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Investigating the nuclear response of Te isotopes to SN neutrinos

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Outline

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    iii. SN- *ν* detection by terrestrial experiments (COBRA)
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Neutrino Sources

1) Astrophysical Neutrino Sources

i. Solar Neutrinos

ii. Supernova Neutrinos

iii. Atmospheric Neutrinos

iv. Cosmological Neutrinos

2) Laboratory Neutrino Sources

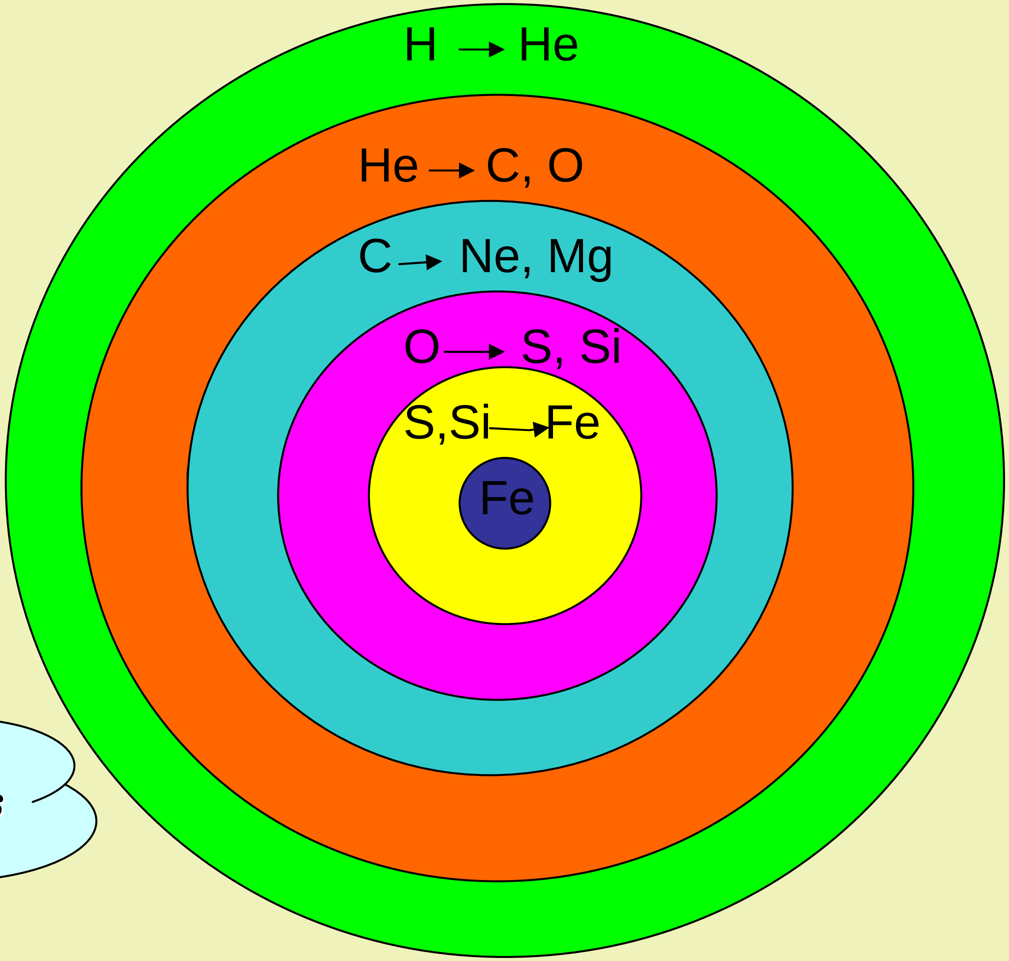
i. Reactor neutrinos
   - Beta decay neutrinos
   - Slow – pion and muon decay neutrinos

ii. Accelerator ν (high energy neutrino beams)

Star evolution and ν-production mechanisms

- At the end of hydrostatic burning a massive star ~ 8 Msun consists of concentric shells that are the relics of its previous burning phases

- When the mass of the iron core exceeds the M_{Ch} =1.4 Msun, the gravitational pull > thermal pressure

