SEARCH FOR NEW RESONANCE PRODUCTION IN $Z\gamma \rightarrow ll\gamma$ FINAL STATE AT $\sqrt{s}$ = 13 TeV USING CMS DETECTOR AT THE LHC

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Standard Model and Beyond..

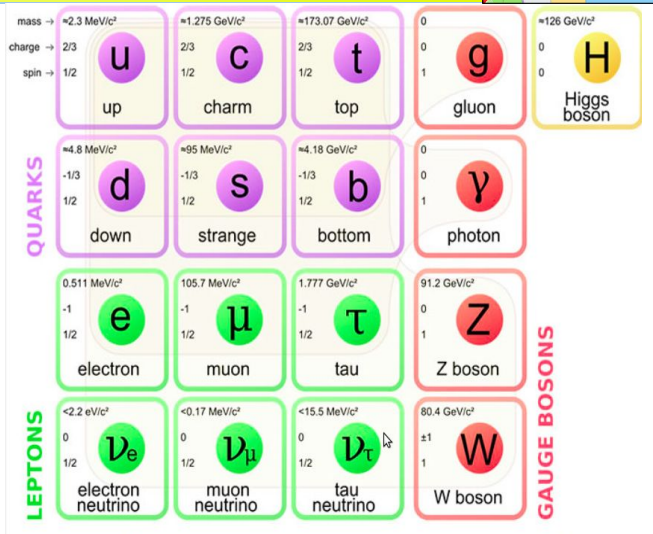
- The Standard Model of physics describes the known fundamental particles and forces that operate at the tiny quantum scale.

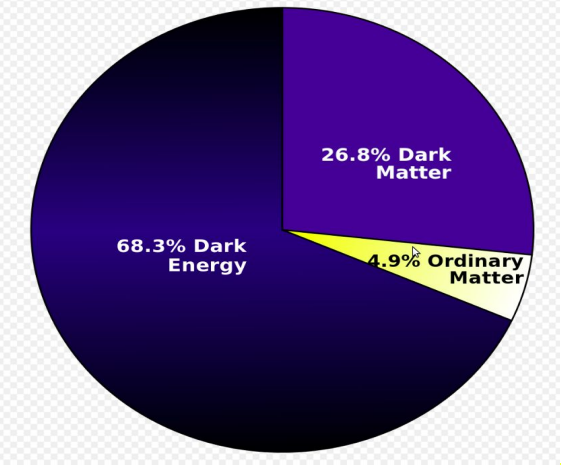
SM provides the excellent description of experimental data, yet doesn't provide answers to:

- Dark matter and Dark energy
- Fails to explains matter-antimatter asymmetry
- Three families of leptons or quarks

Models to Explain these questions and many more:

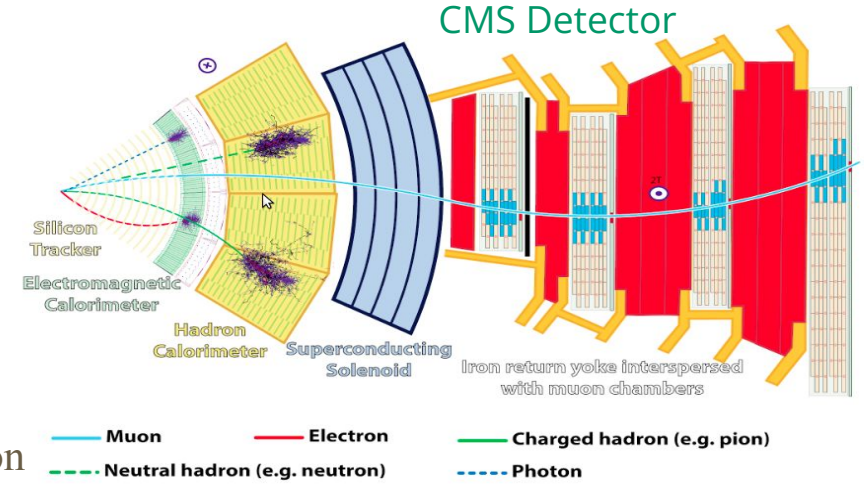
- SUSY
- 2 HDM





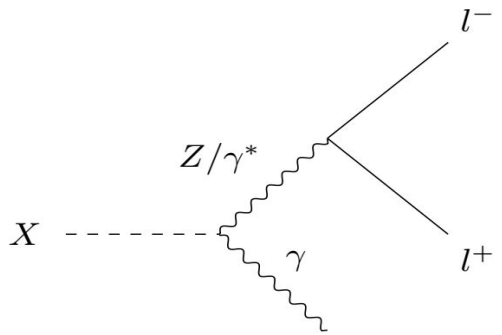
CMS Detector at the LHC and Physics Analysis..

- LHC is a discovery machine and expected to reveal BSM Physics.
- CMS is a general purpose detector designed to search for new physics.
  - e.g, Discovery of Higgs boson in 2012.



Motivation Behind Physics Analysis:

- Many theories predict the existence of heavy boson with spin-0 decaying to SM bosons.
- In this analysis, probe is for $X \rightarrow Z\gamma \rightarrow ll\gamma$ channel where Z decaying leptonically (same flavor e or μ) + 1 photon where "X" is a new scalar boson.
- Search is in the phase space $M_{Z\gamma} > 130$ GeV , for narrow (0.014%) and wide resonance widths (5.6%).
- Work is in progress…



Previous Published Analysis

Event Selection

Leptonic	Hadronic
2 same-flavor leptons and 1 photon	1 large-radius jet and 1 photon
• Trigger	• Trigger
➡ $e^+e^-\gamma$: double-photon trigger	➡ Jet and single-photon triggers
➡ $\mu^+\mu^-\gamma$: single-muon triggers	• Jet
• Lepton	➡ Anti k_T with distant param = 0.8
➡ Electron: p_T > 65 GeV / 10 GeV, $\|\eta\|$ < 2.5	➡ p_T > 200 GeV, $\|\eta\|$ < 2.0
➡ Muon: p_T > 52 GeV / 10 GeV, $\|\eta\|$ < 2.4	➡ 75 GeV < m_J < 105 GeV
➡ 50 GeV < m_{ll} < 130 GeV	➡ 3 categories: b-tagged / τ_{21} tagged / untagged
• Photon	• Photon
➡ p_T > 65 GeV / 40 GeV, $\|\eta\|$ < 2.5	➡ p_T > 200 GeV, $\|\eta\|$ < 1.44
➡ ΔR > 0.4 from both leptons	➡ ΔR > 1.1 from the selected jet
• Zγ	• Zγ
➡ $p_T(\gamma) / m_{ll\gamma}$ > 0.34	➡ $p_T(\gamma) / m_{J\gamma}$ > 0.34

Event Selection used in previous analysis.

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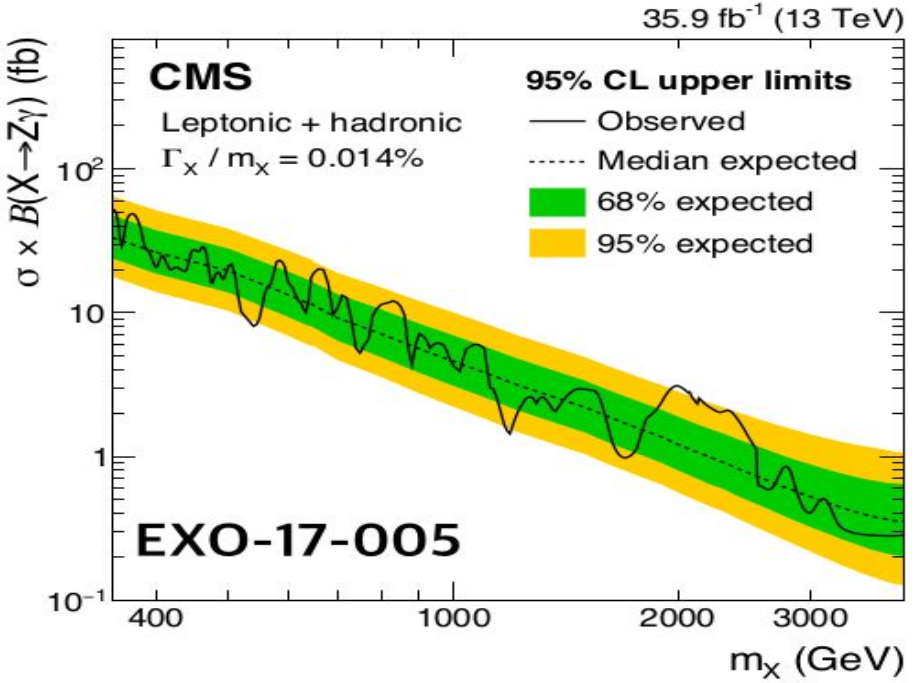
Results from previous published analysis



Strategy and Plan of Work

- Selecting events with 2 leptons (same flavor e or μ) + 1 photon to reconstruct Mass of Zɣ .
- Interpretation of $M_{Z\gamma}$ >130 GeV, both for narrow-width (0.014%) and wide-width (5.6%) resonances.
- **Fit data to background model to look for any excess of events** .
- Discriminate signal from background using various selections based on topology and kinematic differences.
- Further optimization for final selection based on the best possible expected limits using MC.
- Zɣ distribution kept blinded until all the selections are finalized.

Improvements From Previous Analysis:

- Full Run-II data which is 3 times more than earlier analysis.
- Search is extend to lower mass region ~ 130 GeV (Earlier it was 300 GeV).

