Results for strongly produced SUSY at CMS

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on behalf of the CMS collaboration
University of California, Santa Barbara

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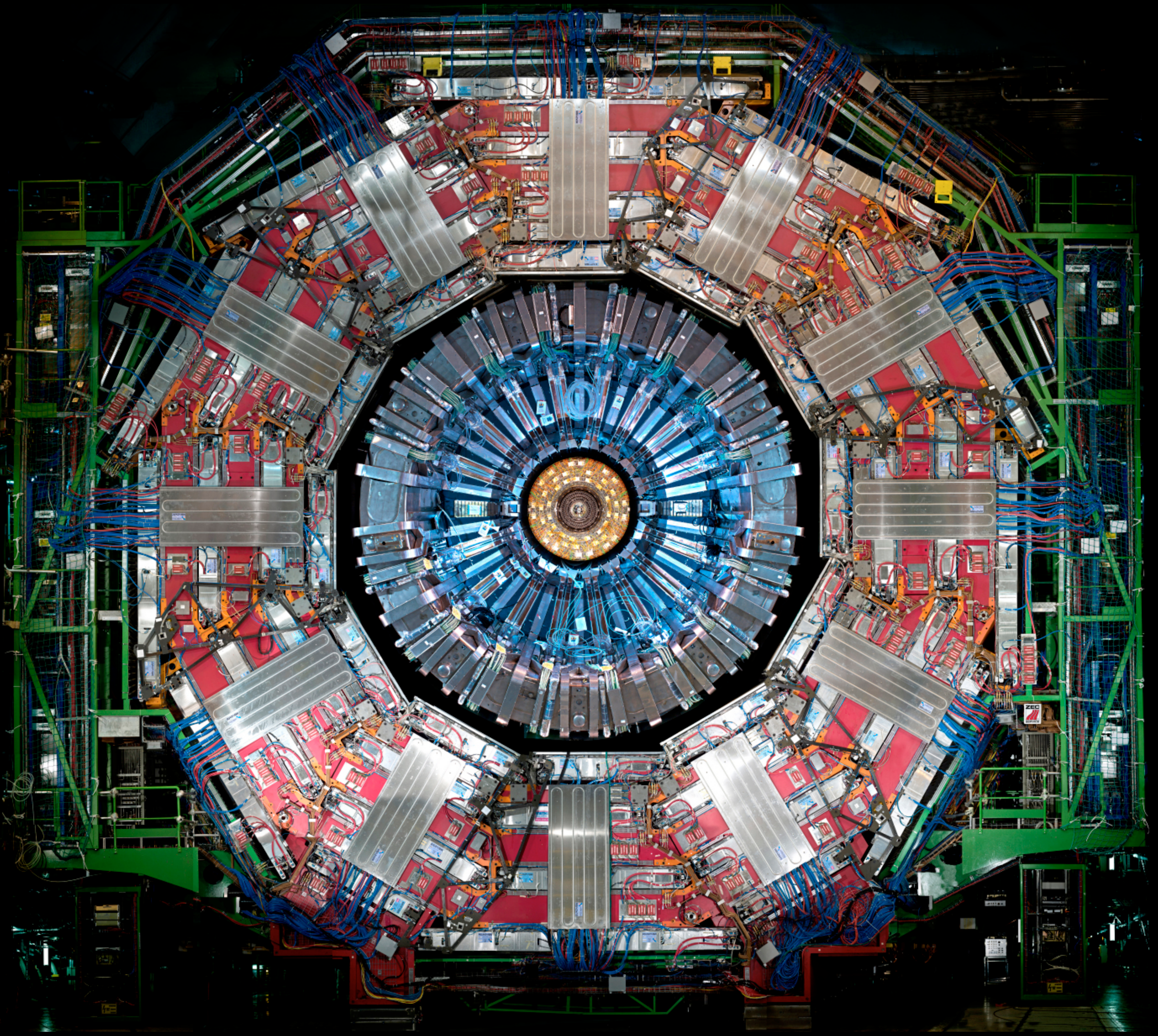
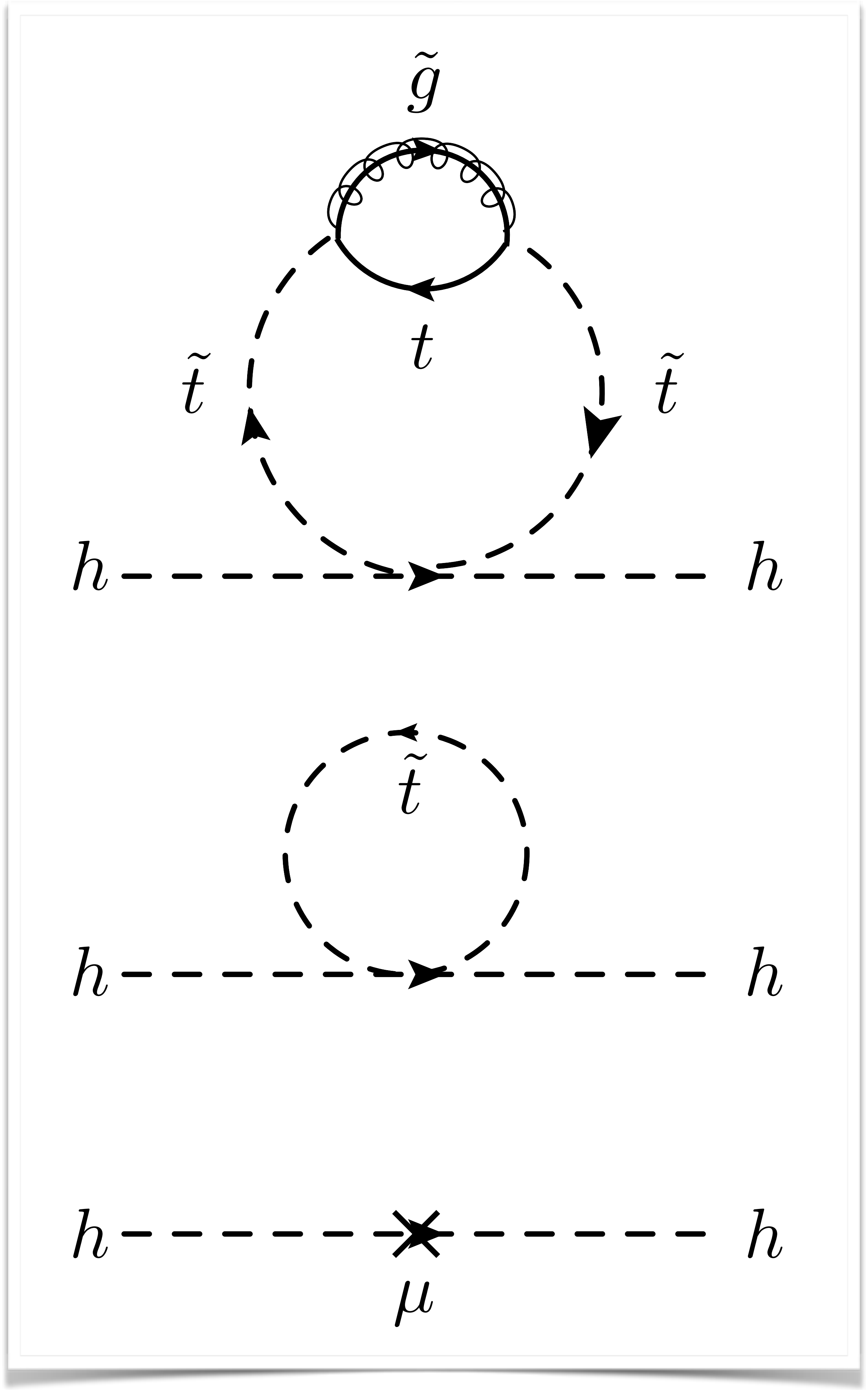
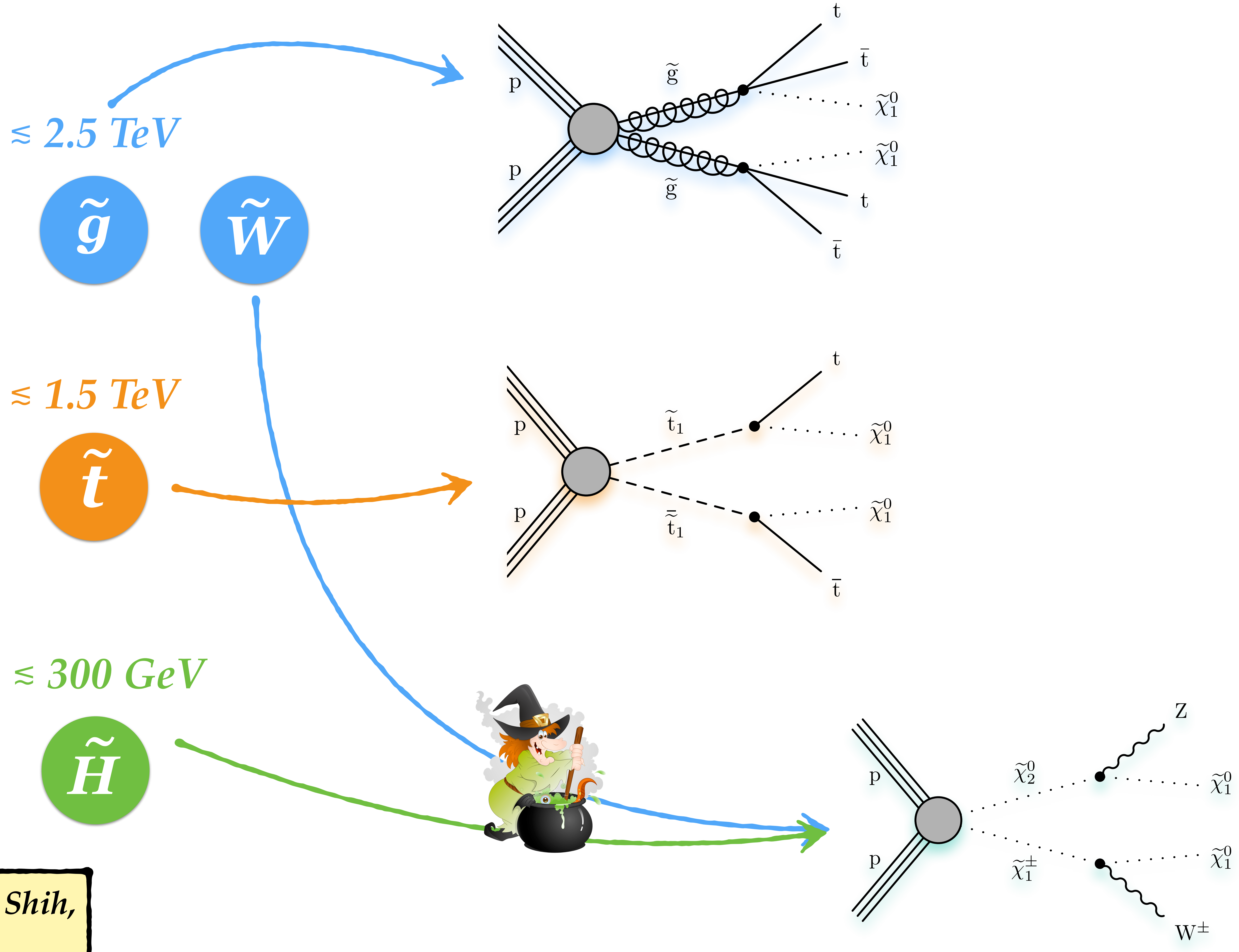


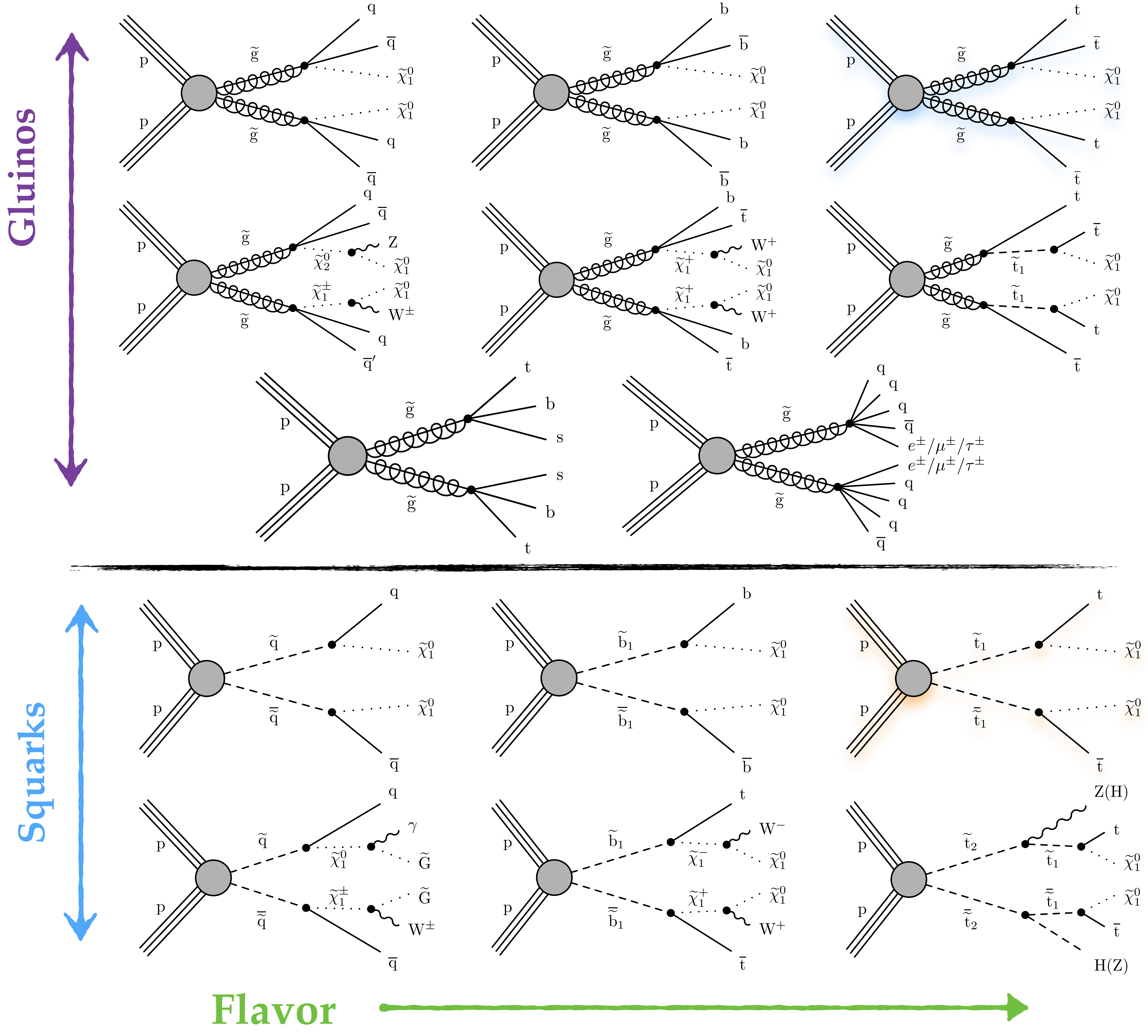
EWK hierarchy problem & Supersymmetry





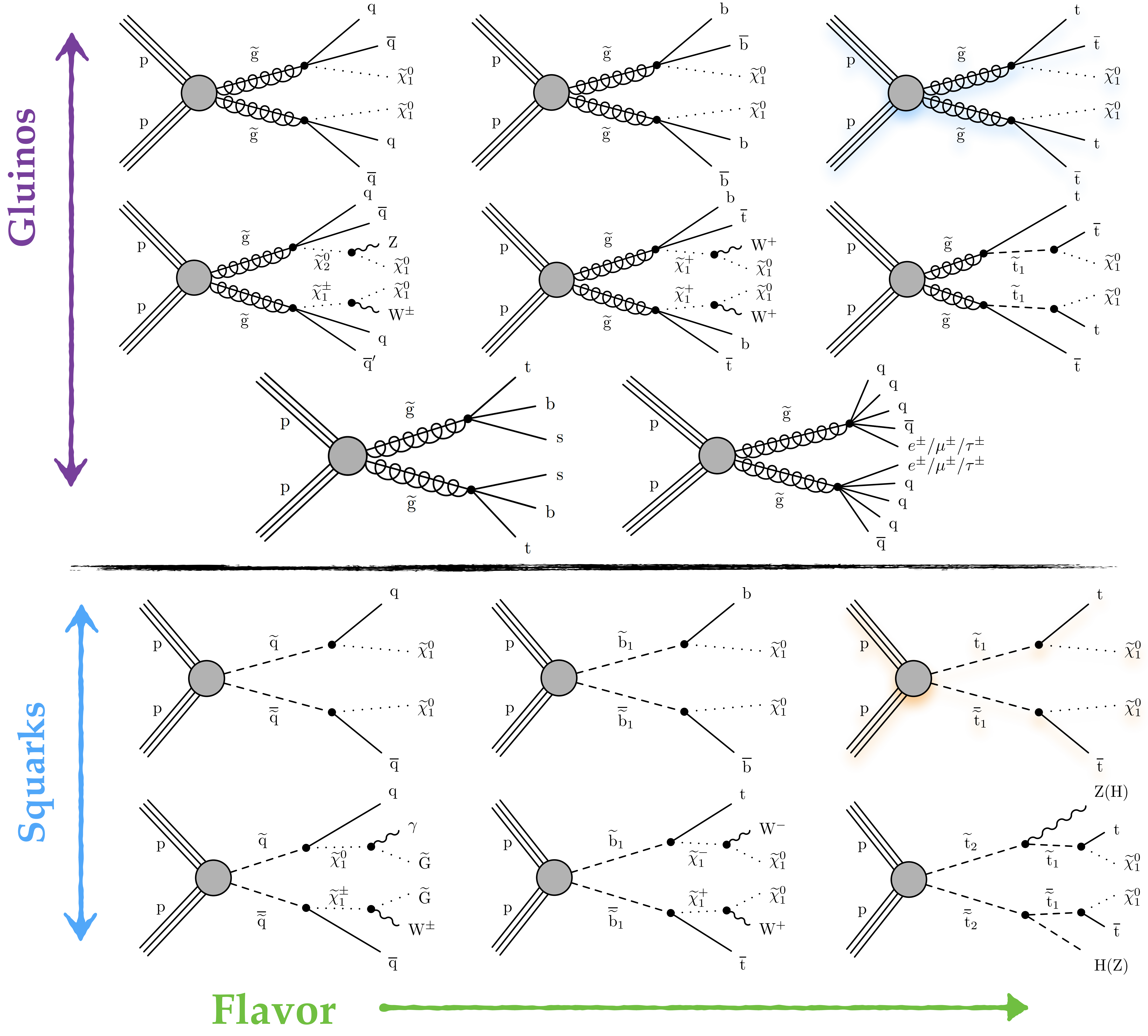
M. Buckley, A. Monteux and D. Shih,
arXiv:1611.05873

Huge landscape of possible final states



★ Final states ~ fully spanning flavor, multiplicity, kinematics

Huge landscape of possible final states



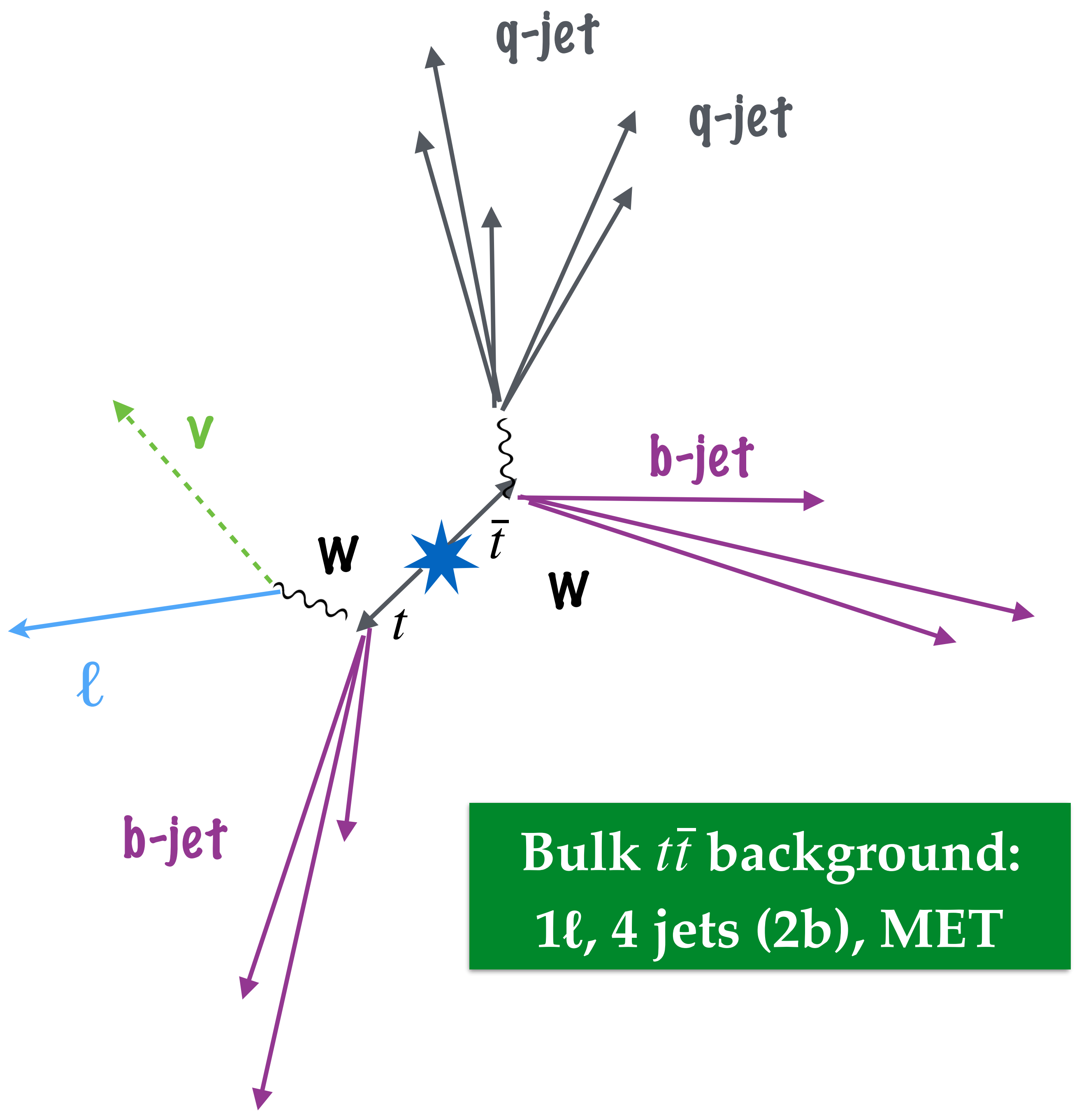
- ★ Final states ~ fully spanning flavor, multiplicity, kinematics
  - ✦ tackle by slicing phase space in bins…
- ★ 0ℓ analyses
  - ✦ maximize covered phase-space
    - • no leptons/tracks with $p_T > 5$-10 GeV
    - • $N_{jets} \geq 2$ and $N_b \geq 0$
    - • M_{T2} or H_T^{miss} (>250-300 GeV)
  - ✦ 4D binning: M_{T2}/H_T^{miss}, H_T, N_{jets}, N_b
- ★ 1ℓ analyses
  - ✦ low multiplicity:
    - • using top tagging
    - • target: stop production
  - ✦ high multiplicity:
    - • using sum of large-R jet masses
    - • target: gluino production

New for LP 2019, focus today!

