Search for Exotic Decays of the Higgs Boson to Photons and Missing Energy

ATLAS-CONF-2018-019

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on behalf of the

ATLAS Experiment

March 13, 2019

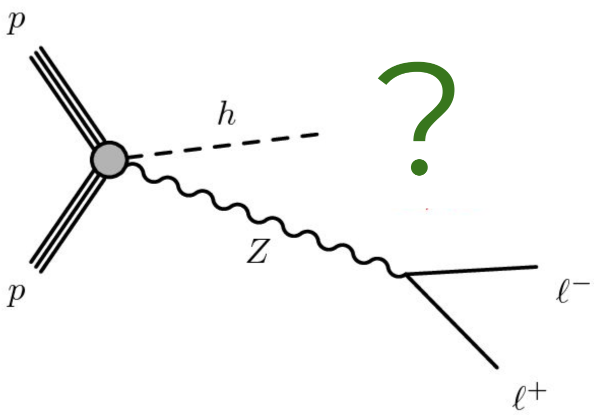
La Thuile 2019
Les Rencontres de Physique de la Vallée d'Aoste

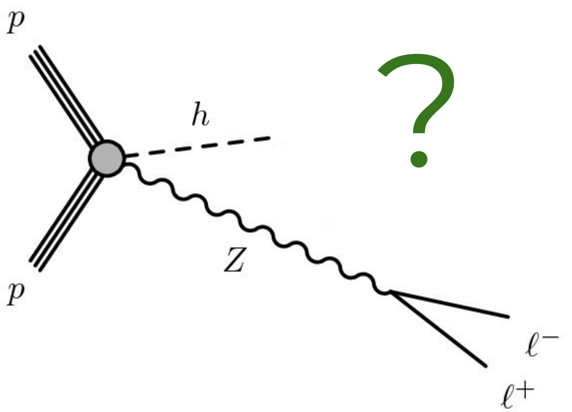
ATLAS EXPERIMENT

Penn

Higgs Physics at LHC/ATLAS

- Higgs measurements have been a cornerstone of the LHC research program
- No significant deviations from the Standard Model
- Bounds on BF(Higgs to undetected decays) ~10-20%
- SUSY solves the Higgs hierarchy problem, then we go look for direct production of these sparticles. [ATLAS SUSY public page]
- Instead, we can use the Higgs as a probe for new physics -- look for Higgs decays to SUSY particles!





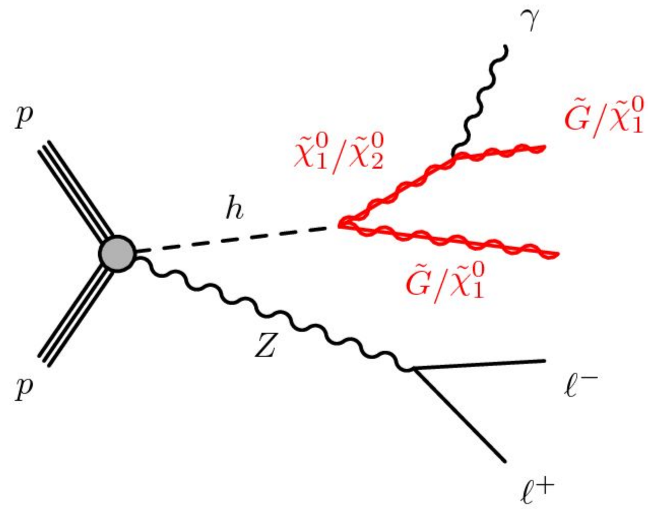
SUSY Higgs Decays

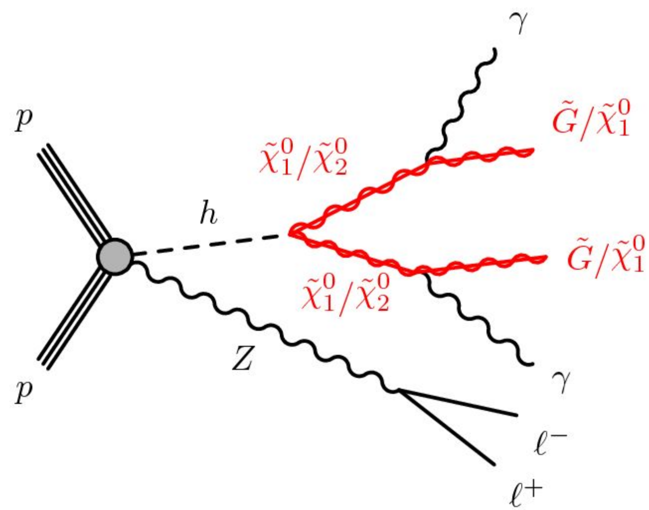
- GMSB(nMSSM) models with 125 GeV Higgs can give rise to electroweak decays

- Many interpretations of a (di)photon+missing energy signature
  - NLSP neutralino one decaying to photon(s) + gravitino LSP
  - NLSP neutralino two decaying to photon(s) + singlino-like LSP neutralino one

- Sensitivity to Bino NSLP models

- Models have Higgs BF of few percent to 15%





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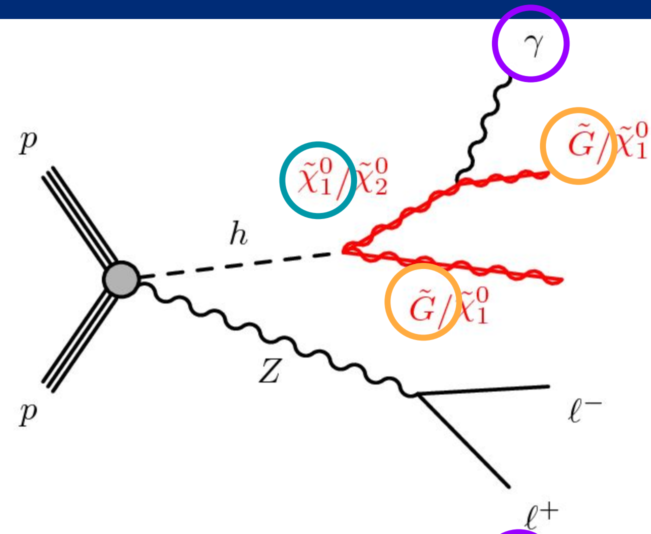

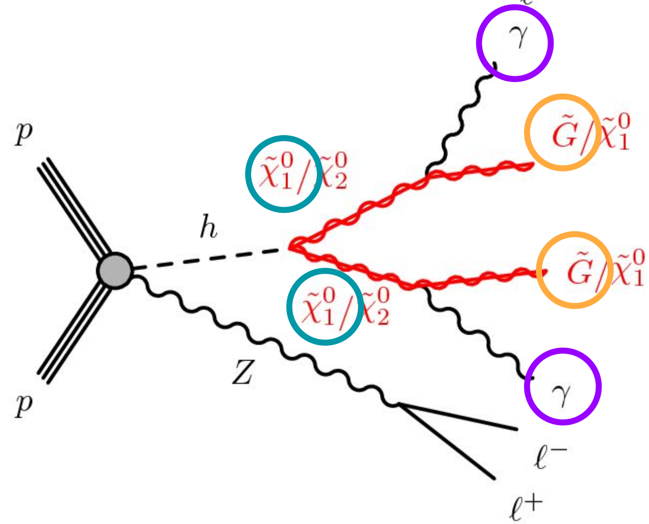

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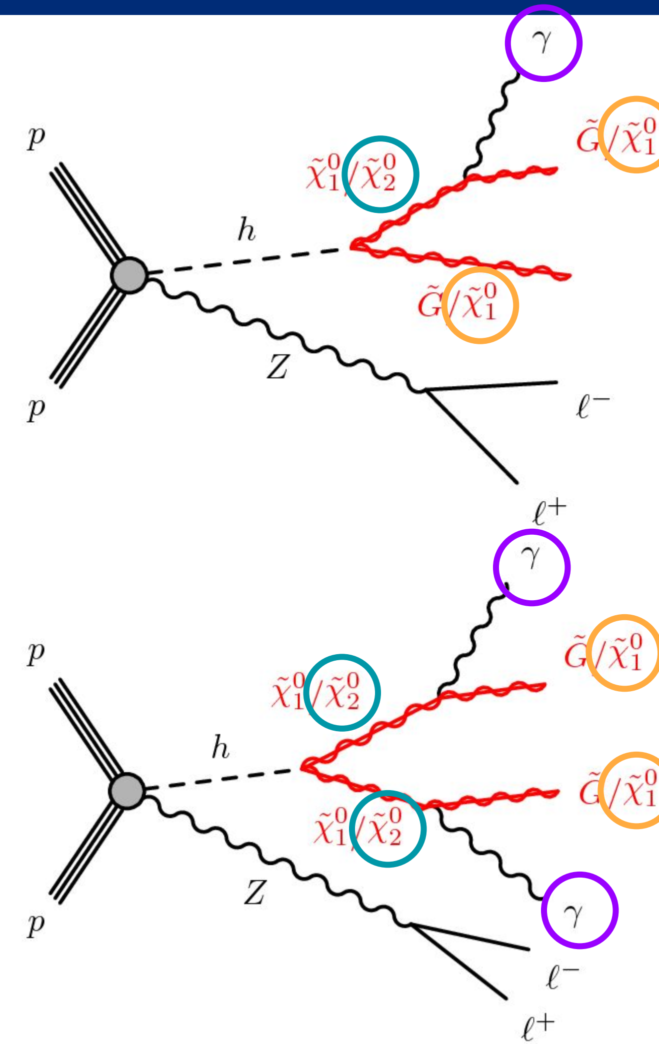
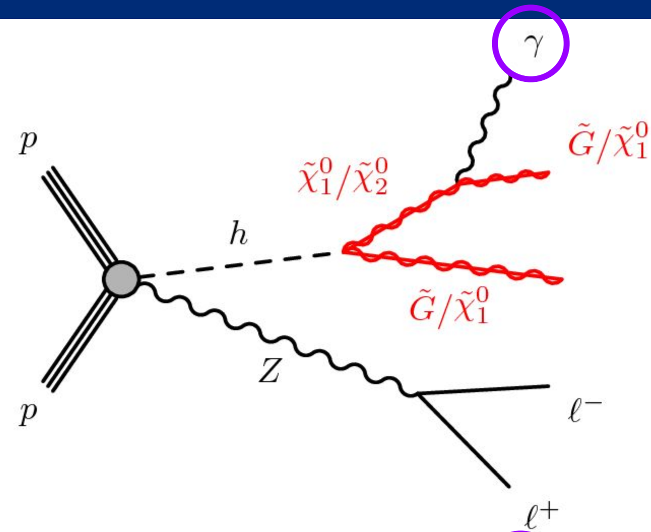


