Development of the comprehensive analysis tools for the supernova neutrino detectors

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Motivation

By combining experiments one can:

- eliminate degeneracies between physics quantities, such as flux, mean energy and the energy shape parameter
- provide experiments with limited energy resolution, such as IceCube with spectral information so that rates can be translated into fluxes
- profit from experiments with low systematic and excellent energy resolution to improve on the normalisation uncertainties of other experiments,
- obtain access to information from all neutrino flavours, and profit in general from the combined statistics of various experiments

Motivation

- Include snowglobes to the global analysis ?
- Need to include all the channels into the snowglobes software in order to be able to simulate detectable signal on existing neutrino experiments around the world.

Channels of interaction

Channel	Observable(s)	Interactions	
$\nu_x + e^- \rightarrow \nu_x + e^-$	C	17/10	per kt
$\bar{\nu}_e + p \rightarrow e^+ + n$	C, N, A	278/165	per kt
$\nu_x + p \rightarrow \nu_x + p$	C	682/351	per kt
$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}^{(*)}$	C, N, G	3/9	
$\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}^{(*)}$	C, N, G, A	6/8	
$\nu_x + {}^{12}\mathrm{C} \rightarrow \nu_x + {}^{12}\mathrm{C}^*$	G	68/25	
$\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + {}^{16}\mathrm{F}^{(*)}$	C, N, G	1/4	
$\bar{\nu}_e + {}^{16}\mathrm{O} \rightarrow e^+ + {}^{16}\mathrm{N}^{(*)}$	C, N, G	7/5	
$\nu_x + {}^{16}\mathrm{O} \rightarrow \nu_x + {}^{16}\mathrm{O}^*$	G	50/12	
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	C, G	67/83	
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	C, A, G	5/4	
$\nu_e + {}^{208}\mathrm{Pb} \rightarrow e^- + {}^{208}\mathrm{Bi}^*$	N	144/228	
$\nu_x + {}^{208}\mathrm{Pb} \rightarrow \nu_x + {}^{208}\mathrm{Pb}^*$	N	150/55	
$\nu_x + A \rightarrow \nu_x + A$	C	9,408/4,974	

C, energy loss of a charged particle; N, produced neutrons; G, deexcitation γs; A, positron annihilation γs

Neutrino-proton scattering with JUNO

- Having this channel would be a unique tool for the liquid scintillators

- It is possible to reconstruct the energy spectrum of ν_x at a large scintillator detector, which is very important to establish the flavor conversions and the total energy of the SN neutrinos

