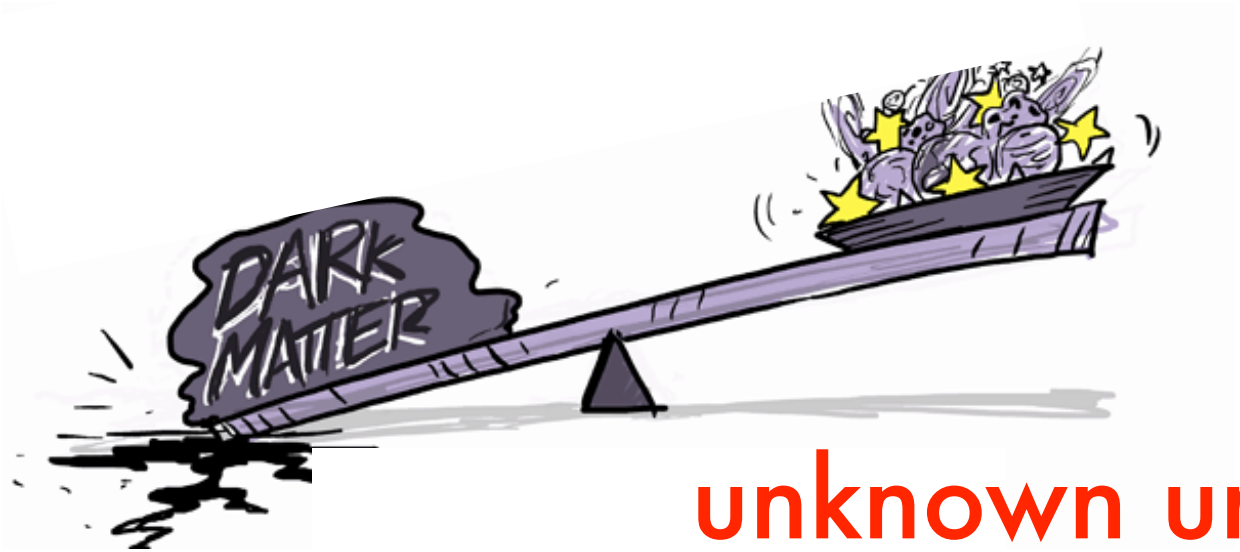
Dark Matter Collider Searches

Daniel Whiteson,
UC Irvine, DaMaSC 2013

What do we know?



unknown unknown

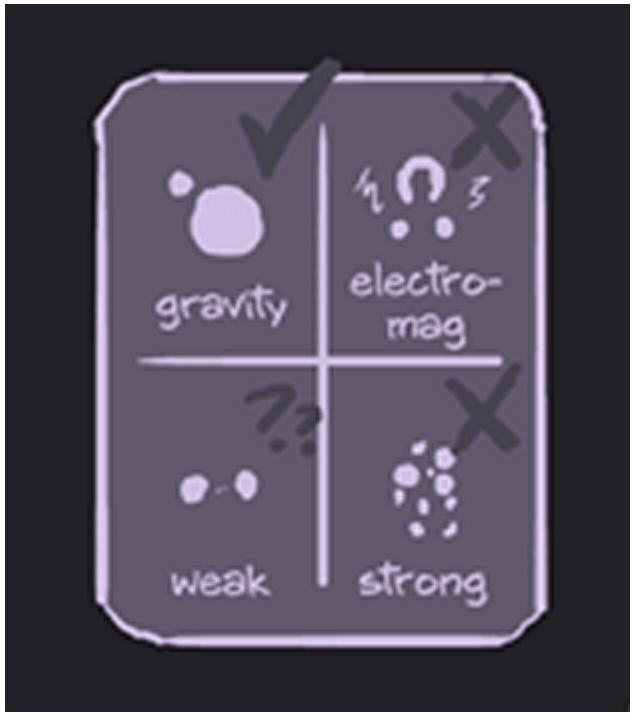
known unknown

known known

Exploration machine

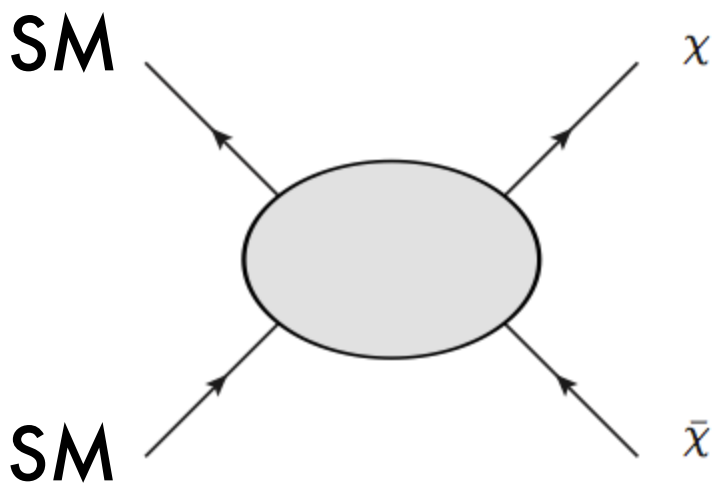
We can create new forms of matter,
even if we have little or no idea of what we are looking for!

Interactions



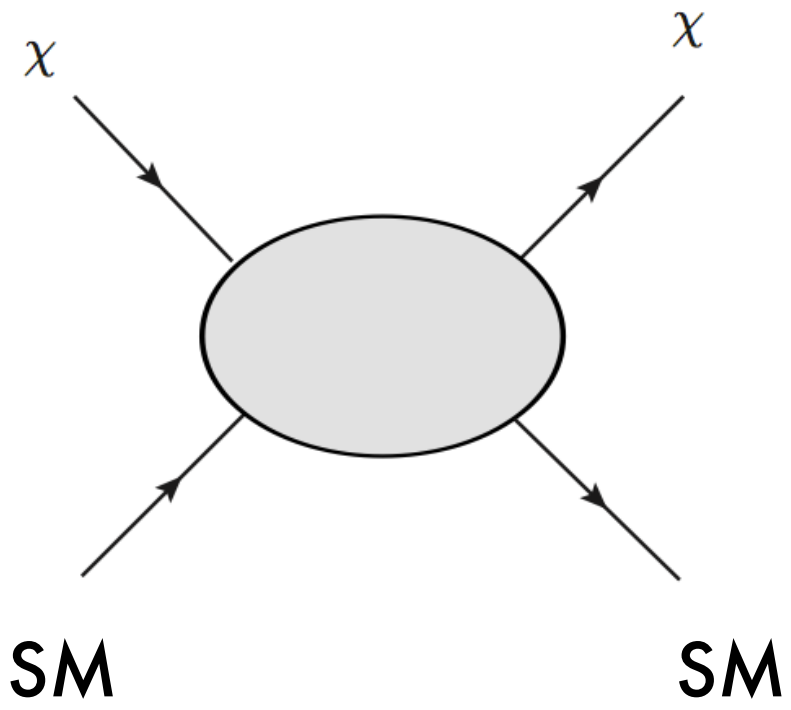
Important caveat:

Requires **some** interaction with SM

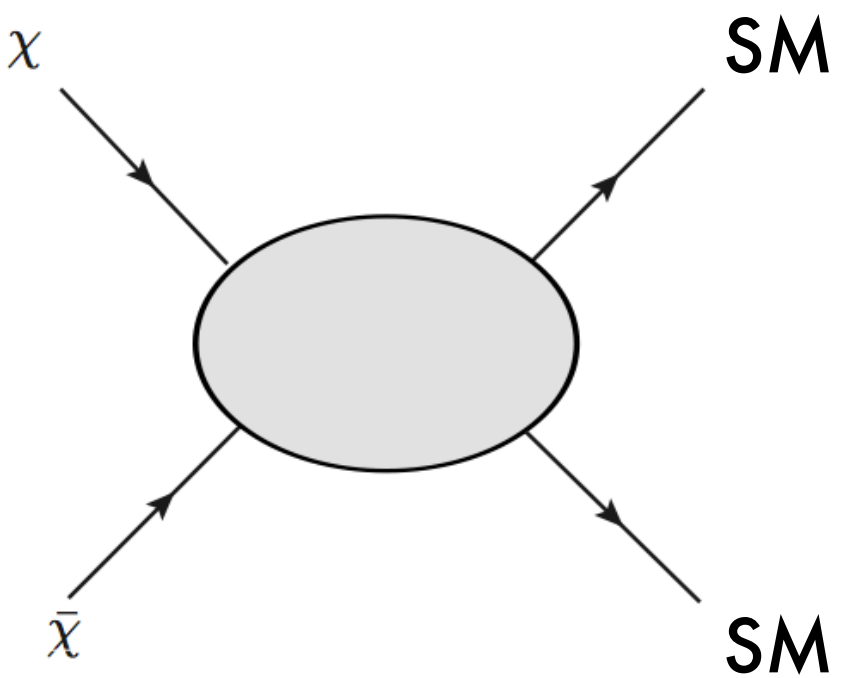


Other experiments

Direct
(Xenon etc)

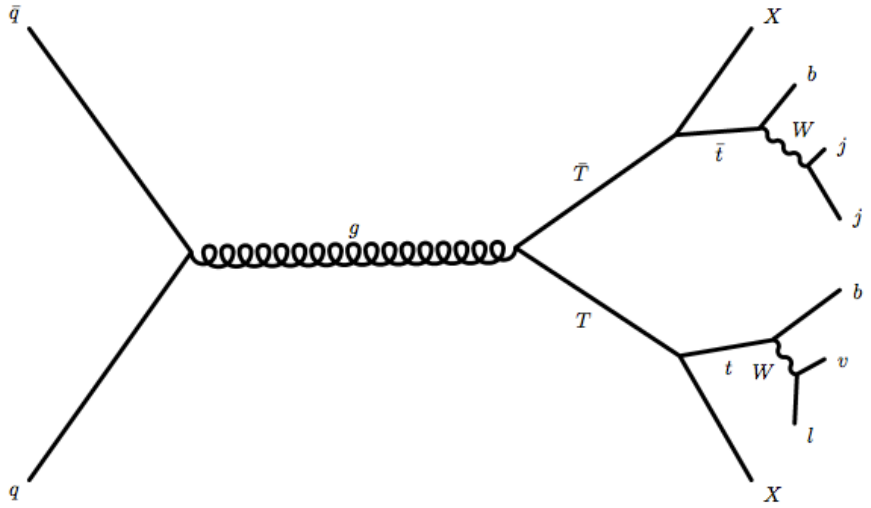


Indirect
(FermiLAT)

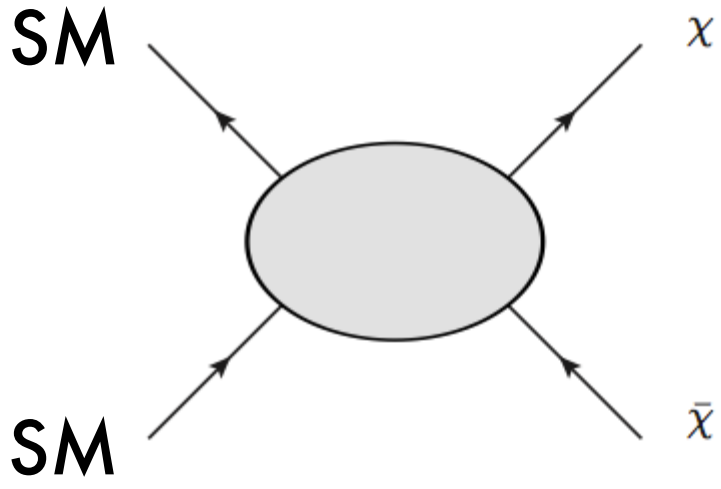


Production

Heavier colored production...



Direct weak production...

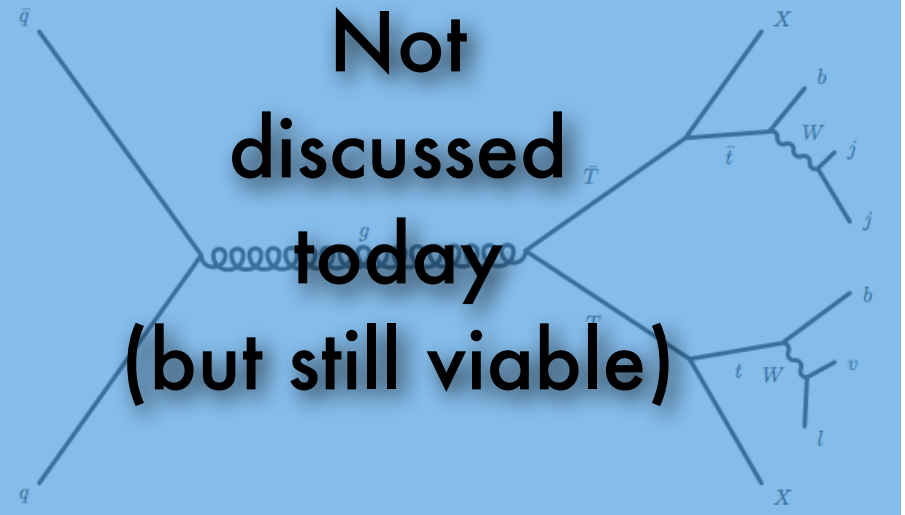


...followed by cascade to WIMPs

..via intermediate heavy particle

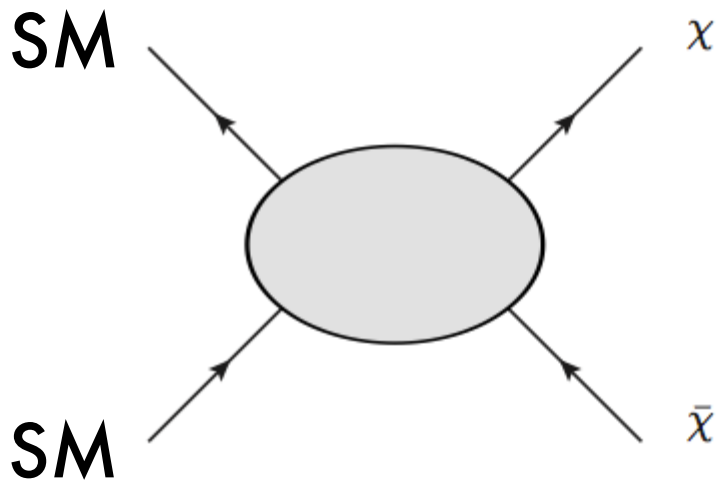
Production

Heavier colored production...



