Supernova Neutrinos in LENA

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

Outline

- Introduction
- Supernova Neutrinos in LENA
- Channel Discrimination
- What can be learned?
- Outlook

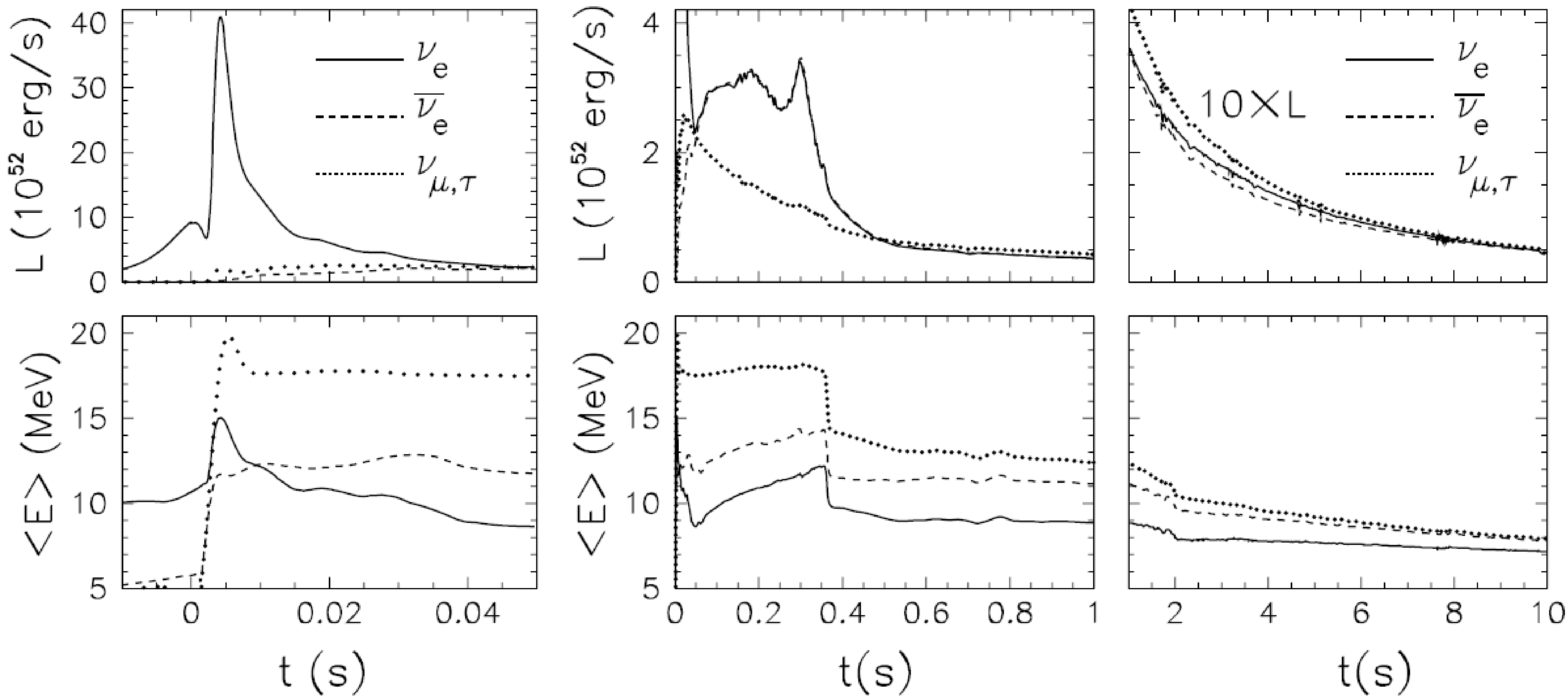
Core-collapse Supernova (SN)

- 1-3 SNe per century in our galaxy
- Neutrinos carry away: $3 \cdot 10^{53}$ erg ($3 \cdot 10^{59}$ MeV)
- Quasi-thermal neutrino spectra
- Timescale of burst: 10 s
- Remnant forms NS ($<25\ M_{sun}$) or BH ($>25\ M_{sun}$)

Expected SN Luminosities

Fischer et al., arXiv:0908.1871: 'Basel' model

Prompt ν_e burst | **Accretion phase** | **Cooling phase**



Open Questions

- Detailed SN explosion mechanism?
- Conditions of collapsing star?
- Cooling of proto neutron star?
- Formation of neutron stars and black holes?
- Nucleosynthesis products?

