Inclusive searches for squark and gluinos at CMS

The 3rd Annual Large Hadron Collider Physics Conference

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on behalf of the CMS collaboration

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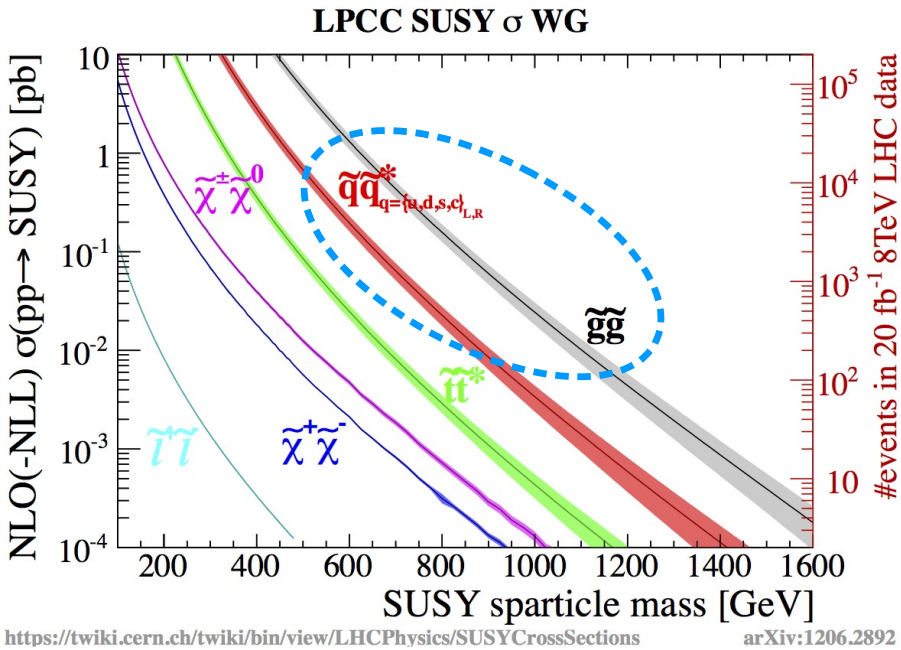
ETH zürich

Motivation

- High gluino/squark production cross-section due to strong coupling to incoming pp
- Heavy sparticles decaying to SM particles
  - Long decay chains with large visible momenta
  - Hadronic decays contributing with higher branching ratio, but leptons possible



- Under R-parity conservation, the Lightest SUSY Particle (LSP) is stable
  - Large missing momenta (E_T^{miss})
  - Natural Dark Matter candidate
- SUSY mass hierarchy unknown → inclusive searches aiming for large sensitivity to a wide variety of signatures
  - inclusive selections
  - with fine categorization of events

Outline

- Selected set of results using $\sqrt{s} = 8$ TeV

SUS-13-012	Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at $\sqrt{s} = 8$ TeV	JHEP 06 (2014) 055
SUS-12-024	Search for gluino mediated bottom- and top-squark production in multijet final states in pp collisions at 8 TeV	PLB 725 (2013) 243-270
SUS-12-028	Search for supersymmetry in hadronic final states with missing transverse energy using the variables α_T and b-quark multiplicity in pp collisions at $\sqrt{s} = 8$ TeV	EPJC 73 (2013) 2568
SUS-13-019	Searches for supersymmetry using the M_{T2} variable in hadronic events produced in pp collisions at 8 TeV	JHEP 05 (2015) 078
SUS-13-004	Search for supersymmetry using razor variables in events with b-tagged jets in pp collisions at $\sqrt{s} = 8$ TeV	PRD 91 (2015) 052018
SUS-13-007	Search for supersymmetry in pp collisions at $\sqrt{s} = 8$ TeV in events with a single lepton, large jet multiplicity, and multiple b jets	PLB 733 (2014) 328-353

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

- Selected set of commissioning plots from the first 13 TeV data

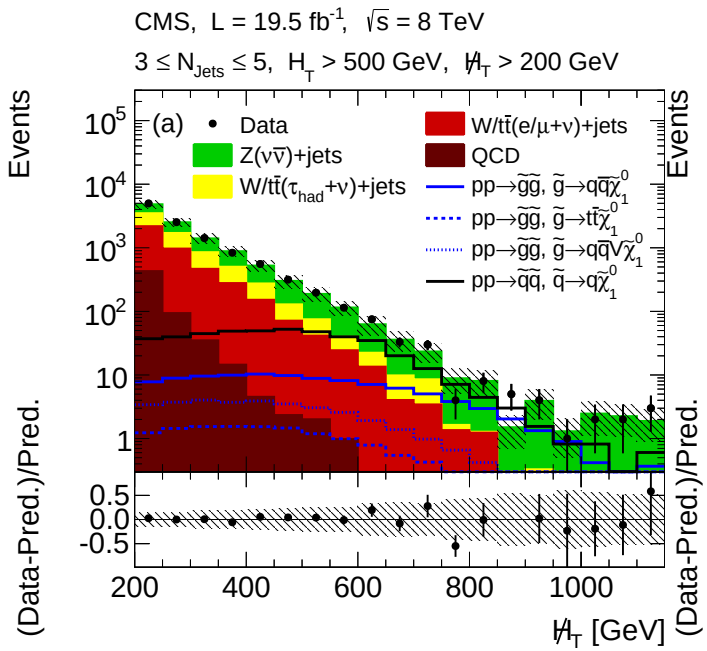
HT + MHT Search (SUS-13-012)

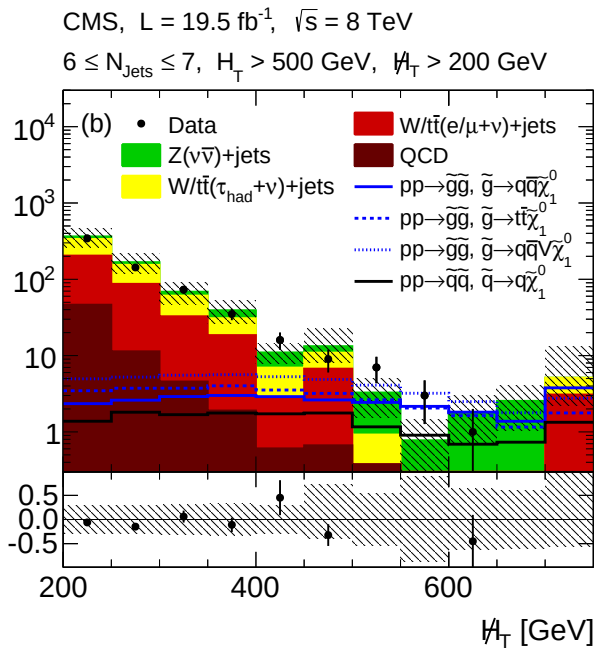
"Classical approach" based on multiple search bins in HT and MHT

- $H_T = \sum_{jets} |\vec{p}_T|$ ➠ visible energy scale
- $\not{H}_T = |-\sum_{jets} \vec{p}_T|$ ➠ invisible energy scale

SELECTION

- Trigger: HLT_HT350_MET100
- At least 3 jets, $p_T > 50$ GeV, $|\eta| < 2.5$
- $H_T > 500$ GeV
- $\not{H}_T > 200$ GeV
- Veto isolated e/μ, $p_T > 10$ GeV
- $\Delta\phi(\not{H}_T, jet) > 0.5, 0.3, 0.3$





Methods based on control data to predict bkgs:

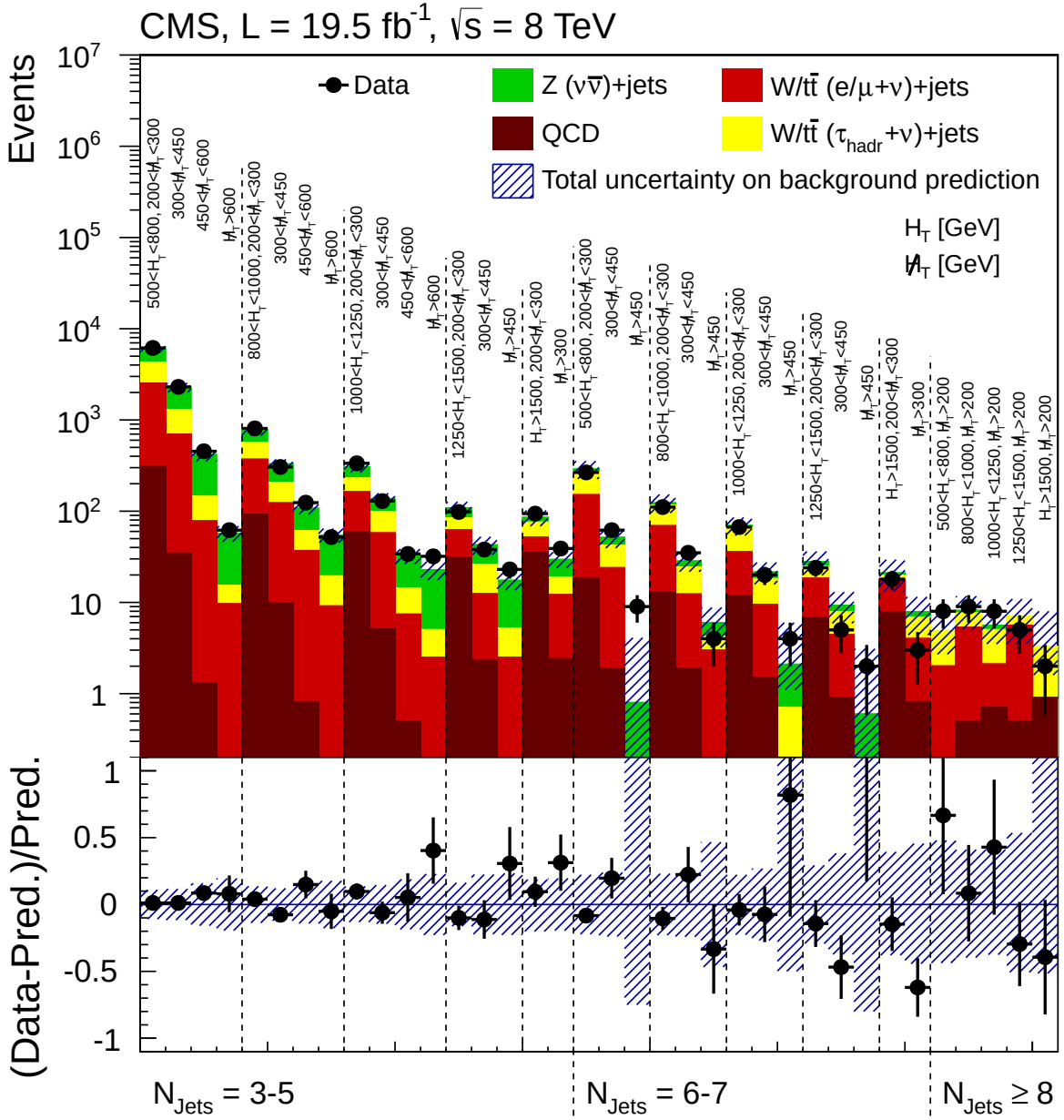
- μ+jets to estimate top and W+jets bkgs
- γ+jets to estimate irreducible $Z \to \nu\bar{\nu}$
- "rebalance and smear" method to estimate QCD multijet

