Bounding the Trigger Inefficiency for $\Upsilon(1, 2, 3S)$

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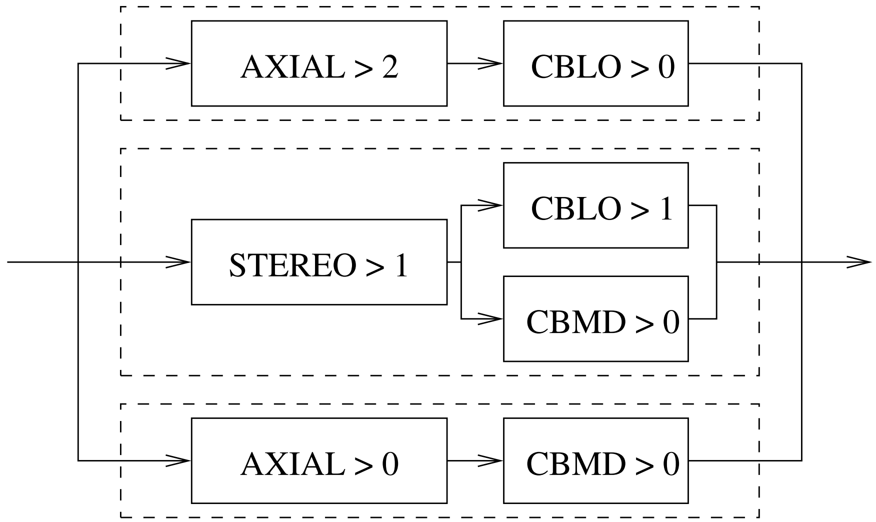
First cut in any analysis: the trigger

Problem: only events which *pass* the trigger can be compared with data

My trigger lines: “Hadron” OR “RadTau” OR “ElTrack”

MC efficiency for these lines is 99.5% (nicely bounded above)

Is the MC generating *too few* untriggered events?



Hadron = (AXIAL > 2) AND (CBLO > 0)

OR

RadTau = (STEREO > 1) AND ((CBLO > 1) OR (CBMD > 0))

OR

ElTrack = (AXIAL > 0) AND (CBMD > 0)

Trigger depends on four variables: $\underbrace{\#\text{AXIAL}, \#\text{STEREO},}_{\text{DR track counting}}$ $\underbrace{\#\text{CBLO}, \#\text{CBMD}}_{\text{CC cluster counting}}$

STEP 1: Check CC cluster counting with "TwoTrack" trigger

STEP 2: Quantify relevance of trigger track efficiency with toy MC

STEP 3.1: Check MC track distribution with 2S to 1S cascade

STEP 3.2: Quantify uncertainty in track distribution with toy MC

STEP 3.3: Fill a loophole in this argument

STEP 1: Check CC cluster counting with "TwoTrack" trigger

P(Υ passes trigger | TwoTrack) = P(event passes trigger | TwoTrack and event is Υ)

These cuts guarantee negligible backgrounds and no lower bounds on CC quantities:

data: TwoTrack trigger AND analysis cuts AND charged energy > 35% COM
AND continuum-subtraction

MC: TwoTrack trigger AND analysis cuts AND charged energy > 35% COM

P(passes "Hadron" OR "RadTau" OR "ElTrack" | all those cuts):

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
data	99.97%	99.48%	99.51%
MC	99.83%	99.86%	99.86%
diff	0.14%	0.38%	0.35%
	±0.20%	±0.31%	±1.00%

STEP 2: Quantify relevance of trigger track efficiency with toy MC

Assuming MC has the right charged particle multiplicity (and that this is well represented by the number of quality tracks), how much does trigger track efficiency/overcounting matter?

Toy MC:

1. pick a random #tracks from the full MC's #tracks distribution
2. for this #tracks, pick a random #CBLO, #CBMD (2-d distributions from full MC)
3. for this #tracks, pick a random #AXIAL (same way)
4. for this #AXIAL, pick a random #STEREO (same way)
5. do this 100,000 times and calculate trigger efficiency

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	99.68%	99.44%	99.50%
Toy MC (baseline)	99.67%	99.54%	99.64%
Get #AXIAL, #STEREO from data	99.56%	99.42%	99.49%
Set #STEREO = #AXIAL	99.79%		
Set #STEREO = #AXIAL = #tracks	99.43%		

(±0.03% in all cases)

