Lighting up Collider Searches for Electroweak States

Ahmed Ismail

ANL/UIC

ICHEP 2016
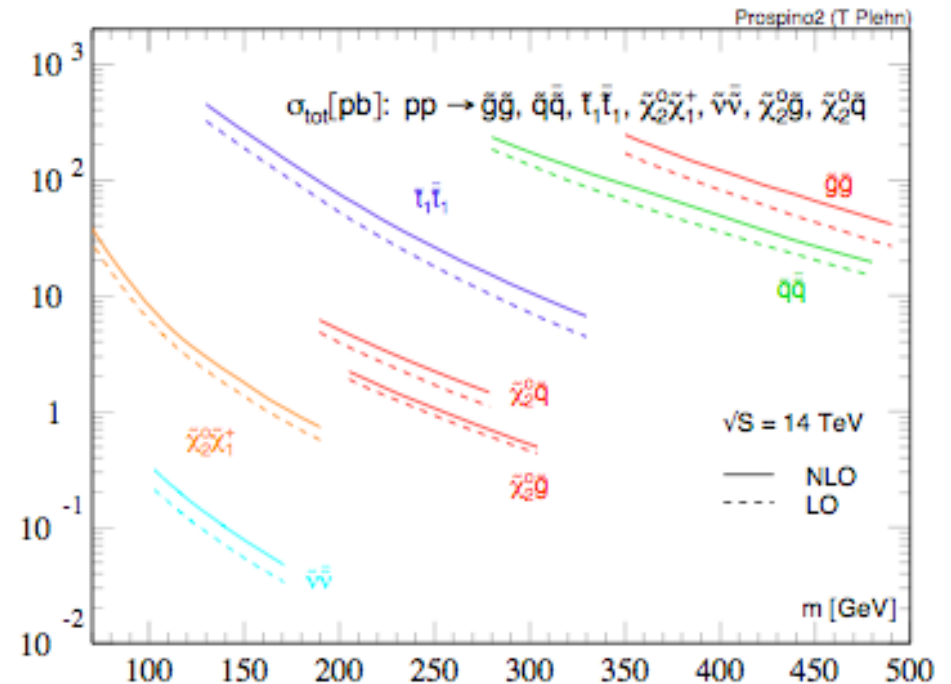
August 4, 2016

New electroweak states and MET

Generic in SM extensions, e.g. WIMPs

Low LHC production cross sections, but often low backgrounds as well

When symmetry protects decay of the lightest neutral component of an EW multiplet, final state contains missing momentum

New electroweak states and MET

Any non-trivial SU(2)$_L$ multiplet χ contains at least one charged particle

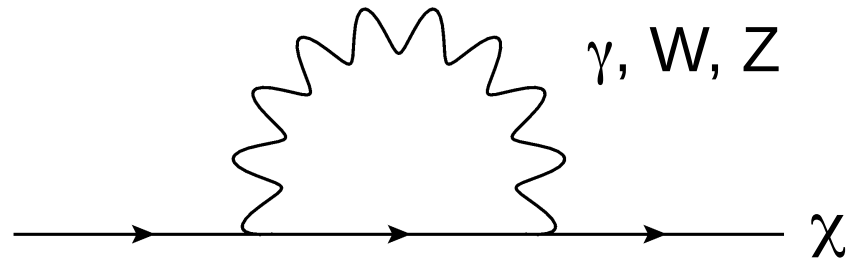One strategy: produce charged particle and look for decay products plus MET
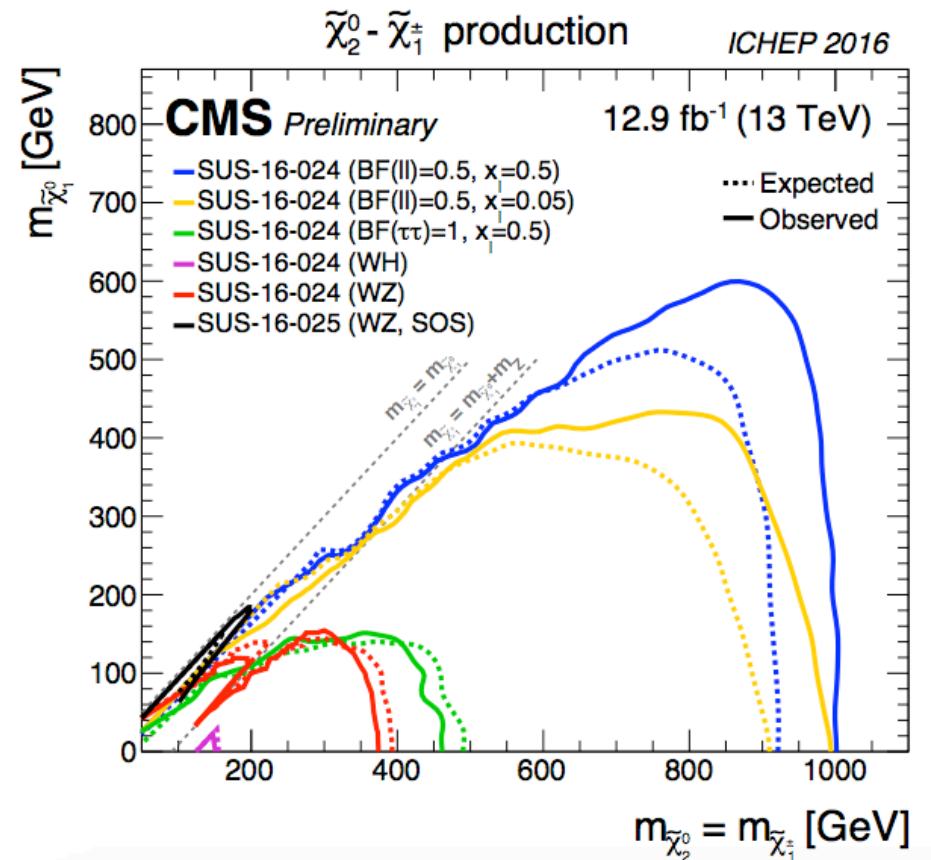
talk by S. Folgueras

