LHC constraints on monojet signatures from electroweakino DM and colored - superpartner decays

JHEP 10 (2022) 150. [hep-ph]/2208.01651
[hep-ph]/2208.04342

7th LHC Reinterpretation Forum

CERN-December 2022

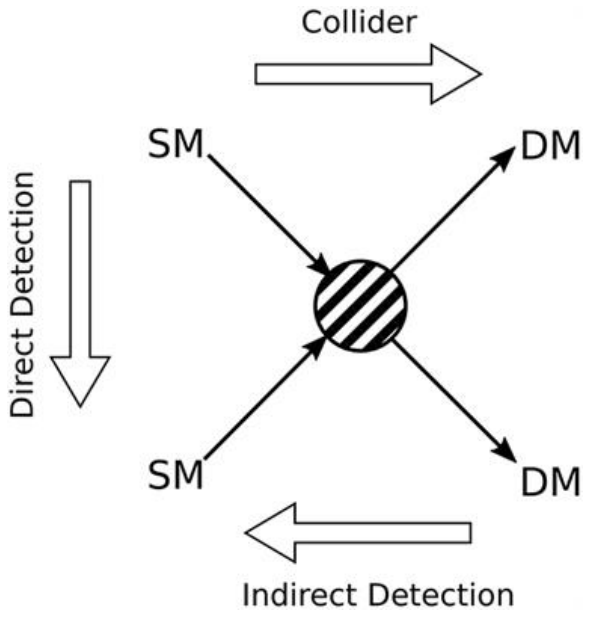
Norway grants

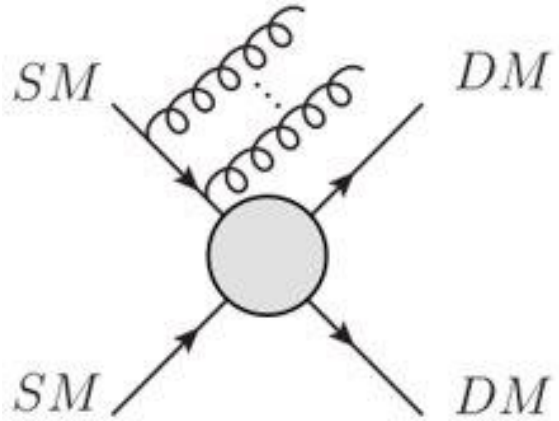
UNIVERSITY OF WARSAW

NATIONAL SCIENCE CENTRE POLAND

Supersymmetric DM

- DM existence strongly suggested by cosmological data.
- Weakly interacting massive particle fits well the picture.
- No direct detection and/or collider signal thus far.
- Supersymmetric partners of gauge and Higgs bosons are strong candidates but remain elusive.





Hadron colliders may produce DM particles in pairs, associated with a few high pT jets originating from initial state QCD radiation

Two SUSY scenarios to re-visit:

I. Light higgsinos/gauginos and rest of the spectrum decoupled. ➔ Jets+MET signal originated from Initial State Radiation.

II. Light squarks/gluinos. ➔ Jets+MET signal originated from the decay of coloured sparticles.

Quick summary of chargino-neutralino sector:

$$\mathcal{L}_{\tilde{\chi}} = \overline{\tilde{\chi}_i^-}(\not{p}\delta_{ij} - P_L(U^* X V^\dagger)_{ij} - P_R(V X^\dagger U^T)_{ij})\tilde{\chi}_j^- + \frac{1}{2}\overline{\tilde{\chi}_i^0}(\not{p}\delta_{ij} - P_L(N^* Y N^\dagger)_{ij} - P_R(N Y^\dagger N^T)_{ij})\tilde{\chi}_j^0$$

$$X = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & \mu \end{pmatrix}$$

diagonalised via $\mathbf{M}_{\tilde{\chi}^+} = U^* X V^\dagger$

$$Y = \begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

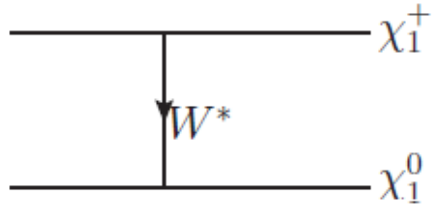
diagonalised via $\mathbf{M}_{\tilde{\chi}^0} = N^* Y N^\dagger$

Small mixing expected if there is a hierarchy between M_1, M_2 and μ and/or particles much heavier than the EW scale.

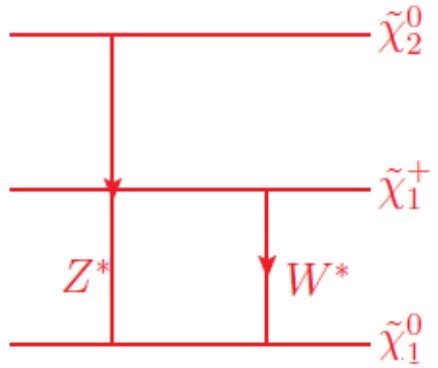
We concentrate in three cases:

bino-wino: almost mass degenerate winos and bino LSP

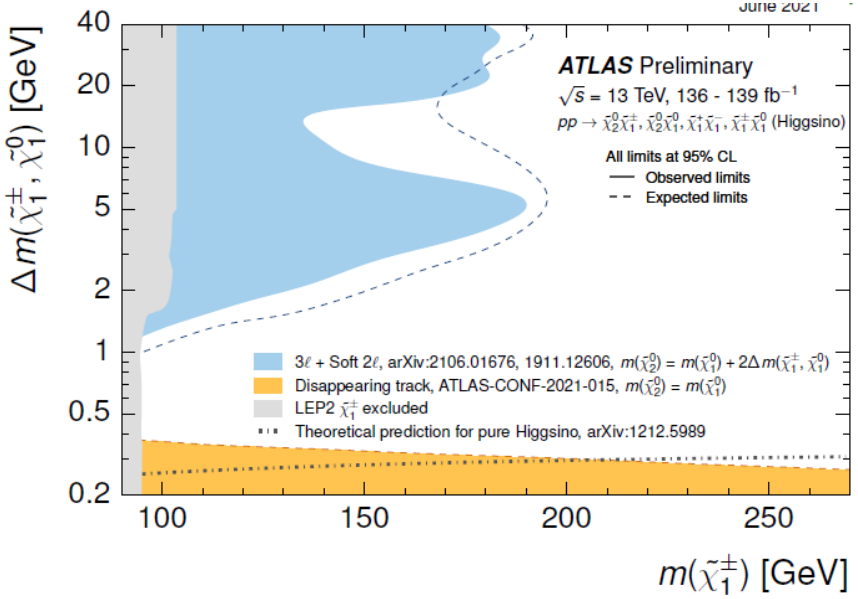
wino LSP: $M_2 \ll M_1, \mu$, two quasi-degenerate states: χ_1^0, $\chi_1^\pm$

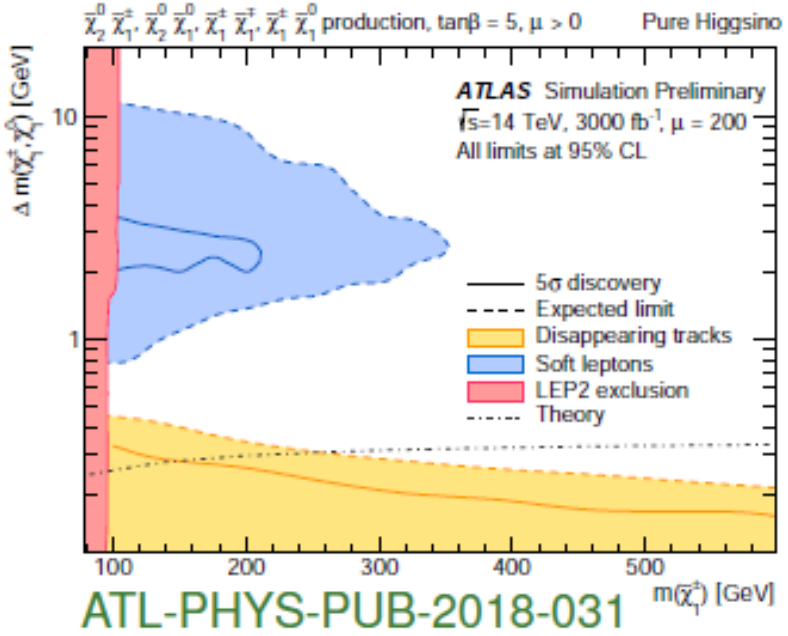


higgsino LSP, $\mu \ll M_1, M_2$, three quasi-degenerate states: $\tilde{\chi}_1^0$, $\tilde{\chi}_1^\pm$, $\tilde{\chi}_2^0$



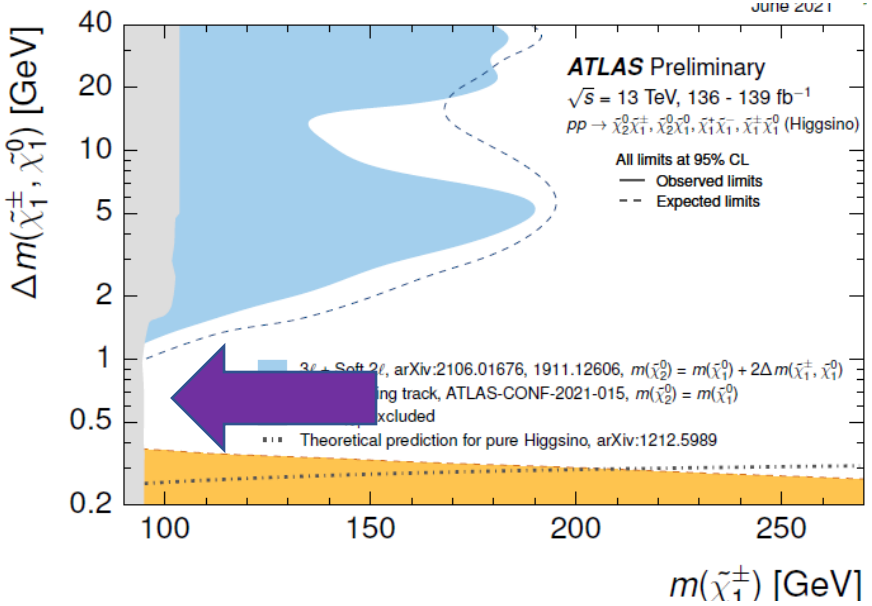
At the LHC this scenarios has been constrained focusing on:

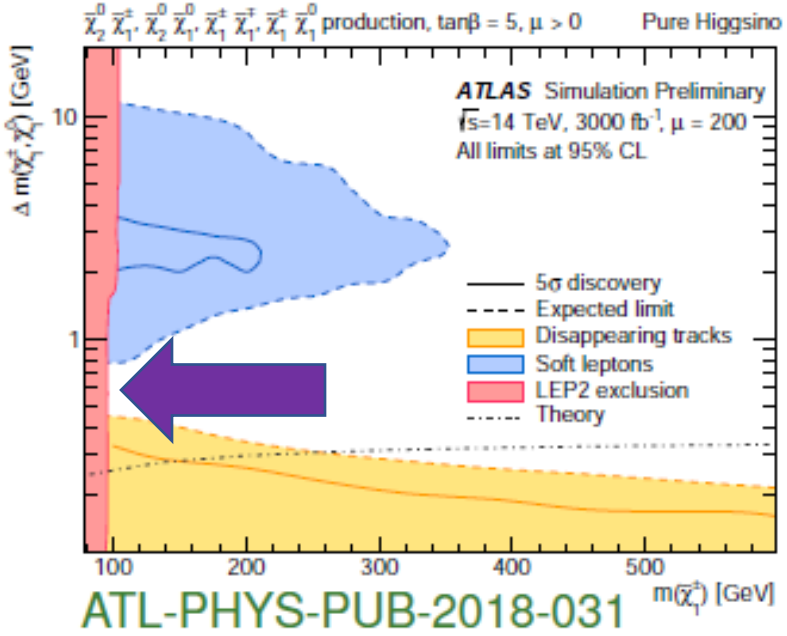




- Disappearing tracks: for sufficiently small mass gap, heavier states are long-lived.
- Soft leptons: For a mass difference $\gtrsim$1 GeV look for soft decay products.
- Long-standing limit at $\sim$ 100 GeV from LEP

At the LHC this scenarios has been constrained focusing on:



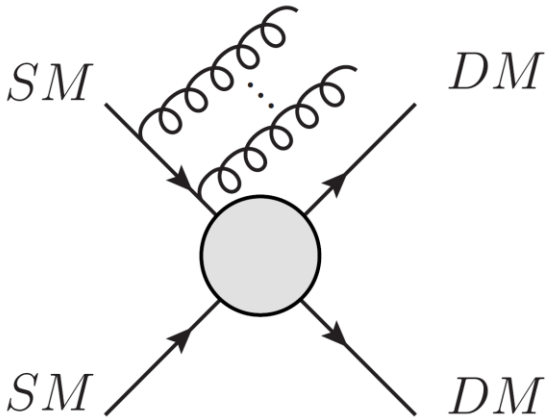


- Disappearing tracks: for sufficiently small mass gap, heavier states are long-lived.
- Soft leptons: For a mass difference $\gtrsim$1 GeV look for soft decay products.
- Long-standing limit at $\sim$ 100 GeV from LEP.

GAP between the two LHC searches. Use Mono/few-jets searches on this region.

Monojet searches from ATLAS and CMS are not sensitive (yet) to *electroweakino* DM. More than one jet emitted is possible, thus *more-than-one-jet* searches may be used also.

- We recast with CheckMATE a general search for squarks and gluinos, arXiv:2010.14293, in total 70 signal regions.
- Basic (preselection) signal requirements:
  - no electrons or muons.
  - 2–6 jets
  - large missing energy > 300 GeV
  - hard leading jet p_T > 200 GeV
  - large effective mass > 800 GeV



- Some overlap of the final states with “mono”-jet.
- We focus on bins with the largest sensitivity (originally intended for squark pair production):

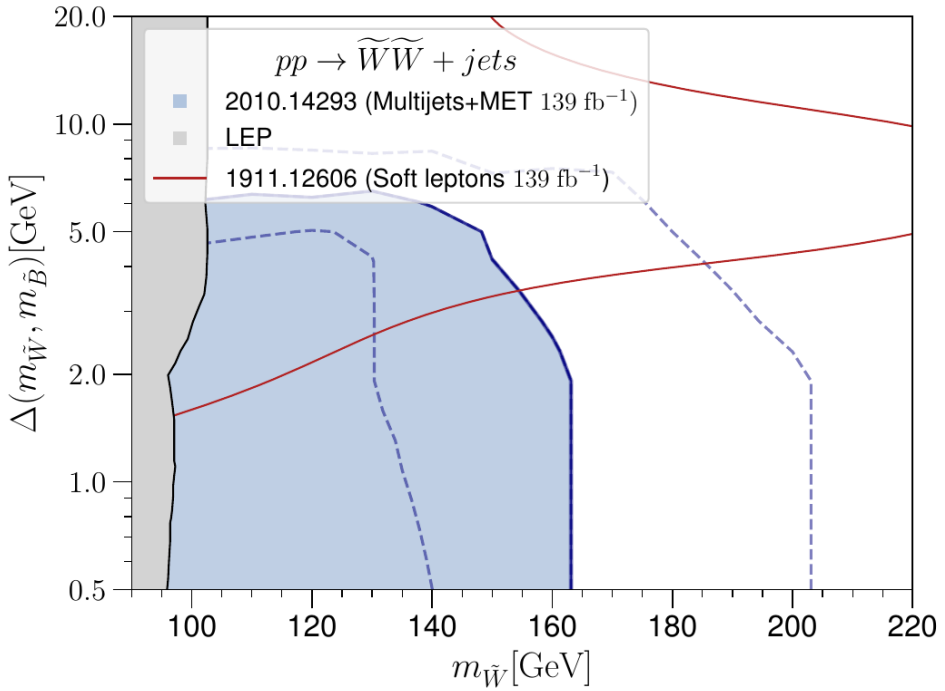
2–3 jets, $p_{\mathrm{T}}^{\mathrm{jet1}}, p_{\mathrm{T}}^{\mathrm{jet2}} > 250$ GeV
effective mass > 1600 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}/\sqrt{H_{\mathrm{T}}} > 16\sqrt{\mathrm{GeV}}$

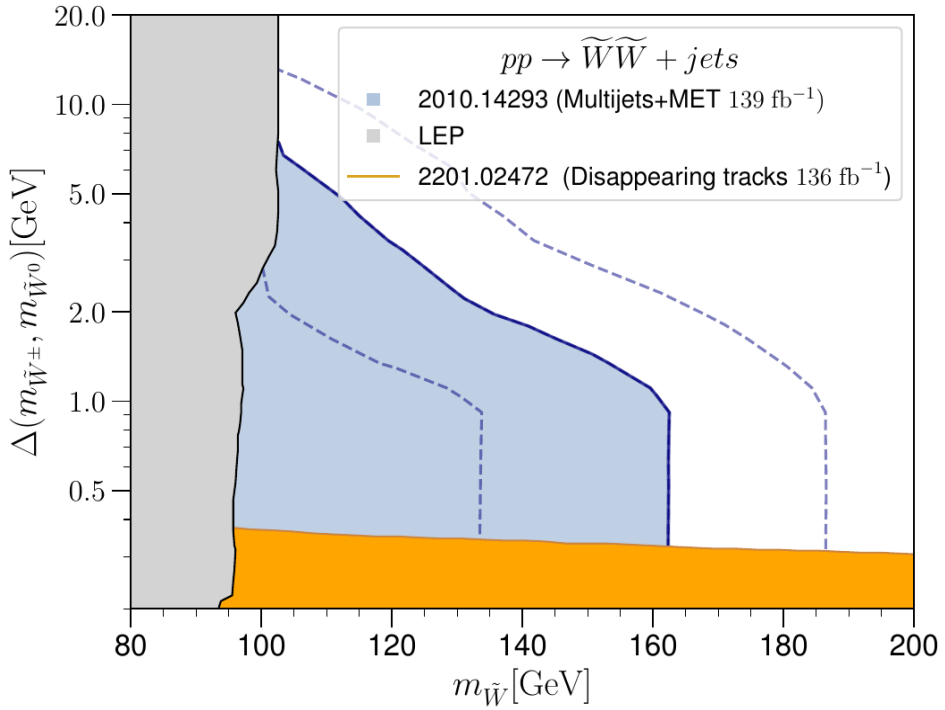
- Multi-bin fit using Histfitter.

