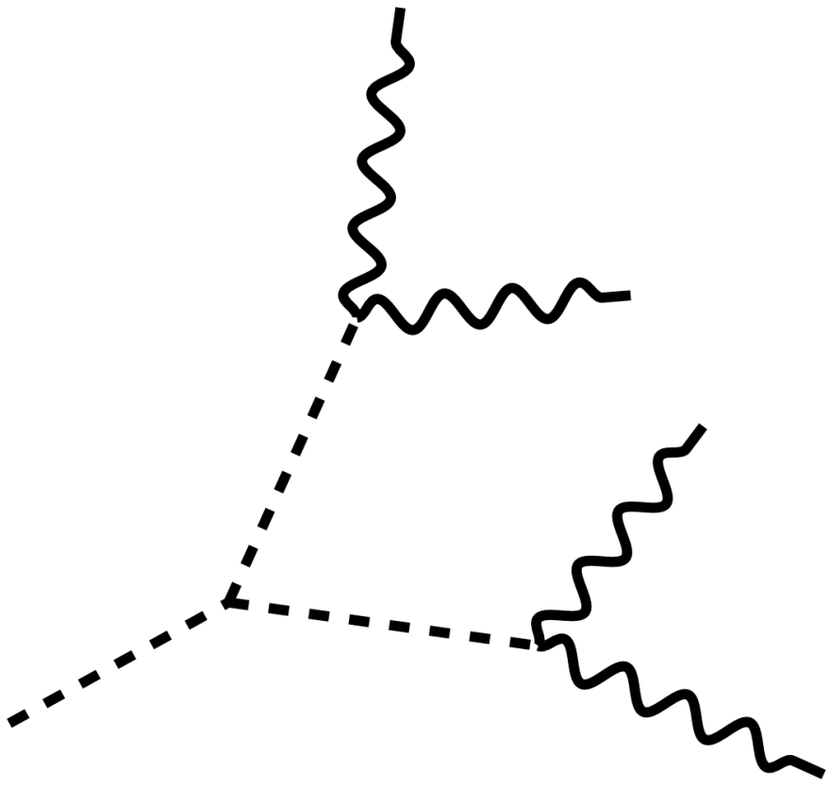
h(125)→aa→γγγγ



Higgs to 4 Gamma Update

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5th March 2018
Hgg Meeting

MOTIVATION

- Explore Beyond the Standard model scenario using final state with 4ɣ
- Exotic decays of the Higgs Boson are of great interest and are well motivated within many extensions of the SM
- In these models, (pseudo) scalar a→ɣɣ can be suppressed (low branching ratios)
  - Non-trivial extensions SM extensions can change that picture by suppressing a→fermions
    - See summary at Exotic Higgs Decays website
  - The 4ɣ state is basically SM background free
  - We can take advantage of high ɣ online/offline reconstruction and identification efficiency
- This analysis considers a non-SM decay of a Higgs Boson (h) decaying to a pair of light pseudoscalars (a), each of which subsequently decays into 2 ɣ's each

DATA & MC SAMPLES

- **Data**
  - Double EG reMiniAOD dataset
  - 36 fb-1 for 2016

- **Signal MC**
  - Generate using Pythia 8
  - Officially produced Summer16 samples
  - m(a) = 100 MeV, 1 GeV to 60 GeV in steps of 5 GeV

- **Background MC**
  - DiPhotons + Jets

DiPhotonJetsBox_M40_80-Sherpa
DiPhotonJetsBox_MGG-80toInf_13TeV-Sherpa

  - Photons + Jets

GJet_Pt-20toInf_DoubleEMEnriched_MGG-40to80_TuneCUETP8M1_13TeV_Pythia8
GJet_Pt-20to40_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8
GJet_Pt-40toInf_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8

  - QCD

QCD_Pt-30to40_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8
QCD_Pt-40toInf_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8
QCD_Pt-30toInf_DoubleEMEnriched_MGG-40to80_TuneCUETP8M1_13TeV_Pythia8

Only used for Signal-background studies

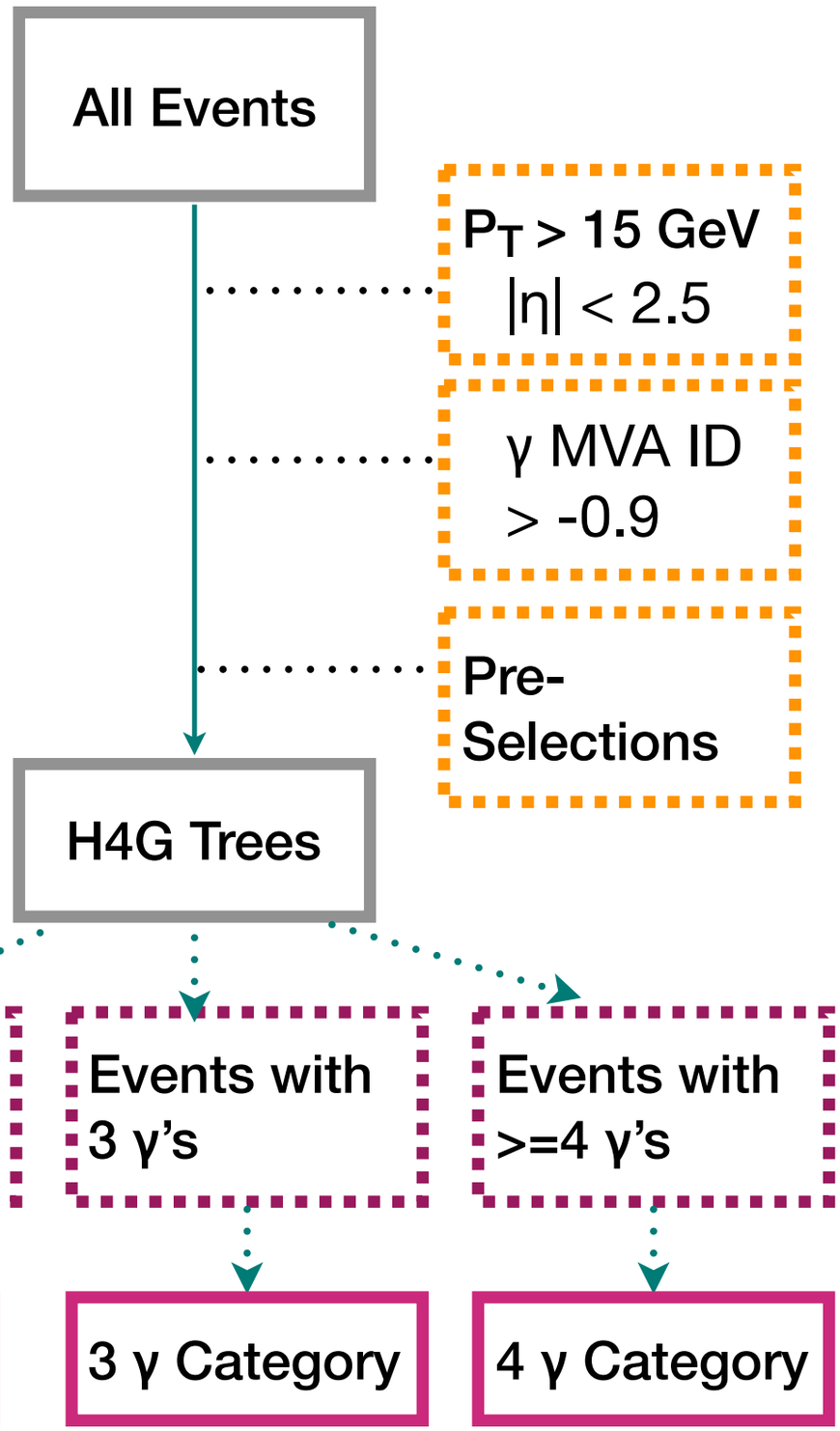
Background modeling to be done directly with data using Discrete Profile method

ANALYSIS STRATEGY

- h(125)→aa→ɣɣɣɣ
- Probing mass region ranging from 100 MeV < m(a) < 60 GeV
- Highly boosted “a’s”
  - Collimated products of “a” decays

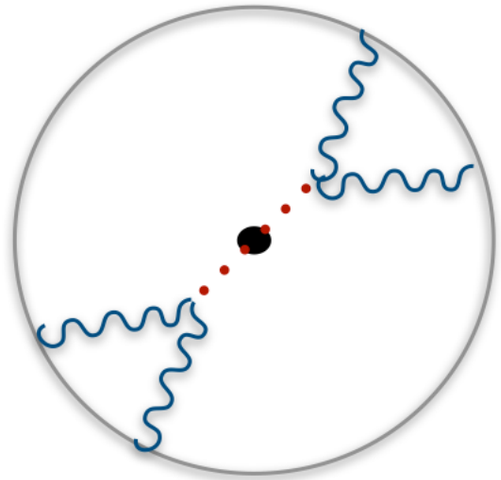
- Depending on m(a) we have different topologies

- Higher the m(a), lower the boost of “a” and better isolated are the decay product photons, i.e large values of ΔR

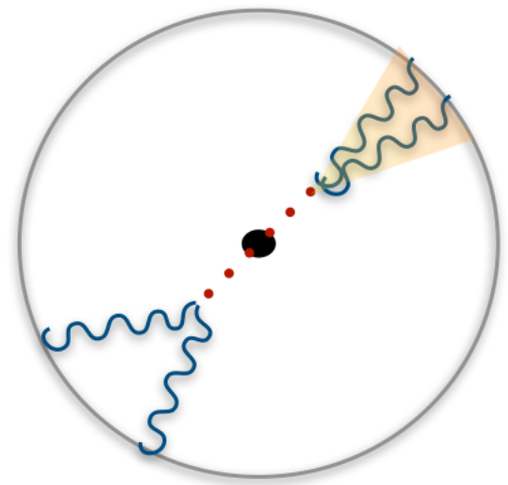


CATEGORIES

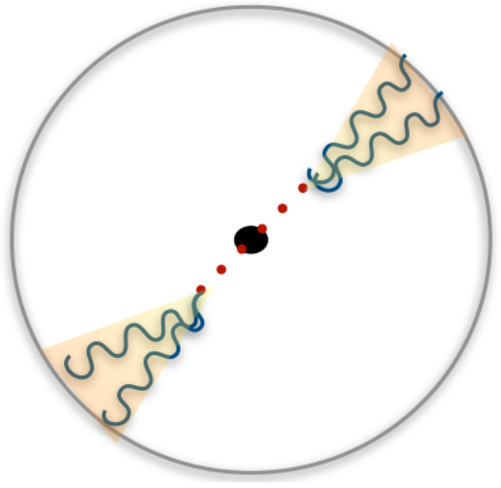
4 Isolated Photons
- "a" is not boosted, the decay products are well isolated
- Select events with at least 4 γ's and then select the 4 highest P_T γ's



2 Isolated Photons + 2 Merged Photons
- Boosted "a" case
- Select events with exactly 3 γ's
- Can be further split into 2 sub-categories
  - 2 Isolated + 2 merged γ's
  - 3 Isolated γ's + 1 missing γ (due to P_T or η cut)



2 Pairs of Merged Photons
- Highly boosted "a" scenario
- Select events with exactly 2 γ's
- Heavily polluted by H->γγ events
- Need to develop a custom MVA ID



TRIGGER & PRESELECTION

- Online selection identical to low mass h→γγ search
- Passing the OR of the two Low mass HLT paths
  - OR Path
    HLT_Diphoton30EB_18EB_R9Id_OR_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55
  - AND Path
    HLT_Diphoton30PV_18PV_R9Id_AND_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55
- **Pre-Selection**
  - Loose Photon ID > -0.9
  - Trigger strategy on MC based on offline selection similar to online

