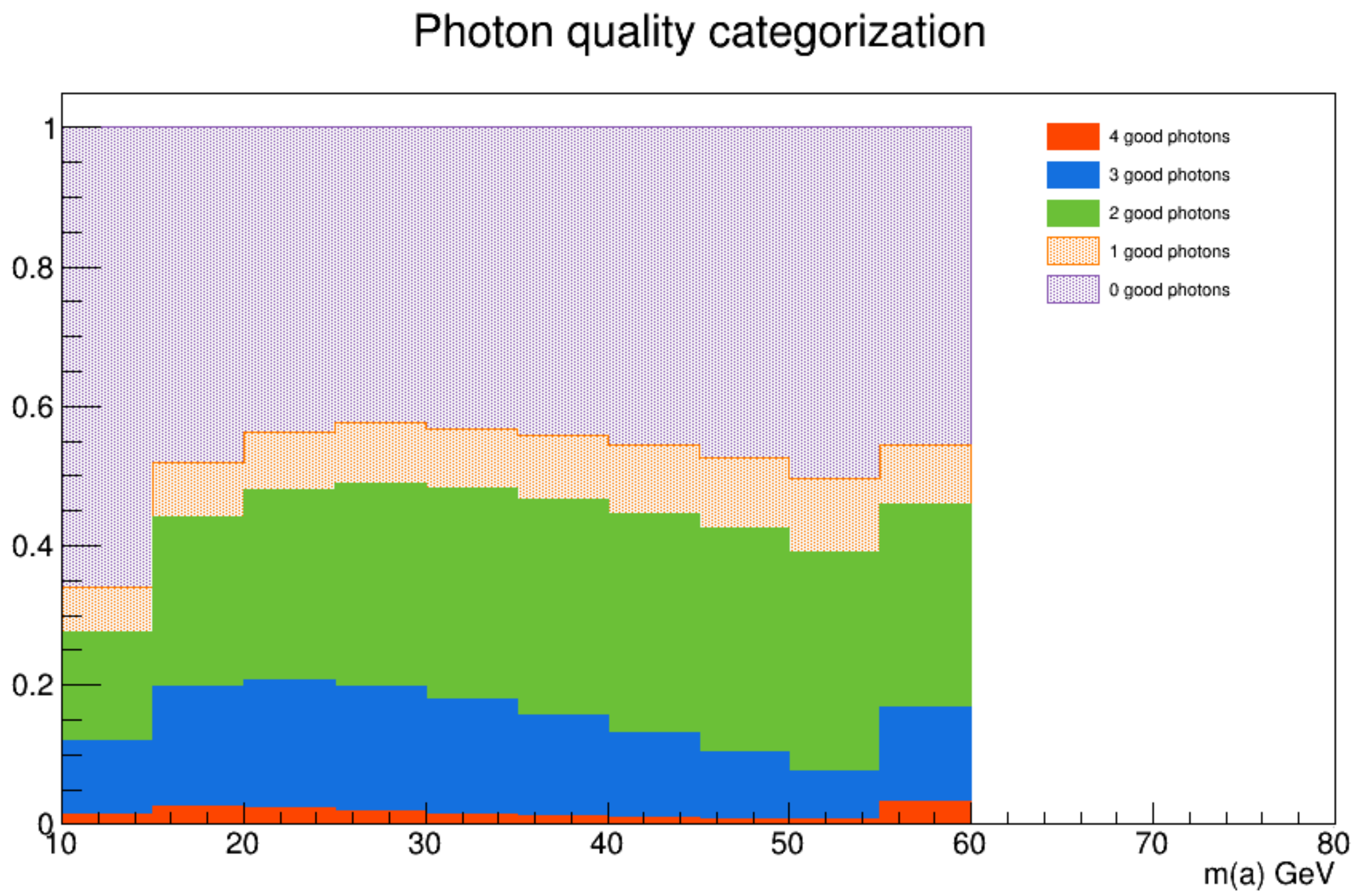
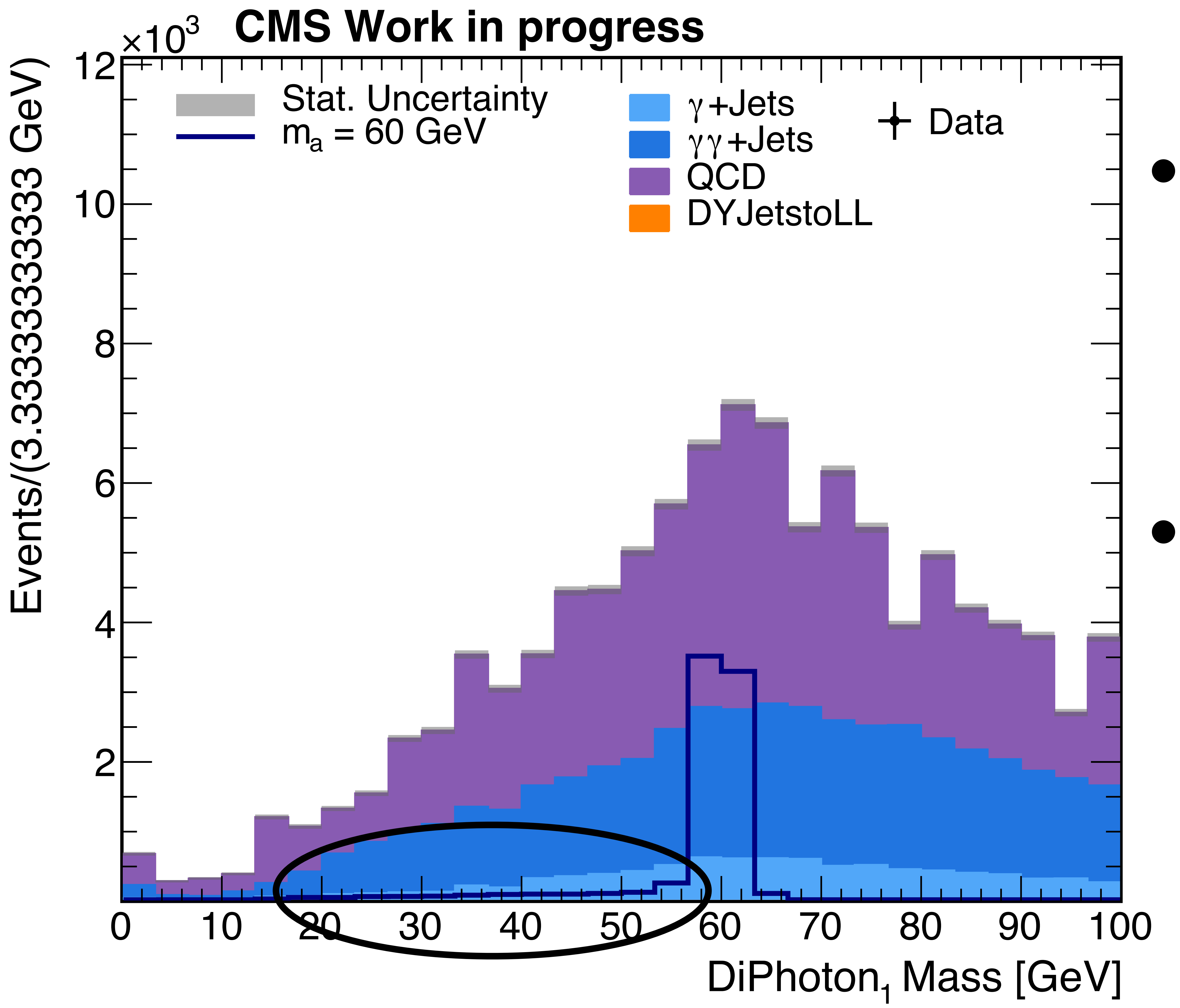
Photon quality distribution

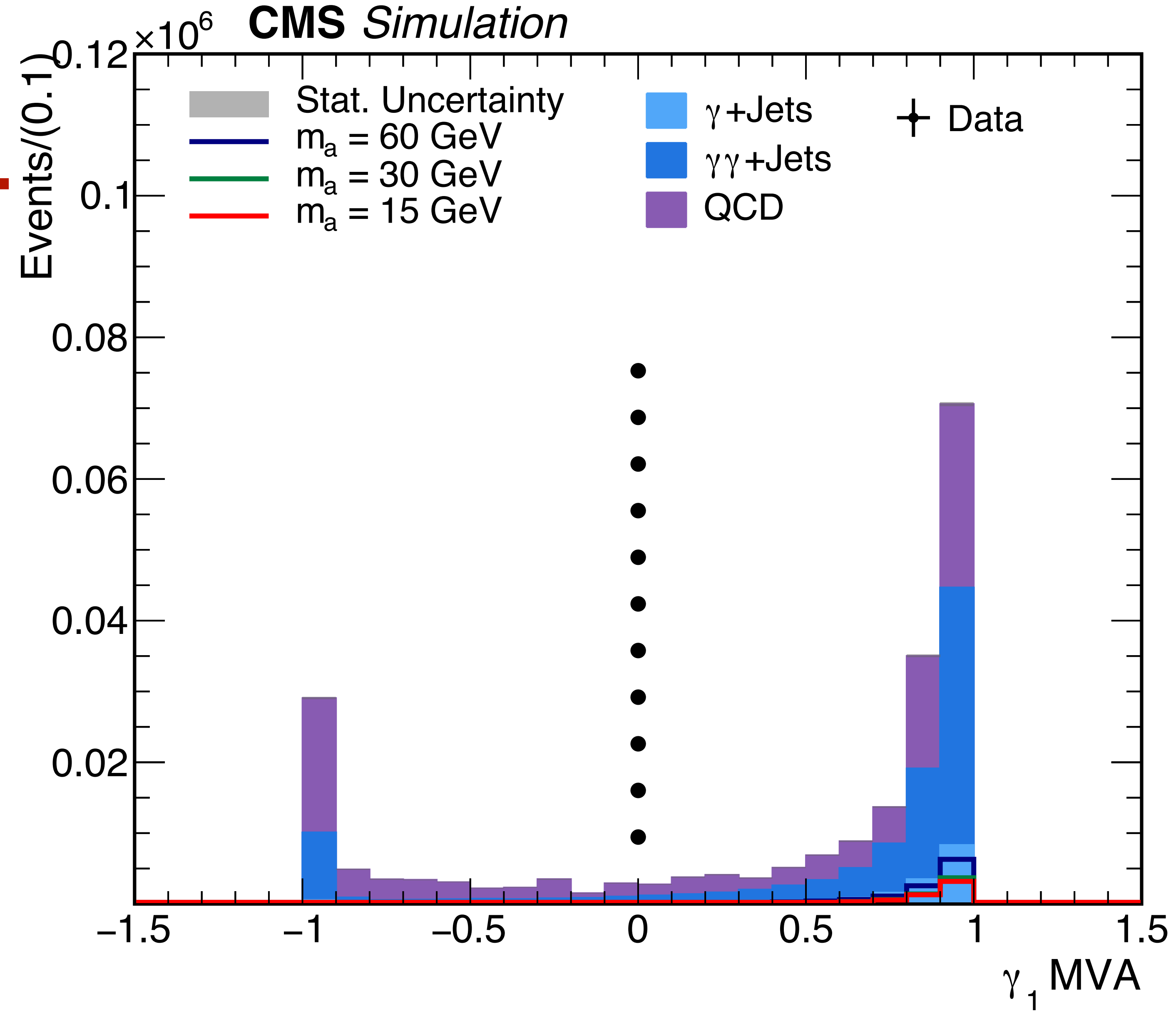
- For events with at least 4 photons (we choose the first 4 highest Pt photons)
- Definitions:
  - Good photon: Come from a di-photon that passed pre-selection
  - Bad photon: Comes from a di-photon that did not pass pre-selection

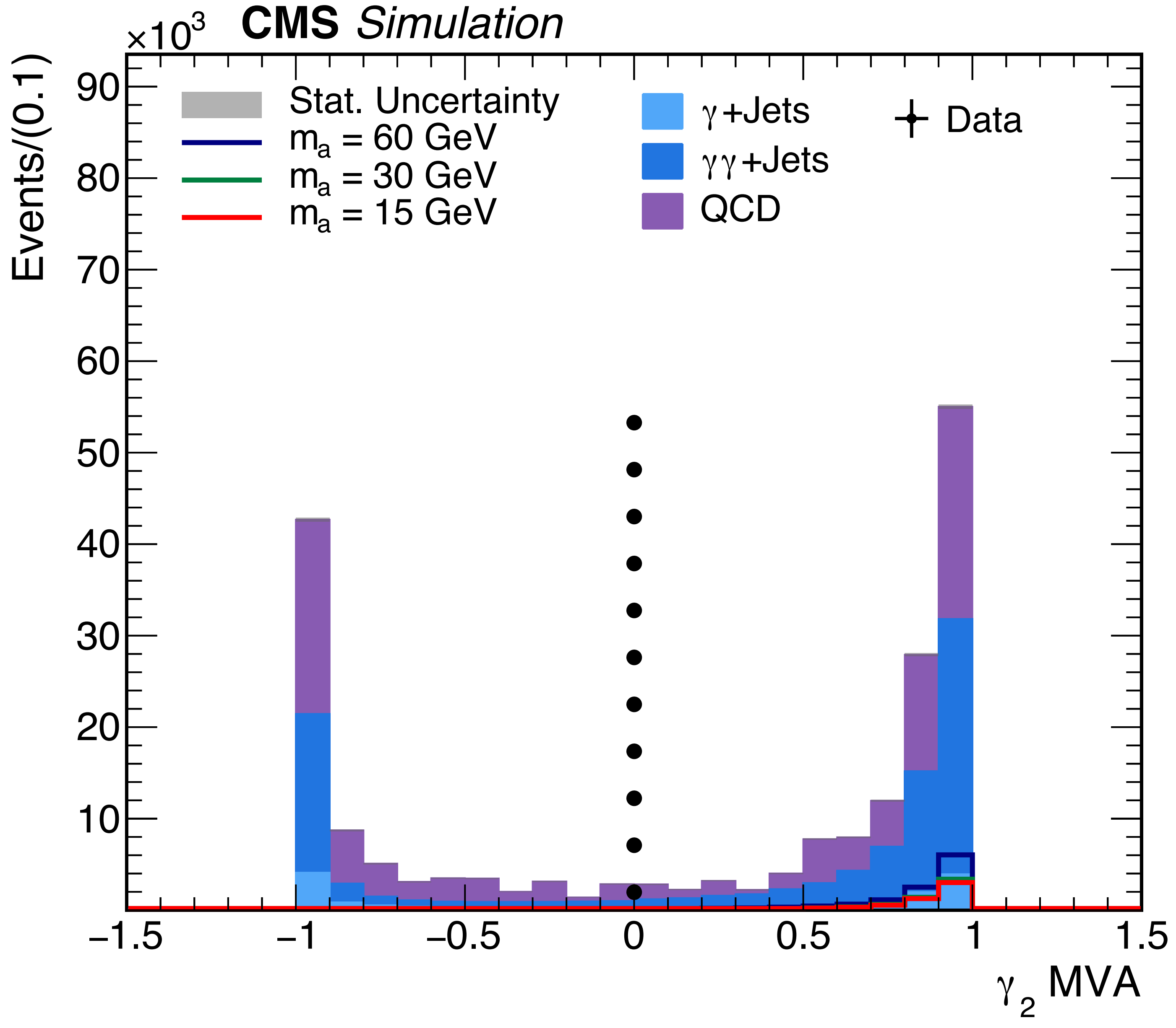


- Events in solid colors are what we are interested in



- This tail could be coming from the case where one of the photons could actually be a jet, and the combination manages to pass the di **γ** mass > 55 GeV pre-selection cut
- Can try to minimize this contribution by applying selections on the photon MVA


CMS Simulation
Events/(0.1)
×10^6
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ_1 MVA


CMS Simulation
Events/(0.1)
×10^3
Stat. Uncertainty
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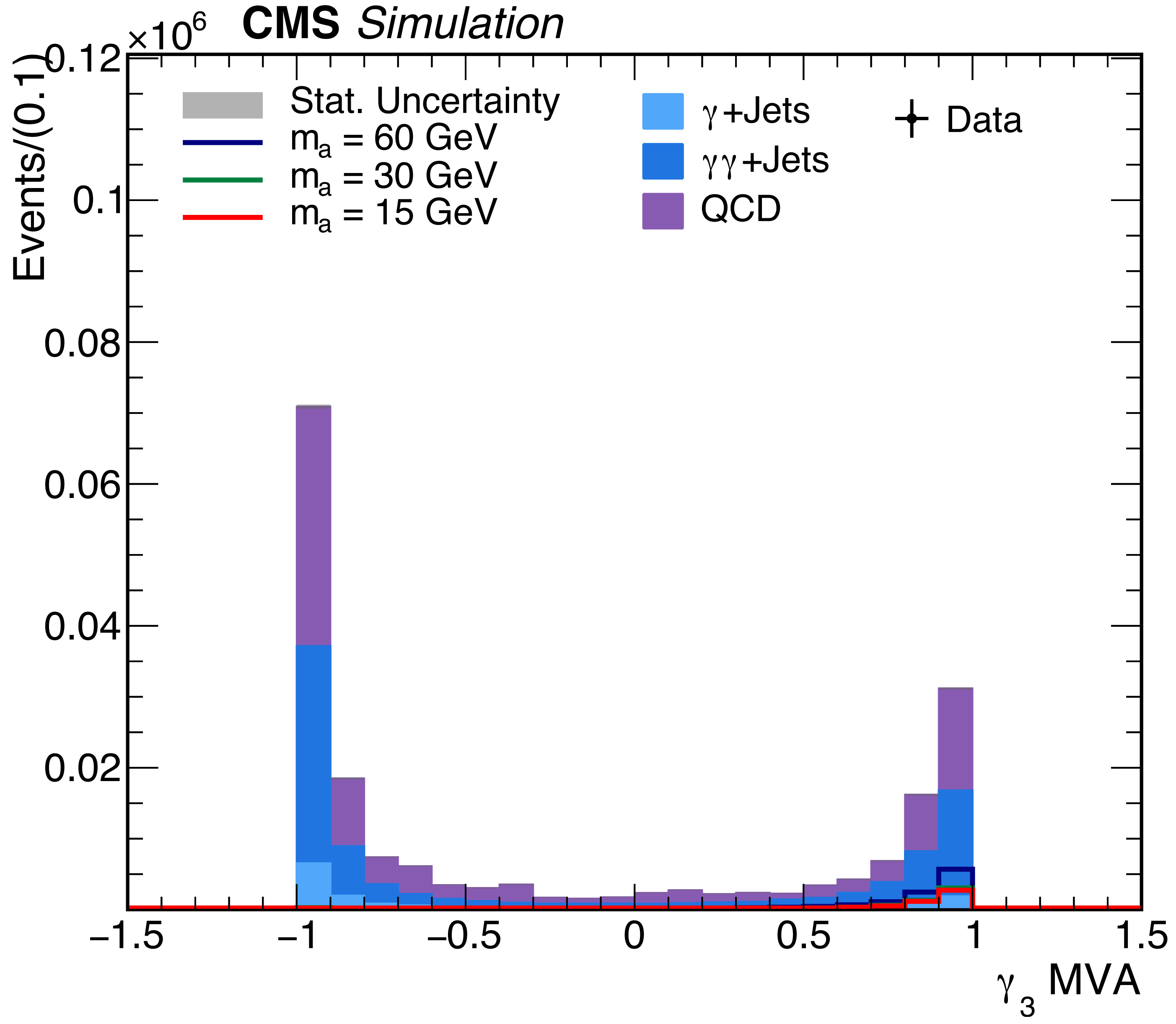
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ_2 MVA


CMS Simulation
Events/(0.1)
×10^6
Stat. Uncertainty
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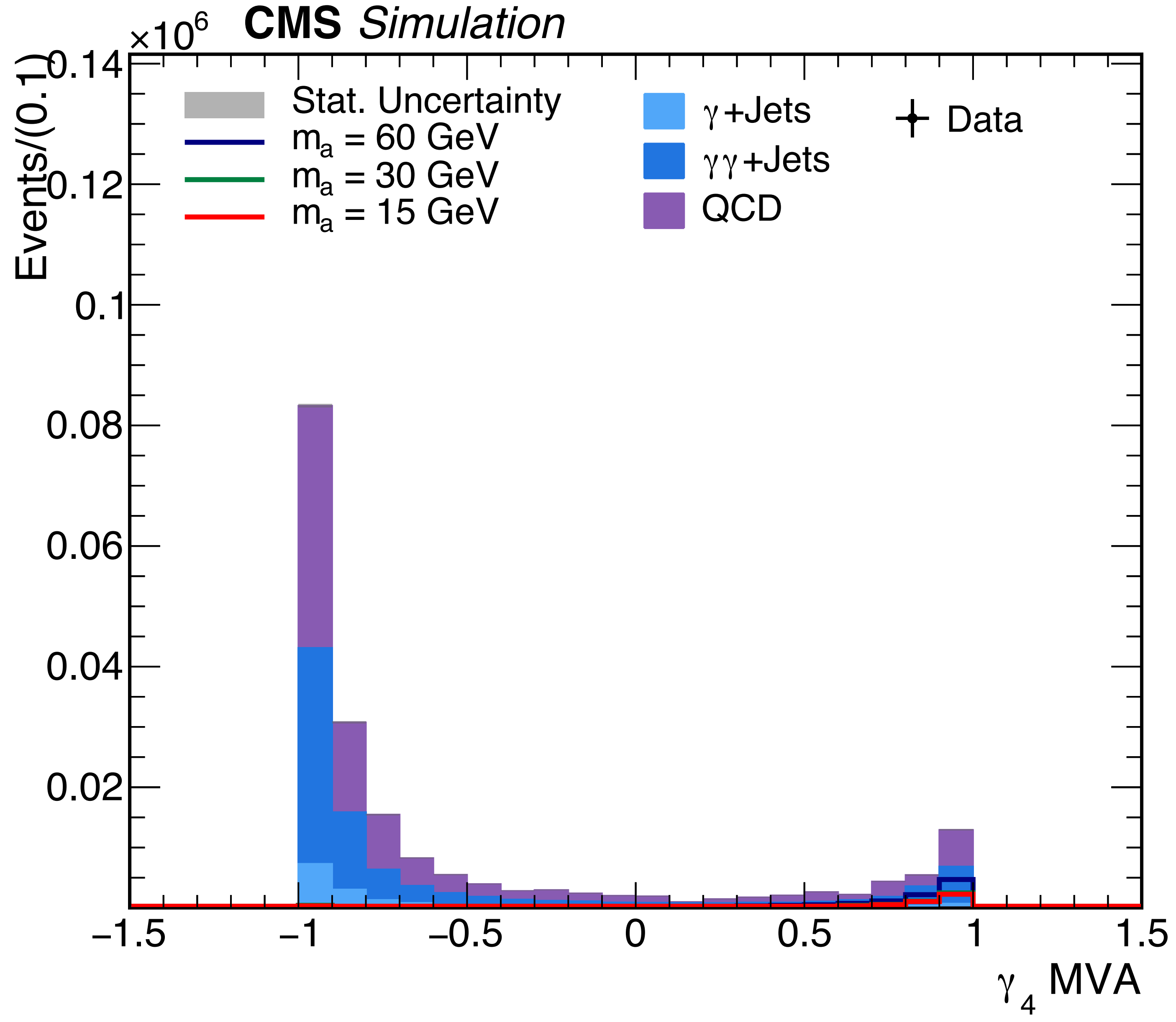
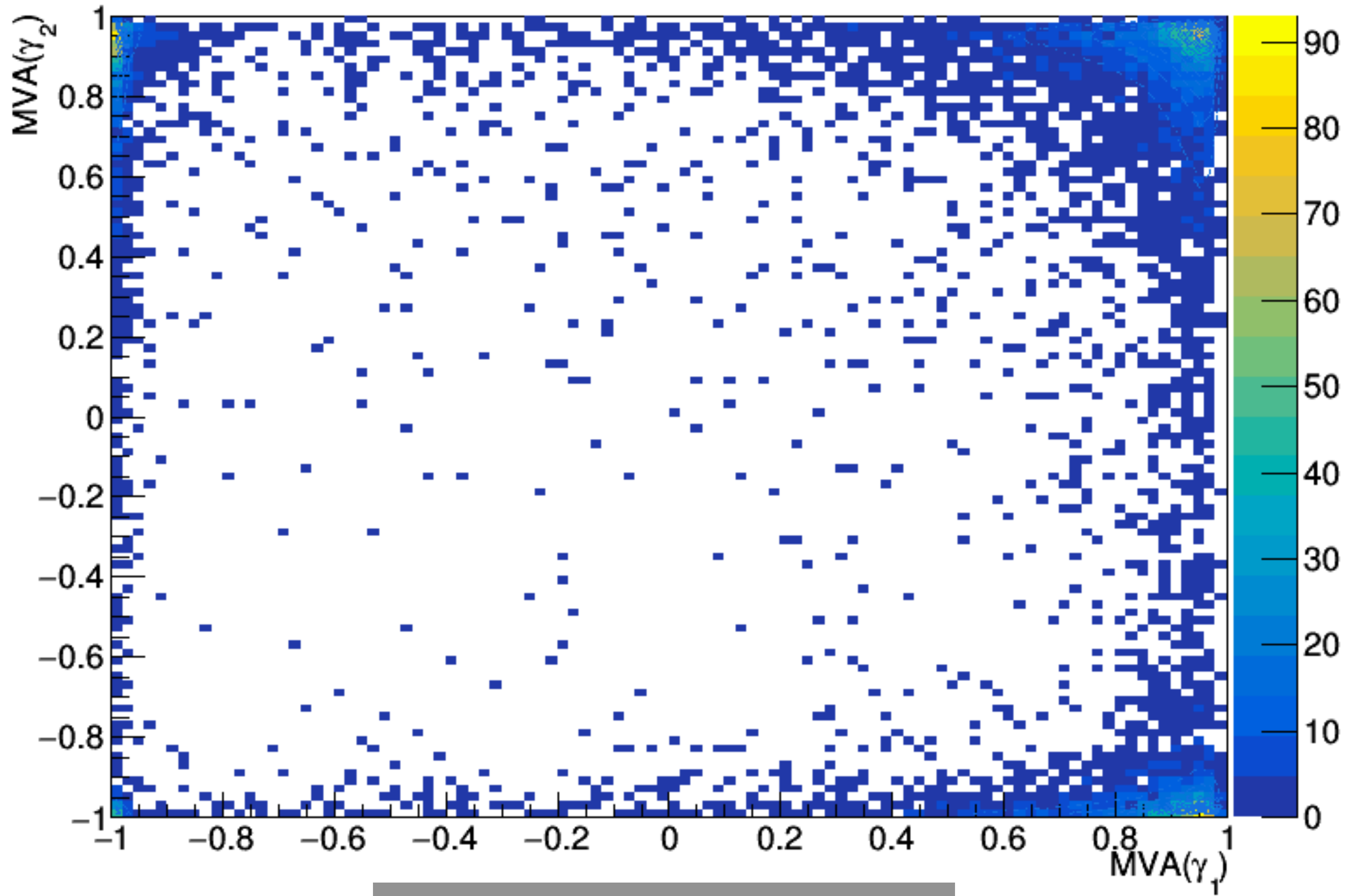
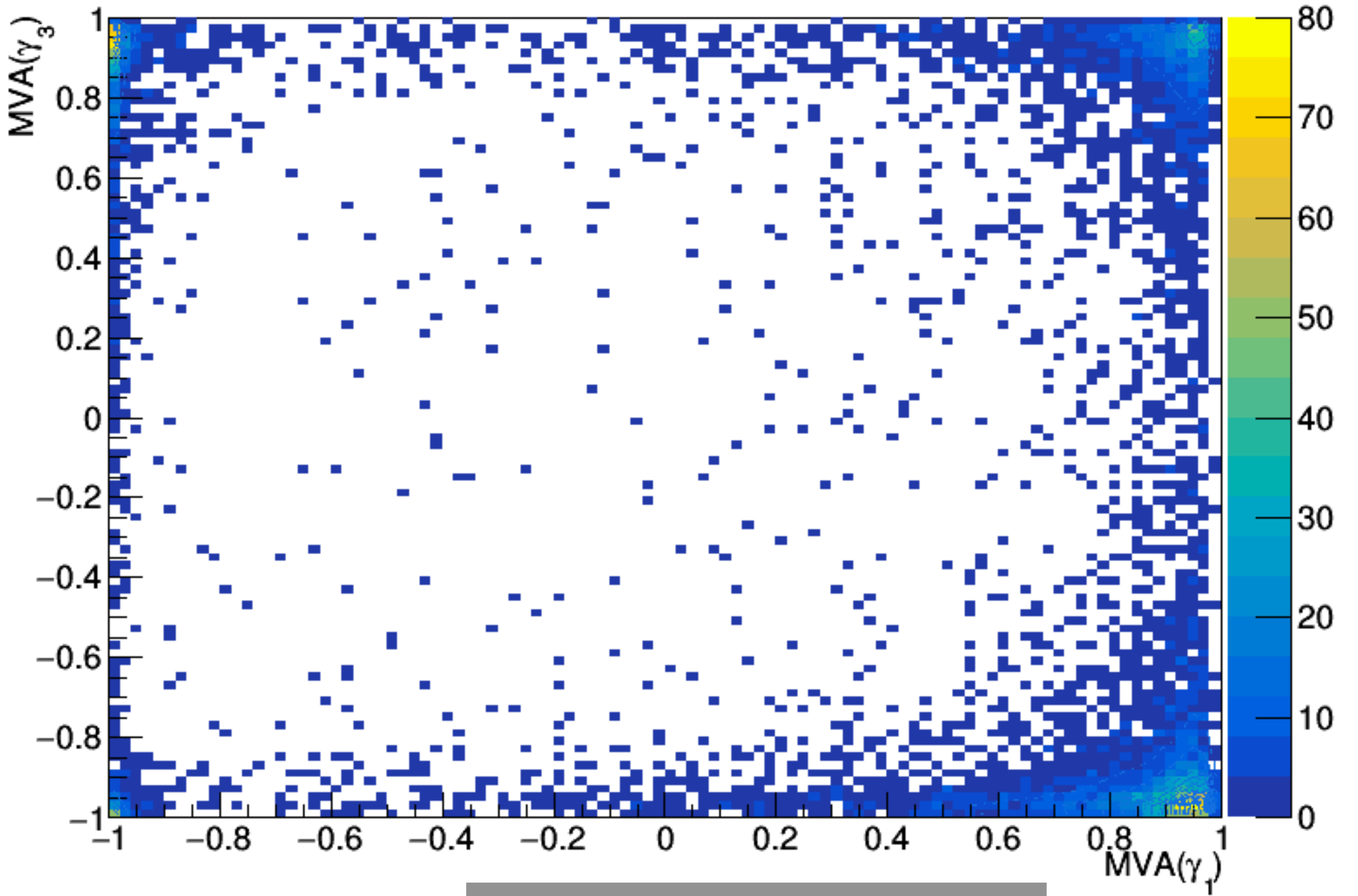
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ_3 MVA


