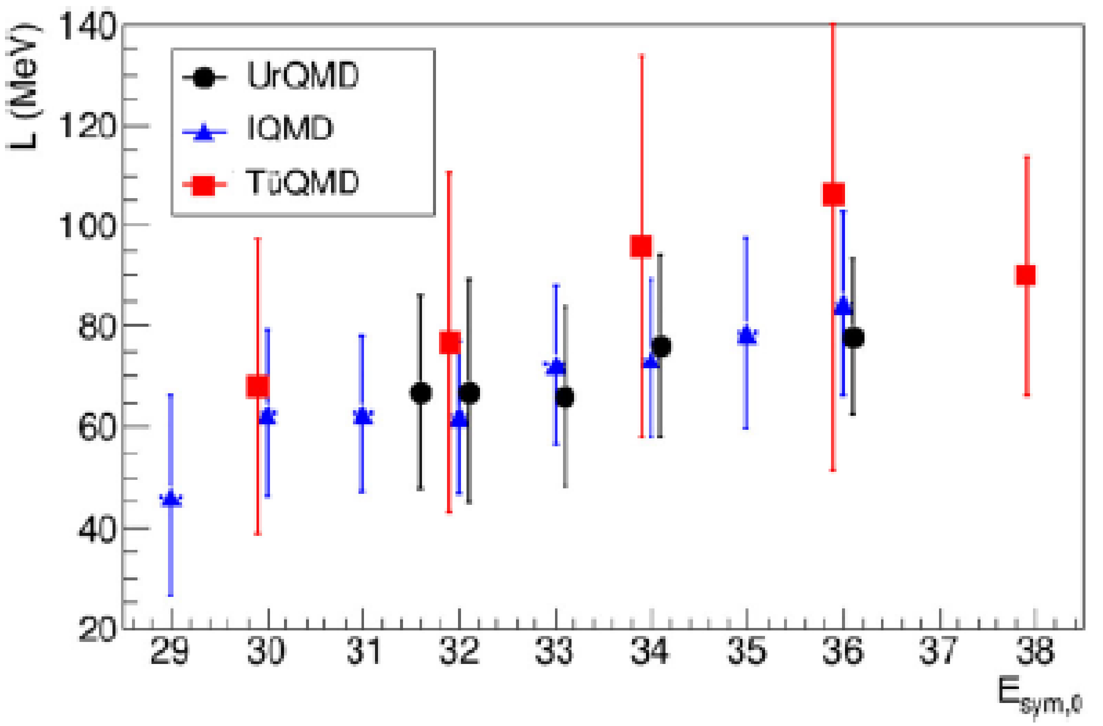
HIC round table discussion

Paolo Russotto on Monday



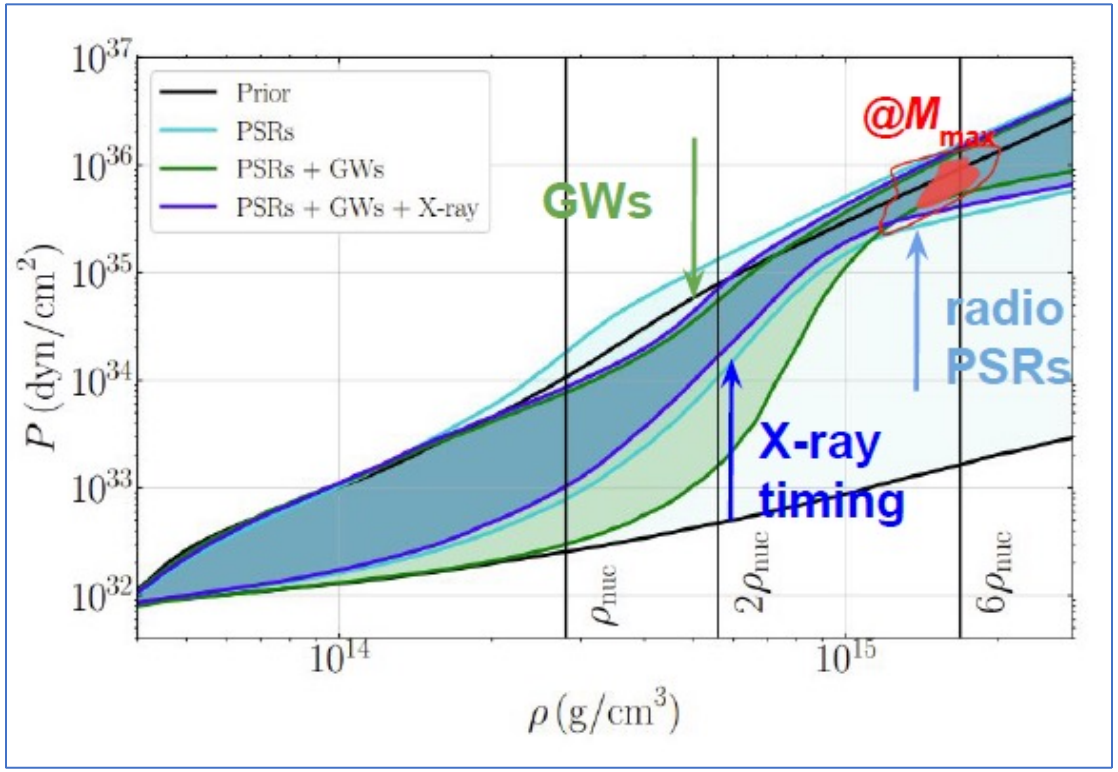
P. Russotto et al., Riv. Nuovo Cimento 46, 1 (2023)

ASY-EOS

Q1: dependence on transport model?

