SUPERSYMMETRIC DARK MATTER AFTER LHC RUN 1

Matthew Dolan, for the MasterCode Collaboration
SLAC National Accelerator Laboratory
and University of Melbourne

THE UNIVERSITY OF MELBOURNE

SLAC NATIONAL ACCELERATOR LABORATORY

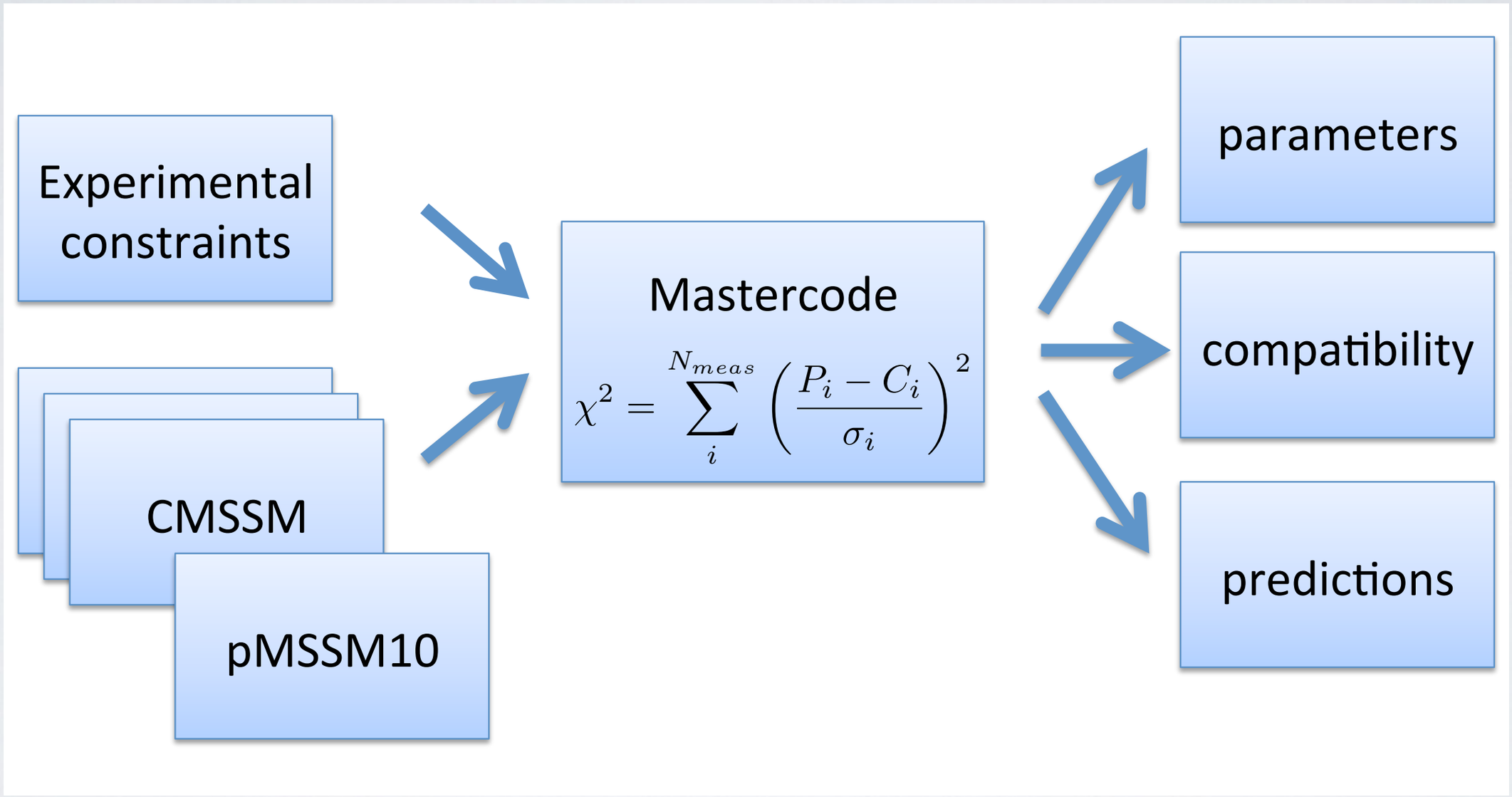
K.J. de Vries[a], **E.A. Bagnaschi**[b], **O. Buchmueller**[a], **R. Cavanaugh**[c,d], **M. Citron**[a], **A. De Roeck**[e,f], **M.J. Dolan**[g], **J.R. Ellis**[h,e], **H. Flächer**[i], **S. Heinemeyer**[j], **G. Isidori**[k], **S. Malik**[a], **J. Marrouche**[e], **D. Martínez Santos**[l], **K.A. Olive**[m], **K. Sakurai**[h], **G. Weiglein**[b]

- Joint theory and experimental collaboration.

- Experimental: CMS, LHCb

- Theory: SUSY, DM, Flavour, Precision Electroweak/Higgs

THE GLOBAL FIT GAME



EXPERIMENTAL CONSTRAINTS

We use a suite of constraints from

- Higgs Physics
- Precision Electroweak
- Direct Detection and Cosmology
- Flavour Physics
- LHC SUSY Searches

SoftSusy, FEWZ, FeynHiggs, SuFla, SuperIso, Micromegas, SSARD, HiggsSignals, HiggsBounds, ATOM

See also yesterday's talk.

DARK MATTER PHENOMENOLOGY

Fits provide a rich dataset.

How is relic density set in the pMSSM?

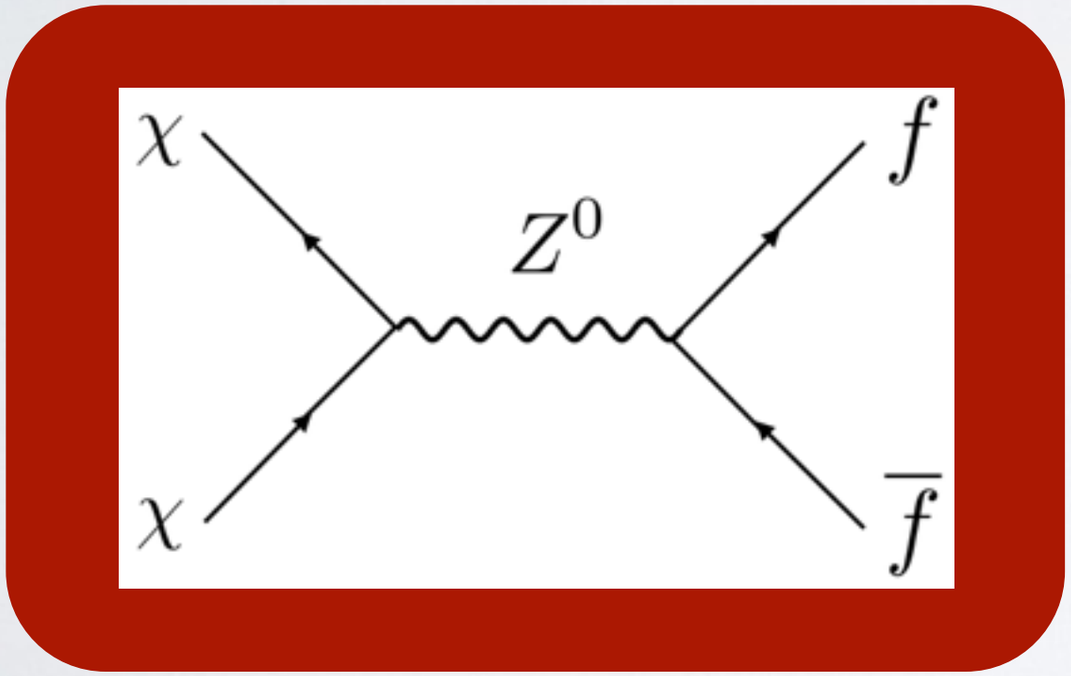
How does LHC probe the pMSSM by mechanism?