Limits over Wino

- bino-wino model
- $\widetilde{W}^{\pm} \to \widetilde{B}^0 W^*, \widetilde{W}^0 \to \widetilde{B}^0 Z^*$
- comparison with ATLAS exclusion (red line)

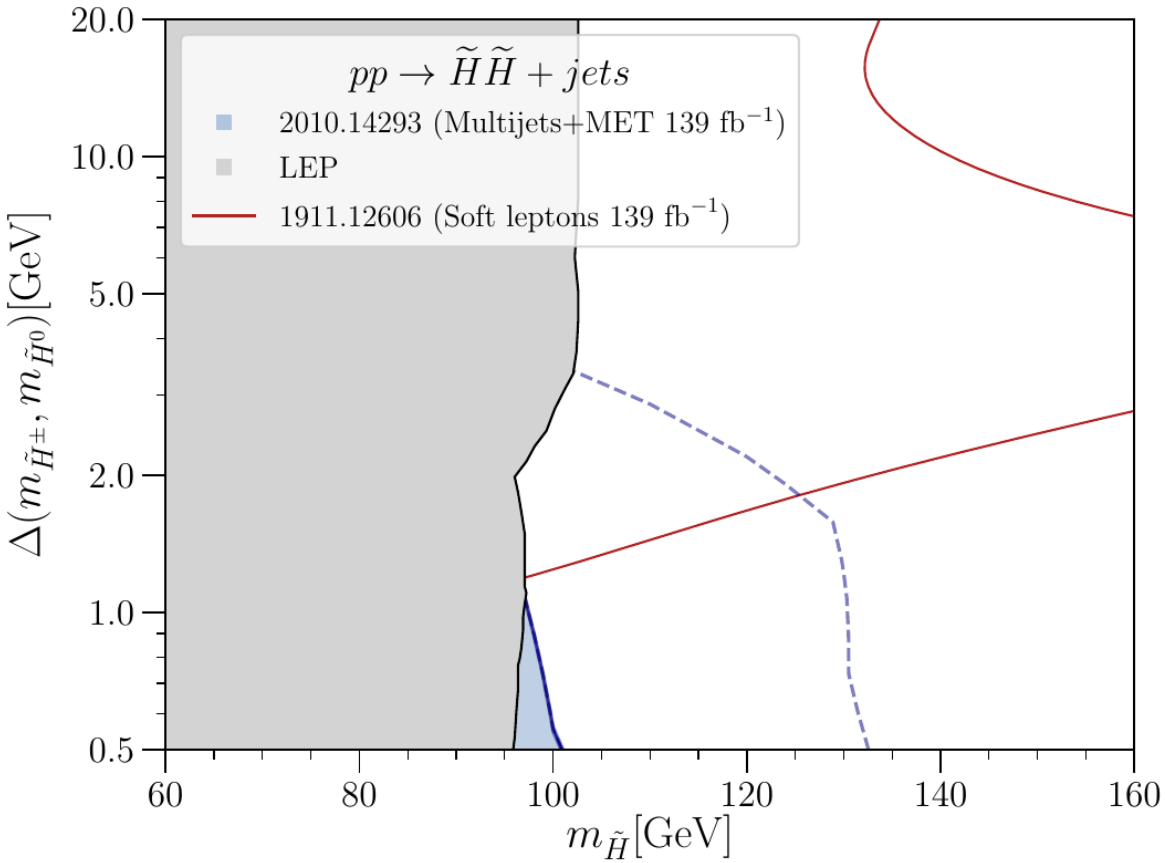
- wino model
- $\widetilde{W}^{\pm} \to \widetilde{W}^0 W^*$
- the new exclusion on top of LEP and long-lived charged wino limits





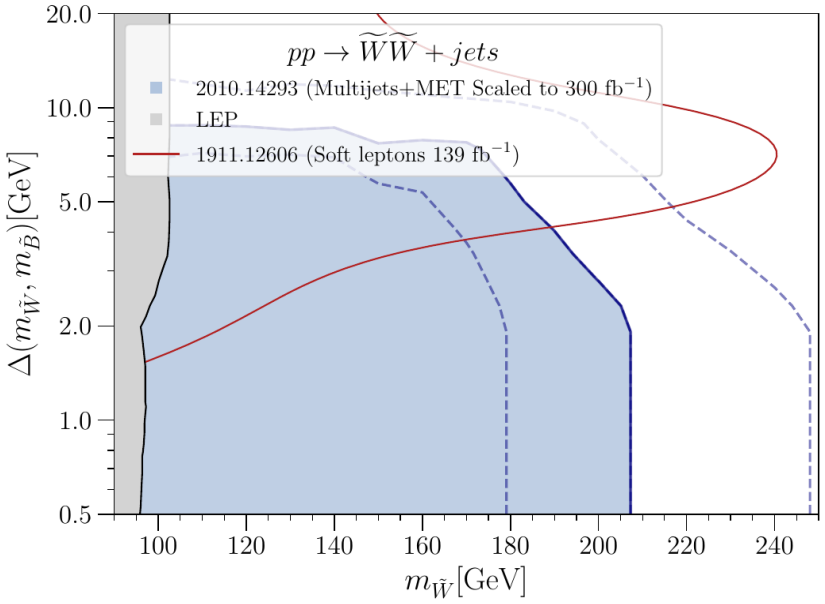
Limits over Higgsino

- higgsino model
- $pp \to \widetilde{H}^{\pm}\widetilde{H}^{0}_{1,2}, \widetilde{H}^{+}\widetilde{H}^{-}, \widetilde{H}^{0}_{1}\widetilde{H}^{0}_{2}$
- $\widetilde{H}^{\pm} \to \widetilde{H}^{0}_{1}W^{*}, \widetilde{H}^{0}_{2} \to \widetilde{H}^{0}_{1}Z^{*}$

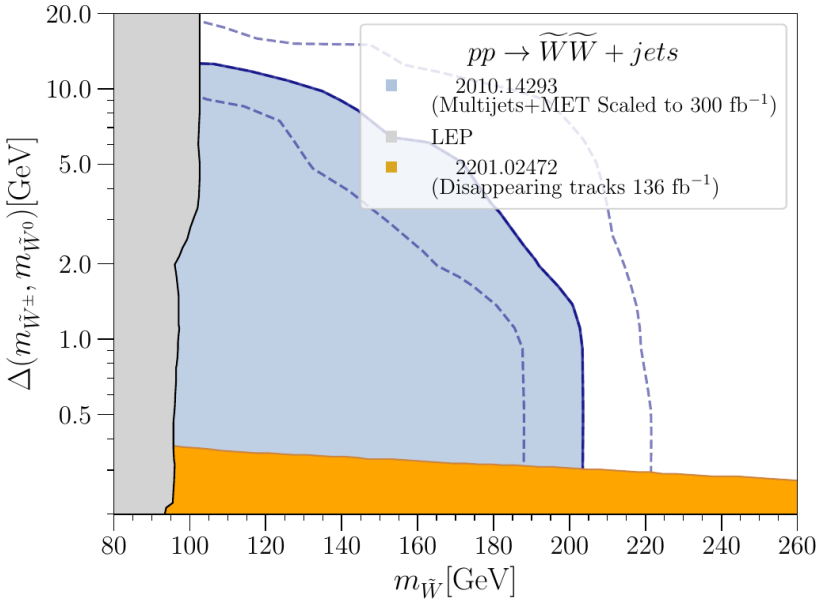


Prospects for Run 3

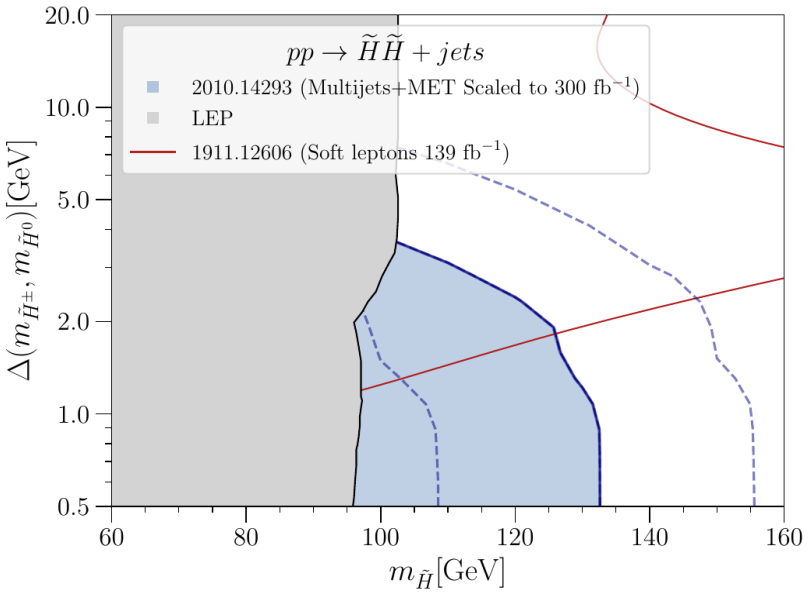
Wino-bino model



Wino model



Higgsino

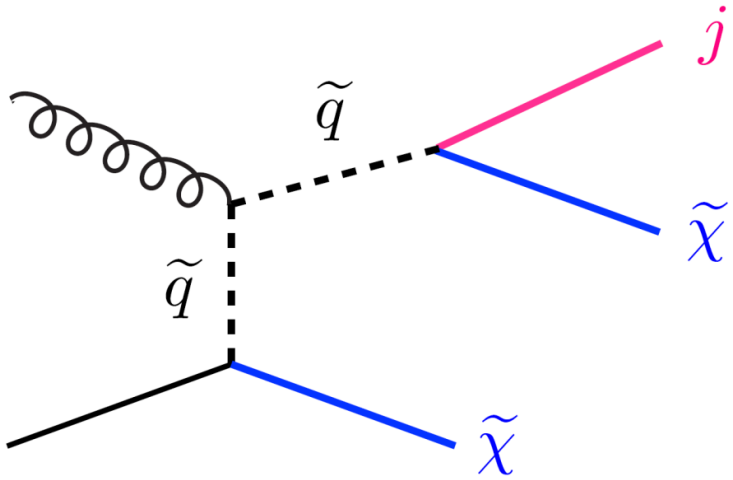


Two SUSY scenarios to re-visit:

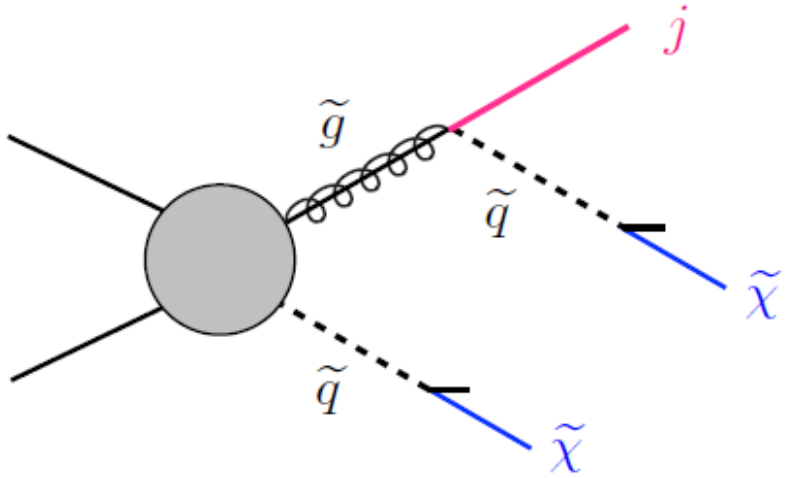
I. Light electroweakinos/gauginos and rest of the spectrum decoupled. ➔ Jets+MET signal originated from Initial State Radiation.

