Event Counting Analysis Example

$\gamma p \rightarrow \pi^0 \eta p \rightarrow 4\gamma p$

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Problem Statement

In my analysis I have used 3 different weights:

1. **Accidental Subtraction** (high intensity beam)
2. C**ombo tracking / uniqueness tracking** (many possible combos per event where only ~1 is True)
3. **Sideband subtraction** (4 photon final state combinatorics in this case)

Distinct purpose for each one. How should we combine them?

Dataset

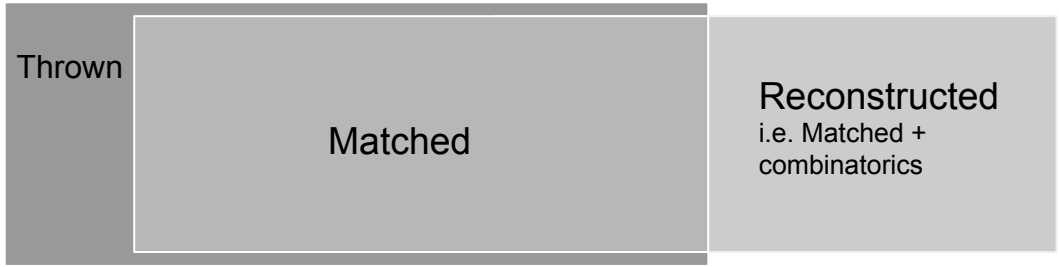
Simulated Independently and summed

$\gamma p \rightarrow a_0(980)\ p \rightarrow \pi^0 \eta\ p \rightarrow 4\gamma\ p$

$\gamma p \rightarrow a_2(1320)\ p \rightarrow \pi^0 \eta\ p \rightarrow 4\gamma\ p$

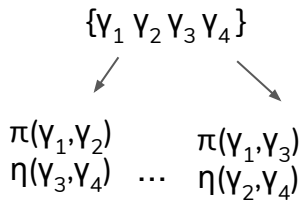
$\chi 2 < 13.3$ with 4 DOF applied unless otherwise noted

Masses Unconstrained



Signal MC

To simplify discussion the proton is not shown



Beam Photons

Prompt Fake
Prompt True
Accidental (non-prompt photons)

x

Spectroscopic Combos

=

Total Combos

Kinematic Fitter

- Adds Kin Fit 4-vectors
- Discards combos whose kinFit did not converge

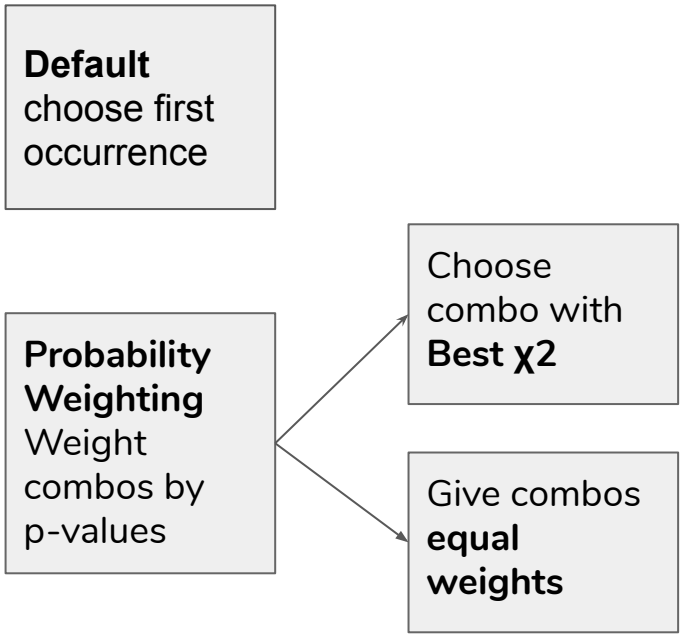
Accidental Subtraction
- Statistically selects TrueBeam

Sideband subtraction
- Does not explicitly count

Combo/Uniqueness tracking
- 1 integrated event per event
- Does not explicitly reduce sidebands nor accidentals

AS = Accidental Subtraction
SB = Sideband Subtraction
CT = Combination Tracking / Uniqueness Tracking

Combo Tracking



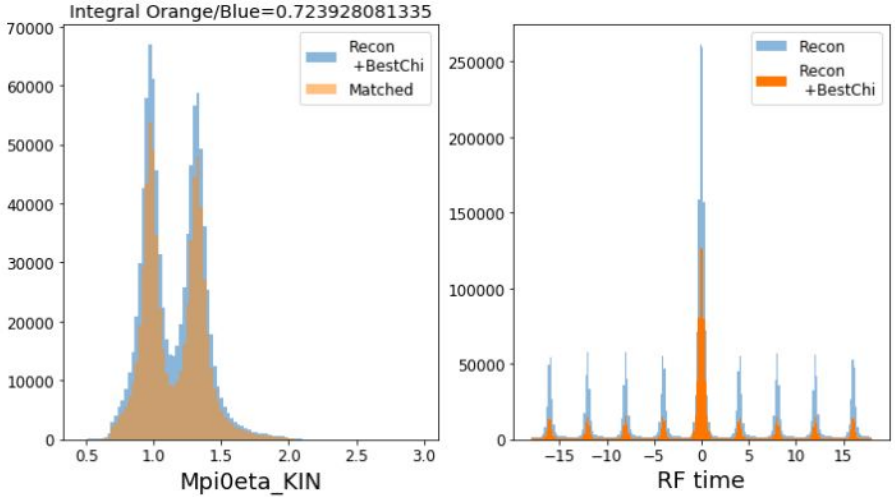
- Depending on what selections you apply these might differ

- χ2 related tracking schemes generally produces similar results

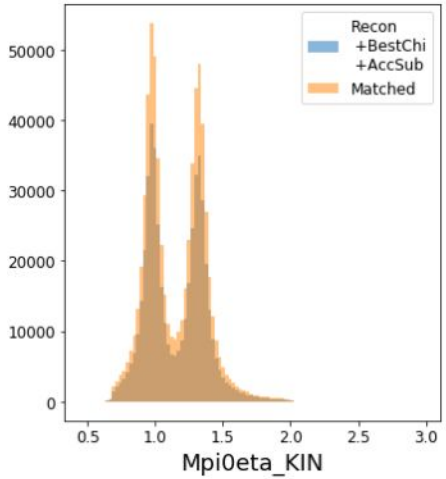
- Most results I will show will be related to **Best χ2**