Direct detection prospects?

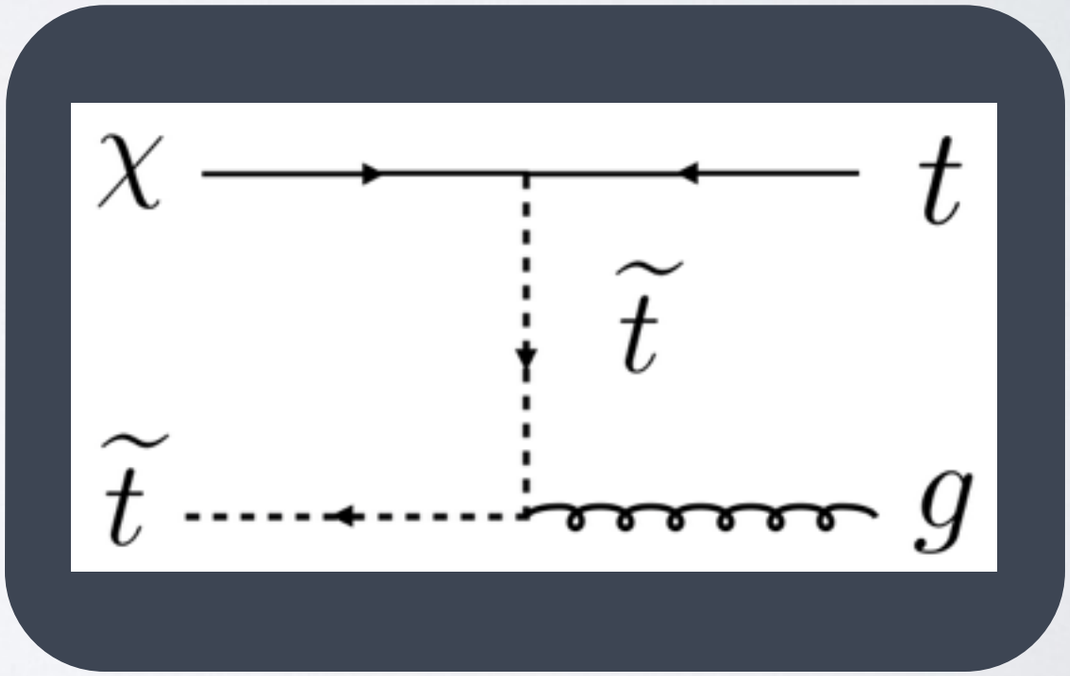
RELIC DENSITY MECHANISMS

Relic density depletion requires relations between sparticle masses.

In the MSSM this happens through resonant DM annihilation ('funnel') or co-annihilation



Resonant/funnel/s-channel



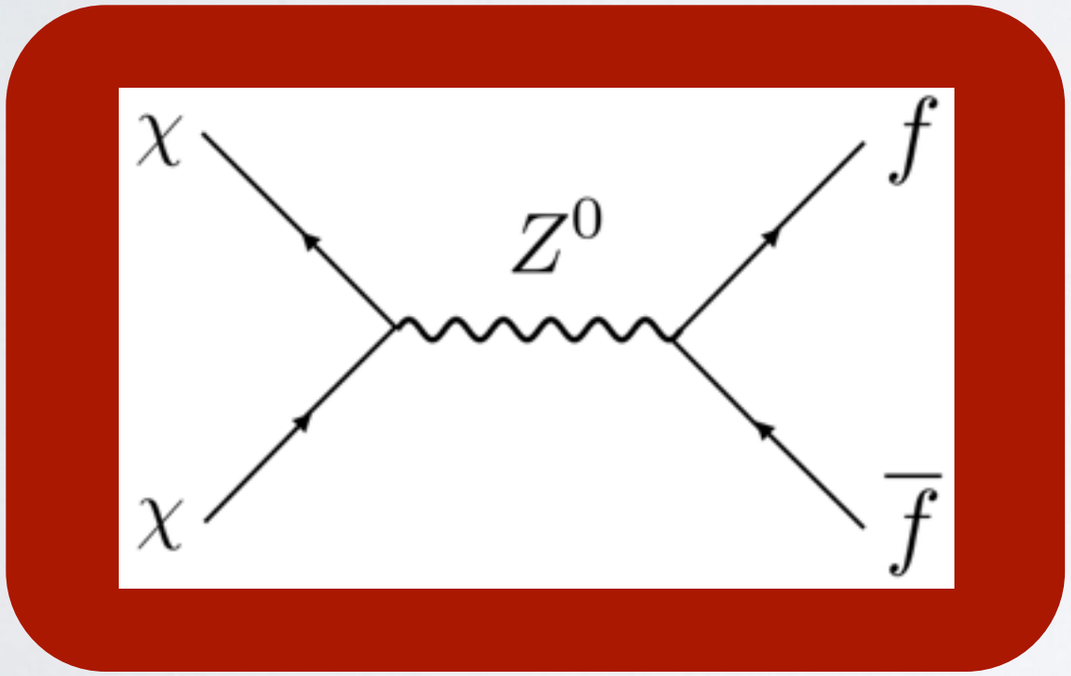
Co-annihilation/t-channel

Credit: Cohen/Wacker 2013

RELIC DENSITY MECHANISMS

Also for:

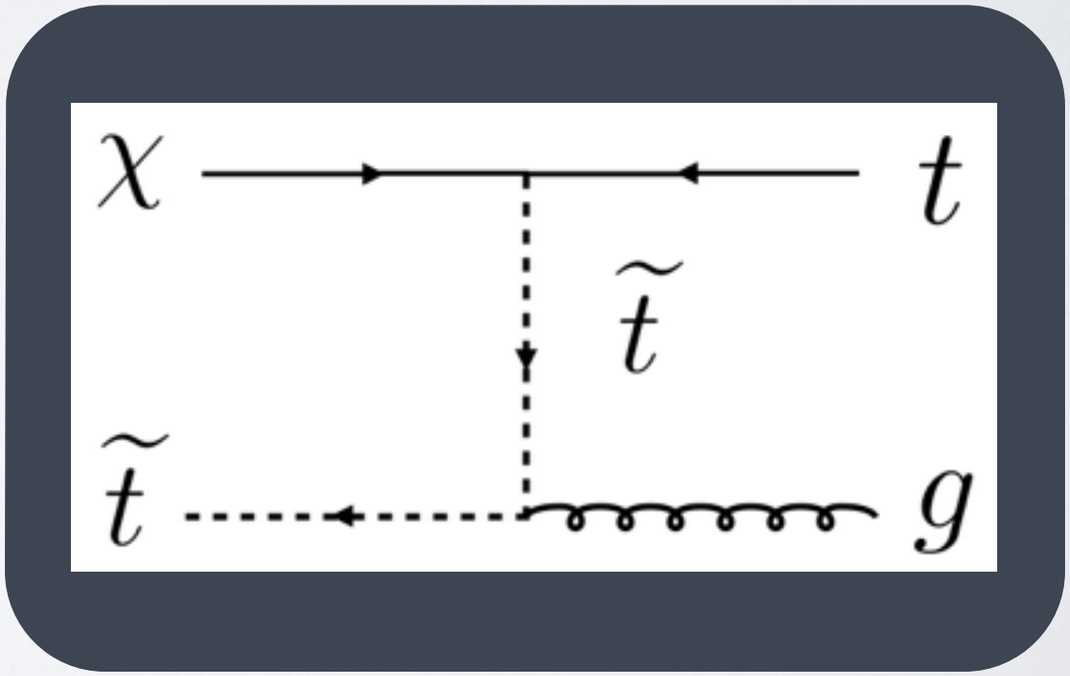
- Light Higgs h
- Heavy Higgs A/H



Resonant/funnel/s-channel

Also for:

- stau co-annihilation
- chargino co-annihilation



Co-annihilation/t-channel

Credit: Cohen/Wacker 2013

RELIC DENSITY MECHANISMS

How to quantify this?

$$\tilde{\tau}_1 \text{ coann. (pink)}: \quad \left(\frac{m_{\tilde{\tau}_1}}{m_{\tilde{\chi}_1^0}} - 1\right) < 0.15\,,$$

$$\tilde{\chi}_1^\pm \text{ coann. (green)}: \quad \left(\frac{m_{\tilde{\chi}_1^\pm}}{m_{\tilde{\chi}_1^0}} - 1\right) < 0.1\,,$$

$$\tilde{t}_1 \text{ coann. (grey)}: \quad \left(\frac{m_{\tilde{t}_1}}{m_{\tilde{\chi}_1^0}}\right) - 1 < 0.2\,,$$

$$A/H \text{ funnel (blue)}: \quad \left|\frac{M_A}{m_{\tilde{\chi}_1^0}} - 2\right| < 0.4\,,$$

$$\text{focus point (cyan)}: \quad \left(\frac{\mu}{m_{\tilde{\chi}_1^0}}\right) - 1 < 0.3\,.$$

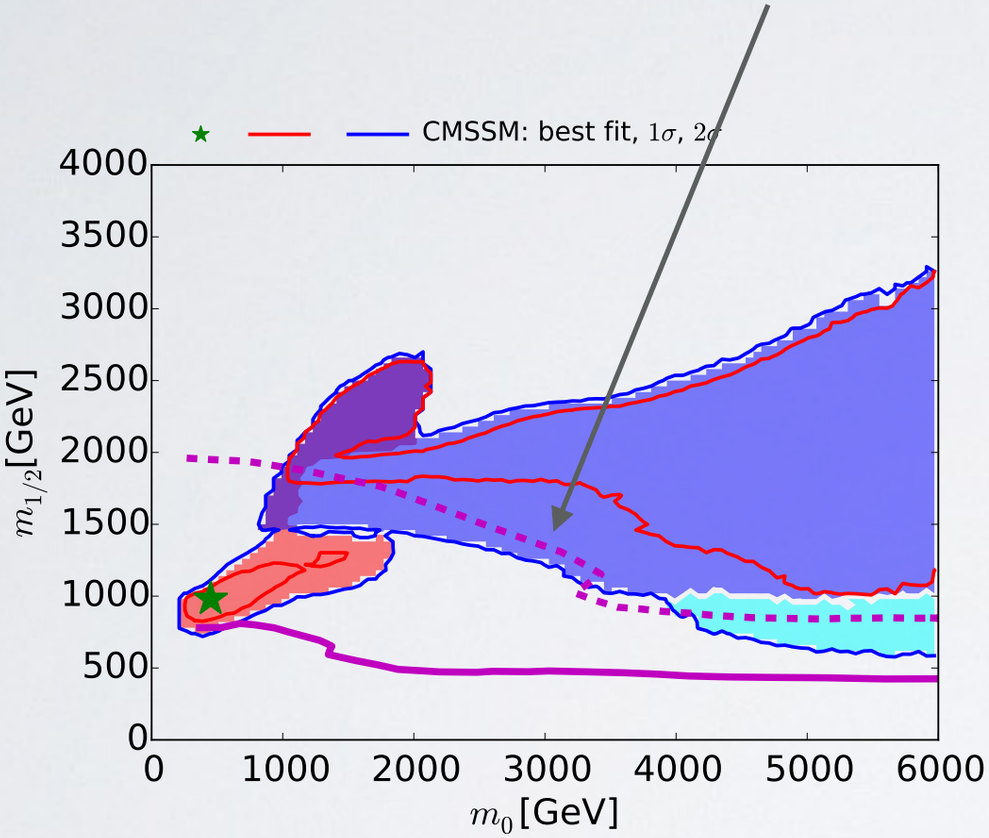
$$h \text{ funnel (magenta)}: \quad \left|\frac{M_h}{m_{\tilde{\chi}_1^0}} - 2\right| < 0.4\,,$$

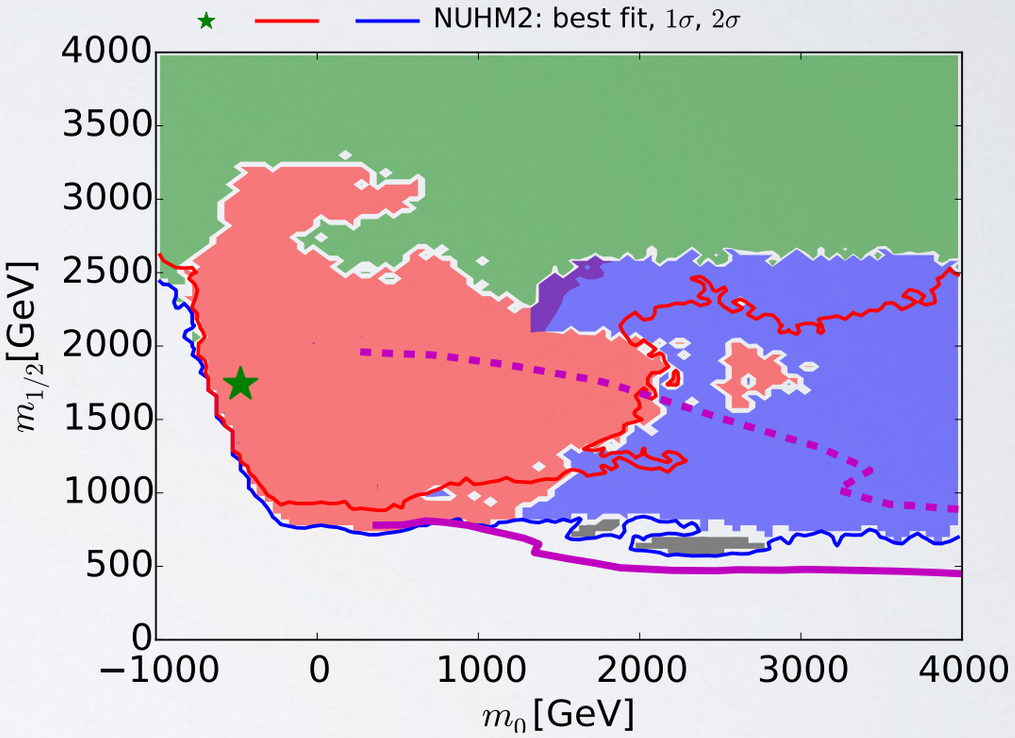
$$Z \text{ funnel (orange)}: \quad \left|\frac{M_Z}{m_{\tilde{\chi}_1^0}} - 2\right| < 0.4\,.$$

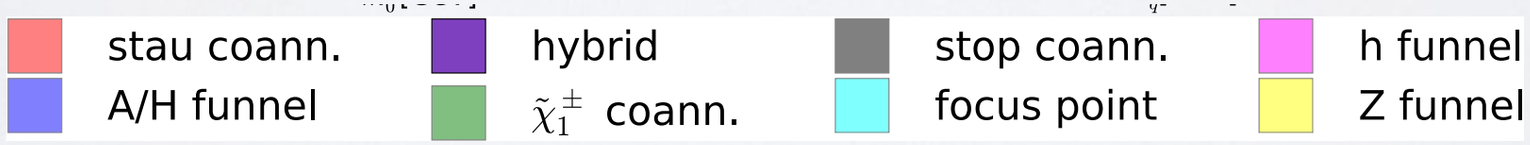
Conditions cross-checked from Micromegas output