Q2: dependence on S_0 ?

Reed Essick at NuSym2022 in Catania



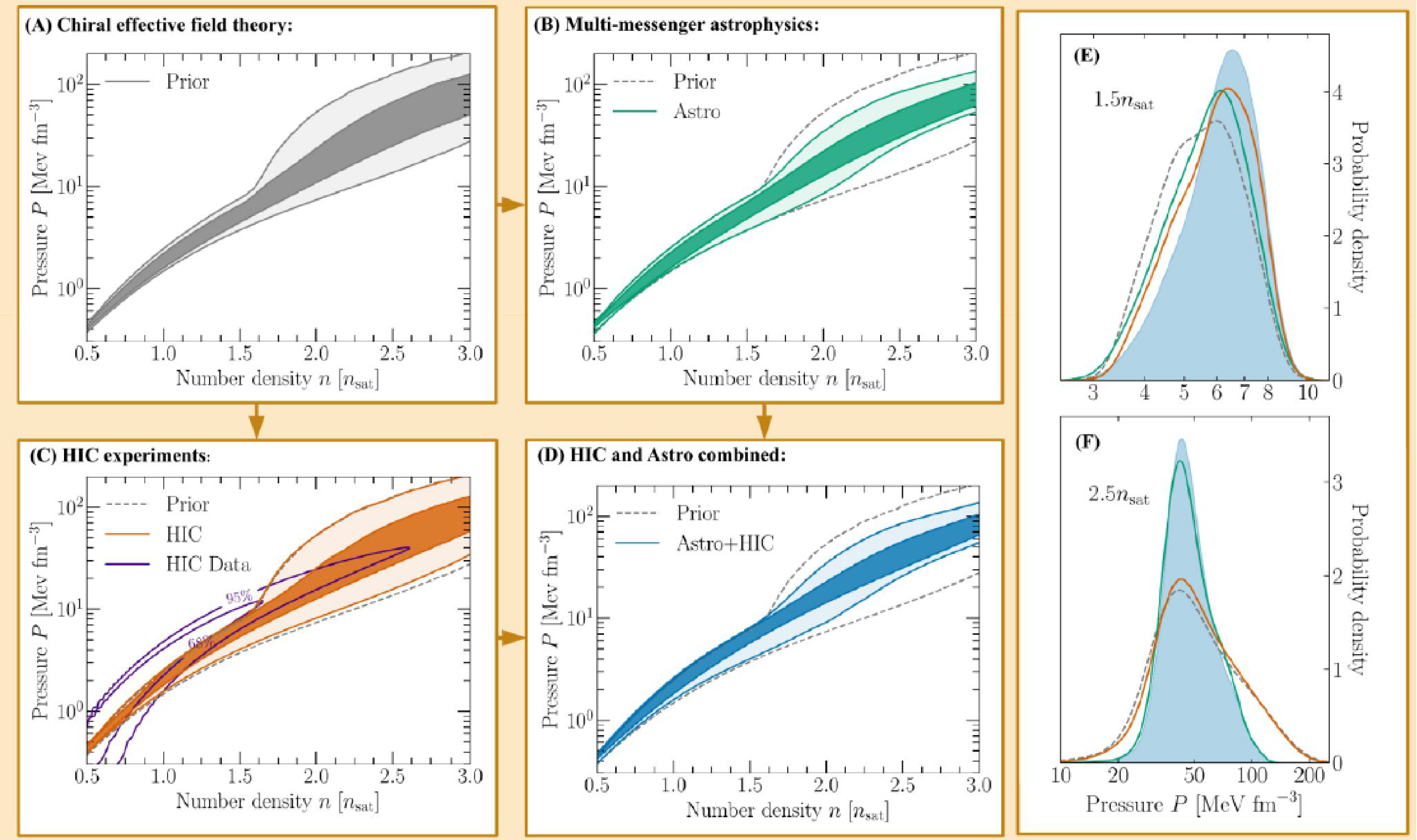
see **Legred+, Landry+**
PRD 104, 063003 (2021)
PRD 101, 123007 (2020)

model-agnostic prior

Q3: how to get better constraints at $\rho < 1.5\ \rho_0$?

