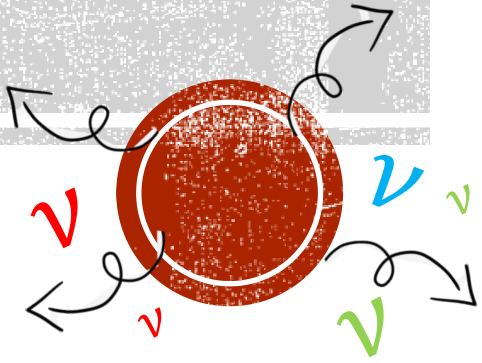
IMPACT OF EOS ON NEUTRINO OPACITIES IN CORE-COLLAPSE SUPERNOVAE

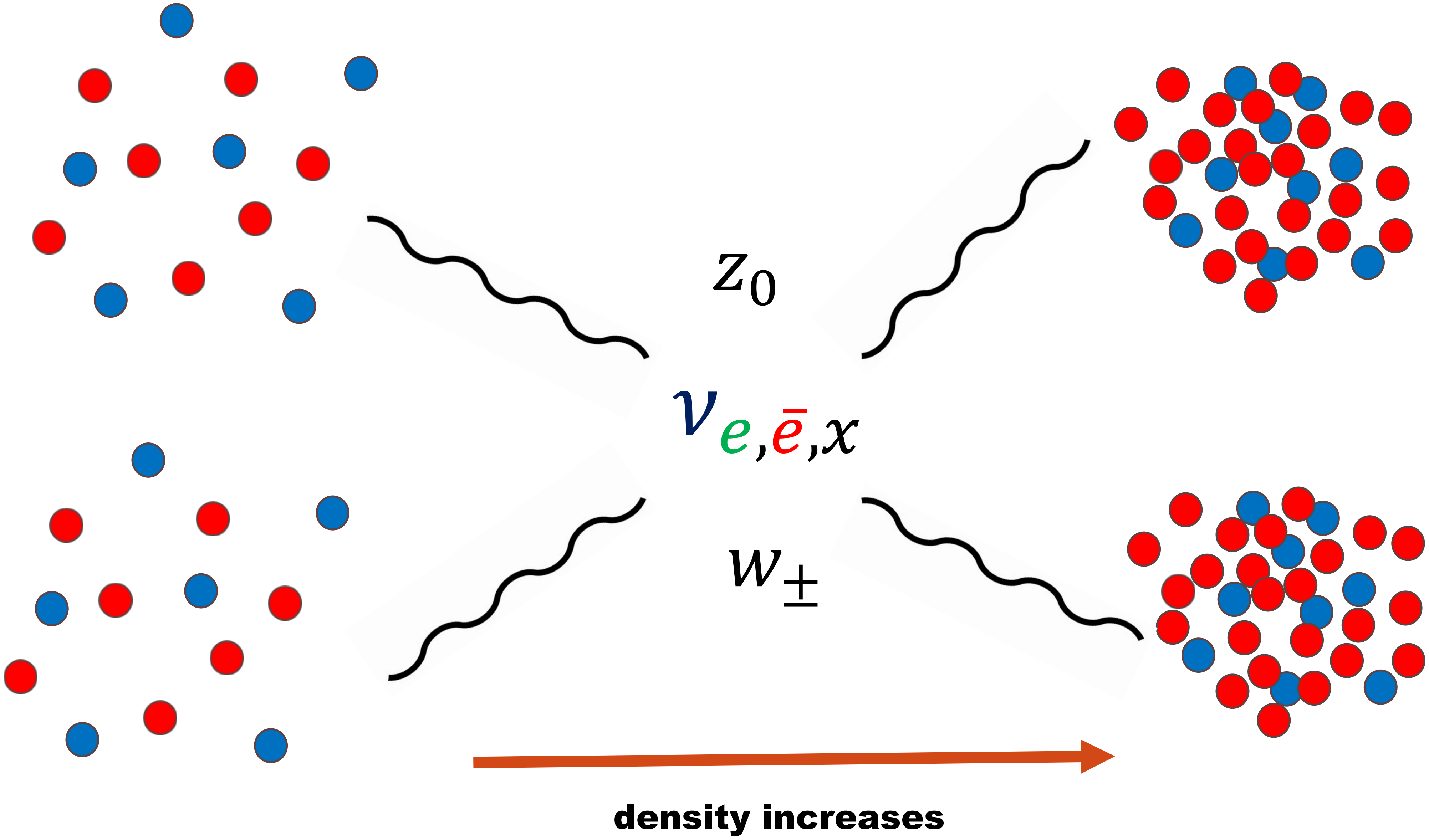
Based on Random Phase Approximations (RPA)



Zidu Lin

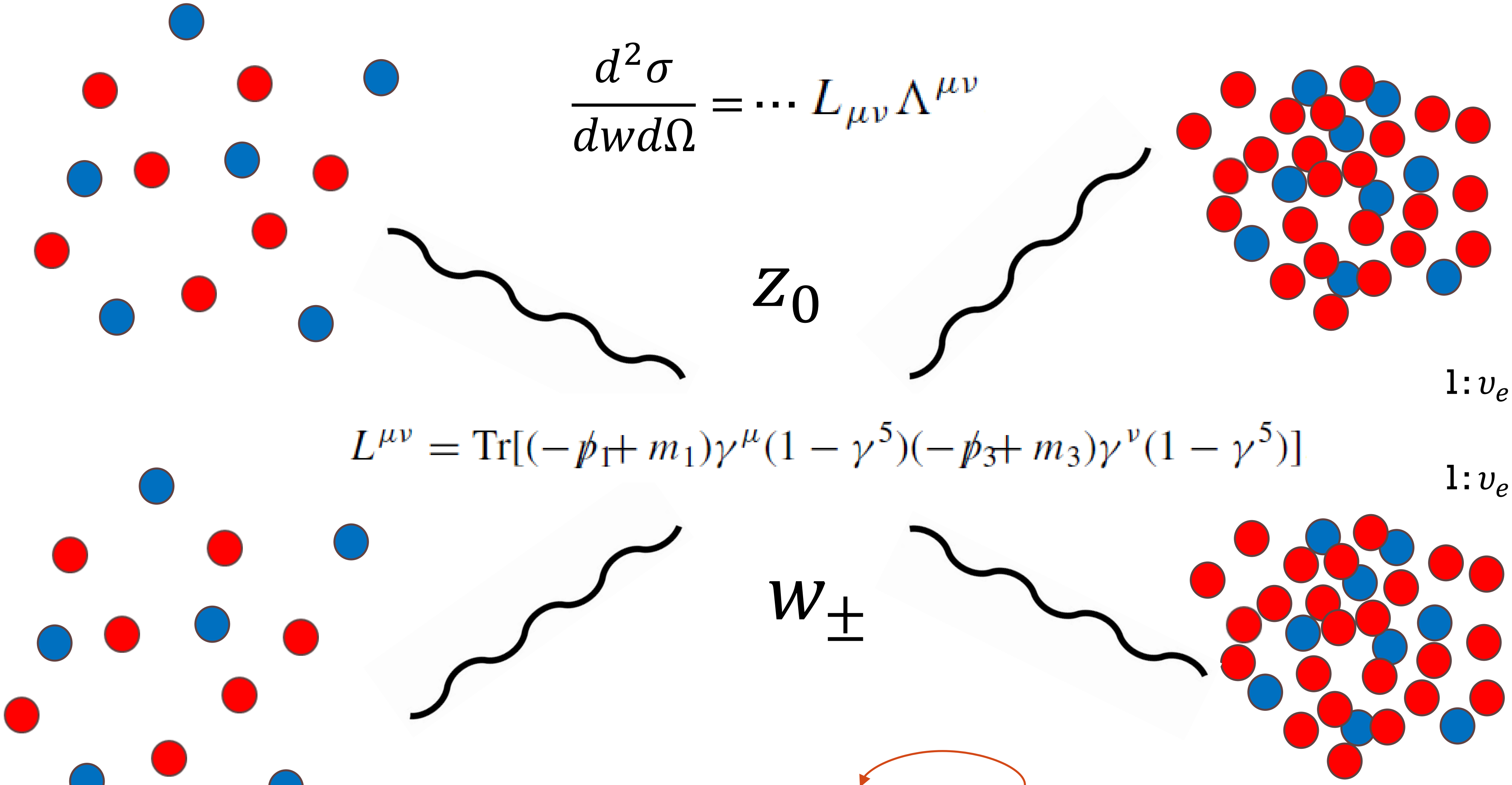
Collaborator: *Andrew Steiner*

NEUTRINO INTERACTIONS IN CCSN



NEUTRINO INTERACTIONS IN CCSN

$$\frac{d^2\sigma}{dwd\Omega} = \cdots L_{\mu\nu}\Lambda^{\mu\nu}$$



1: ν_e 3: ν_e (NC)

