Status of the HALO Detector

Tom Sonley

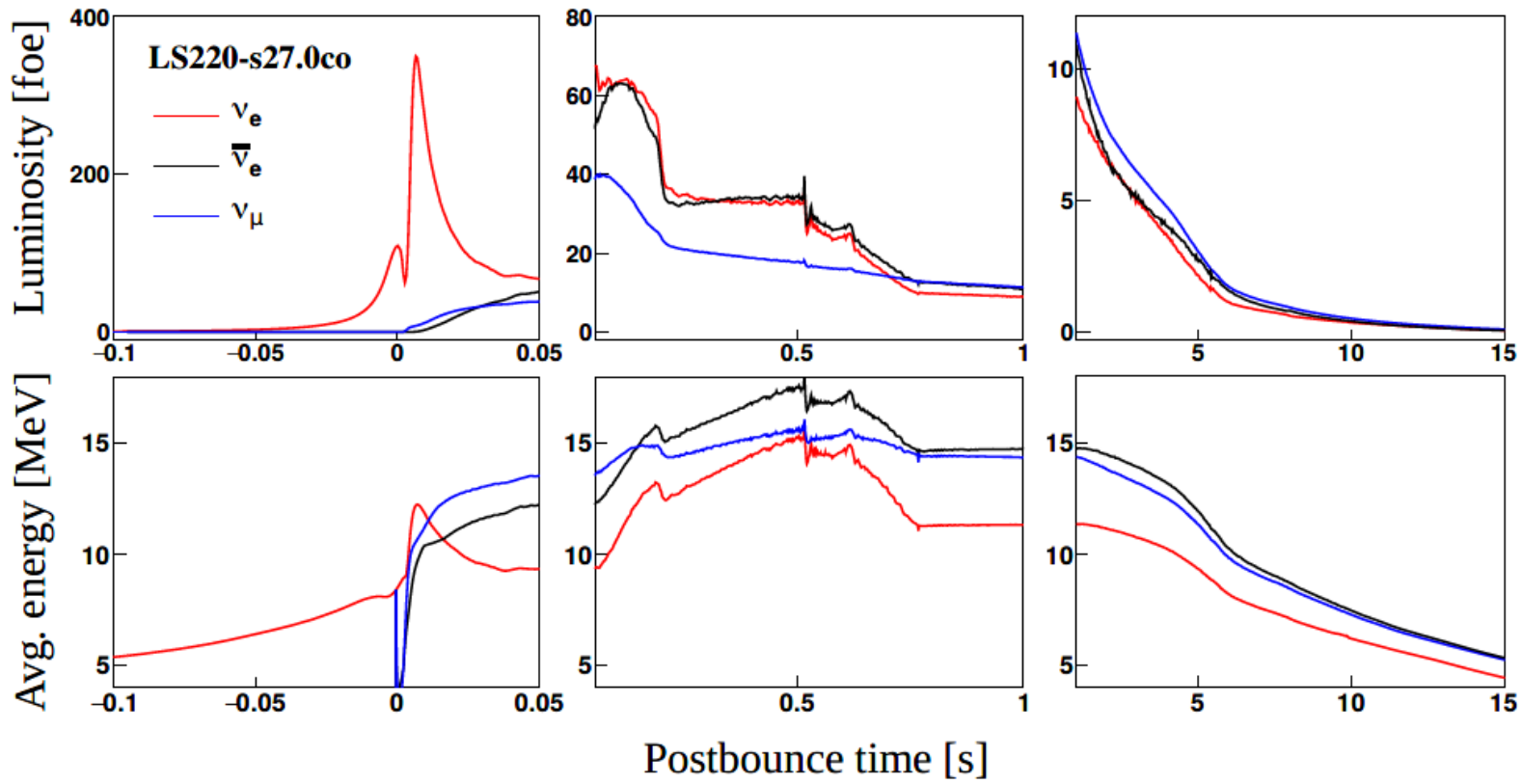
SNOLAB Future Projects Workshop

July 2019

Status Overview

- Commissioned in May 2012
- Connected to SNEWS in October 2015
- 99.3% live fraction in last 2 years
- No supernova neutrino bursts detected
  - P(0 bursts | 7 years) around 70%
- Calibration Run Spring and Summer 2016
- Tune up underway this summer

Supernova models[1]



[1] SN models provided by the Garching group. See A. Mirizzi et al. *Rivista del Nuovo Cimento* Vol. 39 N. 1-2 (2016).

★ CC

$$\nu_e + {}^{A}Pb \rightarrow {}^{A}Bi^{*} + e^{-}$$

$${}^{A}Bi^{*} \rightarrow {}^{A-1,2}Bi + (1,2)n + \gamma$$

★ NC

$$\nu_X + {}^{A}Pb \rightarrow {}^{A}Pb^{*} + \nu_X$$

$${}^{A}Pb^{*} \rightarrow {}^{A-1,2}Pb + (1,2)n + \gamma$$

★ Pb-Isotopes

Isotope	nat. abund. (%)	S_n (MeV)
204	1.4	8.395
206	24.1	8.088
207	22.1	6.738
208	52.4	7.367

In 79 tonnes of lead for a SN @ 10kpc†,

- Assuming FD distribution with T=8 MeV for ν_μ's, ν_τ's.
- 68 neutrons through ν_e charged current channels
  - 30 single neutrons
  - 19 double neutrons (38 total)
- 20 neutrons through ν_x neutral current channels
  - 8 single neutrons
  - 6 double neutrons (12 total)

