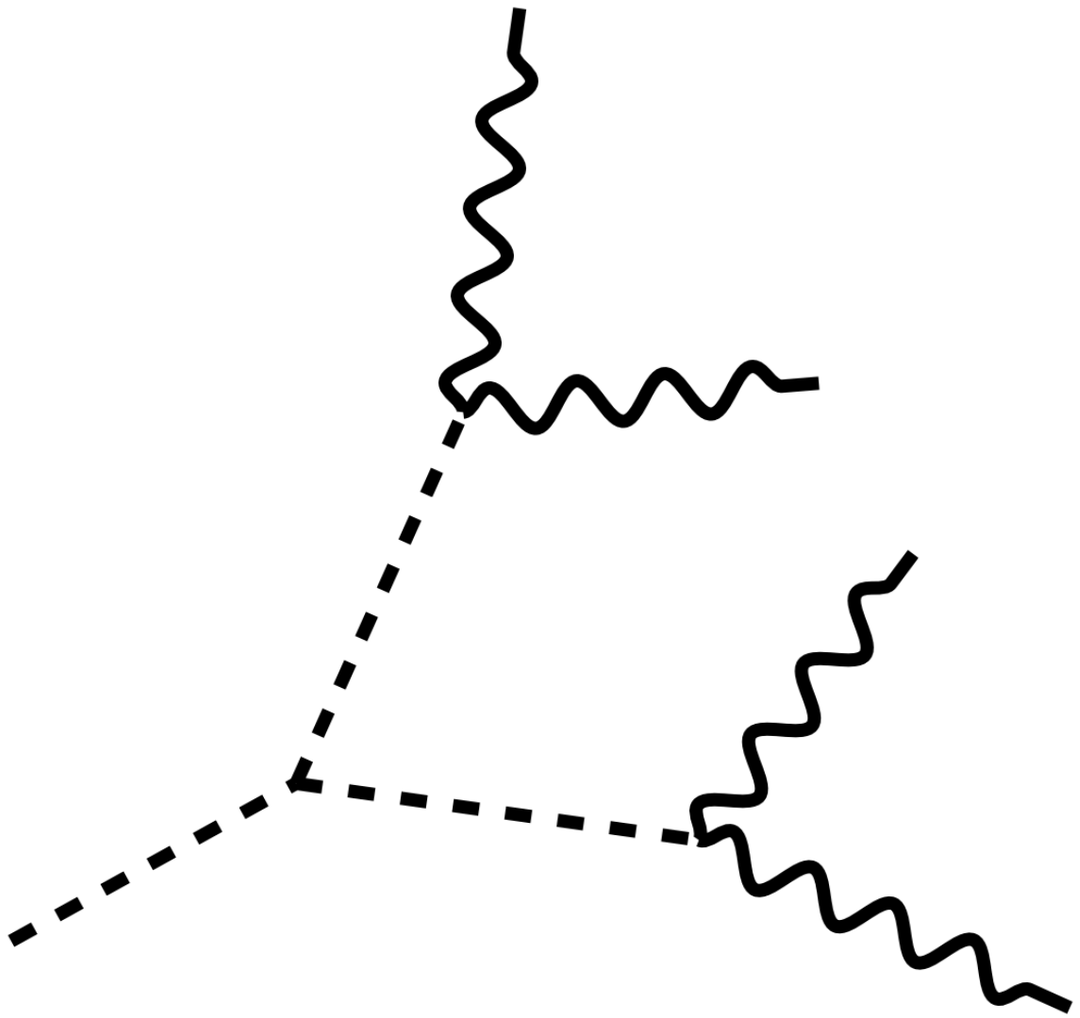

Higgs Exotic Workshop

h(125)→aa→γγγγ

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19th October 2017

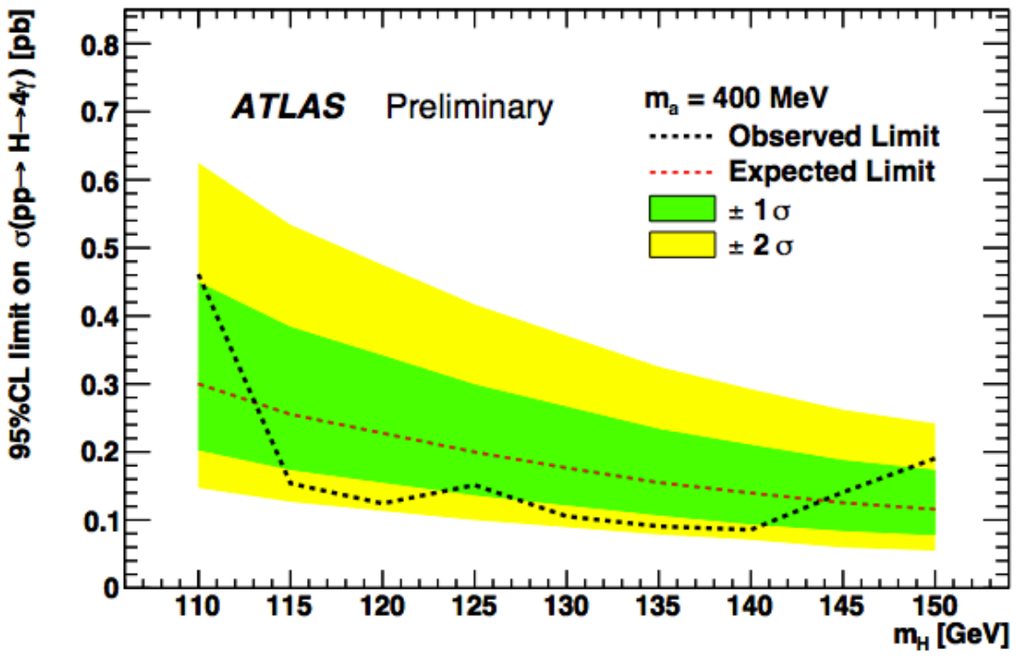
4γ IN A NUTSHELL h(125)→aa→γγγγ

The possibility of light scalars is a very well established scenario

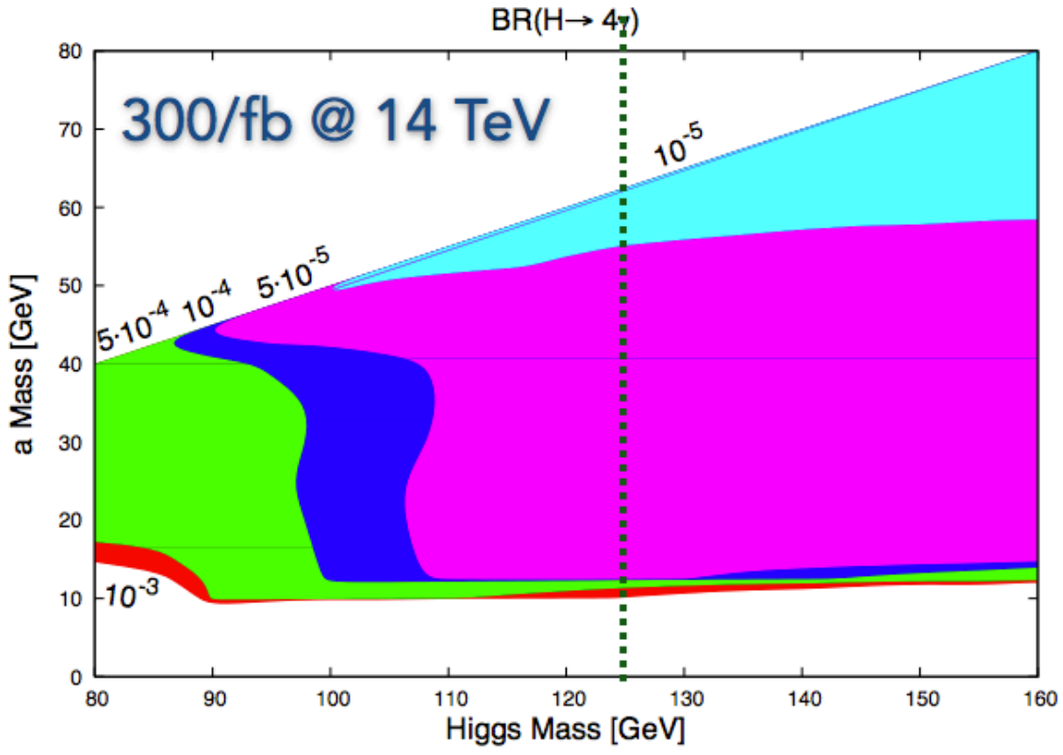
- **The usual suspects (N)MSSM, SM +Singlet ,etc have a subdominant BR (a -> γγ)**
  - Non trivial extensions can suppress a -> fermions
  - The 4γ final state is SM background free and we take advantage of the high online/offline reconstruction + identification efficiency

- The existing studies show sensitivity for discovery down to Br(h(125)→aa→γγγγ) ~ 10^{-5} for 300/fb@14TeV [hep-ph/0608310]

- Existing study from ATLAS - h→γγ analysis reinterpreted as h→aa→4γ search with M(a) < 1 GeV (collimated photons) (only 7 TeV data) [ATLAS-CONF-2012-079]



(c) $m_a = 400$ MeV



SAMPLES BEING USED

DATA:

- Double EG re-Mini AOD dataset
- Corresponds to 35.87 fb^{-1} for 2016

Signal MC:

- Generated using PYTHIA 8
- Officially produced Summer16 samples - DAS Link
- m(a) = 0.1 GeV and 1GeV - 60 GeV in steps of 5 GeV

Background:

- **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

ANALYSIS STRATEGY

All Events → Pre - Selection → Selection based on γ -ID → Trigger Selection → Final 4 γ

Pre -Selection

- At least 4γ with E_T > 15 GeV and |η| < 2.5 - **Good γ's**

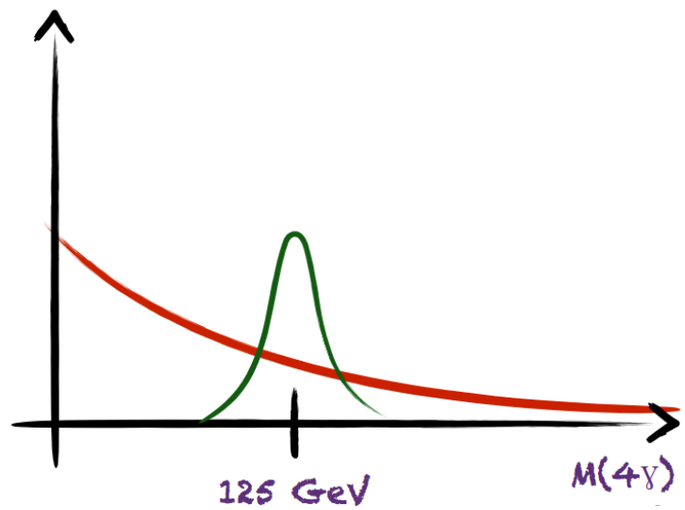
γ-ID Selection

- At least 4 good γ's that pass the Hgg MVA ID requirement
- Good Signal Efficiency
- photonIDMVA > -0.9 for both EB and EE : eliminates a significant fraction of non prompt photons + conserves ~99% efficiency for prompt photons

Trigger Selection

Choose 2 γ 's that pass trigger requirements + 2 other ID-ed γ 's ordered in Et

- Low Mass Diphoton Triggers
- Trigger Paths: One for γγ in EBEB, one for !EBEB
  - HLT_Diphoton30EB_18EB_R9Id_OR_IsoCaloId_AND_HE_R9Id_DoublePixelVeto_Mass55
  - HLT_Diphoton30_18_R9Id_AND_IsoCaloId_AND_HE10p0_R9Id_DoublePixelVeto_Mass55



- **Signal extraction to be done by means of Parametric fit to the M(4γ) distribution**

