Estimation of atmospheric neutrinos background in Borexino

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Atmospheric neutrinos

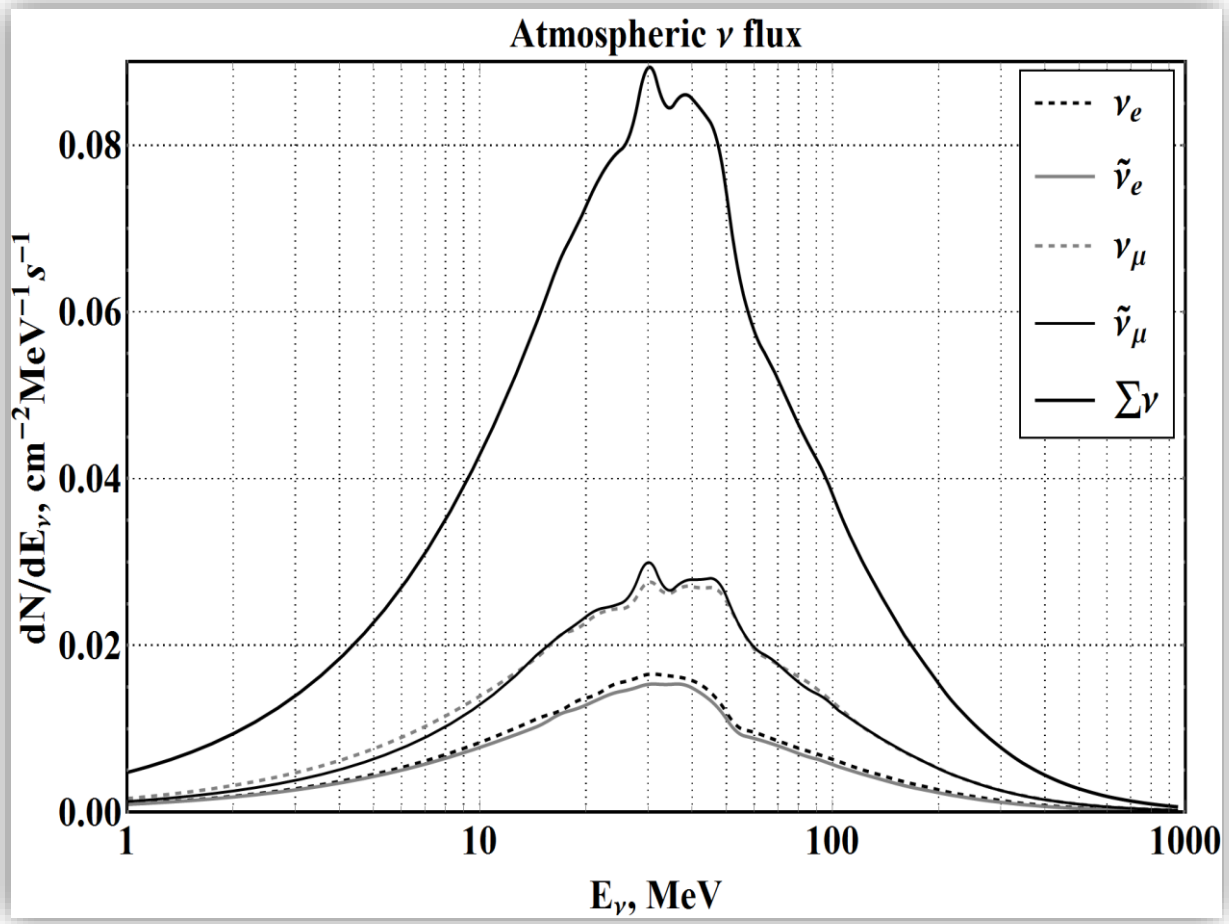
- Cosmic rays interactions with atomic nuclei in atmosphere
- $\pi^{\pm}/K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\overline{\nu}_{\mu})$
- $\mu^{-} \rightarrow e^{-}\overline{\nu}_{e}\nu_{\mu}$
- $\mu^{+} \rightarrow e^{+}\nu_{e}\overline{\nu}_{\mu}$
- $\frac{\nu_{\mu}+\overline{\nu}_{\mu}}{\nu_{e}+\overline{\nu}_{e}} \approx 2$

G. Battistoni, A. Ferrari, T. Montaruli, P.R. Sala

The atmospheric neutrino flux

***below 100 MeV**: The FLUKA results*

Astroparticle Physics, volume 23 issue 5, pp. 526–534, June 2005



Quadratic spline interpolation

Particle composition of Borexino scintillator

Particle	Number / 100 tons	Mass fraction	Natural abundance, %
e^-	3.30531×10^{31}	3.01094×10^{-4}	---
^{1}H	6.00013×10^{30}	1.00414×10^{-1}	99.985
^{12}C	4.45652×10^{30}	8.88027×10^{-1}	98.890
^{13}C	5.00226×10^{28}	0.10801×10^{-2}	1.110
^{2}H	9.00155×10^{26}	3.01056×10^{-5}	0.015
^{16}O	8.52935×10^{26}	2.26541×10^{-4}	99.762
^{14}N	8.51840×10^{26}	1.98075×10^{-4}	99.634
^{15}N	3.12919×10^{24}	7.79427×10^{-7}	0.366
^{18}O	1.70994×10^{24}	5.11072×10^{-7}	0.200
^{17}O	3.24888×10^{23}	9.17086×10^{-8}	0.038

Neutrino proton elastic scattering

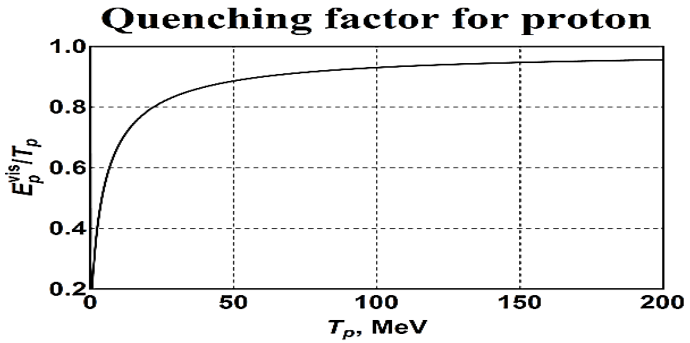
$$\nu + p \rightarrow \nu + p$$

$$\frac{d\sigma}{dT_p} = \frac{G_F^2 m_p^3}{4\pi E_\nu^2}\left(A(Q^2) \mp \frac{(s-u)}{m_p^2}B(Q^2) + \frac{(s-u)^2}{m_p^4}C(Q^2)\right)$$