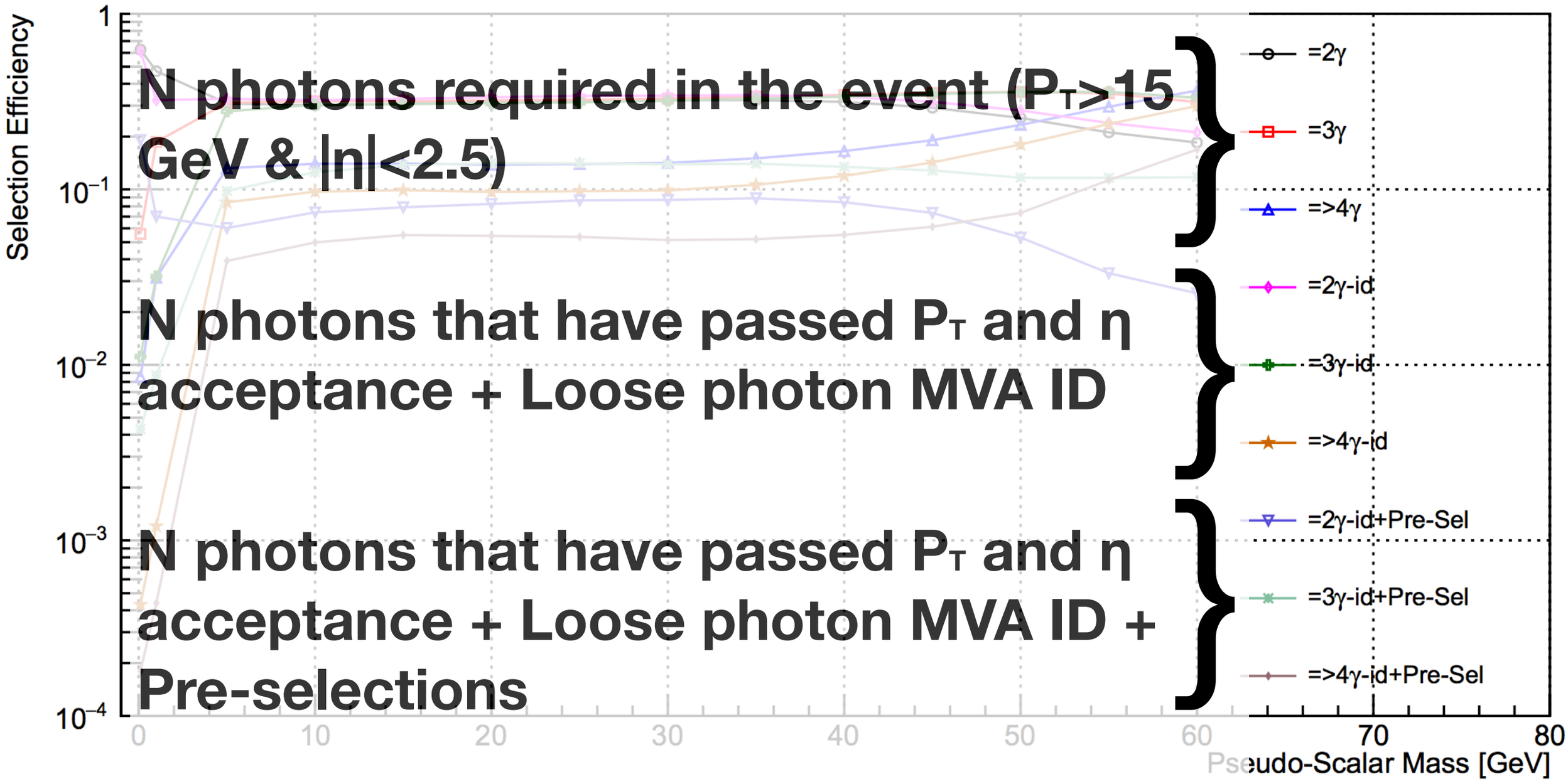
Cut on EE
Cut on EB

Offline Trigger like requirements

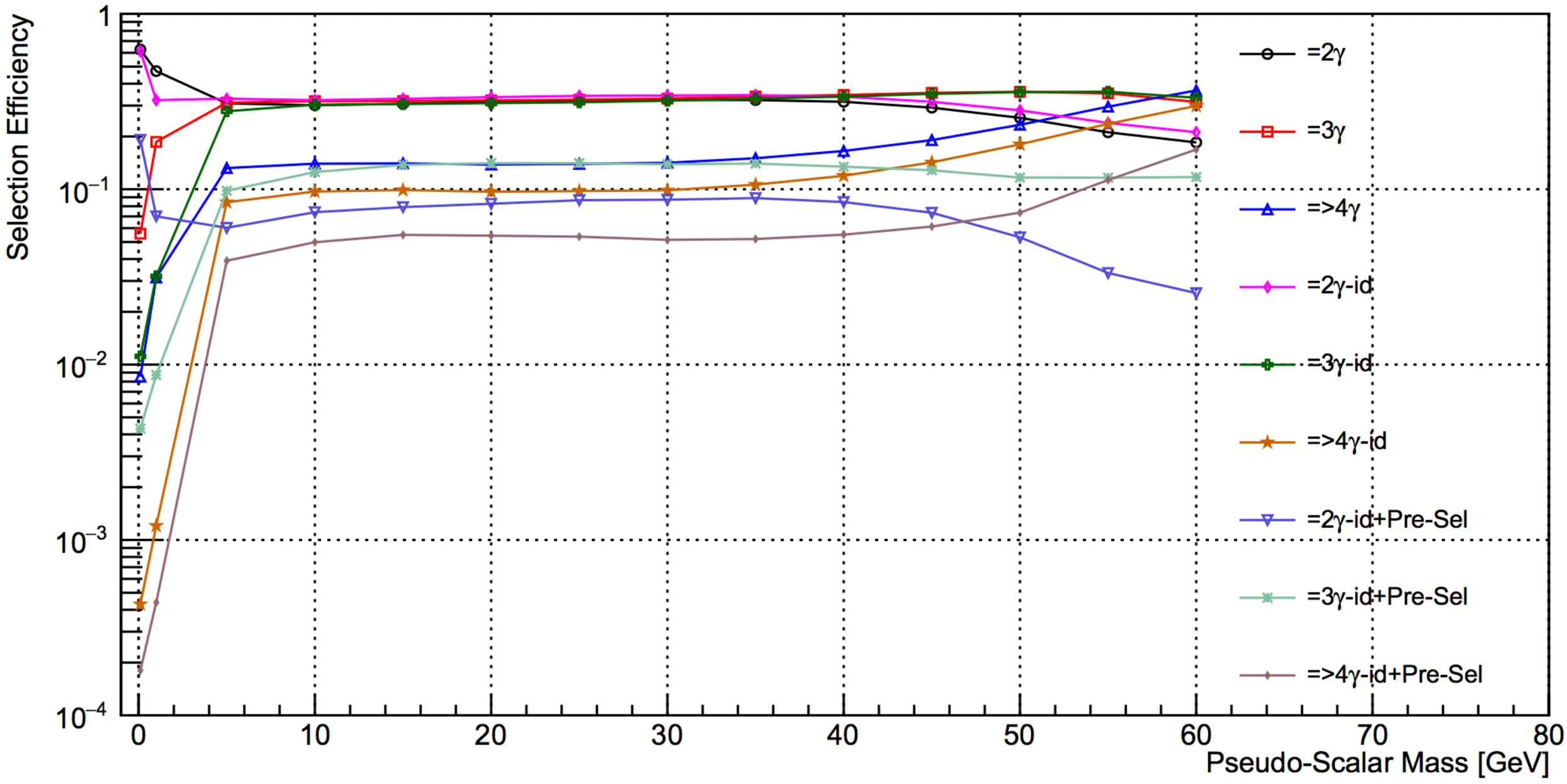
Category		R9	Trigger path	H/E	$\sigma_{i\eta i\eta}$	Pho Iso	Trk Iso
Both photons in EB		> 0.85 > 0.85	OR	< 0.08 < 0.08	-	-	-
		> 0.85 > 0.85	AND	< 0.08 < 0.08	< 0.015 < 0.015	< 6+0.012*Pt < 6+0.012*Pt	< 6+0.002*Pt < 6+0.002*Pt
		>0.5&&<0.85 >0.5&&<0.85	OR	< 0.08 < 0.08	< 0.015 < 0.015	< 6+0.012*Pt < 6+0.012*Pt	< 6+0.002*Pt < 6+0.002*Pt
At least one Photon in EE	Second photon in EB	> 0.9 > 0.85	AND	< 0.08 < 0.08	< 0.035 < 0.015	< 6+0.012*Pt < 6+0.012*Pt	< 6+0.002*Pt < 6+0.002*Pt
	Second Photon in EE	> 0.9 > 0.9	AND	< 0.08 < 0.08	< 0.035 < 0.035	< 6+0.012*Pt < 6+0.012*Pt	< 6+0.002*Pt < 6+0.002*Pt

- $m_{\gamma\gamma}$ > 55 GeV, P_T lead γ> 30 GeV, P_T sub-lead γ> 18 GeV, Pixel Veto applied

SIGNAL EFFICIENCIES



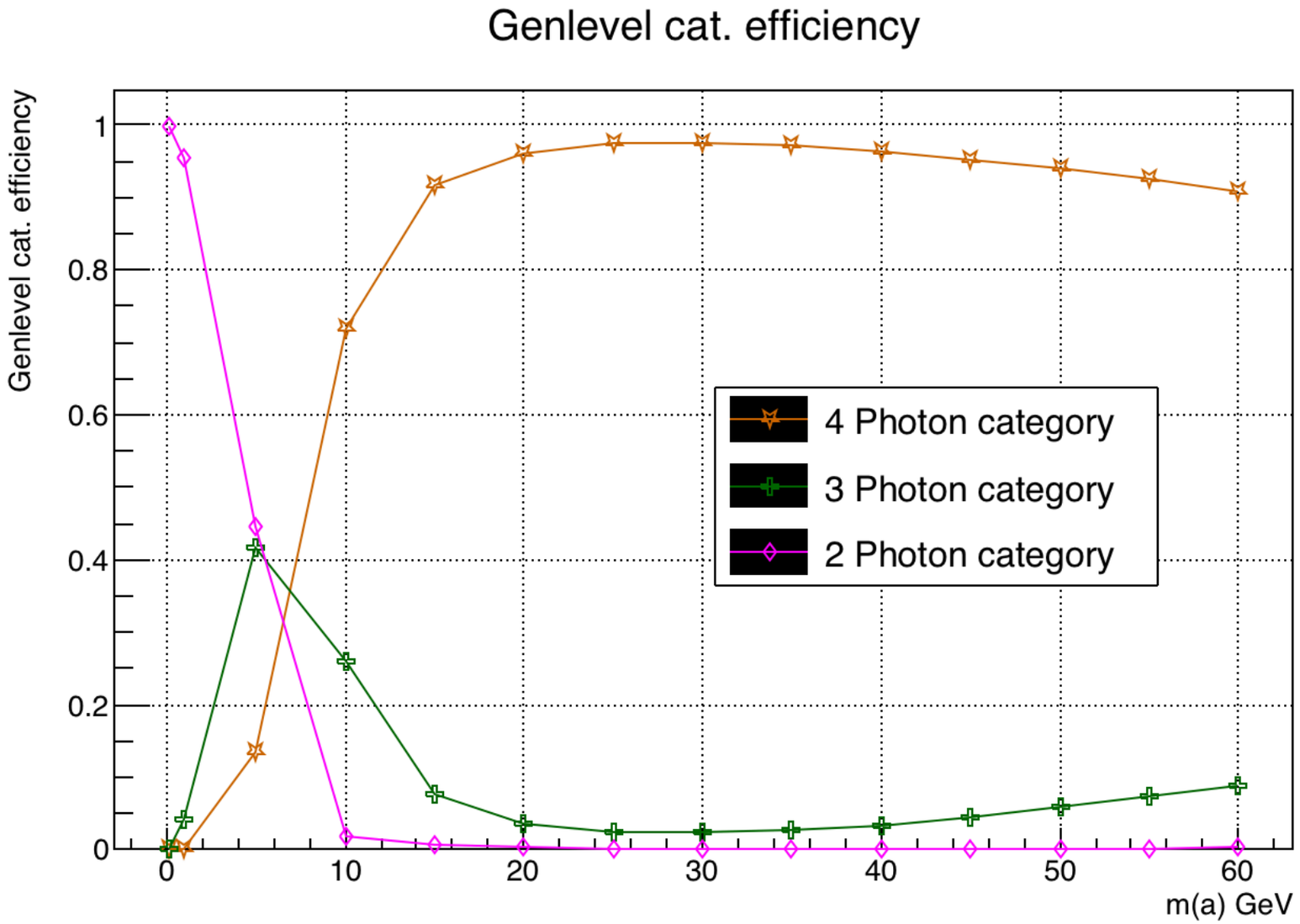
SIGNAL EFFICIENCIES



GEN LEVEL CATEGORIZATION

- Since @ Gen level there are always 4γ's , we look at delta R between each of the 6 photon pairs
- Define 3 categories:
  - No pairs found with deltaR < 0.3 —> 4 Photon Category (all isolated photons)
  - 1 pair found with deltaR < 0.3 —> 3 Photon Category(1 Fat Photon + 2 Isolated Photons)
  - 2 pairs found with deltaR < 0.3 —>2 Photon Category (2 Fat Photons)

- Plot on the right shows fraction of events falling into the 3 categories for different mass points

