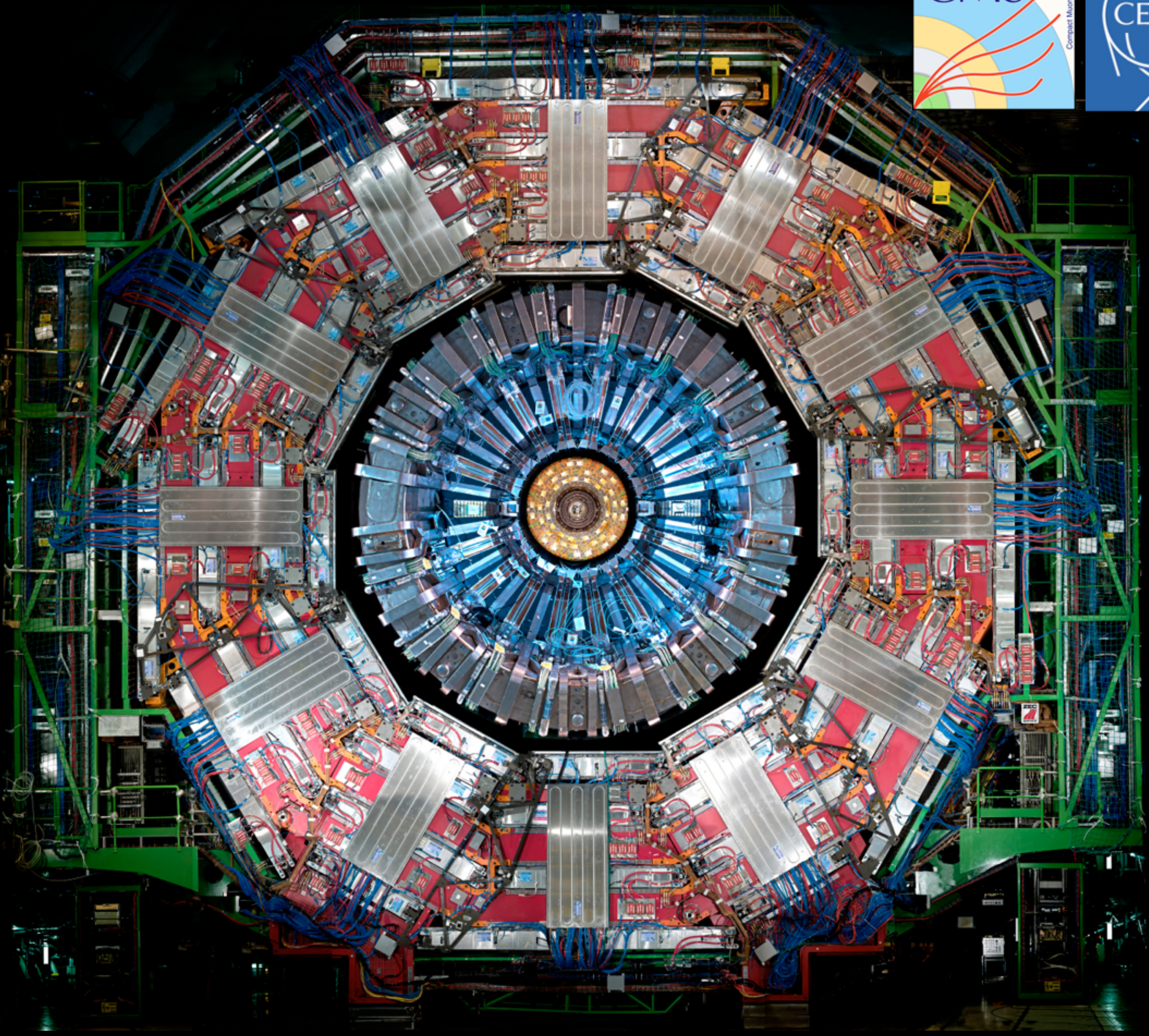
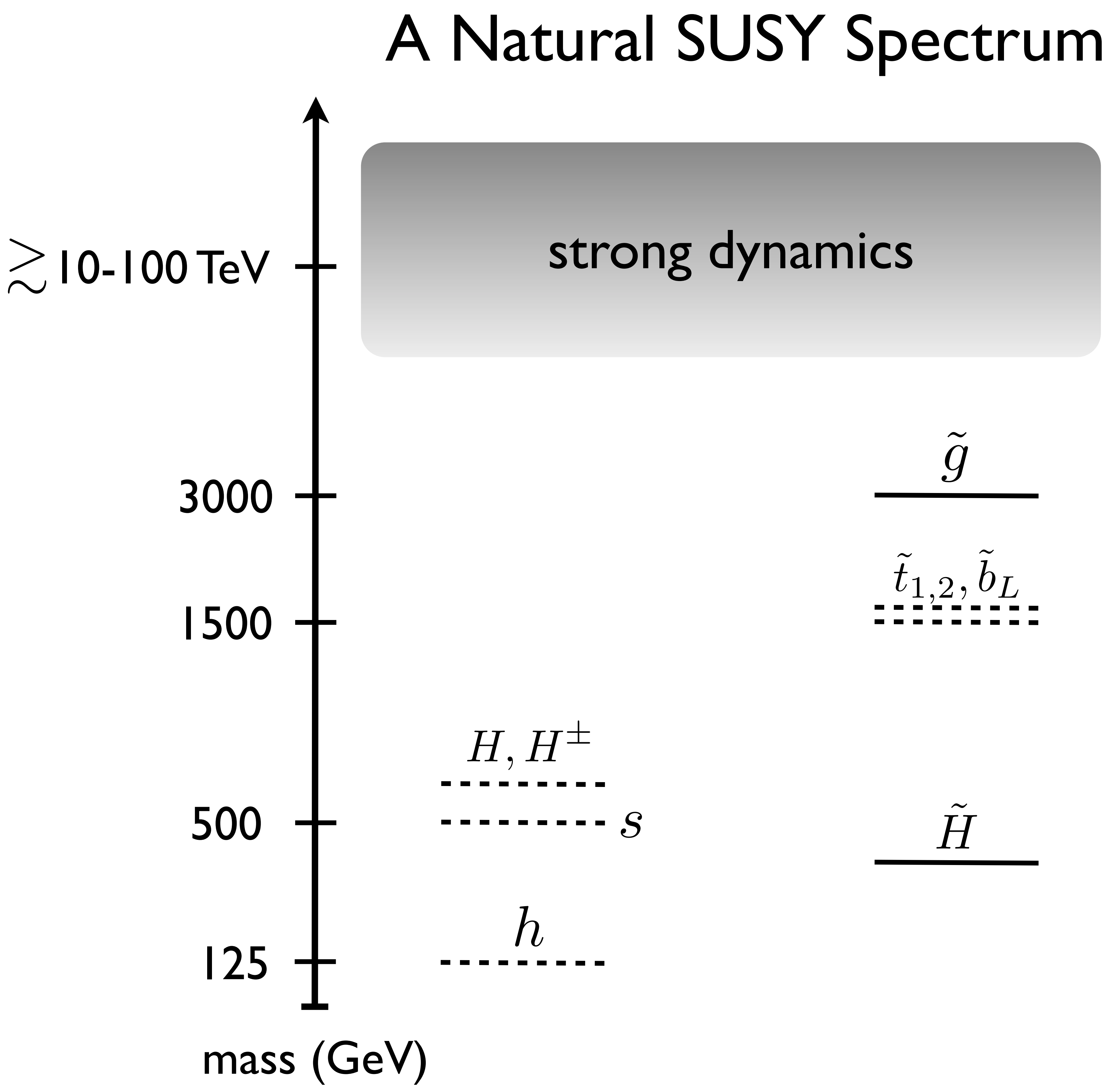
Searches for strongly-produced SUSY at CMS

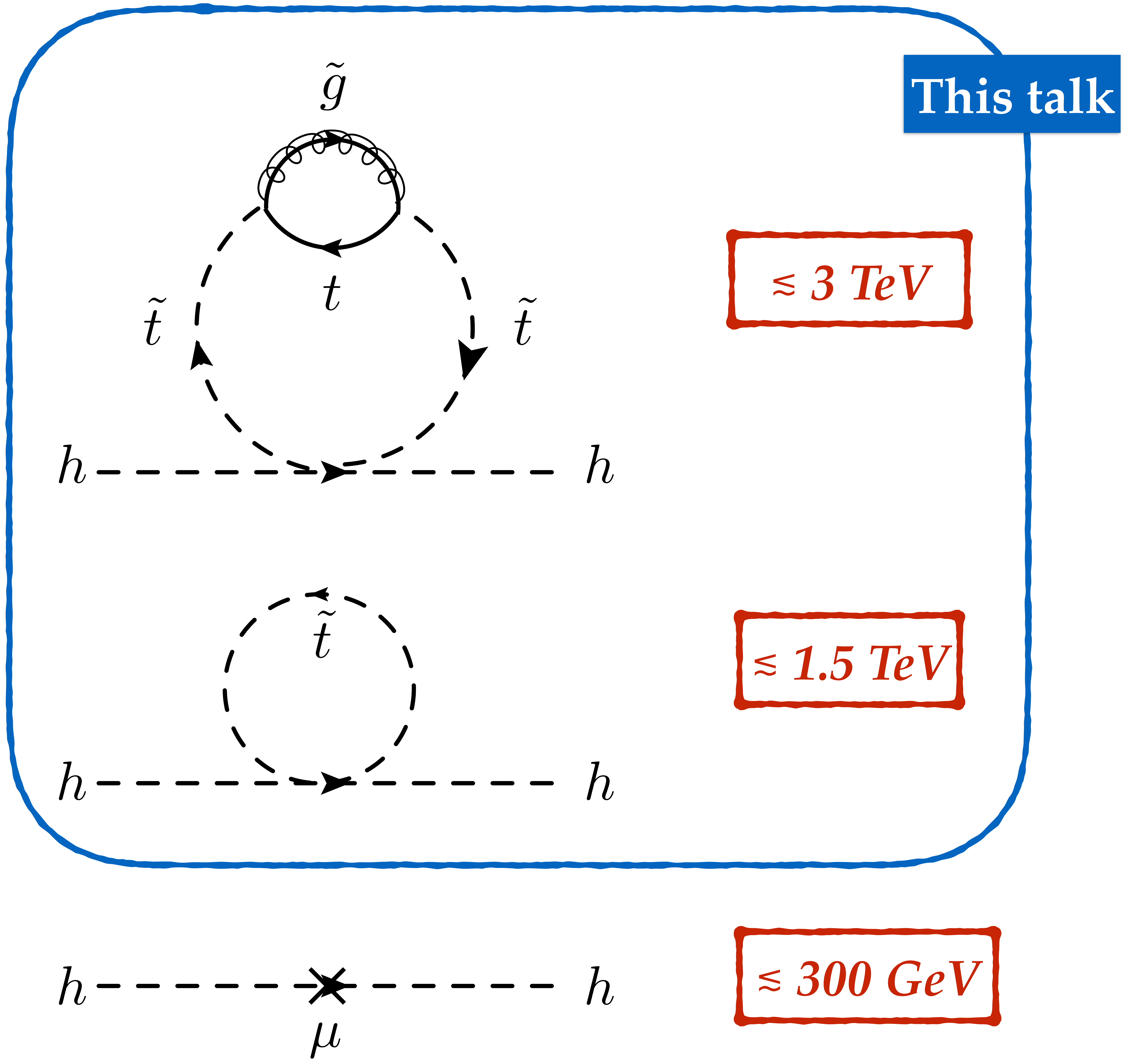
Ana Ovcharova
on behalf of the CMS Collaboration

July 5, 2018
ICHEP 2018, Seoul (South Korea)



