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Neutrinos in Cosmology, in Astro-, Particle- and Nuclear Physics
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Supernova neutrino detection by terrestrial neutrino detection targets

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Outline

- ***Introduction***
    1. Neutrino Production Sources
    2. Supernova Neutrino production
    3. SN- *ν* detection by terrestrial experiments (COBRA)
    4. Neutrino-nucleus reaction cross sections at low energies
- ***Nuclear Response to SN- ν Spectra***
    1. Response of Te isotopes to SN- ν spectra
    2. Convolution (folding) method for:
        - ➢ Differential cross sections **$<d\sigma/d\omega>$**
        - ➢ Double differential cross sections **$<d^2\sigma/d\Omega d\omega>$**

    3. Low energy beam neutrinos in SN- ν searches
        - ➢ Reactor neutrino spectra
        - ➢ Beta - beam neutrino spectra

- ***Summary - Conclusions - Outlook***

Neutrino Sources

1) Astrophysical Neutrino Sources

i. Solar Neutrinos

ii. Supernova Neutrinos

iii. Atmospheric Neutrinos

iv. Cosmological Neutrinos

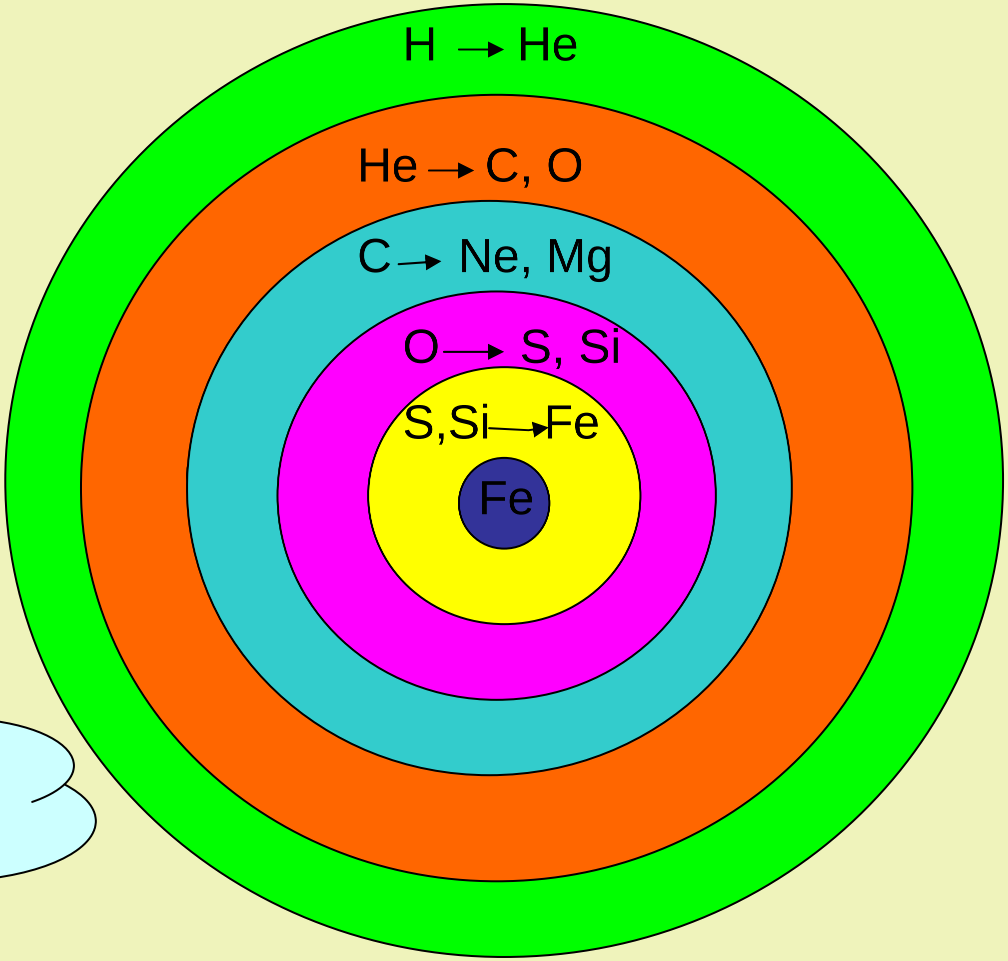
2) Laboratory Neutrino Sources

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



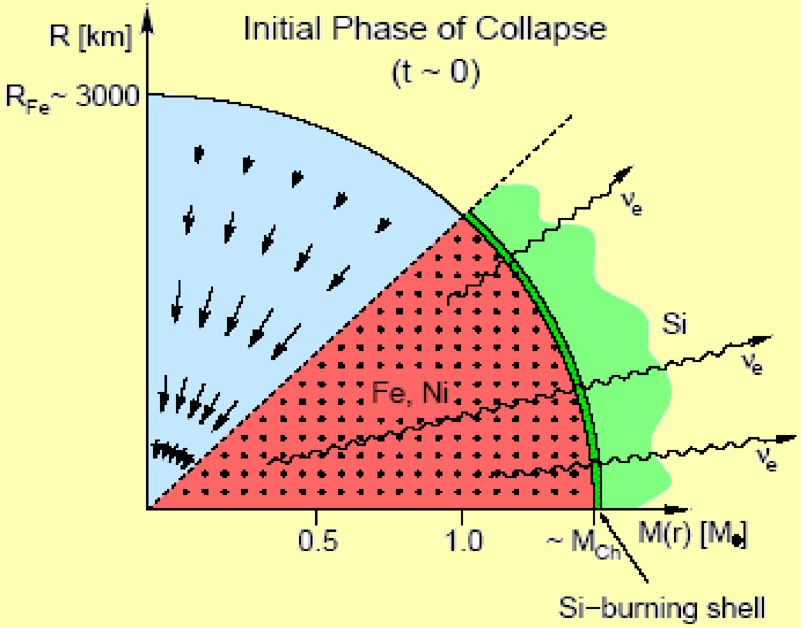
The core-collapse supernova starts!!!

Core-collapse simulation results

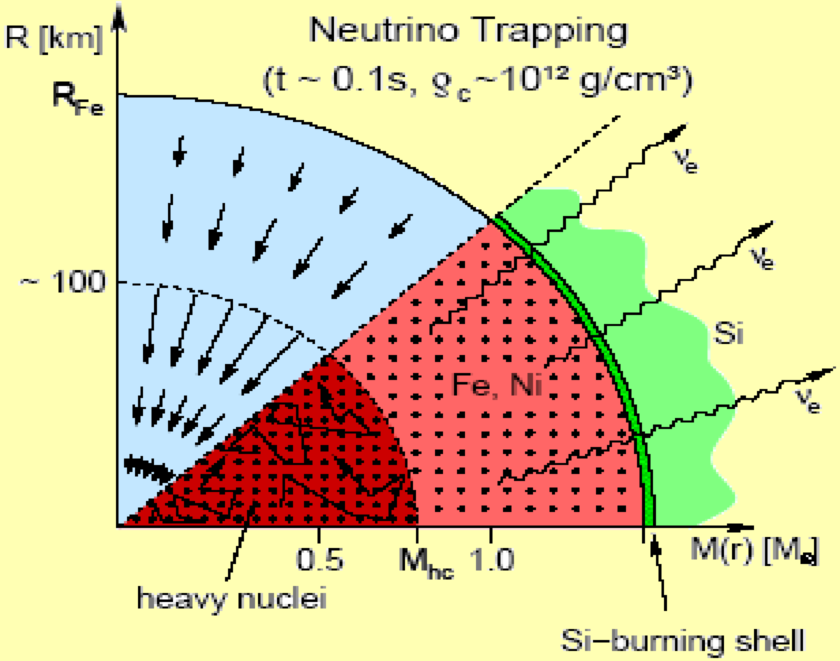
The main stages of stellar evolution (for massive stars) according to Janka et al., are:

- 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

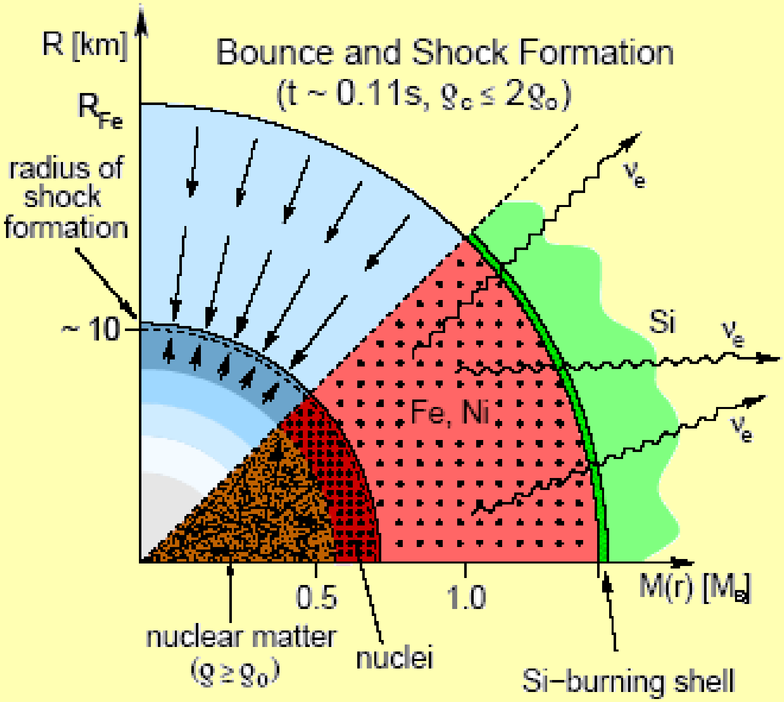
H. Th. Janka, K. Langanke et al, astro-ph/0612072 v1, 2006



