

Neutrino Reactions and Supernova Nucleosynthesis (NuSTAR)

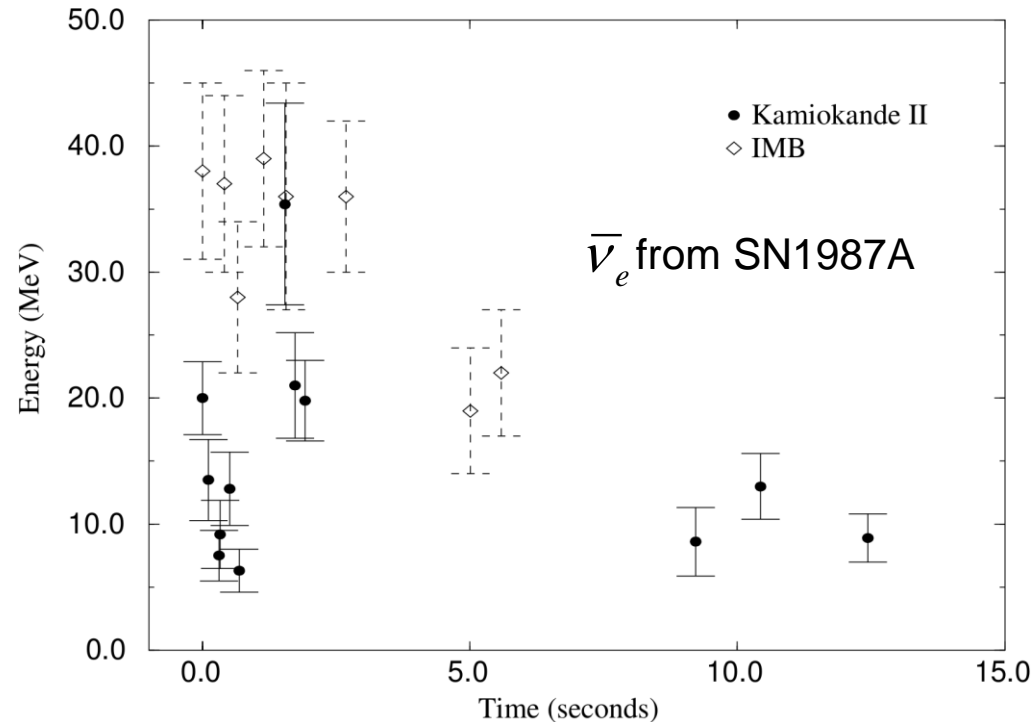
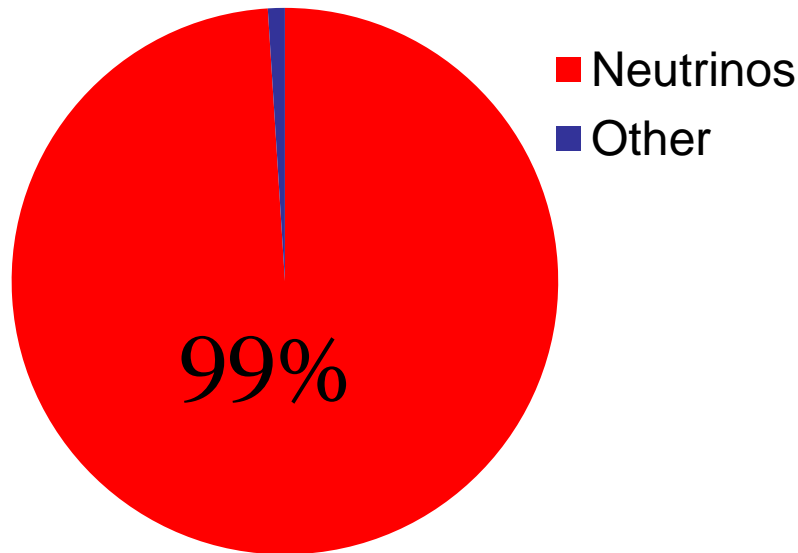
International Conference on Science and Technology for
FAIR in Europe - October 16 – Worms

Andreas Lohs (TU Darmstadt)

