Mono-X Signals from Initial States and Decays

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based on

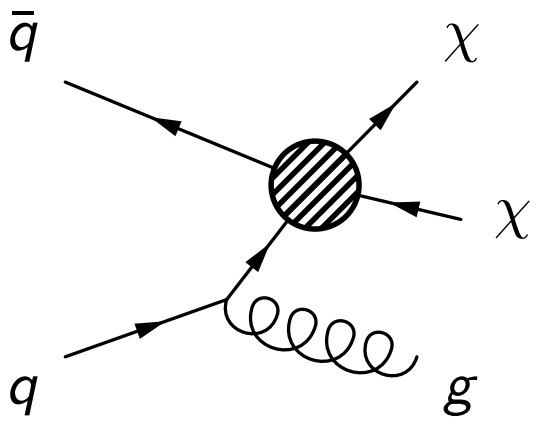
Actual Physics behind Mono-X

EB, J. Horak, T. Plehn, A. Butter [1805.11637]

31 May 2018

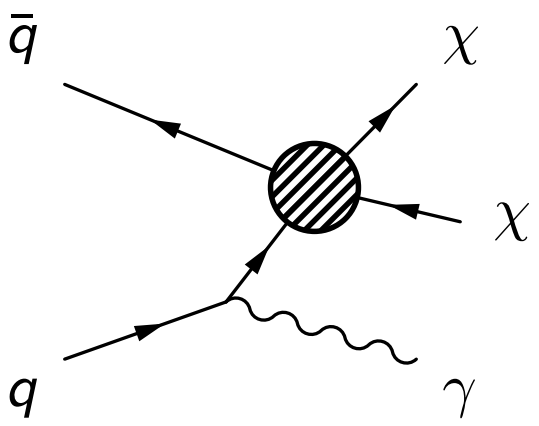
Motivation: Mono-X Initial State Radiation

mono-jet



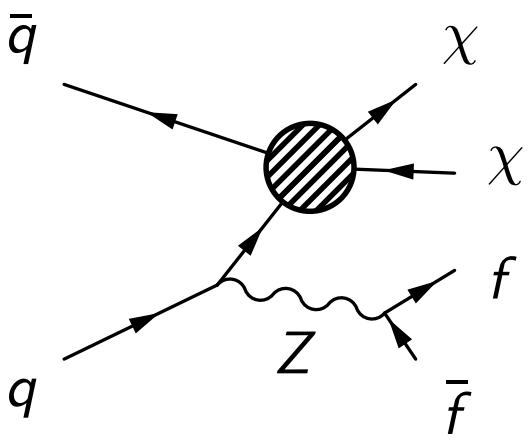
$\sigma_{\chi\chi j} \sim C_F \alpha_S$

mono-photon



$\sigma_{\chi\chi\gamma} \sim Q_q^2 \alpha$

mono-Z



$\sigma_{\chi\chi Z} \sim Q_q^2 s_W^2 \alpha \times \mathrm{BR}(Z \to \ell^+\ell^-)$

$$1 \quad : \quad \frac{1}{40} \quad : \quad 10^{-4}$$

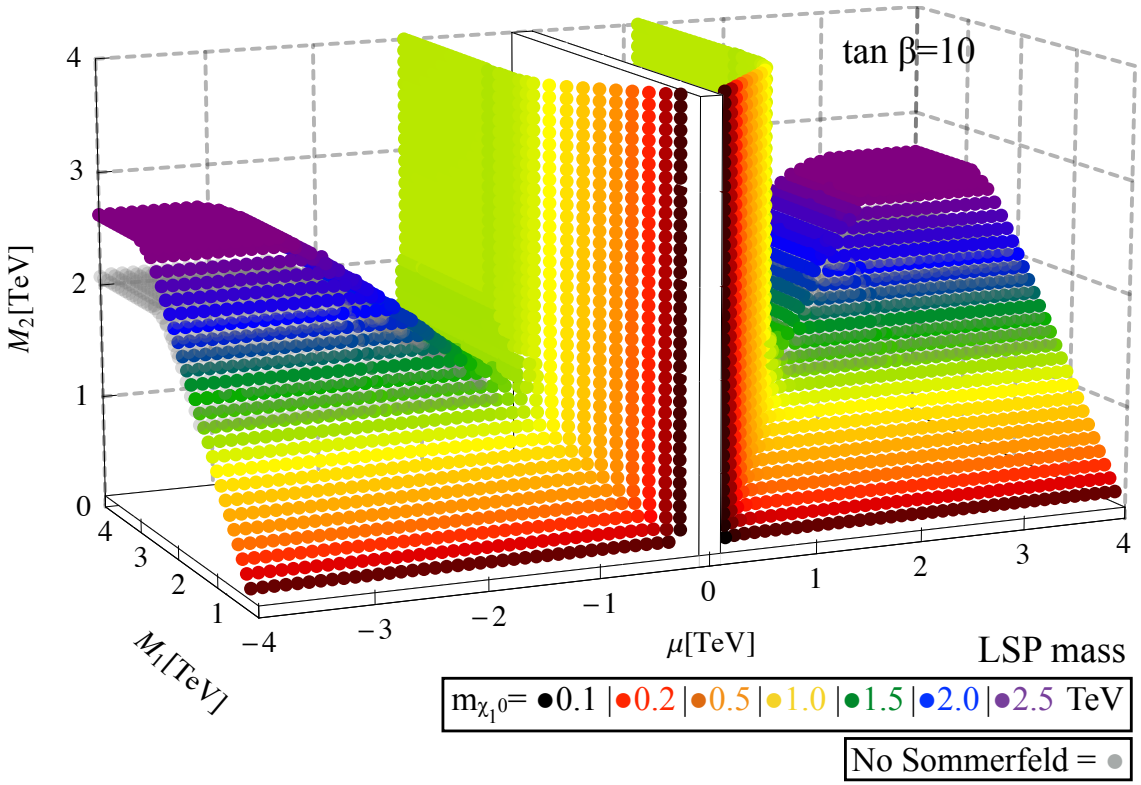
SUSY as toy model

- Consider final state decays for mono-Z, mono-Higgs etc.
- MSSM as WIMP framework