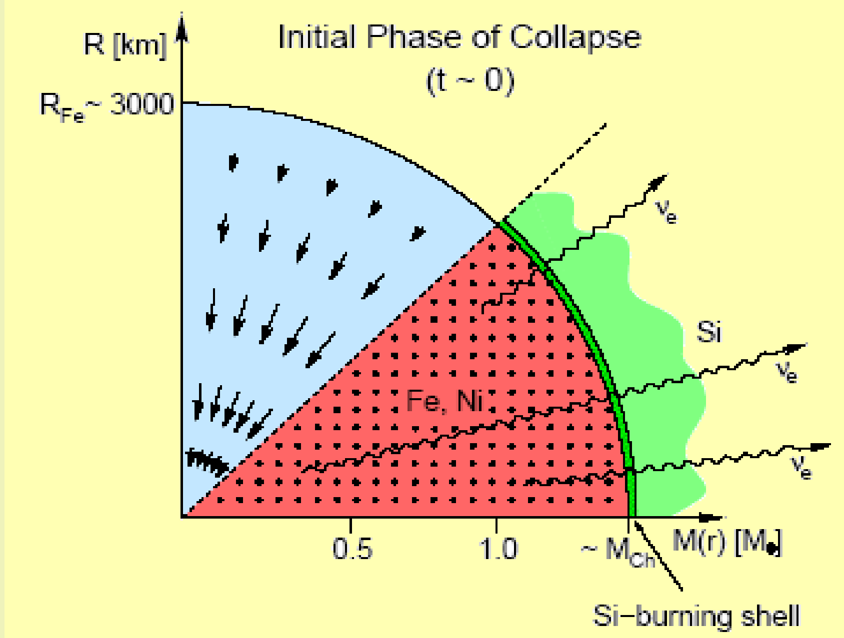


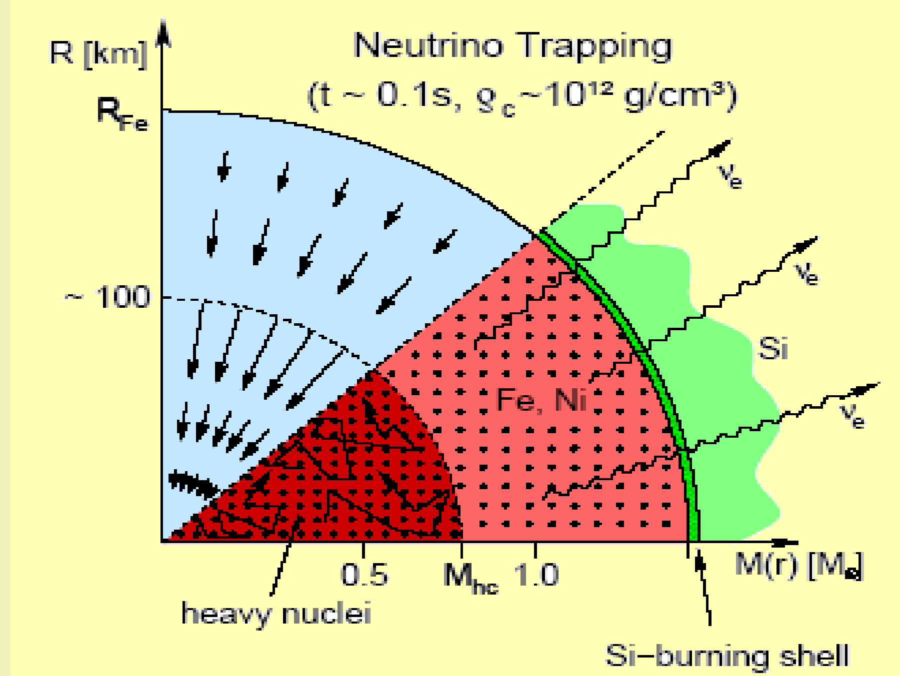
Core-collapse simulation results

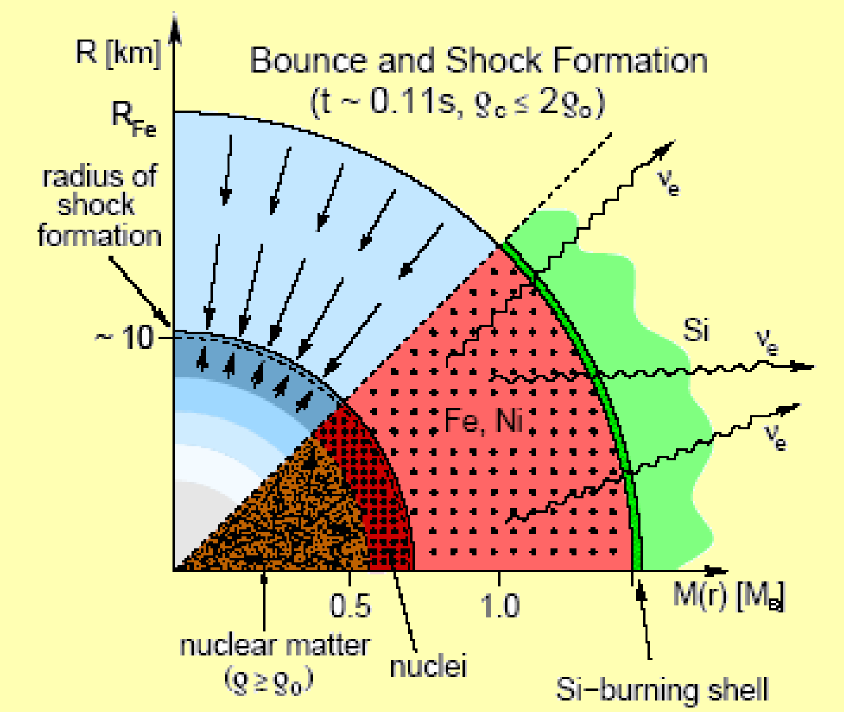
The main stages of stellar evolution (for massive stars) according to Janka et al., are:

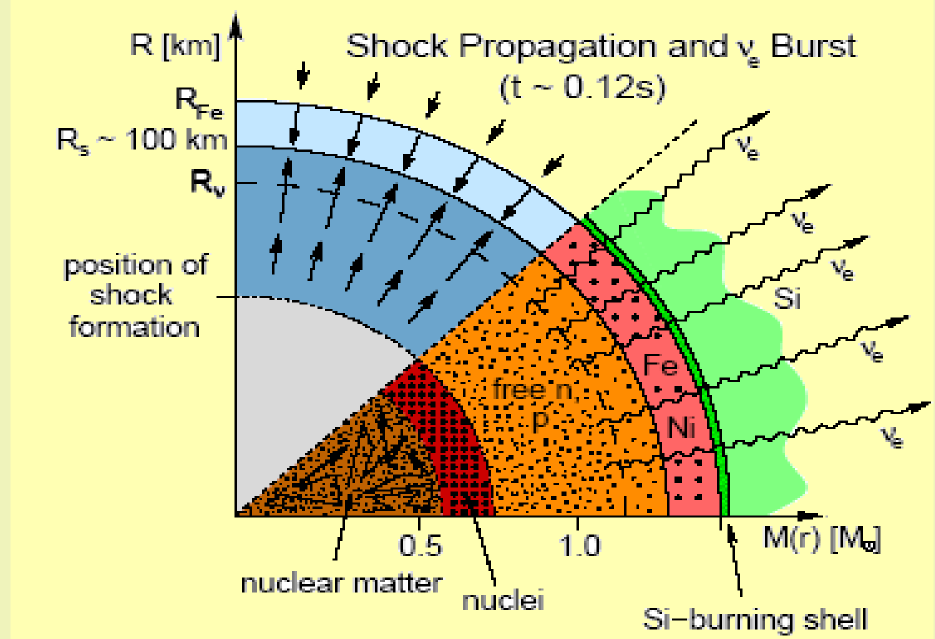
- Initial phase of collapse
- Neutrino trapping
- Bounce and shock formation
- Shock propagation and neutrino burst
- Shock stagnation and neutrino heating
- Neutrino cooling and neutrino driven wind

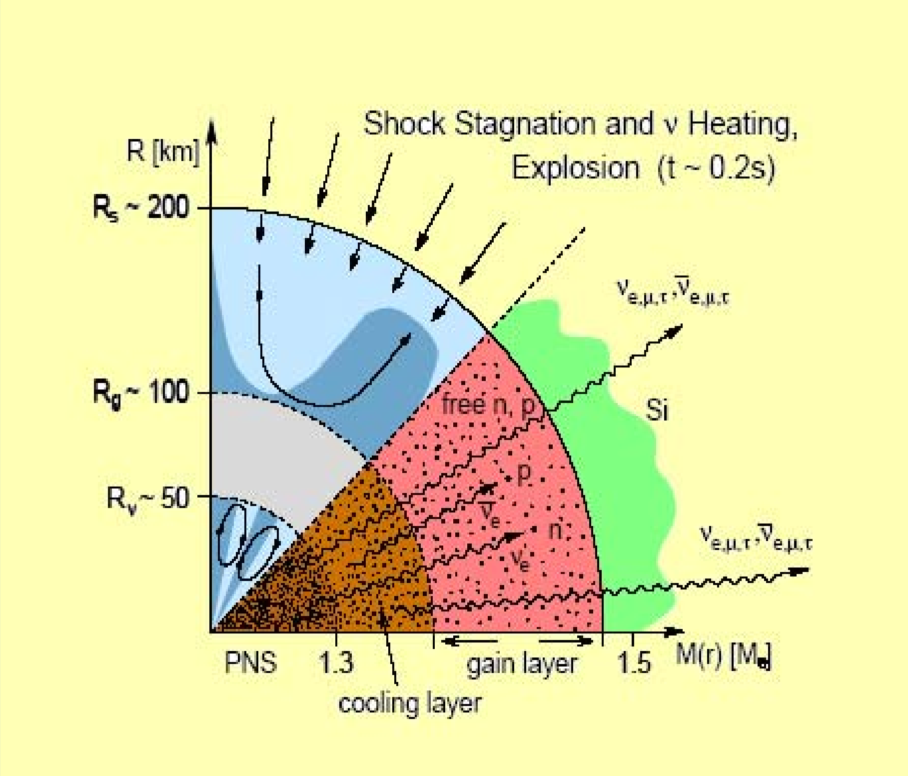
H. Th. Janka, K. Langanke et al, astro-ph/0612072 v1, 2006

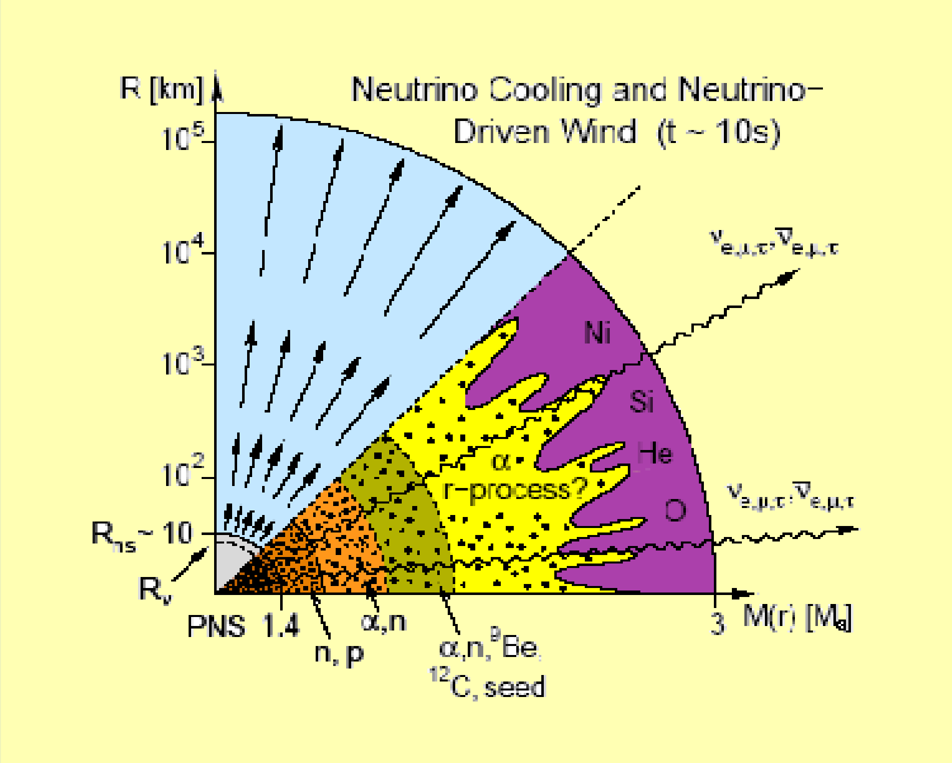

Initial Phase of Collapse
(t ~ 0)
R [km]
R_{Fe} ~ 3000
Si
Fe, Ni
ν_e
ν_e
ν_e
0.5
1.0
~ M_{Ch}
M(r) [$M_\odot$]
Si−burning shell


Neutrino Trapping
(t ~ 0.1s, ϱ_c ~ 10^{12} g/cm³)
R [km]
R_{Fe}
~ 100
Si
Fe, Ni
ν_e
ν_e
ν_e
0.5
M_{hc}
1.0
M(r) [$M_\odot$]
heavy nuclei
Si−burning shell