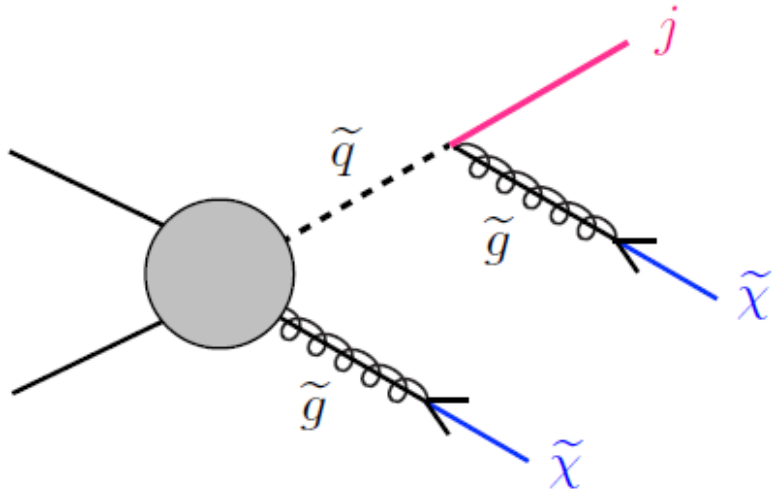
II. Light squarks/gluinos. ➔ Jets+MET signal originated from the decay of coloured sparticles.

I. **Large mass hierarchy between the squarks and the wino (LSP).**
The associated squark-wino production produces a monojet-like signature.

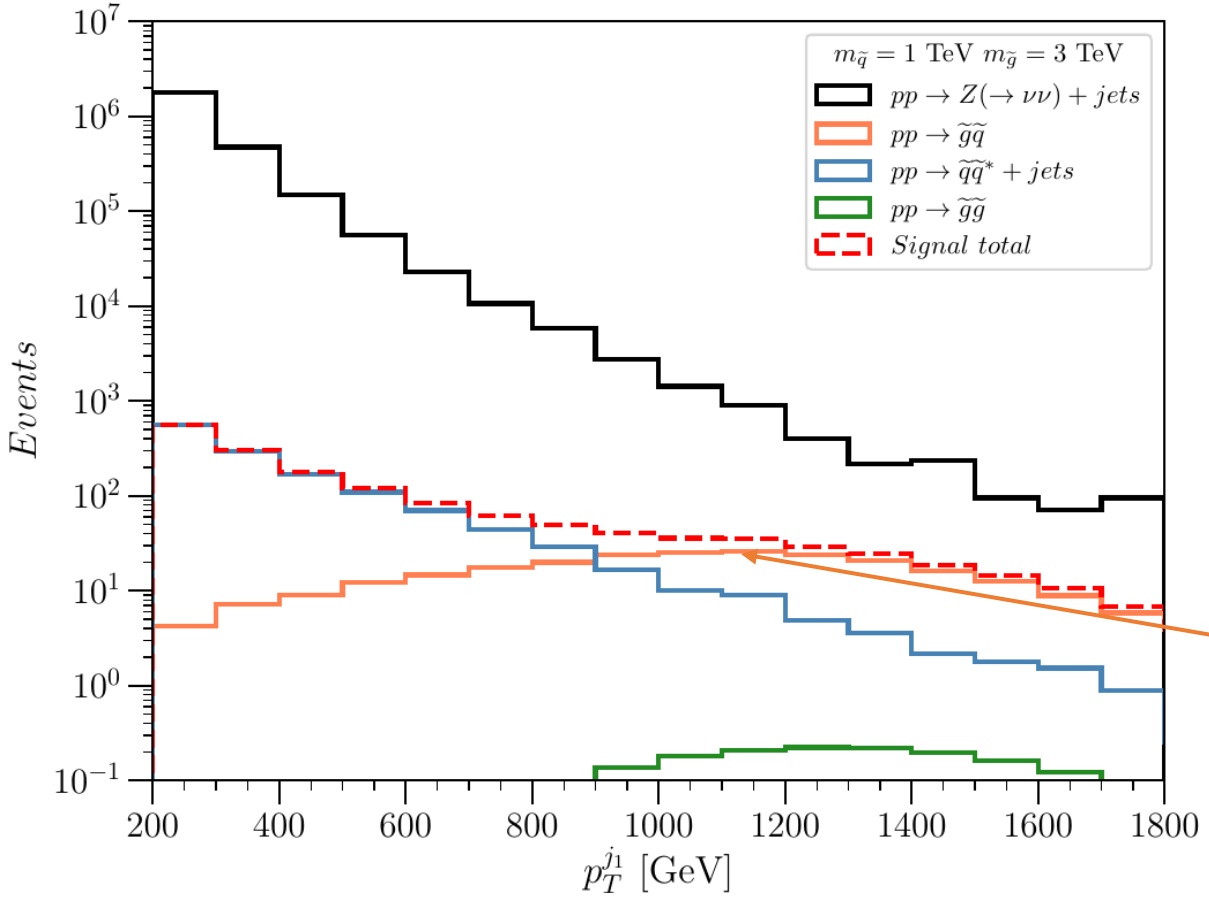


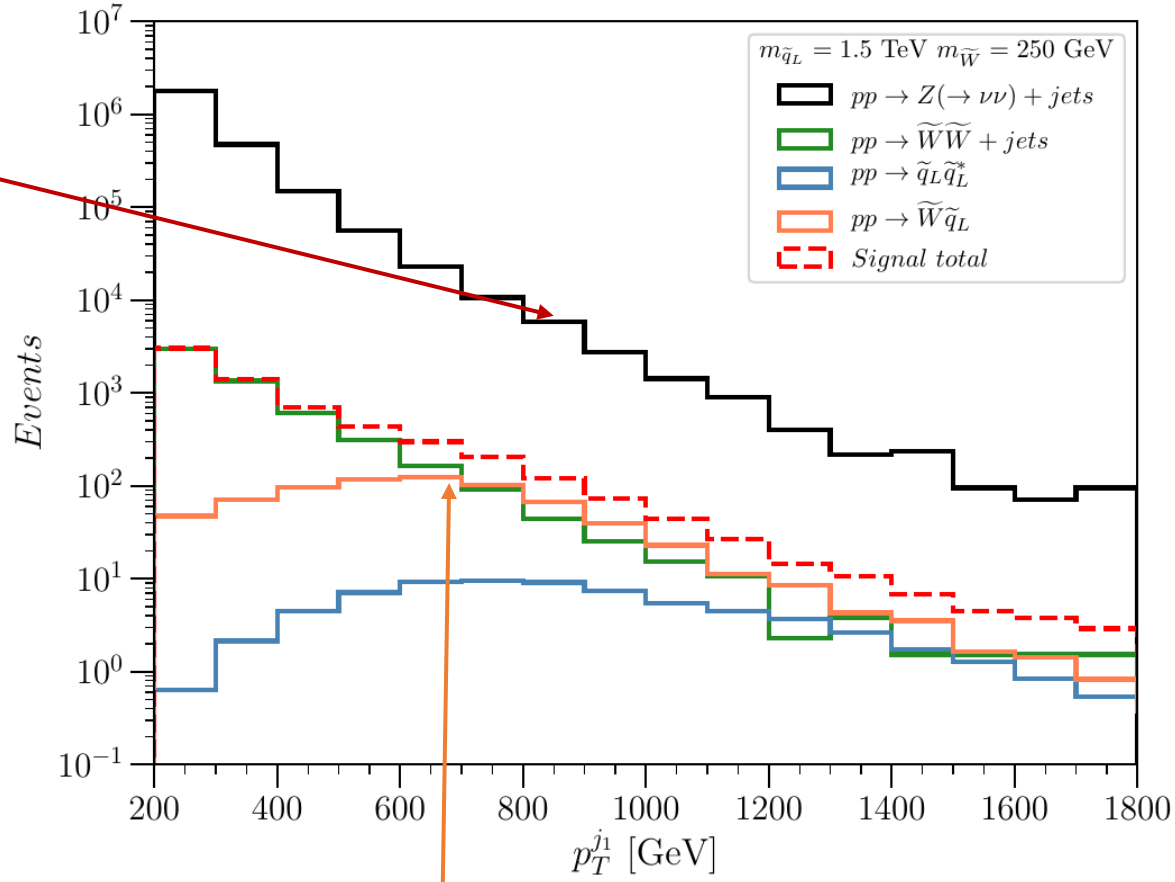
II. **Lighter of squark/gluino is nearly degenerated with LSP.**
The associated gluino-squark production leads to a monojet signal.





QCD radiation has a monotonically falling spectrum and the signal acceptance becomes low once tight pT cuts are imposed on the jets.