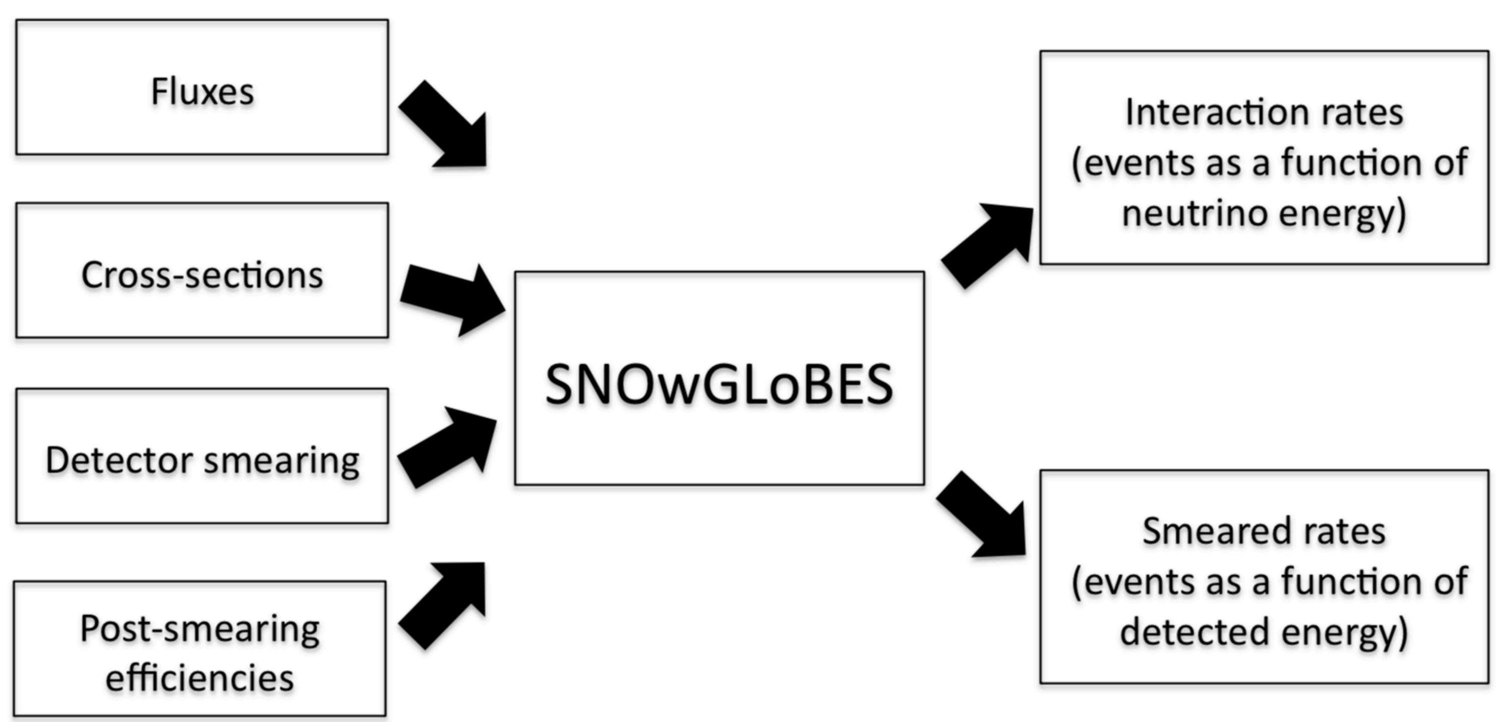
$$\nu + p \rightarrow \nu + p$$

- Although the total cross-section is about four times smaller than the one of the IBD, the contributions from all the neutrinos and antineutrinos of three flavours will compensate for the reduction of cross-section, especially if the average energy of the SN neutrinos is large.

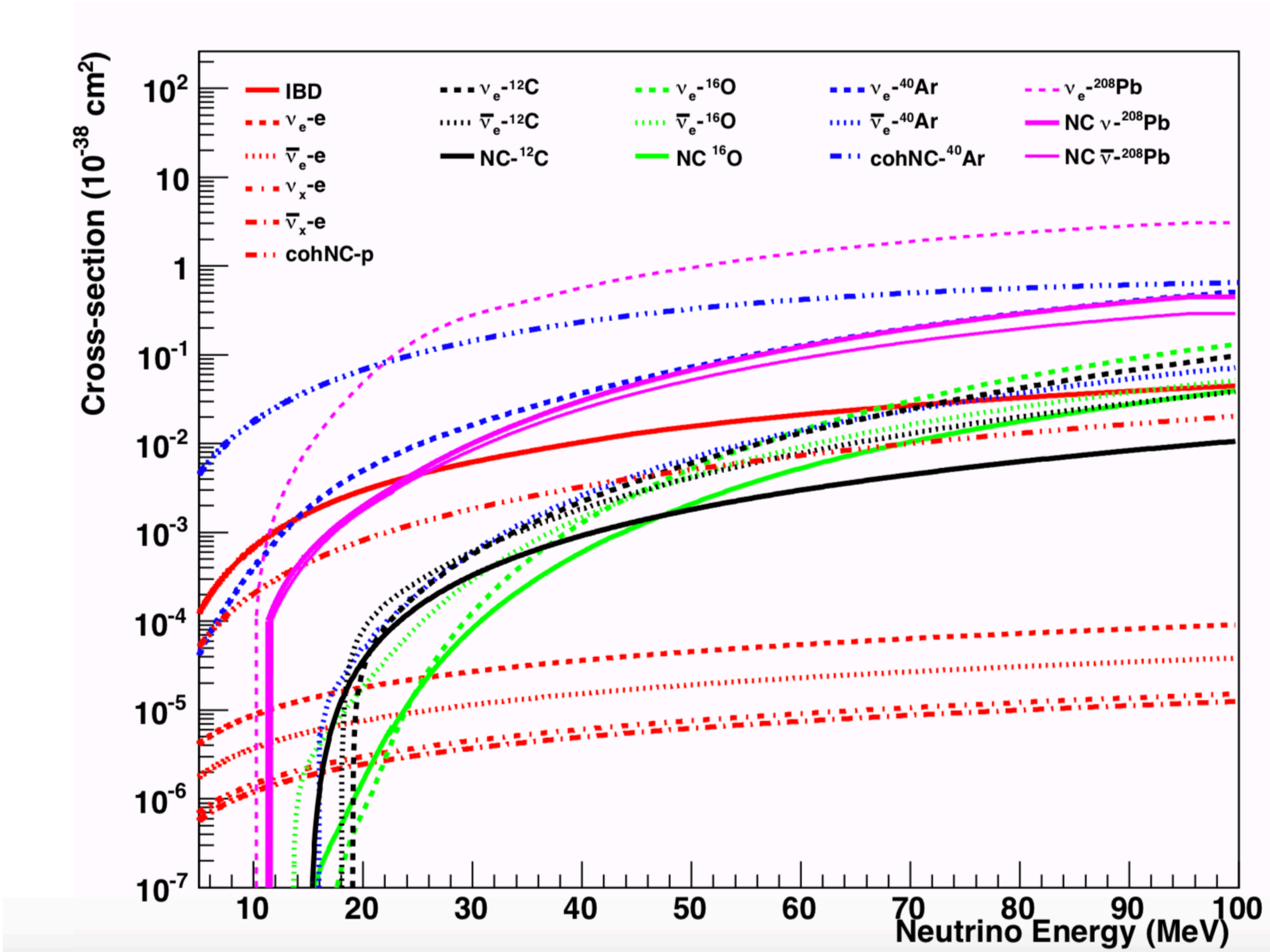
- Proton recoil energy is highly suppressed by the nucleon mass, so the precise determination of the proton quenching factor and low energy threshold are required to reconstruct neutrino energy and accumulate enough statistics.

