Strong SUSY Production in Hadronic Channels with CMS

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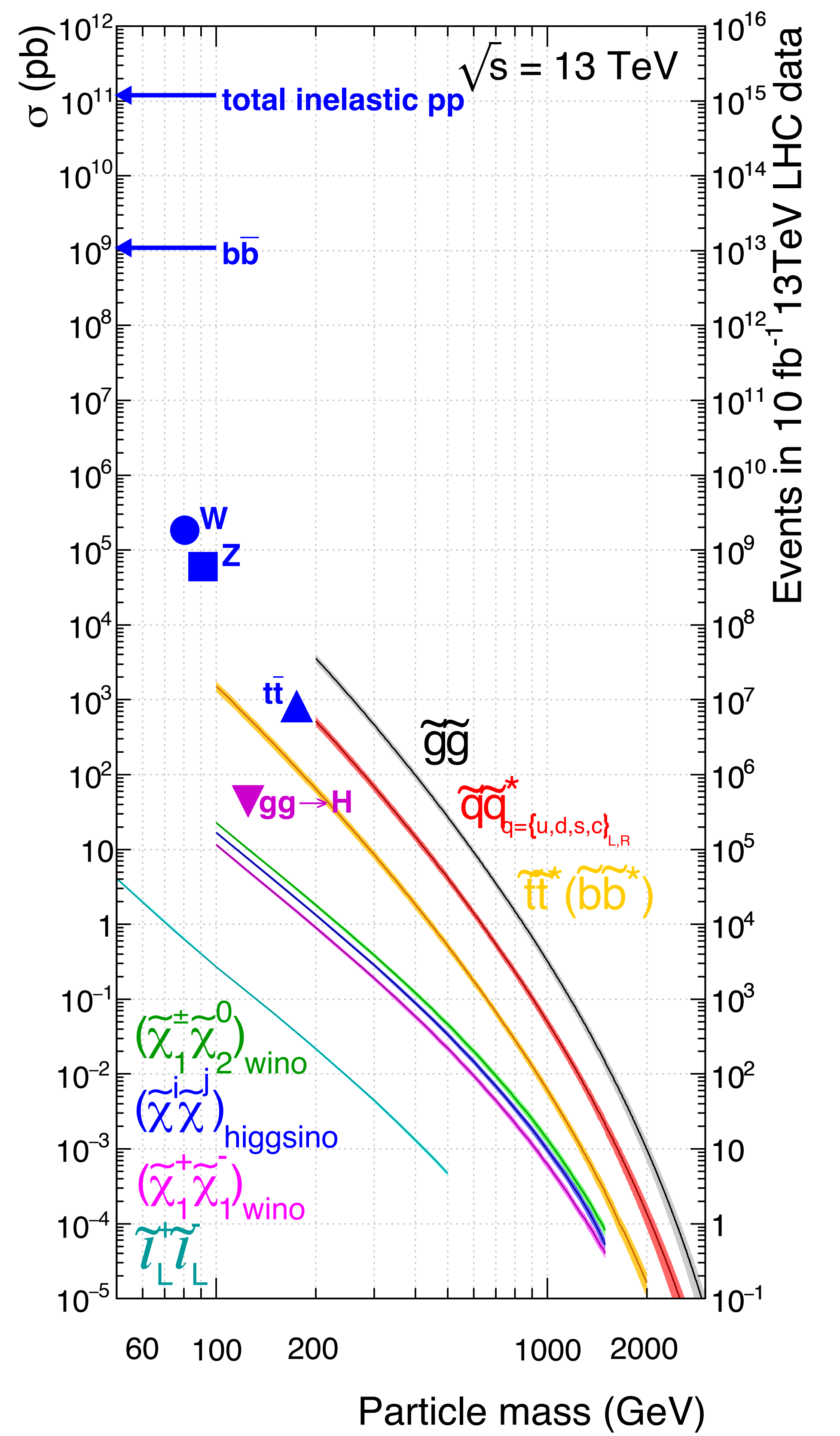
https://indico.cern.ch/event/517784/contributions/2492780/

Strong production in hadronic channel

- Strong production
  - larger cross section than other sparticle production
- Hadronic channels
  - jets and missing energy in final states
  - events with a lepton or photon are vetoed in search regions and are used as control samples
- SMS (simplified model spectra)
  - interpretation of results
- Related parallel talks with CMS SUSY:
  - SUSY strong production (leptonic) with CMS
  - Third generation squarks with CMS
  - SUSY in photons and taus with CMS
  - SUSY electroweak searches with CMS



arxiv:1407.5066

Summary of latest Inclusive SUSY results in hadronic channels

SUS-16-033	jets + MHT	35.9 fb^{-1}	**Focus of today**
SUS-16-036	jets + M_{T2}	35.9 fb^{-1}	**Focus of today**
SUS-16-016	jets + α_T	12.9 fb^{-1}	Stay tuned!
SUS-15-004	jets + razor	2.3 fb^{-1}	Stay tuned!

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS/index.html

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

General Strategy

- Jets and missing transverse energies (MET) as final states
  - Reliant on good performance on jet reconstructions and measurement of energy deposits
- Typical background:
  - top pair or W(→lν)+jets: lost lepton, hadronic τ decay
  - Z(→νν)+jets
  - Multi-jets production
- Inclusive search for broad range of phase space
  - Wide energy range and topologies: H_T ~ few hundred GeV to TeV, $N_{jet} \geq 1$
  - Covering low to high MET environment: few hundred GeV to ~ 1 TeV
  - Sensitivity to broad range of SUSY models

Typical variables

$$H_T = -\sum_{i \in \text{ jet}} \vec{p}_{T,i}$$

$$H_T^{miss} = -\sum_{i \in \text{ jet}} \vec{p}_{T,i}$$

$$E_T^{miss} = -\sum_{i \in \text{ particles}} \vec{p}_{T,i}$$

$$\Delta\phi = \Delta\phi(\vec{p}_{\mathrm{T}i}, \vec{H}_{\mathrm{T}}^{\mathrm{miss}})$$

General Strategy

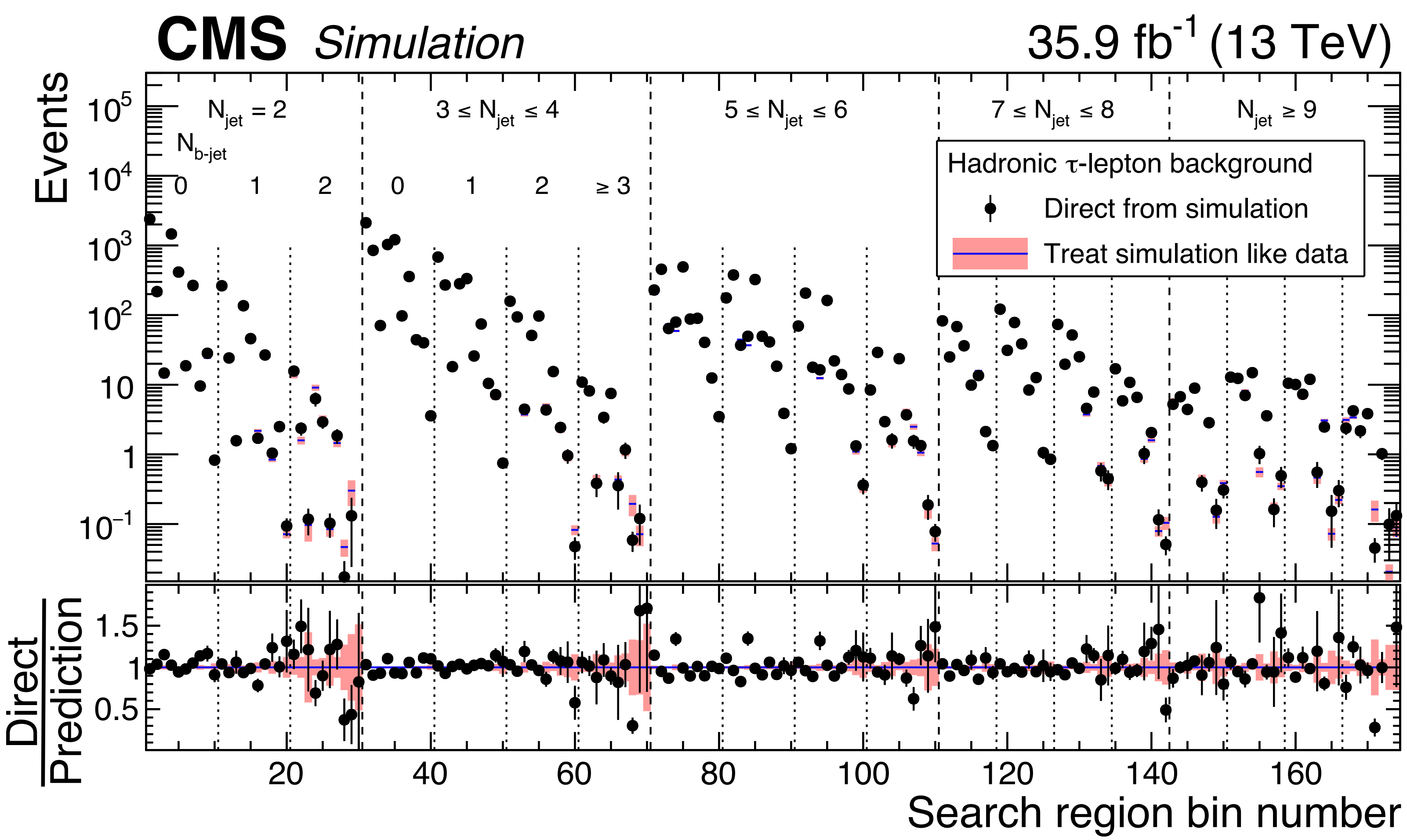
- Employ robust discriminating variables against various backgrounds
  - e.g. M_{T2}, α_T, razor
- Data-driven background estimation from multiple control regions (CRs)
  - Selection mimic as closely as possible the signal region → minimise bias from extrapolations
  - Extensive validation with data in control regions
- Extensive binning scheme with various variables
  - e.g. N_{jet}, N_b, H_T, MHT, MET
- Aggregated signal region
  - Maintain good sensitivities to wide range of models
  - Possible re-interpretation in a simple manner for recasters

Example of CRs:

- Di-lepton: Z(→ll) +jets
- Single photon: γ+jets
- Single lepton: W(→lν) +jets, top pair

