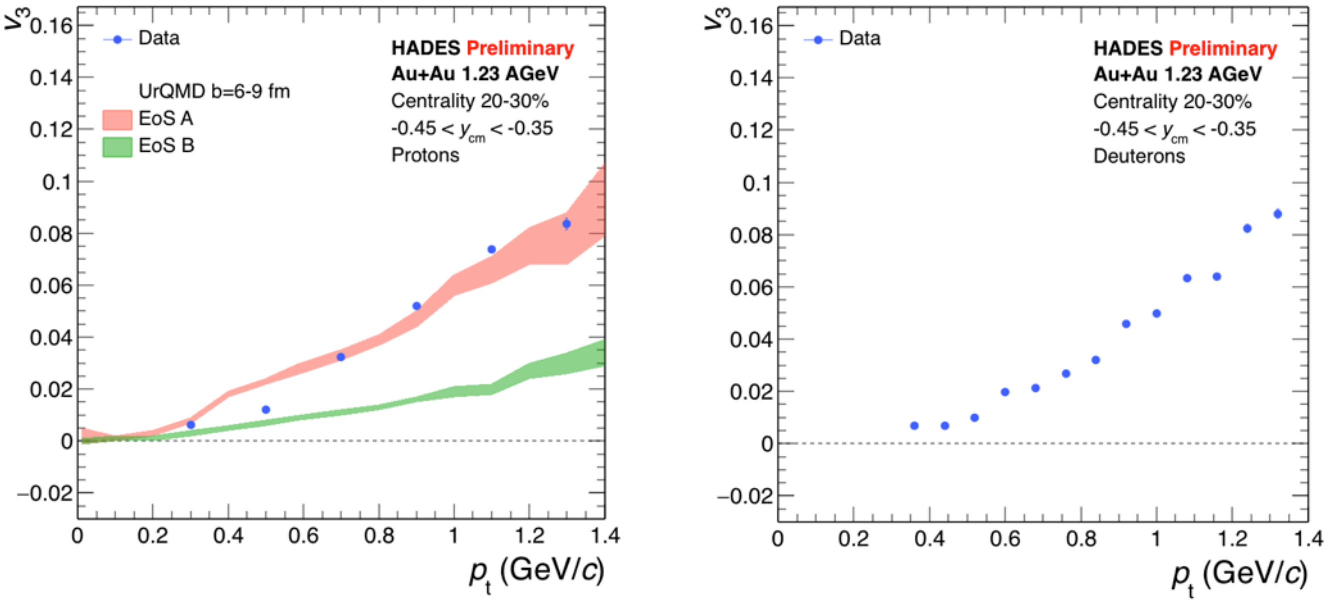
Empirical phase shift data and the corresponding effective spectral functions for the ρ-meson

Pok Man Lo, arXiv:1707.04490v2 [hep-ph]

Bonus slides

Triangular flow $v_3\{\psi_{RP}\}$ and EoS at SIS18

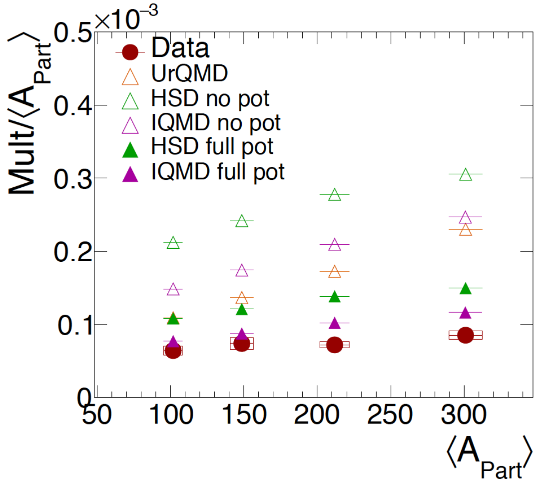
UrQMD3.4 P. Hillmann, J. Steinheimer, M. Bleicher, arXiv:1802.01951



