Neutrino cross sections and nuclear structure

Giampaolo Co'

Dipartimento di Fisica Università del Salento
Istituto Nazionale di Fisica Nucleare sez. di Lecce

NOW08 Conca Specchiulla, Sept. 11, 2008

In collaboration with

Viviana De Donno
Chiara Maieron

Dipartimento di Fisica Università del Salento
Istituto Nazionale di Fisica Nucleare sez. di Lecce

Aim of the talk

How the uncertainties on the nuclear structure affects the ν-nucleus cross section

Aim of the talk

How the uncertainties on the nuclear structure affects the ν-nucleus cross section

Specific case

Precision ν astronomy

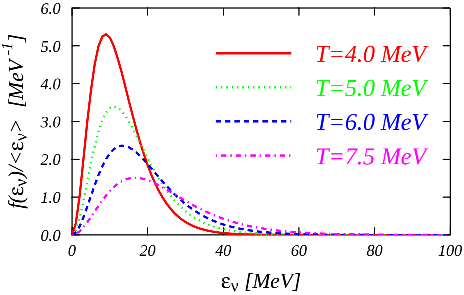
Aim of the talk

How the uncertainties on the nuclear structure affects the ν-nucleus cross section

Specific case

Precision ν astronomy

SUPERNOVAE



Disentangling

$\nu_x, \overline{\nu}_x \longrightarrow$ T =6.0 MeV   T =7.5 MeV

Excitation energy $\omega \leq 100$ MeV
Momentum transfer $q \leq 1.0$ fm^{-1}

Ab initio calculations

Realistic nucleon-nucleon interaction

Nuclear Structure

Ab initio calculations

Realistic nucleon-nucleon interaction

Effective theories

Nucleon-nucleon interactions linked to the theory

Random Phase Approximation (RPA)

$$|\nu> = Q^\dagger_\nu|0> \qquad Q_\nu|0> = 0$$

$$Q^\dagger_\nu = \sum_{ph} X_{ph} a^\dagger_p a_h - \sum_{ph} Y_{ph} a^\dagger_h a_p$$

$$\begin{aligned}
(\epsilon_p - \epsilon_h - \omega) X_{ph} + \sum_{p'h'} [v_{ph,p'h'} X_{p'h'} + u_{ph,p'h'} Y_{p'h'}] &= 0 \\
(\epsilon_p - \epsilon_h + \omega) Y_{ph} + \sum_{p'h'} [u_{ph,p'h'} X_{p'h'} + v_{ph,p'h'} Y_{p'h'}] &= 0
\end{aligned}$$

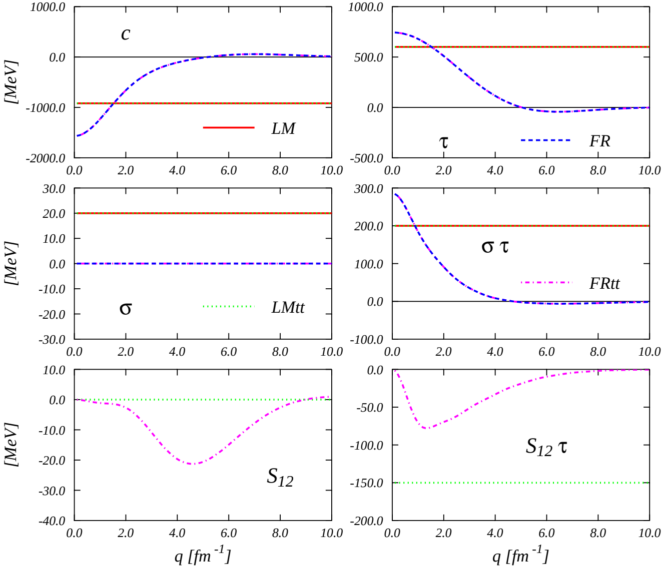
$$\begin{aligned}
v_{ph,p'h'} &= < ph'|V|hp' > - < ph'|V|p'h > \\
u_{ph,p'h'} &= < pp'|V|hh' > - < pp'|V|h'h >
\end{aligned}$$