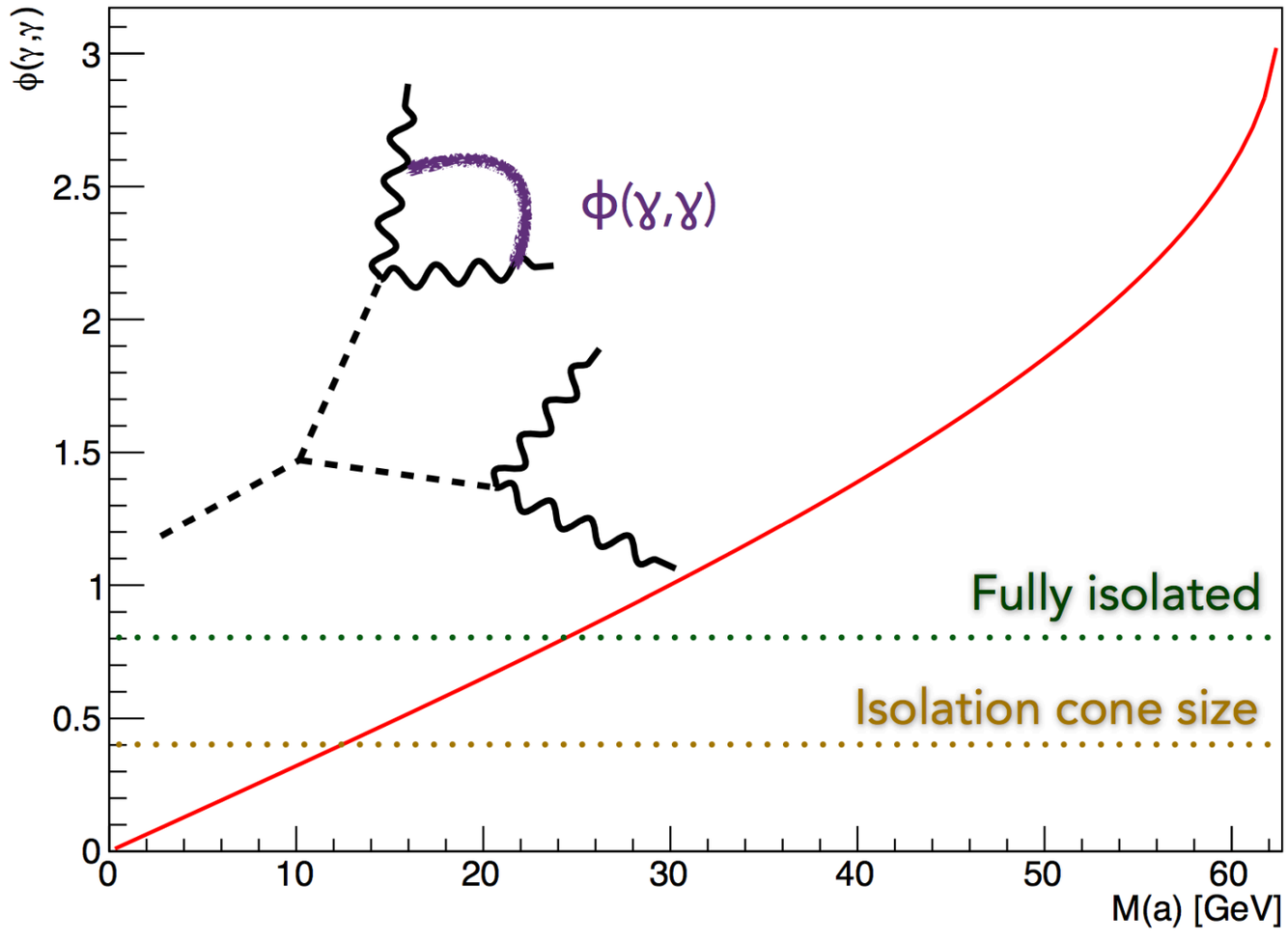
KINEMATIC ANATOMY

- **Low Mass: M(a) < ~ 10GeV** — Merged Photons
- **Medium Mass: ~10GeV < M(a) < 25 GeV** — Isolation problems are possible
- **High Mass: M(a) > 25GeV** — Photons are expected to be well isolated

- First want to investigate the 4γ final state :require 4 well isolated and identified photons
- Also investigate events with 3 and 2 γ's to study the medium and low mass samples

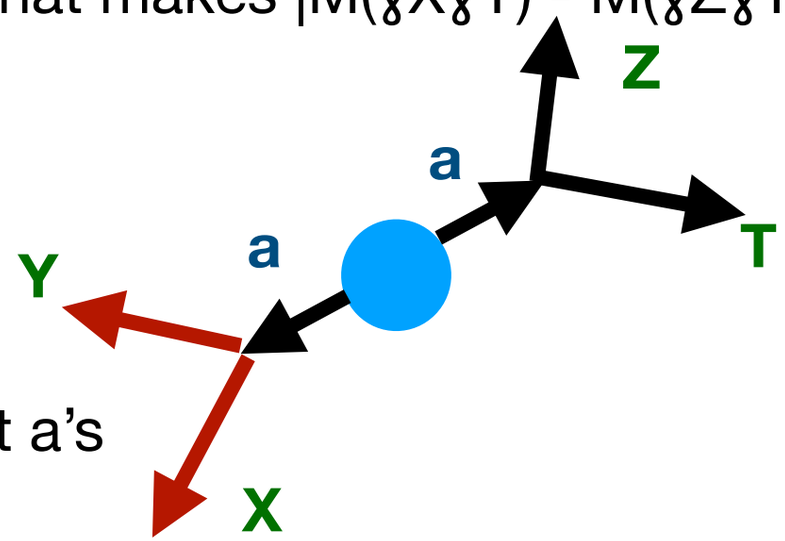
Φ: Angle between photons coming from the same "a"

Assuming "h" at rest and decay to be on the transverse plane

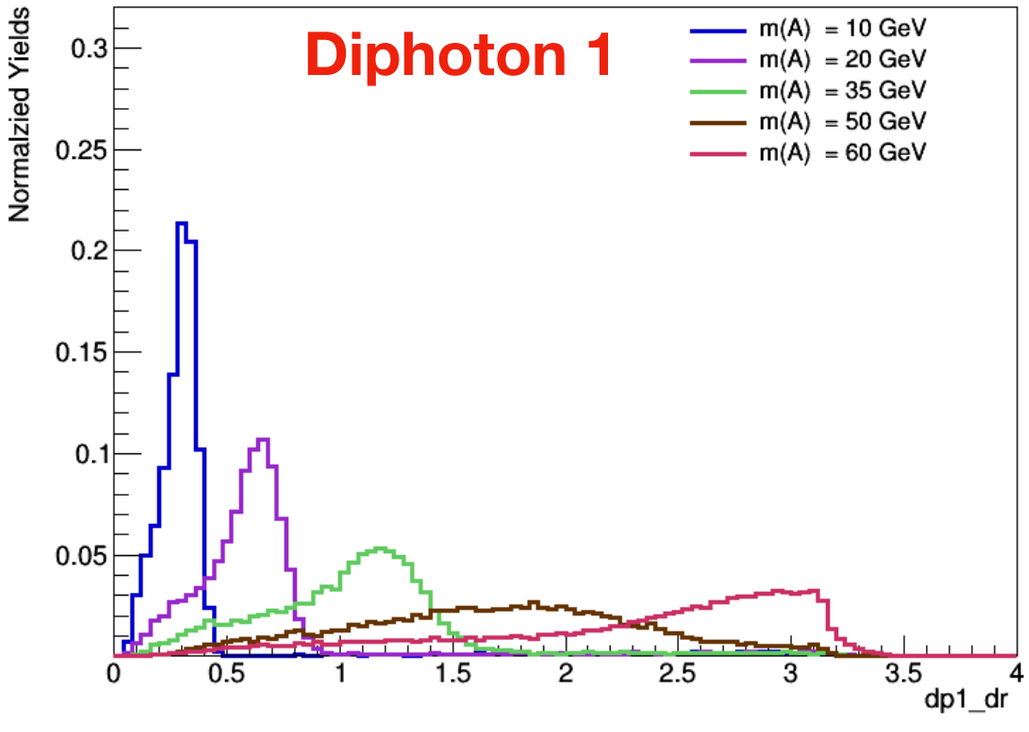


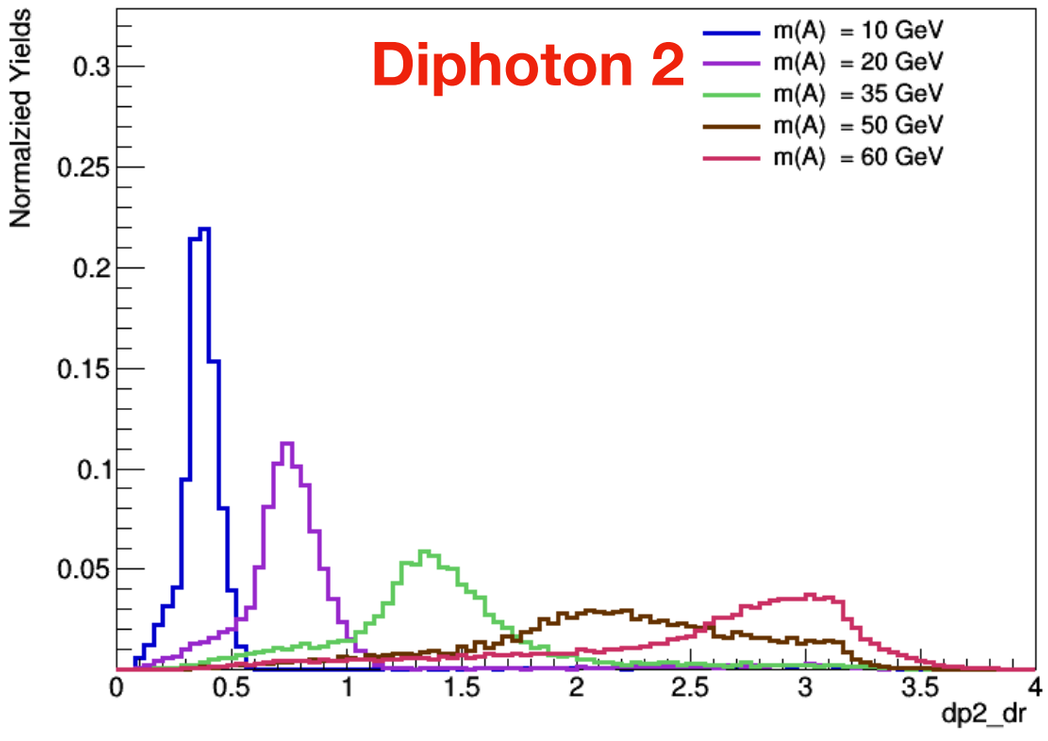
KINEMATIC ANATOMY (2)

- Selecting events with at least 4γ's with min(ΔR)>0.1 and highest E_T
- Arrange the 4 photons into pairs and pick the pair that makes |M(γXγY) - M(γZγT)| minimal order diphoton pairs by sum of photons E_T
- As expected, for M(a) < 20 GeV :
  ΔR(γγ) for same "a" < 0.4
- For high M(a) there are overlaps from γ's of different a's



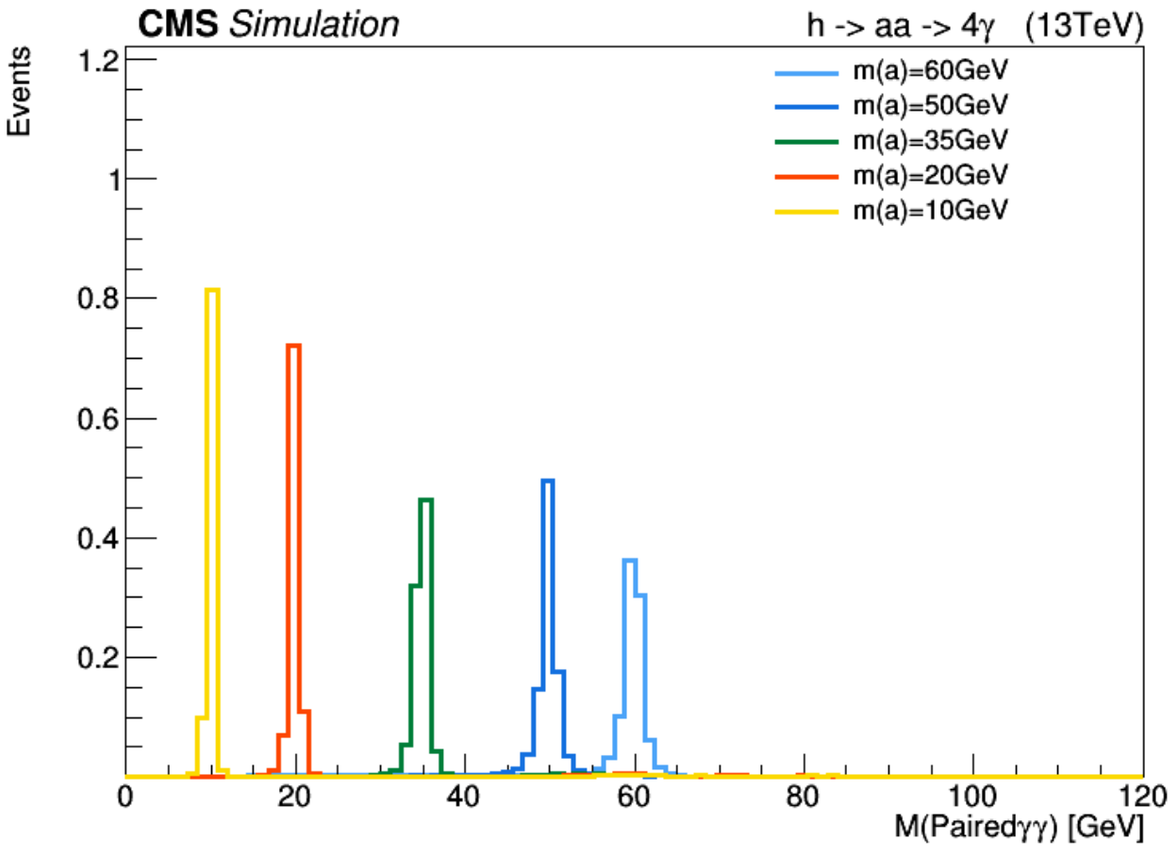
- Since we require at least 4 isolated photons, this is a cause of reduction in signal efficiency for M(a) < 20 GeV