- Electroweakinos encompass
  - singlet (bino)
  - doublet (higgsino)
  - triplet (wino)

  under $SU(2)_L$
- with general mixing

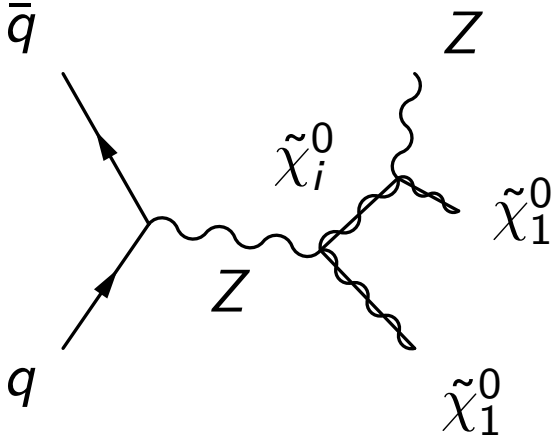
$\Rightarrow$ bino-higgsino LSP



Bramante et al. [1510.03460]

Mono-Z topologies

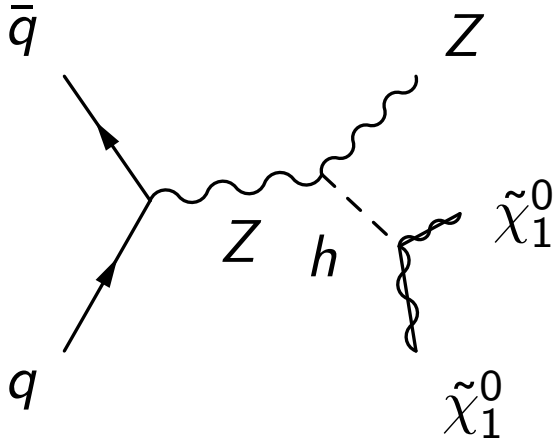
Neutralino decay



$\propto g^2_{Z\tilde{\chi}_i^0\tilde{\chi}_1^0}$

higgsino-higgsino

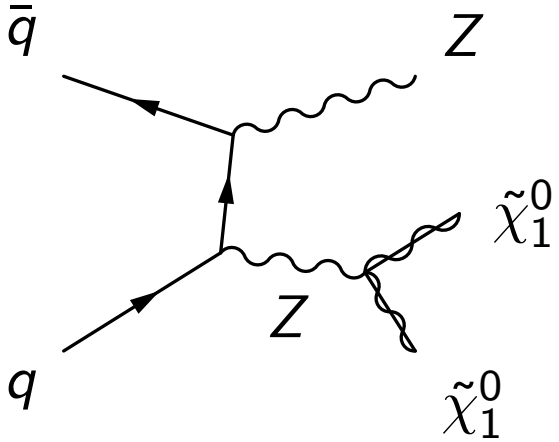
Zh production
(with h portal)



$\propto g_{h\tilde{\chi}_1^0\tilde{\chi}_1^0}$

bino-higgsino

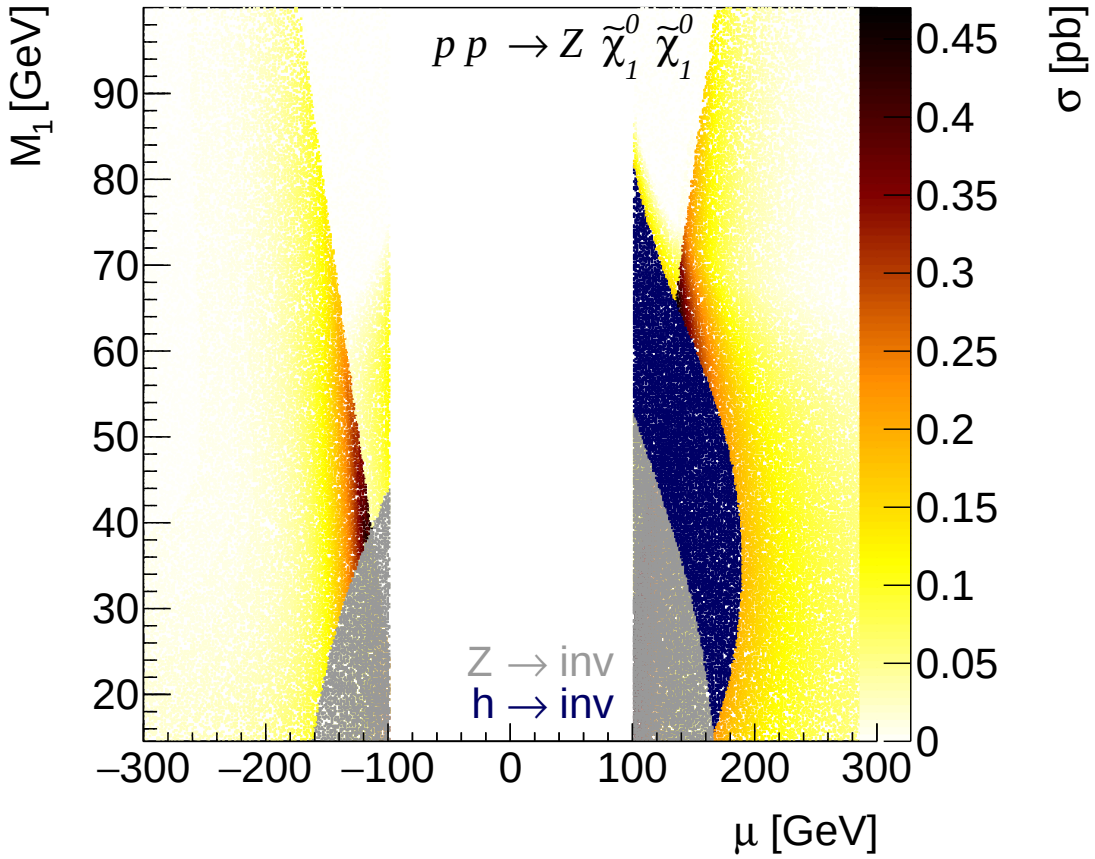
ISR
(with Z-portal)