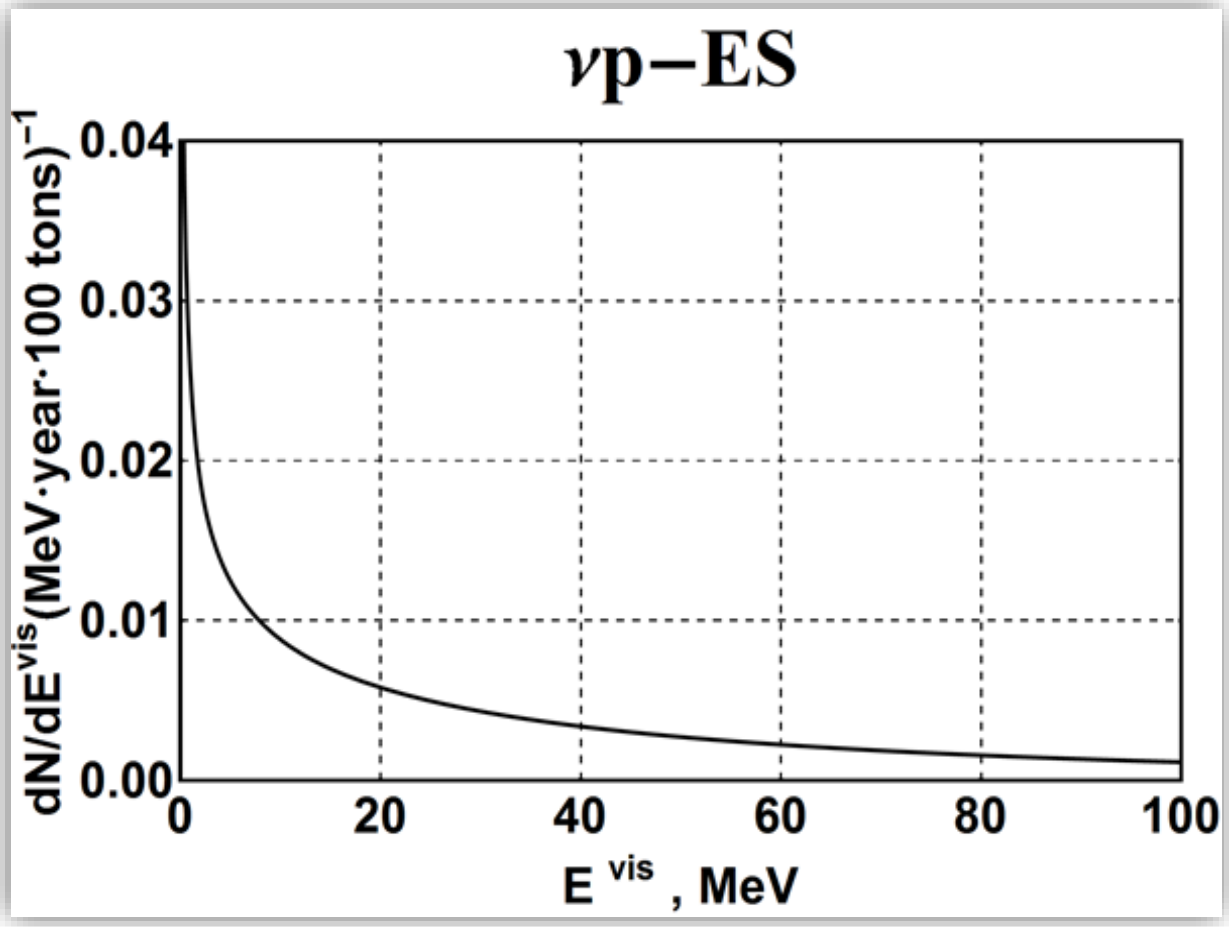
Ahrens, L. A. *et al.*

Measurement of neutrino-proton and antineutrino-proton elastic scattering

Phys. Rev. D 35, pp. 785-809, 1987



Recoil protons / year / 100 tons	
0.25 ≤ E^{vis} ≤ 15 MeV	0.181443
1 ≤ E^{vis} ≤ 100 MeV	0.397184



Inverse beta-decay

$$\bar{\nu}_e + p \rightarrow e^+ + n$$
$$E_\nu > E_{thr} = 1.806 \text{ MeV}$$

$$\frac{d\sigma}{dT_e} = \frac{G_F^2 \cos^2\theta_C}{4\pi m_p E_\nu^2}\left(A(Q^2) - (s-u)B(Q^2) + (s-u)^2 C(Q^2)\right)$$

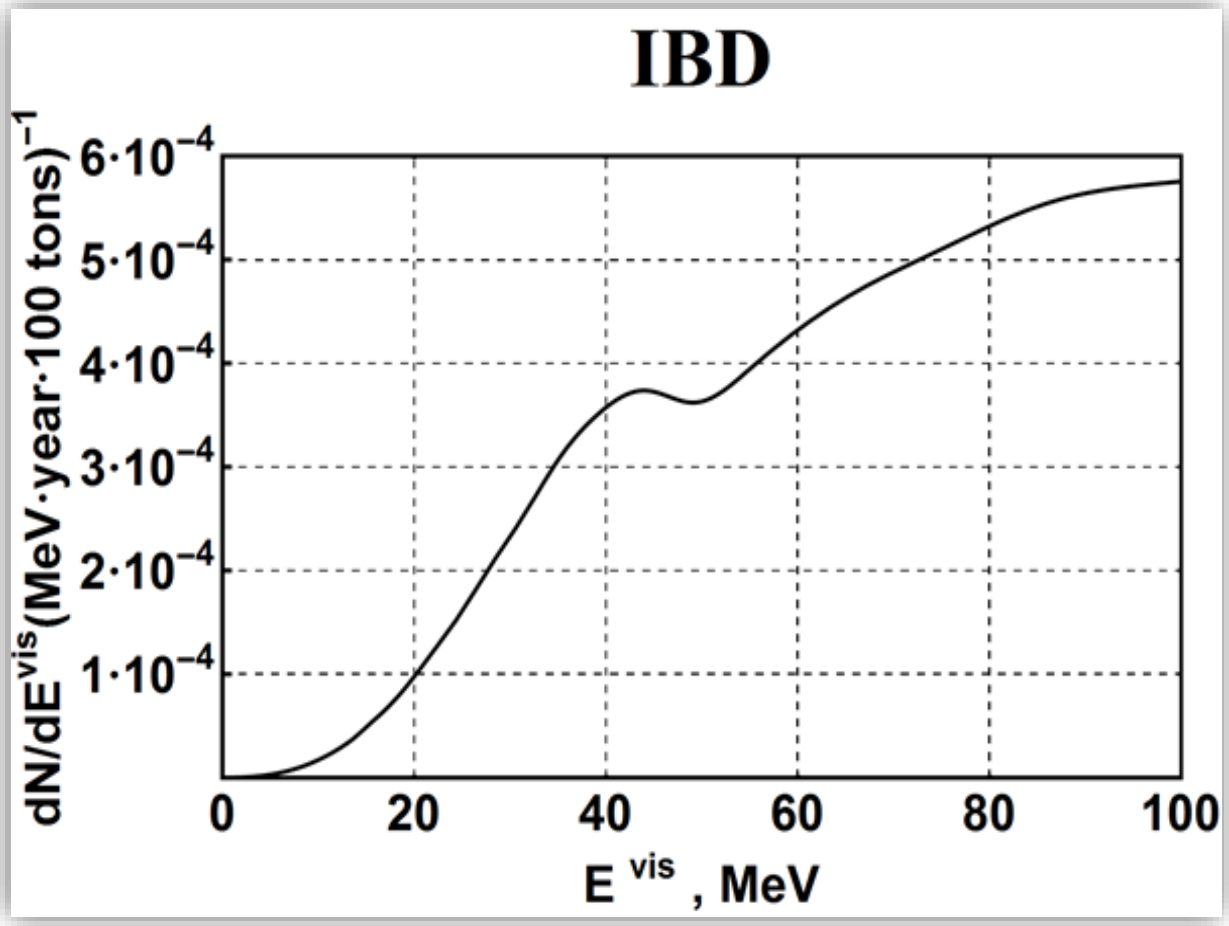
Strumia, A. and Vissani, F.

