Getting ready for LHC run 2:

hunting dark matter at colliders

Adam Martin (amarti41@nd.edu)
University of Notre Dame

UNIVERSITY OF NOTRE DAME

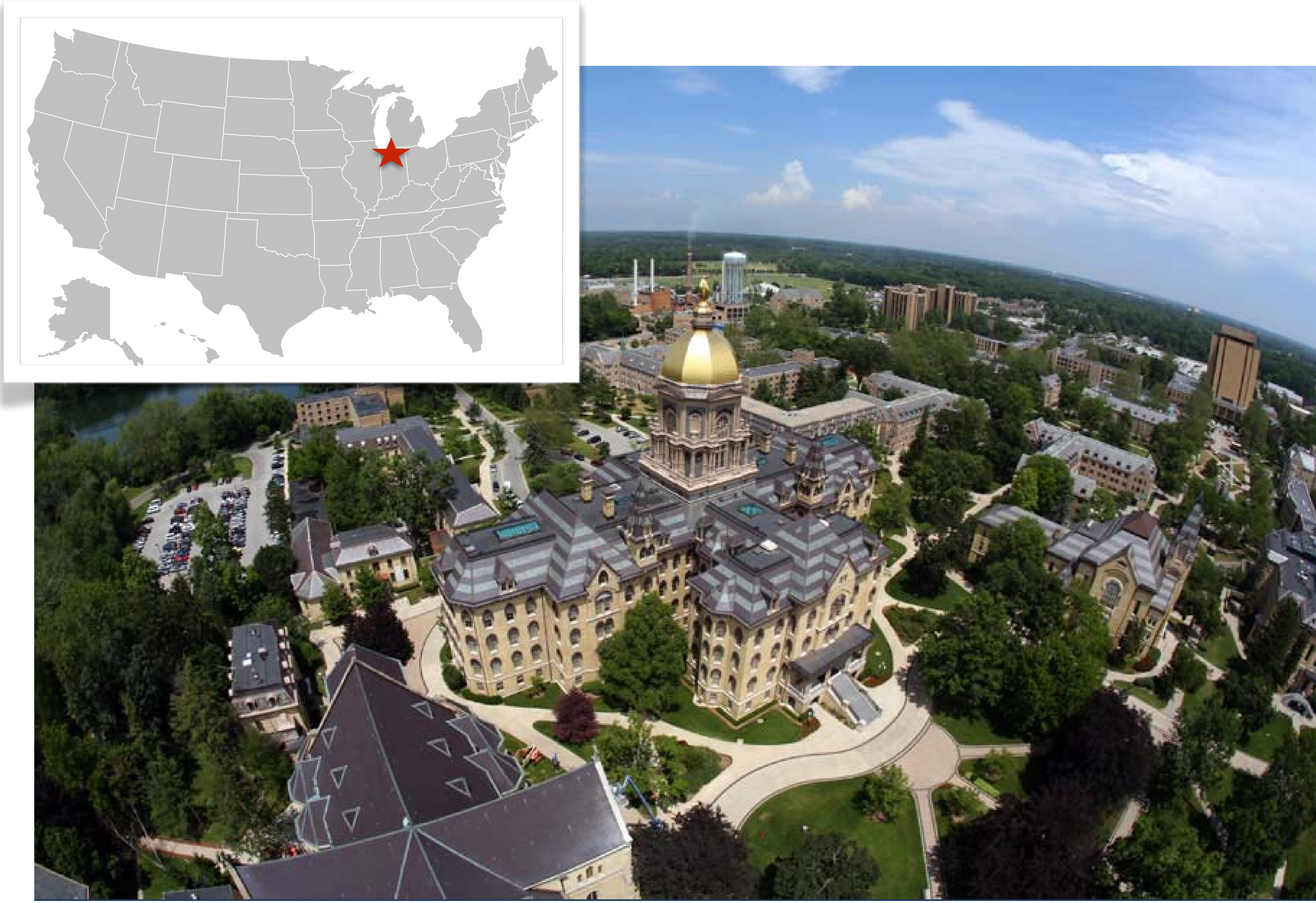
Outline

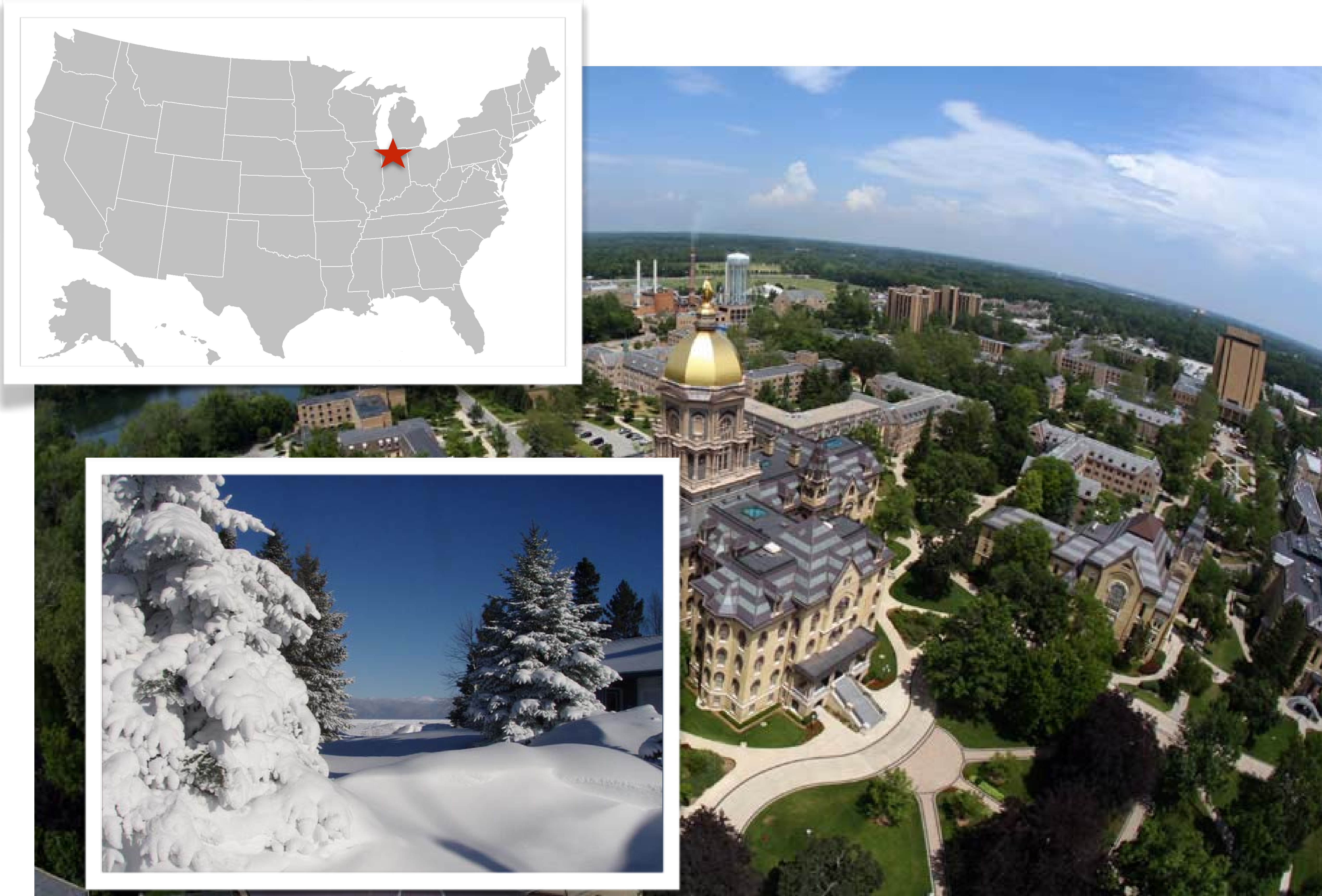
1.) Introduction to Notre Dame High-Energy Physics

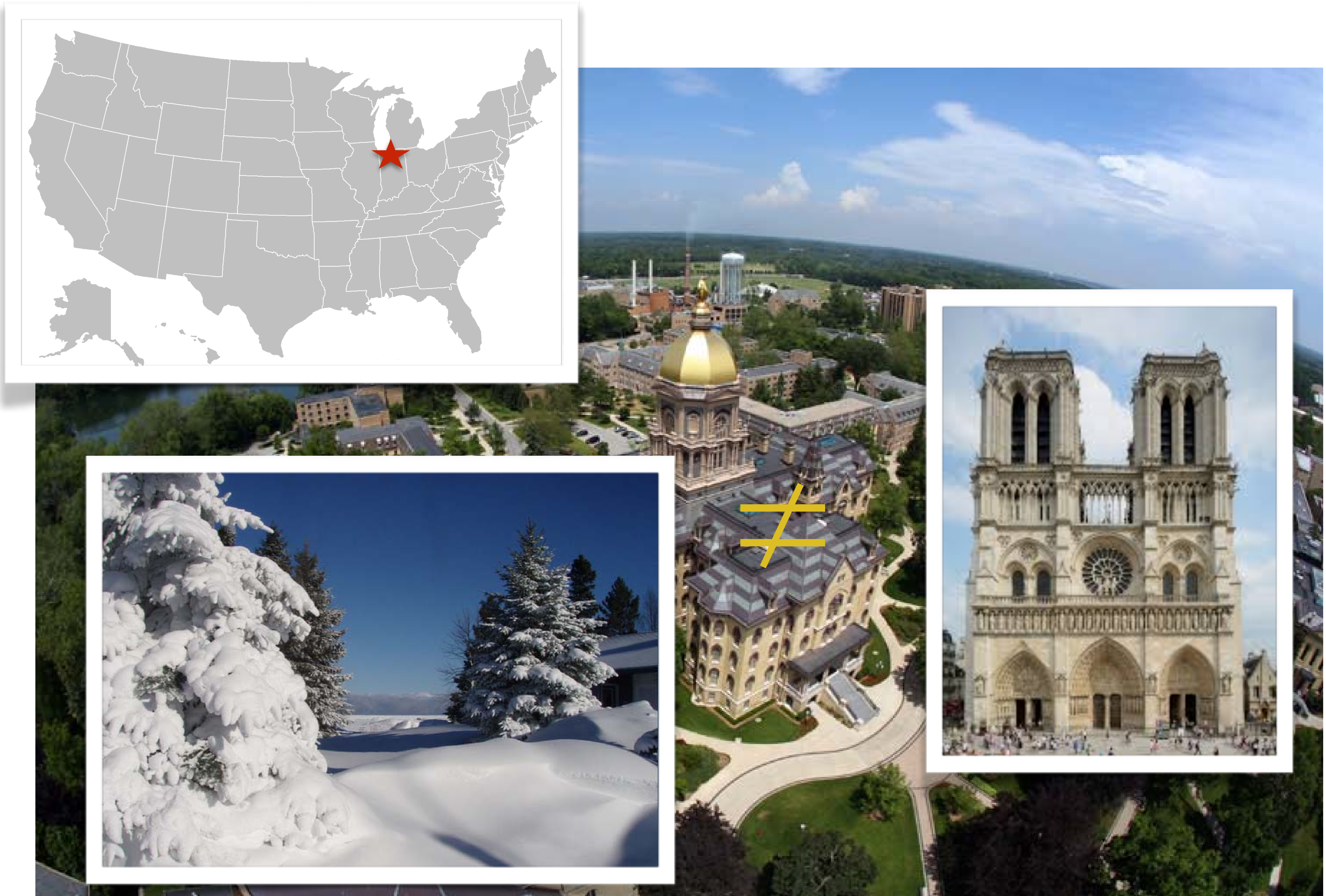
2.) Hunting for (supersymmetric) dark matter at colliders

University of Notre Dame

University of Notre Dame







Particle Physics at Notre Dame

theory

experiment

Particle Physics at Notre Dame

students

Capdevilla, Rodolfo

Alvarado, Carlos

Elahi, Fatemeh

Lehman, Landon

postdocs

Joe Bramante

Nirmal Raj

In addition to the topic I'll talk about

there are several other ideas we're interested in

simple MSSM extensions

inflation

Hilbert series

compressed SUSY spectra

very light Z'

alternatives to freeze-out DM

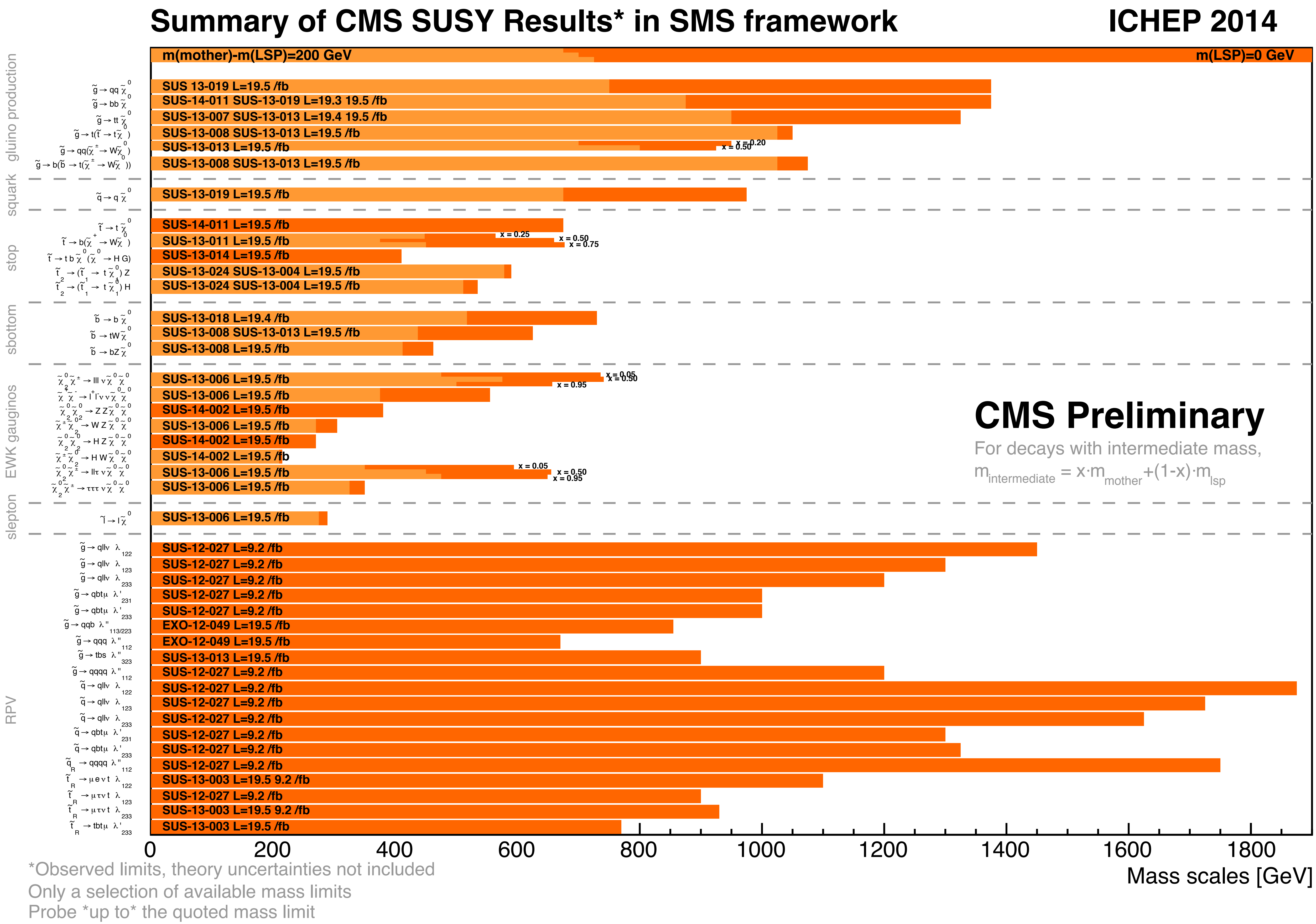
that I'd be happy to discuss

Part II:

Hunting Dark Matter at the LHC

specifically electroweakinos = superpartners of Higgs boson, W, Z, γ

Motivation


Summary of CMS SUSY Results* in SMS framework
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m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
squark
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CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother +(1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