$\propto g_{Z\tilde{\chi}_1^0\tilde{\chi}_1^0}$

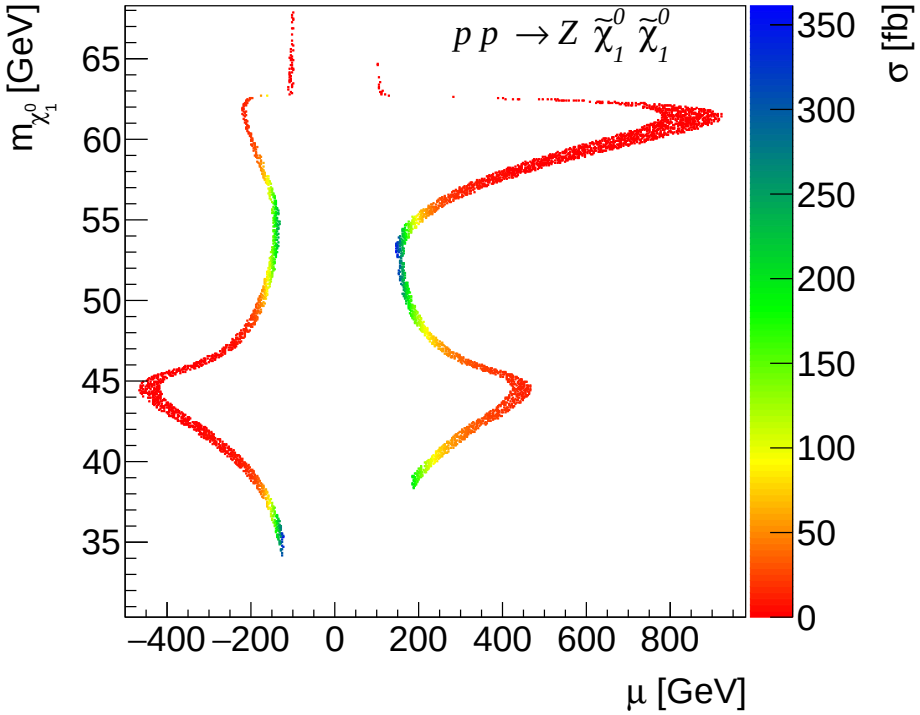
higgsino-higgsino

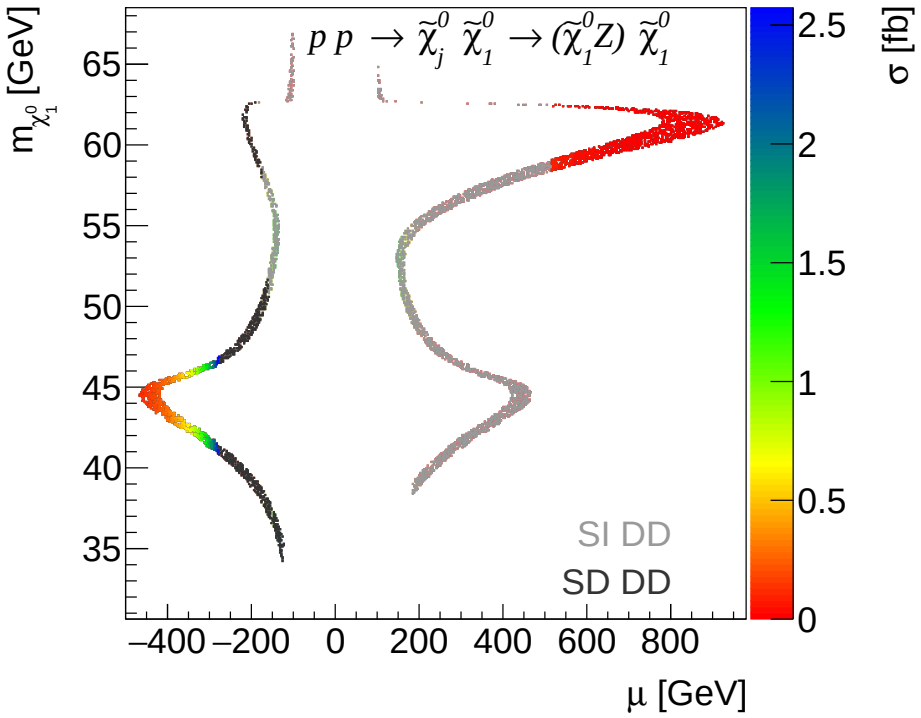
Mono-Z cross section & invisible limits



- LEP limits on $m_{\tilde{\chi}^\pm}$ and $\Gamma_{Z\to inv}$ constrain higgsino portion in LSP
- $h \to inv$: important additional limit constraining bino-higgsino mix
- $\sigma_{\max} \approx 0.5\ \mathrm{pb}$ mostly from $\tilde{\chi}^0_{2,3}$ decay

