Supernova-Neutrinos in LENA

Channel Discrimination

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

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Motivation

- Supernova at 10 kpc would produce about 10^4 events in LENA
- Astrophysics:
  - What are the conditions in collapsing cores of massive stars?
  - Observation of neutronization burst and shock wave
  - Spectroscopy allows implications on average neutrino energies
- Neutrino physics:
  - Determination of θ_{13} and neutrino mass hierarchy
  - Neutrino-antineutrino oscillations
  - Collective oscillations

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- Neutrino physics:
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  - Neutrino-antineutrino oscillations
  - Collective oscillations
- Important: Independent determination of flux and spectra of all ν-flavours
- LENA has multiple targets and reaction channels

Motivation

Detection channels in LENA

Channel Discrimination

Results and Outlook

Overview

Charged-Current (CC) channels

- $\bar{\nu}_e + \mathrm{p} \rightarrow \mathrm{n} + e^+$
- $\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}$
  - ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + \mathrm{e}^- + \bar{\nu}_e$
- $\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$
  - ${}^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + \mathrm{e}^+ + \nu_e$

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Neutral-Current (NC) channels

- $\nu + {}^{12}\mathrm{C} \rightarrow \nu + {}^{12}\mathrm{C}^*(\rightarrow {}^{12}\mathrm{C} + \gamma)$
- $\nu + \mathrm{e}^- \rightarrow \nu + \mathrm{e}^-$
- $\nu + \mathrm{p} \rightarrow \nu + \mathrm{p}$

Inverse Beta Decay (IBD)

$$\bar{\nu}_e + \mathrm{p} \rightarrow \mathrm{n} + e^+$$

- "Golden" detection channel
- Expected number of events is around $1.1 - 1.5 \times 10^4$
- Threshold of 1.8 MeV
- Coincidence by the neutron capturing:
  - $\mathrm{n} + \mathrm{p} \rightarrow \mathrm{d} + \gamma\,(2.2\,\mathrm{MeV})$
  - Neutron is captured after average time of 0.25 ms

This channel provides high-statistics spectral information of $\bar{\nu}_e$

CC-^{12}C channels

$$\bar{\nu}_e + {}^{12}\mathrm{C} \rightarrow e^+ + {}^{12}\mathrm{B}$$

- Expected number of events is around $1.8 - 4.2 \times 10^2$
- Threshold: 14.4 MeV
- Coincidence by decay of ^{12}B:
  - ${}^{12}\mathrm{B} \rightarrow {}^{12}\mathrm{C} + \mathrm{e}^- + \bar{\nu}_e$
  - Half-life of 20.20 ms
  - Q-Value of 13.4 MeV

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$$\nu_e + {}^{12}\mathrm{C} \rightarrow e^- + {}^{12}\mathrm{N}$$

- Expected number of events is around $1.9 - 5.2 \times 10^2$
- Threshold: 17.3 MeV
- Coincidence by decay of ^{12}N:
  - $^{12}\mathrm{N} \rightarrow {}^{12}\mathrm{C} + \mathrm{e}^+ + \nu_e$
  - Half-life of 11.00 ms
  - Q-Value of 16.3 MeV

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Disentanglement of channels provides spectral information of ν_e

NC Channels

$$\nu + e^- \rightarrow \nu + e^-$$

- Expected number of events is around 0.6×10^3
- No threshold, but energy cut because of ^{14}C background: >0.2 MeV

This channel is dominated by ν_e-signal

$$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*(\rightarrow {}^{12}C + \gamma)$$

- Expected number of events is around $0.6 - 1.5 \times 10^3$
- Excited state of carbon has an energy of 15.1 MeV
  - Threshold: >15.1 MeV