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4. for this #AXIAL, pick a random #STEREO (same way)
5. do this 100,000 times and calculate trigger efficiency

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	0.01%	-0.10%	-0.14%
Toy MC (baseline)	0%	0%	0%
Get #AXIAL, #STEREO from data	-0.11%	-0.12%	-0.15%
Set #STEREO = #AXIAL	0.12%		
Set #STEREO = #AXIAL = #tracks	-0.24%		

($\pm$0.03% in all cases)

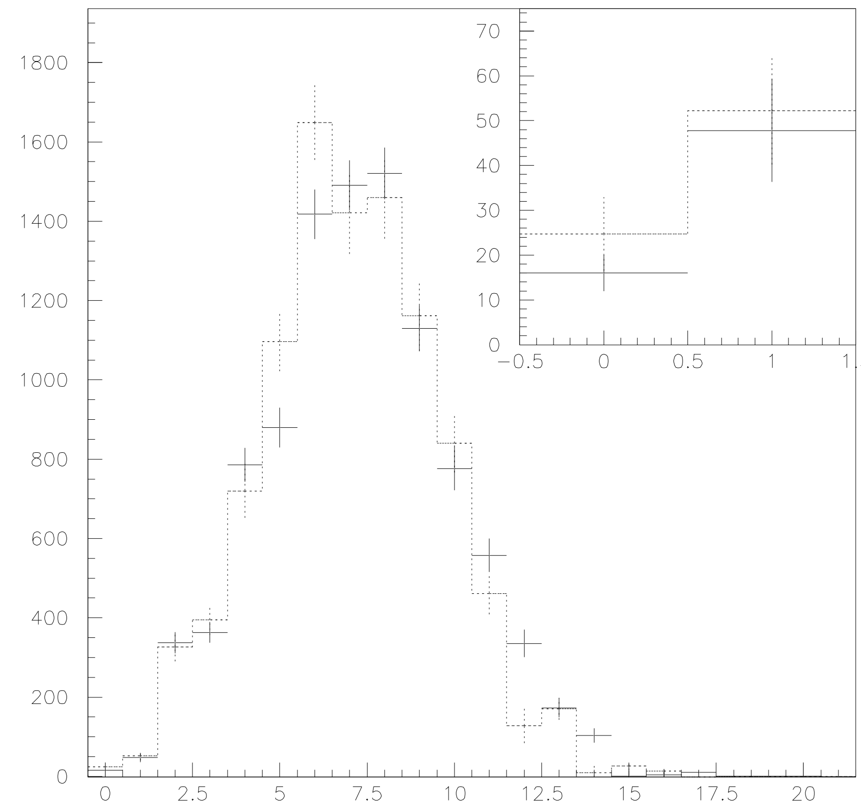
STEP 3.1: Check MC track distribution with 2S to 1S cascade

Verify the assumtion: "MC has the right charged particle multiplicity." (We continue to assume that track distribution represents charged multiplicity.)

$$\Upsilon(2S) \rightarrow \Upsilon(1S)\,\underbrace{\pi^+\pi^-}$$

$\hookrightarrow$ satisfy TwoTrack requirement, L4, and "quality tracks ≥ 2"

1. Get **all** $\Upsilon(2S)$ events from tau subcollection with TwoTrack trigger
2. Plot $\pi^+\pi^-$ missing mass distribution for each number of tracks
3. Count number of $\Upsilon(1S)$ events in each peak
4. Do exactly the same for $\Upsilon(2S)$ MC
5. Plot number of $\Upsilon(1S)$ events per number of non-$\pi^+\pi^-$ tracks $\longrightarrow \longrightarrow \longrightarrow \longrightarrow$



Number of tracks − 2 from Υ(2S) to $\pi^+\pi^-\Upsilon$(1S) cascades, compared with MC

STEP 3.2: Quantify uncertainty in track distribution with toy MC

Instead of replacing the #AXIAL and #STEREO distributions, replace #tracks.

This is how much the uncertainty in MC track distribution matters for correct trigger efficiency.

(For apples-to-apples, we must compare *boosted* data to *boosted* MC.)

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	99.68%	99.44%	99.50%
Toy MC	99.67%	99.54%	99.64%
with boosted MC tracks (baseline)	99.58%		
with boosted data tracks	99.65%		
same with 0-, 1-tracks raised 1σ	99.61%		
same with 100 extra 0-track events	99.35%		
same with 200 extra 0-track events	99.12%		

(The 0-track bin had 20±9 events, so 100 is way too many.)