Bounce and Shock Formation
(t ~ 0.11s, $\varrho_c \leq 2\varrho_0$)
R [km]
R_{Fe}
radius of shock formation
~ 10
Si
Fe, Ni
ν_e
ν_e
ν_e
0.5
1.0
M(r) [$M_\odot$]
nuclear matter ($\varrho \geq \varrho_0$)
nuclei
Si−burning shell


Shock Propagation and ν_e Burst
(t ~ 0.12s)
R [km]
R_{Fe}
R_s ~ 100 km
R_ν
position of shock formation
Si
Fe
Ni
free n, p
ν_e
ν_e
ν_e
ν_e
ν_e
0.5
1.0
M(r) [$M_\odot$]
nuclear matter
nuclei
Si−burning shell


Shock Stagnation and ν Heating, Explosion (t ~ 0.2s)
R [km]
R_s ~ 200
R_g ~ 100
R_ν ~ 50
free n, p
Si
PNS
1.3
gain layer
1.5
M(r) [M_⊙]
cooling layer


Neutrino Cooling and Neutrino-Driven Wind (t ~ 10s)
R [km]
Ni
Si
He
O
α
r-process?
R_ns ~ 10
R_ν
PNS
1.4
n, p
α,n
3
M(r) [M_⊙]


neutrinos of all flavors
are produced!!!

Average energy of SN-ν spectra

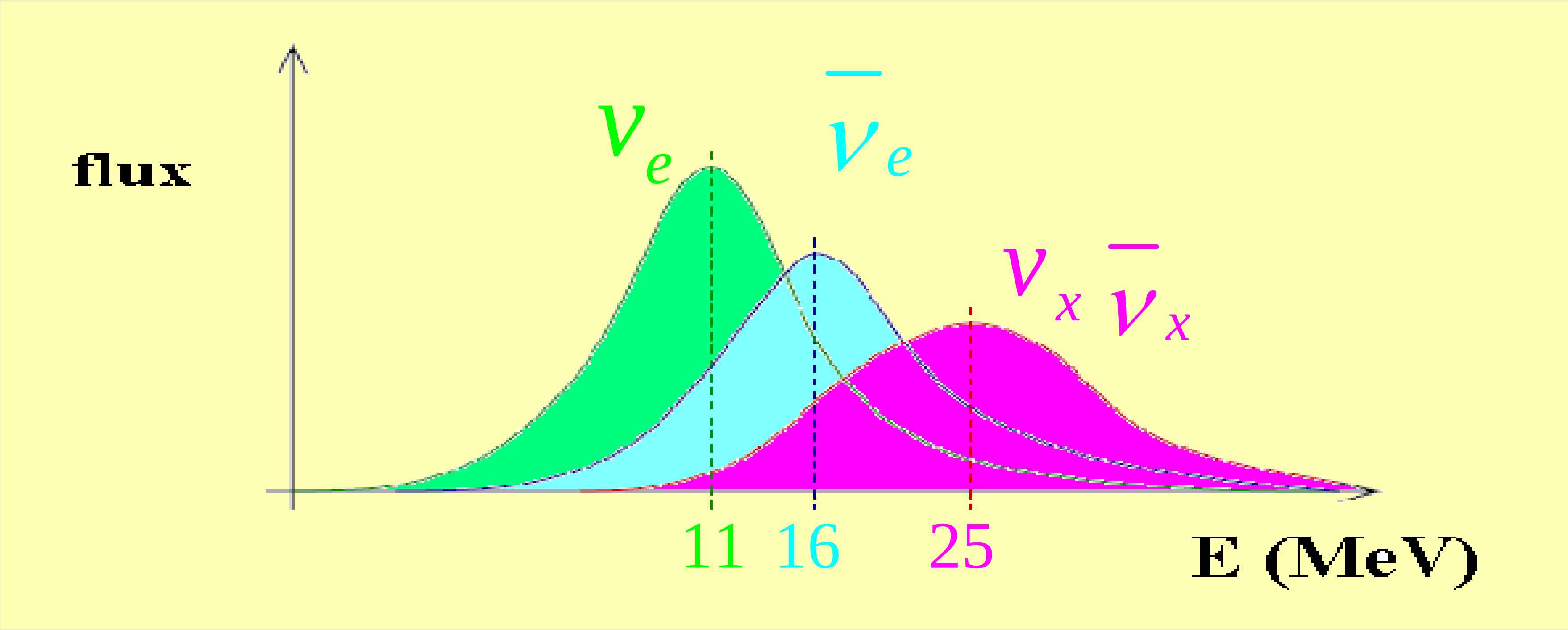
$$\langle E_{\nu} \rangle_e < \langle E_{\bar{\nu}} \rangle_e < \langle E_{\nu,\bar{\nu}} \rangle_x$$

Average energy of emitted neutrinos reflects the **temperature** of matter around the neutrinosphere.

$$T_{\nu_e} \approx 3,5\, MeV$$

$$T_{\bar{\nu}_e} \approx 5\, MeV$$

$$T_{\nu_x} \approx 8\, MeV$$



The Convolution Method in SN-ν Searches

The differential ν-nucleus cross-section **$d\sigma(\varepsilon_\nu,\omega)/d\omega$** is folded by using the expression to study the nuclear response to ***SN-ν*** spectra:

$$\frac{d\sigma(\omega)}{d\omega} = \int_{\omega}^{\infty} \frac{d\sigma(\varepsilon_\nu,\omega)}{d\omega} n(\varepsilon_\nu)\, d\varepsilon_\nu$$

$\omega = E_i - E_f = \varepsilon_i - \varepsilon_f$: excitation energy of the nucleus

The **$n(\varepsilon_\nu)$** is a specific ν –energy distribution normalized to unity as:

$$\int n(\varepsilon_\nu)\, d\varepsilon_\nu = 1$$

Energy distribution for SN-ν

Fermi - Dirac

$$n_{FD}[T,n_{eff}](\varepsilon_\nu) = \frac{1}{F(n_{eff})T^3}\frac{\varepsilon_\nu^2}{Exp\left[\left(\frac{\varepsilon_\nu}{T}\right)-n_{eff}\right]+1}$$

