

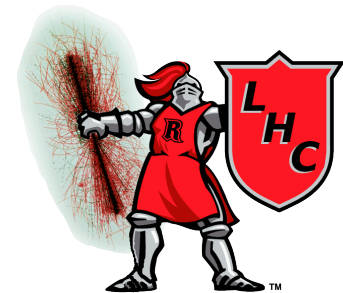
Asymmetric Internal Conversion

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CMS Collaboration

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Photon Conversion

- Leptons

External in Material

$$\gamma \rightarrow ee \quad P(\gamma \rightarrow \mu\mu) / P(\gamma \rightarrow ee) = O(m_e/m_\mu)^2$$

Internal in Vacuum

$$\gamma^* \rightarrow ll \quad P(\gamma \rightarrow \mu\mu) / P(\gamma \rightarrow ee) = O(\ln(m_e/m_\mu))$$

- Hadrons

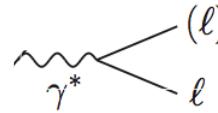
Internal in Vacuum

$$\gamma^* \rightarrow \text{hadrons}$$

Internal Photon Conversion to Leptons

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Optical Theorem



$$m_{\ell\ell} \frac{d\mathcal{P}(\gamma^* \rightarrow \ell\ell)}{dm_{\ell\ell}} = \frac{2\alpha}{3\pi} \left(1 - \frac{4m_\ell^2}{m_{\ell\ell}^2}\right)^{1/2} \left(1 + \frac{2m_\ell^2}{m_{\ell\ell}^2}\right)$$

Soft singularity

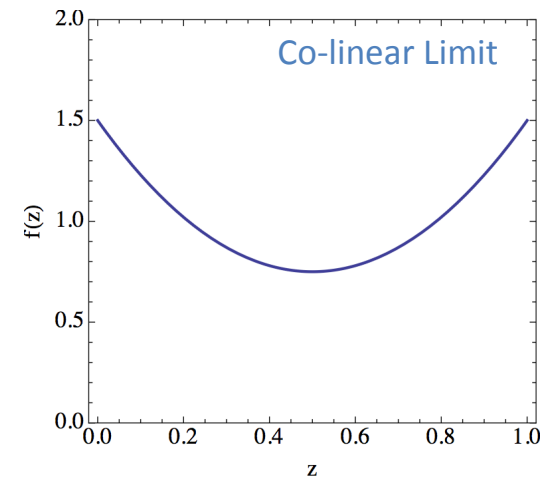
$$\mathcal{P}(\gamma^* \rightarrow \ell\ell) = \int_{2m_\ell}^\mu dm_{\ell\ell} \frac{d\mathcal{P}(\gamma^* \rightarrow \ell\ell)}{dm_{\ell\ell}} = \frac{2\alpha}{3\pi} \left[\ln(\mu/m_\ell) - \frac{5}{6} + \mathcal{O}(m_\ell/\mu)^4 \right]$$

Both e and μ

Momentum Fraction

$$\frac{1}{\mathcal{P}(\gamma_T^* \rightarrow \ell\ell)} \frac{d\mathcal{P}(\gamma_T^* \rightarrow \ell\ell)}{dz} \equiv f_T(z, \beta) = \frac{2 - \beta^2 + (1 - 2z)^2}{2\beta(1 - \beta^2/3)}$$

$$f_T(z, \beta) = \frac{3}{4} [1 + (1 - 2z)^2] + \mathcal{O}(m_\ell/m_{\ell\ell})^2$$



