Dark Matter with mono-jet

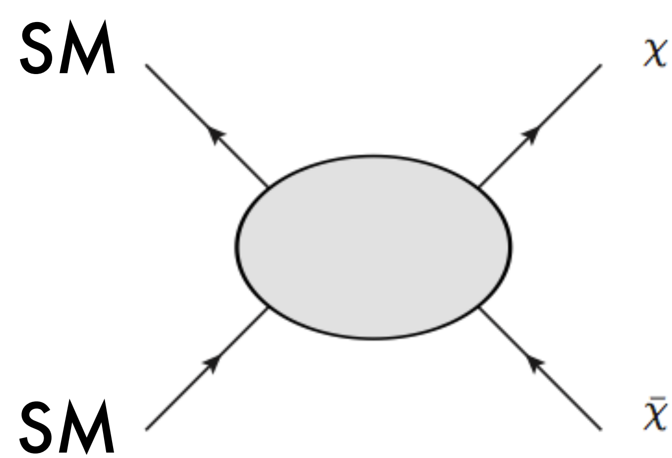
Daniel Whiteson, Ning Zhou, David Berge, Tim Tait, LianTao Wang

PRELIMINARY

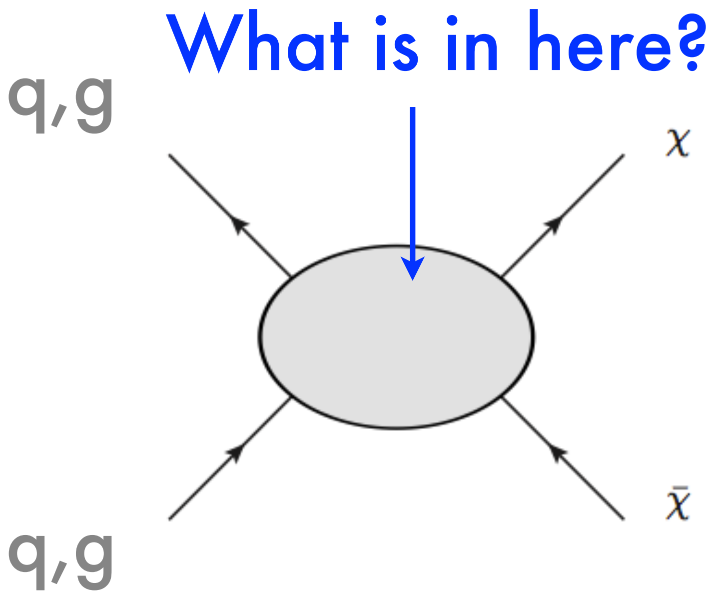
Interactions

Important caveat:

Requires **some** interaction with SM



Effective field theories



A few possibilities

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

Allows connections to direct, indirect exp.

$$\sigma_0^{D1} = 1.60\times 10^{-37}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{20\mathrm{GeV}}{M_*}\right)^6,$$

$$\sigma_0^{D5,C3} = 1.38\times 10^{-37}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{300\mathrm{GeV}}{M_*}\right)^4,$$

$$\sigma_0^{D8,D9} = 9.18\times 10^{-40}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{300\mathrm{GeV}}{M_*}\right)^4,$$

$$\sigma_0^{D11} = 3.83\times 10^{-41}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{100\mathrm{GeV}}{M_*}\right)^6,$$

$$\sigma_0^{C1,R1} = 2.56\times 10^{-36}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2 \left(\frac{10\mathrm{GeV}}{M_*}\right)^4,$$

$$\sigma_0^{C5,R3} = 7.40\times 10^{-39}\mathrm{cm}^2 \left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2 \left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2 \left(\frac{60\mathrm{GeV}}{M_*}\right)^4.$$

Validity

<u>The effective field theory approach</u>

- assumes the mediator is heavy
- the interaction can be modeled as a 4f vertex

<u>Assuming simple structure:</u>

- mediator mass M, couplings g1, g2
- Require: $M > Q^2$, $g1g2 < 16\pi^2$

- not universally applicable, but very broadly

Goal

In context of snowmass, we would like to know:

- What is the power of the proposed facilities to probe DM, via both effective field theories and explicitly specified mediators?