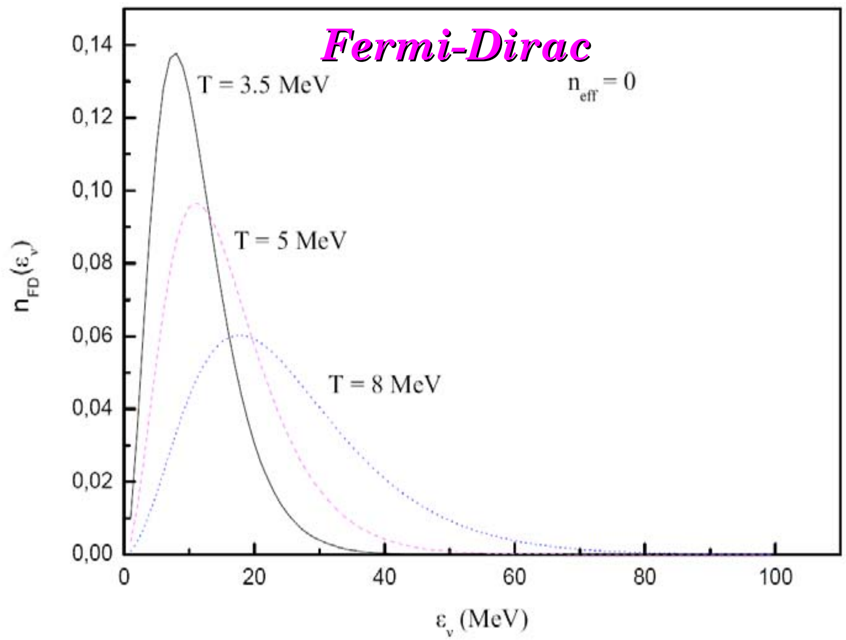
Power - law

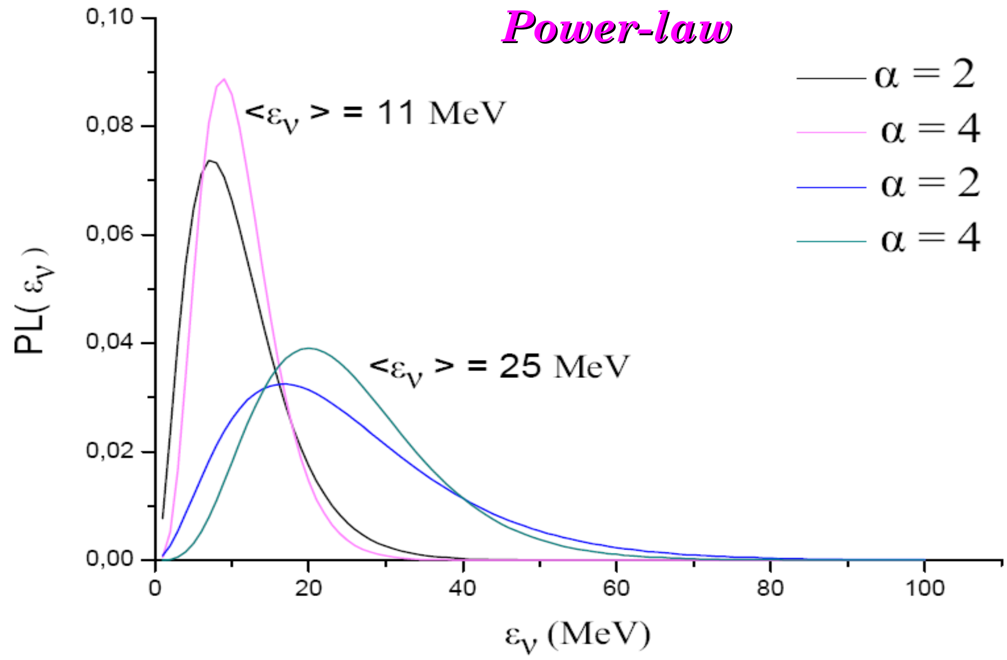
$$n_{PL}[\langle\varepsilon_\nu\rangle,a](\varepsilon_\nu) = \frac{1}{c}\left(\frac{\varepsilon_\nu}{\langle\varepsilon_\nu\rangle}\right)^\alpha e^{-(a+1)\frac{\varepsilon_\nu}{\langle\varepsilon_\nu\rangle}}$$

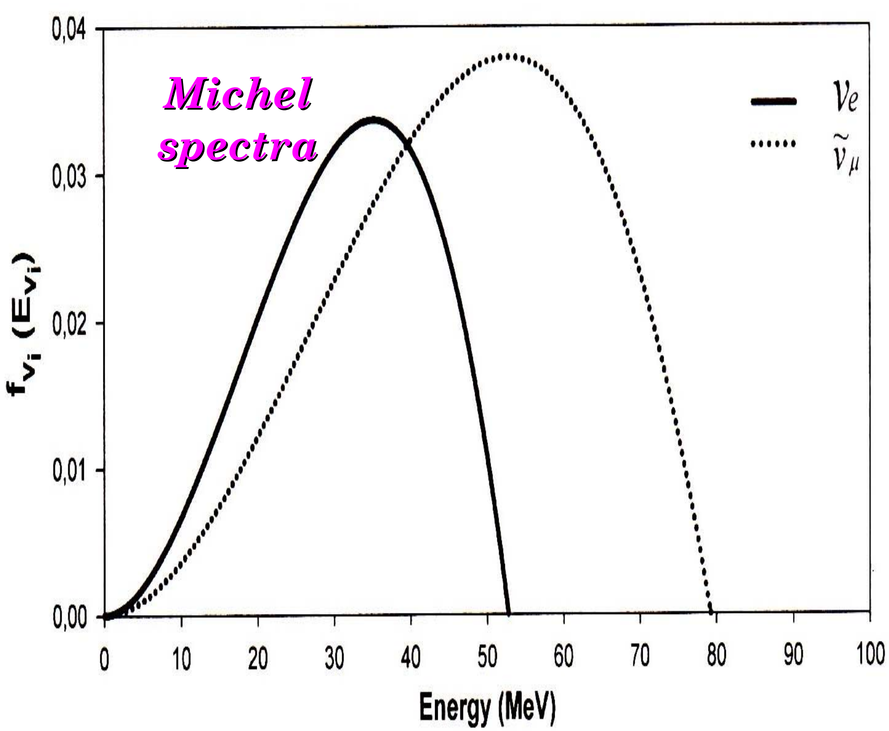
Reactor neutrino spectrum

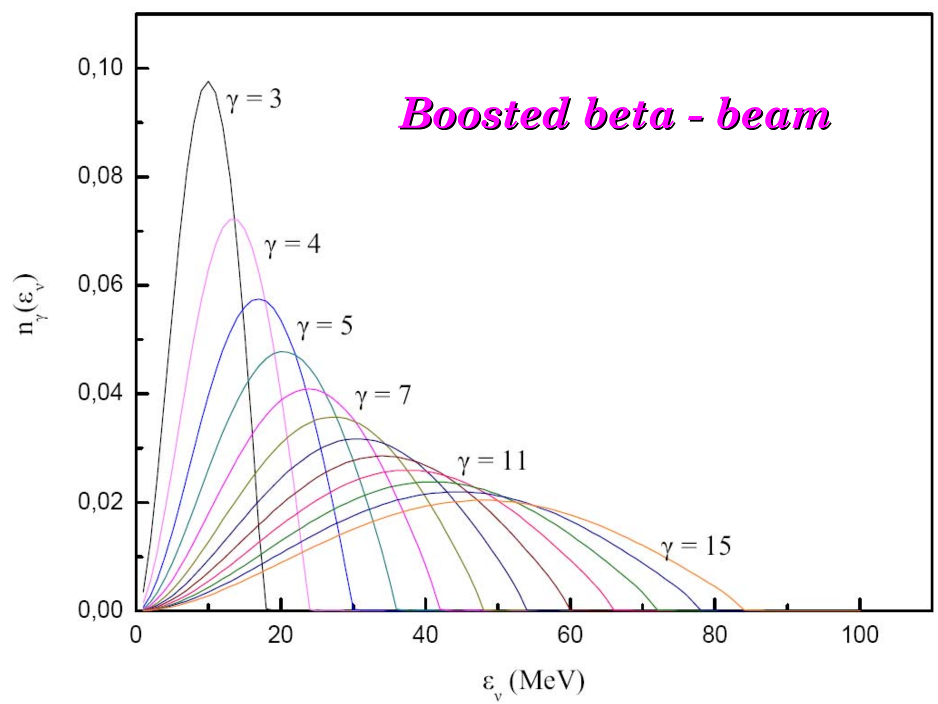
$$n_{\nu_e}(\varepsilon_{\nu_e}) = \frac{96\varepsilon_{\nu_e}^2}{m_\mu^4}(m_\mu - 2\varepsilon_{\nu_e})$$

Boosted beta-beam neutrino spectra


Fermi-Dirac
T = 3.5 MeV
$n_{eff} = 0$
T = 5 MeV
T = 8 MeV
$n_{FD}(\varepsilon_\nu)$
ε_ν (MeV)
0,14
0,12
0,10
0,08
0,06
0,04
0,02
0,00
0
20
40
60
80
100


Power-law
$\alpha = 2$
$\alpha = 4$
$\alpha = 2$
$\alpha = 4$
$<\varepsilon_\nu> = 11$ MeV
$<\varepsilon_\nu> = 25$ MeV
$PL(\varepsilon_\nu)$
ε_ν (MeV)
0,10
0,08
0,06
0,04
0,02
0,00
0
20
40
60
80
100


Michel spectra
ν_e
$\tilde{\nu}_\mu$
$f_{\nu_i}(E_{\nu_i})$
Energy (MeV)
0,04
0,03
0,02
0,01
0,00
0
10
20
30
40
50
60
70
80
90
100


Boosted beta - beam
$\gamma = 3$
$\gamma = 4$
$\gamma = 5$
$\gamma = 7$
$\gamma = 11$
$\gamma = 15$
$n_\gamma(\varepsilon_\nu)$
ε_ν (MeV)
0,10
0,08
0,06
0,04
0,02
0,00
0
20
40
60
80
100

Low-energy beta-beams in SN-ν physics

Low – energy *beta-beams* can provide information about SN-ν interactions the interpretation of a SN –ν signal in a terrestrial detector.

