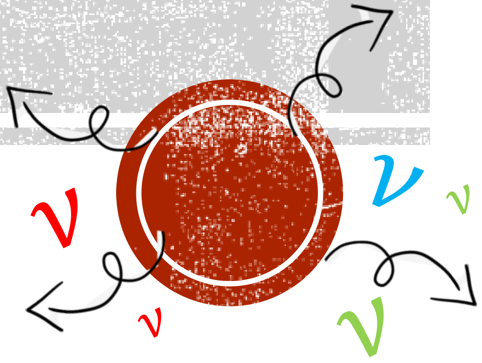
IMPACT OF EOS ON NEUTRINO OPACITIES IN CORE-COLLAPSE SUPERNOVAE

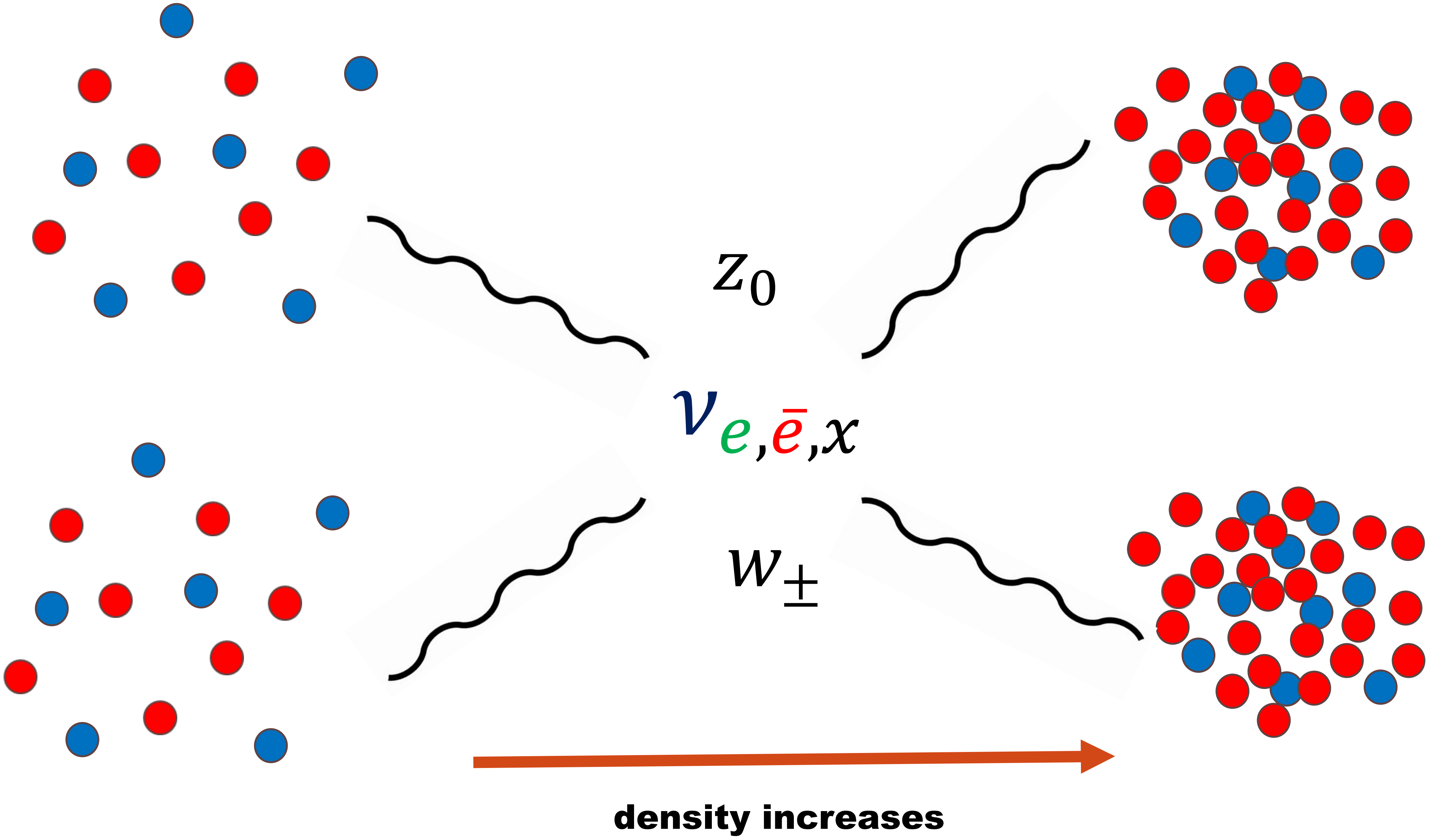
Based on Random Phase Approximations (RPA)