Precise quasielastic neutrino/nucleon cross-section

Phys. Lett. B 564, pp. 42-54, 2003

Double event	
Prompt	e^+ annihilation
Delayed	*n* capture (τ ≈ 254.5 μs)

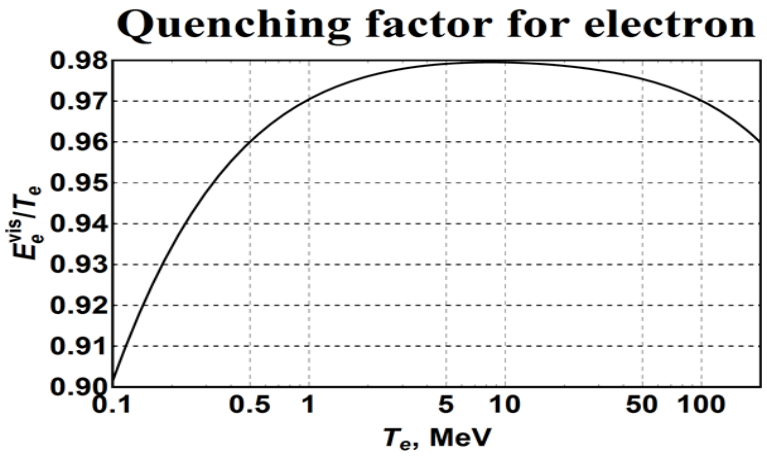
Positrons / year / 100 tons	
0.25 ≤ E^{vis} ≤ 15 MeV	**0.000205**
1 ≤ E^{vis} ≤ 100 MeV	**0.033788**



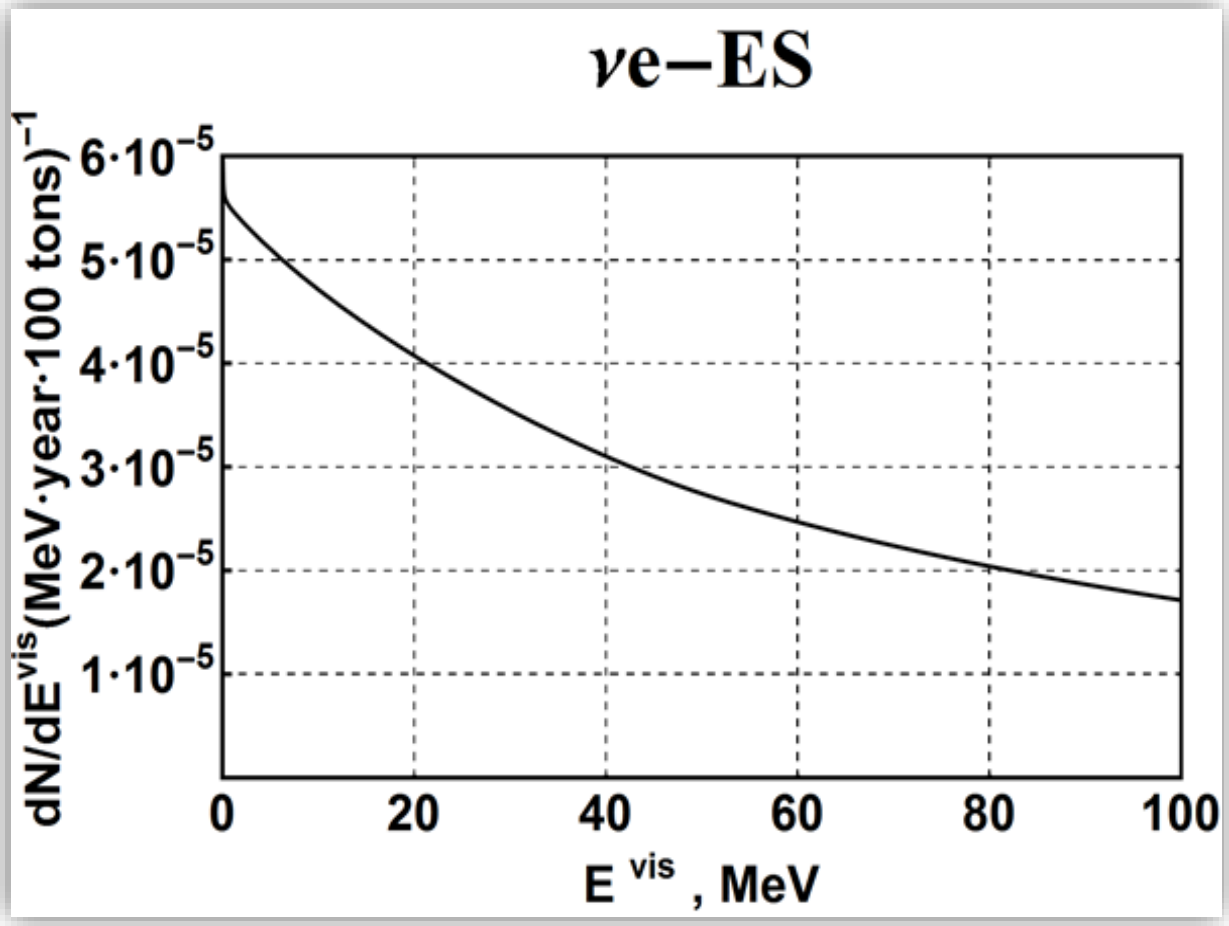
Neutrino electron elastic scattering

$$\nu + e \rightarrow \nu + e$$

$$\frac{d\sigma}{dT_e} = \frac{2G_F^2 m_e}{\pi E_\nu^2}\left(g_L^2 E_\nu^2 + g_R^2 (E_\nu - T_e)^2 - g_L g_R m_e T_e\right)$$



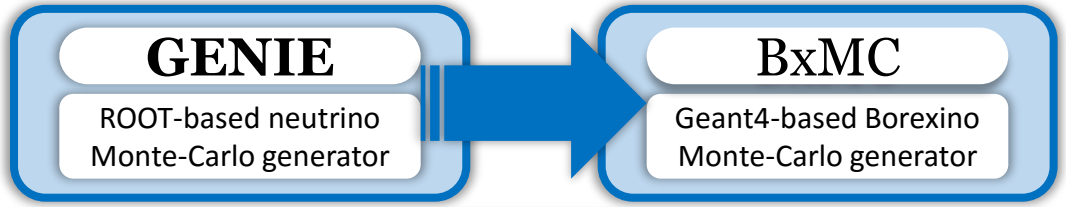
Electrons / year / 100 tons	
0.25 ≤ E^{vis} ≤ 15 MeV	0.000725
1 ≤ E^{vis} ≤ 100 MeV	0.002981



