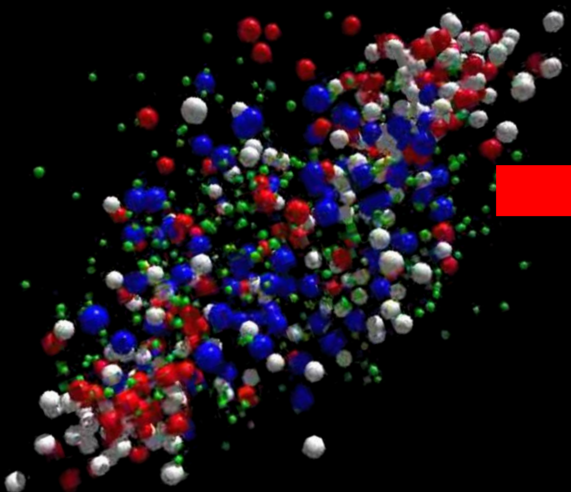
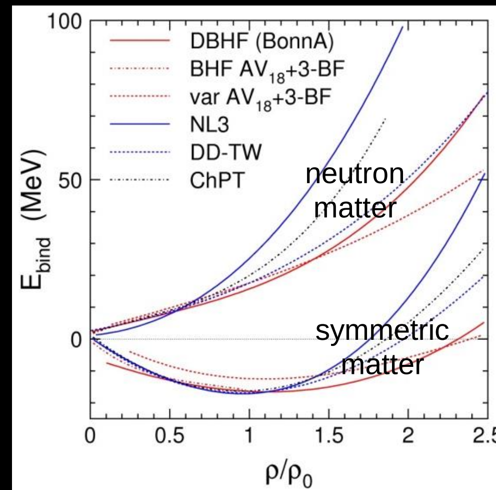
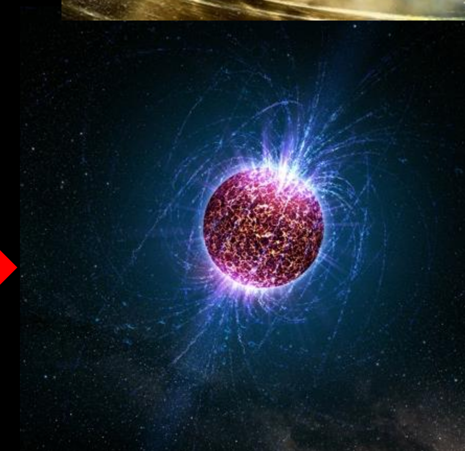
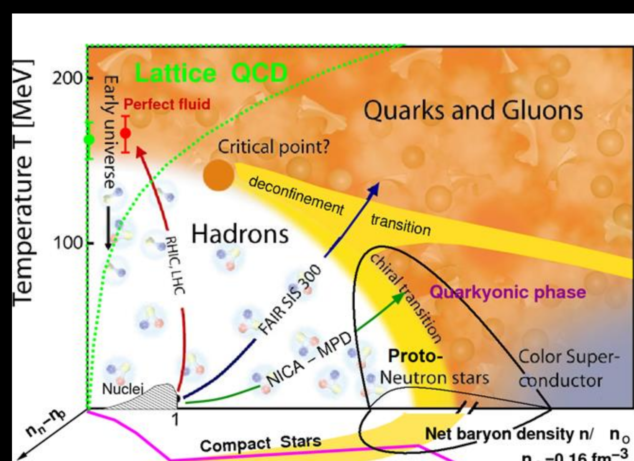
Closing remarks 3rd CBM China workshop

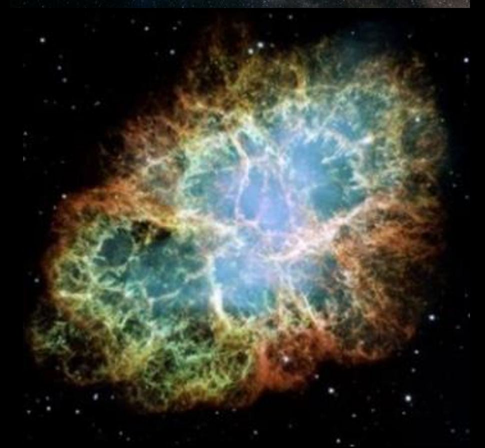
Peter Senger





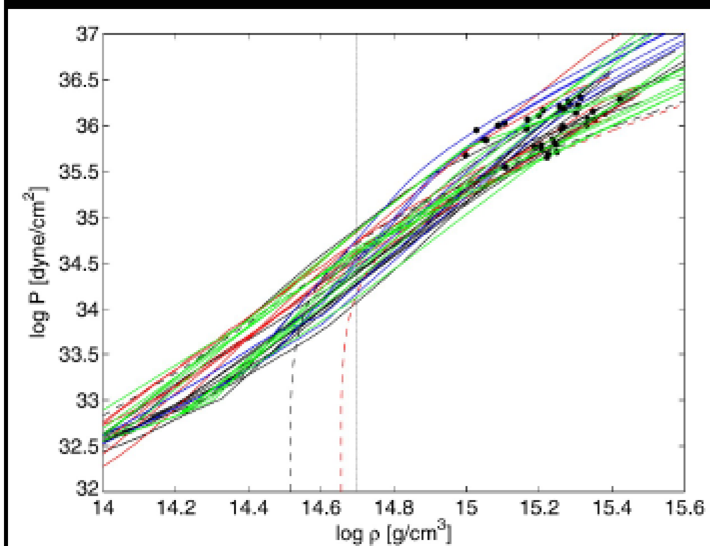




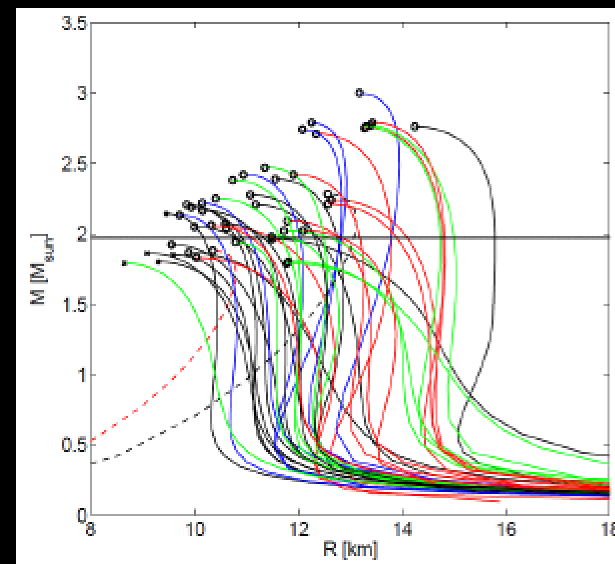


Introductory remark

- Mass-radius relation (of non-rotating NSs) and EoS are uniquely linked through Tolman-Oppenheimer-Volkoff (TOV) equations



TOV



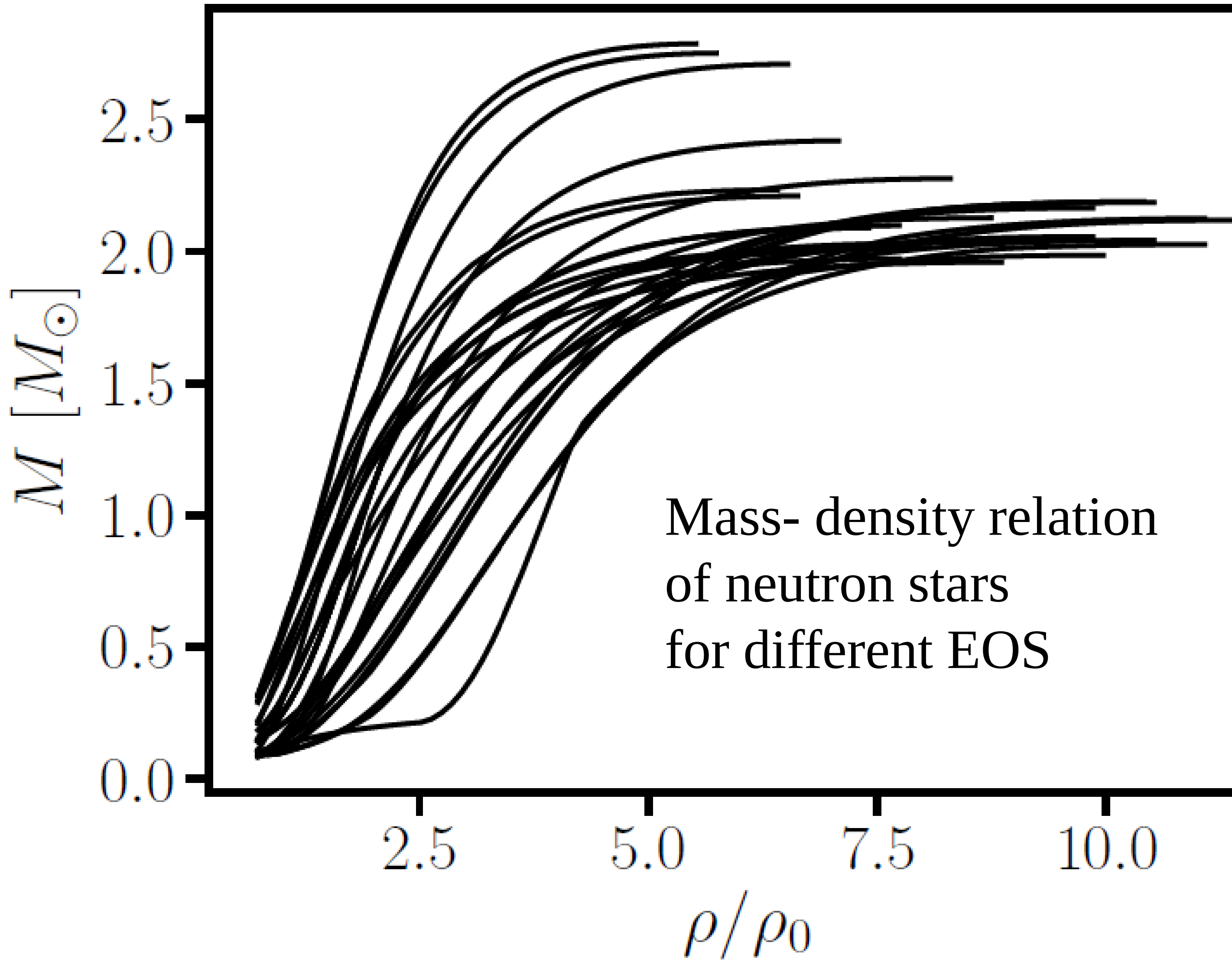
Theory: P(ρ) ⟵ currently ⟶ Observation: R(M)

future

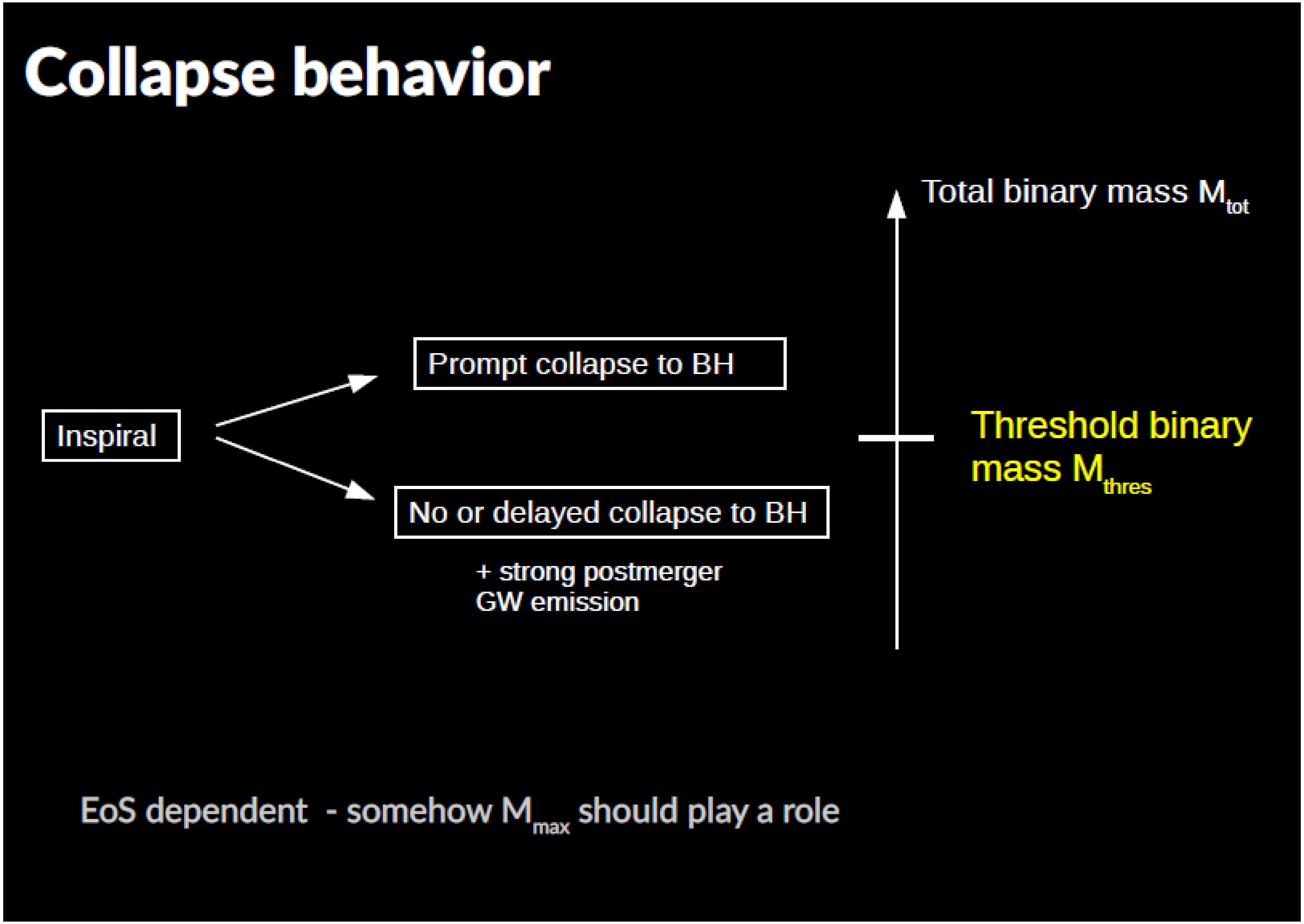
→ NS properties (of non-rotating stars) and EoS properties are equivalent !!!

