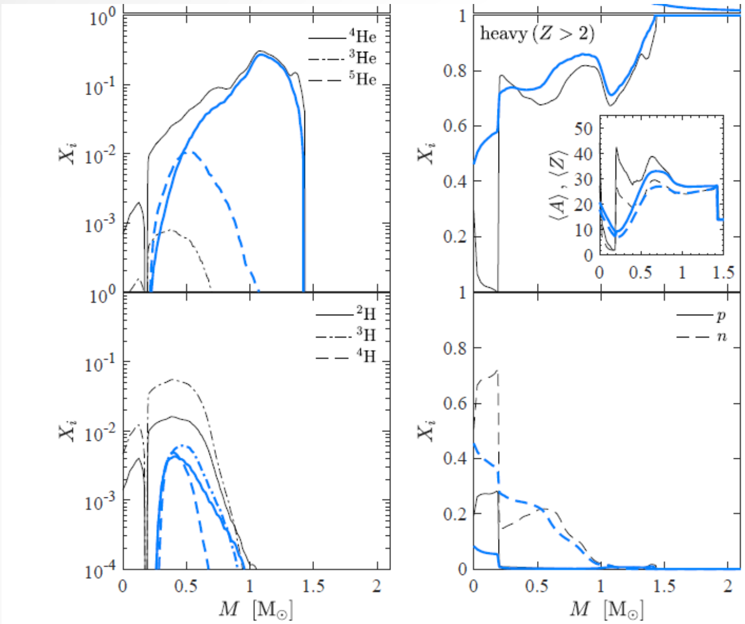
Calibrating the in-medium modifications the clusters energy

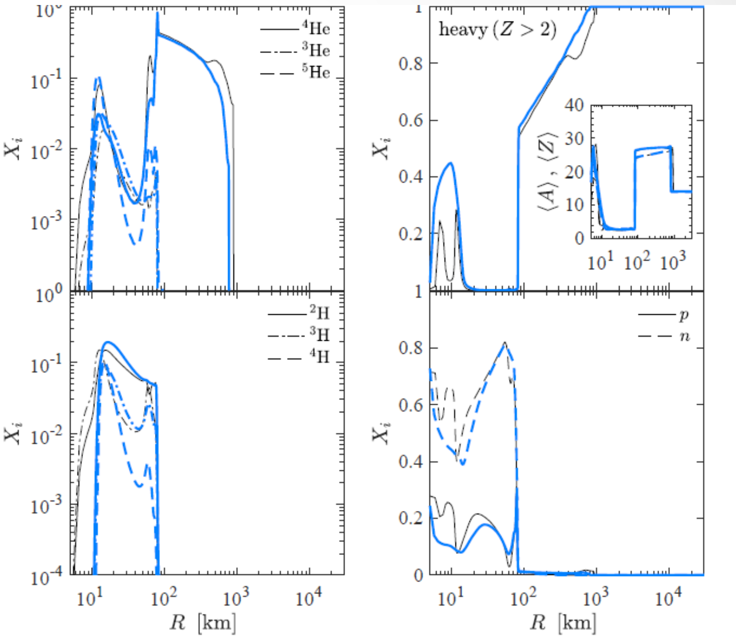
Main author: Tiago Custodio (Uni.Coimbra and Uni.Caen)

