Observing Supernova Neutrinos to Late Times

Shirley Li
In collaboration with John Beacom (OSU), Luke Roberts (MSU)

Flavor Observations with Supernova Neutrinos
INT, August 2016

Timescales in a SN

0 s 1 s

Explosion dynamics

2D, 3D simulations

detectable
(SN 1987A)

Timescales in a SN

0 s — 1 s — 10 s

Explosion dynamics	Contraction (deleptonization)
2D, 3D simulations	1D simulations
detectable (SN 1987A)	detectable (SN 1987A)

Timescales in a SN

0 s	1 s	10 s	100 s

Explosion dynamics	Contraction deleptonization	Core Cooling
2D, 3D simulations	1D simulations	1D simulations
detectable (SN 1987A)	detectable (SN 1987A)	??

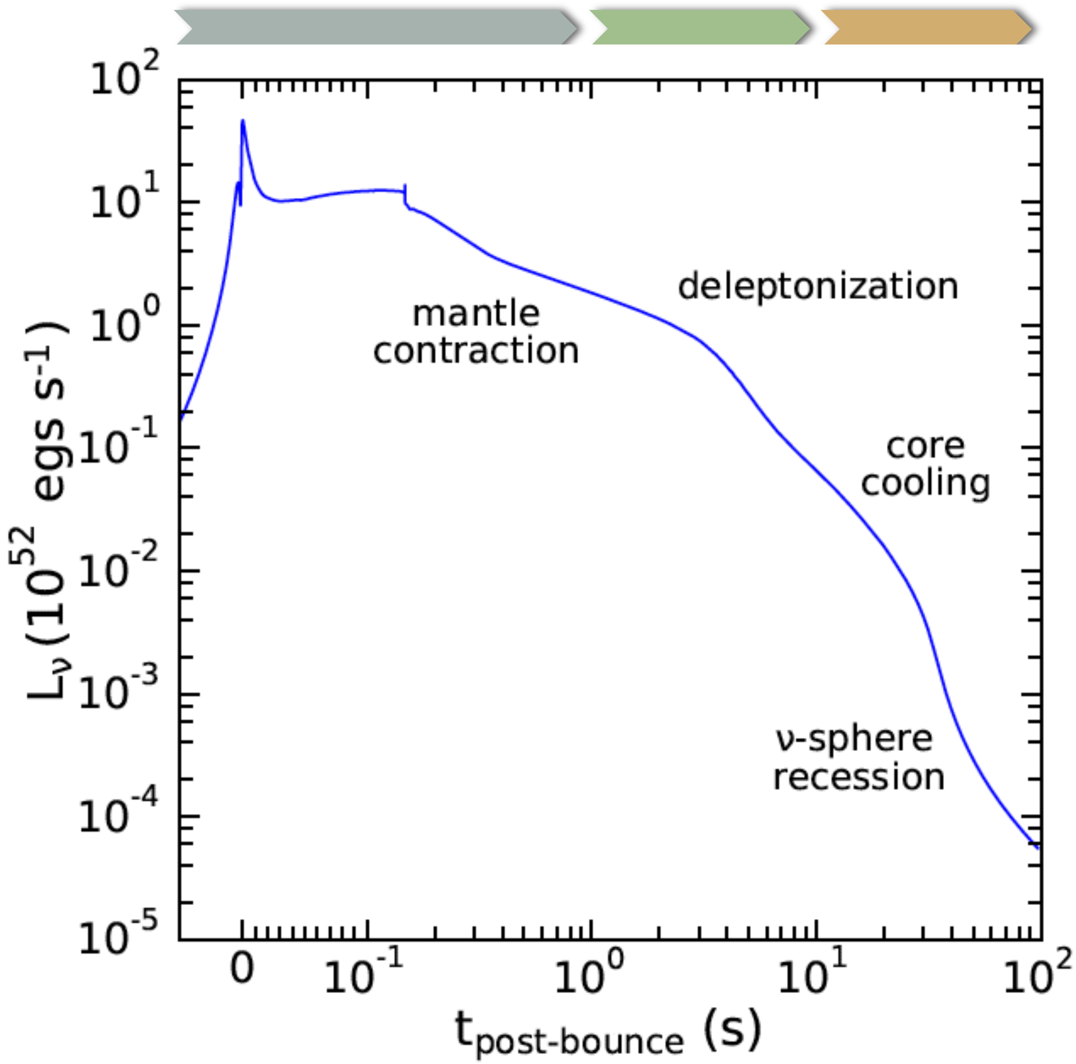
Timescales in a SN

0 s | 1 s | 10 s | 100 s

Explosion dynamics	Contraction deleptonization	Core Cooling
2D, 3D simulations	1D simulations	1D simulations
detectable (SN 1987A)	detectable (SN 1987A)	detectable! (with care)

MOTIVATION

Late time physics: PNS cooling



Why late-time neutrinos?

- Goal:
  - Connect SN physics and NS physics
  - Probe finite temperature nuclear matter
  - Probe black hole formation
- Advantage:
  - Less dynamic
  - Moderate neutrino mixing effects
  - More robust constraint on nuclear physics
- Measurable:
  - For a CCSN at 10 kpc, ~ 250 events in Super-K

Context

Previous works:

Simulation-focused: Burrows & Lattimer 1986, J. A. Pons et al 2001, T. Fischer et al 2010, L. Huedepohl et al 2010, *L. F. Roberts et al 2012*