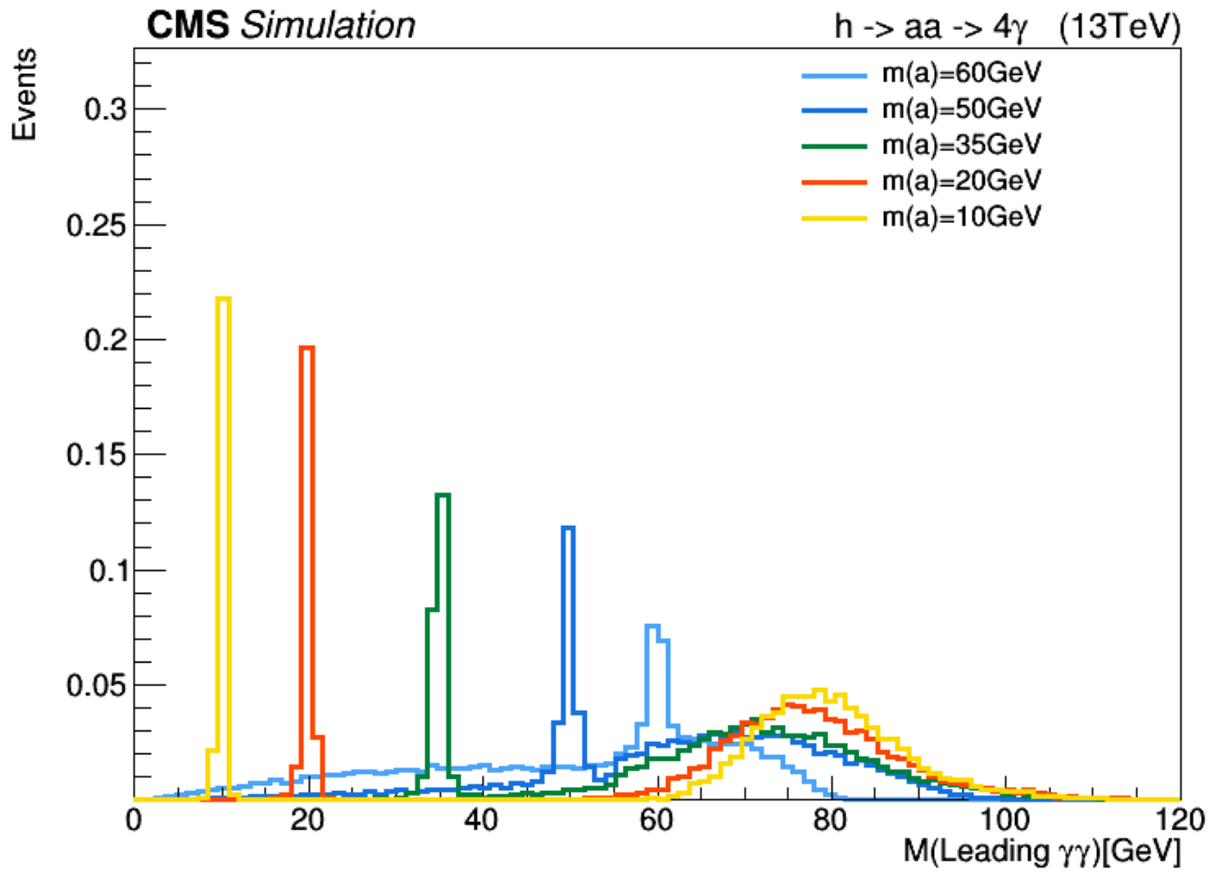




PHOTON PAIRING

- The |M(ɣXɣY) - M(ɣZɣT)| minimizer pairing provides good M(γγ) resolution



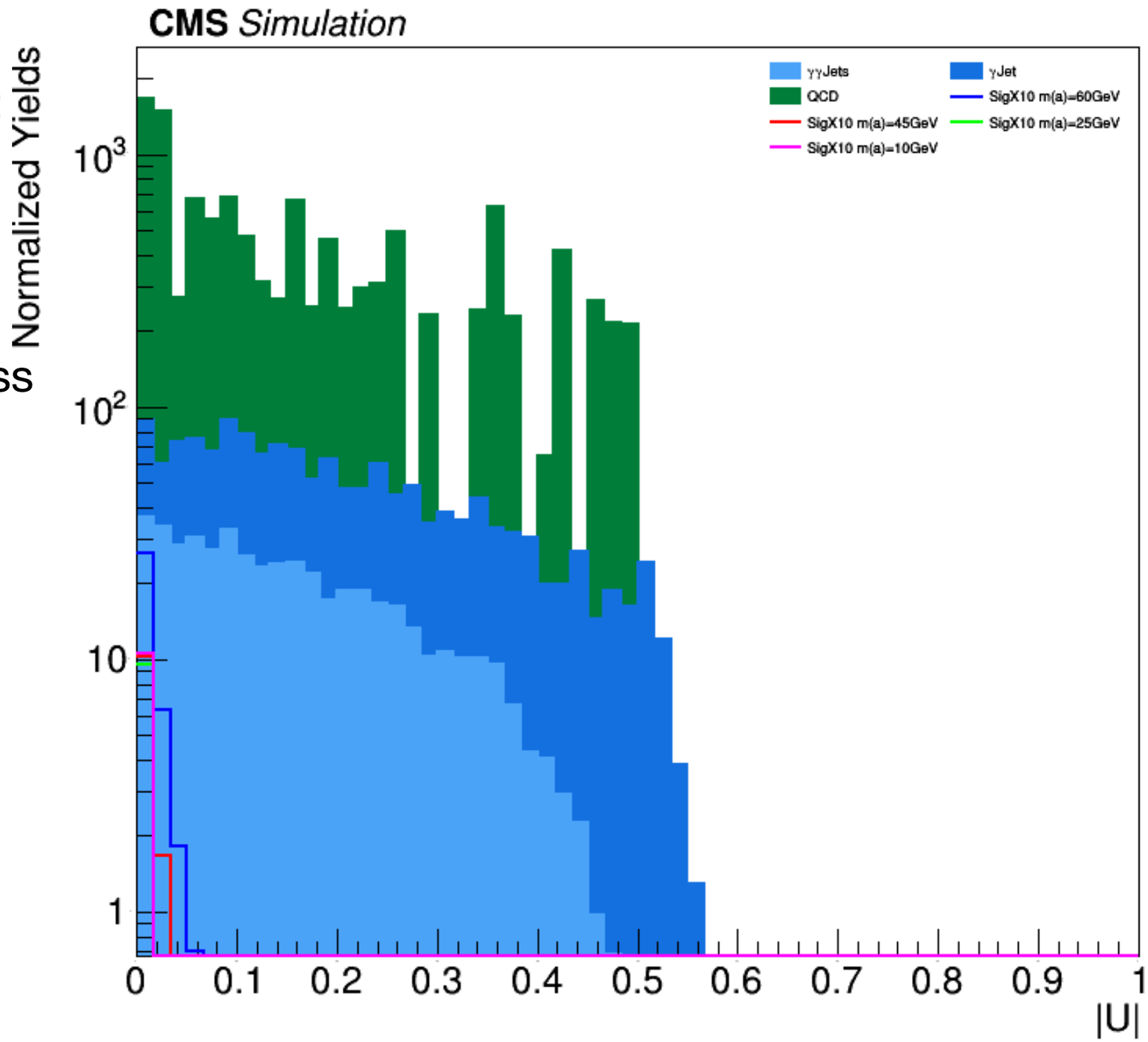


PHOTON PAIRING (2)

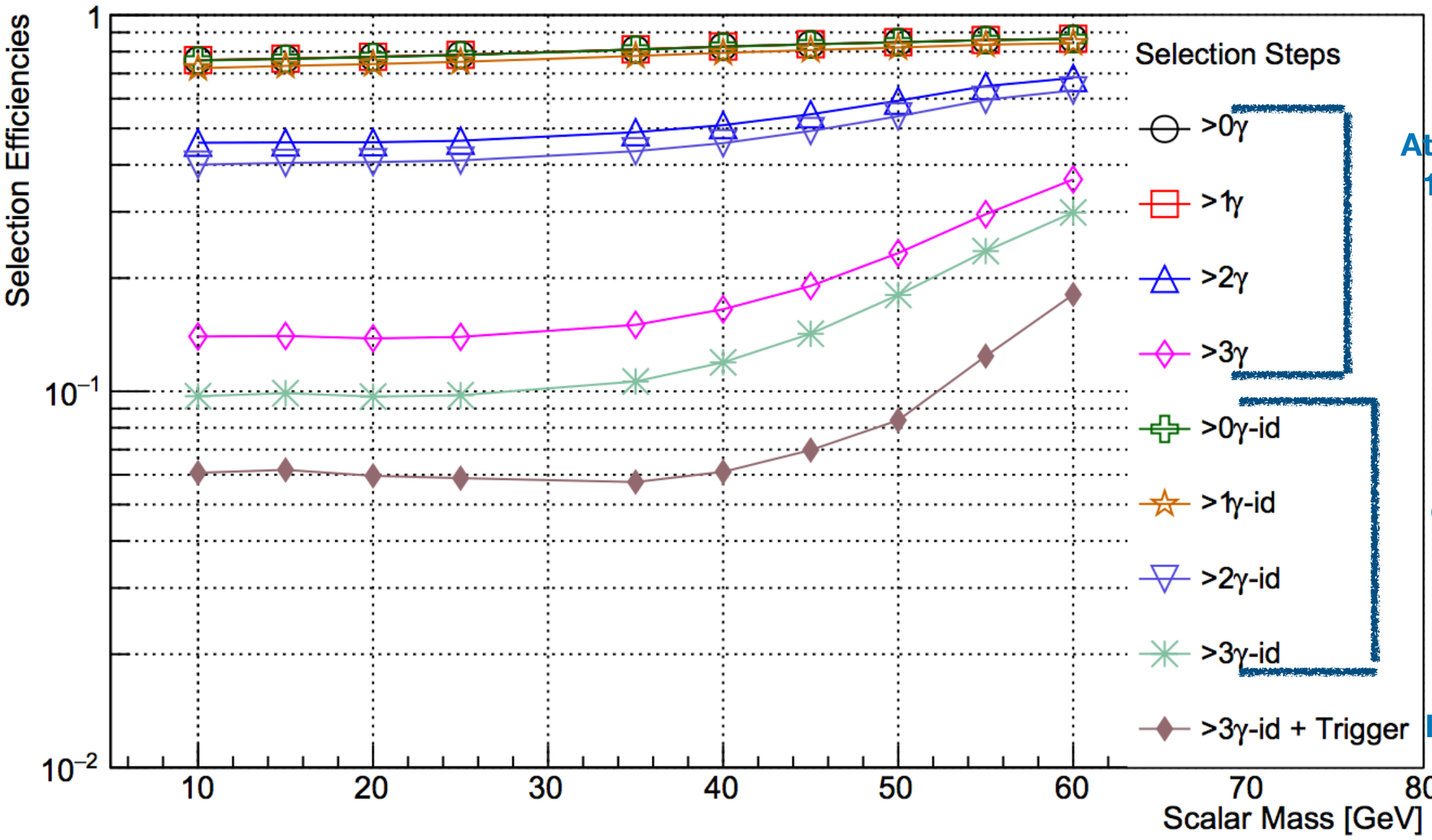
- With the photon pairing we expect:
  - For signal diphotons, Mass difference ~0
  - For background diphotons, Mass difference > 0