This channel provides information on total flux of all flavours

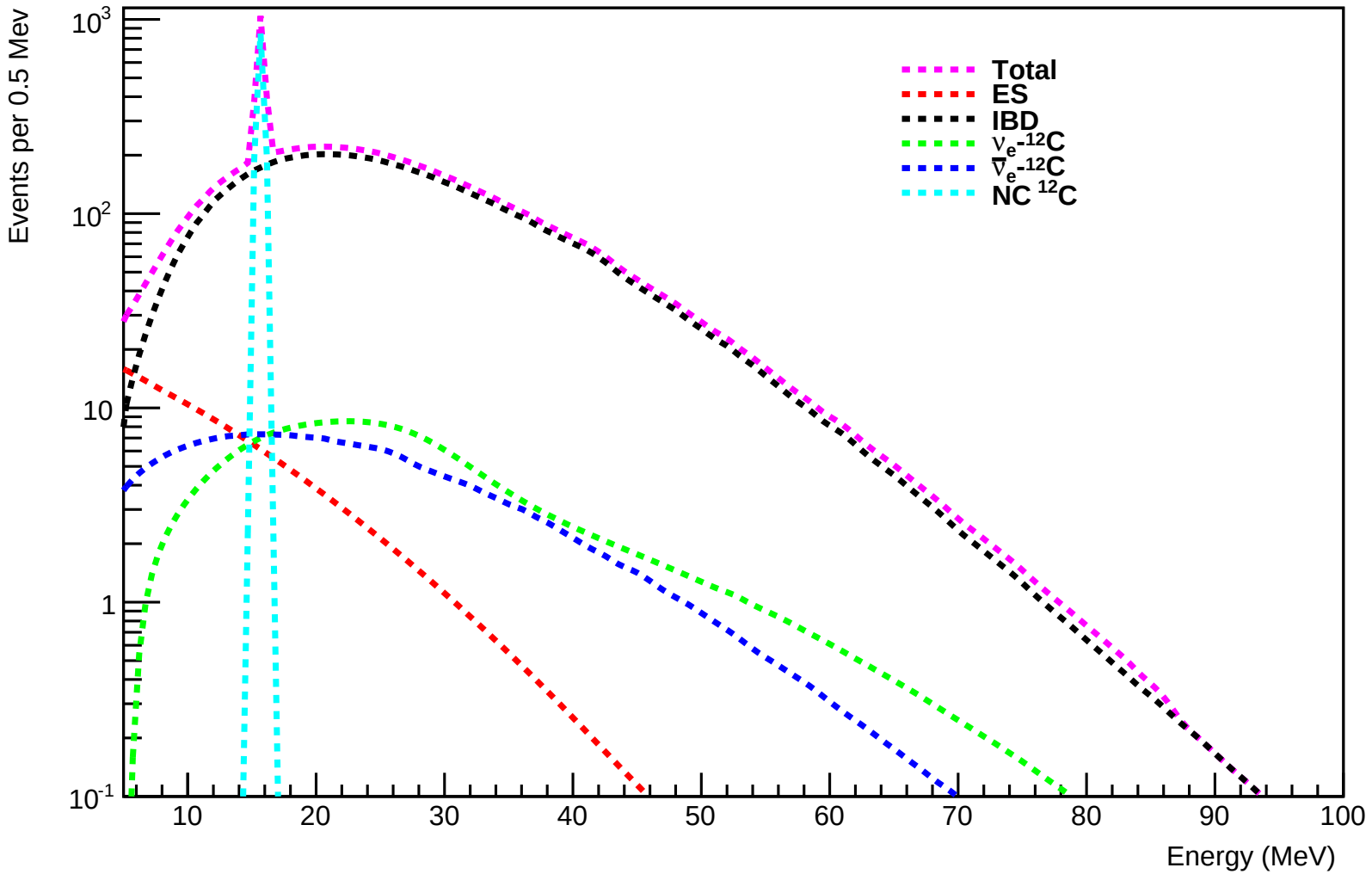
NC Channels II

$$\nu + \mathrm{p} \rightarrow \nu + \mathrm{p}$$

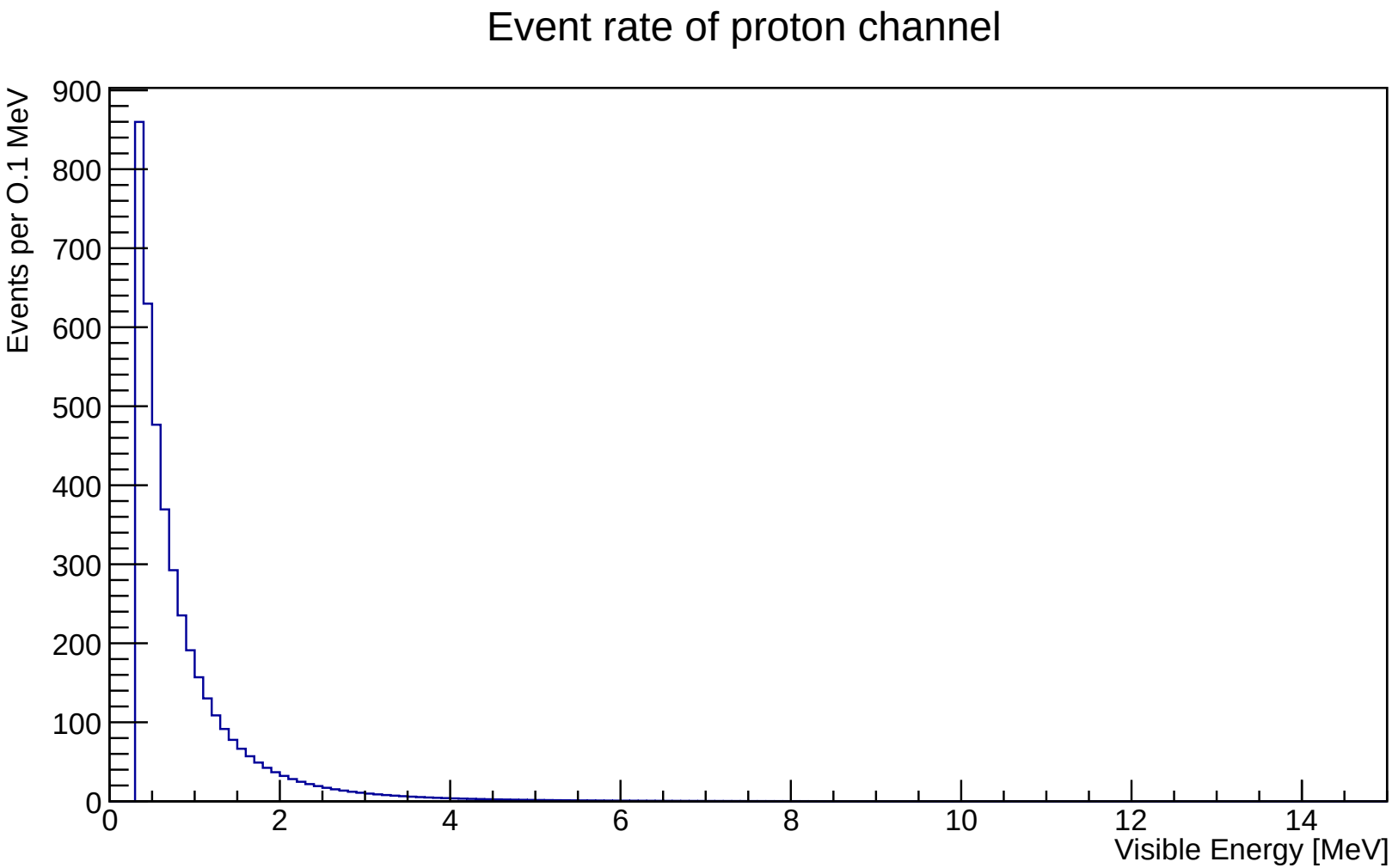
- Expected number of events is around $1.3\text{-}4.4 \times 10^3$
- Low recoil energies (visible in liquid scintillator)
- No threshold, but energy cut because of ^{14}C background: $>0.2\,\mathrm{MeV}$
  - Corresponding to $\sim$25 MeV in neutrino energy

This channel provides information on flux of ν_μ and ν_τ

Event spectra as function of visible energy



Proton channel



Approach

1. Find IBD coincidences
2. Find CC-^{12}C coincidences
3. Distinguish the CC-^{12}C channels by fitting the beta spectra
4. Distinguish the NC spectra with energy cuts