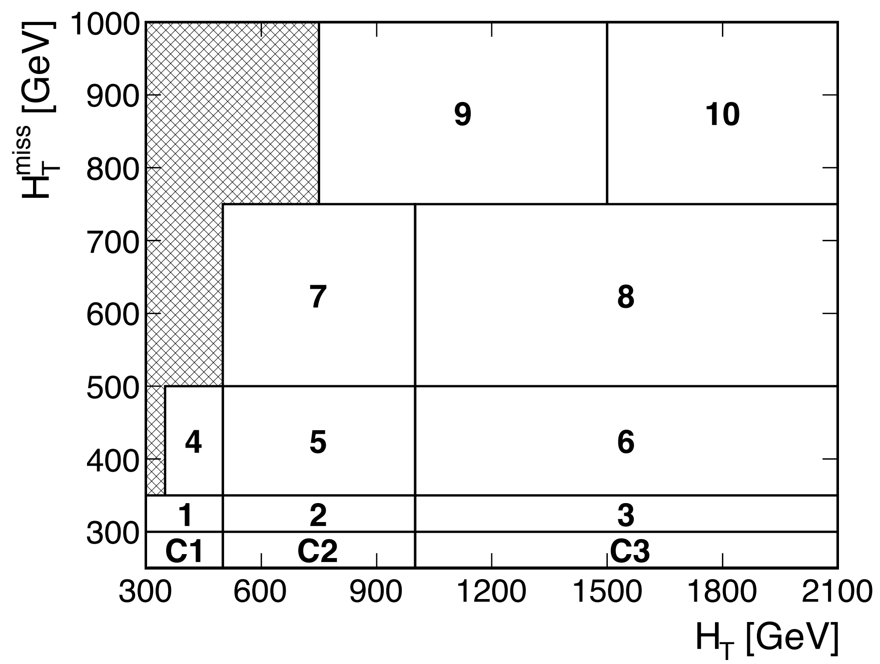
jets + MHT

- Four dimensional exclusive binning in N_{jet}, N_b, H_T and MHT
- Some background estimation methods
  - Lost lepton: event weighting with efficiencies of various lepton acceptance effect
  - Hadronic τ: muon p_T smearing of μ+jets sample with detector response templates



arXiv:1704.07781, Submitted to Phys. Rev. D

Binning



N_{jet}: 2, 3-4, 5-6, 7-8, ≥ 9
N_b: 0,1, 2, ≥ 3

Run 1 results

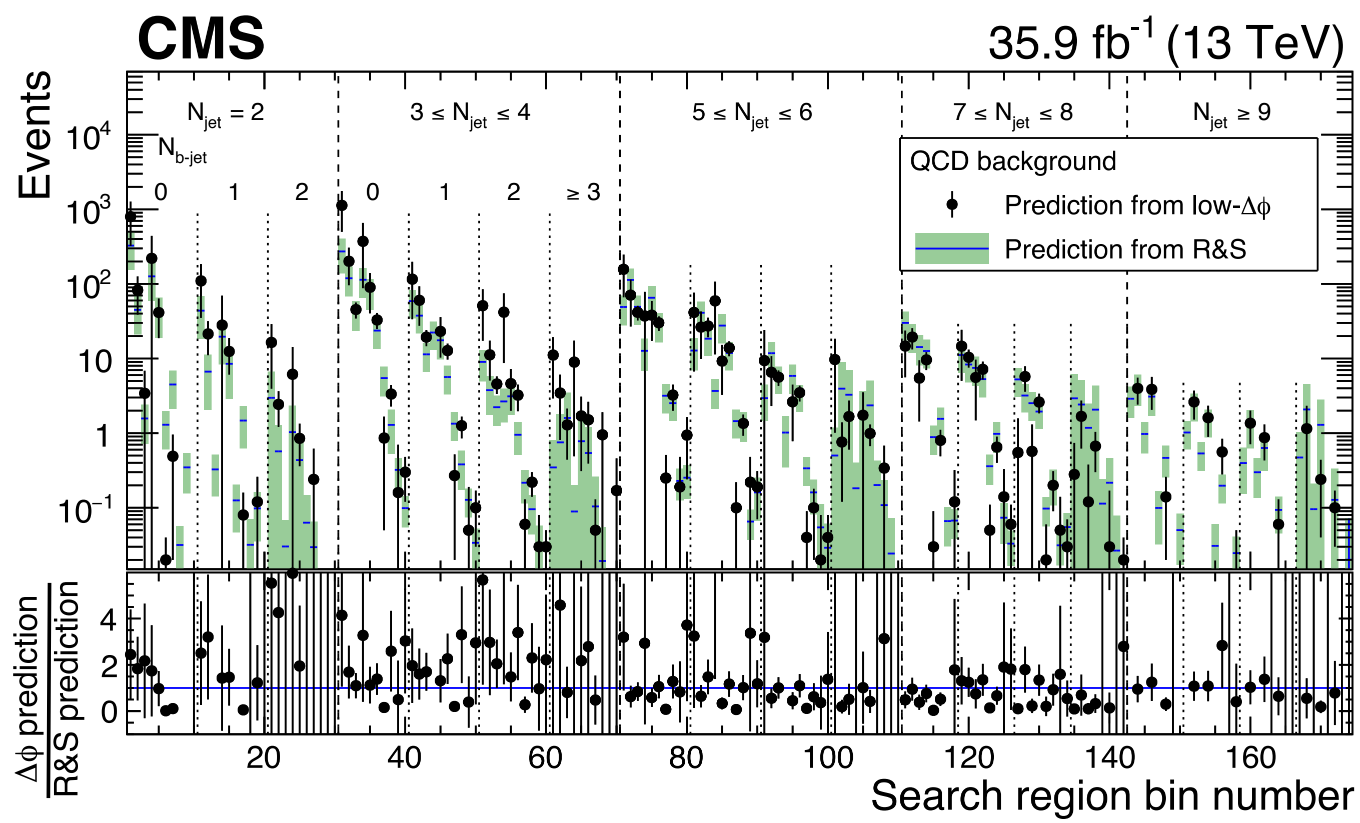
- SUS-13-012, JHEP 06 (2014) 055
- SUS-12-024, PLB 725 (2013) 243
- SUS-12-011, PRL 109 (2012) 171803
- SUS-10-005, JHEP 08 (2011) 155

