Bounds on Dark Matter Interactions with Electroweak Gauge Bosons

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1210.0525

Dark Matter @LHC
KICP 2013

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Dark Matter EFTs

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We want to use _____ to bound DM interactions with _____ and
(an experiment) (some SM particles)

to compare these limits with those from _____ on these same interactions.
(another experiment)

joke stolen from R. Cotta

Dark Matter EFTs

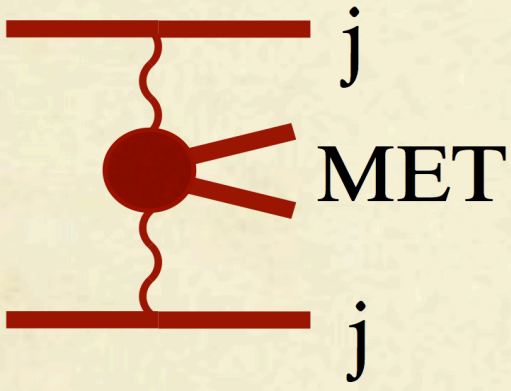
We want to use _____ to bound DM interactions with _____ and
(an experiment) (some SM particles)

to compare these limits with those from _____ on these same interactions.
(another experiment)

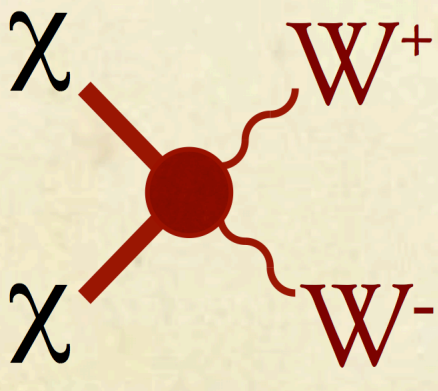
joke stolen from R. Cotta

We want to use 2j+MET(VBF) to bound DM interactions with $\gamma, Z^0, W^{\pm}$ and
(an experiment) (some SM particles)

to compare these limits with those from Dwarf Galaxy Observations on these same interactions.
(another experiment)



Vector Boson fusion @LHC



Cosmic Annihilation products

Dark Matter EFT and VBF

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Why VBF?

- Probes $\chi\chi$ interactions with EW gauge bosons
- Relate to indirect DM searches

» However, expect weaker constraints than mono-jet signatures

Assumptions:

- Respect $U(1)_{em}$ gauge invariance
- χ is Dirac fermion
- UV completions will result in non-trivial combinations of operators for collider subprocesses WW, ZZ, $\gamma\gamma$, γZ
  - » Weight processes and add incoherently
  - » Assume most simple structure

Set of χχV and χχVV operators

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Name	Expression	Norm.	Vertices	Sub-Procs.	Ann.
$dim = 5$:					
D5a	$\bar{\chi}\chi V^{a\mu}V^a_\mu$	Λ^{-1}	4pt	ZZ,WW	v^2
D5b	$\bar{\chi}i\gamma_5\chi V^{a\mu}V^a_\mu$	Λ^{-1}	4pt	ZZ,WW	1
D5c	$\bar{\chi}\sigma_{\mu\nu}t^a\chi V^{a\mu\nu}$	Λ^{-1}	3/4pt	A,Z,WW	1
D5d	$\bar{\chi}\sigma_{\mu\nu}t^a\chi \widetilde{V}^{a\mu\nu}$	Λ^{-1}	3/4pt	A,Z,WW	1 (VV), v^2 $(f\bar{f})$
$dim = 6$:					
D6a	$\bar{\chi}\gamma_\mu t^a D_\nu\chi V^{a\mu\nu}$	Λ^{-2}	3/4pt	A,Z,WW	1
D6b	$\bar{\chi}\gamma_\mu\gamma_5 t^a D_\nu\chi V^{a\mu\nu}$	Λ^{-2}	3/4pt	A,Z,WW	1 (VV), v^2 $(f\bar{f})$
$dim = 7$:					
D7a	$\bar{\chi}\chi V^{\mu\nu}V_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	v^2
D7b	$\bar{\chi}i\gamma_5\chi V^{\mu\nu}V_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	1
D7c	$\bar{\chi}\chi V^{\mu\nu}\widetilde{V}_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	v^2
D7d	$\bar{\chi}i\gamma_5\chi V^{\mu\nu}\widetilde{V}_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	1

Set of χχV and χχVV operators

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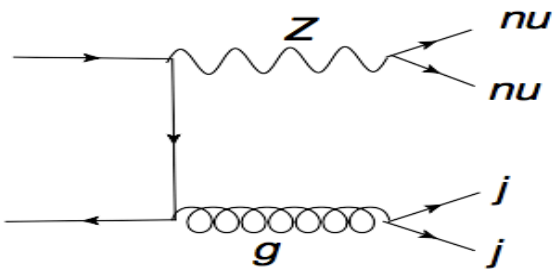
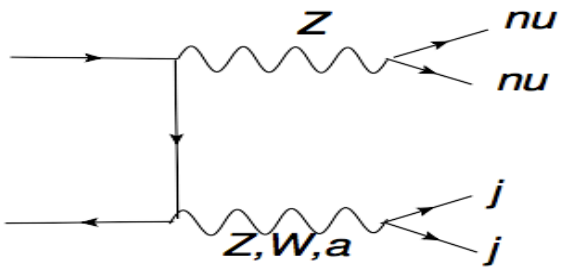
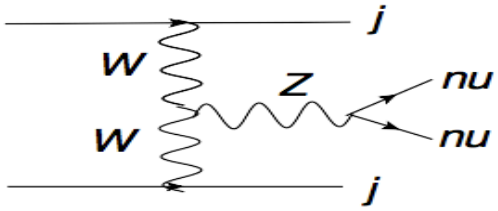
Name	Expression	Norm.	Vertices	Sub-Procs.	Ann.
$dim = 5$:					
D5a	$\bar{\chi}\chi V^{a\mu}V^a_\mu$	Λ^{-1}	4pt	ZZ,WW	scalar mediator
D5b	$\bar{\chi}i\gamma_5\chi V^{a\mu}V^a_\mu$	Λ^{-1}	4pt	ZZ,WW	pseudoscalar mediator
D5c	$\bar{\chi}\sigma_{\mu\nu}t^a\chi V^{a\mu\nu}$	Λ^{-1}	3/4pt	A,Z,WW	Dipole operators
D5d	$\bar{\chi}\sigma_{\mu\nu}t^a\chi \widetilde{V}^{a\mu\nu}$	Λ^{-1}	3/4pt	A,Z,WW	
$dim = 6$:					
D6a	$\bar{\chi}\gamma_\mu t^a D_\nu\chi V^{a\mu\nu}$	Λ^{-2}	3/4pt	A,Z,WW	1
D6b	$\bar{\chi}\gamma_\mu\gamma_5 t^a D_\nu\chi V^{a\mu\nu}$	Λ^{-2}	3/4pt	A,Z,WW	vector mediator
$dim = 7$:					
D7a	$\bar{\chi}\chi V^{\mu\nu}V_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	v^2
D7b	$\bar{\chi}i\gamma_5\chi V^{\mu\nu}V_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	1
D7c	$\bar{\chi}\chi V^{\mu\nu}\widetilde{V}_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	arise @ 1-loop
D7d	$\bar{\chi}i\gamma_5\chi V^{\mu\nu}\widetilde{V}_{\mu\nu}$	Λ^{-3}	4pt	AA,AZ,ZZ,WW	1