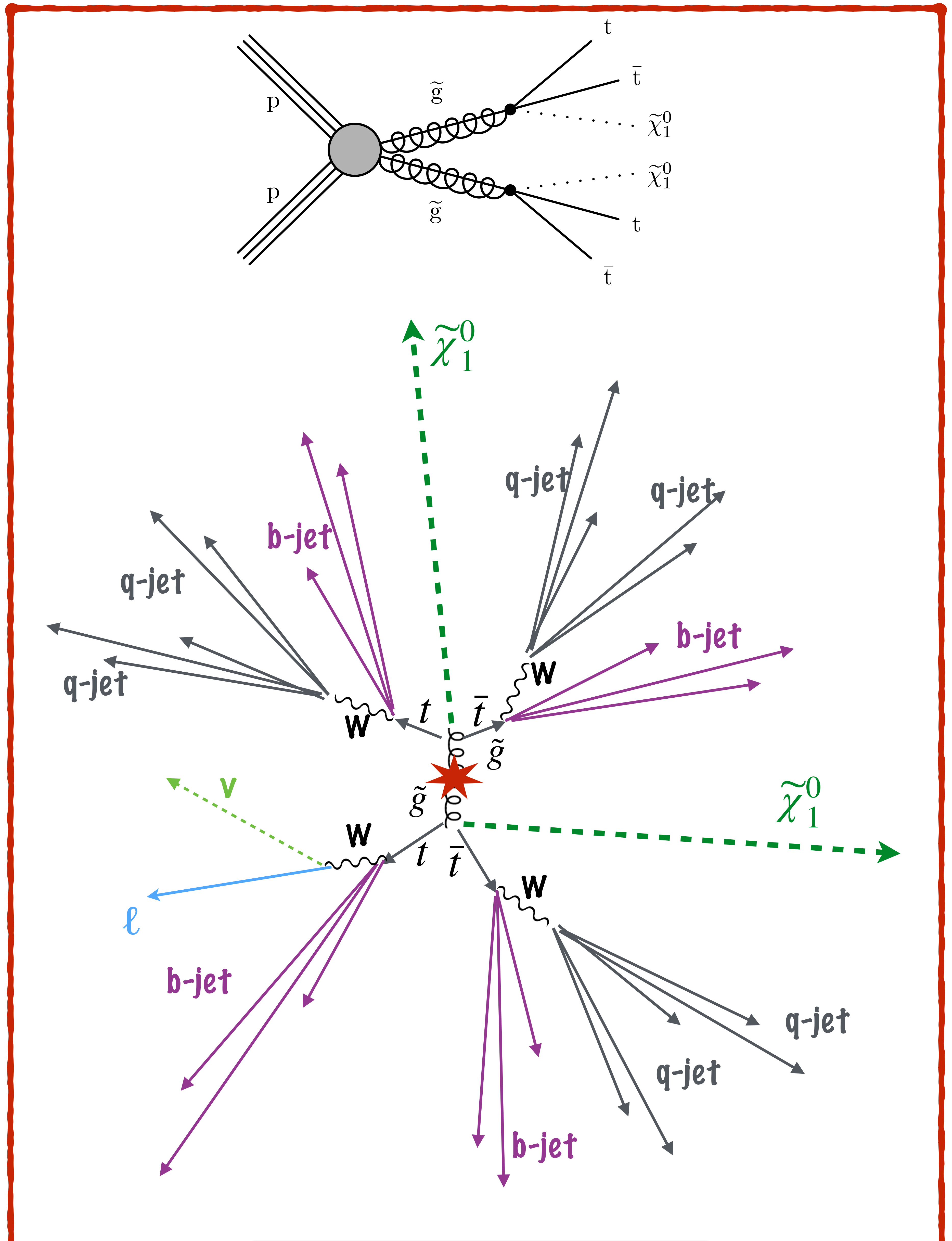
- ★ SS 2ℓ or $\geq 3\ell$ analysis
  - ✦ can trigger on leptons instead of MET
    - • access compressed spectra and RPV

High multiplicity 1ℓ: Selection

CMS-SUS-19-007



Bulk $t\bar{t}$ background: 1ℓ, 4 jets (2b), MET



Signal: 1ℓ, 10 quarks, 4 of them b-quarks, MET

- ★ **Single lepton**
- ★ **MET > 200 GeV, $S_T = H_T + p_T(\ell) > 500$ GeV**
  - ✦ ensures being on trigger plateau
  - ✦ cut bulk of tt background
- ★ **$N_{jets} \geq 7$ ➞** further reduce tt, enter ISR dominated regime
- ★ **$N_b \geq 1$ ➞** significant reduction in non-top backgrounds

High multiplicity 1ℓ: Selection

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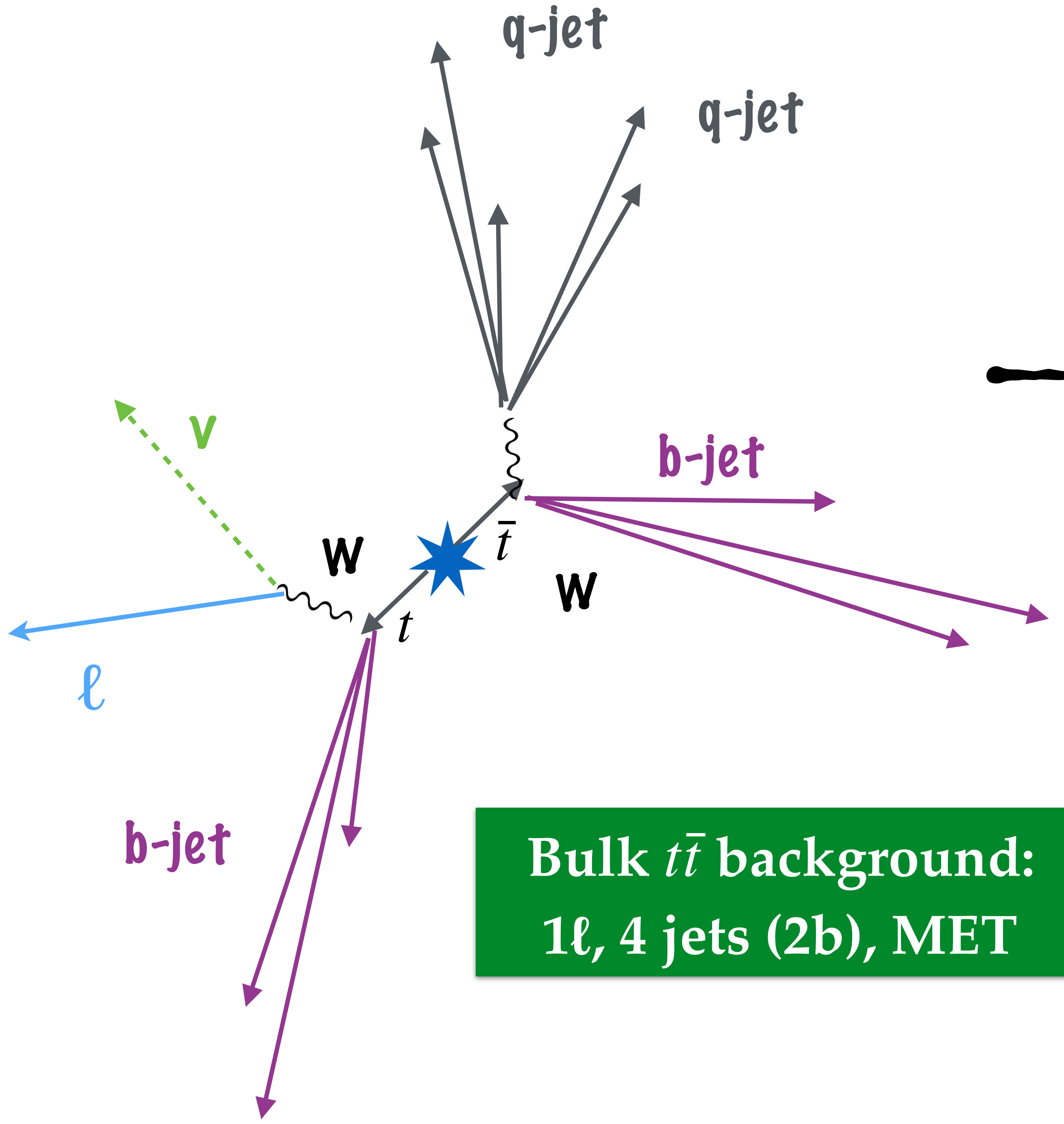

Bulk $t\bar{t}$ background:
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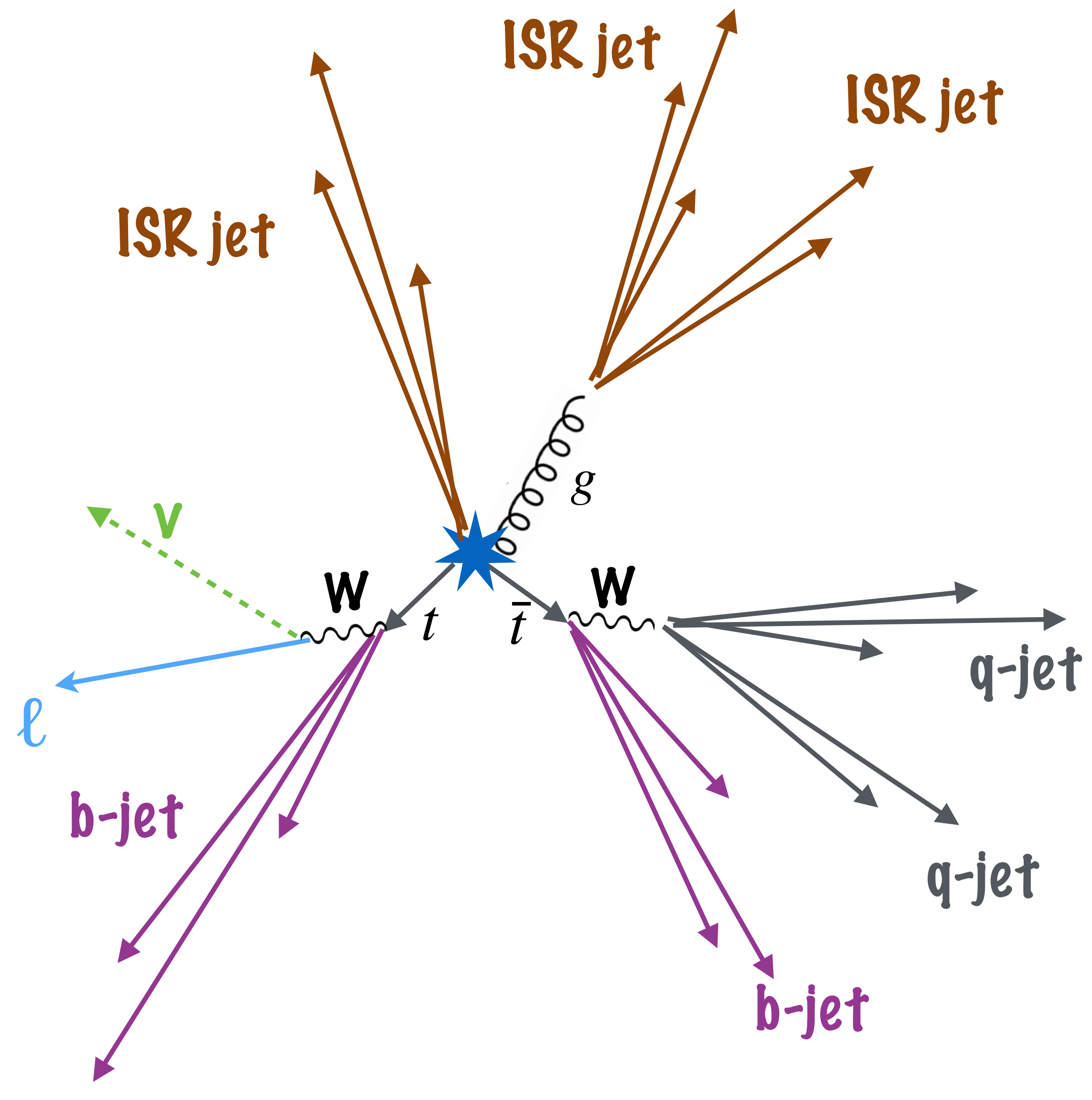
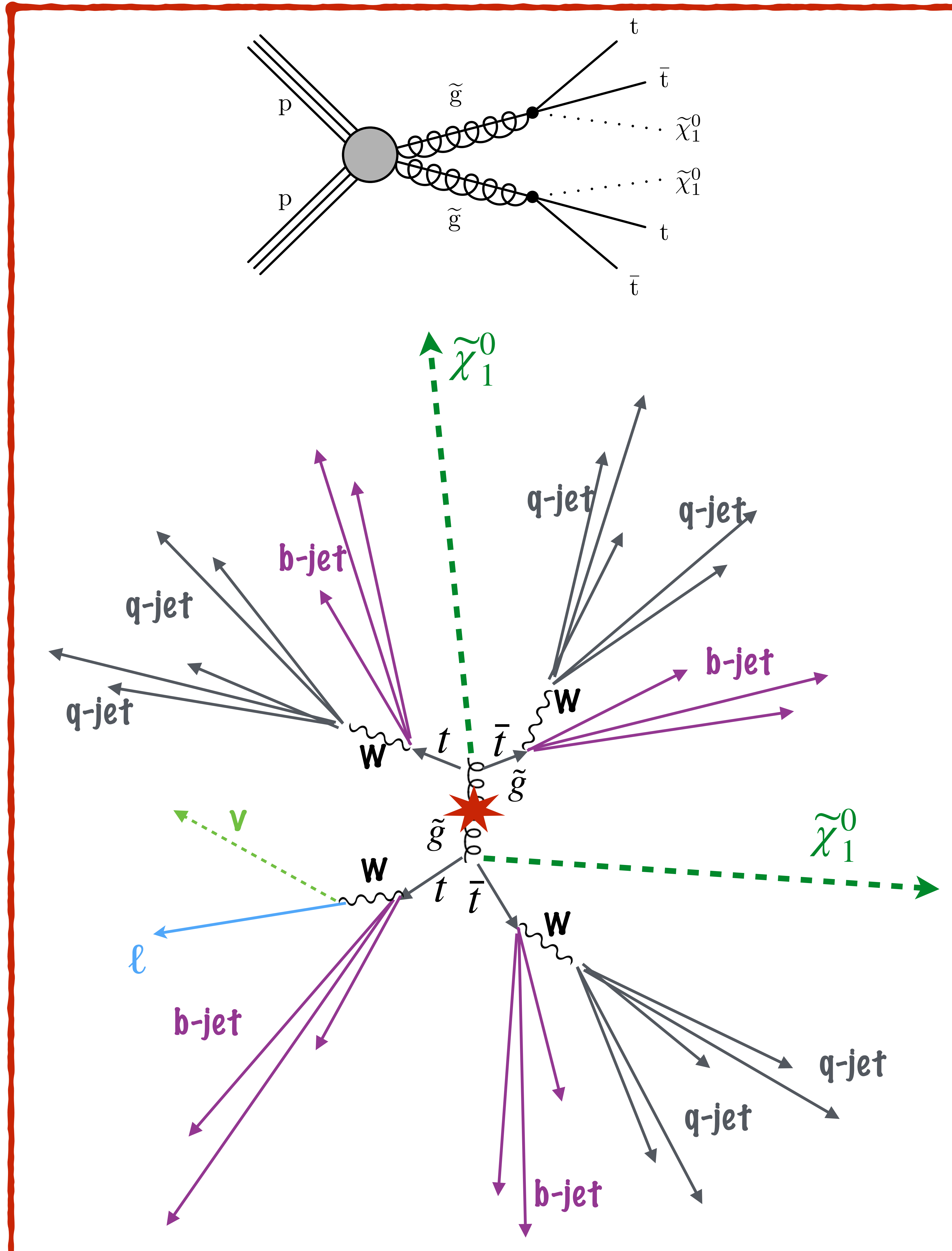
Baseline



$t\bar{t}$ + ISR:
1ℓ, many jets (≥ 2b), high MET



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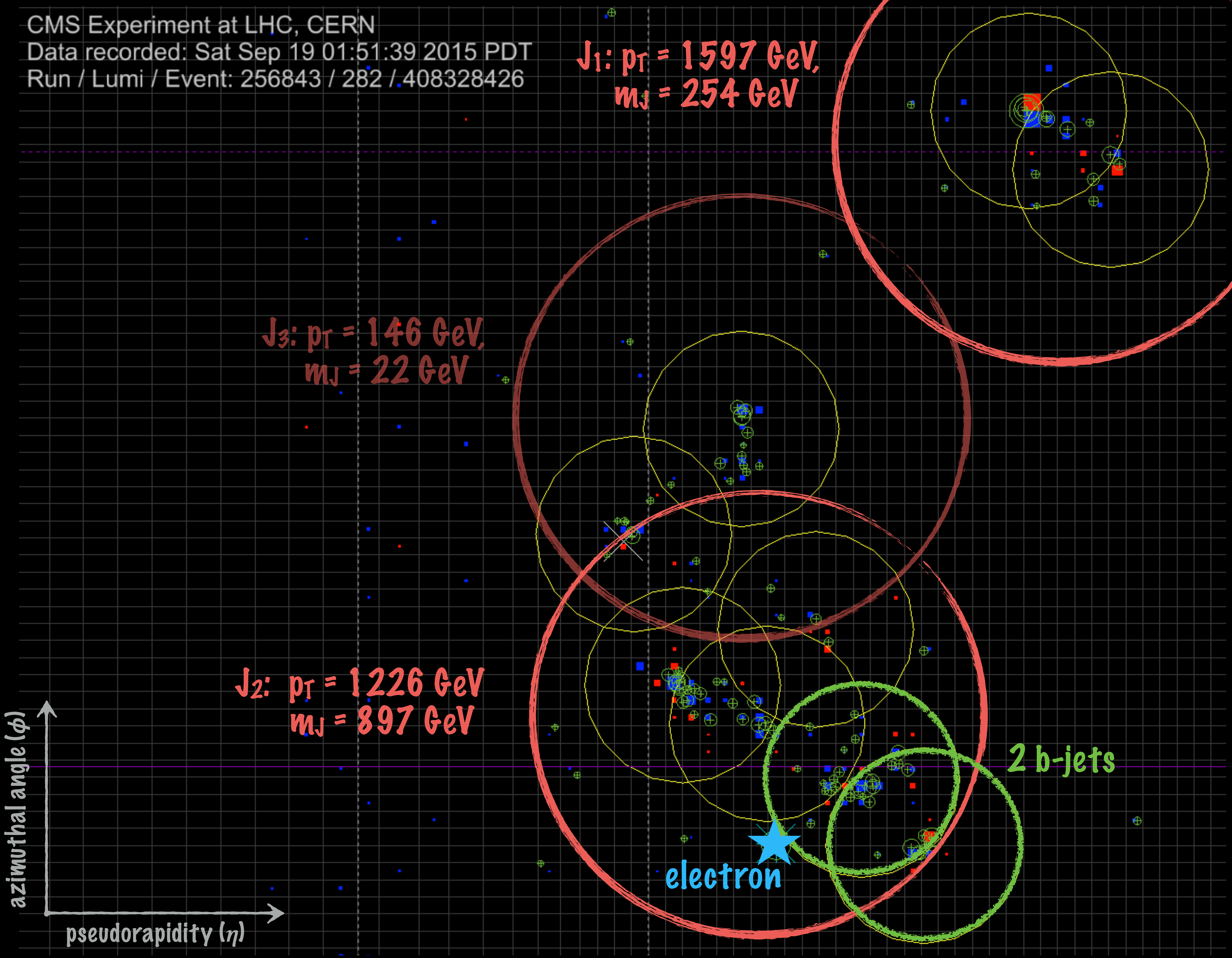
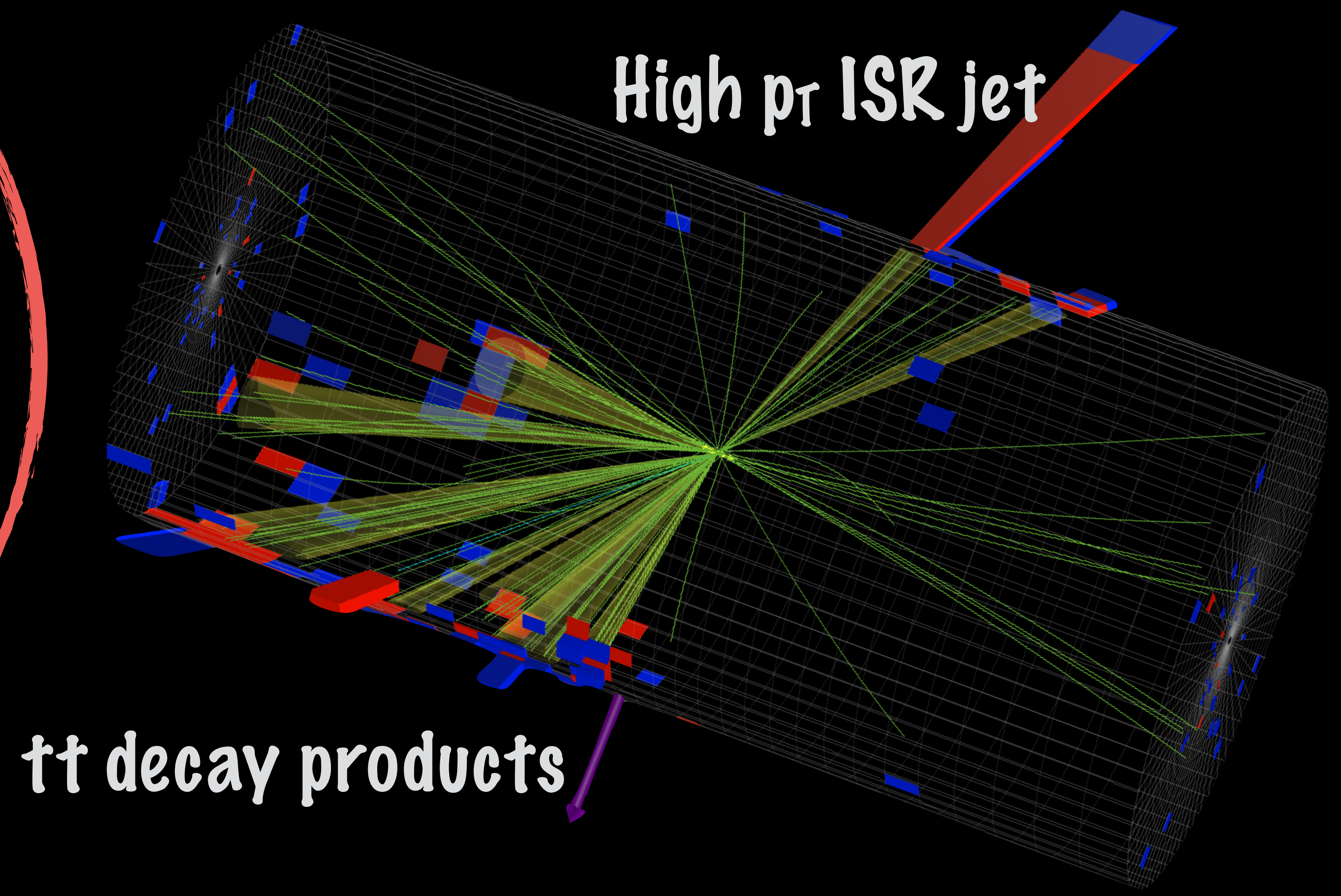
Sum of large-R jet masses