(not all displayed EoS compatible with all nuclear physics constraints)

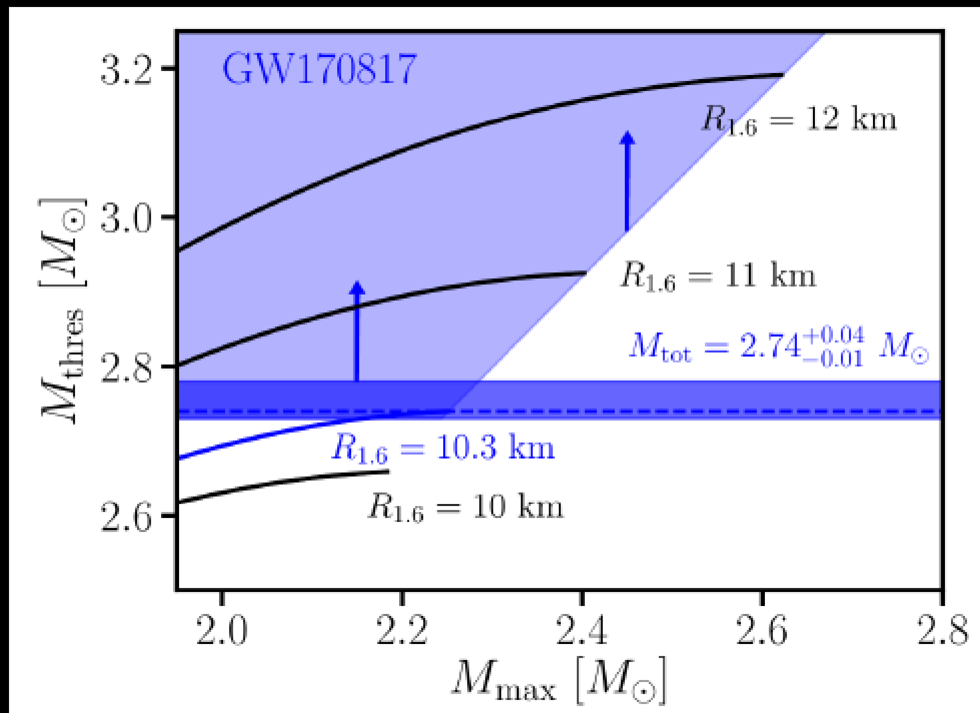
Andreas Bauswein



Andreas Bauswein



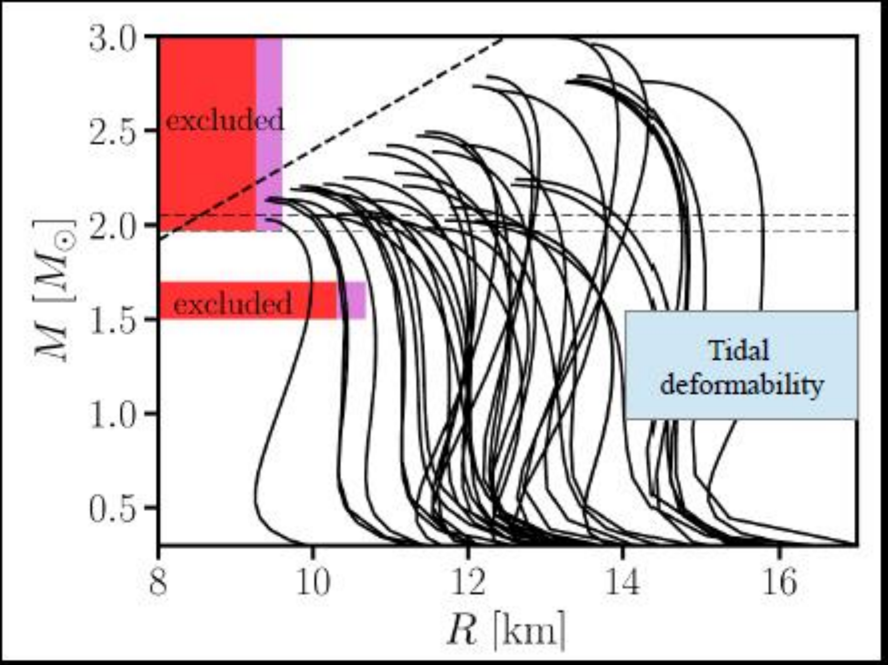
Andreas Bauswein



$$M_{thres} = \left(-3.6 \frac{G\, M_{max}}{c^2\, R_{1.6}} + 2.38\right)\ M_{max}$$

$$v_S = \sqrt{\frac{dP}{de}} \leq c \;\rightarrow\; M_{max} \leq \kappa R_{1.6} \;\Rightarrow\; M_{thres} \geq 1.2 M_{max}$$

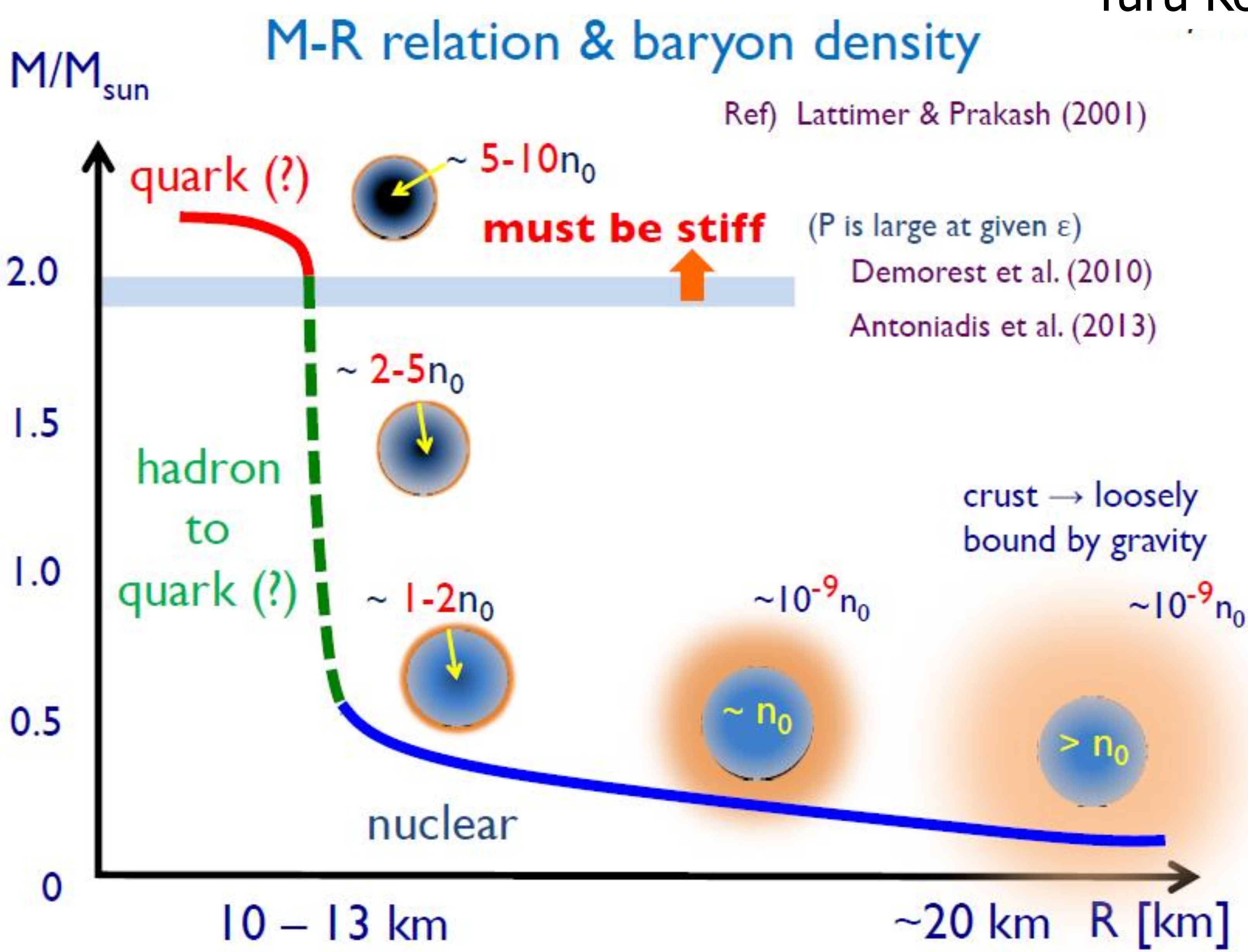
NS radius constraint from GW170817



Bauswein et al. 2017

- $R_{1.6}$ > 10.7 km
- Excludes very soft nuclear matter

Turu Kojo

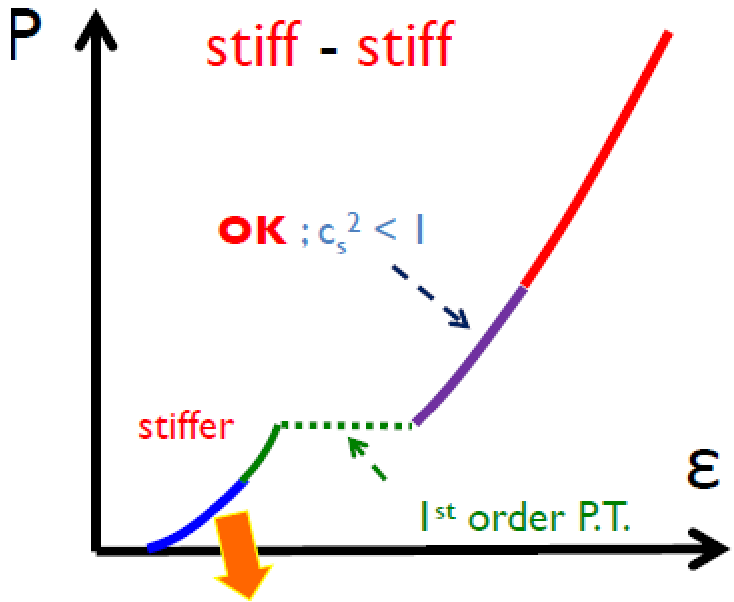


M-R relation & baryon density
M/M_sun
Ref) Lattimer & Prakash (2001)
quark (?)
~ 5-10n_0
must be stiff
(P is large at given ε)
Demorest et al. (2010)
Antoniadis et al. (2013)
2.0
~ 2-5n_0
1.5
hadron
to
quark (?)
crust → loosely
bound by gravity
1.0
~ 1-2n_0
~10^-9 n_0
~10^-9 n_0
0.5
~ n_0
> n_0
nuclear
0
10 – 13 km
~20 km
R [km]

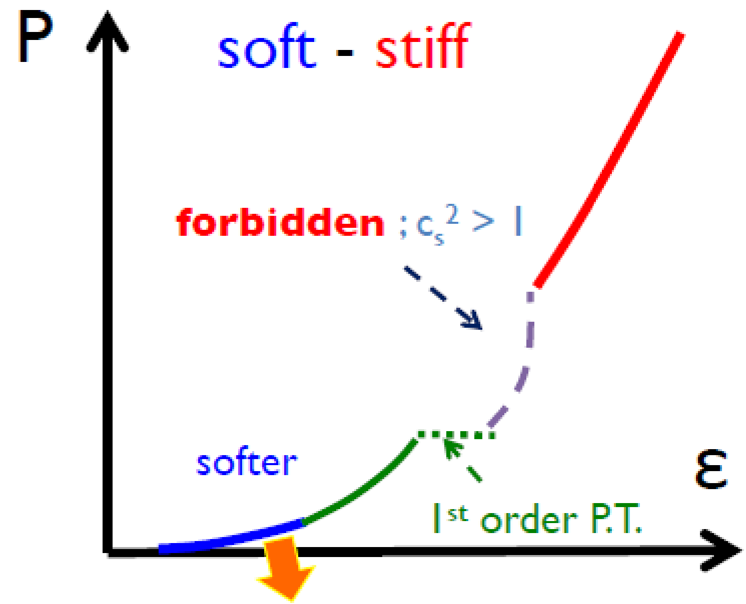
Turu Kojo

Soft-Stiff v.s. Stiff-Stiff EoS

[more systematic analyses → Han-Alford-Prakash 13]



larger R (> ~13 km)



smaller R (< ~13 km)

Small NS Radius ⟺

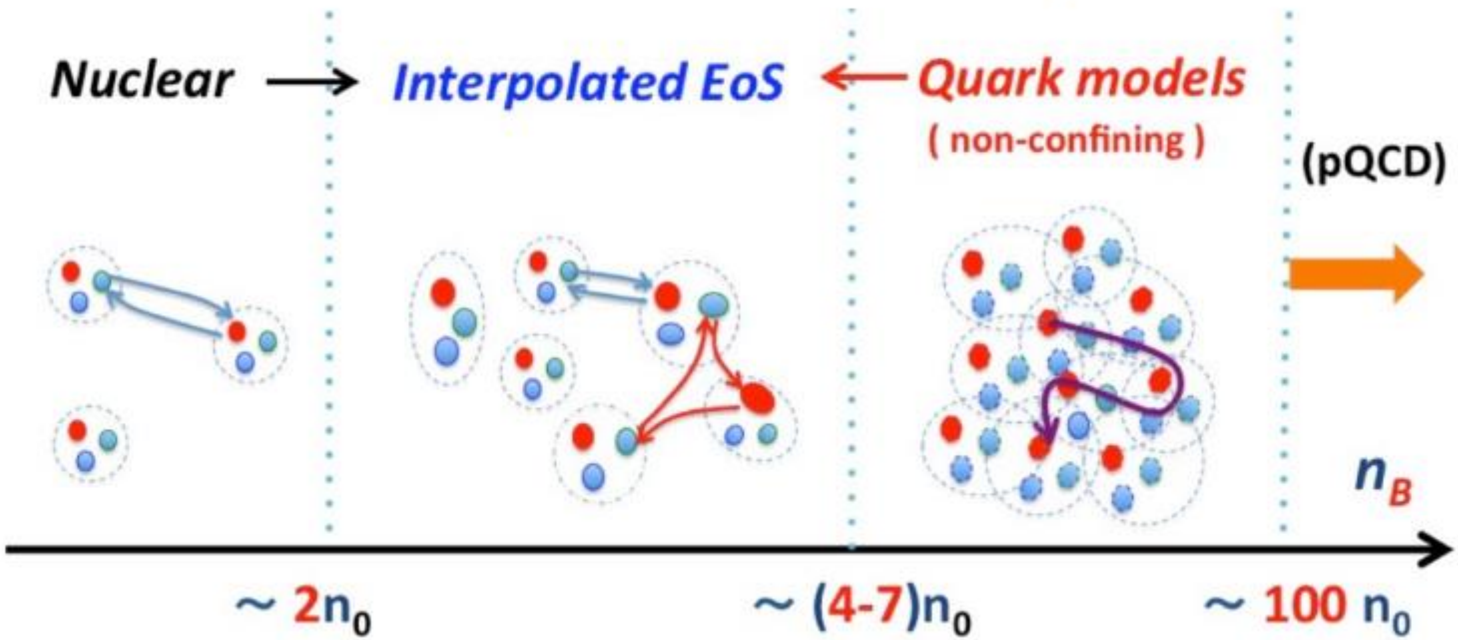
- soft nuclear EoS at (1.5-2) n_0
- crossover or weak 1st P.T.

