

Detecting

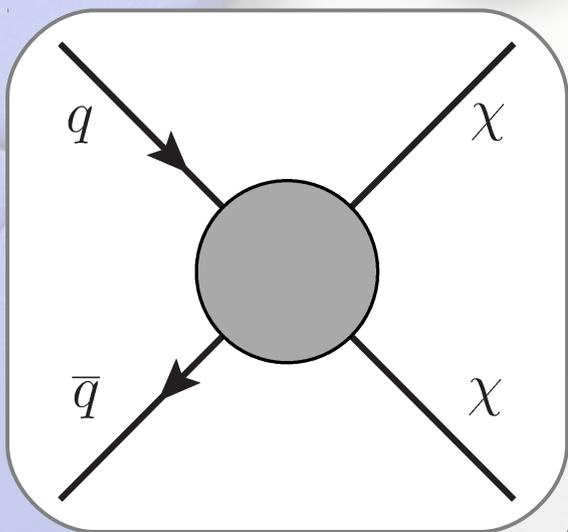
*Dark
Matter*

**at the LHC with
Electroweak
Bremsstrahlung**

Ahmad Galea,
with: N. Bell,
J. Dent, T. Jacques,
L. Krauss and T. Weiler.

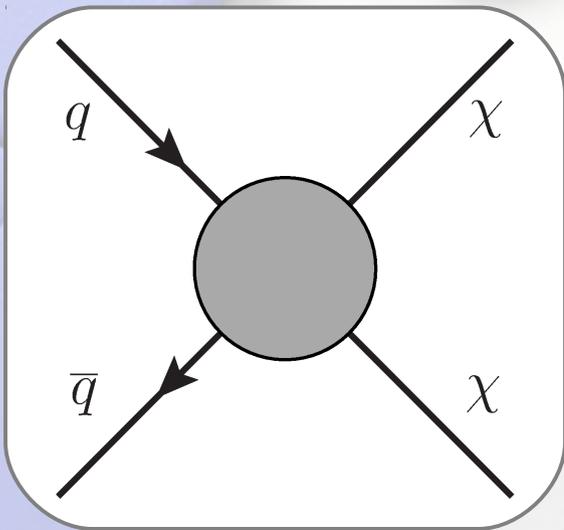
Dark Matter at the LHC

- If WIMP couples to quarks, possibility of production at LHC.



Dark Matter at the LHC

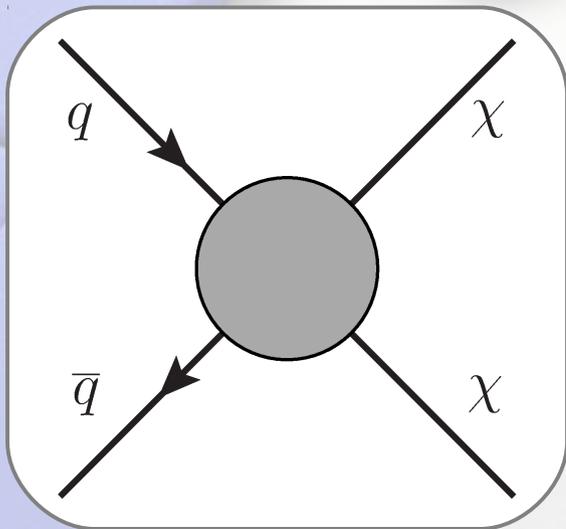
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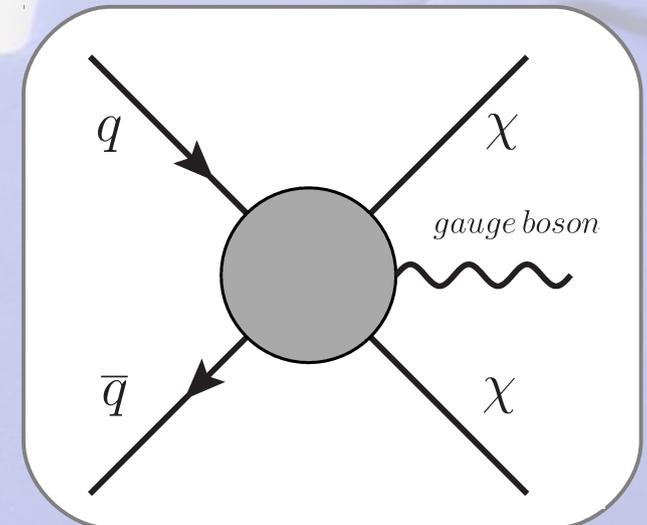
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- Need visible final state to reconstruct missing transverse energy.

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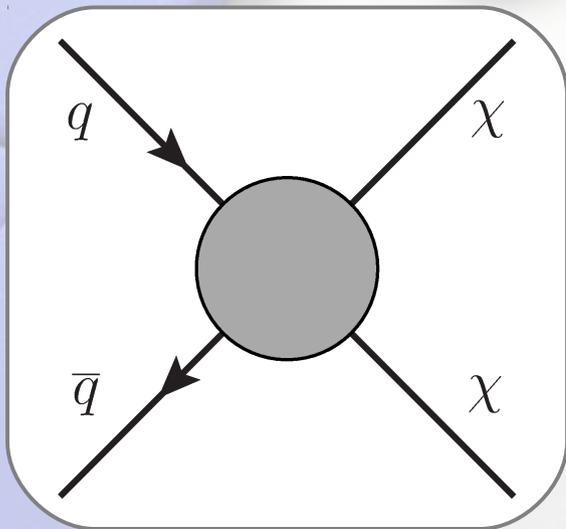
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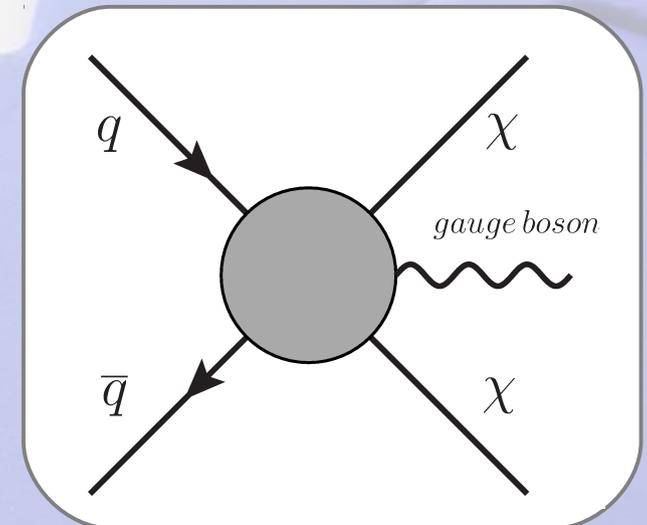
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Dark Matter visible as high p_T object + missing ET

Bremsstrahlung

- Gluon radiation – high cross section large backgrounds (1109.4398).