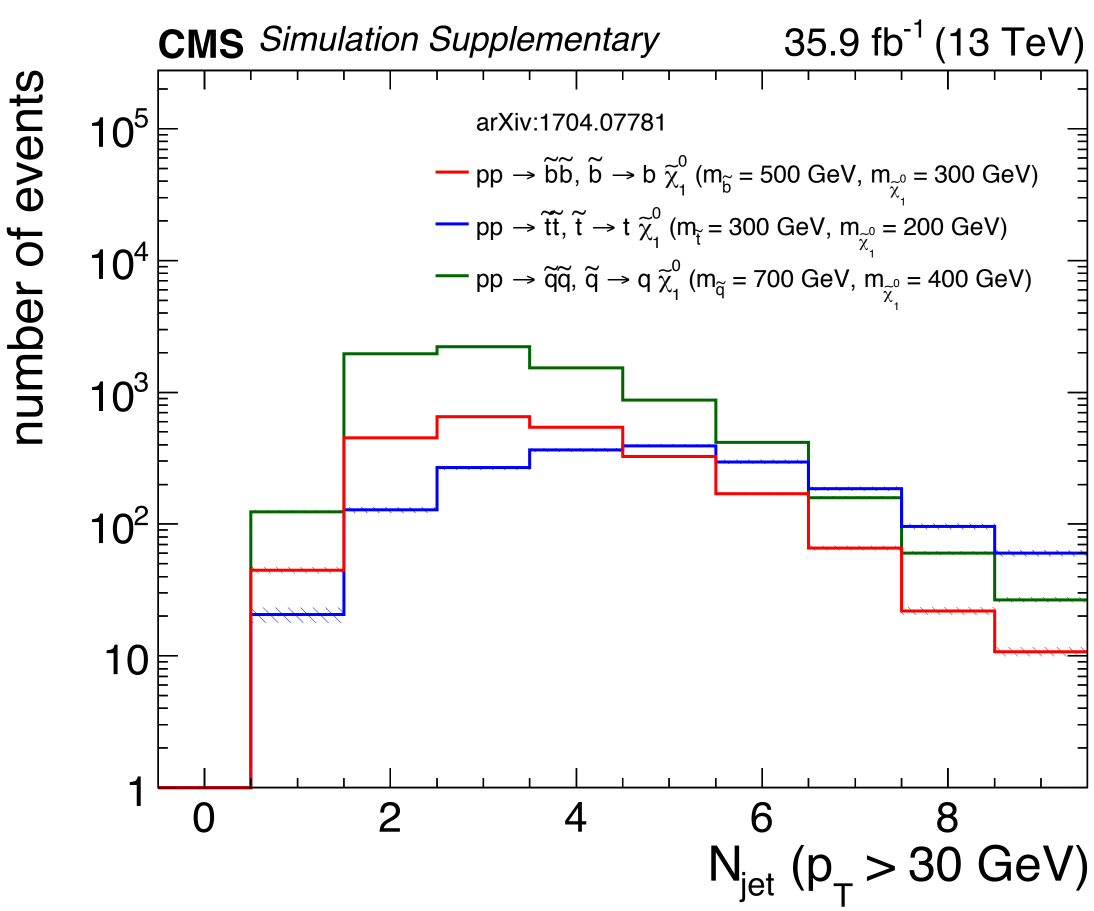
Run 2 results

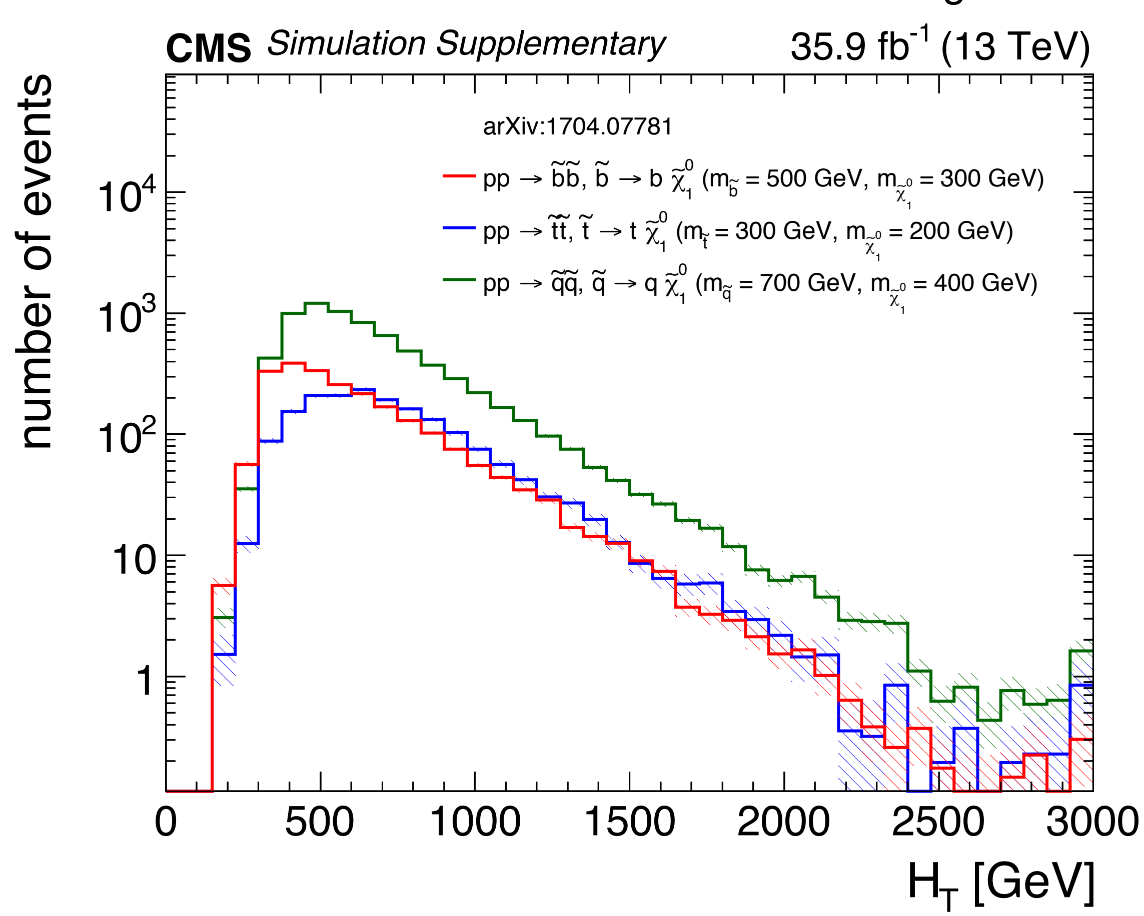
- SUS-15-002, PLB 758 (2016) 152

jets + MHT

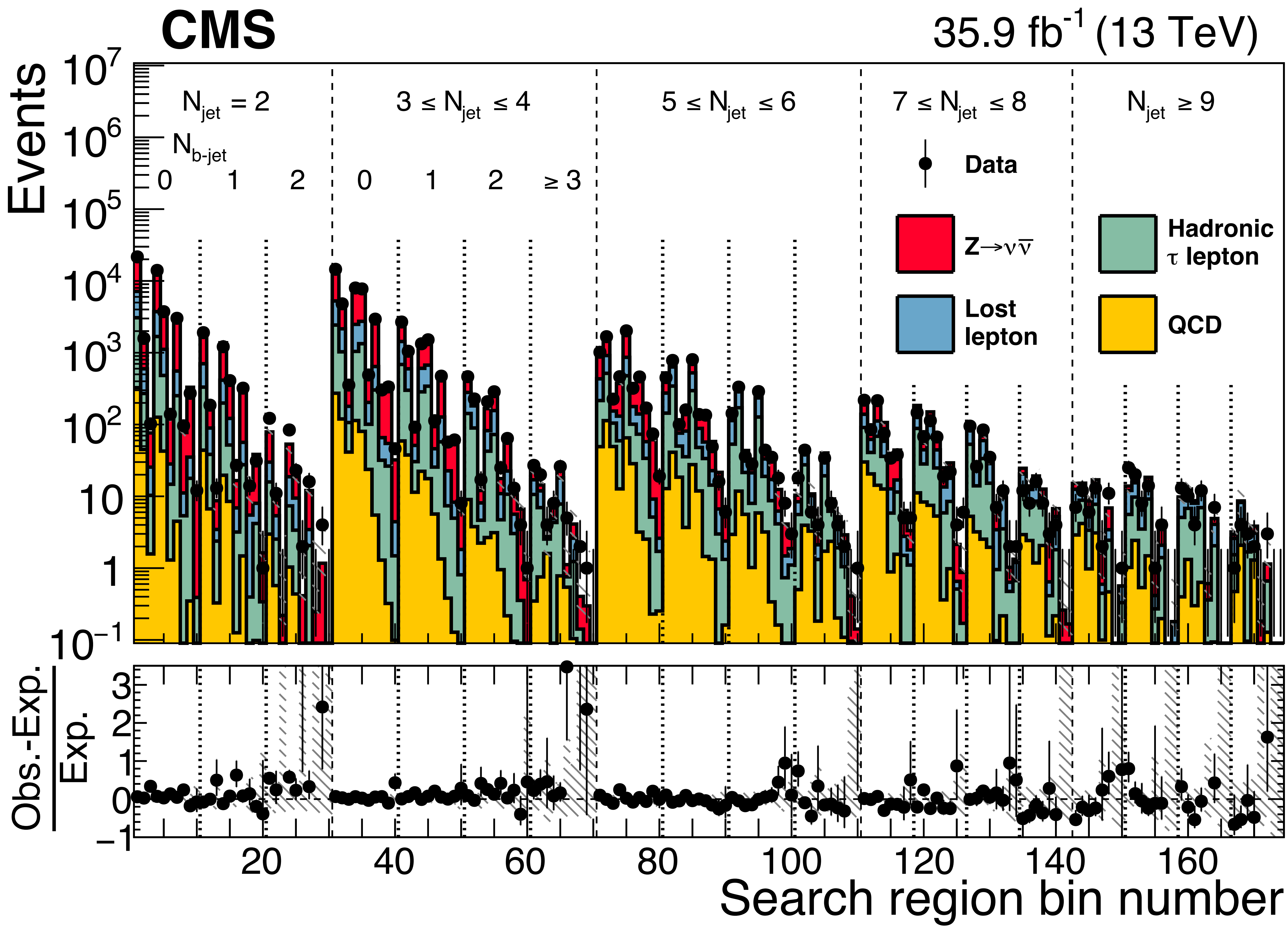
- Recent updates:
  - Additional independent QCD background estimation method with rebalance and smear technique
  - Extended lower N_{jet} to 2 and 3; and lower H_T threshold to 300 GeV
    - Increase sensitivity to squark pair production







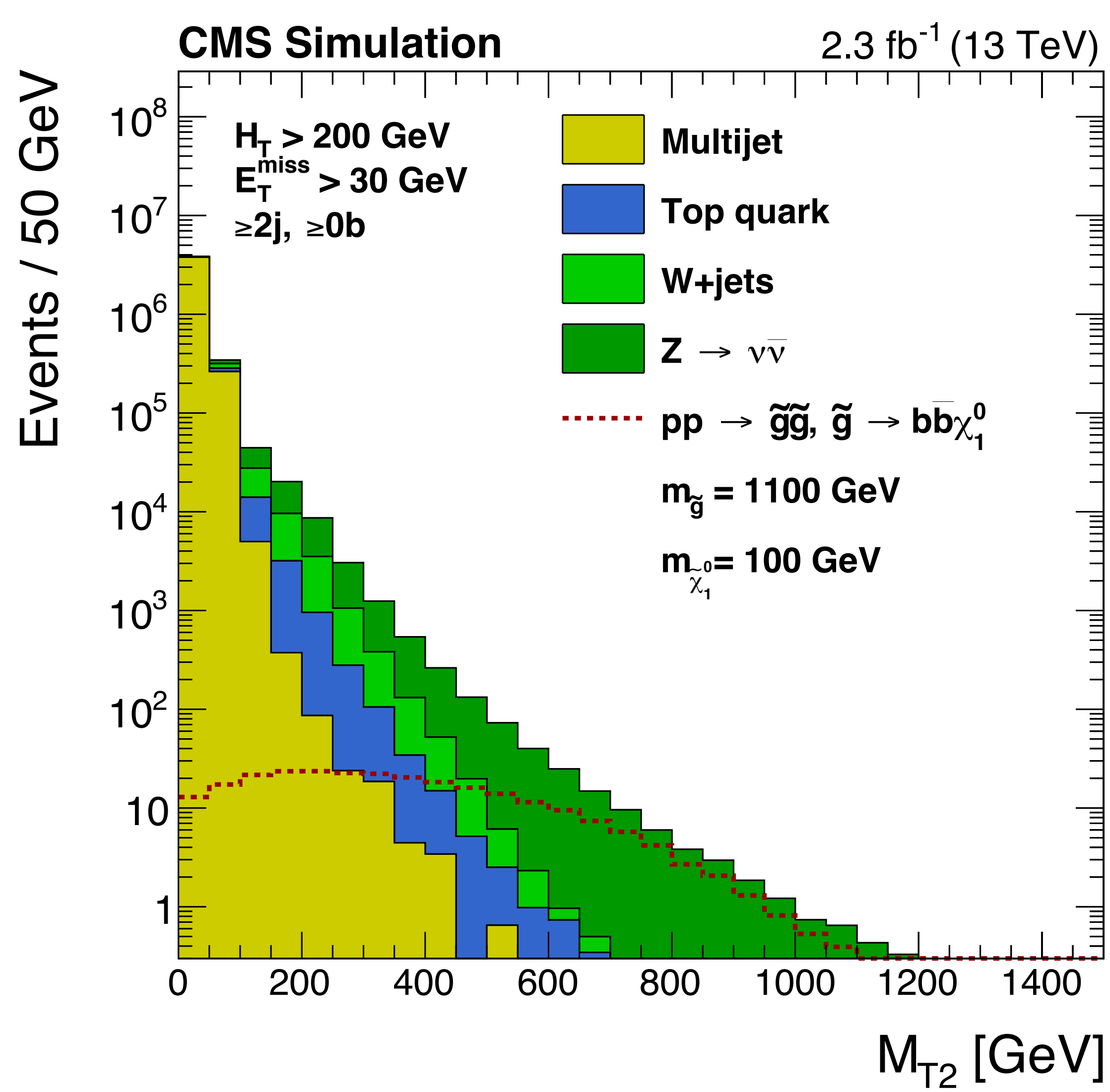
jets + MHT: Result



jets + M_{T2}

- M_{T2} as important discriminating variable
  - e.g. against QCD background
- Four dimensional exclusive binning in N_{jet}, N_b, H_T and M_{T2}
- Some background estimation methods:
  - Lost lepton: transfer factor from single lepton control region
  - Z(→νν) +jets: data-driven estimate with μμ+jets sample corrected by acceptance effect, branching fraction

