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

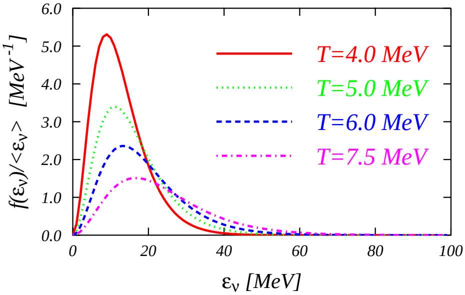
Precision ν astronomy

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

Nuclear Structure

Ab initio calculations

Realistic nucleon-nucleon interaction

Effective theories

Nucleon-nucleon interactions linked to the theory

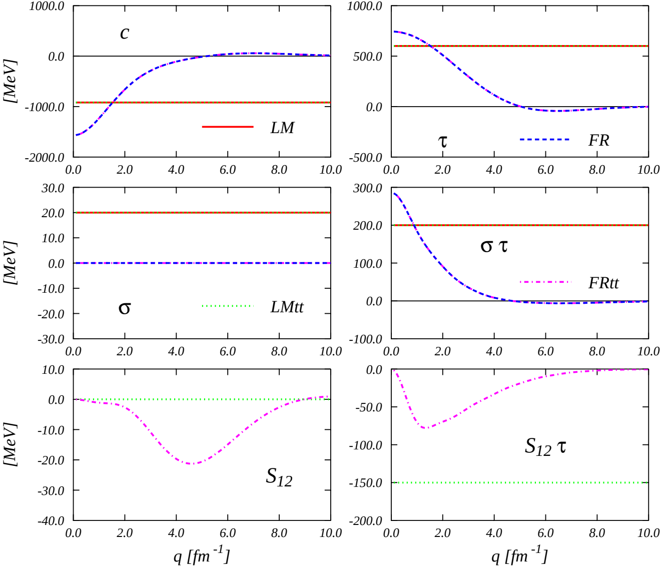
How the uncertainties related to the choice of the effective interaction affect the ν-nucleus cross section?

Effective interaction

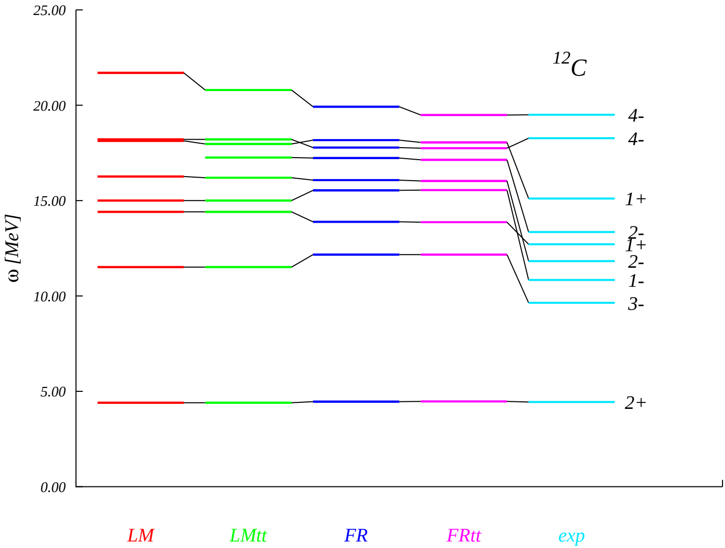
$$
\begin{aligned}
V_{eff}(r) &= V_1(r,\rho) + V_2(r)\,\vec{\tau}(1)\cdot\vec{\tau}(2) \\
&+ V_3(r)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2) + V_4(r)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2)\,\vec{\tau}(1)\cdot\vec{\tau}(2) \\
&+ V_5(r)\,S_{12}(r) + V_6(r)\,S_{12}(r)\vec{\tau}(1)\cdot\vec{\tau}(2)
\end{aligned}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