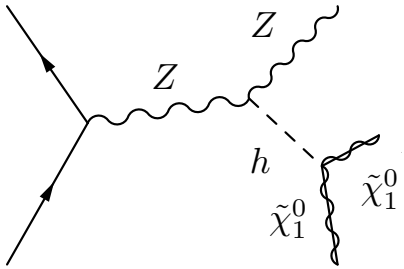
Relic density and direct detection

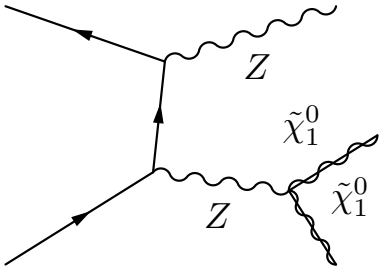


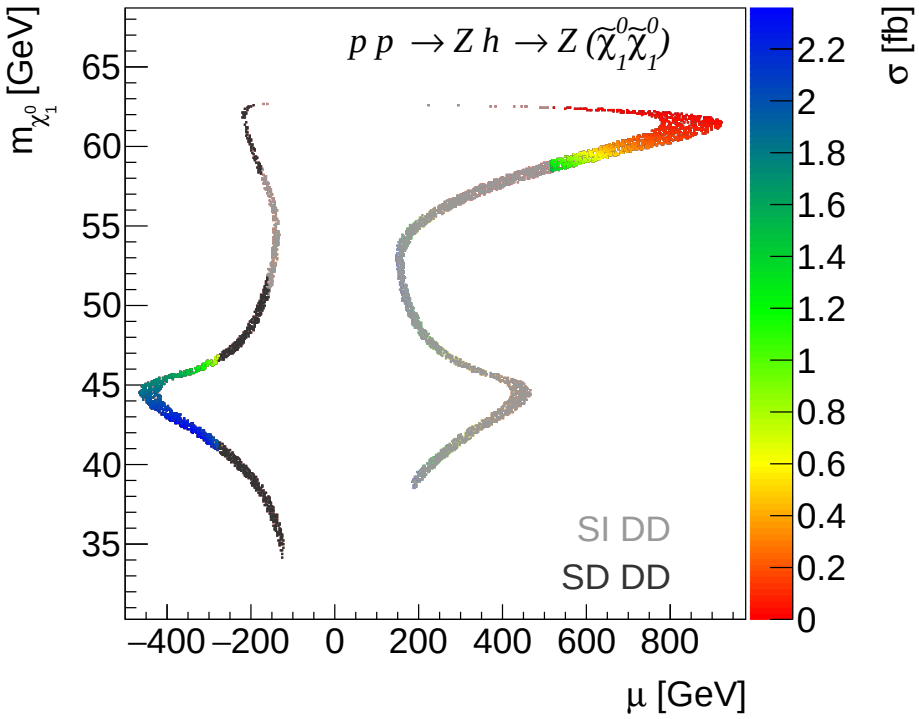


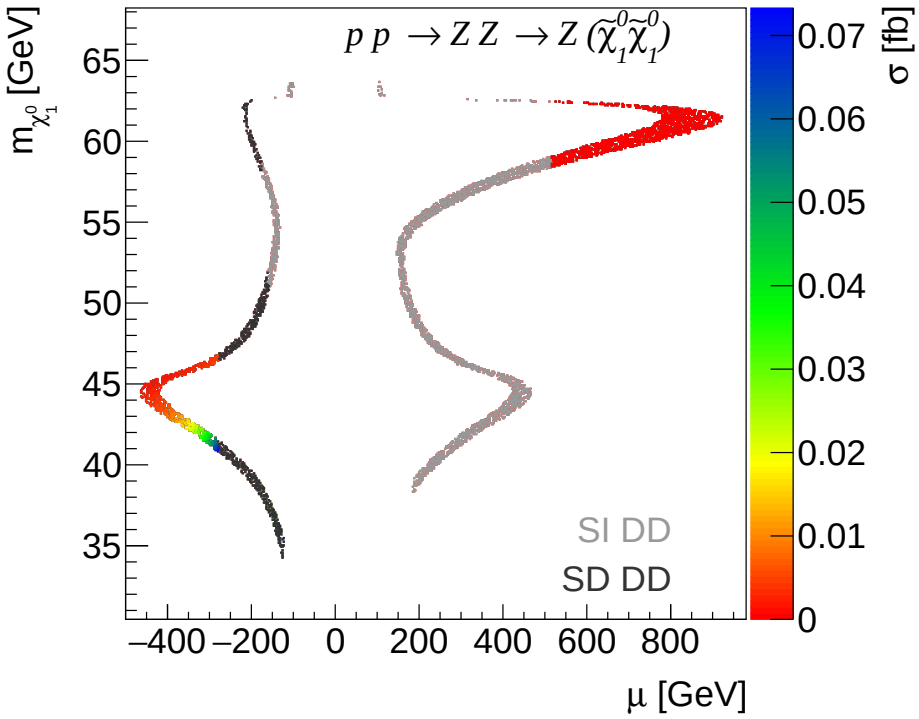
- Z and Higgs s-channel annihilation can give correct relic density
- couplings $g_{h\tilde{\chi}_1^0\tilde{\chi}_1^0}$ and $g_{Z\tilde{\chi}_1^0\tilde{\chi}_1^0}$ highly constrained by direct detection
  - $\rightarrow$ push LSP mass very close to Z and h poles