T.Fischer et al Phys. Rev. C **102**(2020) 055807

SN dynamics and cluster in-medium effects

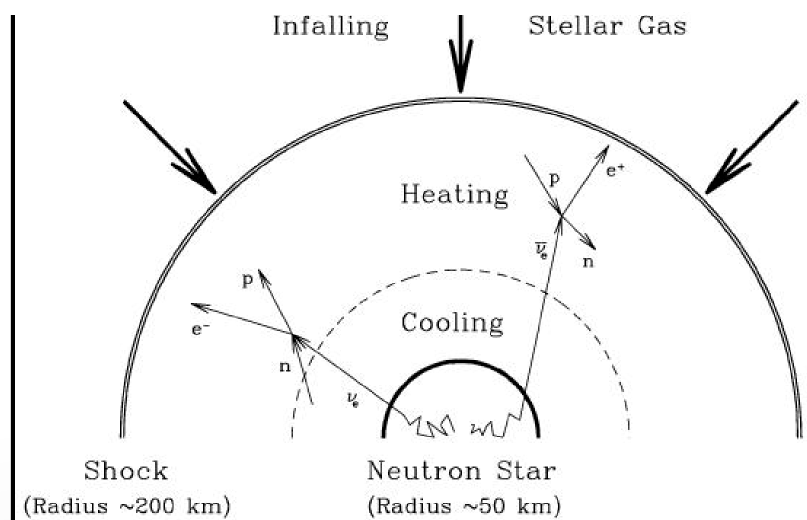


(a) At about 0.5 ms before core bounce



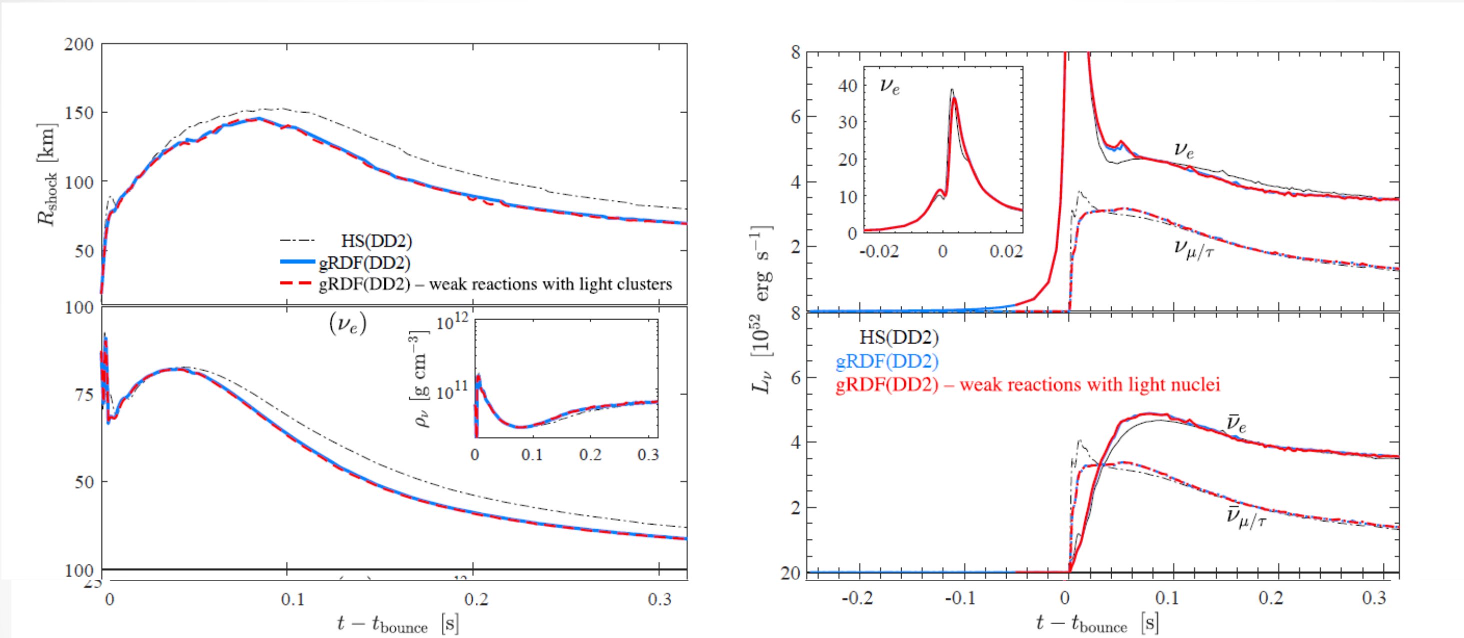
(a) At 10 ms after core bounce

- The energy deposition in the gain region depends on the position of the ν–sphere
- Neutrino opacity is due to scattering off nucleons and nuclei
- **Composition depends on the in-medium modifications to the**
- **binding energy**



T.Fischer et al Phys. Rev. C **102**(2020) 055807

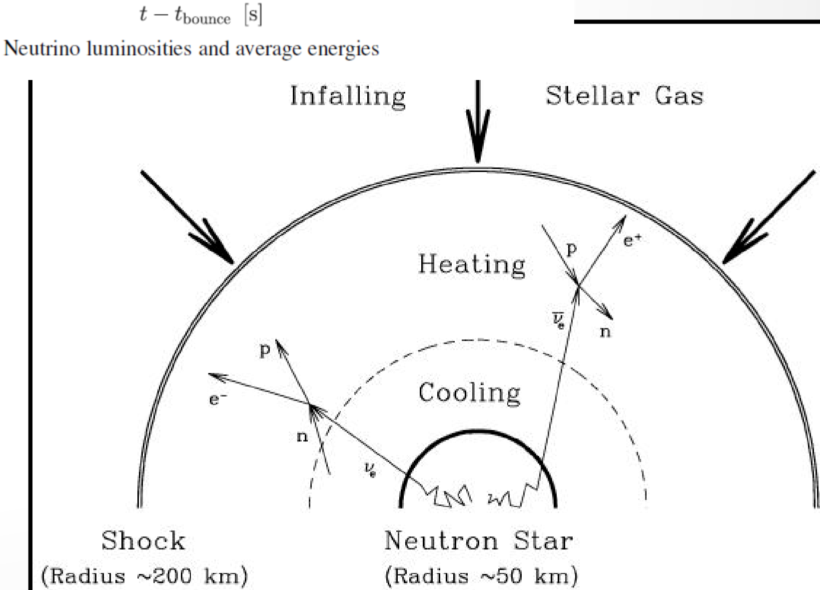
SN dynamics and cluster in-medium effects



(a) Shock radii and neutrinospheres

(b) Neutrino luminosities and average energies

- The energy deposition in the gain region depends on the position of the ν–sphere
- Neutrino opacity is due to scattering off nucleons and nuclei
- **Binding energy shifts might affect the ν–sphere position**
- **and ν luminosity**



Modeling the in-medium effects

- *Quasi-particle approach*

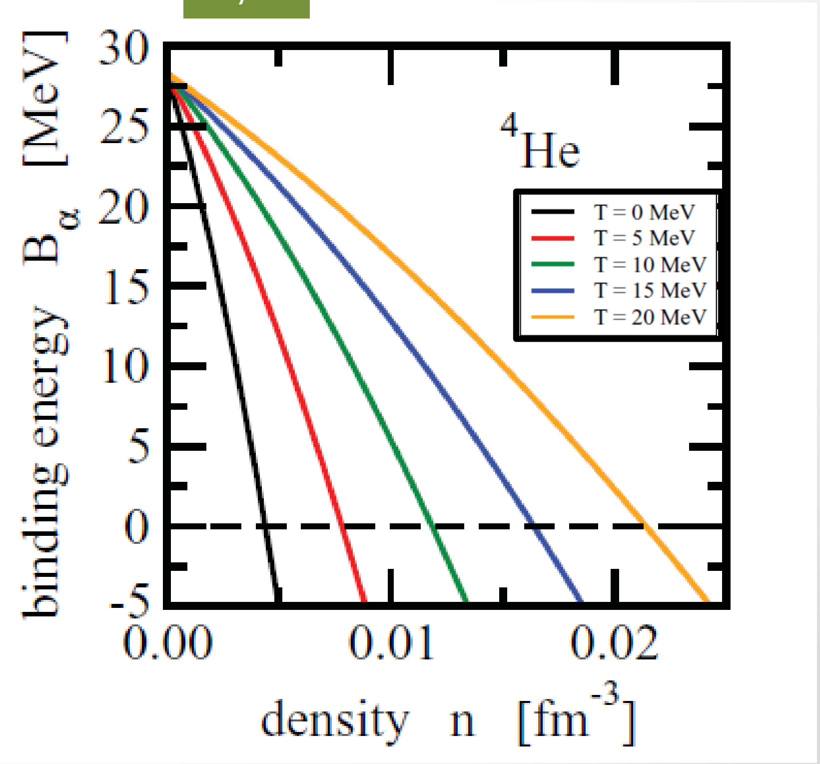
$$\mathcal{L} = -\sum_{i\in F}\bar{\psi}_i(\gamma_\mu D_{\mu i} + m_i^*)\,\psi_i - \frac{1}{2}\sum_{i\in S}\left[(D_{\mu i}\psi_i)^2 + m_i^{*2}\psi_i^2\right] + \sum_{i\in V}\left[(D_{\mu i}\psi_{\nu i} - D_{\nu i}\psi_{\mu i})^2 - \frac{1}{2}m_i^{*2}\psi_{\mu i}^2\right]$$

$$+\mathcal{L}_{\sigma\omega\rho}$$

n,p,t,^{3}He,... | ^{4}He, ^{6}He,... | d,...

