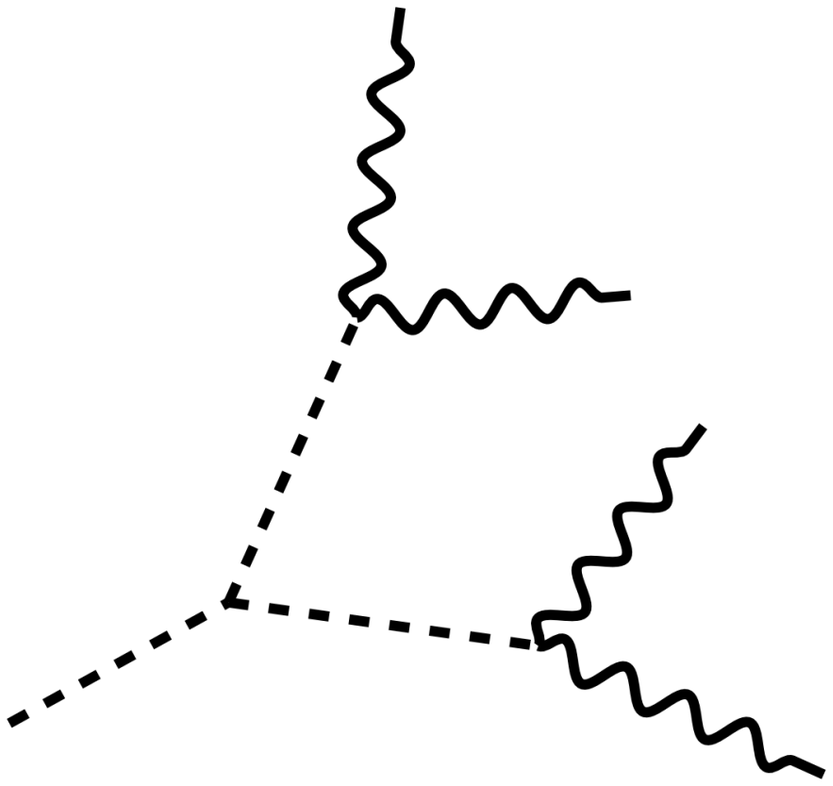
h(125)→aa→γγγγ



Higgs to 4 Gamma Update

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20th February 2018
NEU 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

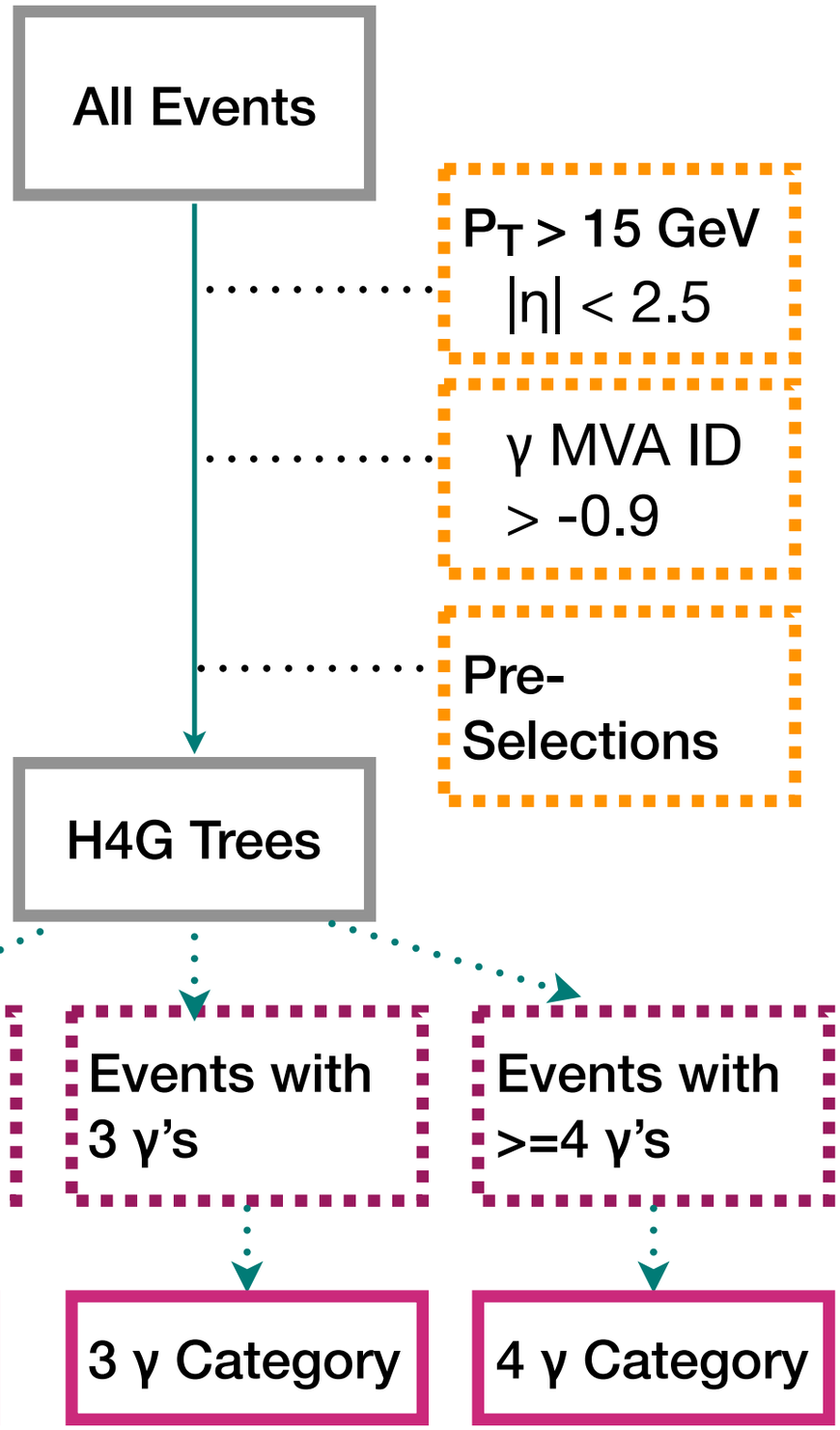
QCD_Pt-30to40_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8
QCD_Pt-40toInf_DoubleEMEnriched_MGG-80toInf_TuneCUETP8M1_13TeV_Pythia8
QCD_Pt-30toInf_DoubleEMEnriched_MGG-40to80_TuneCUETP8M1_13TeV_Pythia8

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

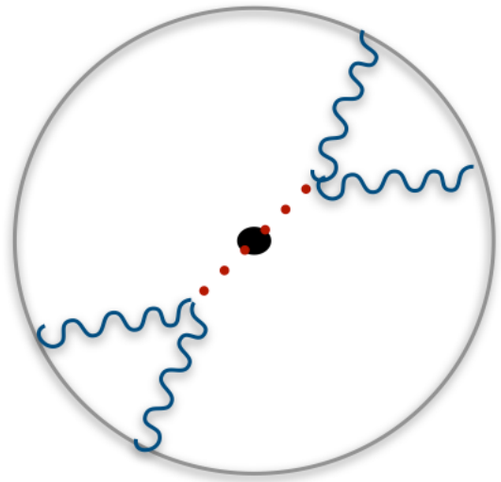
- Depending on m(a) we will have different topologies

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

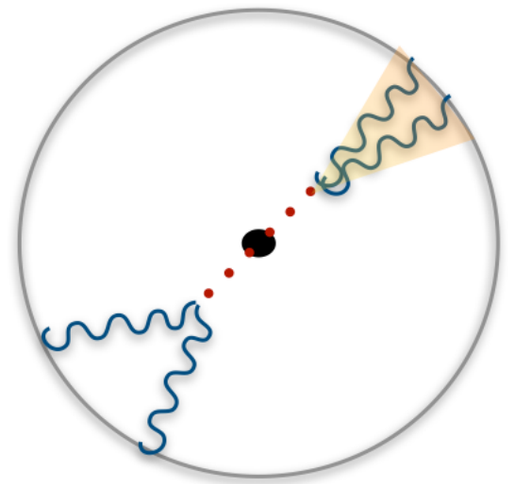


CATEGORIES

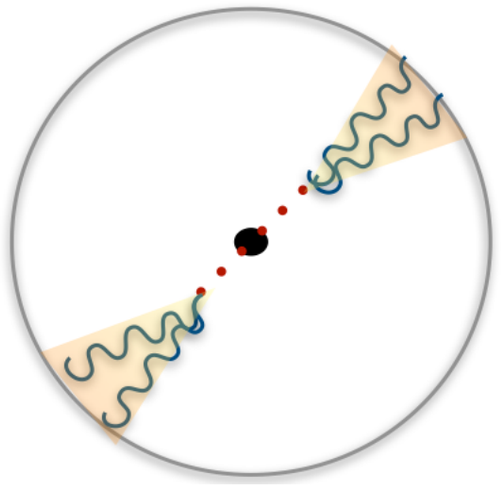
4 Isolated Photons
- "a" is not boosted, the decay products are well isolated
- Select events with at least 4 γ's and then select the 4 highest P_T γ's



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
  - Different kind of photon pairs being considered according to their η and R9 values