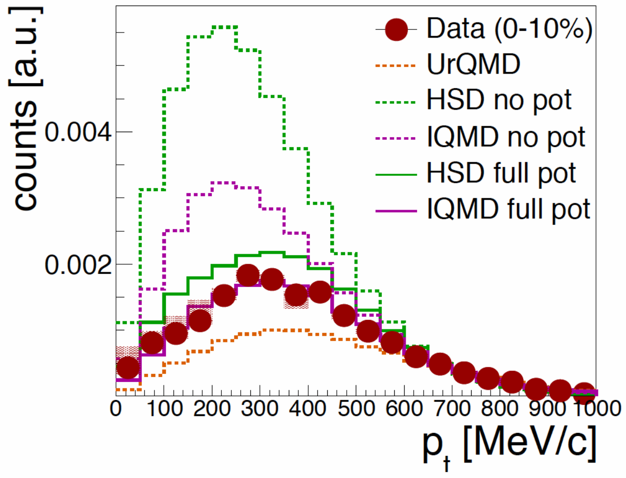
UrQMD predicts high sensitivity of v_3 to EoS

Microscopic Description

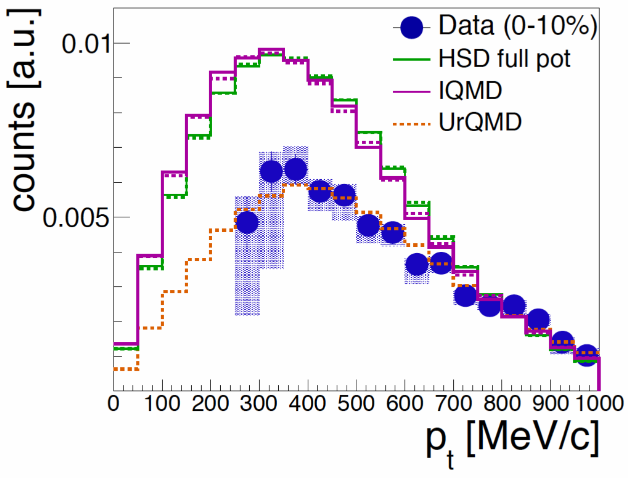
Λ, K_S^0 production compared to transport models



(normalization: 600<pt<900 MeV/c)



(normalization: 700<pt<1000 MeV/c)

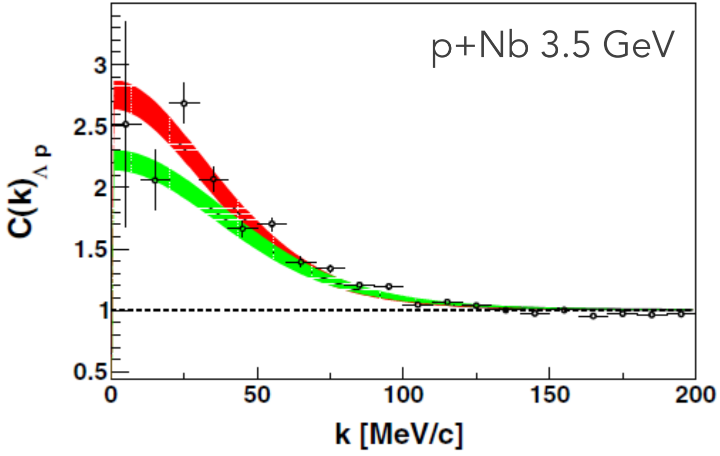


- "no pot" - state-of-the-art transport model calculations overestimate yield and low p_t
- "full pot" - inclusion of repulsive KN potential (U_{opt}=+40 MeV · ρ/ρ_0) → describes trends better

- Λ p_t spectrum best described by UrQMD (no potential!)
- No simultaneous description of K and Λ results

