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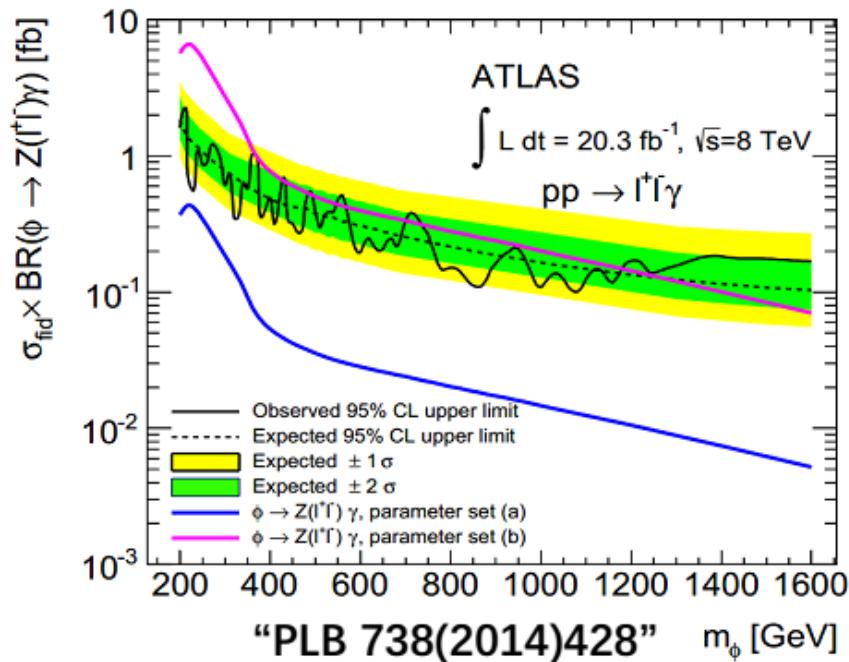
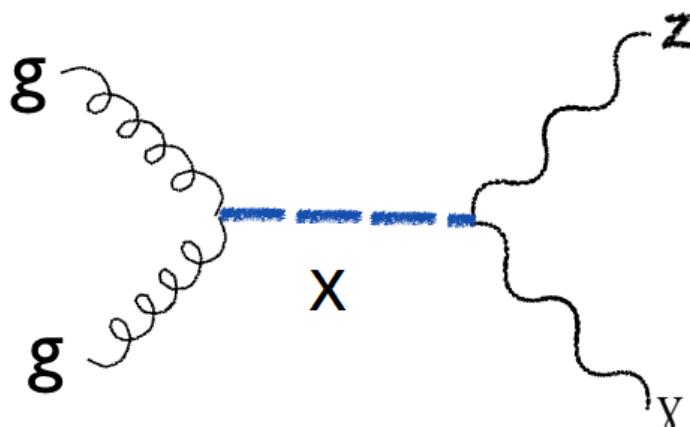
Search for high-mass $Z\gamma$ resonance in pp collisions at $\sqrt{s} = 13\text{TeV}$

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On behalf of the ATLAS Collaboration

Introduction

- ◆ **Motivation:** beyond Standard Model prediction that **extension of the Higgs sector or additional gauge fields** decaying to **ZZ , $\gamma\gamma$ or $Z\gamma$ final states**
- ◆ Both the Z bosons and photons in pair production can be measured well with relatively low backgrounds.
- ◆ **Run1, 8TeV:** searched narrow width boson $X \rightarrow Z\gamma$, $Z \rightarrow e^+e^-/\mu^+\mu^-$ Set limit at 95% CL on $\sigma_{\text{fid}} \times \text{Br}$ in 200-1600 GeV.



OUTLINE

- $X \rightarrow Z\gamma$ in Leptonic Z decay (0.25-1.6TeV) + hadronic Z decay (0.7-2.75TeV) with 3.2fb^{-1} 2015 data (PLB Paper [Link](#))
 - ◆ Signal extraction
 - ◆ Results
- $X \rightarrow Z\gamma$ in Leptonic Z decay (0.25-2.5TeV) with 13.3fb^{-1} 2015+2016 data, (ICHEP note [Link](#))
 - ◆ Signal extraction
 - ◆ Results