SUSY Higgs Decays

If Higgs mass < 2 * **NLSP mass :**

Gravitino LSP $h \rightarrow \tilde{\chi}_1^0 \tilde{G} \rightarrow \boxed{\gamma}\tilde{G}\tilde{G}$

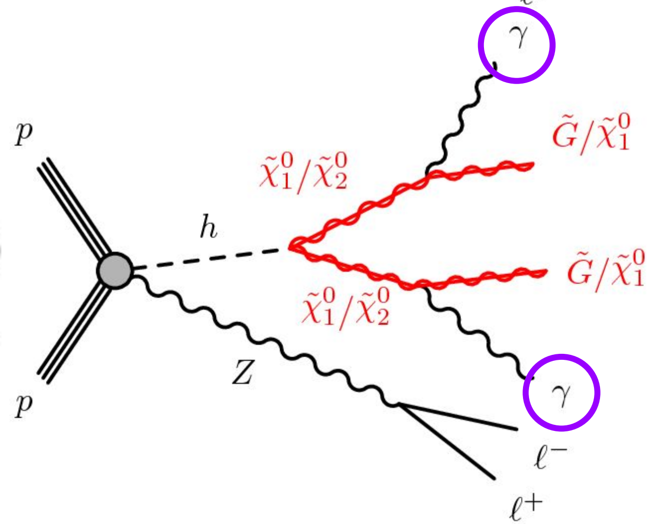
Neutralino LSP $h \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^0 \rightarrow \boxed{\gamma}\tilde{\chi}_1^0 \tilde{\chi}_1^0$



If Higgs mass > 2 * **NLSP mass :**

Gravitino LSP $h \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \boxed{\gamma}\tilde{G}\boxed{\gamma}\tilde{G}$

Neutralino LSP $h \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow \boxed{\gamma}\tilde{\chi}_1^0 \boxed{\gamma}\tilde{\chi}_1^0$



Signal Region Selection Criteria

- Generated signal events with SUSY simplified model framework*
- Optimized selection criteria to be sensitive over entire phase space
  - Over NLSP and LSP masses (across mono/di-photon decays)

Event Level

- **Dilepton OR Single lepton triggers**
- **Veto on presence of jets**
- **Veto if not exactly two leptons**

Photon

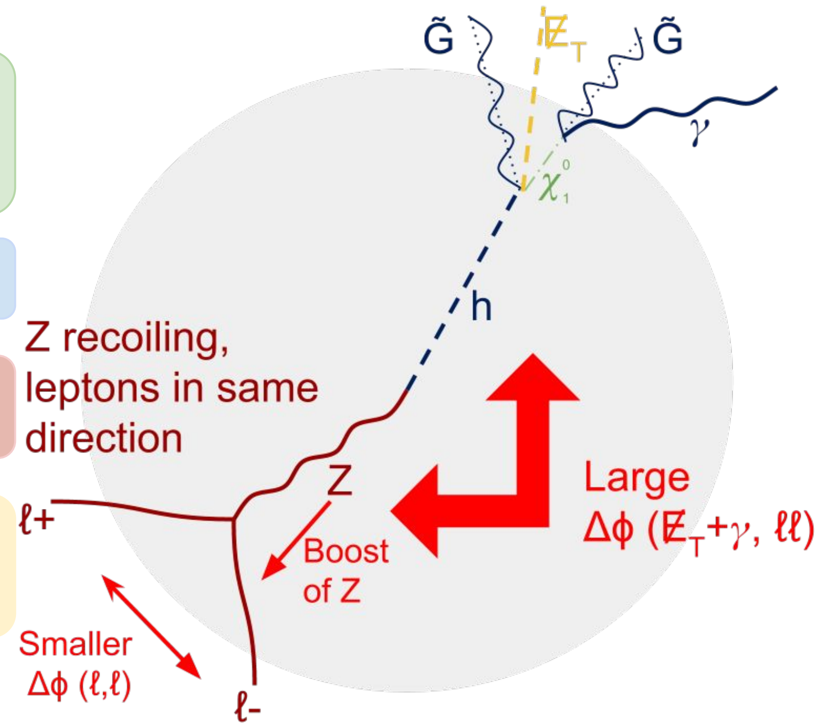
- ***At least one*** **photon with tightest ID and calorimeter isolation**

Real Z

- **Dilepton pair consistent with Z boson (10 GeV window)**

Signal Topology

- **$\not\!\!E_T$ > 95 GeV**
- Define Higgs and Z systems,
  - **Require balance in ϕ and p_T**

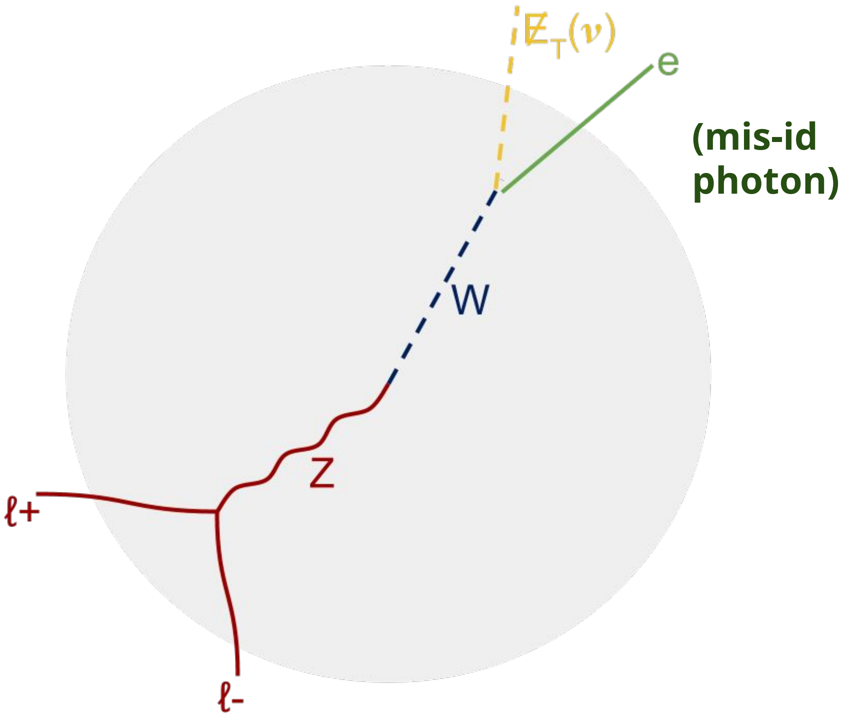


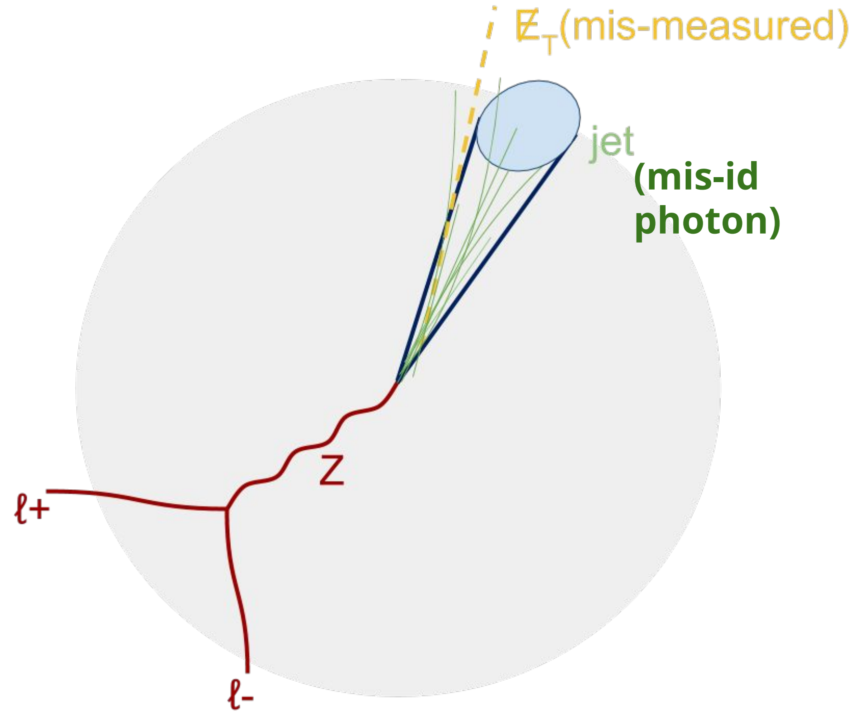
* Phys. Rev. D79 (2009) 075020, J. Phys. G39 (2012) 105005