CONSTRAINED MODELS

300/fb 95% exclusion estimate





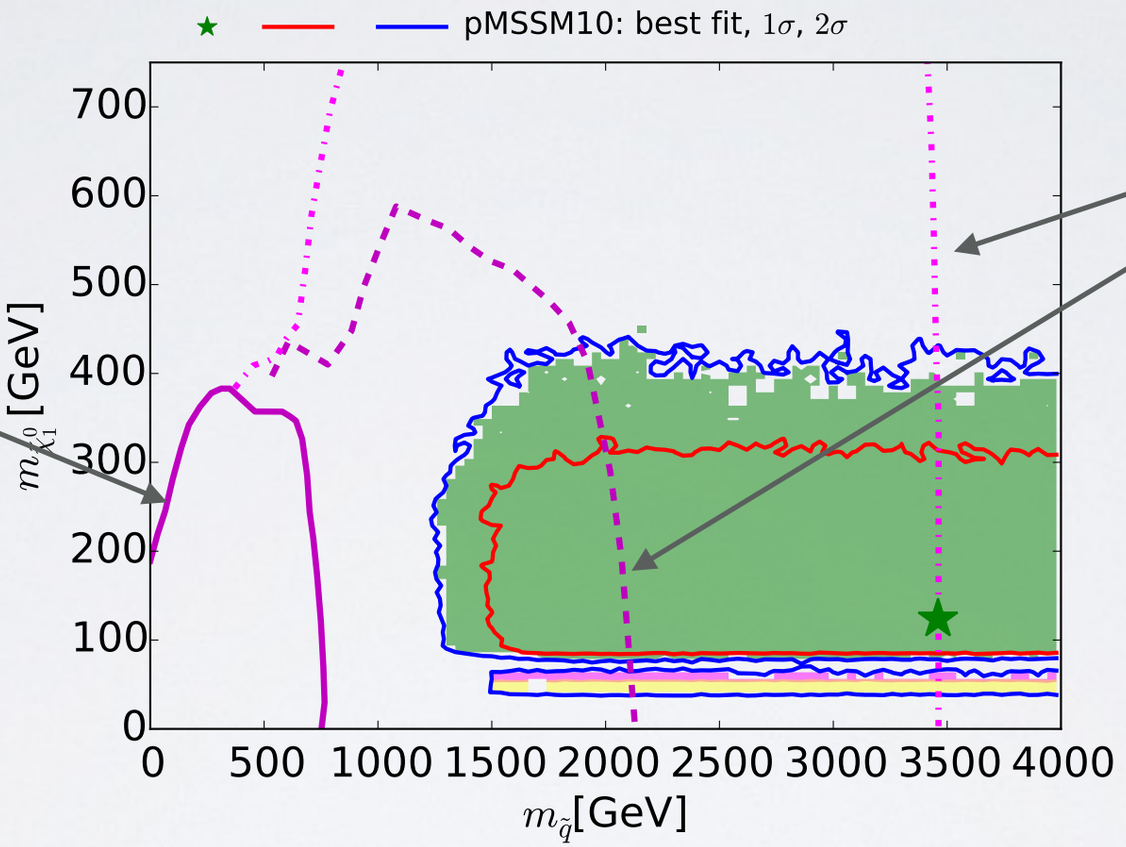


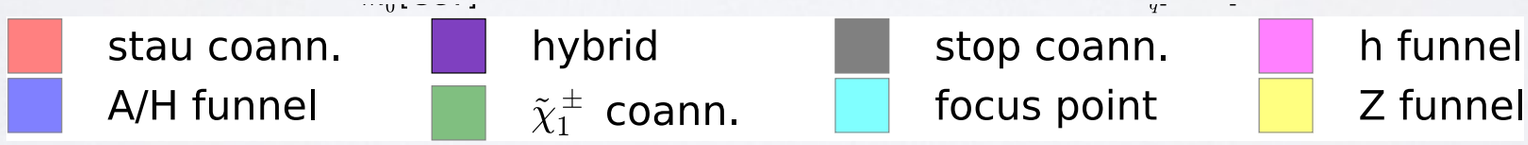
PMSSM RESULTS

Squark Neutralino mass plane

Current LHC exclusion with decoupled gluinos

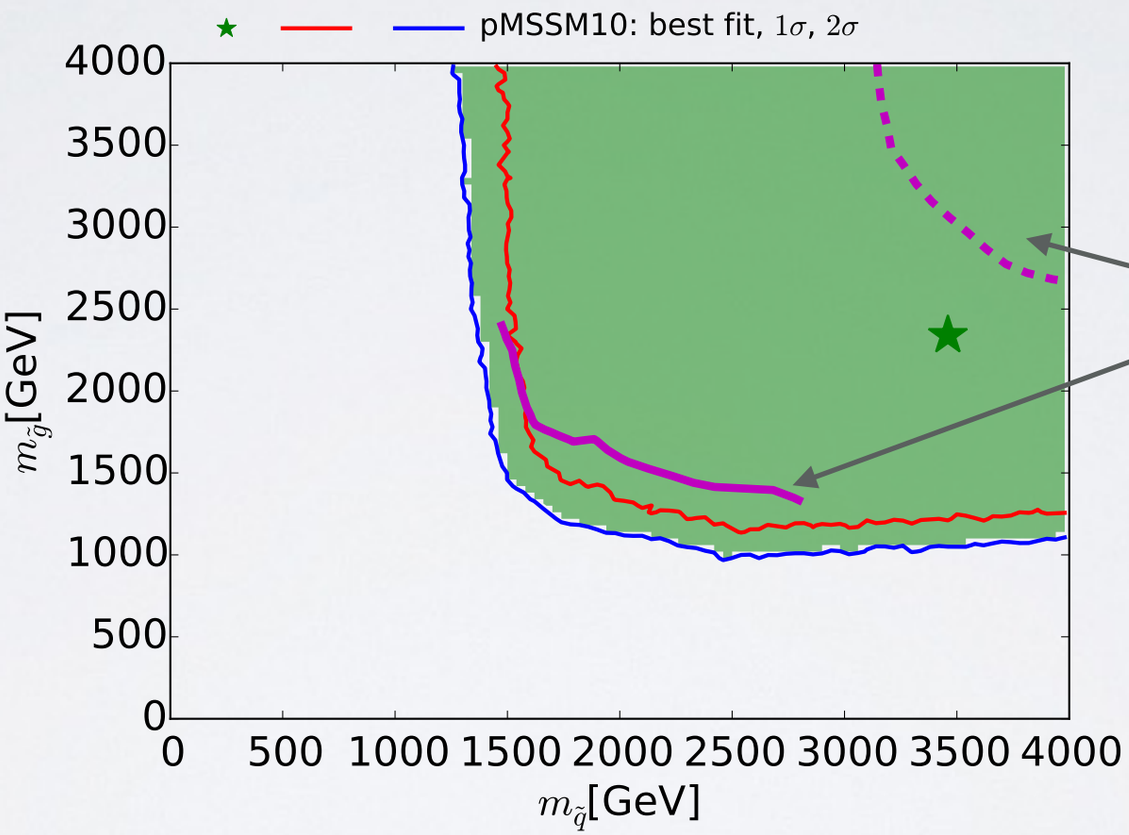
Estimates of 3000/fb reach with and w/out decoupled gluinos