If charged/neutral splitting is large enough, leptons from χ^+ decay are visible

Mass splitting

Small mass difference from radiative corrections

γ, W, Z

χ

$$M(\chi^+) - M(\chi^0) = \left(1 + \frac{2Y}{c_w}\right)\frac{\alpha_2}{2}M_W\left(1 - c_w\right)$$

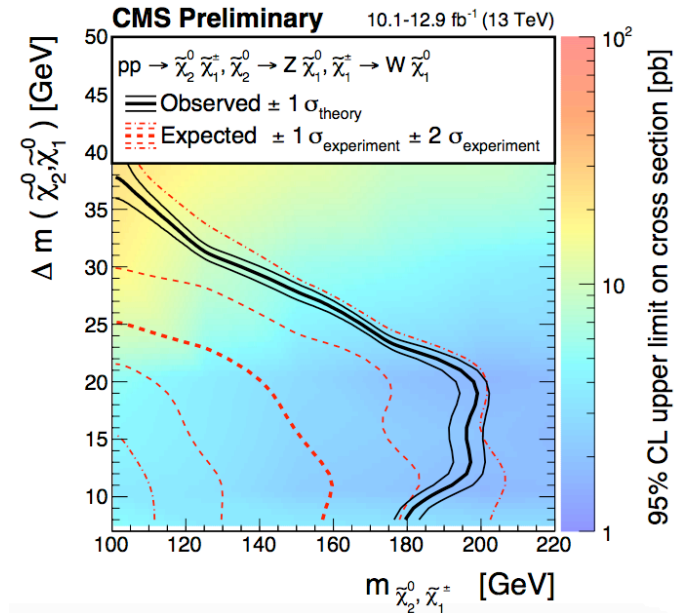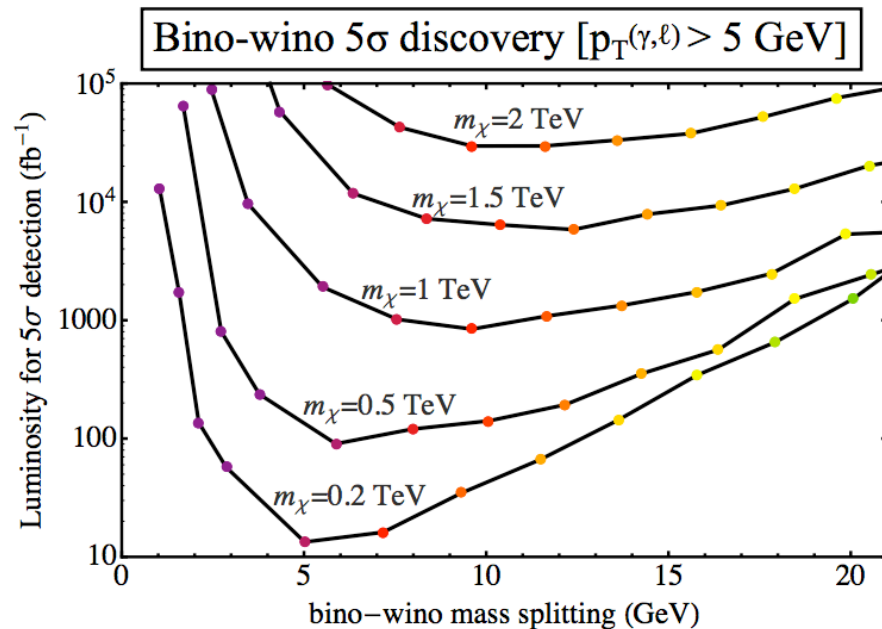$$\approx 166 + 189(2Y) \text{ MeV}$$

Extra splitting possible from EWSB

$$\mathcal{L} \supset \frac{i}{\Lambda}\left(\bar{\chi}\vec{\sigma}\chi\right)\left(H^\dagger\vec{\sigma}H\right) \to M(\chi^+) - M(\chi^0) \sim \frac{v^4}{\Lambda^2 m_\chi}$$

Signatures: large splitting

For > ~several GeV mass splittings, can still use leptons from $\chi^+ \to \chi^0 + W^*$