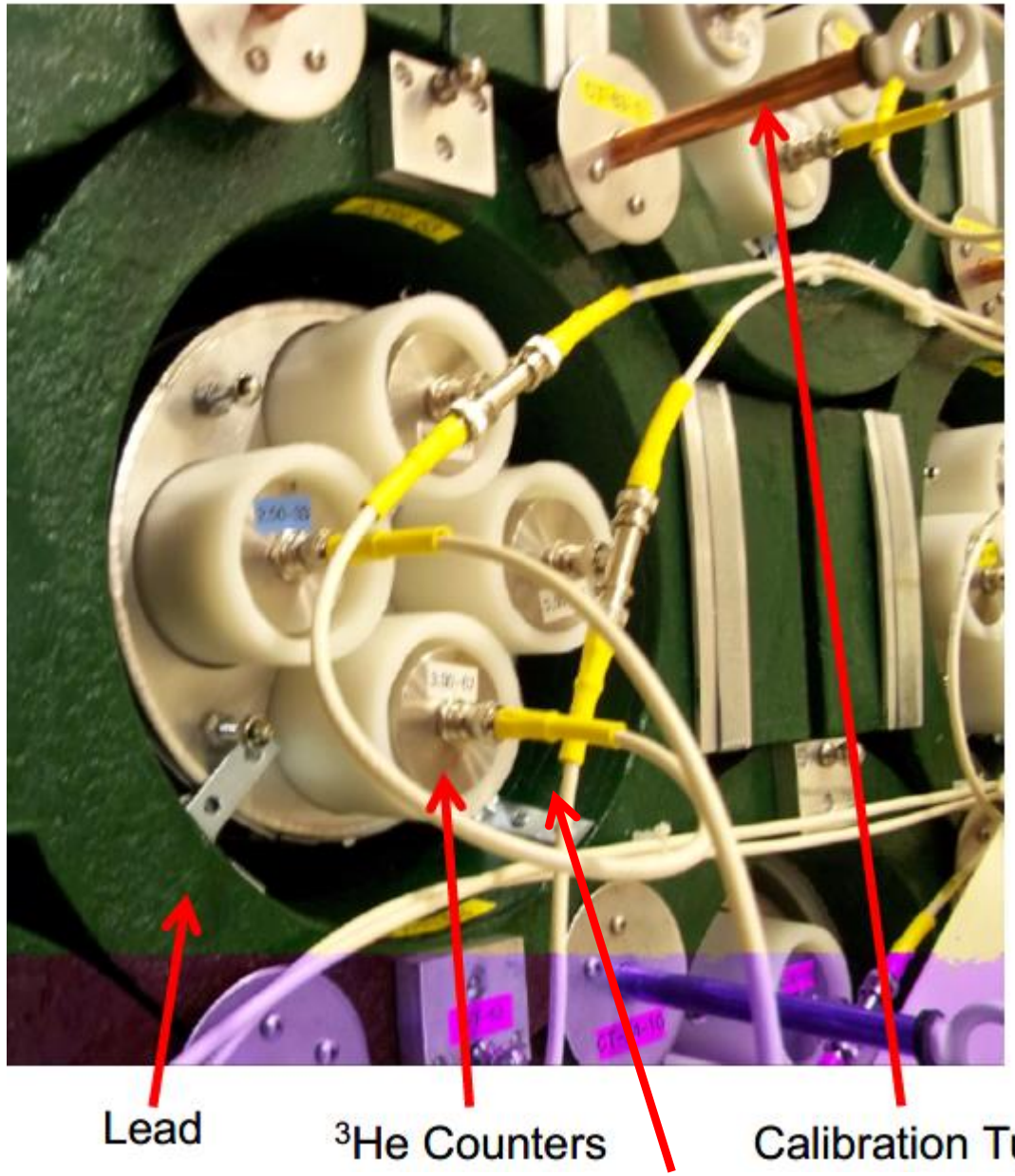
~ 88 neutrons liberated

~ 25 detected neutrons

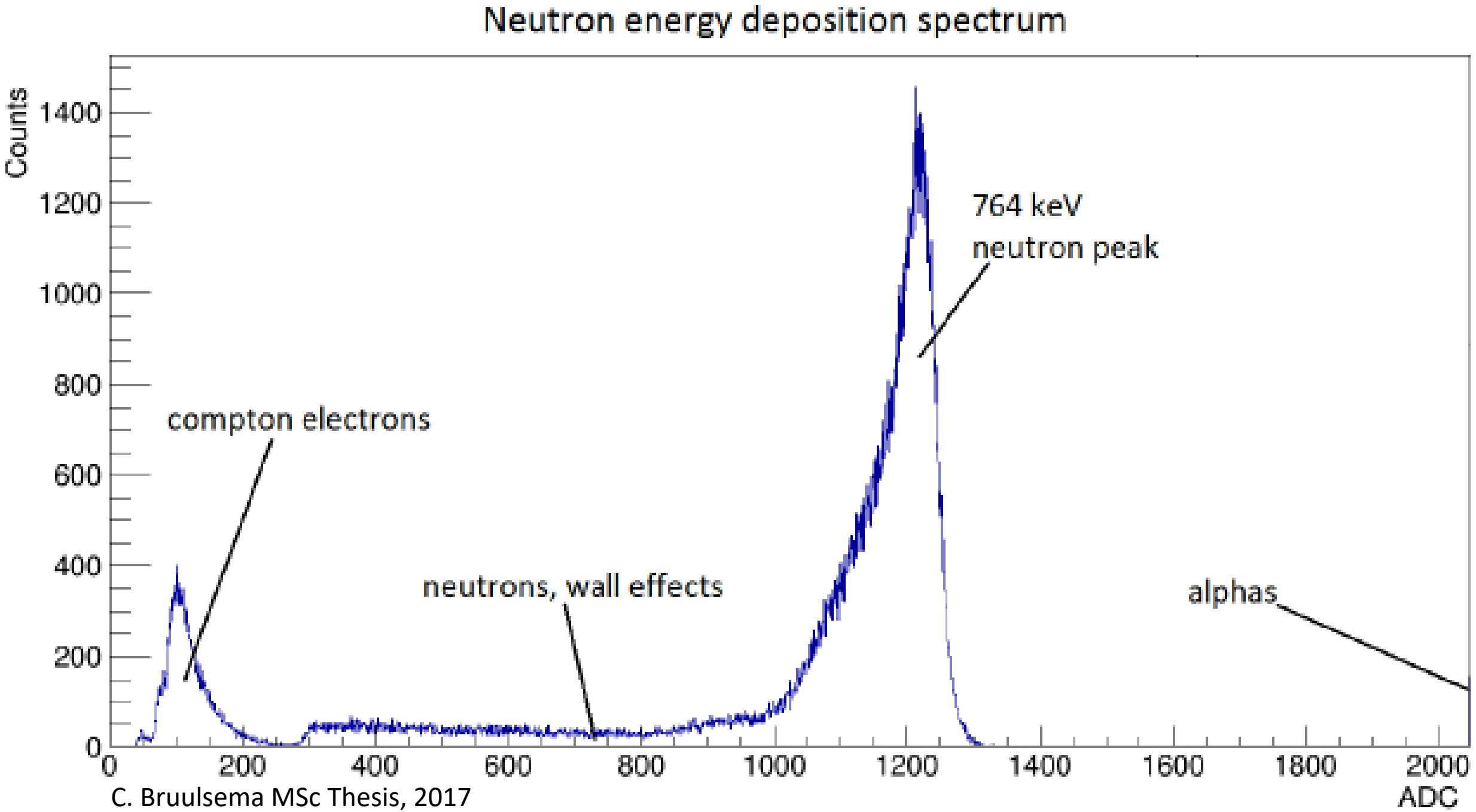
- 28% average detection efficiency

†- cross-sections from Engel, McLaughlin, Volpe, Phys. Rev. D 67, 013005 (2003)

- Re-using SNO's "NCD" ^{3}He proportional counters
- 5 cm diameter x 3m in length, ultra-pure CVD Ni tube (600 micron wall thickness)
- 2.5 atm (85% ^{3}He, 15% CF_4, by pressure)
- Four detectors with HDPE moderator tubes in each of 32 columns of lead rings
- Gain matched and paired for 64 channels total of readout
- neutron capture lifetime of 200 us is fast enough to resolve most SN features, and potentially allow triangulation with other detectors (~500 us).

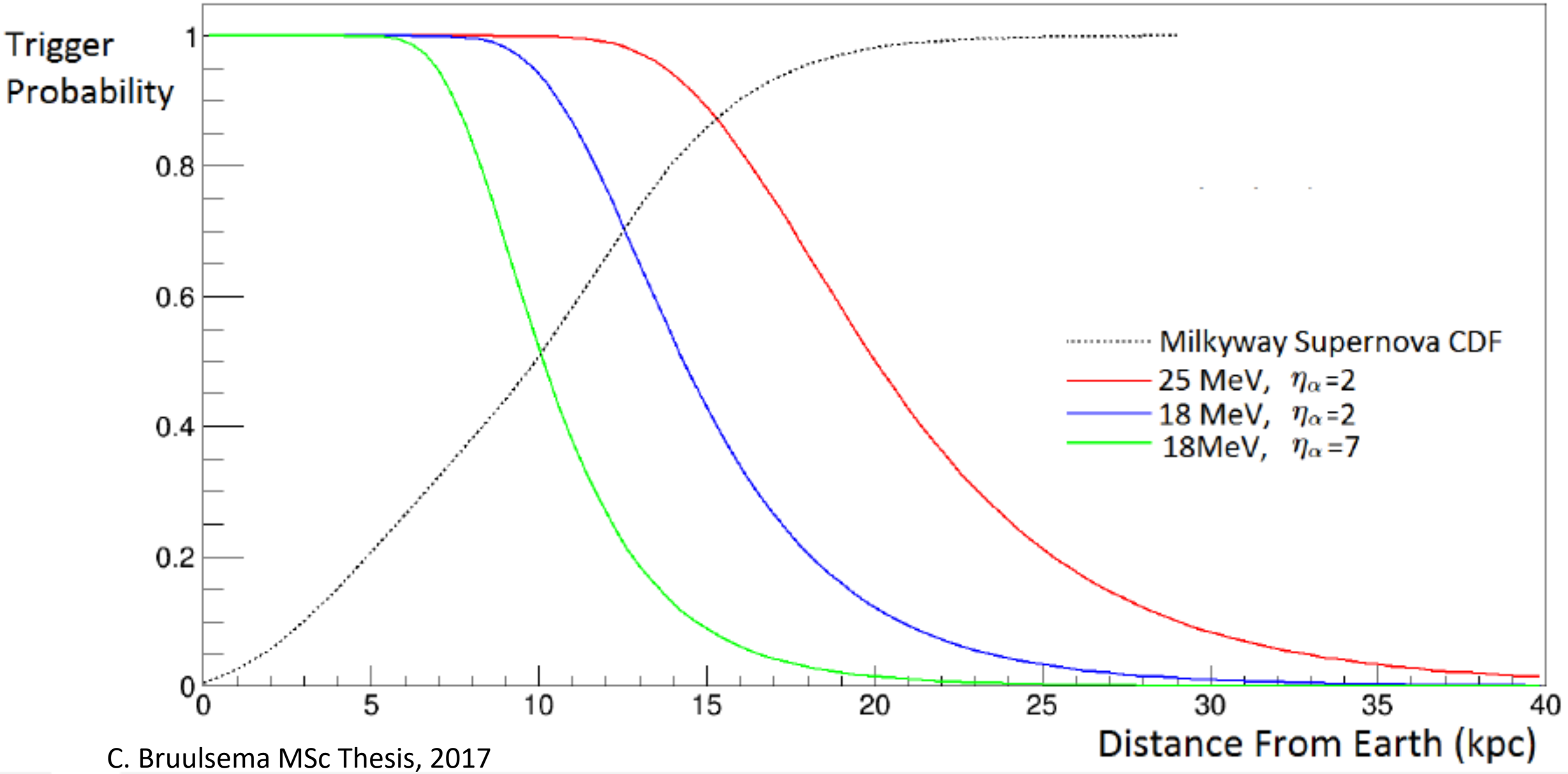


Steel Support Ring (on bottom 5 of 7 layers)



C. Bruulsema MSc Thesis, 2017

Supernova Detection Range



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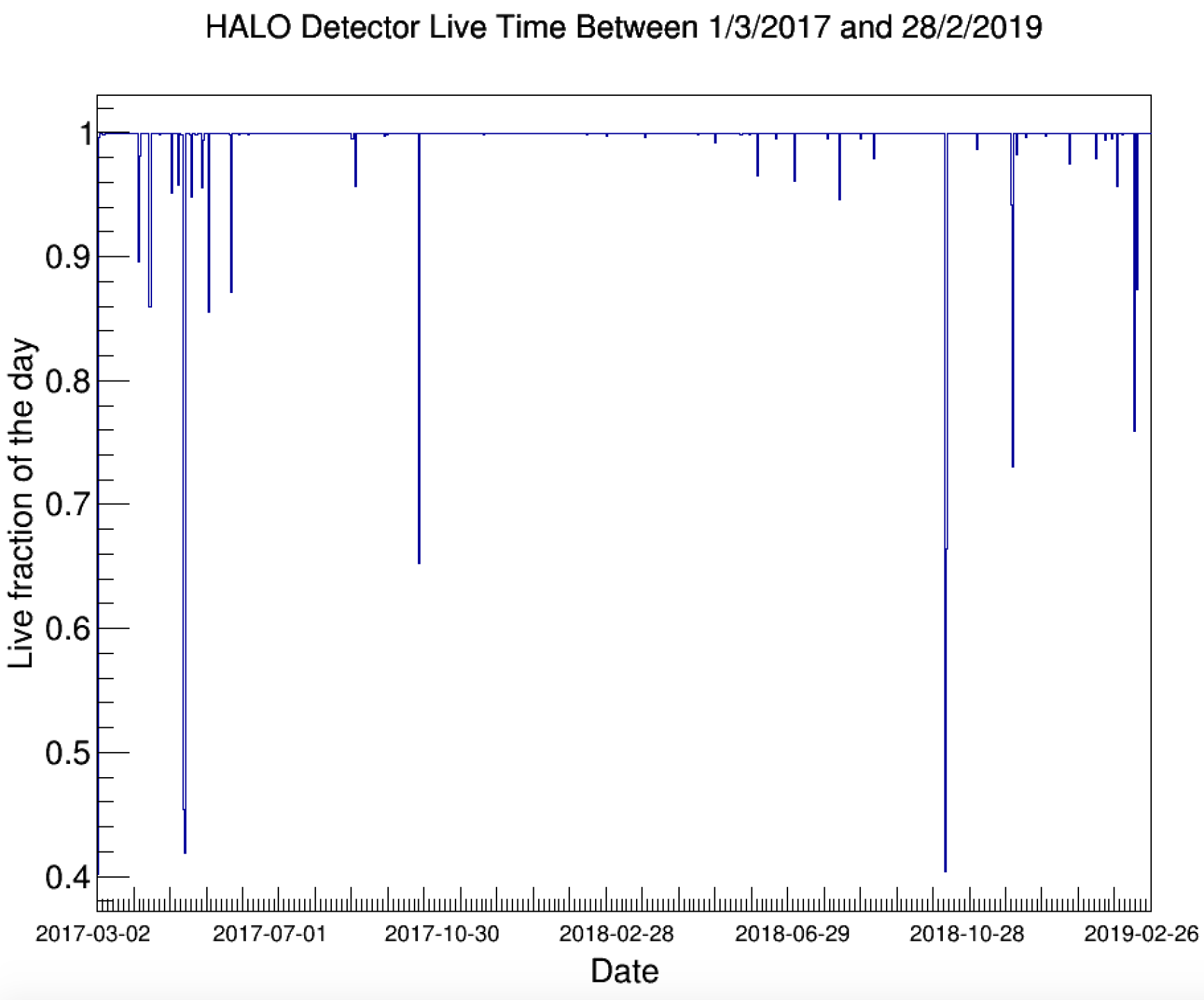


