Complementarity of Indirect and Collider DM Searches

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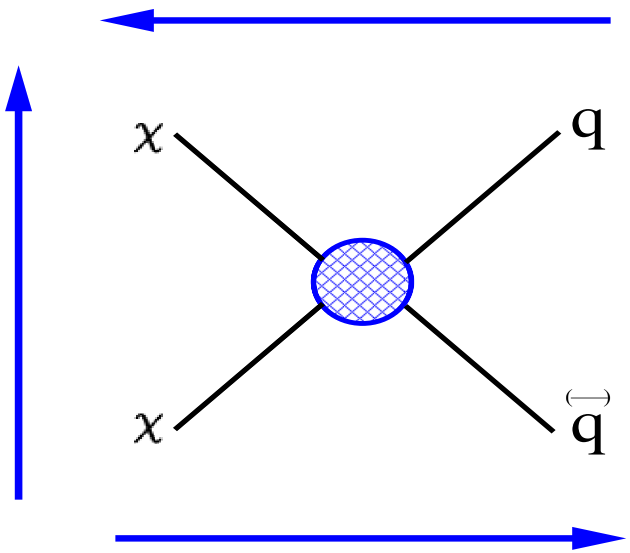
Different aspects of the DM interactions with ordinary matter

Accelerator Searches (DM production) LHC (ILC)

Direct Detection

(DM-nuclei scattering)

DAMA/LIBRA
CDMS
XENON
KIMS
COUPP
ZEPLIN
CoGeNT
CRESST
ANAIS
SIMPLE
...



Many DM models can be probed by the different experimental techniques

Constraints in one sector might affect observations in the other two.

"Redundant" detection can be used to extract DM properties

Indirect Detection

(DM annihilation)

PAMELA
Fermi
MAGIC
AMS

ANTARES
IceCube
CTA
...

COMPLEMENTARITY of DM searches

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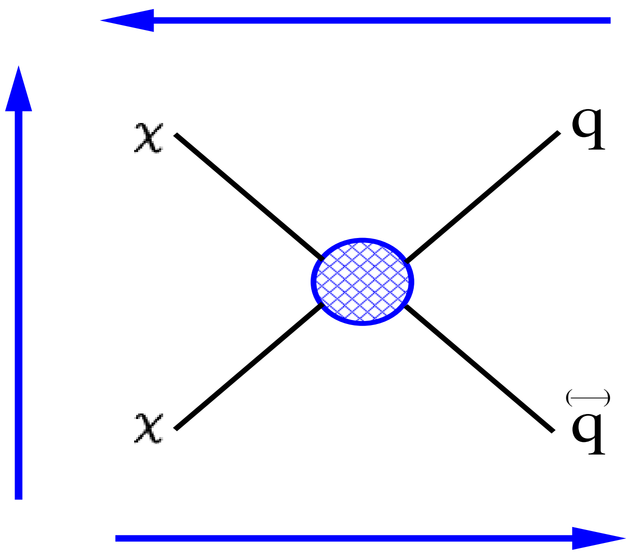

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Indirect Detection

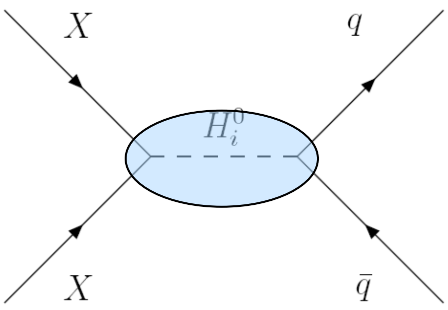
(DM annihilation)

Related to the Freeze-out of DM particles in the Early Universe

COMPLEMENTARITY of DM searches

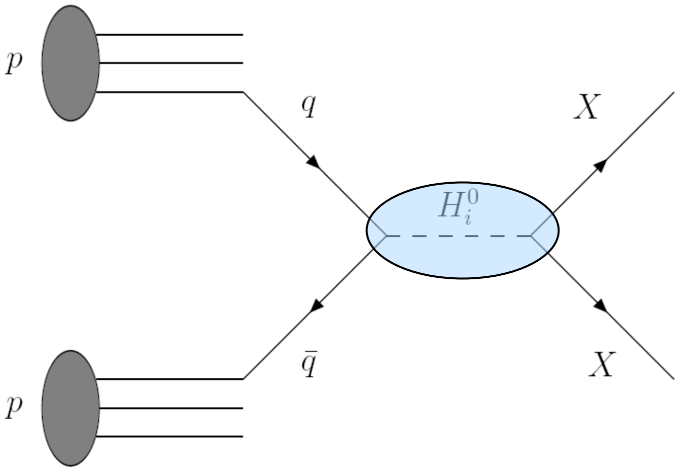
It is very tempting to say that Accelerator and Indirect searches probe the same diagrams... however

DM annihilation (Early Universe)



"Inverse" process

DM Production in colliders?



Missing transverse energy

Problematic: does not leave a good signal (no hard energy deposition for detectors to trigger upon) (not impossible : very light WIMPs)

If the spectrum of new physics is heavy might not be able to test directly the DM couplings to SM matter (problem for estimating the relic abundance)

GIVEN THE SUBTLETIES OF DM ANNIHILATION IN THE EARLY UNIVERSE, THIS MAKES IT DIFFICULT TO TAKE A MODEL INDEPENDENT APPROACH.

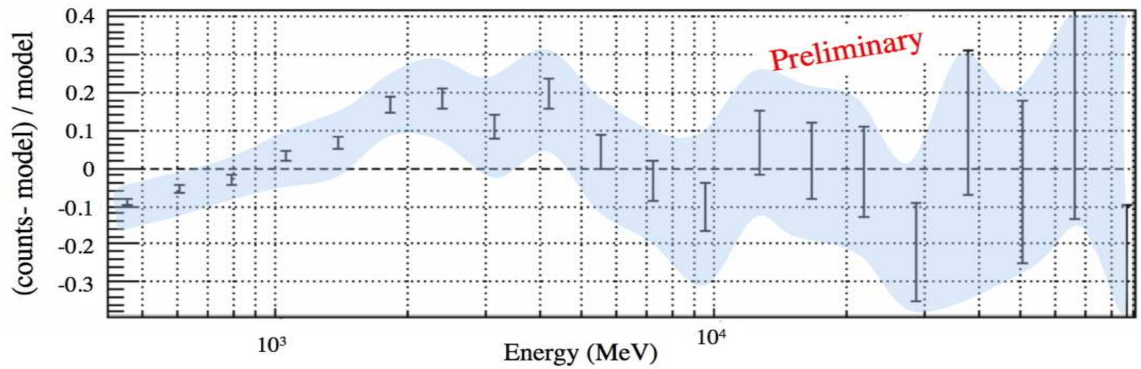
Combining constraints or testing potential observations

One obvious way in which collider searches can complement indirect ones is by constraining potential observations or by combining bounds on the operators describing DM interaction.

Gamma rays from the Galactic centre (Fermi LAT data)

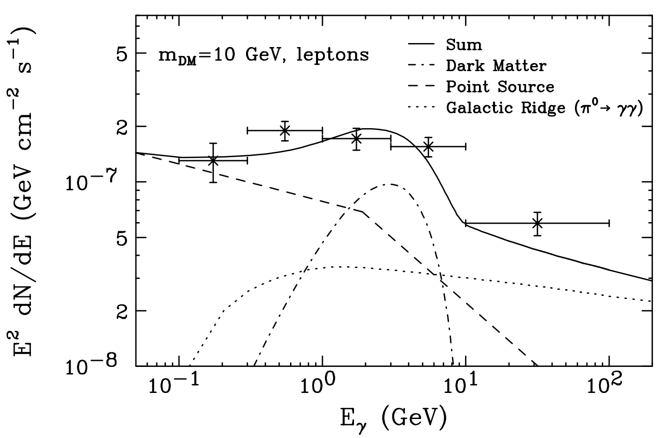
Excess for light DM?

