Cosmogenic backgrounds in neutrino detectors

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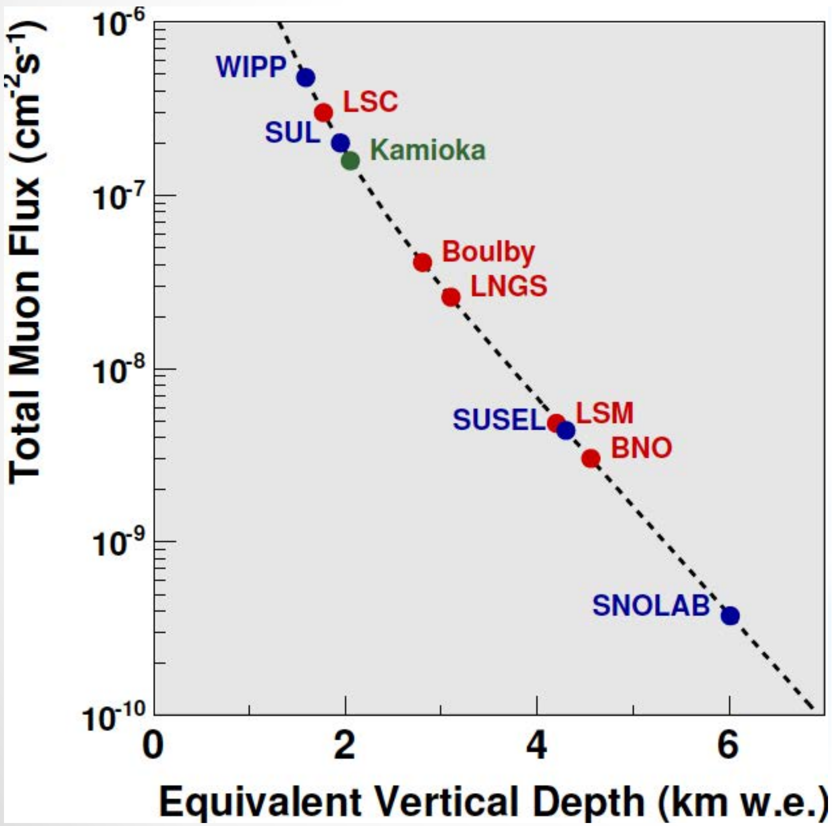
The Ohio State University

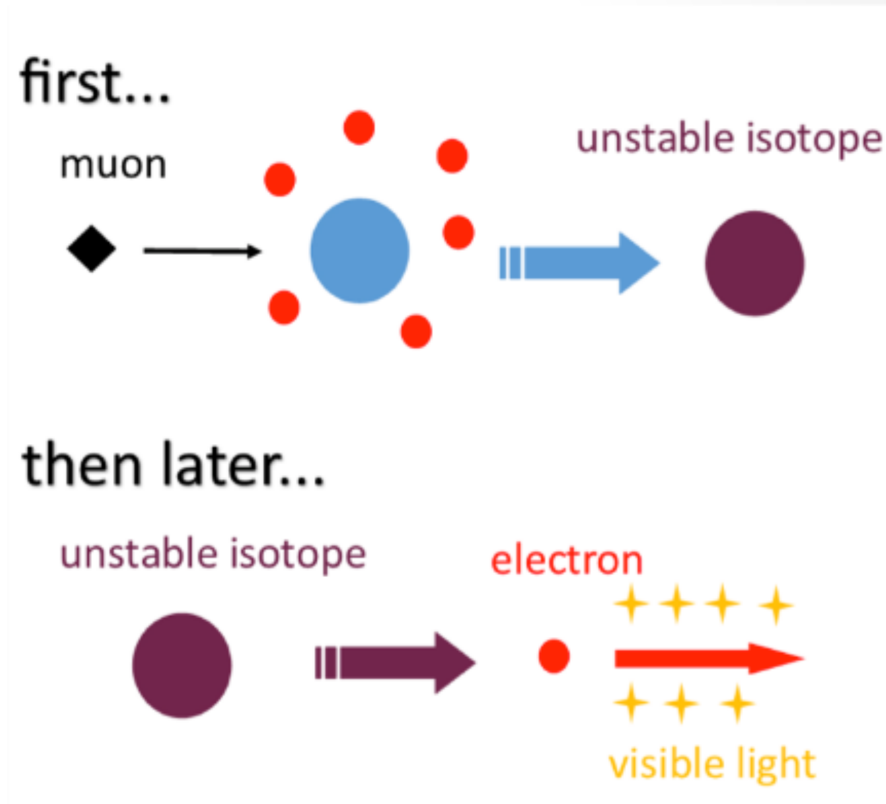
NNN16, Beijing

What are cosmogenic backgrounds?