Finding the coincidence events

IBD coincidence cut values

- Position cut: 600 mm
- Time cut: 3 ms
- Energy: 1.7 - 2.7 MeV

CC-^{12}C coincidence cut values

- Position cut: 450 mm
- Time cut: 150 ms
- Energy: $<$20 MeV

Finding the coincidence events

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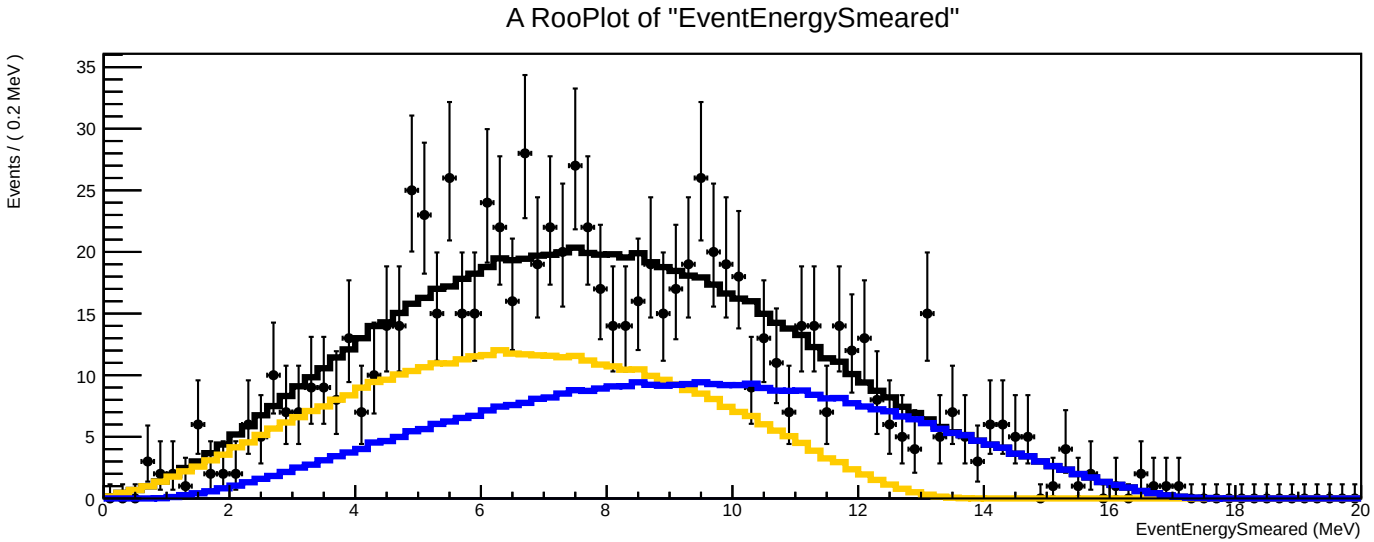
NC energy cut values

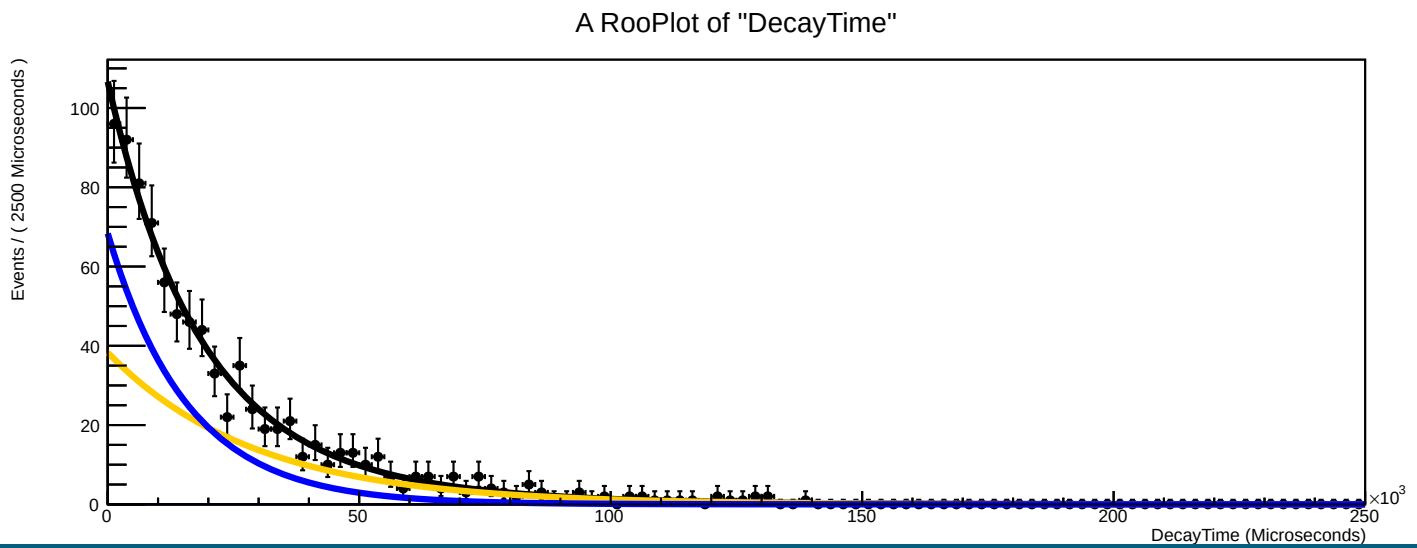
- ν – ^{12}C scattering: 14.0 - 16.0 MeV
- ν – e^- scattering: 3.5 - 14.0 MeV and $>$16 MeV
- ν – p scattering: 0 - 3.5 MeV