First Attempt

Calculate CT weight considering **ALL** possible combos



- Applying best χ2 weight overestimates total integral. (Not all events have a “matched” combo)
- CT seems to affect sidebands more. Still need to accidental subtract

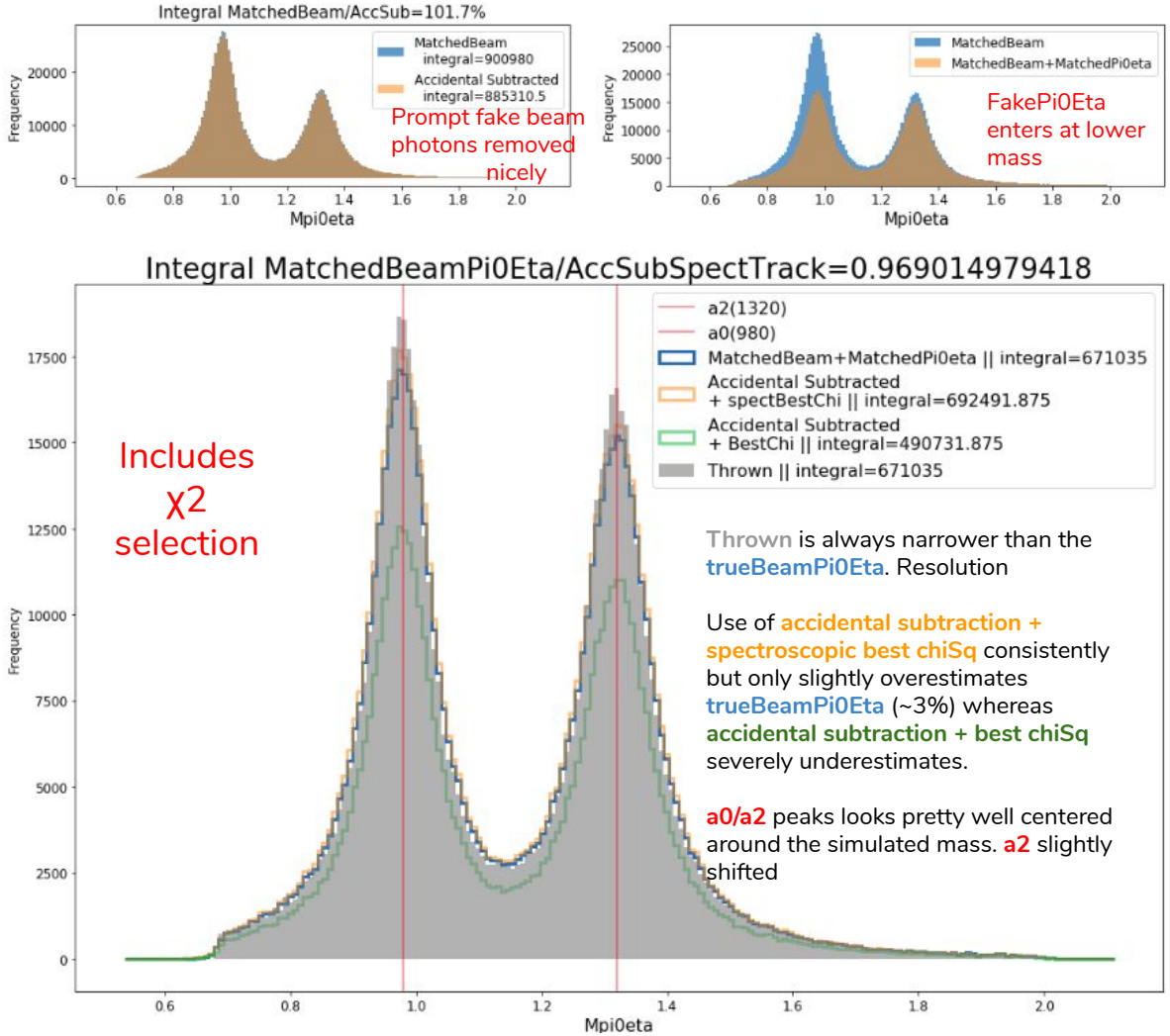


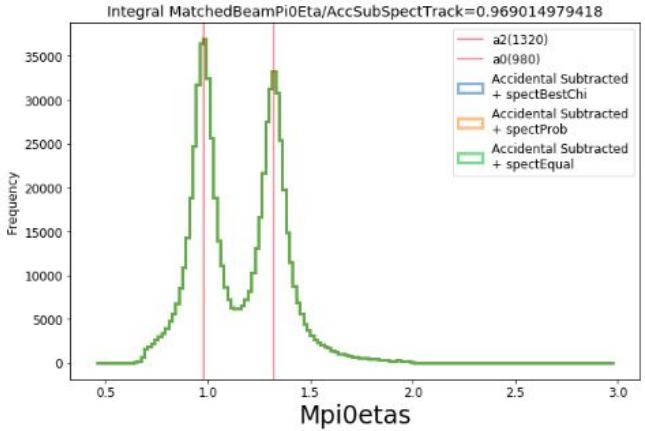
- Apply both best χ2 and accidental subtraction to reconstructed MC severely oversubtracts

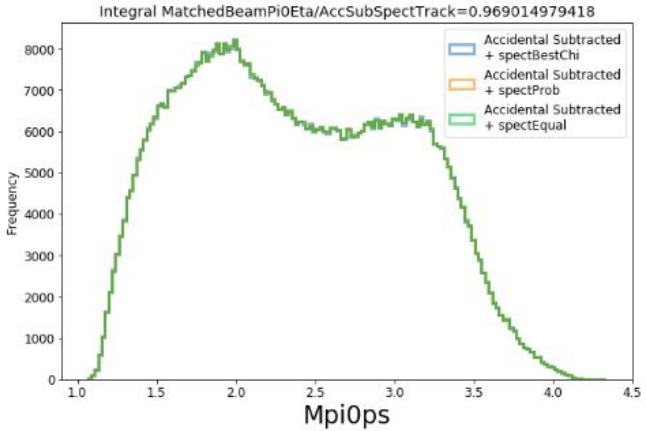
Reason: Accidental Subtraction also counts