Backgrounds and Estimation

Major Data Driven Backgrounds:

- **Electrons mis-identified as photons**
  - Primarily arising from *W(eν)Z(ℓℓ)*
- **Jets mis-identified as photons**
  - Mostly coming from *Z+jets*





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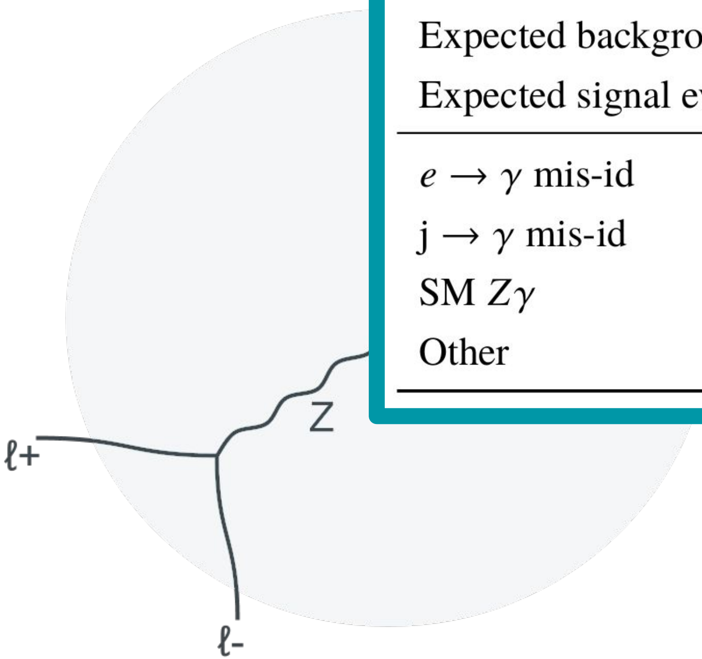
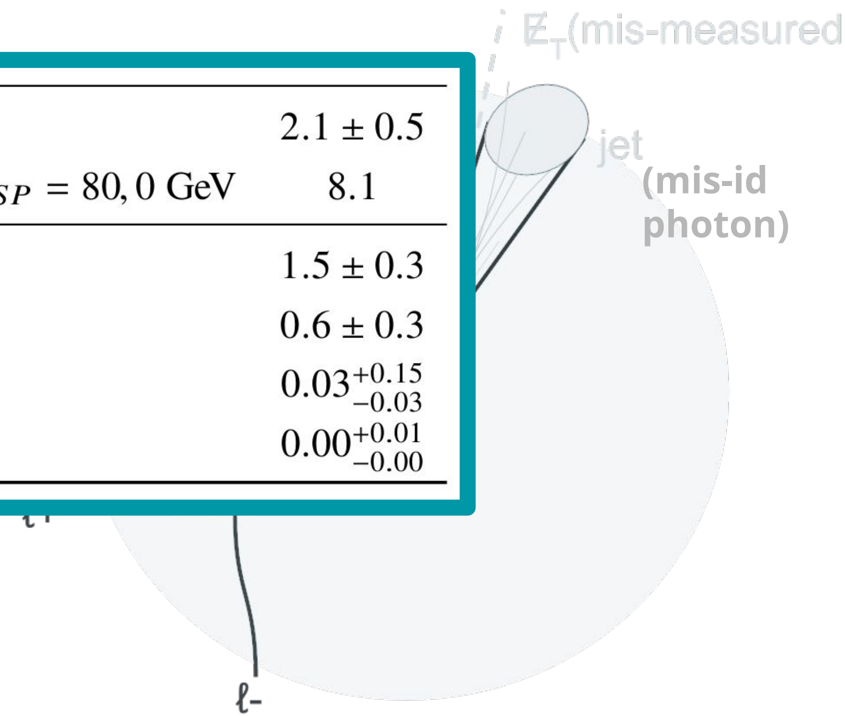


Expected background events	2.1 ± 0.5
Expected signal events m_{NLSP}, m_{LSP} = 80, 0 GeV	8.1
$e \rightarrow \gamma$ mis-id	1.5 ± 0.3
j $\rightarrow \gamma$ mis-id	0.6 ± 0.3
SM $Z\gamma$	$0.03^{+0.15}_{-0.03}$
Other	$0.00^{+0.01}_{-0.00}$

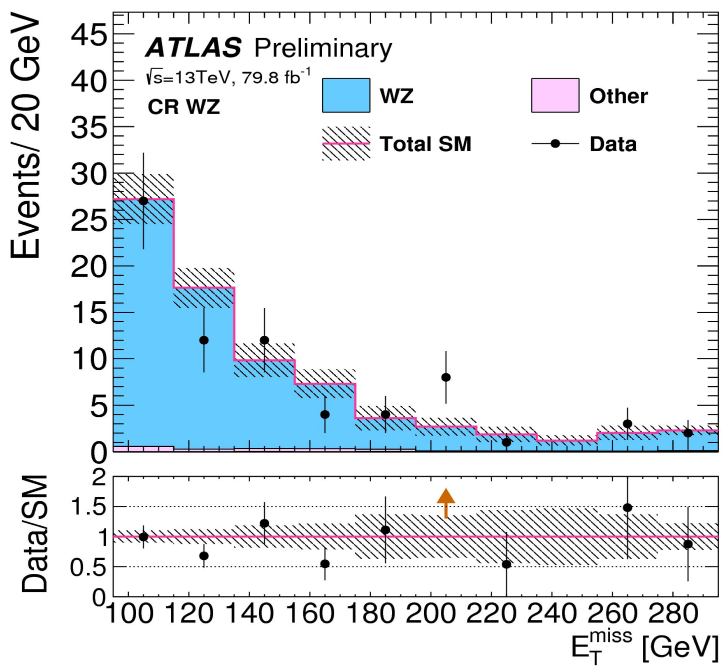


Electron Mis-identified as Photons

- Measure electron-to-photon mis-identification rate in data Z→ee events
- **Construct region with same SR criteria, but with an electron rather than a photon**
- SR estimate for mis-identified electron background is given by the data in this region multiplied by the electron-to-photon mis-identification rate

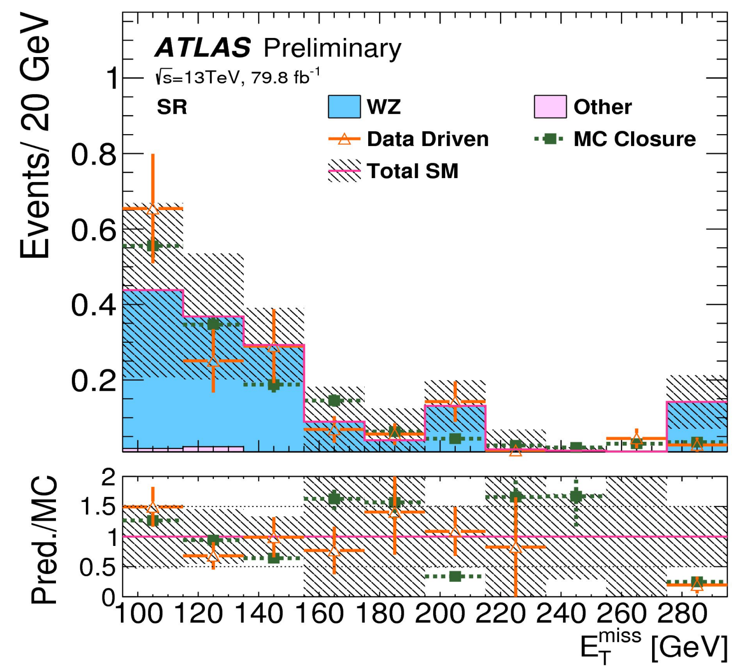
WZ Monte Carlo with <u>electron</u> selected

Data, selecting <u>electron</u>



WZ data with <u>electron</u> * data driven mis-id rate

WZ Monte Carlo with <u>photon</u> selected

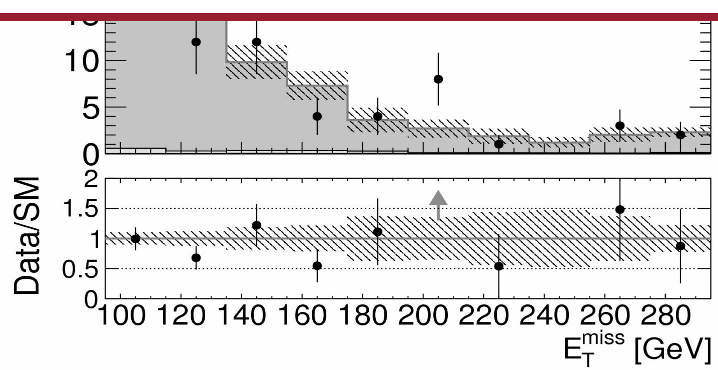


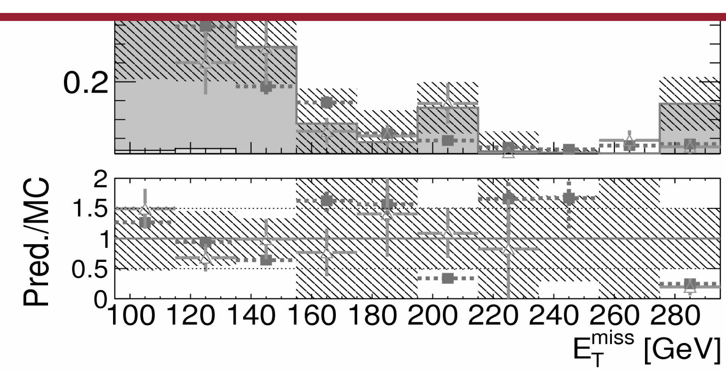
Estimate used in analysis. 1.5 events

Jets Mis-identified as Photons

- Measure electron-to-photon mis-identification rate in data Z→ee events
- **Construct region with same SR criteria, but with an electron rather than a photon**
- SR estimate for mis-identified electron background is given by the data in this region multiplied by the electron-to-photon mis-identification rate