Snowglobes

It is a public software for computing interaction rates and distributions of observed quantities for supernova burst neutrinos in common detector materials.



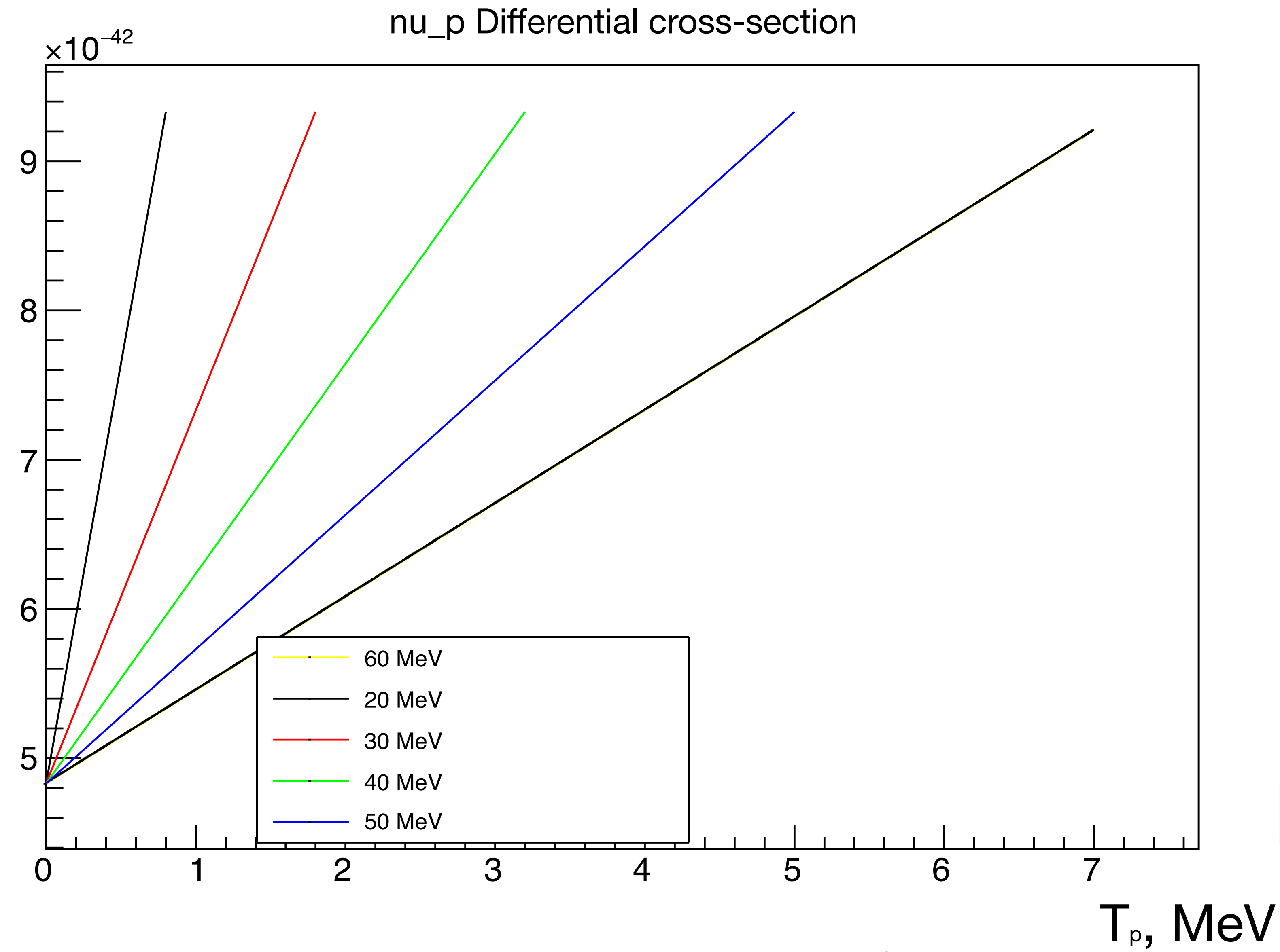
Cross sections



Neutrino-proton elastic scattering