Search with 2015 data

◆ Data: 3.2 fb⁻¹ 2015 data

◆ Resonance Search strategy

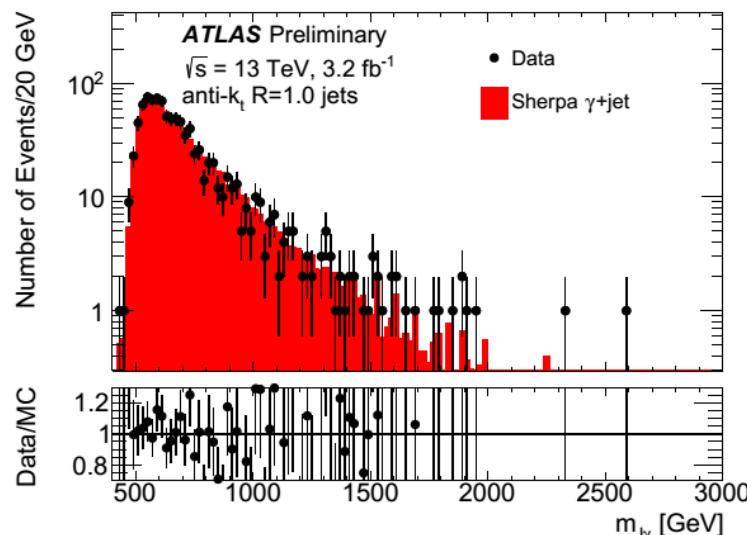
$$\sigma(pp \rightarrow X) \times Br(X \rightarrow Z\gamma) = \frac{N_{obs}}{Lumi. \times \varepsilon_x \times B(Z \rightarrow ll)}$$

leptonic channel ($Z\gamma \rightarrow l^+l^-\gamma$)

- ◆ Photon: $P_T > 0.3 \cdot M_{ll\gamma}$, where $M_{ll\gamma} > 200$ GeV
- ◆ 2 leptons (e+e-/μ+μ-) selection:
 - ◆ $|d0|, |\eta|$ cut, $P_T (> 10$ GeV), Medium ID, Isolation
 - ◆ **Z mass window**
- ◆ Main background: $Z + \gamma$, $Z + \text{Jet}$

hadronic channel ($Z\gamma \rightarrow q\bar{q}\gamma$)

- ◆ Photon selection: $P_T > 200$ GeV
- ◆ Boosted large-R jet selection:
 - ◆ anti-kt, $R=1.0$, $P_T (> 200$ GeV), $|\eta| < 2$
 - ◆ **Z-boson-tagged**
- ◆ Main background: $\gamma + \text{Jet}$



Signal+Background fit

S+B fit on $Z\gamma$ mass With Gluon-Gluon fusion Higgs (spin0, narrow width)

