Evaluating Reactor Antineutrino Signals for WATCHMAN

for the WATCHMAN Collaboration
Steve Dye
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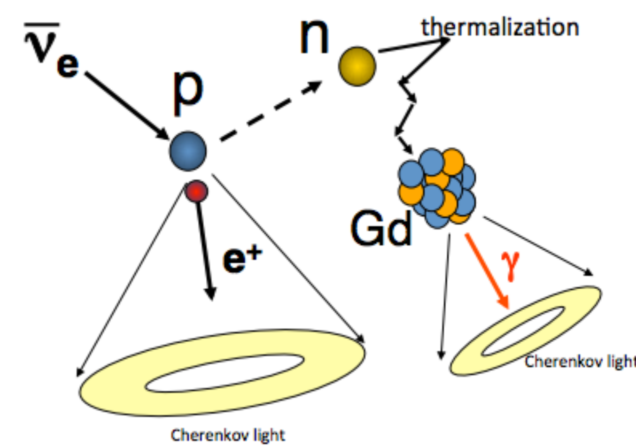
WATCHMAN Project

- **Non-proliferation remote monitoring demonstrator of a single reactor site**
- **A 1-kT Gd-loaded, water-based anti-neutrino detector for remote fission reactor monitoring**
- **Project goal is to observe reactor on/off at typically 10-30 km standoff from the reactor**

- Rationale is to develop a medium-sized detector that can be scaled to MT masses required for longer standoff distance
- Physics goals include directional SN detection and sterile neutrino searches
- Provides test-bed for R&D- WbLS, LAPPD, etc.

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



WATCHMAN Collaboration

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Reactor Antineutrino Signals at Morton and Boulby

- arXiv:1611.01575

… presents calculations of reactor antineutrino interactions, from quasi-elastic neutrino-proton scattering (IBD) and elastic neutrino-electron scattering (ES)

… signal from the proximal reactor and background from all other registered reactors

… interaction rates and kinetic energy distributions of positrons from (IBD) and electrons from (ES)

… reactor-site combinations are Perry-Morton (PM) on the southern shore of Lake Erie in the U.S. and Hartlepool-Boulby (HB) on the western shore of the North Sea in U.K.

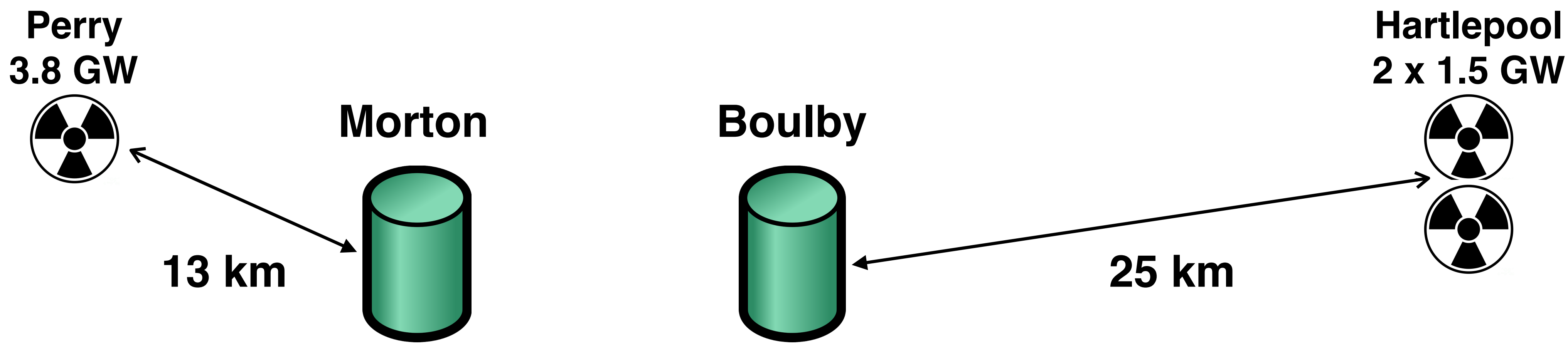
… signal from the proximal reactor is about five times greater at the Morton site than at the Boulby site due to shorter reactor-site separation distance, larger reactor thermal power, and greater neutrino oscillation survival probability

… although background from all other reactors is larger at Morton than at Boulby, the fraction of the total rate is smaller at Morton than at Boulby

… Hartlepool power plant has two cores whereas the Perry plant has a single core

… Boulby offers an opportunity for demonstrating remote reactor monitoring under more stringent conditions than does Morton

Reactor-Site Combos



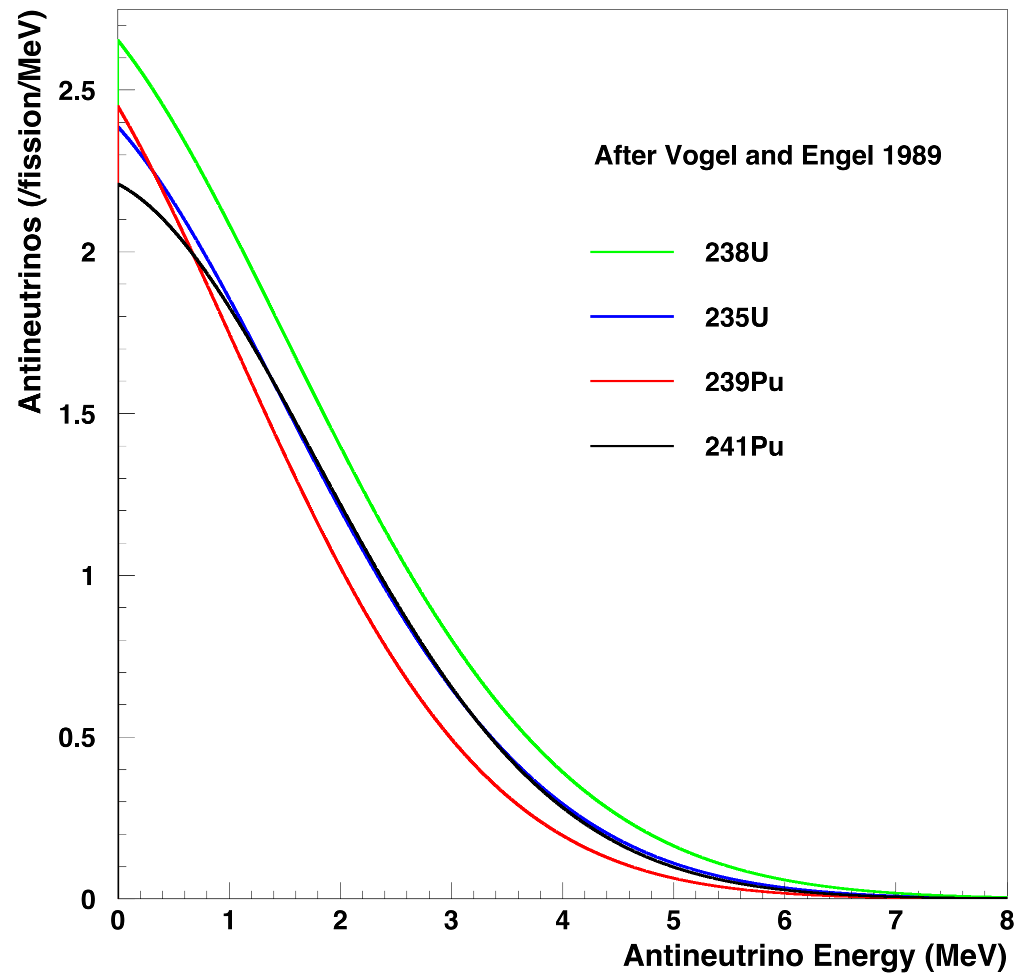
	P_{th}(MW)	Type	Cores	L(m)	D(m.w.e.)
Perry-Morton	3758	BWR	1	13000	1560
Hartlepool-Boulby	3000	GCR	2	25000	2800