99.3% Livetime

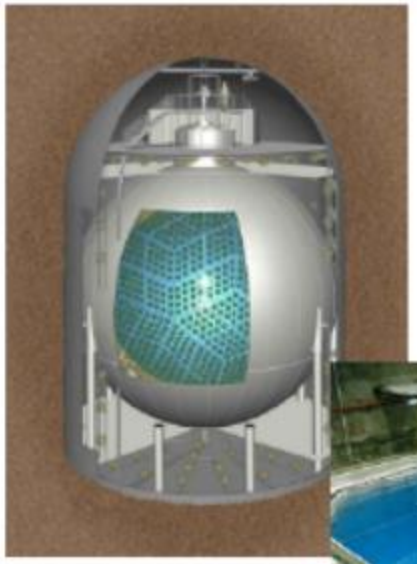
Losses of Livetime:

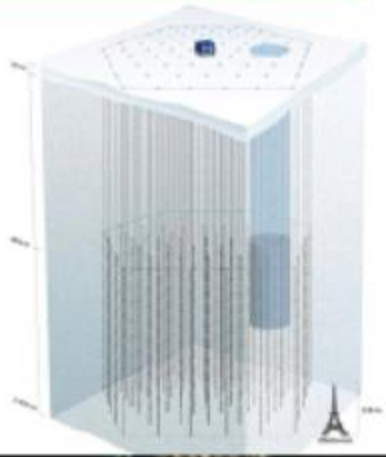
- Power Outages 2017
- DAQ crashes in 2018-2019

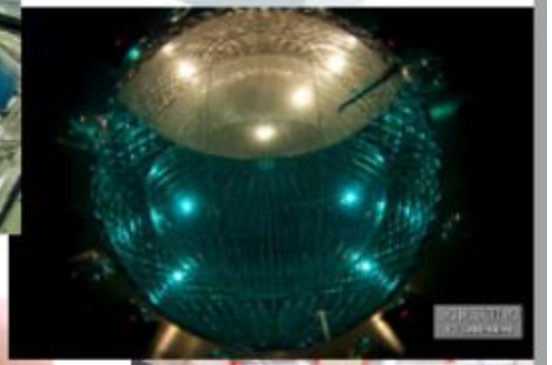
The Experiments

UMD DULUTH

- Currently:
  - Super-K
  - LVD
  - IceCube
  - Borexino
  - Daya Bay
  - Kamland
  - HALO
- Alumni:
  - MACRO, SNO, AMANDA
- Operational but not SNEWS contributors:
  - Baksan, μBoone
- Near-Future participants
  - NOvA, Km3Net, SNO+







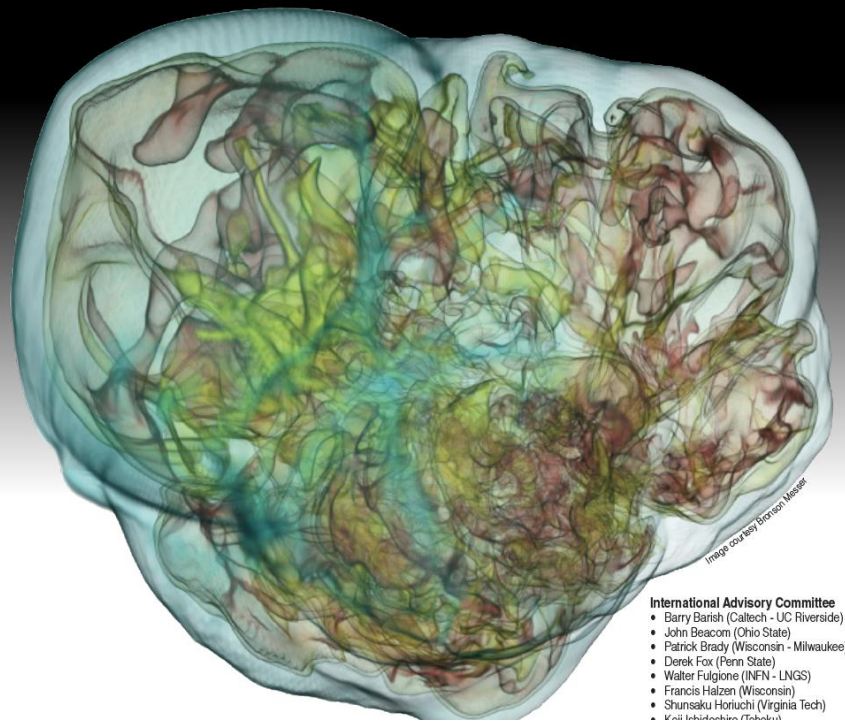
A. Habig

SuperNova Early Warning System

SNEWS 2.0 Workshop

Supernova Neutrinos in the Multi-Messenger Era

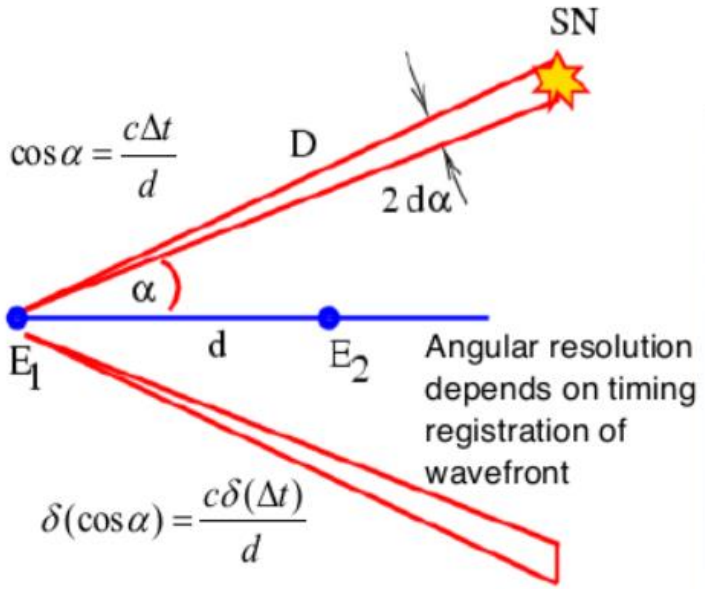
June 14-17, 2019
Laurentian University, Sudbury, Canada



International Advisory Committee

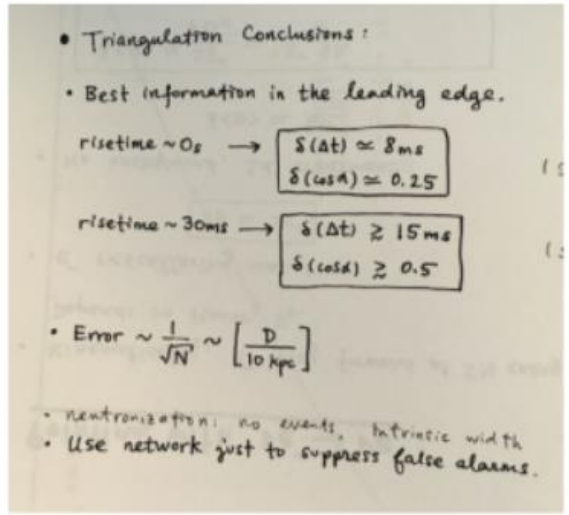
- Barry Barish (Caltech - UC Riverside)
- John Beacom (Ohio State)
- Patrick Brady (Wisconsin - Milwaukee)
- Derek Fox (Penn State)
- Walter Fulgione (INFN - LNGS)
- Francis Halzen (Wisconsin)
- Shunsaku Horiuchi (Virginia Tech)
- Koji Ishidoshiro (Tohoku)

Triangulation



Angular resolution depends on timing registration of wavefront

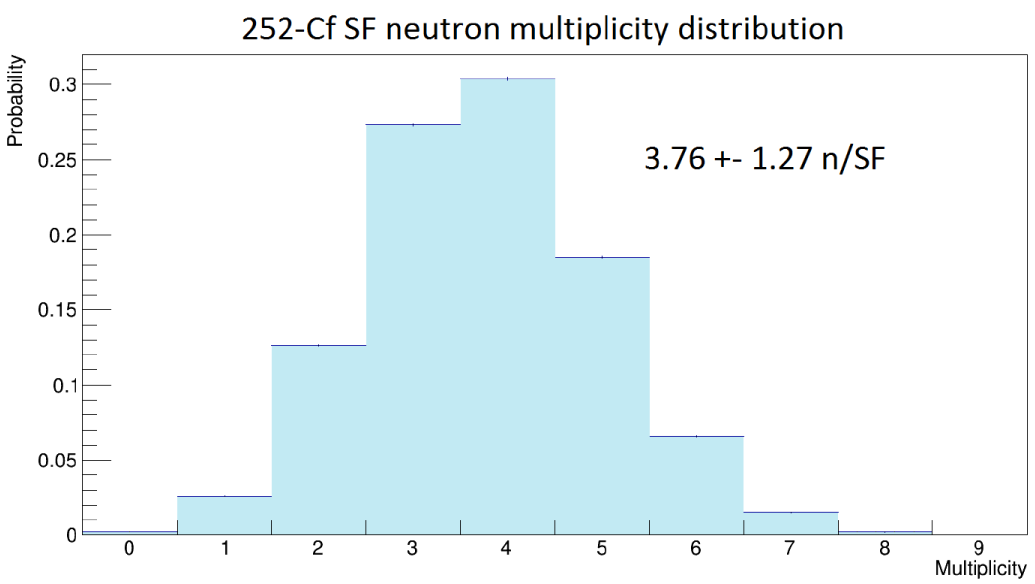
In 1998, John Beacom was pretty down on this....



