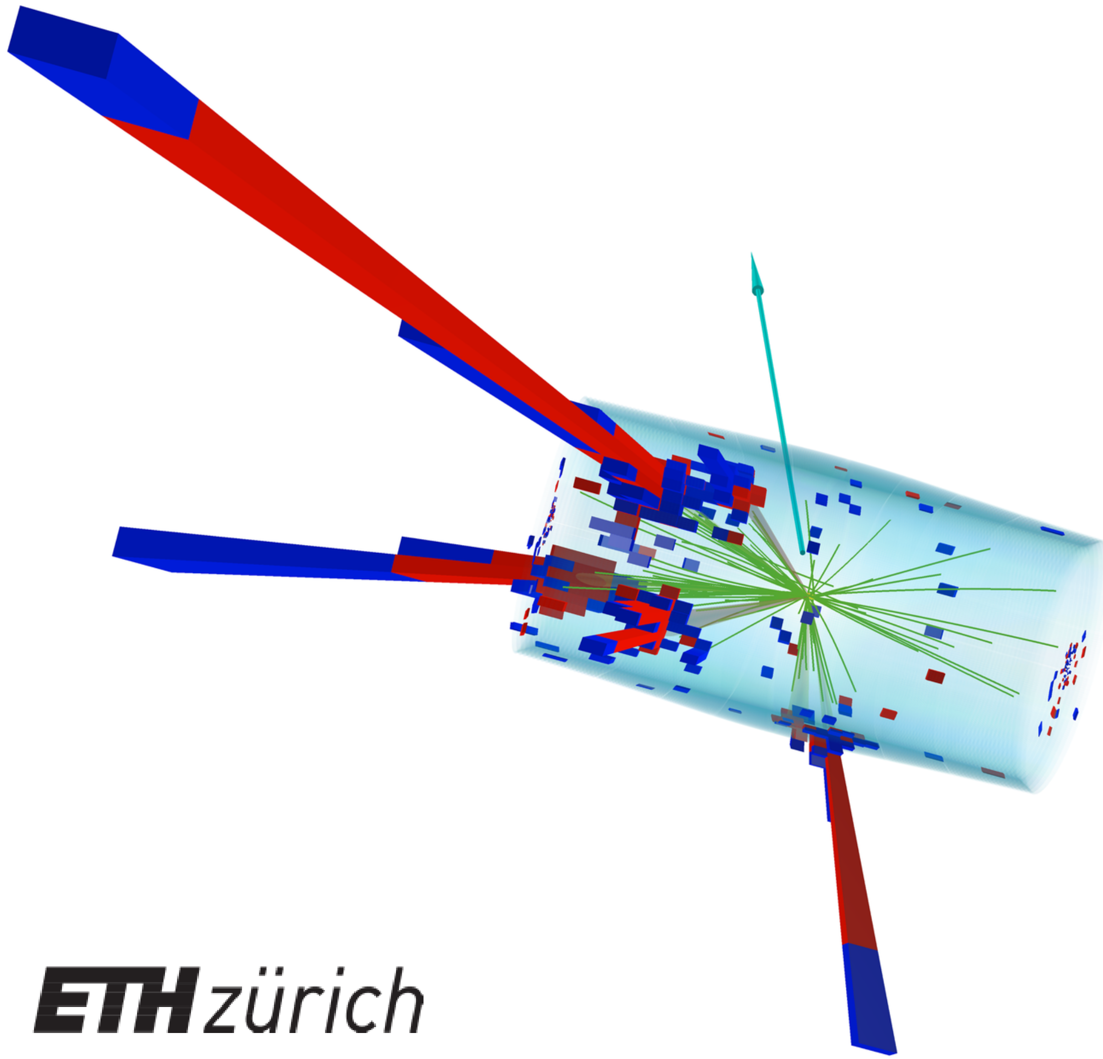
Searches for SUSY via strong production in fully hadronic final states at CMS



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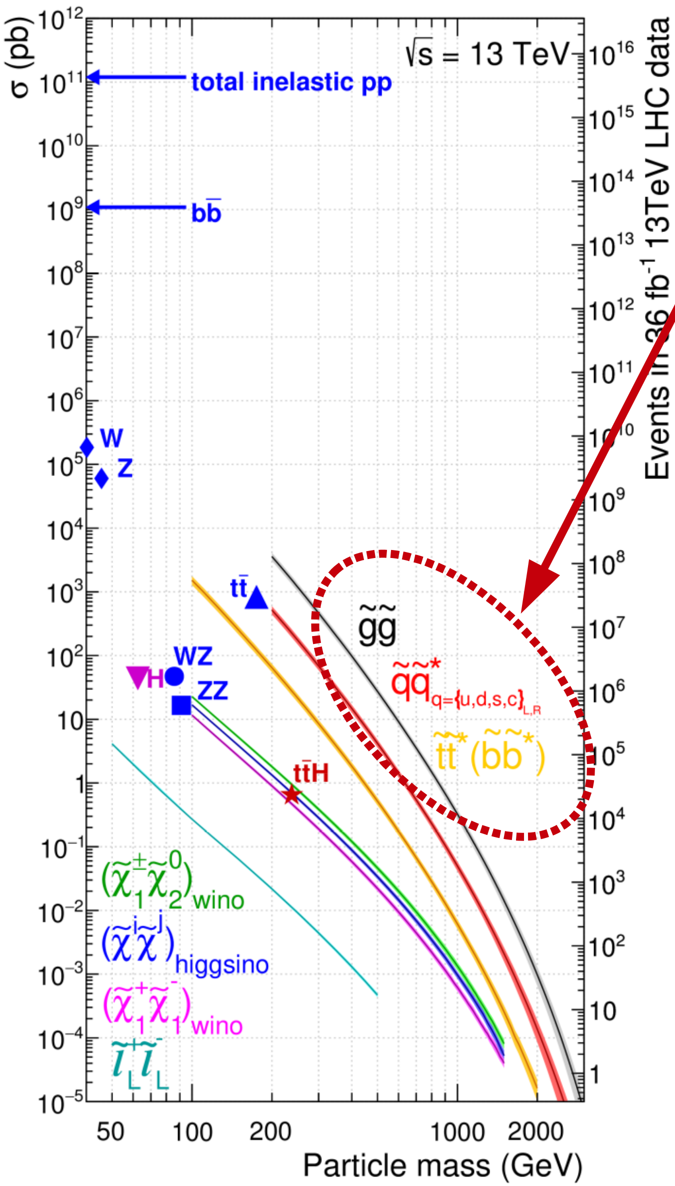
ETH Zürich