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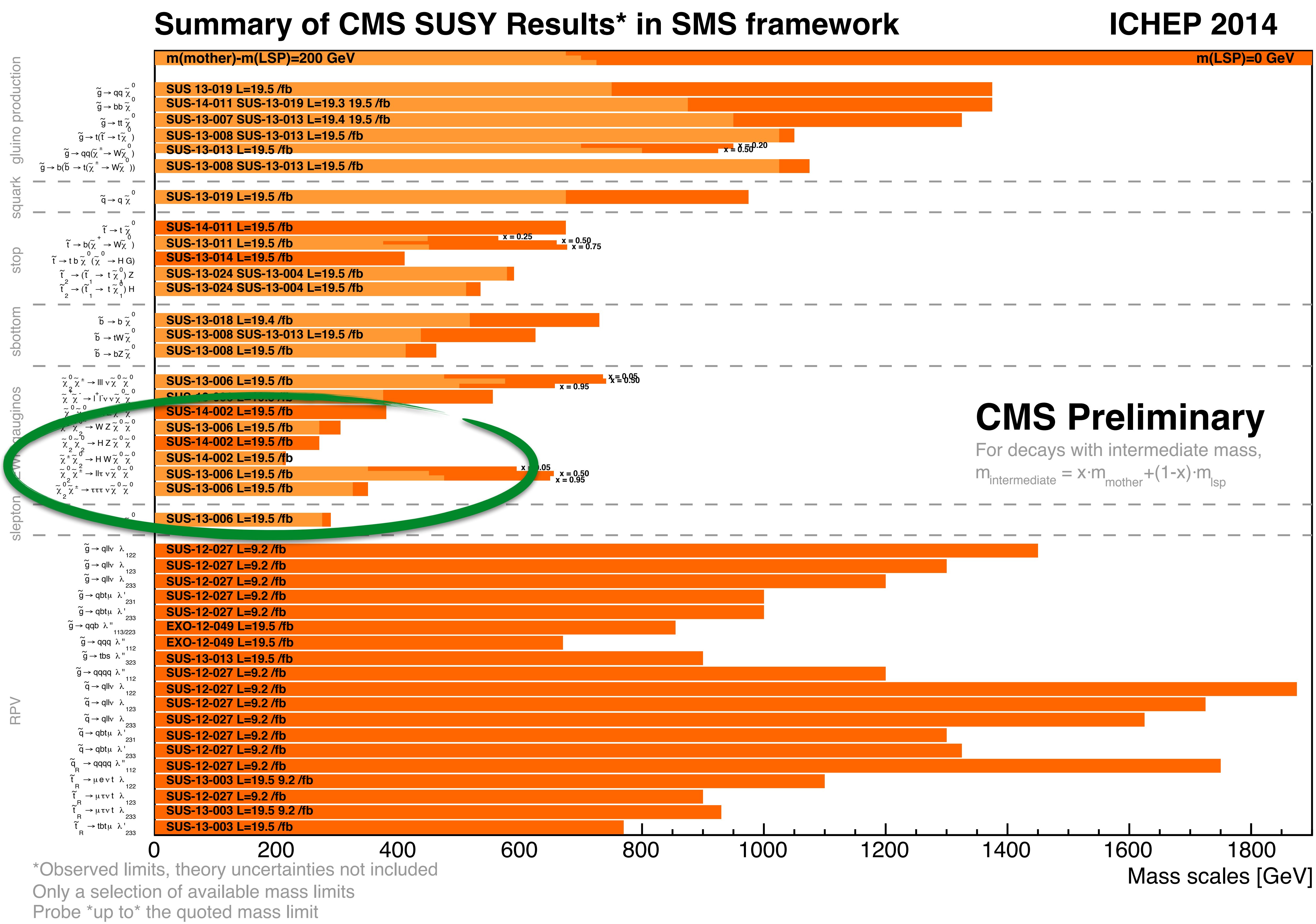

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Why electroweakinos?

electroweakinos = admixtures of Higgsino, Bino, Wino

charginos (Higgsinos, Winos): $(\widetilde{W}^+, \widetilde{H}_u^+, \widetilde{W}^-, \widetilde{H}_d^-)$

$$\mathbf{X} = \begin{pmatrix} M_2 & g v_u \\ g v_d & \mu \end{pmatrix} = \begin{pmatrix} M_2 & \sqrt{2} s_\beta \, m_W \\ \sqrt{2} c_\beta \, m_W & \mu \end{pmatrix}$$

neutralinos (all 4): $\psi^0 = (\widetilde{B}, \widetilde{W}^0, \widetilde{H}_d^0, \widetilde{H}_u^0)$

$$\mathbf{M}_{\widetilde{N}} = \begin{pmatrix} M_1 & 0 & -c_\beta \, s_W \, m_Z & s_\beta \, s_W \, m_Z \\ 0 & M_2 & c_\beta \, c_W \, m_Z & -s_\beta \, c_W \, m_Z \\ -c_\beta \, s_W \, m_Z & c_\beta \, c_W \, m_Z & 0 & -\mu \\ s_\beta \, s_W \, m_Z & -s_\beta \, c_W \, m_Z & -\mu & 0 \end{pmatrix}$$

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$\mathbf{X}$

in the limit $m_{\tilde{Q}}, m_{\tilde{L}} \gg m_X$:

phenomenology set by 4 parameters:

M_1, M_2, μ, $\tan\beta$

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Naturalness: Higgsino mass is related to the Z mass

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weak scale

to avoid big cancellations, both of these should be weak scale (~100 GeV) too!

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Dark Matter: lightest superparticle is stable, can be DM

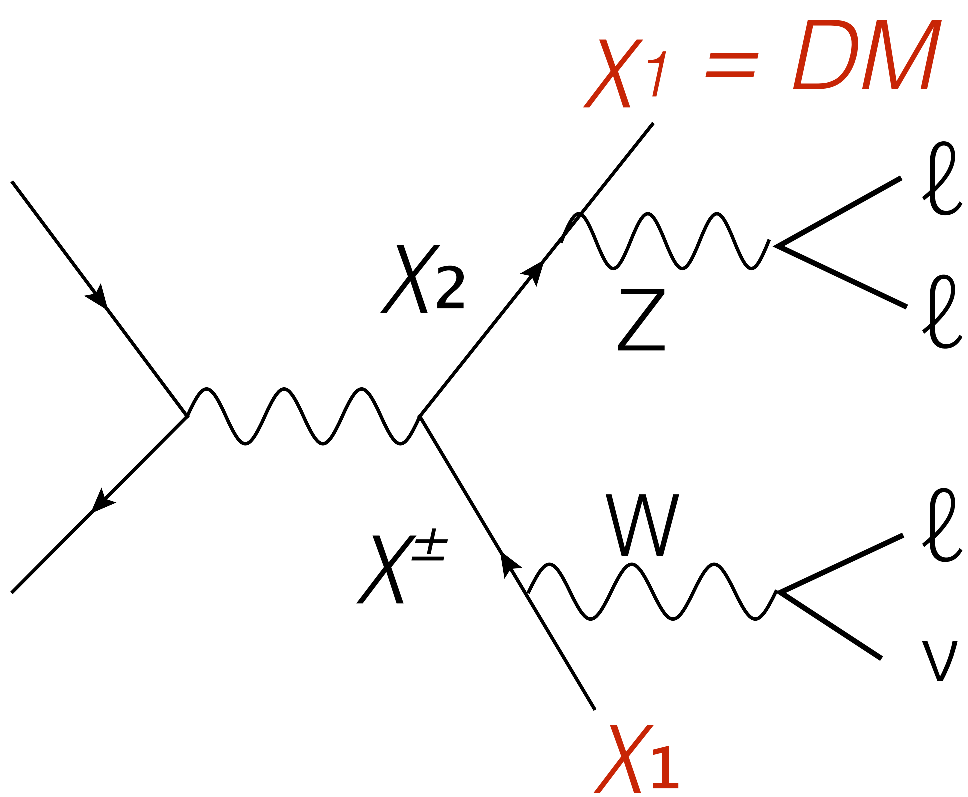
right amount of DM achieved from admixtures of electroweakinos, mass ~ 100 GeV - TeV

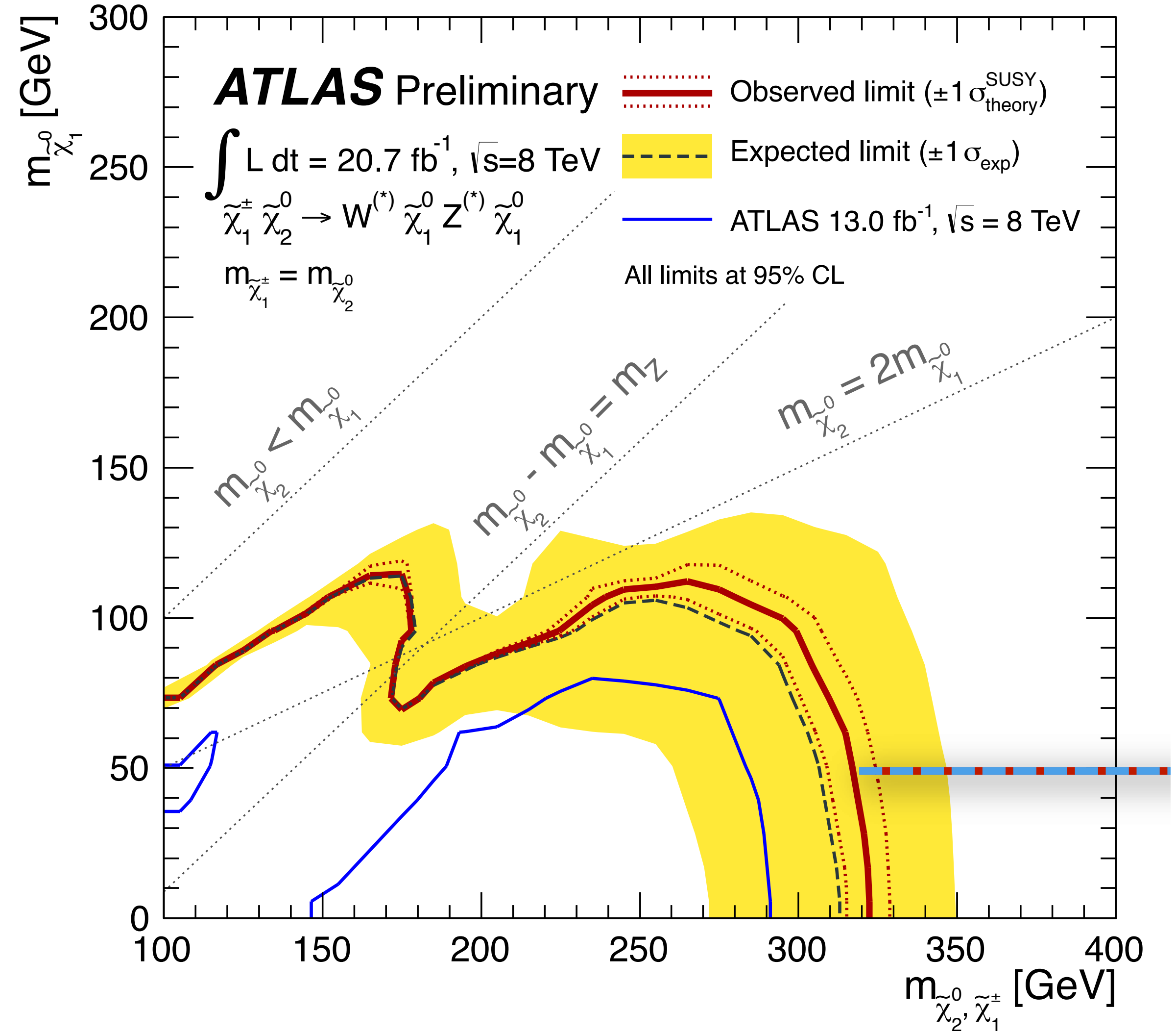
"Well-tempered electroweakino" scenario

[Arkani-Hamed, Delgado, Giudice '06]

Current electroweakino searches

"tri-lepton" searches:





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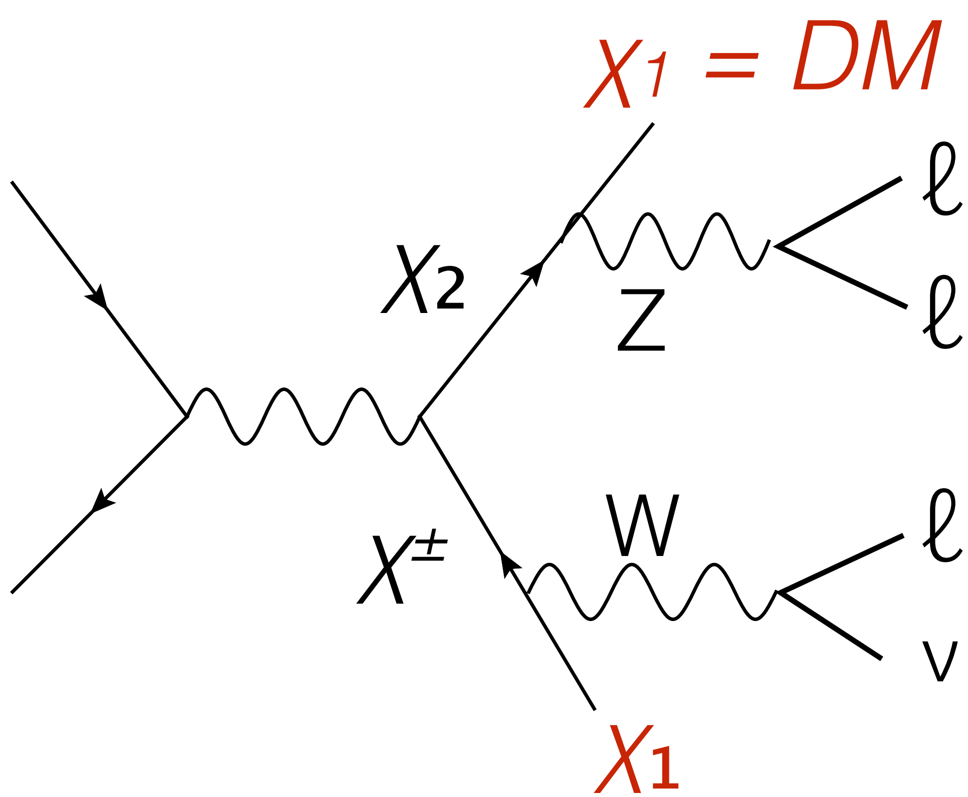

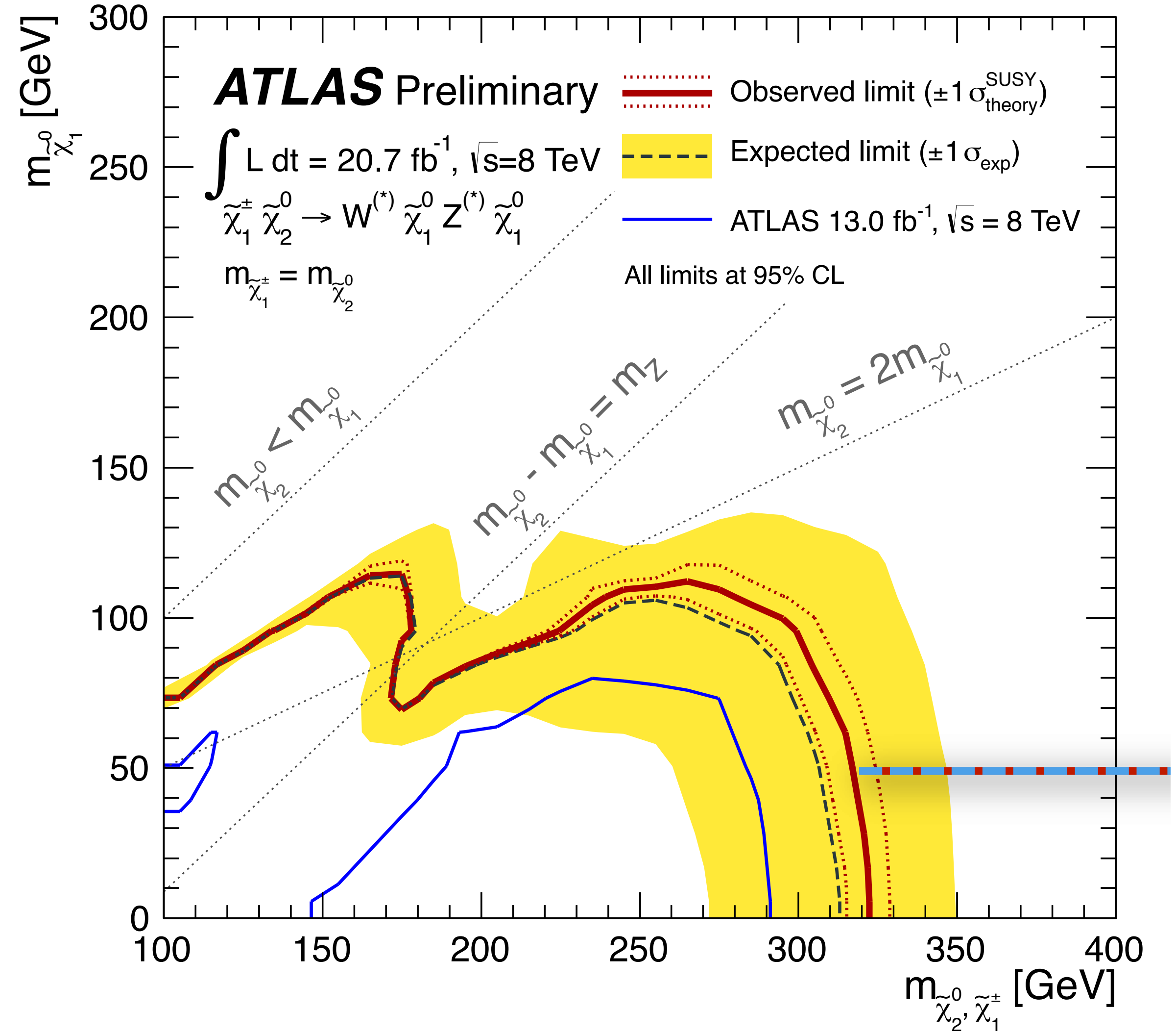

struggle when the states are nearly degenerate ($m_{\chi 2} \sim m_{\chi\pm} \sim m_{\chi 1}$)

leptons become inefficient to trigger upon (25 GeV for single lepton trigger, 17 GeV/8 GeV for 2-lepton)…
Doesn't improve at 14 TeV