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

- Can be used as a **handle on S/B**



SIGNAL EFFICIENCIES



At least N γ's with Et > 15 GeV and |η| < 2.5

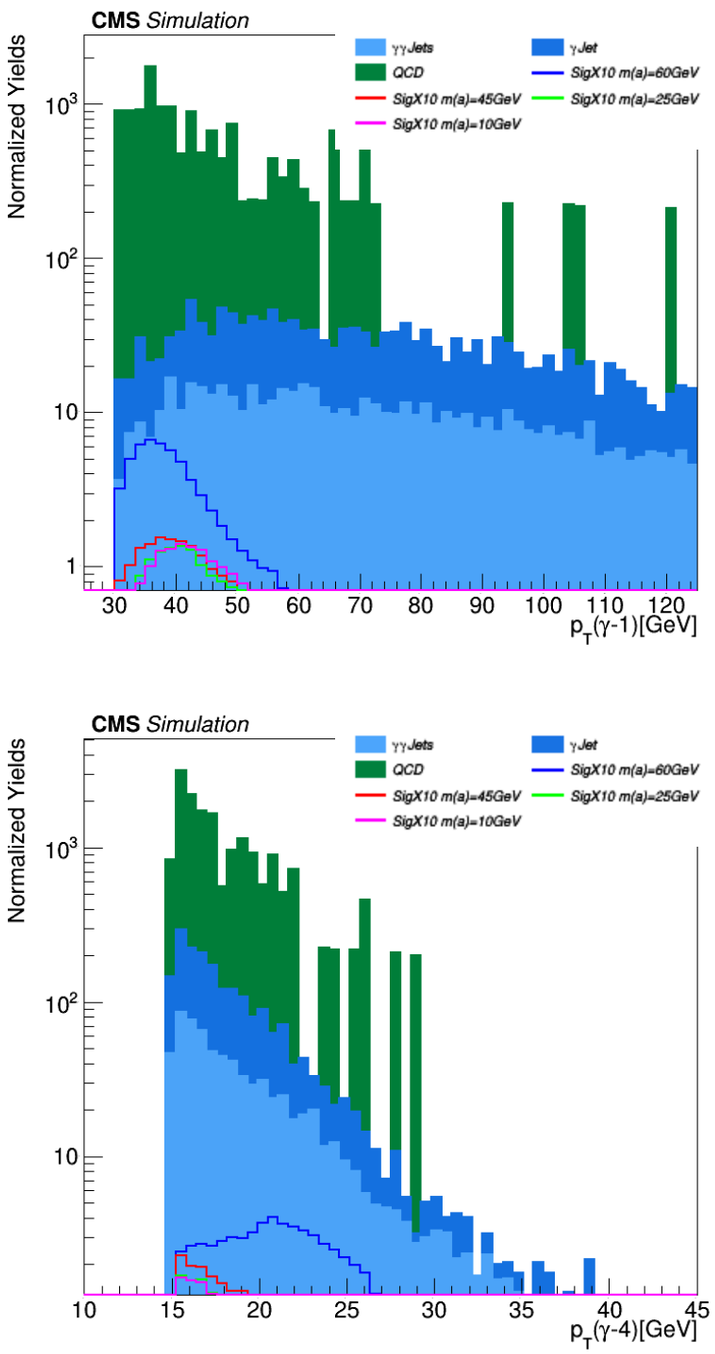
Good γ's

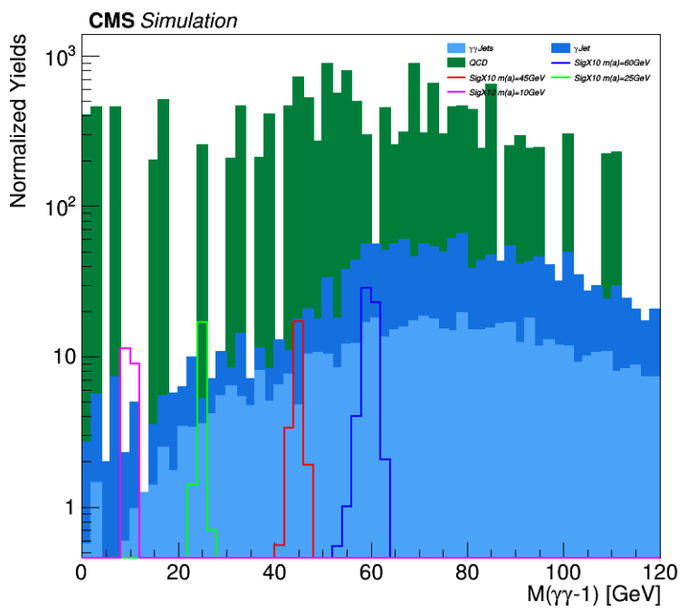
Good γ's + Photon MVA requirement

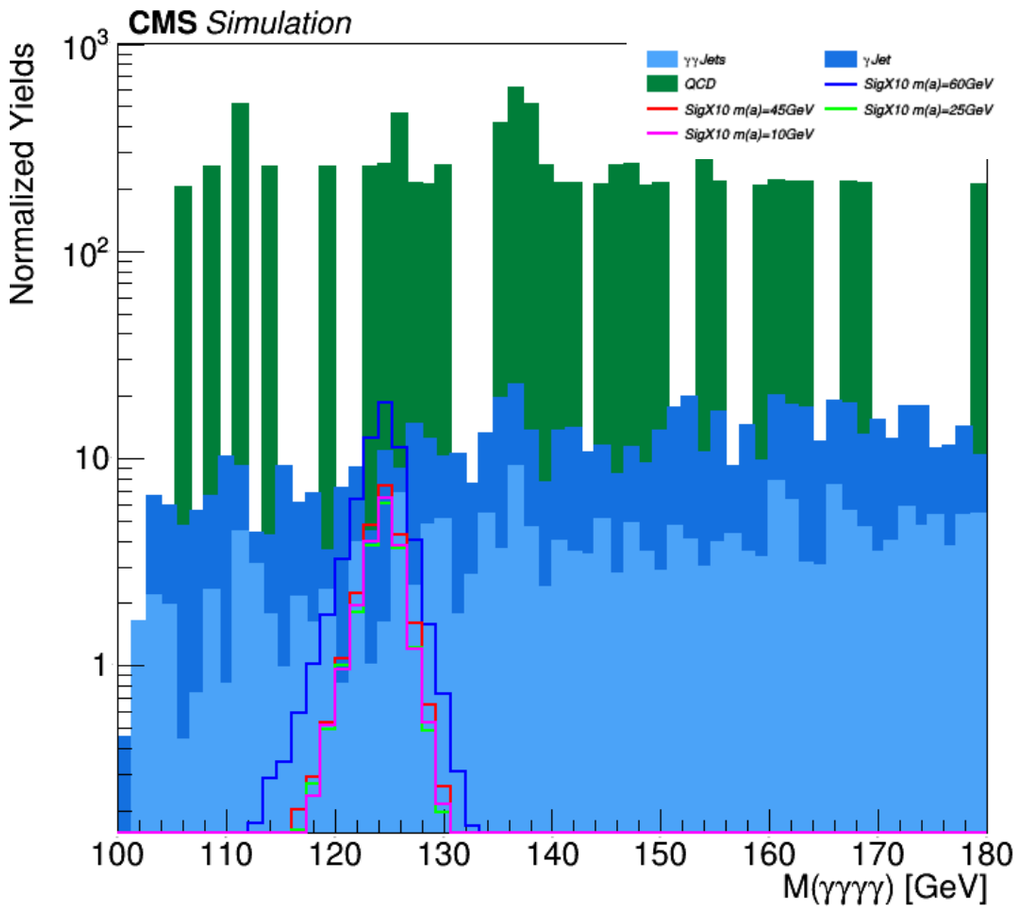
ID'ed 4γ's + Trigger

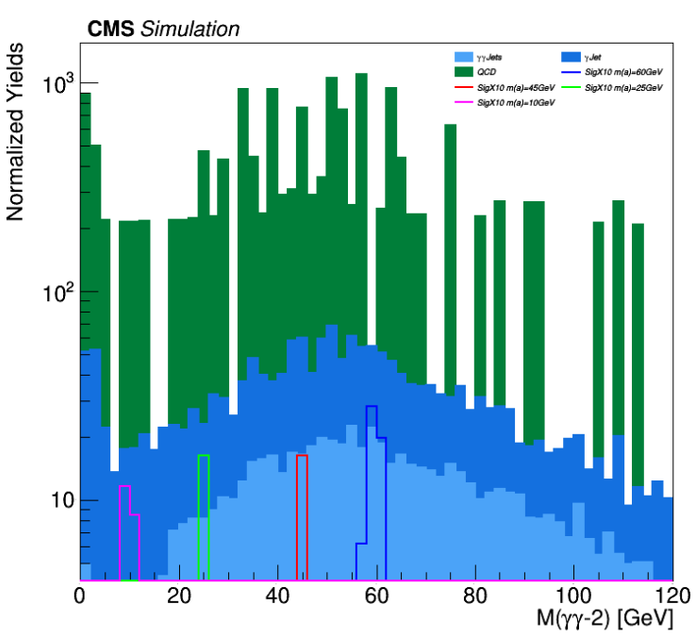
PLOTS AFTER SELECTION

Plots showing QCD, Diphoton Jets and GJets Background MC with Signal MC (scaled to 1 1pb) - Both in Signal region







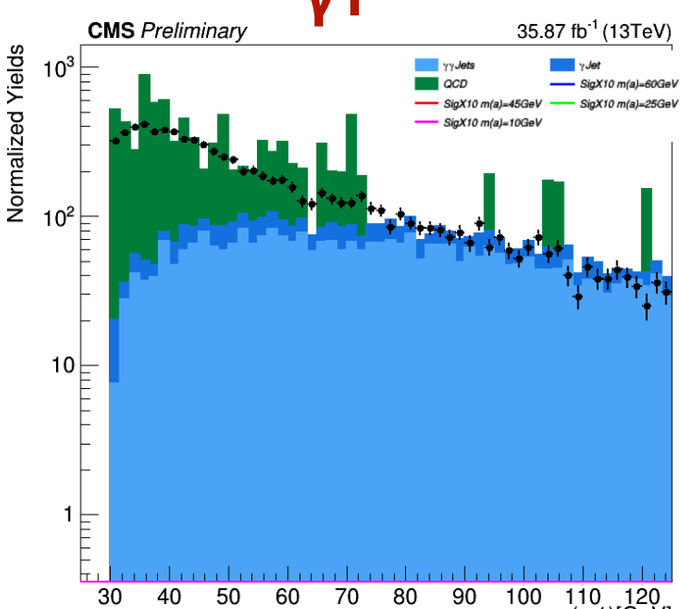


m(a) : 60,45,25 and 10 GeV

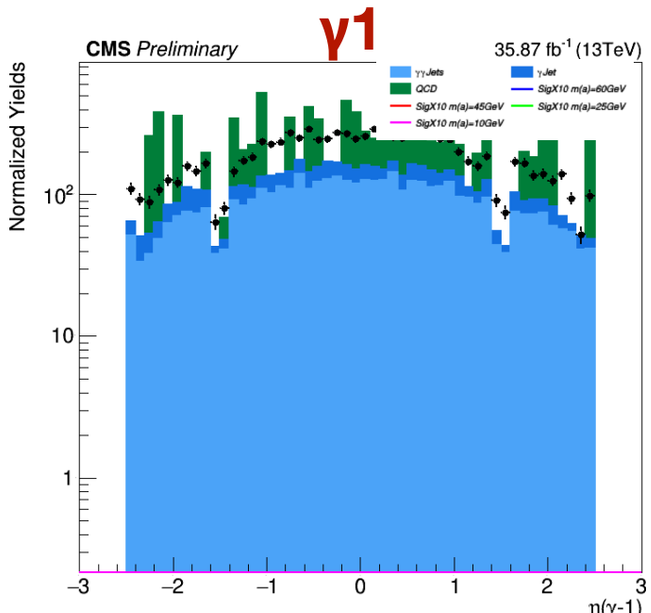
SIGNAL REGION PLOTS

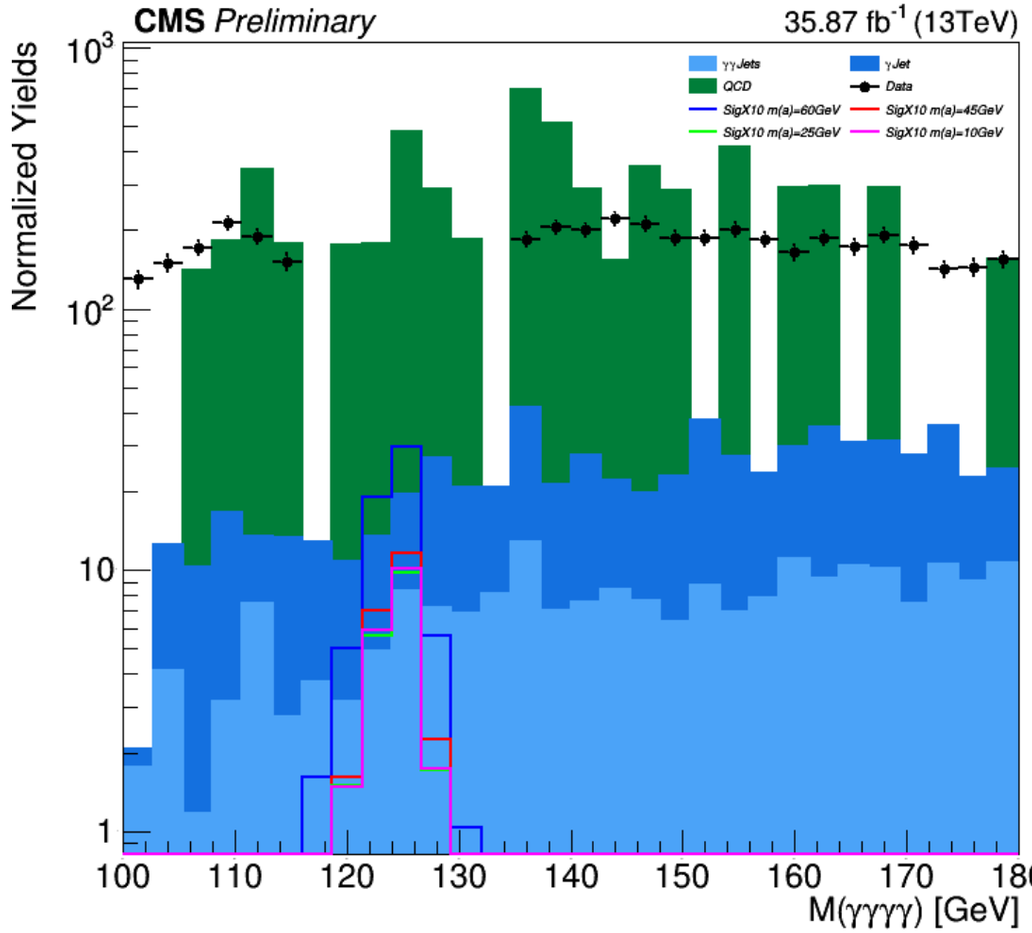
Blinding region: 115 < M(γγγγ) < 130 GeV