Event Selection: $Z\gamma \rightarrow e^-e^+\gamma$ / $\mu^-\mu^+\gamma$ (2017)

The studies are performed with 2017 Data corresponding to luminosity : 41.7 fb^{-1}

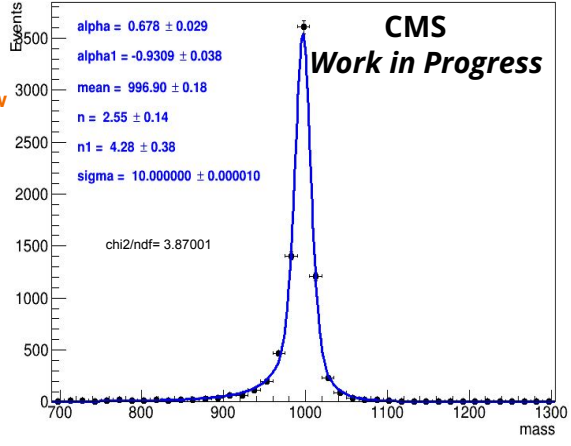
Selection	Electron Channel	Muon Channel
Trigger	Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_v OR Photon200_v	IsoMu27_v OR Photon200_v
Lepton Acceptance	P_T > 25 / 15 GeV, |η| < 2.5 (excluding the ECAL gap)	P_T > 26 / 10 GeV, |η| < 2.5
Lepton ID	Cut-based WP Loose	HighPt Muon ID / Loose Muon ID
Photon Acceptance	P_T > 15 GeV, |η| < 2.5 (excluding the ECAL gap)	P_T > 15 GeV, |η| < 2.5 (excluding the ECAL gap)
Photon ID	Cut-based WP loose	Cut-based WP loose
Event Kinematics	$\Delta R_{l\gamma}$ > 0.4 , 70 GeV < Z(m_{ll})< 110 GeV, pho pT / $m_{ll\gamma}$ > 15/130	$\Delta R_{l\gamma}$ > 0.4 , 70 GeV < Z(m_{ll})< 110 GeV, pho pT / $m_{ll\gamma}$ > 15/130

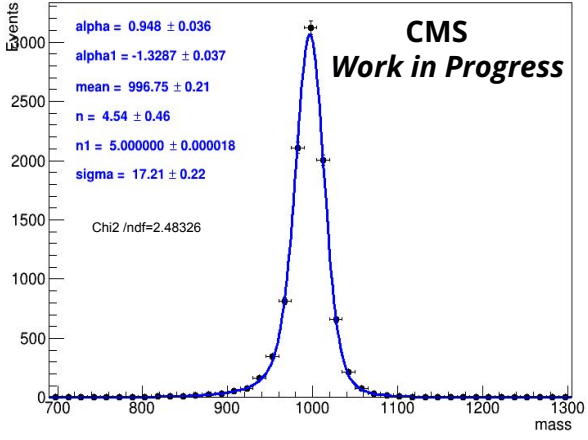
Signal Shapes $Z\gamma \rightarrow e^-e^+\gamma$ / $\mu^-\mu^+\gamma$ (2017)

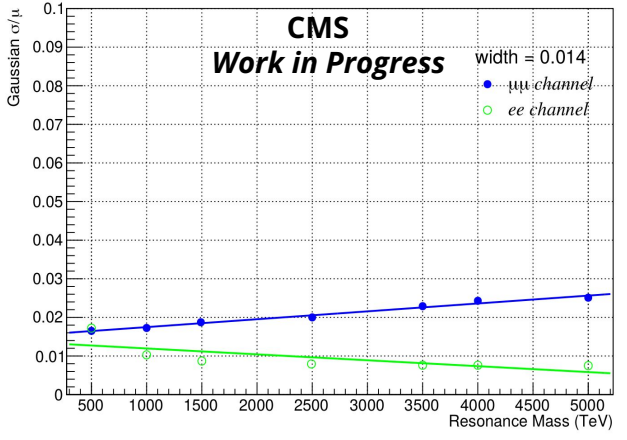
These invariant mass distributions of $Z\gamma$ are fitted with Double Side Crystal ball function as a function of resonance mass.

$Z\gamma \rightarrow e^-e^+\gamma$ Mass of ZG = 1 TeV . $Z\gamma \rightarrow \mu^-\mu^+\gamma$

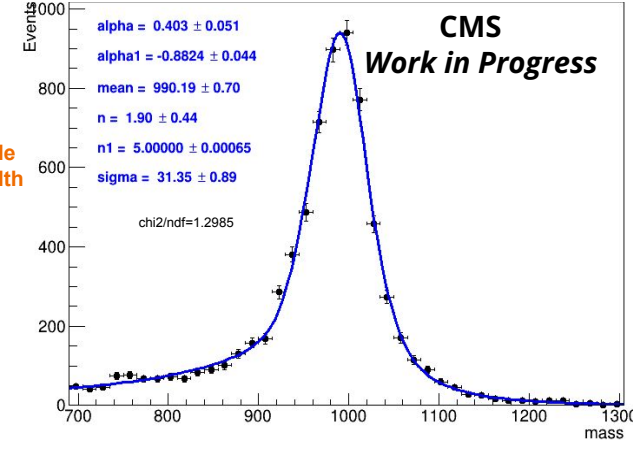
Narrow Width

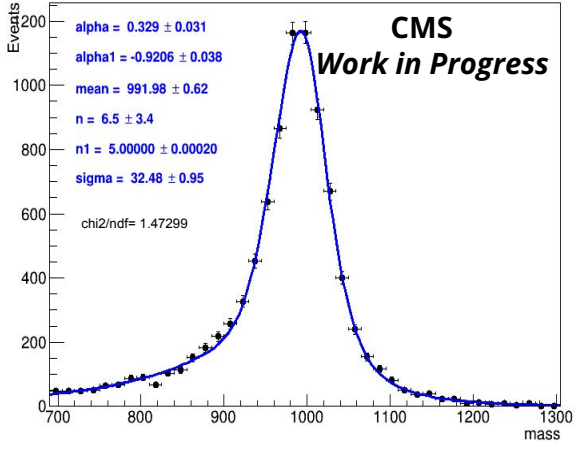


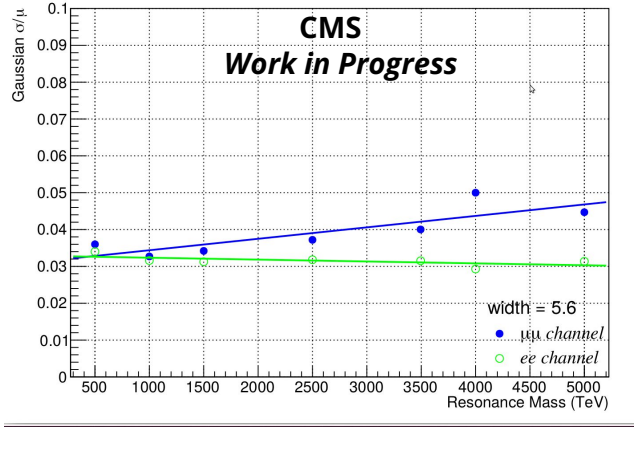




Wide Width

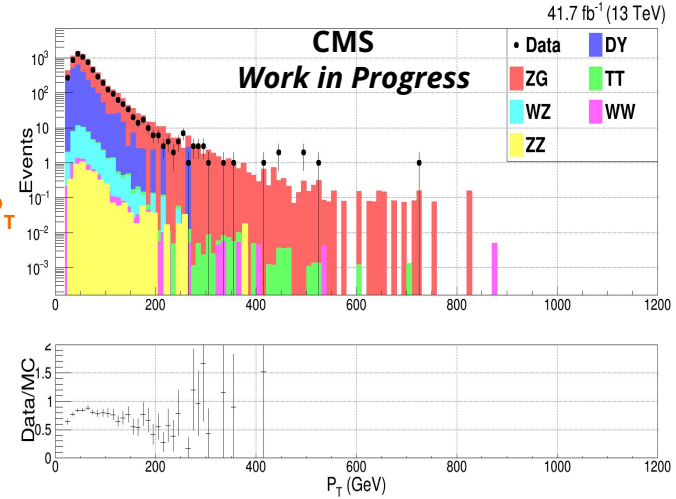




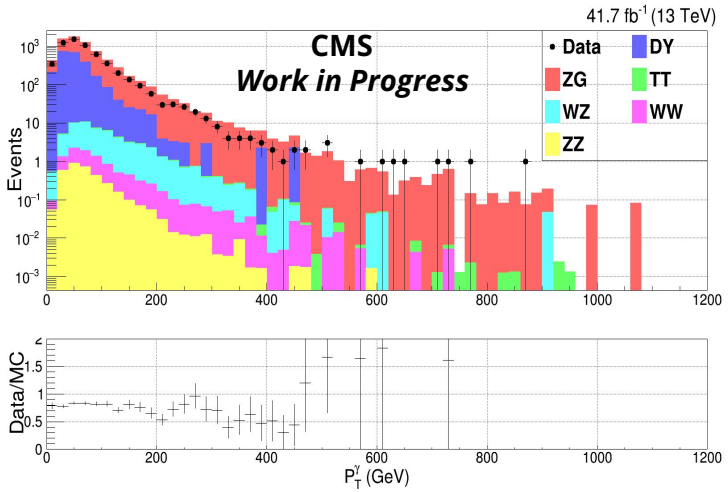


P_T and η distributions for $Z\gamma \rightarrow e^-e^+\gamma$(2017)