leptonic channel

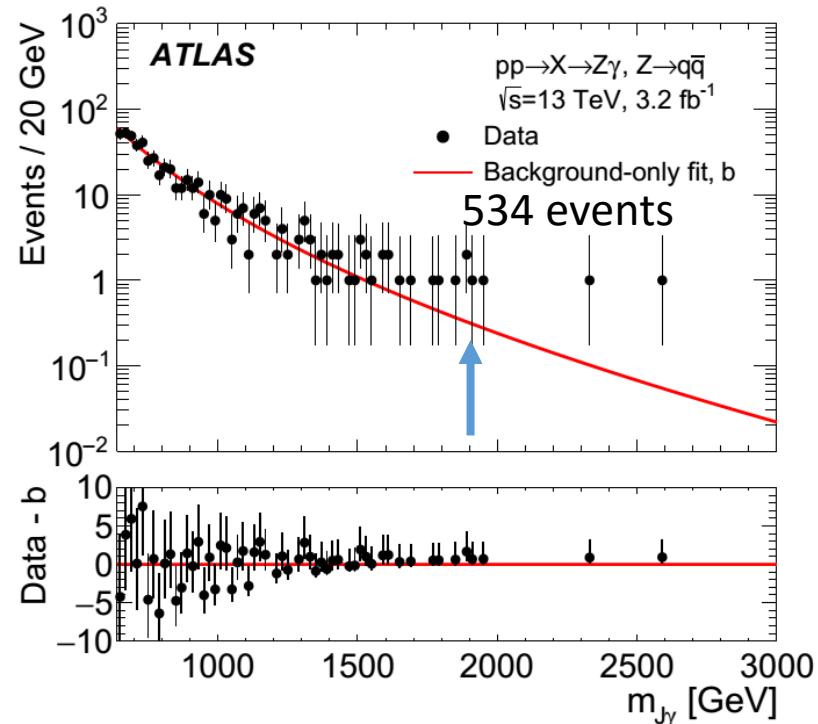
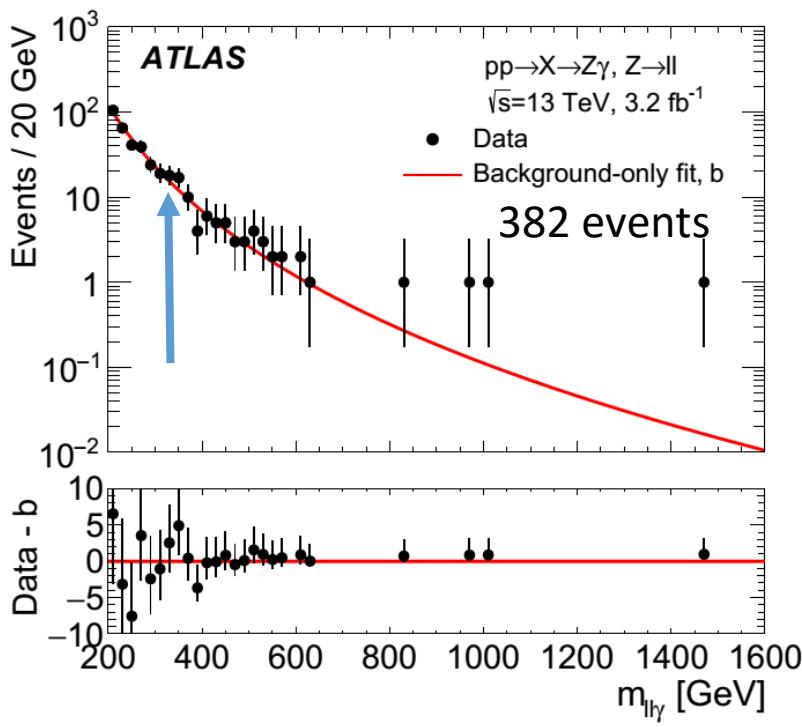
Fit in **0.2-1.6TeV**, signal search in **0.25 - 1.5 TeV**

- ◆ Signal: **Double-sided crystal ball**
- ◆ Background: analytic parametrization
- ◆ Largest deviation: **Local Z0 = 2 σ at 350GeV**

hadronic channel

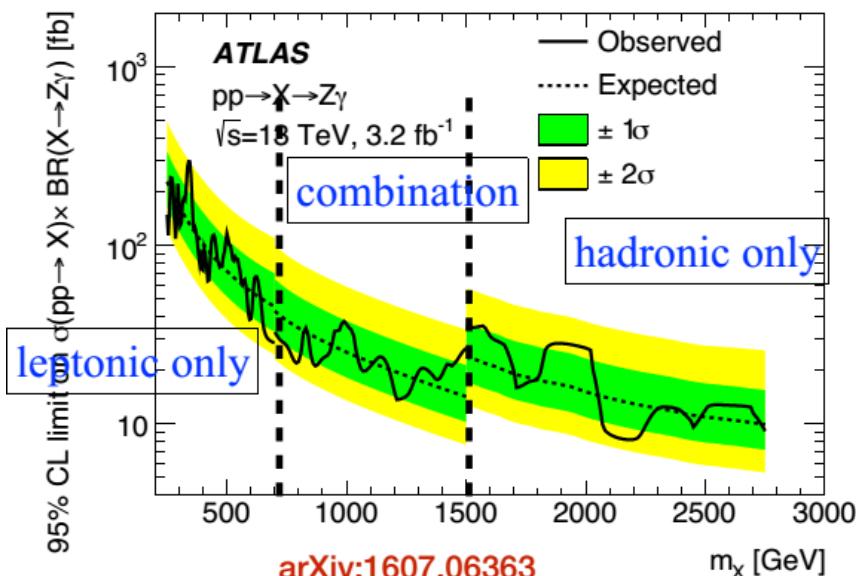
Fit in **0.64-3TeV**, signal search in **0.7-2.75 TeV**

- ◆ Signal: **Crystal ball + Gaussian**
- ◆ Background: analytic parametrization
- ◆ Largest deviation: **Local Z0 = 1.8 σ at 1.9TeV**



