Suppressing ω-ish Backgrounds in $\gamma+p \rightarrow p+4\gamma$

D. Mack

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Motivation in Terms of 4γ Physics

The Wuhan U. and JEF groups are primarily interested in the spectroscopy of $M(\eta\pi^0)$ and rare decays such as $\eta^{(\prime)} \rightarrow \pi^0 2\gamma$.

The dominant 4γ channels are $2\pi^0$ and $\eta\pi^0$. Bad combos of the dominant decays tend to swamp weaker channels such as 2η, $\eta'\pi^0$, $\pi^0 2\gamma$, and η2γ.

We soon plan to assign, if possible, each 4γ event to at most one of the dominant channels. If the CL for being a $2\pi^0$ event is significant, and higher than any other hypothesis, then we will consider it to be a true $2\pi^0$ event and no other hypothesis such as $\pi^0 2\gamma$ will be considered.

While Nian Qin (Wuhan U.) was pursuing an earlier, sequential version of this filtering, it became clear that $\omega+\pi^0$ with a missing photon is another dominant channel:
http://argus.phys.uregina.ca/cgi-bin/private/DocDB/ShowDocument?docid=3171
(for an earlier, confusing mention of the problem see D. Alde et al., ZPC 54, 549-551 (1992))

Weak channel spectroscopy, or rare decay searches, are susceptible to this bkg if $M(4\gamma) > M(\omega+\pi^0)$ modulo detector resolution. This means the rare decay $\eta \rightarrow \pi^0 2\gamma$ is not affected by bad combos from $\omega+\pi^0$, but the corresponding η’ decay will indeed be affected.

The purpose of these slides is to more formally characterize the $\omega+\pi^0$ background to see if our preliminary cuts are missing something.

$\omega+\pi^0$ Bkg Due to a Missing Photon

Bright sources of 5 photons such as $b_1^0 \rightarrow \omega+\pi^0$ (see next slide) can leak into our 4γ distributions via a missing photon.* Missing photons take two forms:

i. Photons of low energy (passing our missing energy or CL cut) which are either below shower reconstruction threshold or lost down a hole in the acceptance. We'll call these "truly missing photons".

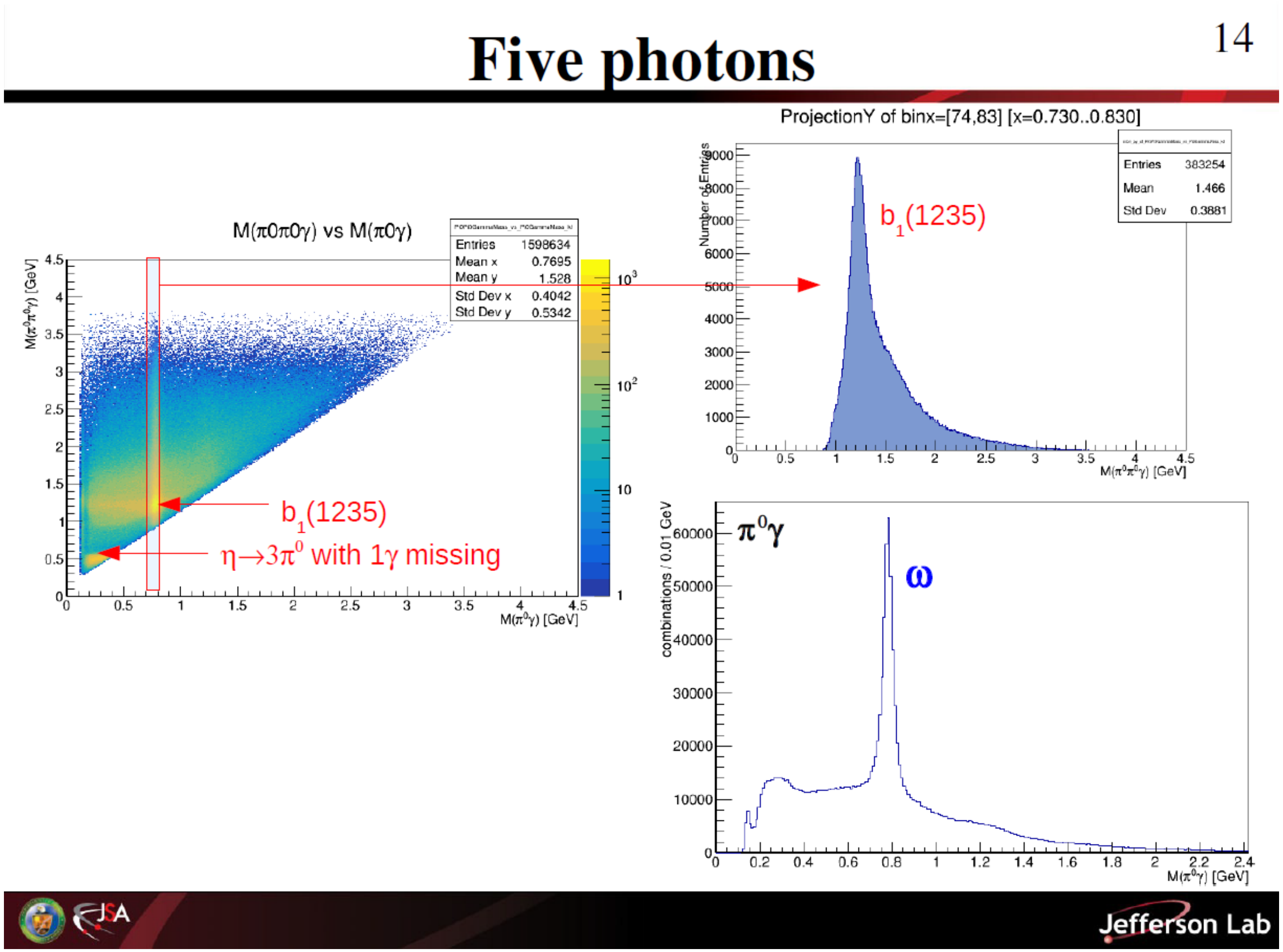
ii. Photons where two showers overlap and are reconstructed as a single shower. The photons can be of any energy, and cuts on missing energy and CL probably aren't helpful. We call these "merged photons".