Zidu Lin

Collaborator: *Andrew Steiner*

NEUTRINO INTERACTIONS IN CCSN



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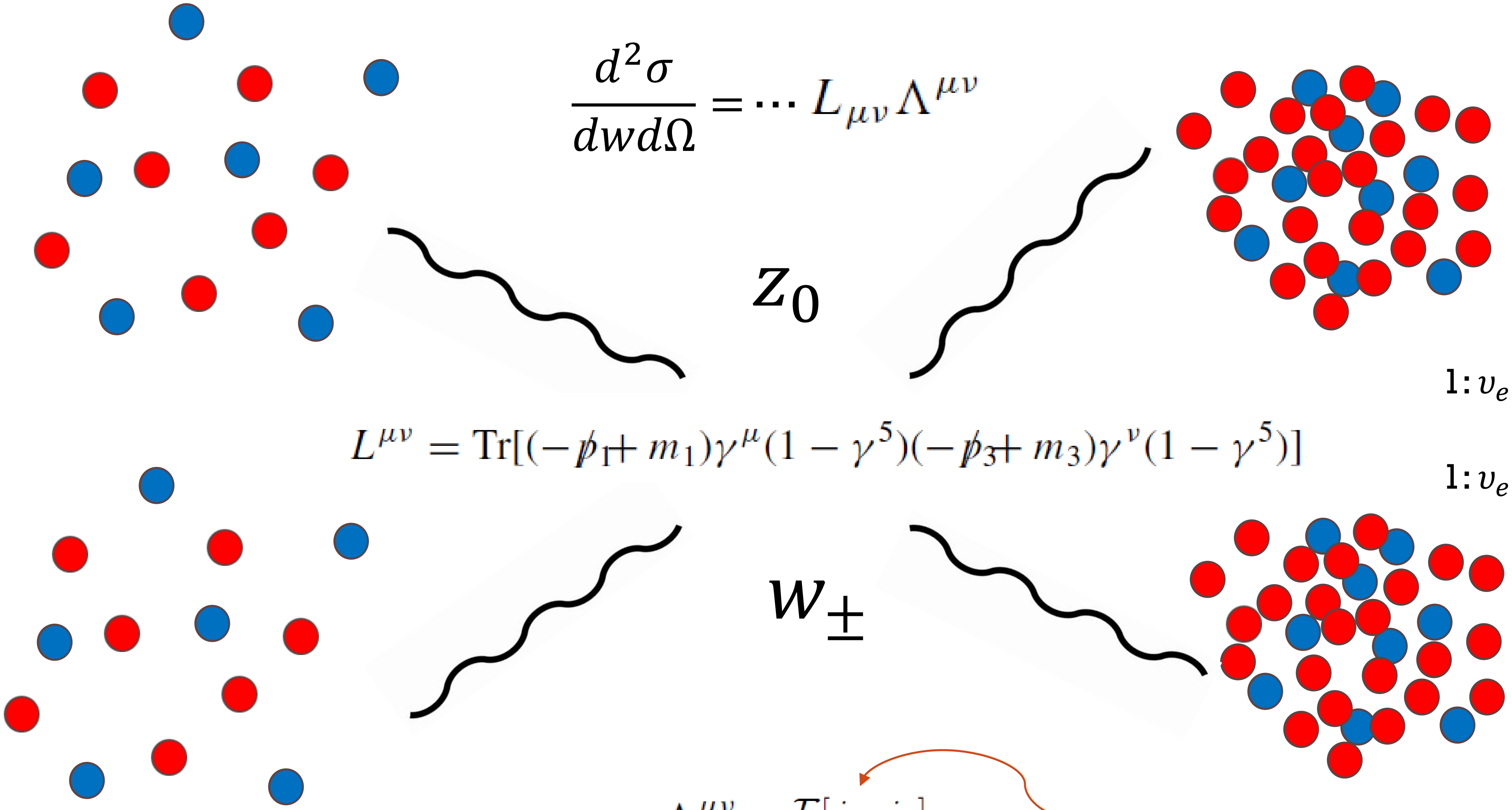
NEUTRINO INTERACTIONS IN CCSN

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



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

1: v_e 3: v_e (NC)

1: v_e 3: e (CC)

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

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 (rows 1–5)

Model dependent (rows 6–13)

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:

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

$U = \mu - \mu_0$

EoS →

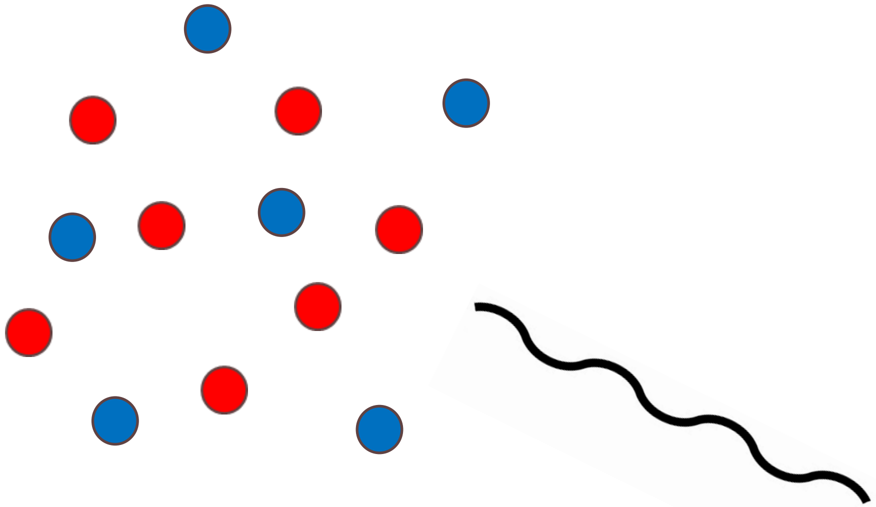
MF : U_P U_N μ_P μ_N M_P^* M_N^*

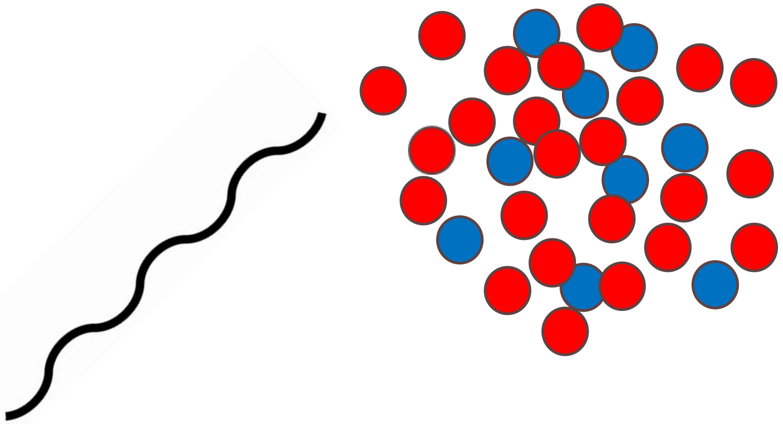
RPA : F_0 F_0' G_0 G_0'

Random phase approximation (RPA):