Zh and Z-ISR topologies





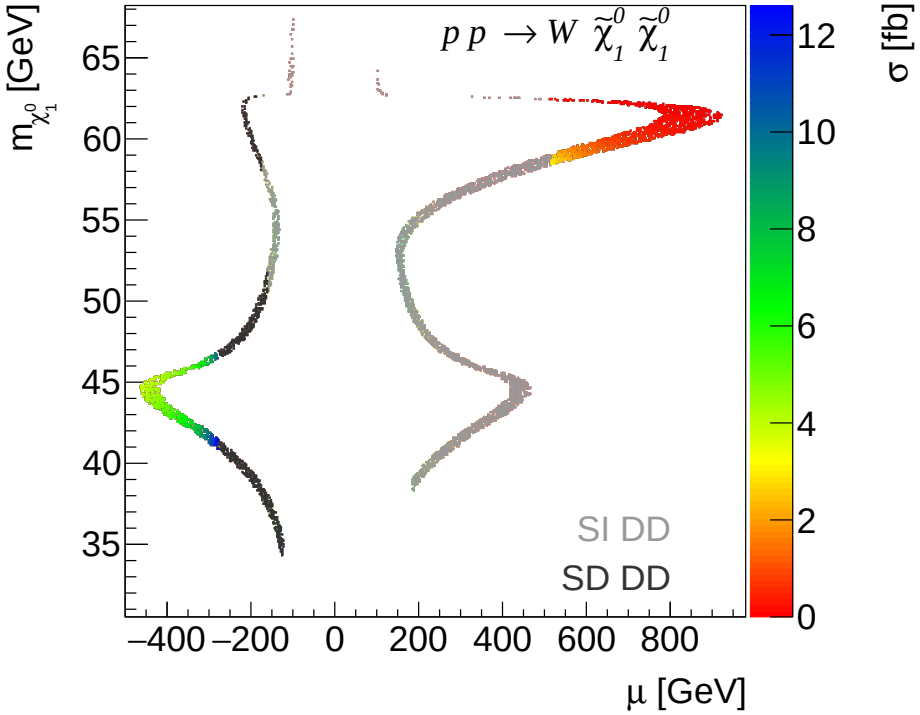


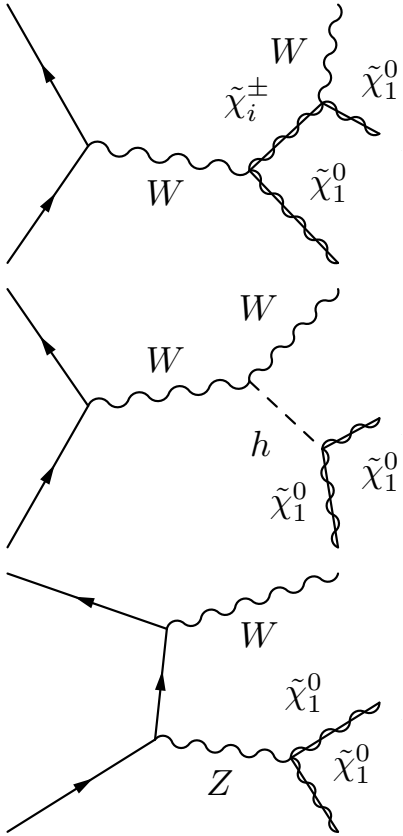


Zh represents a leading contribution

Z-ISR is negligible

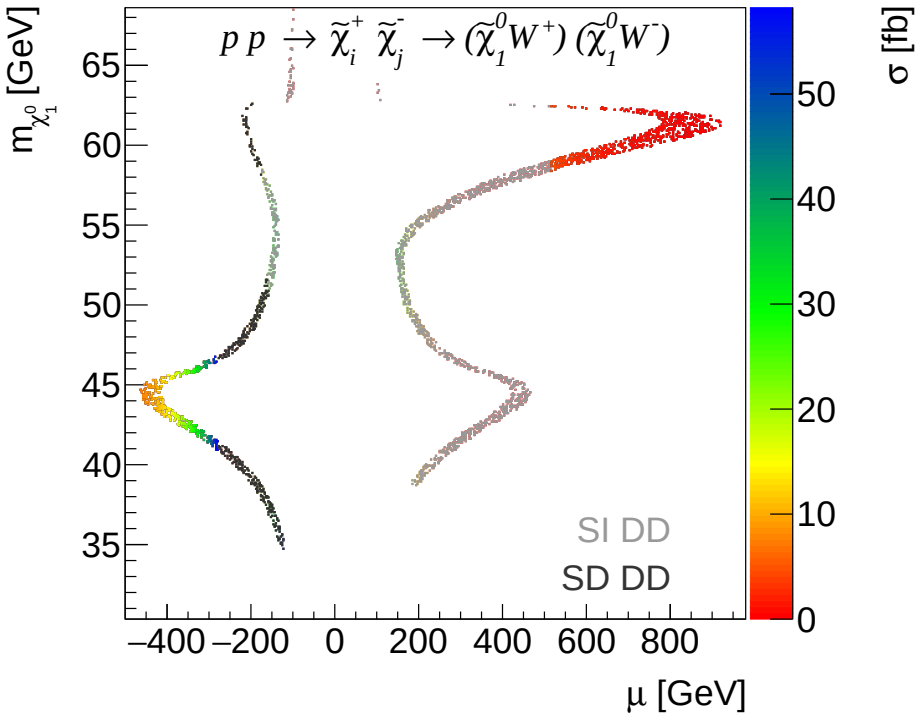
Mono-W

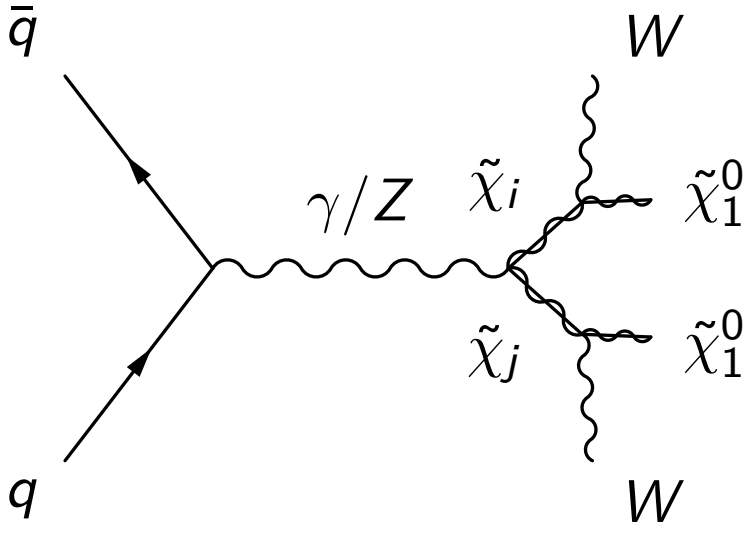




- Mono-W topologies analogous to mono-Z
- Mono-W rates larger than mono-Z rate (in contrast to EFT arguments)