VBF Backgrounds @LHC



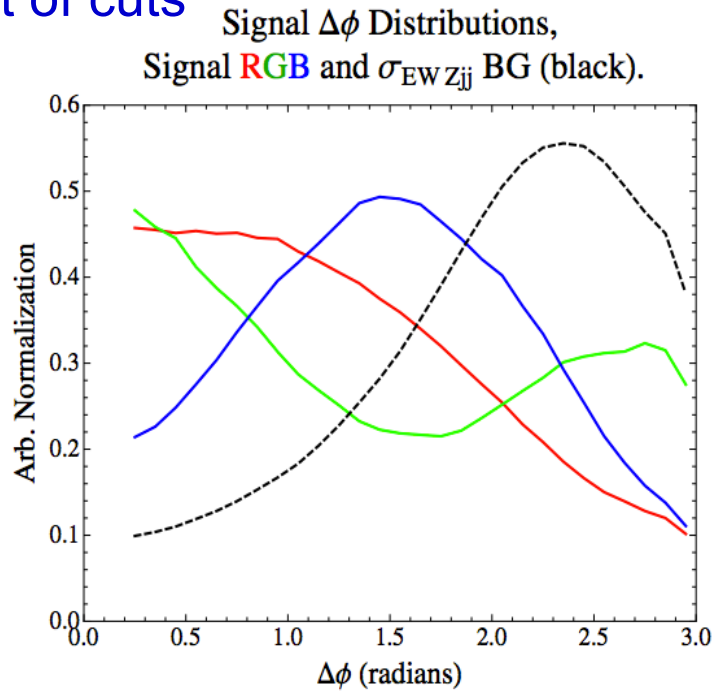




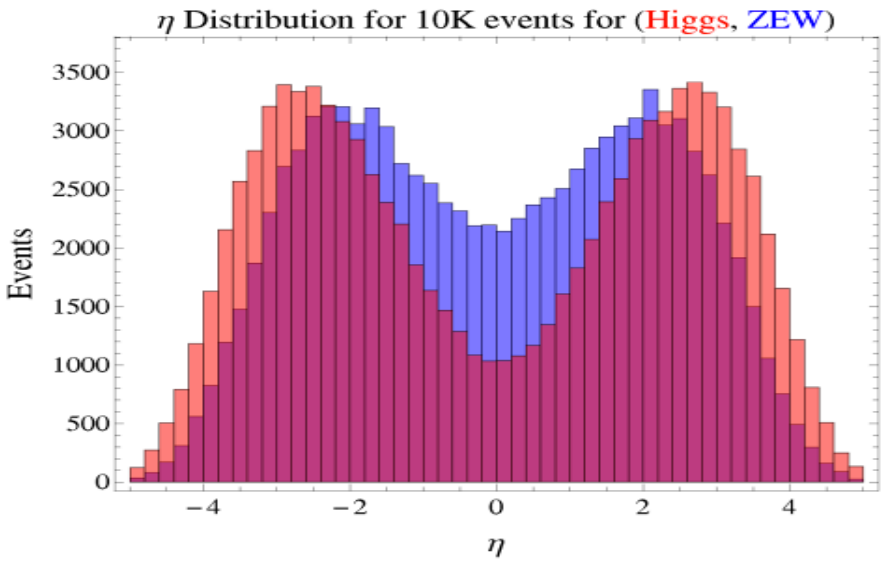
Piggy-back on invisible Higgs studies: devise set of cuts

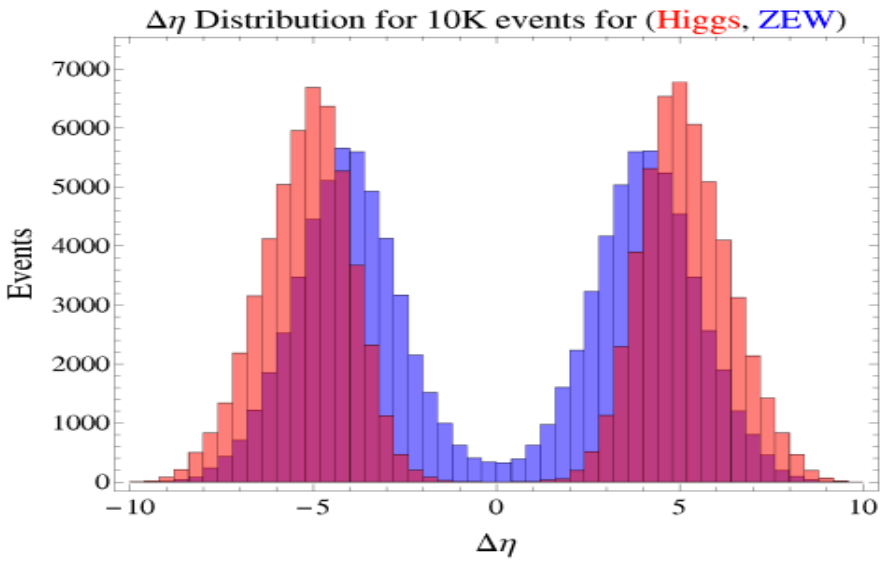
Eboli, Zeppenfeld: hep-ph/0009158

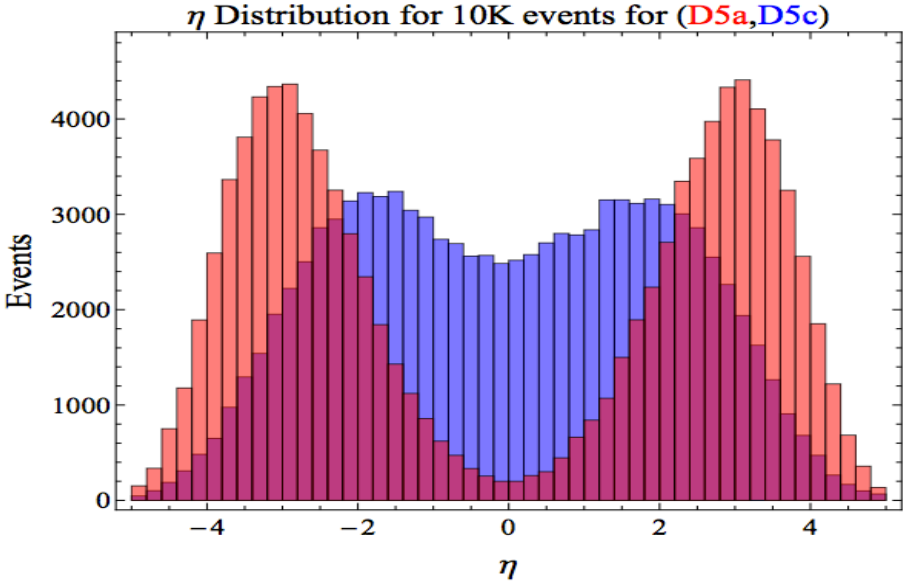
σ (fb)	QCD Zjj		QCD Wjj		EW Zjj		EW Wjj		Total	
	[51]	Here	[51]	Here	[51]	Here	[51]	Here	[51]	Here
Eqs. (6-8)	1254	1055	1284	906	151	148	101	85	2790	2194
Eqs. (6-9) + C.J.V.	71.8	56.6	70.2	47.3	14.8	14.6	9.9	8.2	167	127

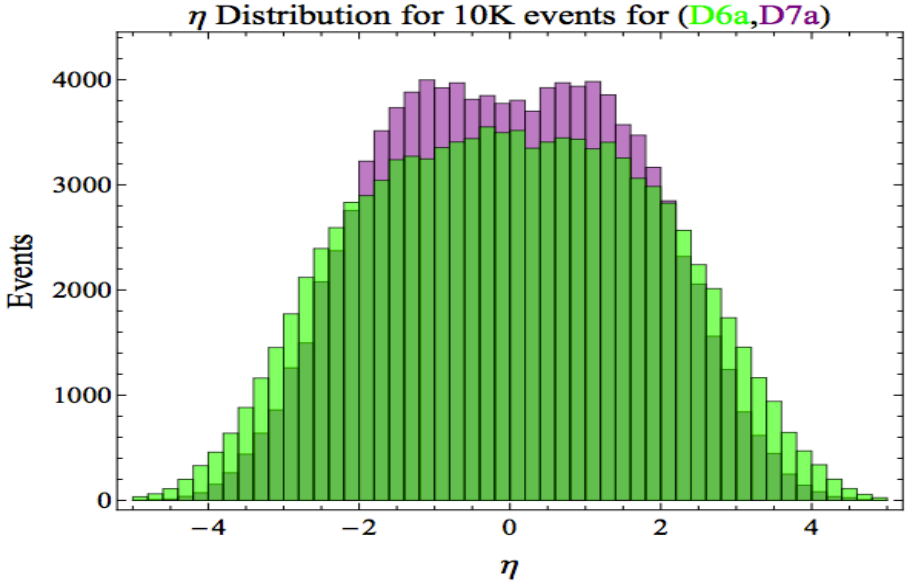


Pseudorapidity Dependence of signal and background



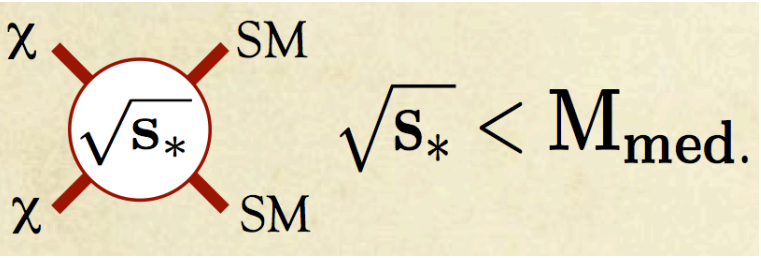






Validity of Effective Field Theory

EFT is valid when:

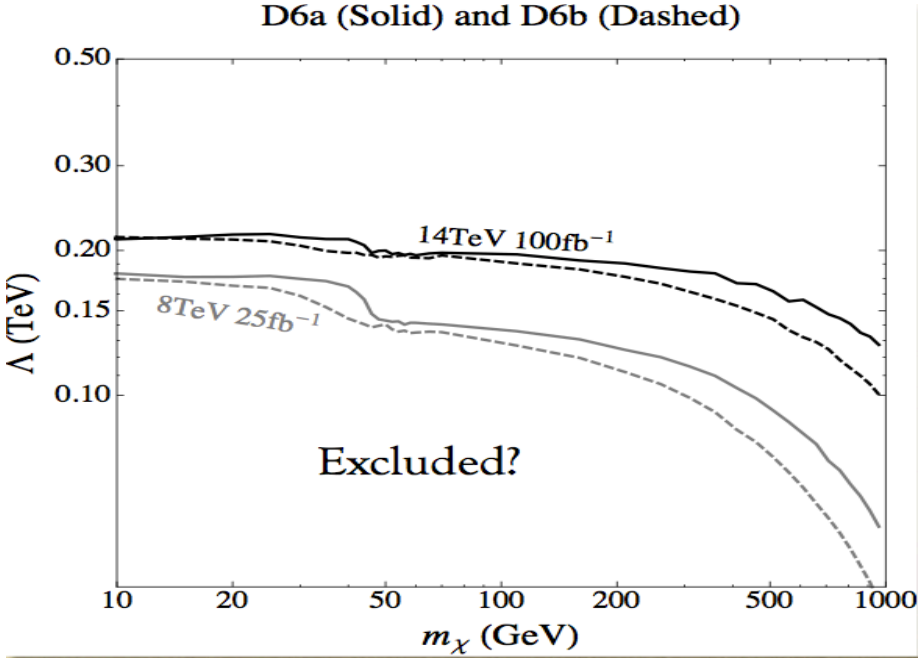


$$\sqrt{s_*} < M_{\text{med.}}$$

Scattering: $M_{\text{med.}} > |q|, (\ll m_\chi)$

Annihilation: $\sim m_\chi$

Production: $\sim p_T$



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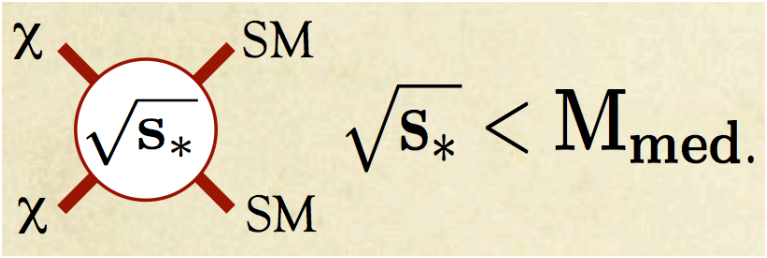


$$\sqrt{s_*} < M_{med.}$$

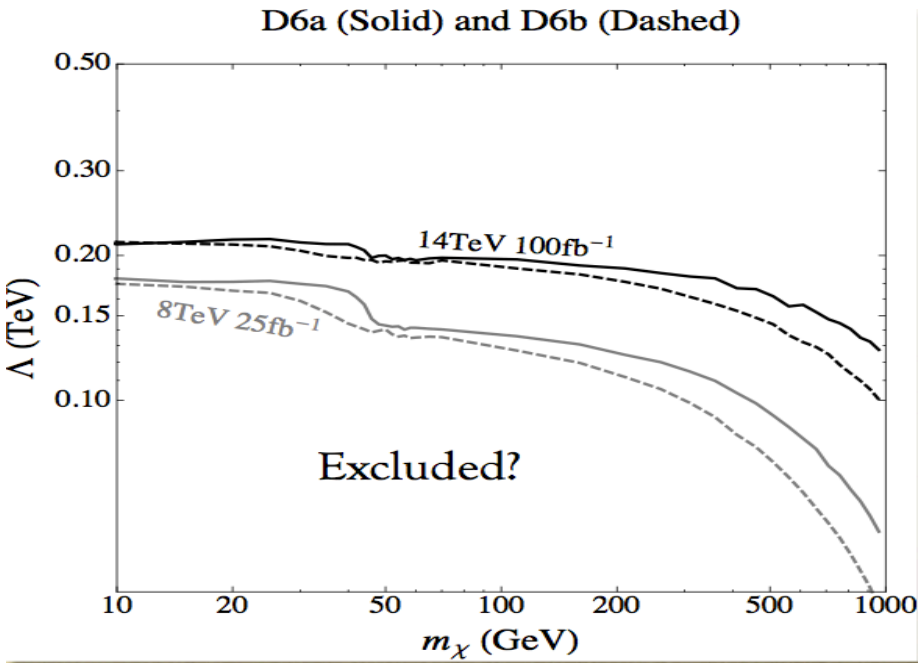
Scattering: $M_{med.} > |q|, (\ll m_\chi)$