Effective interaction

$$
\begin{aligned}
V_{eff}(r) &= V_1(r,\rho) + V_2(r)\,\vec{\tau}(1)\cdot\vec{\tau}(2) \\
&+ V_3(r)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2) + V_4(r)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2)\,\vec{\tau}(1)\cdot\vec{\tau}(2) \\
&+ V_5(r)\,S_{12}(r) + V_6(r)\,S_{12}(r)\vec{\tau}(1)\cdot\vec{\tau}(2)
\end{aligned}
$$

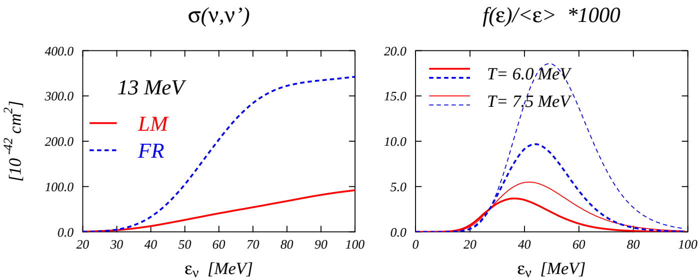
$$
S_{12}(r) = 3\frac{\vec{\sigma}(1)\cdot\vec{r}\;\;\vec{\sigma}(2)\cdot\vec{r}}{r^2} - \vec{\sigma}(1)\cdot\vec{\sigma}(2)
$$

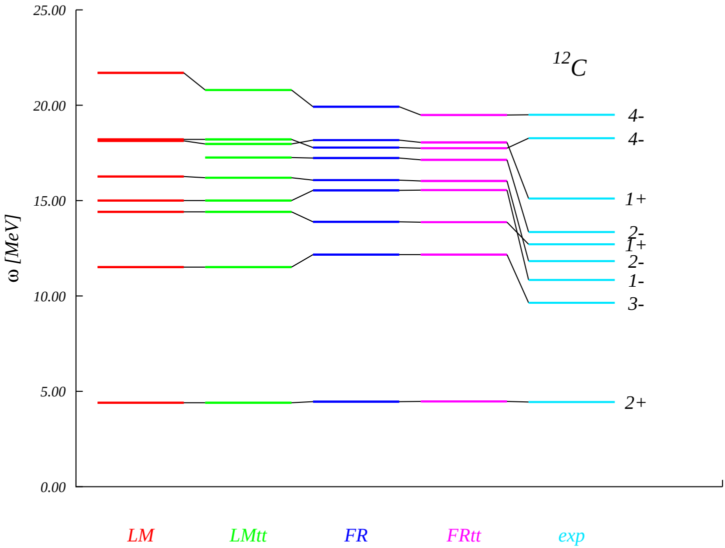
$$
\begin{aligned}
&V_1(r,\rho) = V_c(r) + V_\rho(r)\rho(r)^\alpha \\
&\rho(r_{12}) = [\rho(r_1)\rho(r_2)]^{1/2} \\
&\alpha = 1
\end{aligned}
$$

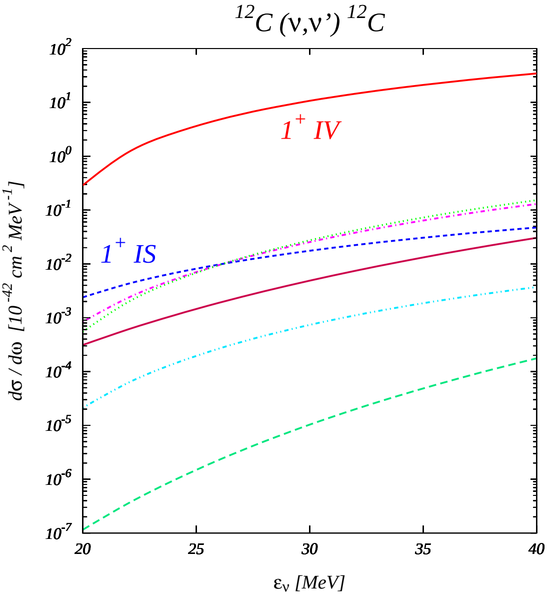


c
τ
σ
σ τ
S_{12}
S_{12} τ
LM
FR
LMtt
FRtt
[MeV]
q [fm^{-1}]