CMS-SUS-19-007





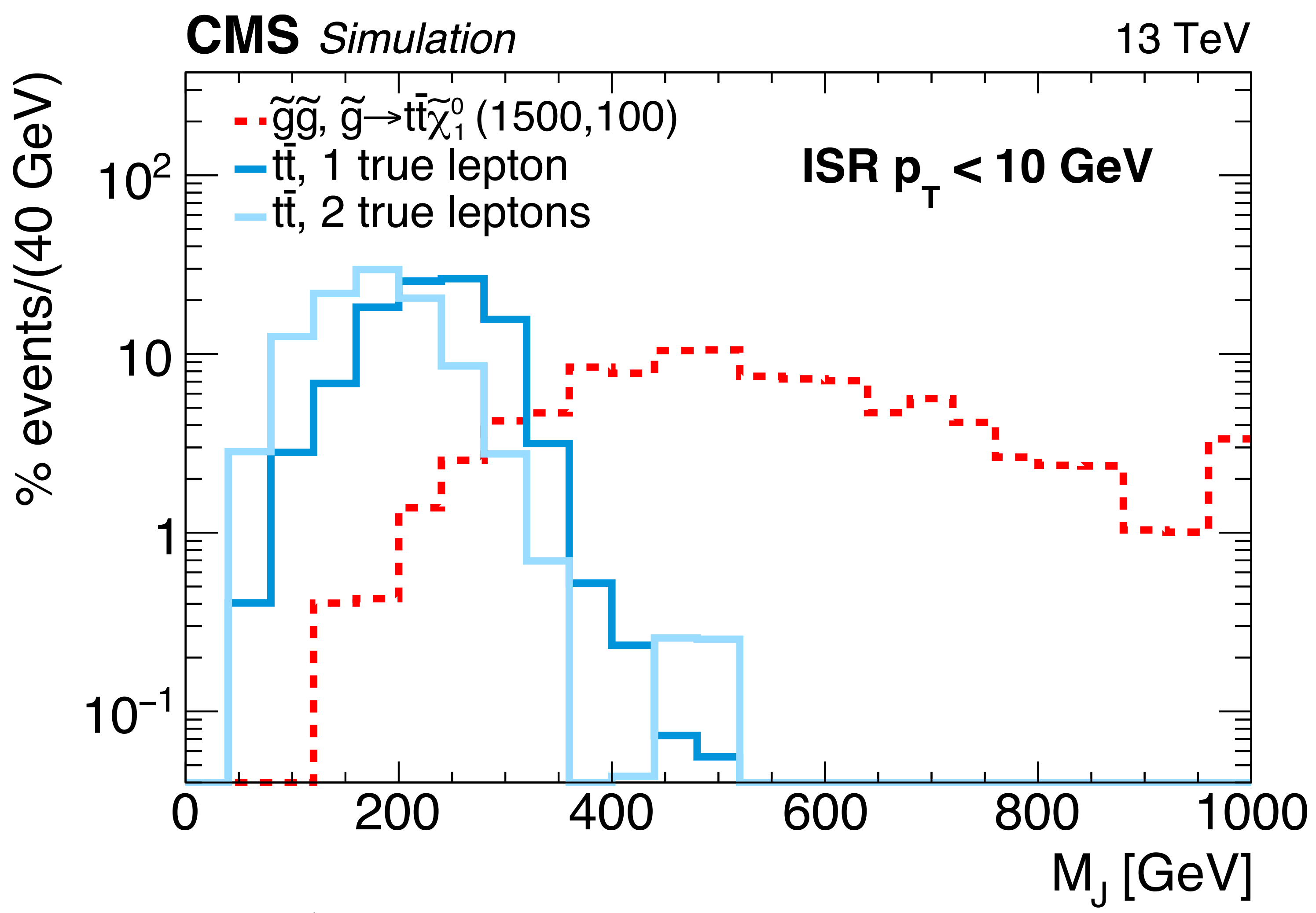
$$M_J = \sum_{J_i = large-R\, jets} m(J_i)$$

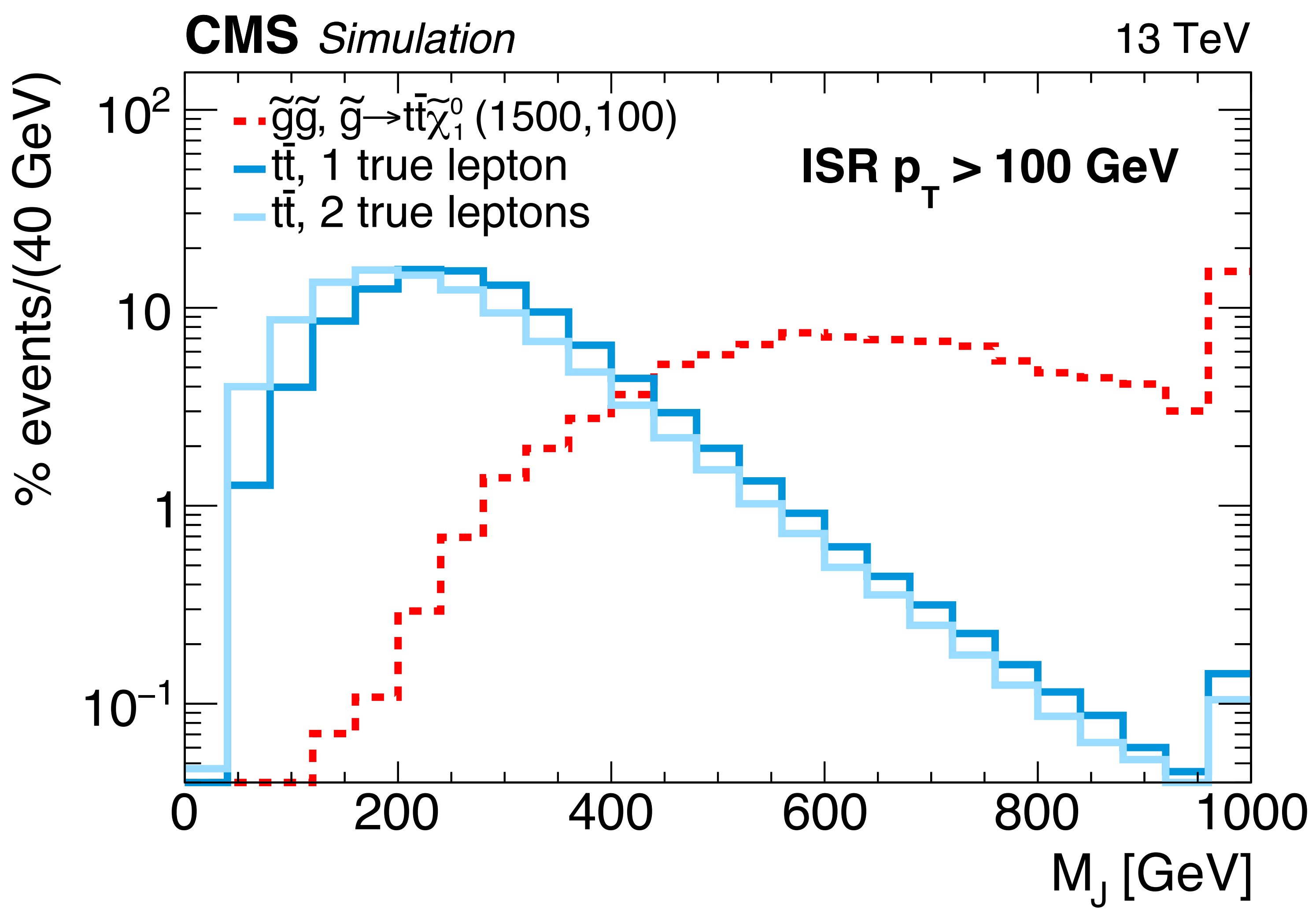
"Jet Substructure by Accident"
T. Cohen, E. Izaguirre, M. Lisanti, H. Lou
arXiv: 1212.1456

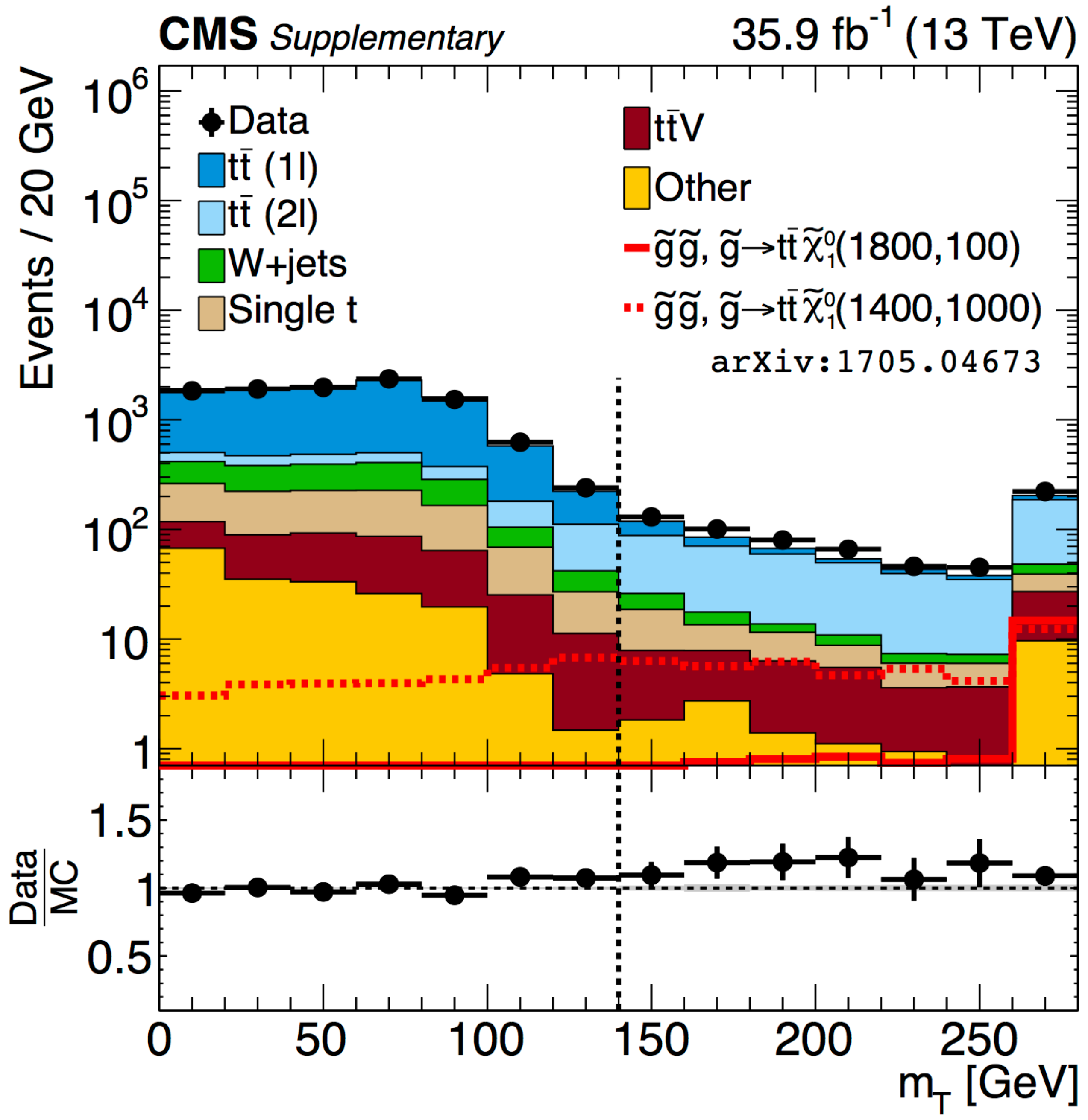
- ★ M_J grows with correlated high p_T activity
  - ✦ Individual high p_T jets have minimal contribution

Background estimate in a nutshell

CMS-SUS-19-007







★ Key observation:

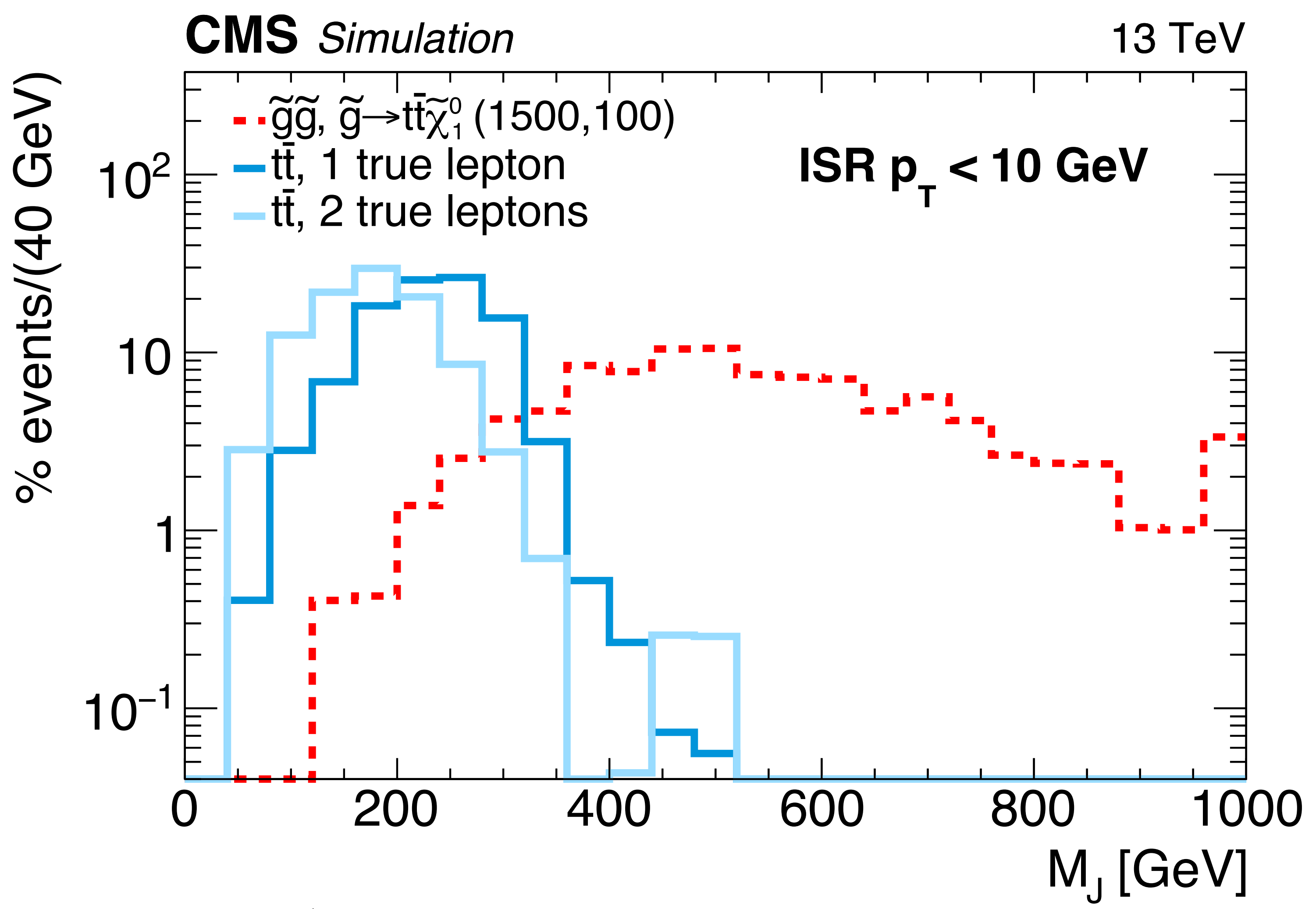
- ✦ 1ℓ and 2ℓ $t\bar{t}$ have the same M_J shape in high ISR regime!

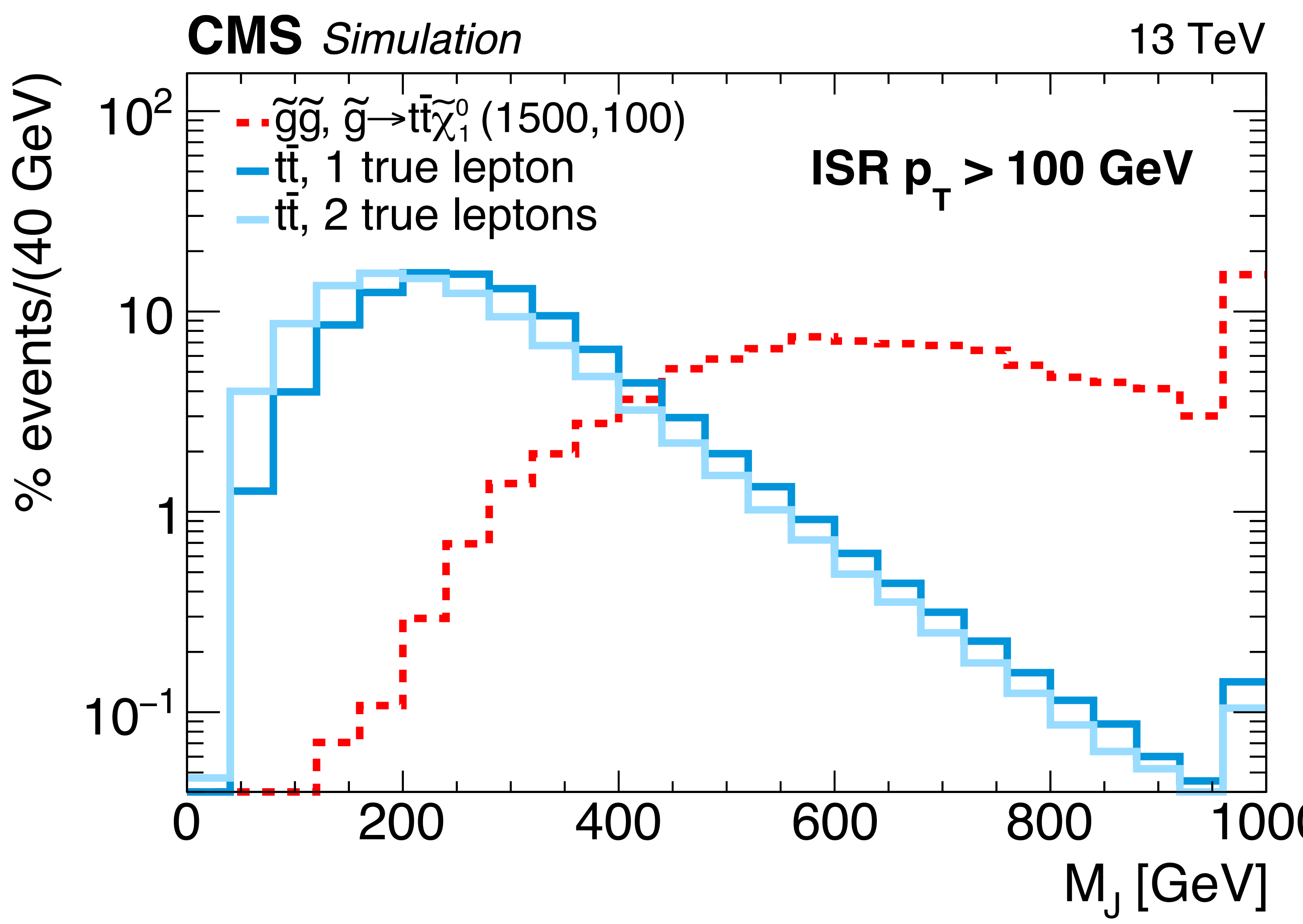
★ Separate regions enriched in 1ℓ vs 2ℓ $t\bar{t}$ using m_T

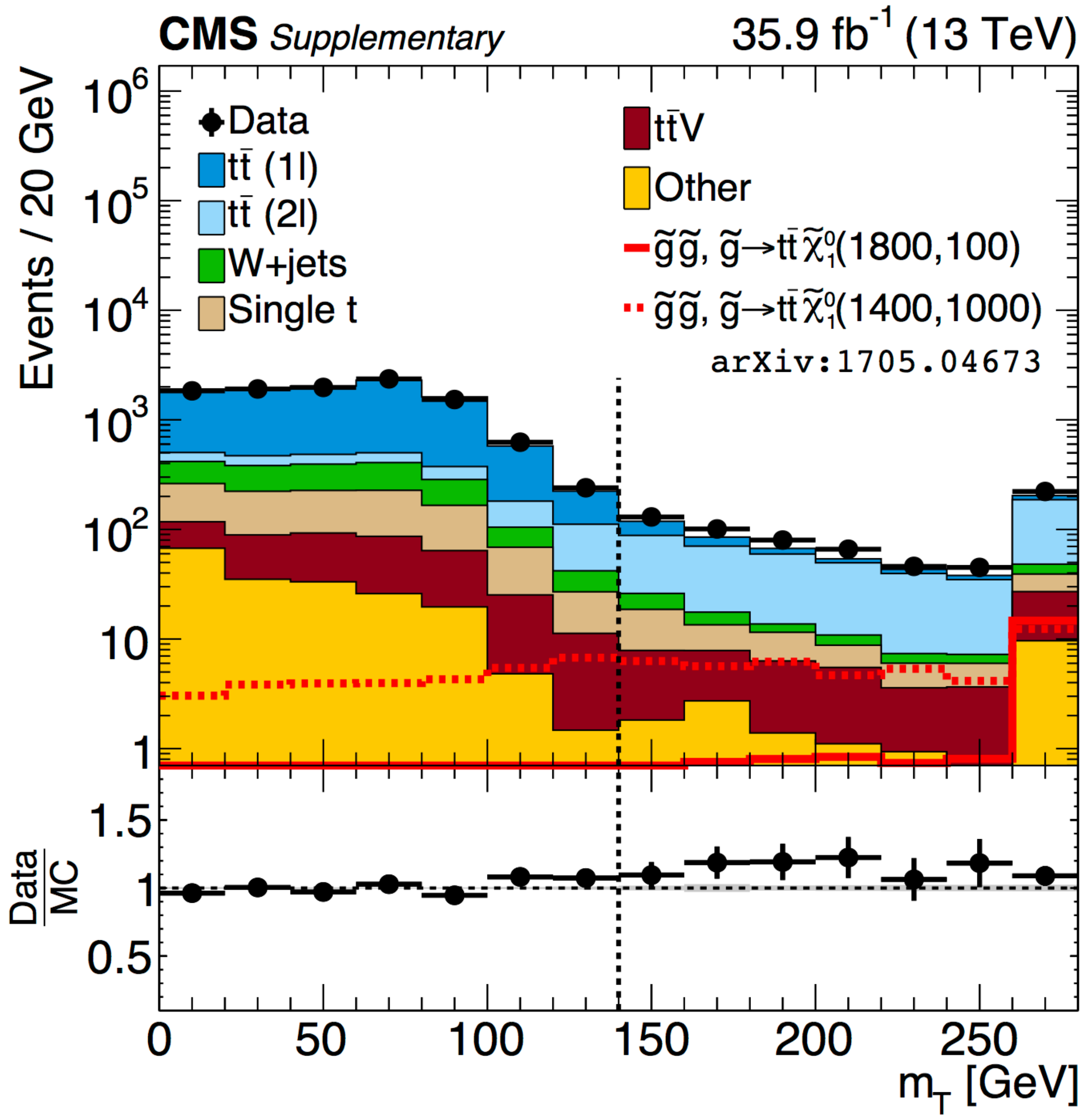
$$m_T = \sqrt{2 p_T^{\ell} p_T^{\text{miss}} [1 - \cos(\Delta\phi_{\ell,\vec{p}_T^{\text{miss}}})]}$$

Background estimate in a nutshell

CMS-SUS-19-007







- ★ Key observation:
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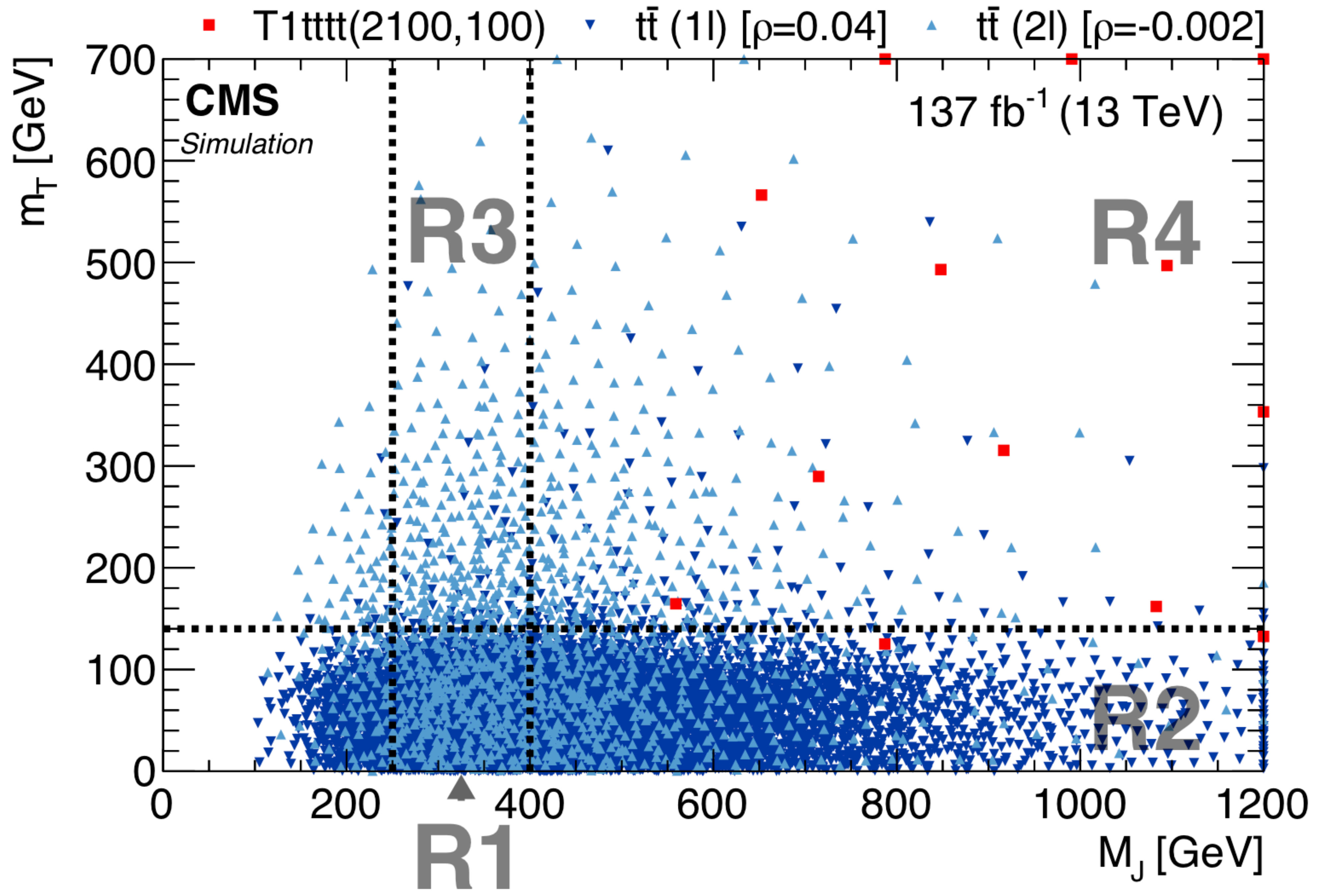
- ★ Separate regions enriched in 1ℓ vs 2ℓ $t\bar{t}$ using m_T