$$m_i^* = m_i^0 - \Sigma_i$$
$$= m_i^0 - g_s^i(n)\langle\sigma\rangle \quad \text{(RMF approx)}$$
$$\approx m_i^0 - A_i g_s(n)\langle\sigma\rangle - \Delta B_i(n,T)$$

ad-hoc prescription



- S.Typel et al,PRC81(2010)015803

Modeling the in-medium effects

- *Quasi-particle approach*

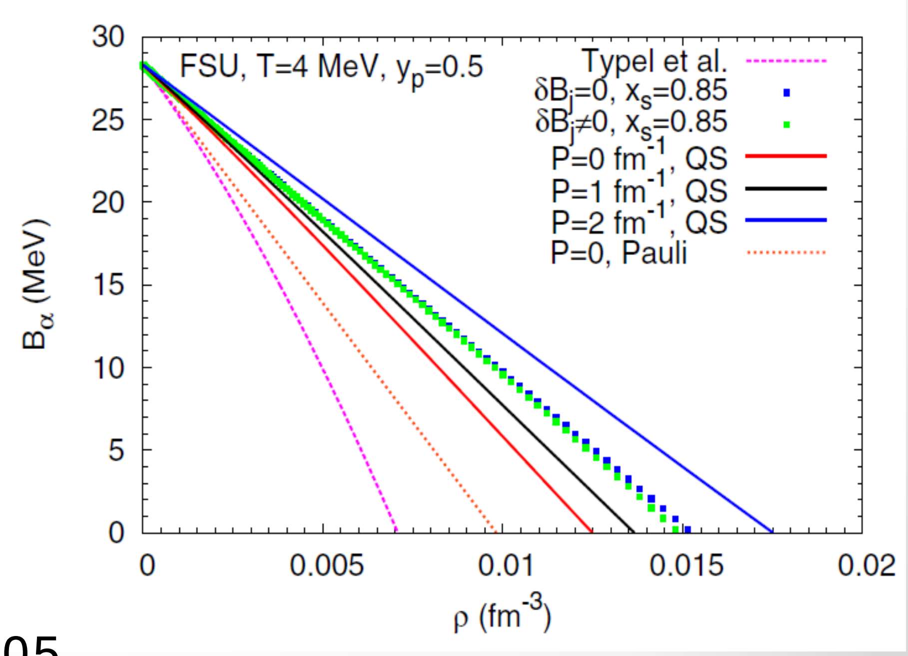
$$\mathcal{L} = -\sum_{i\in F}\bar{\psi}_i(\gamma_\mu D_{\mu i} + m_i^*)\,\psi_i - \frac{1}{2}\sum_{i\in S}\left[(D_{\mu i}\psi_i)^2 + m_i^{*2}\psi_i^2\right] + \sum_{i\in V}\left[(D_{\mu i}\psi_{\nu i} - D_{\nu i}\psi_{\mu i})^2 - \frac{1}{2}m_i^{*2}\psi_{\mu i}^2\right]$$

$$+\mathcal{L}_{\sigma\omega\rho}$$

n,p,t,^{3}He,... | ^{4}He, ^{6}He,... | d,...

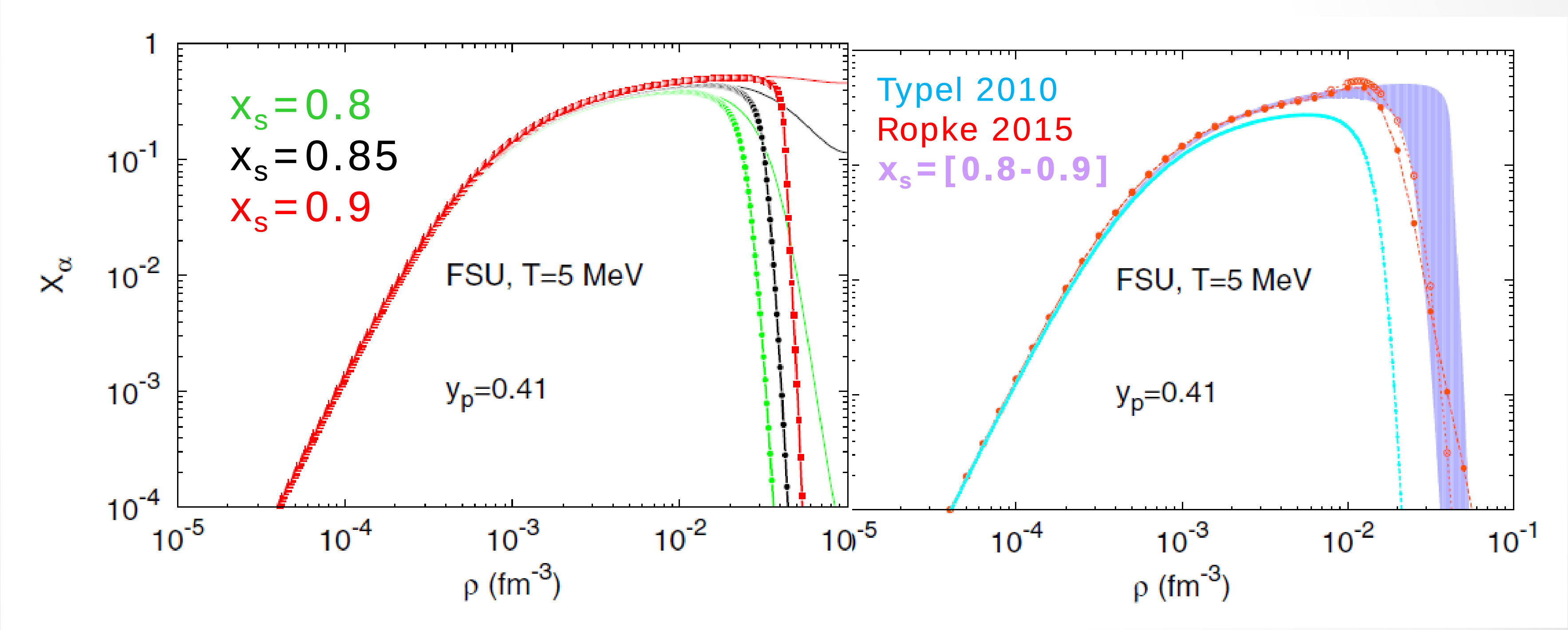
$$m_i^* = m_i^0 - \Sigma_i$$
$$= m_i^0 - g_s^i(n)\langle\sigma\rangle \quad \text{(RMF approx)}$$
$$\approx m_i^0 - A_i \boldsymbol{x_s}(n,T) g_s(n)\langle\sigma\rangle$$