HT + MHT RESULTS

36 search regions categorized in N_j, H_T and $\not{H}_T$

- N_j: 3-5, 6-7, ≥ 8
- H_T [GeV]: 500-800, 800-1000, 1000-1250, 1250-1500, >1500
- $\not{H}_T$ [GeV]: 200-300, 300-450, 450-600, >600 (merge bins at higher N_j, H_T regions)

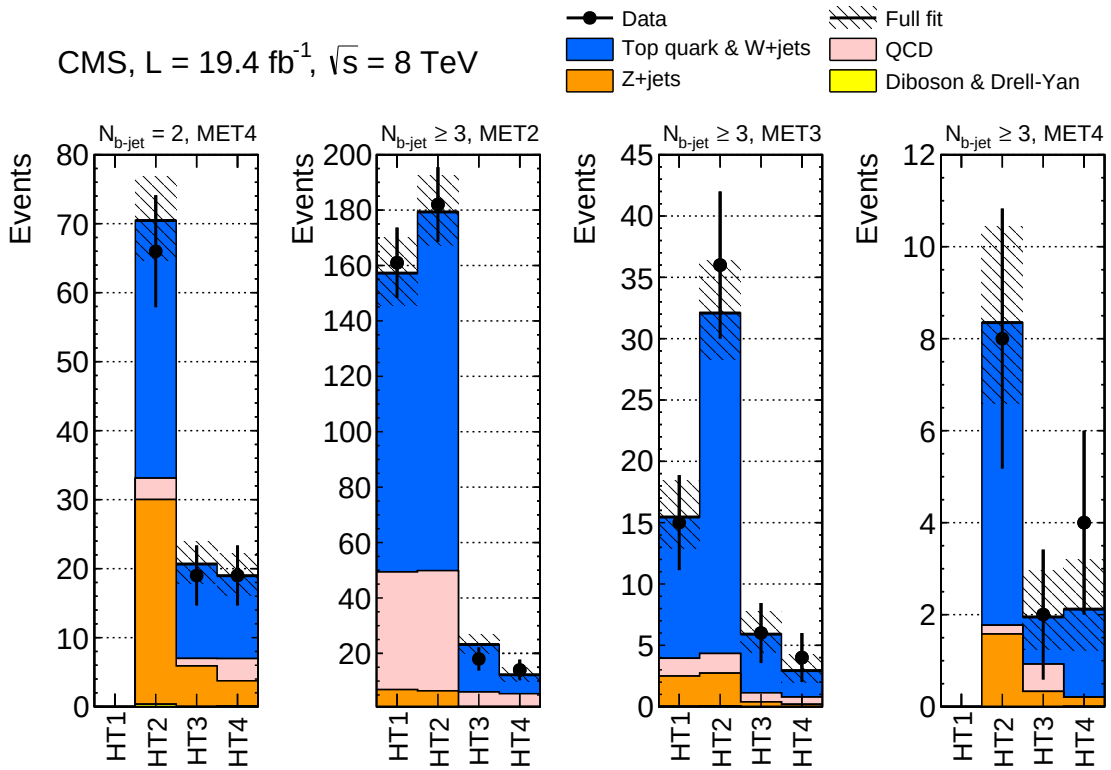
✔ Data consistent with SM background predictions



HT + MET + b-jets Search (SUS-12-024)

Similar search strategy to previous analysis using MET and b-jets

- ≥ 3 jets, $p_T > 50$ GeV, two leading with $p_T > 70$ GeV
- $H_T > 400$ GeV
- $E_T^{\text{miss}} > 125$ GeV
- no electron, muon, isolated charged-particle track, $p_T > 10, 10, 15$ GeV
- at least one b-tagged jet, $p_T > 50$ GeV,
- normalized $\Delta\hat{\phi}_{\text{min}} > 4.0$



- Data control regions to predict backgrounds:
  - single lepton control sample to estimate top and W+jets bkgs
  - $Z \to e^+e^-(\mu^+\mu^-)$ control sample to estimate $Z \to \nu\bar{\nu}$
  - low $\Delta\hat{\phi}_{\text{min}}$ control sample to estimate QCD
- Categorize search regions in N_b, H_T, E_T^{miss}

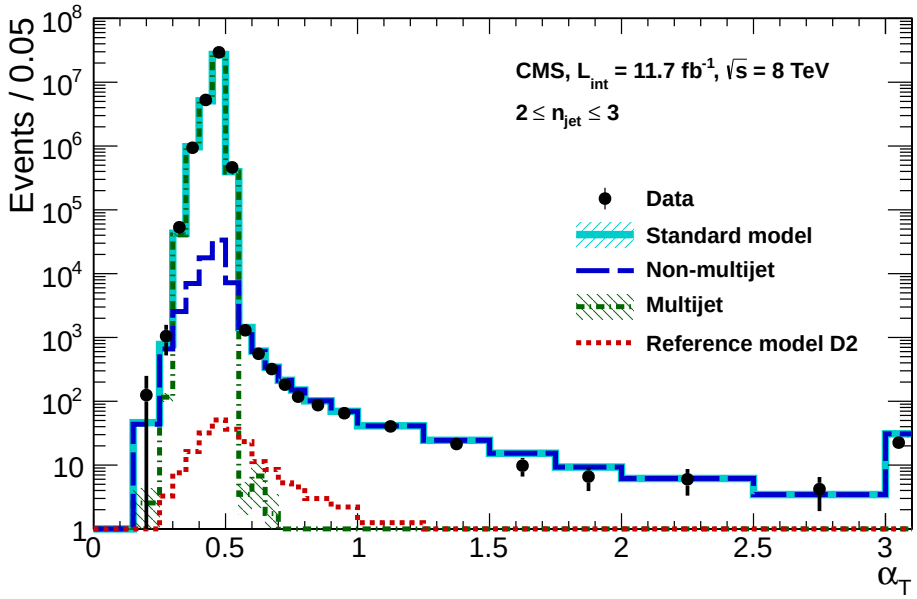
Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)

α_T Search (SUS-12-028)

α_T variable designed for a strong suppression of QCD

$$\alpha_T = \frac{E_T^{j2}}{M_T^{dijet}} = \frac{1}{2} \times \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}}$$

- perfectly balance dijet system $\alpha_T = 0.5$
- imbalanced back-to-back configuration $\alpha_T < 0.5$
- for multi-jet events, jets are merged into two pseudo-jets



SELECTION

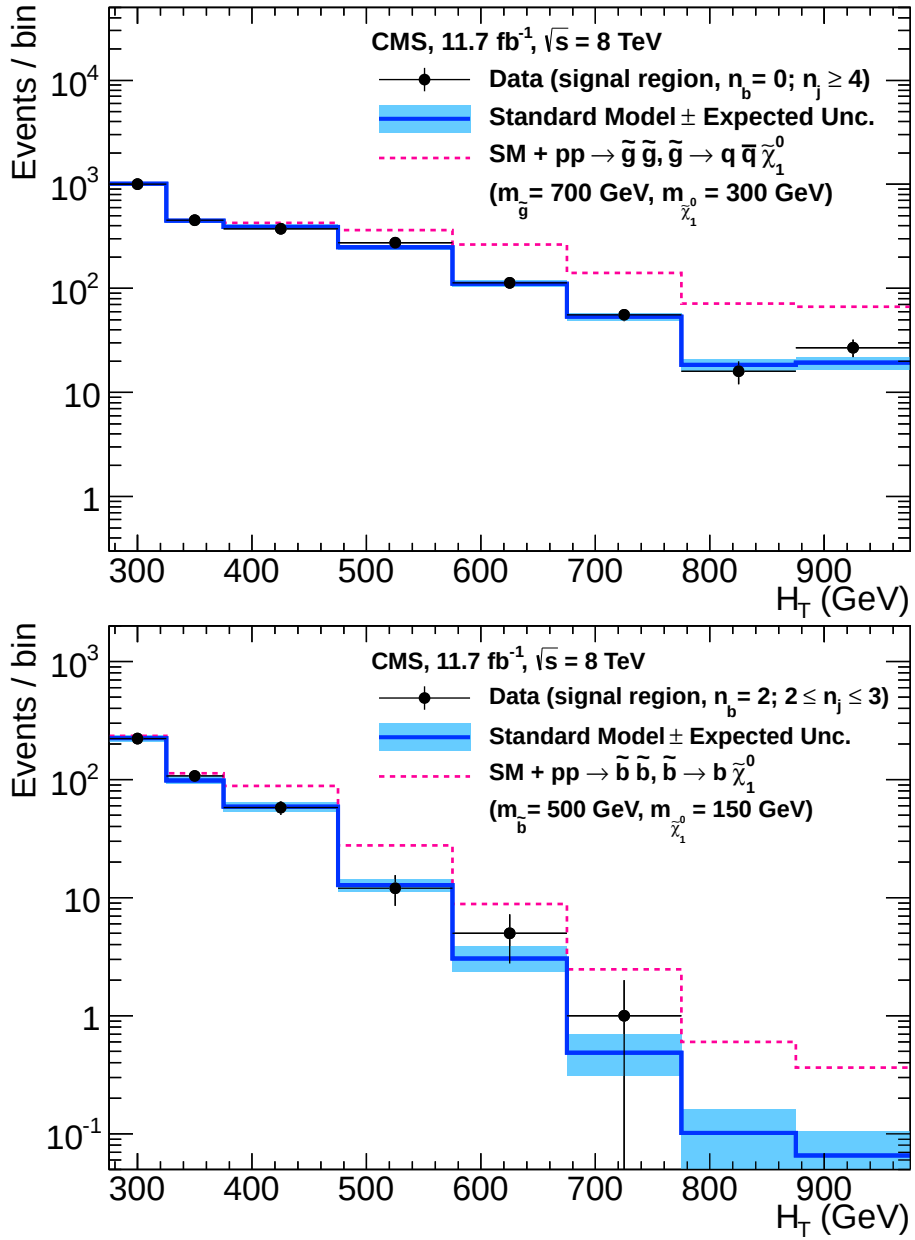
- Trigger: H_T-α_T dedicated triggers
- At least 2 jets with $p_T > 100$ GeV, $|\eta| < 3.0$
- $H_T > 275$ GeV
- $\alpha_T > 0.55$
- Veto isolated electron/muon (photon) with $p_T > 10(25)$ GeV