Backgrounds induced by cosmic rays and their products



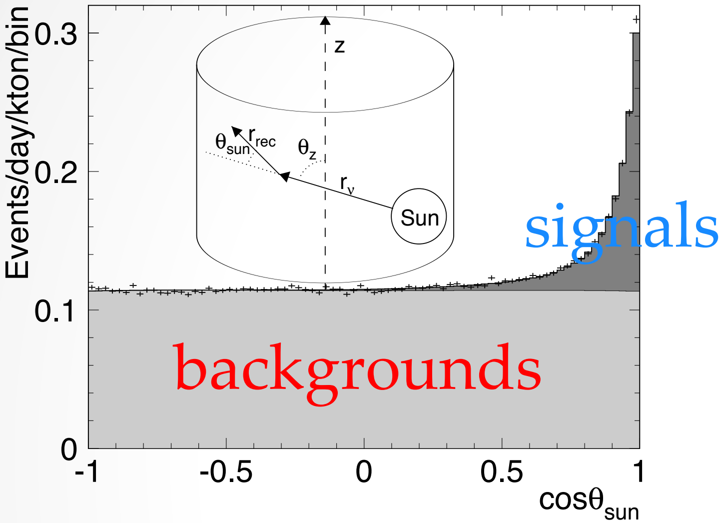
Gomez-Cadenas *et al.*, 2012



The physics they affect

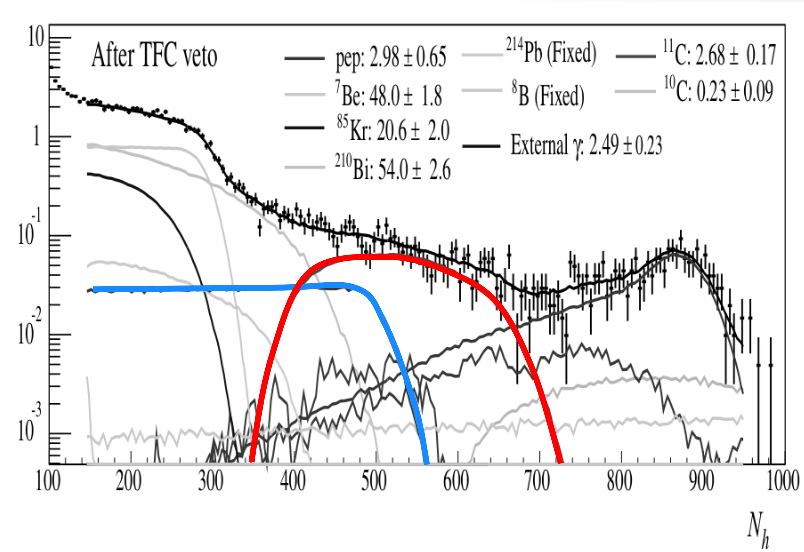
Super-K 2016

^{8}B solar neutrino



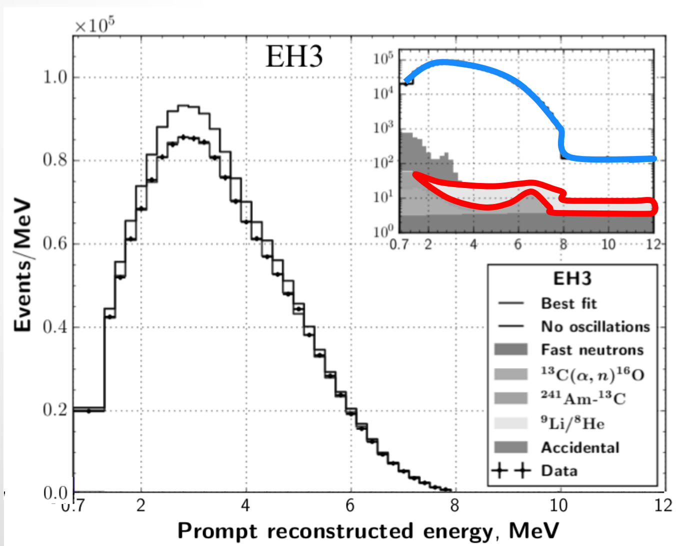
pep, CNO solar neutrino

Borexino 2014



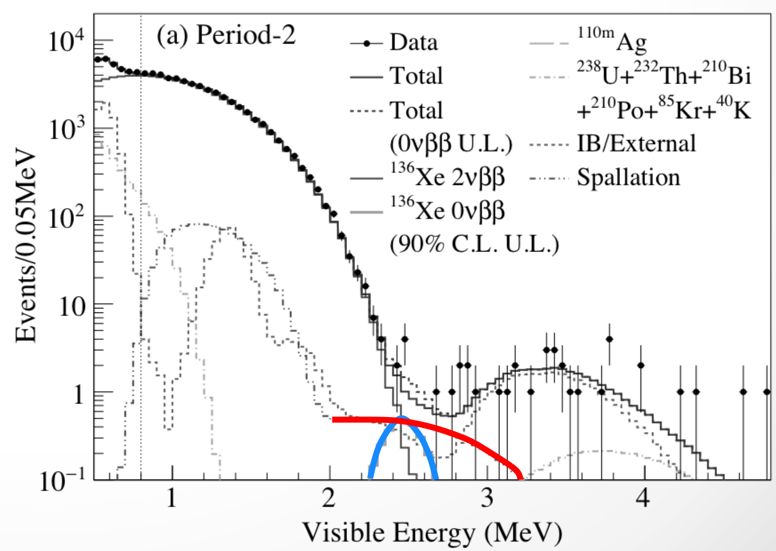
Daya Bay 2016

reactor neutrino



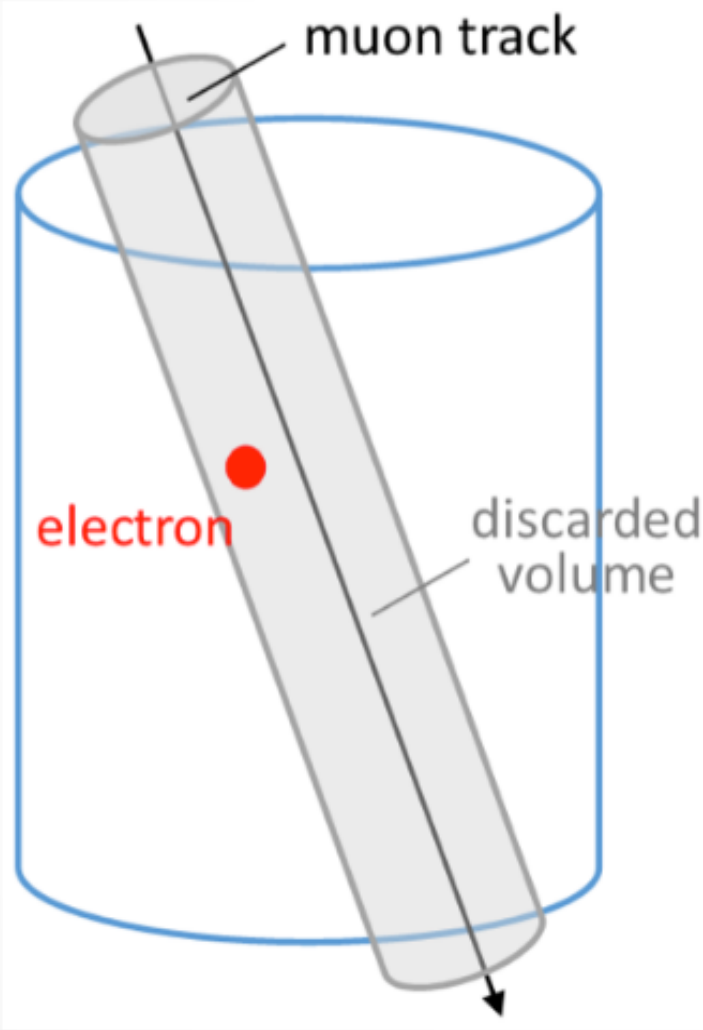
0νββ

KamLAND-Zen 2016



Current rejection methods

Example: Super-K



Muon rate: 2 Hz

vs.

Isotope lifetime: ~ 10 s

Remove 90% backgrounds

Lose 20% signals

Much better background reduction is possible

Simulations are improving

- Packages: FLUKA, GEANT4
- A factor of ~ 2 accuracies in ^{12}C & ^{16}O

Borexino 2013

	GEANT4 Model III	GEANT4 Model IV	FLUKA	Borexino
	— $\langle E_\mu \rangle = 283 \pm 19$ GeV —			
Isotopes	Yield $[10^{-7} (\mu\, g/cm^2)^{-1}]$			
^{12}**N**	1.11 ± 0.13	3.0 ± 0.2	0.5 ± 0.2	< 1.1
^{12}**B**	30.1 ± 0.7	29.7 ± 0.7	28.8 ± 1.9	56 ± 3
^{8}**He**	< 0.04	0.18 ± 0.05	0.30 ± 0.15	< 1.5
^{9}**Li**	0.6 ± 0.1	1.68 ± 0.16	3.1 ± 0.4	2.9 ± 0.3
^{8}**B**	0.52 ± 0.09	1.44 ± 0.15	6.6 ± 0.6	14 ± 6
^{6}**He**	18.5 ± 0.5	8.9 ± 0.4	17.3 ± 1.1	38 ± 15
^{8}**Li**	27.7 ± 0.7	7.8 ± 0.4	28.8 ± 1.0	7 ± 7
^{9}**C**	0.16 ± 0.05	0.99 ± 0.13	0.91 ± 0.10	< 16
^{11}**Be**	0.24 ± 0.06	0.45 ± 0.09	0.59 ± 0.12	< 7.0
^{10}**C**	15.0 ± 0.5	41.1 ± 0.8	14.1 ± 0.7	18 ± 5
^{11}**C**	315 ± 2	415 ± 3	467 ± 23	886 ± 115
Neutrons	Yield $[10^{-4} (\mu\, g/cm^2)^{-1}]$			
	3.01 ± 0.05	2.99 ± 0.03	2.46 ± 0.12	3.10 ± 0.11

Super-K 2016

Isotope	Y_i in water	Expected [13]
^{12}B	11.7±0.1±0.6	12
^{12}N	1.6±0.1±0.1	1.3
^{16}N	23.4±1.9±1.7	18
^{11}Be	<10.0	0.81
^{9}Li w/o n-tag	0.5±0.2±0.2	1.9
^{9}Li w/ n-tag	0.51±0.07±0.09	1.9
^{8}He/^{9}C	<0.9	1.1
^{8}Li/^{8}B,	4.9±0.2±0.2	18.8
^{15}C	<3.9	0.82