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

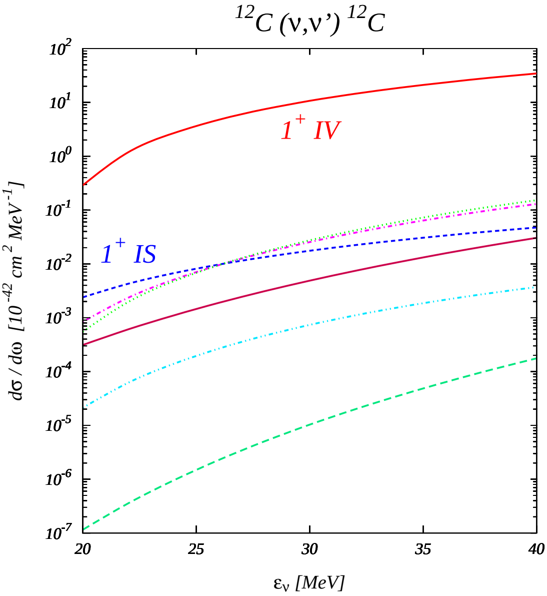
$$
\begin{aligned}
&V_1(r,\rho) = V_c(r) + V_\rho(r)\rho(r)^\alpha \\
&\rho(r_{12}) = [\rho(r_1)\rho(r_2)]^{1/2} \\
&\alpha = 1
\end{aligned}
$$


c
LM
τ
FR
σ
LMtt
σ τ
FRtt
S12
S12 τ
[MeV]
q [fm -1]

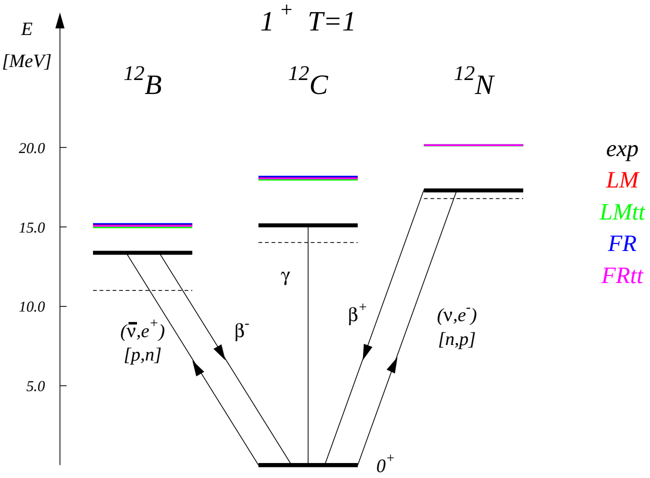
^{12}C



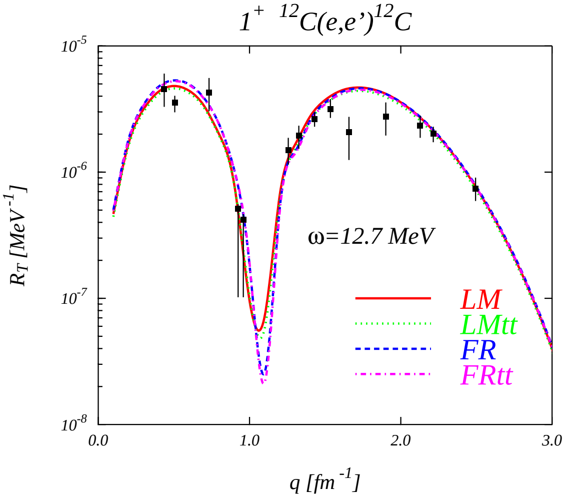
25.00
20.00
15.00
10.00
5.00
0.00
ω [MeV]
12C
4-
4-
1+
2-
1+
2-
1-
3-
2+
LM
LMtt
FR
FRtt
exp