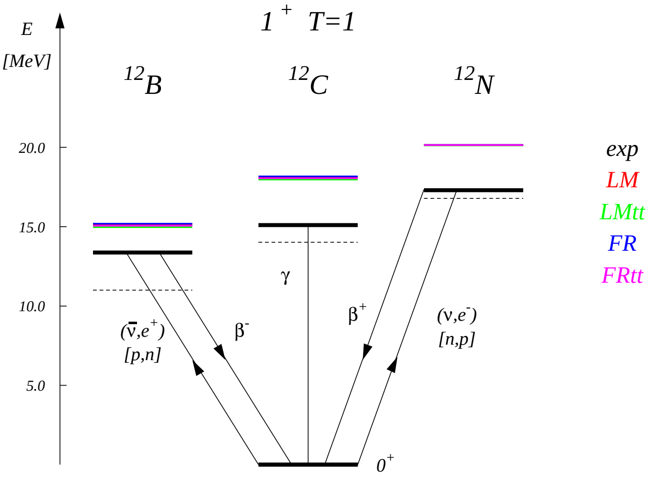
^{208}Pb (ν,ν') ^{208}Pb

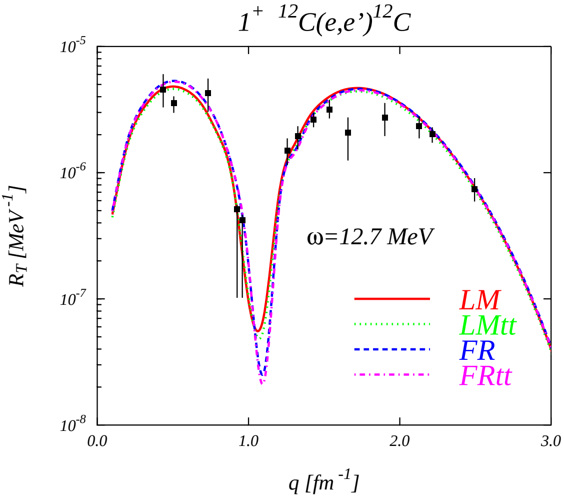



25.00
20.00
15.00
10.00
5.00
0.00
ω [MeV]
12C
4-
4-
1+
2-
1+
2-
1-
3-
2+
LM
LMtt
FR
FRtt
exp



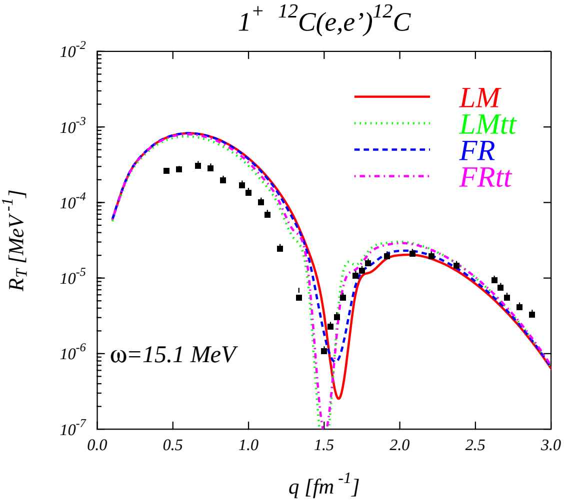
$^{12}C\ (\nu,\nu')\ ^{12}C$
1^+ IV
1^+ IS
$d\sigma / d\omega\ [10^{-42}\ cm^2\ MeV^{-1}]$
ϵ_ν [MeV]
20
25
30
35
40
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}