Statistical procedures

- No significant excess found
- Set limit on 95% CL limit on $\sigma(pp \rightarrow X) * \text{Br}(X \rightarrow Z\gamma)$
- Uncertainties on limit (dominant by statistic uncertainty)
 - Leptonic channel systematic Un.:
e/ γ resolution (4%-0.5%), spurious signal (3%-2%), luminosity (0.5%)
 - Hadronic channel systematic Un.:
jet mass resolution (4.3%-2.1%), jet energy resolution (5.3%-1.0%)



$\sigma(pp \rightarrow X) * \text{BR}(X \rightarrow Z\gamma)$	Minimum limit	Maximum limit
Observed limits	290 fb for $m_X = 340 \text{ GeV}$	8.2 fb for $m_X = 2.15 \text{ TeV}$
Expected limits	230 fb for $m_X = 250 \text{ GeV}$	10 fb for $m_X = 2.75 \text{ TeV}$

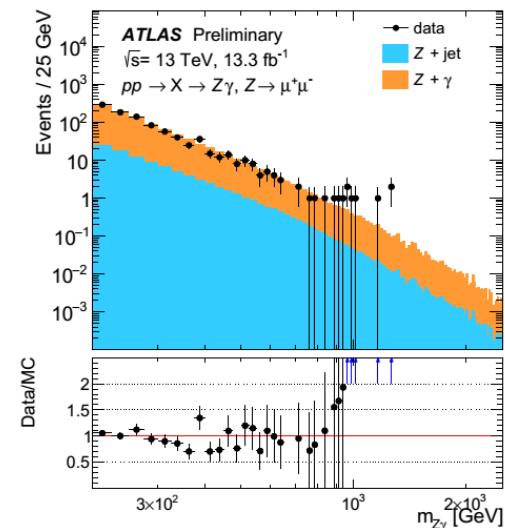
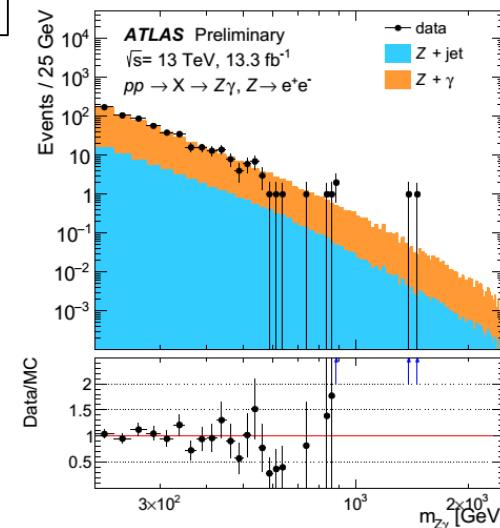
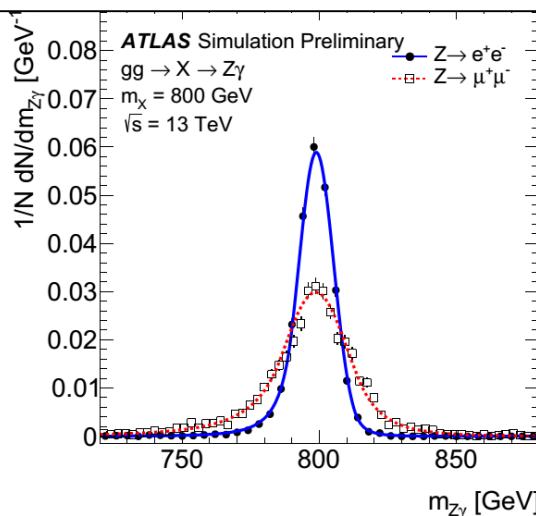
Search with 2015+2016 data

- ◆ Data: 3.2 fb⁻¹ 2015 data + 13.3 fb⁻¹ 2016 data
- ◆ Leptonic channel ($Z \rightarrow ee/\mu\mu$) search only
 - Optimized to ee+ $\mu\mu$ categories for different resolution
 - Extended the fit region from 1.6 TeV to 2.5 TeV

- ◆ Photon: $P_T > 0.3 * M_{lly}$, where $M_{lly} > 200$ GeV
- ◆ 2 leptons (e+e-/ $\mu^+\mu^-$) selection:
 - ◆ $|d0|, |\eta|$ cut, $P_T (> 10$ GeV), Medium ID, Isolation
 - ◆ Z mass window
- ◆ Main background: Z+ γ , Z+Jet

+

Selection optimization
From 1.6TeV to 2.5TeV:
Looser lepton isolation cut (track only)
Looser $\mu^-\mu^+$ overlap removal cut