Schwaller and Zurita, 1312.7350; Han et al., 1401.1235; Low and Wang, 1404.0682

talk by S. Folgueras

Lower splittings can be probed with mixings among multiple states, e.g. using photons from neutral-neutral radiative decays
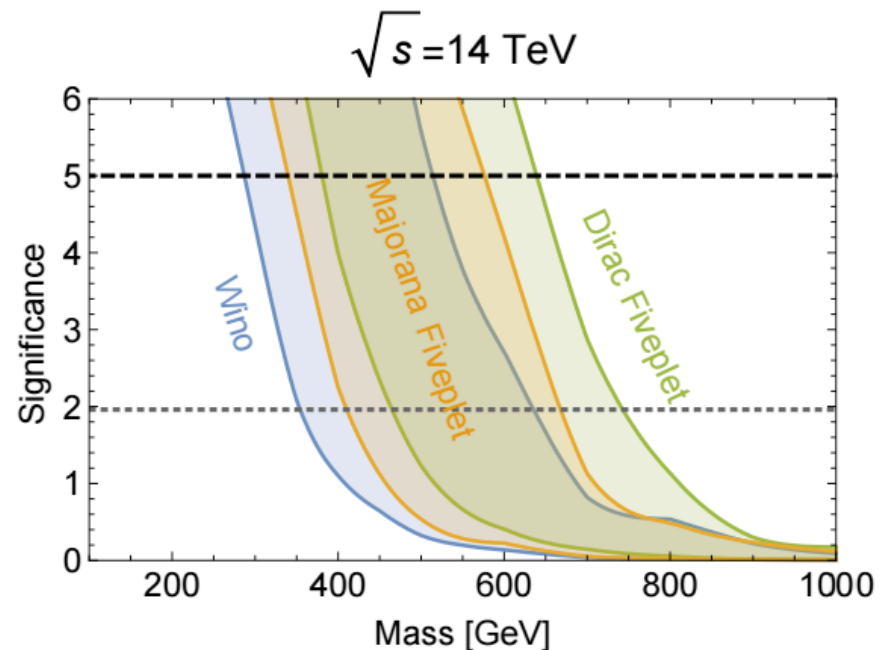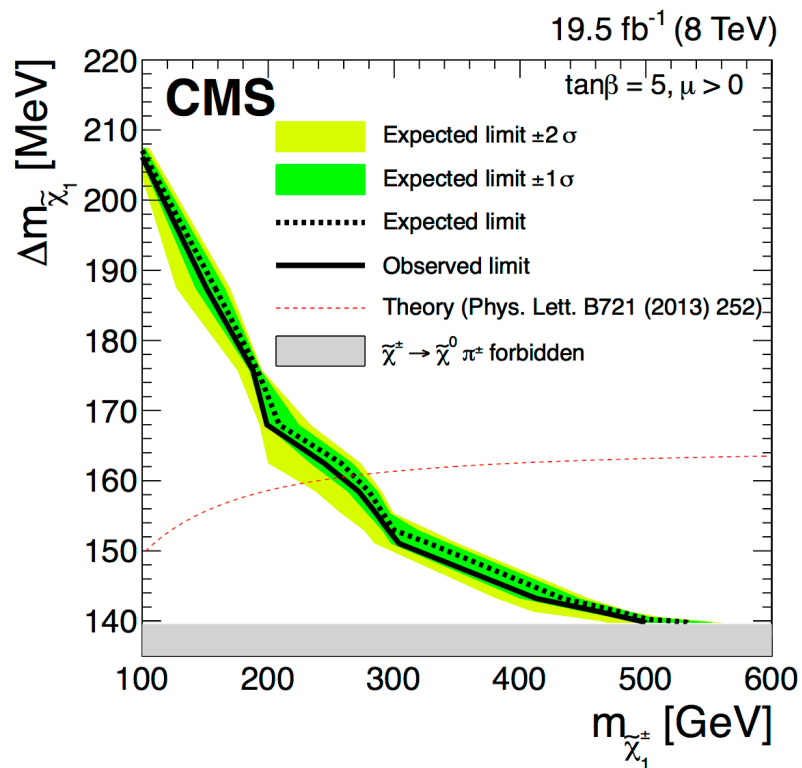
Bramante et al., 1412.4789

5

Signatures: small splitting

For mass difference below 200 MeV, $\chi^+ \to \chi^0 + \pi^+$ gives disappearing tracks