1+ T=1
E
[MeV]
12B
12C
12N
20.0
15.0
10.0
5.0
exp
LM
LMtt
FR
FRtt
(ν̄,e+)
[p,n]
β-
γ
β+
(ν,e-)
[n,p]
0+



Data: Buti et al. PRC 33 (1986) 755

^{12}C : 1^{+} Isovector

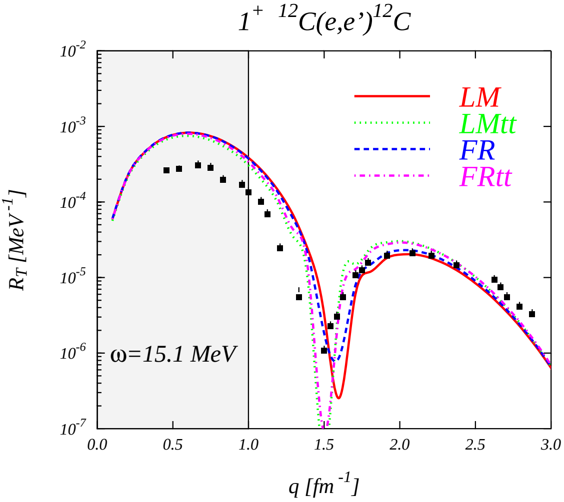


Data: Hicks et al. PRC 36 (1987) 485

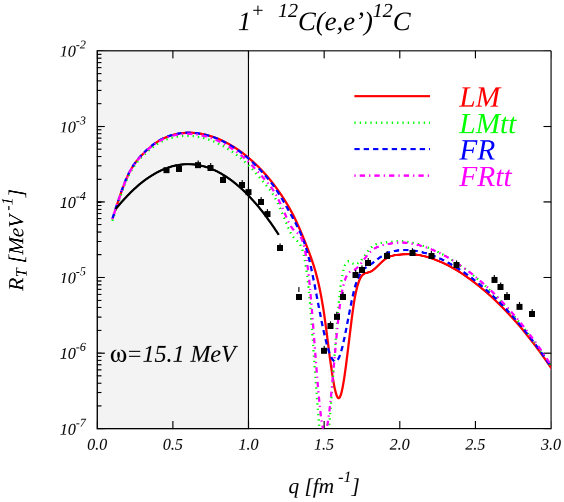
$$\left(\frac{d^2\sigma}{d\Omega d\epsilon}\right)_{e,e'} = \sigma_M \frac{1}{2J_i+1}\Big[v_L | < J_f || C^V_J || J_i > |^2 + v_T | < J_f || T^V_J || J_i > |^2 \Big]$$

$$\begin{aligned}\left(\frac{d^2\sigma}{d\Omega d\epsilon}\right)_{\nu,\nu'} = & \; G^2 \frac{\epsilon'_\nu}{\epsilon_\nu} \frac{1}{2J_i+1}\Big[w^A_C | < J_f || C^A_J || J_i > |^2 + \\ & + w^A_L | < J_f || L^A_J || J_i > |^2 + w^V_L | < J_f || C^V_J || J_i > |^2 + \\ & + w^A_{LC} Re\big(< J_f || C^A_J || Ji >< J_f || C^A_J || J_i >^* \big) \\ & + w^A_T | < J_f || T^A_J || J_i > |^2 + w^V_T | < J_f || T^V_J || J_i > |^2 \\ & + w^{AV}_T Re\big(< J_f || T^A_J || Ji >< J_f || T^V_J || J_i >^* \big) \Big]\end{aligned}$$