1: ν_e 3: e (CC)

$$L^{\mu\nu} = \mathrm{Tr}[(-\not{p}_1 + m_1)\gamma^{\mu}(1-\gamma^5)(-\not{p}_3 + m_3)\gamma^{\nu}(1-\gamma^5)]$$

$$\Lambda^{\mu\nu} = \mathcal{F}[j_{\mu}, j_{\nu}]_{q,\omega}$$

All the many-body effects (and uncertainties) are here

CORRECTIONS THAT MATTER FOR ν OPACITIES

● Phys.Rev.D65:043001,2002

▲ Phys.Rev.C58:554-571,1998

■ Phys. Rev. C59:2888, 1999

★ This work

Table II Corrections to ν Opacities

	Correction	
1.	Phase space	● ▲ ■ ★
2.	Matrix element	
	a. recoil	
	b. weak magnetism	●
	c. form factors	
	d. strange quarks	
3.	Pauli blocking	▲ ■ ★
4.	Fermi/thermal motion of initial nucleons	▲ ■ ★
5.	Coulomb interactions	▲ ★
6.	Mean field effects	■ ★
7.	NN Correlations in RPA	▲ ■ ★
8.	NN Correlations beyond RPA	
9.	Meson exchange currents	
10.	Other components such as hyperons	
11.	Other phases such as meson condensates or quark matter	
12.	Corrections from superfluid/ superconductor pairing	
13.	Nonuniform matter	
14.	Magnetic field effects	

Model Independent

Model dependent

This work focus on correction 6th+7th

Table from Phys.Rev.D65:043001,2002

THEORETICAL FRAMEWORK

$$\frac{d^2\sigma}{dwd\Omega} = \cdots L_{\mu\nu}\Lambda^{\mu\nu}$$

Non-Relativistic limit

$$L_{\mu\nu}\Lambda^{\mu\nu} \approx (1+\cos\theta)W_V + (3-\cos\theta)W_A$$

$$W_V = V^2 S_V(q,w) \qquad W_A = A^2\, S_A(q,w)$$

Neutral Current (NC):

$$V = C_V^n = \frac{1}{2};$$

$$A = C_A = -\frac{1.26}{2}$$

Charged Current (CC):

$$V = g_V = 1;$$

$$A = g_A = 1.26$$

Linear Response Theory:

$$S(q_0, \mathrm{q}) = \frac{1}{1-\exp[-\left(q_0 + \frac{\mu_2-\mu_4}{T}\right)]} Im[\Pi_{V/A}]$$

Random phase approximation (RPA):

$$Im[\Pi_{V/A}] = Im[\frac{\Pi^{MF}}{1-v_{V/A}\Pi^{MF}}]$$

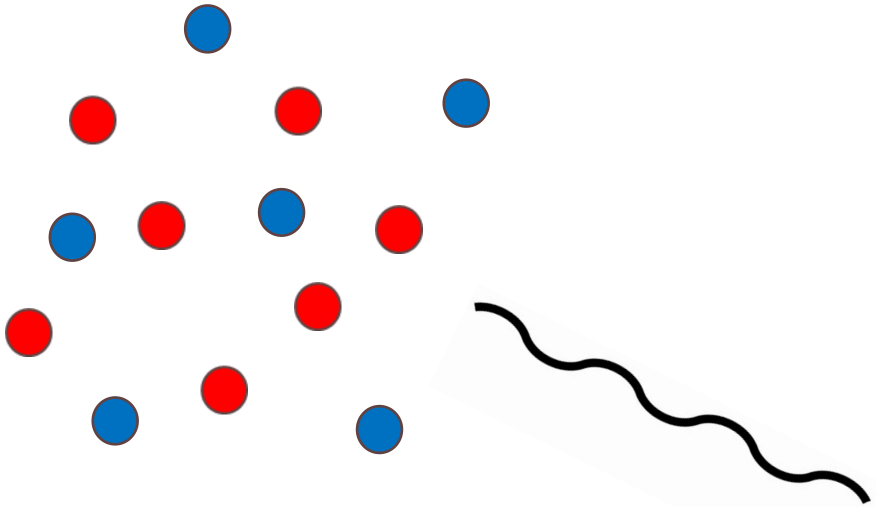
$U = \mu - \mu_0$

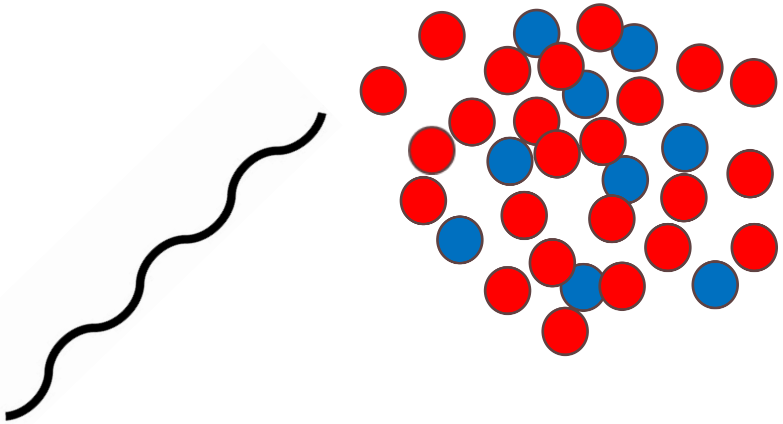
EoS

MF : U_P U_N μ_P μ_N M_P^* M_N^*

RPA : F_0 F_0' G_0 G_0'

WHERE EOS MATTERS





Virial EoS

$$Im\left[\Pi_{V/A}\right] = Im\left[\frac{\Pi}{1 - v_{V/A}\Pi}\right]$$

Skyrme EoS

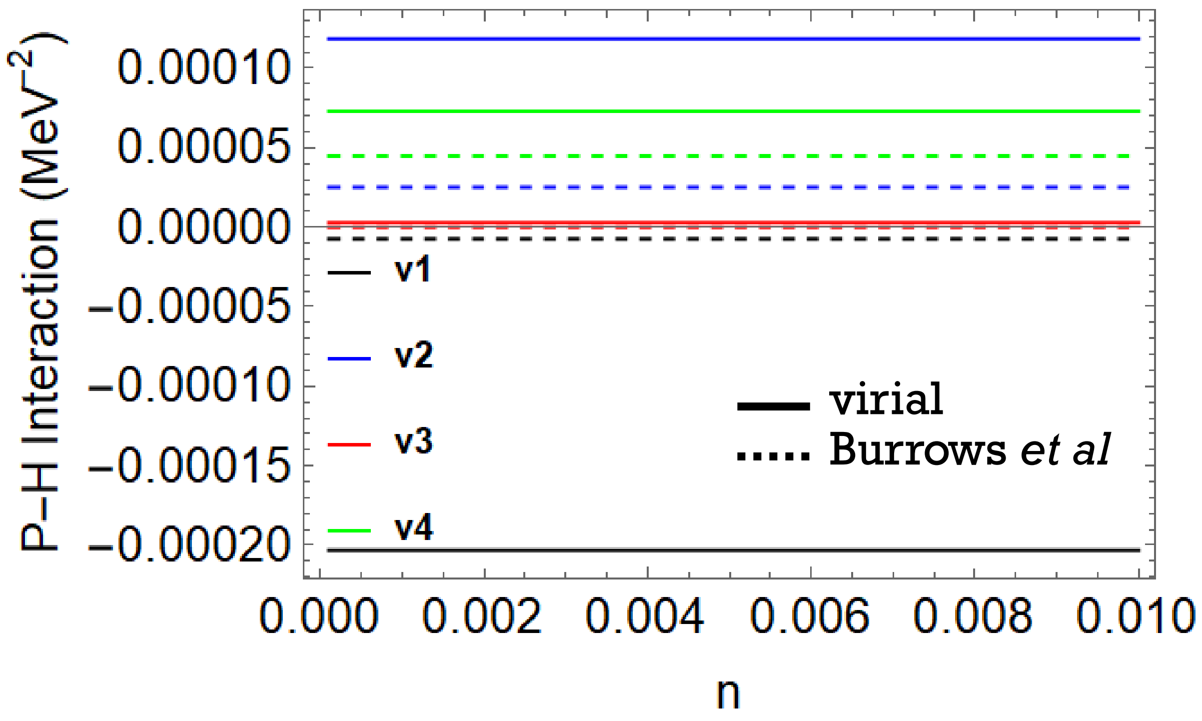
F_0 F_0' G_0 G_0'