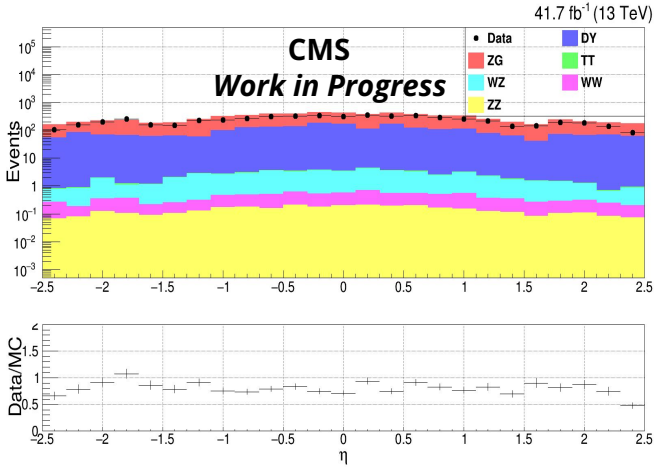
Leading Electron P_T



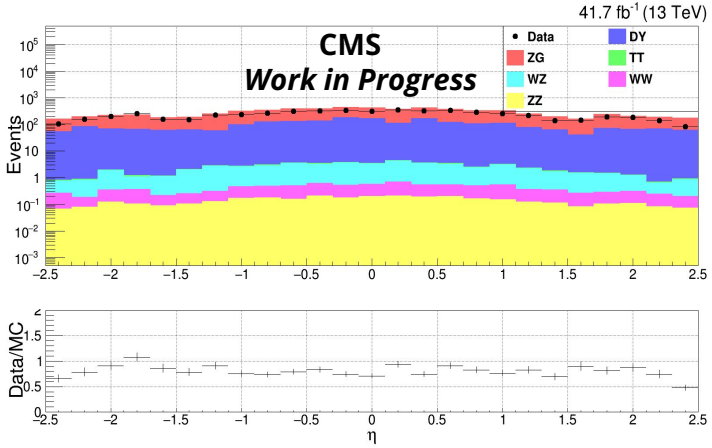
Photon P_T



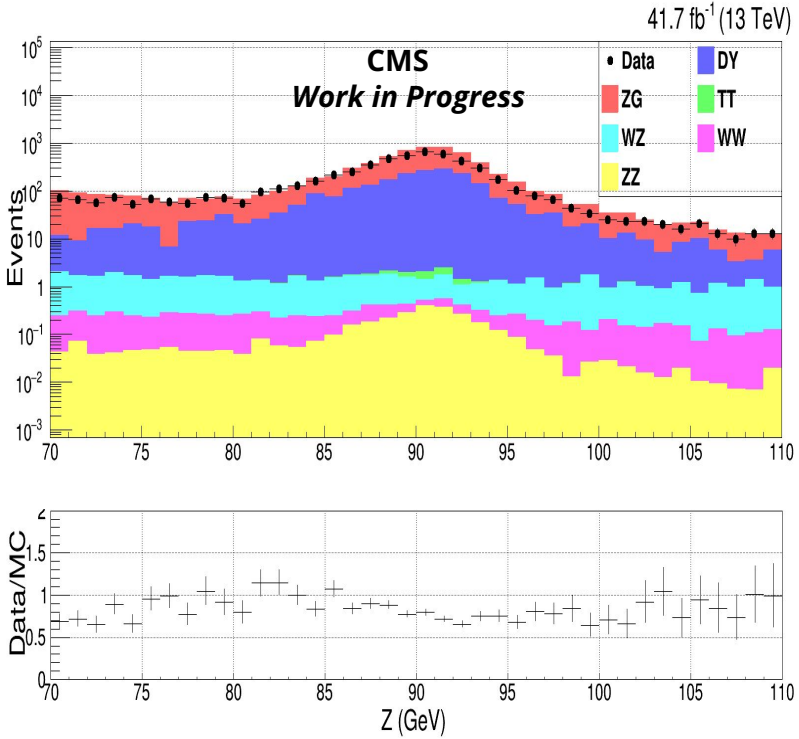
Leading Electron η



Photon η

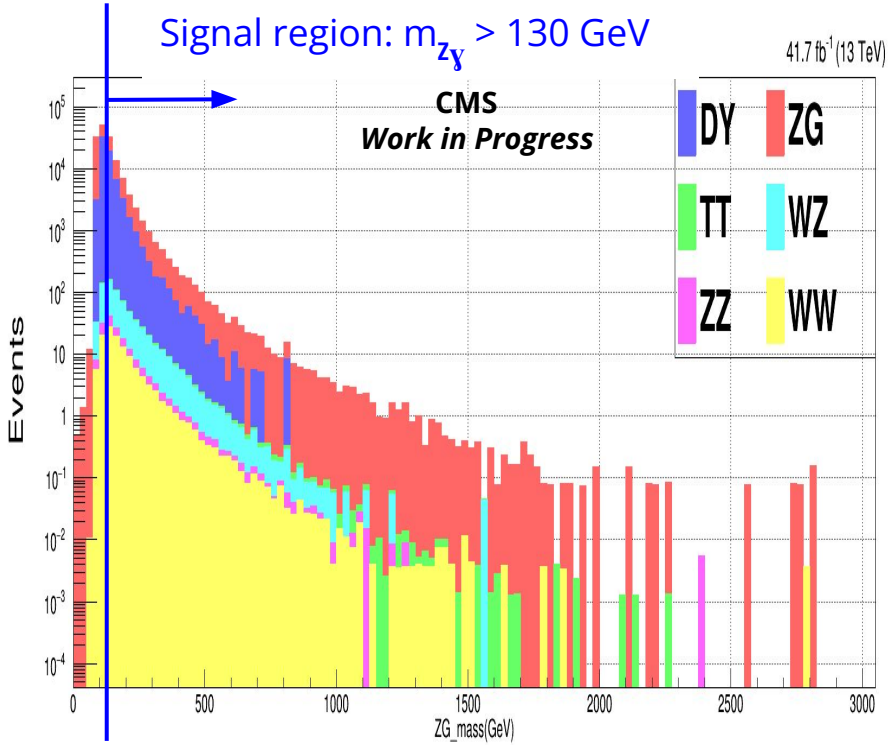


Z and Zγ Mass distribution for $Z\gamma \rightarrow e^{-}e^{+}\gamma$ (2017)



Z Mass Distribution

Signal region: $m_{Z\gamma} > 130$ GeV

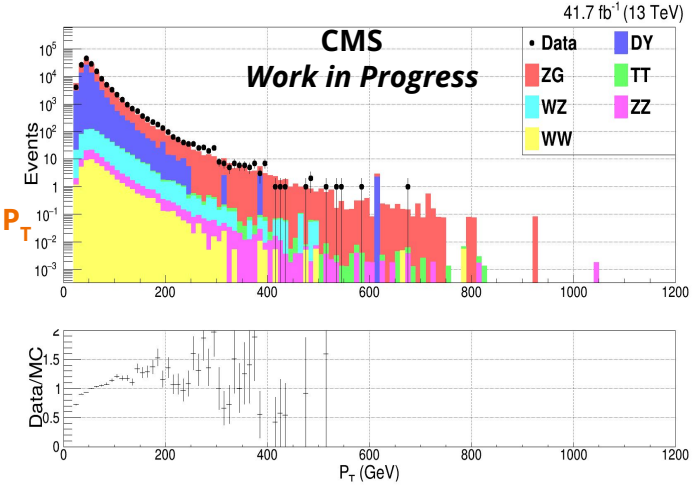


- Smoothly falling shape starting from 130 GeV

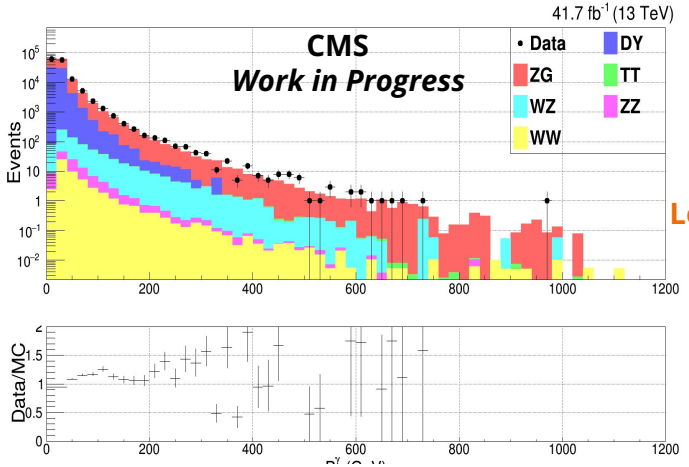
Zγ Mass Distribution

P_T and η distributions for $Z\gamma \rightarrow \mu^-\mu^+\gamma$(2017)