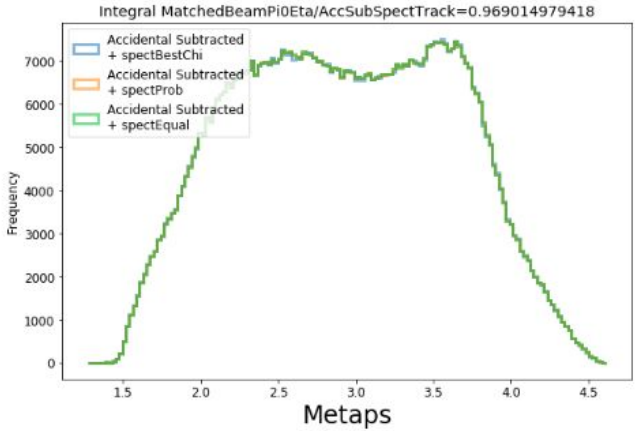
Second Attempt

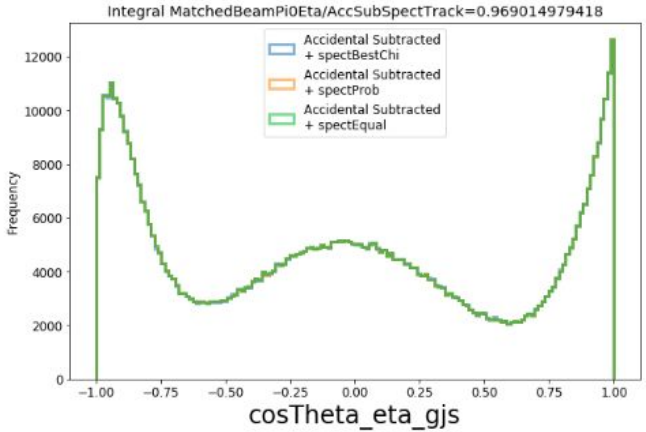
Calculate CT weight considering **SPECTROSCOPIC** possible combos









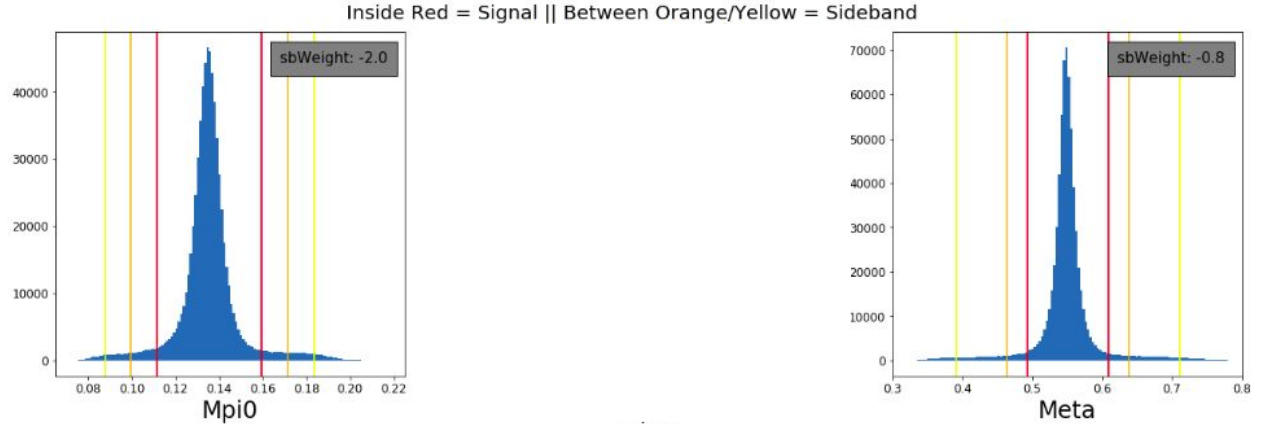


Only a χ2 selection

Compare the M(πη), M(πp), M(ηp), cosThetaGJ distributions using the 3 different tracking schemes **{best χ2, equal weights, probability weights}** only looking at spectroscopic combos

Almost identical

Seems to work...
Try to include sideband subtraction



SB | SKIP | SIG | SKIP | SB

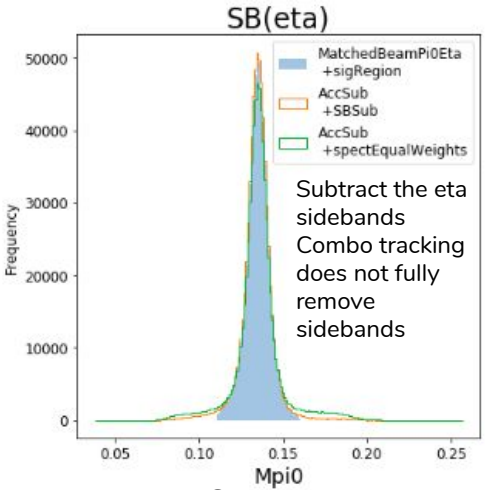
Red lines from double gaussian fit extracting 4 weighted sigma region.
This is our signal region.

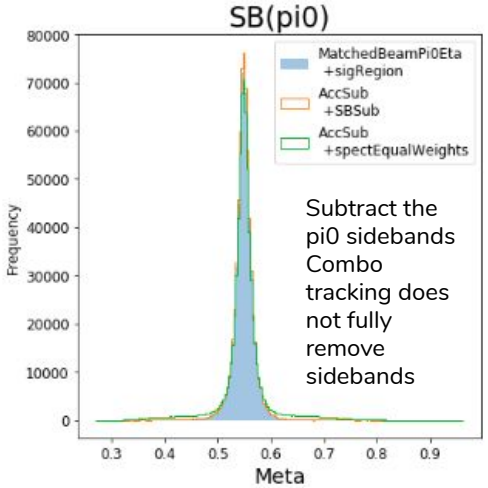
We calculate the weights independently and then just multiply them

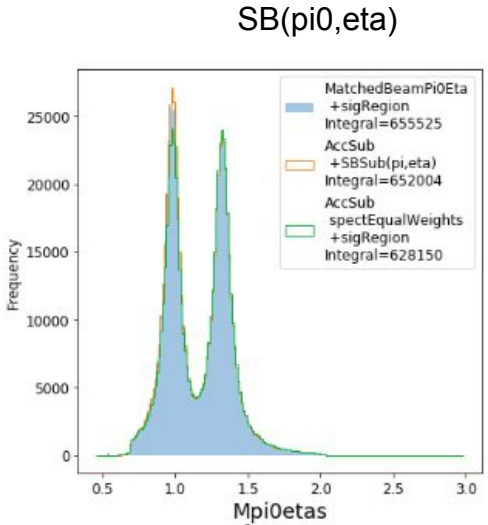
- Probably some correlations we need to consider when using kinematic fitted values but that is a question for later