Opening Angle

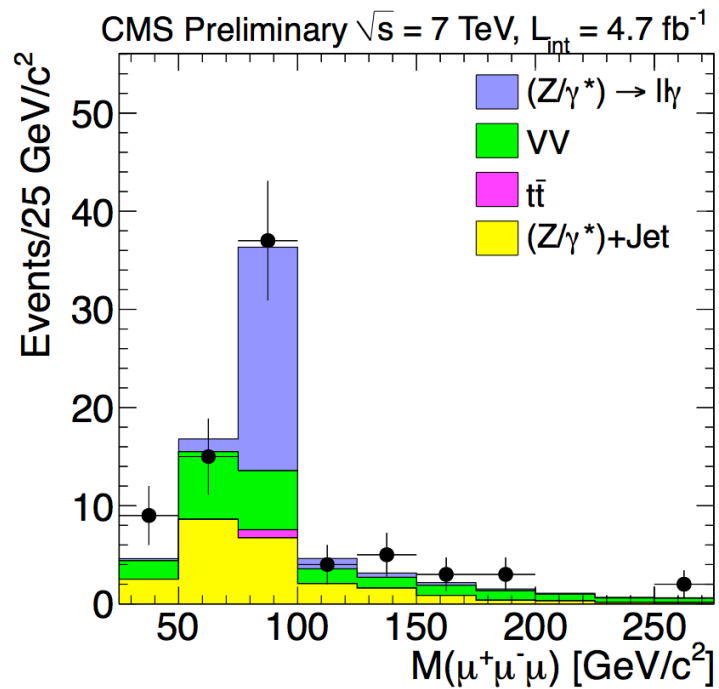
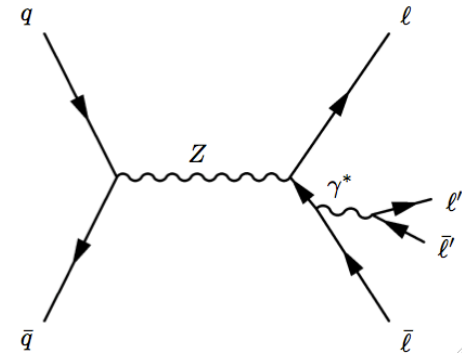
$$\tan \varphi_{\ell\ell} = \frac{m_{\ell\ell}}{2|\vec{p}_{\ell\ell}|} \frac{\sqrt{\beta^2 - (1 - 2z)^2}}{z(1 - z)} + \mathcal{O}(m_{\ell\ell}^2/(|\vec{p}_{\ell\ell}|m_\ell))^3$$

Asymmetric Internal Conversion $\gamma^* \rightarrow e (e), \mu (\mu)$
with Trailing Lepton Lost -
Yields "Fake" Isolated Electrons and Muons

Internal Photon Conversion to Leptons

CMS Observation:

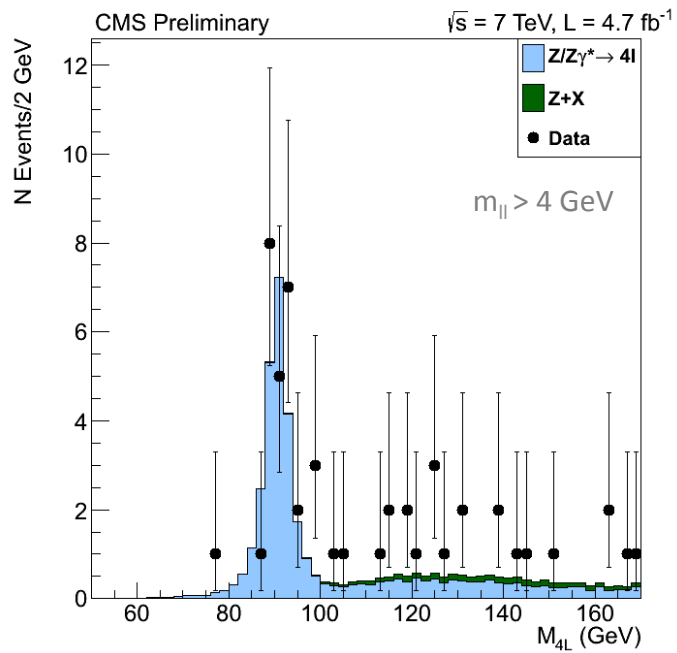
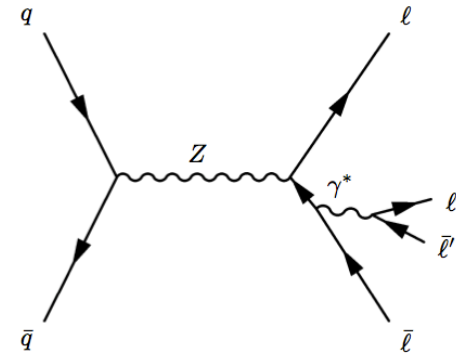
$$Z \rightarrow l l l (l) = l l \gamma^* \rightarrow l l l (l)$$



Internal Photon Conversion to Leptons

CMS Observation:

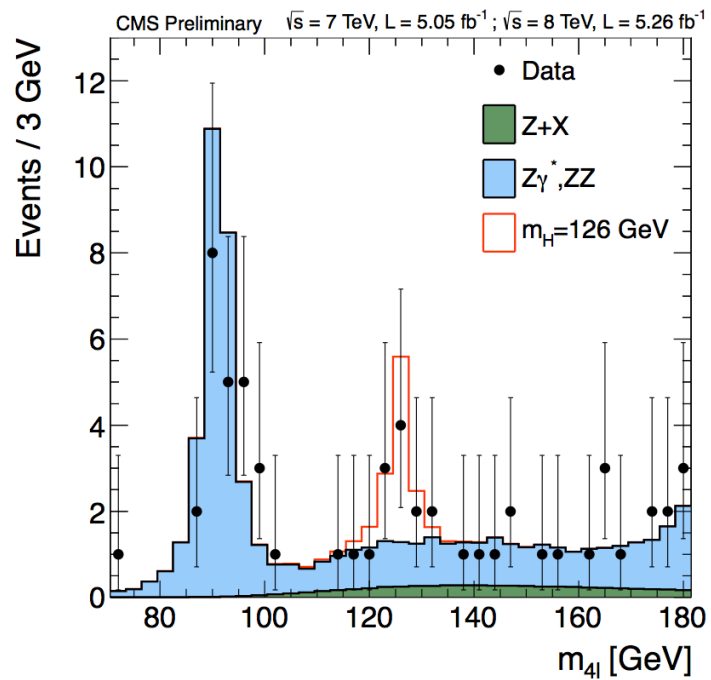
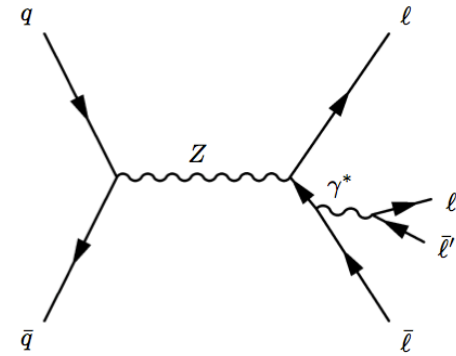
$Z \rightarrow llll$



Internal Photon Conversion to Leptons

CMS Observation:

Higgs, Z \rightarrow llll



Internal Photon Conversion to Leptons

Asymmetric Internal Conversion - Fake Lepton Backgrounds

- Multi-Lepton Searches for New Physics

$$X \ell \ell \gamma^* \rightarrow X \ell \ell \ell (\ell)$$

- Di-lepton Search for Higgs

$$\text{Higgs} \rightarrow WW \rightarrow \ell \nu \ell \nu$$

$$W \gamma^* \rightarrow \ell \nu \ell (\ell)$$

Internal Photon Conversion to Leptons

Data Driven Estimates for Internal Conversion Fake Leptons

- Conversion Lepton / Photon Fake Rate

$$\int d\Phi_{X\ell\ell} |\mathcal{A}(\text{init} \rightarrow X\ell\ell)|^2 \simeq \int d\Phi_{X\gamma^*} |\mathcal{A}(\text{init} \rightarrow X\gamma^*)|^2 \mathcal{P}(\gamma^* \rightarrow \ell\ell) \quad \text{Leading Log}$$

$$\mathcal{P}(\gamma^* \rightarrow \ell(\ell))|_{\text{exp}} \equiv \frac{\Gamma(Z \rightarrow \ell\ell\ell(\ell))}{\Gamma(Z \rightarrow \ell\ell\gamma)}|_{\text{exp}}$$

$$d\sigma(\text{init} \rightarrow X\ell(\ell)) \simeq d\sigma(\text{init} \rightarrow X\gamma) \mathcal{P}(\gamma^* \rightarrow \ell(\ell))|_{\text{exp}}$$

- Charge Conjugation Symmetry

$$P(\gamma^* \rightarrow l^+ (l^-)) = P(\gamma^* \rightarrow l^- (l^+))$$

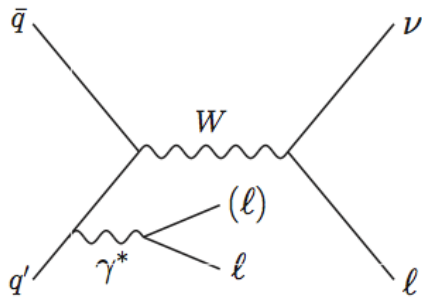
- Resolved Di-Lepton / Lepton Conversion

Higgs \rightarrow $WW \rightarrow l \nu l \nu$

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Internal Conversion Monte Carlo