...followed by cascade to WIMPs

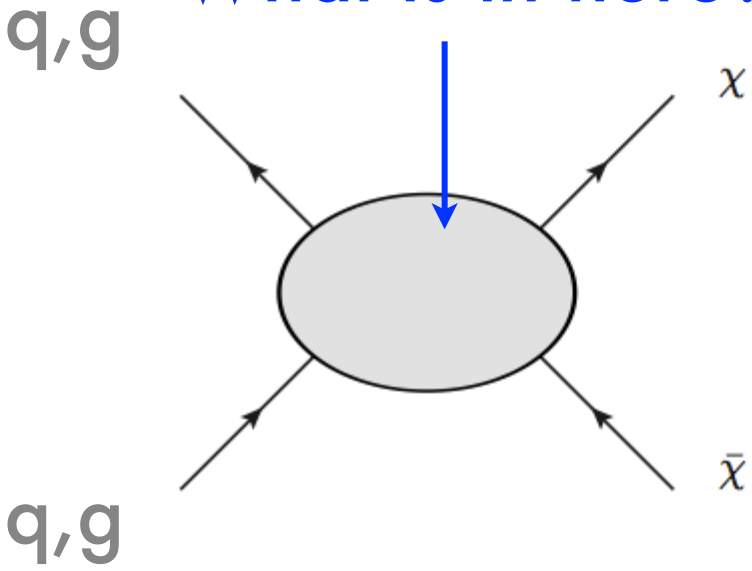
Direct weak production...



..via intermediate heavy particle

Effective field theories

What is in here?



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.

$$\sigma_0^{D1} = 1.60\times10^{-37}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{20\mathrm{GeV}}{M_*}\right)^6,$$

$$\sigma_0^{D5,C3} = 1.38\times10^{-37}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{300\mathrm{GeV}}{M_*}\right)^4,$$

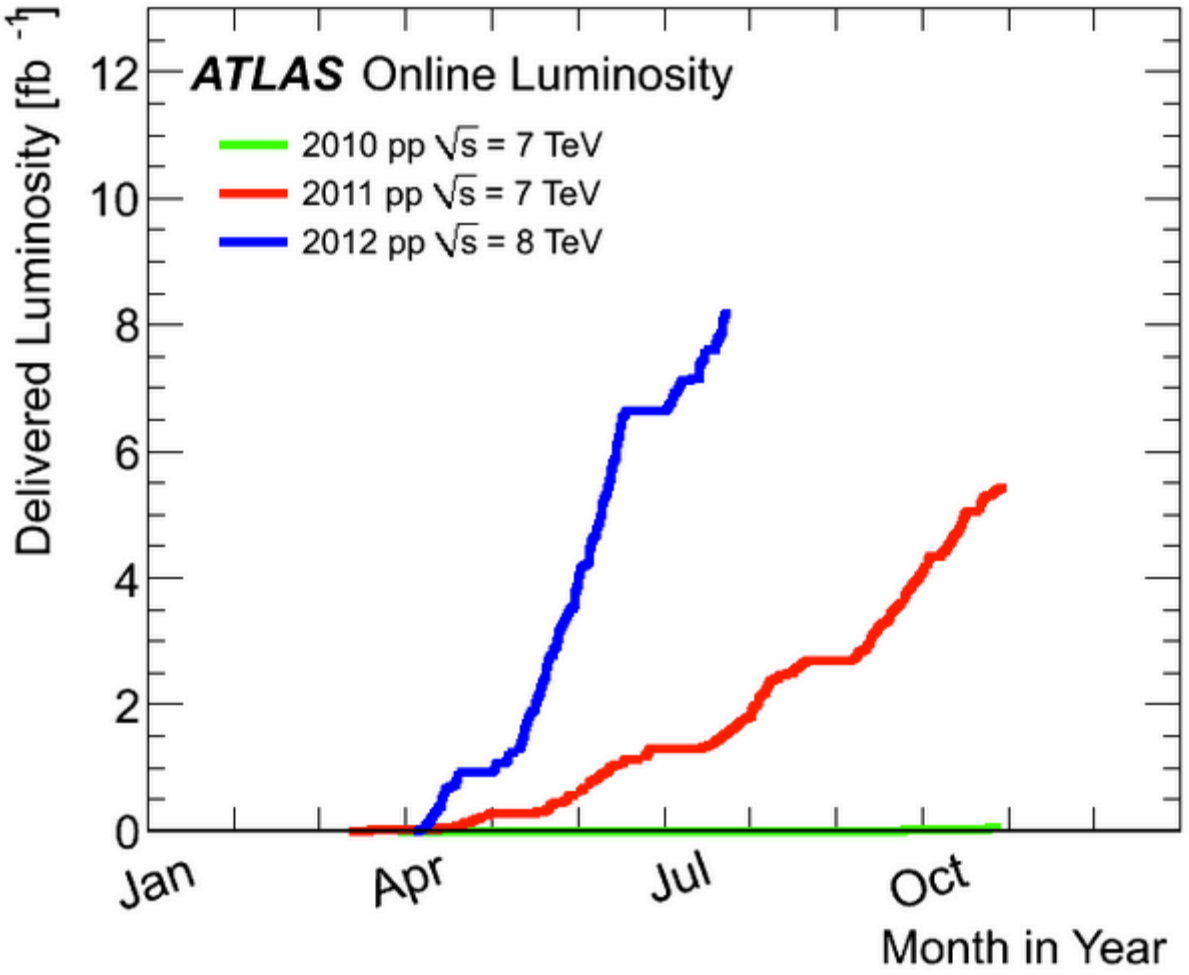
$$\sigma_0^{D8,D9} = 9.18\times10^{-40}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{300\mathrm{GeV}}{M_*}\right)^4,$$

$$\sigma_0^{D11} = 3.83\times10^{-41}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{100\mathrm{GeV}}{M_*}\right)^6,$$

$$\sigma_0^{C1,R1} = 2.56\times10^{-36}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2\left(\frac{10\mathrm{GeV}}{M_*}\right)^4,$$

$$\sigma_0^{C5,R3} = 7.40\times10^{-39}\mathrm{cm}^2\left(\frac{\mu_\chi}{1\mathrm{GeV}}\right)^2\left(\frac{10\mathrm{GeV}}{m_\chi}\right)^2\left(\frac{60\mathrm{GeV}}{M_*}\right)^4.$$

LHC dataset

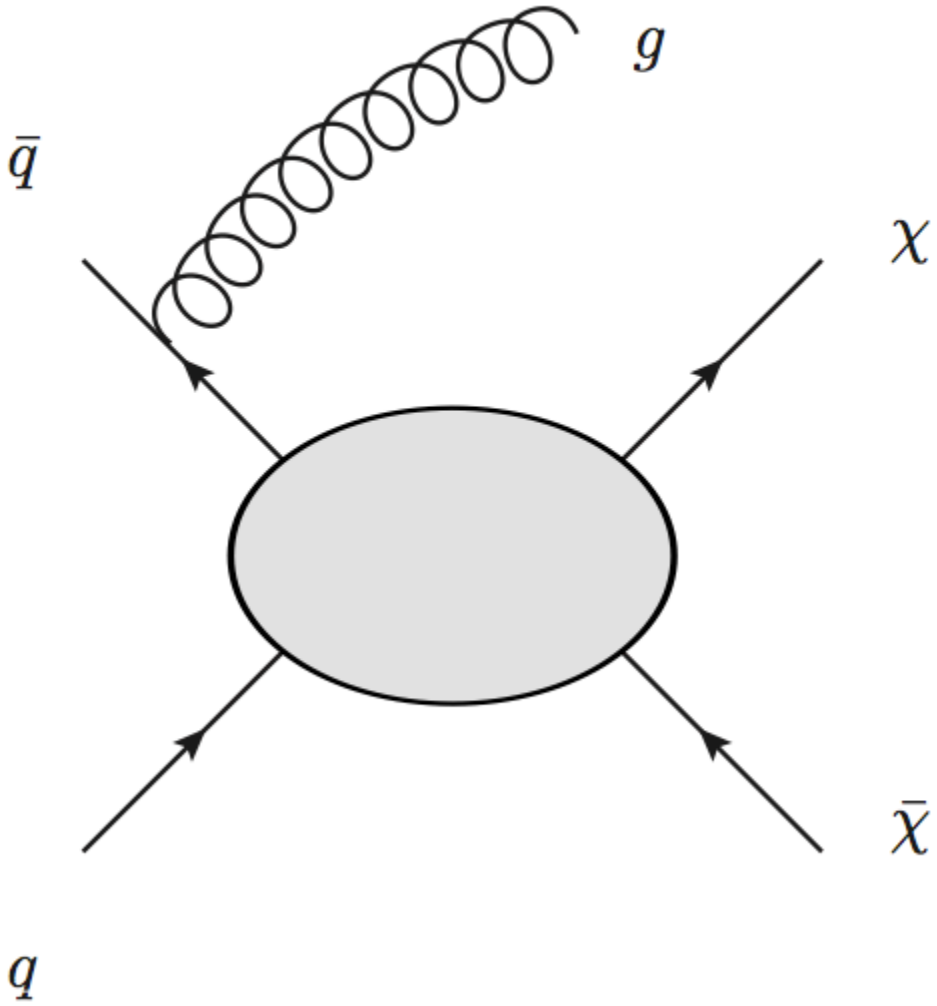


Today's results use 2011 data.

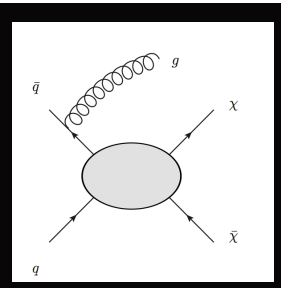
Collider searches

I. Mono-jet
II. Mono-photon
III. Mono-Z
IV. Mono-anything else
V. Mono-everything (combination!)

Mono-jet



Mono-jet



ATLAS selection

MET > 350 (500)

1 or 2 jets, p_T> 350(500), 30

veto lepton

dPhi(j2,MET) > 0.5

CMS selection

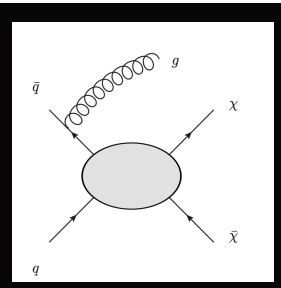
MET > 350

1 or 2 jets, p_T> 110,30

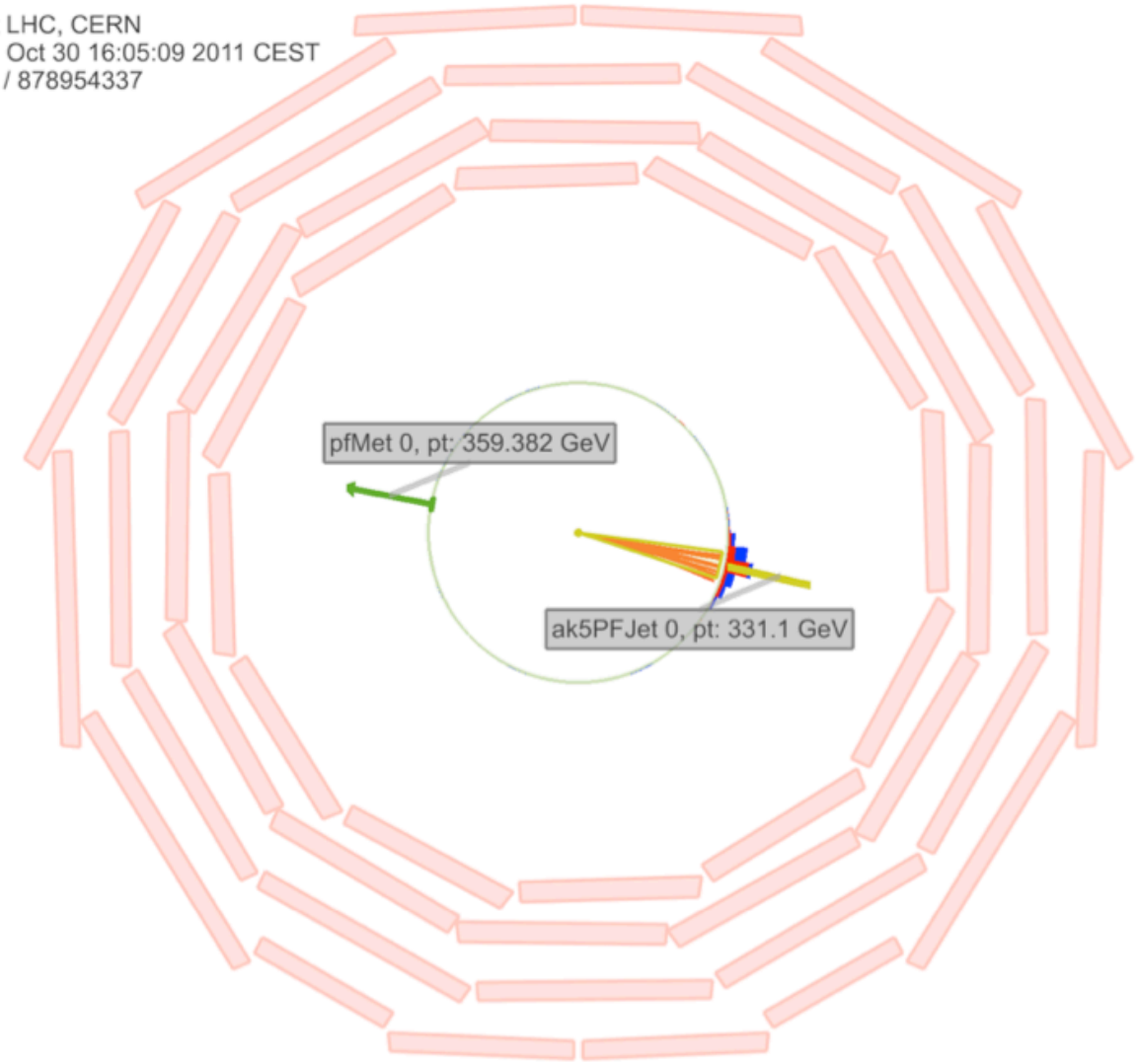
veto lepton

dPhi(j,j) < 2.5

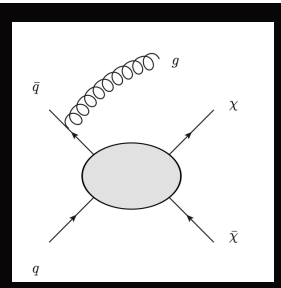
Event display



CMS Experiment at LHC, CERN
Data recorded: Sun Oct 30 16:05:09 2011 CEST
Run/Event: 180250 / 878954337
Lumi section: 481



Mono-jet



ATLAS selection

MET > 350 (500)

1 or 2 jets, pT> 350(500), 30

veto lepton

dPhi(j2,MET) > 0.5

	MET>350	MET>500
Z→νν	500	58
W+jets	228	24
tt+t	4	-
QCD	8	-
Other	7	1
Total	$750_{\pm 60}$	$83_{\pm 14}$
Data	785	77