https://arxiv.org/abs/hep-ph/0205220v1

$$\frac{d\sigma}{dT_p} = \frac{G_F^2 M_p}{2\pi E_\nu^2}\left[(c_V + c_A)^2 E_\nu^2 + (c_V - c_A)^2 (E_\nu - T_p)^2 - (c_V^2 - c_A^2) M_p T_p\right]$$



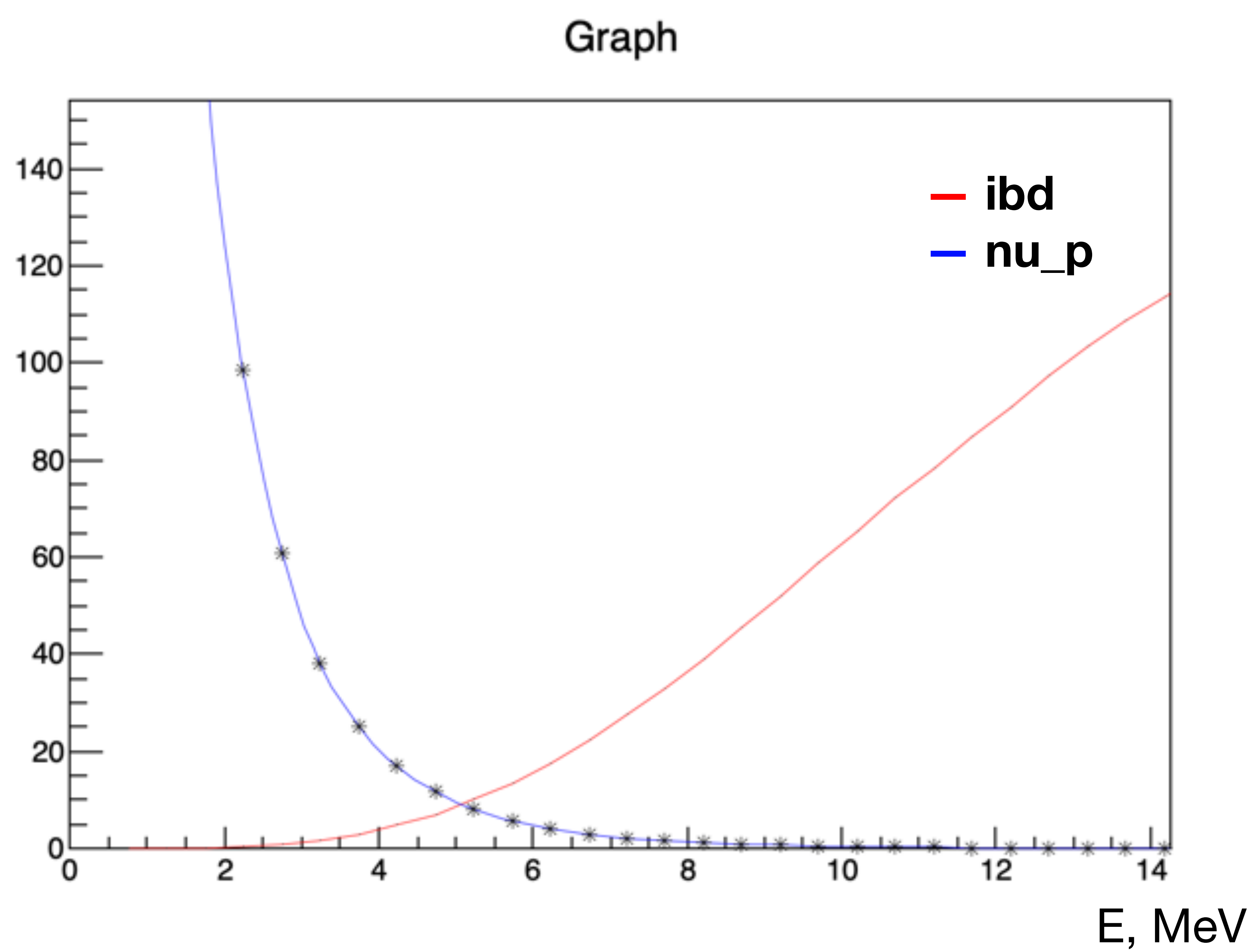
$$c_V = \frac{1 - 4\sin^2\theta_w}{2} = 0.04$$

