IPhT CEA-Saclay

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Wino-like Minimal Dark Matter at colliders

Based on 1407.7058 with Marco Cirelli and Filippo Sala

Physics Challenges in the face of LHC-14

Madrid 22-23/09 2014

Minimal Dark Matter

Minimalistic approach: add to SM an extra gauge multiplet and search for assignments giving a viable DM candidate

Requirements for DM: stable, neutral and allowed by DM searches

$$\mathscr{L}_{\rm SM} + c \begin{cases} \bar{\mathcal{X}}(i\not{D} + M)\mathcal{X} & \text{when } \mathcal{X} \text{ is a spin 1/2 fermionic multiplet} \\ |D_\mu \mathcal{X}|^2 - M^2|\mathcal{X}|^2 & \text{when } \mathcal{X} \text{ is a spin 0 bosonic multiplet} \end{cases}$$

Stable for large enough repr. , 5 (7) for fermions (scalars), renormalizable and dim 5 operators do not lead to fast decays

Constraints from DM searches: no colored, Y=0 to avoid large Z-mediated SI scattering cross section with nuclei. Pure SU(2) multiplets

Cirelli, Fornengo, Strumia hep-ph/0512090

Minimal Dark Matter

From Cirelli, Strumia 0903.3381

Quantum numbers			DM can	DD	Stable?
$SU(2)_L$	$U(1)_Y$	Spin	decay into	bound?	
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×
4	1/2	S	HHH^*	×	×
4	1/2	F	(LHH^*)	×	×
4	3/2	S	HHH	×	×
4	3/2	F	(LHH)	×	×
5	0	S	(HHH^*H^*)	√	×
5	0	F	–	√	√
5	1	S	$(HH^*H^*H^*)$	×	×
5	1	F	–	×	√
5	2	S	$(H^*H^*H^*H^*)$	×	×
5	2	F	–	×	√
6	1/2, 3/2, 5/2	S	–	×	√
7	0	S	–	√	√
8	1/2, 3/2 ...	S	–	×	√

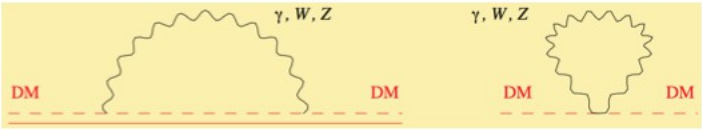
DM mass fixed for a thermal relic to match measured DM abundance.
Mass in the multi-TeV range (10 TeV for 5-plet and 25 TeV for 7-plet)

Triplet DM candidate

Quantum numbers			DM can	DD	Stable?
$SU(2)_L$	$U(1)_Y$	Spin	decay into	bound?	
2	1/2	S	EL	×	×
2	1/2	F	EH	×	×
3	0	S	HH^*	√	×
3	0	F	LH	√	×
3	1	S	HH, LL	×	×
3	1	F	LH	×	×

Fermionic triplet **stable** if L or B-L is respected (or at least matter parity)

Lightest component is **neutral**
Mass splitting at 2 loop $\Delta M = 164.5 \pm 0.5$ MeV



Ibe et al. 1212.5989

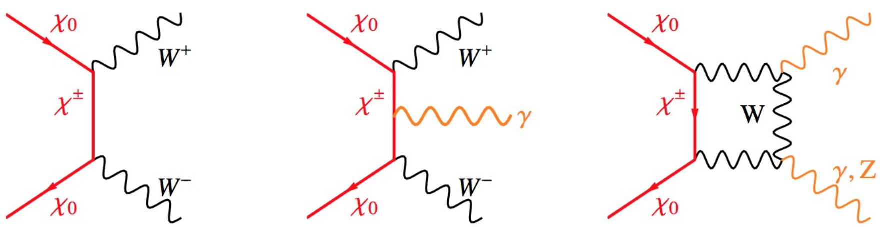
Capture low-energy pheno of SUSY models with **WINO LSP** and heavy scalars

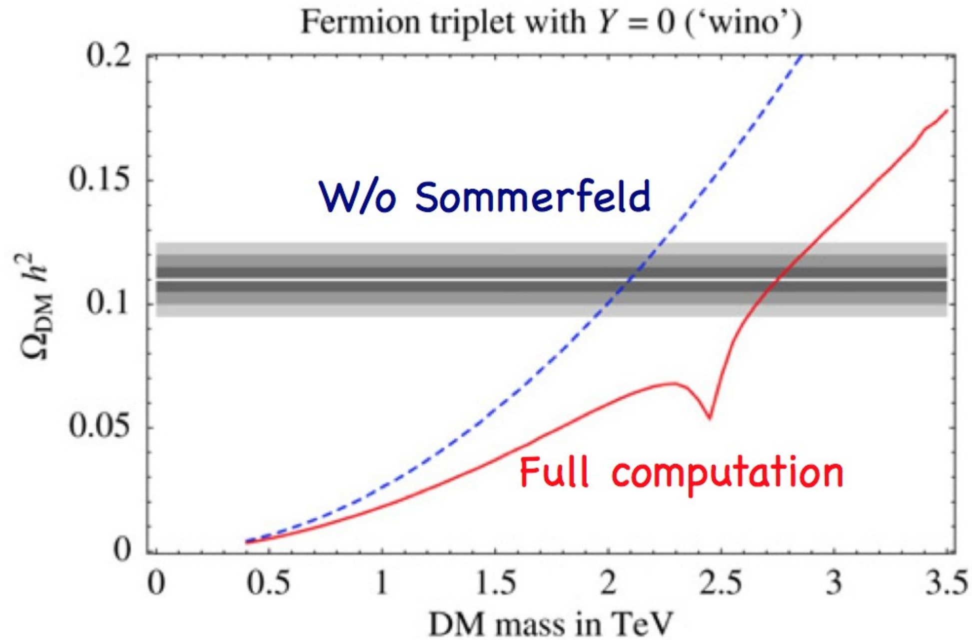
Relic abundance

Dominant annihilation channel is WW
Relic abundance calculation should include:

Coannihilations with charged state in the multiplet

Sommerfeld corrections



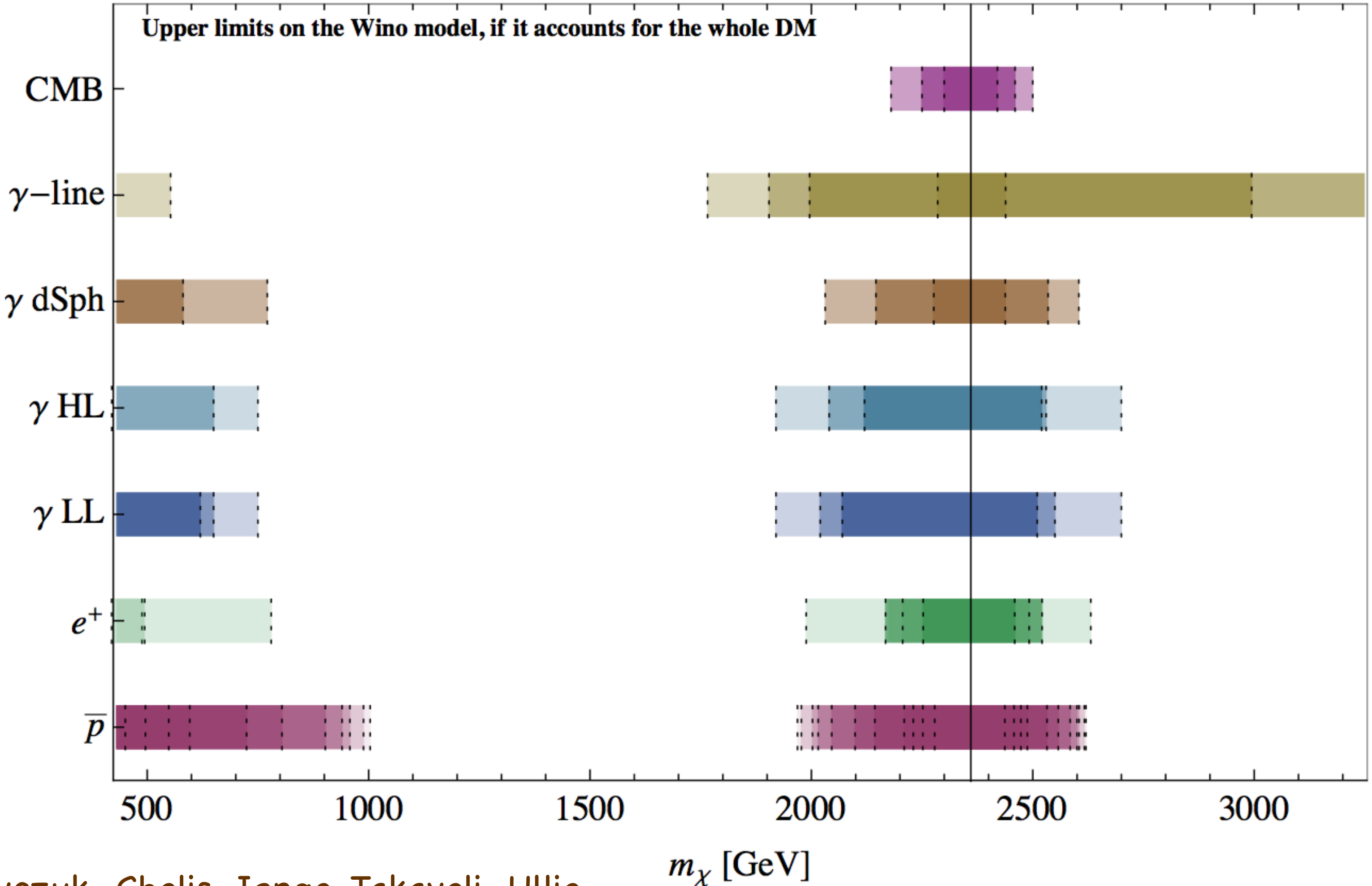


Correct abundance for M around 3 TeV.
Under-abundant (over-abundant) for a lighter (heavier) triplet
All masses possible for non-thermal production

Cirelli,, Strumia, Tamburini 0706.4071

Indirect detection bounds

Bounds depend on astrophysical assumptions like DM density profiles, cosmic-rays propagation… Shading corresponds to different choices



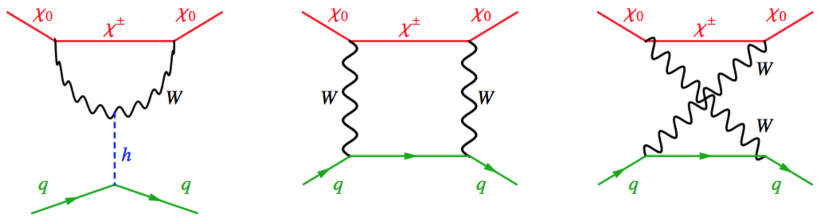
From Hryczuk, Cholis, Iengo, Takavoli, Ullio 1401.6210

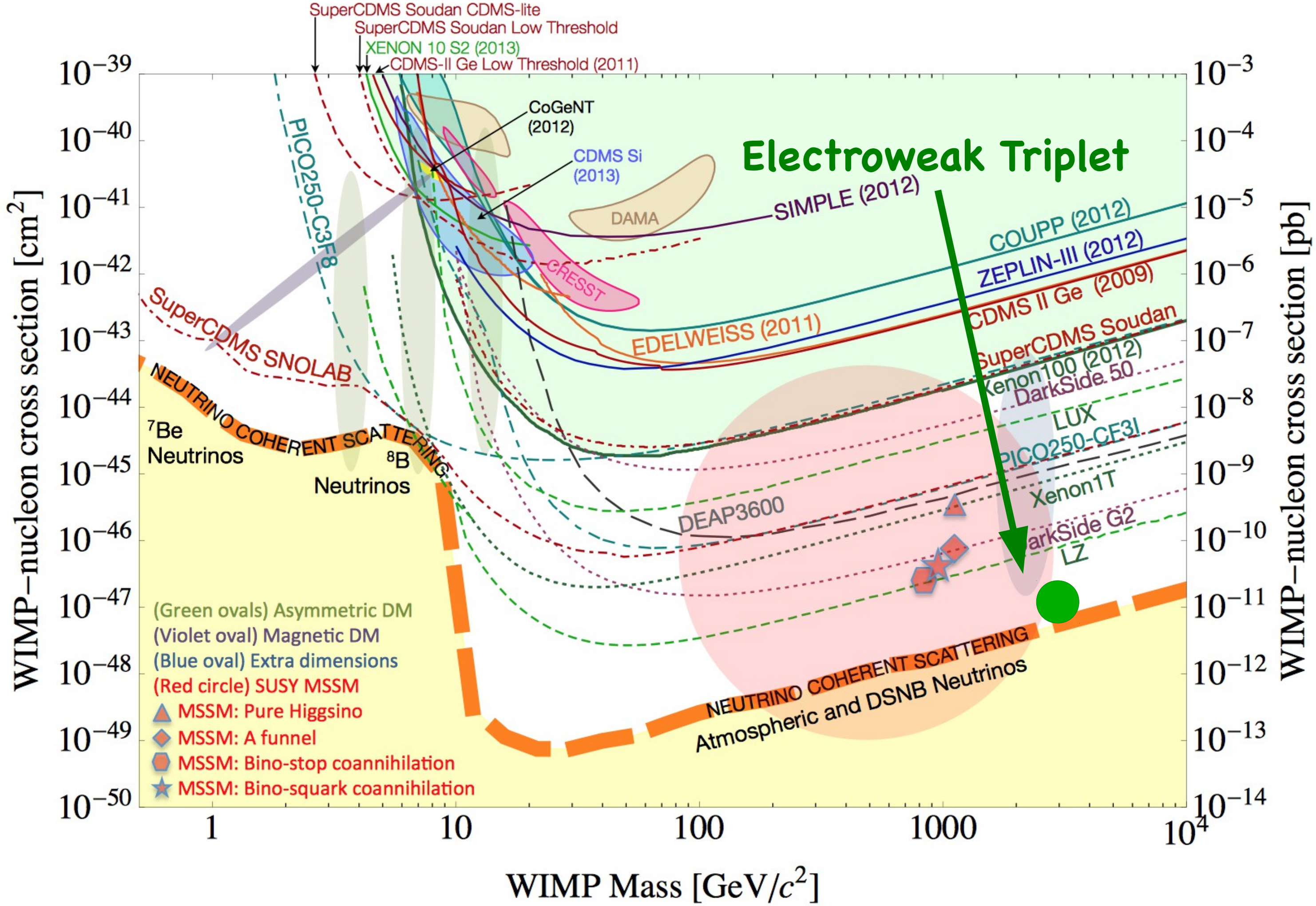
See also Cohen et al. 1307.4082 Fan, Reece 1307.4400

Direct detection

Cross-section $\sigma_{SI} = 1.3\ 10^{-47}\ cm^2$

Hill, Solon 1309.4092

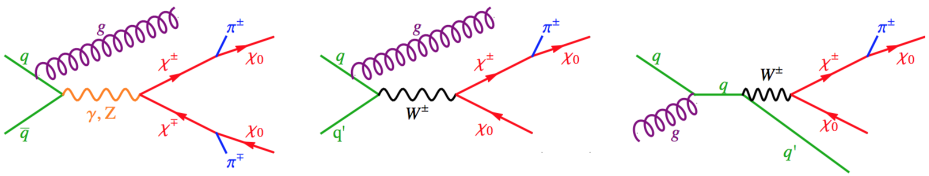




Triplet at Hadron Collider

Mass splitting between charged and neutral components around 165 MeV

Charged state decays into DM + soft pions



Channel considered: mono-jet, mono-photon, Vector Boson Fusion, disapperaring tracks