γ1

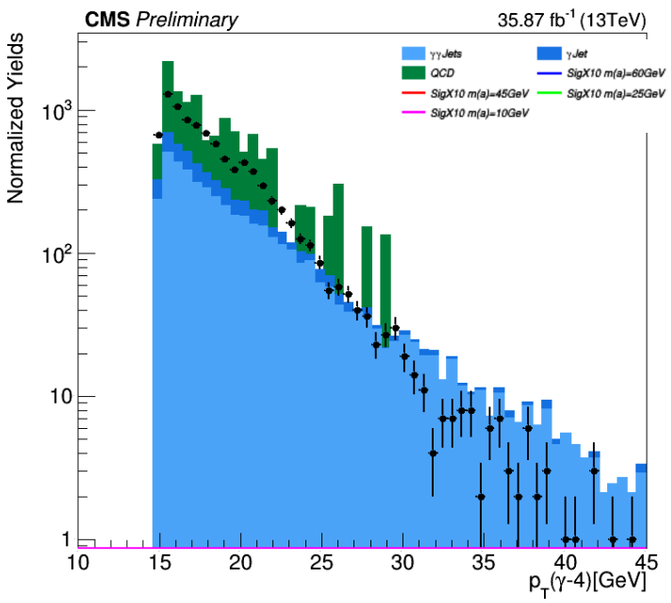


γ1

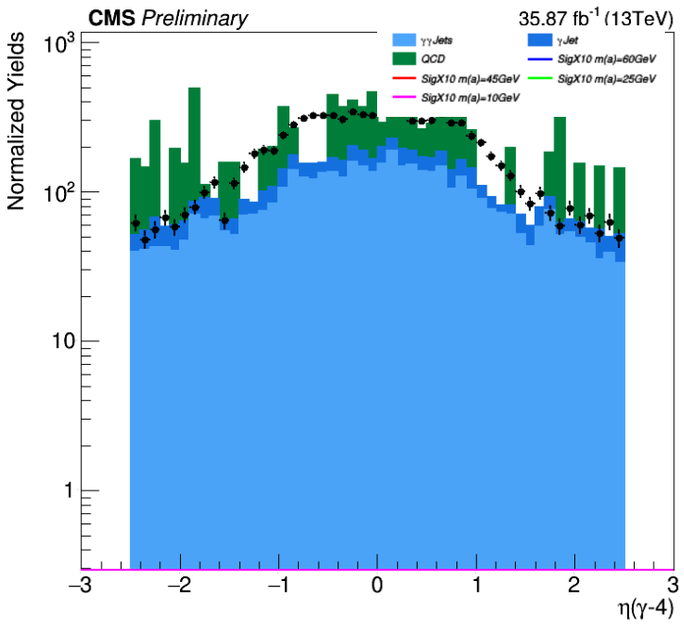




γ4



γ4



m(a) : 60,45,25 and 10 GeV

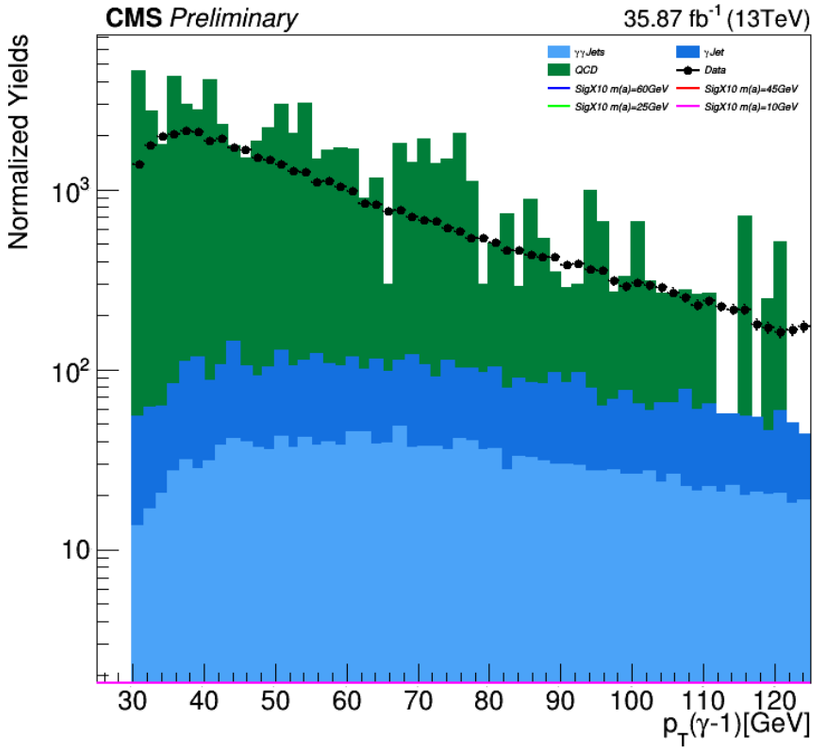
Caveat : Trigger SF's and Efficiencies are not applied to MC yet

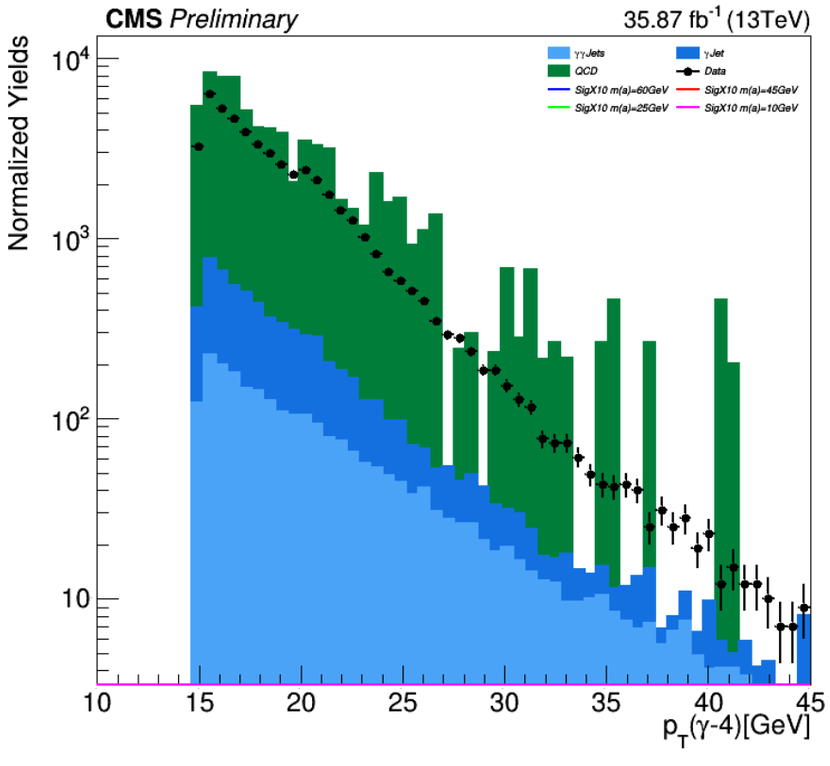
The cause of mismatch between MC and Data

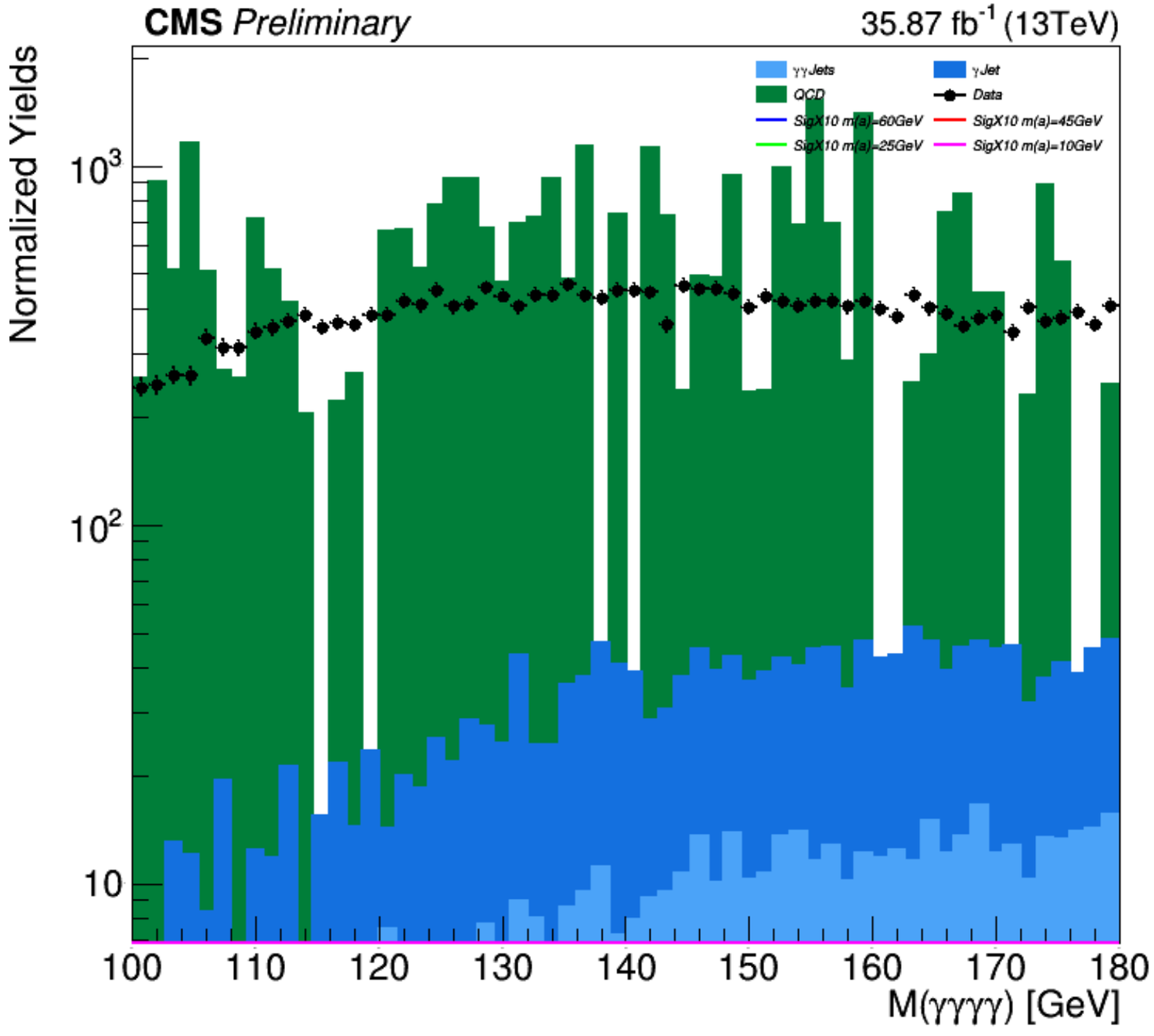
Background MC will just be used to validate simulation of signal and to develop the analysis