^{12}C : 1^+ Isovector



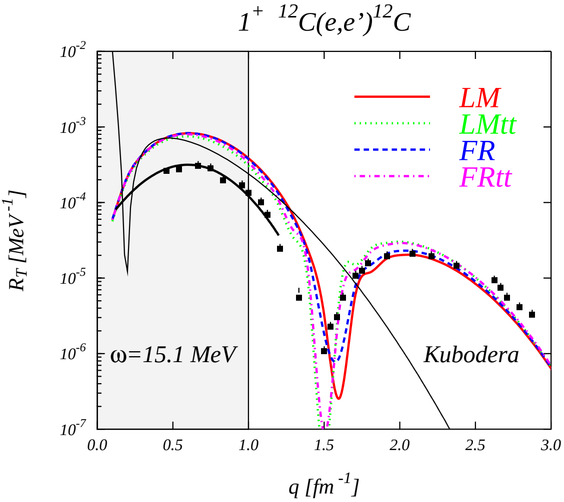
^{12}C : 1^{+} Isovector



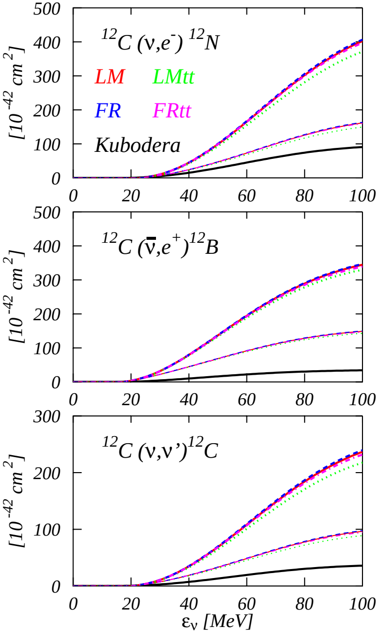
$$Q(q) = \frac{| < J_f || T_J^{exp}(q) || J_i > |^2_{e,e'}}{| < J_f || T_J^{V}(q) || J_i > |^2_{RPA}}$$

$$\left(\frac{d^2\sigma}{d\Omega d\epsilon} \right)^{scal}_{\nu,\nu'} = Q(q) \left(\frac{d^2\sigma}{d\Omega d\epsilon} \right)^{RPA}_{\nu,\nu'}$$

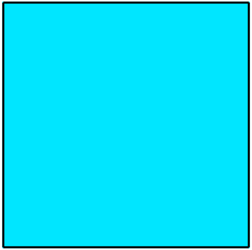
^{12}C : 1^+ Isovector

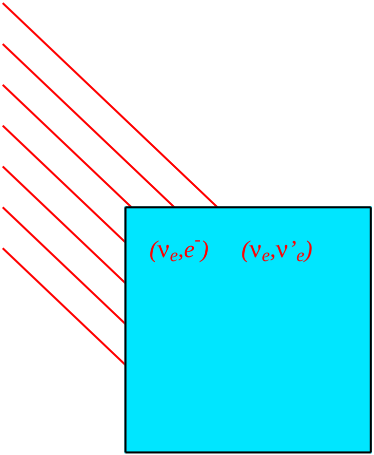


M. Fukugita, Y. Kohyama and K. Kubodera, Phys. Lett. B 212 (1988) 139.

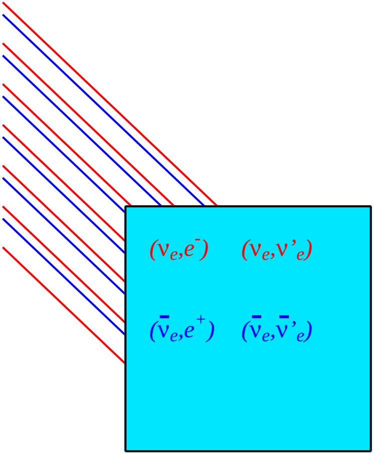


$^{12}C\ (\nu,e^-)\ ^{12}N$
LM
LMtt
FR
FRtt
Kubodera
$^{12}C\ (\bar{\nu},e^+)\ ^{12}B$
$^{12}C\ (\nu,\nu')\ ^{12}C$
$[10^{-42}\ cm^2]$
ϵ_ν [MeV]