Neutrinos in Supernovae

Core collapse supernovae release huge amount of energy

Supernova energy

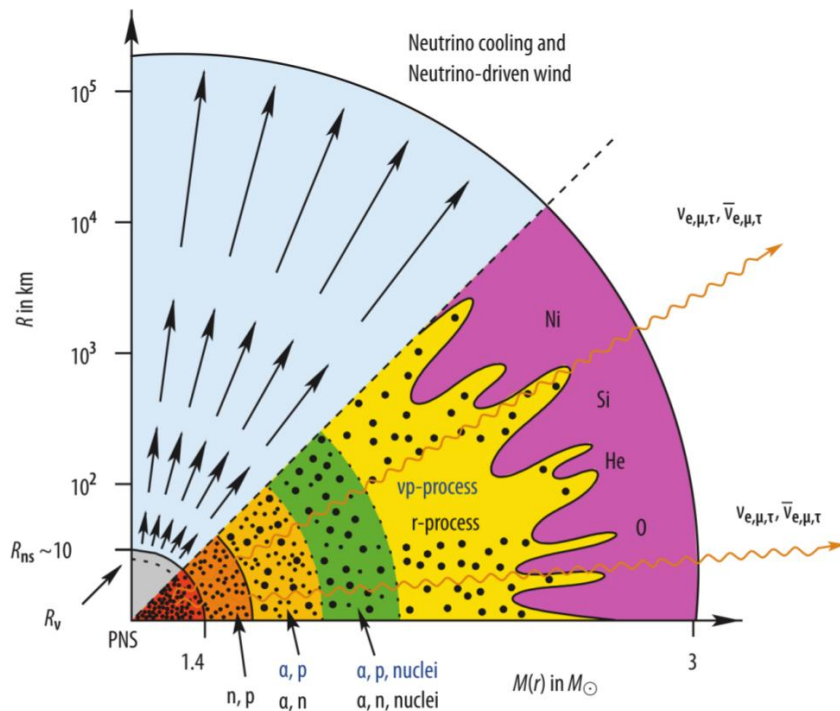
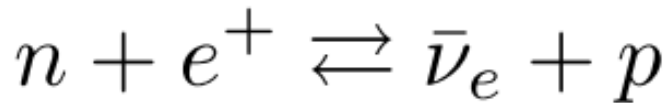
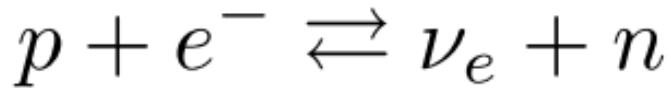


How far does the nucleosynthesis of heavy elements depend on neutrino physics?

Neutrinos and Nucleosynthesis

Interior of the neutron star:

Neutrino production mechanism



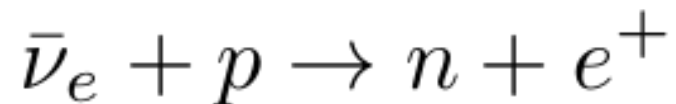
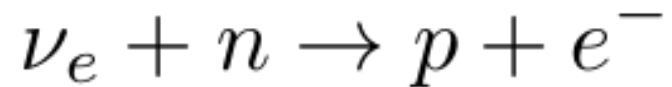
$$\langle E_{\bar{\nu}_e} \rangle - \langle E_{\nu_e} \rangle$$

$$\Downarrow$$

$$Y_e$$

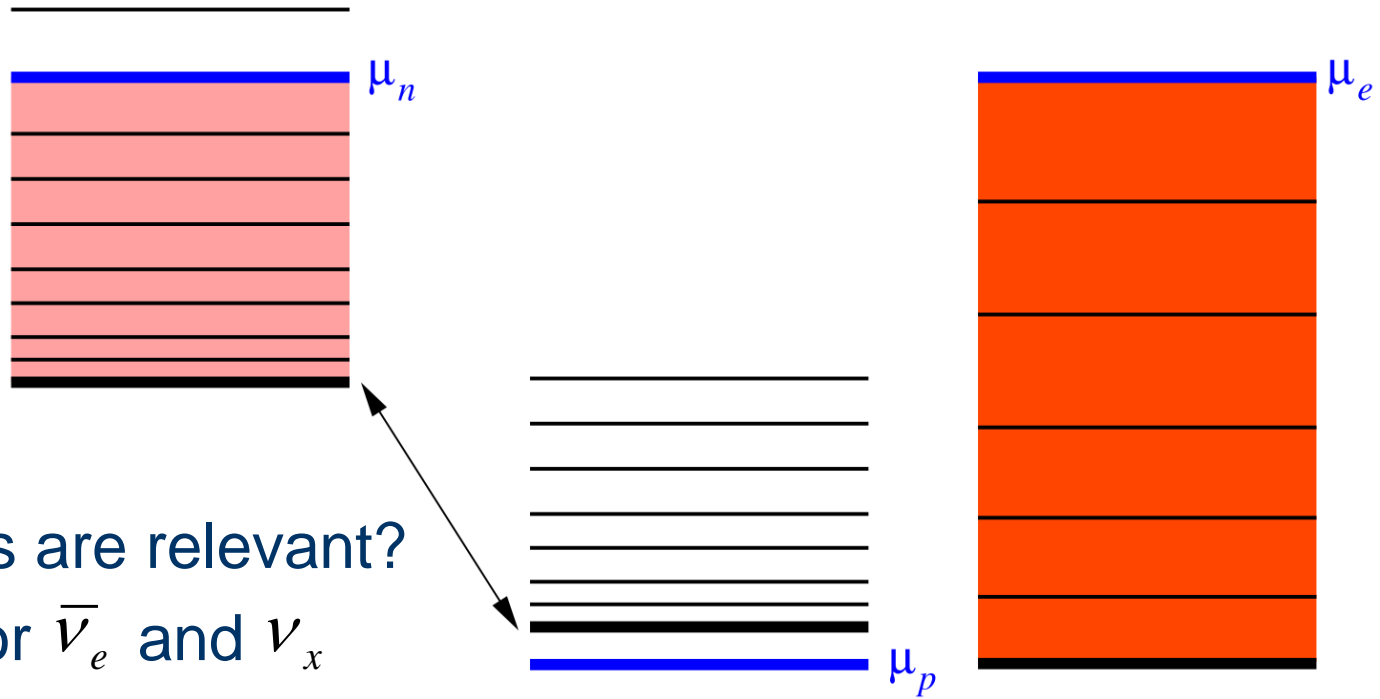
Neutrino Driven Wind Ejecta:

Neutrino absorption ejects matter
Spectrum determines composition



Uncertainties in Neutrino Physics

What is the correct Equation of state?



Which reactions are relevant?

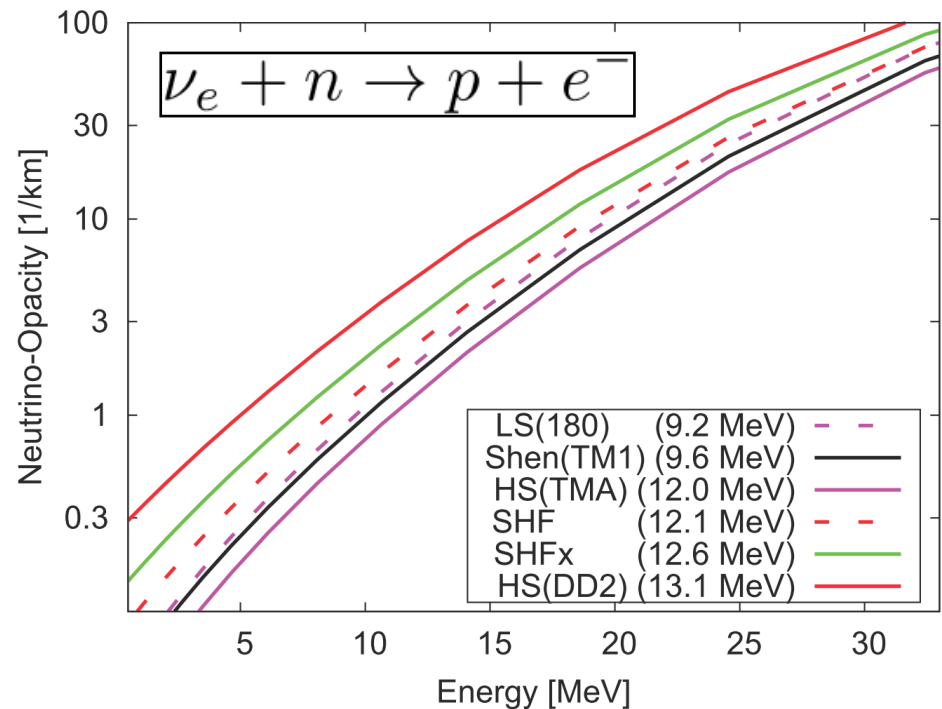
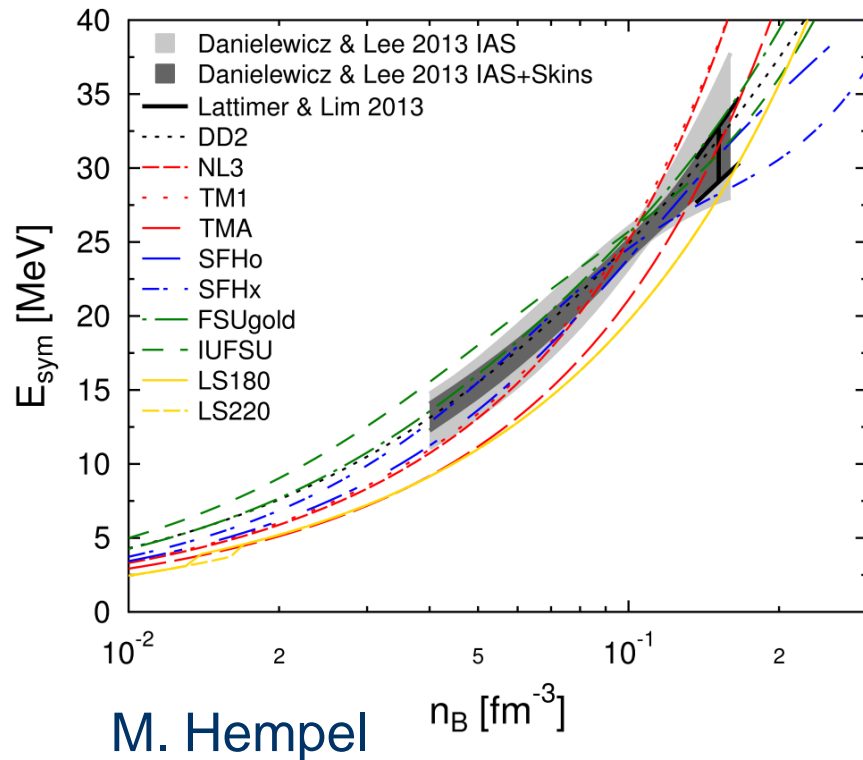
- Not obvious for $\bar{\nu}_e$ and ν_x

How to treat neutrino interactions?