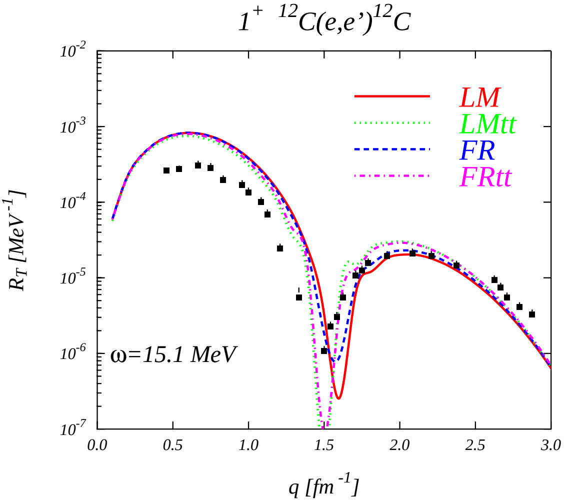
^{12}C (ν,ν') ^{12}C
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
1^{+} IV
1^{+} IS
dσ / dω [10^{-42} cm^{2} MeV^{-1}]
20
25
30
35
40
ε_{ν} [MeV]


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

^{12}C : 1^+ Isoscalar



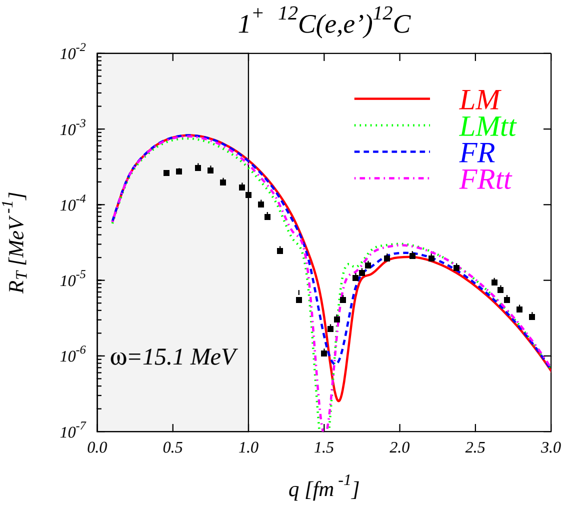
^{12}C : 1^+ Isovector



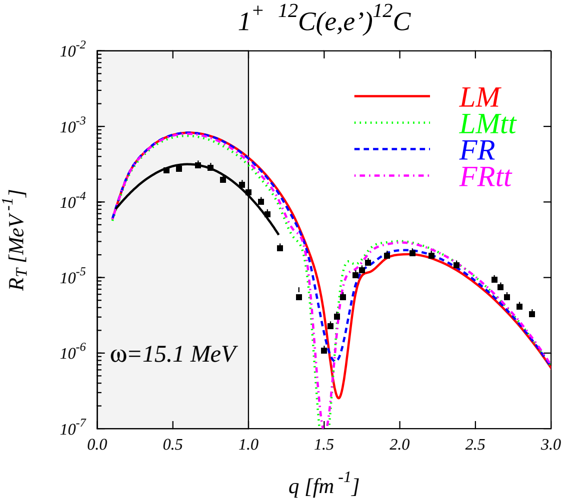
$$
\begin{aligned}
\left(\frac{d^2\sigma}{d\Omega d\epsilon}\right)_{e,e'} &= \sigma_M \frac{1}{2J_i+1}\Big[v_L | < J_f || C_J^V || Ji > |^2 \\
&+ v_T | < J_f || T_J^V || Ji > |^2 \Big]
\end{aligned}
$$

$$
\begin{aligned}
\left(\frac{d^2\sigma}{d\Omega d\epsilon}\right)_{\nu,\nu'} &= G^2 \frac{\epsilon'_\nu}{\epsilon_\nu} \frac{1}{2J_i+1}\Big[w_C^A | < J_f || C_J^A || J_i > |^2 + \\
&+ w_L^A | < J_f || L_J^A || J_i > |^2 + w_L^V | < J_f || C_J^V || J_i > |^2 + \\
&+ w_{LC}^A Re\big(< J_f || C_J^A || Ji >< J_f || C_J^A || J_i >^* \big) \\
&+ w_T^A | < J_f || T_J^A || J_i > |^2 + w_T^V | < J_f || T_J^V || J_i > |^2 \\
&+ w_T^{AV} Re\big(< J_f || T_J^A || Ji >< J_f || T_J^V || J_i >^* \big) \Big]
\end{aligned}
$$