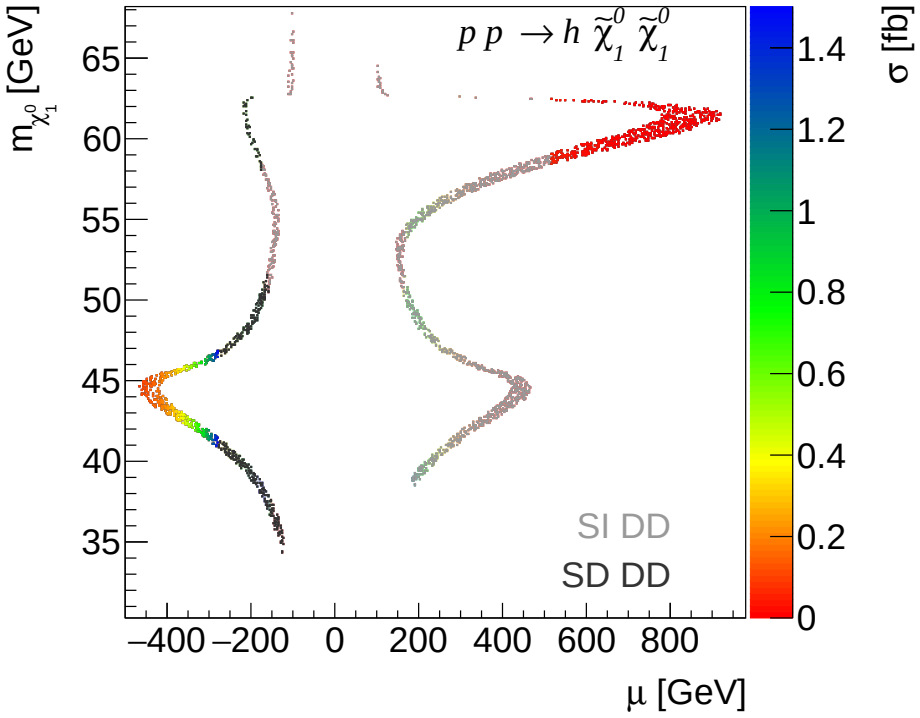
Mono-W pairs

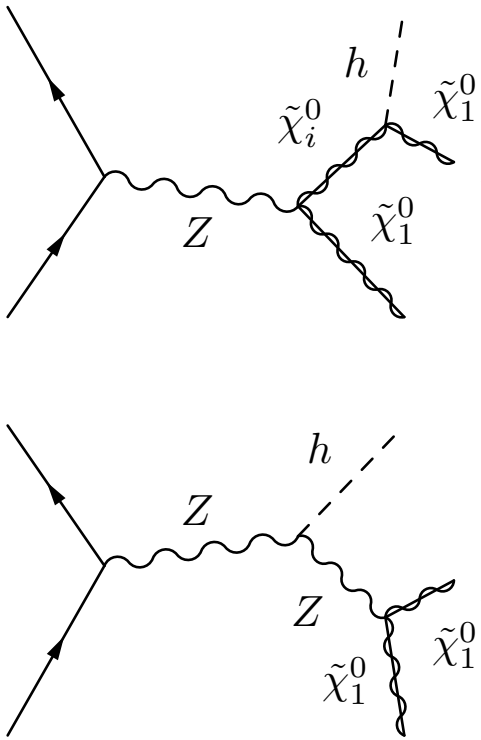




- Chargino pair production decoupled from direct detection (except for higgsino mass)
- Larger rates than for mono-W production
- Pair contribution to mono-W is removed if jet/lepton veto is used

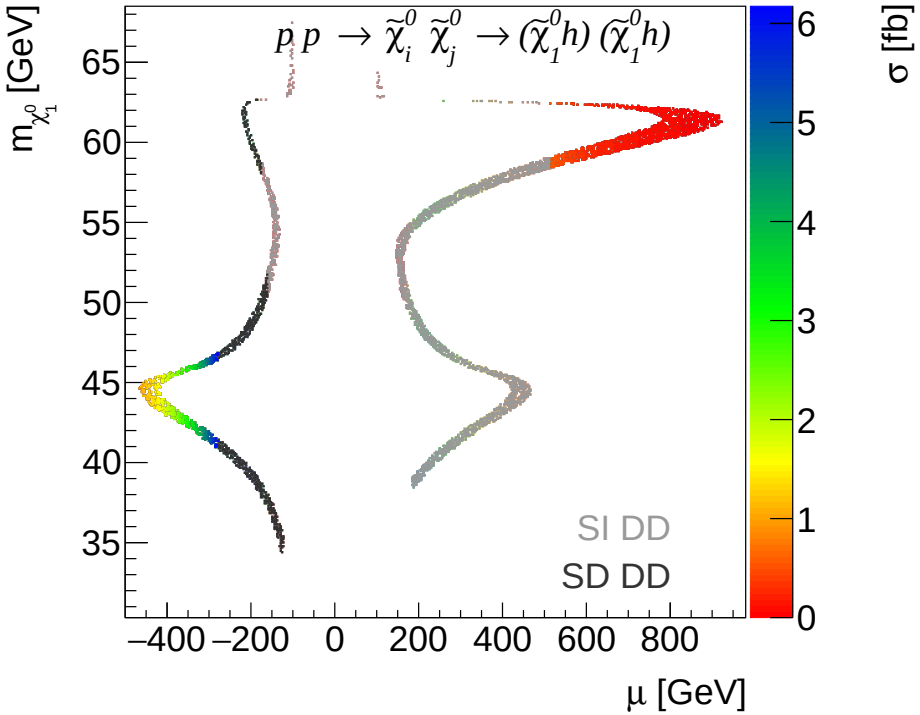
Mono-Higgs

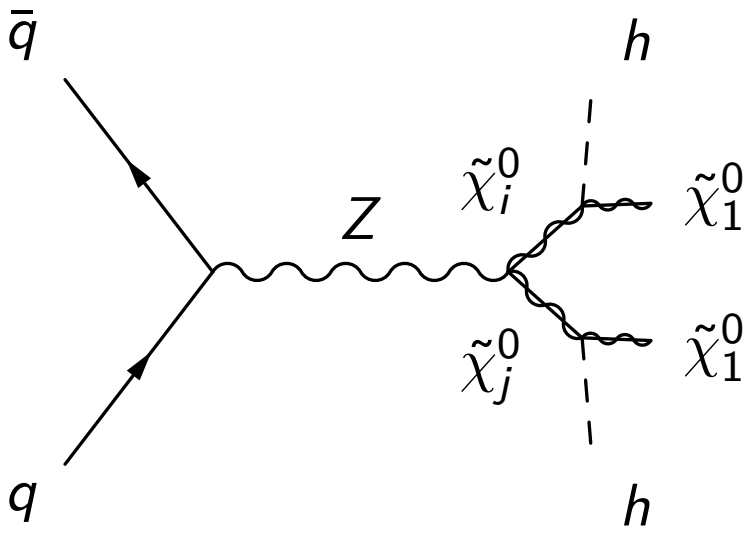




- cross section small to begin with, $\lesssim 40\ \mathrm{fb}$
- with relic density + DD constraints: tiny cross section

Better idea: Mono-Higgs pairs





- cross section small: production of two heavy neutralinos $\times \mathrm{BR}^2$
- but couplings not constrained by direct detection
- analysis currently under study
- remaining constraint: Z / Higgs pole condition for relic density