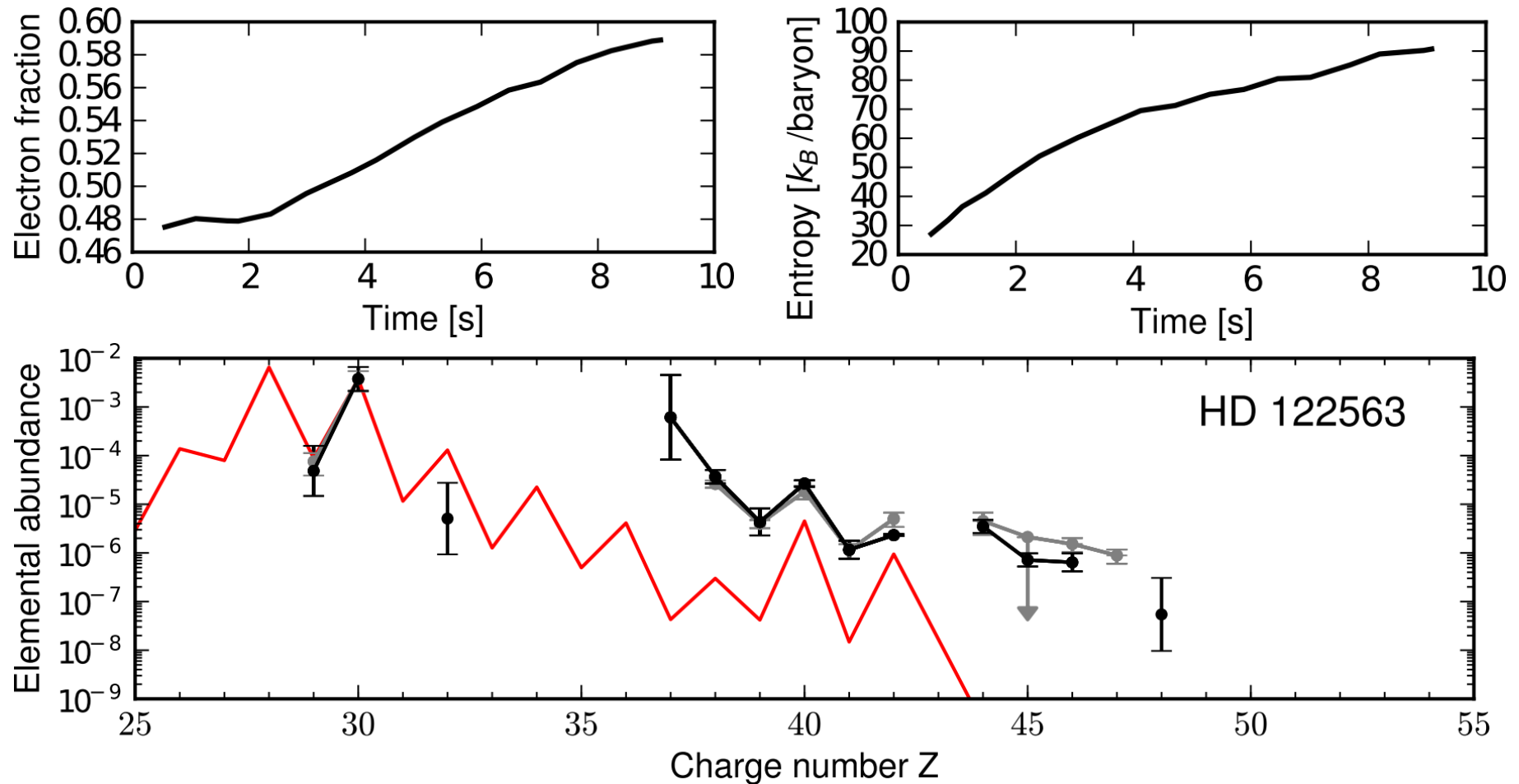
- inelasticity, relativity, medium effects, weak magnetism ...

High density Equation of State

- Key quantity: energy difference between neutrons and protons
→ symmetry energy
- Significant constraints from theory, experiments, astronomy:
 - chiral EFT, IAS, neutron skin, multifragmentation, NS-masses