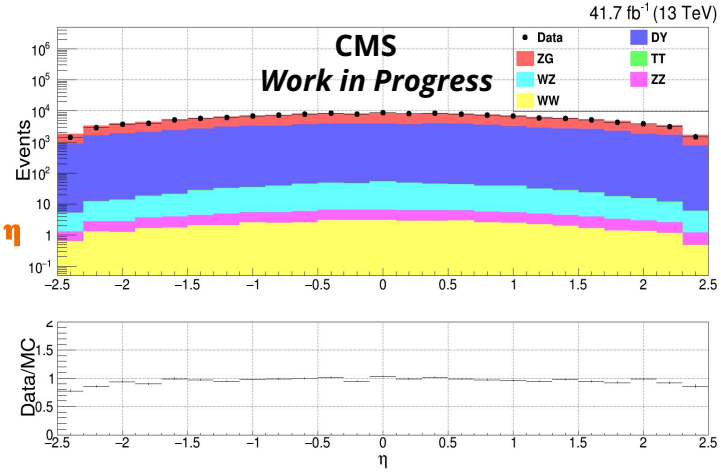
Leading Muon P_T



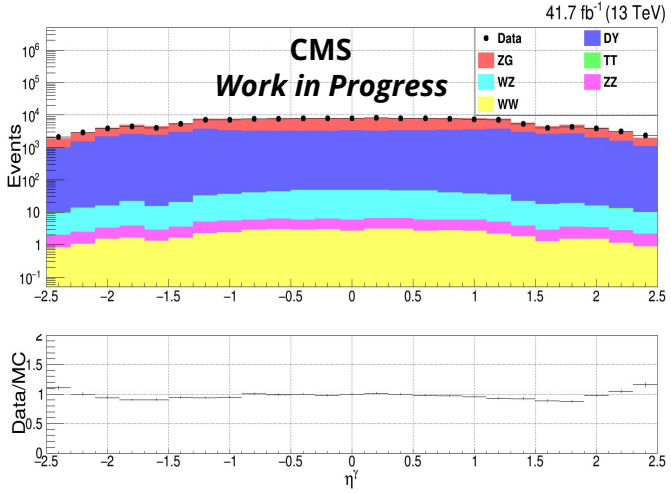
Leading Photon P_T



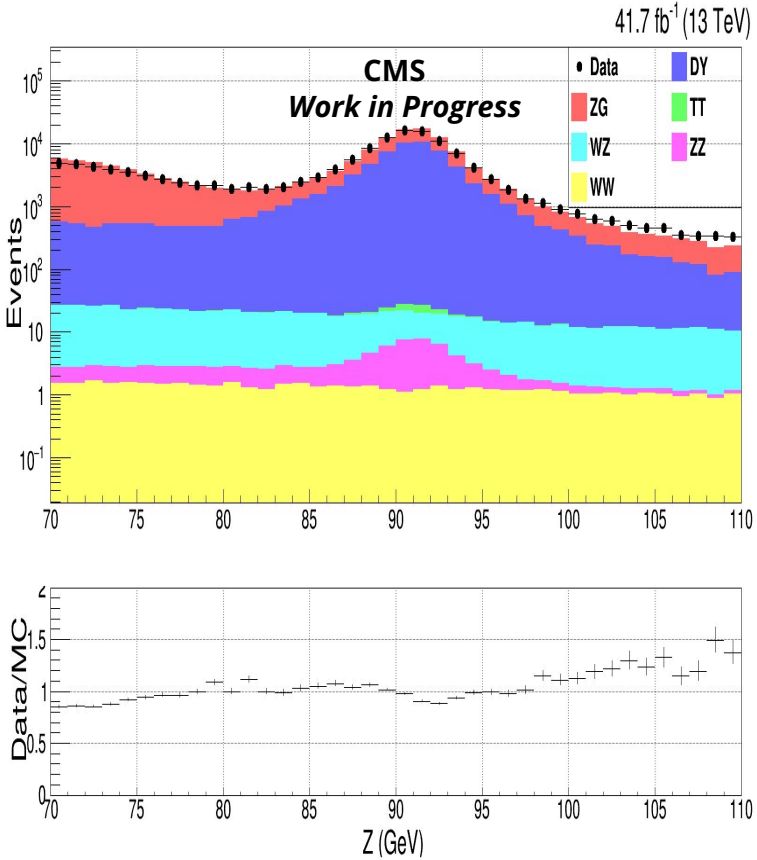
Leading Muon η



Leading Photon η

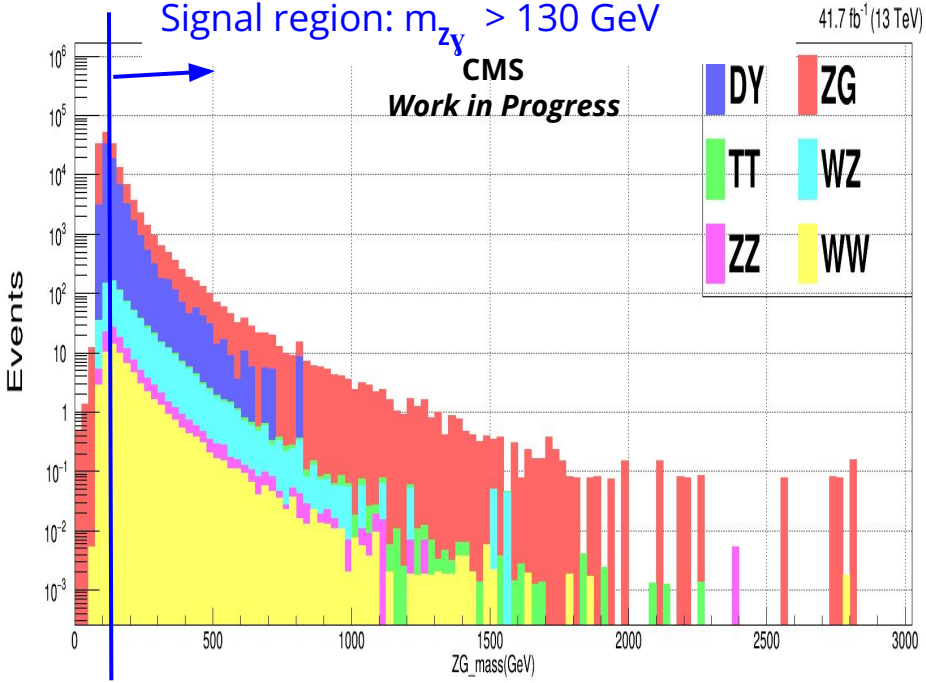


Z and Zγ Mass distribution for $Z\gamma \rightarrow \mu^-\mu^+\gamma$ (2017)



Z Mass Distribution

Signal region: $m_{Z\gamma}$ > 130 GeV



- Smoothly falling shape starting from 130 GeV

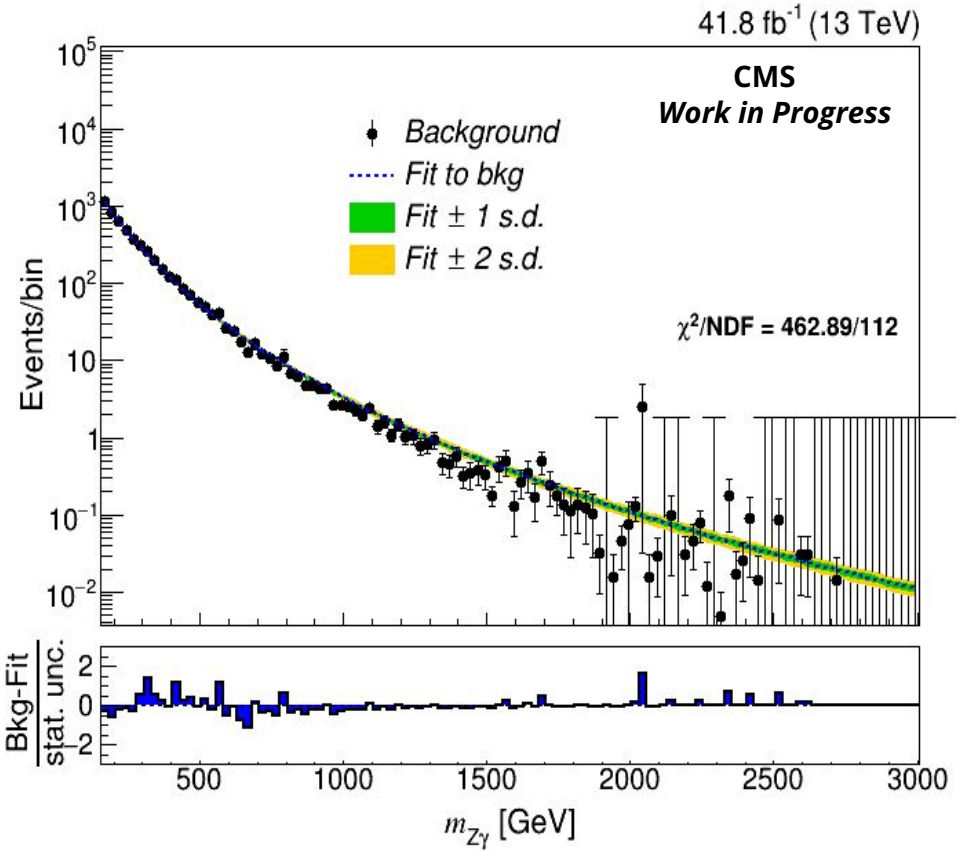
Zγ Mass Distribution

Efficiency table for Zγ → μ⁻μ⁺γ (2017)

Cut Flow	Data(SingleMuon) (%)	ZG(%)	DY(%)	Signal 1 TeV (%) (w.r.t. Combined decay)
Passing Triggers(Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_v OR Photon200_v)	4.371e+08	2.325e+06	2.538e+08	1.498e-08
Passing Vertex Level Cut	4.371e+08	2.325e+06	2.538e+08	1.498e-08
Pass MuId(HighPt /Cut Based Loose)	4.069e+08	943186	8.468e+07	6.999e-09
Pass Electron Eta(<2.5) and Pt (>25/15) (excluded Eta region)	4.189e+07	579185	3.842e+07	4.656e-09
Pass Z(μ^-+ μ^+) selection	3.029e+07	238680	3.553e+07	4.068e-09
Pass Photon Id(Cut Based Loose)	572780	161001	616617	3.188e-09
Pass Photon Eta(< 2.5) and Pt (>15GeV)cut	237389	135246	254143	3.131e-09
Pass dR >0.4(lead Ele &Pho + SubLead Ele & Pho)	160592	80849.6	157603	3.131e-09
Pass PhoPt/Zγ mass > 15/130	144011	79221.9	68838.6	3.129e-09