Bremsstrahlung

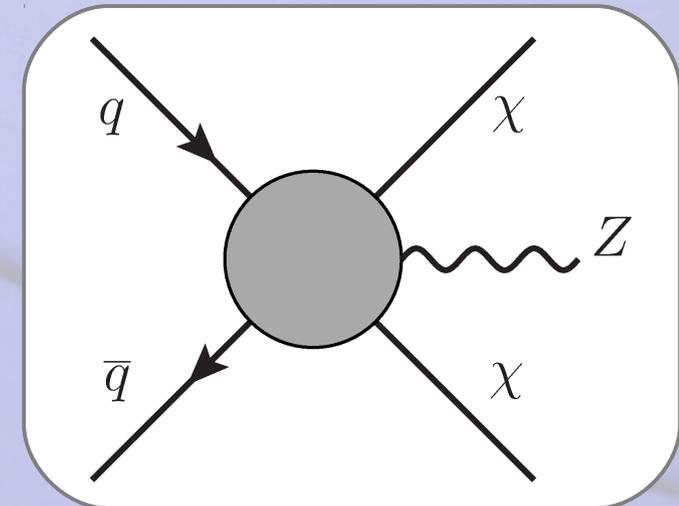
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Electroweak Processes

- Z – easily reconstructible invariant mass.
- Decays leptonically with a small branching fraction, has few backgrounds.



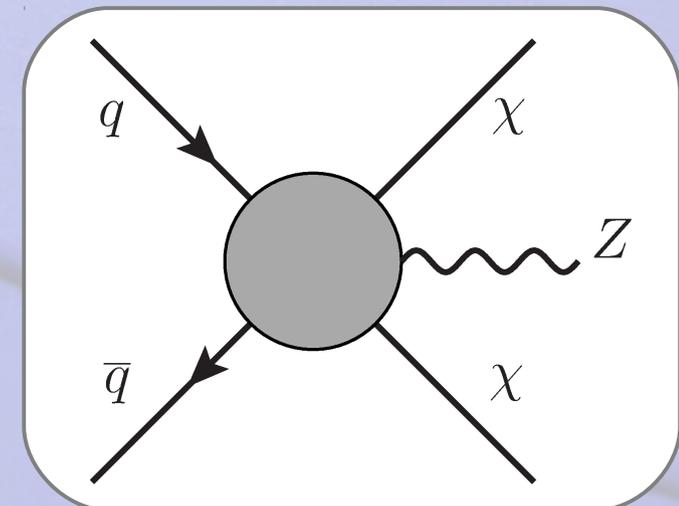
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Signal: Z + missing ET



Backgrounds

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Leptonic Backgrounds

$$ZZ \rightarrow \bar{\nu}\nu \quad \mu^+\mu^-$$

$$W^+Z \rightarrow \nu l^+ \quad \mu^+\mu^-$$

$$W^-Z \rightarrow \bar{\nu} l^- \quad \mu^+\mu^-$$

$$W^+W^- \rightarrow \nu\mu^+ \quad \bar{\nu}\mu^-$$

Backgrounds

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Leptonic Backgrounds

$$\begin{array}{ll} ZZ & \rightarrow \bar{\nu}\nu \quad \mu^+\mu^- \\ W^+Z & \rightarrow \nu l^+ \quad \mu^+\mu^- \\ W^-Z & \rightarrow \bar{\nu} l^- \quad \mu^+\mu^- \\ W^+W^- & \rightarrow \nu\mu^+ \quad \bar{\nu}\mu^- \end{array}$$

- ZZ/WW will have largest mET.
- WW largest x-section, no Z.

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QCD Backgrounds

$$\begin{array}{l}
 t\bar{t} \rightarrow b\bar{b} W^+W^- \\
 Z + jets
 \end{array}$$

- Large x-section, looks a lot like WW (can be removed with cuts).
- Miss-measurement, remove with mET cut.

Illustrative Toy Model

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- Introduce Majorana DM particle χ , coloured scalar doublet η .

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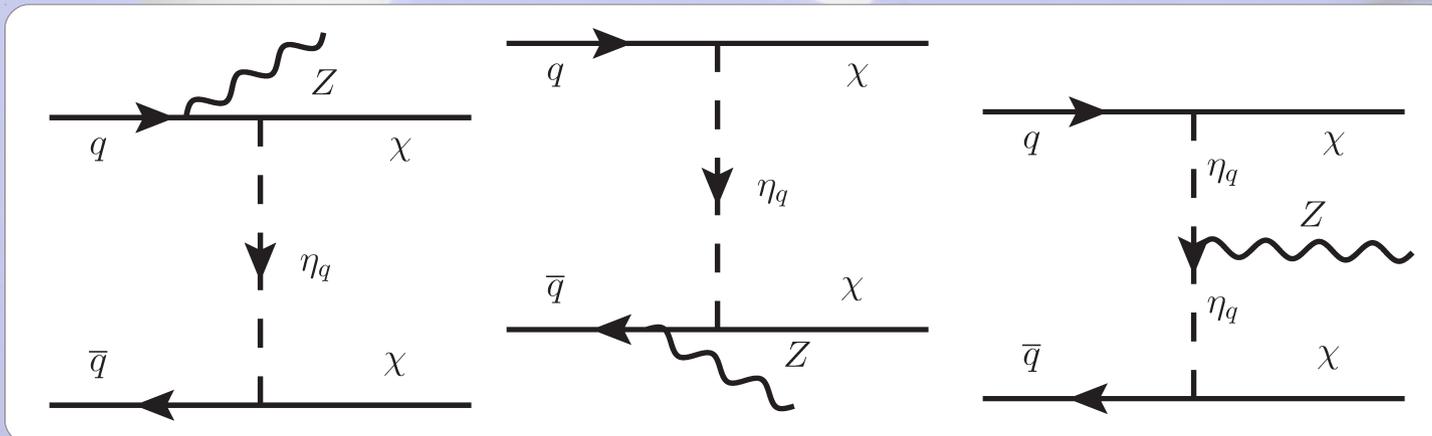
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- Allows for processes:



Event Selection

Kinematic cuts

- Invariant mass cut.

$$61.2\text{GeV} < m_{\mu\mu} < 121.2\text{GeV}$$

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Kinematic cuts

- Invariant mass cut.
- Inclusive Muon $p_T > 50\text{GeV}$.