* We can also get events from ω+γ final states without a missing photon. These are valid 4γ events of course. We can expect to see them in $\eta' \rightarrow \omega+\gamma$ (BR = 2.8%)

5γ from Simon's Survey

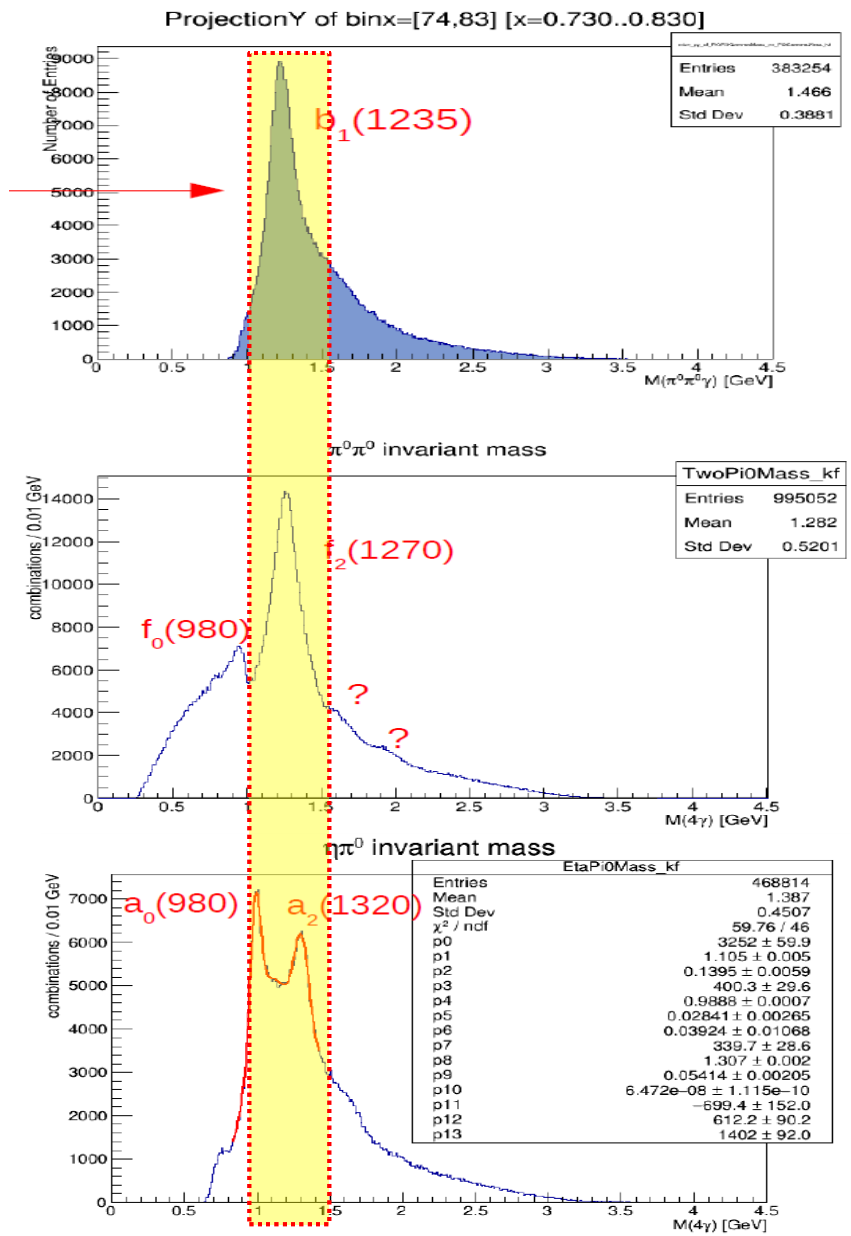
http://argus.phys.uregina.ca/cgi-bin/private/DocDB/ShowDocument?docid=3187