Neutrino carbon-12 reactions

CC: $\nu + {}^{12}C \rightarrow e^{\pm}/\mu^{\pm} + \cdots + X$

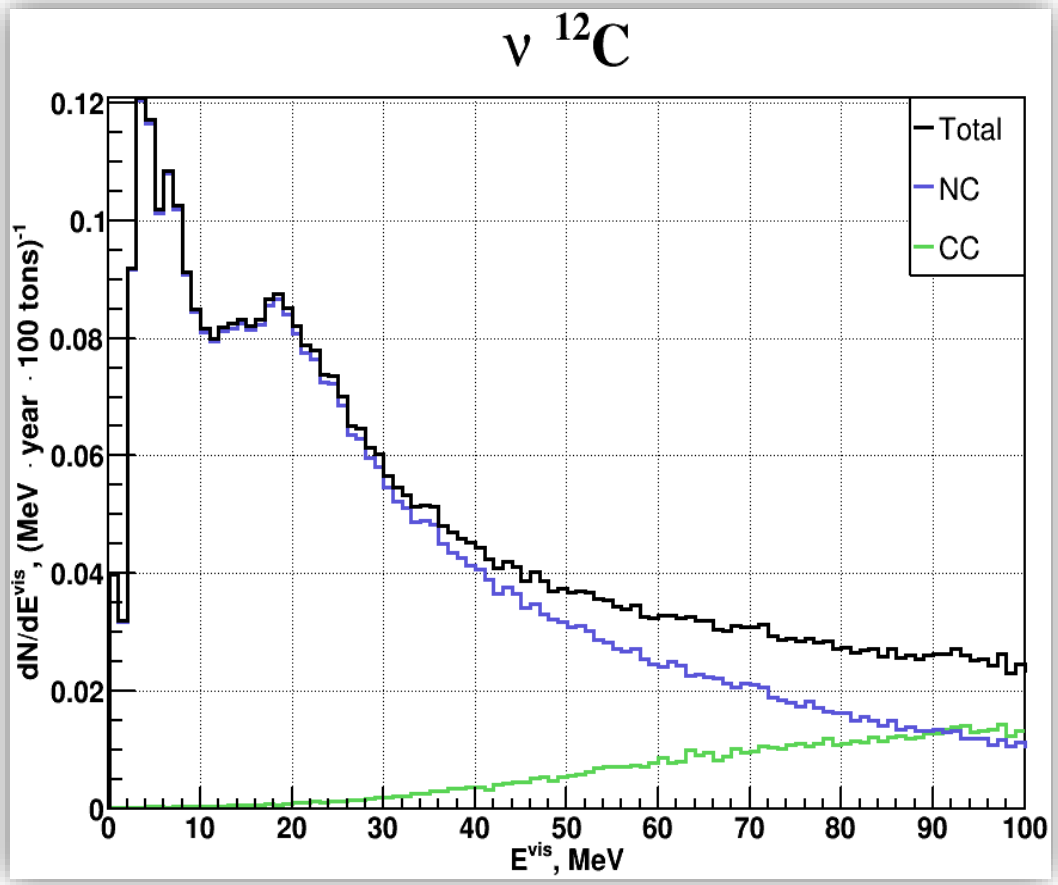
NC: $\nu + {}^{12}C \rightarrow \nu + \cdots + X$



- 600k+ events normalized by $\sum_{i,j} \int dE_{\nu_i} flux_i(E_{\nu_i}) \sigma_j(E_{\nu_i})$
- Double events mimic IBD

Long-lived residual nuclei				
	^{9}C, ^{8}He, ^{9}Li	^{8}Li, ^{8}B, ^{6}He	^{10}C	^{11}C
τ ~	0.2 s	1.2 s	27.8 s	29.3 min

Events / year / 100 tons		
	$\nu^{12}C$ – CC	$\nu^{12}C$ – NC
$0.25 \le E^{vis} \le 15$ MeV	0.005962	1.282274
$1 \le E^{vis} \le 100$ MeV	0.619615	4.156067