$pp \rightarrow l \nu l (l)$



Asymmetric Internal Conversion -

1. Carve Out IR singular
Region of Phase Space

2. Integrate Over
Unobserved Lepton

$$p_{T1}, p_{T2} > 5 \text{ GeV}$$

$$p_{T3} > 0.1 \text{ GeV}$$

$$m_{ll} > 2 m_l$$

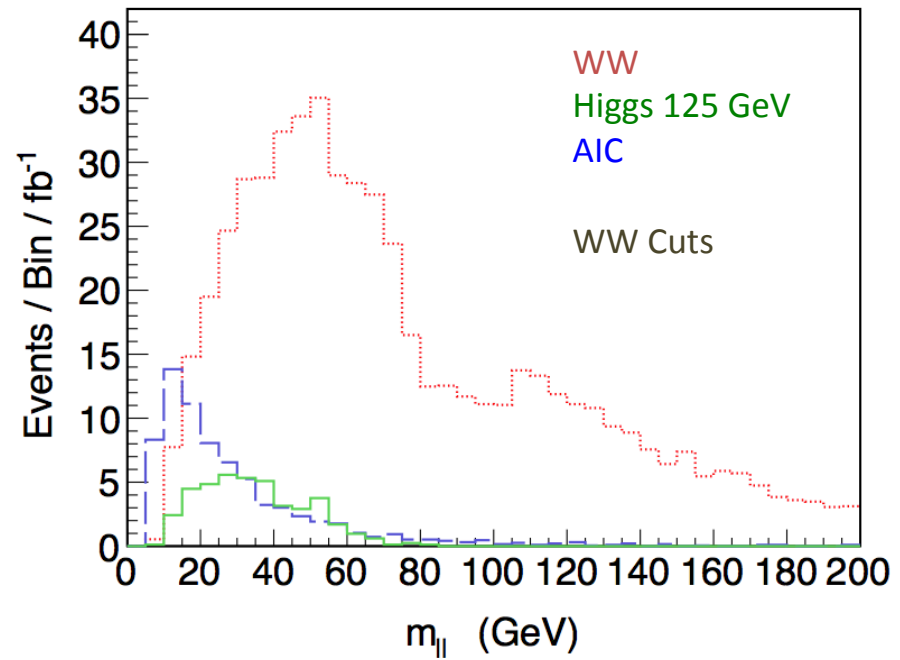
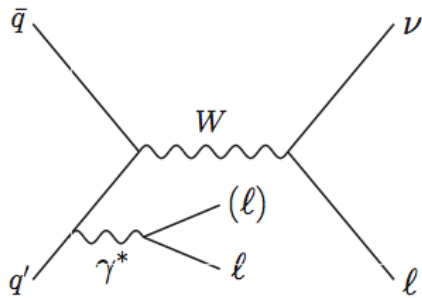
Madgraph 5 modification

Higgs \rightarrow $WW \rightarrow l \nu l \nu$

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Internal Conversion Monte Carlo

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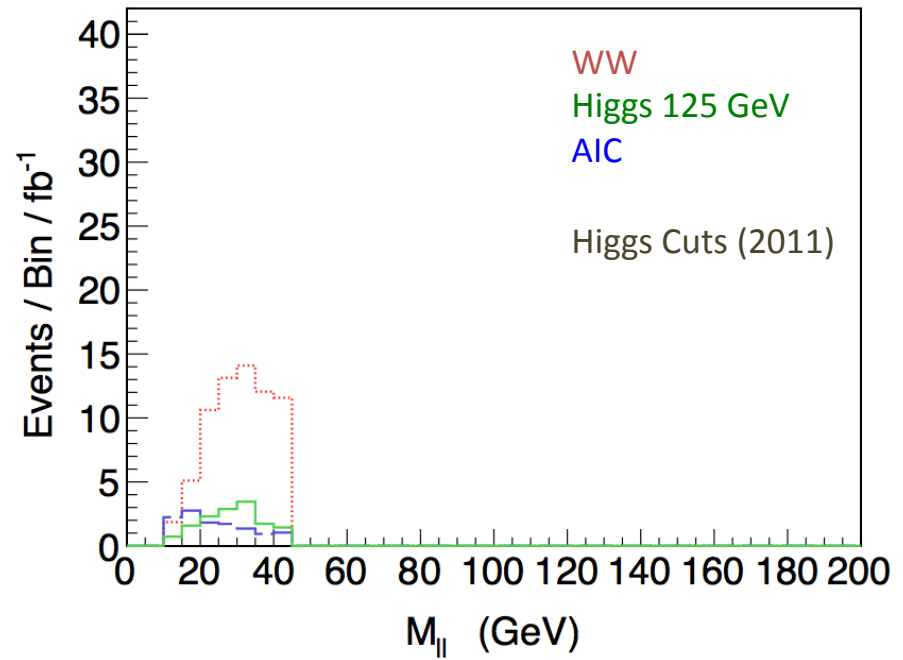
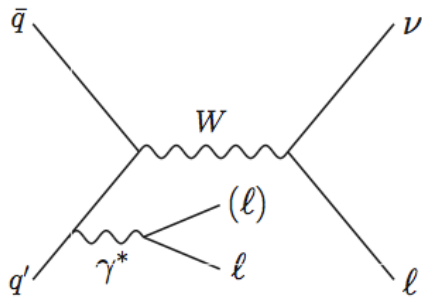


