X + MET versus model-specific signatures: pros and cons.

Kai Schmidt-Hoberg

Mandate:

“The contribution should highlight the complementarity between “simple” X + MET signatures that will have been discussed in the preceding session and “complex” model-specific signatures, as in e.g., supersymmetric models with dark matter candidates...”

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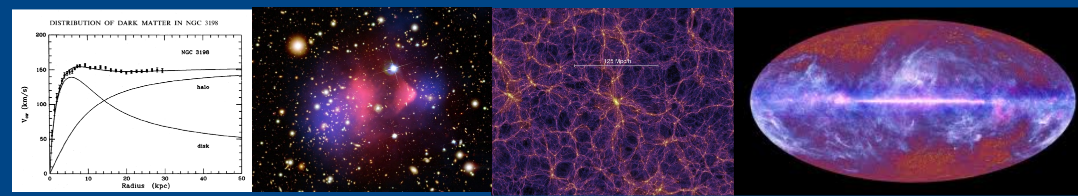
erc

DESY

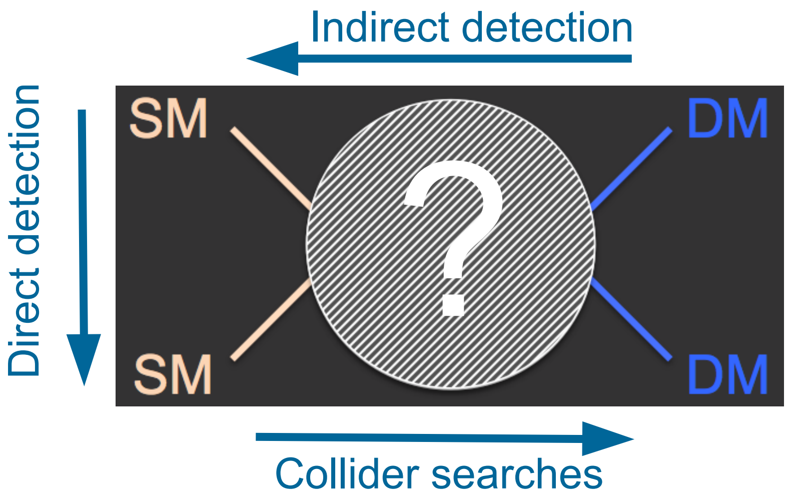
Dark matter – how will it reveal itself?

Dark matter exists!



...but we know next to nothing
about its particle physics properties

Q: So how does it show up at colliders (if at all)?
A: ???
Q: How likely will it be in MET + X?
A: ???



Theory for dark matter

Need models for dark matter to shape expectations (and experimental search strategies)

UV

- Tackle fundamental problems such as e.g. hierarchy problem and look for implications
  - WIMPs
  - …
- **Well-motivated** dark matter candidates, but also **strong theoretical bias**

IR

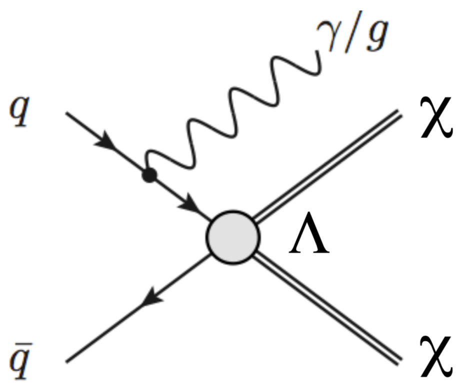
- Naturalness arguments suggest new physics at the LHC
- Nothing yet → motivates broader thinking.
- **As model independent as possible**
- **EFTs** or **simplified models**

DM production

> Expected signatures?

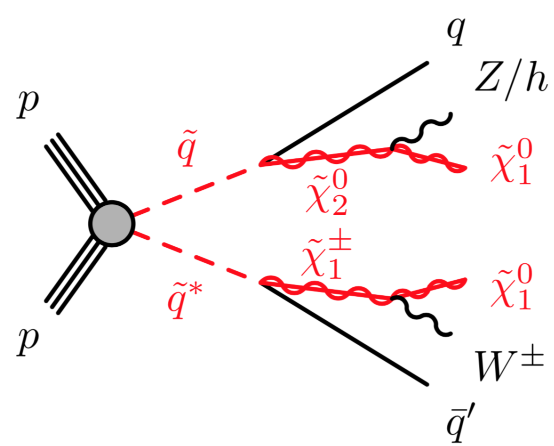
IR

Directly → Mono-X



UV

via decay chains
→ lots of stuff

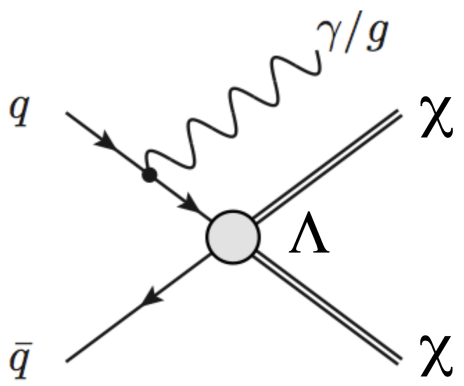


DM signatures

Plan: IR→ UV (simplified model → SUSY scenarios → other signatures)

IR

Directly → Mono-X



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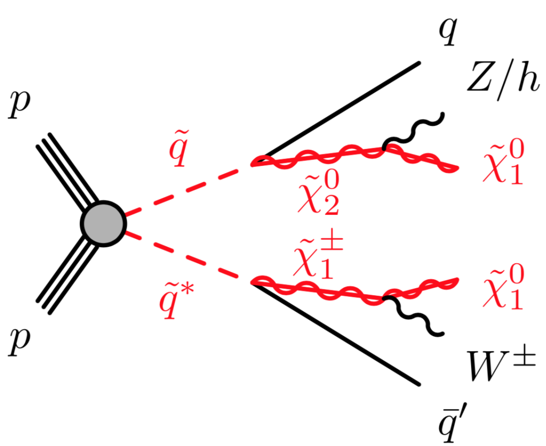
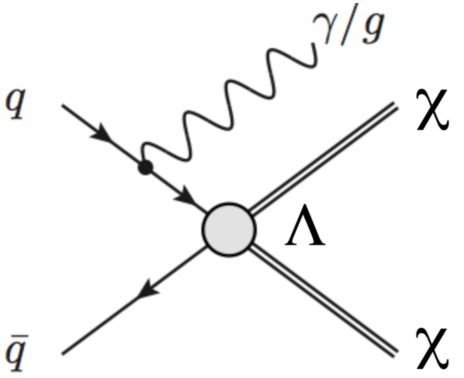


EFTs or Mono-X only

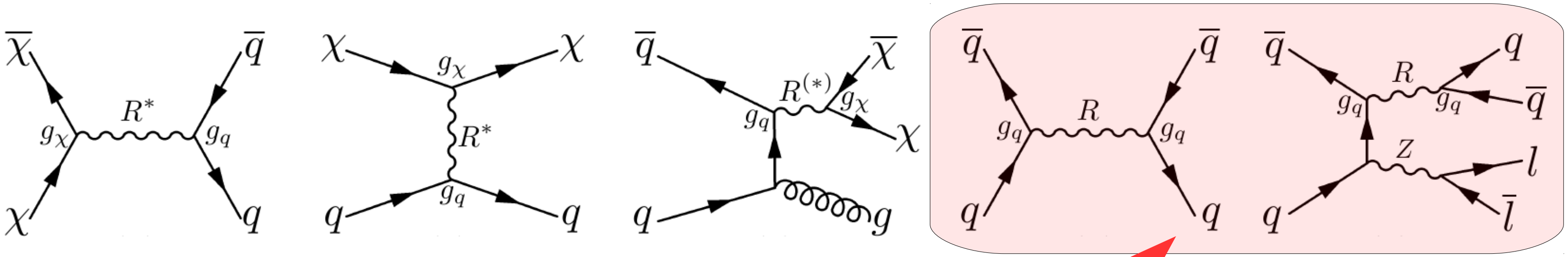
- **EFTs:** If mediating particles are sufficiently **heavy,** valid to use **effective operators**