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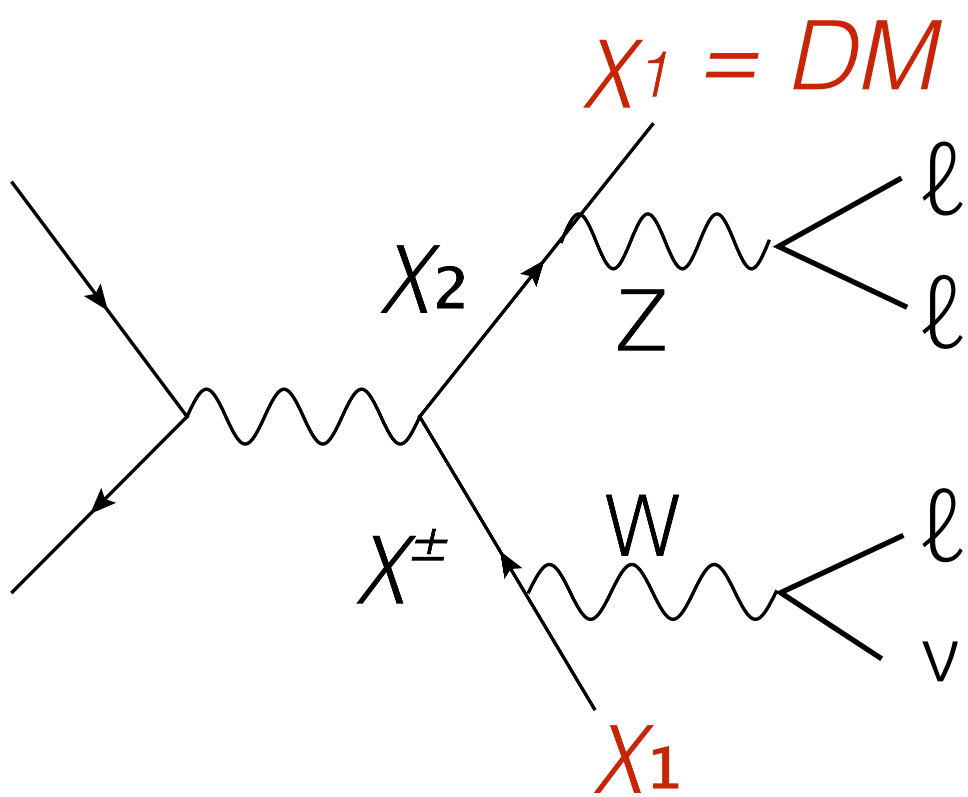

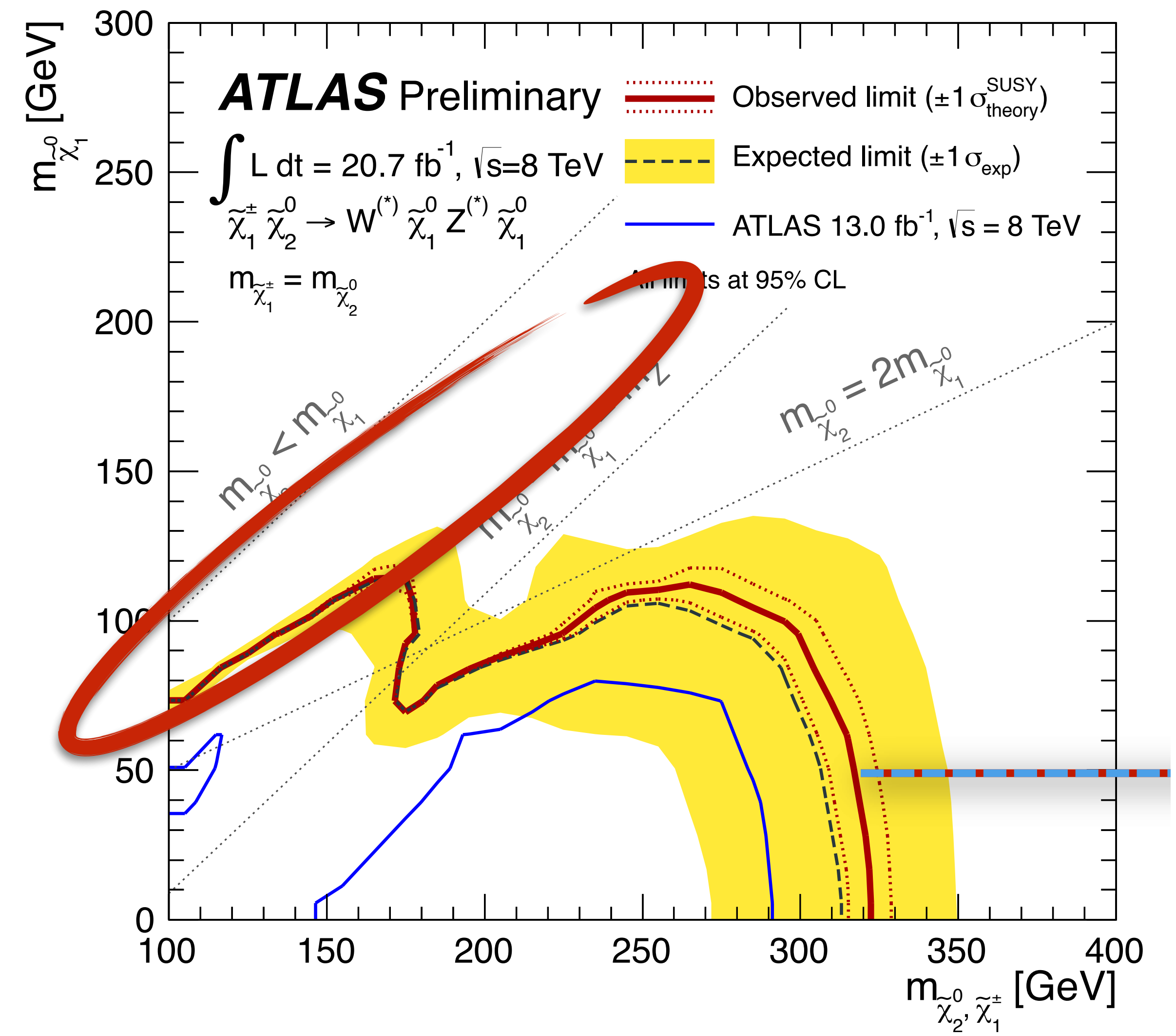

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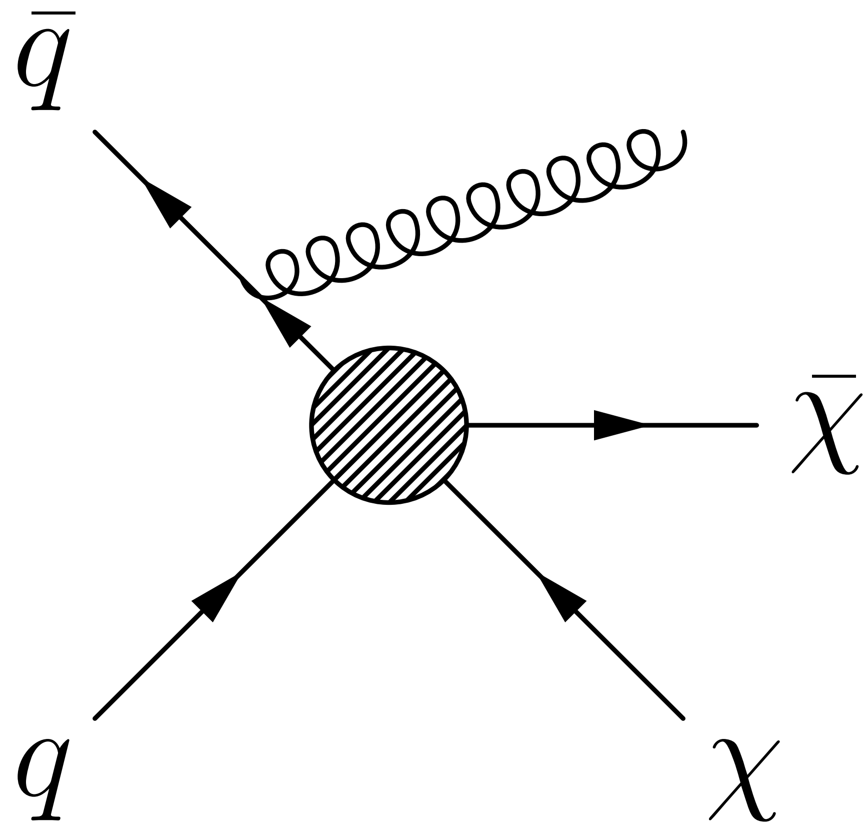
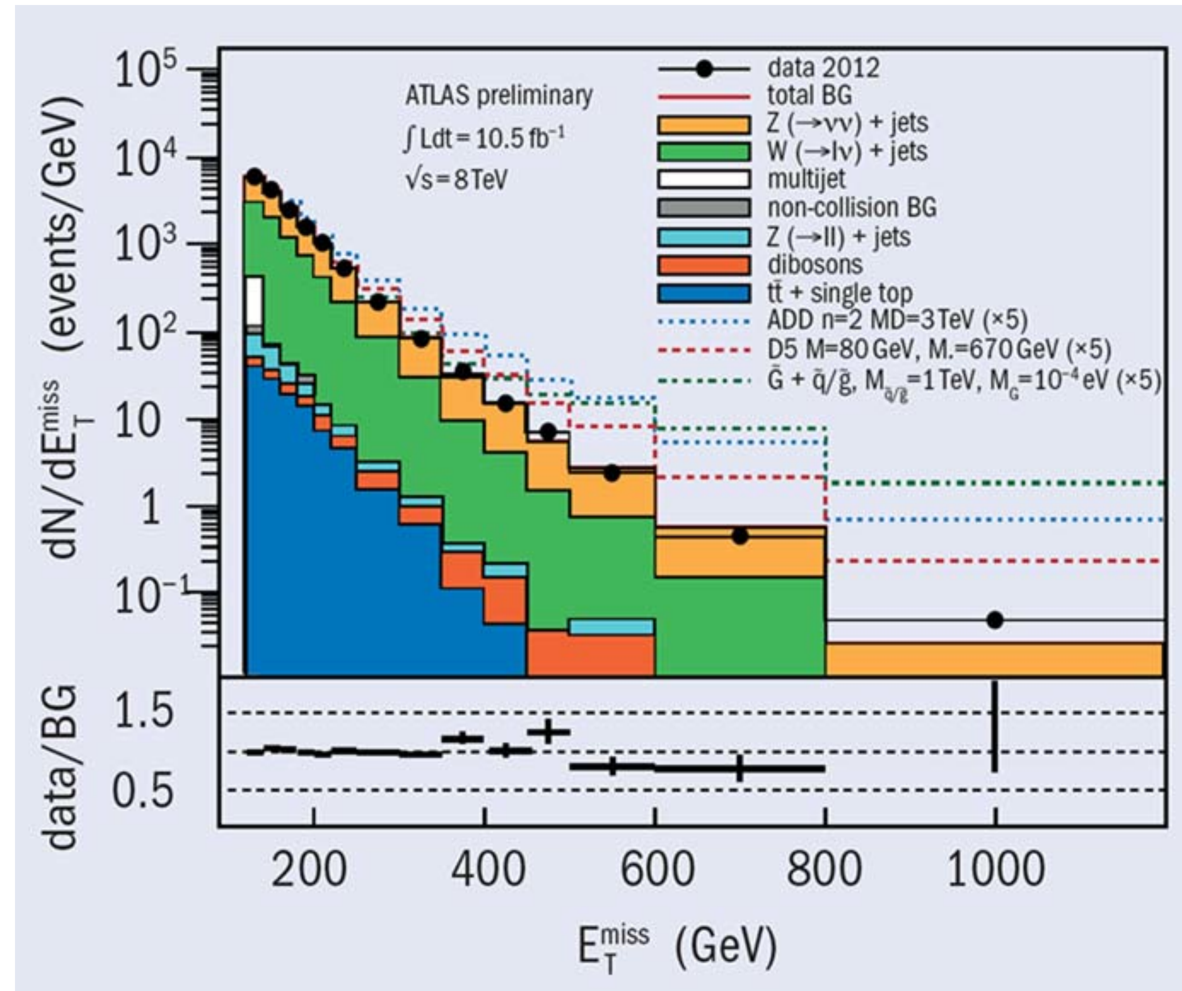
Monojet searches

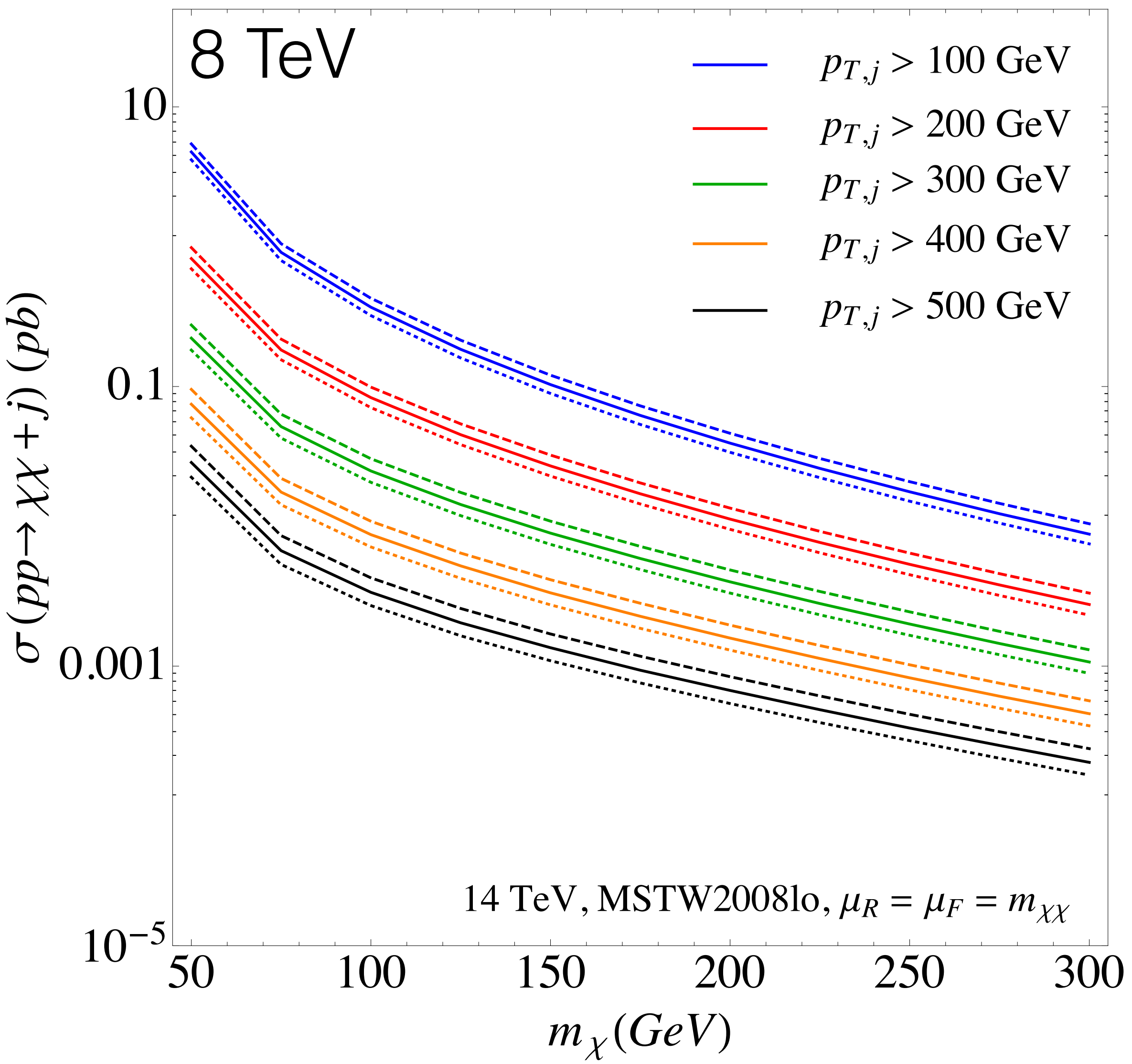




model independent, ideal for degenerate spectra

less to distinguish signal from background; limits degrade as the invisible-SM interaction becomes less contact-like