Consistent yields for nucleosynthesis

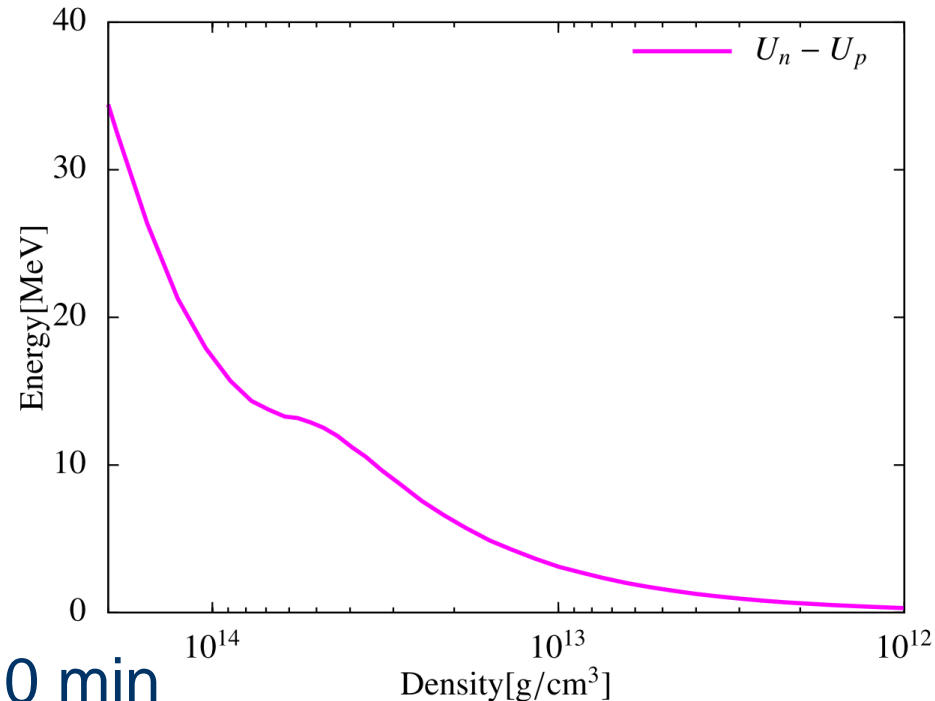
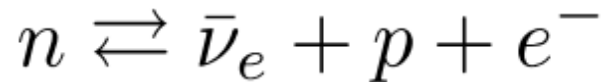
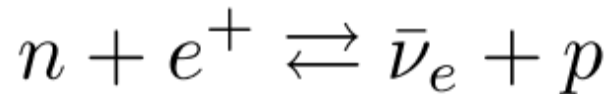


Martinez-Pinedo, Fischer, Lohs, Huther, PRL 109 (2012) 251104

Martinez-Pinedo, Fischer, Huther, JPhG 41 (2014) 044088

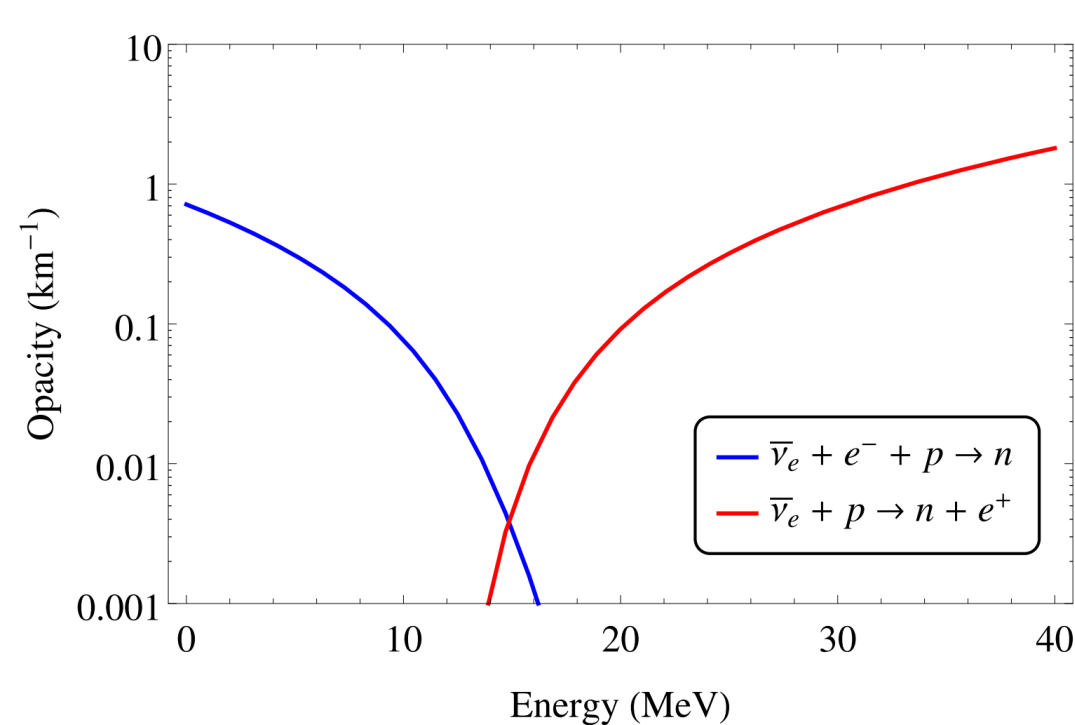
Neutron decay at high density

- Low energy $\bar{\nu}_e$ cannot be absorbed on protons or produced from positron capture for large $U_n - U_p$