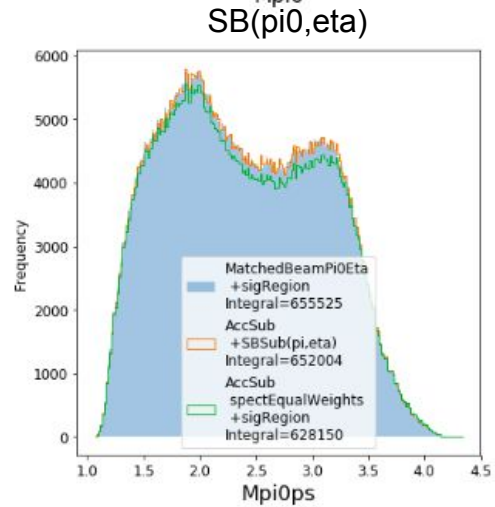
For π the sideband is from [6,8] weighted sigma
---- sideband weight = -2

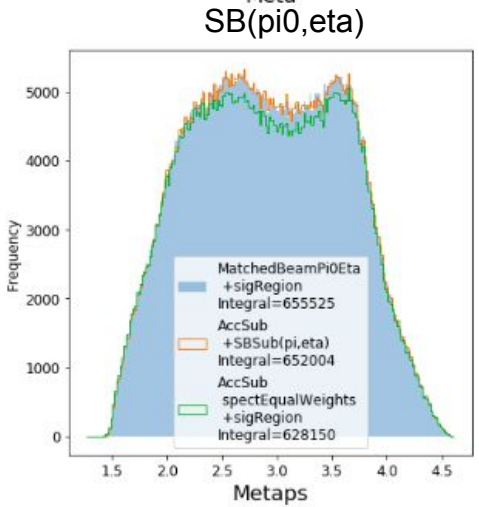
For η the sideband is from [6,11] weighted sigma
---- sideband weight = -0.8

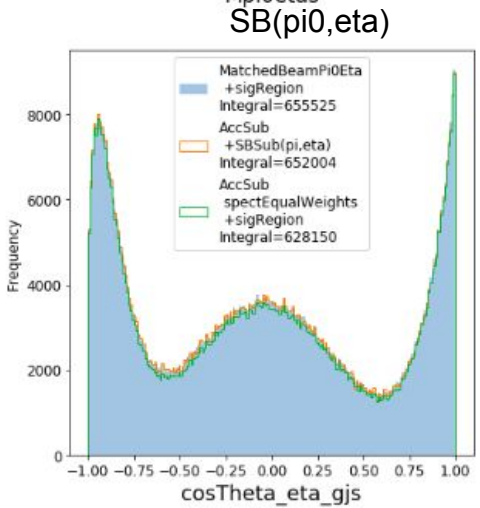








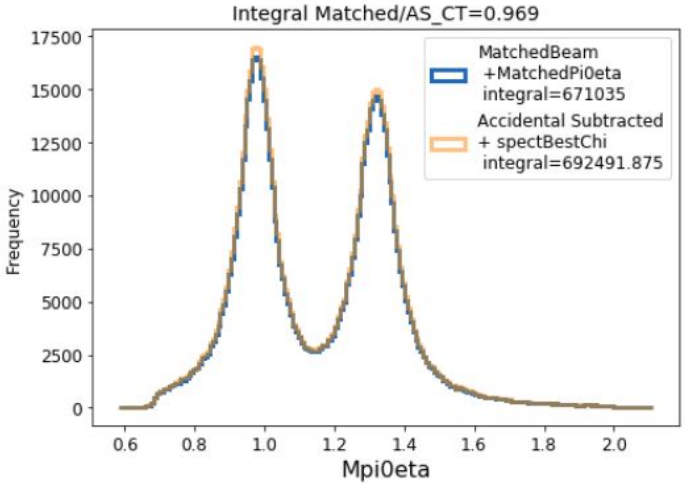


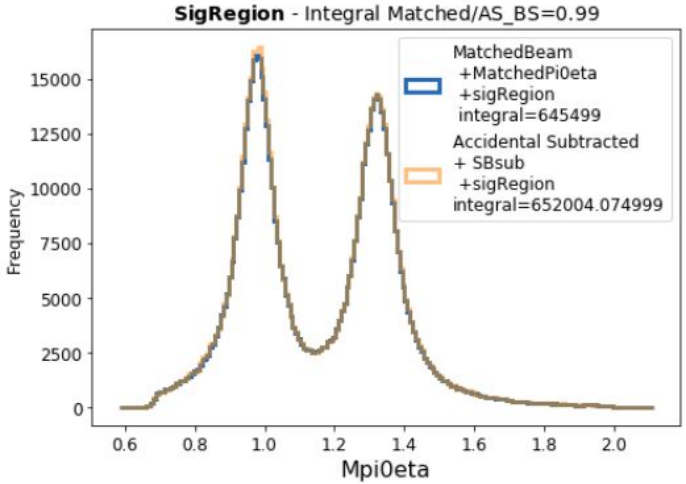


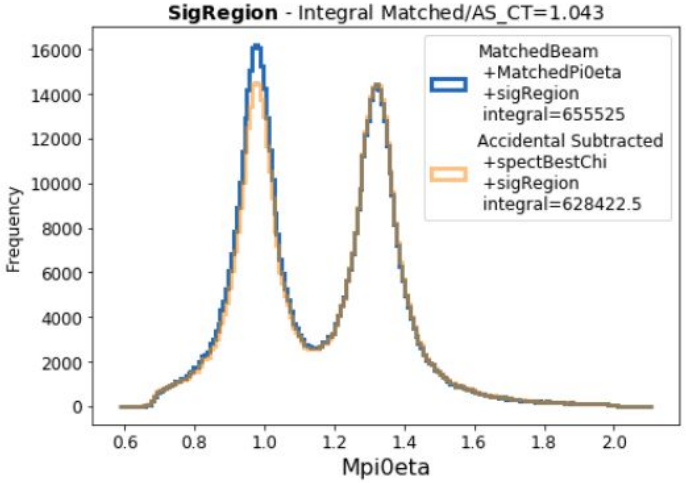
Need to globally select out the pi0eta signal region to compare to SB method

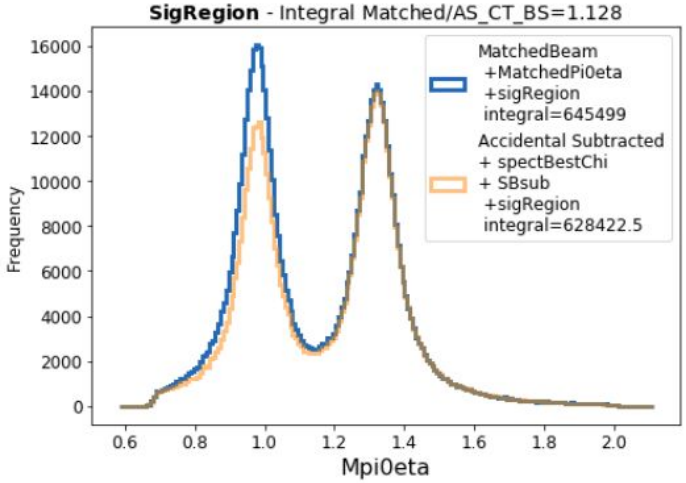
Green curves (AS+CT) underestimates the yields and significantly reduces the a0 peak

SB and CT results are very similar!