CMS Simulation
Events/(0.1)
×10^6
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ_4 MVA

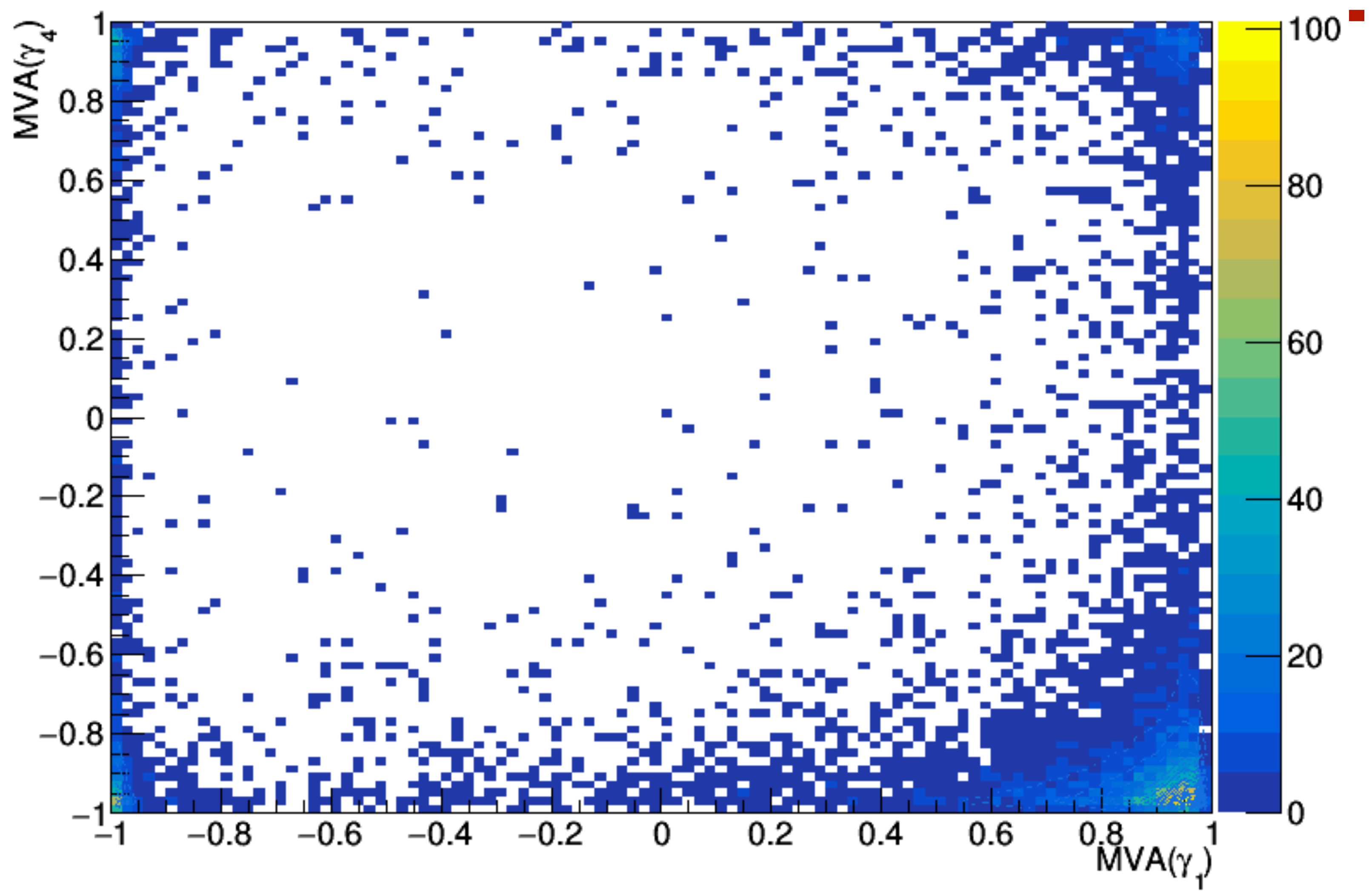
DiPhotons + Jet: 2D plots of MVA distributions (all diphoton combinations)



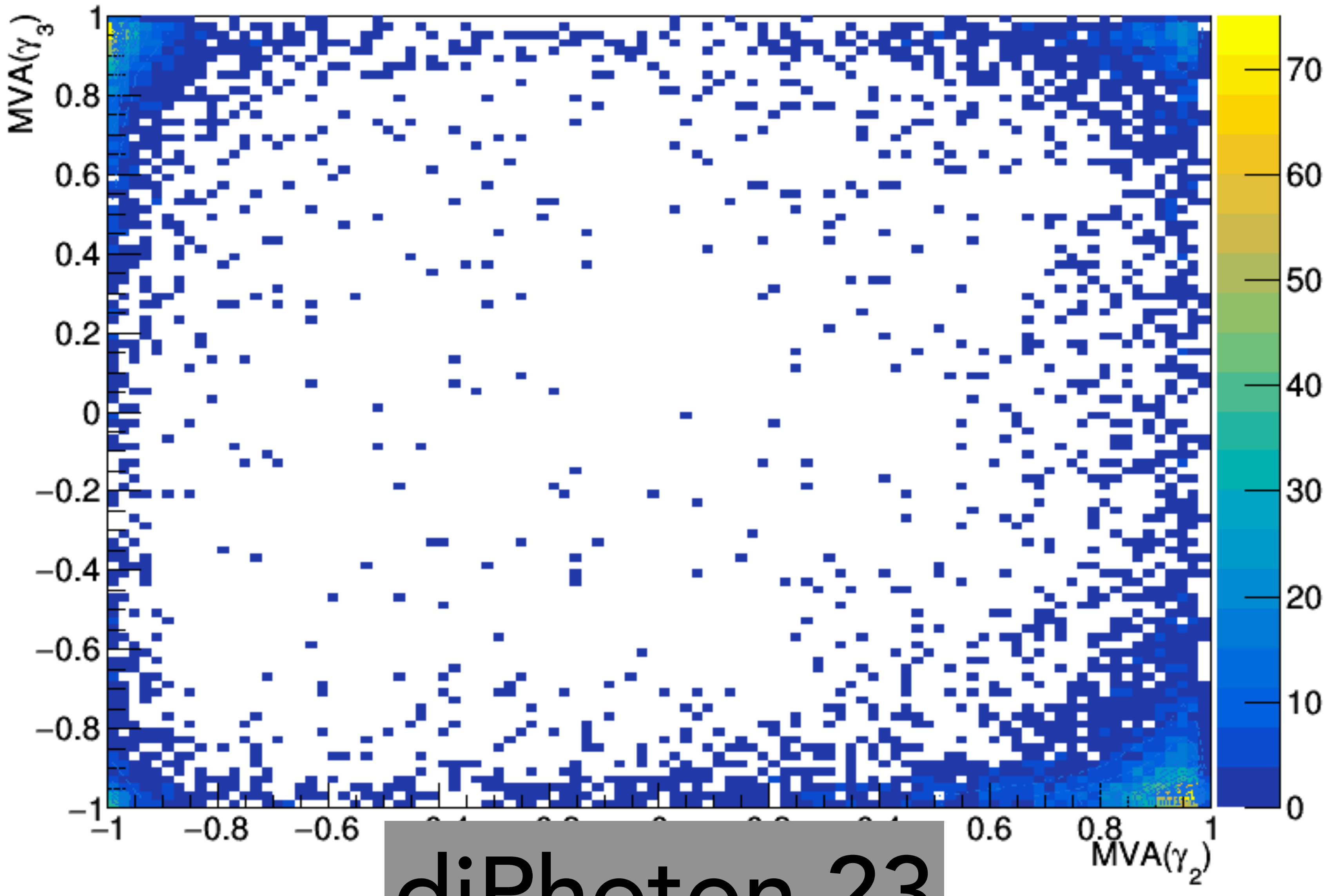
diPhoton 12



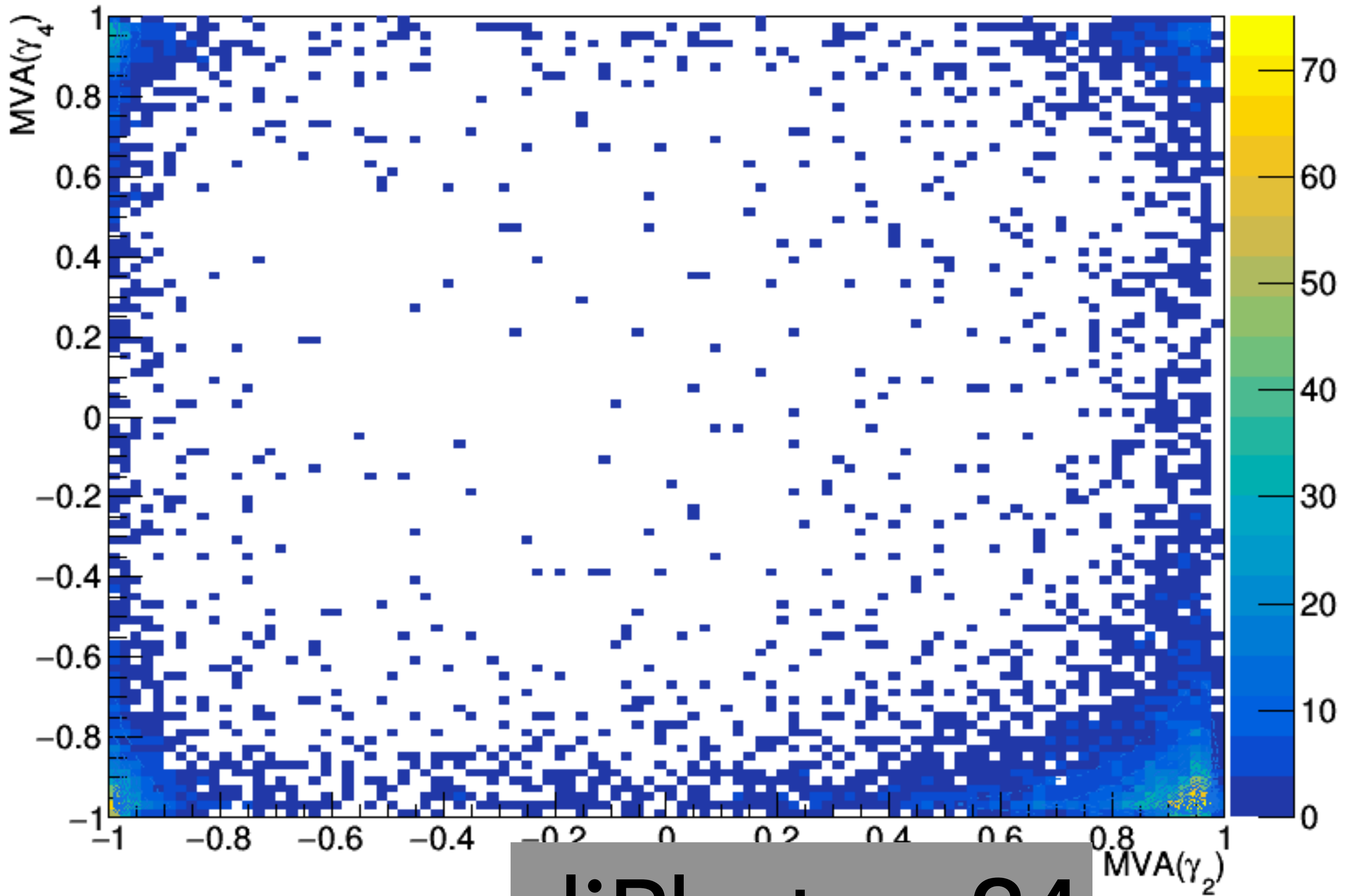
diPhoton 13



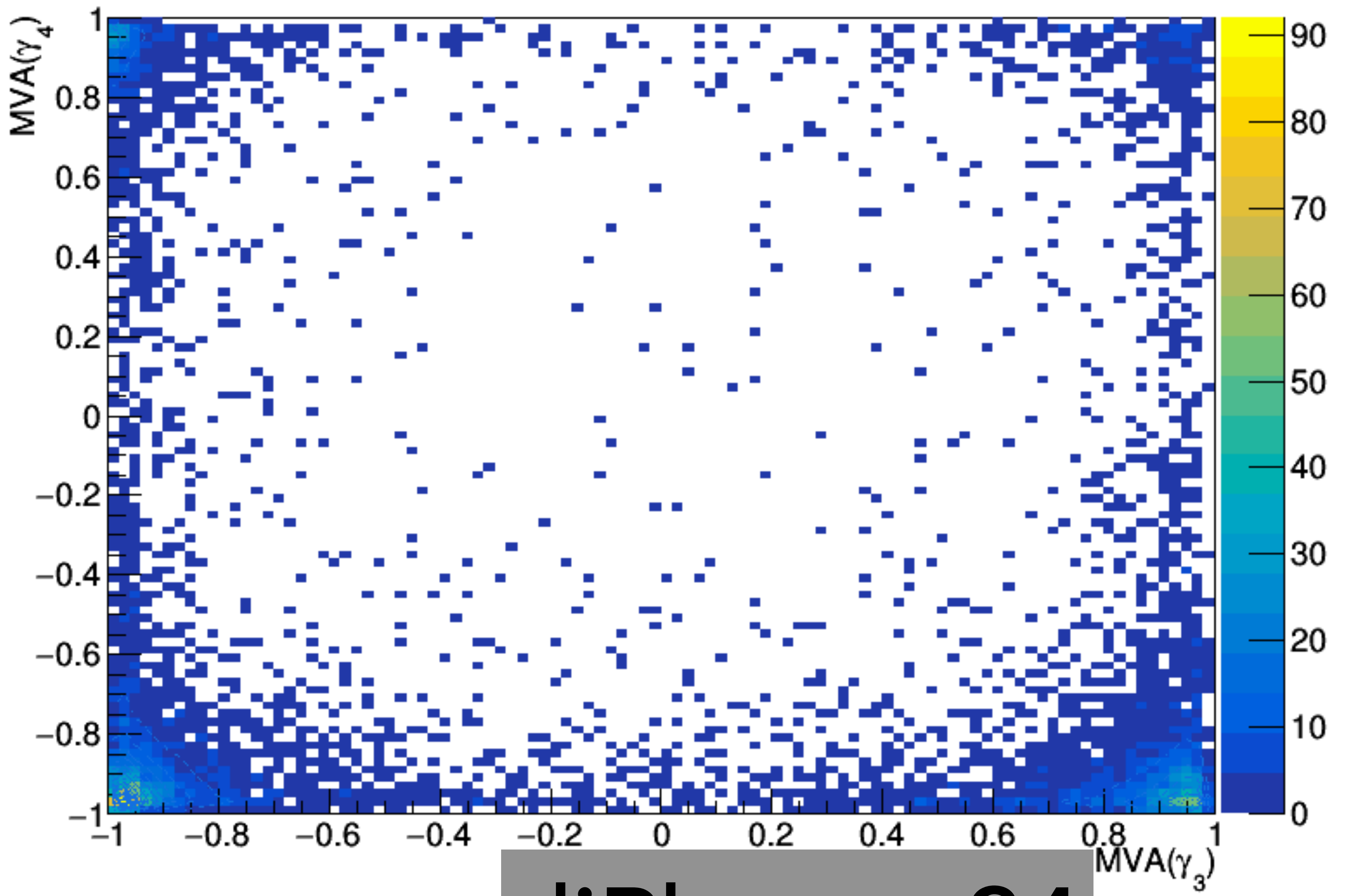
diPhoton 14



diPhoton 23

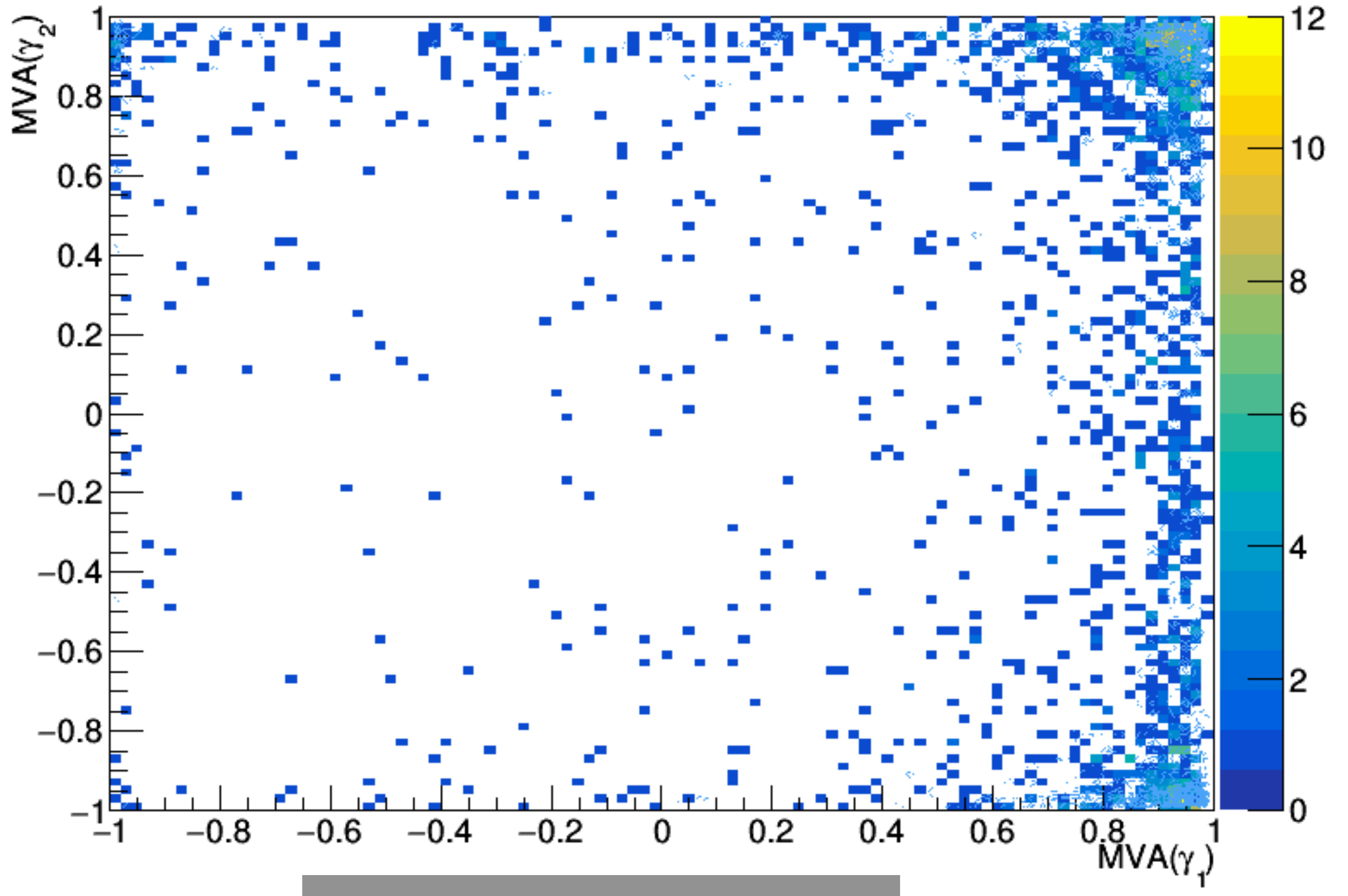


diPhoton 24

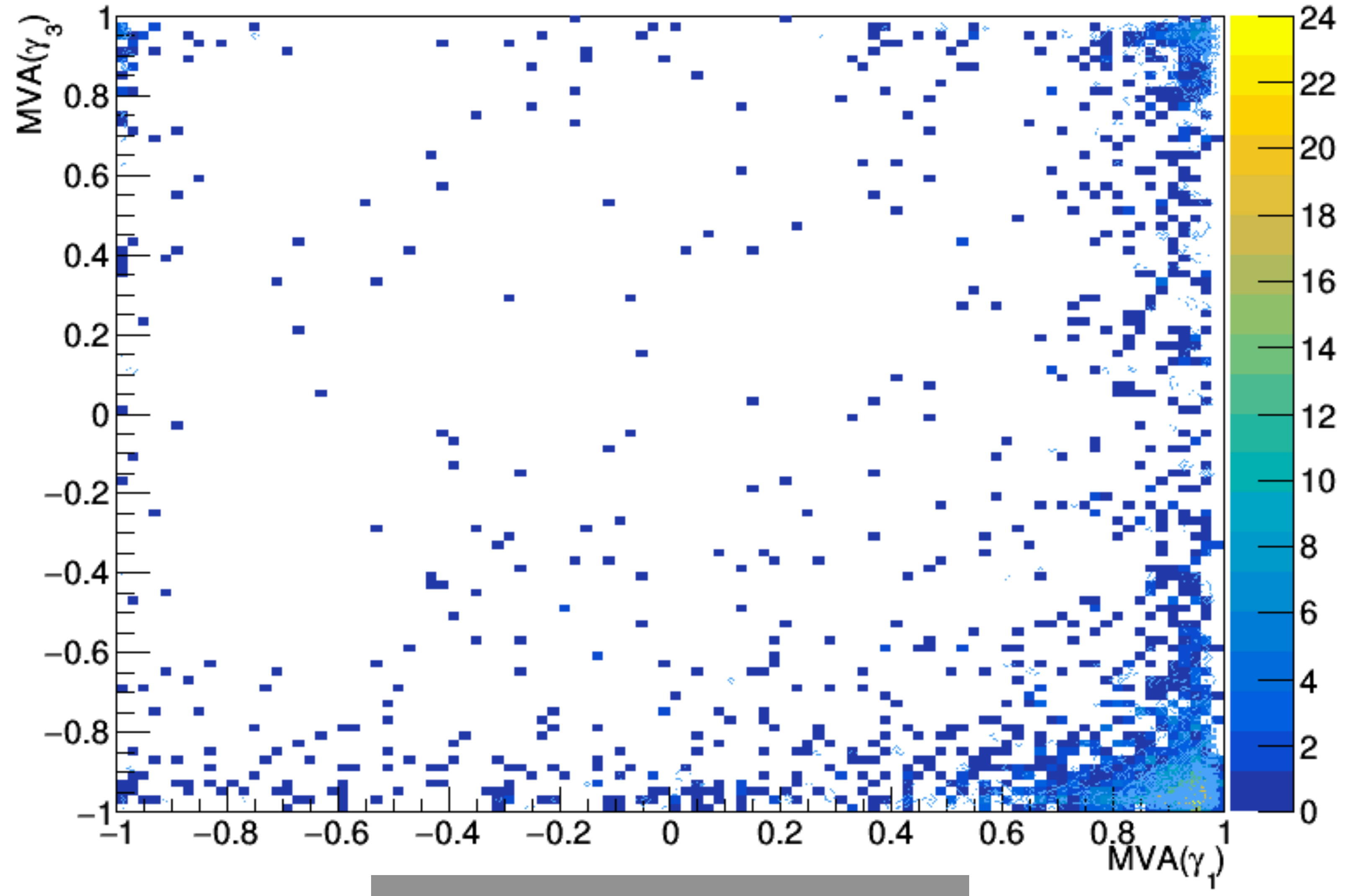


diPhoton 34

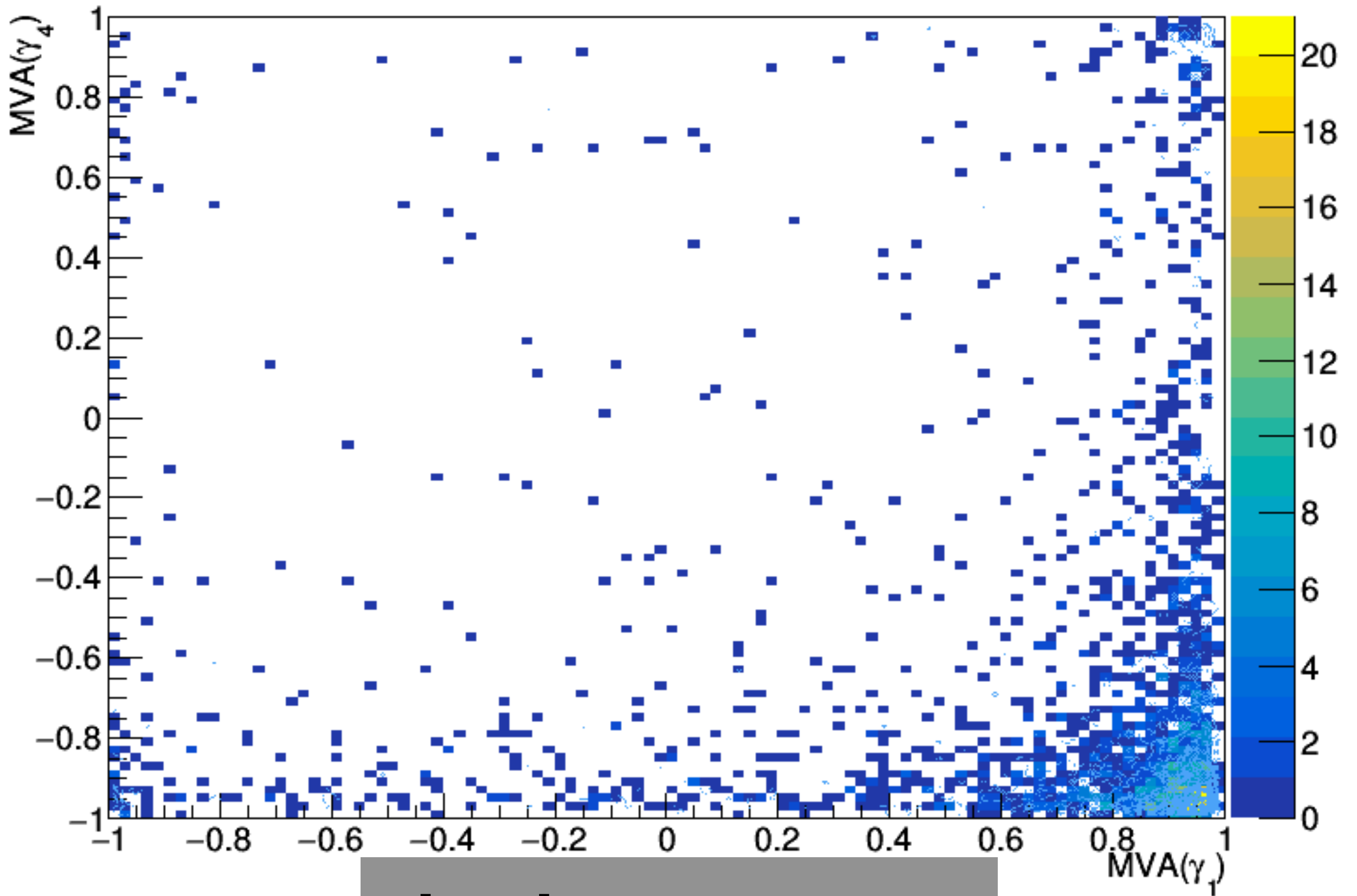
Photon + Jet: 2D plots of MVA distributions (all diphoton combinations)



