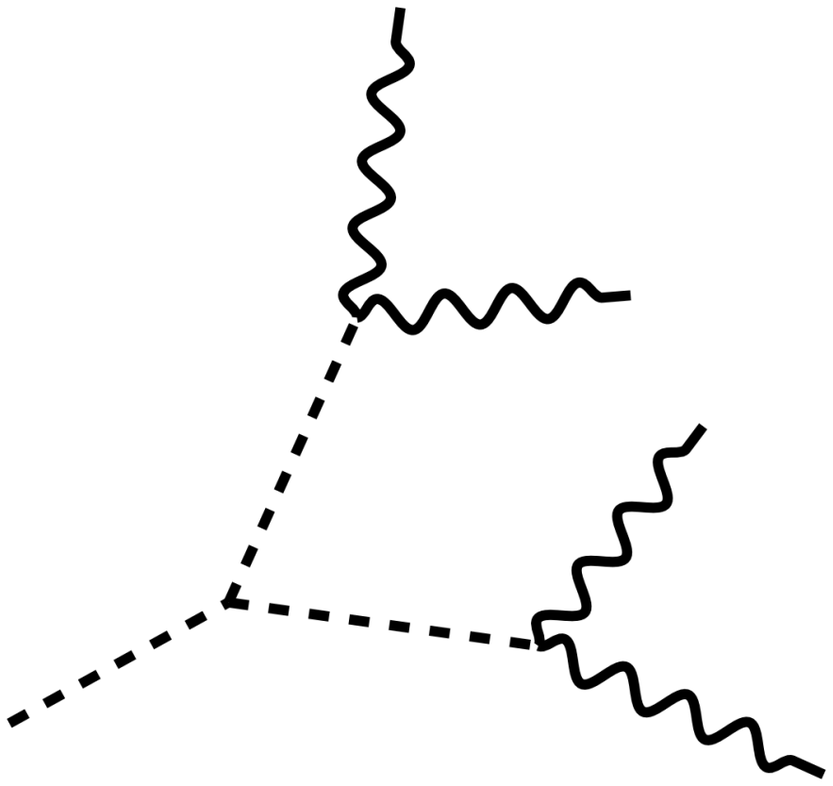
h(125)→aa→γγγγ



Higgs to 4 Gamma Update

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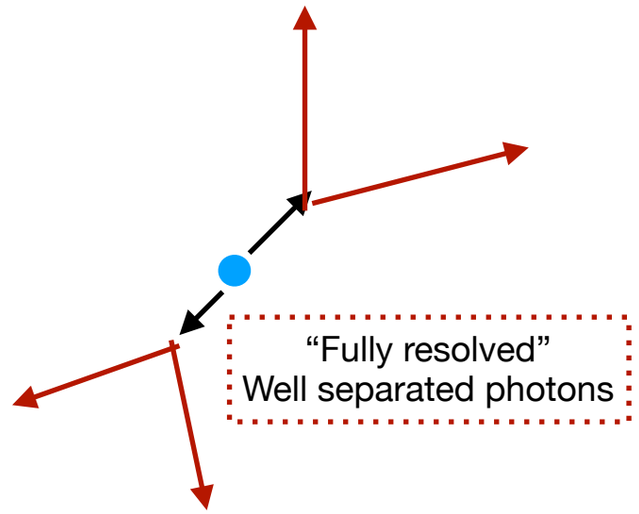
22nd January 2018
Higgs Exo Meeting

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

ANALYSIS STRATEGY

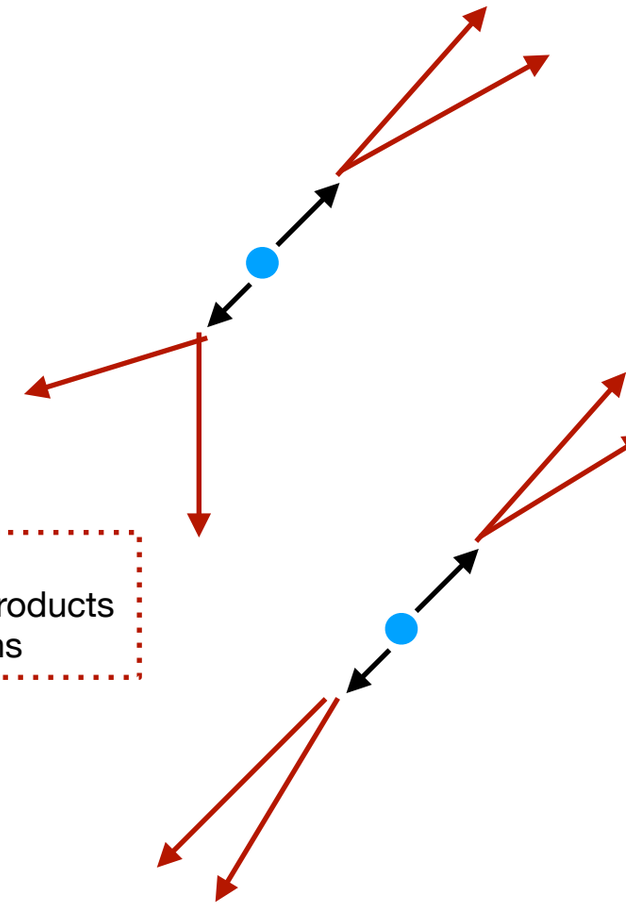
- h(125)→aa→γγγγ
- Probing mass region ranging from 100 MeV < m(a) < 60 GeV
- Highly boosted “a’s”
  - Collimated products of “a” decays



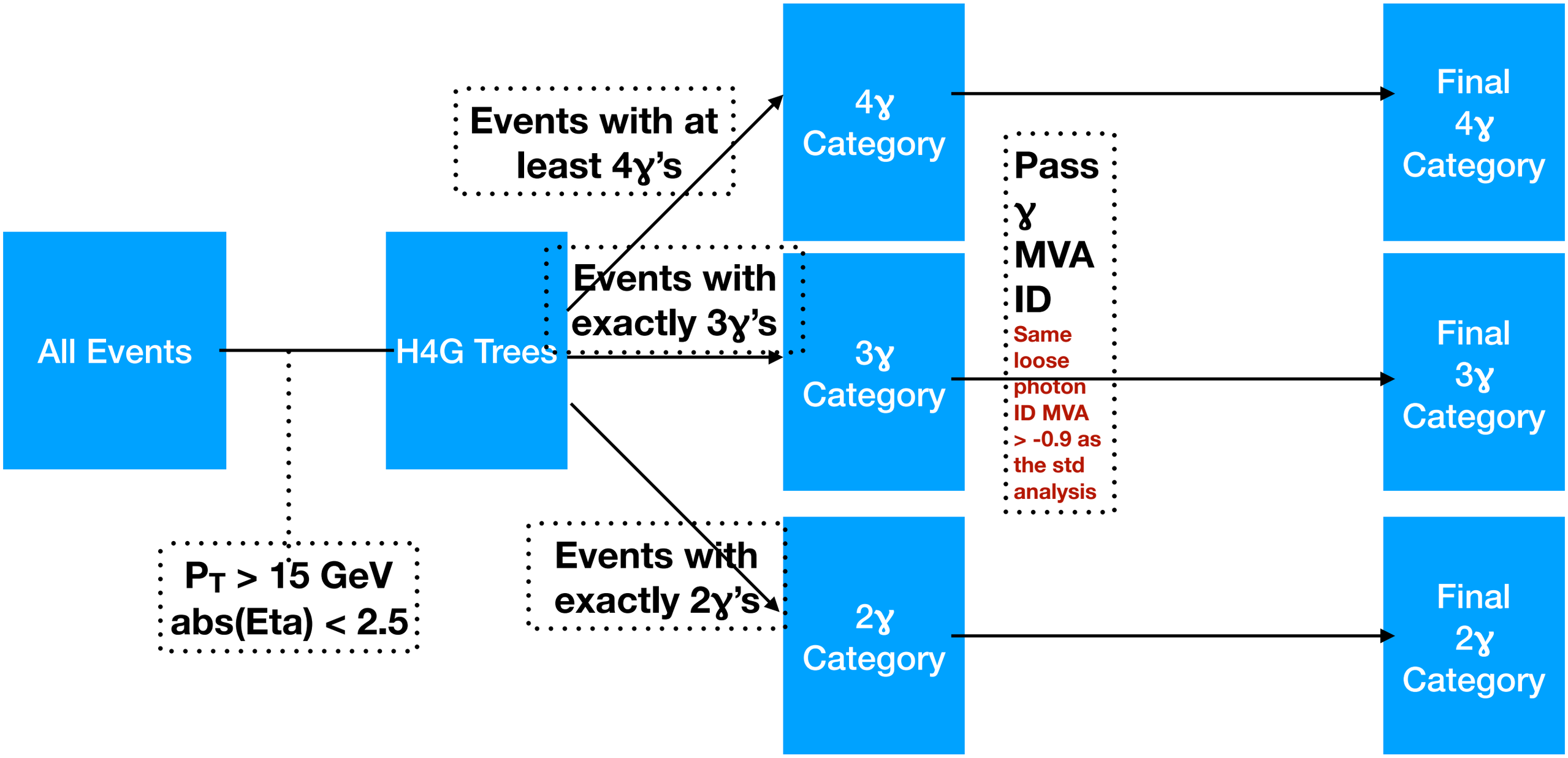
- Depending on m(a) we will have different topologies

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

- 3 possible scenarios
  1. All of the 4 photons are well isolated
     - Select events with at least 4 photons and select 4 photons with the highest P_T
  2. 2 Isolated photons + 2 merged photons
     - Select events with 3 photons
  3. 2 sets of merged photon pairs
     - Select events with 2 photons



ANALYSIS STRATEGY



- Signal extraction/limit setting to be done by performing a parametric fit on M(γγγγ)