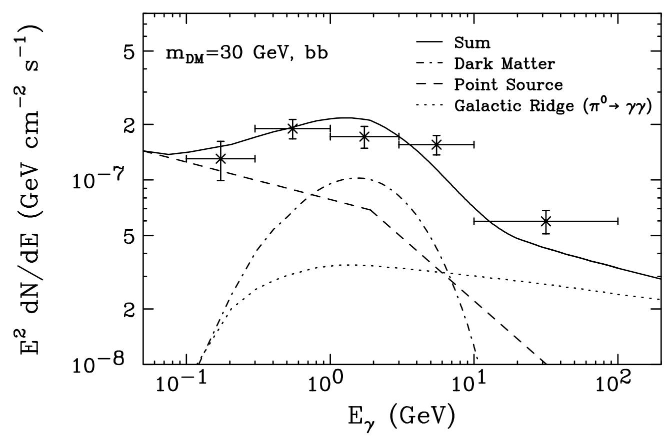
$$\sigma v = 7 \times 10^{-27}\ \mathrm{cm}^3/\mathrm{s}$$



Not yet confirmed by Fermi

Cañadas, Morselli, Vitale 2010





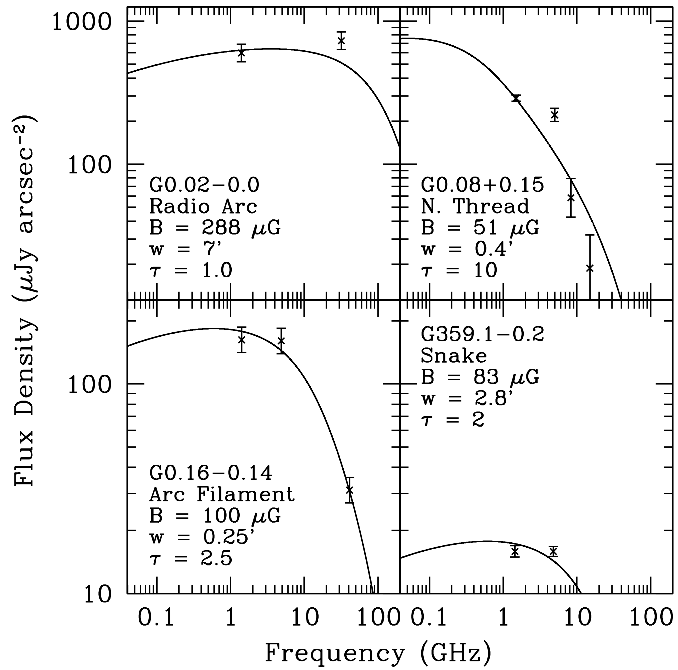
Hooper, Goodenough 2011; Hooper, Linden 2011

Hints for very light DM in indirect searches

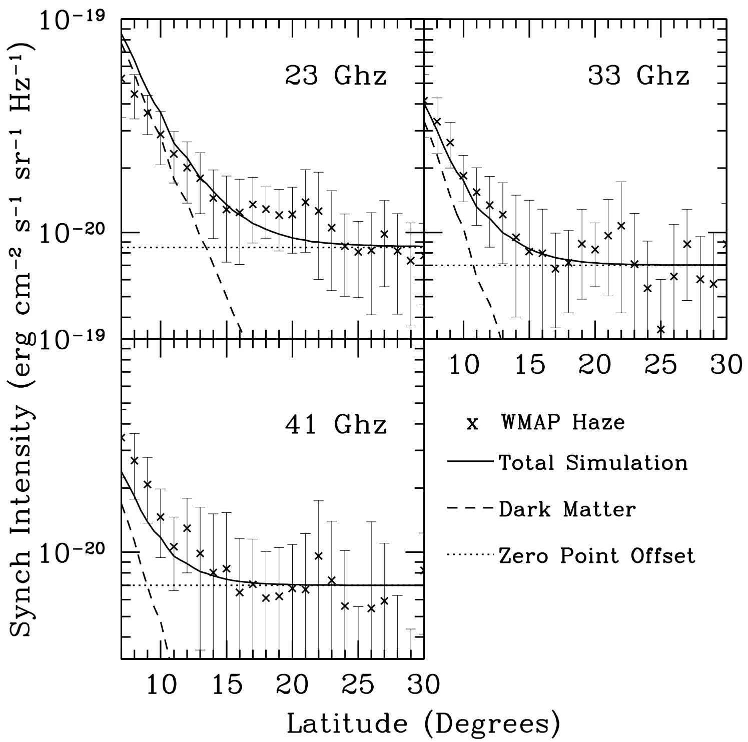
Synchrotron emission from radio filaments in the inner galaxy

Seem to contain spectrum of e^+e^- peaked at 10 GeV

Consistent with thermal very light WIMPs?



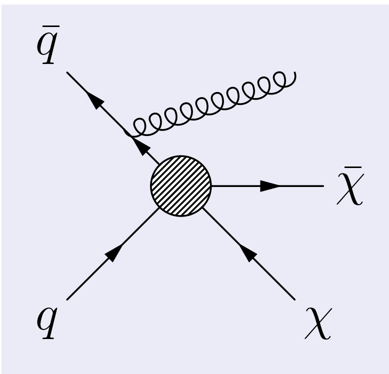
Linden, Hooper, Yusuf-Zadeh 2011

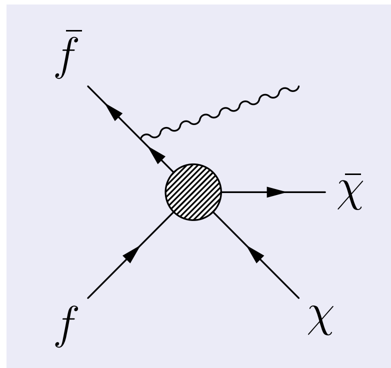


WMAP Haze (excess of microwave emission in the inner 20◦ around the center of the Milky Way)

Could be further evidence of light (thermally produced) DM (m~10 GeV) annihilating mostly into leptons.

Very light WIMPs can be searched for in colliders.

