Monojet signatures from gluino and squark decays

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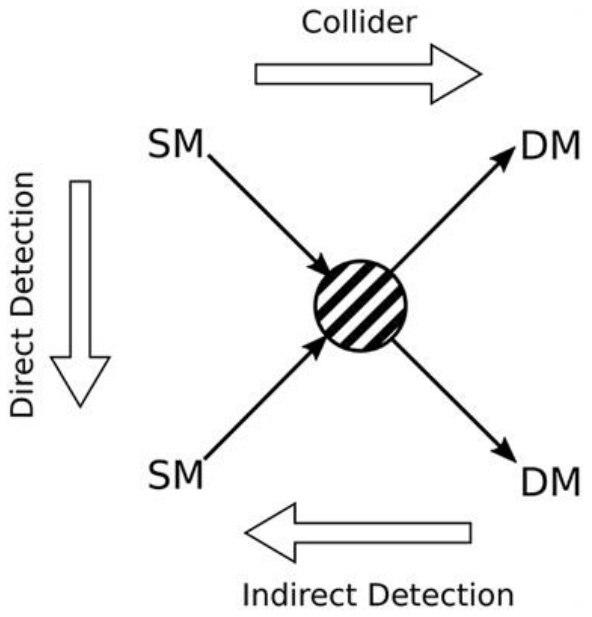
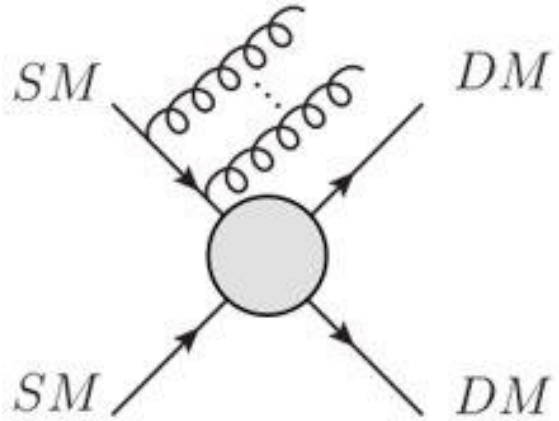
Supersymmetric DM

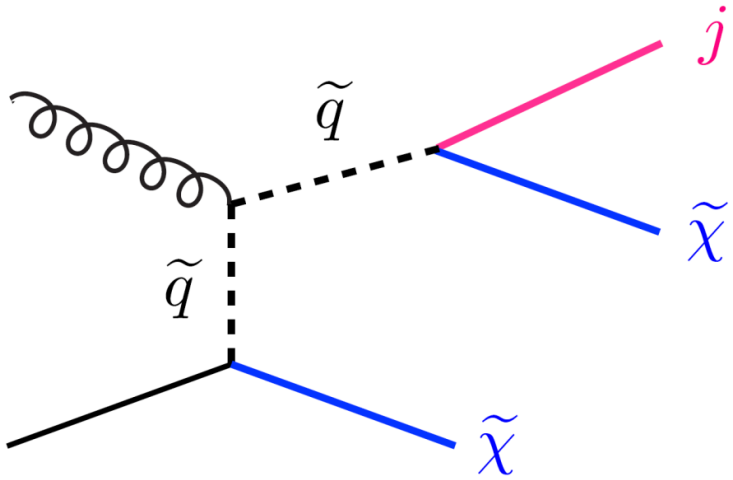
- DM existence strongly suggested by cosmological data.
- Weakly interacting massive particle fits well the picture.
- No direct detection and/or collider signal thus far.
- Supersymmetric partners of gauge and Higgs bosons are strong candidates but remain elusive.



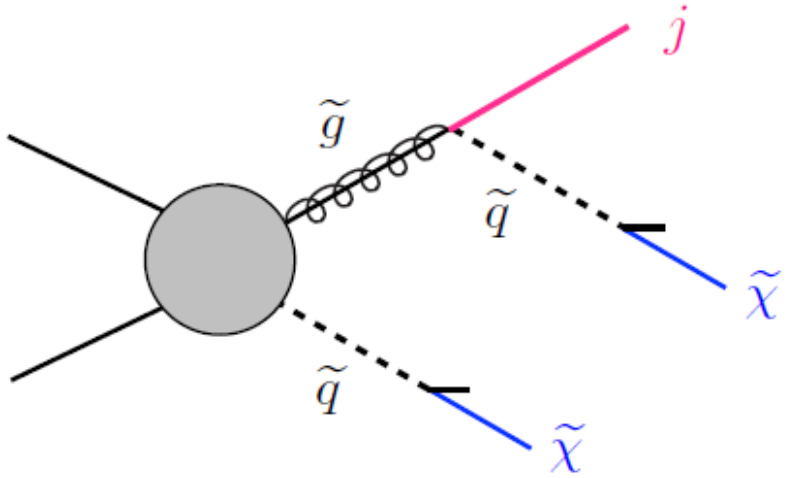


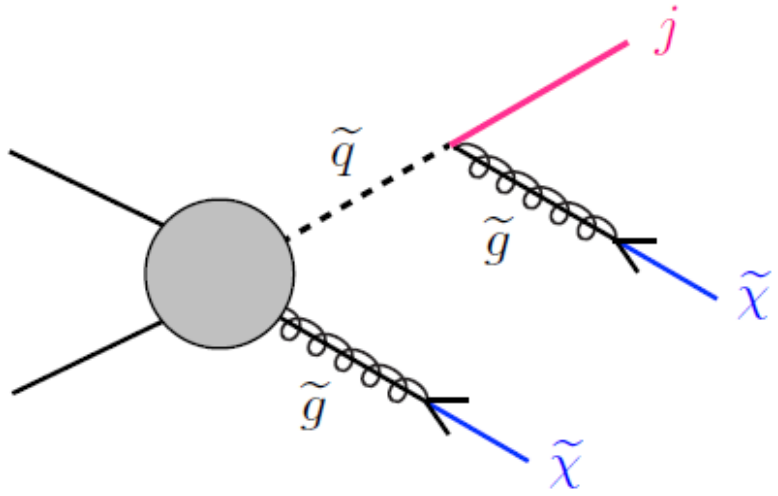
Hadron colliders may produce DM particles in pairs, associated with a few high pT jets originating from initial state QCD radiation