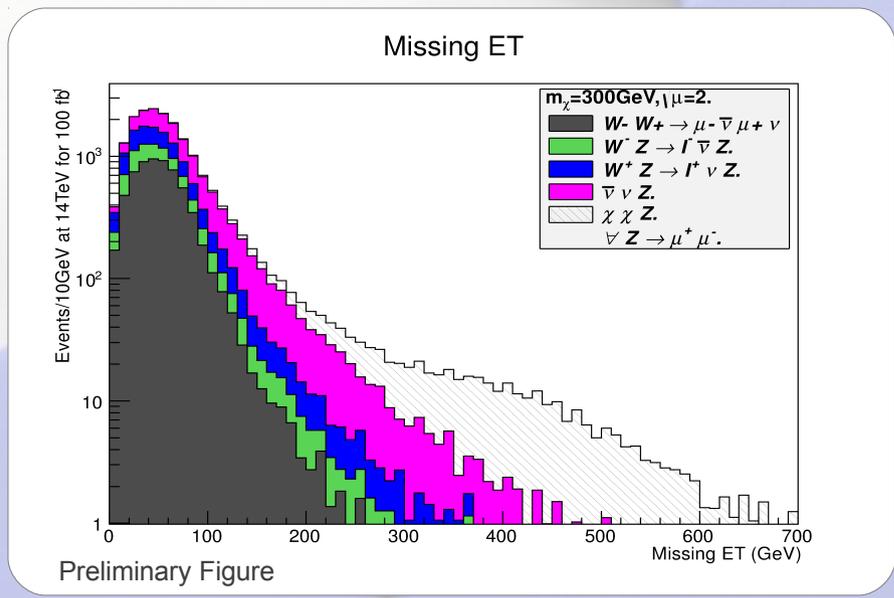
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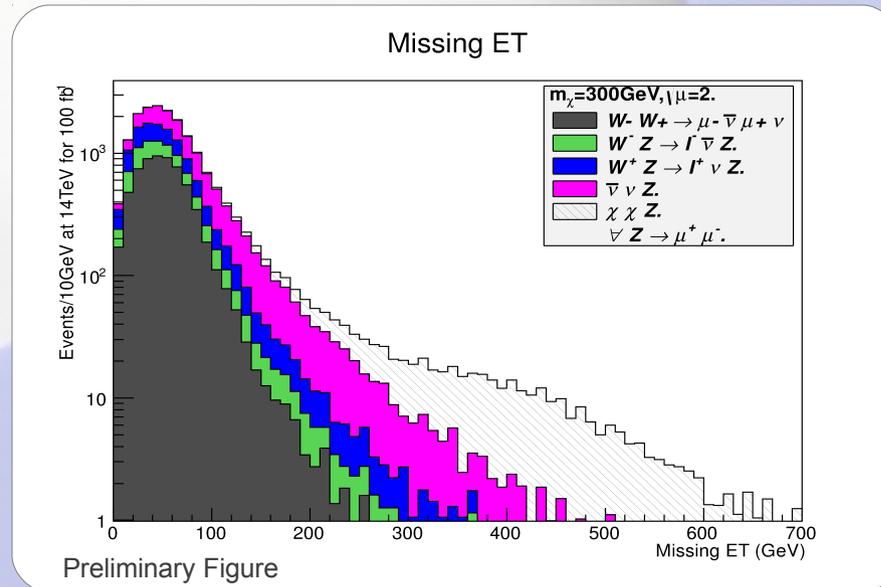


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- Missing ET $> 100\text{GeV}$.

Event Selection

Geometric cuts

- Z boosted, muons co-linear,

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Geometric cuts

- Z boosted, muons co-linear, low ΔR .