(Top Row) - Comparing AS+CT and AS+SB where the latter requires a selection on the signal region

(Bot Left) - AS+CT with a selection on the signal region

(Bot Right) - AS+CT+BS with a selection on the signal region

Cannot make a selection on Mpi0/Meta after doing CT

CT not compatible with SB

Beam photons

RF time

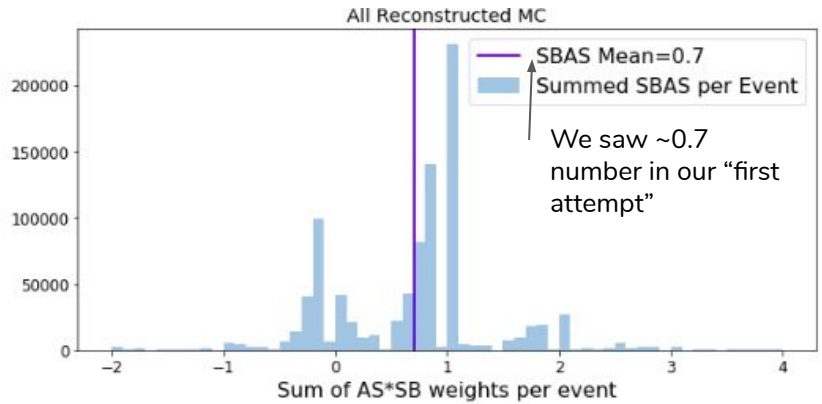
SpectCombo

M(π)

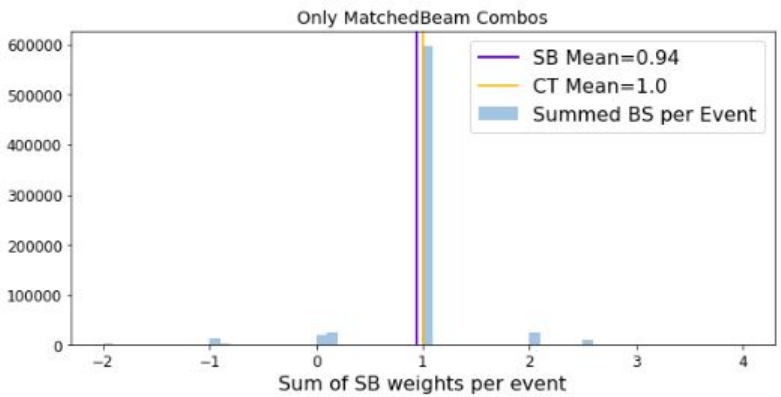
Given this scenario:

1. AS and SB together will effectively fill an **integrated weight of 1** for this event
2. Deviations from the ideal scenario will fill with an **integrated weight of X** for the event.
3. CT will strictly fill event with **integrated weight of 1** at whatever stage we want to include it: { entire combo, spectroscopic combos }
4. SB has better performance, do CT if not performing SB

For each event sum up the SB*AS weight over all combos. Histogram.



Select all Matched Beam Combos. For each event sum up SB and CT weight over all combos. Histogram.



Backup

Methods of doing combination tracking

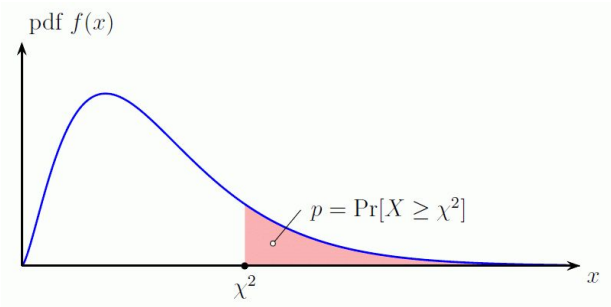
Best χ2 vs Weight by #combos passed selections in event

Both are limits of another approach. We cannot easily compare two χ2 values but given:

$\chi_1^2,\ \chi_2^2,\ \chi_3^2$. We can convert all χ^2 into probabilities p_1, p_2, p_3. Then the weight for each combo would be $\frac{p_i}{\sum p_i}$

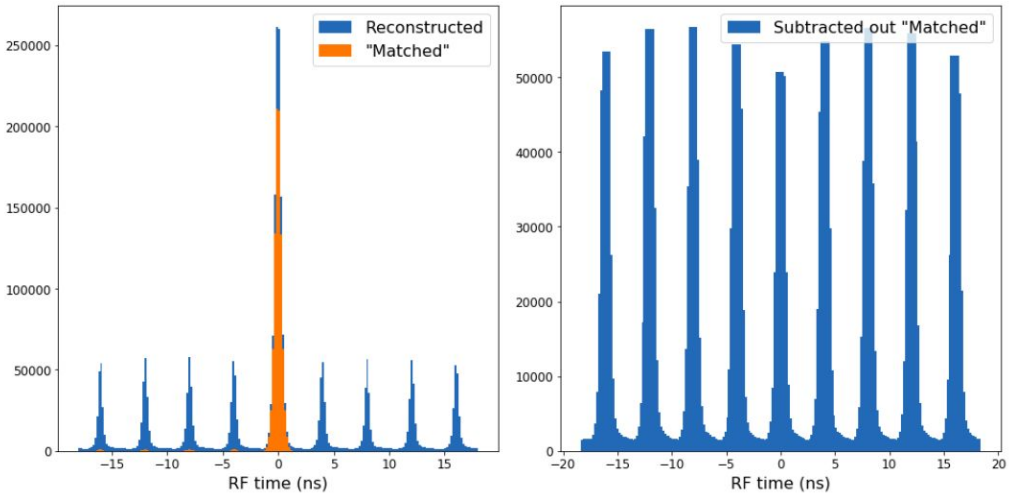
Best χ2 is when $\chi2_i << \{\chi2_j\}$ for $i \neq j$
Weighted approach is when $\chi2_i = \chi2_j$ for all i,j