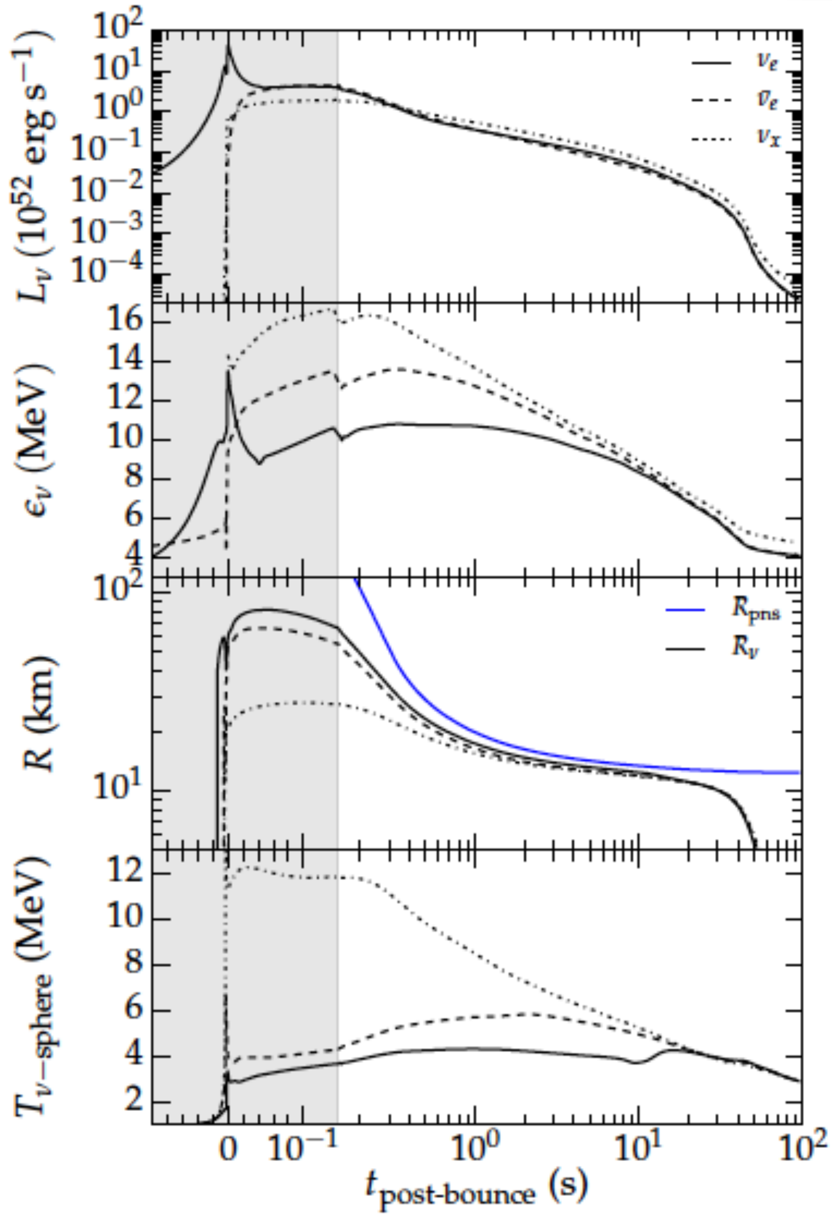
What's needed:

- Proposed next generation experiments
- Better background rejection
- Spectrum, time, flavor

LATE TIME SIGNALS

Simulation results

- PNS: 1.5 $M_\odot$
- Progenitor: 15 $M_\odot$



Roberts & Reddy 2016

Shirley Li (OSU)

Late time detection channels

Large cross sections

Multi - 10 kton

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

Super-K

JUNO

$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$

DUNE

Late time detection channels

Large cross sections

Multi - 10 kton

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

Super-K

JUNO

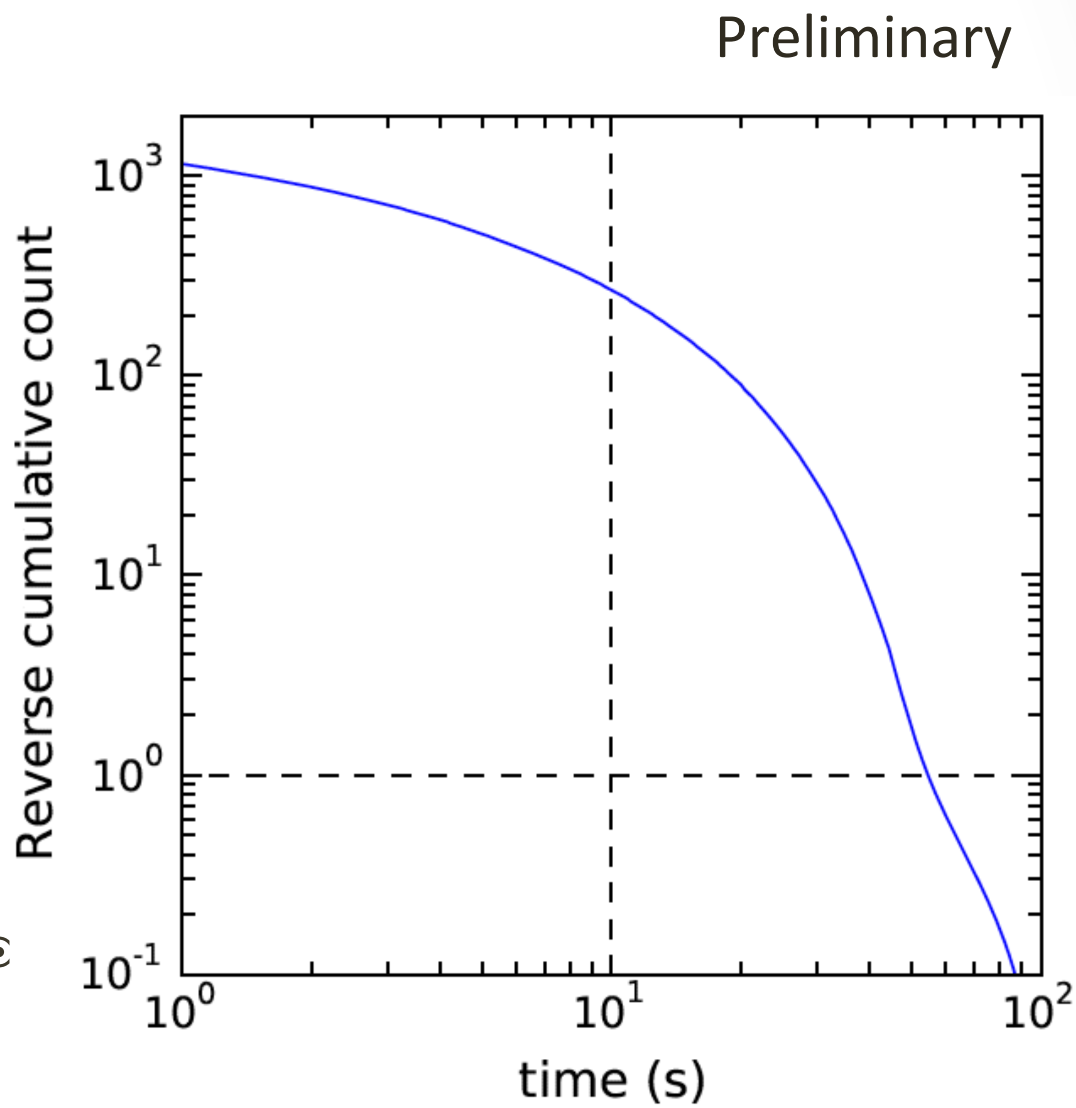
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