Focus on LHC 14 TeV with L=3000 fb^{-1} and future 100 TeV pp collider with L=3000 fb^{-1}

$$\text{Significance} = \frac{S}{\sqrt{B + \alpha^2 B^2 + \beta^2 S^2}}$$

Sum in quadrature statistic and systematic errors

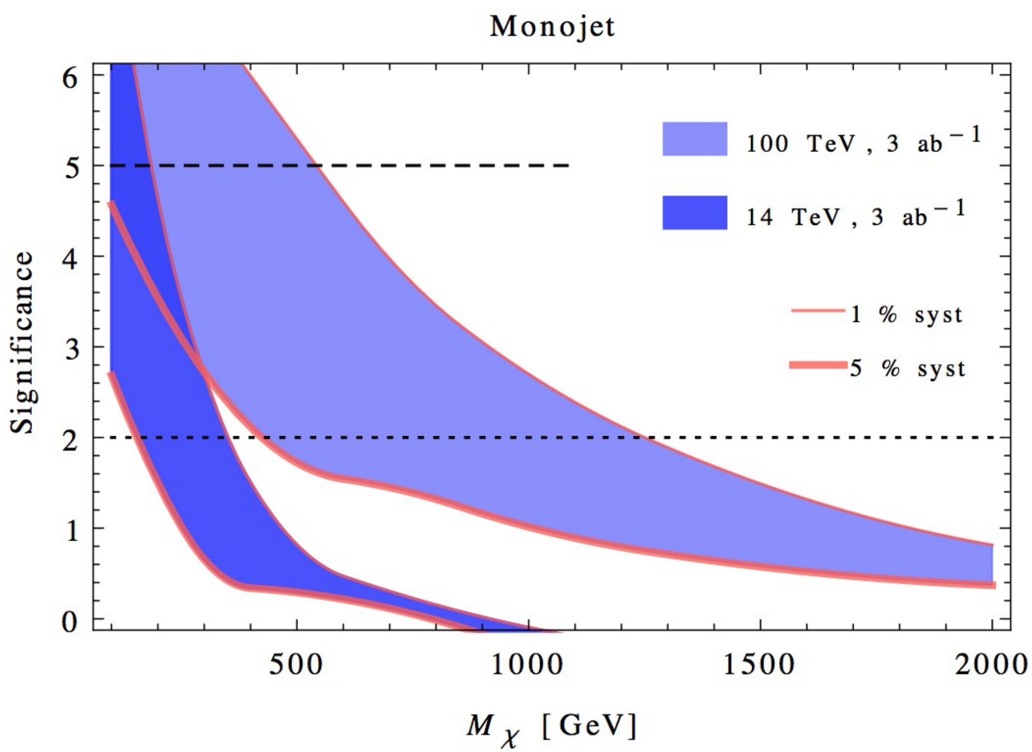
For a recent analysis of Wino LSP at 14-100 TeV with mono-jet and disappearing tracks

Low, Wang 1404.0682

Monojet

Background: mainly Z(nu nu)+jets and W(l nu)+jets
Cuts on jets, MET, leptons similar to ATLAS-CMS mono-jet analysis rescaled to optmize sensitivity

Madgraph5 + Pythia + Delphes

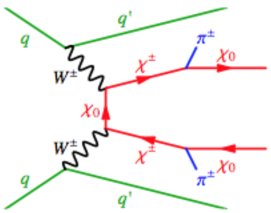


Systematic errors are crucial!

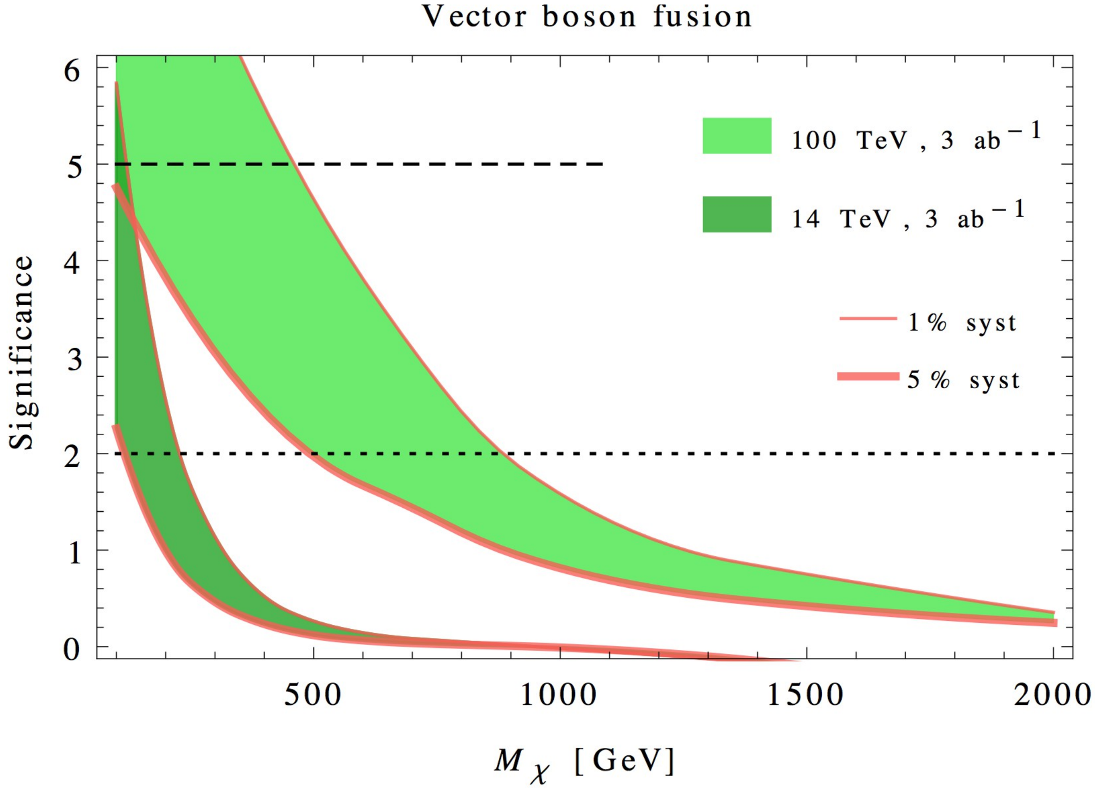
See also Low, Wang 1404.0682

Dijet channel

VBF processes characterized by 2 forward jets
Apply cuts on rapidity, invariant mass and pT to reduce QCD background

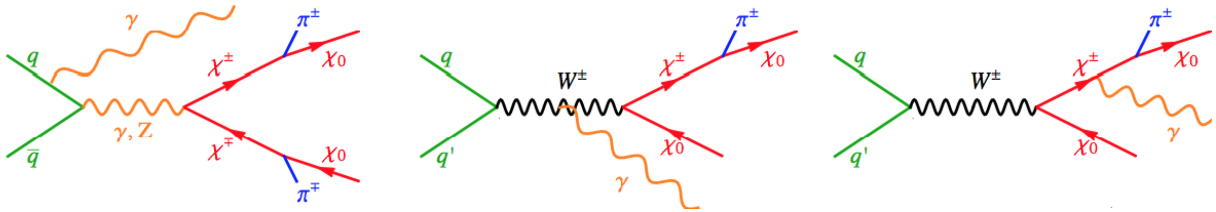


Cuts	14 TeV	100 TeV 3 ab^{-1}	100 TeV 30 ab^{-1}
$\not{E}_T$[TeV]	$0.4 - 0.7$	$1.5 - 5.5$	$1.5 - 5.5$
$p_T(j_{12})$ [GeV]	40 (1%), 60 (5%)	150	200
M_{jj} [TeV]	1.5 (1%), 1.6 (5%)	6 (1%), 7 (5%)	7
$\Delta\eta_{12}$	3.6	3.6	3.6 (1%), 4 (5%)
$\Delta\phi$	$1.5 - 3$	$1.5 - 3$	$1.5 - 3$
$p_T(j_3)$ [GeV]	25	60	60
$p_T(\ell)$ [GeV]	20	20	20
$p_T(\tau)$ [GeV]	30	40	40