- Signal regions categorized in bins of N_j, N_b and H_T
  - jet multiplicity: 2-3, ≥ 4
  - b-tag: 0, 1, 2, 3, ≥ 4 b-jets
  - HT bins: 275-325-375-475-575-675-775-875-

α_T Results

- Backgrounds estimated with transfer factors using data control regions:
  - μ + jets
  - $Z \to \mu\mu$ + jets
  - γ + jets

✔ Data consistent with SM background predictions

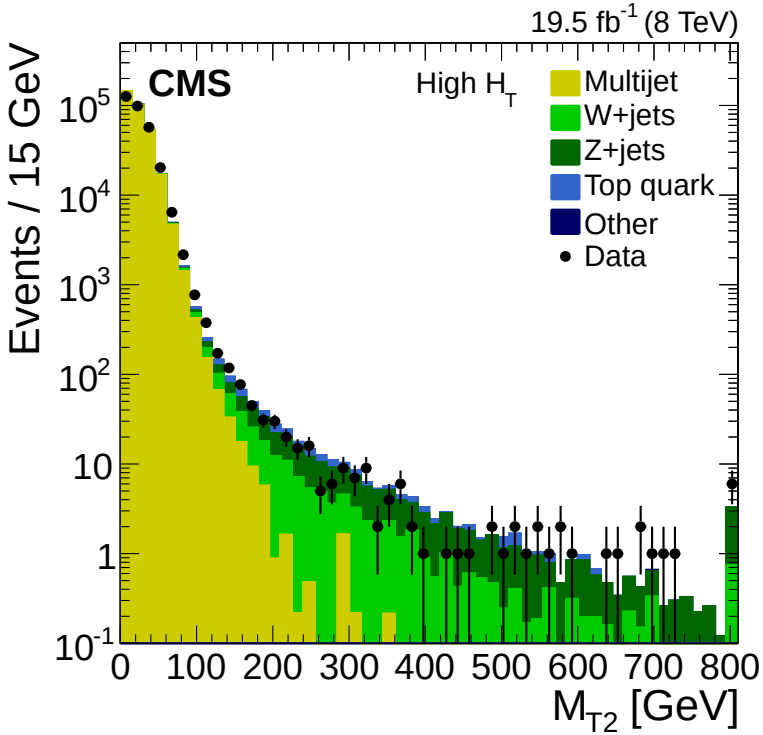


M_{T2} Search (SUS-13-019)

- M_{T2} is a generalization of the transverse mass for decay chains with two unobserved particles

$$M_{T2} = \min_{p_T^{\chi(1)}+p_T^{\chi(2)}=p_T^{\text{miss}}} \left[\max\left(m_T^{vis(1)}, m_T^{vis(2)}\right)\right]$$

- multijet events divided into 2 pseudo-jets associated to two visible systems
- M_{T2} sensitive to genuine E_T^{miss}
- QCD highly suppressed by M_{T2}



Selection

- Triggers: H_T-only and H_T+E_T^{miss}
- ≥ 2 jets, $p_T > 40$ GeV, $|\eta| < 2.4$
- $H_T > 450$ GeV
- $M_{T2} > 100 - 200$ GeV
- veto e/μ/τ, $p_T > 10, 10, 20$ GeV
- $\Delta\phi_{min}(\not{E}_T, jet_{1,2,3,4}) > 0.3$, jet $|\eta| < 5.0$

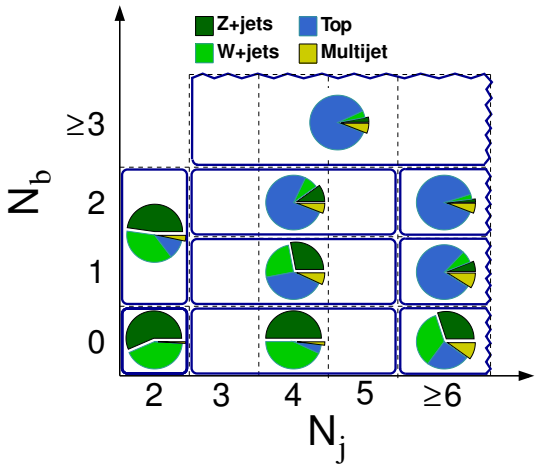
- Backgrounds estimated from data control regions
  - e/μ/*tau*+jets to estimate top and W+jets bkgs
  - γ+jets to estimate irreducible $Z \to \nu\bar{\nu}$
  - low $\Delta\phi_{min}$ to estimate QCD multijet

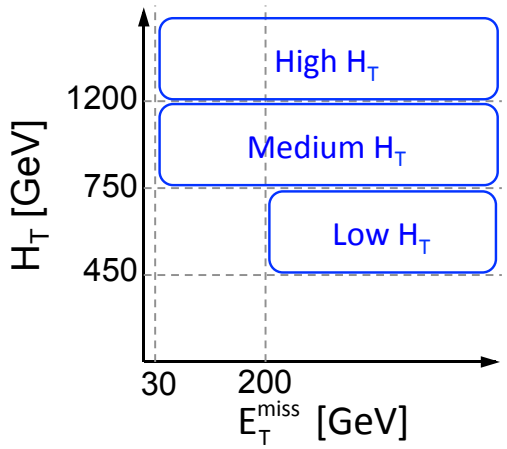
✻ Bonus: optimized search and interpretation for Higgs in SUSY cascades

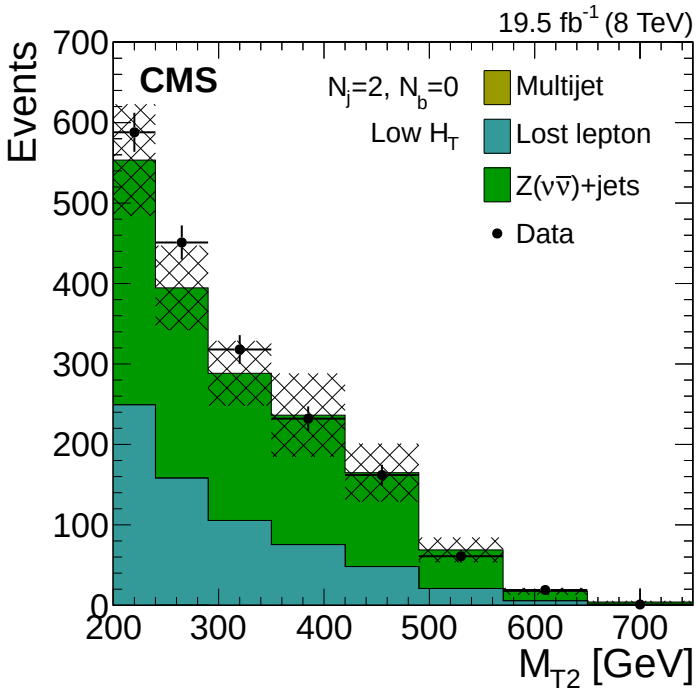
M_{T2} RESULTS

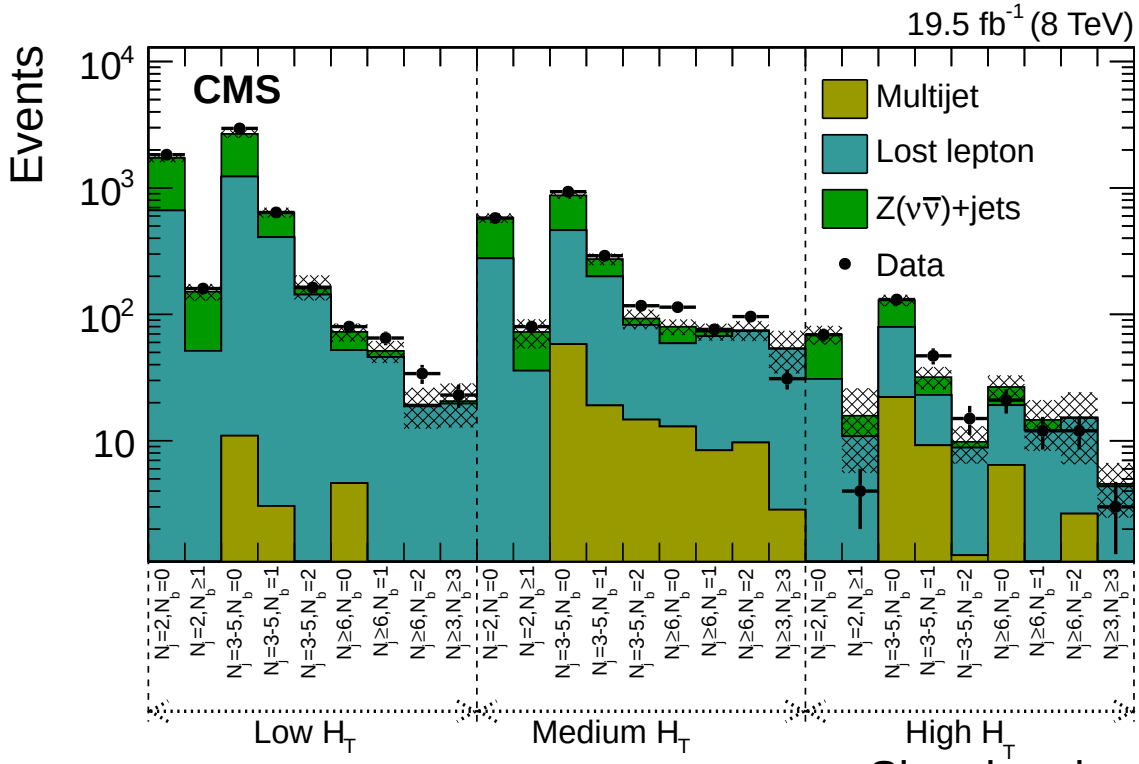
- Search regions categorized in bins of N_j, N_b, H_T, M_{T2}