Reactor Spectrum Model

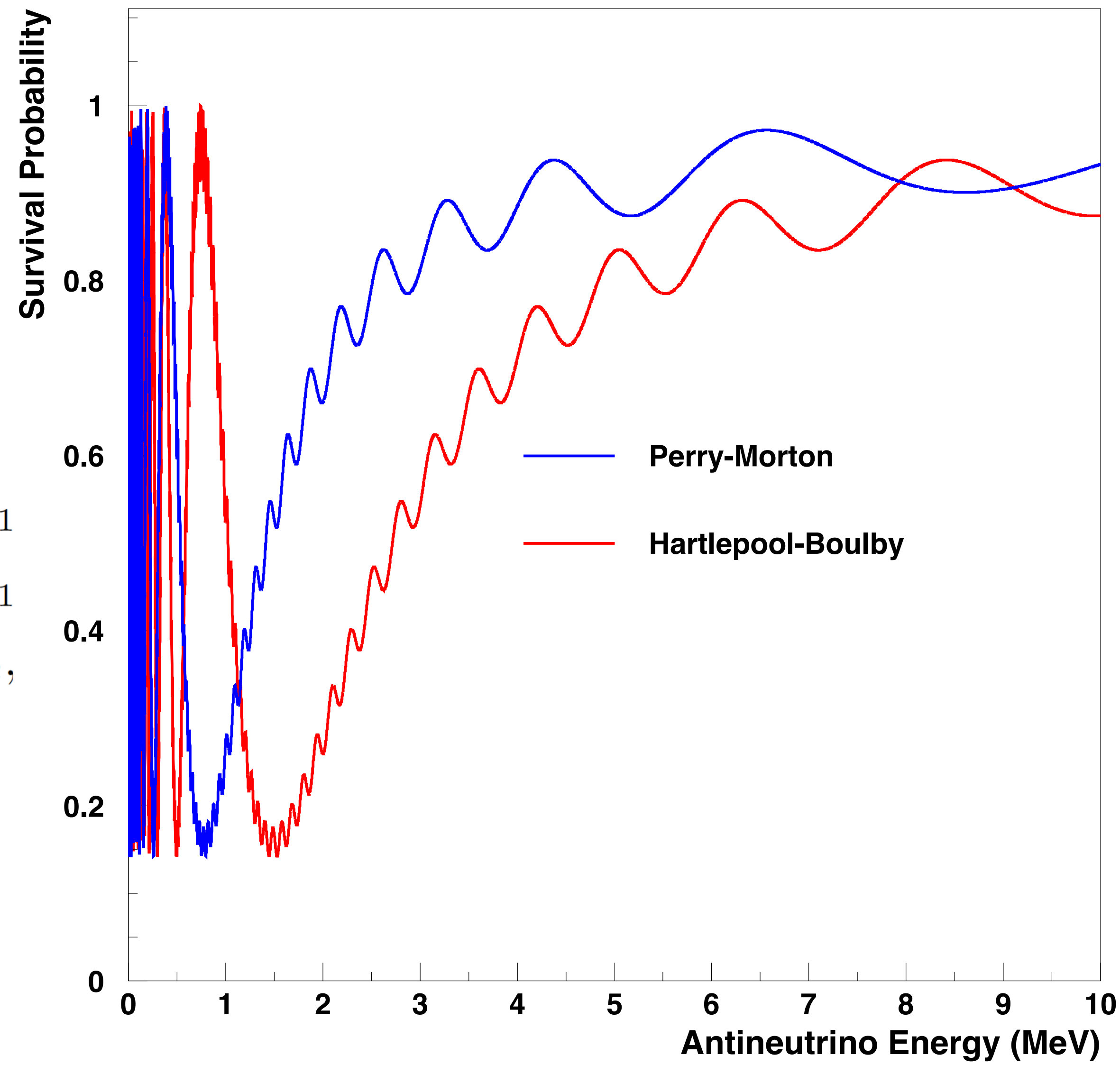
$$\lambda(E_\nu) = \exp(a_0 + a_1 E_\nu + a_2 E_\nu^2)$$

$$dR/dE_\nu = P_{th} \sum_i \frac{p_i}{Q_i} \lambda_i(E_\nu)$$

	^{235}U	^{238}U	^{239}Pu	^{241}Pu
p_i	.56	.08	.30	.06
Q_i (MeV)	202.4	206.0	211.1	214.3



Oscillations



$$P_{e\to\mu,\tau}(L,E_\nu) = \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\Delta_{21} + \cos^2\theta_{12}\sin^2 2\theta_{13}\sin^2\Delta_{31} + \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2\Delta_{32},$$

$$\Delta_{ij} = 1.27(|\delta m^2_{ji}|L)/E_\nu$$

$$\delta m^2_{ji} = m^2_j - m^2_i$$

$\sin^2\theta_{12}$	δm^2_{21}	$\sin^2\theta_{13}$	δm^2_{31}
.297	$7.37\times10^{-5}\text{eV}^2$	.0214	$2.50\times10^{-3}\text{eV}^2$

