First Look at MC-Based Theia DBD Sensitivity

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University of Chicago

Theia Workshop
April 13, 2018

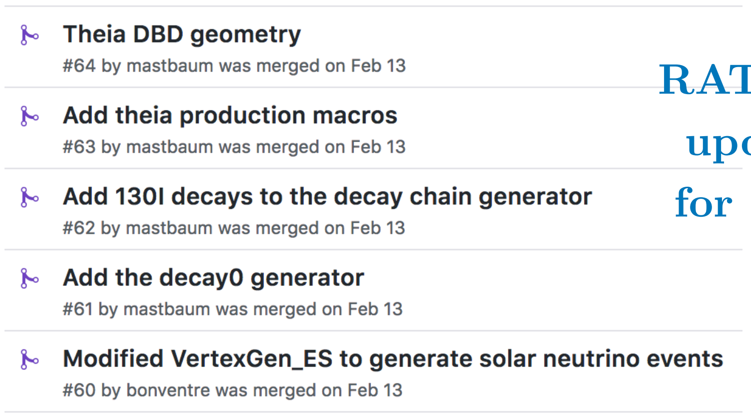
Background Model

- RAT-PAC MC run at Boston University (thanks Aobo Li & Chris Grant!)
- Extracted true quenched energy & energy centroid position from Ntuples
  - N.B. Quenched energy looks funny for DBD (smeared down), used truth
- Built finely-binned 2D PDFs in energy & radius for the analysis code

Background	**Events/y**	**Notes**
$2\nu\beta\beta$	7.37×10^7	MC above 1.5 MeV (8.88%)
^{8}B Solar ν ES	3200	Reweighted in T_e (see text)
^{10}C	167	Reduced $\times 3$ per KamLAND
^{130}I	14.9	Ground state
^{130m}I	78.1	Excited state
^{208}Tl	87	
Balloon ^{214}Bi	1.21×10^5	

Valentina's Background Table

Background Model


Theia DBD geometry
#64 by mastbaum was merged on Feb 13
Add theia production macros
#63 by mastbaum was merged on Feb 13
Add 130I decays to the decay chain generator
#62 by mastbaum was merged on Feb 13
Add the decay0 generator
#61 by mastbaum was merged on Feb 13
Modified VertexGen_ES to generate solar neutrino events
#60 by bonventre was merged on Feb 13

RAT-PAC updates for DBD

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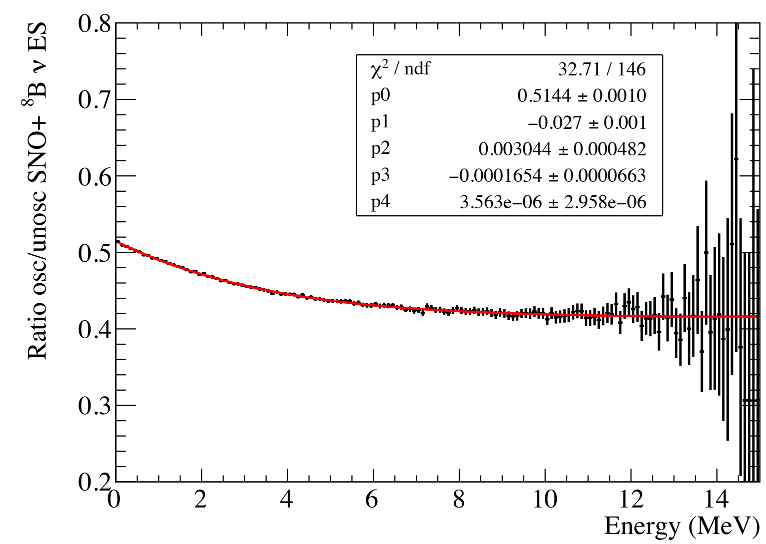
Reweight electron energy to osc/unosc ratio from SNO+...