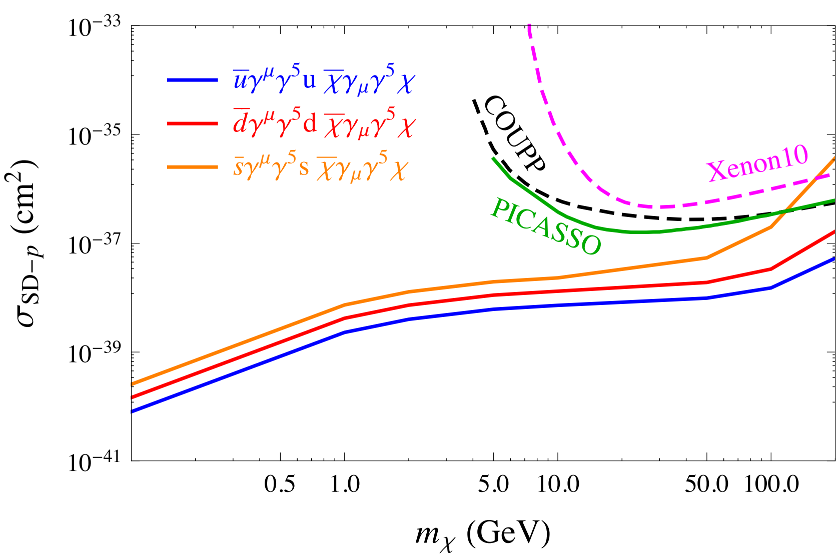




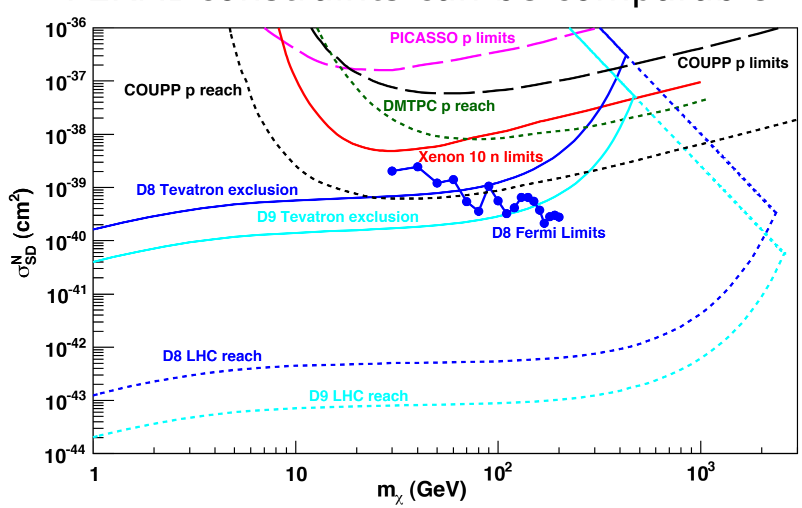
Dark matter production with initial state radiation

Leads to stringent bounds dependent on the DM effective operators to fermions

Goodman et al. '10
Rajaraman '11
Aaltonen et al. '12
Chatrchyan '12



FERMI constraints can be comparable



Goodman et al. '10

Can colliders discover dark matter?

A “stable” particle at the detector scale does not imply stability in Cosmological scales

- Upon detection... How can we test it is the dark matter?

Reconstruct its relic abundance (possible to some extent if DM couplings are measured)

- How well can we do this? (It depends on the model and the region of the parameter space)

EXERCISE

1) Choose a point in the (SUSY) parameter space

Benchmark in the Constrained MSSM satisfying all experimental constraints (*)

2) Use the predicted spectrum determination (e.g. in LHC or LC) as constraints (use as mock data)

Dependent on the specific benchmark point

3) Scan in the phenomenological MSSM (24 parameters) for the best fit regions

Using Bayesian statistics and Monte Carlo scanning techniques

4) Determine the posterior distribution function for the relic abundance

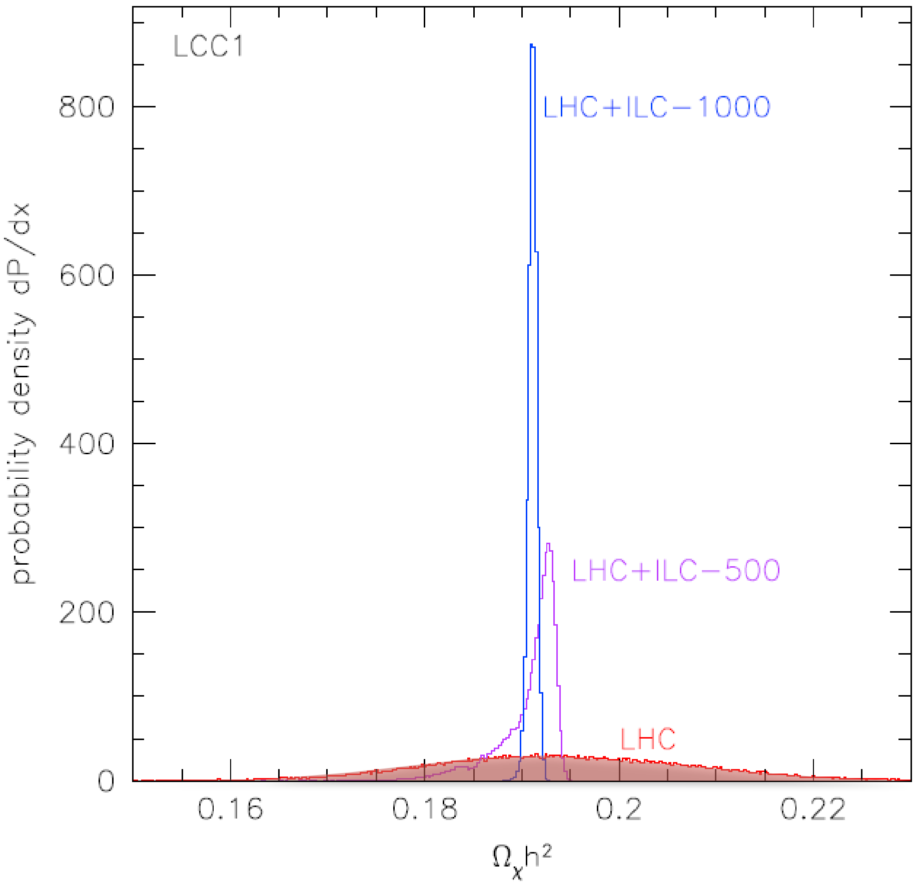
In some regions of the parameter space the relic density can be well determined

E.g., for the LCC1 point, where most of the spectrum can me measured

Point	m_0	$m_{\frac{1}{2}}$	$\tan\beta$	A_0
LCC1	100	250	10	-100
LCC2	3280	300	10	0
LCC3	213	360	40	0
LCC4	380	420	53	0

But this is in general not the case, especially if the SUSY spectrum gets heavier

Notice that these points are already excluded by LHC. They are used here for illustrative purposes.



Baltz, Battaglia, Peskin, Wizanskt '06

For other points of the parameter space things get more complicated

E.g., for the LCC3 point where masses are heavier

Point	m_0	$m_{\frac{1}{2}}$	$\tan\beta$	A_0
LCC1	100	250	10	-100
LCC2	3280	300	10	0
LCC3	213	360	40	0
LCC4	380	420	53	0

Predicted for LHC @ 14 TeV and luminosity of 300 fb^{-1}

Notice that these points are already excluded by LHC. They are used here for illustrative purposes.

