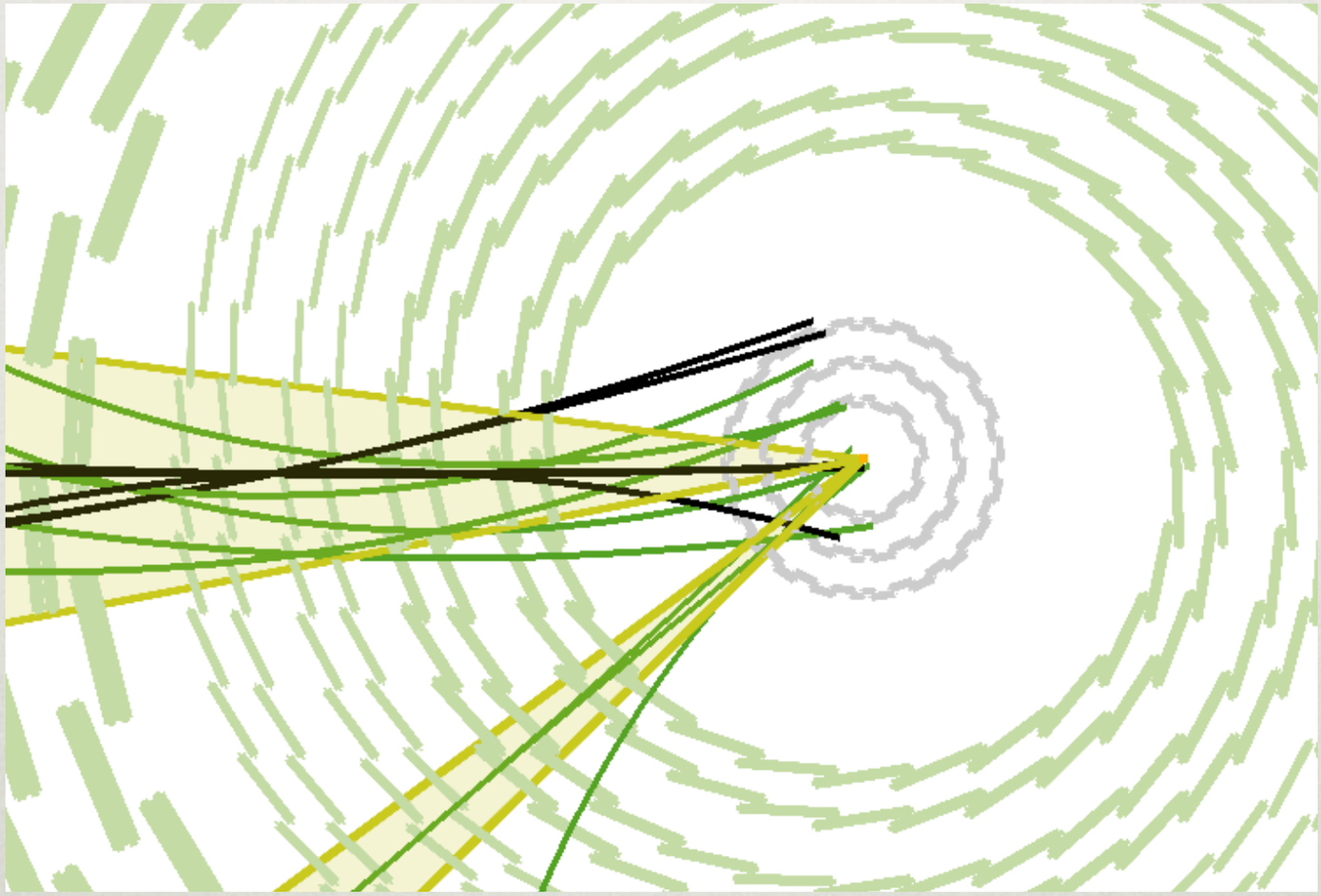
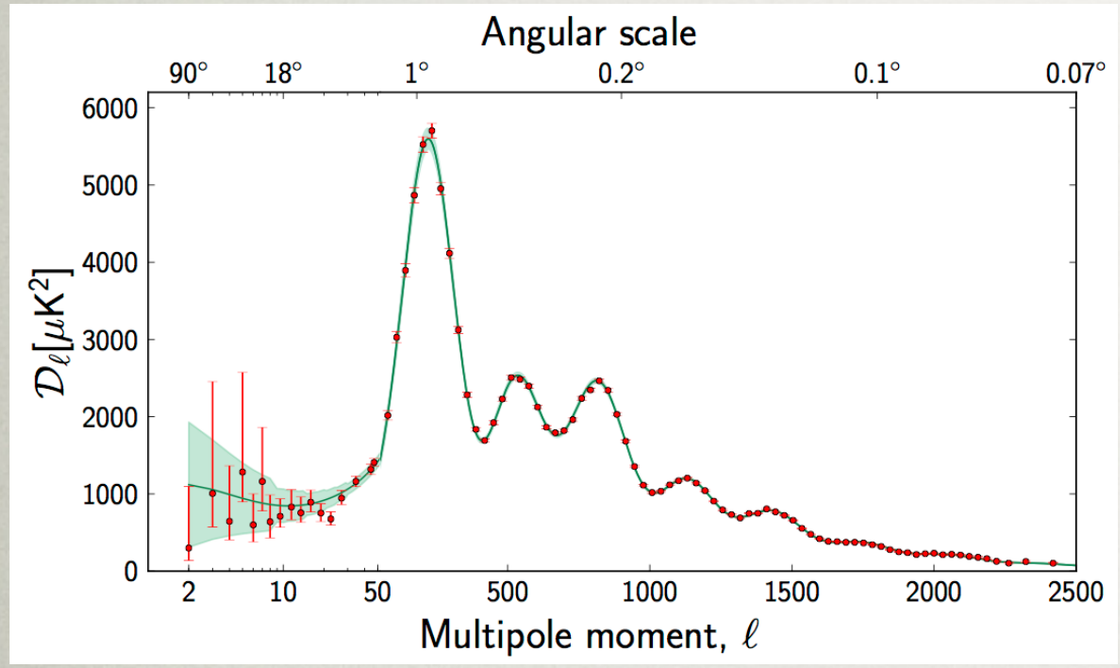
DISCOVERING HIDDEN SECTORS WITH LONG-LIVED PARTICLES