Peter Pang yesterday

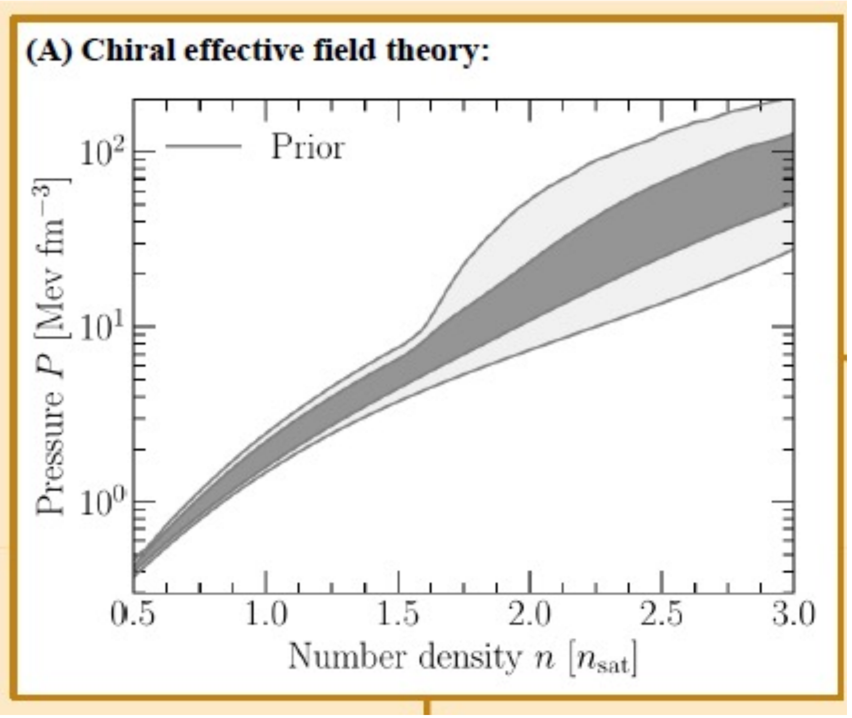
Huth et al., Nature 606, Fig. 1



contours at 68% and 95% credibility

Prior in Huth et al.

EFT ->1.5 ρ_0

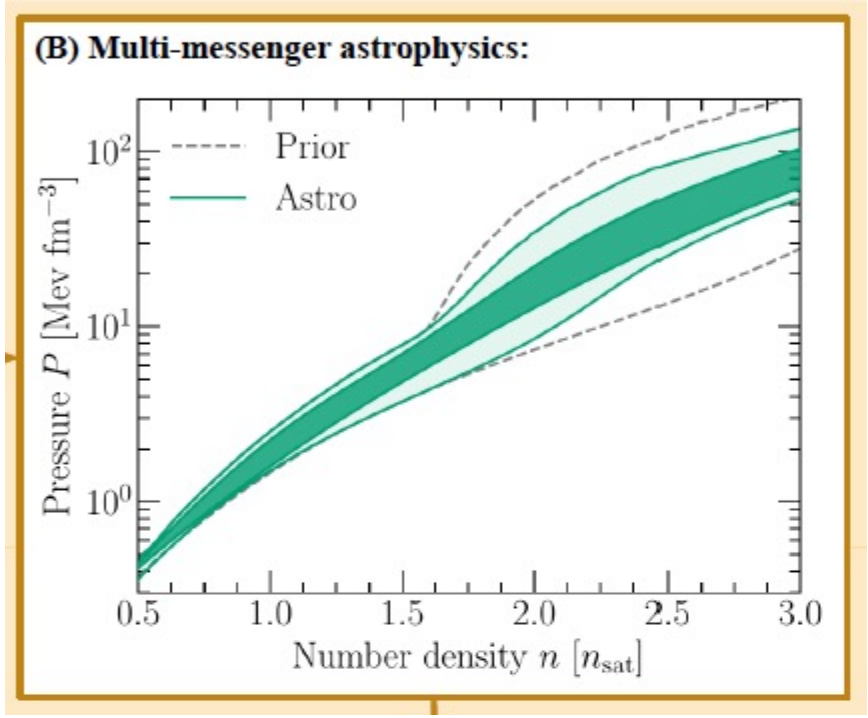


stability $c_s > 0$
causality $c_s < c$
segments
with $c_s = 0$

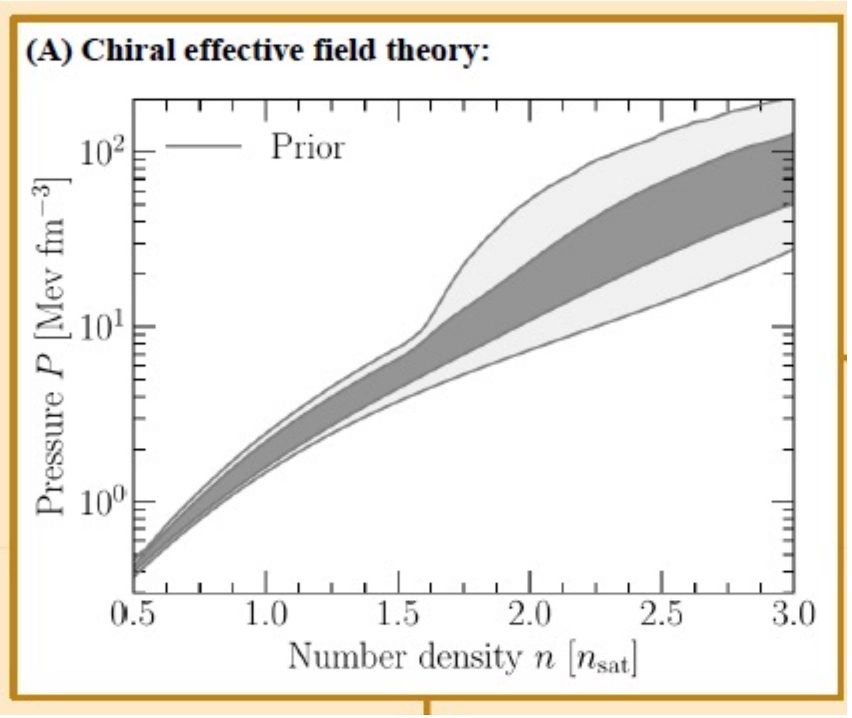
$M_{max} \geq 1.9\ M_{sun}$

see **Essick+** PRC 102 (2020) for χEFT breakdown scale:

„NICER observations suggest that the EoS stiffens relative to χEFT predictions at or slightly above nuclear saturation density.“ (using radius of PSR J0030 + 0451)



EFT ->1.5 ρ_0



stability $c_s > 0$
causality $c_s < c$
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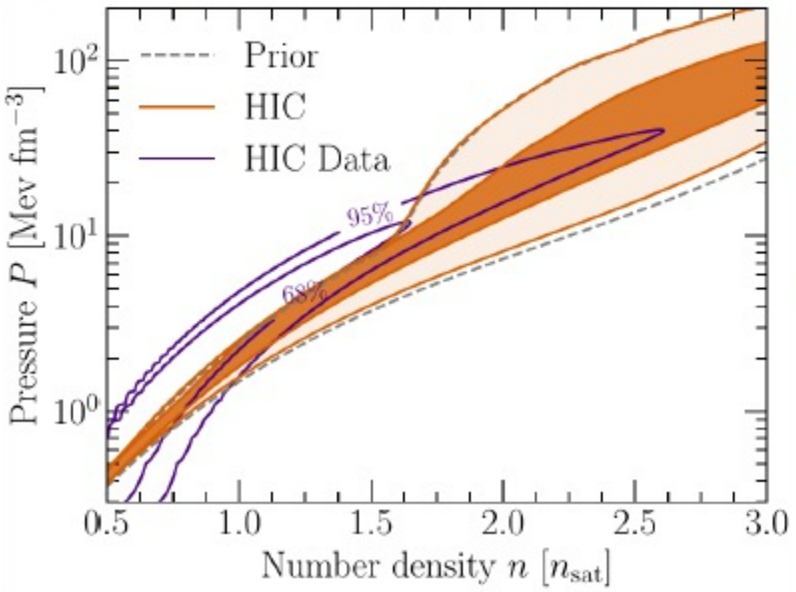
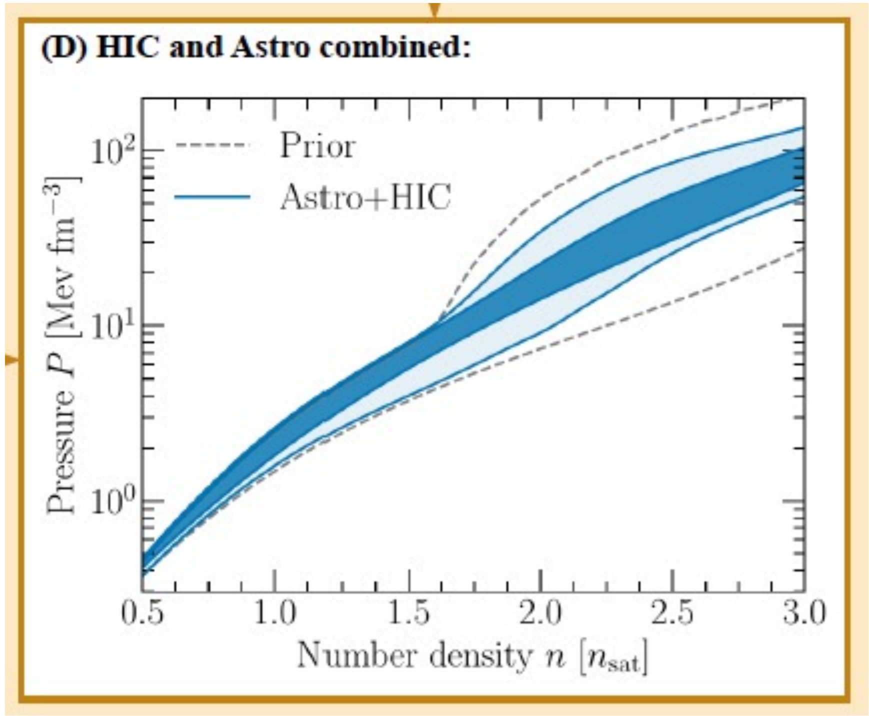
$M_{max} \geq 1.9\ M_{sun}$

(C) HIC experiments:





Q4: is the prior too soft?

Huth+ (Extended Data and Supplementary Tables)

adopted: χEFT up to 1.5 n_{sat},

$R_{1.4}$ = 12.01 +0.78 -0.77 km (95%)