Monojet searches



[Han, Kribs, AM, Menon 1401.1235]

for pure Higgsinos

recasting mono-jet searches on 8 TeV data, limits are

$m_\chi \gtrsim$ 80 GeV

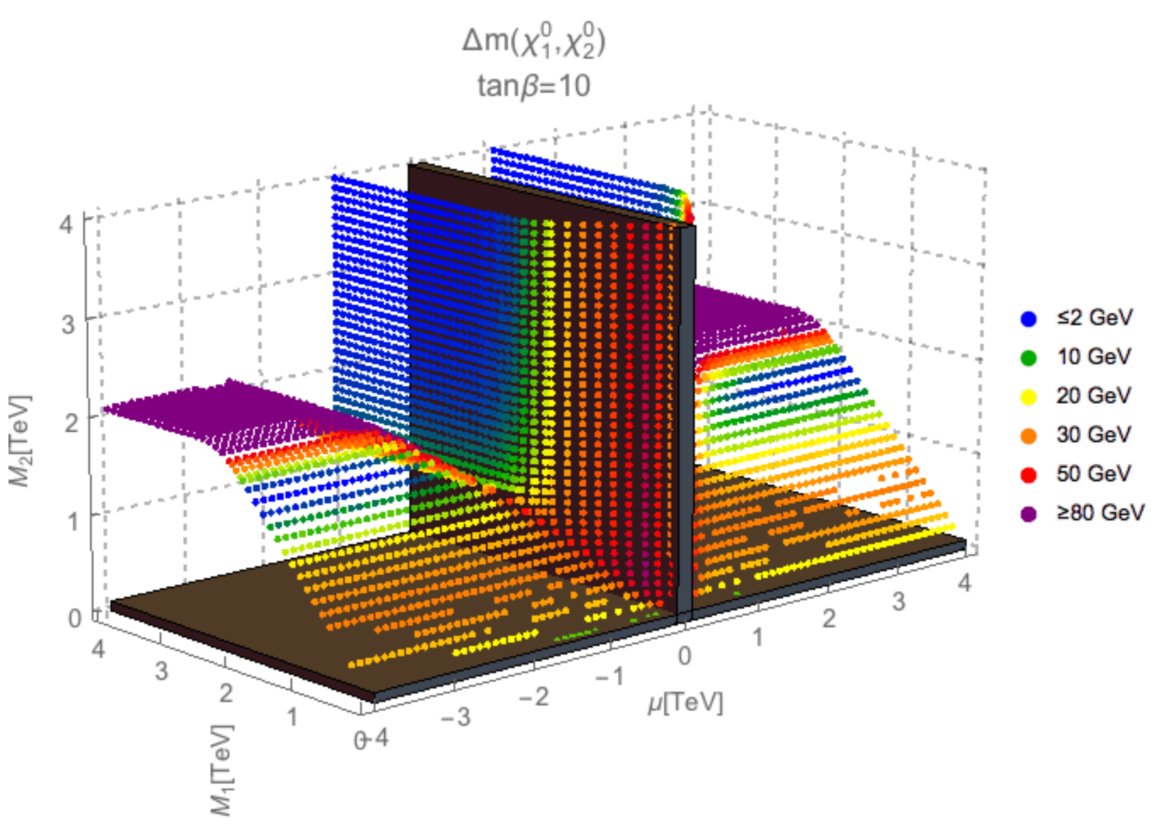
no better than LEPII bound!

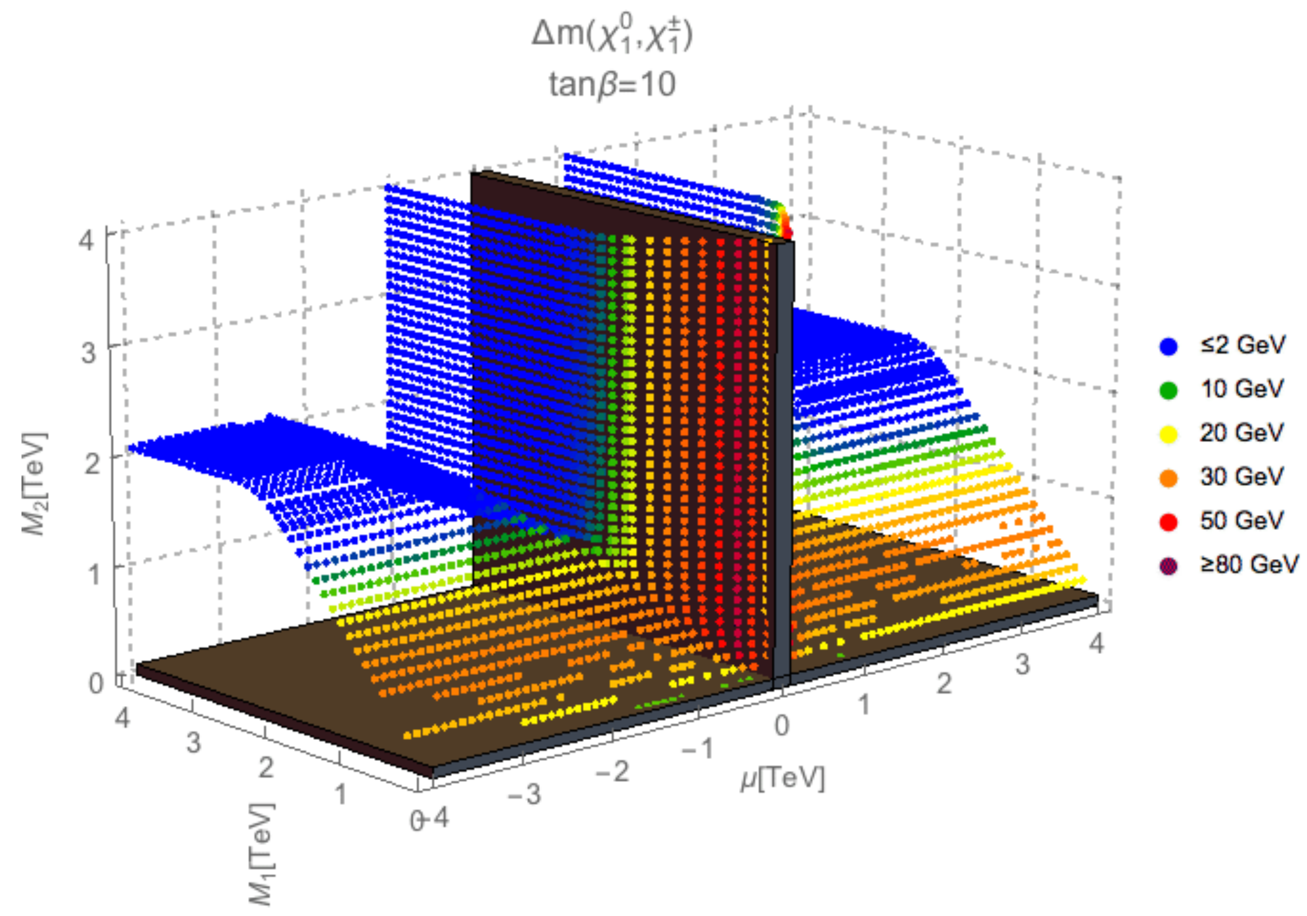
projected to 14 TeV, high L, limits still feeble

Why electroweakinos?

LHC limits are weakest when states are nearly degenerate

but approximately-degenerate spectra are exactly what is required for well-tempered scenarios to fit DM abundance





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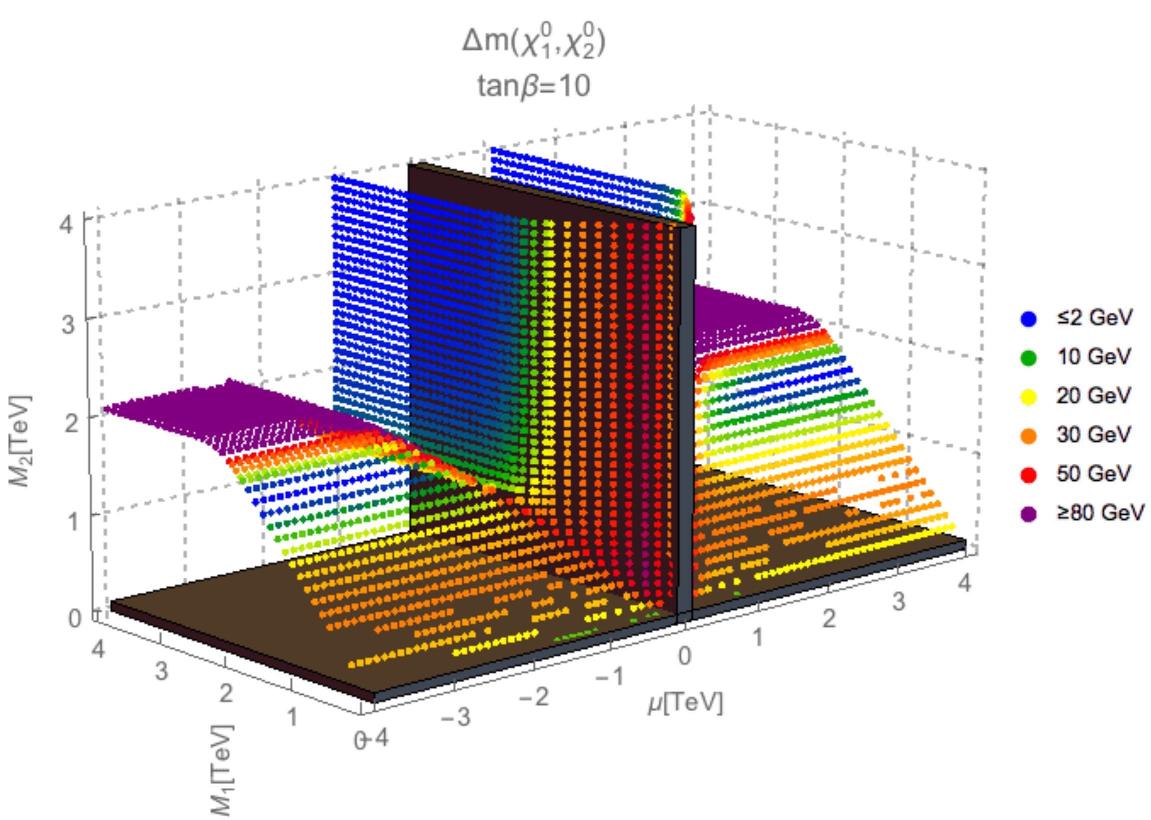