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

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

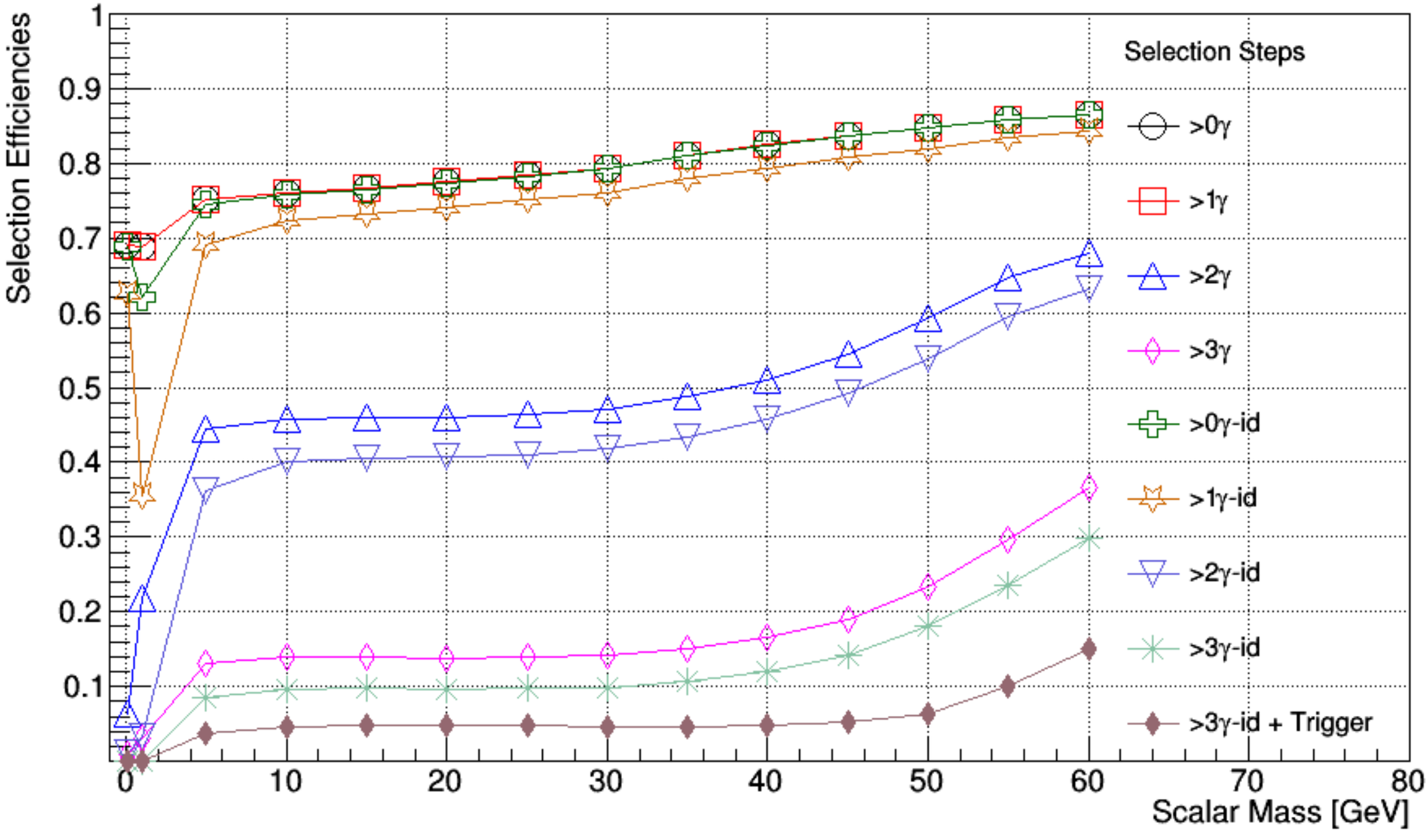
Offline Trigger like requirements

Category		R9	H/E	$\sigma_{i\eta i\eta}$	Pho Iso	Trk Iso
Both photons in EB		> 0.85	< 0.08	-	-	-
		> 0.5 && < 0.85	< 0.08	< 0.015	4 GeV	6 GeV
At least one Photon in EE	Second photon in EB	> 0.85	< 0.08	< 0.015	4 GeV	6 GeV
	Second Photon in EE	> 0.9	< 0.08	< 0.035	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

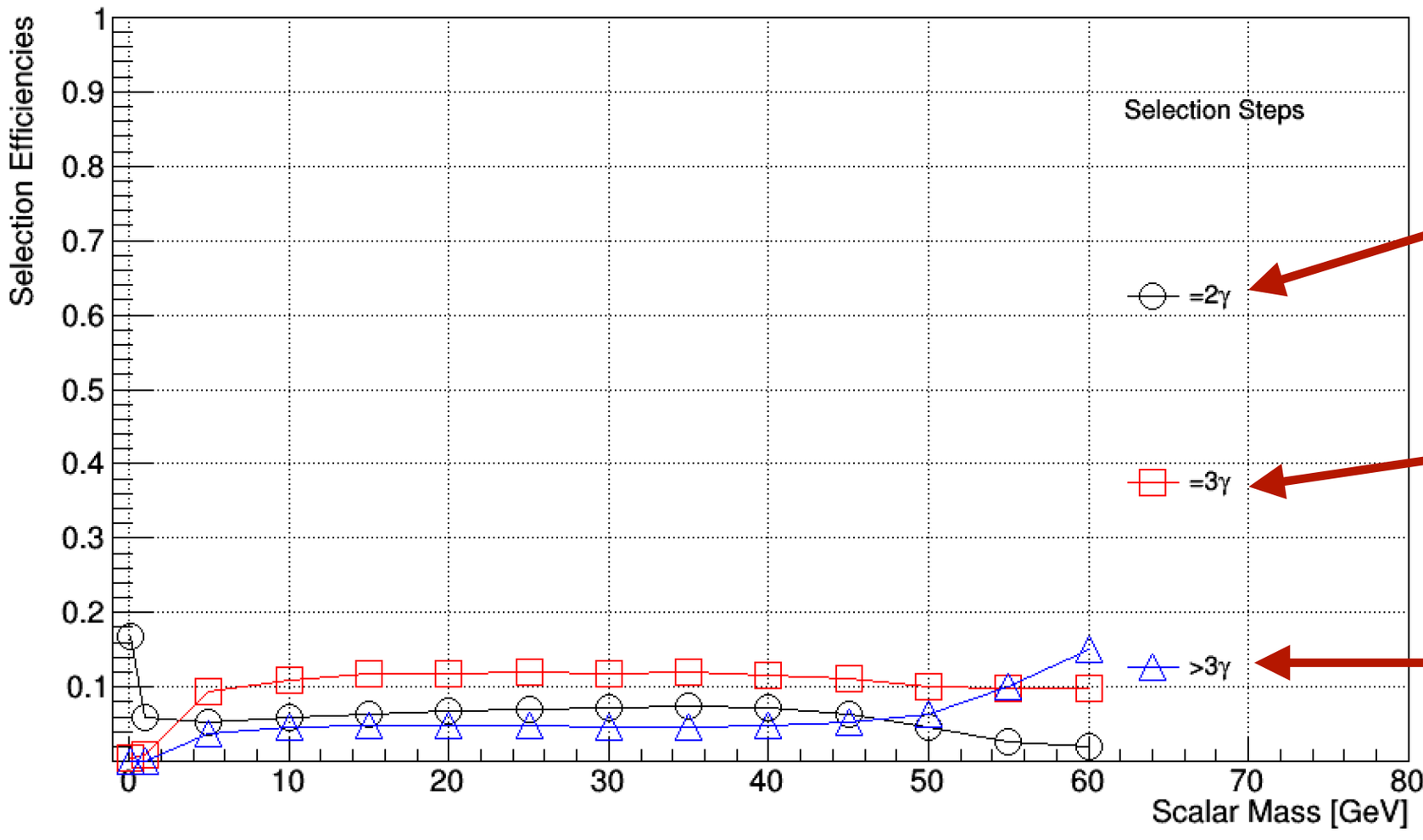
SIGNAL EFFICIENCIES

- Cut flow plot showing efficiencies at each step of the analysis for the 4-photons reconstructed final state



SIGNAL EFFICIENCIES

- Cut flow plot showing efficiencies at each step of the analysis for the 4-photon , 3-photon and 2 -photon reconstructed final state

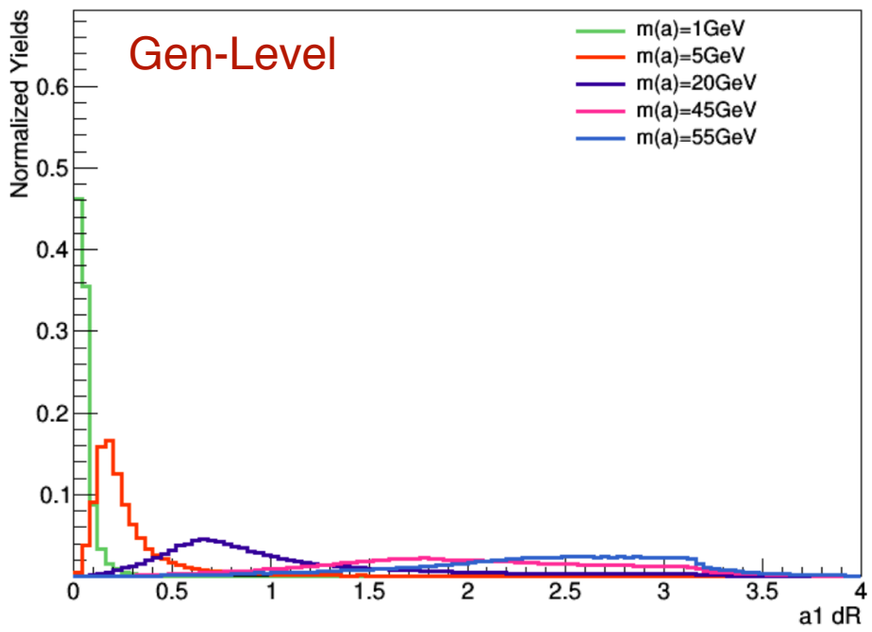


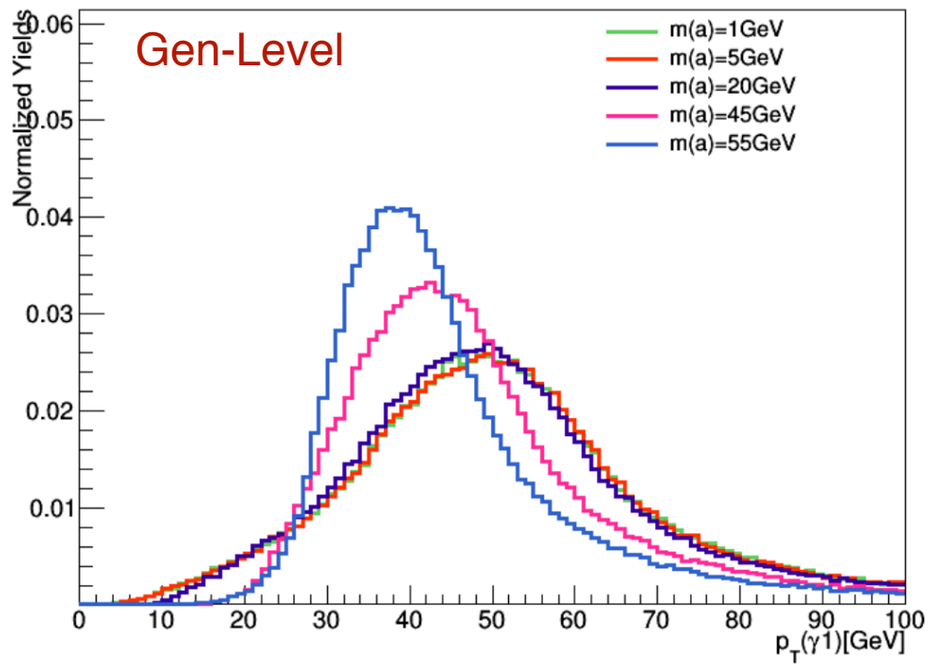
Number of events that have 2 ɣ's, all of which have passed photon ID + preselection cuts
2 Photon Category

