In search of something new and different:

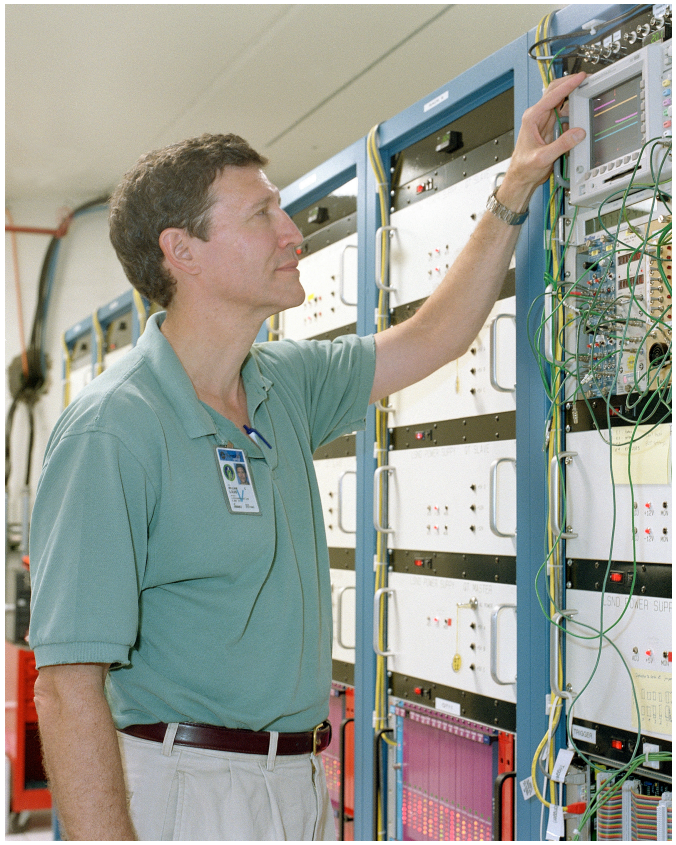
Looking for Paraphotons in Double Chooz…
A very first look at what we can do

Janet Conrad,
June 12, 2008
Outer Veto Group Meeting

1. a Para-what???
2. Backgrounds
3. Resurrected code and initial results

This work is being done in collaboration with Bill Louis from MiniBooNE

Bill



The idea:

Look for new neutral particles which are produced in reactors and decay to multiple photons.

I will show that a decay to 3 photons will make a distict signature in the detector…

motivated by a model by Nelson & Walsh, arXiv:0711.1363

This model…

introduces a Z' with B-L coupling

(originally introduced to motivate light masses)

~10 keV mass

coupling strength $g^2/e^2 = 10^{-9}$

2.5 ns lifetime

Branching ratios: $B(\nu\nu) \sim 100\%$, $B(\gamma\gamma\gamma) \sim 10^{-7}$

This was developed for different reasons,
but does provide an explanation for the MiniBooNE low E events

A very back-of-envelope look at rates from this model

Some factors:

For every "photon" produced in reactor, frac paraphotons:	1E-9
Branching ratio for 3γ decay	1E-7
Beam reduction due to decay before detector	1E-1
If the detector is about 2m across, frac that decays;	1E-2
Total reduction factors…	1E-19

Estimates of the prompt γ-ray flux based on experiments[16] give about one prompt γ per $\bar{\nu}$ from decays of excited fission fragments.

Donnelly, et al,
PRD 18:5, 1978, 1607

Lets imagine the photon-neutrino ratio is 1:1
Then at the near detector the neutrino flux is 1E22 per year

=> 1000 events/year

Doing a little more research, from:

PHYSICAL REVIEW C VOLUME 7, NUMBER 3 MARCH 1973

Prompt Gamma Rays from $^{235}U(n,f)$, $^{239}Pu(n,f)$, and Spontaneous Fission of ^{252}Cf† p. 1173

V. V. Verbinski, Hans Weber, and R. E. Sund

typo???