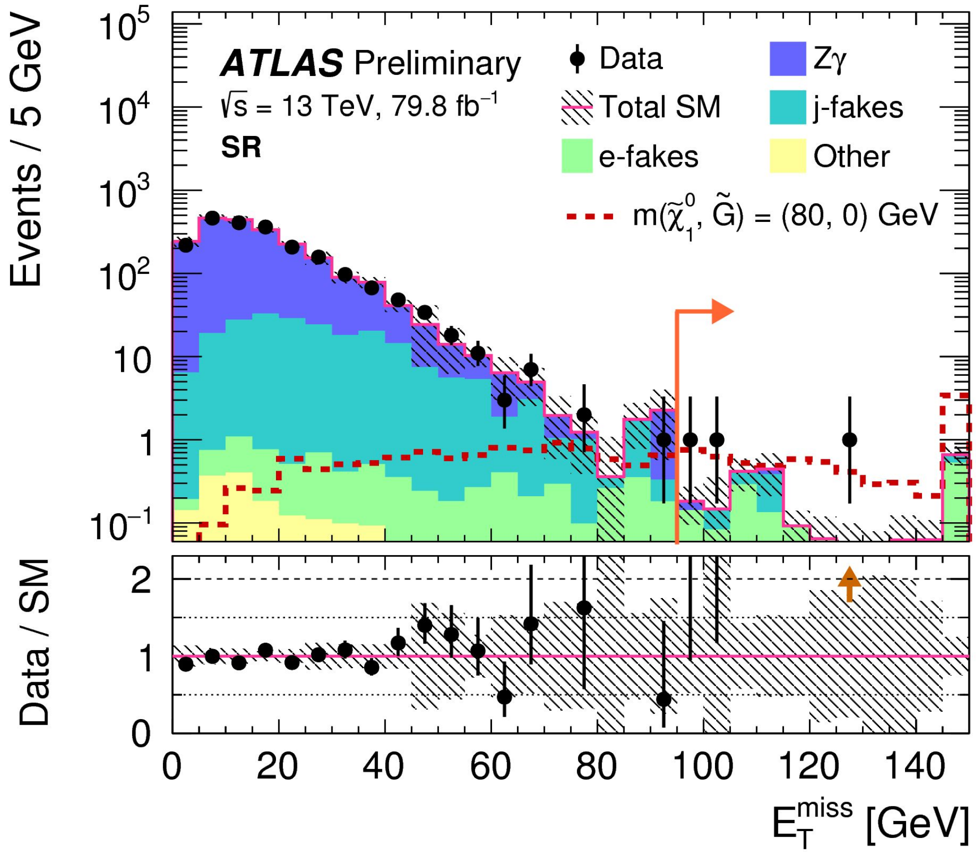
Same basic technique used for jet background: Construct SR-like region with photon-like objects ("pseudo photon") and scale by mis-identification factor





1.5 events

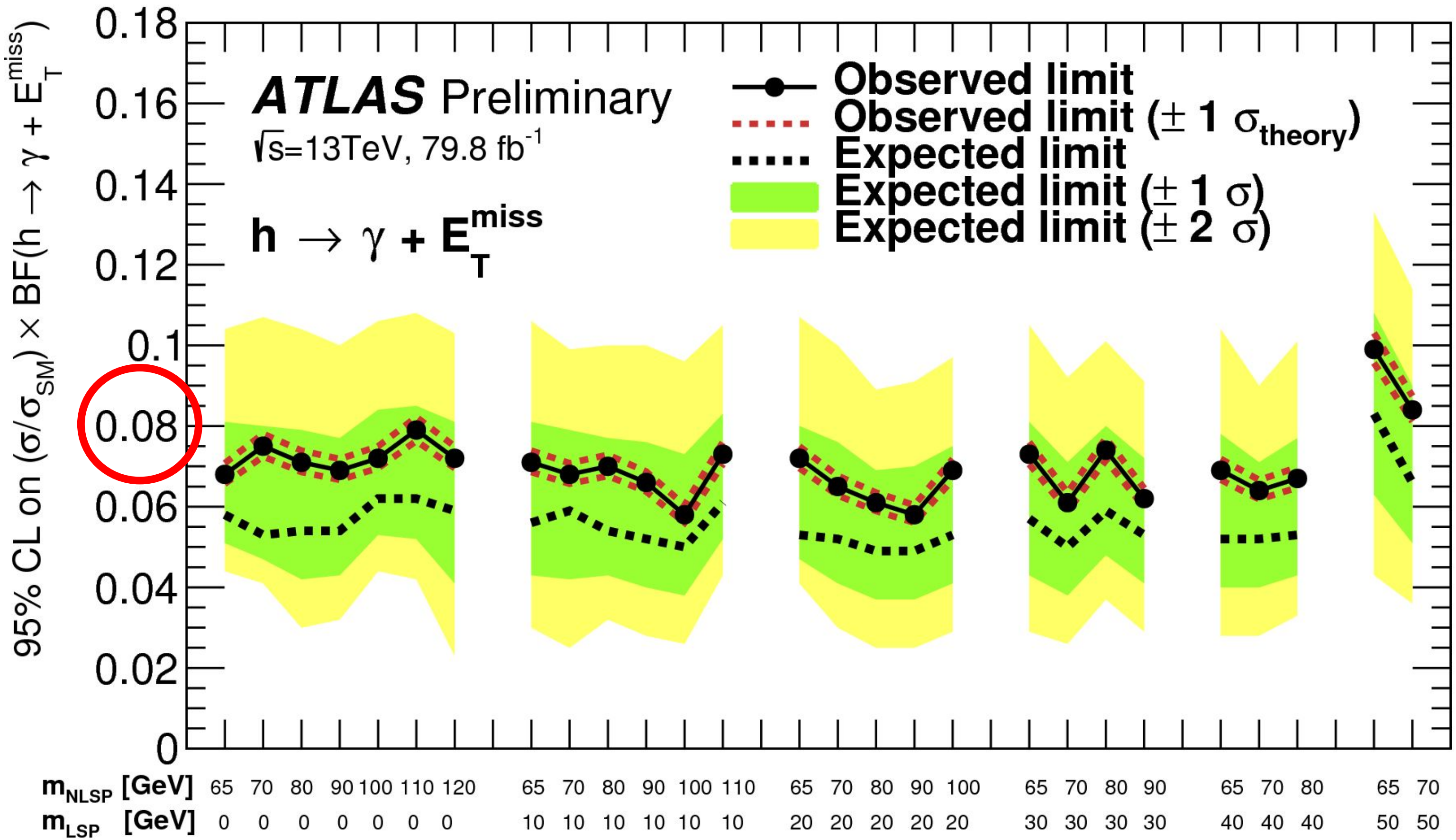
Results



Observed events	3
Expected background events	2.1 ± 0.5
Expected signal events m_{NLSP}, m_{LSP} = 80, 0 GeV	8.1
$e \to \gamma$ mis-id	1.5 ± 0.3
$j \to \gamma$ mis-id	0.6 ± 0.3
SM $Z\gamma$	$0.03^{+0.15}_{-0.03}$
Other	$0.00^{+0.01}_{-0.00}$