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

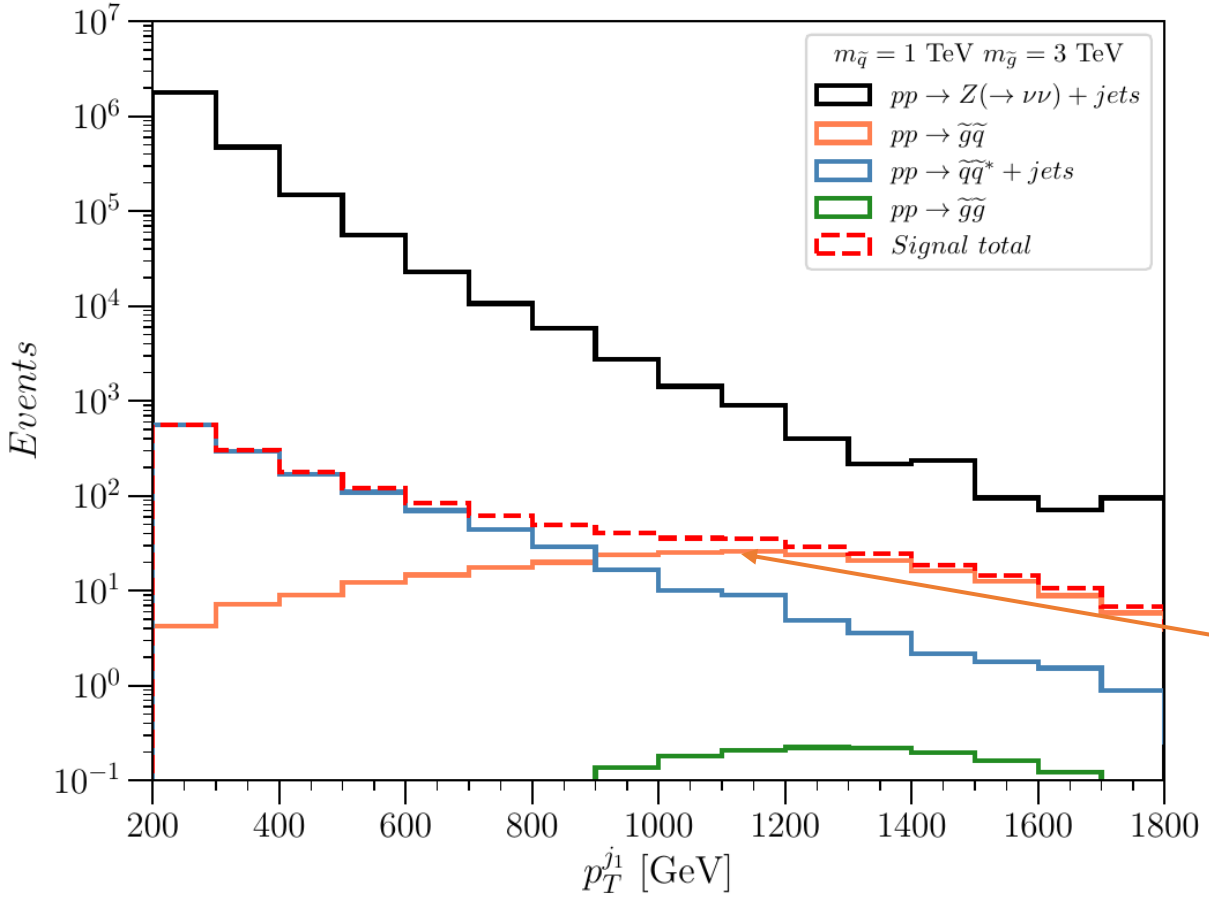


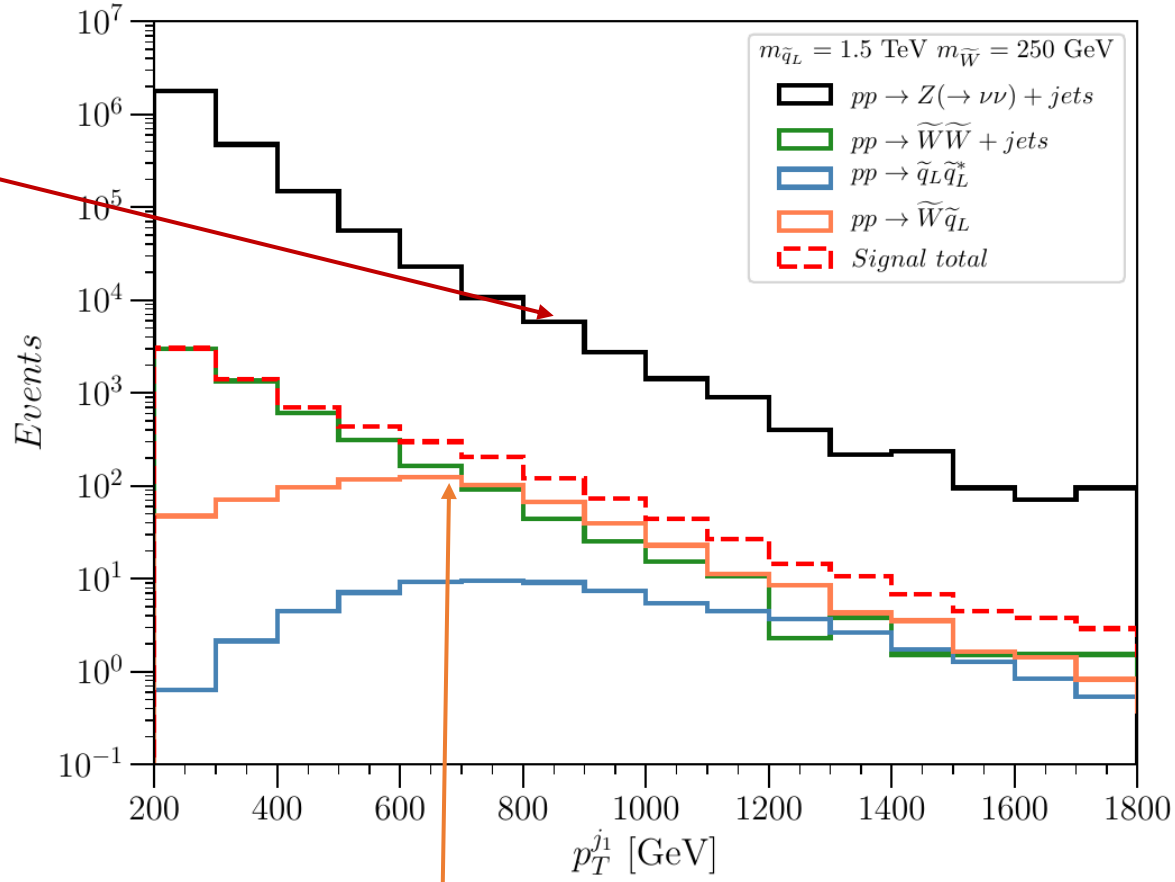
II. **Lighter of squark/gluino is nearly degenerated with LSP.**
The associated gluino-squark production leads to a monojet signal.