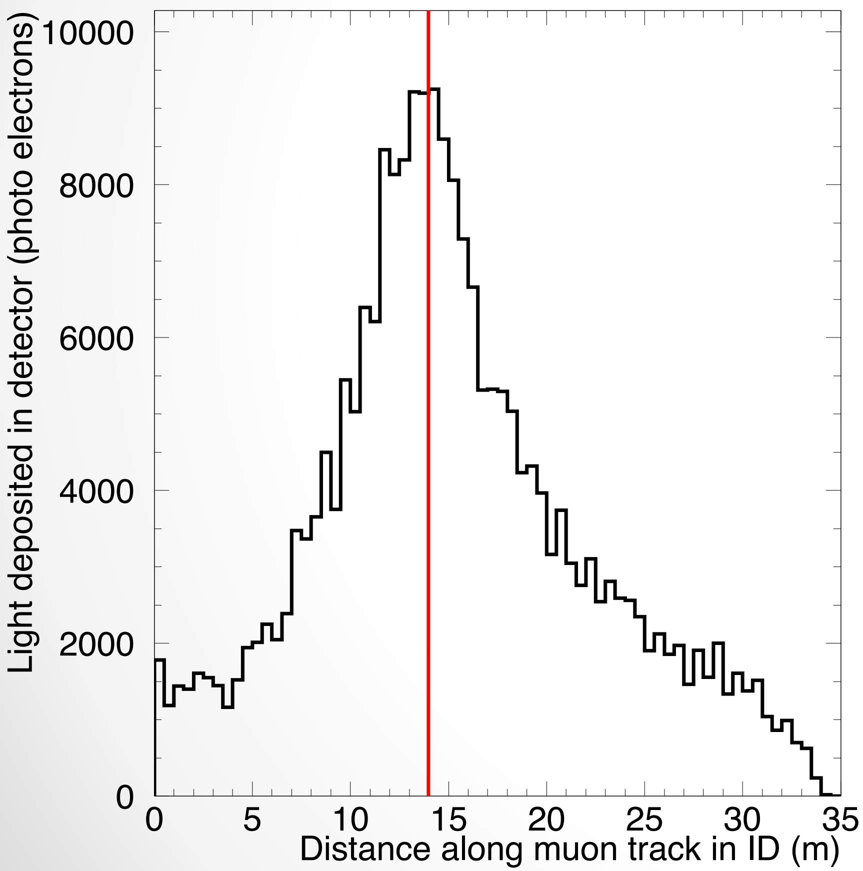
- More studies with heavier materials

EXO-200 2016

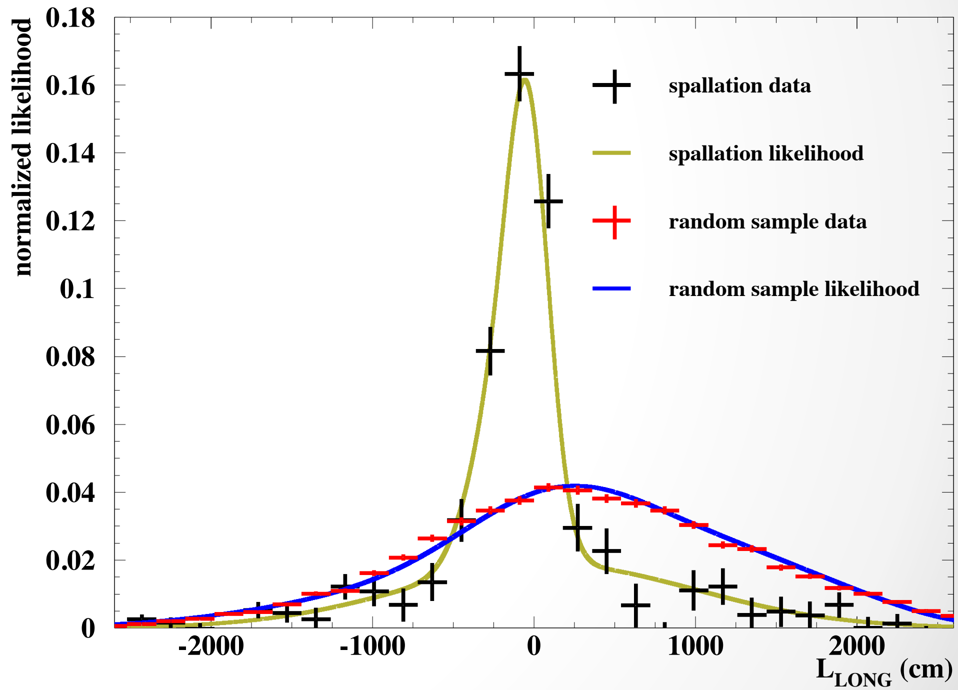
Zhu *et al.*, in prep

The puzzle

Muon light profile

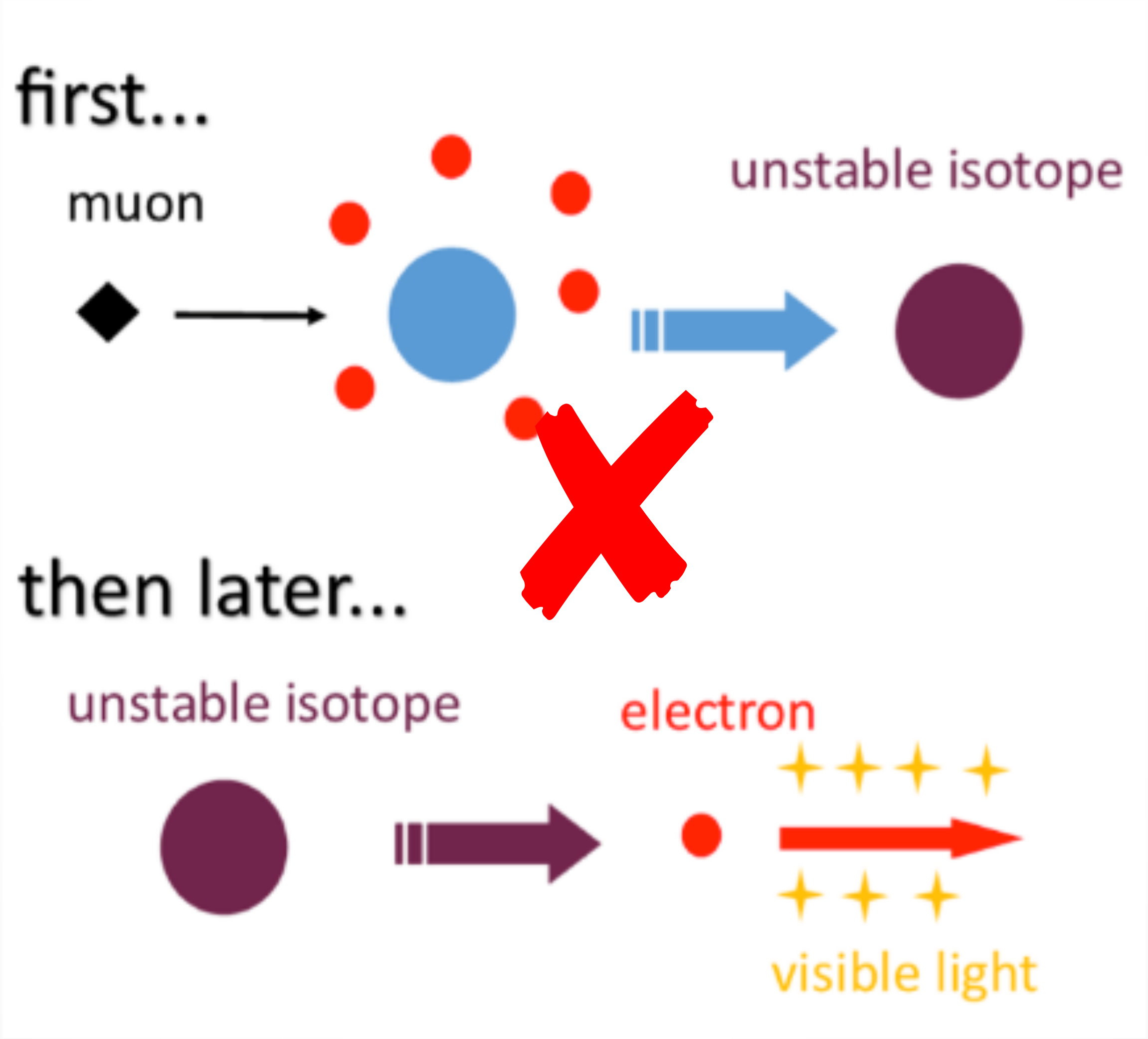


Correlation with cosmogenics



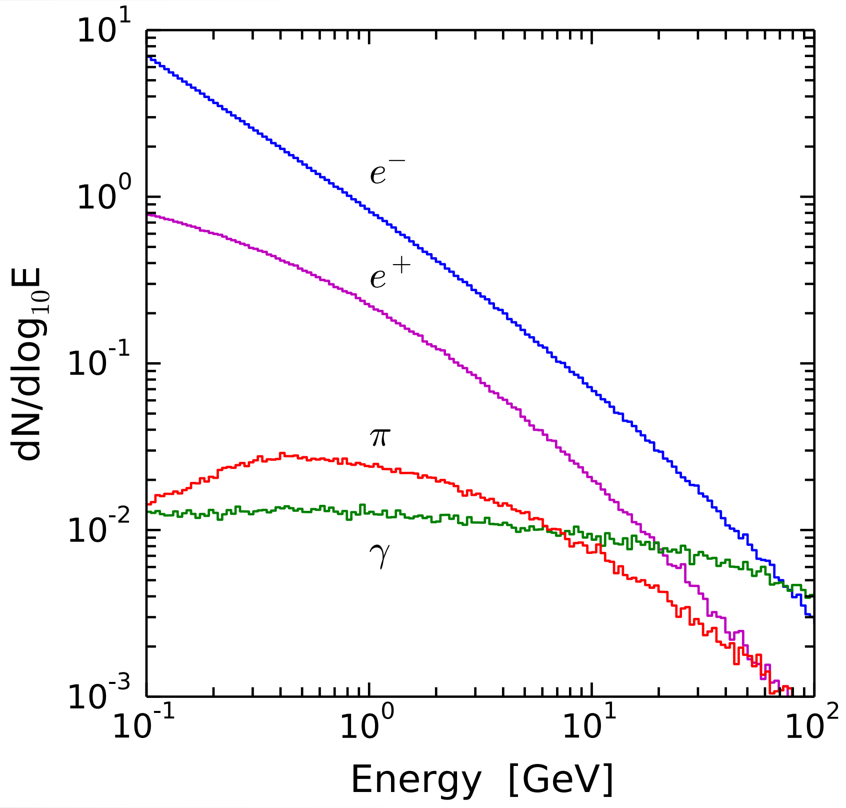
Super-K
2012

Understanding the production mechanism



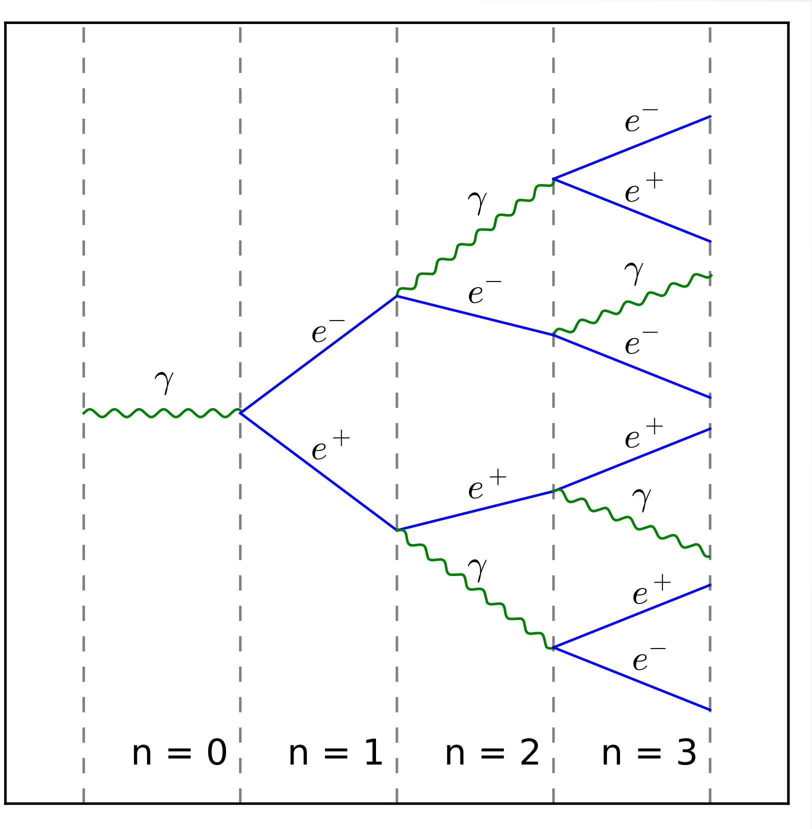
1. Muons produce showers

Muon secondary spectra