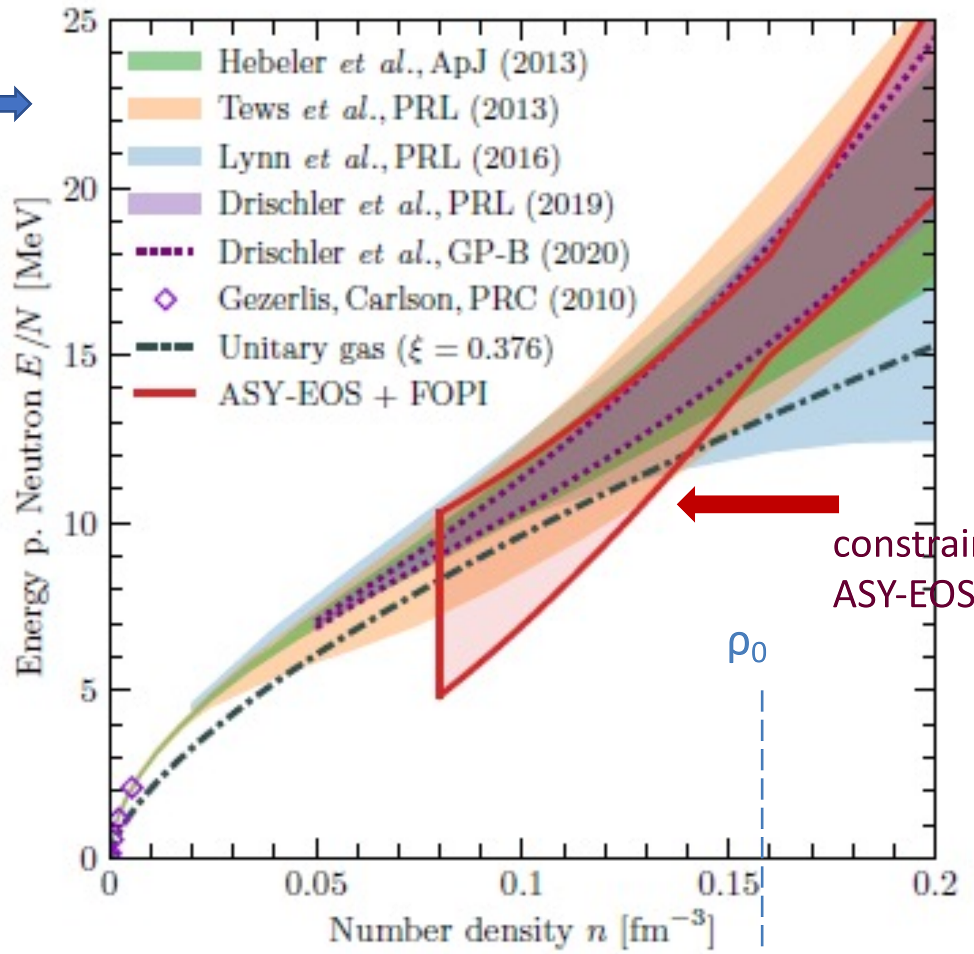
12.56 +1.07 –1.01 χEFT up to 1.0 n_{sat}

Q5: how reliable is χEFT above 1.0 n_{sat} ?

χEFT and HIC

EFT predictions

pure neutron matter



constraint deduced from ASY-EOS and FOPI data

Huth et al., Nature 606, 276

Extended Data Fig. 4

Q6: can HIC be useful?

HIC Relativistic energies

- Wealth of new high statistic data (HADES, Star, Spirit, AsyEOS ..) allow for multi-differential analysis and model comparisons. And much more to come (see future session, directly afterwards).

- How do we extract the most precise conclusions out of the data?
    1. Systematic model to data comparison
    2. Systematic uncertainties vs. Statistical errors
    3. New observables