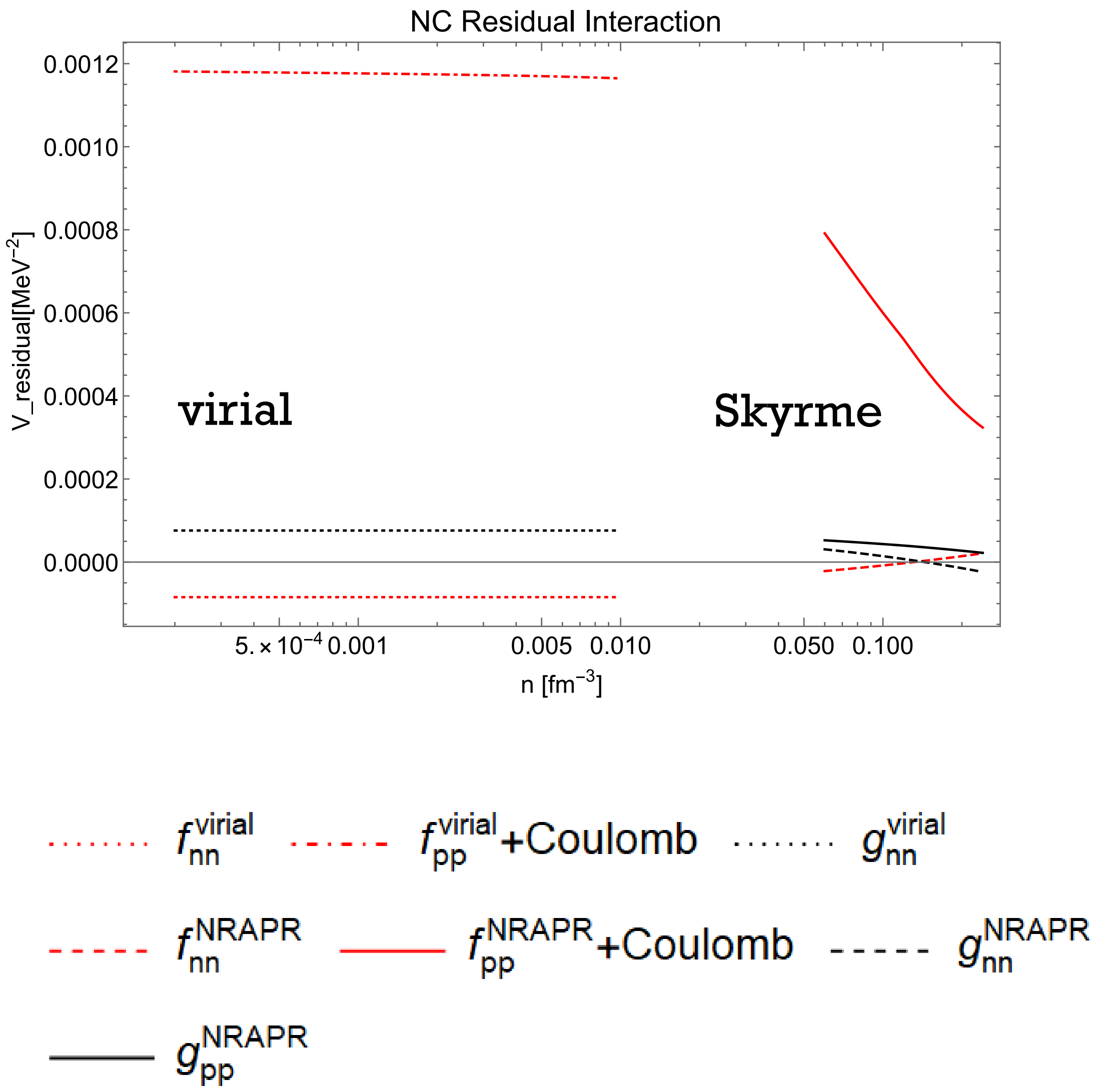
U_P μ_P M_N^* U_N μ_N M_P^*

In principle, they are density-, temperature-, and Y_e dependent !

density increases

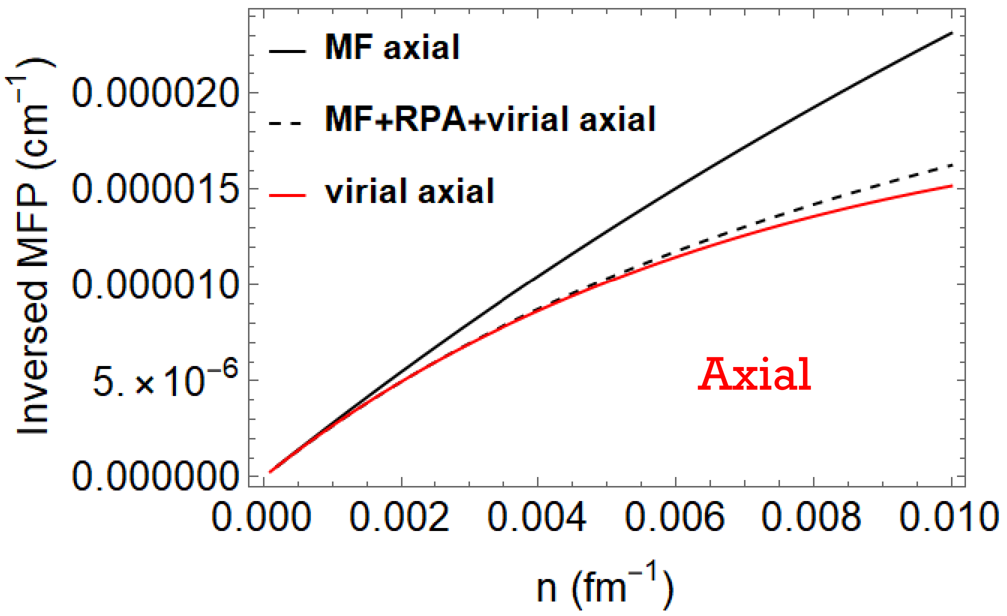
P-H INTERACTIONS

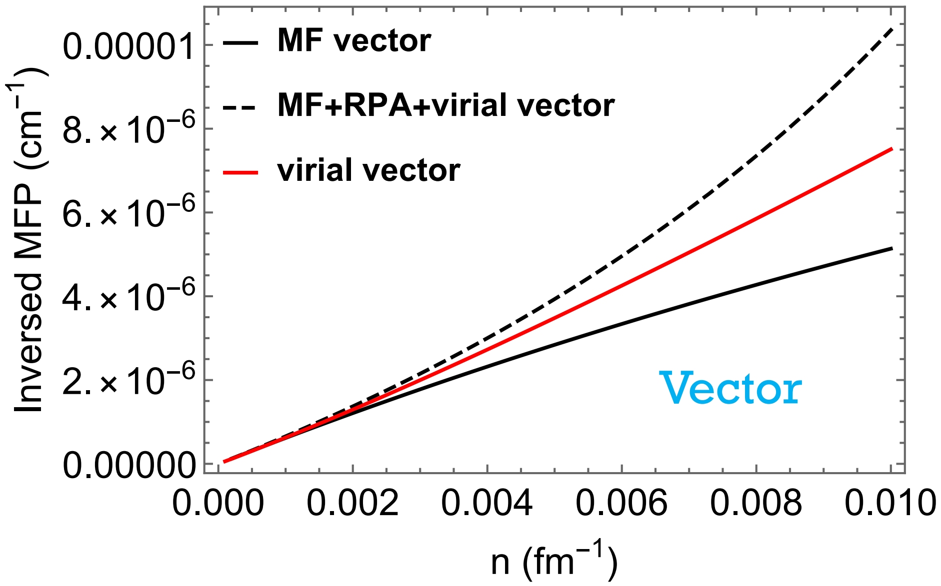




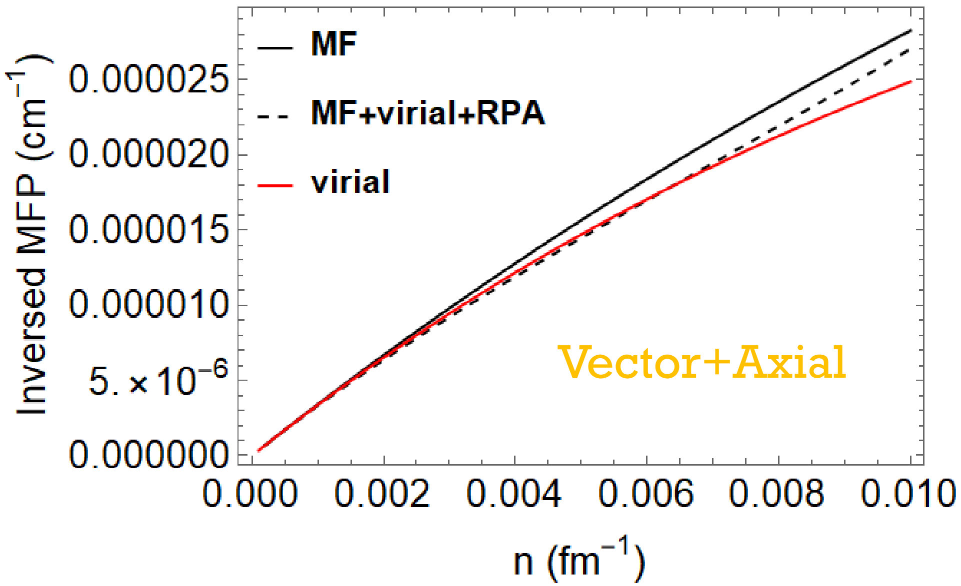
At low densities, only 1 EoS (virial) for sure; at high densities, a lot of candidate EoSs (including skyrme)…

HOW WELL DOES RPA BEHAVE AT LOW DENSITIES?