Supernova Neutrinos in LENA

SN Detection Channels in LENA

Channel	Type	Reaction	Subsequent Reaction	E_{thr} [MeV]
IBD	CC	$\bar{\nu}_e + p \rightarrow n + e^+$	$n + p \rightarrow d + \gamma$	1.8
$\bar{\nu}_e$ - ^{12}C	CC	$\bar{\nu}_e + {}^{12}C \rightarrow e^+ + {}^{12}B$	$^{12}B \rightarrow {}^{12}C + e^- + \bar{\nu}_e$	14.4
ν_e - ^{12}C	CC	$\nu_e + {}^{12}C \rightarrow e^- + {}^{12}N$	$^{12}N \rightarrow {}^{12}C + e^+ + \nu_e$	17.3

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NC - ^{12}C	NC	$\nu + {}^{12}C \rightarrow \nu + {}^{12}C^*$	$^{12}C^* \rightarrow {}^{12}C + \gamma$	15.1
ν - e	NC	$\nu + e^- \rightarrow \nu + e^-$	-	~0.2
ν - p	NC	$\nu + p \rightarrow \nu + p$	-	~0.2

General Approach

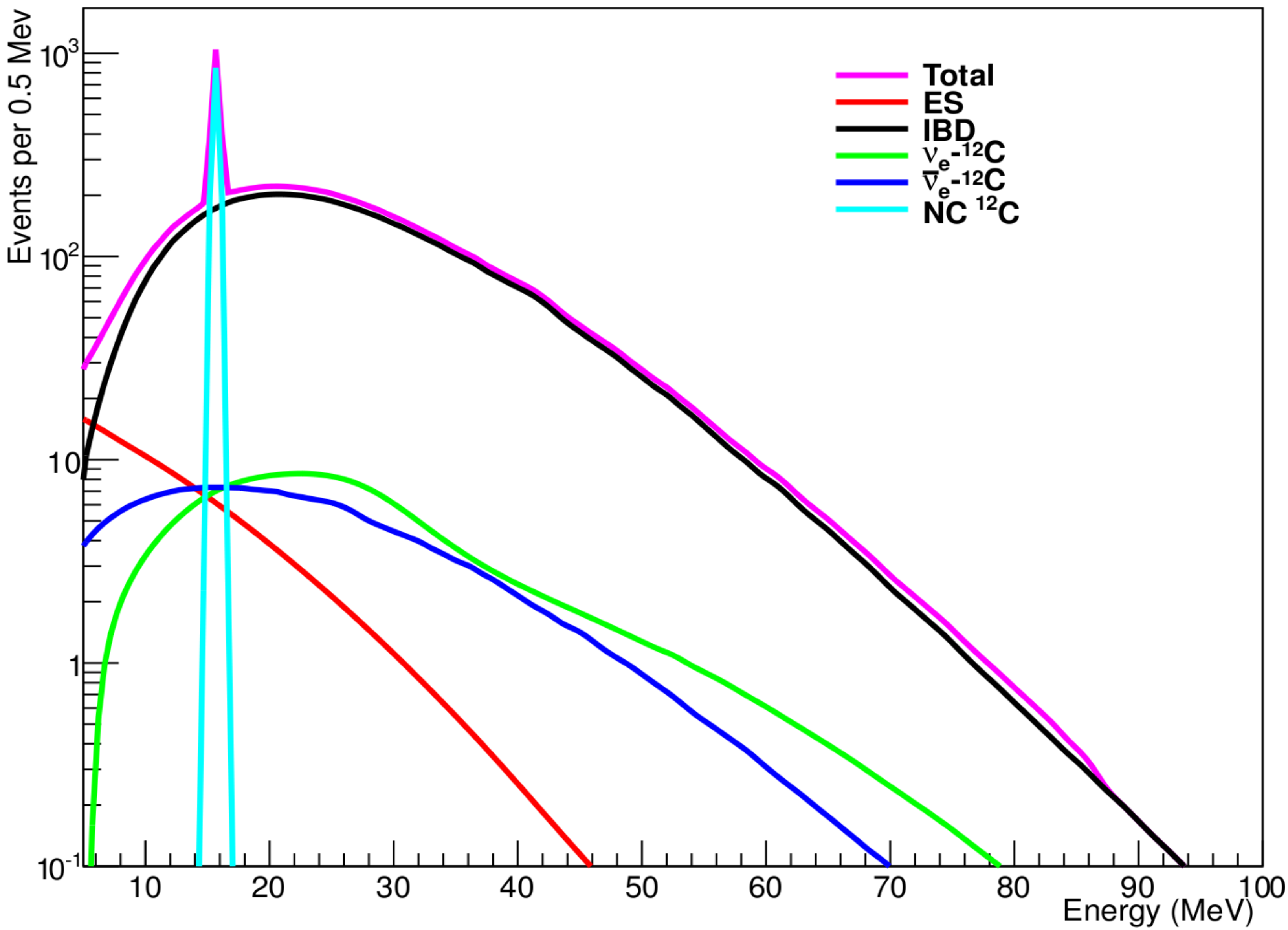
- Calculate energy spectra
  - Input: Fluxes, cross-sections, detector smearing
  - 50 kT of LAB
  - Distance of 10 kpc
- Create a Monte-Carlo data set for SN-Signal
  - Use calculated event spectra
  - Create position (resolution: σ_{xy}= 83 mm, σ_z=100mm)
  - Create detection time (uniform / time dependent)
  - Create coincidence events
- Develop / optimize channel discrimination strategy