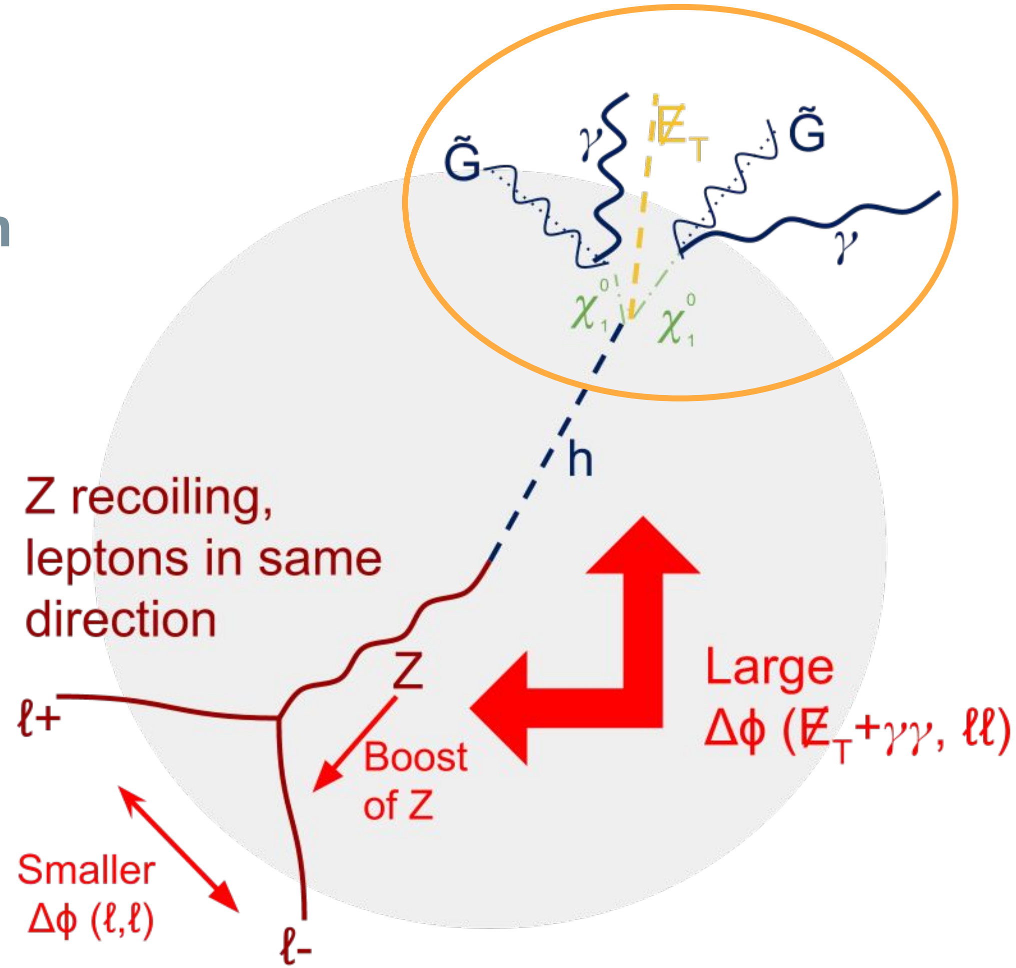
- **No significant excess seen in 2015-2017 data**
- Use results to set upper limits on Higgs BF to mono/di-photon + missing energy decays

Higgs to monophoton + $\not{E}_T$

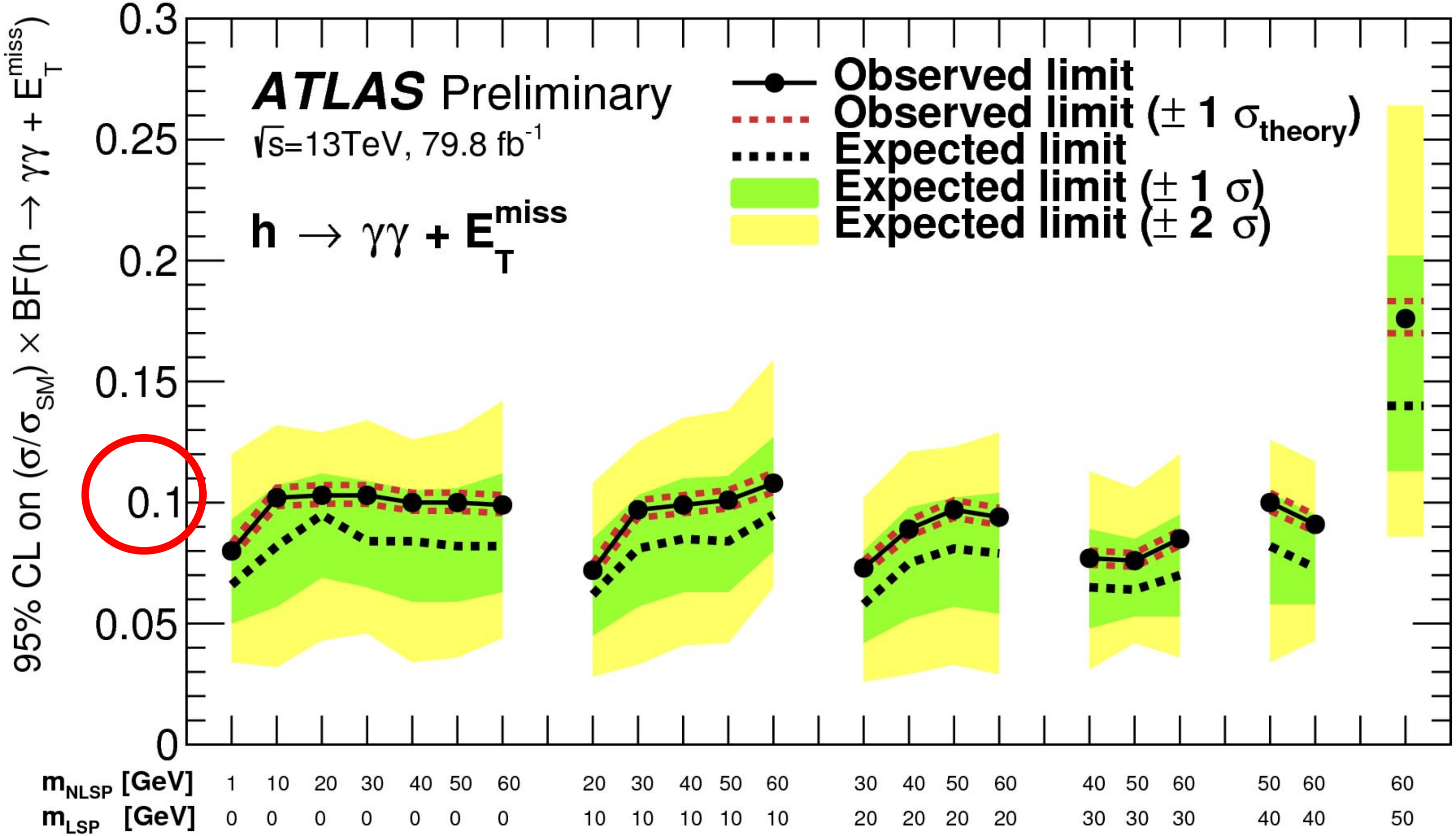


Higgs to diphoton + $\not{E}_T$

- If event contains two photons, build Higgs system 4-vector with both photons
- Improves discrimination of balance in ϕ and p_T cuts, though smaller kinematic acceptance of signal
- Re-interpret results with at least one photon decays



Higgs to diphoton + $\not{E}_T$



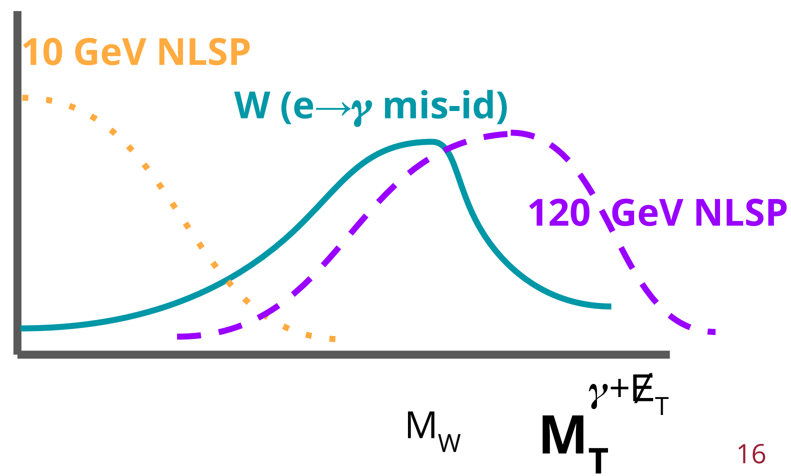
Conclusion and Outlook

★ Set upper limits on Higgs BF(neutralinos and gravitinos) to:

- 8% or less across majority of monophoton region
- 11% or less across majority diphoton region
- Results include massive LSPs scenarios

★ Future work

- Hope to be sensitive to sub percent level branching fractions of Higgs decays
- Improved analysis techniques
  - Dedicated signal regions for mono/di-photon decays
  - Multi-bin fits and improved discriminating variables
  - Interest in longer lived decays of neutralinos