F. Capozzi et al., Neutrino masses and mixings: Status of known and unknown 3 parameters," arXiv:1601.07777 (2016)

Cross Sections

$$\sigma^{IBD}(E_e) = \sigma_0^{IBD} p_e E_e$$

$$\sigma_0^{IBD} = \frac{2\pi^2}{m_e^5 f^R \tau_n}$$

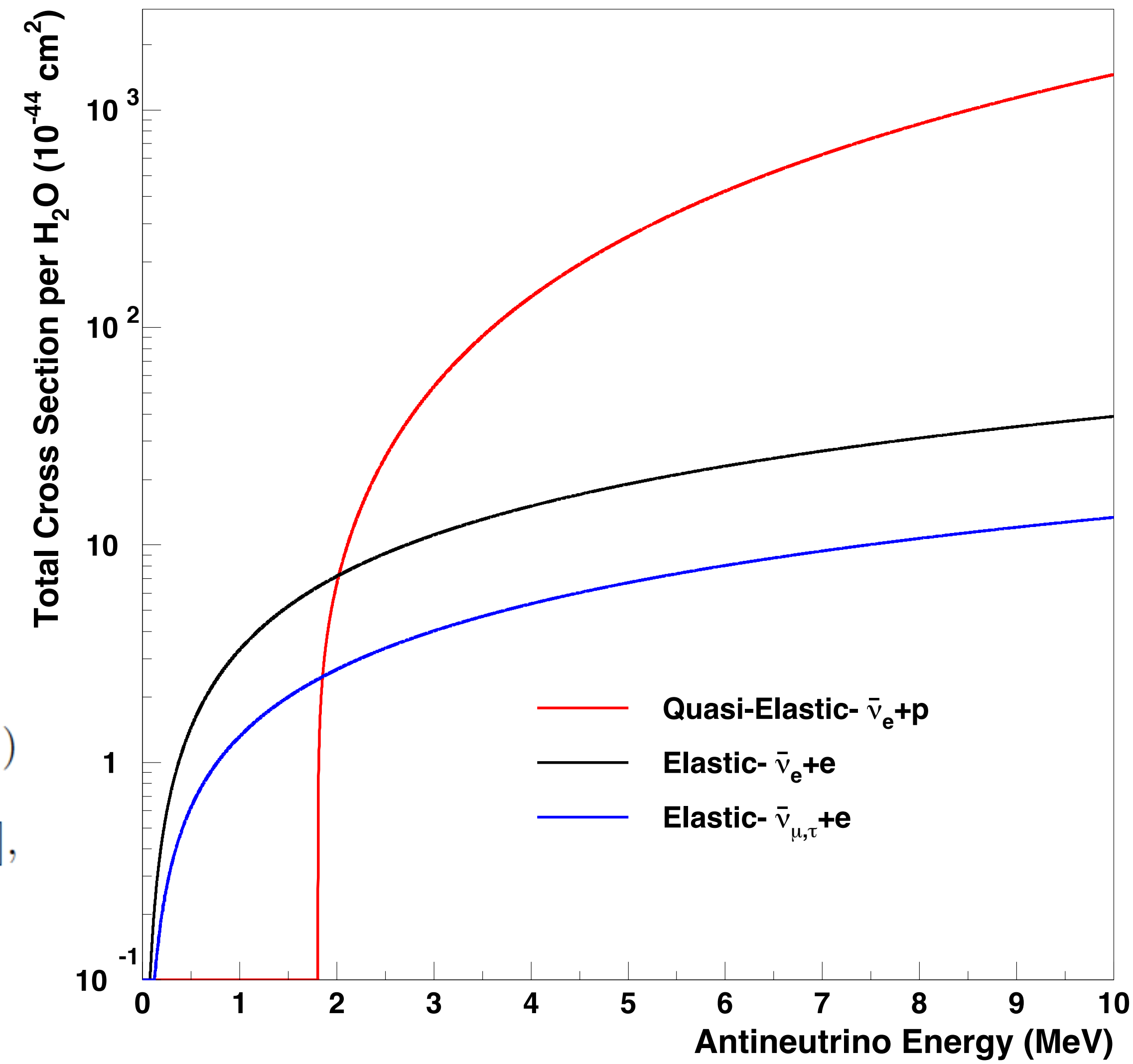
$$\sigma_0^{IBD} = \frac{G_F^2 cos^2\theta_C}{\pi}(1+\Delta_{inner}^R)(1+3\lambda^2)$$

$$\sigma_0^{IBD} = 9.62 \times 10^{-44}\ \mathrm{cm}^2/\mathrm{MeV}^2$$

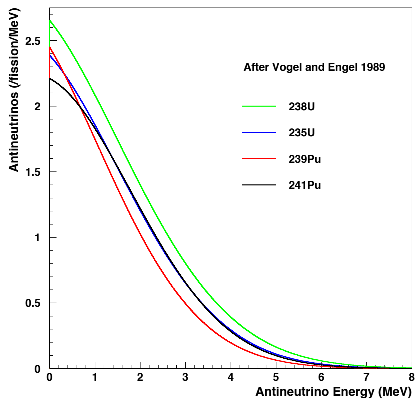
$$\sigma_0^{ES} = \frac{G_F^2 m_e}{6\pi} = 1.436 \times 10^{-45}\mathrm{cm}^2/\mathrm{MeV}$$

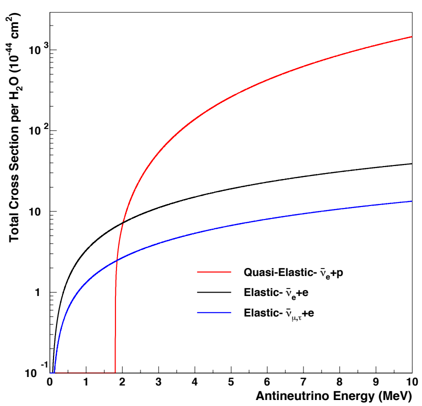
$$\sigma_{\overline{\nu}_e}^{ES}(E_\nu) = \frac{G_F^2 m_e}{6\pi} E_\nu[(1+4\sin^2\theta_W + 16\sin^4\theta_W) - (3\sin^2\theta_W + 6\sin^4\theta_W)\frac{m_e}{E_\nu}],$$

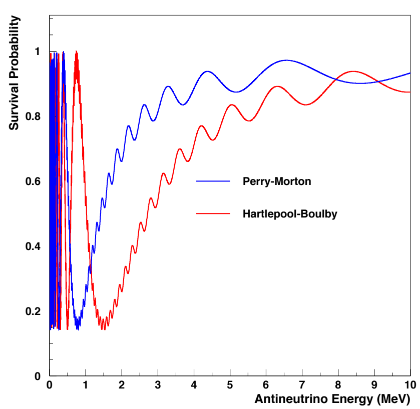
$$\sigma_{\overline{\nu}_{\mu,\tau}}^{ES}(E_\nu) = \sigma_0^{ES} E_\nu[(1-4\sin^2\theta_W + 16\sin^4\theta_W) - (3\sin^2\theta_W + 6\sin^4\theta_W)\frac{m_e}{E_\nu}].$$