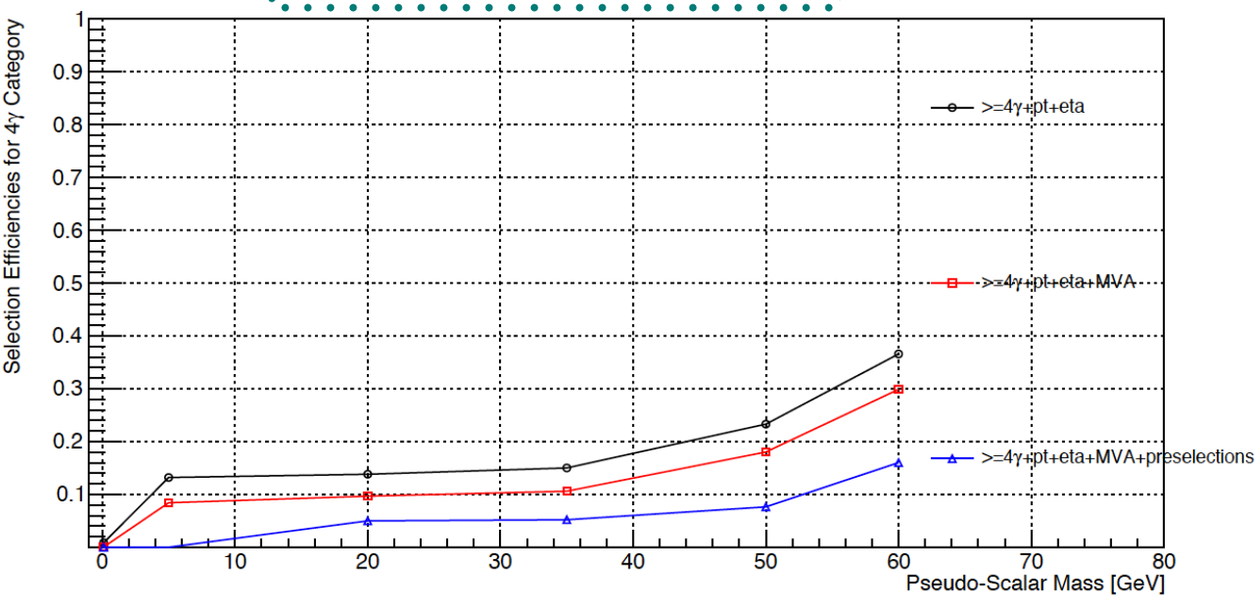
Offline Trigger like requirements

Category		R9	H/E	$\sigma_{i\eta i\eta}$	Pho Iso	Trk Iso
Both photons in EB		> 0.5	< 0.07	< 0.0105	< 4 GeV	< 6 GeV
At least one Photon in EE	Second photon in EB	> 0.85	< 0.07	< 0.0105	< 4 GeV	< 6 GeV
At least one Photon in EE	Second photon in EE	> 0.9	< 0.035	< 0.0275	< 4 GeV	< 6 GeV

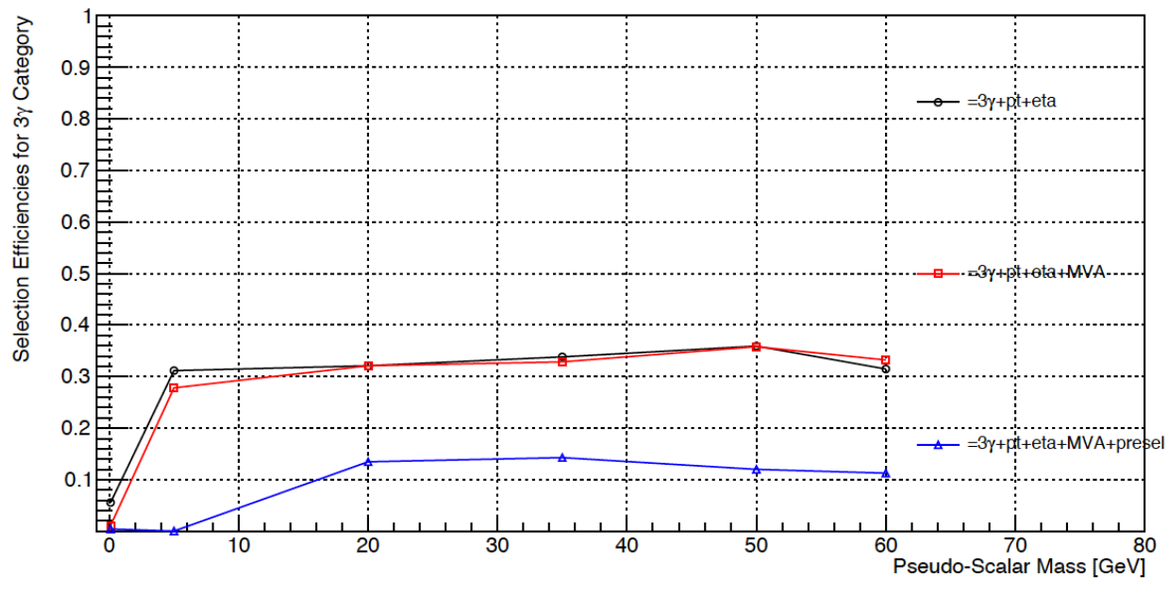
- $m_{\gamma\gamma}$ > 55 GeV, P_T lead γ> 30 GeV, P_T sub-lead γ> 18 GeV, Pixel Veto applied