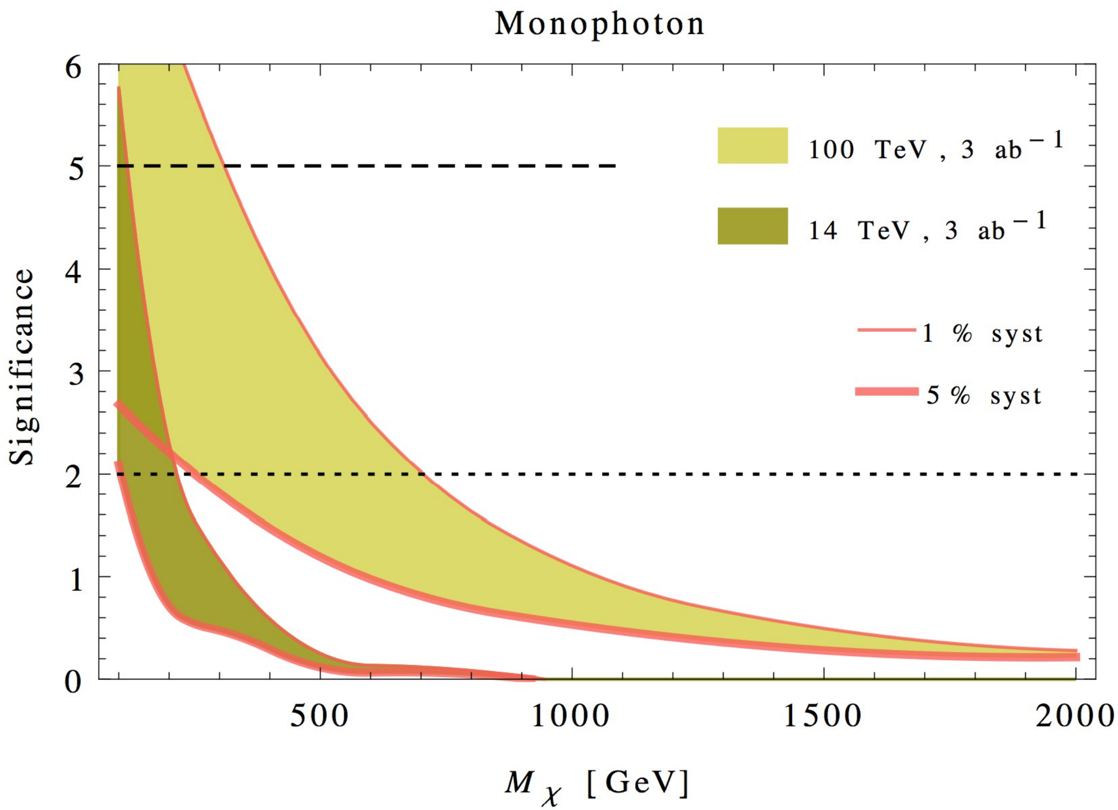


Smaller sensitivities than mono-j

Mono-photon

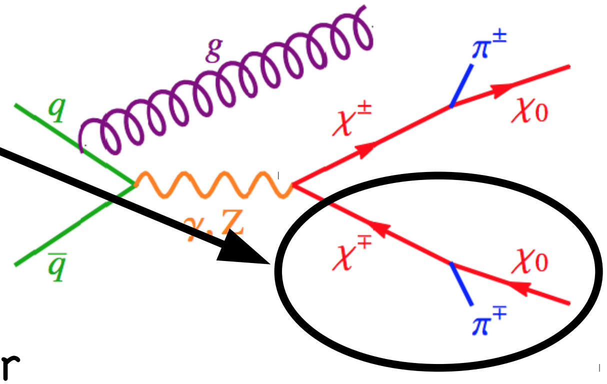


Qualitatively the same: systematics are crucial. 100 TeV increase the reach of a factor 3-4



Disappearing tracks

Lifetime of charged particle around 0.2 ns
Charged tracks of ~ 10 cm

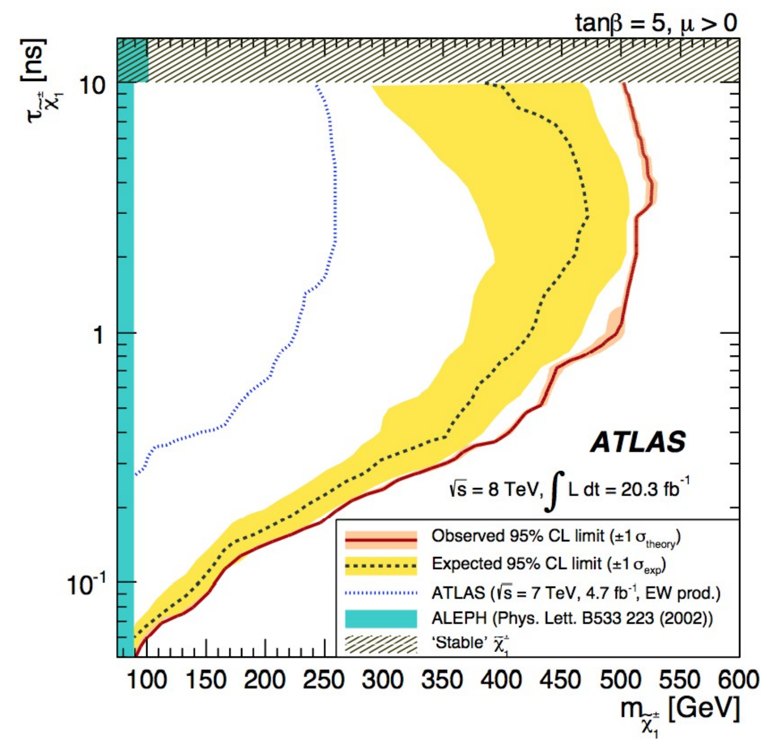


Backgrounds:

- interactions of charged hadrons in the detector

- unidentified leptons

- pT mis-measured tracks
  (dominant at large pT)

