h(125)→aa→γγγγ

Hgg Working Group Meeting

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Overview of the updates

- Last presentation
  - Link
  - Strategy to divide the analysis into 3 broad categories depending on m(a)

- This presentation:
  - Present trigger studies
  - Aim of these studies is to establish that the low mass $h \to \gamma\gamma$ online triggers can be utilized by us

Triggers and Pre-Selection

- For 2016
  - **OR** of the two Di-photon triggers is applied
    - HLT_Diphoton30EB_18EB_R9Id_OR_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55
    - HLT_Diphoton30PV_18PV_R9Id_AND_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55

- To achieve good data/simulation comparison, a pre-selection that is tighter than the online selection is applied on data and Monte Carlo (same strategy as the one used by both Std and Low mass $h \to \gamma\gamma$ analyses)

		R9 (5x5)	HoE	$\sigma_{i\eta i\eta}$ (5x5)	pfPhoIso	TrackerIso
Both photons in barrel	Barrel	> 0.5	< 0.07	< 0.0105	< 4 GeV	< 6 GeV
At least one in endcap	Barrel	> 0.85	< 0.07	< 0.0105	< 4 GeV	< 6 GeV
At least one in endcap	Endcap	> 0.9	< 0.035	< 0.0275	< 4 GeV	< 6 GeV

- Electron Veto: no Pixel seed
- p_T leading γ > 30 GeV, p_T subleading γ > 18 GeV
- For both γ's $|\eta| < 2.5$, but not in the ECAL EB-EE gap
- $M_{\gamma\gamma} > 55$ GeV

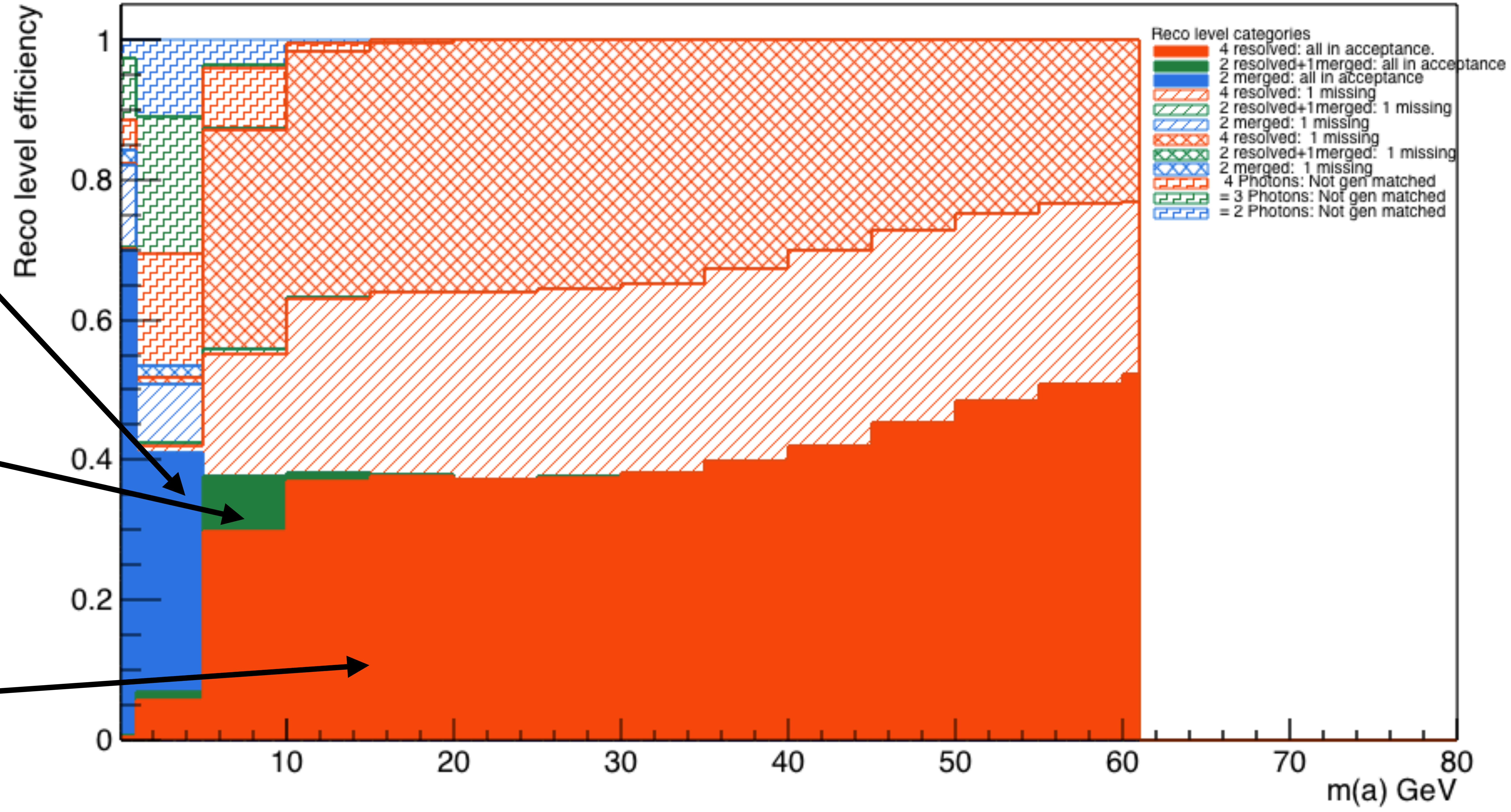
Recap: Reco level categorization

Possible to reconstruct the 4γ invariant mass in these categories and the following slides will present trigger/pre-selection efficiencies for these 3 categories