Works for Y = 0 multiplets with radiative splitting
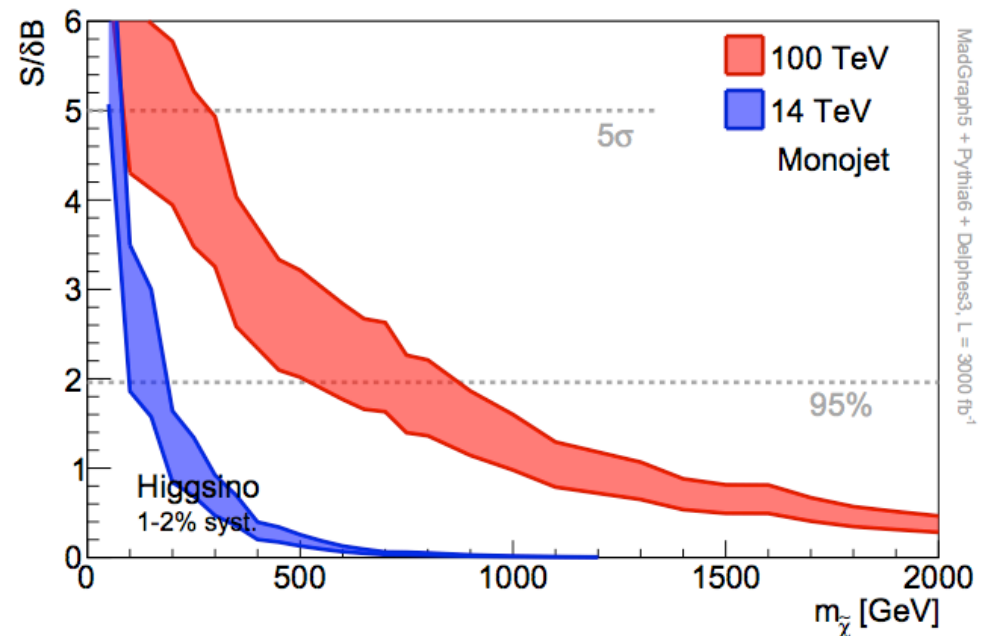
Ostdiek, 1506.03445

Intermediate splittings?

For mass differences between O(1-10) GeV, leptons from χ^+ decay are too soft

Current limit is essentially ~100 GeV from LEP

Use mono-X searches

Baer, Mustafayev, Tata 1401.1162; Low and Wang, 1404.0682; Anandakrishnan, Carpenter, Raby 1407.1833; ...

Potential for improvement but highly sensitive to systematic error; S/B is small

Beyond monojets

Eventual sensitivity of monojet analysis limited by systematic uncertainty on extracting backgrounds from control regions

Table 1: Summary of the statistical and systematic contributions to the total uncertainty on the $Z(\nu\nu)$ background.

| E_T^{miss} (GeV) $\rightarrow$	>250	>300	>350	>400	>450	>500	>550
(1) $Z(\mu\mu)$+jets statistical unc.	1.7	2.7	4.0	5.6	7.8	11	16
(2) Background	1.4	1.7	2.1	2.4	2.7	3.2	3.9
(3) Acceptance	2.0	2.1	2.1	2.2	2.3	2.6	2.8
(4) Selection efficiency	2.1	2.2	2.2	2.4	2.7	3.1	3.7
(5) R_{BF}	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total uncertainty (%)	5.1	5.6	6.6	7.9	9.9	13	18

CMS, 1408.3583

Can afford to use final state with lower statistics instead

Photon final-state radiation

Even if χ^+ decays promptly and invisibly, it can still produce electroweak radiation

Radiation tends to be emitted in direction of χ^+, i.e. can look for photon aligned with missing energy in monojet events
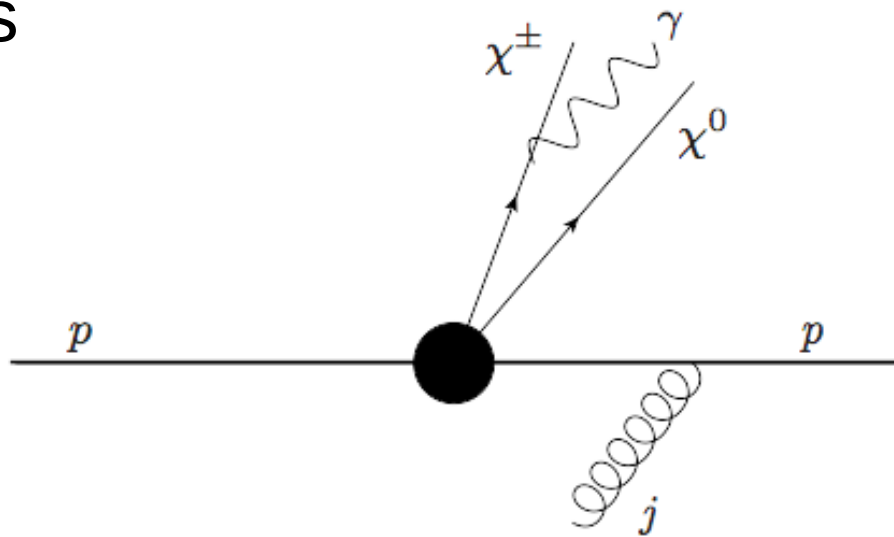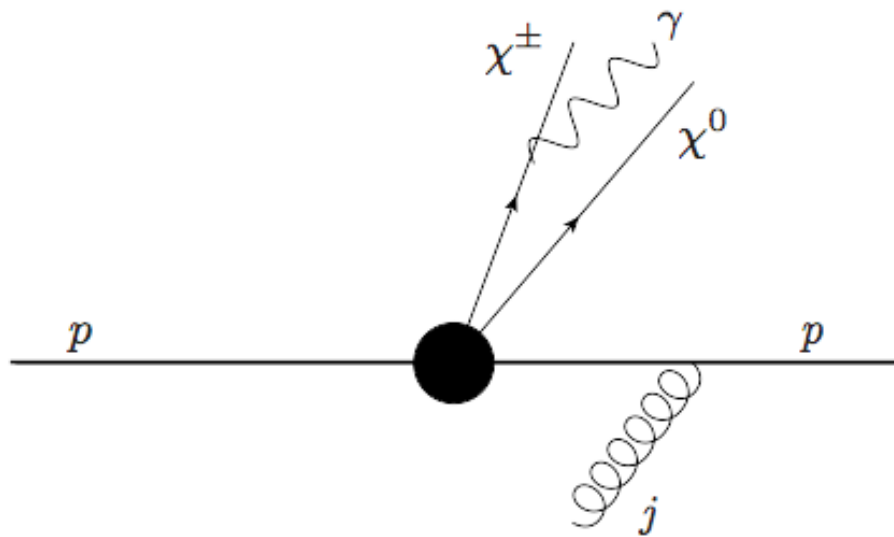