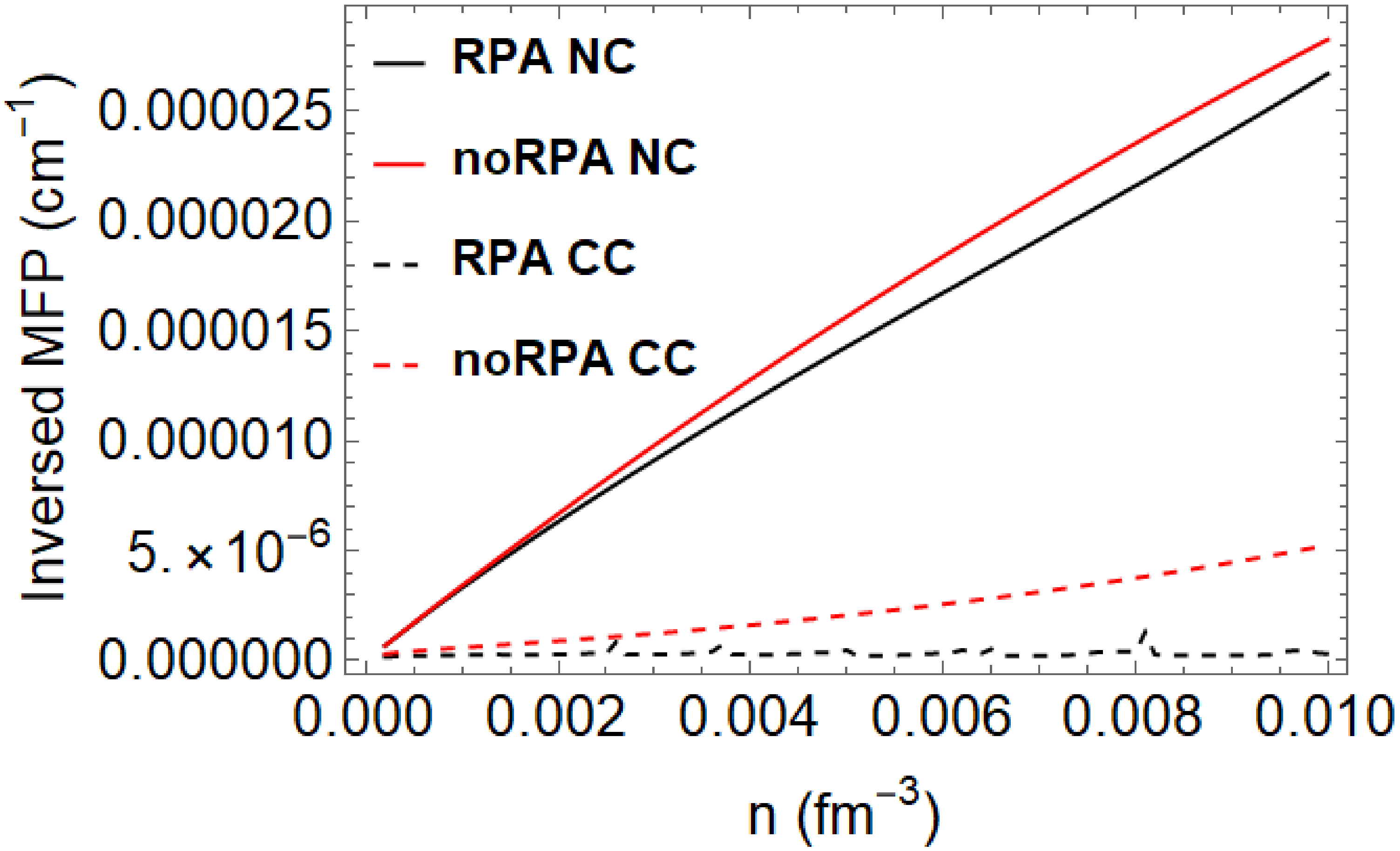




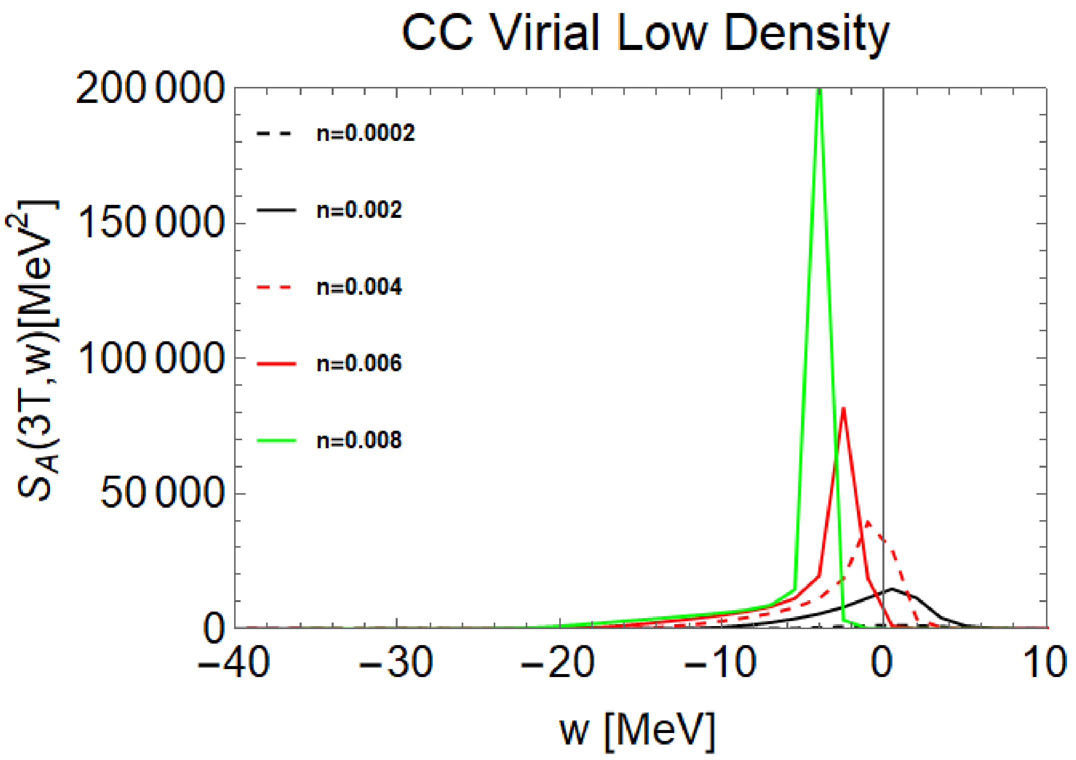
Preliminary Results

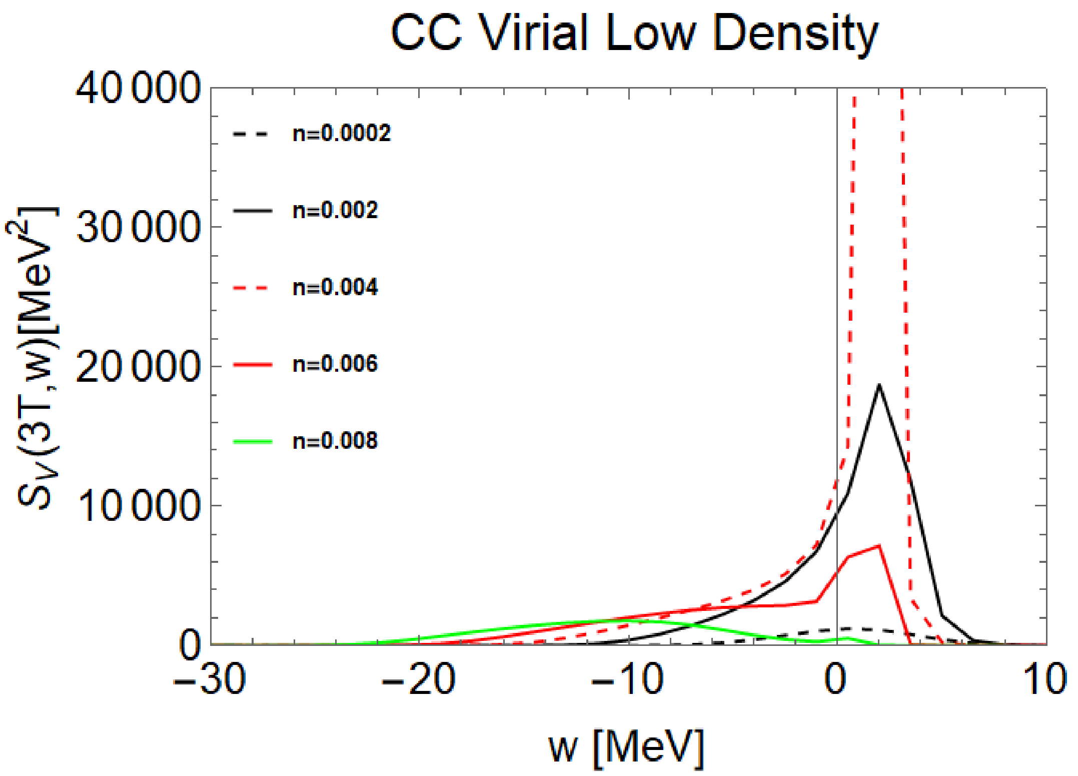


STATIC RESPONSE AT LOW DENSITY