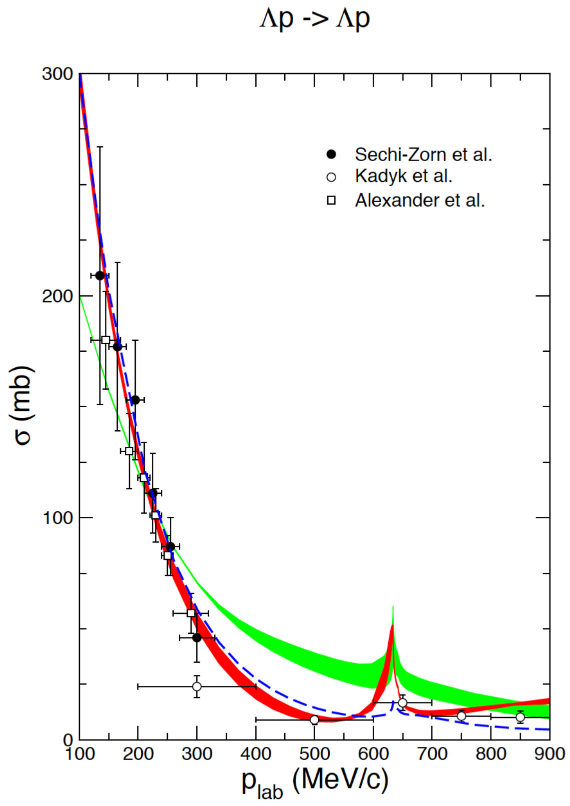
YN, YNN interactions

ΛN correlation function



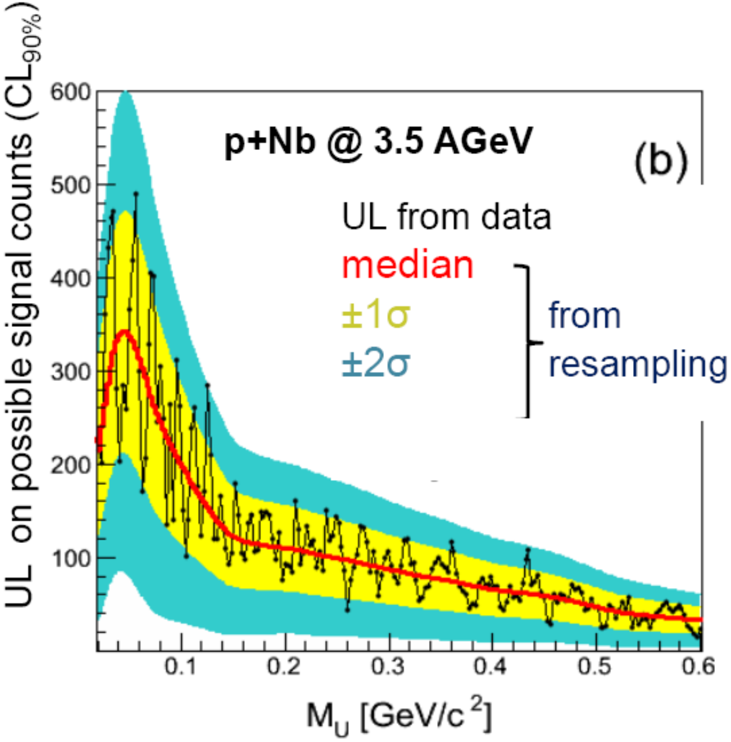
HADES collab., PRC 94 (2016) no.2, 025201

J. Haidenbauera et al., arXiv:1304.5339v1 [nucl-th]

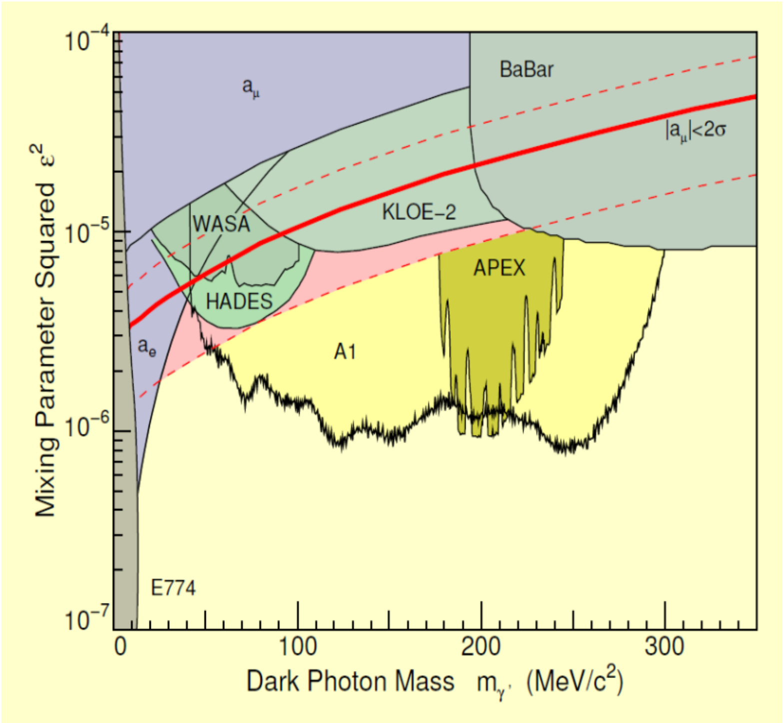


The red band shows the chiral EFT results to NLO, the green band are results to LO

Dark Photons



New A1 results



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M_U [GeV/c²]

Phys. Lett. B 731 (2014), pp. 265-271