DUNE

Hundreds of events after 10 s

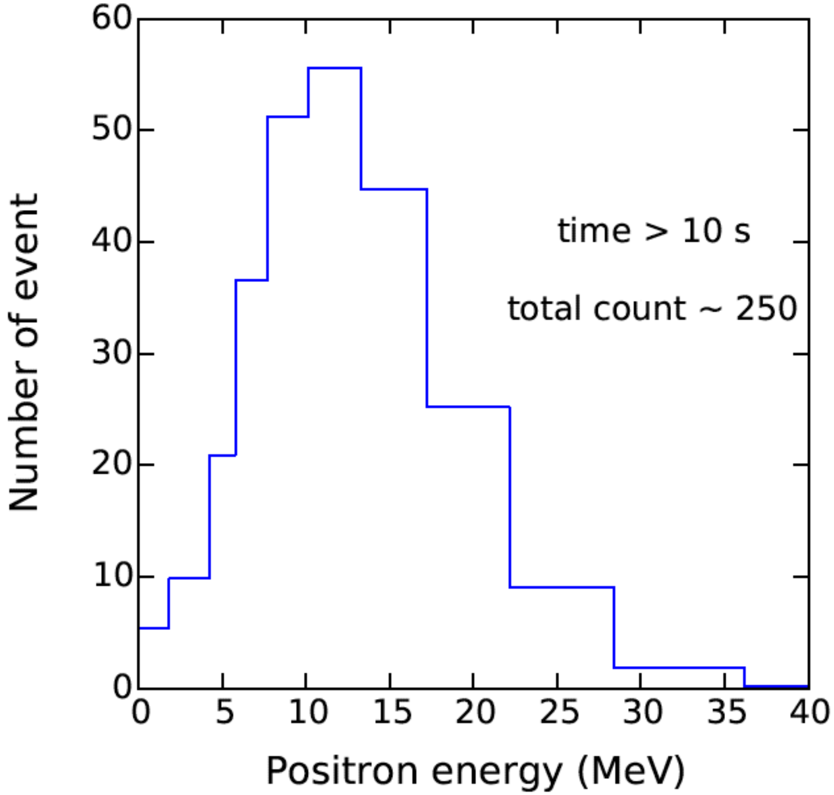
- CCSN at 10 kpc
- 22.5 kton water
- 100% detection efficiency

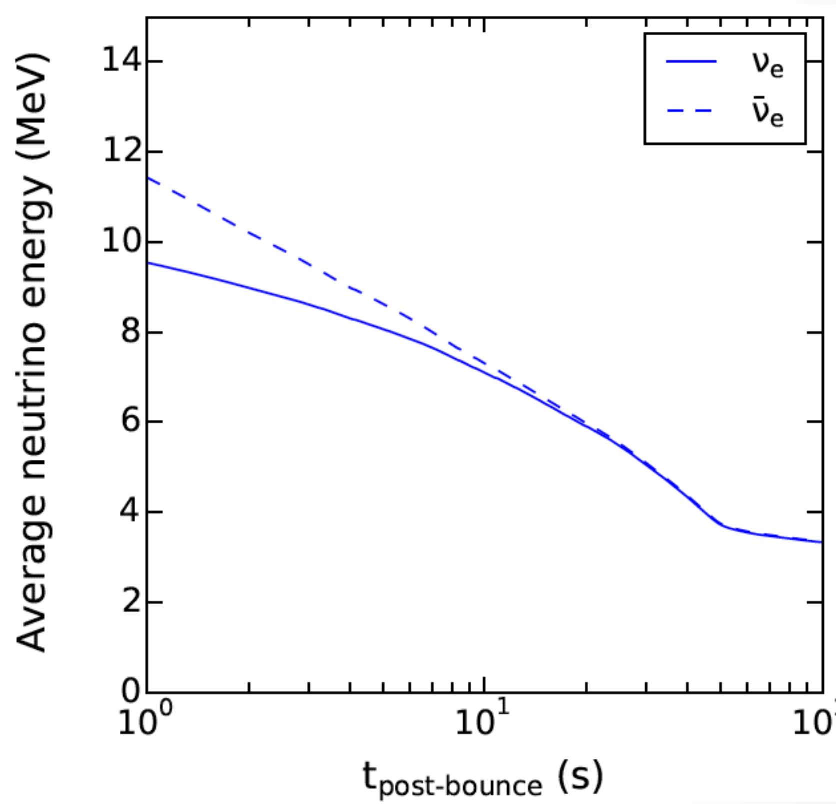
- PNS: 1.5 $M_\odot$
- Progenitor: 15 $M_\odot$