Photon energy range (MeV)	Protons/Fission ^{235}U	^{239}Pu	^{252}Cf
0.14–0.3	0.833	1.267	1.270
0.3–0.5	1.318	1.473	1.855
0.5–0.7	1.182	1.219	1.613
0.7–1.0	1.191	1.097	1.067
1.0–1.5	1.072	0.998	0.838
1.5–2.0	0.461	0.450	0.442
2.0–2.5	0.258	0.268	0.292
2.5–3.0	0.158	0.175	0.183
3.0–4.0	0.143	0.173	0.160
4.0–5.0	0.050	0.0714	0.058
5.0–6.0	0.021	0.0265	0.019
6.0–7.0	0.0098	0.0104	0.0057
7.0–10.0	0.0027	0.0015	0.0004
0.14–10.0	6.70	7.23	7.80

I'll claim that backgrounds push us to a >2.5 MeV window…

About 0.4 photons/ fission

to scale to $\bar{\nu}$:

About 4 $\bar{\nu}$/fission above 2 MeV

factor of 0.4/4= 0.1

So my calculation of 1000 events may be off by up to x0.1…
On the other hand there may be other sources of few MeV γ's
e.g. n-capture, longer lived decays…

For the remaining discussion lets assume that there will be
100 to 1000 signal events/year
compare to 165,000 IBD/years --> 0.06% to 0.6%

It seems like it would be worth a "generic search"
which would limit the parameters of any light Z' production

But can we find them?

signal and backgrounds

Paraphotons decay to 3γ

At DC energies, γ's Compton Scatter.
The radiation length is about 40 cm.
So the scattering produces sources of scintilation light
all over the tank

At each Compton Scatter the γ loses about
2/3 of its energy,

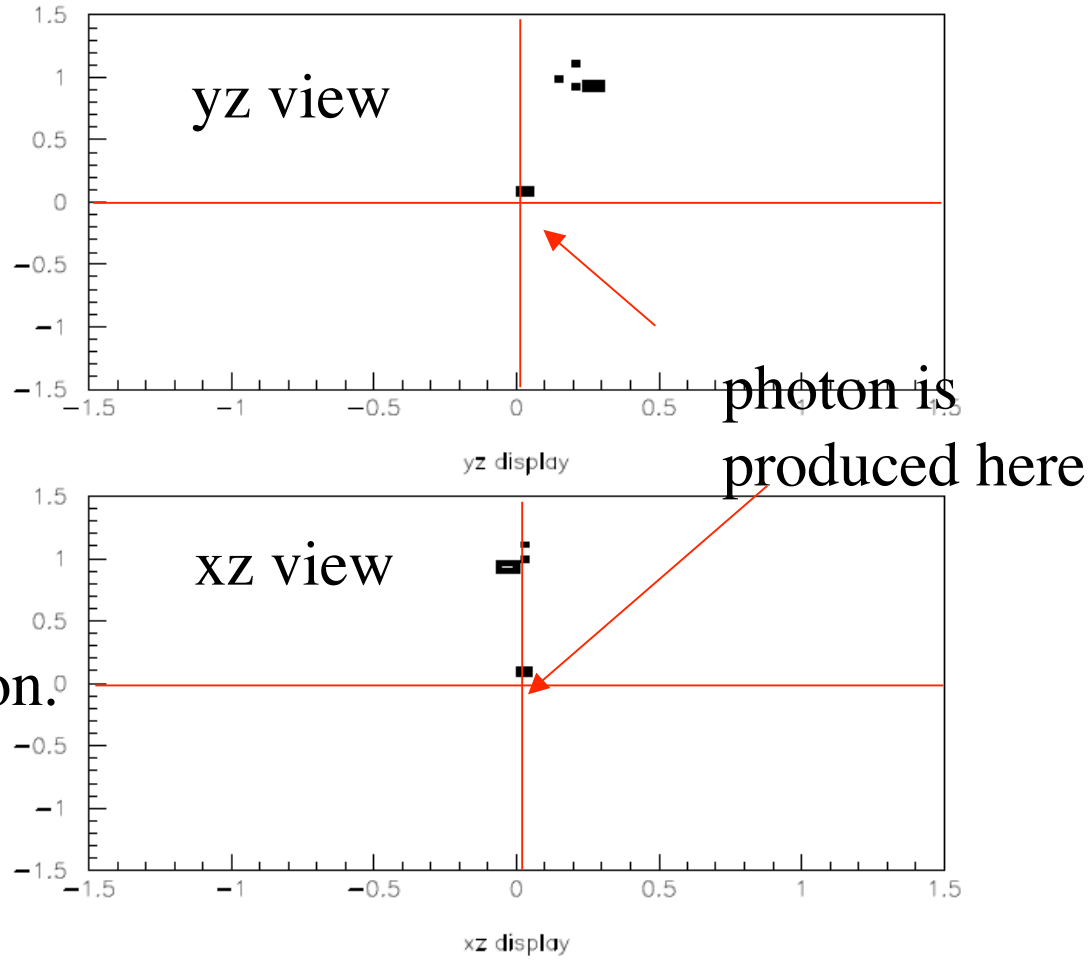
An example <u>single</u> 5 MeV compton scattering photon, produced pointed upward (along z)…

The energy deposited is "diffuse," not pointlike

Typically there are 2 major clusters of light-sources.