CMS selection

MET > 350

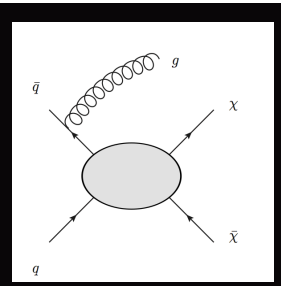
1 or 2 jets, pT> 110,30

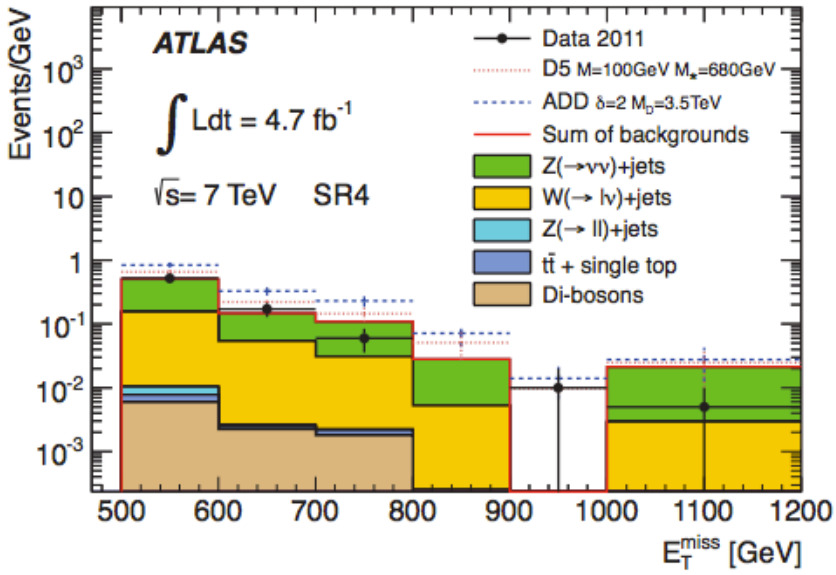
veto lepton

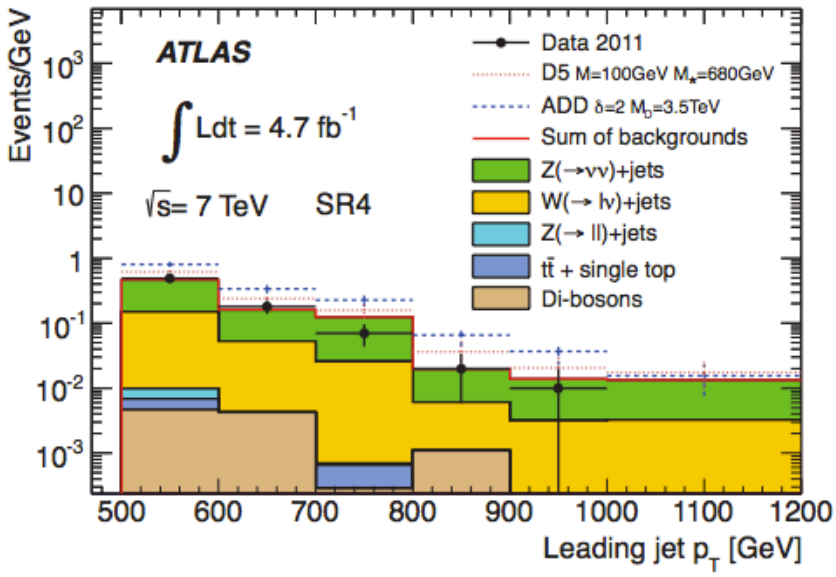
dPhi(j,j) < 2.5

Z→νν	900
W+jets	312
tt+t	9
QCD	1
Other	2
Total	$1224_{\pm 101}$
Data	1142

Mono-jet


$\bar{q}$
g
χ
$\bar{\chi}$
q


ATLAS
$\int$ Ldt = 4.7 fb^{-1}
$\sqrt{s}$= 7 TeV SR4
Data 2011
D5 M=100GeV M$_*$=680GeV
ADD δ=2 M$_D$=3.5TeV
Sum of backgrounds
Z(→νν)+jets
W(→ lν)+jets
Z(→ ll)+jets
tt̄ + single top
Di-bosons
Events/GeV
E$_T^{miss}$ [GeV]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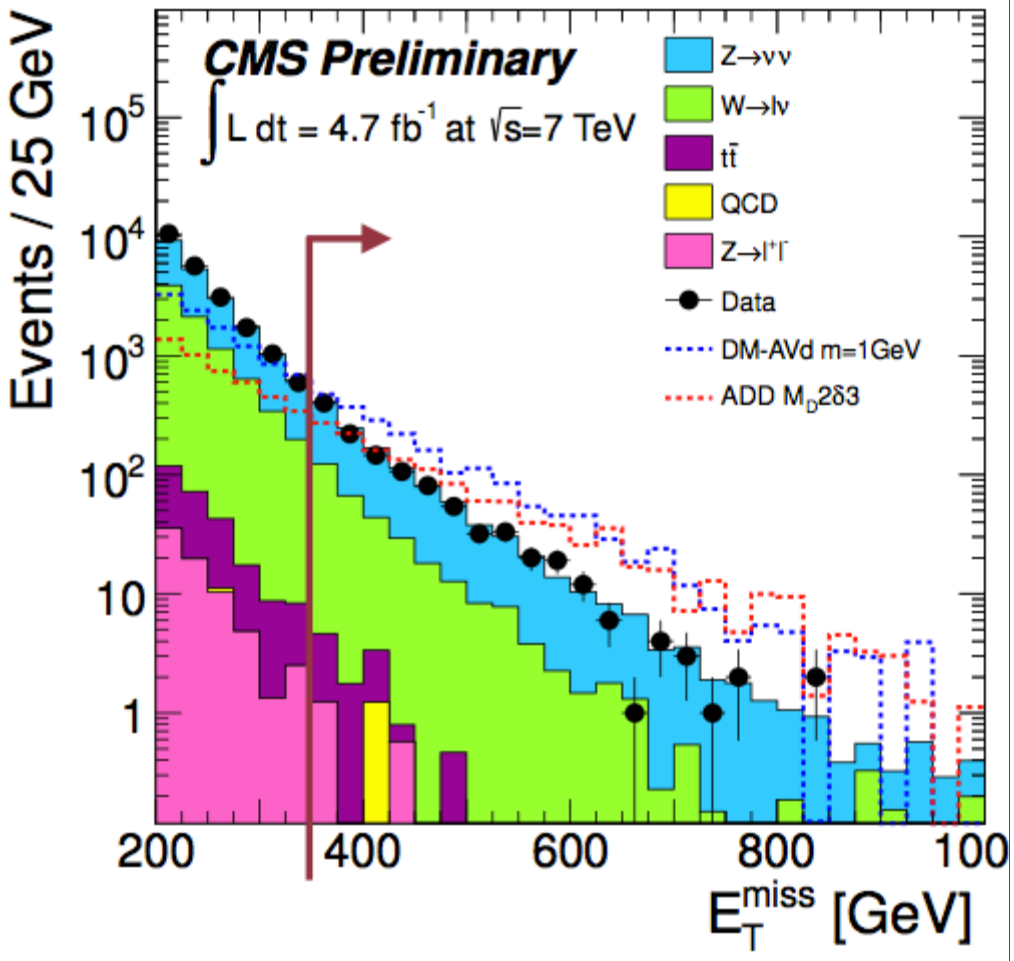
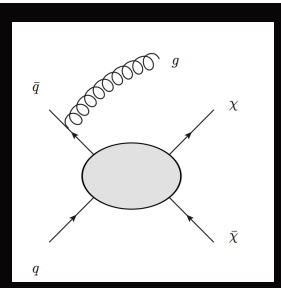
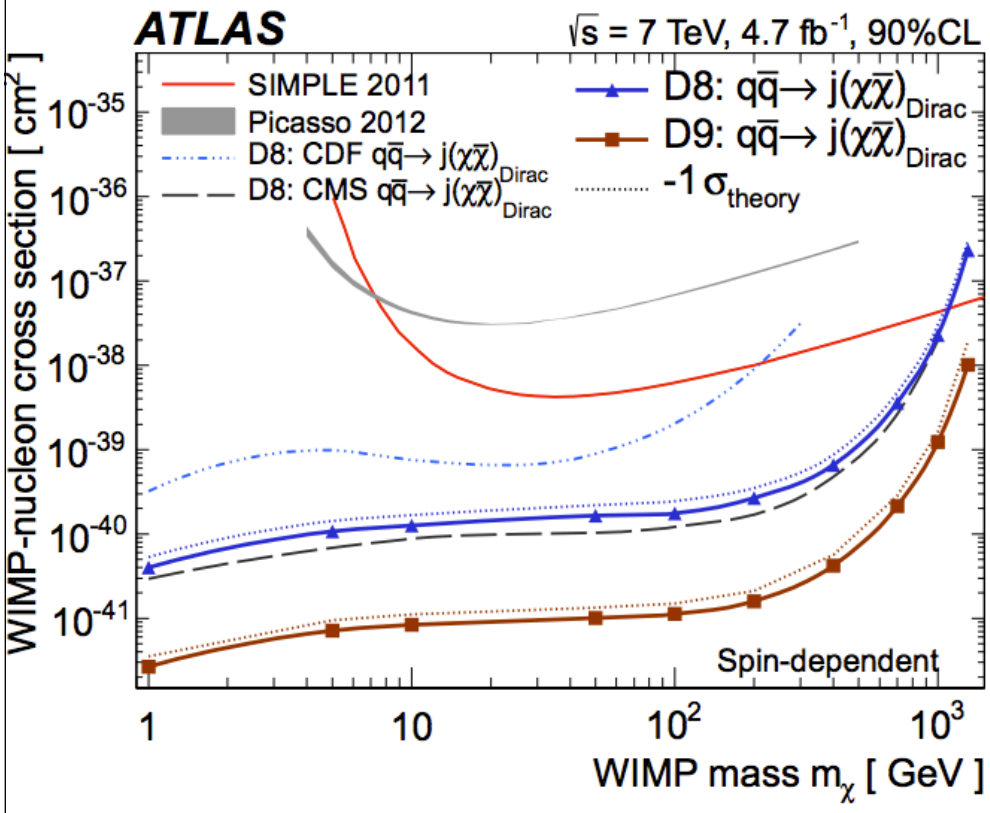
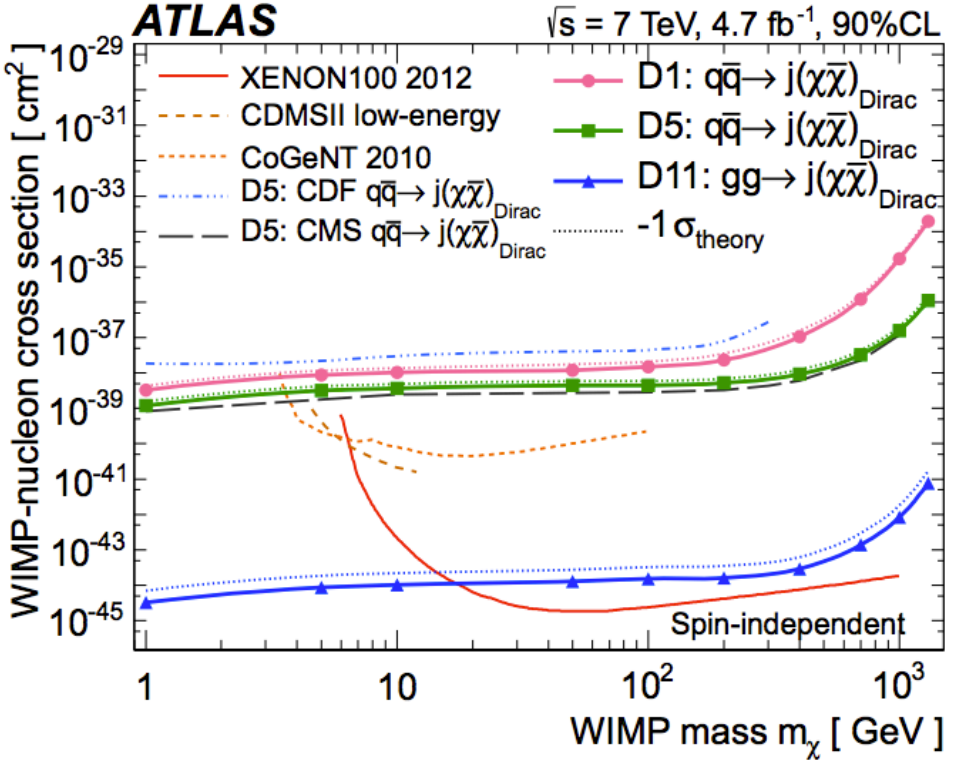
ADD δ=2 M$_D$=3.5TeV
Sum of backgrounds
Z(→νν)+jets
W(→ lν)+jets
Z(→ ll)+jets
tt̄ + single top
Di-bosons
Events/GeV
Leading jet p$_T$ [GeV]


CMS Preliminary
$\int$ L dt = 4.7 fb^{-1} at $\sqrt{s}$=7 TeV
Z→νν
W→lν
tt̄
QCD
Z→l$^+$l$^-$
Data
DM-AVd m=1GeV
ADD M$_D$2δ3
Events / 25 GeV
E$_T^{miss}$ [GeV]