- **Mono-X the only signature!**



$$\frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

- If the mediator is accessible at the LHC, additional signatures are possible



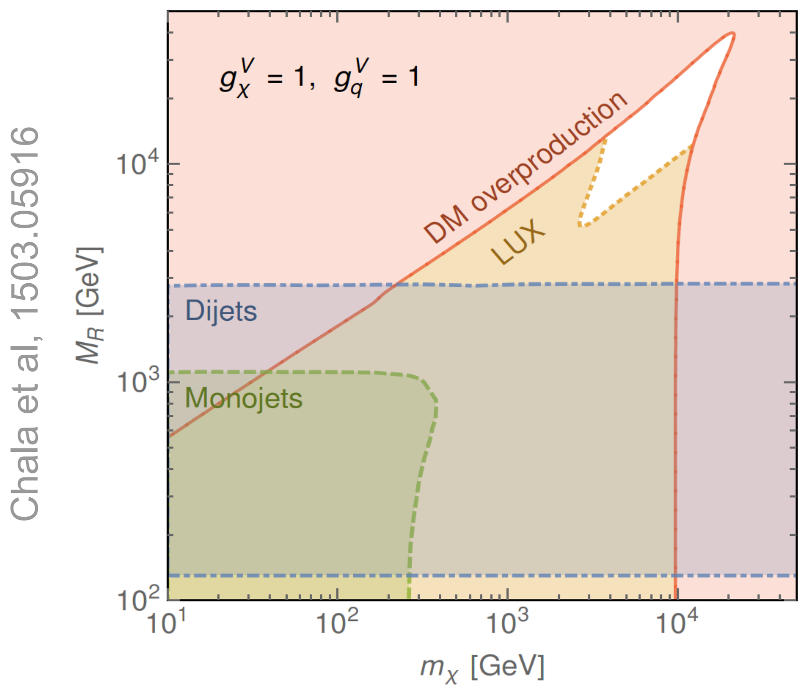
Interactions not present in the EFT

→ Sarah Malik's talk

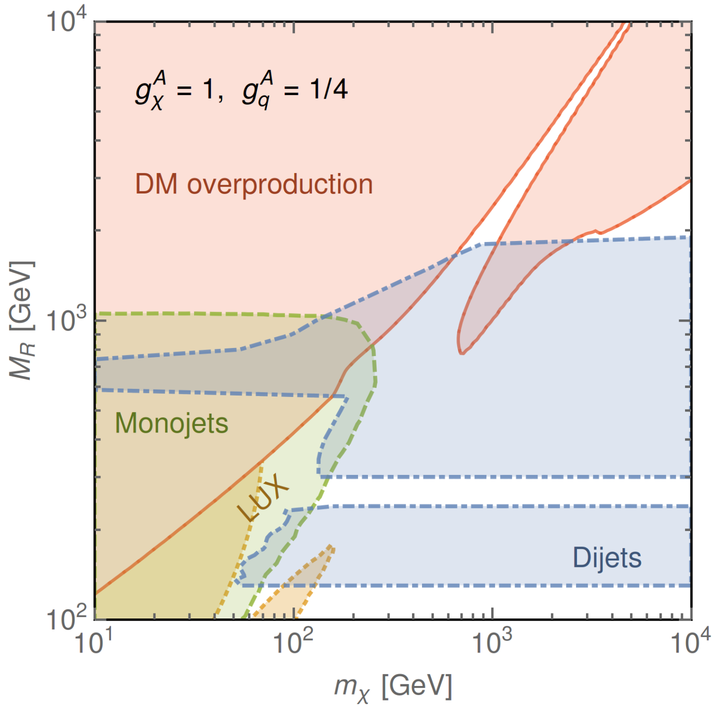
- Complementarity of all searches:
  - Where do we expect to see DM first?

Where do we expect to see DM first?

Vector couplings



Axial couplings

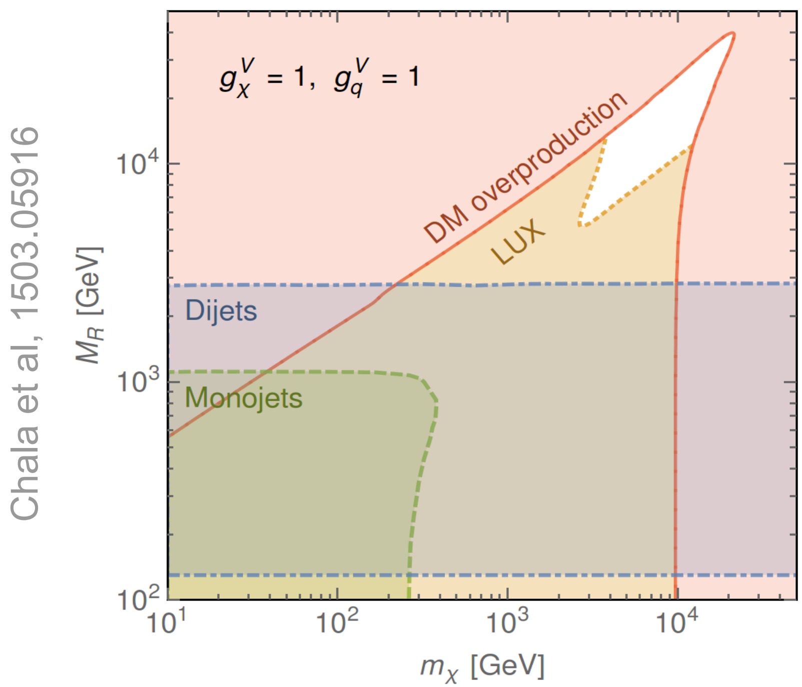


- Direct detection experiments are the obvious discovery channel for vector couplings

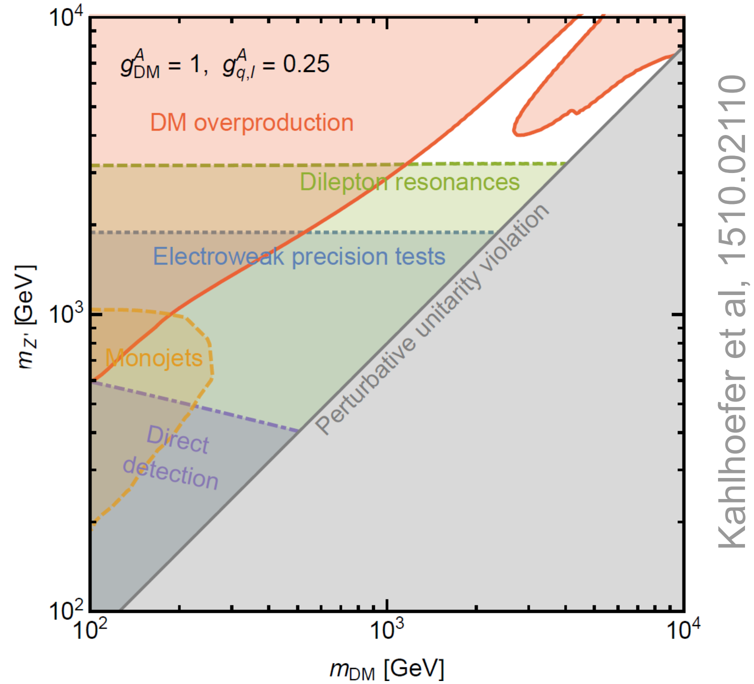
- Almost no constraints from direct detection
- Strong complementarity between monojet and dijet searches

Where do we expect to see DM first?

Vector couplings



Axial couplings



- Direct detection experiments are the obvious discovery channel for vector couplings

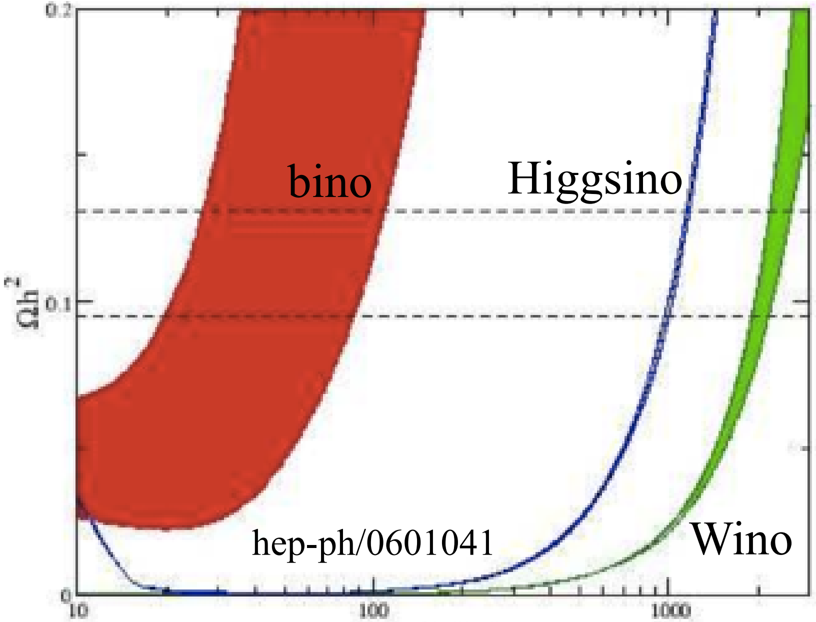
- But: issues with unitarity and gauge invariance → Felix' talk!
- Picture different again – monojets typically not competitive
- Need dark Higgs
→ Talk by Michael Duerr!