^{12}C : 1^+ Isovector



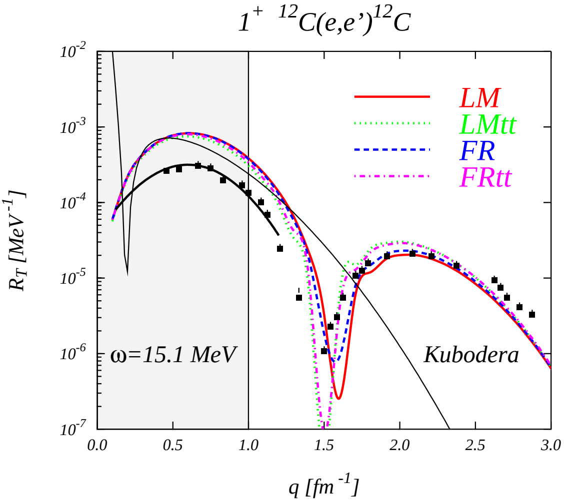
^{12}C : 1^+ Isovector



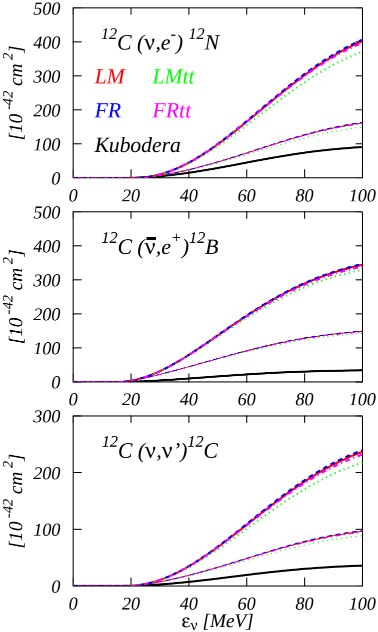
$$Q(q) = \frac{| < J_f || T_J^{exp}(q) || J_i > |^2_{e,e'}}{| < J_f || T_J^{V}(q) || J_i > |^2_{RPA}}$$

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

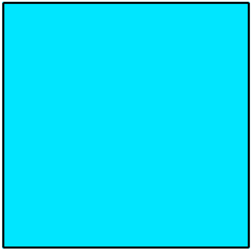
^{12}C : 1^+ Isovector

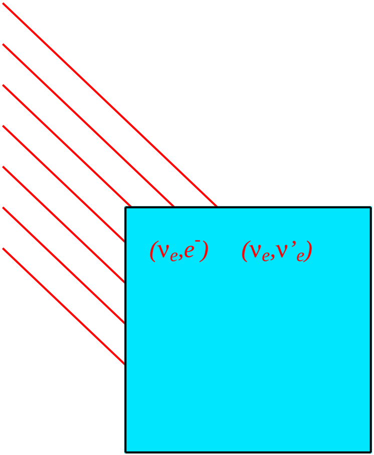


M. Fukugita, Y. Kohyama and K. Kubodera, Phys. Lett. B 212 (1988) 139.

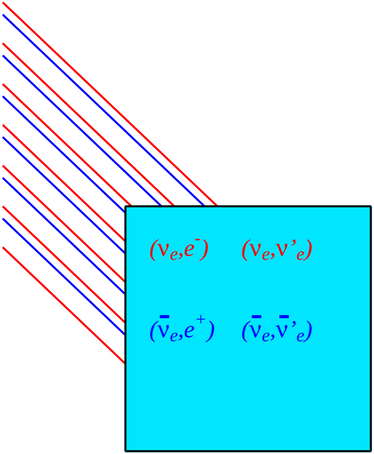


$^{12}C\ (\nu,e^-)\ ^{12}N$
LM
LMtt
FR
FRtt
Kubodera
$^{12}C\ (\bar{\nu},e^+)^{12}B$
$^{12}C\ (\nu,\nu')^{12}C$
$[10^{-42}\ cm^2]$
ε_ν [MeV]