Number of Events

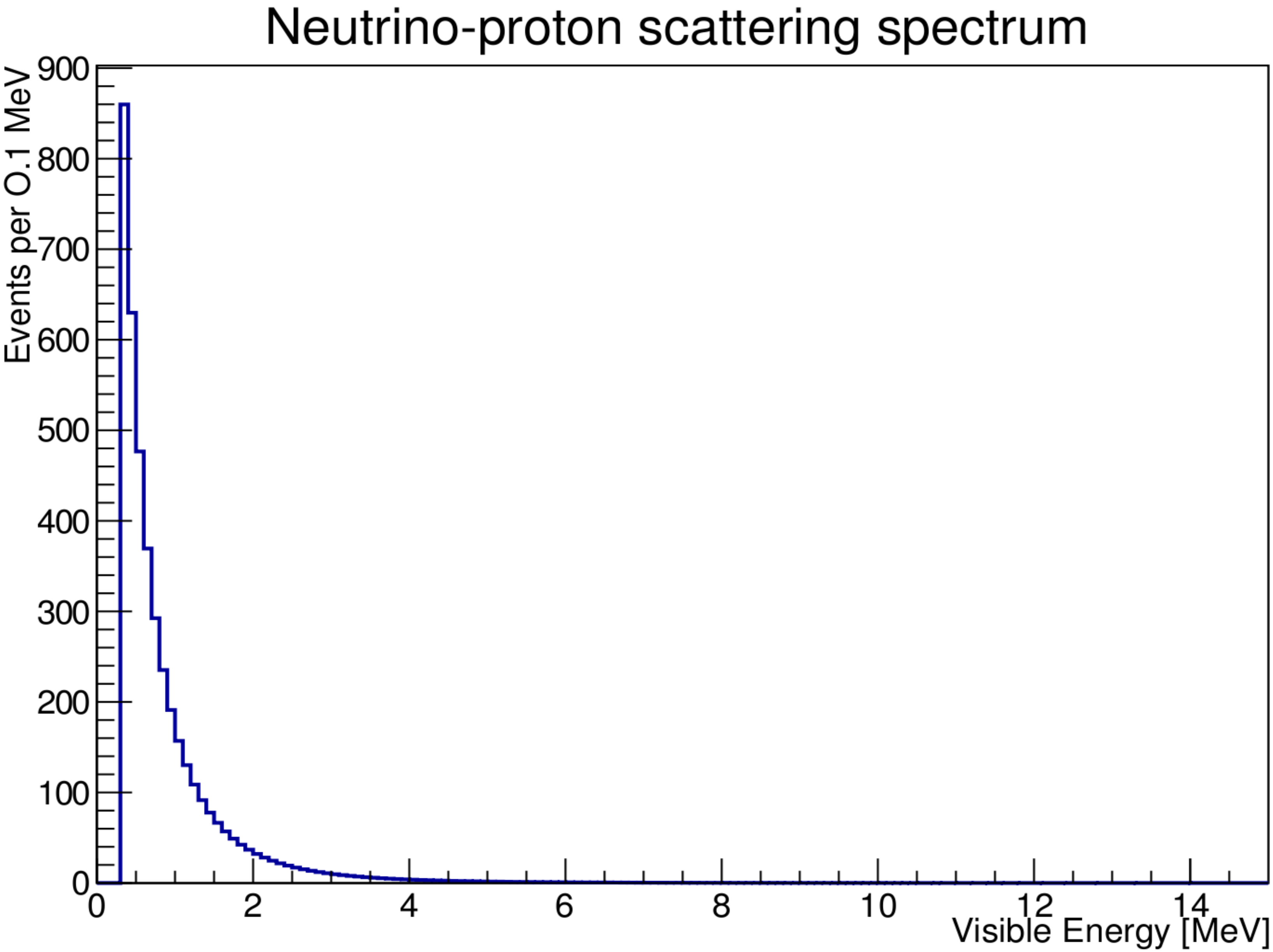
- 50 kT of LAB, 10 kpc, GVKM flux

Channel	Type	Number of Events
IBD	CC	9250
ν-p	NC	4179
NC-^{12}C	NC	1296
ν-e	NC	496
ν_e-^{12}C	CC	468
$\bar{\nu}_e$-^{12}C	CC	459
Total number of events:		**16148**

Smeared Rates as function of visible energy



Proton Channel



Channel Discrimination

Strategy

1. Find IBD coincidences
2. Find CC-C12 coincidences

   2.1 Distinguish the CC-C12 channels by fitting the beta spectra
3. Distinguish the NC spectra with energy cuts

   3.1 Include pulseshape information

Finding the coincidence events

IBD coincidence cuts (Neutron capture)