Method

Simple extrapolations

Start from published 7 TeV 5/fb analyses

Extrapolate: much easier than recreating analysis in theory space

Extrapolations:

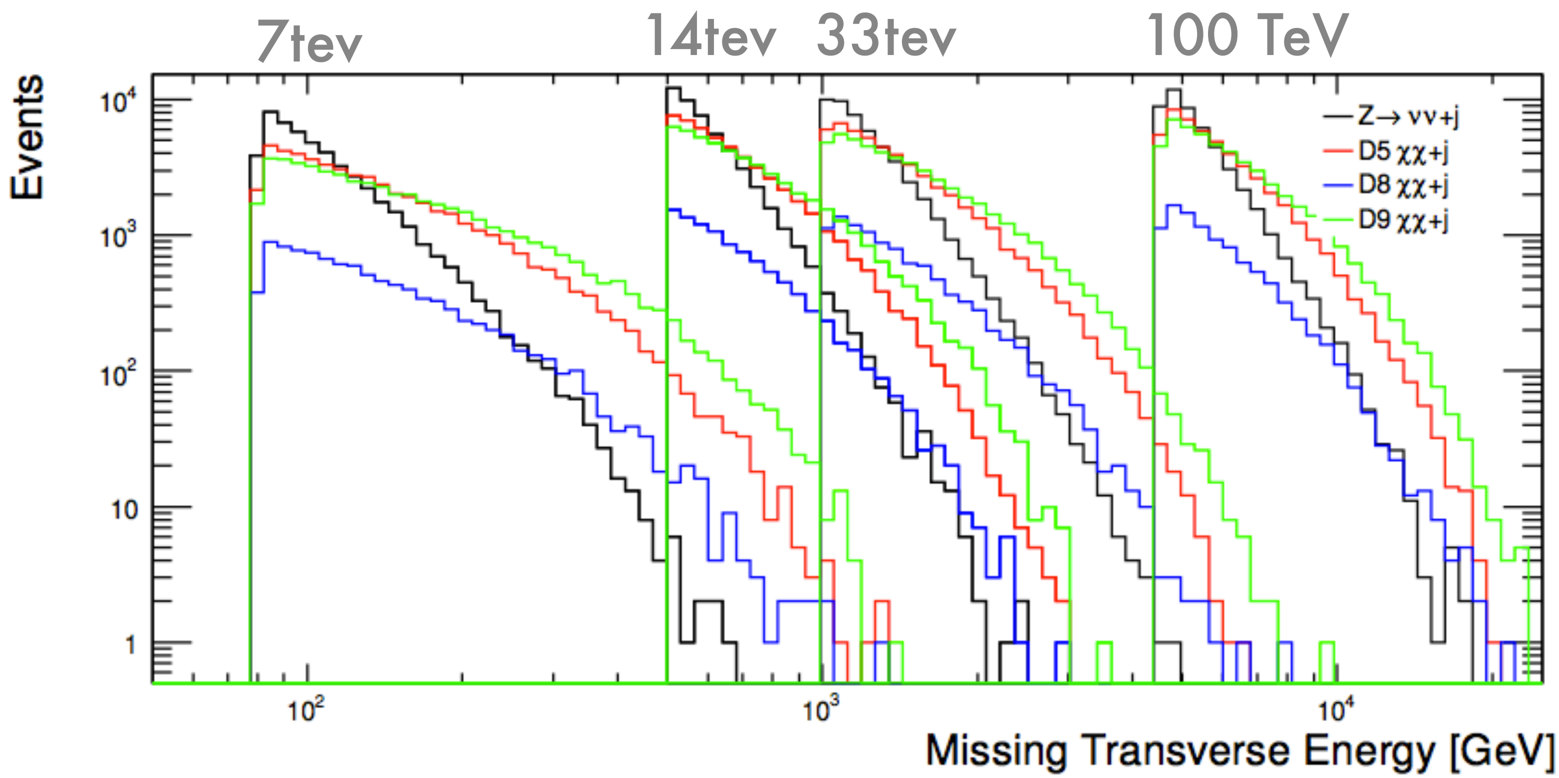
MET threshold efficiency

Signal cross-sections

Background cross-sections

Background uncertainty

MET threshold



Thresholds will have to rise

- QCD larger at higher energy
- Trigger thresholds higher for higher lumi

Estimate efficiency drops using parton-level MET

$\sqrt{s}$ [TeV]	$\not{E}_T$ [GeV]	$\mathcal{L}$ [fb^{-1}]
7	350	4.9
14	550	300
14	1100	3000
33	2750	3000
100	5500	3000