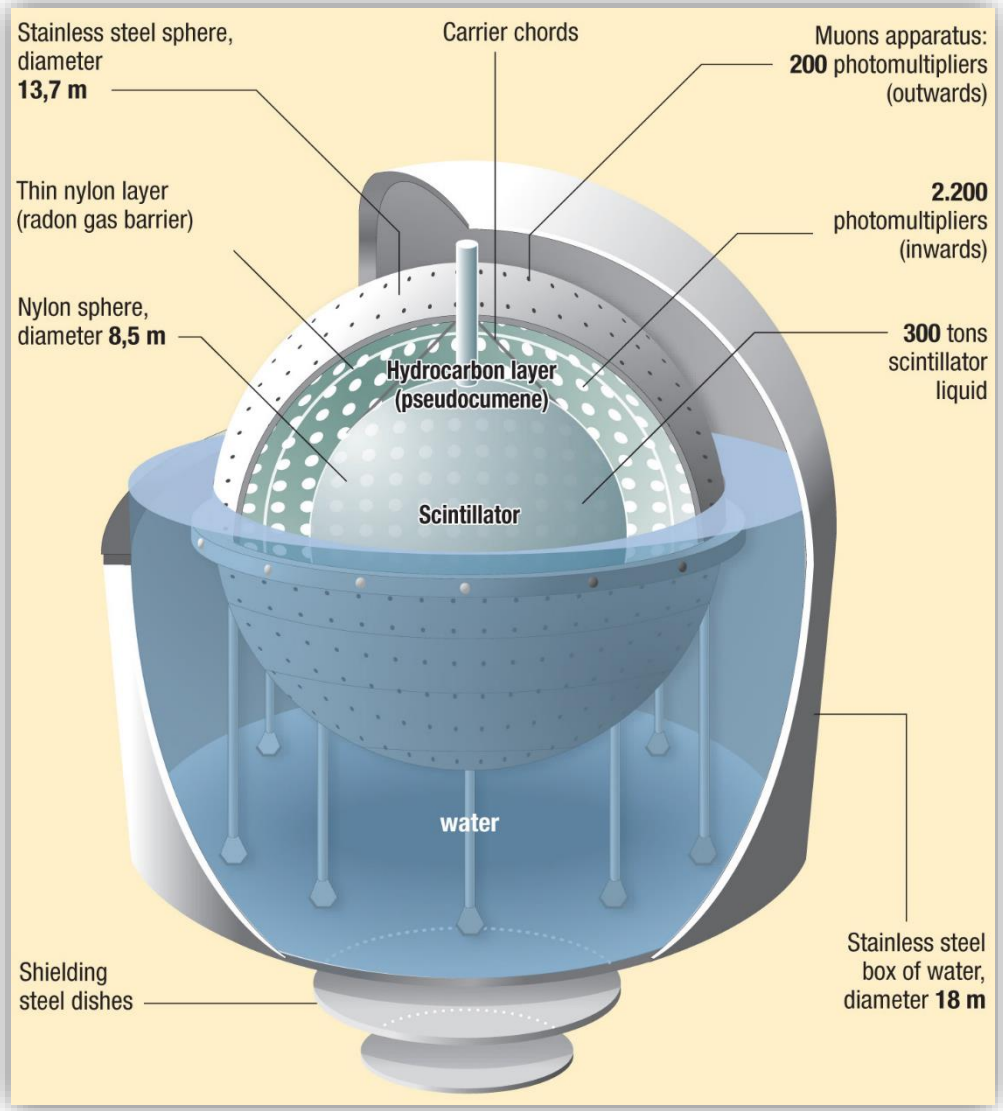
Results

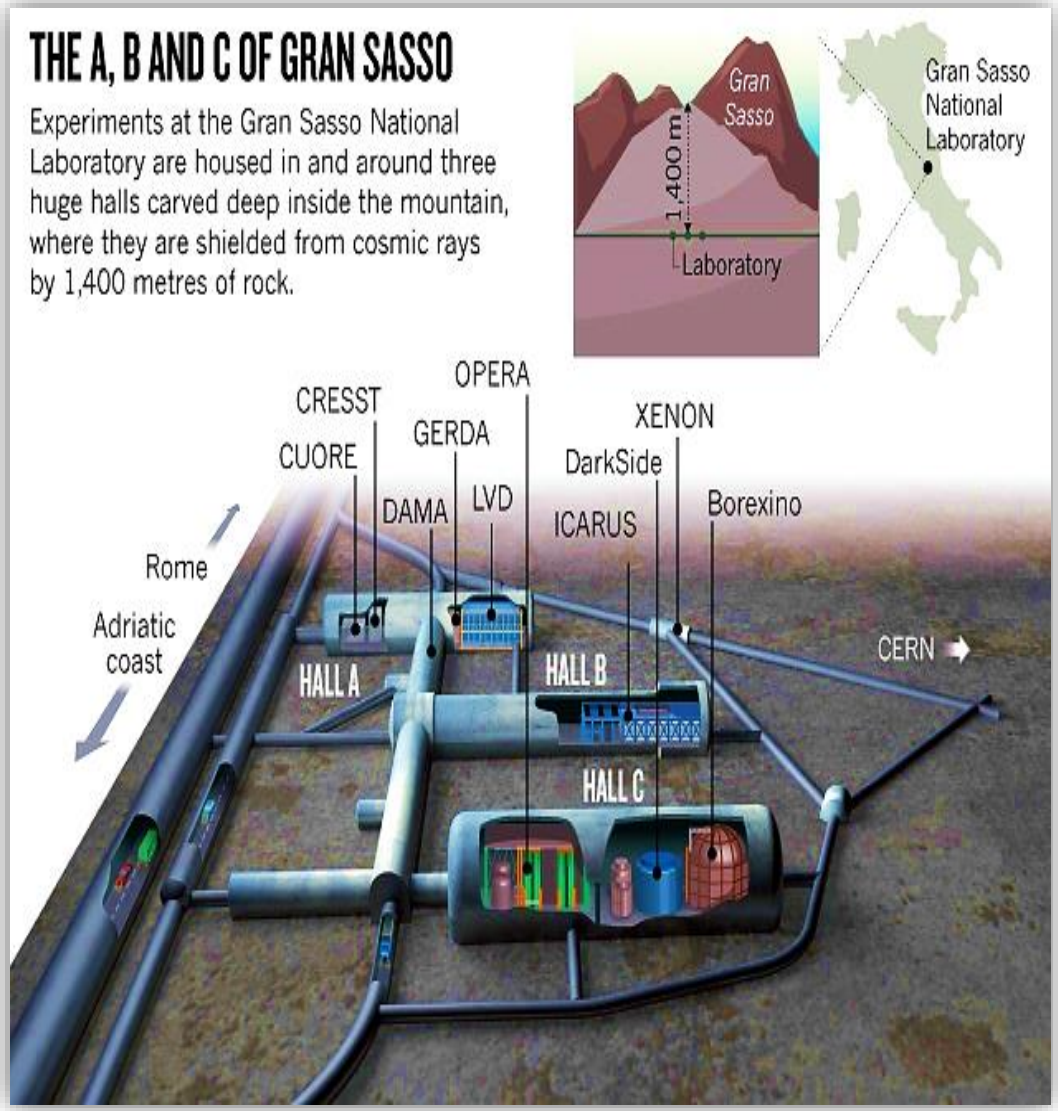
	$0.25 \leq E^{vis} \leq 15$ MeV	$1 \leq E^{vis} \leq 100$ MeV
vp-ES	**0.181443**	**0.397184**
IBD	**0.000205**	**0.033788**
ve-ES	**0.000725**	**0.002981**
$\nu^{12}C$ – CC	**0.005962**	**0.619615**
$\nu^{12}C$ – NC	**1.282274**	**4.156067**

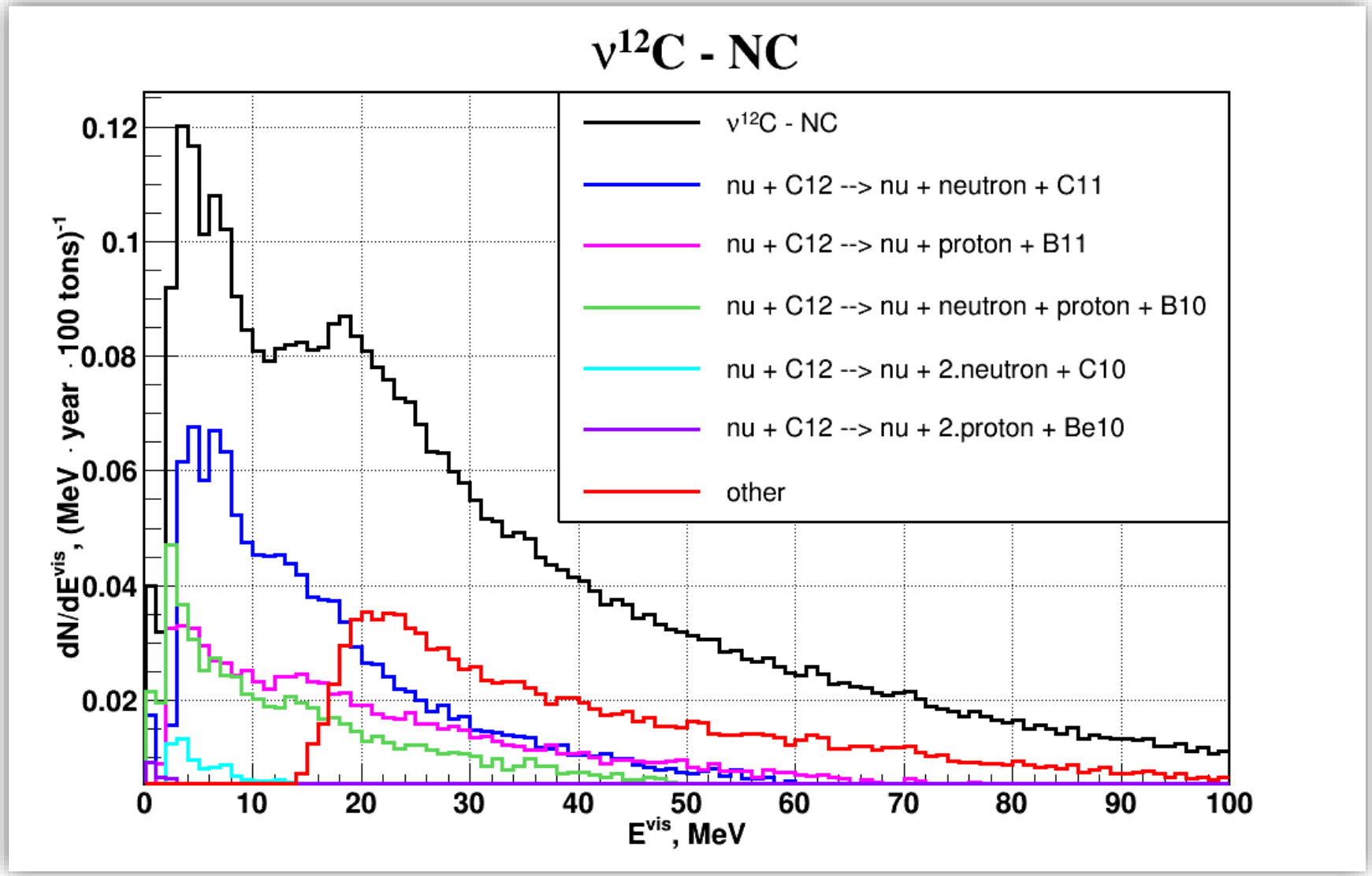
Atmospheric neutrinos should be thought as an important source of background for some kinds of processes in Borexino with few expected events per year.