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

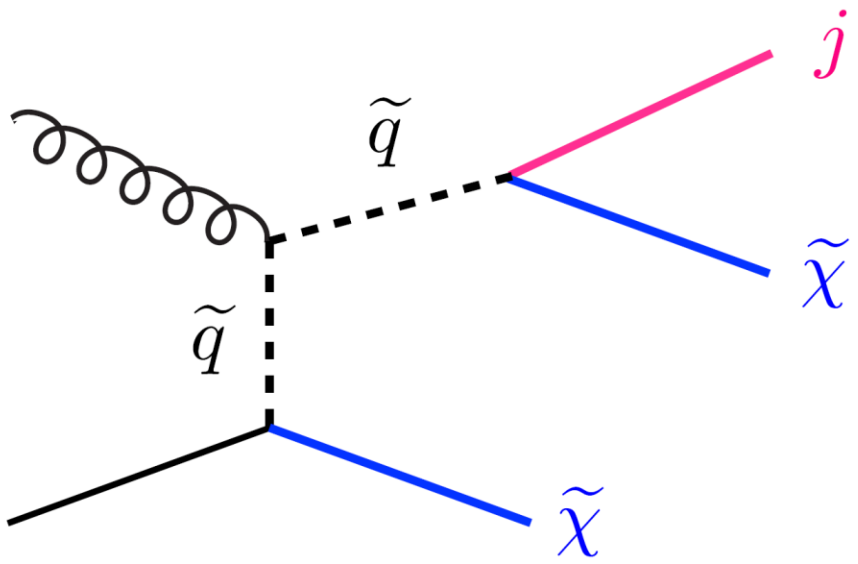




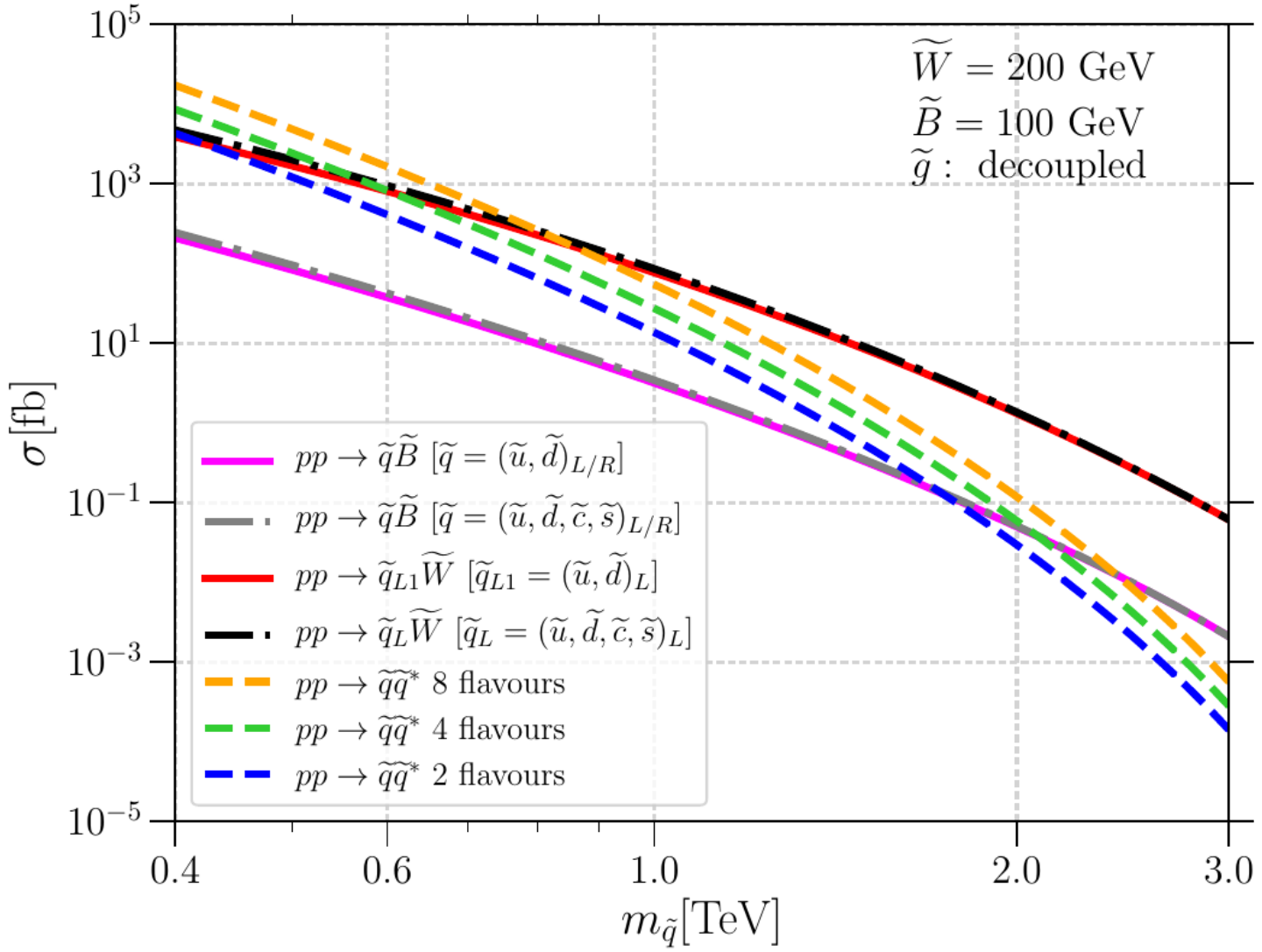
Unlike ISR, in these processes the q-jet has the **energy scale characterised by the mass differences** between the squark and neutralino in (I) and the squark and gluino in (II).

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 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
- We 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

- Multi-bin fit of the binned exclusive classification of events using Histfitter/pyhf.

Analysis based on a multi-bin fit with a simplified background model

We build the simplified likelihood following the prescription in ATL-PHYS-PUB-2021-038:

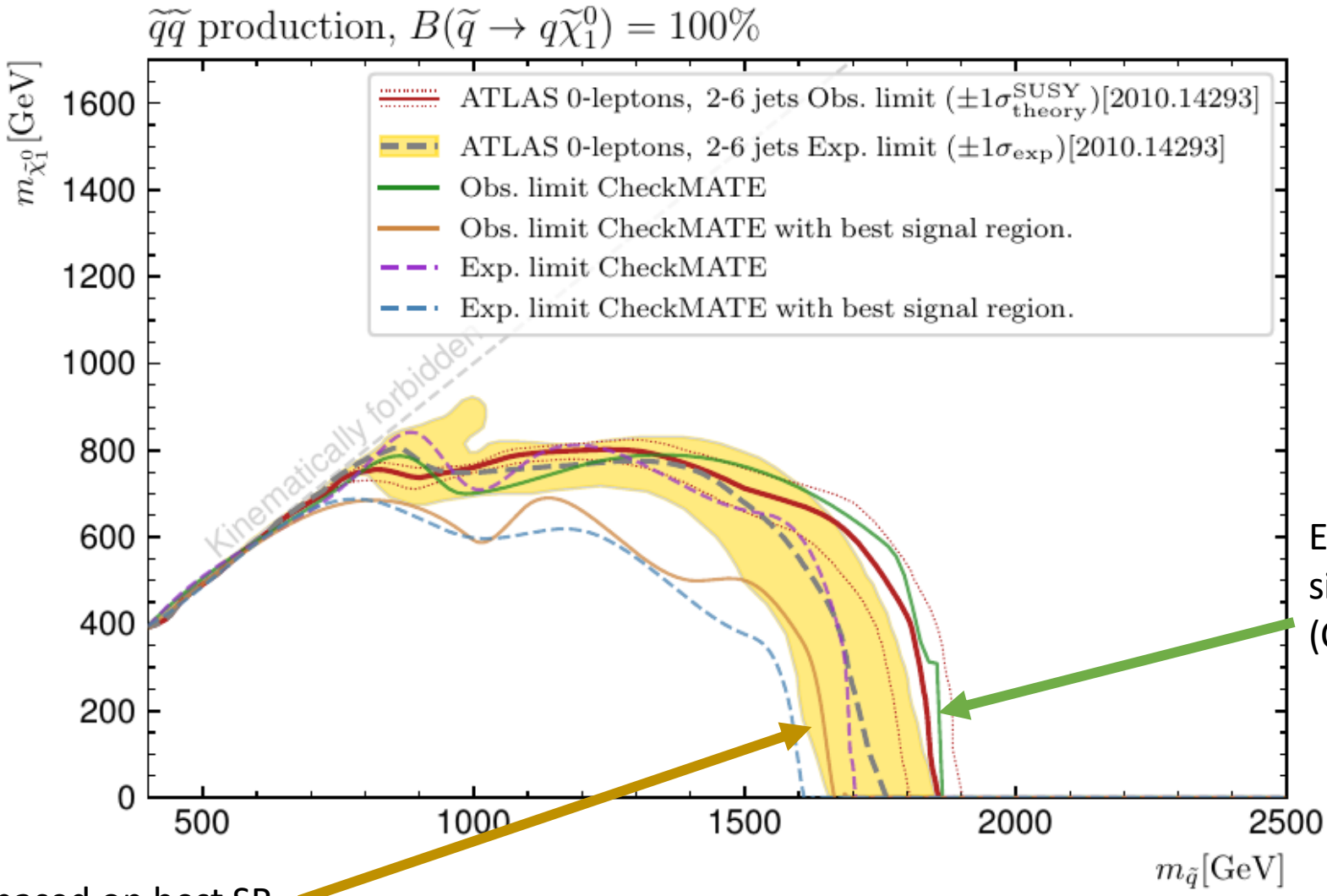
- *"In the simplified likelihood introduced herein, the background model is approximated with a single background sample, representing the total SM background rate in the different analysis channels. "*
- *"The pre-fit sample rate of the total background sample is set to the total post-fit background rate obtained in the background-only fit in the full likelihood"*
- *"…the complete set of nuisance parameters in the original full likelihood is reduced to a single constrained parameter… . It is constrained by a Gaussian G(α = 0 | α. σ = 1) and is correlated over all bins in each channel"*

$$L(n_{obs}|\mu,\theta) = \prod_{i=0}^{n_{bins}} \frac{(\mu s_i + b_i + \theta_b)^{n_{obs_i}} e^{-(\mu s + b_i + \theta_b)}}{n_{obs_i}} e^{-\frac{(\theta_b)^2}{2\sigma^2}}$$

Profile likelihood ratio test to find the 95% upper limit on signal strength (μ) using the CLs method.

We obtain comparable results for selected points using the full statistical model published by ATLAS in .json format

Validation of the ATLAS results



Exclusion based on simplified Likelihood (CheckMATE)

Exclusion based on best SR (CheckMATE)

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

- Squark pair production.

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

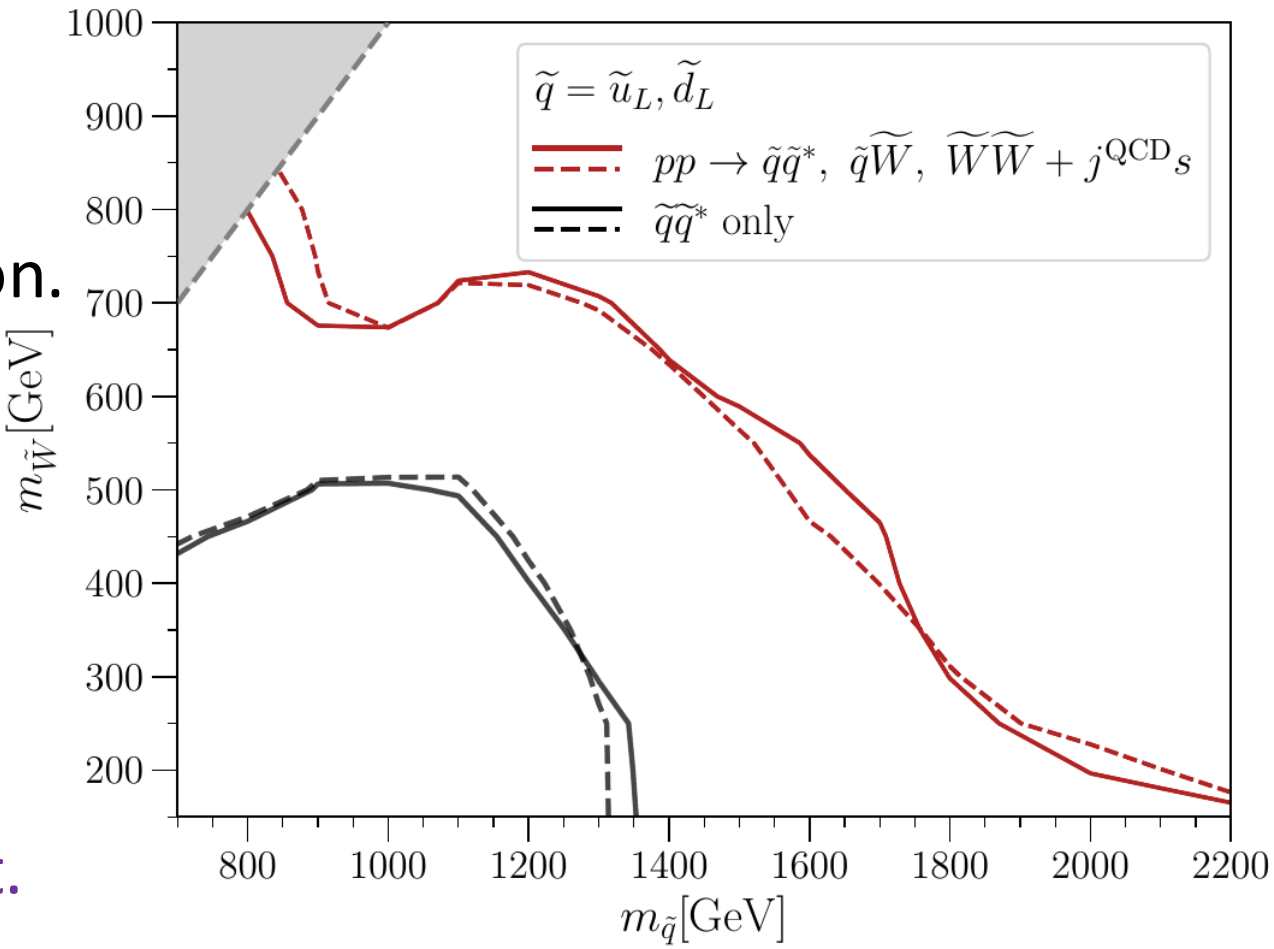
- Squark-wino associated production.