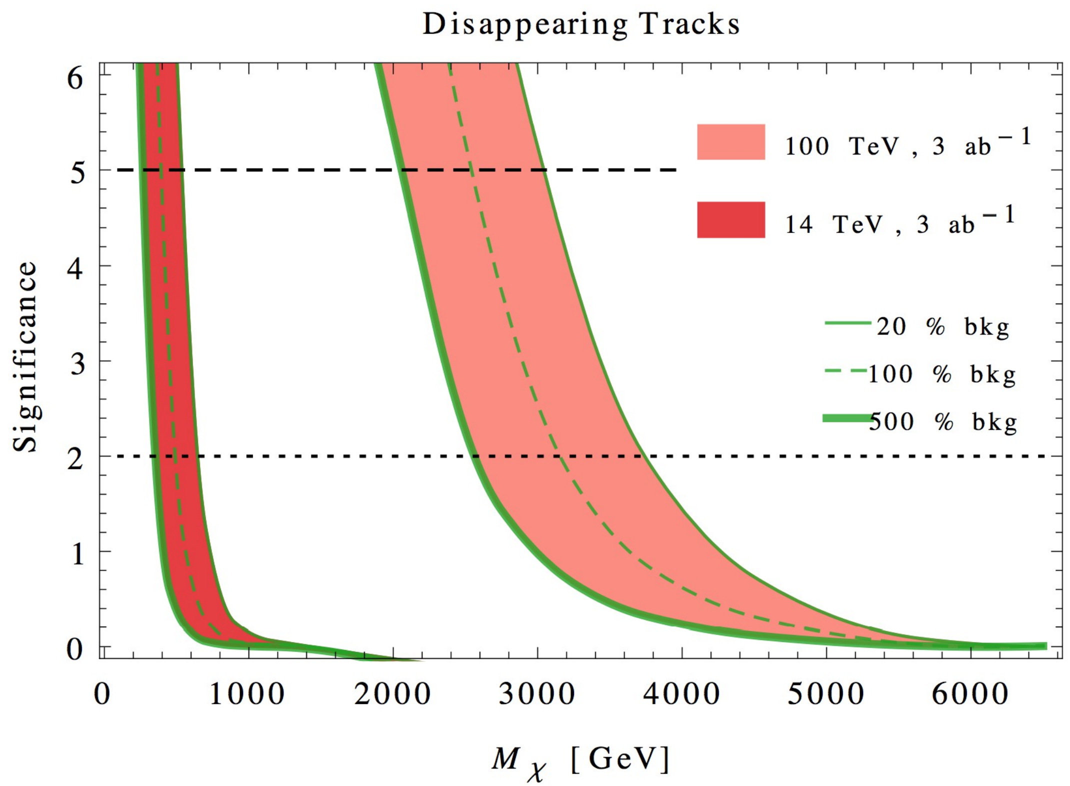


ATLAS 8 TEV with 20 fb^{-1}

Bound M>270 GeV (95% CL)

Disappearing tracks

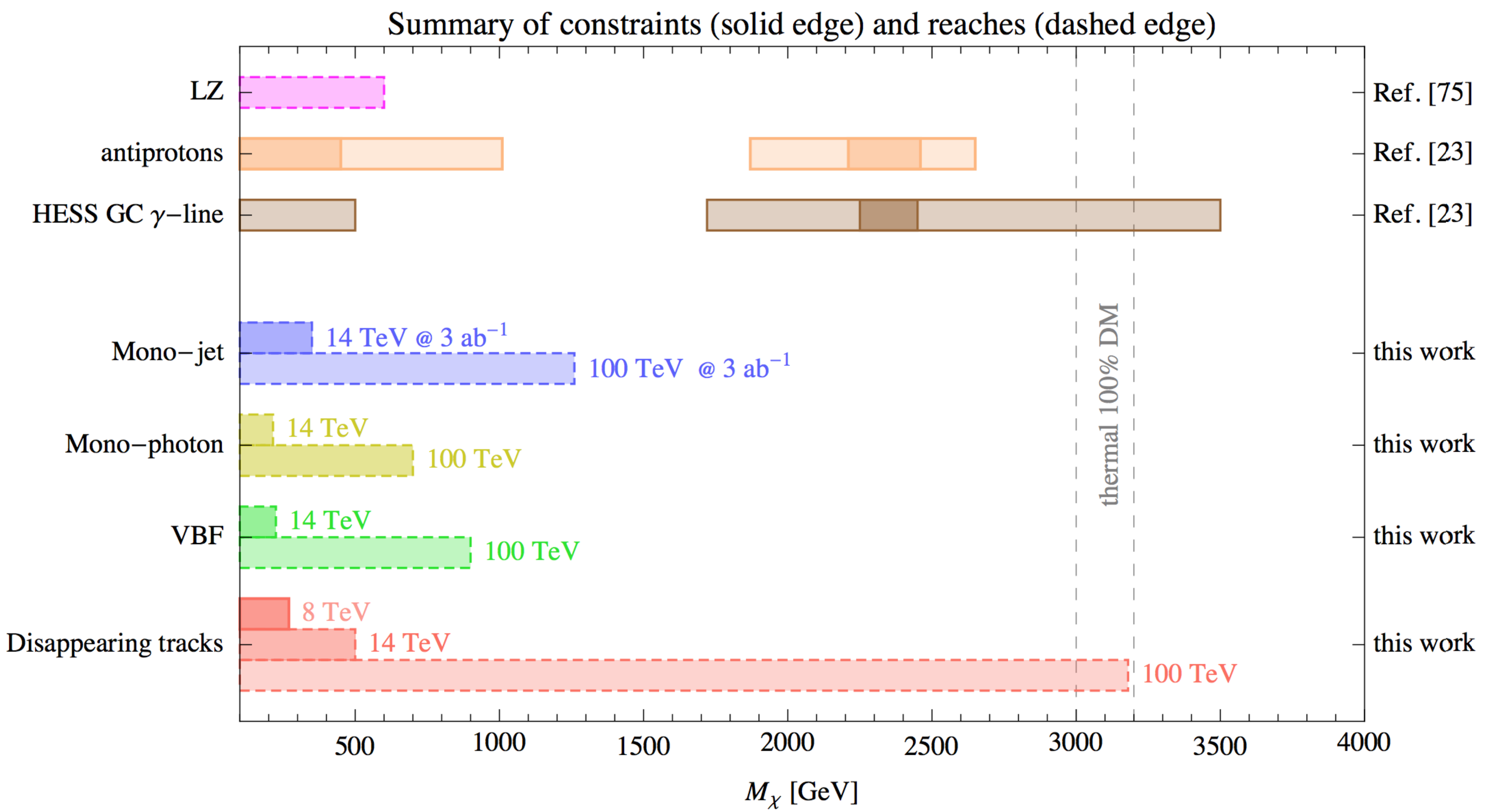
Estimate the sensitivity extrapolating the 8-TeV background rescaling with the jets+MET events cross-sections