Higgs \rightarrow $WW \rightarrow l \nu l \nu$

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Internal Conversion Monte Carlo

$pp \rightarrow l \nu l (l)$

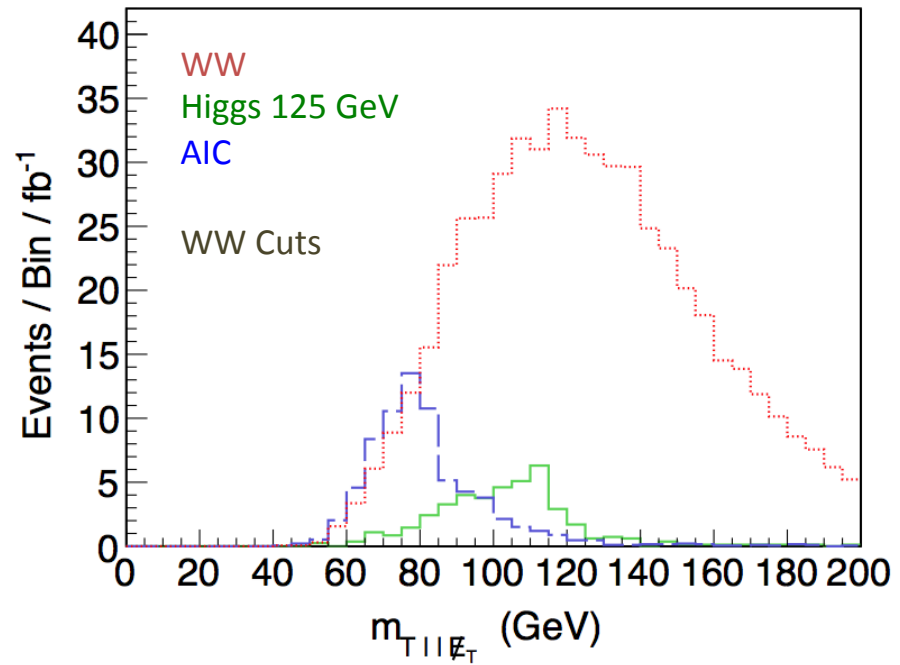
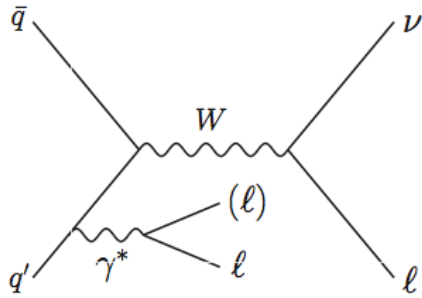


Higgs \rightarrow $WW \rightarrow l \nu l \nu$

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Internal Conversion Monte Carlo

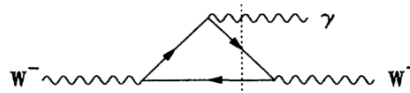
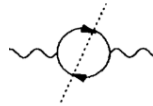
$pp \rightarrow l \nu l (l)$



Internal Conversion Monte Carlo

Neglected:

- Gauge Invariance $O(\alpha)$



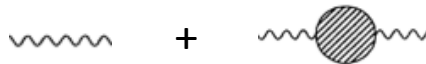
$$m_l \ll m_{\gamma^*} \ll m_W$$

$$g_{WW\gamma} = g_{WW\gamma} (1 + i \Gamma_W / m_W) \quad (\text{Bauer, Zeppenfeld})$$

Would Correct most of Leading Logarithm



- (Non-Perturbative) QCD Corrections at Low m_{γ^*}



For Lepton Conversions:

$$O(\Gamma(V_h \rightarrow l l) / \Gamma(V_h \rightarrow \text{hadrons})) R(ee \rightarrow \text{hadrons}) \text{ correction}$$

For Inclusive Hadron Conversions: Use $R(ee \rightarrow \text{hadrons})$

Internal Photon Conversion to Leptons

Asymmetric Internal Conversion -
Fake Lepton Backgrounds $\gamma^* \rightarrow e (e), \mu (\mu)$

Important Background for

Multi-lepton Searches
Higgs $\rightarrow WW \rightarrow l \nu l \nu$

Data Driven Fake Rate Methods to Estimate Backgrounds

Monte Carlo -

Carve Out IR Singular Region of Conversion Phase Space
Integrate Over Unobserved Lepton

Extra Slides