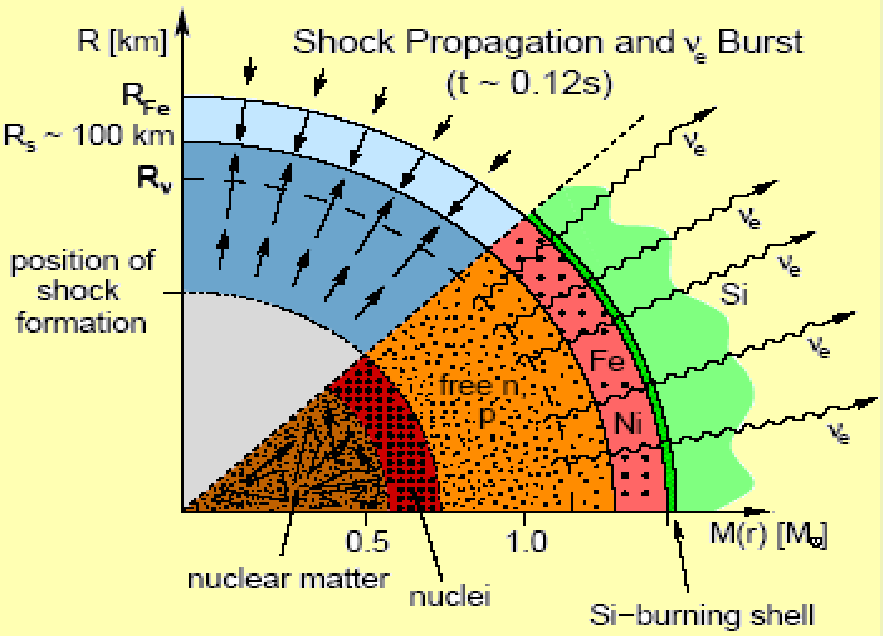
Initial Phase of Collapse (t ~ 0)



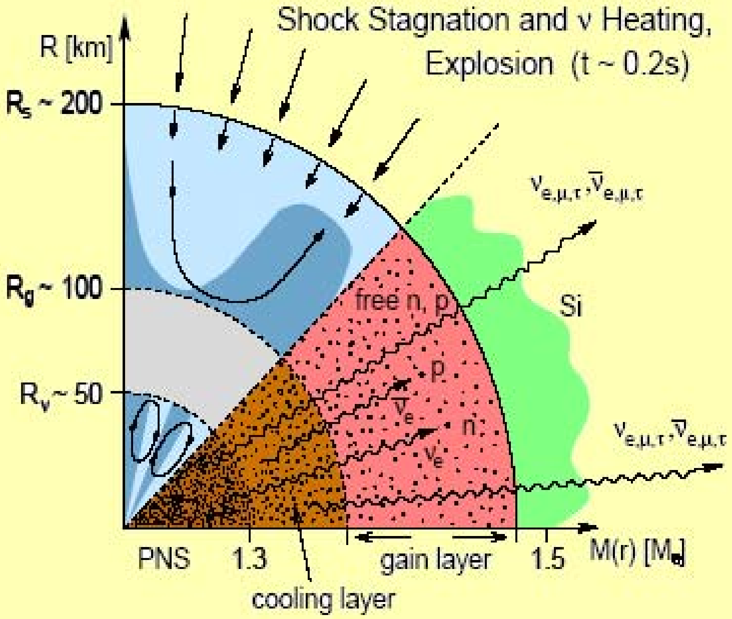
Neutrino Trapping (t ~ 0.1s, ϱ_c ~10^{12} g/cm³)

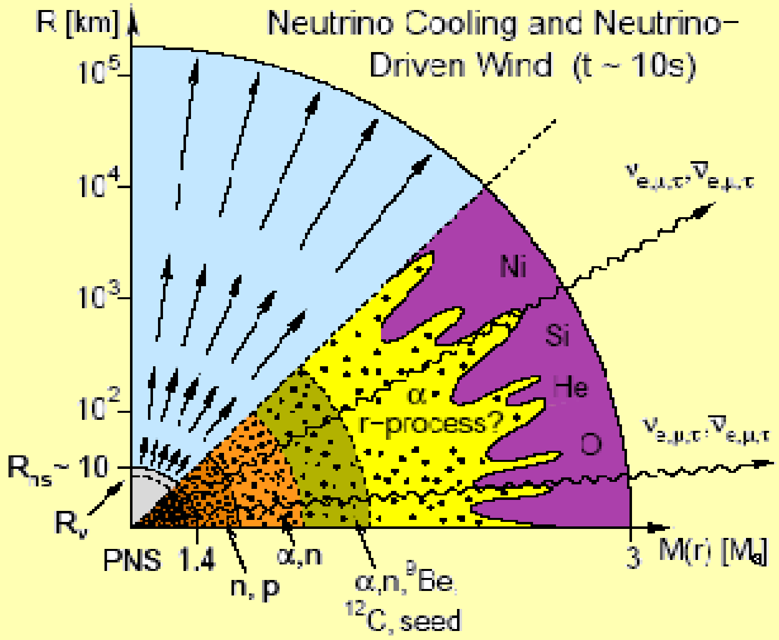


Bounce and Shock Formation (t ~ 0.11s, $\varrho_c \leq 2\varrho_o$)



Shock Propagation and ν_e Burst (t ~ 0.12s)





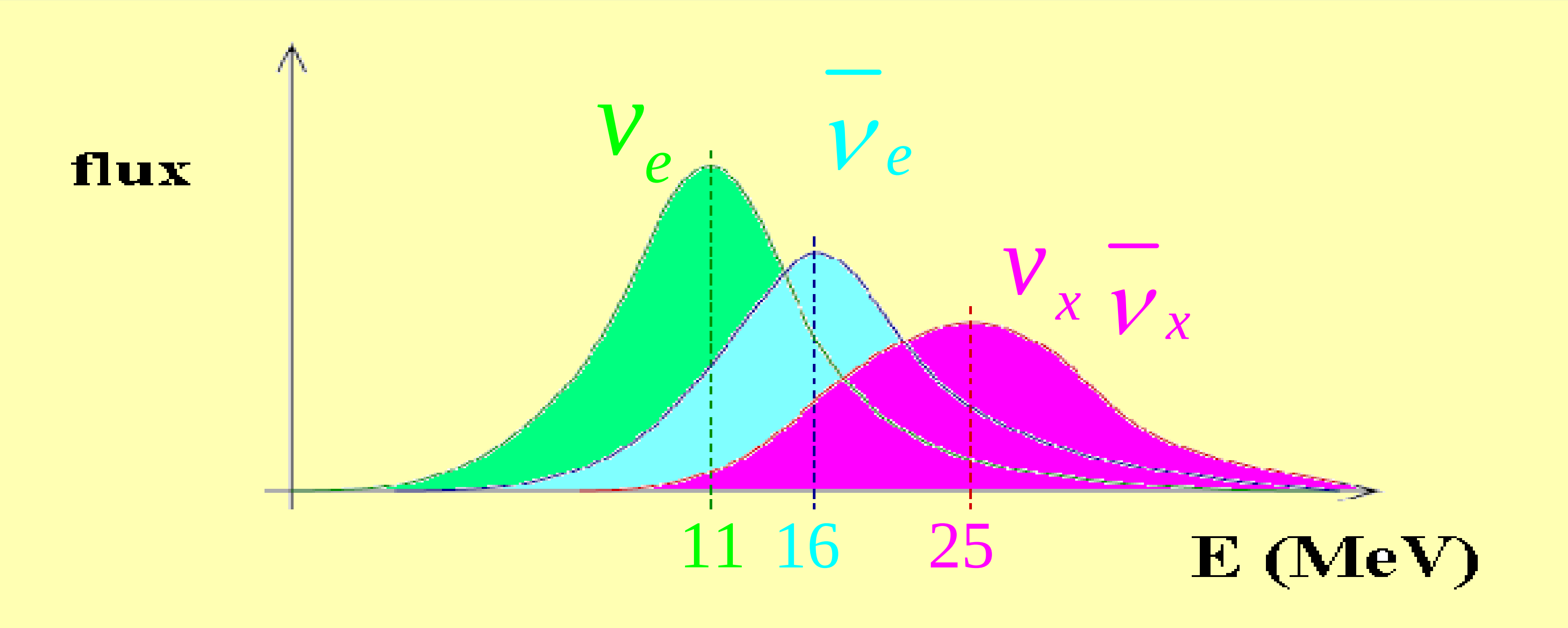
neutrinos of all flavors
are produced!!!