CMS-PAS-SUS-16-036



Binning for high H_T regions

H_T Range [GeV]	Jet Multiplicities	M_{T2} Binning [GeV]
[1000, 1500]	2 – 3j, 0b	[200, 400, 600, 800, 1000, 1200, ∞]
	2 – 3j, 1b	[200, 400, 600, 800, 1000, 1200, ∞]
	2 – 3j, 2b	[200, 400, 600, 800, 1000, ∞]
	4 – 6j, 0b	[200, 400, 600, 800, 1000, 1200, ∞]
	4 – 6j, 1b	[200, 400, 600, 800, 1000, 1200, ∞]
	4 – 6j, 2b	[200, 400, 600, 800, 1000, ∞]
	≥ 7j, 0b	[200, 400, 600, 800, 1000, ∞]
	≥ 7j, 1b	[200, 400, 600, 800, ∞]
	≥ 7j, 2b	[200, 400, 600, 800, ∞]
	2 – 6j, ≥ 3b	[200, 400, 600, ∞]
	≥ 7j, ≥ 3b	[200, 400, 600, ∞]
[1500, ∞]	2 – 3j, 0b	[400, 600, 800, 1000, 1400, ∞]
	2 – 3j, 1b	[400, 600, 800, 1000, ∞]
	2 – 3j, 2b	[400, ∞]
	4 – 6j, 0b	[400, 600, 800, 1000, 1400, ∞]
	4 – 6j, 1b	[400, 600, 800, 1000, 1400, ∞]
	4 – 6j, 2b	[400, 600, 800, ∞]
	≥ 7j, 0b	[400, 600, 800, 1000, ∞]
	≥ 7j, 1b	[400, 600, 800, ∞]
	≥ 7j, 2b	[400, 600, 800, ∞]
	2 – 6j, ≥ 3b	[400, 600, ∞]
	≥ 7j, ≥ 3b	[400, ∞]

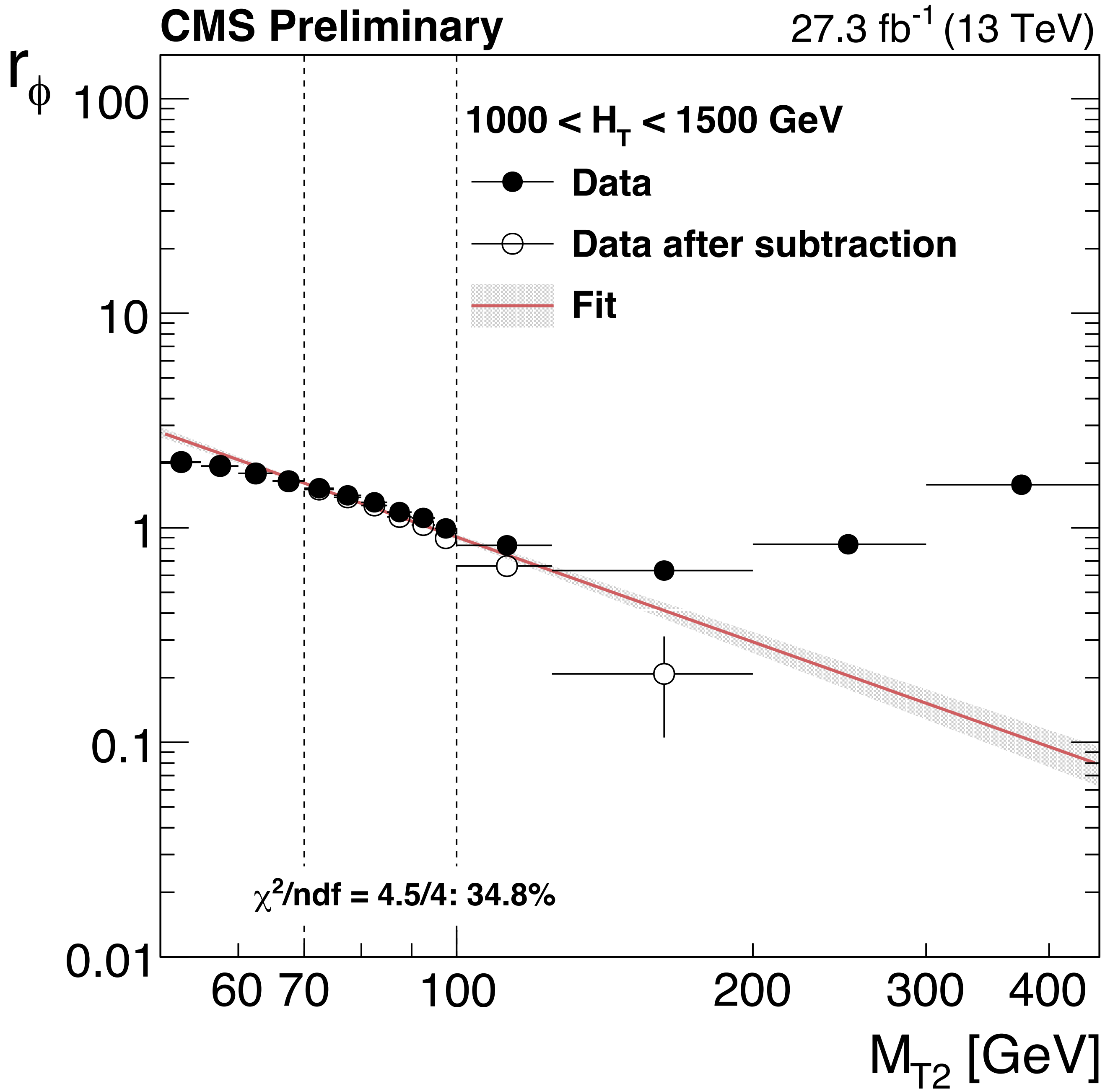
Run 1 results

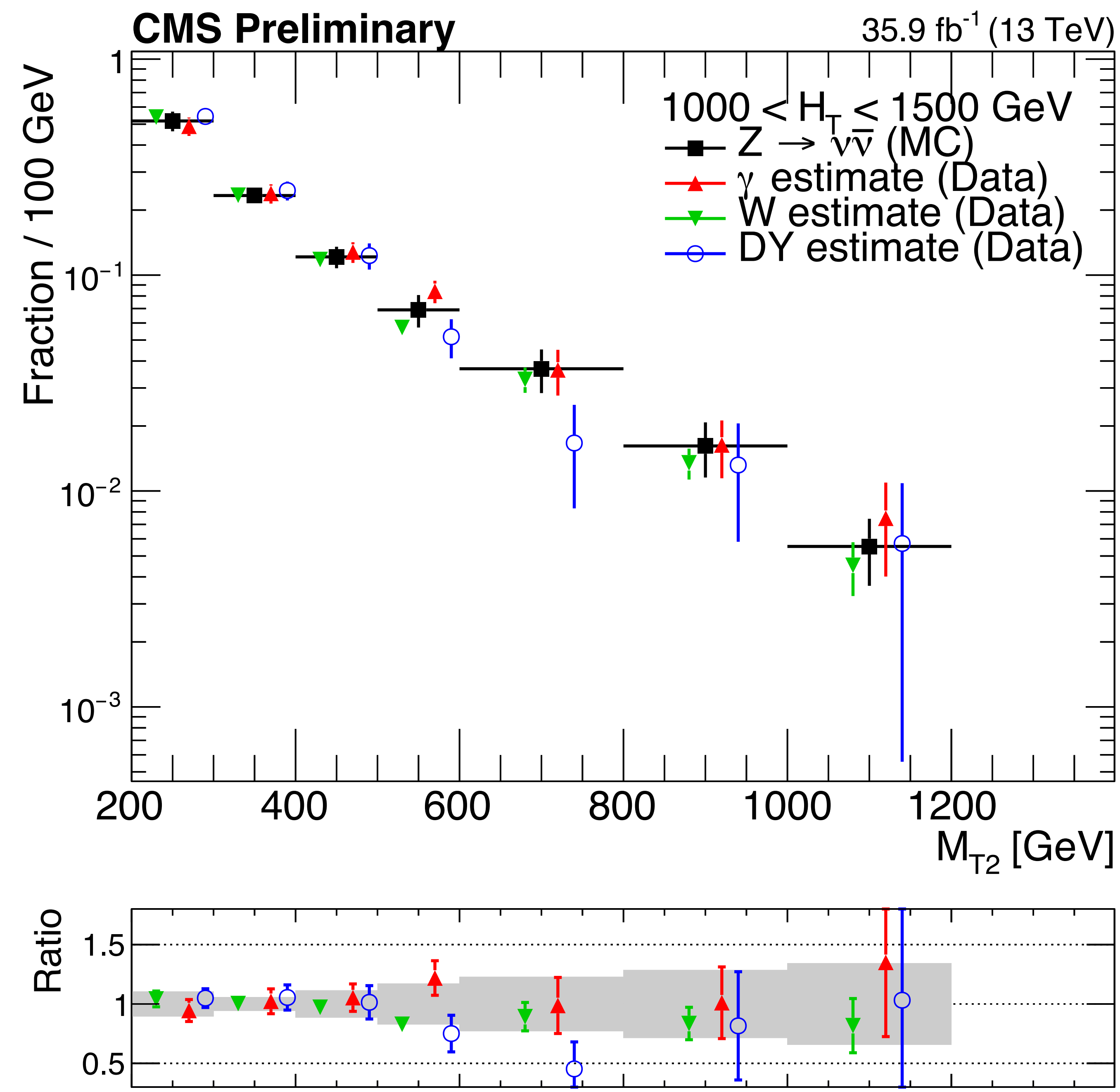
- SUS-14-015, arXiv:1602.03169
- SUS-13-019, JHEP 05 (2015) 078
- SUS-12-002, JHEP 10 (2012) 018