$$\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$$

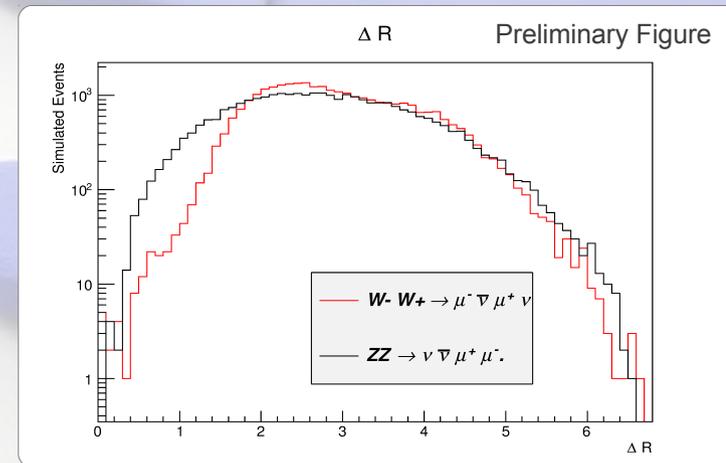
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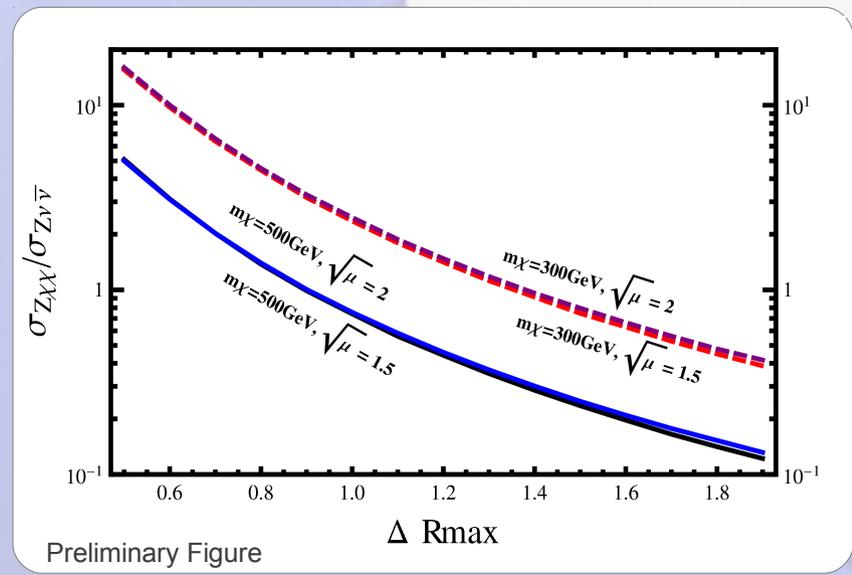
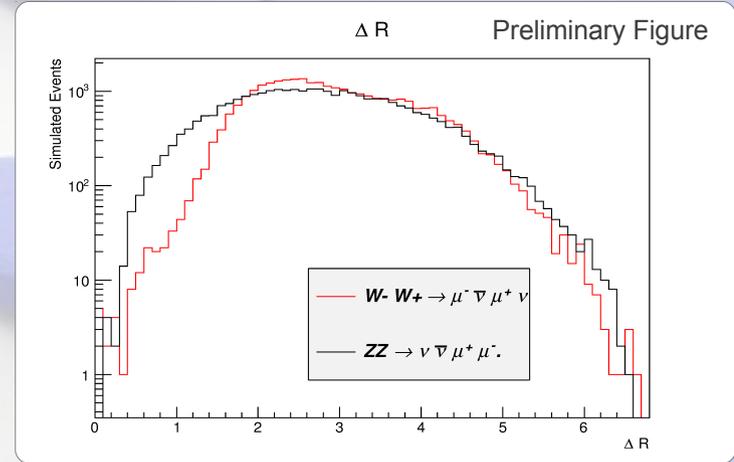
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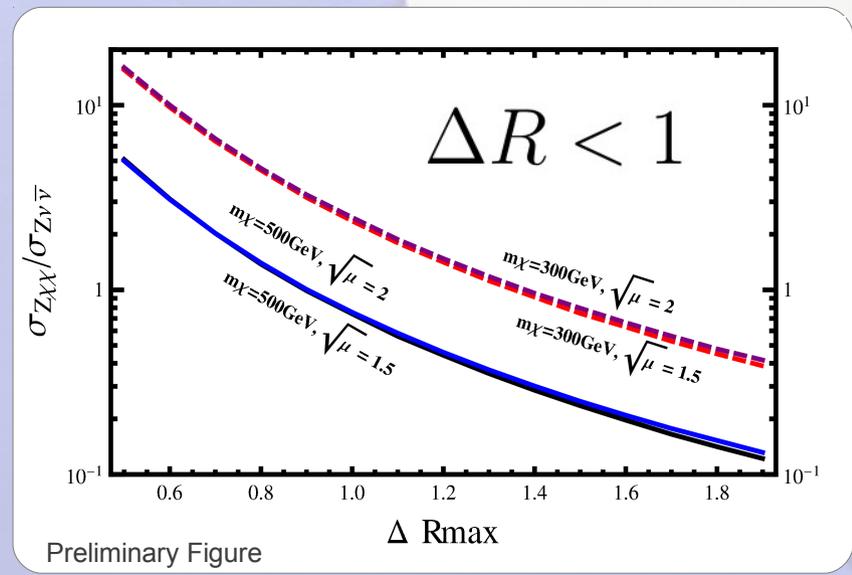
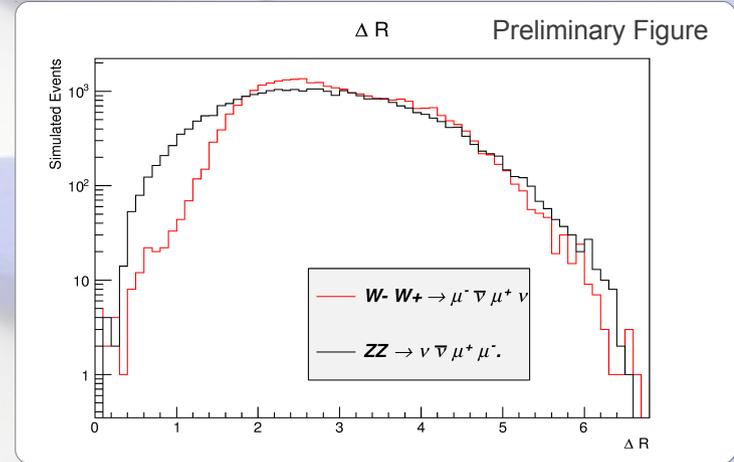
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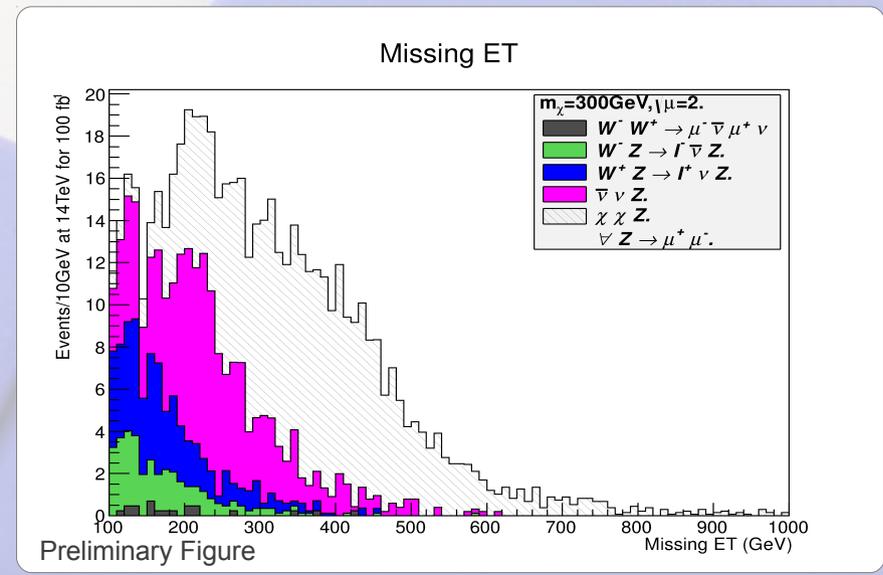
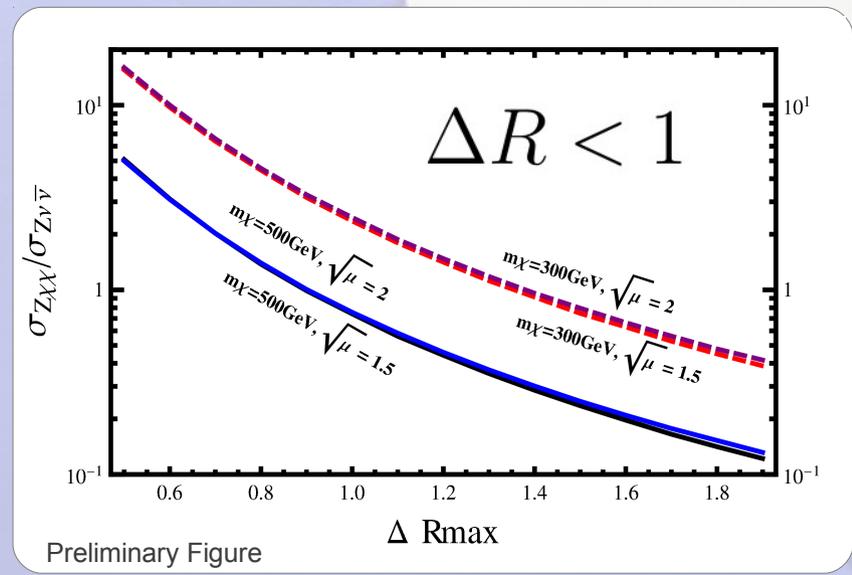
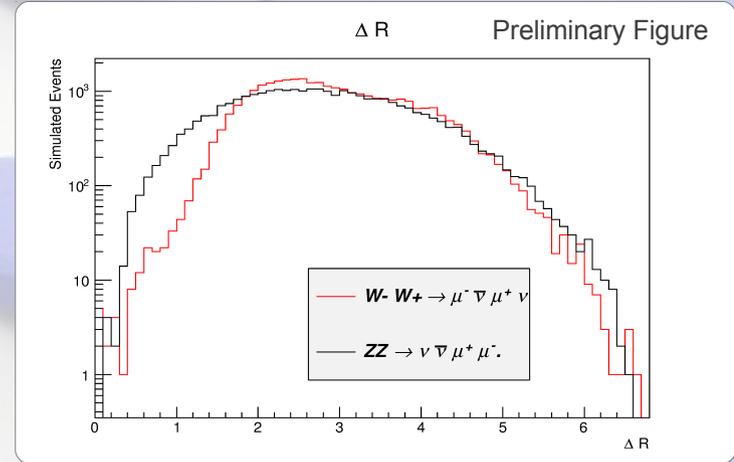