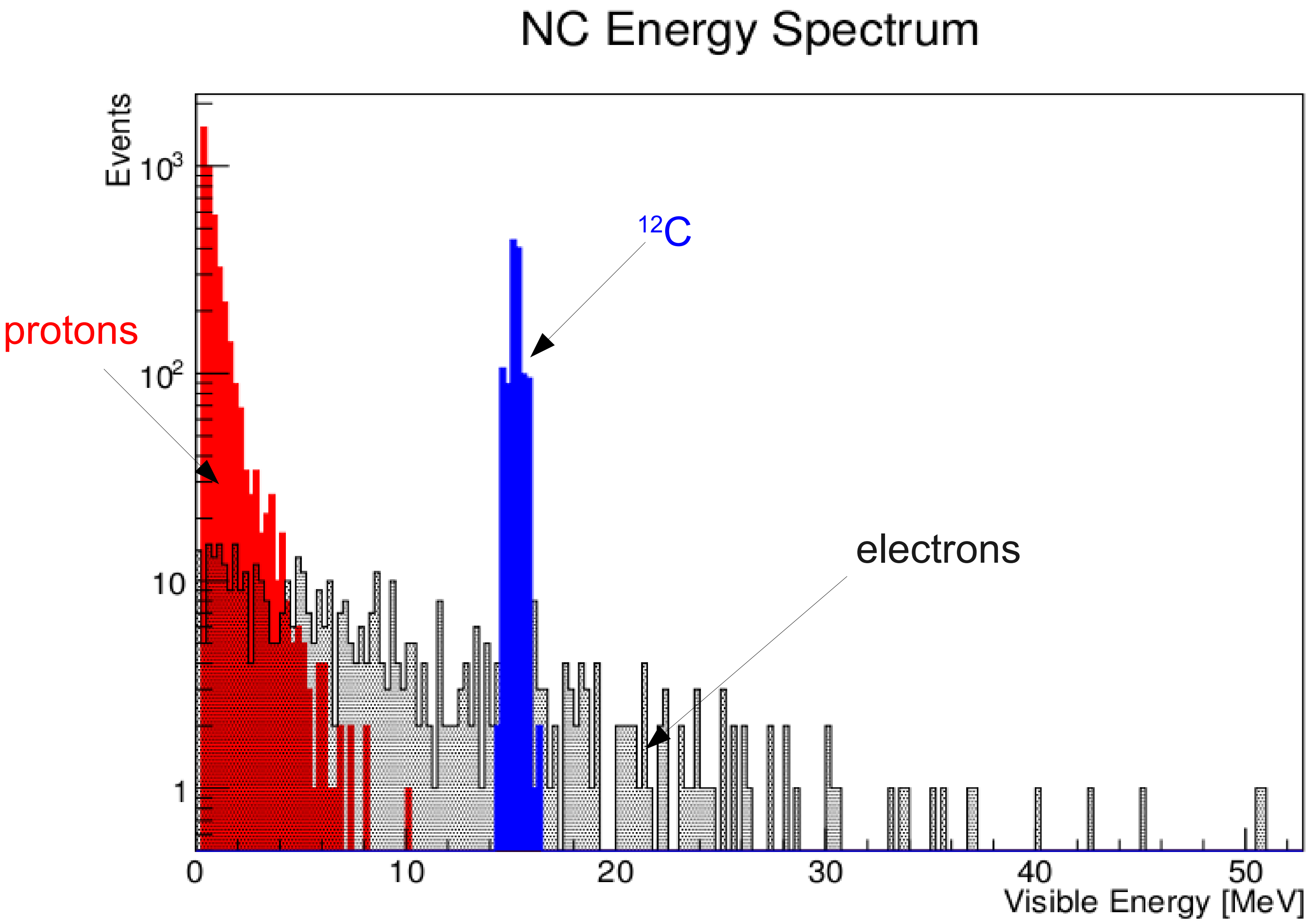
- Position cut: 600/550 mm
- Time cut: 3 ms
- Energy cut: 1.8 - 2.6 MeV

CC-^{12}C coincidence cuts (Beta decay)

- Position cut: 500/450 mm
- Time cut: 150 ms
- Energy cut: <18 MeV

Distinction of the CC-^{12}C channels

- How many events are associated with each spectrum?
- Challenge: distinguish two similar beta decays
  - Half-life: 20.20 ms and 11 ms
  - Q-Value: 13.4 MeV and 16.4 MeV
- Approach: simultaneous fit of energy and time spectra
- Input: shape of the beta spectra and half-lifes