About 25% of the 5γ events are $2\pi^0\gamma$, many from the $b_1^0 \rightarrow \omega+\pi^0$ decay.



Potential 5γ →4γ Leakage

Top plot –
$\omega+\pi^0$ spectrum “source” from Simon’s survey



Bottom two plots –
Mass spectra for the two dominant 4γ signals from Simon’s survey

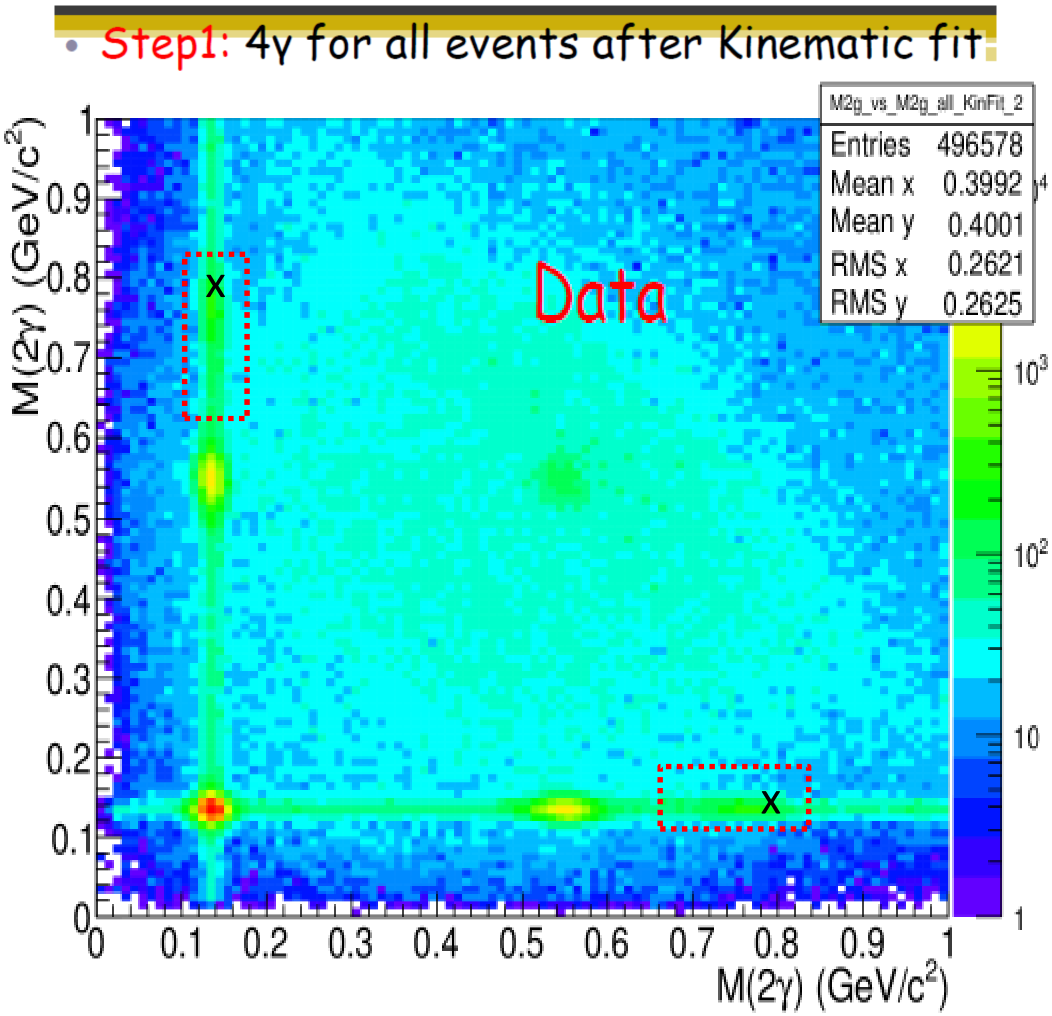
The detailed handling of the $\omega+\pi^0$ bkg has the potential to impact important spectral features of even the dominant 4γ channels.