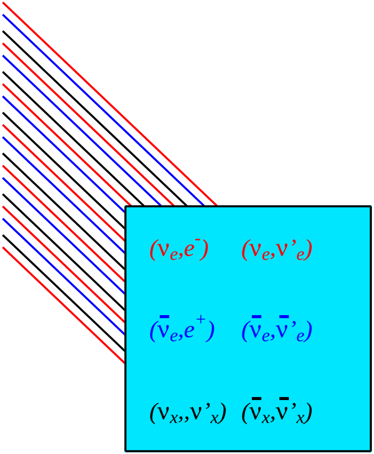




$$N_{nc} = (\nu_e, \nu'_e)$$
$$N_{np} = (\nu_e, e^-)$$



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



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

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

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)

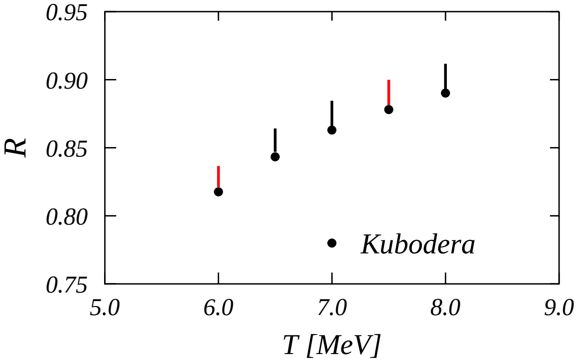
Number of events	$\nu + e^-$	$\overline{\nu} + e^+$	NC T=6.0 MeV	NC T=7.5 MeV
Kubodera	7	9	25	32
N_{min}	8	43	64	84
N_{max}	14	63	112	151

[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

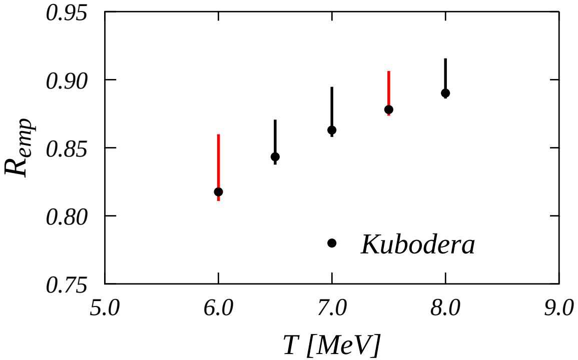
$$N_{np} = N(\nu_e, e^-)_4$$

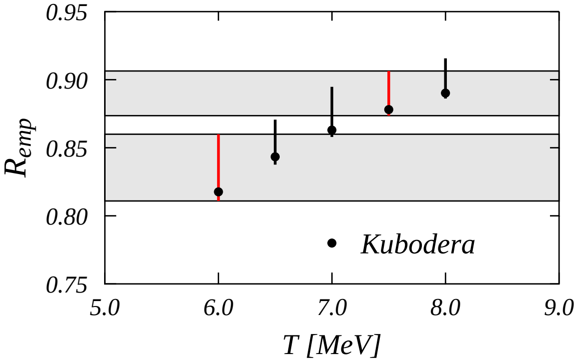
$$N_{pn} = N(\overline{\nu}_e, e^+)_5$$

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

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

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


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


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, in the giant resonance region

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Large uncertainties above the nucleon emission threshold, in the giant resonance region

Discrete excitations better described.
Uncerainties on the global magnitude of the cross sections

Conclusions

Nuclear structure uncertainties are relevant for precision ν astromomy

Uncertainties are large above the nucleon emission threshold (giant resonance region)

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

Ratios of observables stable against 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$\pm$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$\pm$0.12

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

^{208}Pb (ν,ν') ^{208}Pb