✔ Data consistent with SM background predictions









Razor Search (SUS-13-004)

- Razor variables computed from pseudo-jets assuming pair-produced new physics

$$M_R \equiv \sqrt{(E_{j_1} + E_{j_2})^2 - (p_z^{j_1} + p_z^{j_2})^2}$$

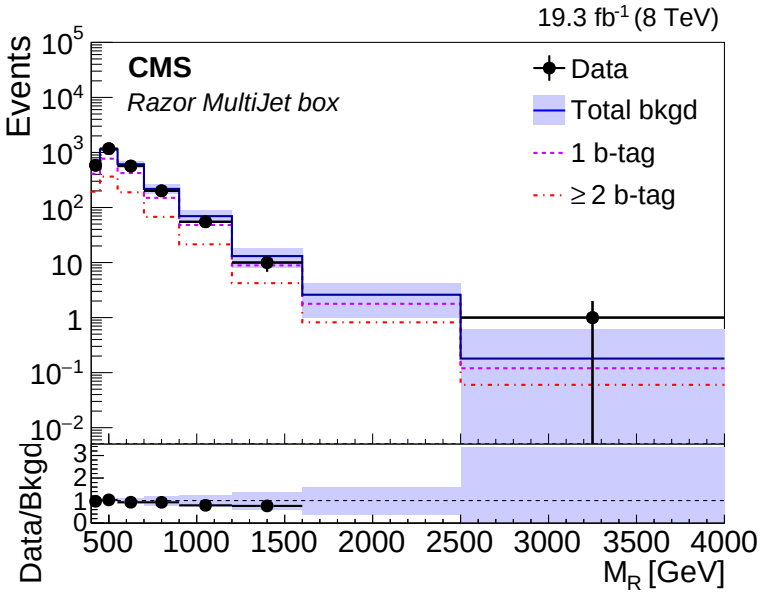
$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{miss} \cdot (\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$

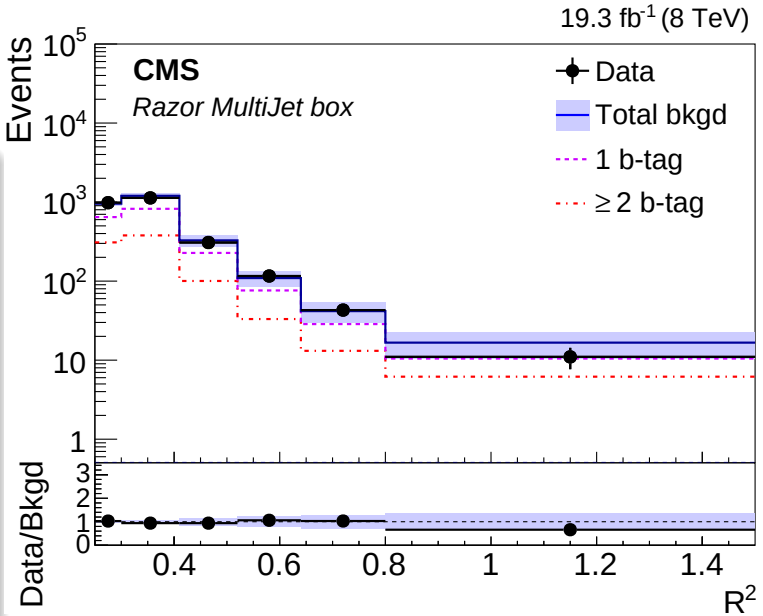
$$R \equiv \frac{M_T^R}{M_R}$$

- R^2: invisible energy scale
- M_R: mass scale, peaks at $\frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}$
- 2d analytical shape is fit in bkg-enriched sideband and extrapolated to signal region

Selection

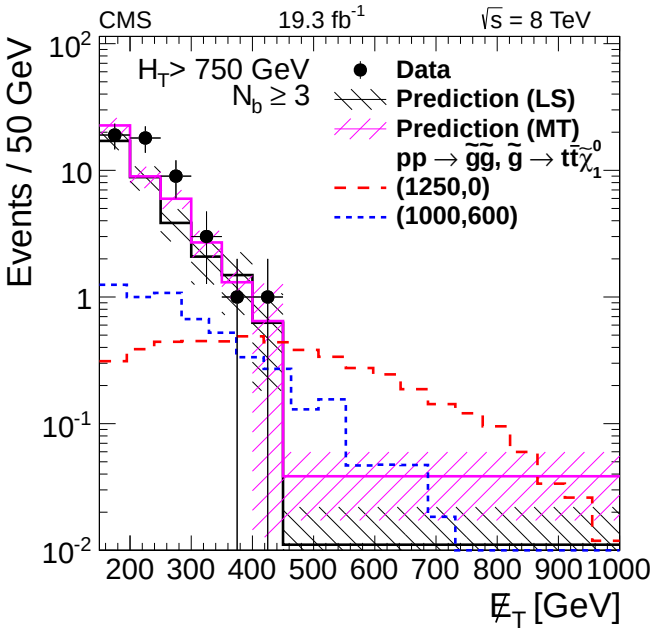
- Trigger: Razor-specific triggers
- At least 2 jets with $p_T > 80$ GeV, $|\eta| < 2.4$
- At least 1 b-tagged jet
- M_R/R^2 (>300-400GeV/0.15-0.25) driven by trigger
- Categorize events in orthogonal "boxes" based on jet and b-jet multiplicities, and lepton content

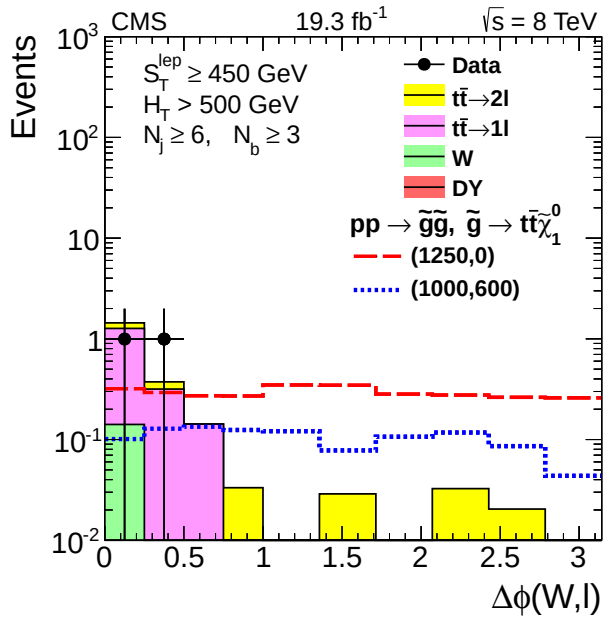




SINGLE LEPTON SEARCH (SUS-13-007)

- Gluino decaying to 3rd generation squark has high probability to contain leptons and b-quarks
- Selection
  - Trigger: lepton15+HT350+MET45
  - One isolated electron/muon, $p_T > 25$ GeV, $|\eta| < 2.5/2.4$
  - $H_T > 400$ GeV
  - $N_j \geq 6$, $N_b \geq 2$
- Two complementary search approaches
  1. $\not{E}_T + H_T$ search
     - Two background estimation techniques: lepton spectrum (LS) and $\not{E}_T$ template (MS)
  2. $S_T^{\text{lep}} + \Delta\phi(W, \ell)$ search
     - S_T^{lep}: scalar sum of $\not{E}_T$ and lepton p_T
     - $\Delta\phi(W, \ell)$: azimuthal angle between W and lepton. Highly suppresses top bkg