Turu Kojo

To Do (work in progress)

- include corrections from quark substructure

- beyond MF
- from eff. models to microscopic calculations

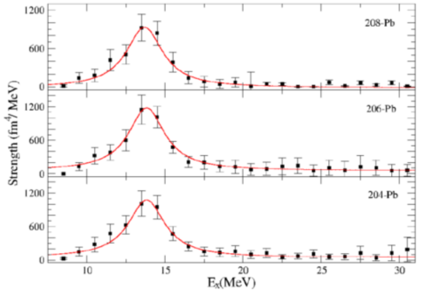


- composition to be determined

Then the matter should be heated up → predictions for HMNS

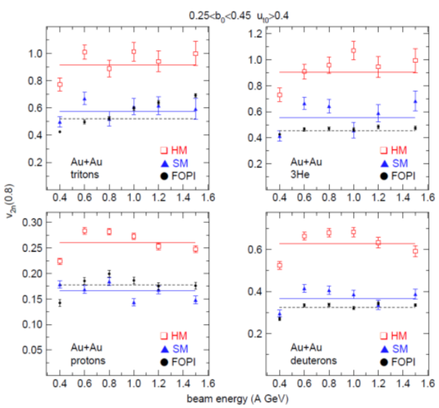
EOS from laboratory experiments

Giant Dipole Resonance



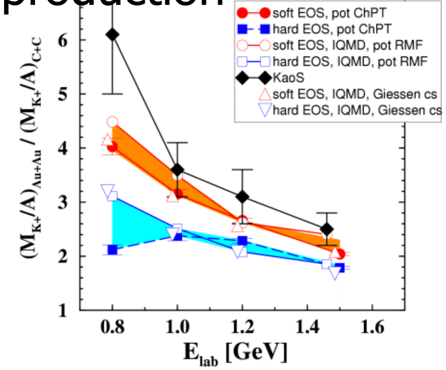
$\rho = \rho_0$

Fragment elliptic flow

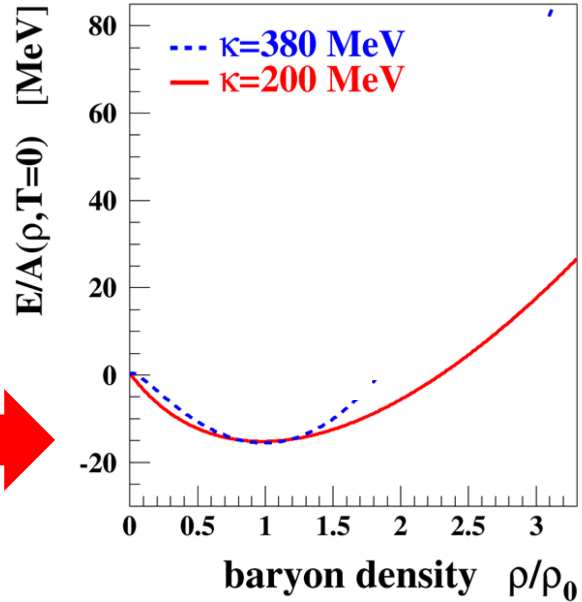


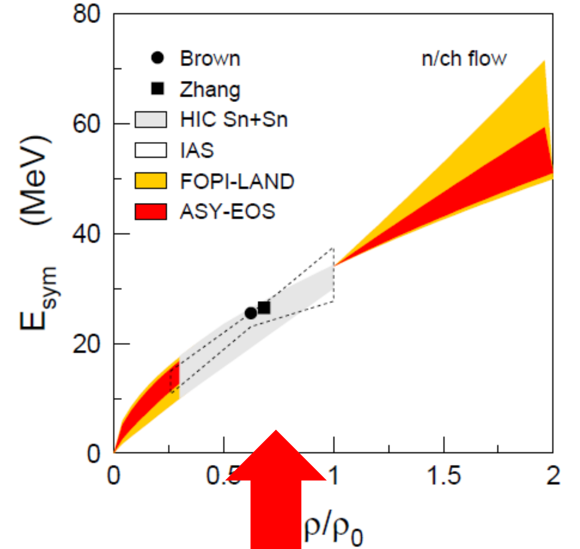
ρ = 1-3 ρ_0

Subthreshold strangeness production

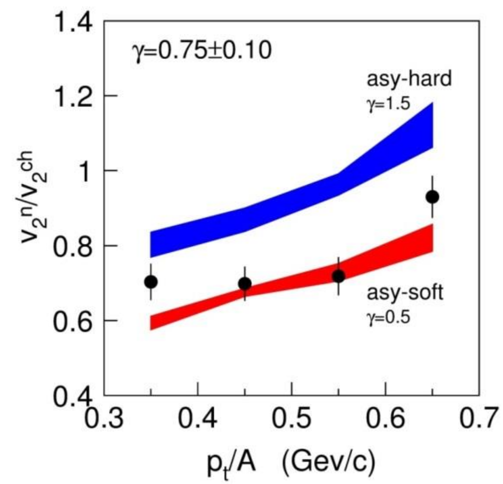


ρ = 1-3 ρ_0

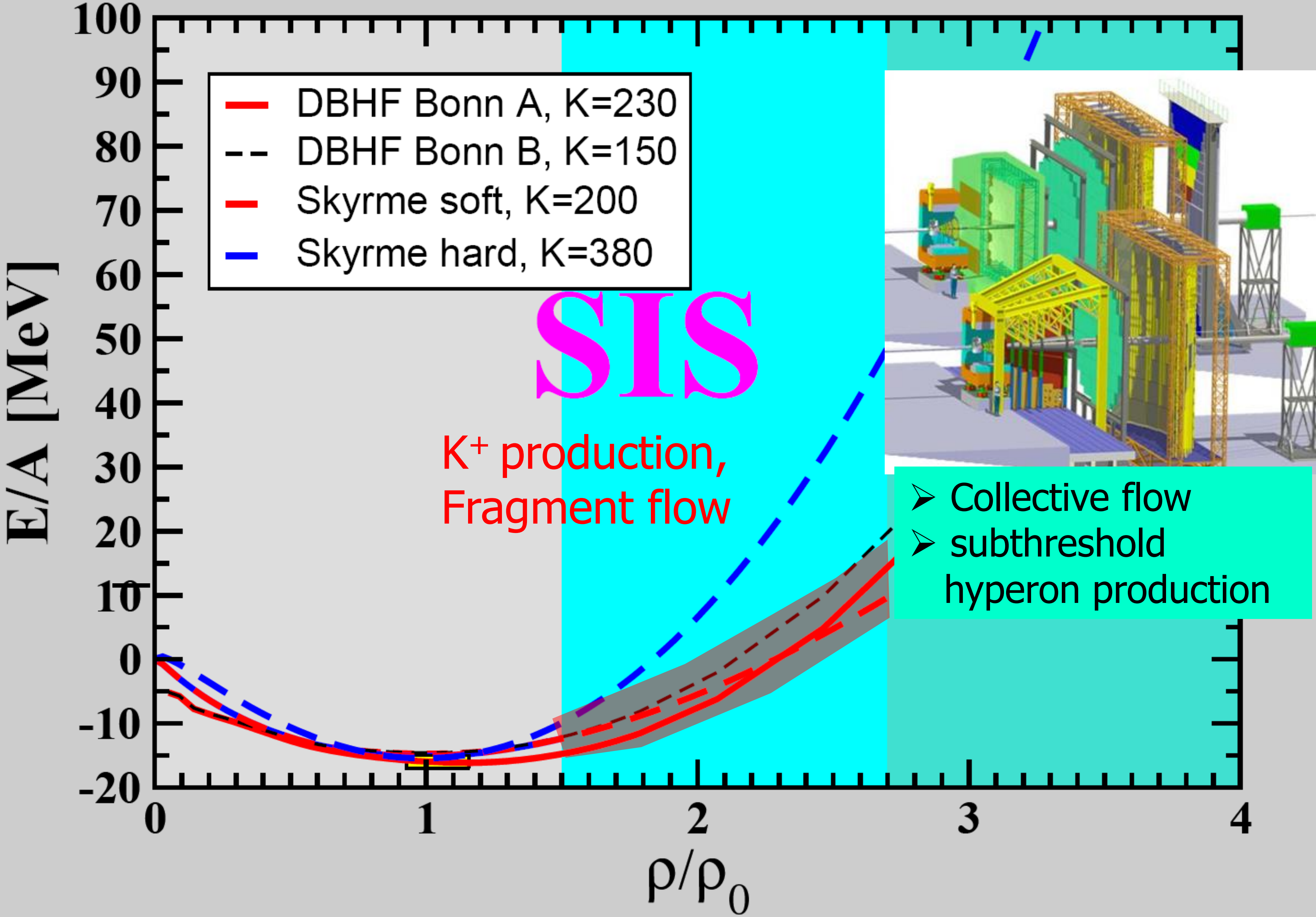




Fragment and neutron elliptic flow



nuclear matter EOS



Physical Goal 2: Esym(ρ) at high baryon density

Zhigang Xiao

$$E(\rho,\delta)=E_0(\rho)+\delta^2E_{sym}(\rho)=a_V+\frac{\kappa}{18}\varepsilon^2-\frac{\kappa^2}{162}\varepsilon^3+\ldots+\delta^2\left(E_{sym}+\frac{L}{3}\varepsilon+\ldots\right)$$

κ:Compressibility

E_{sym}

- Proton fraction
- M-R relation
- ρ_c for D-Urca
- Transition density
- ……

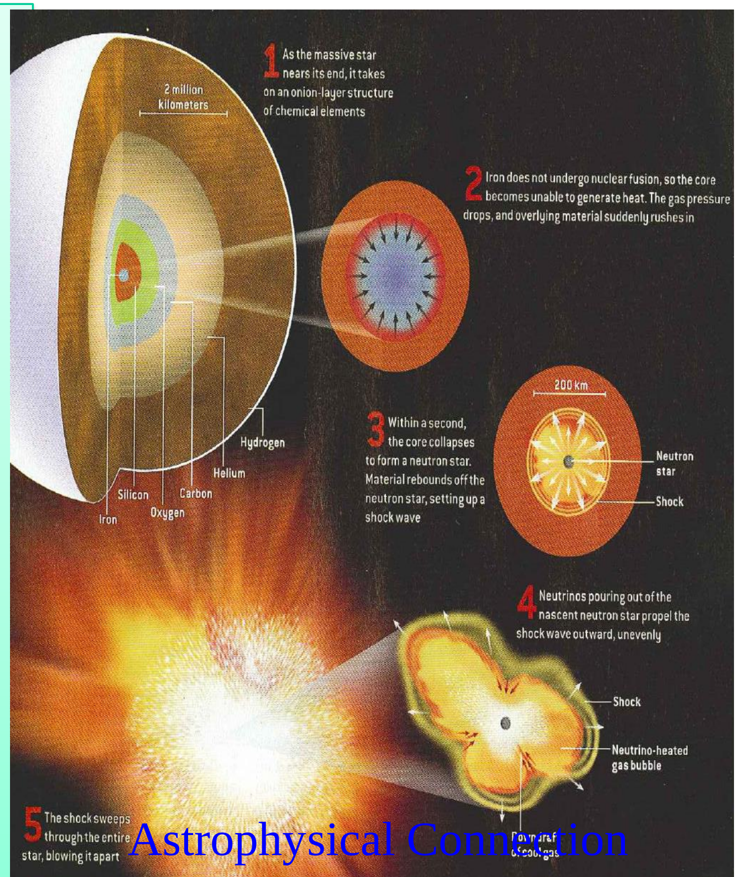
Phy. Rep. 442(2007) 109; NPA777(2006)479

PRC76(2007),015801; PRC75(2007) 015801

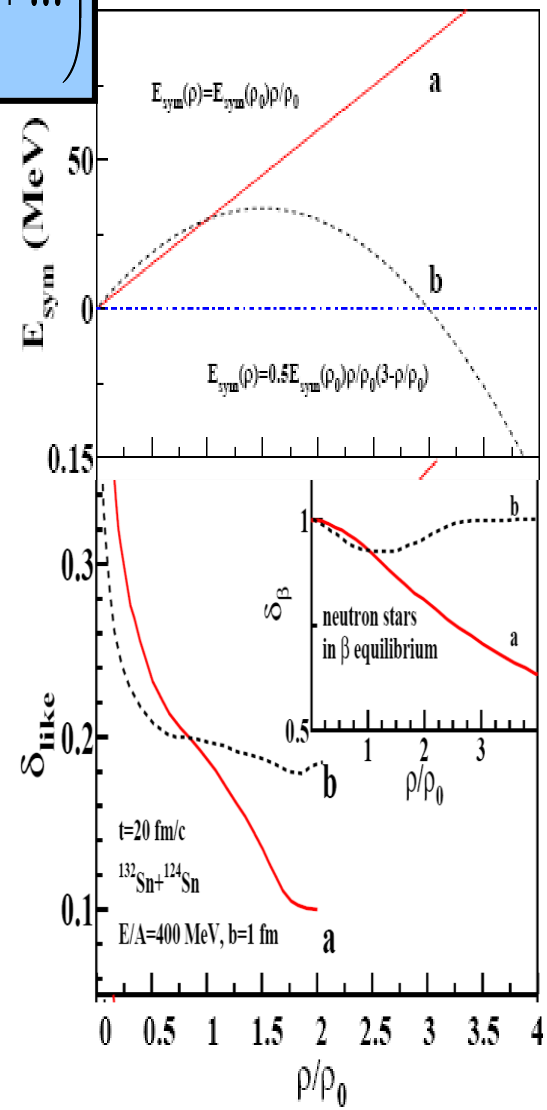
PRC74 (2006),035802; Astro. J. 676 (2008) 1170