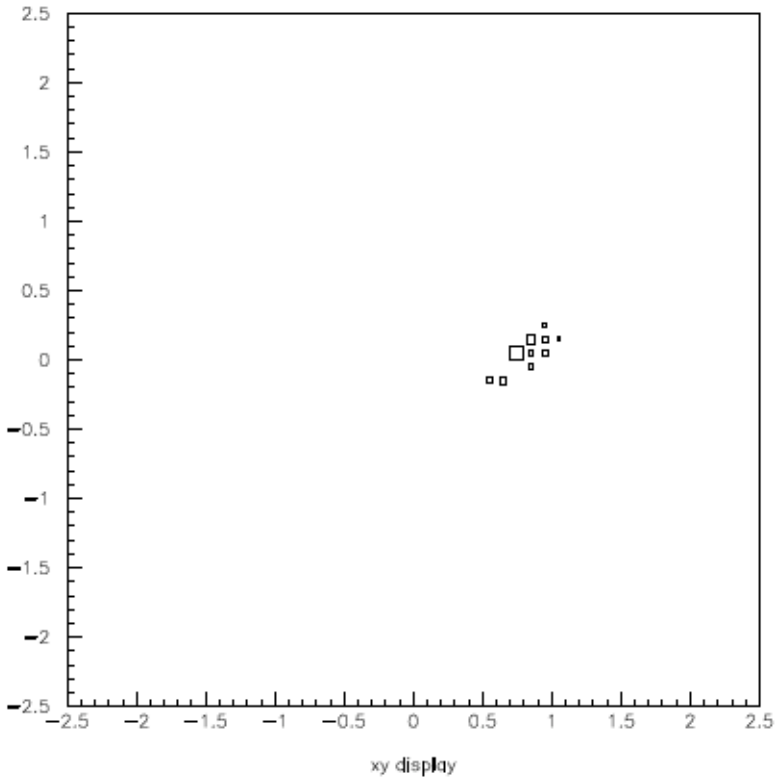
At high energies the "walk" preserves production direction.

Right now I don't use this, but we might in the future.



A 3 photon signal will look like 3 of these.

In other words, there are about 6 light sources, distributed in a “diffuse” manner



This is a 3.25 MeV paraphoton that decayed to 3 1.08 MeV photons.

If we can find a way to measure “diffuseness” we may be able to isolate these events.

This should look really different than…

A electron of the same visible energy

this is a single energy deposit

The first 1/2 of the IBD event (before neutron capture)

This has a big deposit of energy and

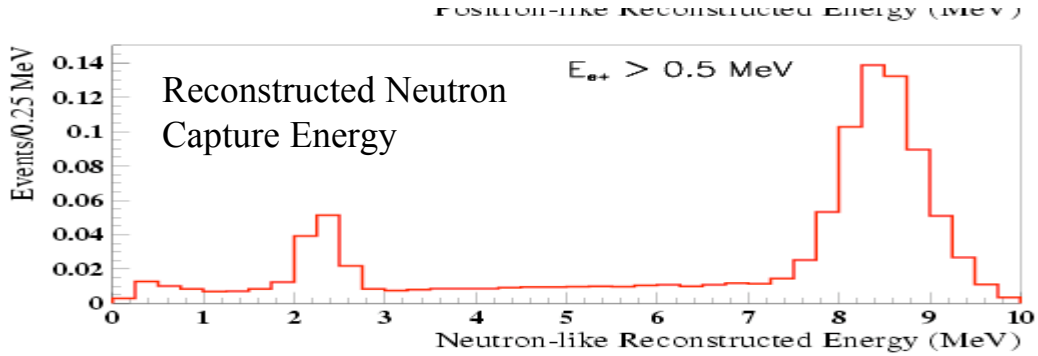
two sets of clusters from the 0.5 MeV γs

A single 2.2 MeV photon from a neutron capture.