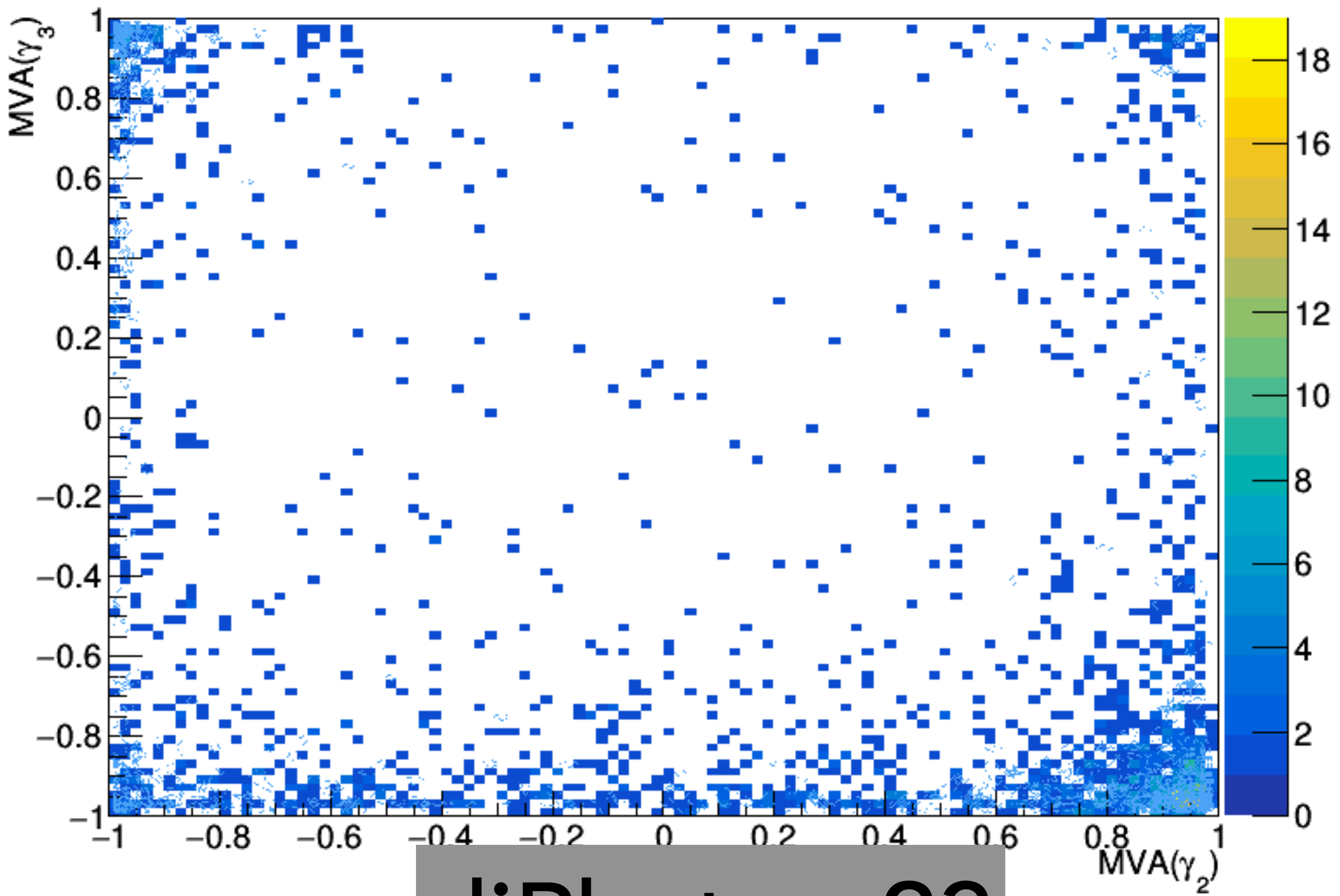
diPhoton 12



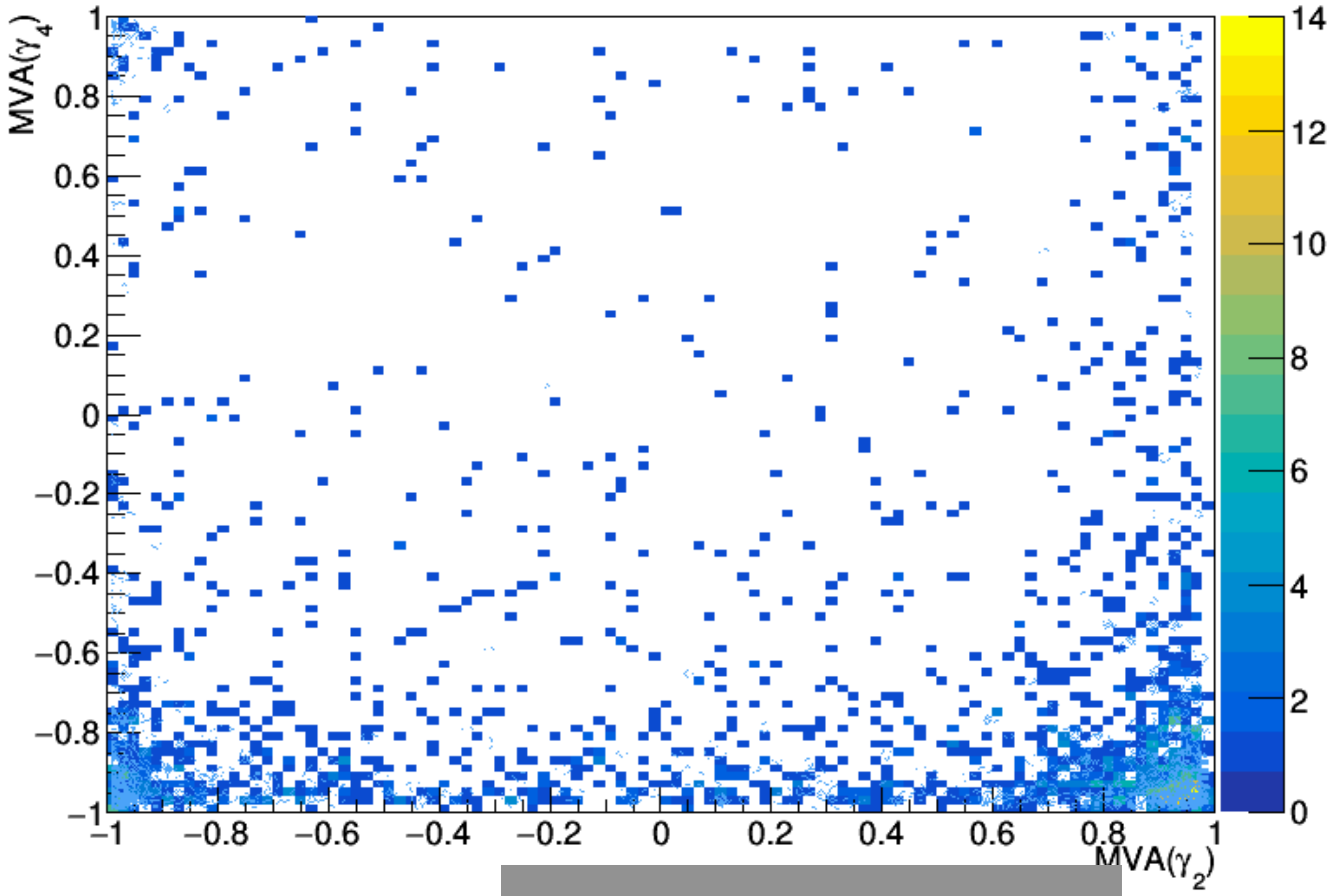
diPhoton 13



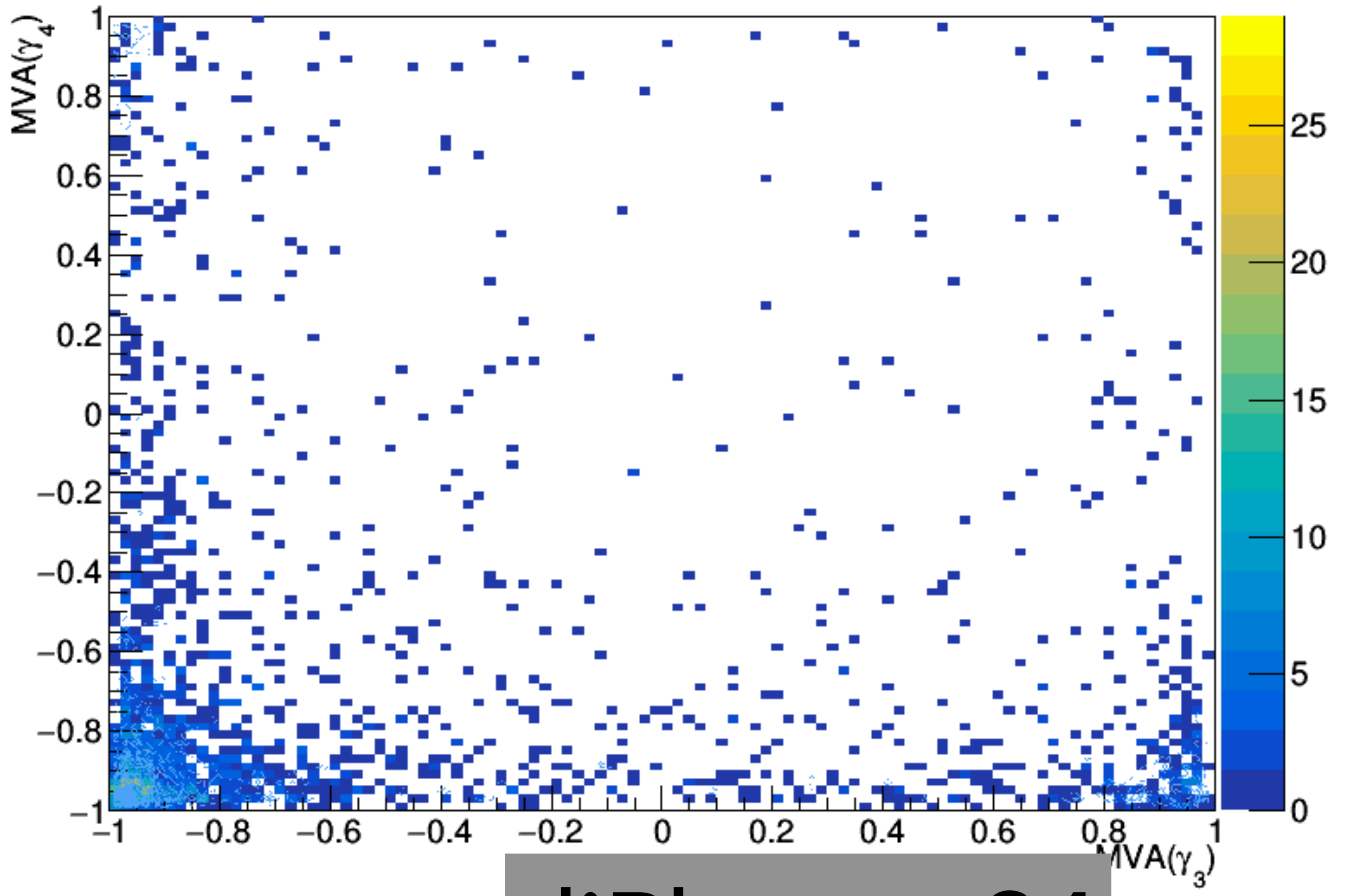
diPhoton 14



diPhoton 23

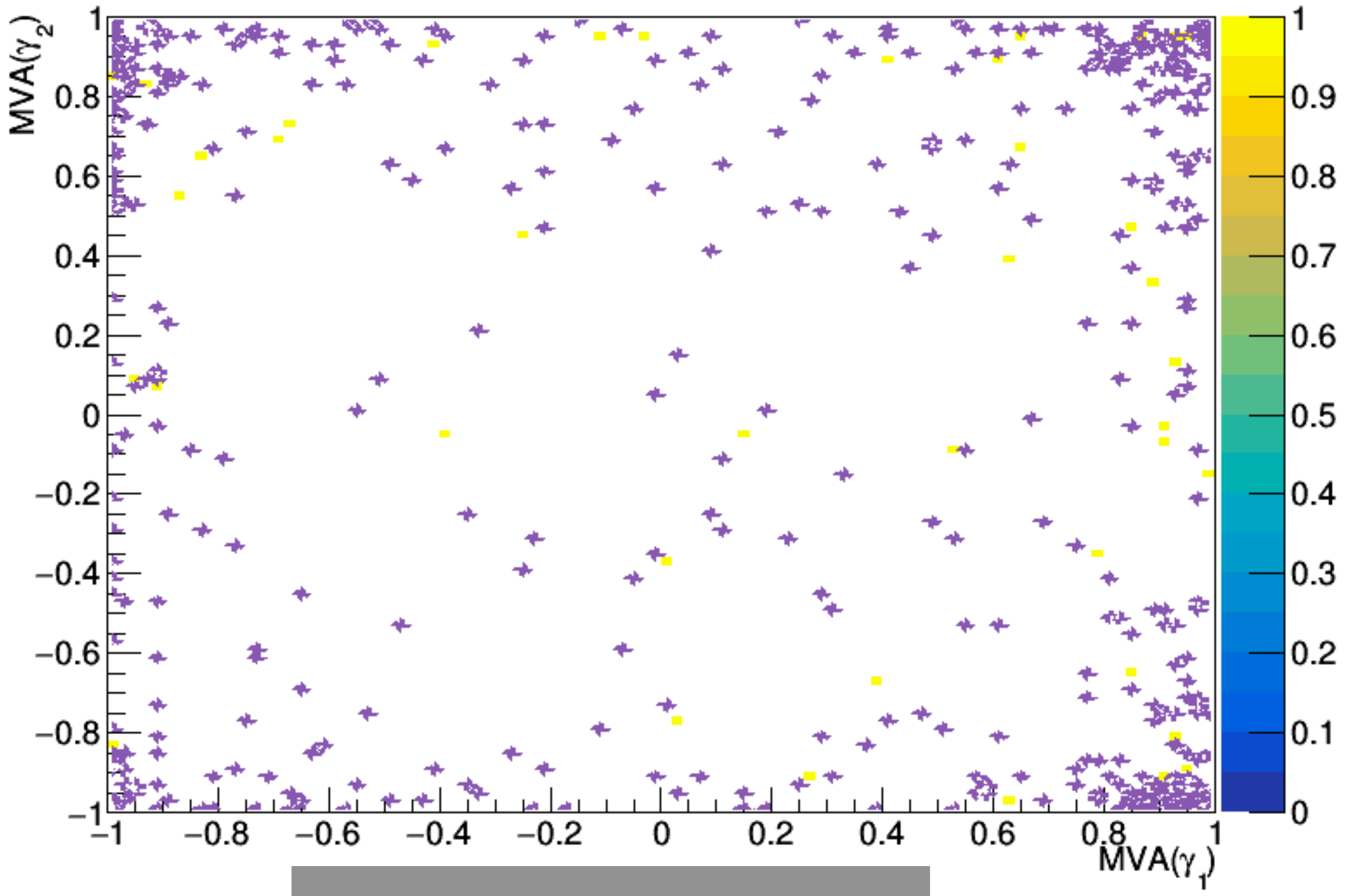


diPhoton 24

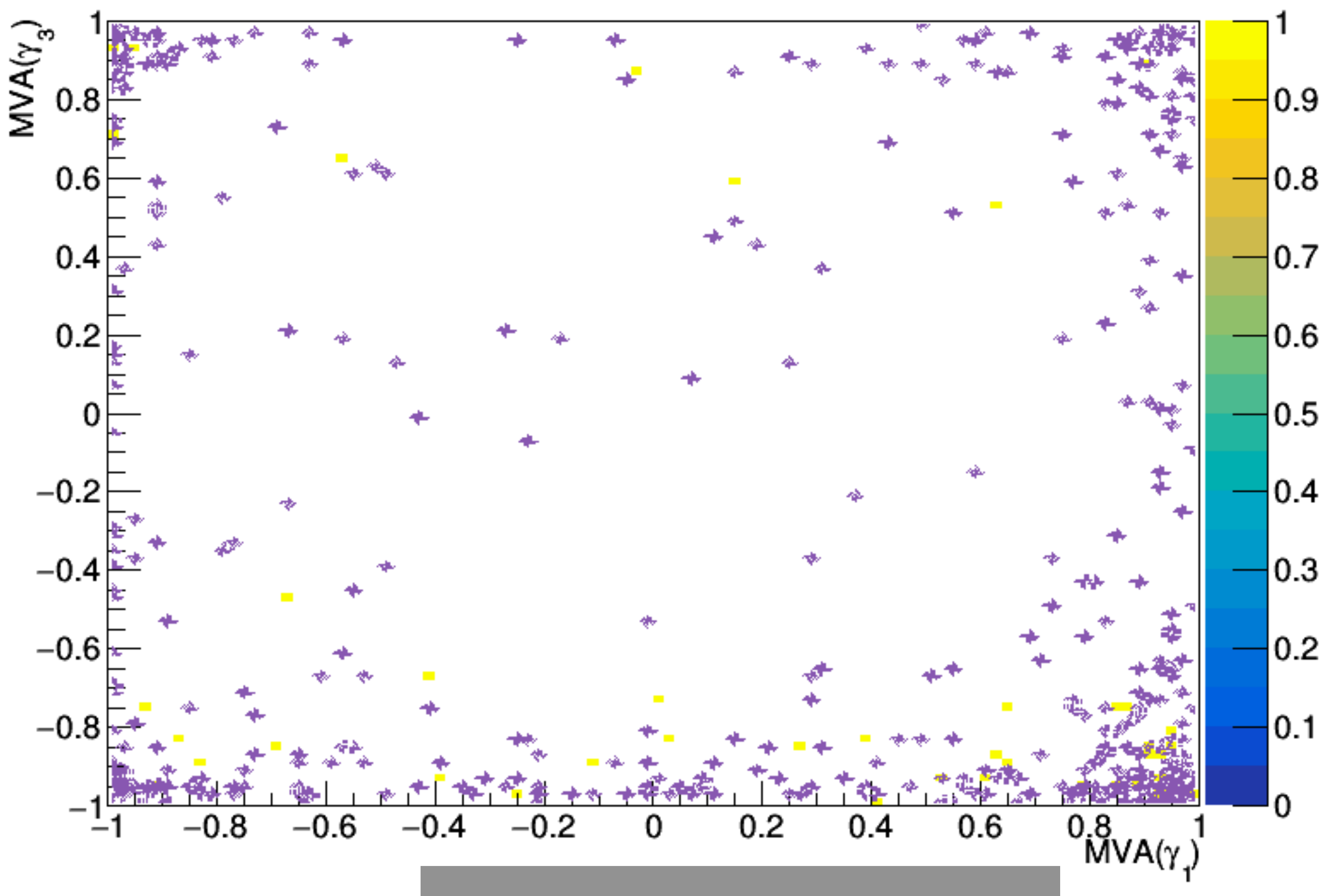


diPhoton 34

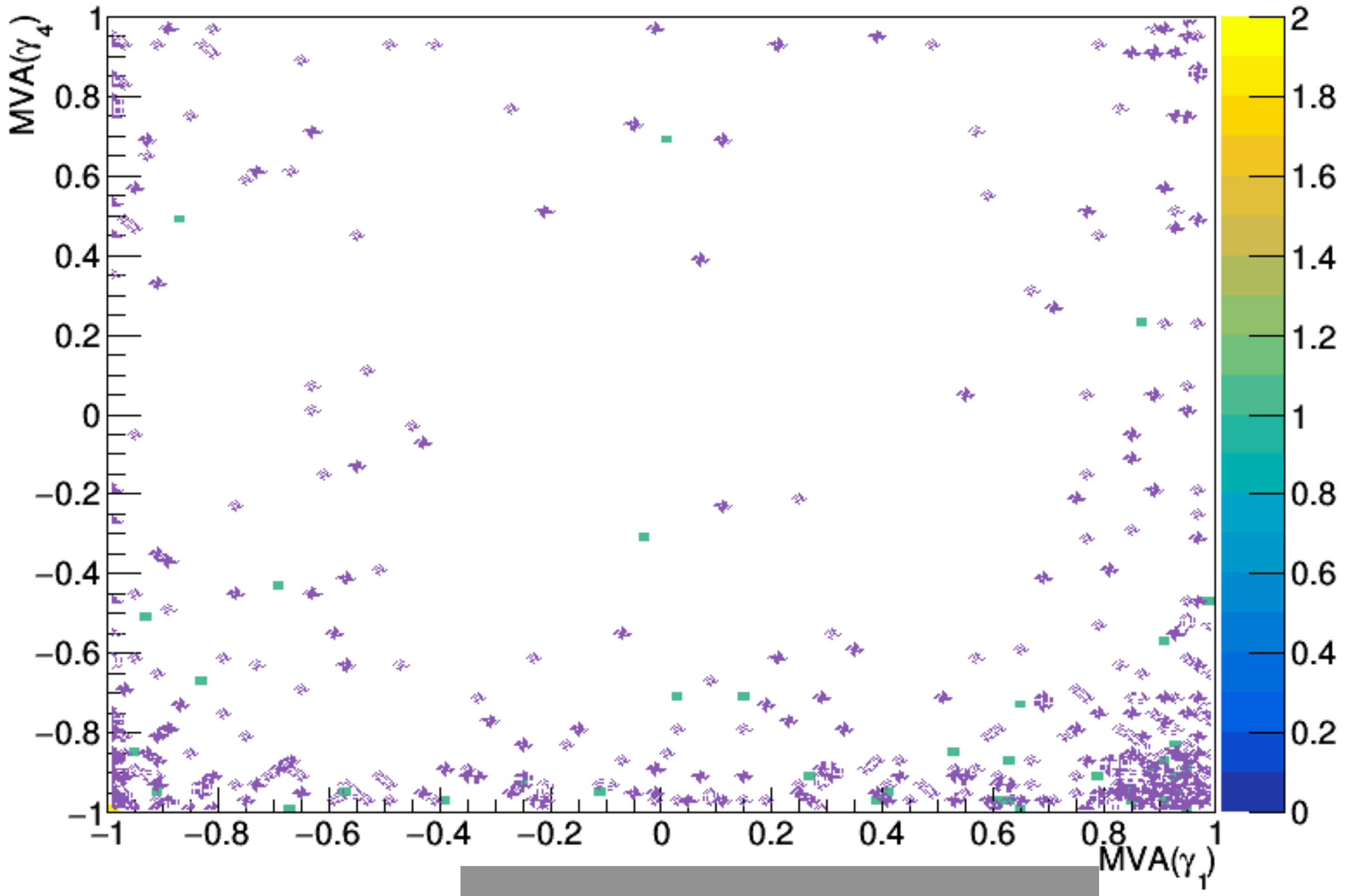
QCD + Jet: 2D plots of MVA distributions (all diphoton combinations)