Natural SUSY expectations

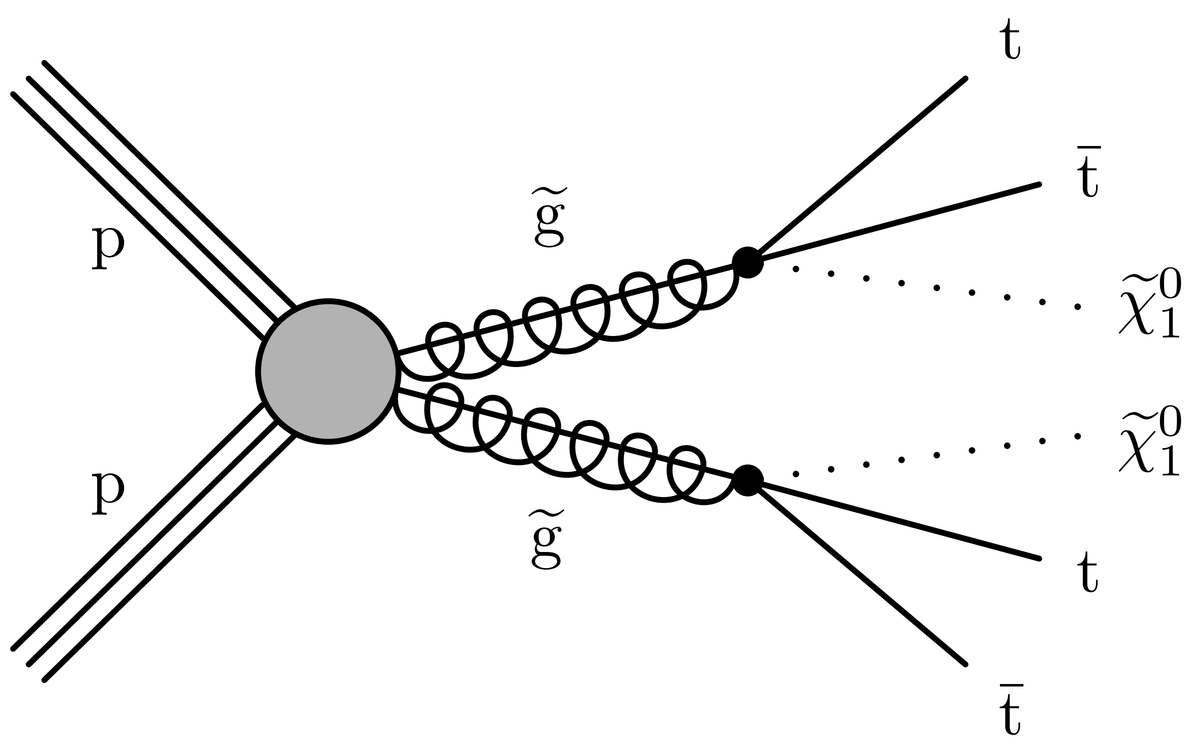


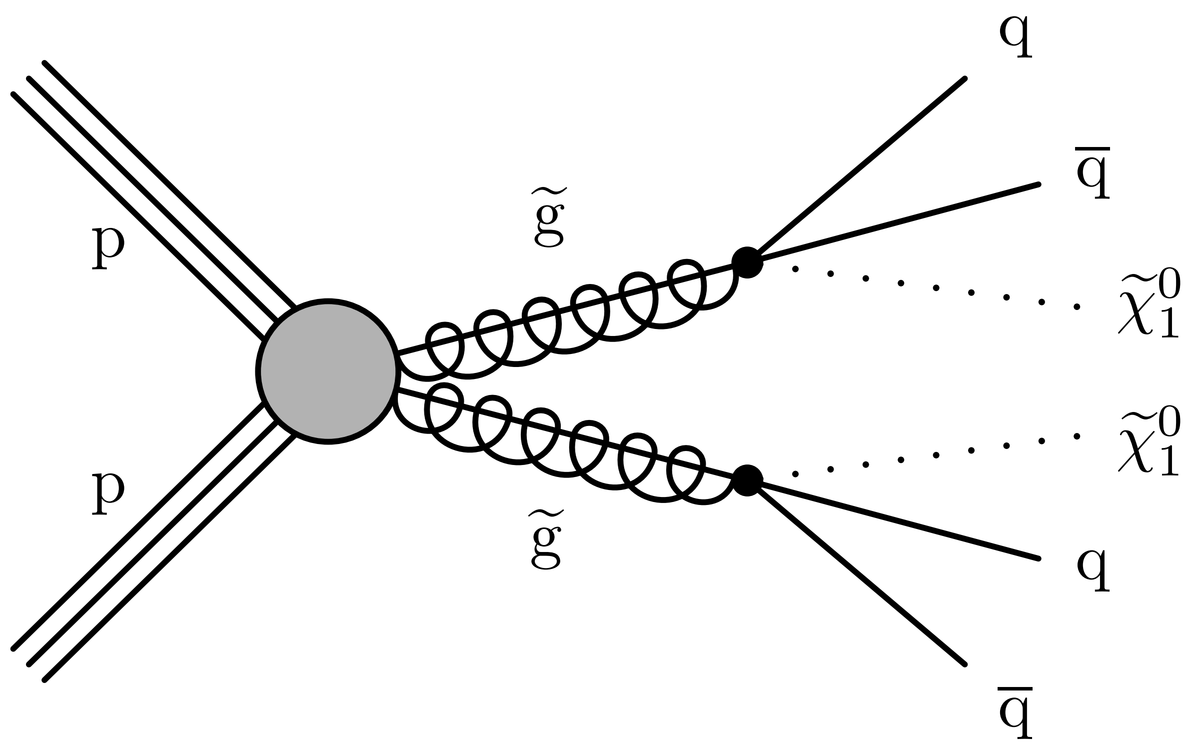


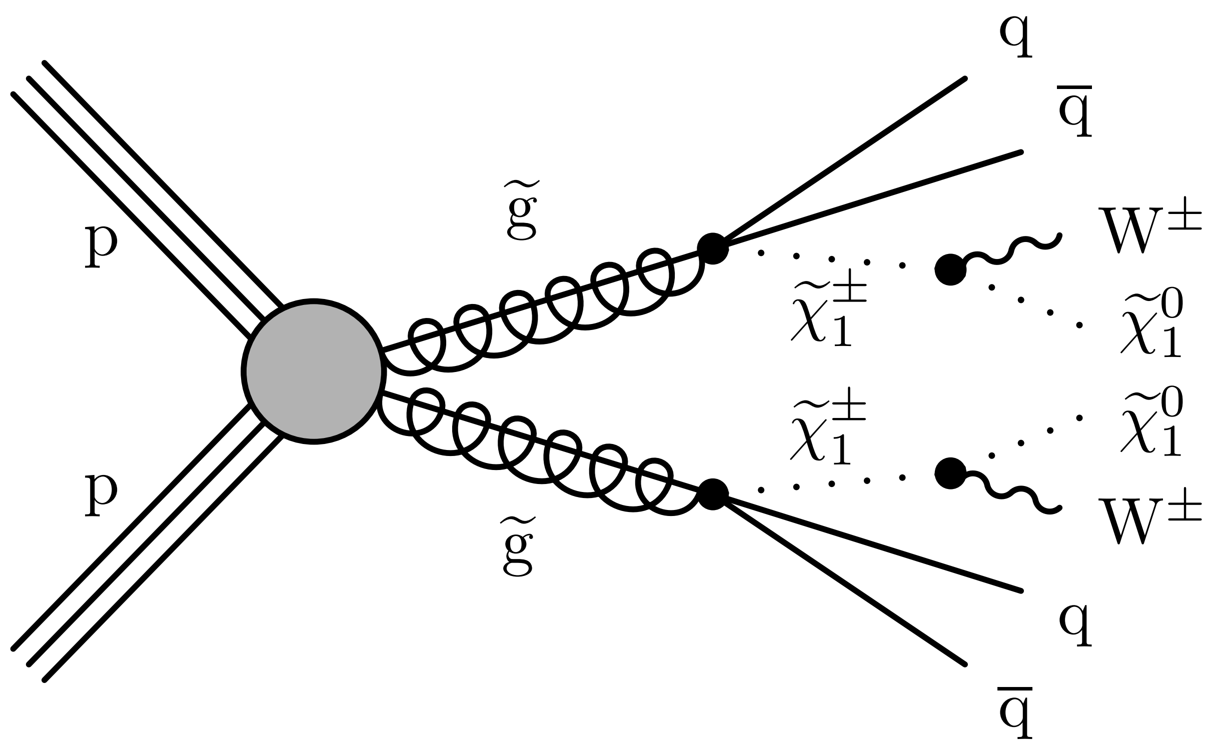
Hall, Pinner, Ruderman: arXiv:1112.2703

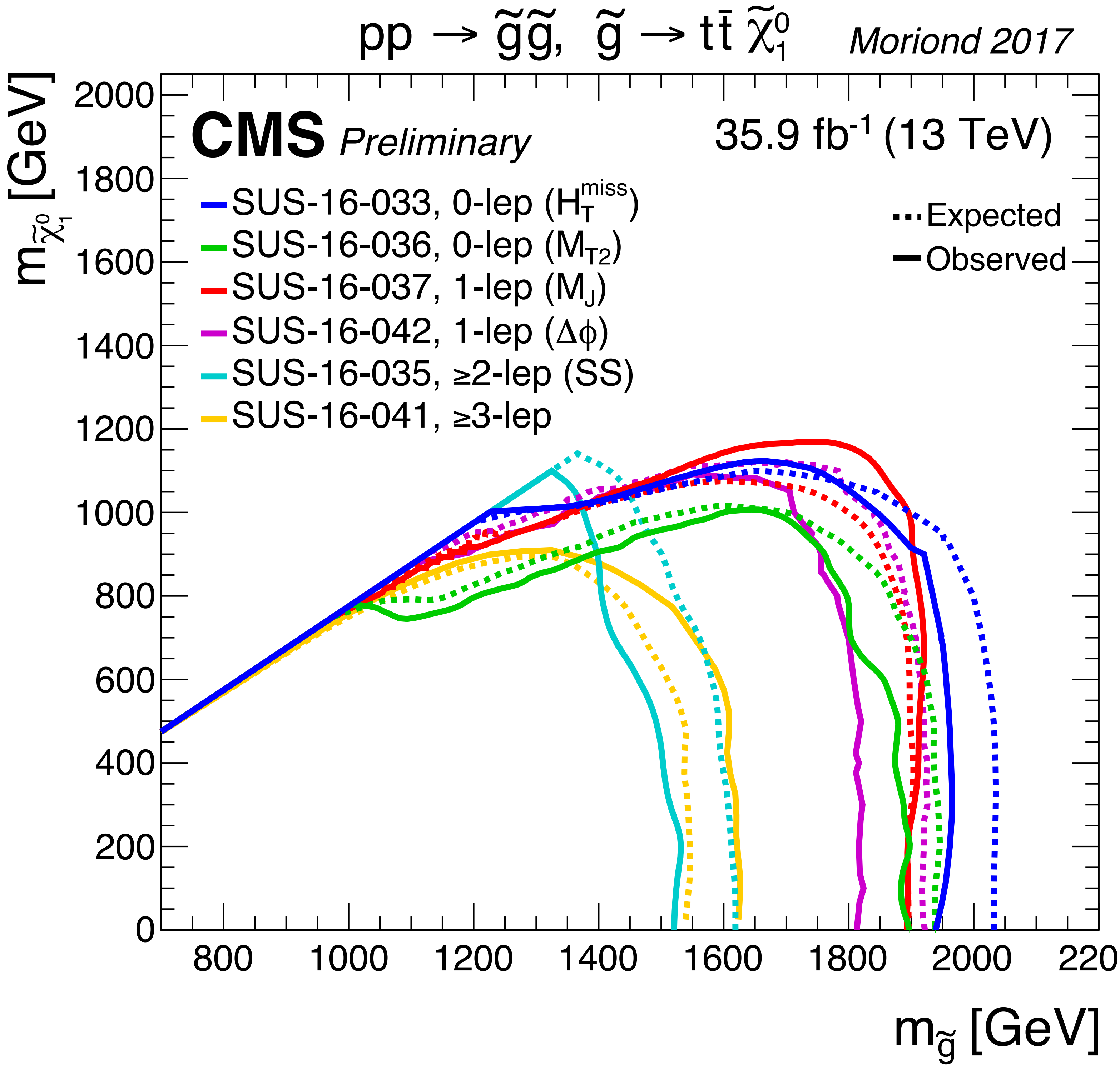
Diagrams by D. Shih

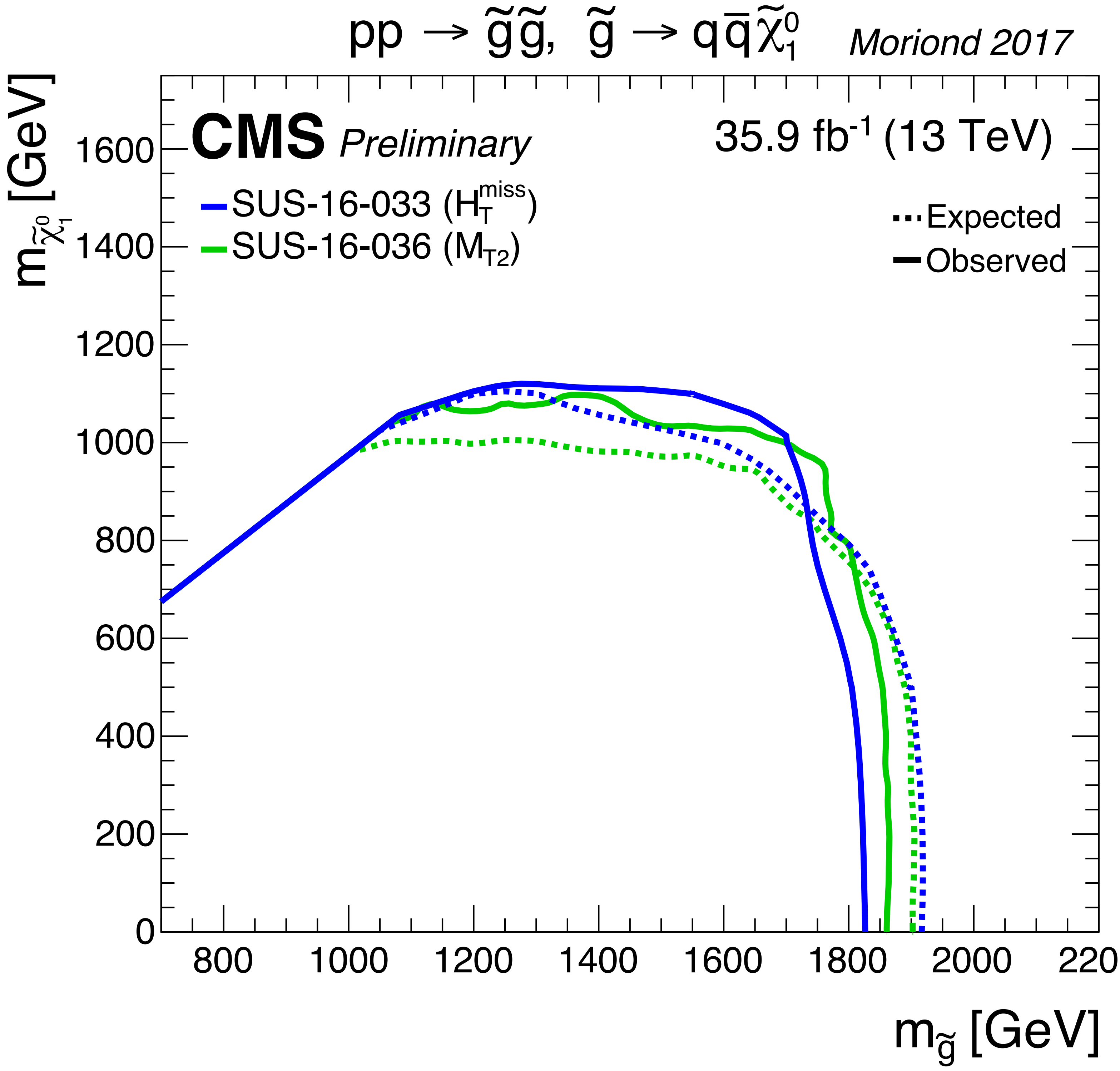
Gluino results

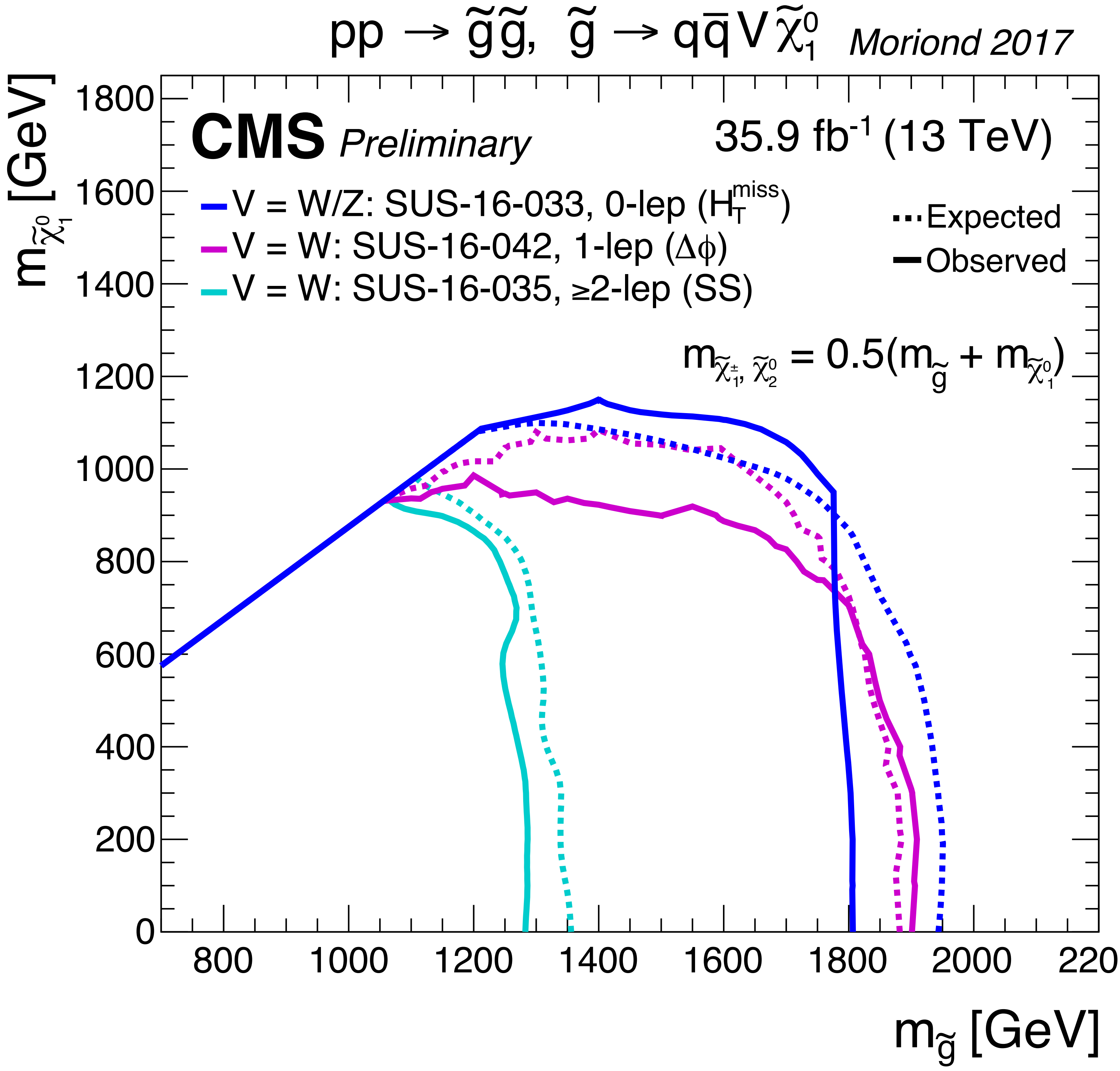






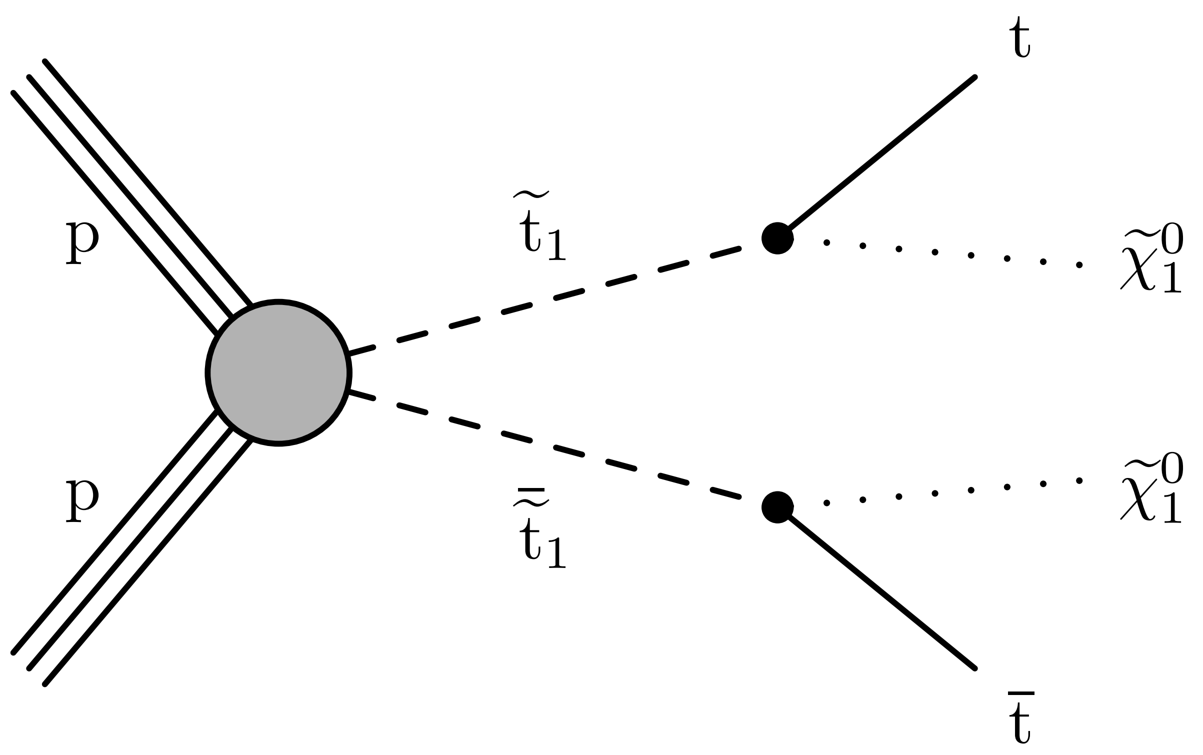


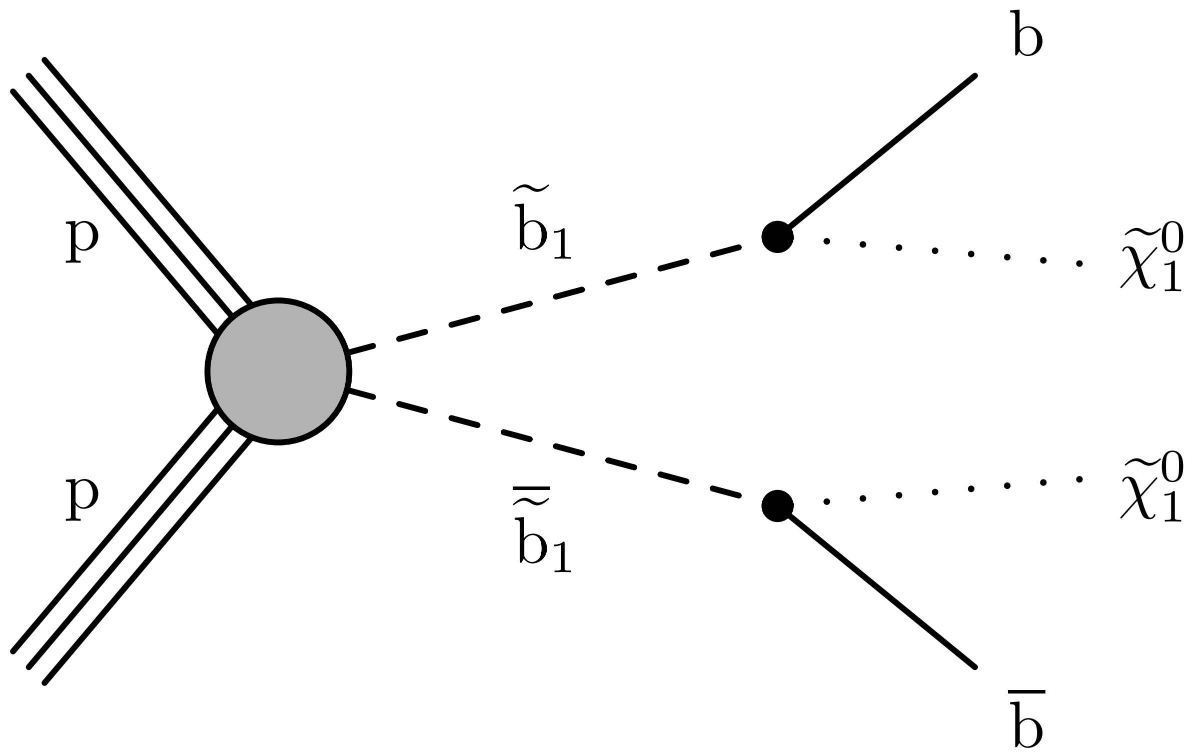


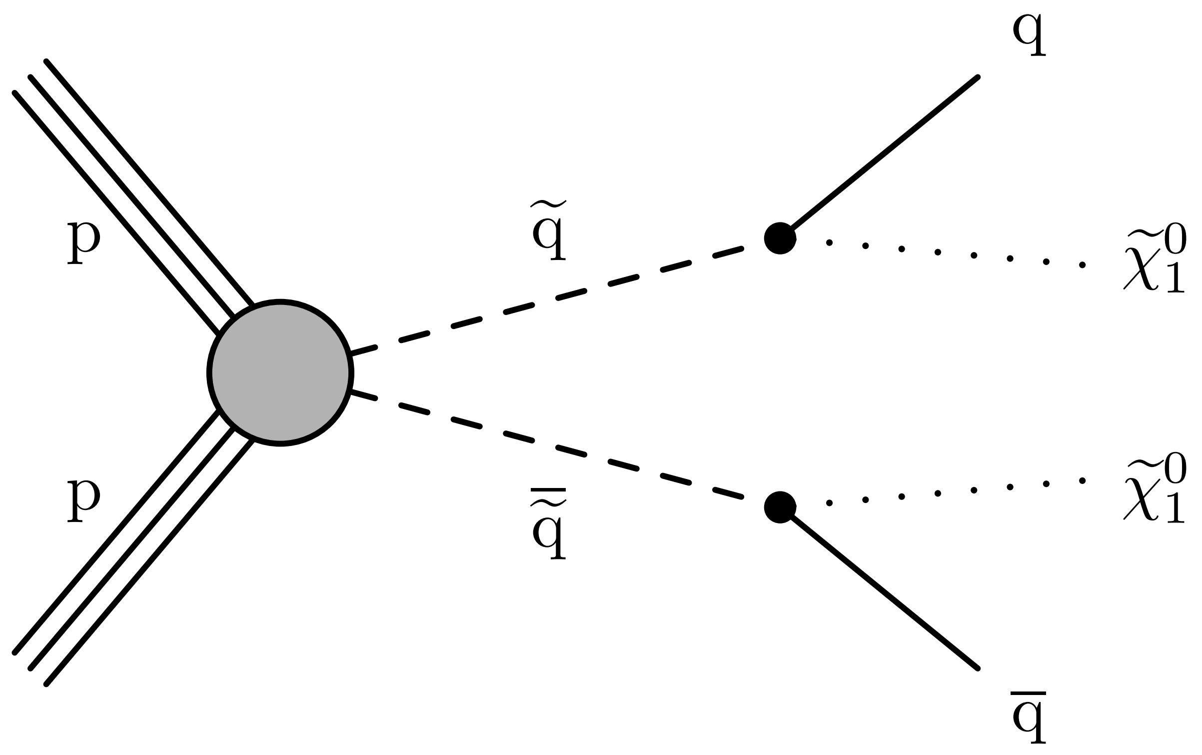


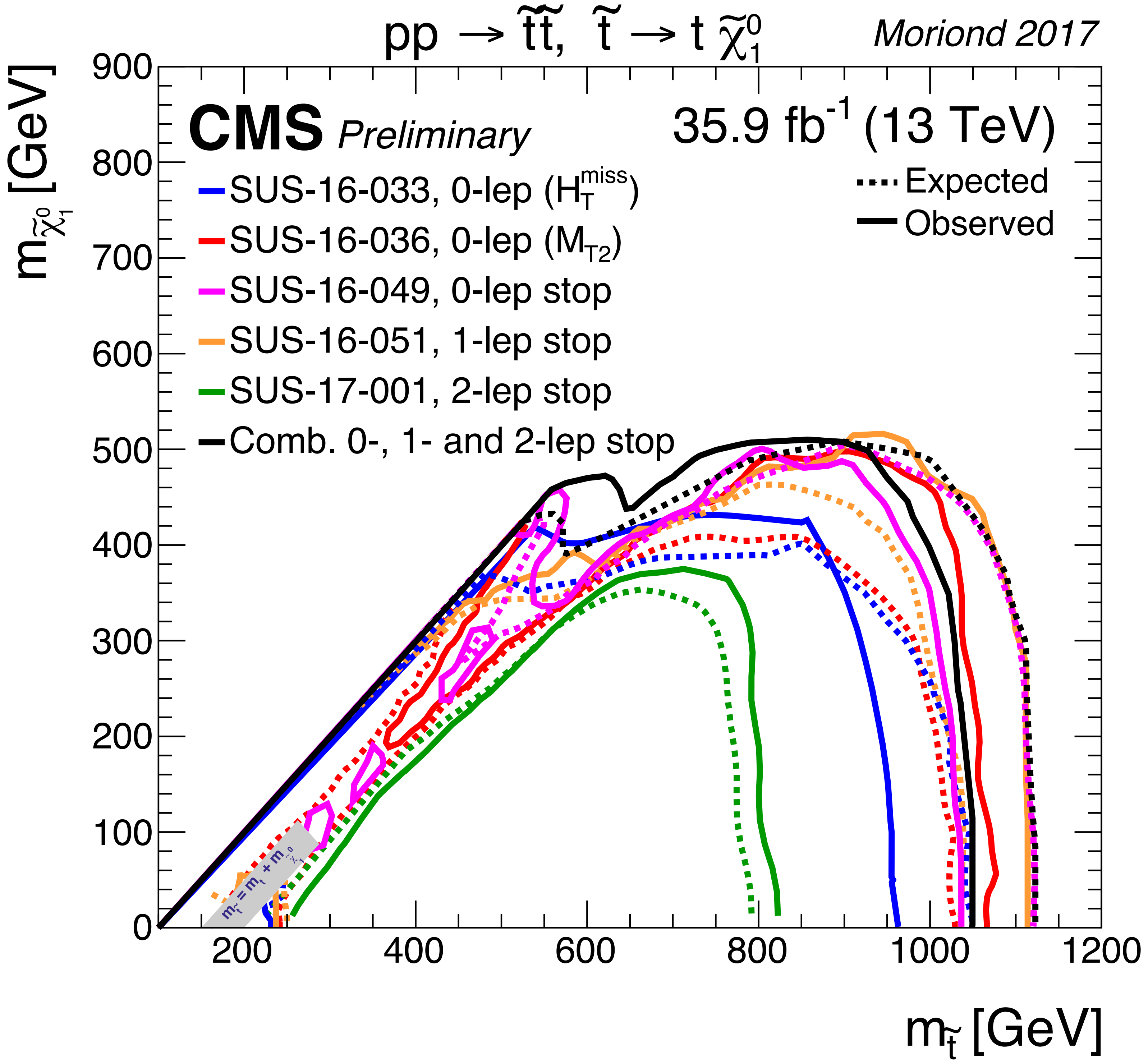
Similar reach of ~ 1.9 TeV in various final states as long as the event has high missing energy