We construct linear combinations of boosted beta beam spectra $n_{\gamma i}$:

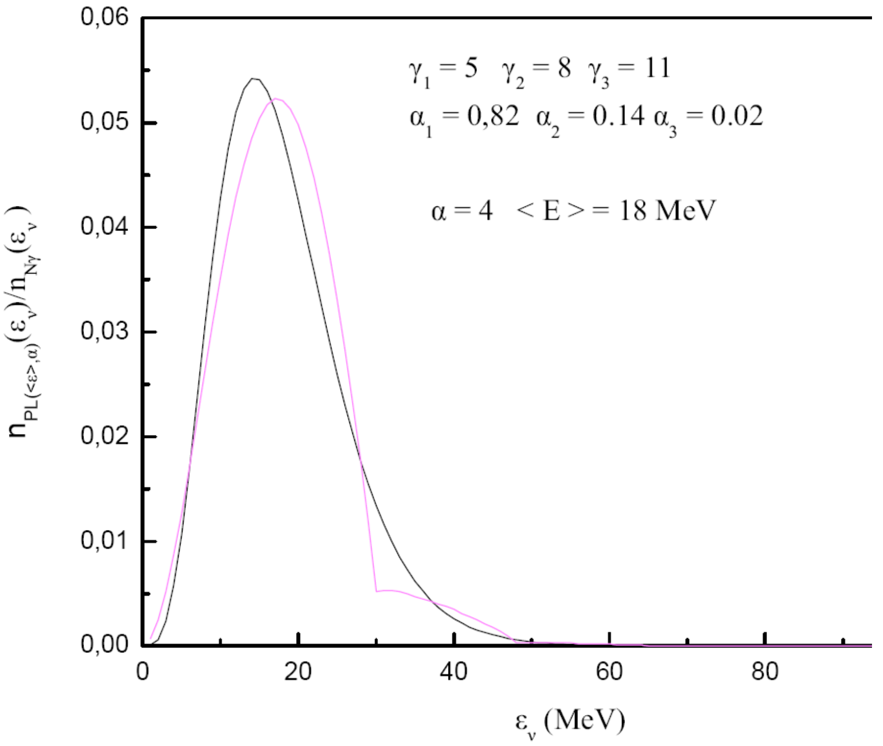
$$n_{N_\gamma}(\varepsilon_\nu) = \sum_{i=1}^{N} a_i n_{\gamma_i}(\varepsilon_\nu)$$

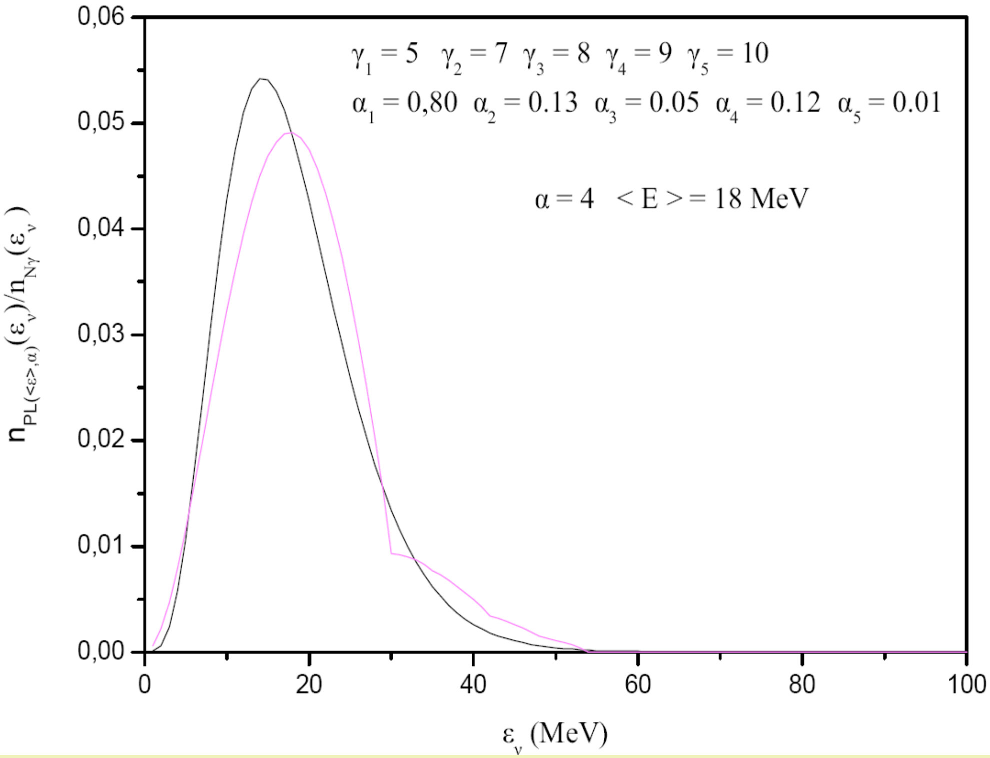
The expansion coefficients $a_{i=1,2,\dots,N}$ for the boost factors $\gamma_{i=1,2,\dots,N}$ are obtained by minimizing the expression

$$\int_{\varepsilon_\nu} d\varepsilon_\nu \left| n_{N_\gamma}(\varepsilon_\nu) - n_{SN}(\varepsilon_\nu) \right|$$

N.Jachowicz and G.C.McLauyhlin, Phys. Review C 77,2008

Power-law fitting with 3-5 boost components

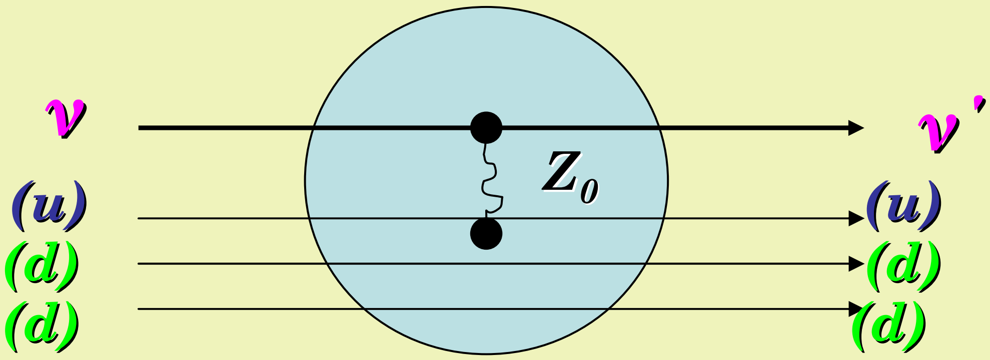




Nuclear response to SN-ν of COBRA target

The aim of this work is to study the response to SN-ν of the nuclear isotopes ***Zn***, ***Te***, contained in the ***COBRA*** detector, through the neutral current reactions

$$^{128,130}Te(\nu_e,\nu_e{}')\,^{128,130}Te^* \qquad ^{64,68}Zn(\nu_e,\nu_e{}')\,^{64,68}Zn^*$$