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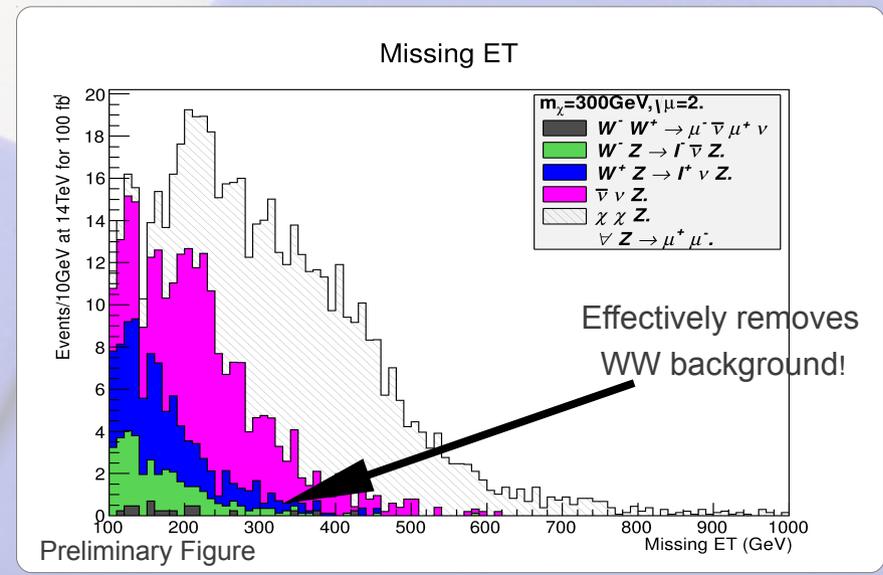
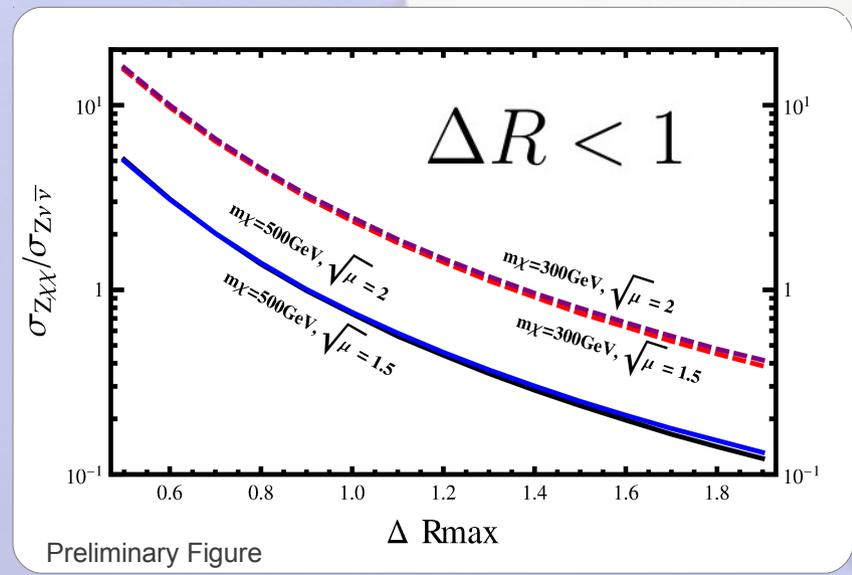
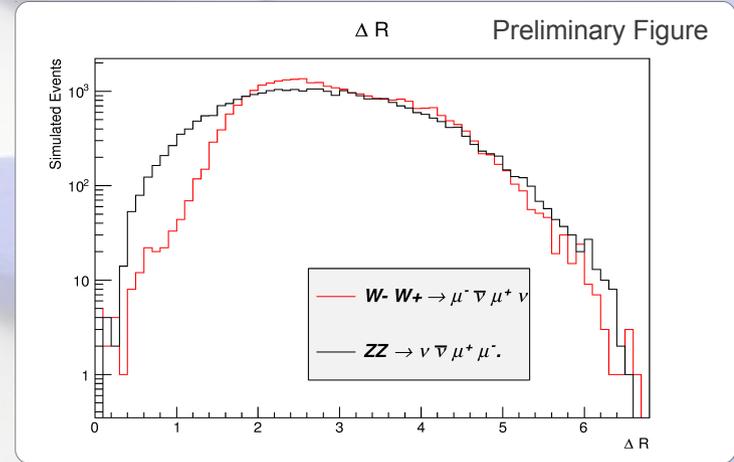
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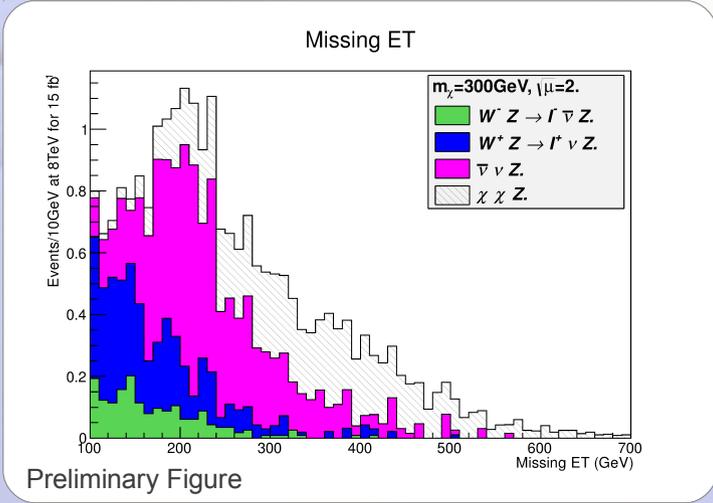
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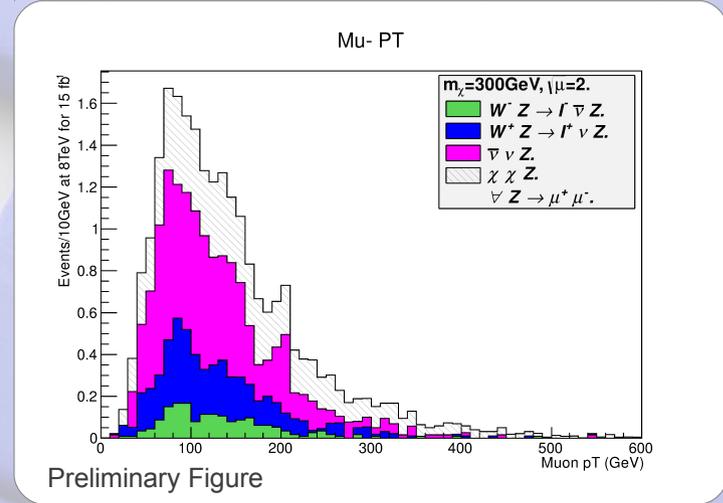
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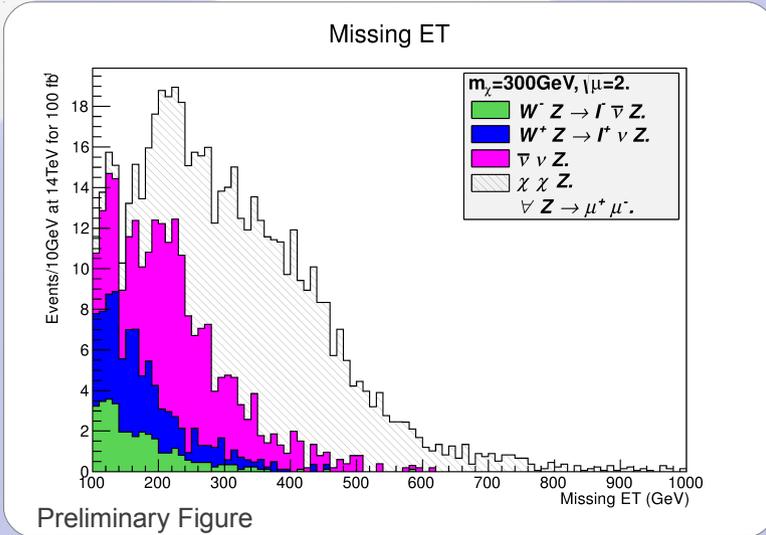
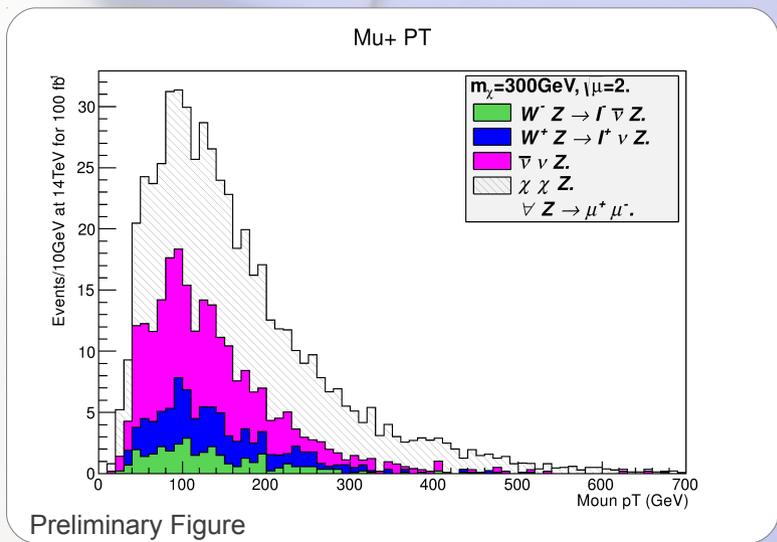
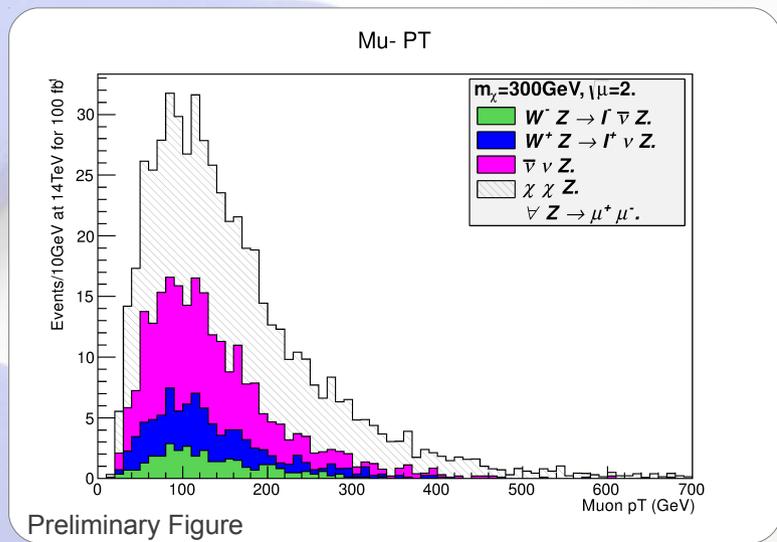
Results: Early Data