Average energy of SN-ν spectra

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

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

$$\boxed{T_{\nu_e} \approx 3,5\,MeV} \quad \boxed{T_{\bar{\nu}_e} \approx 5\,MeV} \quad \boxed{T_{\nu_x} \approx 8\,MeV}$$



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:

$$\left[\frac{d\sigma(\omega)}{d\omega}\right]_{fold} = \int_{\omega}^{\infty} \frac{d\sigma(\varepsilon_\nu,\omega)}{d\omega} n(\varepsilon_\nu)\, d\varepsilon_\nu$$

$\omega = E_i - E_f = \varepsilon_i - \varepsilon_f$: 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

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

Power - law

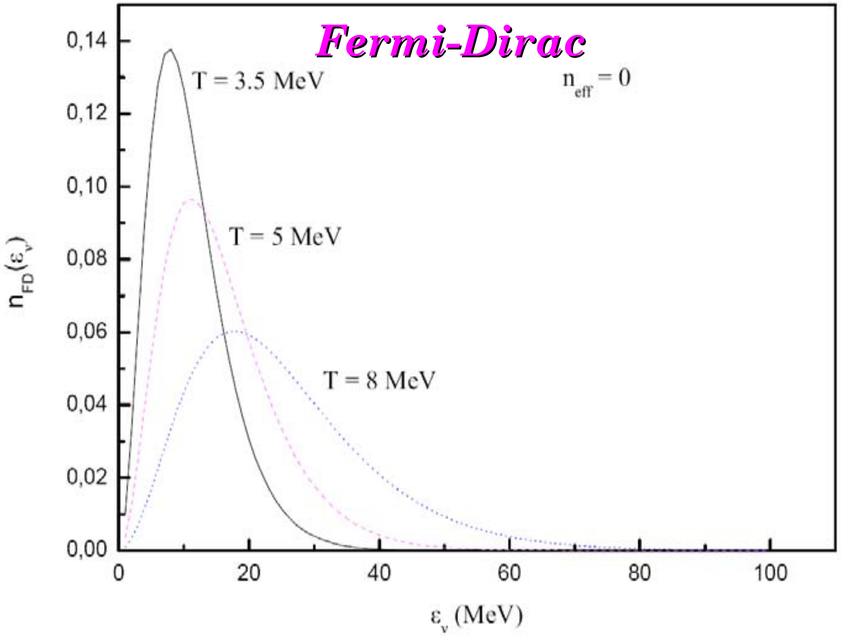
$$n_{PL}[\langle\varepsilon_\nu\rangle,a](\varepsilon_\nu)=\frac{1}{c}\left(\frac{\varepsilon_\nu}{\langle\varepsilon_\nu\rangle}\right)^{\alpha}e^{-(a+1)\frac{\varepsilon_\nu}{\langle\varepsilon_\nu\rangle}}$$

Reactor neutrino spectrum

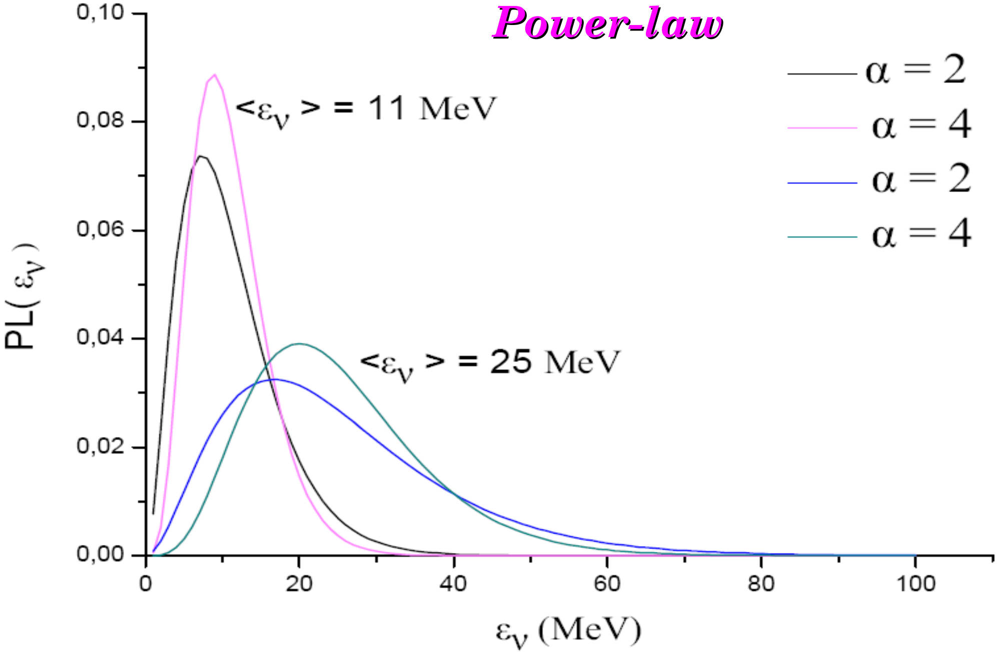
$$n_{\nu_e}(\varepsilon_{\nu_e})=\frac{96\varepsilon_{\nu_e}^2}{m_\mu^4}(m_\mu-2\varepsilon_{\nu_e})$$

Boosted beta-beam neutrino spectra

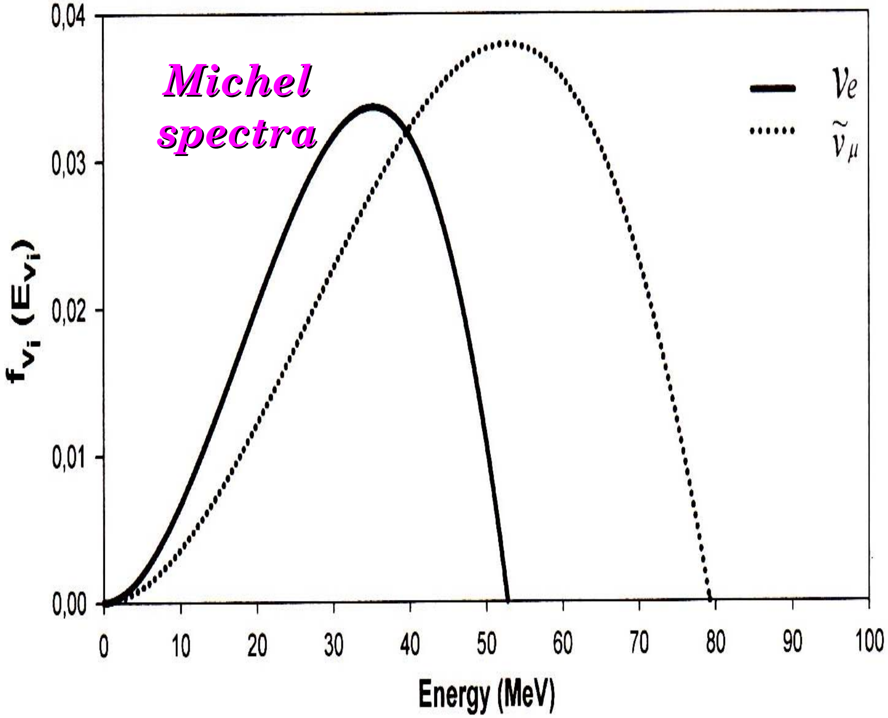
$$n_{\gamma_i}(\varepsilon_\nu)=\frac{\ln 2}{m_e ft}F(\pm Z,E_e)E_eP_e\frac{\varepsilon_\nu^2}{\gamma^2(1+u^2)}\frac{1}{2\gamma(1-u)}$$