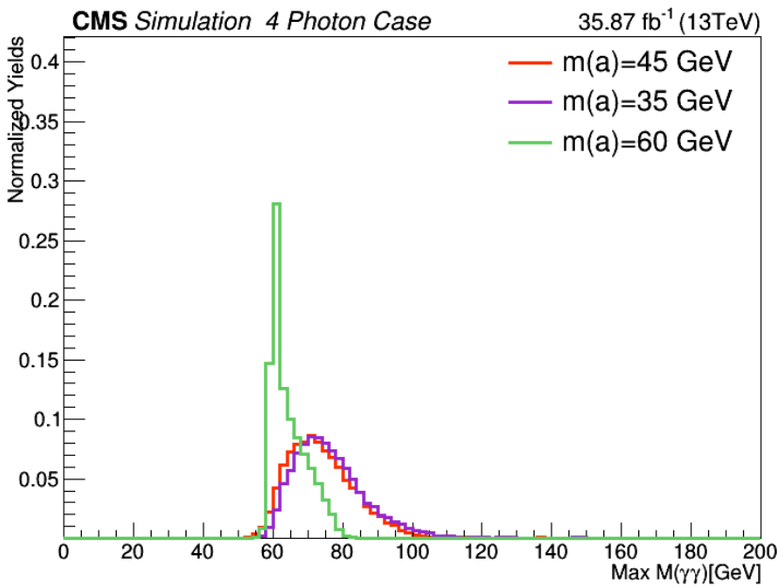


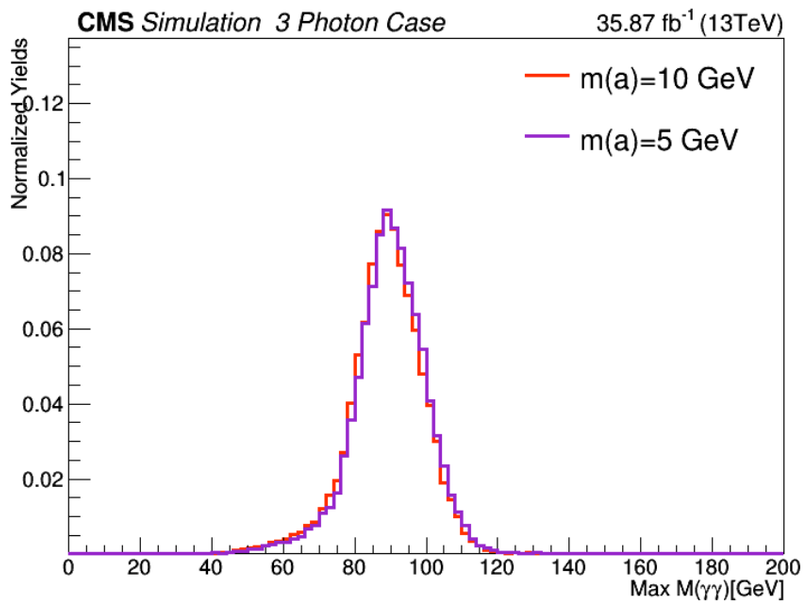
$m_{\gamma\gamma}$ > 55 GeV CUT

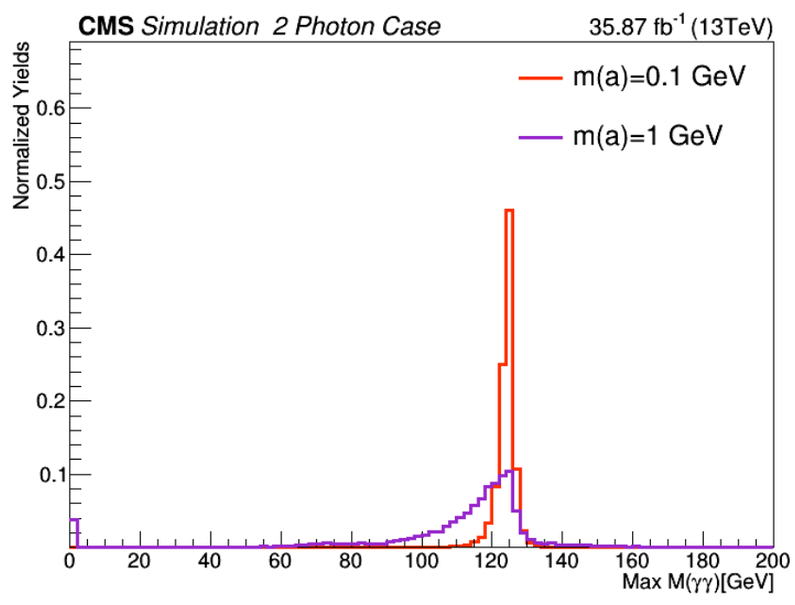
- Due to combinatorics, there is always one photon pair that passes the $m_{\gamma\gamma}$ > 55 GeV cut

- In the 4 photon category
  - 6 possible photon pairs
- In the 3 photon category
  - 3 possible photon pairs
- In the 2 photon category
  - 1 photon pair

- Shown below is the distribution(reco-level) of the maximum diphoton mass out of all possible combinations for each of the 3 categories

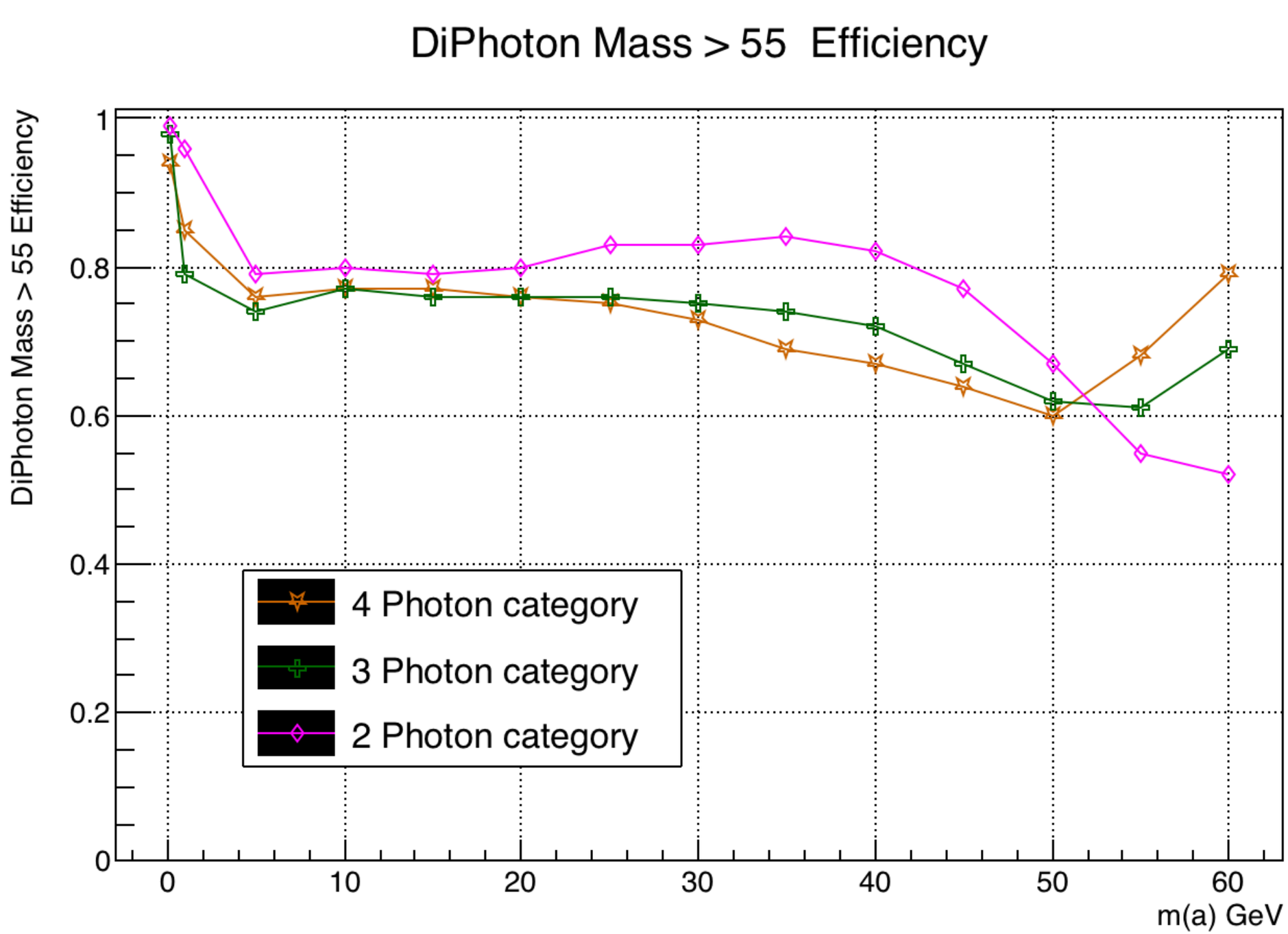






$m_{\gamma\gamma}$ > 55 GeV CUT

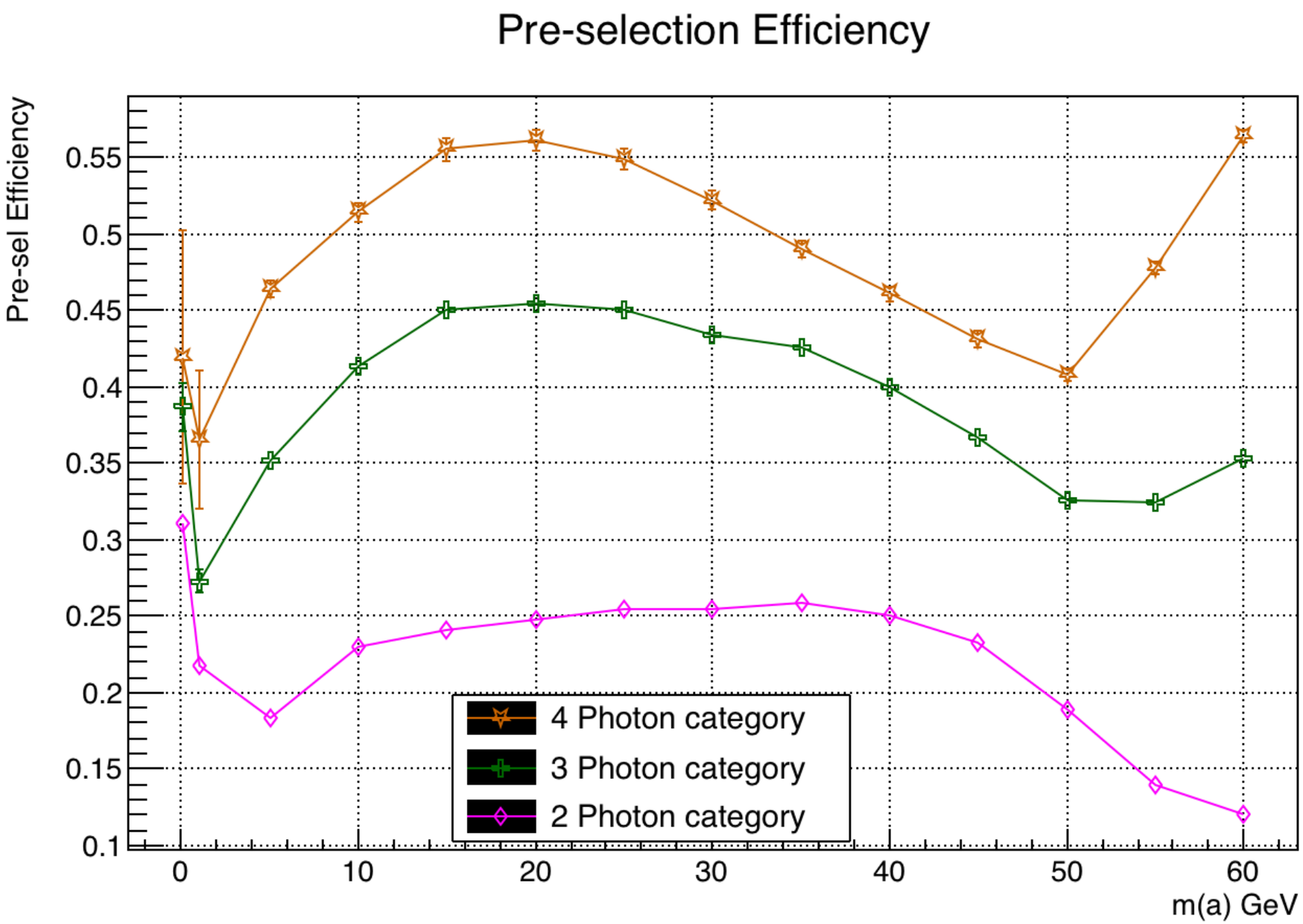
- Efficiency of the $m_{\gamma\gamma}$ > 55 GeV cut



PRE-SELECTION EFFICIENCY

- Efficiency of the pre-selection cuts for each of the 3 categories

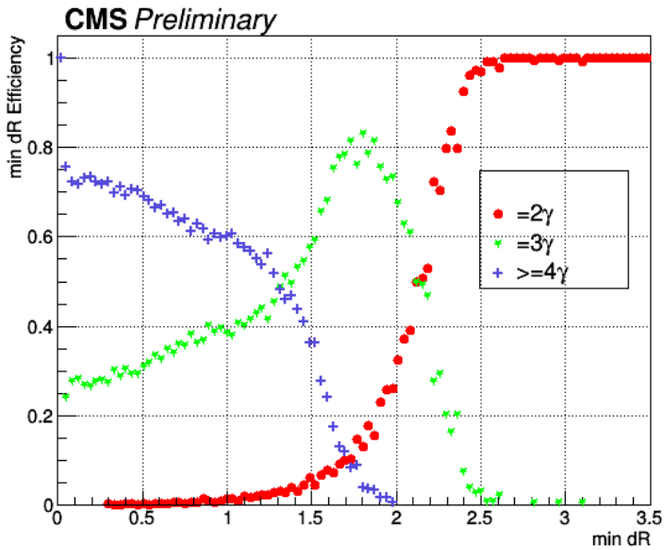
- Efficiency = $\frac{\text{\# of events that pass acceptance cuts + Photon MVA + Pre-selections}}{\text{\# of events that pass acceptance cuts + Photon MVA}}$

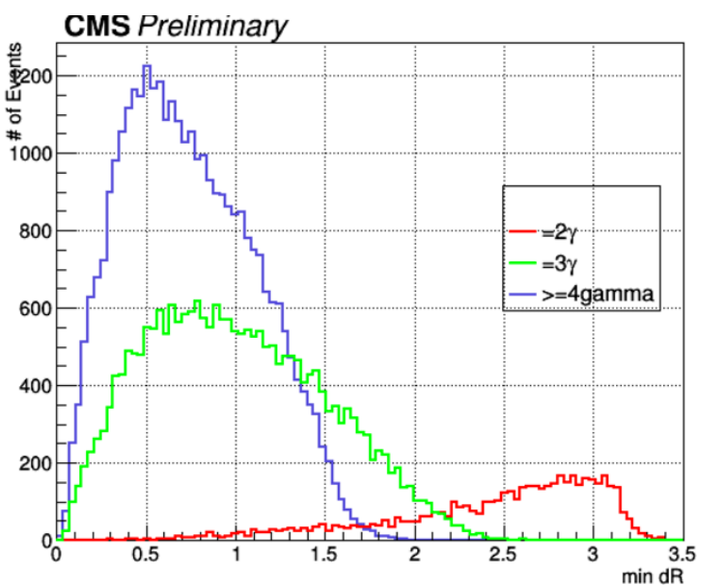


MIN. dR EFFICIENCY

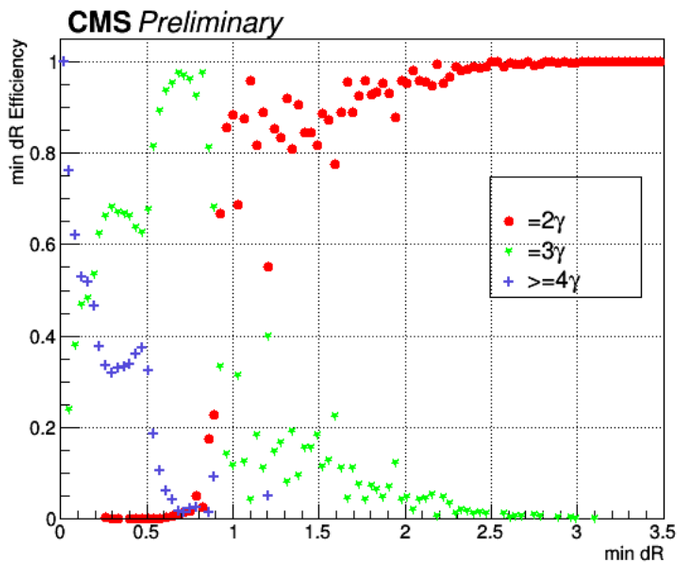
- Efficiency of the 3 categories as a function of min dR (minimum of the delta R calculated between different photon pairs)