AI, Izaguirre, Shuve
1605.00658

Pay statistical price of α but benefit from low backgrounds and extra kinematic handle

Photon final-state radiation

In addition to Z background, W + jet with photon radiation from missed lepton becomes more important, since it is naturally aligned with the missing energy

AI, Izaguirre, Shuve
1605.00658

Search is *independent* of charged-neutral mass splitting

Experimental considerations

Recoil against hard jet provides alignment but also trigger, enabling acceptance of softer photons

Can estimate main backgrounds from data as for monojet search, e.g. $Z + \gamma + j$ from (hard) γ + (soft) $\gamma + j$, and $W + \gamma + j$ from control region with isolated hard leptons $\rightarrow$ expect similar control of systematics
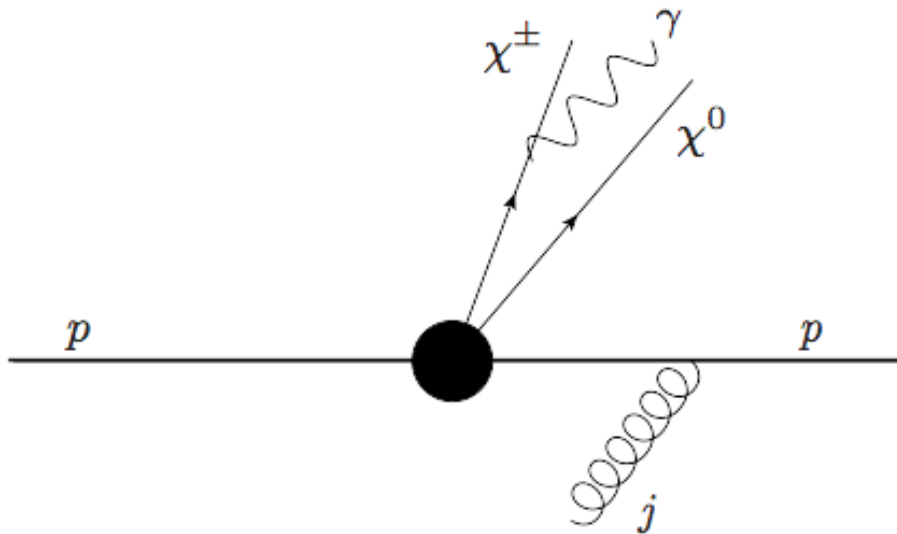
Cuts on extra jets, leading jet p_T / MET ratio reduce backgrounds from tops, QCD

Photon + jet + MET search

Trigger on hard jet and missing energy, then look for soft photon (15 GeV) with small angular separation from MET

Backgrounds: Z + γ + j, W + γ + j, tops, QCD fakes

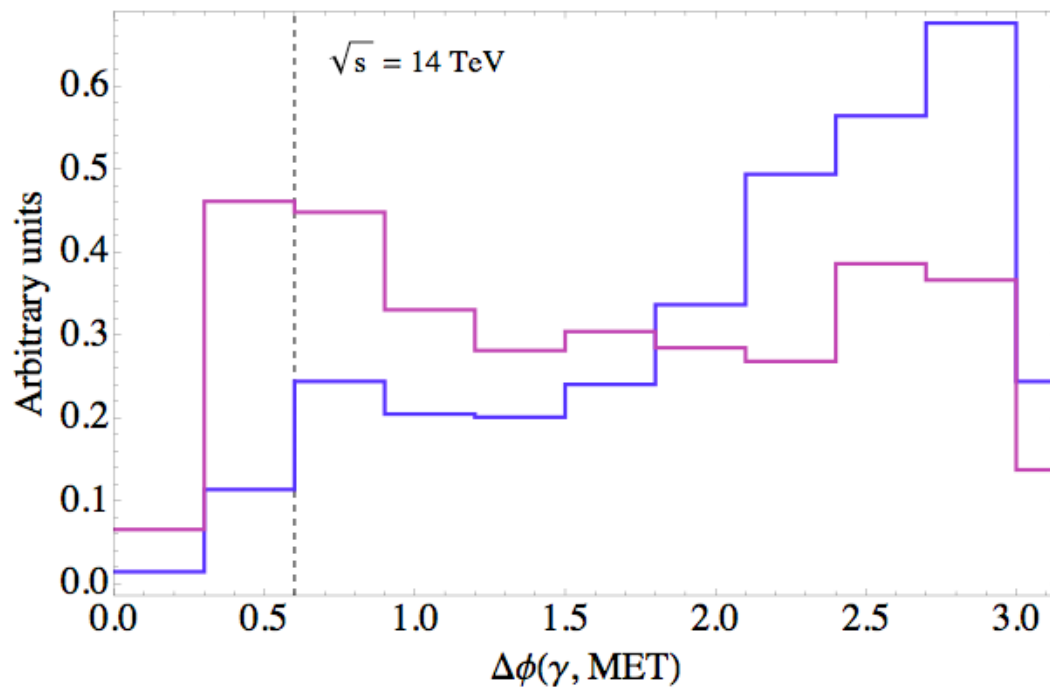Require photon $m_T > m_W$, $p_T(j_1)$ / MET > 0.5