Number of events that have 3 ɣ's, all of which have passed photon ID + preselection cuts
3 Photon Category

Number of events that have 4 or more ɣ's, all of which have passed photon ID + preselection cuts
4 Photon Category

SIGNAL EFFICIENCY Vs M(a)





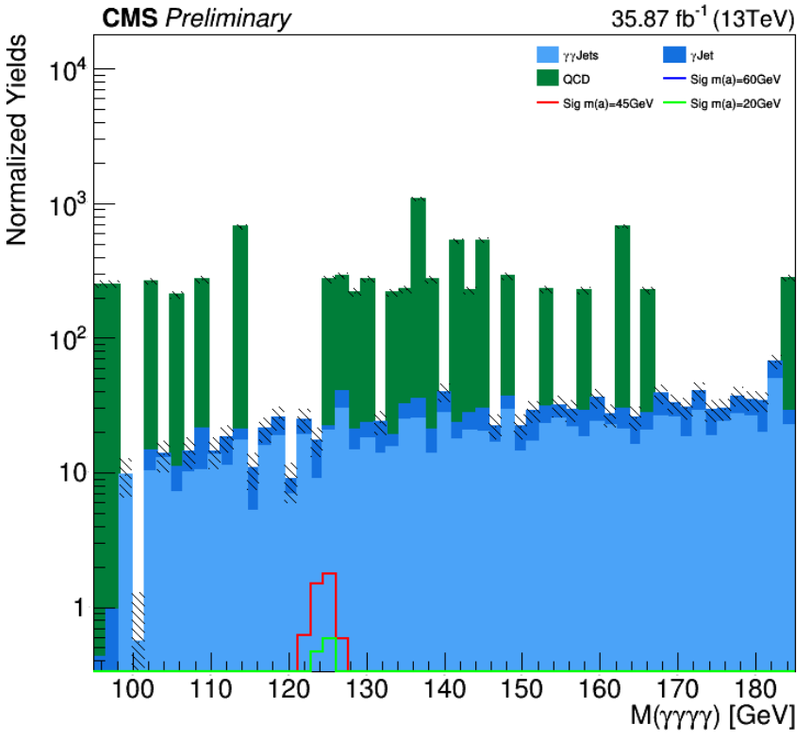
Distribution of ΔR between photons coming from the same "a"

Distribution of P_T of the leading photon

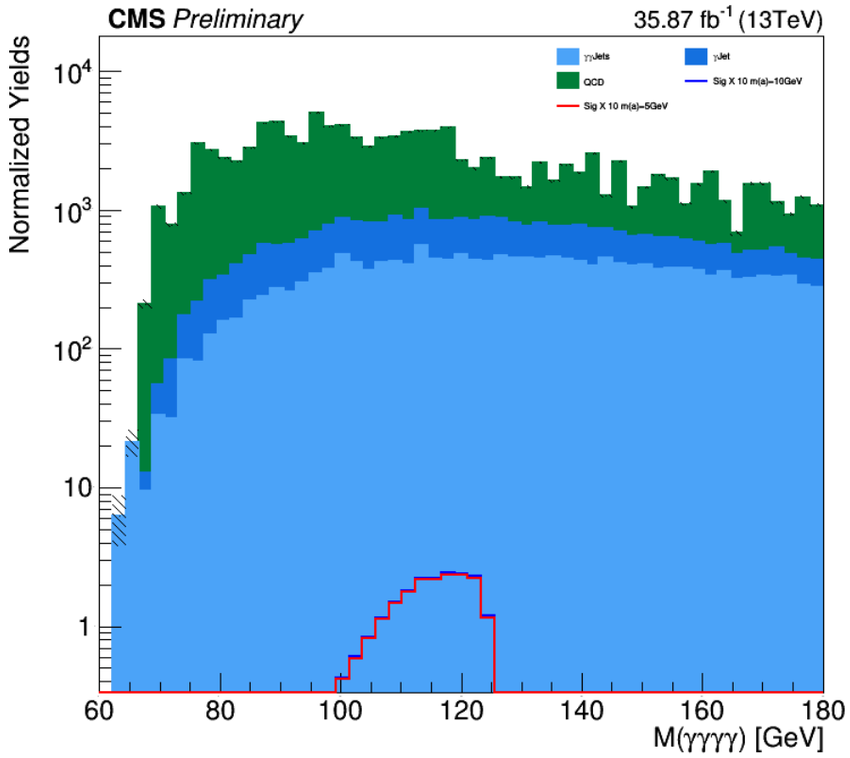
- Higher m(a) ⇾ lower boost of the "a" boson
  - Larger values of ΔR (calculated between two photons from the same "a")
  - Signal efficiency improves with increase in m(a)

SIGNAL & BACKGROUND COMPARISON

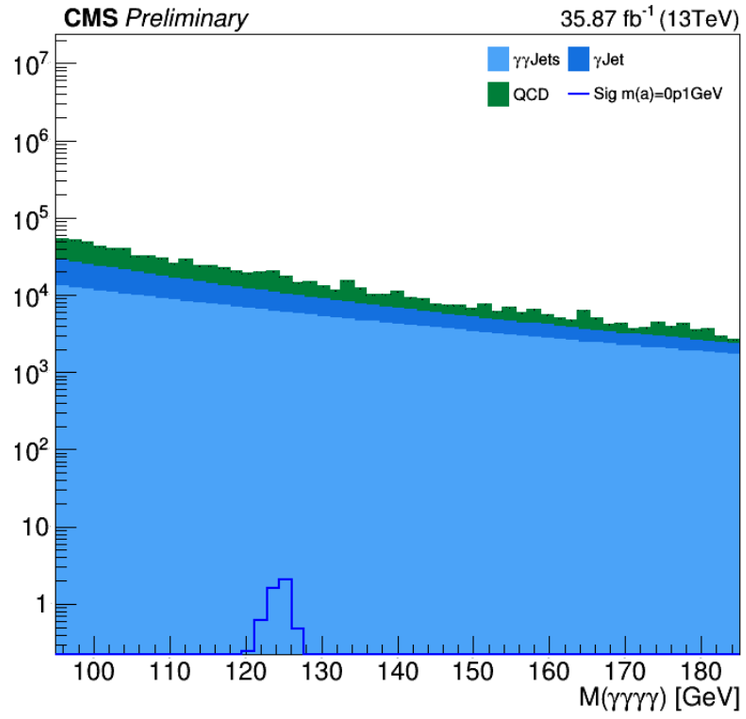
- Plots showing Background and Signal MC comparison
- Are only being used as a guide to determine the fitting and blinding range for the 4 photon, 3 photon and 2 photon categories