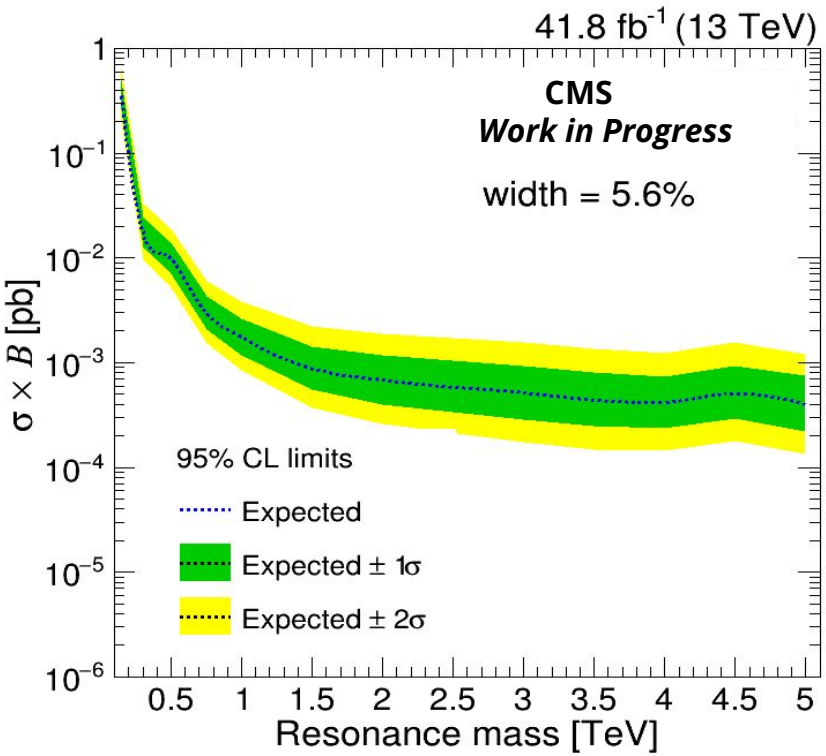
Background Parameterisation

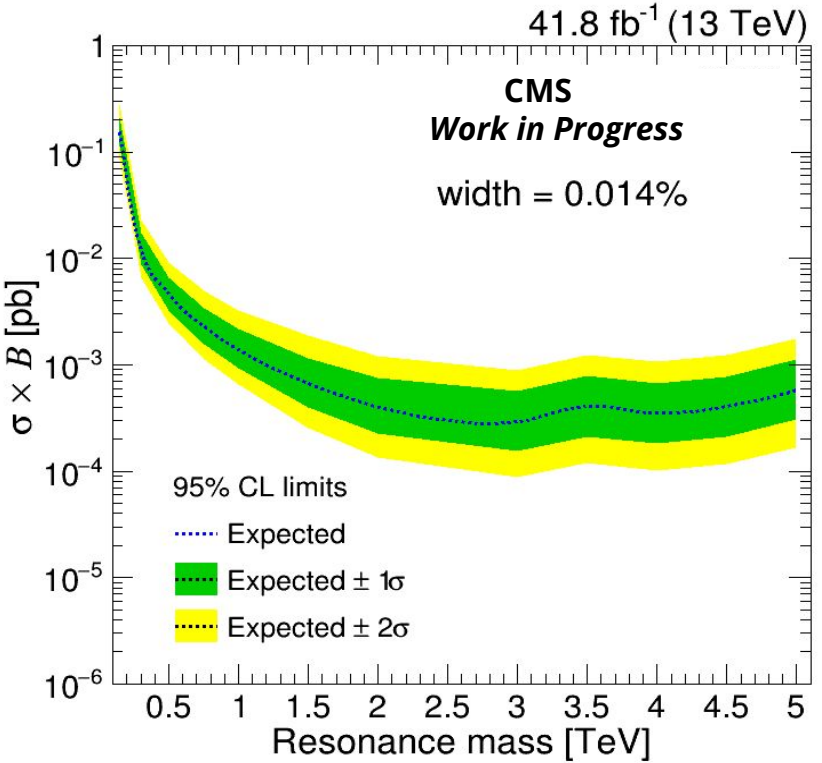
- Background Parameterised by a smoothly falling function of invariant mass:
  - $f(M_{Z\gamma}) = M_{Z\gamma}^{\,a + b \log(M_{Z\gamma})}$
- Bias Studies will be performed with alternative functions.
- Fisher and Goodness of Fit tests will also be performed for p-value significance.



Expected Limit Plots for $Z\gamma \rightarrow e^{-}e^{+}\gamma$ (2017)

- Upper cross-section limits are produced using maximum likelihood approach.
- A combined fit of signal and background function is performed to data distribution.





Systematic Uncertainties not considered

Summary and Future Plans

- Study of full Run-2 data and systematics is in progress.
- Data and MC modeling looks reasonable.. further improvements are possible.
- Un-blinding of data after final optimizations.

Backup!!

Data and Monte Carlo Samples (2017):

Data

Luminosity : 41.7 fb^{-1}

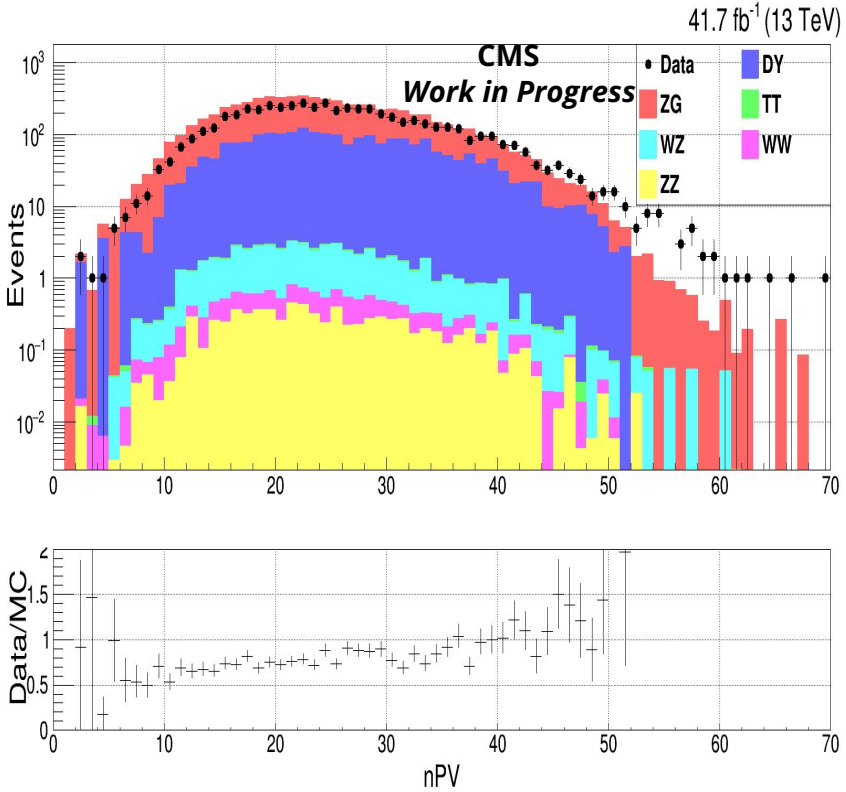
- **Datasets Used Electron Channel** :
  - /DoubleEG/Run2017*-09Aug2019_UL2017-*/MINIAOD
  - /SinglePhoton/Run2017*-09Aug2019_UL2017-*/MINIAOD
- **Dataset Used Muon Channel** :
  - /SingleMuon/Run2017*-09Aug2019_UL2017-*/MINIAOD

MC

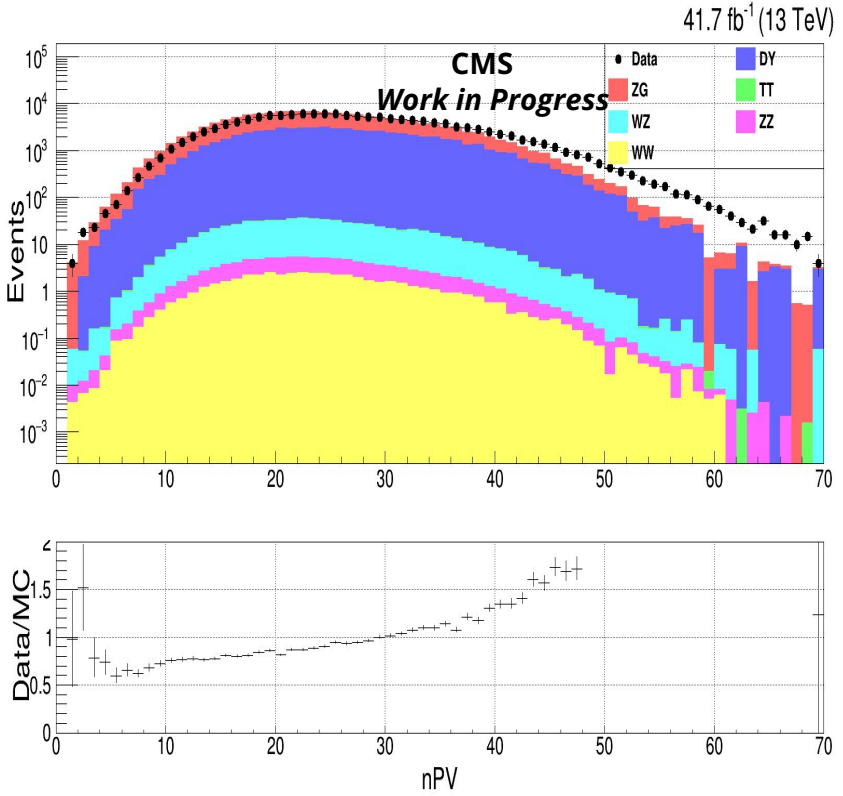
- **Signal MC** :

  /GluGluSpin0ToZG_ZToLL_W-[w]_M[m]_TuneCP2_13TeV_pythia8/*/MINIAODSIM
  - [w] = 0.014, 5.6
  - [m] = 130,150,200,250,300,400,500,750 1000,1250,1500,1750,2000,2500,3000,3500,4000,4500,5000.
- **Major Backgrounds : DYJetstoLL(LO) and ZGToLLG(NLO)**
  - DYJetsToLL_M-50_TuneCP5_13TeV-madgraphMLM-pythia8
  - ZGToLLG_01J_5f_TuneCP5_13TeV-amcatnloFXFX-pythia8

Pileup Reweighting (2017)