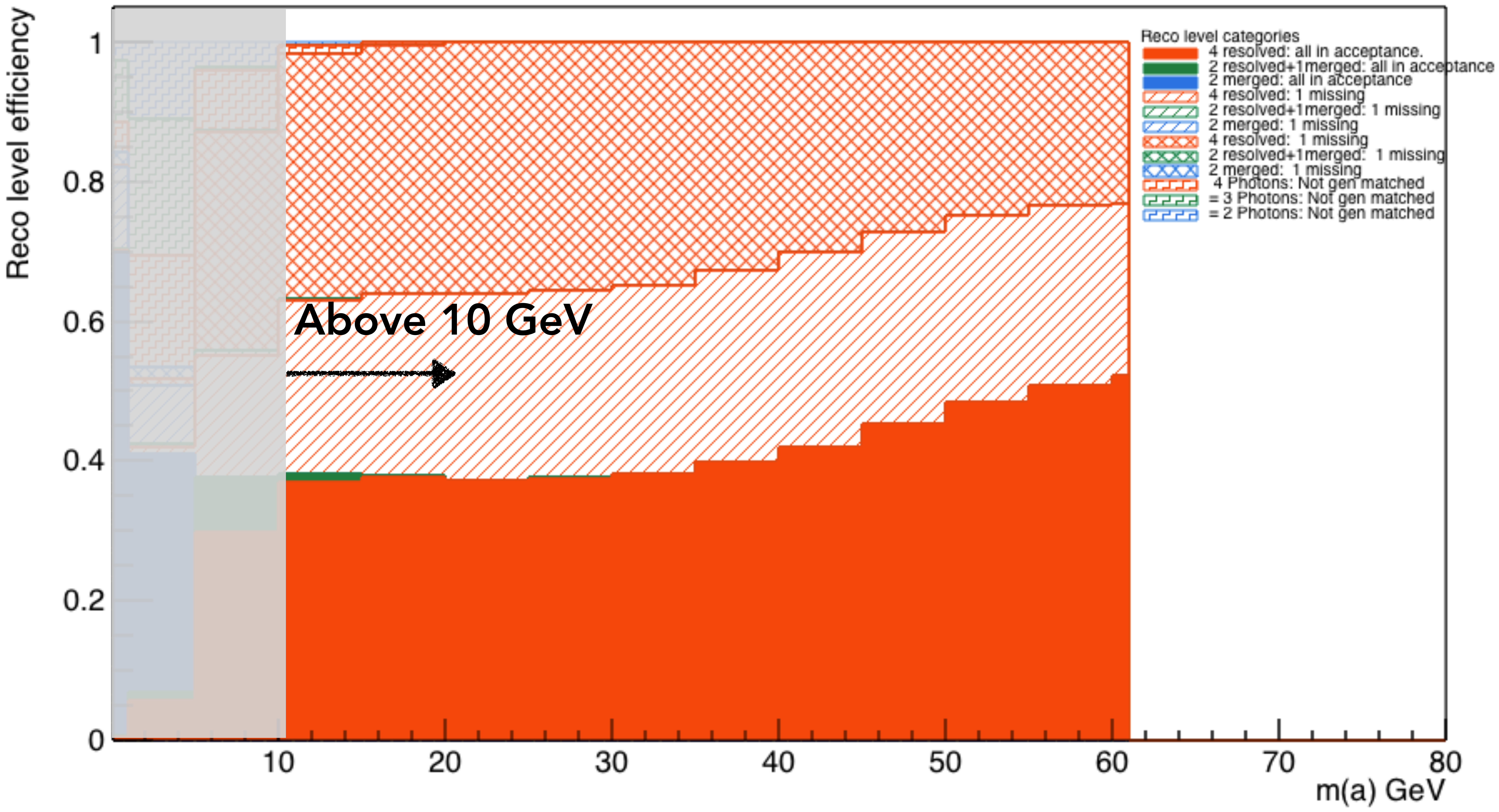
2 pairs of merged reconstructed γ's

2 resolved + 1merged reconstructed γ's

4 reconstructed resolved γ's

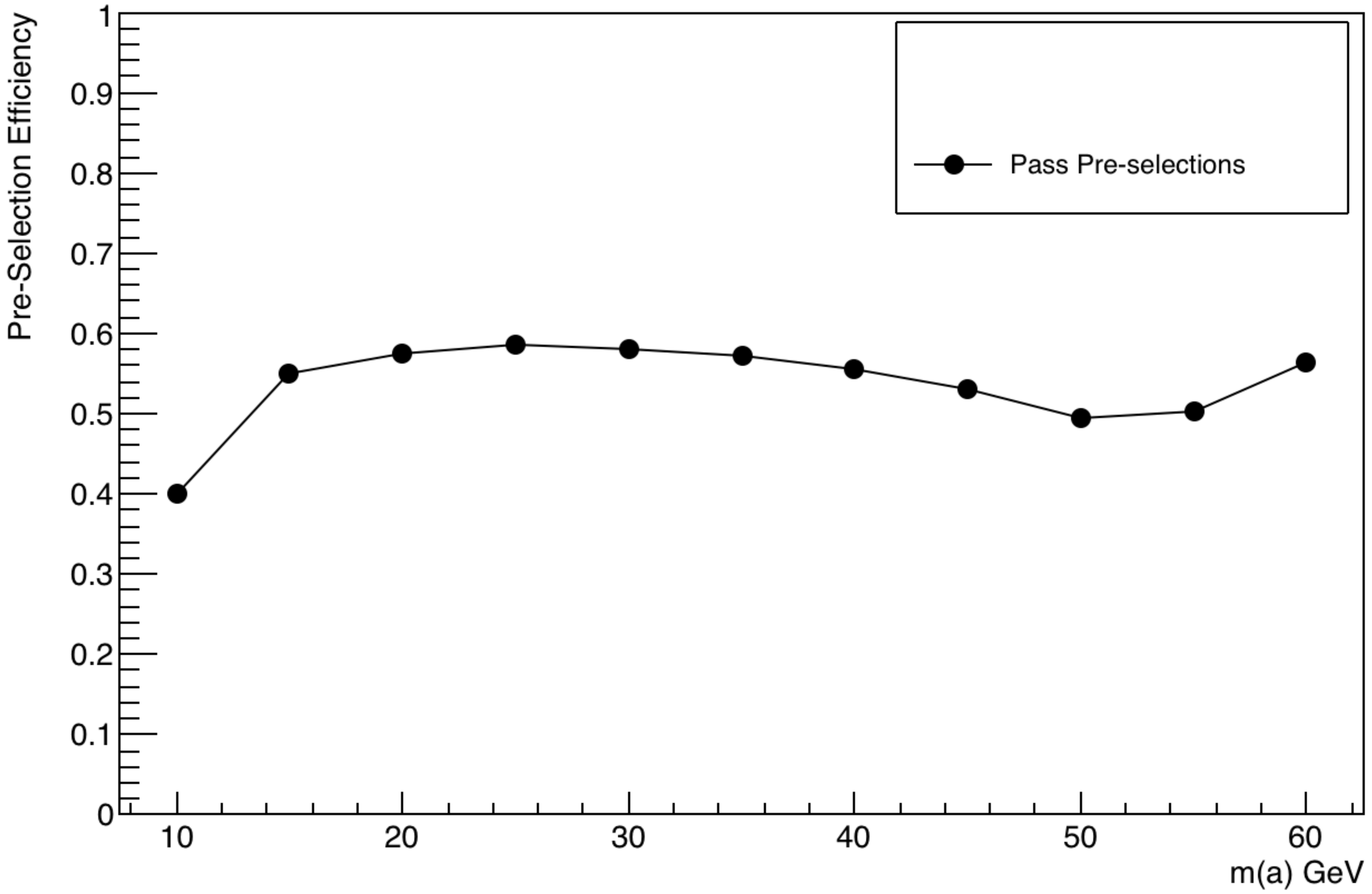


4 Resolved Photons case



4 Resolved Photons case: Pre-selection Efficiency

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance)}}$$



Detector acceptance:

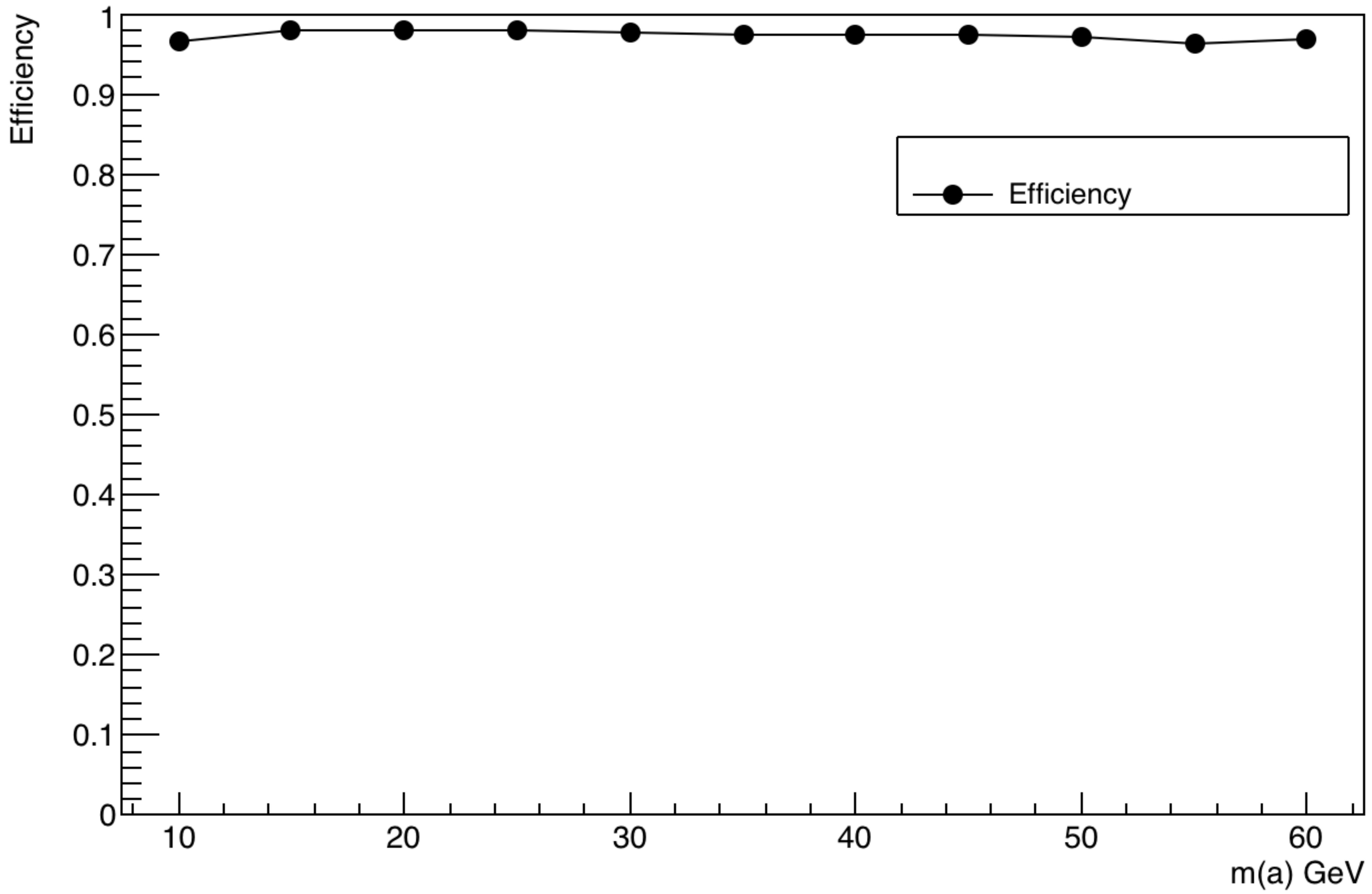
- p_T γ1 > 30 GeV
- p_T γ2 > 18 GeV
- p_T γ3 > 10 GeV
- p_T γ4 > 10 GeV
- For all γ's $|\eta| < 2.5$

- For **m(a) > 10 GeV** the **fully resolved** topology is the dominant one (**26% for m(a) = 10 GeV** to **46% for m(a) = 60 GeV)**

4 Resolved Photons case: Trigger Efficiency

- Efficiency of trigger on the pre-selected events

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection \& Trigger}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection}}$$



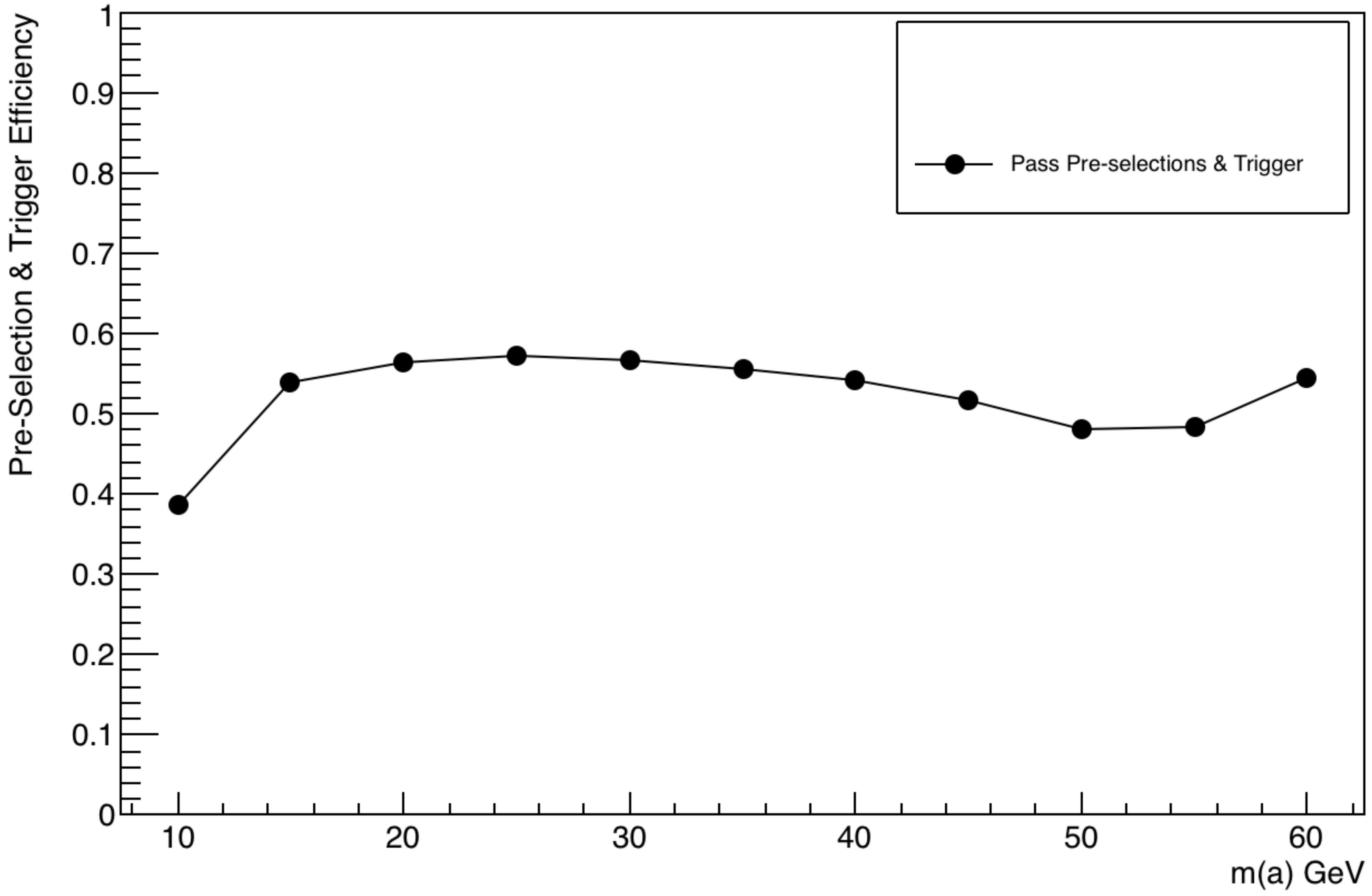
Detector acceptance:

- p_T γ1 > 30 GeV
- p_T γ2 > 18 GeV
- p_T γ3 > 10 GeV
- p_T γ4 > 10 GeV
- For all γ's $|\eta| < 2.5$

4 Resolved Photons case: Pre-selection & Trigger Efficiency

- Trigger refers to the trigger bit stored in the MC samples

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection \& Trigger}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance)}}$$

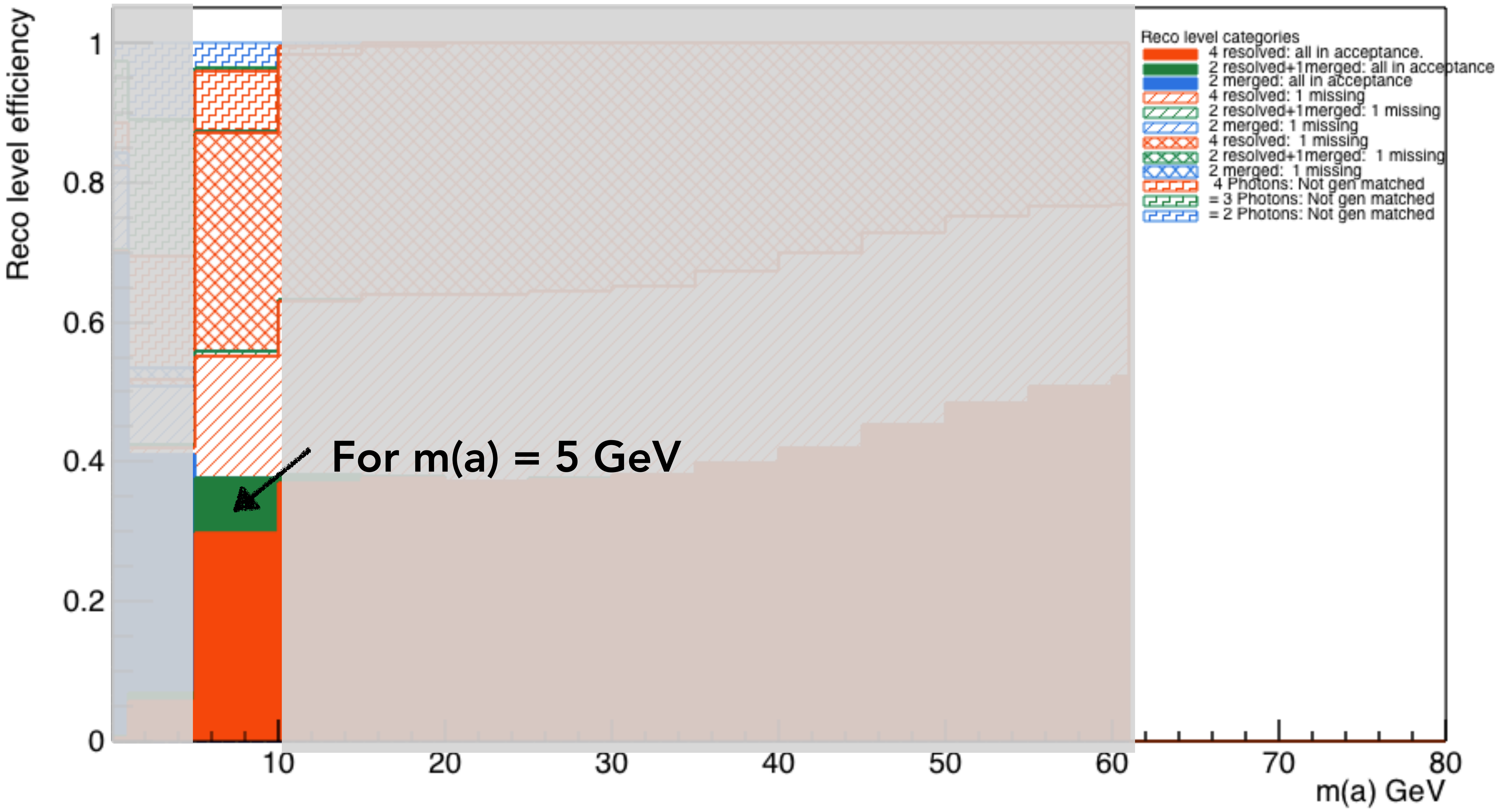


Detector acceptance:

- $p_T\ \gamma 1 > 30$ GeV
- $p_T\ \gamma 2 > 18$ GeV
- $p_T\ \gamma 3 > 10$ GeV
- $p_T\ \gamma 4 > 10$ GeV
- For all γ's $|\eta| < 2.5$

- From this simple study, we can see that the existing low mass diphoton triggers have an efficiency ranging from 40% for m(a) = 10 GeV to ~55% for m(a) = 60 GeV

2 Resolved + 1 Merged Photons case



2 Resolved + 1 Merged Photons case

Detector acceptance:
- $p_T\ \gamma 1 > 30$ GeV
- $p_T\ \gamma 2 > 18$ GeV
- $p_T\ \gamma 3 > 10$ GeV
- For all γ's $|\eta| < 2.5$

5 GeV

$$\varepsilon_{3\gamma,\ \text{preselection}} = \frac{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance) + pass pre-selection}}{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance)}}$$