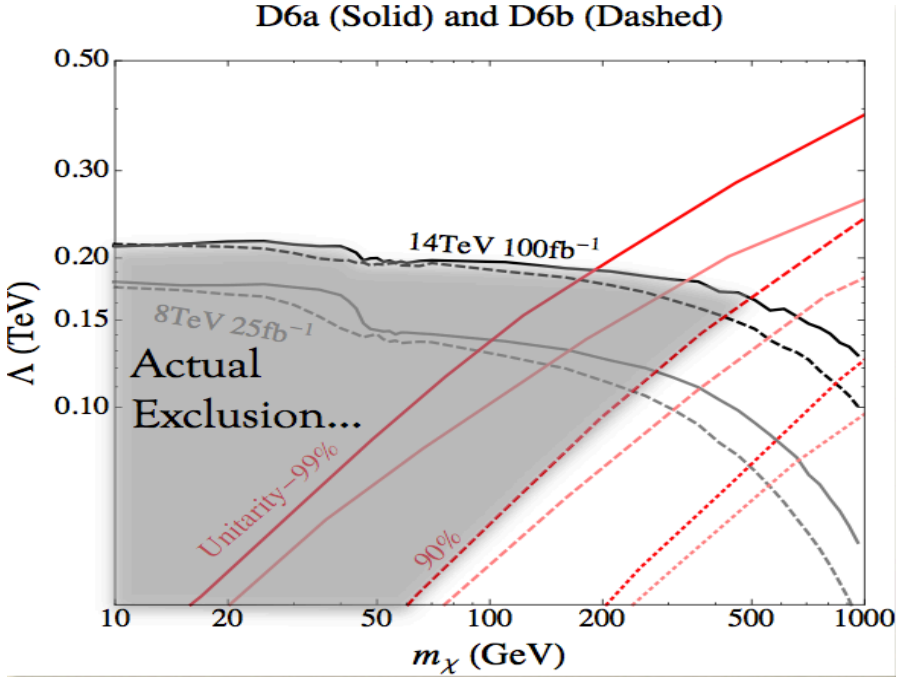
Annihilation: $\sim m_\chi$

Production: $\sim p_T$

Employ partial wave analysis: $|a_0(qq \rightarrow \chi\chi)| < 1/2$

99%, 90%, 50% VBF events obey this limit





LHC VBF Results

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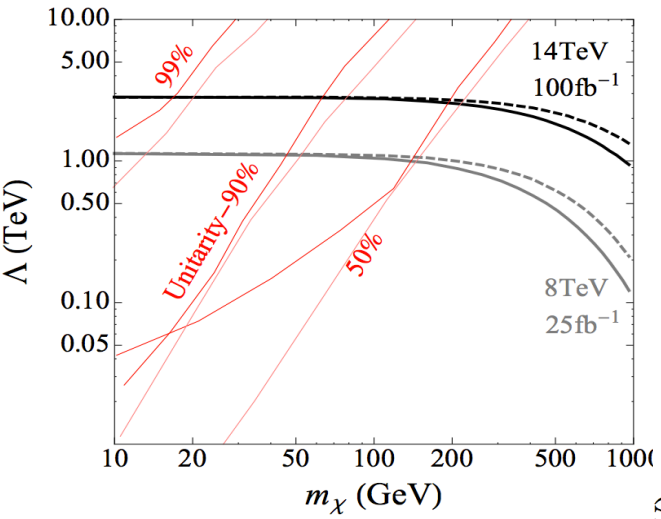
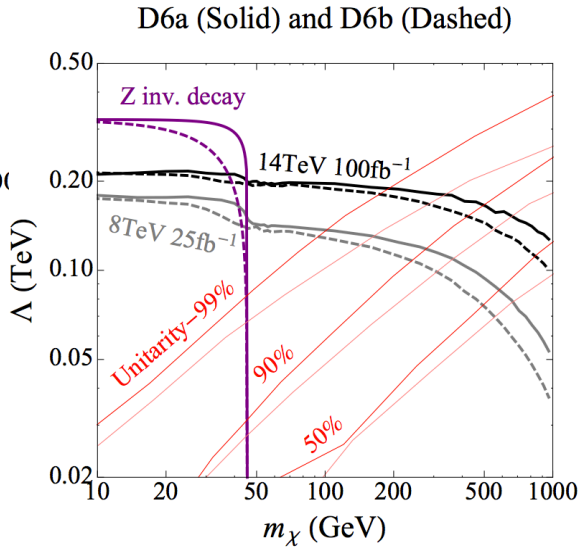
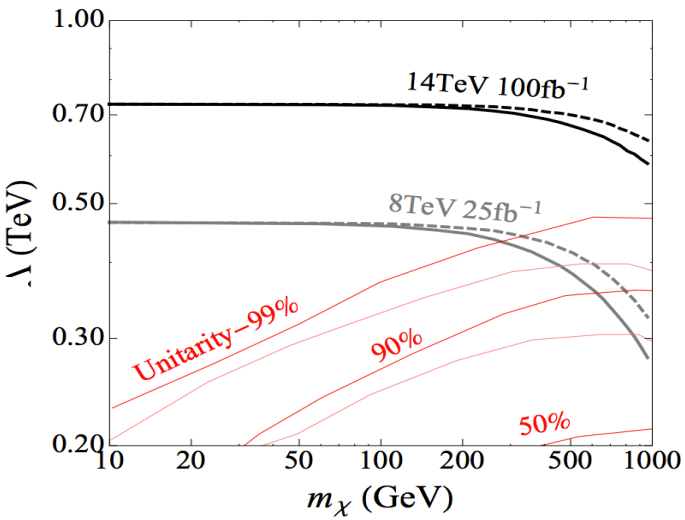
D5a (Solid) and D5b (Dashed)



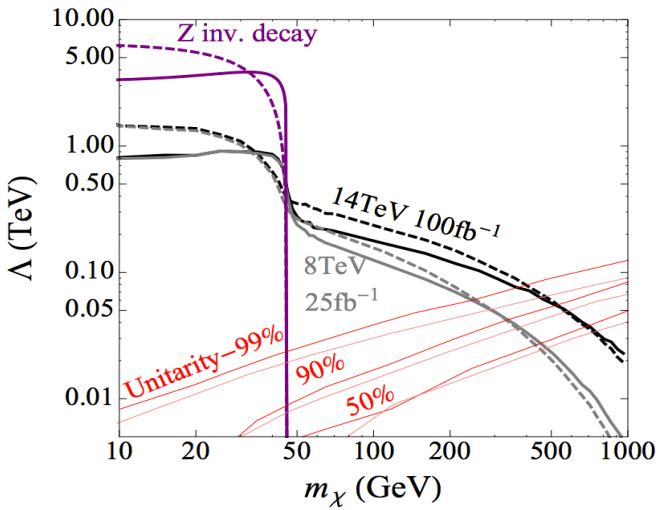
D6a (Solid) and D6b (Dashed)



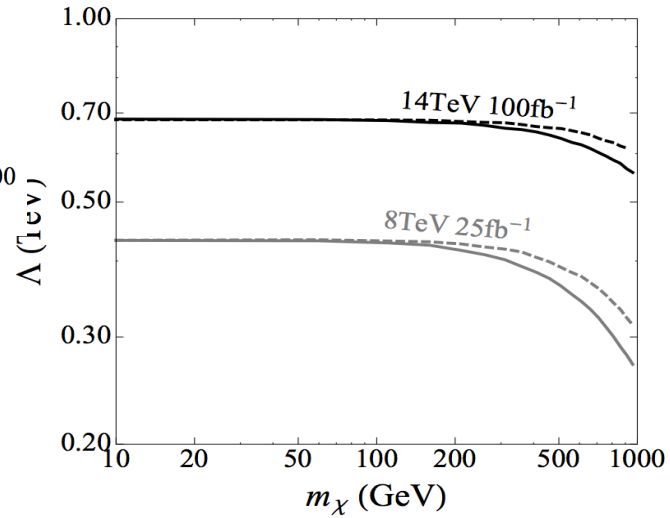
D7a (Solid) and D7b (Dashed)



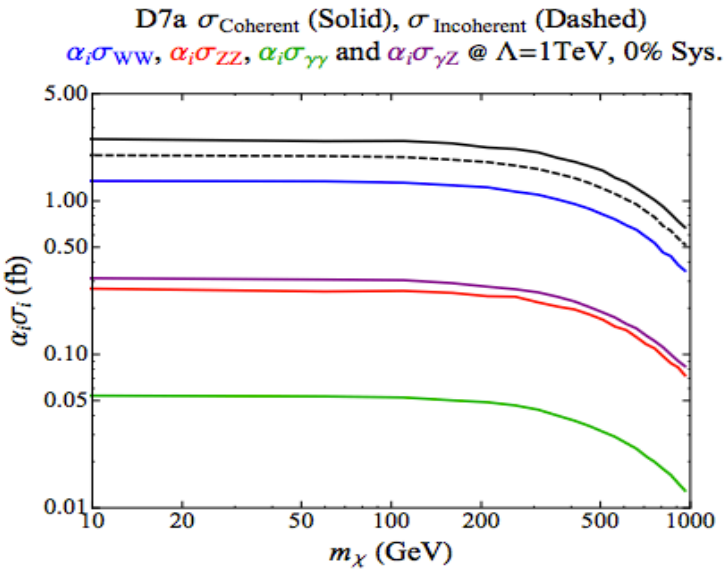
D5c (Solid) and D5d (Dashed)

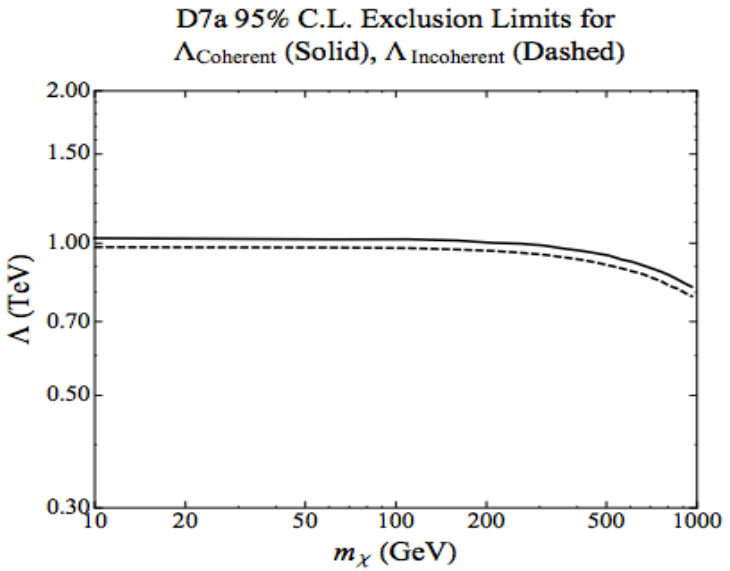


D7c (Solid) and D7d (Dashed)