$$c_A = \frac{1.27}{2}$$

$$\frac{G_F^2 E_\nu^2}{\pi}\left(c_V^2 + 3c_A^2\right)$$

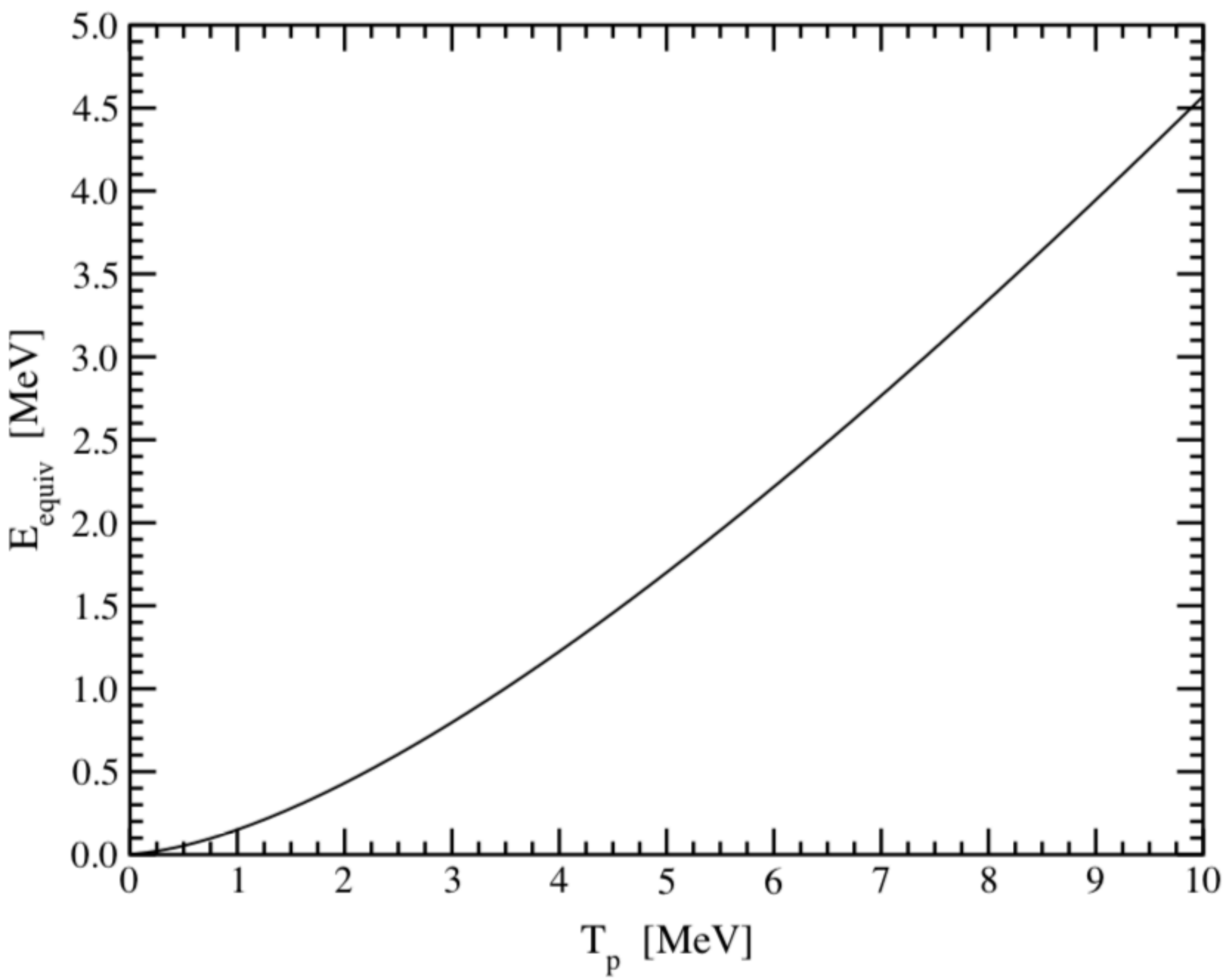
$$\frac{\sigma_{tot}(\nu_\mu + e^-)}{\sigma_{tot}(\nu_\mu + p)} \sim \frac{G_F^2 E_\nu m_e}{G_F^2 E_\nu^2} \sim \frac{m_e}{E_\nu}$$