Phy. Rep. 411(2005) 325; PLB 642, 436 (2006)

……



Astrophysical Connection



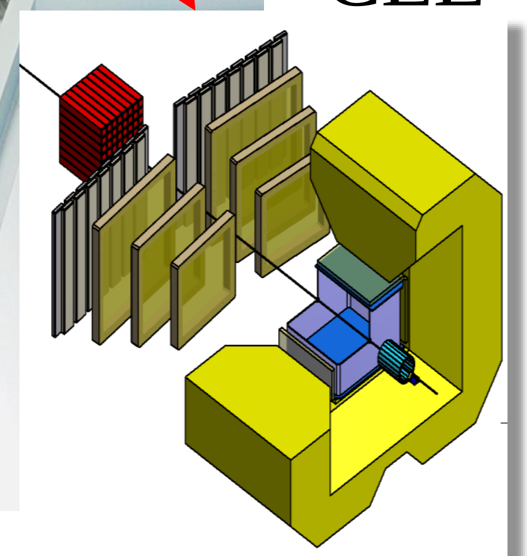
HIRFL-CSR complex

SFC: ≤ 10 AMeV (H.I.), 17~35 MeV (p)

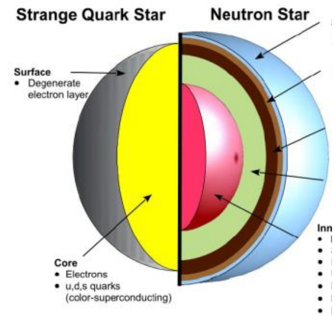
SSC: ≤100 AMeV (H.I.), ≤ 110 MeV (p)

CSRm: ≤1000 AMeV (H.I.), ≤ 2.8 GeV (p)

CEE

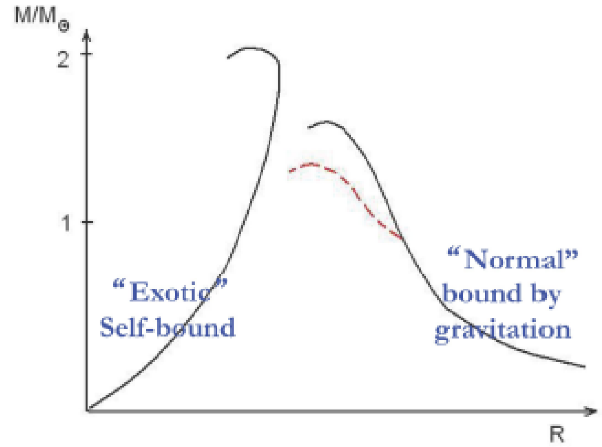


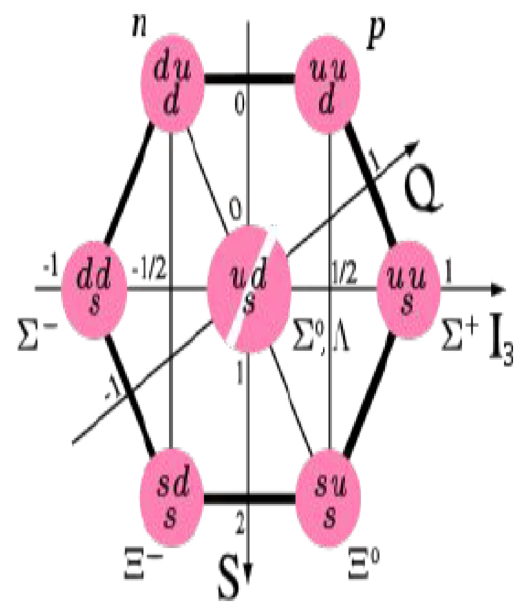
Physics case: EOS symmetry energy



Ang Li

- Two-branch picture?
- Any strangeness phase transition leads to softer EOS (lower M_{TOV}) (Hyperon puzzle) (e.g., ***AL*** et al. 2006, 2010, 2013, 2016);
- Nucleonic EOS sufficiently stiff, or only weak soften (late appearance) of Delta(1232)/hyperon/Kaon/quark (e.g., ***AL*** et al. 2015);
- Universal baryonic repulsive three-body force, or stiff quark core;
- Study of hyperon interaction (NY,YY,NNY,NYY,YYY) through hyperonnuclei/scattering experiments <u>VERY IMPORTANT</u> (e.g., ***AL*** et al. 2007, 2013; Hu, ***AL*** et al. 2014).



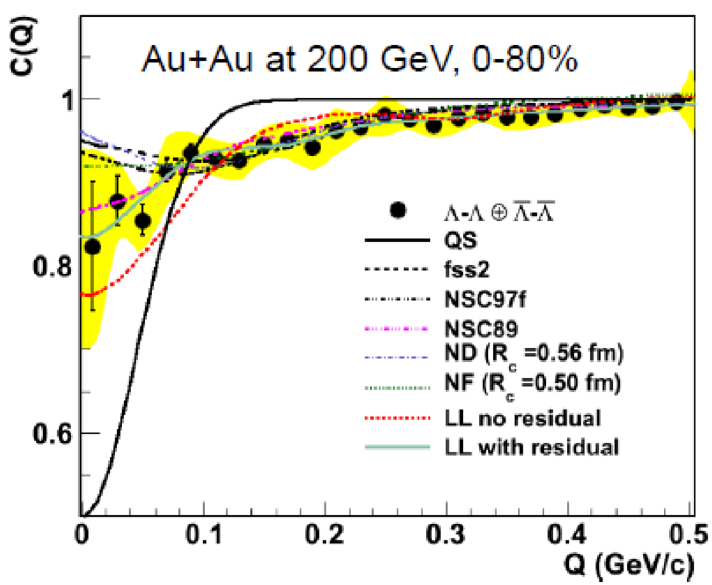


Hyperon puzzle in neutron stars: ΛN and ΛΛ Interaction

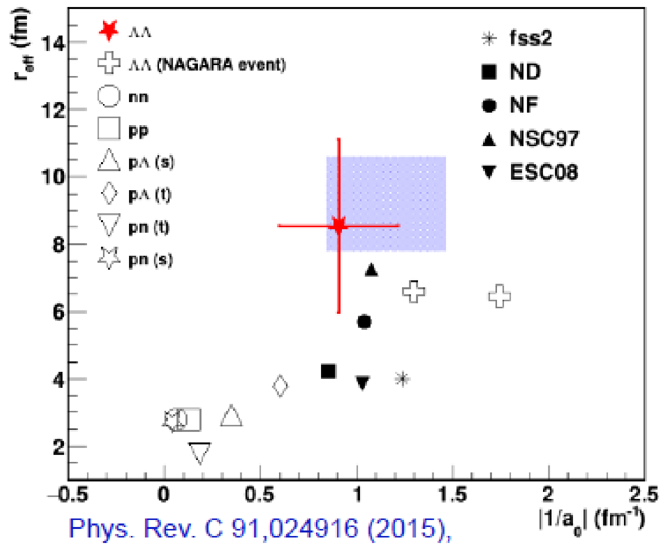
Jinhui Chen

Lambda-Lambda Correlation Function

STAR Col. Phys. Rev. Lett. **114**, 022301 (2015)



$$|a_{\Lambda\Lambda}| < |a_{p\Lambda}| < |a_{NN}|$$

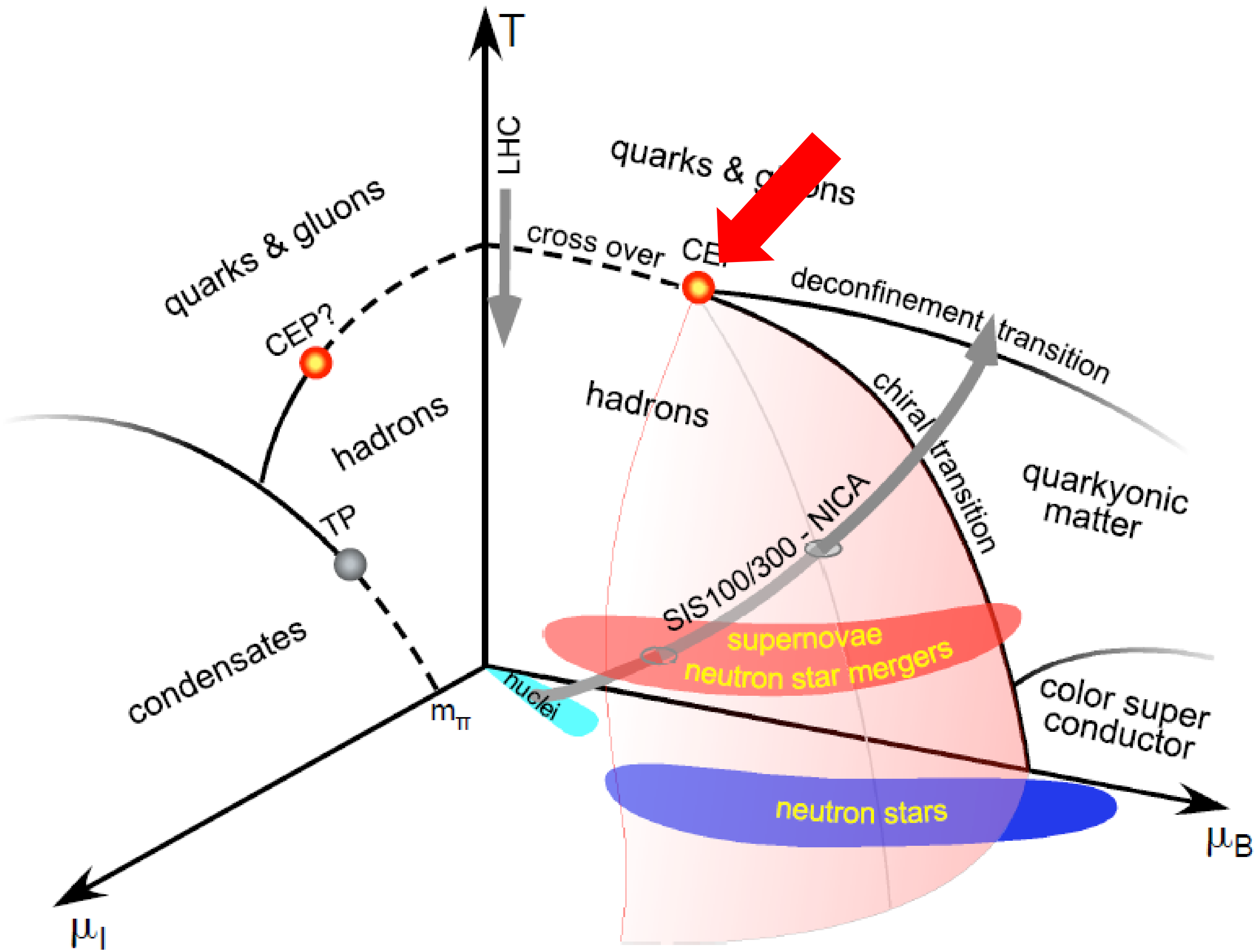


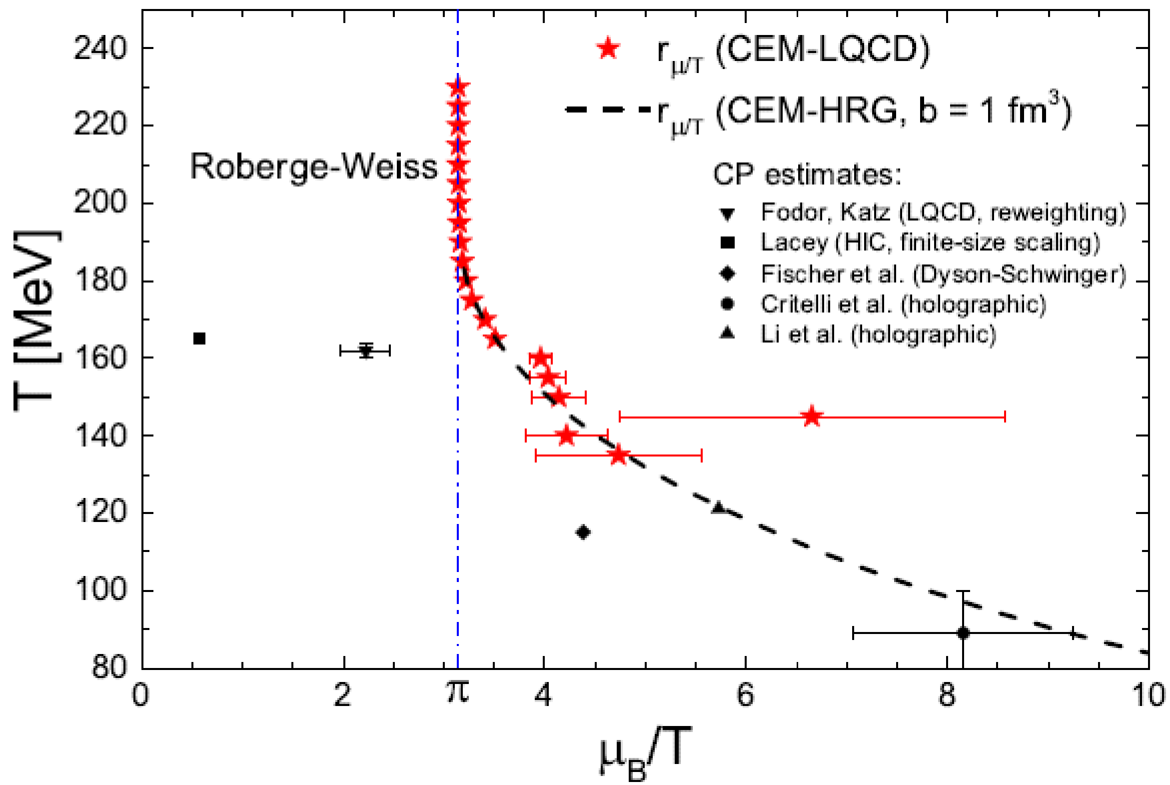
Phys. Rev. C 91,024916 (2015),
Prog. Part. Nucl. Phys. 95 (2017) 279