Photon + jet + MET search

Trigger on hard jet and missing energy, then look for soft photon (15 GeV) with small angular separation from MET

Backgrounds: Z + γ + j, W + γ + j, tops, QCD fakes

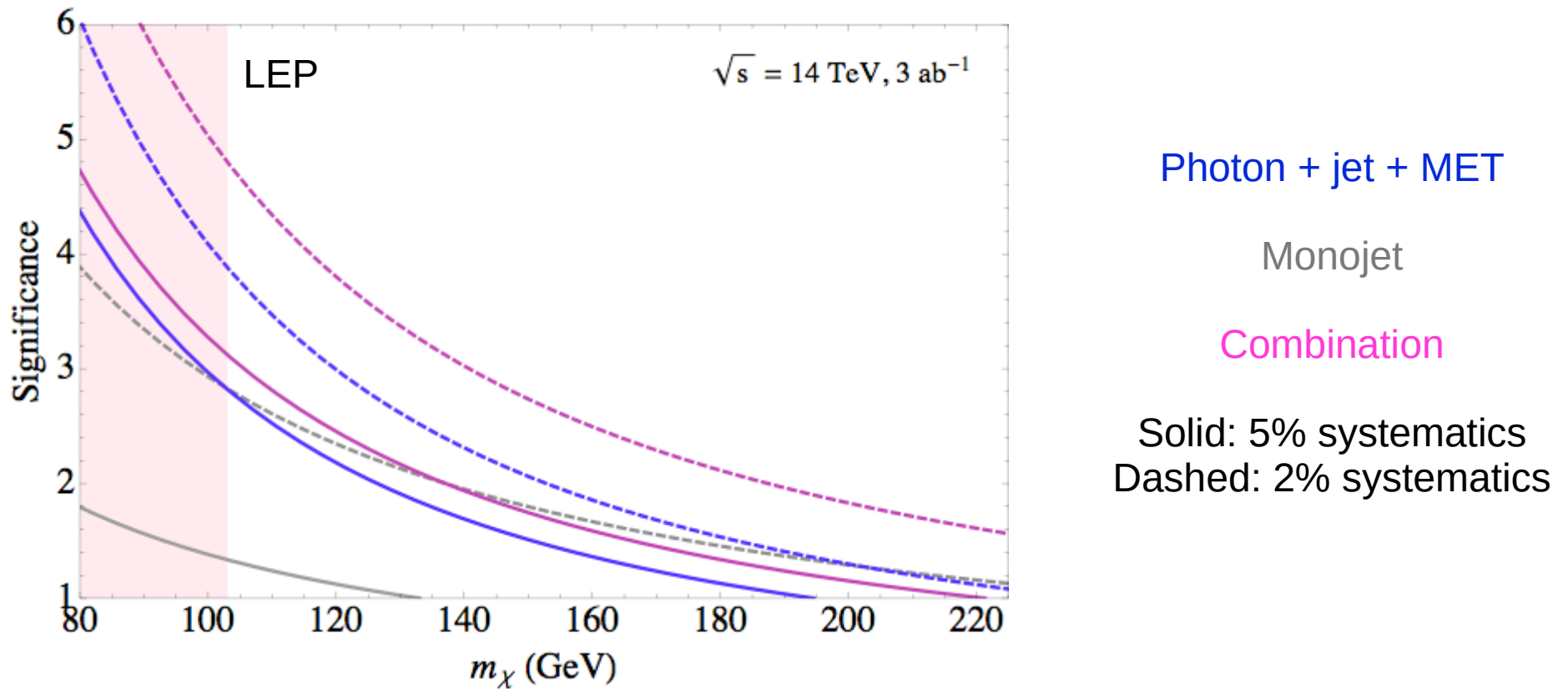Optimize further cuts on jet p_T, MET, $\eta(\gamma)$

