Calibration of HALO

(Helium And Lead Observatory)

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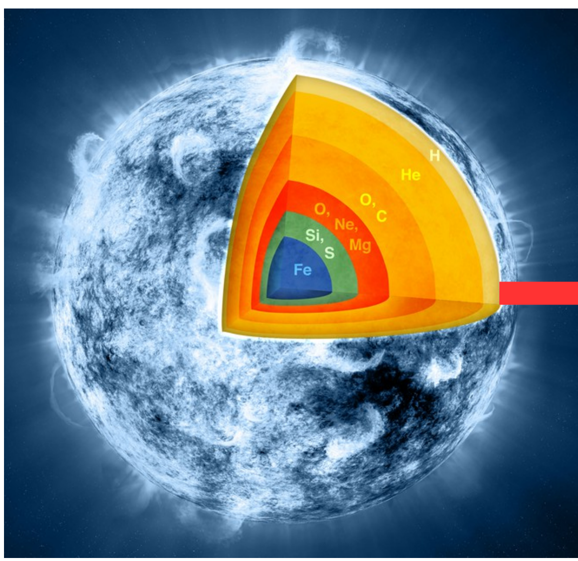
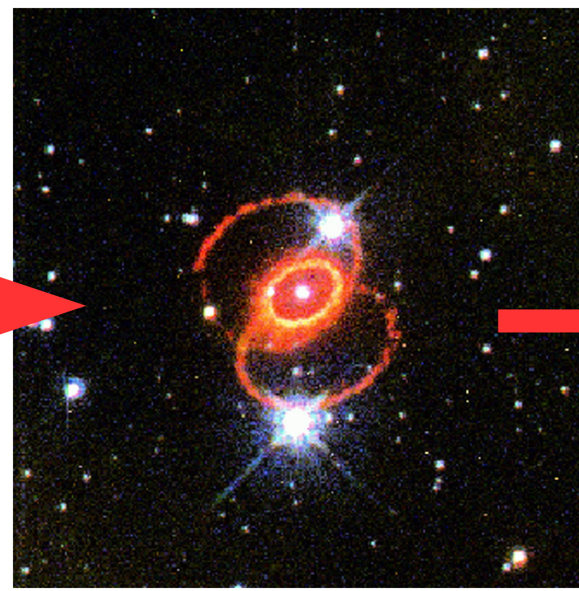
HALO

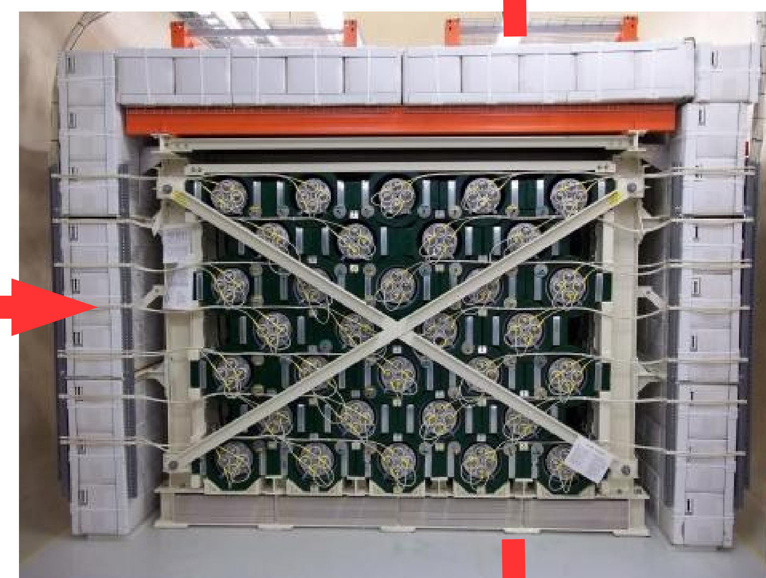
Supernovae

- When the inert iron core of a star reaches 1.4 solar masses, it collapses
- 99% of the released energy is in the form of neutrinos