Mass	Benchmark value, μ	LHC error, σ
$m(\widetilde{\chi}_1^0)$	139.3	14.0
$m(\widetilde{\chi}_2^0)$	269.4	41.0
$m(\widetilde{e}_R)$	257.3	50.0
$m(\widetilde{\mu}_R)$	257.2	50.0
$m(h)$	118.50	0.25
$m(A)$	432.4	1.5
$m(\widetilde{\tau}_1) - m(\widetilde{\chi}_1^0)$	16.4	2.0
$m(\widetilde{u}_R)$	859.4	78.0
$m(\widetilde{d}_R)$	882.5	78.0
$m(\widetilde{s}_R)$	882.5	78.0
$m(\widetilde{c}_R)$	859.4	78.0
$m(\widetilde{u}_L)$	876.6	121.0
$m(\widetilde{d}_L)$	884.6	121.0
$m(\widetilde{s}_L)$	884.6	121.0
$m(\widetilde{c}_L)$	876.6	121.0
$m(\widetilde{b}_1)$	745.1	35.0
$m(\widetilde{b}_2)$	800.7	74.0
$m(\widetilde{t}_1)$	624.9	315.0
$m(\widetilde{g})$	894.6	171.0
$m(\widetilde{e}_L)$	328.9	50.0
$m(\widetilde{\mu}_L)$	228.8	50.0

Baltz, Battaglia, Peskin, Wizansky '06

For other points of the parameter space things get more complicated

- A large part of the spectrum is well determined (notice that this is becoming a rather optimistic statement)

Most of the slepton and squark masses are measured

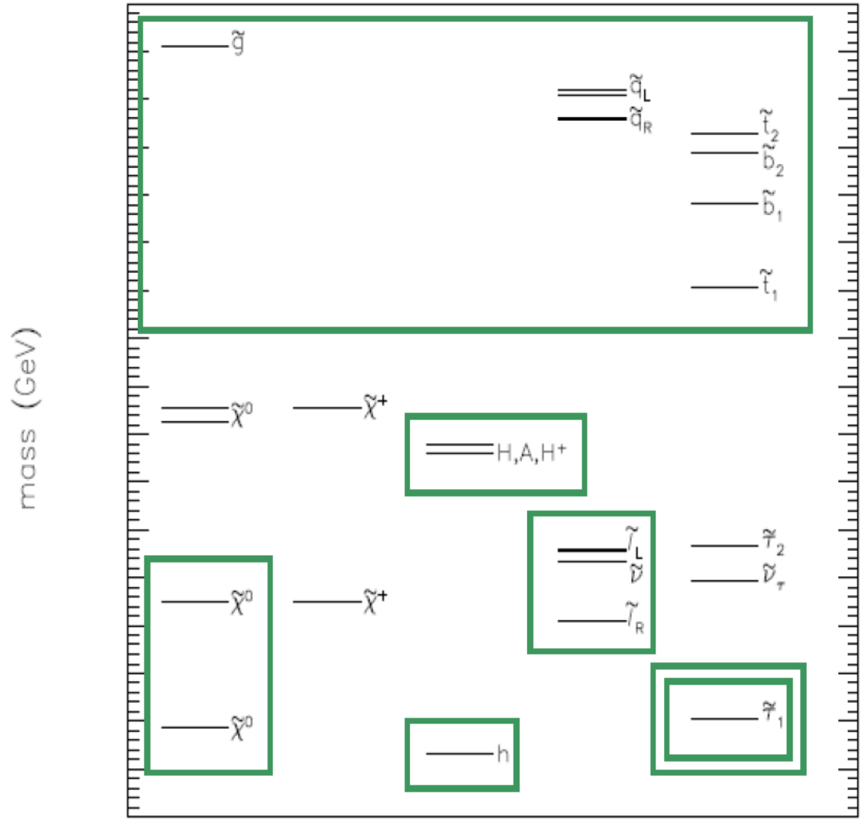
The neutralino-stau mass difference measured up to a few GeV

Studying the signal in $3\tau + \text{jet} + \not{E}_T$

$$\tilde{\chi}_2^0 \to \tau\tilde{\tau} \to \tau\tau\tilde{\chi}_1^0$$

3 identified τ candidates with $|\eta| < 2.5$ and $E_T > 40$, 40 and 20 GeV respectively
1 jet with $E_T > 100$ GeV and $|\eta| < 2.5$
$\not{E}_T > 100$ GeV
$\not{E}_T + E_T^{\text{jet1}} > 400$ GeV
$M_{\tau\tau}^{\text{vis}} < 100$ GeV where only $\tau_1\tau_3$ and $\tau_2\tau_3$ invariant mass combinations are considered

See e.g., Dutta, Arnowitt '08



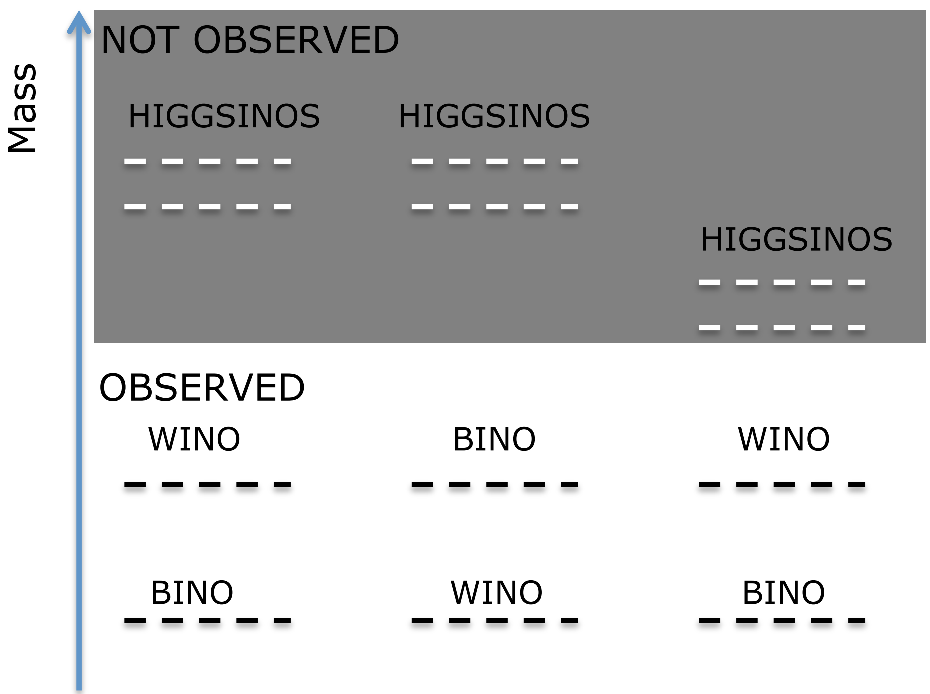
But not all the neutralinos (and no chargino) are measured...

This is a situation that is conceivable, especially if the SUSY spectrum is heavy (as it seems to be the case)

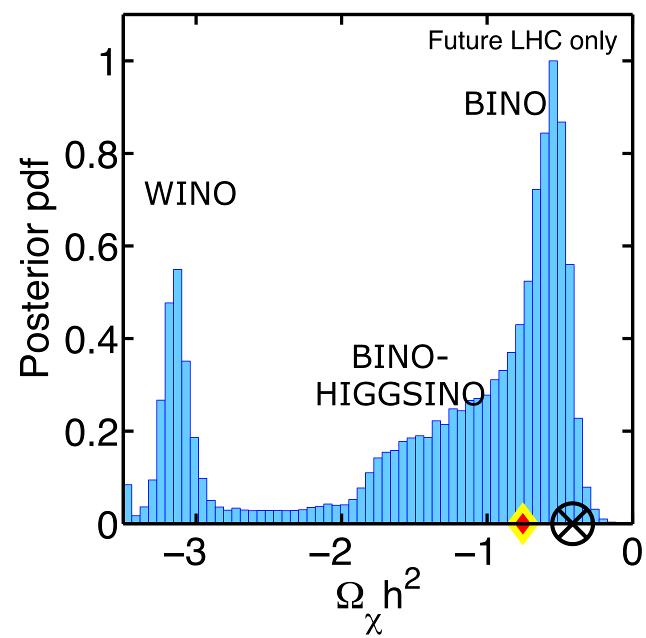
Multiple neutralino compositions are equally viable