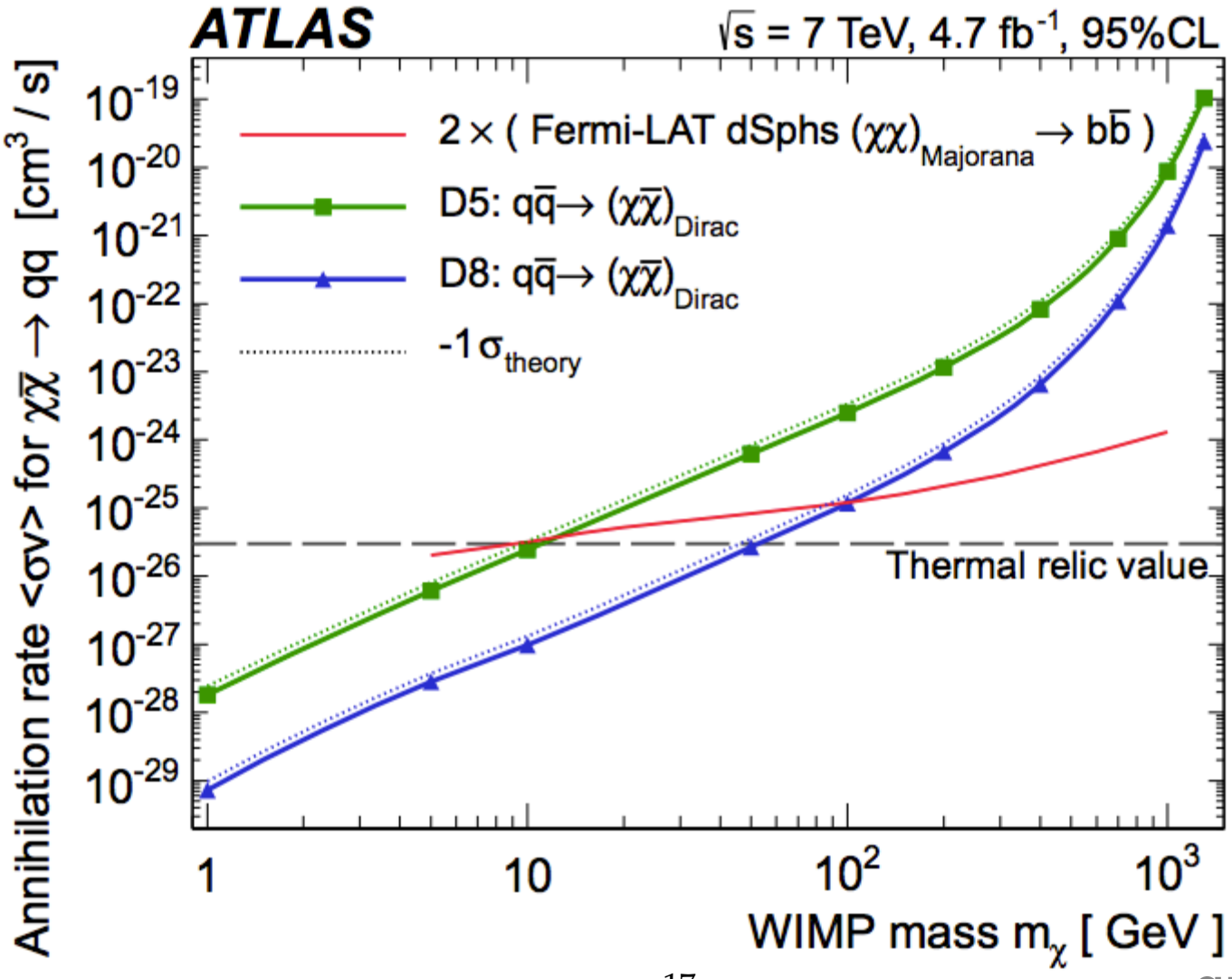
Mono-jet limits





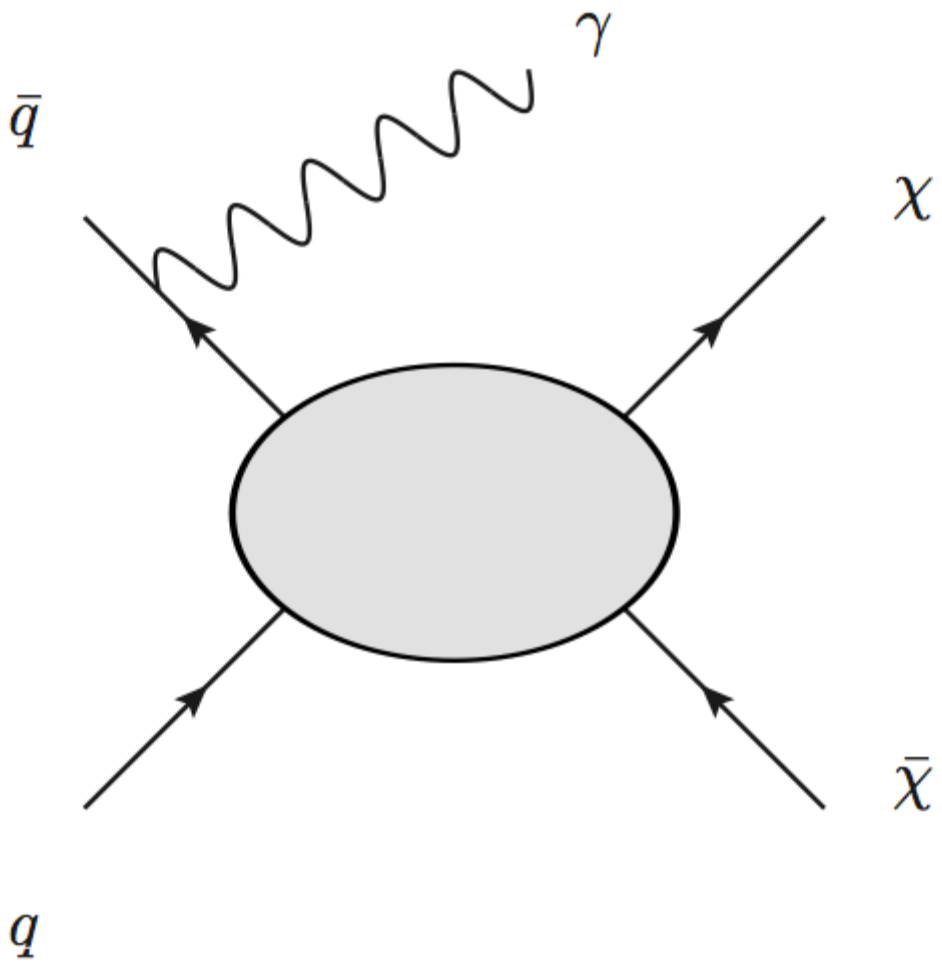


annhiliation rates

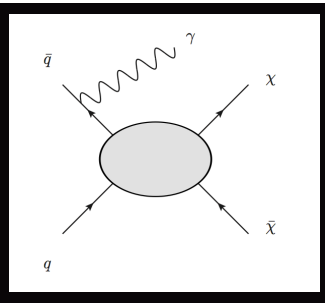


arXiv:1210.4491

Mono-photon



Mono-photon



ATLAS selection

MET > 150
photon p_T>150
0 or 1 jet with p_T>30
0 leptons
Object isolation, separation

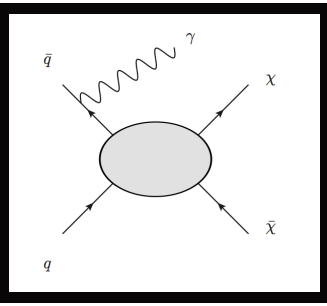
Z→νν	93
WΥ	24
W/Z+jets	18
Other	2
Total	$137_{\pm 20}$
Data	116

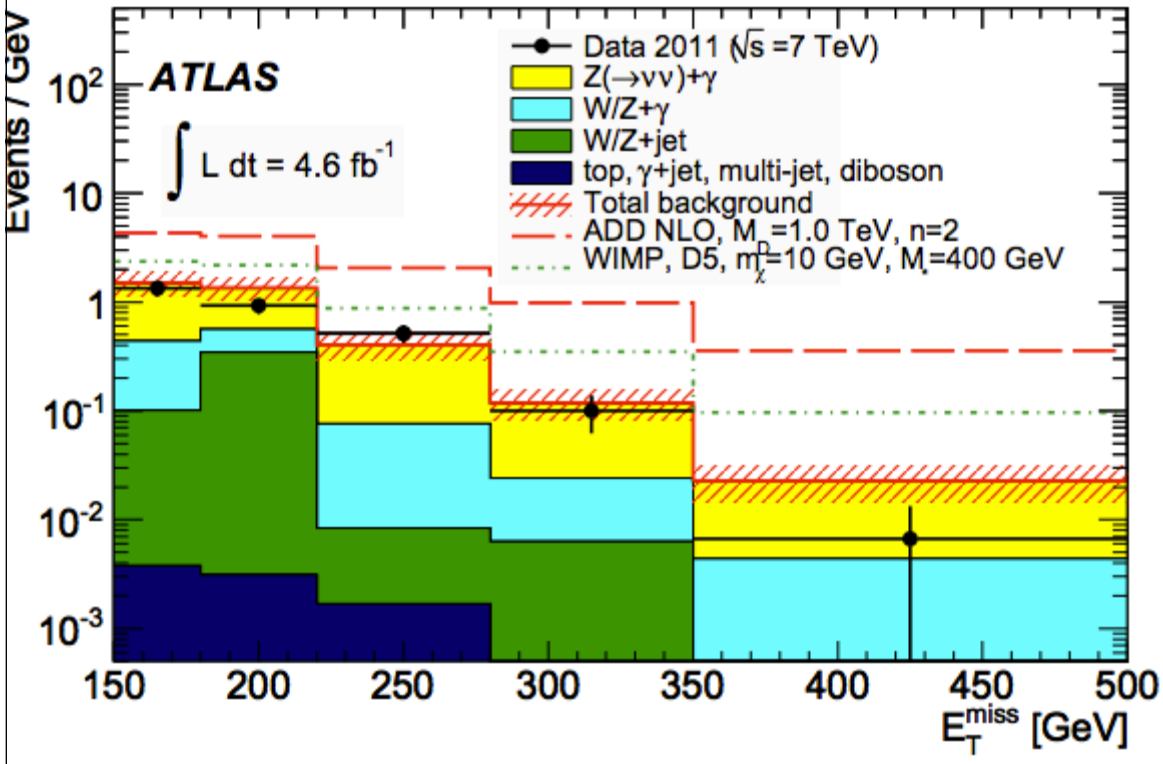
CMS selection

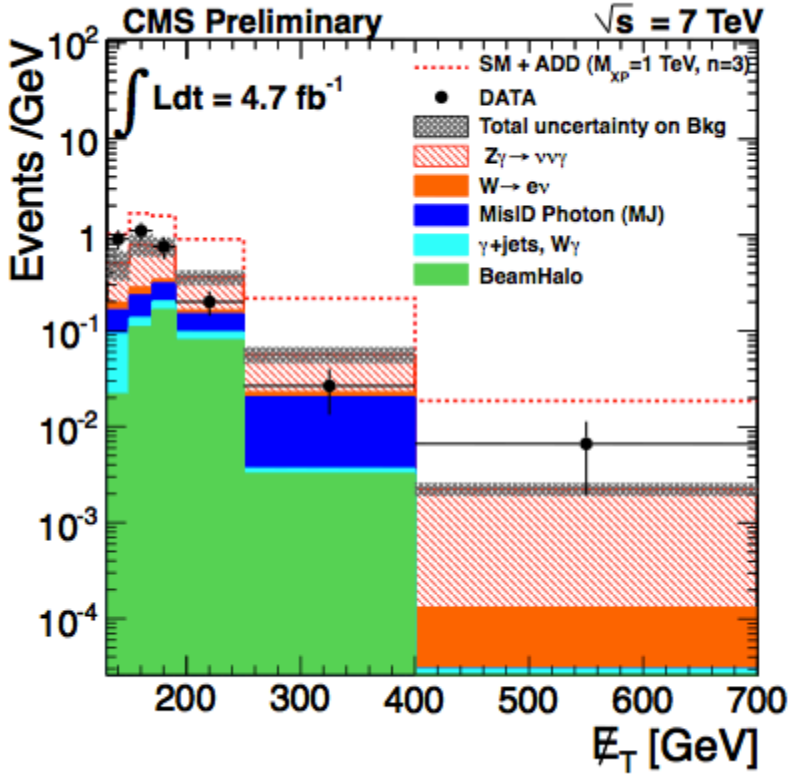
MET > 130
photon p_T>145
0 jets with p_T>40
0 leptons
Object isolation, separation