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(For apples-to-apples, we must compare *boosted* data to *boosted* MC.)

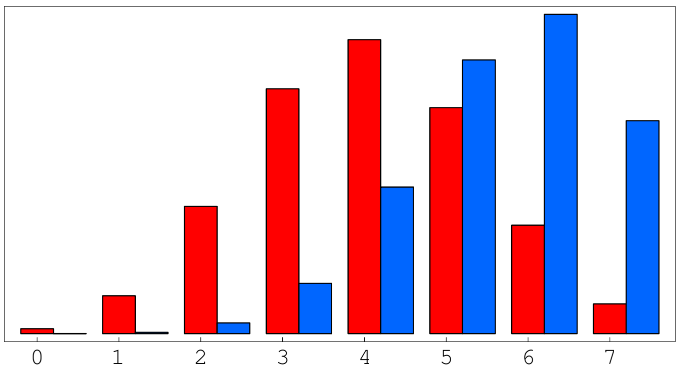
	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	0.10%	–	–
Toy MC	0.09%	–	–
with boosted MC tracks (baseline)	0%		
with boosted data tracks	0.07%		
same with 0-, 1-tracks raised 1σ	0.03%		
same with 100 extra 0-track events	-0.23%		
same with 200 extra 0-track events	-0.46%		

(The 0-track bin had 20±9 events, so 100 is way too many.)

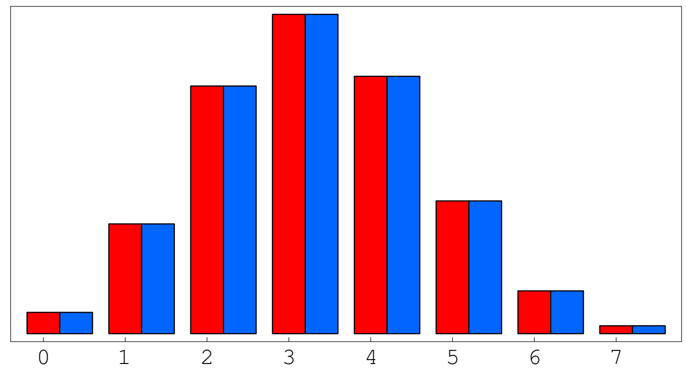
STEP 3.3: Fill a loophole in this argument

We assumed: "number of quality tracks represents charged particle multiplicity."

If MC generator overestimates number of charged particles and CLEOG underestimates tracking efficiency, data and MC can have the same track distribution while MC has too few trigger-failing events.



Number of Charged Particles



Number of Quality Tracks

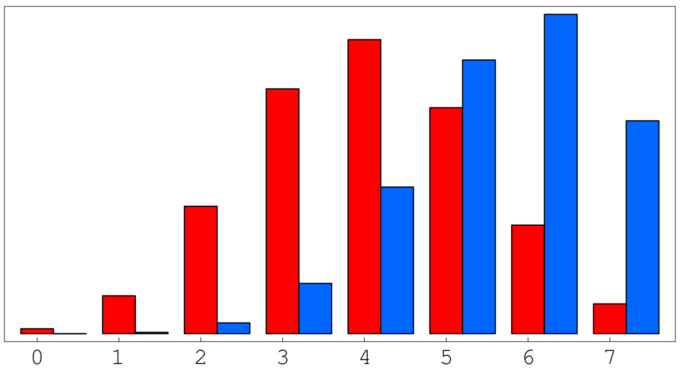
Technique #1: Put data track distribution AND data trigger distributions into toy MC

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
with boosted MC tracks (baseline)	99.58%		
with boosted data tracks and trigger	99.47%		

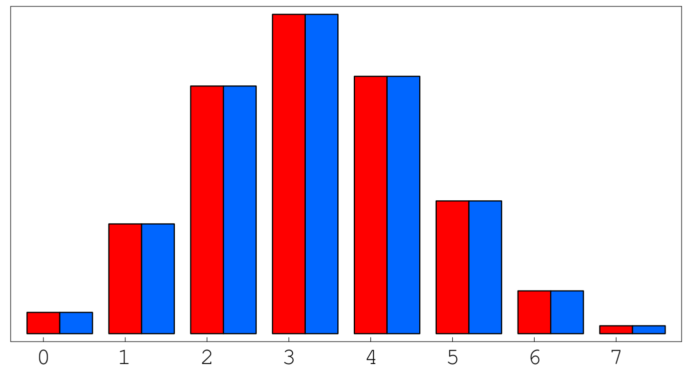
STEP 3.3: Fill a loophole in this argument

We assumed: “number of quality tracks represents charged particle multiplicity.”