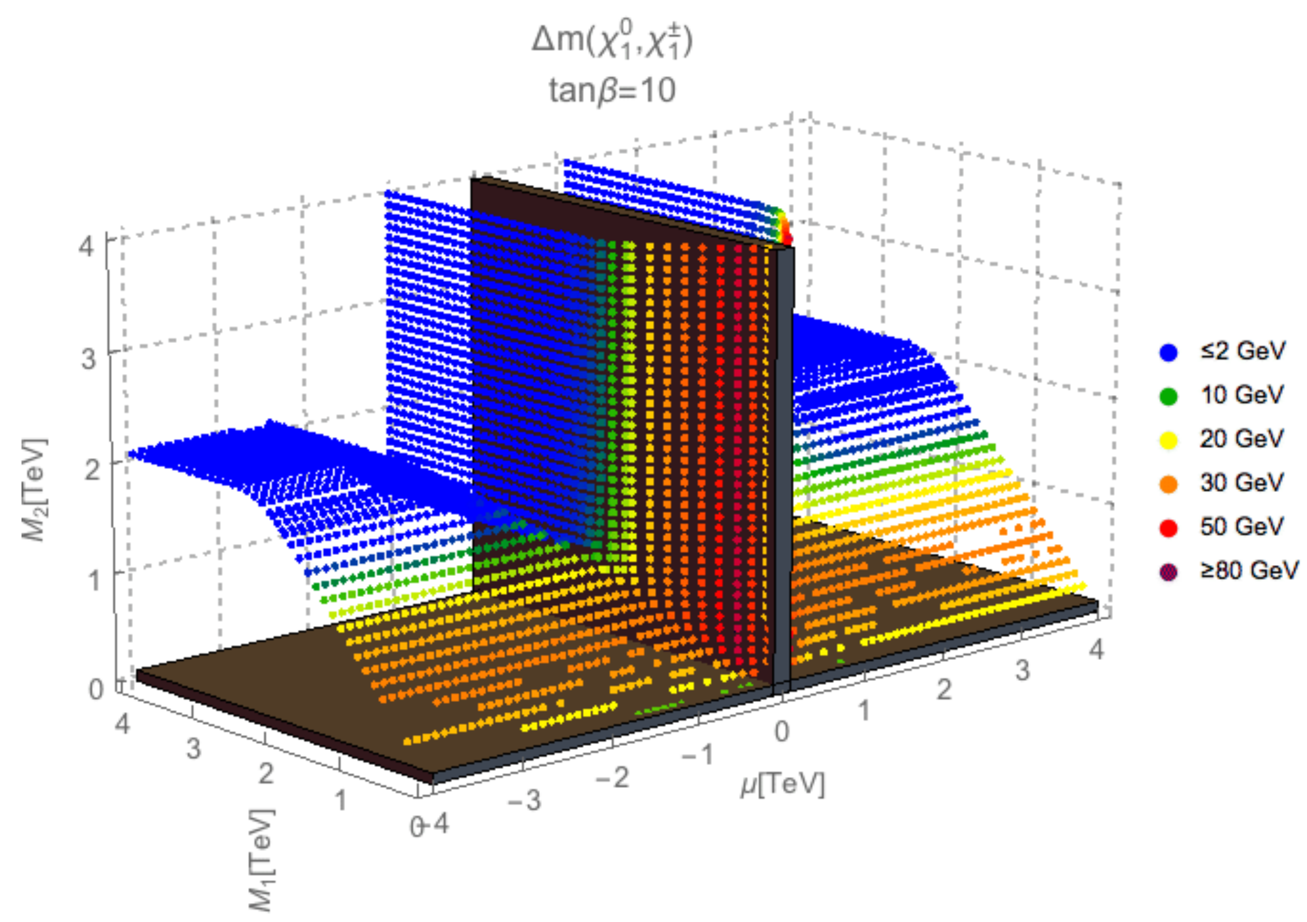

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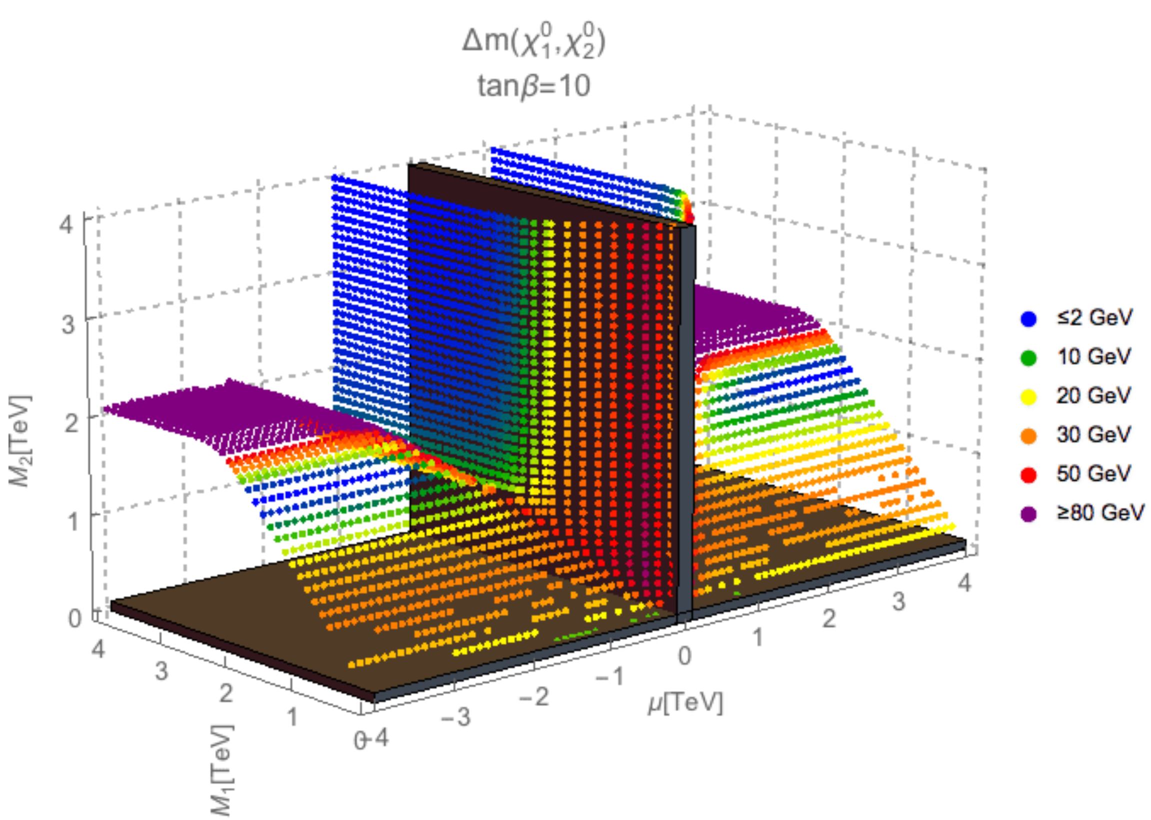
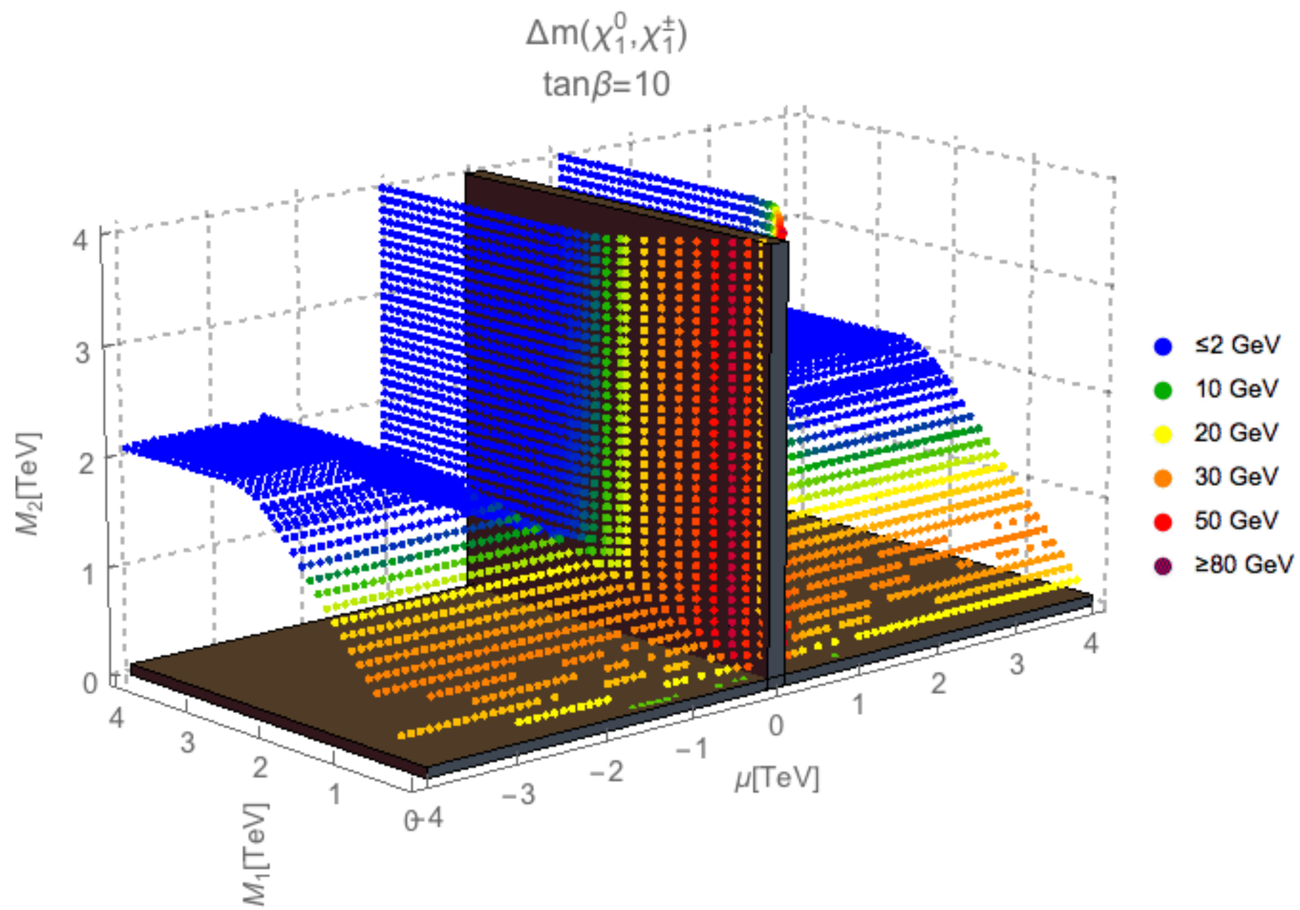
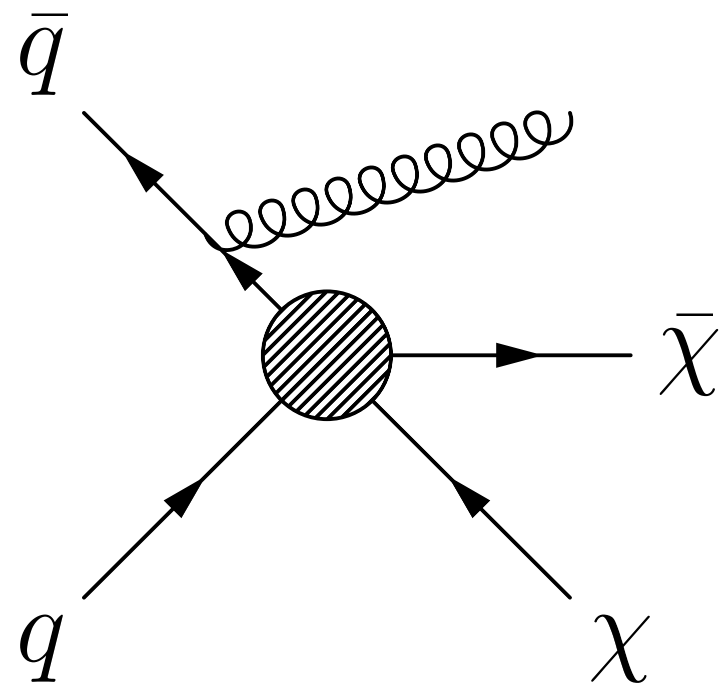




improved searches needed

One possibility: Improve mono-jet searches

the problem with tri-lepton searches is triggering; solve this by requiring hard initial-state jet, as in mono-jet



once triggered upon, event can be analyzed using lower, off-line thresholds ($\gtrsim$ 7 GeV for $e^{\pm}$, $\gtrsim$ 3 GeV for $\mu^{\pm}$)

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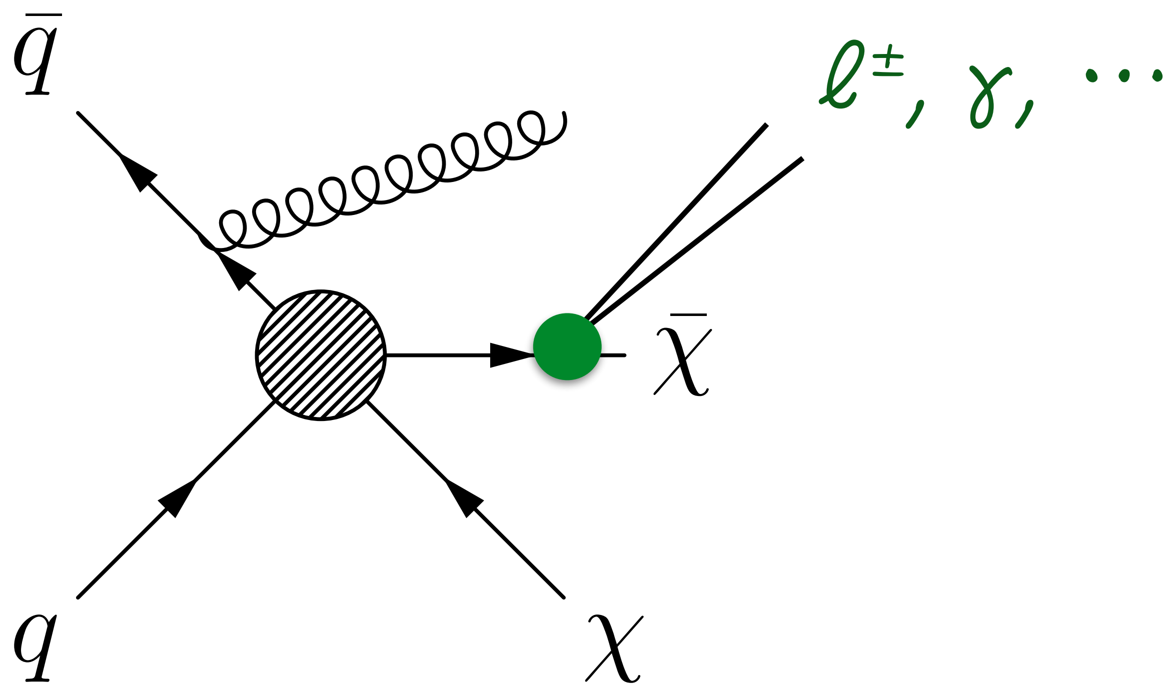

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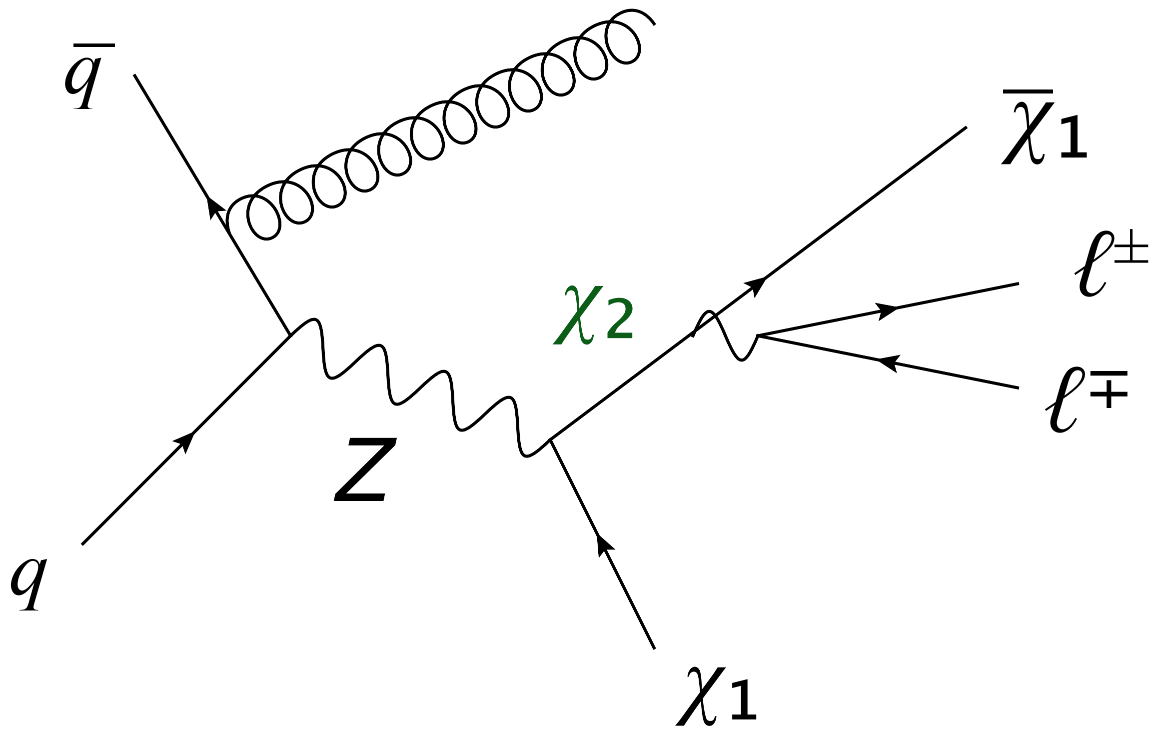
Example: jet + $\ell^+\ell^-$+ MET



[Han, Kribs, AM, Menon 1401.1235]

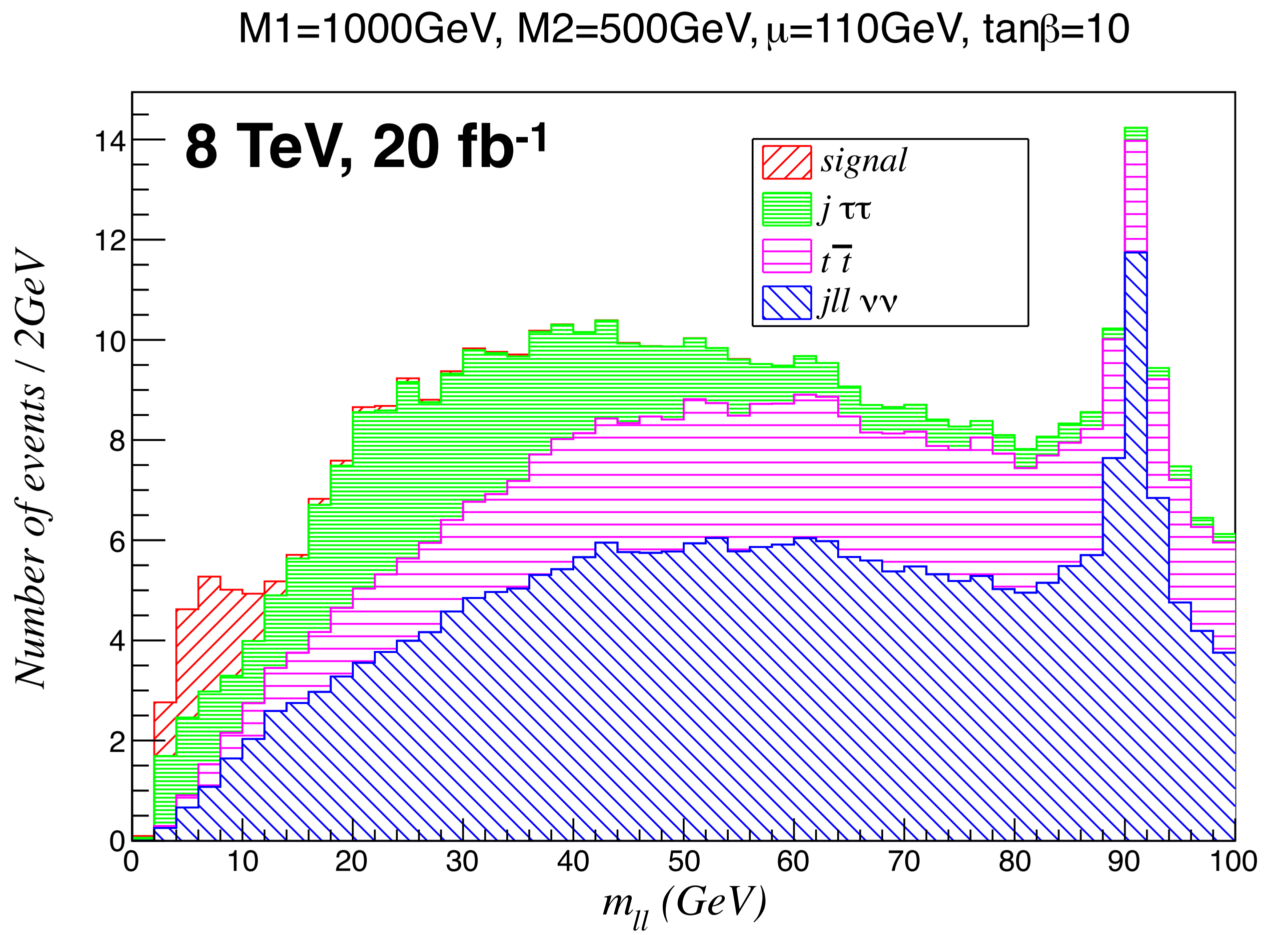
basic cuts: jet p_T > 100 GeV,
$|\eta_j|$ < 2.5,
MET > 100 GeV

