Sensitivity of a Prompt CMS Analysis to Long-Lived Models

University of BRISTOL

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Ben Krikler

Overview

The SUSY AlphaT 2016 analysis

Adapting standard simplified models to include LLPs

Results and Sensitivity discussions

The AlphaT analysis

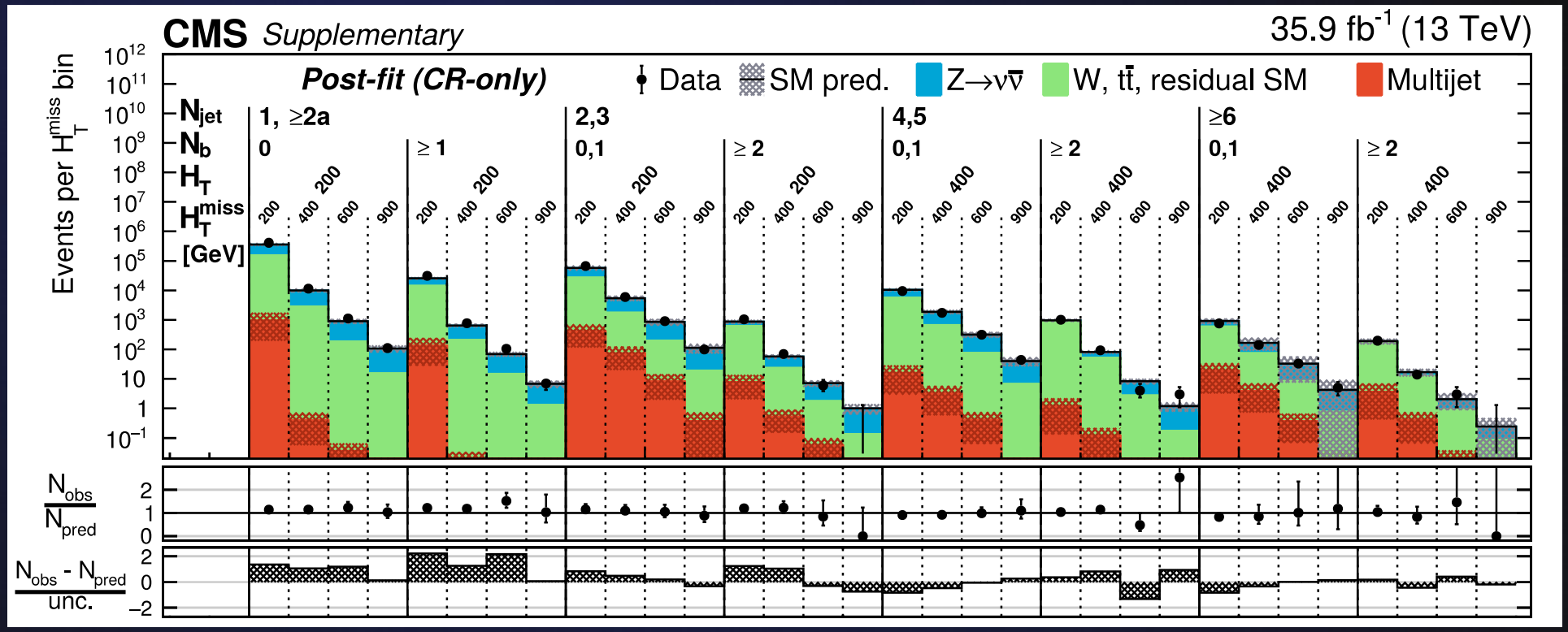
- Jets + MET search:
  - Inclusive search over all-hadronic final state
  - Uses α_T (AlphaT) and $\Delta\phi^*_{min}$ (biased-delta phi) variables to reduce QCD background to negligible levels
  - Fitting over 253 signal bins based on: H_T, H_T^{miss}, number of jets, and number of b-tagged jets
  - Additional simplified binning scheme with only 32 bins
- No specific treatment for long-lived particles
  - No dedicated reconstruction or object tagging
  - Selections optimised on prompt signals and not changed
- Access to paper and supplementary material:
  - Accepted for JHEP to be published very soon
  - ArXiv: https://arxiv.org/abs/1802.02110
  - Supplementary info to aid reinterpretation at public webpage: https://cms-results.web.cern.ch/cms-results/public-results/publications/SUS-16-038/index.html

The AlphaT analysis: Selections

Physics object acceptances	
Jet	$p_T > 40\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
Photon	$p_T > 25\,\text{GeV}$, $\lvert\eta\rvert < 2.5$, isolated in cone $\Delta R < 0.3$
Electron	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.5$, $I^{\text{rel}} < 0.1$ in cone $0.05 < \Delta R(p_T) < 0.2$
Muon	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.5$, $I^{\text{rel}} < 0.2$ in cone $0.05 < \Delta R(p_T) < 0.2$
Single isolated track (SIT)	$p_T > 10\,\text{GeV}$, $\lvert\eta\rvert < 2.5$, $I^{\text{track}} < 0.1$ in cone $\Delta R < 0.3$
Baseline event selection	
All-jet final state	Veto events containing photons, electrons, muons, and SITs within acceptance
p_T^{miss} quality	Veto events based on filters related to beam and instrumental effects
Jet quality	Veto events containing jets that fail identification criteria or $0.1 < f_{h^\pm}^{j_1} < 0.95$
Jet energy and sums	$p_T^{j_1} > 100\,\text{GeV}$, $H_T > 200\,\text{GeV}$, $H_T^{\text{miss}} > 200\,\text{GeV}$
Jets outside acceptance	$H_T^{\text{miss}}/p_T^{\text{miss}} < 1.25$, veto events containing jets with $p_T > 40\,\text{GeV}$ and $\lvert\eta\rvert > 2.4$
Signal region	Baseline selection +
α_T threshold (H_T range)	0.65 (200–250 GeV), 0.60 (250–300), 0.55 (300–350), 0.53 (350–400), 0.52 (400–900)
$\Delta\phi^*_{\text{min}}$ threshold	$\Delta\phi^*_{\text{min}} > 0.5$ ($n_{\text{jet}} \geq 2$), $\Delta\phi^{*\,25}_{\text{min}} > 0.5$ ($n_{\text{jet}} = 1$)

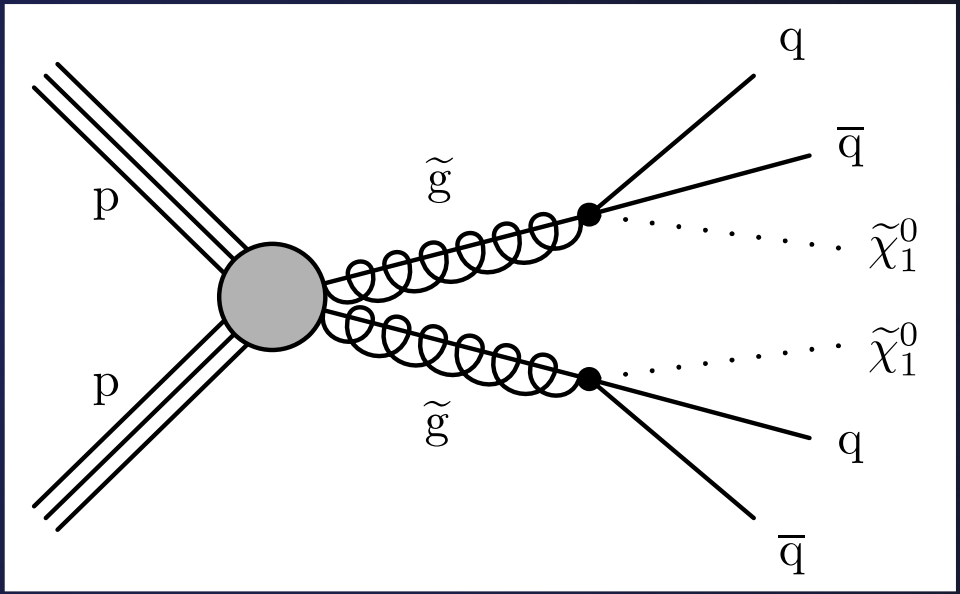
- Data-driven background estimations by fitting to sideband and control regions

Results



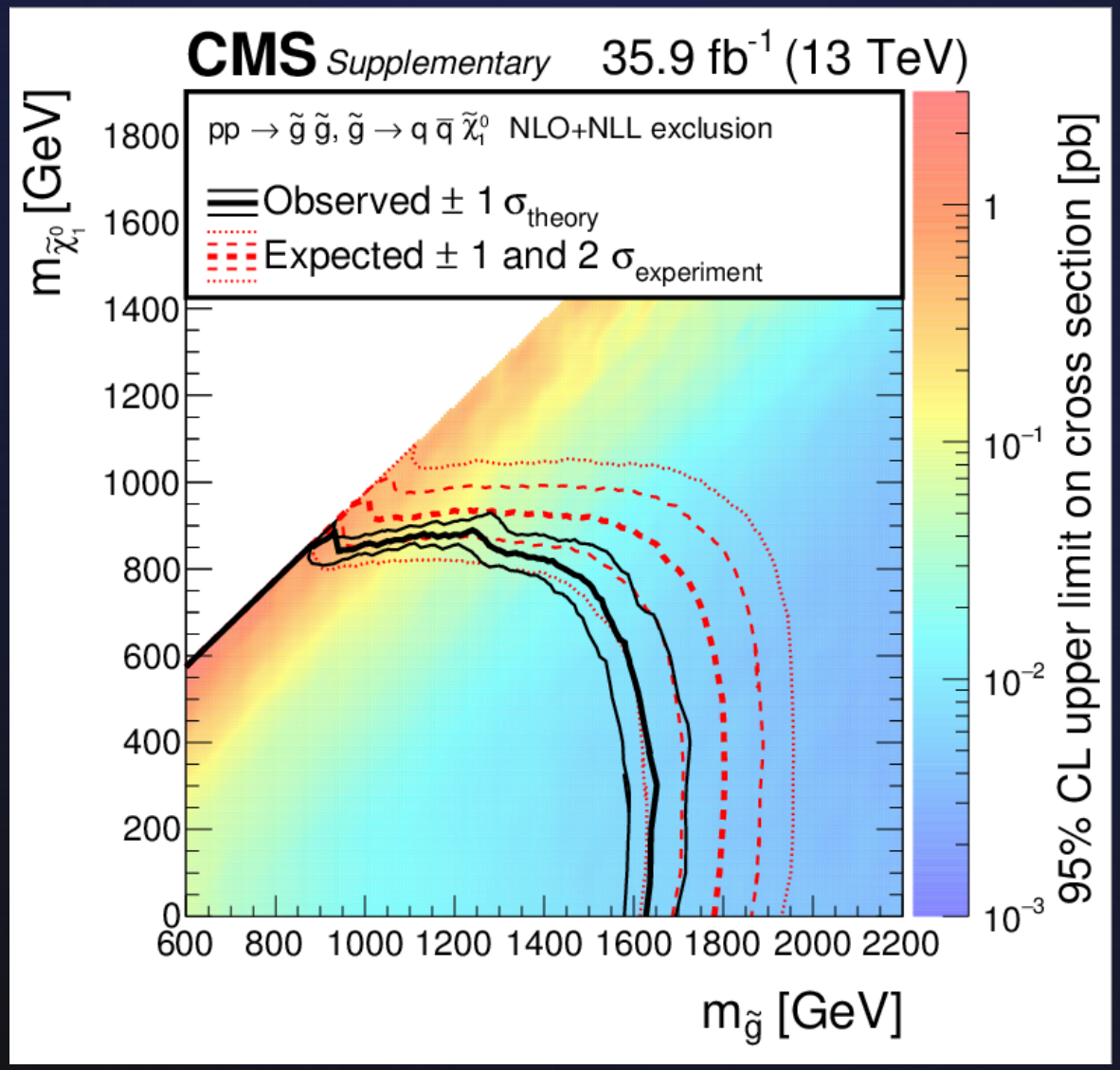
- Simplified binning scheme
- Predictions for signal region, having fit to control regions