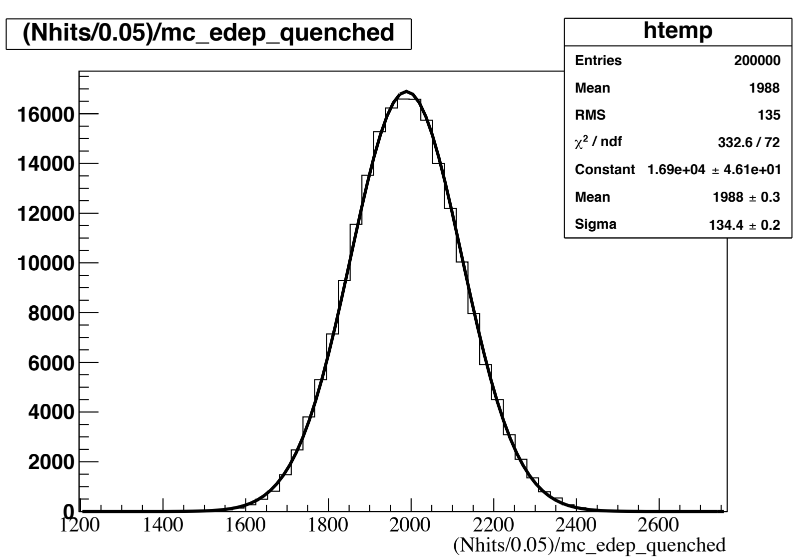
...then rescale to the expected number inside the balloon (3200)

(overall a small effect since it's pretty flat)

Counting Analysis

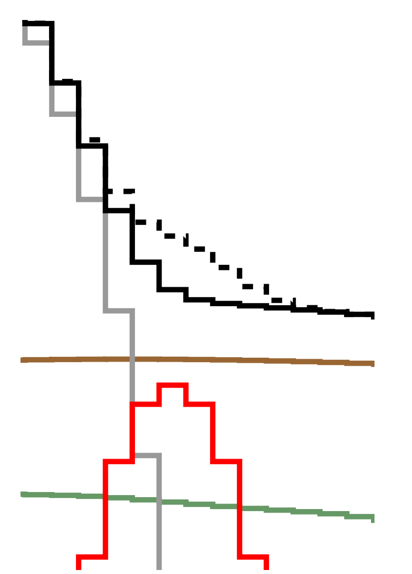
- Single-bin counting analysis for DBD signal
- Andy's code from SNO+ sensitivity estimates
  - Analytic smearing for energy resolution
  - Set your light yield, fiducial volume, loading
  - Load signal/background MC via PDFs

Light Yield



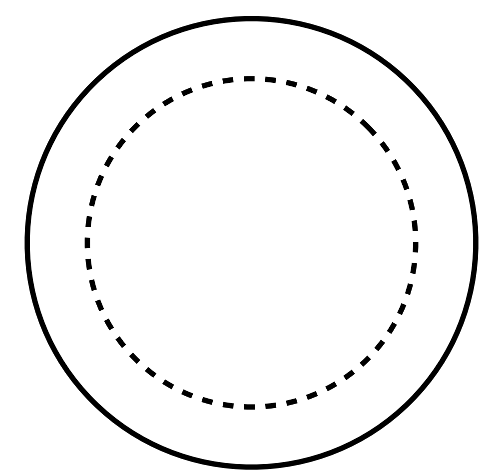
Scale MC Nhits from
5% up to 90% coverage
1800 hits/MeV

Energy ROI



Asymmetric ROI to reduce 2nu
-0.5sigma to +2sigma
(SNO+ is -0.5 to +1.5)