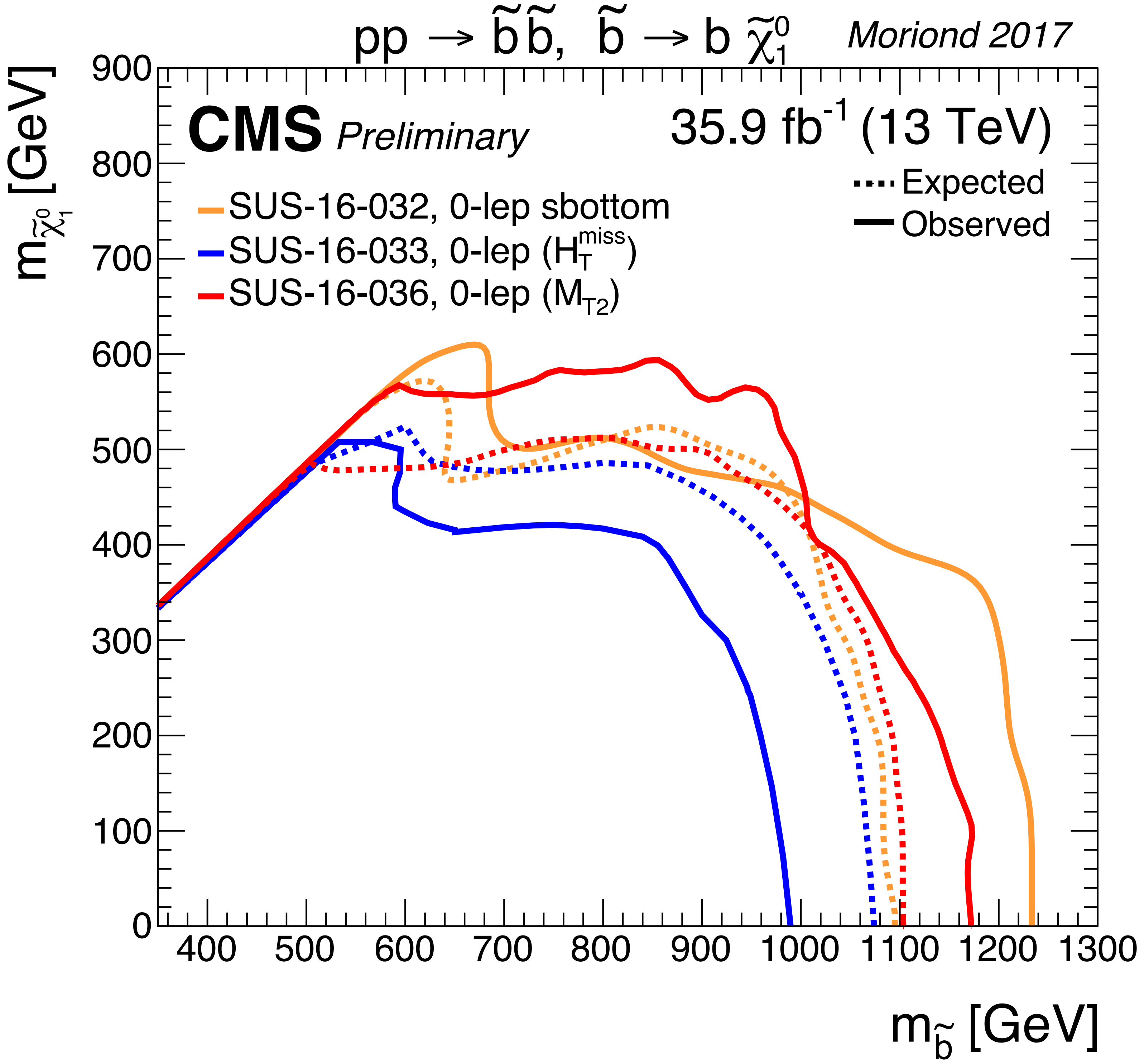
Squark results

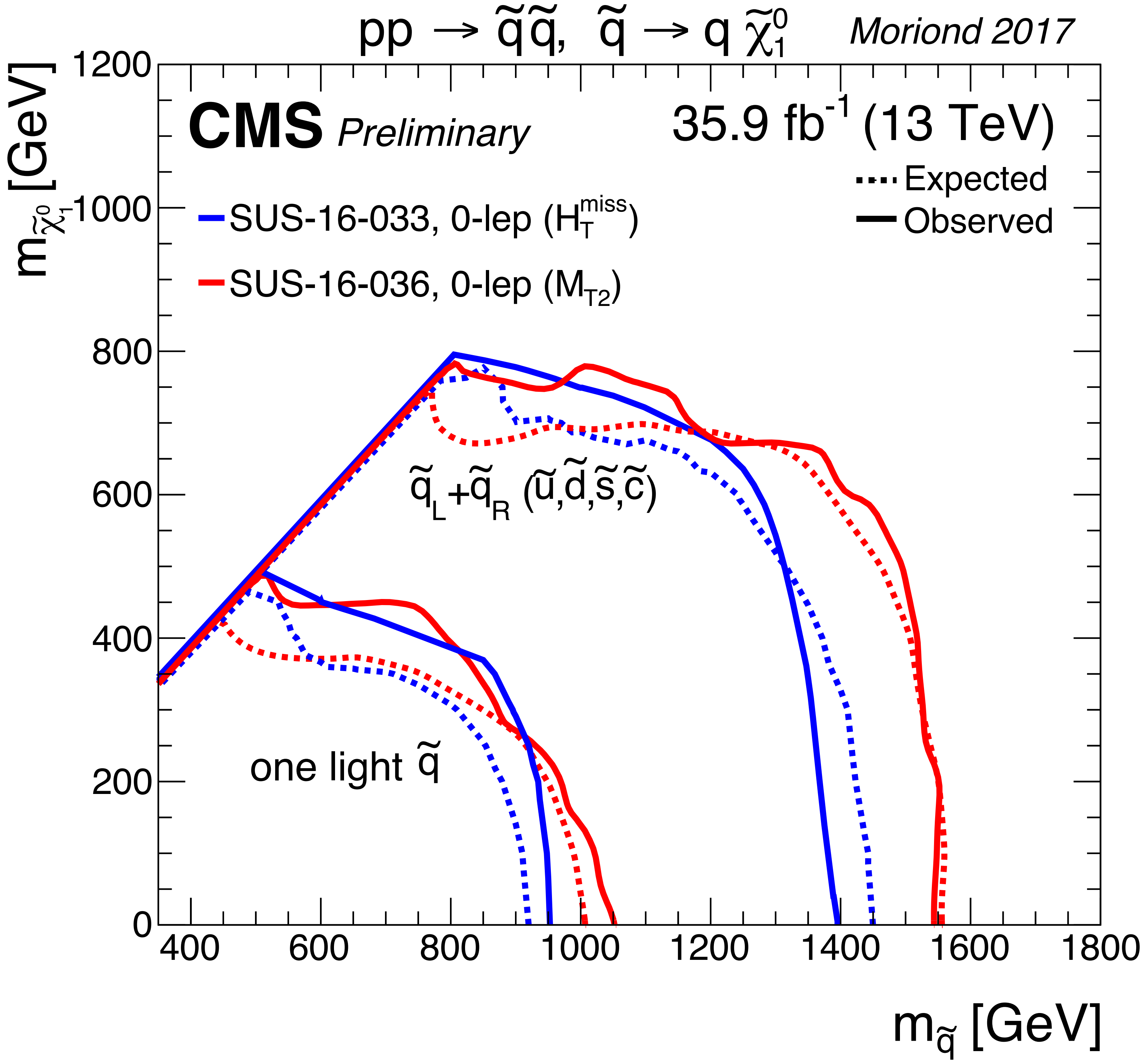












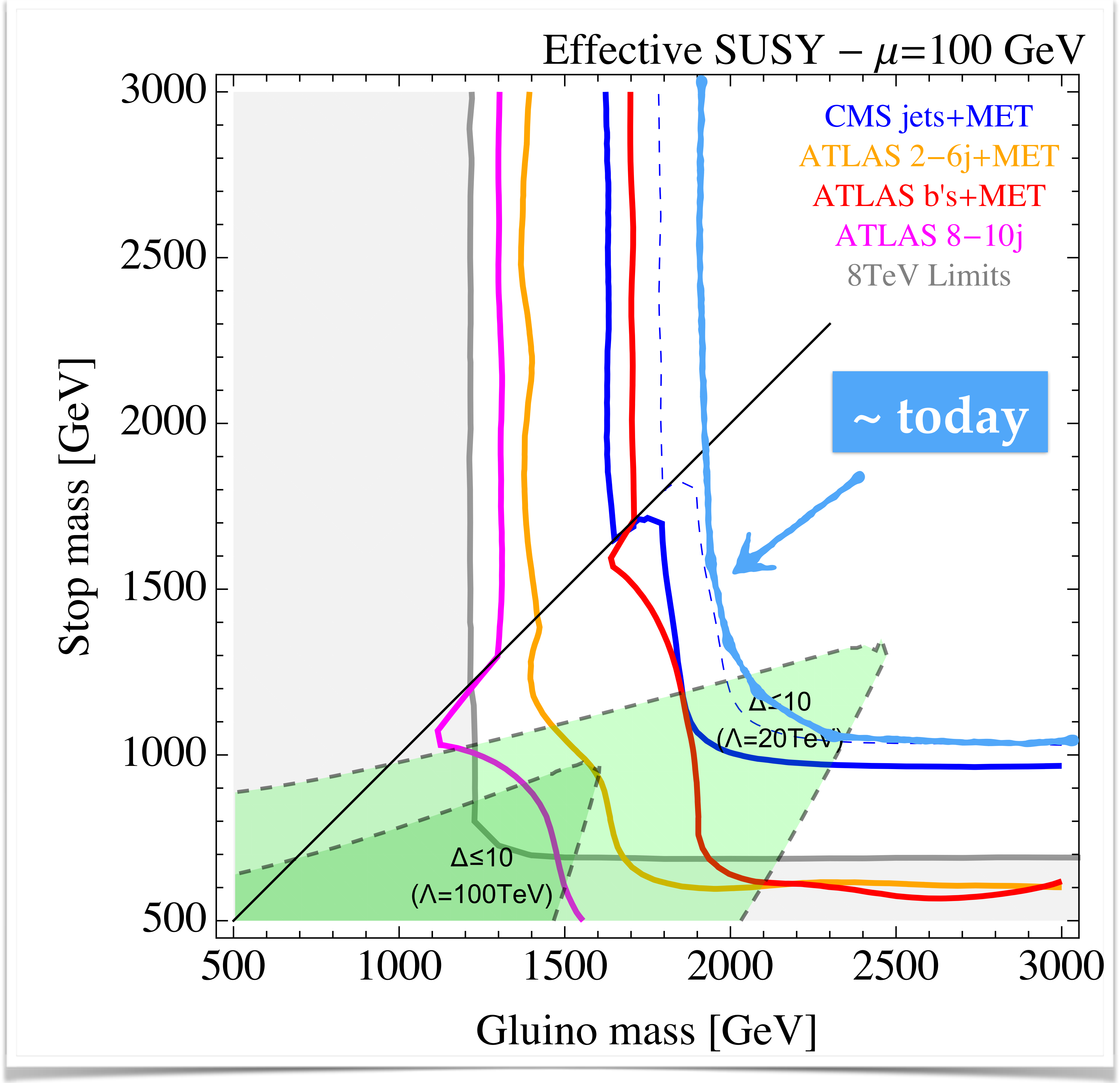
Again, similar reach of ~ 1.1 TeV for various flavors of squarks (when not assumed degenerate).

Status of Natural SUSY

Buckley, Feld, Macaluso, Monteux, Shih: arXiv:1610.08059

- ★ **Reinterpretation** of SUSY coverage based on results from 13fb^{-1} dataset shown at ICHEP’16
  - ✦ assuming Higgsino mass ≲ 300 GeV
  - ✦ in context of various SUSY breaking messenger scales

- ★ Natural SUSY models with **high missing energy** signatures now have very **limited room left** for realization

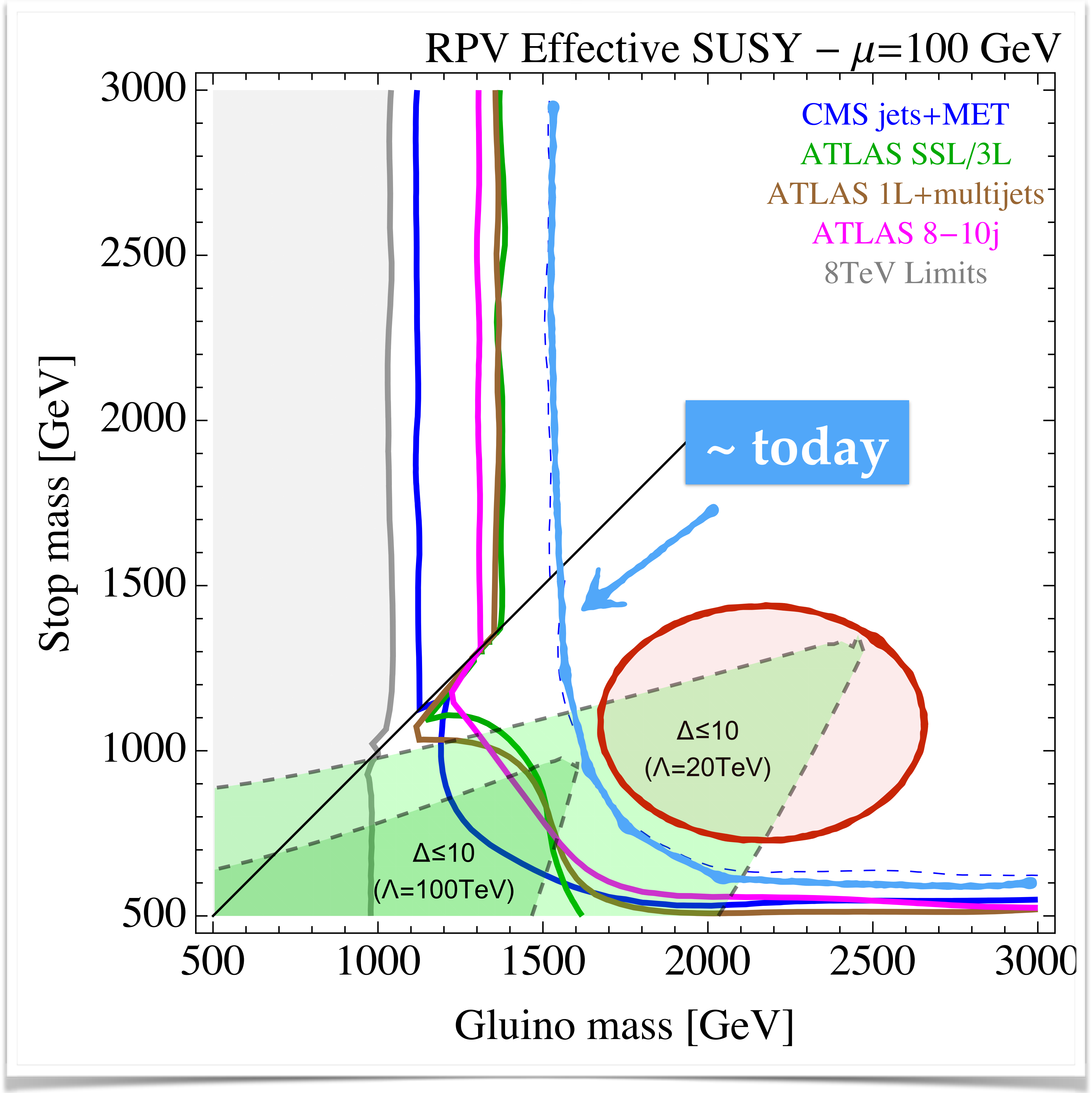


Natural SUSY with high MET

Status of Natural SUSY

Buckley, Feld, Macaluso, Monteux, Shih: arXiv:1610.08059

- ★ **Reinterpretation** of SUSY coverage based on results from 13fb^{-1} dataset shown at ICHEP’16
  - ✦ assuming Higgsino mass ≲ 300 GeV
  - ✦ in context of various SUSY breaking messenger scales
- ★ Natural SUSY models with **high missing energy** signatures now have very **limited room left** for realization
- ★ Alternative scenarios leading to **low missing momentum** such RPV / Stealth SUSY still offer a **significant unexplored phase-space** with better than 10% tuning for low messenger scales



Natural SUSY with low or no MET

Exploring beyond ...

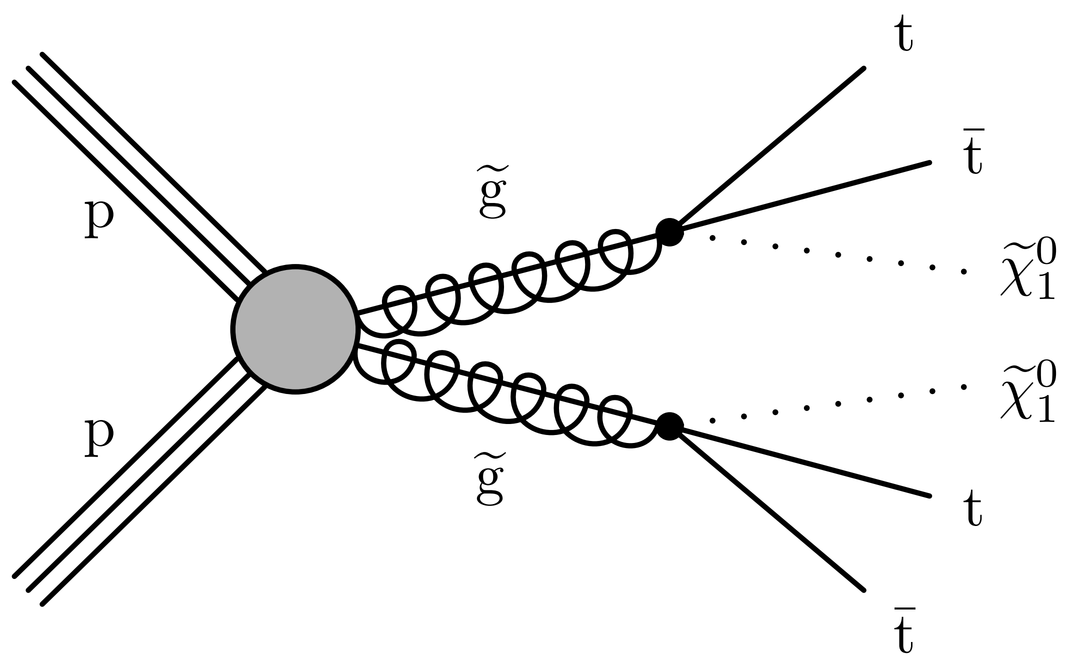
Vanilla SUSY

High Missing Energy

Long-lived particles

Example:

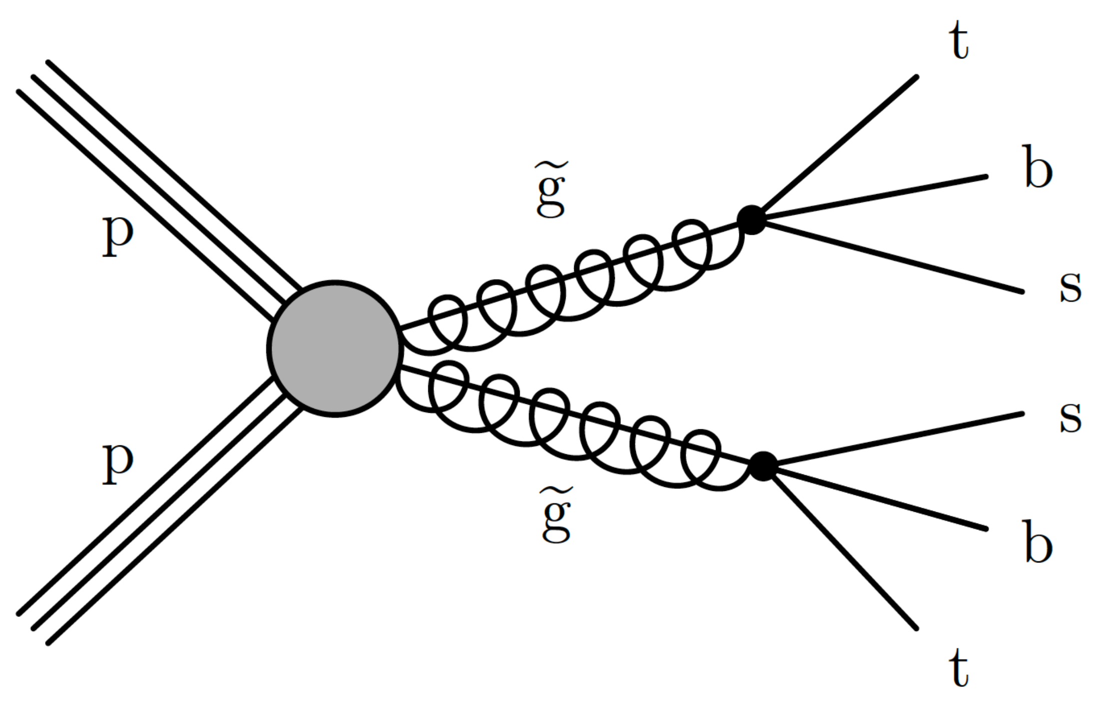
Split SUSY



No Missing Energy

Example:

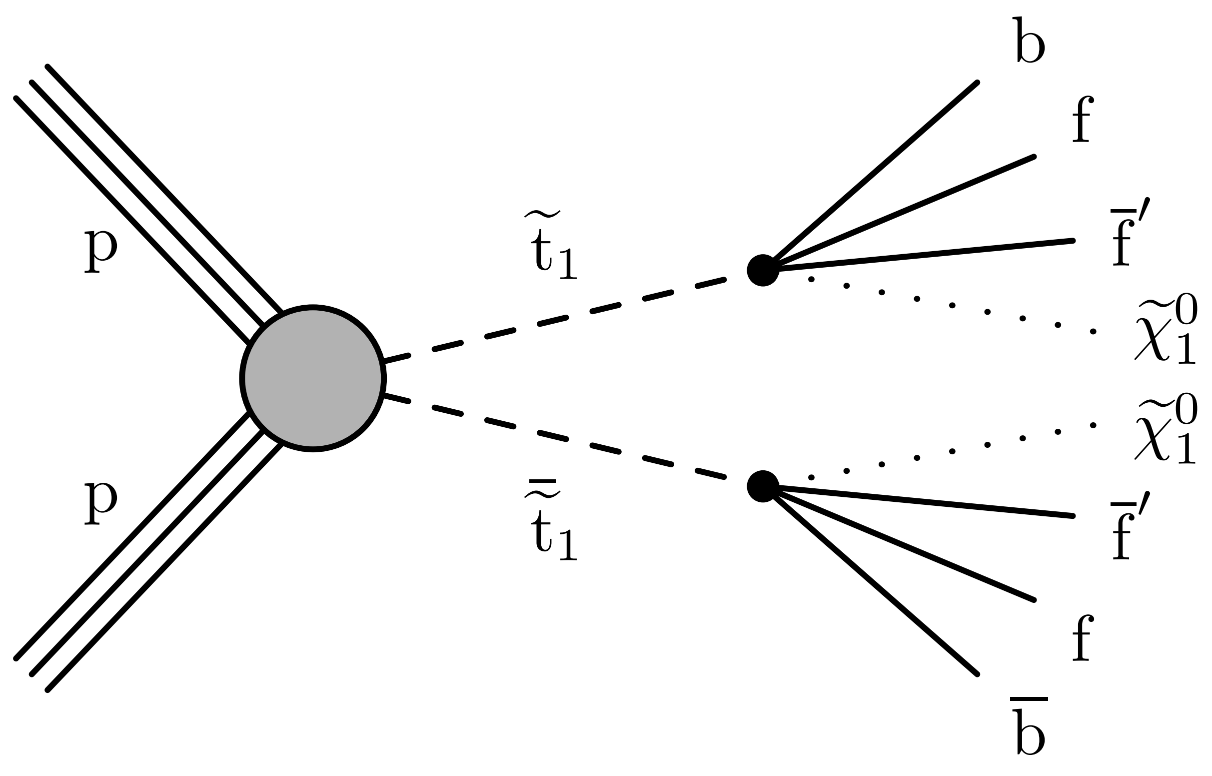
RPV SUSY



Soft decay products

Example:

Compressed SUSY

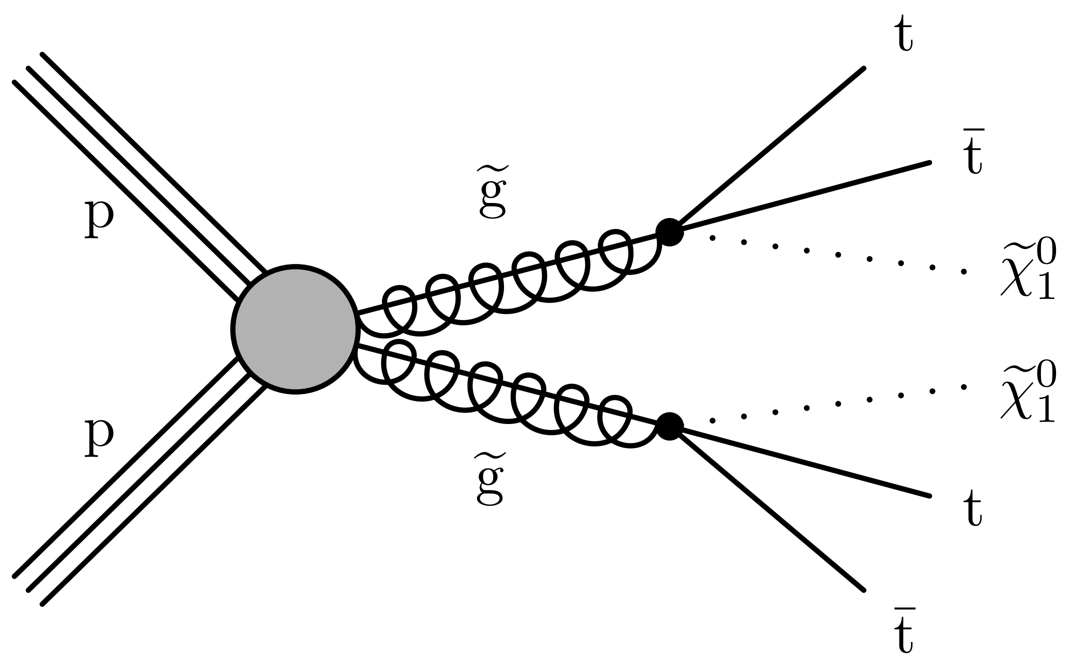


Exploring beyond …

Vanilla SUSY
High Missing Energy

Long-lived particles

Example:
Split SUSY

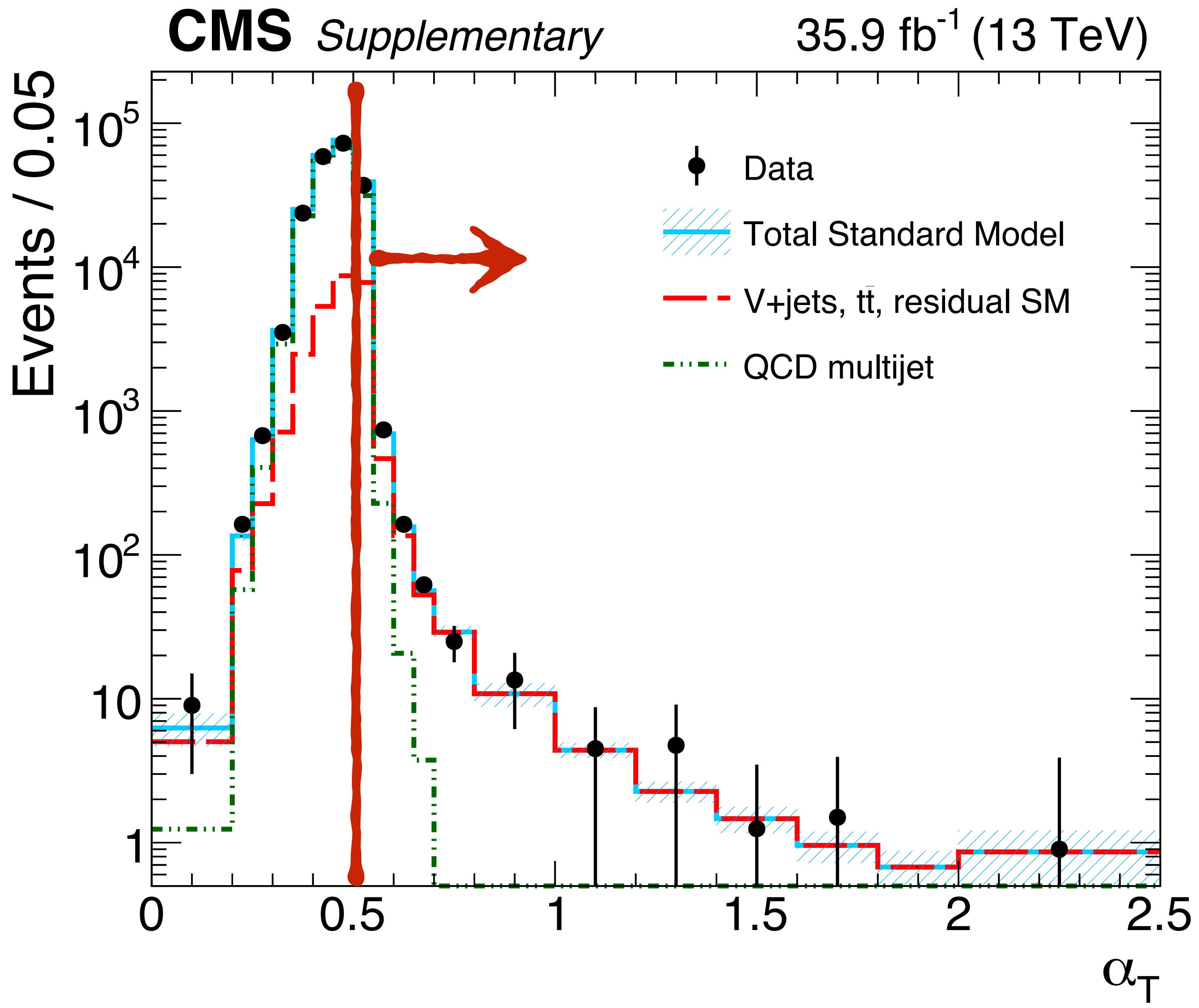


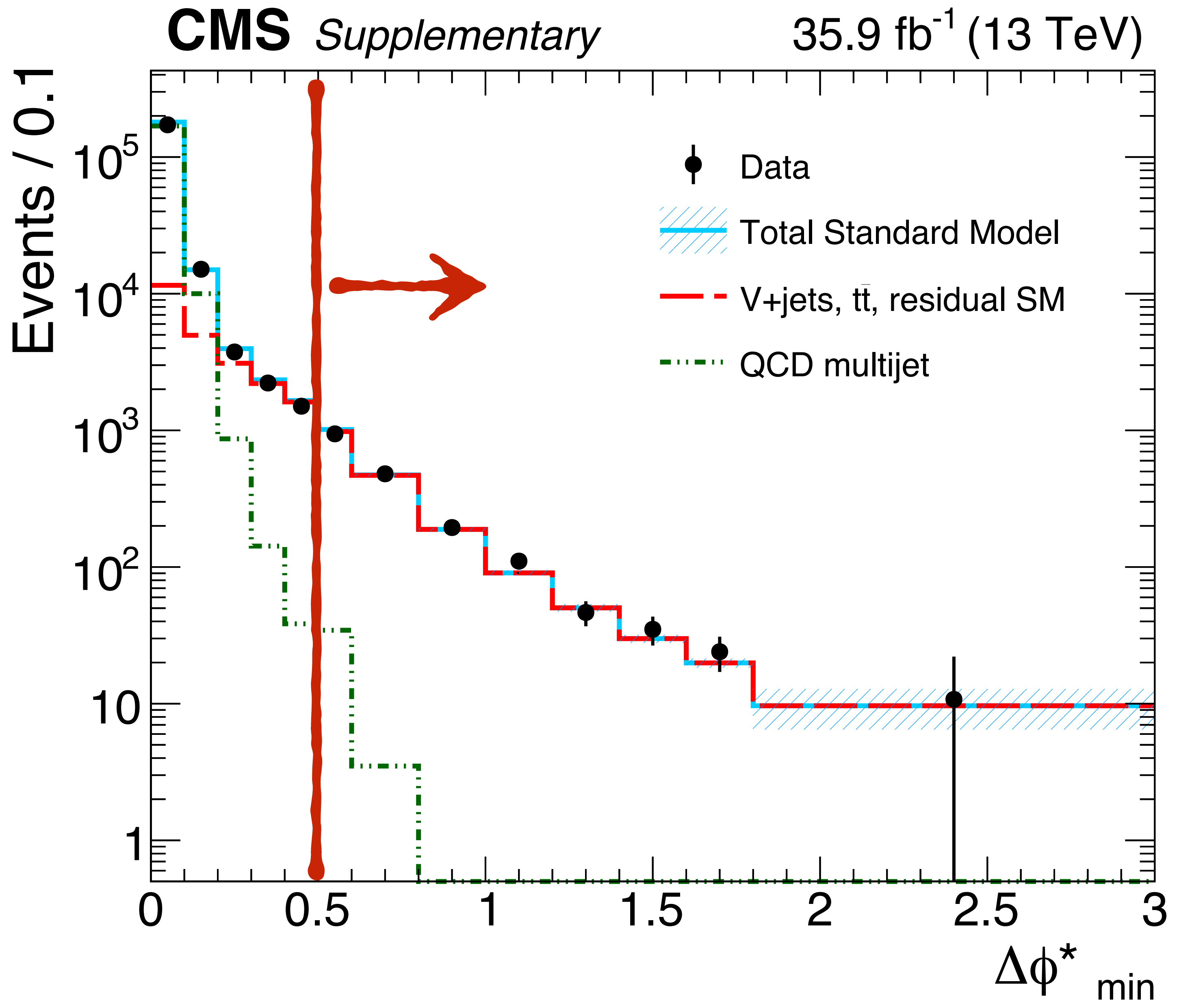
- ★ Long-lived particles
  - ✦ talk on dedicated searches later today
  - ✦ this talk: **reach of prompt searches** for displaced decays
- ★ Interpretation in **Split SUSY**
  - ✦ **does not solve hierarchy** problem, but still **offers gauge unification** and **dark matter**

Inclusive jets+MET

CMS-SUS-16-038
arXiv:1802.02110 , JHEP05 (2018) 025

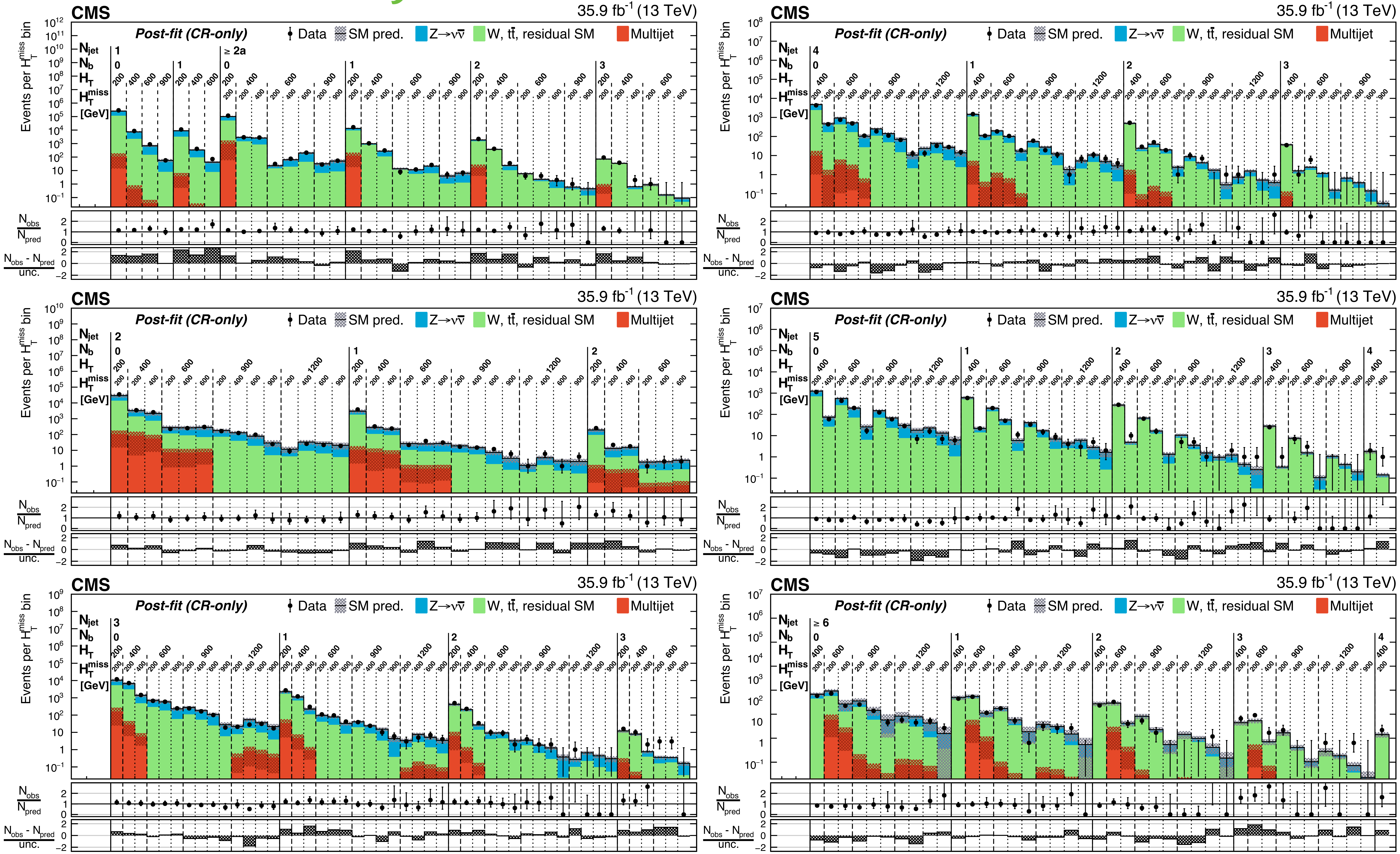
- ★ **Maximize** the covered **phase-space**
  - ✦ require at least 1-jet and veto leptons
  - ✦ $H_T^{miss} > 200$ GeV
- ★ Reduce **multijet** background to **<< 1%** with specialized variables: $\boldsymbol{\alpha_T}$ **and** $\boldsymbol{\phi^*_{min}}$
- ★ Remaining dominant backgrounds from **tt+jets, W(→ ℓν)+jets and Z(→νν)+jets**
  - ✦ estimated by extrapolating yields from corresponding **μ+jets** and **μμ+jets control regions** in data
- ★ Bin phase space to increase sensitivity to various models
  - ✦ bins in **H_T, H_T^{miss}, N_{jets} and N_b**
  - ✦ a total of **254 bins**