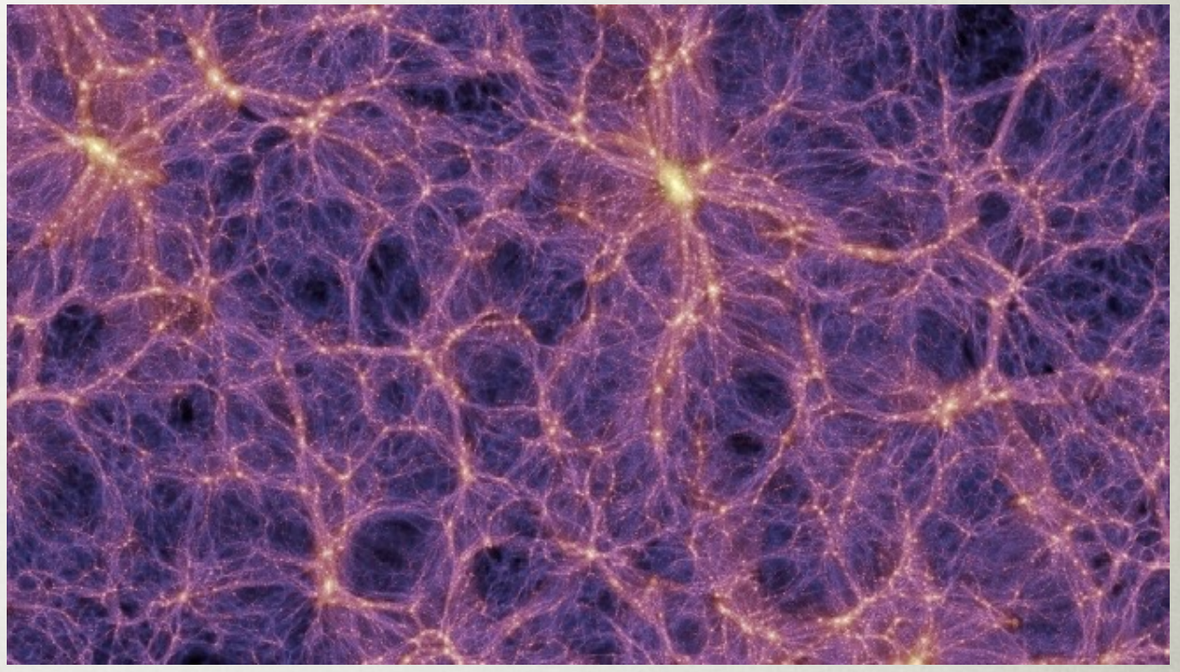


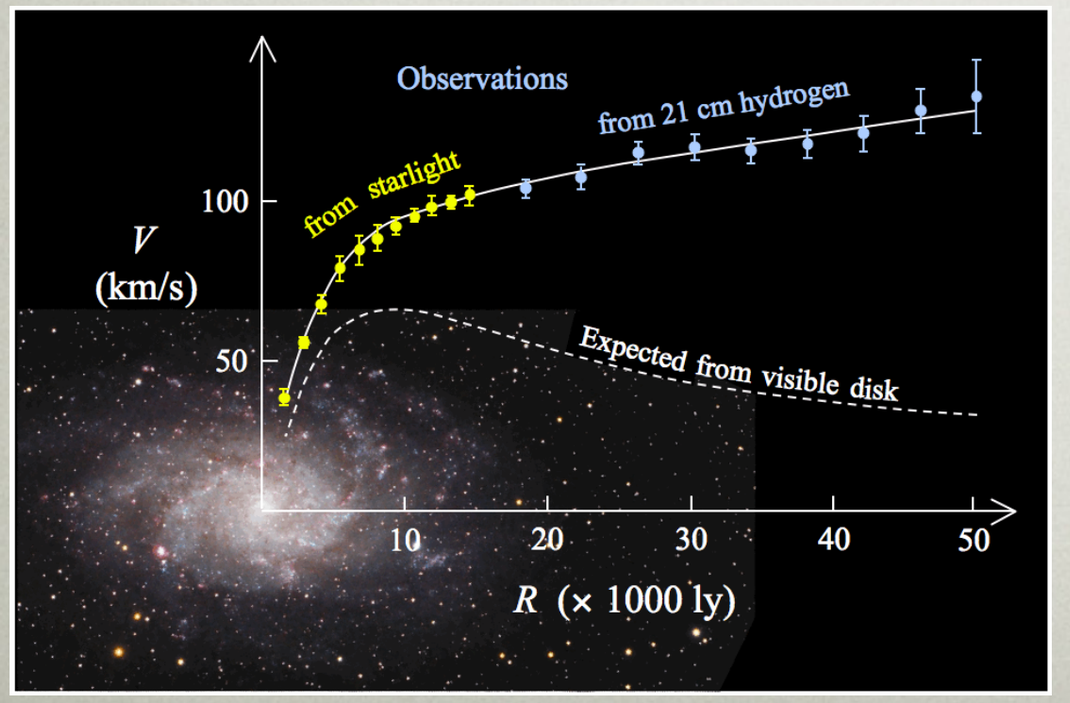
Brian Shuve — SLAC

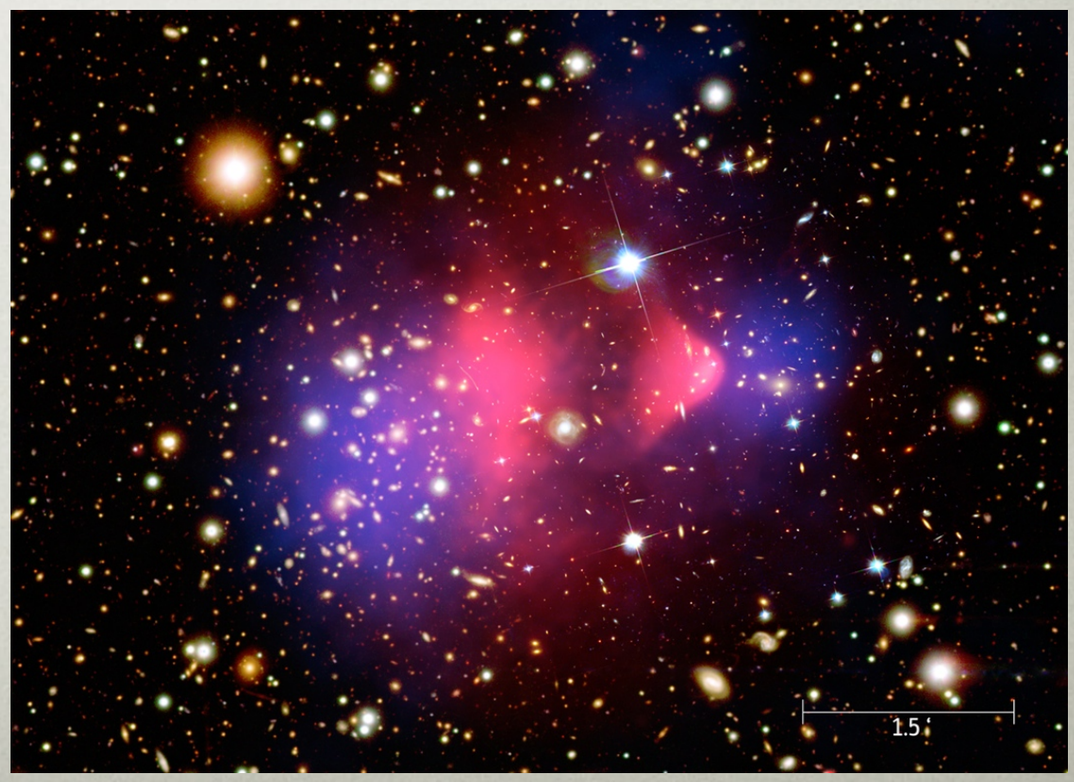
LHC Users Meeting @ LBL — 4 November 2016

Plentiful evidence for new dark particle(s) that interact very feebly with the SM:

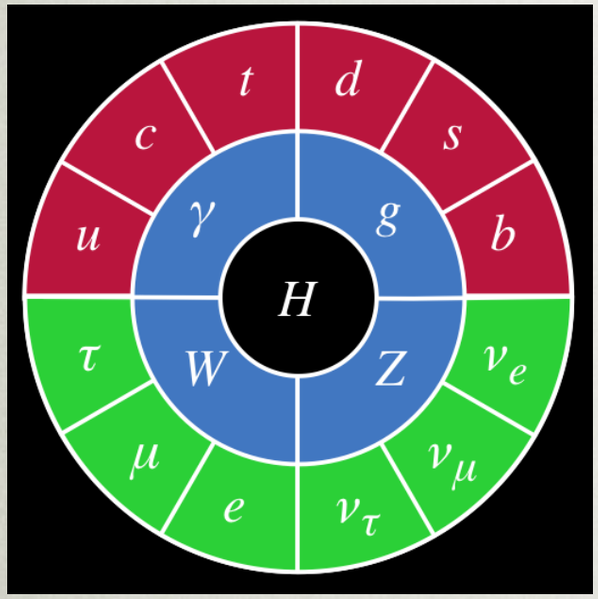




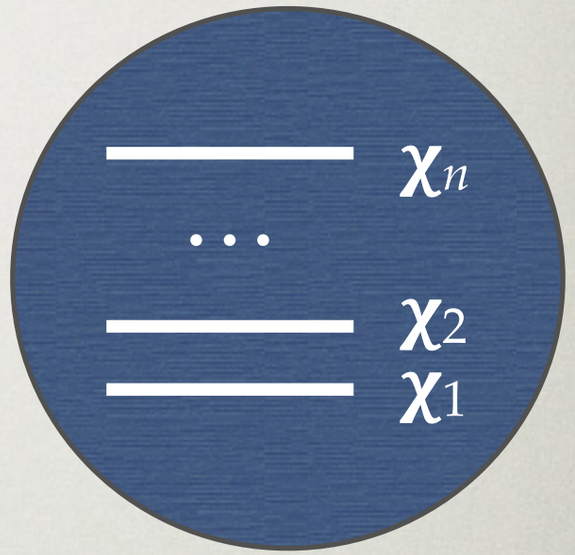


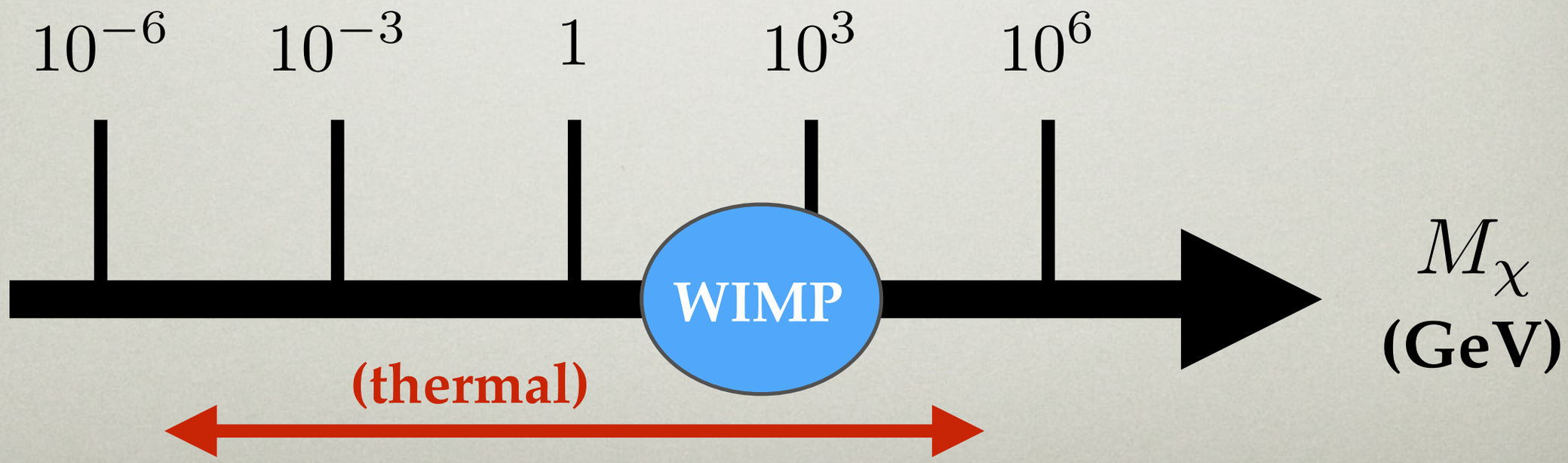


Thermal DM models connect abundance with mass & coupling:



$$\frac{\alpha_\chi^2}{M_\chi^2} \sim \frac{10^{-9}}{\mathrm{GeV}^2}$$



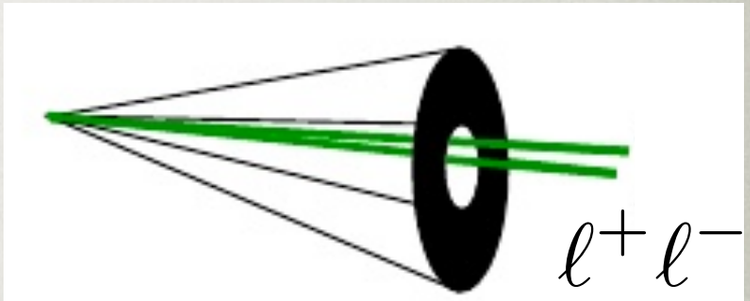


Light DM & Dark Sectors

Signatures:

- Low-mass particles need a kick to be seen

- New particles are often **boosted**

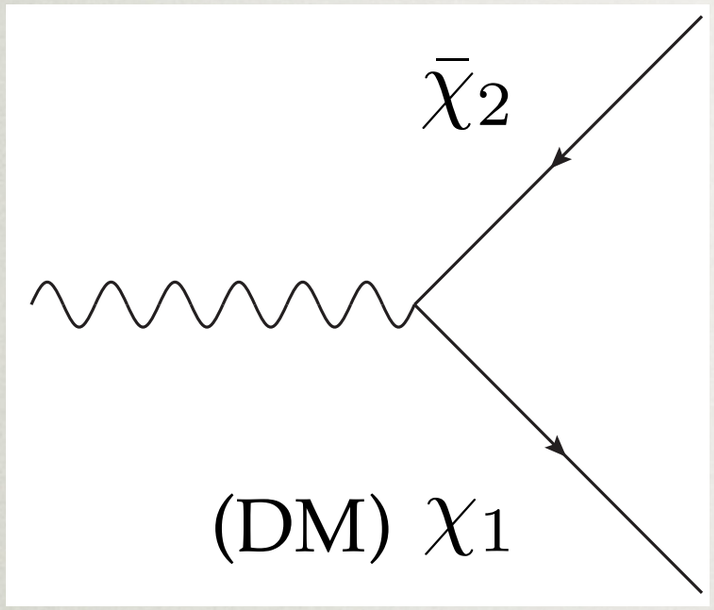


- Can often get **long lifetimes** due to combination of small mass ratios, mixing angles, …

$$c\tau(\pi^{\pm}) \sim 10 \text{ m} \qquad c\tau(D^{\pm}) \sim 0.1 \text{ mm}$$

c.f. hidden valleys (Strassler, Zurek 2006)