BACKUP

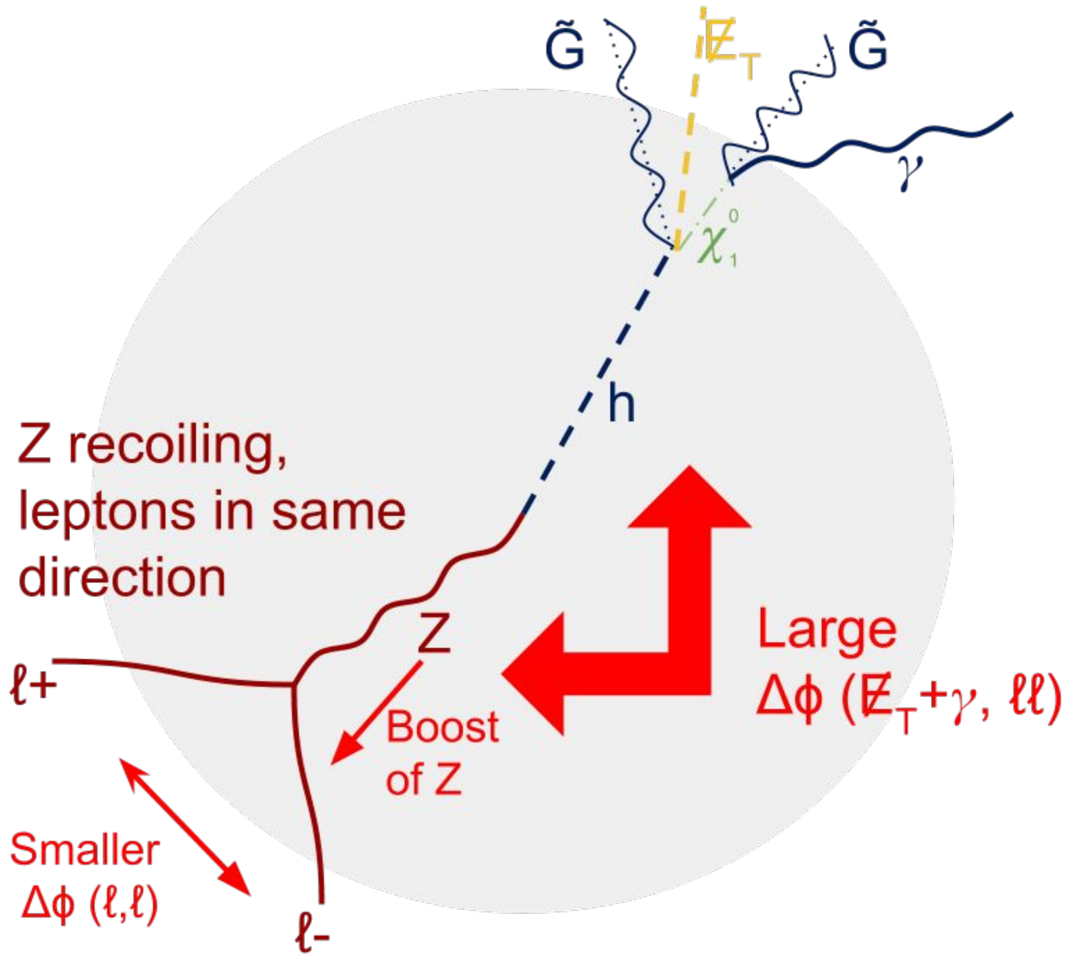
Signal Event Topology

Construct variables with
4 vectors of dilepton pair
And photon (diphoton) + MET

Bal_{pT} =

$$\frac{|p_{\mathrm{T}}^{\ell\ell} - p_{\mathrm{T}}^{\gamma\, E_{\mathrm{T}}^{\mathrm{miss}}}|}{p_{\mathrm{T}}^{\gamma\, E_{\mathrm{T}}^{\mathrm{miss}}}}$$

$$\Delta\phi(\ell\ell, \gamma\, E_{\mathrm{T}}^{\mathrm{miss}})$$



Signal Region Selection Criteria

- Generated signal events with SUSY simplified model framework □
- Optimized selection criteria to be sensitive over entire phase space
  - Over NLSP and LSP masses (across mono/di-photon decays)

Event Level

- **Dilepton OR Single lepton triggers**
- **Vetos: jet (> 30 GeV), Number leptons != 2**
- **Select hardest vertex (Z vertex)**

Photon

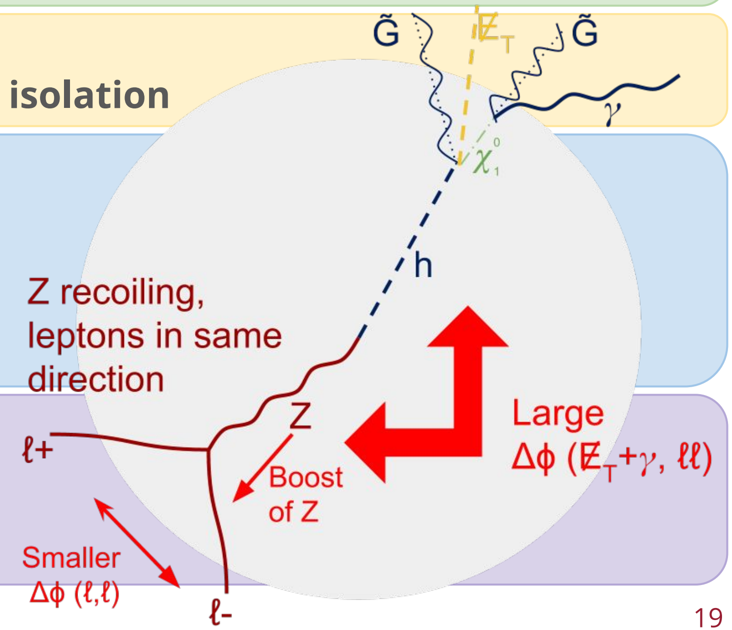
- **At least 1 Photon p_T > 25GeV**
  - **Tight ID and requiring the tightest isolation**

Real Z

- **2 Leptons p_T > 25, 20 GeV**
  - **(Medium ID and loosely isolated electrons and muons)**
- **10 GeV dilepton Z mass window**
- **$\Delta\phi(\ell,\ell) < 1.4$**

Signal Topology

- **<u>MET > 95 GeV</u>**
- **$\Delta\phi(\ell\ell, \text{MET}+\gamma) > 2.8$**
- **$|p_T^{\ell\ell} - p_T^{\text{MET}+\gamma}| \,/\, p_T^{\text{MET}+\gamma} < 0.2$**



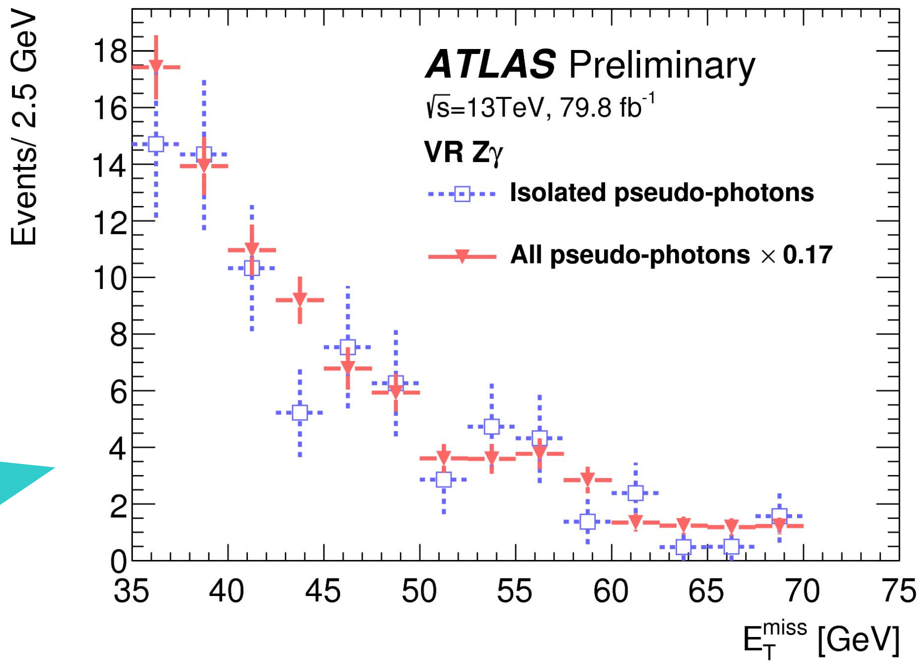
□ Phys. Rev. D79 (2009) 075020, J. Phys. G39 (2012) 105005

Jets Mis-identified as Photons

Same basic technique used for this background: Construct SR-like region with photon-like objects ("pseudo photon") and scale by mis-identification factor

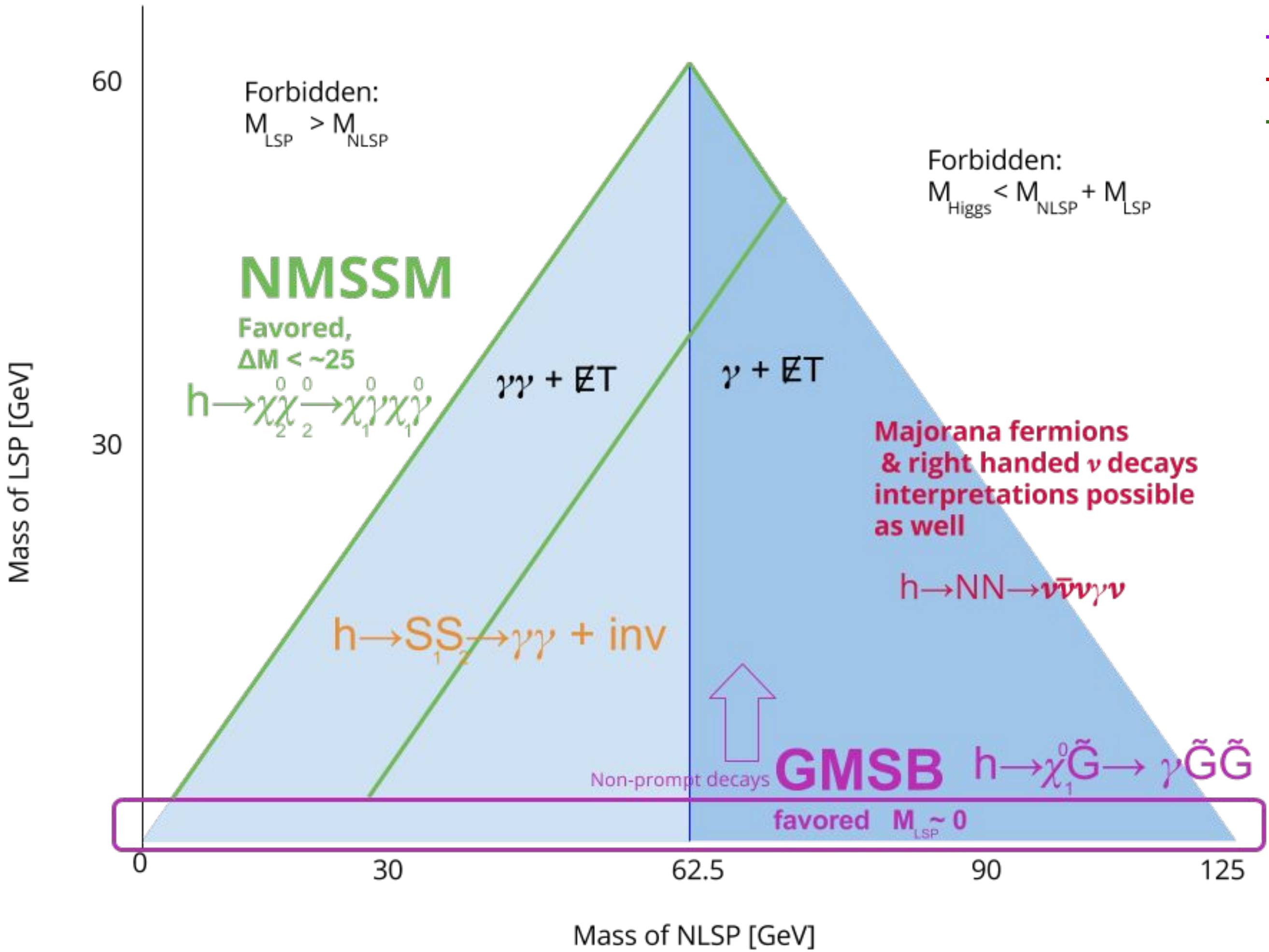
- Measure the mis-identification rate in samples enriched with pseudo photons
    - pseudo photons are constructed by reversing photon ID criteria
- Nominally, select *isolated* pseudo photons with SR criteria (rather than photon) and apply fake factor
- !! Low statistics: 83% of pseudo photons are not isolated as they are jet-like
- Extrapolate further by selecting all pseudo photons and scaling, example in validation region shown