Fiducial Volume



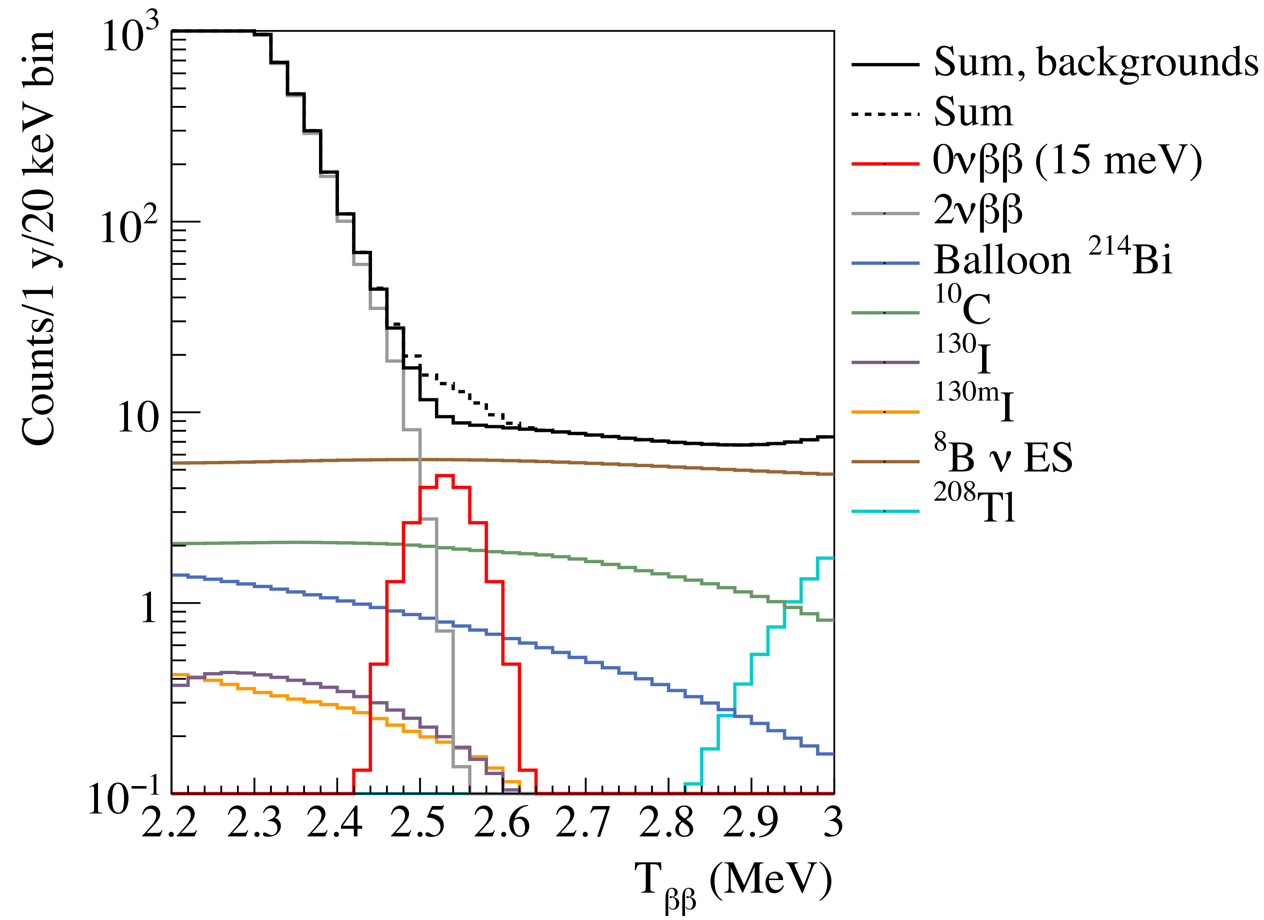
Scanned 6.5-7.5 m to optimize sensitivity

$\boldsymbol{R = 7}$ **m**

Counting Analysis

Signal	Events
$0\nu\beta\beta$ (15 meV)	147.3
$2\nu\beta\beta$	11.9
^{8}B Solar ES	265.88
^{10}C	90.0
^{130}I	7.9
^{130m}I	7.8
^{208}Tl	0.007
Balloon ^{214}Bi	35.3
Total	418.8

Results



90% CL Sensitivity:
(Feldman-Cousins)