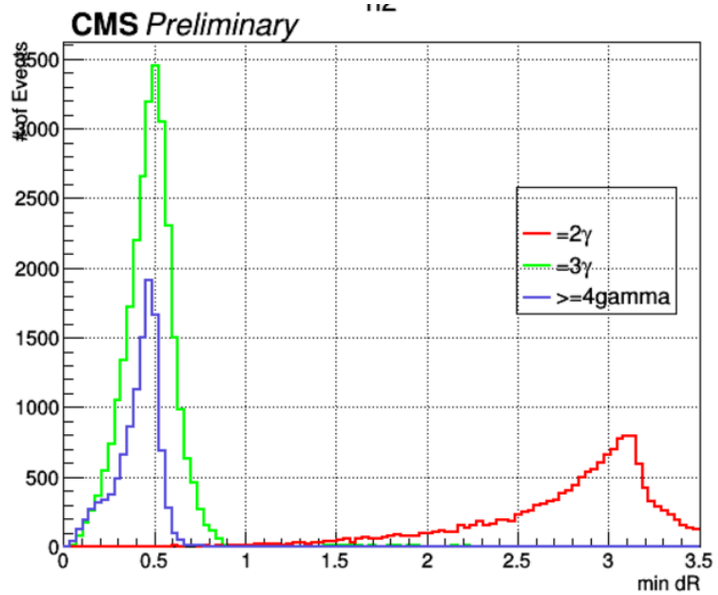
m(a) = 60 GeV



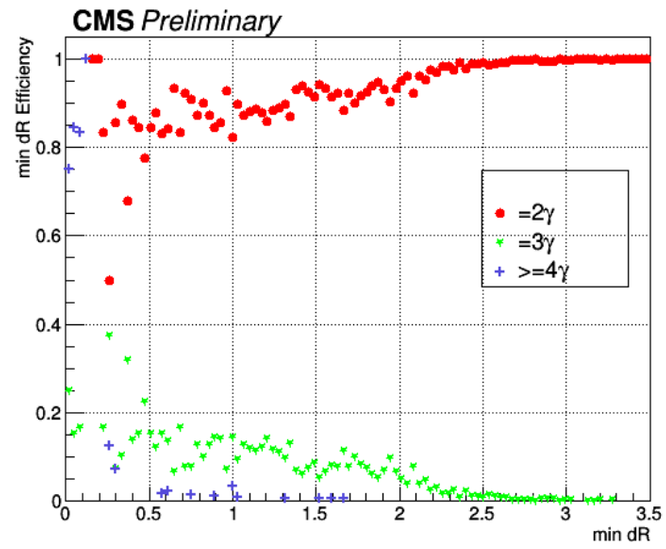


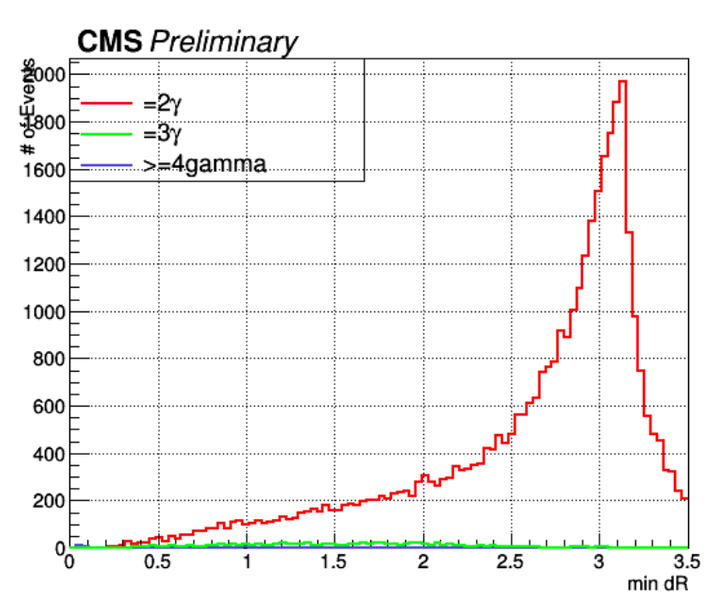
m(a) = 15 GeV





m(a) = 0.1 GeV

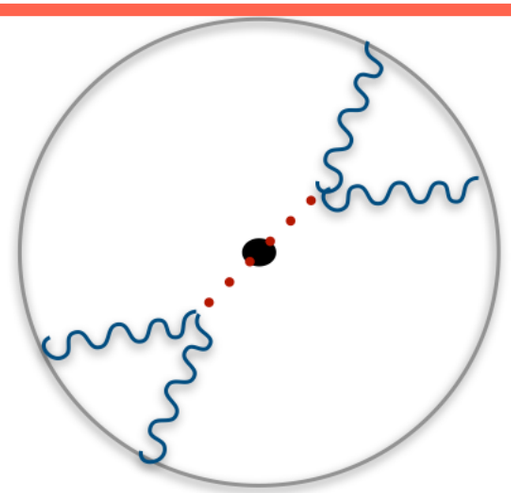




CATEGORIES

Rest of the Presentation

4 Isolated Photons
- "a" is not boosted, the decay products are well isolated
- Select events with at least 4 γ's and then select the 4 highest P_T γ's



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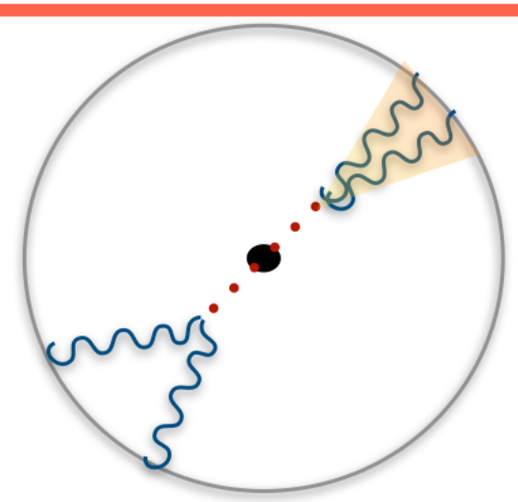
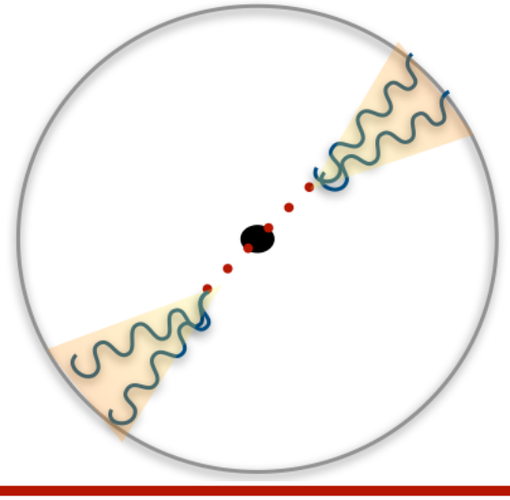
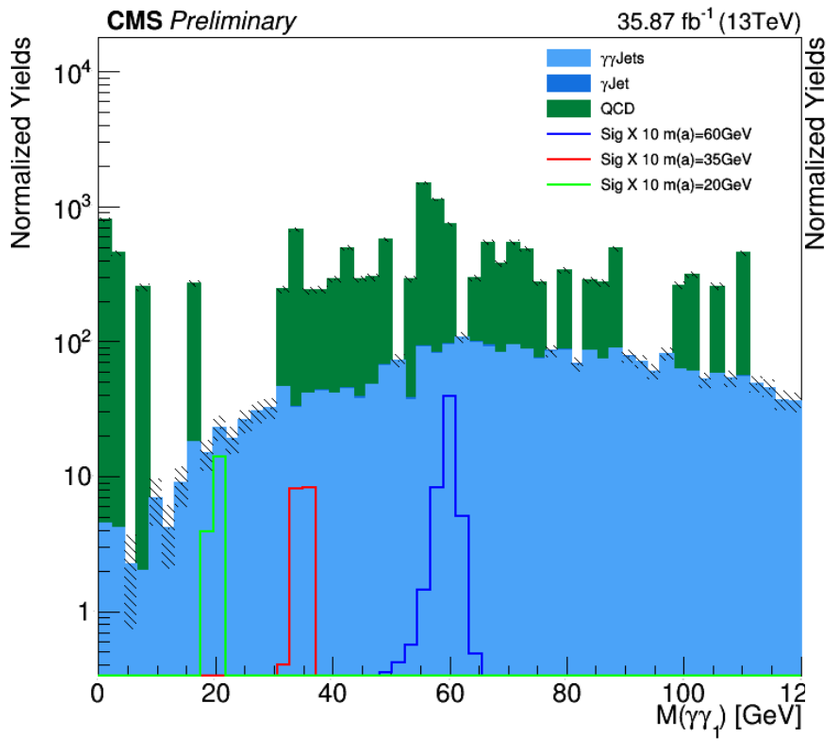


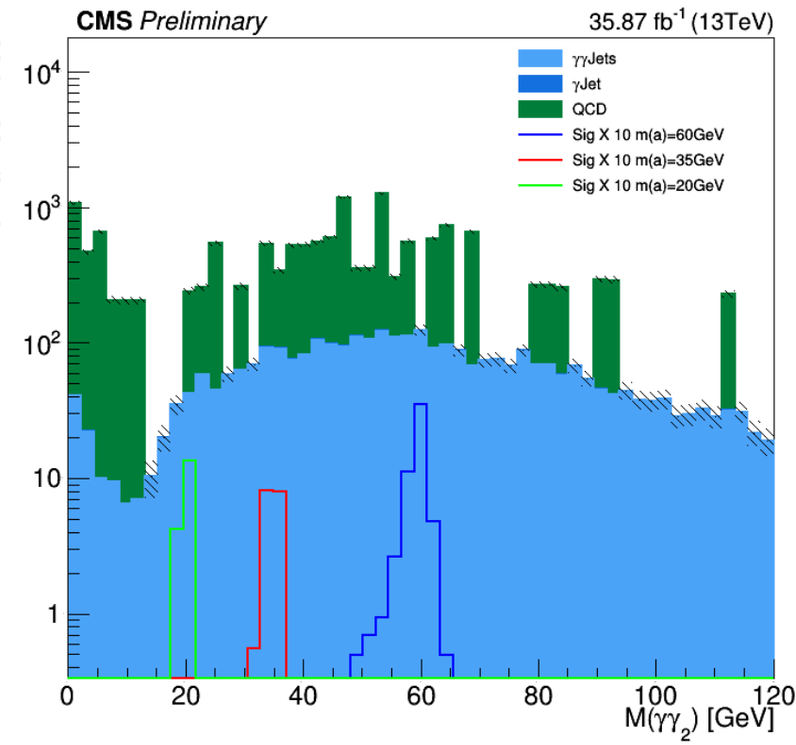
2 Pairs of Merged Photons
- Highly boosted "a" scenario
- Select events with exactly 2 γ's
- Heavily polluted by H->γγ events
- Need to develop a custom MVA ID