This should have two hits, so look less diffuse

Still it is a worry -- we might want to require

Evis>2.2 MeV



Gd produces multiple photons when it captures, so we need to stay away from the Gd peak(s)

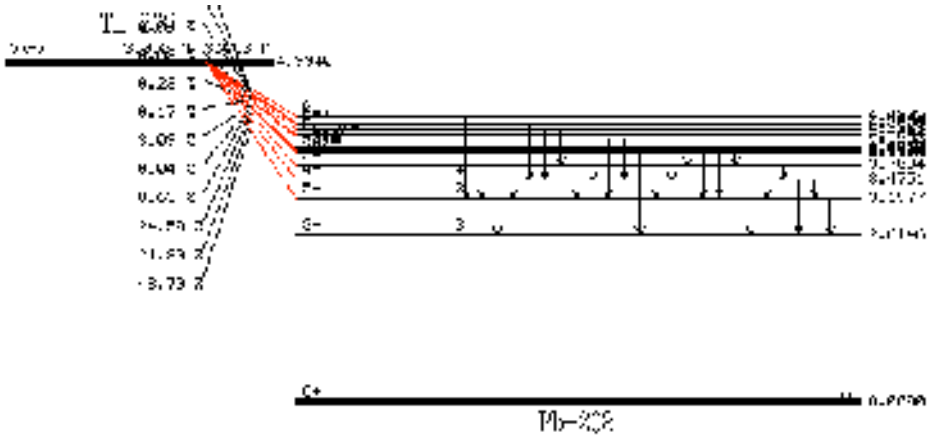
Is there a Gd capture peak at 5 MeV?

Since the paraphoton signal is dead by ~5 MeV, we might want to put on an upper limit…

Two events types I am sorta worried about…

1) A single high energy photon enters the tank

2) 208Tl decays with a Qvalue of 5 MeV and a 2.8 MeV γ



There is also a Bismuth decay to worry about…

Both of these event types are most likely to occur near the edge of the detector -- a vertex cut should help reduce these!

A worry is the dissolved Tl and Bi…

A third type that is a definite worry…

3) An IBD event where the neutron captures immediately
and produces a 2.2 MeV γ

From the Monte Carlo for braidwood,
0.1% of IBD events captured earlier than the
the trigger window.
Not all of these would be a background,
though, since from the point of view of timing,
the light will still appear to be late.

Only 16% of the IBD events capture on H.

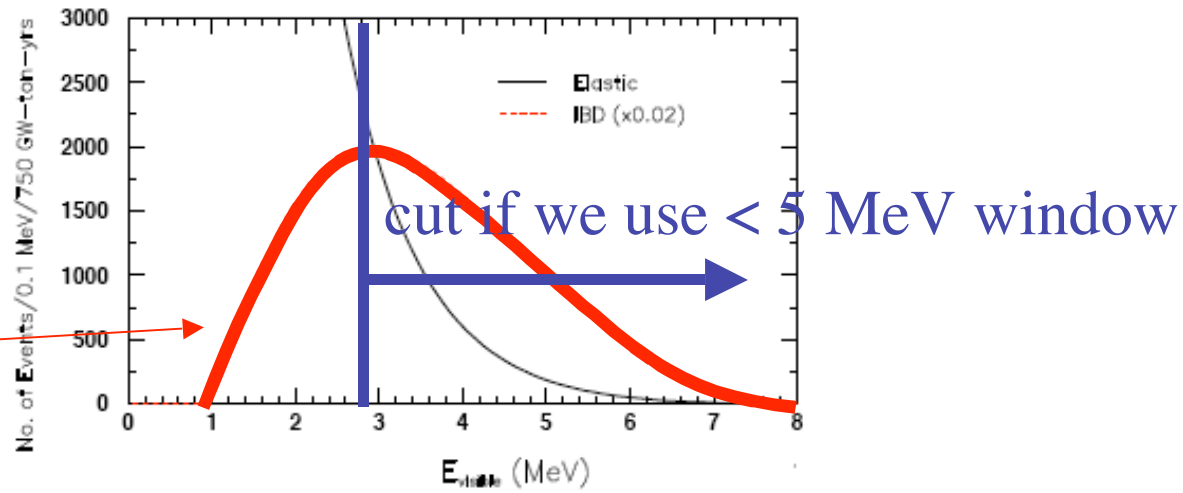
So, only 0.016% of are likely to be this kind of event.

Our signal is 0.06% to 0.6%…

If our signal turns out to be more like 0.06%,
we may need another cut on these events.

In this case an upper energy cut of 5 MeV helps a lot!

A cut on the visible energy distribution helps a lot!



Note: the energy dependence of paraphotons is steeply falling with energy.

The Tl and Bi backgrounds and the IBDs with early captures do not have the same energy dependence

We may be able to fit for the energy dependence of background vs. signal

Resurrected code and initial results

Once, long ago, there were ideas for experiments at Braidwood and Kraznoyarsk…

What is left over is vertex finding code.

It assumes a spherical detector with an inner region doped with scintillator.

The vertex is found using the relative time of the hits in the phototubes.

The scintillator is assumed to be PPO, which has a 3 ns fast component.