Validation Region for Z+γ

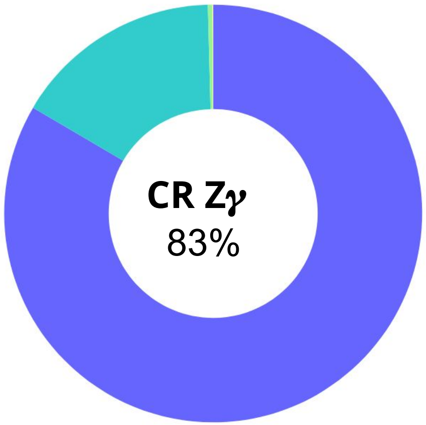


Theory Motivations

arXiv:0909.3523
arXiv:1312.4992
arXiv:1203.4563



Backgrounds and Estimation



Major Backgrounds:

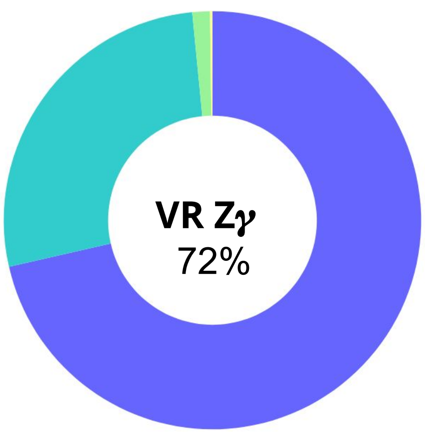
Data Driven estimation

- Electrons mis-identified as photons
  - Primarily arising from *WZ*
- Jets mis-identified as photons
  - Mostly coming from *Z+jets*

Monte Carlo Simulation estimation

- $Z\gamma$
- ttbar+γ, $Z\gamma\gamma$
  - WW, ZZ->($\ell\ell\nu\nu$), other top/ttbar **negligible**
  - H->$Z\gamma$, Z(H->$\gamma\gamma$), Z(H->WW) **negligible**

Construct control and validation regions to measure and validate background estimations.



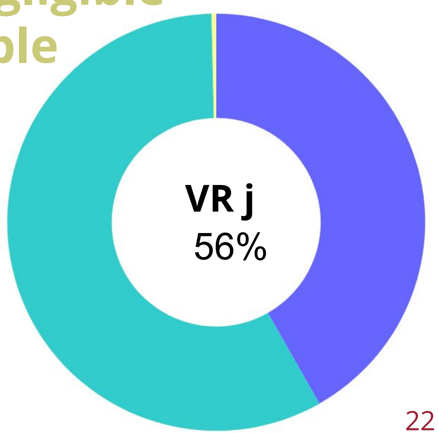
$Z\gamma$

Jet Fakes

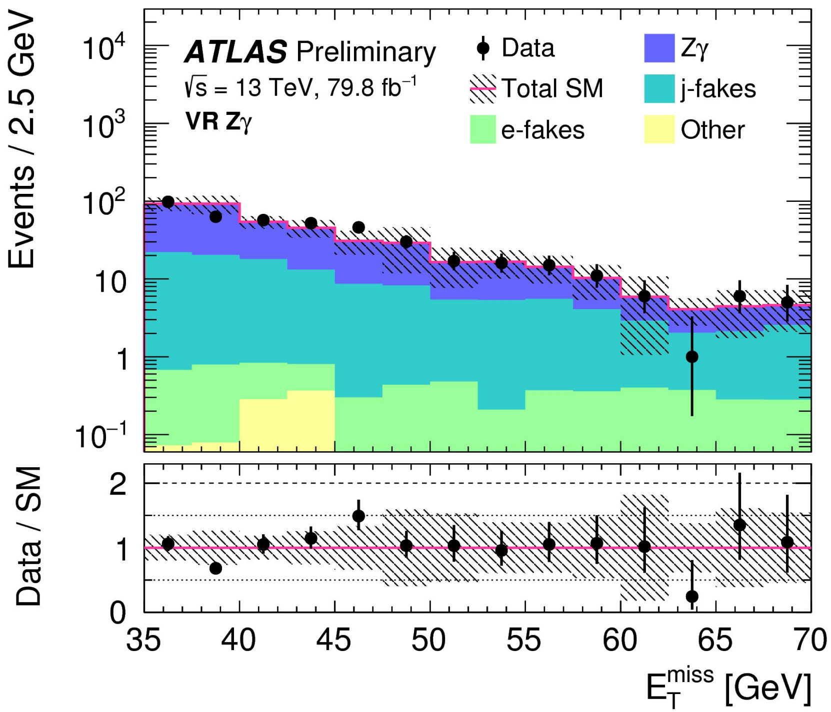
Electron Fakes

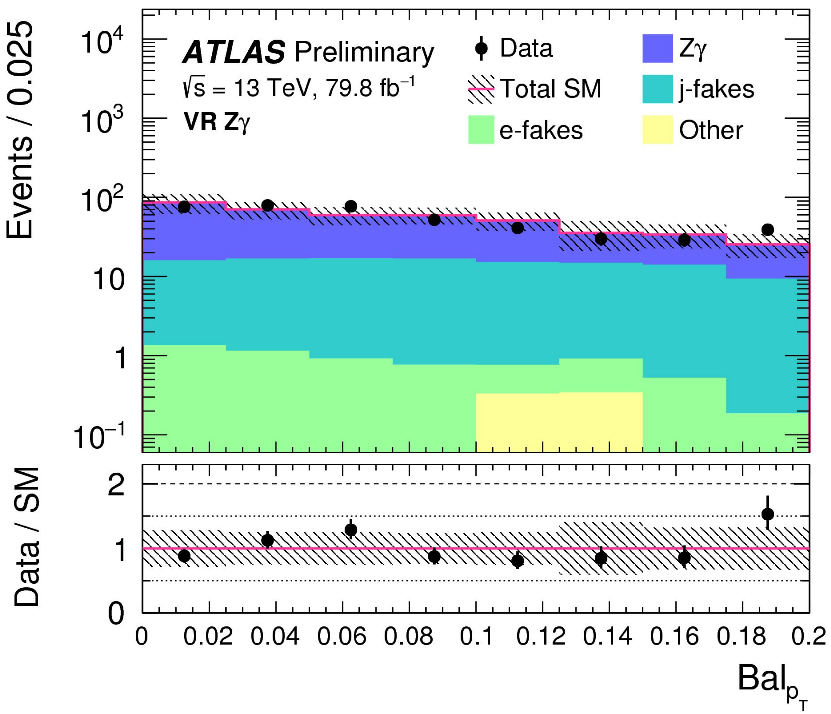
Other

($tt\gamma$, $V\gamma\gamma$)