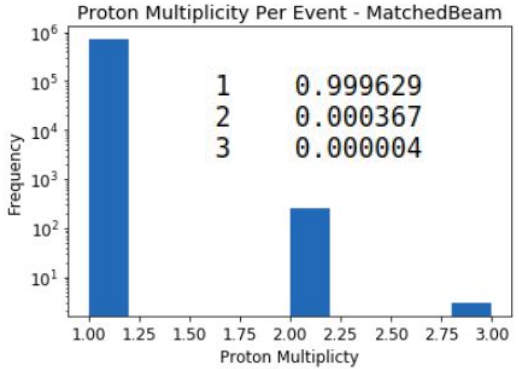
- At first glance it would seem that Best χ2 has high bias, weighting scheme has low bias but omits useful information. Compromise?
- Does not matter that the bottom sum can be > 1 since we really care about how much more likely one combo is than another

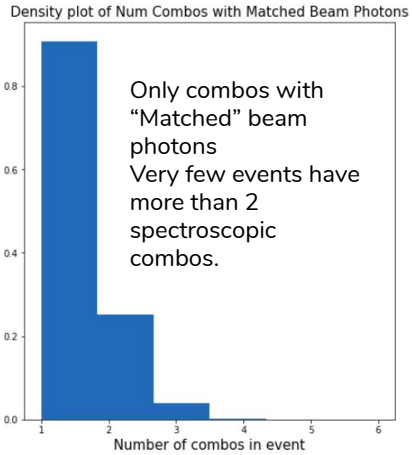


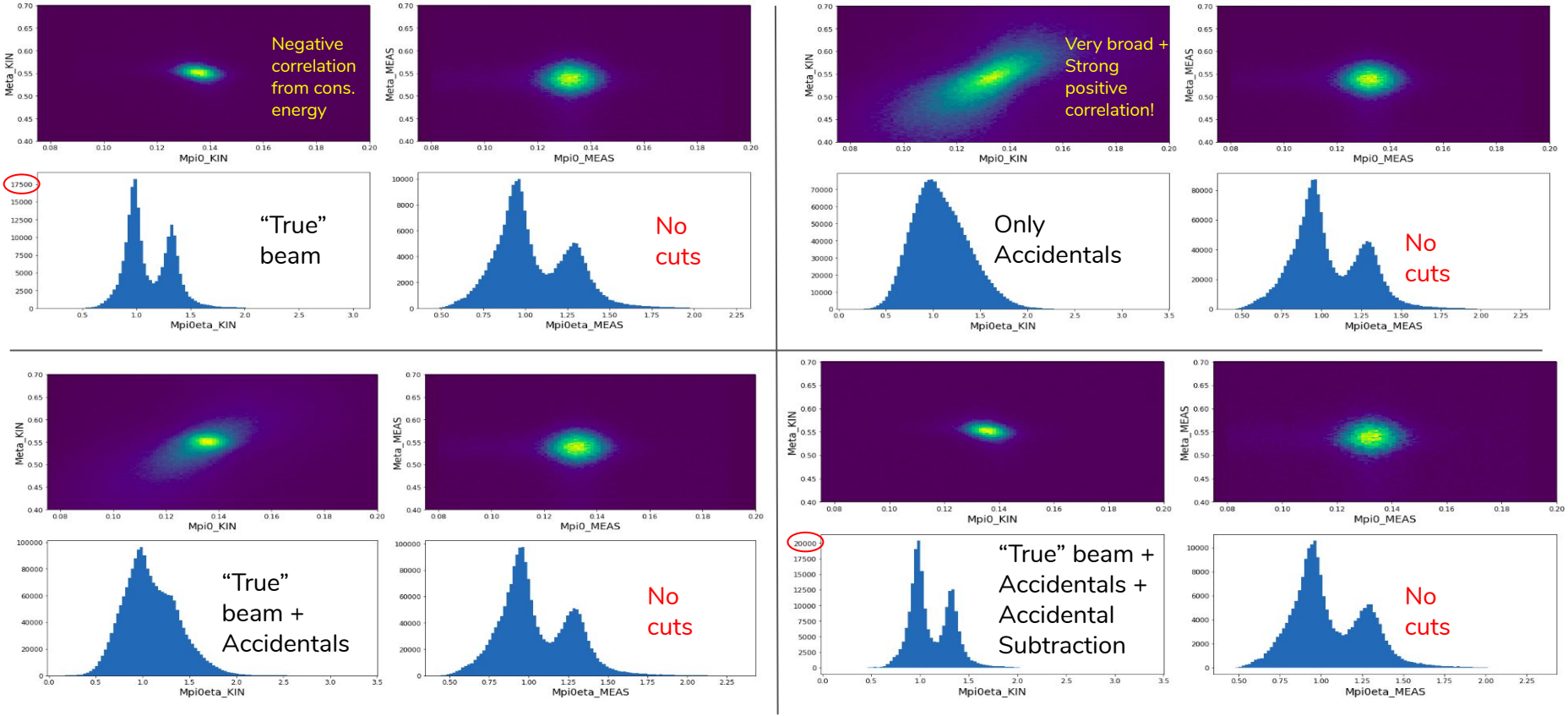
Removing Accidentals Before checking Spectroscopic combinatorics

- Equate the photon beam energies (rare to have accidentals hit the same tagger counter) to get the "True" beam photon.