Neutrino Physics





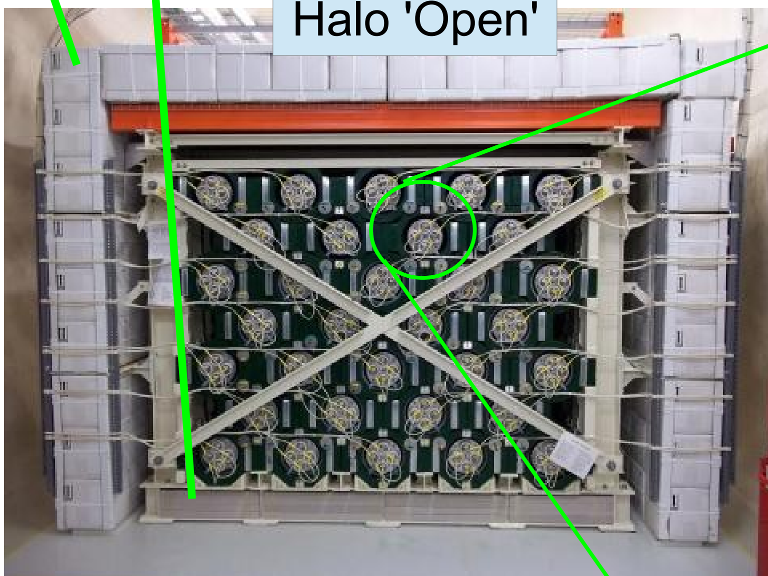


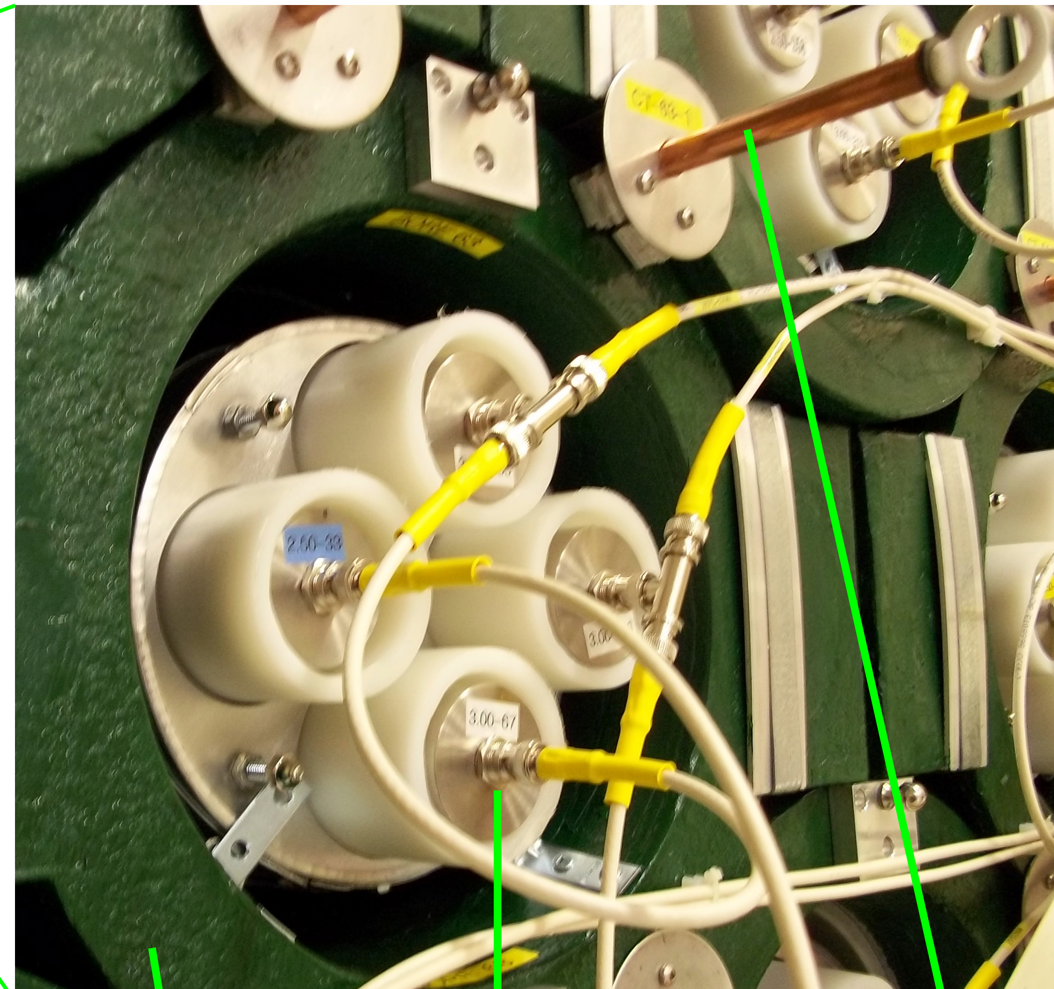
http://www.space.com/17075-pictures-chandra-x-ray-observatory-space-telescope.html

https://www.spacetelescope.org/images/

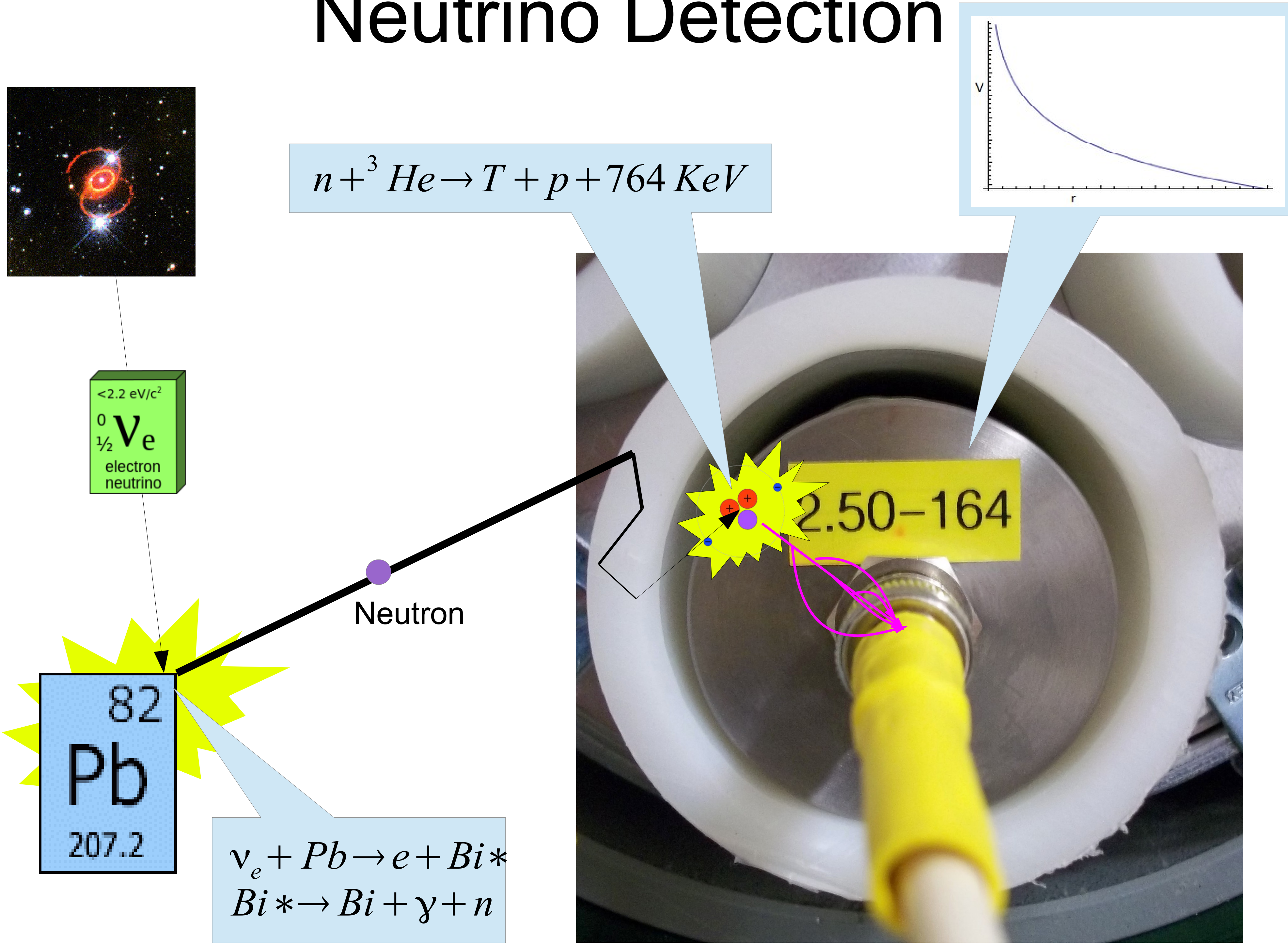
Detector

HALO consists of an array of helium-3 counters in 79 tons of lead shielded by water and plastic