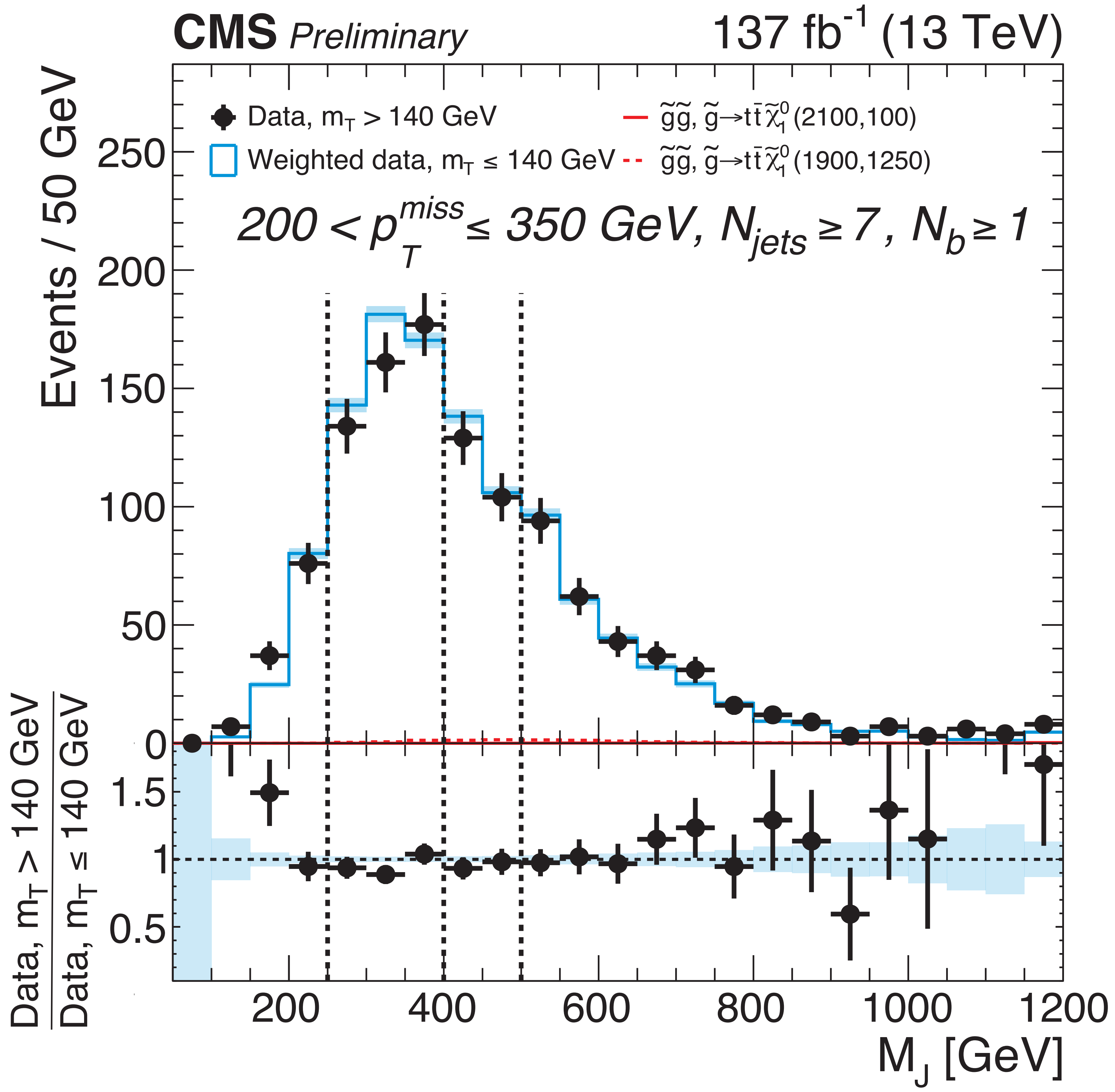
$$m_T = \sqrt{2 p_T^{\ell} p_T^{\text{miss}} [1 - \cos(\Delta\phi_{\ell, \vec{p}_T^{\text{miss}}})]}$$

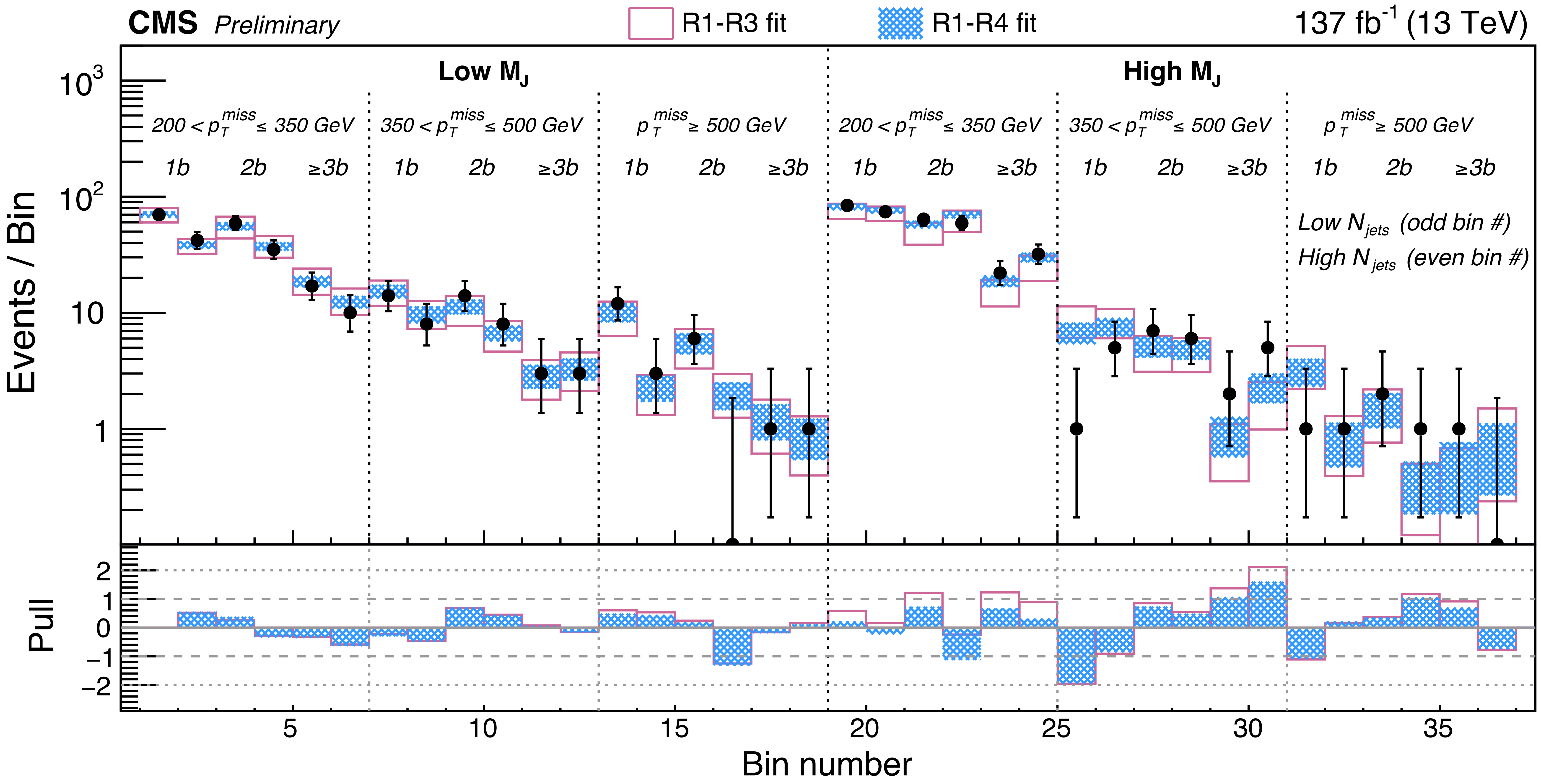
- ★ Build an ABCD with M_J and m_T plane
  - ✦ use M_J shape low m_T (R1-R2) ➞ predict M_J shape high m_T (R3-R4)
  - ✦ normalization from low M_J+high m_T region (R3)
    - ➞ prediction @ high M_J+high m_T signal region (R4)
- ★ Correction for residual correlation between ABCD variables derived from simulation
  - ✦ modeling of correlation checked in data control samples
- ★ Additional binning in MET, N_{jets} and N_b to enhance sensitivity



Comparison of prediction to observed yields

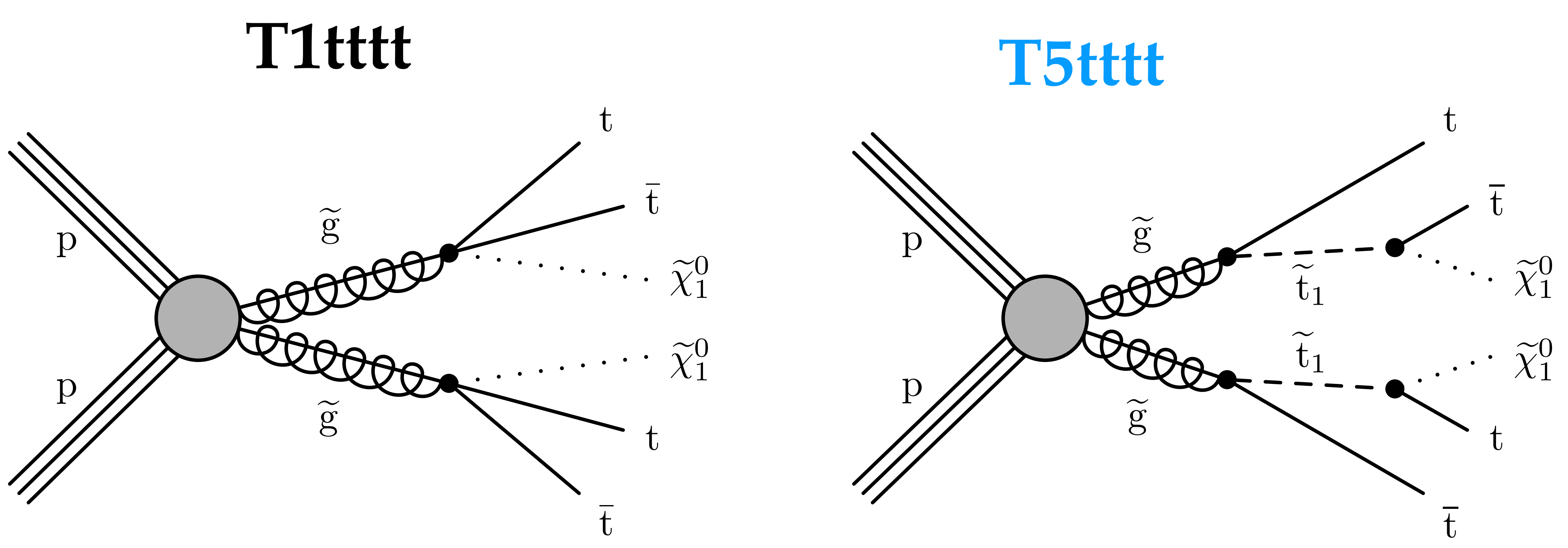
CMS-SUS-19-007

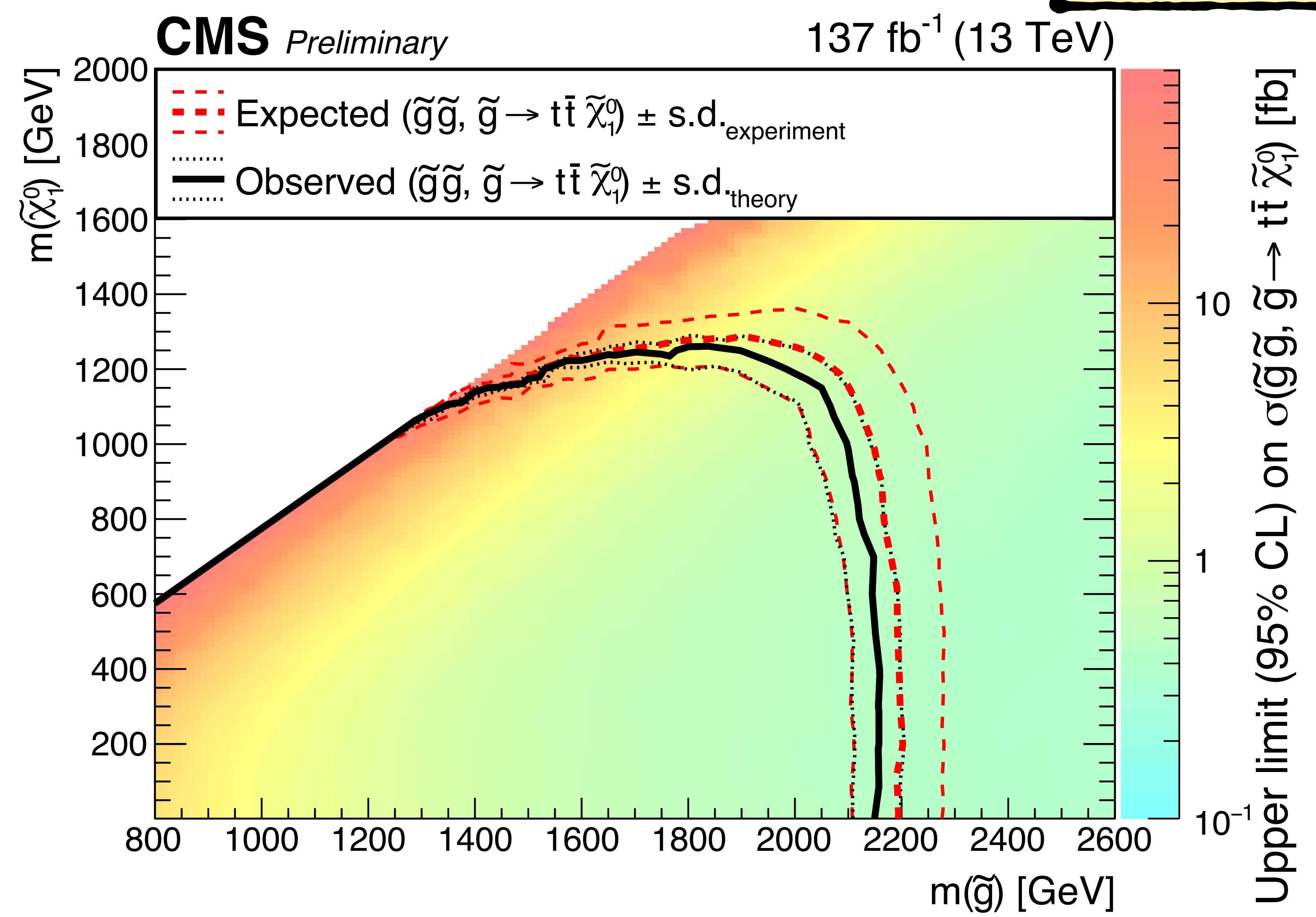


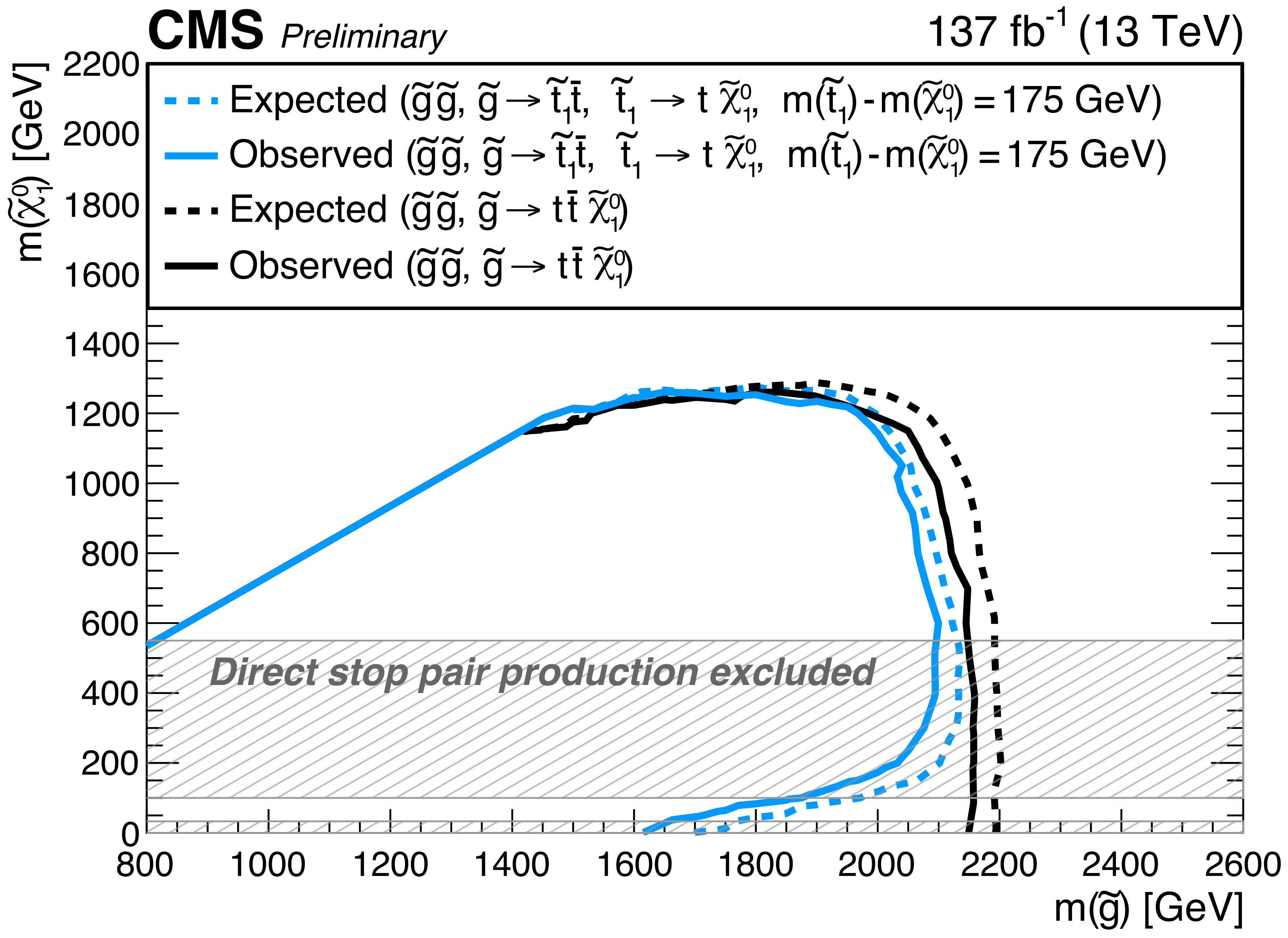


- ★ Excellent agreement between low-m_T and high-m_T M_J shapes
- ★ Observed yields agree with predictions - largest pull due to apparent downward fluctuation in the data