Z→νν	43
WΥ	3
W/Z+jets	15
Other	11
Total	$72_{\pm 9}$
Data	73

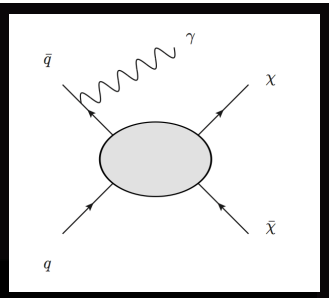
Mono-photon

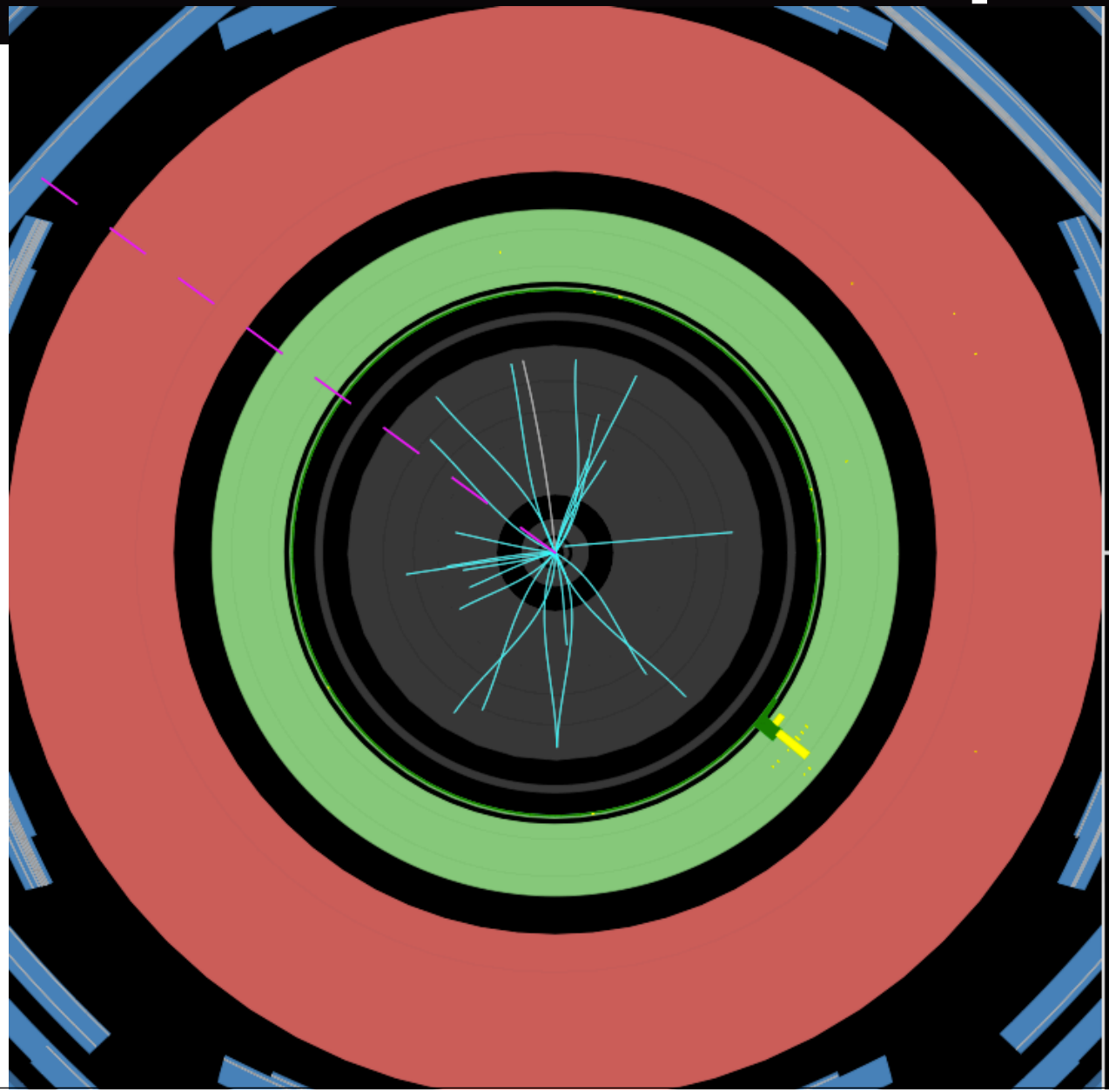

$\bar{q}$
γ
χ
q
$\bar{\chi}$

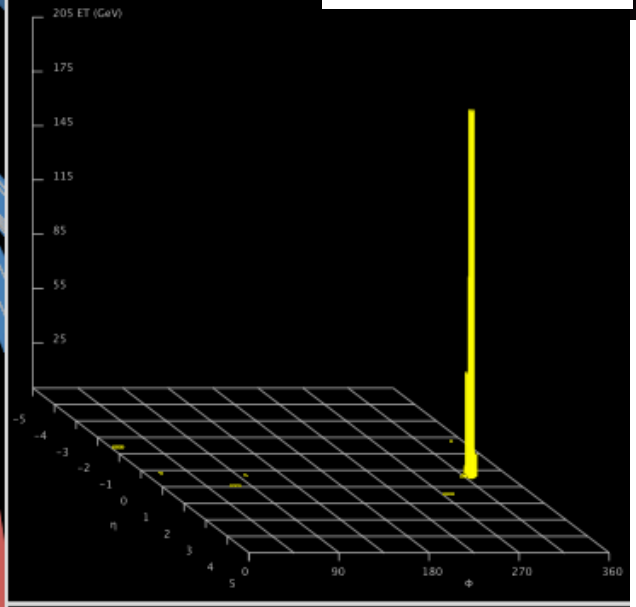

ATLAS
$\int$ L dt = 4.6 fb^{-1}
Data 2011 ($\sqrt{s}$ =7 TeV)
Z($\rightarrow\nu\nu$)+γ
W/Z+γ
W/Z+jet
top, γ+jet, multi-jet, diboson
Total background
ADD NLO, M_D=1.0 TeV, n=2
WIMP, D5, m_χ=10 GeV, M_*=400 GeV
Events / GeV
E_T^{miss} [GeV]


CMS Preliminary
$\sqrt{s}$ = 7 TeV
$\int$ Ldt = 4.7 fb^{-1}
SM + ADD (M_{xp}=1 TeV, n=3)
DATA
Total uncertainty on Bkg
$Z\gamma \rightarrow \nu\nu\gamma$
$W \rightarrow e\nu$
MisID Photon (MJ)
γ+jets, Wγ
BeamHalo
Events /GeV
$\not\!\!E_T$ [GeV]

Event display





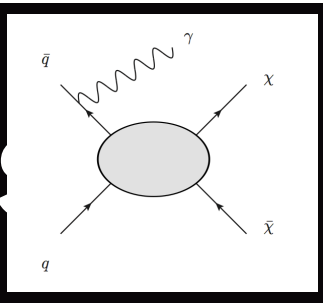


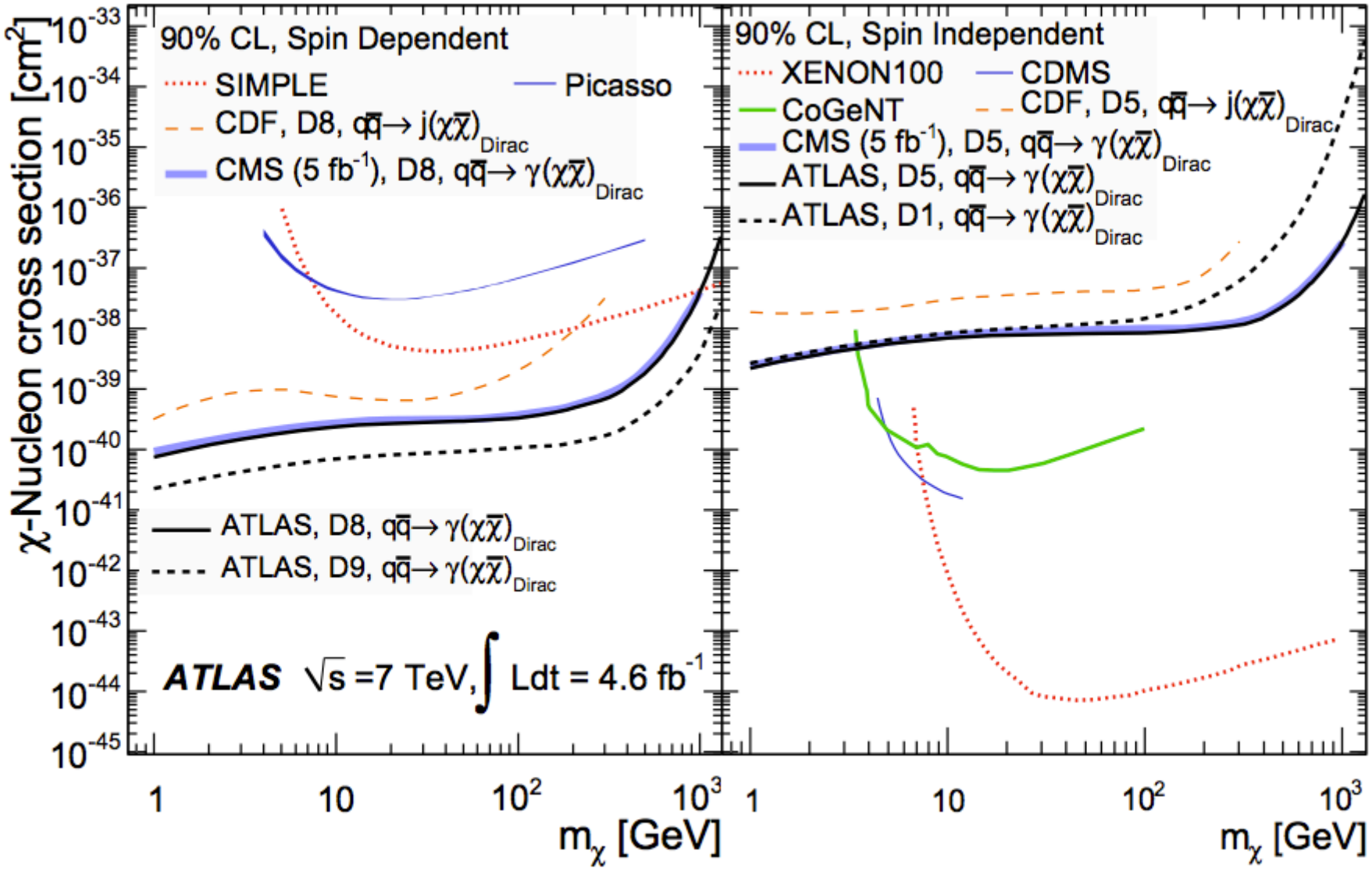
ATLAS EXPERIMENT

Run Number: 179710, Event Number: 19174449

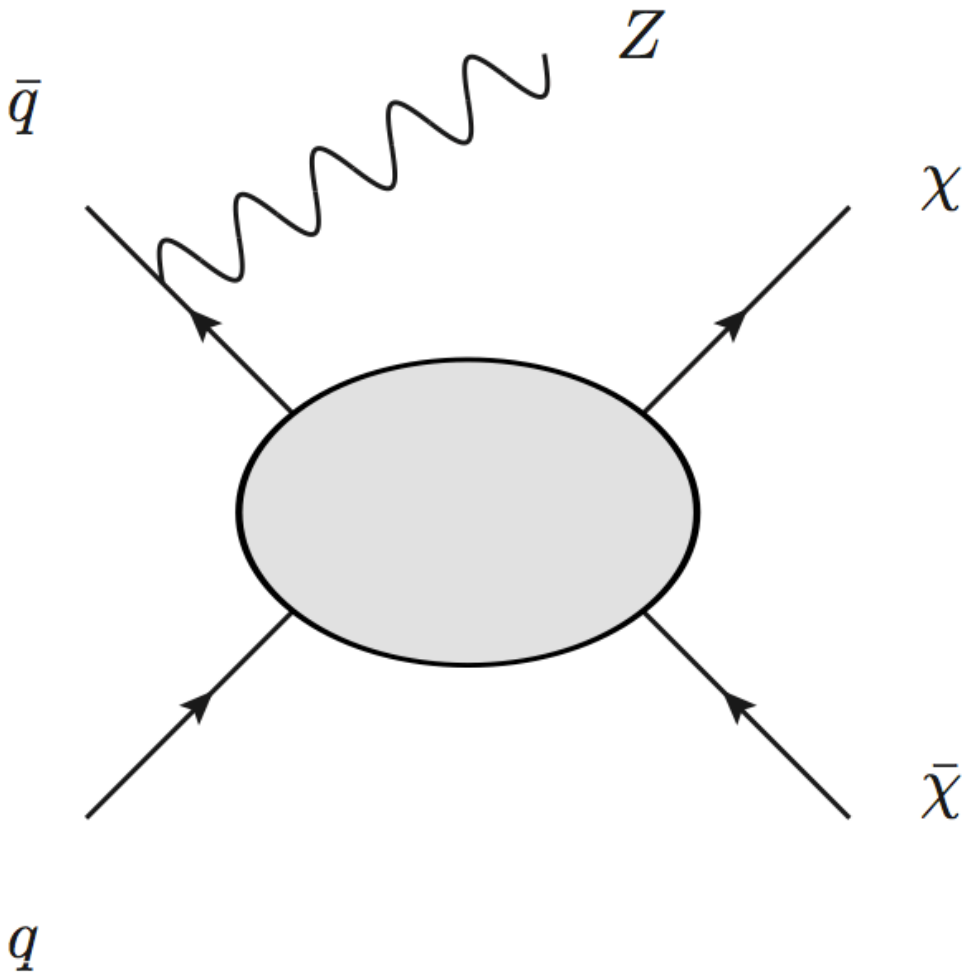
Date: 2011-04-15 03:48:32 CEST

Mono-photon limit





Mono-Z



Mono-Z

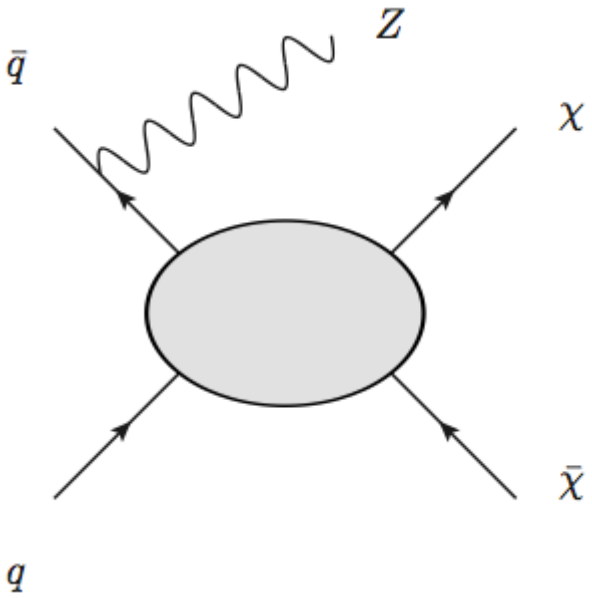
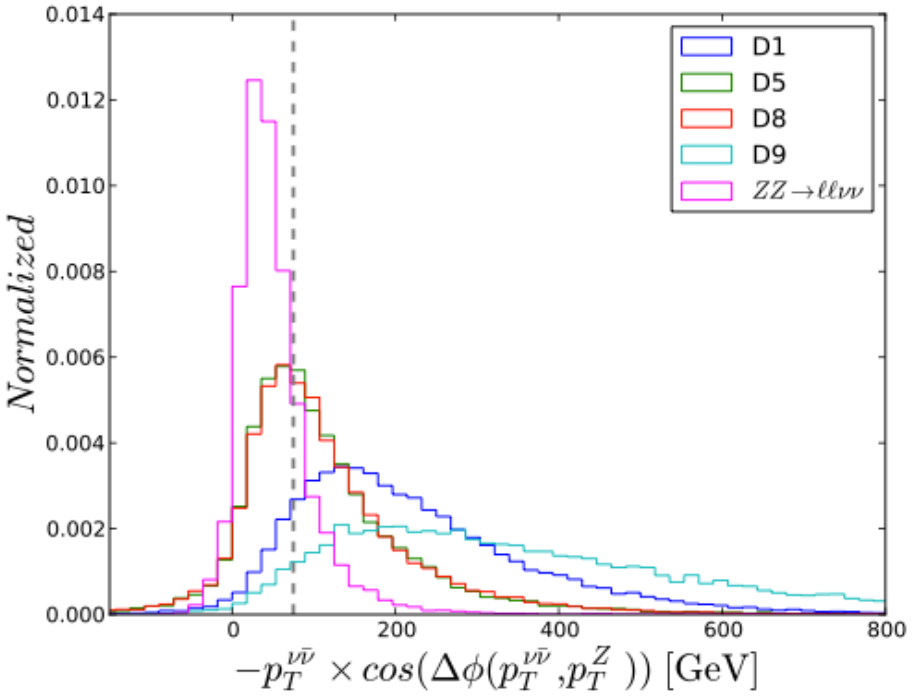


TABLE II: Expected backgrounds and observed data in the ATLAS $ZZ \to \ell\ell\nu\nu$ analysis [8] in pp collisions at $\sqrt{s} = 7$ TeV with integrated luminosity of 4.6 fb^{-1}. The first uncertainty is statistical and systematic and the second uncertainty is luminosity.