Free parameter



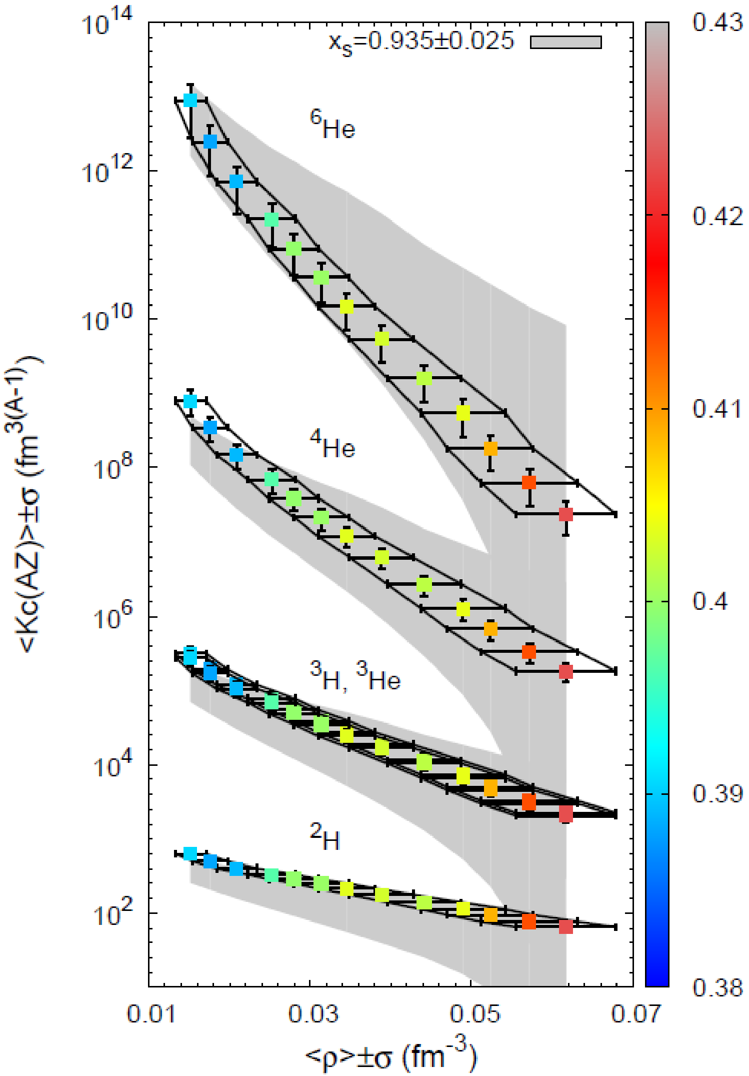
H.Pais et al,PRC97(2018)045805

Calibrating the in-medium effects



H.Pais et al,PRC97(2018)045805

Calibrating the in-medium effects



$$K_C(N,Z) = \frac{n_{NZ}}{n_{01}^Z n_{10}^N} = \frac{\omega_{NZ}}{A\omega_{01}^Z \omega_{10}^N} n_B^{-(A-1)}$$

n=density
ω =mass fraction

- INDRA Xe+Sn central collision data sampled in bins of radial velocity(≡emission time?)
- Mapping: v_i *EXP* ⇔ $(n_B, T, y_P)_i$ *RMF*
- y_P deduced from data
- T, n_B tentatively deduced from a (modified) ideal gas formula
- Hyp: x_s=cst.