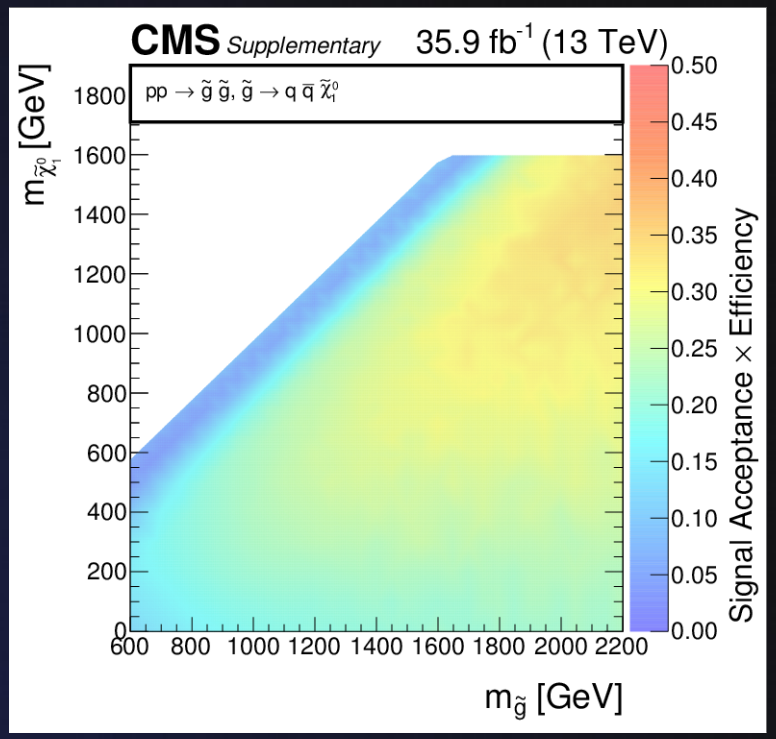
The T1qqqq model



- Gluino pair production
- Decay gluinos via intermediate, highly virtual squarks
- Final state: four light-flavour quarks, two LSPs
- Gluino production in MadGraph LO, decay using Pythia

Vanilla T1qqqq

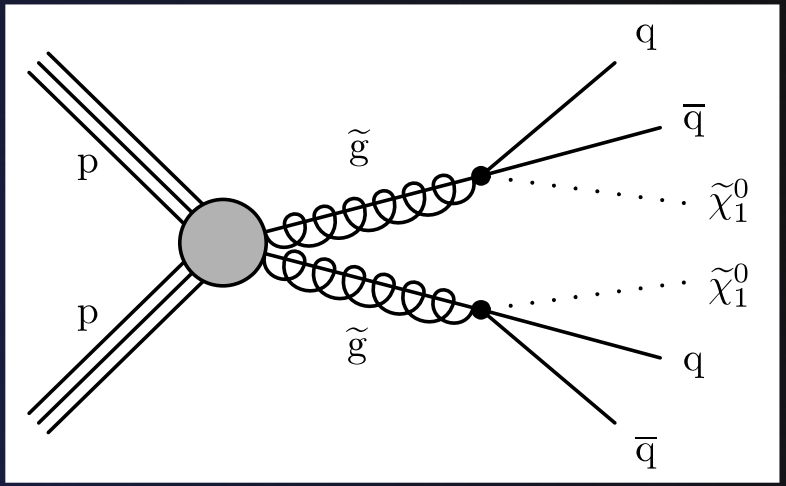




- Exclude up to M_{gluino} = 1650 GeV M_{LSP} = 900 GeV
- Sensitivity driven by high-N_{jet}, low-$N_{b\text{-}jet}$ bins

T1qqqqLL: Long-lived gluinos

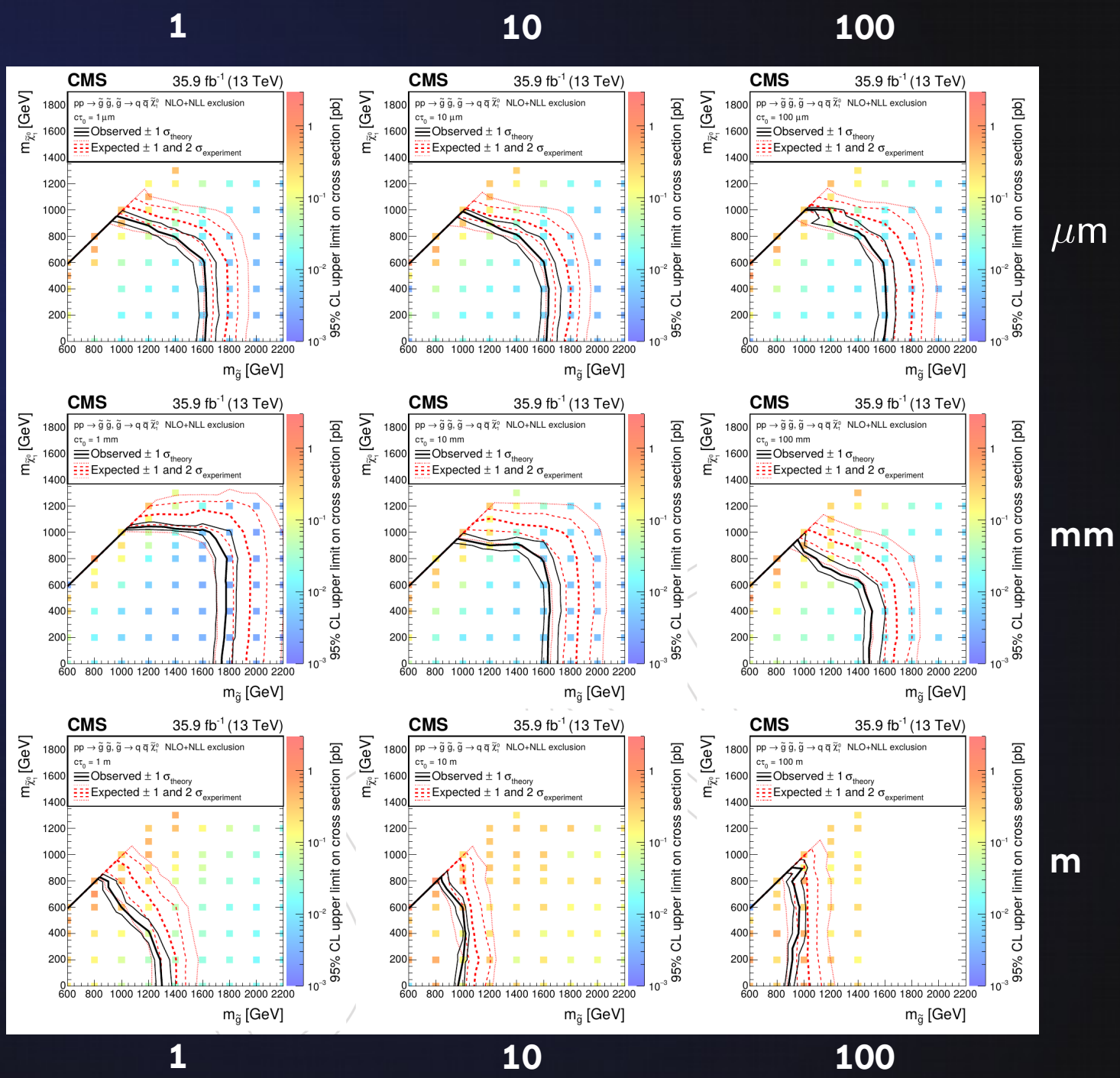
- Take T1qqqq
  - Immediate long-lived extensions
  - Already has very off-shell squarks
    → decrease gluino width
    → gluino becomes long-lived
    → Split SUSY
  - Implement by adjusting gluino lifetime in Pythia
  - $c\tau_0$: gluino rest-frame lifetime in metres



- T1qqqqLL: $c\tau_0$ values from 1 μm to 100 m and "meta-stable" gluinos
- Use CMS FullSim for T1qqqqLL, compared to FastSim for T1qqqq
- R-hadronisation model:
  - Long-lived gluinos can form meta-stable, bound states with SM contents
  - Particularly important for larger values of c-tau
  - Material affects of detector R-hadron interactions could become important