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

WHERE EOS MATTERS





Virial EoS

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

Skyrme EoS

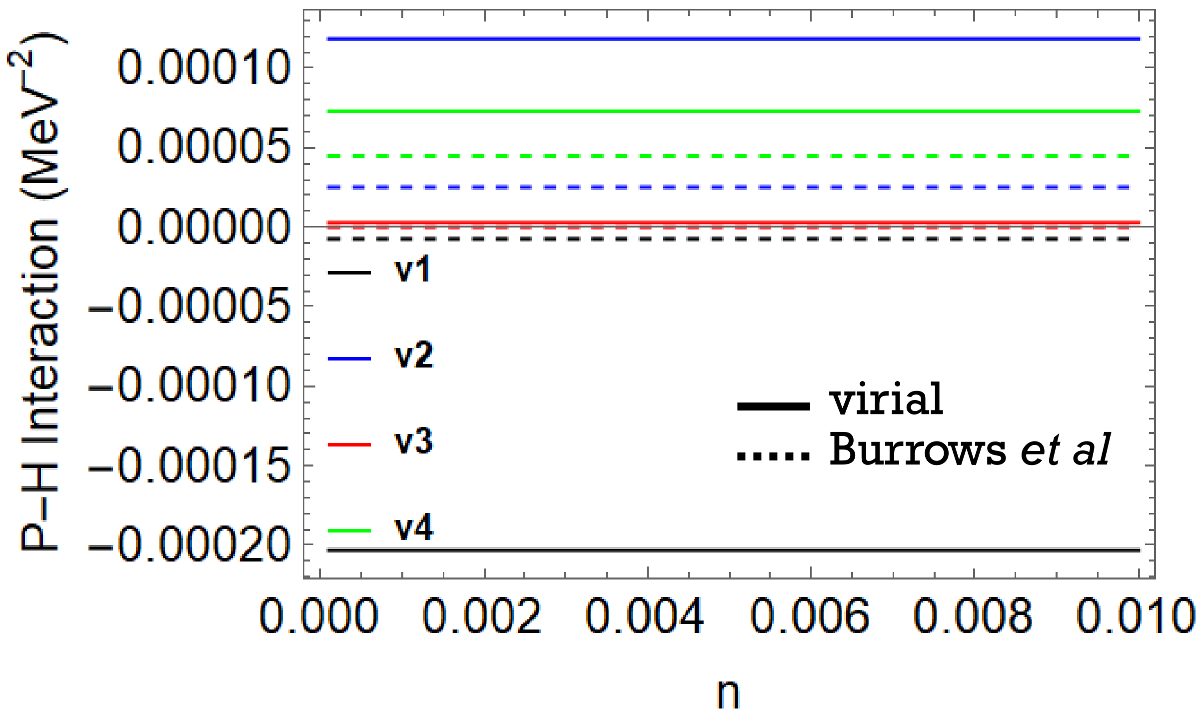
F_0 F_0' G_0 G_0'