CONTROL REGION PLOTS

Events with 3 good γ's that pass and 1 good γ that fails PhotonMVA ID



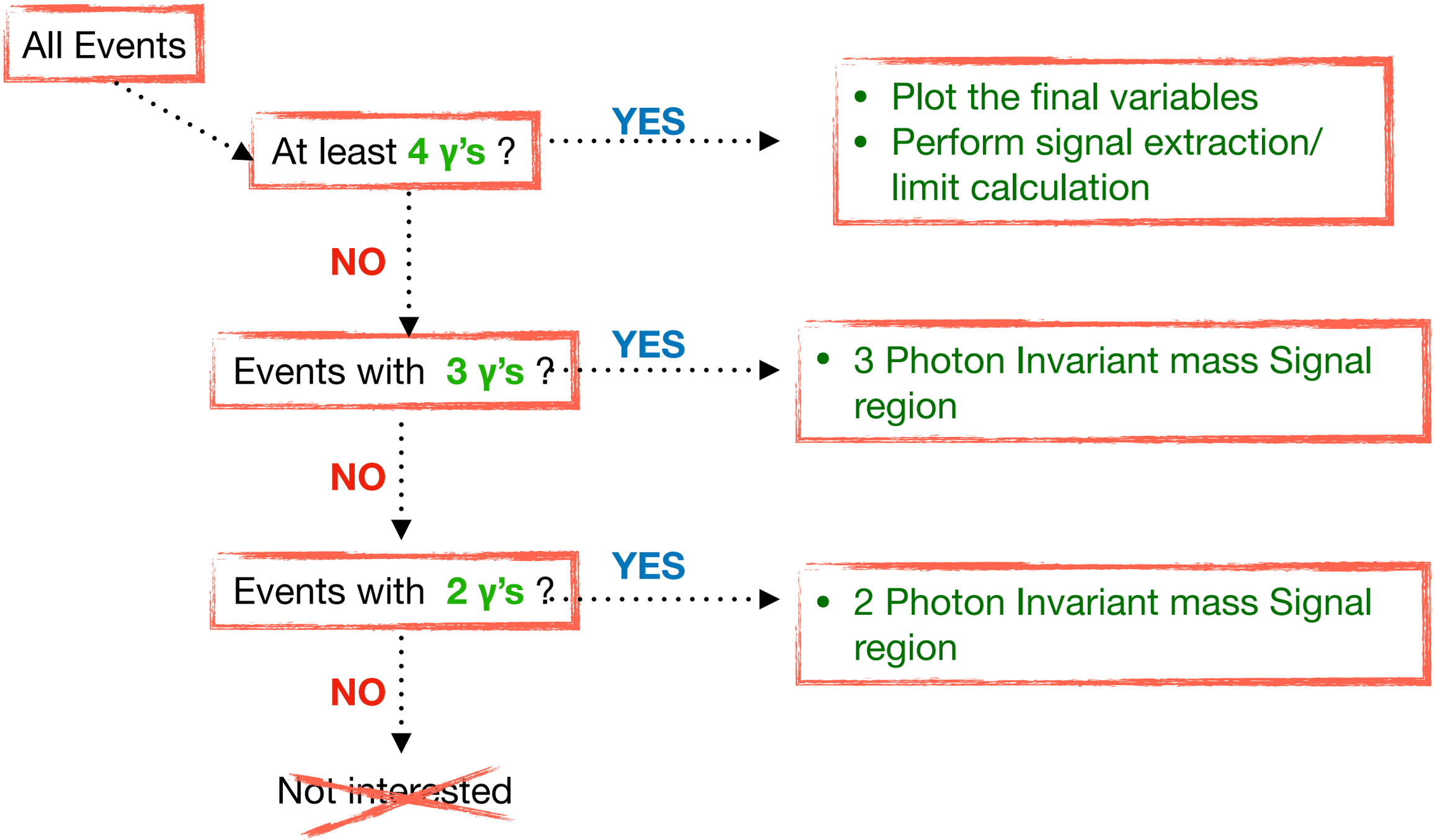




m(a) : 60,45,25 and 10 GeV

CATEGORIZATION STRATEGY

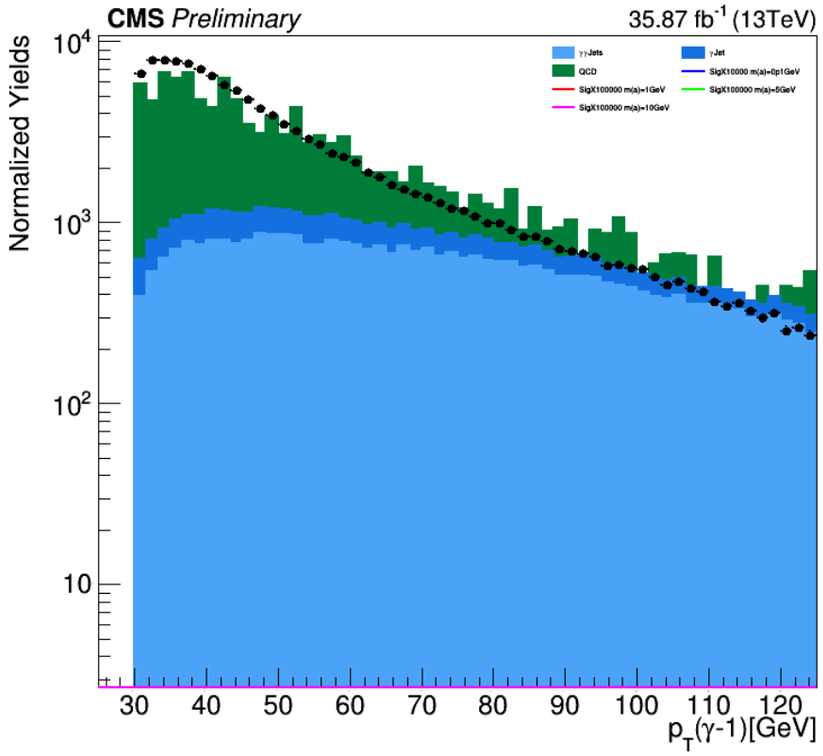
- For low mass “a”, two γ’s could be merged enough to mimic a single γ
- In that case our current requirement of at least 4 γ is not efficient

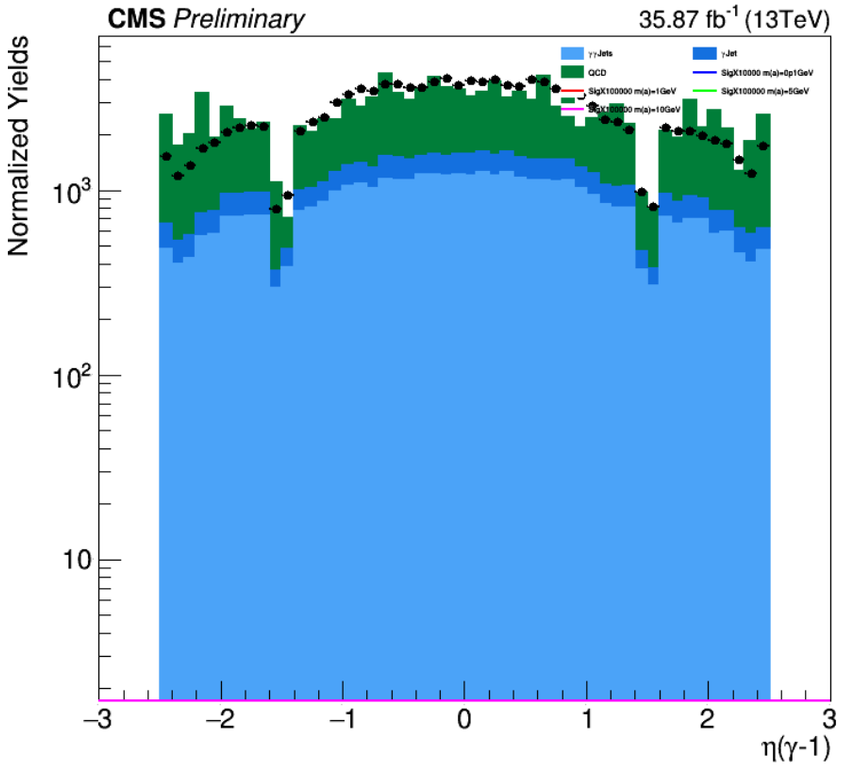


3 PHOTON CATEGORY

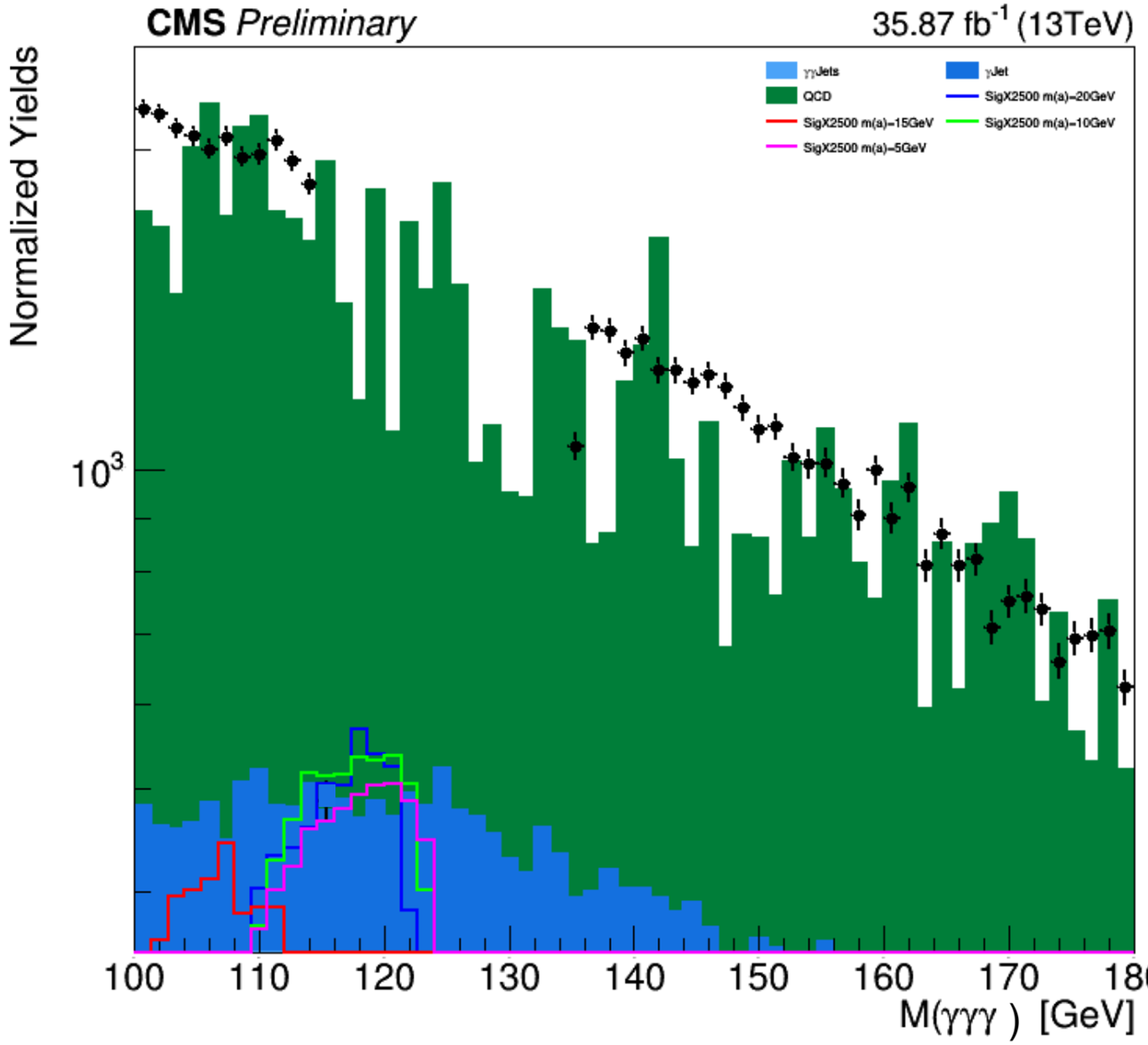
Blinded signal region

Blinding region: 115 < M(γγγ) < 130 GeV





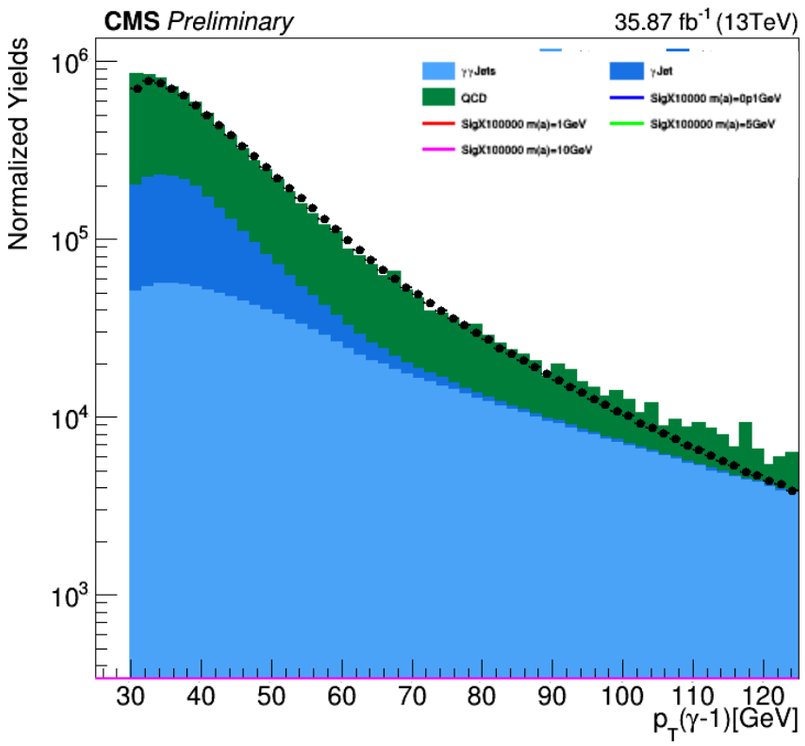
Signal mass samples :
m(a) = 20, 15,10, 5 GeV