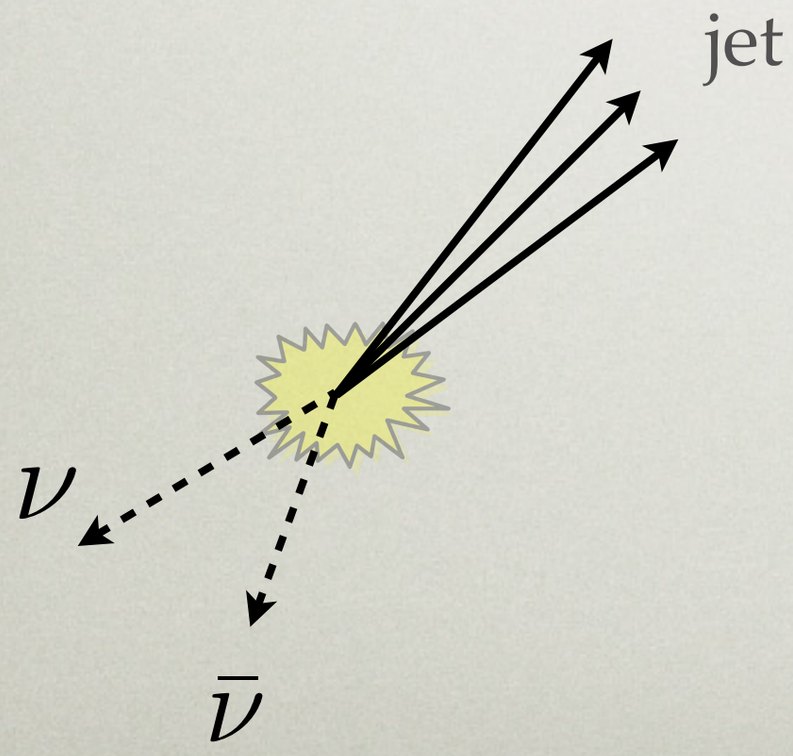
Compelling Example: 2-state dark matter



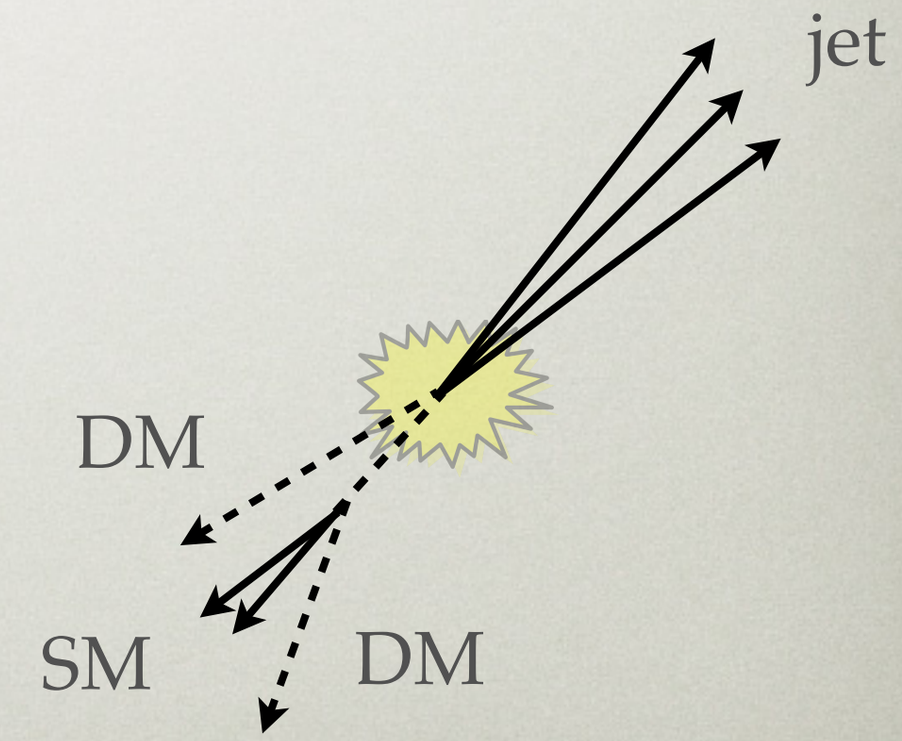
Inelastic dark matter

Tucker-Smith, Weiner, hep-ph/0101138

- 2 nearly degenerate "dark" states
- Representative of many hidden sectors

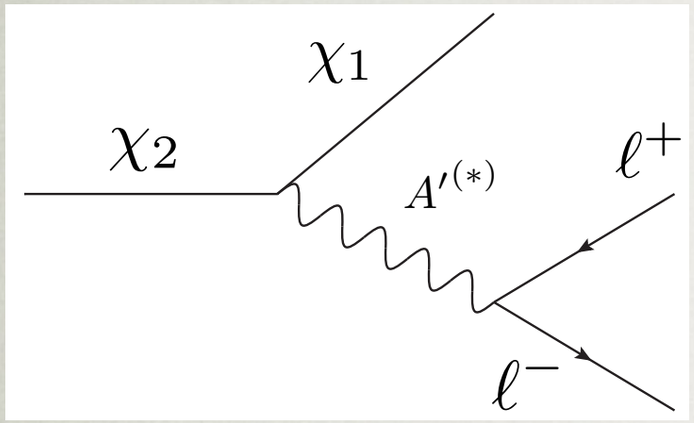


vs.



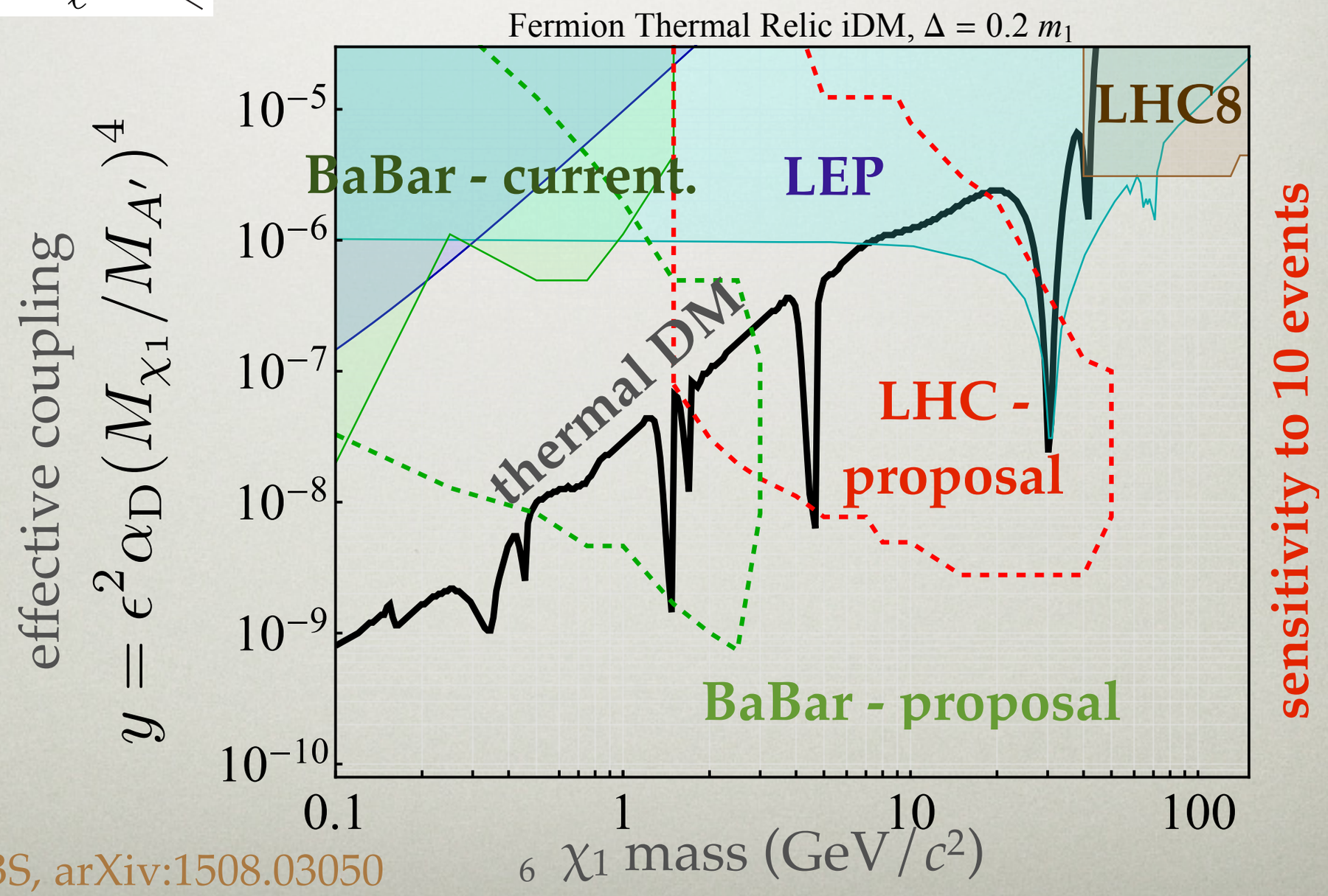
Bai, Tait, arXiv:1109.4144;
Izaguirre, Krnjaic, BS, arXiv:1508.03050

Compelling Example: 2-state dark matter



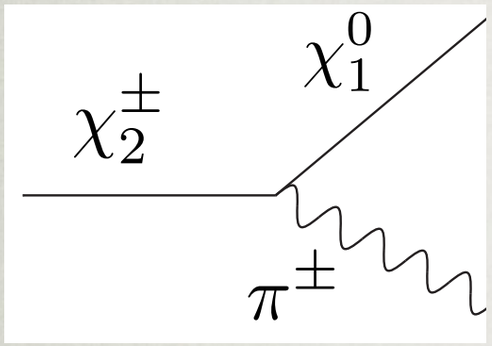
Concrete model: dark photon

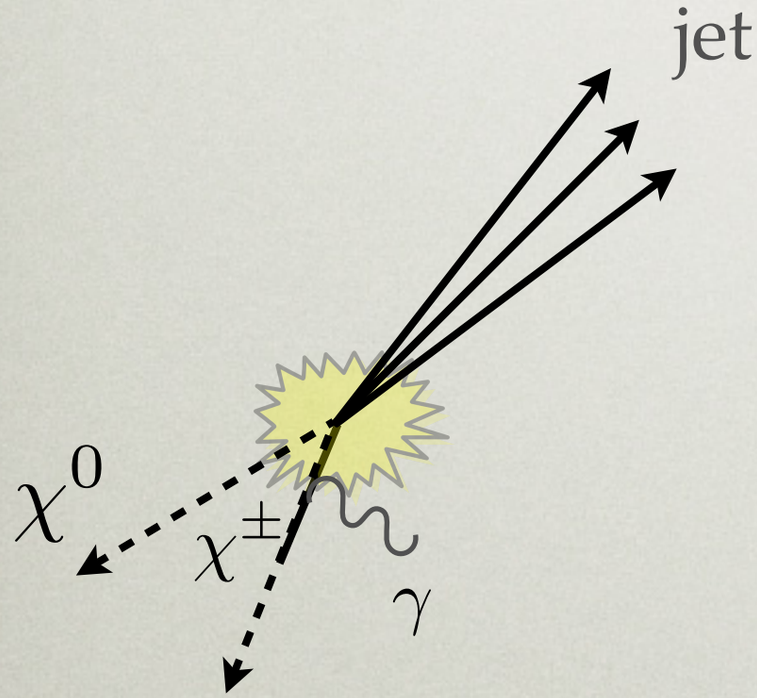
- *Distinctive signal:* collimated, soft, displaced dimuon aligned with MET