OF SURVIVING EVENTS

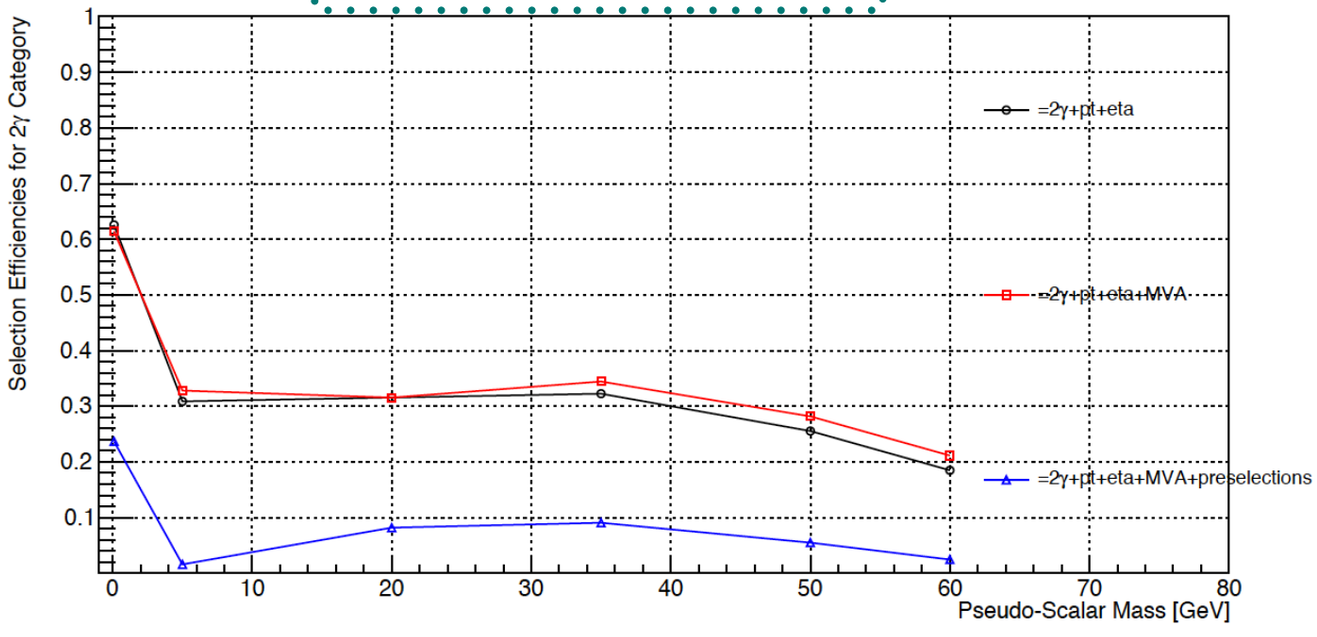
4 Photon Category



3 Photon Category



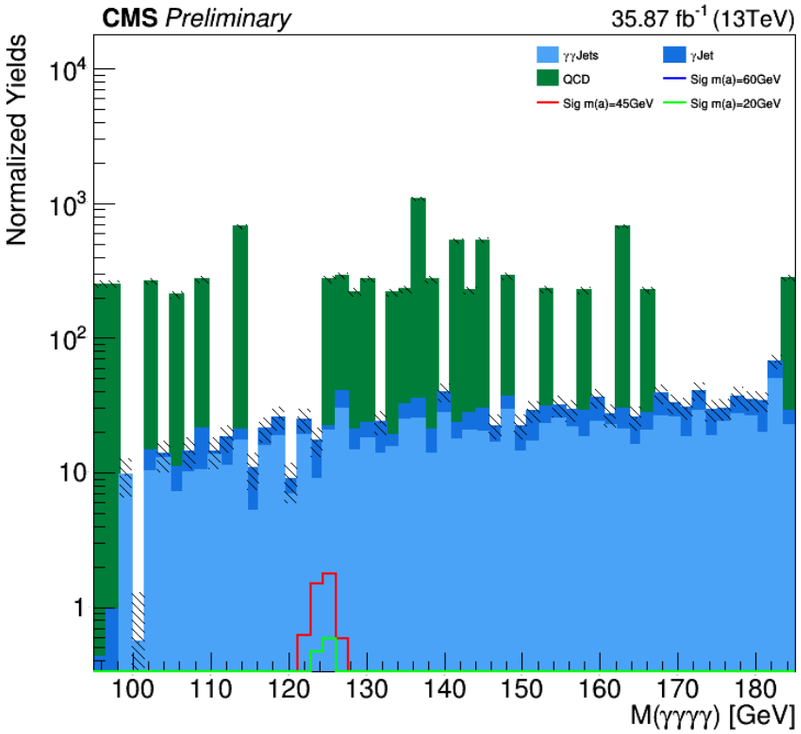
2 Photon Category



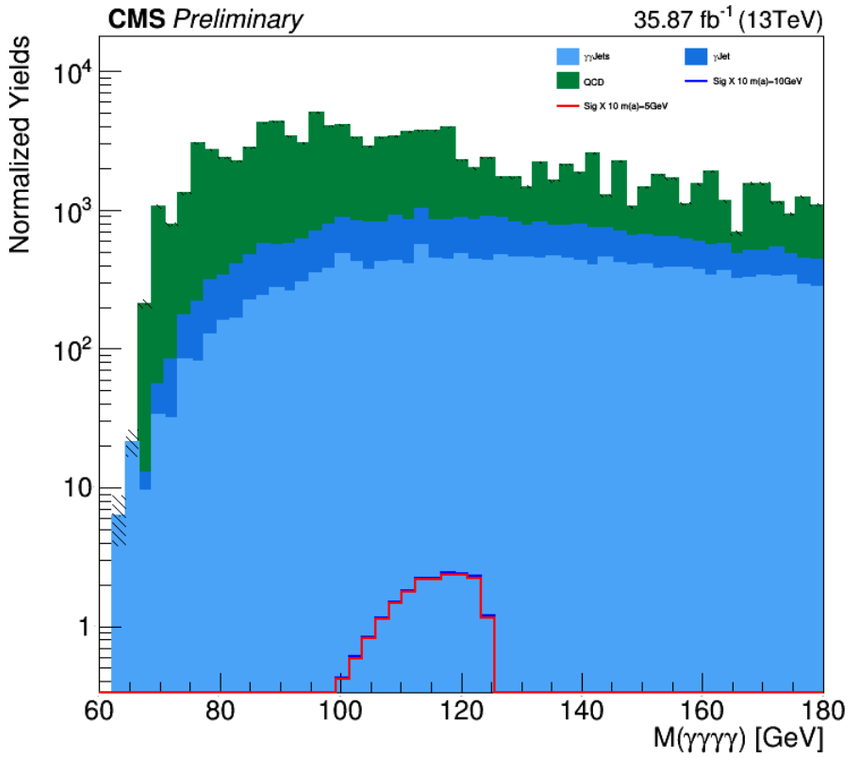
- Number of events that survive in each of the 3 categories
- Have been split into events that pass the acceptance **P_T > 15 GeV and |η| < 2.5**
- Events that pass the loose **Photon MVA > -0.9**
- Events that pass **pre-selections**

SIGNAL & BACKGROUND COMPARISON

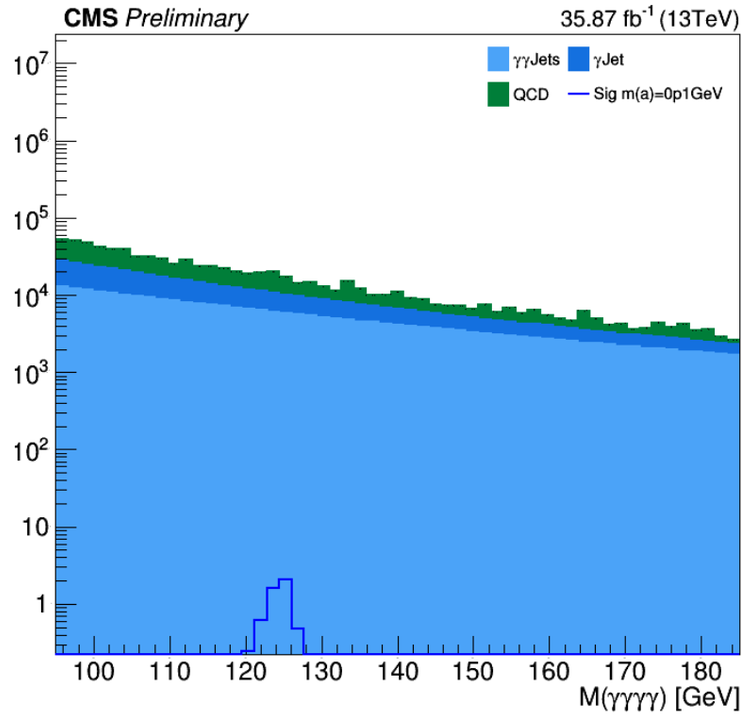
- Plots showing Background and Signal MC comparison
- Are only being used as a guide to determine the fitting and blinding range for the 4 photon, 3 photon and 2 photon categories



4ɣ Category
Fitting range: [100,180] GeV
Blinding range: [115,135] GeV



3ɣ Category
Fitting range: [80,180] GeV
Blinding range: [95,135] GeV



2ɣ Category
Fitting range: [100,180] GeV
Blinding range: [115,135] GeV

SIGNAL MODEL

- Signal shape modeled by a sum of 3 gaussians

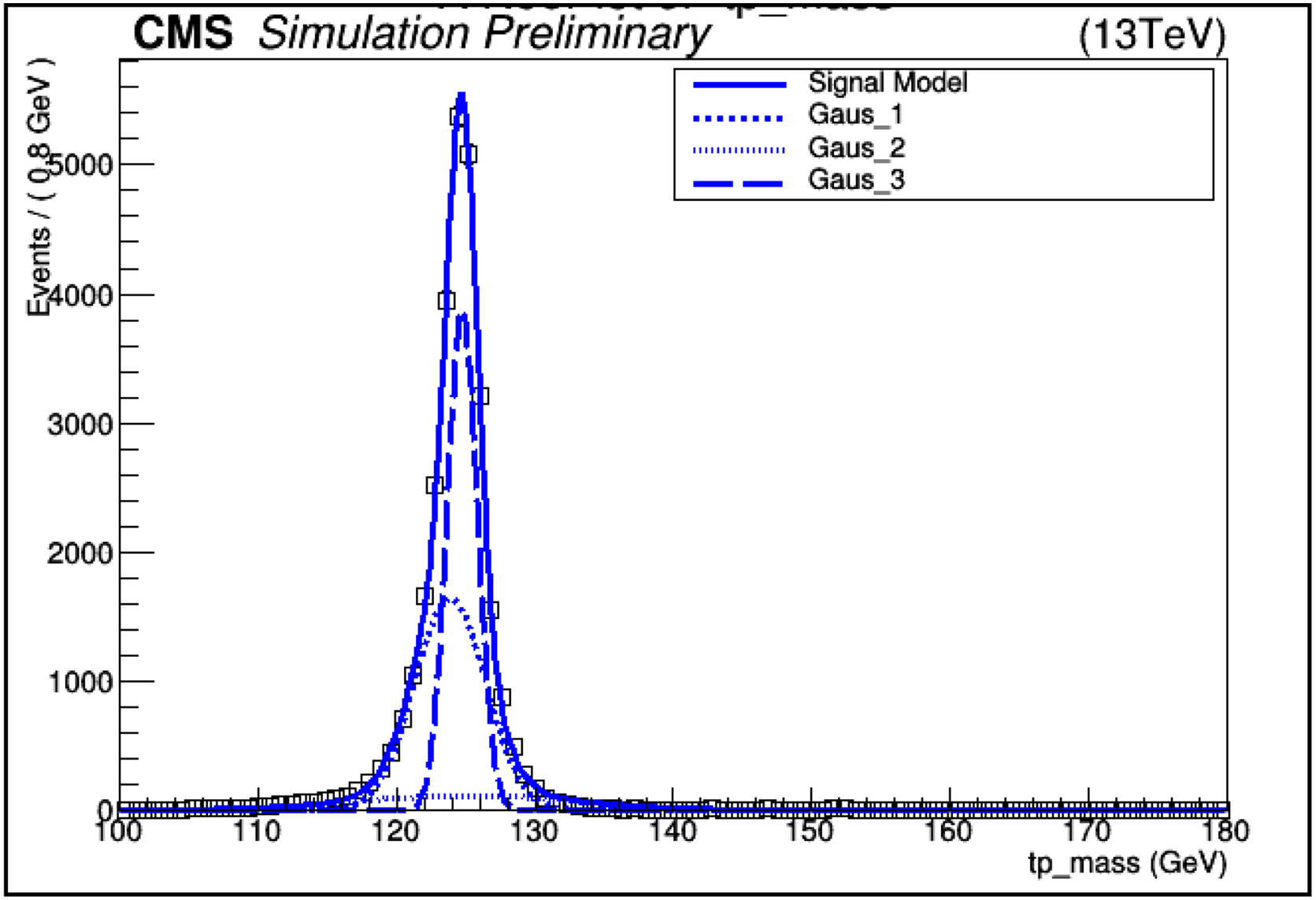
Fit of signal shape

4γ Category

MC: h→aa→γγγγ

m(a) = 60 GeV

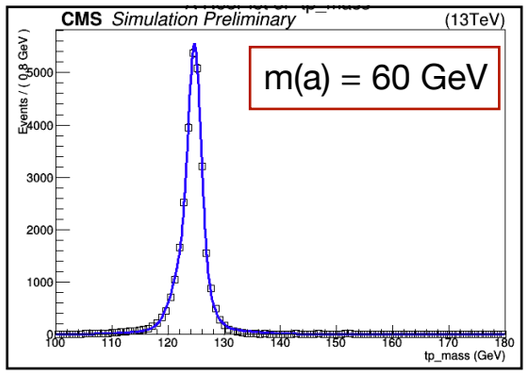
The 3 Gaussian components of the final Signal model are shown here

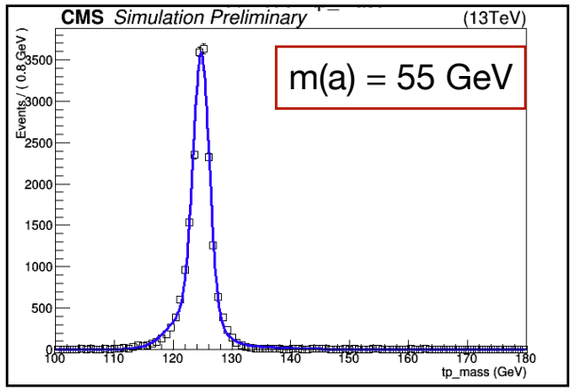


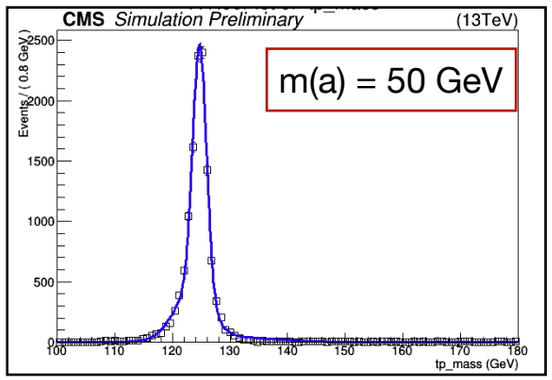
- For the 4 Photon category, consider the mass points from m(a) = 15 to 60 GeV
- The signal fits for these are shown on the next slide