Neutrino proton scattering with snowglobes for scint20kt case



Quenching

$$E_{equiv}(T_p) = \int_0^{Tp} \frac{dE}{1 + k_B(dE/dx)}$$

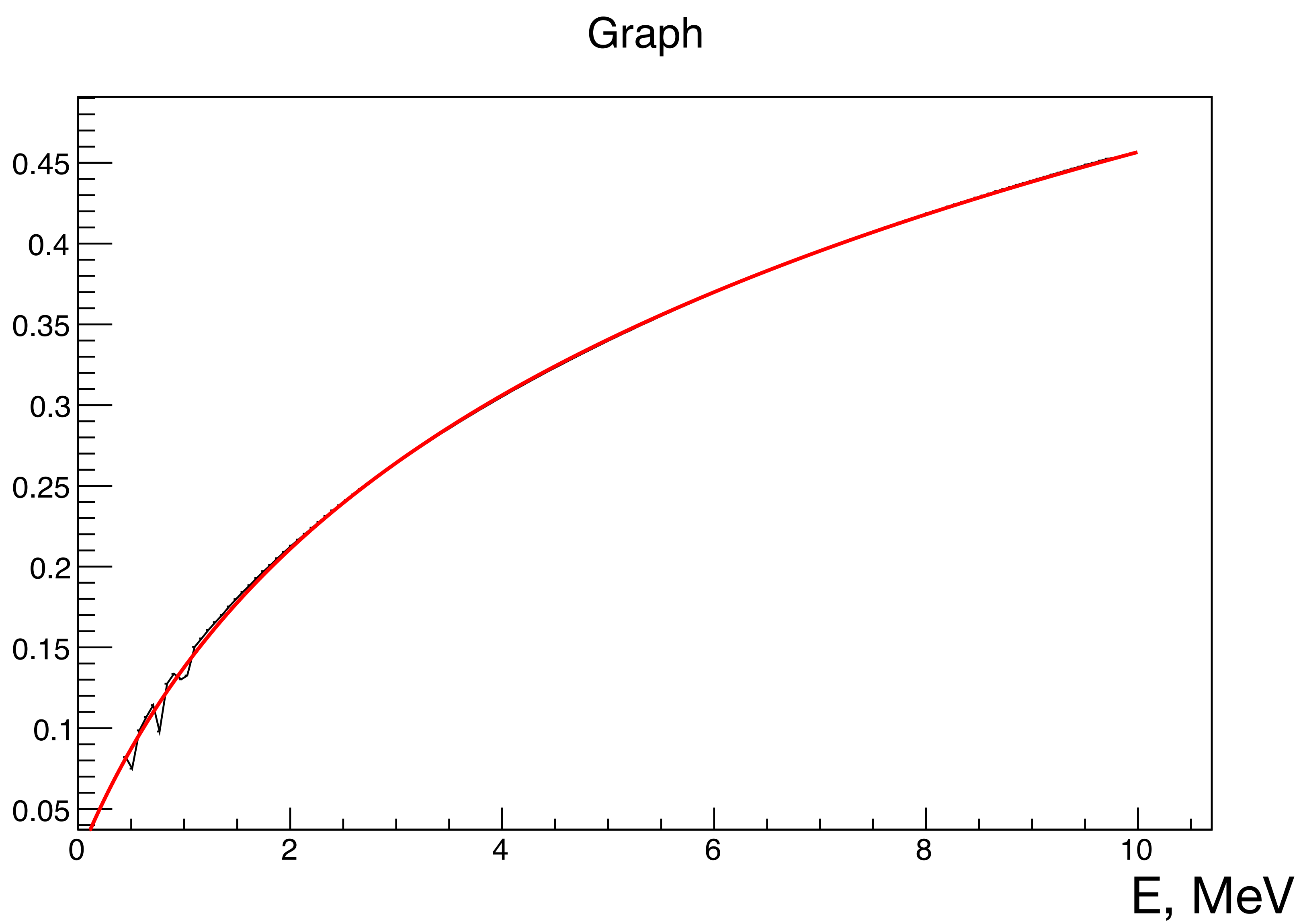