The reconstruction of the relic density presents various maxima (spanning three orders of magnitude)

We would not know if the neutralino is the dark matter



LCC3 point LHC @ 14 TeV, 100 fb-1



Bertone, D.G.C., Fornasa, Ruiz de Austri Trotta ‘10

This would be a more serious problem for a heavier spectrum

Multiple neutralino compositions are equally viable

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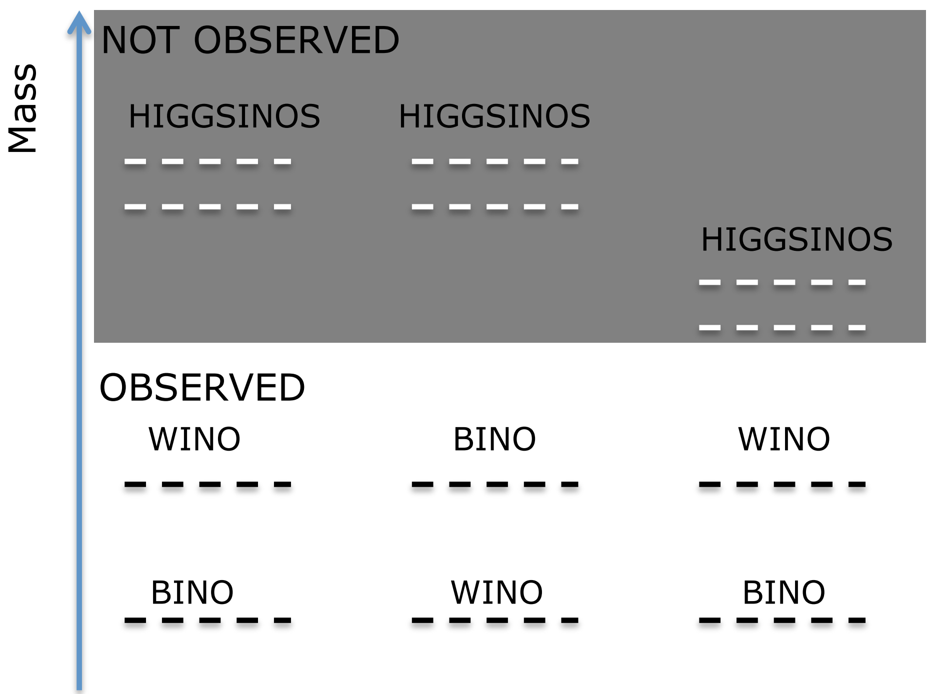
We would not know if the neutralino is the dark matter



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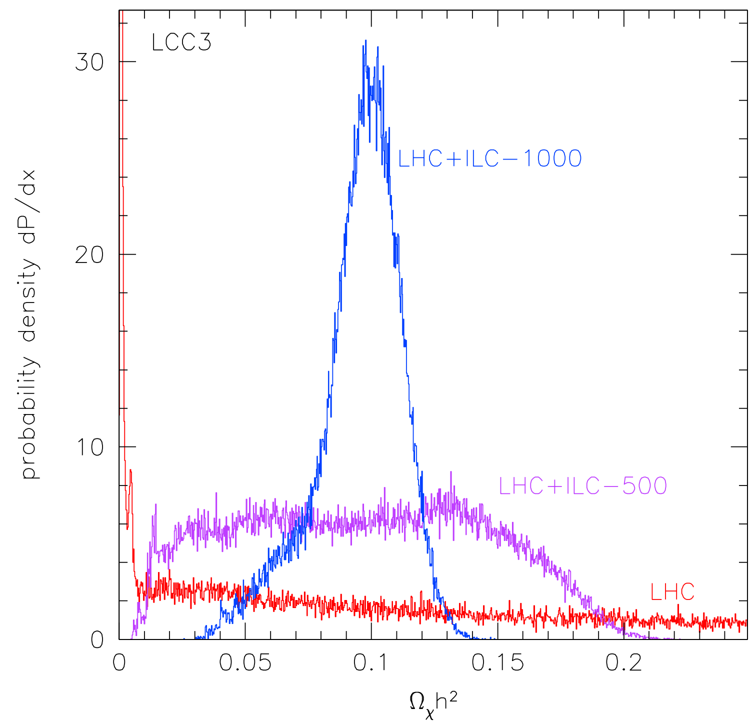
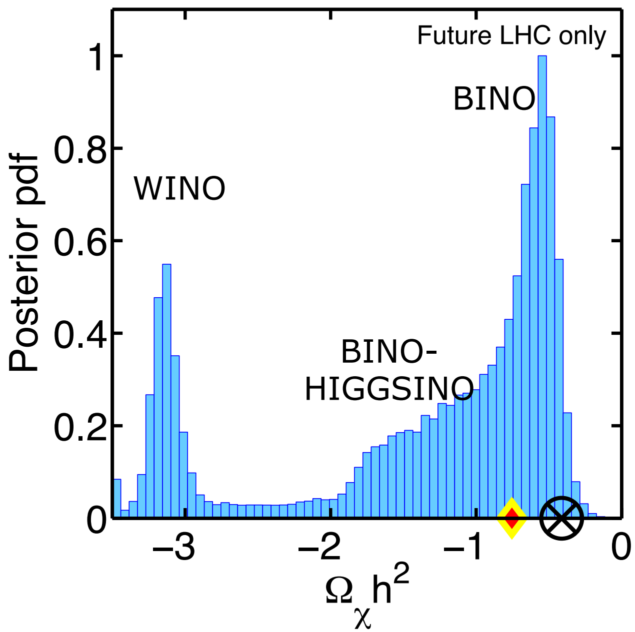


Baltz, Battaglia, Peskin, Wizanskt '06

Even assuming data from a linear collider @500 GeV the uncertainty might be large.

This uncertainty also appears in the predictions from direct DM detection

This provides one potential source of complementarity, if DM was observed in e.g, CDMS or XENON



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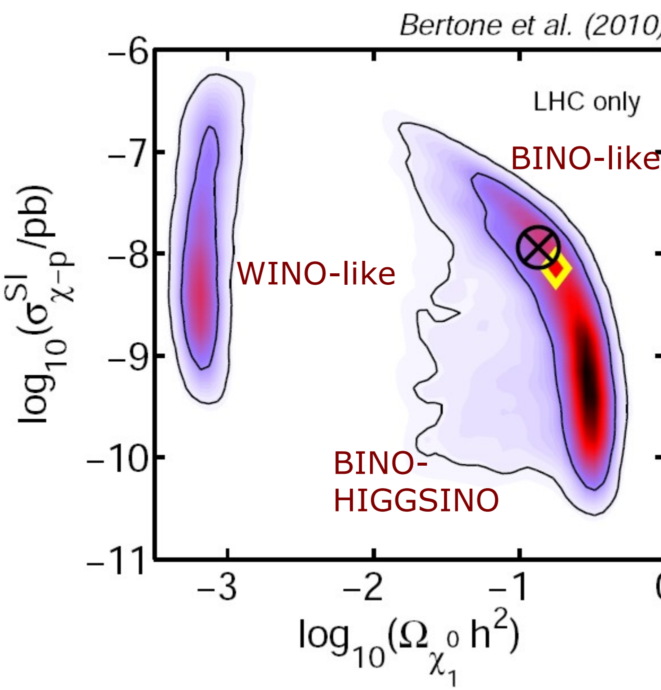