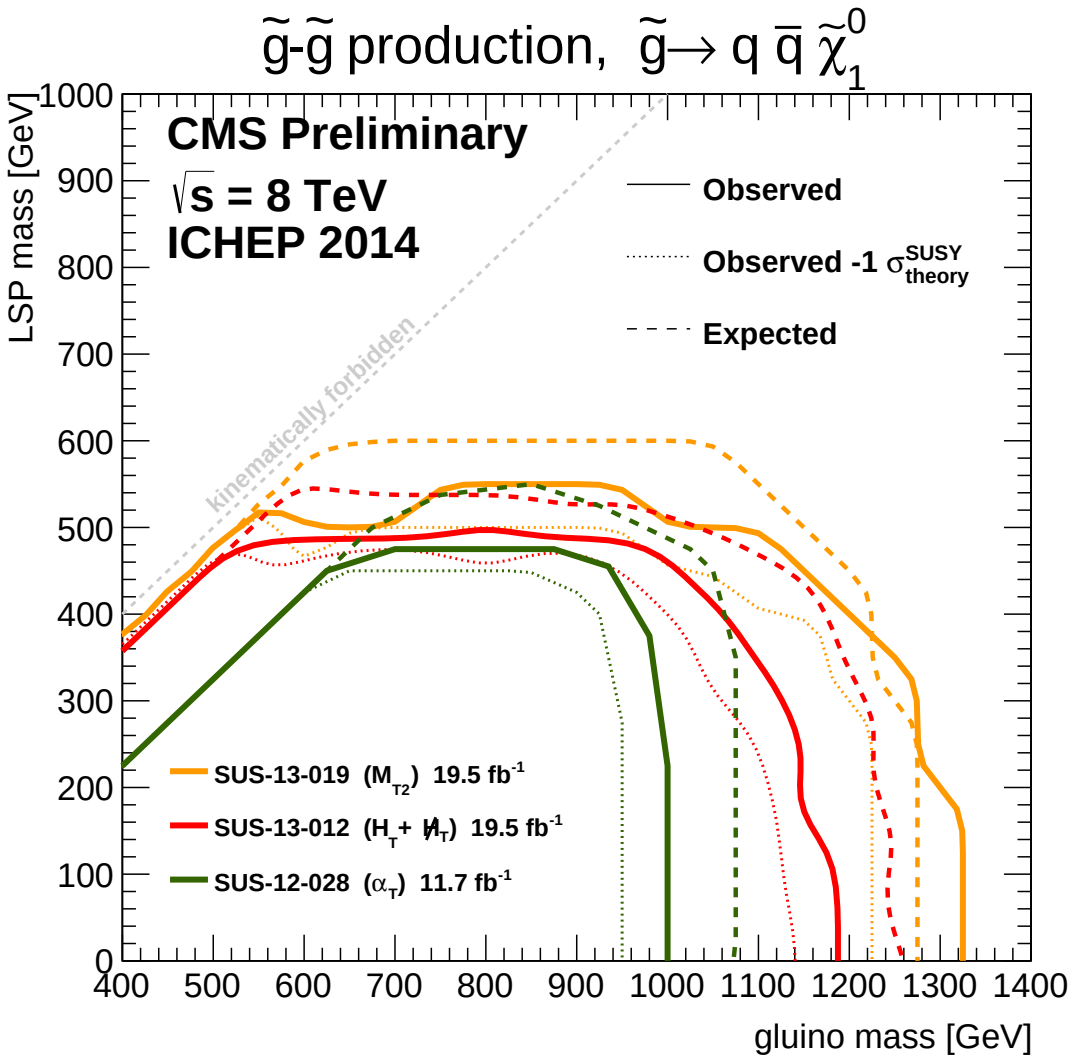


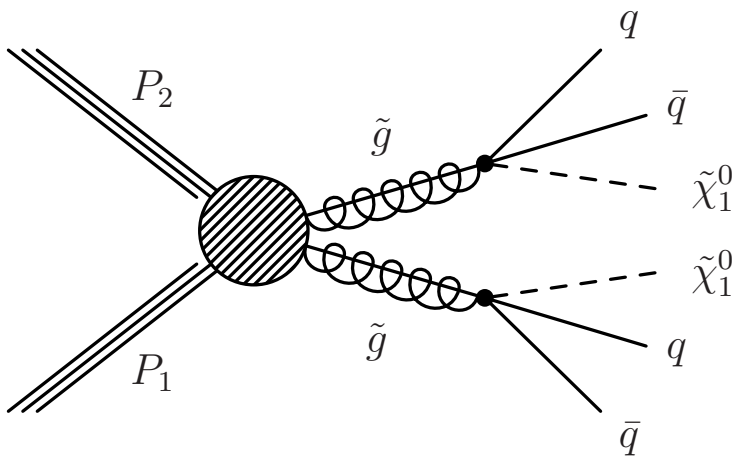


Interpretation

- Interpretation of the results in
  1. Simplified Model Spectra
  2. cMSSM/mSUGRA plane