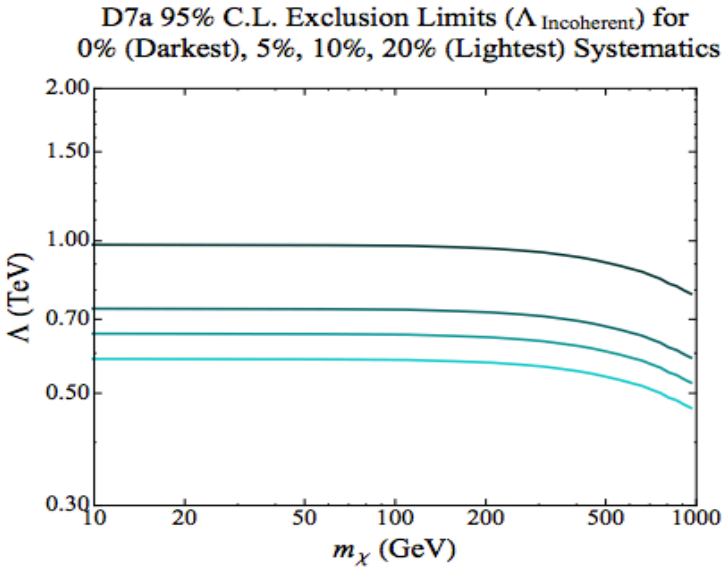


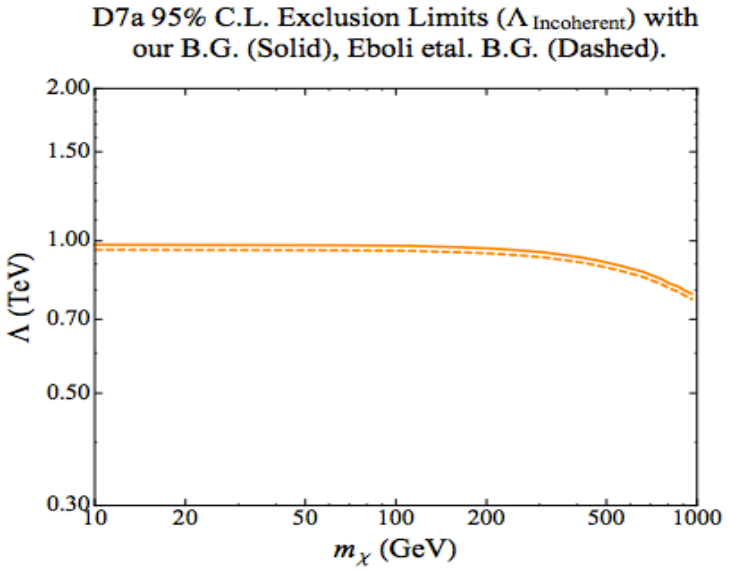
Effects of Uncertainties on LHC Constraints





14 TeV
100 fb^{-1}





Indirect dark matter searches

Include data from:

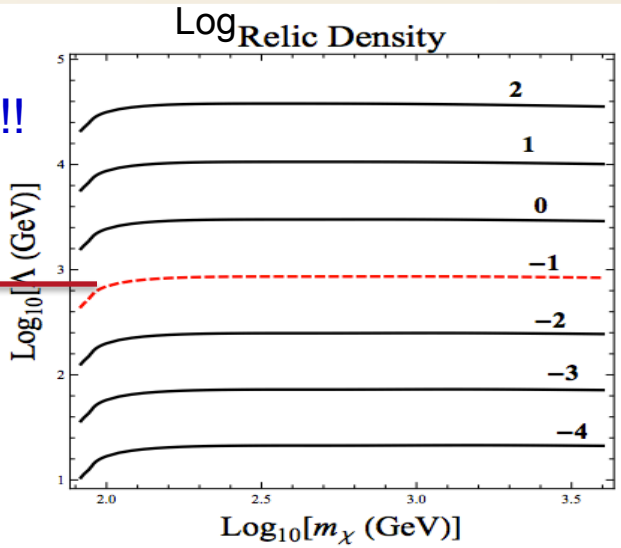
- Continuum γ-spectra from dwarf spheroidal galaxies for annihilation into SM final states
  - » (Fermi 10 MW dwarf spheroids data + Veritas Segue I)
- γ-ray lines for annihilations into γγ and γZ (Fermi)
  - » Assume NFW profile (bounds weaken ~30-40% w/ isothermal profile)
- Ratio of anti-proton/proton cosmic ray flux (Pamela)
  - » Assume NFW profile

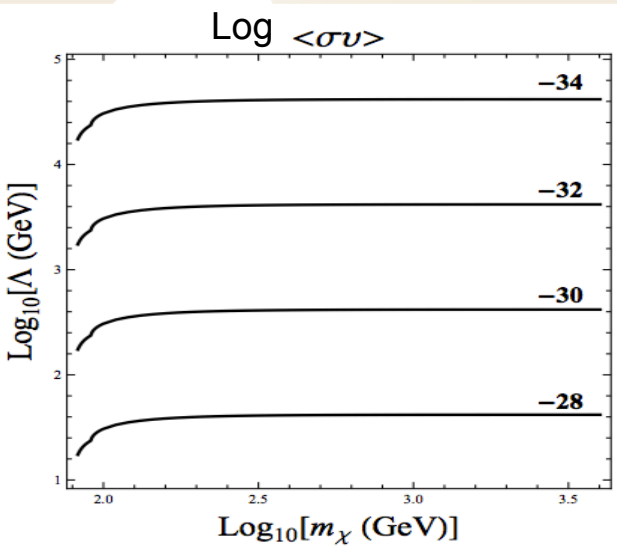
Strength of indirect limits depends on velocity suppression of operator

Indirect Search Results

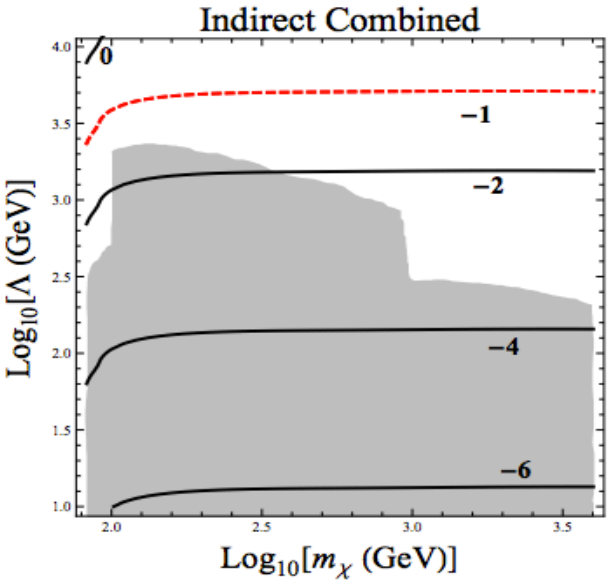
Operator D5a
No indirect constraints!!