=> $x_s = 0.935 \pm 0.025$

H.Pais & INDRA coll. PRL 125(2020)012701

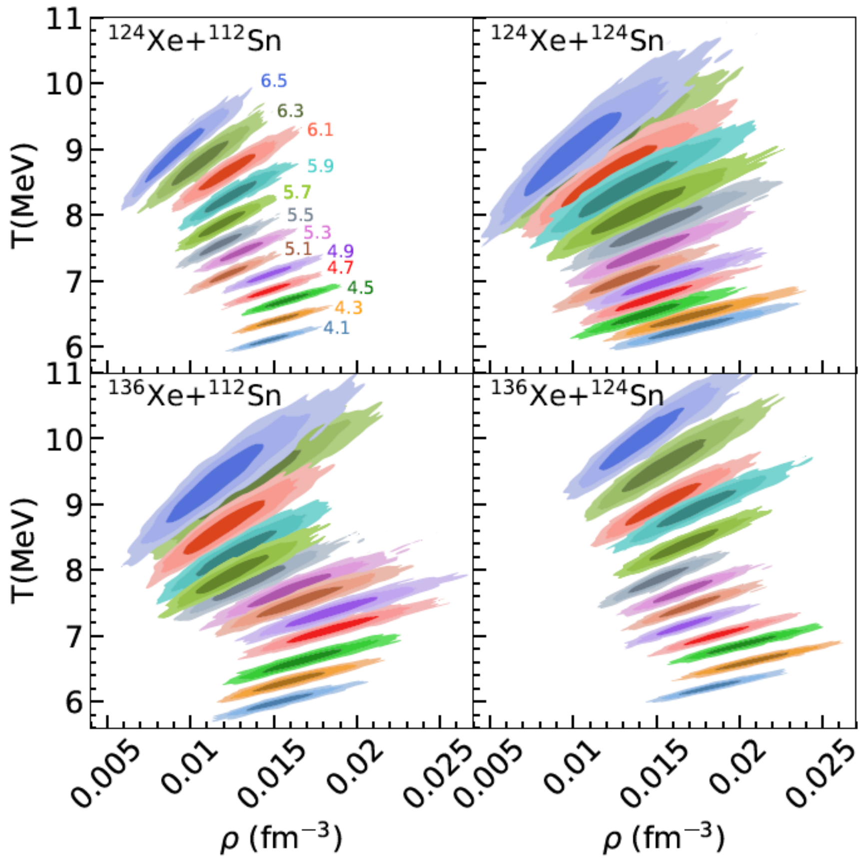
Tiago's thesis

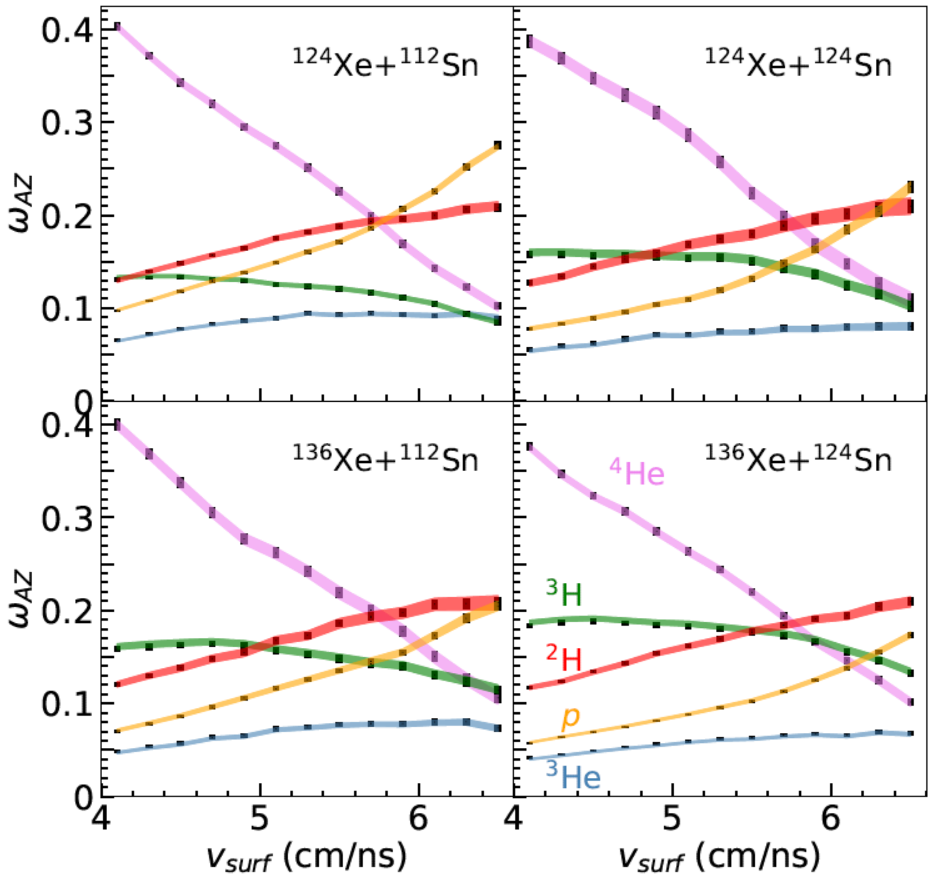
- 4 different data sets $X_i = 1, \cdots, 4$ from INDRA ^{136,124}Xe + ^{124,112}Sn @ 32 A.MeV*
- EoS Model: FSU-RMF
- Bayesian inference (NSMC**) of the unknown parameters $\boldsymbol{\theta_i = (T, n_B, x_s(T, n_B))_i}$ directly from the mass fractions for each sample $\{\omega(A,Z)\}_i$ labelled by the radial velocity bin and data set $i = (v_i, X_i)$

$$p_i(\theta|\{\omega_{AZ}\}) = \frac{p_\theta}{Z} \prod_{AZ} \mathcal{L}(\omega^i_{AZ}|\theta) \quad \mathcal{L}(\omega^i_{AZ}|\theta) = e^{-\frac{\left(\omega^{exp}_{AZ}(i) - \omega^{th}_{AZ}(\theta)\right)^2}{2\sigma^2_{AZ}(i)}}$$

* A.Rebillard-Soulié et al, JPhysG 51(2023)015104
** PyMultiNest: J. Buchner 10.1214/23-ss144 (2021)