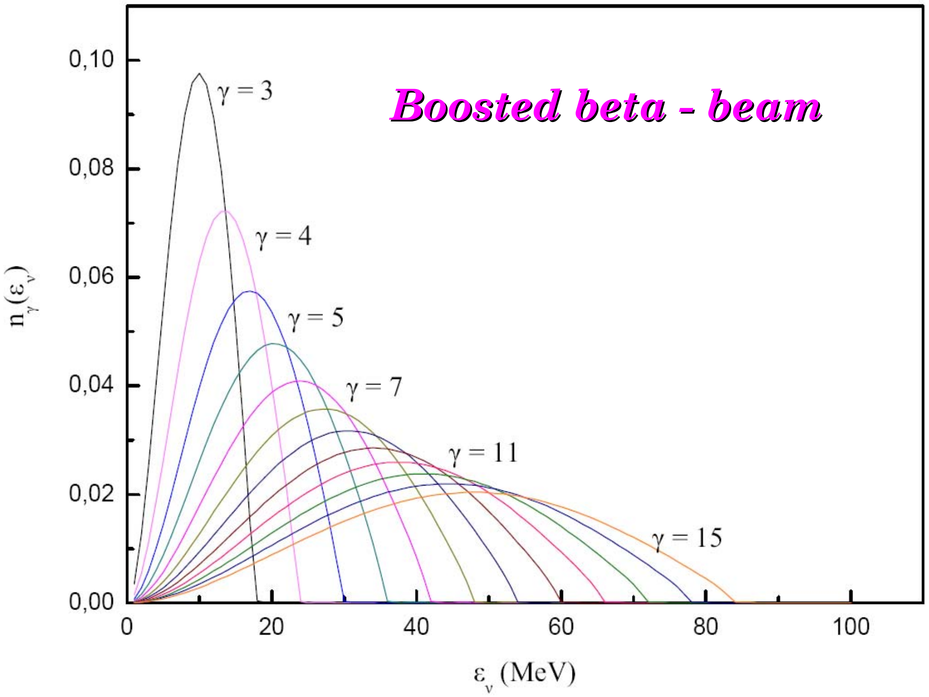
Fermi-Dirac



Power-law



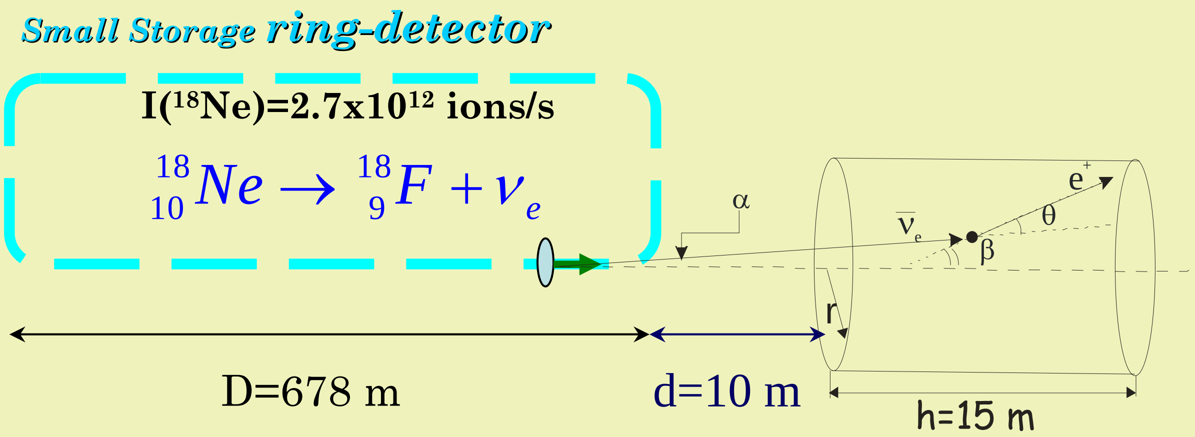
Michel spectra



Boosted beta - beam

Low-energy beta-beams in SN-ν physics

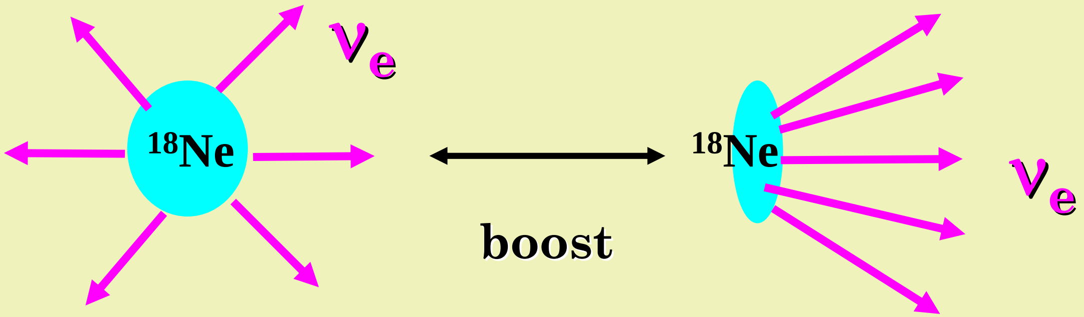
Low – energy *beta-beams* can provide information about SN-ν.



Small Storage ring-detector

I(^{18}Ne)=2.7x10^{12} ions/s

$$^{18}_{10}Ne \rightarrow {}^{18}_{9}F + \nu_e$$



C. Volpe, J. Phys. G30, L1 (2004) *C. Volpe, J. Phys. G34, R1 (2007)*

J. Serreau, C. Volpe: Phys.Rev. C70 (2004) 055502

Low-energy beta-beams in SN-ν physics

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

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

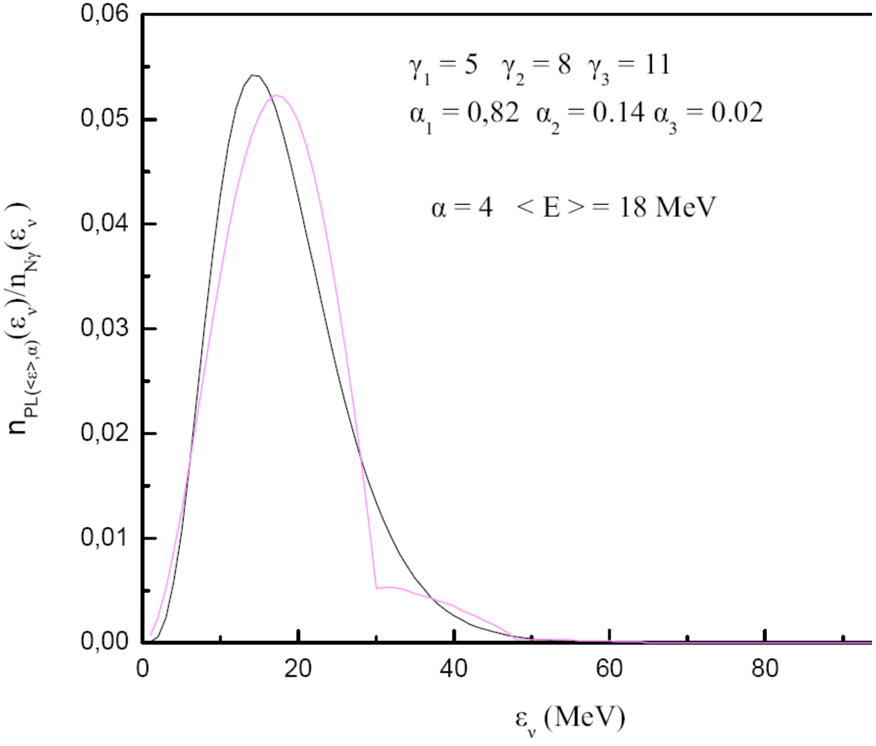
The expansion coefficients $a_{i=1,2,\ldots,N}$ for the boost factors $\gamma_{i=1,2,\ldots,N}$ are obtained by minimizing the expression

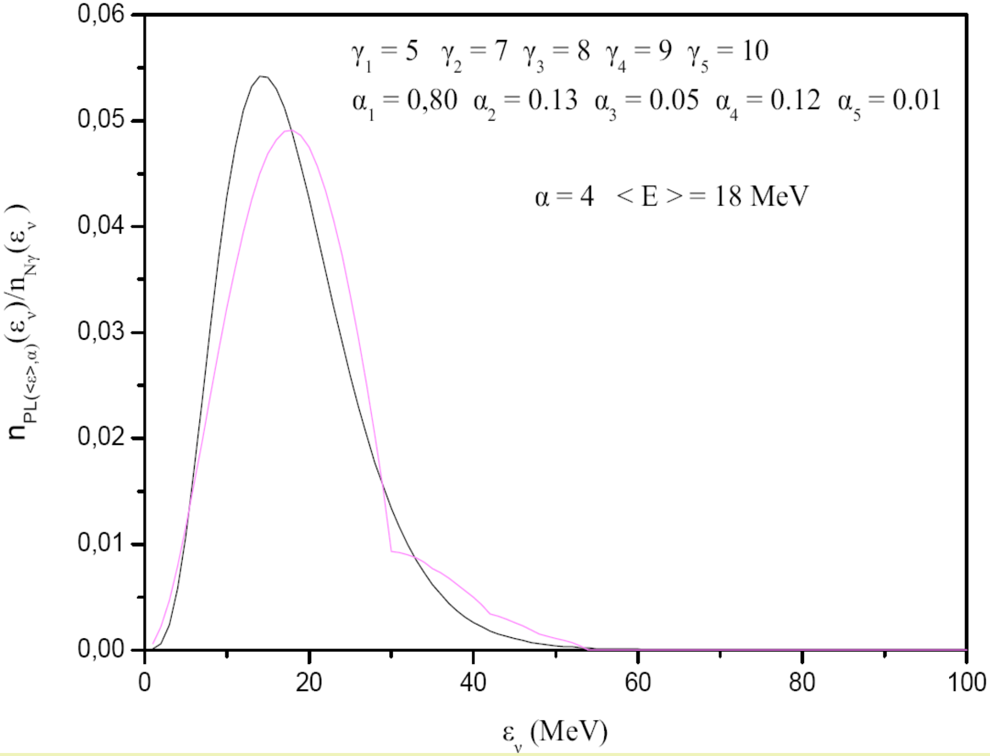
$$\int_{\varepsilon_\nu} d\varepsilon_\nu \left| n_{N_\gamma}(\varepsilon_\nu) - n_{SN}(\varepsilon_\nu) \right|$$