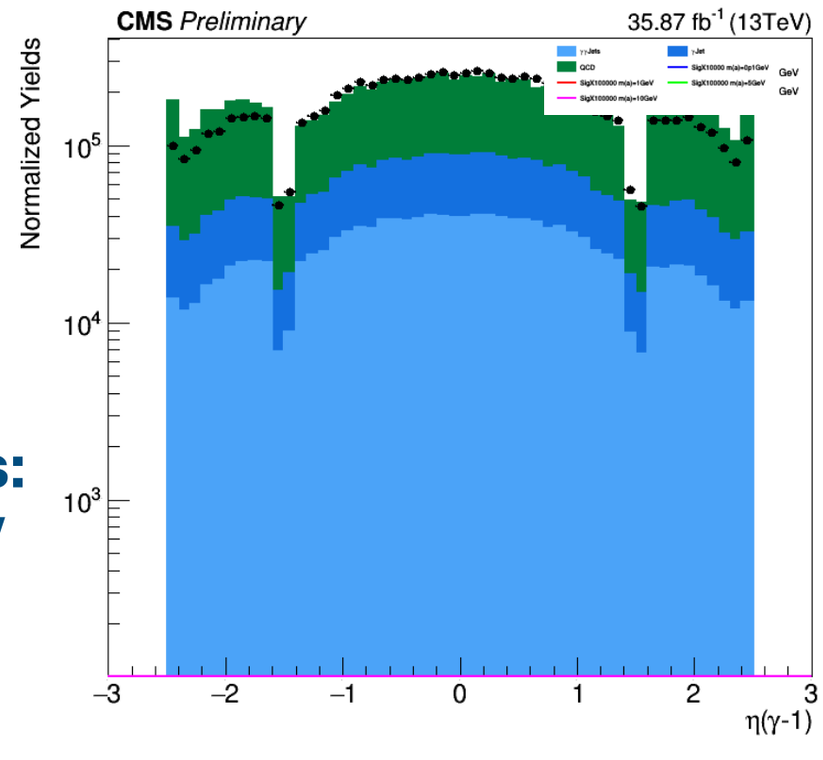
2 PHOTON CATEGORY

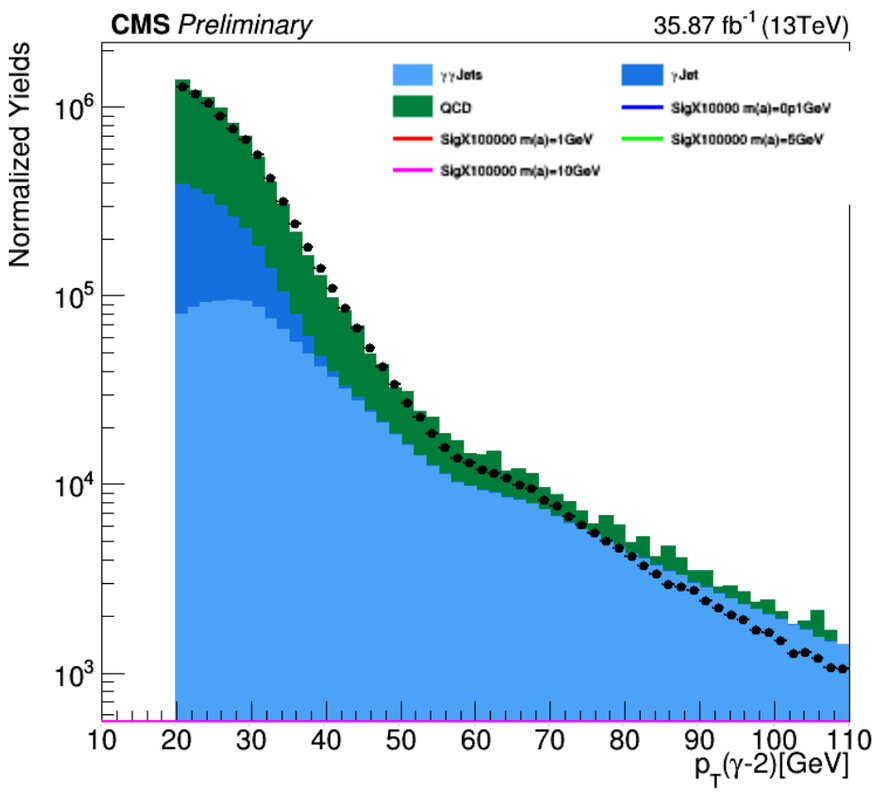
Blinded signal region

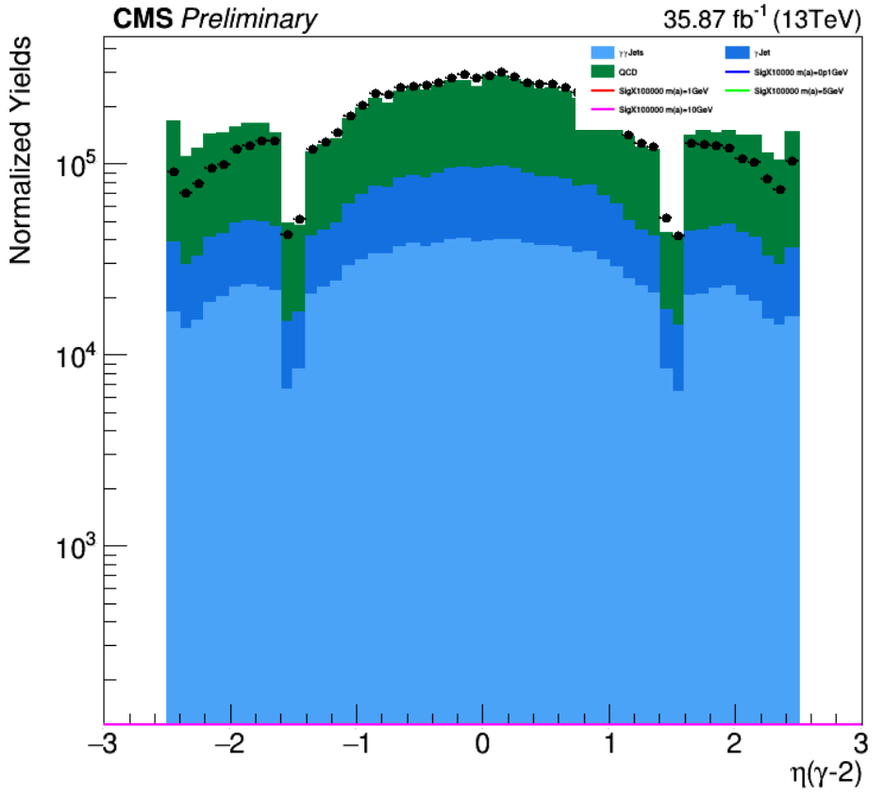
Blinding region: 115 < M(γγ) < 130 GeV



Signal Mass samples: m(a) =10,5,1,0.1 GeV





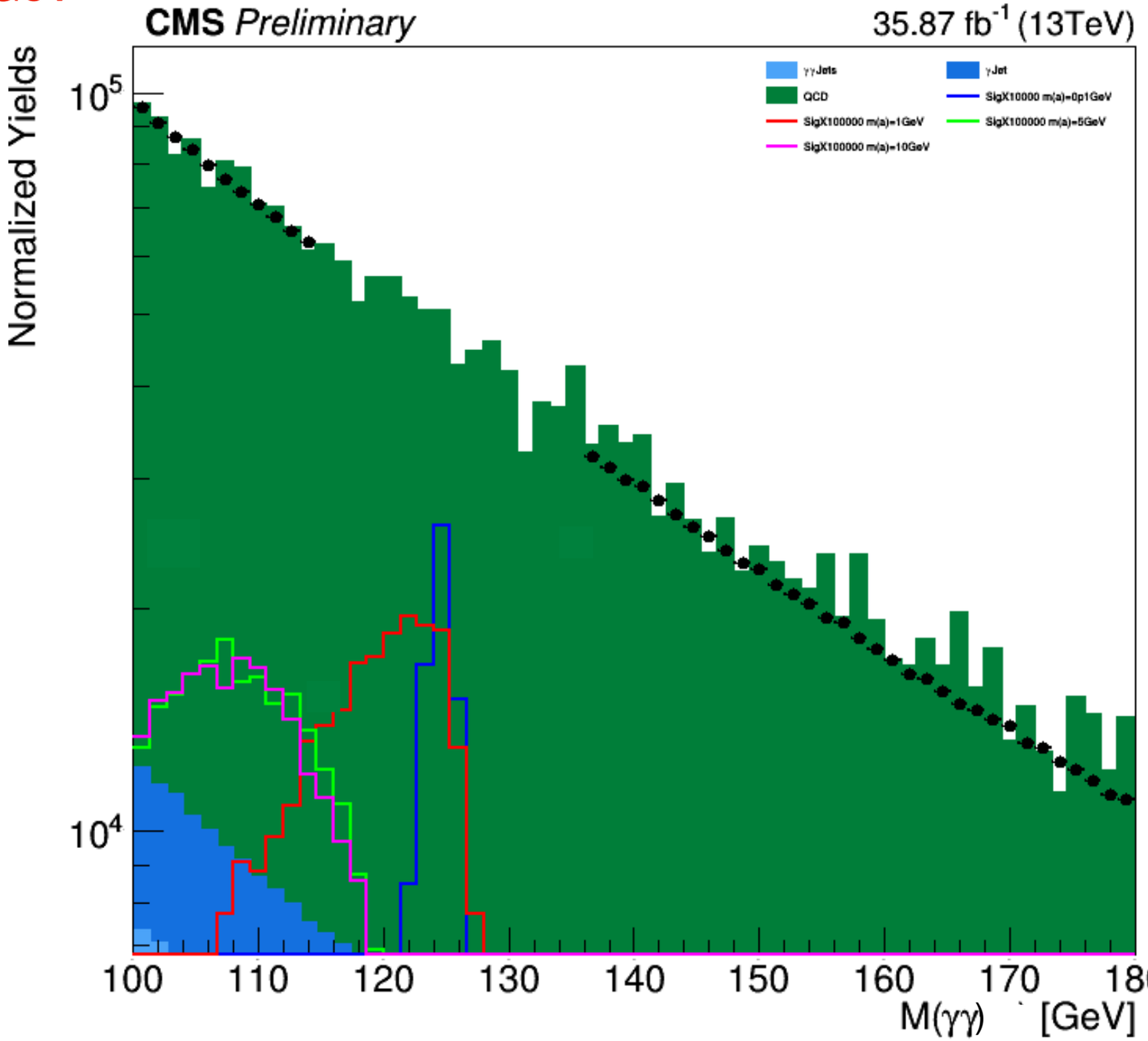


2 PHOTON CATEGORY

Blinding region: 115 < M(ɣɣ) < 130 GeV

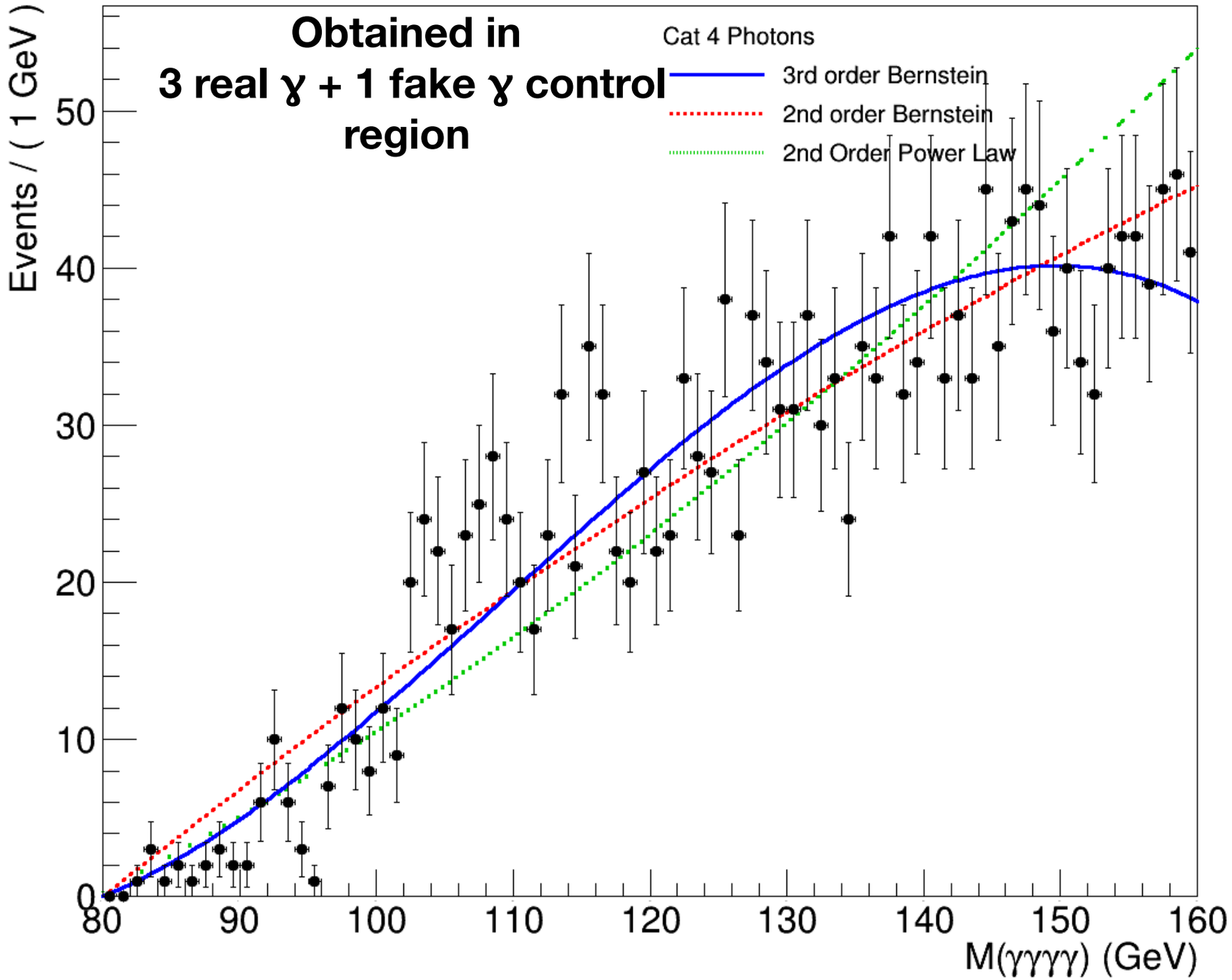
Better MC/Data agreement than 4 photon category distributions since the MC samples are Double EM enriched

Signal Mass samples: m(a) =10,5,1,0.1 GeV



BACKGROUND ESTIMATION

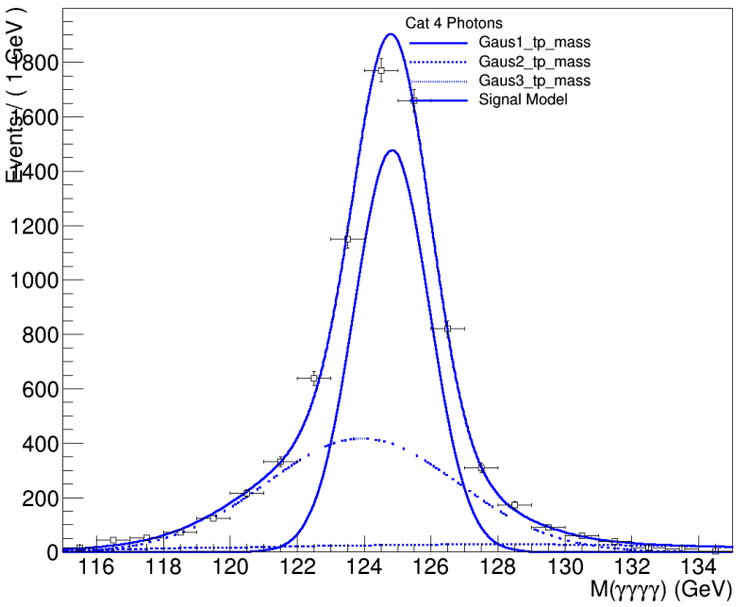
First look at Background Fit



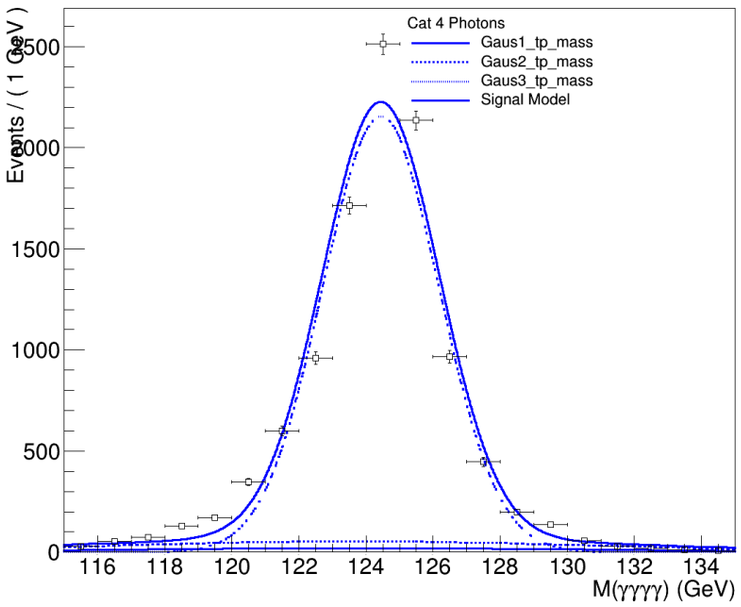
SIGNAL MODELLING

Signal shape fits for the 4ɣ category

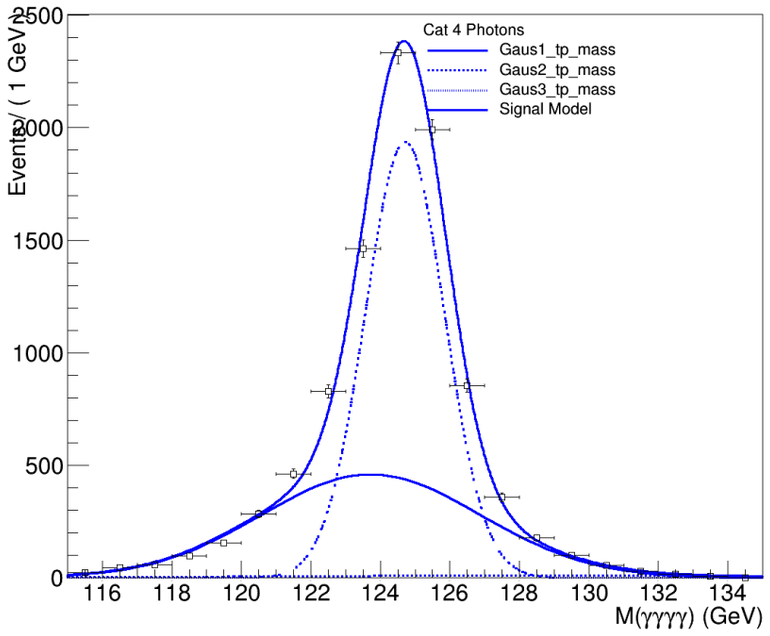
Final Signal Shape - Sum of Three Gaussians



m(a)=50GeV



m(a)=20GeV



m(a)=5GeV

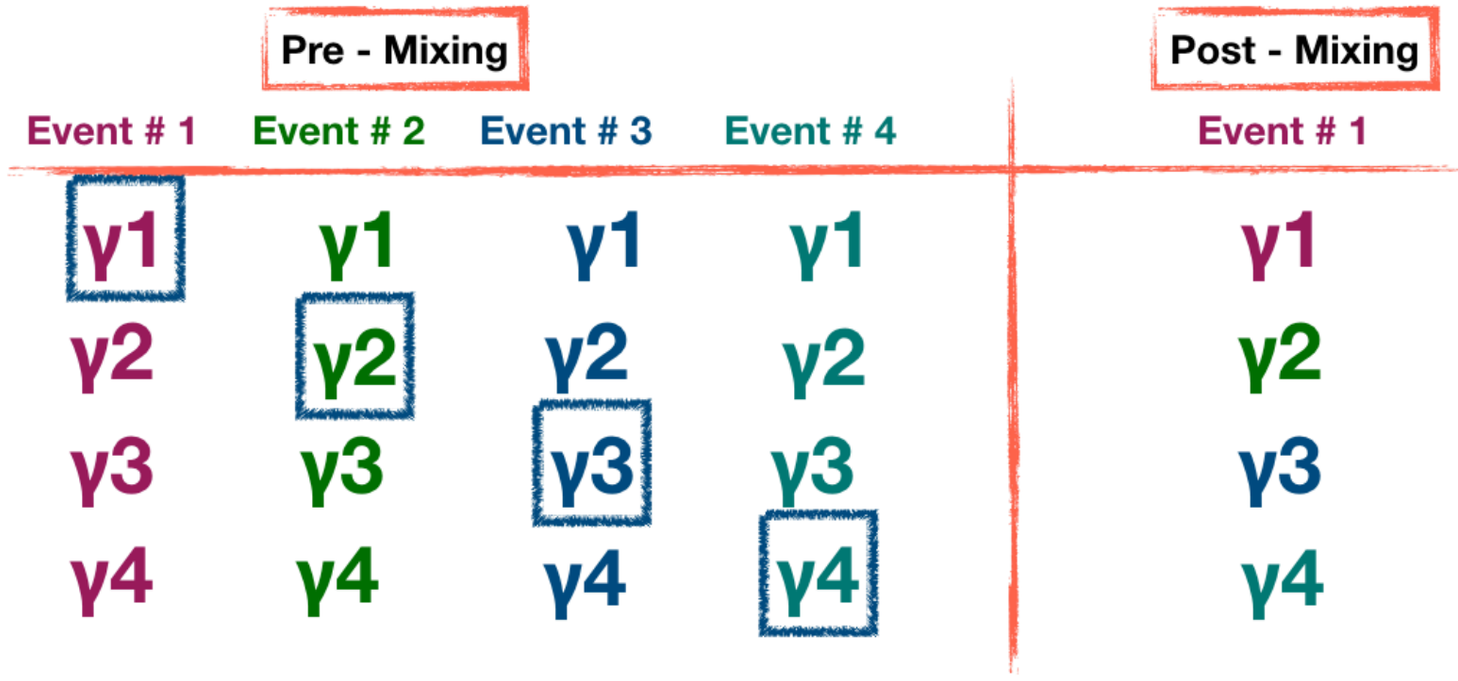
EVENT MIXING - PRELIMINARY

- To perform closure tests on the background model - require a dataset similar to our expected background in terms of kinematics + statistics
- Control Region - Events with 3 good γ's that pass + 1 good γ that fails the Photon ID
- Artificially create combinatronics background by exchanging γ's between events - MIXING