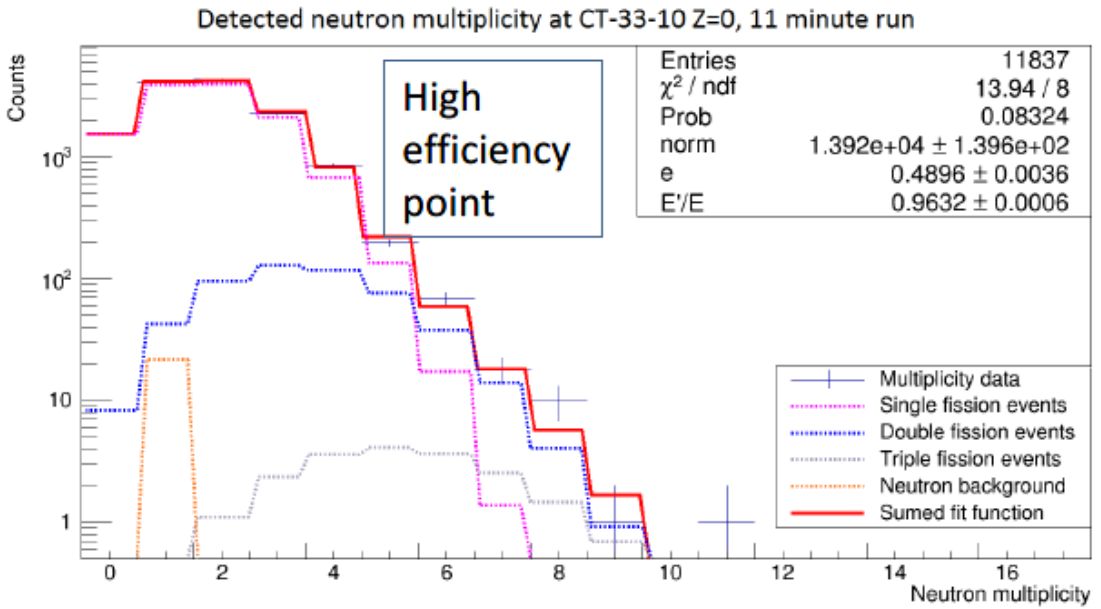
Can a supernova be located by its neutrinos?
John F. Beacom, P. Vogel (Caltech). Nov 1998. 10 pp.
Published in **Phys.Rev. D60 (1999) 033007**

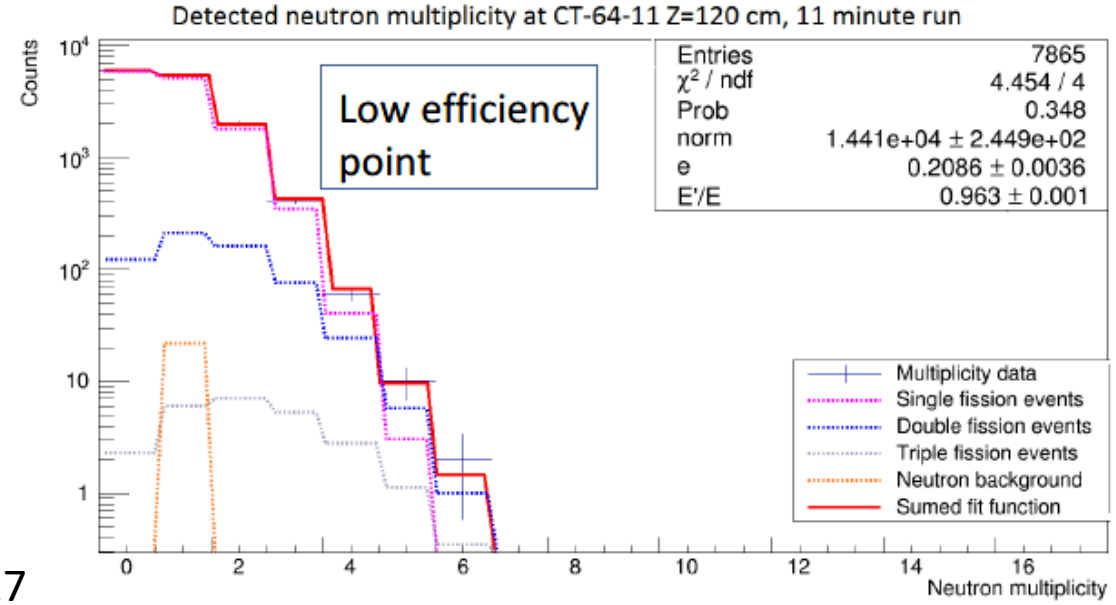
Conclude that triangulation is not a good prospect
... too low stats, also hard in practice;
requires extensive data exchange to account for detector response...

2016 Calibration Campaign



- 20 Bq ^{252}Cf source
- 192 locations
- ~ 5 days of livetime





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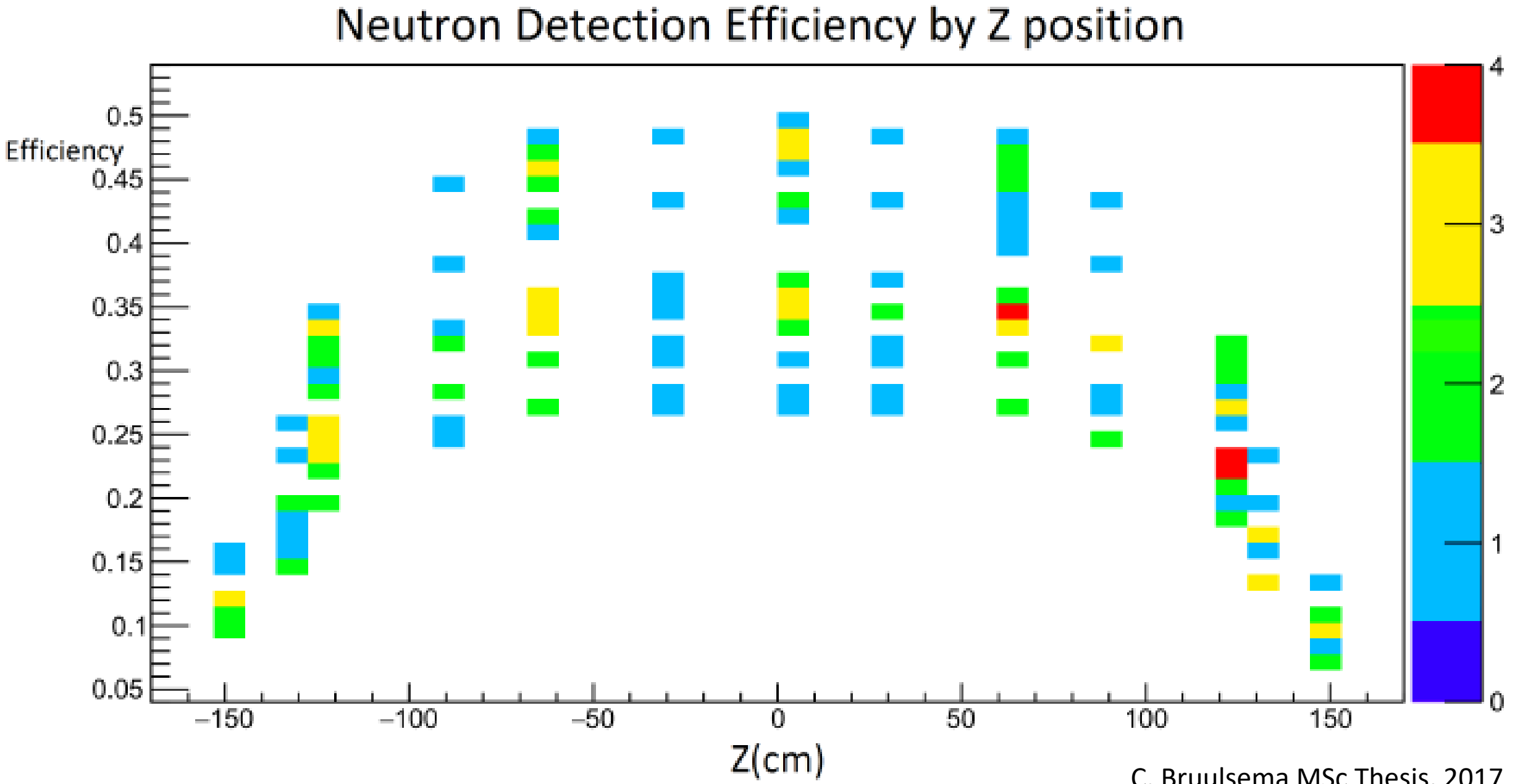

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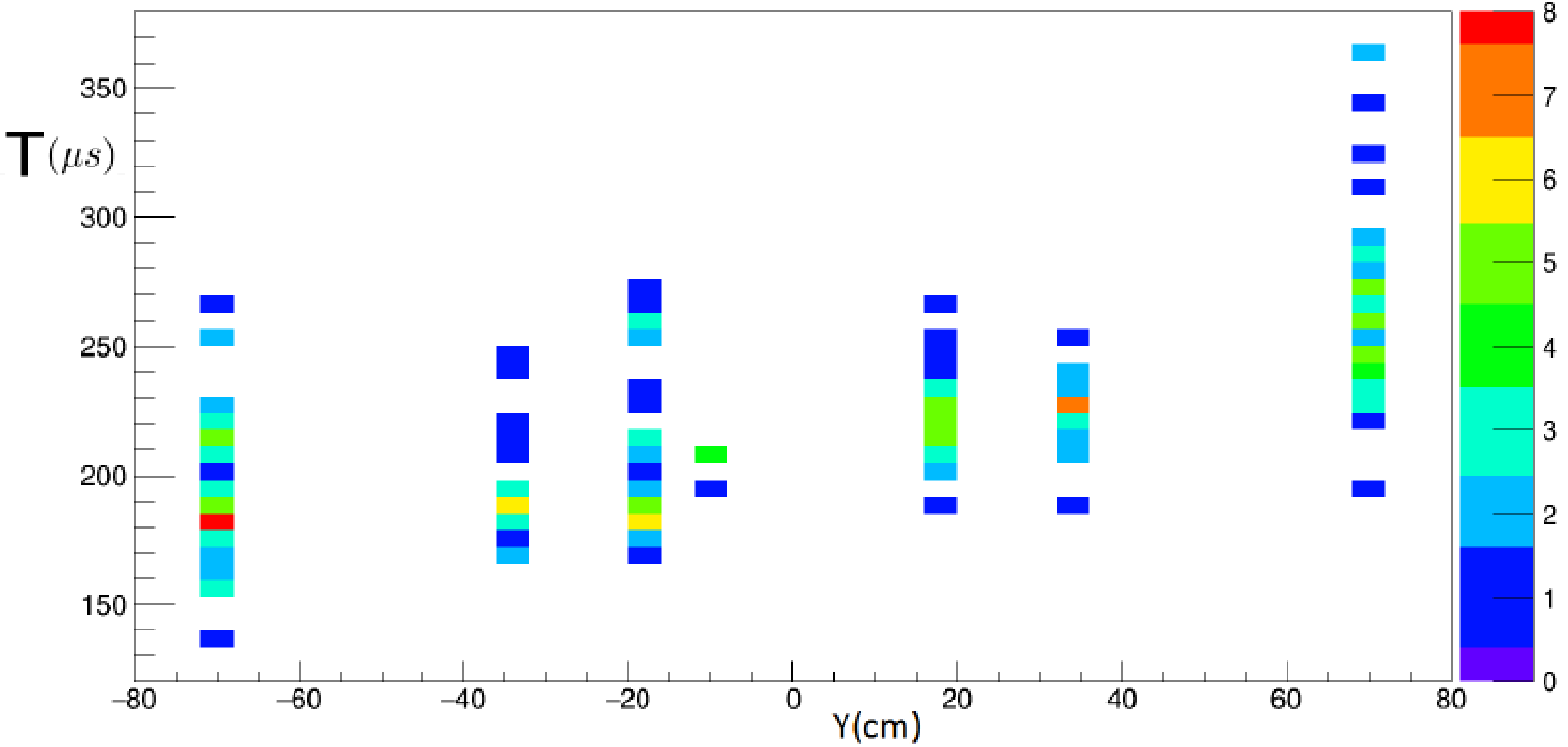
Fit neutron capture time by height in the detector