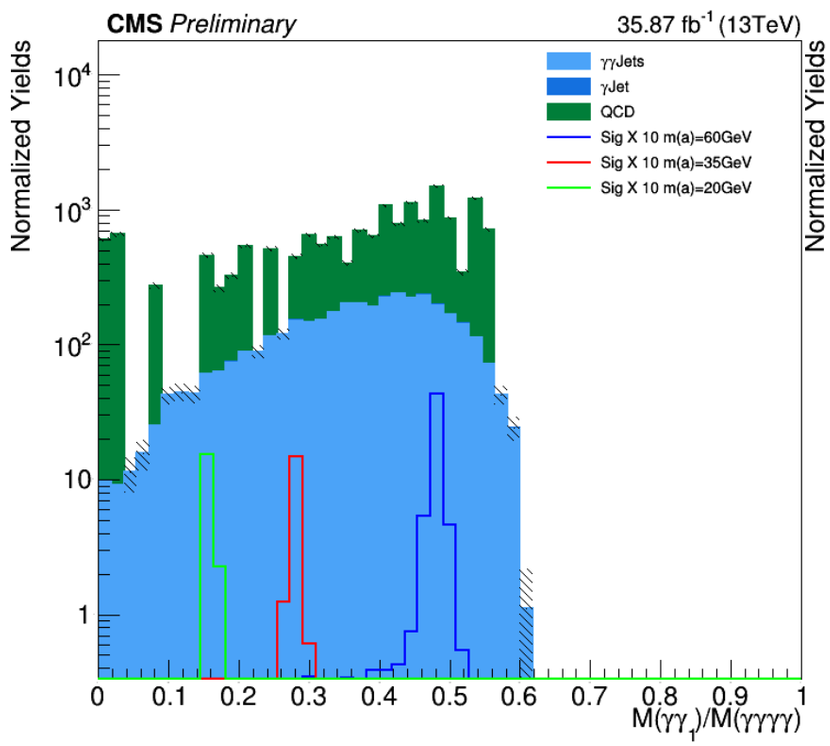


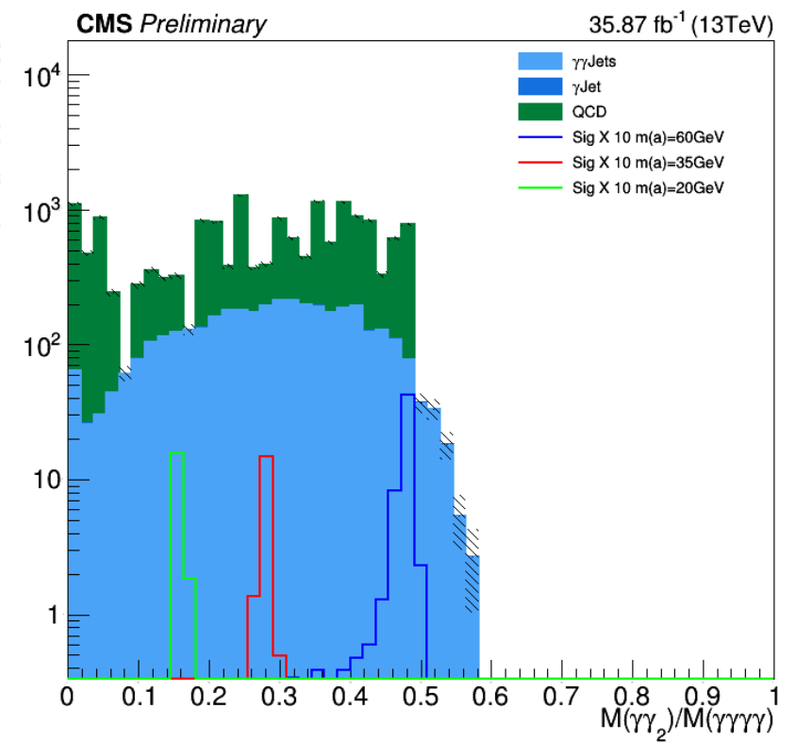
BACKGROUND SIGNAL COMPARISON

- Background and Signal MC comparison plots for the **4γ category** are shown
- DiPhoton Mass and ratio of diphoton to tetra photon mass shown
- Signal m(a) = 60, 35 and 20 GeV





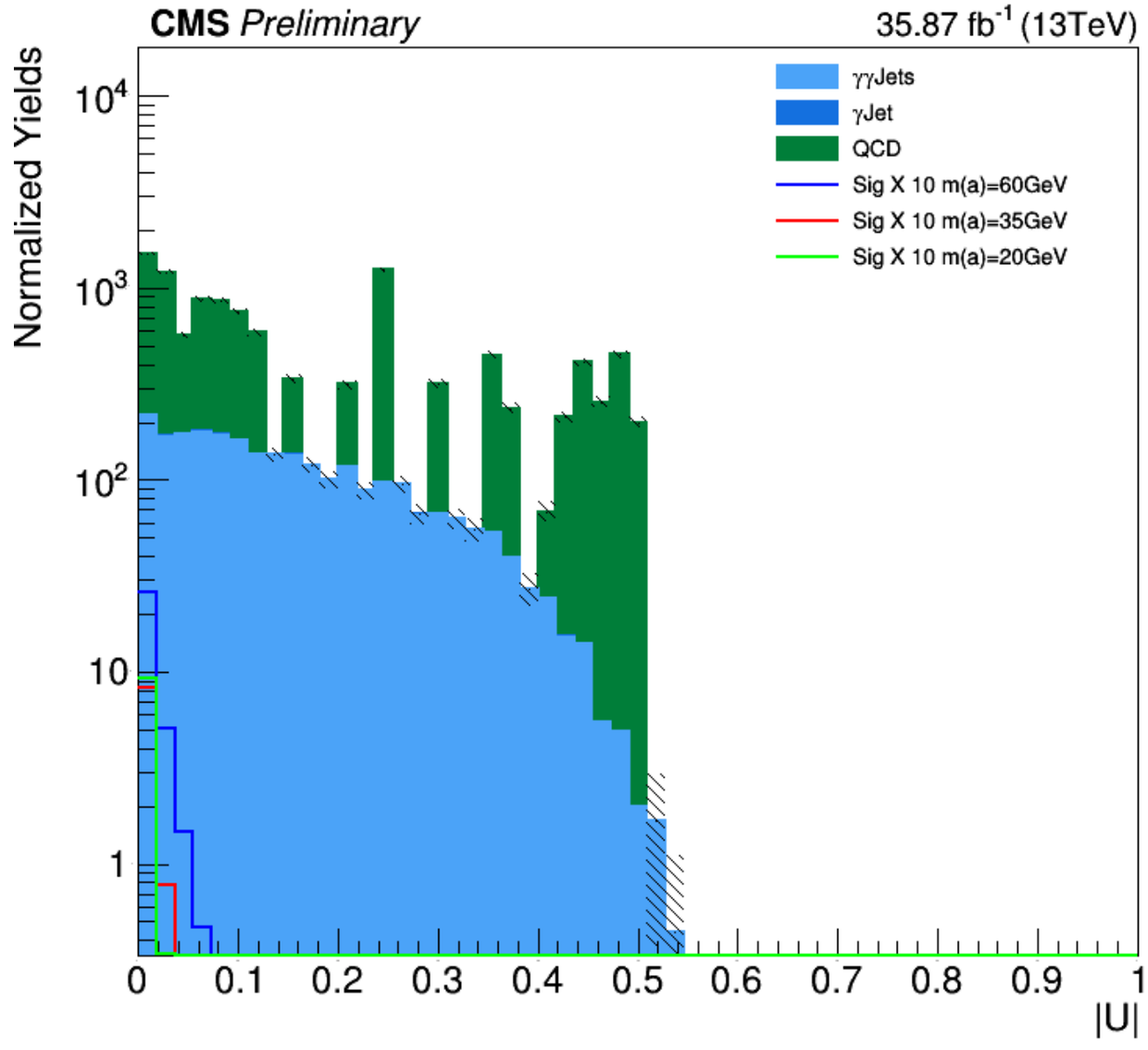




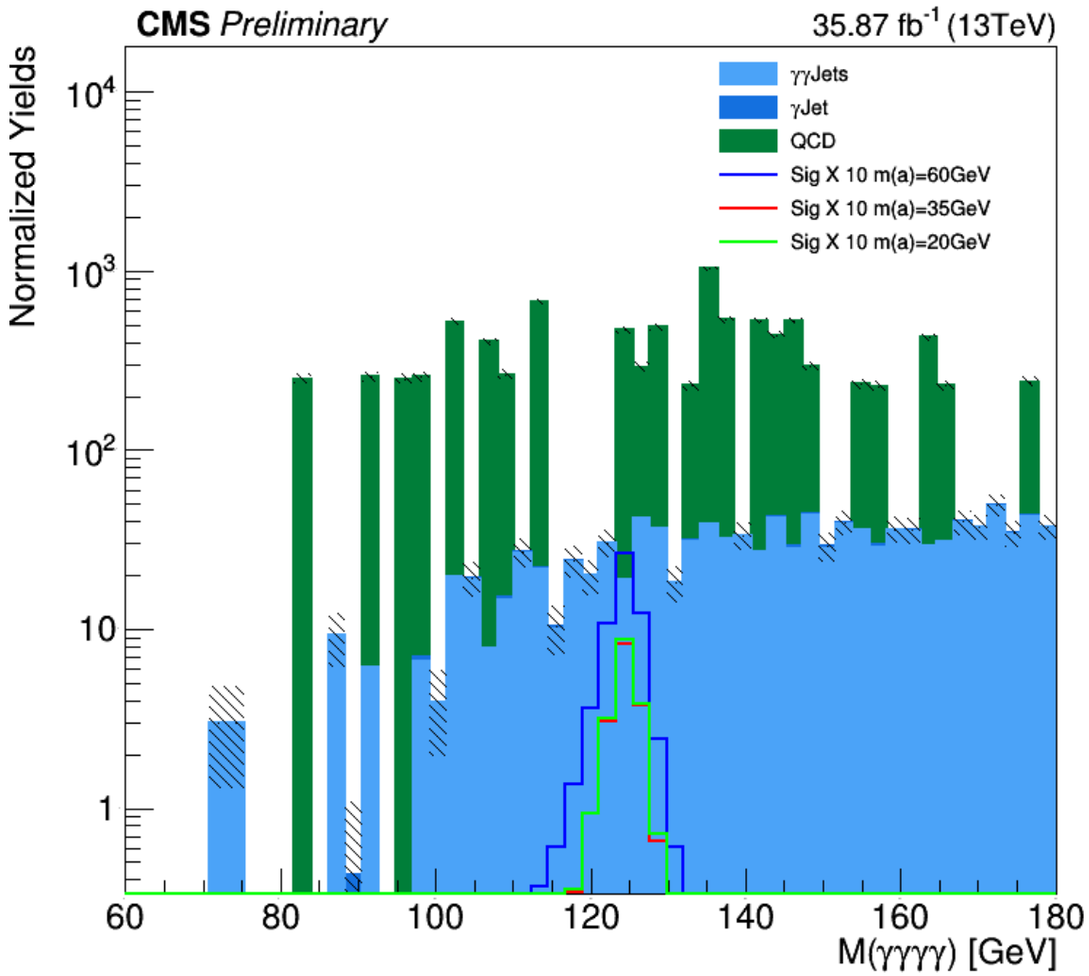
BACKGROUND SIGNAL COMPARISON

- Mass difference between signal diphotons ~0
- Mass difference between background diphotons > 0
- We can use a measure of this mass unbalances as a handle on S/B

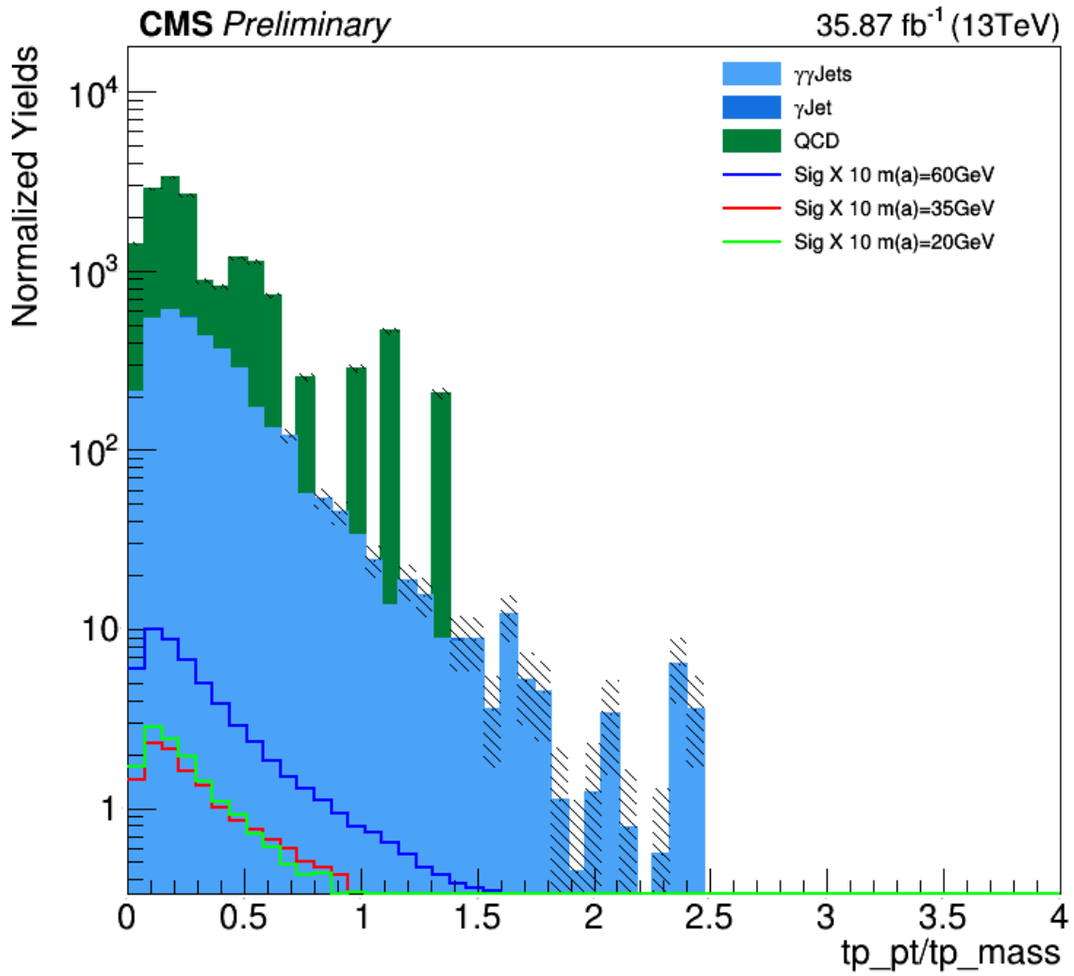
$$|U_M| = \left| \frac{M(\gamma\gamma_1) - M(\gamma\gamma_2)}{M(\gamma\gamma_1) + M(\gamma\gamma_2)} \right|$$