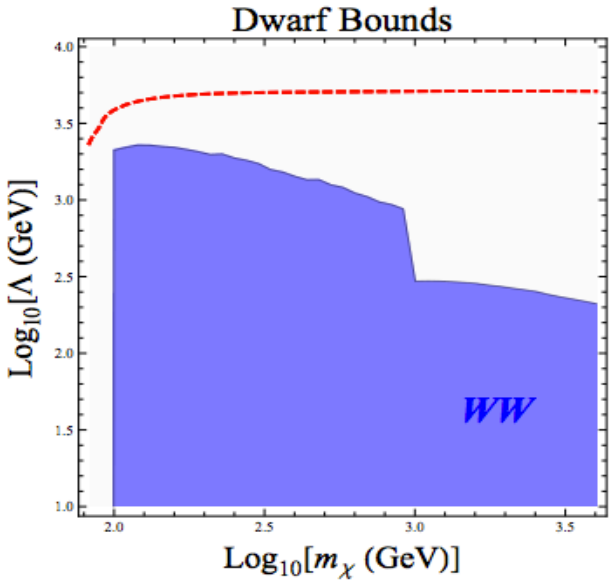
WMAP measurement
Thermal cosmology

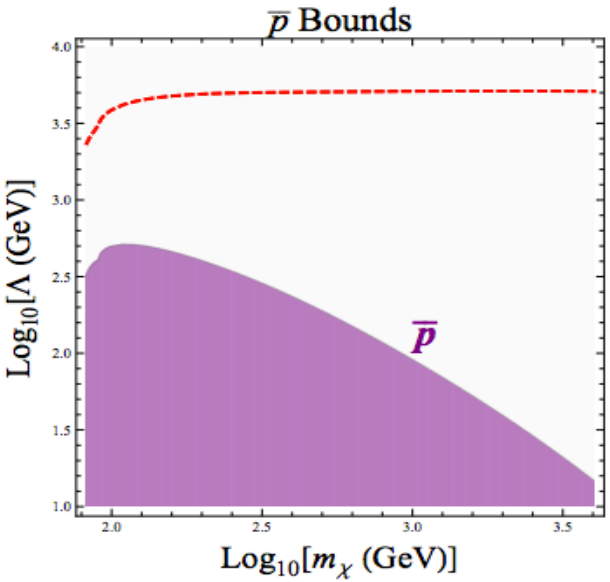




Operator D5b







Indirect Search Results

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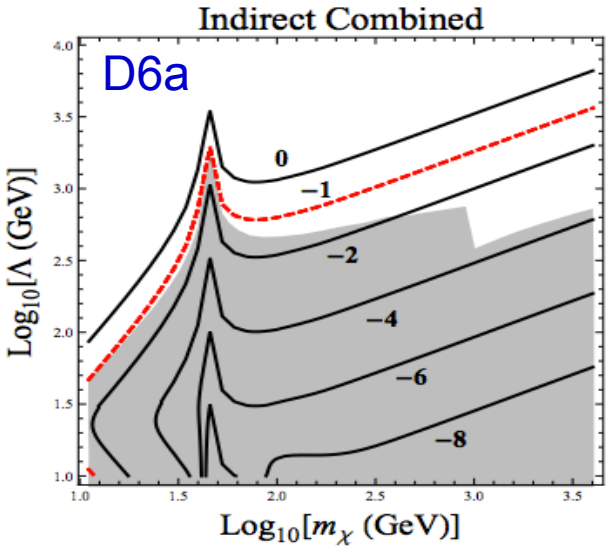
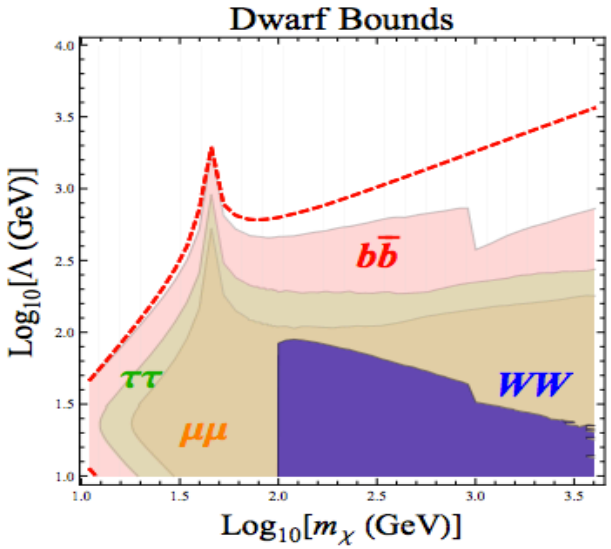
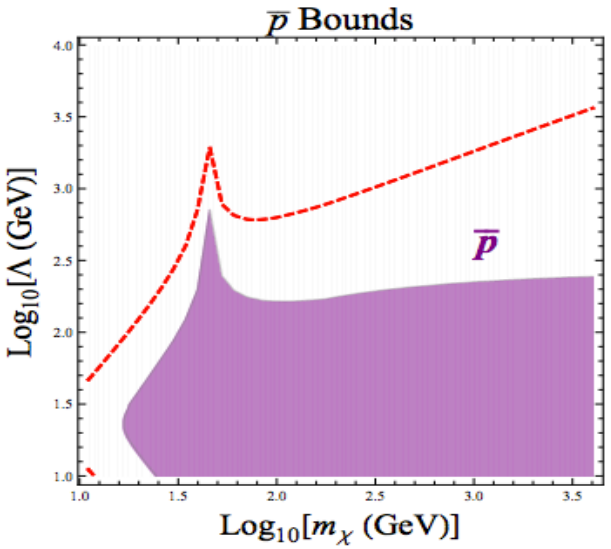
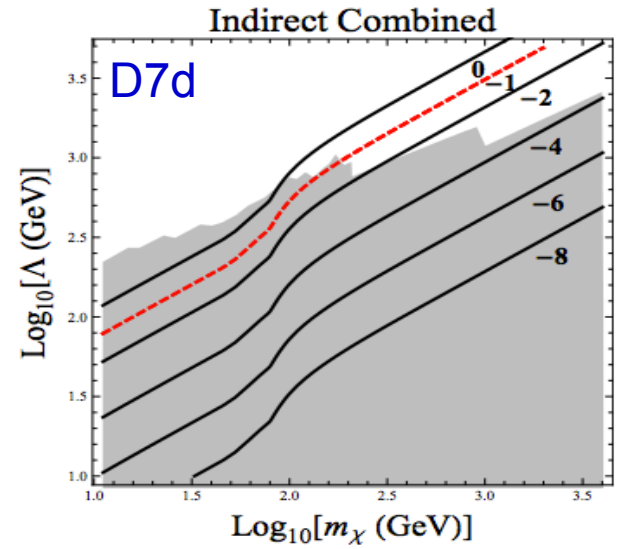
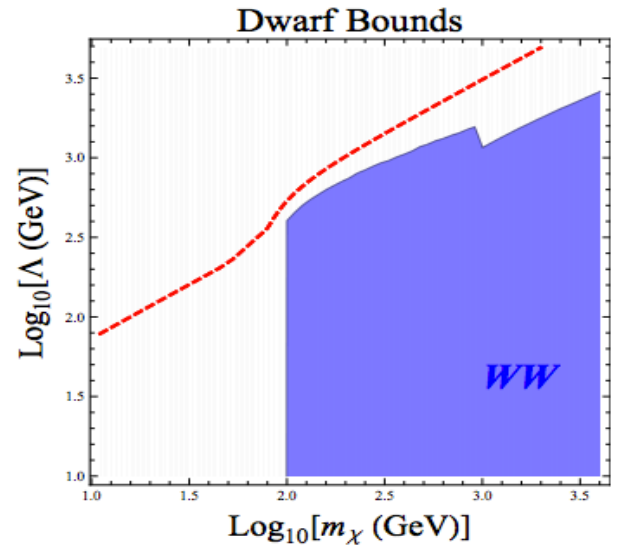
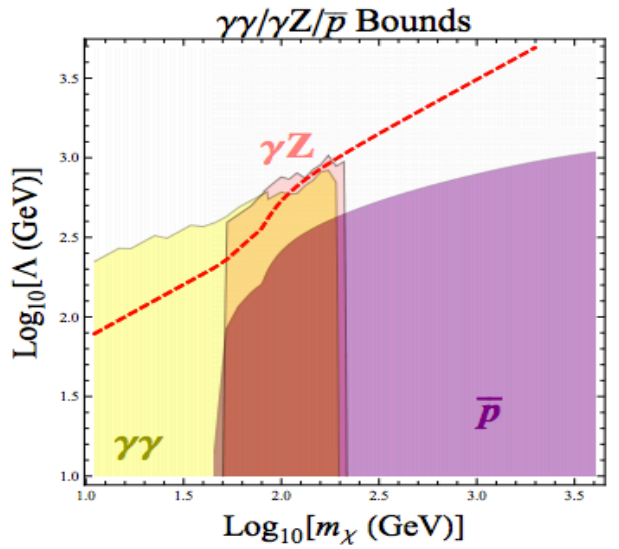