Full-blown models – here: SUSY

> Neutralinos (mixture of bino, Wino and Higgsino) and gravitino good dark matter candidates

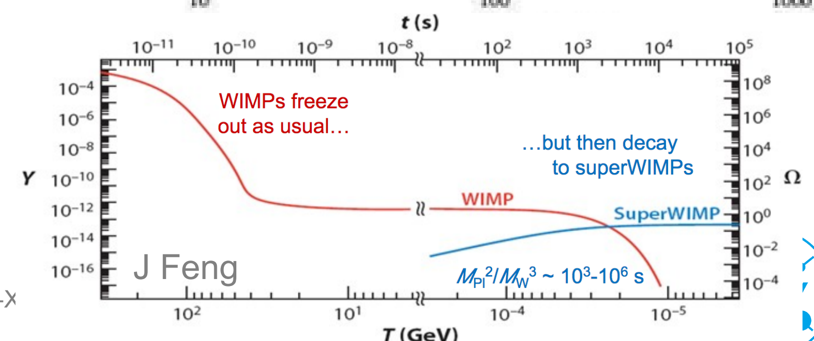
> Neutralino relic abundance? → freeze out

- Bino: Typically need to finely tune via coannihilations or resonances :-(
- Wino: m ~ 3TeV, challenged by ID
  Lisanti et al 1307.4082
- Higgsino: m ~ 1TeV, looking good :-)

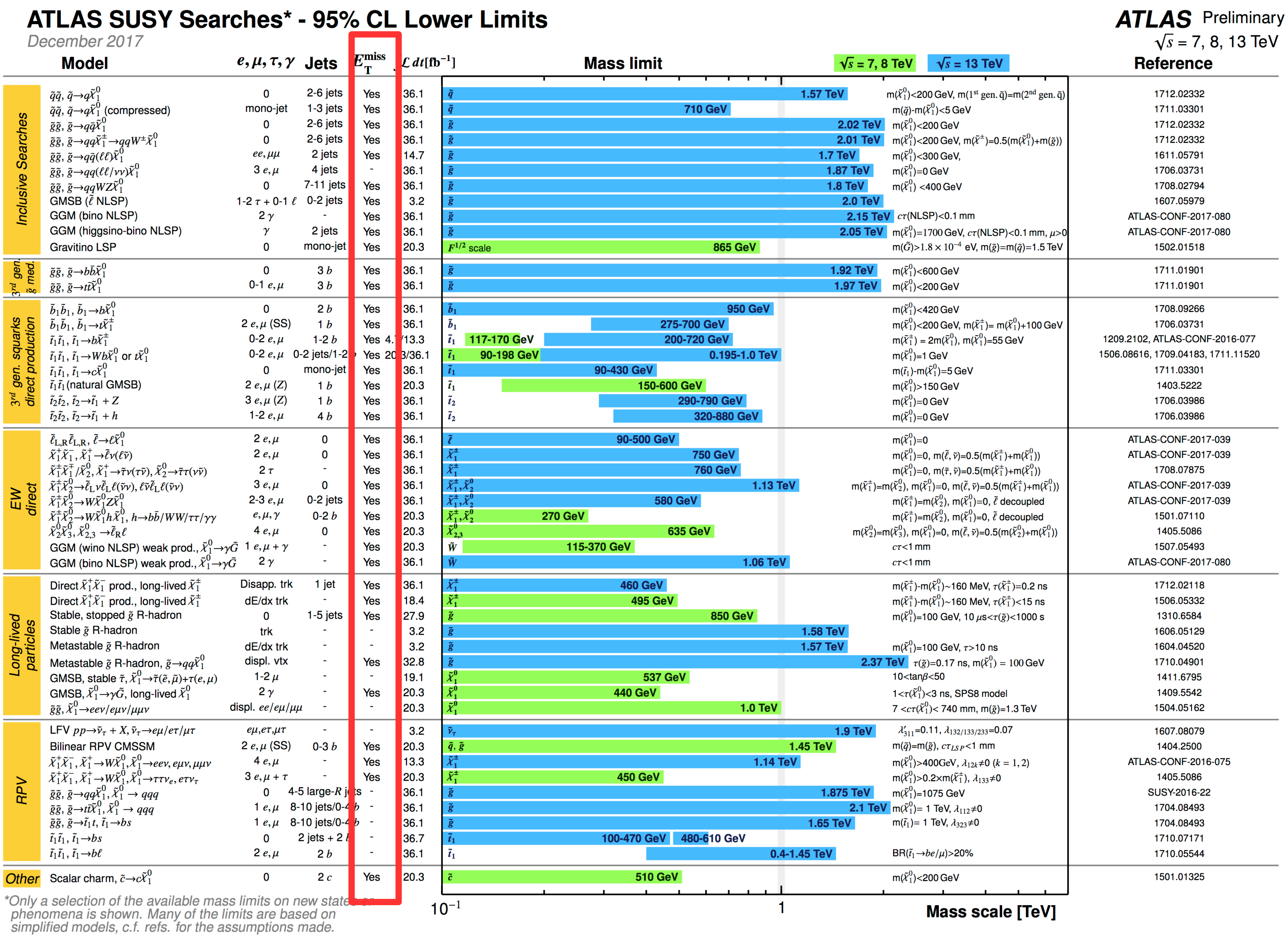


> Pure states → very small DD cross sections

- Gravitino: 'UV freeze in' or superWIMP



Overview SUSY channels



Overview SUSY channels

ATLAS Preliminary
$\sqrt{s}$ = 7, 8, 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$
Inclusive Searches	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	36.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$	2 jets	Yes	14.7
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e, μ	4 jets	-	36.1
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2
	GGM (bino NLSP)	2 γ	-	Yes	36.1
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	36.1
	Gravitino LSP	0	mono-jet	Yes	20.3

Reference
1712.02332
1711.03301
1712.02332
1712.02332
1611.05791
1706.03731
1708.02794
1607.05979
ATLAS-CONF-2017-080
ATLAS-CONF-2017-080
1502.01518
1711.01901
1711.01901
1708.09266
1706.03731
1209.2102, ATLAS-CONF-2016-077
506.08616, 1709.04183, 1711.11520
1711.03301
1403.5222
1706.03986
1706.03986
ATLAS-CONF-2017-039
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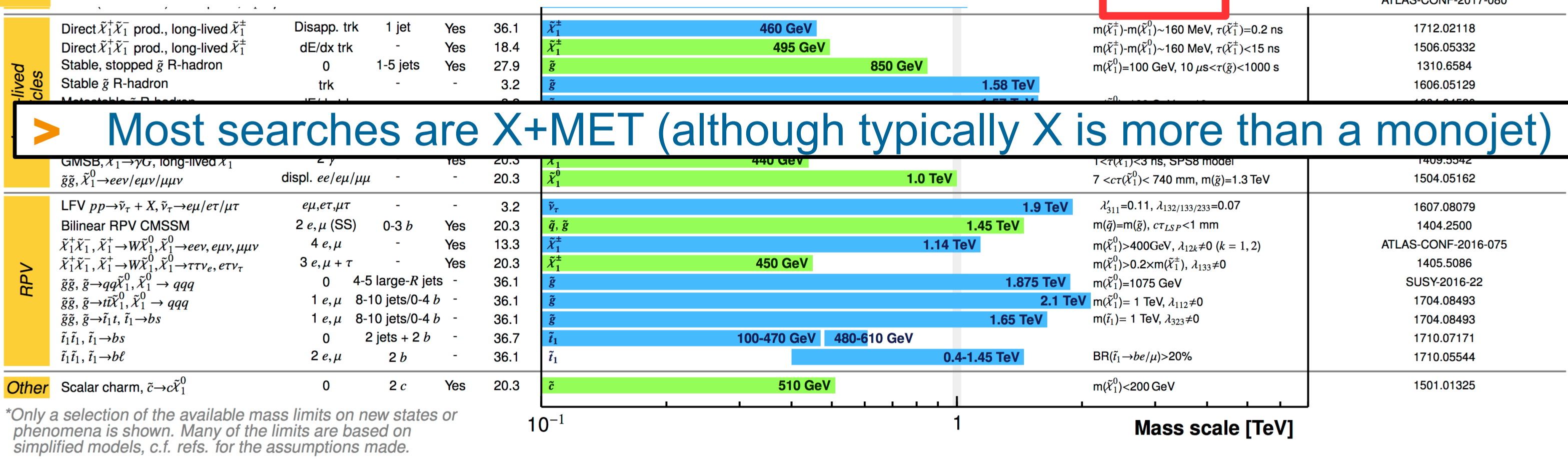
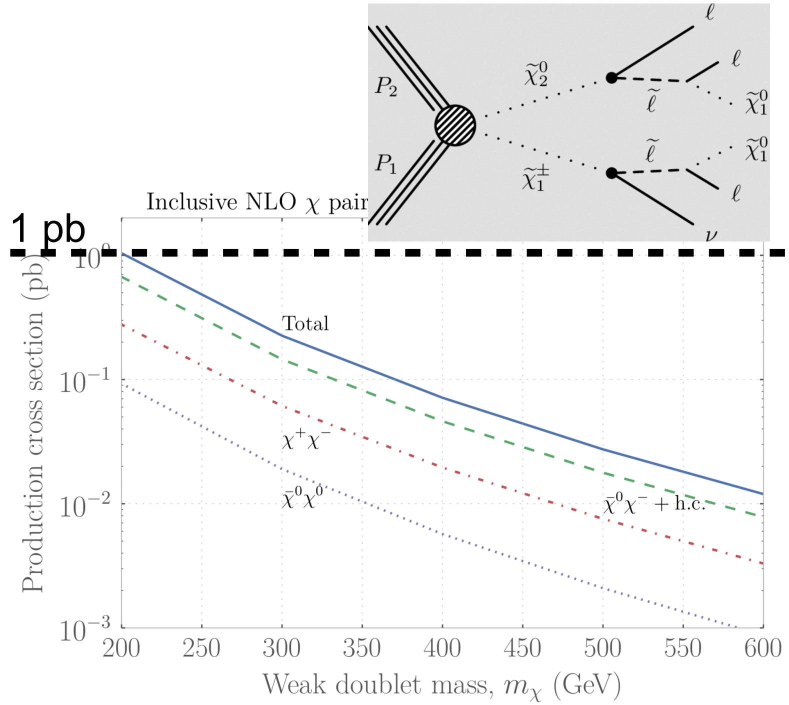
ATLAS-CONF-2017-080