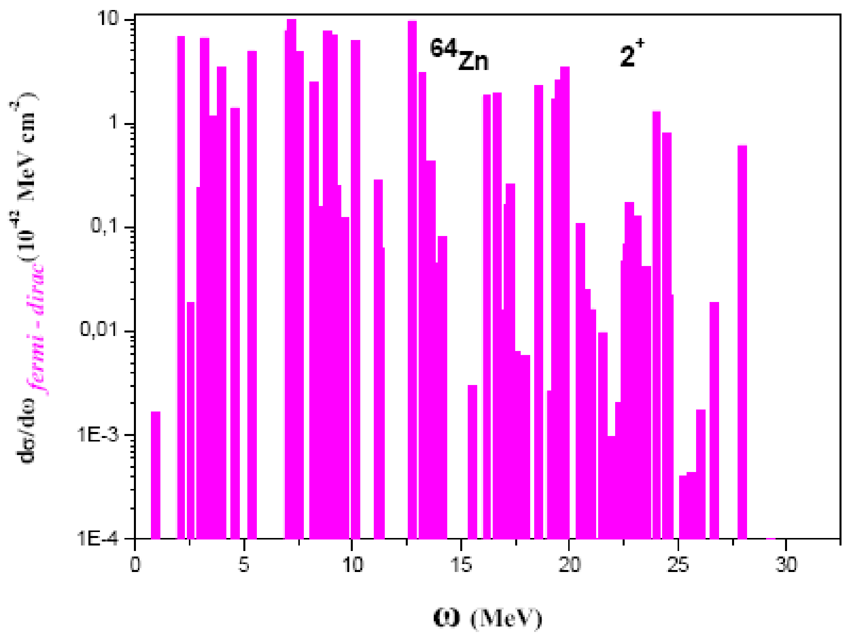


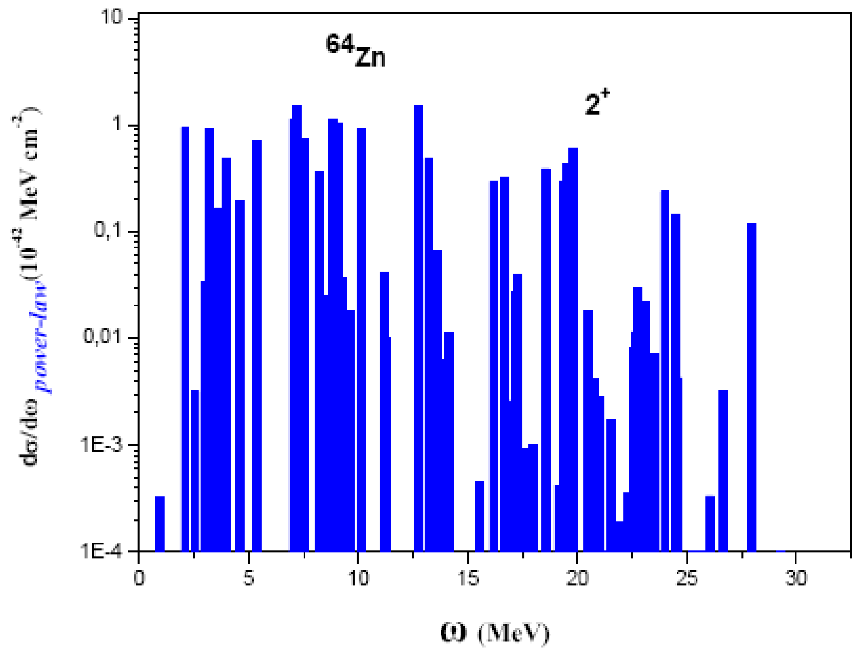
$$\nu + (Z,A) \rightarrow (Z,A)^* + \nu'$$

$$\bar{\nu} + (Z,A) \rightarrow (Z,A)^* + \bar{\nu}'$$

K. Zuber, Phys. Lett. B 519, 1–7 (2001); Prog. Part. Nucl. Phys. 57, 235–240 (2006);

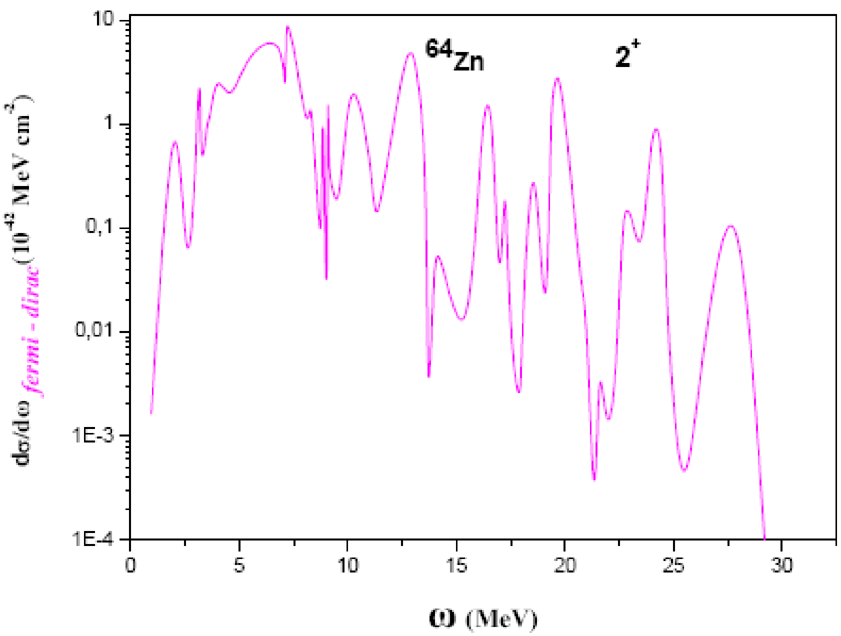
Results of the convolution for ^{64}Zn

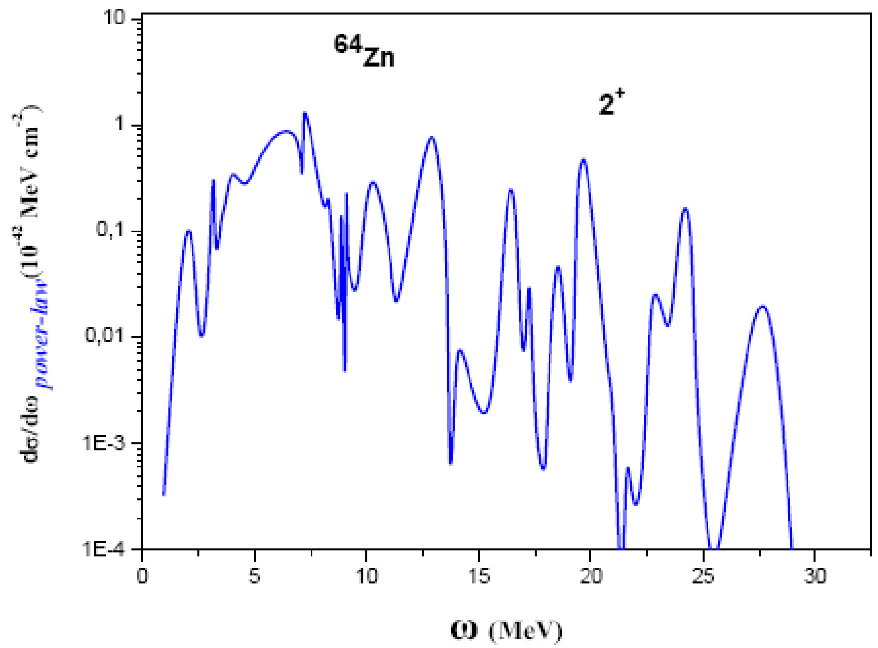




Convoluted differential cross-section using Fermi-Dirac (left) and power-law (right)

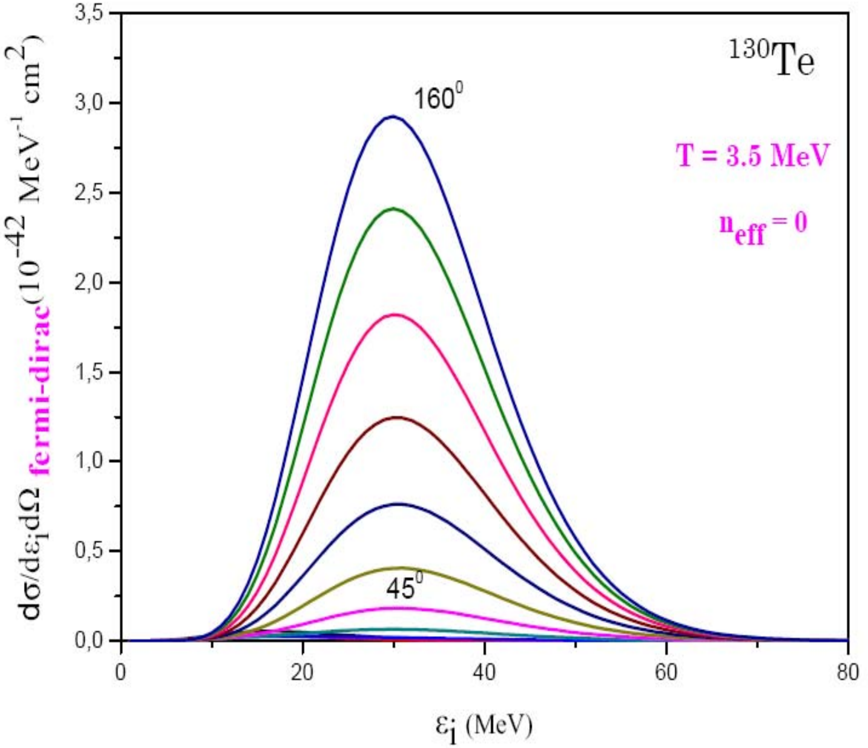
Results of the convolution for ^{64}Zn

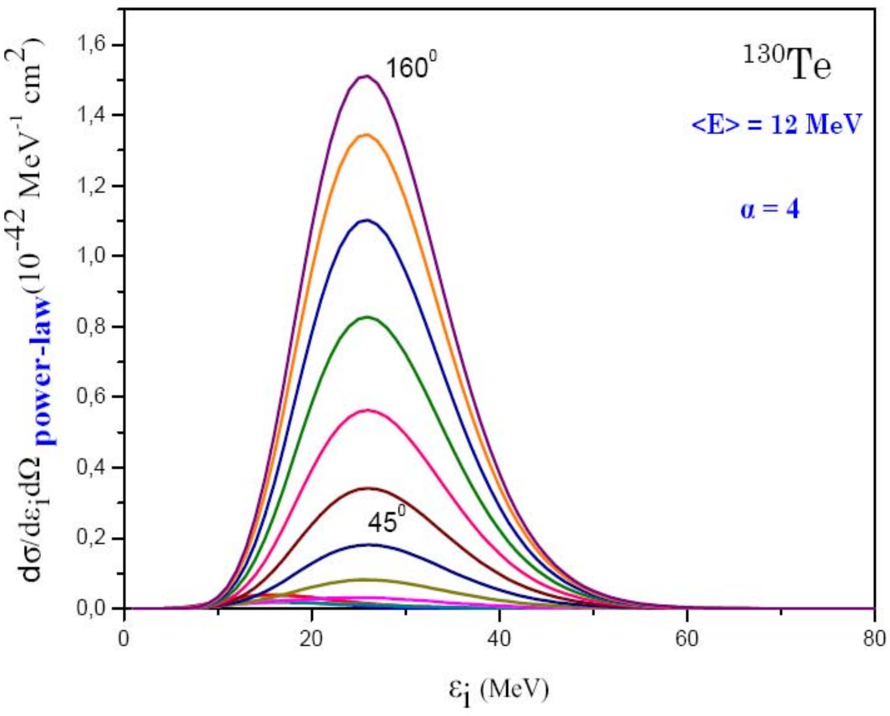




Convoluted differential cross-section using Fermi-Dirac (left) and power-law (right)