$Z\gamma \rightarrow e^{-}e^{+}\gamma$



$Z\gamma \rightarrow \mu^{-}\mu^{+}\gamma$

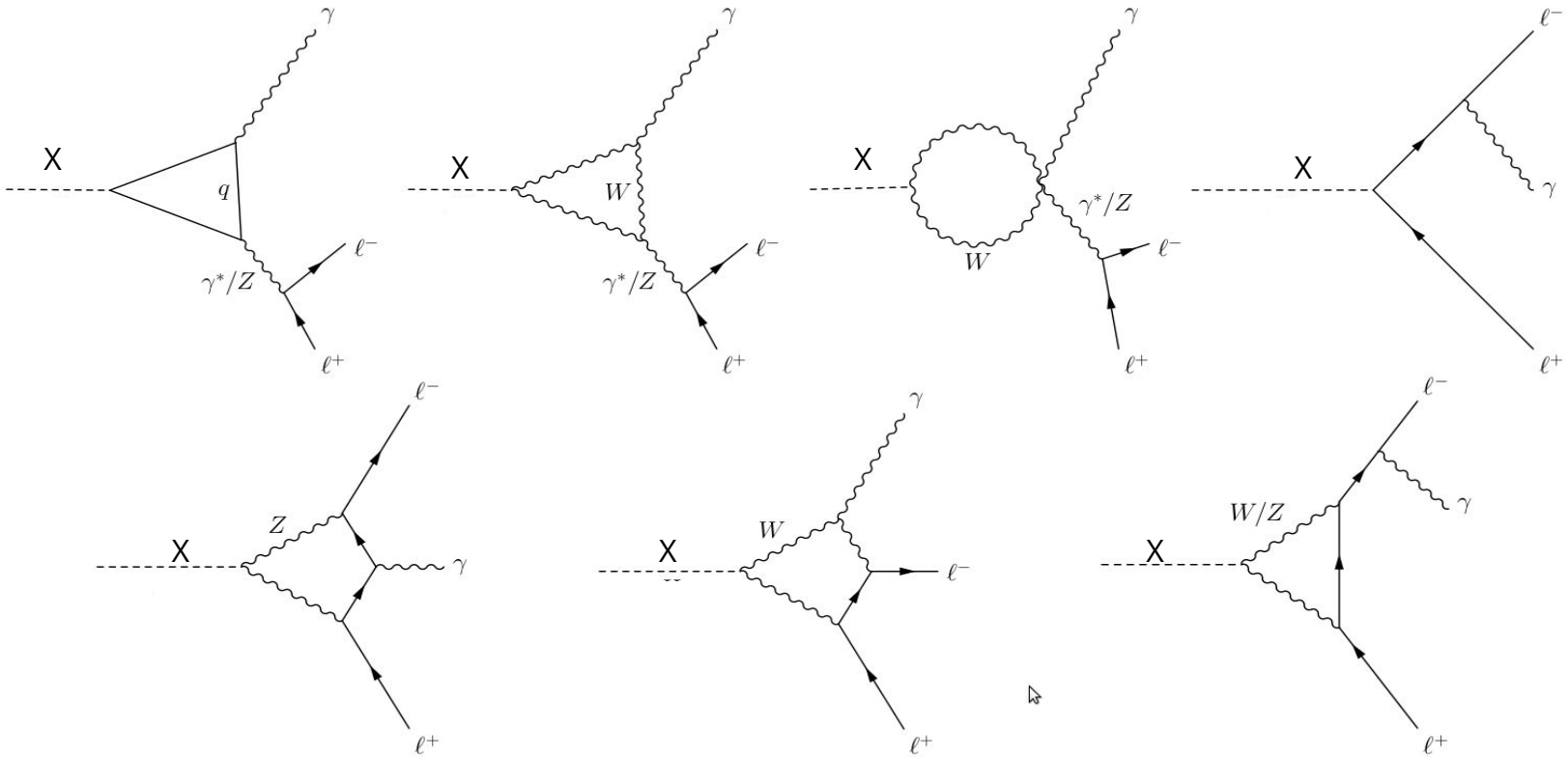
Efficiency table for $Z\gamma \rightarrow e^{-}e^{+}\gamma$ (2017)

Cut Flow	Data(SinglePhoton)(%)	Data(DoubleEGamma)(%)	ZG(%)	DY(%)	Signal 1 TeV (%) (w.r.t. Combined decay)
Passing Triggers(Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_v OR Photon200_v)	2.325e+07	5.881e+07	2.325e+06	2.537e+08	4.383e-08
Passing Vertex Level Cut	2.324e+07	5.881e+07	2.324e+06	2.537e+08	4.383e-08
Pass EleId(Cut Based Loose)	1.758e+06	3.133e+07	728929	6.645e+07	1.824e-08
Pass Electron Eta(<2.5) and Pt (>25/15) (excluded Eta region)	262197	1.819e+07	218601	2.390e+07	9.426e-09
Pass Z(e^{-} + e^{+}) selection	184592	1.597e+07	93187.4	2.012e+07	7.590e-09
Pass Photon Id(Cut Based Loose)	182603	1.580e+07	92638.4	1.992e+07	7.533e-09
Pass Photon Eta(< 2.5) and Pt (>15GeV)cut	182411	1.579e+07	92499.3	1.990e+07	7.528e-09
Pass dR >0.4(lead Ele &Pho + SubLead Ele & Pho)	872	4984	4729.18	2457.36	4.802e-09
Pass PhoPt/$Z\gamma$ mass > 15/130	863	4834	4708.3	2333.56	4.797e-09

Efficiency table for $Z\gamma \rightarrow e^{-}e^{+}\gamma$ (2017)

Cut Flow	Data(Single Photon)(%)	Data(DoubleE Gamma)(%)	ZG(%)	DY(%)	Signal 1 TeV (%) (w.r.t. Combined decay)
Passing Triggers(Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_v OR Photon200_v)	100	100	100	100	100
Passing Vertex Level Cut	99.93	99.99	100	100	100
Pass EleId(Cut Based Loose)	7.56	53.27	31.36	26.19	41.61
Pass Electron Eta(<2.5) and Pt (>25/15) (excluded Eta region)	1.12	30.93	9.40	9.42	21.50
Pass Z(e^{-} + e^{+}) selection	0.79	27.15	4.00	7.93	17.31
Pass Photon Id(Cut Based Loose)	0.79	26.86	3.98	7.85	17.18
Pass Photon Eta(< 2.5) and Pt (>15GeV)cut	0.78	26.84	3.97	7.84	17.17
Pass dR >0.4(lead Ele &Pho + SubLead Ele & Pho)	0.0038	0.0085	0.203	7.80	10.95
Pass PhoPt/$Z\gamma$ mass > 15/130	0.0037	0.0082	0.202	0.0009	10.94

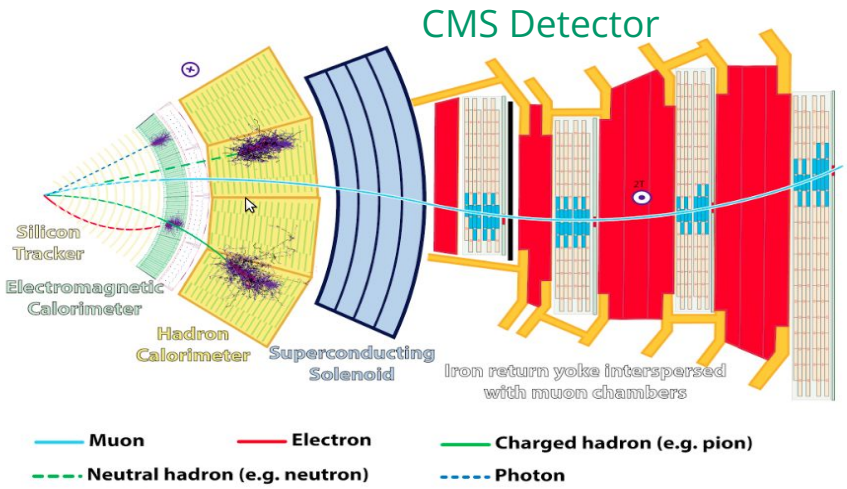
Dominant SM Feynman diagrams for X -> Zγ-> llγ

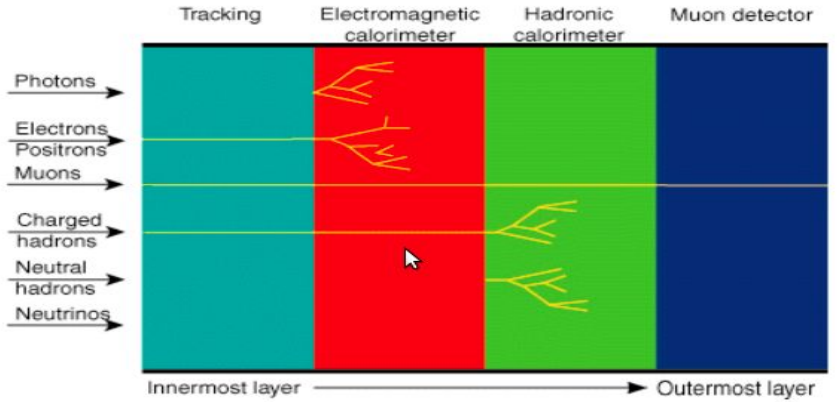


Dominant Feynman diagrams contributing to the $X \to \ell\ell\gamma$ process.

CMS Detector

- CMS magnet is a solenoid with magnetic field of 3.8 T.
- Inside solenoid, there are 3 sub detectors.
- Tracker has two parts, inner pixel and outer strip detector which enables charged particles to be tracked and their momenta to be measured.
- ECAL is made of lead tungstate ($PbWO_4$) crystal and it measures the energy of electrons and photons.
- HCAL is comprised of brass and plastic scintillators, and measures energy of charged and neutral hadrons.
- Muon Detector is installed outside the magnet of the CMS with 4 sub gaseous detectors: Drift Tubes (DT), Cathode Strip Chambers (CSC) , Resistive Plate Chambers (RPC) and newly installed Gas Electron Multiplier (GEM) sub-detector.