C. Bruulsema MSc Thesis, 2017

Future Prospects

- Continue watching for supernovae on a galactic timescale
- Improve Pb-ν cross section measurements
- HALO 1kT

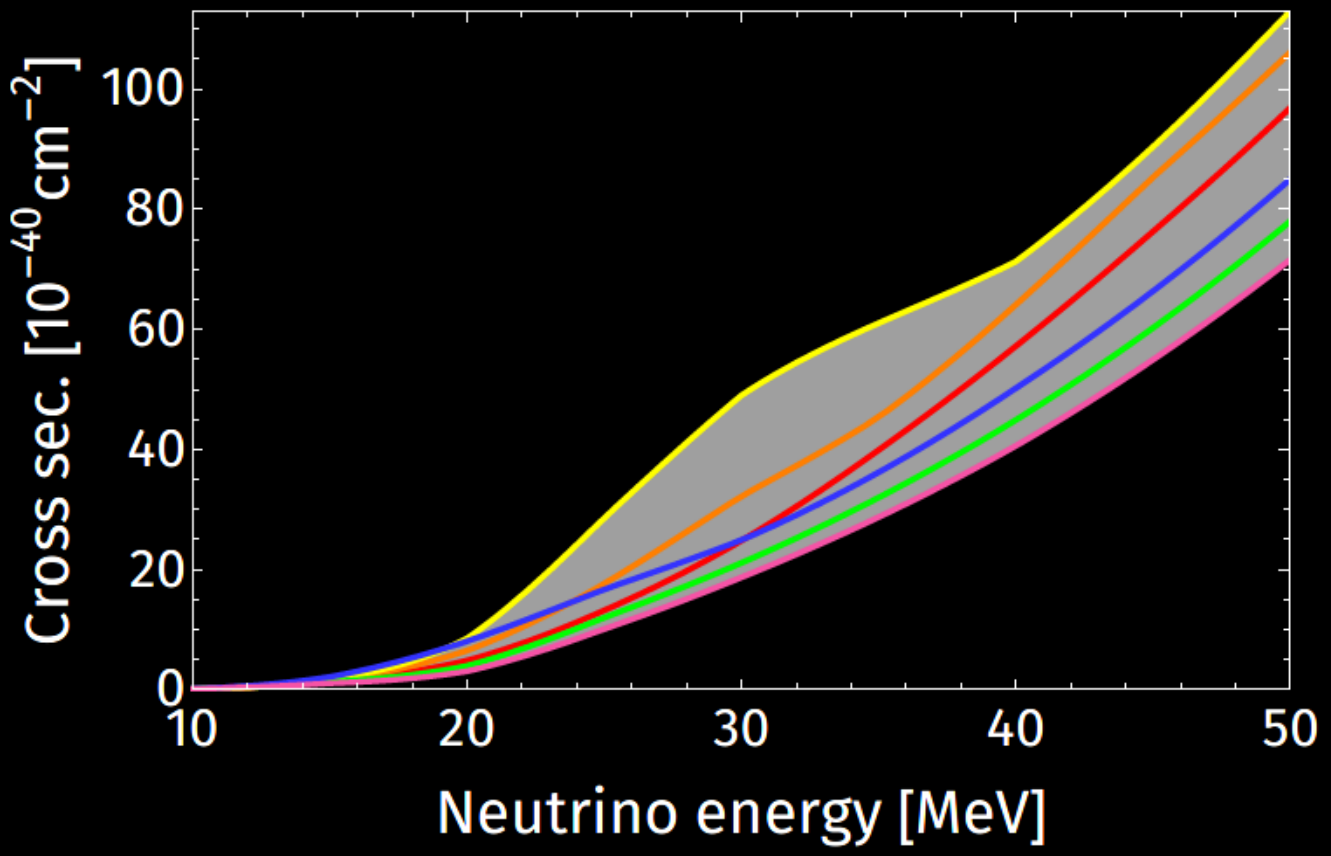
Cross sections on the market

	Lead isotopes			Cross sec.		CC/NC			
	204	206	208	1n, 2n	total	ν_e	$\overline{\nu}_e$	ν	$\overline{\nu}$
Kolbe	✗	✗	✓	✗	✓	✓	✗	✓	✗
Engel	✗	✗	✓	✓	✓	✓	✗	✓	✓
Lazauskas	✗	✗	✓	✗	✓	✓	✓	✗	✗
Almosly	✓	✓	✓	✗	✓	✓	✓	✓	✓

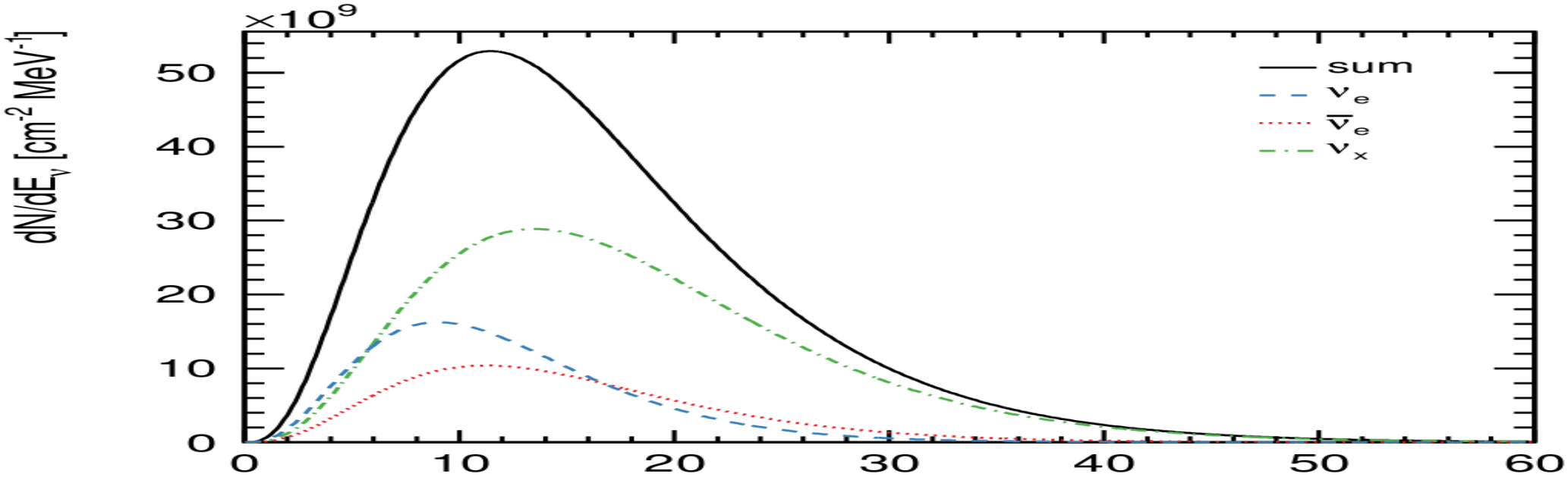
- E. Kolbe, K. Langanke, Phys. Rev. C63 (2001).
- J. Engel, G.C. McLaughlin, C. Volpe, Phys. Rev. D67 (2003).
- R. Lazauskas, C. Volpe, Nucl. Phys. A792 (2007).
- W. Almosly et al., Phys. Rev. C94 (2016) no.4 and Phys. Rev. C99 (2019) no.5.