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

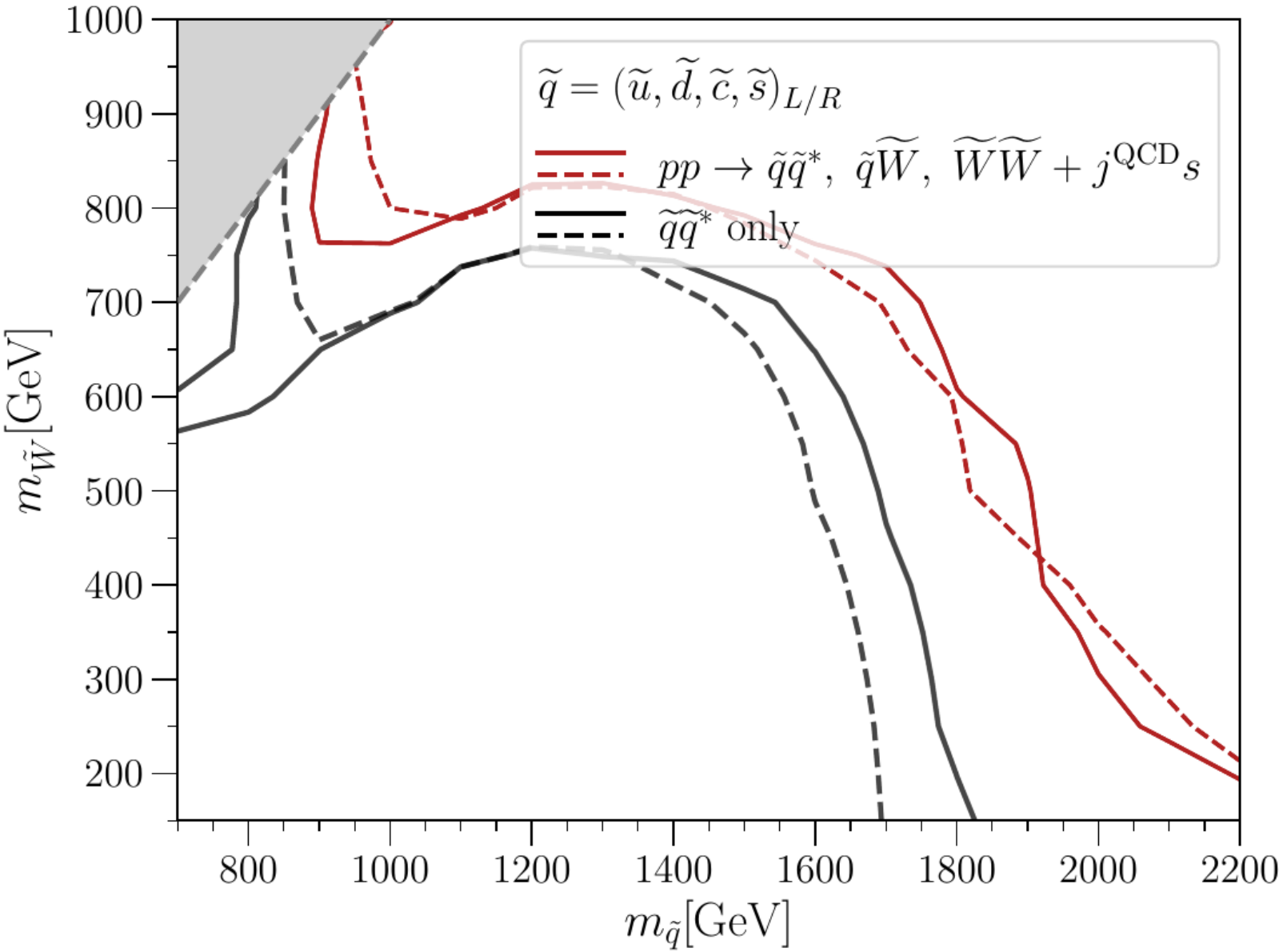
- Wino pair production + ISR jets.

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

Only 1st generation left squarks light.

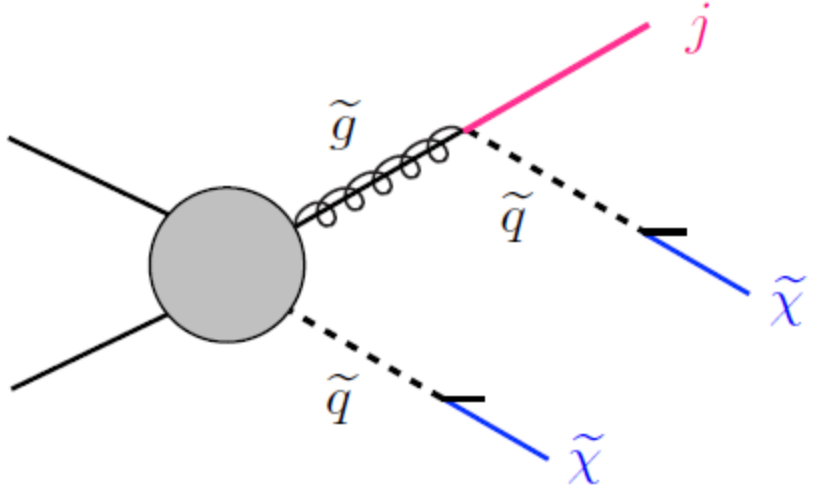


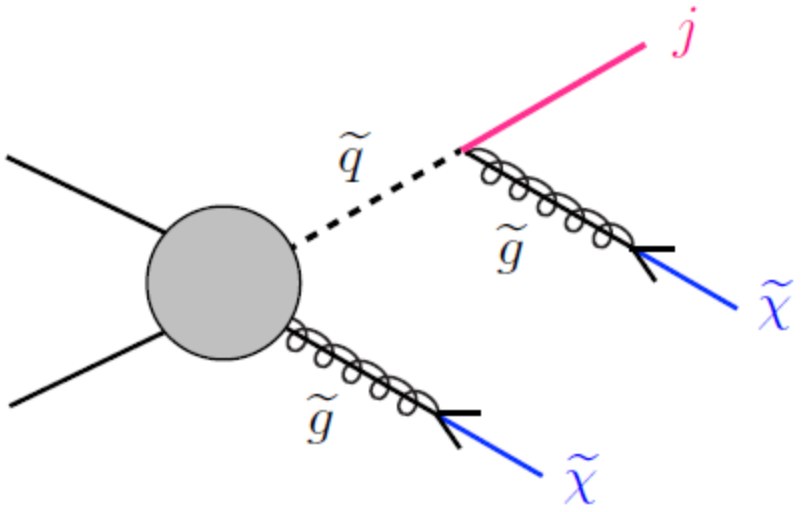
Also if squarks 8-fold degenerated.