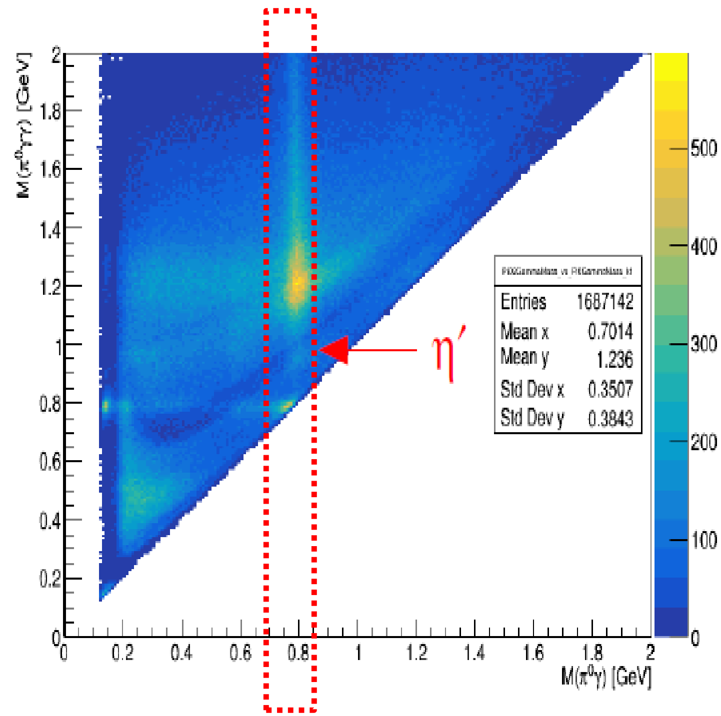
In Nian’s preliminary sequential filtering, we indeed saw significant qualitative changes in the bottom two spectra.

ω-ish Backgrounds in 4γ

The significant presence of the ω can be seen in 4γ plots:

- in $M(\pi^0+\gamma)$ as a narrow locus in the right plot from Simon, and
- in M(2γ) as broad blobs in the left plot from Nian, shifted below the nominal mass.





$\omega+\pi^0$ With Truly Missing Photons

Here I examine the 3 ways to truly lose a photon, what the result looks like, and possible ways to cut this bkg. My notation is:

$$\pi^0\,\omega \rightarrow \pi^0_1\ [\gamma_B\,\pi^0_2]_\omega \rightarrow \gamma_{11}\gamma_{12}\ [\gamma_B\,\gamma_{21}\gamma_{22}]_\omega$$

where the B subscript denotes the bachelor photon.