	$ee\nu\nu$	$\mu\mu\nu\nu$	$\ell\ell\nu\nu$
Background	20.8 ± 2.7	26.1 ± 3.3	46.9 ± 5.5
SM $ZZ \to \ell\ell\nu\nu$	17.8 ± 1.8	21.6 ± 2.2	39.3 ± 4.0
Total	38.6 ± 3.8	47.7 ± 4.6	86.2 ± 7.2
Data	35	52	87

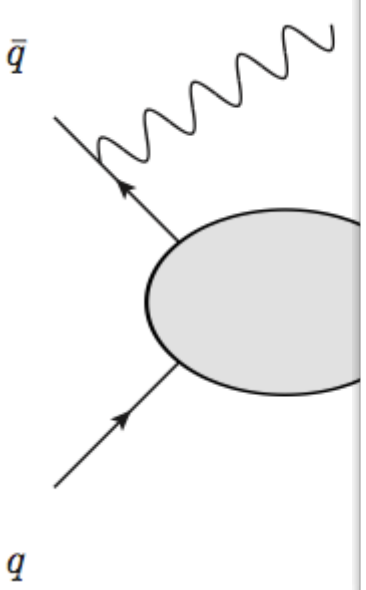


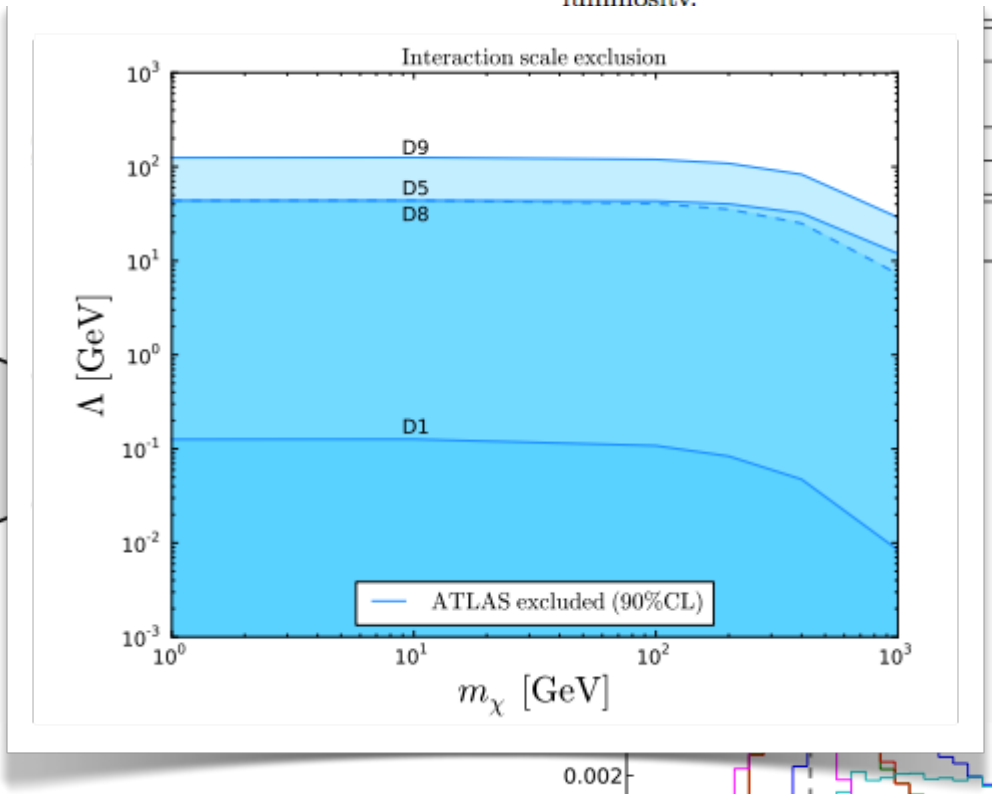
A. Nelson, T. Tait, C. Shimmin, DW
1212.3352

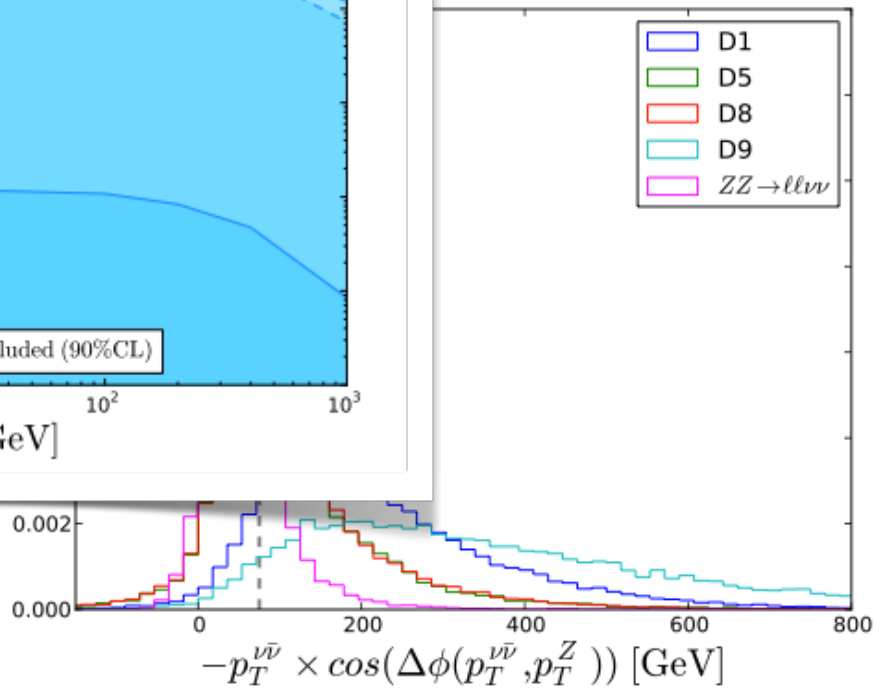
Mono-Z

TABLE II: Expected backgrounds and observed data in the ATLAS $ZZ \to \ell\ell\nu\nu$ analysis [8] in pp collisions at $\sqrt{s} = 7$ TeV with integrated luminosity of 4.6 fb^{-1}. The first uncertainty is statistical and systematic and the second uncertainty is luminosity.

	$\mu\mu\nu\nu$	$\ell\ell\nu\nu$
	26.1 ± 3.3	46.9 ± 5.5
	21.6 ± 2.2	39.3 ± 4.0
	47.7 ± 4.6	86.2 ± 7.2
	52	87





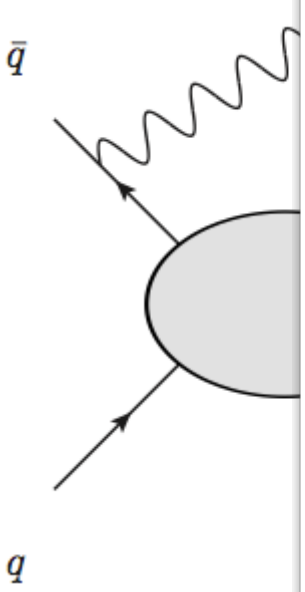


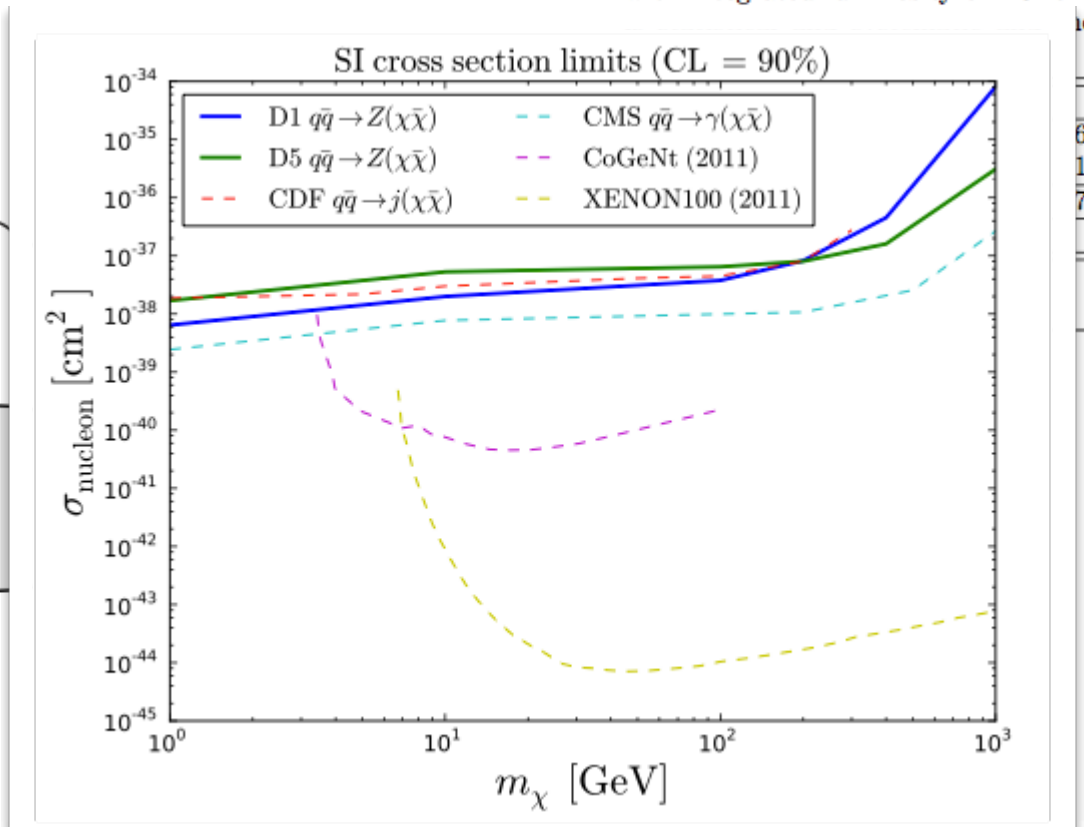
A. Nelson, T. Tait, C. Shimmin, DW
(to appear)

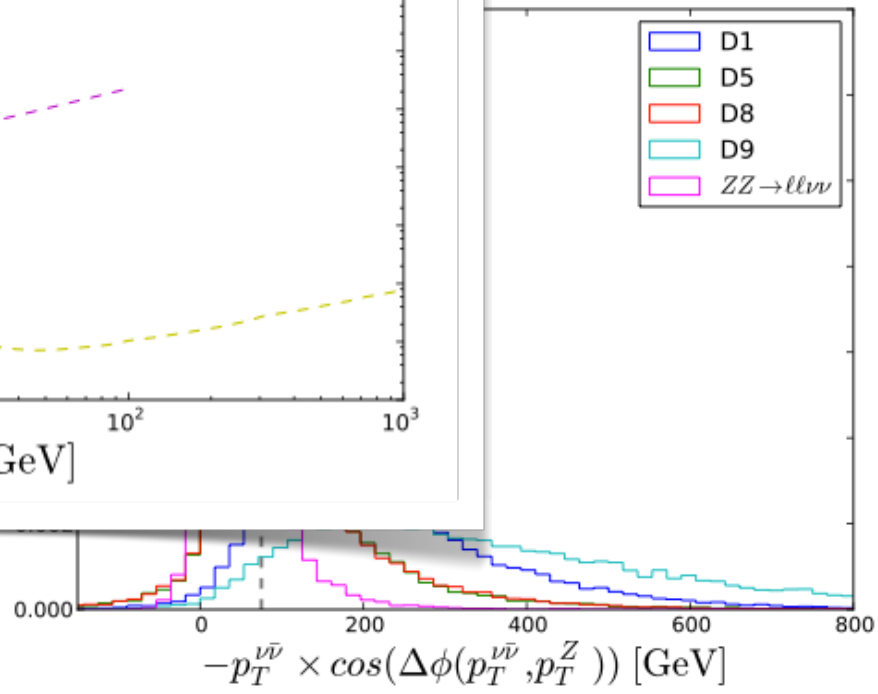
Mono-Z

TABLE II: Expected backgrounds and observed data in the ATLAS $ZZ \to \ell\ell\nu\nu$ analysis [8] in pp collisions at $\sqrt{s} = 7$ TeV with integrated luminosity of 4.6 fb^{-1}. The first uncertainty ... second uncertainty is

	$\mu\mu\nu\nu$	$\ell\ell\nu\nu$
	6.1 ± 3.3	46.9 ± 5.5
	1.6 ± 2.2	39.3 ± 4.0
	7.7 ± 4.6	86.2 ± 7.2
	52	87