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)**

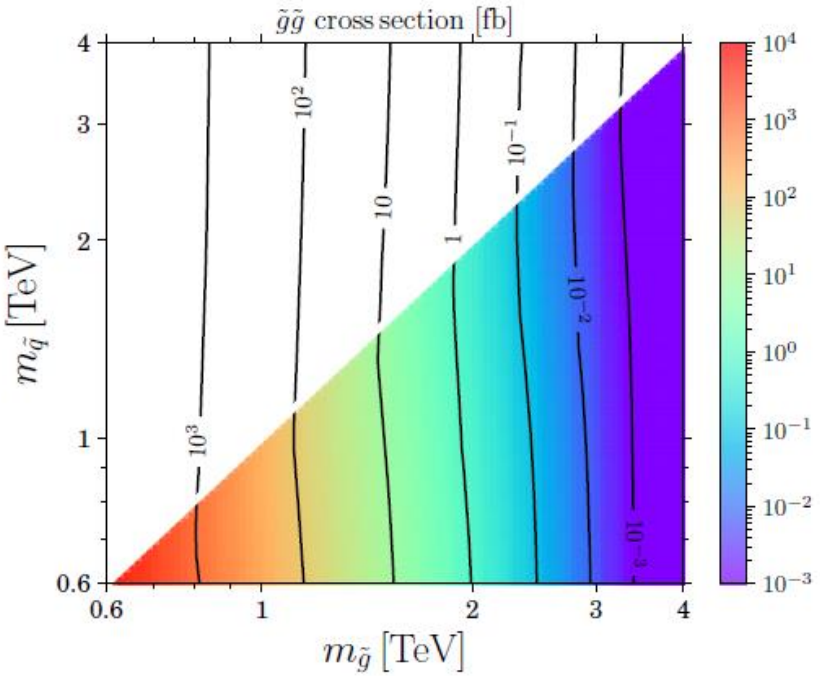
Case $m_{\tilde{q}} > m_{\tilde{g}}$:

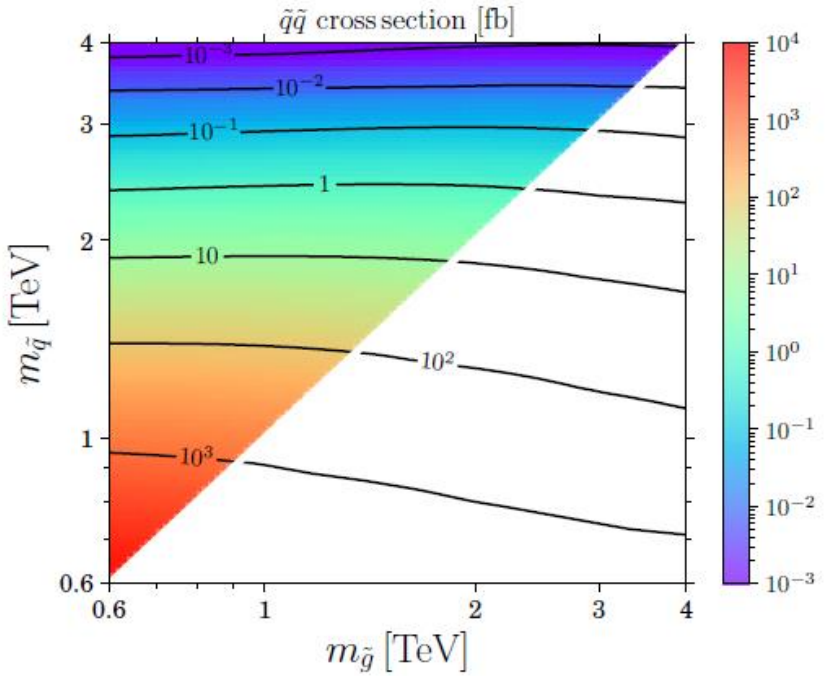
$pp \to \tilde{g}\tilde{q},\ \tilde{q} \to q\tilde{g}$ $\cdots$ **(b1)**

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

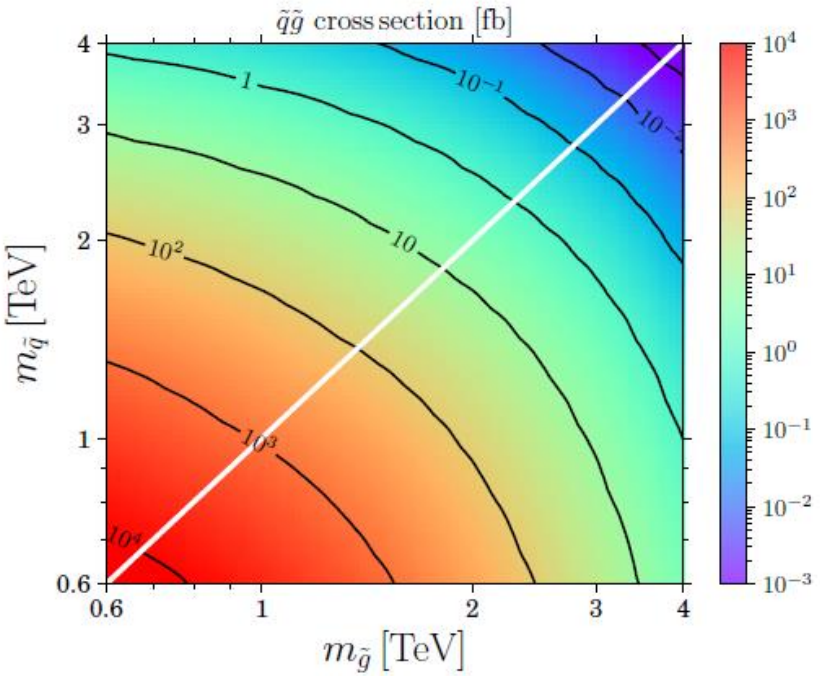
$pp \to \tilde{g}\tilde{g} + \mathrm{ISR}$ $\cdots$ **(b3)**