—> Ratio of E_{equiv} and T_p gives a quenching coefficient

Fit of the quenching coefficient gives parametrisation

Quenching coefficient

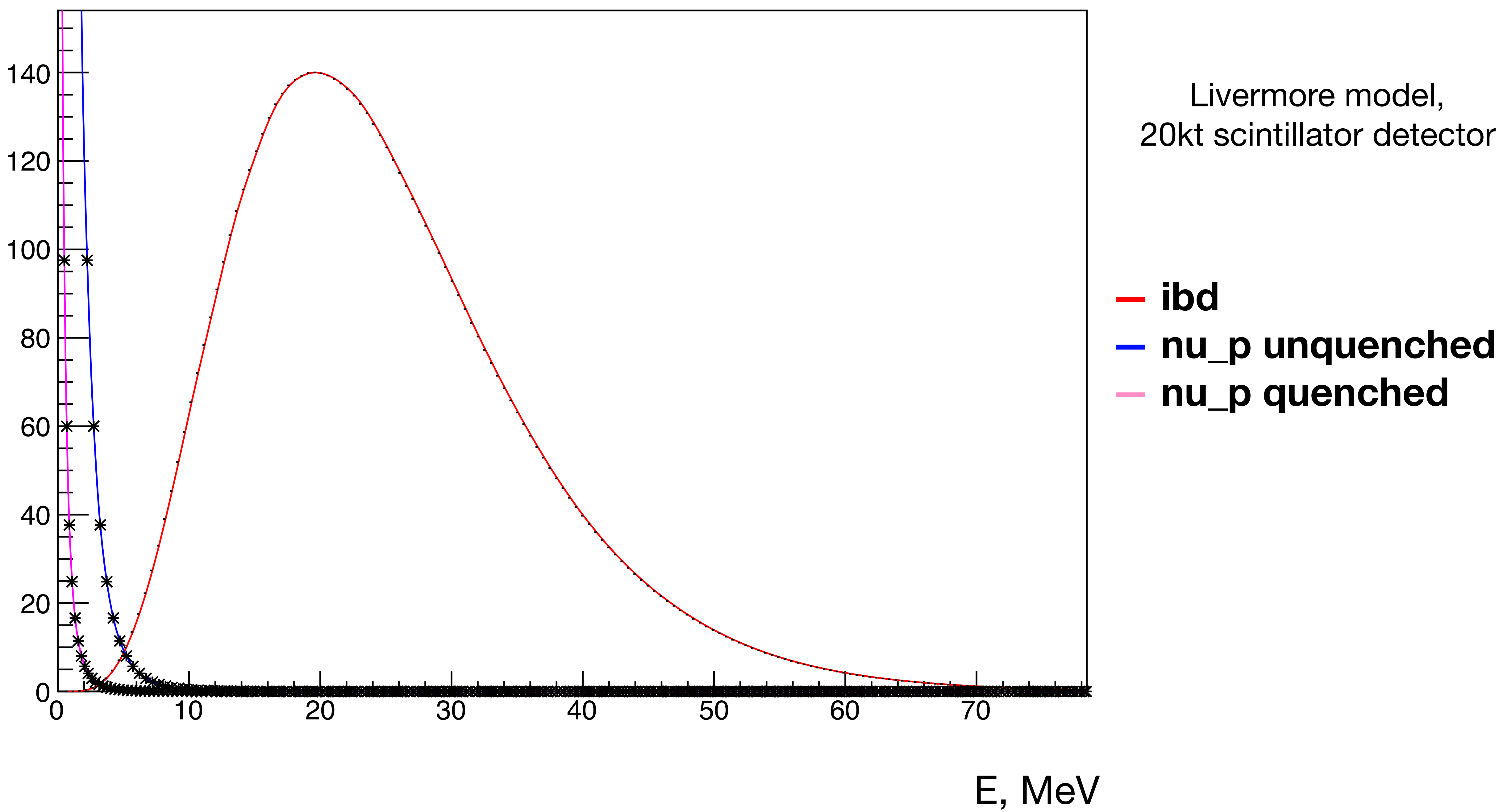
Fitting function: $$f(x) = A + B * ln[C * x + D]$$