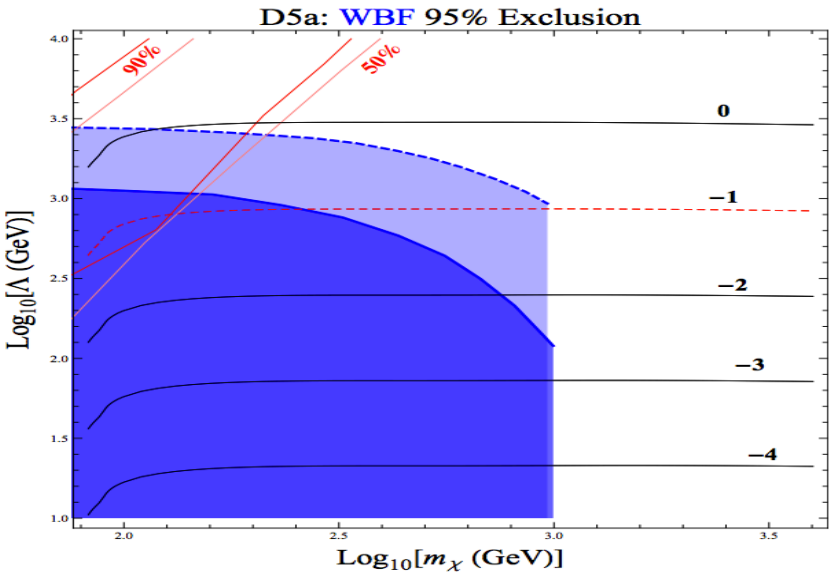


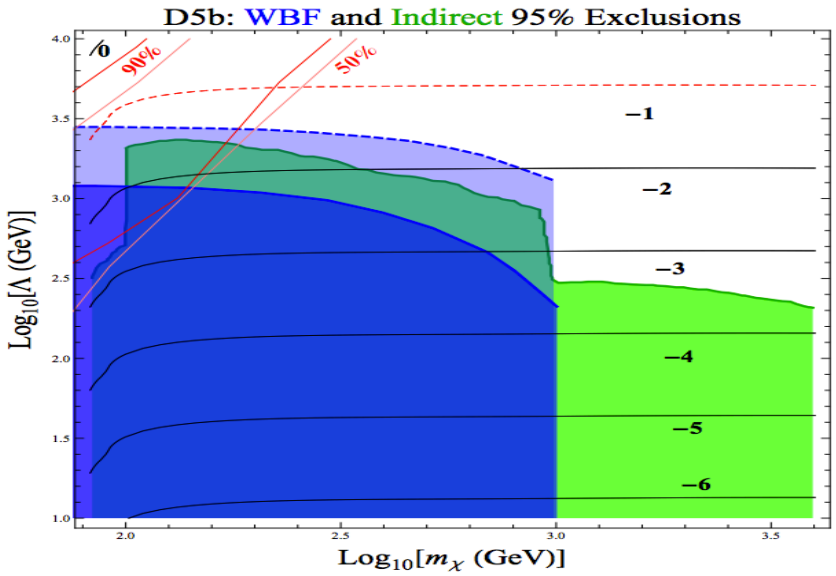


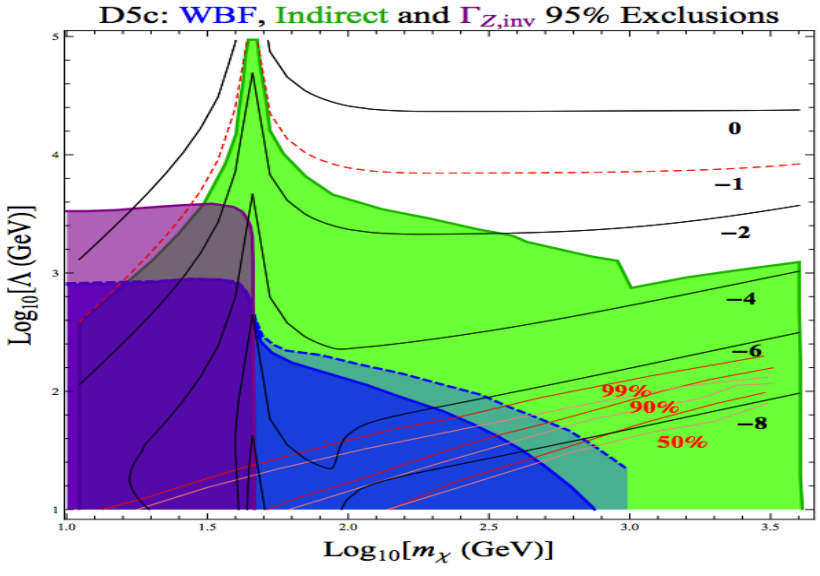


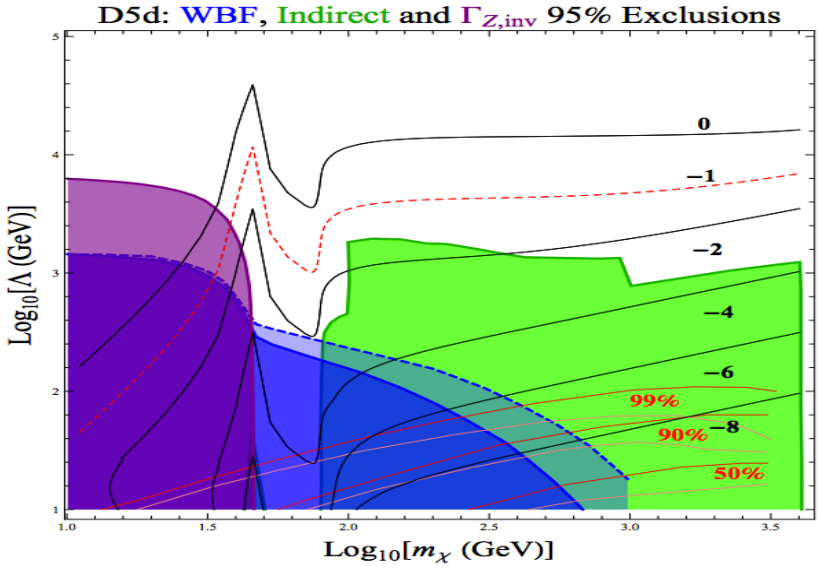


Combined Constraints: D5a-d

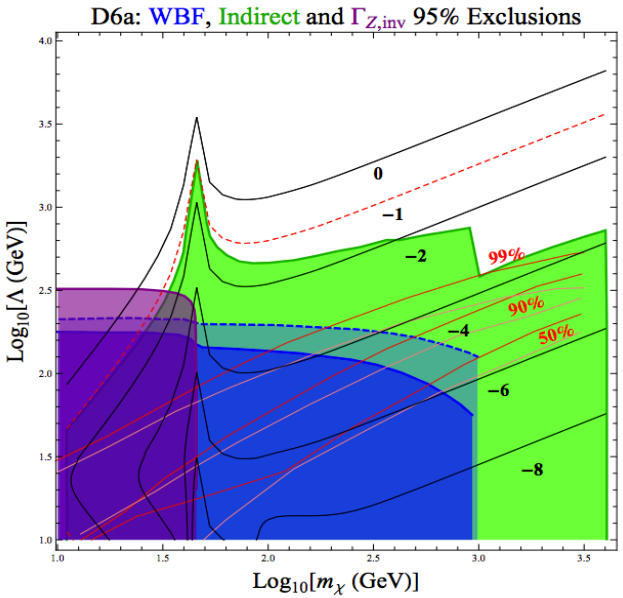


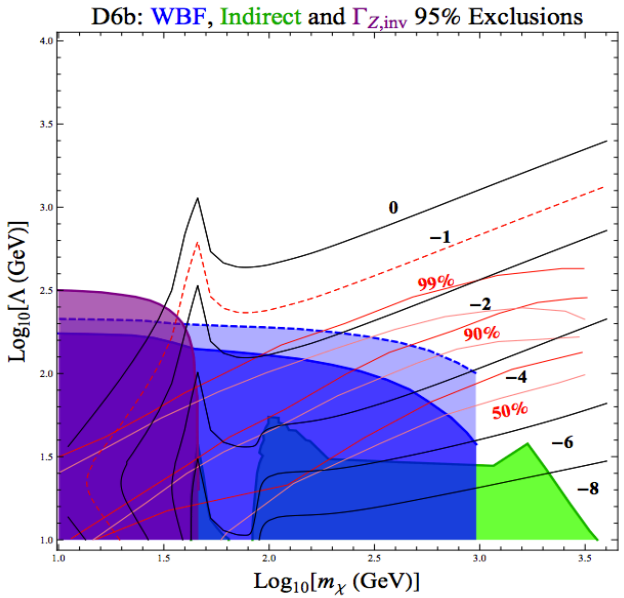


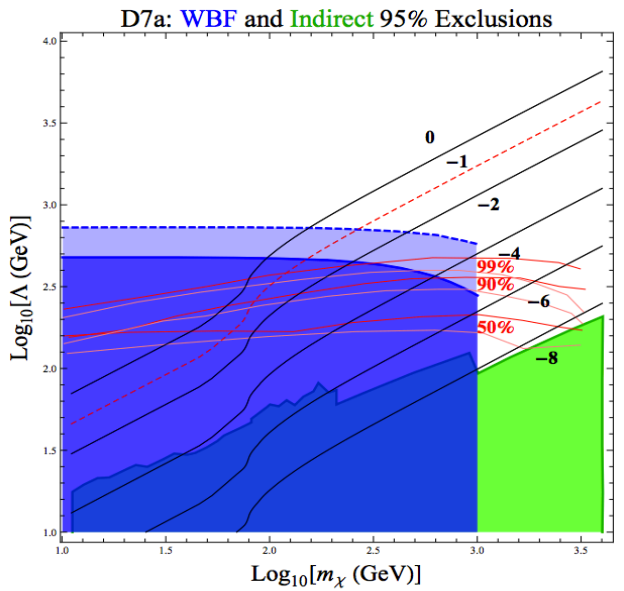


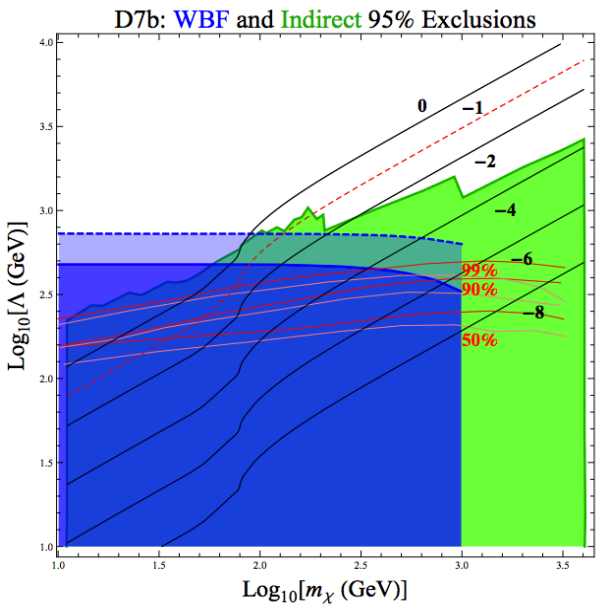


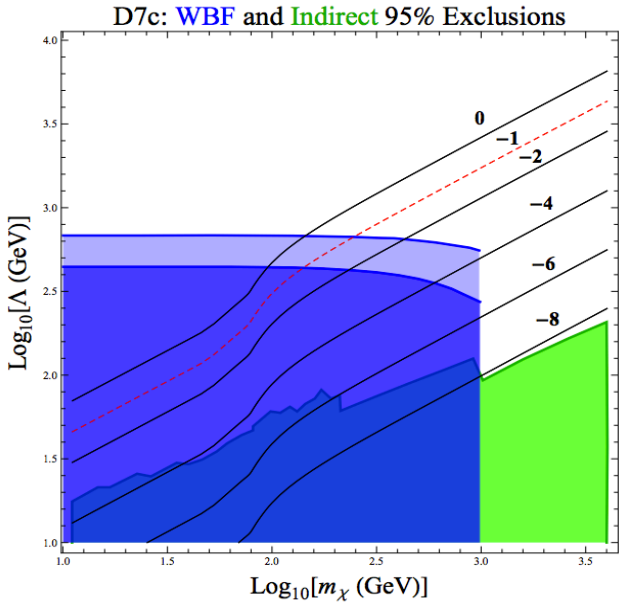
Combined Constraints: D6-D7

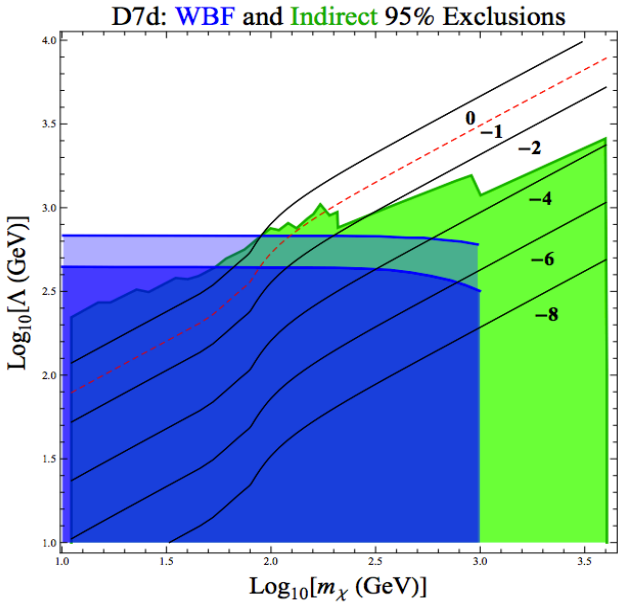












Summary: EW boson probes of dark matter

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- Provides complement to monjet and direct detection searches
- Interactions with EW gauge bosons probed for cut-offs in the weak-scale values, ~100's GeV to few TeV
- Relatively light dark matter requires additional structure in UV theory to avoid overclosing the universe

BACKUP

Assumed weighted combination for collider subprocesses

SLAC

D5a : $$\frac{1}{\Lambda}\bar{\chi}\chi\left(\frac{Z^{\mu}Z_{\mu}}{2}+W^{+\mu}W_{\mu}^{-}+h.c.\right)$$