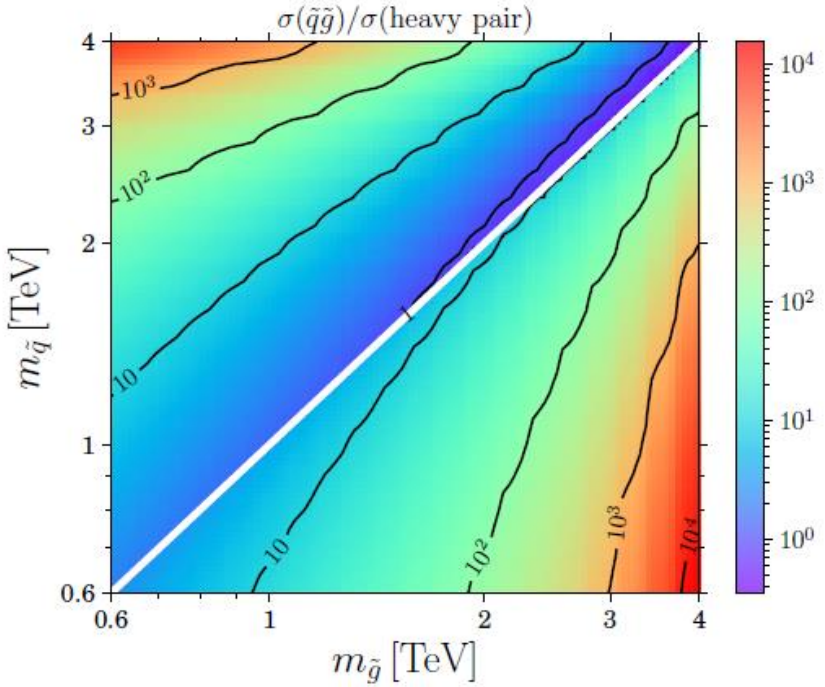
The cross section of the associated production is almost always larger than that of the (a2) and (b2) processes

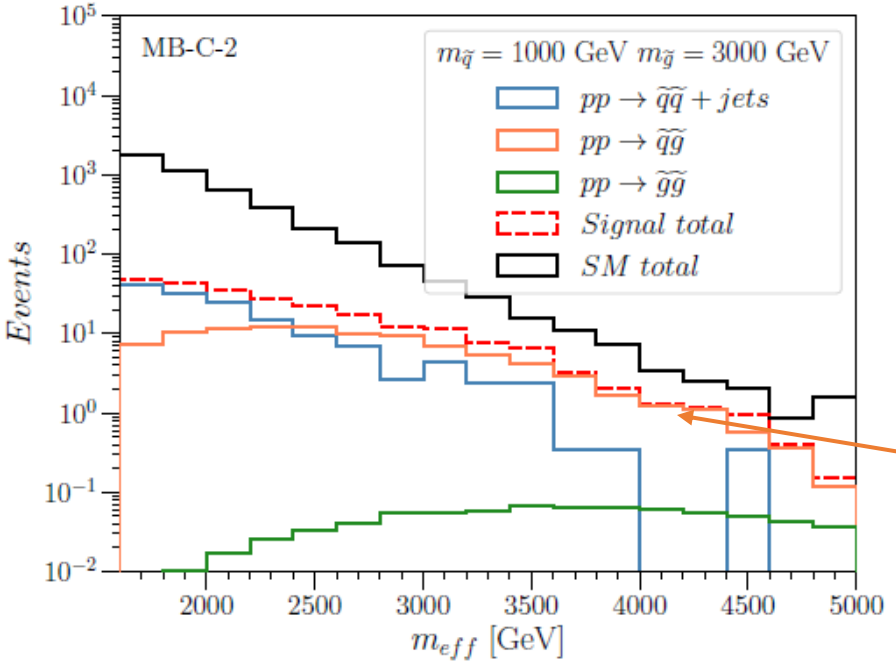


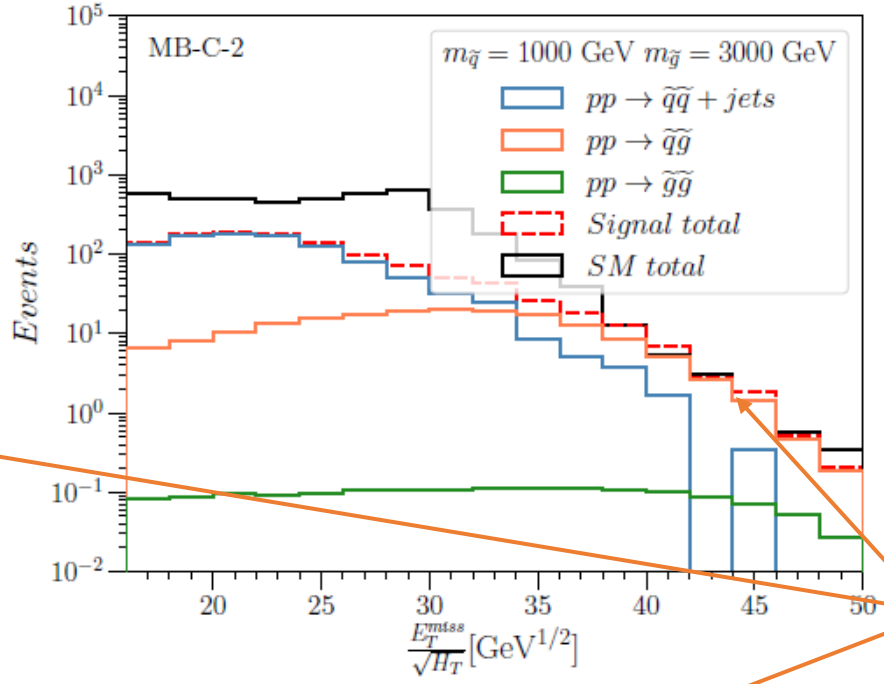


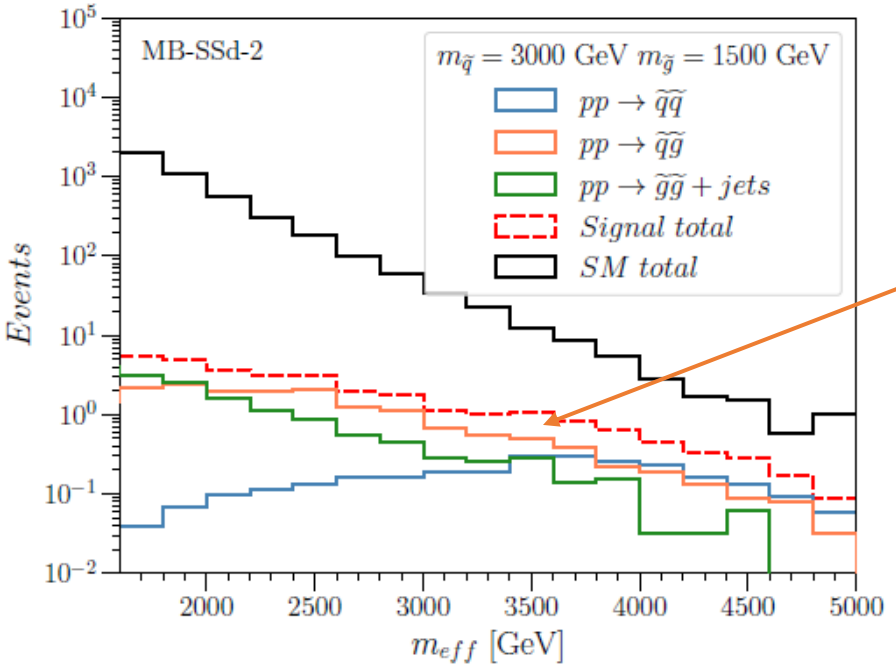
Relative rate of the associatted production is enhanced particulartly in the hierarchical mass regions .