DYNAMIC RESPONSE AT LOW DENSITY





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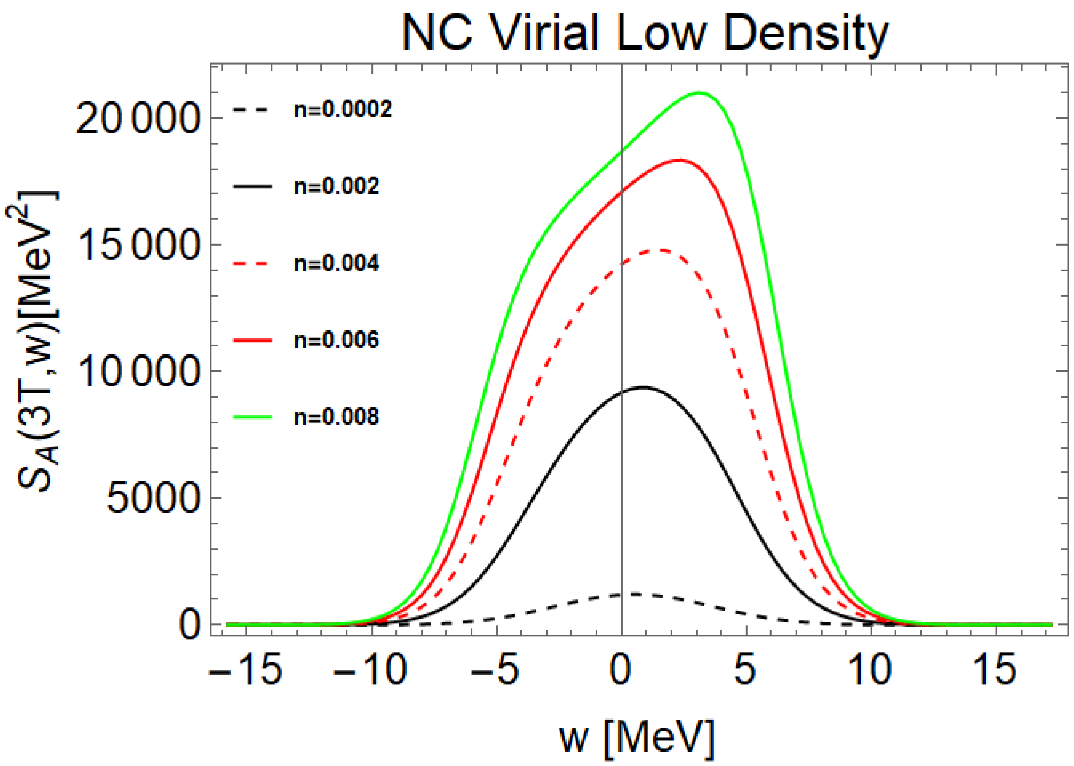
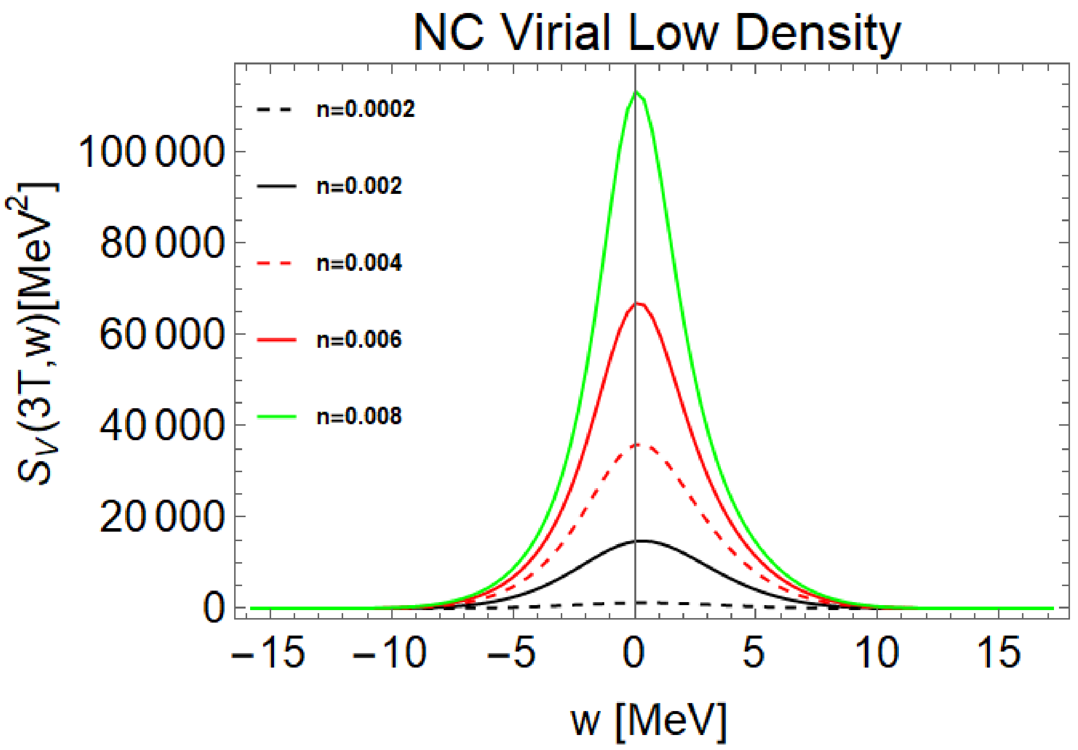
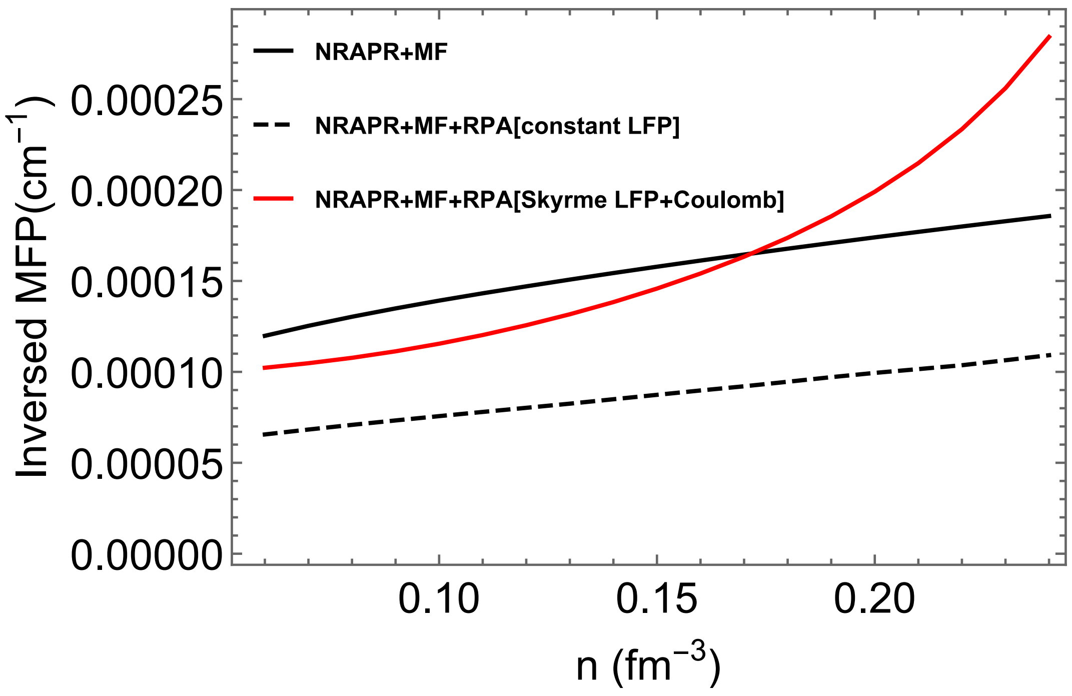