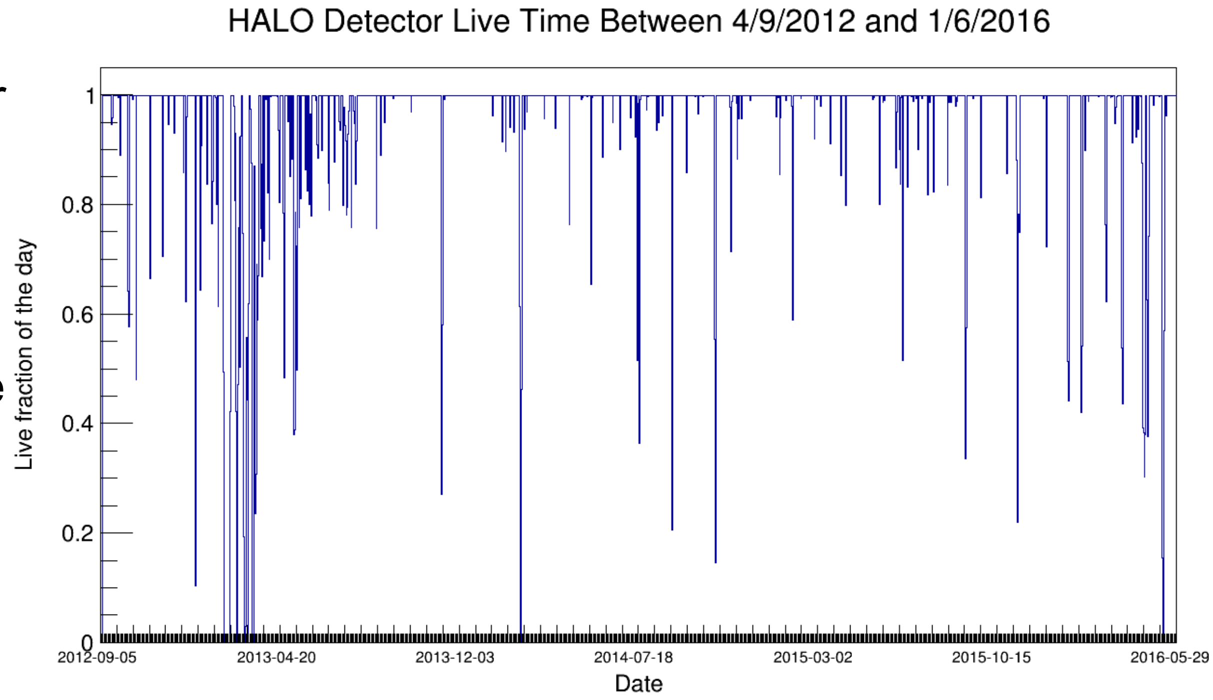


Neutrino Detection

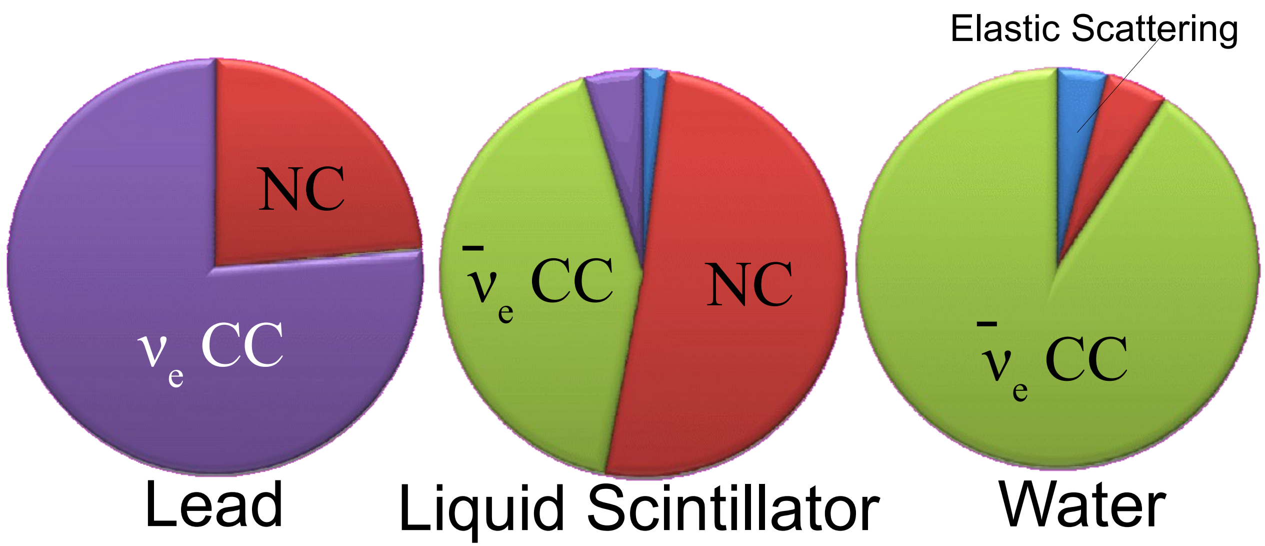


HALO is ready to provide unique flavor sensitivity

- 95% duty factor since September 2012
- Connected to SNEWS since October 9 2015
- Interruptions will get shorter once shutdown and start-up of halo is automated.