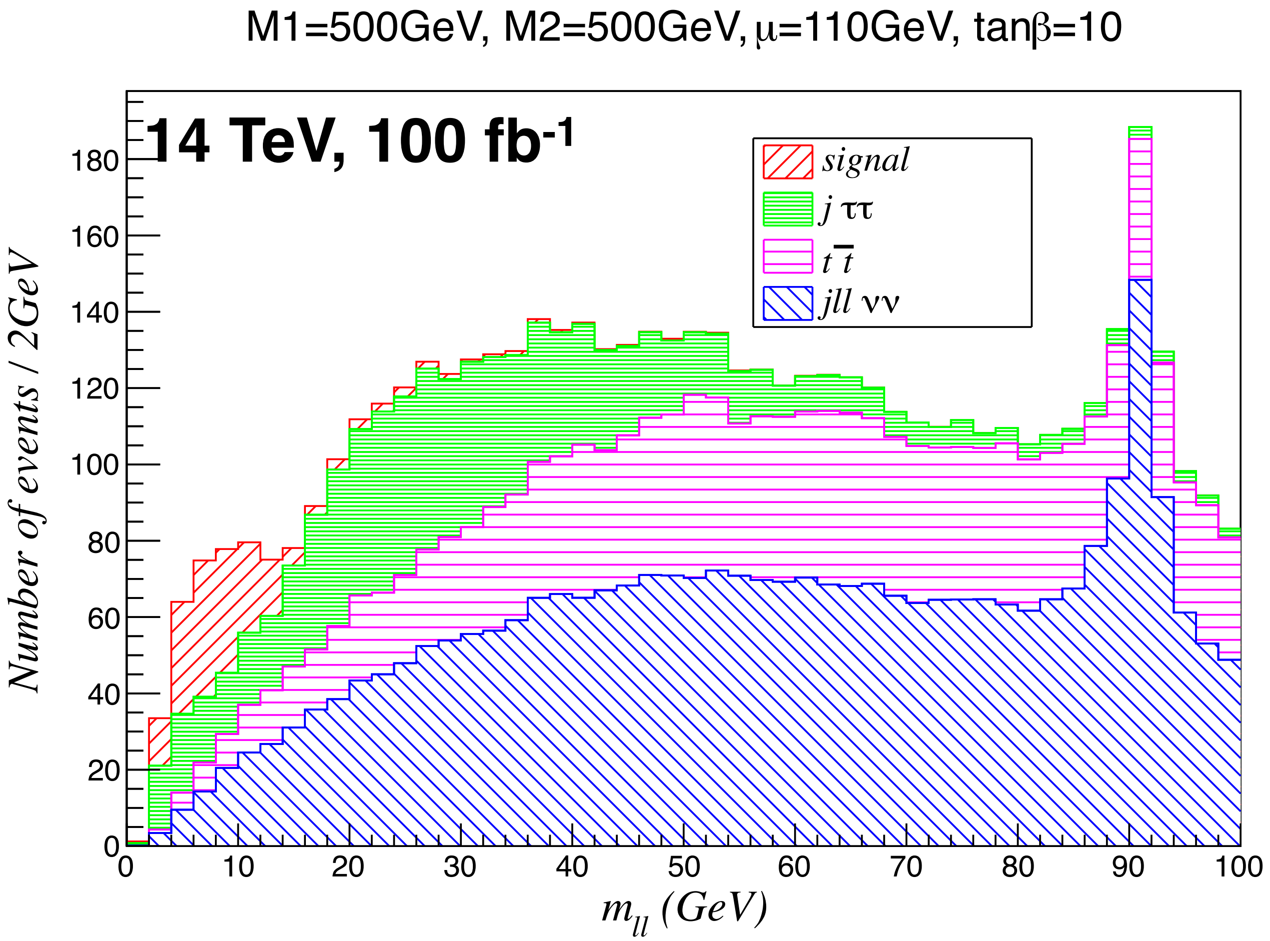
for triggering

then require 2 leptons,
p_T > 7 GeV, $|\eta_\ell|$ < 2.5

there are SM backgrounds (WW+j, $t\bar{t}$,$\tau^+\tau^-$+j), but they can be controlled with cuts

Example: jet + ℓ⁺ℓ⁻+ MET





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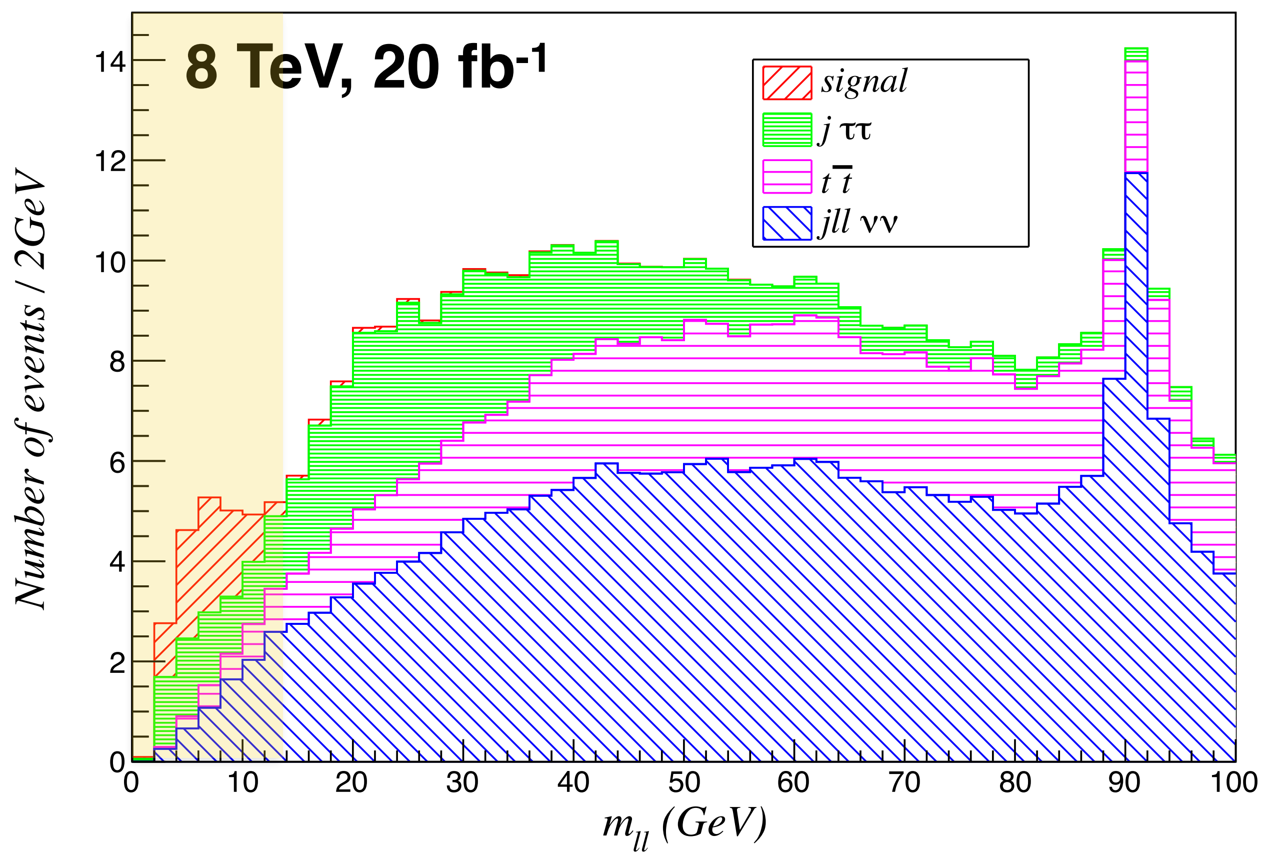
M1=1000GeV, M2=500GeV, μ=110GeV, tanβ=10



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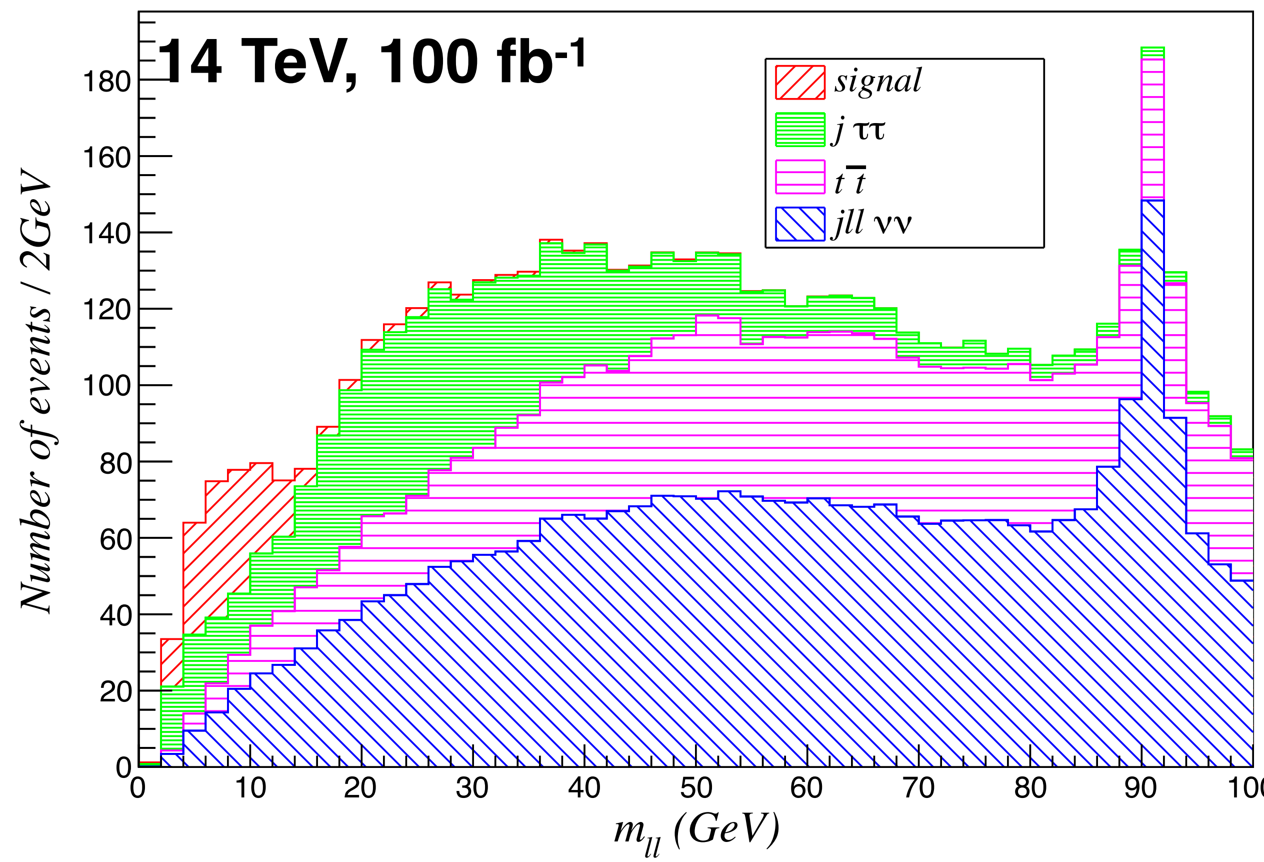

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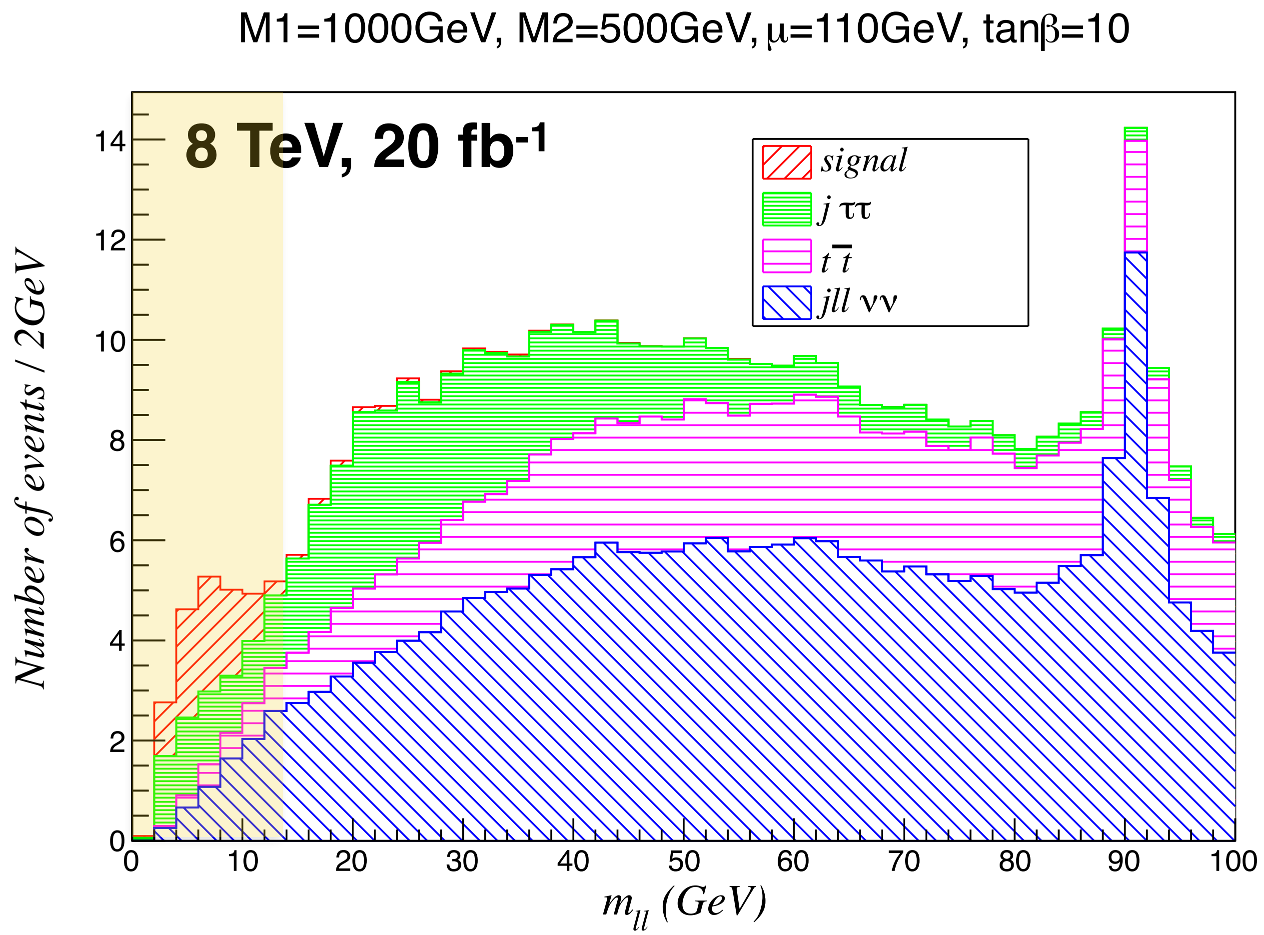