125 GeV Higgsino

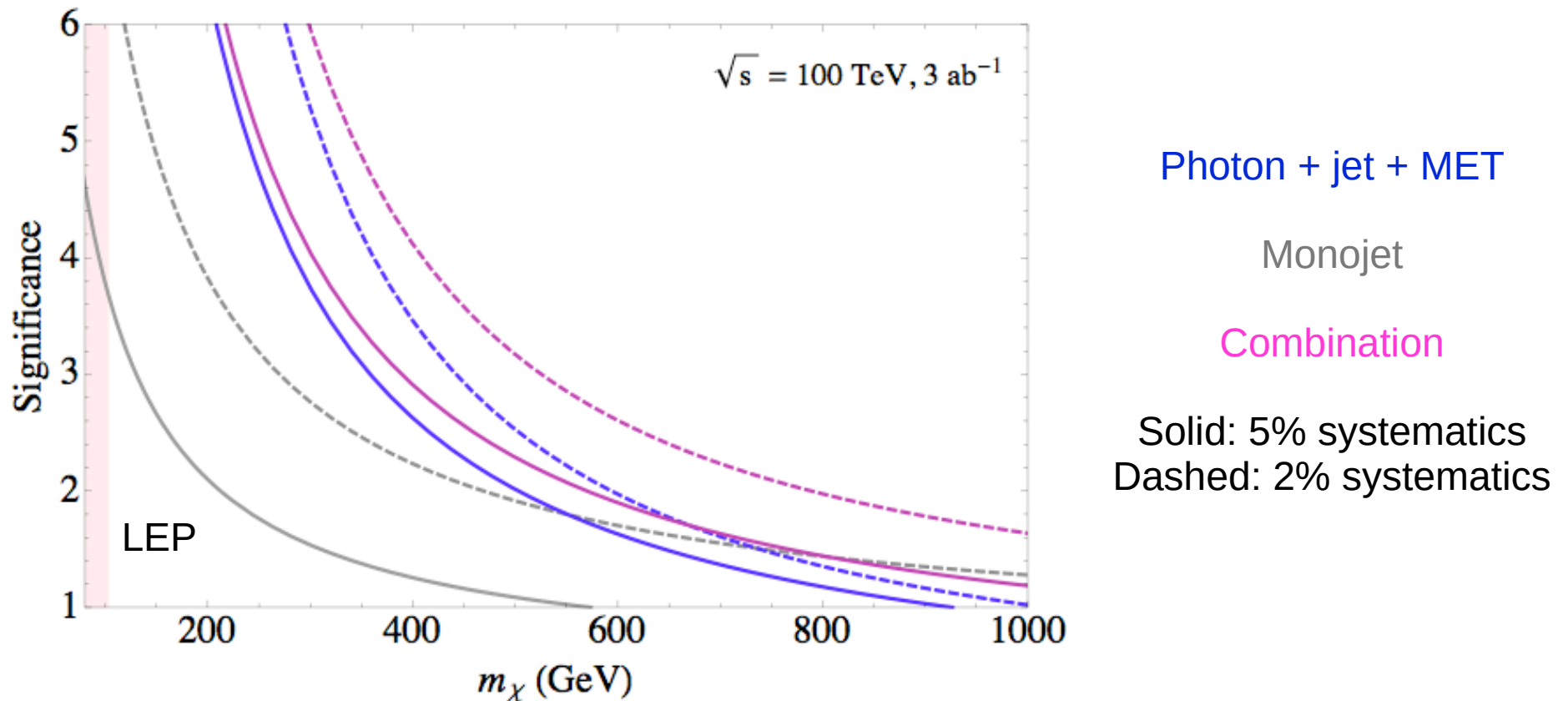Z, W backgrounds

Results - Higgsino

For larger systematic uncertainties, photon + jet search improves on LEP limit where monojet is fundamentally limited

Photon + jet + MET

Monojet

Combination

Solid: 5% systematics
Dashed: 2% systematics

Results - Higgsino

At 100 TeV, combining photon + jet with monojet channel can increase exclusion reach from ~ 450 to 750 GeV, with improved systematics

$\sqrt{s} = 100$ TeV, 3 ab^{-1}

Photon + jet + MET

Monojet

Combination

Solid: 5% systematics
Dashed: 2% systematics

Summary

Charged states in an SU(2)$_L$ multiplet may decay invisibly, but still leave photon final state radiation

Can look for photon in events with a hard ISR jet and missing energy, using kinematics to discriminate against backgrounds

Photon + jet can provide equal or better sensitivity than monojets to new electroweak states, depending on systematics that will be achievable
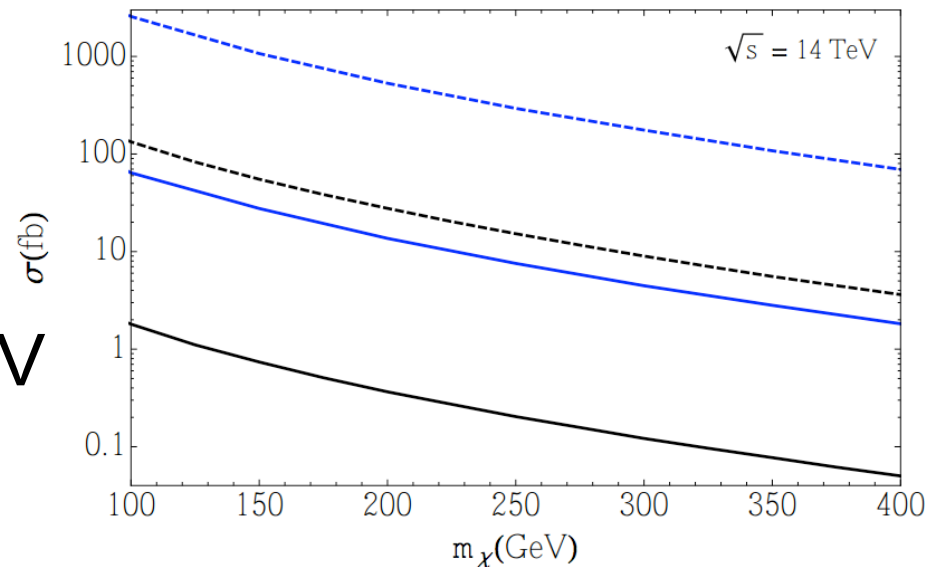
Benchmark models