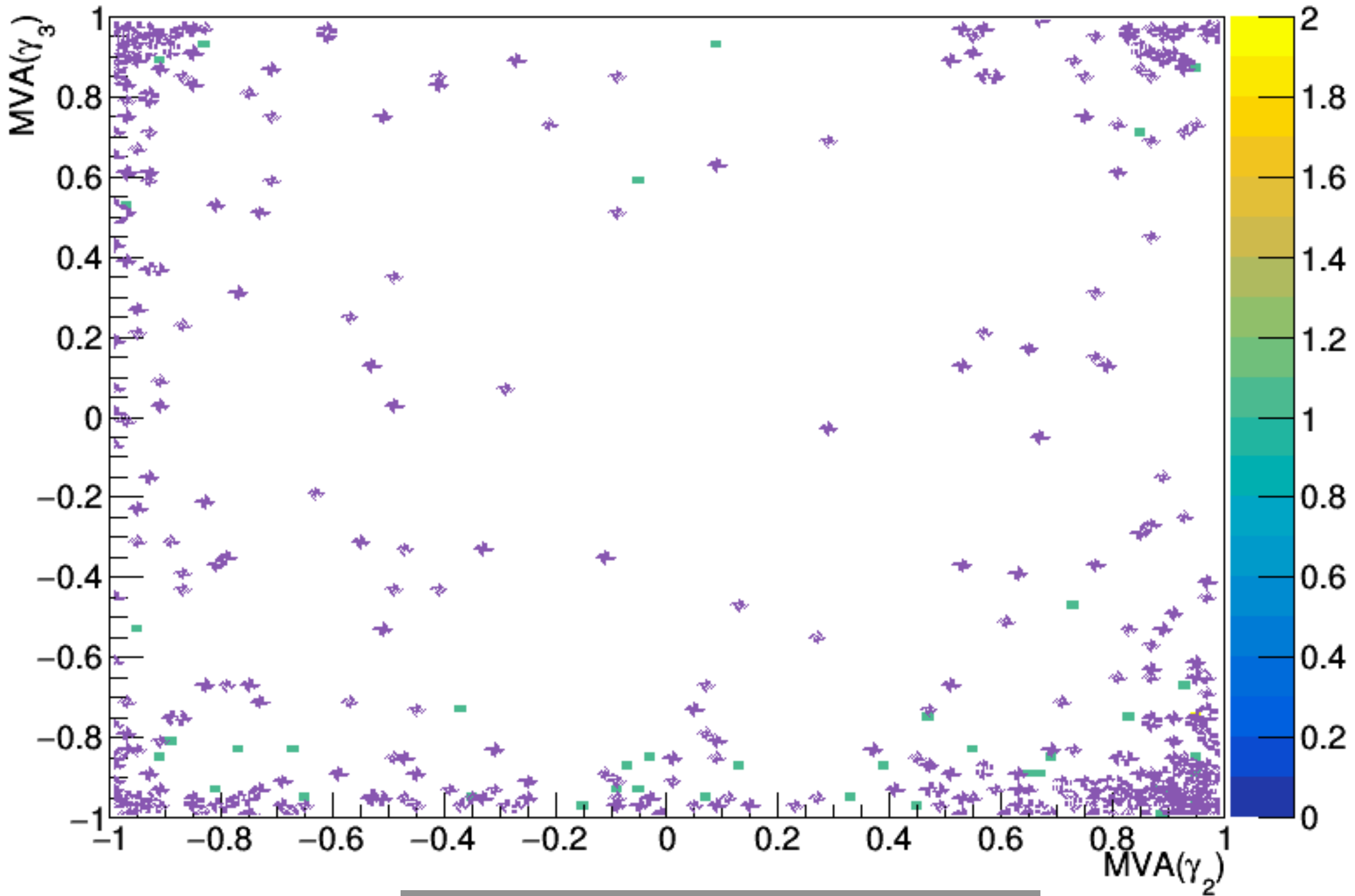
diPhoton 12



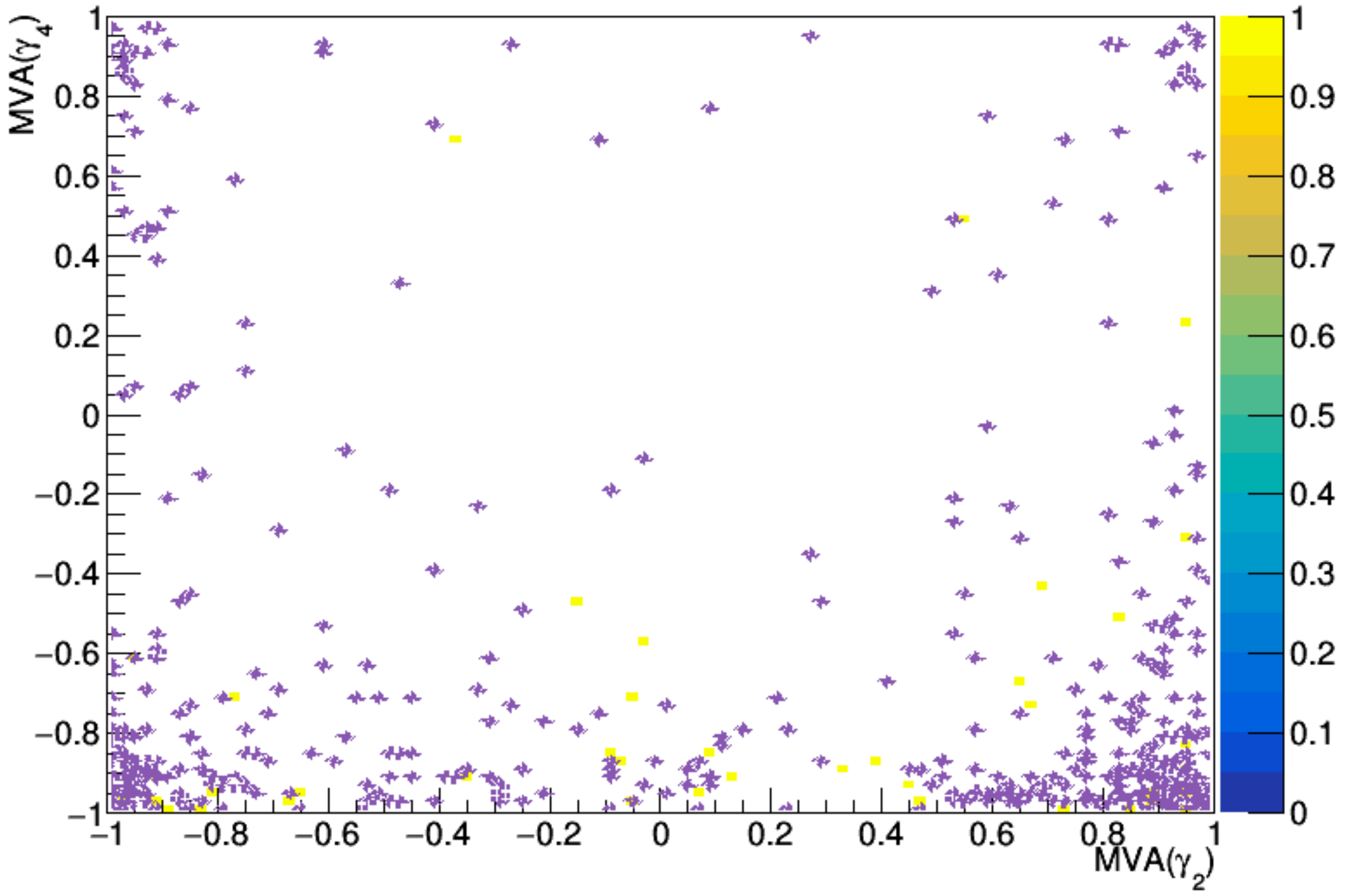
diPhoton 13



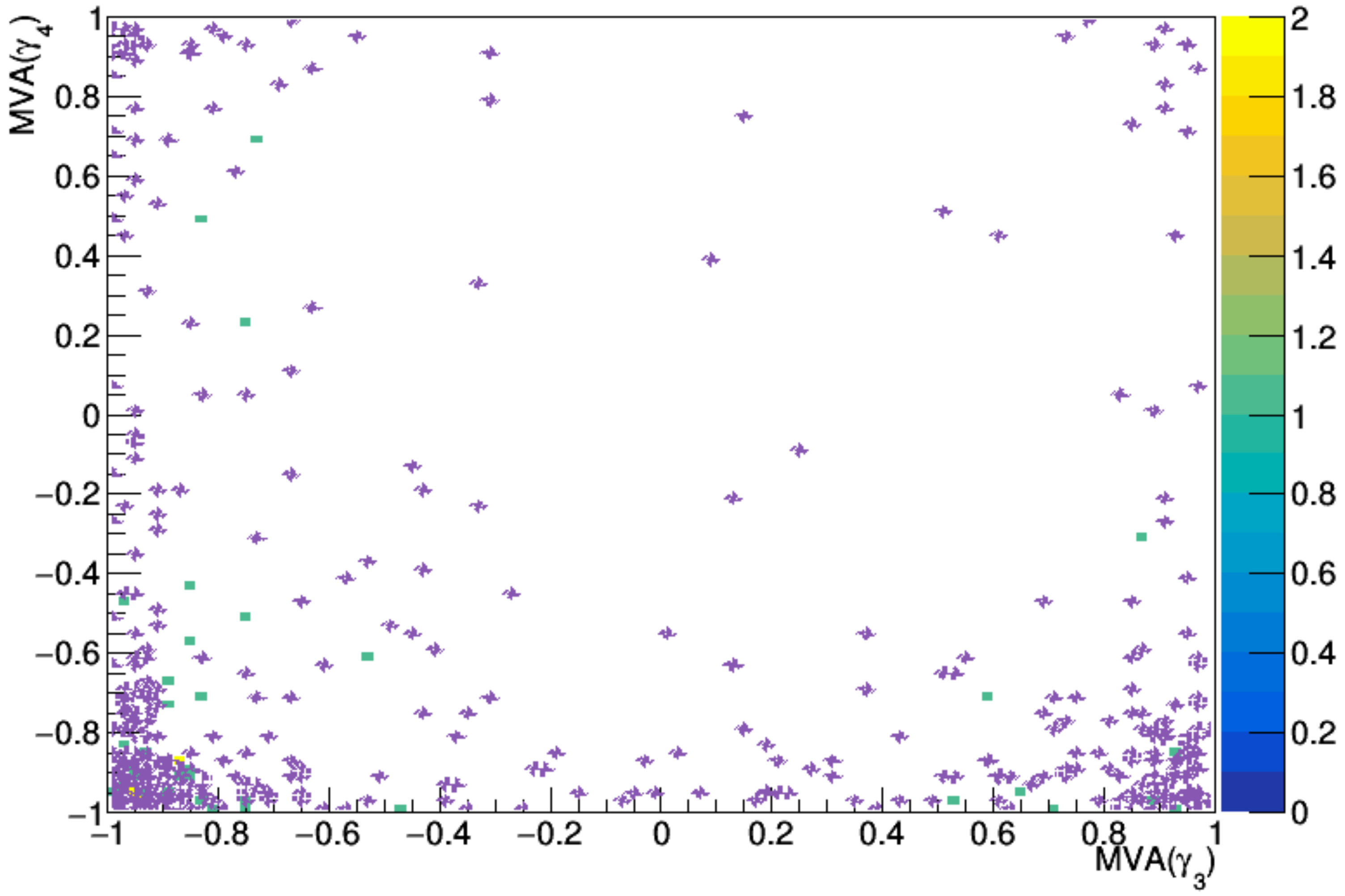
diPhoton 14



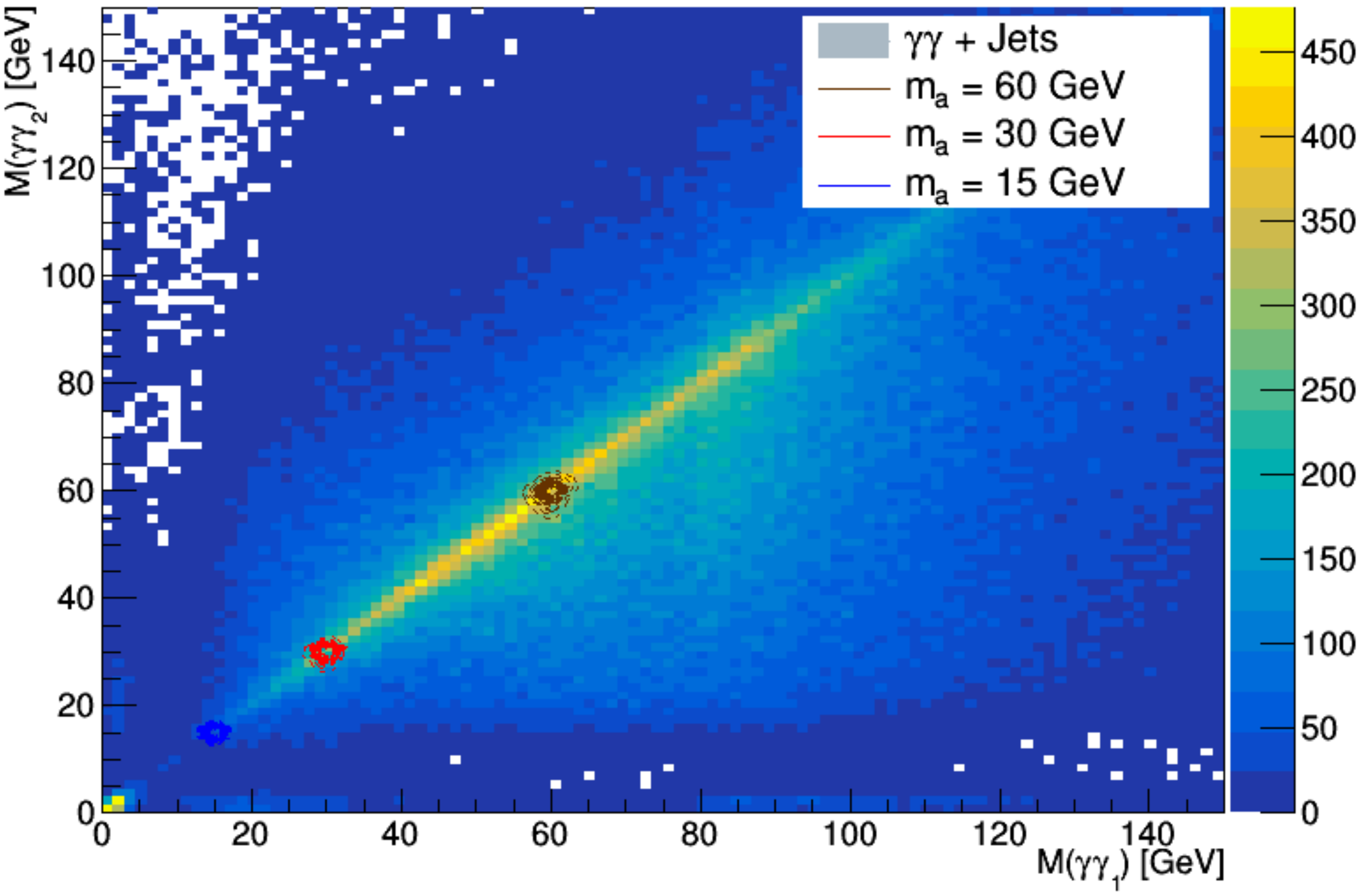
diPhoton 23

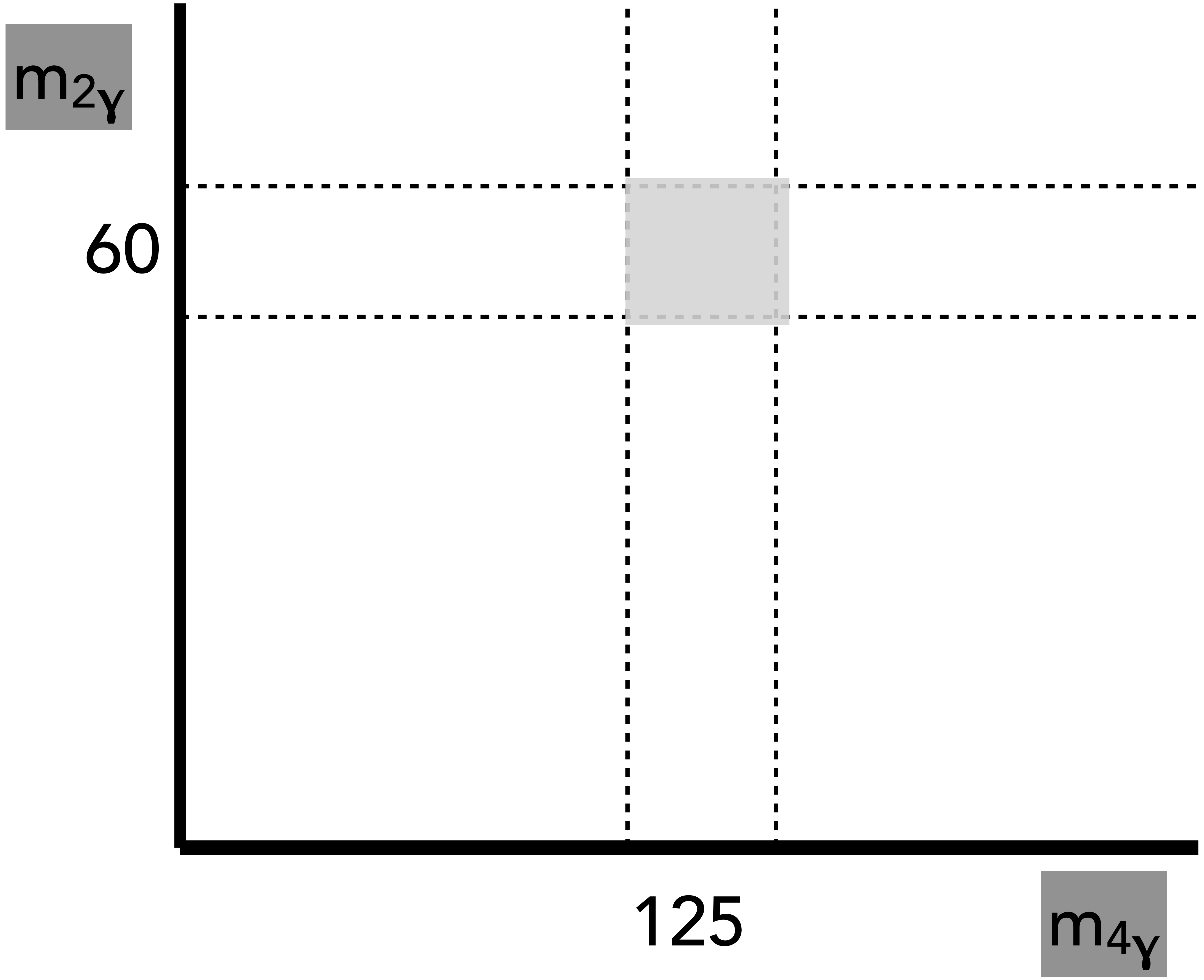


diPhoton 24

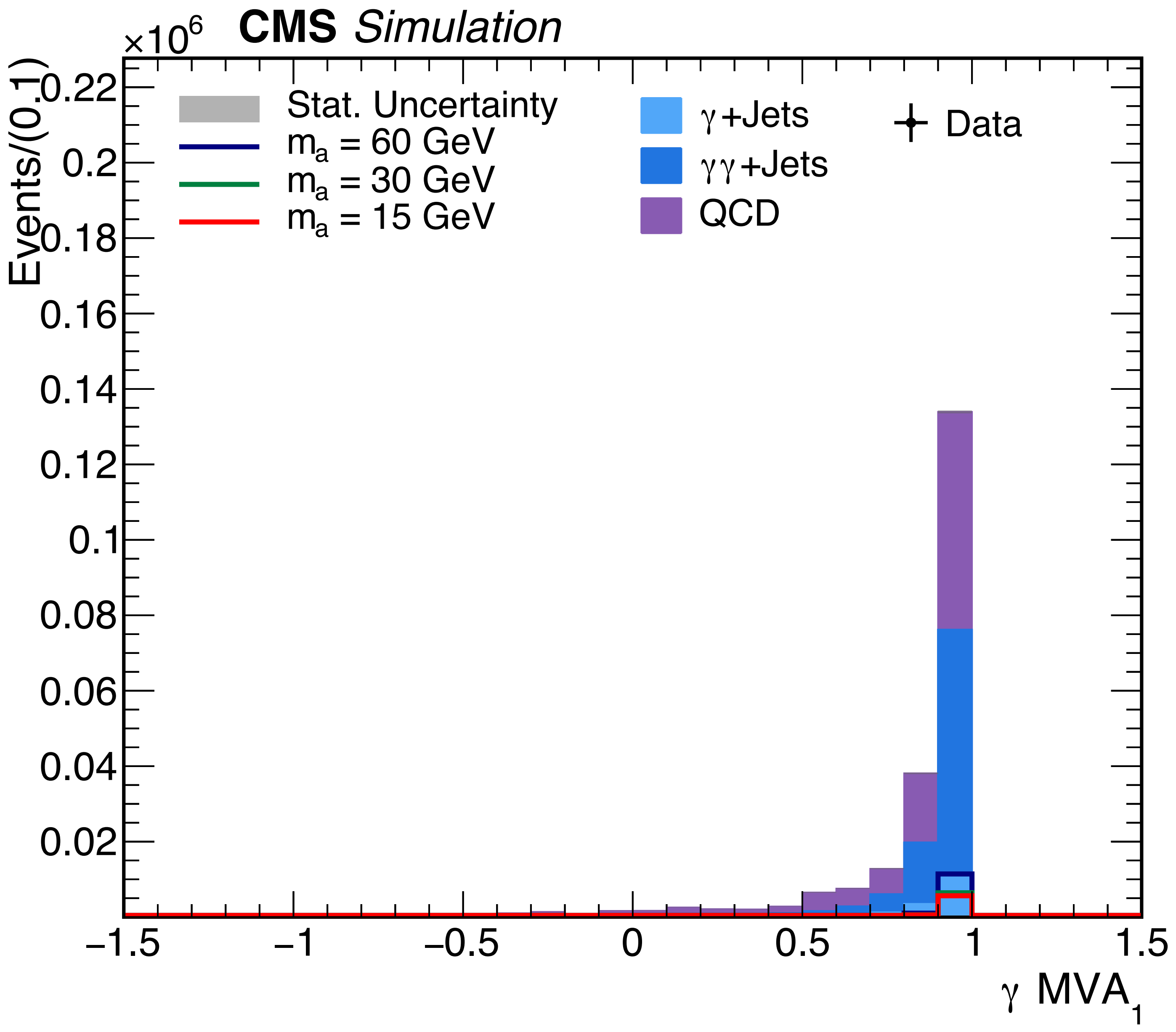


diPhoton 34

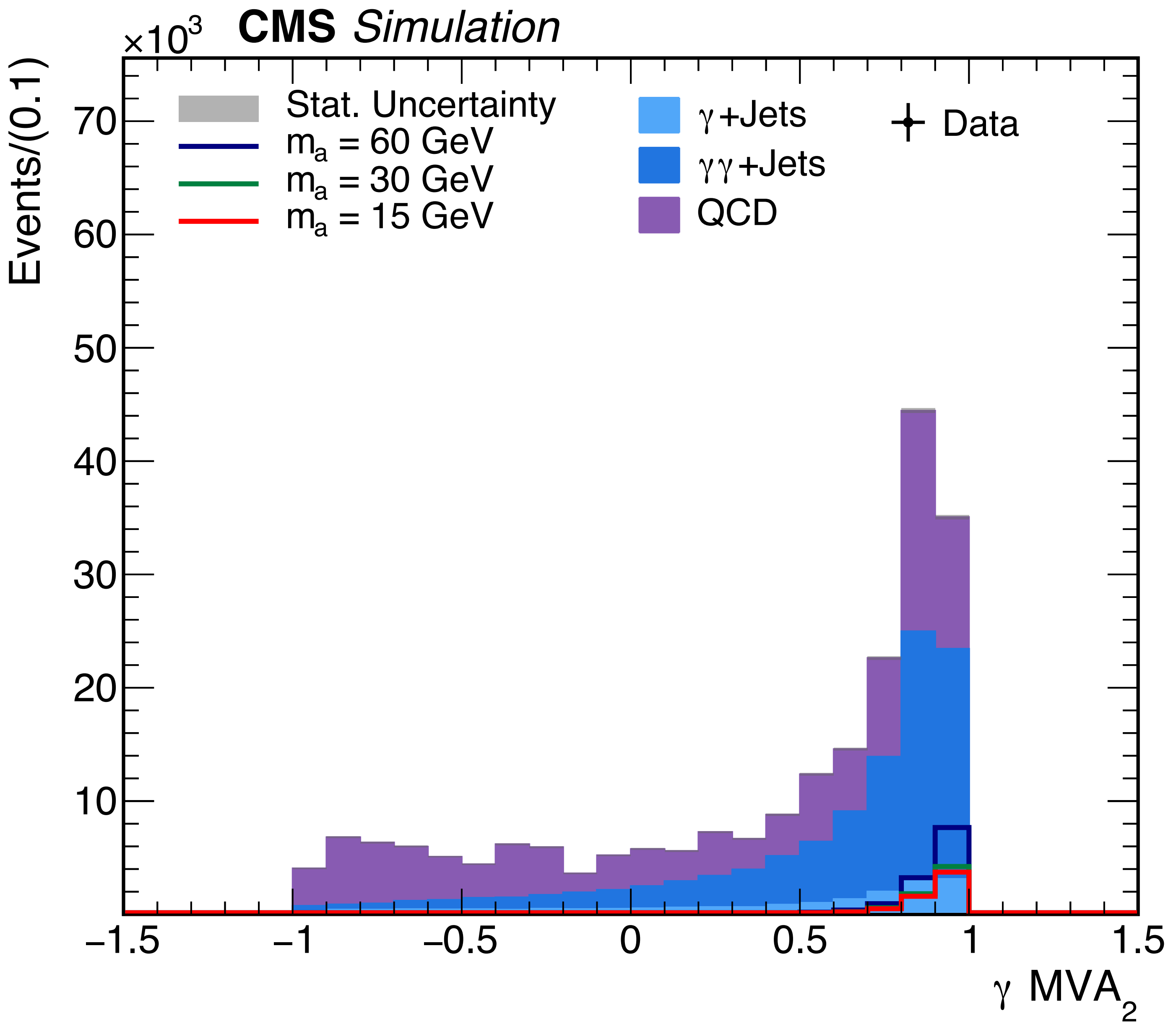

γγ + Jets
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
$M(\gamma\gamma_2)$ [GeV]
$M(\gamma\gamma_1)$ [GeV]



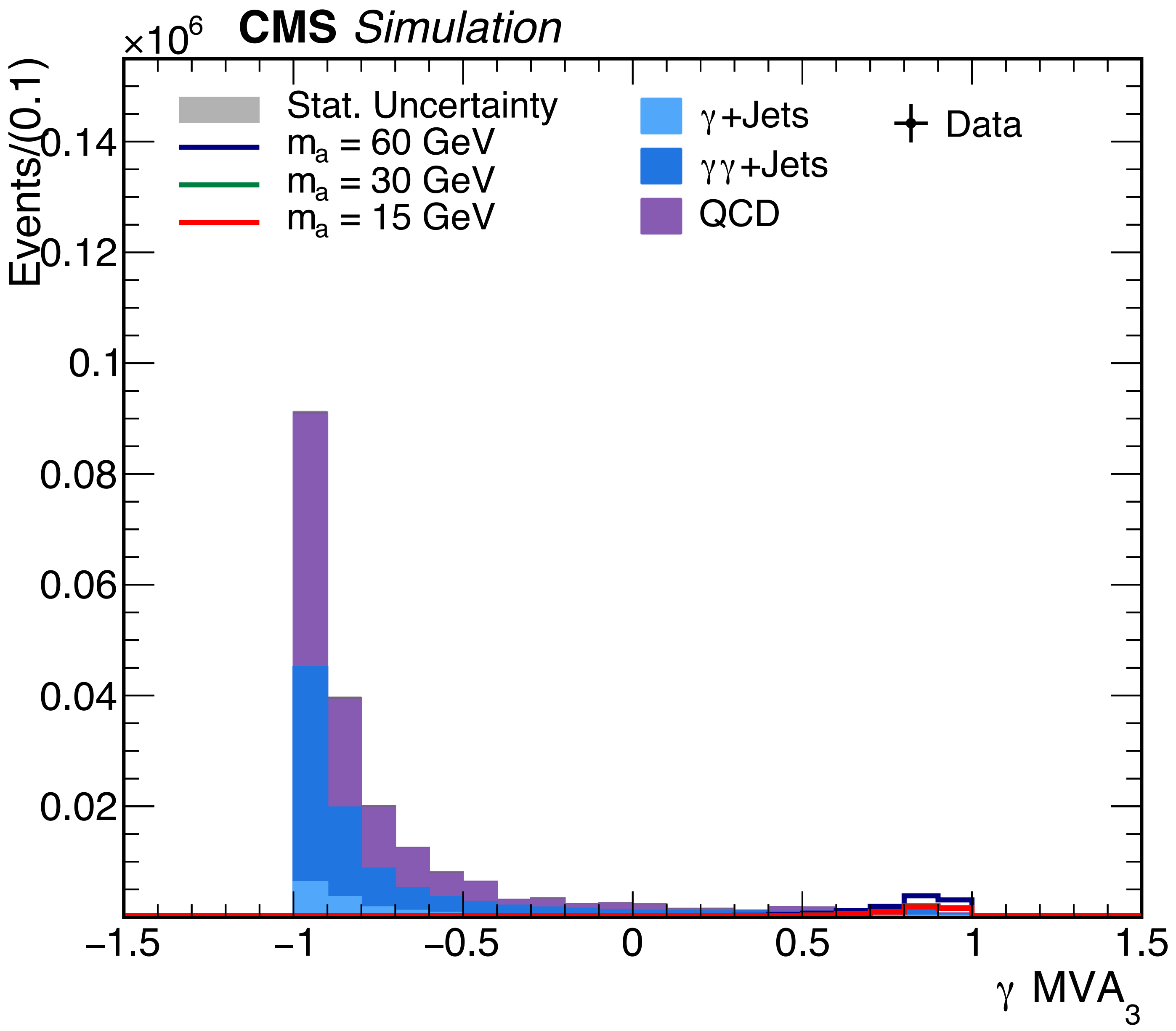
- For each m(a), apply selection on $m_{2\gamma}$ and fit $m_{4\gamma}$