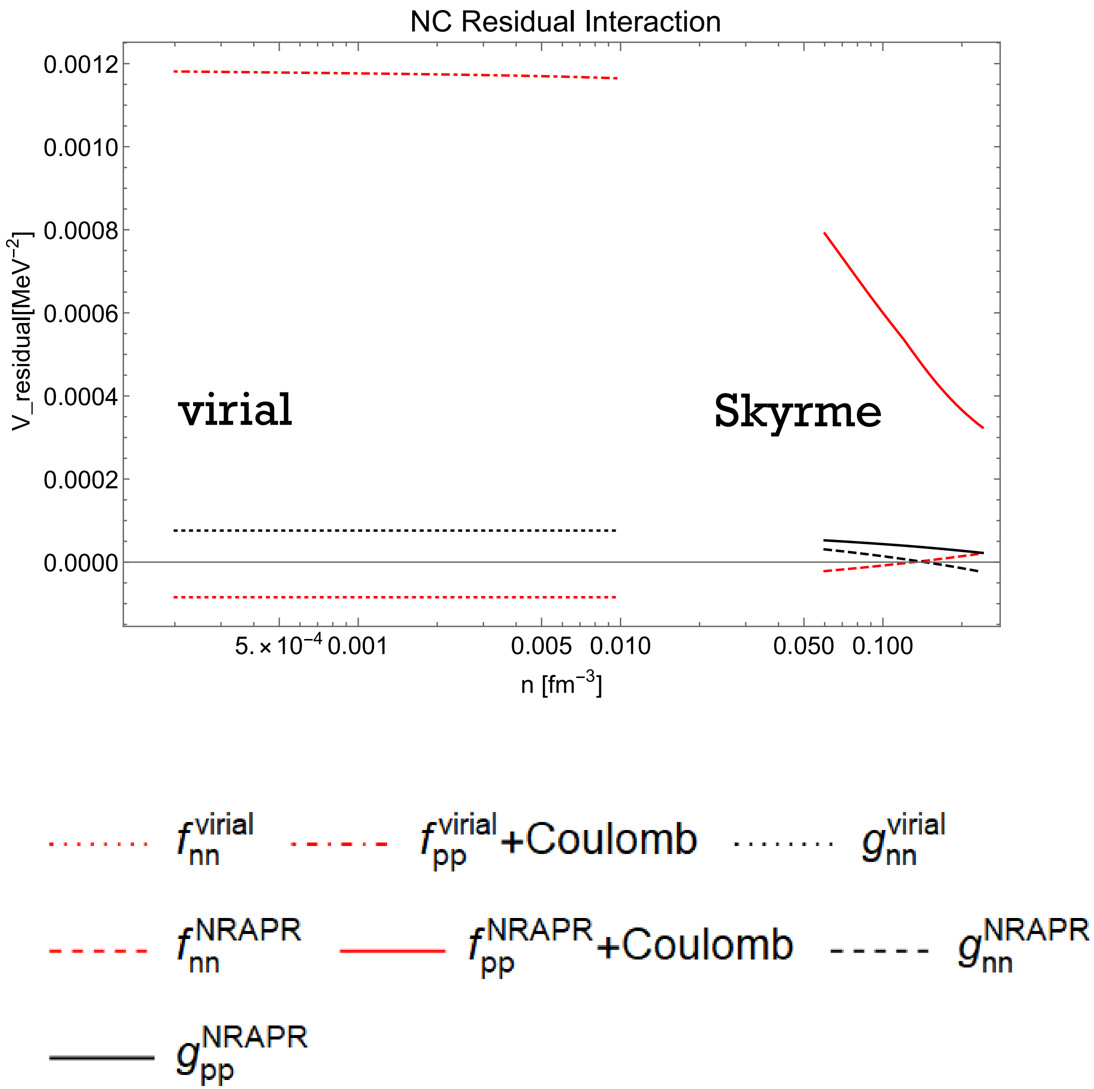
U_P μ_P M_N* U_N μ_N M_P*

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)…

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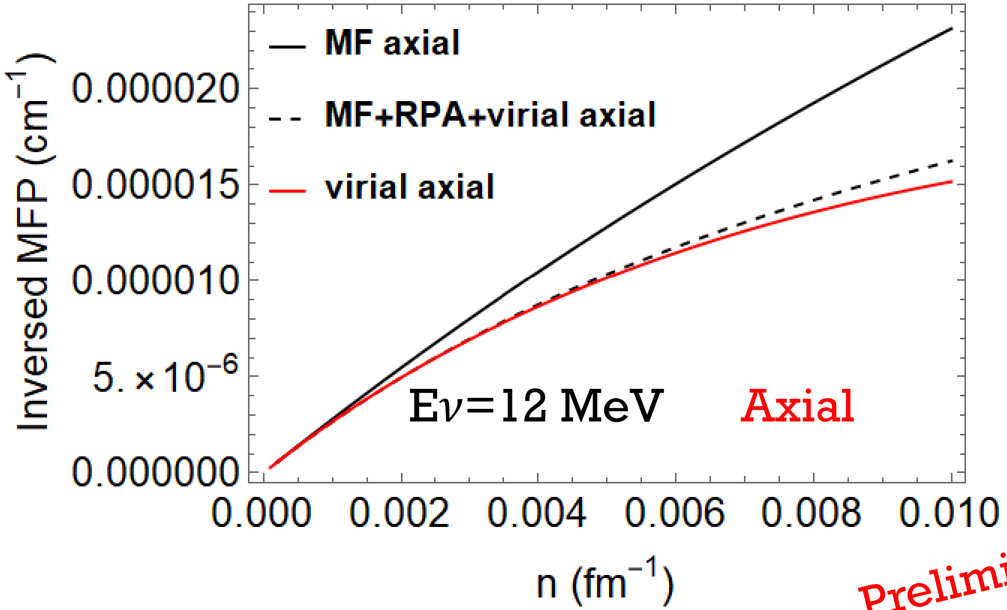
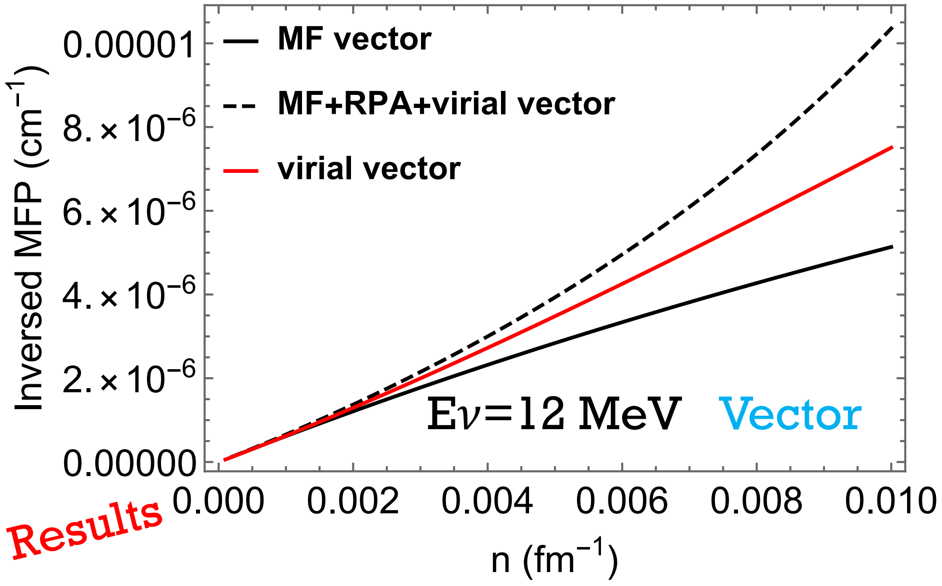
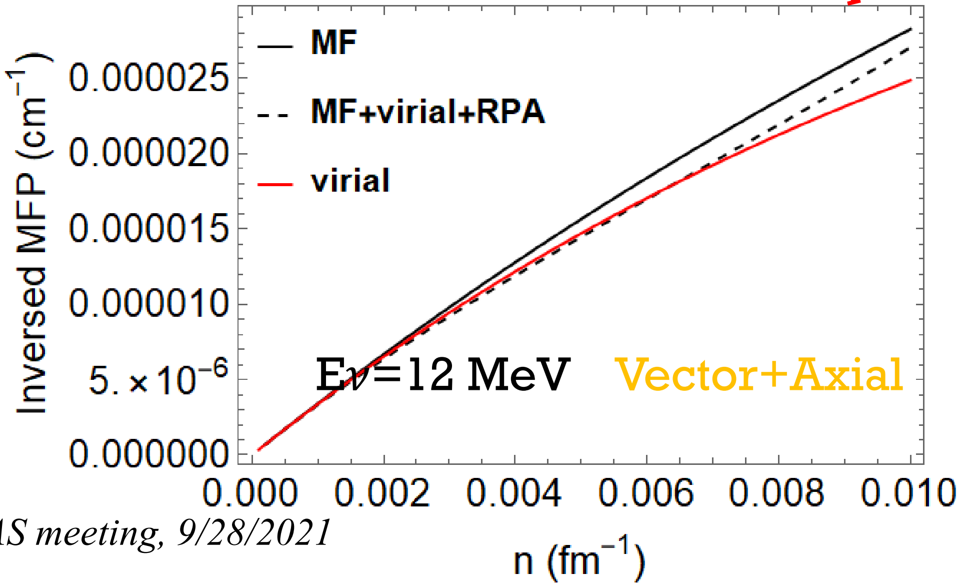
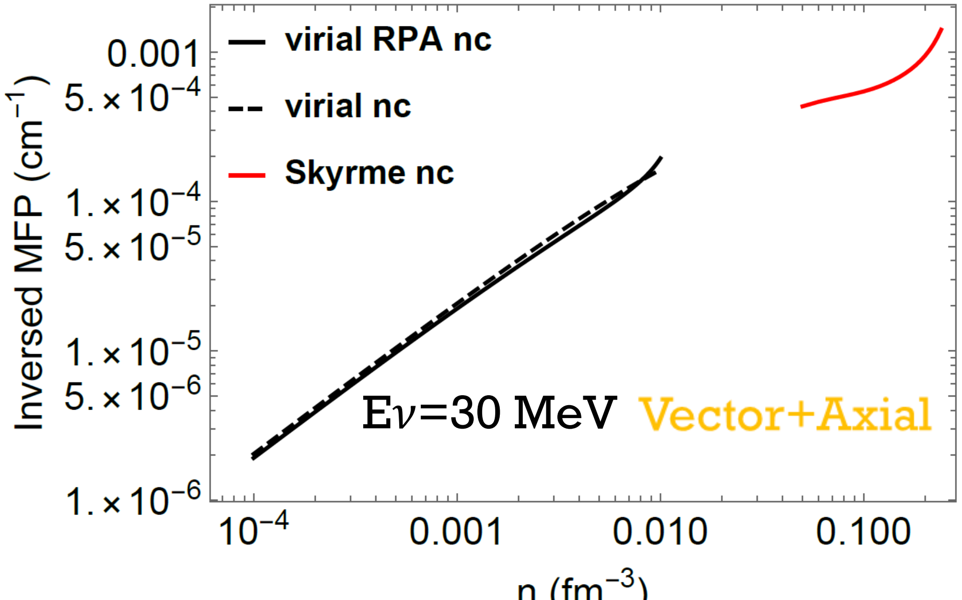
HOW WELL DOES RPA BEHAVE FOR NC?