☑ All model fits to data suggest that a rather weak interaction is present between ΛΛ pairs

t → for triplet state
s → for singlet state
n-n → Phys. Lett. B, 80 (1979) 187
p-n → Phys. Rev. C 66, 047001 (2002)
p-p → Mod. Phys. 39 (1967) 584
p-Λ → Phys. Rev. Lett. 83, 3138 (1999)
ΛΛ → Phys. Rev. C 66, 024007(2002)
ΛΛ → Nucl. Phys. A 707 (2002) 491

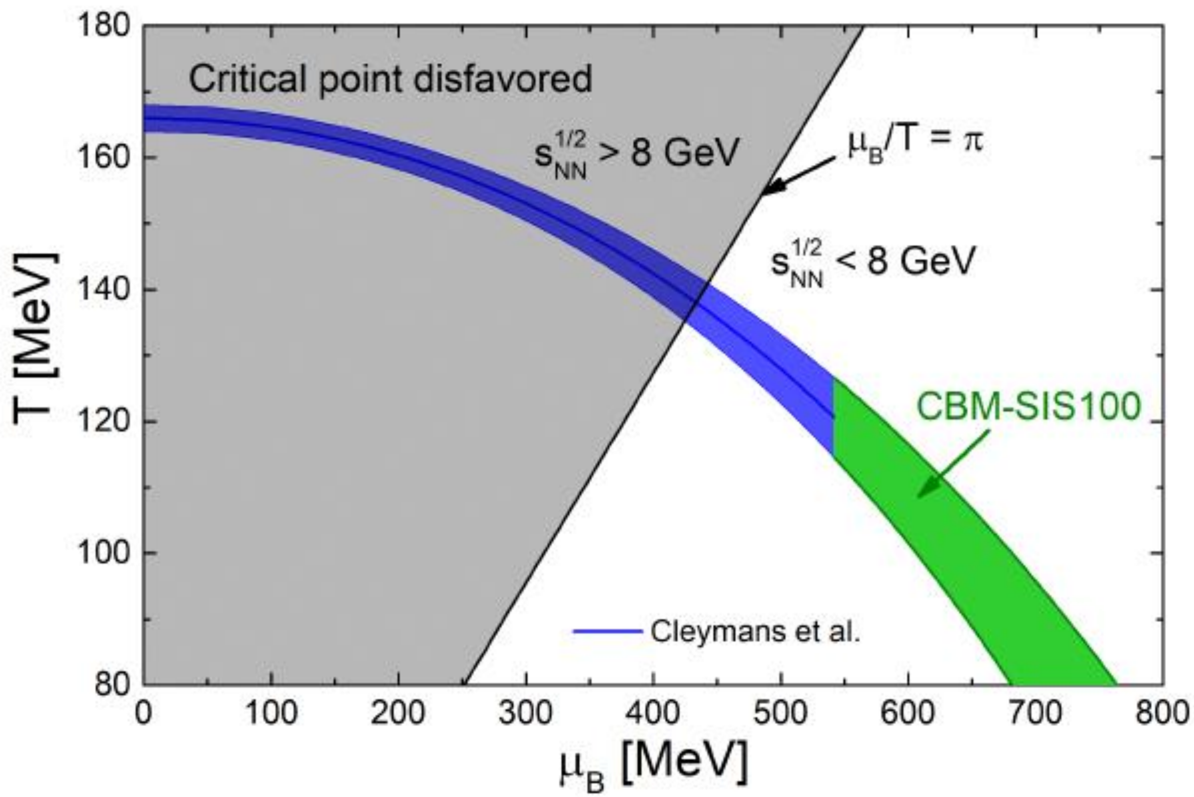
Exploring the QCD phase diagram





- LQCD susceptibilities at $\mu = 0$ are consistent with the Roberge-Weiss type transition in the complex μ_B/T plane [Roberge, Weiss, NPB '86]
- No evidence for a phase transition at $\mu_B/T \lesssim \pi$

Where to look for a critical point

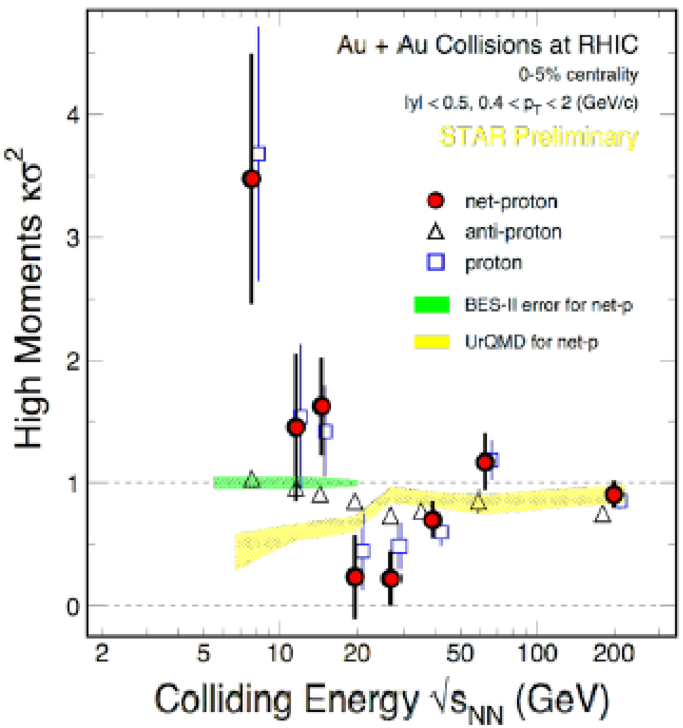


CBM may be in the right spot!

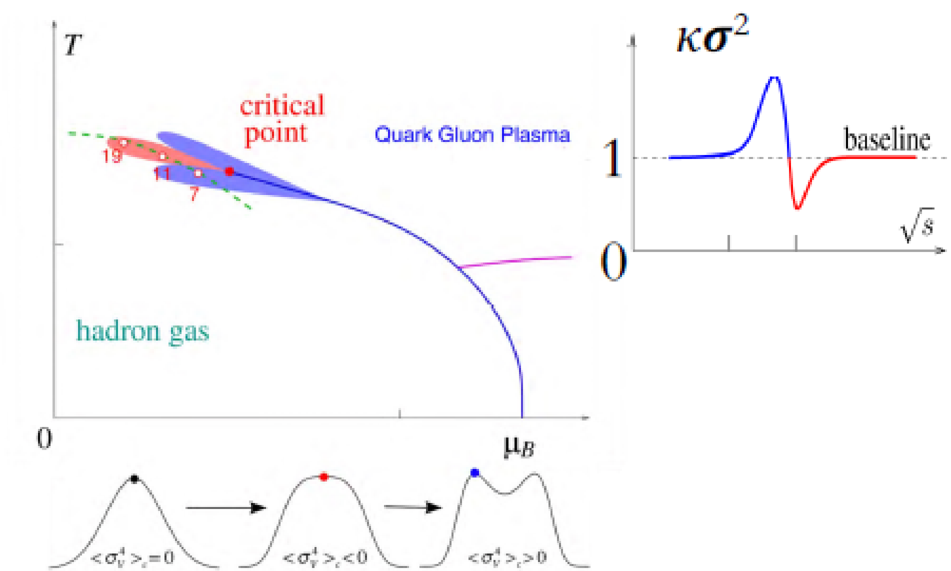
4th order Net-Proton Fluctuations $\kappa\sigma^2 = C_4/C_2$

➢ First observation of the non-monotonic energy dependence of fourth order net-proton fluctuations. Hint of entering Critical Region ??

STAR Data



σ field Model

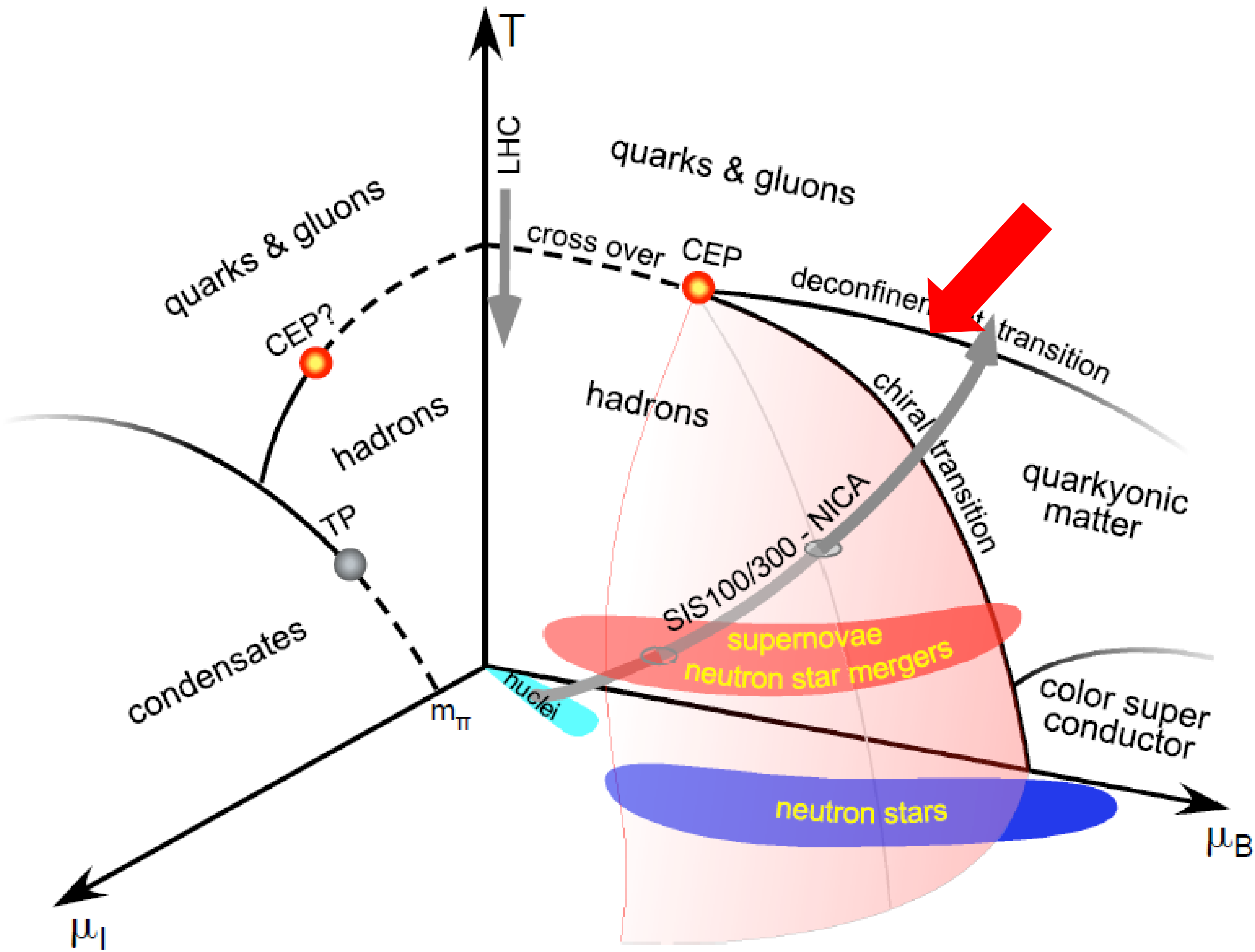


Critical signal: Oscillation Structure

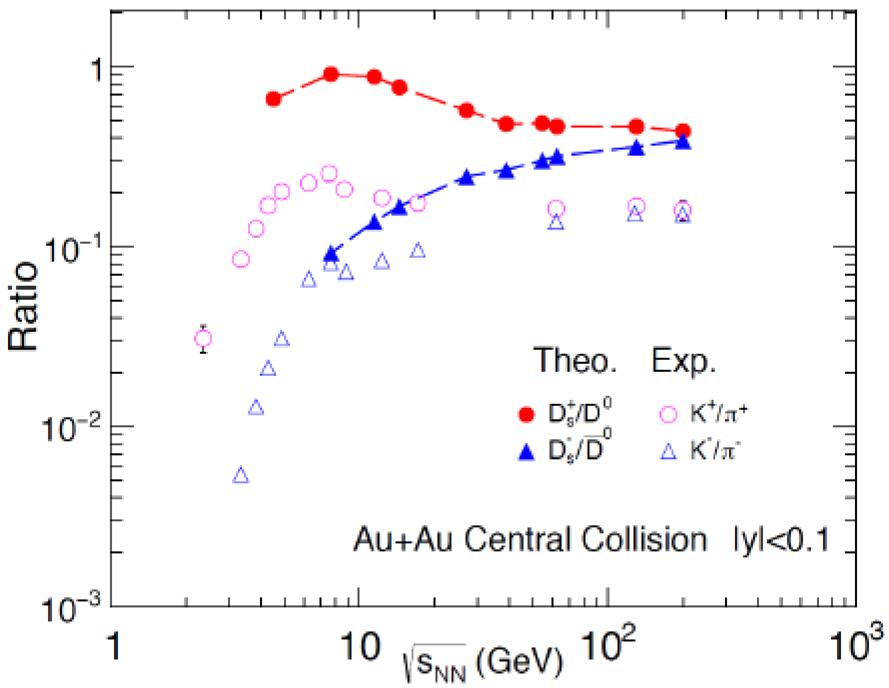
STAR, PRL105,022302 (2010); PRL112,032302 (2014).
STAR, CPOD2014 and QM2015