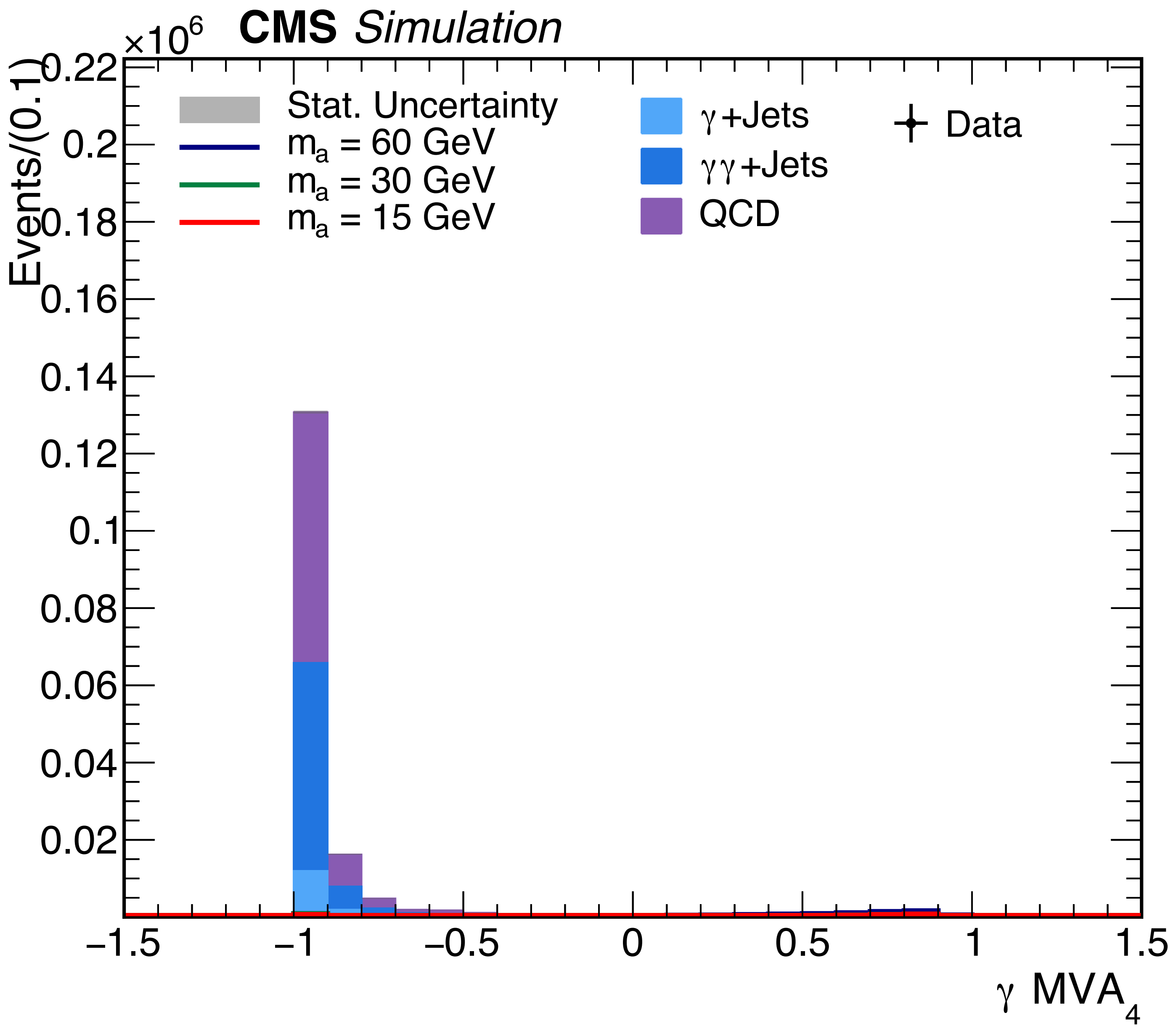
CMS Simulation
×10^6
Events/(0.1)
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ MVA_1



CMS Simulation
×10^3
Events/(0.1)
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ MVA_2

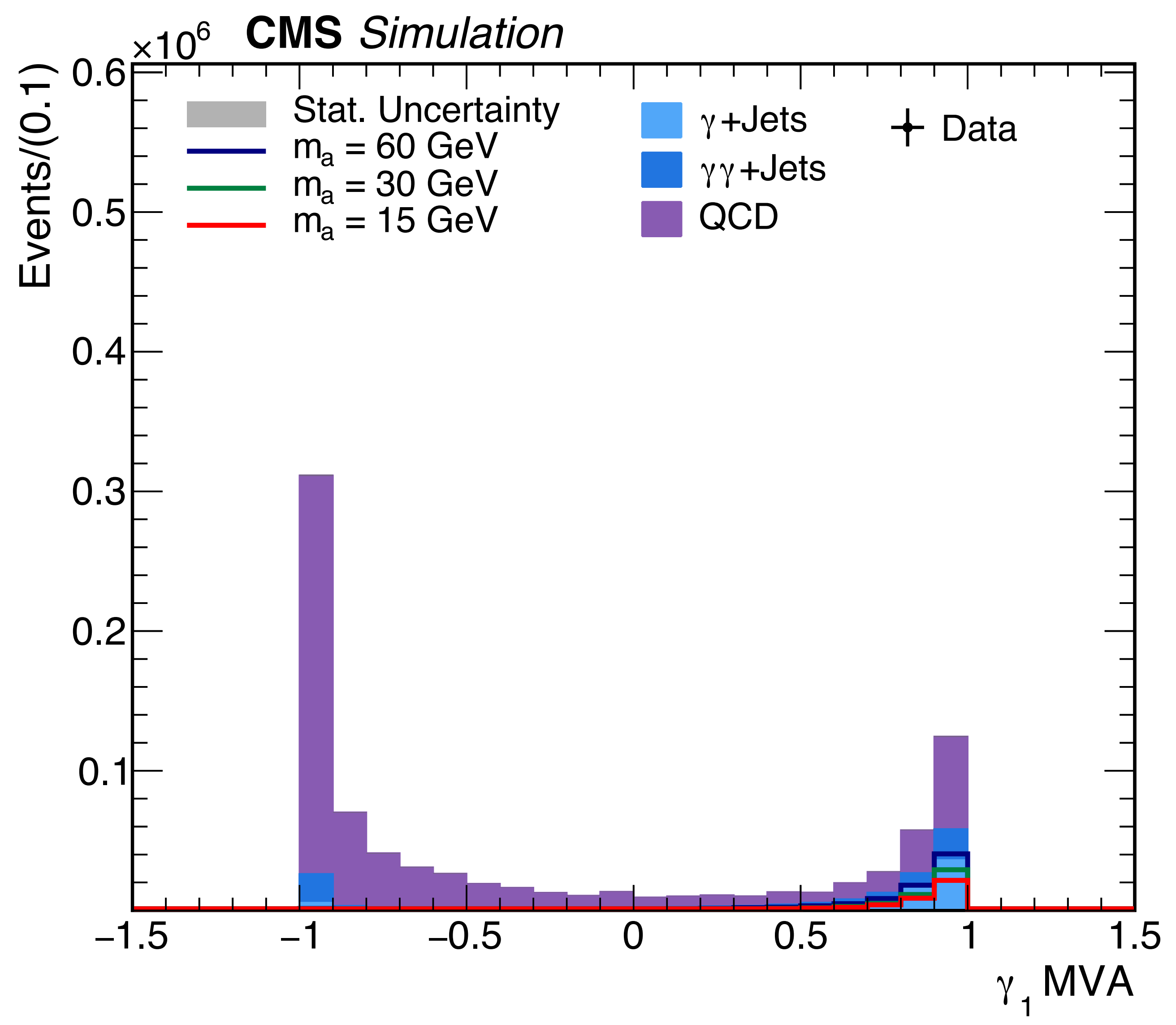


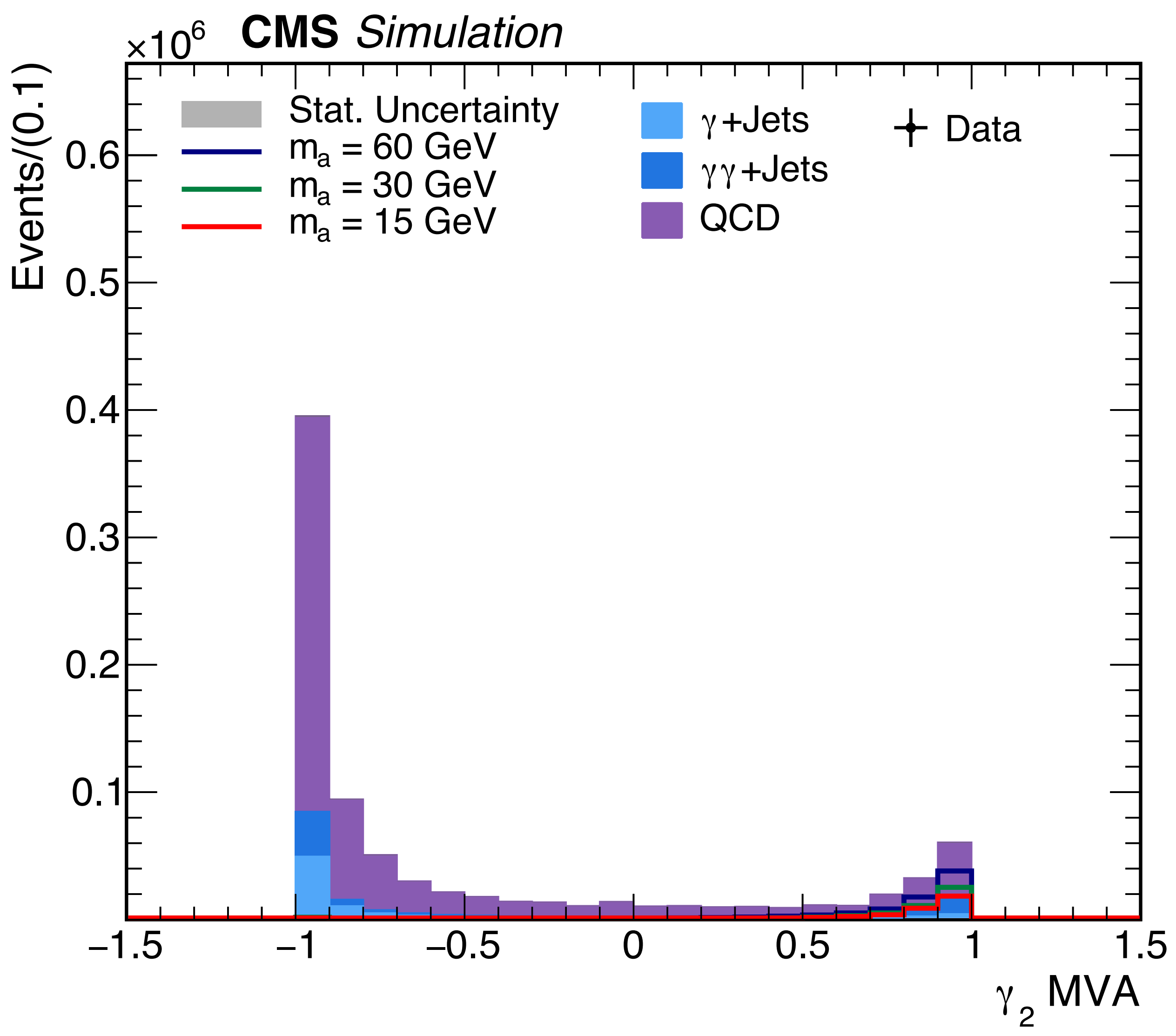
CMS Simulation
×10^6
Events/(0.1)
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ MVA_3

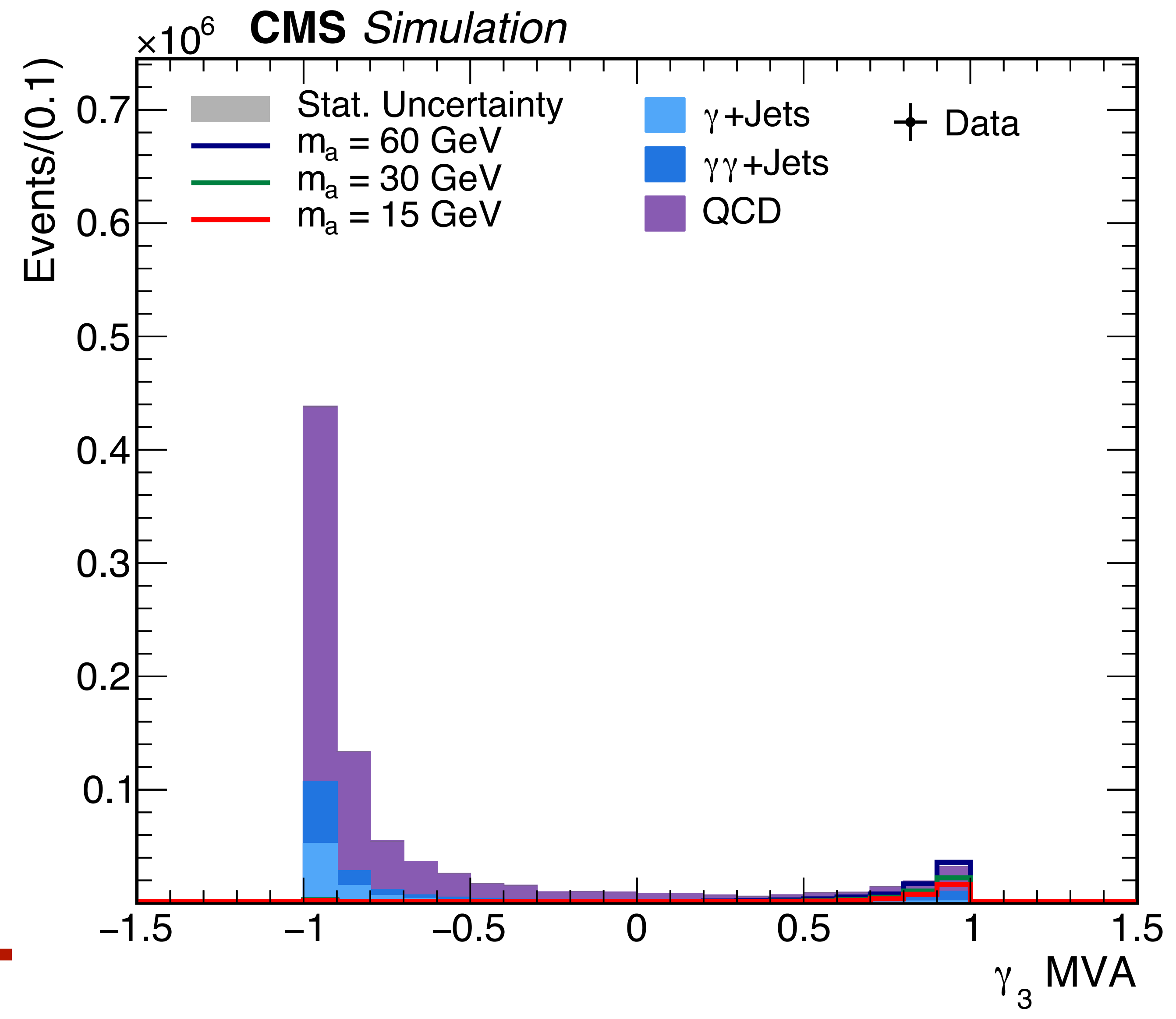


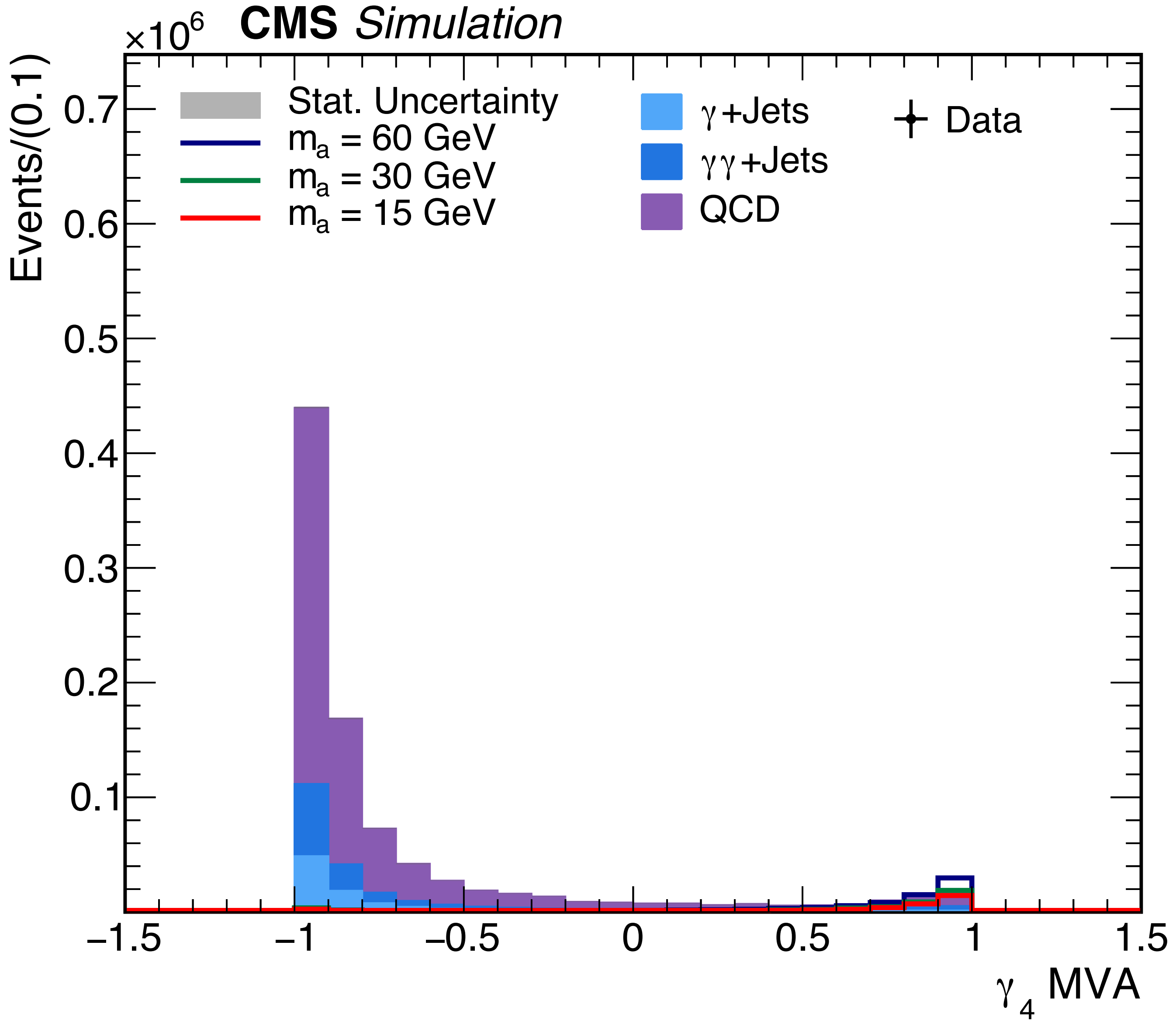
CMS Simulation
×10^6
Events/(0.1)
Stat. Uncertainty
m_a = 60 GeV
m_a = 30 GeV
m_a = 15 GeV
γ+Jets
γγ+Jets
QCD
Data
γ MVA_4

MVA distribution of bad quality photons









h(125)→aa→γγγγ

NEU Meeting

22nd August 2018

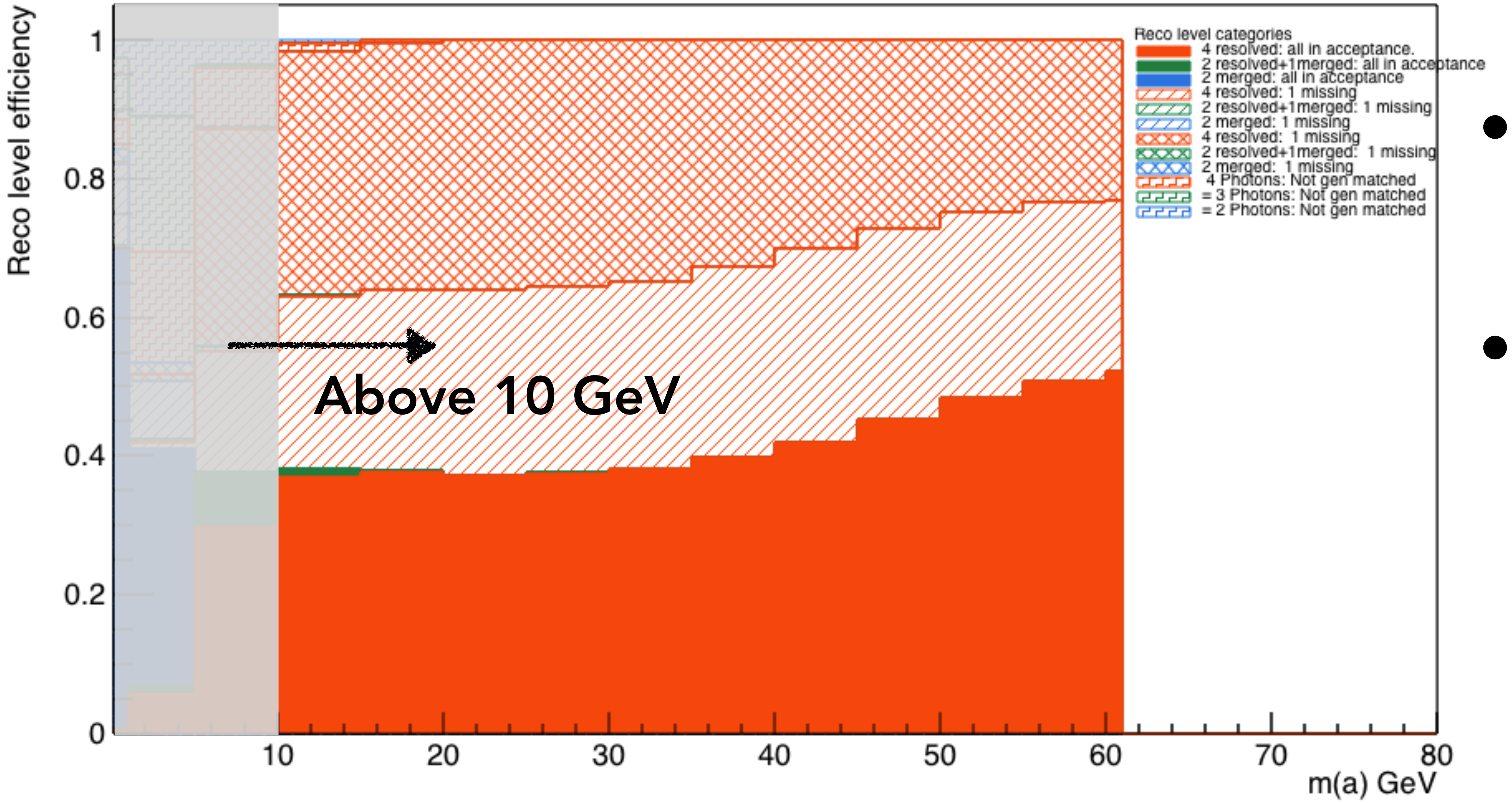
Tanvi Wamorkar[1], Toyoko Orimoto[1], Andrea Massironi[2]
[1] Northeastern University
[2] INFN Milano-Bicocca and CERN

Overview of the updates

- Presented at the Hgg working group meeting
  - Link
  - Presented trigger and pre-selection studies to help establish that the low mass $h \to \gamma\gamma$ online triggers can be utilized by us

- This presentation:
  - Focus on m(a) > 5 GeV — Resolved photons case
  - Present signal and background MC comparison

Recap: 4 Resolved Photons case



- Using Gen-Reco matching, we can flag γ's @Reco level as resolved or merged
- Moving forward, we can use this information and design the analysis for m(a) > 5 GeV

Background MC samples

- Background MC samples:

  - 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

- Was also asked by the Hgg convenors to add DYJetstoLL sample as a check
  - DYJetsToLL_M-50_TuneCUETP8M1_13TeV-amcatnloFXFX-pythia8

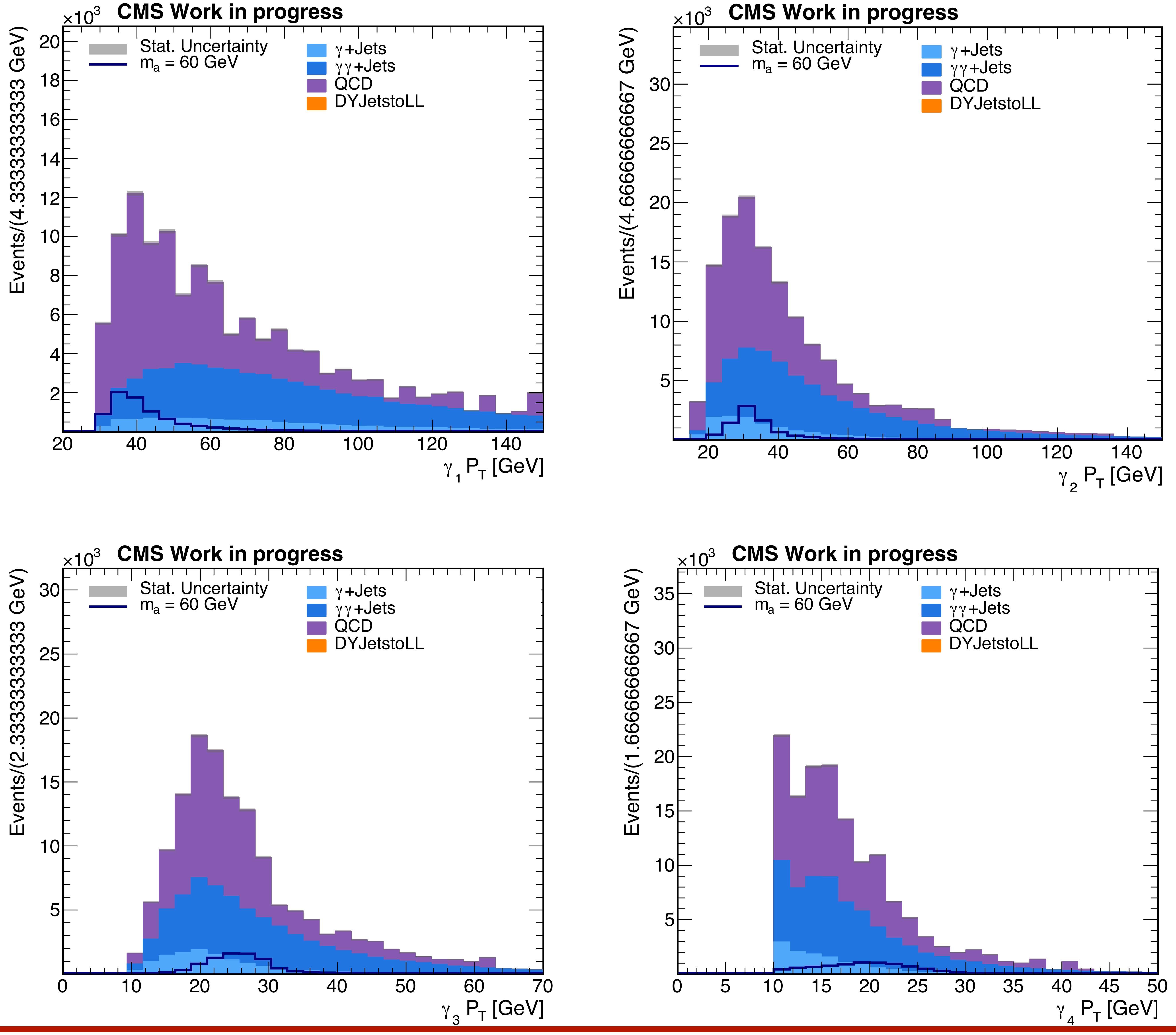
Selections applied

- Event selection (for m(a) > 5 GeV)
  - Events w/ at least 4 γ's
  - Event must pass AND of the trigger bit and the pre-selection requirements (pre-selection is tighter than the online trigger selections)