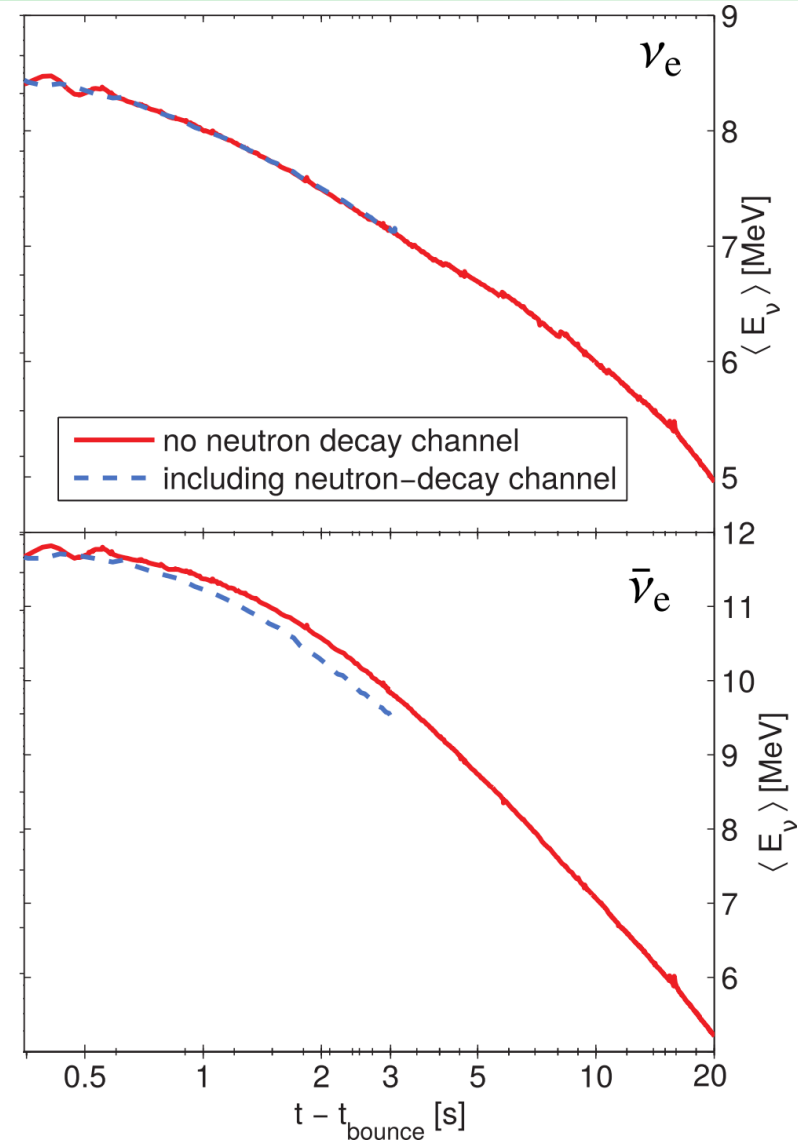


- Neutron lifetime in vacuum ~ 10 min
- Strong interaction increases Q-value for nucleon conversion
→ Decay rate raises

Neutron decay at high density

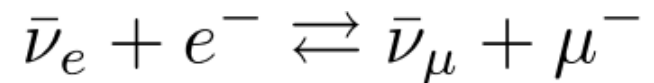
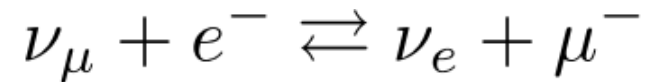
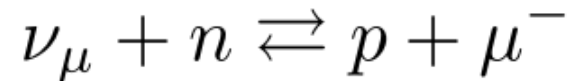
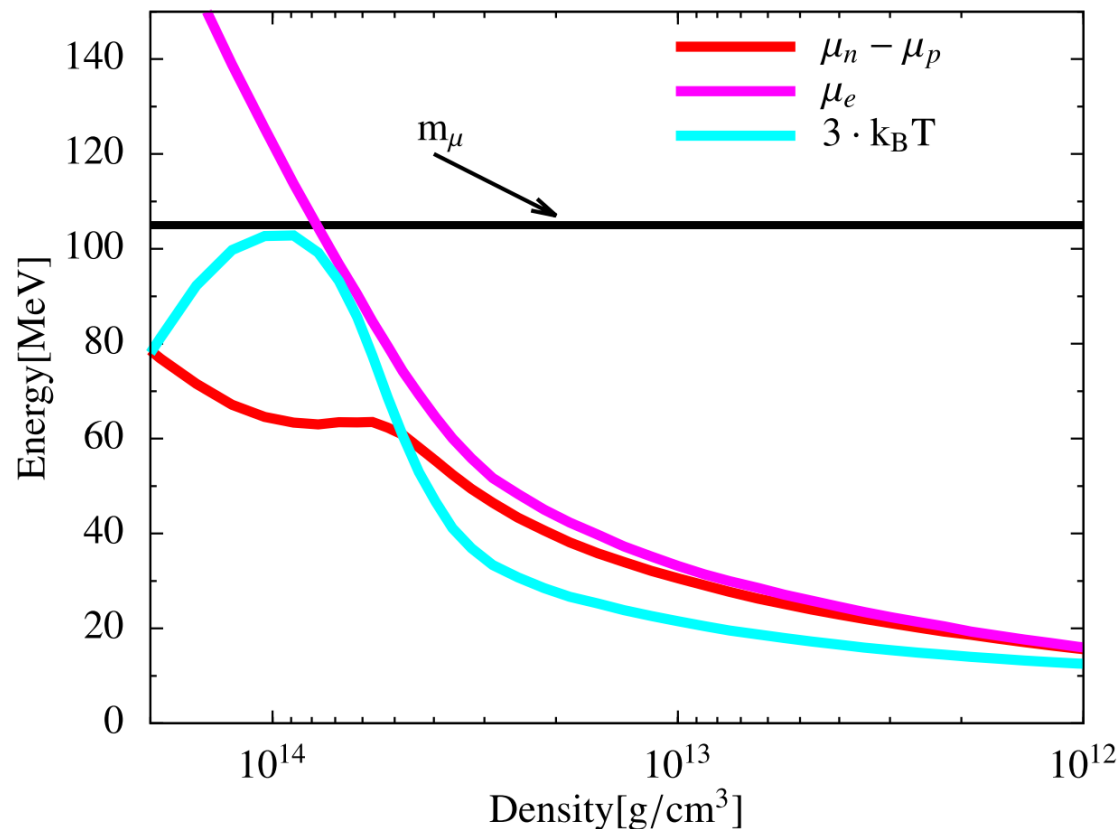