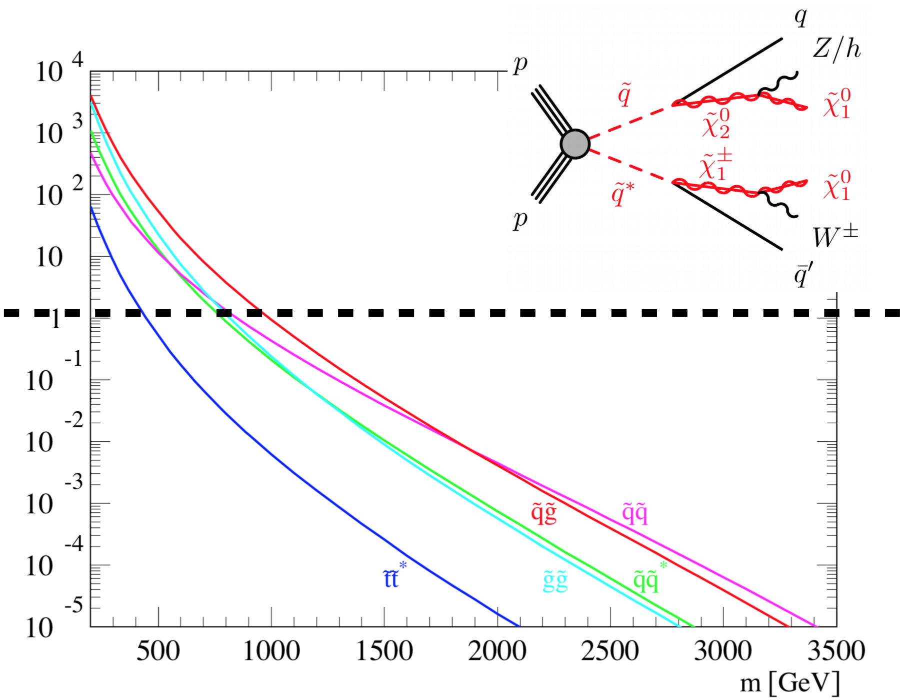
> Most searches are X+MET (although typically X is more than a monojet)

Strong vs EW production

- Monojets for SUSY?
- Direct DM (or electroweakino) production: cross sections too small
- Relevant constraints via strong production (if other particles too soft).



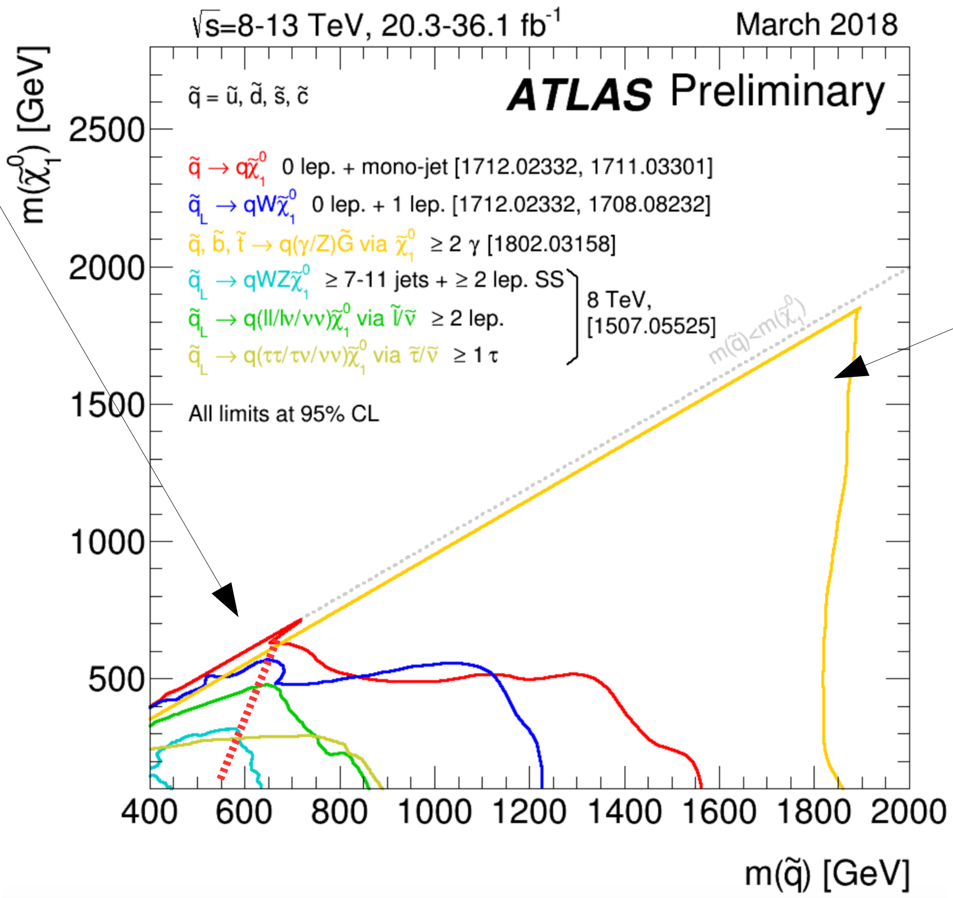
Mahbubani et al, 1703.05327

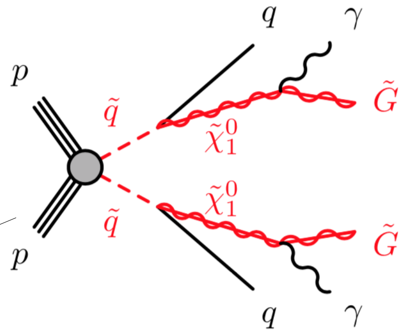


al. et Plehn et al, 1407.5066

Monojets for the MSSM

- Monojets can give the leading constraints for very compressed spectra.





- **Not** the same models (so no 1-1 comparison)!

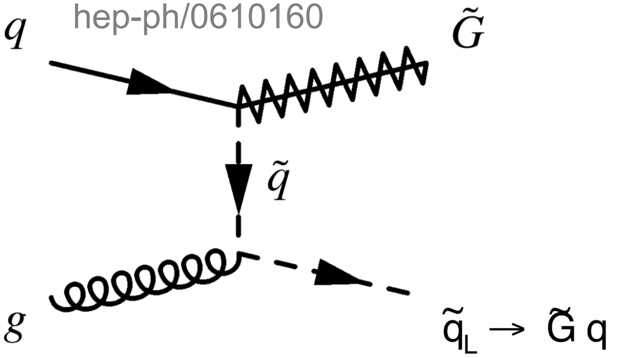
Monojets for the MSSM

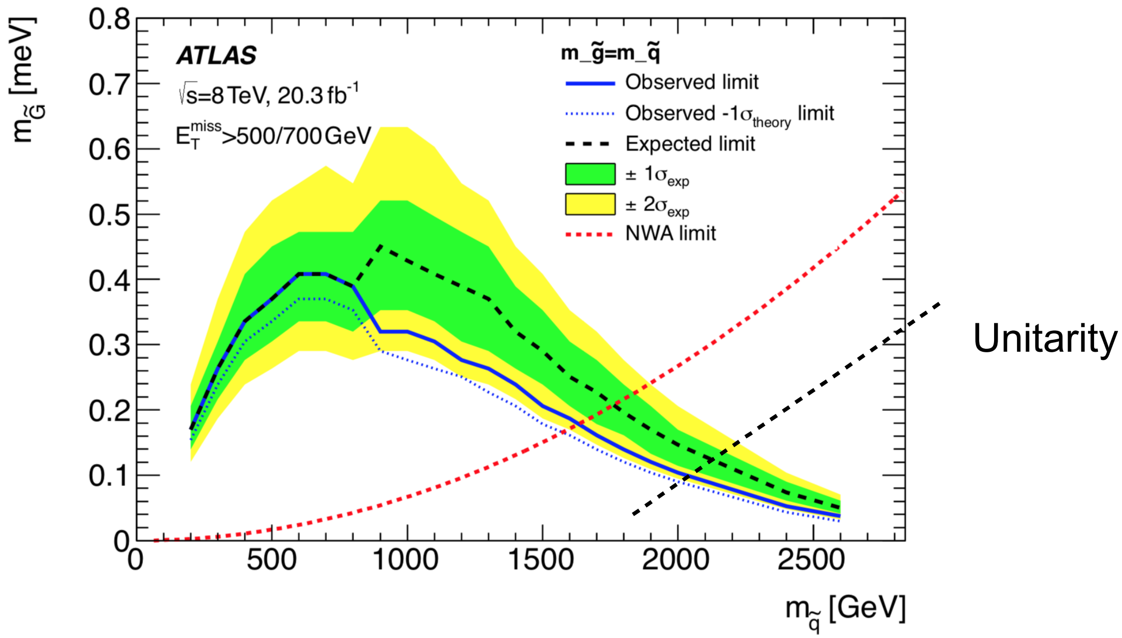
- Monojets also relevant for a very light gravitino LSP (without ISR)