Upgraded energy
8TeV, 15fb⁻¹
integrated luminosity.



Results



- Design energy of 14TeV for 100fb⁻¹ of data.

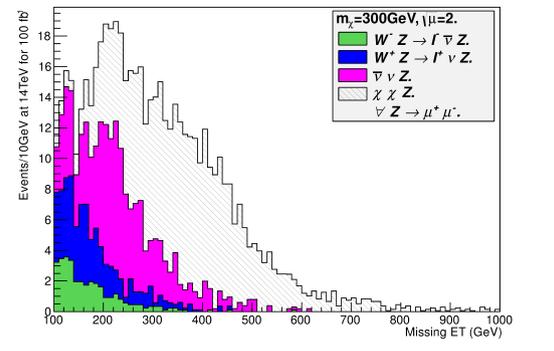
$$m_{\chi} = 300\text{GeV}$$

$$\sqrt{\mu} = 2$$

- Clearly visible above backgrounds

Results

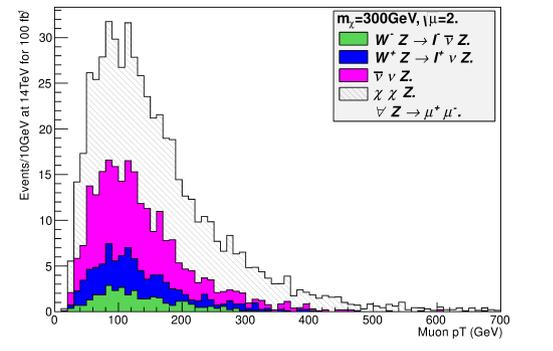
Preliminary Figure Missing ET



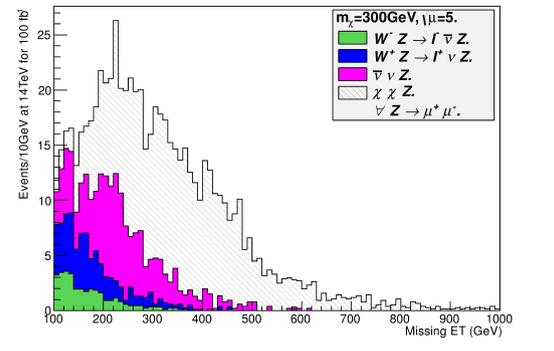
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Preliminary Figure Mu-PT



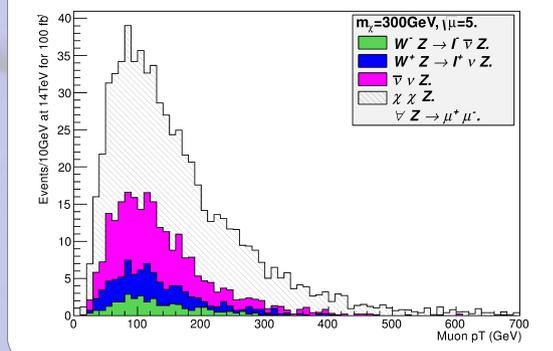
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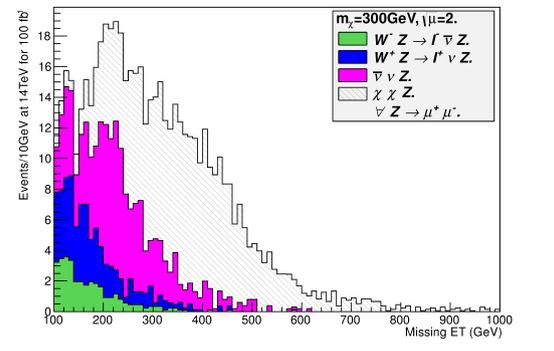
$$\sqrt{\mu} = 5$$