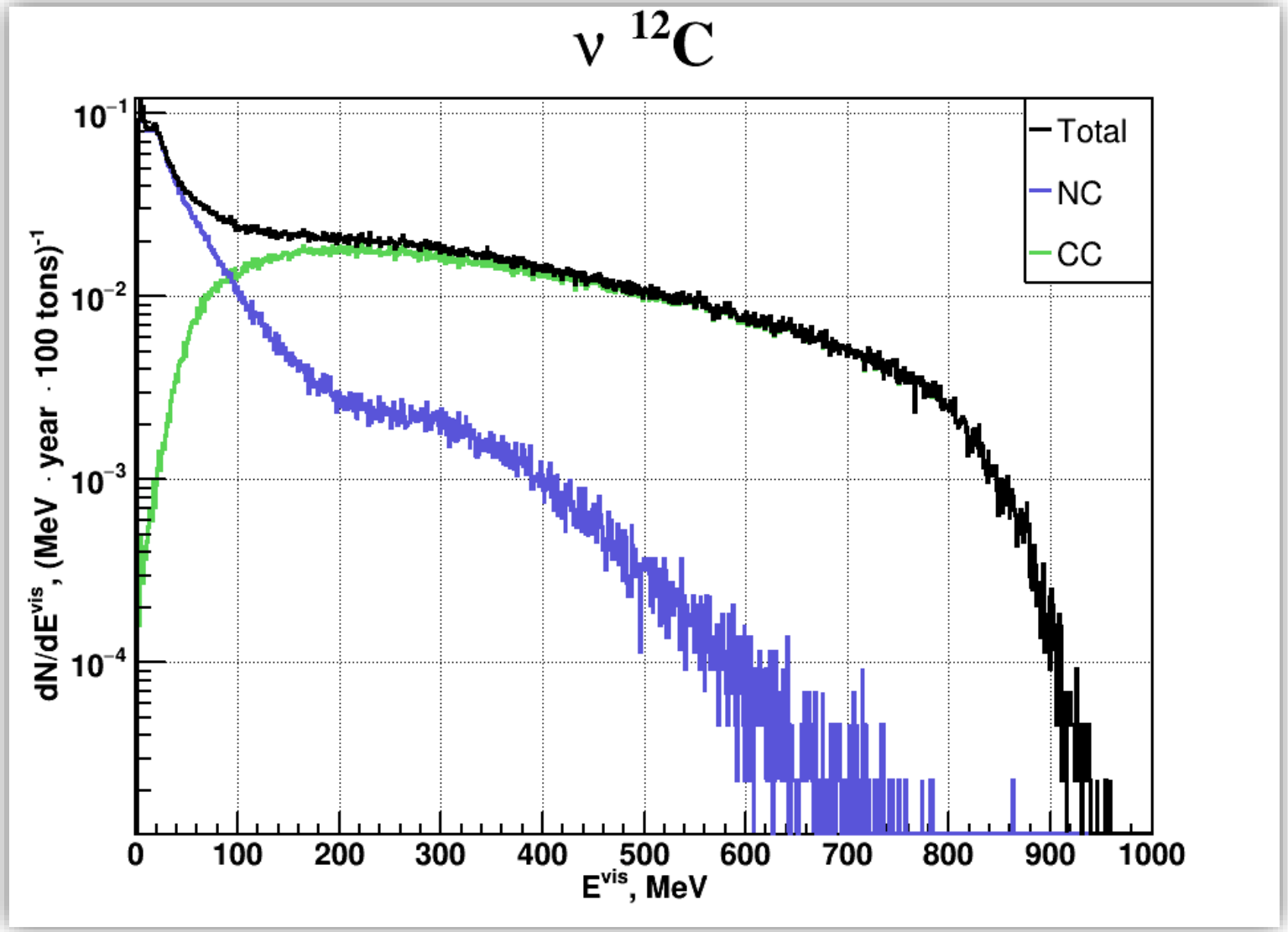
Backup

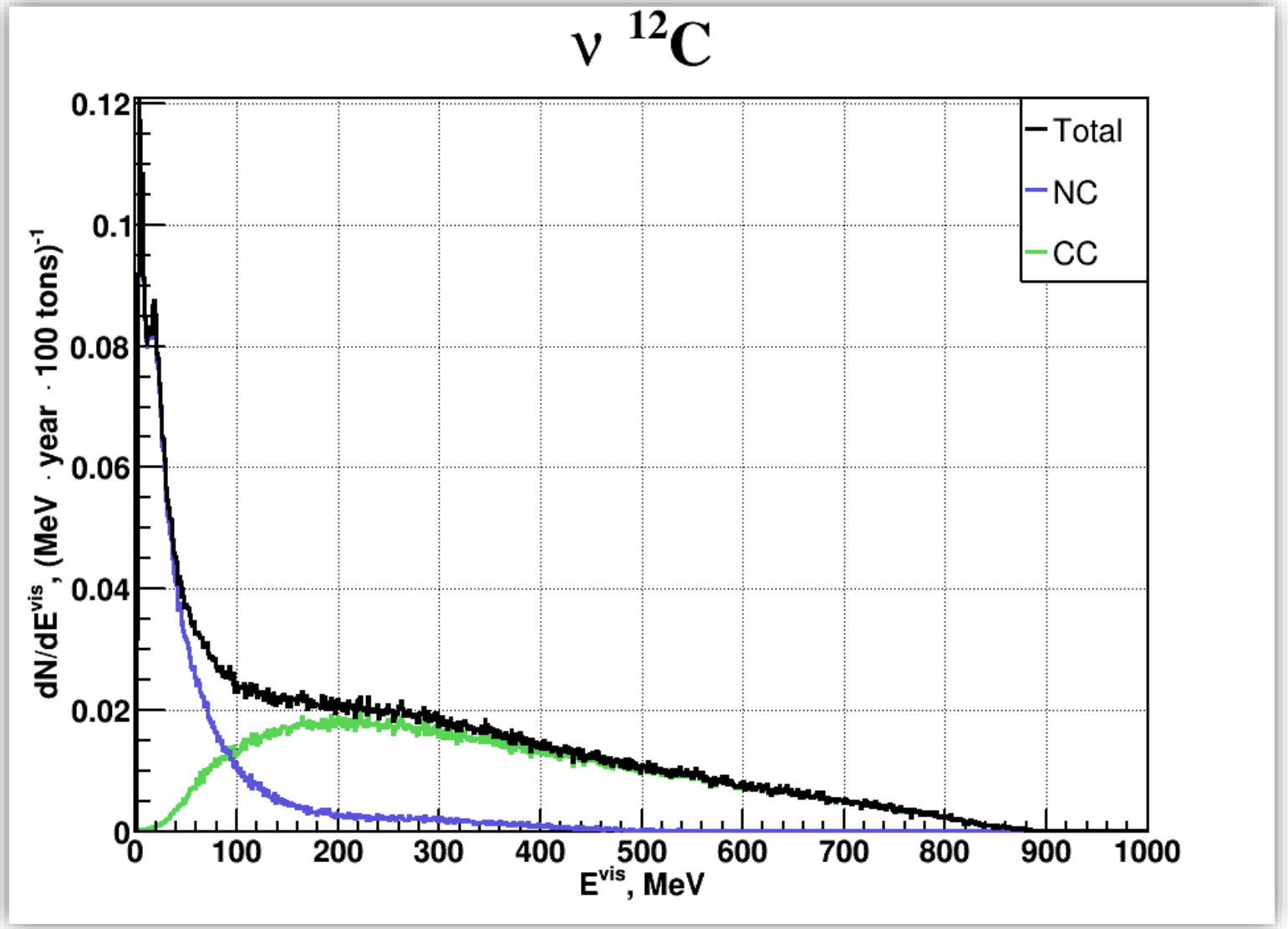
Borexino detector

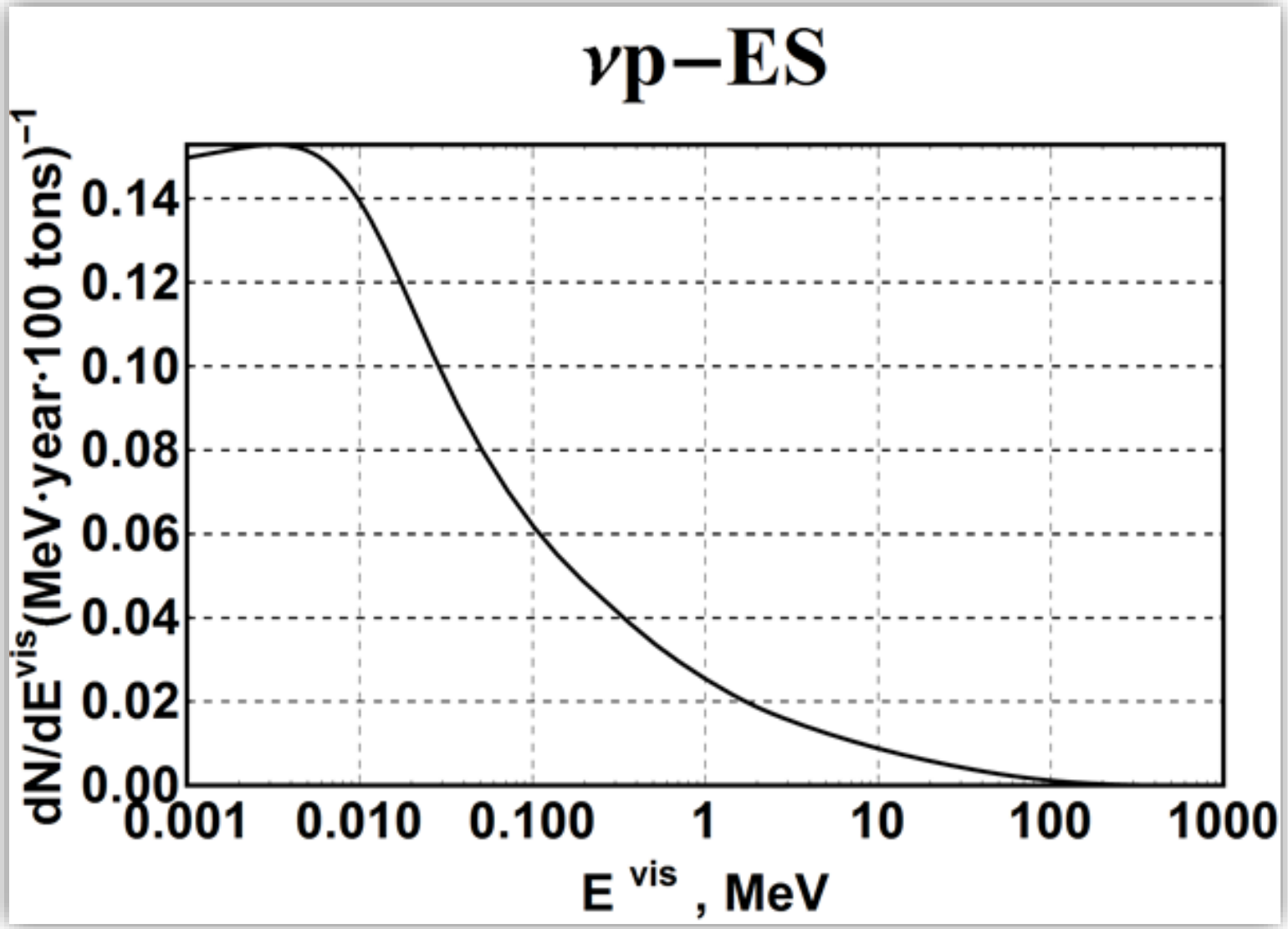


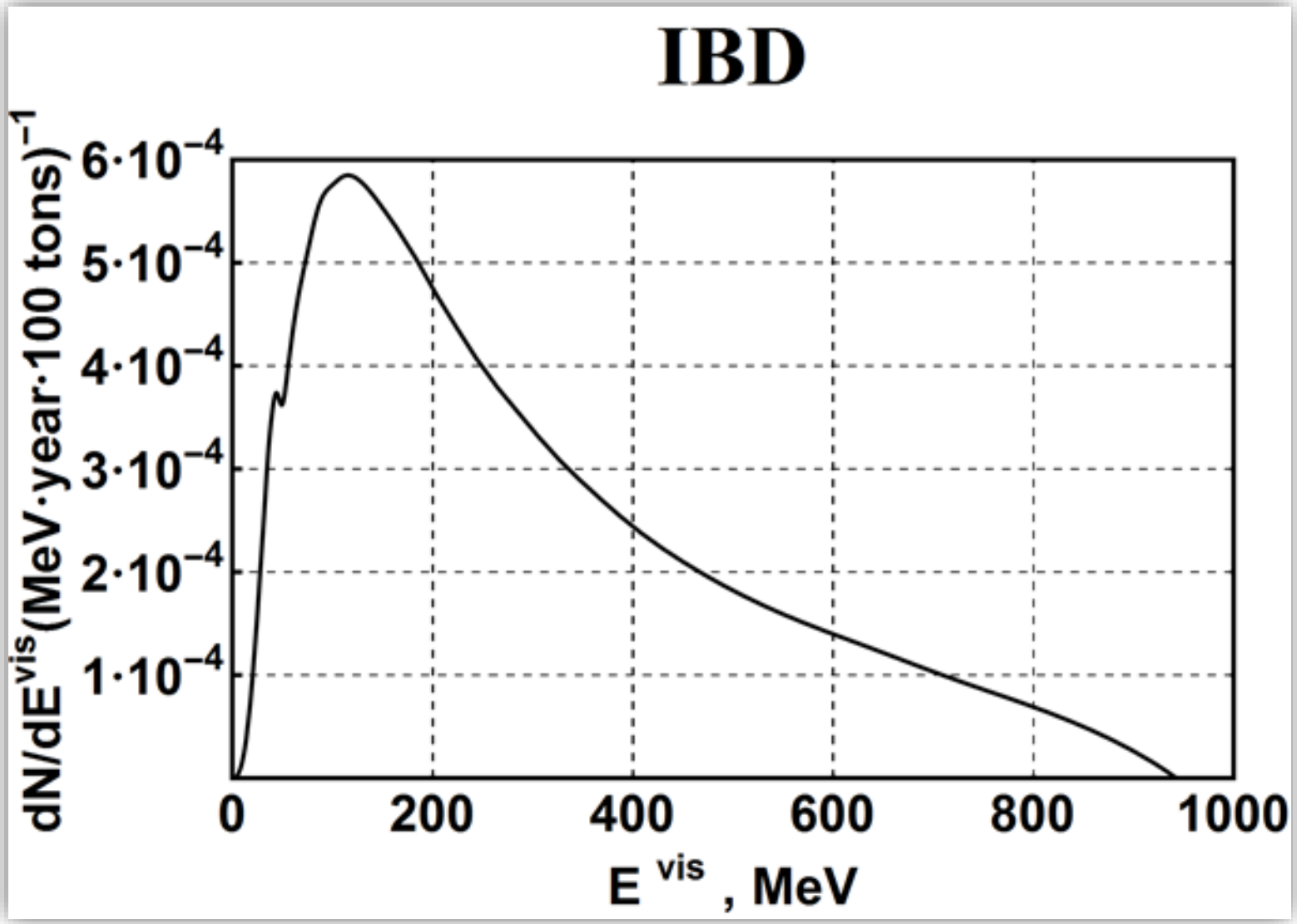


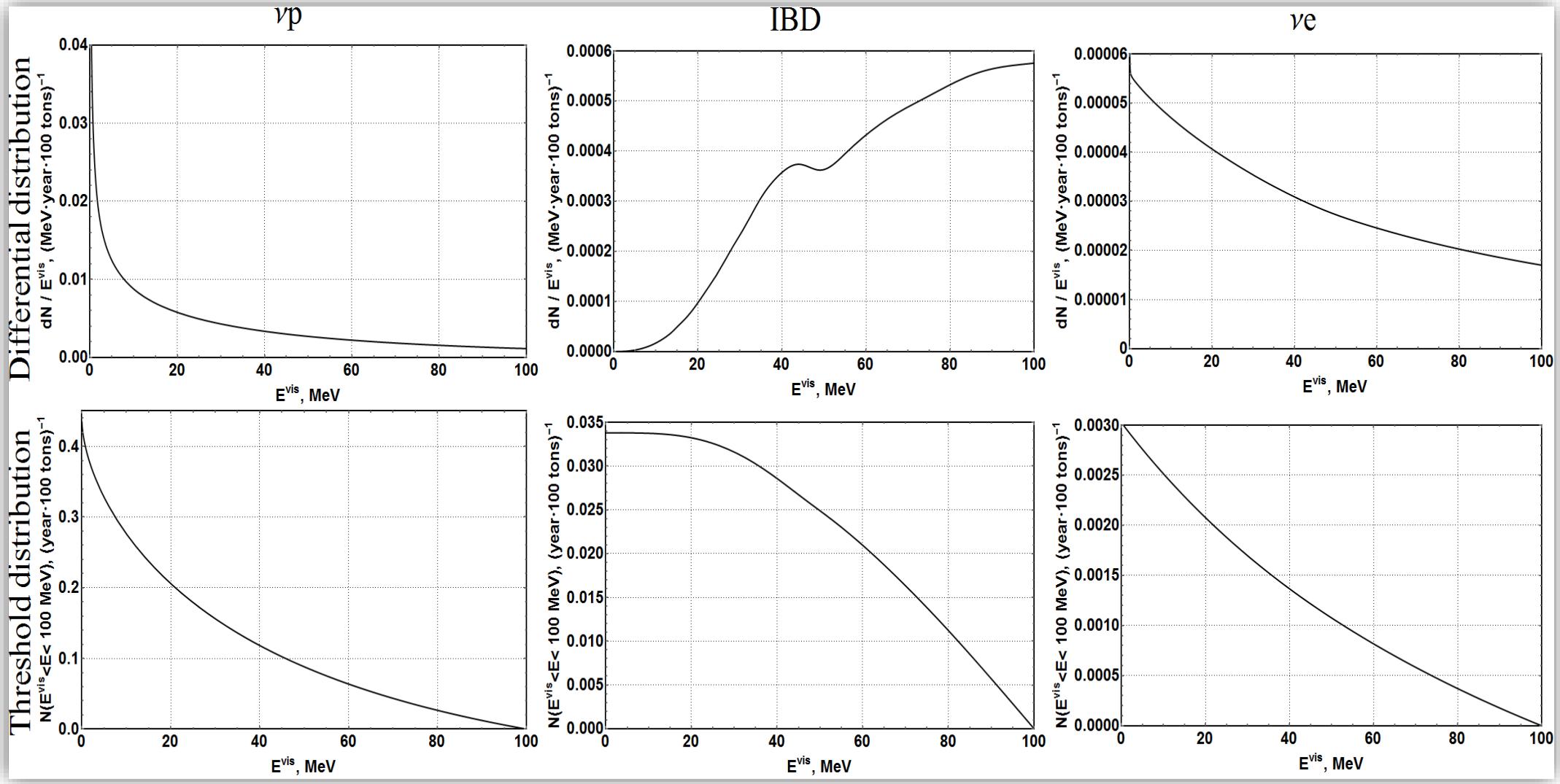

ν12C - NC
ν12C - NC
nu + C12 --> nu + neutron + C11
nu + C12 --> nu + proton + B11
nu + C12 --> nu + neutron + proton + B10
nu + C12 --> nu + 2.neutron + C10
nu + C12 --> nu + 2.proton + Be10