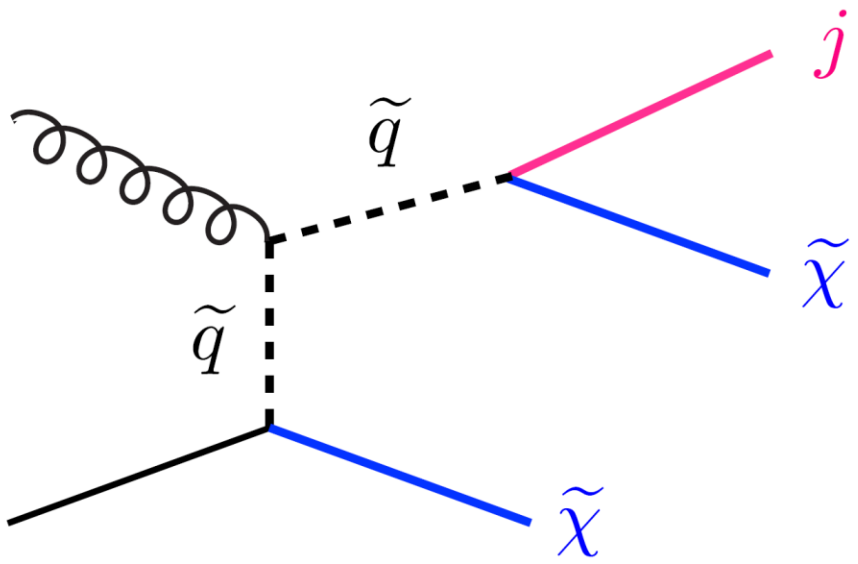




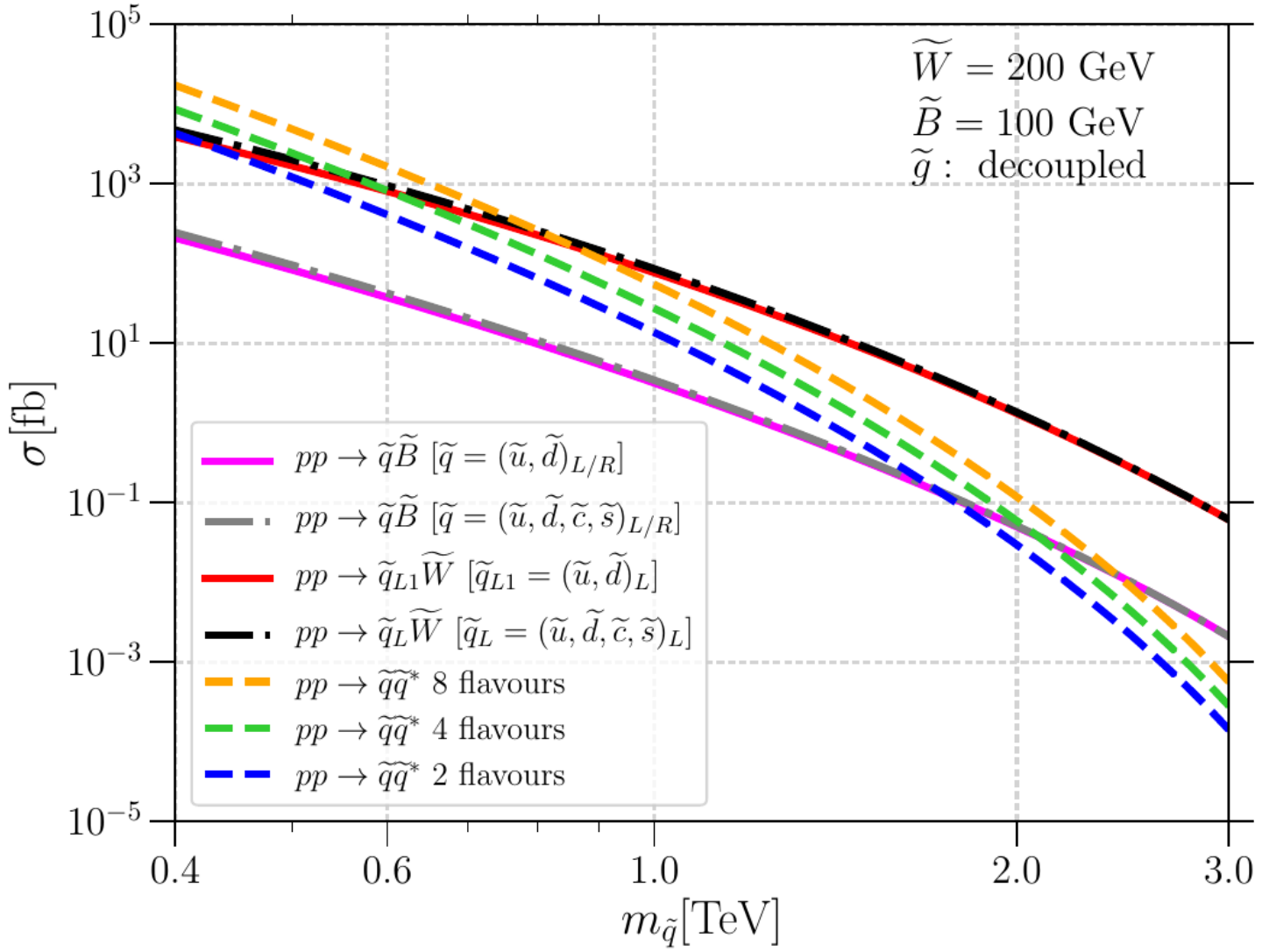
Unlike ISR, in these processes the q-jet has the **energy scale characterised by the mass differences** between the squark and neutralino in (I) and the squark and gluino in (II).

Mono-jets from squark-wino production

- An isolated energetic jet could result from the associated production of squarks together with electroweakinos.
- Specifically sensitive to 1st generation of squarks.
- Not relevant for higgsino-like electroweakinos.



- This signal is generally disregarded in front of strong production of squarks.
- For wino-like neutralino/chargino and squark mass ~ 1 TeV, the cross section is competitive with squark pair production (m_W = 200 GeV).
- For bino-like neutralino, the cross section becomes relevant for squark mass > 2 TeV (m_B = 100 GeV).



We use again the search for squarks and gluinos : arXiv:2010.14293.
Focus on the regions with the largest sensitivity: MB-C-2 and MB-SSd-2

jets + E_T^{miss} (139 fb^{-1}) **MB-C-2**
e, μ veto
$E_T^{\text{miss}} > 300$
$p_T^{j1} > 600$, $\lvert\eta^{j1}\rvert < 2.8$
$p_T^{j2} > 50$, $\lvert\eta^{j2}\rvert < 2.8$
$N_j(p_T > 50, \lvert\eta\rvert < 2.8) \leq 3$
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.4$
$(E_T^{\text{miss}}/\sqrt{H_T}, m_{\text{eff}})$ binned

jets + E_T^{miss} (139 fb^{-1}) **MB-SSd-2**
e, μ veto
$E_T^{\text{miss}} > 300$
$p_T^{j1} > 250$, $\lvert\eta^{j1}\rvert < 2$
$p_T^{j2} > 250$, $\lvert\eta^{j2}\rvert < 2$
$N_j(p_T > 50, \lvert\eta\rvert < 2.8) \leq 3$
$\Delta\phi(\text{jet}, \mathbf{p}_T^{\text{miss}}) > 0.8$
$(E_T^{\text{miss}}/\sqrt{H_T}, m_{\text{eff}})$ binned

Improvement of the limit based on the combination of the signals:

- Squark pair production.

$$pp \to \widetilde{q}\widetilde{q}$$

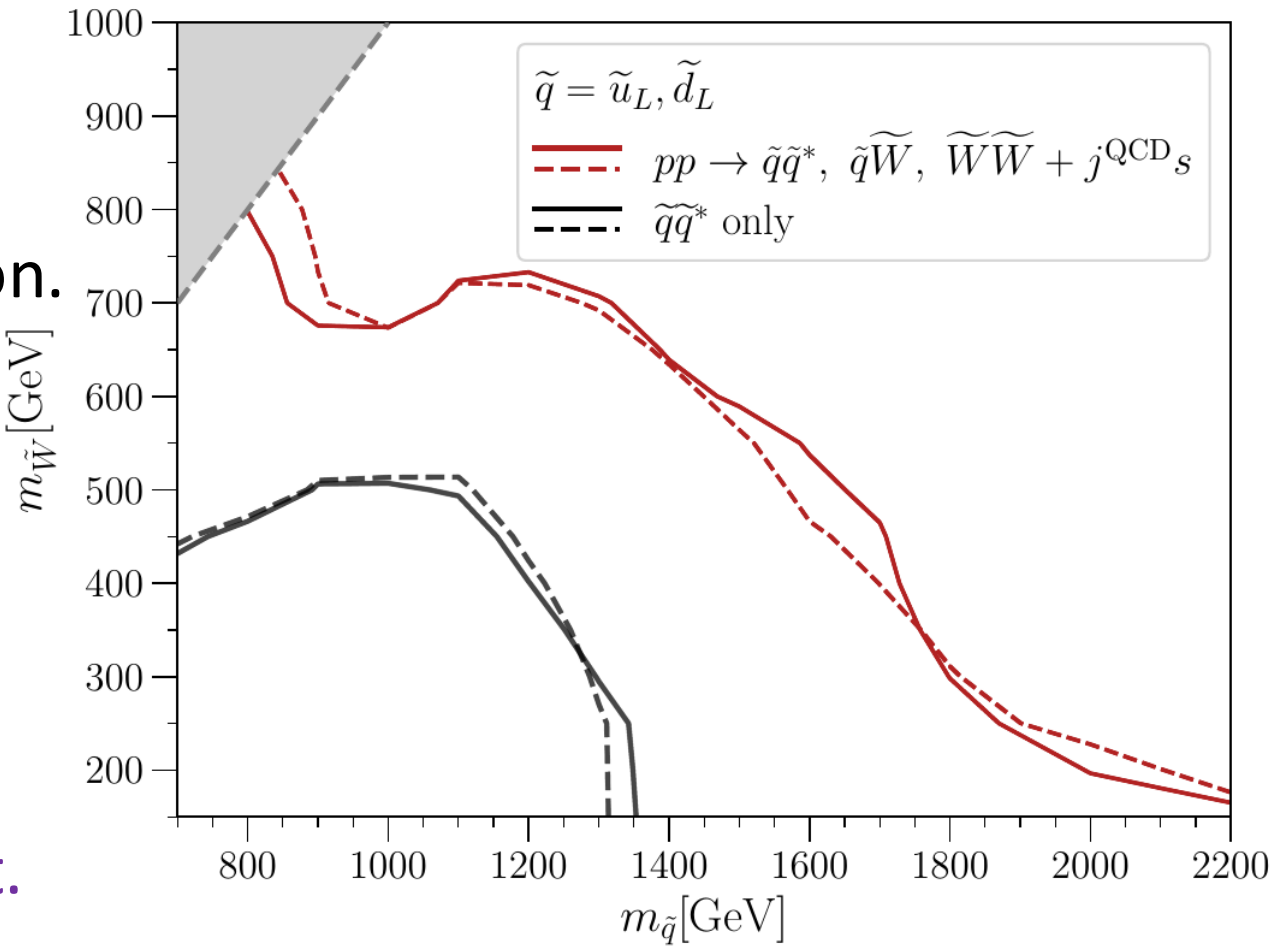
- Squark-wino associated production.