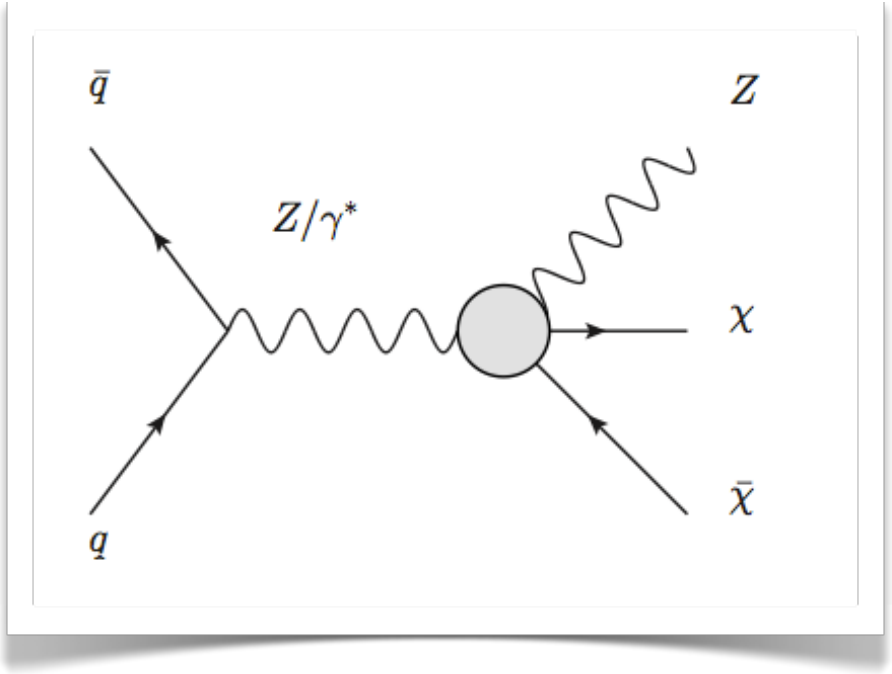


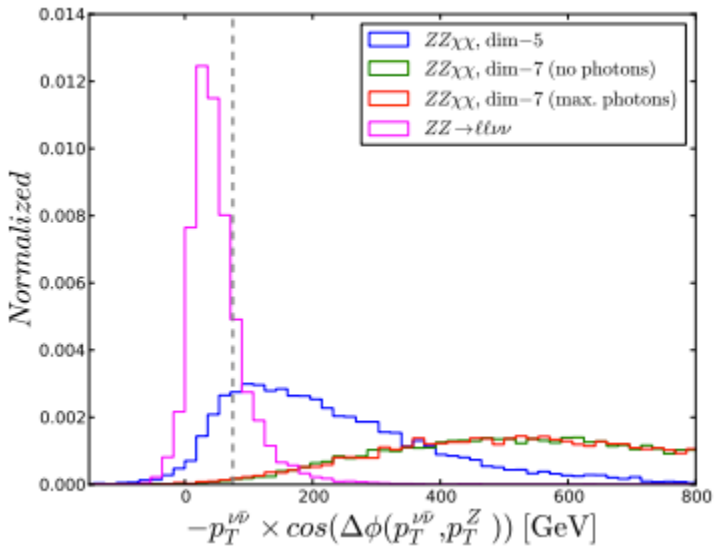


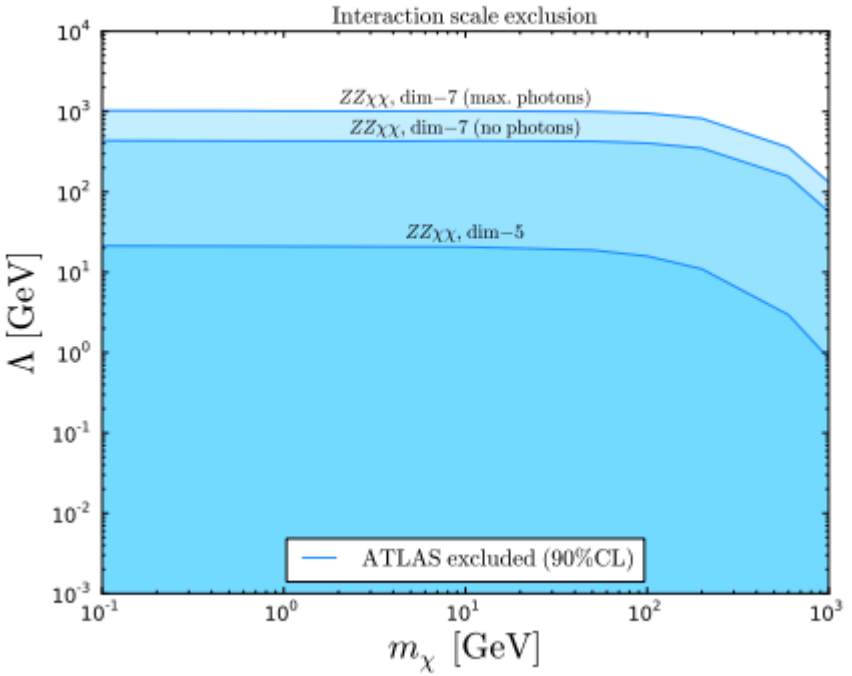


A. Nelson, T. Tait, C. Shimmin, DW
(to appear)

Mono-Z

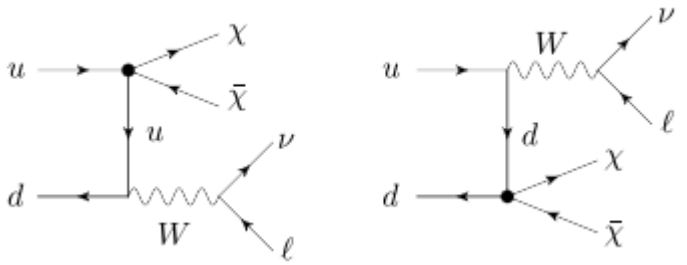


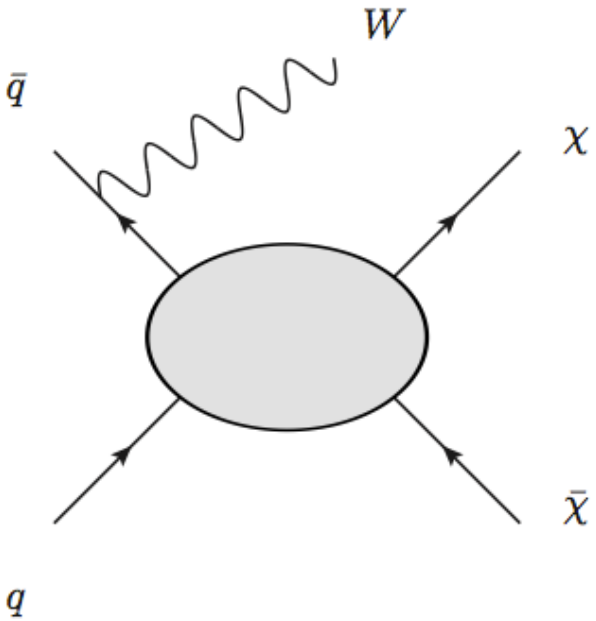




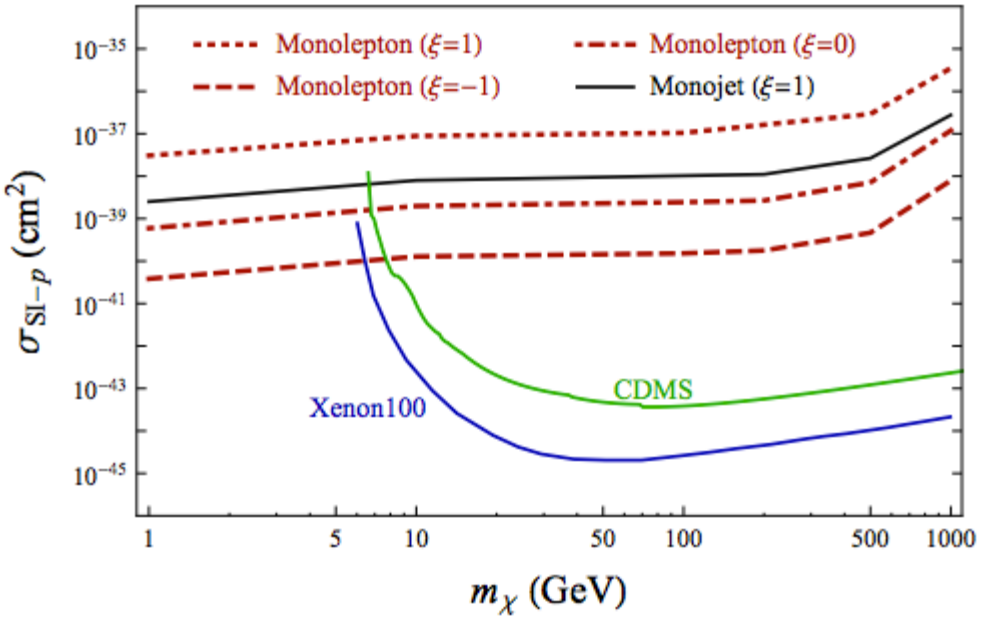
A. Nelson, T. Tait, C. Shimmin, DW
(to appear)

mono-W



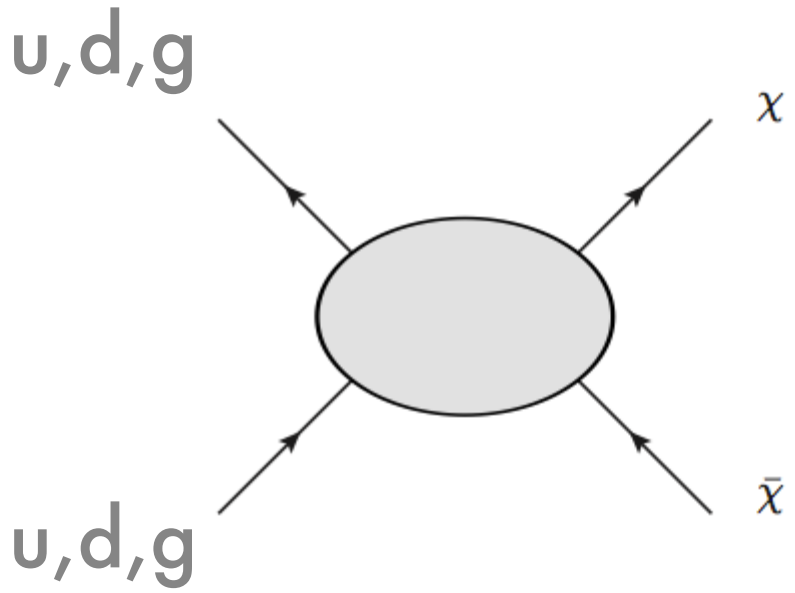


Tait and Bai
1208.4361



Collider power

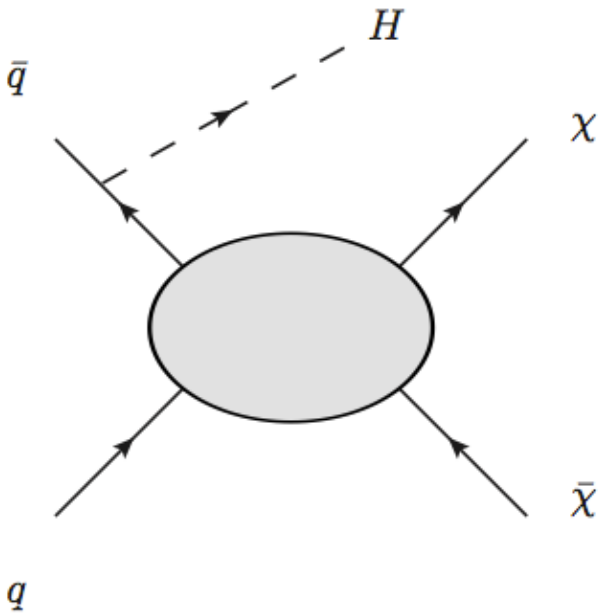
Unique possibility



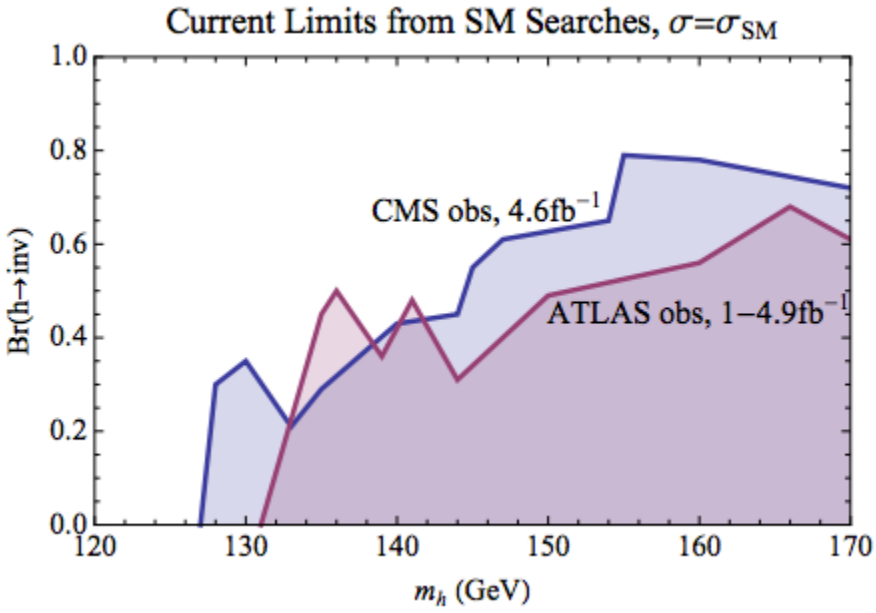
to probe up-type, down-type and gluon couplings

higgs bandwagon

Mono-Higgs



Invisible Higgs



Bai, Draper, Shelton
1112.4496

Combination

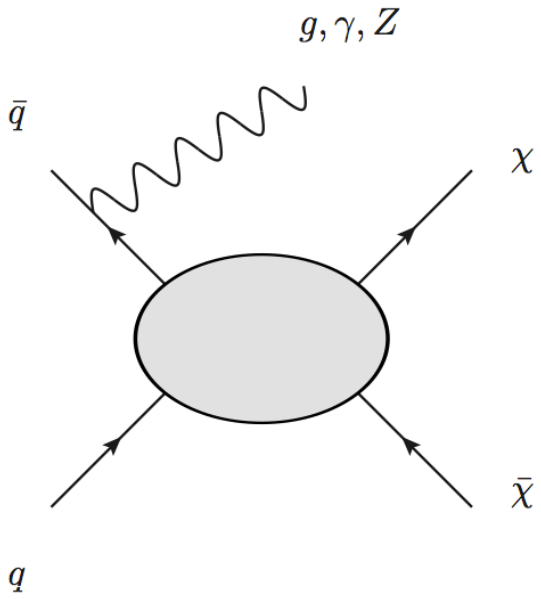
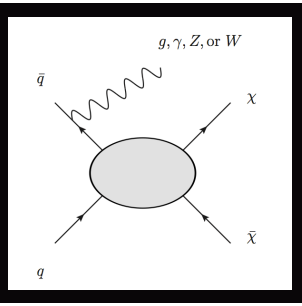


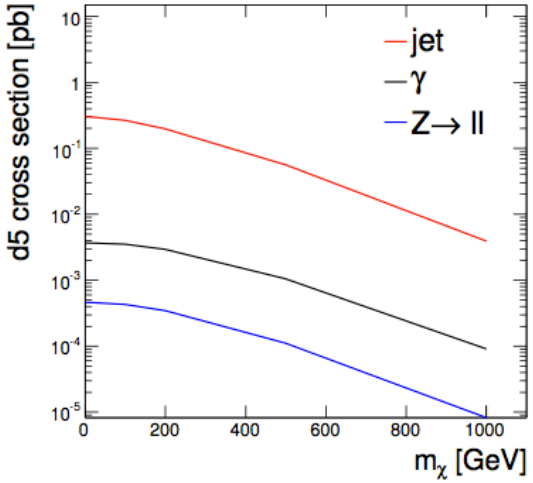
TABLE III: 90% CL limits on N_{events}, efficiencies for $m_\chi = 10$ GeV, and limits on $\sigma(pp \to \chi\chi + X)$ using the D5 operator. In the case of the $Z + \not{E}_T$ final state, the efficiency is relative to $Z \to \ell\ell$ decays only.