Energy spectrum

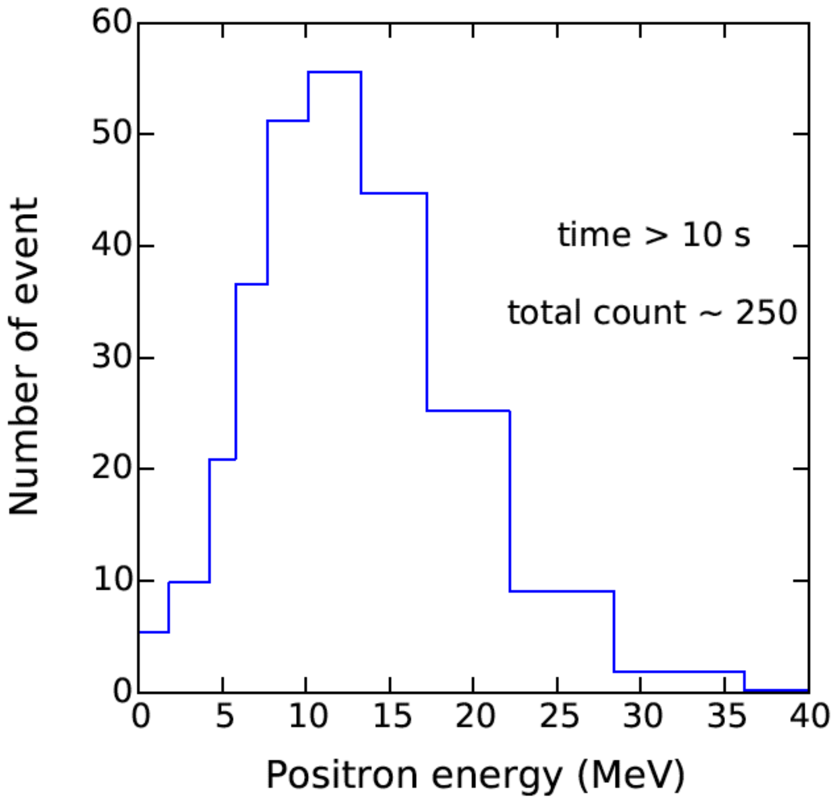
Preliminary



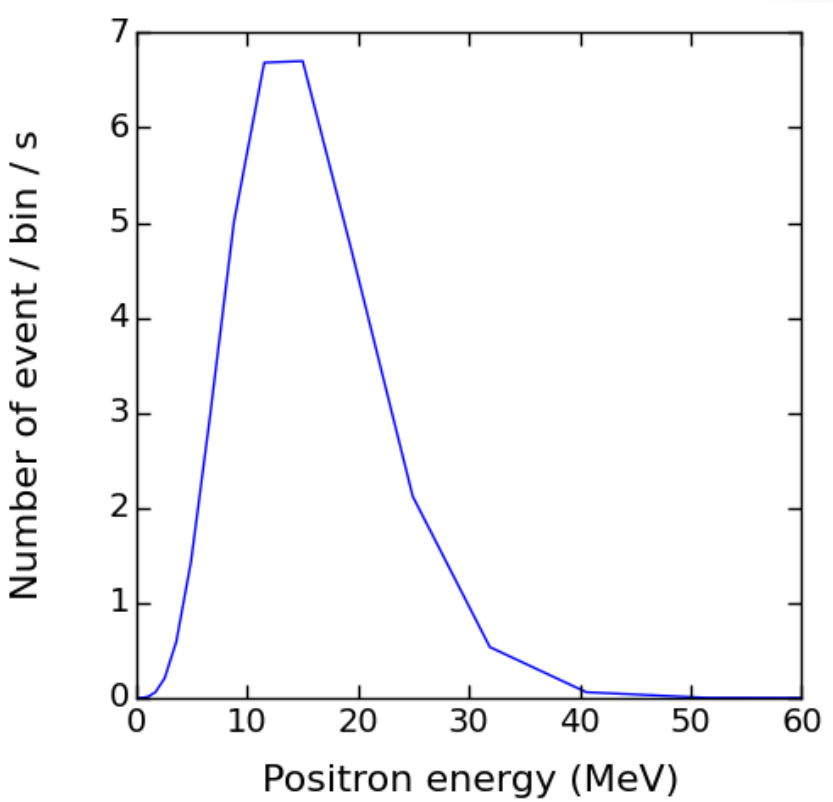


Energy spectrum

Preliminary

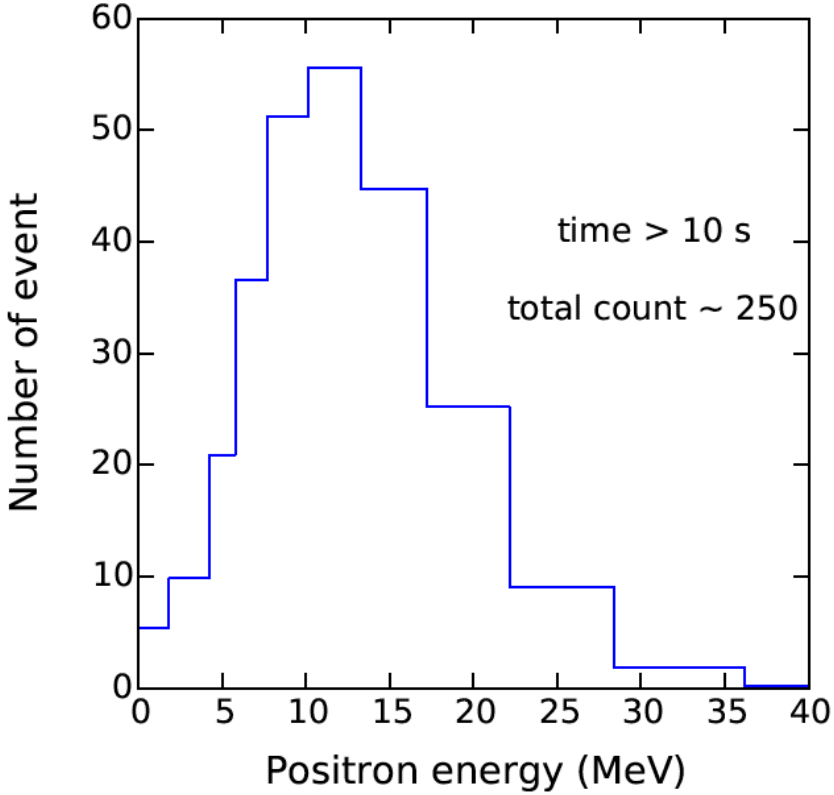


t = 10 s

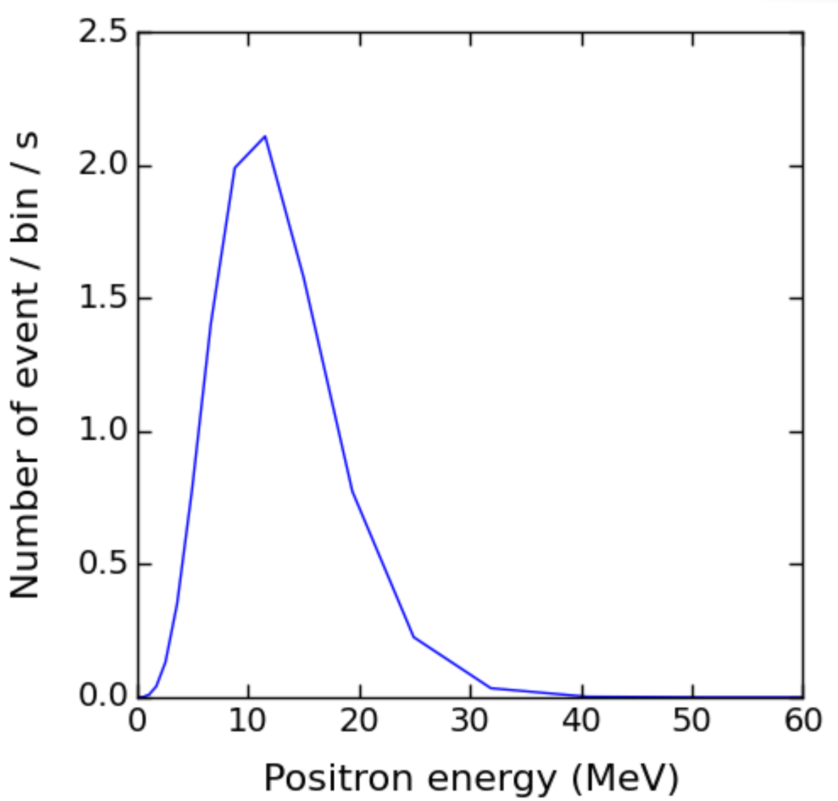


Energy spectrum

Preliminary

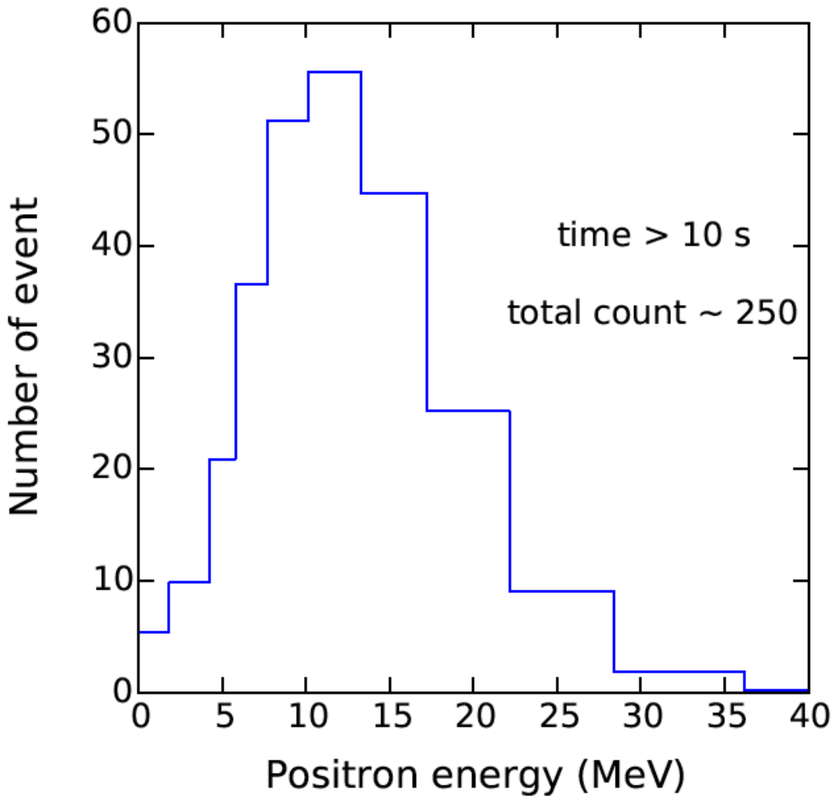