		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

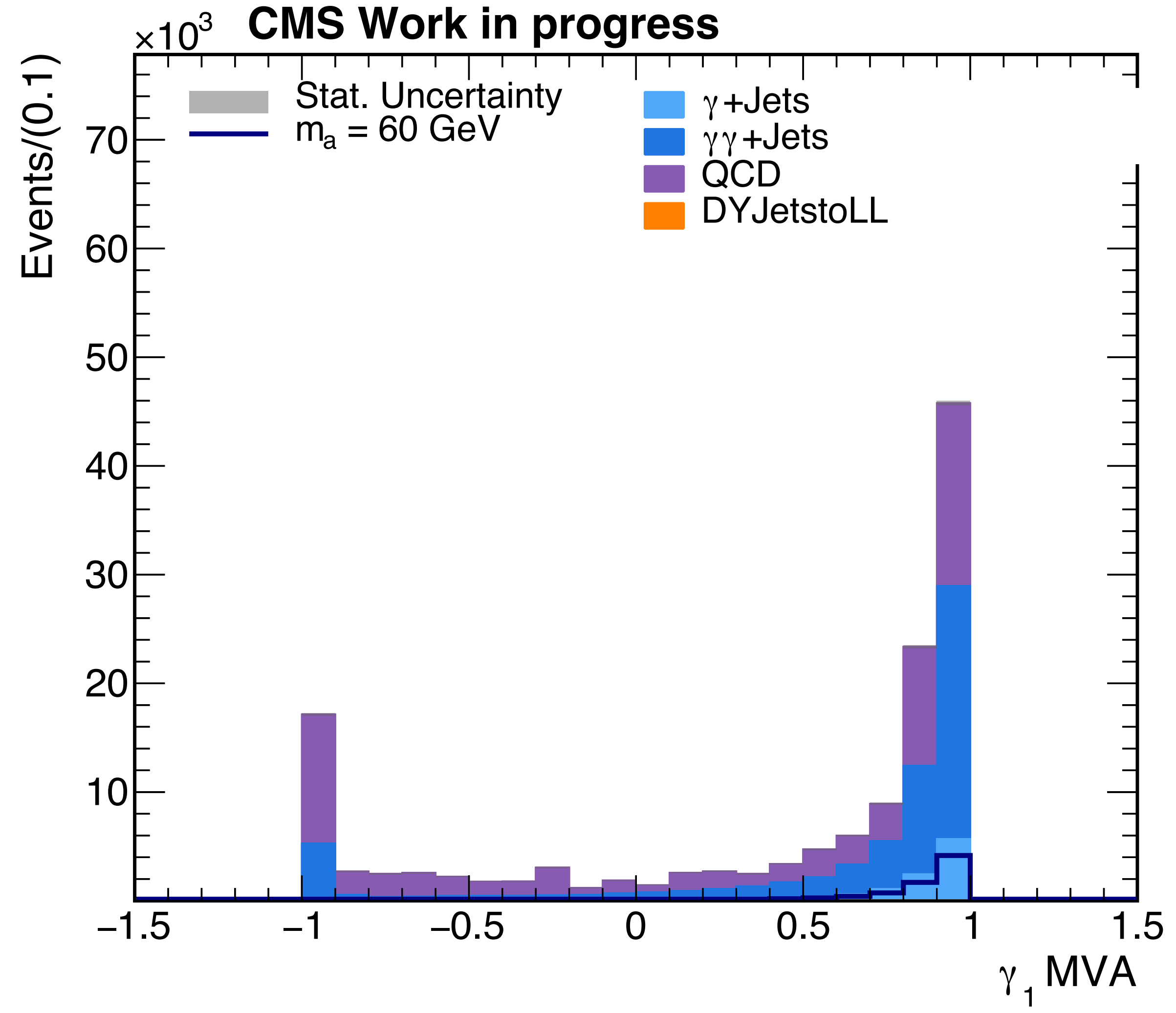
- Electron Veto: no Pixel seed
- p_T leading γ > 30 GeV, p_T subleading γ > 18 GeV
- For both γ's $|\eta| < 2.5$, but not in the ECAL EB-EE gap
- $M_{\gamma\gamma} > 55$ GeV

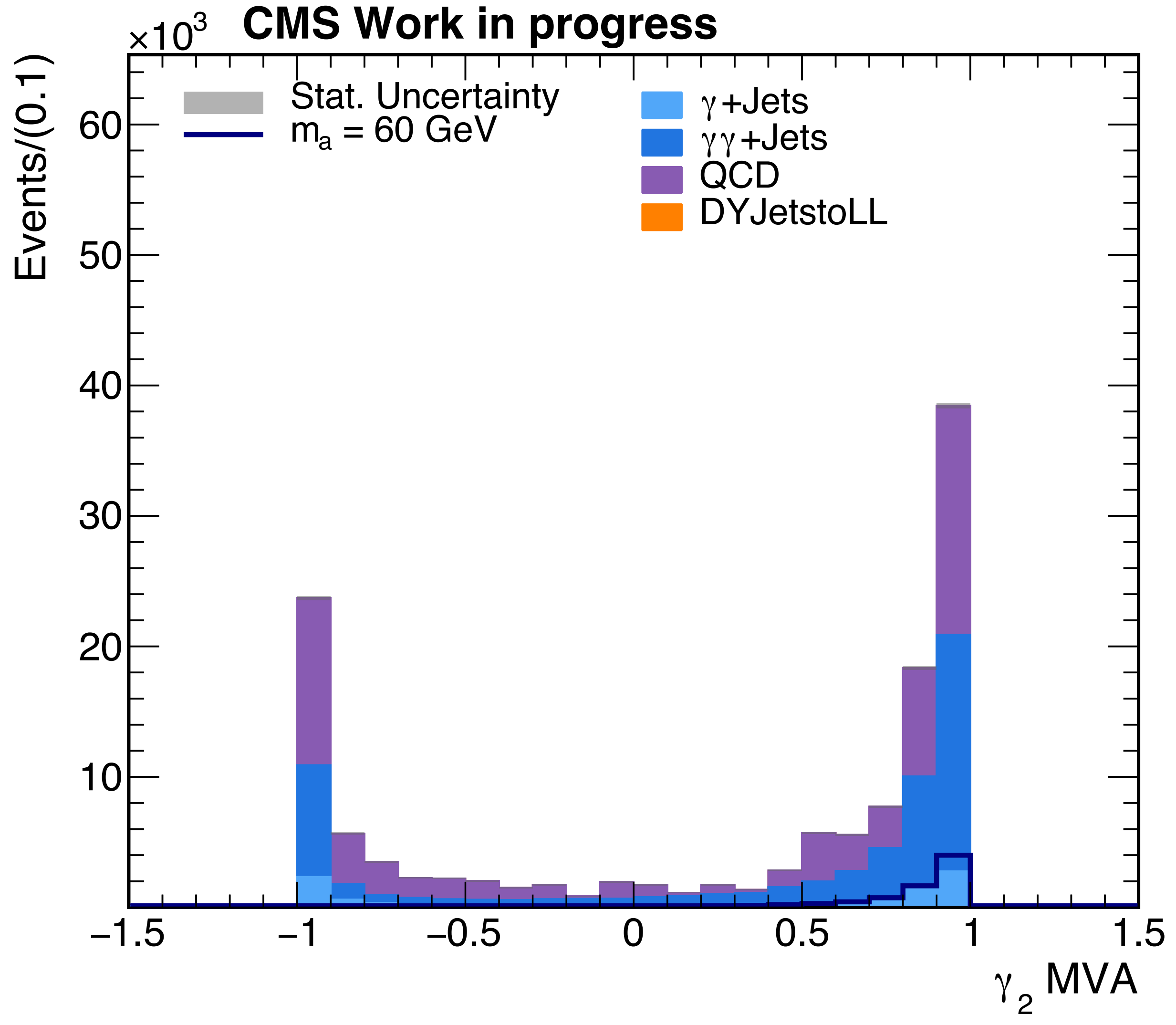
P_T distribution

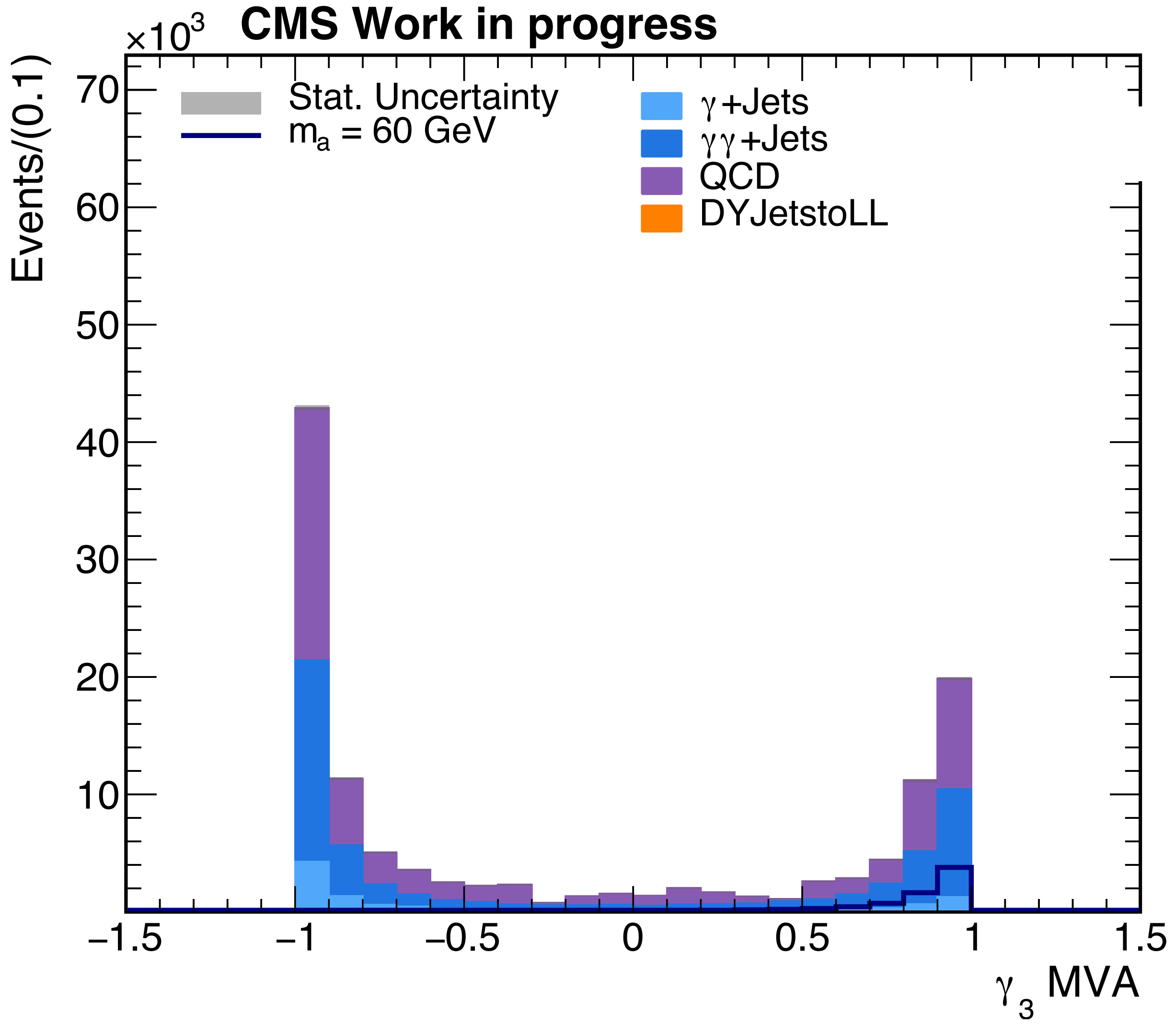


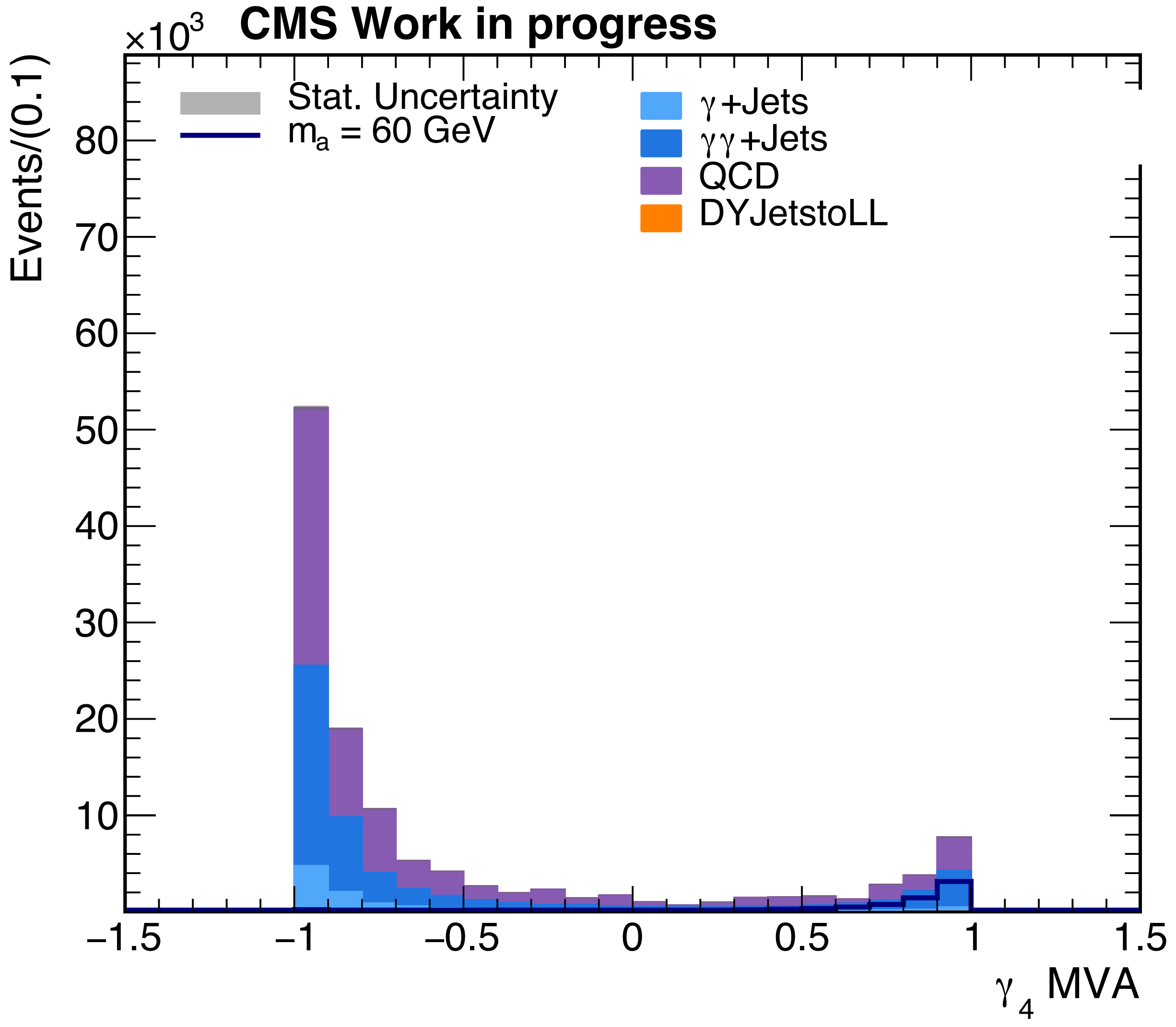
- P_T distribution of the 4 γ's
- The signal MC γ's are gen-matched (to ensure the reco level γ's are resolved)
- All MC samples have been scaled by $\frac{Luminosity * Xsection}{MCWeights}$
- For signal MC, chosen Xsection = 0.5 pb^{-1}
- DYJetstoLL sample has minimal contribution because of the requirement of 4 γ's

γ MVA score







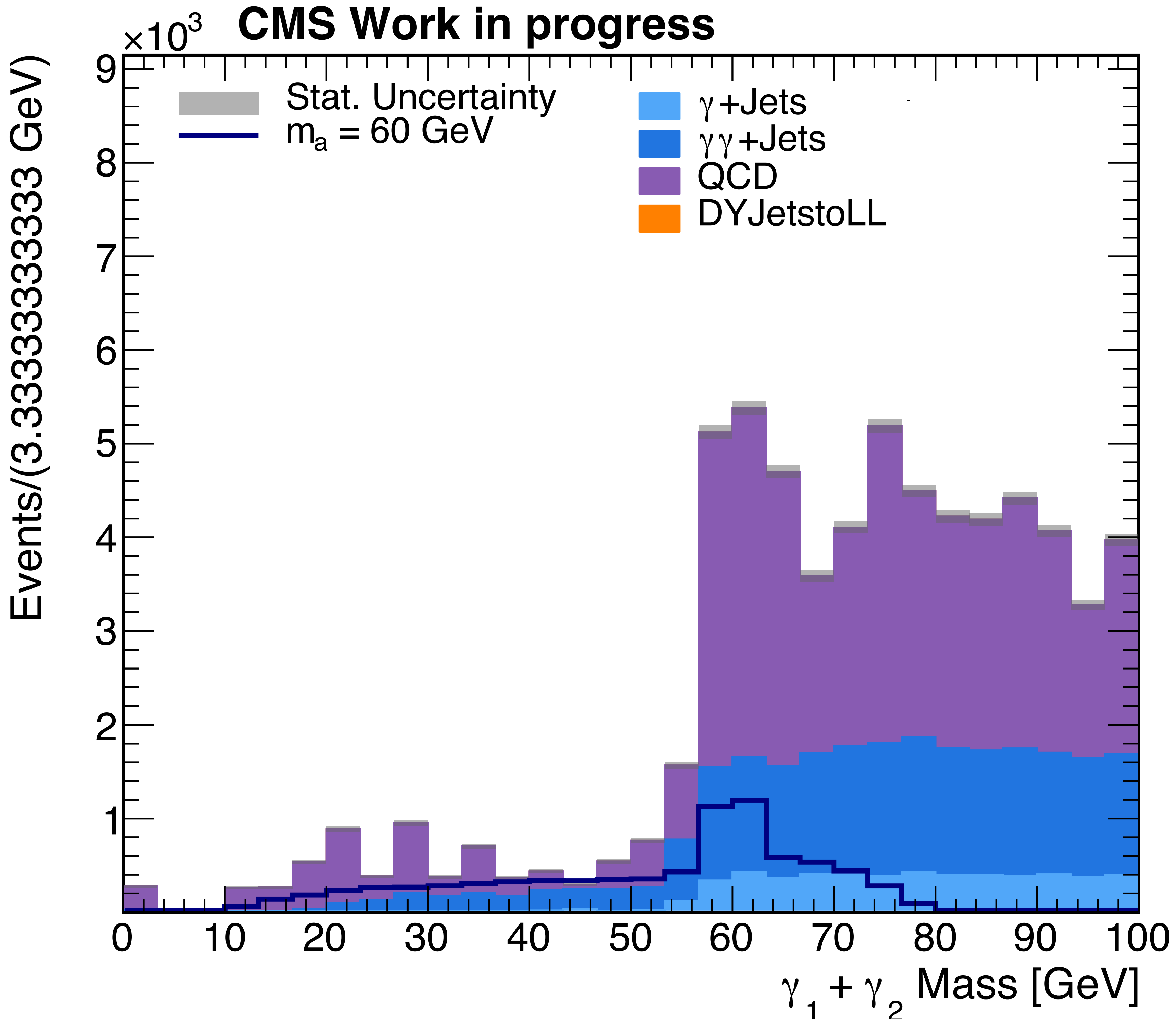


- MVA score of the 4 γ's

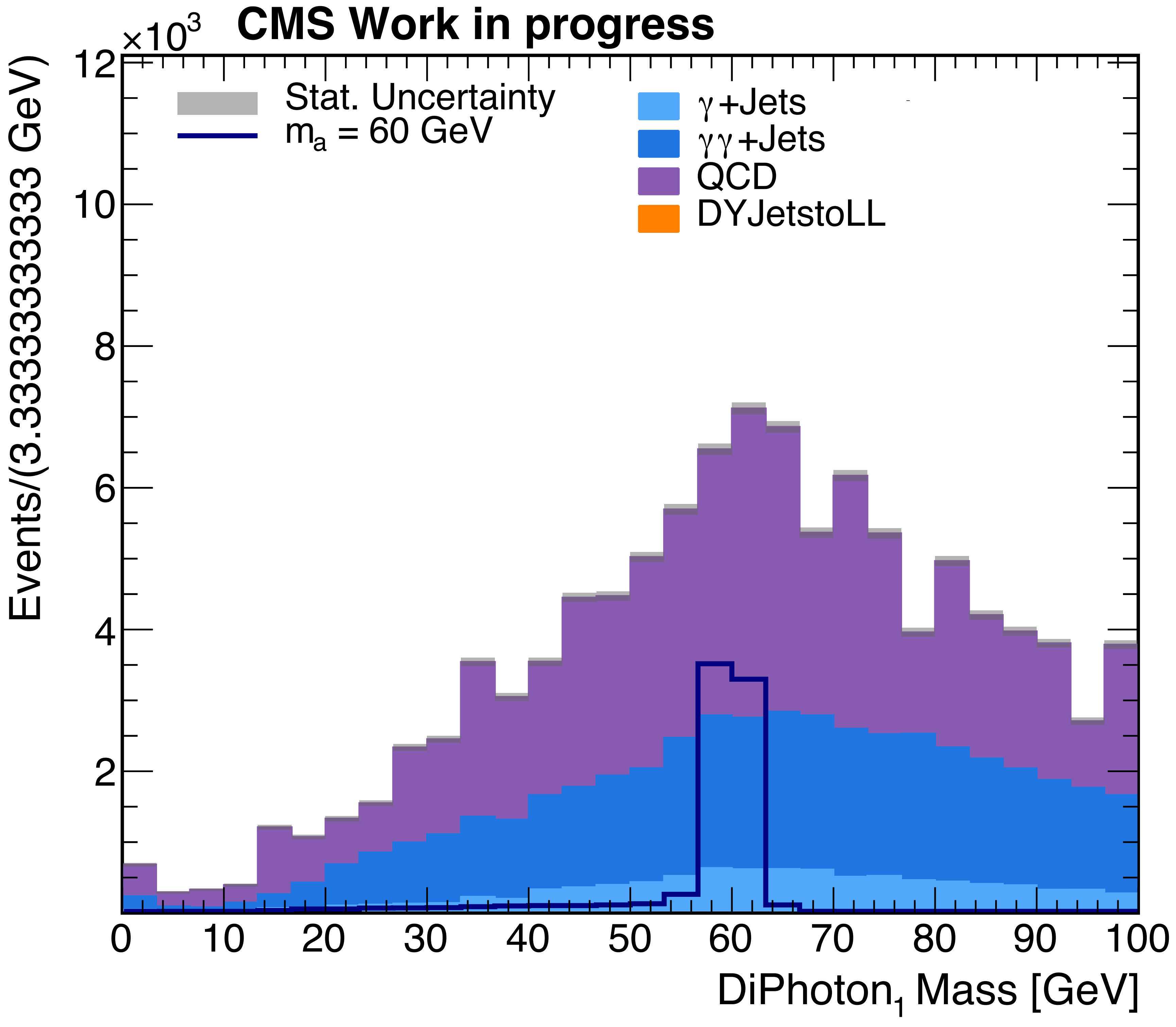
- The γ's are P_T ordered
- MC samples γ+Jets and $\gamma\gamma$+Jets, have at least 1 real γ and a Double-EM Enriched filter is applied during production to the γ+Jets and QCD samples
- This is why the first two γ's in background MC also have a high MVA score
- Discriminating power comes from the MVA score for the 3rd and 4th γ
- Based on these distributions, we can choose a selection on MVA score that keeps very high signal efficiency

Di-Photon Pairing

- From the 4 final γ's, we select pairs that make di-photons with most similar masses
  - Performs better than pairing the leading and sub-leading γ