$R < 34.2$ counts

$T_{1/2} > 8.1 \times 10^{27}$ years

$m_{\beta\beta} < 7.3$ meV

Counting Analysis

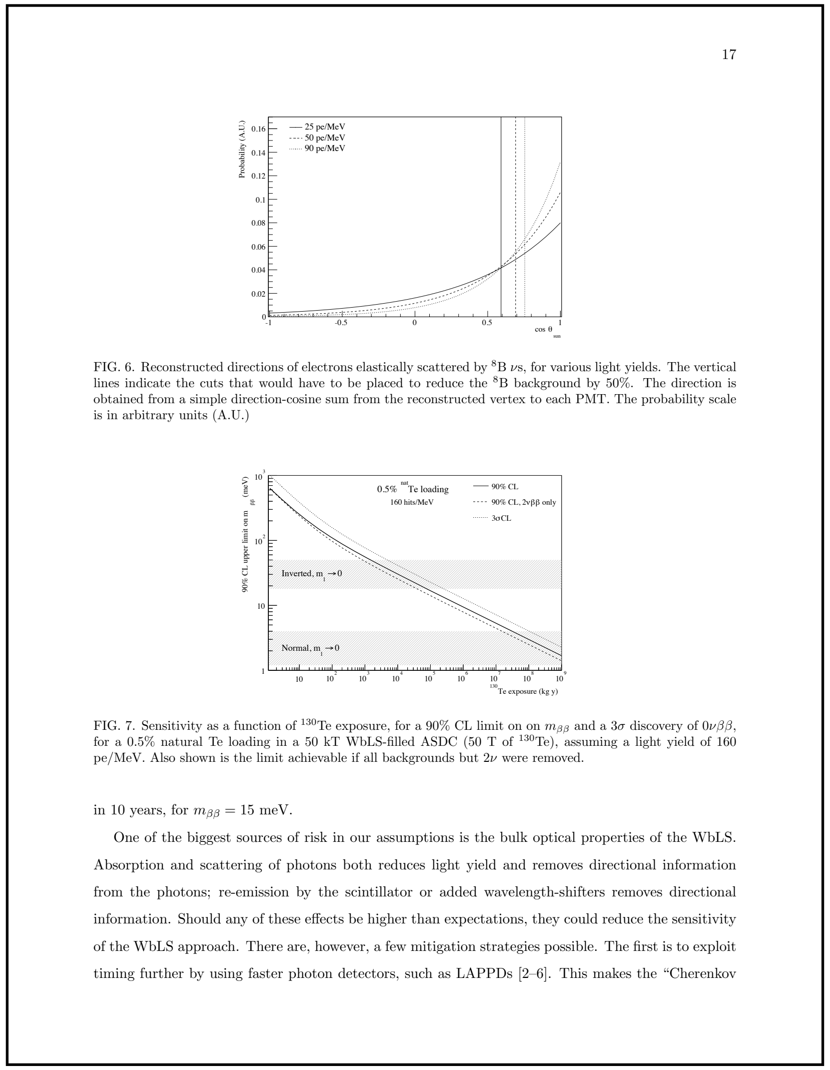

17

FIG. 6. Reconstructed directions of electrons elastically scattered by ^{8}B νs, for various light yields. The vertical lines indicate the cuts that would have to be placed to reduce the ^{8}B background by 50%. The direction is obtained from a simple direction-cosine sum from the reconstructed vertex to each PMT. The probability scale is in arbitrary units (A.U.)

FIG. 7. Sensitivity as a function of ^{130}Te exposure, for a 90% CL limit on on $m_{\beta\beta}$ and a 3σ discovery of $0\nu\beta\beta$, for a 0.5% natural Te loading in a 50 kT WbLS-filled ASDC (50 T of ^{130}Te), assuming a light yield of 160 pe/MeV. Also shown is the limit achievable if all backgrounds but 2ν were removed.

in 10 years, for $m_{\beta\beta} = 15$ meV.