Izaguirre, Krnjaic, BS, arXiv:1508.03050

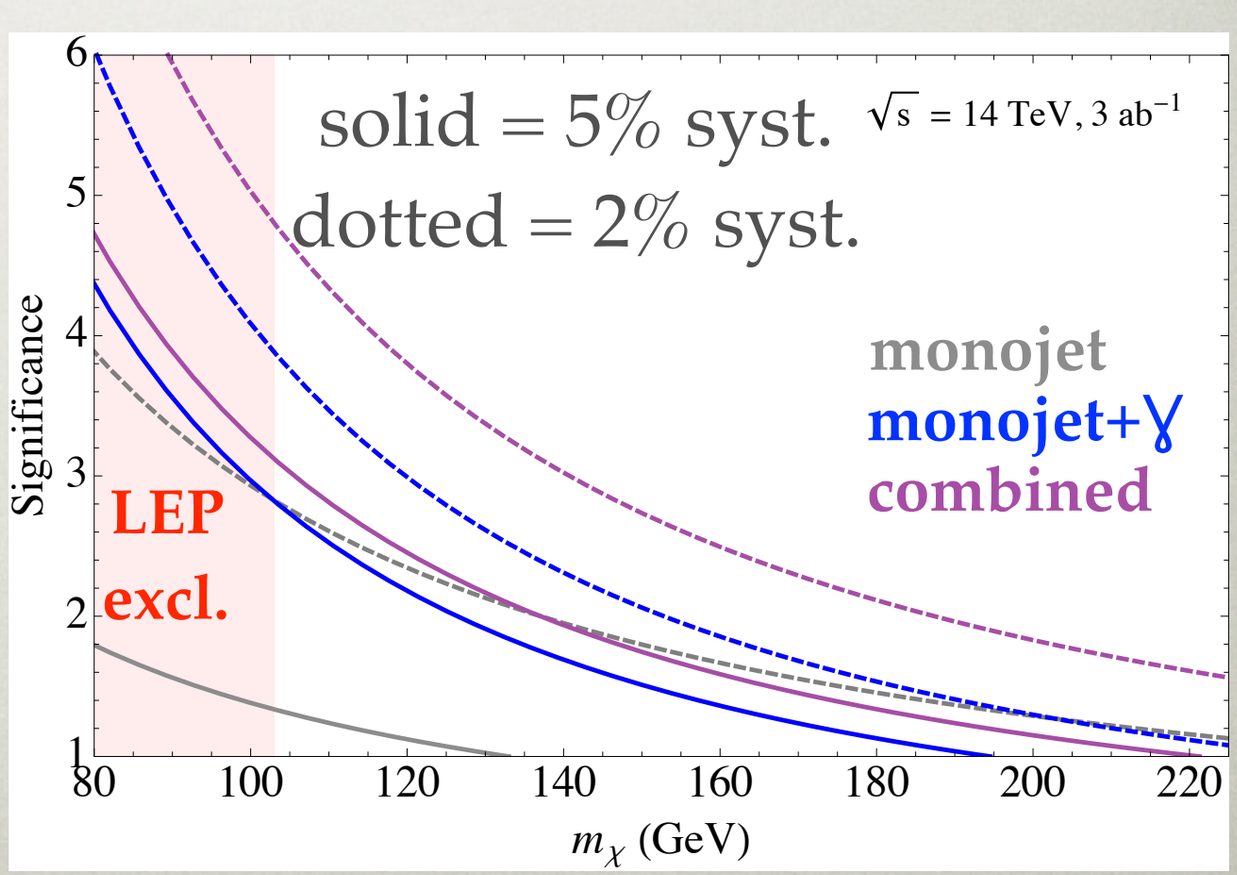
Compelling Example: 2-state dark matter





Concrete model: EW doublet

- heavier state decays to **soft pion**, otherwise invisible
- use photon radiation from long-lived charged state!



Ismail, Izaguirre, BS, arXiv:1605.00658

Summary

- New searches at the LHC and low-energy experiments can discover striking signals of new physics that would otherwise be missed!

- Complement existing searches for high-mass or pairs of displaced objects

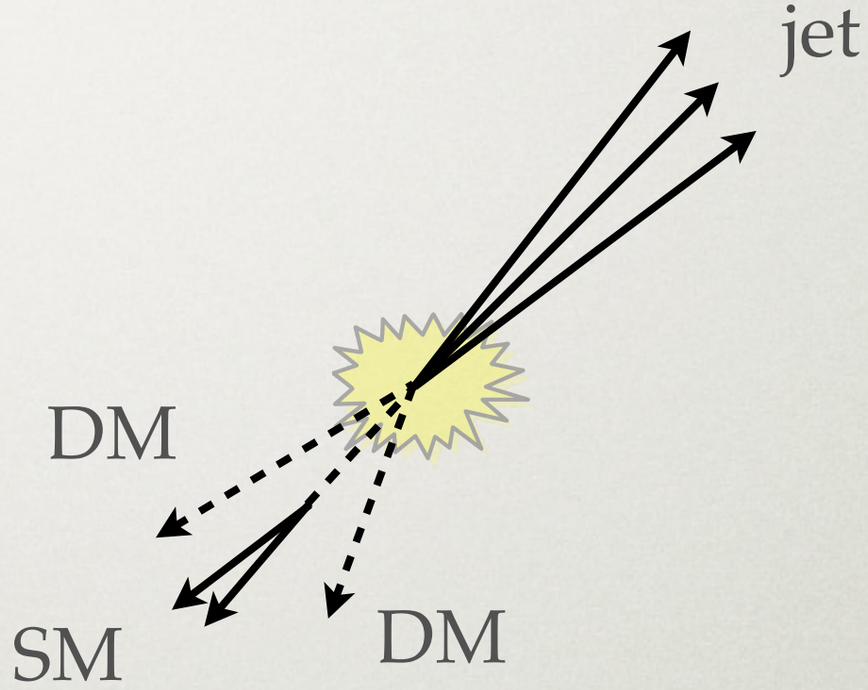
- Many examples of other long-lived particles searches for hidden sectors giving neutrino masses, baryon asymmetry, etc.

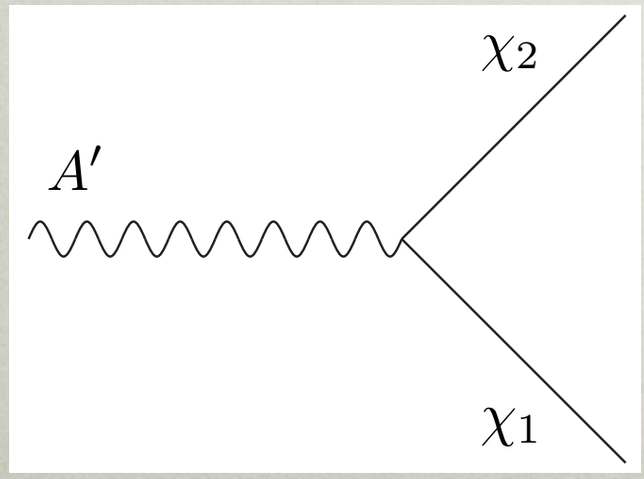
  e.g., arXiv:1504.02470, arXiv:1604.0699, arXiv:1409.6729, …

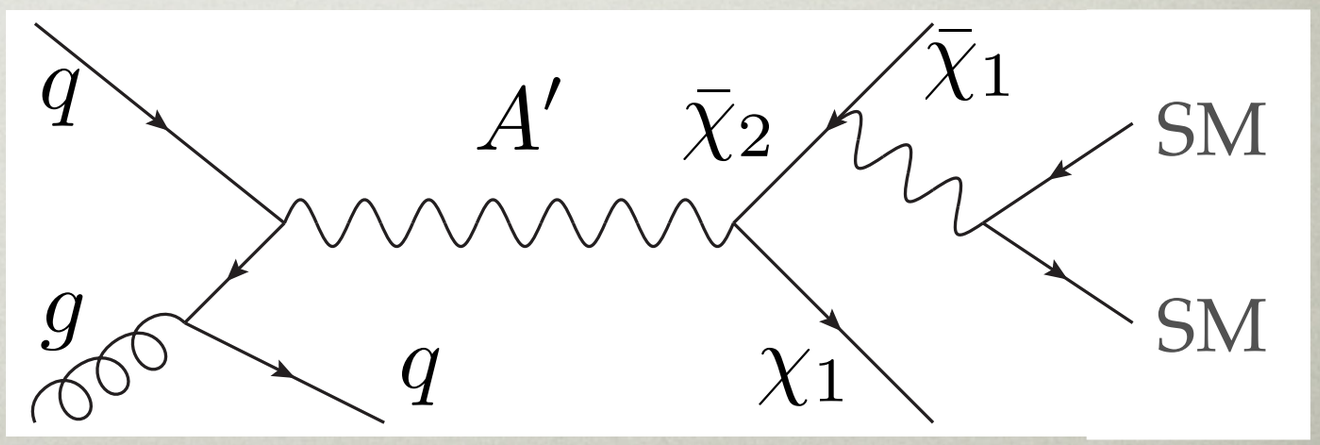
Back-up slides

Extended Dark Sectors

- We can also have dark sectors with a **new force/interaction**
- *E.g.,* inelastic dark matter