Run 2 results

- SUS-16-015, CMS-PAS-SUS-16-015 (2016)

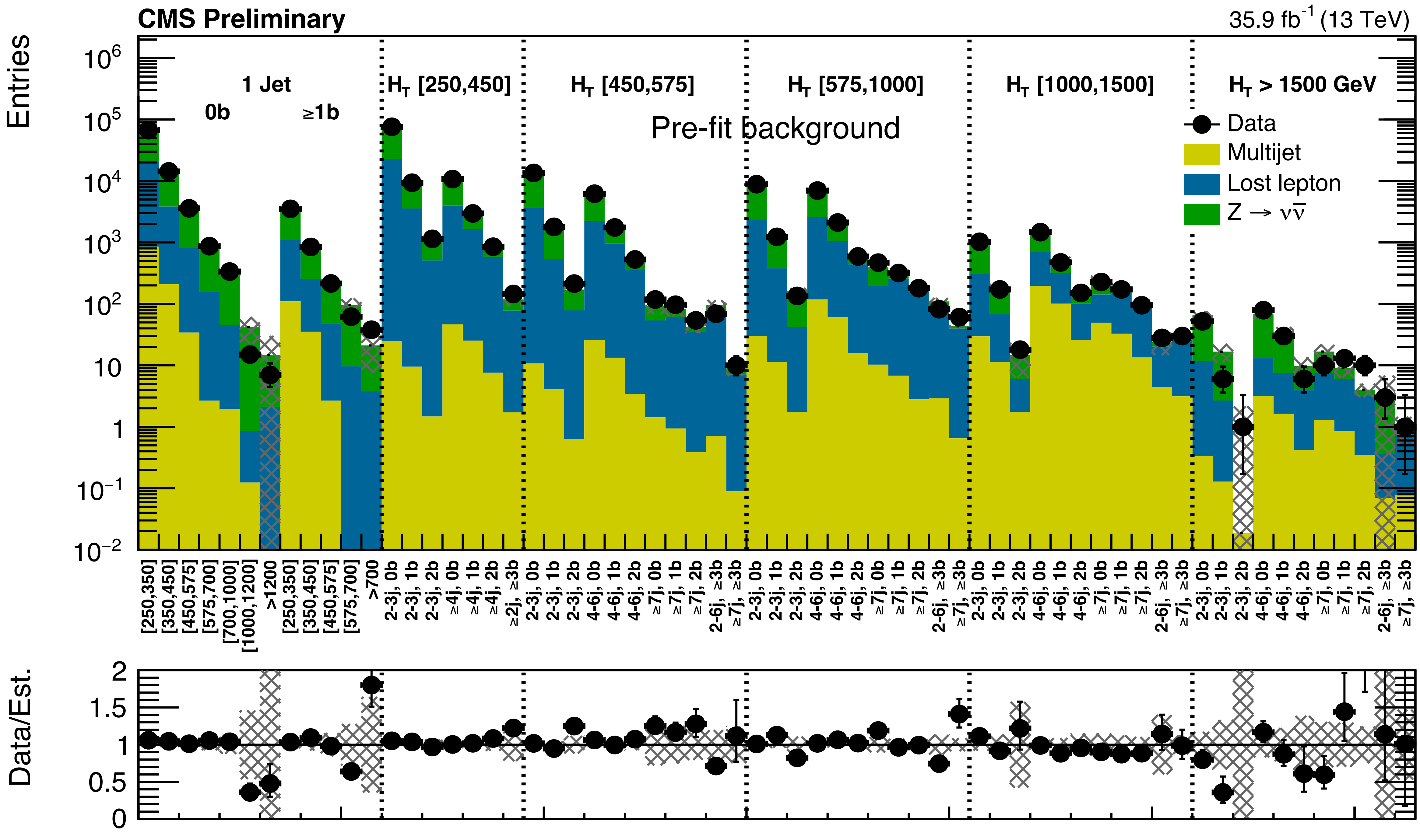
jets + M_{T2}



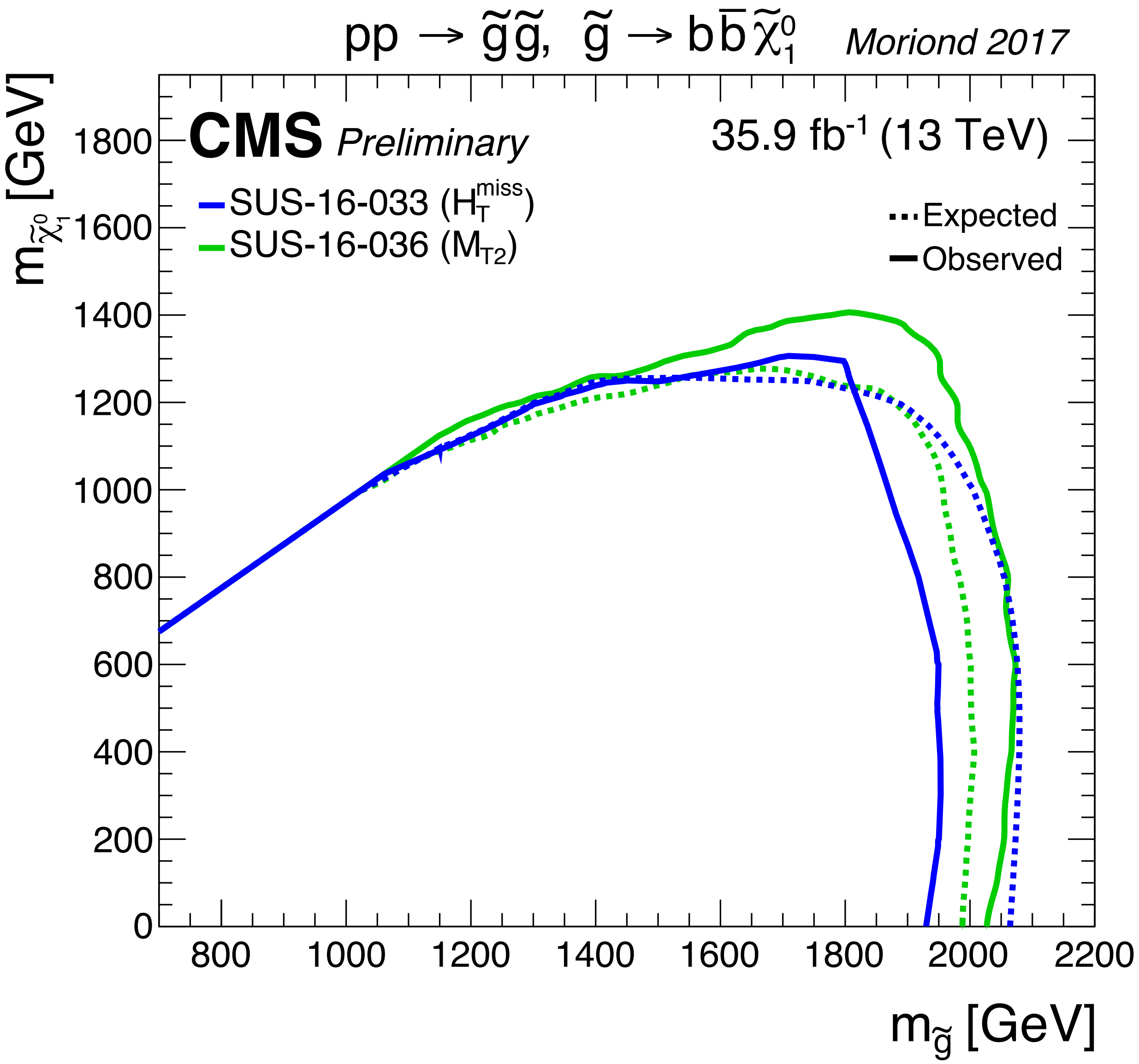


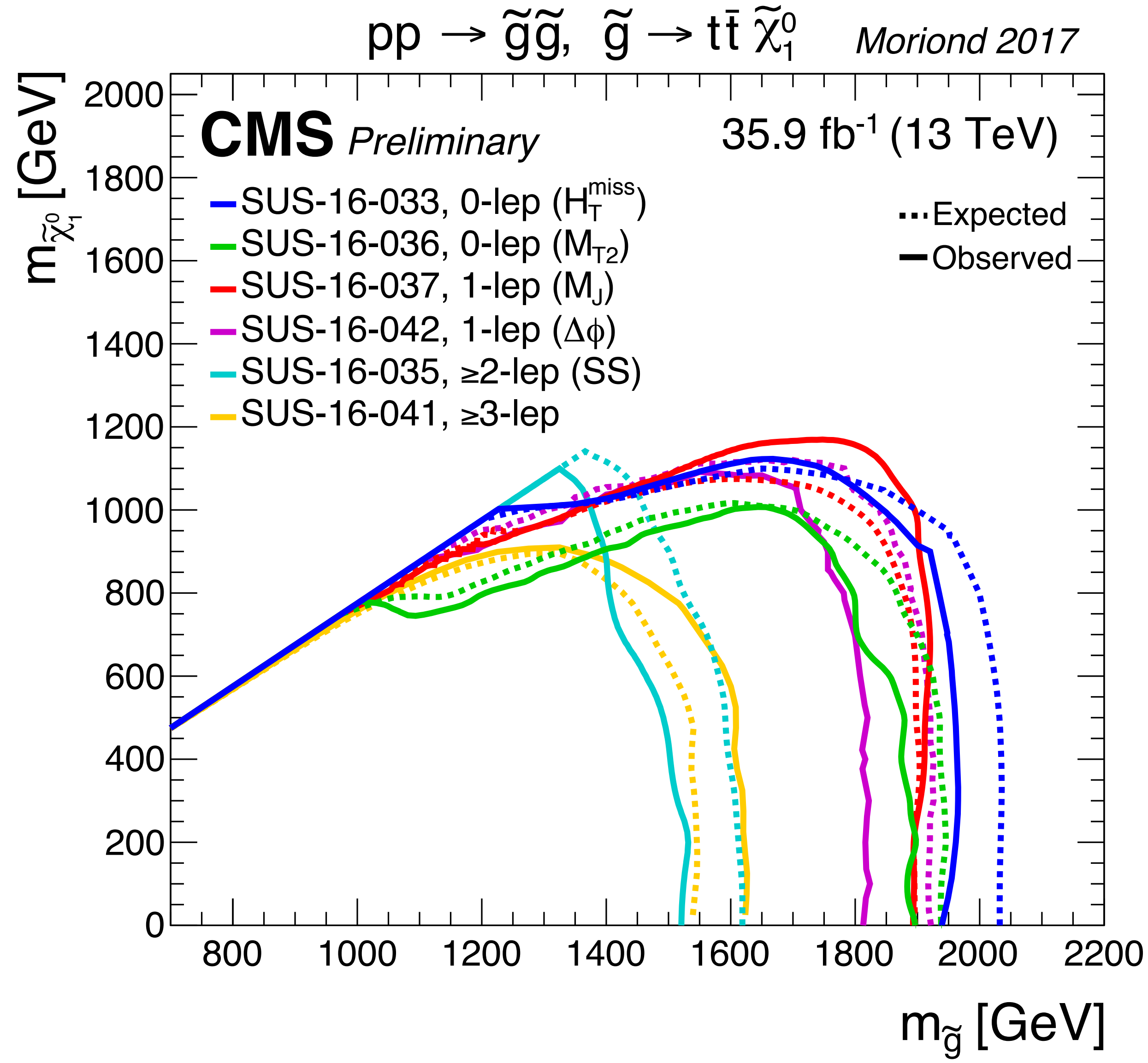
- QCD background estimation by extrapolation from $\Delta\phi_{min}$ sideband
- Extensive validation of modelling of M_{T2} variable with data in γ +jets, W → lν, Z → ll control sample