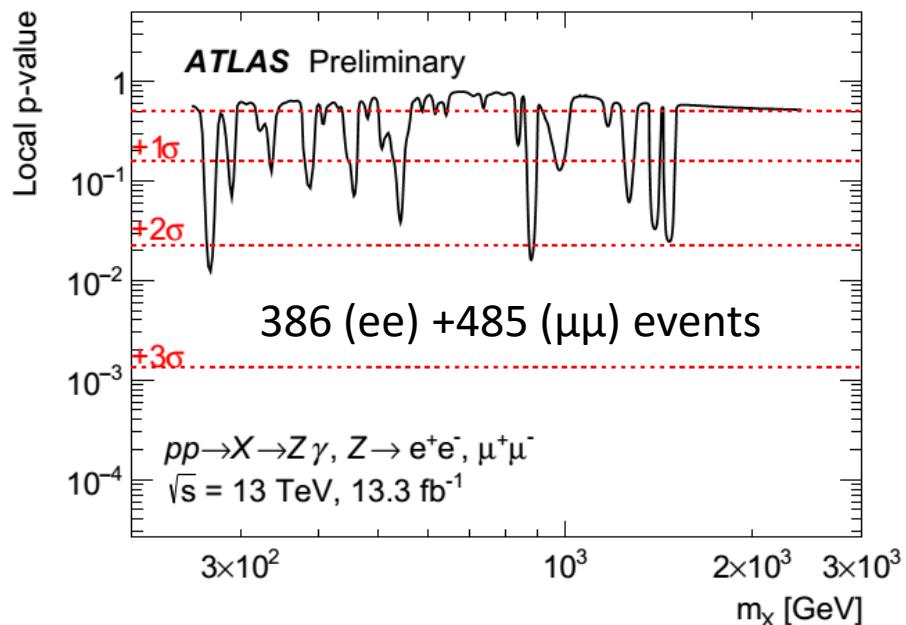
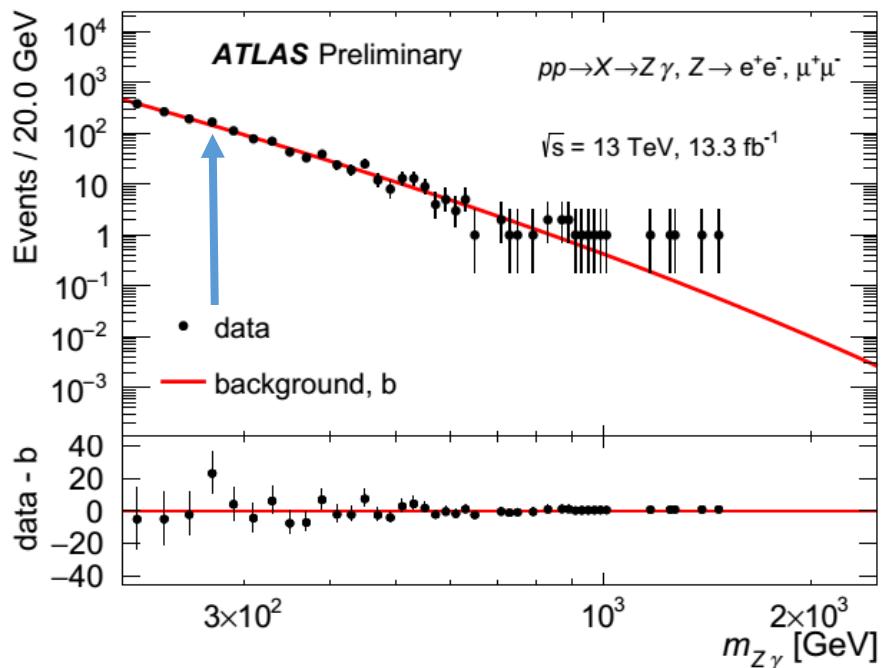


Signal+Background fit

S+B fit on $Z\gamma$ mass With Gluon-Gluon fusion Higgs (spin0, narrow width)

Fit in 0.2-2.5TeV, search in 0.25-2.4TeV

- **Signal:** Double-sided crystal ball
- **Background:** analytic parametrization
- **Largest mass point:** ~1.5TeV (ee) / ~1.3TeV ($\mu\mu$)
- Largest local significance: ~ 2.2σ at 268GeV