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

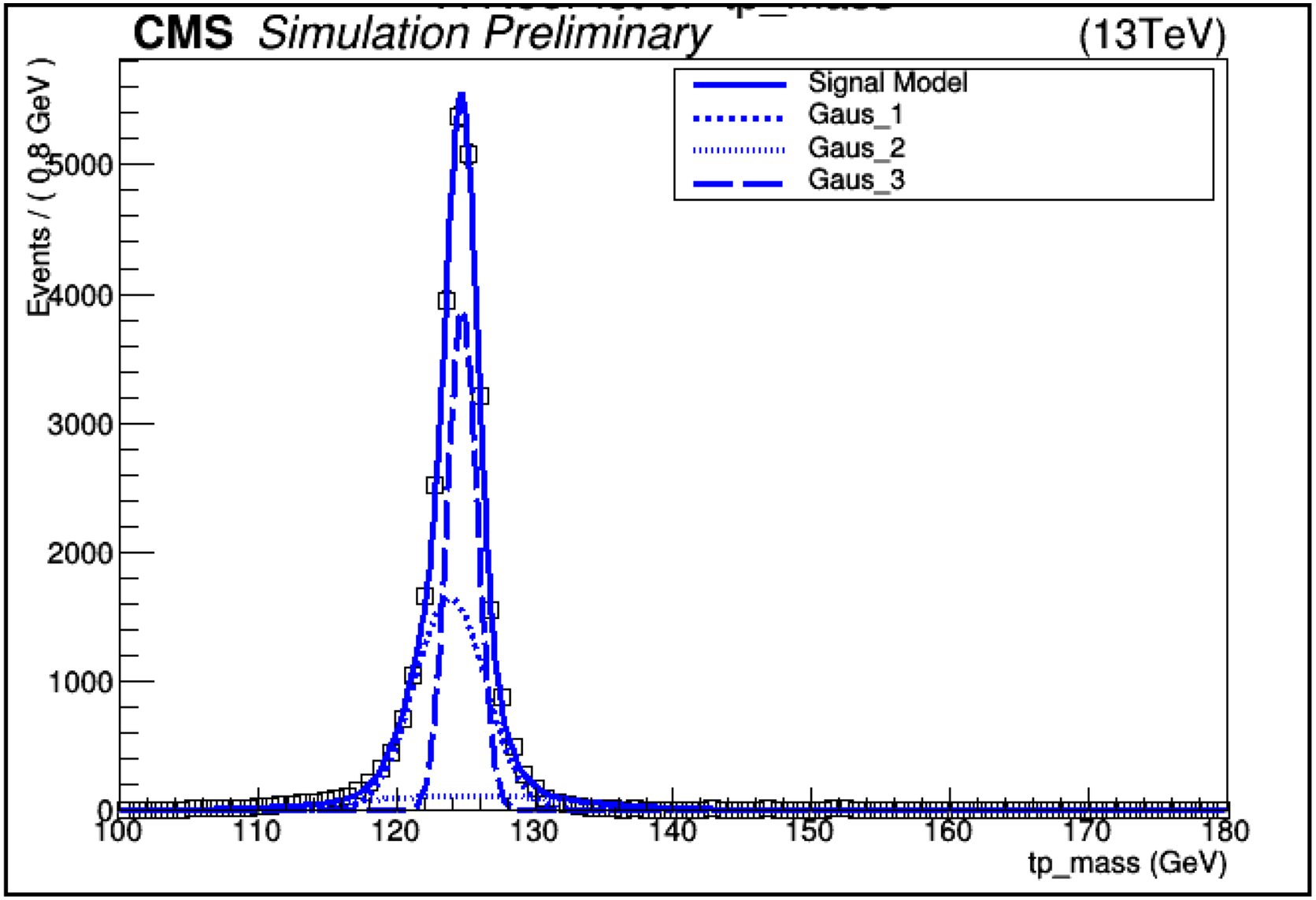
Fit of signal shape

4γ Category

MC: h→aa→γγγγ

m(a) = 60 GeV

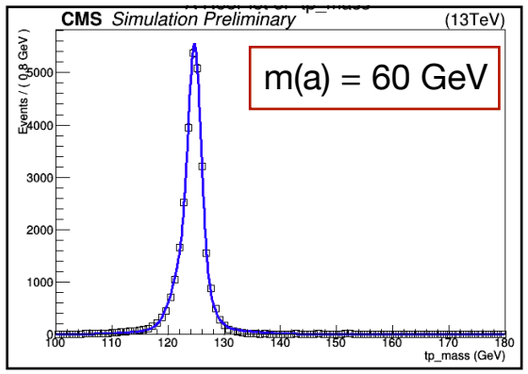
The 3 Gaussian components of the final Signal model are shown here

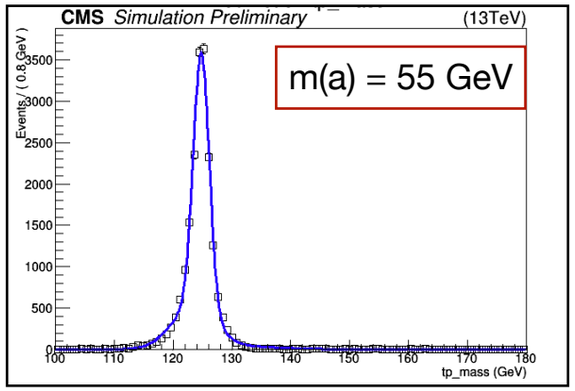


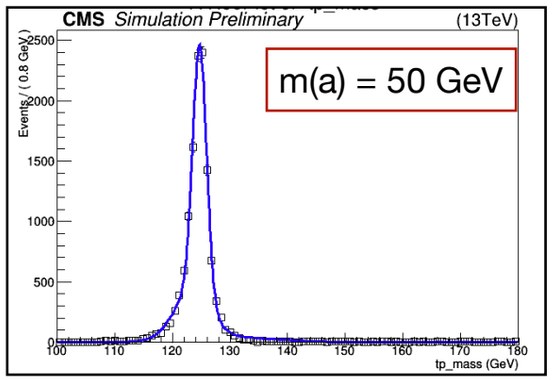
- For the 4 Photon category, consider the mass points from m(a) = 15 to 60 GeV
- The signal fits for these are shown on the next slide