$$\sigma \sim 1/m_{\tilde{G}}^2$$

$$m_{\tilde{G}} \propto F/M_{\rm Pl}$$

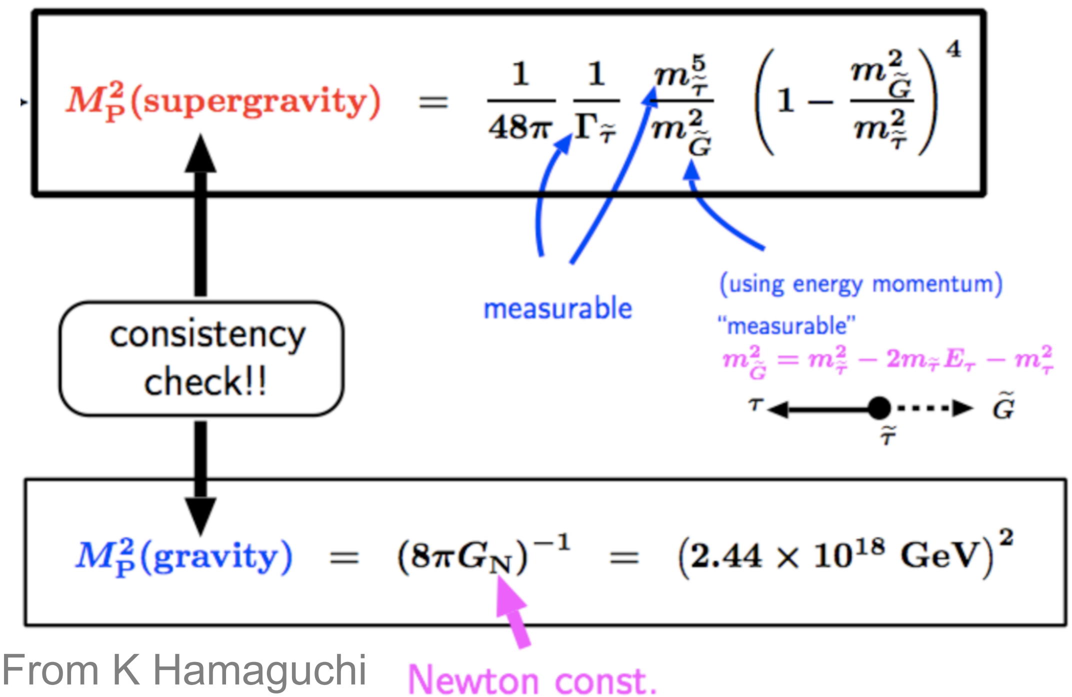
Klasen et al,
hep-ph/0610160



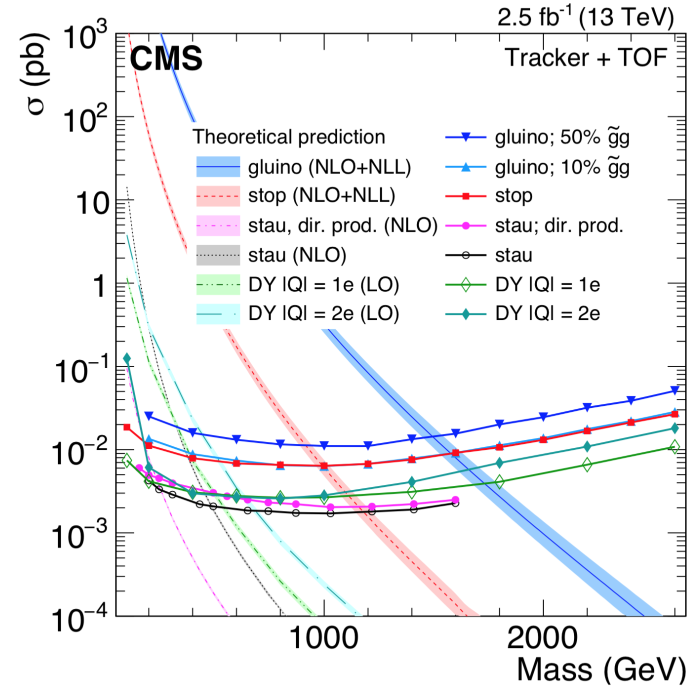


Weak scale gravitino

- Dark matter production may also happen completely **without large MET**
- Consider a heavier gravitino → very weakly coupled
- NLSP can be charged (e.g. stau) and have very long lifetime
- Collider signature: **'stable', charged, massive particles** (no MET)

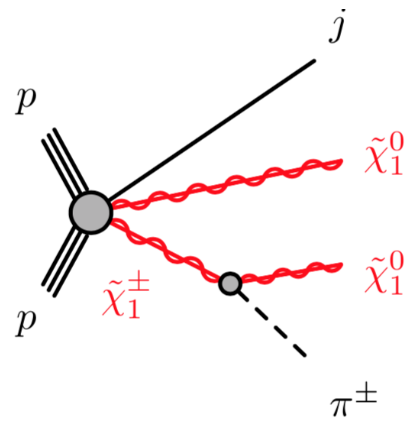


From K Hamaguchi

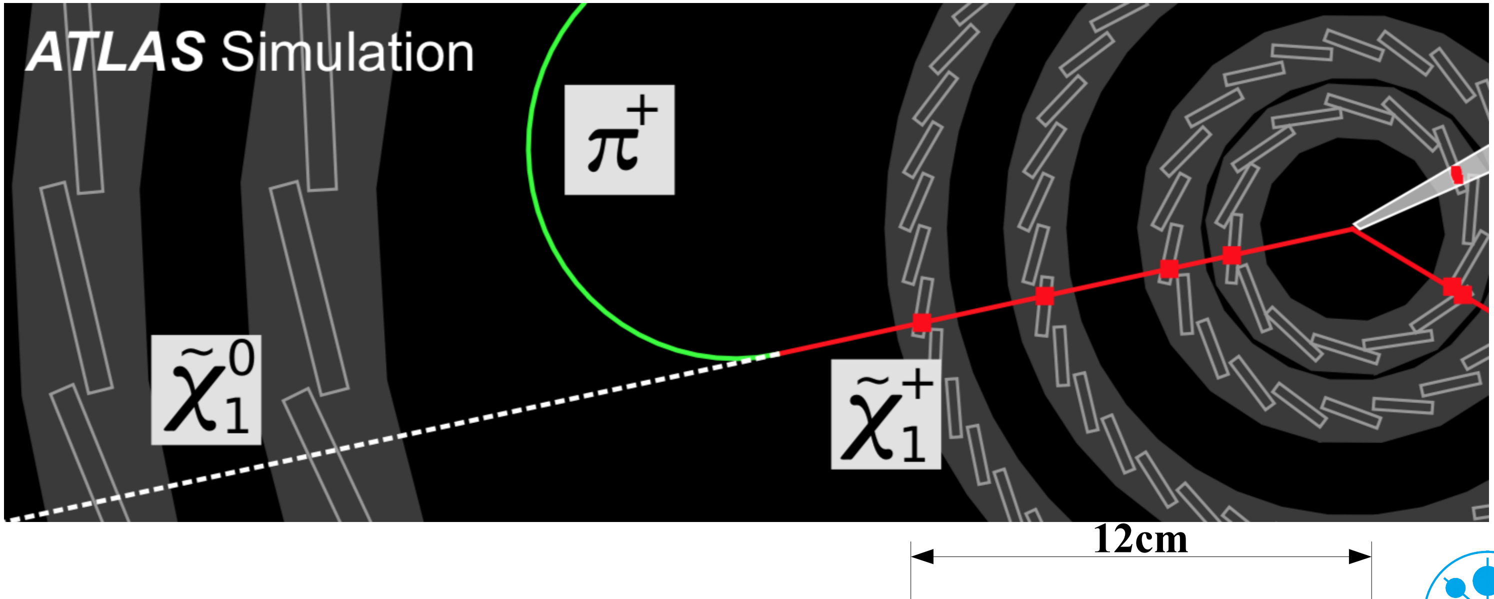


Higgsino/Wino dark matter

- Direct Electroweakino production?