BACKGROUND SIGNAL COMPARISON



Tetraphoton Mass distribution



Ratio of Tetraphoton P_T to Mass distribution

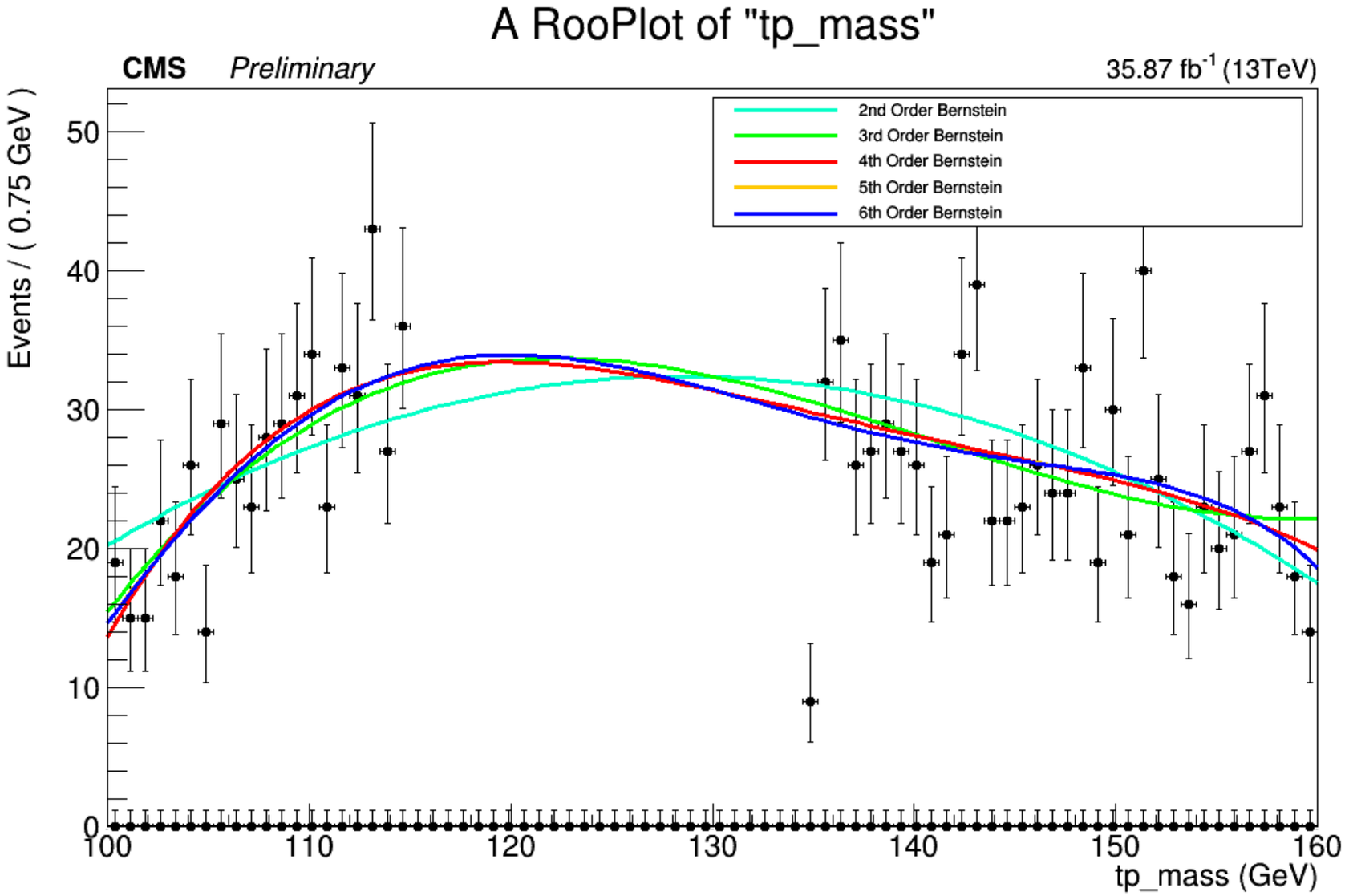
BACKGROUND MODEL

- Background modeled by fitting analytic functions to tetra photon mass distribution
- 100 < M(γγγγ) < 160 GeV
  - Blinding range : 115 < M(γγγγ) < 135 GeV

For the 4γ category

Cuts applied:

- 100 < M(γγγγ) < 160 GeV
- 0.05< $M(\gamma\gamma_1)/M(\gamma\gamma\gamma\gamma)$ < 0.55
- 0.05< $M(\gamma\gamma_2)/M(\gamma\gamma\gamma\gamma)$ < 0.55
- $M(\gamma\gamma_1)-M(\gamma\gamma_2)/M(\gamma\gamma\gamma\gamma)$ < 0.25
- PT(γγγγ)/M(γγγγ) < 1.7



- Study of other functions for fitting ongoing

SIGNAL MODEL

- Signal shape modeled by a sum of gaussians

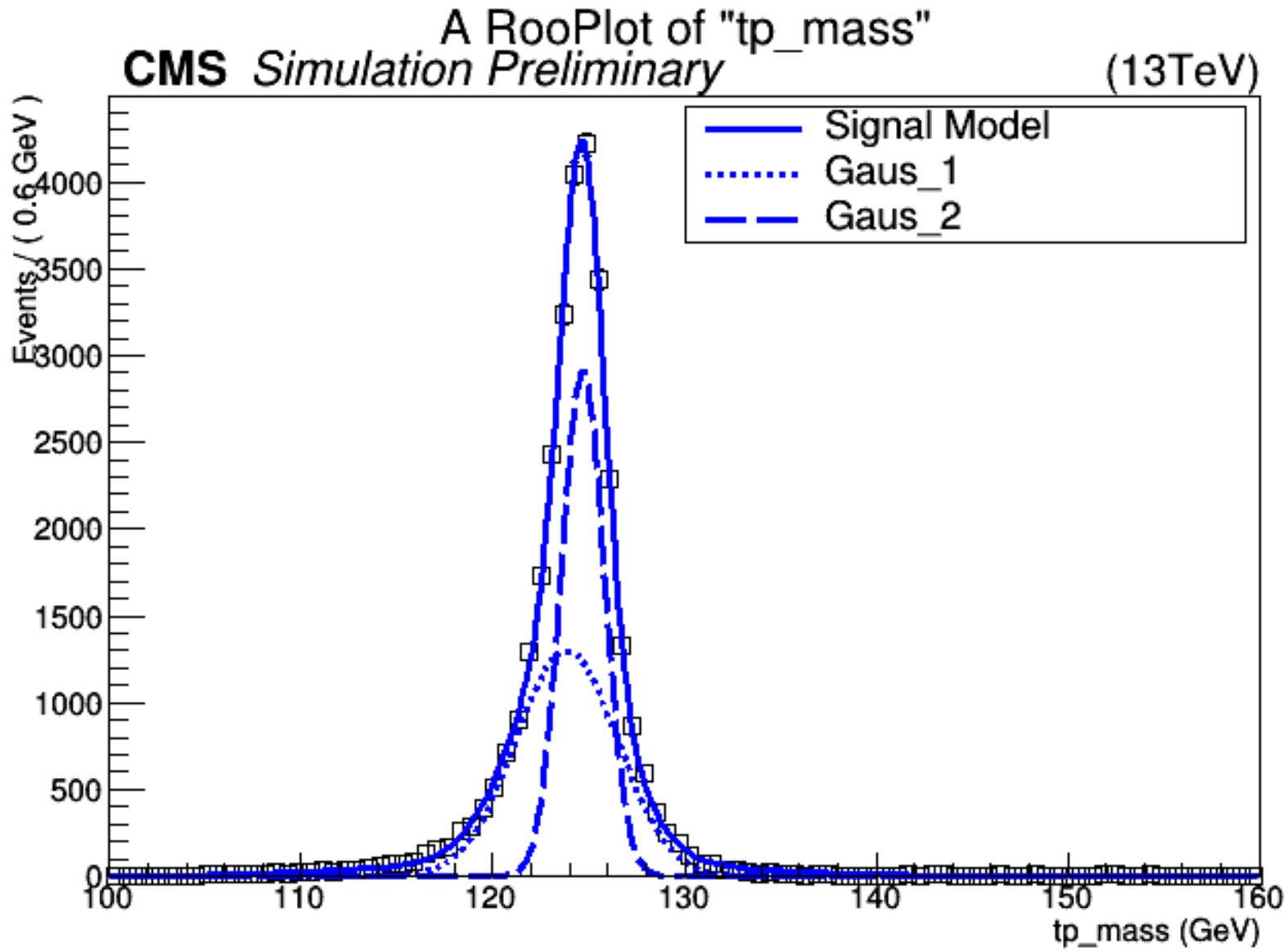
Fit of signal shape

4γ Category

MC: h→aa→γγγγ

m(a) = 60 GeV

The 2 Gaussian components of the final Signal model are shown here



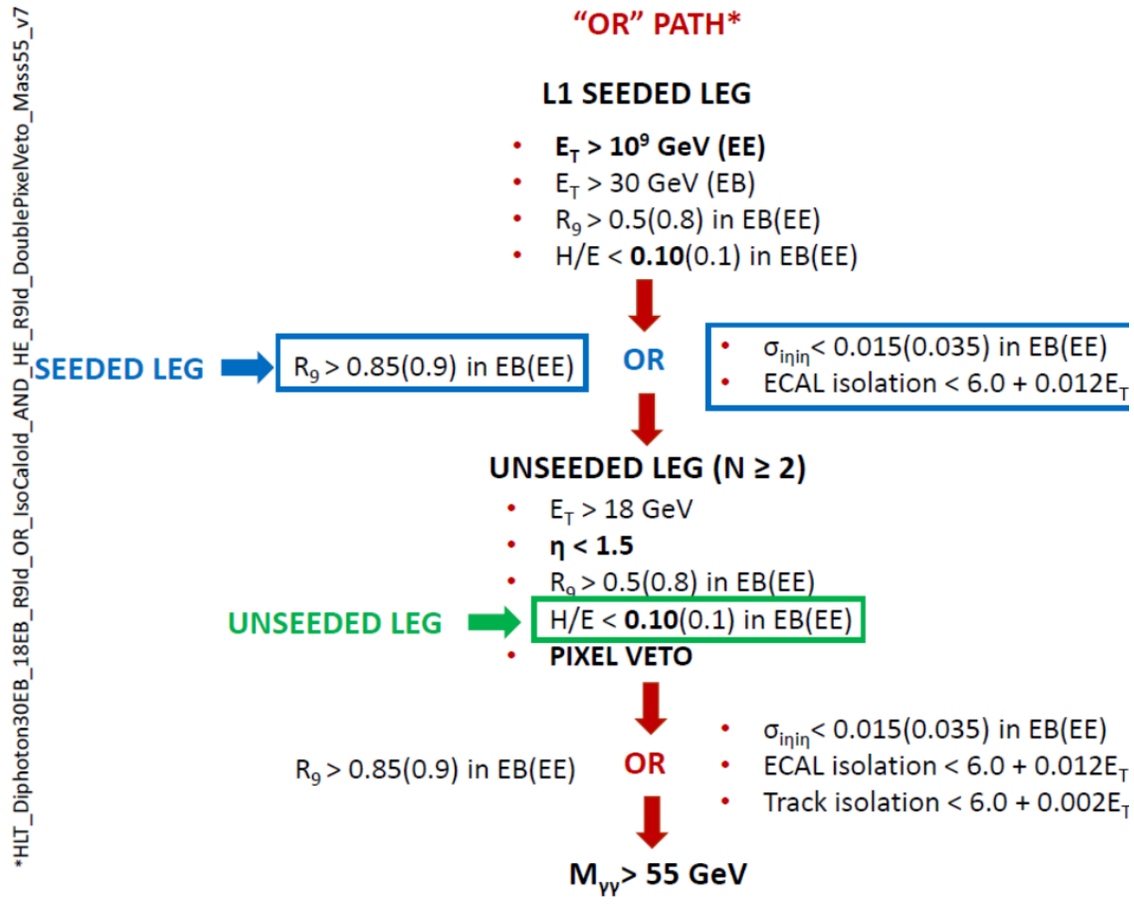
SUMMARY & OUTLOOK

- The analysis strategy for h(125)→aa→γγγγ was presented
- Signal efficiency for different categories shown