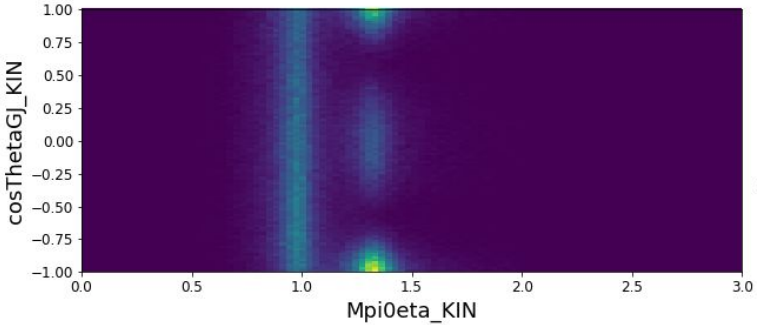


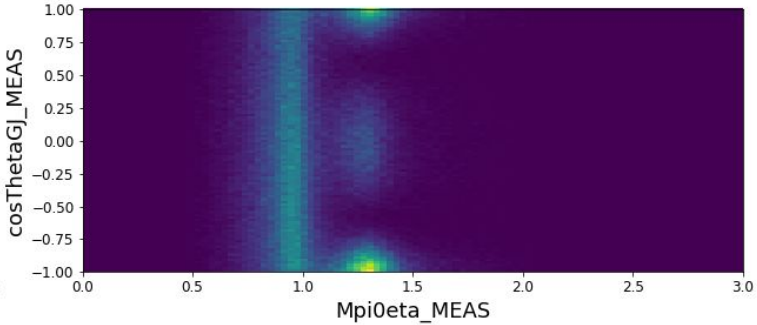
- These are all recon values, not thrown. "True" would consist of all the reconstructed combos that have the correct beam photon. Accidentals would consist of all the combos that does not contain the correct beam photon (I include other prompt photons also).

* Binning is different

“True” beam

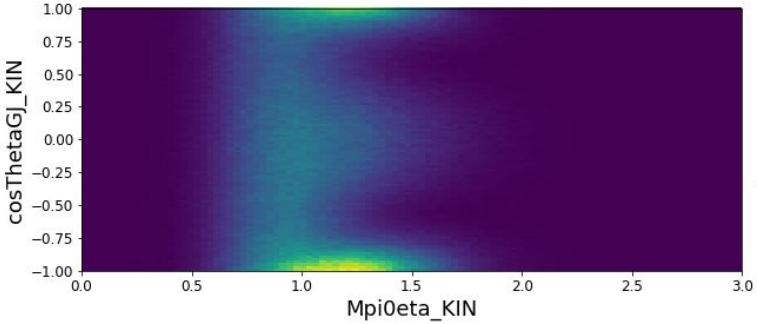
No cuts

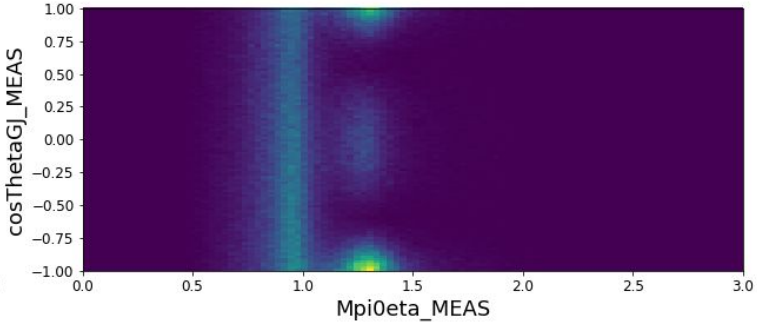




Only Accidentals

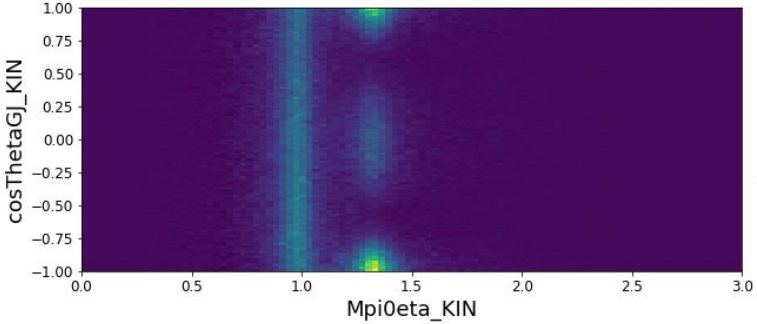
No cuts

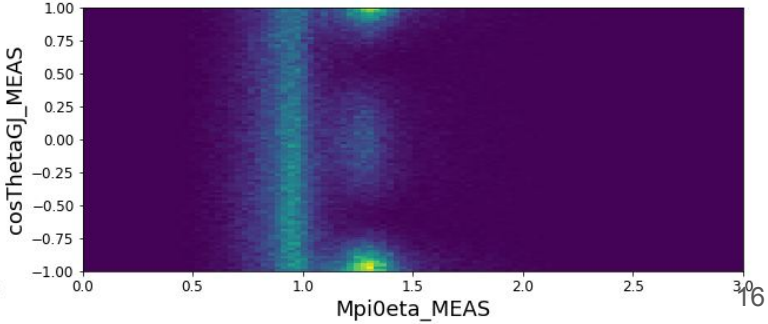




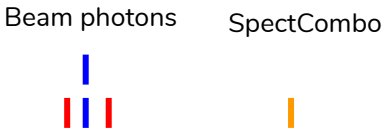
Accidental Subtracted looks like “True” - Good!

No cuts





Working through a very specific ideal example to highlight the problems



OVERALL GOAL: We want a total integrated amount of 1 in our histogram per event.

Propose:

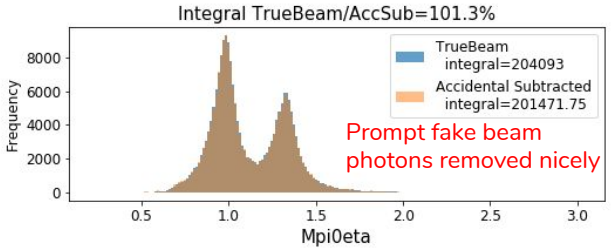
$$W_{ij} = \frac{p_{ij}}{\sum_{j \in spect} p_{ij}}$$