0.035 +/- 0.002

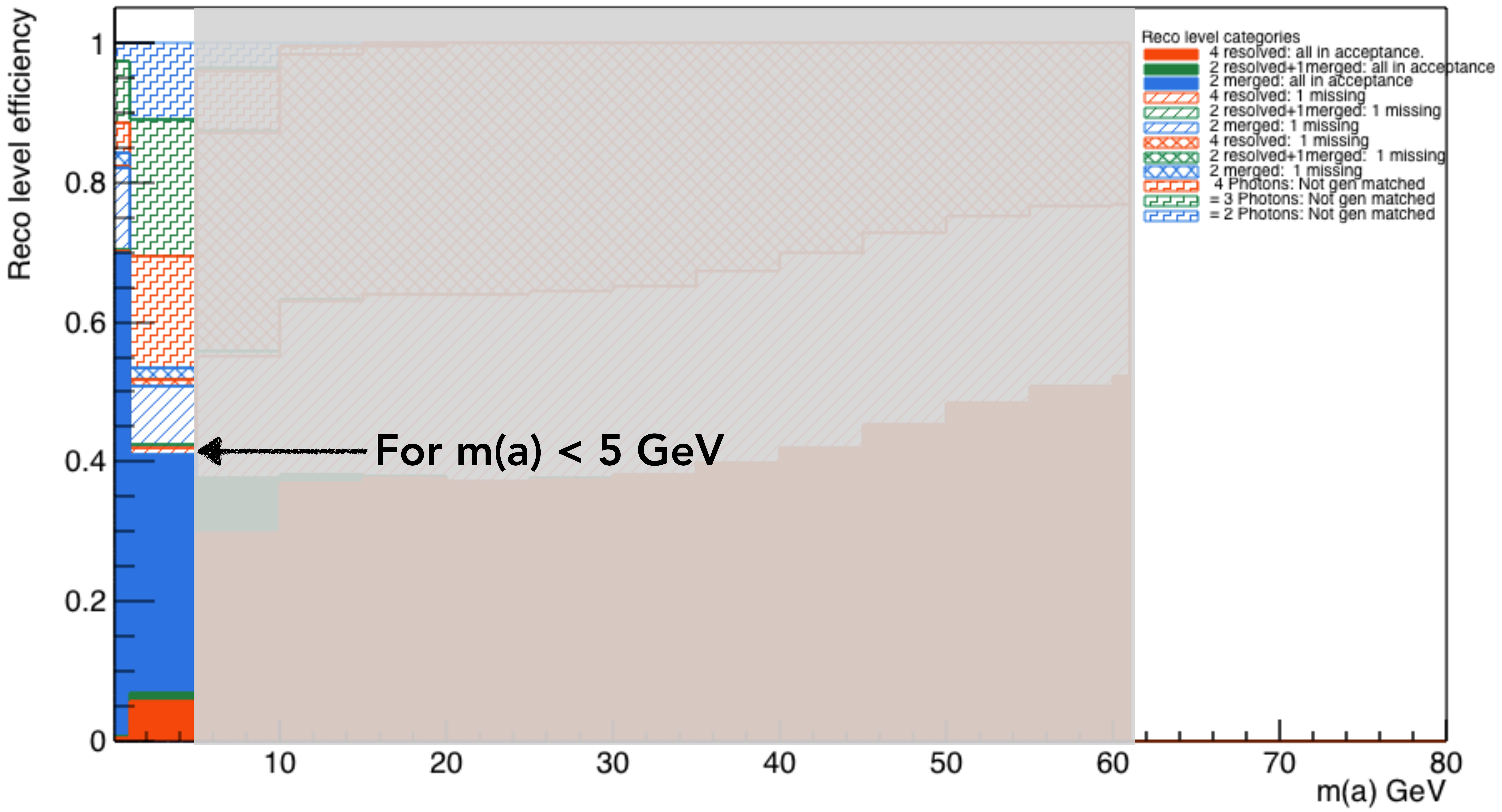
$$\varepsilon_{3\gamma,\ \text{trigger}} = \frac{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance) + pass (pre-selection \& trigger)}}{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance) + pass pre-selection}}$$

0.82 +/- 0.06

$$\varepsilon_{3\gamma,\ \text{preselection \& trigger}} = \frac{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance) + (pass pre-selection \& trigger)}}{\text{\# of events w/ 2 resolved + 1 merged photons (all photons within detector acceptance)}}$$

0.029 +/- 0.001

2 Pairs of Merged Photons case



2 Pairs of Merged Photons case

Detector acceptance:

- p_T $\gamma 1 > 30$ GeV
- p_T $\gamma 2 > 18$ GeV
- For all γ's $|\eta| < 2.5$

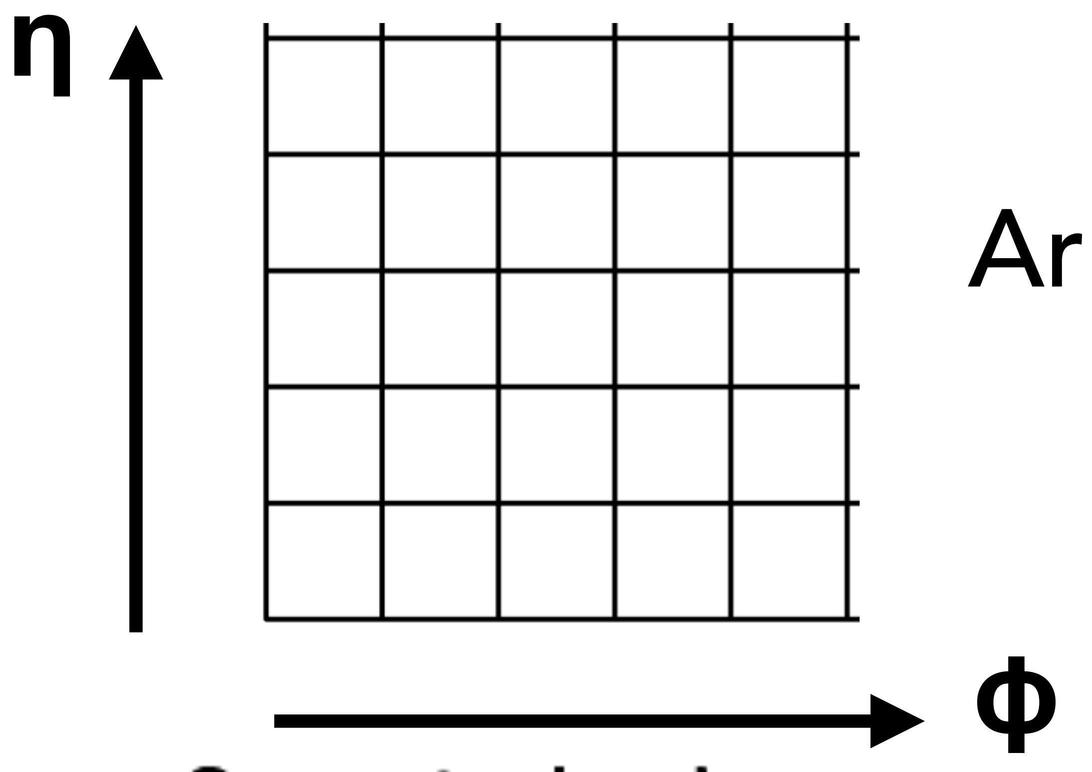
$$\varepsilon_{2\gamma,\ \text{preselection}} = \frac{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\\ \text{+ pass pre-selection}\end{array}}{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\end{array}}$$

$$\varepsilon_{2\gamma,\ \text{trigger}} = \frac{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\\ \text{+ pass (pre-selection \& trigger)}\end{array}}{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\\ \text{+ pass pre-selection}\end{array}}$$

$$\varepsilon_{2\gamma,\ \text{preselection \& trigger}} = \frac{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\\ \text{+ (pass pre-selection \& trigger)}\end{array}}{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons}\\ \text{(all photons within detector acceptance)}\end{array}}$$