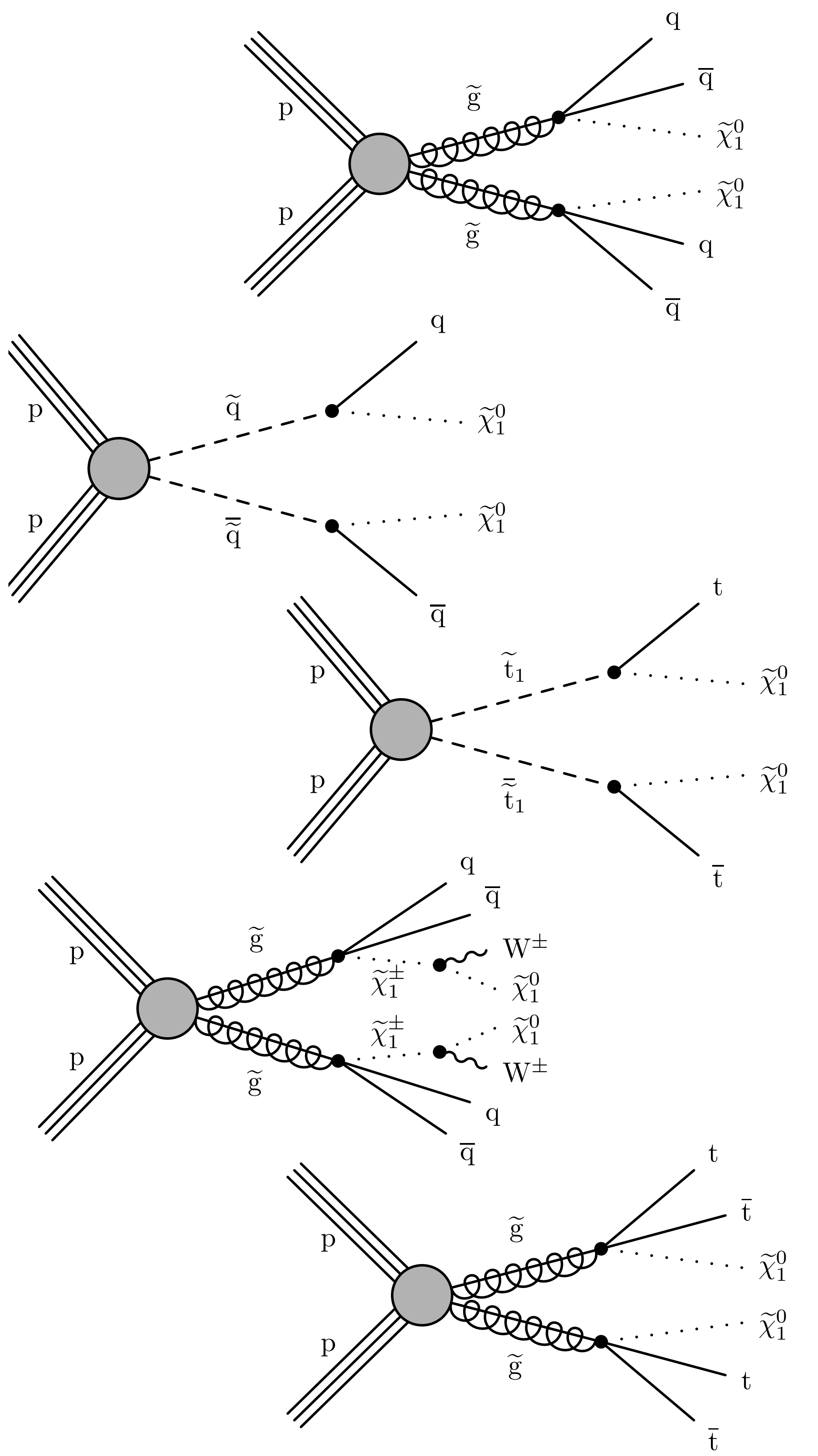




Inclusive jets+MET

CMS-SUS-16-038



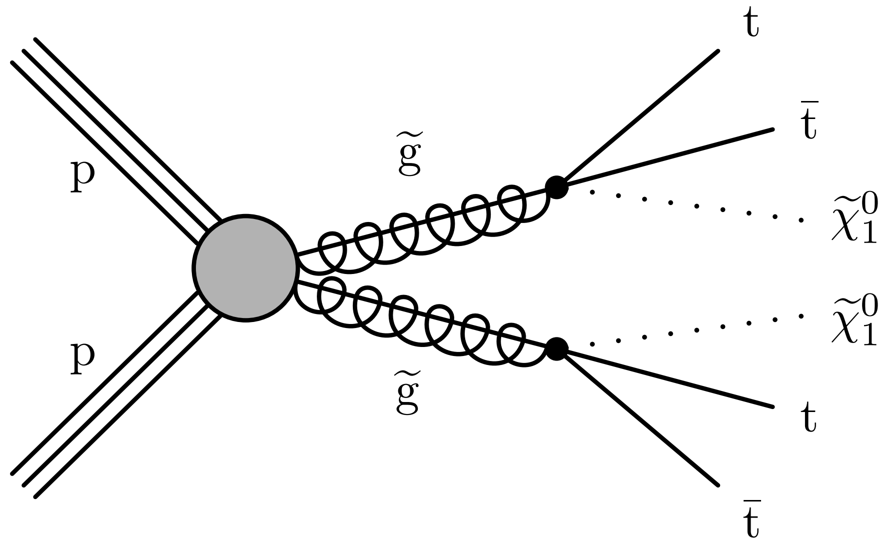


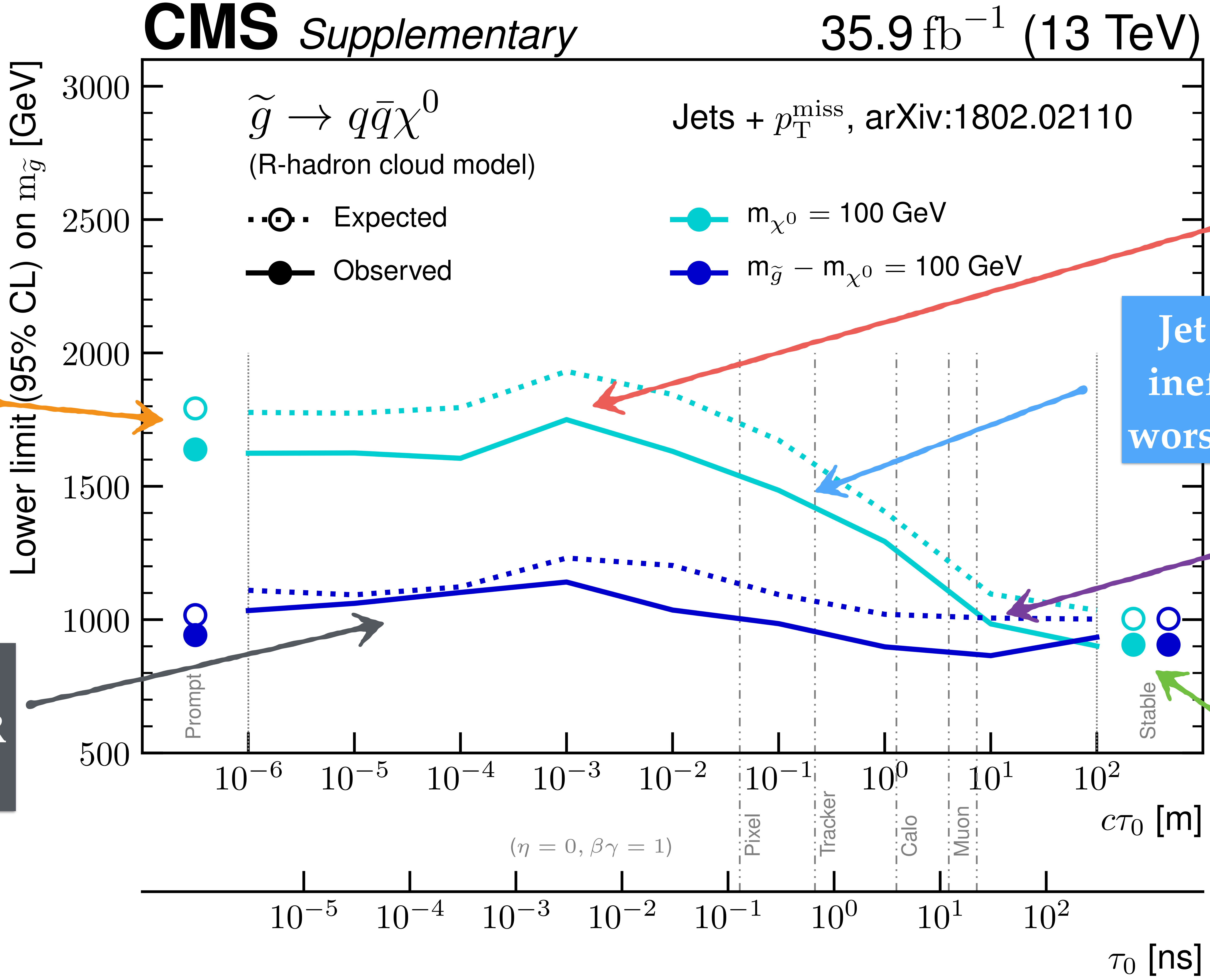
Sensitive to most topologies!

Also, a remarkable achievement of SM…

Inclusive jets+MET vs. Split SUSY

CMS-SUS-16-038





Prompt decays: much better sensitivity at large Δm

Compressed case: leading jet generally ISR → sensitivity flat

Bump in sensitivity from b-tagging for $c\tau$ ~ 1mm

Jet cleaning cuts on lead jet inefficient for displaced jets; worse with more displacement

Leading jet no longer from gluino, but ISR → sensitivity flattens

Limit holds all the way to stable gluinos

Sensitivity to 1 TeV gluinos across the full lifetime range !!

Exploring beyond …

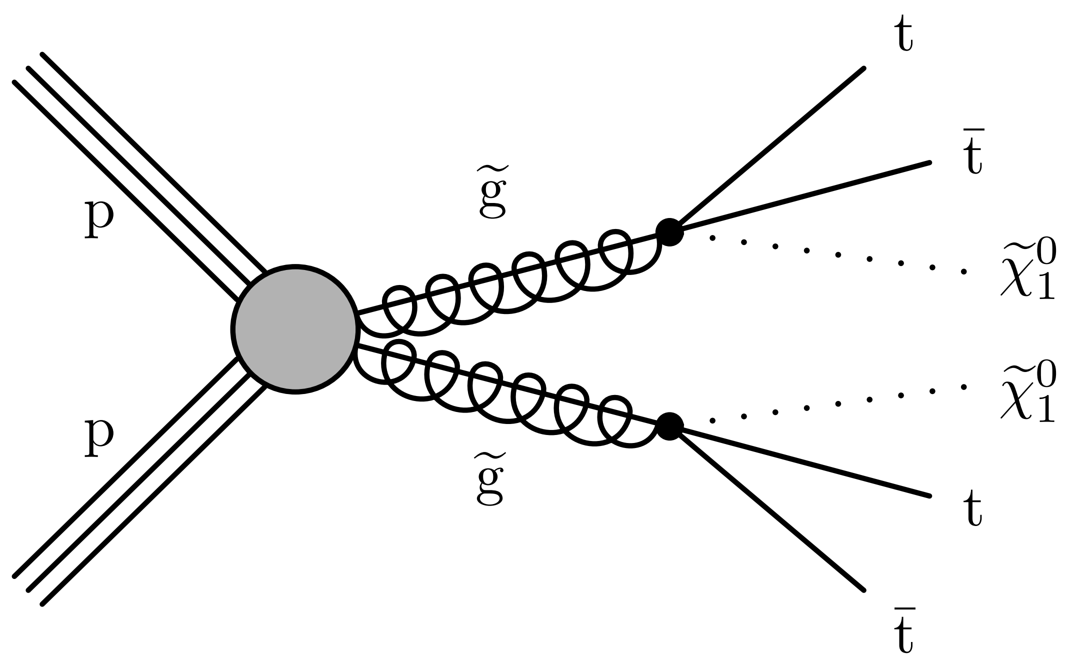
Vanilla SUSY

High Missing Energy

Long-lived particles

Example:

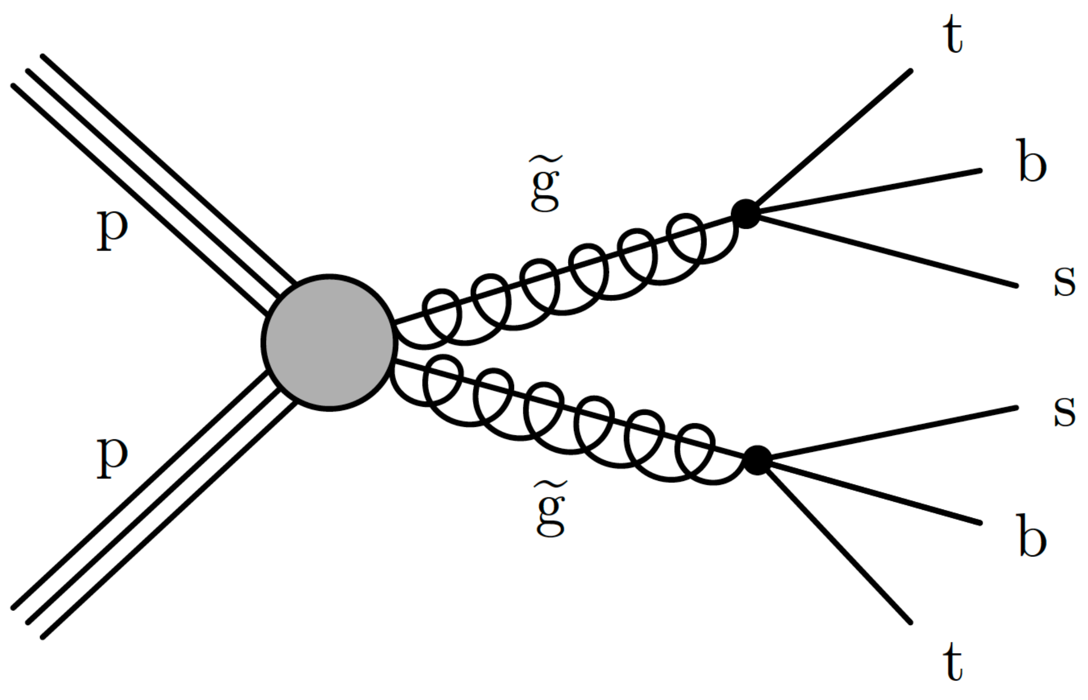
Split SUSY



No Missing Energy

Example:

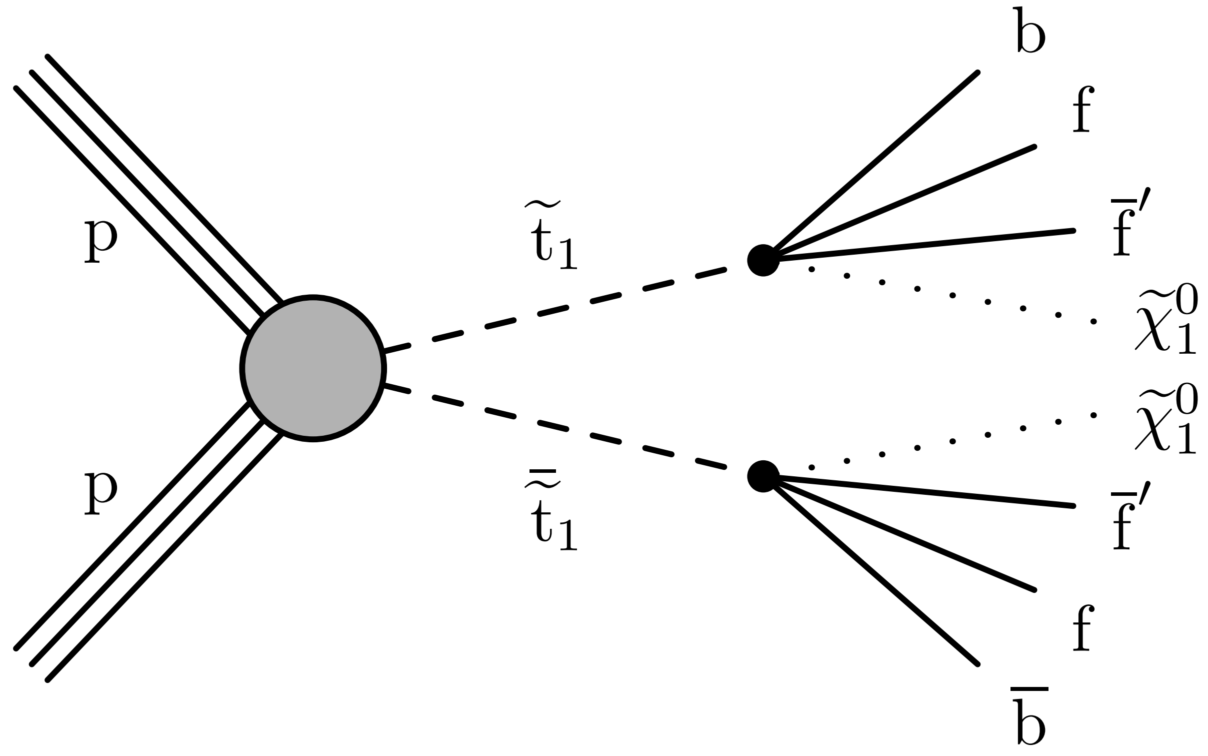
RPV SUSY



Soft decay products

Example:

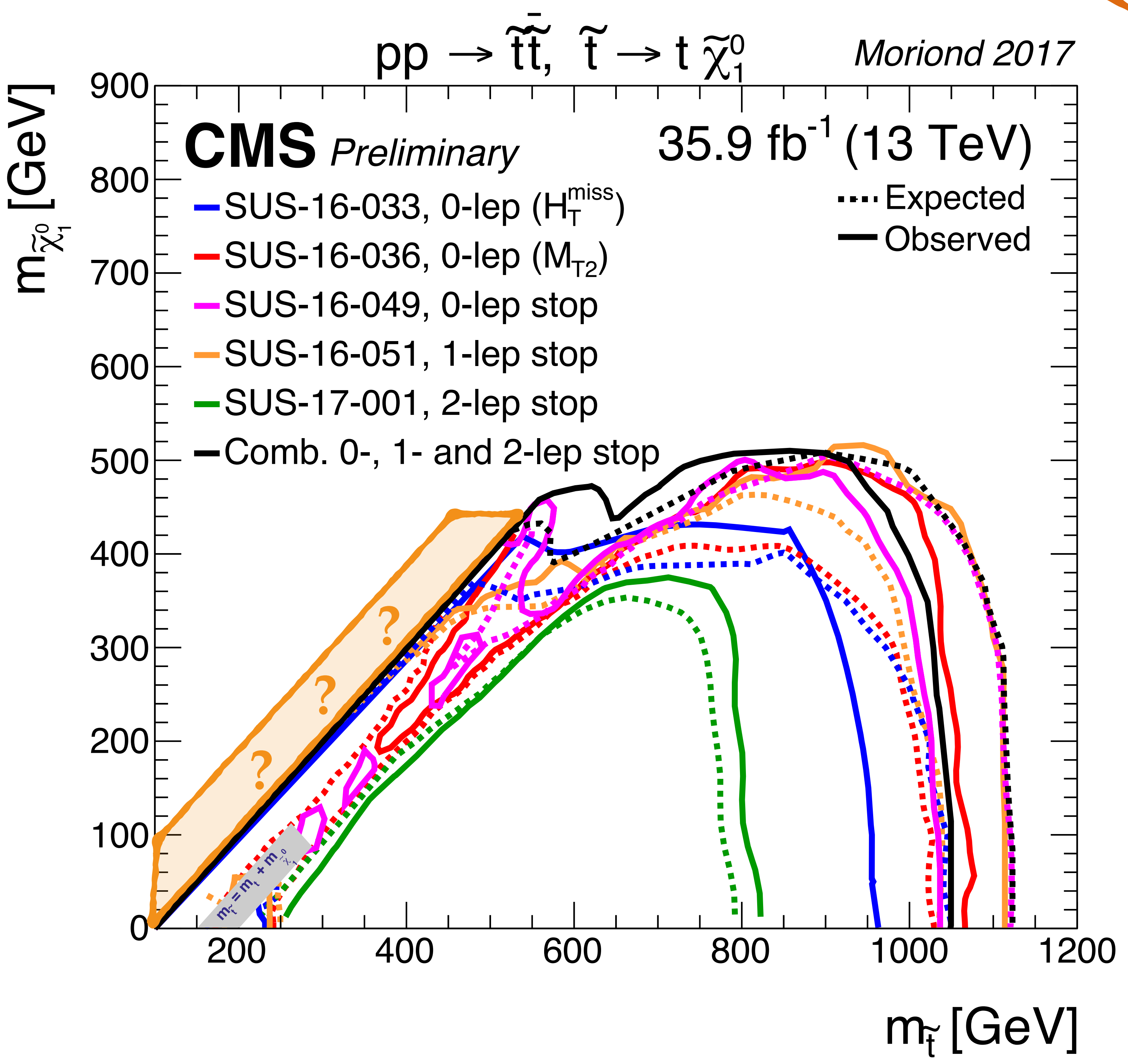
Compressed SUSY



Exploring beyond …

Vanilla SUSY

High Missing Energy

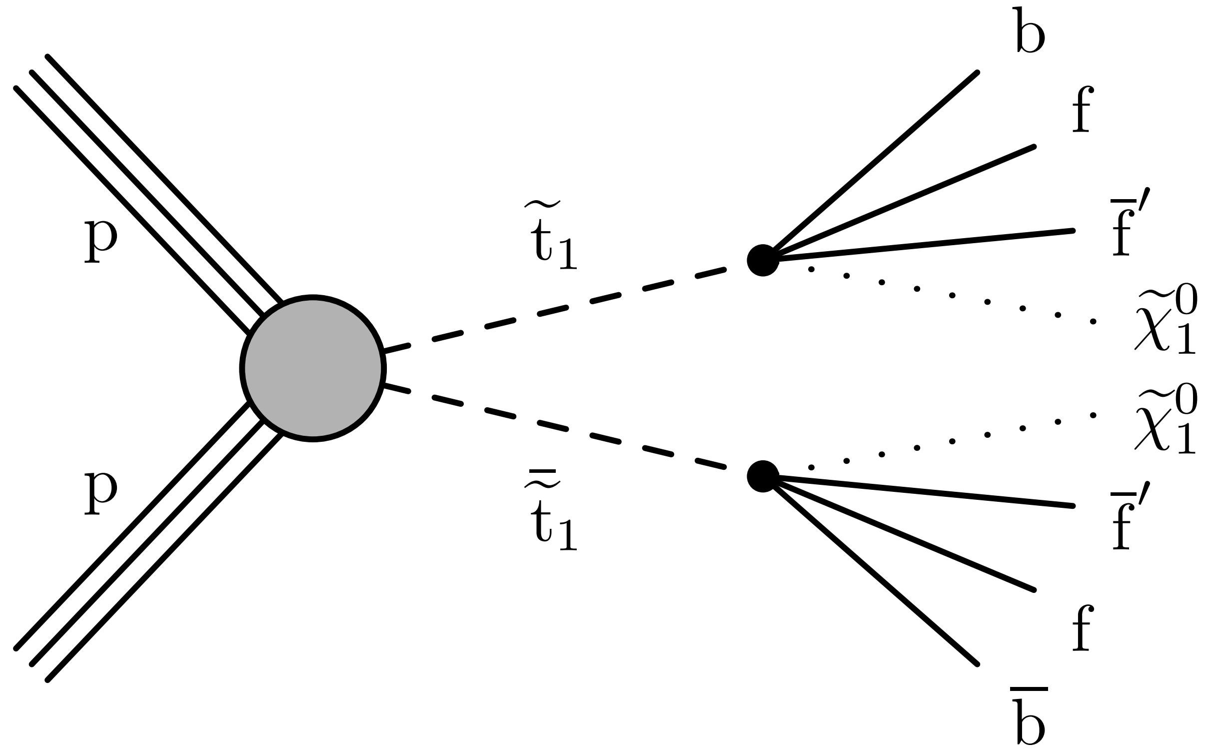


- ★ Limits always weaker when LSP mass approaches the mass of the produced squark/gluino
  - ✦ **visible activity significantly softer**
  - ✦ less missing energy
- ★ Easy to build models with such spectra, while **keeping SUSY features of appeal**

Soft decay products

Example:

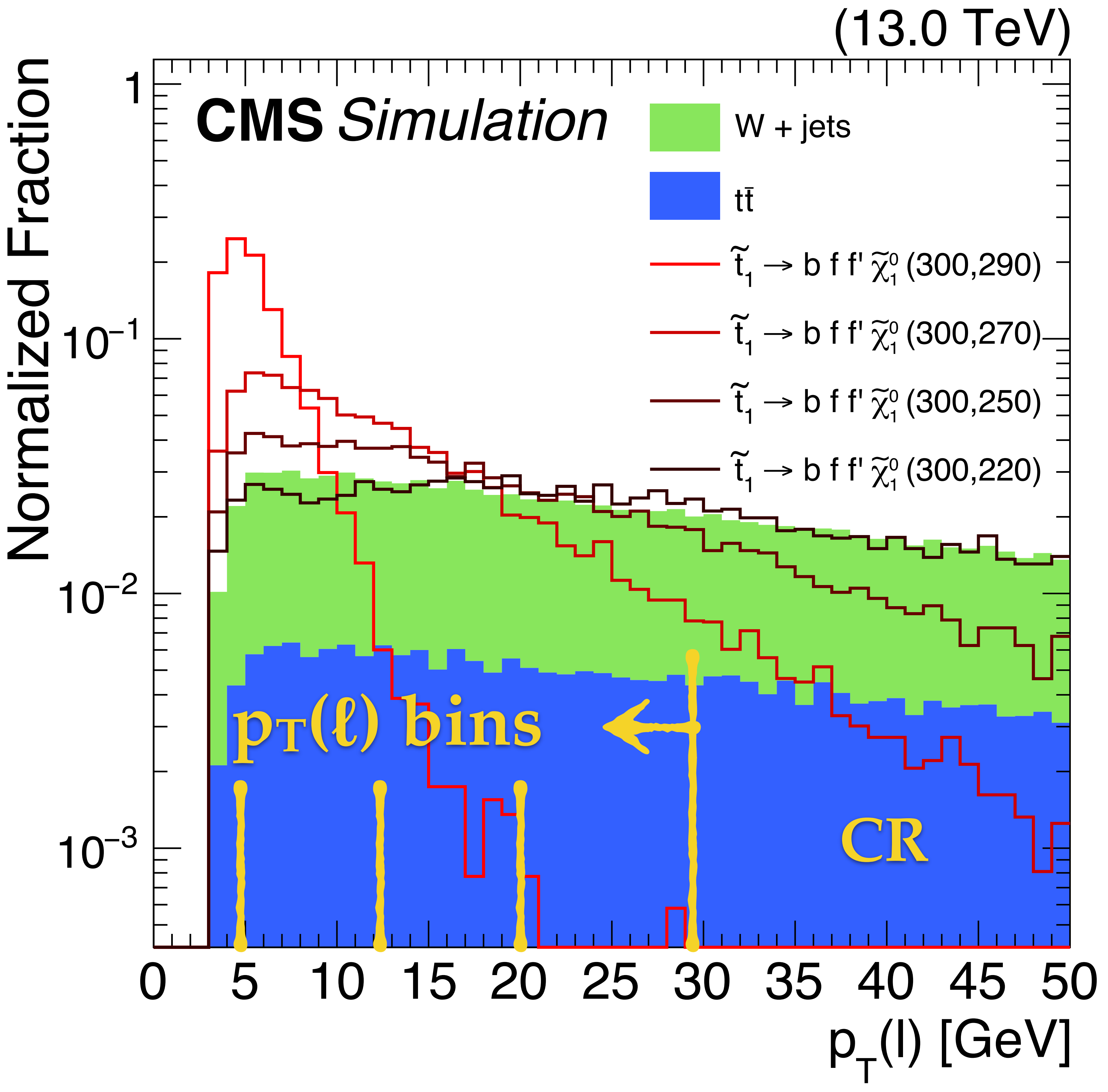
Compressed SUSY

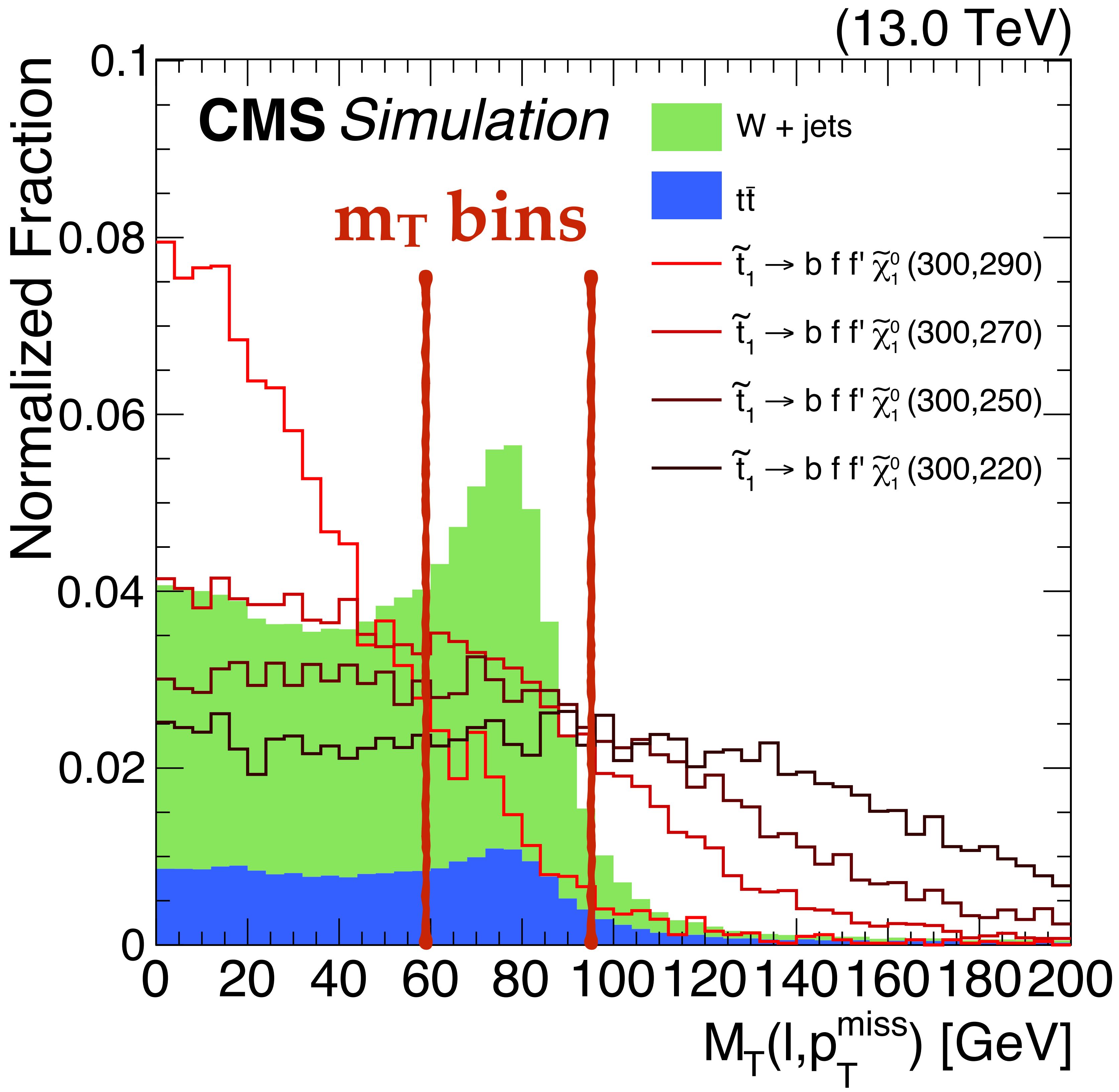


Soft 1ℓ search

CMS-SUS-17-005
arXiv:1805.05784 , Submitted to JHEP

- Tackle difficult final state by requiring jet from initial state radiation **(ISR) with $p_T > 100$ GeV**
  - energy picked up by LSPs → can reach high MET regime, allows to trigger events
- Require 1 lepton with **p_T>3.5 GeV for muons** or **p_T > 5 GeV for electrons** → W+jets dominated
- Using two approaches
  - **cut and count (C&C)**: more versatile, sensitivity to additional models, e.g. chargino mediated decay
  - **MVA-based**: better reach for the targeted 4-body decay model

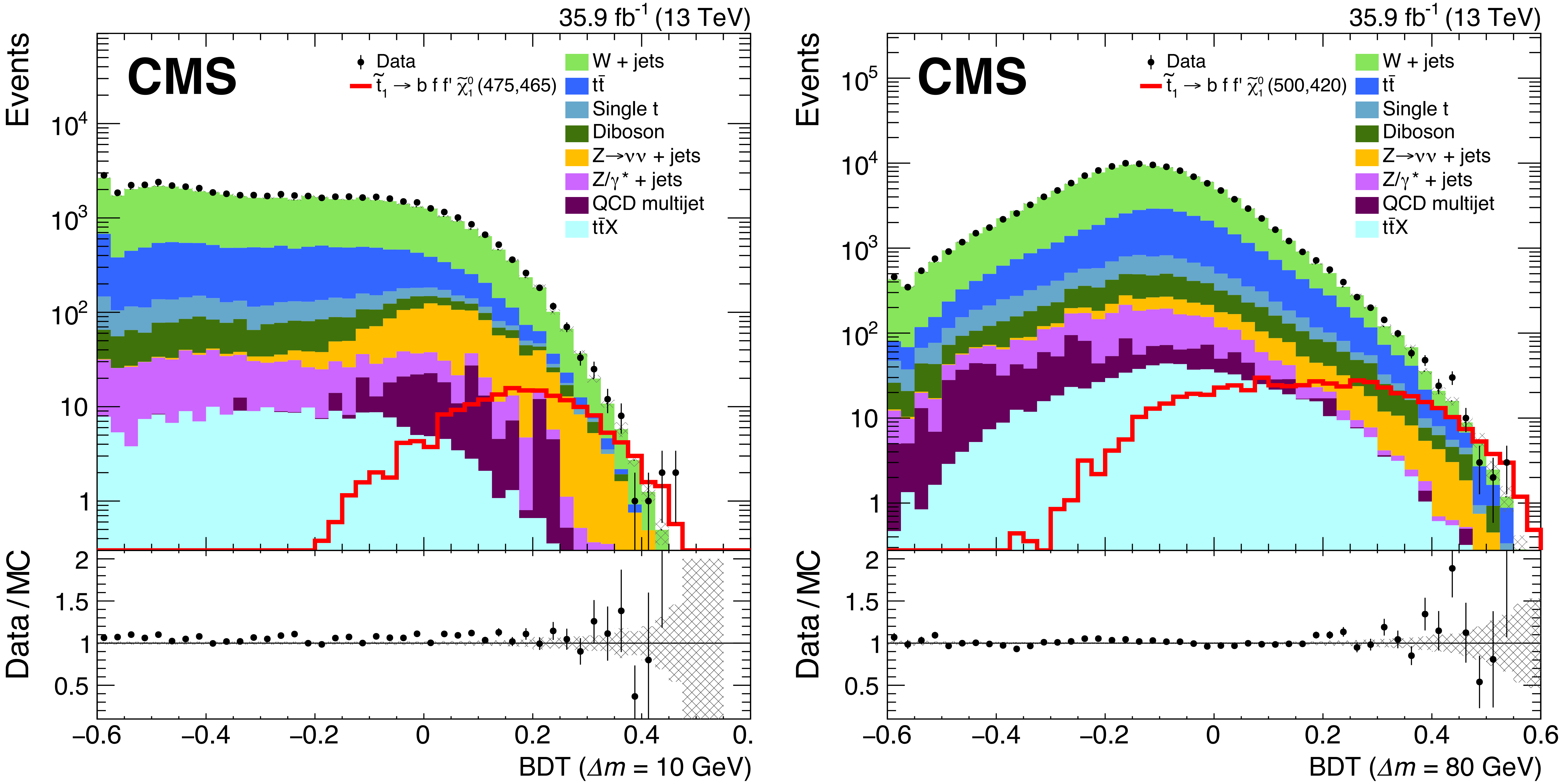




Soft 1ℓ search

CMS-SUS-17-005

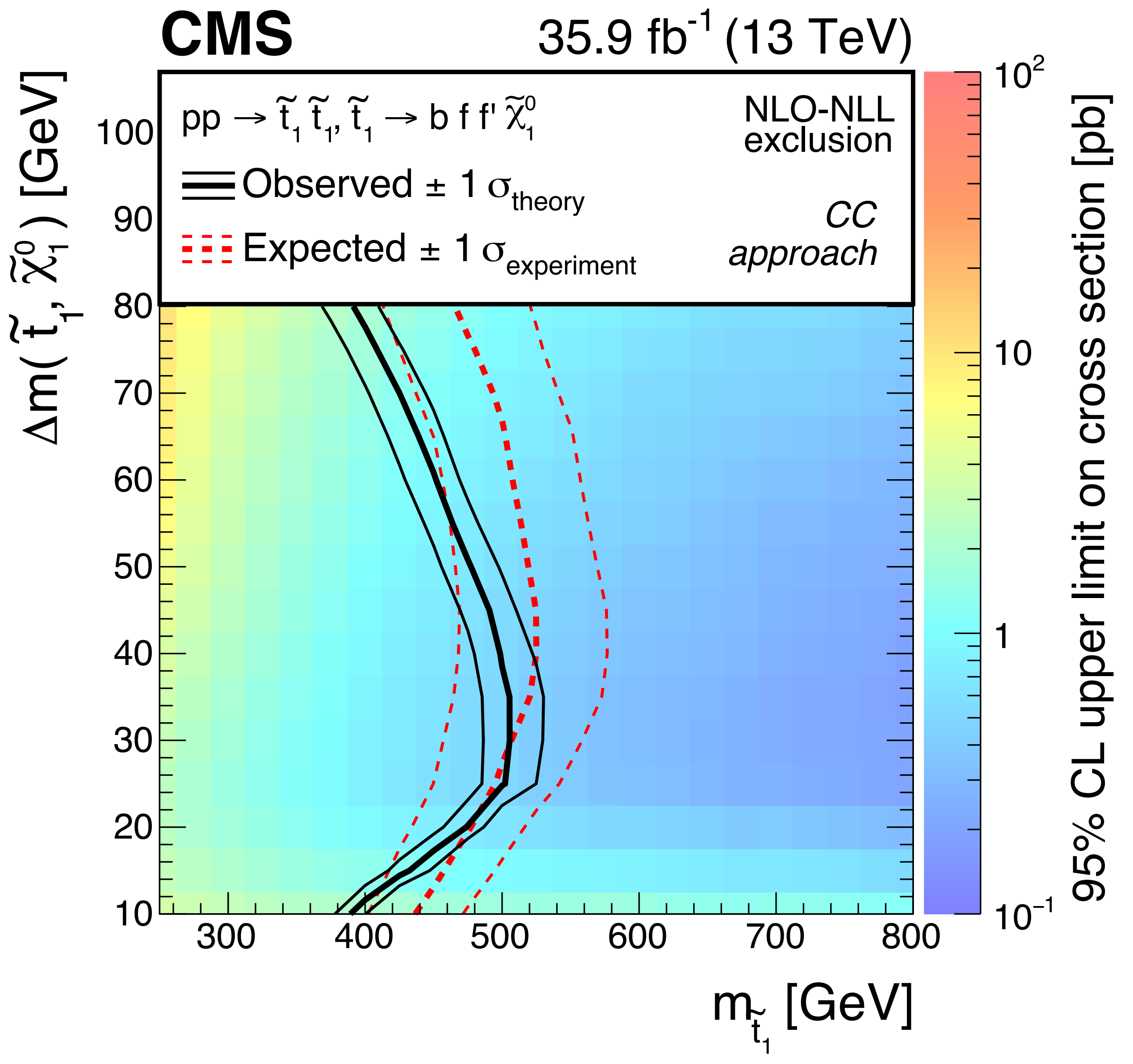
- ★ Stop and LSP **mass splitting** largely **determines event kinematics**
- ★ MVA → trained an **independent BDT for each Δm** between 10 and 80 GeV in 10 GeV steps
  - ✦ Input variables for BDT optimized using discovery significance
    - lepton kinematics, m_T, MET, H_T, N_{jets}, N_b, p_T (lead jet), p_T (lead b-jet), ΔR (ℓ, lead b-jet)
- ★ C&C → **bin** in the two strongest variables: **lepton p_T and m_T**

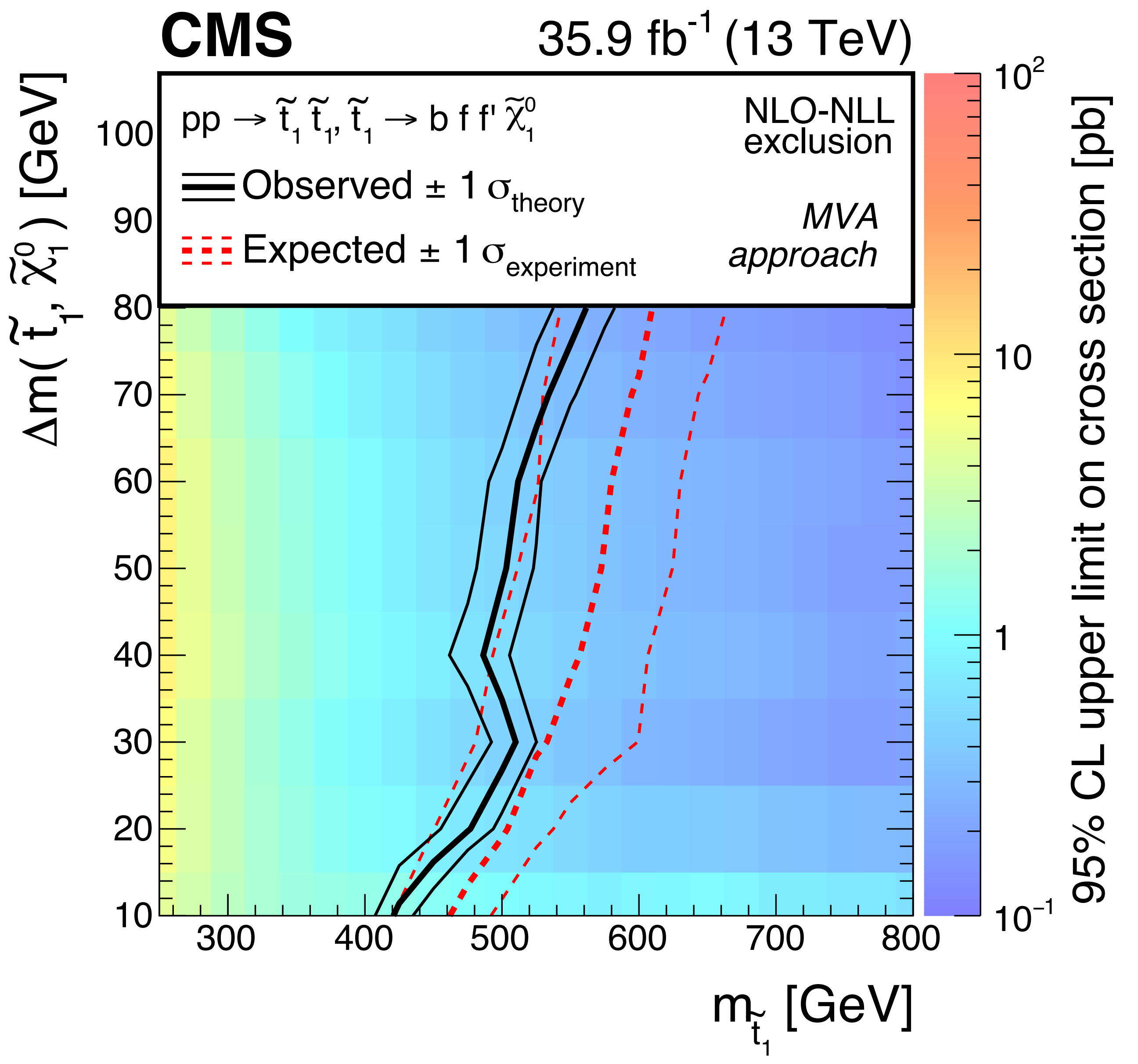


- ★ Prompt background
  - ✦ **normalize simulation in control regions** at low BDT score (MVA) or high lepton p_T (C&C)
- ★ Non-prompt background
  - ✦ important for phase space with high m_T and very low p_T(ℓ)
  - ✦ **extrapolate from control region** with looser lepton isolation via an efficiency for fakes derived in data

Soft 1ℓ search vs. Compressed SUSY

CMS-SUS-17-005



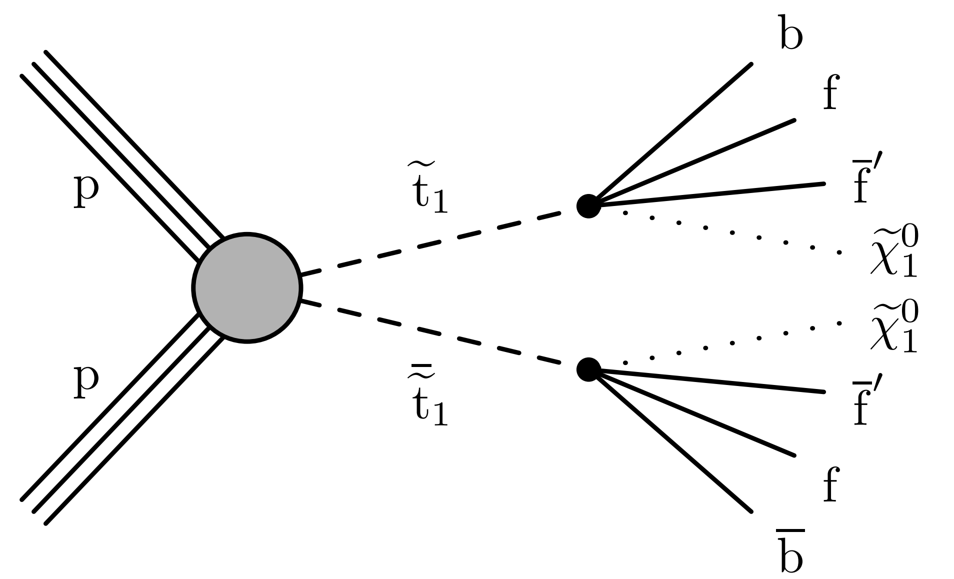


Comparison between C&C and MVA for 4-body model

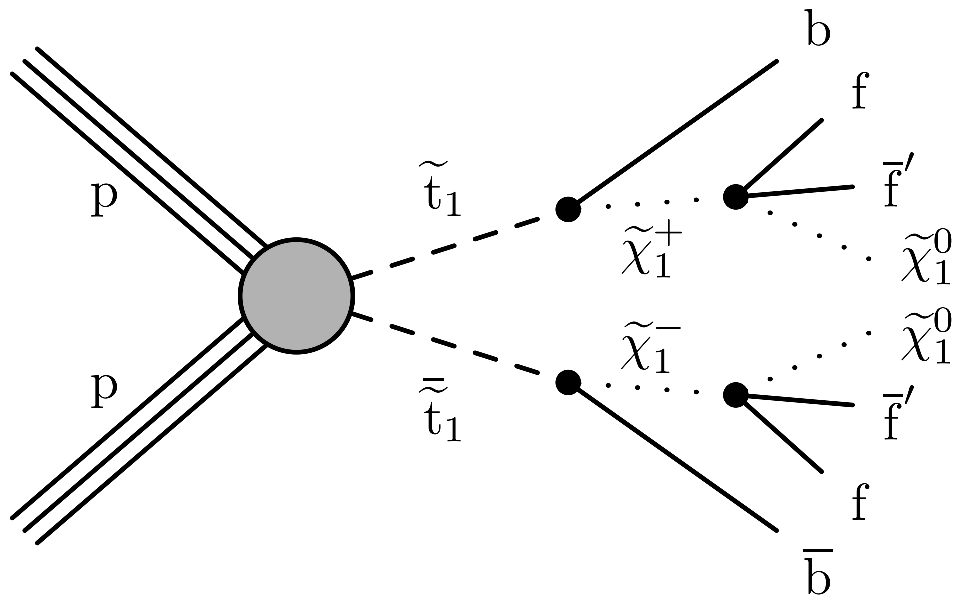
Additional sensitivity from MVA-based optimization extends the reach by up to ~150 GeV at high Δm

Exclusion up to ~0.5 TeV for a range of Δm, significantly lower than reach for non-compressed high-MET signatures!