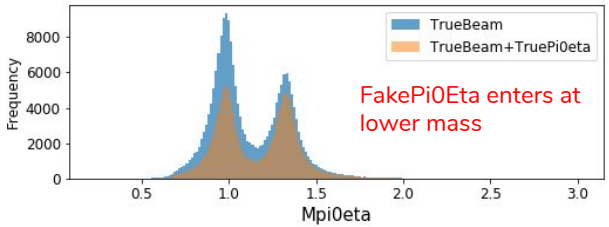
$$\sum_{j \in spect} W_{ij} = 1$$

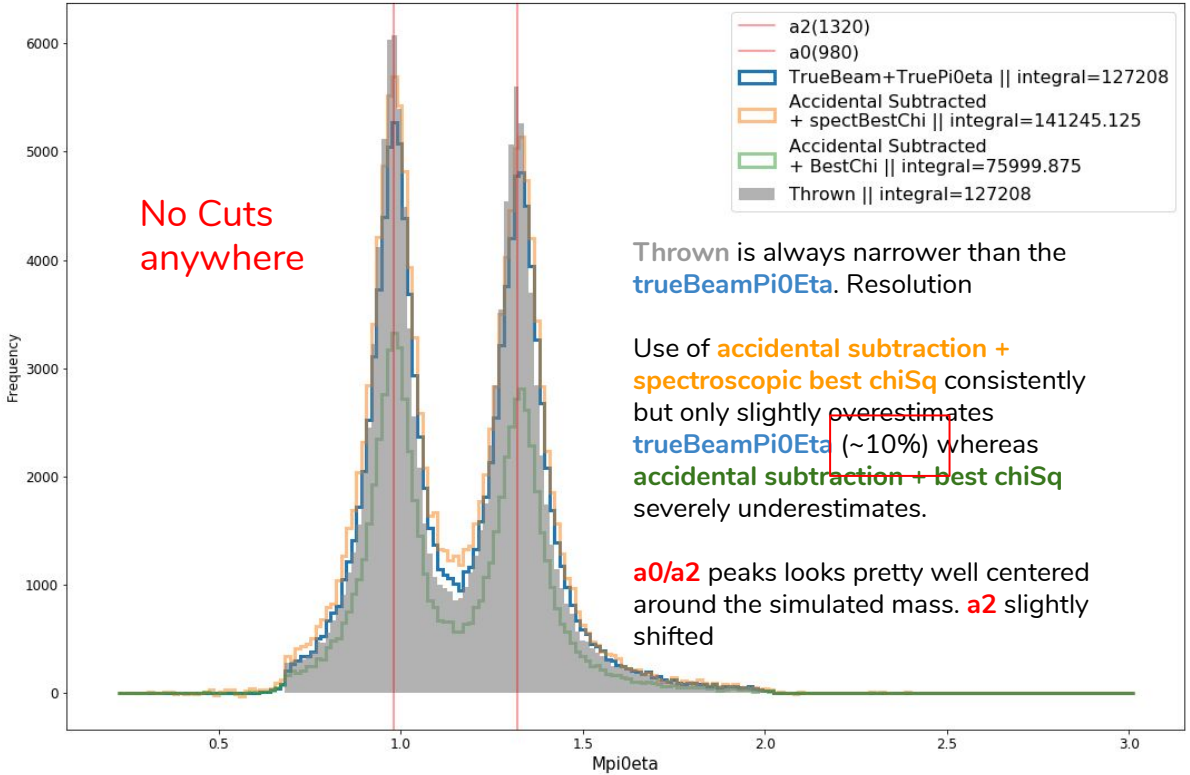
$$\sum_{i \in beam} \sum_{j \in spect} W_{ij} = N_{Beam}$$

Given 2 prompt photons, 2 accidentals, 1 spectCombo:

- If no combo tracking: accidental subtraction would make it seem like we have 1 prompt and 1 spectCombo. i.e. the two accidentals will cancel the effects of one of the prompt photons. In total this would have a weight of 1 for this event. This is what we want.
- Since we know all 3 tracking schemes are related we will look at "equal" weights first. If we use "equal" weights then we would basically have the same situation as above but scaled by ¼ since each combo is scaled by ¼. This is not what we want since the total event weight is now ¼.
- The combo counting and accidentals are not independent and in some ways double counts. When doing combo tracking, we need to ignore extra beam photons. How can we do this?
  - For "equal" weight each combo weight should then be $1/N_{Spect}$ where N_{spect} is the number of unique spectroscopic combos for a **given** beam photon. In this case there is only one spectCombo and thus one value of j. Then, $W_{ij} = 1$ for all i,j.
  - "BestChiSq" would then be related to the best chiSq among the spectroscopic combos for **each** beam photon i. Then, $W_{ij} = \{1,0\}$ for every j.





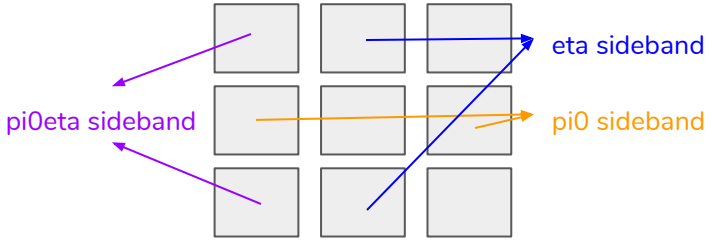


Thrown is always narrower than the trueBeamPi0Eta. Resolution

Use of accidental subtraction + spectroscopic best chiSq consistently but only slightly overestimates trueBeamPi0Eta (~10%) whereas accidental subtraction + best chiSq severely underestimates.

a0/a2 peaks looks pretty well centered around the simulated mass. a2 slightly shifted

SB weight distribution

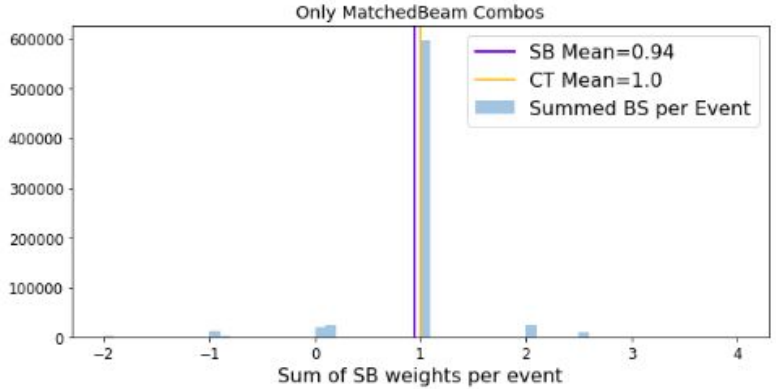


Selected Matched Beam Photons

```
1  df_summedSBperEvent.value_counts().iloc[:10]
```

```
 1.0    597442
 2.0     26041
 0.2     24898
 0.0     19495
-1.0     12293
 2.6     11470
-2.0      4089
-0.8      3867
 1.2       773
 1.6       752
Name: sbWeight, dtype: int64
```

Weight	Source (+ any number in skip region)
1.0	One combo in signal
2.0	Two combos in signal
0.2	In eta sideband + one in signal
0.0	In the skip region
-1.0	One in pi0 sideband + one in signal
2.6	One in signal + one in pi0eta sideband
-2.0	One in pi0 sideband
-0.8	One in eta sideband



Histogramming the above data:

1. We can also plot the **mean of the Sums = 0.94**
2. Mean of the summed CT weights = 1 as expected by construction