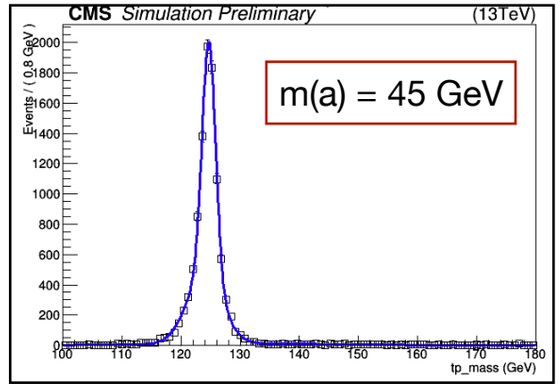
SIGNAL MODEL

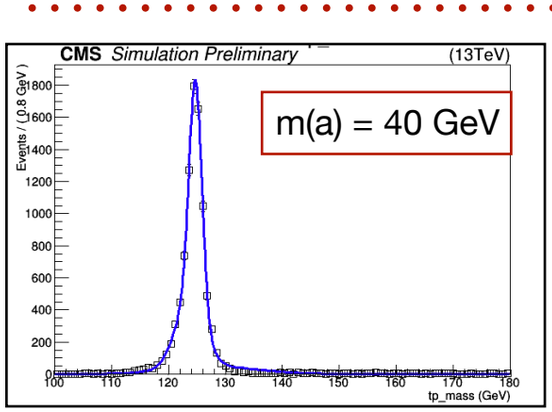
- For the 4γ Category

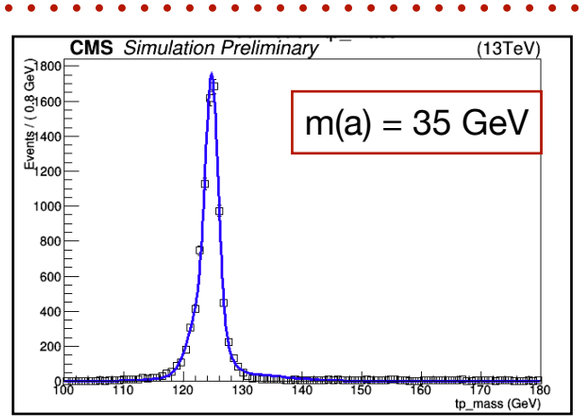


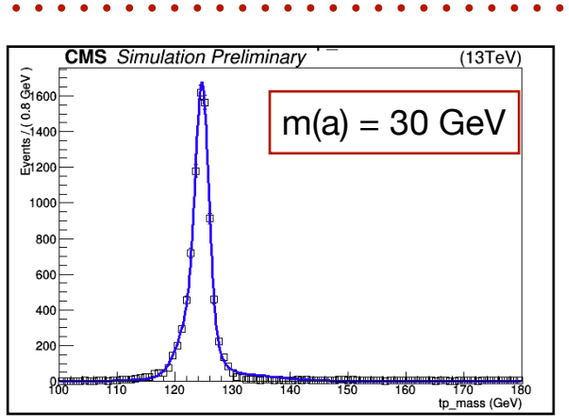


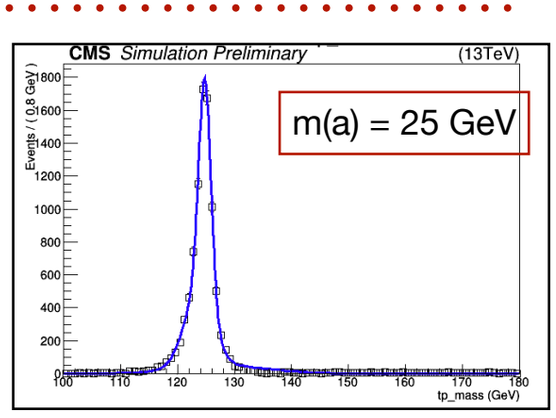


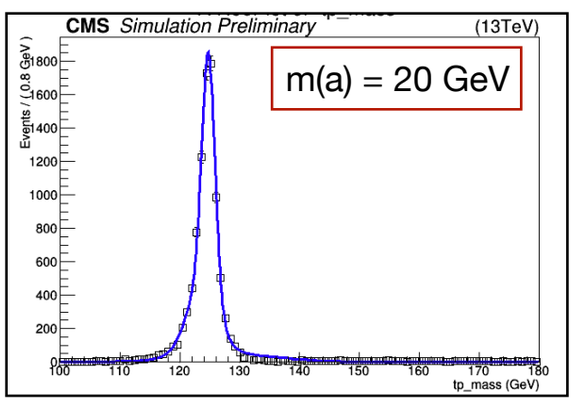


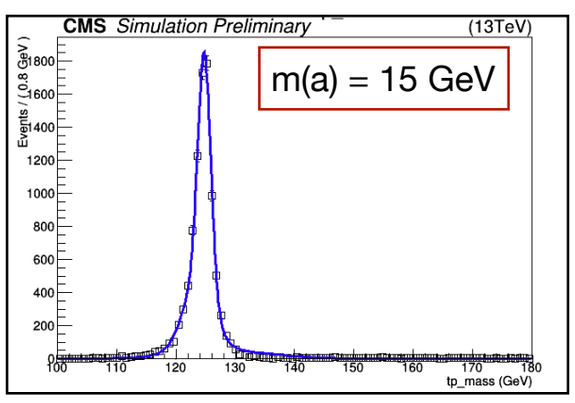












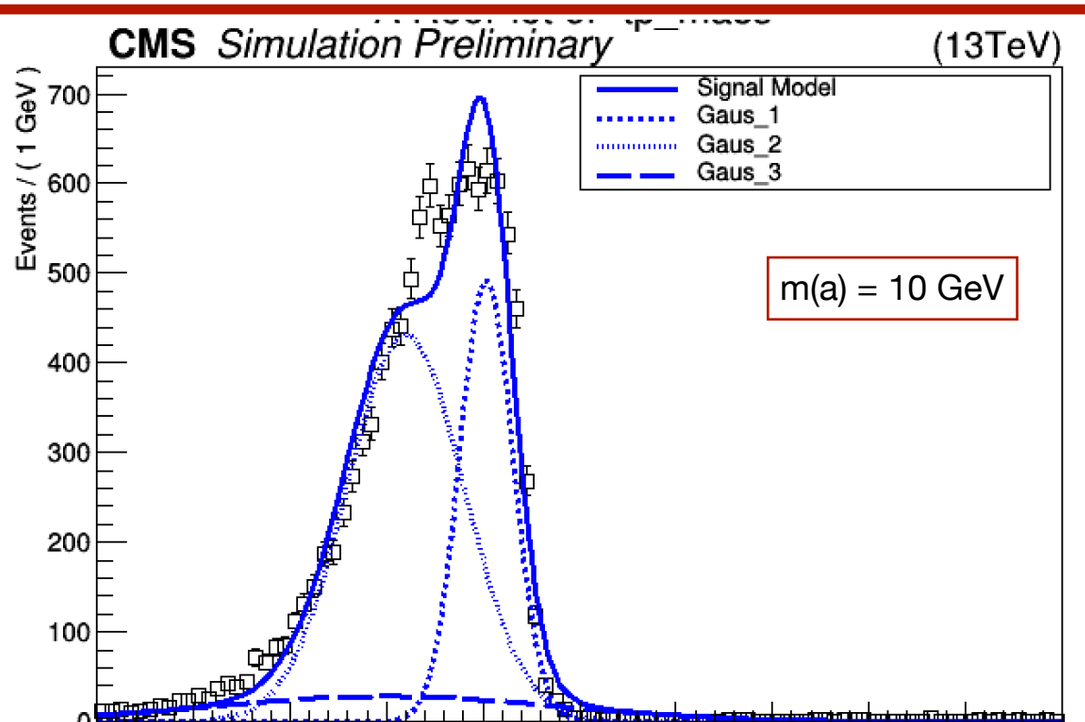
Gaussian PDF fits to Signal MC samples

SIGNAL MODEL

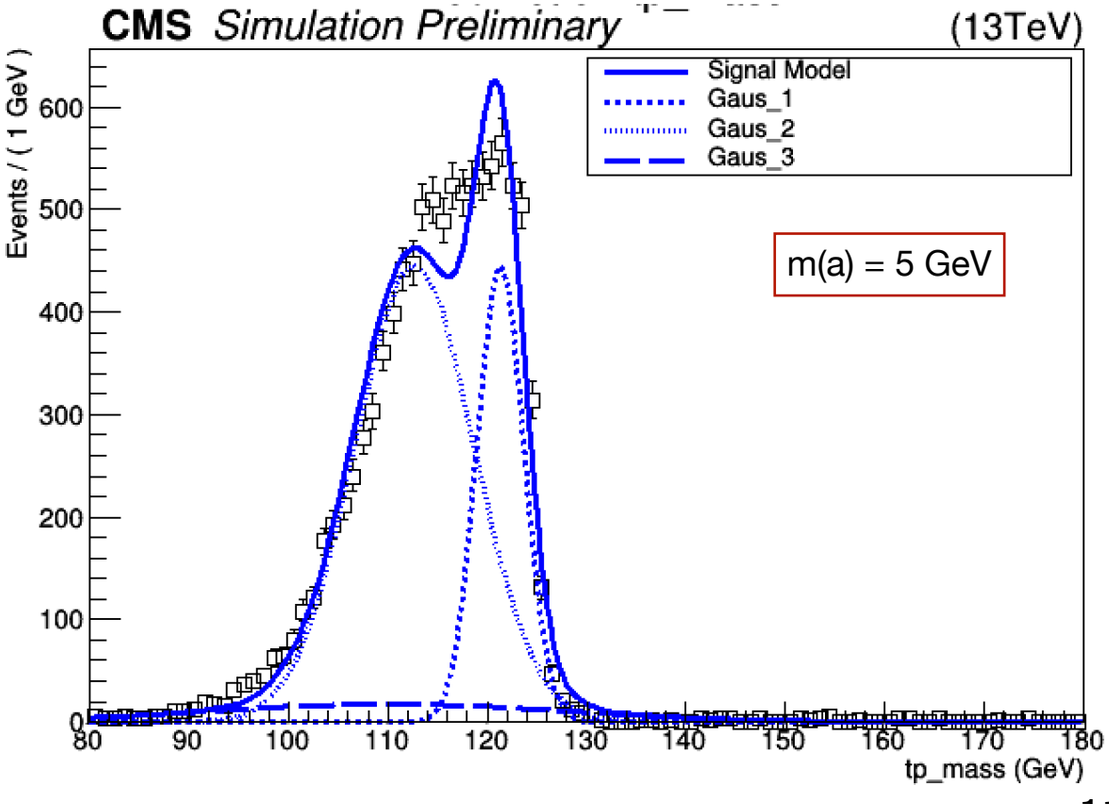
Fit of signal shape for **3ɣ Category**

m(a) = 10 GeV, 5 GeV

The 3 Gaussian components of the final Signal model are shown here



- These events are populated by events of 2 kind:
  1. Events with just 3ɣ's (with the 4th ɣ being lost due to Pt or eta cut)
  2. Events with 2 Isolated + 1 Fat photon (=2 merged Photons)
- Work is on-going to do gen-reco level matching