t = 20 s

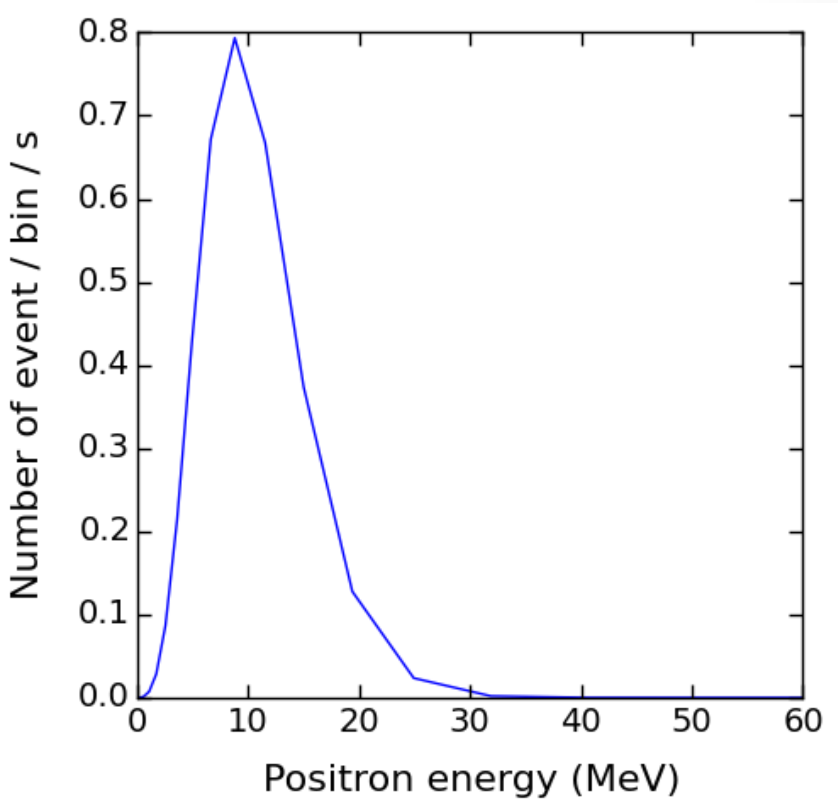


Energy spectrum

Preliminary

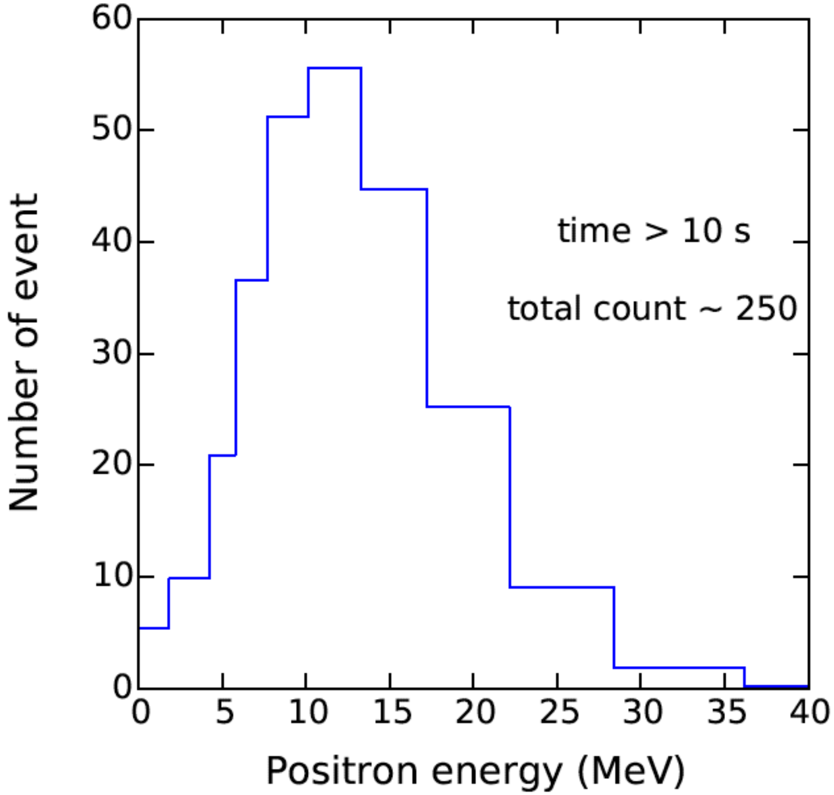


t = 30 s

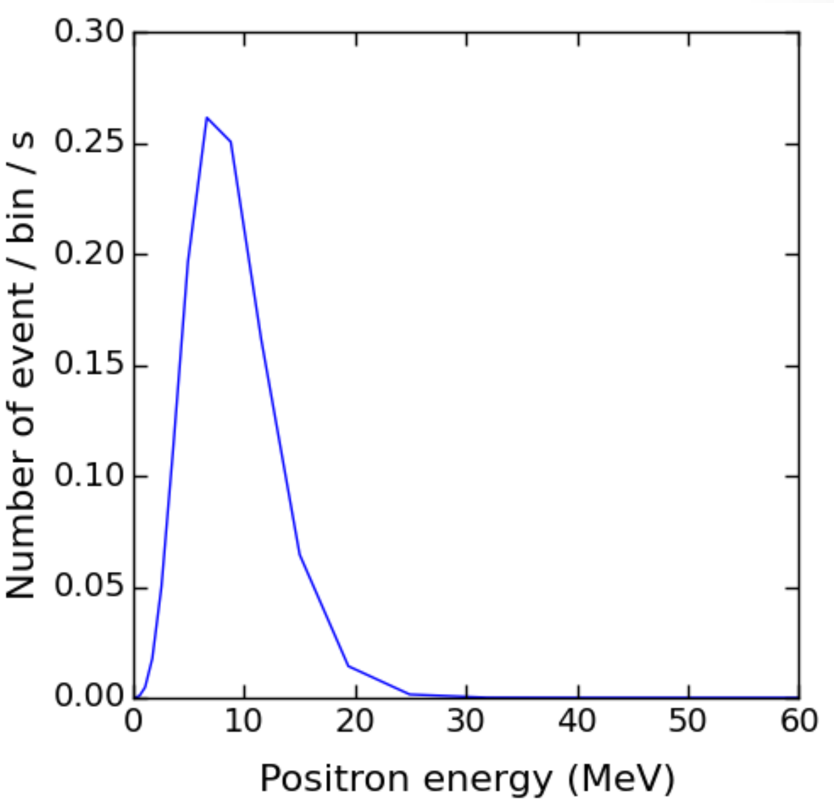


Energy spectrum

Preliminary

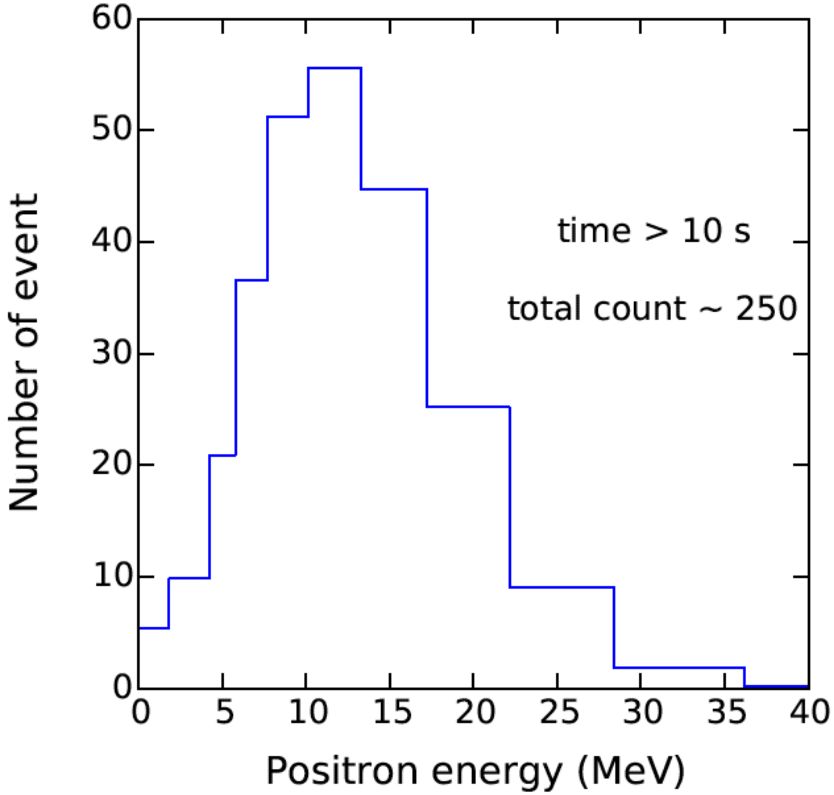


t = 40 s

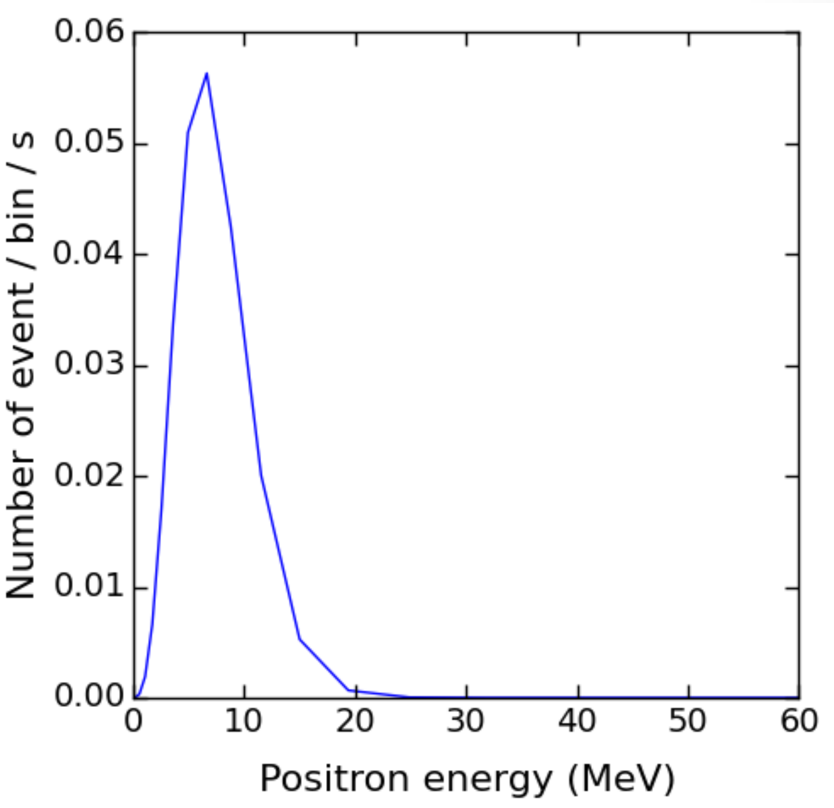


Energy spectrum