SUSY interpretation

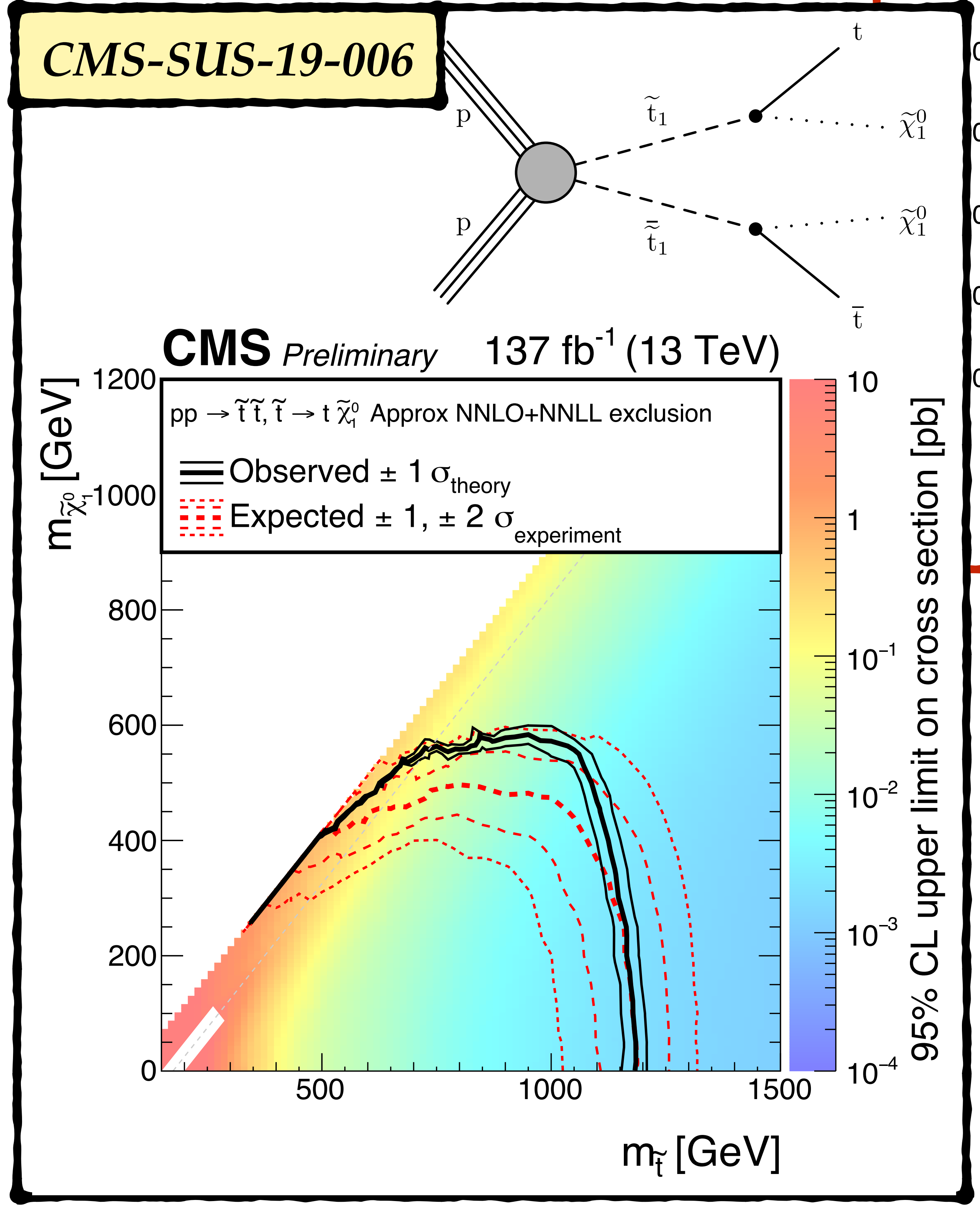


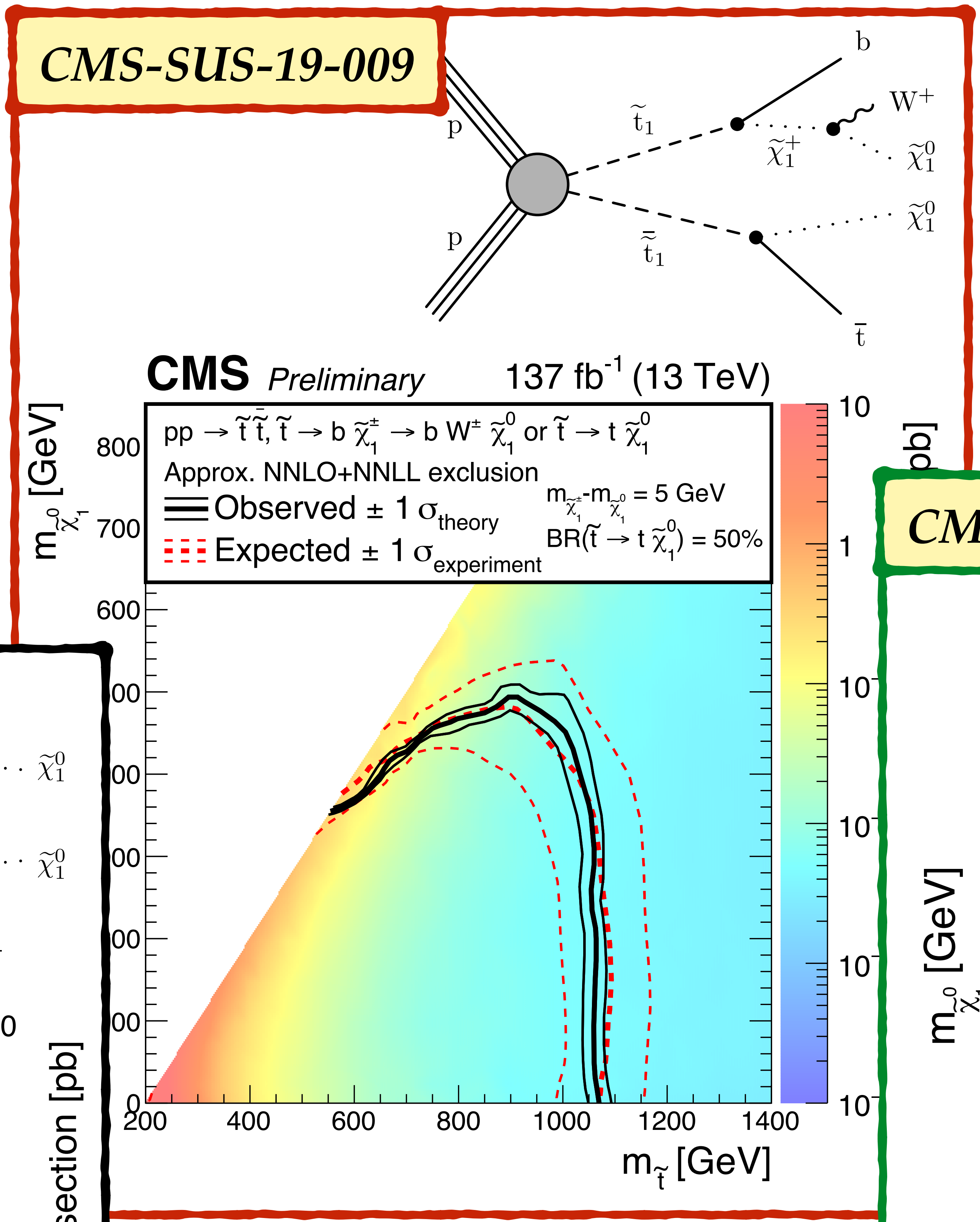


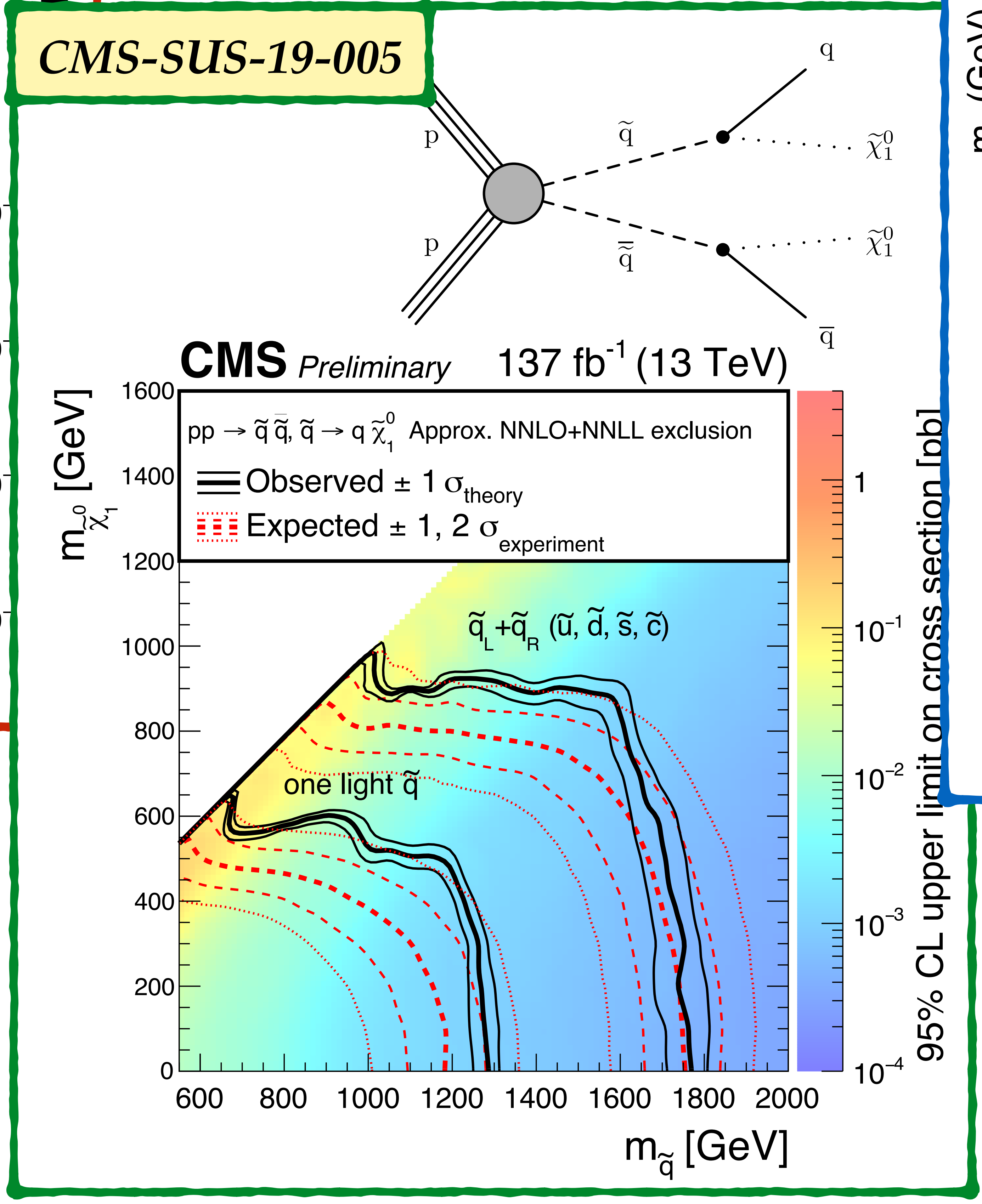


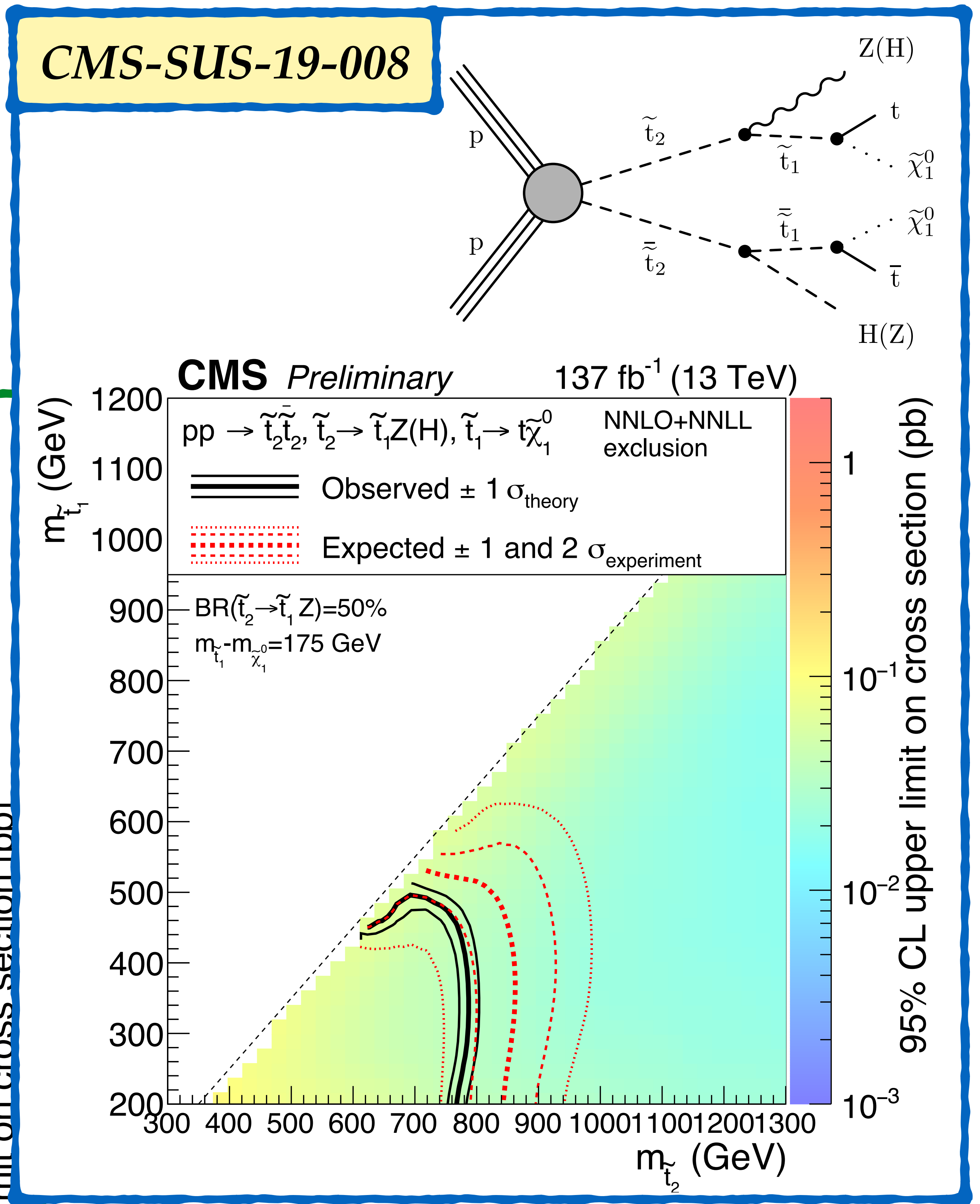
- ★ Excluding T1tttt for $m_{gluino} < 2150$ GeV for low m_{χ}
- ★ T5tttt compliments by allowing the possibility of intermediate stop, $\Delta(m_{stop}, m_{\chi})$ is fixed to 175 GeV
- ★ T5tttt kinematics
  - ✦ MET given by kinematics of 2-body instead of 3-body decay
  - ✦ → at low LSP masses boost picked up by top → MET is highly suppressed

Squarks highlights



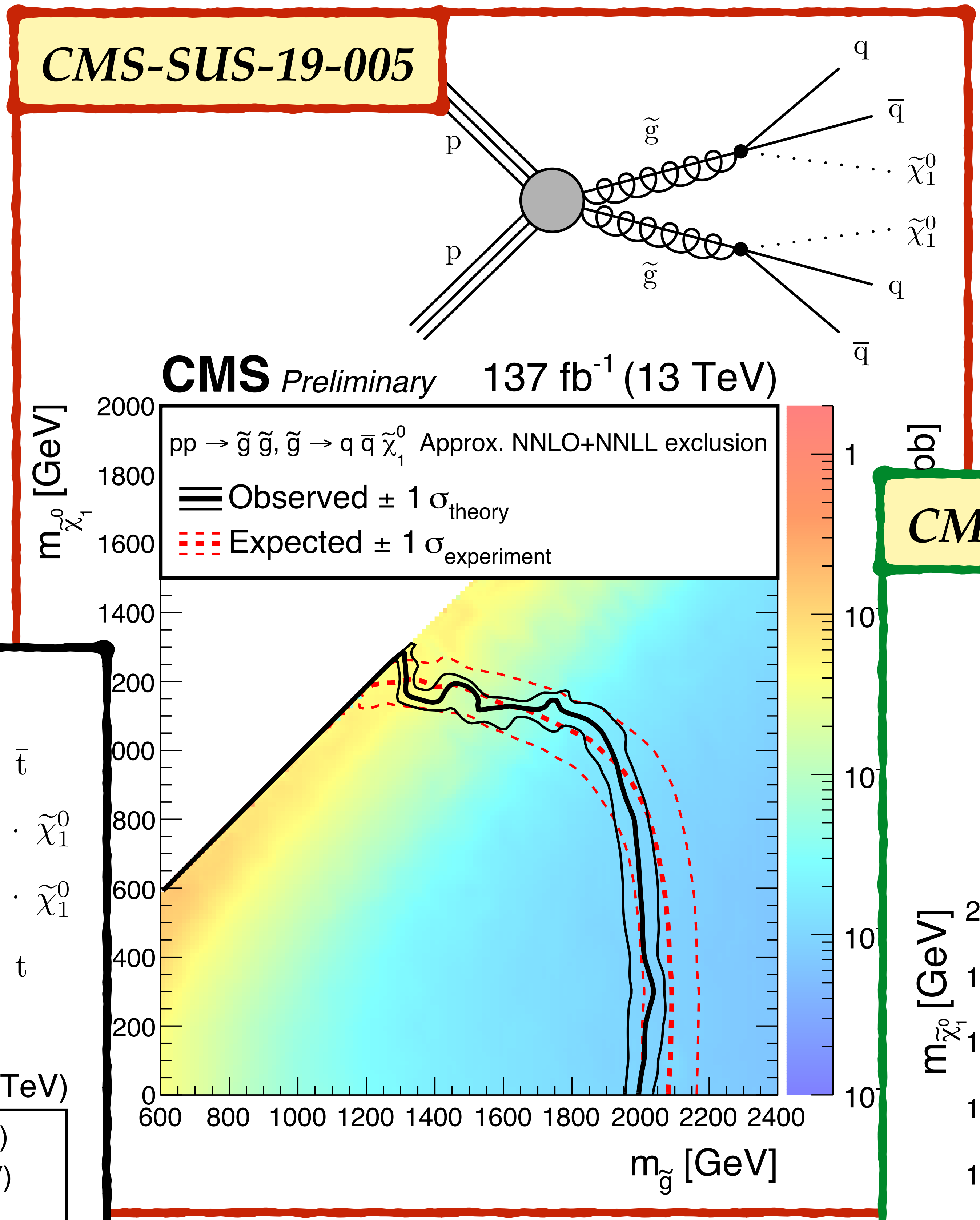


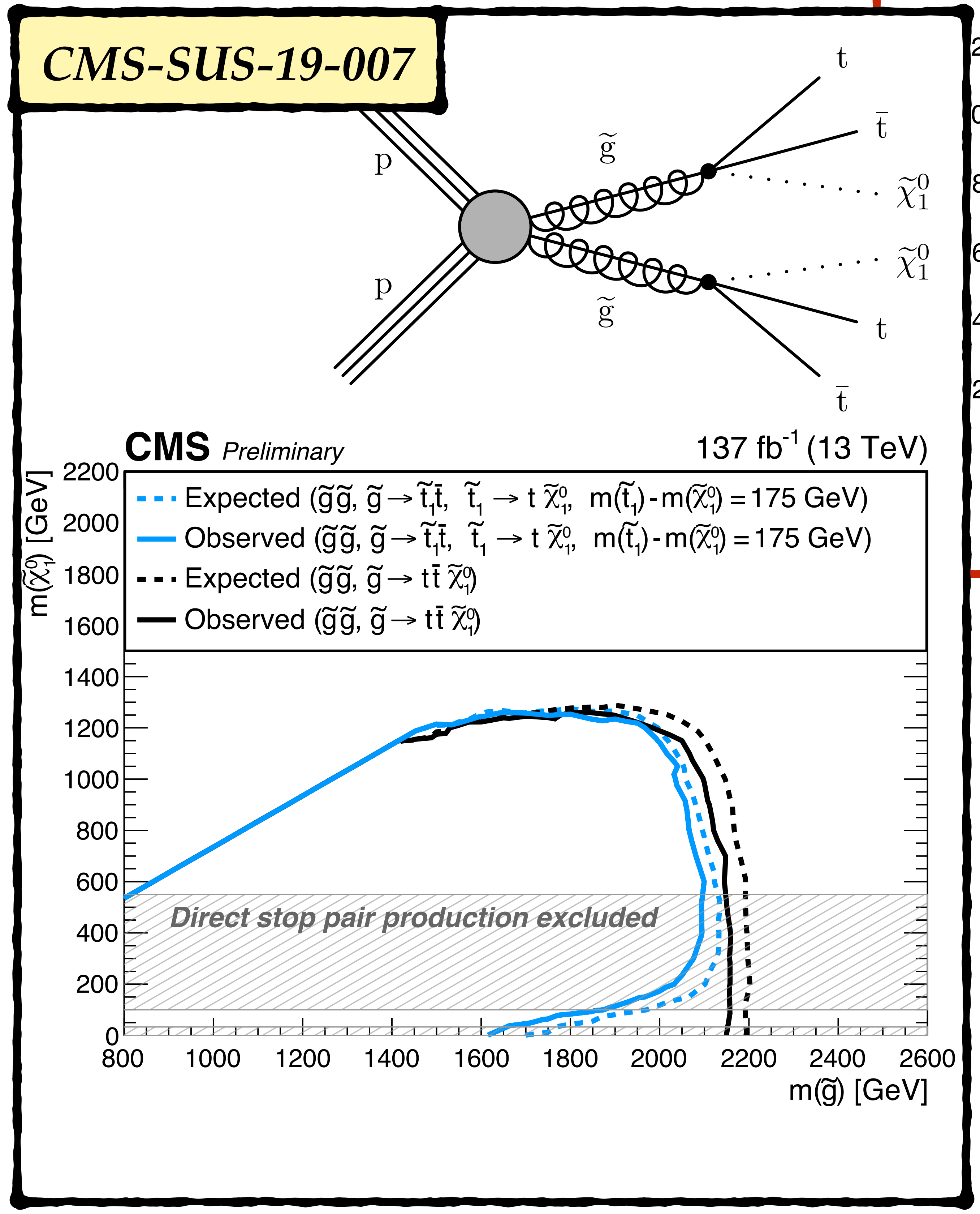


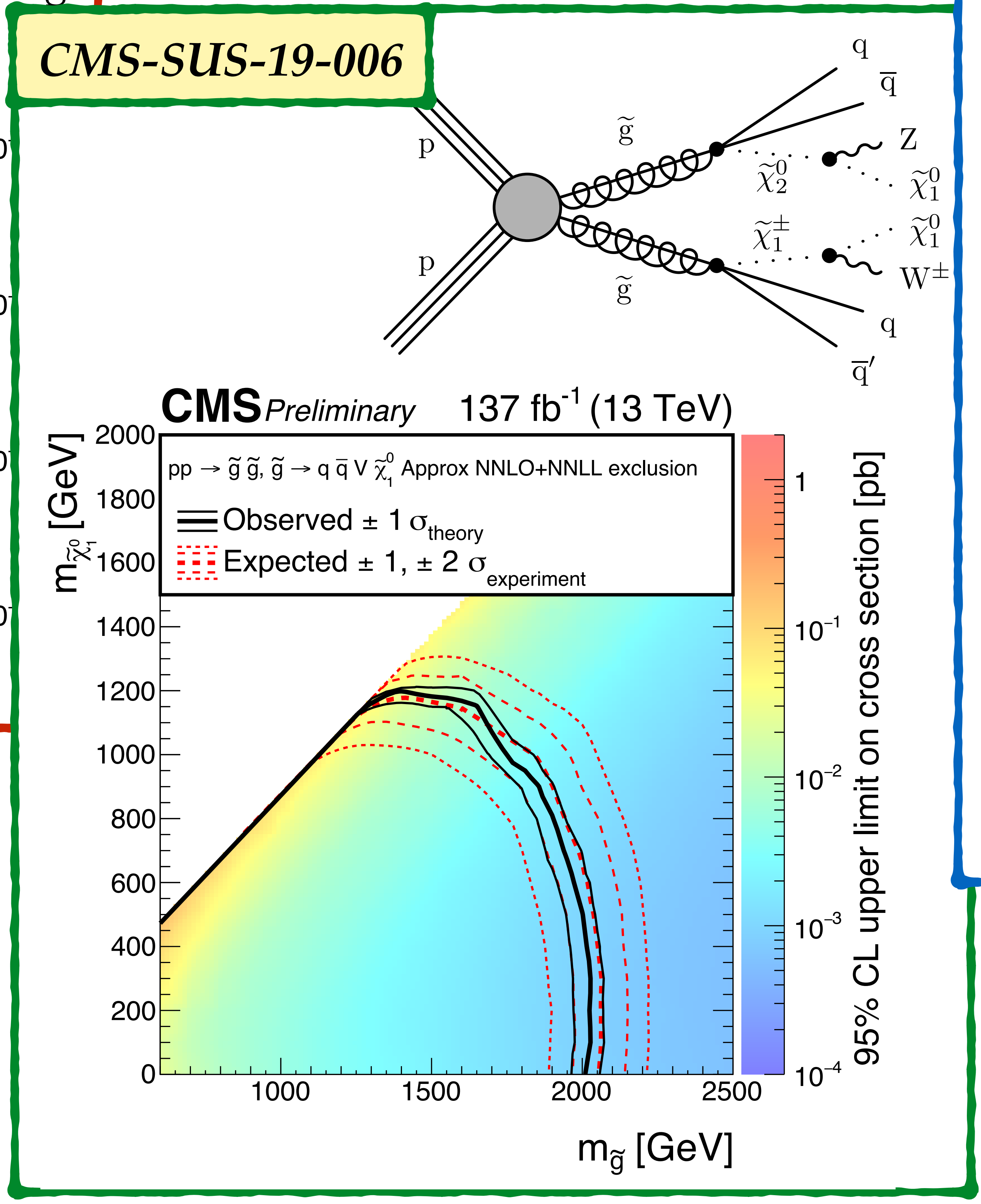


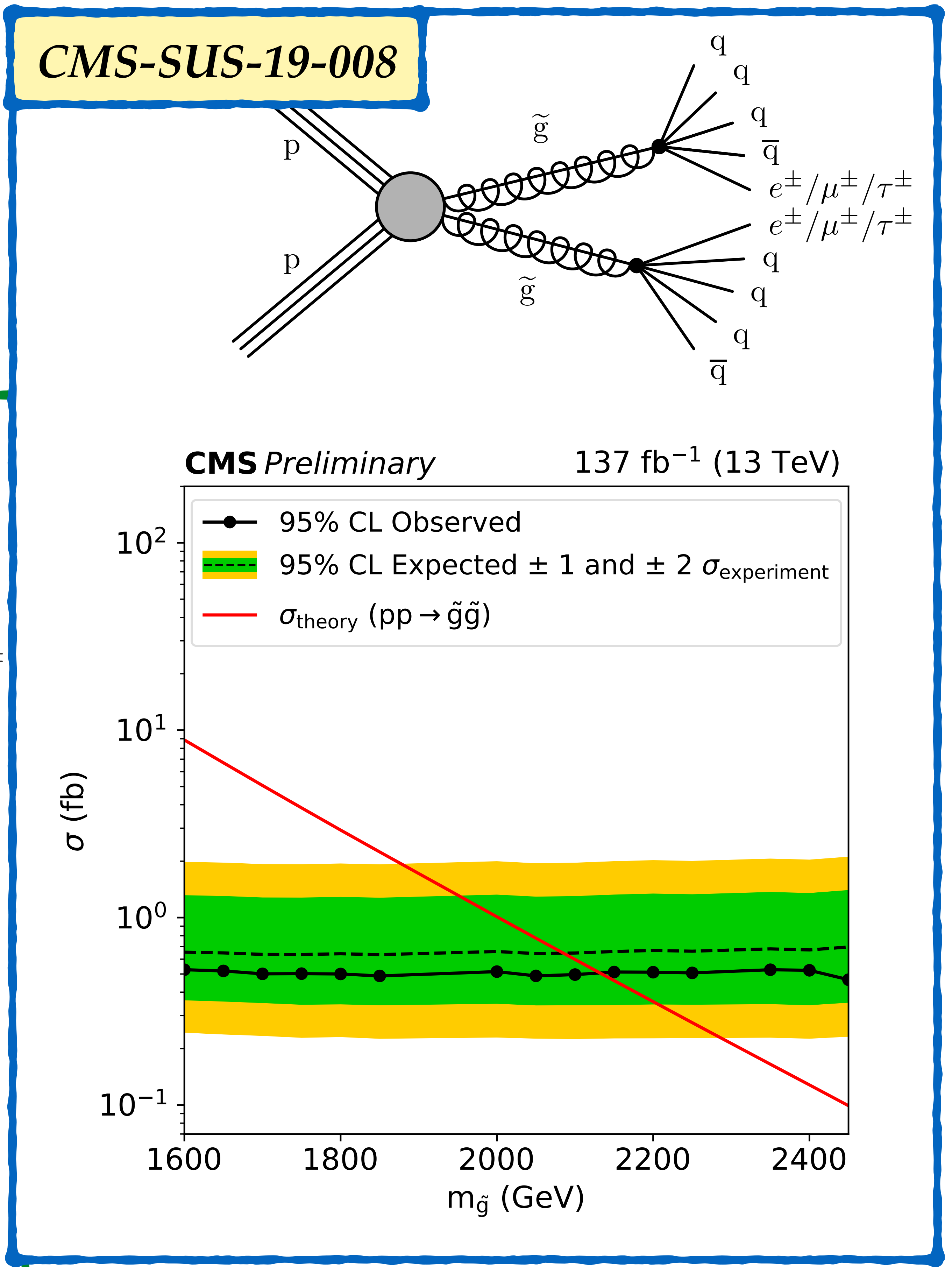
- ★ Squark limits at low LSP mass now at ~ 1200-1300 GeV
  - ✦ complex decay chains or mass spectra compression can significantly lower these limits