M. A. Stephanov, PRL102, 032301 (2009).
M. A. Stephanov, PRL107, 052301 (2011).

Exploring the QCD phase diagram

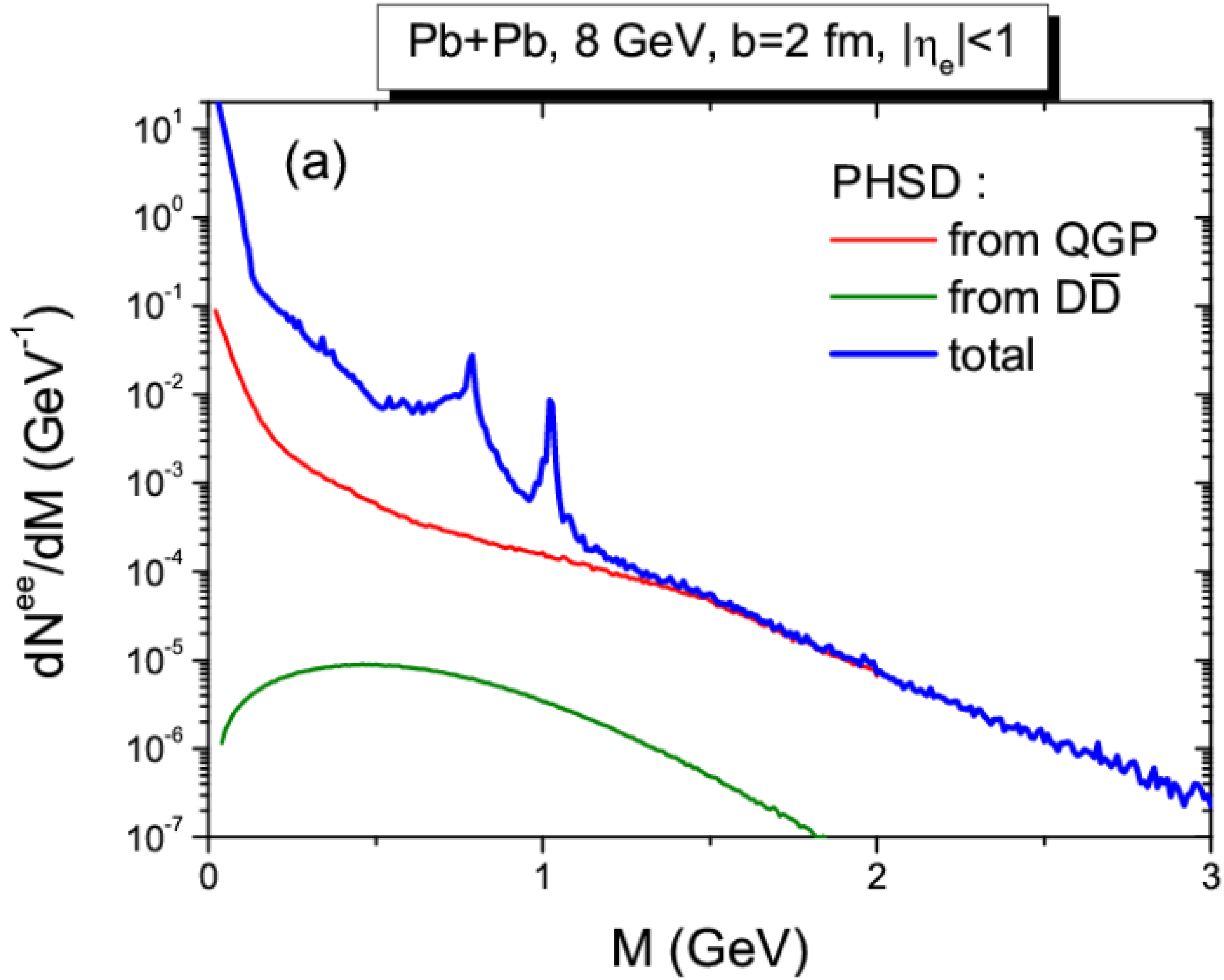


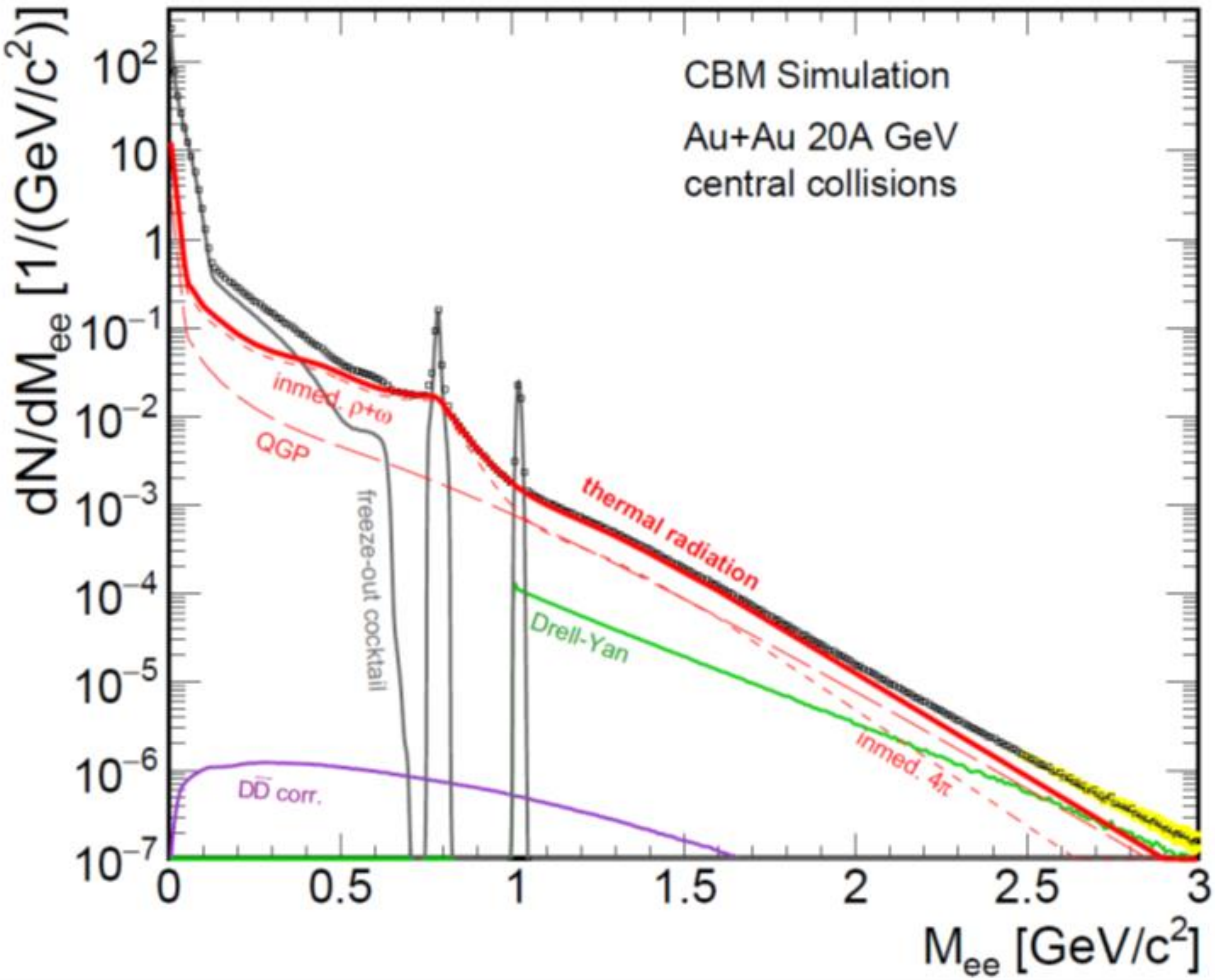
Comparison with K/π



■ *All the lines are controlled by strangeness enhancement, charm conservation and baryon density effects.*

Pierre Moreau

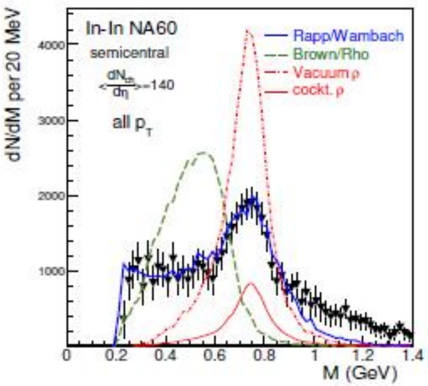




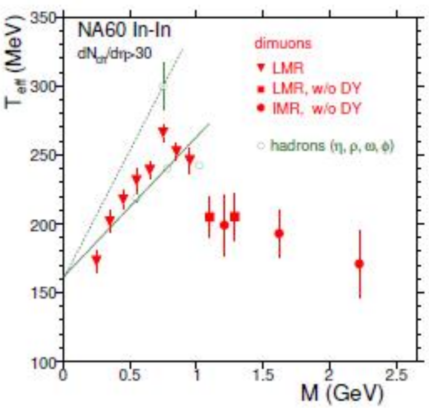
CBM Simulation
Au+Au 20A GeV
central collisions
dN/dM_ee [1/(GeV/c^2)]
M_ee [GeV/c^2]
inmed. ρ+ω
QGP
freeze-out cocktail
thermal radiation
Drell-Yan
inmed. 4π
DD̄ corr.