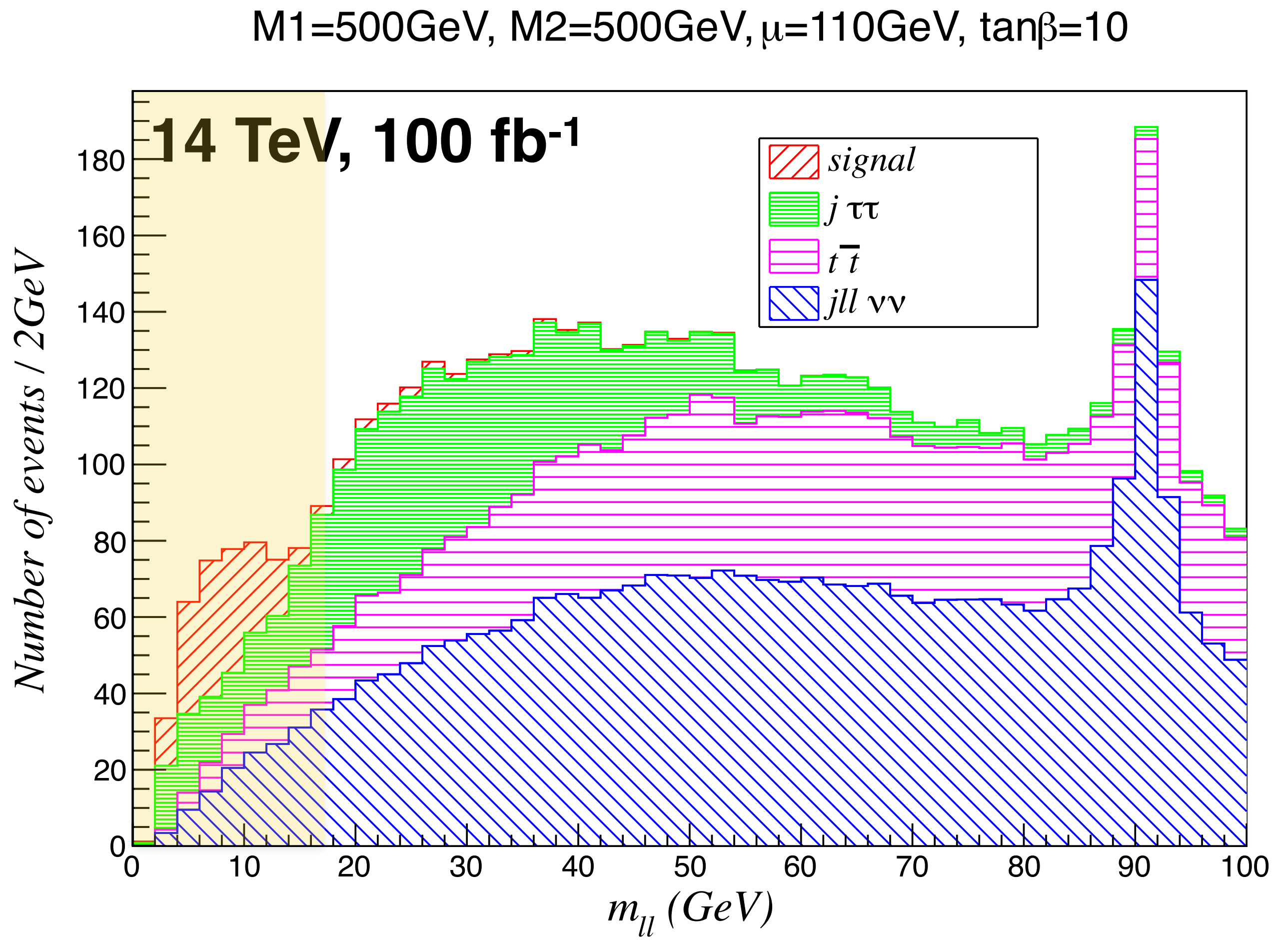

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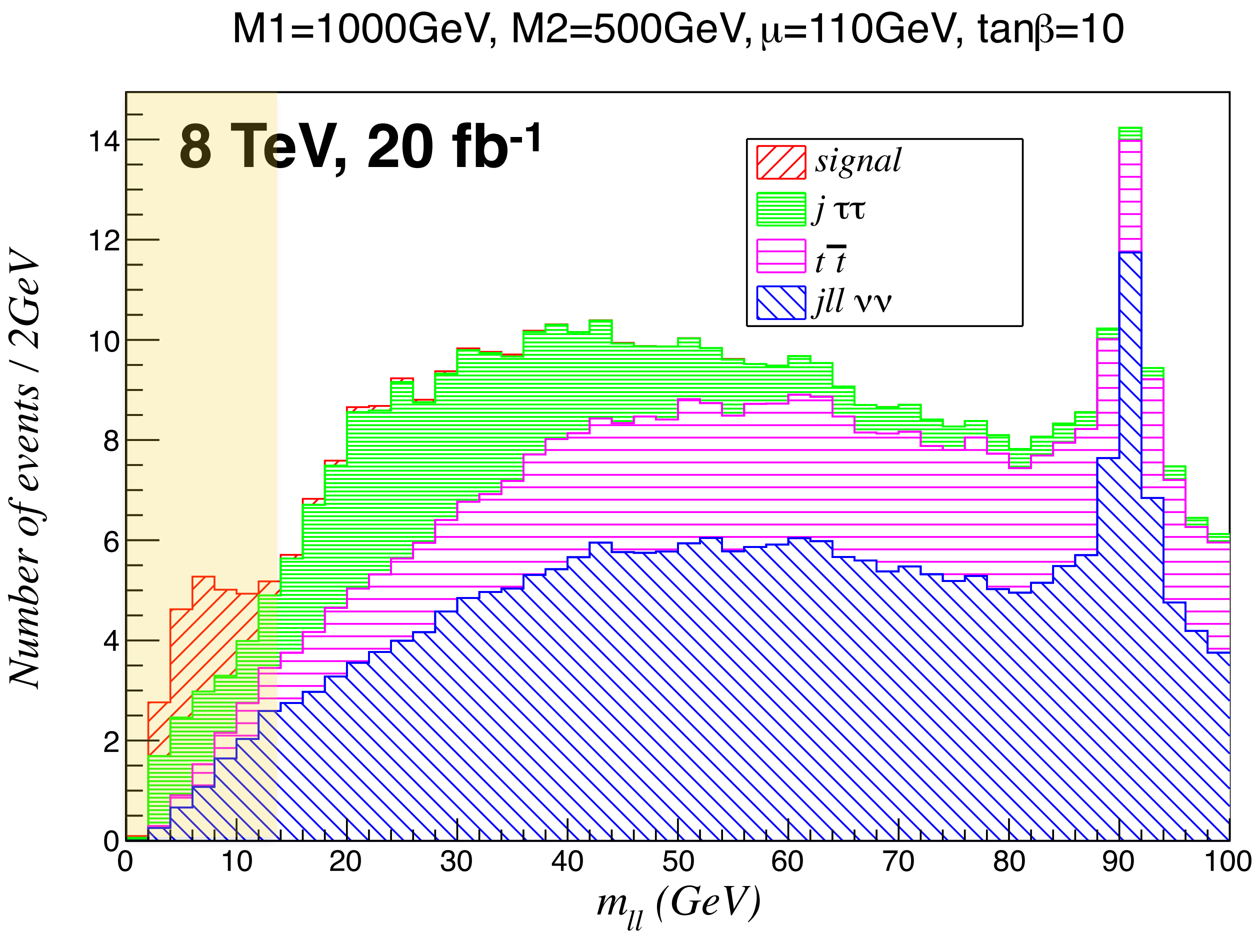

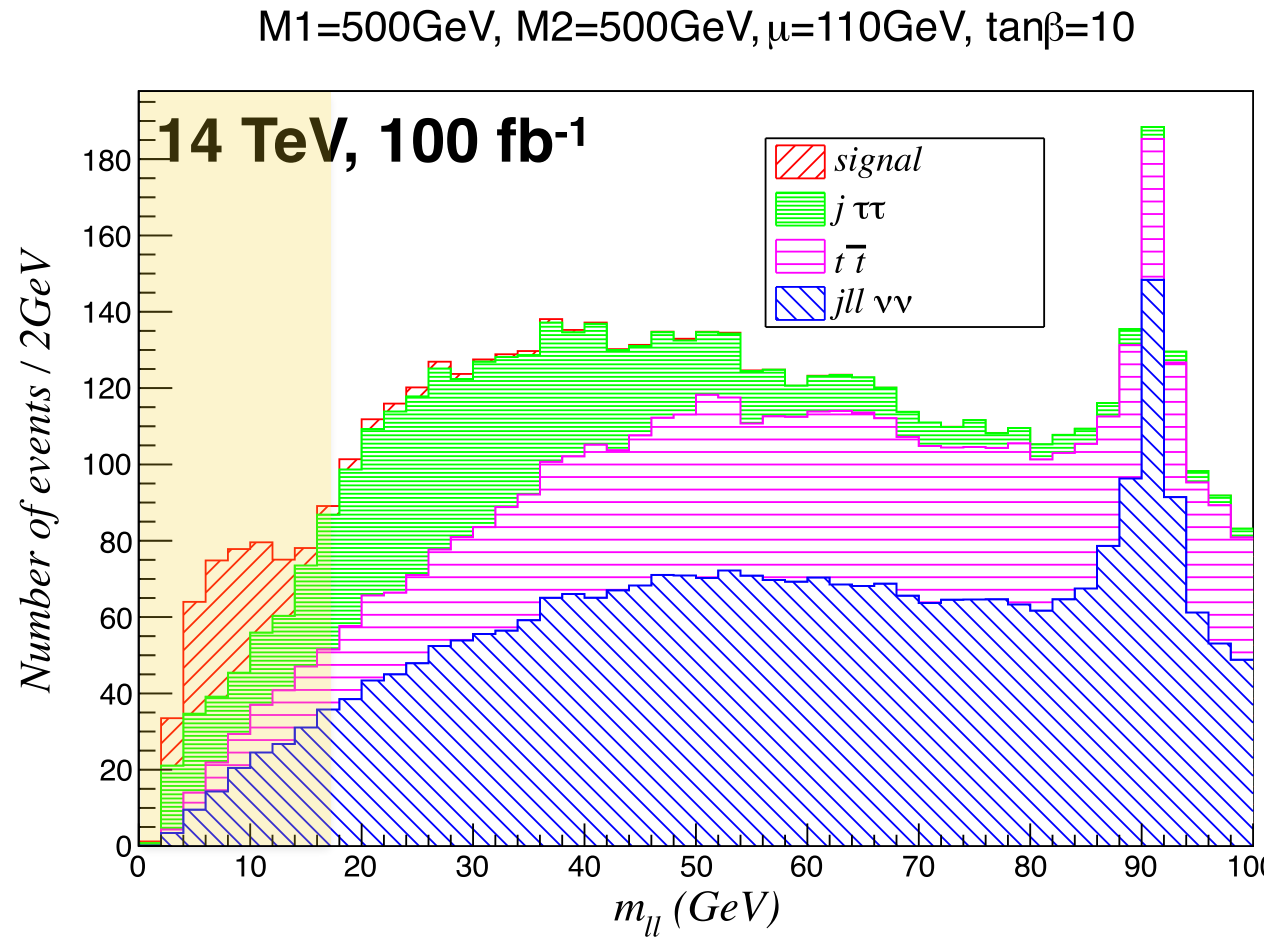

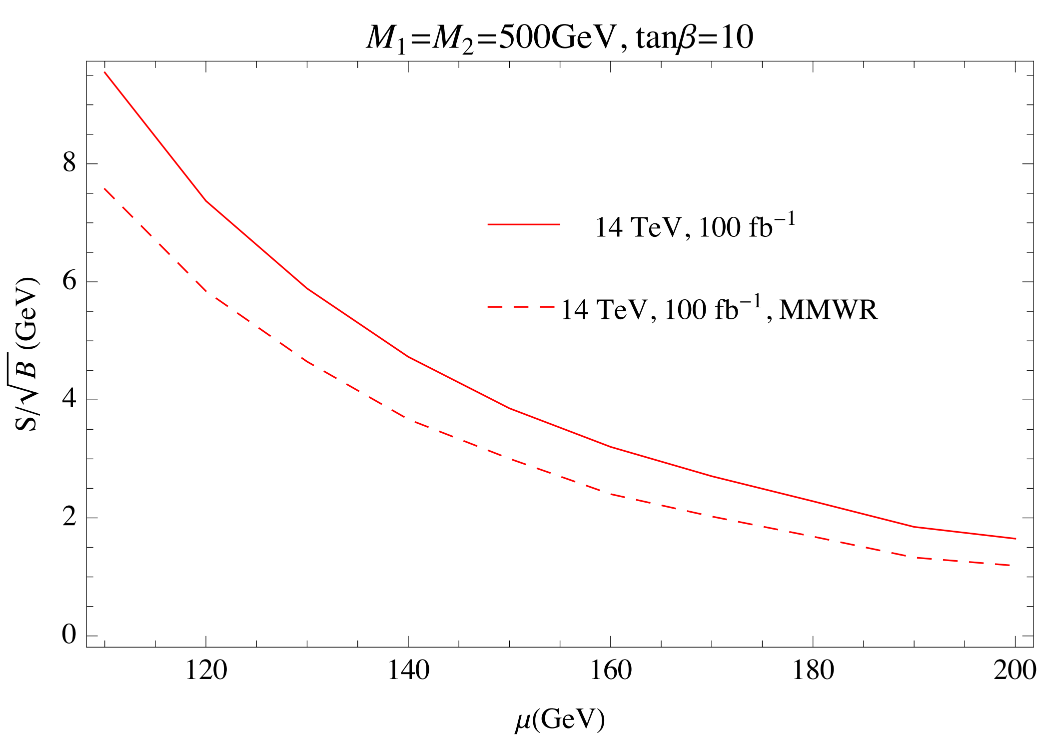

sensitive to spectra
other searches
cannot see!

Improving mono-jet searches: jet + $\ell^+\ell^-$+ MET

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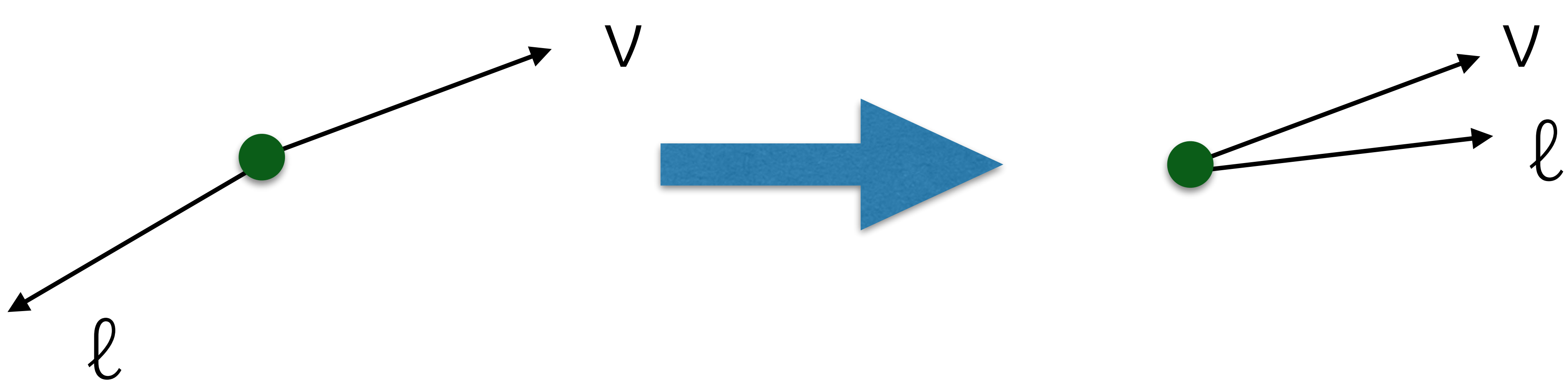
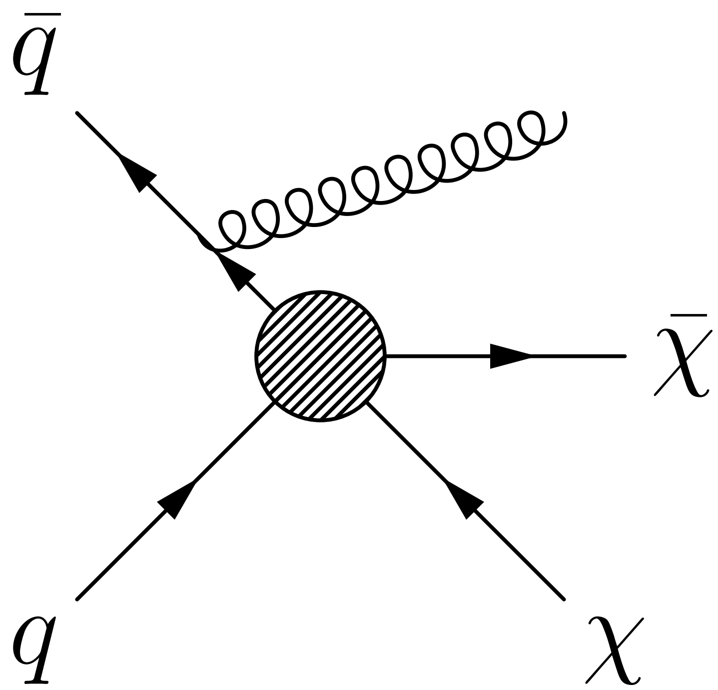
- in background (di-boson), MET and lepton come from the **same** particle (W)



large MET ↔ **high p_T** leptons

Now that we know the trick, can be applied to lots of other SUSY DM signals/final states



Ex.