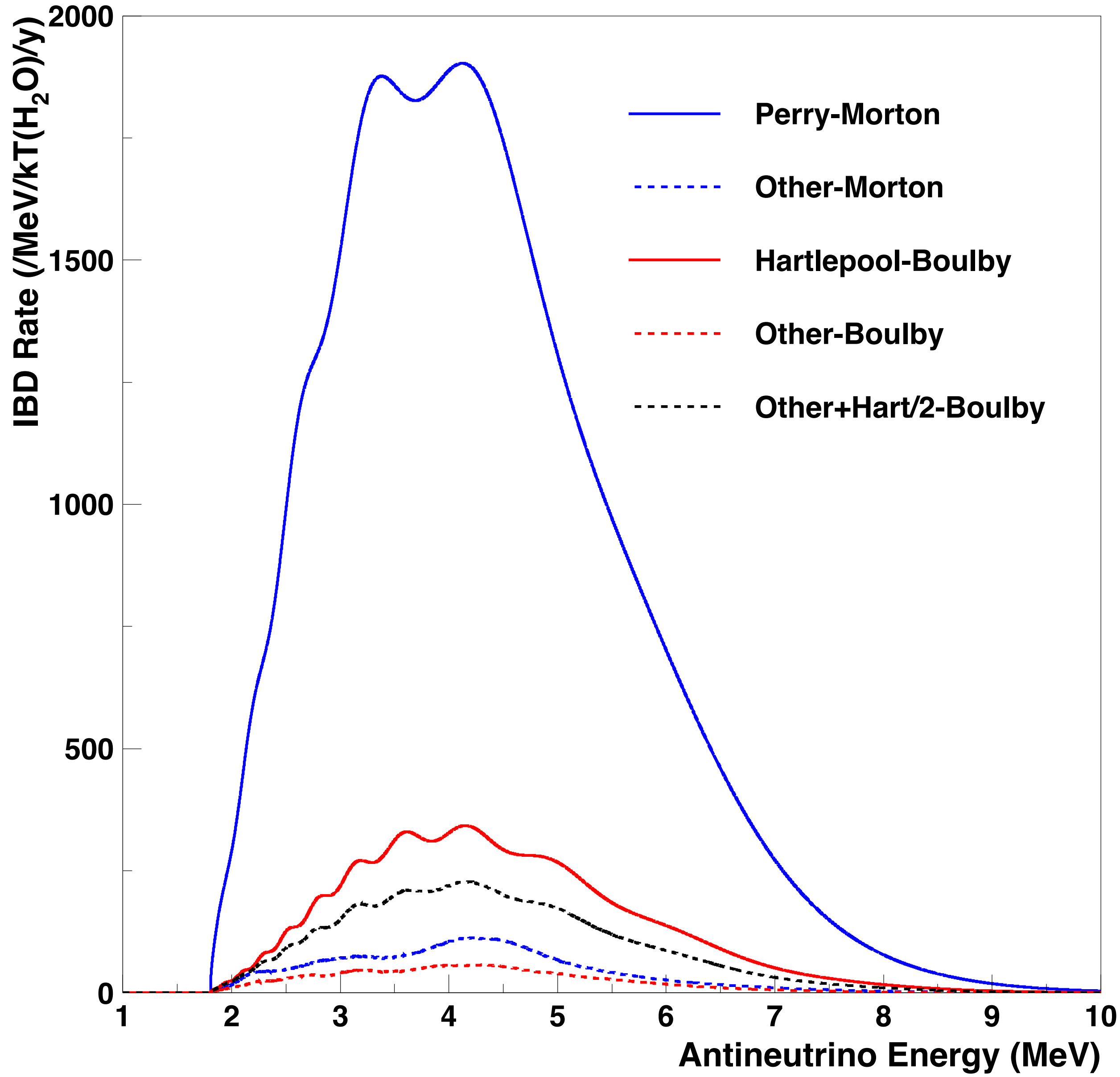


IBD Interaction Spectra



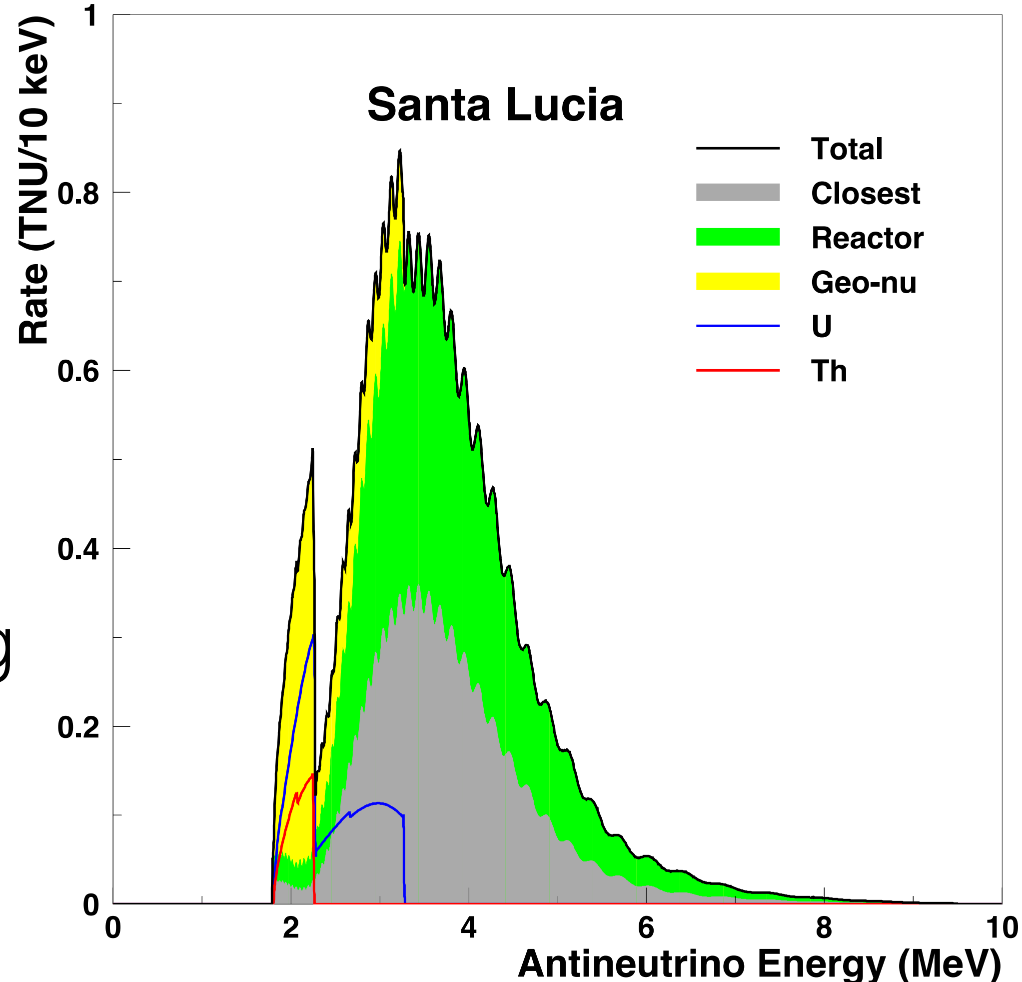




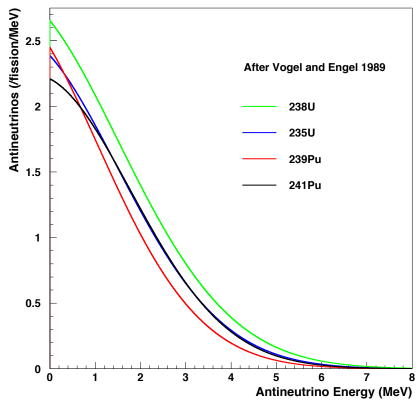


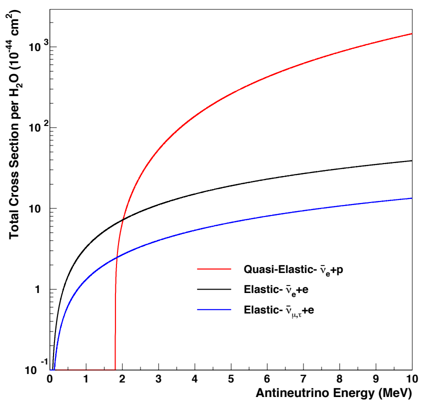
geoneutrinos.org

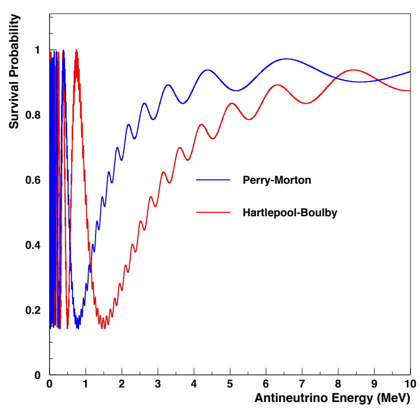
- site developed by A. Barna
- supported by WATCHMAN
- “Web Application for Modeling Global Antineutrinos” arXiv:1510.05633
- http://geoneutrinos.org/reactors