- Decreasing average energy of $\bar{\nu}_e$
 - Spectral change will affect nucleosynthesis yields
- Rising Y_e ?

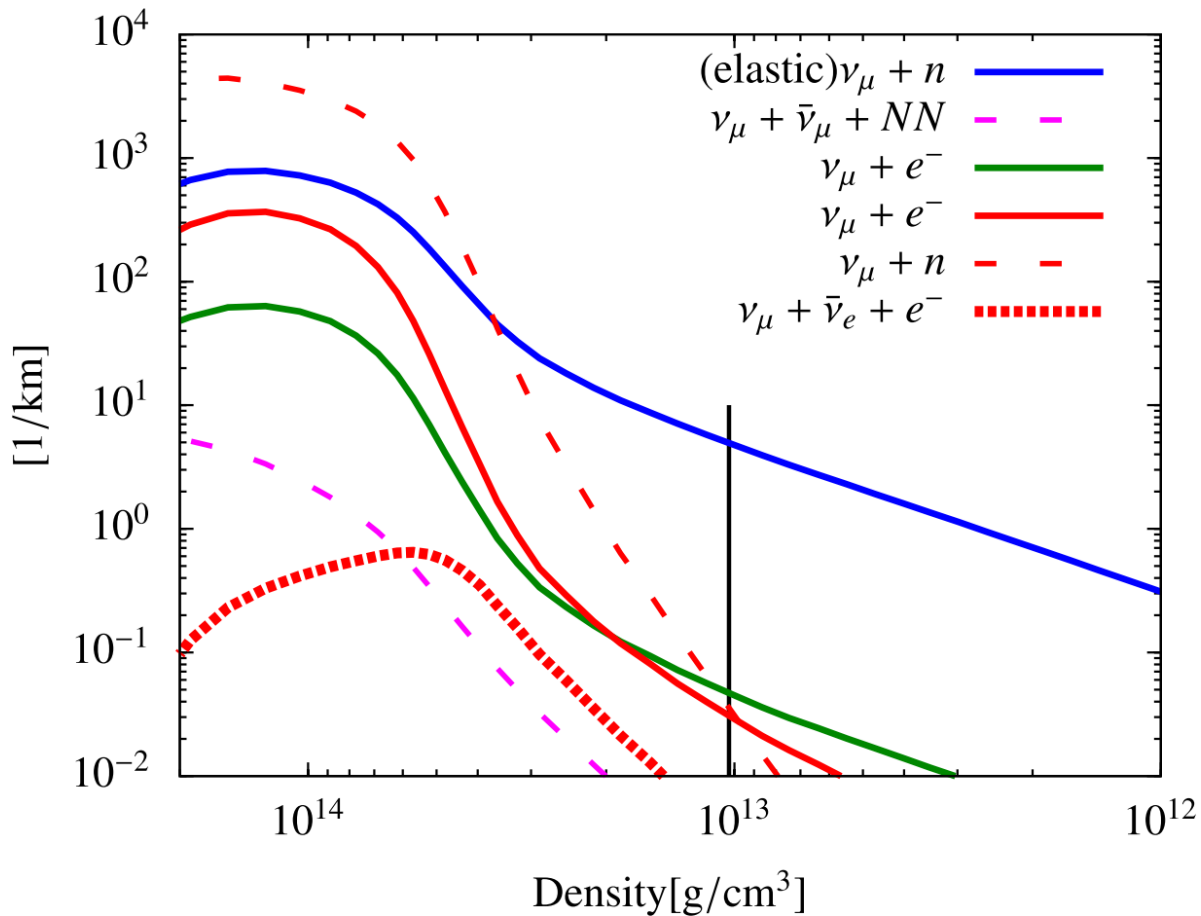


Charged-current interactions for muon neutrinos

- For all ν_x : neutral-current interaction (almost) the same
- Charged-current reaction for ν_μ must overcome Q-value of m_μ