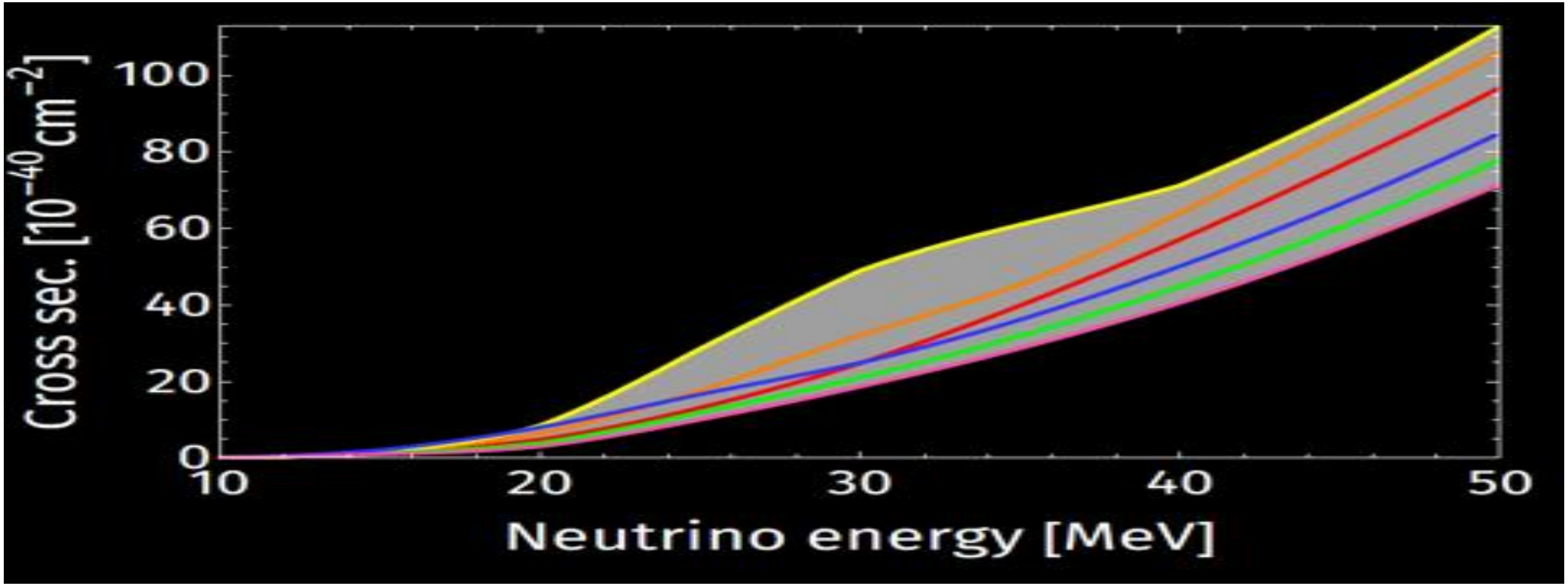
Slides by A. Gallo Rosso

Charged-current ν_e cross section

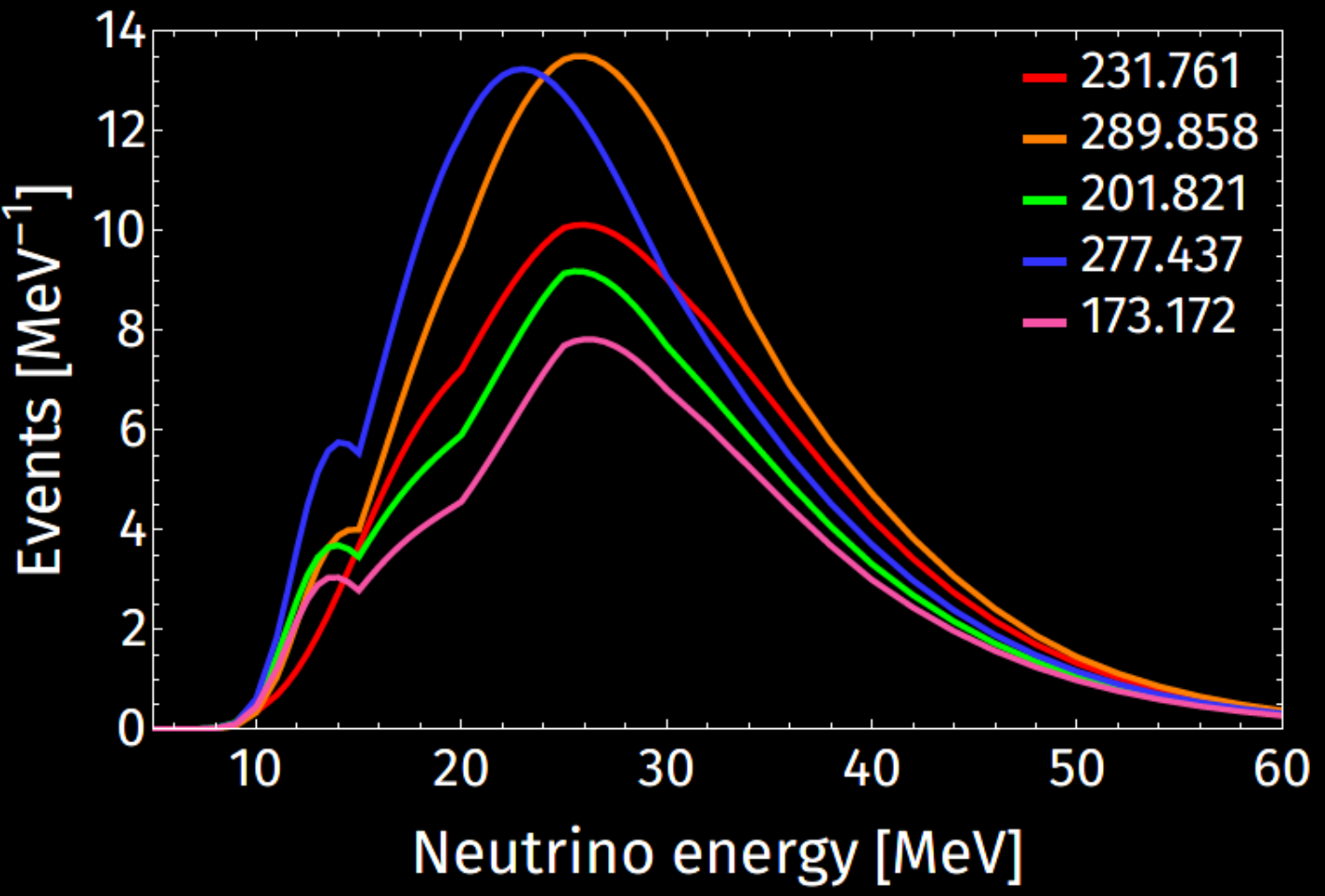


Kolbe and Langanke (2001)
Engel et al. (2003)
Lazauskas and Volpe (2007)
Almosly et al. (2016) SkM*
Almosly et al. (2016) SkX
Almosly et al. (2016) SLy4

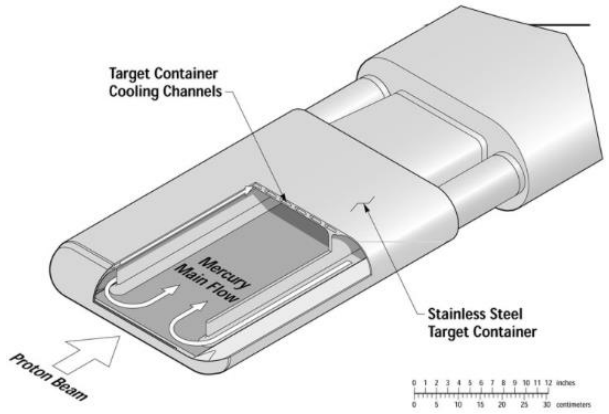

dN/dE$_\nu$ [cm^{-2} MeV^{-1}]
x10^9
0
10
20
30
40
50
0
10
20
30
40
50
60
sum
ν_e
$\bar{\nu}_e$
ν_x


Cross sec. [10^{-40}cm^{-2}]
0
20
40
60
80
100
10
20
30
40
50
Neutrino energy [MeV]

Charged-current ν_e events NH



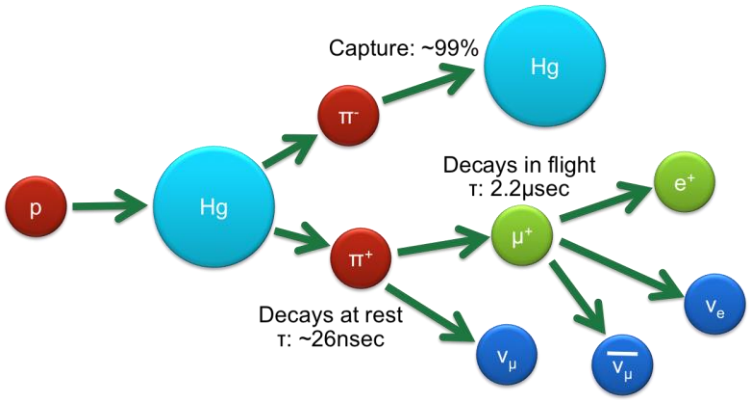
K. Scholberg

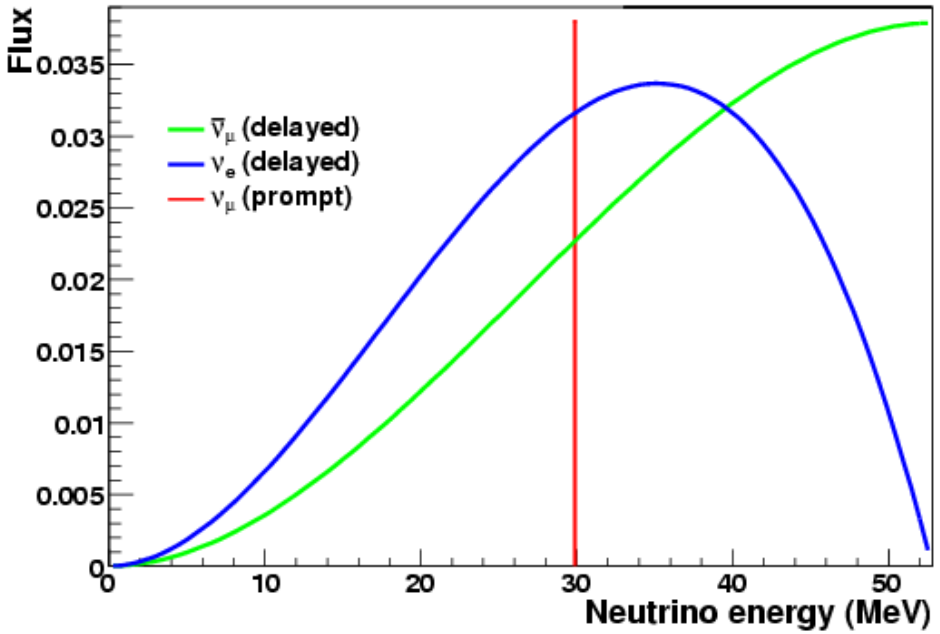


Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

Stopped-Pion (π DAR) Neutrinos

K. Scholberg





$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

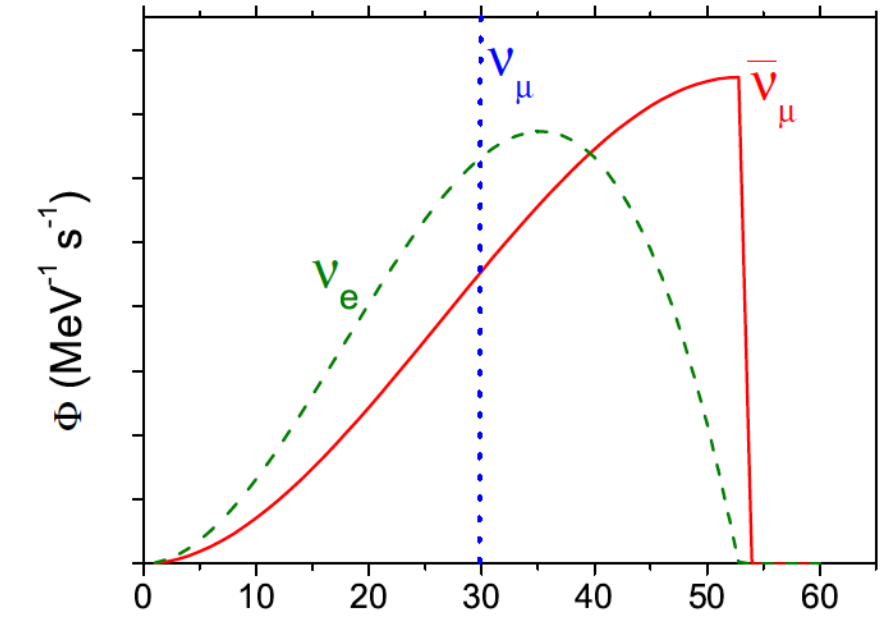
2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

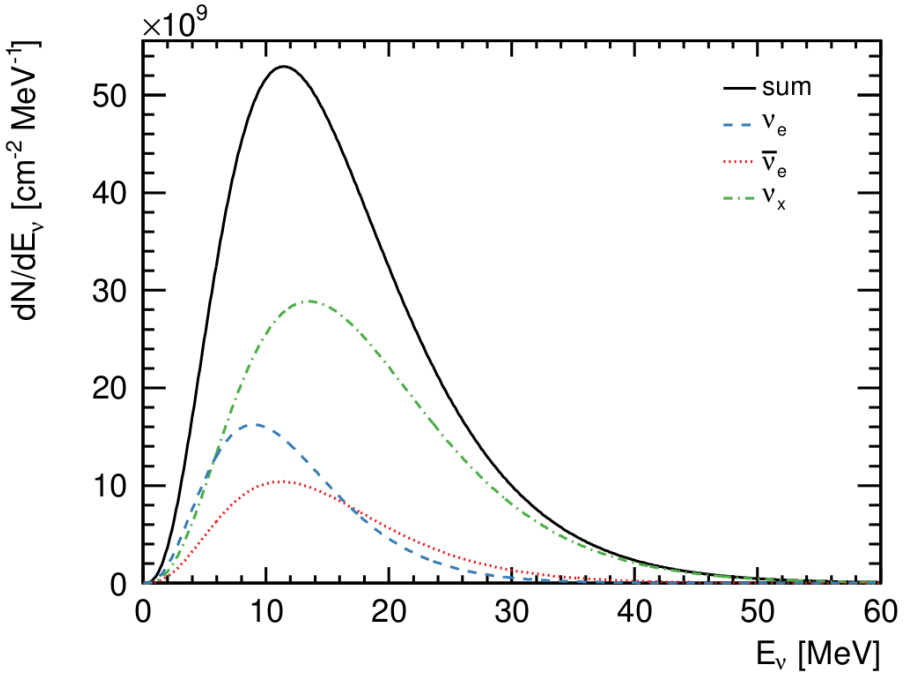
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$ DELAYED (2.2 μs)