Validation Regions

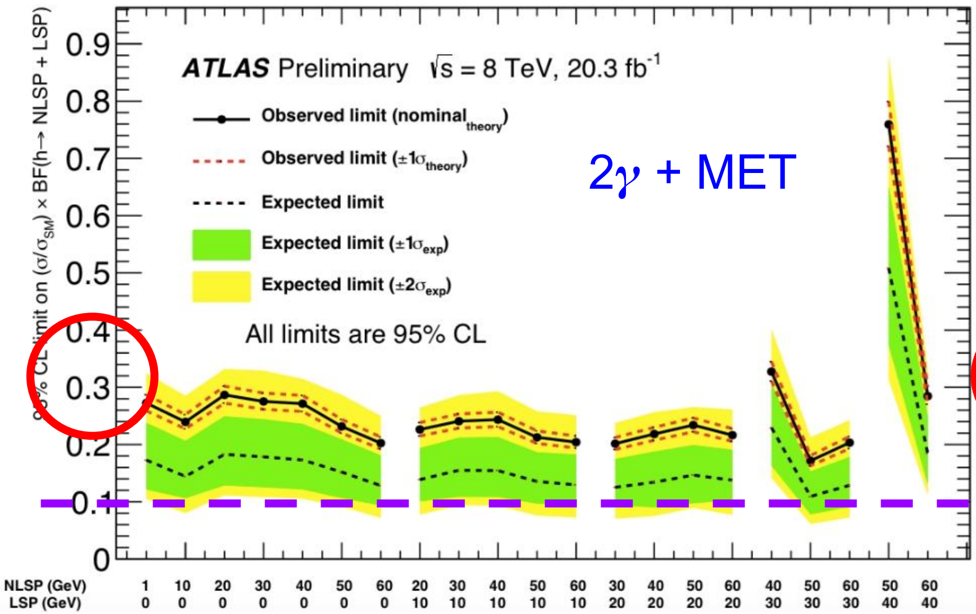


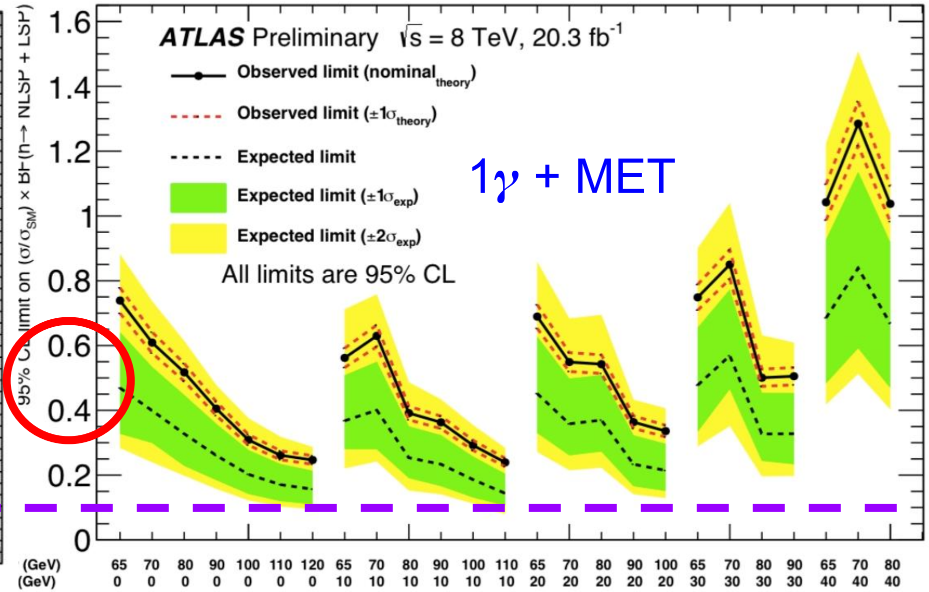


Systematics

Total background expectation	2.1
Total systematic uncertainty	± 0.5 [22%]
Uncertainty component	
CR WZ and jet fake sample size	± 0.3 [15%]
Stat. error of $\kappa_{\text{tight}}^{\text{j}\to\gamma}$	± 0.3 [12%]
$E_{\text{T}}^{\text{miss}}$ dependence of $\xi_{data}^{e\to\gamma}$	± 0.1 [7%]
Jet energy resolution	± 0.1 [6%]
$\xi_{MC}^{e\to\gamma}$ closure	± 0.1 [5%]
$E_{\text{T}}^{\text{miss}}$ soft-term resolution	± 0.1 [5%]
CR correlation $\kappa_{\text{tight}}^{\text{j}\to\gamma}$	$\pm{<}0.1$ [3%]
Pseudo photon scaling $\kappa_{\text{tight}}^{\text{j}\to\gamma}$	$\pm{<}0.1$ [2%]
Window dependence of $\xi_{data}^{e\to\gamma}$	$\pm{<}0.1$ [2%]
Photon/lepton energy scale	$\pm{<}0.1$ [2%]
Photon isolation	$\pm{<}0.1$ [2%]
$\langle\mu\rangle$ dependence of $\xi_{data}^{e\to\gamma}$	$\pm{<}0.1$ [1%]
Jet energy scale	$\pm{<}0.1$ [1%]

Previous Results: ATLAS Run1: VBF





Target

- ATLAS Run 1 VBF results
- Slight excess in Run 1 (1.1 σ)
- Best upper limits of BR(H->Neutralinos) for
  - 1 photon case: 21%
  - 2 photon case: 25%

- 2 photons when $M_{NLSP} < M_H/2$
- When $M_{NLSP} < M_H/2$, H->NN expected to dominate
- BR(H->NN) range from a few percent to 15% depending on model parameters

CMS Run 1 Z(ℓ= e,μ)H

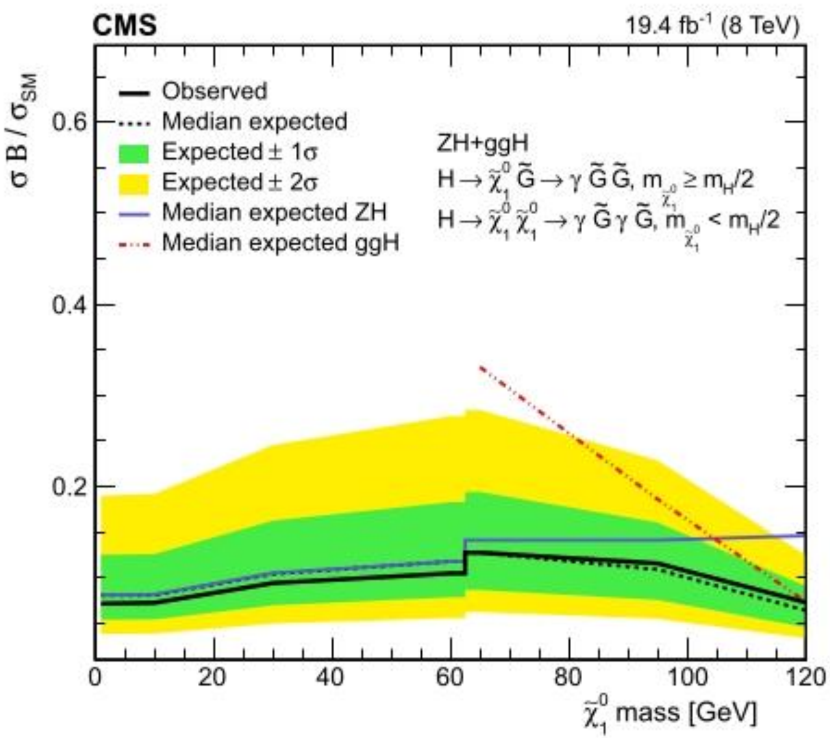


Fig. 6. Expected and observed 95% CL upper limits on $\sigma\,\mathcal{B}/\sigma_{SM}$ for $m_H = 125$ GeV as a function of $m_{\tilde{\chi}_1^0}$ assuming the SM Higgs boson cross sections, for the ZH and ggH channels and their combination, with $\mathcal{B} \equiv \mathcal{B}(H \to \tilde{\chi}_1^0\tilde{\chi}_1^0)\,\mathcal{B}(\tilde{\chi}_1^0 \to \tilde{G} + \gamma)^2$ for $m_{\tilde{\chi}_1^0} < m_H/2$ and $\mathcal{B} \equiv \mathcal{B}(H \to \tilde{\chi}_1^0\tilde{G})\,\mathcal{B}(\tilde{\chi}_1^0 \to \tilde{G} + \gamma)$ for $m_{\tilde{\chi}_1^0} \geq m_H/2$.

- **7-13% percent upper limits assuming *massless* gravitino**
- **Phys. Lett. B780 (2018) 118**

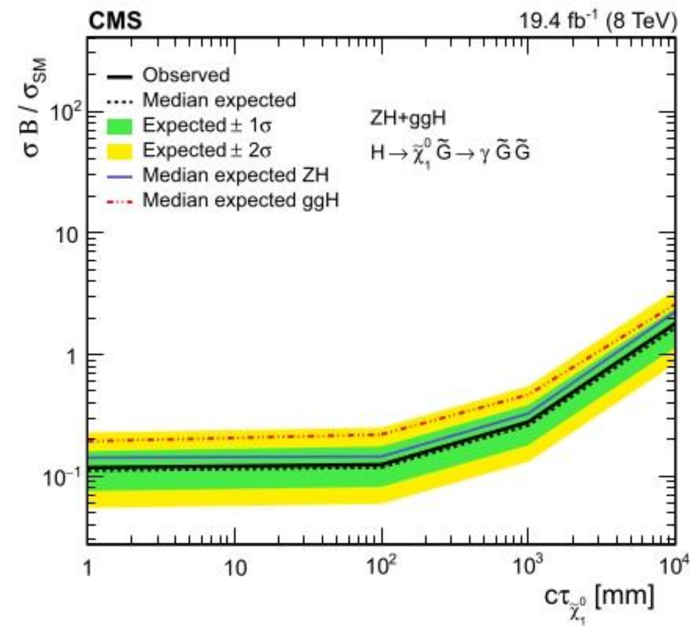


Fig. 8. Expected and observed 95% CL upper limits on $\sigma_H\,\mathcal{B}$ as a function of $c\tau_{\tilde{\chi}_1^0}$ for $m_H = 125$ GeV and $m_{\tilde{\chi}_1^0} = 95$ GeV, where $\mathcal{B} \equiv \mathcal{B}(H \to \tilde{\chi}_1^0\tilde{G})\,\mathcal{B}(\tilde{\chi}_1^0 \to \tilde{G} + \gamma)$.