Signal extrapolation

First approximation:

Calculated sigma(XXj) with MG5

Did ME+PS matching for 0,1jet.

$$N_{\rm sig}(\sqrt{s},\ \mathcal{L},\ \not\!\!E_{\rm T} > X) = \mathcal{L} \times \epsilon_0 \frac{\epsilon_{\not E_{\rm T} > X}}{\epsilon_{\not E_{\rm T} > 350}} \times \sigma(\sqrt{s})$$

Allows for increasing MET thresholds

Background extrapolation

First approximation:

Calculated sigma(XXj) with MG5

Did ME+PS matching for 0,1jet.

Allows for increasing MET thresholds

Extrapolation Factor

$$E_b(\sqrt{s},\ \mathcal{L},\ \not{E}_{\mathrm{T}} > X) = \frac{\mathcal{L}}{5\ \mathrm{fb}^{-1}} \times \frac{\epsilon_{\not{E}_{\mathrm{T}}>X}}{\epsilon_{\not{E}_{\mathrm{T}}>350}} \times \frac{\sigma(\sqrt{s})}{\sigma(\sqrt{s}=7)}$$

Linear scaling of Background

$$N_{\mathrm{bg}}(\sqrt{s},\ \mathcal{L},\ \not{E}_{\mathrm{T}} > X) = E_b \times N_{\mathrm{bg}}^{\sqrt{s}=7,\mathcal{L}=5,\not{E}_{\mathrm{T}}>350}$$

BG uncertainty

Uncertainty

Dominant contribution is data statistics in control region (CR).

CR has similar MET cut to signal region, similar data statistics.

Extrapolation Factor

$$E_b(\sqrt{s}, \mathcal{L}, \not{E}_T > X) = \frac{\mathcal{L}}{5} \times \frac{\epsilon_{\not{E}_T > X}}{\epsilon_{\not{E}_T > 350}} \times \frac{\sigma(\sqrt{s})}{\sigma(\sqrt{s} = 7)}$$

1/sqrt scaling of Background

$$\frac{\Delta N_{\rm bg}}{N_{\rm bg}}(\sqrt{s},\ \mathcal{L},\ \not{E}_{\rm T} > X) = \frac{1}{\sqrt{E_b}} \left(\frac{\Delta N_{\rm bg}}{N_{\rm bg}}\right)^{\sqrt{s}=7, \mathcal{L}=5, \not{E}_{\rm T}>350}$$