Scenario	Example Detected Combo (missing photon in parenthesis)	Looks Like	Exclusive Cut	Potential Inclusive Cut	Comments
#1 lose γ_{1i}	γ_{11}--$[\gamma_B\,\gamma_{21}\gamma_{22}]_\omega$ (**γ_{12}**)	$\gamma\omega$ (2 combos)	$M(\pi^0+\gamma) \sim M_\omega$	$\gamma+p \rightarrow p\gamma(X)$ $M_x \sim M_\omega$	This cut will also remove valid signals such as $\eta' \rightarrow \omega\gamma$
#2 lose γ_{2i}	$\gamma_{11}\gamma_{12}\ [\gamma_B\,\gamma_{21}$--$]_\omega$ (**γ_{22}**)	π^0 + light ω (2 combos)	$M(2\gamma) \sim M_{\pi 0}$ .AND. $M(2\gamma) \lesssim M_\omega$	$\gamma+p \rightarrow p\pi^0(X)$ $M_x \sim M_\omega$	Potential "good combo" background in $\pi^0 + \eta$.*
#3 lose γ_B	$\gamma_{11}\gamma_{12}$ [-- $\gamma_{21}\gamma_{22}]_\omega$ (**γ_B**)	$2\pi^0$ (1 combo)	none	$\gamma+p \rightarrow p\pi^0(X)$ $M_x \sim M_\omega$	Definite "good combo" background in $2\pi^0$

Only soft missing photons relevant. Otherwise, event is removable by kin fit or ME cut.

*A combination of shower threshold and CL cut must ensure the light ω cannot overlap with the η

$\omega+\pi^0$ With Two Showers Merged

Here I characterize the 5 ways to merge two showers, what the result looks like, and possible ways to cut this bkg. My notation is again:

$$\pi^0\omega \rightarrow \pi^0_1\ [\gamma_B\pi^0_2]_\omega \rightarrow \gamma_{11}\gamma_{12}\ [\gamma_B\gamma_{21}\gamma_{22}]_\omega$$

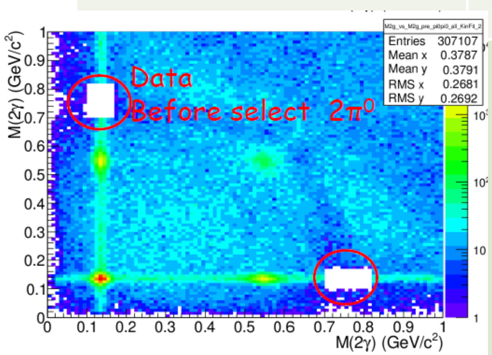
where the B subscript denotes the bachelor photon.

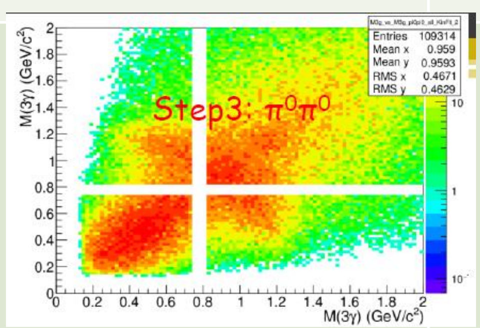
Scenario	Example Detected Combo	Looks Like	Exclusive Cut	Potential Inclusive Cut	Comments
#4 merge π^0_1 photons	$\gamma_{11}+\gamma_{12}\ [\gamma_B\gamma_{21}\gamma_{22}]_\omega$	$\gamma\omega$ (1 combo)	$M(\pi^0+\gamma) \sim M_\omega$	$\gamma+p \rightarrow p\gamma(X)$ $M_x \sim M_\omega$	Unlikely in FCAL.
#5 merge γ_B with a γ_{2i}	$\gamma_{11}\gamma_{12}\ [\gamma_B+\gamma_{21},\gamma_{22}]_\omega$	$\pi^0+\omega(2\gamma)$, $\pi^0 2\gamma$ (2 combos)	$M(2\gamma) \sim M_{\pi 0}$ .AND. $M(2\gamma) \sim M_\omega$	$\gamma+p \rightarrow p\pi^0(X)$ $M_x \sim M_\omega$	
#6 merge π^0_2 photons	$\gamma_{11}\gamma_{12}\ [\gamma_B, \gamma_{21}+\gamma_{22}]_\omega$	$\pi^0+\omega(2\gamma)$, $\pi^0 2\gamma$ (1 combo)	$M(2\gamma) \sim M_{\pi 0}$ .AND. $M(2\gamma) \sim M_\omega$	$\gamma+p \rightarrow p\pi^0(X)$ $M_x \sim M_\omega$	Unlikely in FCAL.
#7 merge γ_B with a γ_{1i}	$\gamma_B+\gamma_{11},\gamma_{12}\ [\_\_, \gamma_{21}\gamma_{22}]_\omega$	$\pi^0 2\gamma$ (2 combos)	None!?	None!?	It will have to be simulated for $\eta' \rightarrow \pi^0 2\gamma$
#8 merge γ_{1i} with a γ_{2j}	$\gamma_{11}+\gamma_{21},\gamma_{12}\ [\gamma_B, \_\_\ \gamma_{22}]_\omega$	4γ (4 combos)	None!?	None!?	It would have to be simulated for $\eta^{(\prime)} \rightarrow 4\gamma$