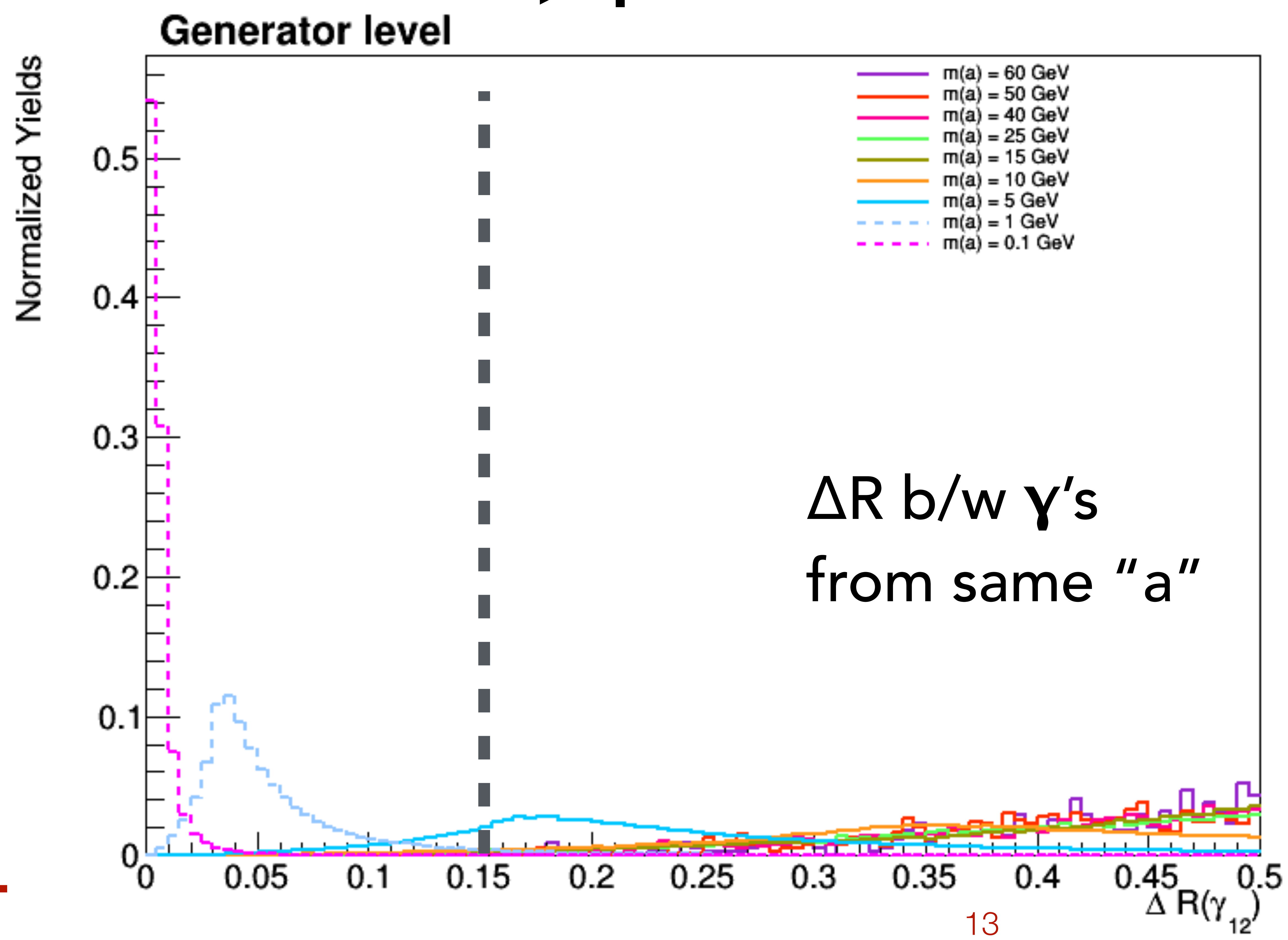
	100 MeV	**1 GeV**
$\varepsilon_{2\gamma,\ \text{preselection}}$	0.461 +/- 0.002	0.130 +/- 0.002
$\varepsilon_{2\gamma,\ \text{trigger}}$	0.978 +/- 0.006	0.966 +/- 0.016
$\varepsilon_{2\gamma,\ \text{preselection}}$ & trigger	0.451 +/- 0.002	0.126 +/- 0.002

2 pairs of Merged Photons case (2)



Array of 5x5 crystals

- Selections at the online level are based on 5x5 and Supercluster based variables
- For m(a) < 5 GeV, photons are mostly merged
- Since for m(a) < 5 GeV, the event would look like H->γγ, the diphoton object is then the Higgs (and not "a")



2 pairs of Merged Photons case (2)

- Major difference b/w the standard and low-mass diphoton trigger is in the diphoton mass cut
  - For standard $h \to \gamma\gamma$: $M_{\gamma\gamma} > 90$ GeV
  - For low mass $h \to \gamma\gamma$: $M_{\gamma\gamma} > 55$ GeV

- Checking the efficiency of applying the trigger bit (on applying an OR of the std $h \to \gamma\gamma$ and the low mass $h \to \gamma\gamma$ triggers)

$$\varepsilon_{2\gamma,\ \text{trigger}} = \frac{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons} \\ \text{(all photons within detector acceptance)} \\ \text{+ pass trigger}\end{array}}{\begin{array}{l}\text{\# of events w/ 2 pairs of merged photons} \\ \text{(all photons within detector acceptance)}\end{array}}$$

- For m(a) = 100 MeV, trigger efficiency increases from 70% to 83%

Conclusions

- For the 4 resolved γ's category, (where all the 4 γ's are within detector acceptance — possible to reconstruct the 4γ mass here) the existing low mass triggers have an efficiency of around ~50% (efficiency of applying pre-selection && trigger)

- For the 2 pairs of merged γ's category,
  - The pre-selection & trigger efficiency is ~45% for m(a) = 100 MeV
  - More investigation can be done (eg. Looking at the std $h \to \gamma\gamma$ trigger in this category)

- Next steps:

  - Started producing 2017 MC Signal MicroAOD's with the 94X flashgg recipe
  - For the 4 resolved γ's category, look at data/ MC comparisons to find discriminating variables

Backup

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance)}}$$

m(a)	Efficiency	Uncertainty
10	0.400	0.003
15	0.551	0.004
20	0.576	0.004
25	0.586	0.004
30	0.580	0.004
35	0.571	0.003
40	0.557	0.003
45	0.530	0.003
50	0.494	0.003
55	0.503	0.003
60	0.563	0.003