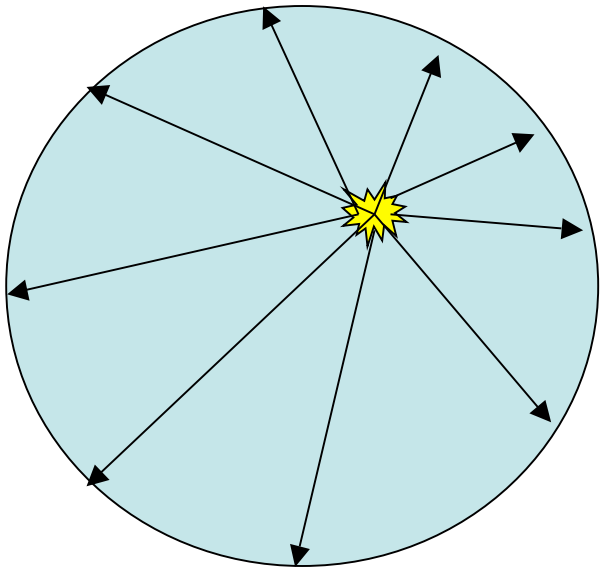
Vertices are generated randomly throughout the tank.
The fitter assumes all of the light comes from a single point.
It then tries to fit for the most likely source…
The likelihood of an event is based on how well this fits.

electrons, which deposit all of their energy at once,
give low likelihood values.

IBD events (disregarding the n capture) give moderate
likelihood values.

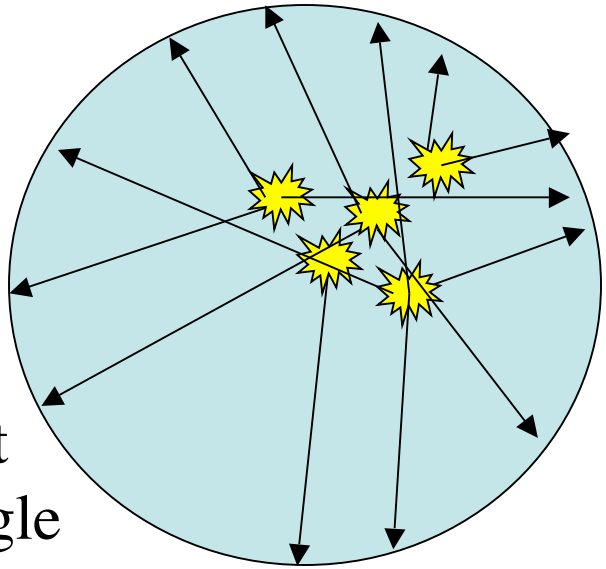
It turns out that 3 photons in the tank do not look at all
like they come from a single point.
So they give large likelihood values.

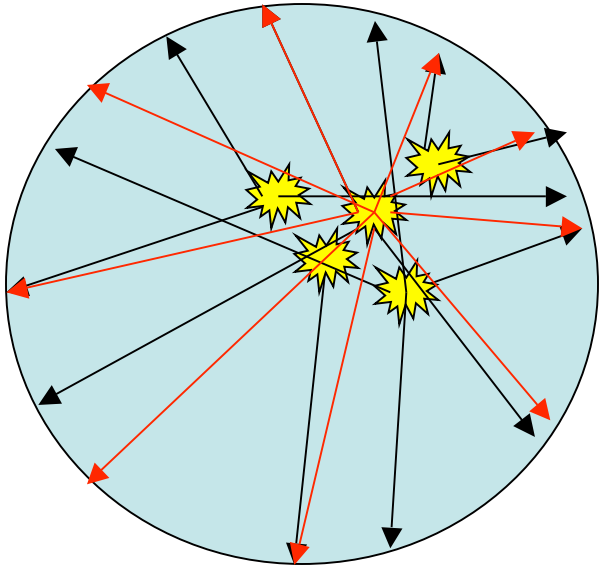
Shown graphically…



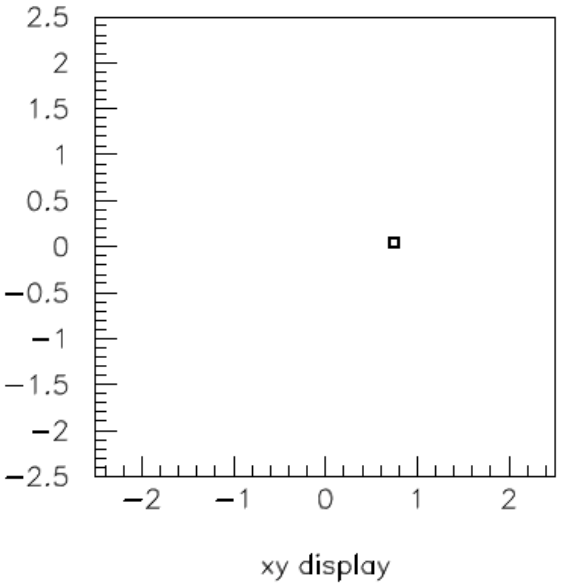
This is the case where the timing of the hits will be consistent with a single source of light - a fit to a single source will be good.