Preliminary

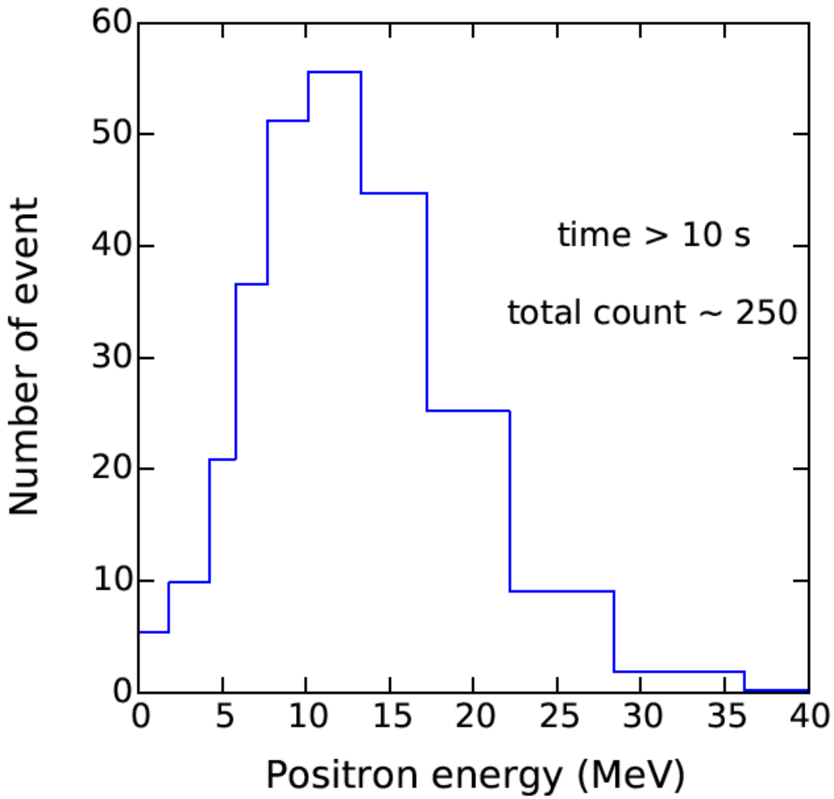


t = 50 s

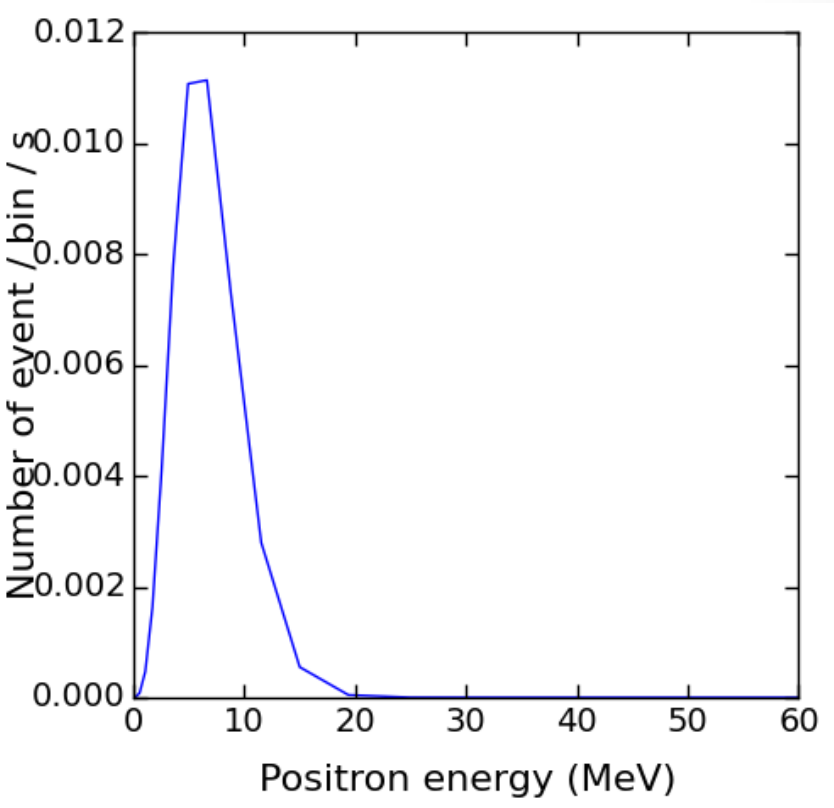


Energy spectrum

Preliminary



t = 60 s



BACKGROUNDS

Signal vs. backgrounds

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

Backgrounds: Any MeV electron, positron, gamma from other sources