Distinguish of the CC-^{12}C channels

- Figure out how many events are associated with each spectrum
- Challenge: Distinguish two beta spectra with similar decay properties:
  - Half-life: 20.20 ms and 11 ms
  - Q-Value: 13.4 MeV and 16.4 MeV
- Approach: Simultaneous fitting energy and decay time spectra (RooFit)
- Input: Shape of the beta spectra and half-life

Plot of simultaneous Fit with RooFit





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Results

Over efficiency: false identified events / correct identified events
Cut efficiency: correct identified events / true number of events

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Channel	**Over efficiency**	**Cut efficiency**
IBD	0.1%<	99,9%>
CC-^{12}C	1%	99%
NC total	1%	99%
NC ^{12}C-ν	2%	99%>
NC p–ν	3%	98%
NC e-ν	$\sim$ 25%	$\sim$ 67%

Results

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Cut efficiency: correct identified events / true number of events

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- Distinction between CC-^{12}C channels: Error of about 7%

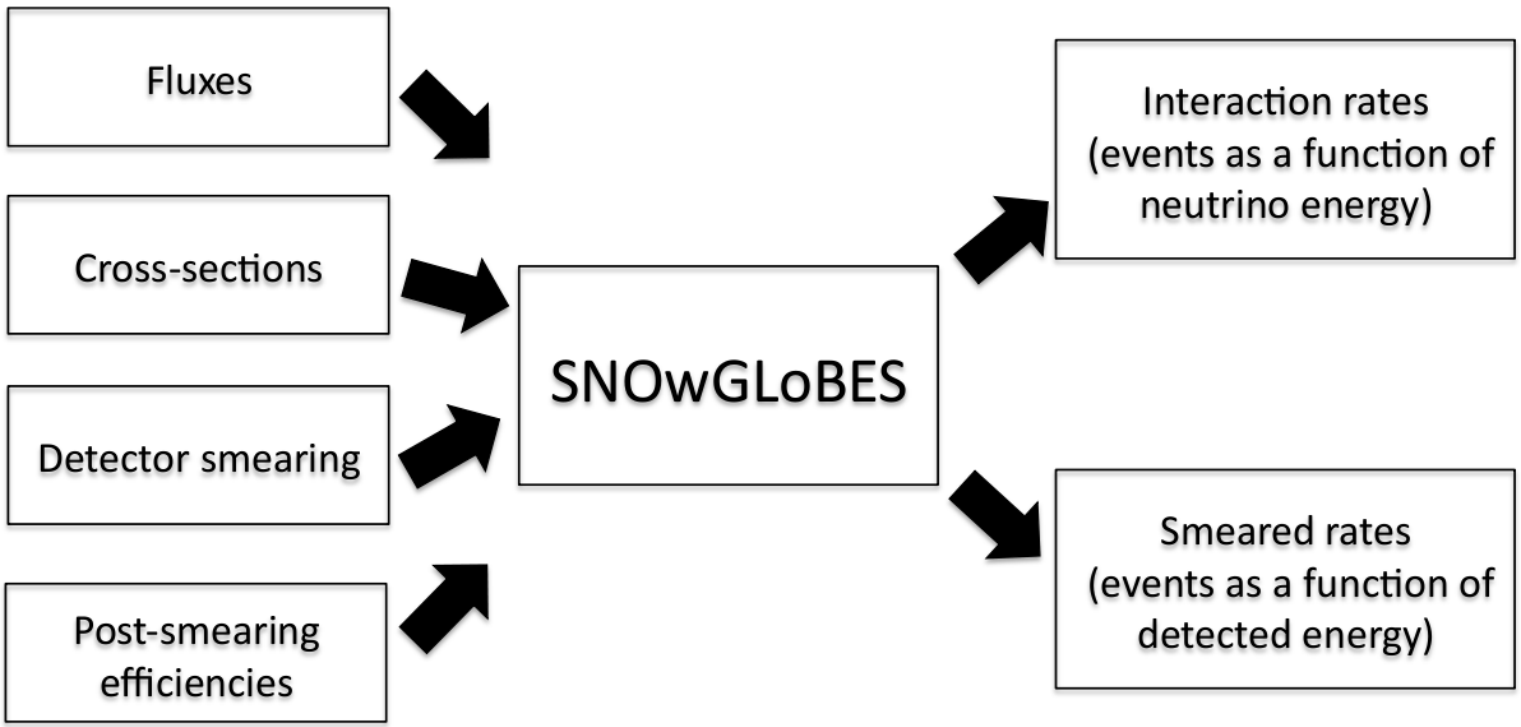
Outlook

- Move to full GEANT4 Monte-Carlo
- Use PMT pulse shape for NC channel distinction
- Move to time-varying neutrino spectra
- Study ^{14}C background to ν-p scattering
- Physics output: What can be learned

Thank you for your attention

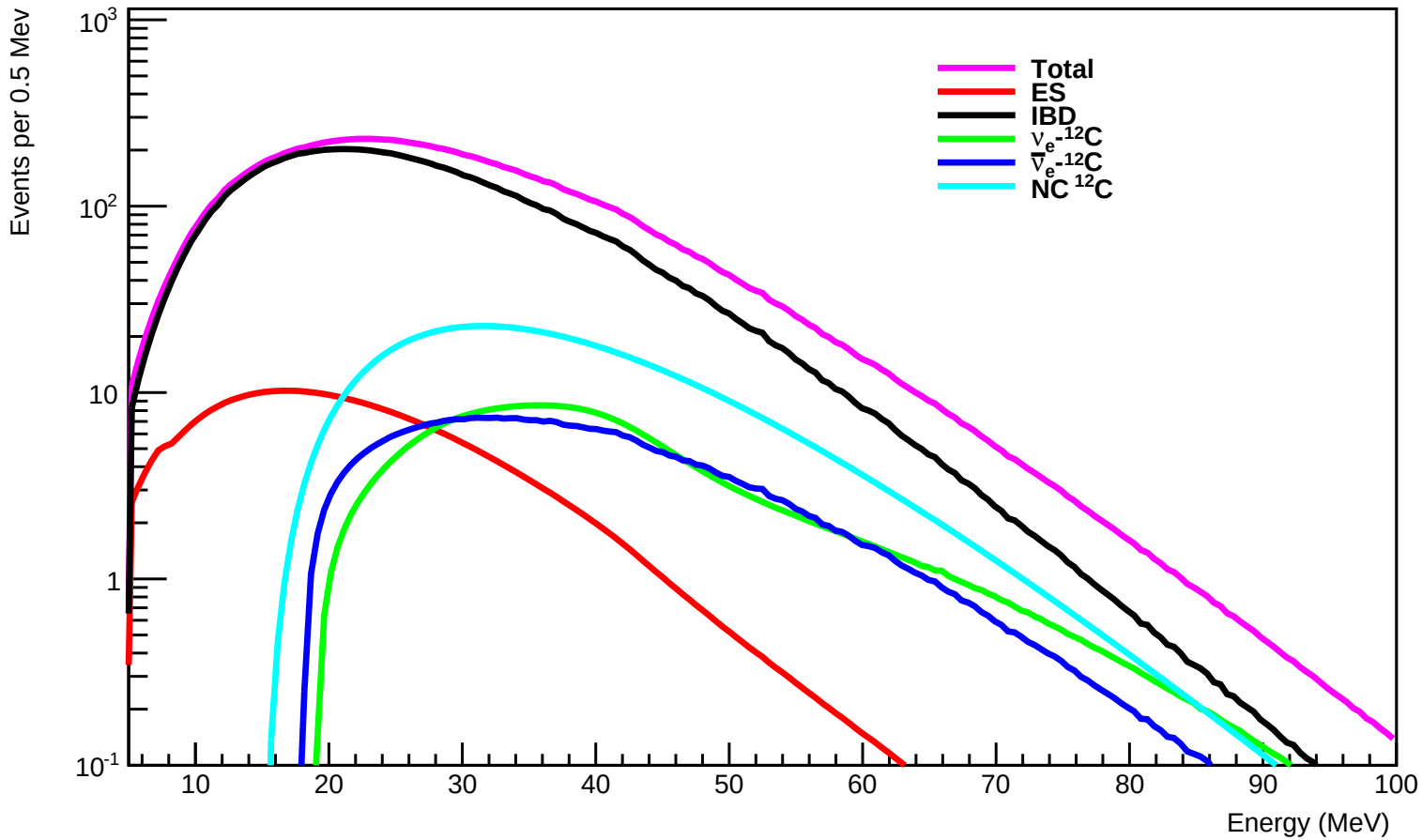
SNOwGLoBES: SuperNova Observatories with GLoBES