See also Low, Wang 1404.0682

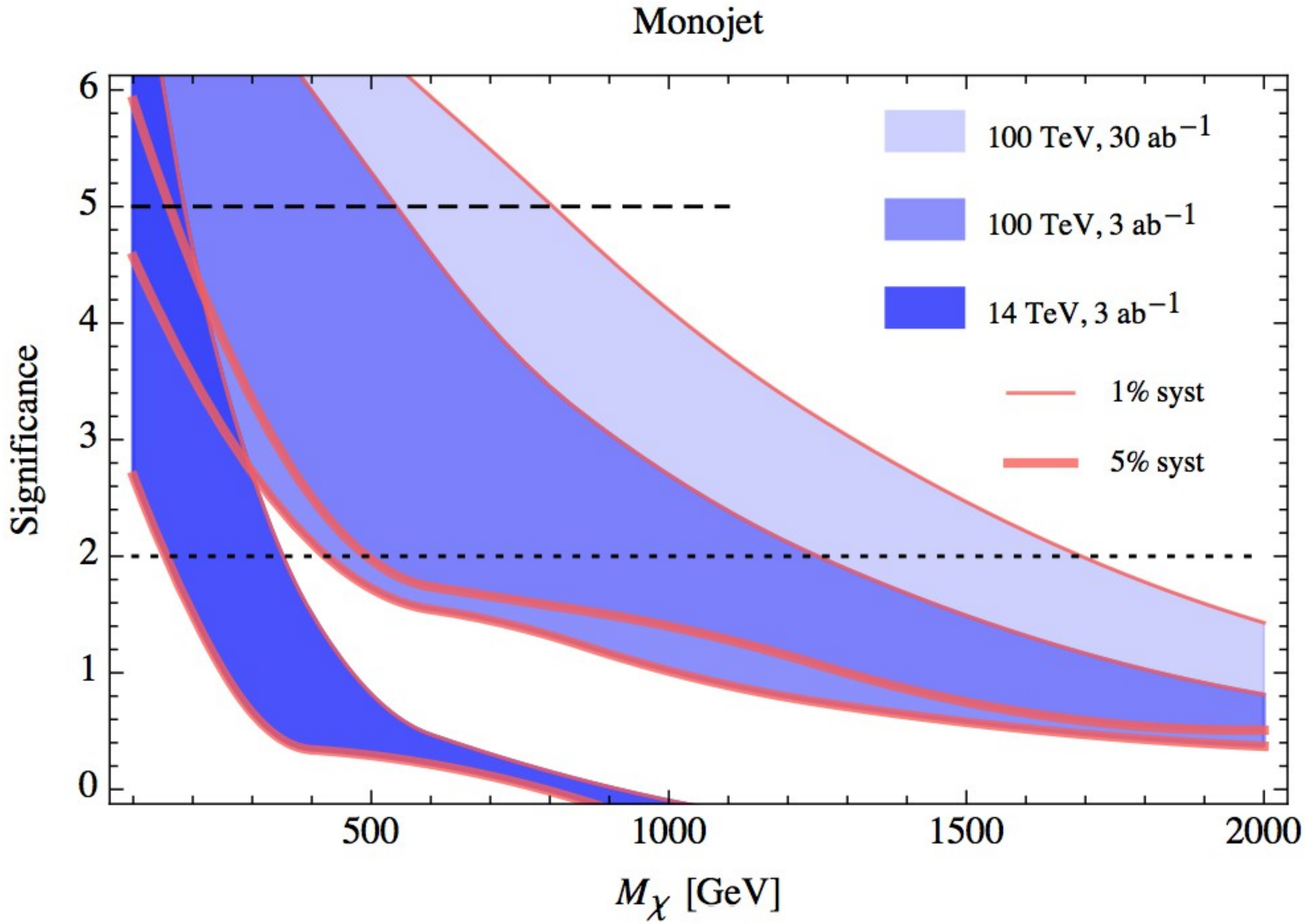
Summary

Indirect searches good probe of EW triplet DM BUT still large astro-uncertainties
LHC-14 cover part of non-thermal DM scenario / DM under-abundant
100 TeV collider could potentially test thermal WINO.



THANKS

Monojet


Monojet
Significance
M_χ [GeV]
100 TeV, 30 ab^{-1}
100 TeV, 3 ab^{-1}
14 TeV, 3 ab^{-1}
1% syst
5% syst
0
1
2
3
4
5
6
500
1000
1500
2000

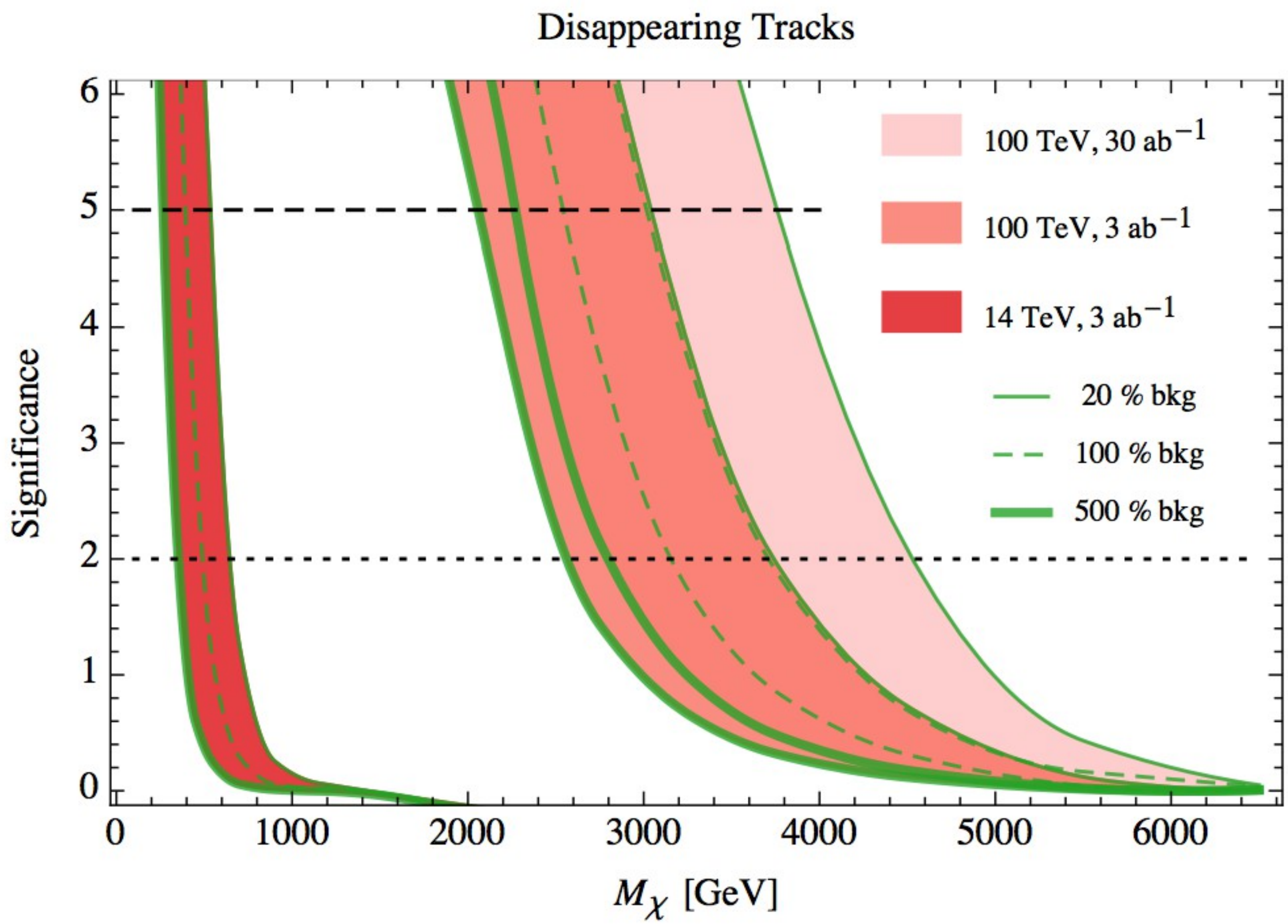
Monojet

Cuts	14 TeV	100 TeV 3 ab^{-1}	100 TeV 30 ab^{-1}
$\not{E}_T$[TeV]	$0.8 - 1.6$	$3 - 7$	$3 - 7$
$p_T(j_1)$ [TeV]	0.4	1.4	1.5
$p_T(j_2)$ [GeV]	$50 - 250$	$100 - 500$	$100 - 500$
η_1	2.2	2.2	2.2
$\Delta\phi$	2.2	2.2	2.2
$p_T(\ell)$ [GeV]	20	20	20
$p_T(\tau)$ [GeV]	30	40	40

Disappearing tracks

Cuts	14 TeV	100 TeV 3 ab^{-1}	100 TeV 30 ab^{-1}
$\not{E}_T$ [TeV]	0.22	1.4	1.4
$p_T(j_1)$ [TeV]	0.22	1.0	1.0
$\eta(j_1)$	2.8	2.8	2.8
$p_T(j_2)$ [GeV]	70	500	500
p_T^{track} [TeV]	0.32	2.1	2.1