SNS is the facility to measure cross sections at SN-relevant energies

- huge fluxes ~ 1 SN/day at 20 m
- good energy overlap between DAR neutrinos and SN spectra
- pulsed beam structure





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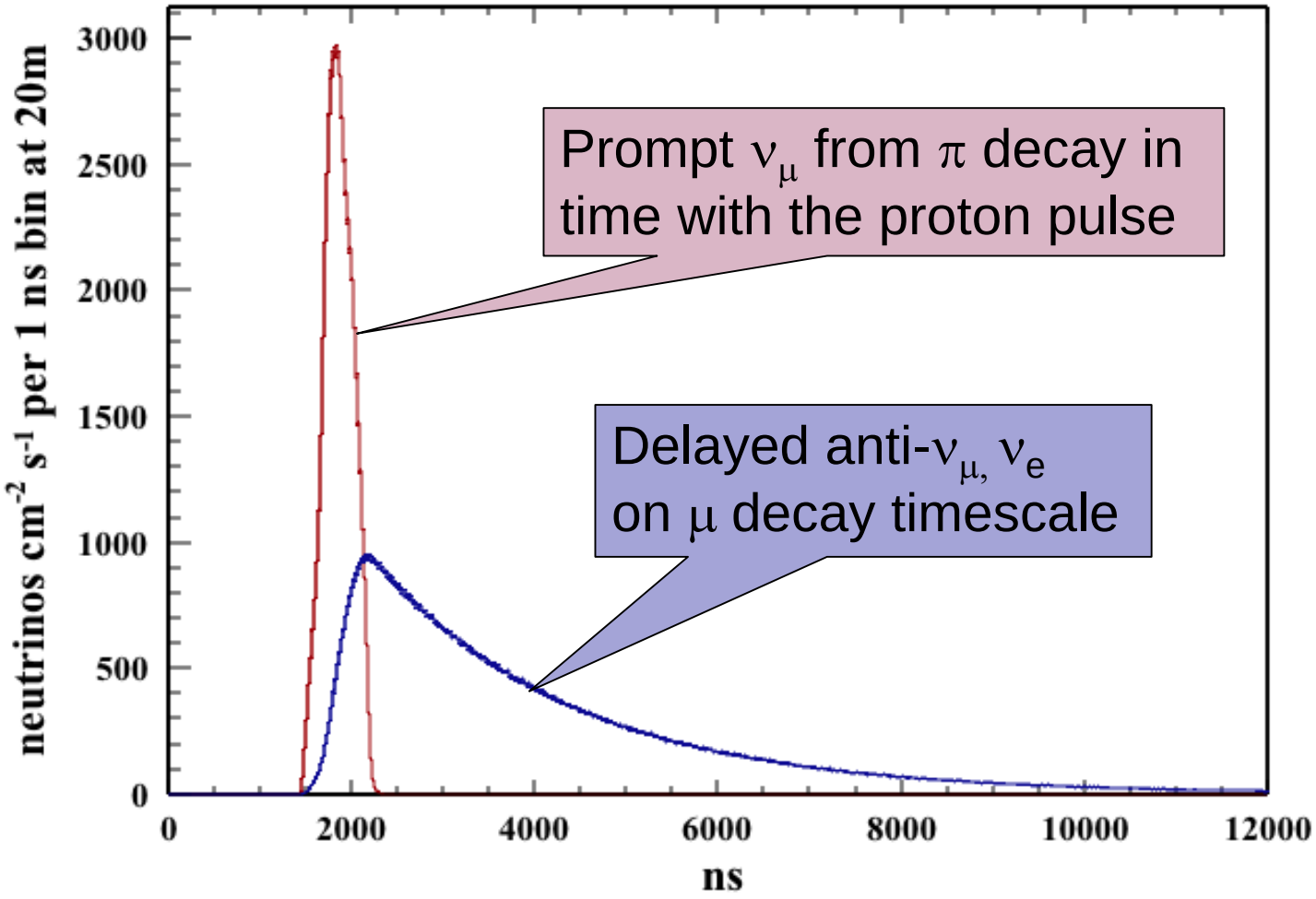
Time structure of the SNS source

60 Hz *pulsed* source



Background rejection factor ~few x 10^{-4}

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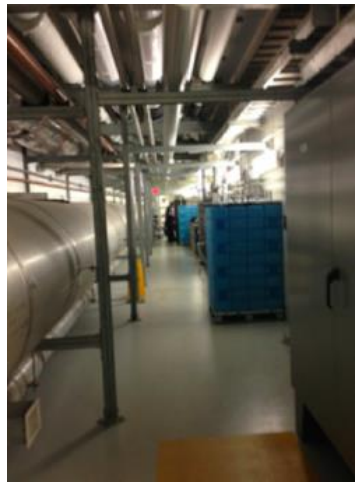
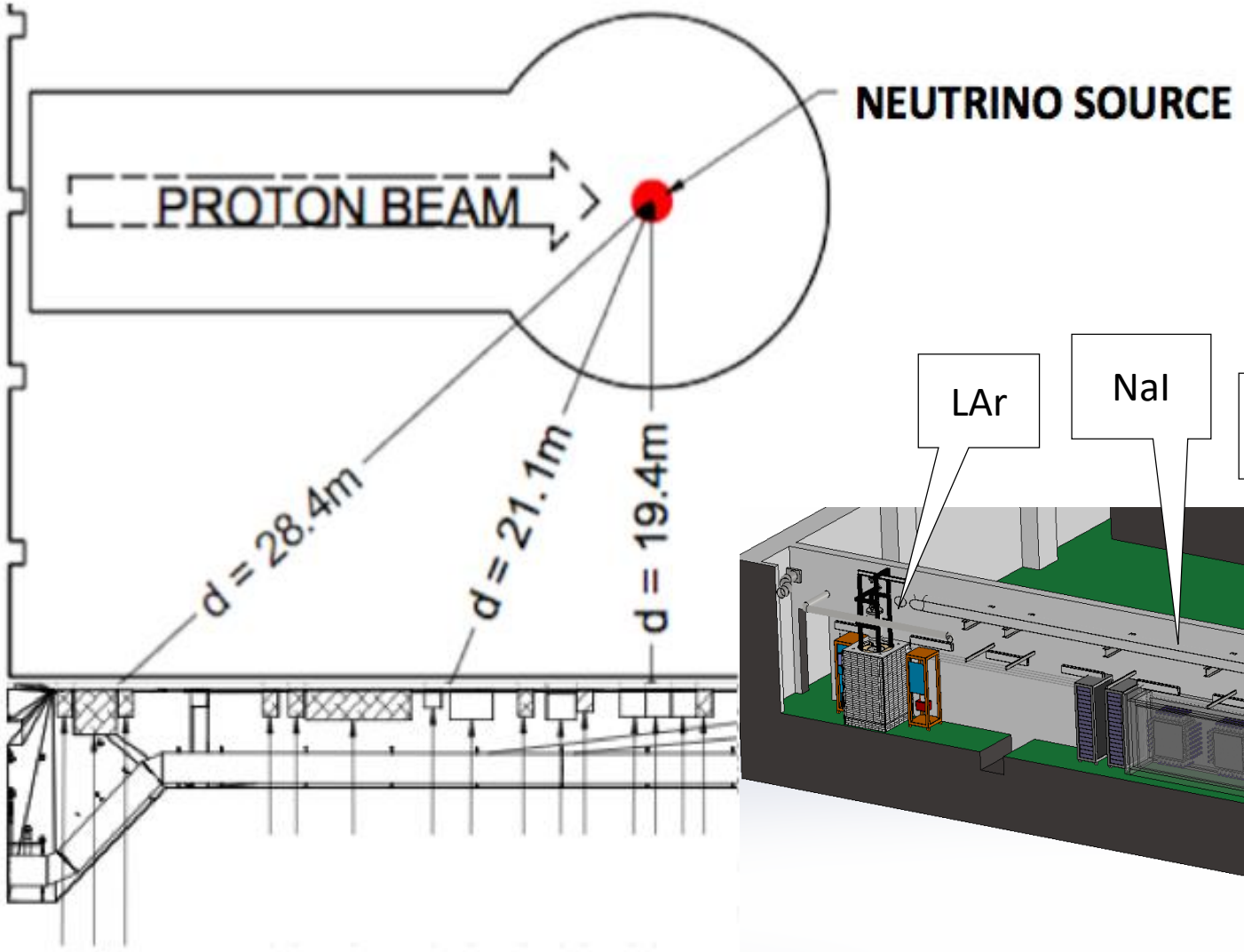
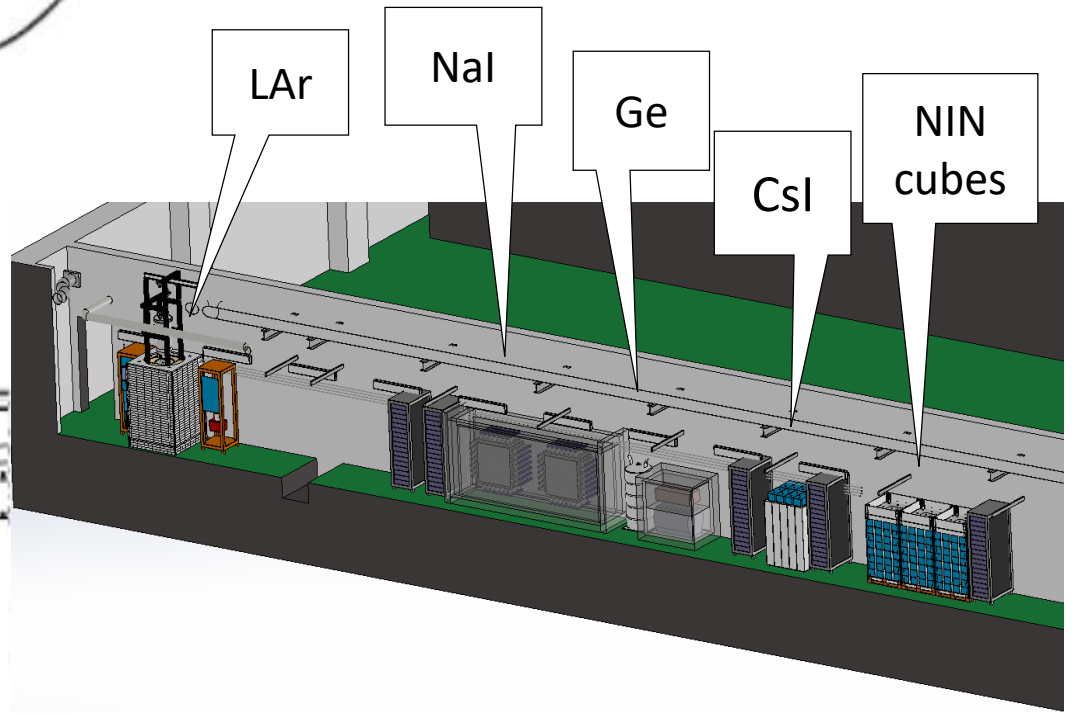
Siting for deployment in SNS basement