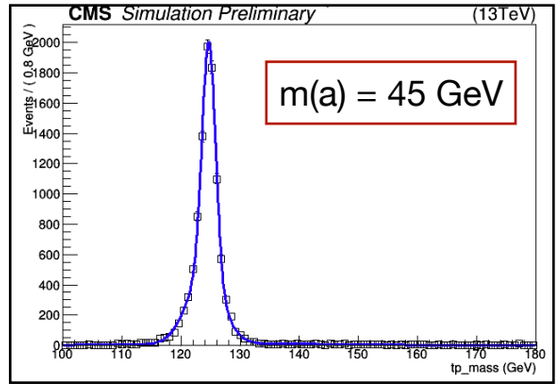
SIGNAL MODEL

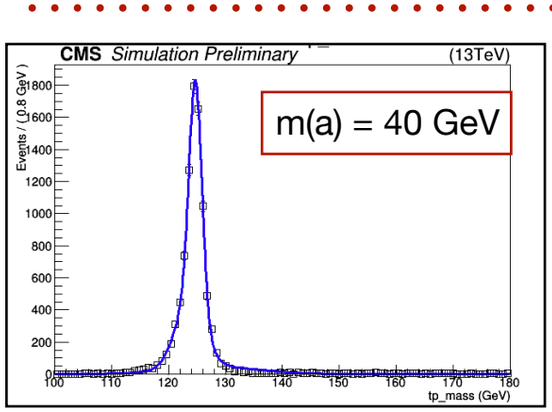
- For the 4γ Category

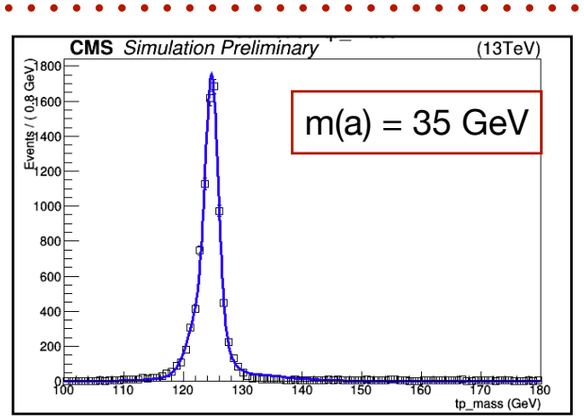


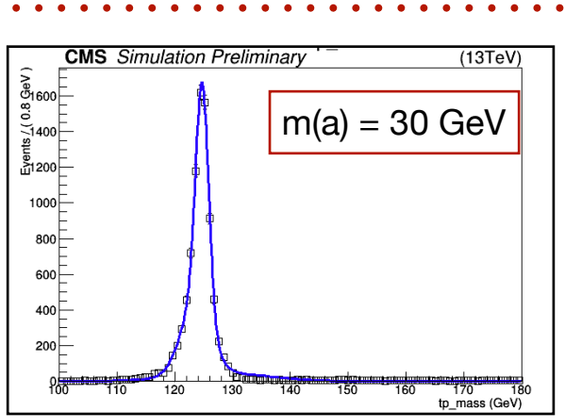


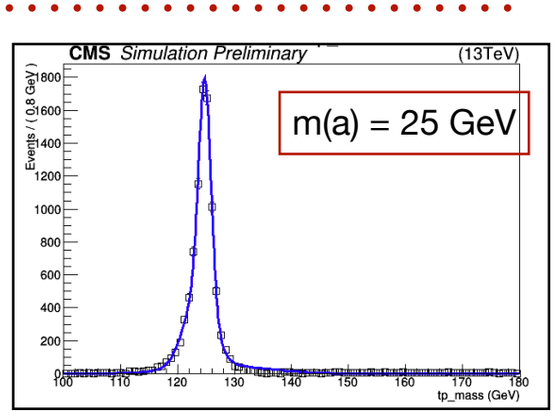


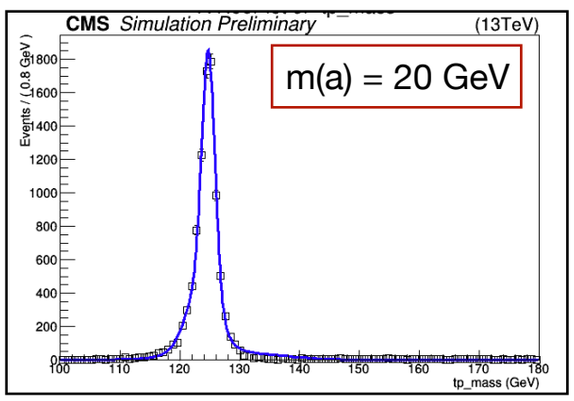


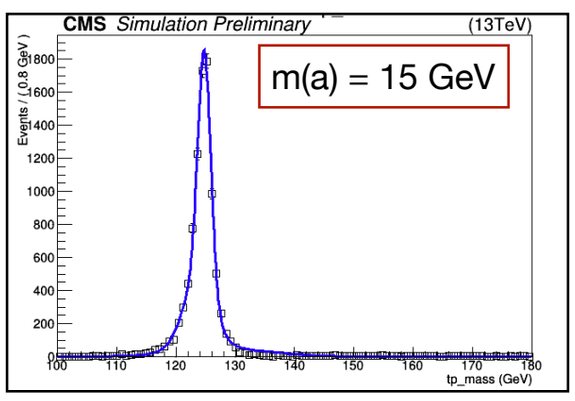












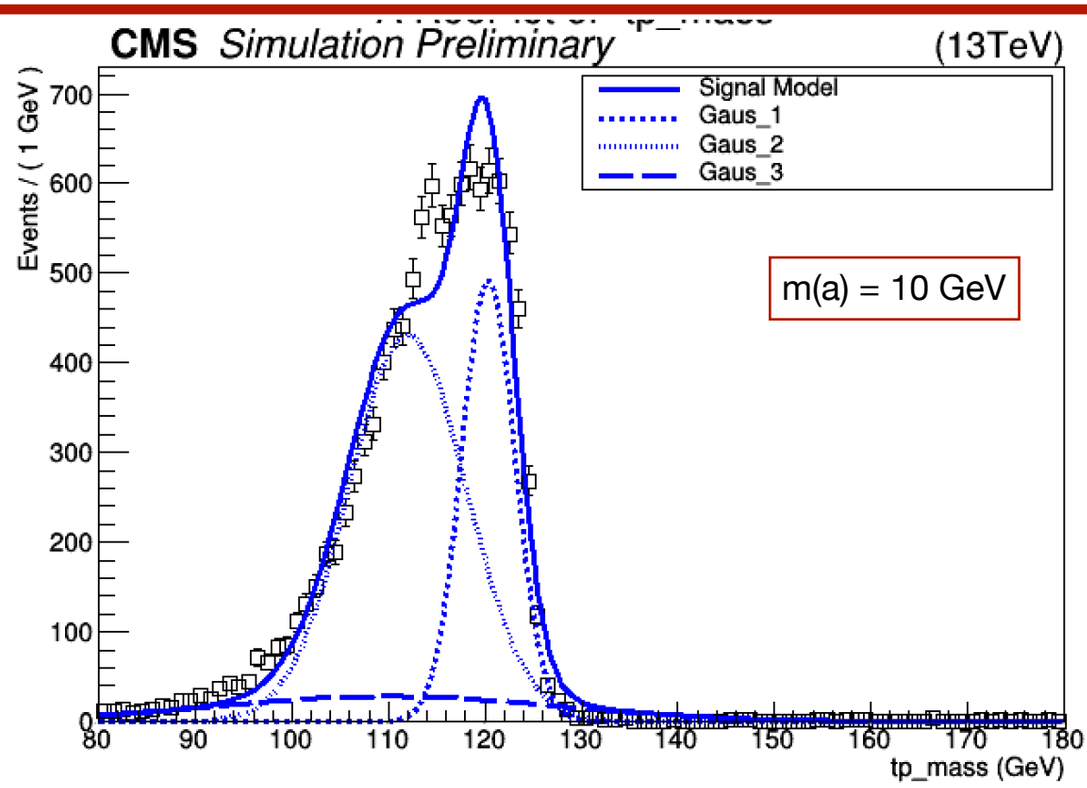
Gaussian PDF's fit to Signal MC samples

SIGNAL MODEL

Fit of signal shape for
3ɣ Category

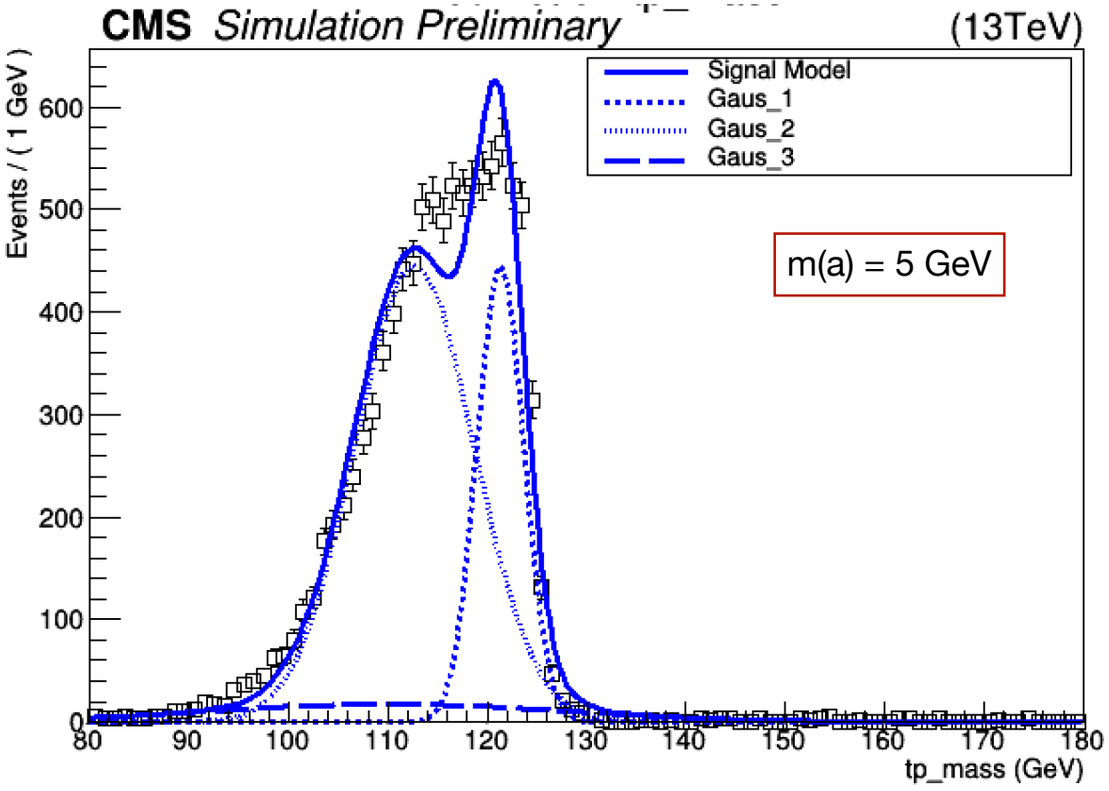
m(a) = 10 GeV, 5 GeV

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)

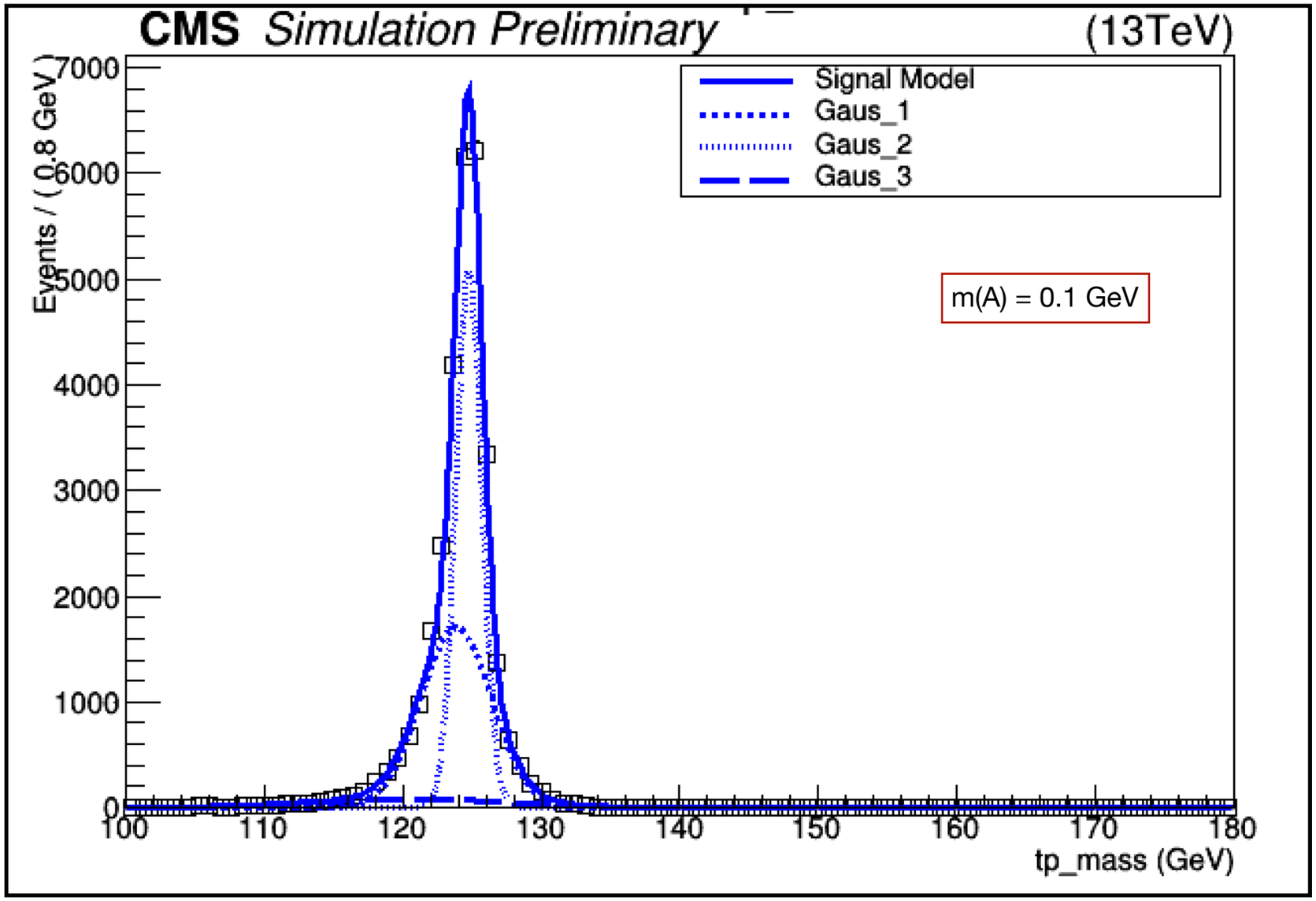


SIGNAL MODEL

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

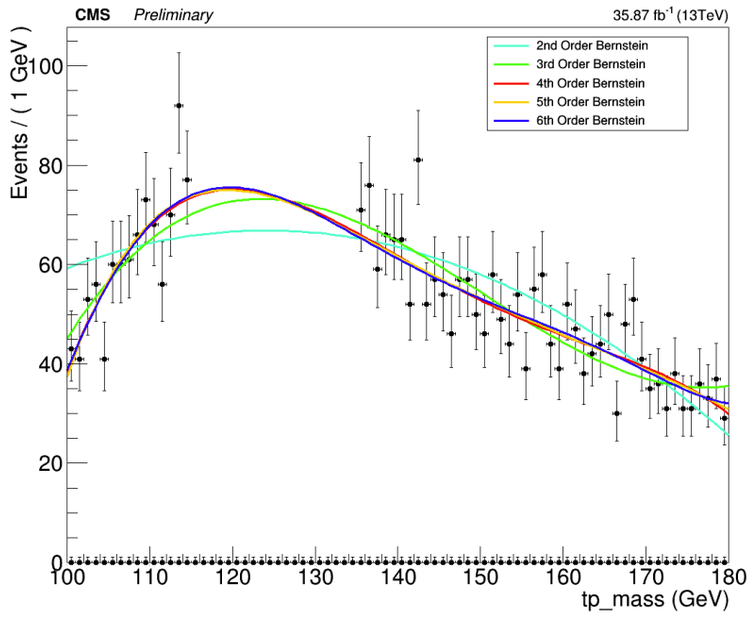
→ Work ongoing for the determination of representative set of functions from within a family using F-test