- HALO is the only lead-based supernova detector, giving unique electron neutrino sensitivity.
- Energy resolution from single vs double neuron events



Calibration with a Cf252 source has advantages caused by the multiplicity distribution

- Fixed high multiplicity: Multiplicity counting error drops by a factor of $\sqrt{1-E}$, single counting error increases.
- Cf multiplicity: 0 to 8 neutrons, 3.75718 +- 1.27 neutrons per fission

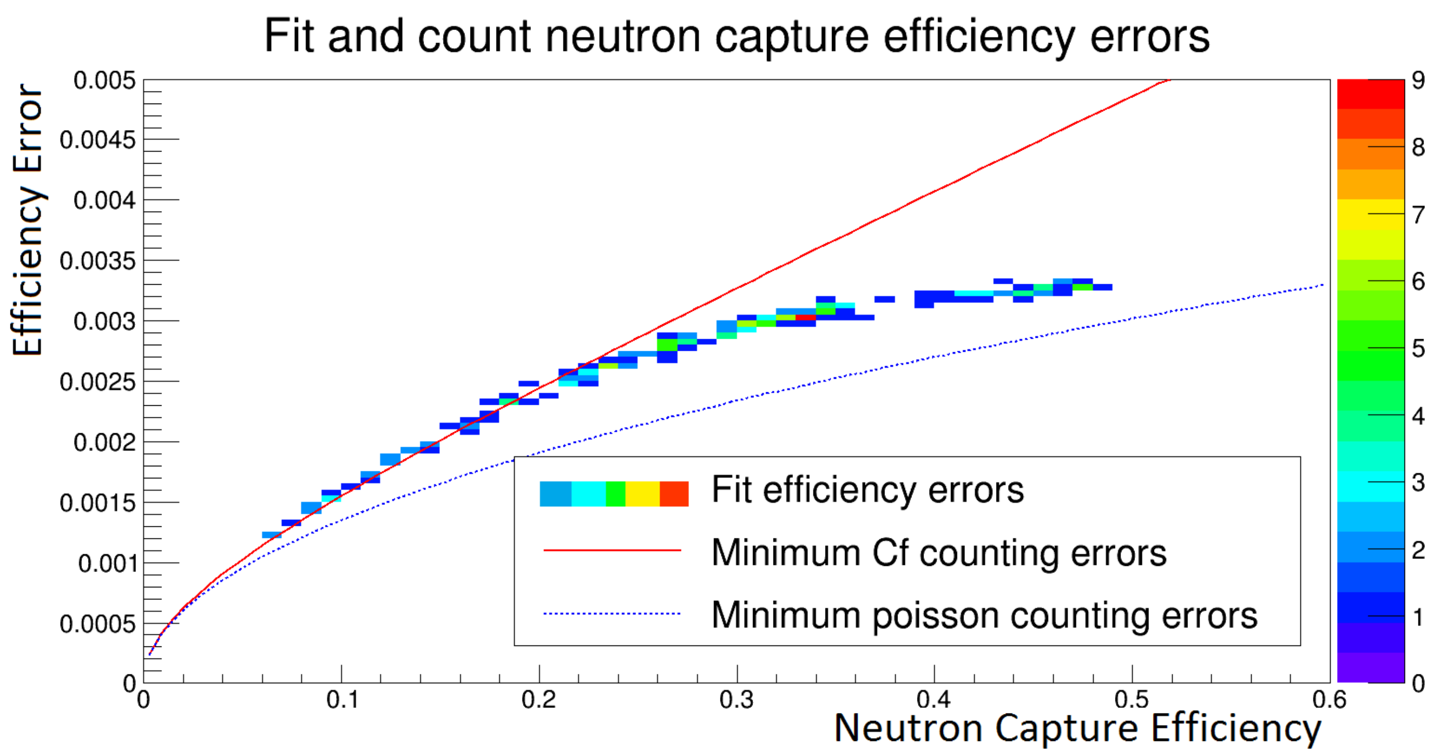
  → known number of fissions still gives better information than a perfectly known source strength

Counting Cf Neutrons:

$$\delta E = \frac{\sqrt{\sum_{k=0}^{8} k^2 \sum_{j=k}^{8} \binom{j}{k} E^k (1-E)^{j-k} p(j)}}{\sqrt{n_f} * 3.75718}$$

Counting Poisson Neutrons:

$$\delta E = \sqrt{\frac{E}{n_f * 3.75718}}$$



A fit function based on the likelihood of detecting different multiplicities models the detected distribution well

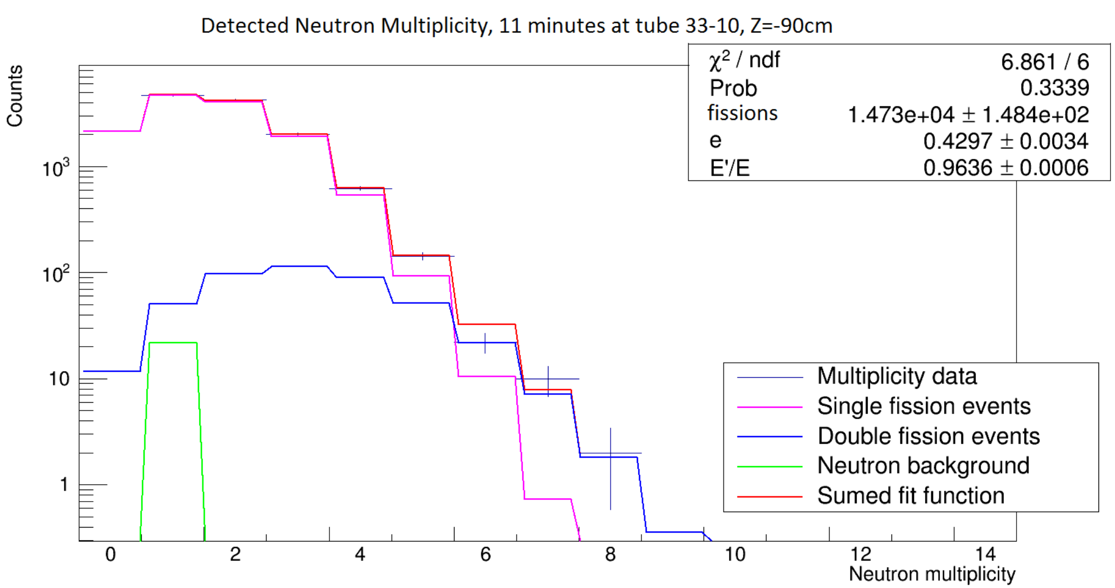
- First order fission pileup:

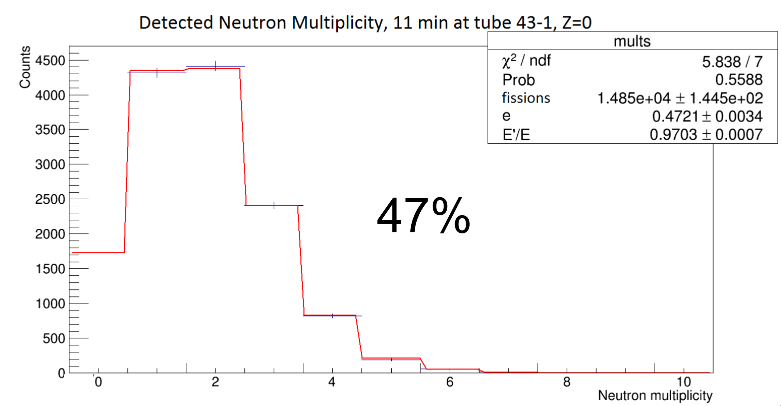
$$N_i = n_f * \sum_{j=0}^{16} \binom{j}{i} * E^i * (1-E)^{j-i} * ((2*exp(-\frac{n_f*W}{T})-1)*p(j) + (1-exp(-\frac{n_f*W}{T}))*pp(j))$$

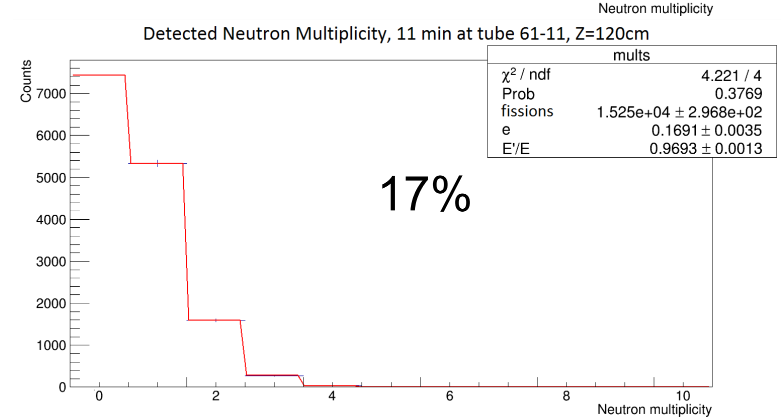
- Counter dead time gives a lower efficiency E' after the first neutron:

$$N_i = n_f * \sum_{j=0}^{16} \sum_{k=0}^{j-i} \binom{j-k-1}{i-1} * E * E'^{i-1} * (1-E)^k * (1-E')^{j-k-1} * ((2*exp(-\frac{n_f*W}{T})-1)*p(j) + (1-exp(-\frac{n_f*W}{T}))*pp(j))$$

- Multiplicity analysis can determine both source activity and neutron capture efficiency







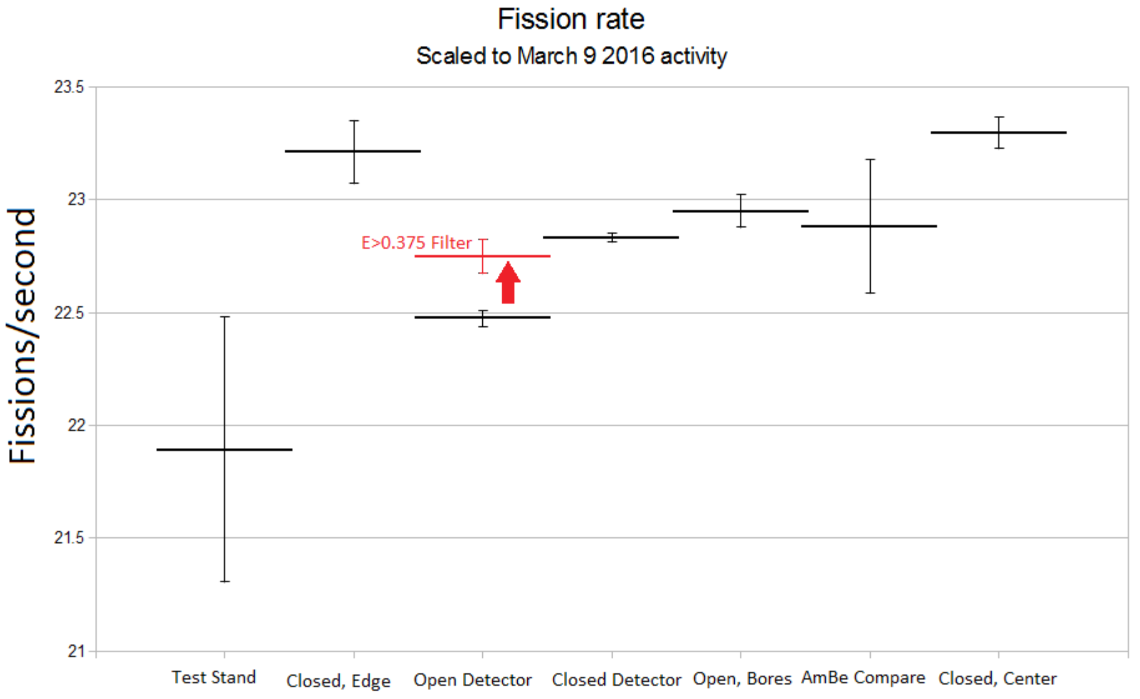
Different procedures still have some unknown but manageable inconsistencies

Closed Detector: 192 points, 40 hours of data

- Fission rate of 22.8338 +- 0.0210 Hz March 9, Verified by AmBe neutron source comparison of 22.9+-0.3 Hz
- Chi-squared 1227.5/1140: p=0.0358

Open Detector: 125 points, 8 hours of data

- Different fission rate of 22.475 +- 0.0354 Hz!
- Currently seems fission rate is lower with low efficiency and low data per efficiency fit.