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection \& Trigger}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance)}}$$

m(a)	Efficiency	Uncertainty
10	0.386	0.003
15	0.539	0.004
20	0.564	0.004
25	0.573	0.004
30	0.567	0.004
35	0.556	0.003
40	0.543	0.003
45	0.517	0.003
50	0.480	0.003
55	0.484	0.003
60	0.545	0.003

$$\varepsilon_{4\gamma} = \frac{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection \& Trigger}}{\text{\# of events w/ 4 resolved photons (all photons within detector acceptance) + pass pre-selection}}$$

m(a)	Efficiency	Uncertainty
10	0.965	0.009
15	0.979	0.007
20	0.979	0.007
25	0.978	0.007
30	0.977	0.007
35	0.975	0.007
40	0.975	0.007
45	0.975	0.007
50	0.972	0.006
55	0.964	0.006
60	0.969	0.006

"OR" PATH

L1 SEEDED LEG

- **E_T > 10^9 GeV (EE)**
- E_T > 30 GeV (EB)
- R_9 > 0.5(0.8) in EB(EE)
- H/E < **0.10**(0.1) in EB(EE)

R_9 > 0.85(0.9) in EB(EE) **OR**
- $\sigma_{i\eta i\eta}$ < 0.015(0.035) in EB(EE)
- ECAL isolation < 6.0 + 0.012E_T

UNSEEDED LEG (N ≥ 2)

- E_T > 18 GeV
- **η < 1.5**
- R_9 > 0.5(0.8) in EB(EE)
- H/E < **0.10**(0.1) in EB(EE)
- **PIXEL VETO**

R_9 > 0.85(0.9) in EB(EE) **OR**
- $\sigma_{i\eta i\eta}$ < 0.015(0.035) in EB(EE)
- ECAL isolation < 6.0 + 0.012E_T
- Track isolation < 6.0 + 0.002E_T

$M_{\gamma\gamma}$ > 55 GeV

"AND" PATH

L1 SEEDED LEG

- E_T > 30 GeV (EE)
- E_T > 30 GeV (EB)
- R_9 > 0.5(0.8) in EB(EE)
- H/E < **0.10**(0.1) in EB(EE)

R_9 > 0.85(0.9) in EB(EE) **"AND"**
- $\sigma_{i\eta i\eta}$ < 0.015(0.035) in EB(EE)
- ECAL isolation < 6.0 + 0.012E_T

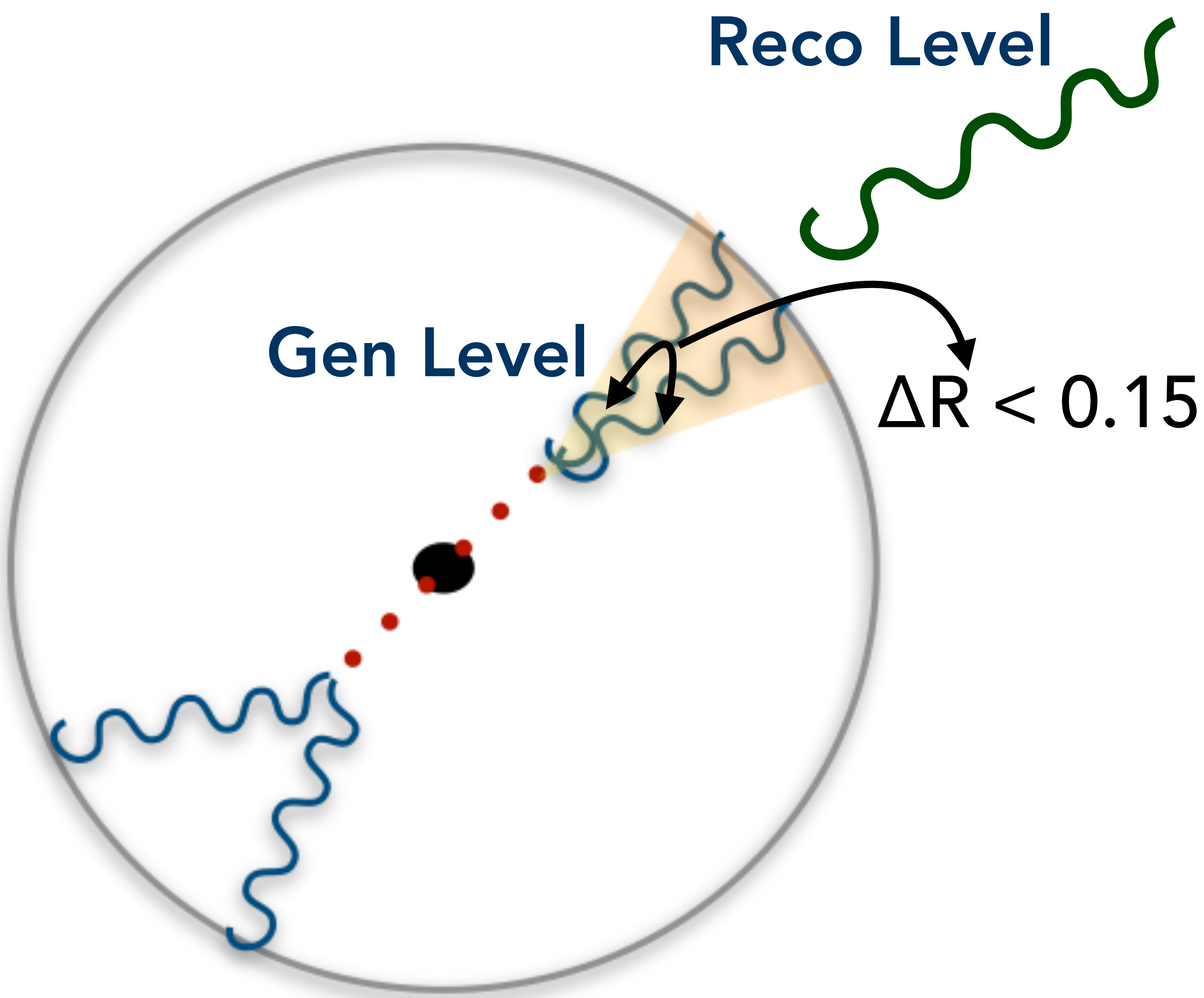
UNSEEDED LEG (N ≥ 2)

- E_T > 18 GeV
- **η < 2.5**
- R_9 > 0.5(0.8) in EB(EE)
- H/E < **0.10**(0.1) in EB(EE)
- **PIXEL VETO**

R_9 > 0.85(0.9) in EB(EE) **"AND"**
- $\sigma_{i\eta i\eta}$ < 0.015(0.035) in EB(EE)
- ECAL isolation < 6.0 + 0.012E_T
- Track isolation < 6.0 + 0.002E_T