But this is a case where the hits are not from a single source, and a fit to a single source (red) will be poor

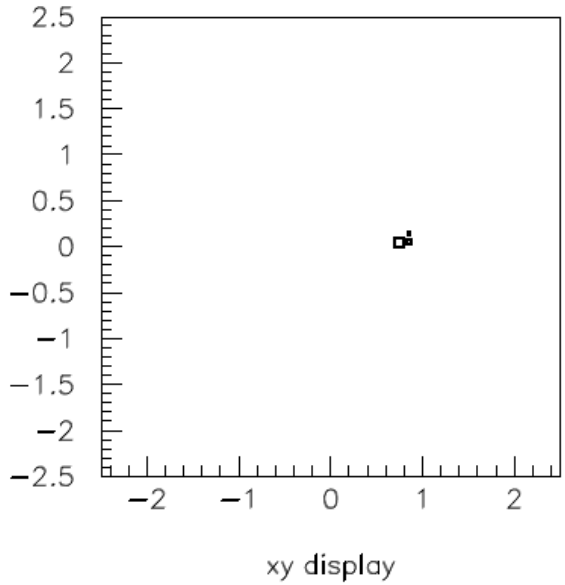




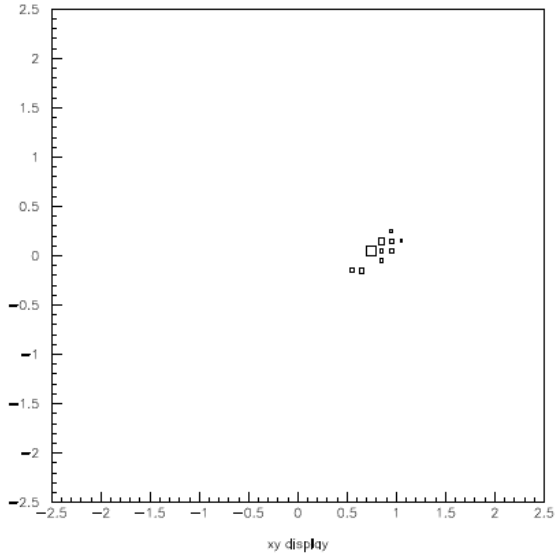
Here are “event displays” of 3 events all depositing 3.25 MeV of energy.