$\Rightarrow$ go beyond MSSM

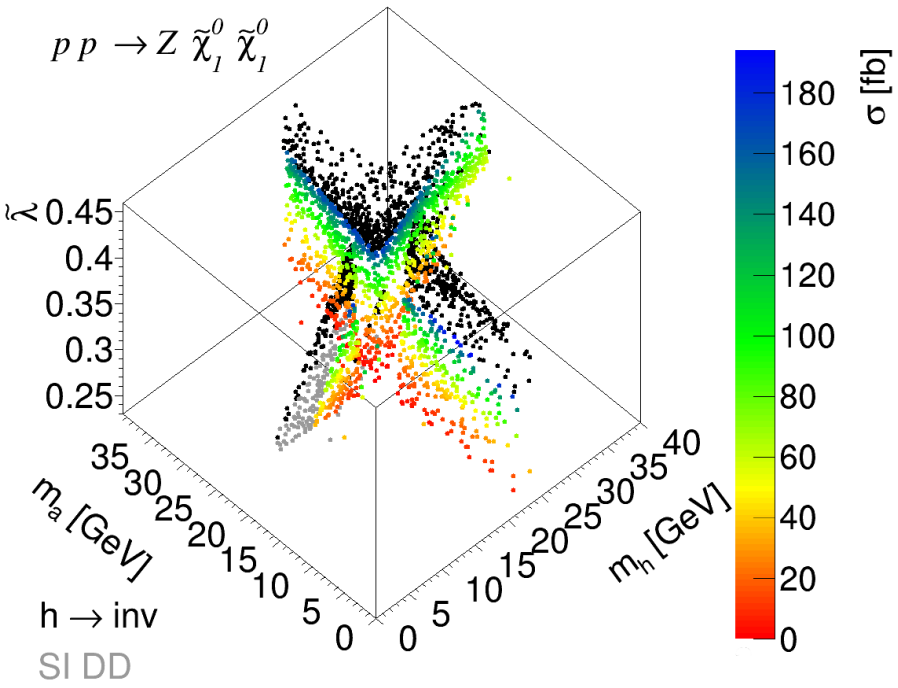
Final state decays beyond the MSSM

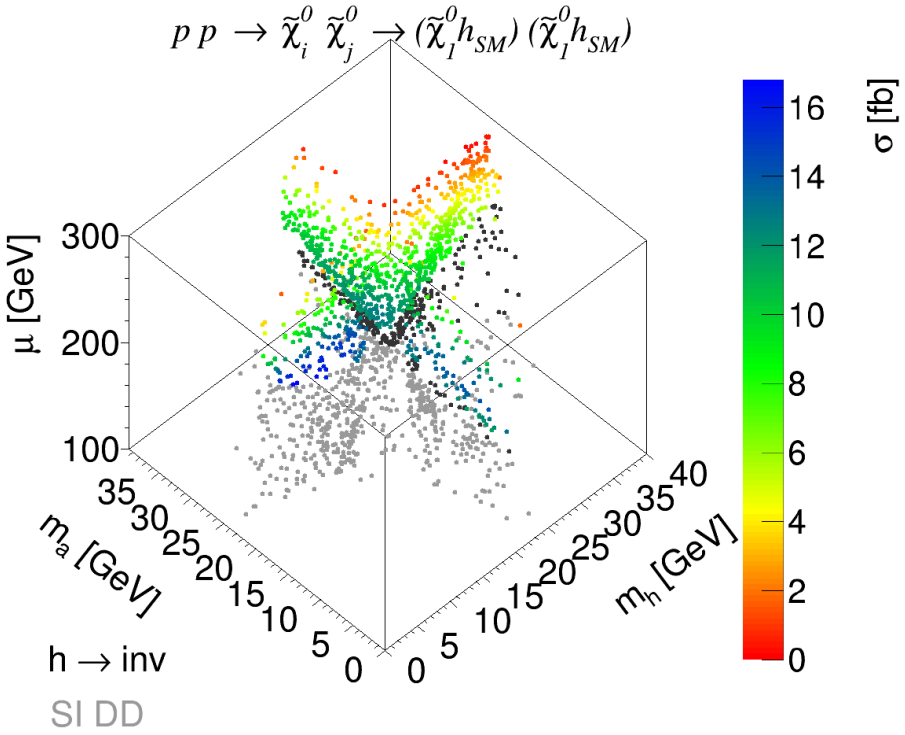
NMSSM:

- additional light scalar and pseudoscalar annihilation channels
- structurally similar to 2HDM + a, but also including a light scalar
- efficient annihilation also for light ($\lesssim 10\ \mathrm{GeV}$) singlino-like DM
  $\rightarrow$ DD bounds much weaker

- much larger $\mathrm{BR}\,(h \rightarrow inv)$ possible since not suppressed by direct detection [Butter et al. ,1507.02288]