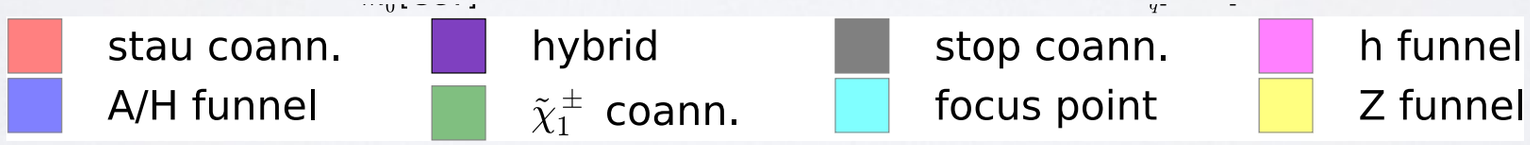




PMSSM RESULTS

Squark Gluino mass plane





PMSSM RESULTS

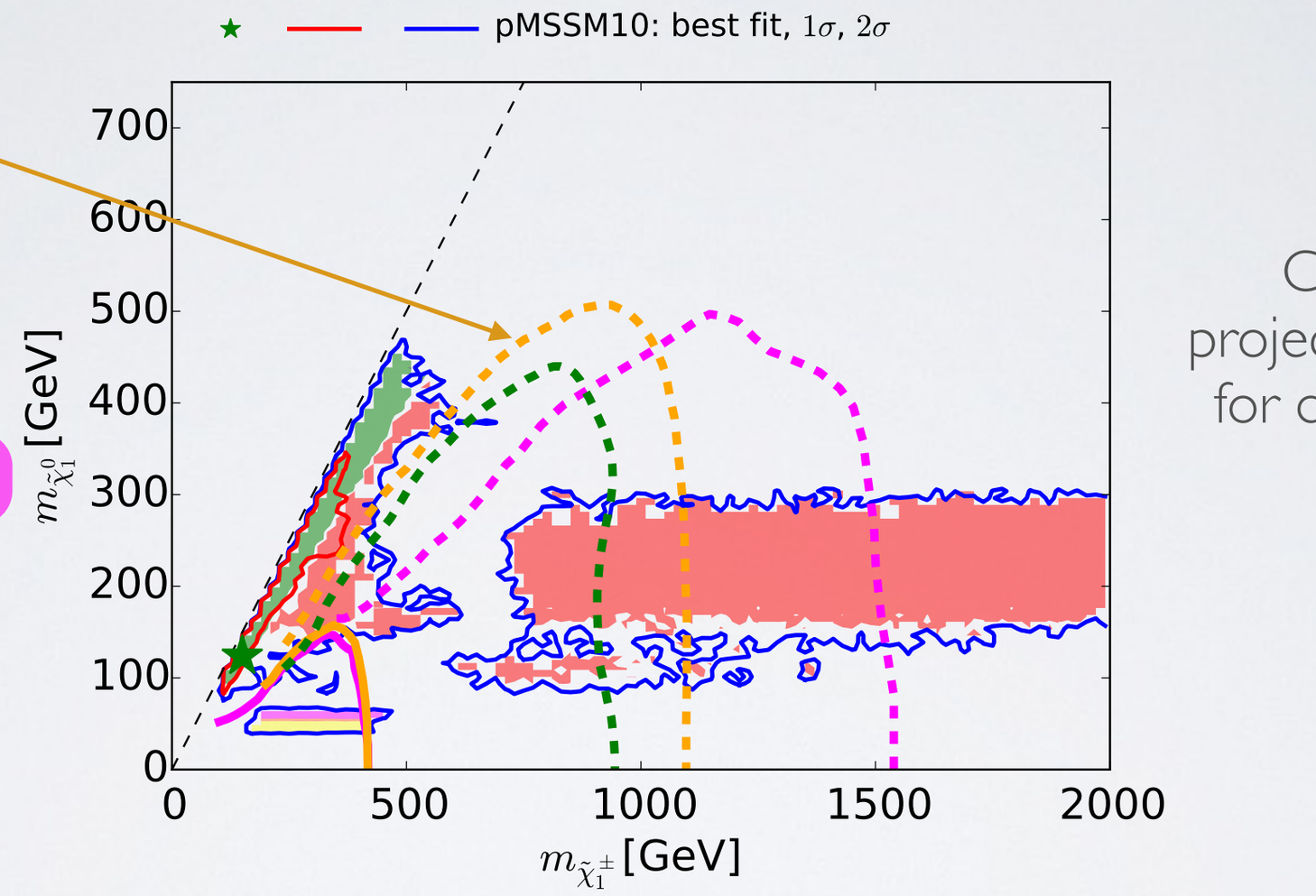
Lightest chargino-neutralino mass plane

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow W/Z + \not{E}_T$

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow W/h + \not{E}_T$

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm} \rightarrow \tau, \tilde{\tau} \rightarrow 2,3\tau's + \not{E}_T$

3000/fb 95% CL

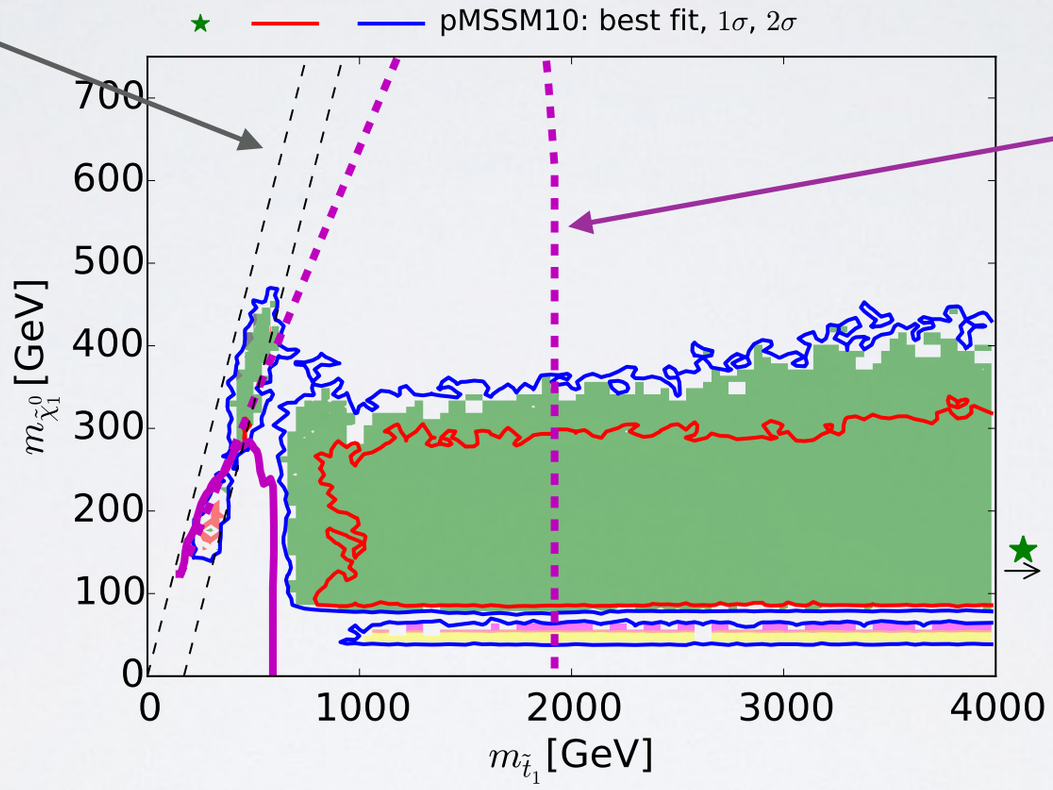


Current and projected SMS limits for different decay channels.