Li & Beacom 2015

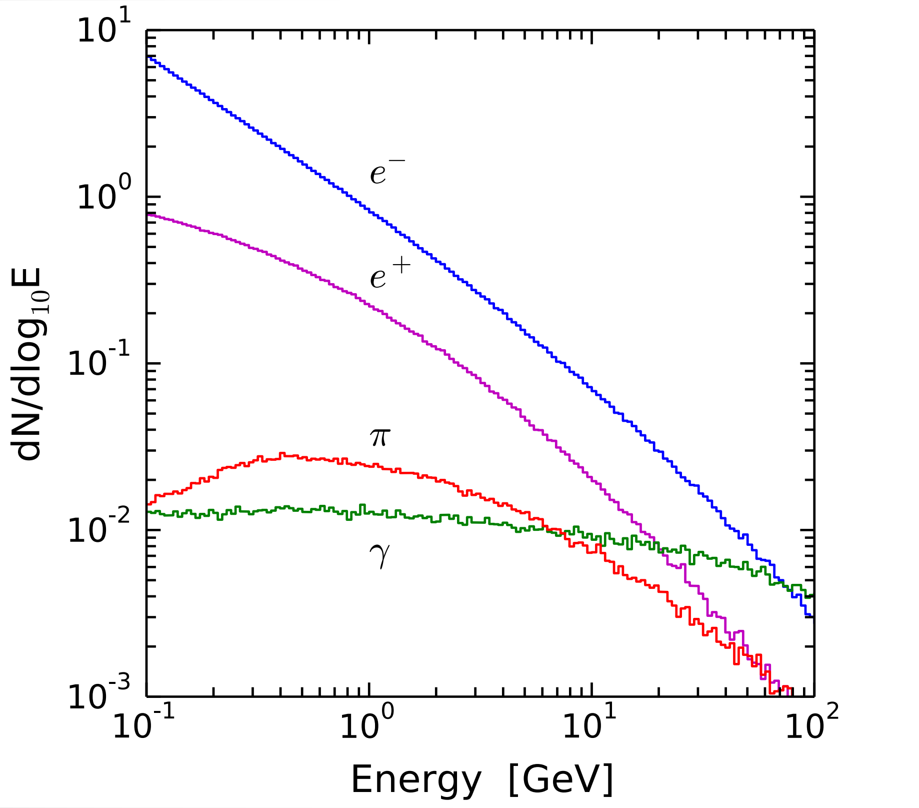
E.M. Shower



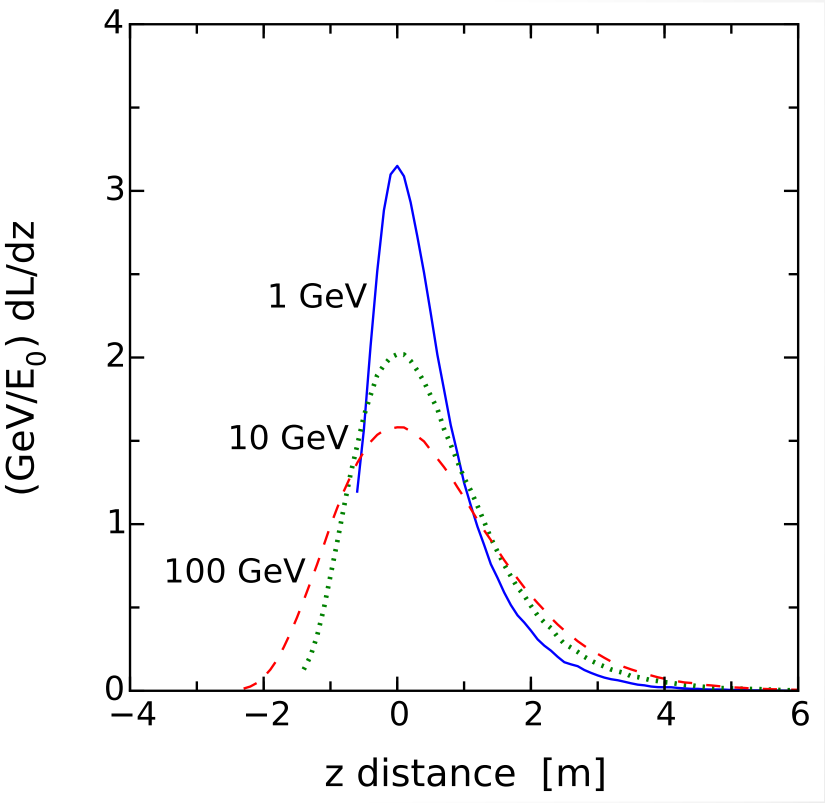
Shower rate is low, ~ 0.5 per Super-K muon

1. Muons produce showers

Muon secondary spectra



Shower profile



Li & Beacom 2015

Shower length is small, ~ 5 m

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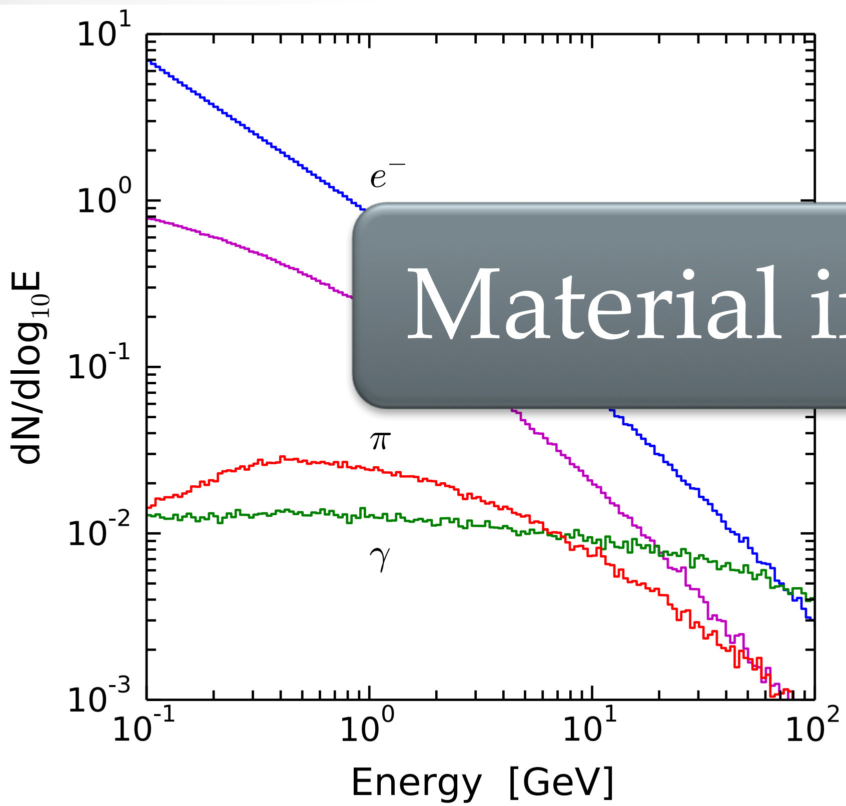
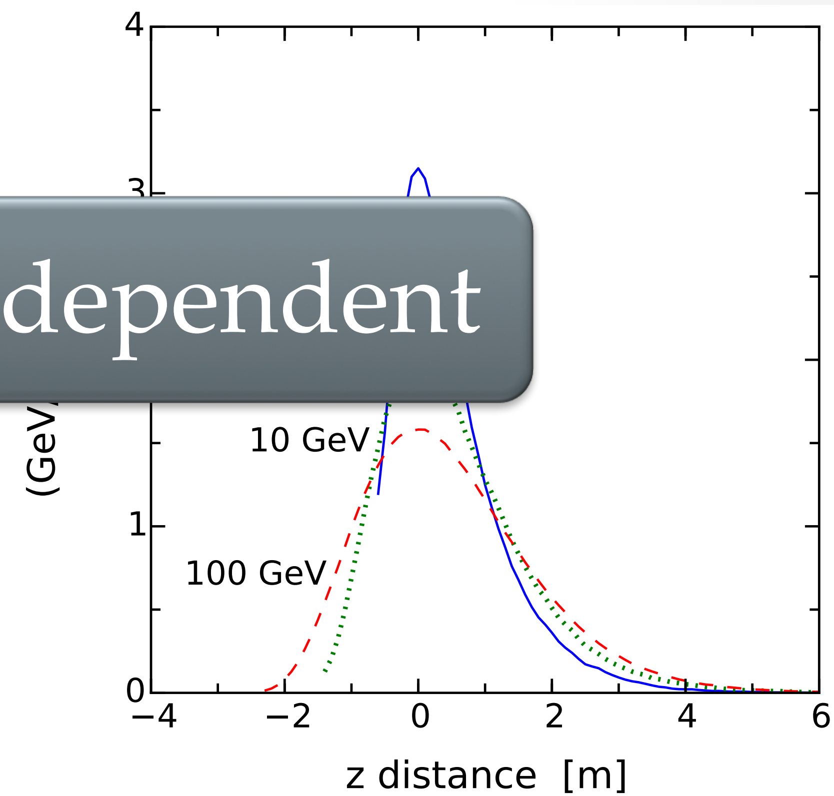
Muon secondary spectra