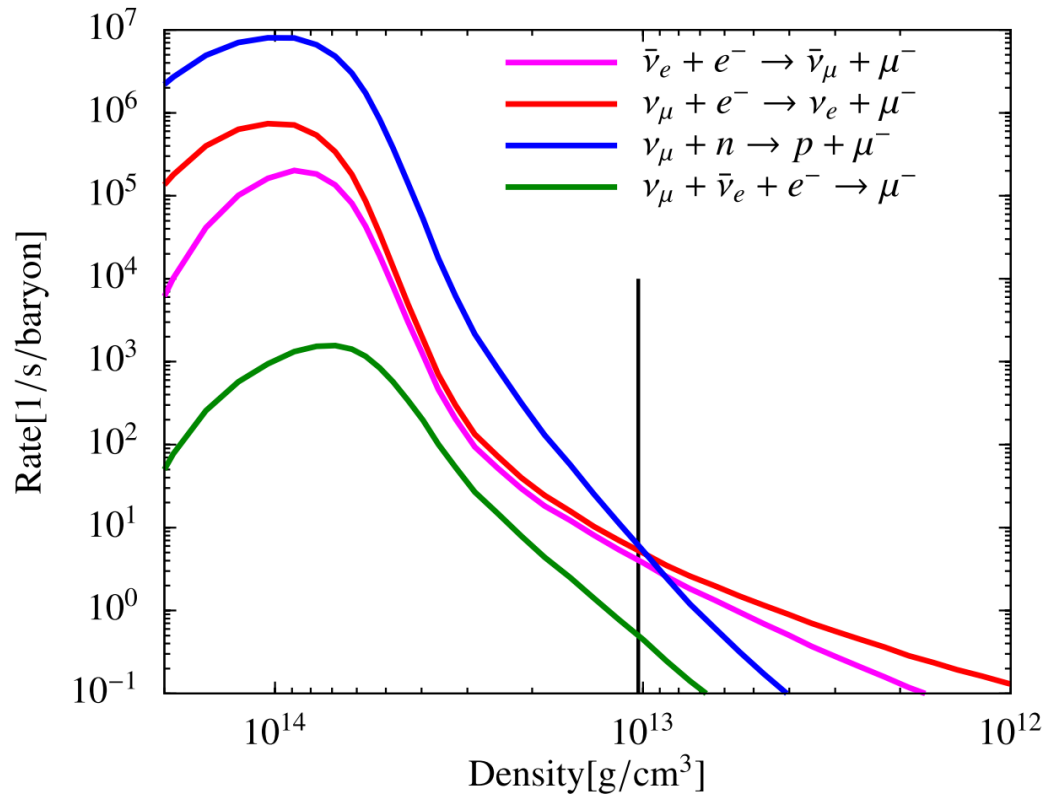
Charged-current interactions for muon neutrinos



- Charged-current reaction for ν_μ significant at high densities
- Spectral differences between ν_μ and $\bar{\nu}_\mu$

Net Muon production

- Muon production faster than dynamical timescale



$$Y_\mu \leq 0.01$$

- Effect on overall deleptonization (feedback)?
- Oscillations between ν_μ and ν_τ ?

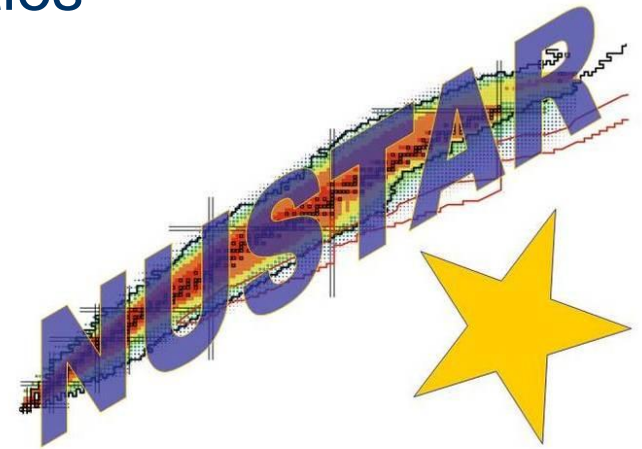
Summary and Conclusion

Improved microphysics for neutrino-matter interaction

- Nucleosynthesis consistent with EoS
- Probing nuclear physics at high densities

Additional neutrino reactions

- Neutron decay
- Charged current muonic interactions



Collaborations to implement reactions in dynamic supernova simulations (Garching, Wrocław)