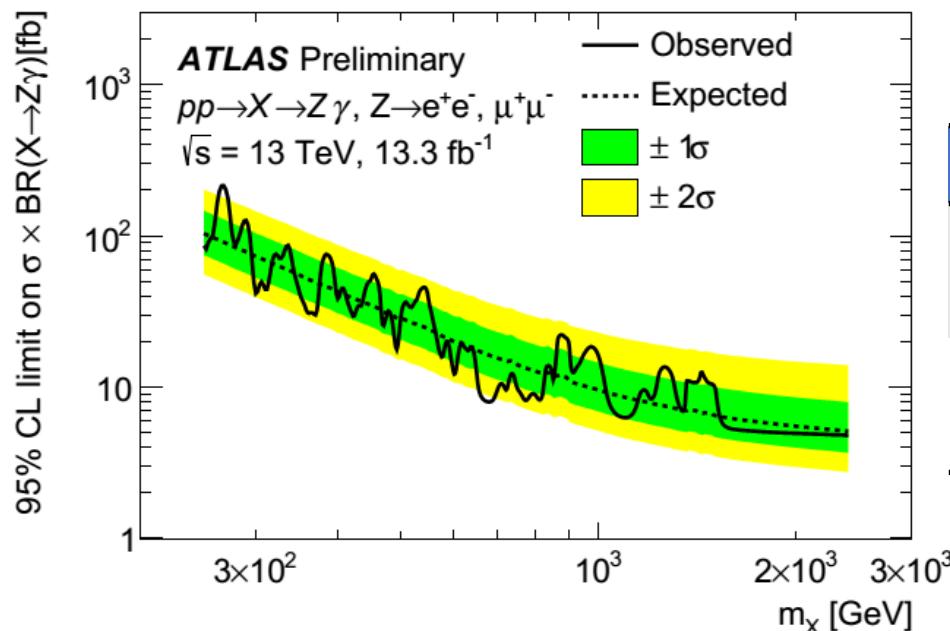
Statistic results

No significant excess founded beyond background-only hypo.

□ Uncertainties on limit:

Statistic error dominant

Systematic Un.: e/ γ resolution (1.0%-0.1%), spurious signal (0.4%-0.1%), luminosity (0.1%)



	Max	Min
Obs limit	215 fb for $m_X = 270 \text{ GeV}$	5 fb for $m_X = 2.4 \text{ TeV}$
Exp limit	103 fb for $m_X = 250 \text{ GeV}$	5 fb for $m_X = 2.4 \text{ TeV}$

Conclusion

◆ In ATLAS Run-II

- ◆ Z+ γ resonance search performed using 3.2 fb⁻¹ 13TeV 2015 data
 - ◆ Search in 0.2-1.6TeV in ee/ $\mu\mu$ Z decay channel and 0.65-2.75TeV in hadronic Z decay channel
- ◆ Z+ γ resonance search performed using 13.3 fb⁻¹ 13TeV 2015+2016 data
 - ◆ Search in 0.2-2.4TeV in ee/ $\mu\mu$ Z decay channel
- **No significant local excess found, set limit on 95% CL limit on $\sigma(pp \rightarrow X) * Br(X \rightarrow Z\gamma)$**

◆ Further study is ongoing by

- ◆ Extending to higher mass range of Z(ee/ $\mu\mu$) γ final state search
- ◆ Improving signal sensitivity
- ◆ Updating with full 2016 dataset
- ◆ New results is coming very soon!

backup

- Thanks

Samples

◆ Data

- 2015 Paper: 3.2 fb-1 2015 data
- 2016 ICHEP note: 3.2 fb-1 2015 data + 10.1 fb-1 2016 data

◆ Signal MC

- NWA ($\Gamma=4\text{MeV}$) mass points: 200, 300, 500, 700, 750, 800, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000

◆ Background MC

- $Z+\gamma$ Sherpa **full-sim** in photon pt slices
- $Z+\gamma$ Sherpa **fast-sim (high-stat)** in $M_{Z\gamma}$ slices (only ICHEP 2016)
- $Z+jet$ Sherpa 2.2 **full-sim** with Pt slices and Jet flavor slices

◆ Derivation (HIGG1D2):

- at least one photon and two leptons

Selection Criteria

◆ Signal/di-lepton trigger (dividing 2015 and 2016 data)