1. Systematic model to data comparison

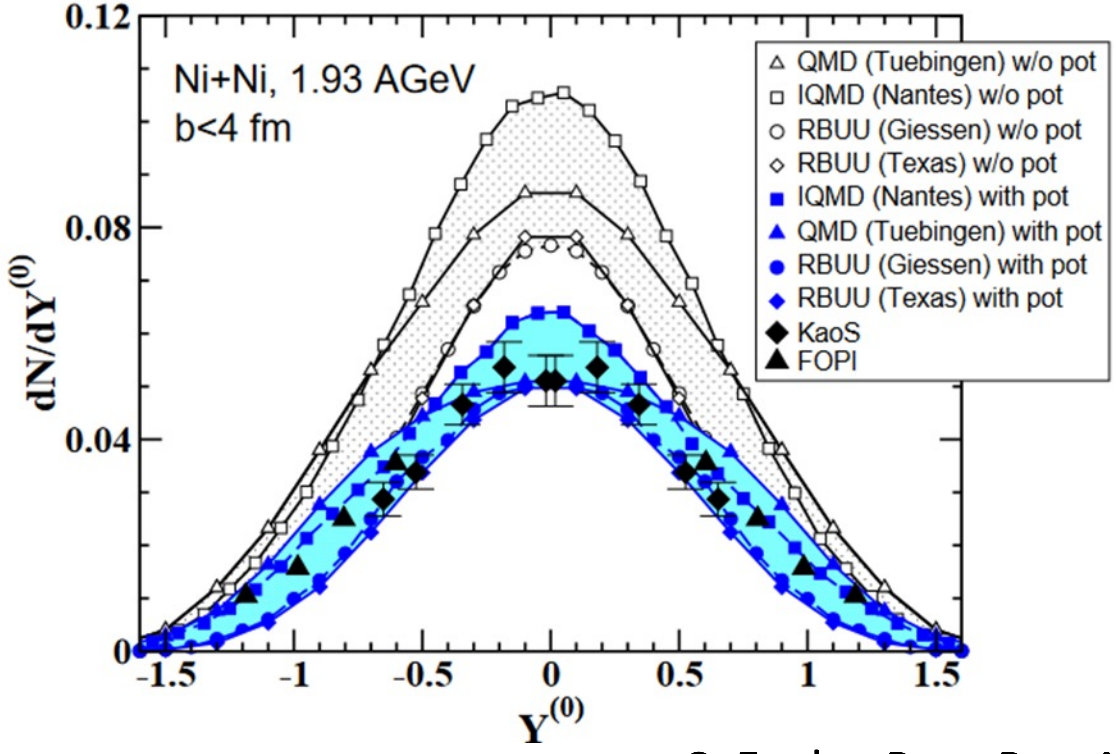
- Bench mark observables, now and then

20 years ago: EOS for symmetric matter derived from subthreshold K^+ production

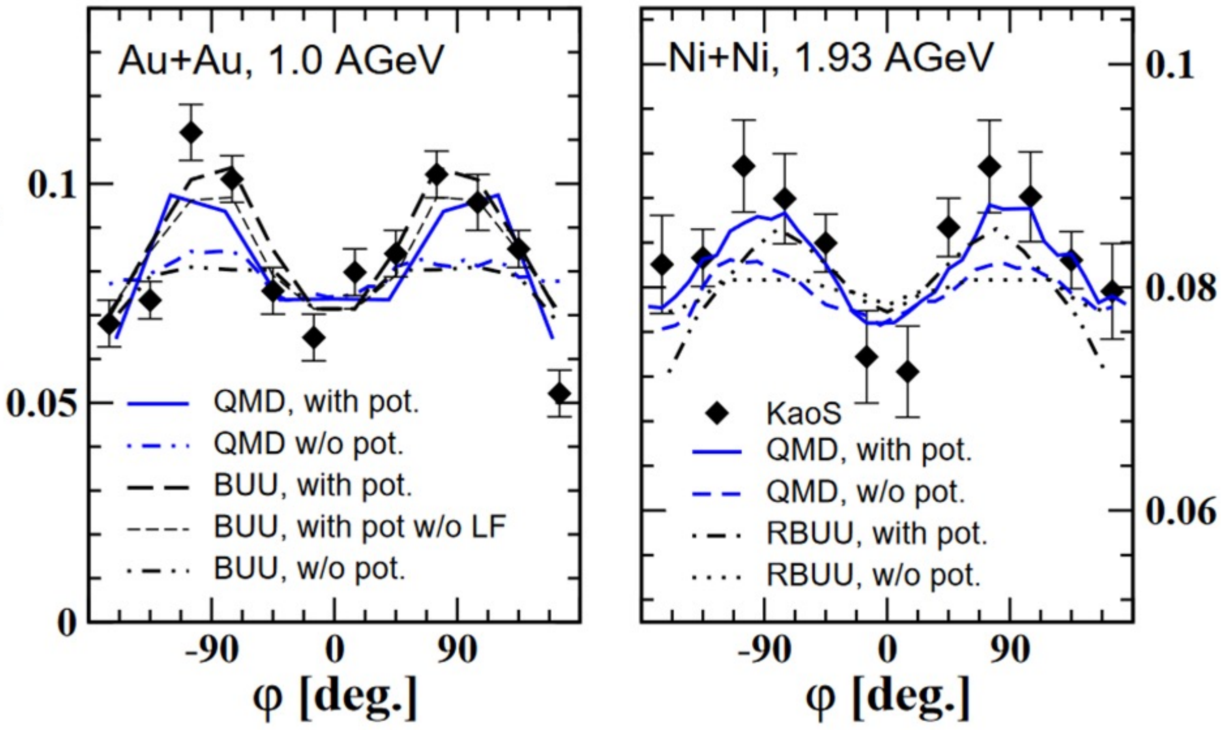
The models included momentum dependent interactions, in-medium cross section.

Important: Benchmark observables, reference measurements, excitation functions

K^+ yields: data from KaoS and FOPI



K^+ azimuthal angular distributions in semi-central collisions



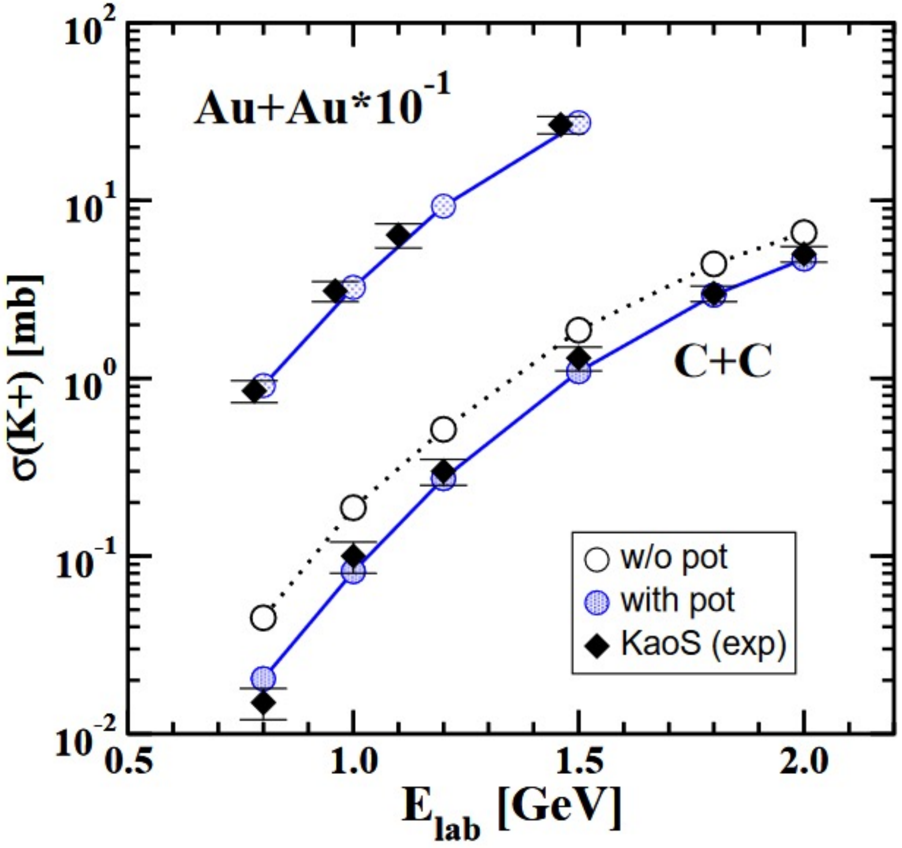
C. Fuchs, Prog.Part.Nucl.Phys.56:1-103,2006