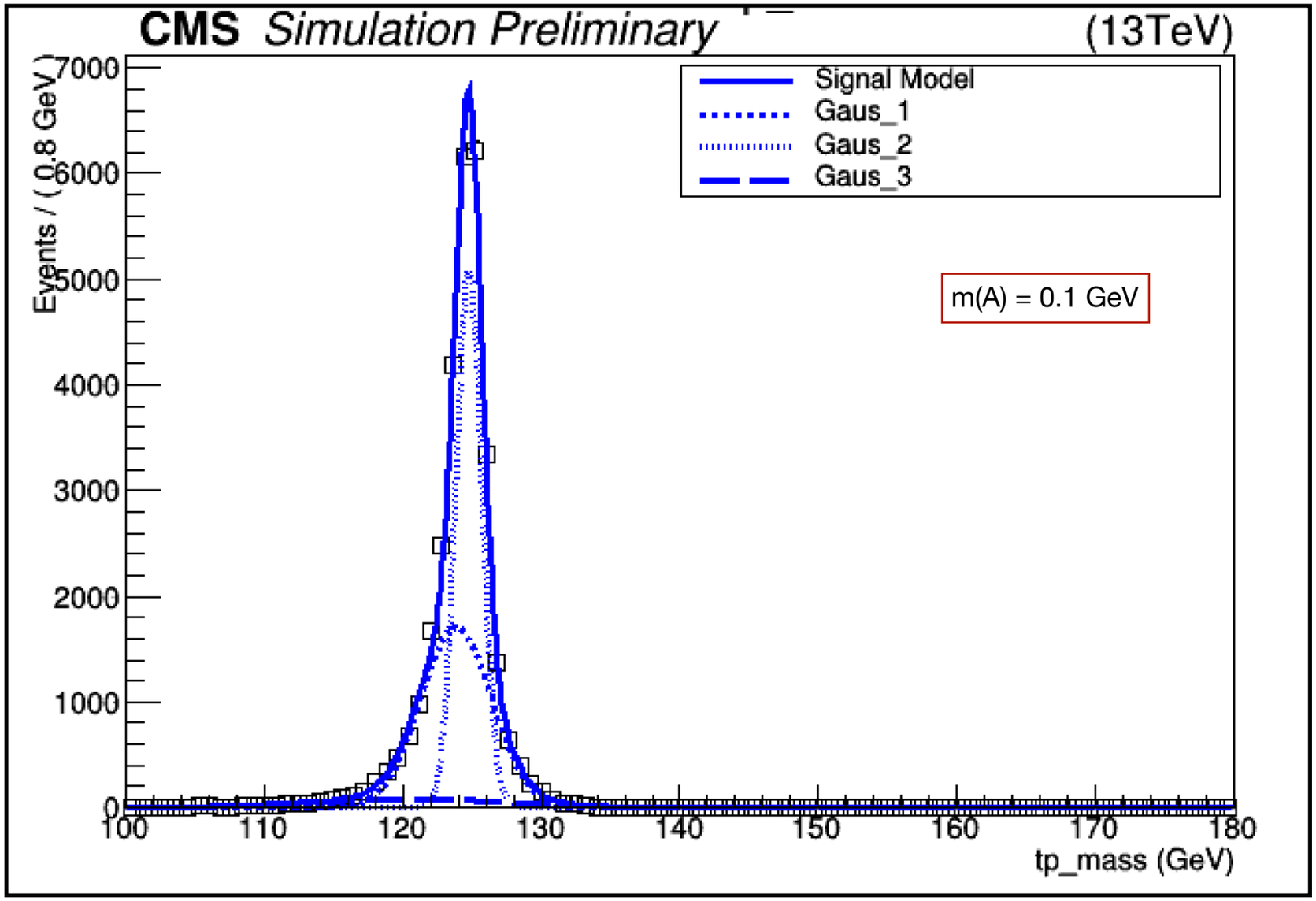


SIGNAL MODEL

Fit of signal shape for
2γ Category

m(a) = 0.1 GeV

The 3 Gaussian components of the final Signal model are shown here



BACKGROUND MODELING

- Discrete Profiling (“Envelope”) method adapted

- The background is modeled by fitting analytic functions to the observed tetra photon mass distributions

- Consider different families of functions
  - Family of Bernstein Polynomials
  - Chebychev Polynomial
  - Sum of Power Law functions

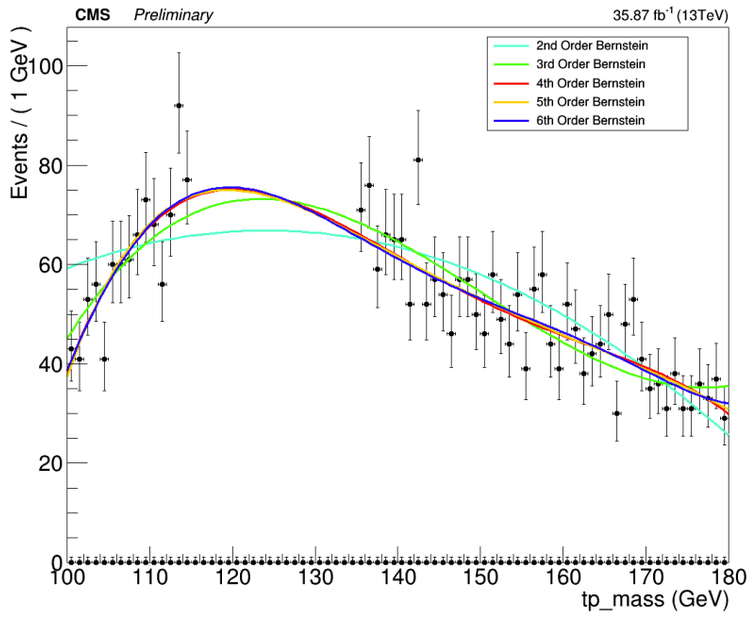
→ Work ongoing for the determination of representative set of functions from within a family using F-test

- Blinding range:
  - 4 Photon category → [115,135] GeV
  - 3 Photon category → [95,135] GeV
  - 2 Photon category → [115,135] GeV

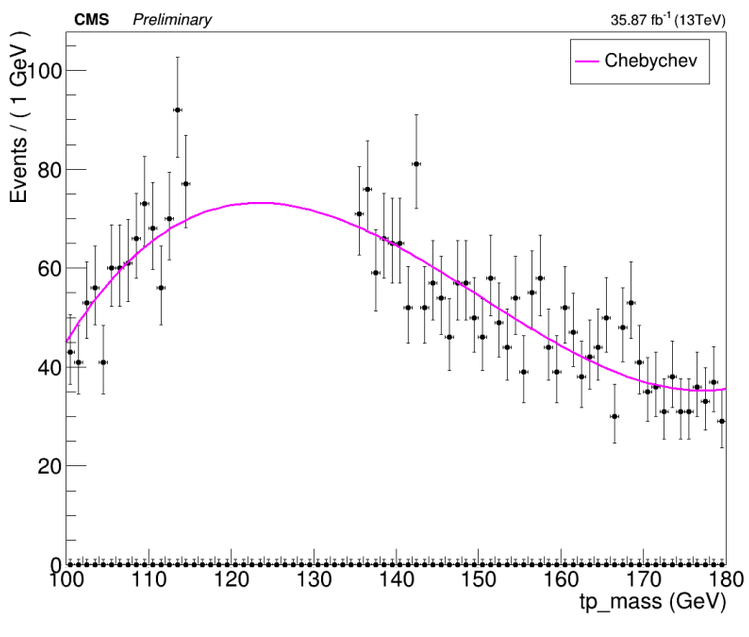
→ Fit range still to be optimized

BACKGROUND MODELING

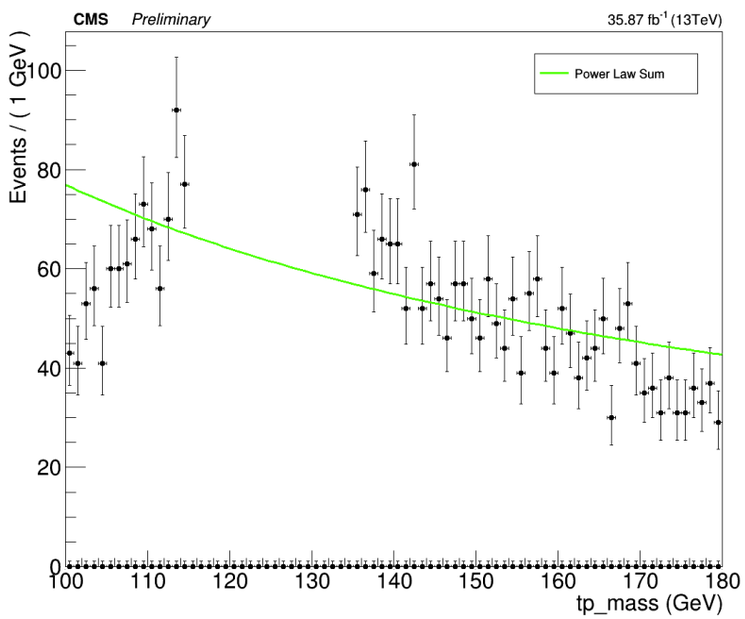
Family of Polynomials in Bernstein Basis