other
dN/dE^vis, (MeV · year · 100 tons)^-1
E^vis, MeV
0.12
0.1
0.08
0.06
0.04
0.02
0
10
20
30
40
50
60
70
80
90
100


ν ¹²C
Total
NC
CC
dN/dE^vis, (MeV · year · 100 tons)^-1
E^vis, MeV
10^-1
10^-2
10^-3
10^-4
0
100
200
300
400
500
600
700
800
900
1000


ν ¹²C
Total
NC
CC
dN/dE^vis, (MeV · year · 100 tons)^-1
E^vis, MeV
0
0.02
0.04
0.06
0.08
0.1
0.12
0
100
200
300
400
500
600
700
800
900
1000


νp−ES
dN/dE^vis (MeV·year·100 tons)^−1
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.001
0.010
0.100
1
10
100
1000
E^vis, MeV


IBD
dN/dE^vis(MeV·year·100 tons)^-1
6·10^-4
5·10^-4
4·10^-4
3·10^-4
2·10^-4
1·10^-4
0
200
400
600
800
1000
E^vis, MeV


νp
IBD
νe
Differential distribution
dN / E^vis, (MeV·year·100 tons)^-1
E^vis, MeV
Threshold distribution
N(E^vis<E< 100 MeV), (year·100 tons)^-1
E^vis, MeV