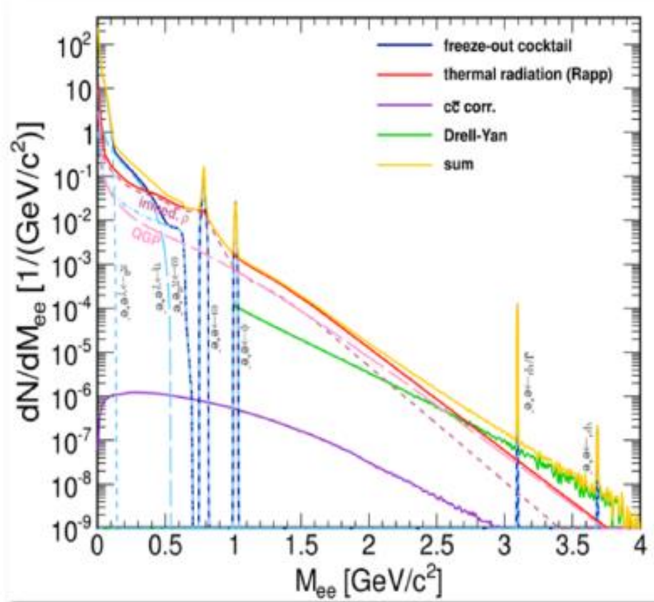
Joachim Stroth

Spectrometer



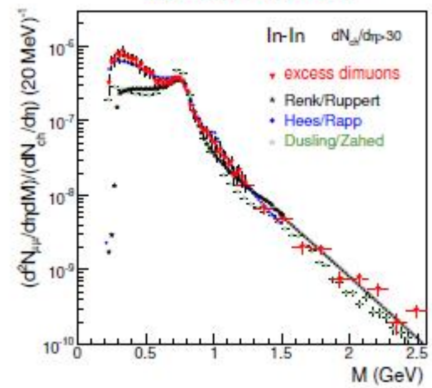
Barometer $(d_N/dp_\perp)$



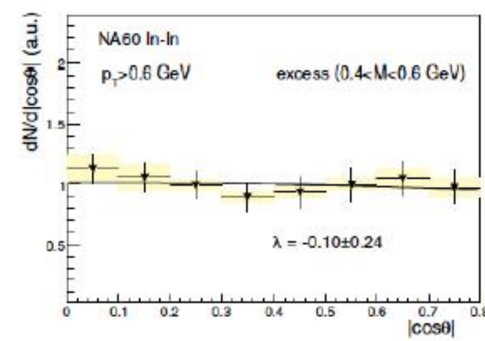


All data from NA60

Thermometer



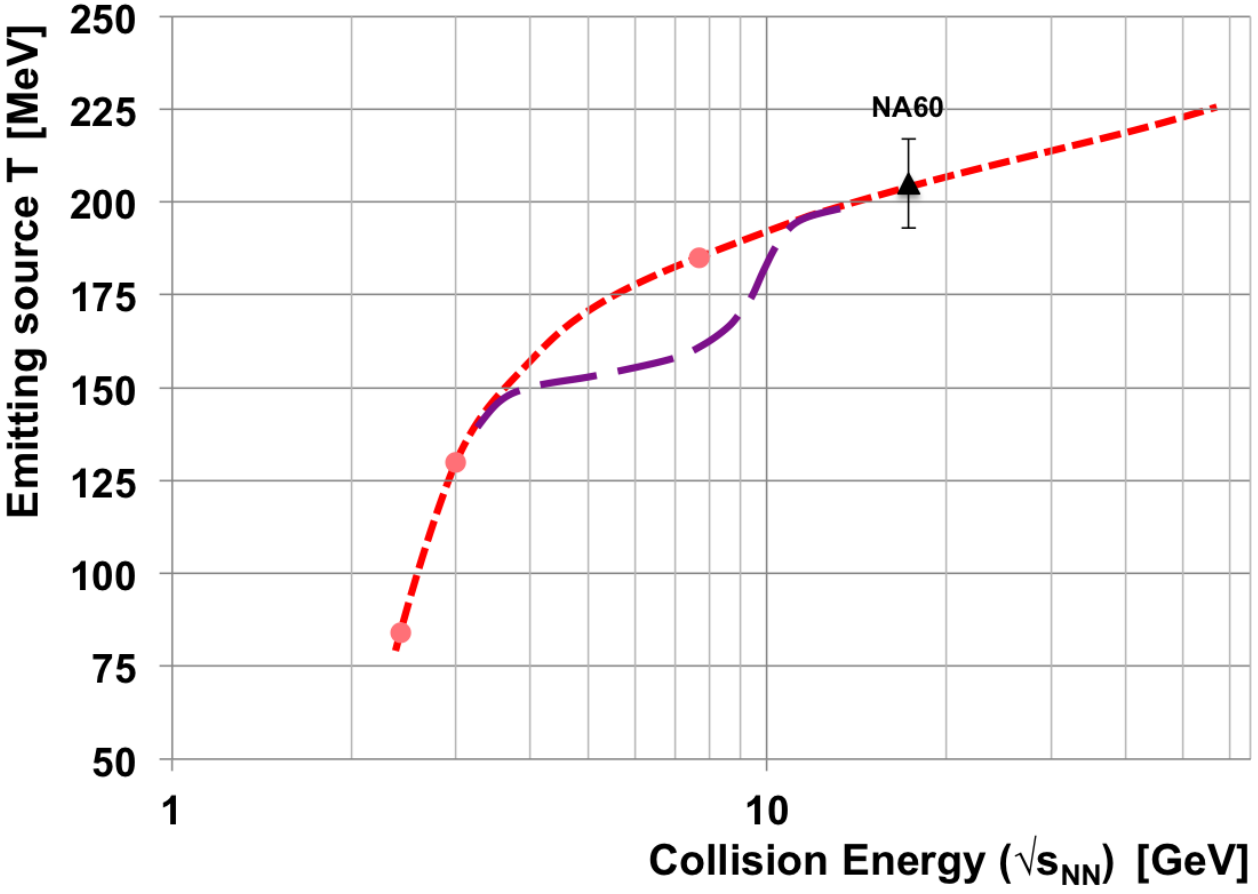
Polarimeter



Search for caloric curve

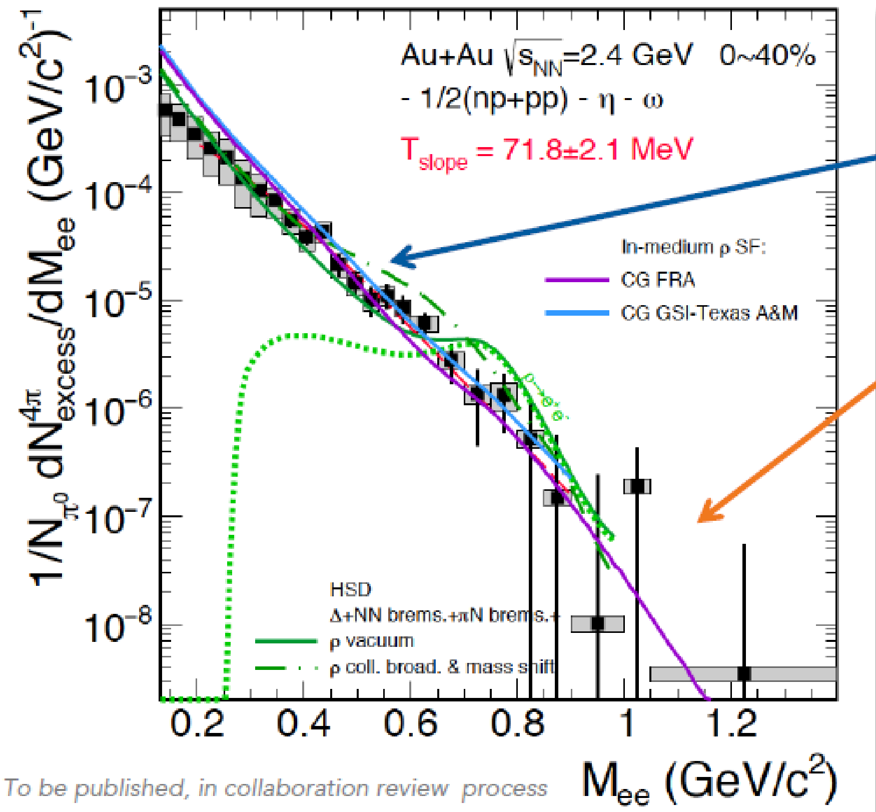
Joachim Stroth

Slope of dilepton invariant mass spectrum
1 GeV/c^2 < M_{inv} < 2.5 GeV/c^2



Joachim Stroth

Dileptons from HADES Au+Au 1.23*A* GeV

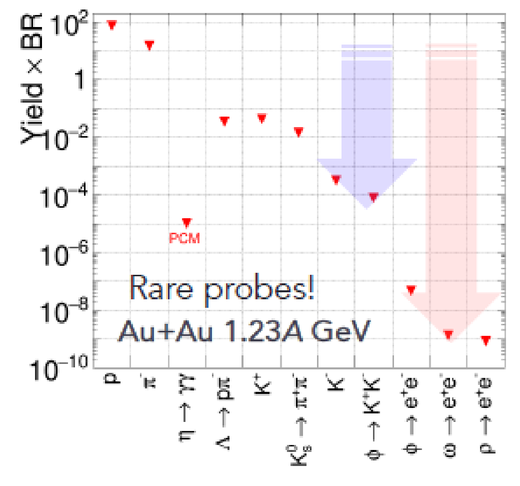


0.3 < M < 0.7 GeV:

- 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

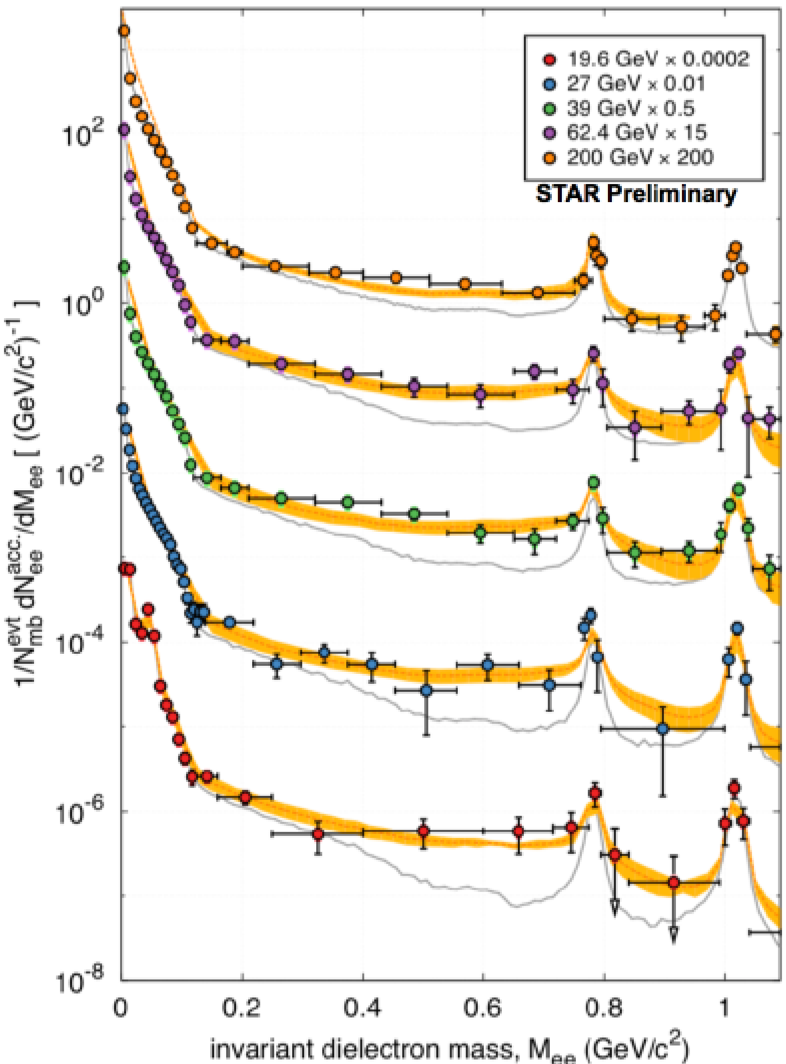


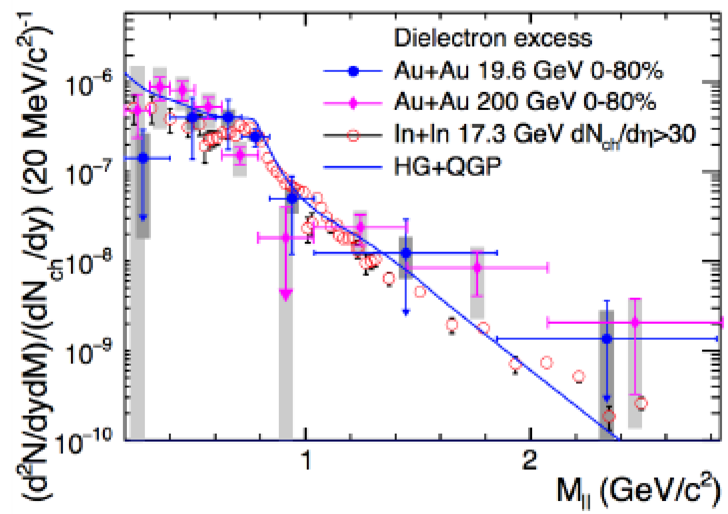
- Microscopic transport[2]:
  - vacuum ρ spectral function and Δ regeneration
  - & explicit broadening and density dependent mass shift
- Coarse-grained UrQMD[3]
  - thermal emissivity with in-medium propagator [4]
  - $\rho - a_1$ chiral mixing[5] (not measured so far)

(4) Rapp, van Hees; arXiv:1411.4612v
(2) E. Bratkovskaya;
(3) CG FRA Endres, van Hees, Bleicher; arXiv:1505.06131
CG GSI-TAMU; Galatyuk, Seck, et al. arXiv:1512.08688
(4) Rapp, Wambach, van Hees; arXiv:0901.3289
(5) Rapp, Hohler; arXiv:1311.2921v

Jochim Stroth

Dilepton excess spectra in BES-I

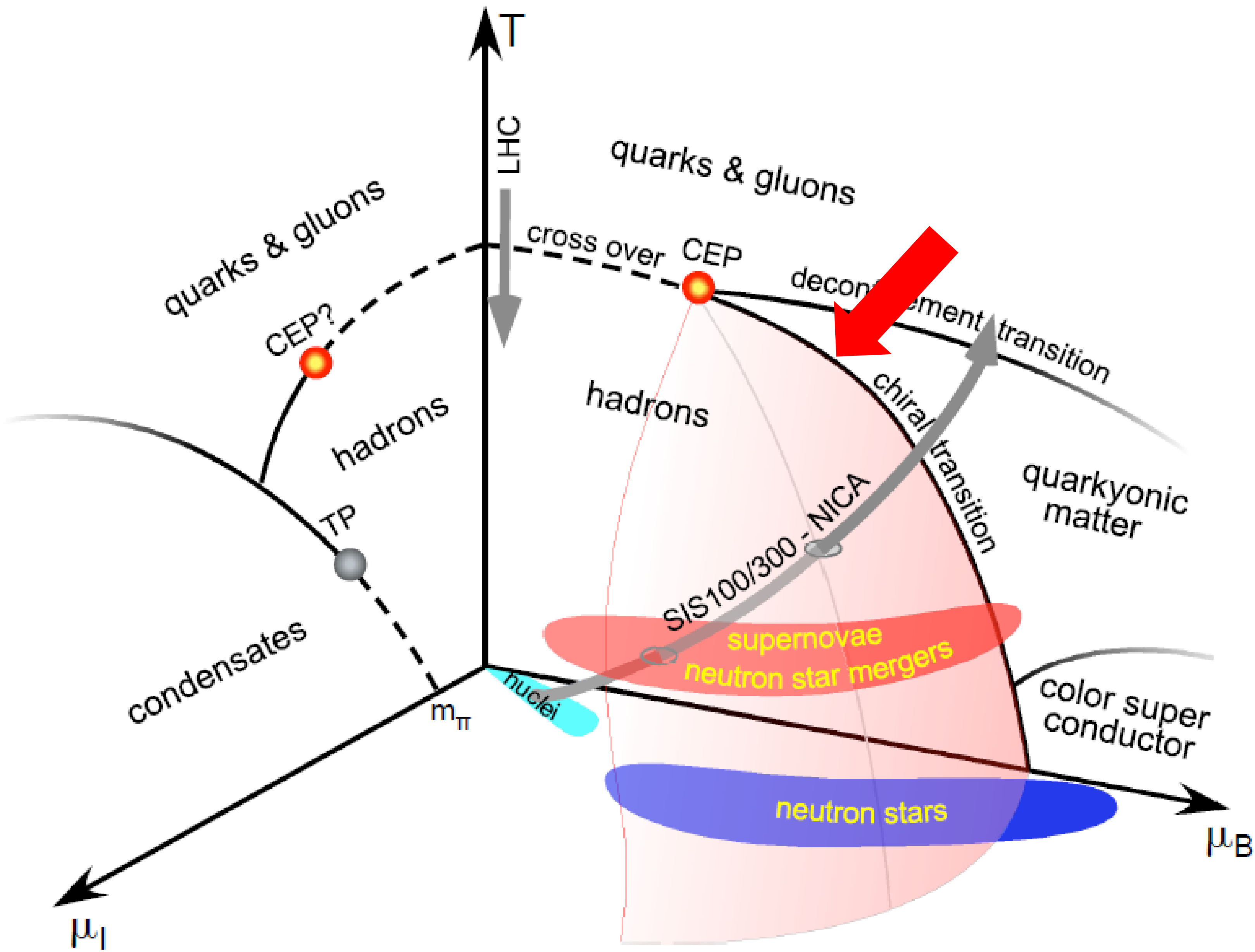




AuAu@19.6,200: STAR, PLB750 64 2015
AuAu@27,39,62&UU@193: S. Yang, Quark Matter 2015
InIn@17.3: NA60, EPJ C59 607 2009
Theory: R. Rapp, PRC 63 (2001) 054907

Consistent with ρ in-medium modification.
Weak collision energy dependence
=> Leptons are blindly emitted in HG + QGP.

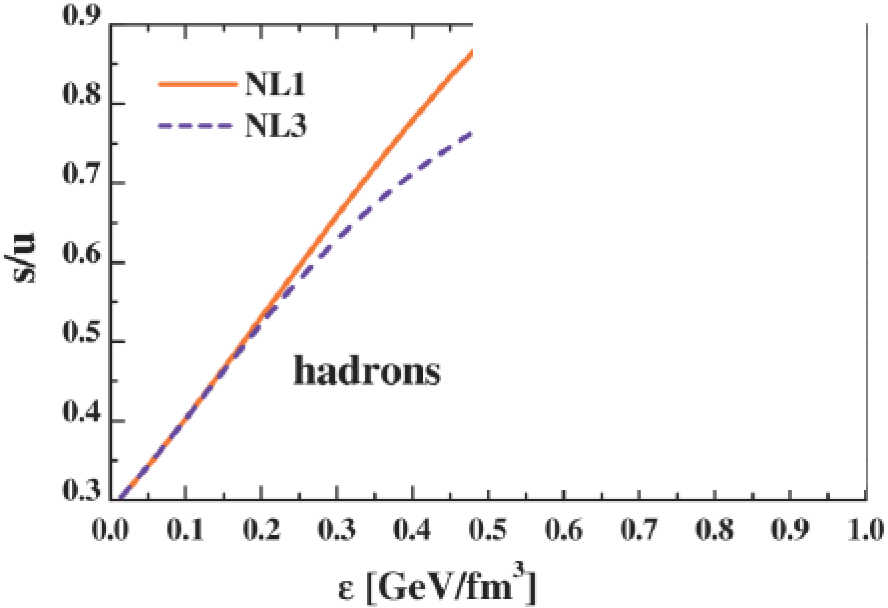
Exploring the QCD phase diagram



Pierre Moreau

- **Hadronic phase $\varepsilon < \varepsilon_c$:** As a consequence of the chiral symmetry restoration (CSR), the strangeness production probability increases with the local energy density ε

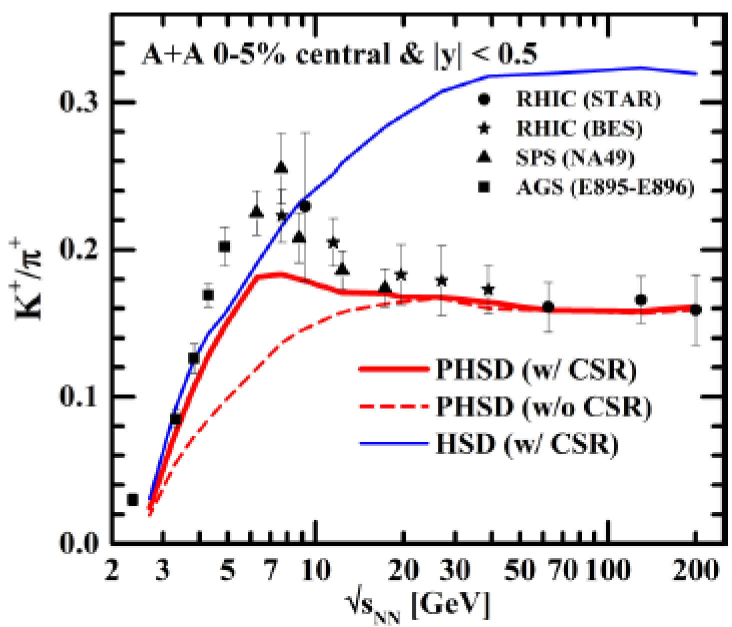
- **QGP phase $\varepsilon > \varepsilon_c$:** the string decay doesn't occur anymore and this effect is therefore suppressed.