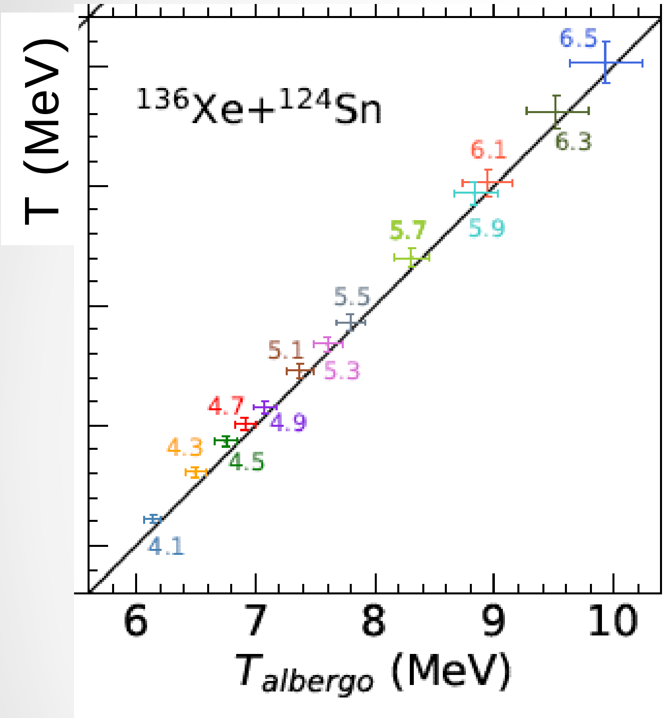
Tiago's thesis

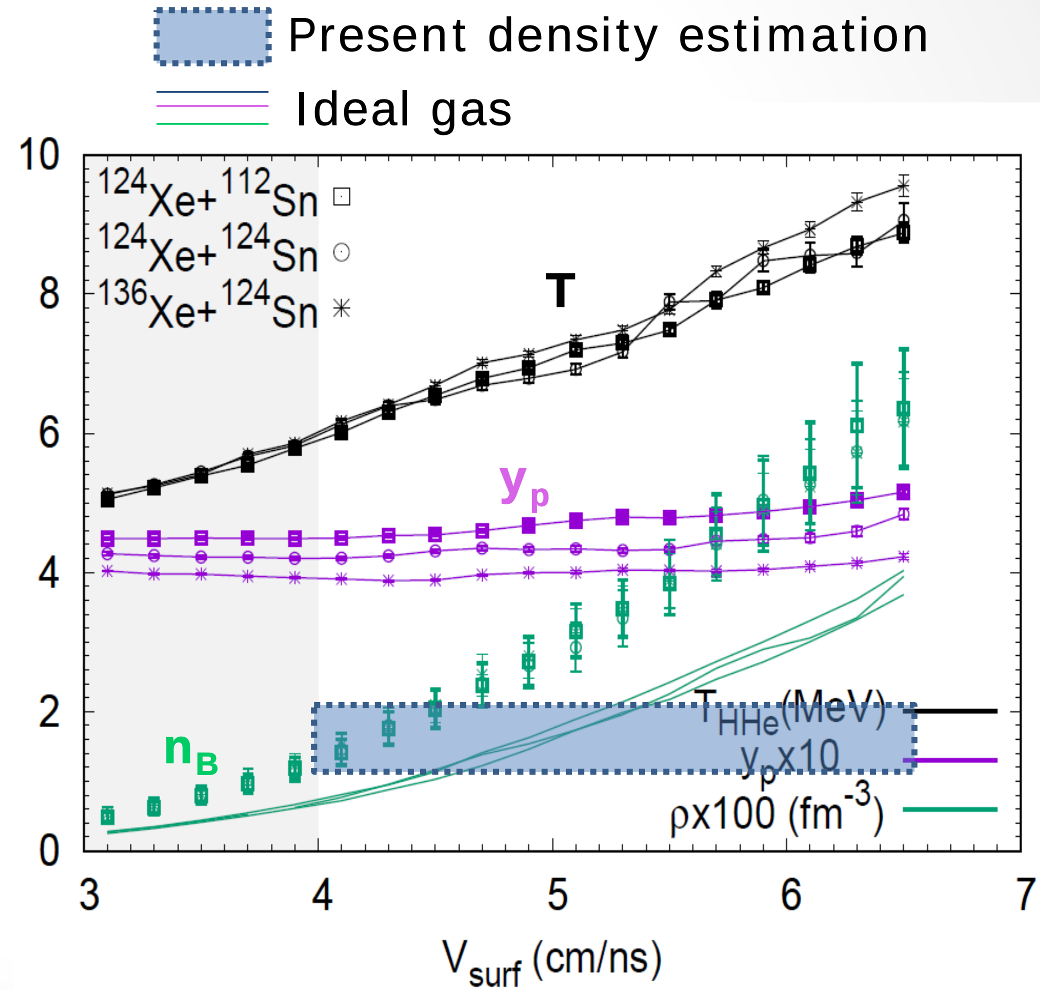




Comparison with the parameter estimation

from the classical ideal gas

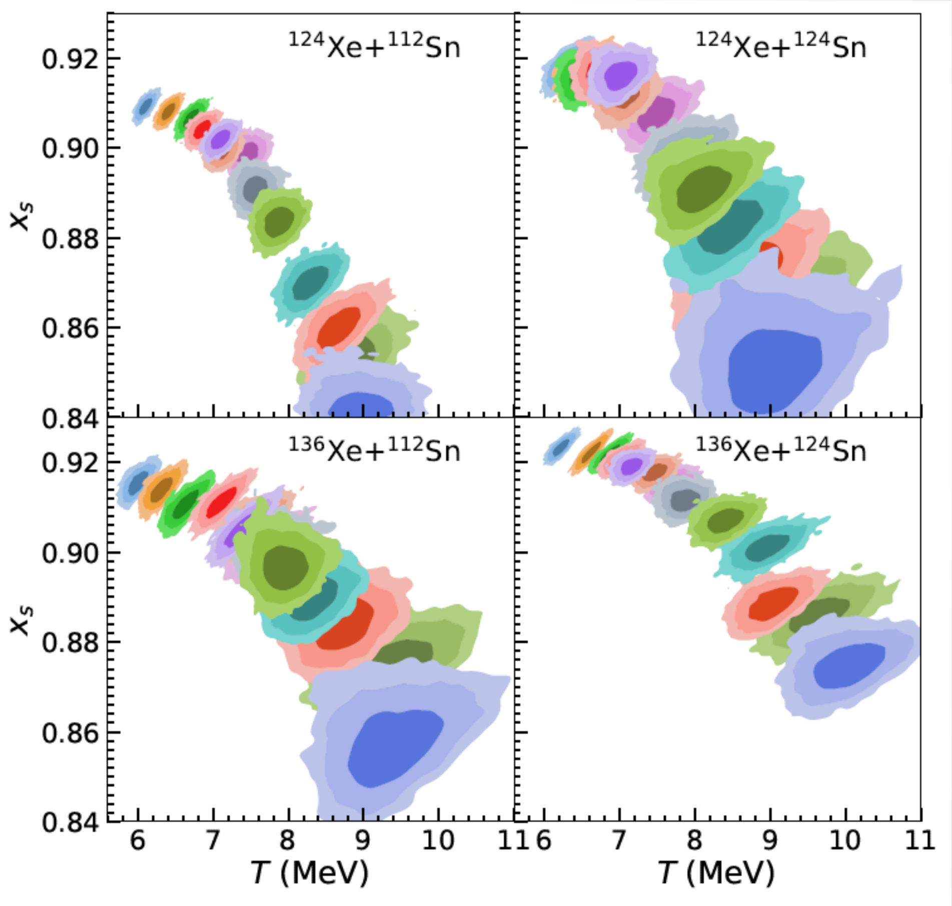




H.Pais et al Jphys.G 47(2020)105204

Posteriors for the coupling modification $x_s(n_B,T)$

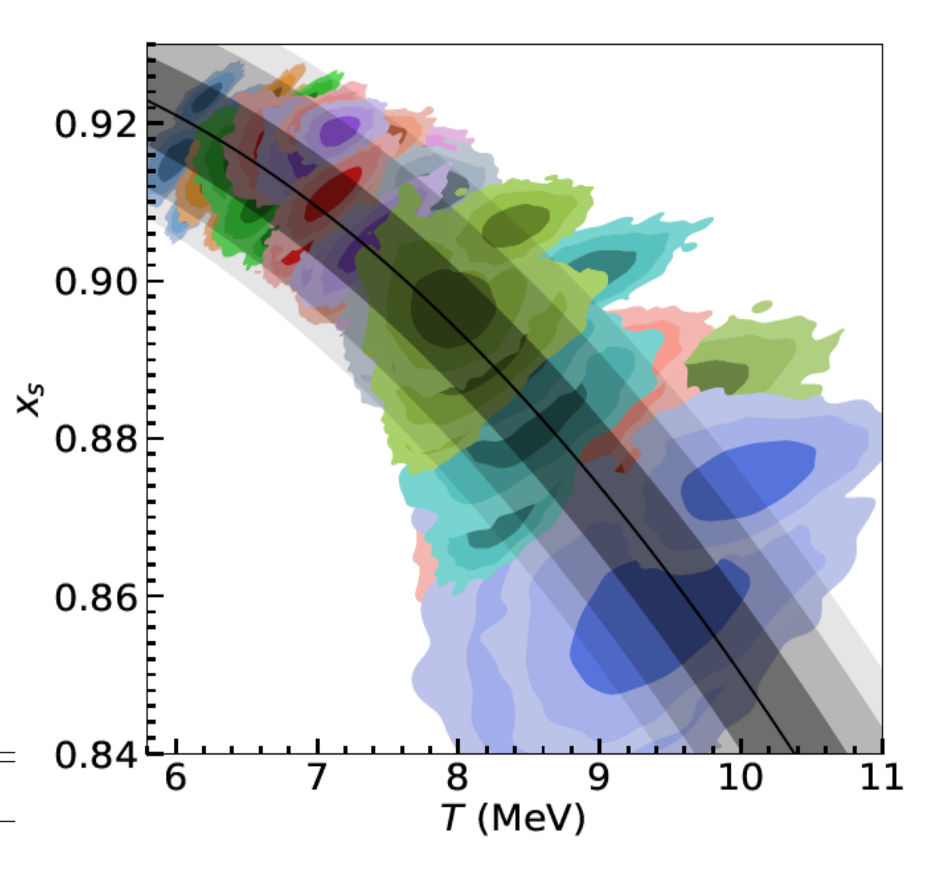
- The independent analyses of the 4 systems lead to compatible results as a function of T
- This confirms the validity of the statistical approach