Preliminary comparisons between the calibration data and current montecarlo are close

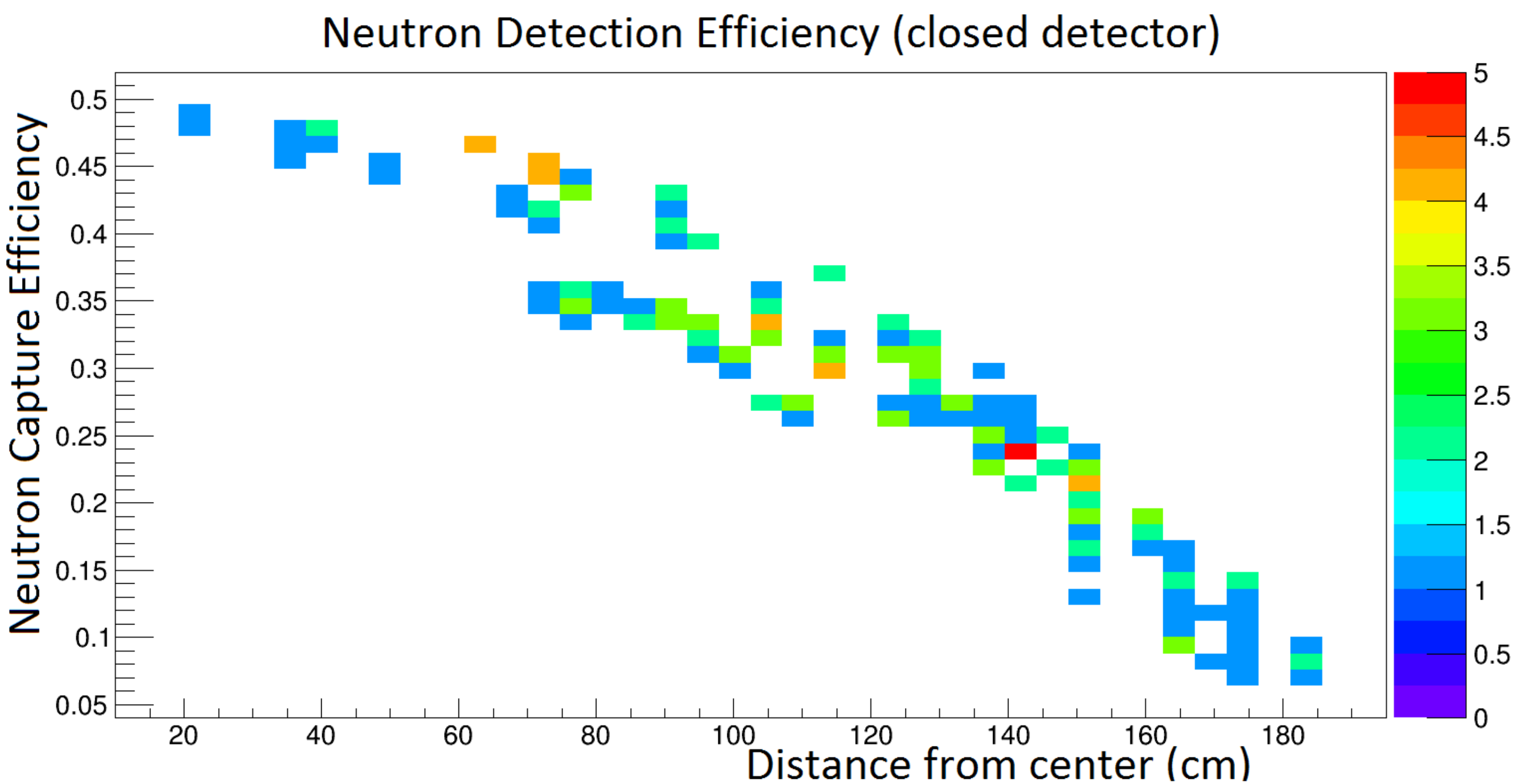
Closed Detector: 6 points compared

- Chi squared 20/6, relative error 1.5%

Open Detector: 17 points simulated for efficiency

- Chi squared 18/17, relative error 3.5%

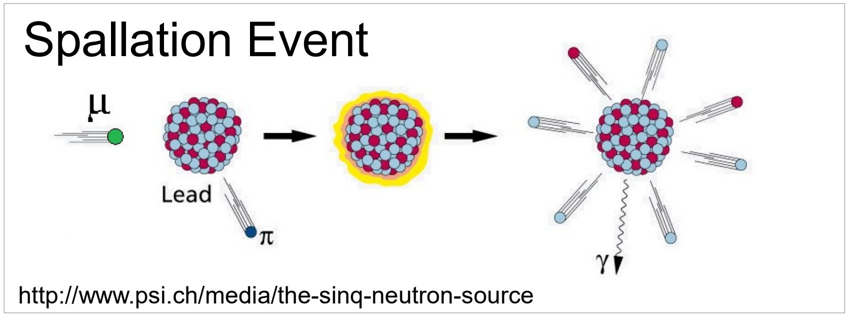
Neutron detection efficiency for neutrons from lead is about 30%.

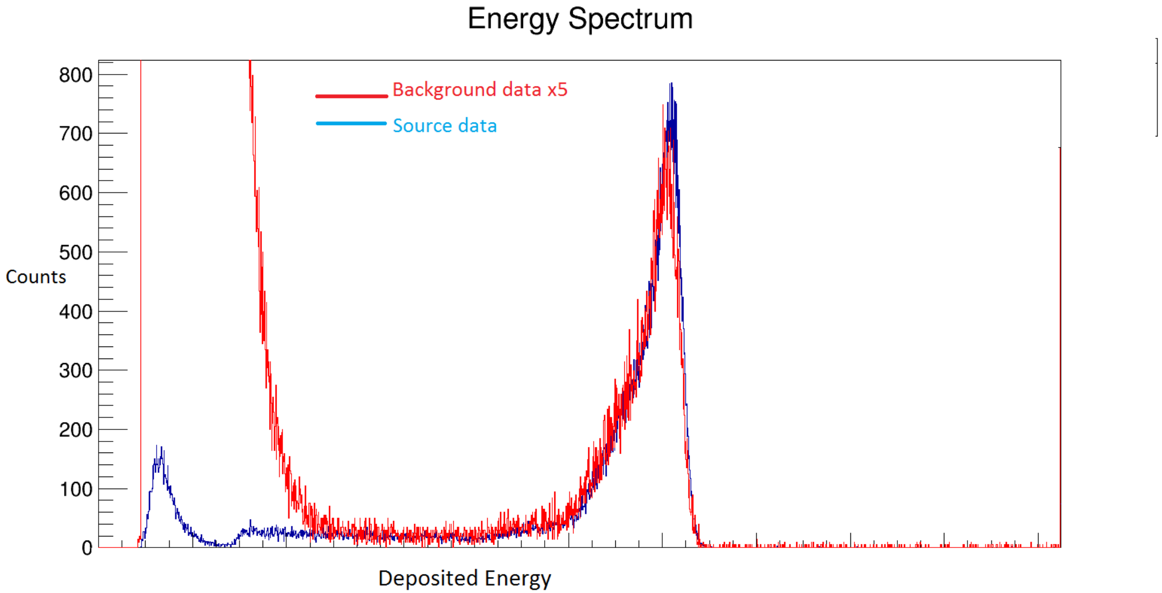


HALO can effectively discriminate against non-supernova bursts

Half of supernova neutrinos arrive within the first two seconds.