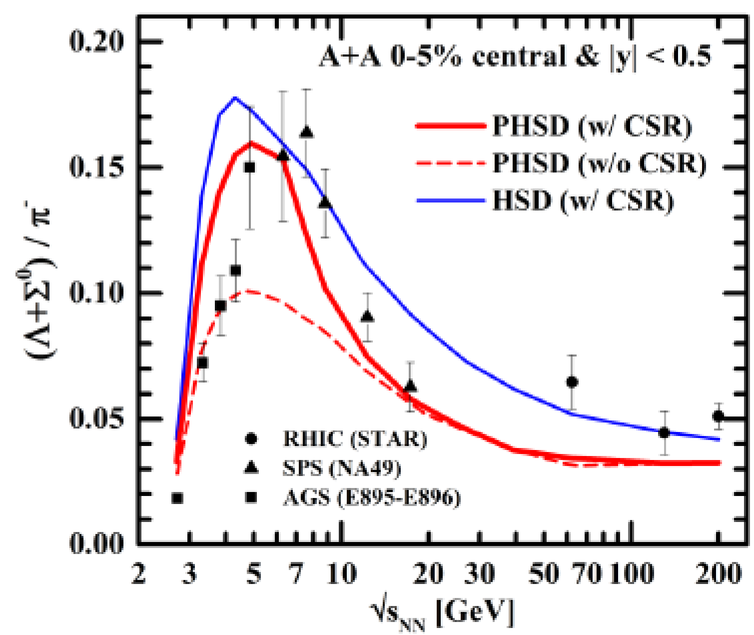


Chiral symmetry restoration in the hadronic phase

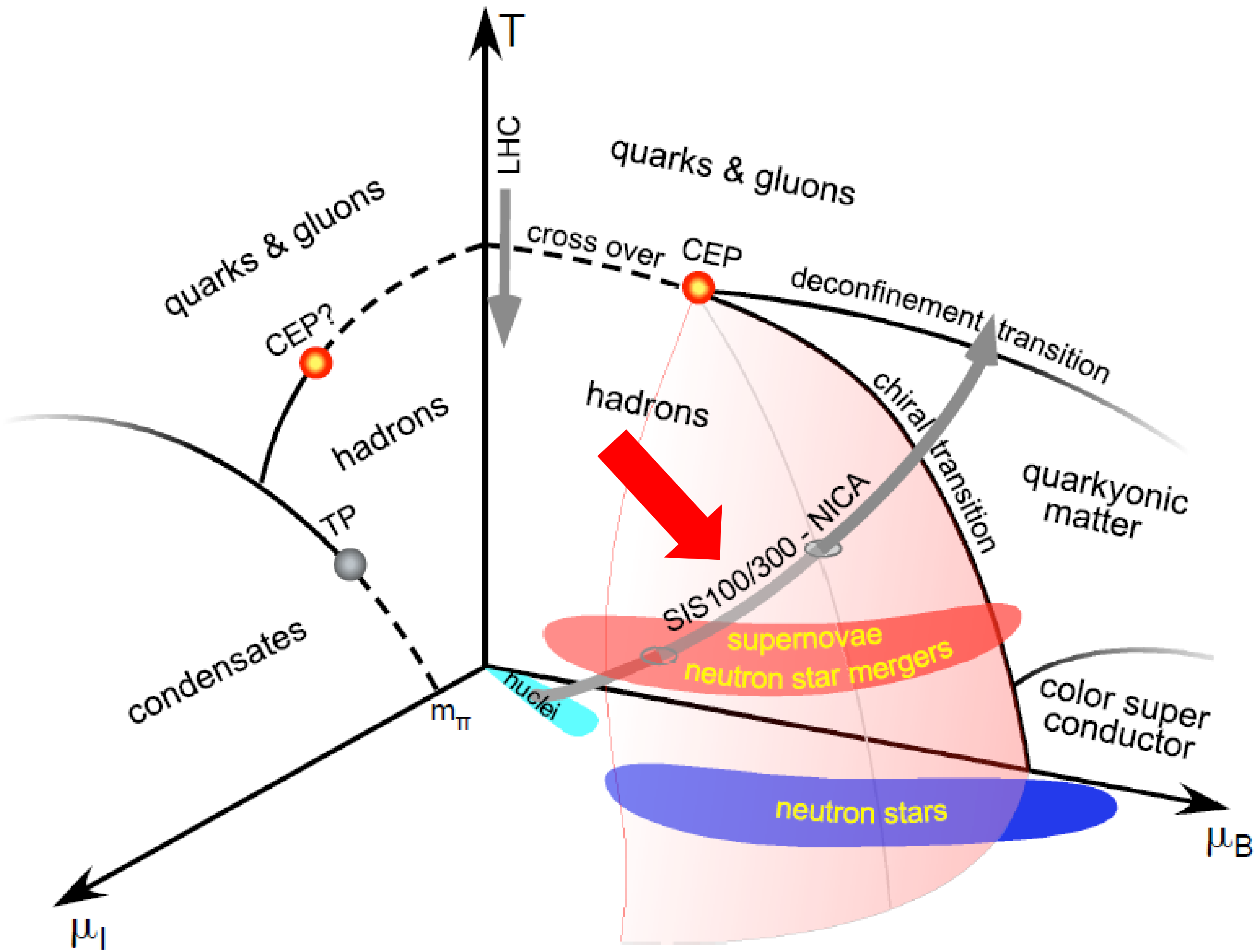
- **The strangeness enhancement seen experimentally at FAIR/NICA energies probably involves the approximate restoration of chiral symmetry in the hadronic phase**

W. Cassing, A. Palmese, P. Moreau, E.L. Bratkovskaya - **Phys.Rev. C93 (2016), 014902**





Exploring the QCD phase diagram



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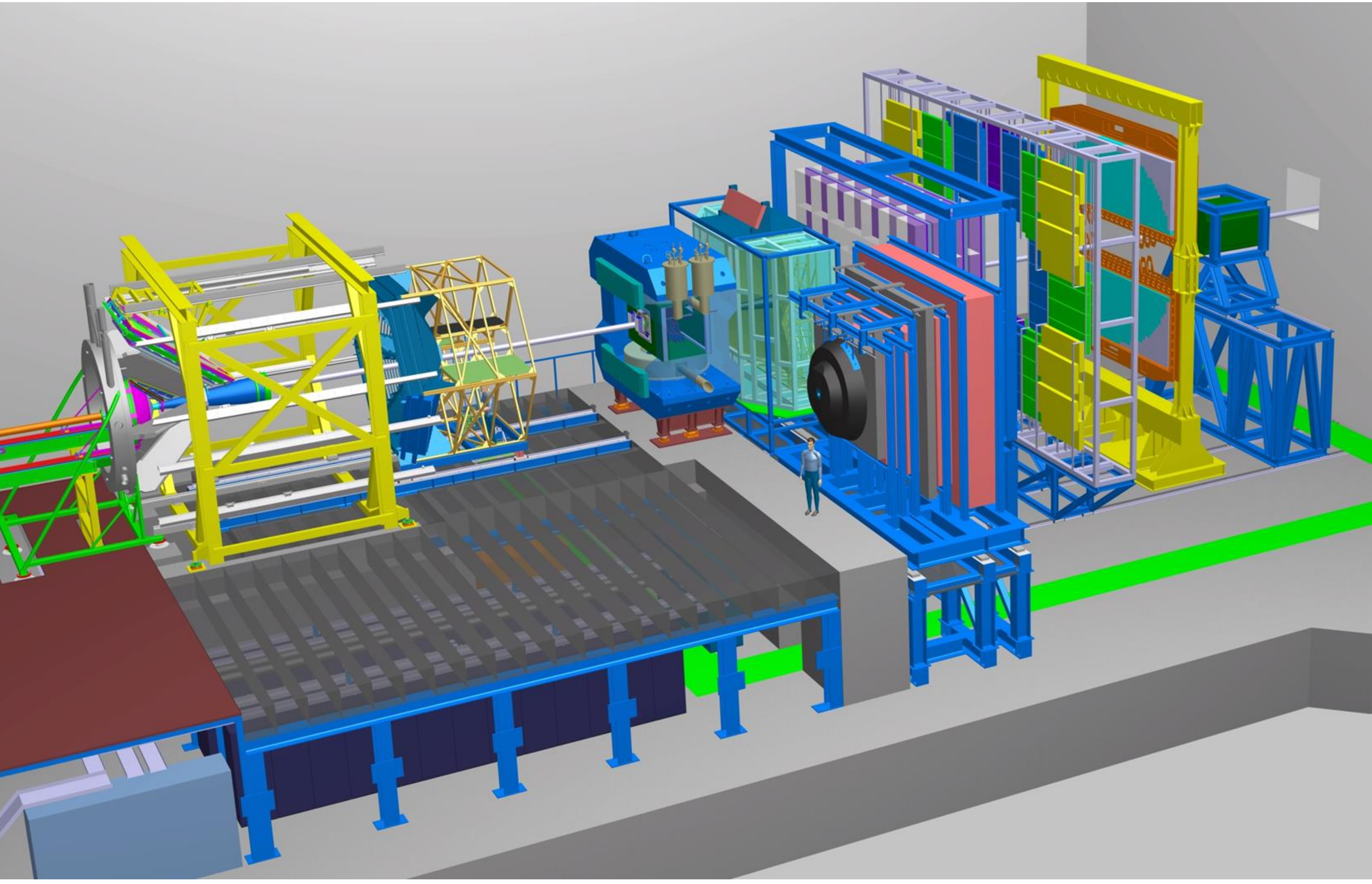

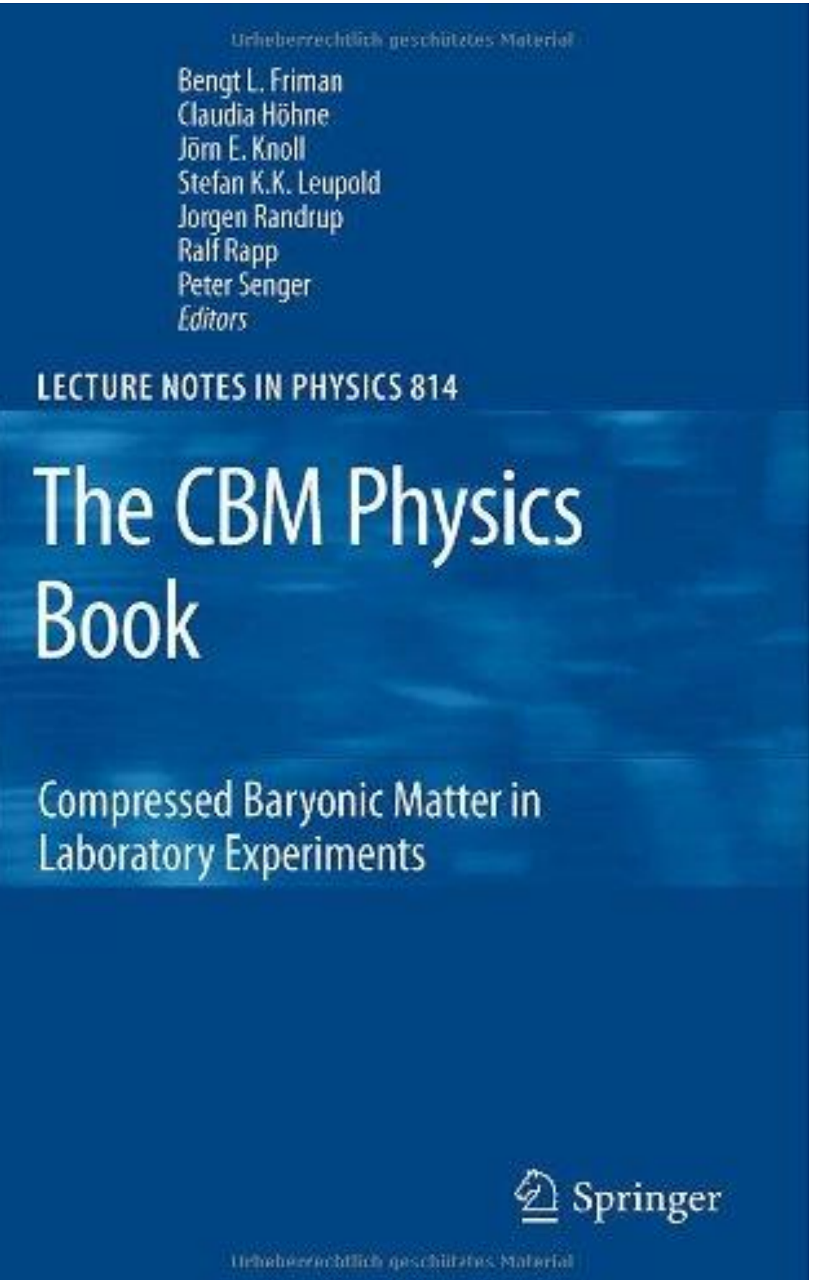

Intensify discussions with colleagues from theory and astrophysics !

The CBM Physics Book

Compressed Baryonic Matter in Laboratory Experiments

Foreword by Frank Wilczek

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