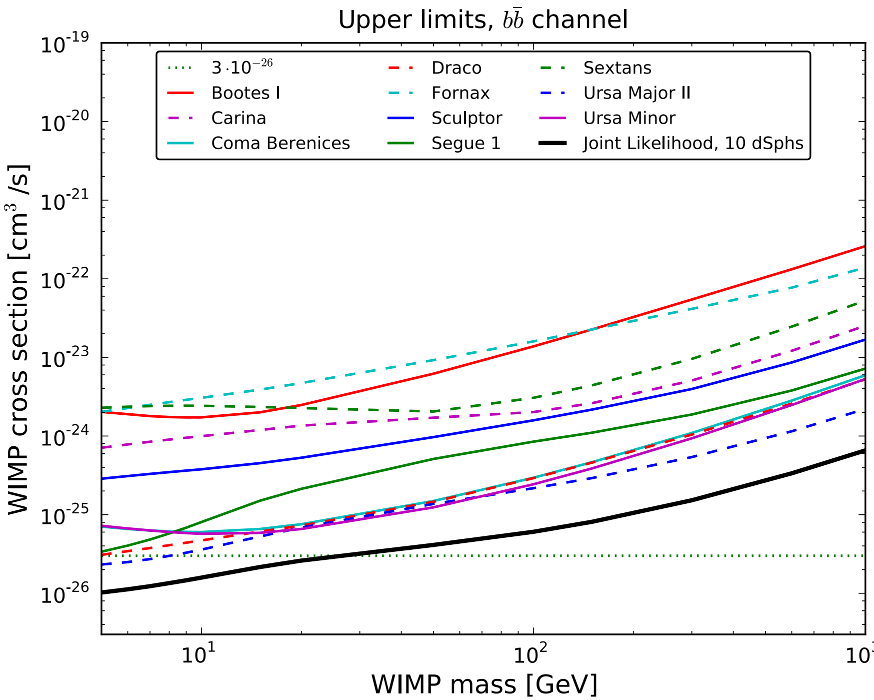
Bertone, D.G.C., Fornasa, Ruiz de Austri Trotta '10

Combination with Indirect detection (gamma ray searches)

For the LCC3 point, we determine the gamma ray flux that could be observed in dwarf Spheroidal galaxies

Imposing Fermi-LAT bound from the non-observation of gamma ray signal

$$\frac{d\Phi_\gamma}{dE_\gamma}(E_\gamma,\Psi) = \frac{d\Phi_{PP}}{dE_\gamma}(E_\gamma) \times \mathrm{los}(\Psi,\Delta\Omega)$$



Particle Physics-dependent terms

$$\frac{d\Phi_{PP}}{dE_\gamma}(E_\gamma) = \frac{1}{4\pi}\frac{(\sigma v)}{2m^2_{\tilde{\chi}^0_1}}\sum_f \frac{dN^f_\gamma}{dE_\gamma}B_f$$

Astrophysical factor

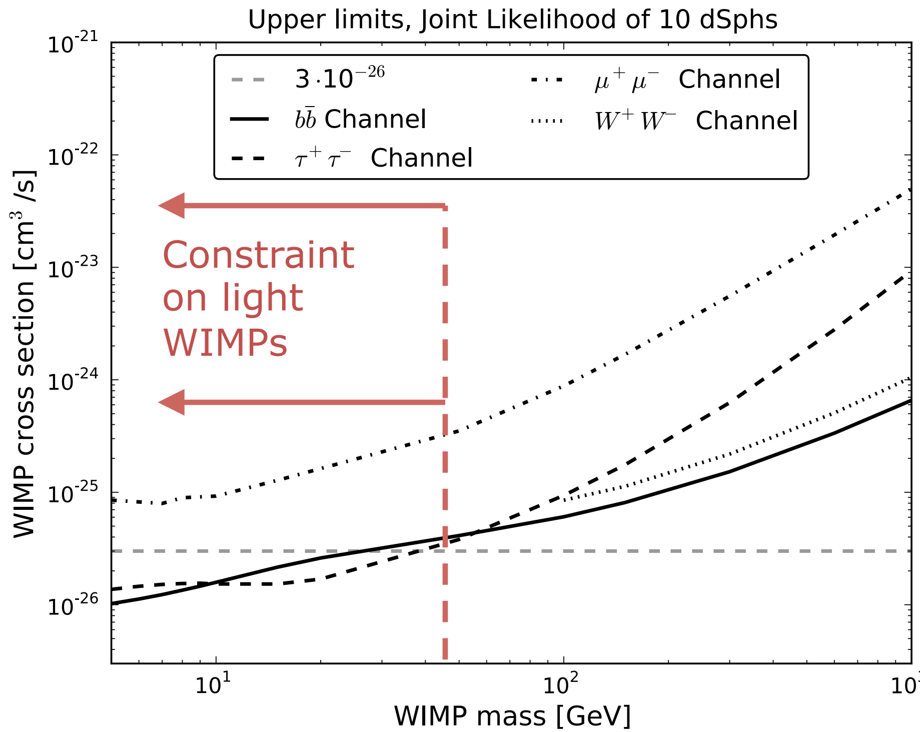
$$\mathrm{los}(\Psi,\Delta\Omega) = \int_{\Delta\Omega}\int \frac{\rho^2(r(s,R_\odot,\Psi))}{s^2}\,ds\,d\Omega$$

dSphs are “ideal” objects: dominated by DM and potentially less affected by uncertainties in J

Fermi-LAT ‘11

No signal from GR in dwarf spheroidals

Fermi-LAT '11

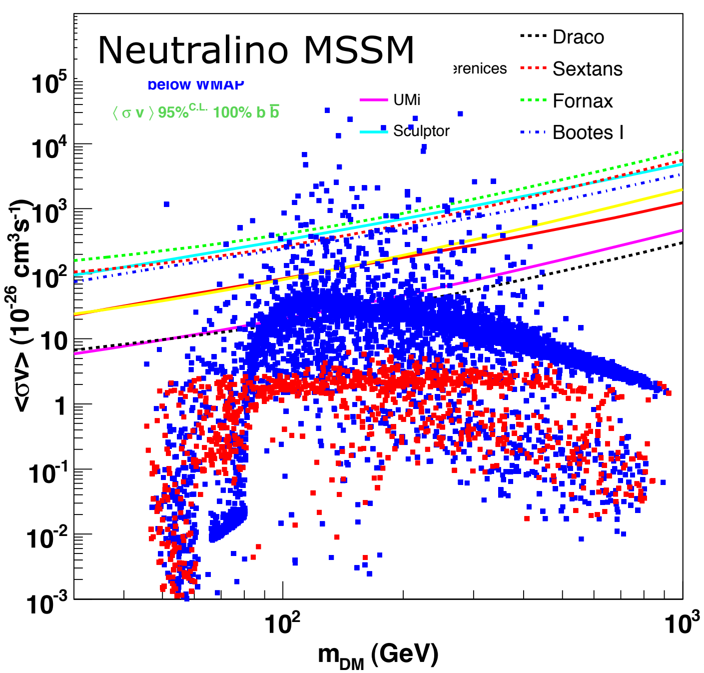


Fermi-LAT observation of Dwarf Spheroidals

Fermi-LAT '11

Thermal cross-section excluded for some channels (bb and ττ)

Bounds are normally expressed for "pure" annihilation channels.