Shower profile



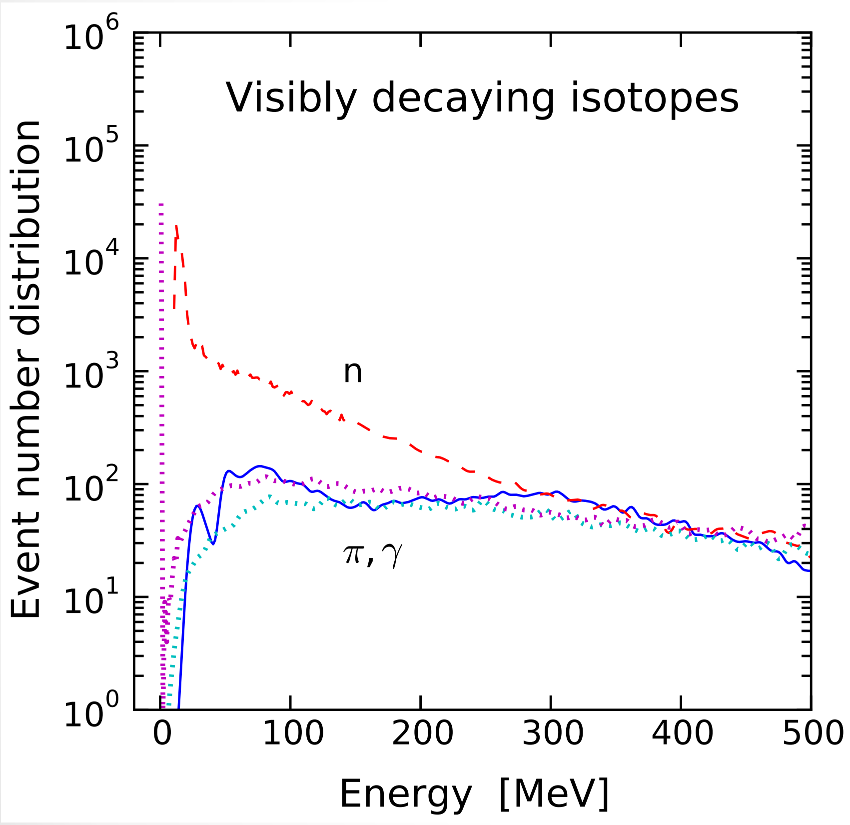
Material independent

Li & Beacom
2015

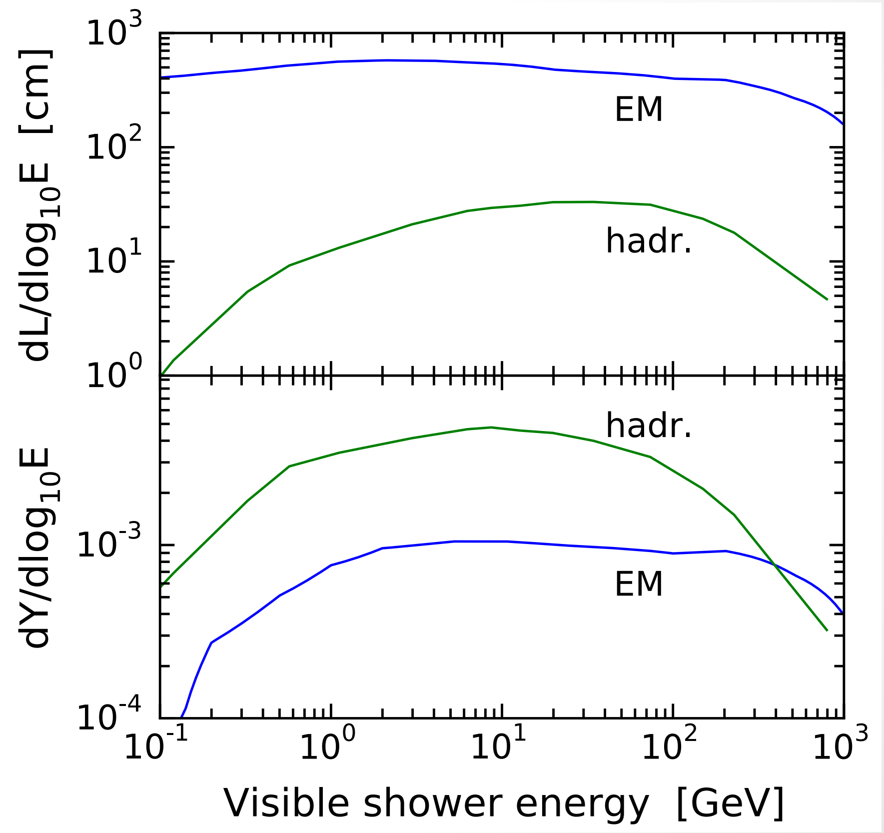
Shower length is small, ~ 5 m

2. Showers produce isotopes

Isotope parent spectra



E.M. vs. hadronic showers



Hadronic showers have π, n; they produce isotopes

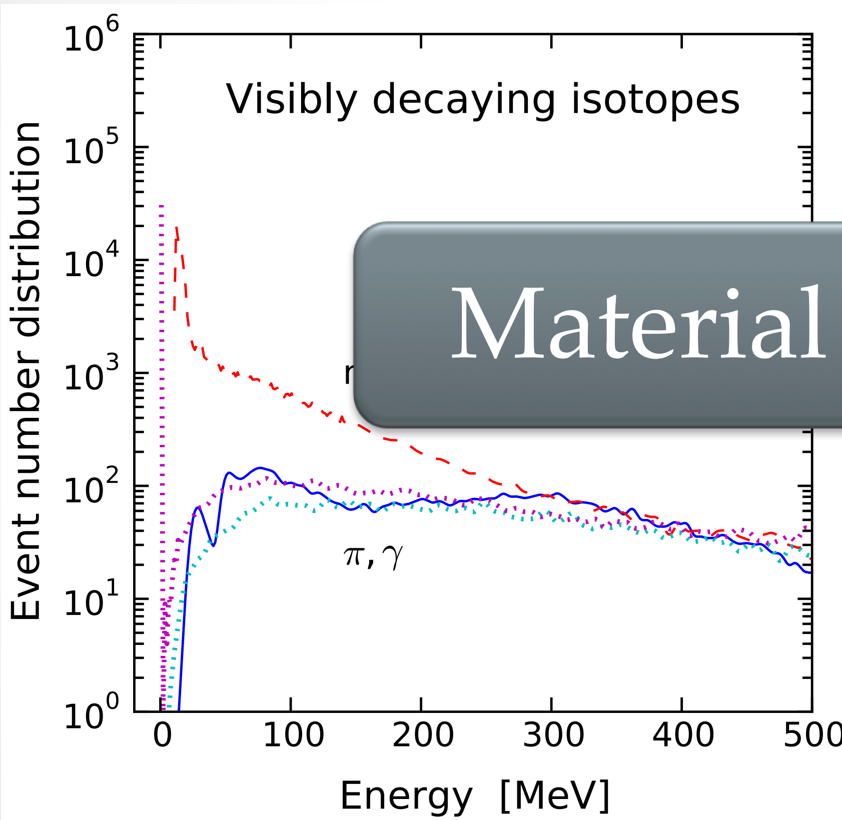