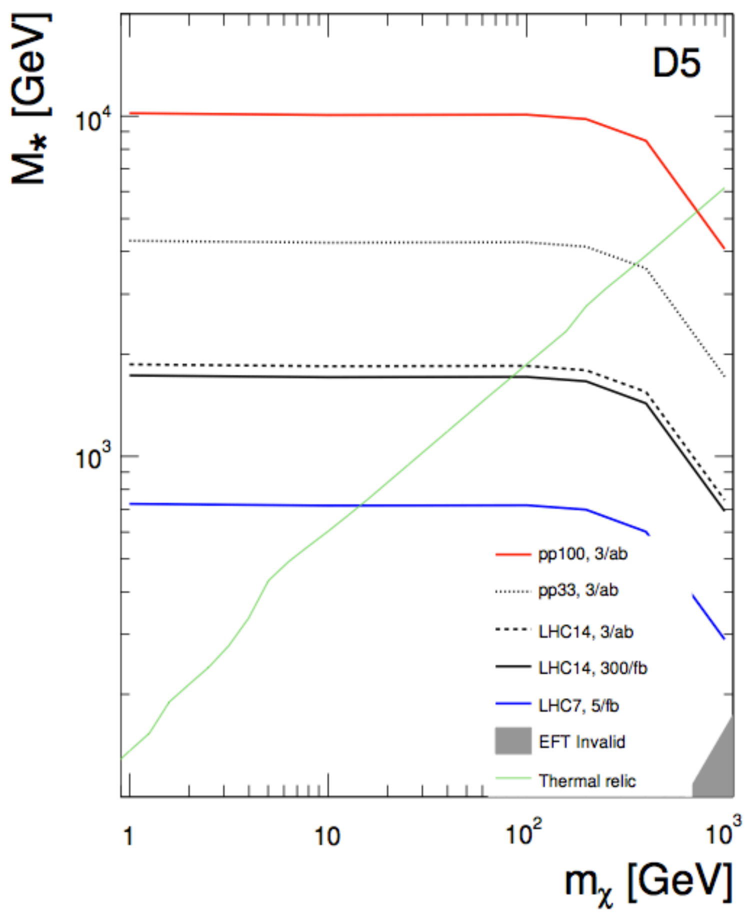
Events

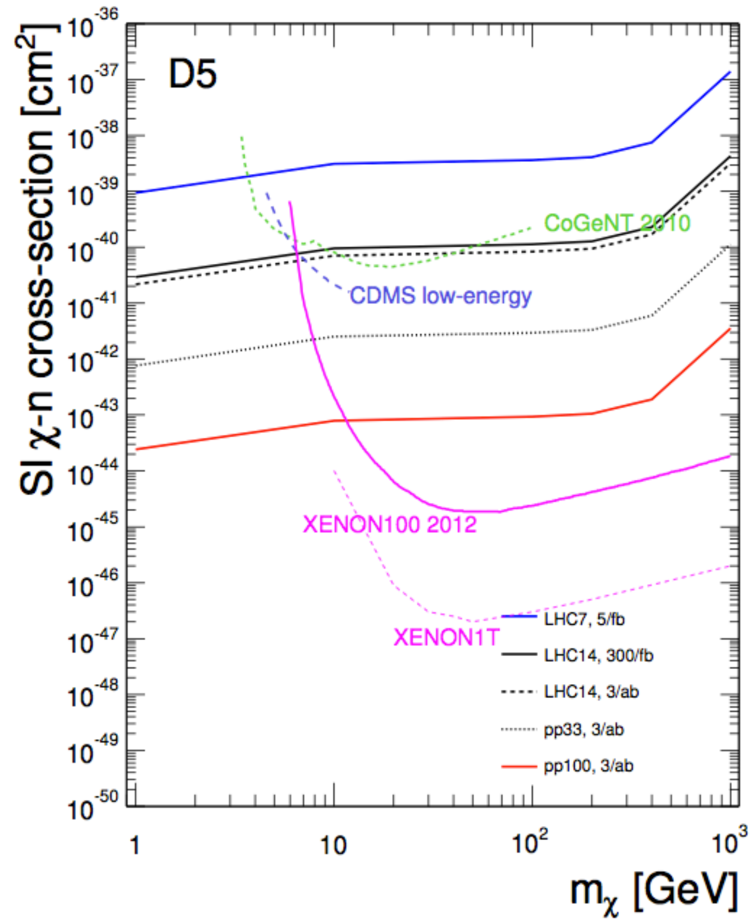
$\sqrt{s}$ [TeV]	$\not{E}_T$ [GeV]	$\mathcal{L}$ [fb^{-1}]	N_{D5}	N_{bg}
7	350	4.9	73.3	1970 ± 160
14	550	300	2500	2200 ± 180
14	1100	3000	3200	1760 ± 143
33	2750	3000	$8.2 \cdot 10^4$	1870 ± 150
100	5500	3000	$3.4 \cdot 10^6$	2310 ± 190