- Trigger threshold: now 4 neutrons in two seconds (was 6 without front shielding)
- Muon induced spallations create burst of neutrons about once per week, but these are filtered by their short duration
- Electronic noise, gamma, and alpha counts excluded by neutron capture ROI and counter wall effects





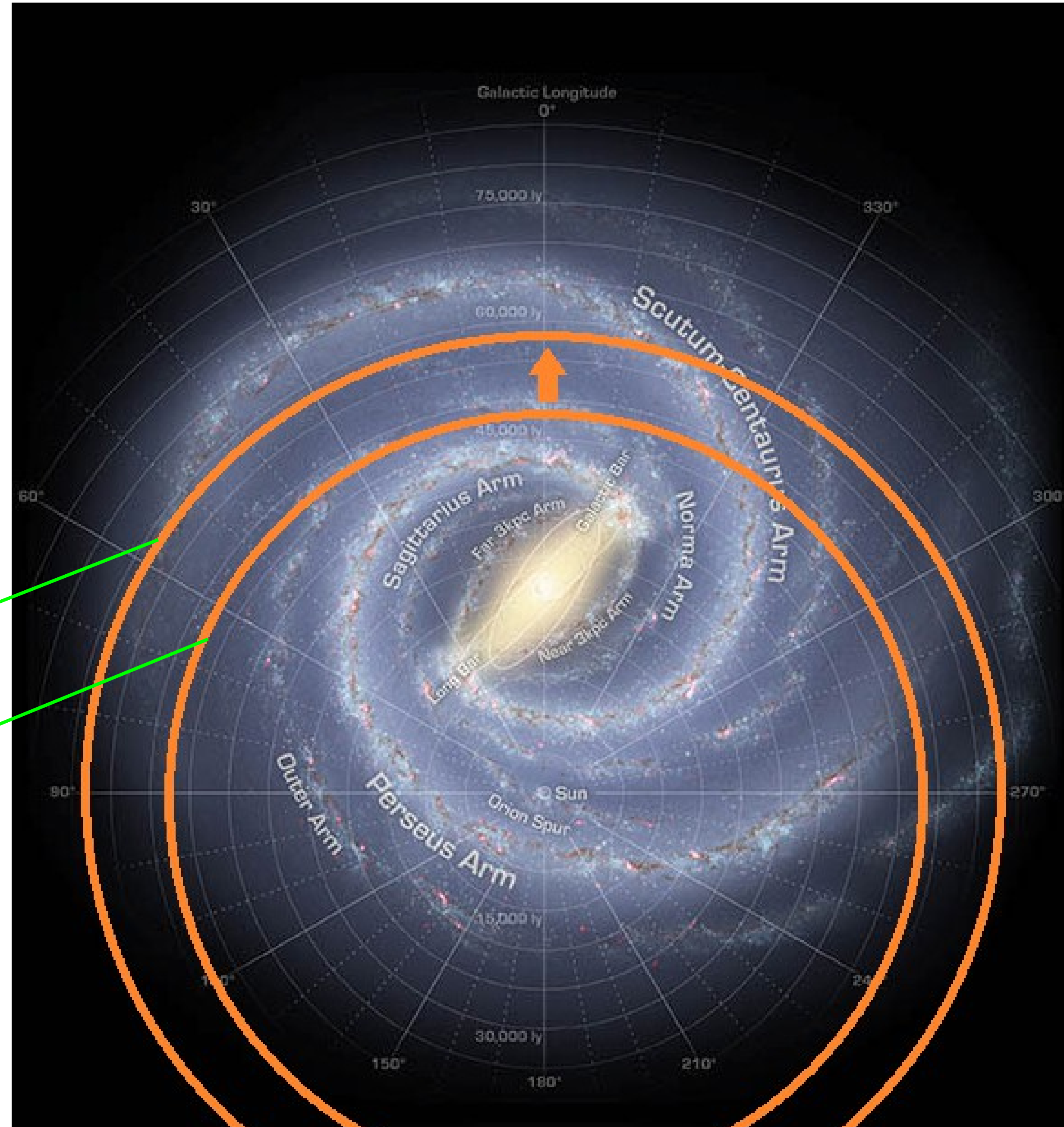
HALO can detect supernovae throughout most of the Milky Way

Resulting range: 18 kpc

- Expected SNEWS alarm rate of 2.36 per year (alarm rate required to be less than 6/yr)
- 3 alarms sent from open detector (1.15 expected)

Closed Detector Range

Open Detector Range



- http://www.spitzer.caltech.edu/images/1925-ssc2008-10b-A-Roadmap-to-the-Milky-Way-Annotated-

The HALO Collaboration

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Backup Slides

Cf252 multiplicity fit

Pile-up multiplicity (first order)

$$N_i = n_f * \sum_{j=0}^{16} \binom{j}{i} * E^i * (1-E)^{j-i} * ((2 * exp(-\frac{n_f * W}{T}) - 1) * p(j) + (1 - exp(-\frac{n_f * W}{T})) * pp(j))$$

Busy Channels → E'<E

$$N_i = n_f * \sum_{j=0}^{16} \sum_{k=0}^{j-i} \binom{j-k-1}{i-1} * E * E'^{i-1} * (1-E)^k * (1-E')^{j-k-1} * ((2 * exp(-\frac{n_f * W}{T}) - 1) * p(j) + (1 - exp(-\frac{n_f * W}{T})) * pp(j))$$