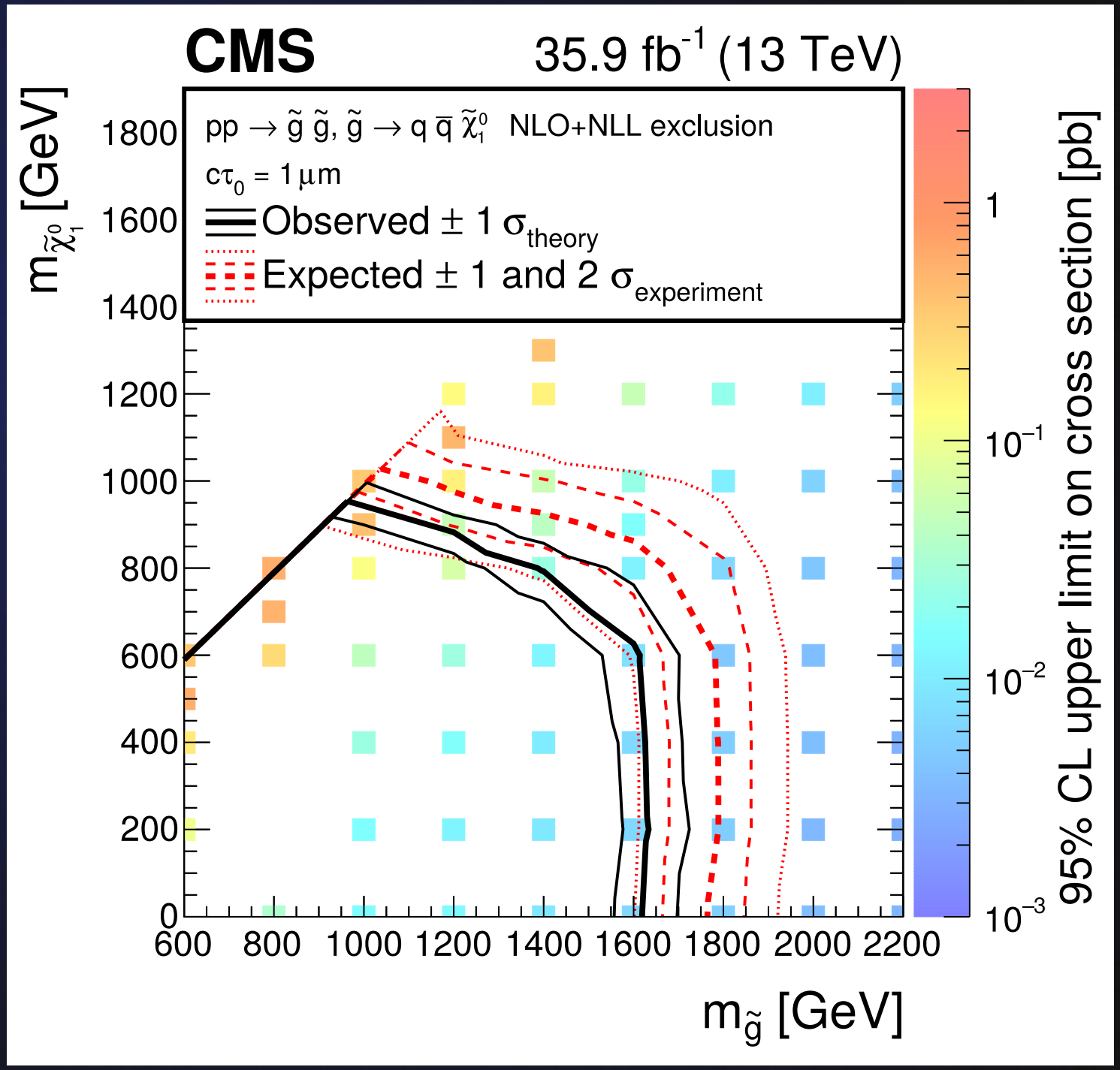
T1qqqqLL

- Cross section limits
- Best limits achieved when $c\tau_0$ = 1 mm



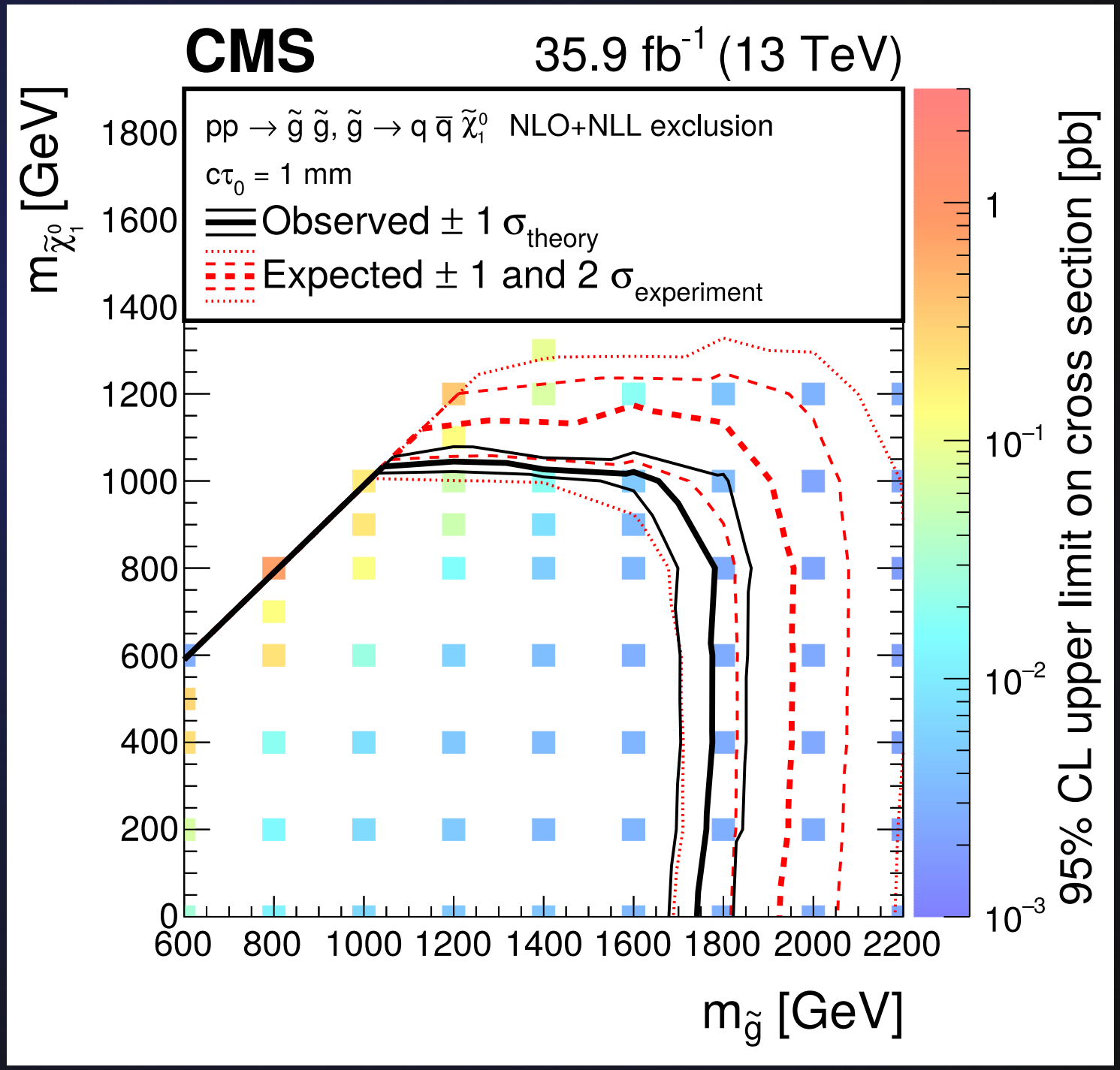
T1qqqqLL

- Cross section limits
- Up to 100 microns:
  - Limits as prompt models



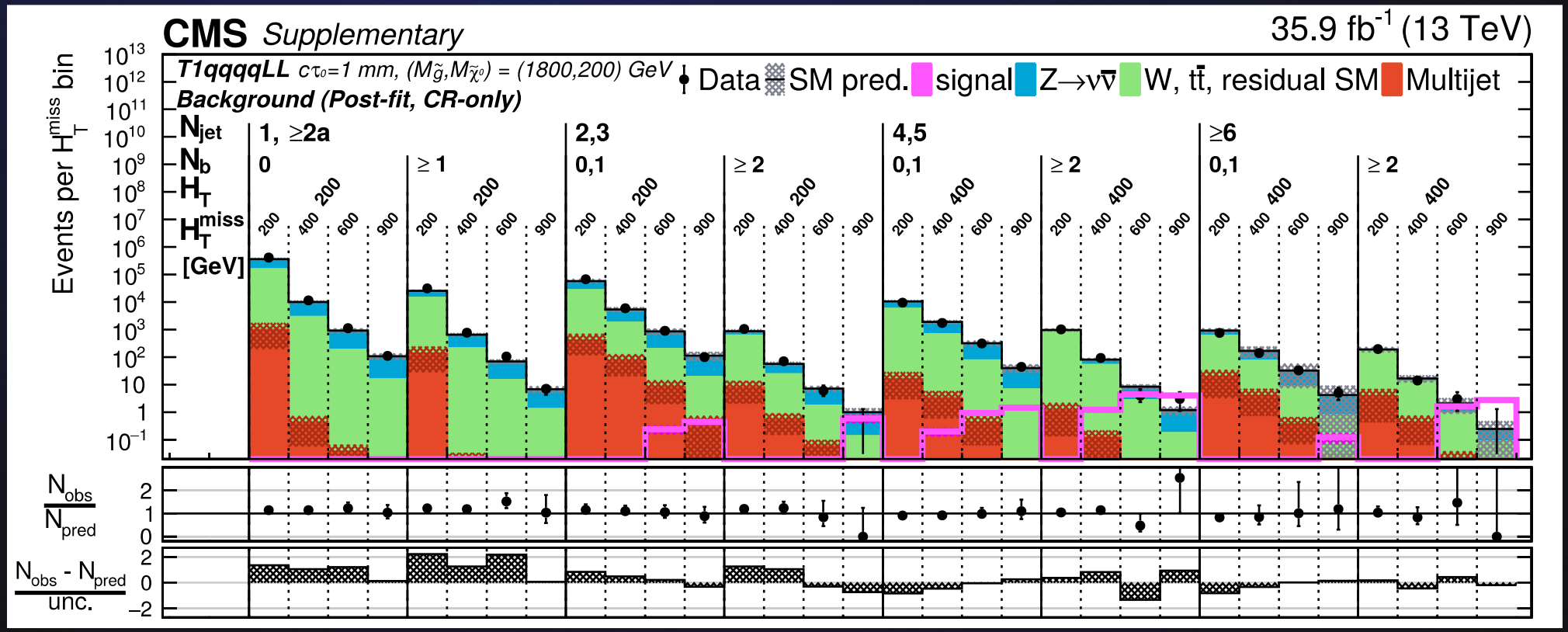
T1qqqqLL

- Cross section limits
- Around 1 mm
  - Gluino events become b-tagged



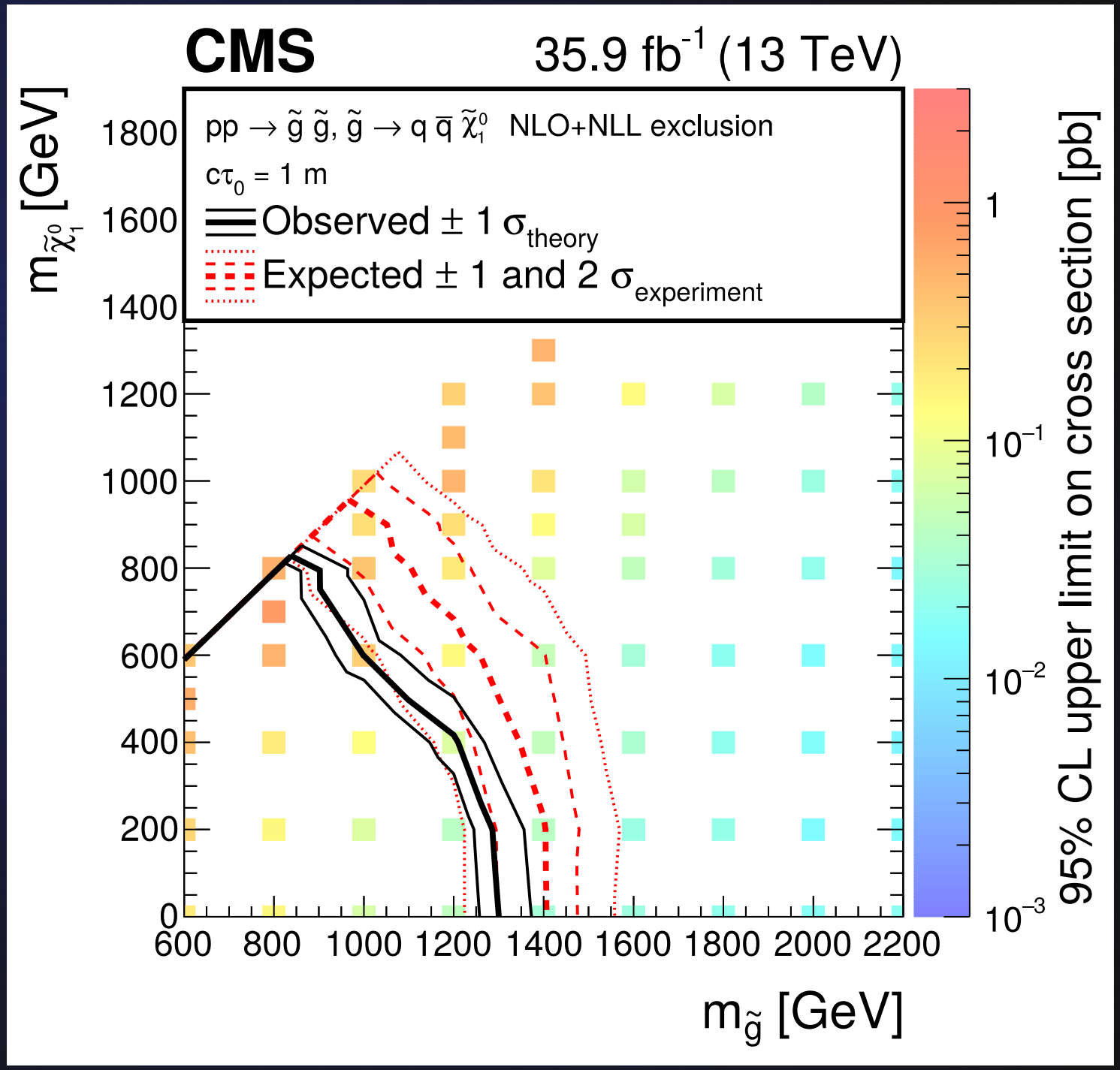