$M_{\gamma\gamma}$ > 55 GeV

Logic of Gen-Reco Matching



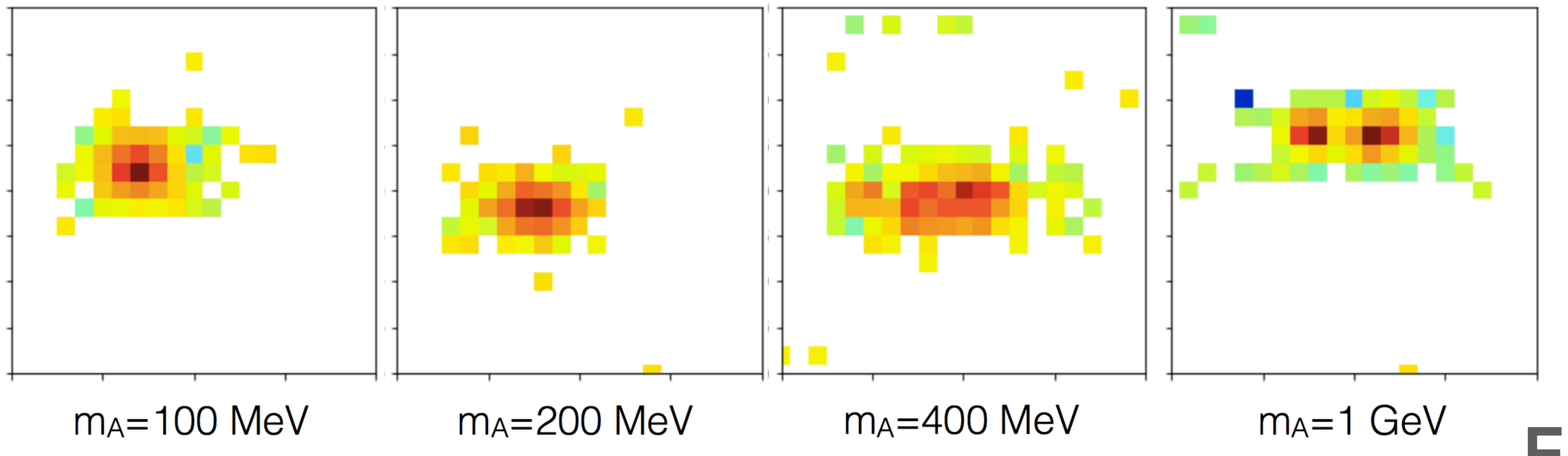
- Start by identifying a merged photon at Gen level (if $\Delta R < 0.15$)
- Loop over the collection of Reco photons and look for one which is close to the Gen-level merged photon within a cone of $\Delta R = 0.15$
- If more than one such Reco photons are found, then the one with the least ΔR is flagged as a merged photon at the Reco-level
- By doing this, we can flag each photon at the Reco level as "resolved" or "merged"
- Next step is to mimic the categories @ Reco level

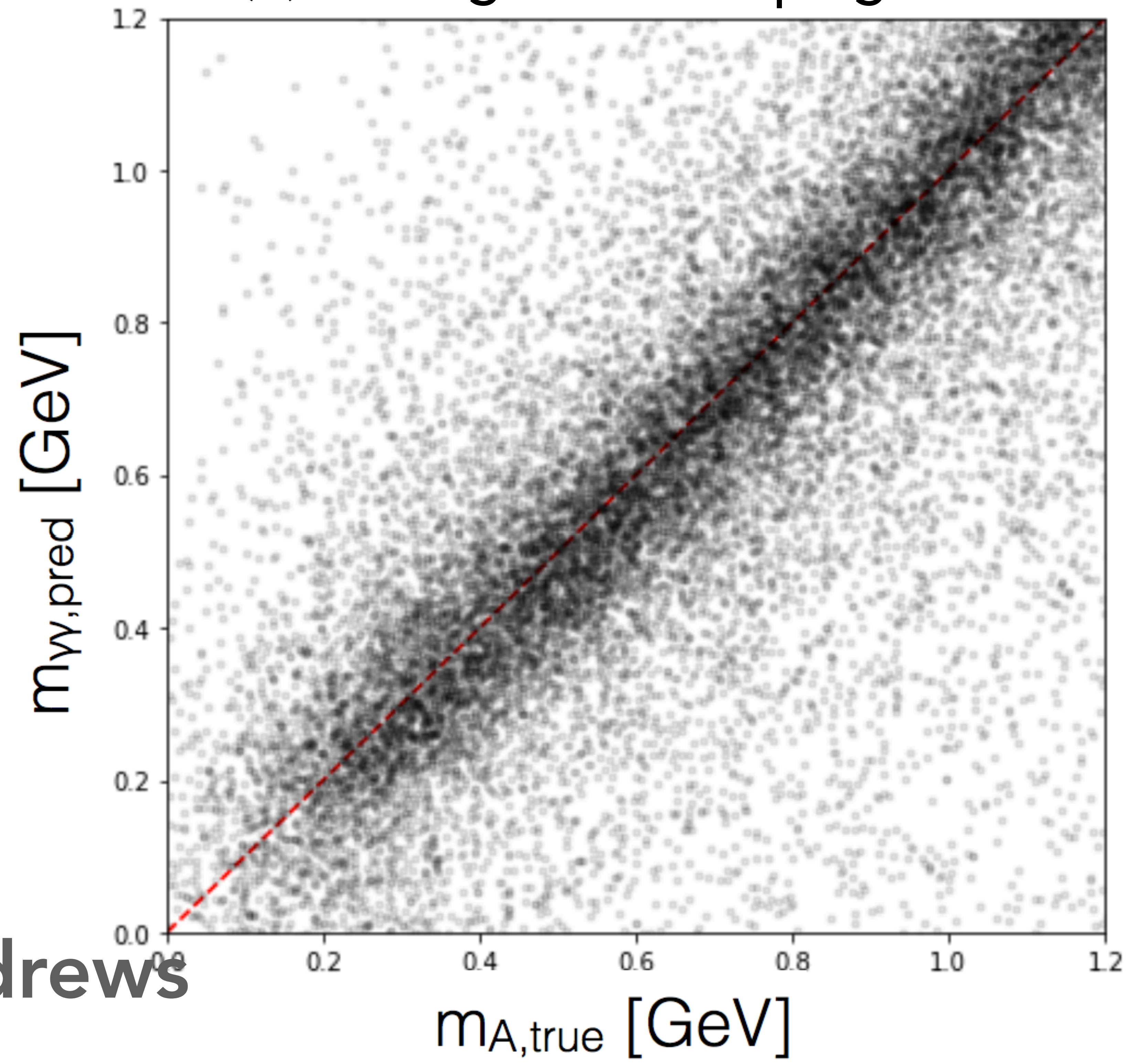
Low mass/Merged photons scenario

- For **m(a) > 10 GeV** the **fully resolved** topology is the dominant one (**26% for m(a) = 10 GeV** to **46% for m(a) = 60 GeV)**

- For **m(a) = 100 MeV and 1 GeV**, the dominant category is **2 pairs of merged γ's (all γ's in acceptance)**
  - However, for this mass regime a separate analysis has to be developed since the **standard photon identification MVA will cease to work**
  - New classification would be needed in this case; In contact with Michael Andrews (from CMU) (working on developing mass regression on merged photon clusters) Link to Michael's presentation

  - **Mass regression on merged photon clusters:**
    For exotic light scalar decays, $A \rightarrow \gamma\gamma$, try to perform mass regression on the merged photon cluster





From Michael Andrews