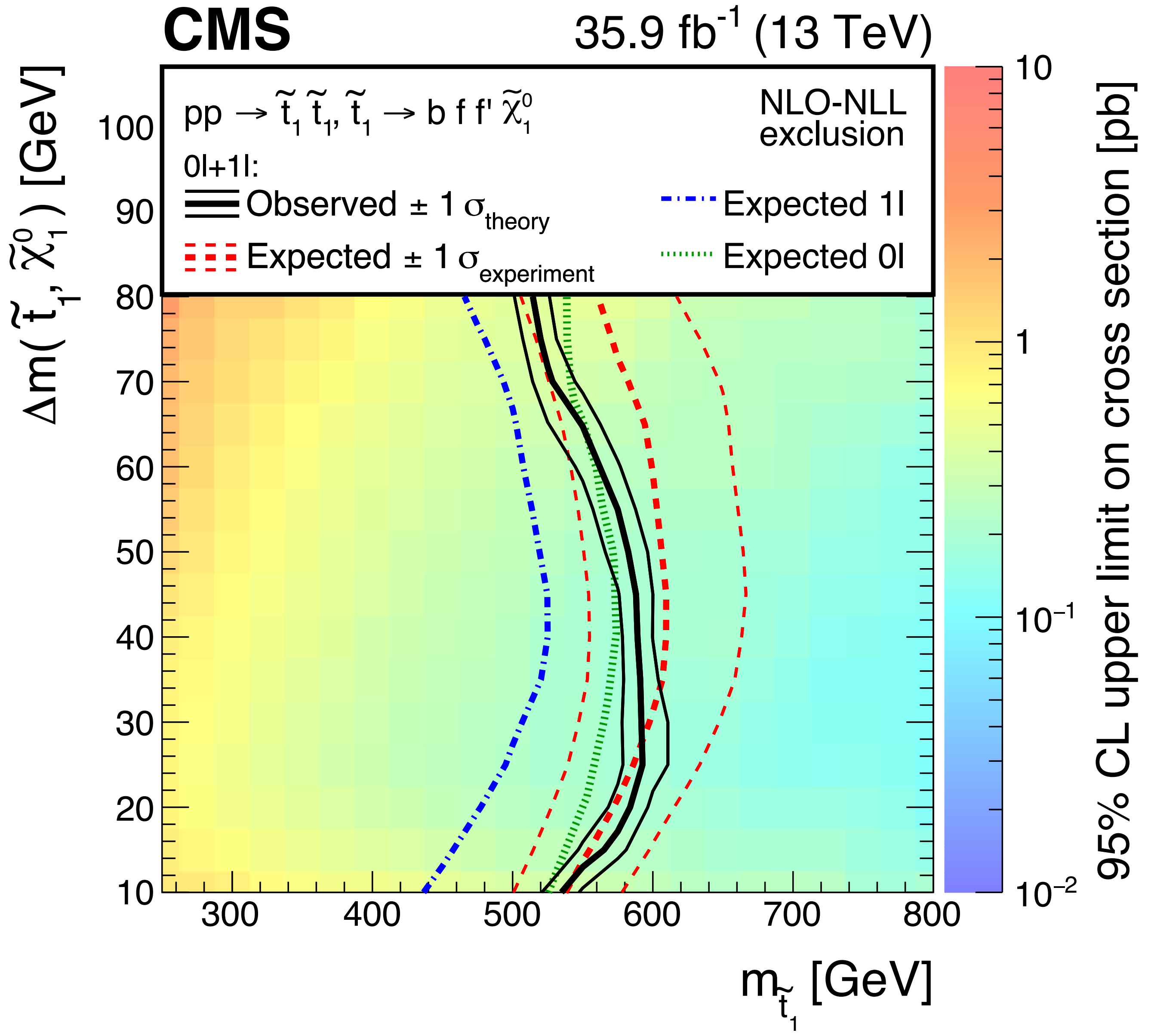
Combination with previous 0ℓ result

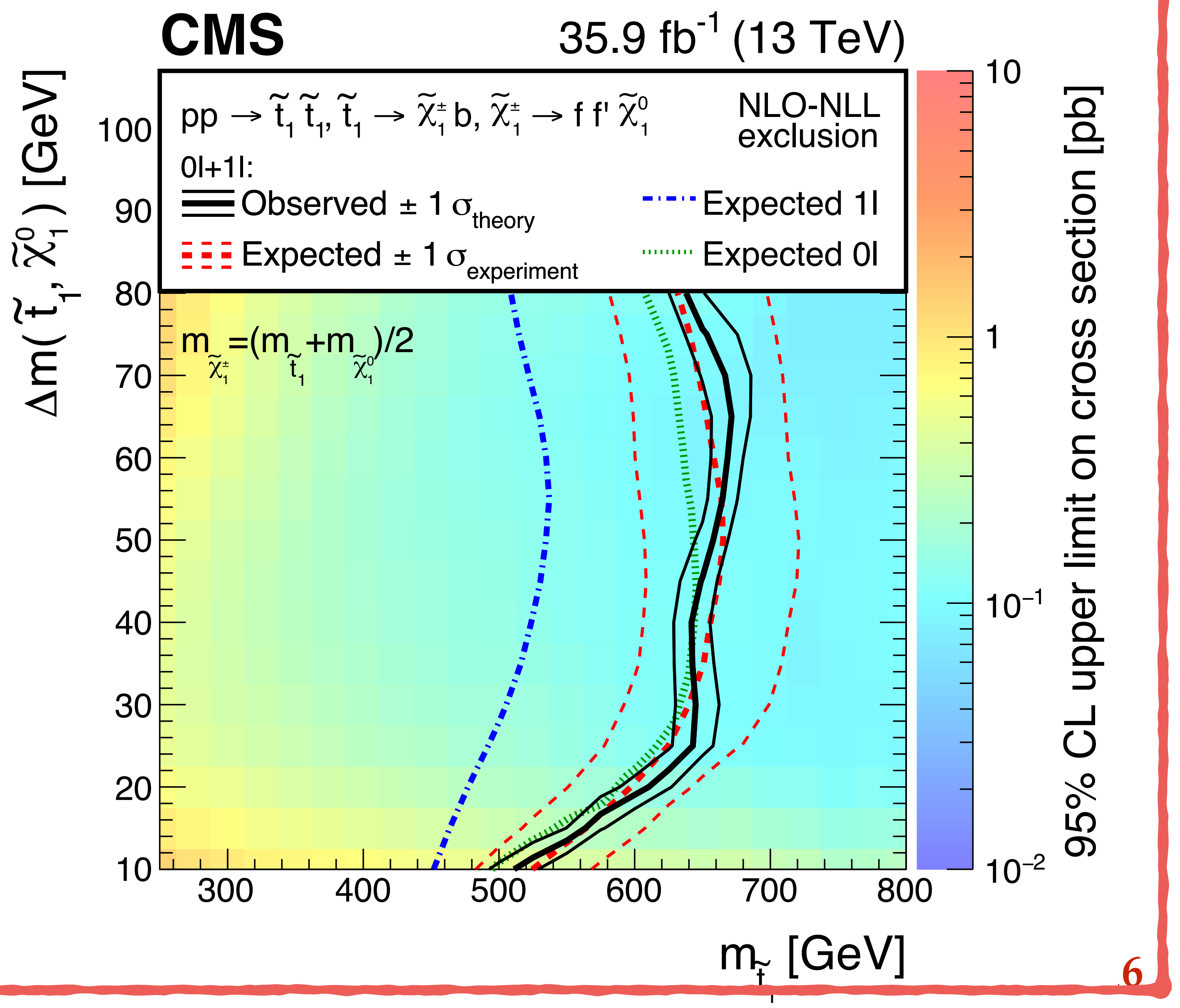


4-body decay



chargino-mediated decay



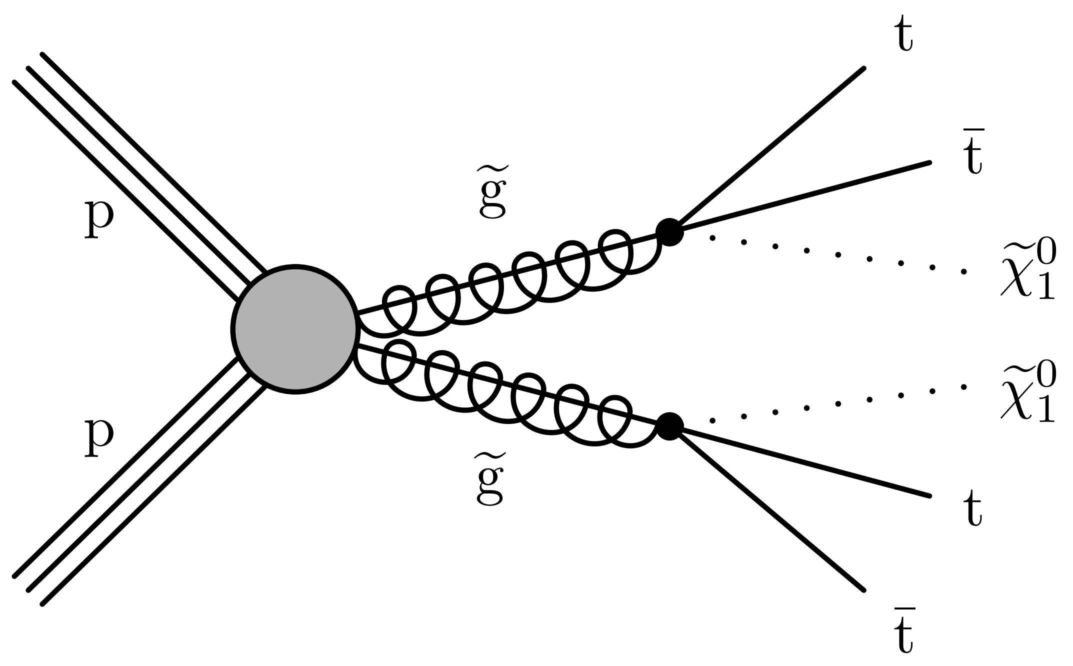


Exploring beyond …

Vanilla SUSY
High Missing Energy

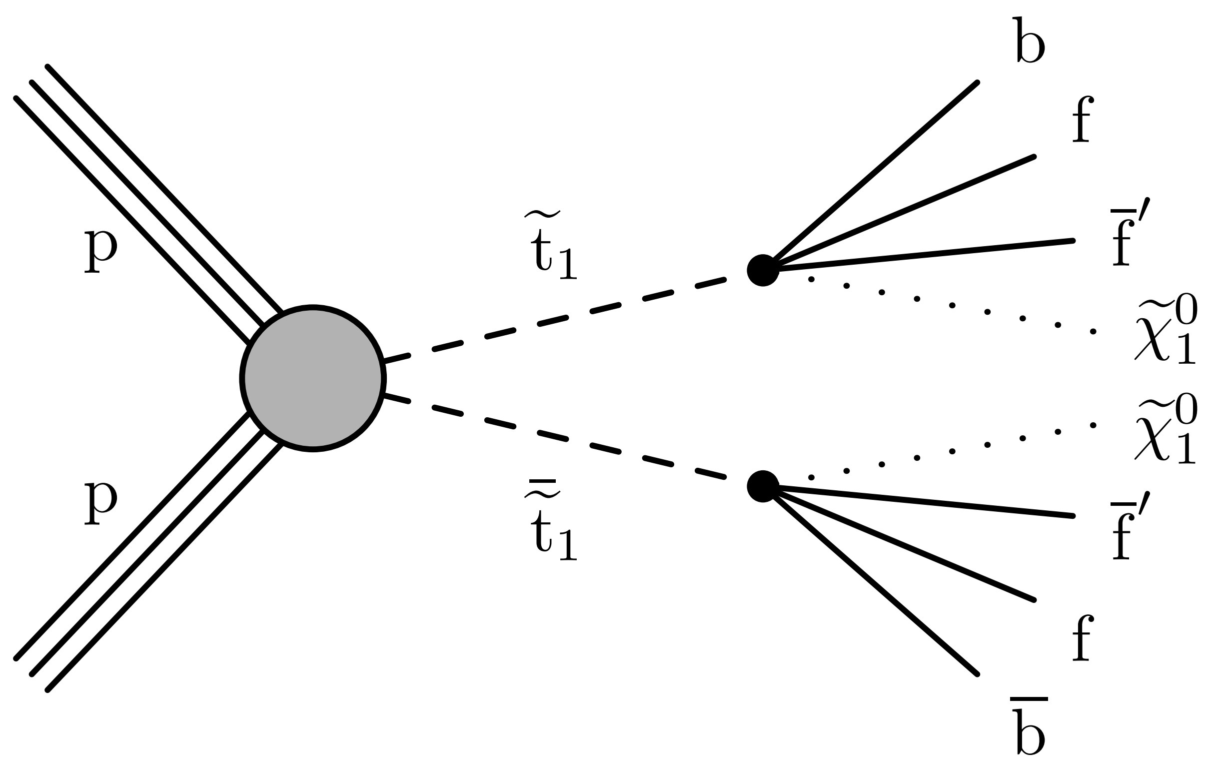
Long-lived particles

Example:
Split SUSY



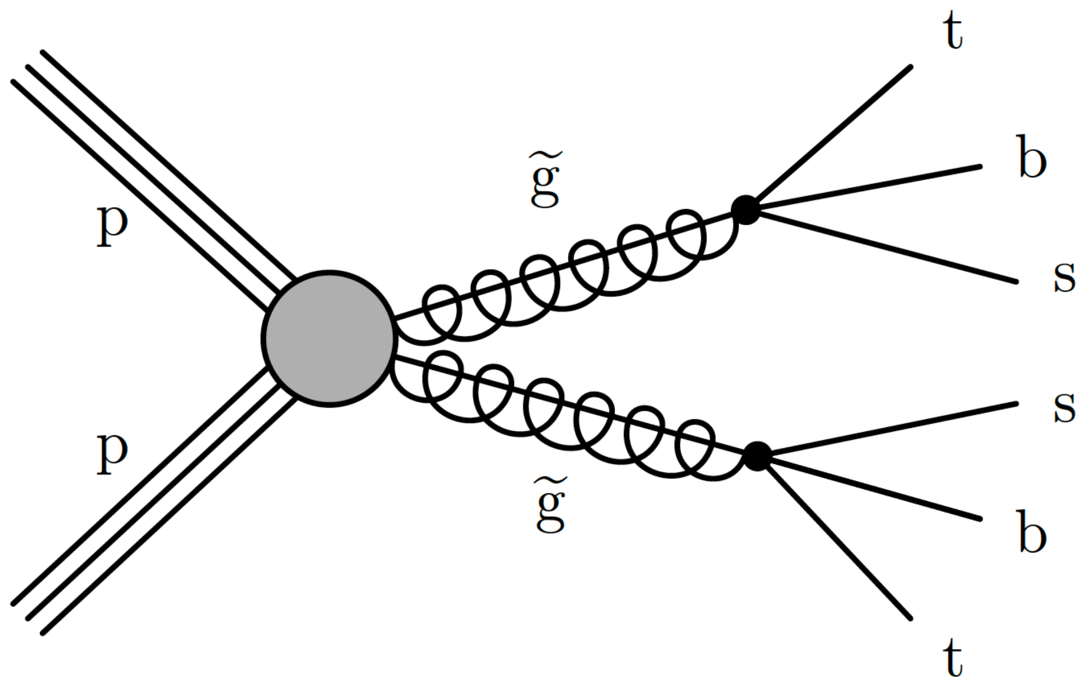
Soft decay products

Example:
Compressed SUSY



No Missing Energy

Example:
RPV SUSY



Exploring beyond …

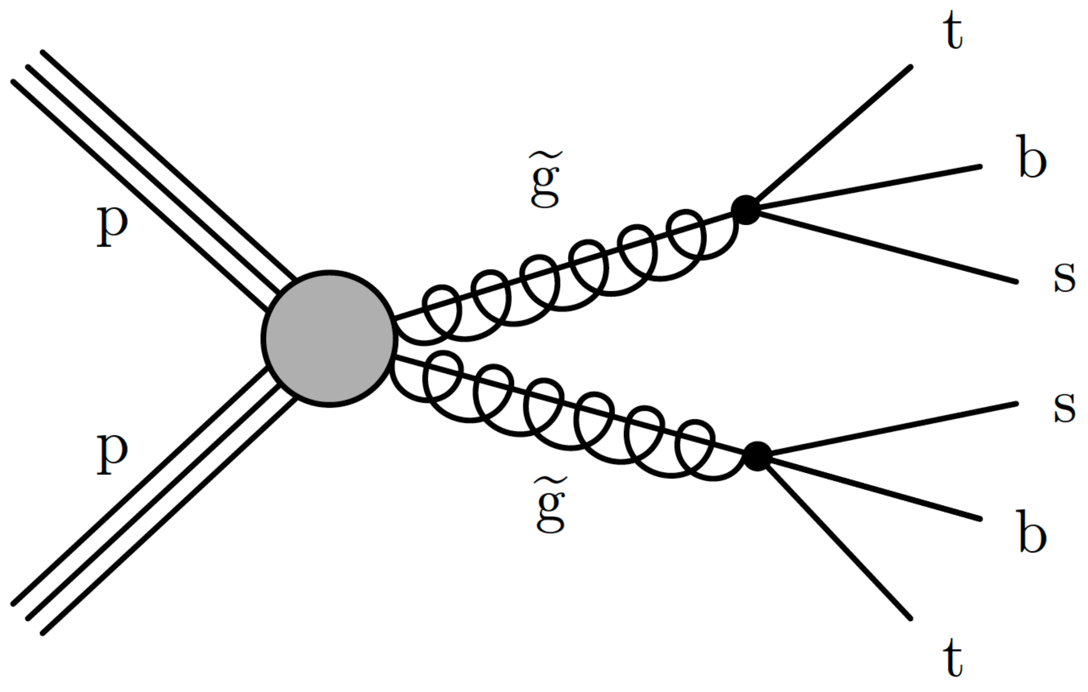
L = ℓ_L/ν_L **E** = ℓ_R
Q = q_L **U,D** = q_R
i,j,k = generation

<u>Vanilla SUSY</u>
High Missing Energy

No Missing Energy

Example:

RPV SUSY



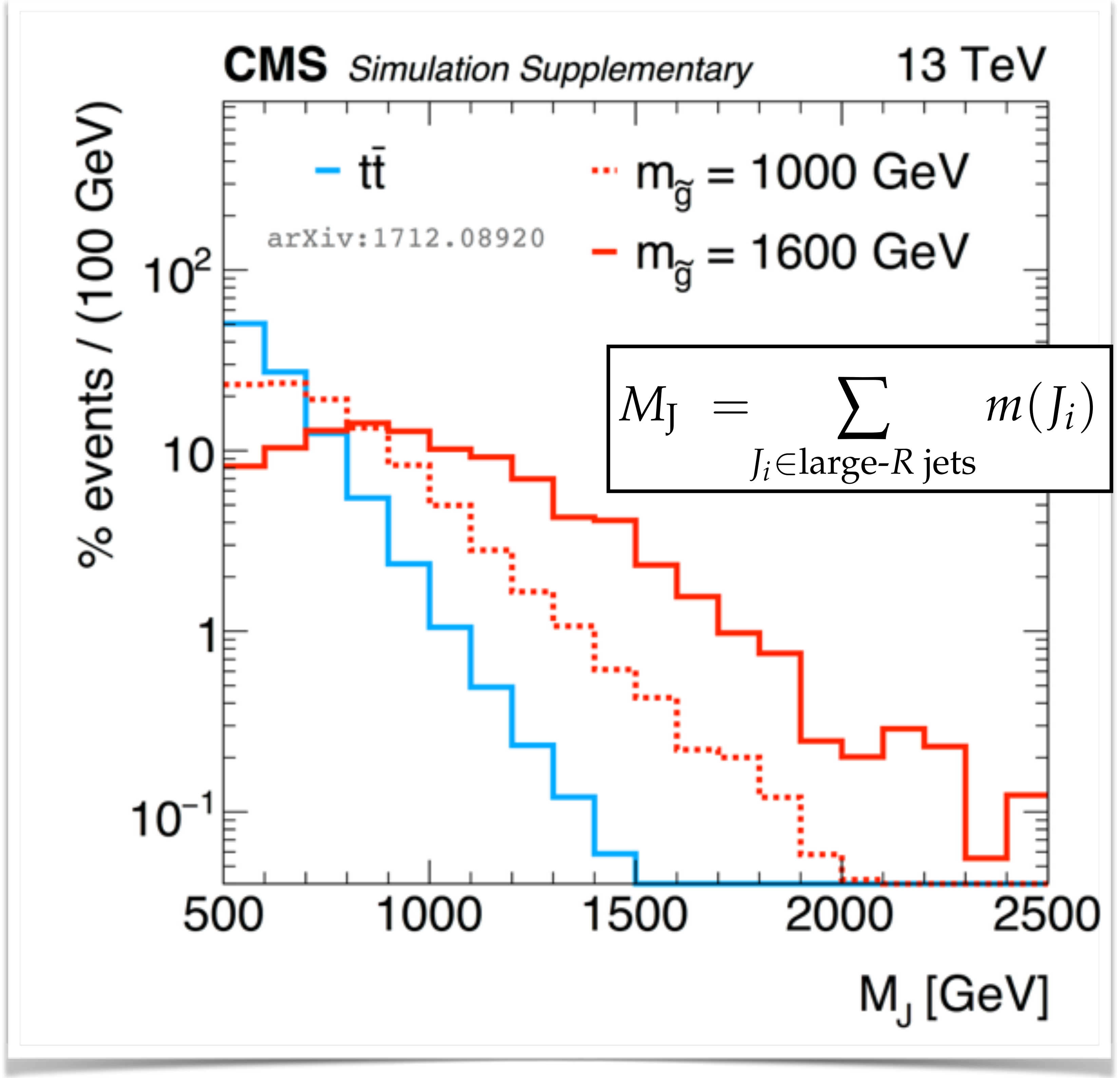
$$W_{\not{R}_p} = \underbrace{\frac{1}{2}\lambda_{ijk}L_iL_jE^c_k + \lambda'_{ijk}L_iQ_jD^c_k}_{\text{Lepton number violation}} + \underbrace{\frac{1}{2}\lambda''_{ijk}U^c_iD^c_jD^c_k}_{\text{Baryon number violation}}$$