(measured neutron backgrounds low,
~ 8 mwe overburden)

View looking
down “Neutrino Alley”







Mayra Cervantes / Sam Hedges

NIN'S MEASUREMENT AT SNS

- Pb Neutrino Cubes (Pb Nube)
  - 2 ~2L liquid scintillator cells, 2 ~1.3L LS cells
  - ~1800lbs of Pb as a target
  - Deployed in 2015
- Fe Neutrino Cubes (Fe Nube)
  - 2 ~2L liquid scintillator cells, 2 ~1.3L LS cells
  - ~1350lbs of Fe as a target
  - Deployed in 2017

The data analysis of the Pb Nube and Fe Nube are ongoing, currently the main efforts are in:

- Calibration of energy scale with a dedicated set of measurements taken at TUNL
- Improvements in particle identification

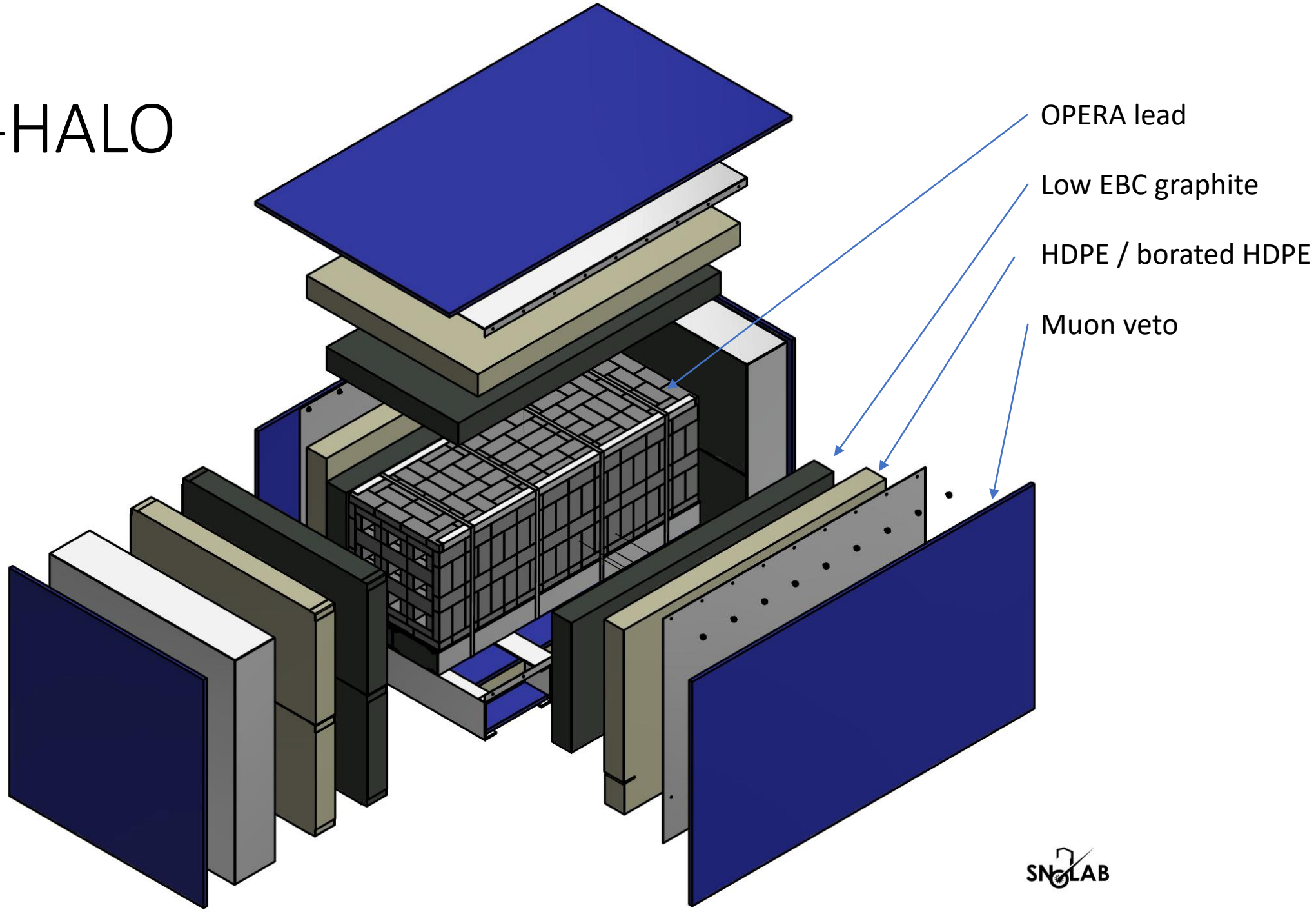
Merits of measuring Pb NINs with “mini-HALO”

- neutron capture efficiency can be measured (not simulated) to 1%
- even smaller sensitivity to details of the NIN energy spectrum
- higher efficiency / multi-tonne
  - higher rate
  - sensitivity to measure 1n and 2n flux averaged cross sections
- Independent systematics relative to NUBE measurement
- Possibility to measure 1n and 2n flux-averaged cross sections

Challenges of measuring Pb NINs with mini-HALO

- long neutron capture time
  - need good muon veto and suppression of other neutron sources
  - need beam-off measurements too
  - could increase # of ^{3}He counters to shorten capture time
- thermal / slow neutron leak-in backgrounds
  - need effective shielding… how effective?
  - DC or 60 Hz modulated?
  - measure with bare / shielded ^{3}He tube…. in Pb NUBE?
- fast neutron backgrounds
  - indistinguishable from signal
  - produce neutrons in target that thermalize and capture with time structure of signal
  - shielding games… neutrinos vary as $1/r^2$, punch-through neutrons f(shielding)
  - choice of location

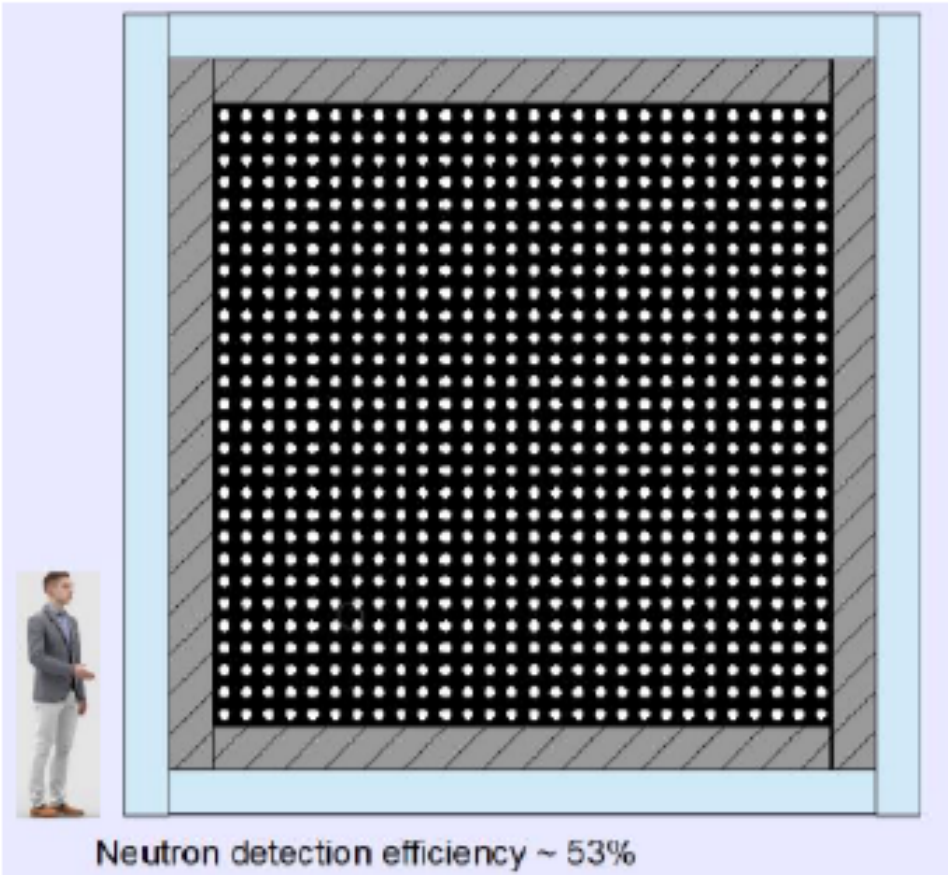
Mini-HALO



Simulations for HALO-1kT

1000 tonnes of Pb (black); 30 cm of graphite on 6 sides (grey); 30 cm of water on 6 sides (blue); plus 28 x 28 array of 5.5 m long 5cm diameter He-3 counters surrounded by 8mm wall thickness polystyrene (C_nH_n) tubes. Nominal lead volume 4.5 x 4.5 x 5.5 m^3.

Note: Graphite and water shielding is not optimized in this geometry. For HALO with ~ twice the environmental neutron flux and comparatively poorer neutron shielding the rate of background neutrons detected in HALO is a very acceptable 15 mHz. Thinner layers of reflector and shielding should be adequate for HALO-1kT. The target value for HALO-1kT is expected to be ~100 mHz.



Goals for HALO-1kT relative to HALO

- larger mass
  - 1000 versus 79 tonnes
  - 12.7 times increase
- higher neutron detection efficiency based on use of 10000 l-atm of He-3
  - 50% versus 28%
  - 1.78 times increase
- increase in signal (mass times efficiency)
  - 23 times
- more efficient use of He-3
  - 10 l-atm/tonne of Pb
  - 46% reduction
- opportunities to do even better
  - potentially more of the OPERA lead could be available
  - higher neutron detection efficiencies have been obtained in simulations
- 10000 l-atm is an arbitrary self-imposed amount of He-3

Status Overview

- Commissioned in May 2012
- Connected to SNEWS in October 2015
- 99.3% live fraction in last 2 years
- No supernova neutrino bursts detected
- Calibration Run Spring and Summer 2016
- Tune up underway this summer
- Cross section measurements underway with more planned
- HALO-1kT at LNGS proposed