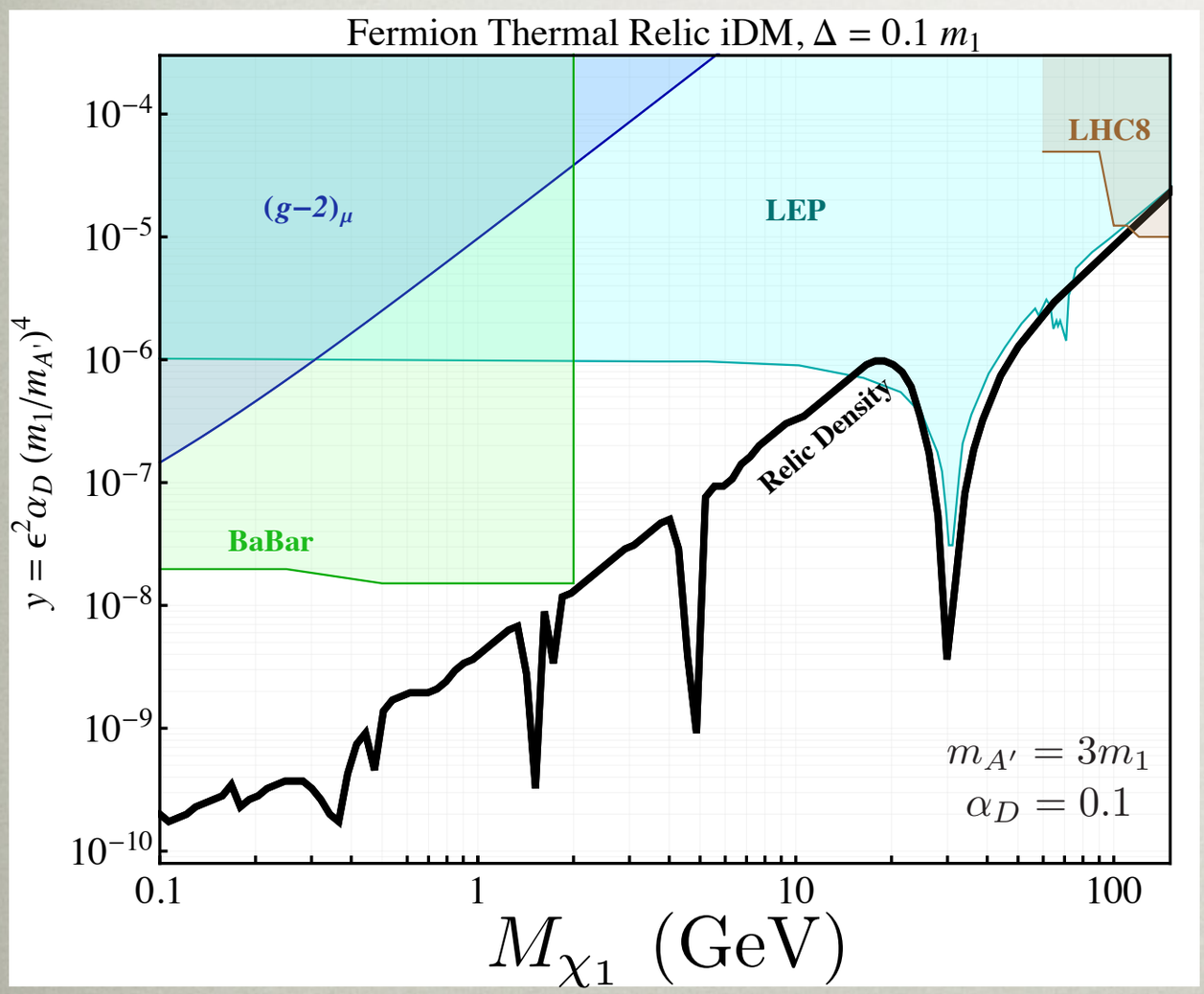


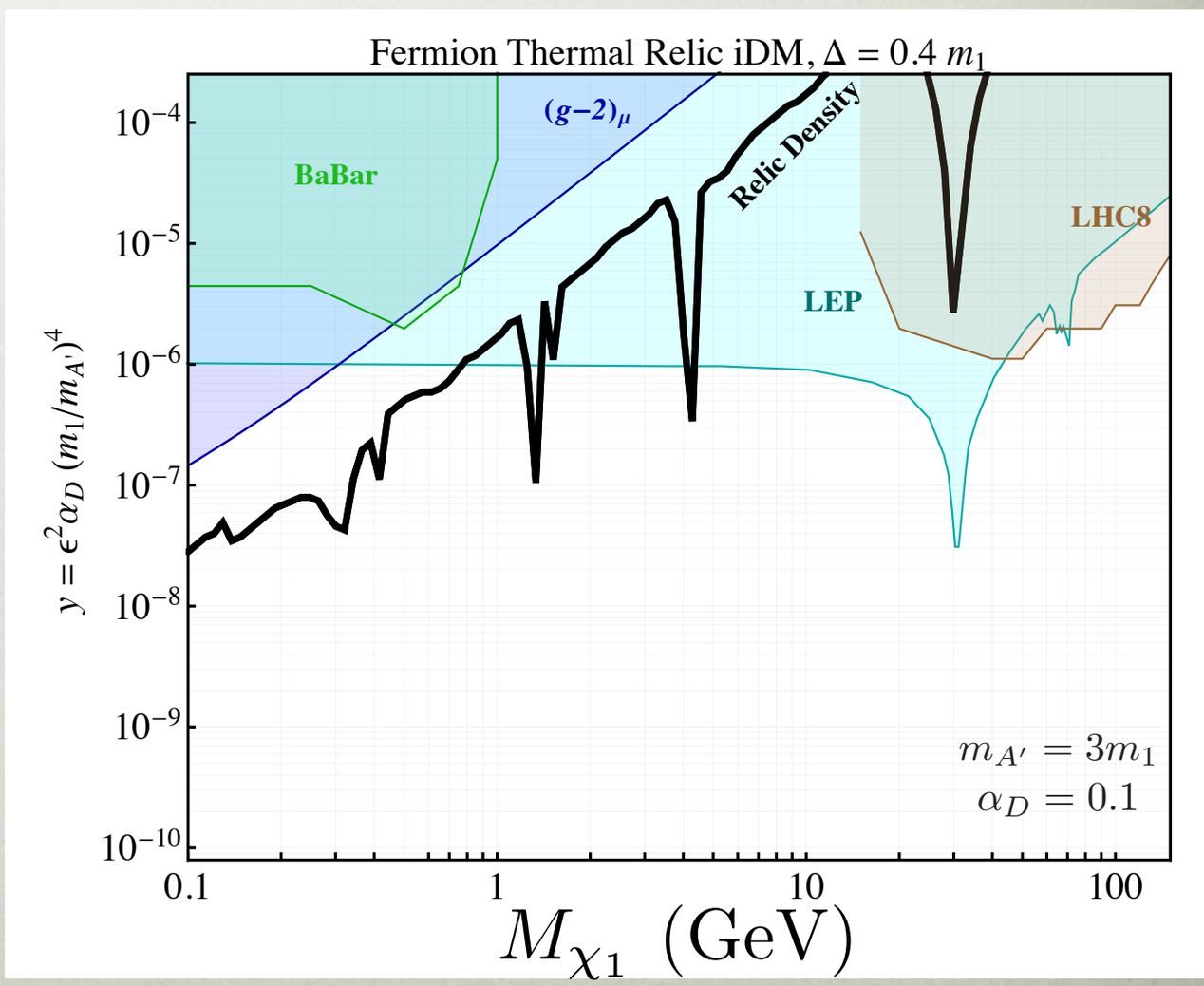
Bai, Tait, 1109.4144;
Izaguirre, Krnjaic, BS 1508.03050

Extended Dark Sectors

- We consider $M_\chi < M_{A'}$ $\Delta \equiv M_{\chi 2} - M_{\chi 1} \ll M_\chi$

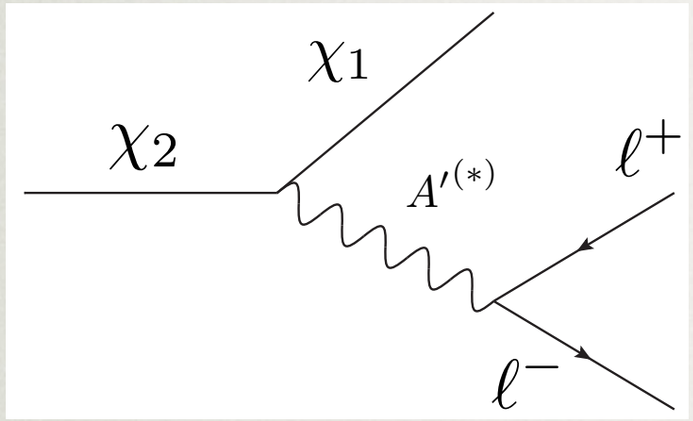
y is "effective coupling"





Izaguirre, Krnjaic, BS 1508.03050

Improving the Searches

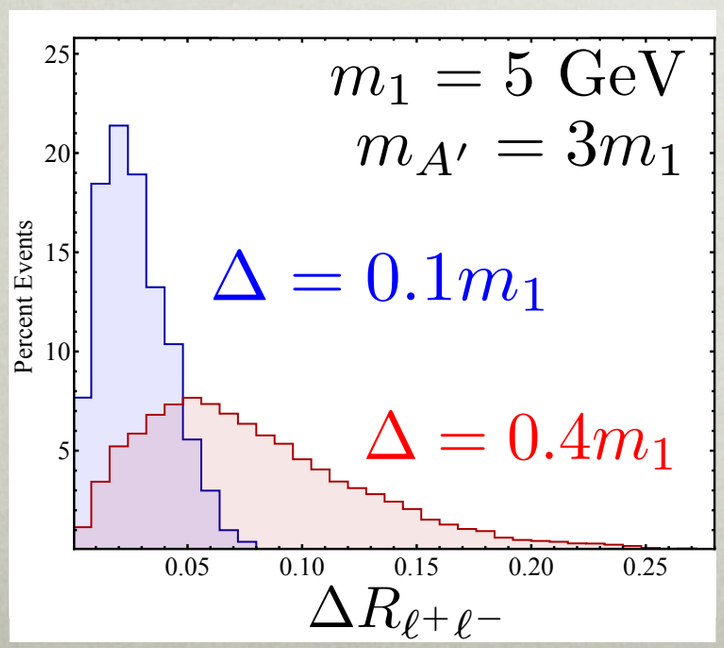


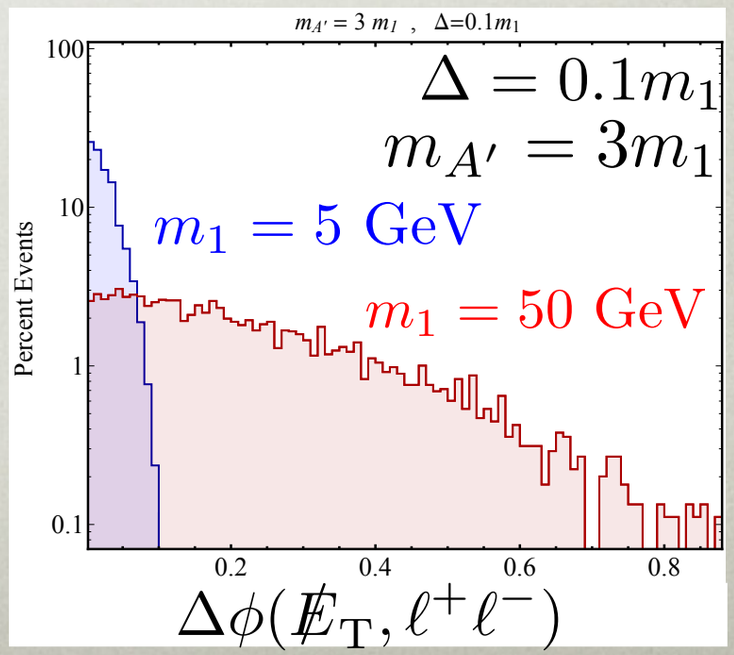
$$\Gamma_{\chi_2} \sim \frac{\alpha \alpha_D \epsilon^2 \Delta^5}{M_{A'}^4}$$

- Get displaced decay!

- The leptons are typically soft, so trigger on monojet + MET

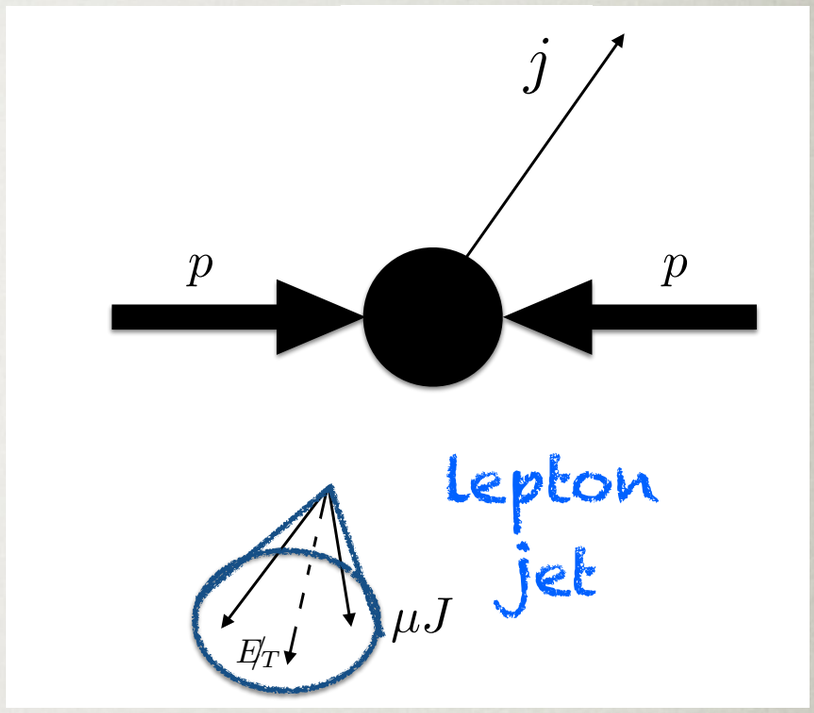
- The DM produced through on-shell A', so typically **boosted**