Preliminary Figure Mu-PT



Results

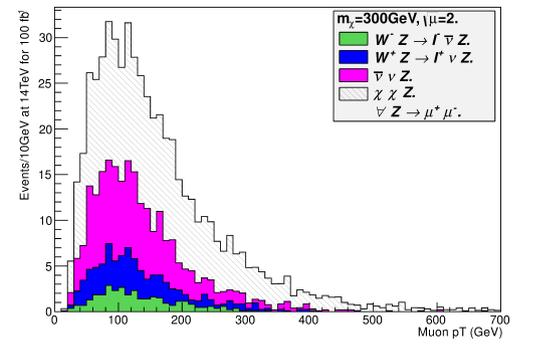
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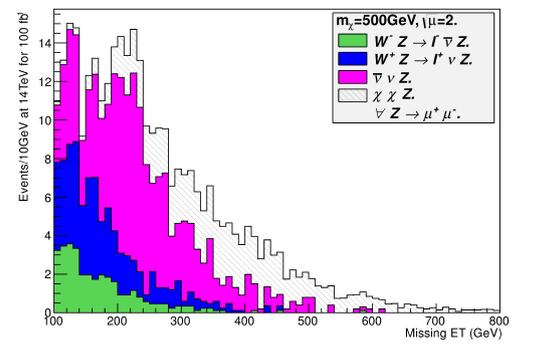
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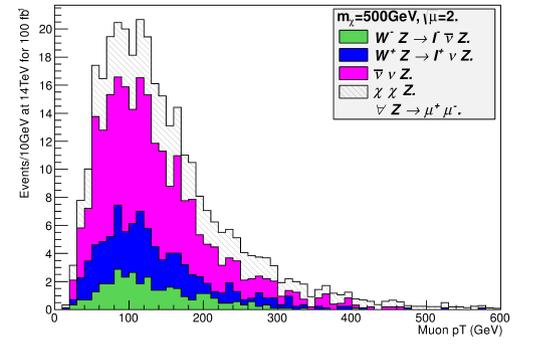
Preliminary Figure Missing ET



$$m_{\chi} = 500 \text{ GeV}$$

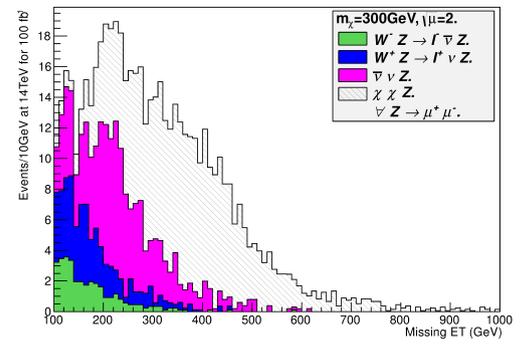
$$\sqrt{\mu} = 2$$

Preliminary Figure Mu-PT



Results

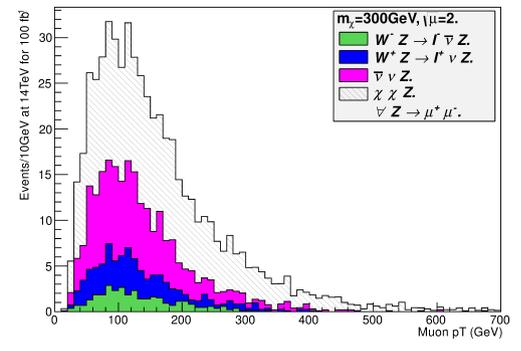
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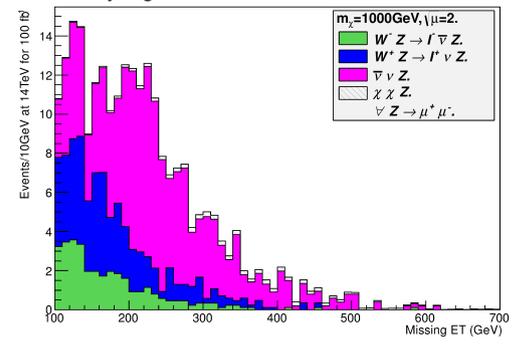
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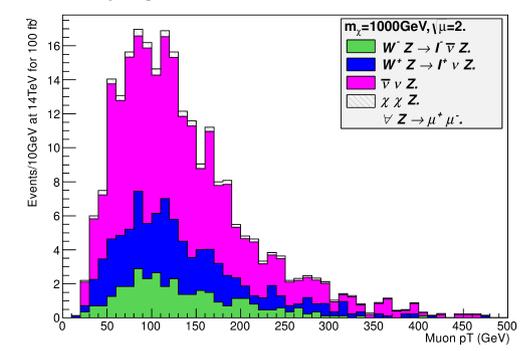
Preliminary Figure Missing ET



$$m_{\chi} = 1000 \text{ GeV}$$

$$\sqrt{\mu} = 2$$

Preliminary Figure Mu-PT



Conclusions

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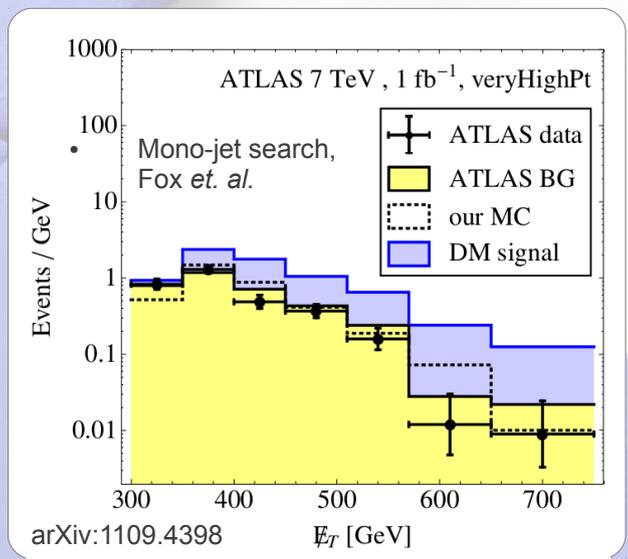
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- $Z \rightarrow \mu\mu$ channel has few backgrounds and is easily distinguishable.
- Competitive with jet and photon searches.
- Models should be constrained by early data.
- Clearly visible at 100fb^{-1} of data, heavy constraints should be placeable.