Chebychev Polynomial



Sums of Power Law functions

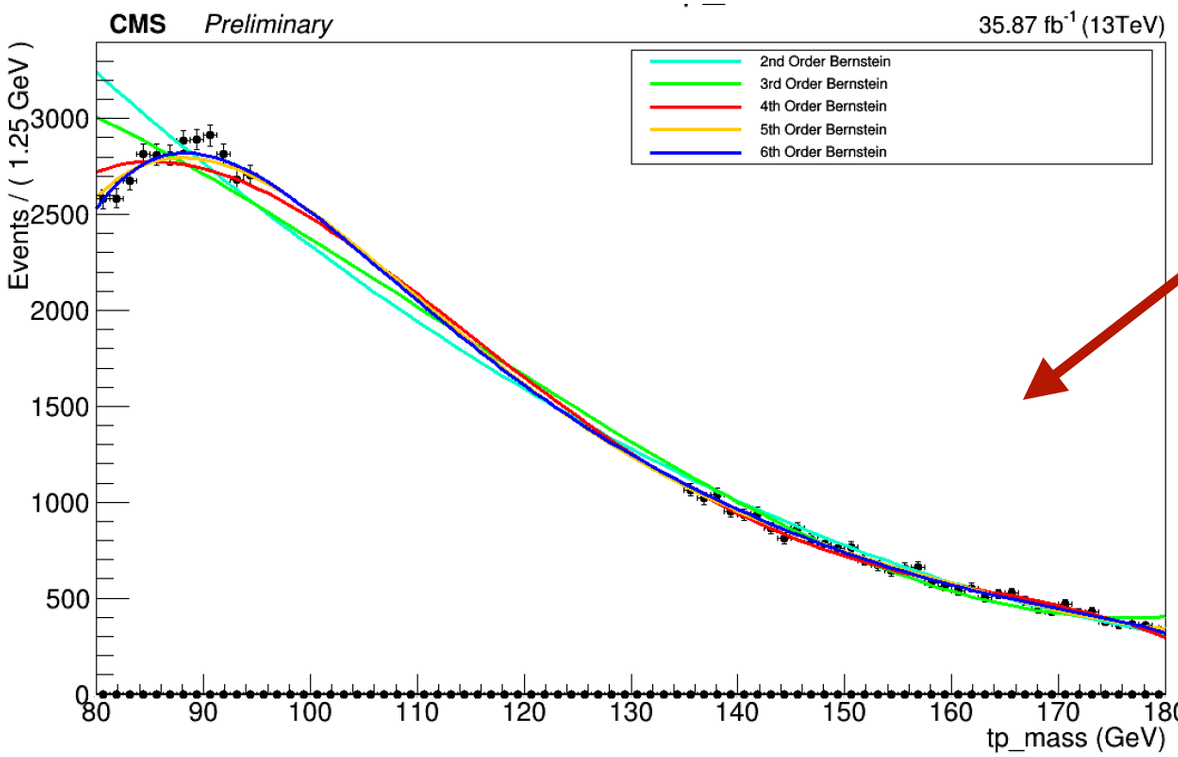


4γ Category

Functions considered:

- Family of Berstein Polynomials
- Chebychev Polynomial
- Sum of Power Law
- Cuts applied on Diphoton mass window:
  - dp1_mass/tp_mass < 0.55
  - dp2_mass/tp_mass < 0.50

BACKGROUND MODELING



3γ Category

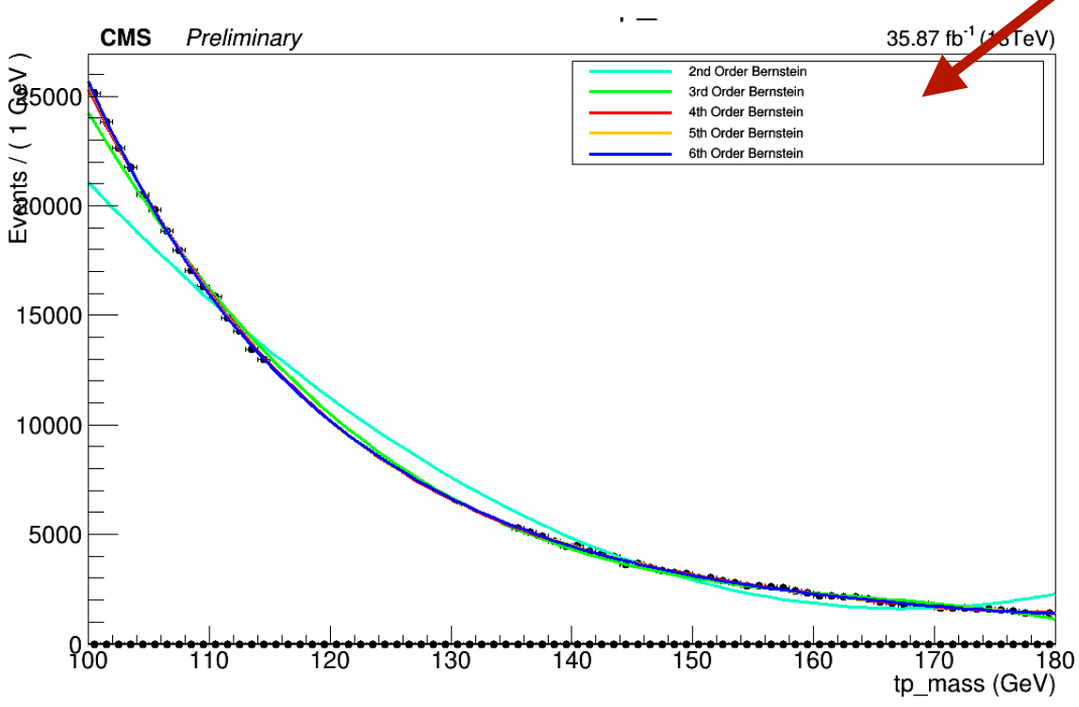
Functions considered:

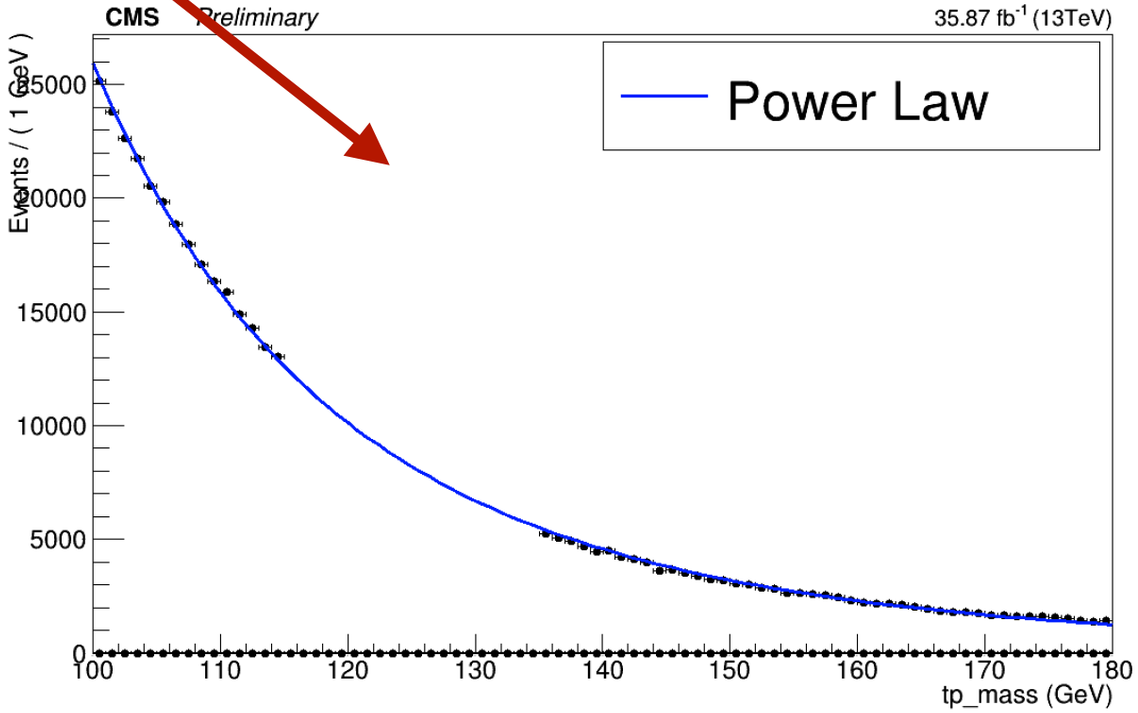
- Family of Bernstein Polynomials

2γ Category

Functions considered:

- Family of Berstein Polynomials
- Sum of Power Law





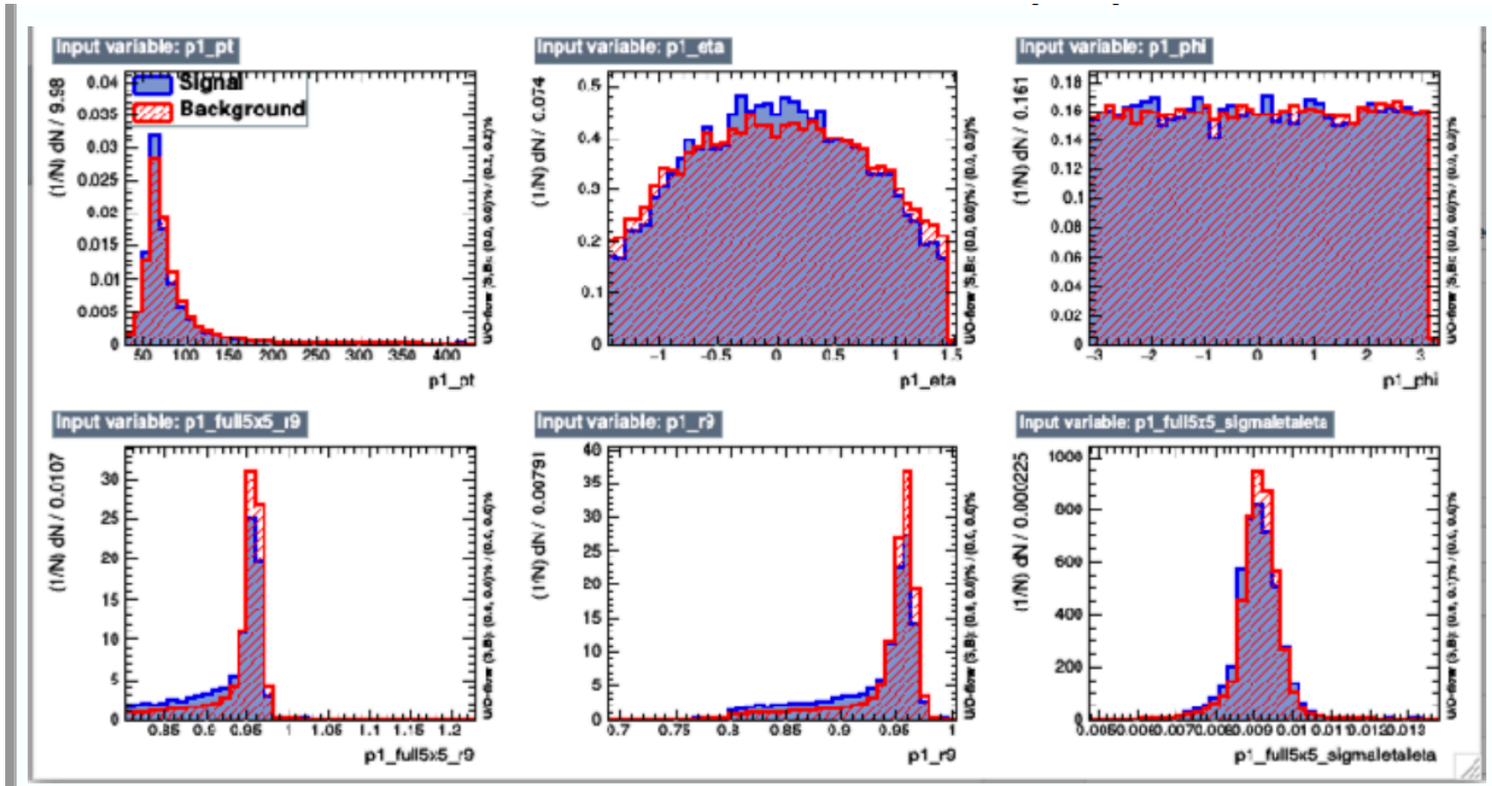
CUSTOM ID FOR 2 PHOTON CATEGORY

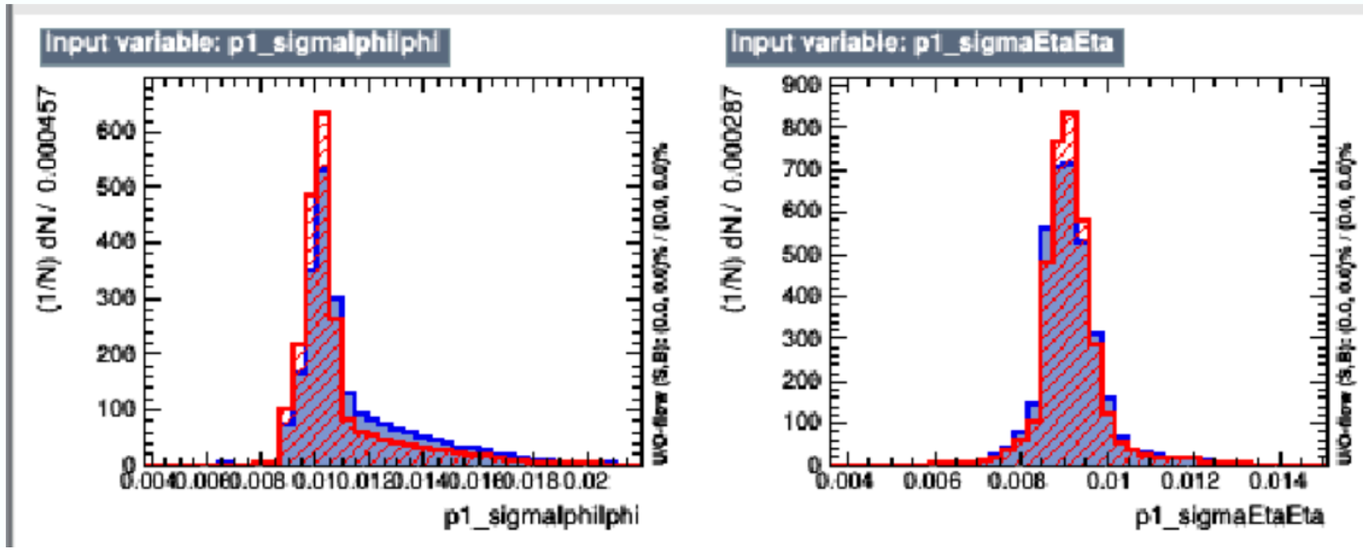
- The Photon MVA being used right now was developed for h->gg and low mass h->gg analysis.
- This MVA will discard the merged photons that look like pi0's
- So the idea is to develop an MVA based on kinematic + ECAL variables that can help us distinguish between the merged and unmerged cas
- Preliminary stage — variables being identified
- First results on the next slide