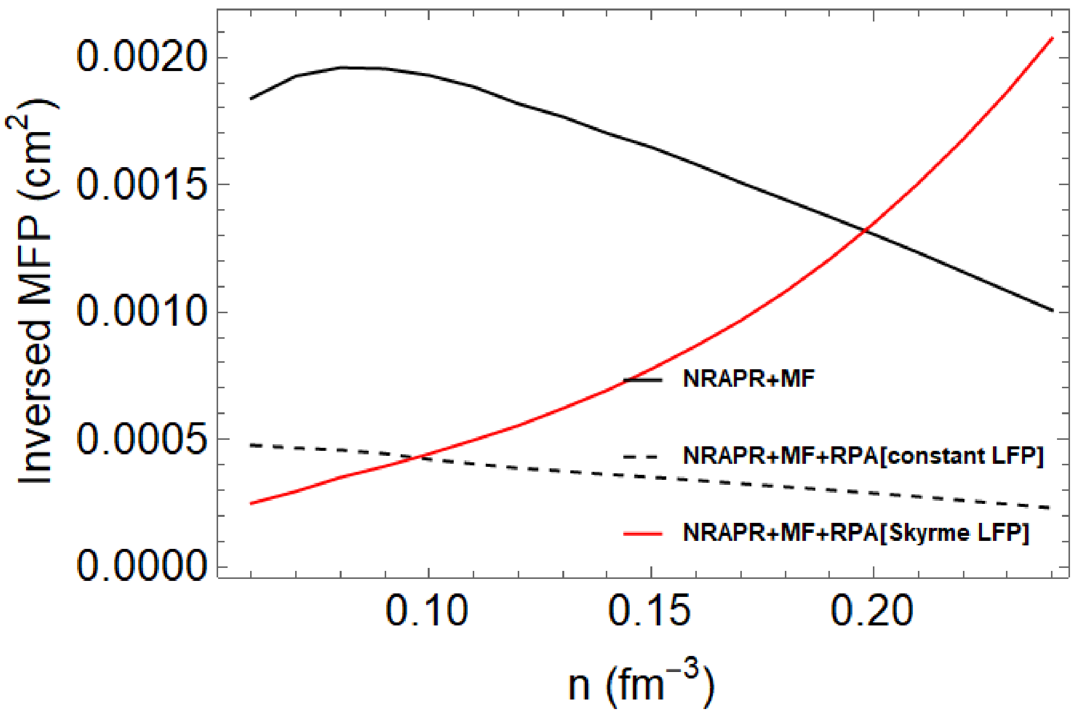


HOW BIG ARE THE IMPACTS FROM EOS AT HIGH DENSITIES?