E.M. showers have γ

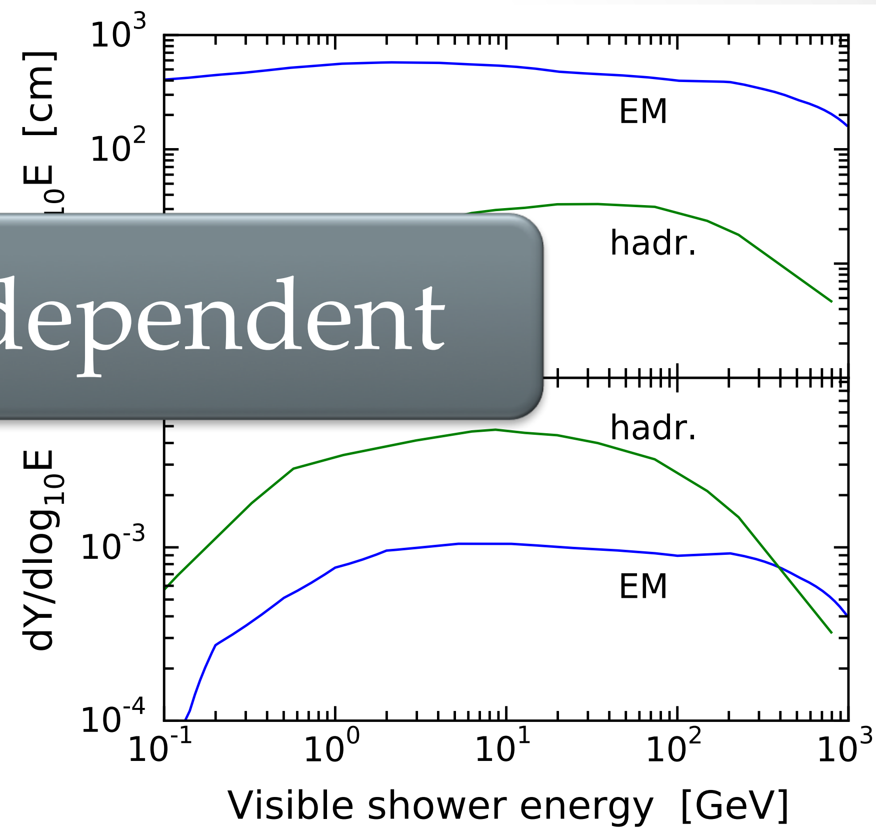
Li & Beacom
2014, 2015

2. Showers produce isotopes

Isotope parent spectra

E.M. vs. hadronic showers





Material dependent

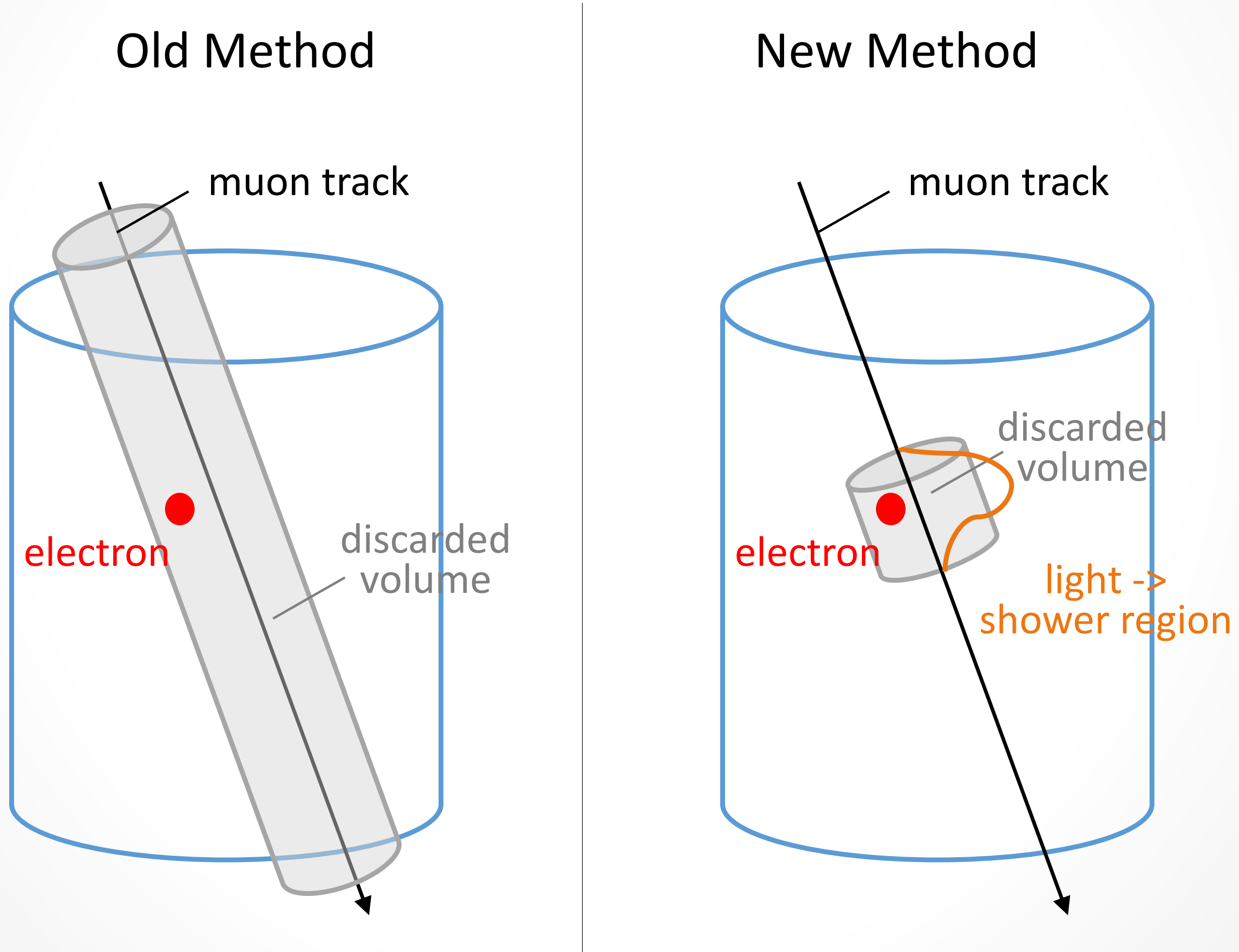
Hadronic showers have π, n; they produce isotopes

E.M. showers have γ

Li & Beacom
2014, 2015

How to apply cuts?