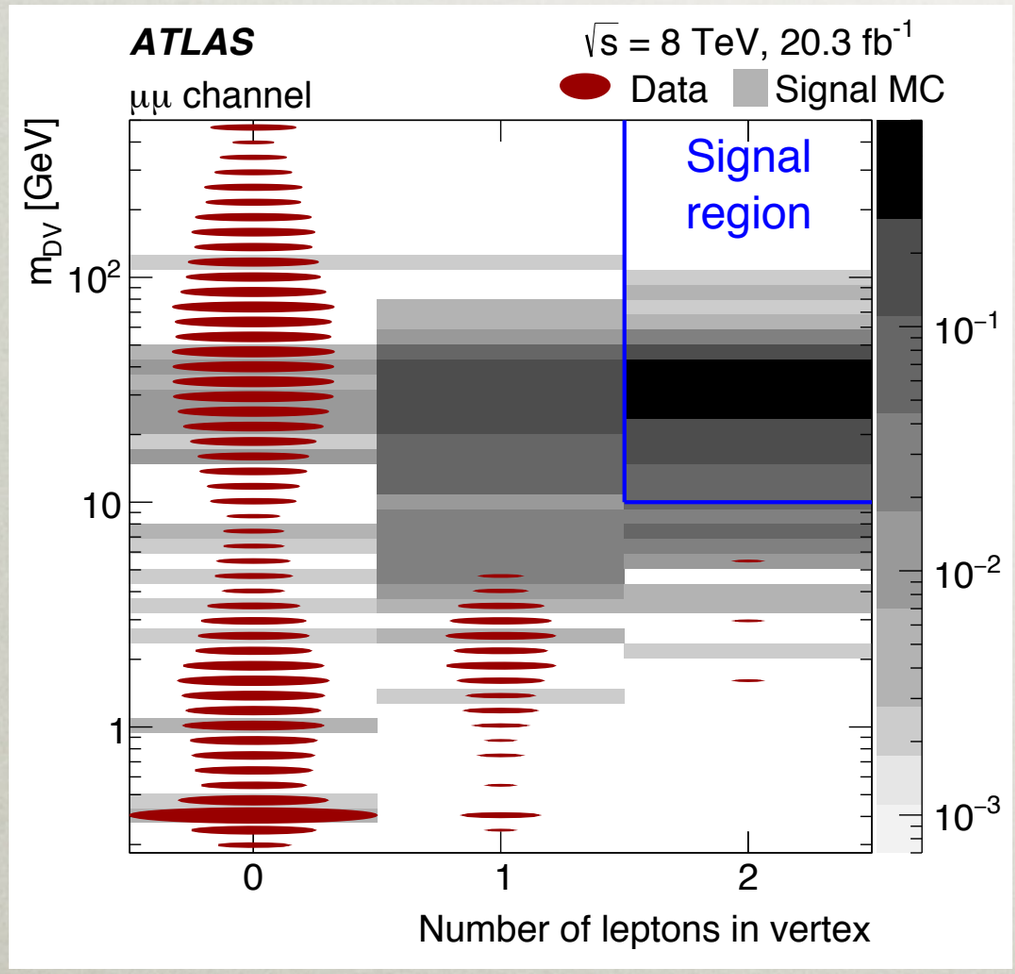




Displaced/Boosted Signatures

- Leptonic backgrounds expected to be negligible





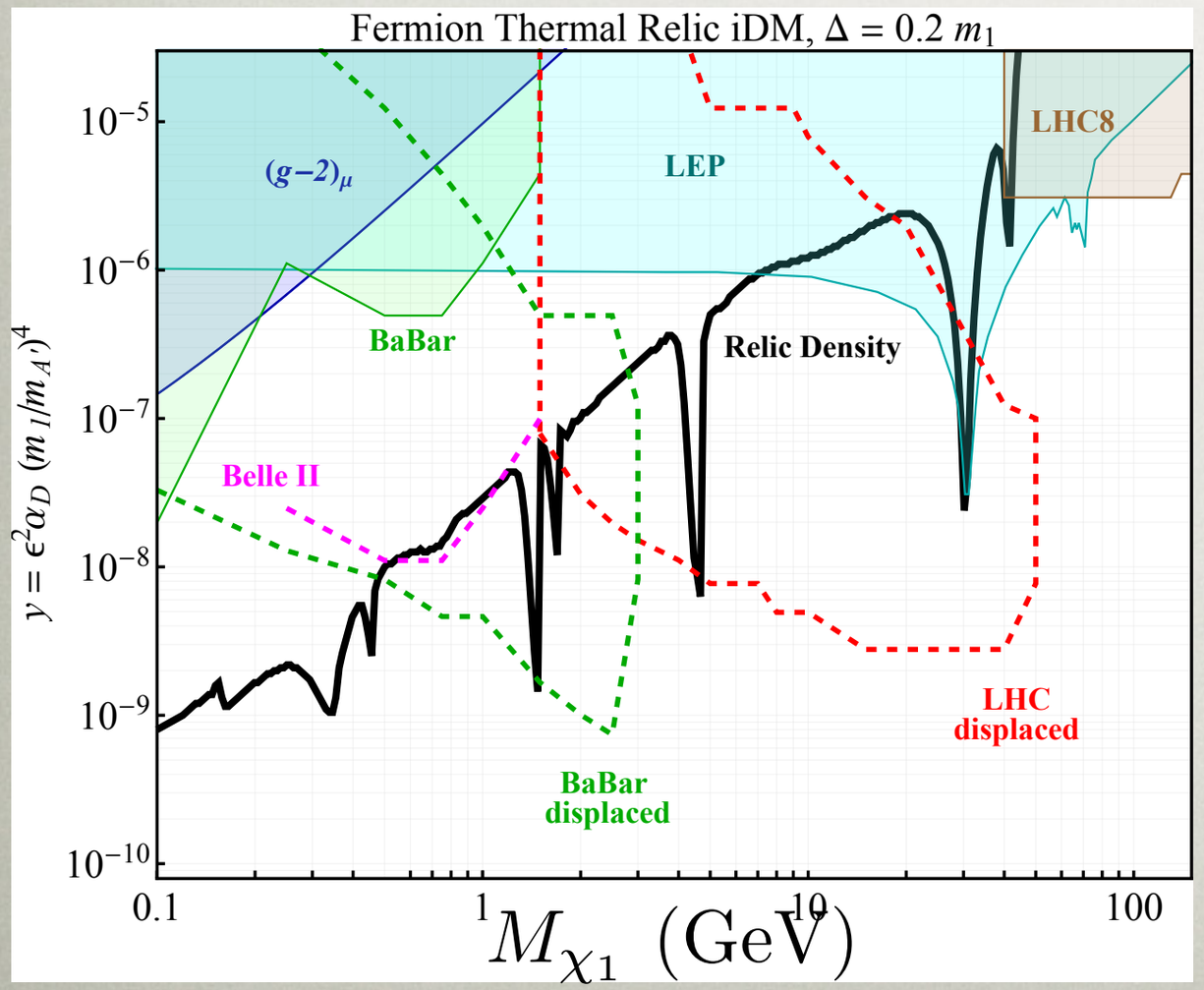
(a)

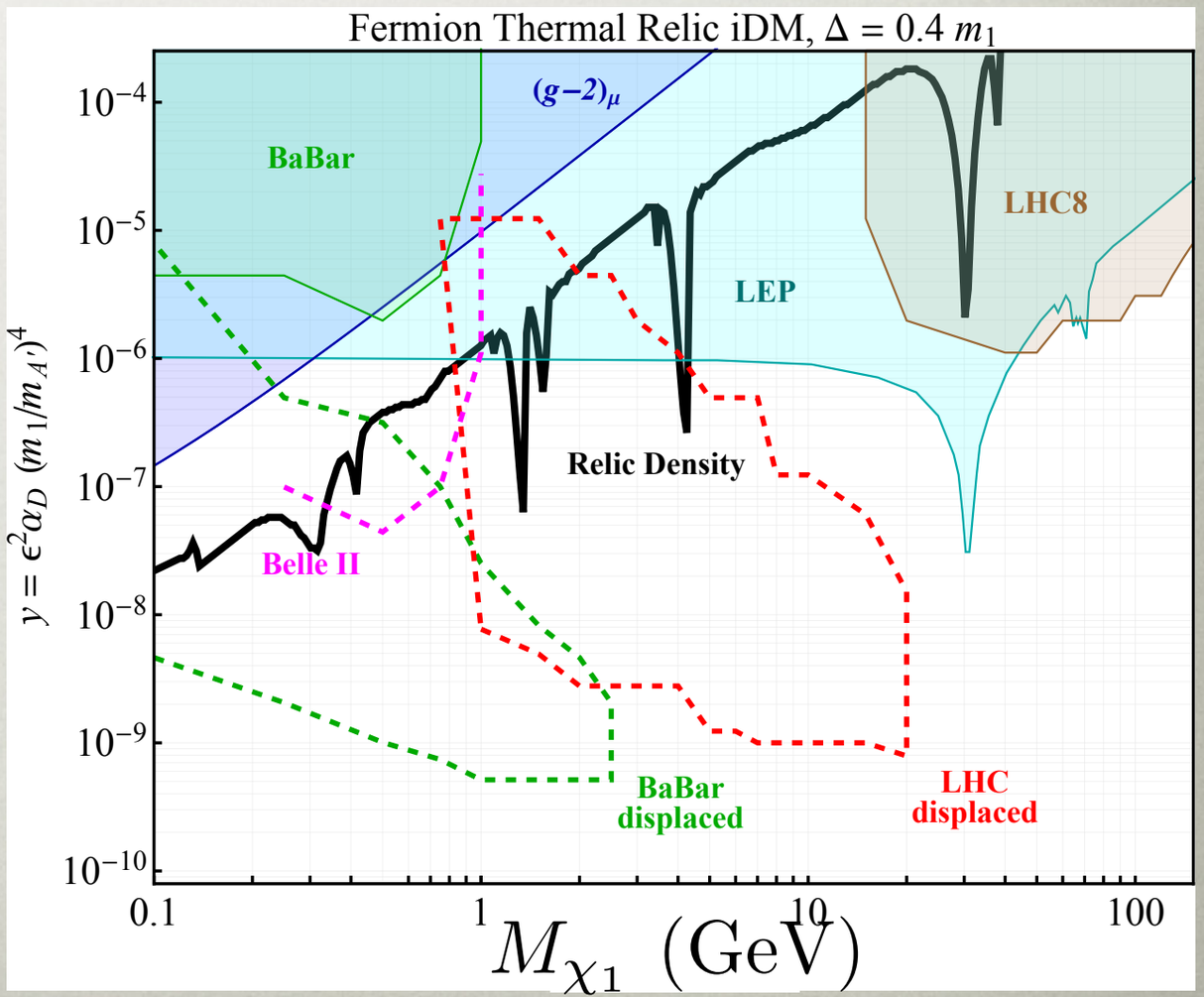
- Also did toy MC simulations

1504.05162

LHC Results

- Monojet + MET
- Soft dimuon vertex (> 1 mm vtx. location and impact param, pT > 5 GeV), close together and aligned with MET
- Backgrounds very low; sensitivity for **10 signal events** (300/fb)





Izaguirre, Krnjaic, BS 1508.03050

Simplest Example: New EW Multiplet

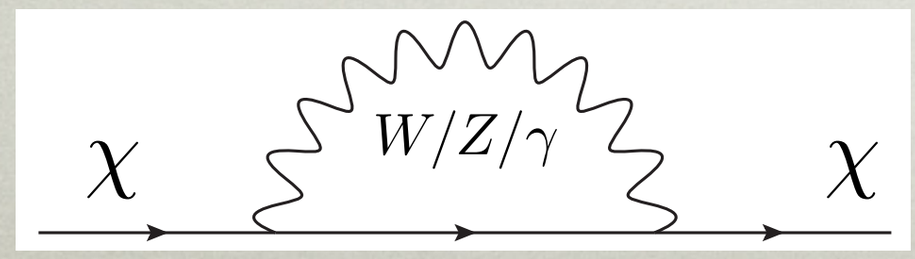
- One of the simplest dark matter scenarios ("minimal DM")