v-p energy cut: 0.2 - 3.5 MeV

v-e energy cut: 3.5 - 14.0 and >16.0 MeV

v-^{12}C energy cut: 14.0 - 16.0 MeV

Channel Discrimination Results

Tagging efficiency: correctly identified / true number of events

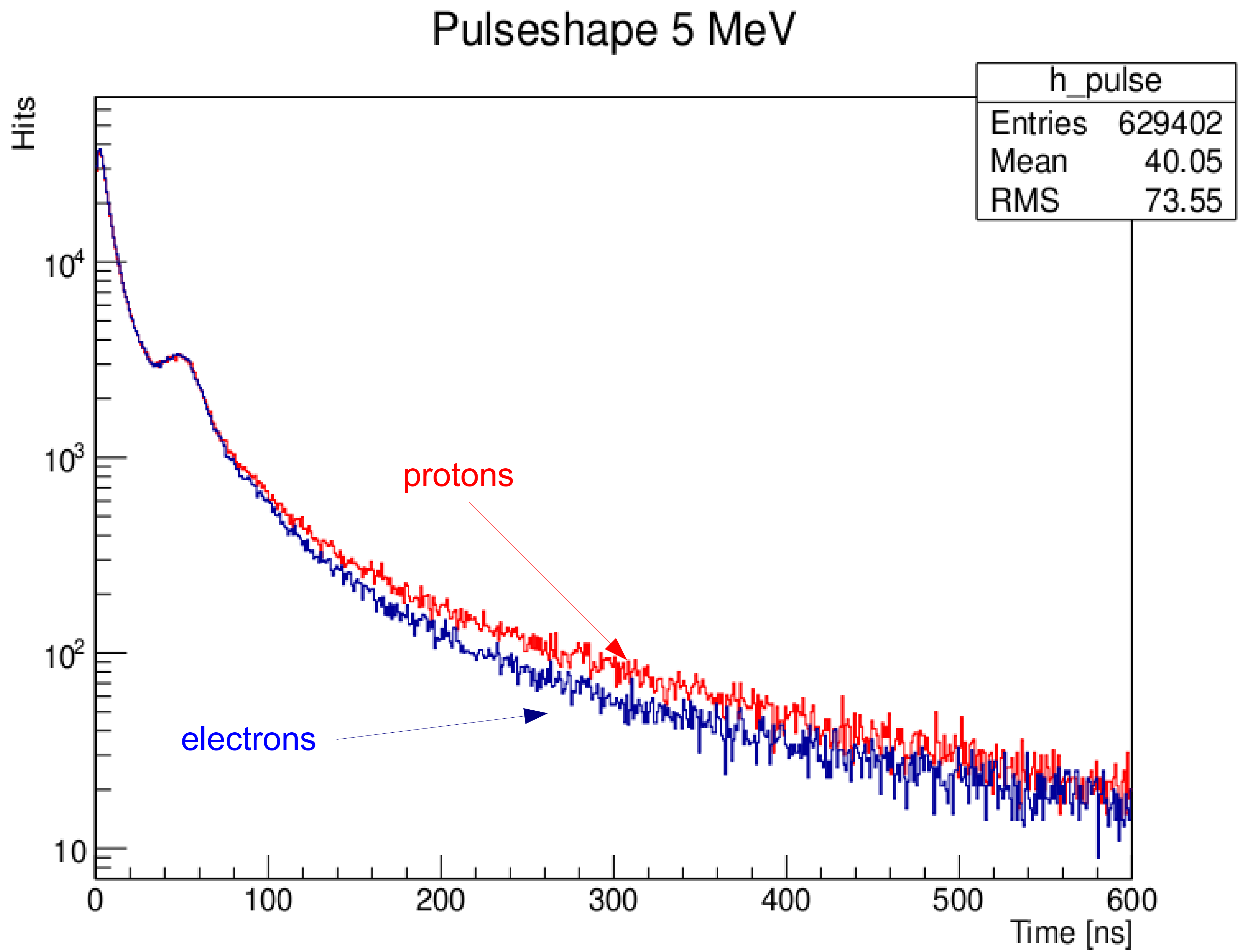
Over efficiency: falsely identified / correctly identified

Channel	Type	Tagging efficiency	Over efficiency
IBD	CC	>99.9%	<0.1%
CC-^{12}C	CC	99%	1%
NC total:		99%	1%
NC-^{12}C	NC	>99%	2%
ν-p	NC	98%	3%
ν-e	NC	~67%	~25%