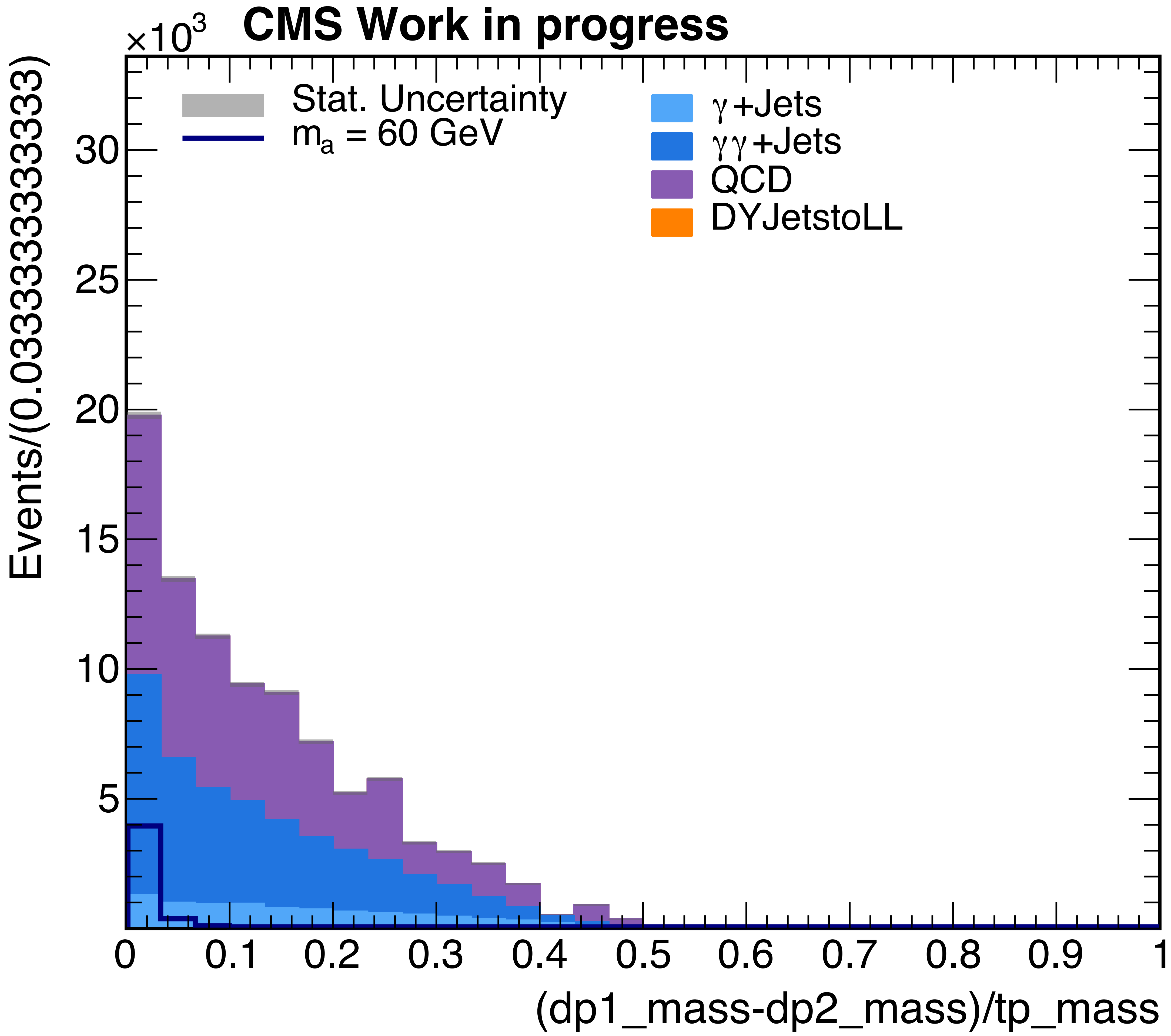


Di-photon created using first 2 γ's

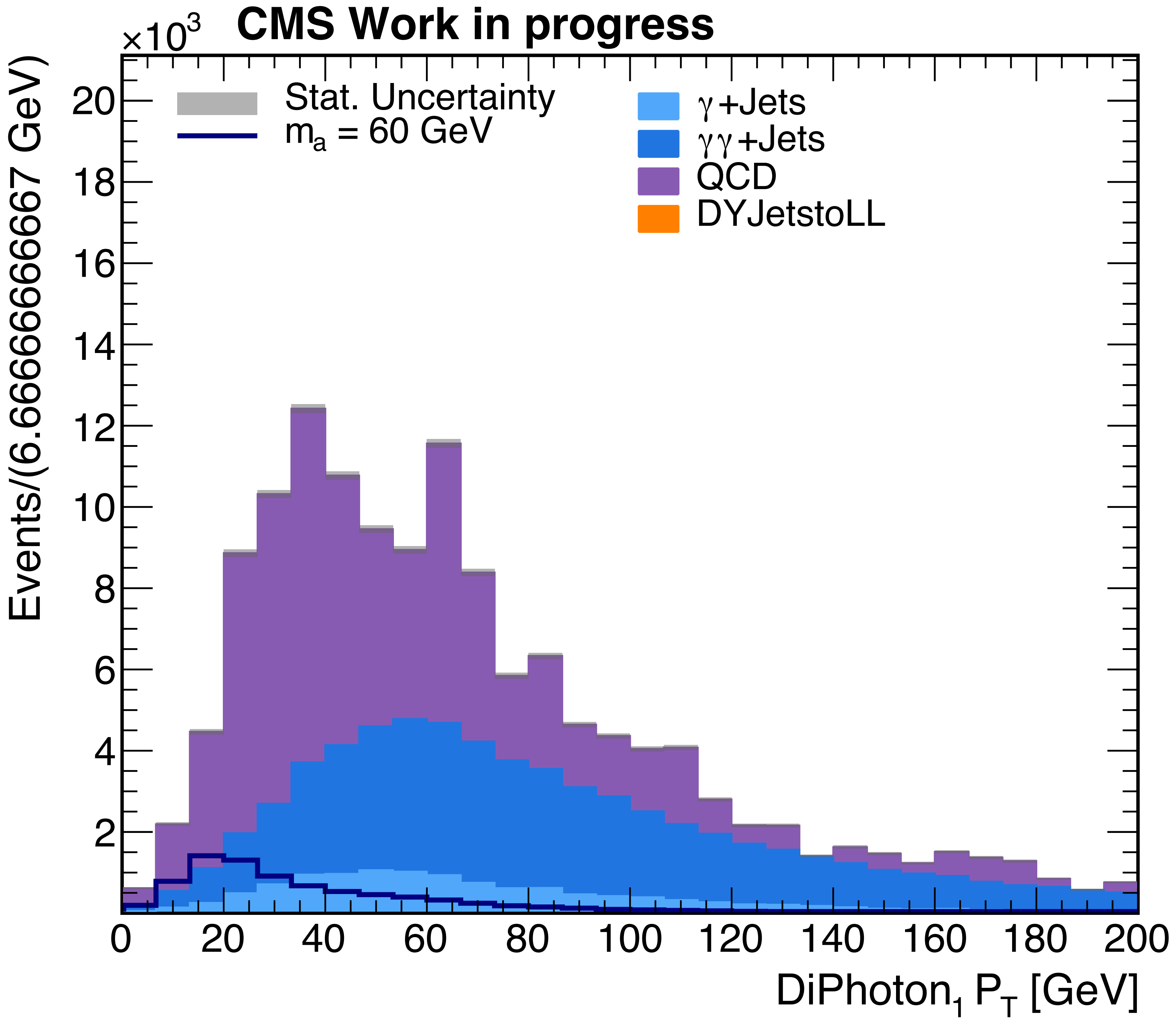


Di-photon created using correct pairing

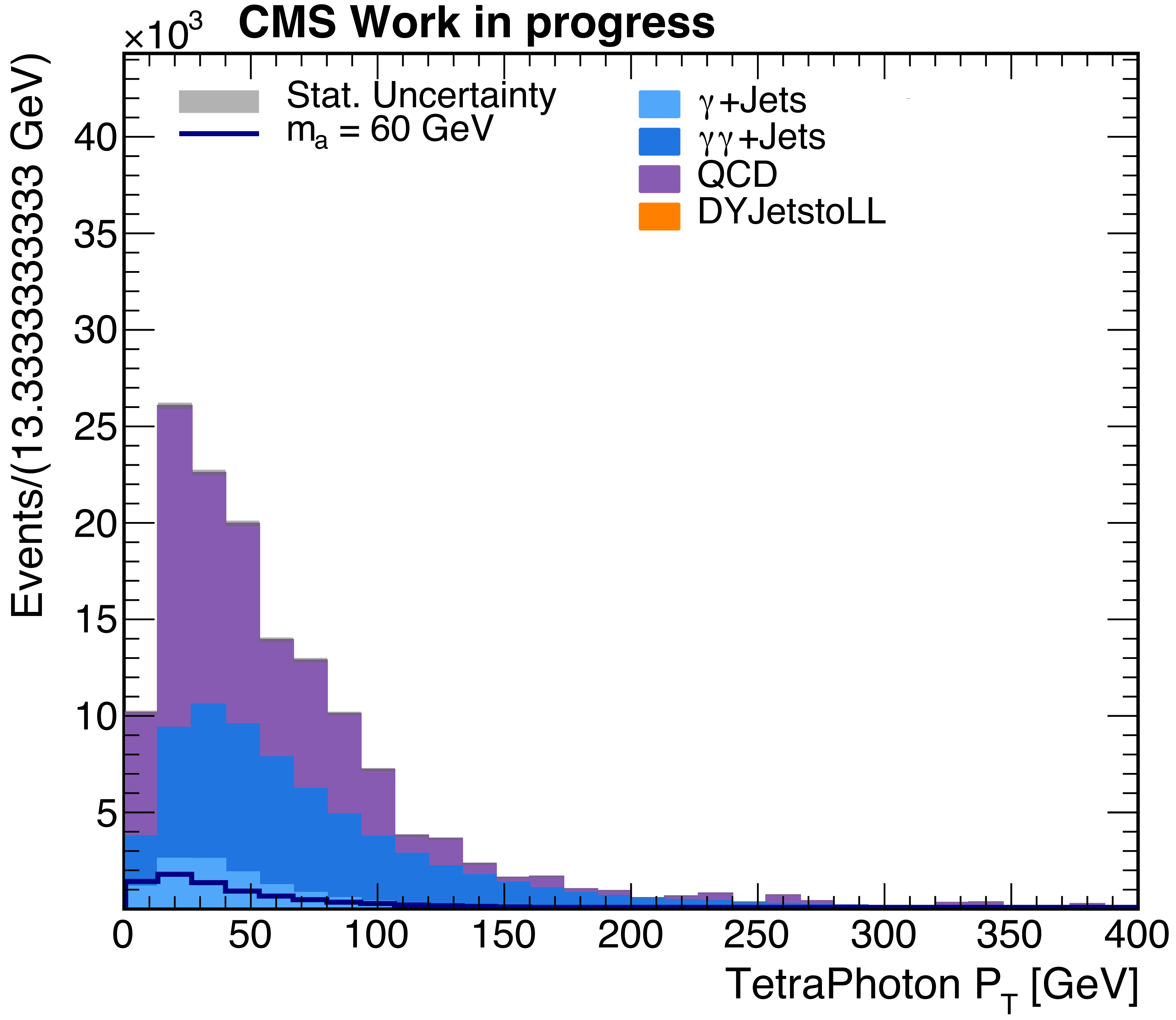
Di-Photon Pairing



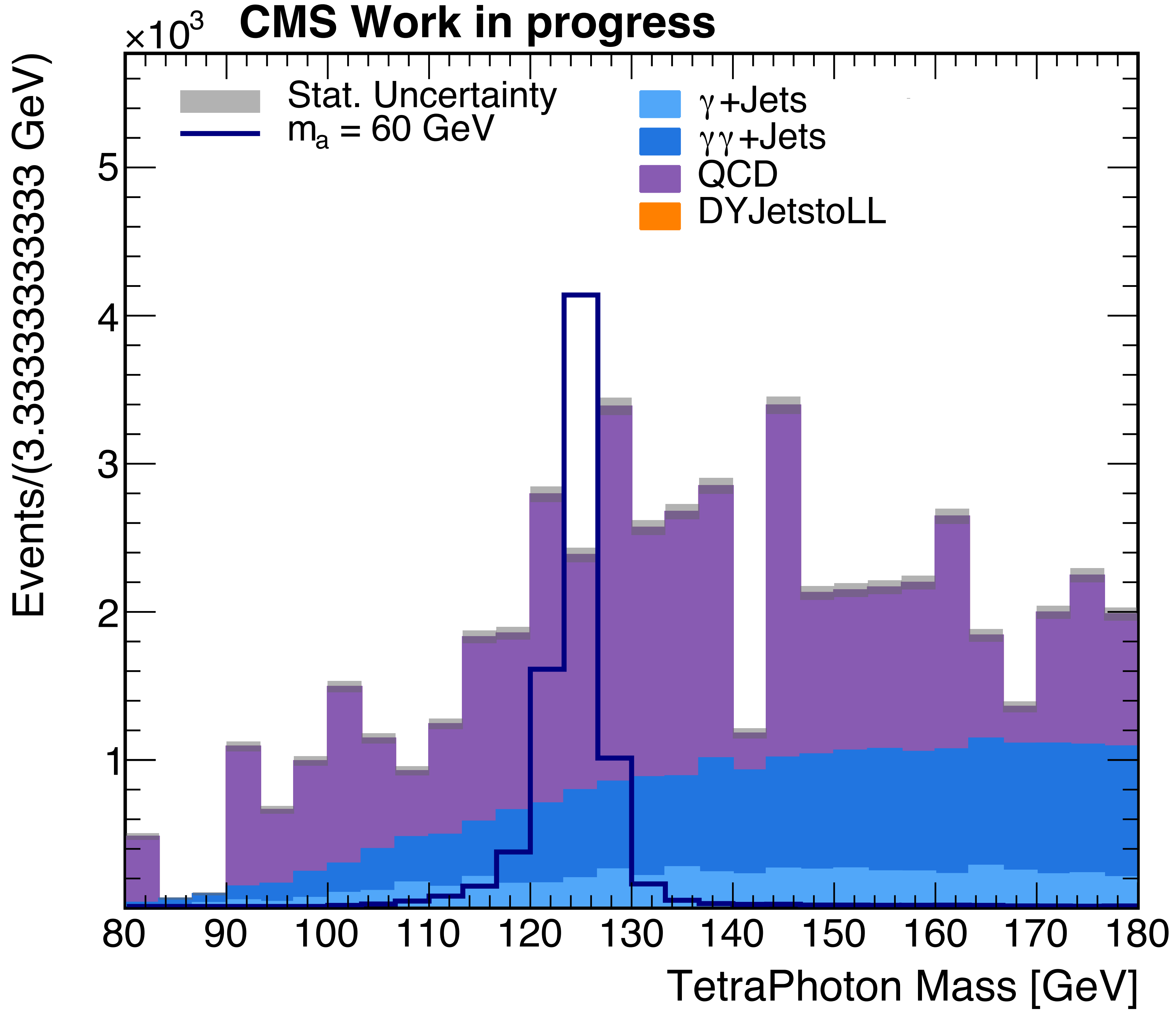
- But, this pairing is also shaping the background MC
- Distribution of $\dfrac{|Mass_{Diphoton1} - Mass_{Diphoton2}|}{Mass_{4\gamma}}$
- Will check the normalized distributions (this is a stack)
  - That can tell us if this variable can be used as a good handle on S/B



- P_T distribution of the Di-photon object



- P_T distribution of the Tetra-photon (Higgs) object



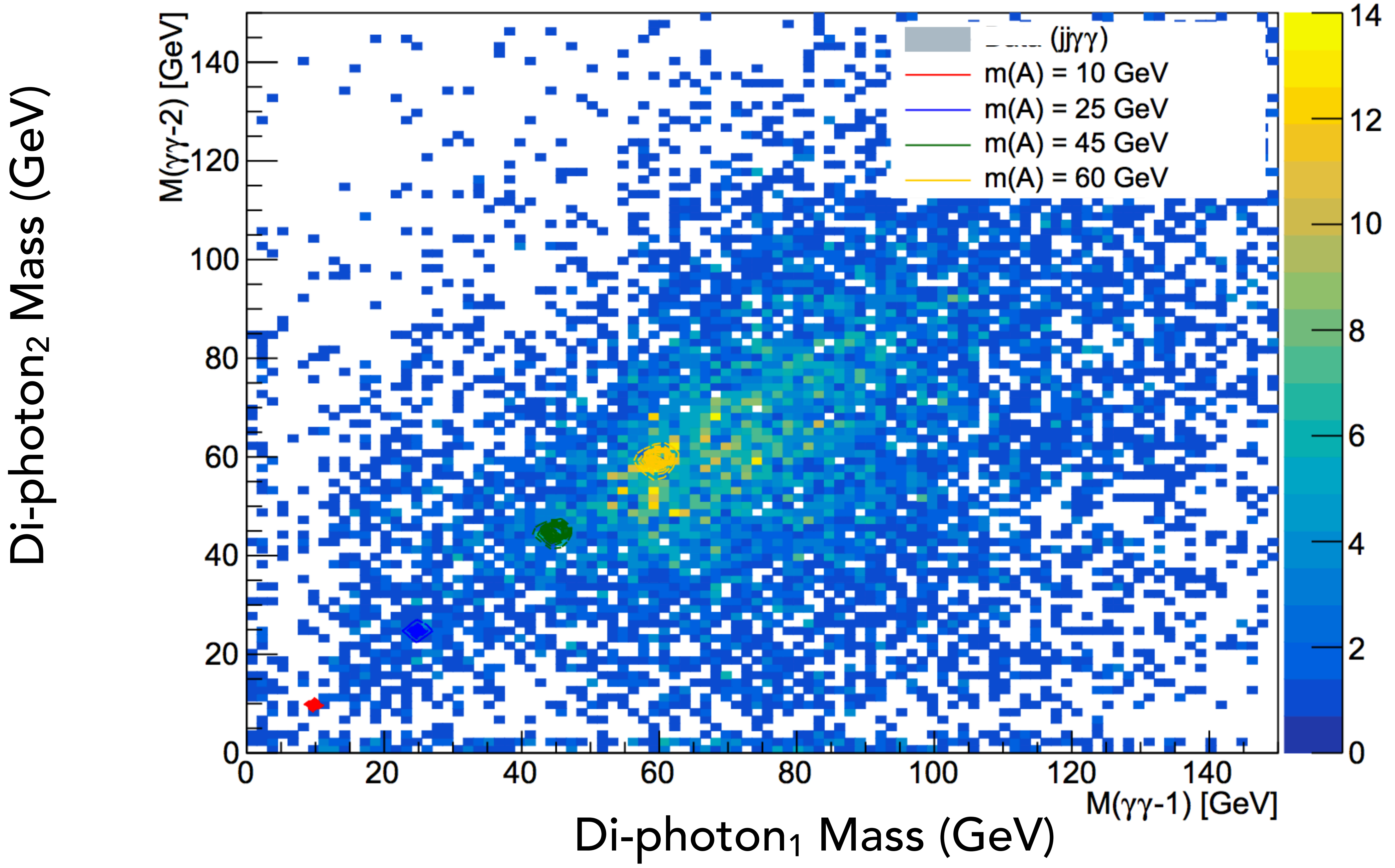
- Mass distribution of the Tetra-photon (Higgs) object

Ideas to define a control region

- Identifying a control region would help perform a closure test on the background modeling

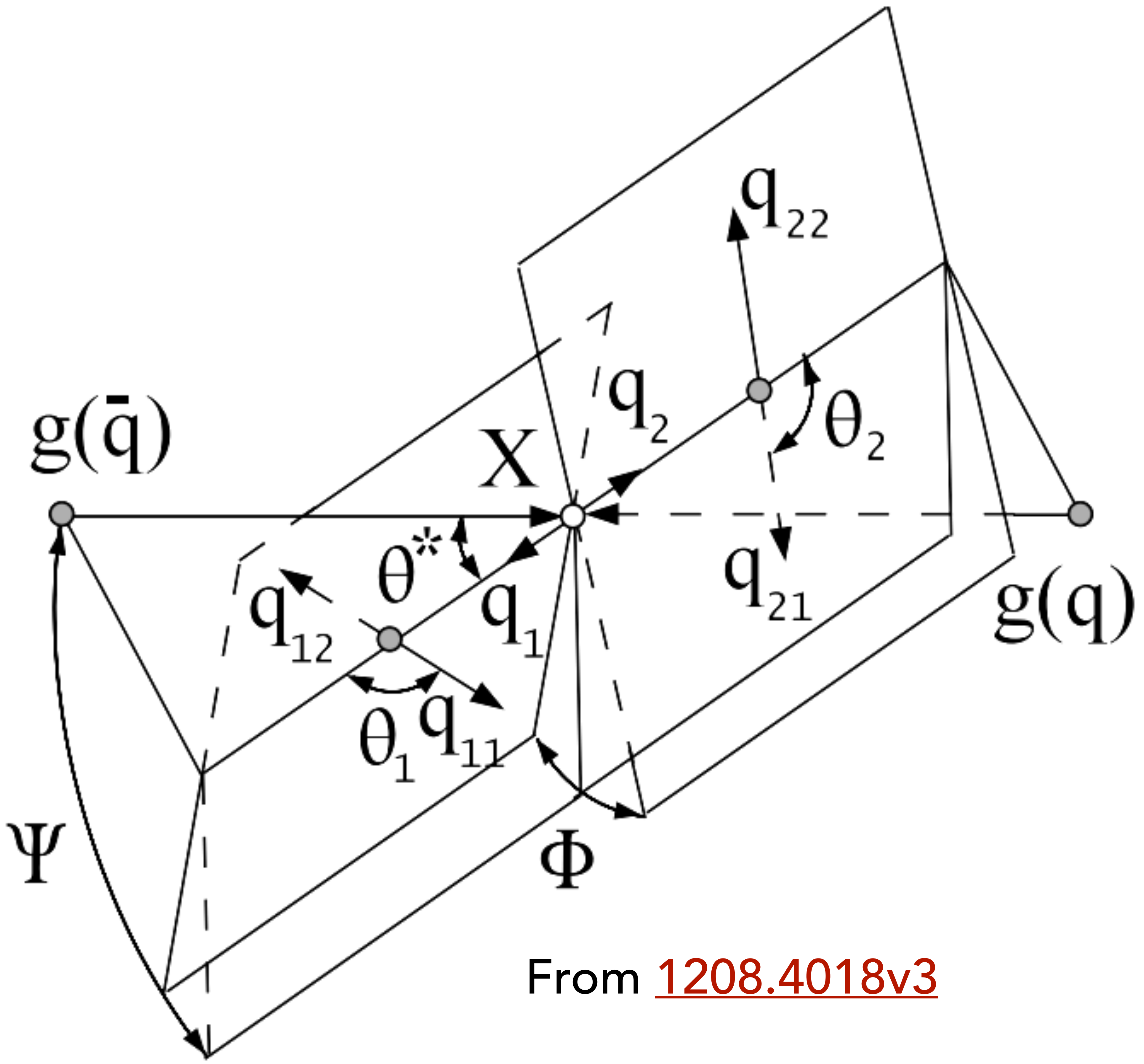
- This can be done by inverting the selection on γ MVA score (for eg: 3 photons + 1 fake photon)

- Another possibility is to utilize the di-photon pairing information
- Since the two di-photons have the same invariant mass, it is interesting to look at the 2D distribution of Di-photon$_1$ mass and Di-photon$_2$ mass

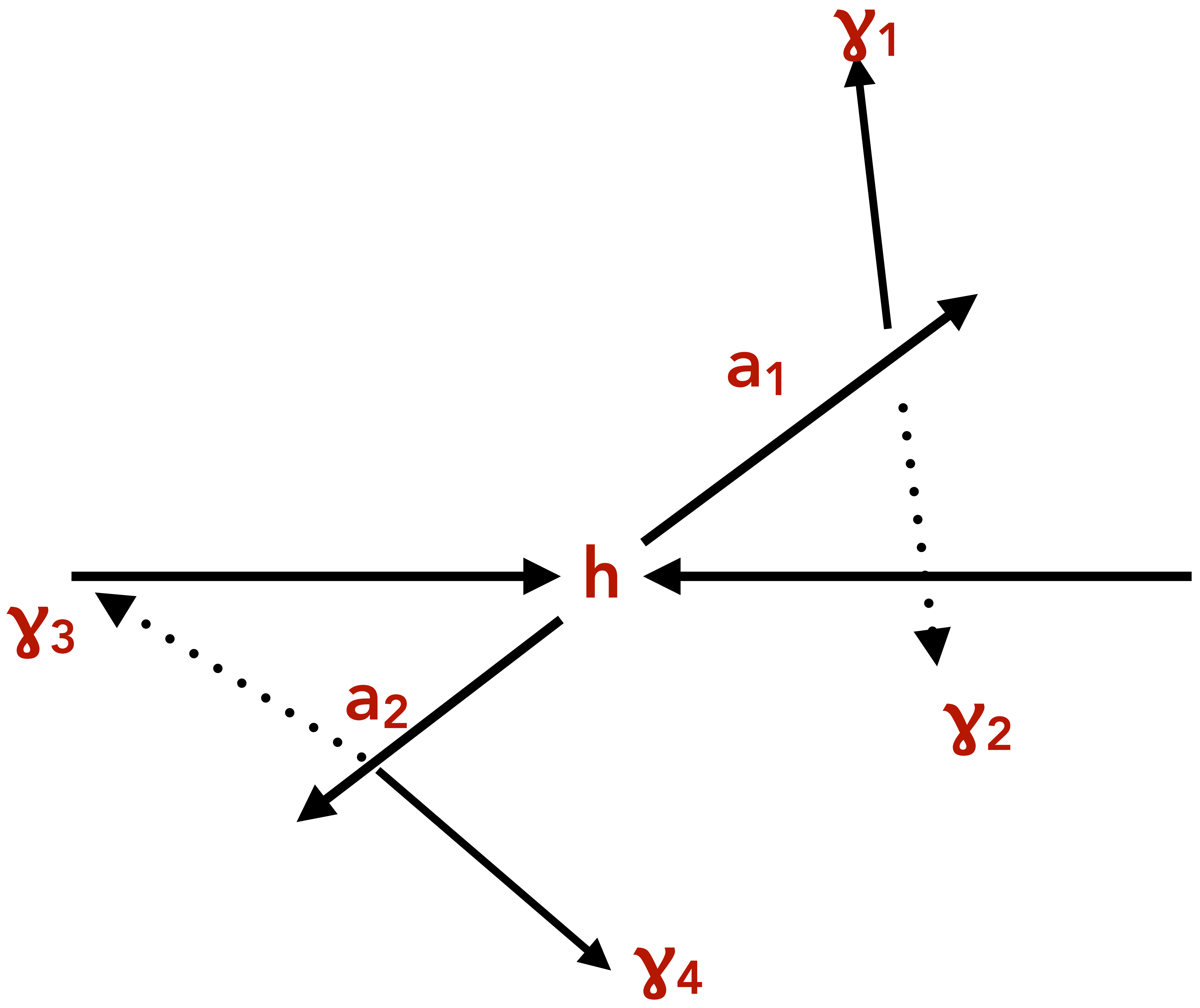


Angular variables

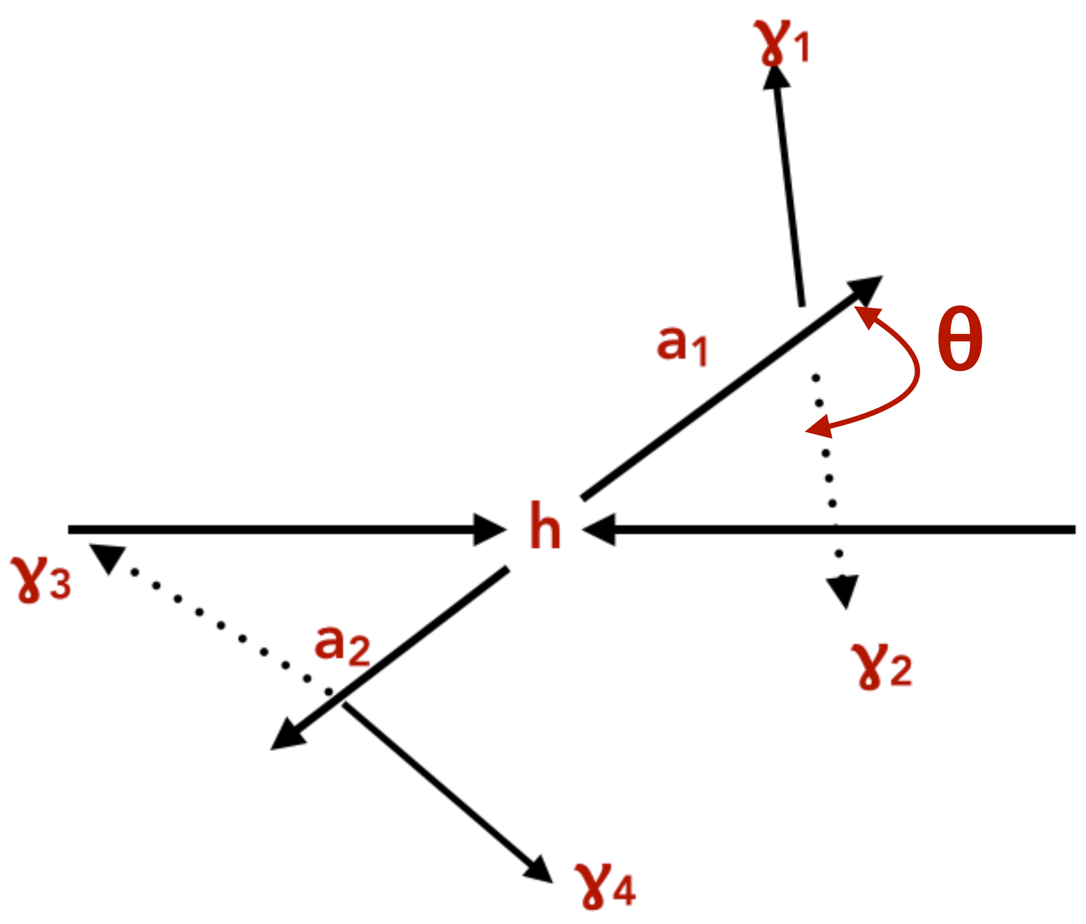
- Since this is a 4-body decay, it could also be interesting to look at different angular variables