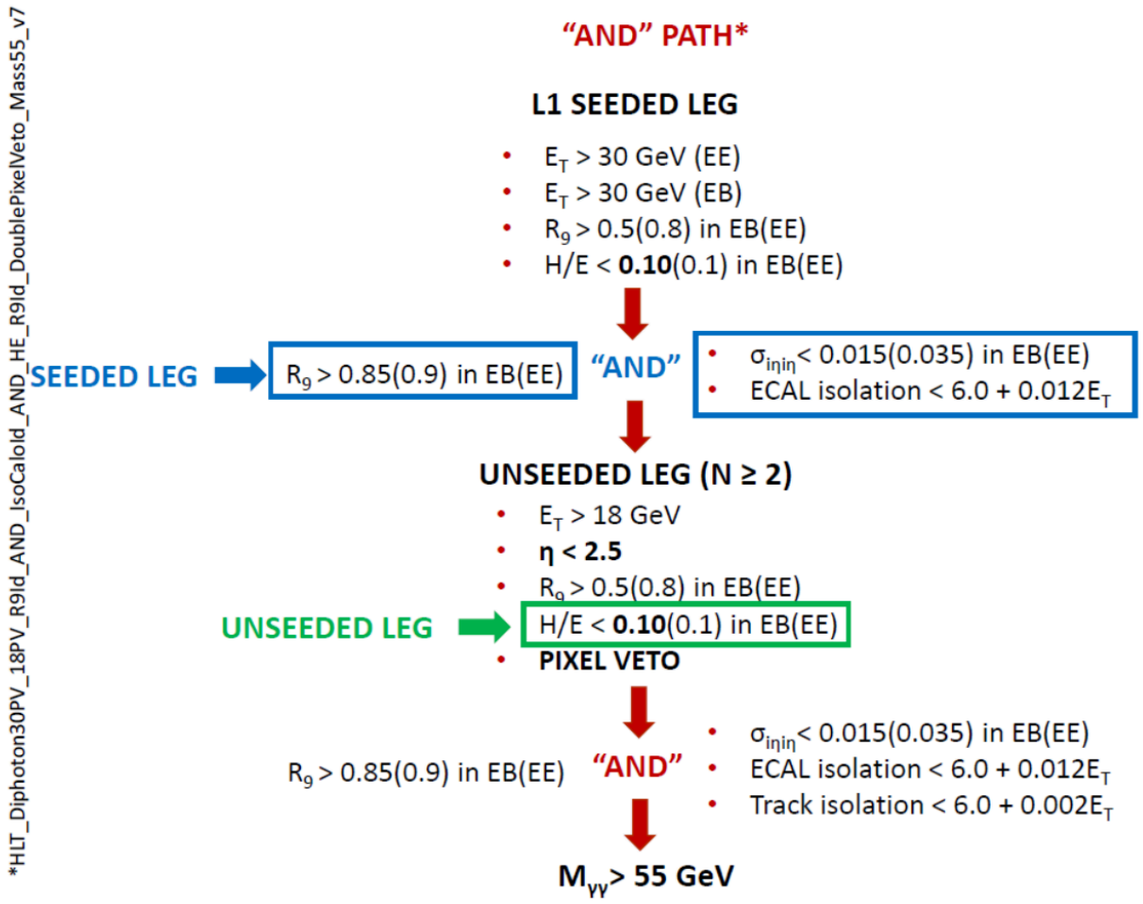
- To Do Next
  - Trigger and pre-selection scale factors for the 4γ category to have this category of the analysis completed
  - For the 3γ category
    - Reco-gen matching to differentiate between the case of 2 Isolated + 2 merged γ's from the 3 Isolated γ's + 1 missing γ (due to P_T or η cut) case

BACKUP

The Low-Mass HLT DiPhoton Trigge



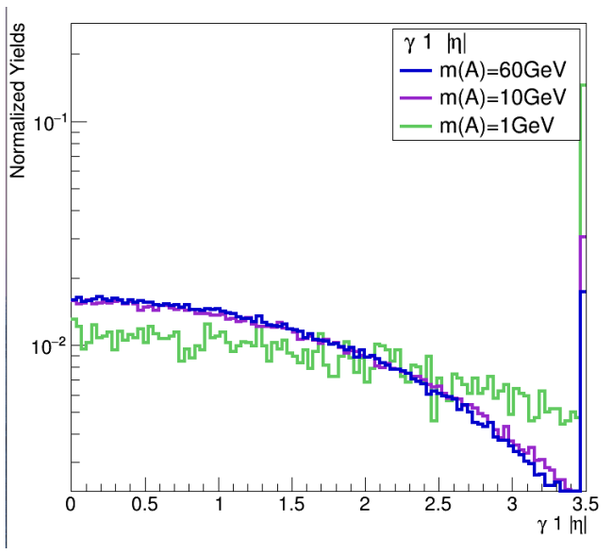
The Low-Mass HLT DiPhoton Trigger

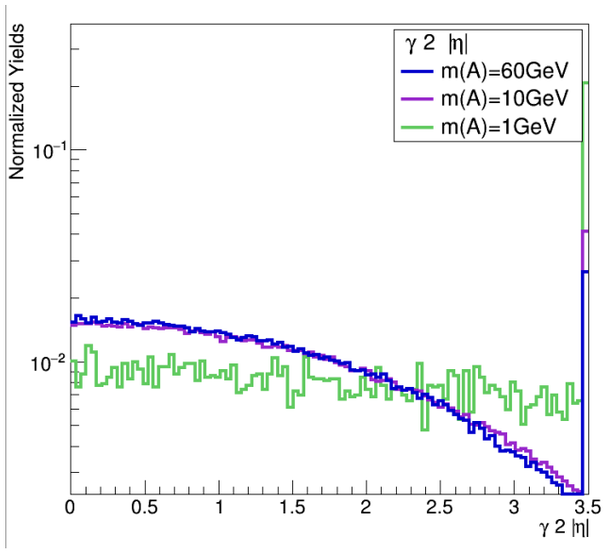


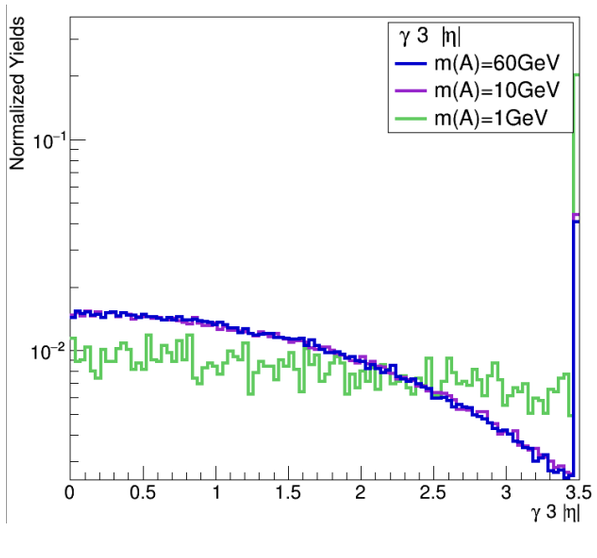
GEN LEVEL DISTRIBUTIONS

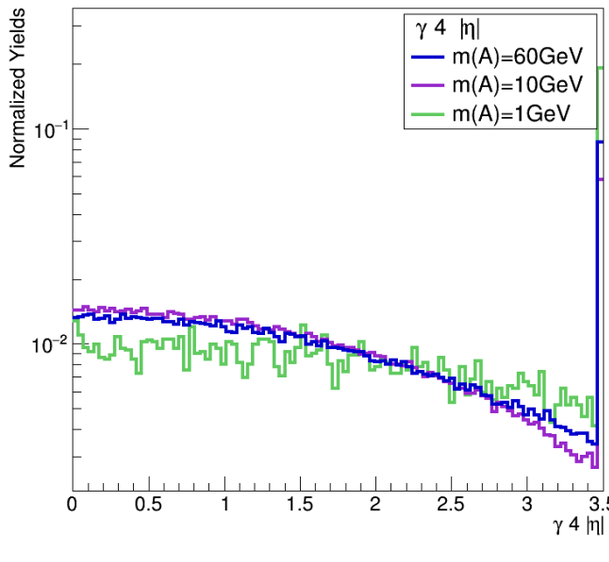
- Shown in the following slides are the distributions for 60 GeV, 10 GeV and 1 GeV
- All plots are normalized to 1
- Overflow bin is also shown

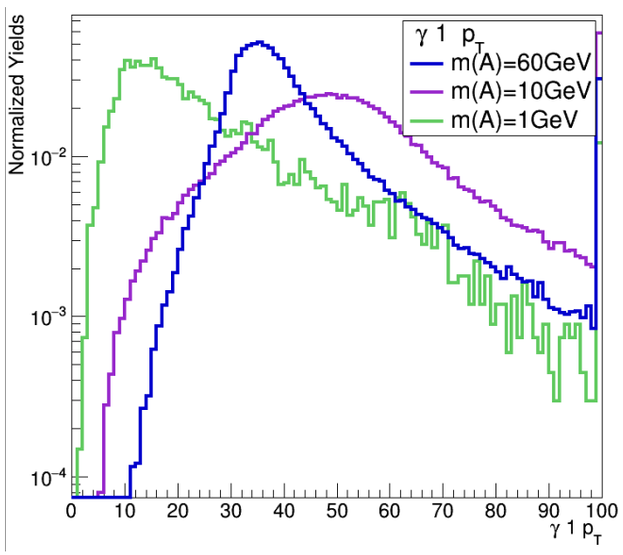
4 Gamma Category : 4 Isolated photon case