Recall

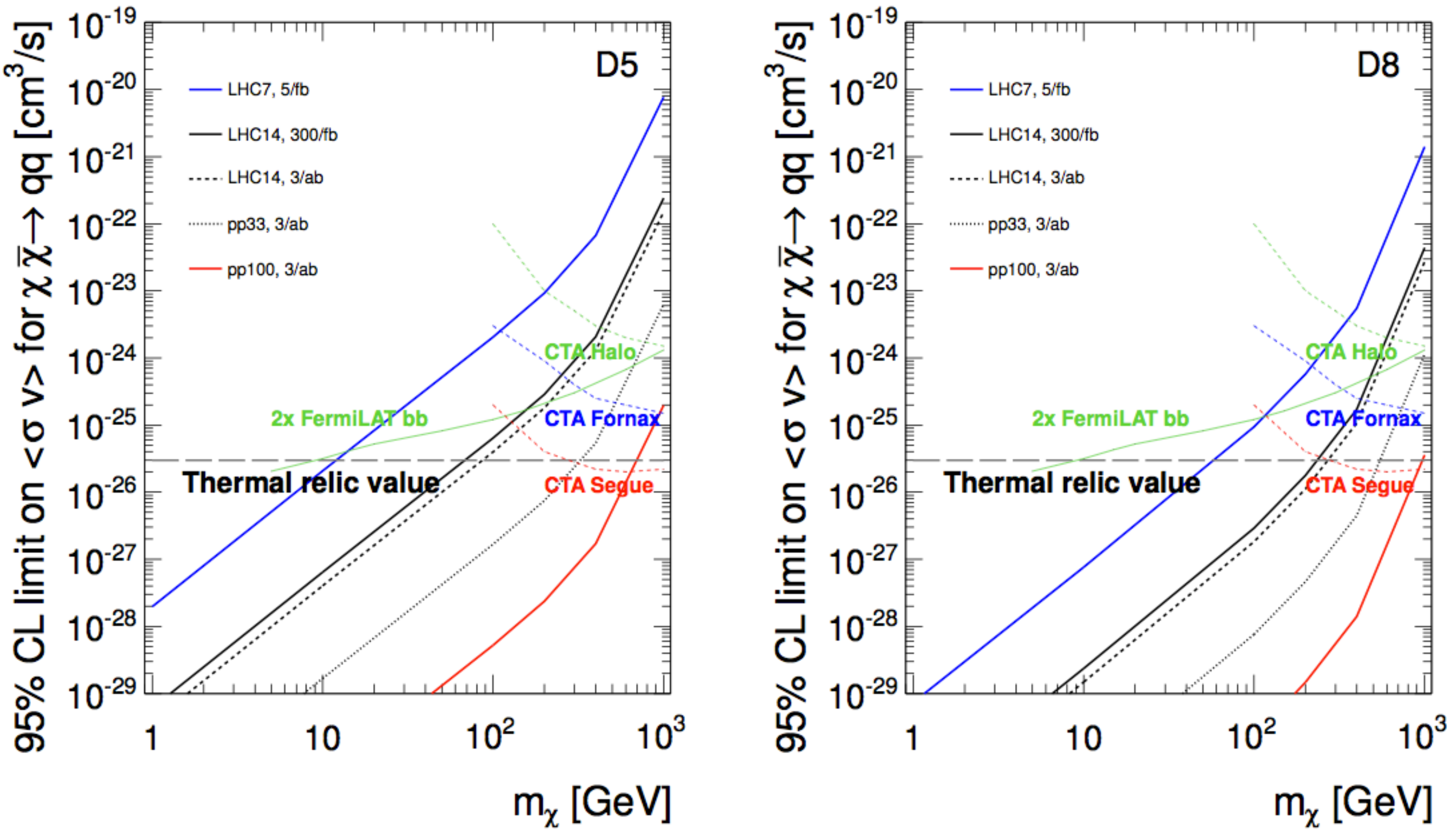
MET cuts increase at each stage

Results: d5


D5
M* [GeV]
10^4
10^3
1
10
10^2
10^3
m_χ [GeV]
pp100, 3/ab
pp33, 3/ab
LHC14, 3/ab
LHC14, 300/fb
LHC7, 5/fb
EFT Invalid
Thermal relic

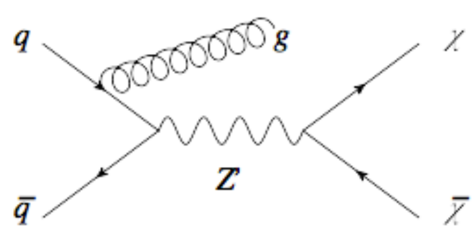

D5
SI χ-n cross-section [cm^2]
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^{-50}
1
10
10^2
10^3
m_χ [GeV]
CoGeNT 2010
CDMS low-energy
XENON100 2012
XENON1T
LHC7, 5/fb
LHC14, 300/fb
LHC14, 3/ab
pp33, 3/ab
pp100, 3/ab