$$pp \to \widetilde{q}_L \widetilde{W}$$

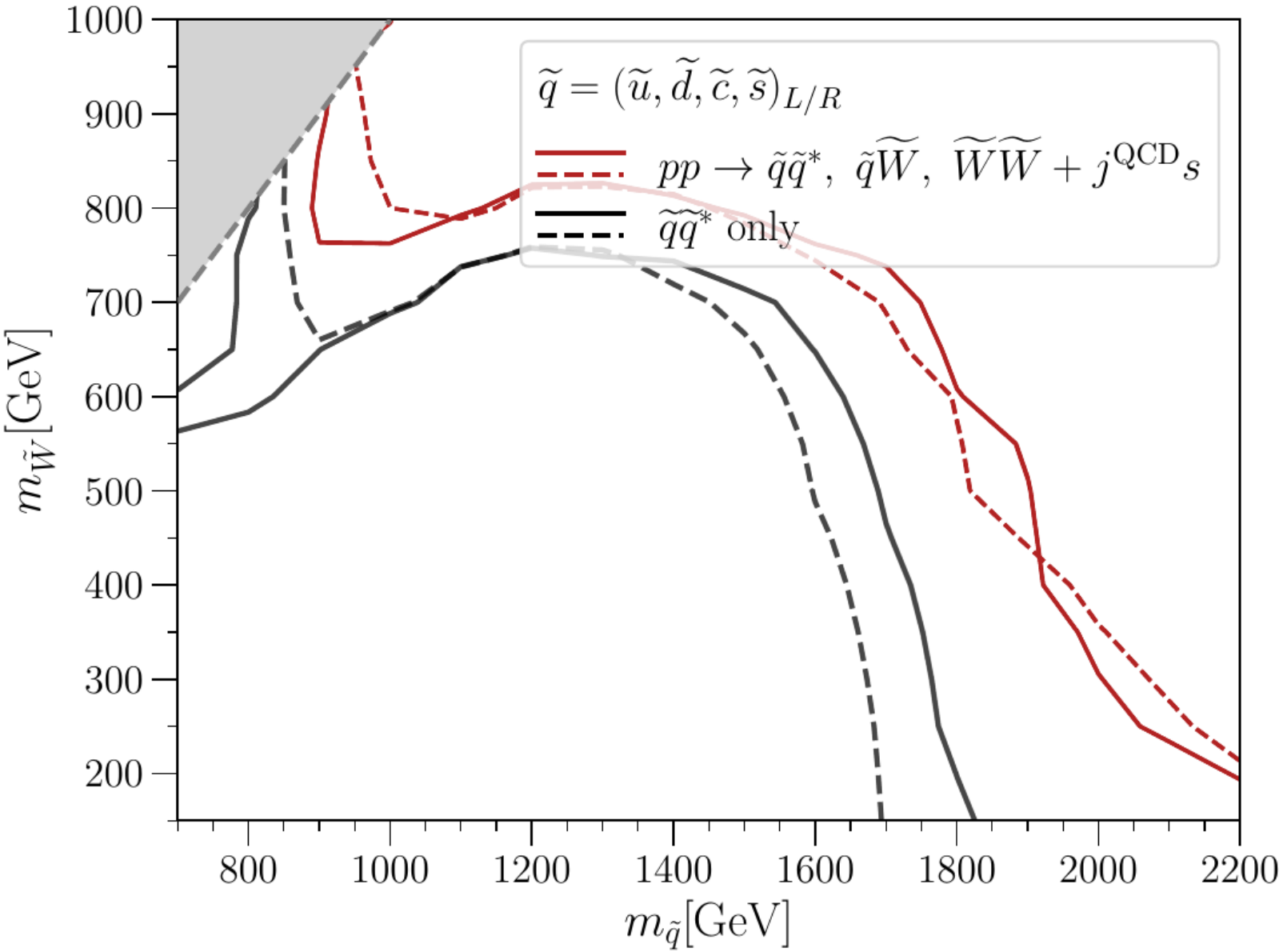
- Wino pair production + ISR jets.

$$pp \to \widetilde{W}\widetilde{W} + jets$$

Only 1st generation left squarks light.

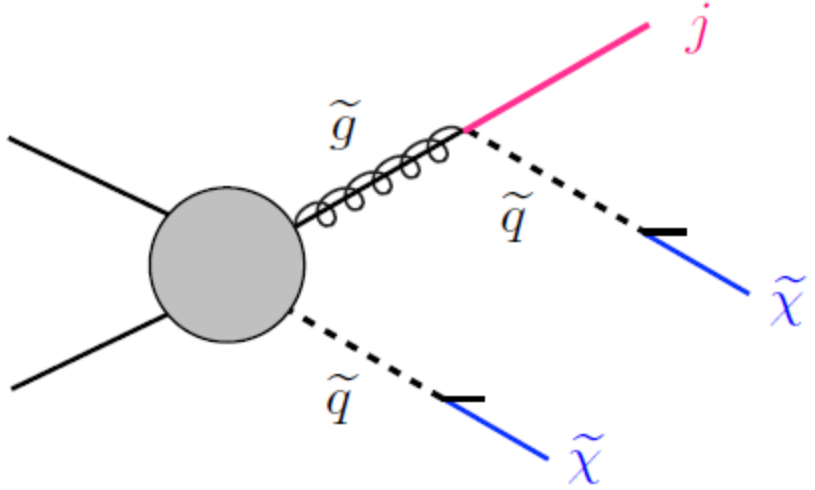


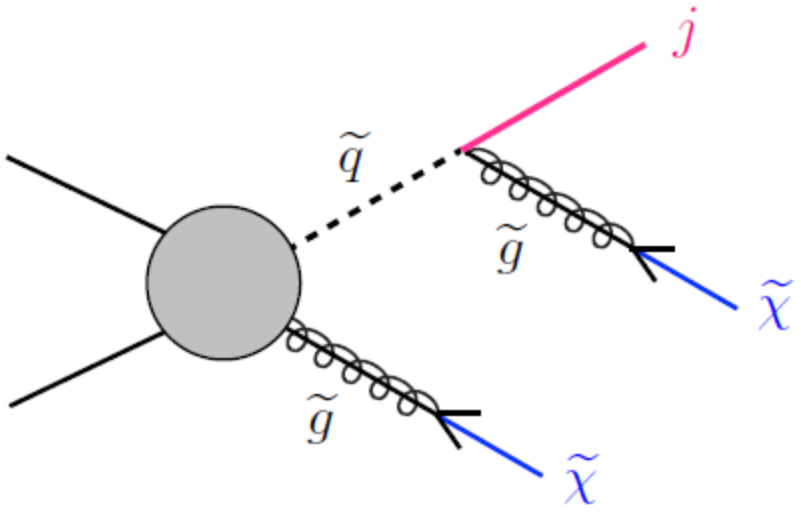
Also if squarks 8-fold degenerated.



Mono-jets from gluino-squark production

If Squark/gluino is degenerate with neutralino (coannihilation!) we have monojets from squark-gluino associated production.





Case $m_{\tilde{g}} > m_{\tilde{q}}$:

$pp \to \tilde{g}\tilde{q},\ \tilde{g} \to q\tilde{q}$ $\cdots$ **(a1)**

$pp \to \tilde{g}\tilde{g},\ \tilde{g}\tilde{g} \to (q\tilde{q})(q\tilde{q})$ $\cdots$ **(a2)**

$pp \to \tilde{q}\tilde{q} + \mathrm{ISR}$ $\cdots$ **(a3)**

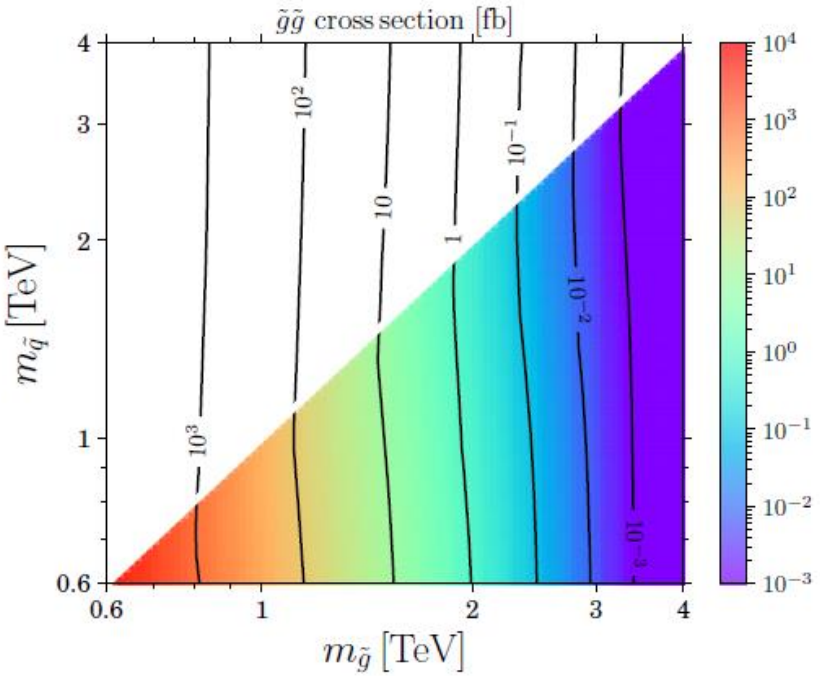
Case $m_{\tilde{q}} > m_{\tilde{g}}$:

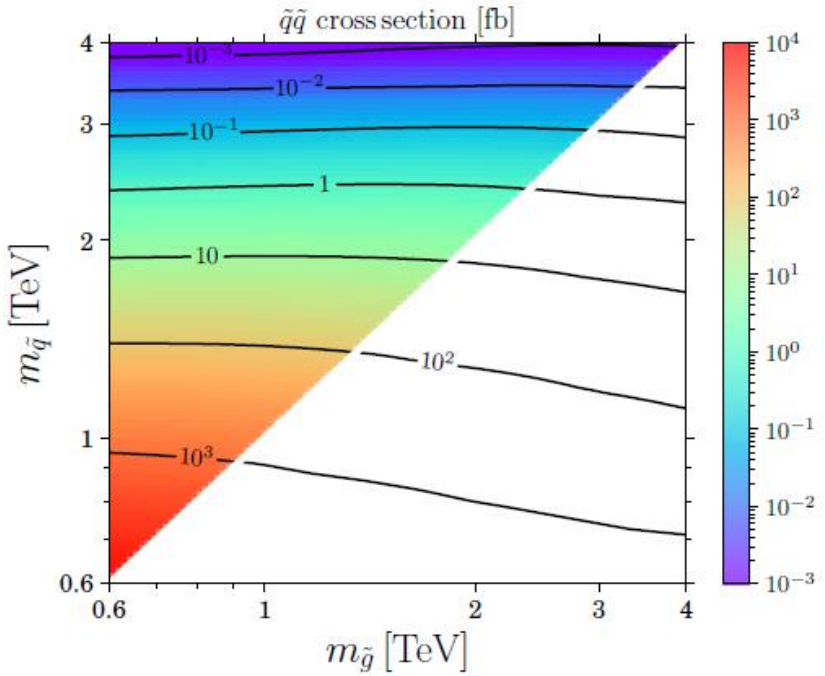
$pp \to \tilde{g}\tilde{q},\ \tilde{q} \to q\tilde{g}$ $\cdots$ **(b1)**

$pp \to \tilde{q}\tilde{q},\ \tilde{q}\tilde{q} \to (q\tilde{g})(q\tilde{g})$ $\cdots$ **(b2)**

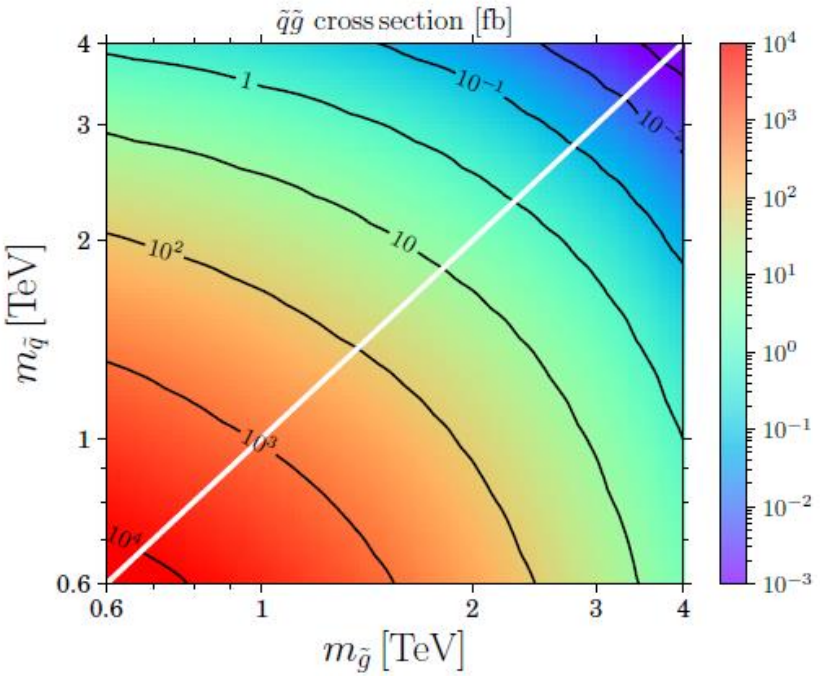
$pp \to \tilde{g}\tilde{g} + \mathrm{ISR}$ $\cdots$ **(b3)**

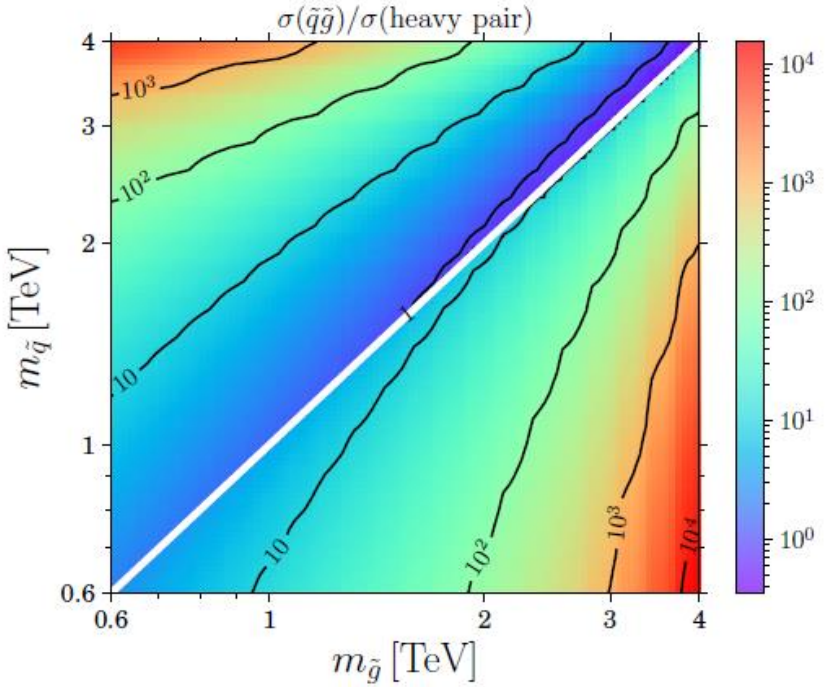
The cross section of the associated production is almost always larger than that of the (a2) and (b2) processes