ℓ + γ + MET final state

occurs when the DM is a wino-bino mixture

important, as wino-bino DM often can't be found by direct/indirect detection

[See *Han 1409.7000, Bramante et al 1412.4789, 1510.03460]*

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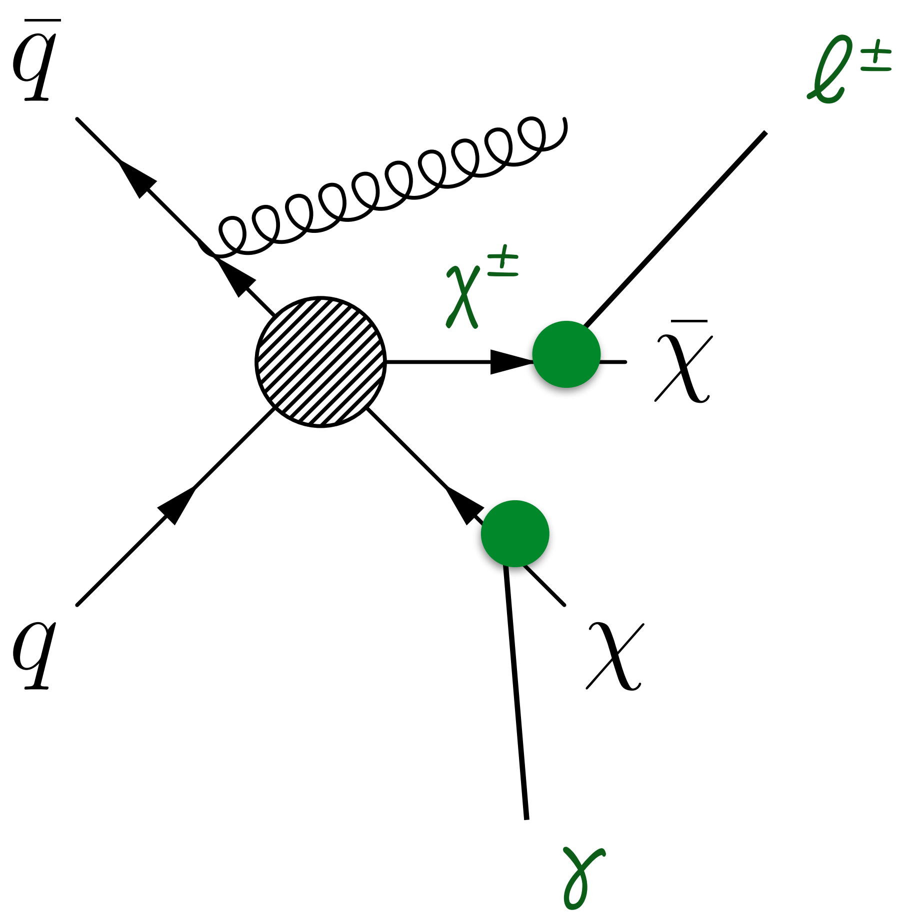

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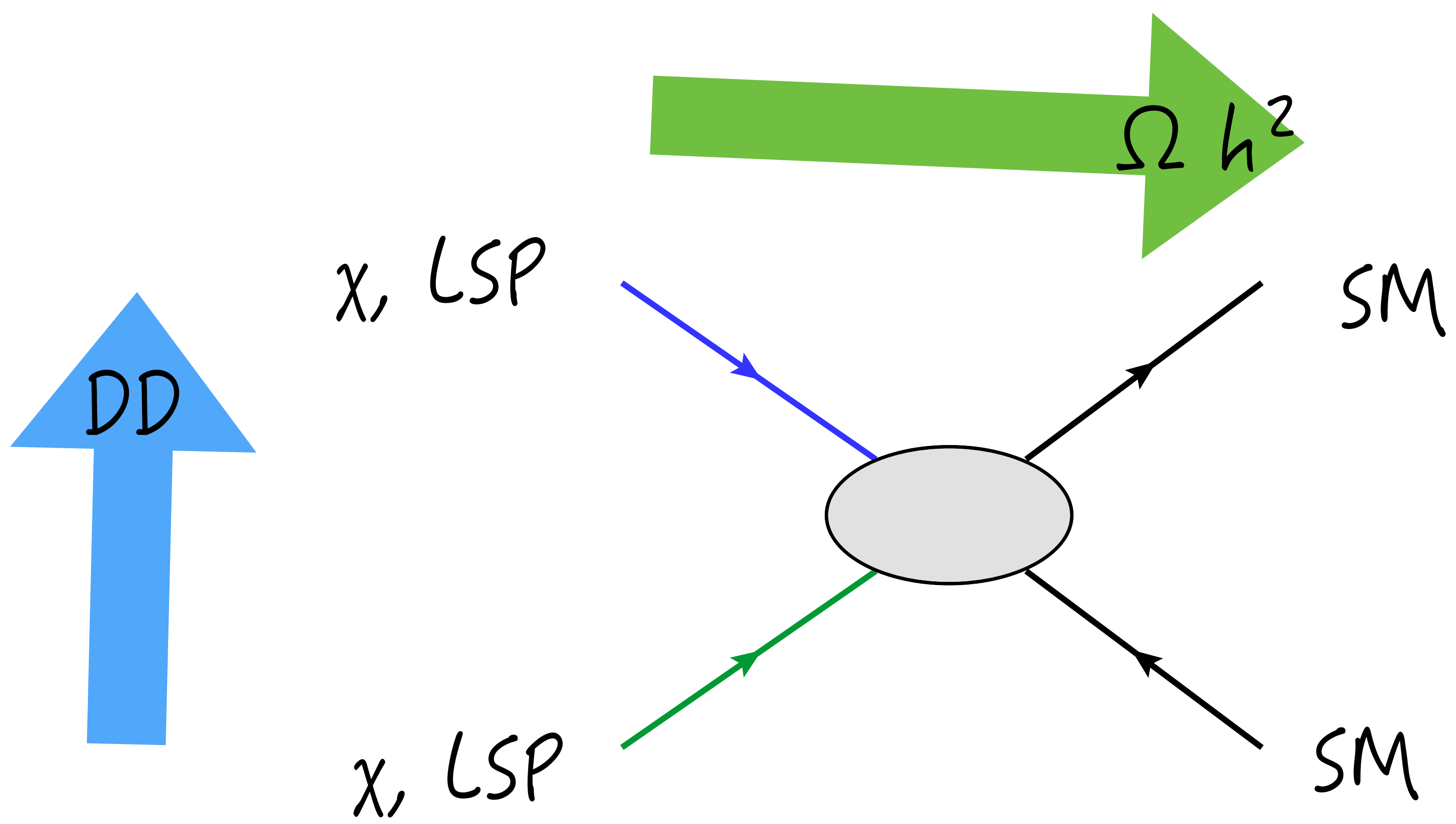

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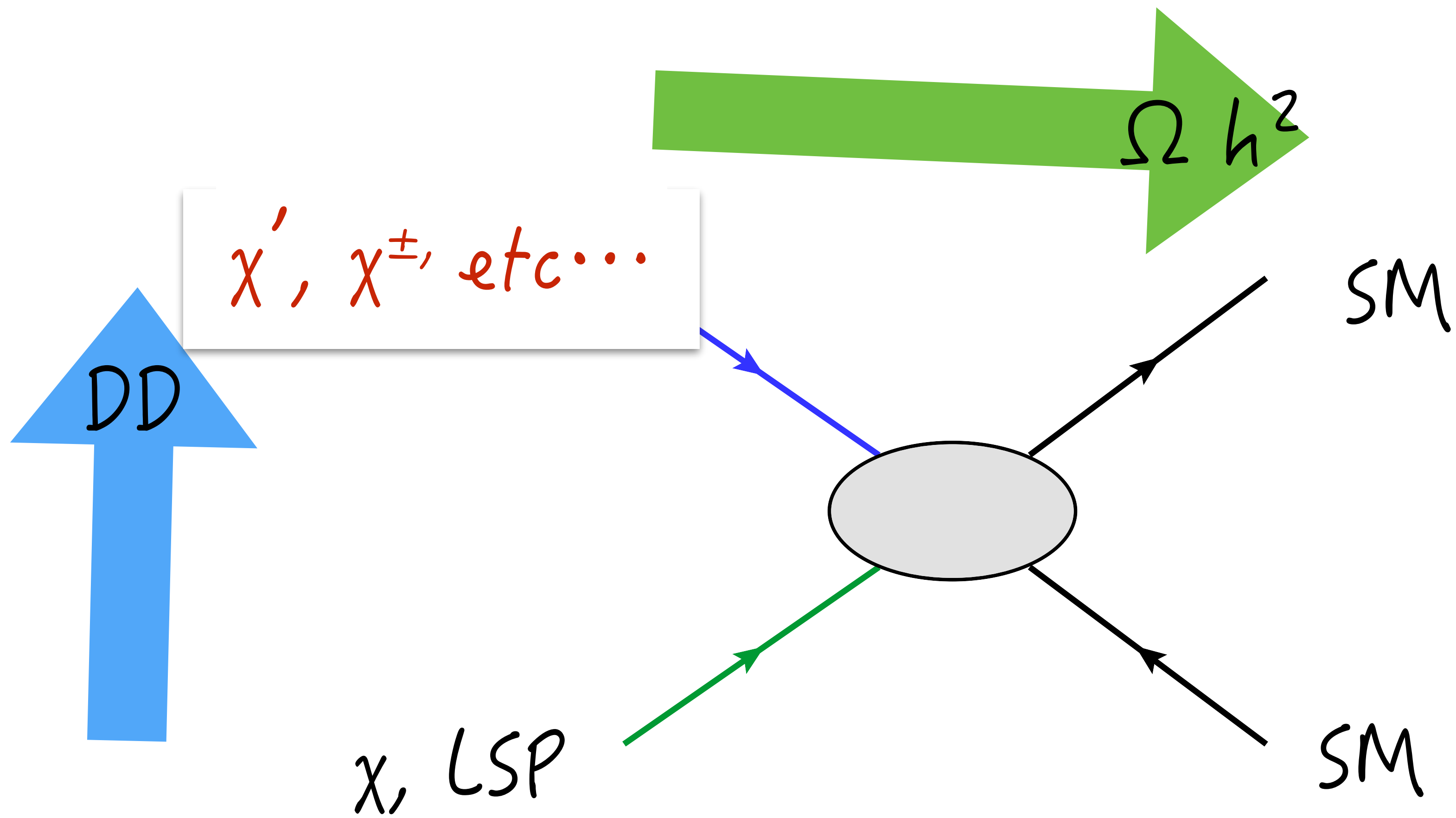

co-annihilation fixes the tension, but co-annihiliating states must be nearly same mass as DM

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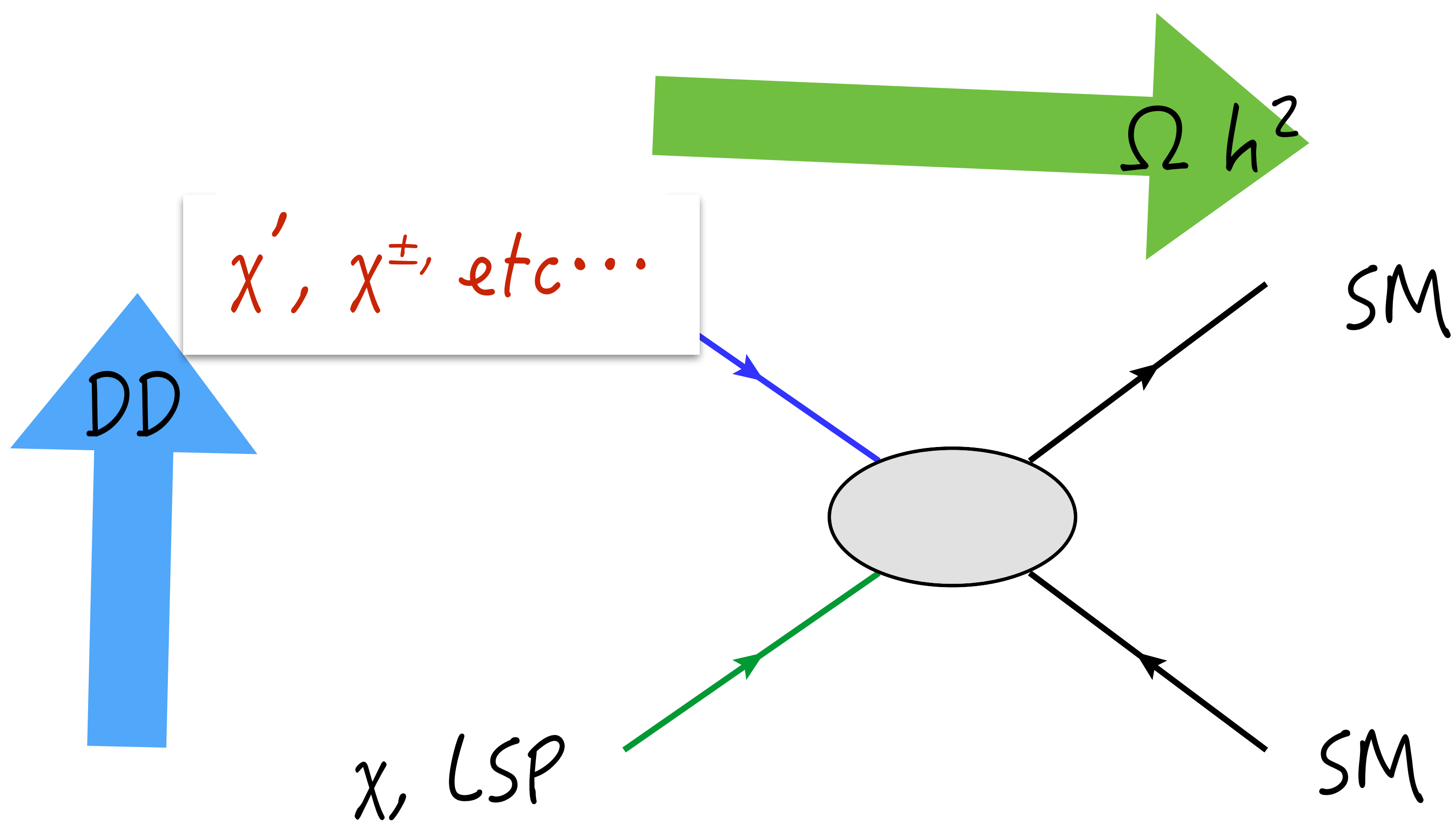
in fact, most current, viable models of EW DM with have a set of states with similar mass



$$\sigma_{eff} \cong \sum_{ij}^{N} \sigma_{ij} \frac{g_i g_j}{g_{eff}^2} \exp\Big(-(m_i + m_j - 2\, m_{LSP})/T \Big)$$

Summarizing

If supersymmetry is the (or part of) the theory beyond the Standard Model, expect the electroweakinos to be light, fairly degenerate

.. this is exactly where they're hard to find

new idea to access these compressed spectra

- use initial radiation to trigger, look for accompanying softer objects ($\ell^+\ell^-$,etc.) offline

- should work for non-SUSY setups too!

look good at simulation level, work better for smaller splittings

THANK YOU!

have a great Masterclass, and hope to see you again soon!