C. Volpe, J. Phys. G30, L1 (2004)

N.Jachowicz, G.C.McLaughlin and C.Volpe, Phys. Review C 77,2008

Power-law fitting with 3-5 boost components

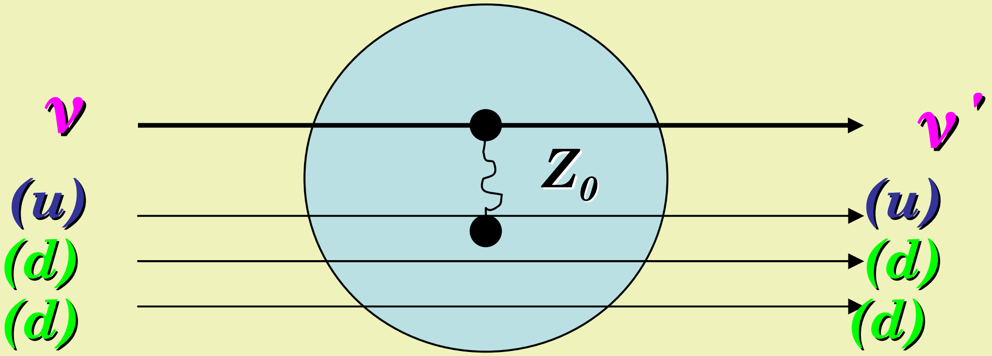




Nuclear response to SN-ν of COBRA target

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

$$^{128,130}Te(\nu_e,\nu_e^{'})^{128,130}Te^*$$

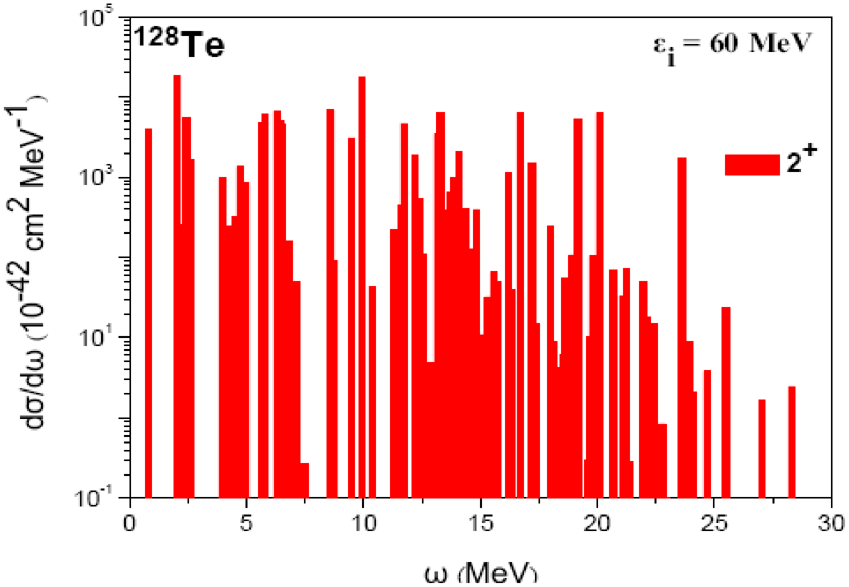


$$\boxed{\nu + (Z,A) \rightarrow (Z,A)^* + \nu^{'}}$$

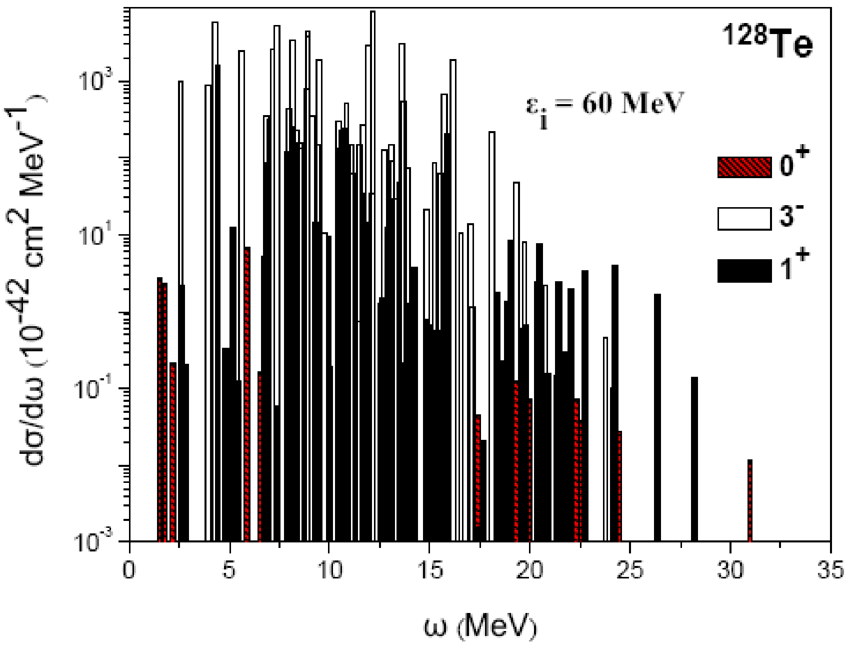
$$\boxed{\bar{\nu} + (Z,A) \rightarrow (Z,A)^* + \bar{\nu}^{'}}$$

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

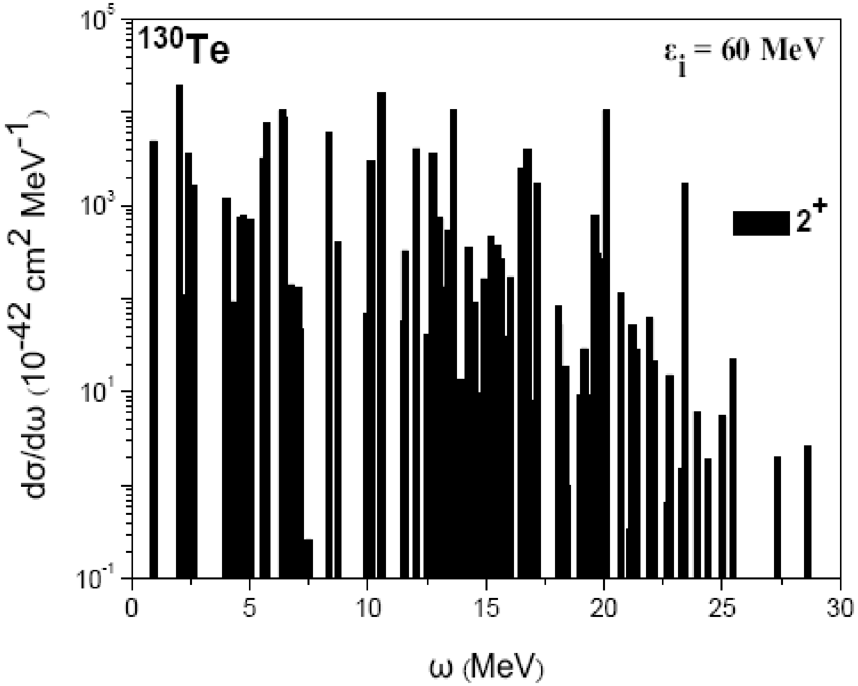
Results for 128,130Te



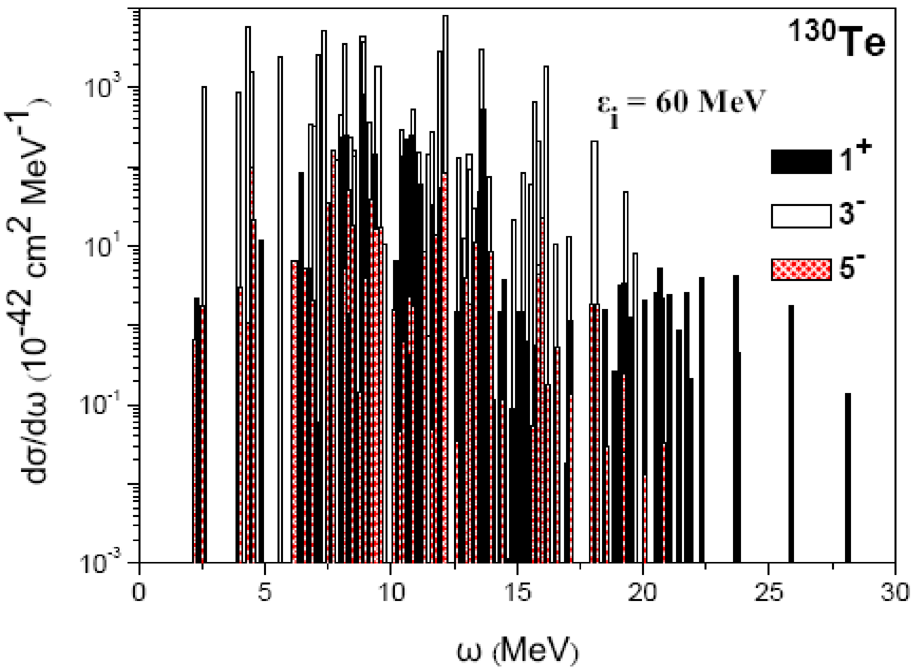
^{128}Te
ε_i = 60 MeV
2$^+$
dσ/dω (10^{-42} cm^2 MeV^{-1})
10^5
10^3
10^1
10^{-1}
0
5
10
15
20
25
30
ω (MeV)