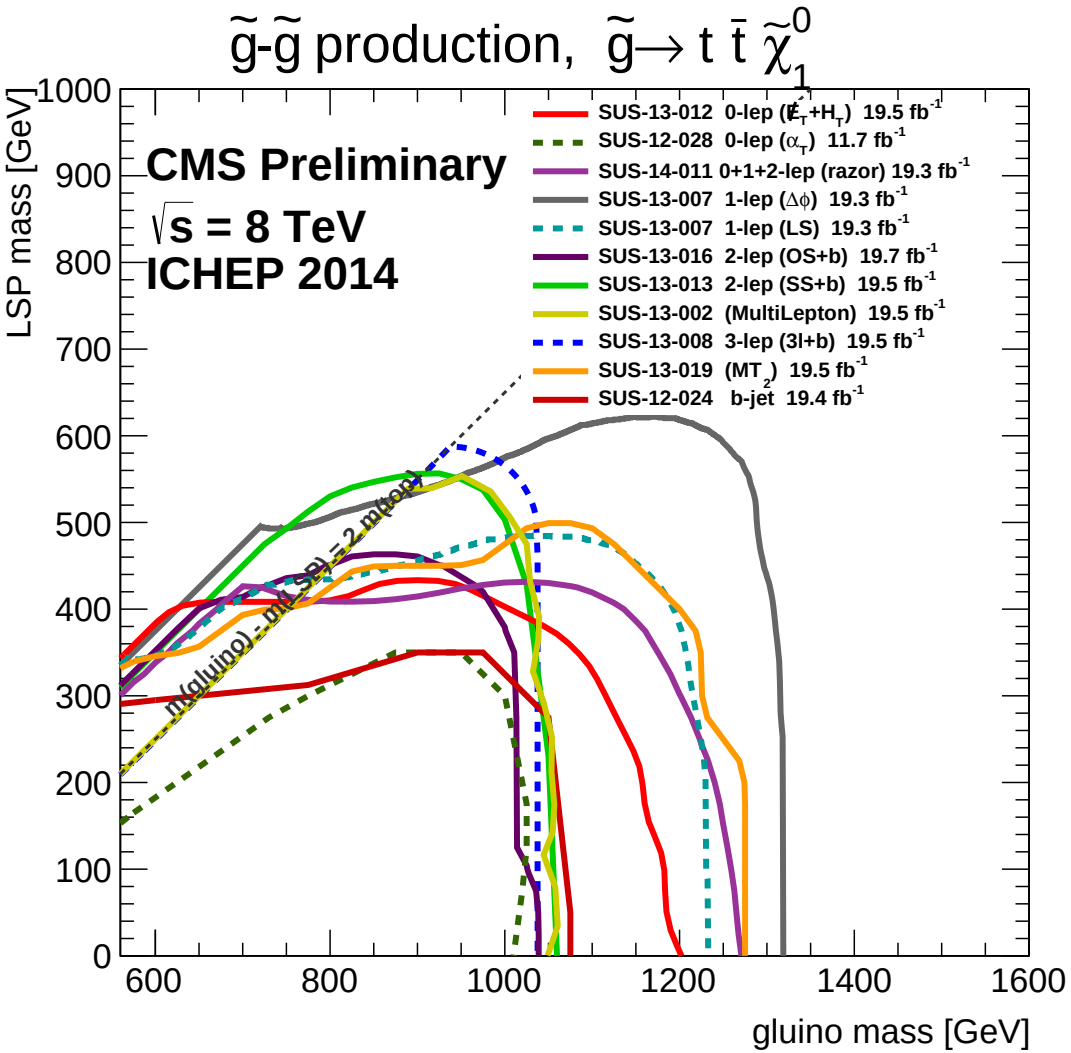
Gluino production

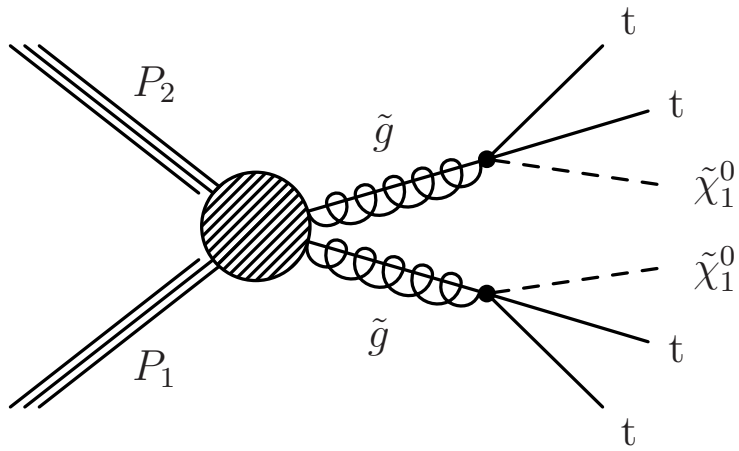




- Gluino pair production
- Probe gluino masses up to $\sim$1.3 TeV

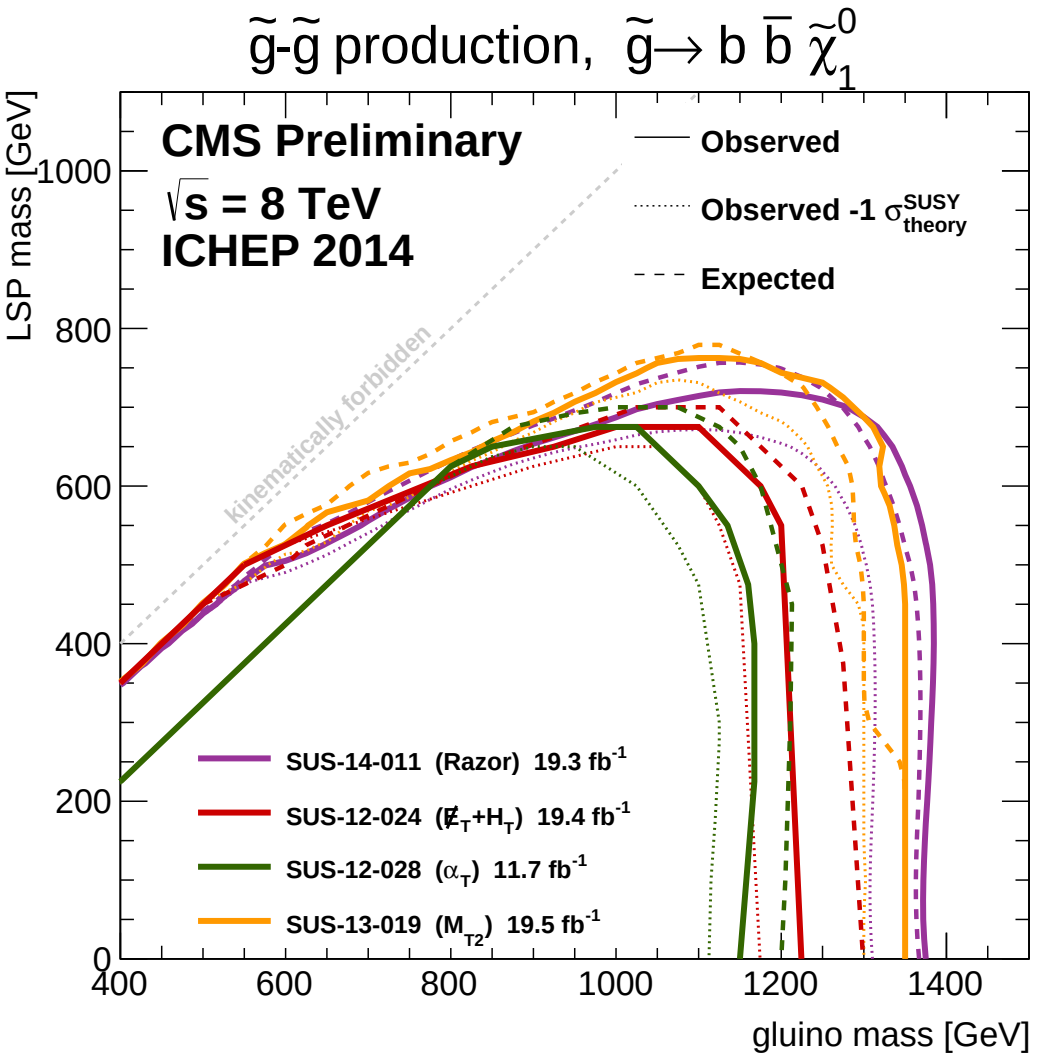
GLUINO PRODUCTION

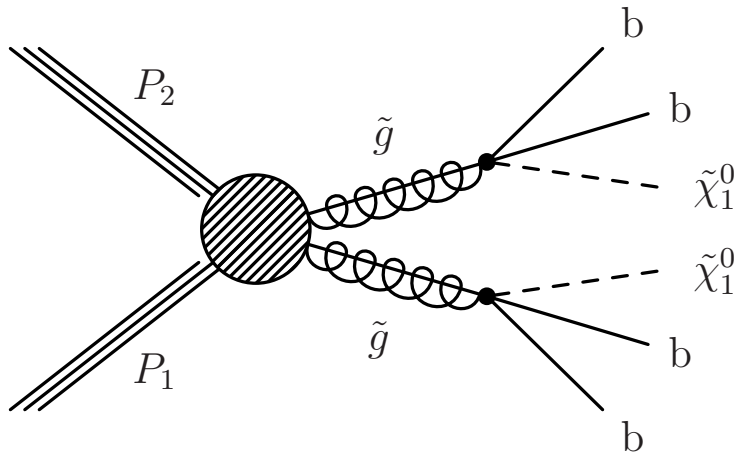




- Gluino mediated stop production
- Most stringent limits from single lepton analysis
- Probe gluino masses up to $\sim$1.3 TeV

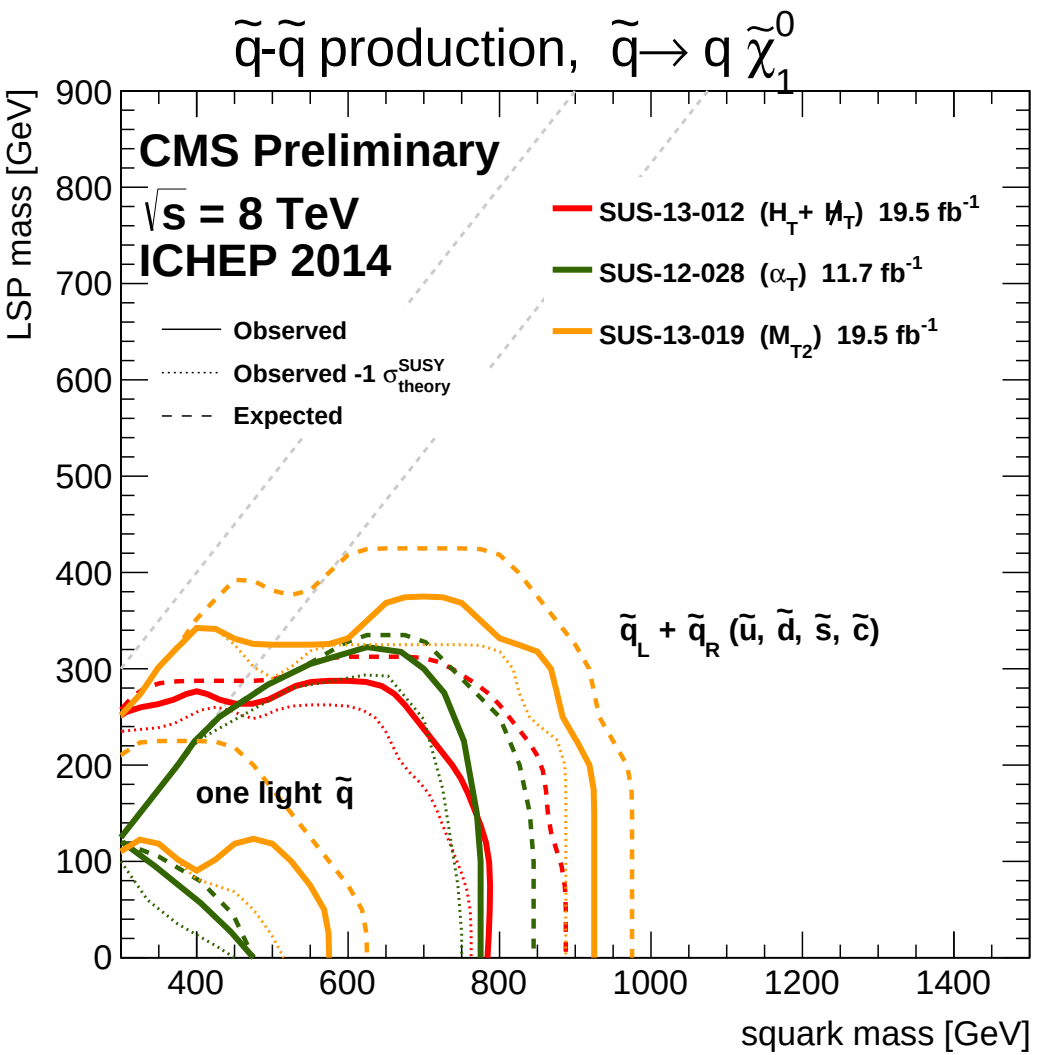
GLUINO PRODUCTION

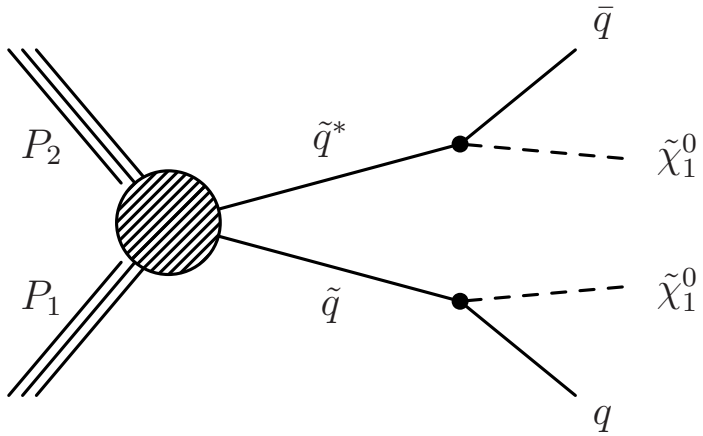




- Gluino mediated sbottom production
- Probe gluino masses up to $\sim$1.35 TeV

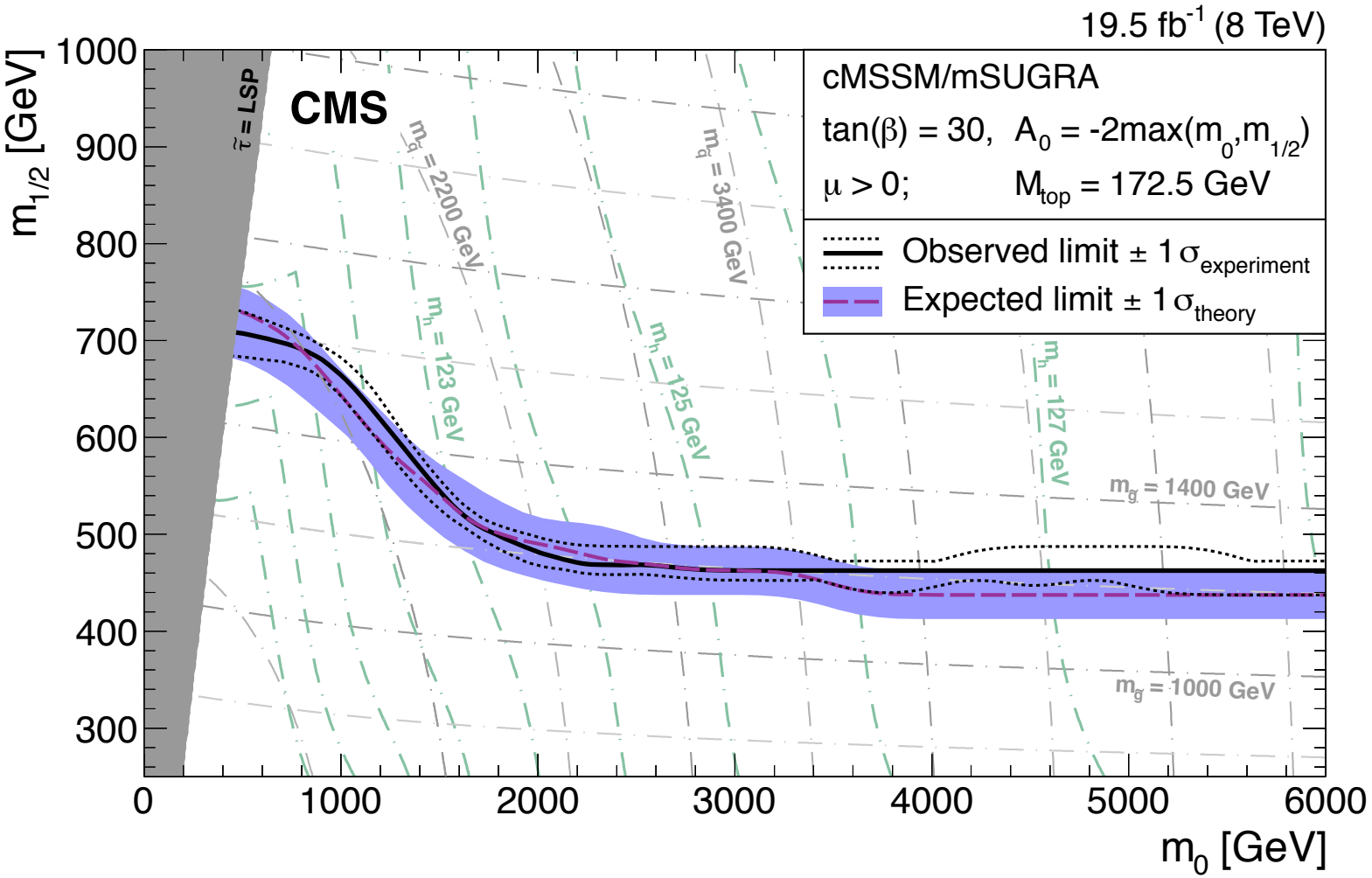
Direct squark production





- Direct squark production assuming two scenarios
- First 2 generations of squarks are degenerate and light
  - Probe squark masses up to ∼900 GeV
- One single light-flavour squark is accesible
  - Probe squark mass up to ∼575 GeV

cMSSM/mSUGRA model



- Probe gluino masses up to $\sim$1.2 TeV, and squark masses up to $\sim$1.5 TeV

Commissioning (CMS-DP-2015-035)