Gluino highlights









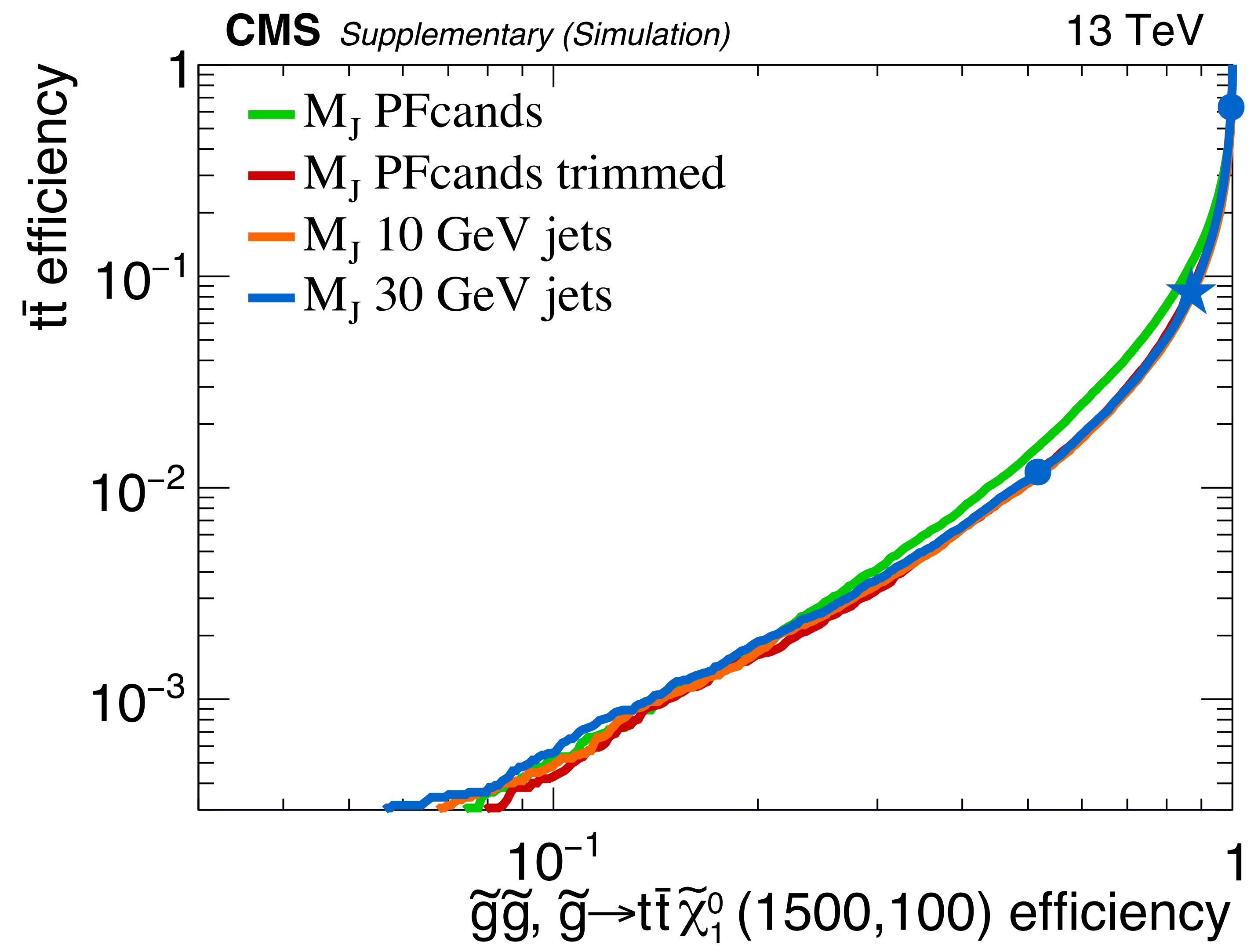
★ Gluino limits at low LSP mass now at ~ 2000-2250 GeV depending on flavor

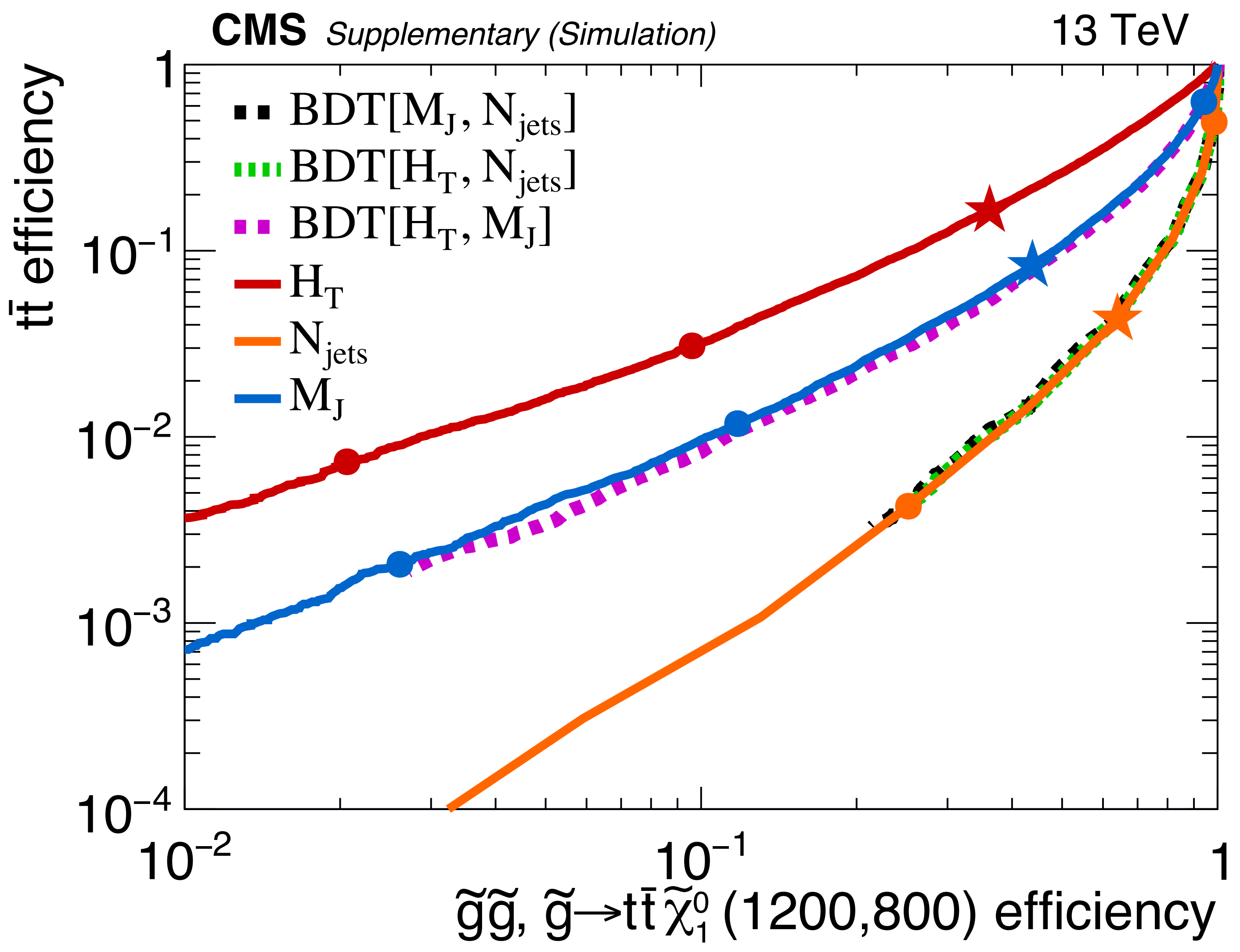
✦ Similar to squarks, mass compression can lead to large reduction in mass reach

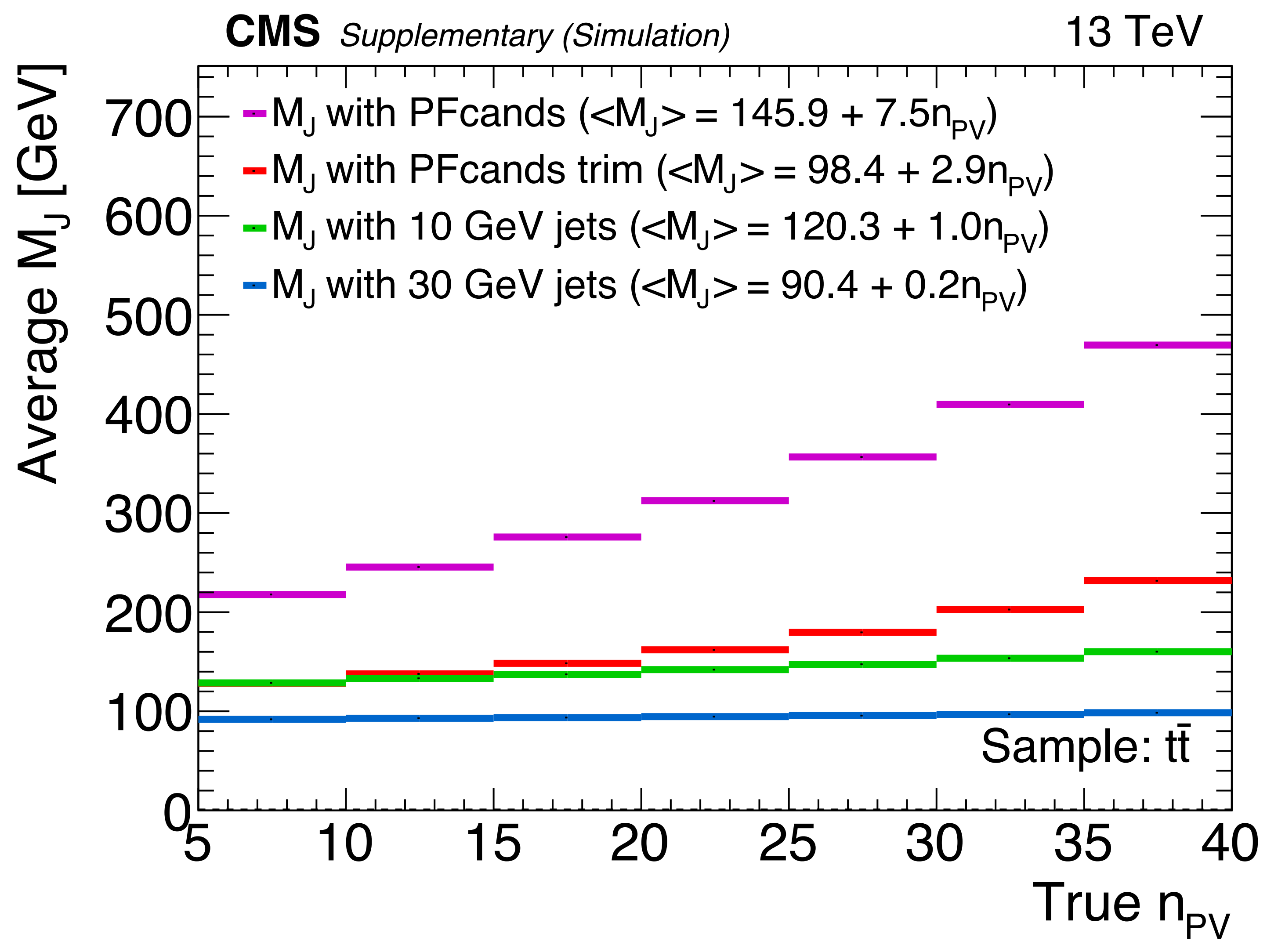
Backup

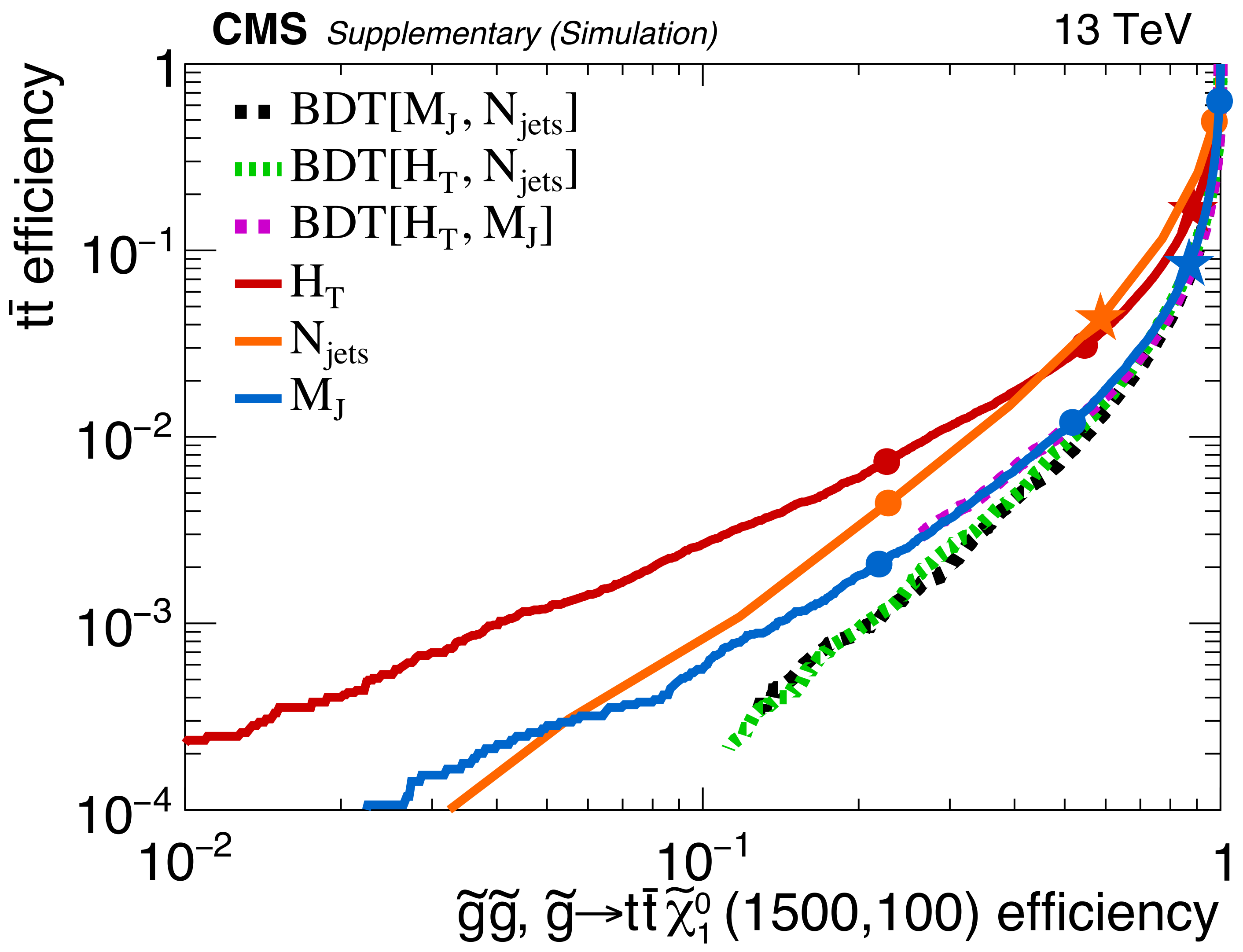
M_J variable further info

SUS-15-007



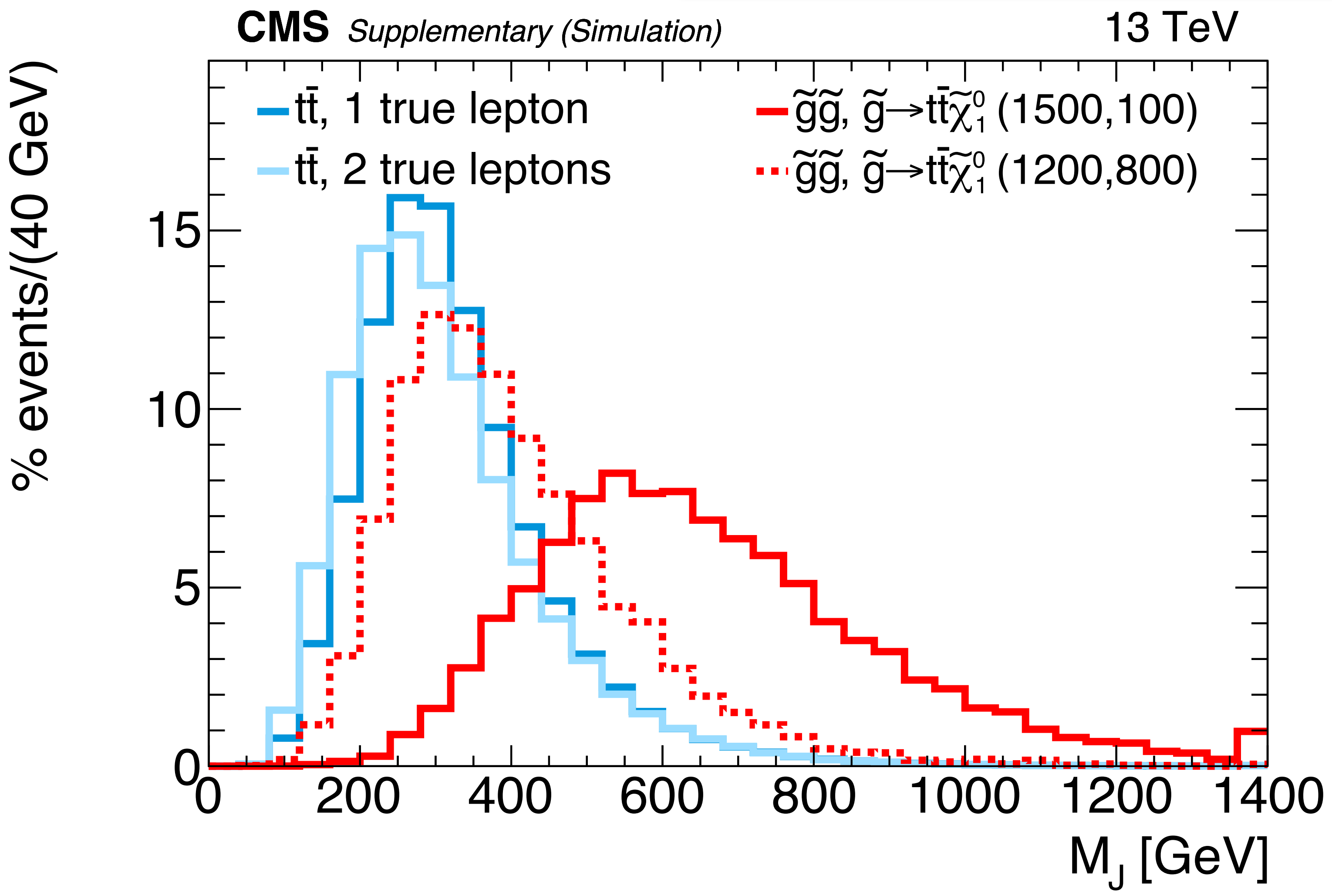


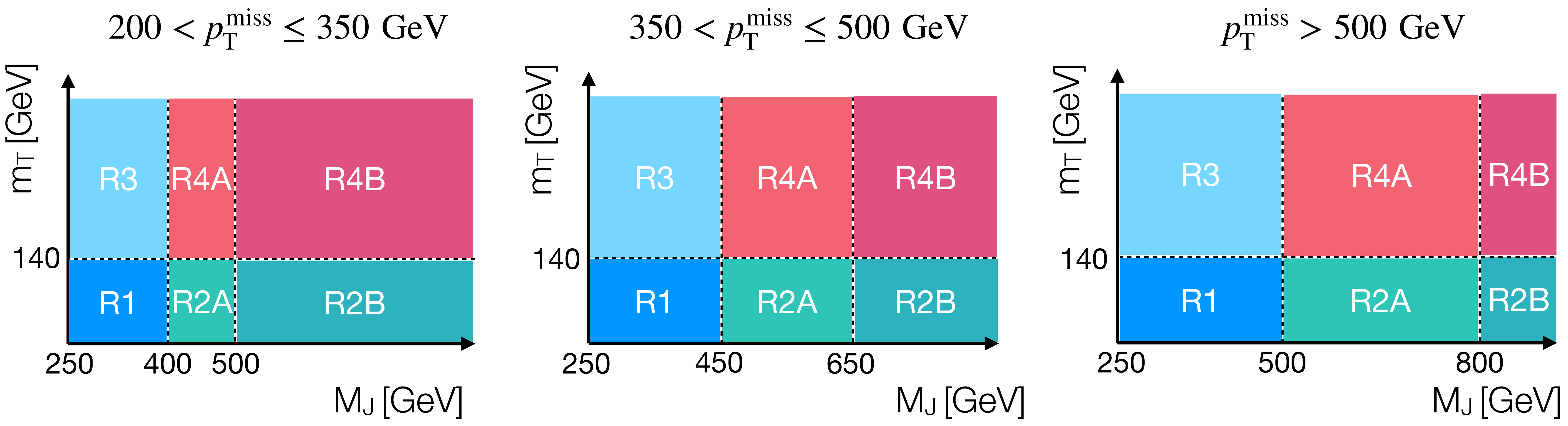




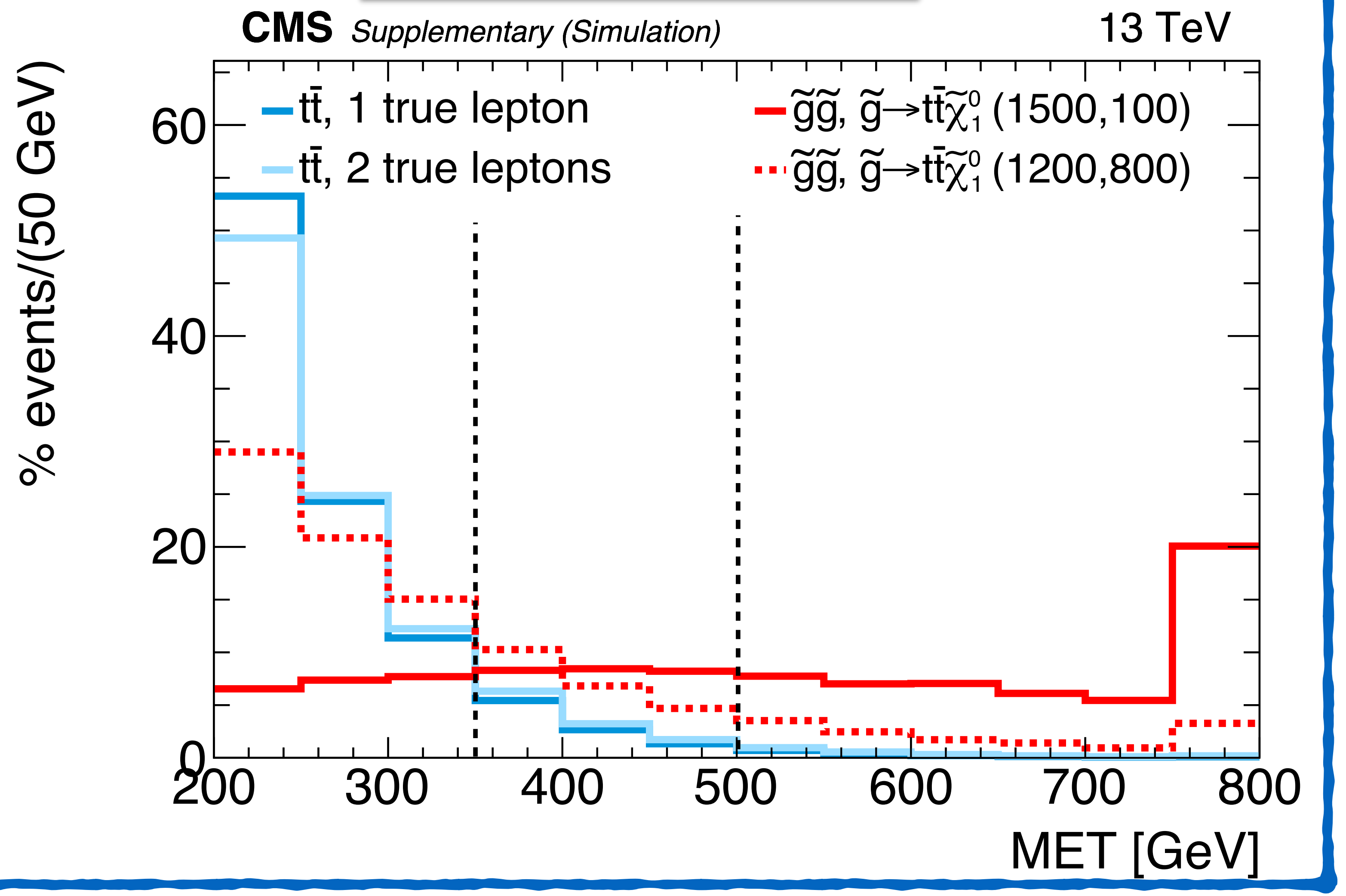
Analysis binning: 4D

M_J: 2 bins, boundaries dependent on MET to compensate for shifting bkg. M_J distribution