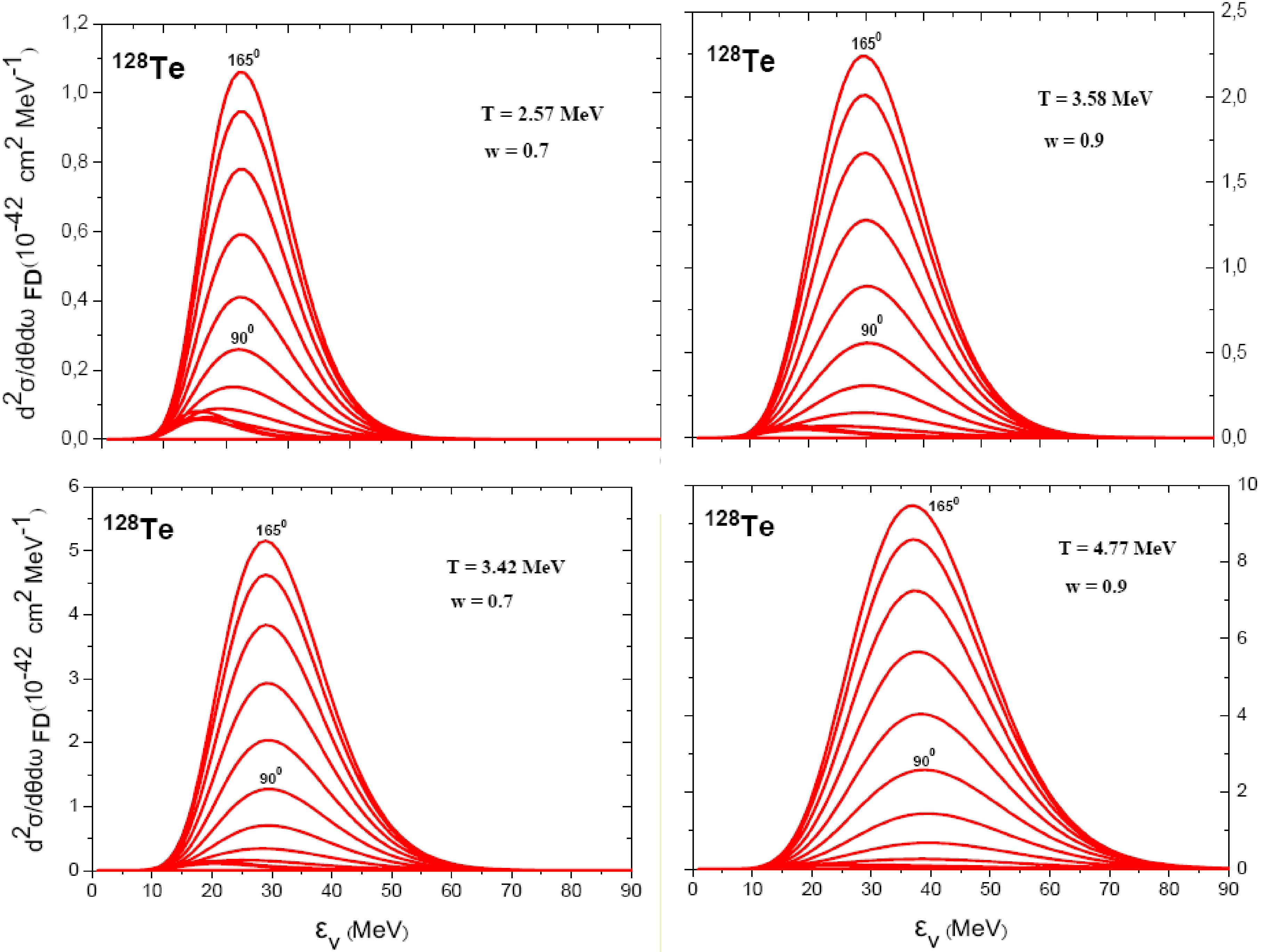
^{128}Te
ε_i = 60 MeV
0$^+$
3$^-$
1$^+$
dσ/dω (10^{-42} cm^2 MeV^{-1})
10^3
10^1
10^{-1}
10^{-3}
0
5
10
15
20
25
30
35
ω (MeV)