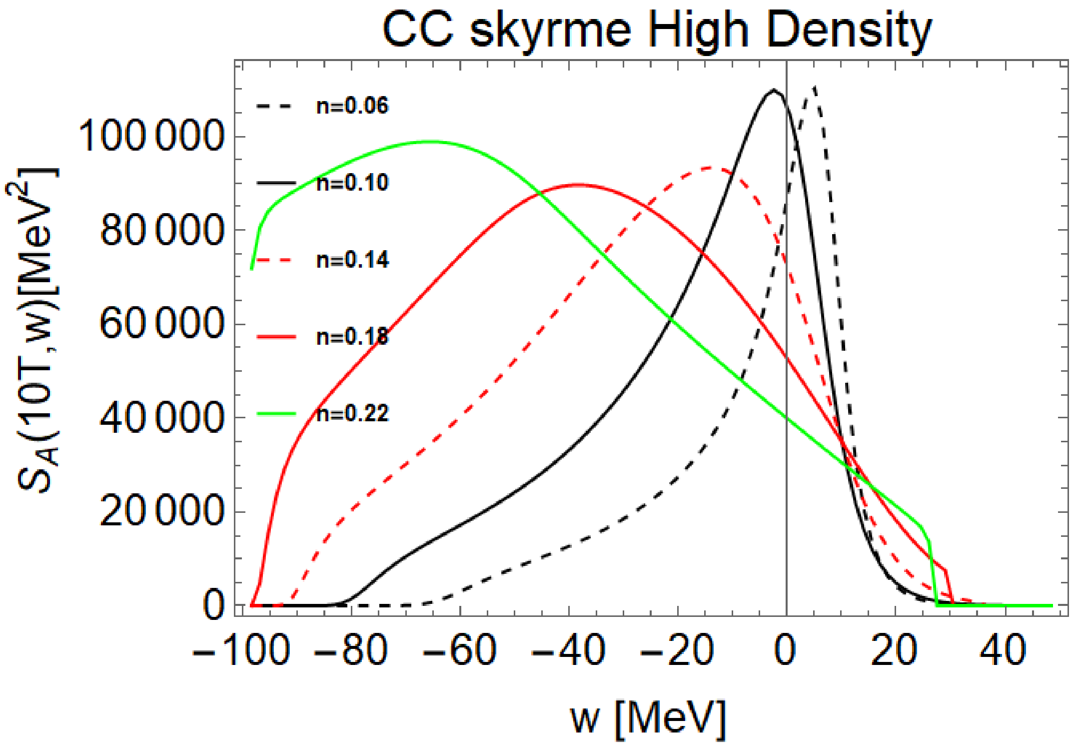
NC

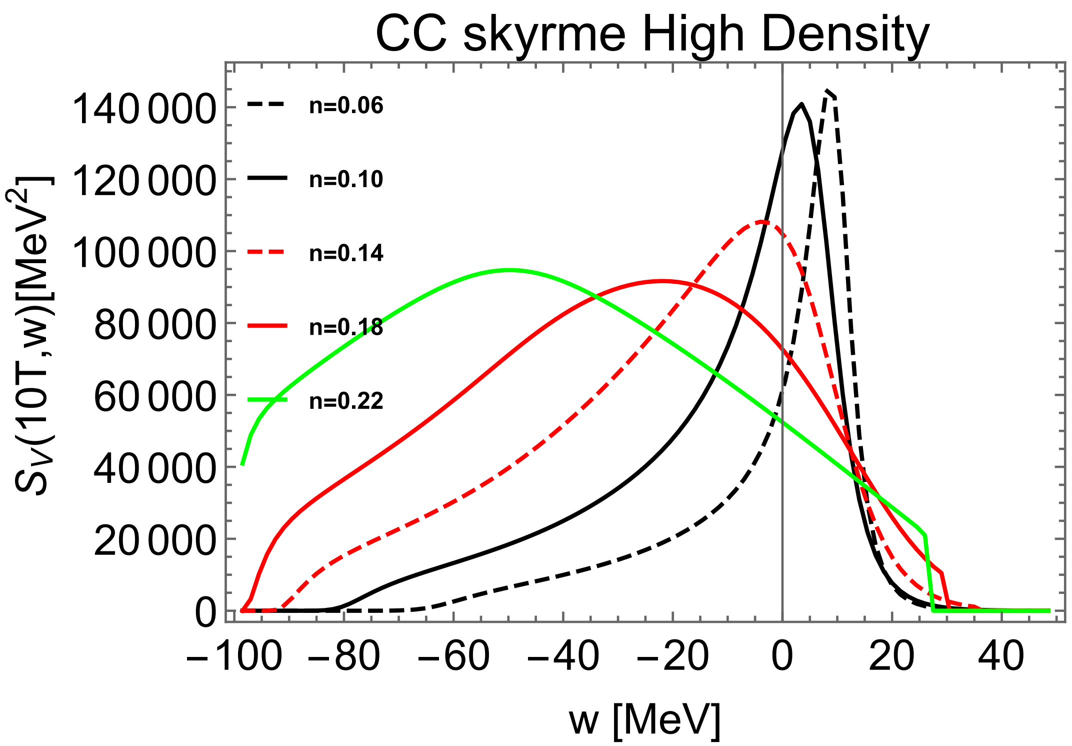


CC

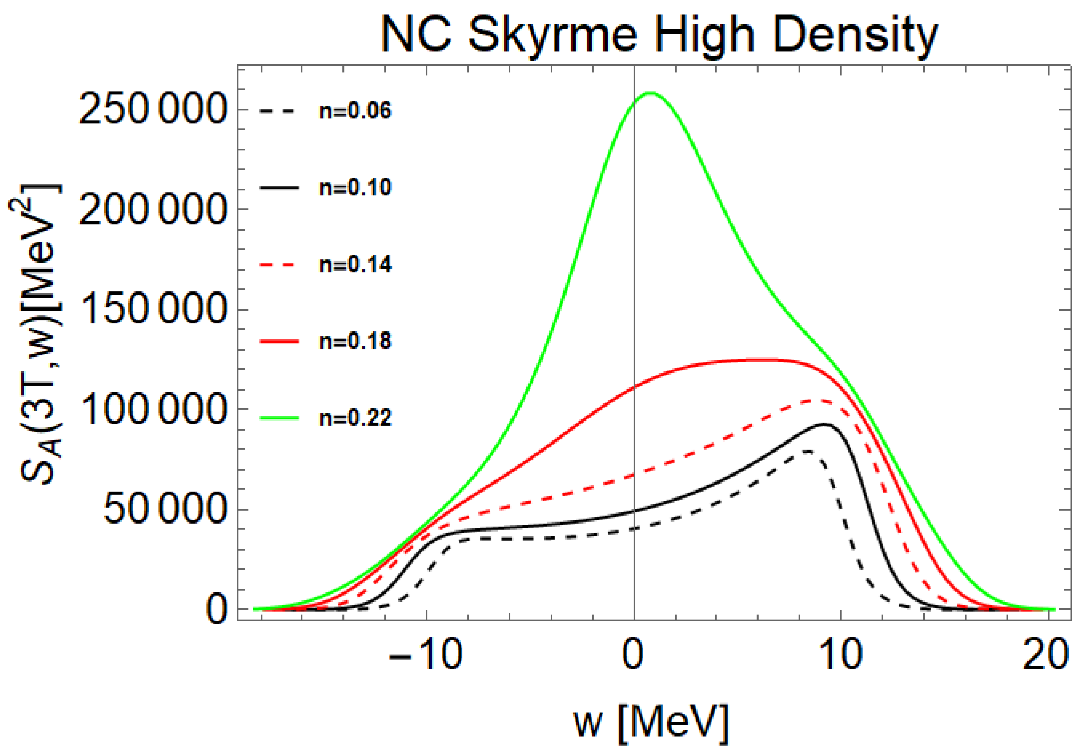


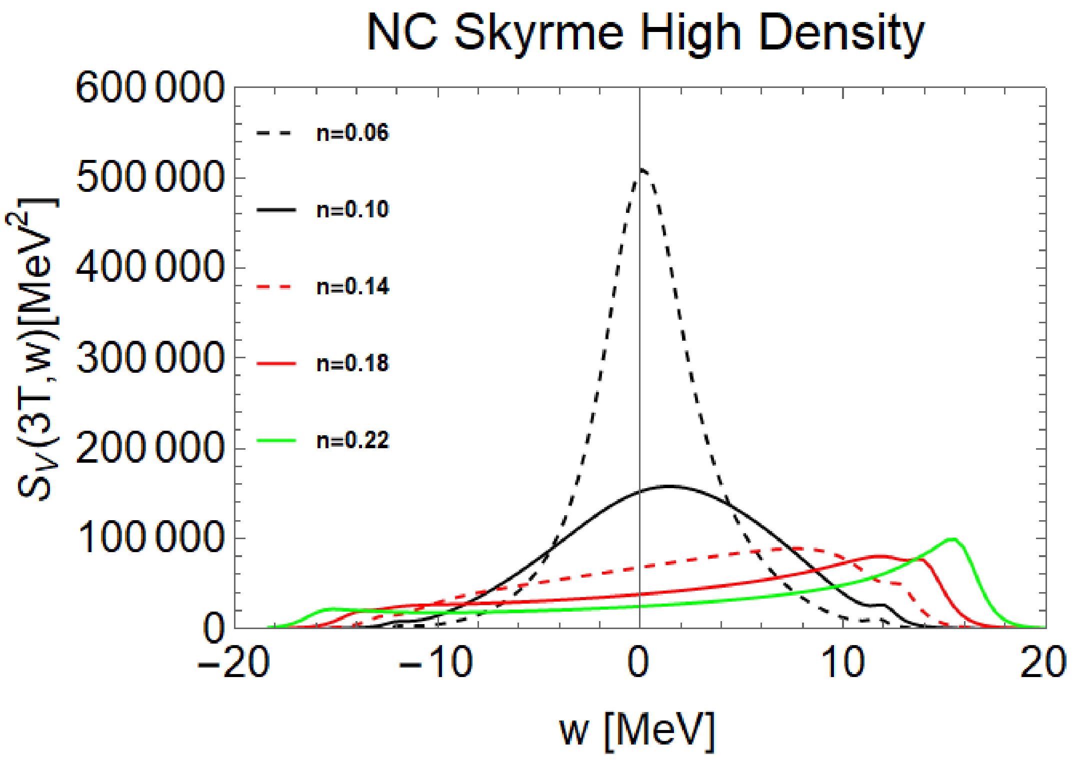
DYNAMIC RESPONSE AT HIGH DENSITY





DYNAMIC RESPONSE AT HIGH DENSITY



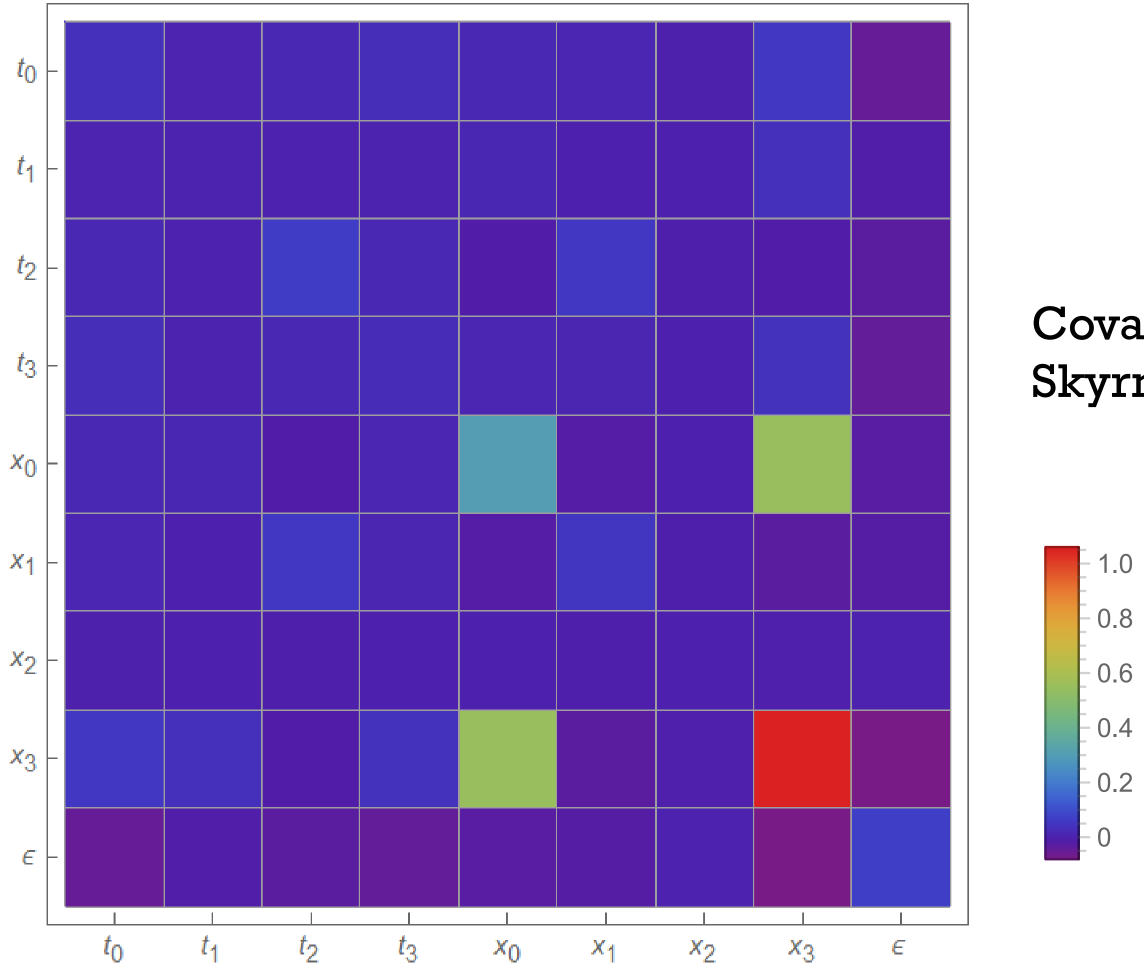


COVARIANCE & CORRELATIONS

$$\mathrm{cov}(A,B) = \mathrm{cov}(B,A) = \sum_{i,j=1}^{F} \left(\frac{\partial A}{\partial x_i}\right)_0 \Sigma_{ij} \left(\frac{\partial B}{\partial x_j}\right)_0 ;$$