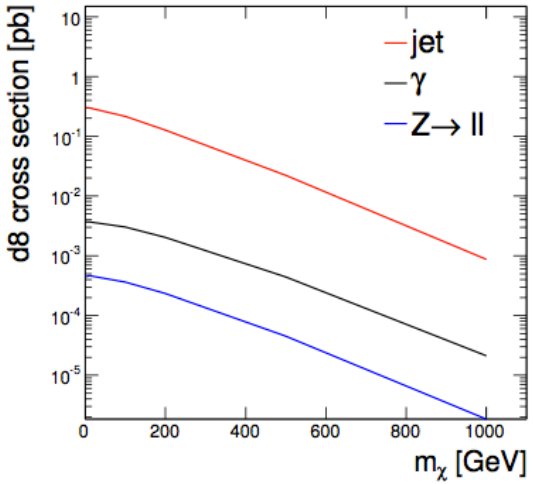
Channel	Bg.	Obs	Limit N	Eff.	Lumi. (fb^{-1})	Limit σ (fb)
ATLAS jet+$\not{E}_T$	750 ± 60	785	139.3	1.7%	4.8	1,700
CMS jet+$\not{E}_T$	1225 ± 101	1142	125.2	2.2%	5.0	1,140
ATLAS $\gamma + \not{E}_T$	137 ± 20	116	27.4	18%	4.6	33
CMS $\gamma + \not{E}_T$	75.1 ± 9.4	73	19.3	11%	5.0	35
ATLAS $Z + \not{E}_T$	86.2 ± 7.2	87	21.7	13%	4.6	36

N. Zhou, DW
(to appear)

Combination







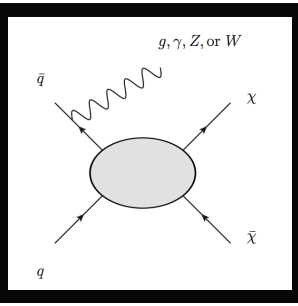
D5, WIMP mass of 10 GeV

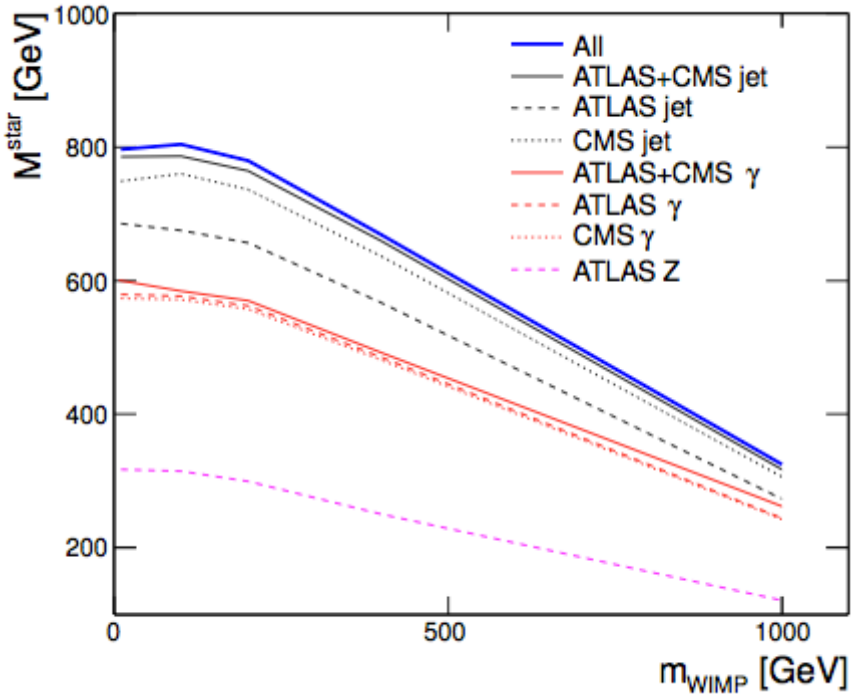
TABLE V: 90% CL limits on $\sigma(pp \to \chi\chi + X)$ for $m_\chi = 10$ GeV, theory prediction for $M_\star = 1$ TeV, and limits on $M_\star$ using the D5 operator. In the case of the $Z + \not{E}_T$ final state, the prections include the $Z \to \ell\ell$ branching fraction.

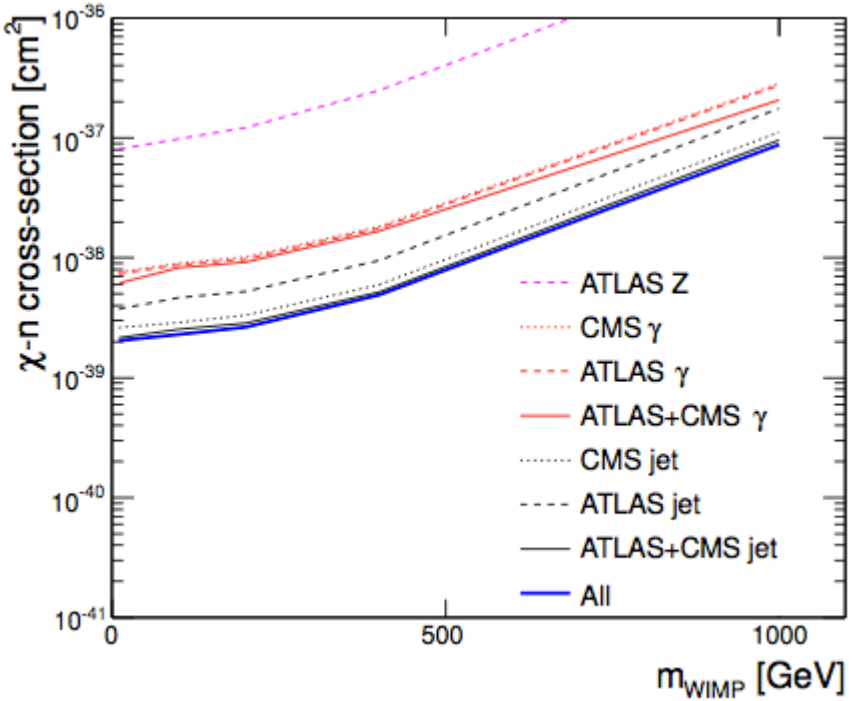
Channel	Limit σ (fb)	Pred. Limit $M_\star$ ($M_\star = 1$ TeV)	$M_\star$ (GeV)		
ATLAS jet+$\not{E}_T$	1,700	370	685	} 785	
CMS jet+$\not{E}_T$	1,140	370	750		
ATLAS $\gamma + \not{E}_T$	33	3.7	580	} 645	} 795
CMS $\gamma + \not{E}_T$	35	3.7	570		
ATLAS $Z + \not{E}_T$	36	0.5	340		

N. Zhou, DW
(to appear)

Combined: D5

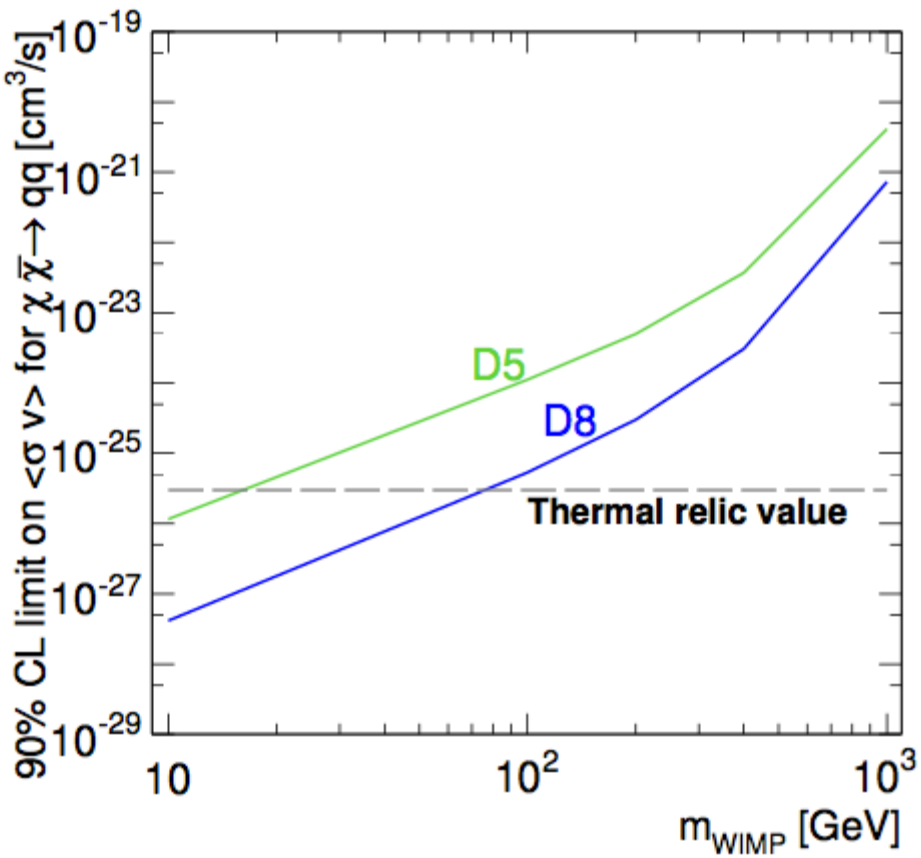


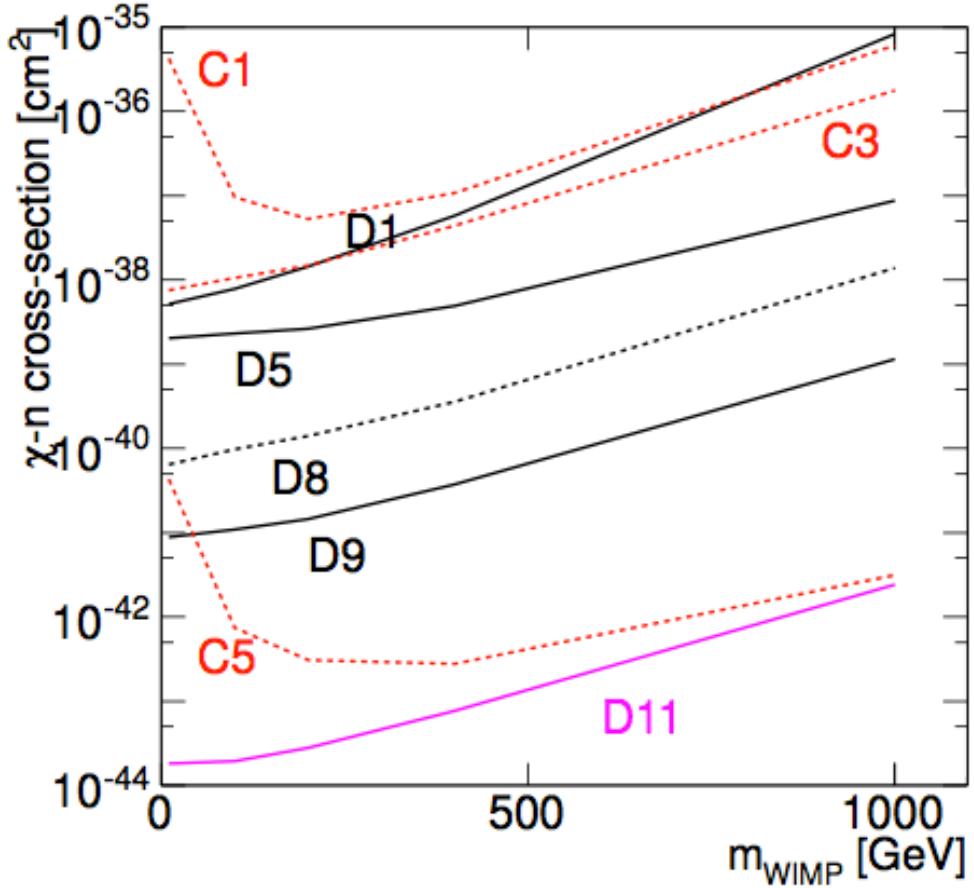




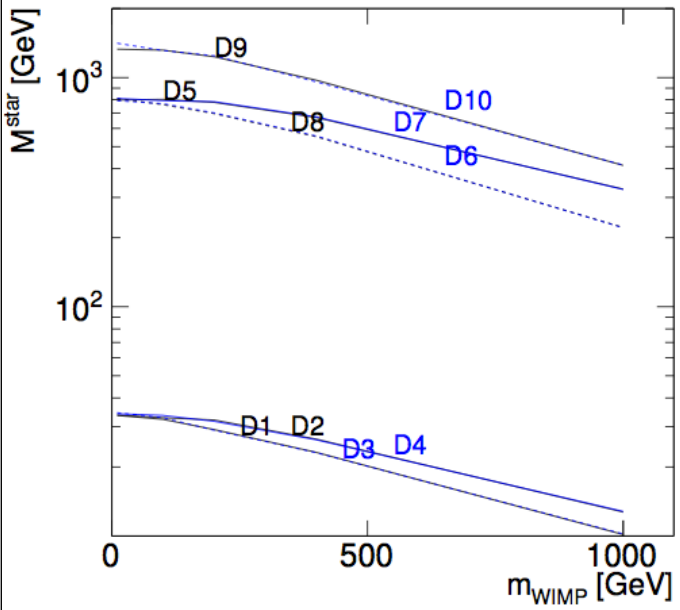
N. Zhou, DW
(to appear)

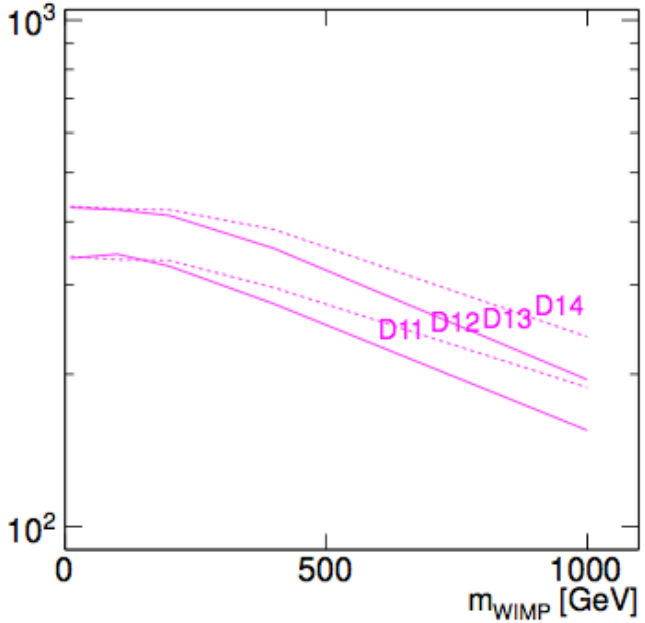
Combined limits

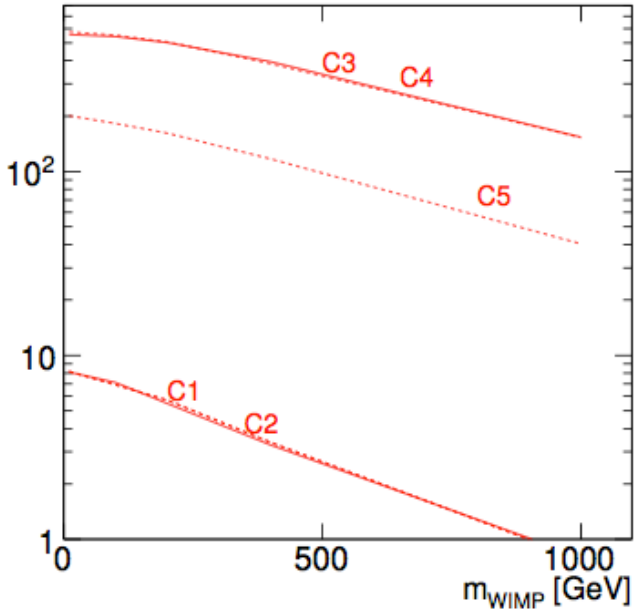




Combined limits







Conclusions

Years after DM is postulated, we still have little idea about what we are doing.

Colliders are a good place for the clueless.

ATLAS+CMS provide powerful, multi-faceted probes.