Effect of Cuts on the 8 Scenarios

The usual cuts that help reduce truly missing photons are a tight missing energy cut (or a high CL cut), and a low cut on unused calorimeter energy.
As far as I know, there are no cuts to help reduce events with merged showers.

Cut To Suppress $\omega+\pi^0$ Background Is	Will Address The Following Scenarios	But Not Address the Following Scenarios	Comments
$M(2\gamma) \sim M_{\pi 0}$ .AND. $M(2\gamma) \lesssim M_{\omega}$	$\gamma_{11}\gamma_{12}\,[\gamma_B\,\gamma_{21}\text{--}]_{\omega}\,(\gamma_{22})$ (2 combos) $\gamma_{11}\gamma_{12}\,[\gamma_B+\gamma_{21},\gamma_{22}]_{\omega}$ (2 combos) $\gamma_{11}\gamma_{12}\,[\gamma_B,\gamma_{21}+\gamma_{22}]_{\omega}$ (1 combo)		A possible alternative inclusive cut is $\gamma+p \rightarrow p\pi^0\,(X)$ $M_x \sim M_{\omega}$.
$M(\pi^0+\gamma) \sim M_{\omega}$	$\gamma_{11}\text{--}[\gamma_B\,\gamma_{21}\gamma_{22}]_{\omega}\,(\gamma_{12})$ (2 combos) $\gamma_{11}+\gamma_{12}\,[\gamma_B\,\gamma_{21}\gamma_{22}]_{\omega}$ (1 combo)		A possible alternative inclusive cut is $\gamma+p \rightarrow p\gamma(X)$ $M_x \sim M_{\omega}$
		$\gamma_{11}\gamma_{12}\,[\text{--}\,\gamma_{21}\gamma_{22}]_{\omega}\,(\gamma_B)$ (1 combo) $\gamma_B+\gamma_{11},\gamma_{12}\,[\_\_,\gamma_{21}\gamma_{22}]_{\omega}$ (2 combos) $\gamma_{11}+\gamma_{21},\gamma_{12}\,[\gamma_B,\_\_\,\gamma_{22}]_{\omega}$ (4 combos)	This will get sorted into $2\pi^0$. Simulate and subtract. **No frigging way to get rid of these last two merging scenarios!?**





Summary

I took a formal look at how the $\omega+\pi^0$ background can get into our 4γ data. The main conclusions are:

1. In addition to testing to see if an event belongs in one of the dominant categories $2\pi^0$ and $\pi^0\eta$, other dominant categories we need to test are $\gamma\omega$ and $\pi^0\omega_{light}$.

2. The cuts we're already doing are reasonable, and might be hard to improve.

Before he left, Nian had implemented two cuts that address 5 of the loss/merge scenarios for the $\omega+\pi^0$ background :

$$M(2\gamma) \sim M_{\pi 0} \text{ .AND. } M(2\gamma) \lesssim M_\omega$$

and

$$M(3\gamma) \sim M_\omega$$

(alternatively, we could consider cutting on $M(\pi^0+\gamma)$).

3. There are two alternative, inclusive cuts (e.g., $M_x \sim M_\omega$ in $\gamma+p \rightarrow p\pi^0(X)$). One or the other might have advantages over our existing cuts.

4. Unfortunately, there appear to be two shower merging scenarios that <u>cannot</u> be flagged as $\omega+\pi^0$ background (at least not obviously). This may eventually have to be simulated.

5. There is a final scenario where $\omega+\pi^0$ with a missing bachelor photon ends up looking like $2\pi^0$. This will get (mis)sorted as a $2\pi^0$ event, so its bad combos won't hurt the $\pi\eta$ or $\pi 2\gamma$ analyses. It can presumably be simulated if someone is interested in doing physics with $2\pi^0$.