Y = ½ doublet (Higgsino):

- light in natural SUSY

- thermal dark matter at 1.0 TeV

- radiative splitting between

charged and neutral state is 340 MeV

Y = 0 quintuplet:

- standard minimal DM candidate

Cirelli, Fornengo, Strumia, hep-ph/0512090

- smallest multiplet that cannot decay to SM fields
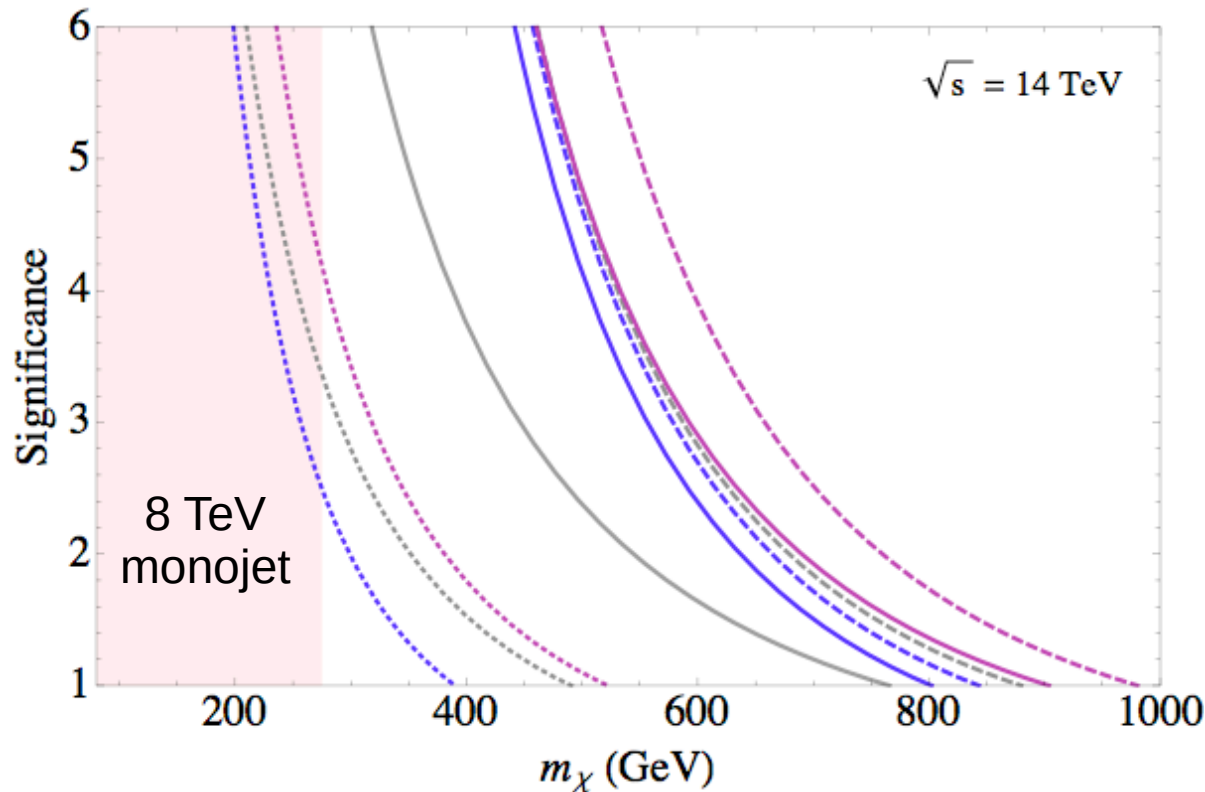
- thermal dark matter at 4.4 TeV

$\sqrt{s} = 14$ TeV

σ(fb)

m_χ(GeV)

Doublet

Quintuplet

Solid: photon + jet + MET
Dashed: jet + MET

Results - Quintuplet

Increased radiation from χ^{++} improves photon + jet + MET

Photon + jet + MET

Monojet

Combination

Dotted: 20 fb^{-1}, 5% systematics
Solid: 3 ab^{-1}, 5% systematics
Dashed: 3 ab^{-1}, 2% systematics

Results - Quintuplet

Thermal DM mass not quite reached at 100 TeV, but photon + jet channel still provides useful information

Photon + jet + MET

Monojet

Combination

Solid: 5% systematics
Dashed: 2% systematics