- Mixing Concept - After doing full event selection, replace 3 out of the 4 selected photons by those in other events

Expected Result of Event Mixing:

- Signal - M(γγ) and M(γγγγ) peaks should be smeared away
- Background - Both mixed and unmixed distributions should appear same

Being Checked!



THINGS TO DO

- Apply **Trigger Scale Factors** and **Efficiencies** to MC samples

- Develop **Event mixing** to perform closure test on background modeling
  (find the best fitting function and do bias studies)

- **Photon ID improvements**
  - Can try to look for a better way to use PhotonID information than using the same cut for all four photons

- Creating **R9 based sub-categorie**s for Four, Three and Two Photon categories
  - R9 based categorization being checked using Gen matching

- Perform limit calculation with **parametric shape analysis** using **Discrete Profiling Method**

- Start **Documentation**

SUMMARY

- Strategy for study of Higgs decay into 4 photons h(125)→aa→ɣɣɣɣ was presented
- Mass samples 0.1,1,5,10,15,20,25,30,35,40,45,50,55,60 GeV studied
- Basic analysis work flow exists and needs to be improved/optimized
- Targeting to arrive at limits with the 2016 data before moving on to 2017 data
- Person Power - **Tanvi** (PhD student), **Andrea** (PostDoc) and **Toyoko** (Senior)