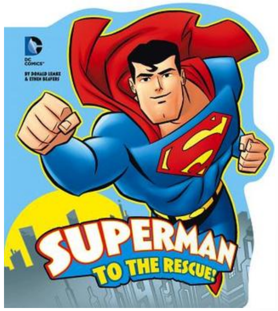
Potential backgrounds

- Radioactivity

  Beta decay e, dominant below a few MeV

✧GADZOOKS! (Beacom & Vagins 2003)

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

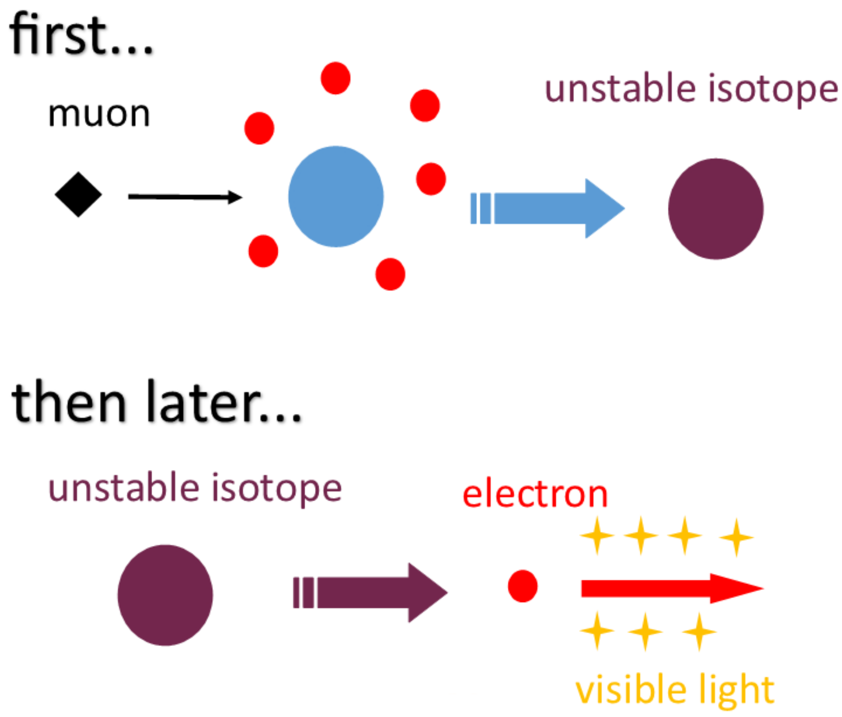


Distinguish between electron and positron

Approved in 2015!