PMSSM RESULTS

Stop neutralino mass plane

$m_{\tilde{t}_1} = m_{\tilde{\chi}_1^0}$ *and* $m_{\tilde{t}_1} = m_t + m_{\tilde{\chi}_1^0}$



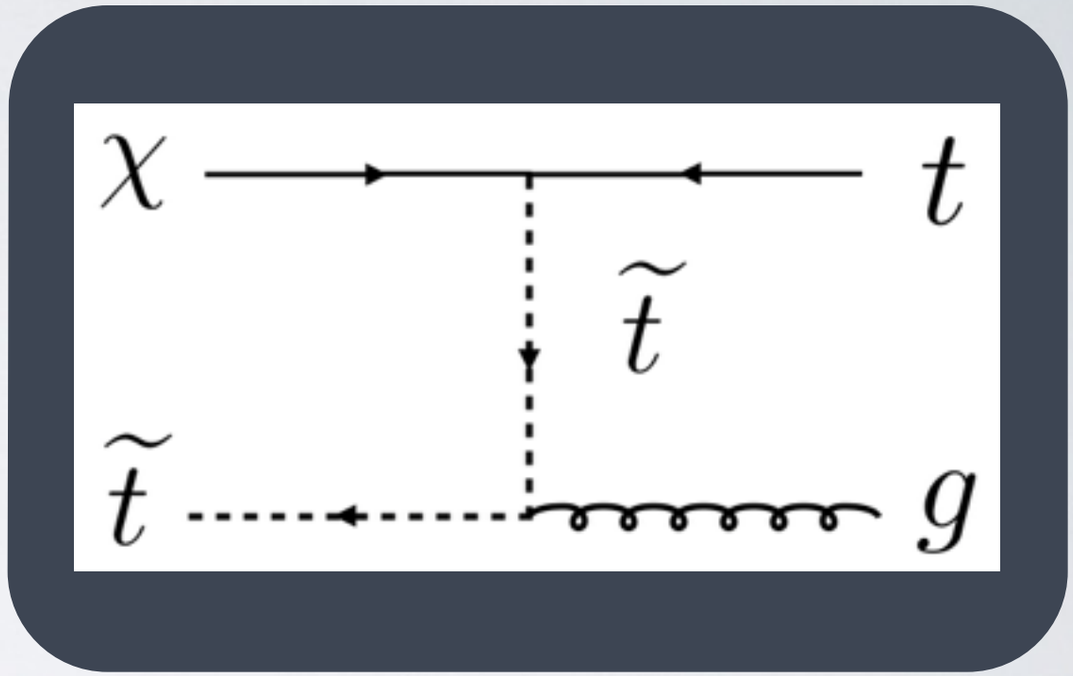
3000/fb 95% CL
100% BR

stau coann.
hybrid
stop coann.
h funnel
A/H funnel
$\tilde{\chi}_1^{\pm}$ coann.
focus point
Z funnel

PMSSM RESULTS

Co-annihilation requires LSP and other sparticle to be near degenerate.

Possibility of long-lived particles?



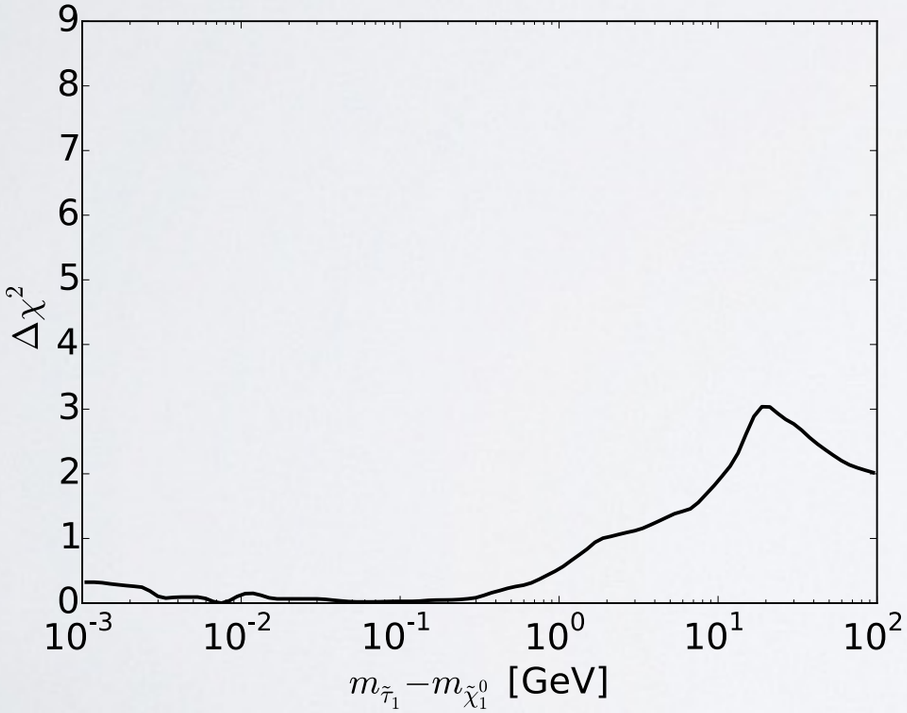
This possibility is not realized in the pMSSM

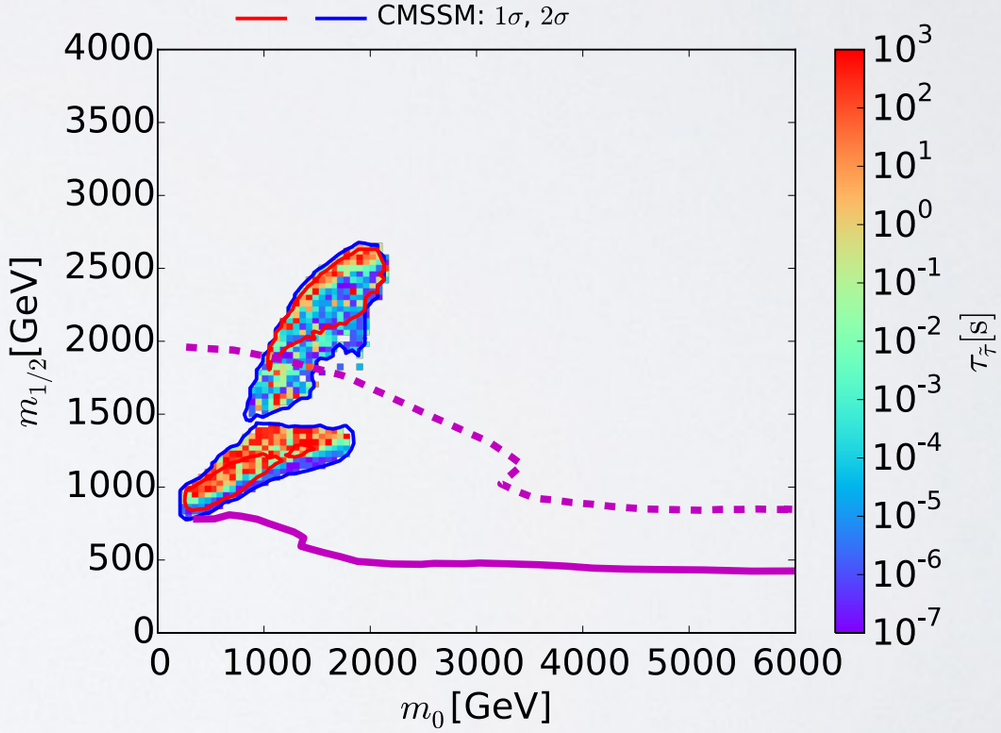
LONG LIVED SPARTICLES

In constrained models, squark/gluino limits also push up the LSP mass

Heavier LSP implies greater NLSP degeneracy for correct annihilation cross-section