Preliminary Results





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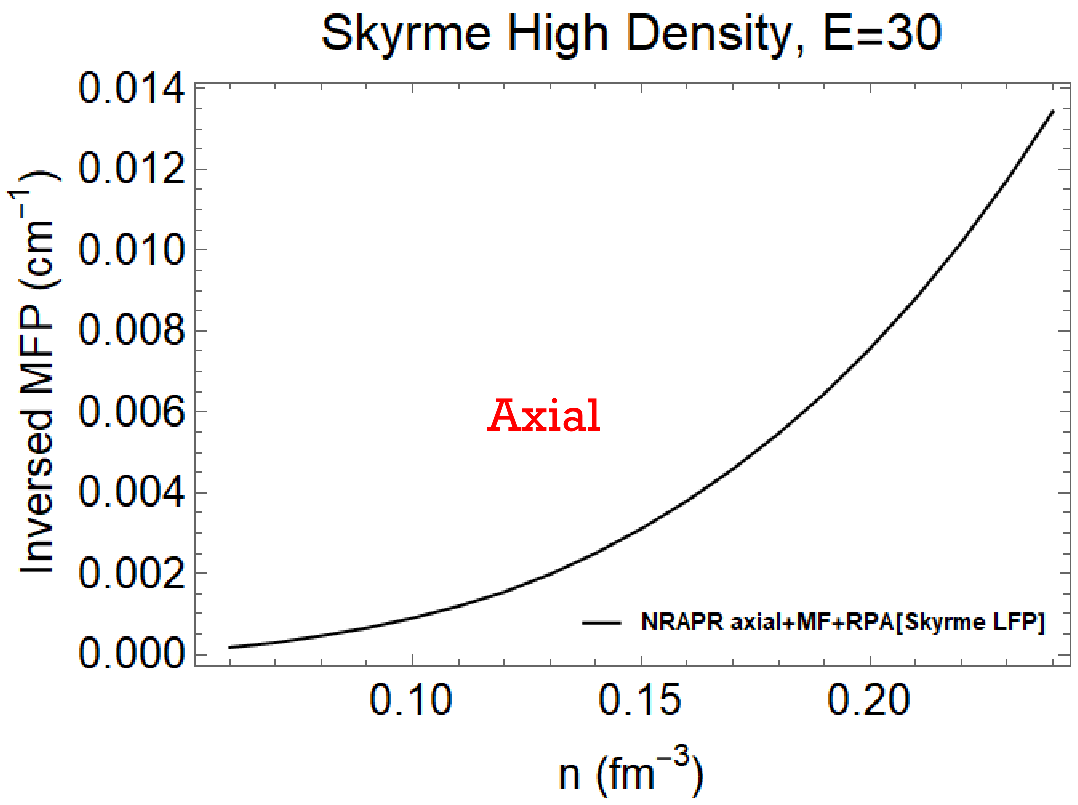
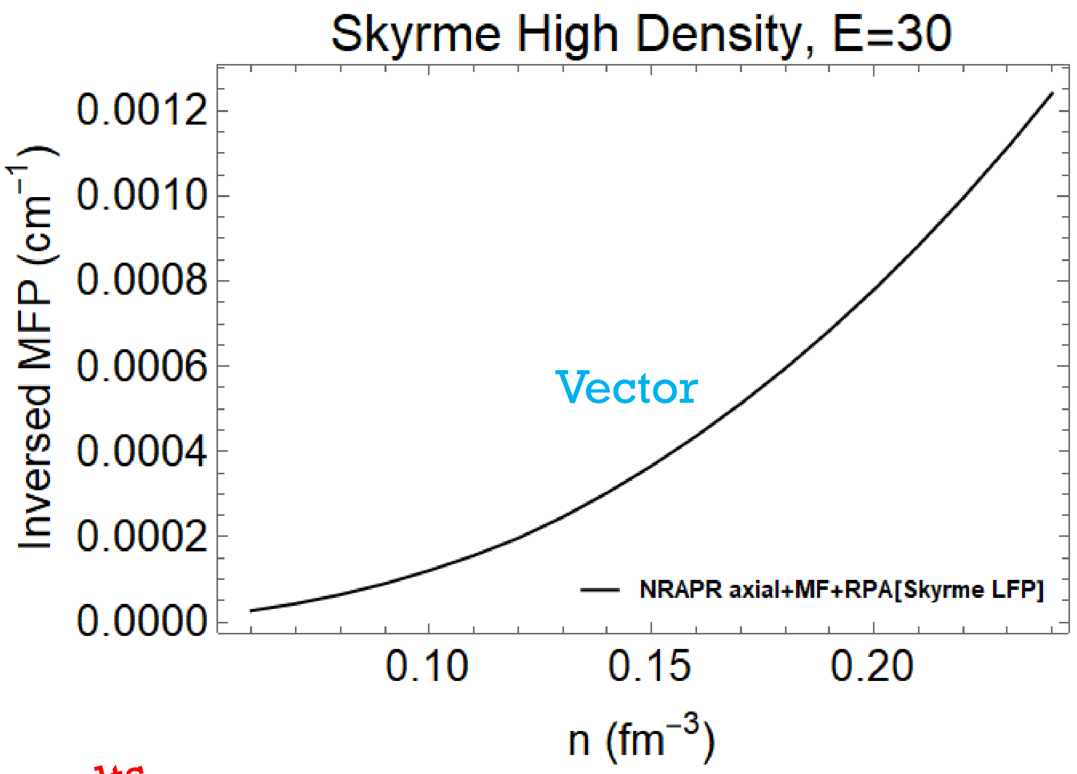
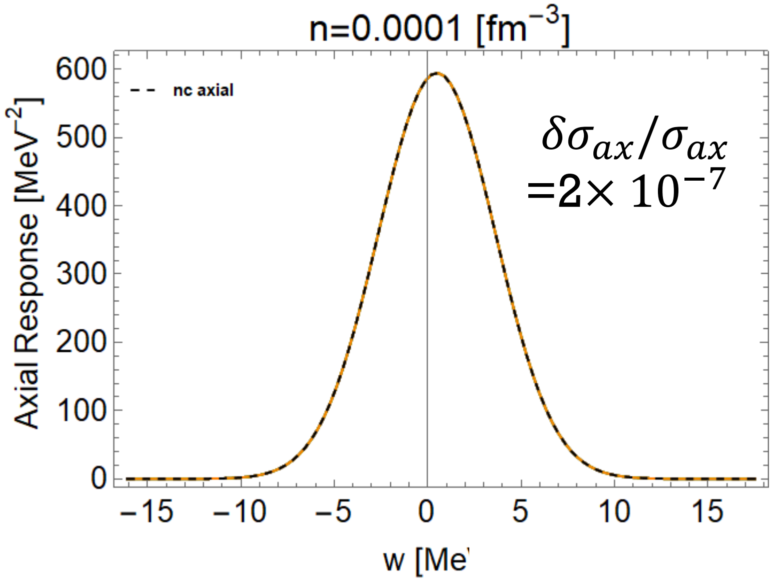
STATIC RESPONSE FOR CC