If MC generator overestimates number of charged particles and CLEOG underestimates tracking efficiency, data and MC can have the same track distribution while MC has too few trigger-failing events.



Number of Charged Particles



Number of Quality Tracks

Technique #1: Put data track distribution AND data trigger distributions into toy MC

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
with boosted MC tracks (baseline)	0%		
with boosted data tracks and trigger	-0.11%		

STEP 3.3: Fill a loophole in this argument

Technique #2: Increase track-finding efficiency by the expected +2% ±1.5%

(I keep the number of generated particles fixed, but increase the tracking efficiency.)

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	99.68%	99.44%	99.50%
Toy MC (baseline)	99.67%	99.54%	99.64%
+5%	99.76%		
+2% + 1.5%	99.71%	99.62%	99.72%
+2%	99.69%	99.61%	99.67%
+2% − 1.5%	99.69%	99.55%	99.68%
−2%	99.69%		
−10%	99.58%		
−20%	99.33%		

$+n\%$ is a simulated increase in MC tracking efficiency, obtained by de-convolving the MC track distribution to first order in $n\%$.

$-n\%$ is a further decrease in MC tracking efficiency via an exact convolution.

STEP 3.3: Fill a loophole in this argument

Technique #2: Increase track-finding efficiency by the expected +2% ±1.5%

(I keep the number of generated particles fixed, but increase the tracking efficiency.)

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
Full MC	0.01%	-0.10%	-0.14%
Toy MC (baseline)	0%	0%	0%
+5%	0.09%		
$+2\% + 1.5\%$	0.04%	0.08%	0.08%
+2%	0.02%	0.07%	0.03%
$+2\% - 1.5\%$	0.02%	0.01%	0.04%
-2%	0.02%		
-10%	-0.09%		
-20%	-0.34%		

$+n\%$ is a simulated increase in MC tracking efficiency, obtained by de-convolving the MC track distribution to first order in $n\%$.

$-n\%$ is a further decrease in MC tracking efficiency via an exact convolution.

Summary of trigger efficiency systematic errors:

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
CC cluster counting (STEP 1)	0.20%	0.31%	0.31%
trigger track efficiency (STEP 2)	0.11%	0.12%	0.15%
reconstructed track distribution (STEP 3.2)	0.08%	0.08%	0.08%
reconstructed track efficiency (STEP 3.3)	0.11%	0.11%	0.11%
	0.27%	0.36%	0.37%

What could still go wrong?

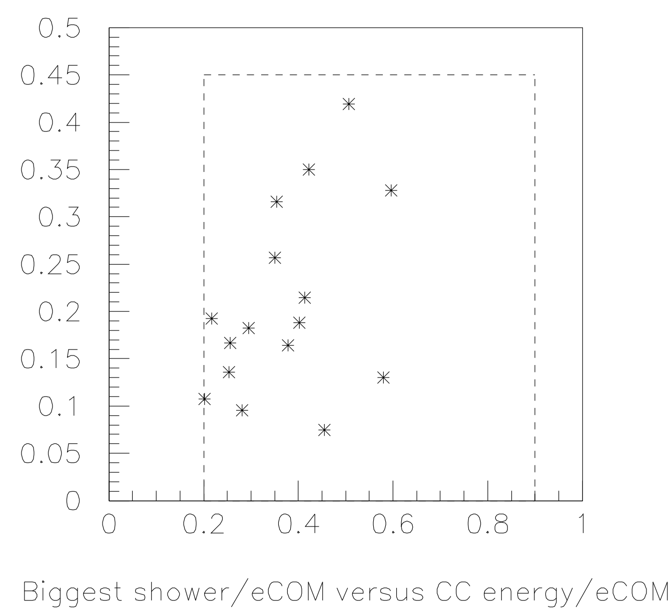
Cascades study could miss events with:

- visible energy $> 20\%$ $\Upsilon(1S)$ mass,
- CC energy $< 90\%$ $\Upsilon(1S)$ mass,

OR

- biggest shower $< 90\%$ $\Upsilon(1S)$ mass / 2

Zero-track events ($\sim \frac{1}{2}$ signal)



(Need about 100 unseen events)