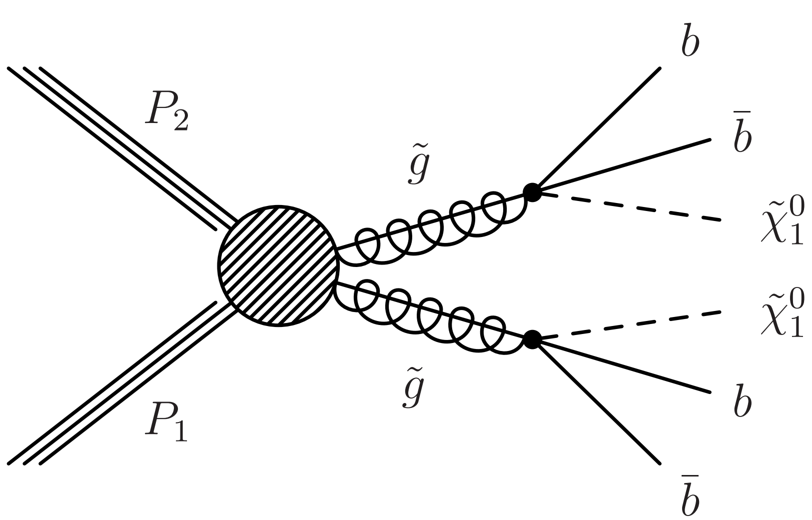
jets + M_{T2}: Result

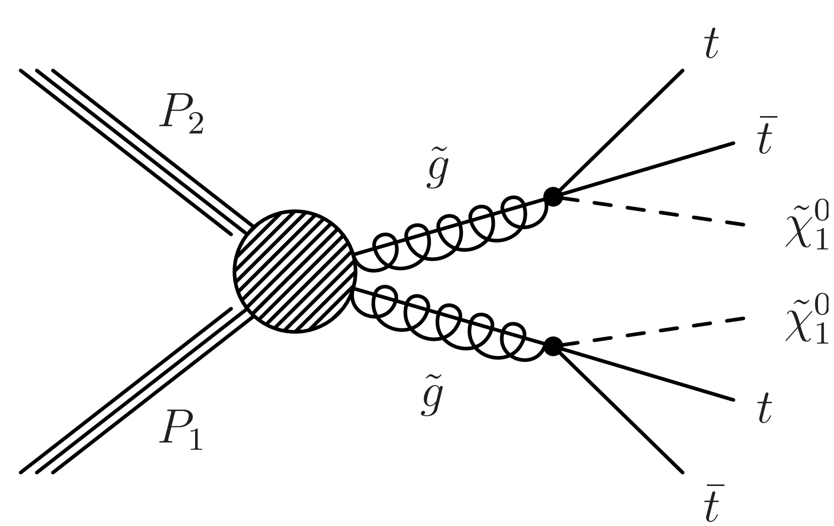


Interpretation I

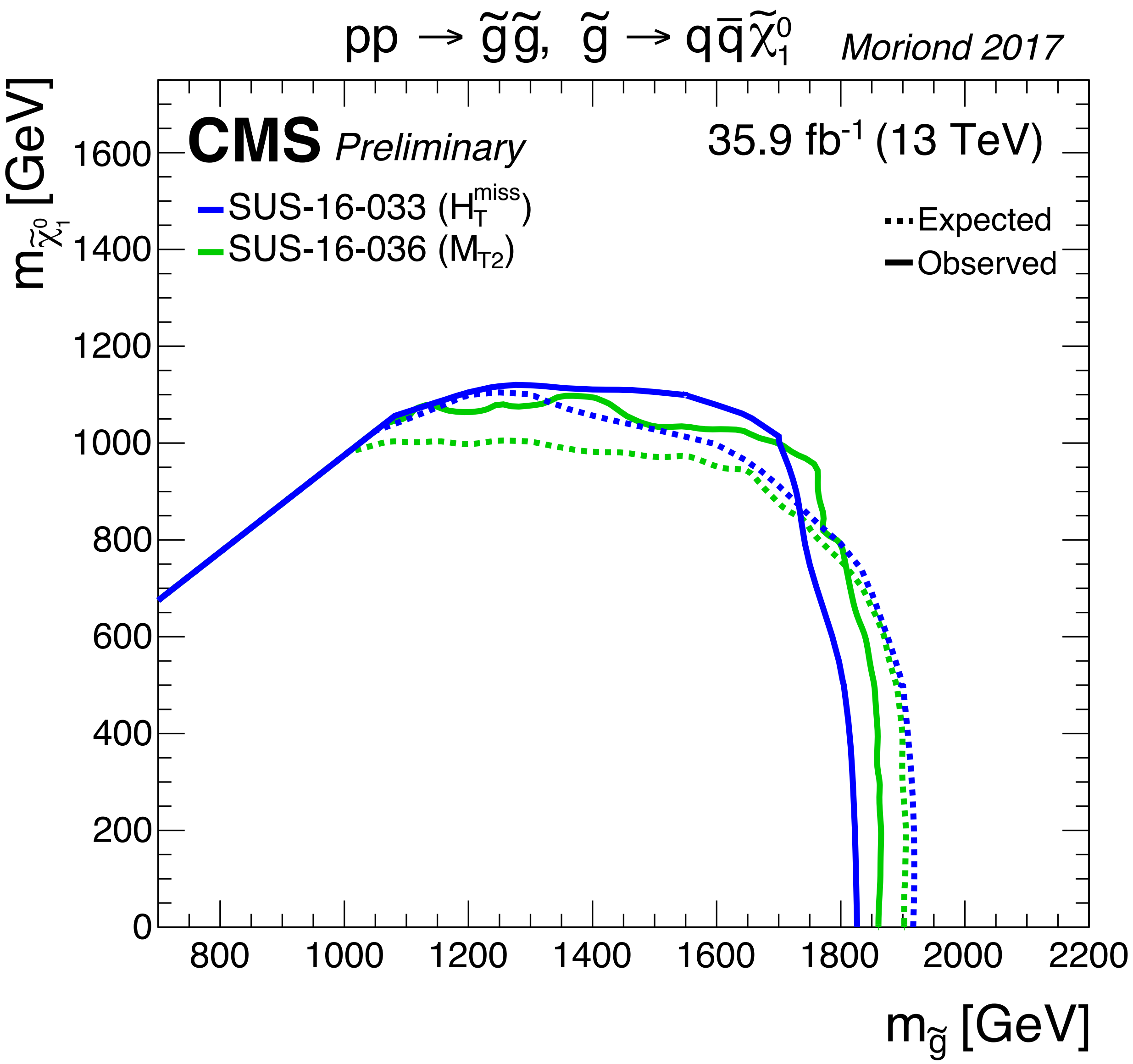


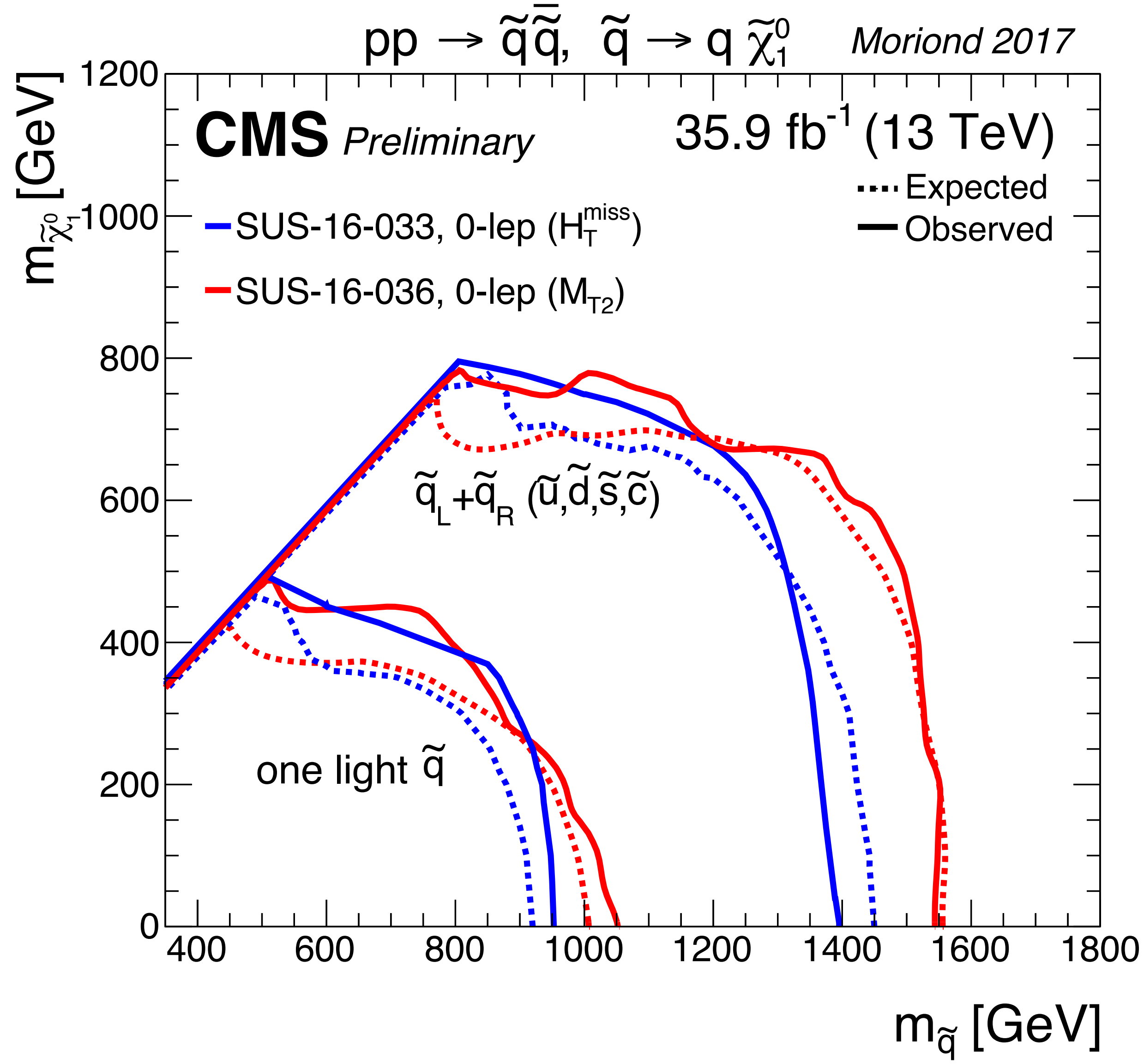


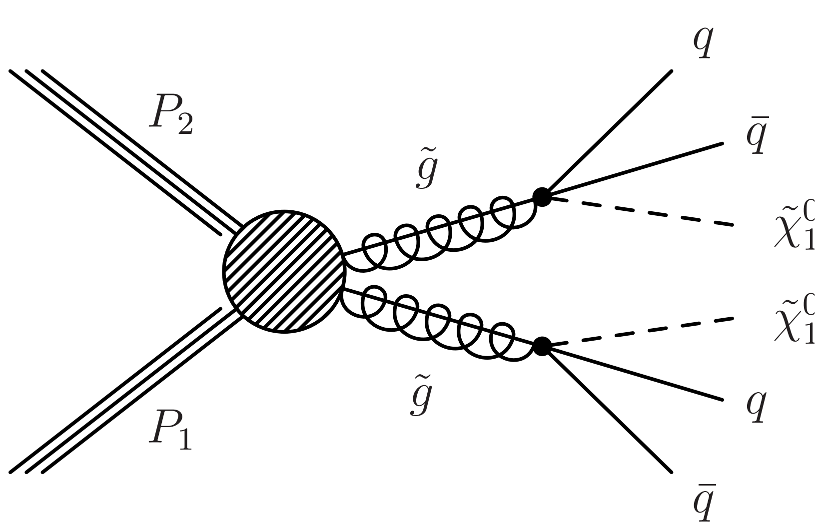


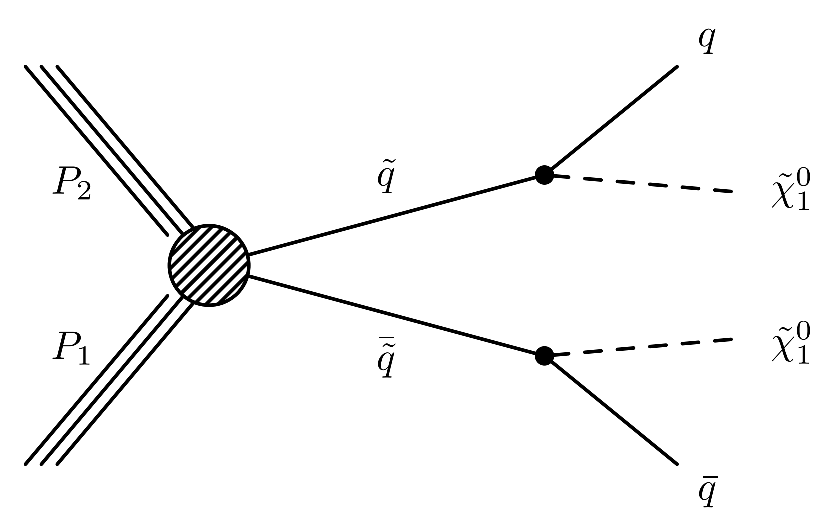


Interpretation II







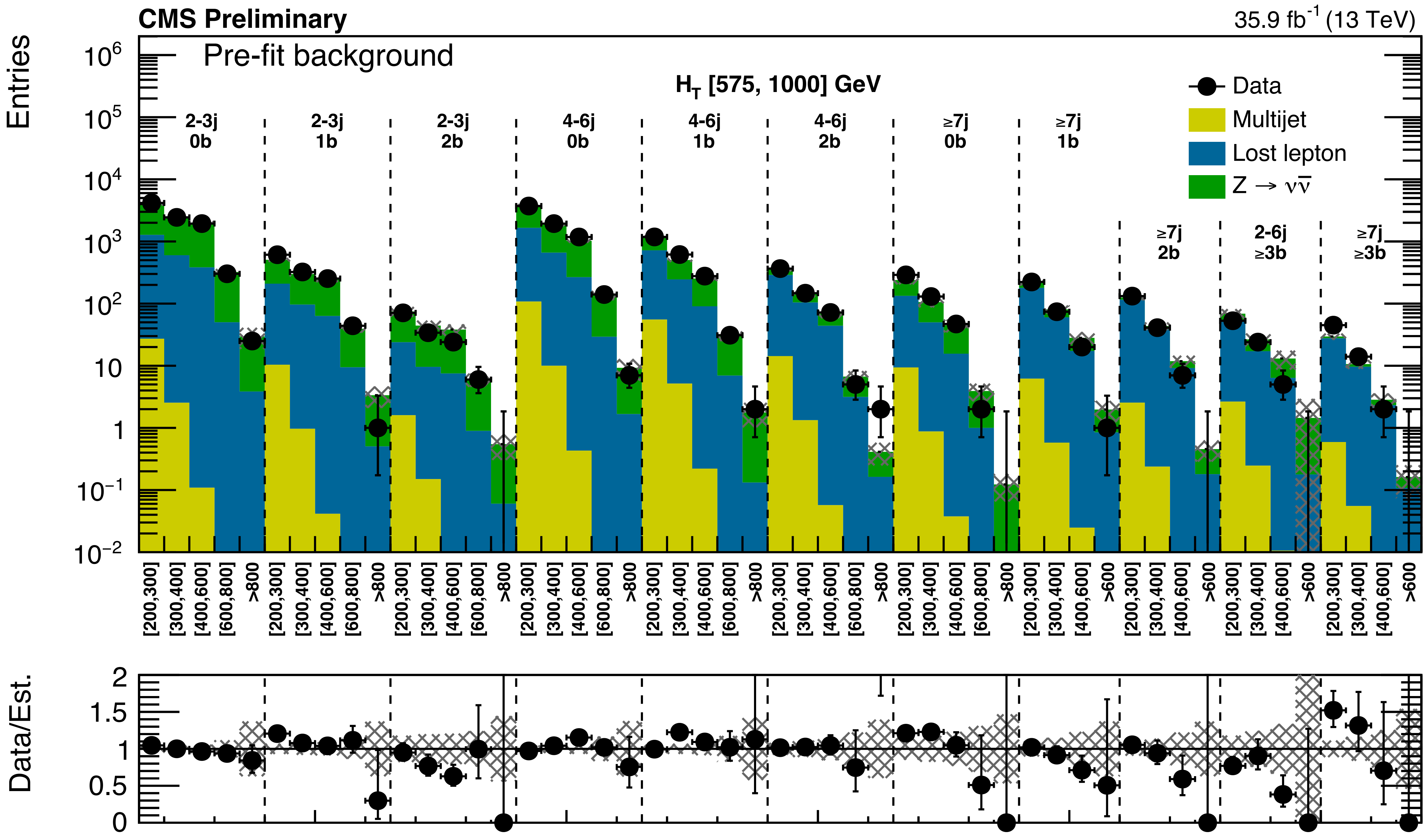


Summary

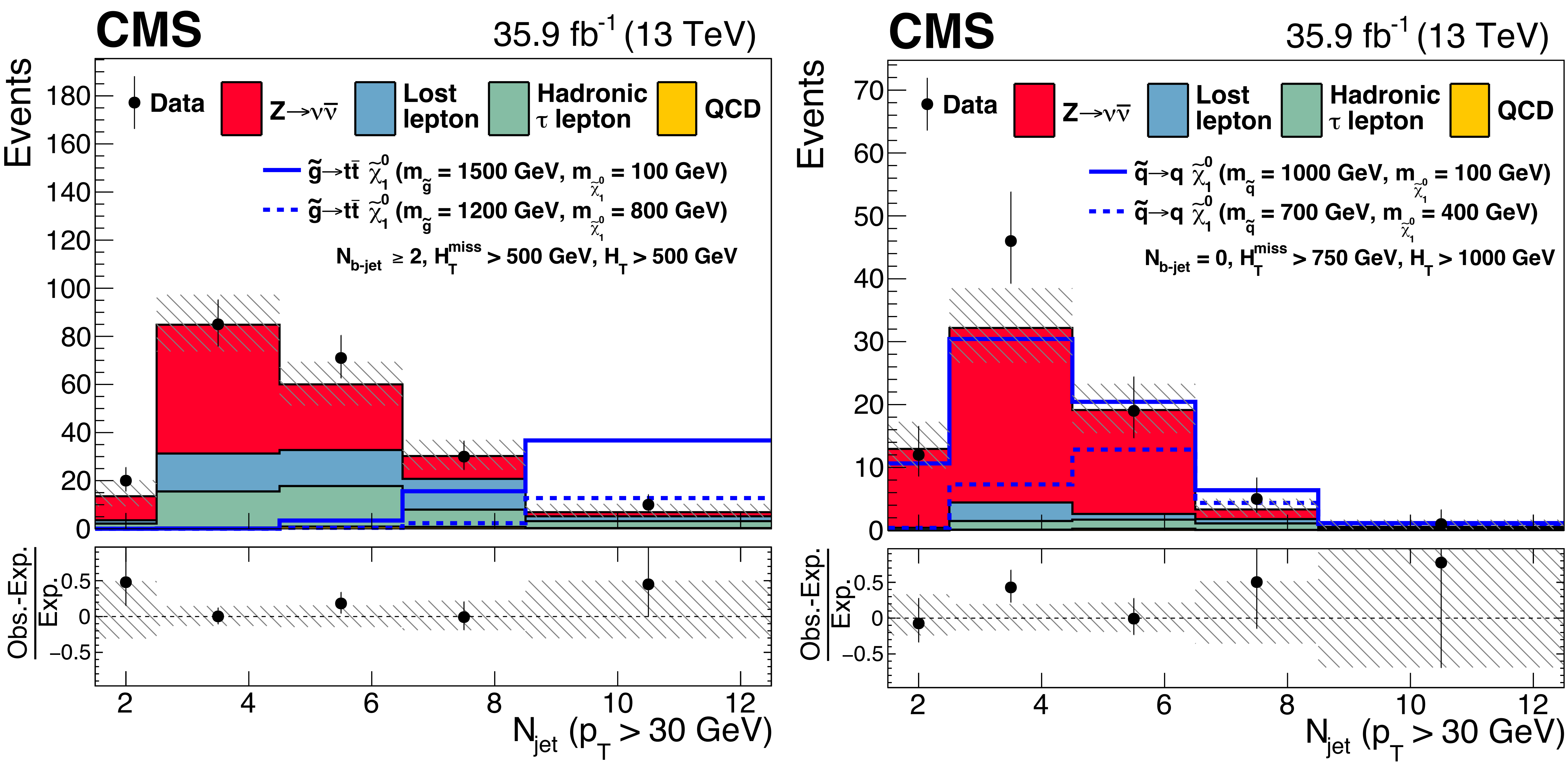
- Significant gains in limits since Run 1 for strongly produced models
- Highlighted results from two inclusive analysis with 35.9 fb^{-1} data collected by CMS
- Within framework of simplified models, exclude up to:
    - gluino masses up to ~ 2 TeV, LSP masses up to ~ 1400 GeV
    - light flavour squarks up to ~ 1500 GeV, LSP masses up to ~ 800 GeV
- More results to come in summer! Stay tuned!

Backup

jets + M_{T2}: Result II



jets+MHT: Result II



jets + M_{T2}: stranverse mass

CMS-PAS-SUS-16-036

$$M_{T2} = \min_{\vec{q}_T + \vec{r}_T = \vec{E}_T^{\text{miss}}} \left[\max\left(M_T(\vec{p}_T^{\,j_1}, M_T(\vec{q}_T), M_T(\vec{p}_T^{\,j_2}, M_T(\vec{r}_T) \right) \right]$$