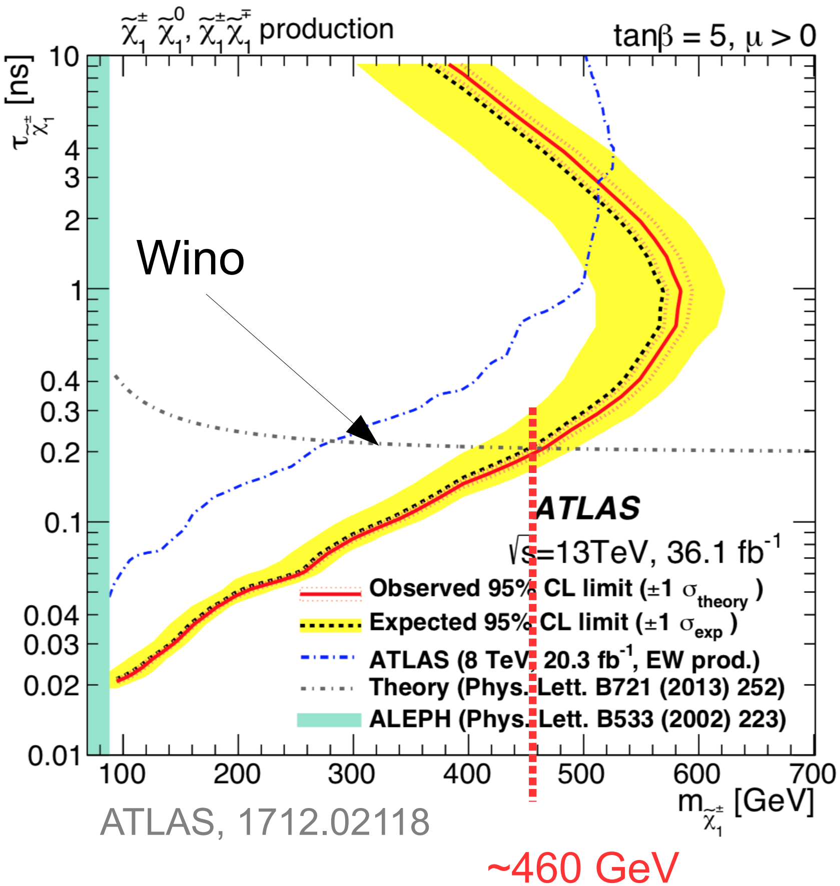


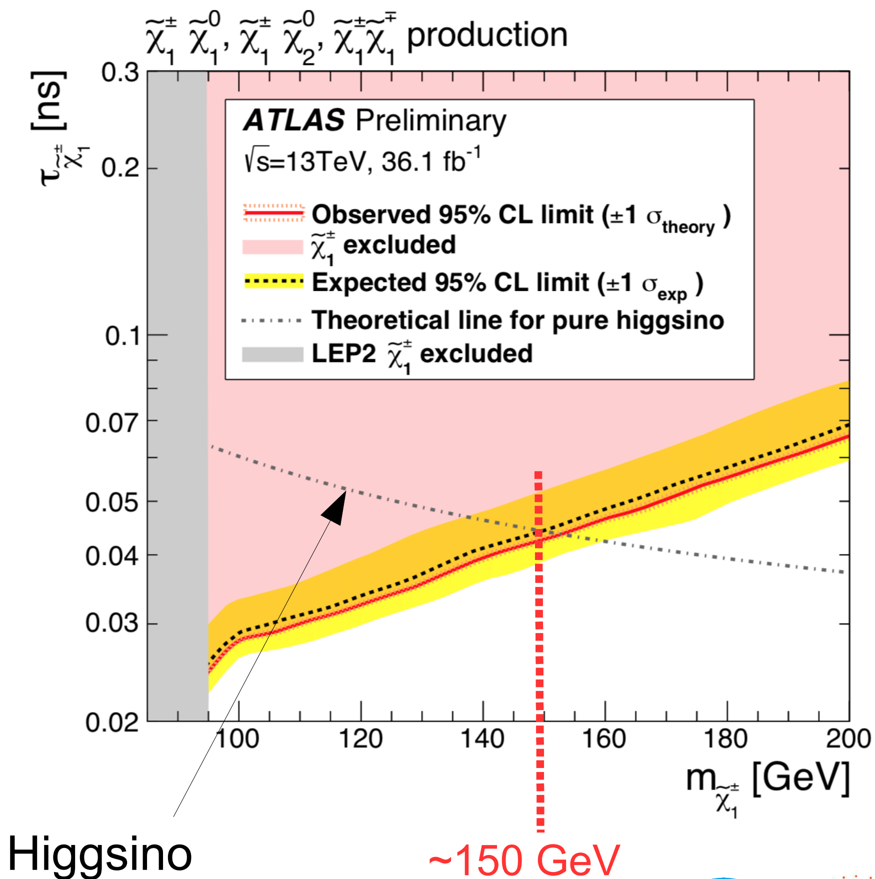
- Dark matter state accompanied by nearly degenerate charged state (chargino)
- Long lifetime (few cm) due to small mass splitting! → disappearing charged tracks!



Higgsino/Wino dark matter

- Relevant constraints for Winos (Δm~160 MeV → 6 cm)
- Higgsinos have larger mass splitting (Δm~350 MeV → 0.7 cm)

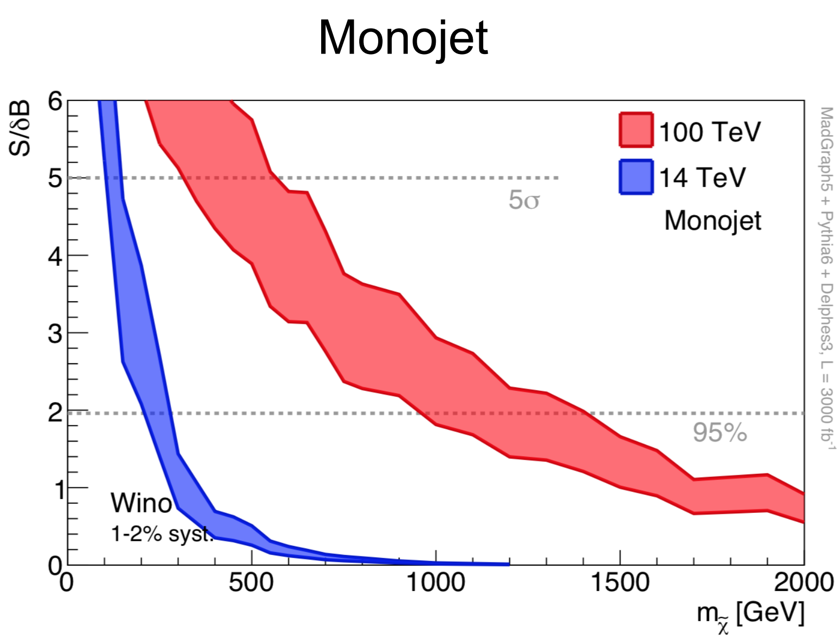


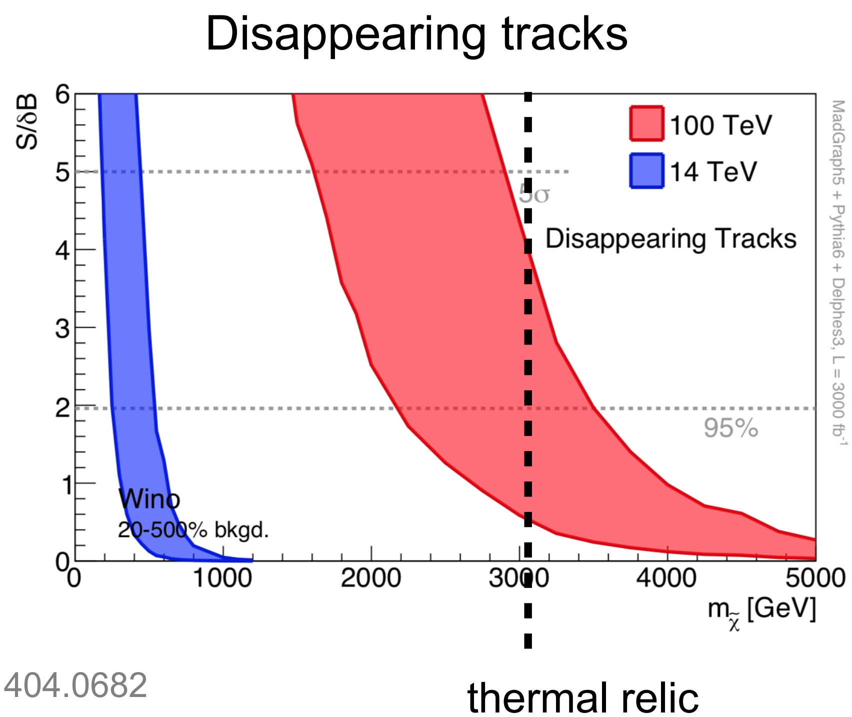


Higgsino/Wino dark matter – the future

- Good prospects for discovery at 100 TeV collider (higher boosts → longer tracks)