CUSTOM ID FOR 2 PHOTON CATEGORY

Abs(eta) < 1.5 ECAL Barrel

Input Variables

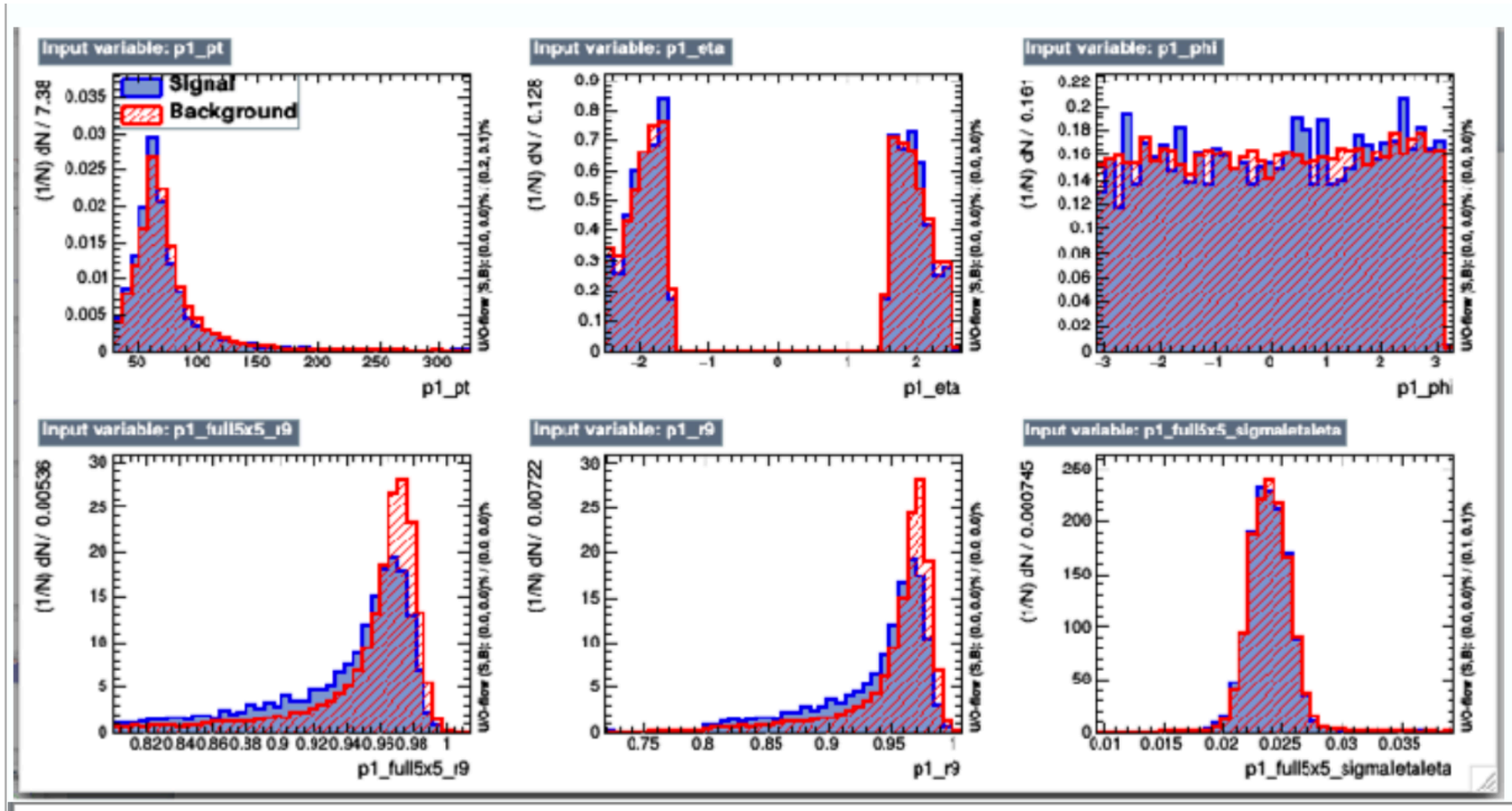


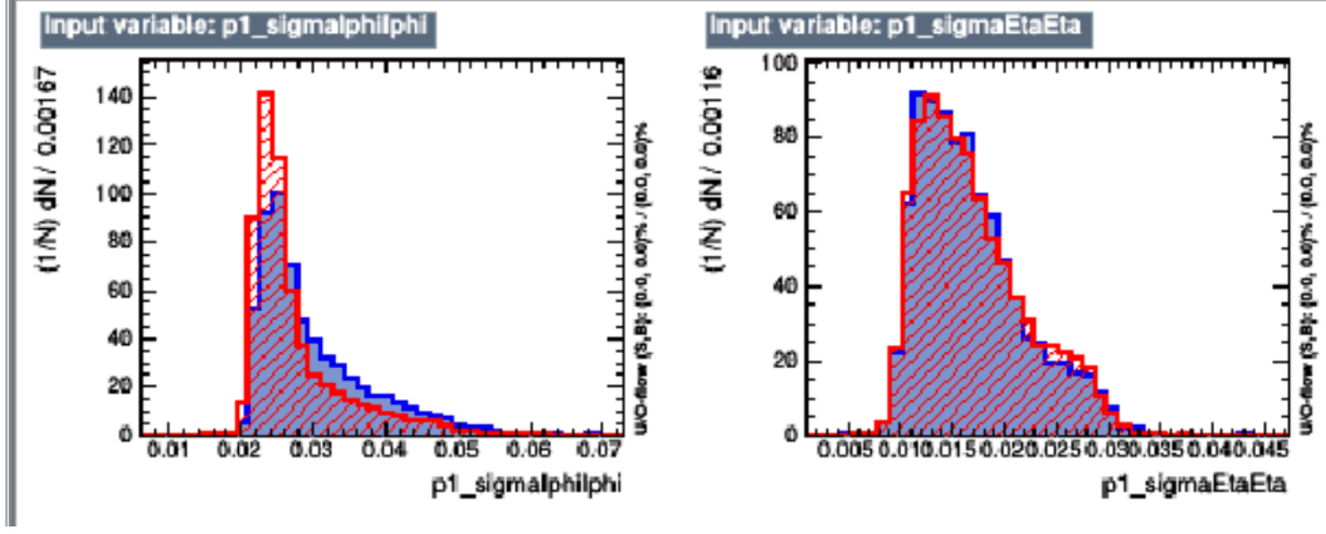


CUSTOM ID FOR 2 PHOTON CATEGORY

Abs(eta) > 1.5 ECAL Endcap

Input Variables





SUMMARY & OUTLOOK

- Presented h(125)→aa→ɣɣɣɣ analysis strategy
- Given the many different ongoing studies and possibilities..
- The first aim is to have the analysis completely ready for the 4 photon category

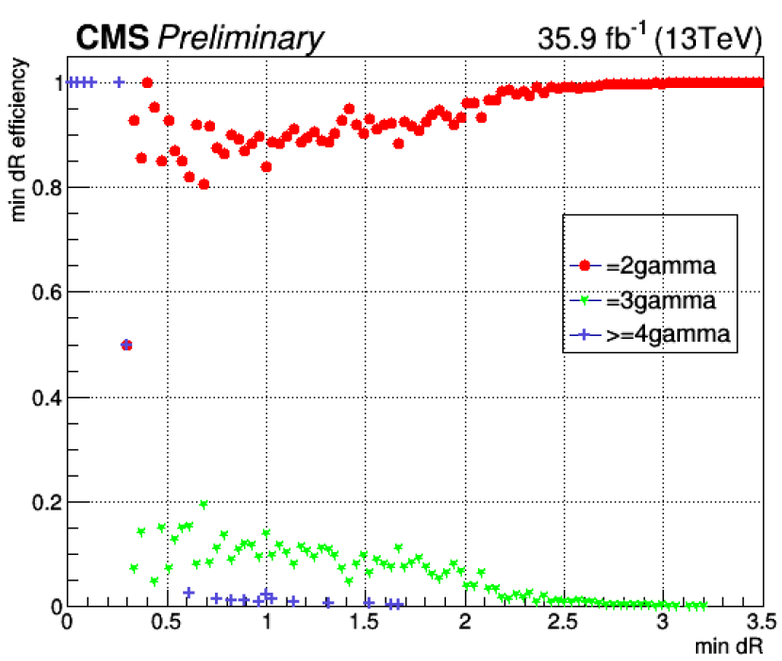
BACKUP

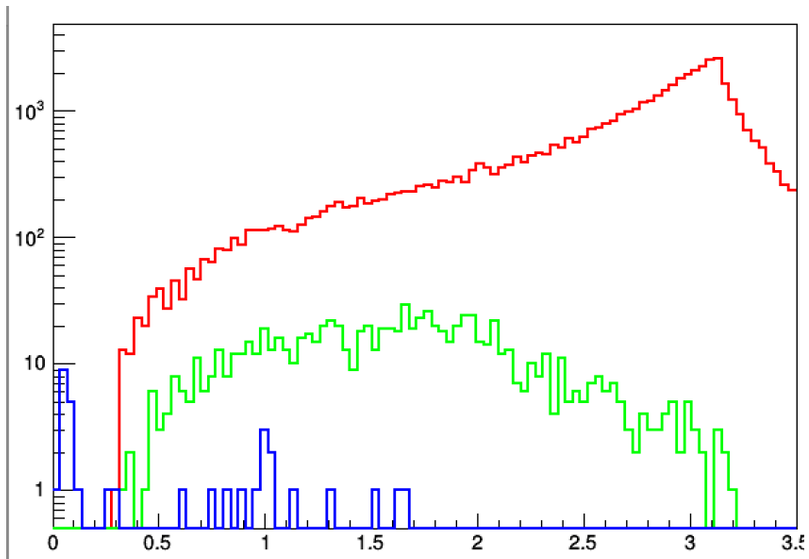
Yields in each category

Yield = #of events after selection * ($L^{*}\sigma_{\gamma\gamma}$ / W)

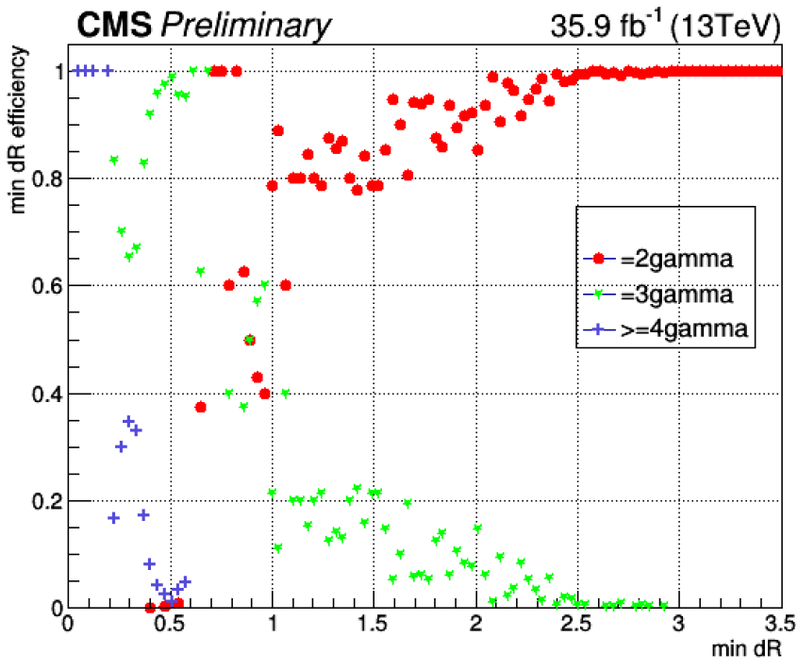
m(a) GeV	4 Photon Cat		3 Photon Cat		2 Photon Cat	
0.1	0.006	0.037	0.159	0.193	8.52	1.57
1	0.002	0.023	0.034	0.089	1.19	0.54
5	0.002	0.022	0.015	0.060	0.57	0.37
10	0.835	0.452	2.788	0.847	2.40	0.78
15	1.674	0.639	4.474	1.083	2.79	0.84
20	1.801	0.664	4.852	1.133	2.94	0.86
25	1.894	0.682	5.067	1.161	3.12	0.89
30	1.841	0.672	5.084	1.163	3.20	0.90
35	1.877	0.679	5.145	1.171	3.26	0.91
40	2.017	0.705	4.987	1.151	3.13	0.89
45	2.263	0.753	4.767	1.128	2.72	0.83
50	2.753	0.831	4.321	1.063	1.97	0.70
55	3.989	1.019	4.207	1.049	1.18	0.53
60	5.766	1.255	4.060	1.032	0.88	0.46

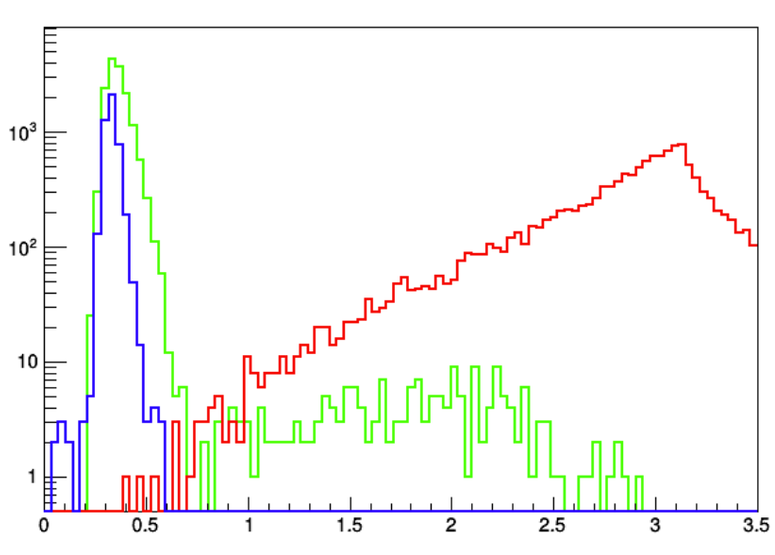
0.1 GeV





10 GeV





60 GeV