$$\mathrm{cov}(A,A) \equiv \mathrm{var}(A) = \sigma_A^2$$

Preliminary Results

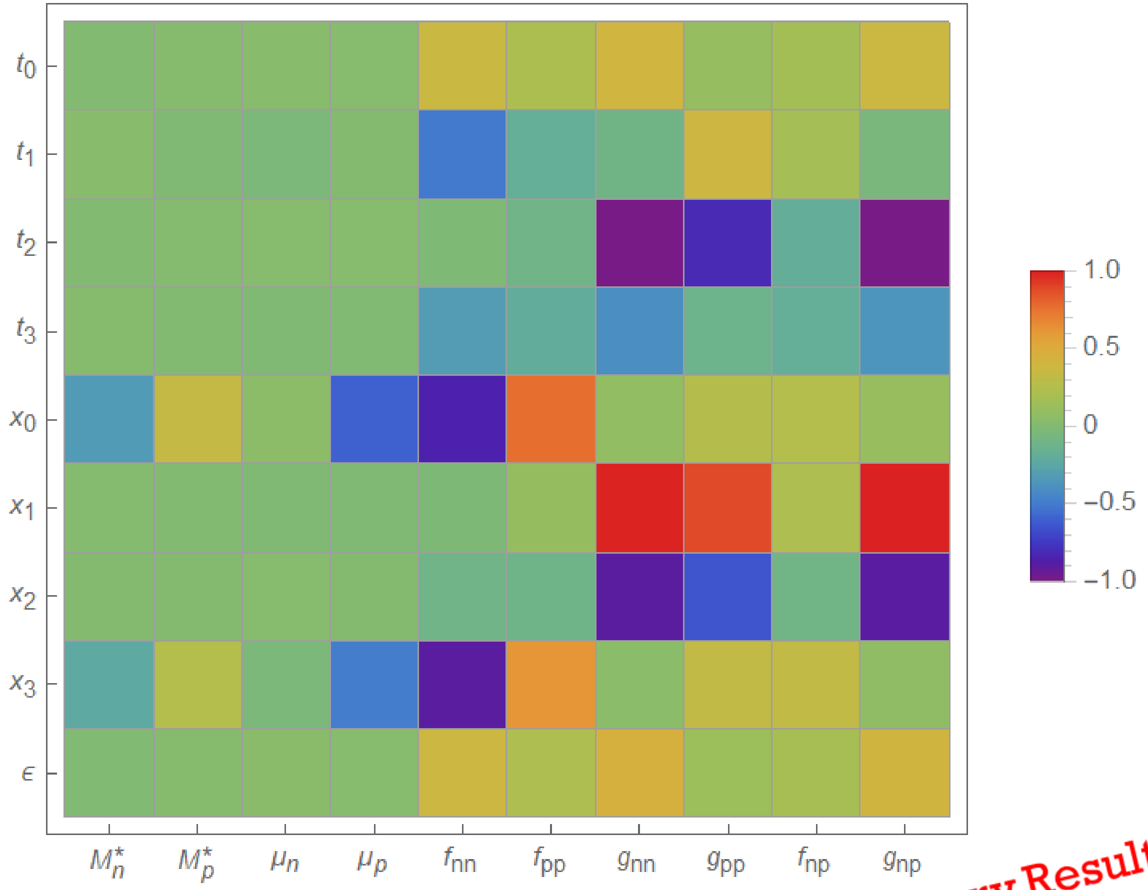


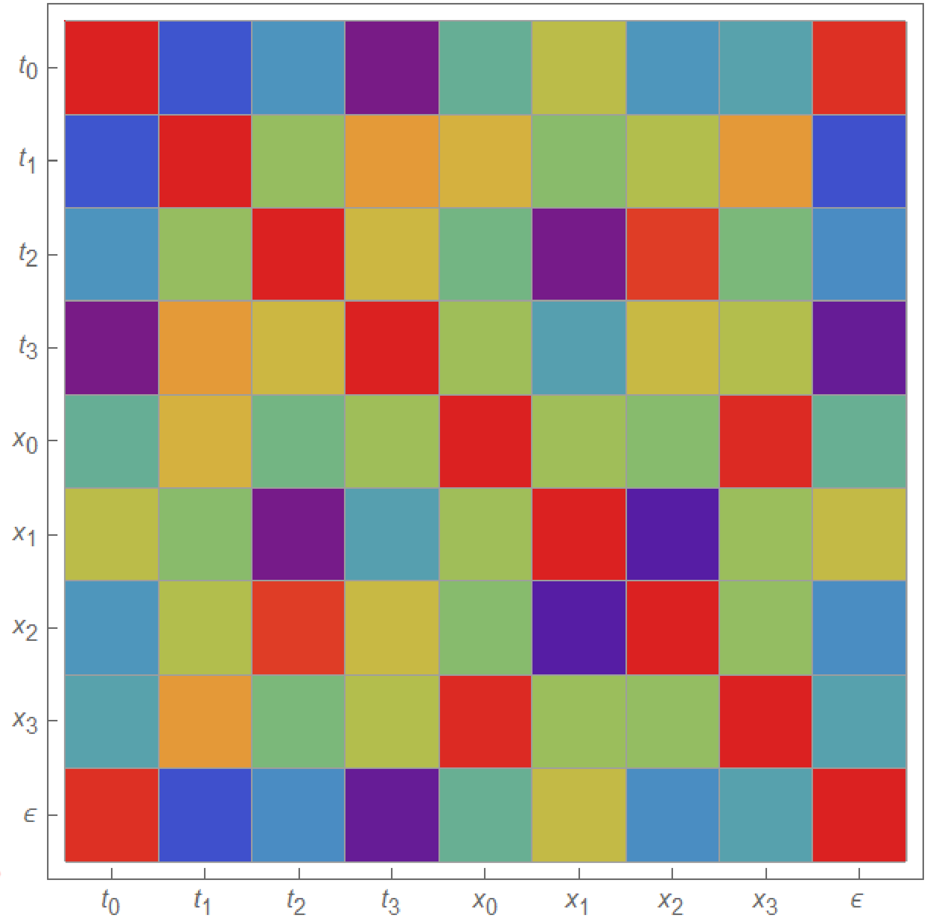
Covariance matrix Σ of Skyrme parameters

Zidu Lin, TEAMS meeting, 8/2/2021

COVARIANCE & CORRELATIONS

Pearson Coefficients: $\rho(A,B) = \dfrac{\mathrm{cov}(A,B)}{\sigma_A \sigma_B}$





Preliminary Results

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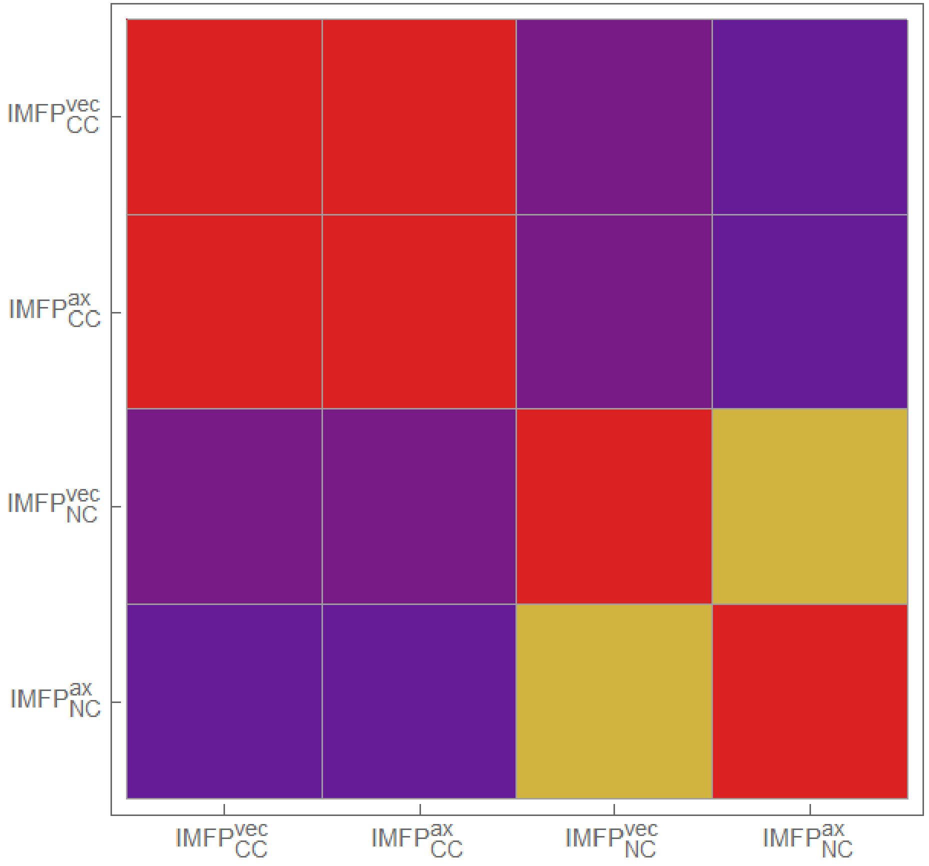

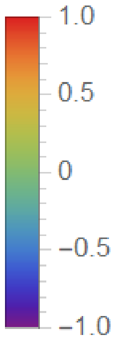

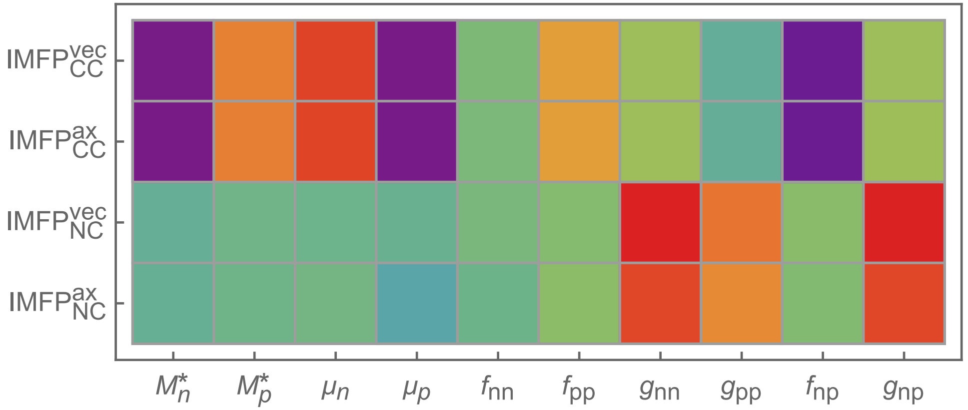

Preliminary Results

CONCLUSION

1. Random phase approximation provides a systematic way to estimate neutrino opacities in both CC and NC channel, from low to high densities

2. EoS and RPA neutrino opacities can be generated together in a consistent way, and the uncertainties of EoS propagates to the calculation of neutrino opacities, especially at high density

3. At low density, the agreement between RPA and virial neutrino response in NC channel may be improved when using the P-H interaction directly derived from virial EoS

LOOKING FORWARD...

a. Relativistic RPA+ EoS at very high density

b. Paricle-hole (ring) +Particle-Particle(ladder) RPA at low density