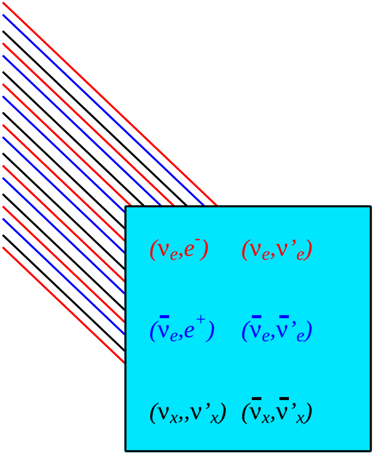




$N_{NC} = (\nu_e, \nu'_e)$
$N_{np} = (\nu_e, e^-)$



$$N_{NC} = (\nu_e, \nu'_e) + (\overline{\nu}_e, \overline{\nu}'_e)$$
$$N_{np} = (\nu_e, e^-)$$
$$N_{pn} = (\overline{\nu}_e, e^+)$$



$$N_{NC} = (\nu_e, \nu'_e) + (\overline{\nu}_e, \overline{\nu}'_e) + (\nu_x, \nu'_x) + (\overline{\nu}_x, \overline{\nu}'_x)$$
$$N_{np} = (\nu_e, e^-)$$
$$N_{pn} = (\overline{\nu}_e, e^+)$$

$$N_i = \frac{1}{4\pi} \frac{E_B f_i}{D^2} \frac{n_t \eta}{< \epsilon_\nu >} \int_{e_{th}}^{\infty} f(\epsilon_\nu) \sigma(\epsilon_\nu) d\epsilon_\nu$$

Supernova parameters

$E_B \sim 5.0\ 10^{52}$ erg $= 8.01\ 10^{60}$ MeV (Energy)

f_i=1/6 (Fraction of the energy carried by ν_i)

D = 10 kpc (Distance from the earth)

LVD parameters [1]

$n_t = 4.23\ 10^{31}$ (Number of ^{12}C target nuclei)

η_{NC} =0.55, $\eta_{np}(\nu, e^-) = 0.75$, $\eta_{pn}(\overline{\nu}, e^+) = 0.90$ (efficiencies)

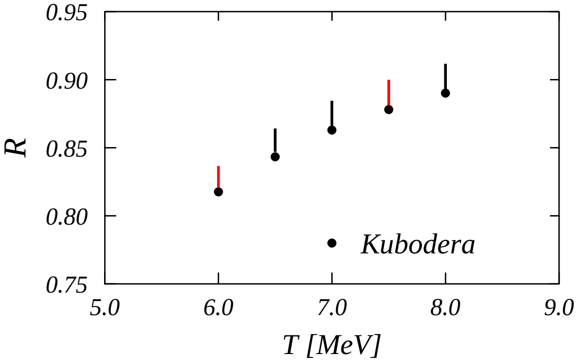
Number of events	$\nu + e^-$	$\overline{\nu} + e^+$	NC T=6.0 MeV	NC T=7.5 MeV
Kubodera	7	9	25	32
N_{min}	8	43	64	84
N_{max}	14	63	112	151

[1] N. Yu. Agafonova *et al.*, Astrop. Phys. 27 (2007) 254

$$N_{NC} = N_{NC}^{T} + N(\nu_e, \nu'_e)_4 + N(\overline{\nu}_e, \overline{\nu}'_e)_5$$

$$N_{NC}^{T} = N(\nu_x, \nu'_x)_T + N(\overline{\nu}_x, \overline{\nu}'_x)_T$$

$$R = \frac{N_{NC}^{T}}{N_{NC}} = \frac{N_{NC} - \left[N(\nu_e, \nu'_e)_4 + N(\overline{\nu}_e, \overline{\nu}'_e)_5\right]}{N_{NC}}$$