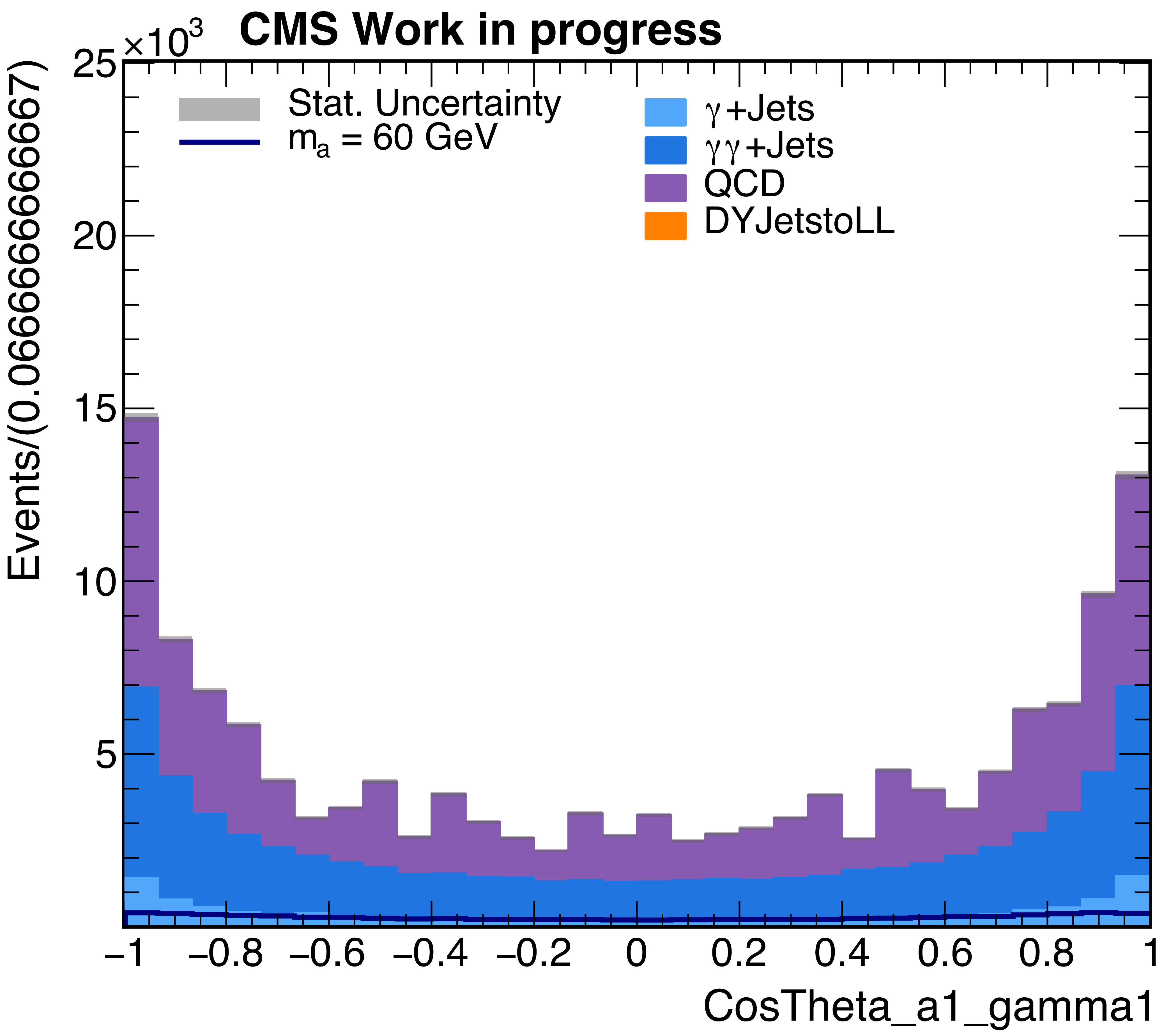


From 1208.4018v3



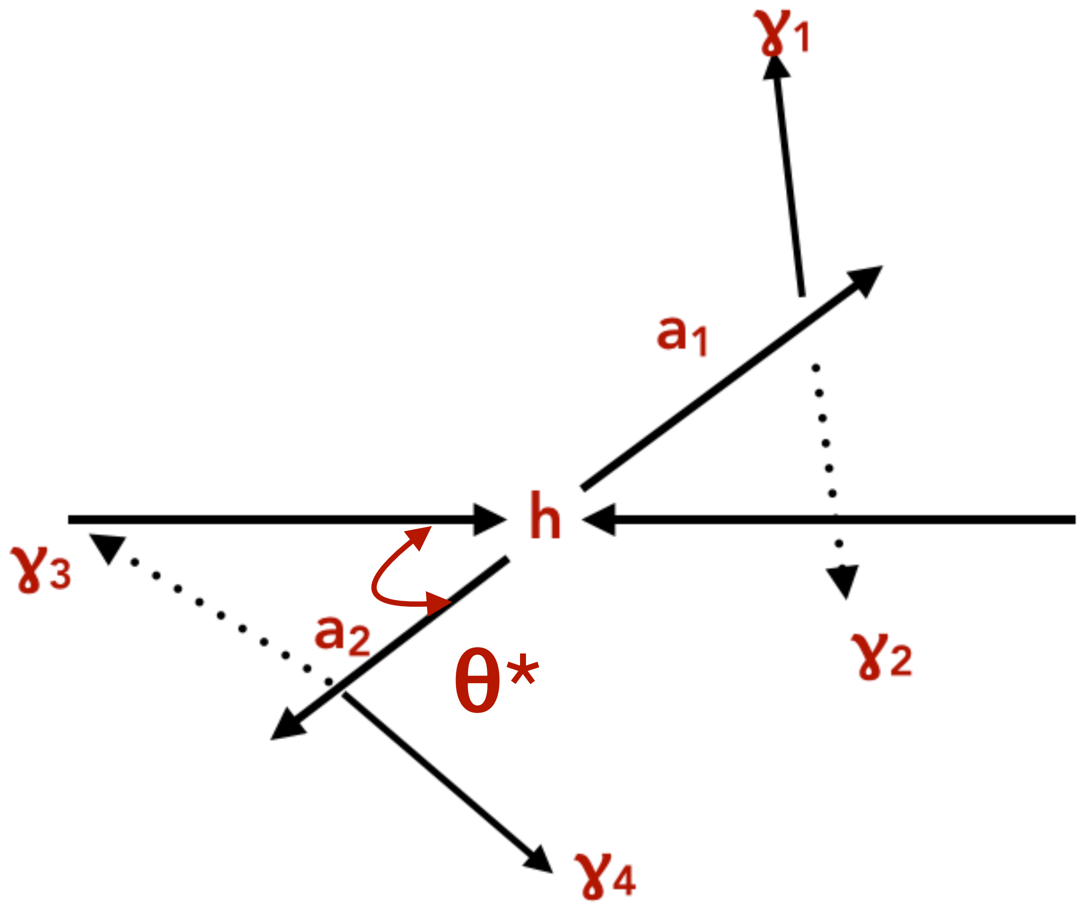
Angular variables

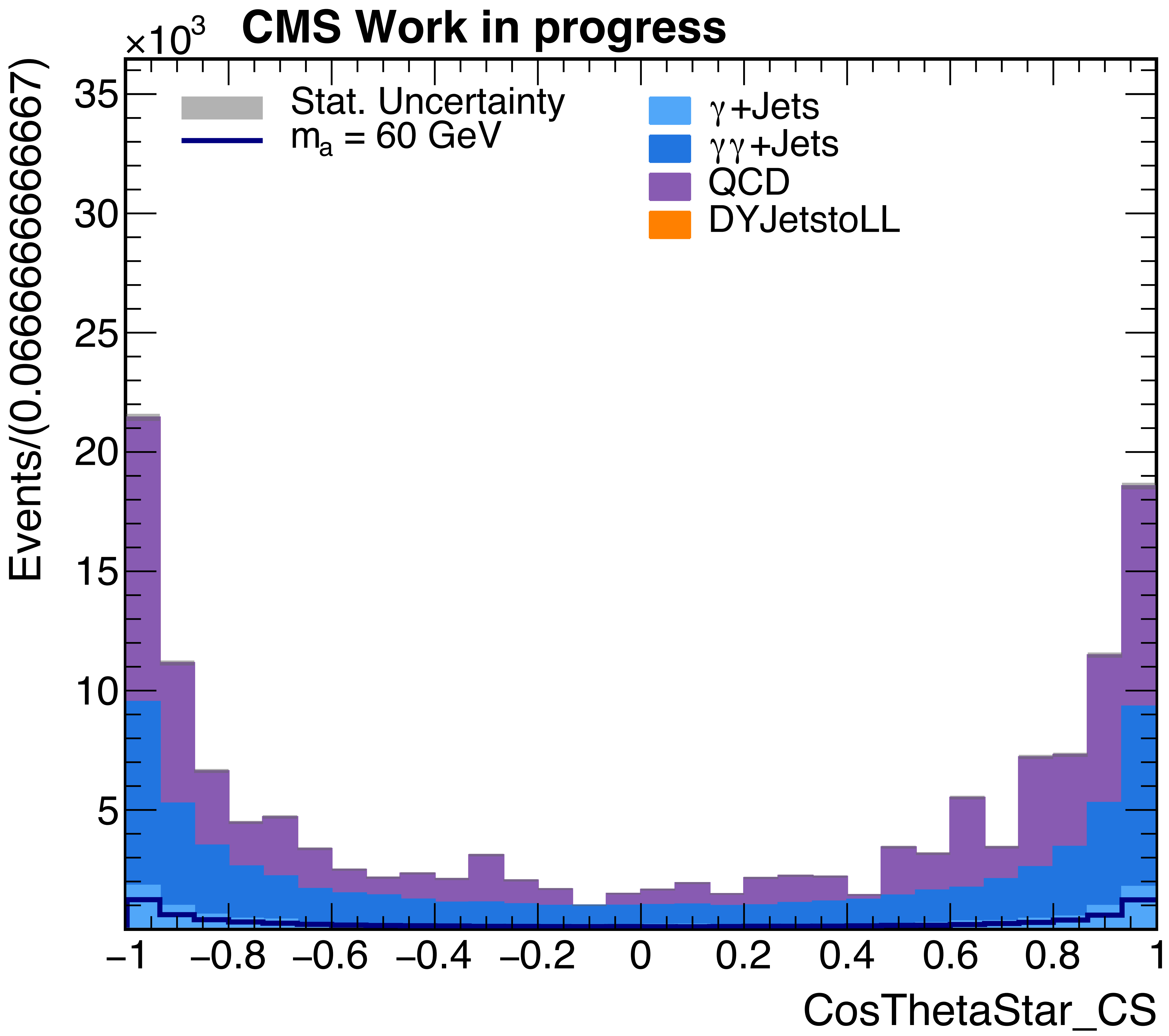




- Cos θ between γ1(3) and a1(2) (di-photon$_1$) in the rest frame of a1(2)
- The distribution is flat for signal MC

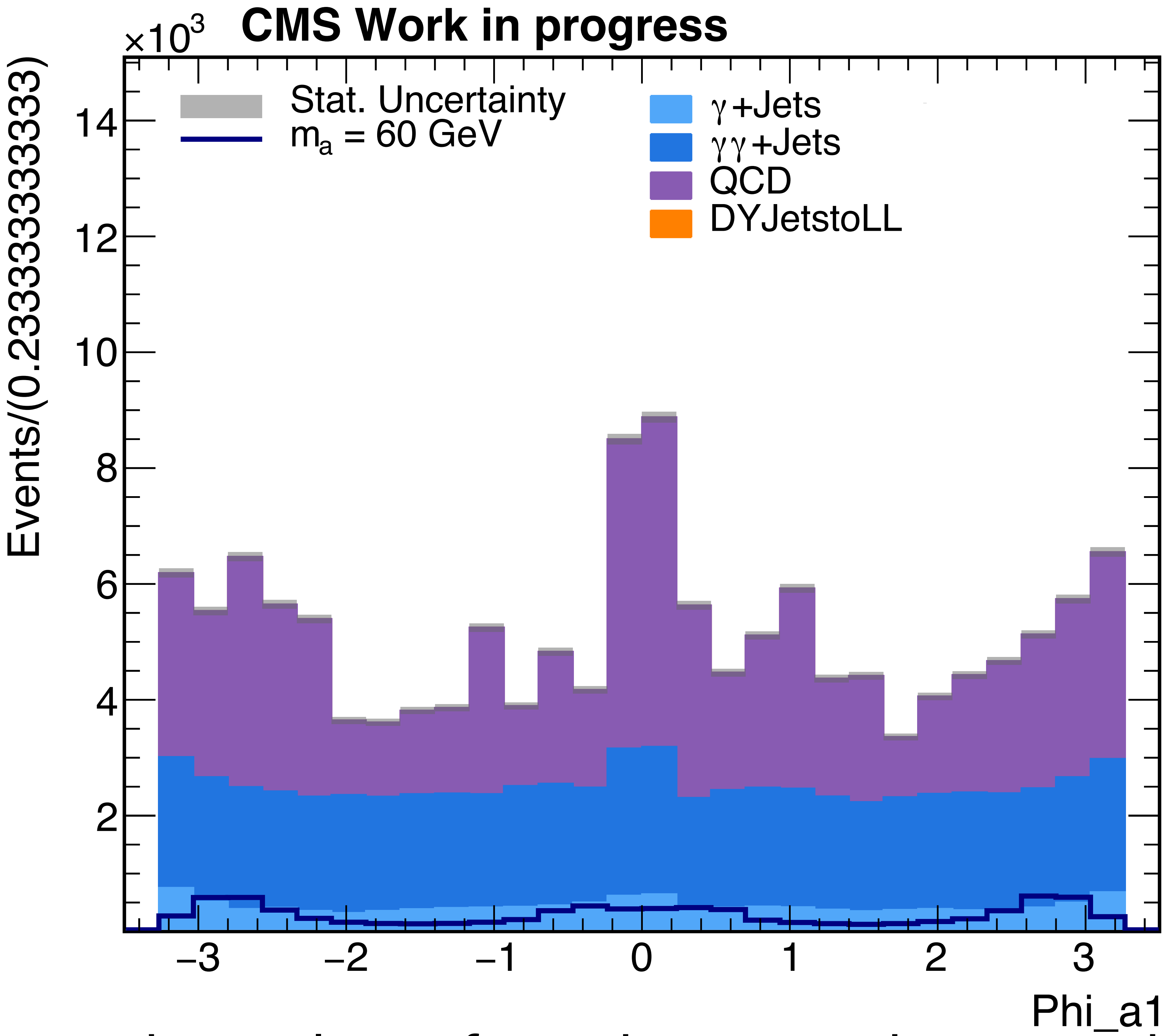
Angular variables

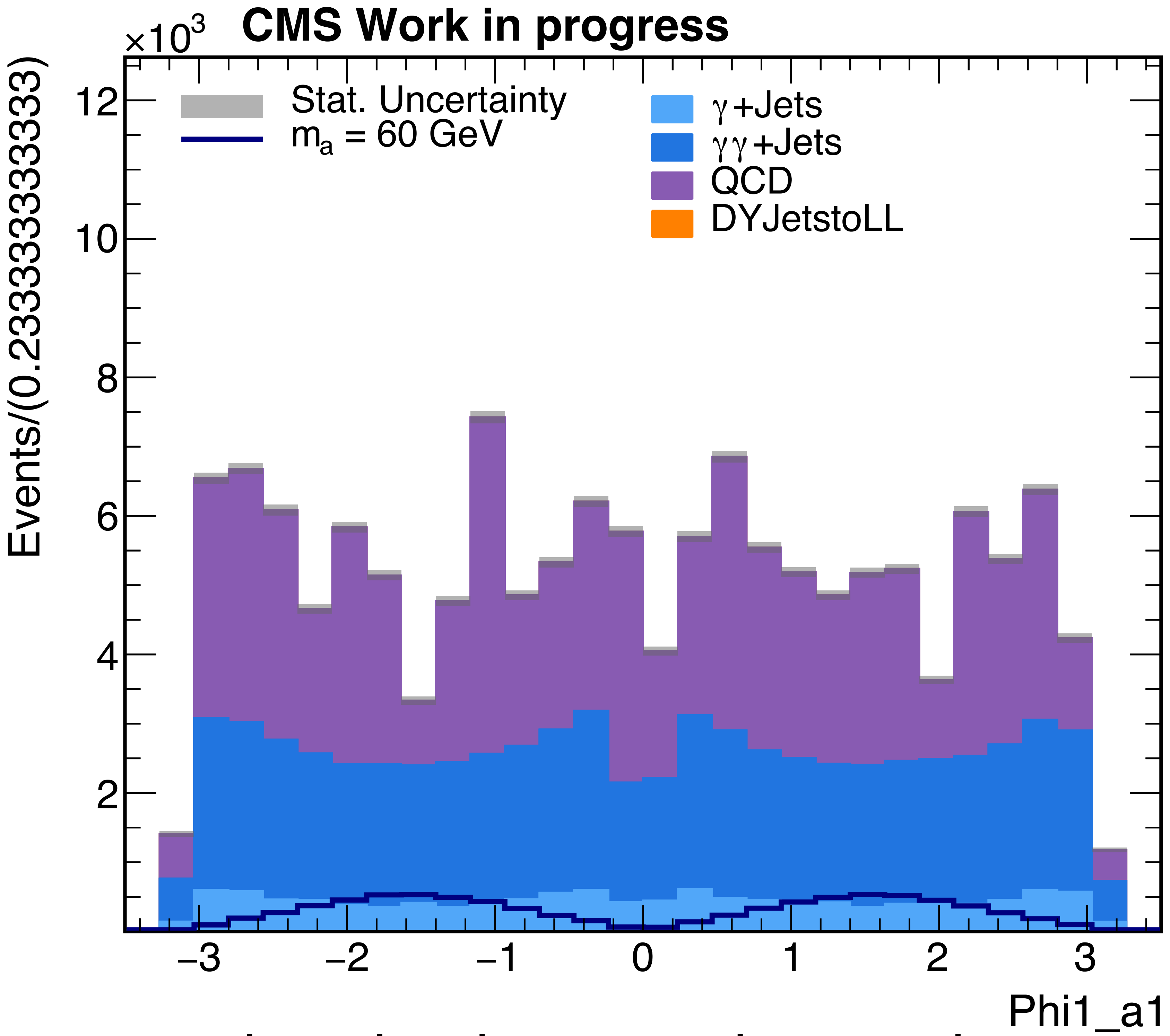




- Cos **θ*** is defined through the unit vector of pseudo scalar "a", in the rest frame of the Higgs

Angular variables





- Can construct three planes from the Higgs decay products and the two pseudoscalar decay products in the Higgs rest frame
- **Φ** and $\mathbf{\Phi_1}$ are the two azimuthal angles b/w these three planes

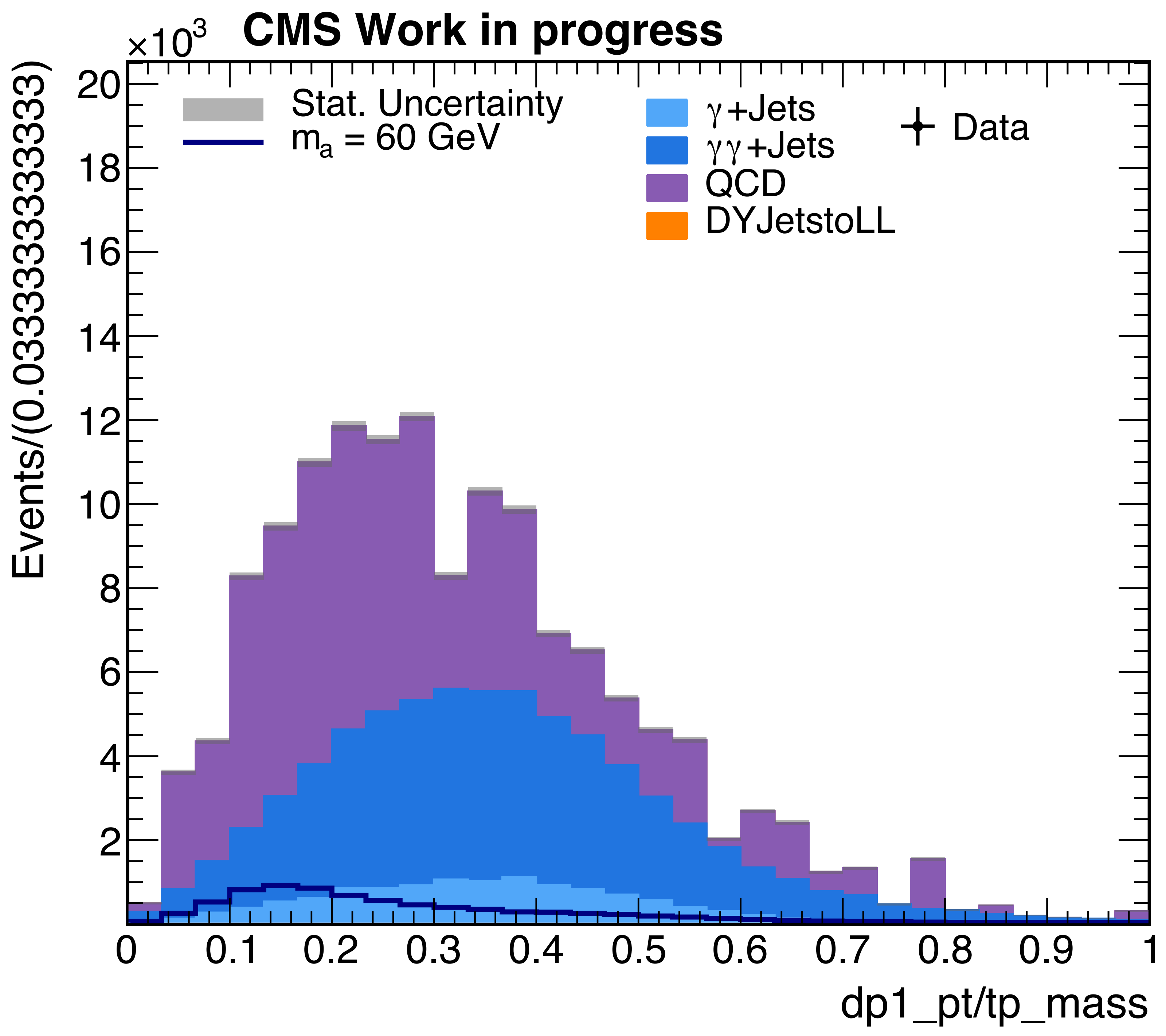
- How to use this information?
  - We cannot apply any selections based on the angular variables
  - But, we can exploit the difference in shapes for signal and background by designing an MVA based on the angular information

Conclusion and next steps

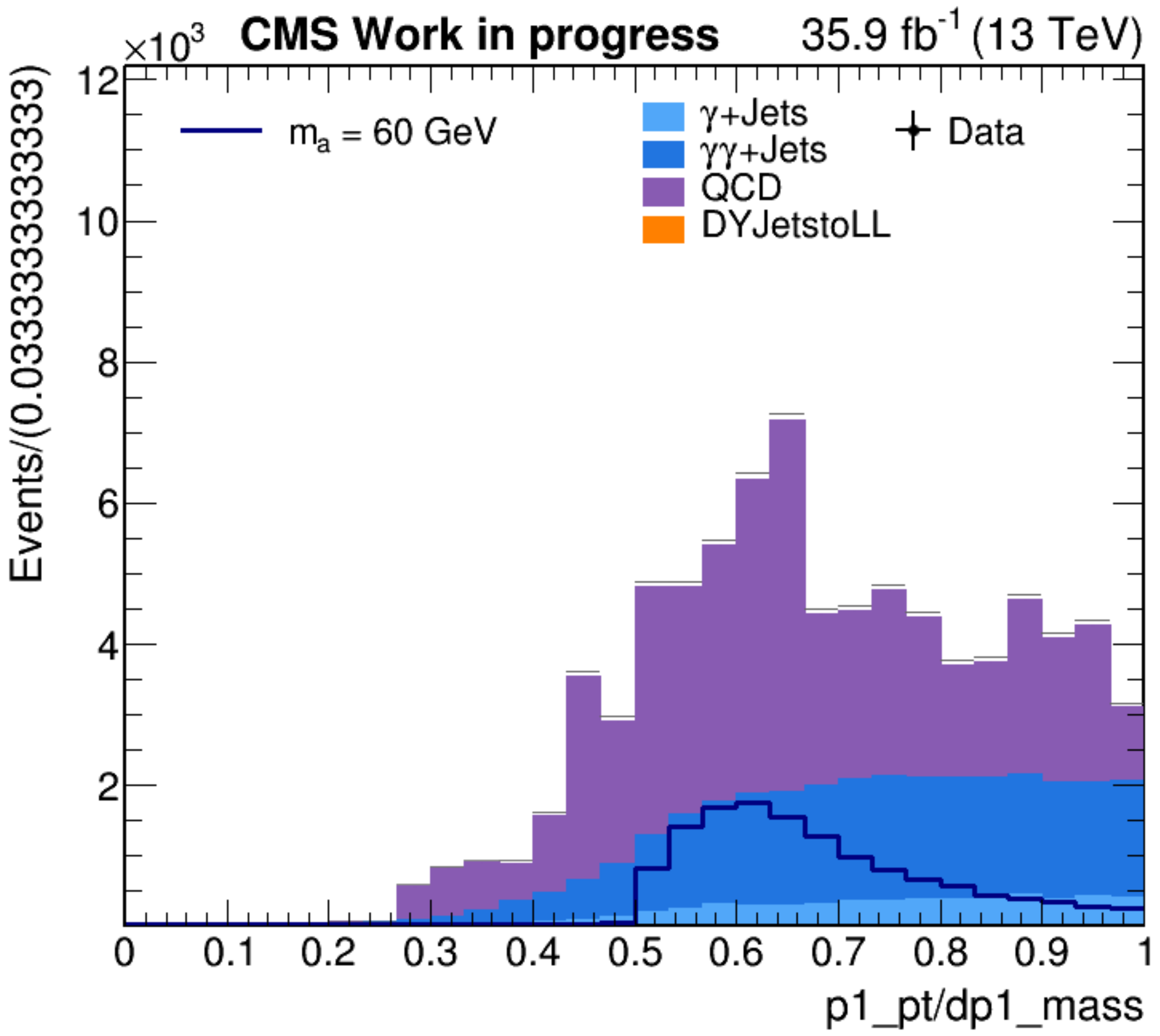
- Looked at the signal and background comparison plots

- Next steps include:
    - Investigating the possibilities of creating a photon signal and control region
    - Studying the angular variables and other possible discriminating variables to design an MVA

Backup



×10^3 CMS Work in progress
Stat. Uncertainty
m_a = 60 GeV
γ+Jets
γγ+Jets
QCD
DYJetstoLL
Data
Events/(0.0333333333333)
dp1_pt/tp_mass



×10^3 CMS Work in progress
35.9 fb^-1 (13 TeV)
m_a = 60 GeV
γ+Jets
γγ+Jets
QCD
DYJetstoLL
Data
Events/(0.0333333333333)
p1_pt/dp1_mass