T1qqqqLL: Signal vs Background

- $c\tau_0$ = 1 mm
- M_{gluino} = 1800 GeV
- M_{LSP} = 200 GeV
- Bottom right of observed limit contour



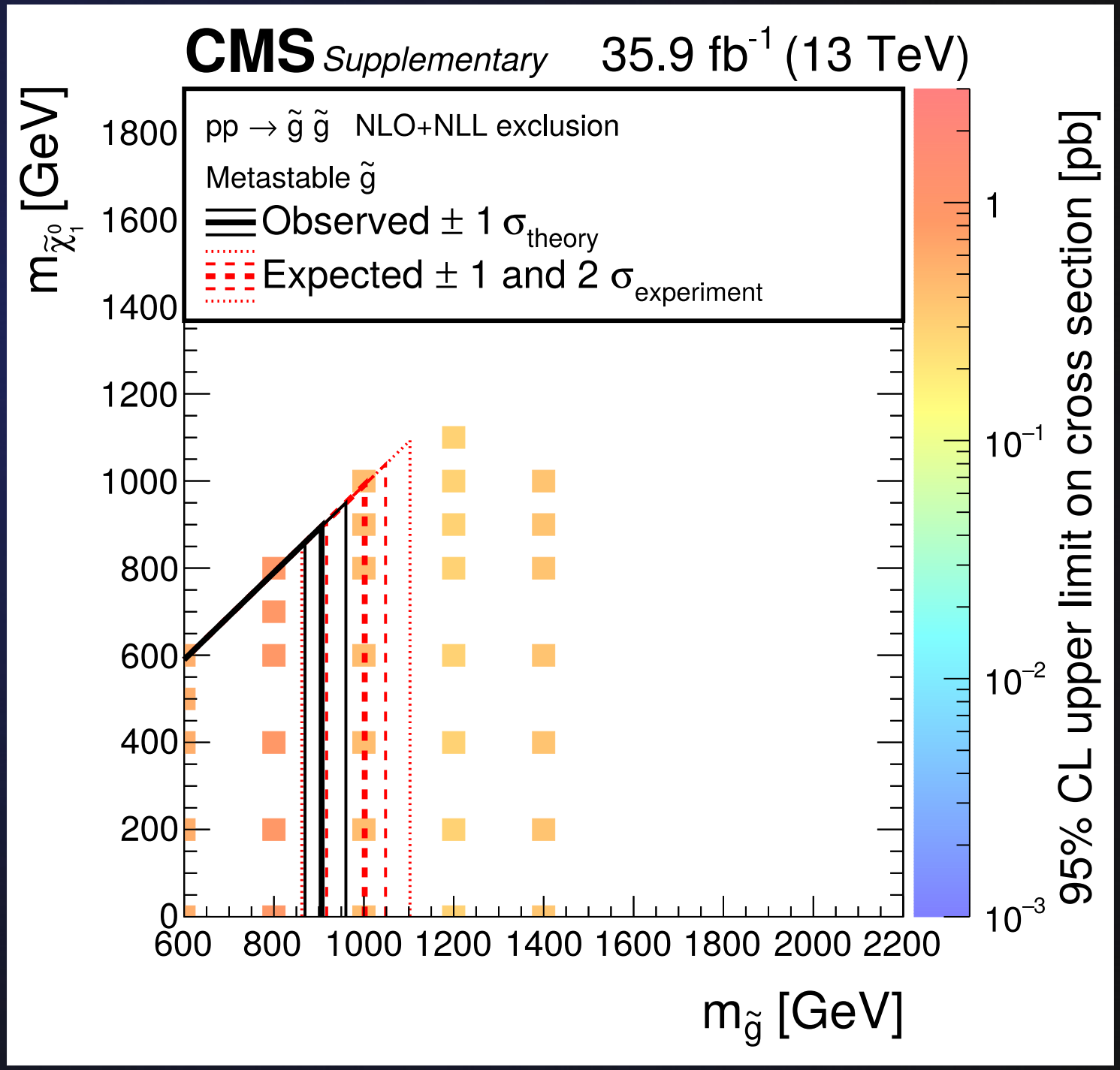
T1qqqqLL

- Cross section limits
- At 1 m, decaying outside tracker:
  - Charged-hadron fraction cut reduces acceptance



T1qqqqLL

- Cross section limits
- Metastable gluinos
  - Depend on ISR jets
  - No sensitivity to LSP mass