Commissioning of key SUSY observables with the first 13 TeV data

- ✻ more in Lara's talk in this session
- ☛ full collection of SUSY commissioning plots at CMS-DP-2015-035
  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS#Commissioning_results_with_2015

Trigger efficiencies

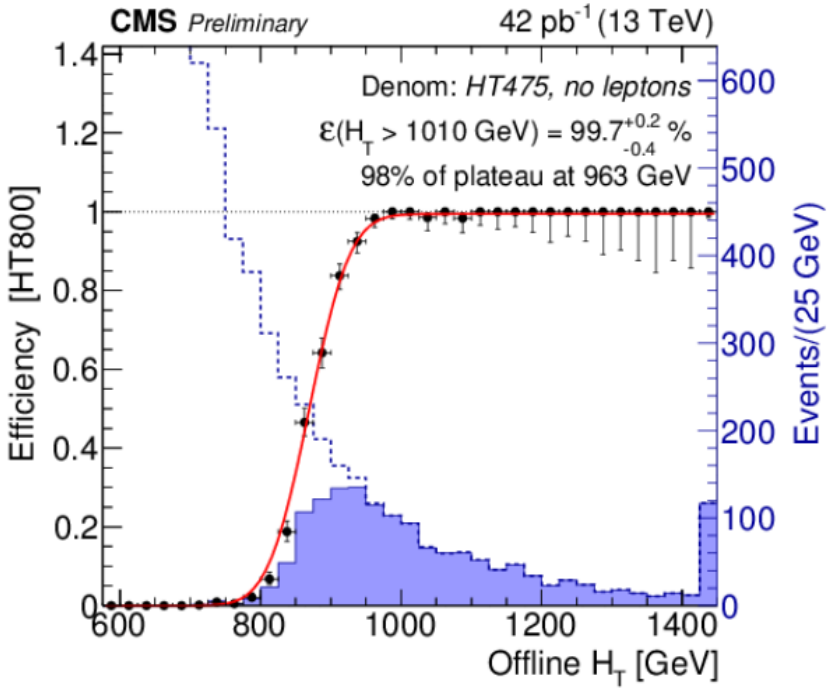
HT800 trigger provides common sample for high mass hadronic gluino search

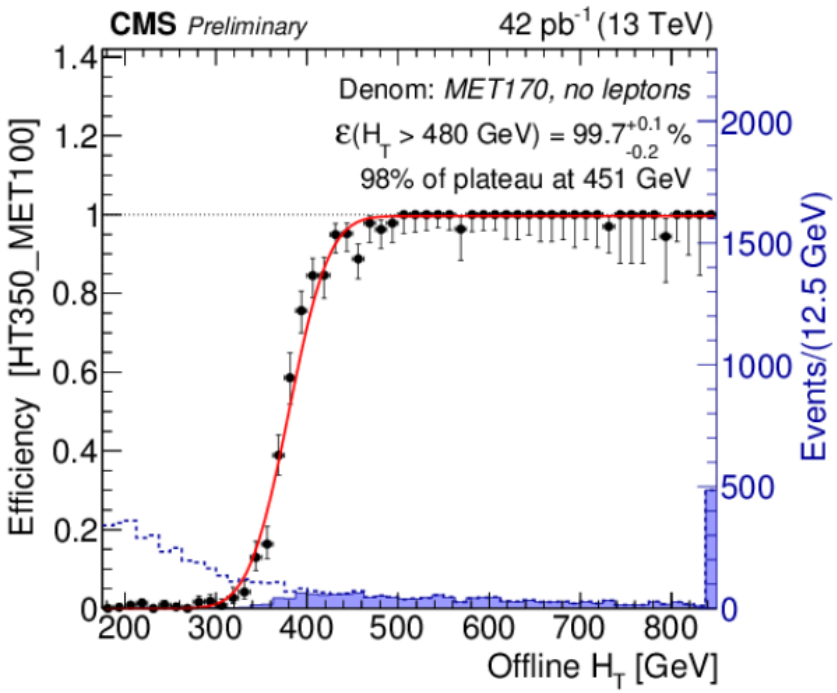
HT350_MET100 trigger targets lower mass, e.g., compressed models

Measure rates and efficiencies with 50 ns data.

Jets and E_T^{miss} calculated using full particle flow objects after a fast pre-filter using calorimeter only.

H_T = scalar sum of AK4 jets with p_T>40 and $|\eta|$<3.





Left: Efficiency of the $H_T > 800$ GeV trigger measured as a function of the H_T calculated offline using jets with $p_T > 40$ GeV and $|\eta| < 3$, as done in the High Level Trigger. Right: Efficiency of the H_T leg of the HT350_MET100 trigger. The shaded histogram corresponds to the numerator in the efficiency calculation, and the dashed line to the denominator. 2

Trigger efficiencies

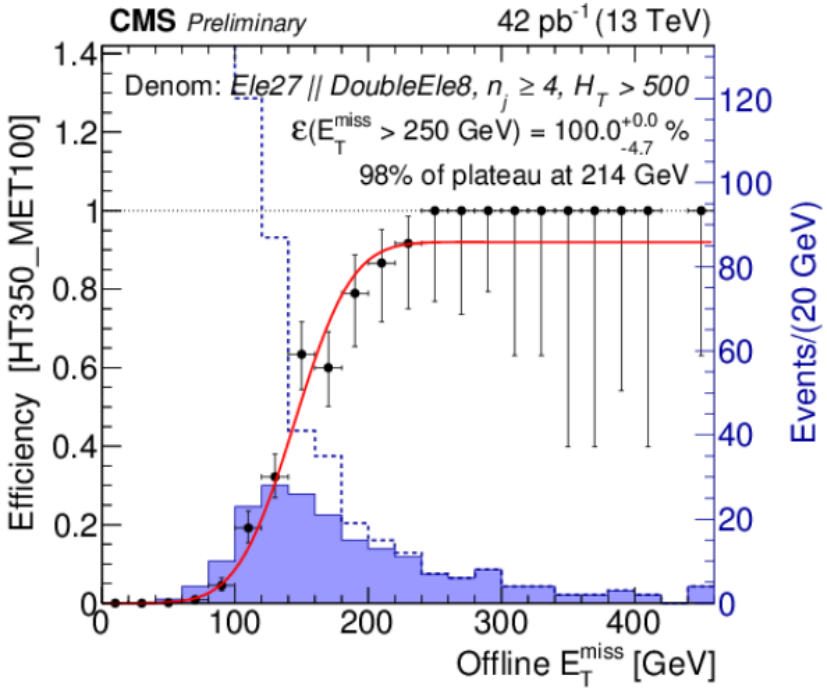
HT800 trigger provides common sample for high mass hadronic gluino search

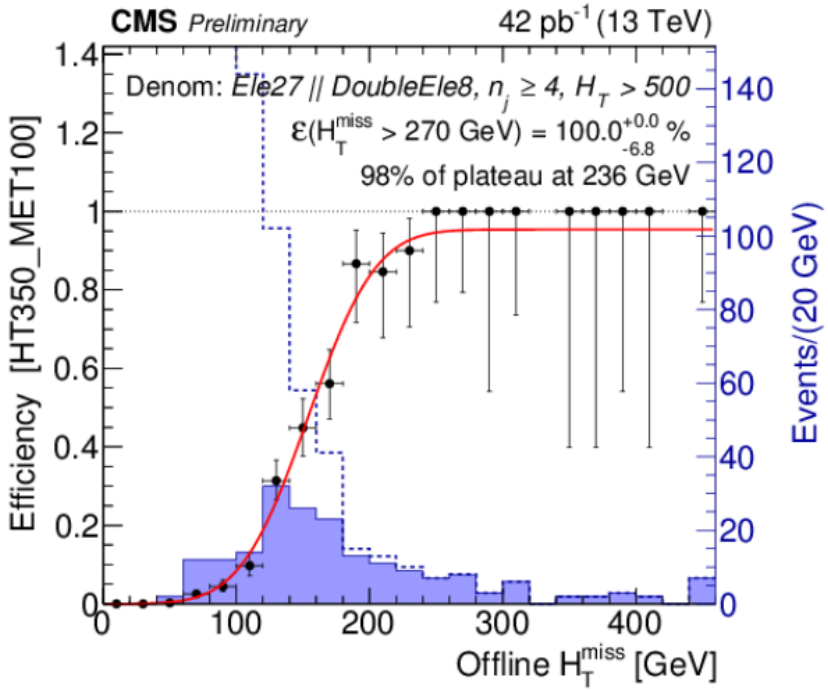
HT350_MET100 trigger targets lower mass, e.g., compressed models

Measure rates and efficiencies with 50 ns data.

H_T = scalar sum of AK4 jets with p_T>40 and $|\eta|$<3.

H_T^{miss} = vector sum of AK4 jets.





Left: Efficiency of the HT350_MET100 trigger measured as a function of E_T^{miss}. Right: Efficiency for the same trigger vs H_T^{miss}, where we require H_T^{miss} and E_T^{miss} to be loosely compatible with $0.5 < H_T^{miss}/E_T^{miss} < 2$. The shaded histogram corresponds to the numerator in the efficiency calculation, and the dashed line to the denominator.