CMSSM



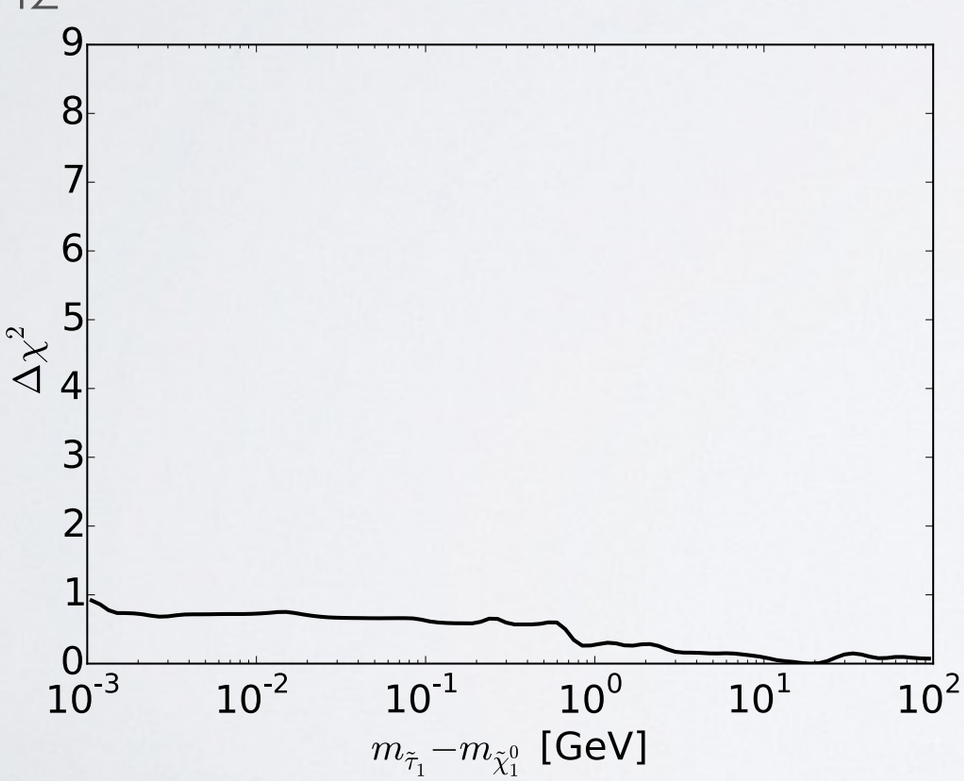


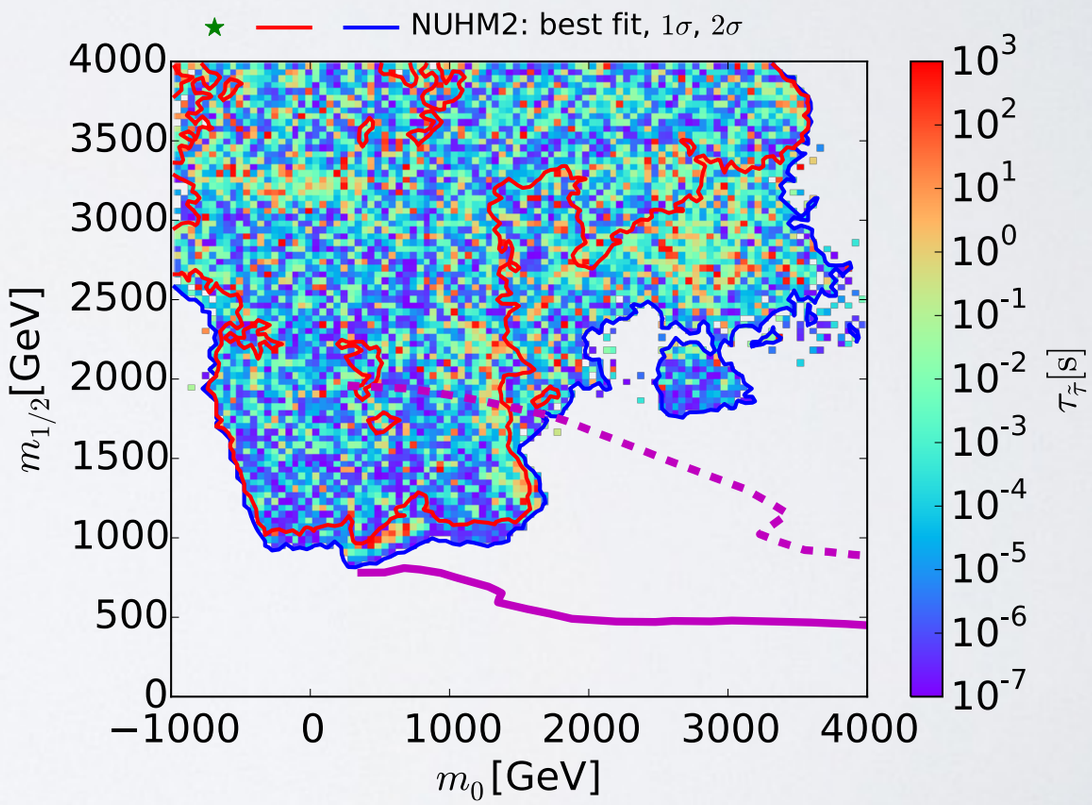
LONG LIVED SPARTICLES

In constrained models, squark/gluino limits also push up the LSP mass

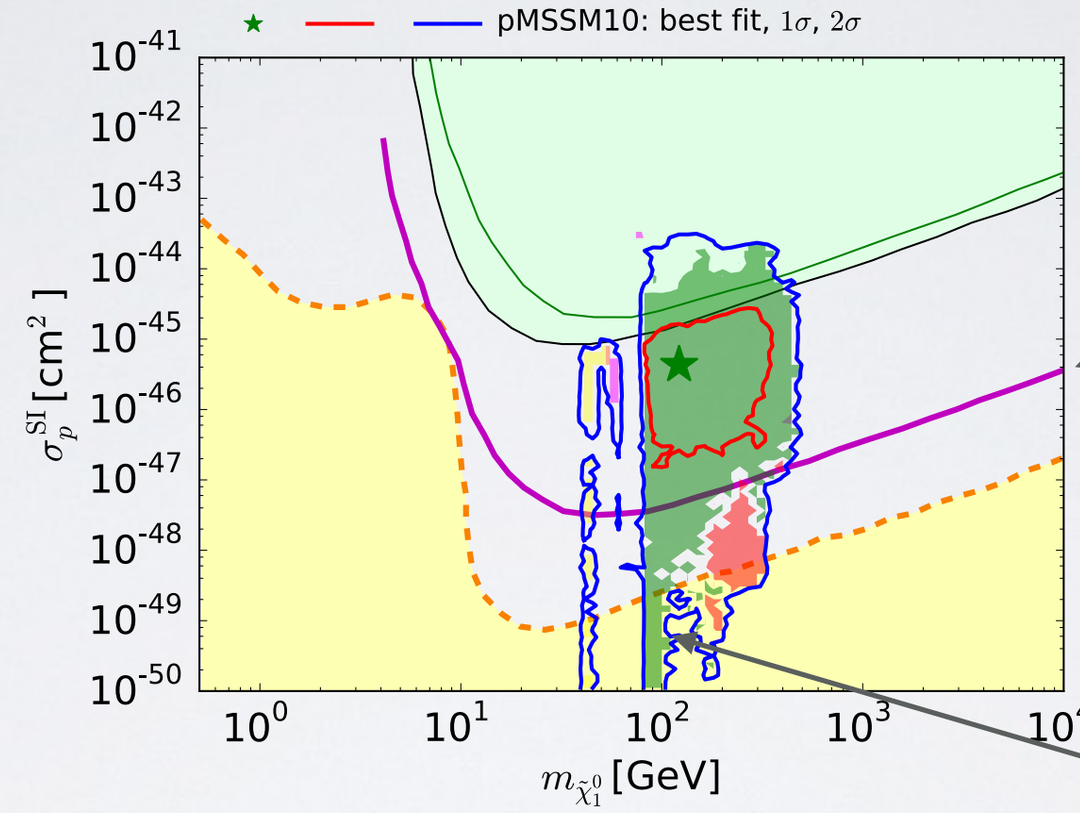
Heavier LSP implies greater NLSP degeneracy for correct annihilation cross-section