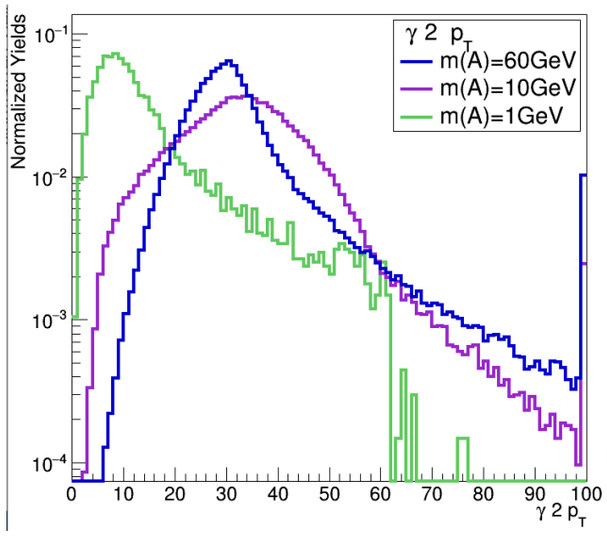


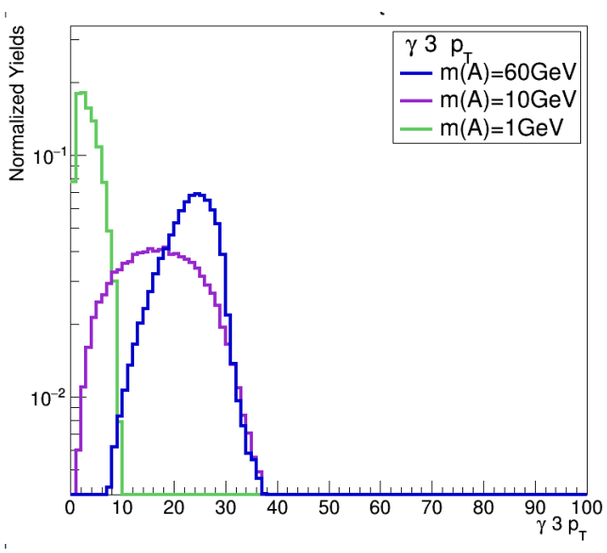


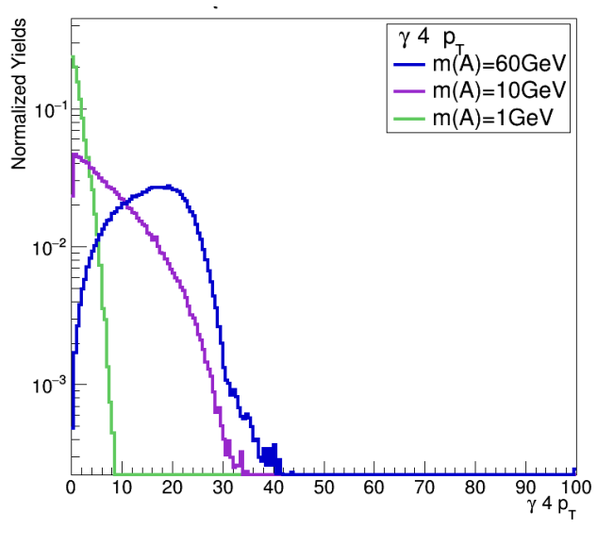






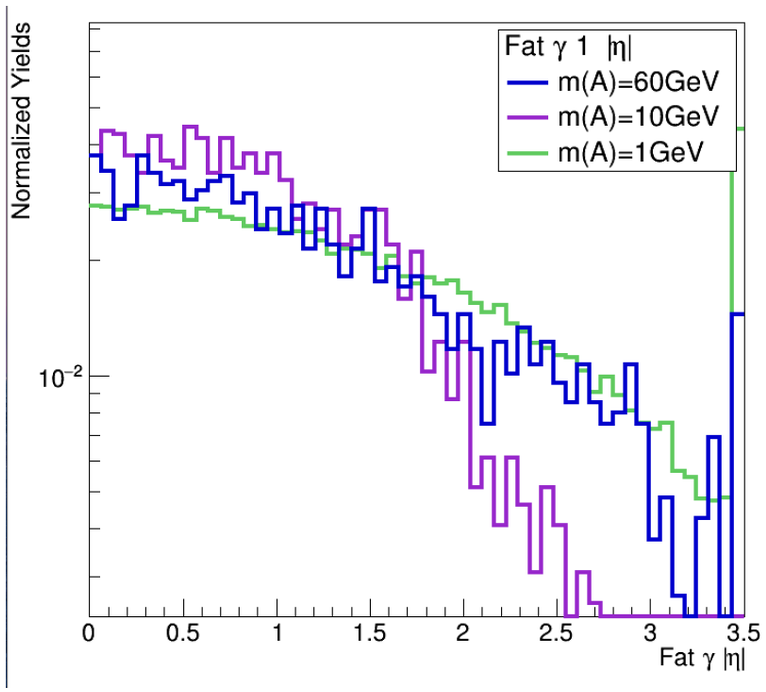


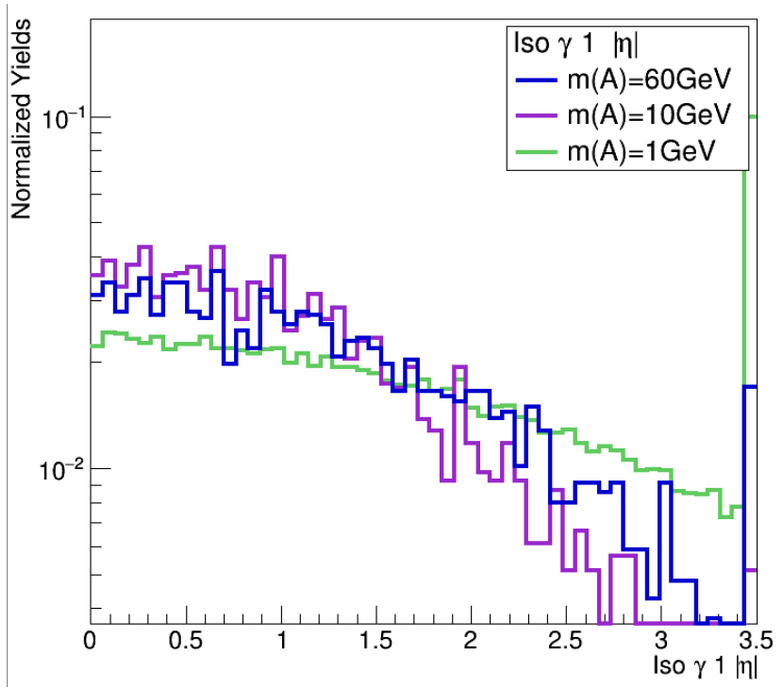


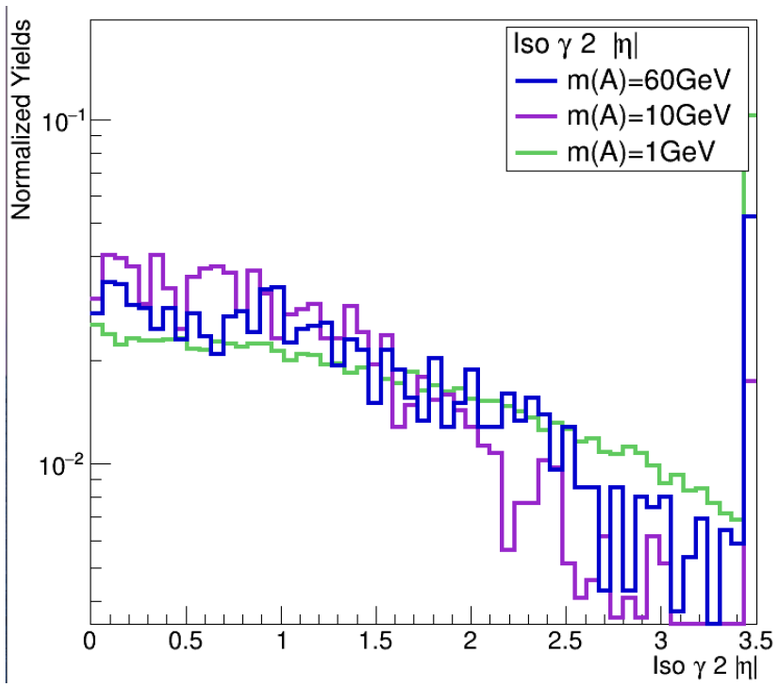


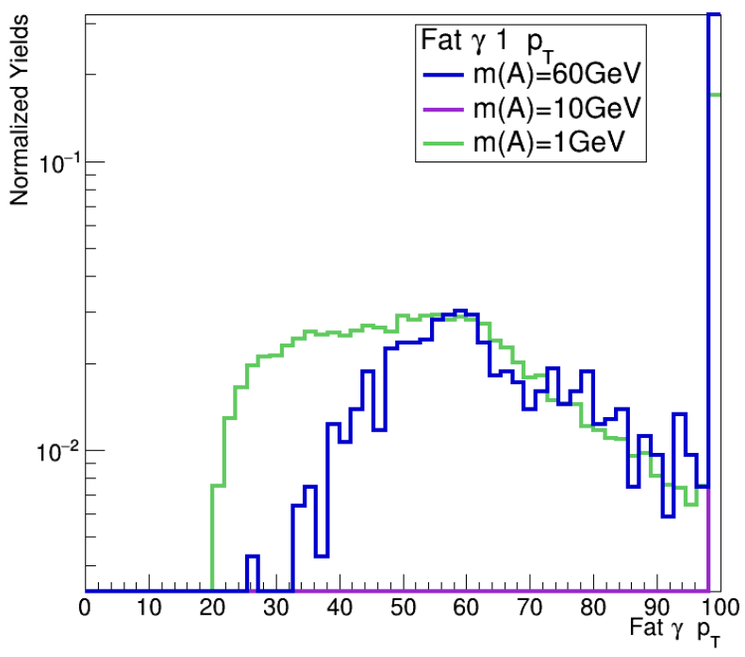
GEN LEVEL DISTRIBUTIONS

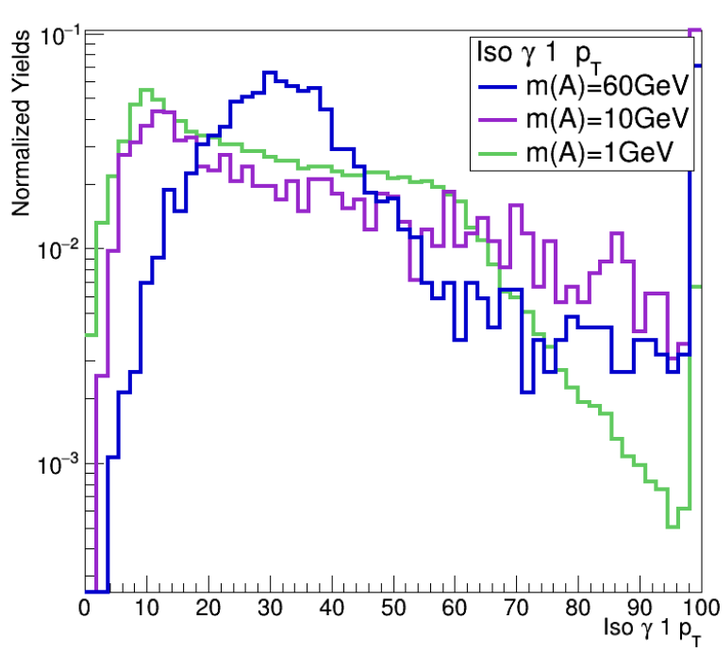
3 Gamma Category : 2 Isolated photons + 2 merged photons case

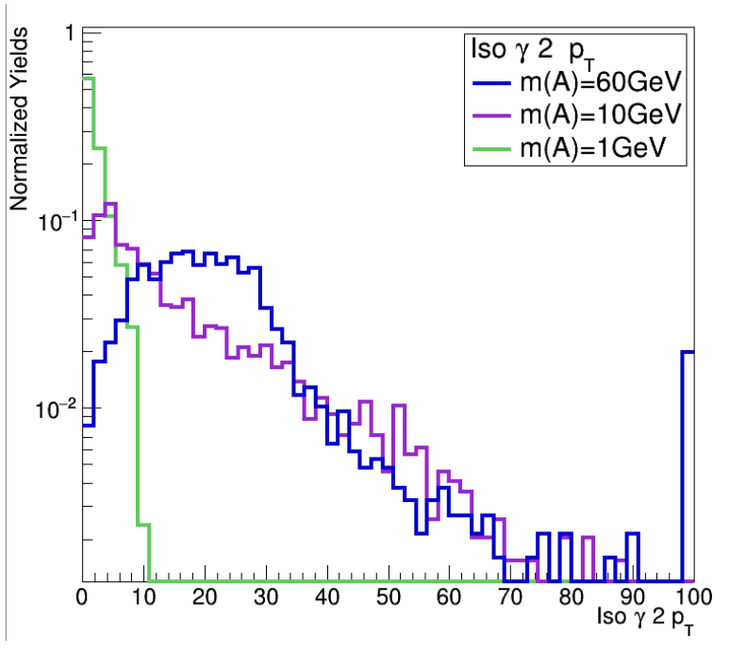






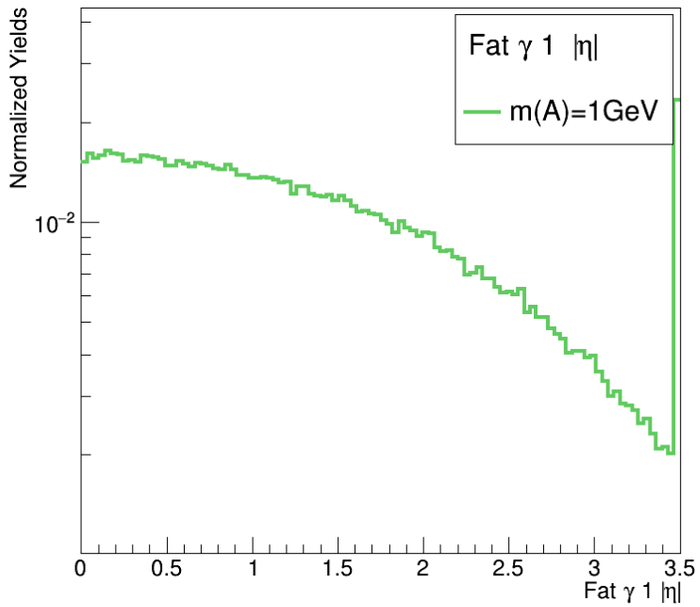


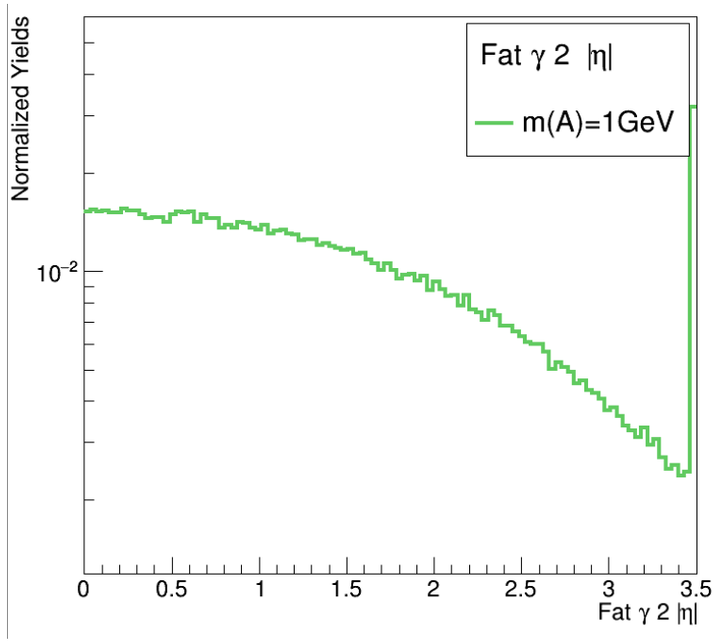


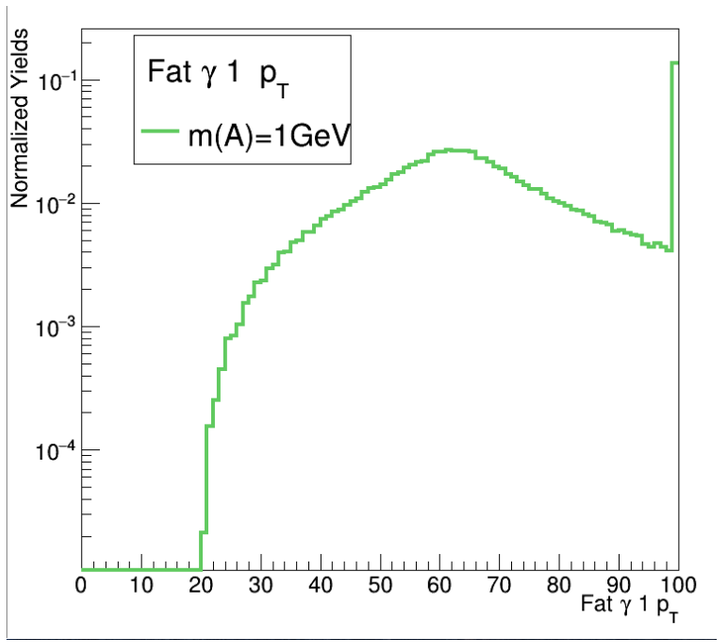


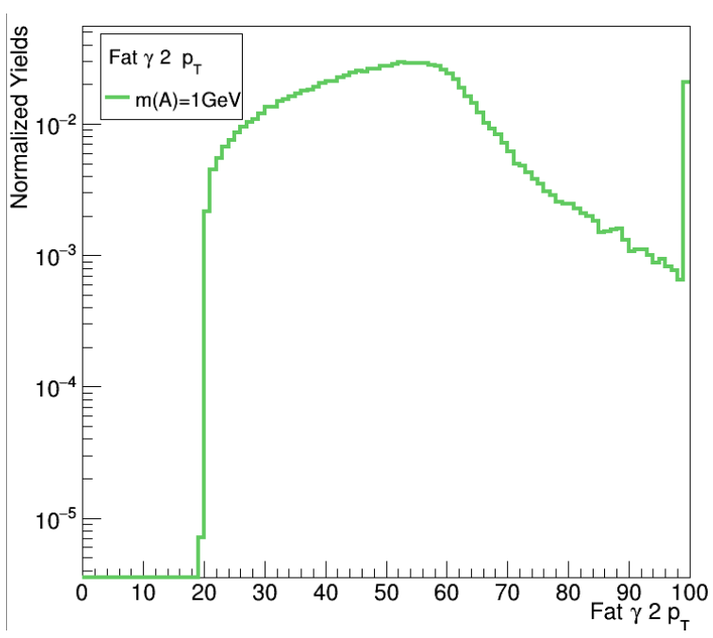
GEN LEVEL DISTRIBUTIONS

2 Gamma Category : 2 pairs of merged photons case









RECO LEVEL DISTRIBUTIONS