Abdo et al. 1001.4531

"Thermal" DM might have a smaller <σv> in the halo

Coannihilation effects,
velocity-dependent cross-section
resonances

We have calculated the value of <σv> for each point in the scan

Simplifications

We considered only the bound from bb

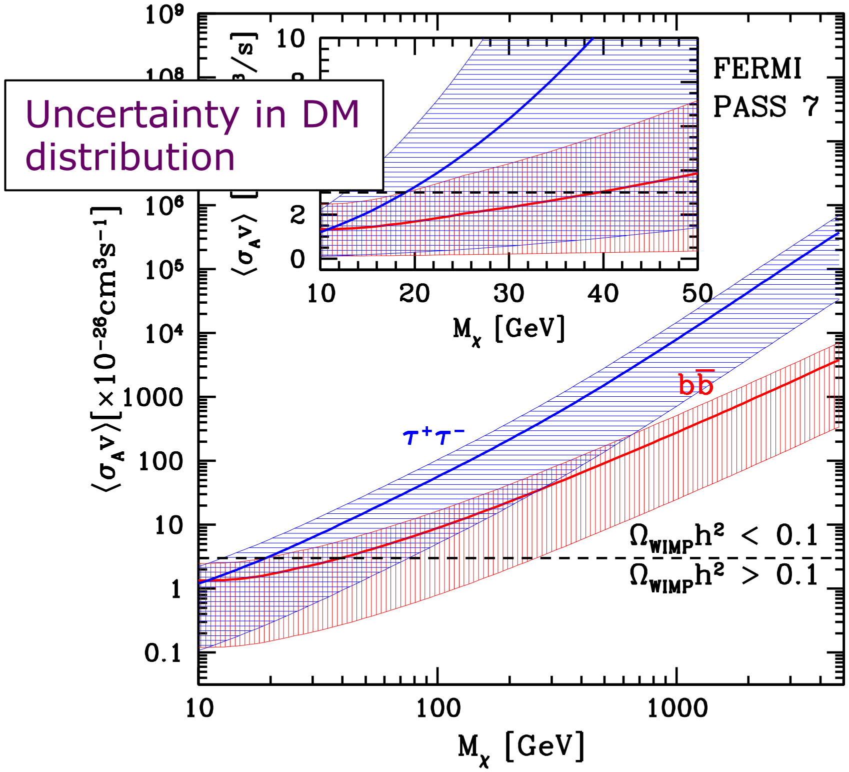
This is not the case for neutralinos in the general parameter space and can be overconstraining general (however notice that it is not too different from WW).

No astrophysical uncertainties included

Uncertainties in the J-factor are expected not to be too sizable for dSphs .

$$J \equiv \int_{\Delta\Omega(\psi)} \int_{\ell} [\rho(\ell,\psi)]^2 \, d\ell \, d\Omega(\psi)$$

However, they may lead to a weakening of the bounds in some channels

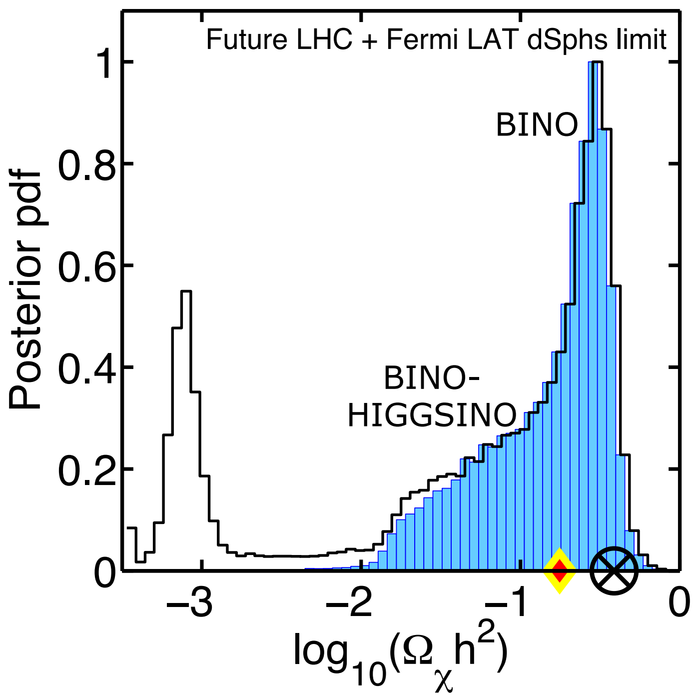


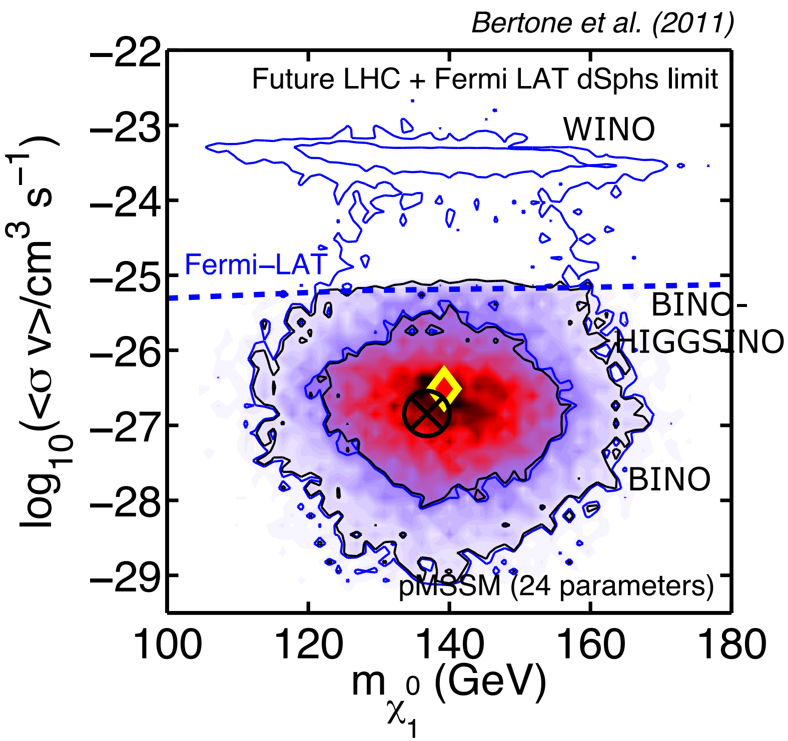
Geringer-Sameth, Koushiappas ‘11

Combination with Indirect detection can also remove degeneracies

For the LCC3 point, we determine the gamma ray flux that could be observed in dwarf Spheroidal galaxies

Imposing Fermi-LAT bound from the non-observation (Wino-like cases are disfavoured)