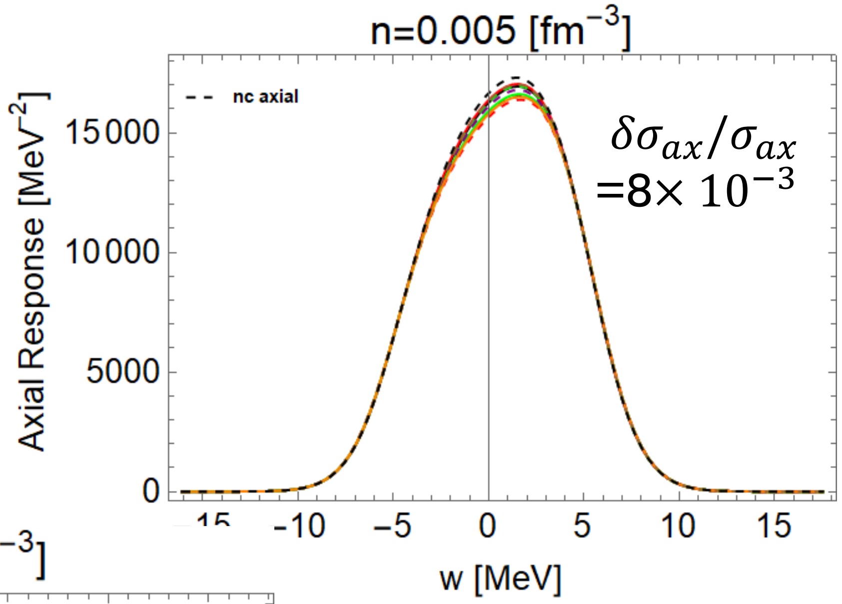




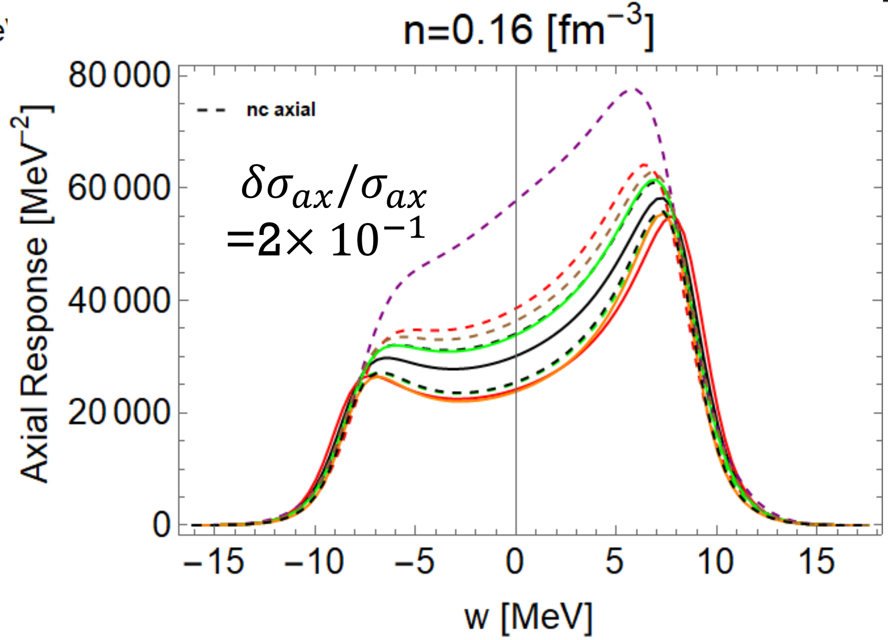
Preliminary Results

HOW BIG ARE THE IMPACTS FROM EOS ON OPACITY?