Disappearing tracks



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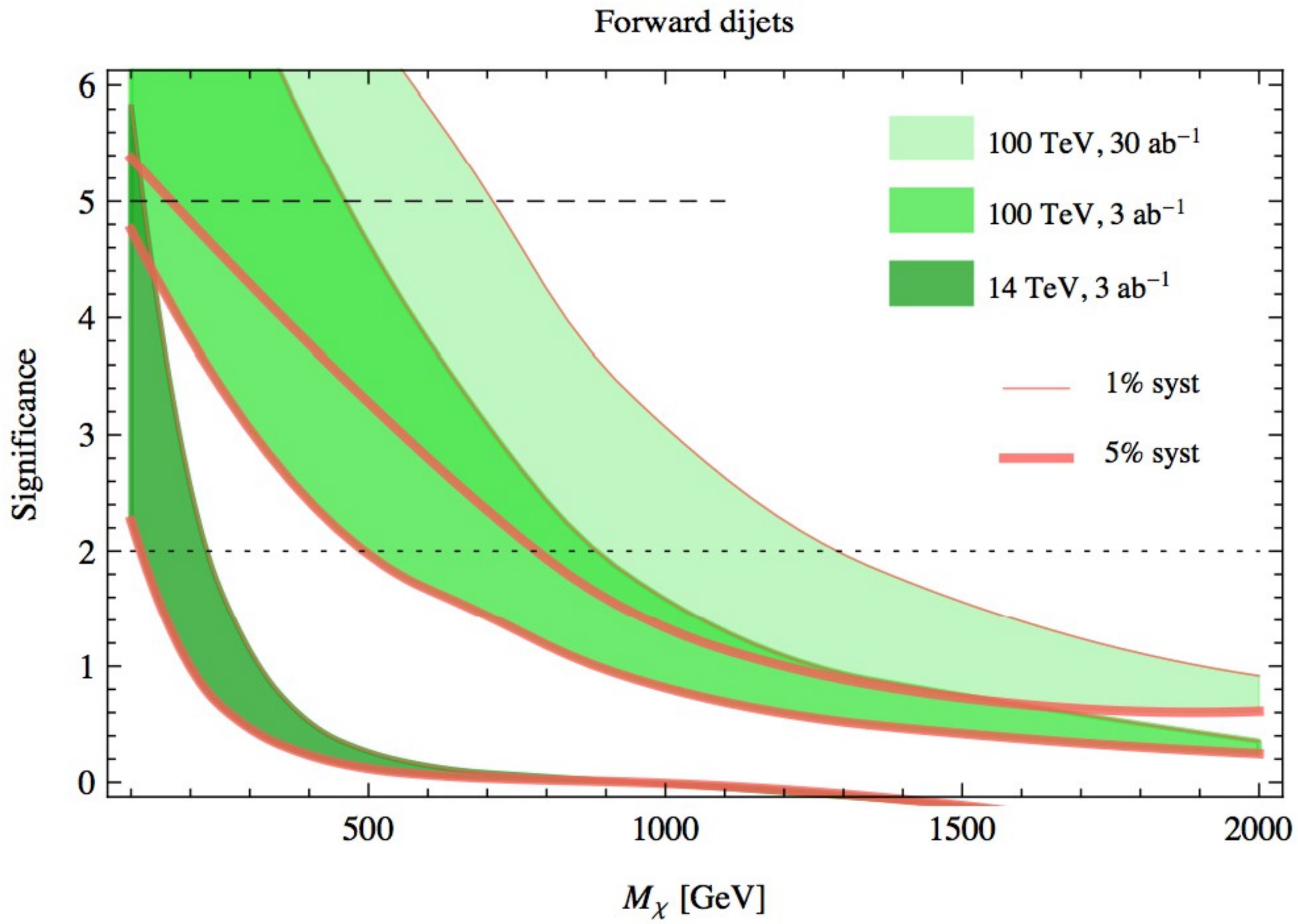
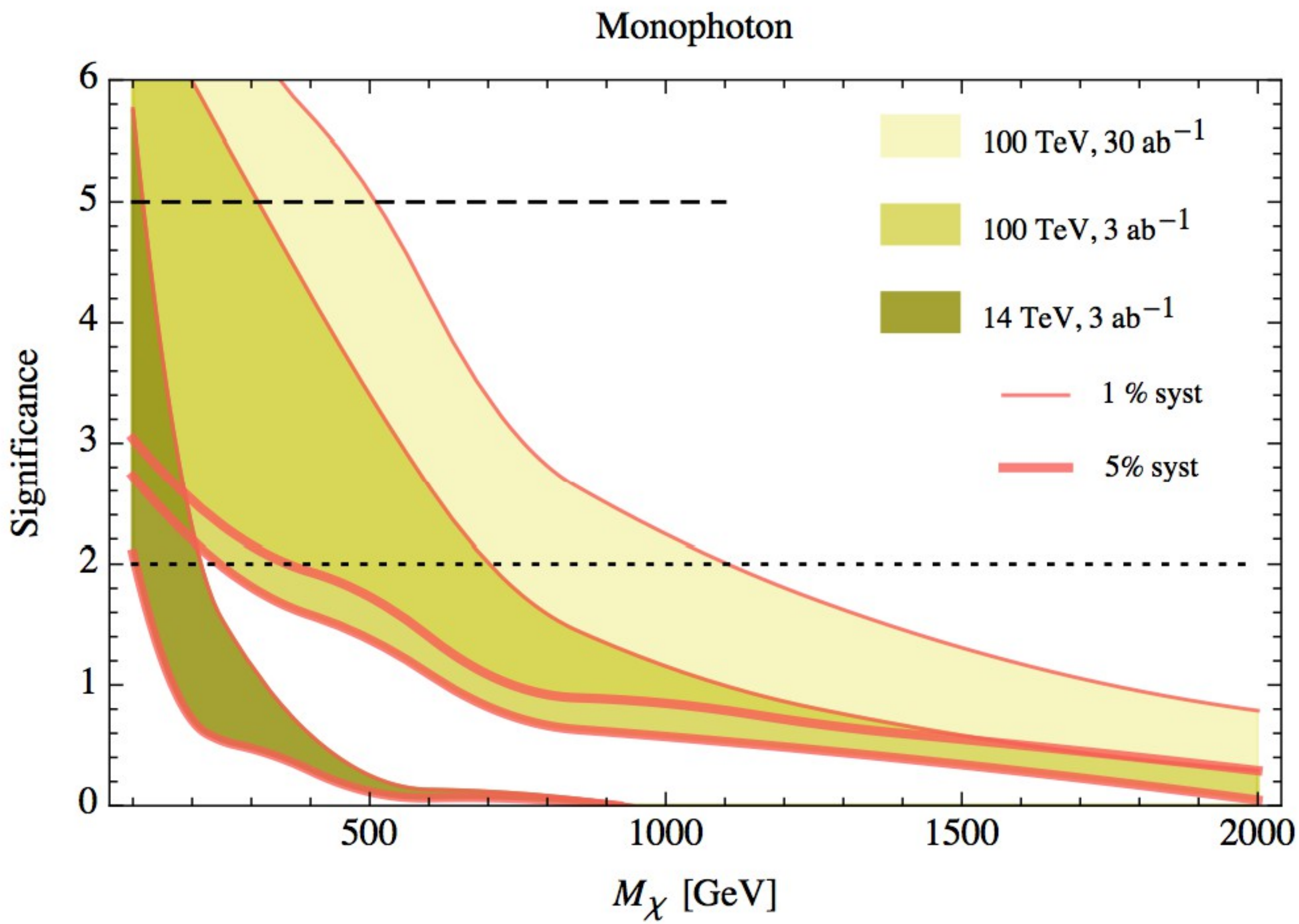
Dijets


Forward dijets
Significance
M_χ [GeV]
100 TeV, 30 ab^{-1}
100 TeV, 3 ab^{-1}
14 TeV, 3 ab^{-1}
1% syst
5% syst
0
1
2
3
4
5
6
500
1000
1500
2000

Monophoton

Cuts	14 TeV	100 TeV 3 ab^{-1}	100 TeV 30 ab^{-1}
$\not{E}_T$[TeV]	$0.3 - 1$	$1 - 3$	$1 - 3.5$
$p_T(\gamma)$ [GeV]	$200 - 500$	$500 - 700$	$500 - 700$
η_γ	1.45	1.45	1.45
$\Delta\phi$	2	2	2
$p_T(j)$ [GeV]	30	100	100
$p_T(\ell)$ [GeV]	20	20	20
$p_T(\tau)$ [GeV]	30	40	40