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

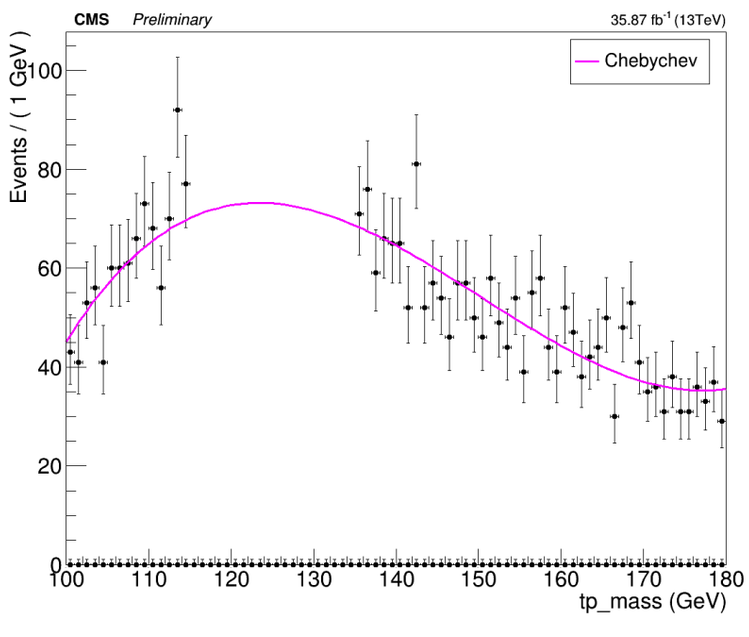
→ Fit range still to be optimized

BACKGROUND MODELING

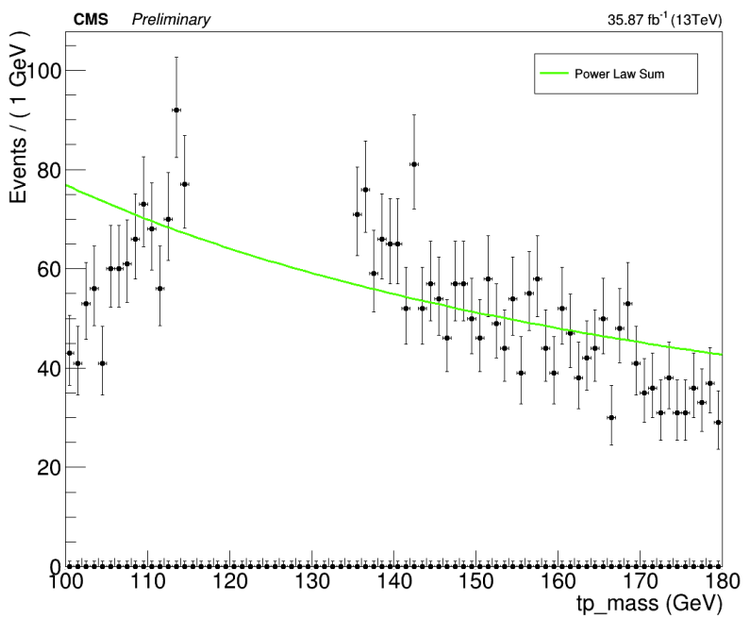
Family of Polynomials in Bernstein Basis



Chebychev Polynomial



Sums of Power Law functions

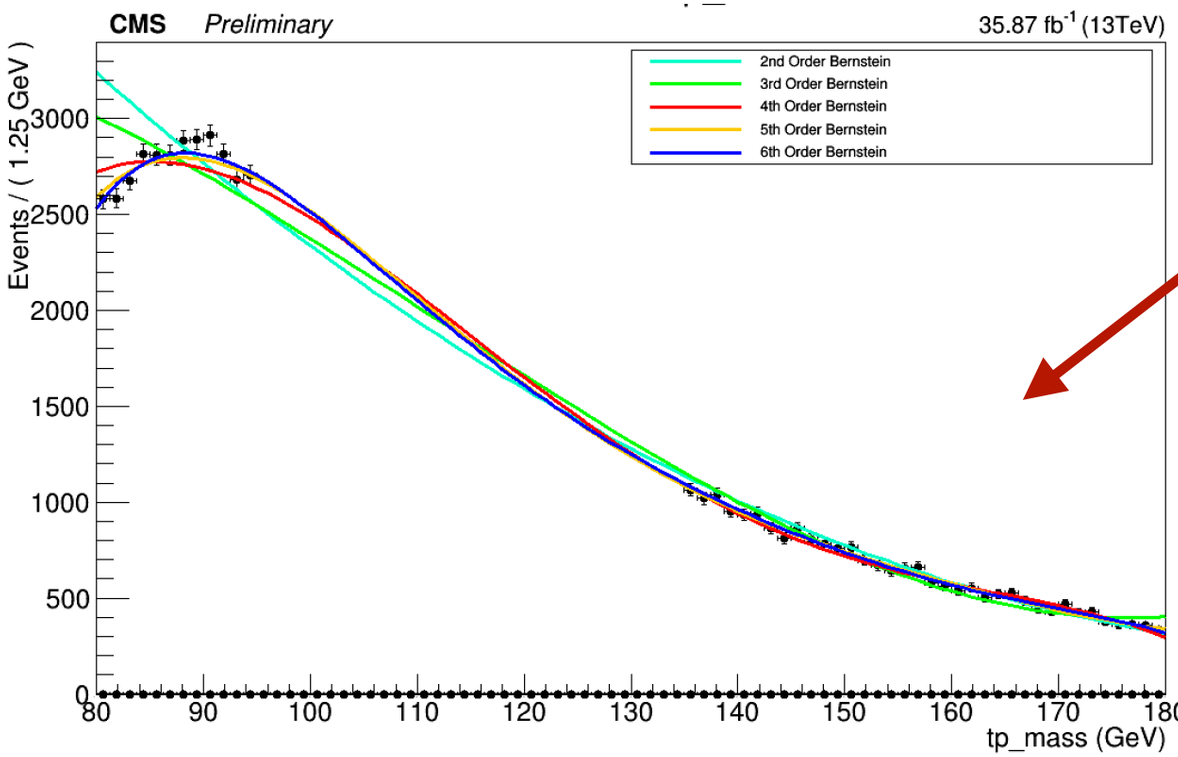


4γ Category

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

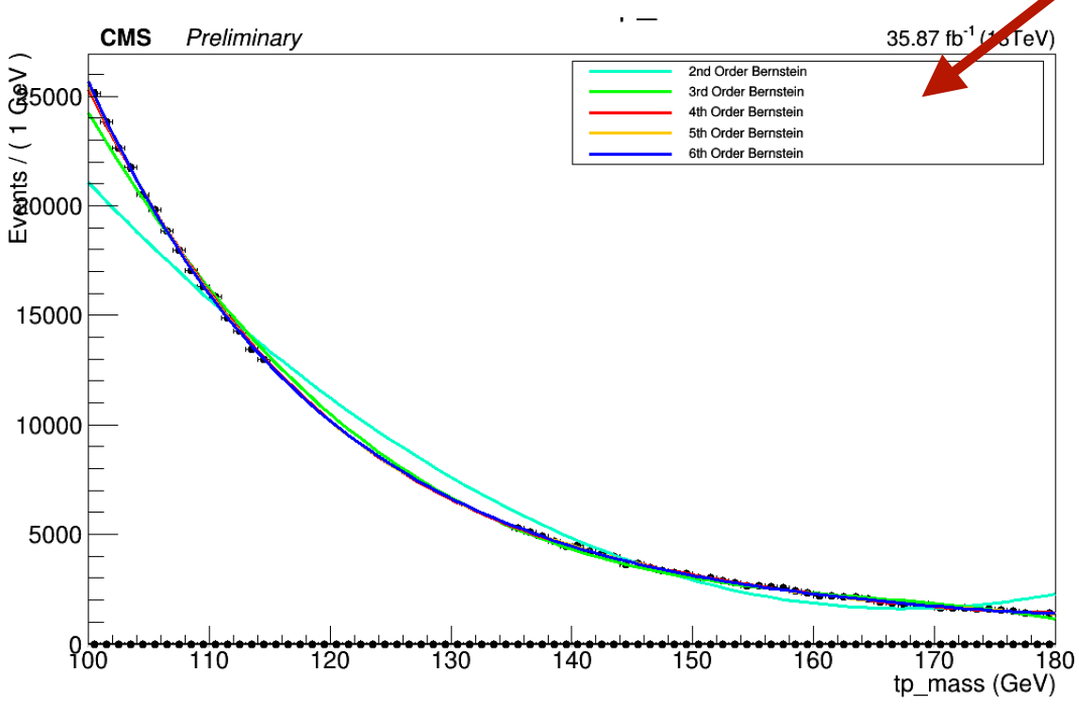
Functions considered:

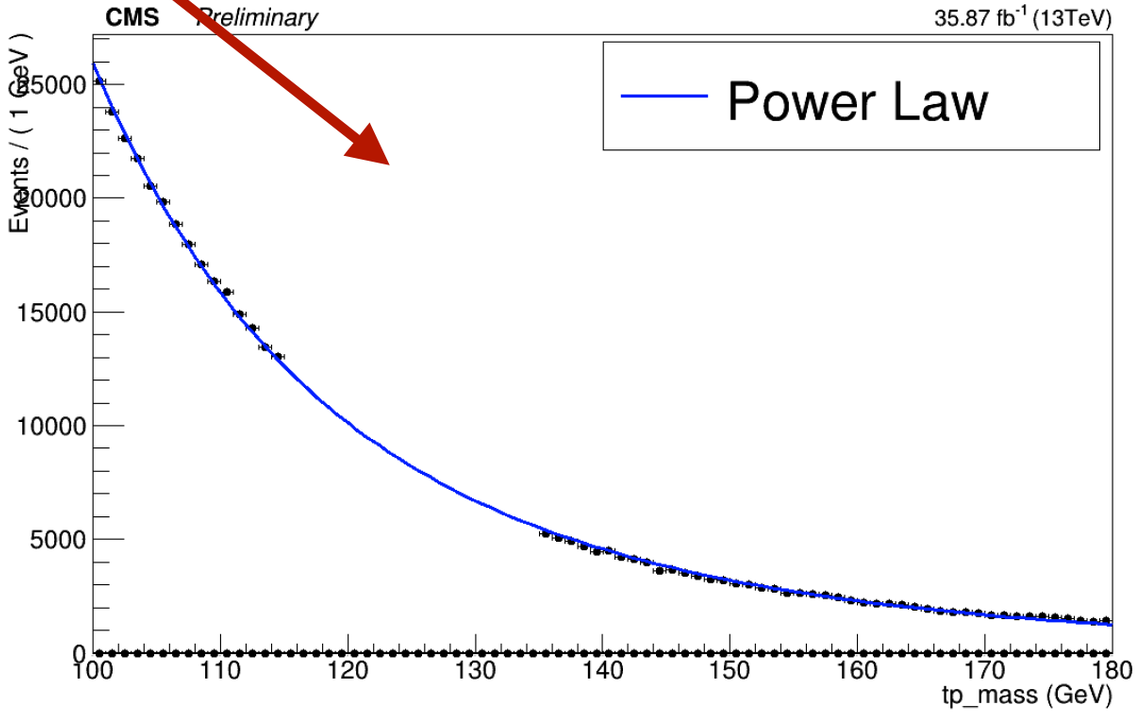
- Family of Bernstein Polynomials

2γ Category

Functions considered:

- Family of Berstein Polynomials
- Sum of Power Law





DIPHOTON/MULTIPHOTON DATA PARKING PROSPECT

- Possibility of low P_T DiPhoton or MultiPhoton Scouting stream
  - But, scouting could be dangerous since Photons are not simple objects
  - Several layers of regressions are applied on Photons in addition to MVA based ID's
  - The availability of all these pieces of information in the reduced data format is very important

- Data Parking may be a better solution
  - The existing HLT paths use Diphoton L1 seeds
  - We need a 3ɣ and 4ɣ seed for the "resolved" topology
  - Relatively long term plan

SUMMARY & OUTLOOK

- Presented h(125)→aa→ɣɣɣɣ analysis strategy

- Studies Ongoing:

  - Development of MVA to distinguish merged photons from isolated photons
  - Background fit bias - Choose representative functions from each family of function to be used in the “Envelope” method.
  - Signal modeling and optimization of the fit range

BACKUP

OFFLINE TRIGGER LIKE CUTS

How well are the offline trigger like requirements emulating the HLT paths?