NC



Preliminary Results

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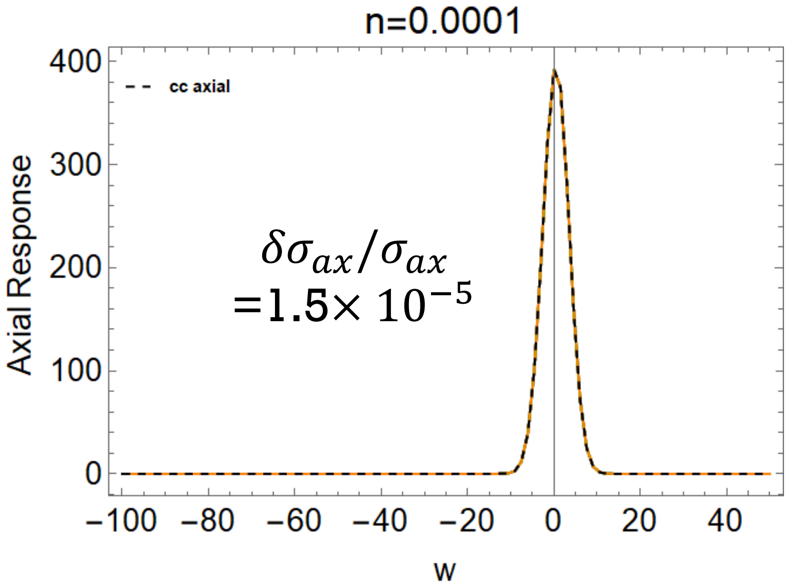
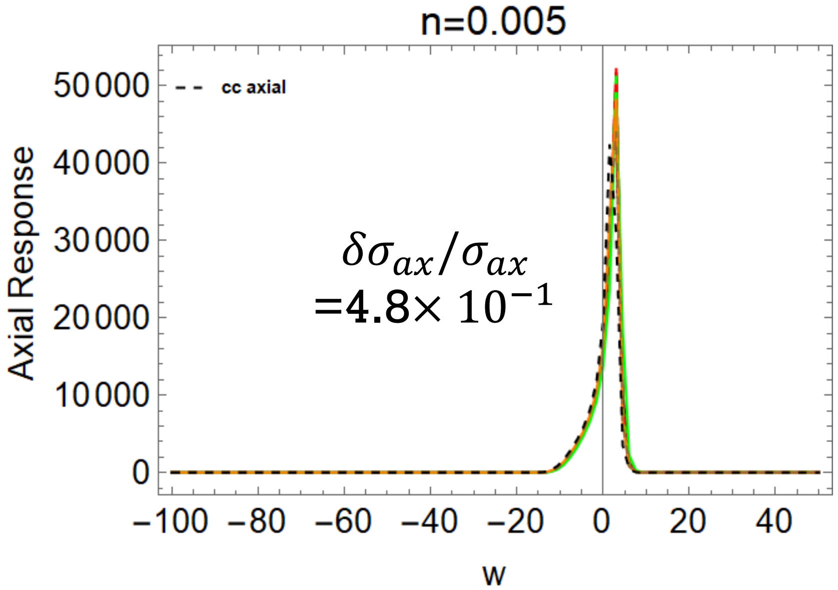
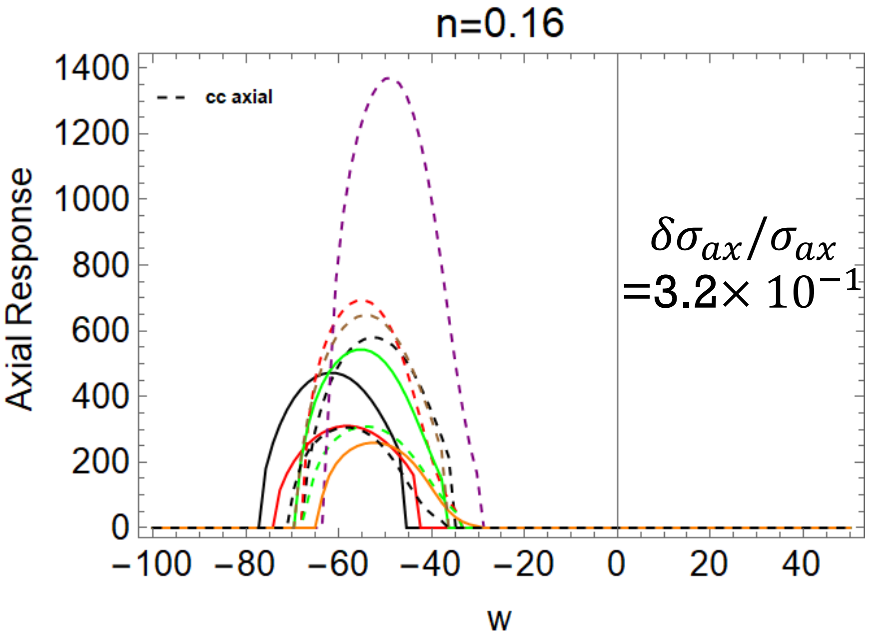




CC



Preliminary Results

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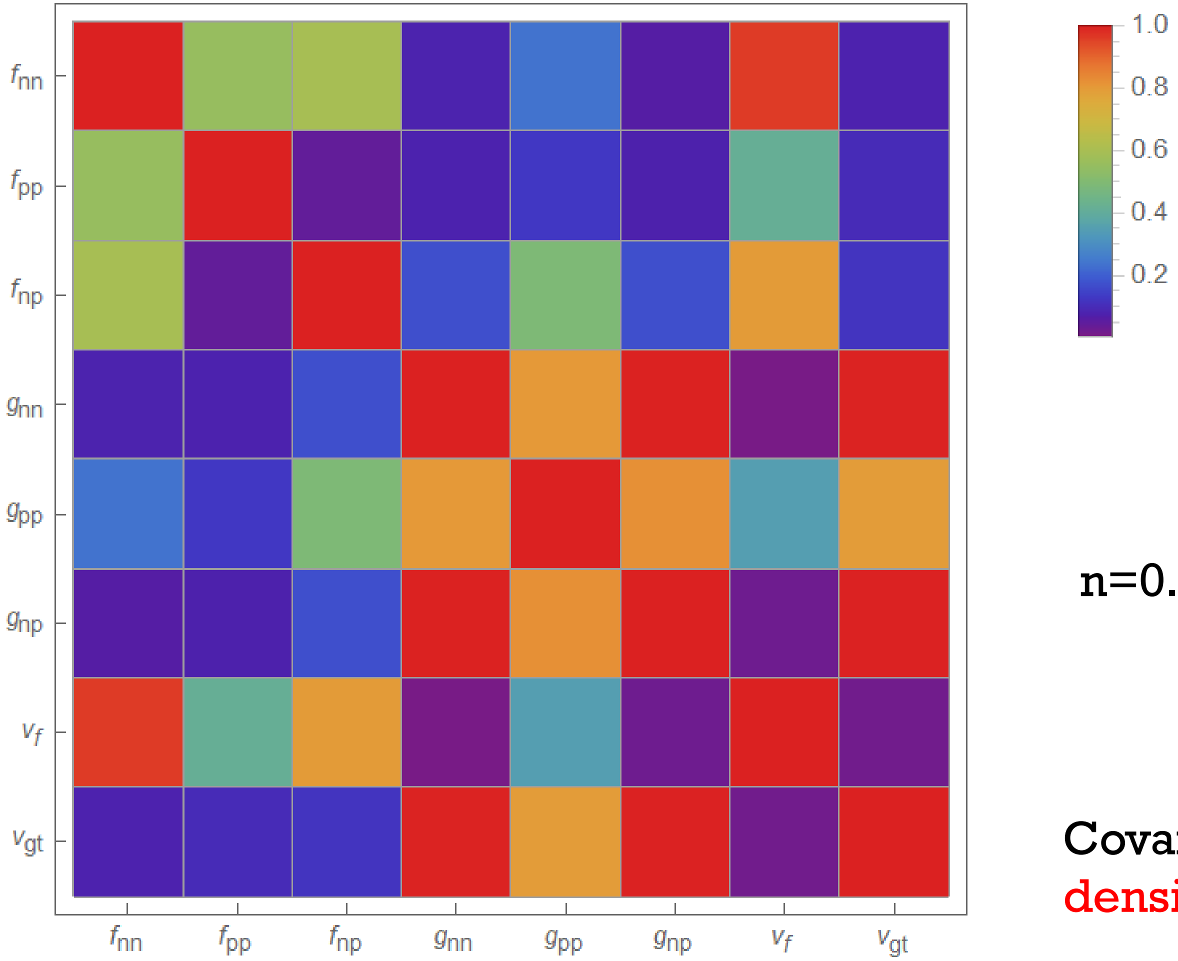
COVARIANCE & CORRELATIONS