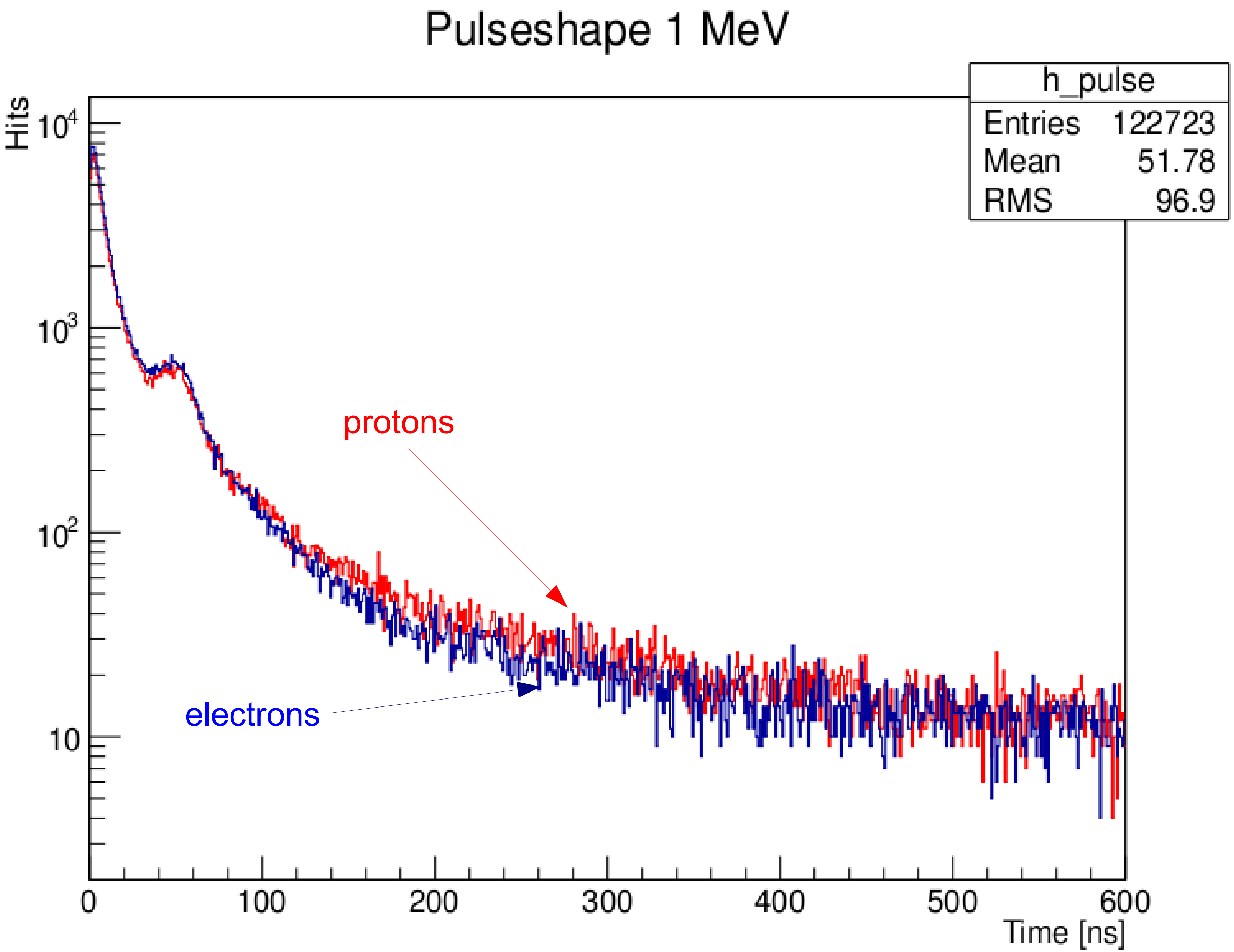
→ Distinction between CC-^{12}C channels: error of about 7%

Pulse Shape Discrimination

- GEANT4 LENA simulation
- Simulated scintillator: LAB
- Simulate electrons and protons (1-6 MeV)
- Calculate time-of-flight correction
- Simulate dark noise:
  - Rate: 50 per μs
  - After- and late-pulse probability 5%
- *Proton pulseshape only roughly implemented*