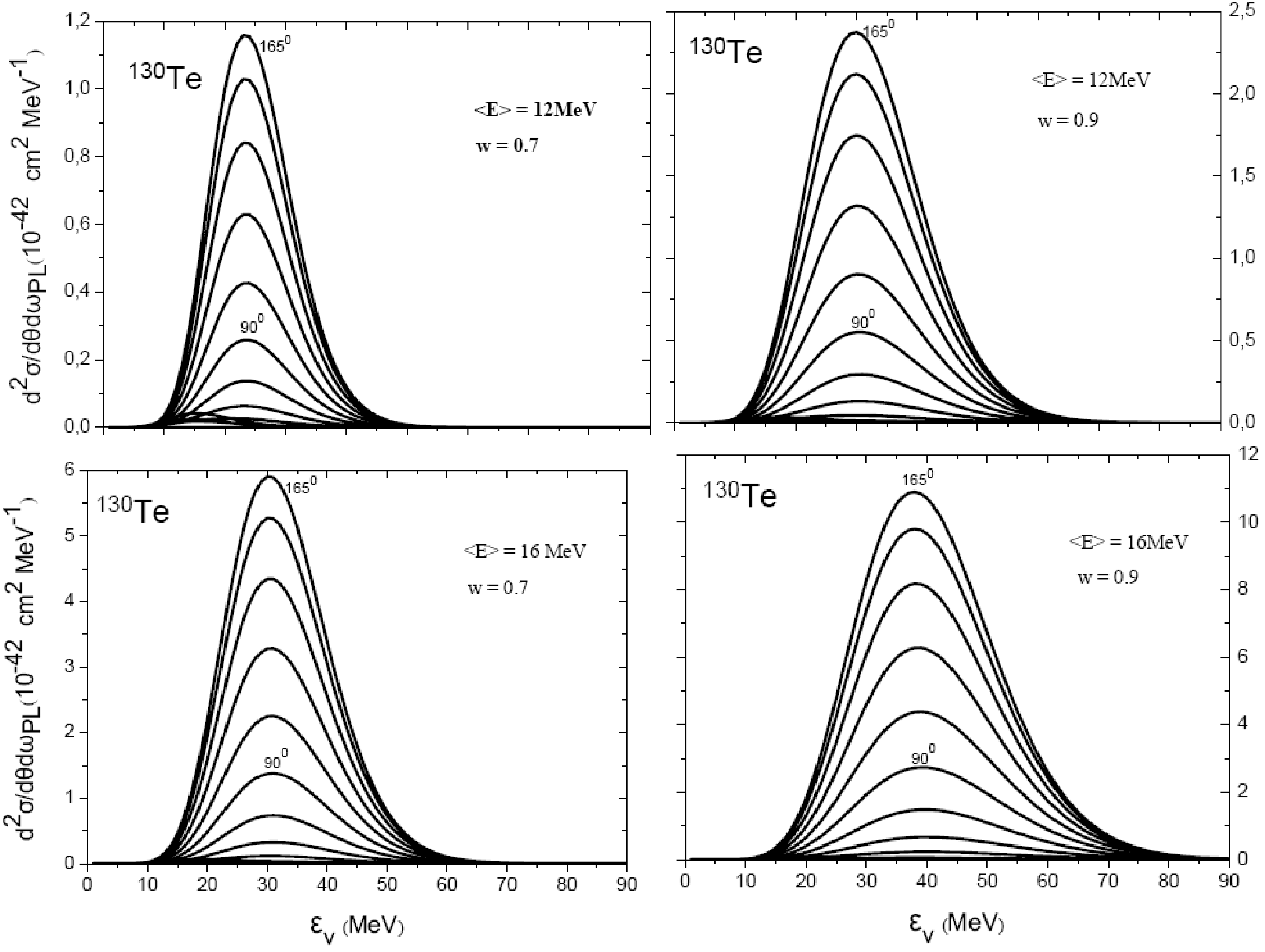


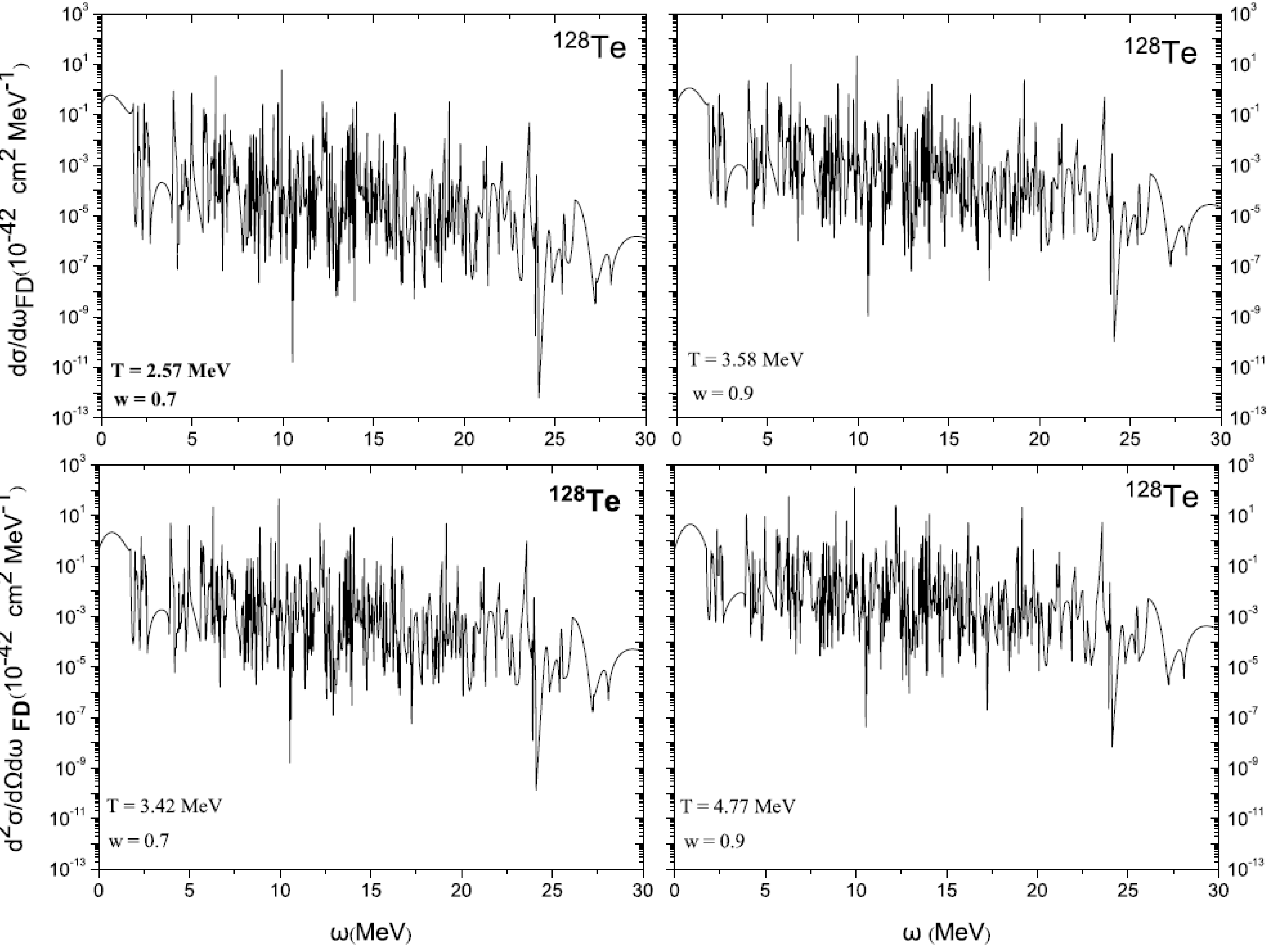
^{130}Te
ε_i = 60 MeV
2$^+$
dσ/dω (10^{-42} cm^2 MeV^{-1})
10^5
10^3
10^1
10^{-1}
0
5
10
15
20
25
30
ω (MeV)

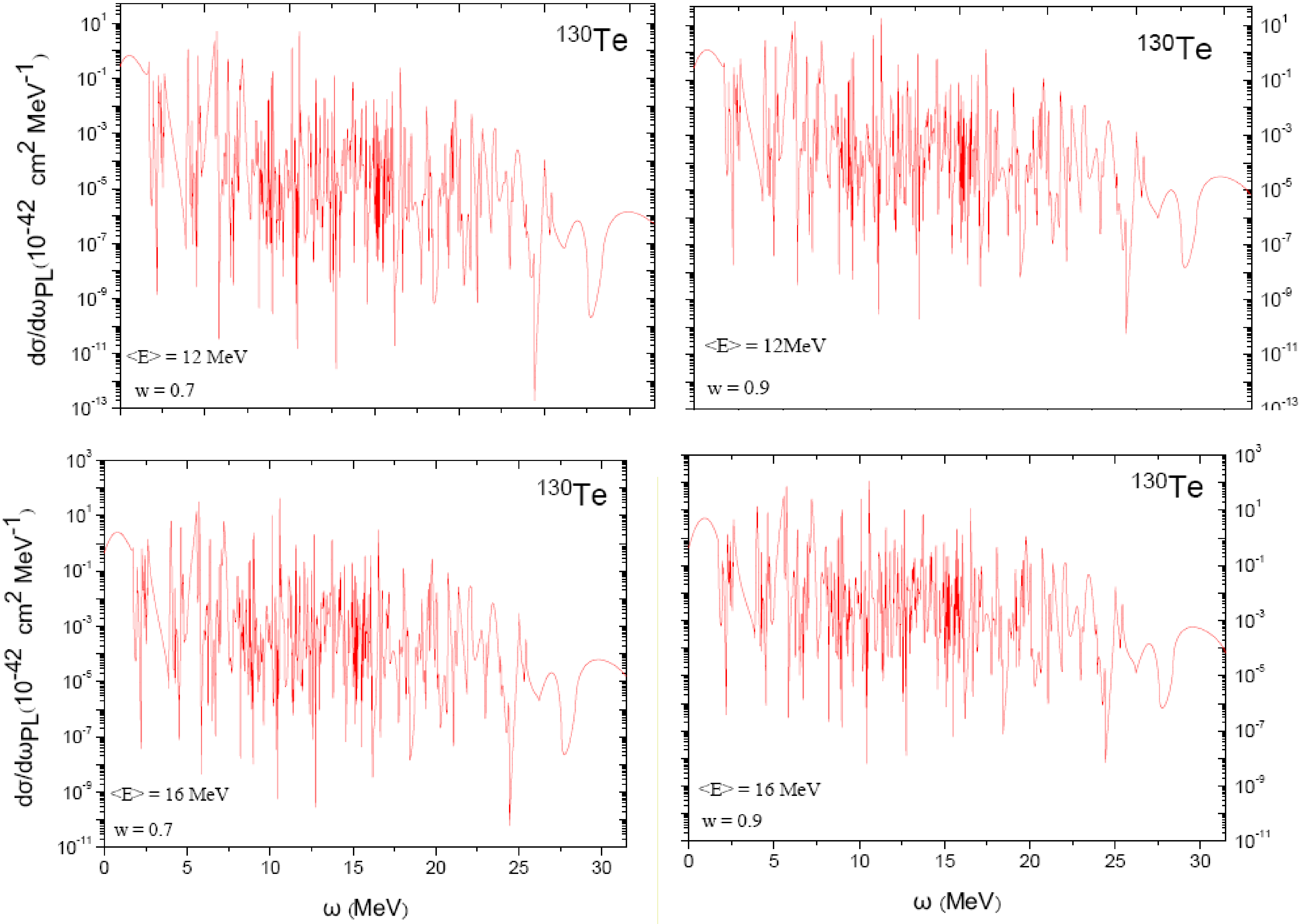


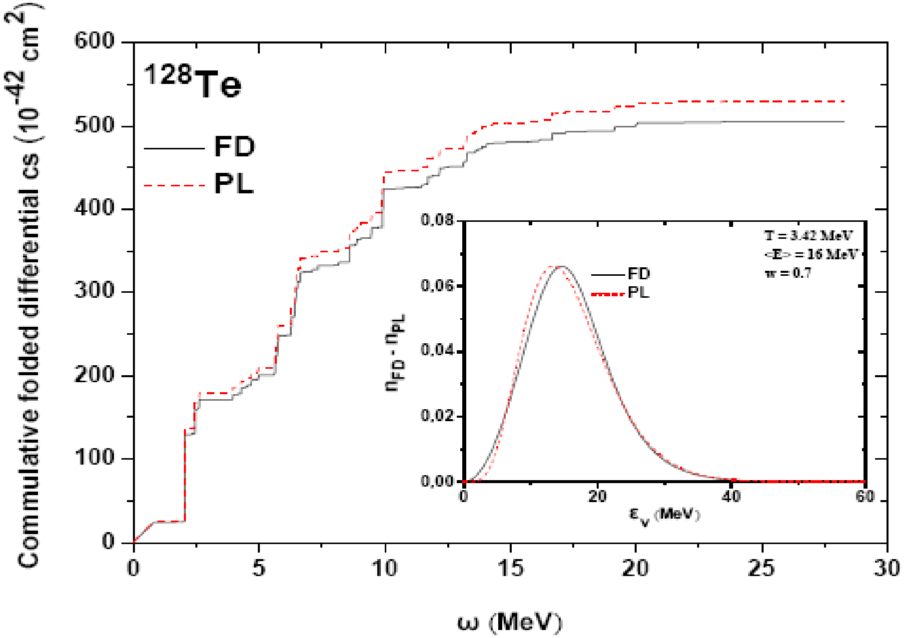
^{130}Te
ε_i = 60 MeV
1$^+$
3$^-$
5$^-$
dσ/dω (10^{-42} cm^2 MeV^{-1})
10^3
10^1
10^{-1}
10^{-3}
0
5
10
15
20
25
30
ω (MeV)


^{128}Te
165^0
90^0
T = 2.57 MeV
w = 0.7
T = 3.58 MeV
w = 0.9
T = 3.42 MeV
w = 0.7
T = 4.77 MeV
w = 0.9
$d^2\sigma/d\theta d\omega_{FD}(10^{-42}\ cm^2\ MeV^{-1})$
ε_ν (MeV)
0,0
0,2
0,4
0,6
0,8
1,0
1,2
0,5
1,5
2,0
2,5
0
1
2
3
4
5
6
8
10
10
20
30
40
50
60
70
80
90