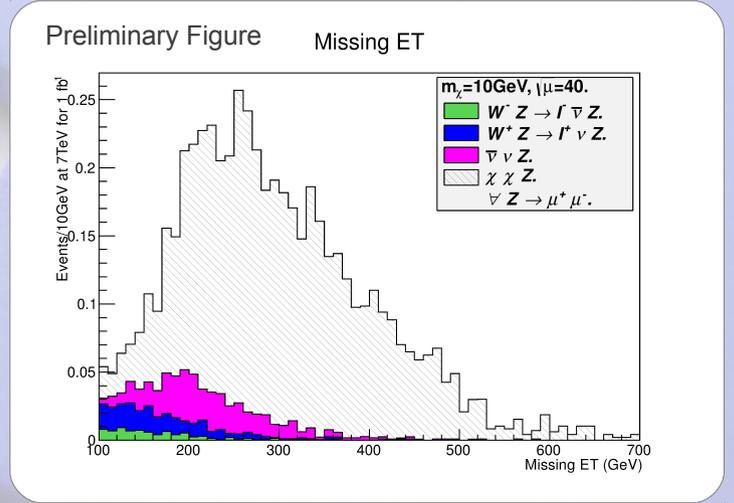
Acknowledgements

- Sincerest thanks to Elisabetta Barberio, Martin White, Antonio Limosani and Tony Shao for helpful discussions on experimental matters.
- Thanks also to Nicholas Setzer and Martin White for help with the relevant software.
- Gratitude to CoEPP for providing avenues for collaboration.

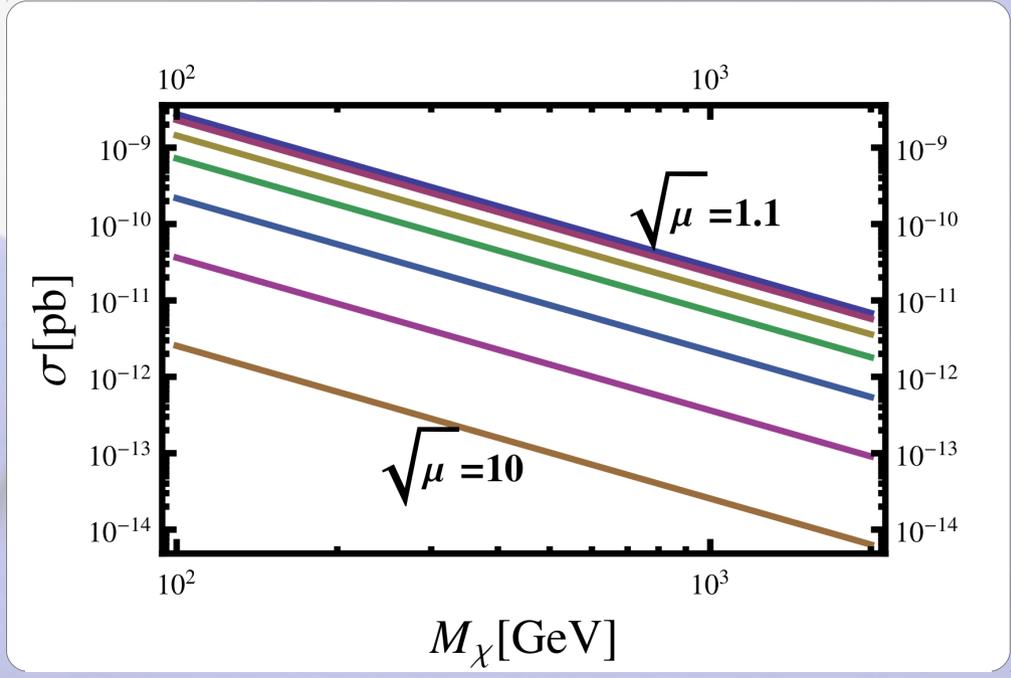
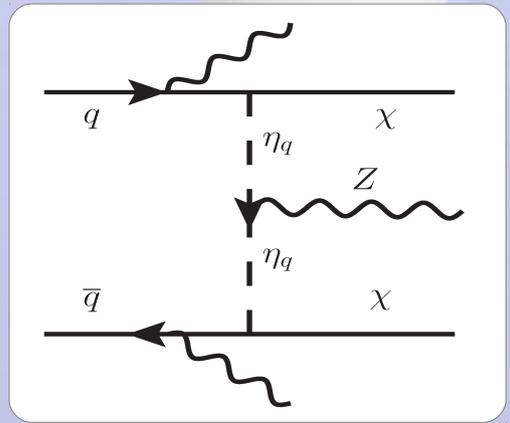
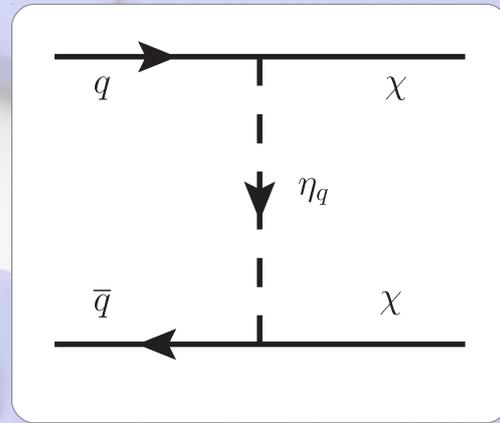
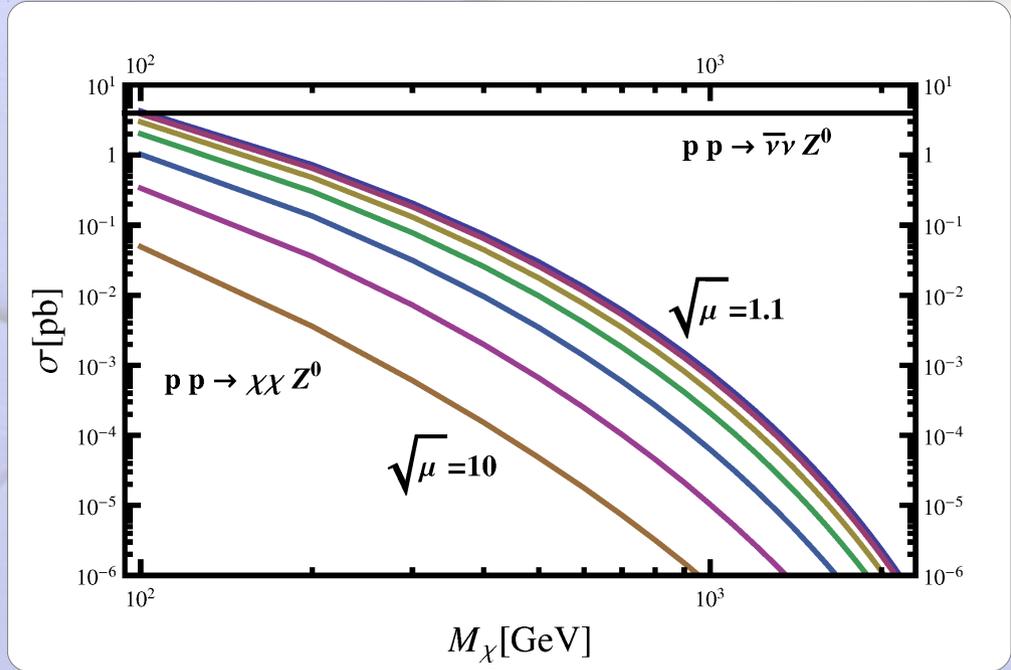
Supplementary Figures



At current LHC running energy of 7TeV and 1 fb^{-1} , signal comparable to jet searches.



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