elastic scatter

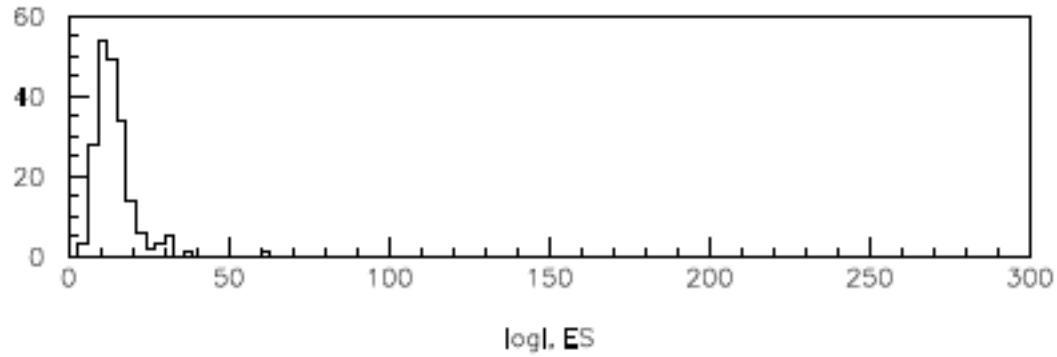


IBD

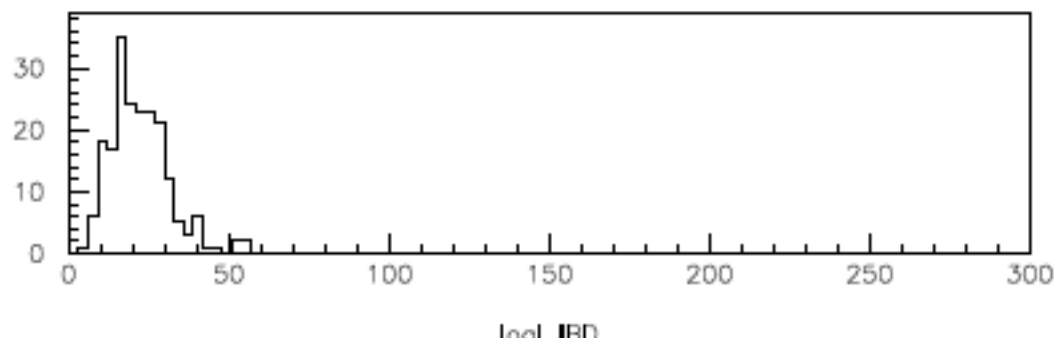


Paraphoton

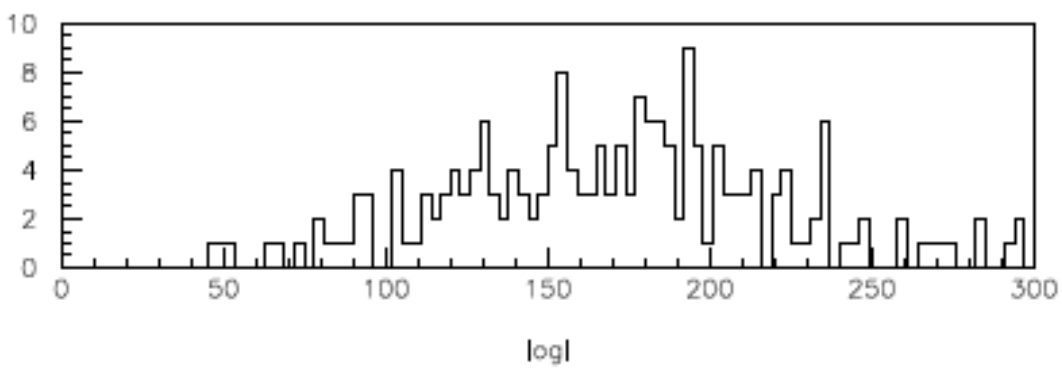
Likelihoods for these 3.2 MeV cases…



nu-e elastic…
One 3.2 MeV electron energy deposit

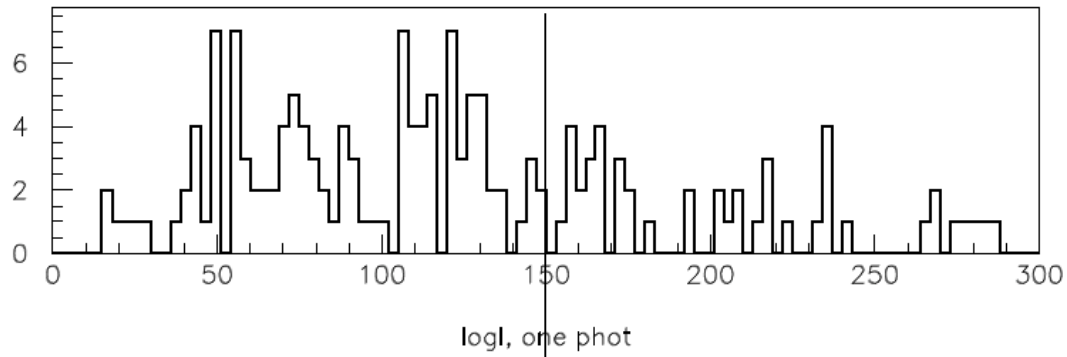


IBD, late n capture:
One 2.2 MeV energy deposit with
two 0.5 MeV photons



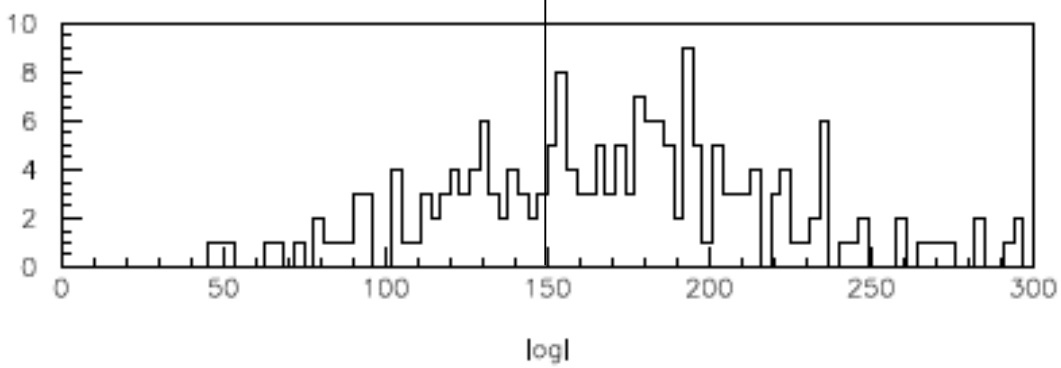
Three 1.08 MeV photons

A single 3.25 MeV photon enters the tank, can we remove with vertex cut?