0.95
0.90
0.85
0.80
0.75
R
5.0
6.0
7.0
8.0
9.0
T [MeV]
Kubodera

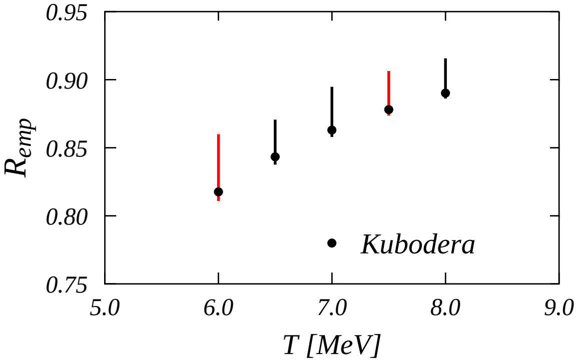
$$N_{np} = N(\nu_e, e^-)_4$$

$$N_{pn} = N(\overline{\nu}_e, e^+)_5$$

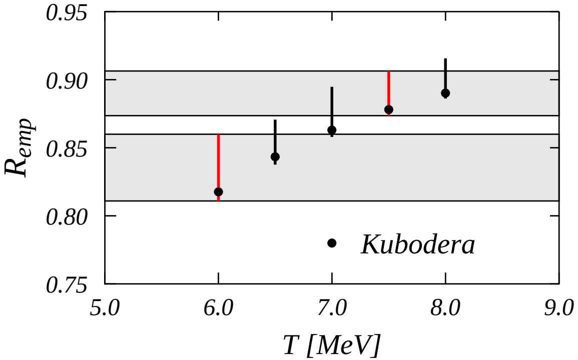
$$R_{emp} = \frac{1}{N_{NC}^{emp}}\Big[N_{NC}^{emp} \quad - \quad N_{np}^{emp} \frac{\int_{e_{th}}^{\infty} f(\epsilon)\sigma_{\nu_e,\nu'_e}(\epsilon)\, d\epsilon}{\eta_{np} \int_{e_{th}}^{\infty} f(\epsilon)\sigma_{\nu_e,e^-}(\epsilon)\, d\epsilon}$$

$$- \quad N_{pn}^{emp} \frac{\int_{e_{th}}^{\infty} f(\epsilon)\sigma_{\overline{\nu}_e,\overline{\nu}'_e}(\epsilon)\, d\epsilon}{\eta_{pn} \int_{e_{th}}^{\infty} f(\epsilon)\sigma_{\overline{\nu}_e,e^+}(\epsilon)\, d\epsilon}\Big]$$

In our simulation N^{emp}=N(Kubodera)



0.95
0.90
0.85
0.80
0.75
R_{emp}
5.0
6.0
7.0
8.0
9.0
T [MeV]
Kubodera


0.95
0.90
0.85
0.80
0.75
R_{emp}
5.0
6.0
7.0
8.0
9.0
T [MeV]
Kubodera

Conclusions

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Large uncertainties above the nucleon emission threshold (Giant resonances)

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Large uncertainties above the nucleon emission threshold (Giant resonances)

Discrete excitations are better described
Uncerainties on the magnitude of the cross sections

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Large uncertainites above the nucleon emission threshold (Giant resonances)

Discrete excitations are better described
Uncertainties on the magnitude of the cross sections

Ratios of observables are stable against cross section uncertainties

μ capture rate

$10^3\ s^{-1}$	LM	LMtt	FR	FRtt	exp [1]
no scal	34.98	33.38	35.14	34.30	
scal	14.10	13.35	14.14	13.76	6.2±0.3

$< \sigma_e >$ from μ decay at rest

$10^{-42}\ cm^2$	LM	LMtt	FR	FRtt	Kub.	exp [2]
no scal	26.55	25.22	26.85	26.64		
scal	14.24	13.55	14.40	14.30	9.19	8.9±0.12

[1] D.F. Measday, Phys. Rep. 354 (1001) 243
[2] L.B. Auerbach *et al.* (LSND), Phys. Rev. C 64 (2001) 065501

Total photoabsorption