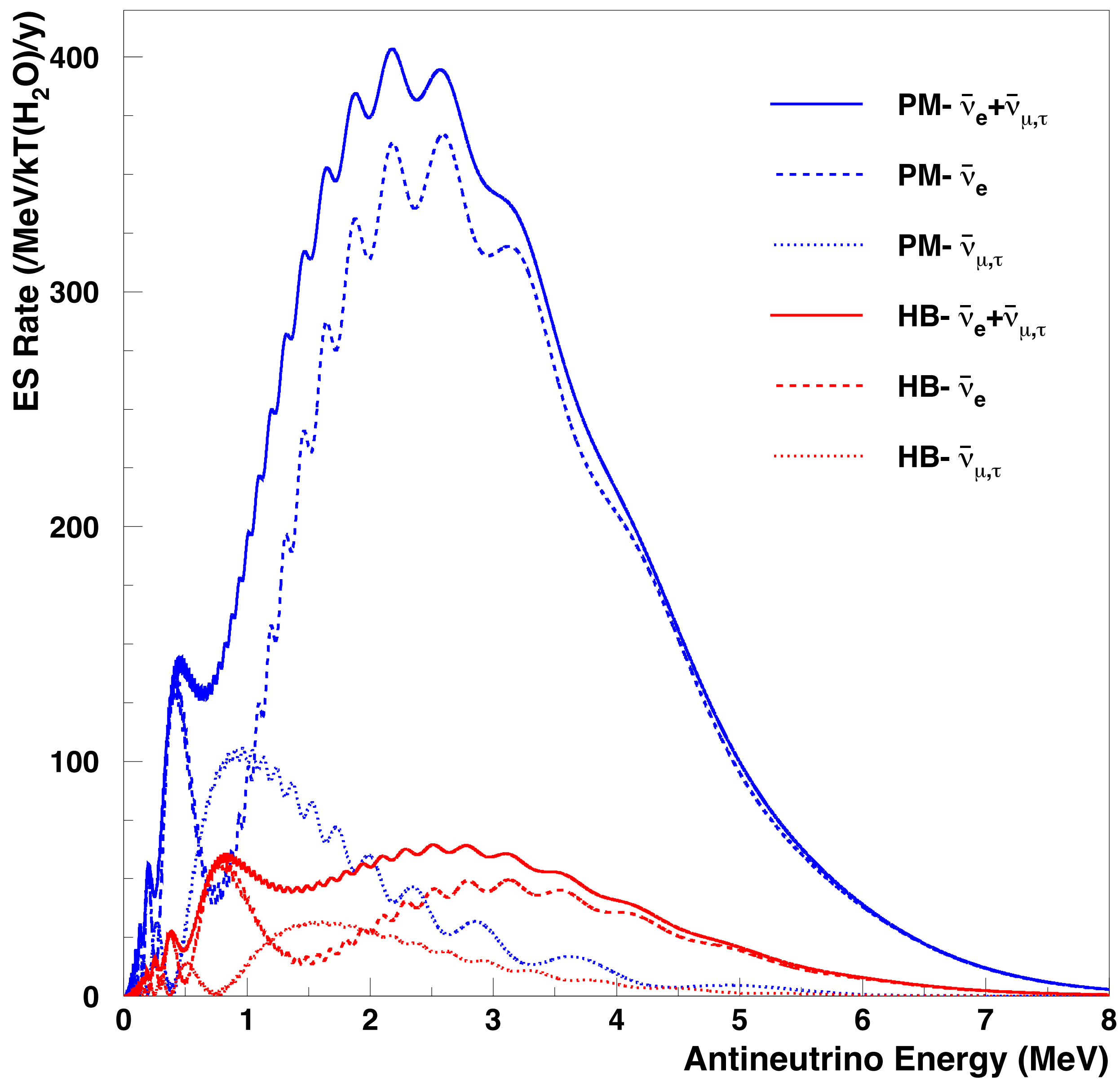


ES Interaction Spectra

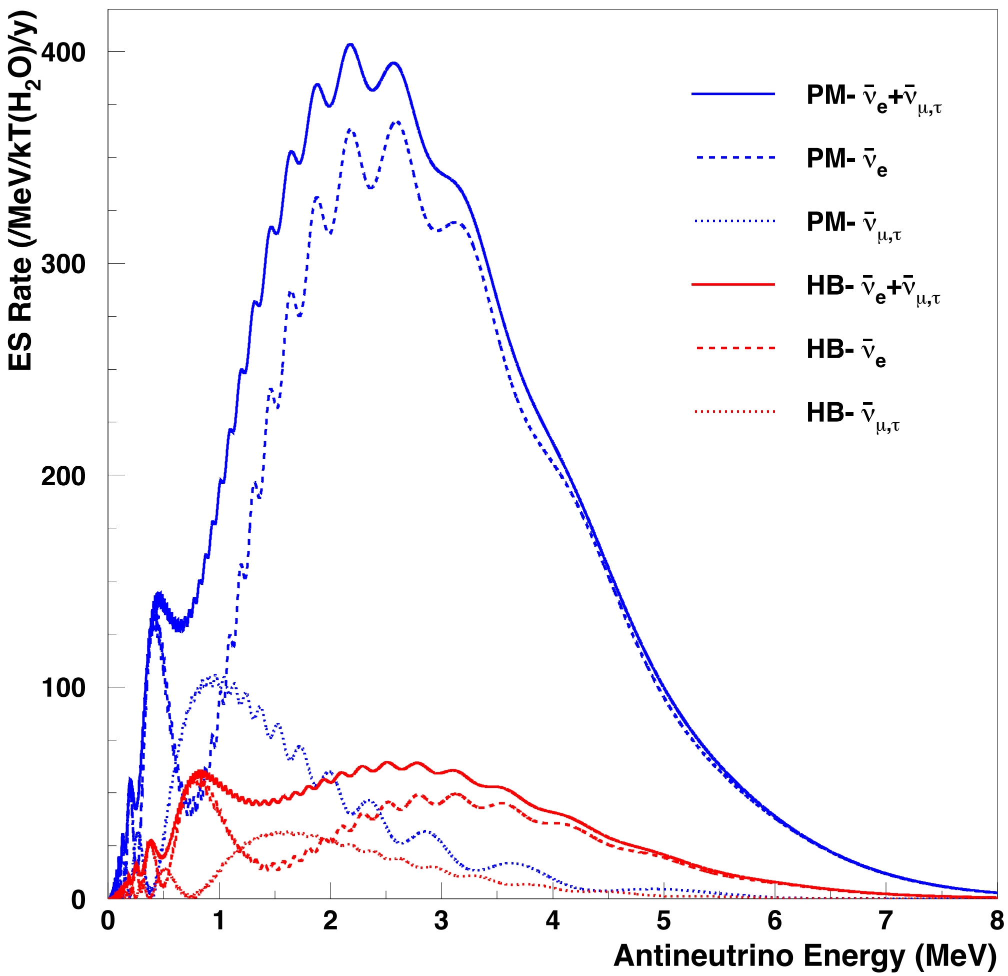


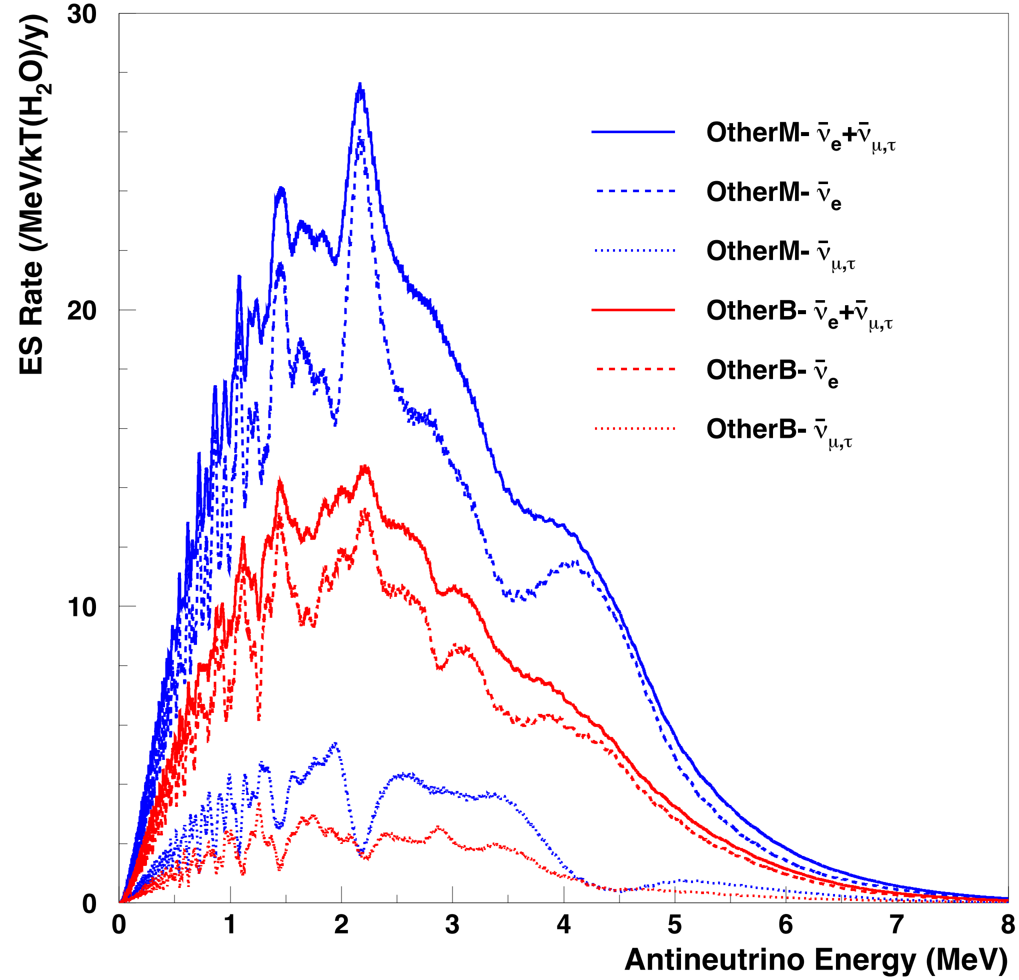




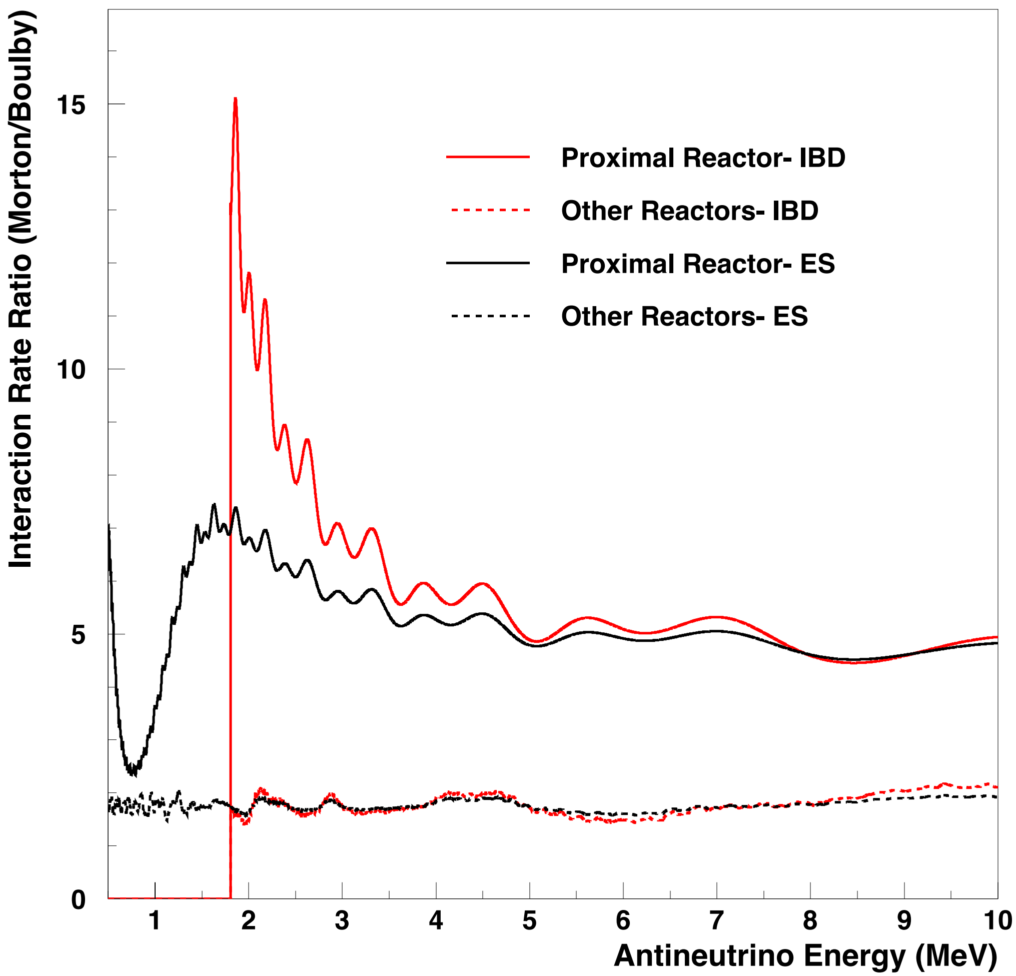


ES Interaction Spectra

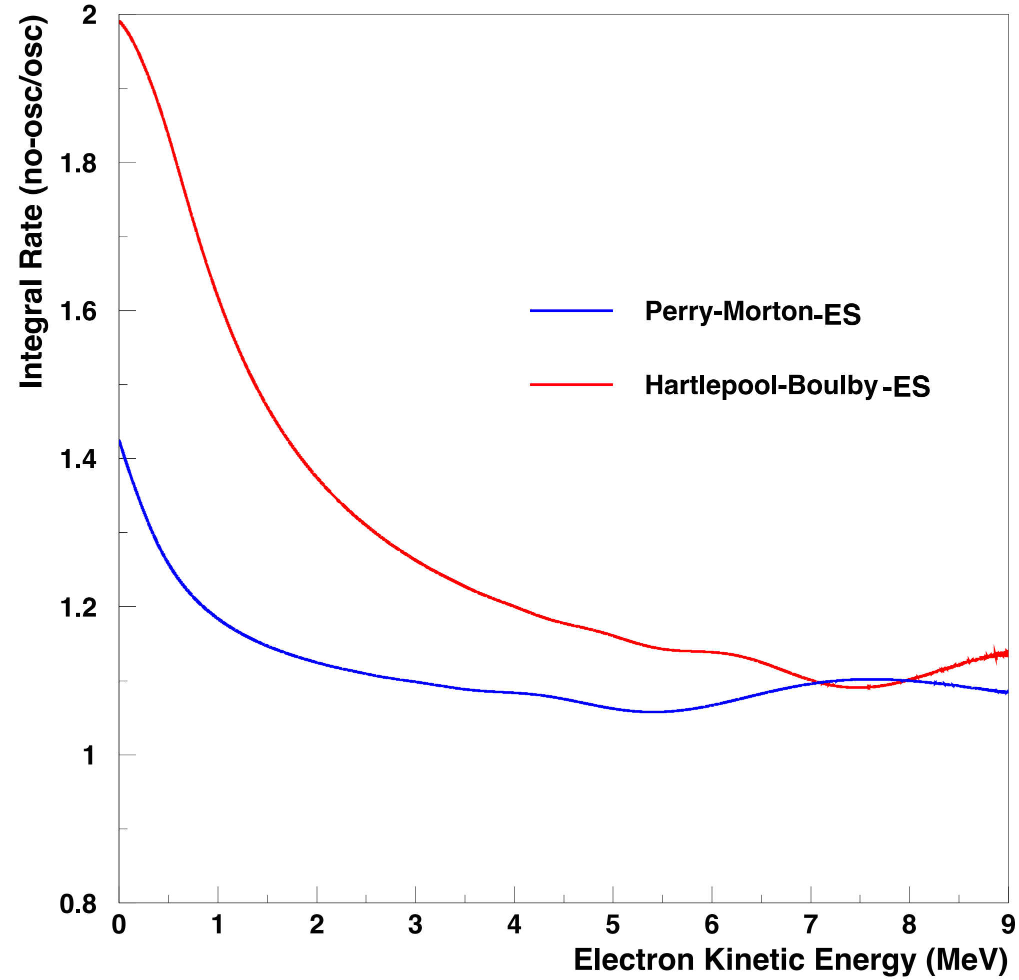




Ratios

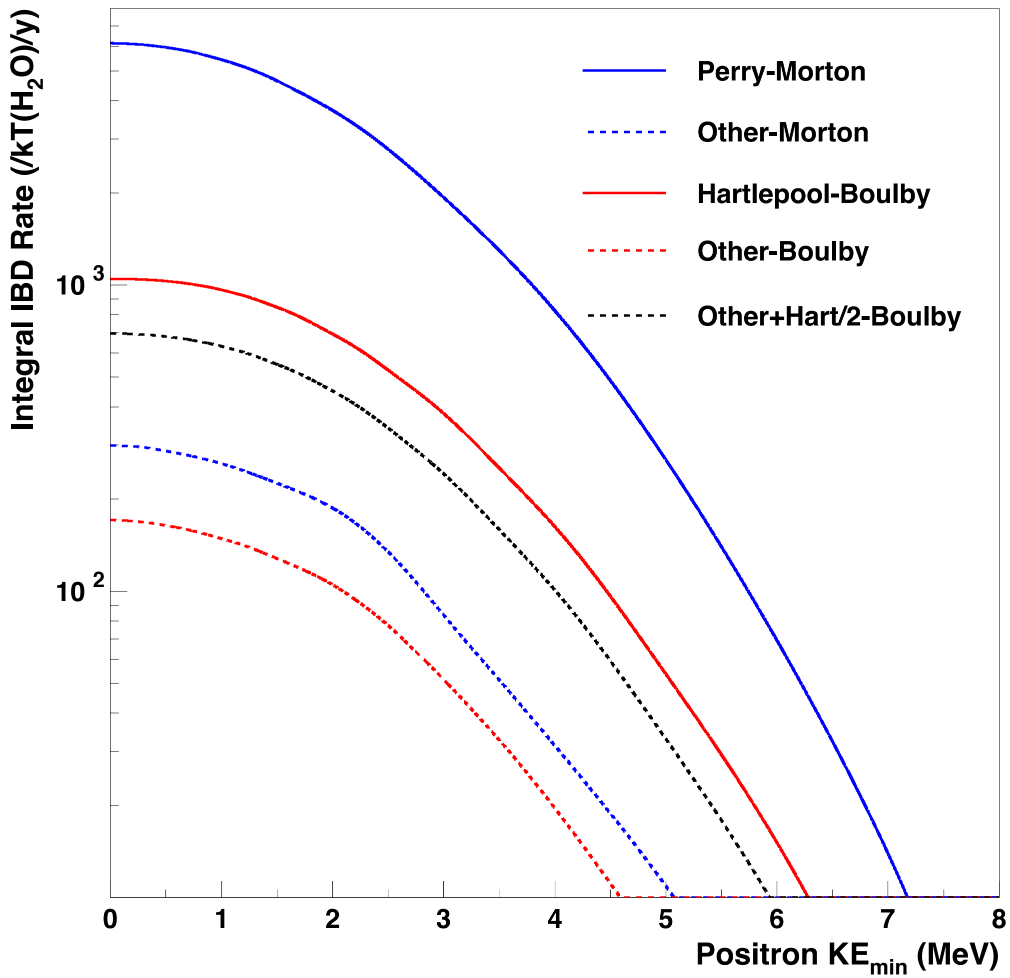


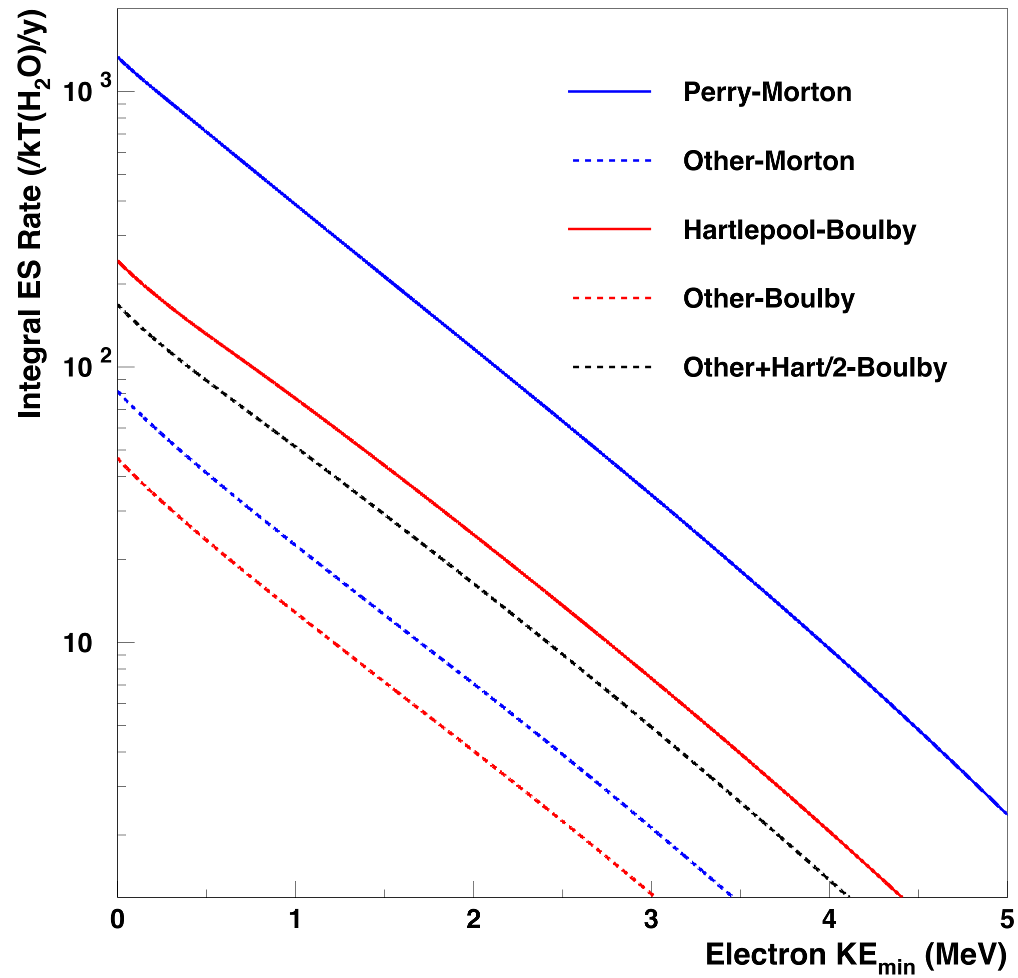
Interaction Rate Ratio (Morton/Boulby)
0
5
10
15
1
2
3
4
5
6
7
8
9
10