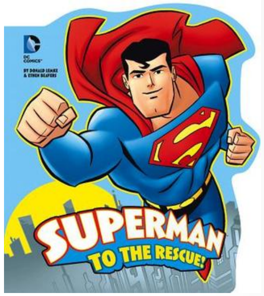
Potential backgrounds

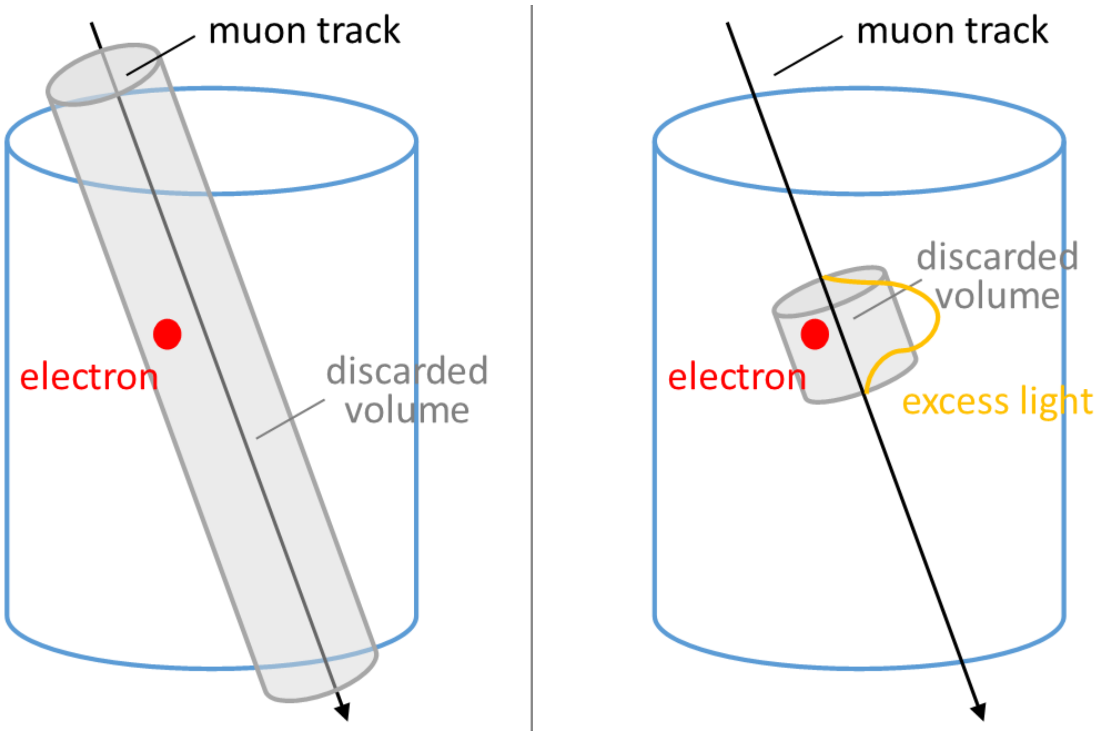
- Cosmic-ray muon induced spallation backgrounds
  - Dominant above a few MeV



Potential backgrounds

- Better spallation rejection method by Li & Beacom





Li & Beacom 2015, 2016a, 2016b

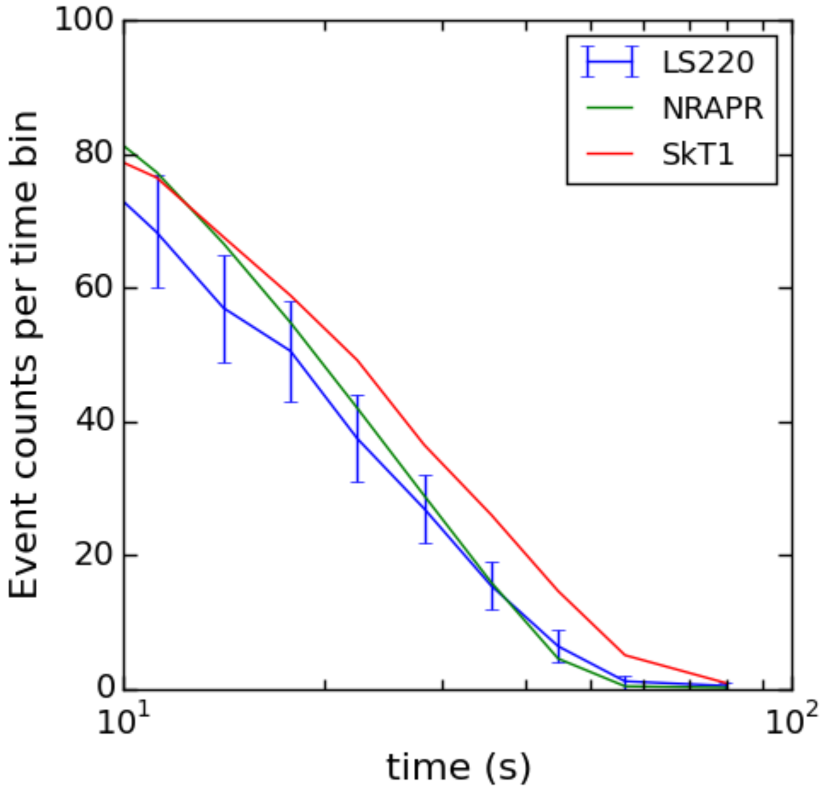
PHYSICS

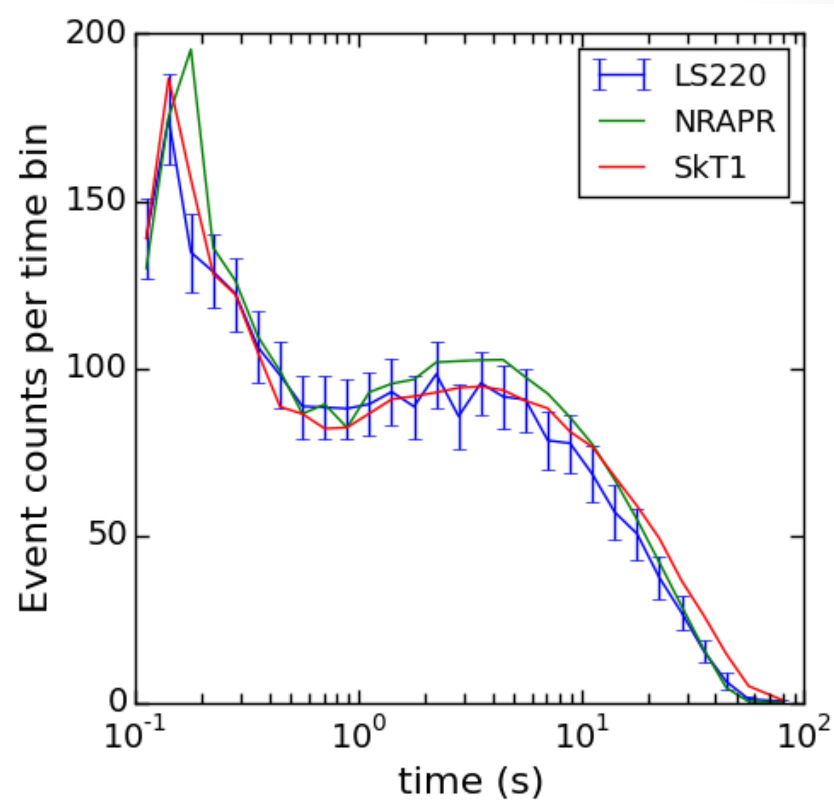
Shirley Li (OSU)

Differentiate models

Three different EoS

Preliminary





EoS tables from Andre
Da Silva Schneider

Other physics

- PNS mass
- Progenitor mass
- Neutrino opacity
- Black hole formation (Beacom, Boyd and Mezzacappa 2000)
- Others?

Conclusion

detectable!
(with care)

- Connect SN physics and NS physics
- A new probe of nuclear physics