Dataflow in SNOwGLoBES

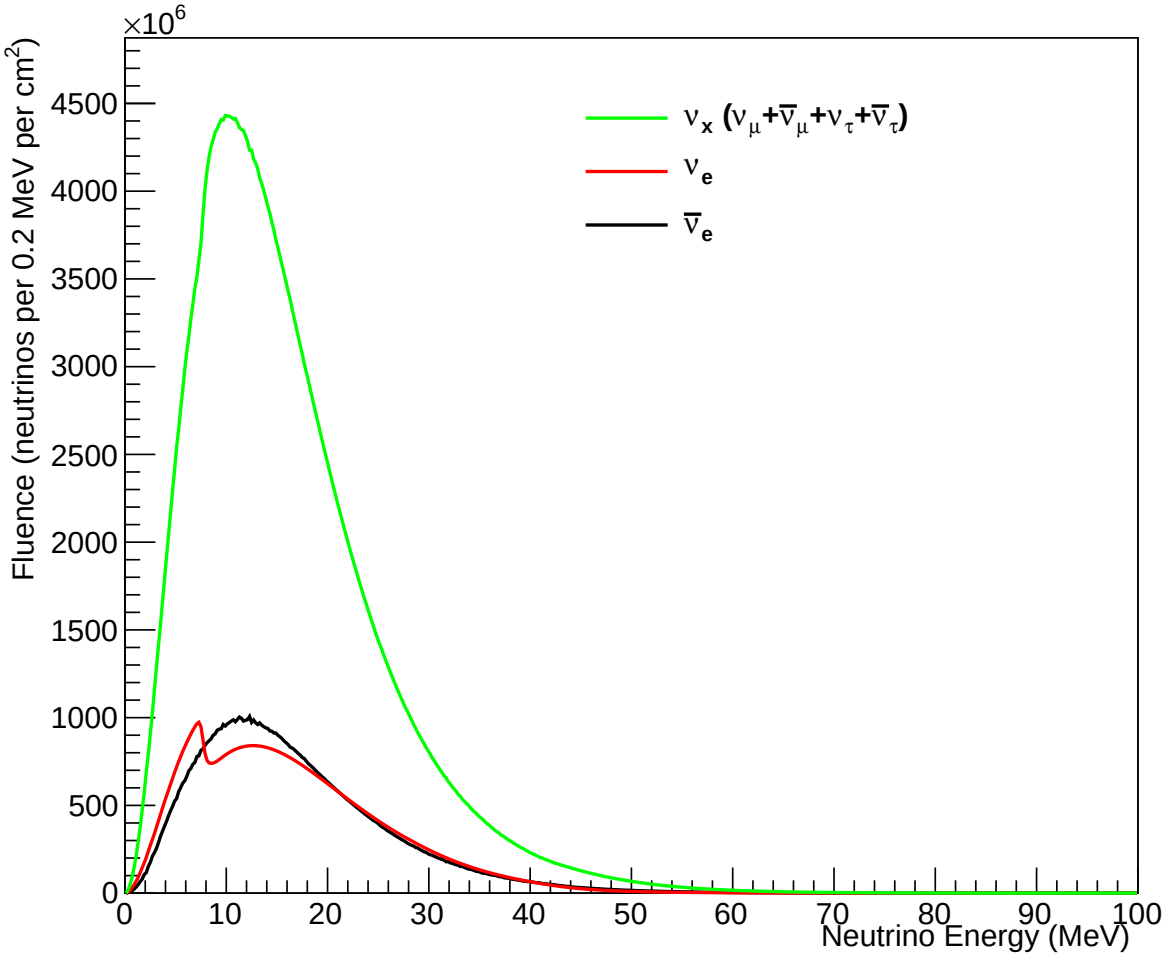


Source: SNOwGLoBES Manual

Event rates as function of neutrino energy



GVKM fluence



Cross sections