Sample		Trigger
Electron	2015 data	2e12+e24_Ihmedium_L1EM20VH+e60medium+e140loose
	2016 data	2e17+e26_Ihtight_nod0_ivarloose+e60medium+e140loose
	MC	2e17+e26_Ihtight_nod0_ivarloose+e60medium+e140loose
Muon	2015 data	mu22_mu8noL1+mu50+ mu26_imedium
	2016 data	mu22_mu8noL1+mu50+ mu26_ivarmedium
	MC	mu22_mu8noL1+mu50+ mu26_ivarmedium

◆ Pre-selection :

- ◆ Harmonized 2015 and 2016 data
- ◆ **2015 Paper lepton isolation:** Loose+GraidentLoose (blocking > 1.5TeV events)
- ◆ **2016 IHCEP lepton Isolation:** LooseTrackOnly (for higher search region)

Cut	electrons	muons	photons
p_T	> 19 GeV	> 24 GeV (leading) > 10 GeV (sub-leading)	> 10 GeV
$ \eta $	$ \eta < 2.47$ exclude $1.37 < \eta < 1.52$	$ \eta < 2.7$ -	$ \eta < 2.37$ exclude $1.37 < \eta < 1.52$
$ d_0 /\sigma_{d_0}$	< 5	< 3	-
Identification	Medium	Medium	Loose

Selection Criteria

◆ Overlap removal

- **muon-muon:** no removal (ICHEP), $\Delta R < 0.2$ (2015 Paper, blocking 2+TeV events)
- **Electron-electron:** $\Delta\eta < 0.075$; $\Delta\varphi < 0.125$;
- **Electron – muon:** $\Delta R < 0.02$ **electron/muon-photon:** $\Delta R < 0.3$



Zee channel overlap is only optimized $< 2.5 \text{ TeV}$,
due to low signal eff from the size-problem of
ele calorimeter reconstruction in higher mass

◆ Final selection

- **Low-mass:** $\gamma \text{ pt} > 15 \text{ GeV}$, $\text{etcone40} - 0.022\text{pt} < 2.45$, tight photon ID
- **High-mass:** $\gamma \text{ pt}/M_{\text{ll}} > 0.3$, $\text{etcone40} - 0.022\text{pt} < 2.45$, tight photon ID
- $M_{\text{ll}} \in [76.18, 106.18] \text{ GeV}$

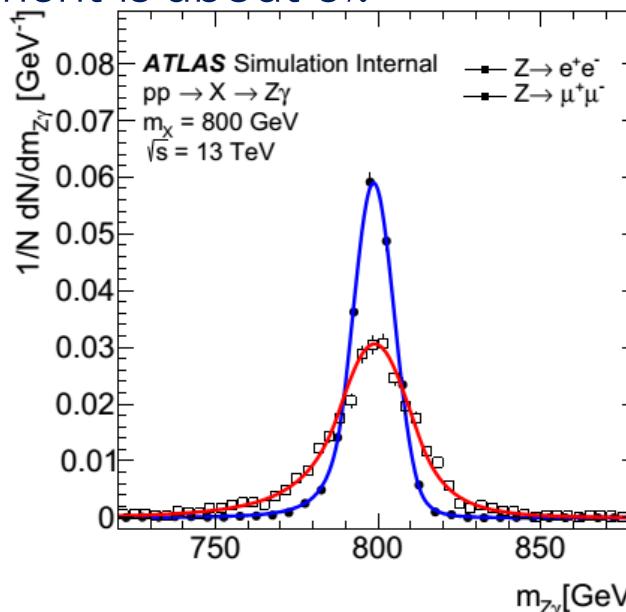
◆ Correction

- **Weight:** MC weight, pileup weight, vertex weight
- **Scale factors:** (photon efficiency/ISO, electron ID/reconstruction/ISO, muon efficiency/ISO, trigger)

Categorization

◆ Cate0: $Z\gamma \rightarrow ee\gamma$, Cate1: $Z\gamma \rightarrow \mu\mu\gamma$

- **ICHEP**: Events divided based on Z decay channel (ee , $\mu\mu$), due to their differing resolution in 3-body mass spectrum
- **2015 Paper**: only one category (inclusive)
- **Table**: signal sensitivity (normalized to 10 fb⁻¹) at 800 GeV
 - The improvement is about 5%