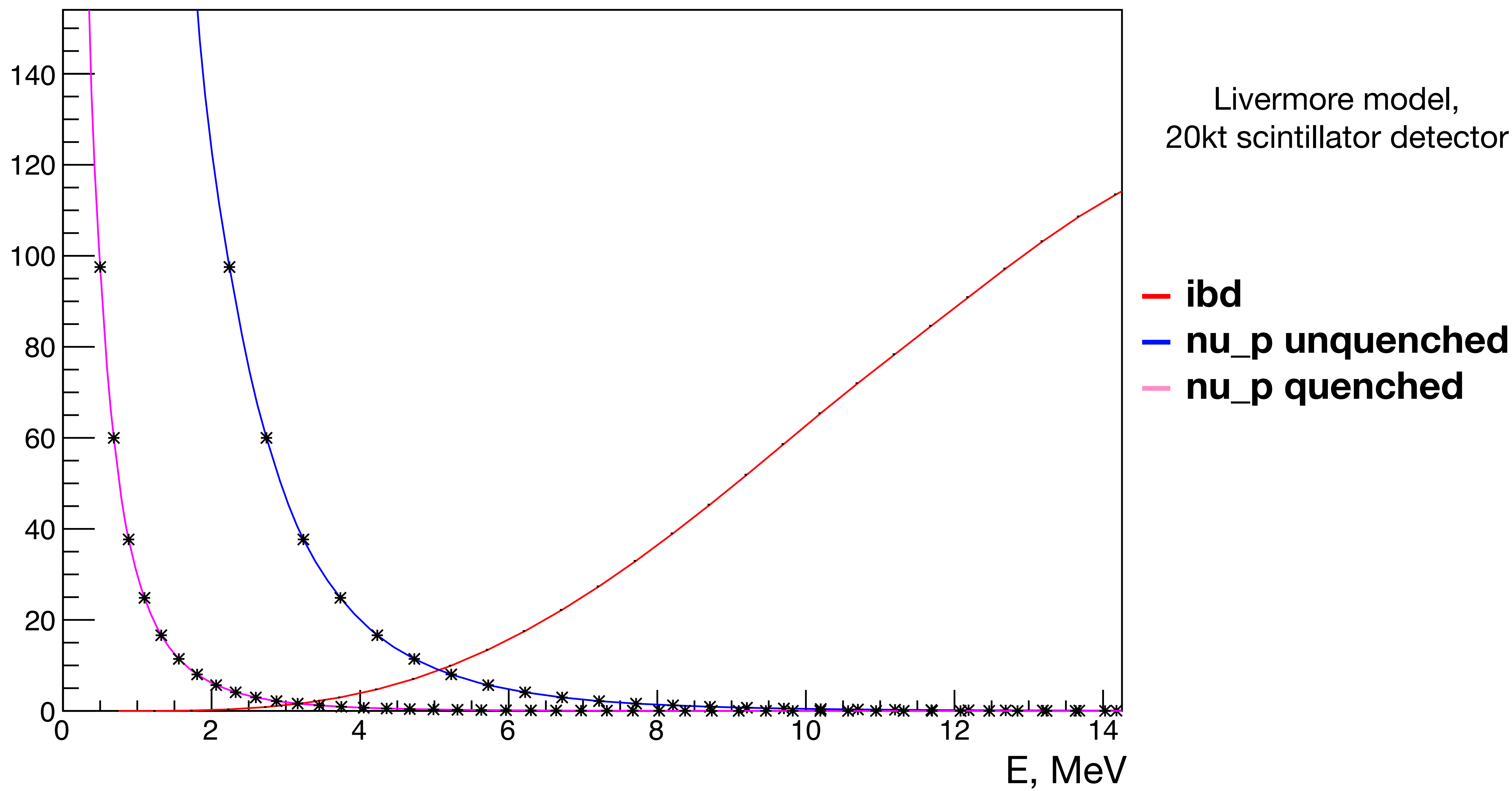
Fit result:

A = -0.347
B = 0.196
C = 5.315
D = 6.454

Neutrino-proton elastic scattering with snowglobes



Neutrino-proton elastic scattering with snowglobes



Summary

- Neutrino-proton elastic scattering works in snowglobes.

- Implement into the snowglobes software a quenching effect + missing channels in order to profit from unique qualities of every possible neutrino observatory available.

- Start global likelihood analysis ? combined results and simulations for different detectors like IceCube which can provide a time-dependent flux and JUNO(Borexino) that gives mostly energy information.

- Combined fit of the several detected channels to obtain flavor dependent neutrino spectra in JUNO (and then include other detectors)

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