More accurate shower tagging

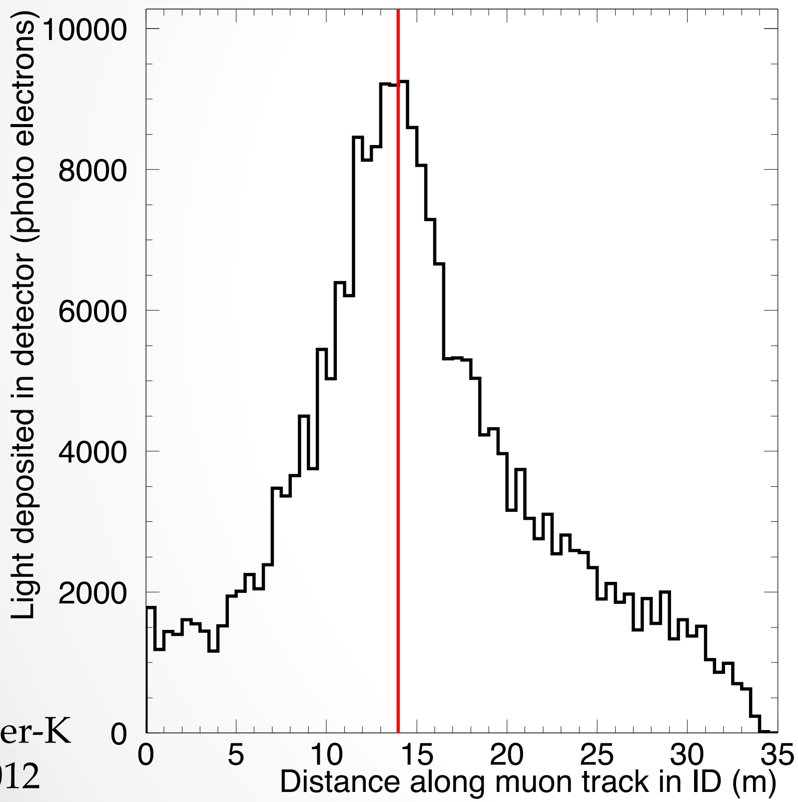


Less volume, less frequent cut => longer rejection time

Ways to identify showers

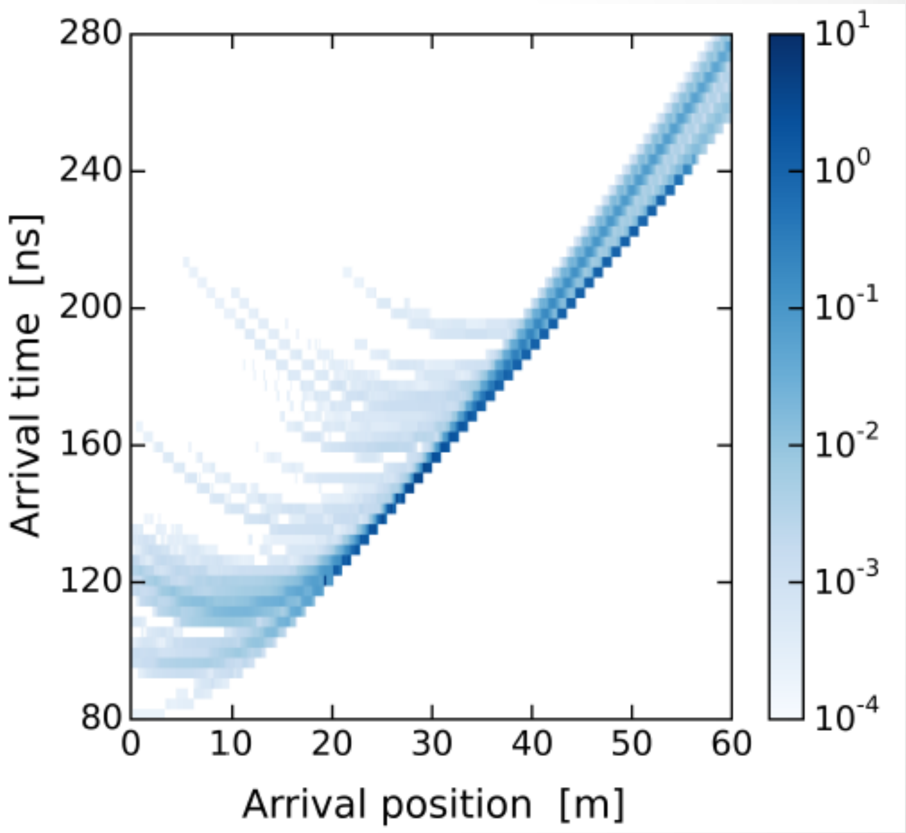
Light

Measured shower profile



Super-K
2012

Photon hit pattern



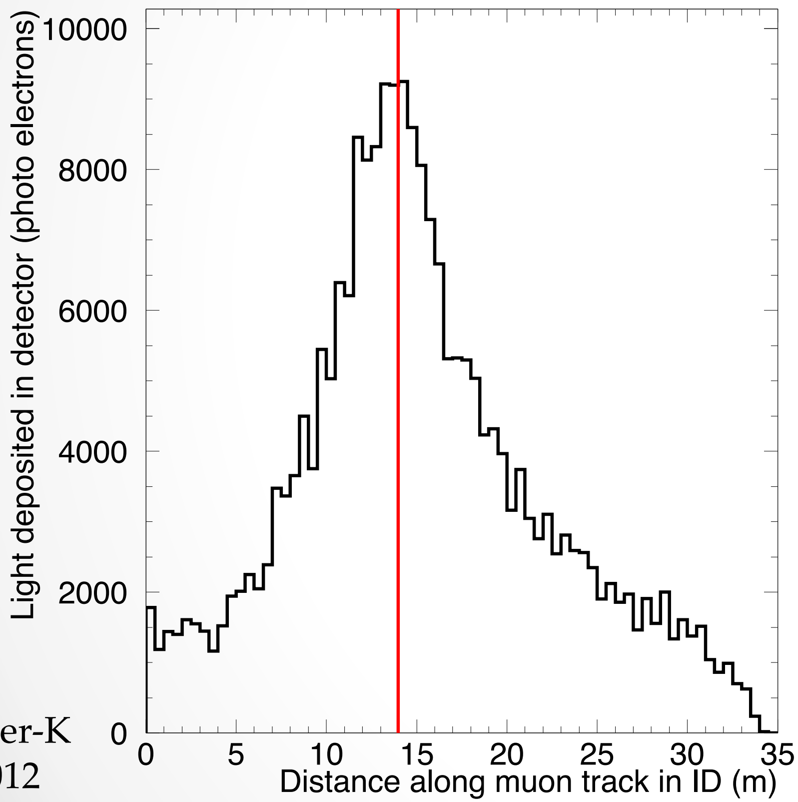
Li & Beacom
2015

Care is needed to properly reconstruct showers

Ways to identify showers

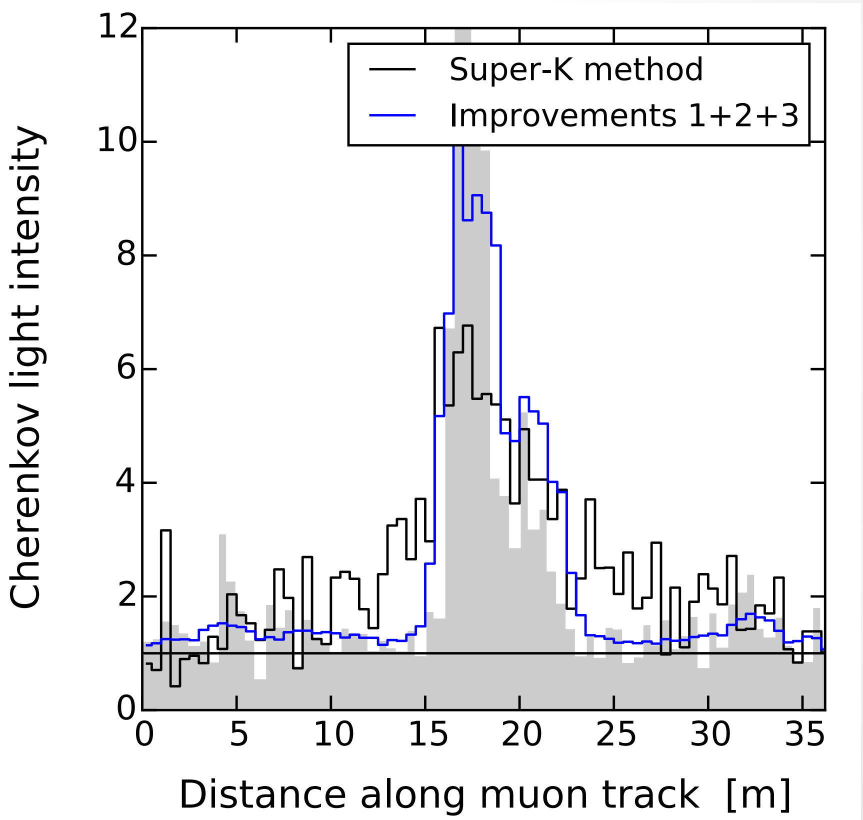
Light

Measured shower profile



Super-K 2012

New reconstruction method



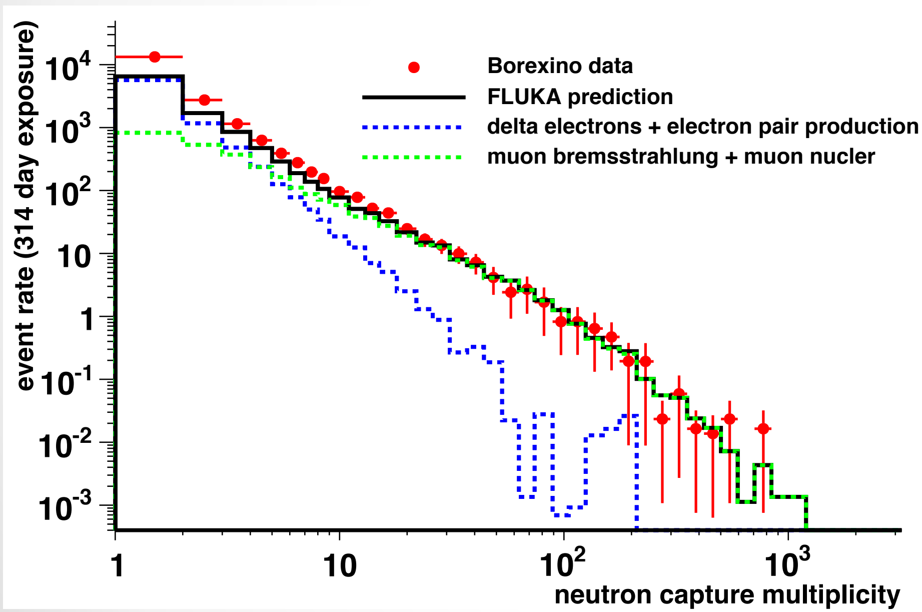
Li & Beacom 2015

Care is needed to properly reconstruct showers

Ways to identify showers

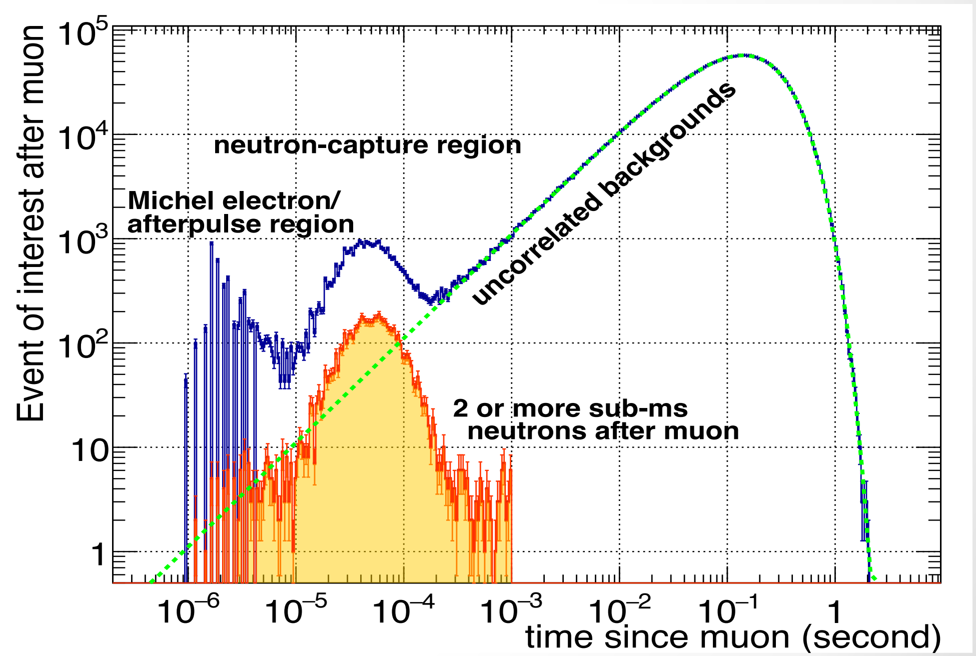
Neutron captures

Neutron multiplicity



Empl *et al.*, 2014

Using neutron captures to tag showers



Dazeley *et al.*, 2016

More efficient way to tag hadronic showers

Conclusions

- Cosmogenic backgrounds are critical for solar (8B, pep, CNO), reactor, $0\nu\beta\beta$ studies
- The main difficulty: no efficient way to tag the background-producing muons
- New opportunities arise: isotopes are made in muon-induced showers