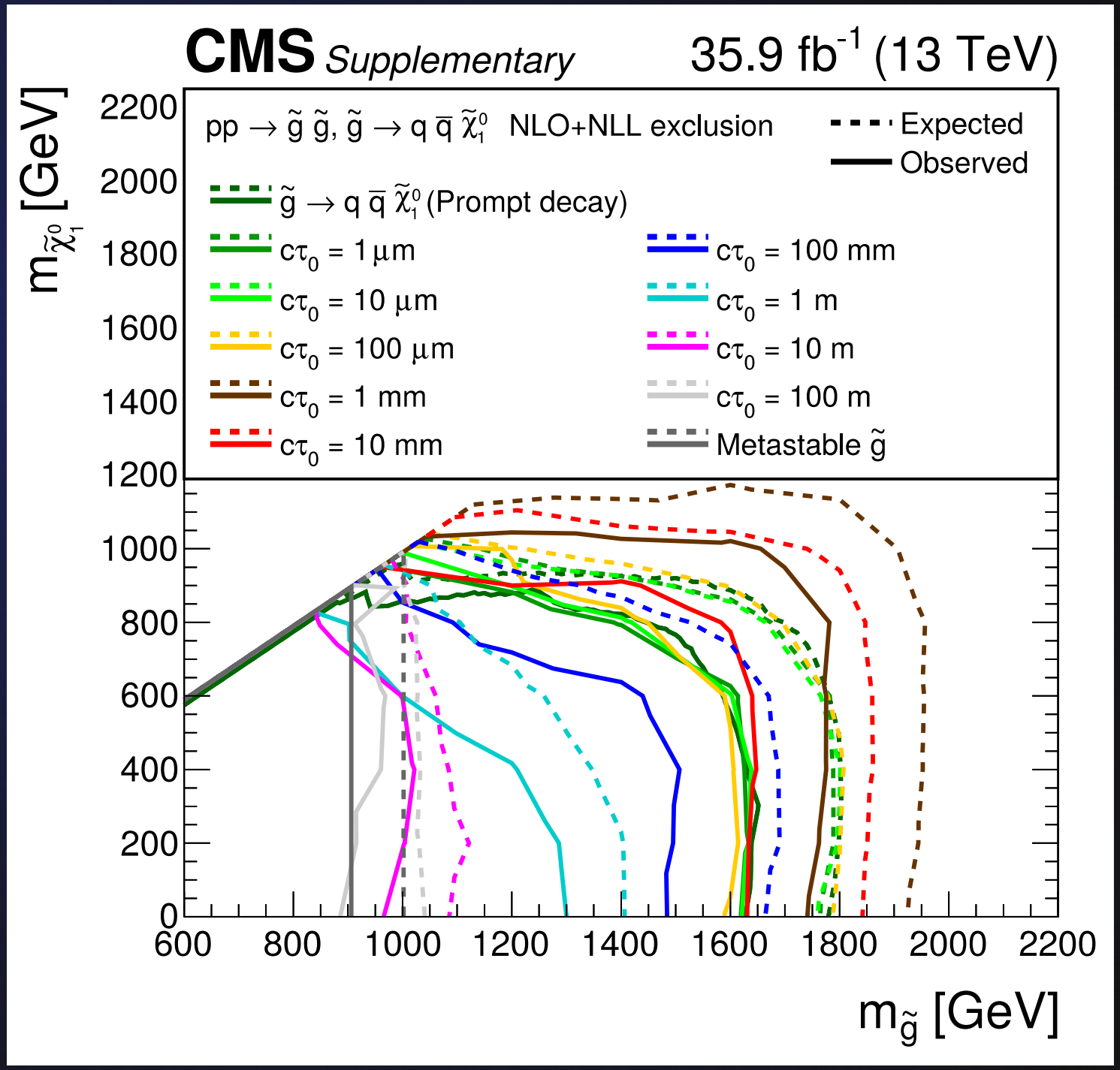


Key sensitivity effects

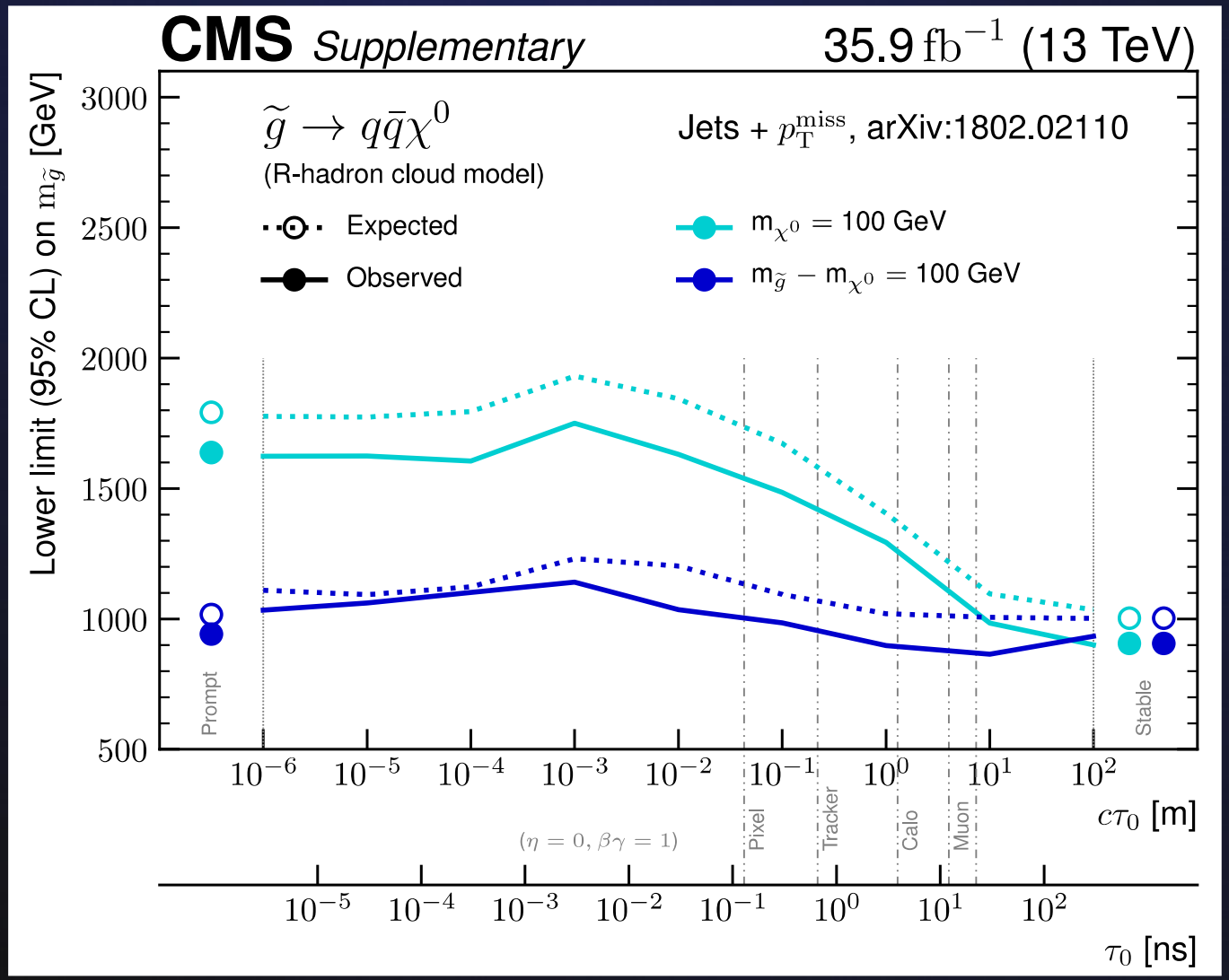
- B-tagging rate
  - Improve sensitivity around b-decay length (~1 mm)
- Charged hadron fraction of leading jet
  - Reduces sensitivity once decays outside of the tracker
- Reliance on ISR as $c\tau_0$ becomes large
  - Gluino escapes undetected

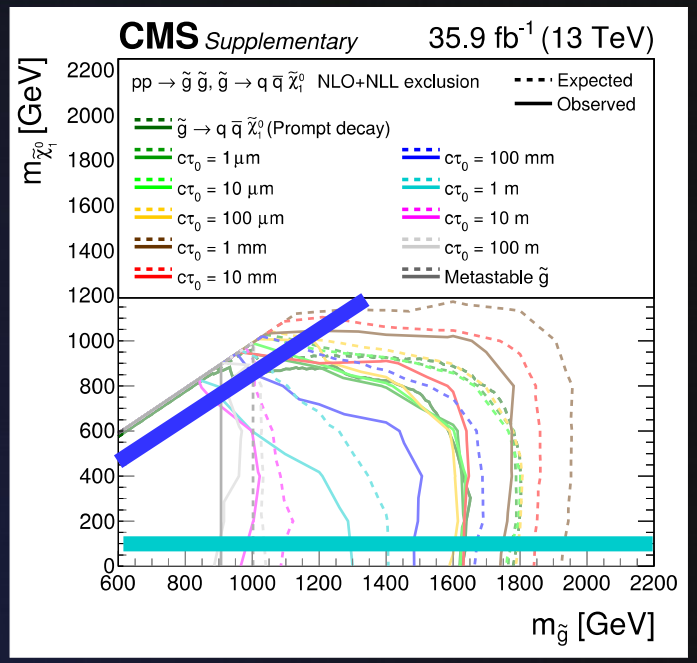
T1qqqqLL

- Limit contours for all considered values of $c\tau_0$



Limits vs $c\tau_0$

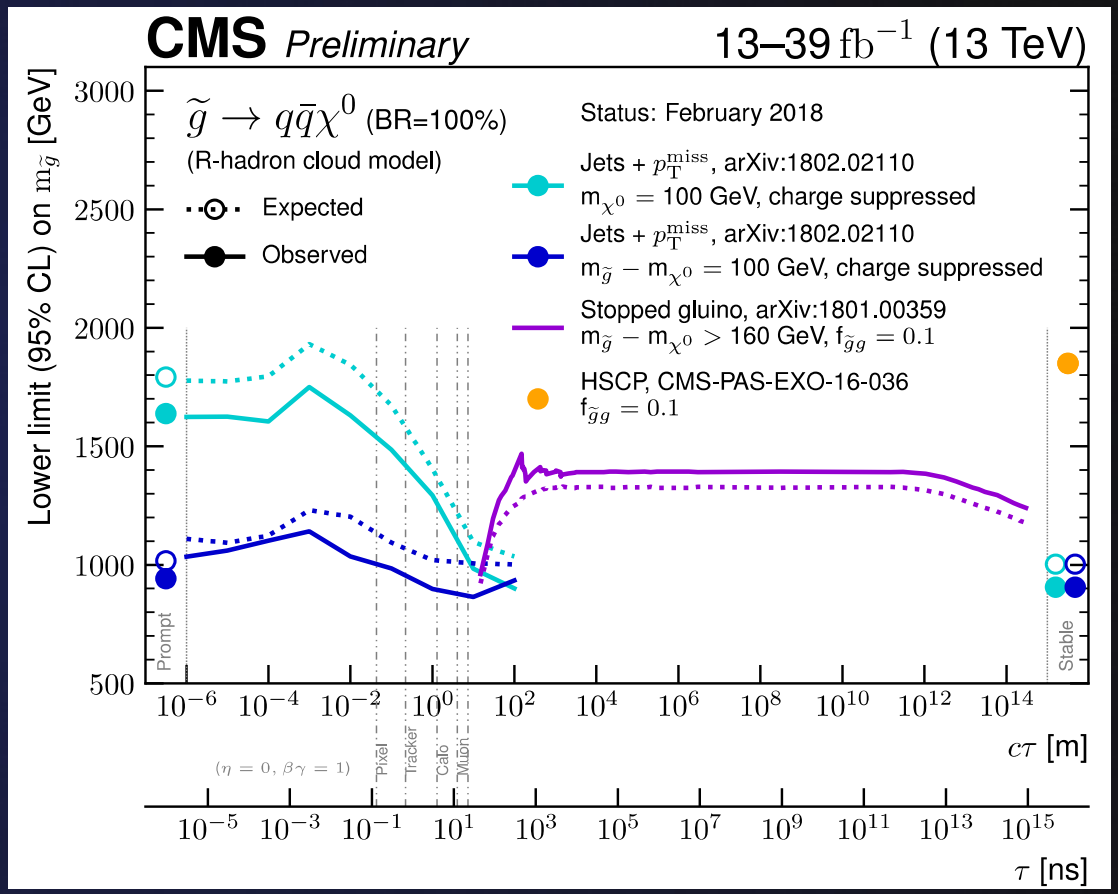




- Limit on gluino mass assuming theoretical cross section for different $c\tau_0$ values

Comparing to other results

- CMS: EXO-16-004
  - Submitted to JHEP in December
  - Public page: http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO-16-004/
  - A dedicated search for out-of-time calorimeter jets
  - T1qqqqLL where gluinos stop in the calorimeter, then decay out-of-time with collisions
- HSCP, CMS-PAS-EXO-16-036
  - dE/dX measurement for hadronised gluinos



- Complementary sensitivity between methods
  - Prompt AlphaT analysis does well for smaller lifetimes
  - EXO-16-004 and HSCP perform better for much larger lifetimes

Summary

- First look at extending standard prompt inclusive search to simplified SUSY models to a LLP regime
- Limits from the AlphaT prompt search:
  - Best observed (expected) limits, $c\tau_0$ =1 mm: M_{gluino} = 1750 (1950) GeV, M_{LSP} = 1050 (1200) GeV
- Sensitivity to full range of $c\tau_0$ values (prompt to meta-stable)
  - Weak dependence on R-hadronisation model
  - Possible due inclusive nature of search and low selection thresholds
- More on this at the LLP workshop later in the week
  - CMS Snapshot (Steven Lowette)
  - CMS Material for Reinterpretation (Juliette Alimena)
- Links to paper and material
  - ArXiv: https://arxiv.org/abs/1802.02110
  - Public webpage: https://cms-results.web.cern.ch/cms-results/public-results/publications/SUS-16-038/index.html

Advert: Additional Material

- Since this is a reinterprations conference, available online material:
  - Covariance matrix (full and simplified binning)
  - Bin contents for data and SM background predictions as csv files (full and simplified binning)
  - Digital limit and signal acceptance x efficiency mass planes for 7 standard SMS models and T1qqqqLL with 6 $c\tau_0$ values
  - Bin contents for signal from four benchmark models
  - Cut flows for four benchmark models