$$M_T(\vec{p}_T, \vec{q}_T) = \sqrt{2(p_T q_T - \vec{p}_T \cdot \vec{q}_T)}$$

- M_{T2} defined for di-jet system
- For events with ≥ 3 jets, form two pseudo-jets to maximize their invariant mass

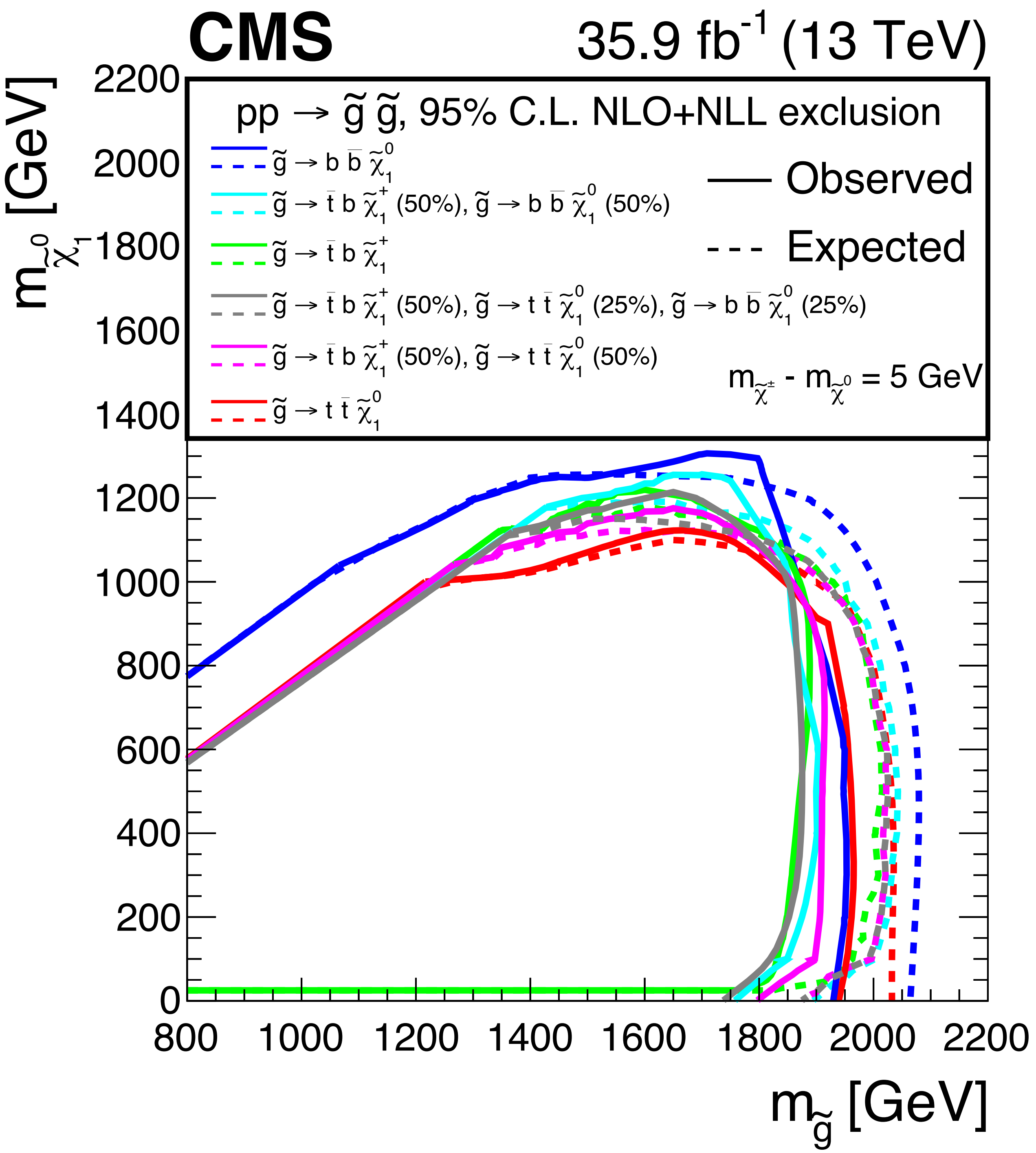
jets + M_{T2}: Binning

CMS-PAS-SUS-16-036

H_T Range [GeV]	Jet Multiplicities	M_{T2} Binning [GeV]
[250, 450]	$2-3$j, 0b	[200, 300, 400, ∞]
	$2-3$j, 1b	[200, 300, 400, ∞]
	$2-3$j, 2b	[200, 300, 400, ∞]
	≥ 4j, 0b	[200, 300, 400, ∞]
	≥ 4j, 1b	[200, 300, 400, ∞]
	≥ 4j, 2b	[200, 300, 400, ∞]
	≥ 2j, ≥ 3b	[200, 300, 400, ∞]
[450, 575]	$2-3$j, 0b	[200, 300, 400, 500, ∞]
	$2-3$j, 1b	[200, 300, 400, 500, ∞]
	$2-3$j, 2b	[200, 300, 400, 500, ∞]
	$4-6$j, 0b	[200, 300, 400, 500, ∞]
	$4-6$j, 1b	[200, 300, 400, 500, ∞]
	$4-6$j, 2b	[200, 300, 400, 500, ∞]
	≥ 7j, 0b	[200, 300, 400, ∞]
	≥ 7j, 1b	[200, 300, 400, ∞]
	≥ 7j, 2b	[200, 300, 400, ∞]
	$2-6$j, ≥ 3b	[200, 300, 400, 500, ∞]
	≥ 7j, ≥ 3b	[200, 300, 400, ∞]
[575, 1000]	$2-3$j, 0b	[200, 300, 400, 600, 800, ∞]