- ★ R-parity violation consequences
  - ✦ nonzero B- or L-number violation alone allowed by current experimental results
  - ✦ least constrained for **B-number violation for 3rd generation couplings**
  - ✦ consequences: **no obvious dark matter** candidate
    - but **many other DM options** possible
- ★ Experimental consequences:
  - ✦ no stable LSP → **no missing energy**
  - ✦ have to rely on additional activity in event

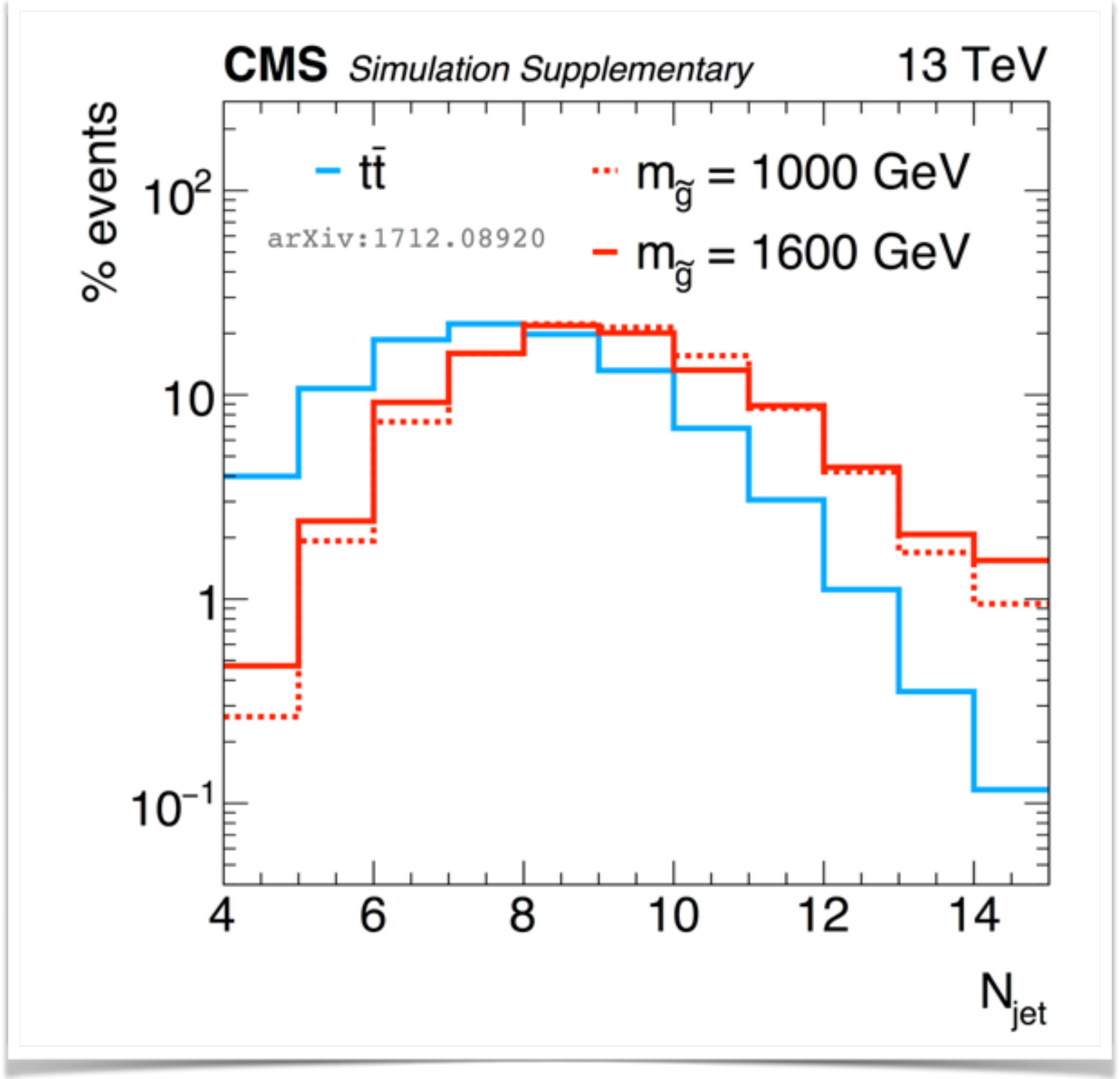
Scalar sum of jet masses

CMS-SUS-16-040
arXiv:1712.08920, Accepted by PLB

- ★ Take advantage of **large hadronic activity** for trigger and background discrimination
  - ✦ $H_T > 1200$ GeV, $N_{jets} \geq 6$
- ★ **Exploit event structure** → hadronic activity from decay of heavy particles → **correlated jets**
  - ✦ recluster event into large-R jets and use scalar **sum of all jet masses (M_J)** to discriminate background
- ★ **Binning in N_{jets} and M_J** to improve sensitivity as a function of gluino mass



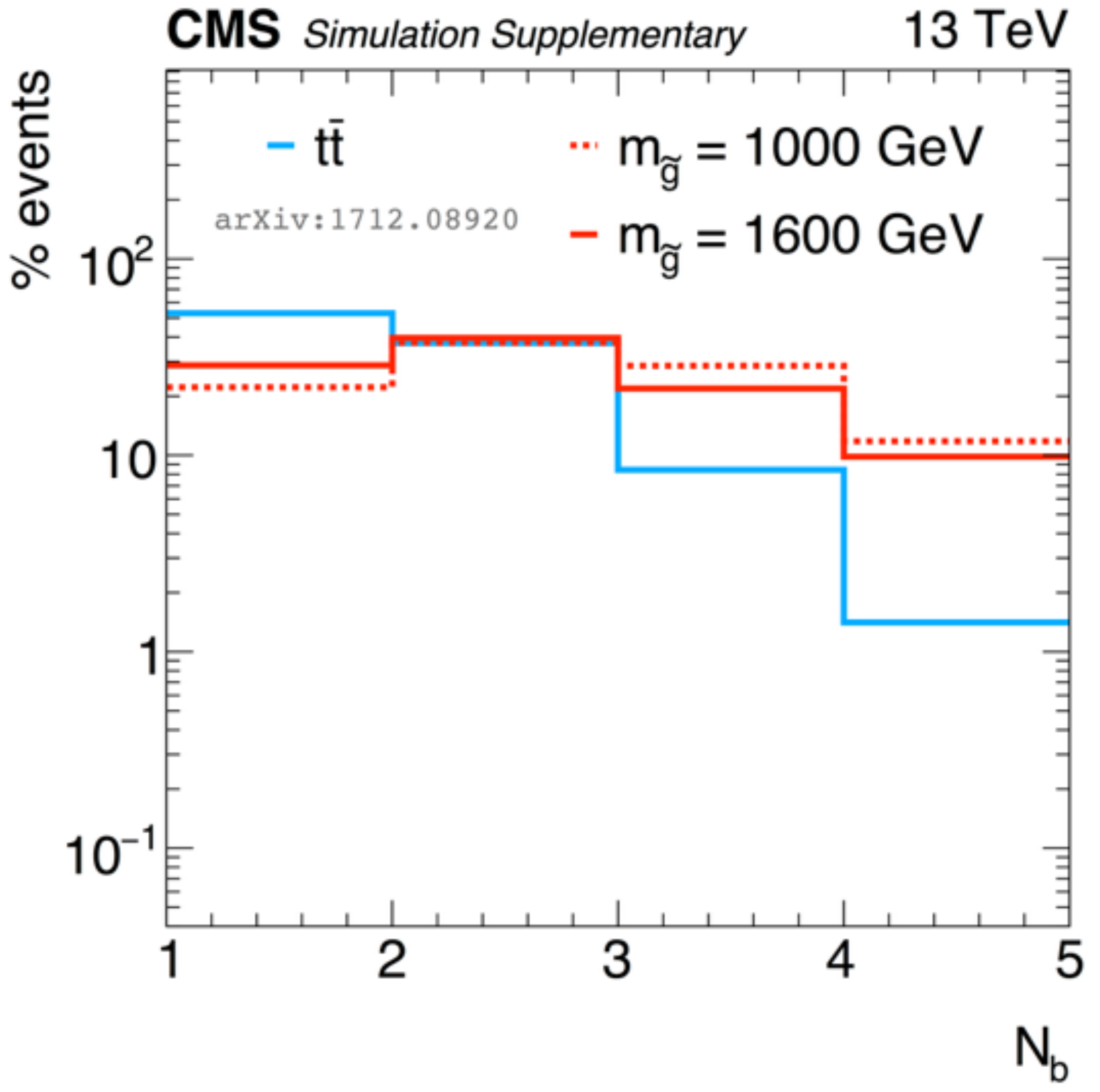
$$M_J = \sum_{J_i \in \text{large-}R\text{ jets}} m(J_i)$$



Scalar sum of jet masses

CMS-SUS-16-040

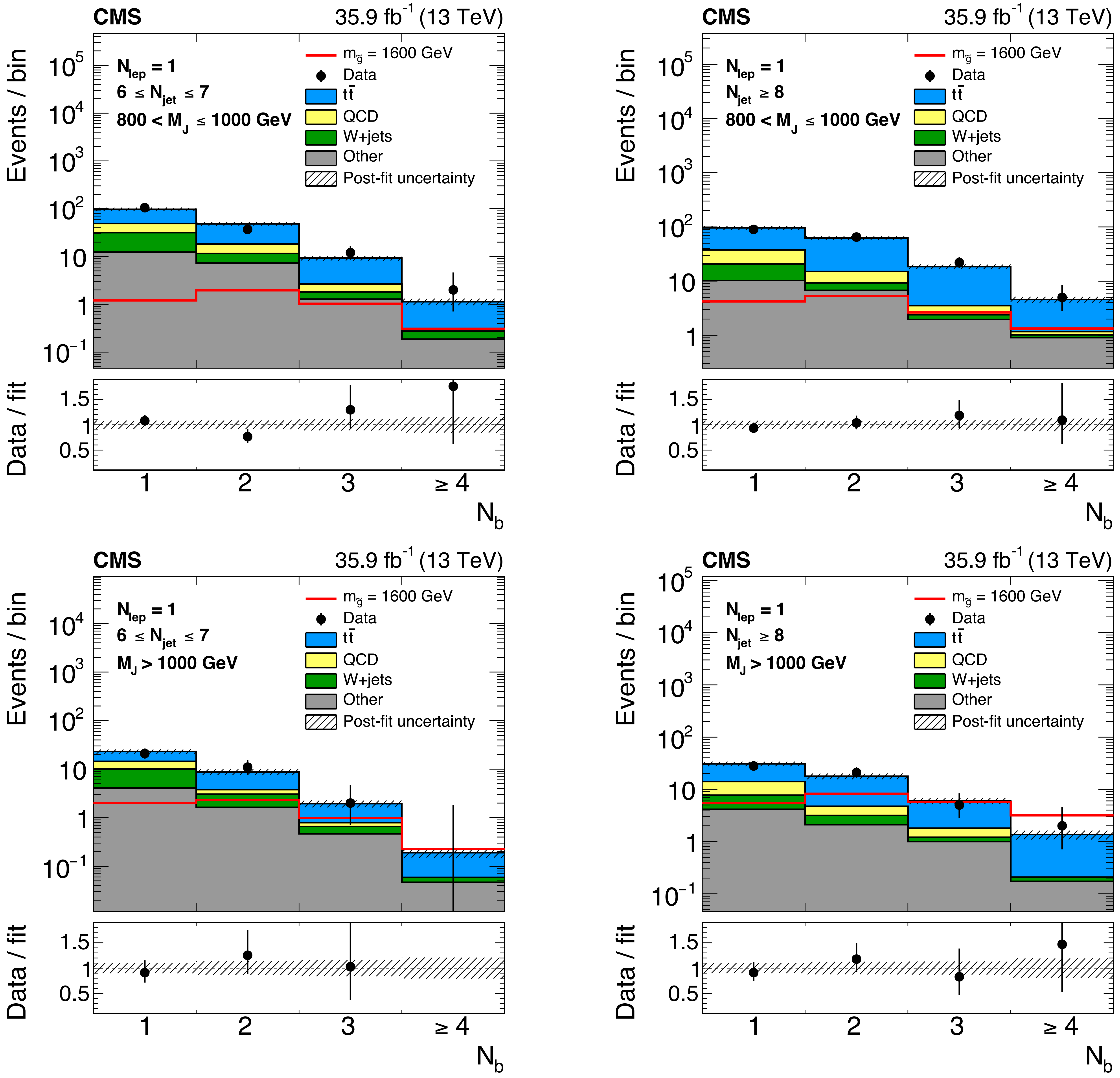
- ★ Targeting final state with 2 top and 2 b quarks → **total of 4 b quarks**
  - ✦ require 1ℓ and $N_b \geq 1$ as baseline
  - ✦ main background → tt+jets
- ★ **Global fit of N_b distribution** in bins of N_{jets} and M_J to extract signal
  - ✦ **N_b shape for each background from MC**
  - ✦ Nuisances on N_b shape from:
    - b-tagging data/MC scale factors
    - **study gluon splitting modeling in data** (largest unc.)
  - ✦ **tt+jets and QCD normalization** constrained **from data** in each N_{jets} and M_J bin
  - ✦ **W+jets normalization** as a function of N_{jets} from 2ℓ control region **in data** dominated by Z+jets

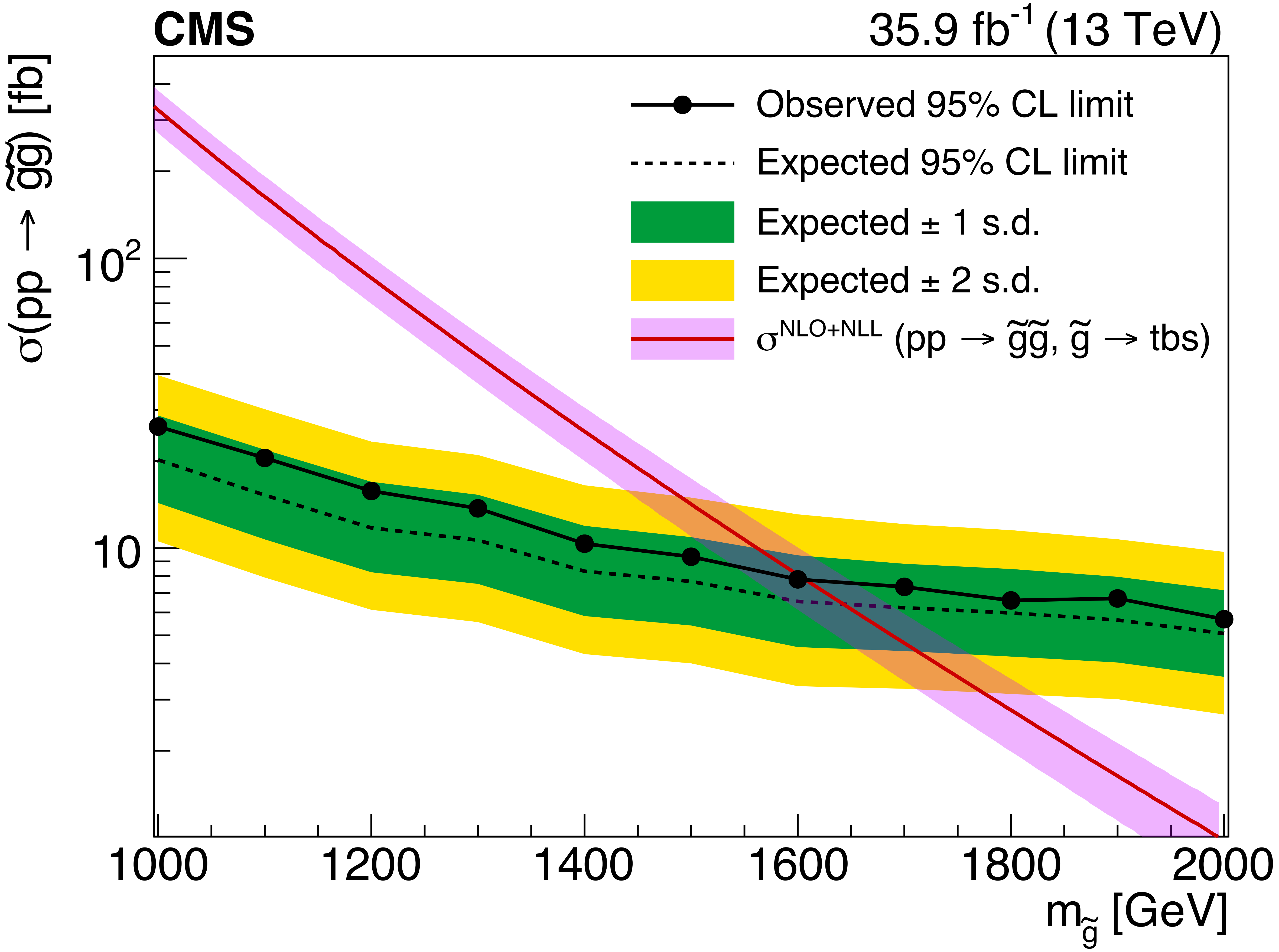


N_{jet} / M_J	4-5	6-7	≥8
500-800 GeV	CR	CR	SR
800-1000 GeV	CR	SR	SR
>1000 GeV		SR	SR most sensitive

Scalar sum of jet masses vs. RPV SUSY

CMS-SUS-16-040

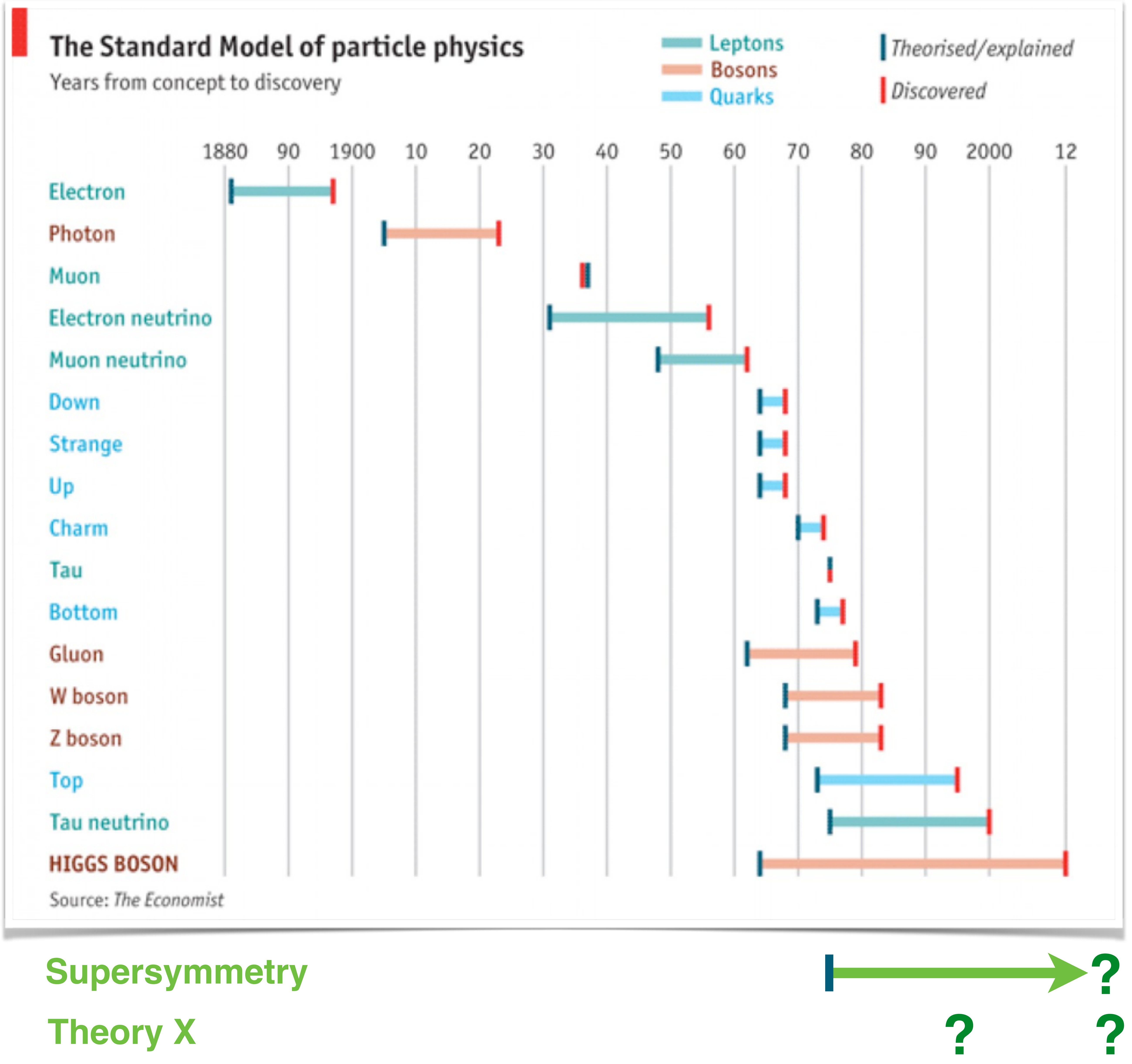




Conclusion

- ★ Excluded gluinos and squarks up to about 1.1 TeV and 1.9 TeV in various final states with high missing energy
  - ✦ **significant challenge to Vanilla SUSY**, but still some room for realization!
- ★ Actively **exploring a broader phase-space** of SUSY models, e.g.:
  - ✦ Split SUSY → long-lived gluinos
  - ✦ Compressed SUSY → soft decay products
  - ✦ RPV SUSY → no missing energy
- ★ With another 100 fb^{-1} of fresh data in the oven, **expect new searches and results soon!**
  - ✦ who knows what might be in those tails?!

Thank you for your attention!



Source: *The Economist*