Event Selection		Benchmark Model			
		T2bb	T2cc	T1bbbb	T1qqqqLL
	m_{SUSY} (GeV)	550	500	1900	1800
	m_{LSP} (GeV)	450	480	100	200
	$c\tau_0$ (mm)	–	–	–	1
Before selection		100.0	100.0	100.0	100.0
Single isolated track, muon, electron, & photon vetos		94.6	97.2	99.4	86.0
Event veto for jets failing ID		94.3	96.8	98.7	85.7
$p_{\mathrm{T}}^{\mathrm{j_1}} > 100$ GeV		62.9	84.3	98.7	85.7
$0.1 < f_{\mathrm{h}^{\pm}}^{\mathrm{j_1}} < 0.95$		59.8	77.4	93.9	82.1
$H_{\mathrm{T}} > 200$ GeV		49.5	64.5	93.9	82.1
$H_{\mathrm{T}}^{\mathrm{miss}} > 200$ GeV		18.8	48.3	88.5	77.4
Event veto for forward jets ($\lvert\eta\rvert > 2.4$)		13.6	35.8	69.9	63.7
$H_{\mathrm{T}}^{\mathrm{miss}}/E_{\mathrm{T}}^{\mathrm{miss}} < 1.25$		12.9	34.1	69.3	60.3
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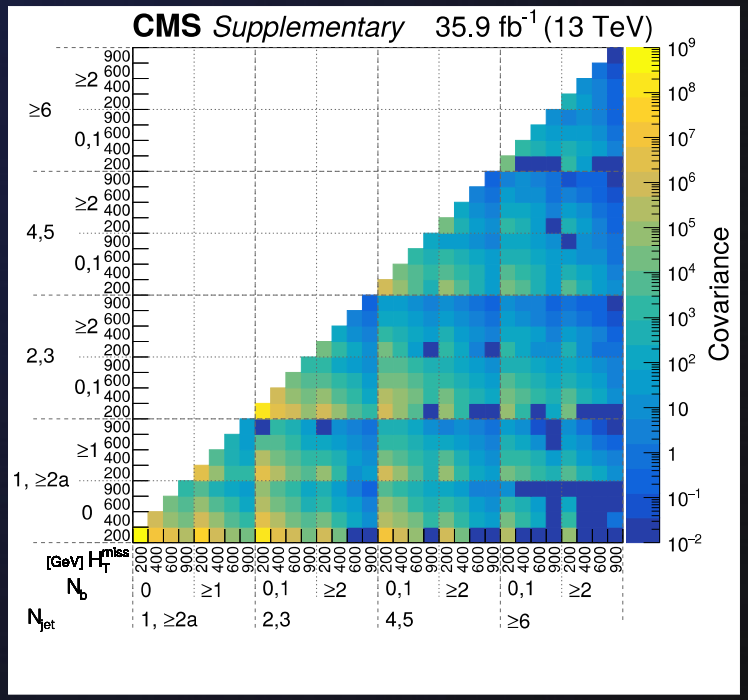
$\Delta\phi^*_{\mathrm{min}} > 0.5$		5.7	20.5	25.1	22.9

Table 2: A summary of the cumulative signal acceptance times efficiency, $\mathcal{A}\epsilon$ [%], for various benchmark models found in Table 4 of the paper, following the successive application of the event selection criteria used to define the signal region. See discussion and Table 1 in the paper for detailed descriptions of the selection.