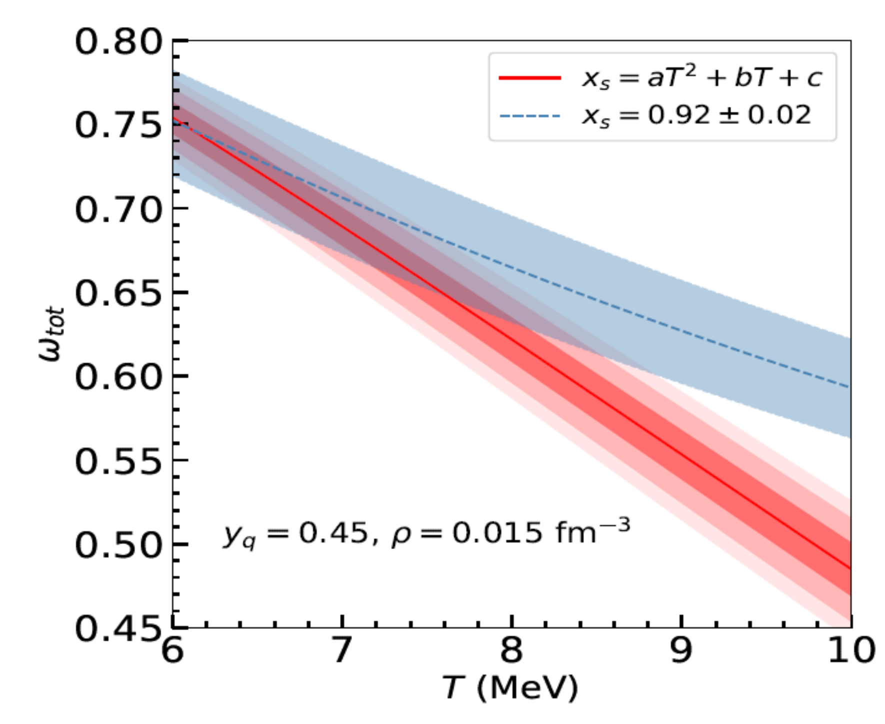
Posteriors for the coupling modification $x_s(n_B,T)$

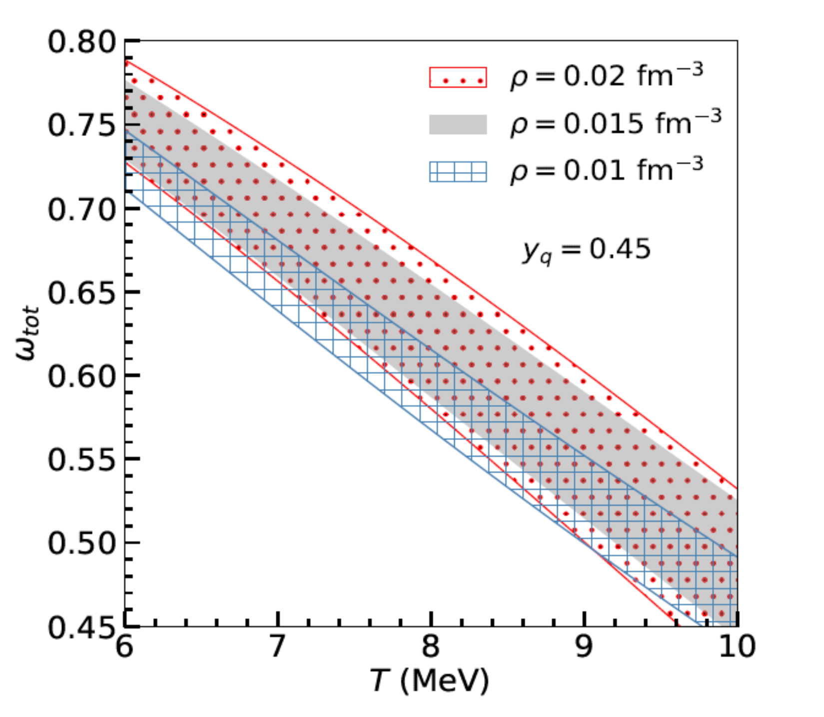
- The independent analyses of the 4 systems lead to compatible results as a function of T
- This confirms the validity of the statistical approach
- Quadratic fit (*Python lmfit*) $x_s = aT^2 + bT + c$
- Hyp: the n_B dependence can be neglected in the probed n_B range

Parameter	Unit	Median	1σ	2σ
a	MeV^{-2}	-0.00203	± 0.00003	± 0.00006
b	MeV^{-1}	0.01477	± 0.00047	± 0.00093
c		0.90560	± 0.0018	± 0.00355



Predictions for general purpose EoS





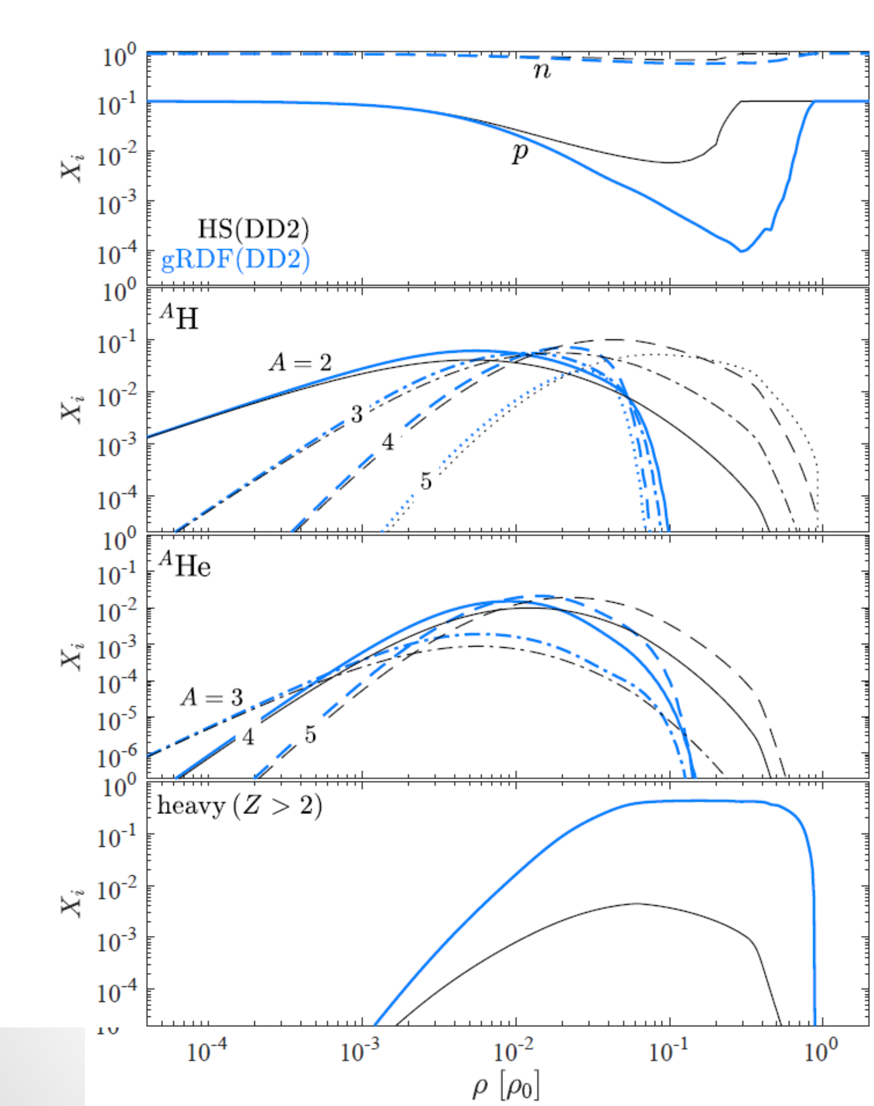
….. To be continued

Caen-Coimbra collaboration

Campus France PESSOA program
(project PHC 47833UB)