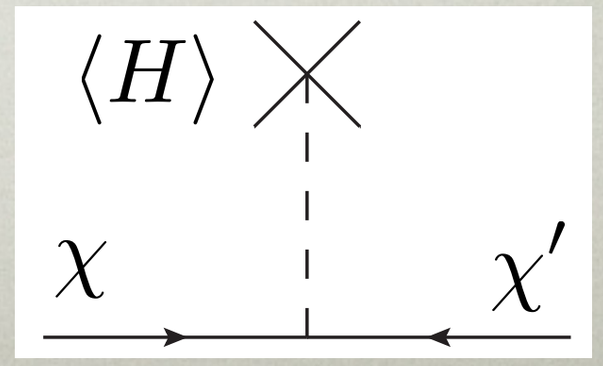
  Cirelli, Fornengo, Strumia, hep-ph/0512090

- Expected in **natural** weak-scale theories (SUSY)
  - *e.g.* Higgsino doublet

$$(\chi^+, \chi^0)$$

- Electroweak symmetry ensures states are **nearly degenerate**

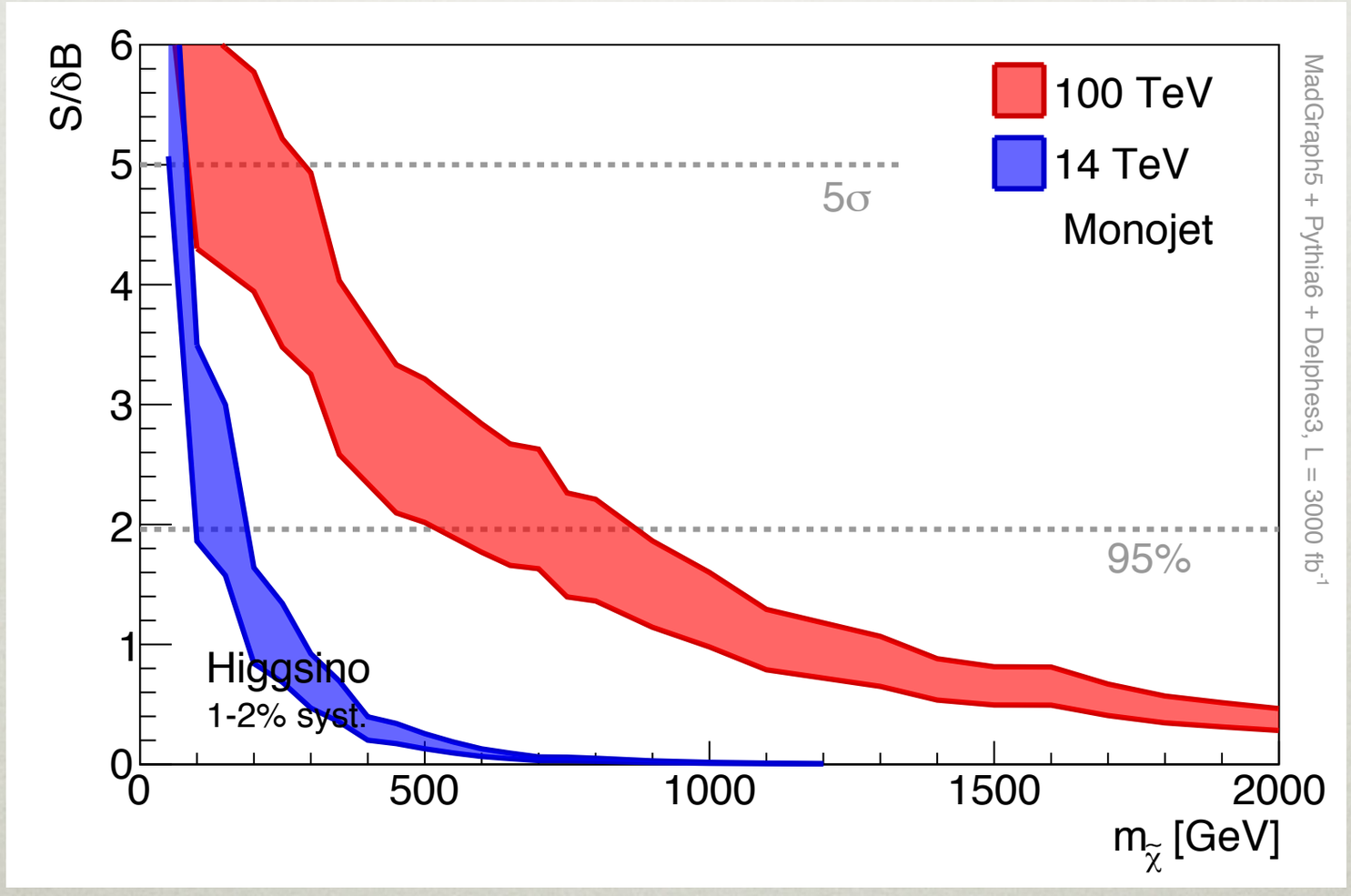




Stoker *et al.*, 1989; Chen *et al.*, 1995; Thomas, Wells, hep-ph/9804359, ...

Higgsino Doublet

- With minimal splittings, dominant decay mode is $\chi^{\pm} \not\to \chi^{0}$
- "Charged" particle is invisible!

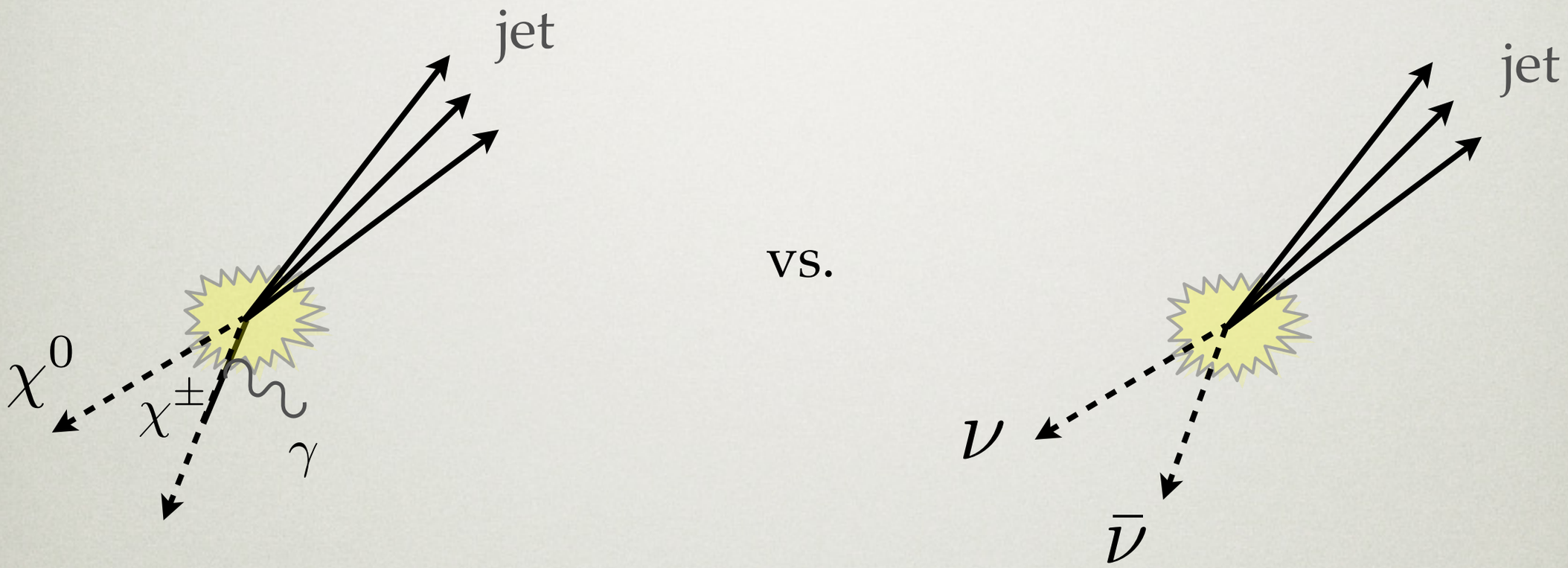


Low, Wang, 1404.0682

Higgsino Doublet

Ismail, Izaguirre, BS, 1605.00658

- Use fact that "invisible" particles are actually **charged**

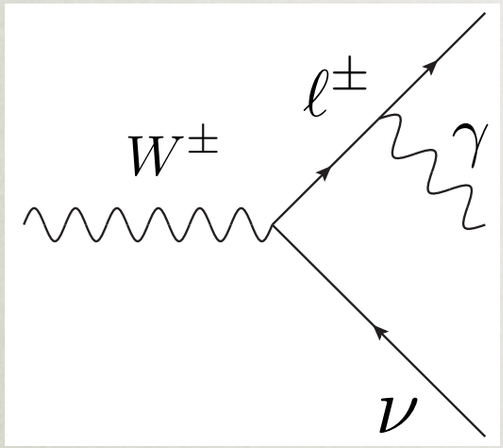


- Can get **soft photon** correlated with MET direction

- Take hit in signal rate to improve S/B

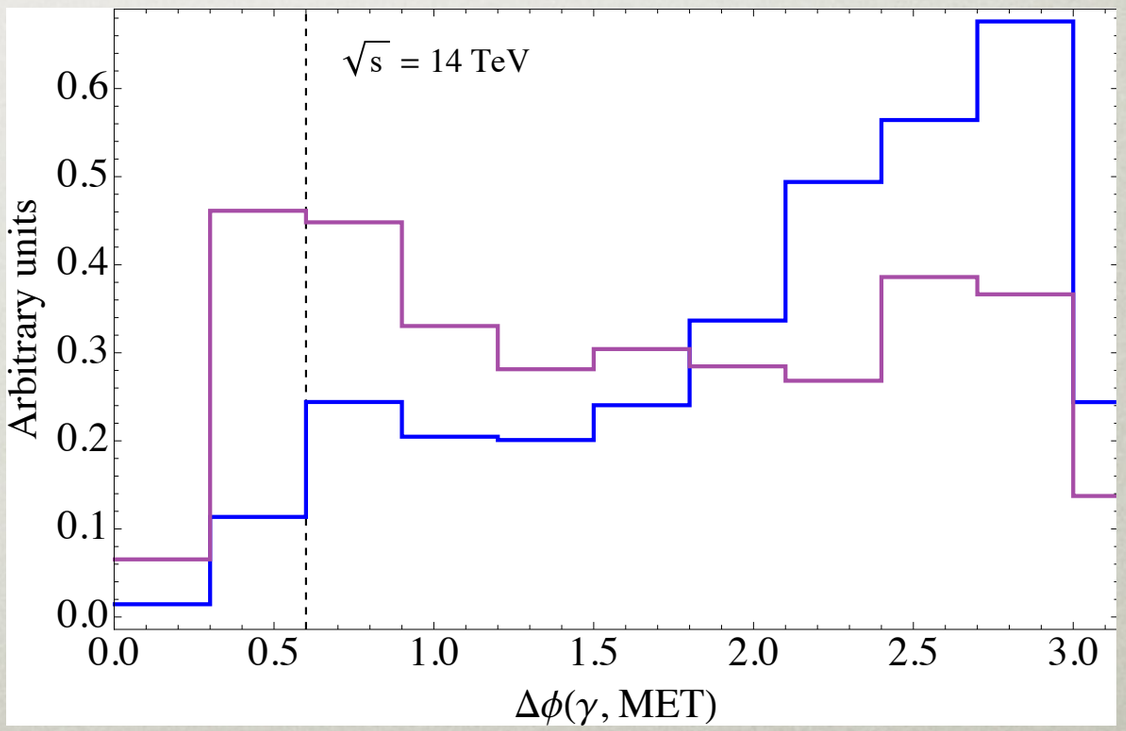
Higgsino Doublet

- Subdominant *W* background becomes very important



$$M_{\mathrm{T}} = \sqrt{2E_{\mathrm{T}}^{\gamma}\not{E}_{\mathrm{T}}[1-\cos\Delta\phi(\gamma,\not{E}_{\mathrm{T}})]}$$