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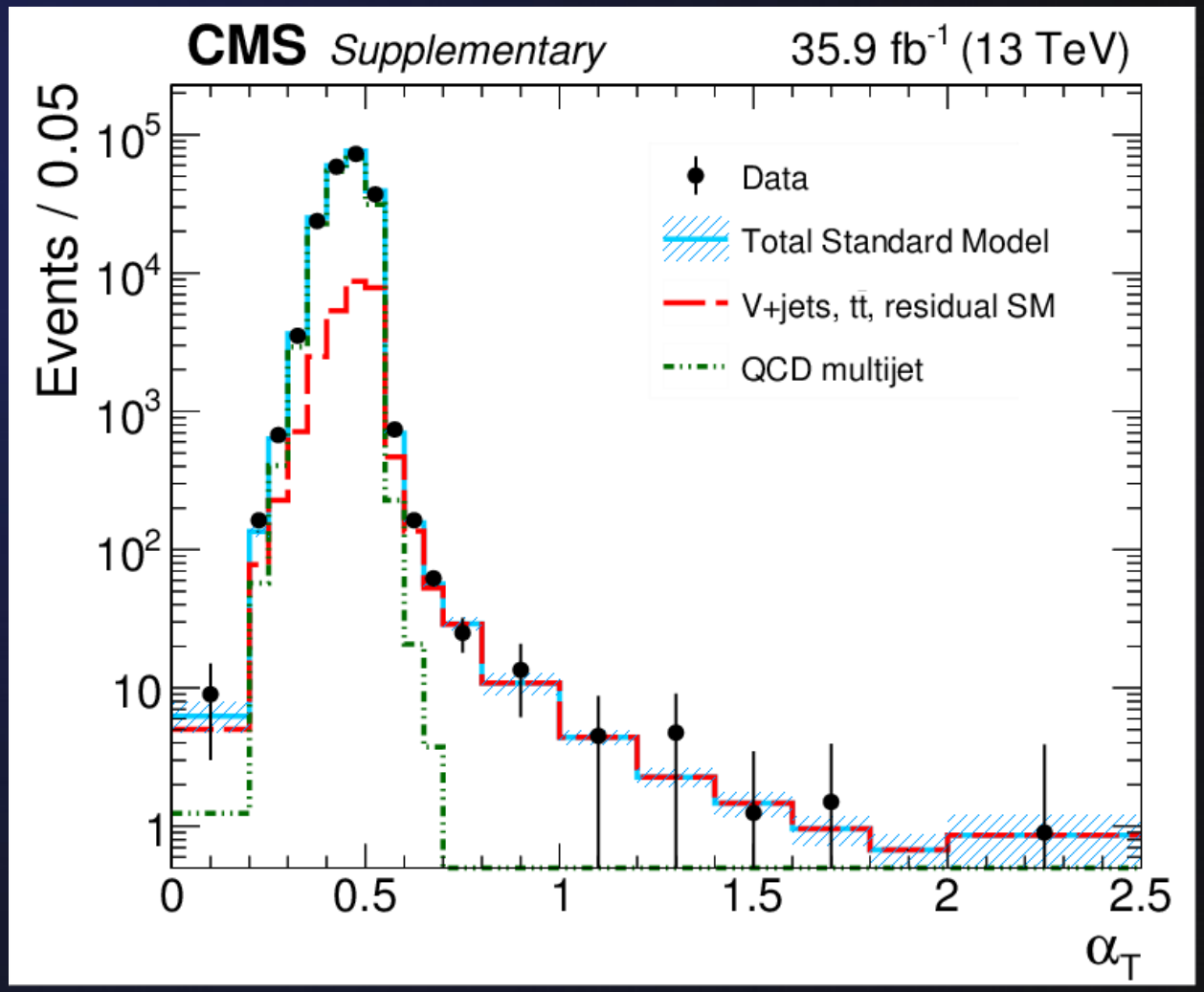
$ column -t -s, CMS-SUS-16-038_Figure_001.csv |head -20
njet  bjet  ht_low  ht_high  mht_low  mht_high  bkg          bkg_err      data
eq1j  eq0b  200.0   400.0    200      inf       254856.0625  26604.055607 291353.0
eq1j  eq0b  400.0   600.0    400      inf       7342.193848  966.182095   8572.0
eq1j  eq0b  600.0   900.0    600      inf       680.055298   121.049535   878.0
eq1j  eq0b  900.0   inf      900      inf       56.934498    14.6372      57.0
eq1j  eq1b  200.0   400.0    200      inf       8864.285156  956.368883   11072.0
eq1j  eq1b  400.0   600.0    400      inf       334.577576   45.115704    406.0
eq1j  eq1b  600.0   inf      600      inf       41.5201      7.551247     71.0
eq2j  eq0b  200.0   400.0    200      inf       29224.53125  7829.808887  34934.0
eq2j  eq0b  400.0   600.0    200      400.0     3274.273438  910.445913   3468.0
eq2j  eq0b  400.0   600.0    400      inf       2176.893066  623.577549   2568.0
eq2j  eq0b  600.0   900.0    200      400.0     276.672485   91.911319    226.0
eq2j  eq0b  600.0   900.0    400      600.0     268.382141   75.608887    253.0
eq2j  eq0b  600.0   900.0    600      inf       284.567871   92.978472    303.0
eq2j  eq0b  900.0   1200.0   200      400.0     179.342911   54.562745    165.0
eq2j  eq0b  900.0   1200.0   400      600.0     130.910461   33.582285    125.0
eq2j  eq0b  900.0   1200.0   600      900.0     78.662025    25.244872    97.0