Wino





Low et al., 1404.0682

Higgsino/Wino dark matter – the future

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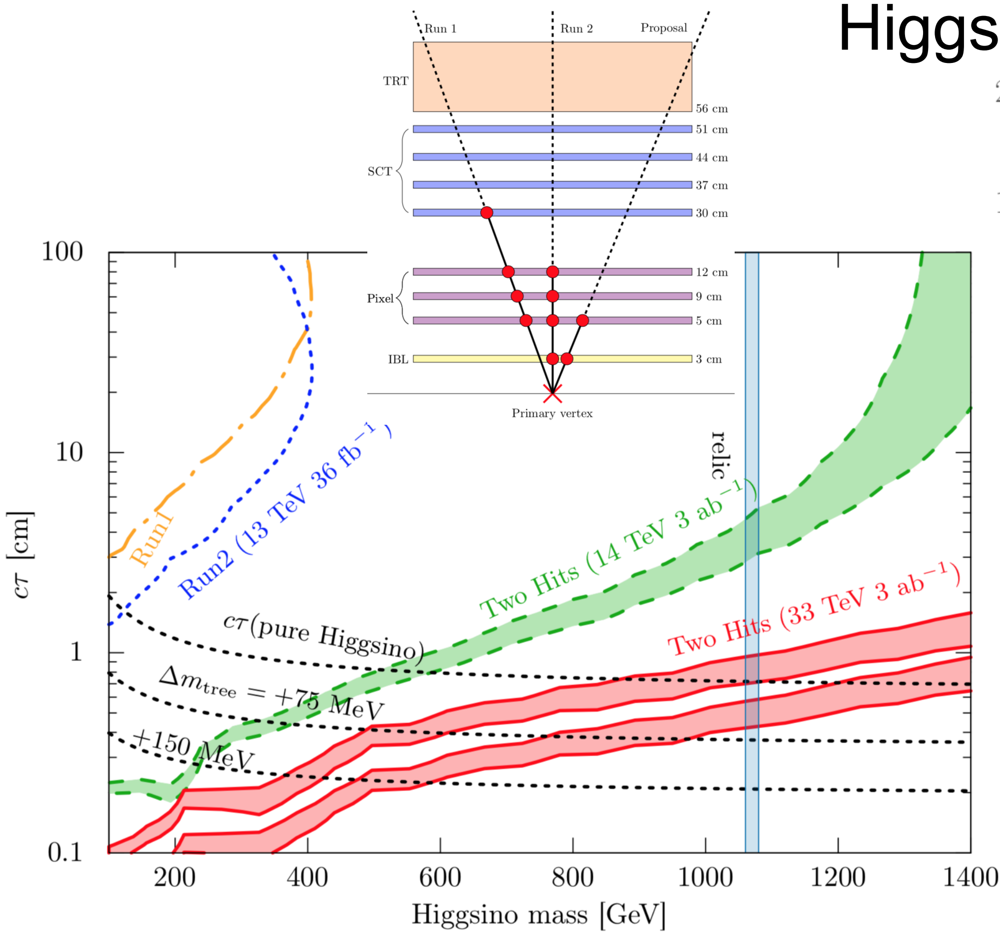
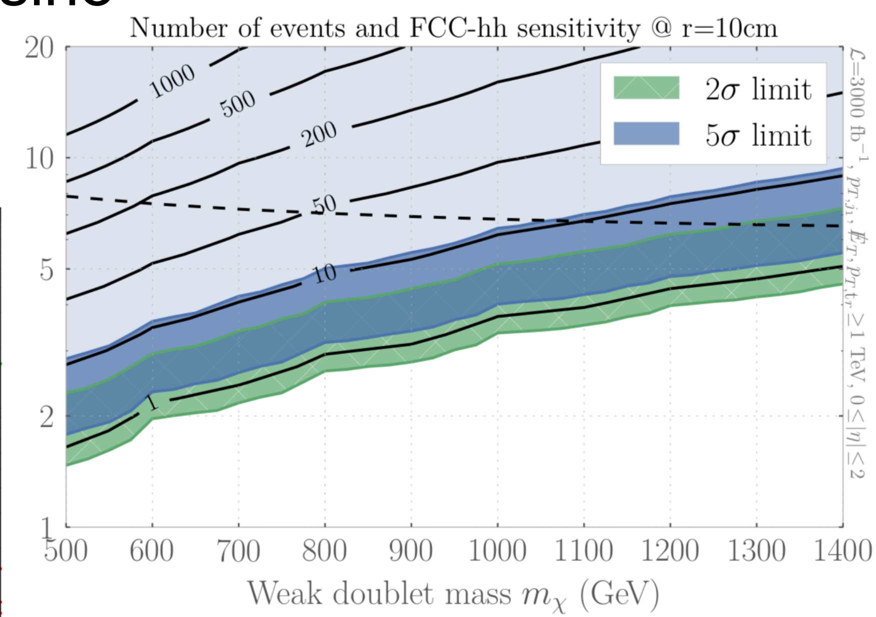


Higgsino



Mahbubani et al, 1703.05327

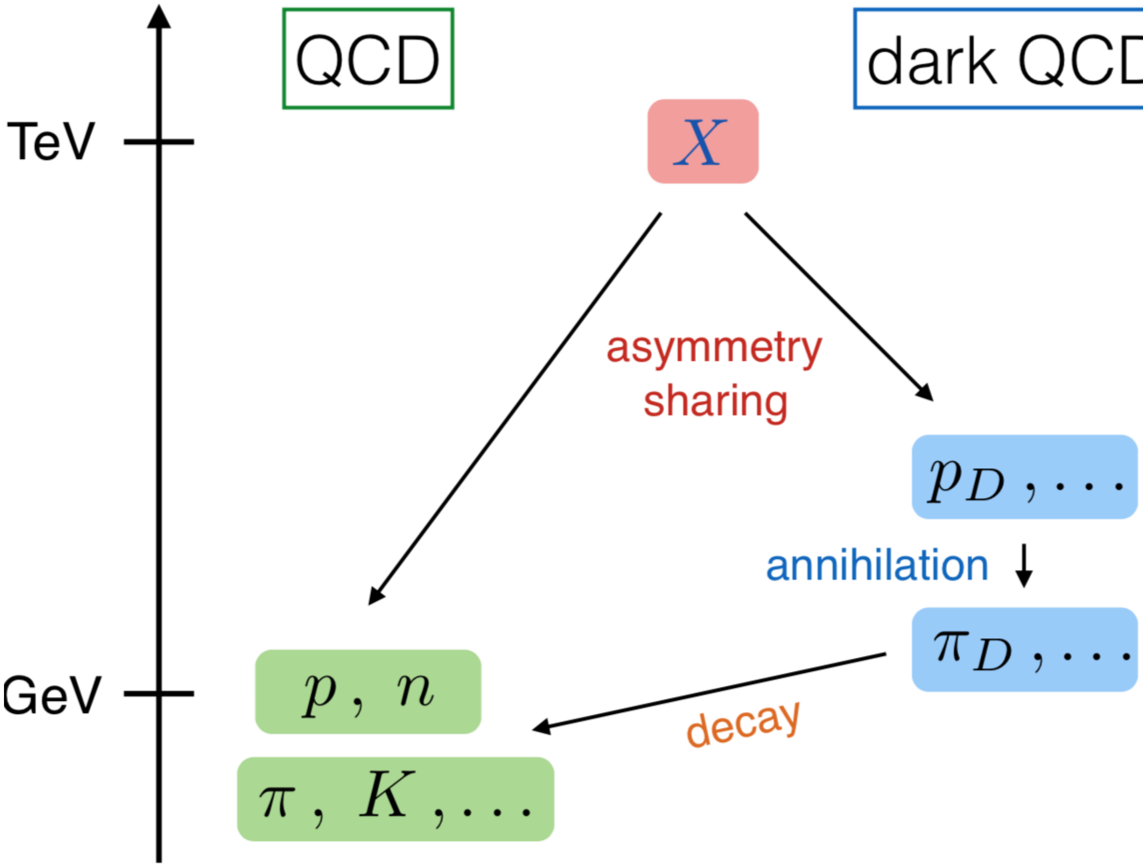
Fukada at al, 1703.09675

Other signatures

Slide from P Schwaller
→ Kathryn Zurek's talk

Hidden valley idea by
Strassler & Zurek

Dark QCD



- SU(N) dark sector with neutral "dark quarks"
- Confinement scale

  $\Lambda_{\mathrm{darkQCD}}$

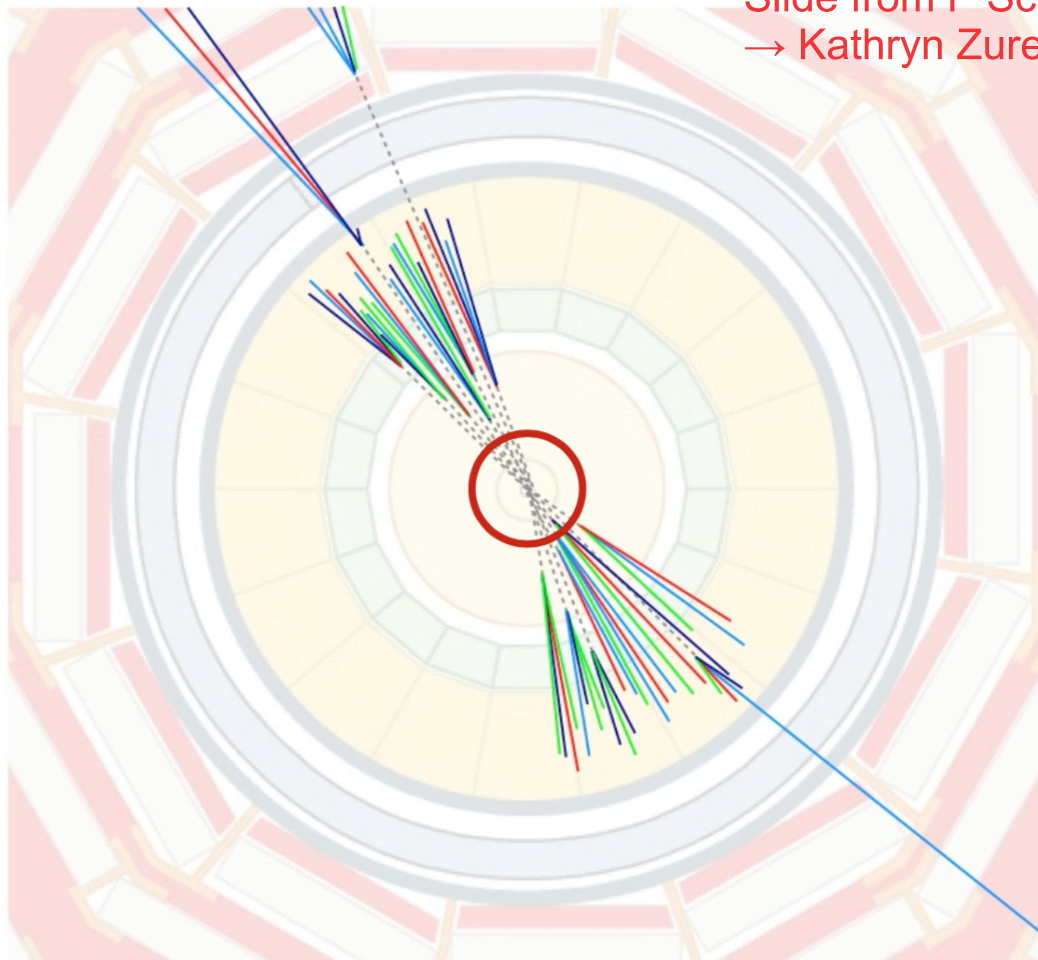
- DM is composite "dark proton"
- "Dark pions" unstable, long lived