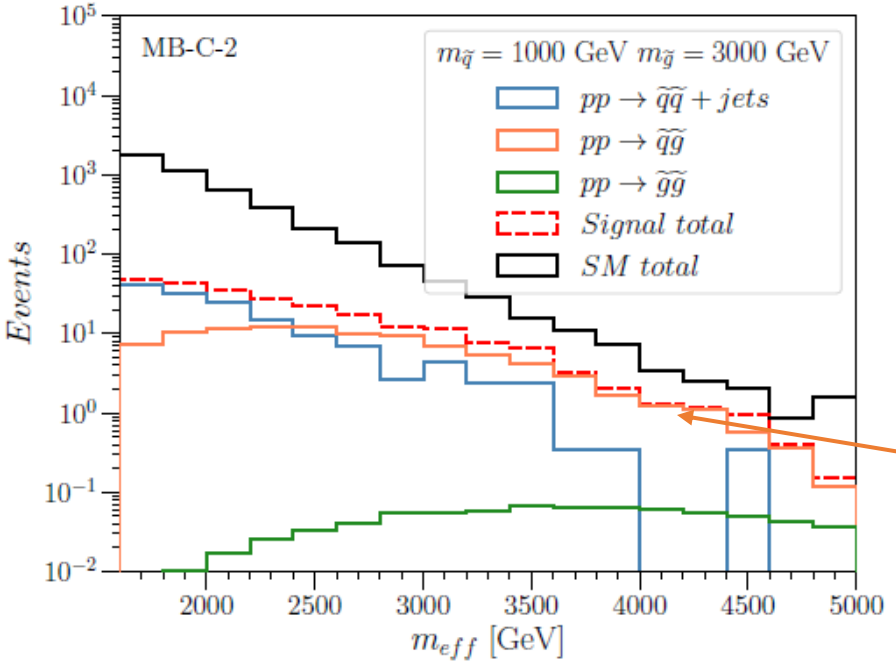


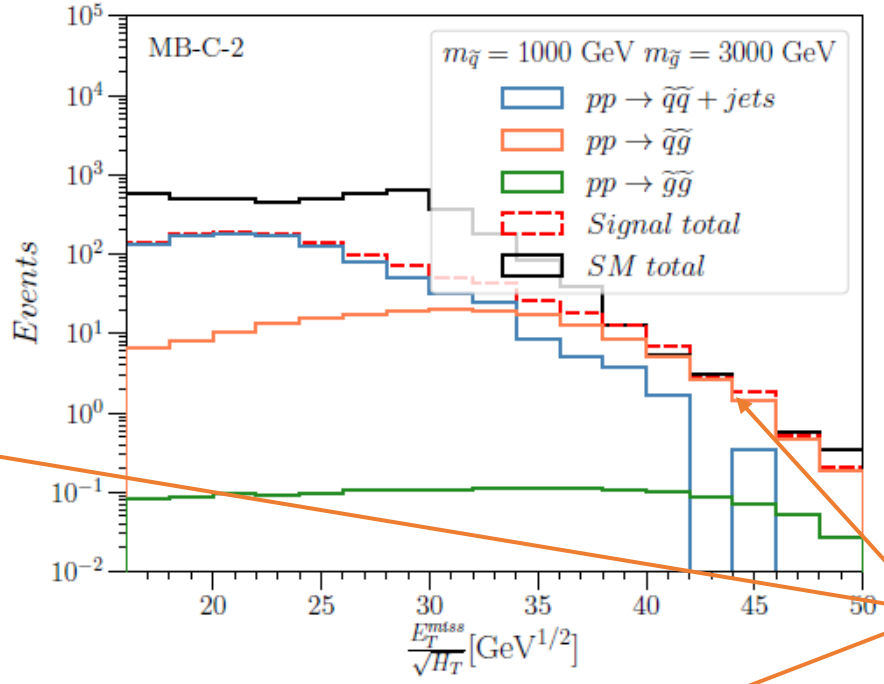


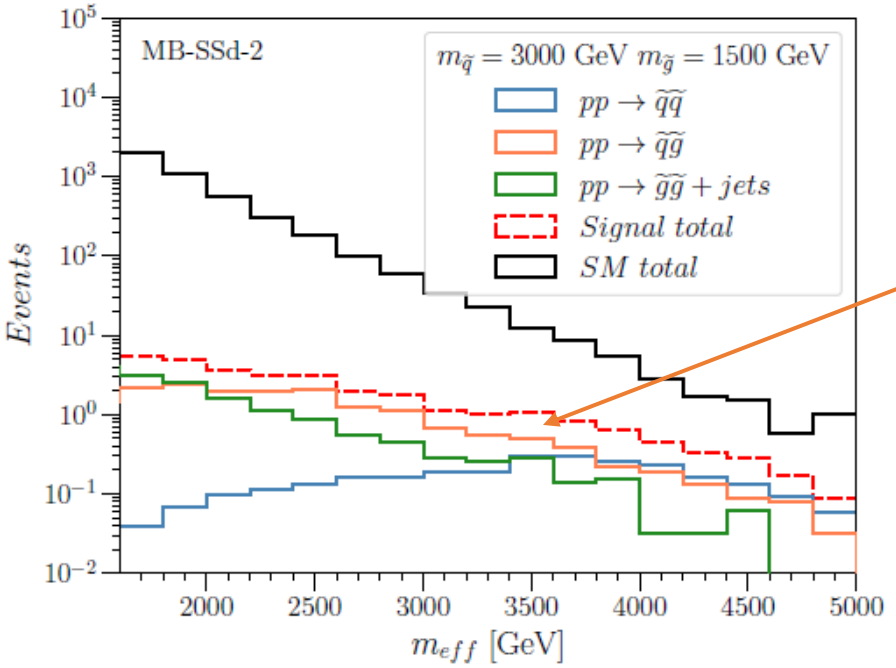
Relative rate of the associatted production is enhanced particulartly in the hierarchical mass regions .

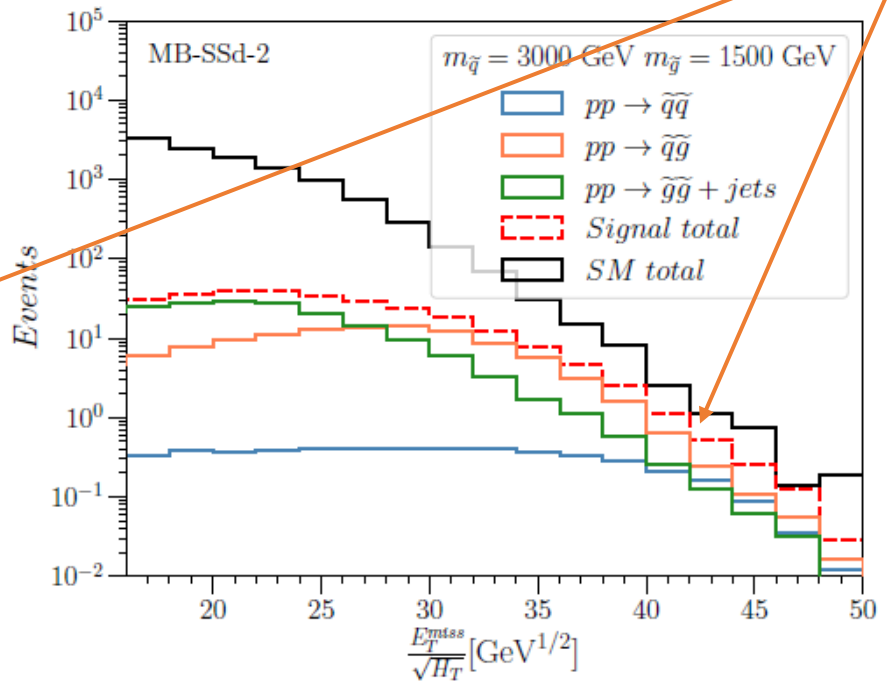






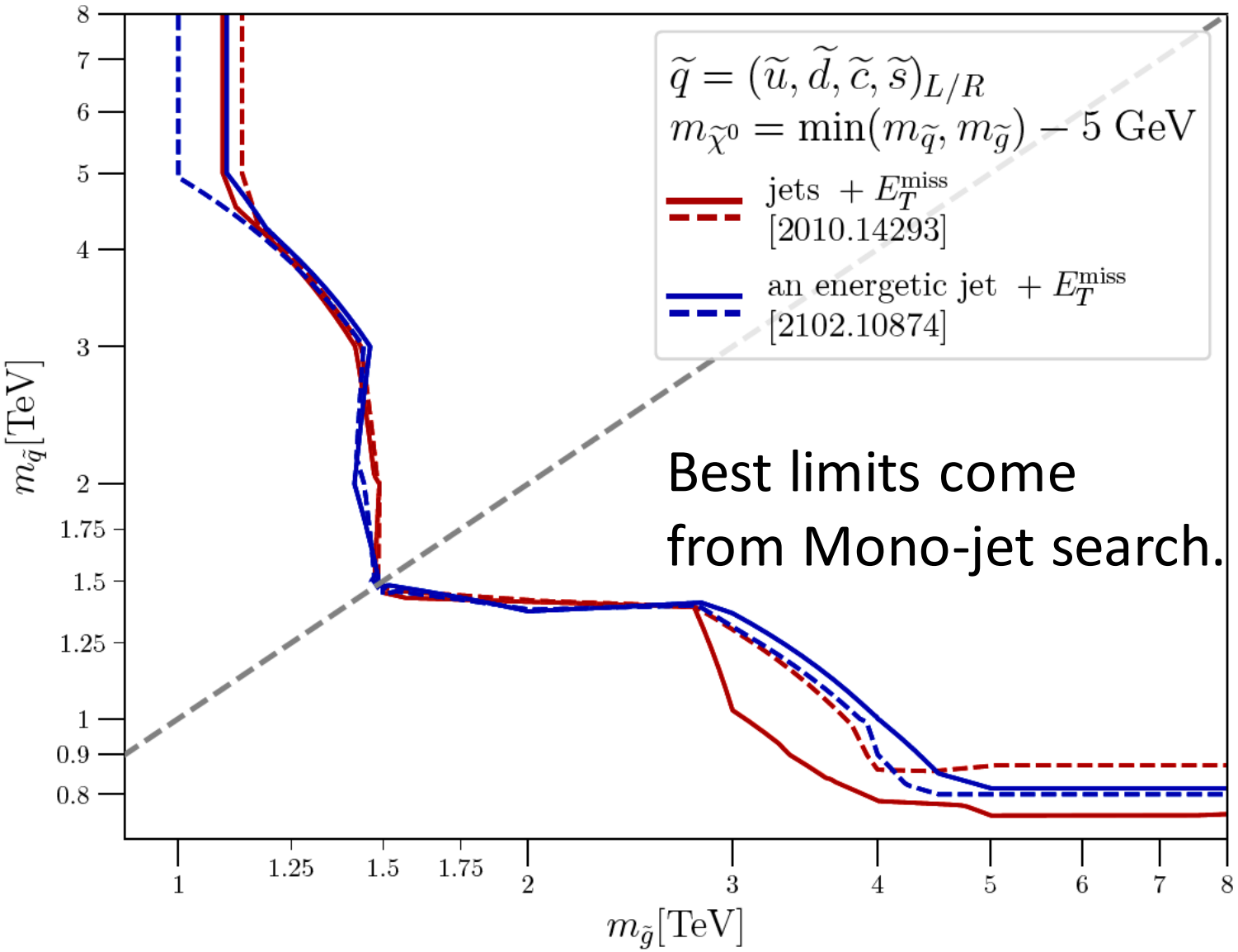






The gluino-squark associated production dominates the signal distributions for higher values of the discriminant variables. $E_T^{\text{miss}}/\sqrt{H_T}$ and m_{eff} .

We compare the limits obtained from recasted Monojet ATLAS (blue) search vs recasted gluino/squark ATLAS search (red).



Summary

- Initial state radiation can give a handle on challenging bits of LSP parameter space.
- Squark search outperforms dedicated monojet analysis for electroweakinos. New constraints closing the gap in (model independent) wino exclusion. Higgsinos more difficult but with some promise. HL prospects to be seen.
- Two distinct SUSY scenarios where a single high pT jet originates from SUSY particle pair production, to which mono- and di-jet event selections are particularly sensitive:
  1. A squark-wino simplified model ➔ non negligible contribution of the associated squark-wino production. Negligible in the squark-bino model with current luminosity but need to be reconsidered for the HL-LHC.
  2. A gluino-squark simplified model with nearly degenerate bino LSP. ➔We derived current exclusion limit on the gluino-squark mass plane

Norway grants

NATIONAL SCIENCE CENTRE POLAND

The research leading to the results presented in this talk has received funding from the Norwegian Financial Mechanism for years 2014-2021, grant nr 2019/34/H/ST2/00707

Understanding the Early Universe: interplay of theory and collider experiments

Joint research project between the University of Warsaw & University of Bergen