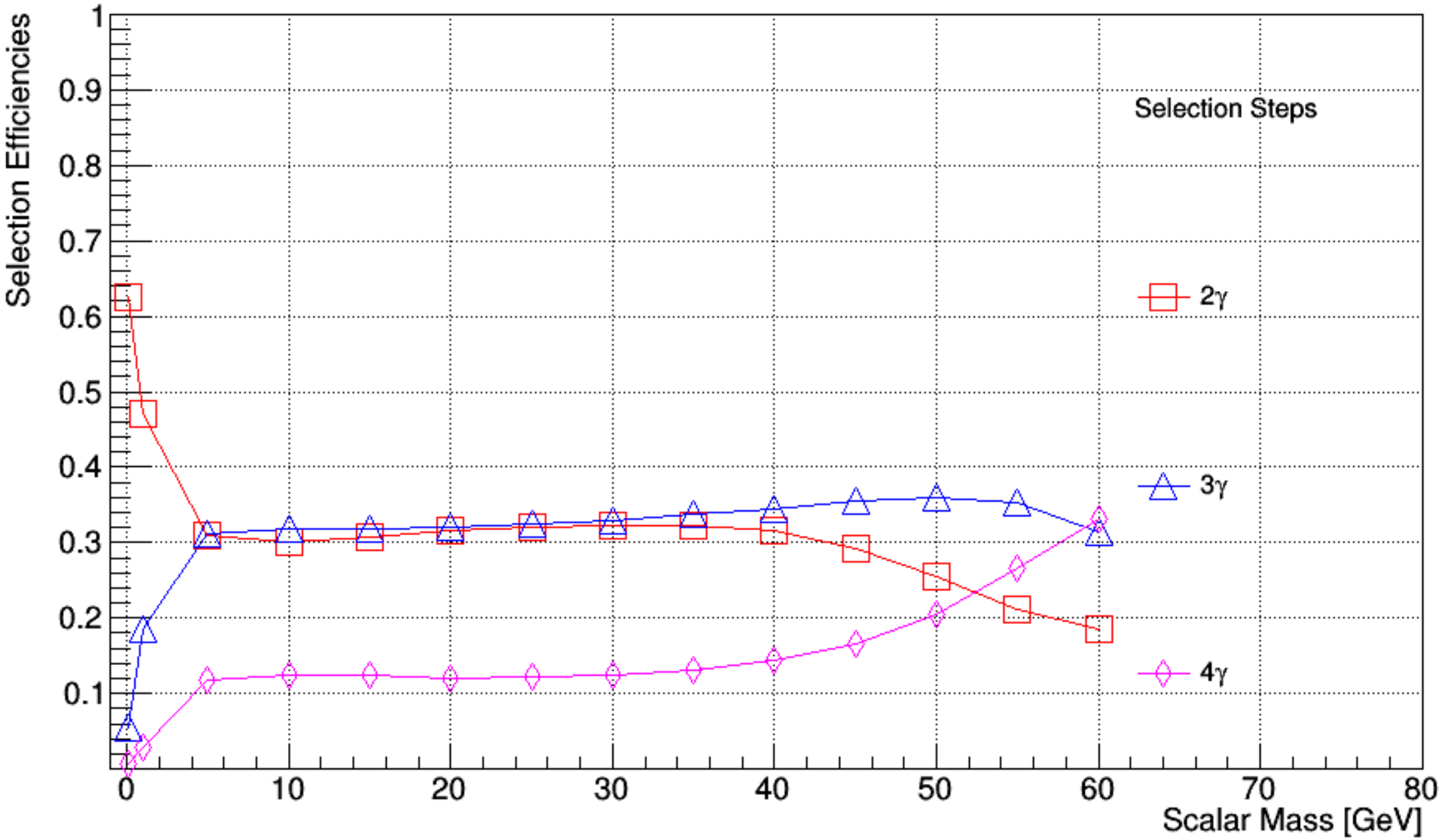
m(a) GeV		Uncertainty
0.1	1.00	0.25
1	0.92	0.15
5	0.97	0.02
10	0.98	0.01
15	0.99	0.01
20	0.99	0.01
25	0.99	0.01
30	0.98	0.01
35	0.98	0.01
40	0.98	0.01
45	0.98	0.01
50	0.98	0.01
55	0.97	0.01
60	0.98	0.01

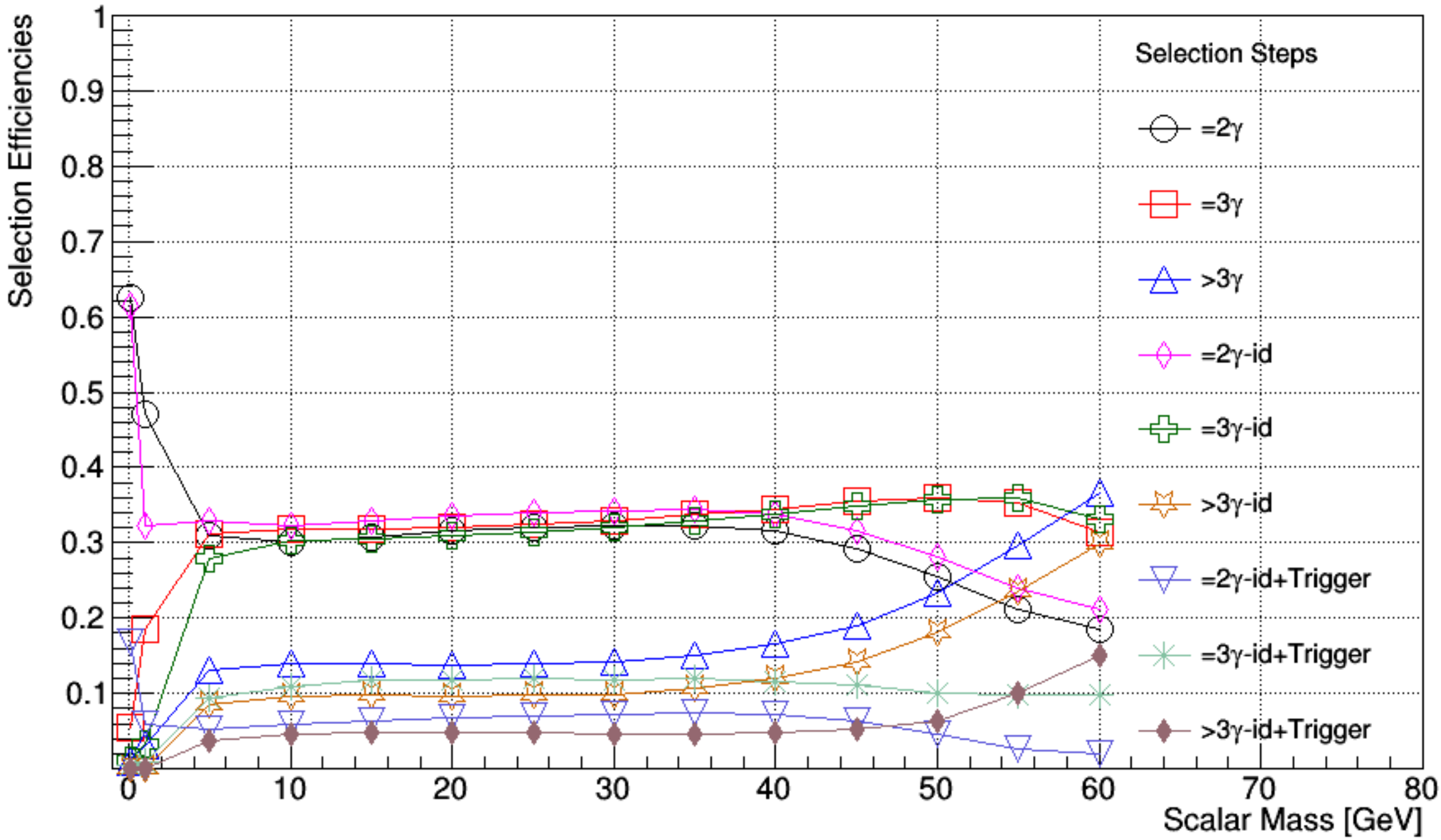
SIGNAL EFFICIENCIES

- Cut flow table showing efficiencies at each step of the analysis for the 4-photons reconstructed final state

m(a)	MicroAOD	>0 photons	>1 photon	>2 photons	>3 photons	>0 photon + ID	>1 photons + ID	>2 photons + ID	>3 Photons + ID	>3 Photons + ID + Offline trigger
0.1	200000	137989	137989	12861	1707	137591	125127	2315	86	31
1	200000	137832	137832	43528	6273	124384	71093	6622	241	78
5	200000	150476	150476	88746	26408	149204	138142	72526	16864	7461
10	195505	148436	148436	89530	27341	148048	141283	78296	18970	8931
15	200000	153208	153208	91736	28067	152972	146585	80969	19778	9810
20	200000	154959	154959	91862	27648	154745	148267	81315	19364	9685
25	200000	156866	156866	92726	27906	156624	150295	82142	19527	9549
30	200000	158757	158757	94077	28290	158541	152181	83679	19712	9089
35	200000	162183	162183	97693	30034	161971	155808	86945	21223	9094
40	200000	165070	165070	101998	33039	164833	158767	91342	23868	9611
45	198033	165743	165743	107947	37744	165552	159888	97436	28172	10579
50	200000	169532	169532	118454	46606	169330	164020	107679	36066	12892
55	199200	171124	171124	129051	58893	170931	166229	118638	46981	19903
60	198014	171377	171377	134776	72436	171161	166811	124965	59171	29935