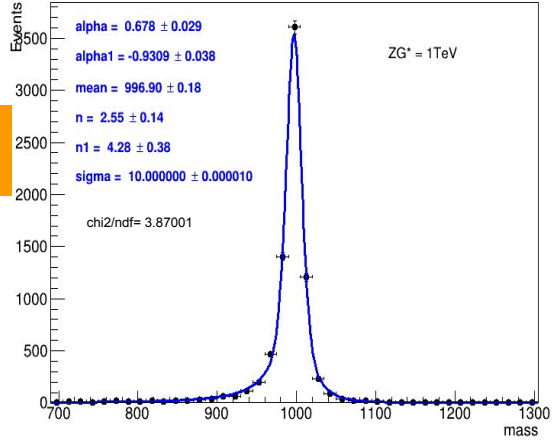


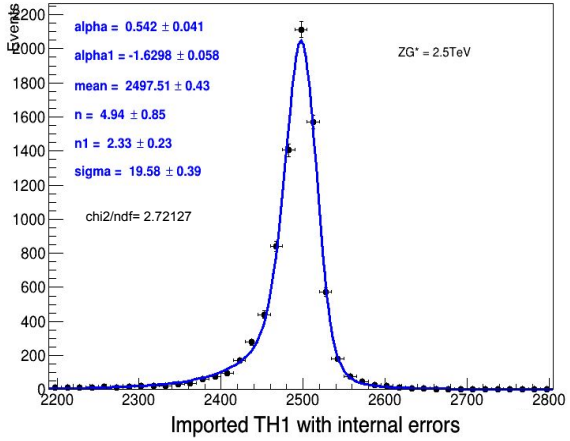


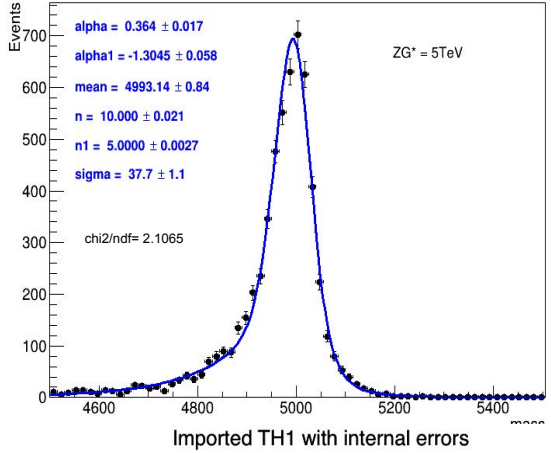
Signal Shapes (Electron and Muon Channel)

These invariant mass distributions of $Z\gamma$ are fitted with Double Side Crystal ball function.

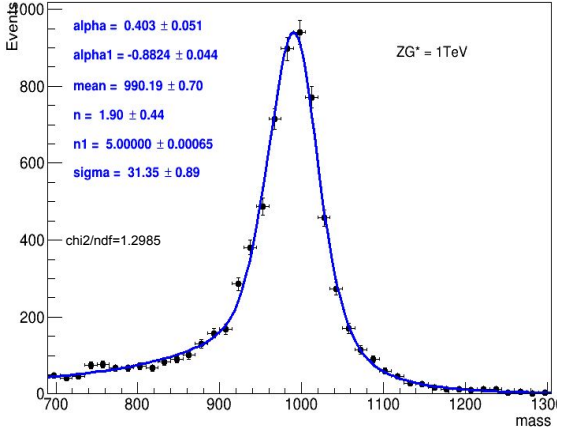
Narrow Width

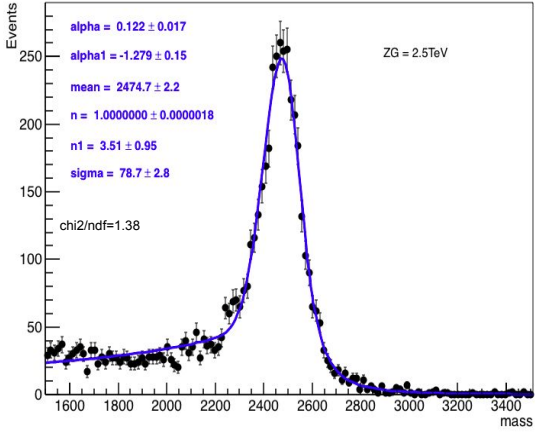


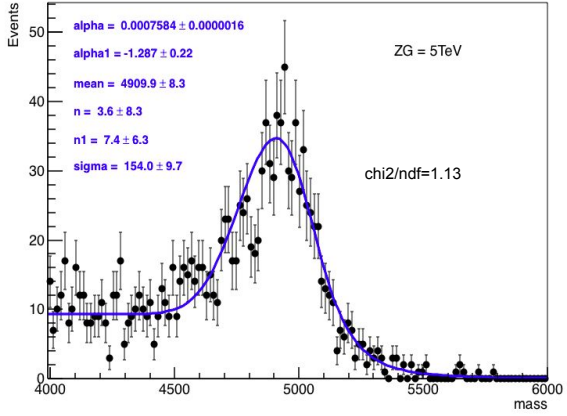




Wide Width



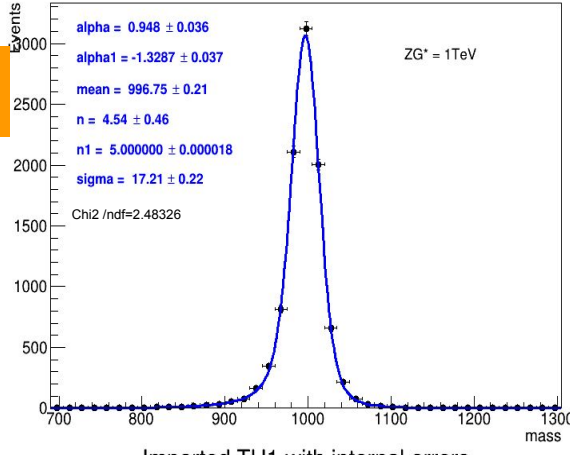


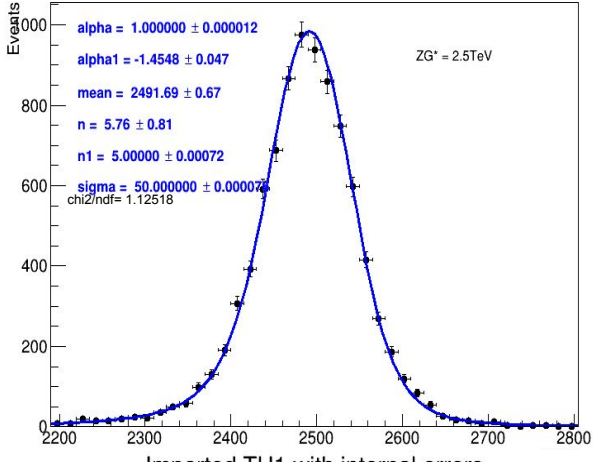


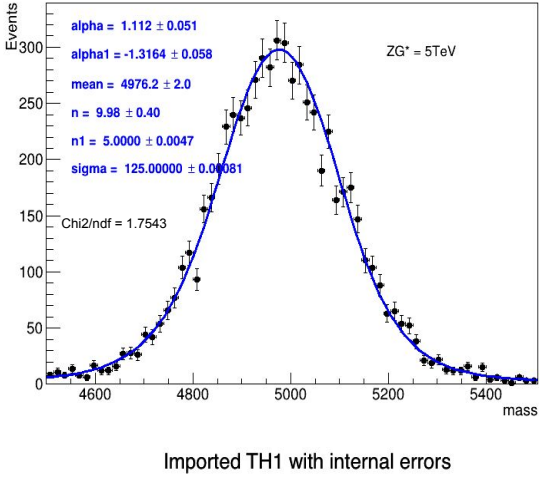
Signal Fit Distributions for narrow and wide width resonance (Muon Channel)

These invariant mass distributions of $Z\gamma$ are fitted with Double Side Crystal ball function.