D5b : $$\frac{1}{\Lambda}\bar{\chi}i\gamma_5\chi\left(\frac{Z^{\mu}Z_{\mu}}{2}+W^{+\mu}W_{\mu}^{-}+h.c.\right)$$

D5c : $$\frac{g_w}{\Lambda}\left(\bar{\chi}\sigma_{\mu\nu}t^3\chi W^{3\mu\nu}+\frac{s_w}{c_w}\frac{Y}{2}\bar{\chi}\sigma_{\mu\nu}\chi B^{\mu\nu}\right)$$

D5d : $$\frac{g_w}{\Lambda}\left(\bar{\chi}\sigma_{\mu\nu}t^3\chi \widetilde{W}^{3\mu\nu}+\frac{s_w}{c_w}\frac{Y}{2}\bar{\chi}\sigma_{\mu\nu}\chi \widetilde{B}^{\mu\nu}\right)$$

D6a : $$\frac{g_w}{\Lambda^2}\left(\bar{\chi}\gamma_{\mu}t^3D_{\nu}\chi W^{3\mu\nu}+\frac{s_w}{c_w}\frac{Y}{2}\bar{\chi}\gamma_{\mu}D_{\nu}\chi B^{\mu\nu}\right)$$

D6b : $$\frac{g_w}{\Lambda^2}\left(\bar{\chi}\gamma_5\gamma_{\mu}t^3D_{\nu}\chi W^{3\mu\nu}+\frac{s_w}{c_w}\frac{Y}{2}\bar{\chi}\gamma_5\gamma_{\mu}D_{\nu}\chi B^{\mu\nu}\right)$$

D7a : $$\frac{1}{\Lambda^3}\bar{\chi}\chi W^{a\mu\nu}W^a_{\mu\nu}$$

D7b : $$\frac{1}{\Lambda^3}\bar{\chi}i\gamma_5\chi W^{a\mu\nu}W^a_{\mu\nu}$$

D7c : $$\frac{1}{\Lambda^3}\bar{\chi}\chi W^{a\mu\nu}\widetilde{W}^a_{\mu\nu}$$

D7d : $$\frac{1}{\Lambda^3}\bar{\chi}i\gamma_5\chi W^{a\mu\nu}\widetilde{W}^a_{\mu\nu}.$$