One of the biggest sources of risk in our assumptions is the bulk optical properties of the WbLS. Absorption and scattering of photons both reduces light yield and removes directional information from the photons; re-emission by the scintillator or added wavelength-shifters removes directional information. Should any of these effects be higher than expectations, they could reduce the sensitivity of the WbLS approach. There are, however, a few mitigation strategies possible. The first is to exploit timing further by using faster photon detectors, such as LAPPDs [2–6]. This makes the "Cherenkov

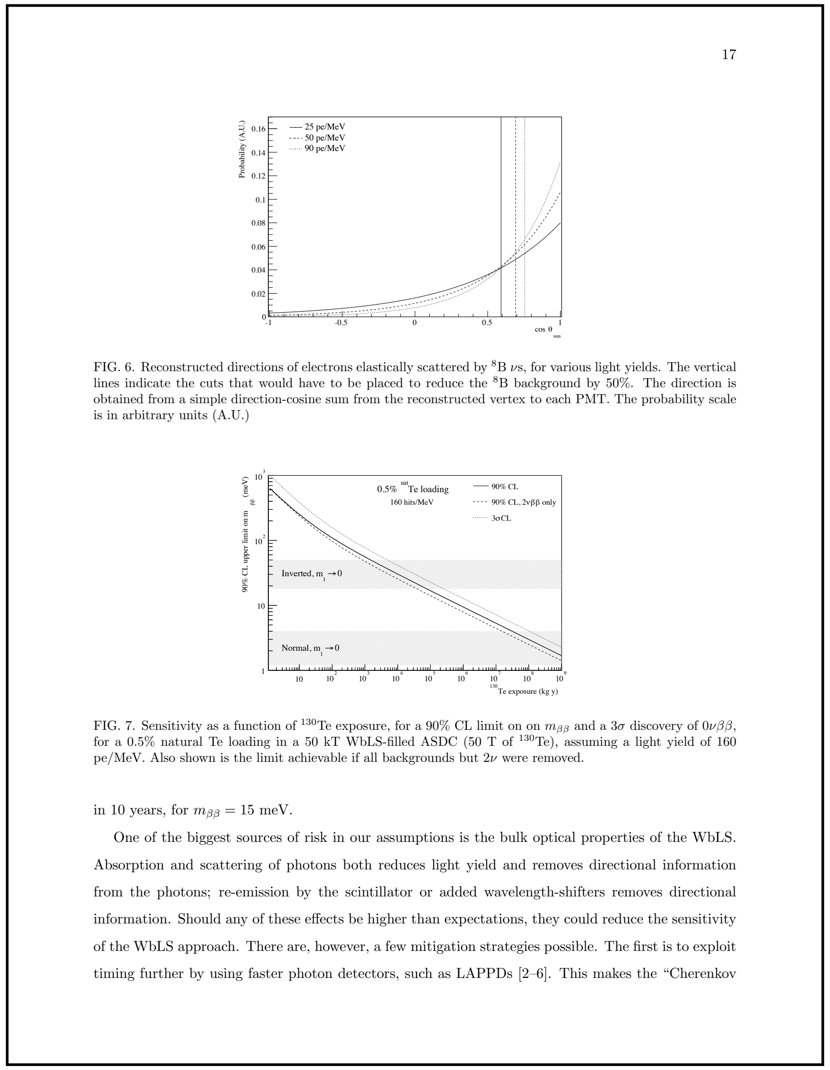
ASDC Whitepaper

October 2014

arxiv:1409.5864