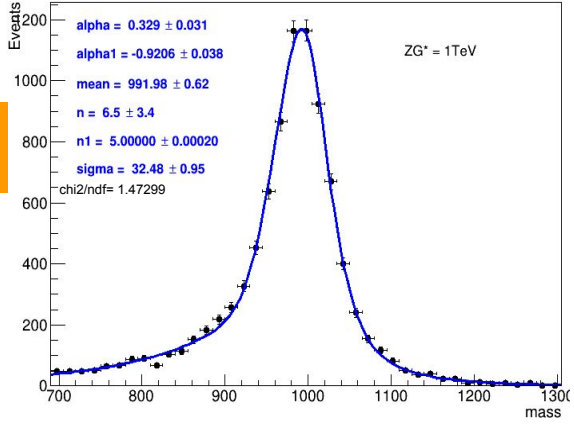
Narrow Width

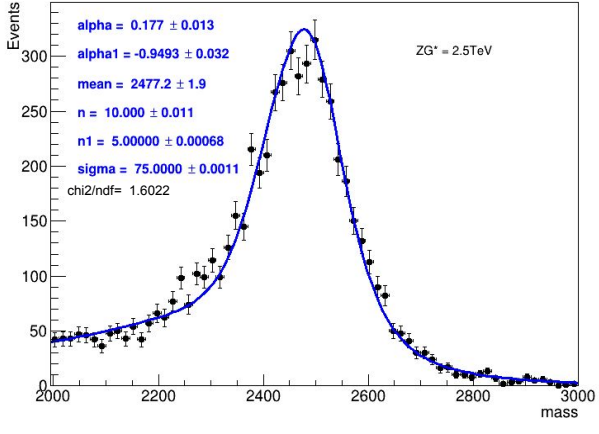


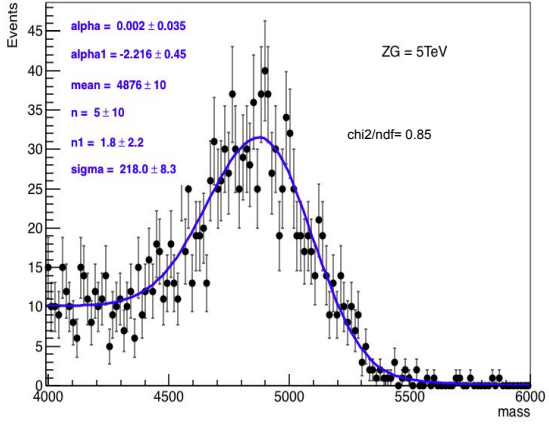




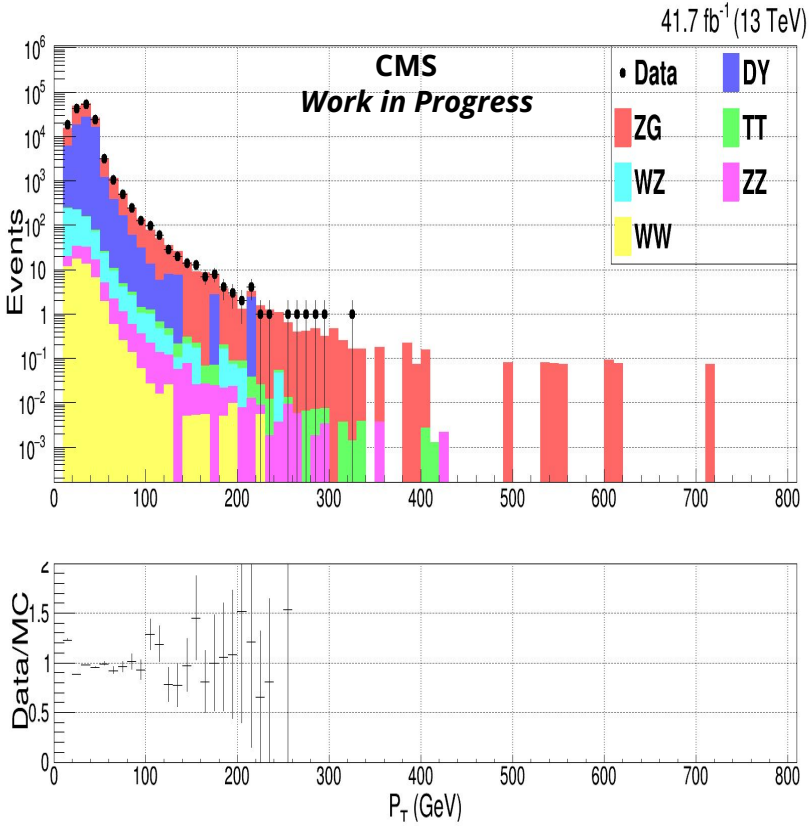
Wide Width



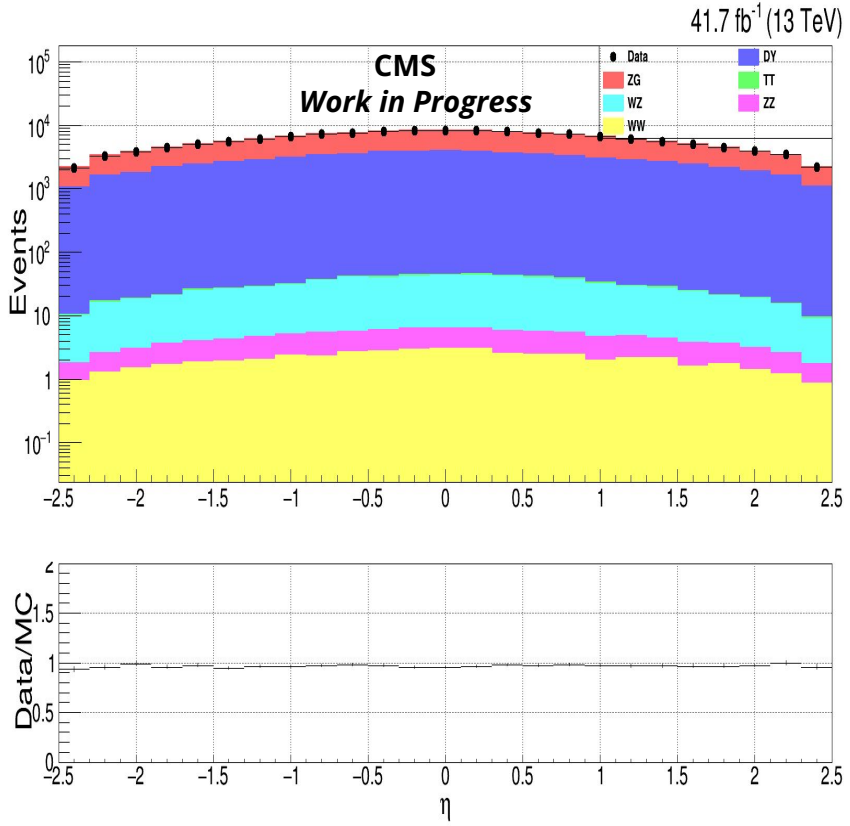




SubLead Lepton Pt and η distributions for Zγ → $\mu^-\mu^+\gamma$ (2017)



Sub Leading Muon Pt

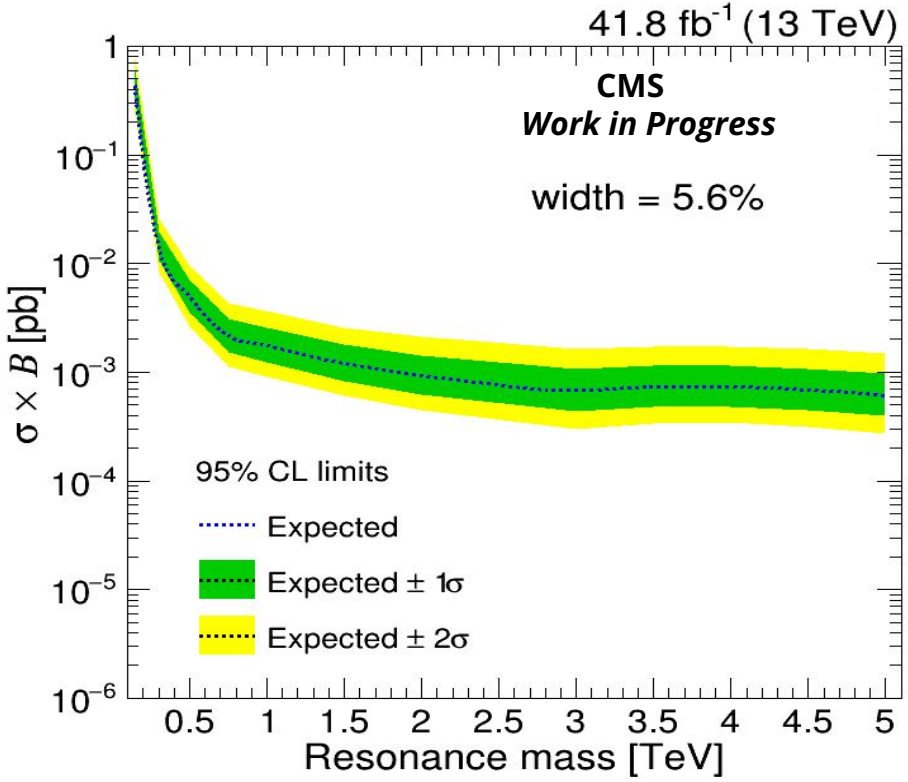


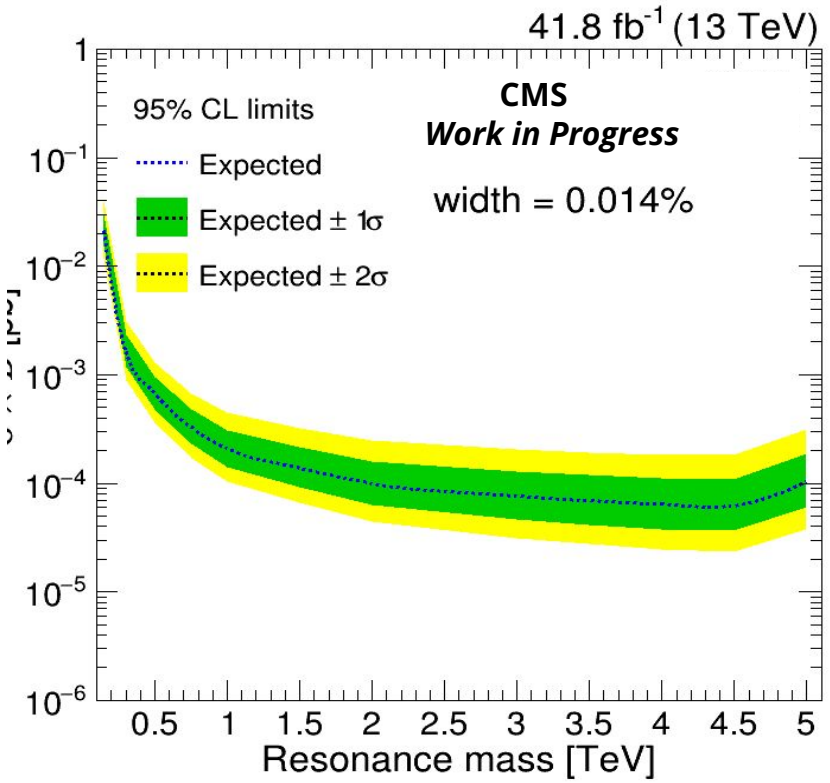
SubLeading Muon η

Efficiency table for Zγ → μ⁻μ⁺γ (2017)

Cut Flow	Data(SingleMuon)(%)	ZG(%)	DY(%)	Signal 1 TeV (%) (w.r.t. Combined decay)
Passing Triggers(Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_v OR Photon200_v)	100	100	5.88108e+07	100
Passing Vertex Level Cut	99.99	100	100	100
Pass MuId(HighPt /Cut Based Loose)	92.74	40.52	33.35	45.31
Pass Electron Eta(<2.5) and Pt (>25/15) (excluded Eta region)	9.24	23.80	15.08	30.74
Pass Z(μ^-+ μ^+) selection	6.88	9.76	13.95	26.95
Pass Photon Id(Cut Based Loose)	0.13	6.56	0.24	21.61
Pass Photon Eta(< 2.5) and Pt (>15GeV)cut	0.052	5.47	0.095	21.09
Pass dR >0.4(lead Ele &Pho + SubLead Ele & Pho)	0.036	3.45	0.062	20.89
Pass PhoPt/Zγ mass > 15/130	0.033	3.38	0.027	20.76

Expected Limit Plots for Zγ → $\mu^-\mu^+\gamma$ (2017)





Systematic Uncertainties not considered