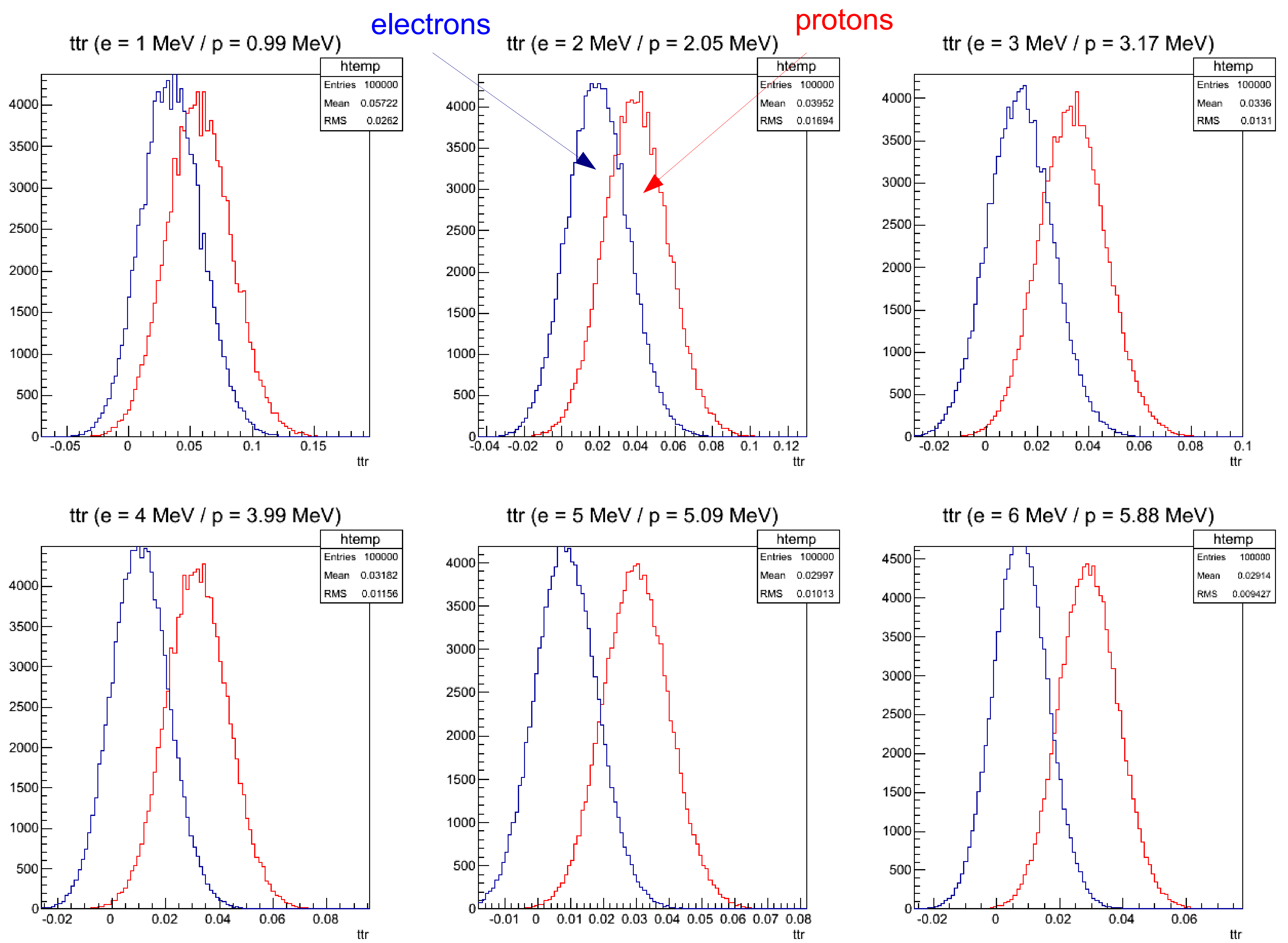


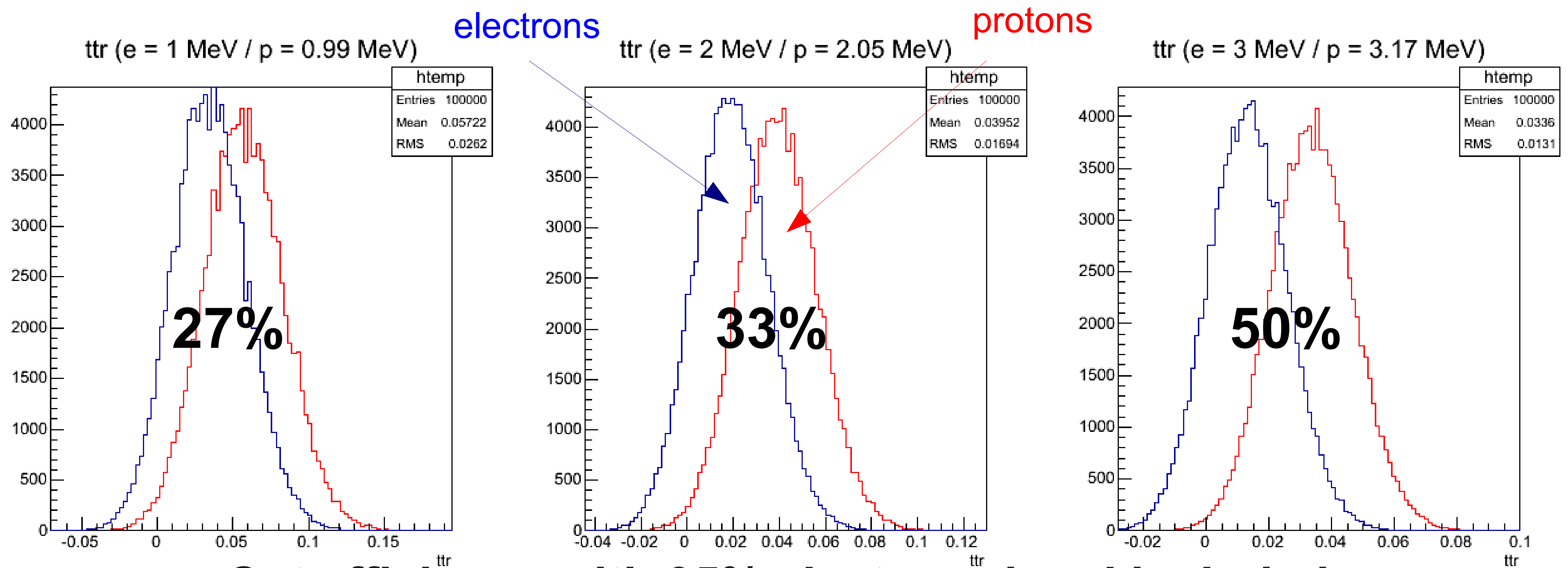
Pulseshape 5 MeV
h_pulse
Entries 629402
Mean 40.05
RMS 73.55
Hits
10
10^2
10^3
10^4
protons
electrons
0
100
200
300
400
500
600
Time [ns]