Model parameter vs parameter:

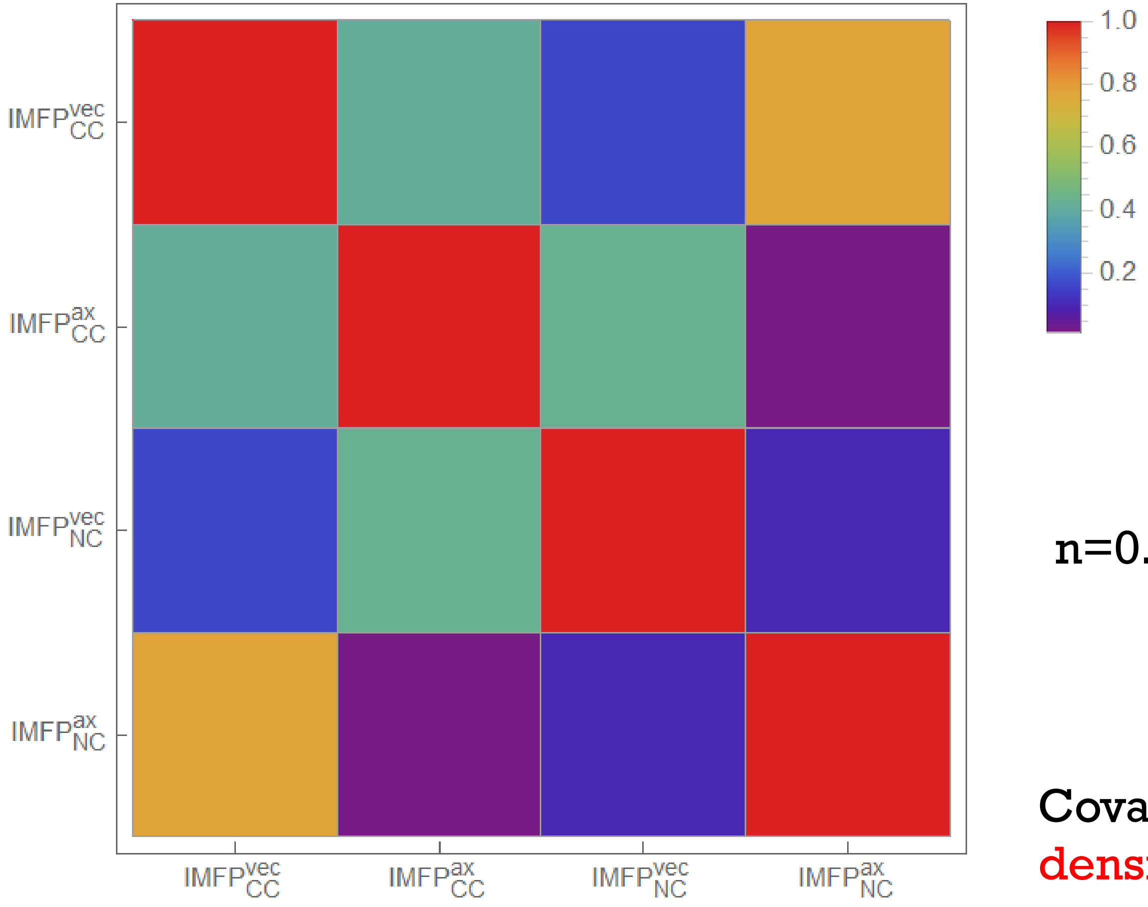
A strong correlation between model parameters underscores the need for both

n=0.16

Preliminary Results

Covariance map is density-dependent

COVARIANCE & CORRELATIONS



"observable" vs "observable":

A strong correlation between observables provides a clear path for its determination

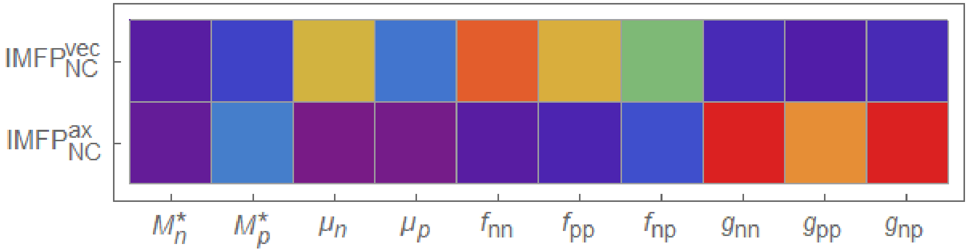
n=0.16

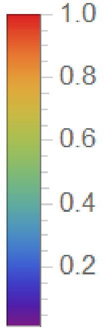
Preliminary Results

Covariance map is density-dependent

COVARIANCE & CORRELATIONS

NC

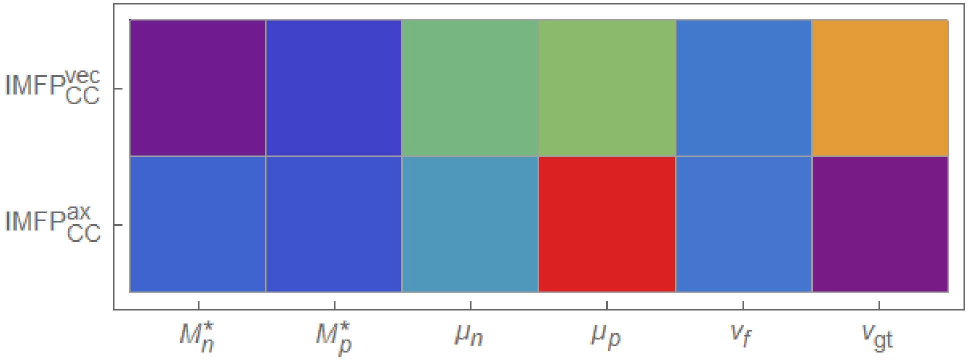




Model parameter vs "observable":

A strong correlation between observables and model parameters reveal the sensitivity of the parameters to a particular kind of physics

CC



n=0.16

Covariance map is density-dependent

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. The role of collective mode in neutrino opacity might need to be revisited, with updated nuclear residual interactions

b. Relativistic RPA+ EoS at very high density