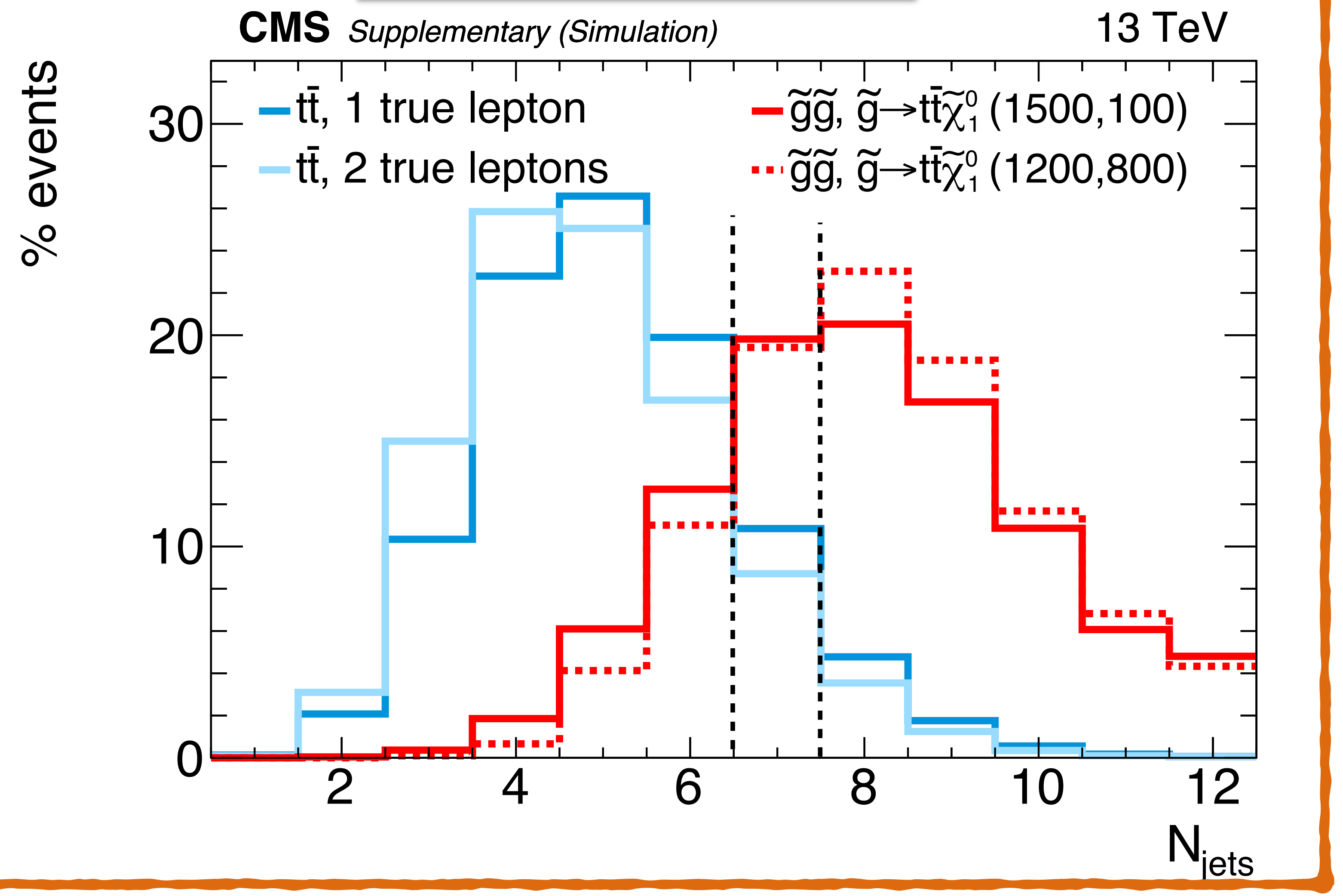




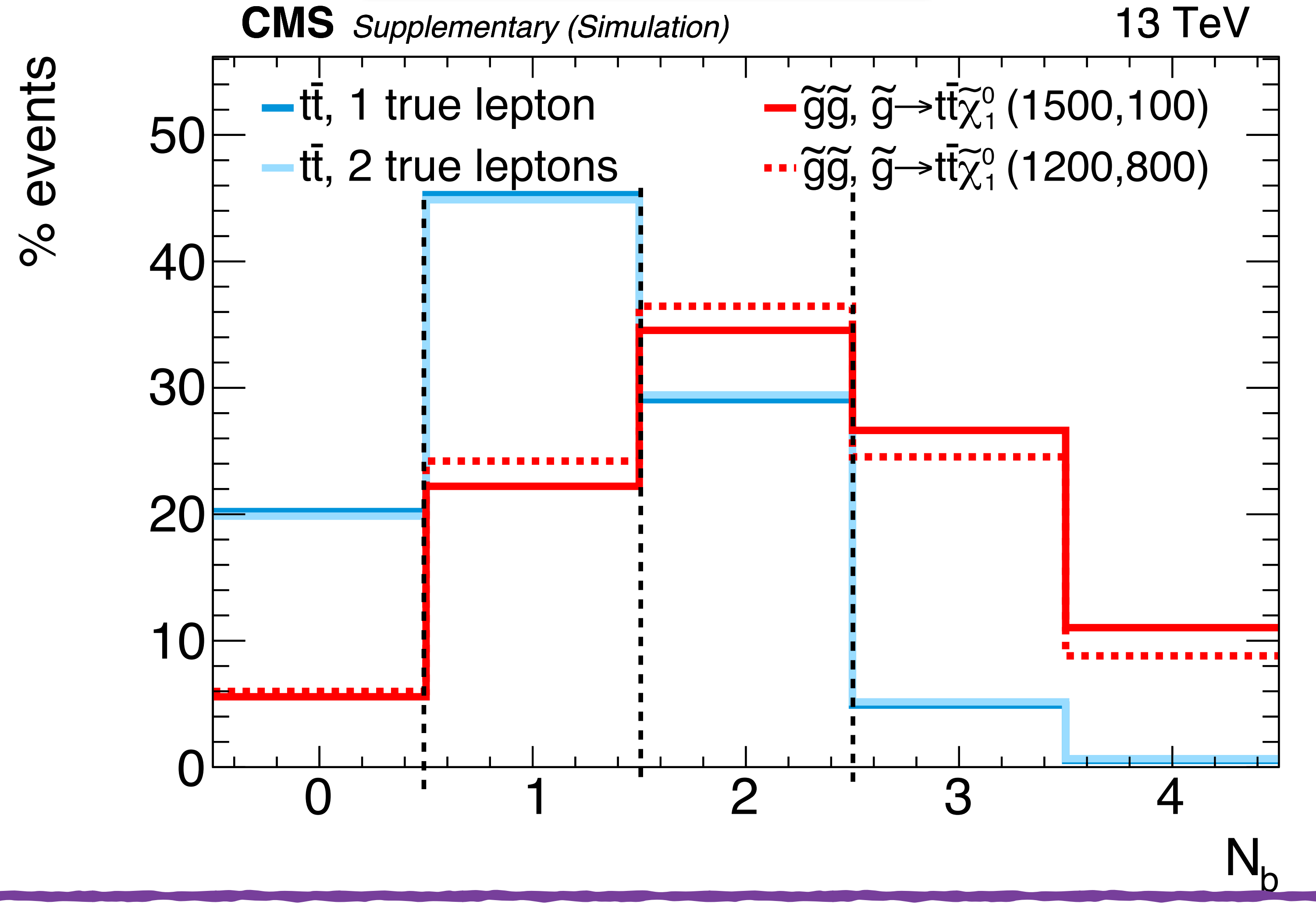
MET: 3 bins



N_{jets} : 2 bins



N_b: 3 bins



Residual correlation between ABCD variables

CMS-SUS-19-007

Standard ABCD

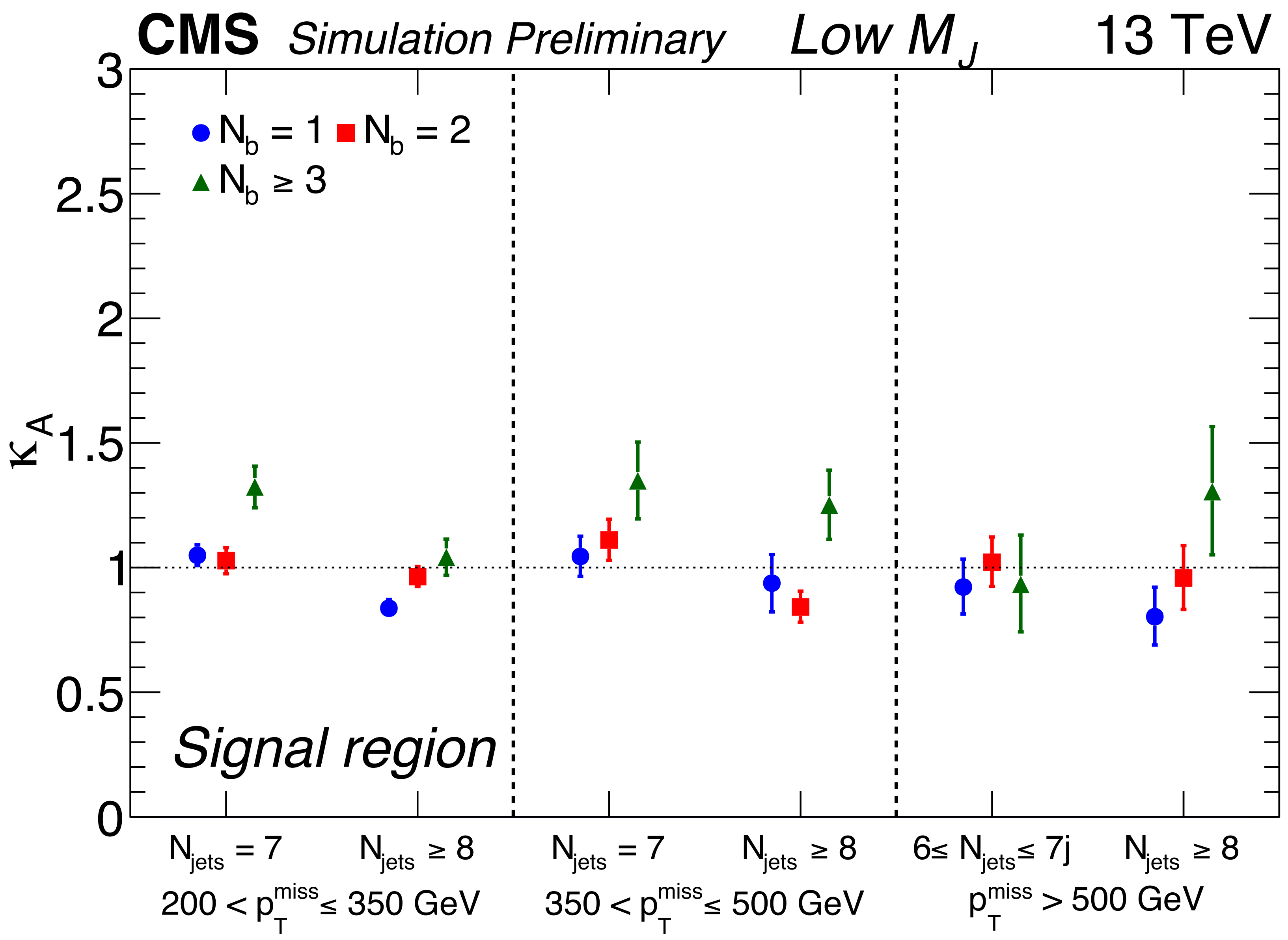
$$\mu_{\rm R4A} = \left(\frac{N_{\rm R2A} N_{\rm R4}}{N_{\rm R4A}}\right)_{data}$$

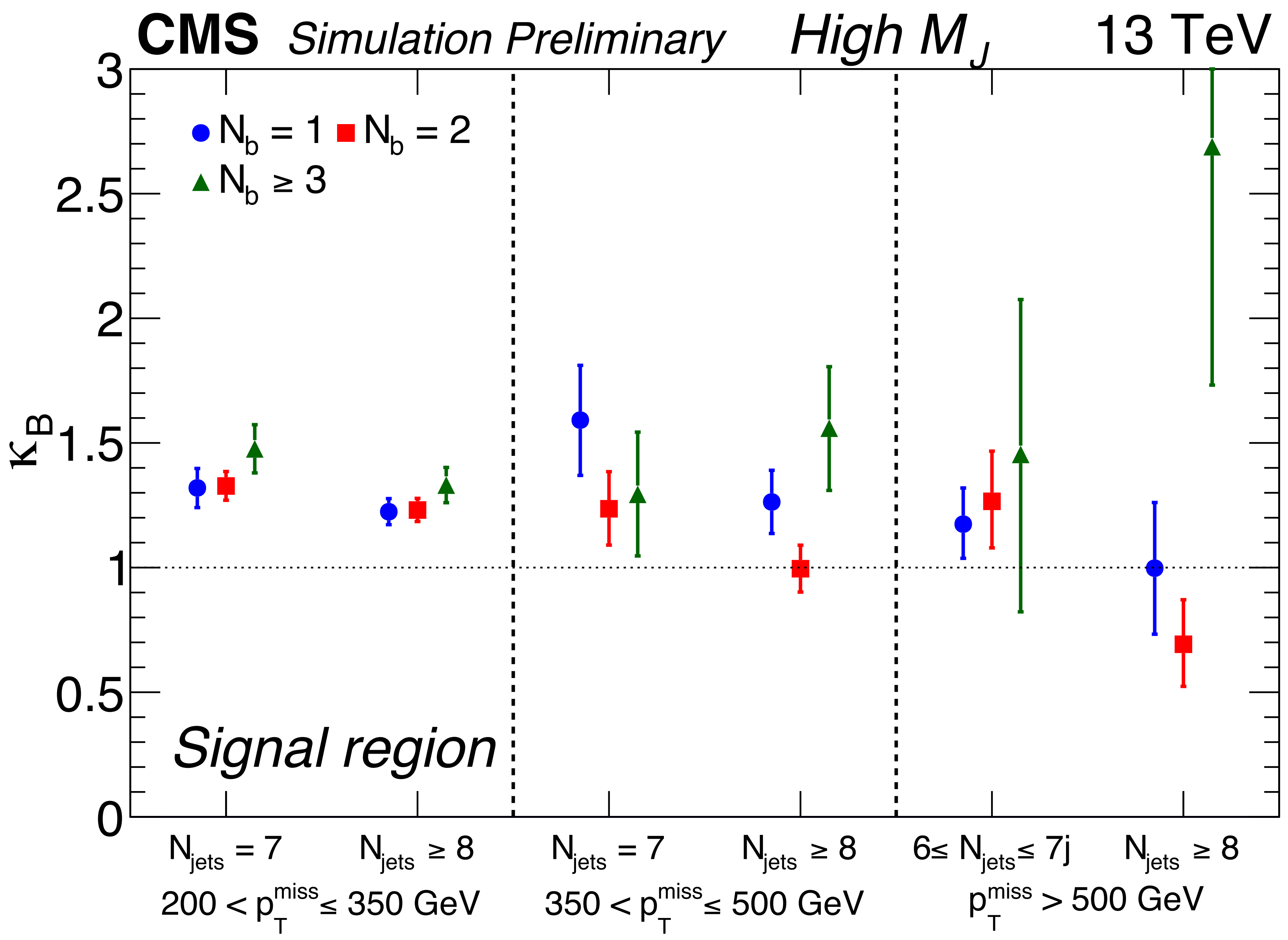
$$\kappa_{\rm A} = \left(\frac{N_{\rm R4A}/N_{\rm R3}}{N_{\rm R2A}/N_{\rm R1}}\right)_{MC}$$

After taking into account residual correlation

$$\mu_{\rm R4A} = \kappa_A \left(\frac{N_{\rm R2A} N_{\rm R4}}{N_{\rm R4A}}\right)_{data}$$

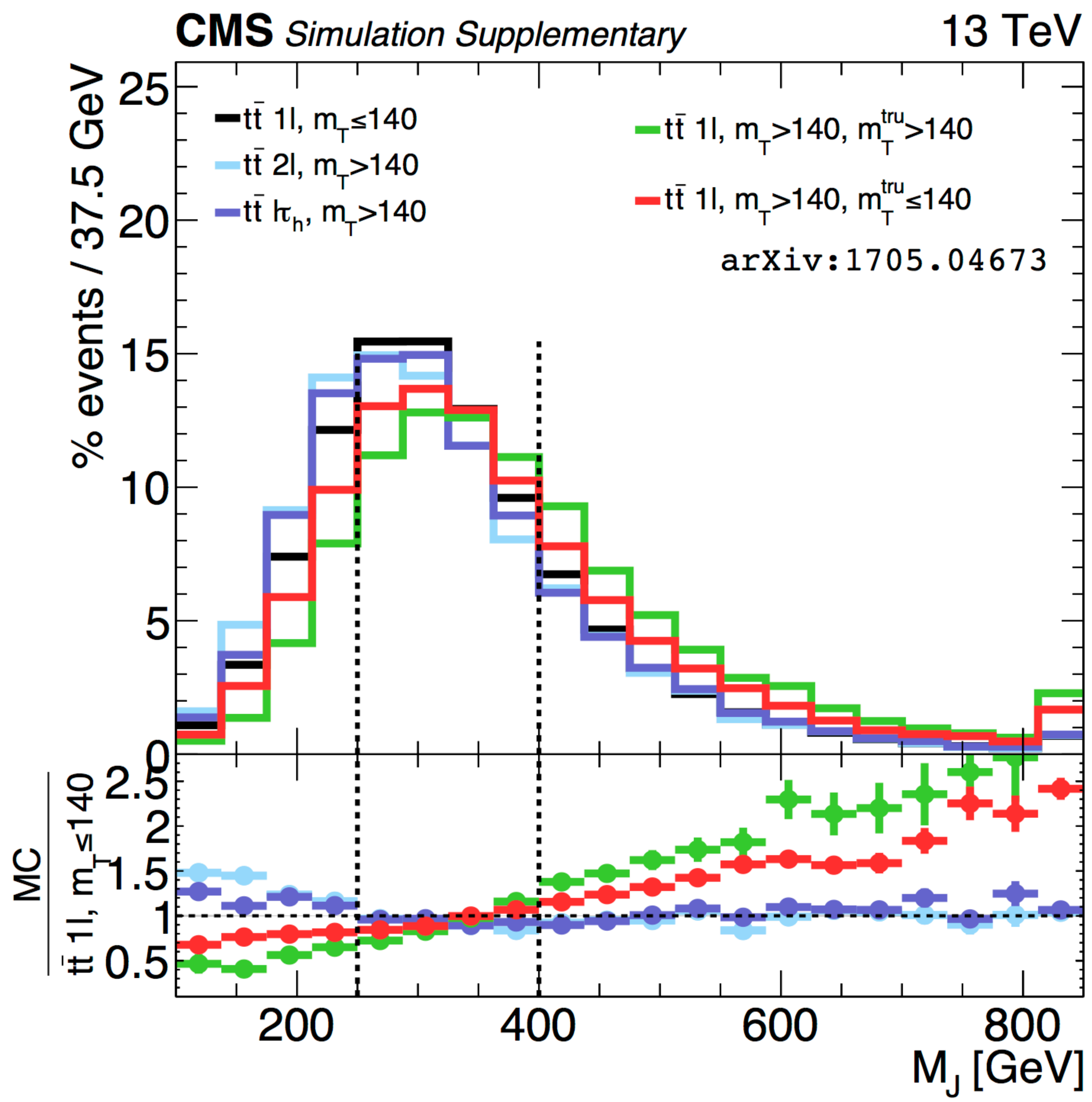
Same goes for "B" regions





- ★ **κ** is a double-ratio correction factor, thus minimizing sensitivity to systematic mismodeling
- ★ Correction close to unity consistent with minimal correlation
- ★ Modeling of correlation checked in data control samples to derive systematics

How does each background category behave?