- **T.Custodio**
- **Caen:** F.Gulminelli, *A.Rebillard-Soulié, R.Bougault, D.Gruyer* } Exp.data analysis (INDRA)
- **Coimbra:** H.Pais, C.Providencia, T.Mallik

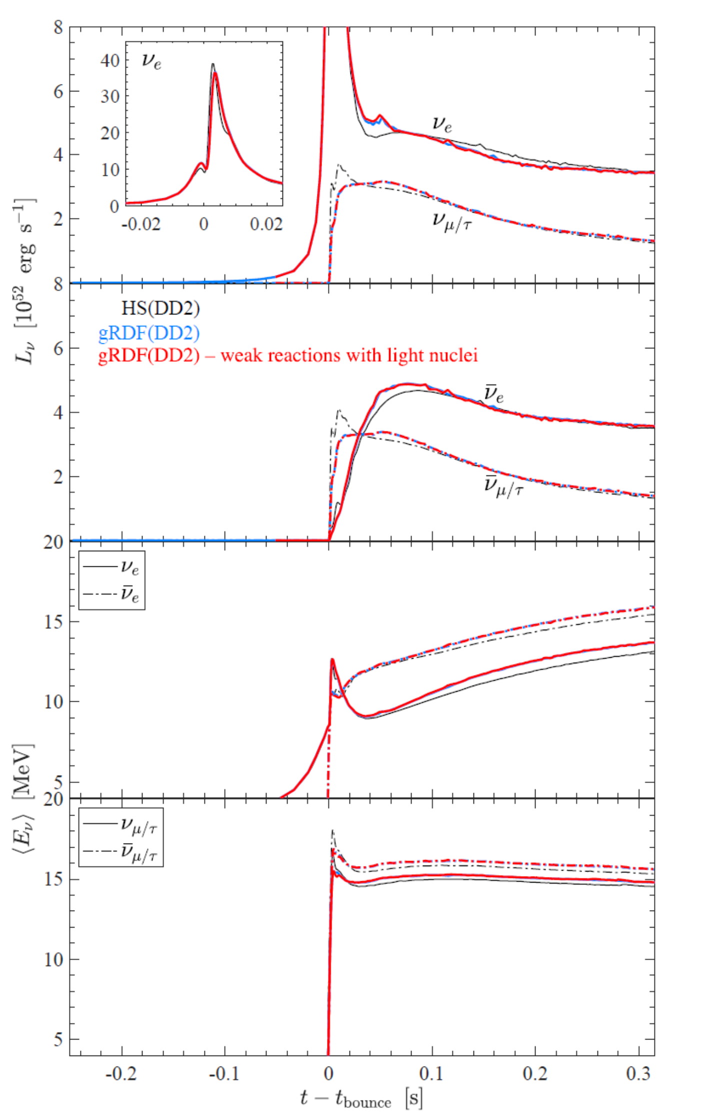
Clusters in-medium effects



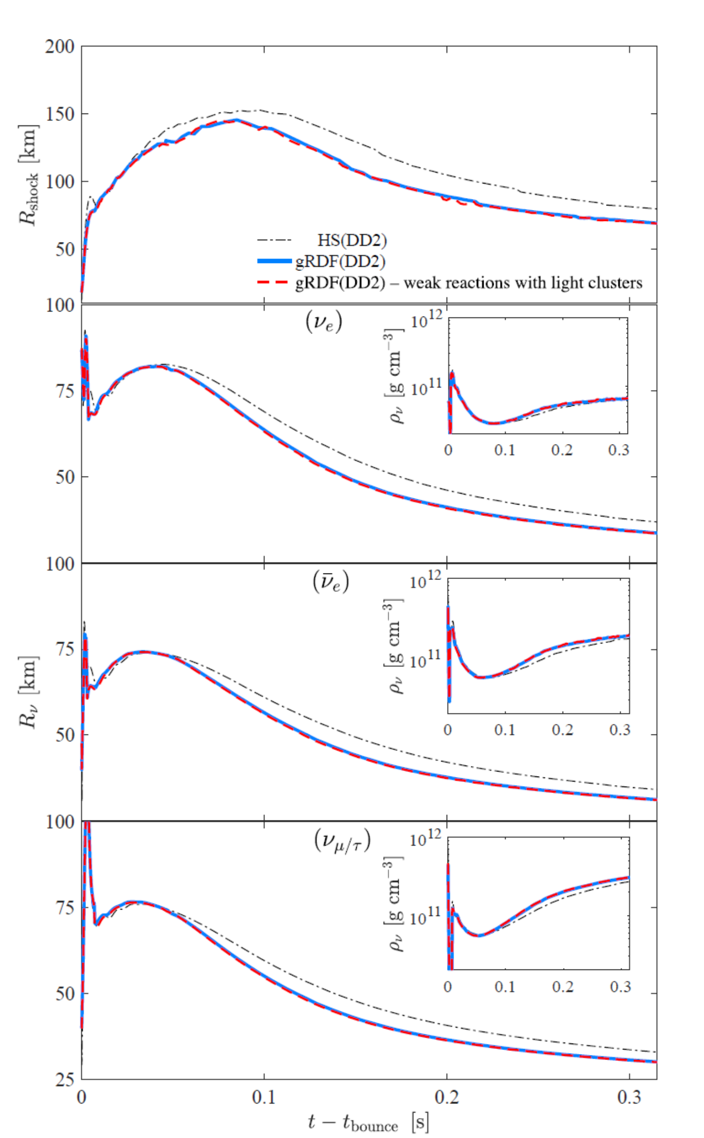
T.Fischer et al PRC102(2020)

- the ETF approach is not very realistic for light clusters!
- Alternative approaches: in-medium modified meson couplings H.Pais, FG PRC 97(2018)045805; quasi-particle virial expansion G.Roepke, PRC101 (2020) 064310

Effect on the CCSN dynamics



(b) Neutrino luminosities and average energies



T.Fischer et al PRC102(2020)