Antineutrino Energy (MeV)
Proximal Reactor- IBD
Other Reactors- IBD
Proximal Reactor- ES
Other Reactors- ES



Integral Rate (no-osc/osc)
0.8
1
1.2
1.4
1.6
1.8
2
0
1
2
3
4
5
6
7
8
9
Electron Kinetic Energy (MeV)
Perry-Morton-ES
Hartlepool-Boulby -ES

Integral Interaction Rates



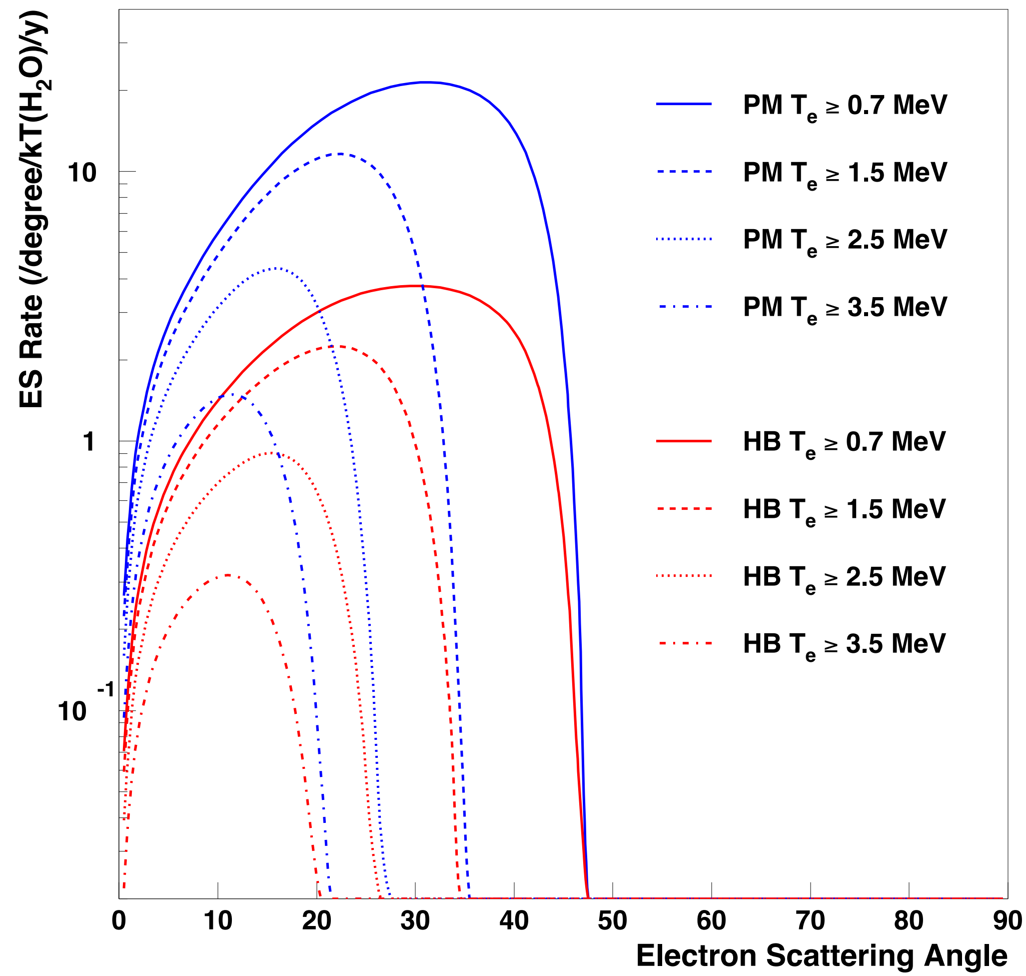


Minimum T_e (MeV)	0.0	0.7	1.5	2.5	3.5	4.5
Perry-Morton	6157	5800	4641	2776	1296	488
Hartlepool-Boulby	1048	1010	846	528	253	96.5
Other-Morton	299	278	225	135	51.4	18.8
Other-Boulby	171	159	129	77.4	32.7	11.1

Minimum T_e (MeV)	0.0	0.7	1.5	2.5	3.5	4.5
Perry-Morton	1330	558	213	63.6	18.2	4.8
Hartlepool-Boulby	242	106	43.9	13.6	4.0	1.0
Other-Morton	81.6	32.2	12.6	3.93	1.13	1.05
Other-Boulby	46.5	18.4	7.18	2.25	0.65	0.18

Angular Distributions

$$\cos\theta = \frac{1 + m_e/E_\nu}{(1 + 2m_e/T_e)^{1/2}}$$



See talk by M. Leyton tomorrow (12/2 at 2p) "Neutrino geoscience and reactor monitoring using elastic scattering in directional-detectors"

Conclusions

- **WATCHMAN is evaluating 2 reactor-site combos**
- **Reactor antineutrino signal calculations completed**
  - **Hartlepool-Boulby more challenging than Perry-Morton**
- **Evaluation of backgrounds almost complete**
  - **Perry-Morton more challenging than Hartlepool-Boulby**
- **Evaluation of reconstructed signal significance ongoing**