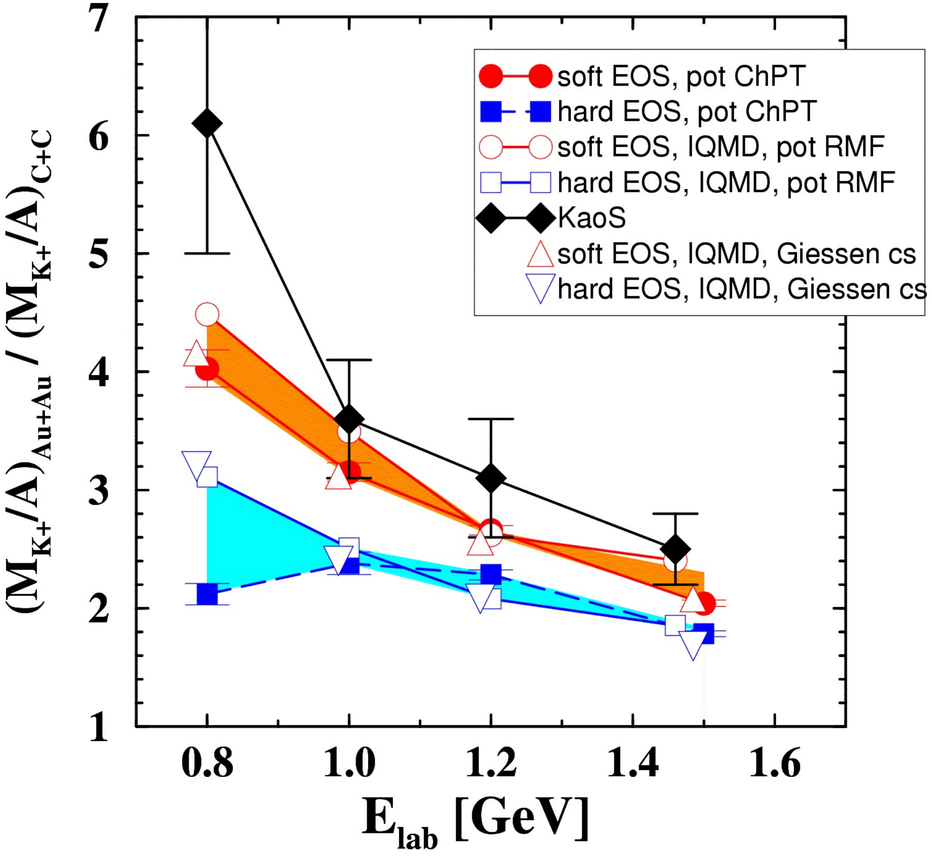
20 years ago: EOS for symmetric matter derived from subthreshold K$^+$ production

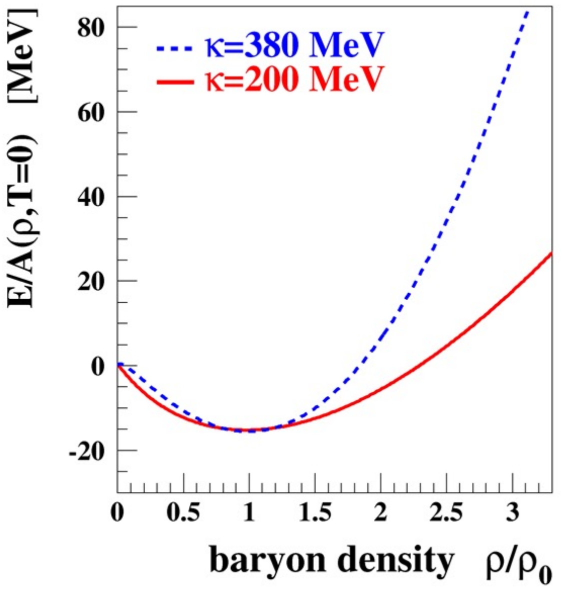
reference measurements,
excitation functions