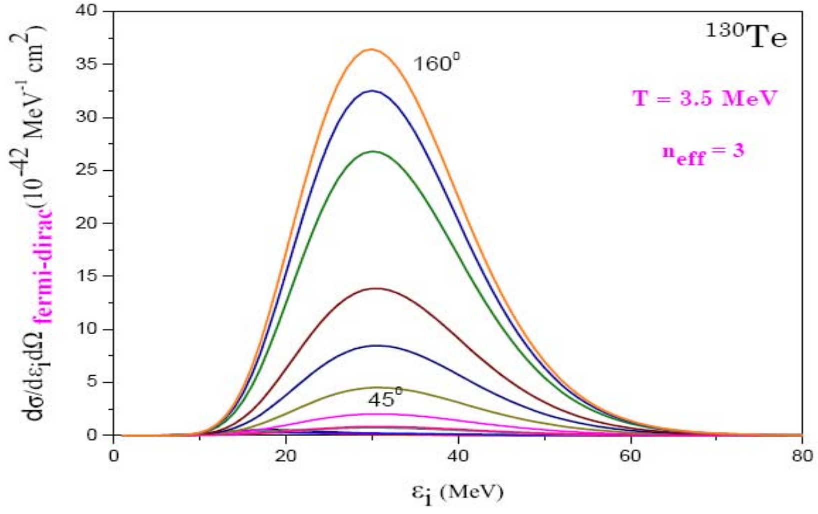
Results of the convolution for ^{130}Te

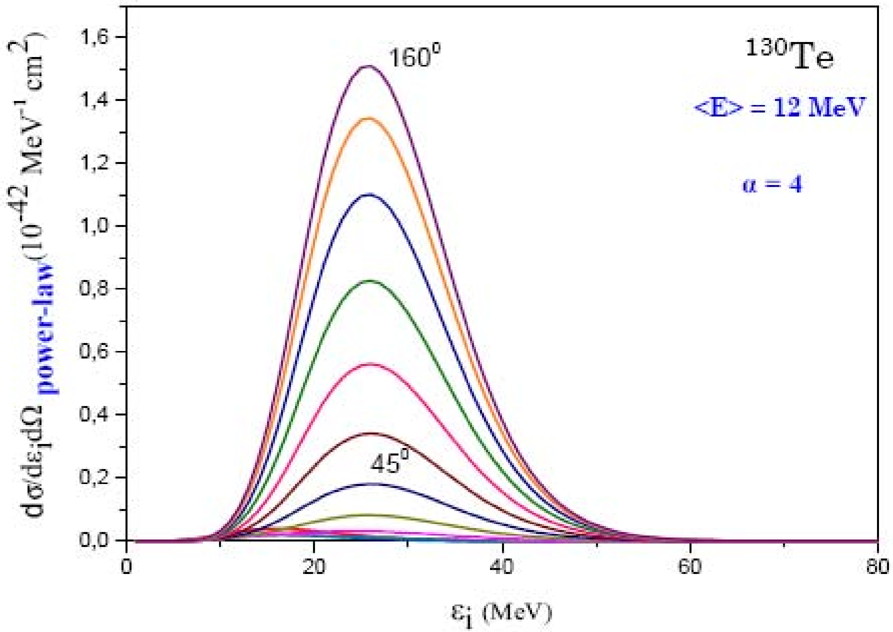




Convoluted double differential cross-section using Fermi-Dirac (left) and power-law (right)