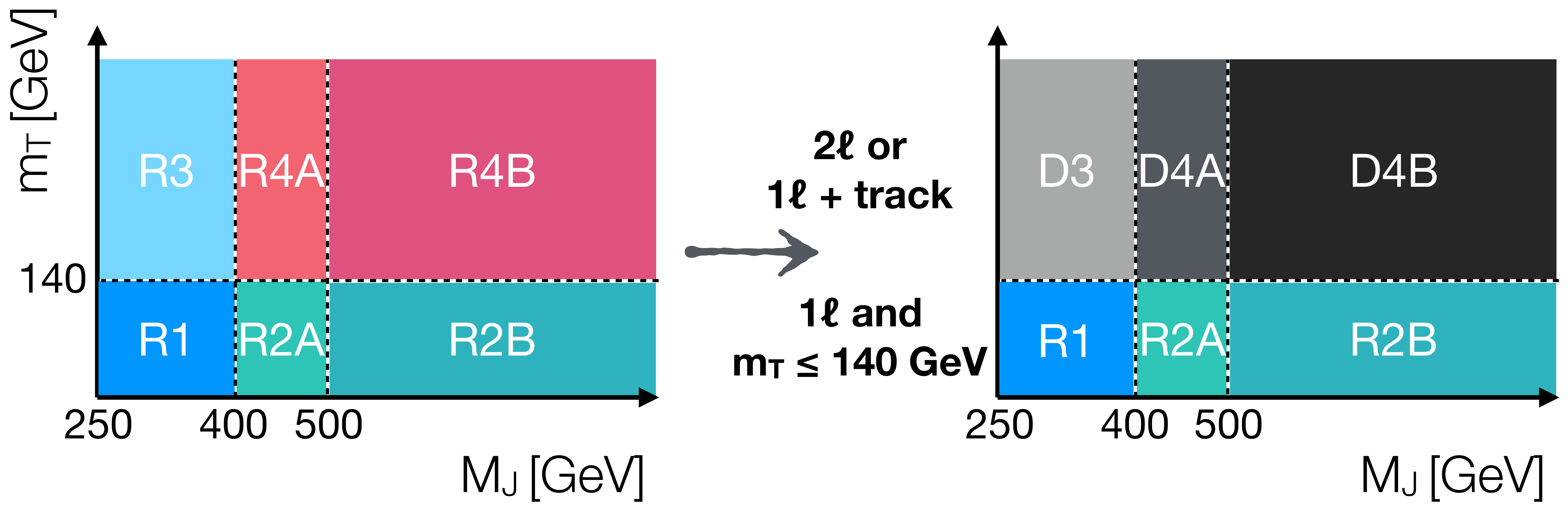


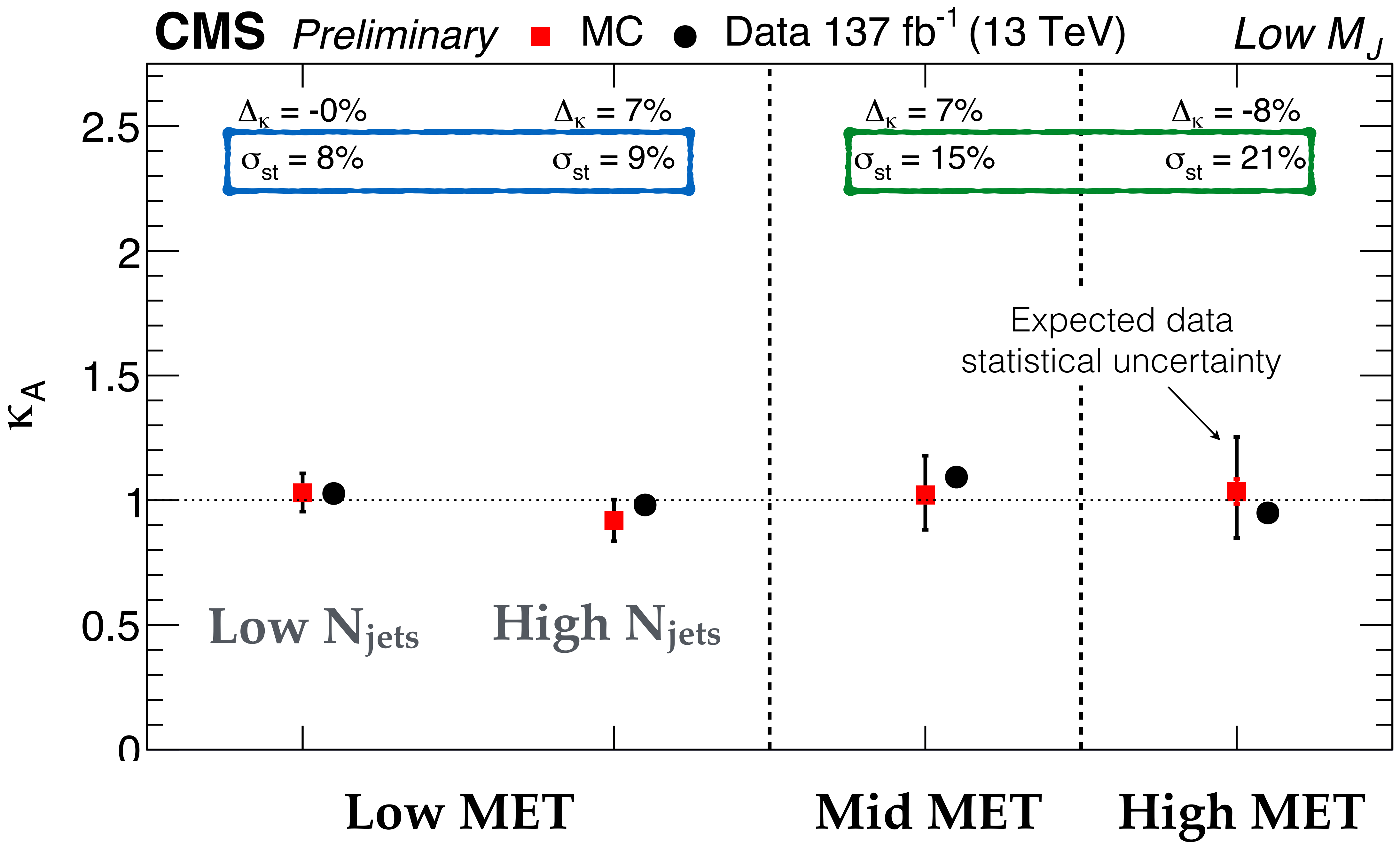
- ★ Background can be understood to comprise of two distinct populations!
- ★ Backgrounds with kappa ~ 1
  - ✦ primarily 2ℓ tt with "lost" lepton
  - ✦ true multi-ν events
    - → m_T not constrained
    - → no reason for events at low and high m_T to have different kinematics
    - → M_J at high and low m_T are the same
- ★ Backgrounds with kappa > 1
  - ✦ 1ℓ tt with mismeasurement
    - fake MET contributes to bring events above m_T threshold
    - fake MET correlated with hadronic activity
    - → high m_T events will have harder M_J distribution
  - ✦ 1ℓ tt with additional ν from hadronic decay
    - MET from additional ν must be large enough to bring event above m_T threshold
    - → correlated with presence of high p_T jets
    - → high m_T events will have harder M_J distribution

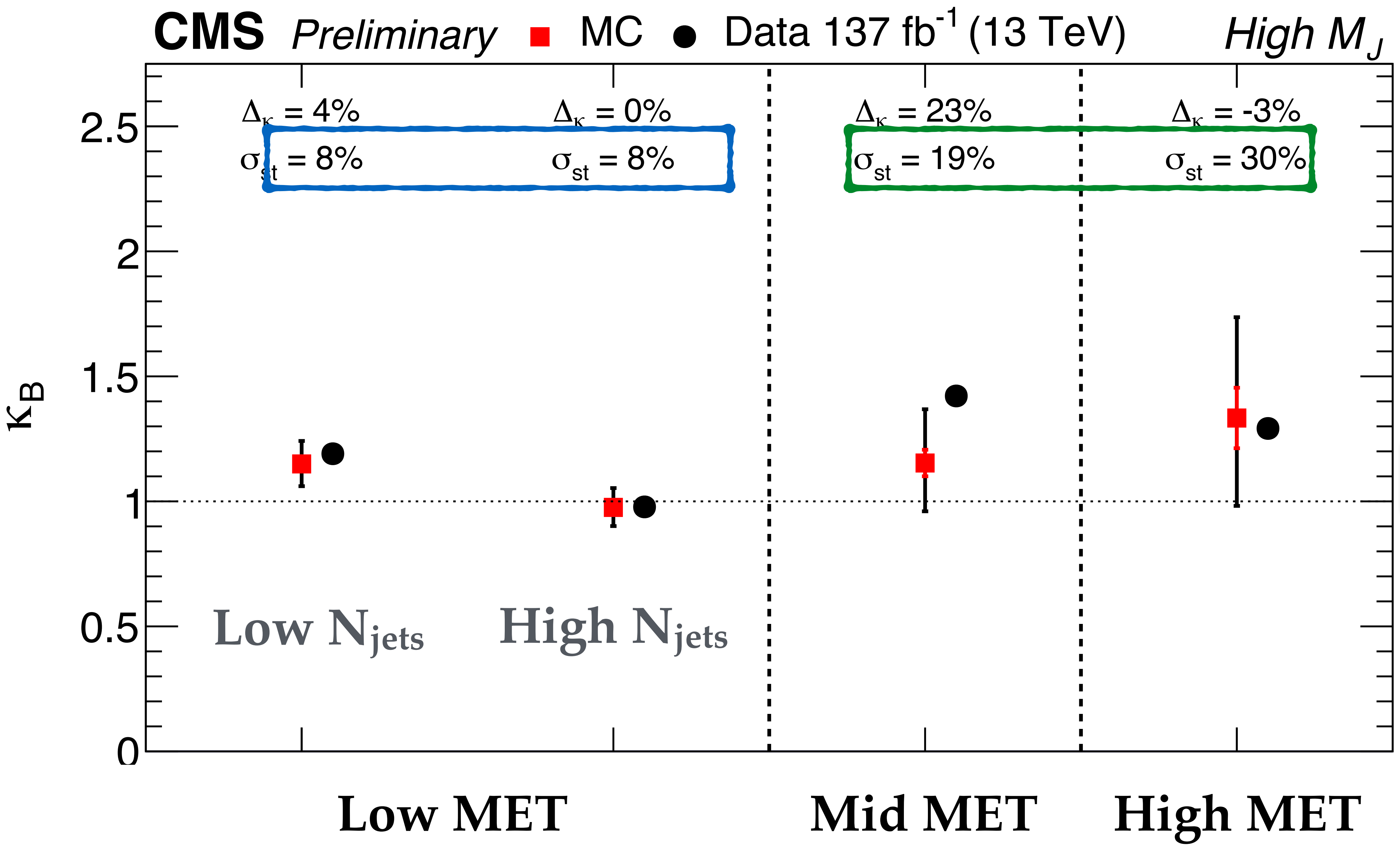
2ℓ control region

- ★ 2ℓ ABCD constructed by replacing high-m_T 1ℓ regions with events with 2ℓ
  - ✦ examined in bins of MET and N_{jets}
- ★ Events with $N_b \geq 2$ excluded due to high signal contamination
- ★ Good agreement between data and MC **κ**'s

example: $200 \leq p_T^{miss} \leq 350$ GeV





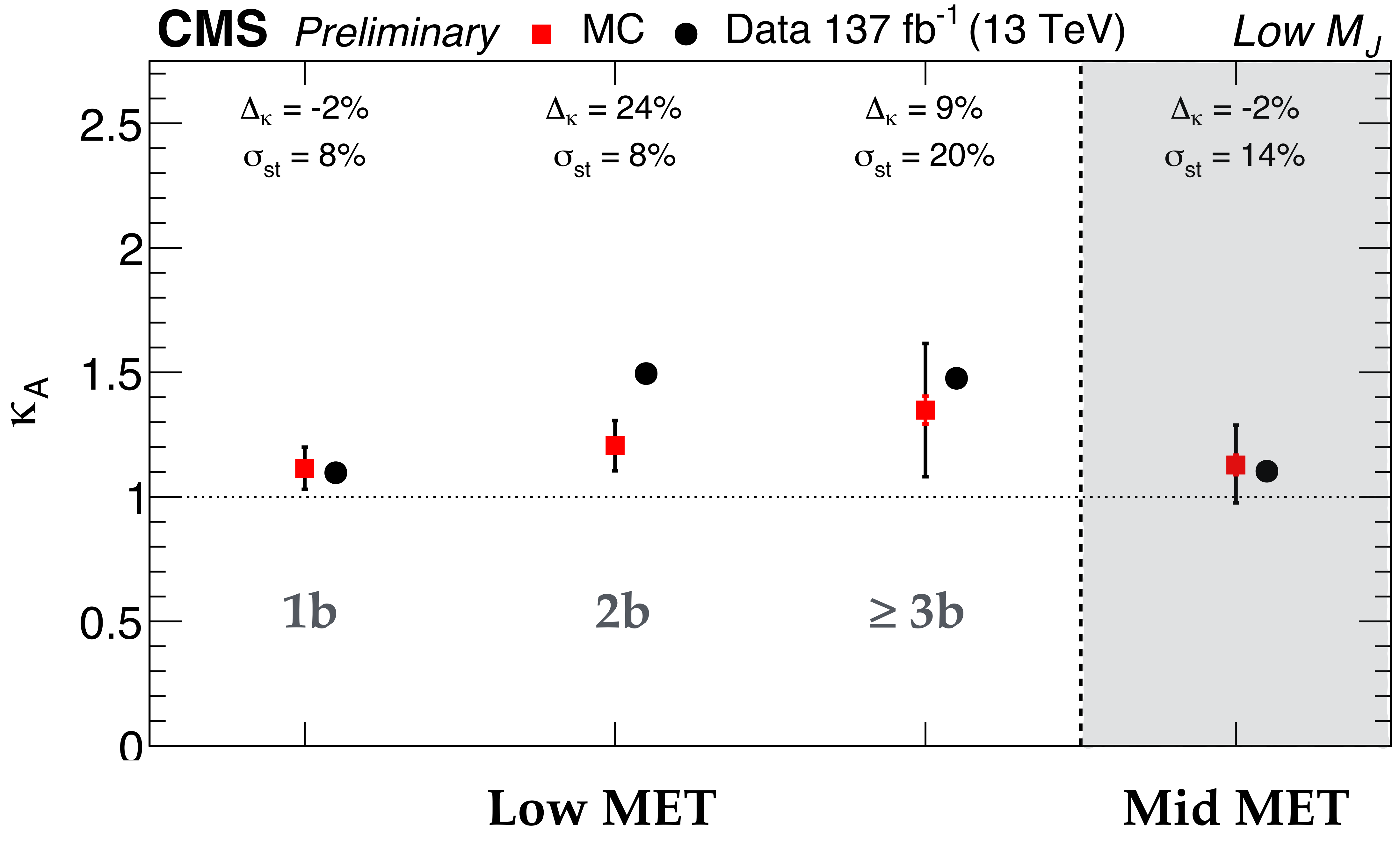


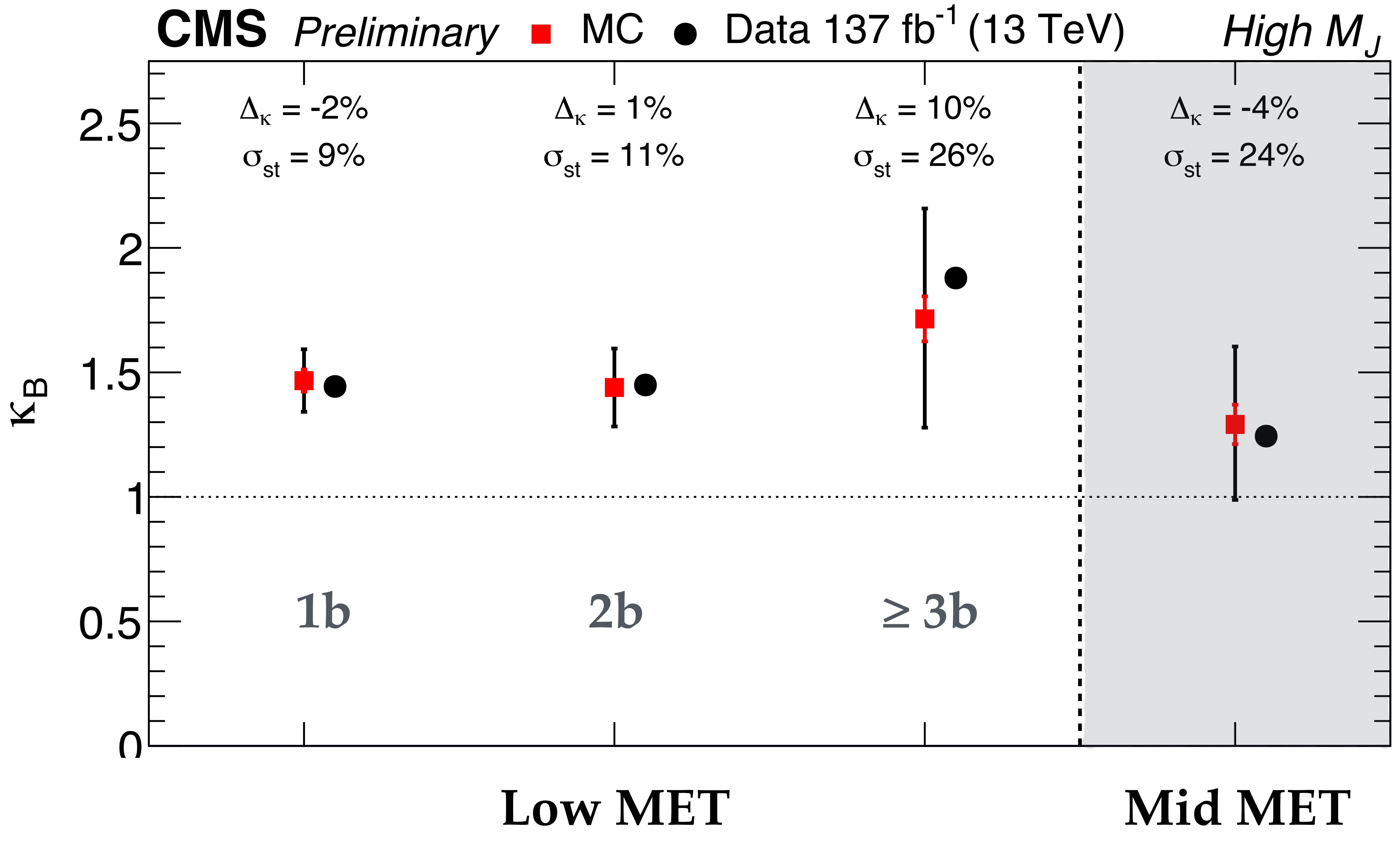
N_{jets}: 8-9% unc.

MET: 15-30% unc.

5-6 jet control region

- ★ 5-6 jet ABCD constructed with same cuts except as main analysis regions except for N_{jets}
  - ✦ background composition similar to signal region ➞ can test mismeasurement modeling
  - ✦ examined in bins of N_b
- ★ Lowest MET bin has the largest contribution from mismeasurement ➞ serves to bound any mismodeling
  - ✦ intermediate MET bin provides additional validation
  - ✦ high MET bin excluded due to signal contamination
- ★ Observed a ~ 3σ deviation in 2b consistent with fluctuation in data based on additional studies
  - ✦ set N_b uncertainty to 10%, 20% and 25% for 1b, 2b and ≥ 3b, respectively





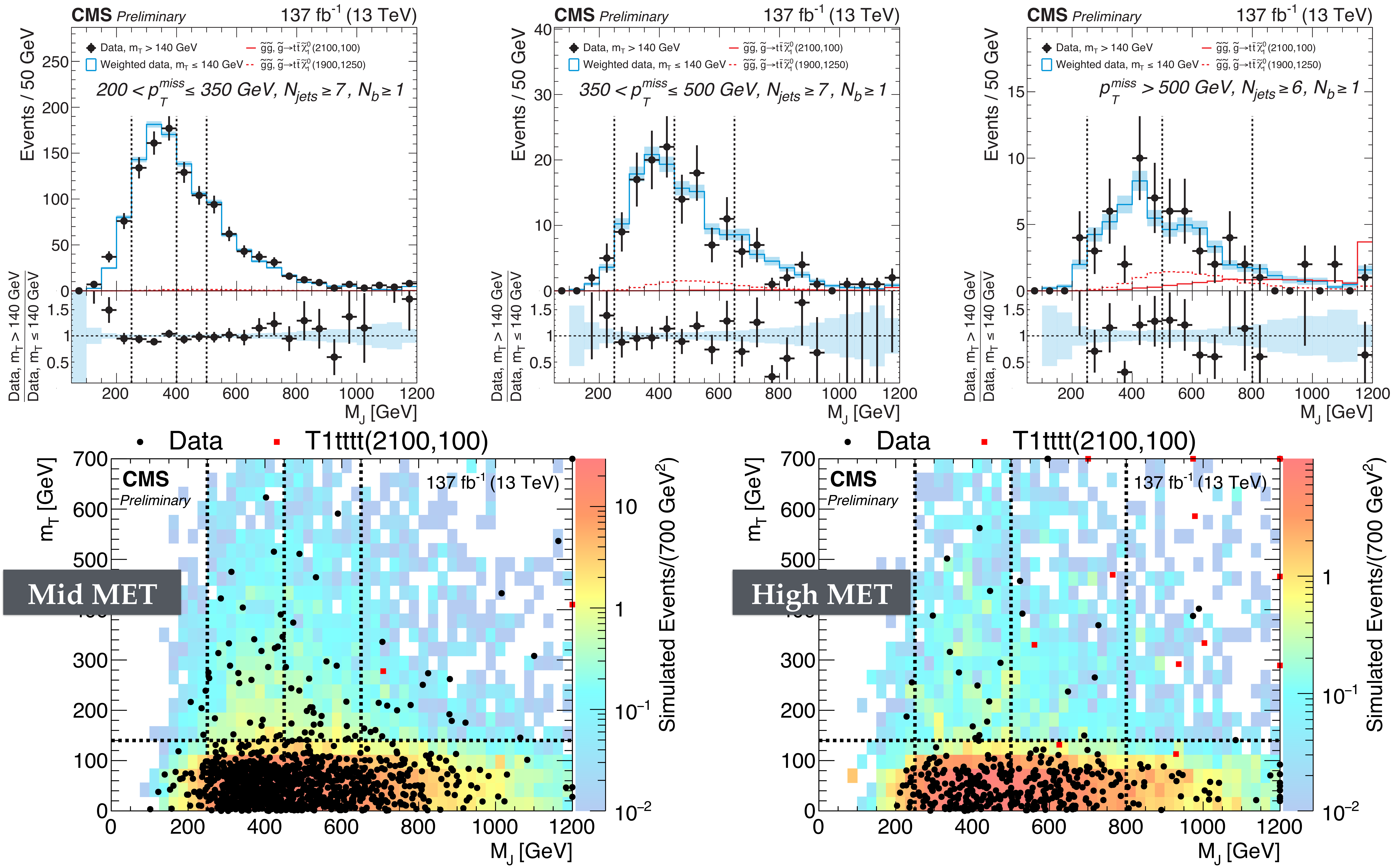
Summary of background systematic uncertainties

- ★ Uncertainties from 2ℓ region and 5-6 jet region combined as uncorrelated sources to arrive at total uncertainty

  - ✦ N_{jets} uncertainty from 2ℓ CR → 9%
  - ✦ N_b uncertainty from 5-6j CR → 10%, 20%, and 25% for 1b, 2b, and ≥ 3b, respectively
  - ✦ MET uncertainty from 2ℓ CR
    - low-M_J bins → 15% and 21 % for medium and high MET, respectively
    - high-M_J bins → 19% and 30 % for medium and high MET, respectively

Total uncertainty ranges between 13% and 39%

Bin	$200 < p_T^{miss} \leq 350$ GeV			$350 < p_T^{miss} \leq 500$ GeV			$p_T^{miss} > 500$ GeV		
	1 b	2 b	≥ 3b	1 b	2 b	≥ 3b	1 b	2 b	≥ 3b
low-M_J (R4A)	13%	22%	27%	20%	27%	31%	25%	30%	34%
high-M_J (R4B)	13%	22%	27%	22%	28%	32%	32%	36%	39%


CMS Preliminary
137 fb^{-1} (13 TeV)
Data, $m_T > 140$ GeV
Weighted data, $m_T \leq 140$ GeV
$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ (2100,100)
$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$ (1900,1250)
$200 < p_T^{miss} \leq 350$ GeV, $N_{jets} \geq 7$, $N_b \geq 1$
$350 < p_T^{miss} \leq 500$ GeV, $N_{jets} \geq 7$, $N_b \geq 1$
$p_T^{miss} > 500$ GeV, $N_{jets} \geq 6$, $N_b \geq 1$
Events / 50 GeV
Data, $m_T > 140$ GeV / Data, $m_T \leq 140$ GeV
M_J [GeV]
Data
T1tttt(2100,100)
m_T [GeV]
Simulated Events/(700 GeV^2)
Mid MET
High MET

Signal systematic uncertainties

- ⋆ Larger uncertainties for more compressed points since acceptance relies more on tails of distributions
- ⋆ range over high MET bins (large Δm) & over high Njets bins (small Δm)

Source	Relative uncertainty [%]	
	T1tttt(2100,100)	T1tttt(1900,1250)
MC sample statistics	3–8	7–15
Renormalization and factorization scales	1–2	2–4
Fast sim. p_T^{miss} resolution	1–2	1–5
Lepton efficiency	7–9	4–5
Trigger efficiency	1	1
b tagging efficiency	2–8	2–8
Mistag efficiency	1	1–3
Jet energy corrections	1–5	2–11
Initial-state radiation	1–7	1–10
Jet ID	1	1
Pileup	1–2	1–4
Integrated luminosity	2.5	2.5