overlap

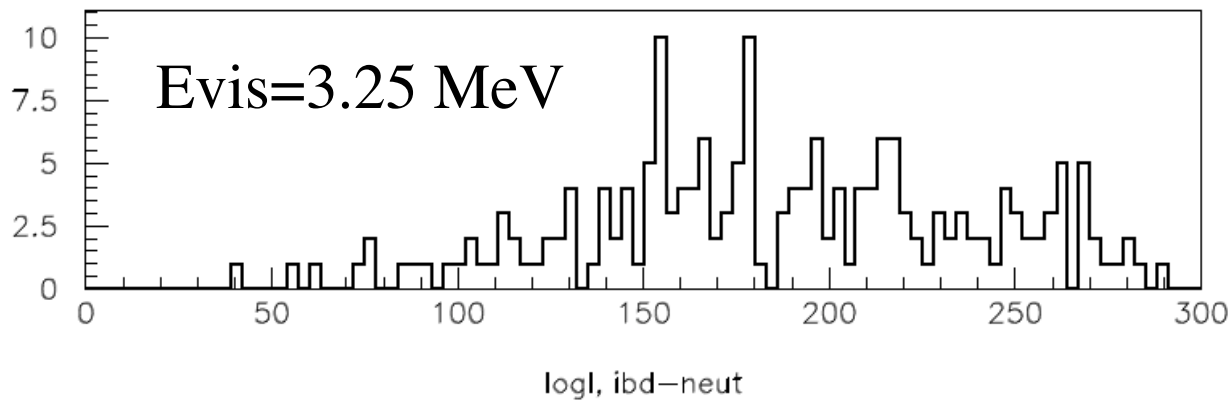
signal:

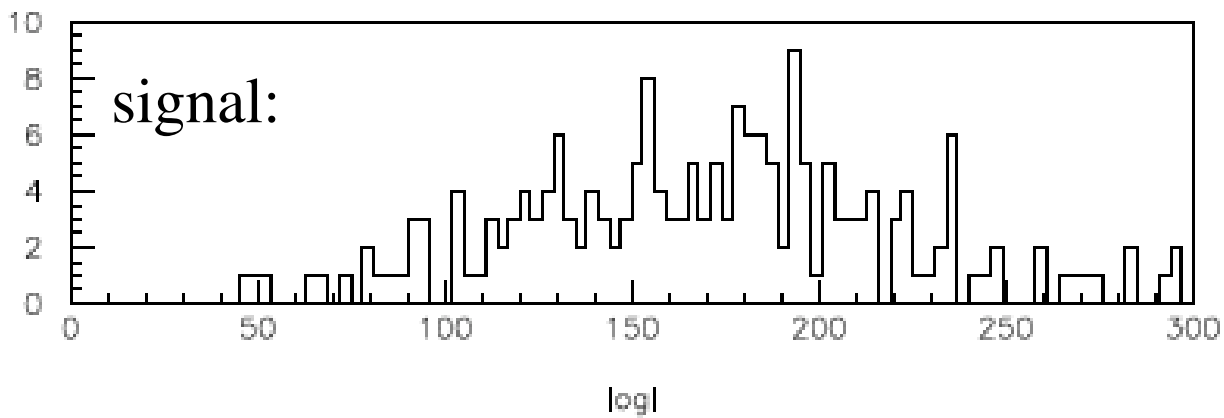


Need to understand rate of single photons in the tank

I expect Tl and Bi will look similar, but I need to examine this.

Second: the ibd+n “early capture” --- look at events <5 MeV





Basically, IBD+n is 3 photons -- 2 at 0.5 MeV
and one at 2.2 MeV….

… so it looks JUST LIKE our signal.

Luckily not a killer because rate is about 0.016% or less…

Conclusion:

Basically, this is a generic search for vector bosons --
any vector boson should decay through 3 gammas.
But there is a model out there as motivation…

We should look at whether we can distinguish
"axion" type decays to only 2 photons too….
Is there any axion space worth exploring?

I think this concept for searches looks promising.

I would like to look at more energies,
and include a 3 body decay spectrum.

Are there any other backgrounds that I have missed?

A comment:

We do not write all of the information on all singles.
We will need to work with the DAQ group to arrange to have paraphoton candidates written out.