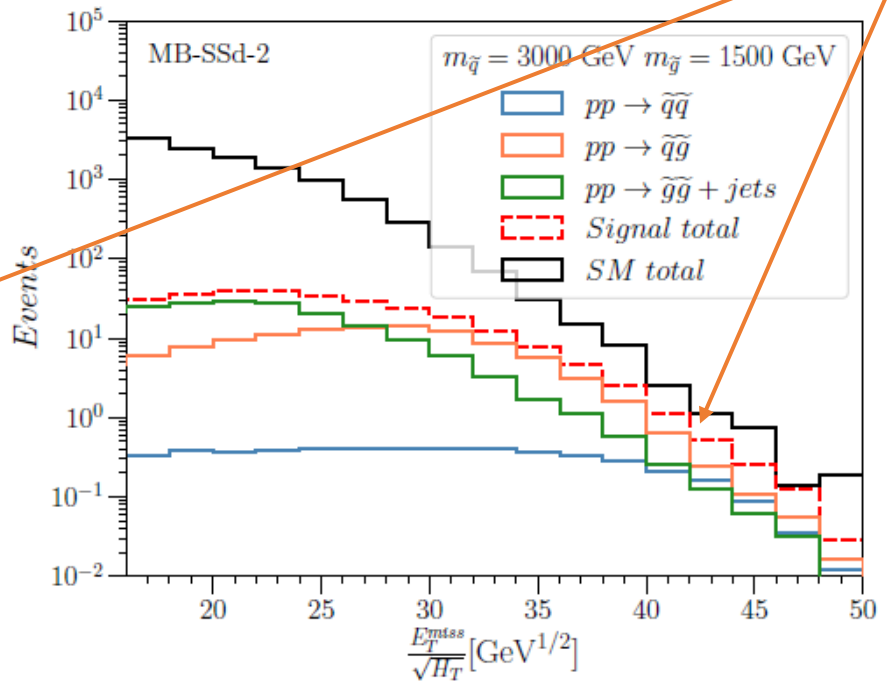






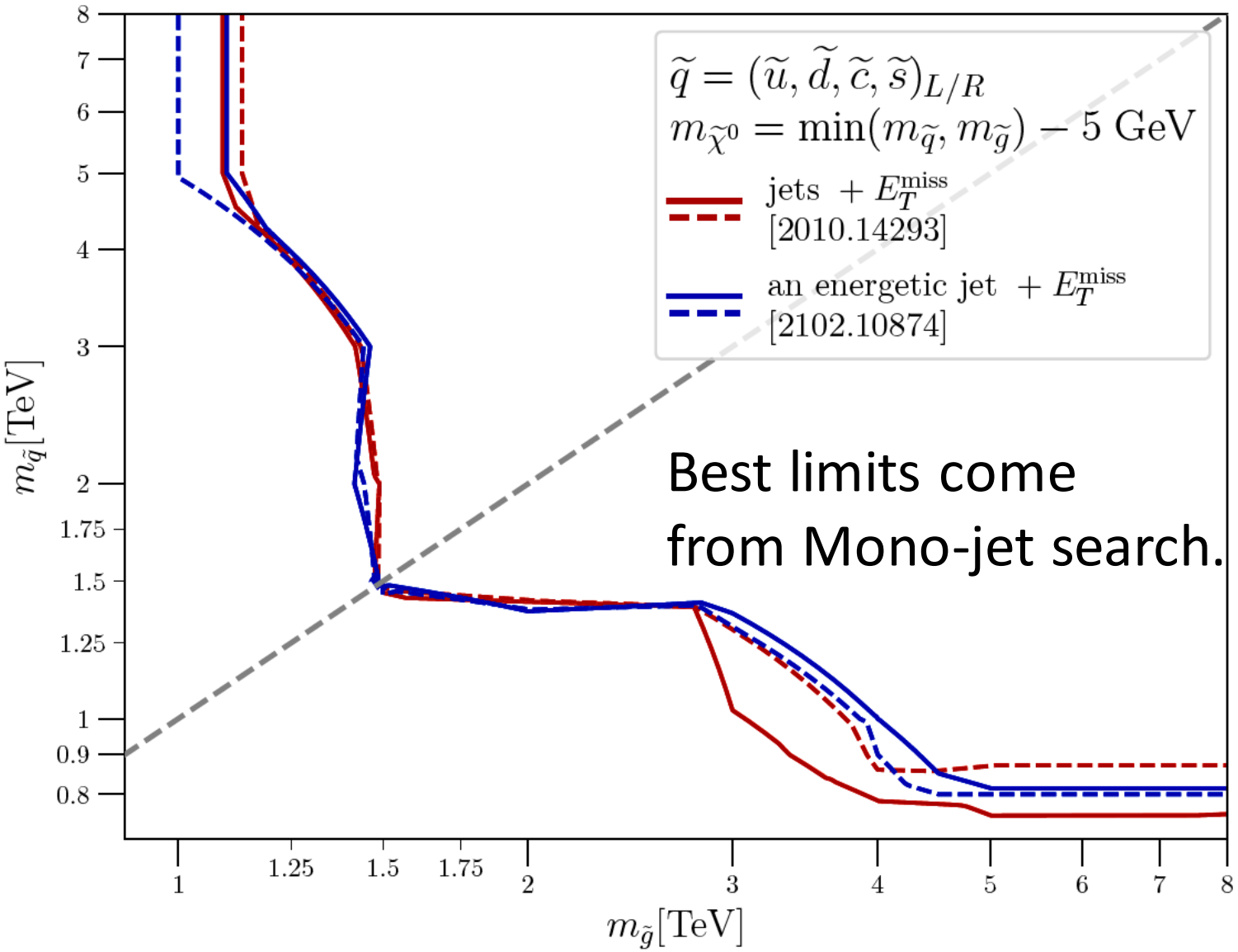






The gluino-squark associated production dominates the signal distributions for higher values of the discriminant variables. $E_T^{\text{miss}}/\sqrt{H_T}$ and m_{eff} .

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



Summary

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

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Understanding the Early Universe: interplay of theory and collider experiments

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