Pulseshape 1 MeV
h_pulse
Entries 122723
Mean 51.78
RMS 96.9
Hits
protons
electrons
Time [ns]
0
100
200
300
400
500
600
10
10^2
10^3
10^4

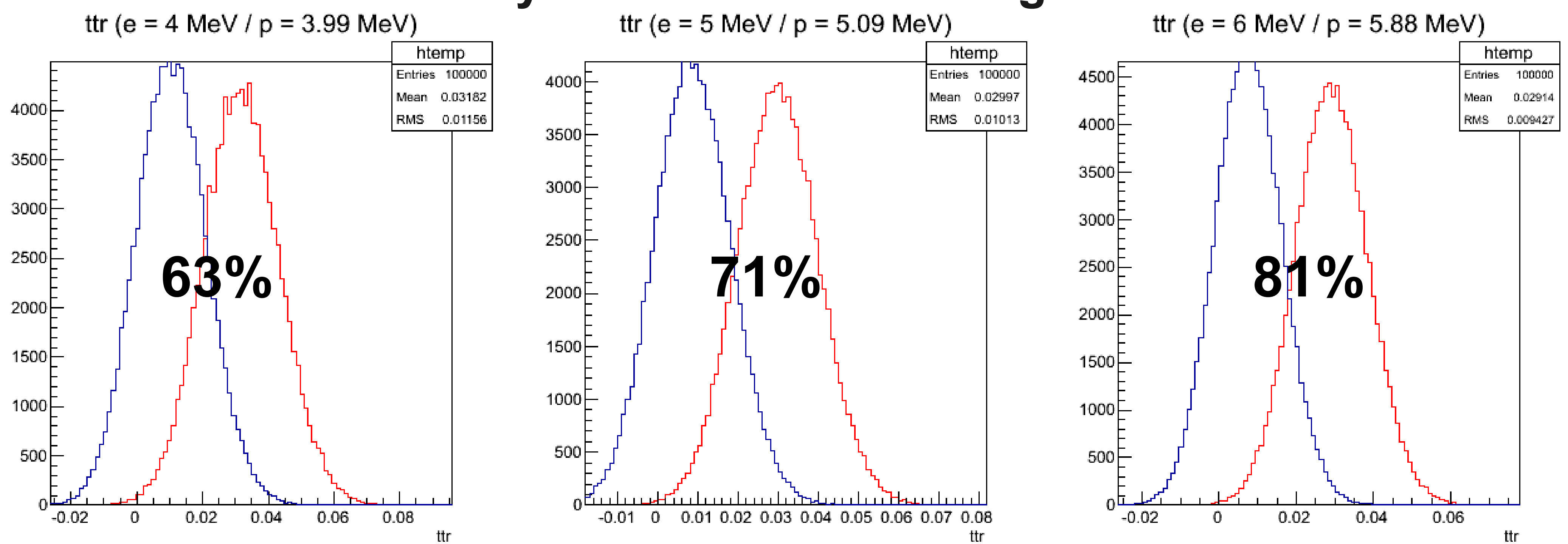
Tail-to-total ratio

- Discrimination between protons and electrons
- Photon emission can be described by exponential decays of a fast and several slow components
- Protons emit more light in the slow components
- Used parameter: Tail-to-total ratio (TTR)
  - Tail interval starting at 90 ns
  - Calculate ratio between tail- and total-interval
- Proton events feature a higher TTR


electrons
protons
ttr (e = 1 MeV / p = 0.99 MeV)
htemp
Entries 100000
Mean 0.05722
RMS 0.0262
ttr
ttr (e = 2 MeV / p = 2.05 MeV)
htemp
Entries 100000
Mean 0.03952
RMS 0.01694
ttr
ttr (e = 3 MeV / p = 3.17 MeV)
htemp
Entries 100000
Mean 0.0336
RMS 0.0131
ttr
ttr (e = 4 MeV / p = 3.99 MeV)
htemp
Entries 100000
Mean 0.03182
RMS 0.01156
ttr
ttr (e = 5 MeV / p = 5.09 MeV)
htemp
Entries 100000
Mean 0.02997
RMS 0.01013
ttr
ttr (e = 6 MeV / p = 5.88 MeV)
htemp
Entries 100000
Mean 0.02914
RMS 0.009427
ttr



Cut efficiency with 95% electron signal included



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What can be learned?

Particle Physics Output

- Determination of neutrino mass hierarchy

  „Probing the neutrino mass hierarchy with the rise time of a supernova burst“, Serpico et al.

- Observation of collective oscillation
- Neutrino-antineutrino oscillation in magnetic fields
- Sterile neutrinos, magnetic moment, spin flavor conversion

Outlook

- Improvement on pulse shape discrimination
  - Measurement of proton pulseshape
- Quantification of mass hierarchy exploration
- Studies on more models
- Concentrate on model-independent analysis

Thank you for your attention