eq2j  eq0b  900.0   1200.0   900      inf       29.319504    13.698029    25.0
eq2j  eq0b  1200.0  inf      200      400.0     11.844943    5.111627     9.0
```

Back-ups

AlphaT

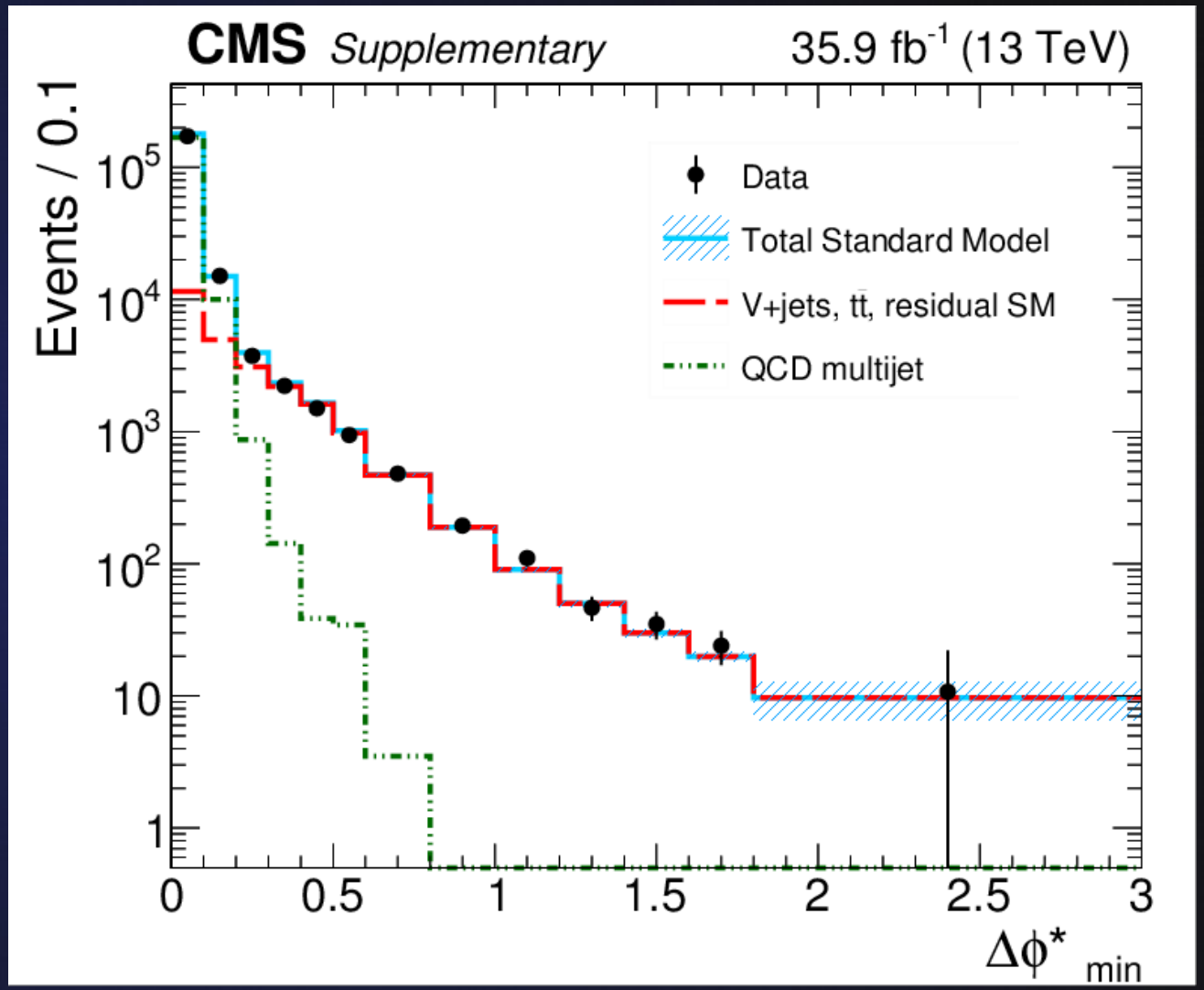
$$\alpha_T = \frac{E_T^{j_2}}{M_T}$$

- In dijet events:
  - AlphaT is the ratio between the sub-leading jet's transverse energy and the dijet mass
  - With no Etmiss in event, cannot exceed 0.5 even with jet energy mis-measurements
  - Robust to detector effects on jet energy resolutions
- Generalising to multi-jet events
  - Cluster all jets into two large pseudo-jets such that difference in scalar ET sums for each pseudo-jet is minimised



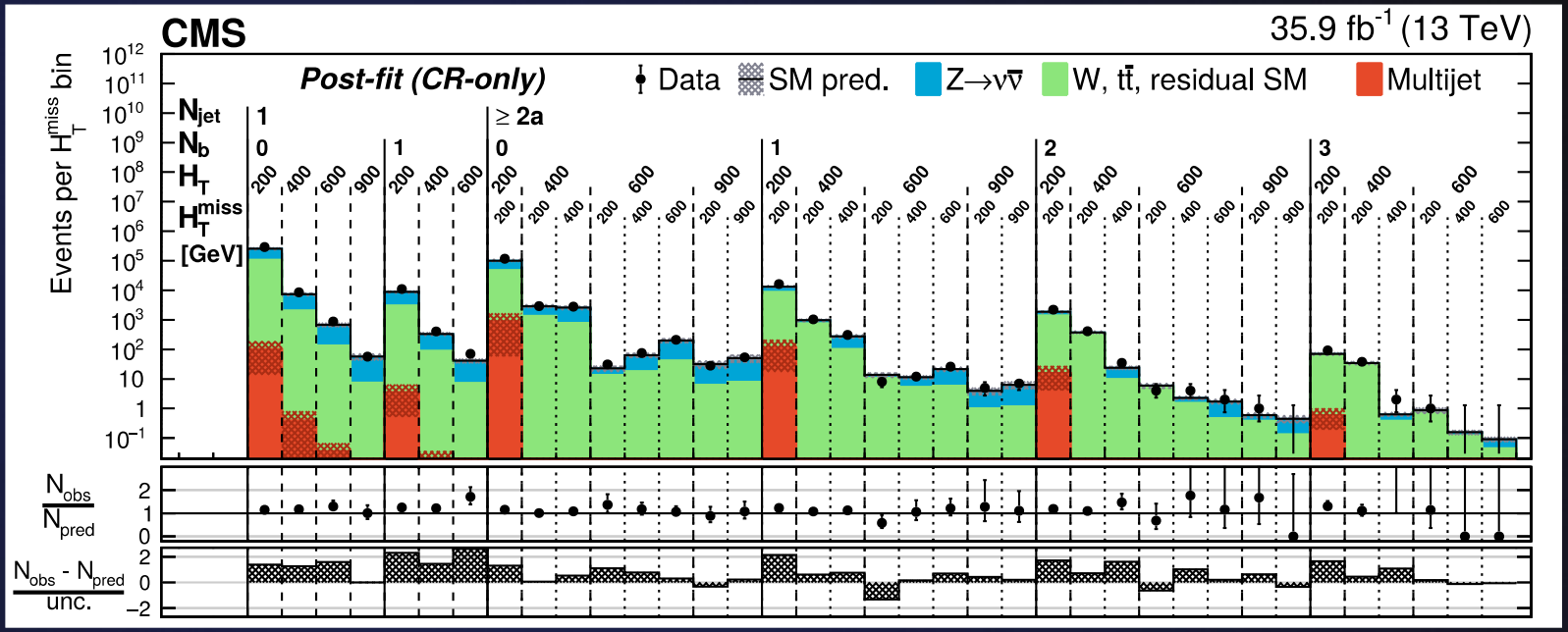
Biased delta-phi

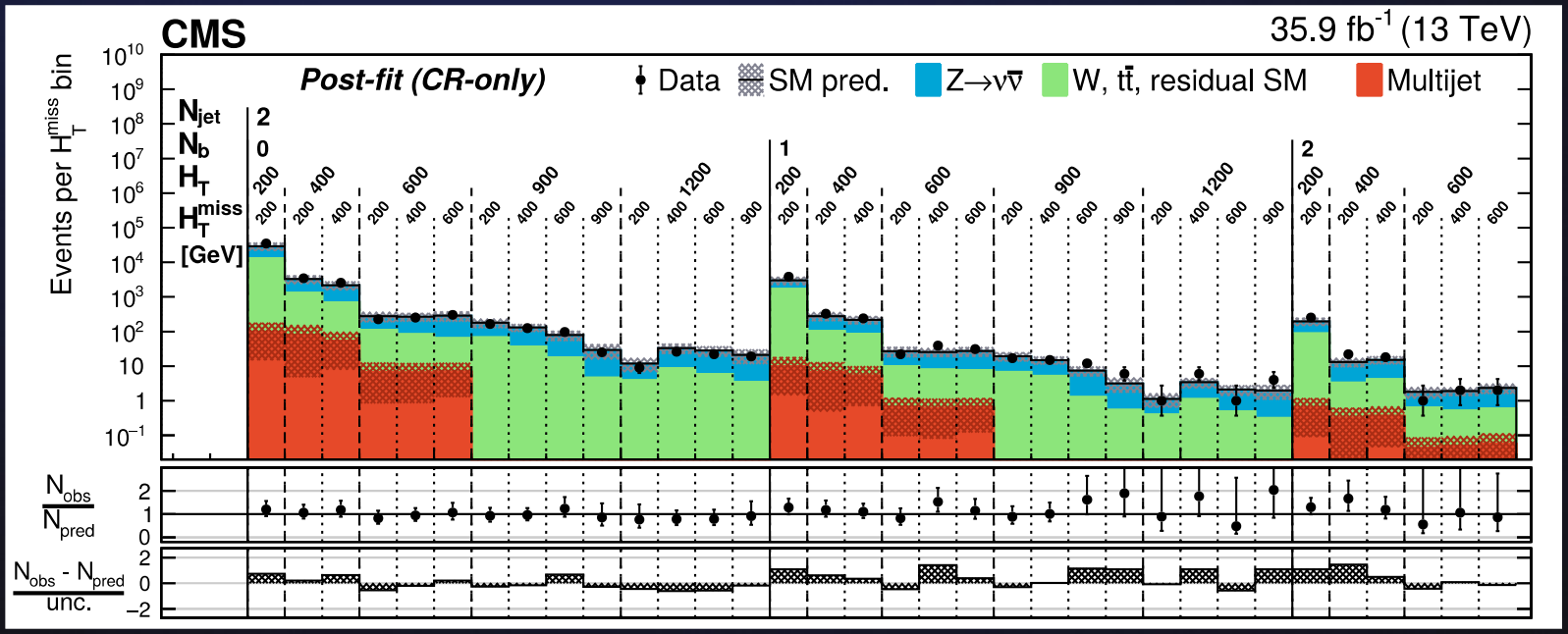
- Minimum for all jets of the angle between the jet and the vector sum of all others
- Peaks close to zero for mismeasured multi-jet events
- Can reach up to 180°



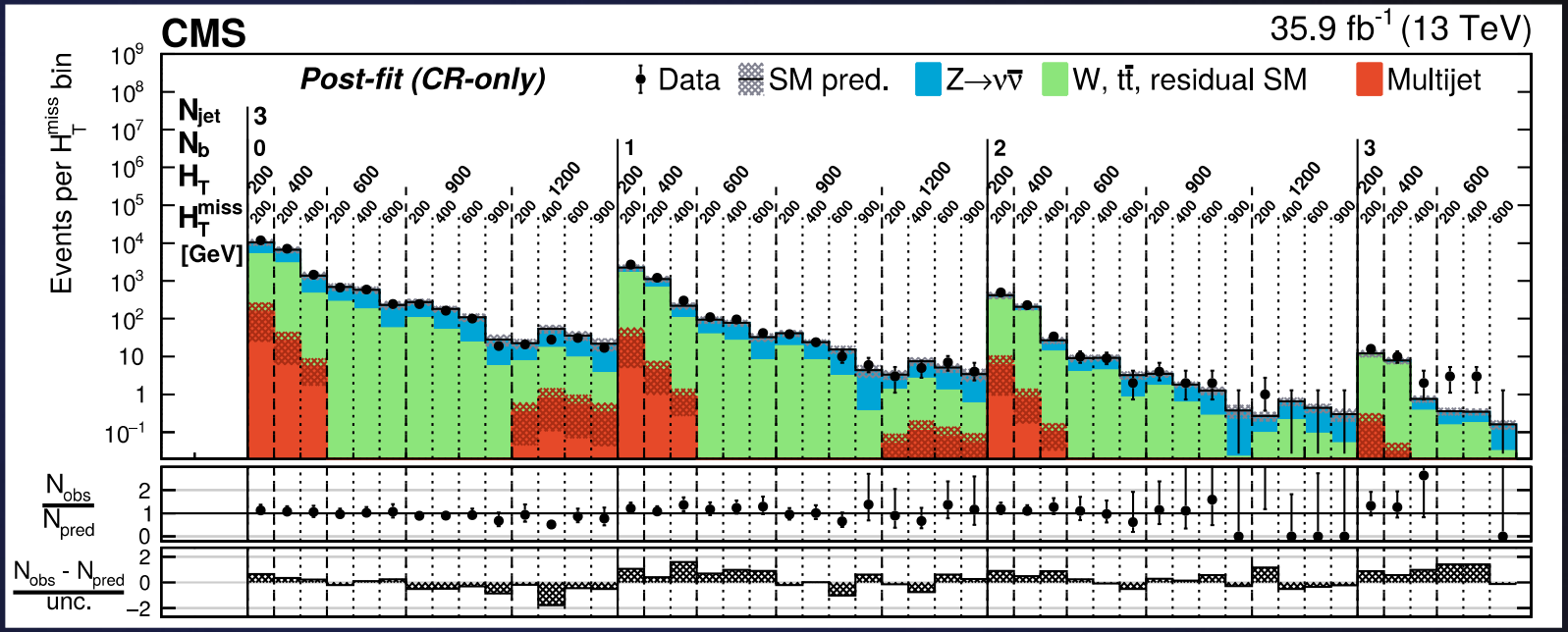
$$\Delta\phi^*_{\text{min}} = \min_{i}\left(\Delta\phi\left(\vec{p}^{\,i}_{T}, \sum_{j\neq i}\vec{p}^{\,j}_{T}\right)\right)$$

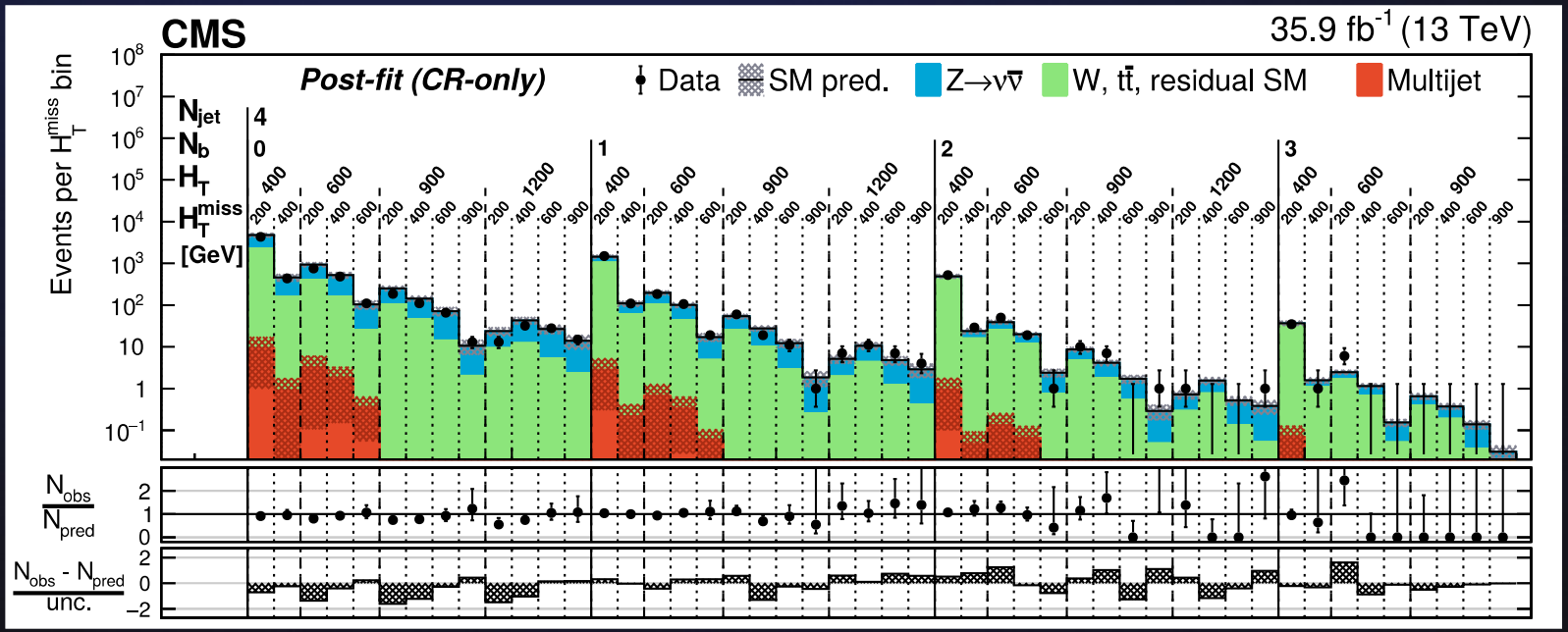
Full binning results (1)





Full binning results (2)





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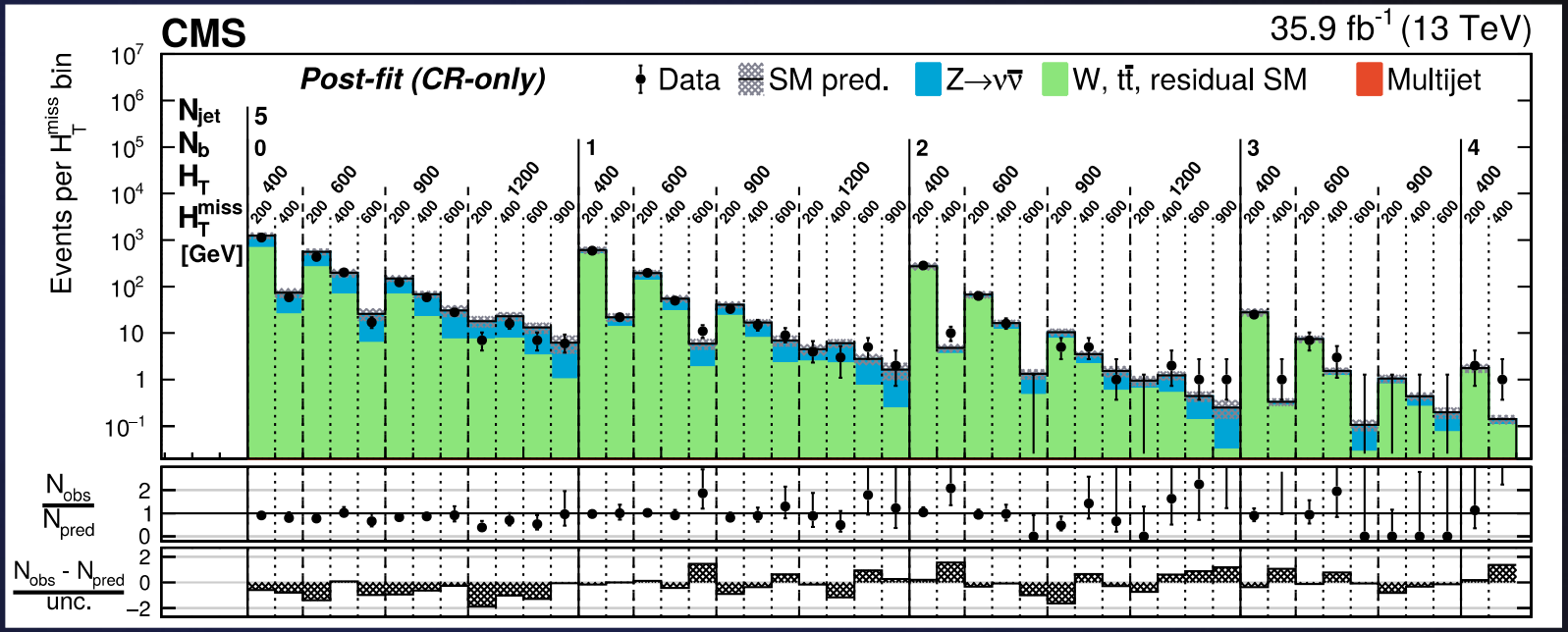

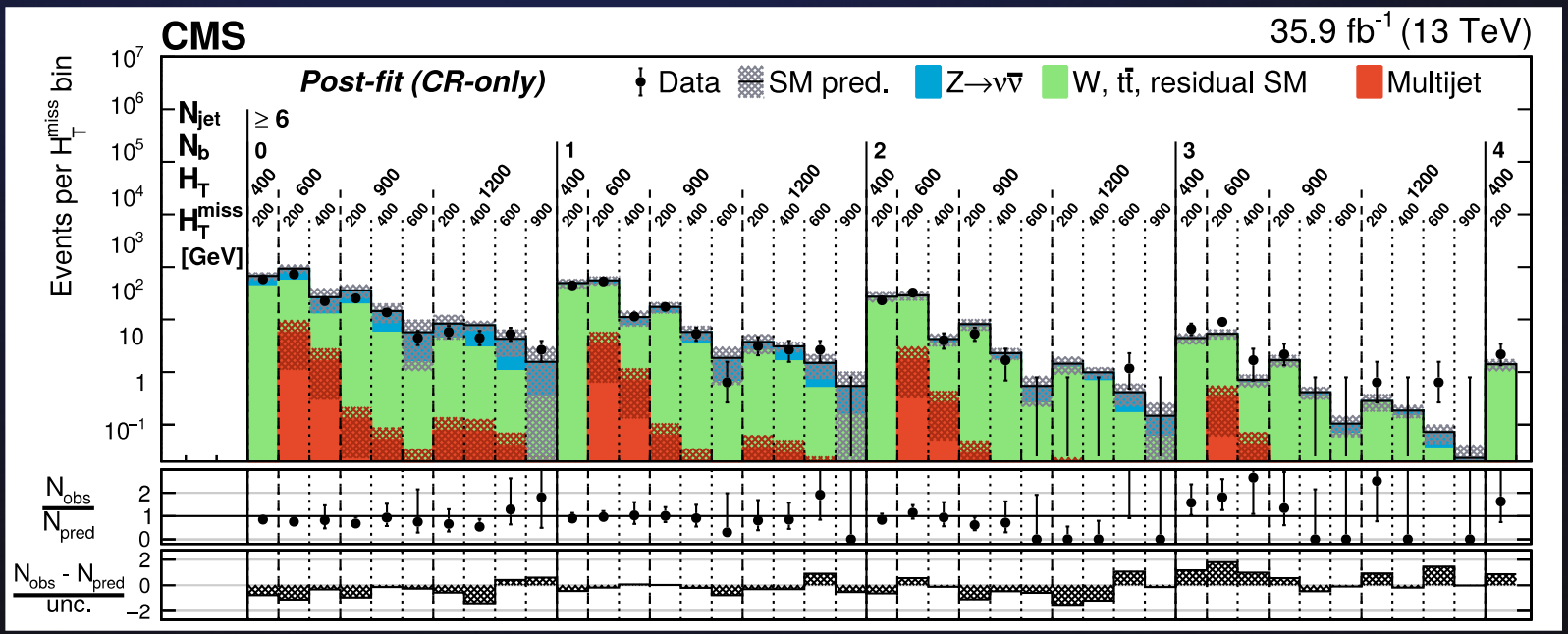

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T1qqqqLL

- Signal acceptance x efficiency
- In general, flat for all model points until about 10^{-2} m, start to decay outside of the tracker
  - Depends on mass values