	$2-3$j, 1b	[200, 300, 400, 600, 800, ∞]
	$2-3$j, 2b	[200, 300, 400, 600, 800, ∞]
	$4-6$j, 0b	[200, 300, 400, 600, 800, ∞]
	$4-6$j, 1b	[200, 300, 400, 600, 800, ∞]
	$4-6$j, 2b	[200, 300, 400, 600, 800, ∞]
	≥ 7j, 0b	[200, 300, 400, 600, 800, ∞]
	≥ 7j, 1b	[200, 300, 400, 600, ∞]
	≥ 7j, 2b	[200, 300, 400, 600, ∞]
	$2-6$j, ≥ 3b	[200, 300, 400, 600, ∞]
	≥ 7j, ≥ 3b	[200, 300, 400, 600, ∞]

N_b	jet p_T binning [GeV]
0	[250,350,450,575,700,1000,1200,∞]
≥ 1	[250,350,450,575,700,∞]

jets+MHT


CMS
35.9 fb^{-1} (13 TeV)
pp → g̃ g̃, 95% C.L. NLO+NLL exclusion
g̃ → b b̄ $\tilde{\chi}^0_1$
g̃ → t̄ b $\tilde{\chi}^+_1$ (50%), g̃ → b b̄ $\tilde{\chi}^0_1$ (50%)
g̃ → t̄ b $\tilde{\chi}^+_1$
g̃ → t̄ b $\tilde{\chi}^+_1$ (50%), g̃ → t t̄ $\tilde{\chi}^0_1$ (25%), g̃ → b b̄ $\tilde{\chi}^0_1$ (25%)
g̃ → t̄ b $\tilde{\chi}^+_1$ (50%), g̃ → t t̄ $\tilde{\chi}^0_1$ (50%)
g̃ → t t̄ $\tilde{\chi}^0_1$
Observed
Expected
$m_{\tilde{\chi}^\pm} - m_{\tilde{\chi}^0}$ = 5 GeV
$m_{\tilde{\chi}^0_1}$ [GeV]
$m_{\tilde{g}}$ [GeV]
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200