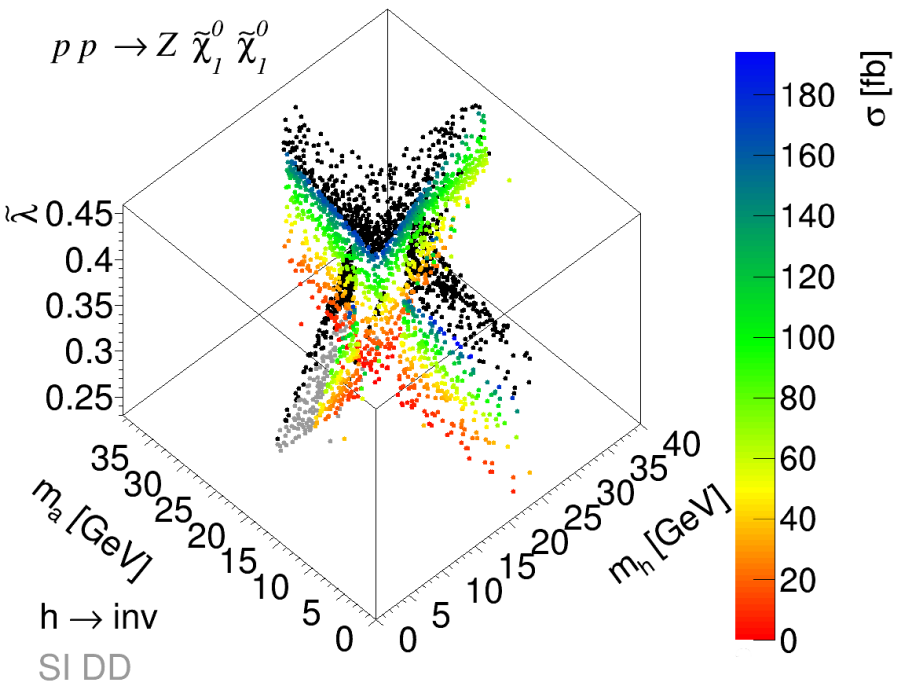
NMSSM annihilation

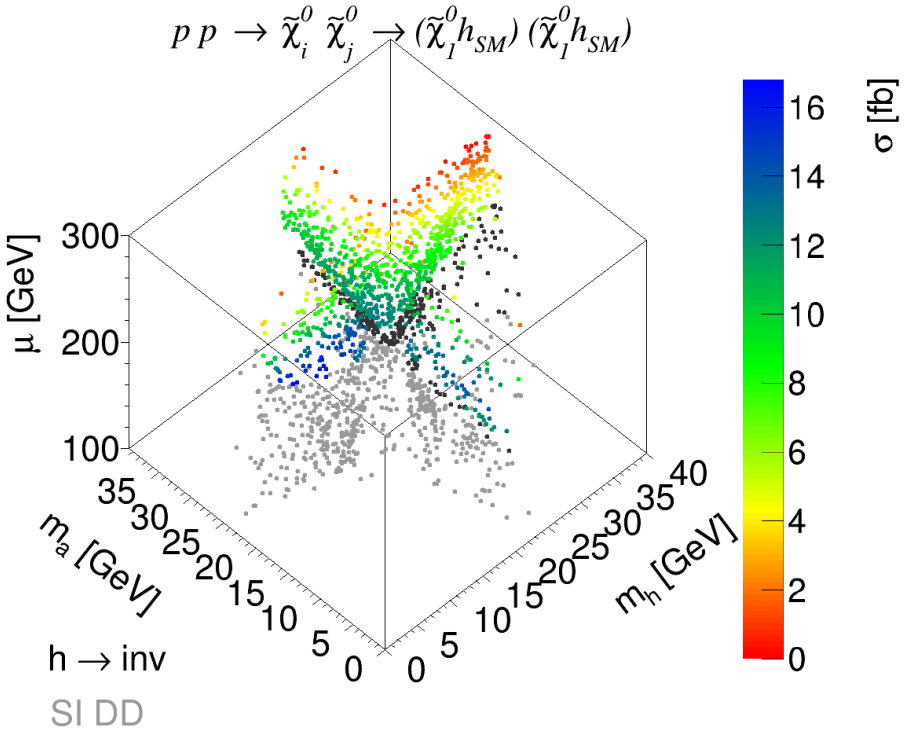




- Annihilation through (pseudo-)scalar slightly off mass shell
- CMB bounds can be relevant for pseudoscalar annihilation (s-wave)

Mono-Z & Mono-Higgs pairs in NMSSM





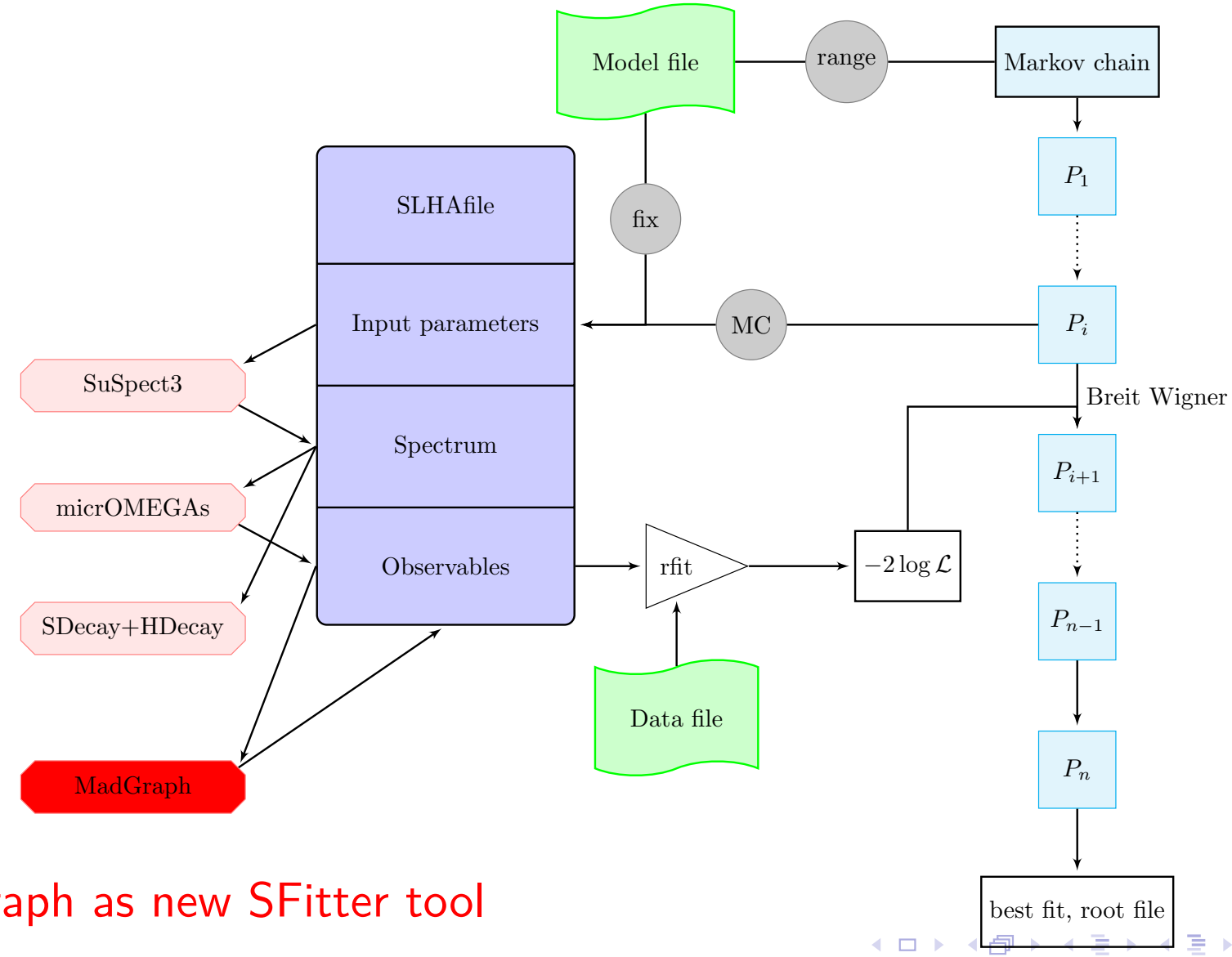
- up to 40 times larger mono-Z cross section than in MSSM (due to larger $\mathrm{BR}\,(h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0)$)
- 3 times larger cross section for mono-Higgs pairs (lighter intermediate neutralinos)
- $h \to inv$ limits gain importance compared to direct detection

Conclusions

- ⇒ For ISR: mono-jet searches by far the most promising
- ⇒ Intermediate on-shell states can lead to large LHC rates
- ⇒ Direct detection is highly constraining
- ⇒ Zh emerges as a leading mono-Z topology
- ⇒ Mono-W appears more promising than mono-Z
- ⇒ mono-Higgs pairs and mono-W pairs motivated by DD
- ⇒ NMSSM can decouple relic density, DD and LHC rates
- ⇒ Much larger LHC rates possible within NMSSM

Backup

Tools / SFitter



MadGraph as new SFitter tool