NUHM2





DIRECT DETECTION PHENOMENOLOGY



Projected LZ bound

Cancellations in matrix elements here

stau coann.
hybrid
stop coann.
h funnel
A/H funnel
$\tilde{\chi}_1^{\pm}$ coann.
focus point
Z funnel

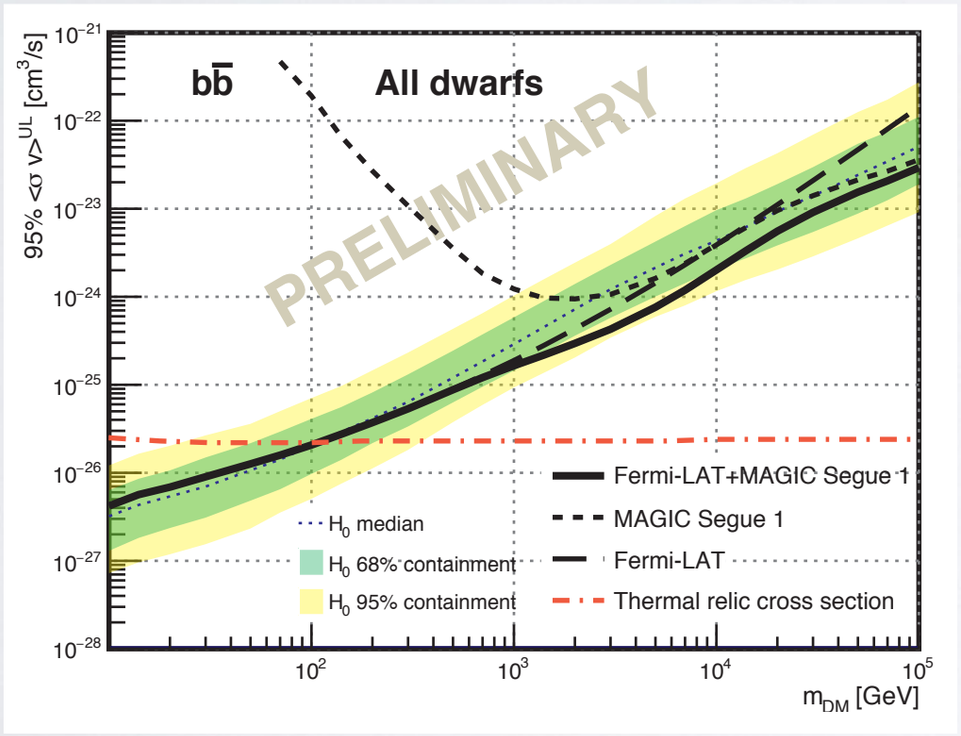
SUMMARY OF DETECTABILITY

DM mechanism	Exp't	Models			
		CMSSM	NUHM1	NUHM2	pMSSM10
$\tilde{\tau}_1$ coann.	LHC	✓ $\not{E}_T$, ✓ LL	(✓ $\not{E}_T$, ✓ LL)	(✓ $\not{E}_T$, ✓ LL)	(✓ $\not{E}_T$), × LL
	DM	(✓)	(✓)	×	×
$\tilde{\chi}_1^{\pm}$ coann.	LHC	–	×	×	(✓ $\not{E}_T$)
	DM	–	✓	✓	(✓)
$\tilde{t}_1$ coann.	LHC	–	–	✓ $\not{E}_T$	–
	DM	–	–	×	–
A/H funnel	LHC	✓ A/H	(✓ A/H)	(✓ A/H)	–
	DM	✓	✓	(✓)	–
Focus point	LHC	(✓ $\not{E}_T$)	–	–	–
	DM	✓	–	–	–
h, Z funnels	LHC	–	–	–	(✓ $\not{E}_T$)
	DM	–	–	–	(✓)

INDIRECT DETECTION

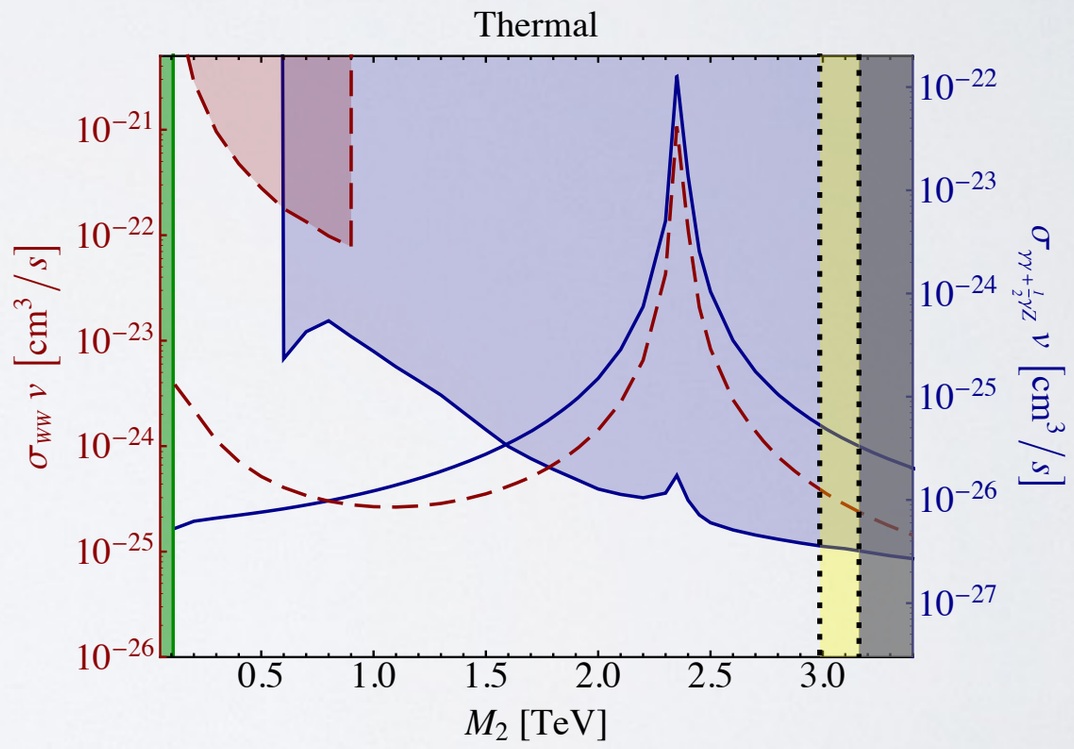
Also Weniger's talk

Will be interesting to incorporate recent Fermi-LAT dwarf satellite limits



Rico, Wood, Drlica-Wagner, Aleksic 2015

Indirect detection constraints from Fermi/HESS constrain heavier (wino) states



Cohen, Lisanti, Pierce, Slatyer 2013

SUMMARY

DD and Collider searches will probe variety of DM mechanisms in near future

Charged track searches in constrained models

Run II + CTA/SKA/HESS/Fermi-LAT = Interesting times ahead!