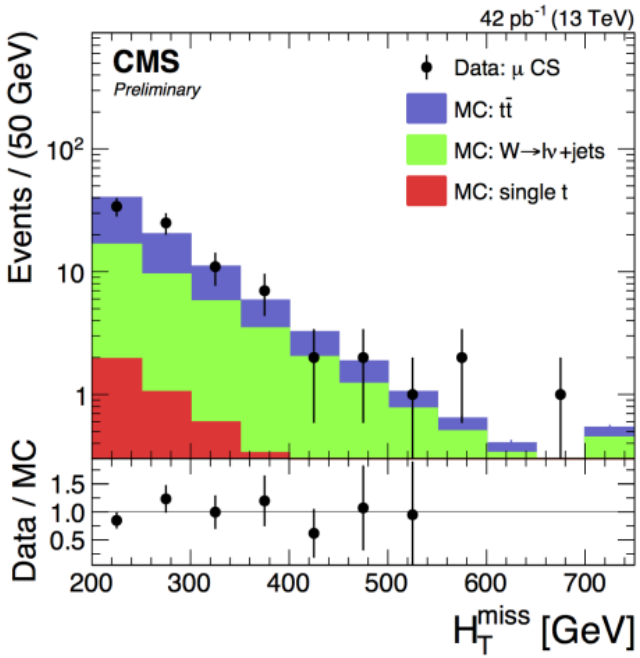
3

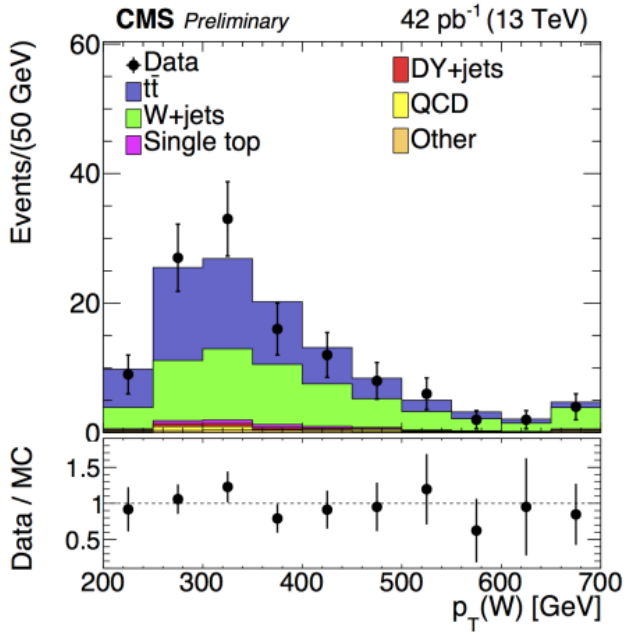
All-hadronic search in H_T and H_T^{miss}

SUS-13-012/12-024

Inclusive search at high H_T and H_T^{miss} in bins of N_j and N_b.

An important background is W or top with missed leptons.
Measure this bkgd in single μ control sample, as a function of kinematics.
Measure the hard-to-model W p_T and use well known W decay properties from MC.





Left: Comparison of H_T^{miss} in data and (normalized) MC using a single μ control sample selected with baseline requirements (4 jets, H_T >500, H_T^{miss} >200). Right: Comparison of p_T(W) in single lepton (e,μ; p_T >10) events with baseline selection, E_T^{miss} >200 and M_T <100. 6

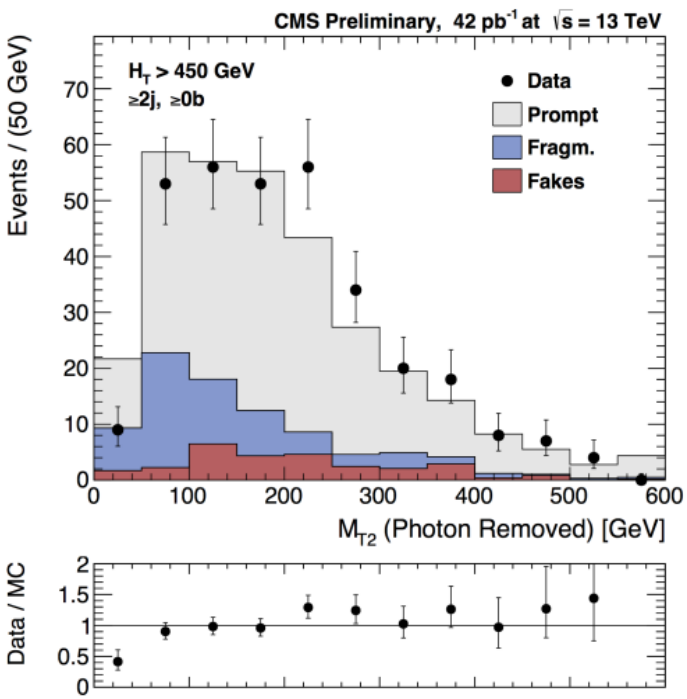
All-hadronic search using M_{T2}

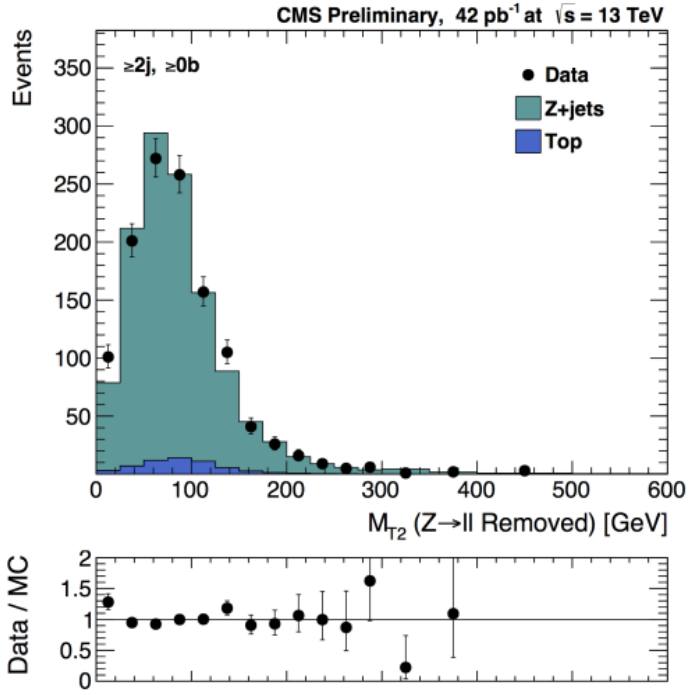
SUS-13-019

Inclusive search with M_{T2} in bins of H_T, N_j and N_b.

M_{T2} = sTransverse mass, designed for final states with 2 missing particles

Another important background is $Z \to \nu\nu$. Estimate with photon sample, multiplied by Z/γ ratio.
Check modeling of MT2 variable in $Z \to \ell\ell$ and γ samples.





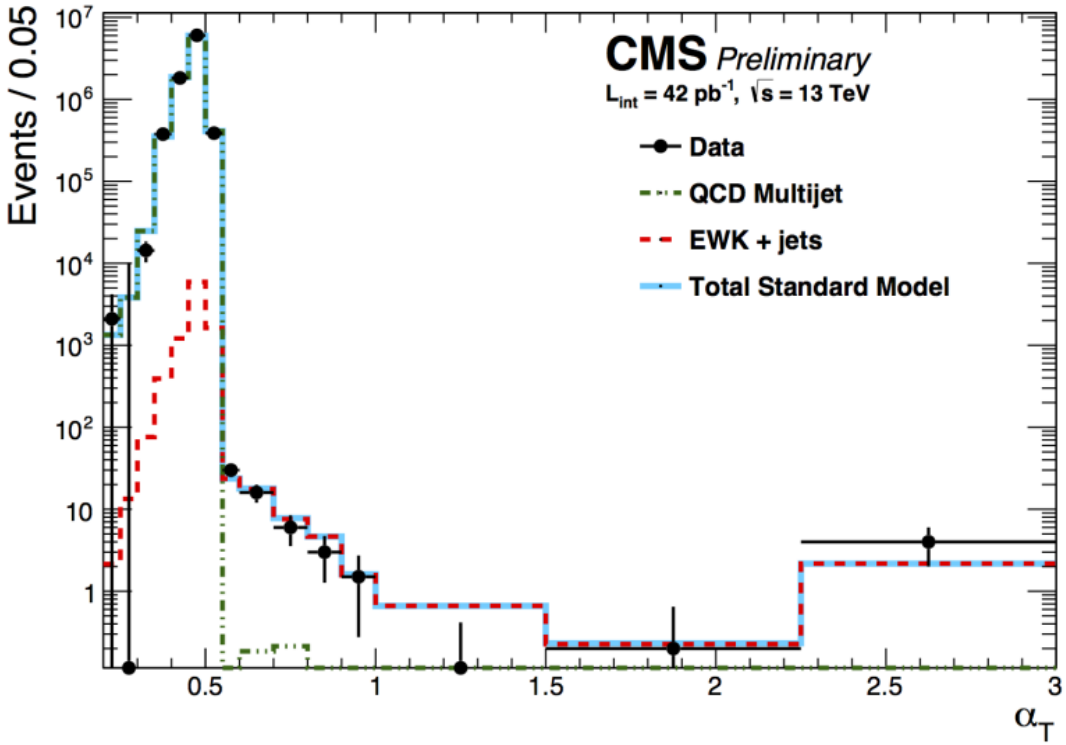
Comparison of M_{T2} distribution in data and (normalized) MC for photon (left) and $Z \to \ell^+\ell^-$ (right) control regions, where the M_{T2} calculation treats γ and Z candidates as invisible.

All-hadronic search using AlphaT

SUS-12-028

Inclusive search with α_T in bins of H_T, H_T^{miss}, N_j and N_b.

AlphaT is a QCD killer, leaving a top and EWK dominated background.



The α_T distribution measured in data with a loose $N_{jets} \geq 2$ and H_T >300 selection. Events with $\alpha_T < 0.55$ are collected with a suite of prescaled-H_T triggers which utilise low H_T thresholds. Values of $\alpha_T > 0.55$ are measured from the H_T-α_T signal triggers with a full analysis selection applied. The data yields are corrected for the prescale of the triggers, and MC is normalized.

Conclusions

- SUSY searches are of crucial importance in the CMS physics program
- Squark and gluino production via strong interaction have highest chances for an early discovery
- CMS has ample coverage of inclusive searches
- Results from 8 TeV data show no evidence for new physics so far
  - Stringent constraints have been set in many SUSY scenarios
- Inclusive SUSY analysis at CMS have shown readiness from the 50ns data at 13 TeV
- CMS eager to analyze 25 ns data at 13 TeV