Sensitivity estimates based on a simple scaling model

Counting Analysis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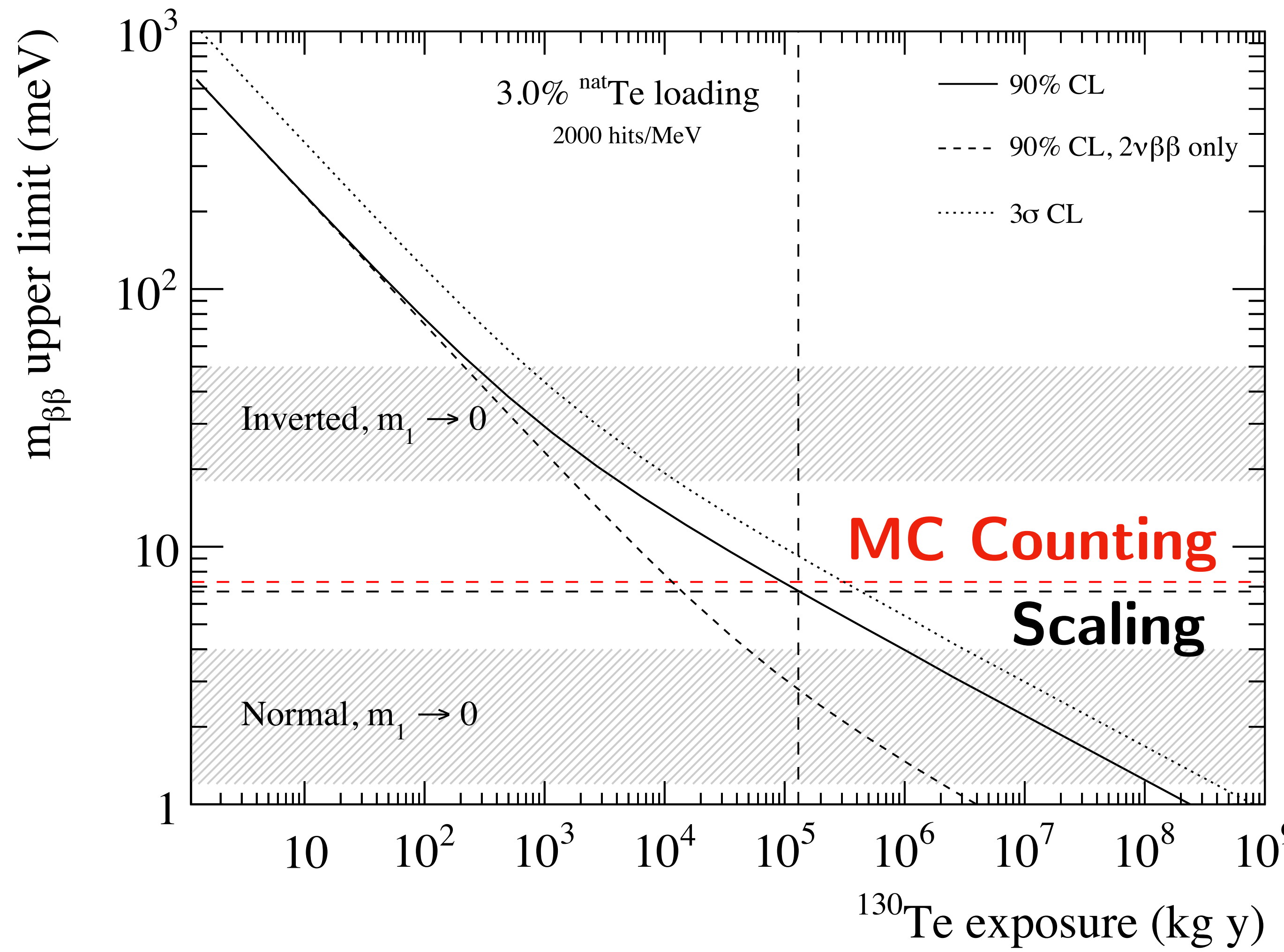

$T_{1/2} > 8.1 \times 10^{27}$ years

$m_{\beta\beta} < 7.3$ meV

Counting Analysis

Partial To Do List

- Monte Carlo
  - Need to improve MC performance to generate high-statistics MC, without factor of 20 light yield scaling
  - Tune optical model, investigate energy smearing, ...
- Analysis
  - Supporting analyses for background reductions: Solar with directionality, externals with timing, ^{214}Bi coincidences (assumed 100%), ^{10}C triple coincidence (using KamLAND), etc.
  - Import multi-d spectral fit from SNO+, systematics, ...