E' Calculations

$$L_r = \sum_i p_i^2$$

$$L_t = \frac{k}{k + (n-k)(1-Lr)}$$

$$\delta L_r = 2 * \sqrt{\sum_i \frac{a_i^3}{a^4}}$$

$$\delta(1 - L_t L_r) = \frac{\sqrt{L_r^2 (1-L_r)^2 nk(n-k) + n^2 k^2 (\delta L_r)^2}}{(k + (n-k)(1-Lr))^2}$$

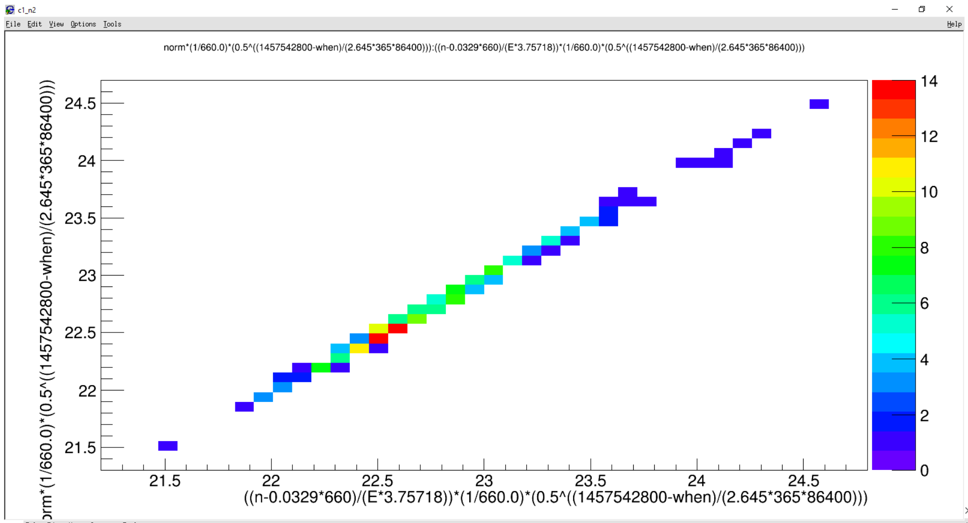
Counting errors

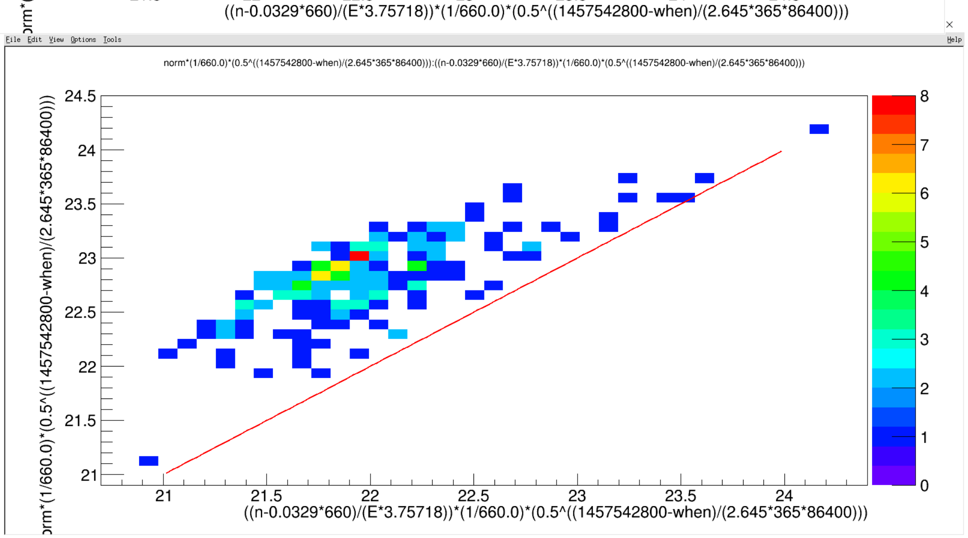
$$dE = \frac{\sqrt{\sum_{k=0}^{8} k^2 \sum_{j=k}^{8} \binom{j}{k} E^k (1-E)^{j-k} p(j)}}{\sqrt{n_f} * 3.75718}$$

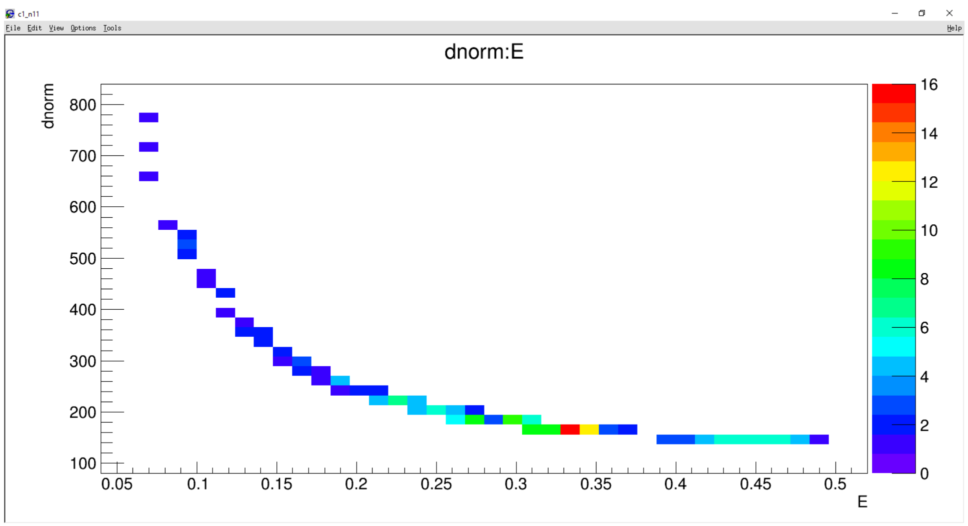
Cf252 multiplicity fit

Multiplicity	Probability	Error
0	0.0021	0.0001
1	0.0260	0.0003
2	0.1267	0.0005
3	0.2734	0.0008
4	0.3039	0.0010
5	0.1848	0.0007
6	0.0657	0.0006
7	0.0154	0.0003
8	0.0020	0.0002

Boldeman, J.W., Hines, M.G.: Nucl. Sci. Eng. 91 (1985) 114







Cf252 multiplicity fit