Experiment: C. Sturm et al., (KaoS Collaboration) Phys. Rev. Lett. 86 (2001) 39

Theory: RQMD Ch. Fuchs et al., Phys. Rev. Lett. 86 (2001) 1974
IQMD Ch. Hartnack, J. Aichelin, J. Phys. G 28 (2002) 1649







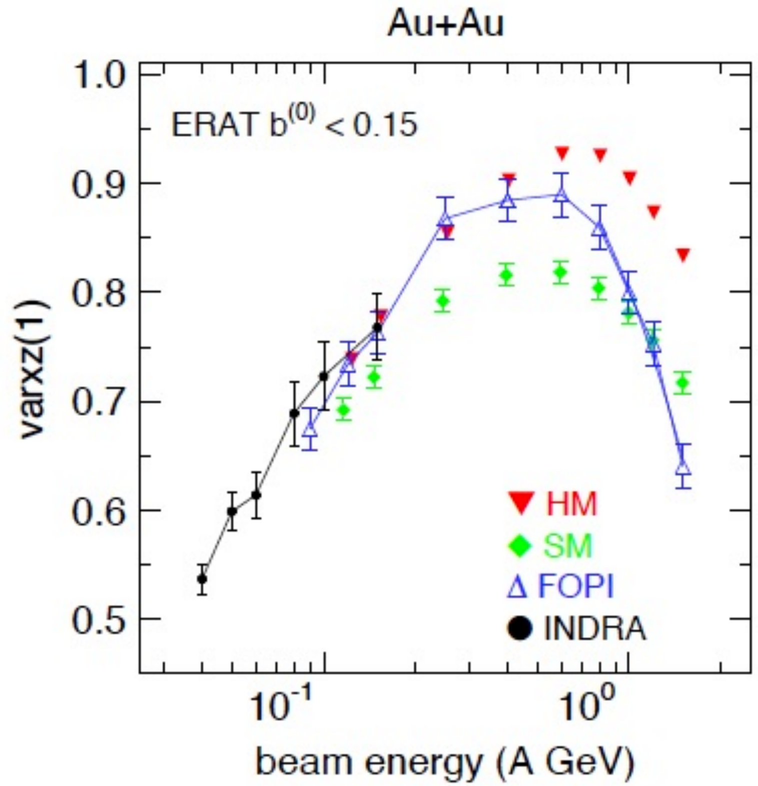
Upcoming HADES measurements of Au+Au and C+C collisions from 0.2 – 0.8 GeV will dramatically improve the data situation and provide stronger constraints on the EOS of symmetric matter.

Proton and light nuclei vs. transport @ $\sqrt{s_{NN}}$ = 2.42 GeV

Systematics of central heavy ion collisions in the 1A GeV regime

W. Reisdorf, [a,1], A. Andronic[a], R. Averbeck[a], M.L. Benabderrahmane[f], O.N. Hartmann[a], N. Herrmann[f], K.D. Hildenbrand[a], T.I. Kang[a,j], Y.J. Kim[a], M. Kiš[a,m], P. Koczoń[a], T. Kress[a], Y. Leifels[a], M. Merschmeyer[f], K. Piasecki[f,ℓ], A. Schüttauf[a], M. Stockmeier[f], V. Barret[d], Z. Basrak[m], N. Bastid[d], R. Čaplar[m], P. Crochet[d], P. Dupieux[d], M. Dželalija[m], Z. Fodor[c], P. Gasik[ℓ], Y. Grishkin[g], B. Hong[j], J. Kecskemeti[c], M. Kirejczyk[ℓ], M. Korolija[m], R. Kotte[e], A. Lebedev[g], X. Lopez[d], T. Matulewicz[ℓ], W. Neubert[e], M. Petrovici[b], F. Rami[k], M.S. Ryu[j], Z. Seres[c], B. Sikora[ℓ], K.S. Sim[j], V. Simion[b], K. Siwek-Wilczyńska[ℓ], V. Smolyankin[g], G. Stoicea[b], Z. Tymiński[ℓ], K. Wiśniewski[ℓ], D. Wohlfarth[e], Z.G. Xiao[a,i], H.S. Xu[i], I. Yushmanov[h], A. Zhilin[g]

(FOPI Collaboration)



also clear that the 'residual' interaction, i.e. the explicit collision term, influences the outcome. The present parameterization of IQMD as used here is obviously not able to reproduce the data, in particular the rapid drop of *varxz(1)* beyond 0.8A GeV is not reproduced. A fair reproduction of a portion (0.25A to 1.0A GeV) of the excitation function was achieved in [50].

[50] T. Gaitanos, C. Fuchs, H. H. Wolter, Phys. Lett. B 609 (2005) 241.

1. Systematic model to data comparison

- Bench mark observables (multi-messenger era)
  - Yields and rapidity distributions of most abundant hadrons.

  Need to be published early (Manpower).

- Comparison on differential observable, how to keep an overview?
  - Bayesian analysis, machine learning etc.?
  - Standardized list of model ingredients and parameters.
  - ..

- Constraints more related to exp. observables than EOS
(avoid systematic bias and ”doppelgängers”)

2. Systematic uncertainties vs. Statistical errors

- Systematic uncertainty estimation:
  - Precise statements how the estimation was done.
  - Steps towards unification between various experiments.
  - Common collision system (C+C?) measurements as references and benchmark for comparison between different experiments?

3. New observables

- Neutron flow at higher energies?
- …