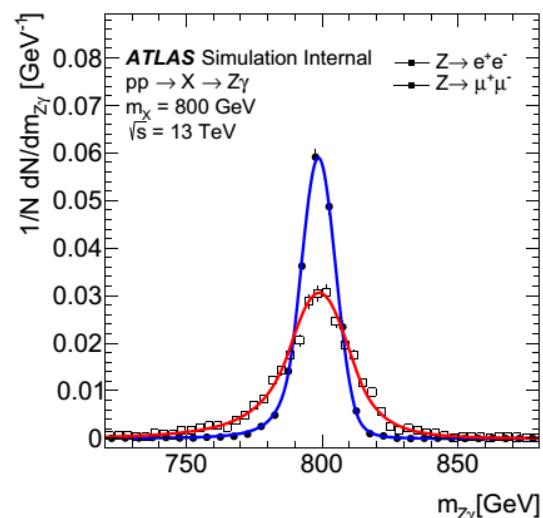
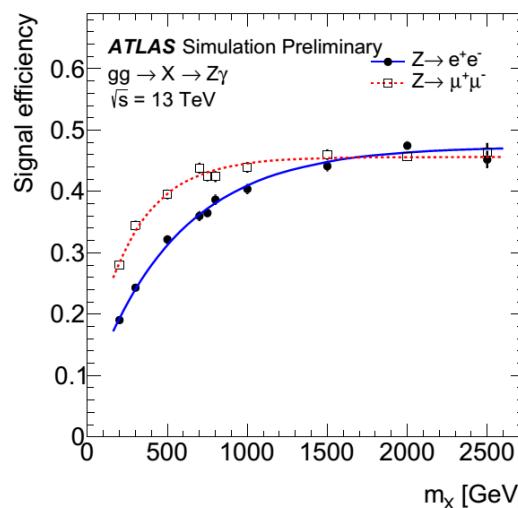
Category	no optimization	$ee\gamma$ and $\mu\mu\gamma$ channels
Sensitivity	0.0527	0.0552

Signal modeling and parameterization

- ◆ **Signal:** Narrow width scalar via gluons fusion
- ◆ **Mass range:** 200-2500 GeV considering the drop of $Z\gamma \rightarrow e^+e^-$ efficiency
- ◆ **Signal Parameterization:** Double-sided crystal ball
- ◆ **Signal efficiency:** $a + b \cdot \exp(cx)$

$$N \cdot \begin{cases} e^{-t^2/2} & \text{if } -\alpha_{Lo} \leq t \leq \alpha_{Hi} \\ \frac{e^{-0.5\alpha_{Lo}^2}}{\left[\frac{\alpha_{Lo}}{n_{Lo}} \left(\frac{n_{Lo}}{\alpha_{Lo}} - \alpha_{Lo} - t \right) \right]^{n_{Lo}}} & \text{if } t < -\alpha_{Lo} \\ \frac{e^{-0.5\alpha_{Hi}^2}}{\left[\frac{\alpha_{Hi}}{n_{Hi}} \left(\frac{n_{Hi}}{\alpha_{Hi}} - \alpha_{Hi} + t \right) \right]^{n_{Hi}}} & \text{if } t > \alpha_{Hi}, \end{cases}$$

Parameter	Fitted function
μ_{CB}	$a_\mu + b_\mu \times x + c_\mu \times x^2 + m_X$
σ_{CB}	$a_\sigma + b_\sigma \times x$
α_{Lo}	$a_{\alpha_{Lo}} + b_{\alpha_{Lo}} / (x + c_{\alpha_{Lo}})$
α_{Hi}	$a_{\alpha_{Hi}} + b_{\alpha_{Hi}} / (x + c_{\alpha_{Hi}})$
x	$(m_X - 100\text{GeV})/100\text{ GeV}$



Background study

- ◆ **Background decomposition:** measure the background fraction for each components with data-driven methods
- ◆ **Background modelling:** get high statistics sample to describe the data
- ◆ **Spurious signal study:** decide the analytic background function used in the final mass spectrum fitting

Background modeling

- ◆ **Main background:** $Z + \gamma$ (irreducible), $Z + \text{jet}$ (reducible)
- ◆ **Background decomposition (result: $\sim 90\% Z + \gamma$ and $\sim 10\% Z + \text{jet}$)**
 - ABCD method and Isolation dynamic template fit method (good agreement)
- ◆ **Background modeling**
 - High-stat $Z + \gamma$ MC + Data-driven $Z + \text{jet}$ shape
 - Varying with $Z + \gamma / Z + \text{jet}$ ratio (poly2, poly3) and $Z + \gamma$ purity (85%-95%)