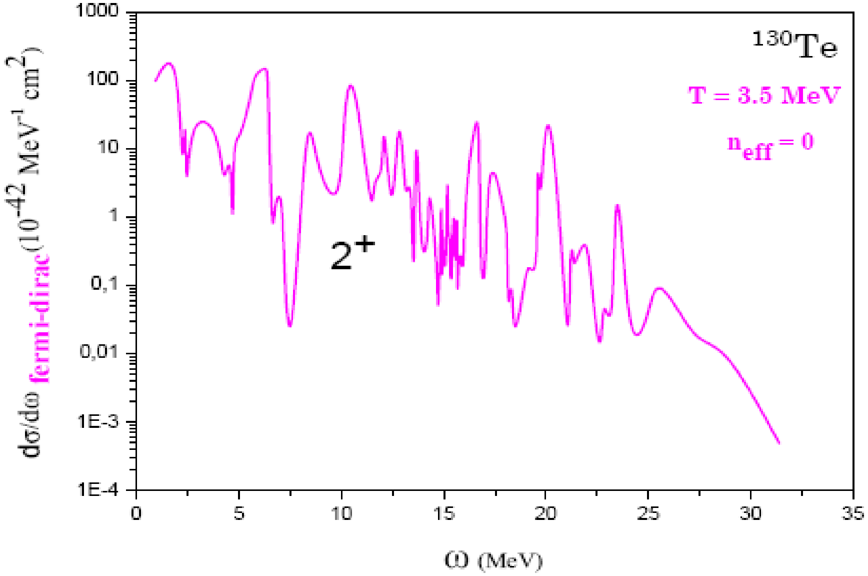
Results of the convolution for ^{130}Te

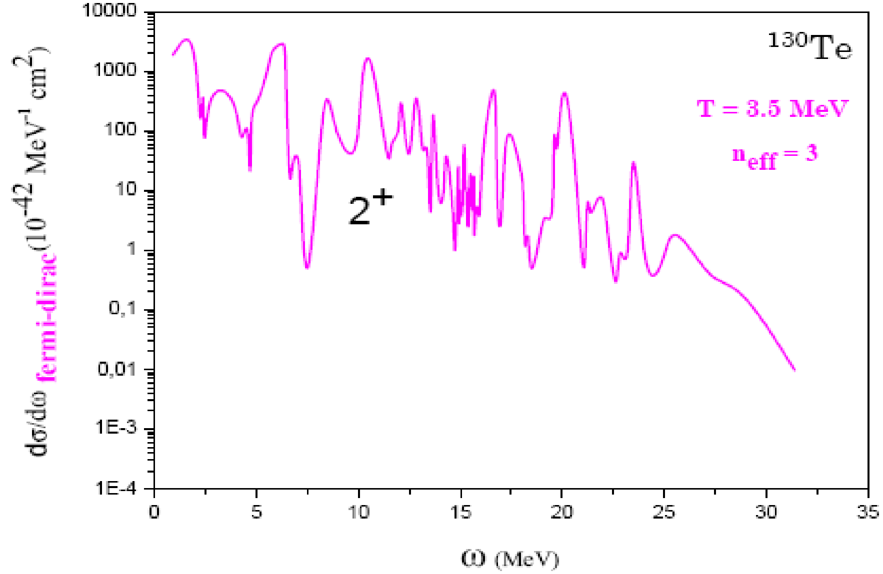


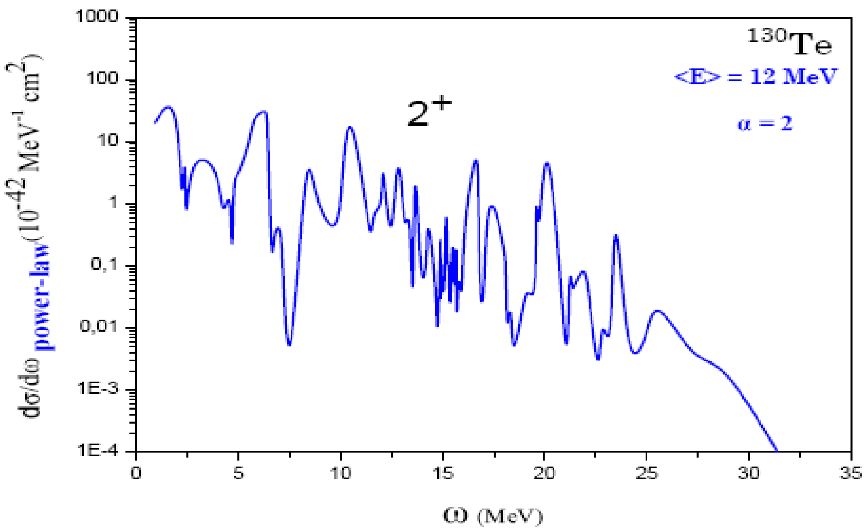


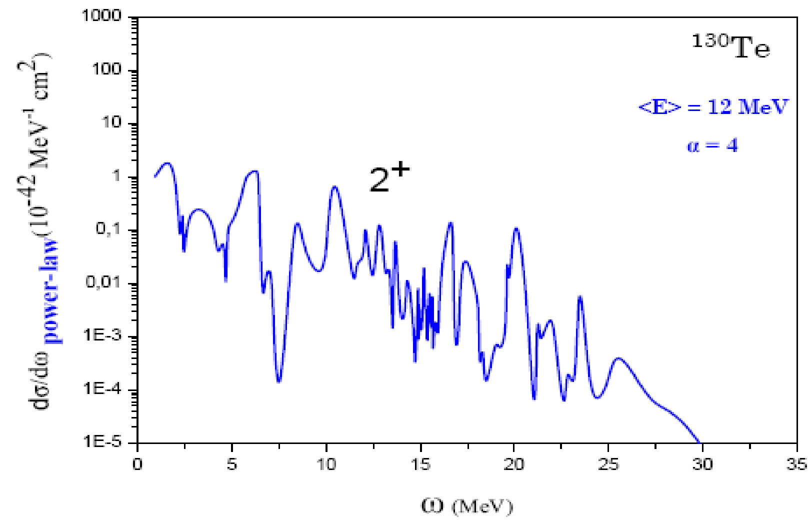
Convoluted double differential cross-section using Fermi-Dirac

Results of the convolution for ^{130}Te

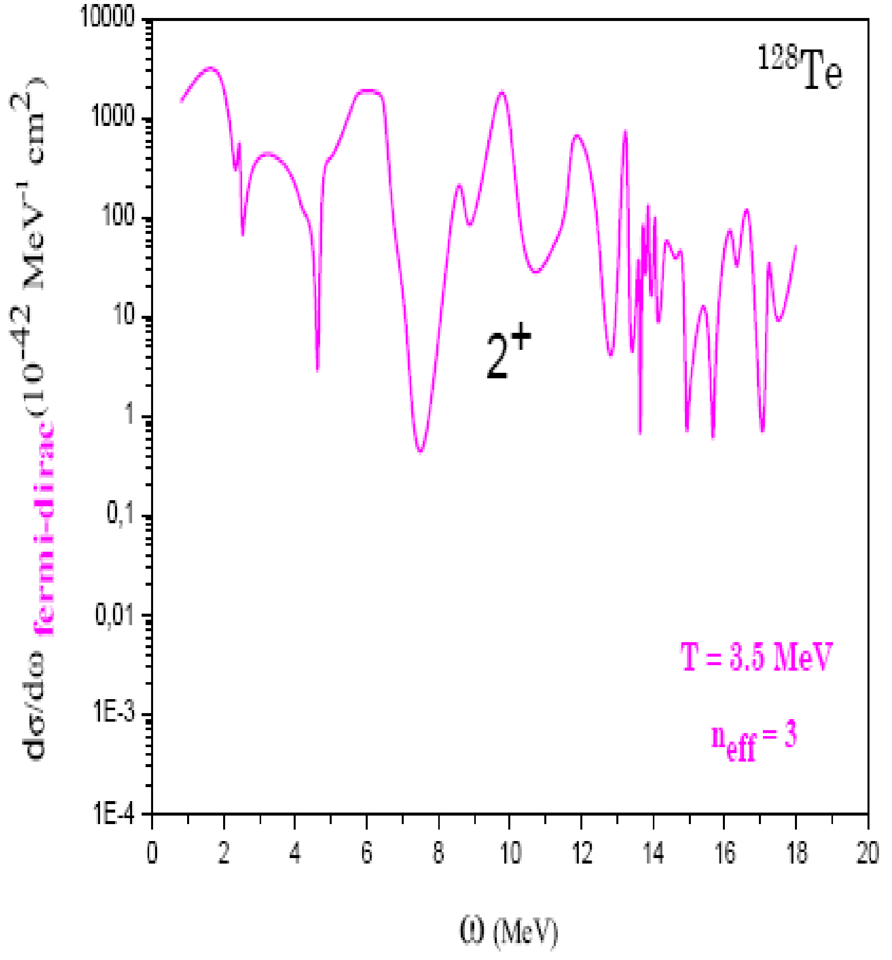


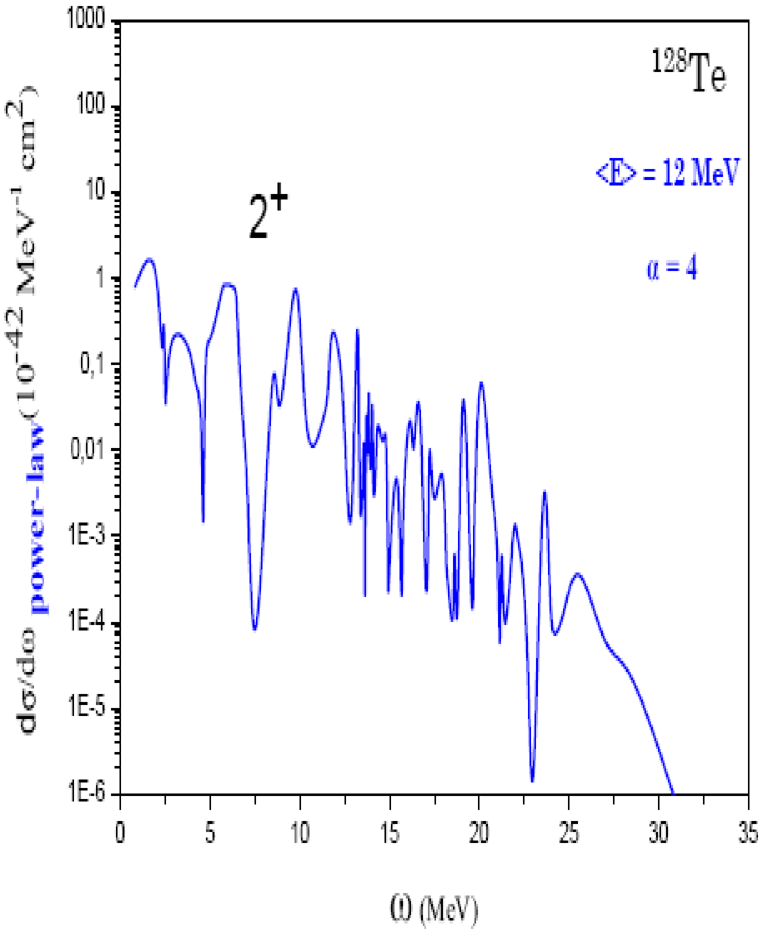






Results of the convolution for ^{128}Te





Summary – Conclusions

➢We study the response of ***Zn*** and ***Te*** isotopes to the SN- **ν** spectra by evaluating the folded:

1) differential cross-sections ***dσ/dω***

2) double deferential cross-sections ***$\langle d^2\sigma/d\Omega d\omega \rangle$***

➢We used the convolution method and employed

(i) Fermi-Dirac neutrino energy distribution
(ii) Power-law neutrino energy distribution
(iii) Reactor neutrino energy distribution
(iv) Linear-combination of ***boosted beta-beam*** neutrinos

They are appropriate for neutrinos produced in Supernova explosions.

➢ We found that there are not dramatical differences between the above distributions. However, shows very interesting characteristics.

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ΕΛΛΑΔΑ 2008

ΥΠΟΥΡΓΕΙΟ ΕΘΝΙΚΗΣ ΠΑΙΔΕΙΑΣ ΚΑΙ ΘΡΗΣΚΕΥΜΑΤΩΝ
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ΕΥΡΩΠΑΪΚΗ ΕΝΩΣΗ
ΣΥΓΧΡΗΜΑΤΟΔΟΤΗΣΗ
ΕΥΡΩΠΑΪΚΟ ΚΟΙΝΩΝΙΚΟ ΤΑΜΕΙΟ
ΕΥΡΩΠΑΪΚΟ ΤΑΜΕΙΟ ΠΕΡΙΦΕΡΕΙΑΚΗΣ ΑΝΑΠΤΥΞΗΣ

Thank you!!!

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