Not yet unambiguous but excludes spurious maxima

Bertone, D.G.C., Fornasa, Pieri, Ruiz de Austri, Trotta '11

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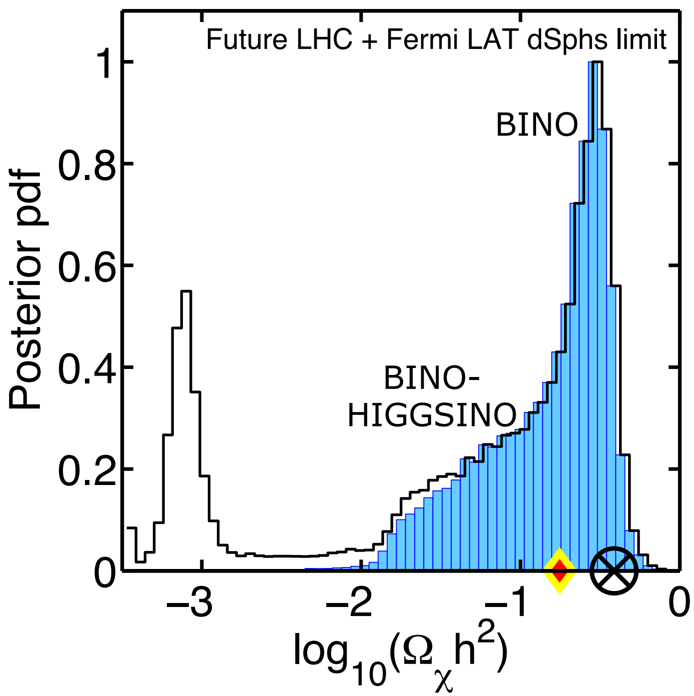
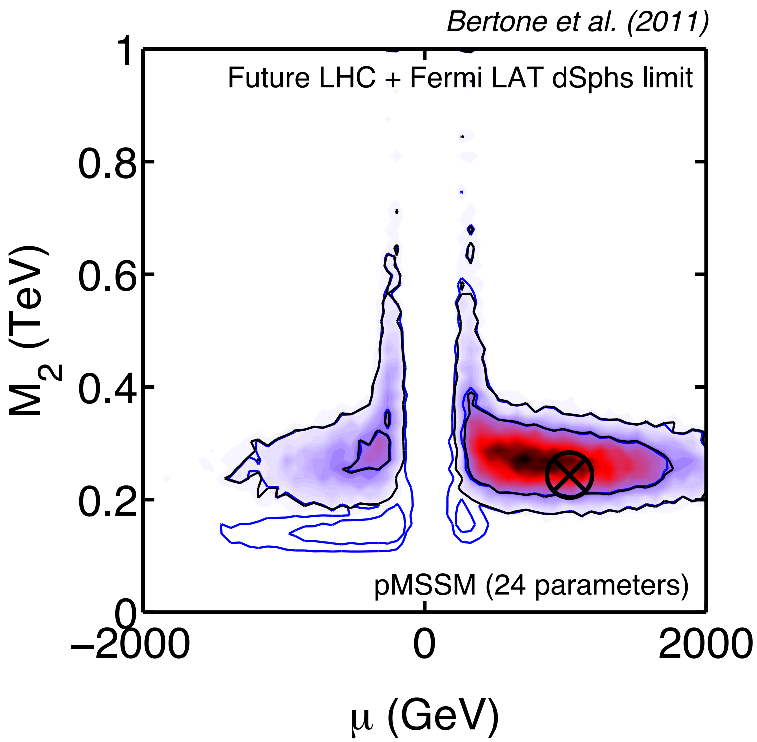




Not yet unambiguous but excludes spurious maxima

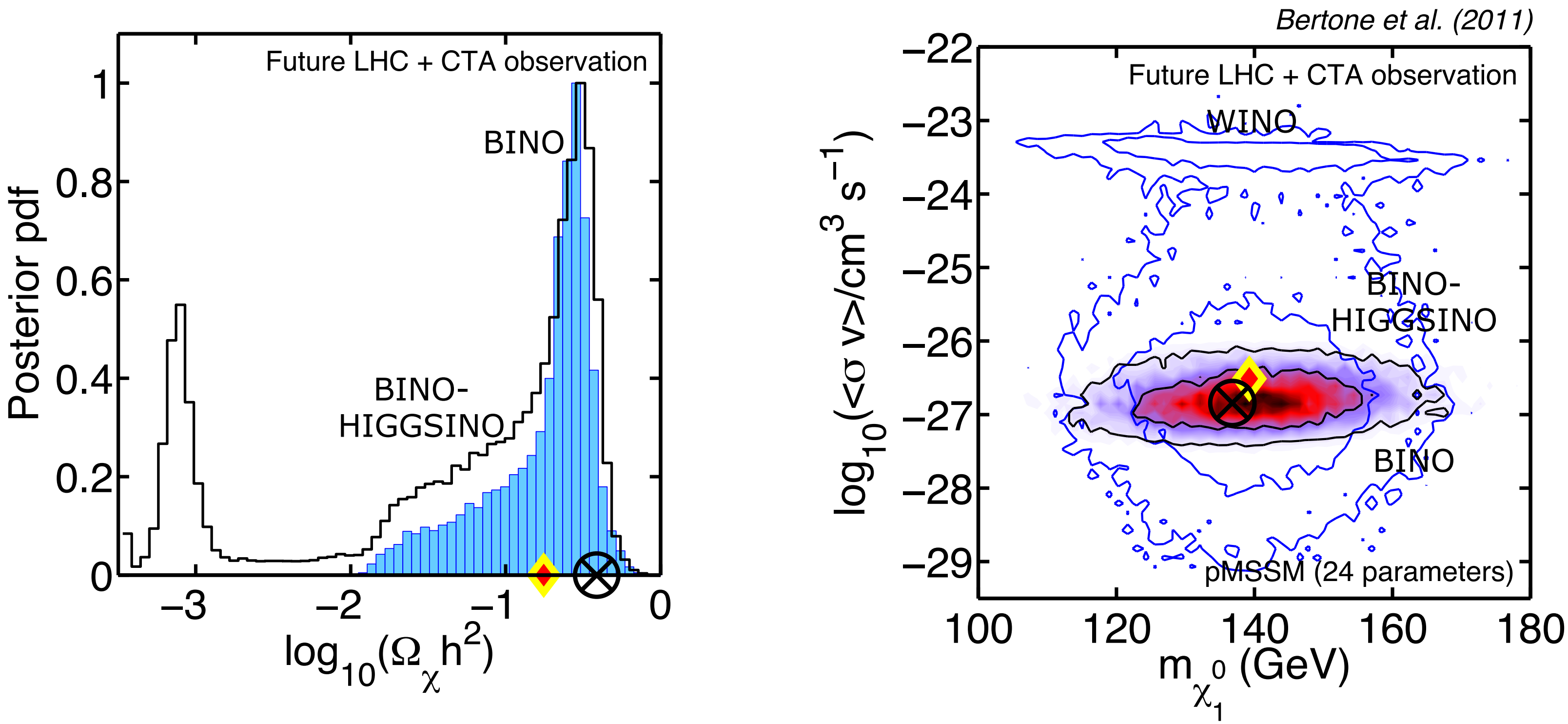
In terms of parameters, the region with small mu parameter is disfavoured

Bertone, D.G.C., Fornasa, Pieri, Ruiz de Austri, Trotta '11

In case of a future detection the relic density reconstruction improves

Hypothetical future CTA observation of Draco

Assuming E_{TH} = 20 GeV and effective area 10^4 m^2



Once more, the relic density is better reconstructed and the spurious maxima disappear

Bertone, D.G.C., Fornasa, Pieri, Ruiz de Austri, Trotta '11

Conclusions

Collider searches and indirect searches can provide complementary bounds on the effective operators that describe the DM interaction with WIMPs

E.g., the region with light WIMPs

The combination of results is crucial in order to make claims about DM

Reconstructing the DM relic density from collider data only might not be possible, especially if the SUSY spectrum is heavy

Indirect bounds (GR considered in this talk) can significantly reduce the uncertainty in the calculated Ωh^2

In case of detection (e.g. CTA) the value of Ωh^2 could be reconstructed (issues with astrophysical uncertainties)