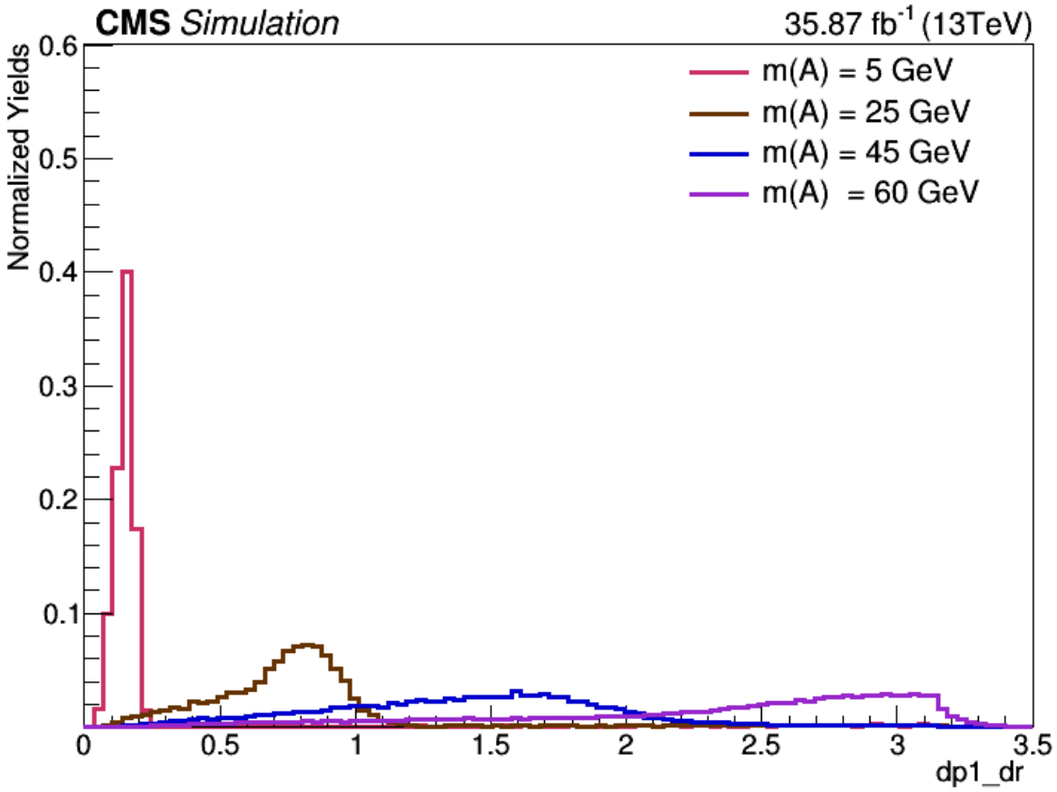
- Events with exactly 2, 3 and 4 photons

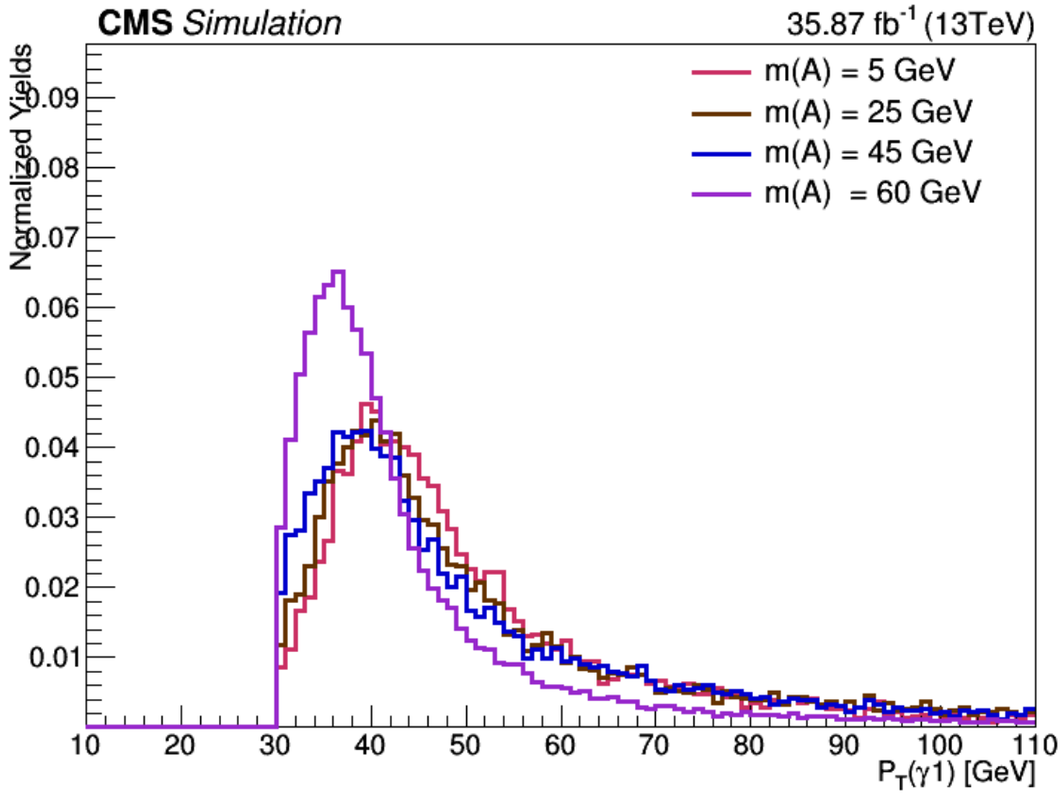



Selection Efficiencies
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60
70
80
Scalar Mass [GeV]
Selection Steps
=2γ
=3γ
>3γ
=2γ-id
=3γ-id
>3γ-id
=2γ-id+Trigger
=3γ-id+Trigger
>3γ-id+Trigger

Final # of events in each category

		4 Photon	3 Photon	2 Photon
m(a)	tot number of events	Skim	Skim	Skim
60	198014	29935	10571	3164
55	199200	19903	10209	4387
50	200000	12892	10244	8023
45	198033	10579	11336	11161
40	200000	9611	11843	12820
35	200000	9094	12515	13221
30	200000	9089	12553	12759
25	200000	9549	12853	12470
20	200000	9685	12790	11919
15	200000	9810	12361	11276
10	195505	8931	11291	10422
5	200000	7461	10161	9173
1	200000	78	766	9572
0.1	200000	31	445	30688



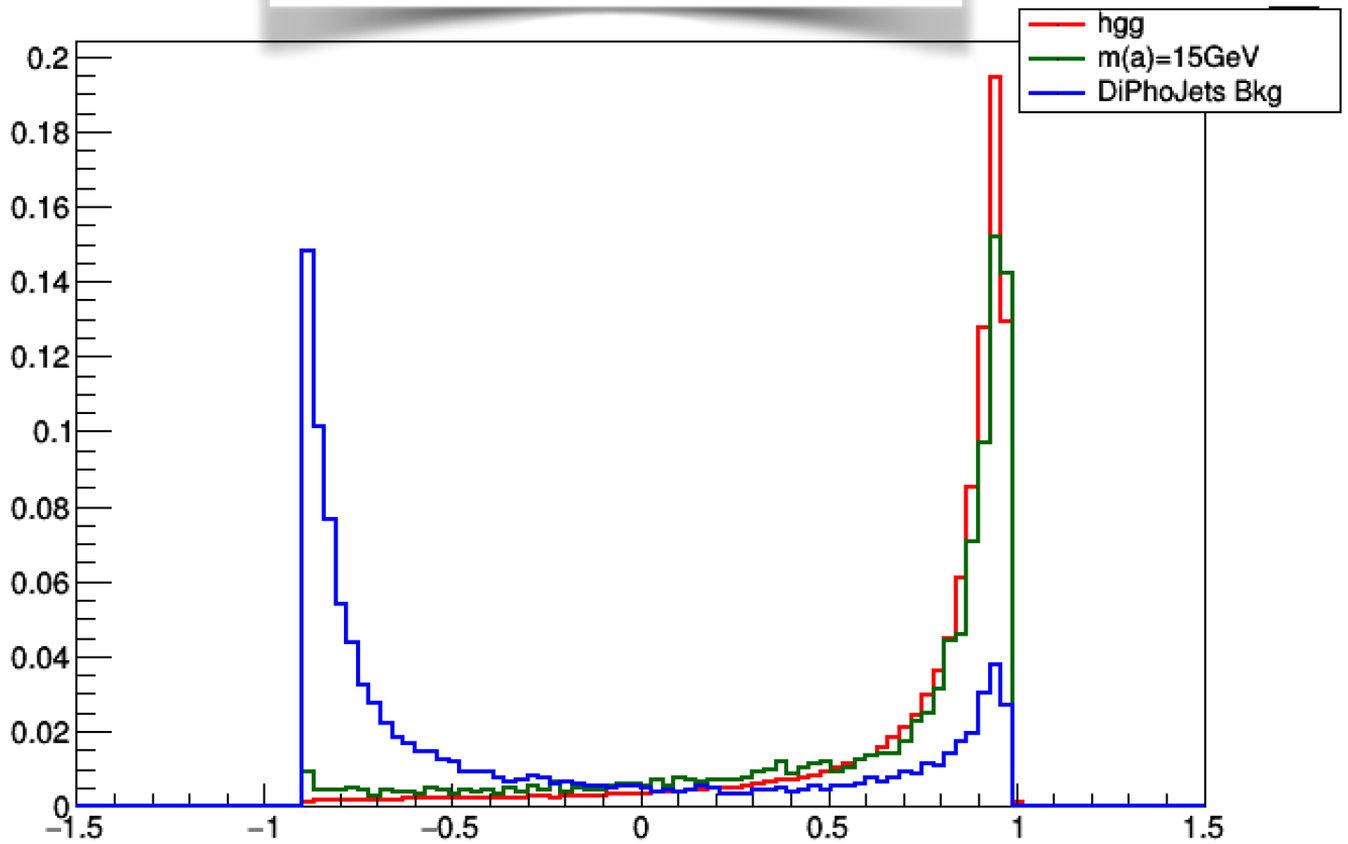


Reco level distributions

PhotonID MVA

- PhotonID MVA was developed for standard Hɣɣ analysis @ Pt 20 GeV and this is a check to show that it works for our samples as well

MVA distribution of
the lowest pT Photon
(For Pt > 20 GeV)



Signal and Background comparison for the 4 photon category