- Need to identify showers better: light, neutron capture

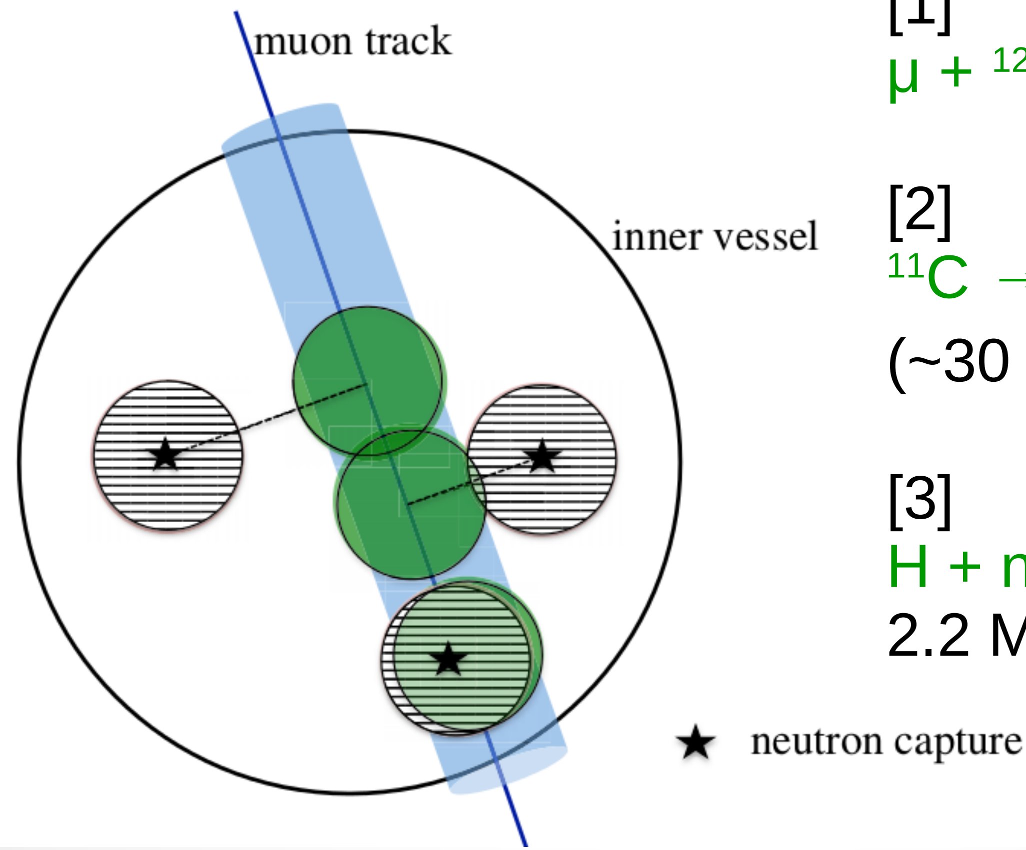
Thank you!

Back up

Current rejection methods

Example: Borexino

Three-Fold Coincidence



[1]
$\mu + {}^{12}C \rightarrow \mu + {}^{11}C + n$

[2]
${}^{11}C \rightarrow {}^{11}B + e^{+} + \nu_e$
(~30 min)

[3]
$H + n \rightarrow D + \gamma$
2.2 Mev (250 μs)

Borexino
2014

Studies with more materials

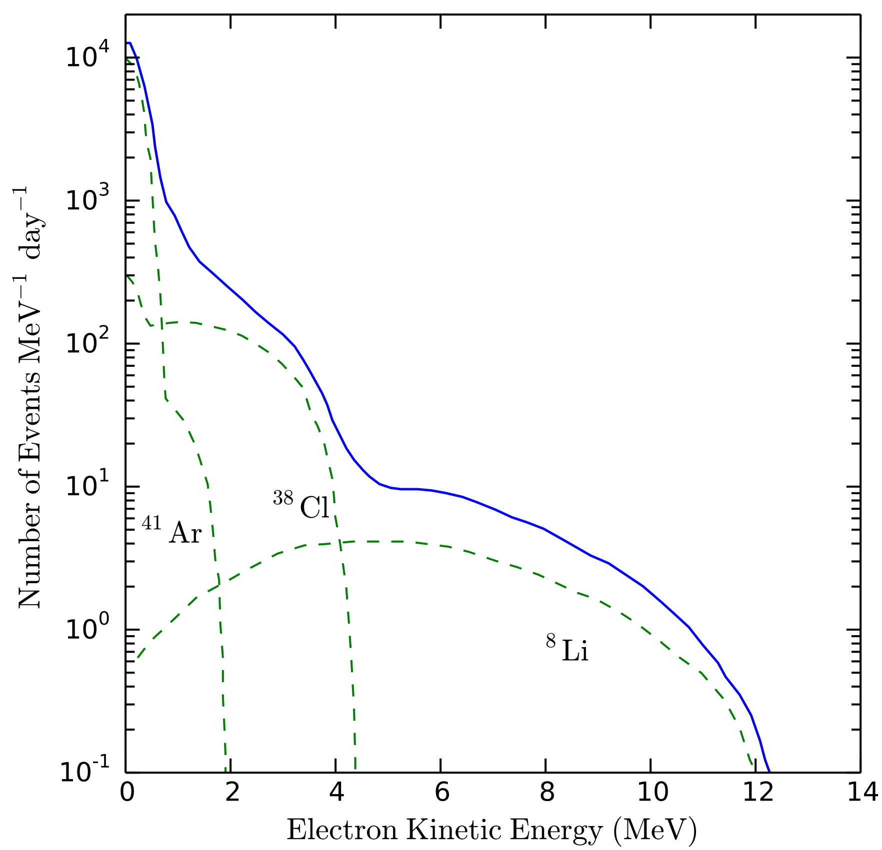
^{136}Xe

Region/ Nuclide	Half-life	Total energy (keV)	2.3–2.6 MeV efficiency	EXO-200 SS ROI efficiency	Geant4 rate (yr^{-1})	FLUKA rate (yr^{-1})
HFE-7000 ^{16}N	7.1 s	10420	0.015%	0.001%	2380 ± 90	2910 ± 110
TPC vessel ^{60}Co	5.3 y	2823	0.19%	0.0002%	2.6 ± 0.3	2.9 ± 0.6
TPC LXe ^{130}I	12 h	2949	8.5%	0.001%	7.3 ± 0.5	21.6 ± 1.8
TPC LXe ^{132}I	2.3 h	3581	5.5%	0.013%	7.7 ± 0.5	22.2 ± 1.8
TPC LXe ^{134}I	53 m	4175	4.5%	0.012%	7.3 ± 0.5	20.4 ± 1.7
TPC LXe ^{135}I	6.6 h	2627	2.9%	0.035%	8.6 ± 0.6	21.6 ± 1.8
TPC LXe ^{135}Xe	9.1 h	1165	—	—	1110 ± 40	1060 ± 40
TPC LXe ^{137}Xe	3.8 m	4173	4.1%	1.5%	439 ± 17	403 ± 16

EXO-200 2016

^{40}Ar

Zhu *et al.*, in prep



More data provided to model hadronic interactions