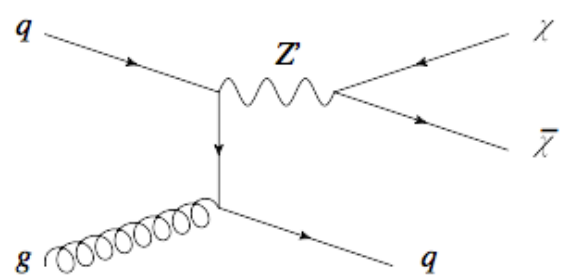
Indirect plane



Light mediator

What if the mediator is too heavy at one collider, but not for the next generation machine?





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Approach

Parameters

$$\frac{1}{M_*} = \frac{g_{Z'}}{M_{Z'}}$$

Take M* from one facility, explore models with g/MZ' = 1/M* at next facility.

Assumptions

Same background approach

Use LO cross-section from model, efficiencies from paper, extrapolated to higher MET cuts.

Assume xs goes like g^2

D5 14 TeV

D5 7 TeV limit is M* = ~780 GeV

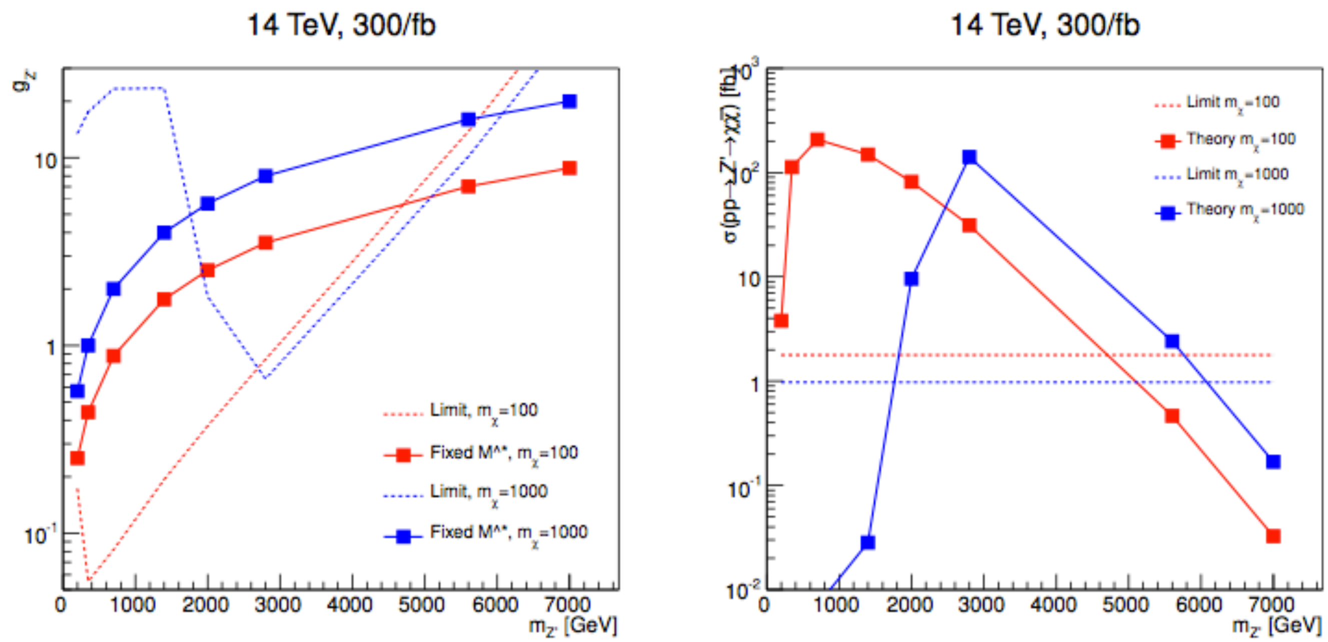

FIG. 7: Sensitivity at $\sqrt{s} = 14$ TeV, $\mathcal{L} = 300$ fb^{-1} to a dark matter pairs produced through a real Z' mediator. Left, expected limits on the coupling $g_{Z'}$ versus Z' mass for two choices of m_χ for events with $\not{E}_T > 550$ GeV; also shown are the values of $g_{Z'}$ which satisfy $g'/m_{Z'} = 1/M_*$, where M_* are limits from $\sqrt{s} = 7$ TeV, $\mathcal{L} = 5$ fb^{-1}. Right, production cross section as a function of Z' mass, compared to expected limits, where $g_{Z'}$ depends on $m_{Z'}$ as in the left pane.