- Photon direction more correlated with MET for signal

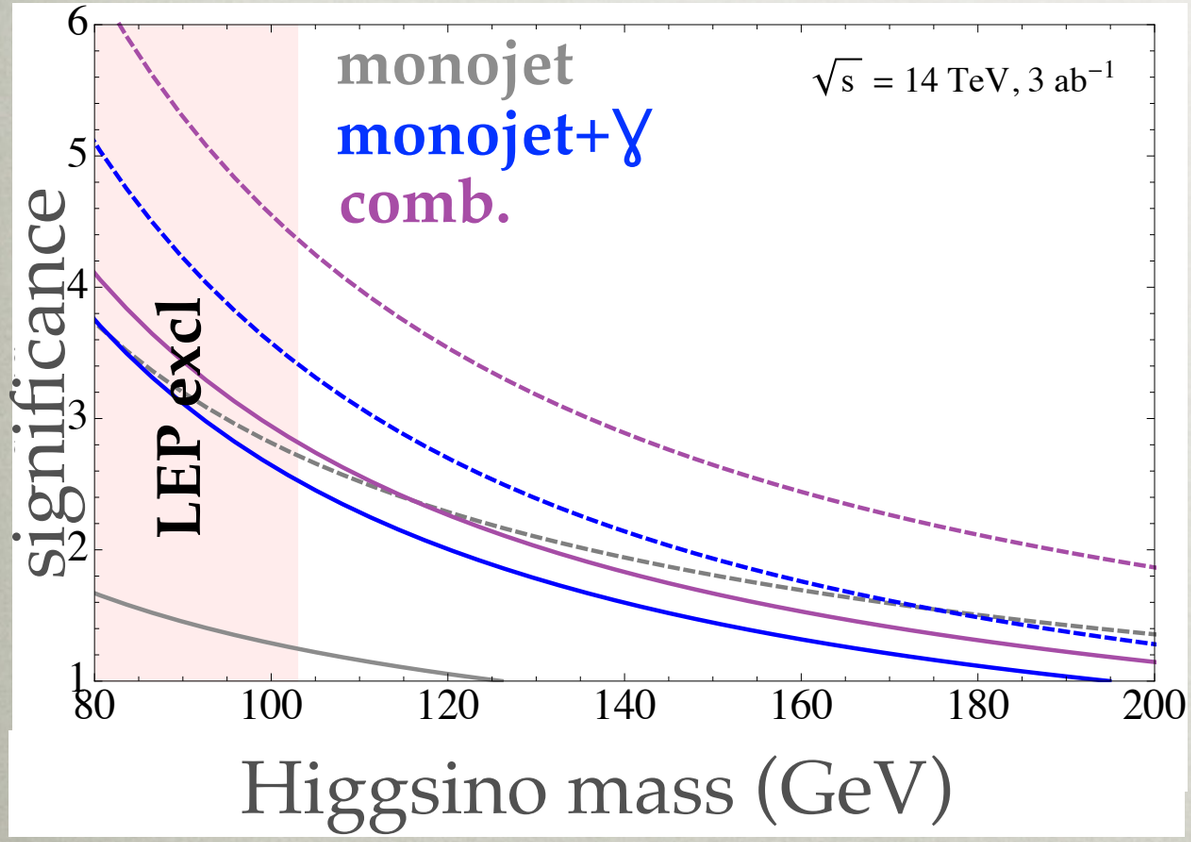


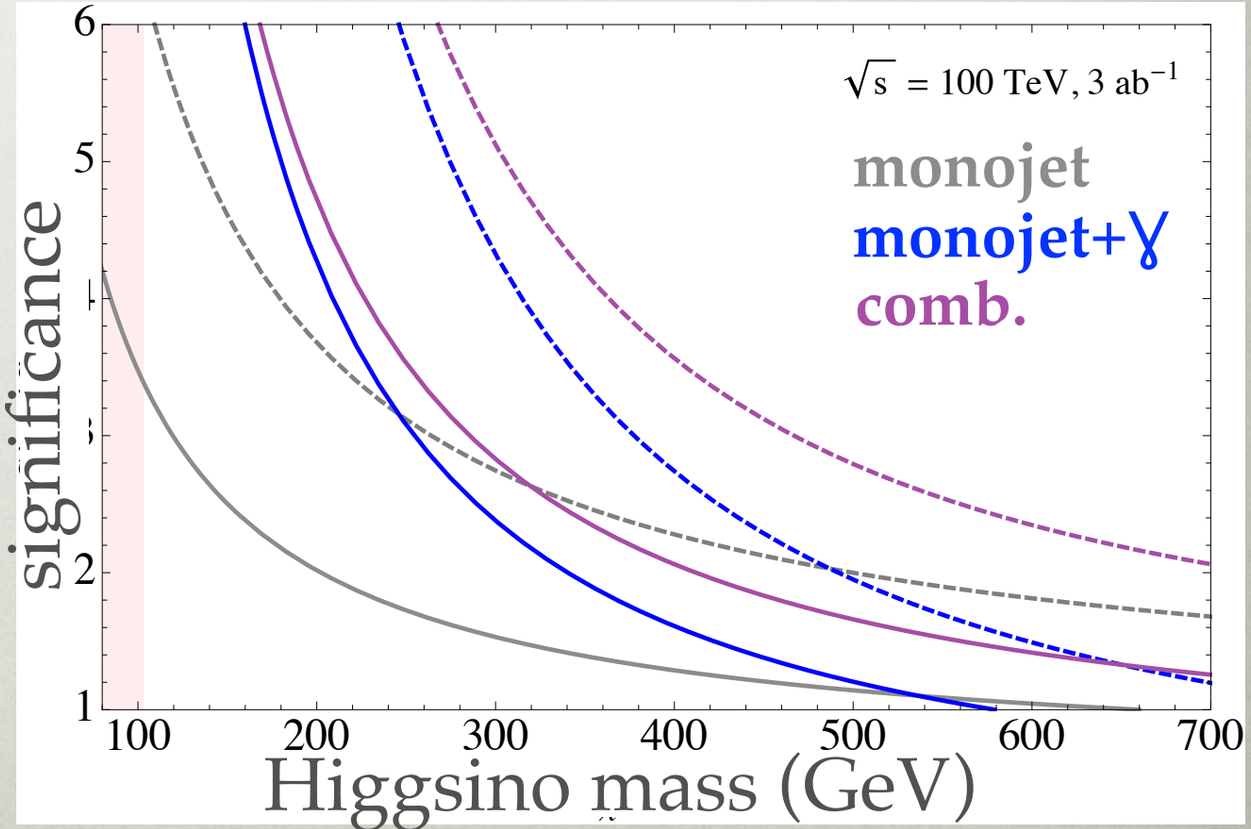
Higgsino Doublet Results

- Optimize over other kinematic cuts (MET, jet p_T, etc.)

HL-LHC **100 TeV, 3/ab**

solid = 5% syst.
dotted = 2% syst.



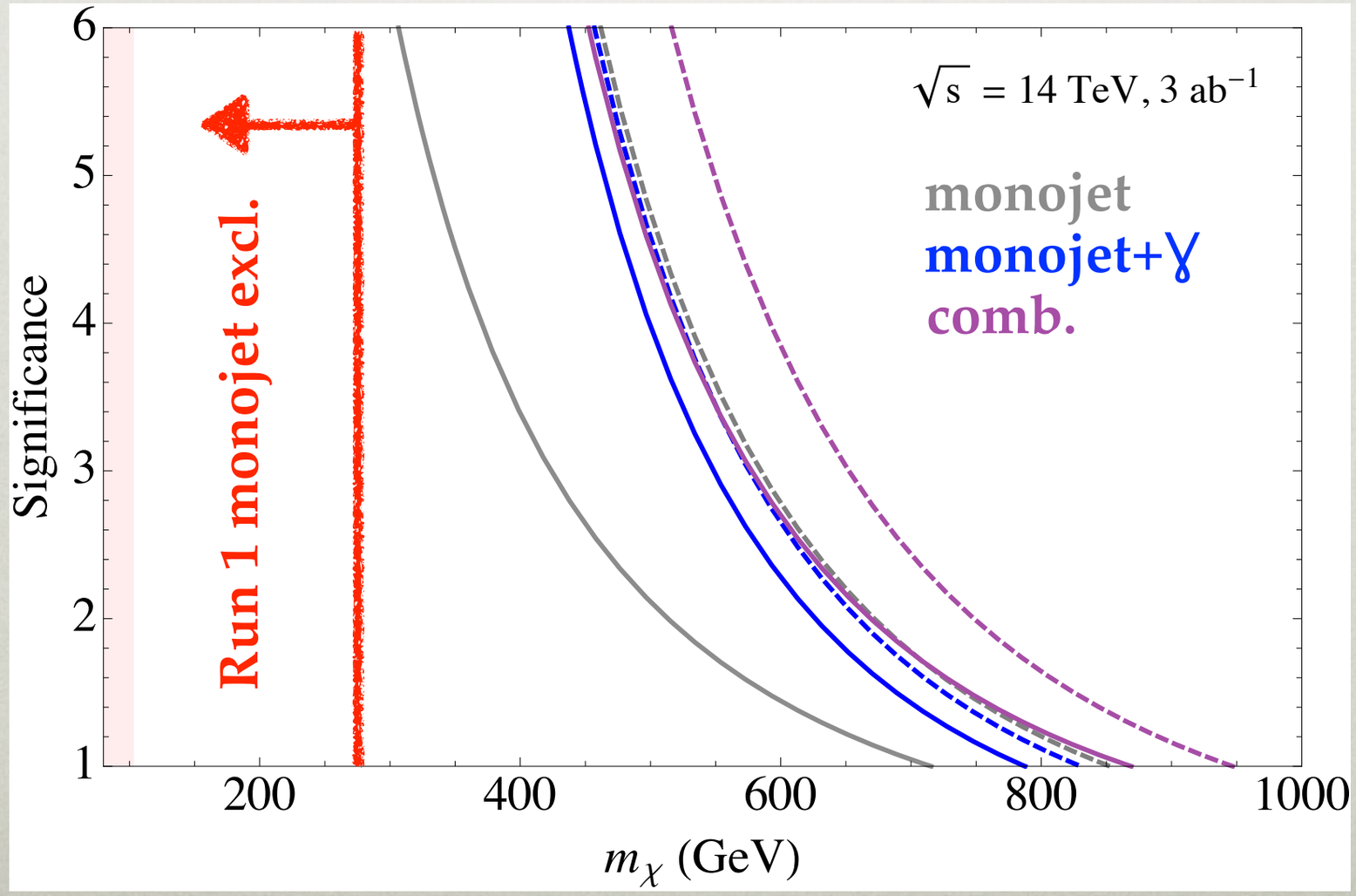


Ismail, Izaguirre, BS, 1605.00658

Quintuplet Results

- Can also consider other states, like a quintuplet with $Y = 0$
- With 20/fb, competitive with current bound (~400 GeV in comb.)

HL-LHC



solid = 5% syst.
dotted = 2% syst.