Other signatures

Emerging Jets at the LHC

Slide from P Schwaller
→ Kathryn Zurek's talk

- Production of mediator, decay to dark quarks
- Characteristic:
  - few/no tracks in inner tracker
- New “emerging” jet signature
- Smoking gun of composite hidden sectors



PS, Stolarski, Weiler, 2015

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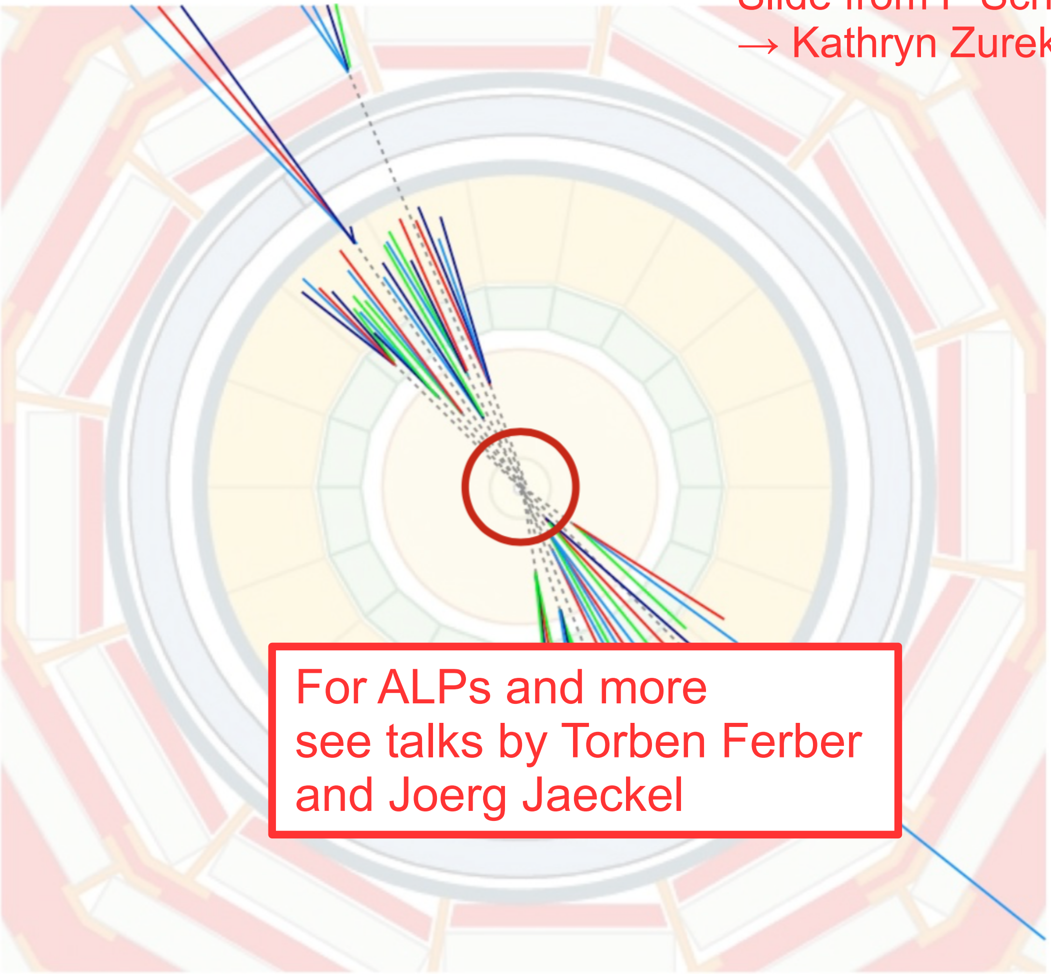


For ALPs and more
see talks by Torben Ferber
and Joerg Jaeckel

PS, Stolarski, Weiler, 2015

Conclusion

IR

✔ Mono-X rather model independent signature

✗ May not give the leading constraint – i.e. DM may be discovered in a different channel (hopefully!!!)

✗ Some DM models don't feature Mono-X at all

UV

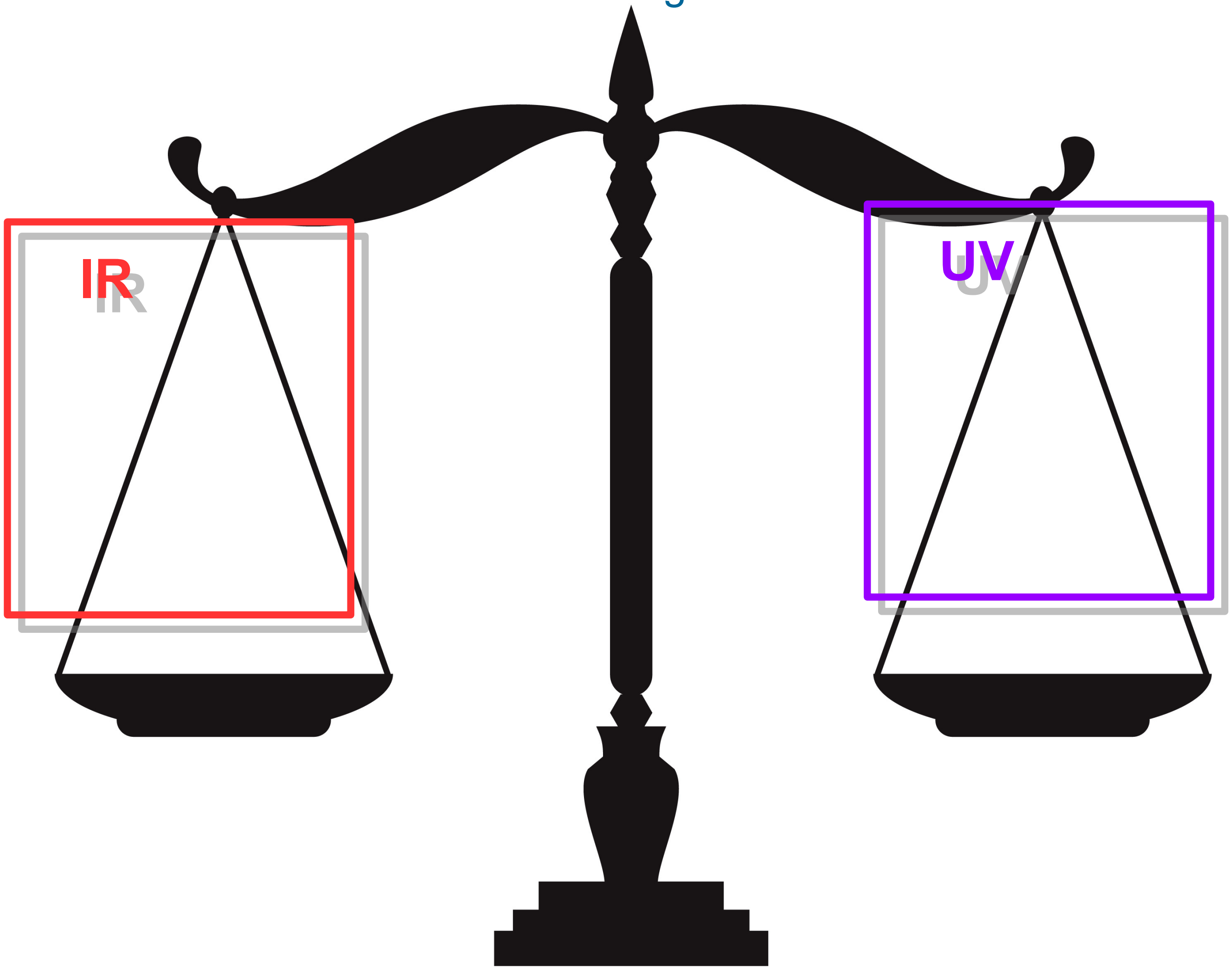
✔ Well-motivated signatures

✔ Study of consistent UV theories may reveal signature which hasn't been thought of

✗ Very model-dependent

Conclusion

Which then should we choose: the generic or the realistic?



Conclusion

Which then should we choose: the generic or the realistic?