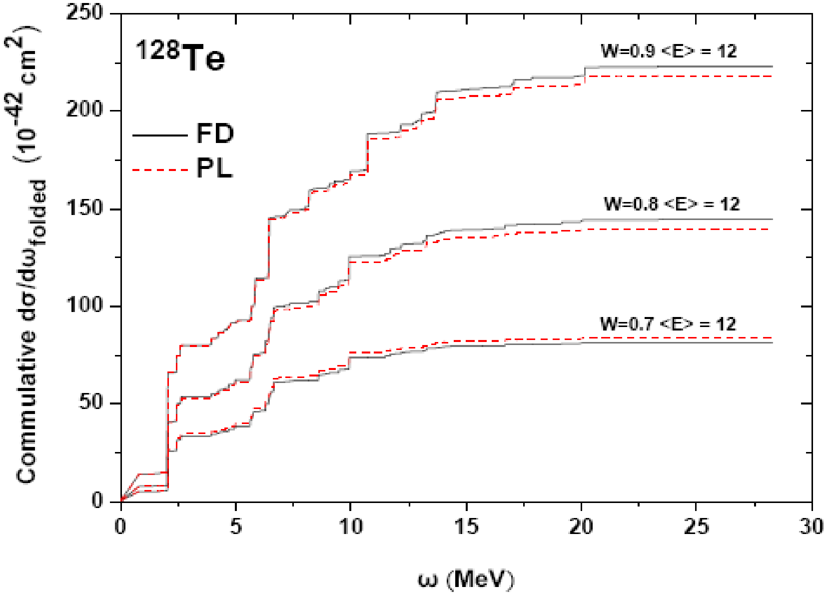

130Te
<E> = 12MeV
w = 0.7
165°
90°
130Te
<E> = 12MeV
w = 0.9
165°
90°
130Te
<E> = 16 MeV
w = 0.7
165°
90°
130Te
<E> = 16MeV
w = 0.9
165°
90°
d²σ/dθdωPL (10⁻⁴² cm² MeV⁻¹)
d²σ/dθdωPL (10⁻⁴² cm² MeV⁻¹)
εν (MeV)
εν (MeV)
0,0
0,2
0,4
0,6
0,8
1,0
1,2
0,0
0,5
1,0
1,5
2,0
2,5
0
1
2
3
4
5
6
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
80
90


^{128}Te
T = 2.57 MeV
w = 0.7
^{128}Te
T = 3.58 MeV
w = 0.9
^{128}Te
T = 3.42 MeV
w = 0.7
^{128}Te
T = 4.77 MeV
w = 0.9
dσ/dω$_{FD}$(10^{-42} cm^2 MeV^{-1})
d^{2}σ/dΩdω$_{FD}$(10^{-42} cm^2 MeV^{-1})
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
0
5
10
15
20
25
30
ω(MeV)
ω (MeV)

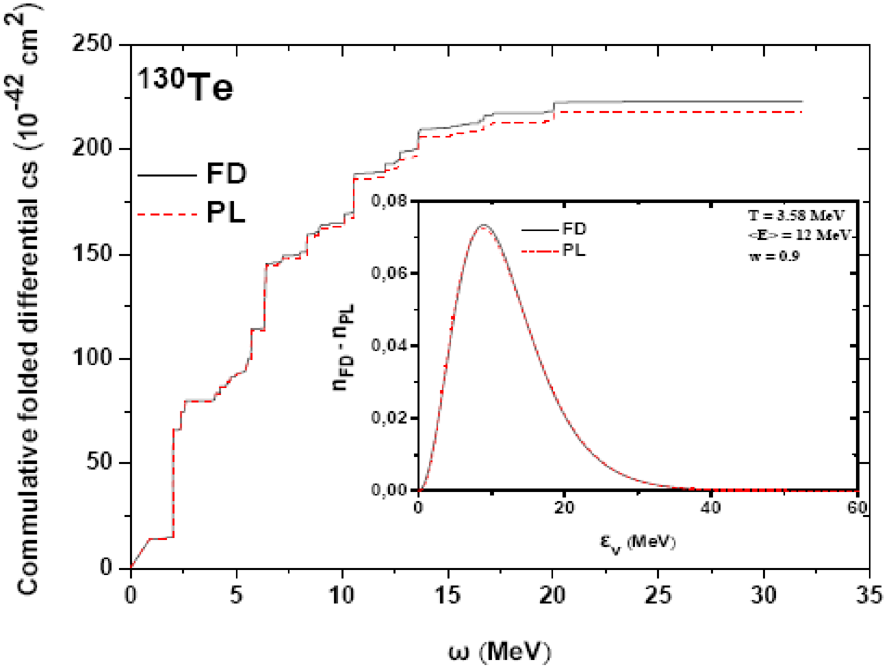

^{130}Te
<E> = 12 MeV
w = 0.7
<E> = 12MeV
w = 0.9
<E> = 16 MeV
w = 0.7
<E> = 16 MeV
w = 0.9
dσ/dω$_{PL}$ (10^{-42} cm^2 MeV^{-1})
ω (MeV)
10^{1}
10^{-1}
10^{-3}
10^{-5}
10^{-7}
10^{-9}
10^{-11}
10^{-13}
10^{3}
0
5
10
15
20
25
30



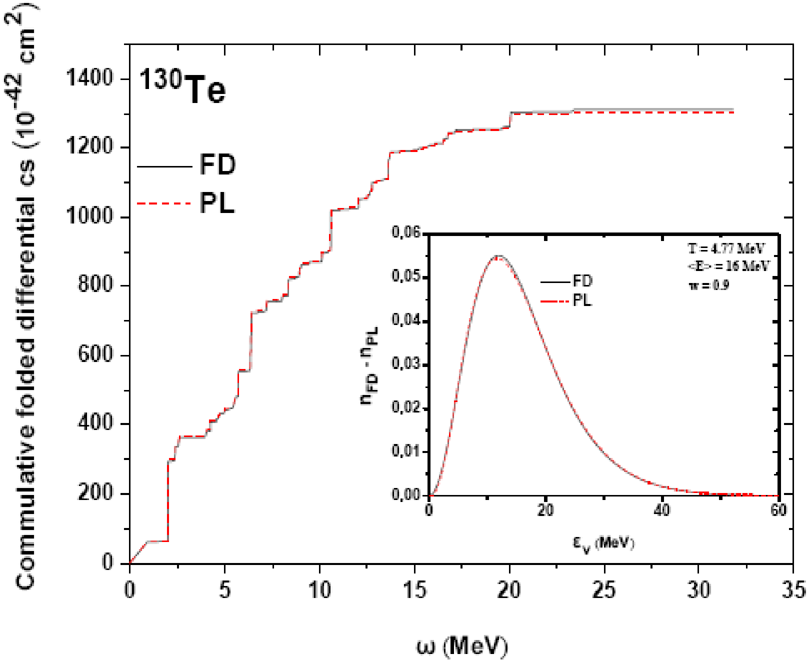
^{128}Te
FD
PL
Commulative folded differential cs (10^{-42} cm^2)
ω (MeV)
0
100
200
300
400
500
600
0
5
10
15
20
25
30
T = 3.42 MeV
<E> = 16 MeV
w = 0.7
FD
PL
n_{FD} - n_{PL}
ε_ν (MeV)
0,00
0,02
0,04
0,06
0,08
0
20
40
60



^{128}Te
FD
PL
W=0.9 <E> = 12
W=0.8 <E> = 12
W=0.7 <E> = 12
Commulative dσ/dω$_{folded}$ (10^{-42} cm^2)
ω (MeV)
0
50
100
150
200
250
0
5
10
15
20
25
30



^{130}Te
FD
PL
Commulative folded differential cs (10^{-42} cm^2)
ω (MeV)
0
50
100
150
200
250
0
5
10
15
20
25
30
35
T = 3.58 MeV
<E> = 12 MeV
w = 0.9
FD
PL
n_{FD} - n_{PL}
ε_ν (MeV)
0,00
0,02
0,04
0,06
0,08
0
20
40
60



^{130}Te
FD
PL
Commulative folded differential cs (10^{-42} cm^2)
ω (MeV)
0
200
400
600
800
1000
1200
1400
0
5
10
15
20
25
30
35
T = 4.77 MeV
<E> = 16 MeV
w = 0.9
FD
PL
n_{FD} - n_{PL}
ε_ν (MeV)
0,00
0,01
0,02
0,03
0,04
0,05
0,06
0
20
40
60

Summary – Conclusions

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

    1) differential cross-sections ***$d\sigma/d\omega$***

    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 low energy neutrinos produced during Supernova explosions.

- We found that there are not dramatical differences between the above distributions.

- Currently we are working on the charged-current neutrinos processes of these isotopes

Thank you!!!

Supervision: T.S.Kosmas University Ioannina (Greece)

Acknowledgments:

I wish to acknowledge financial support from the ΠΕΝΕΔ-03/807, Hellenic GSRT Project