3000/fb

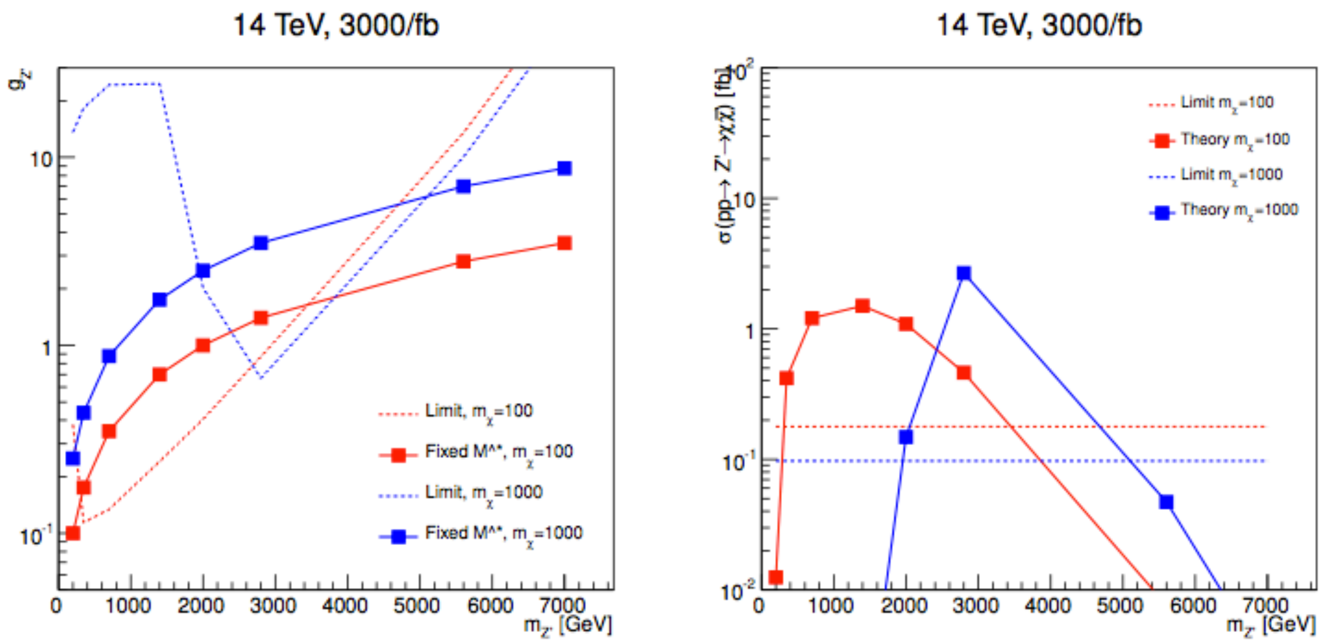

FIG. 8: Sensitivity at $\sqrt{s} = 14$ TeV, $\mathcal{L} = 3000$ fb^{-1} to a dark matter pairs produced through a real Z' mediator. Left, expected limits on the coupling $g_{Z'}$ versus Z' mass for two choices of m_χ for events with $\not{E}_T > 1100$ GeV; also shown are the values of $g_{Z'}$ which satisfy $g'/m_{Z'} = 1/M_*$, where M_* are limits from $\sqrt{s} = 14$ TeV, $\mathcal{L} = 300$ fb^{-1}. Right, production cross section as a function of Z' mass, compared to expected limits, where $g_{Z'}$ depends on $m_{Z'}$ as in the left pane.

Summary

Mono-jet events provide a powerful probe of DM pair production

We have extrapolated 7TeV analyses to future pp colliders