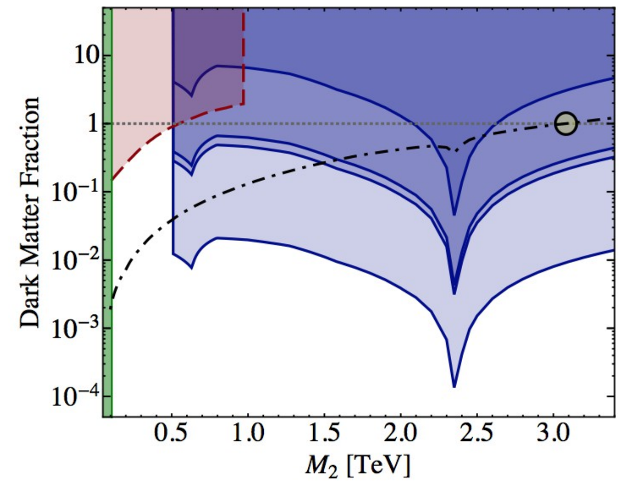
Monophoton



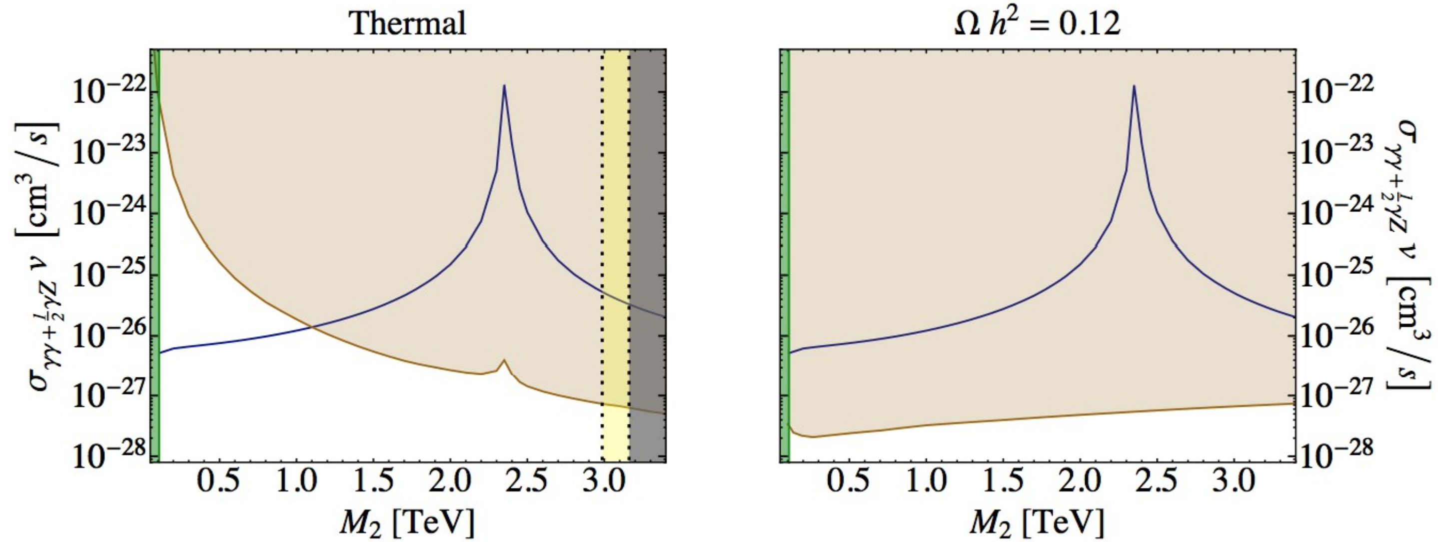
Monophoton
Significance
M_χ [GeV]
0
1
2
3
4
5
6
500
1000
1500
2000
100 TeV, 30 ab^{-1}
100 TeV, 3 ab^{-1}
14 TeV, 3 ab^{-1}
1 % syst
5% syst

Indirect searches

Thermal WINO: current bounds
Shading different profiles
Dod-dashed: cross section for thermal WINO



Prospects for CTA



From Cohen et al. 1307.4082

Relic abundance

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Relic abundance calculation should include:

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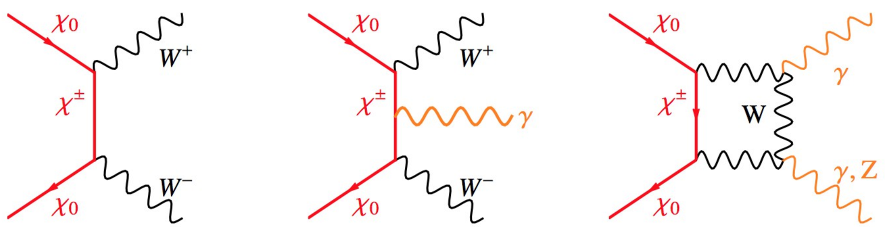

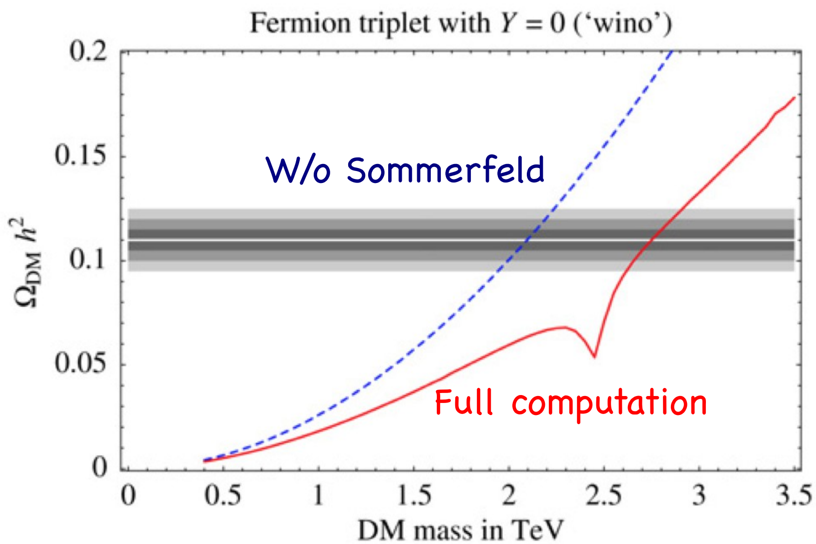

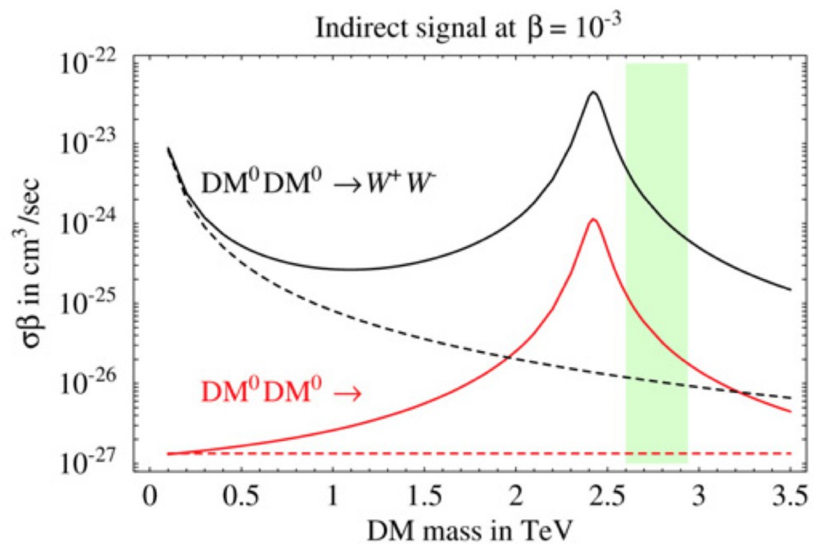

Correct abundance for M around 3 TeV.
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All masses possible for non-thermal production

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