for the CMS collaboration

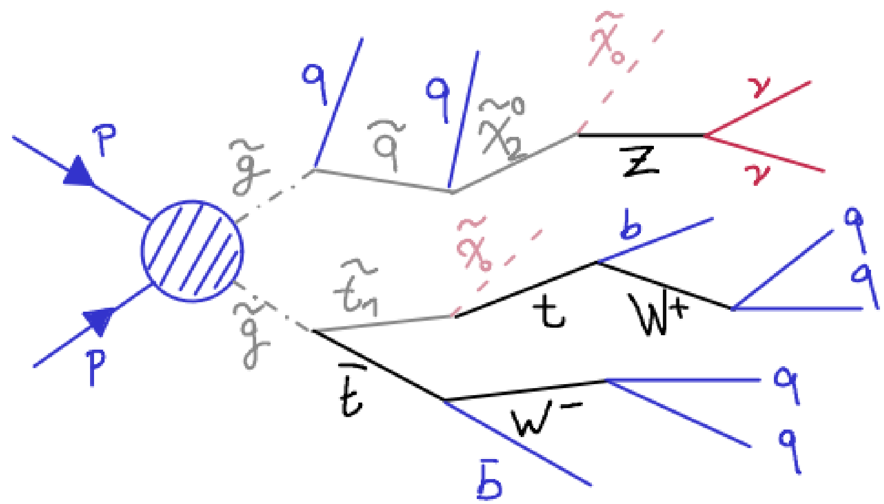
SUSY 2018, Barcelona
23 July 2018

Why fully hadronic?



Largest cross section for **strong production, gluinos & squarks,** of SUSY

Largest branching ratio to jets



Fully hadronic searches of strongly produced SUSY

→ **discovery channel at energy frontier**

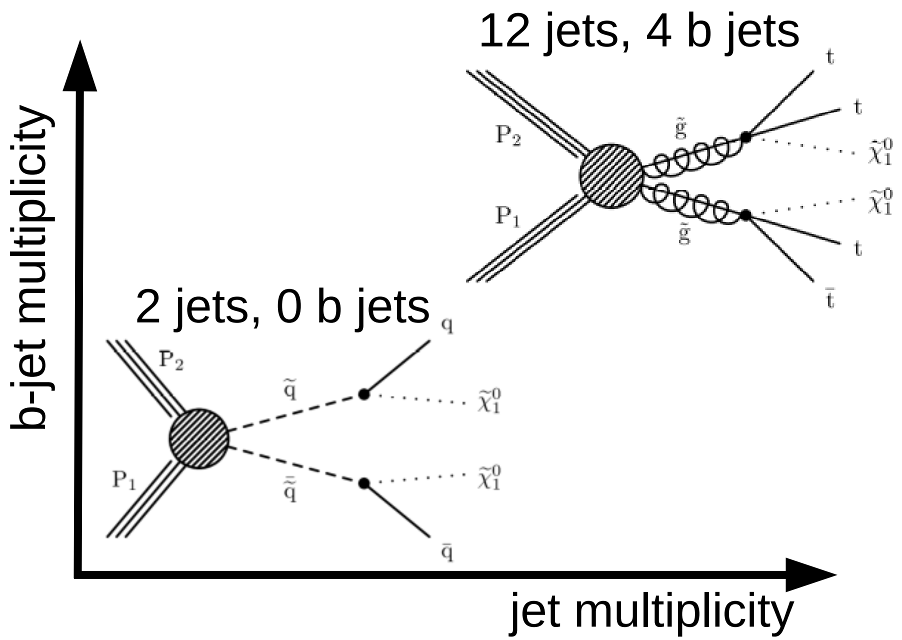
Four fully hadronic searches at CMS at 13 TeV

H_T^{miss}	**SUS-16-033** arxiv1704.07781	35.9 fb^{-1}	Focus on these results in this talk
M_{T2}	**SUS-16-036** arxiv1705.04650	35.9 fb^{-1}	
α_T	**SUS-16-038** arxiv1802.02110	35.9 fb^{-1}	
Razor	**SUS-15-004** arxiv1609.07658	2.3 fb^{-1}	

Strategy for fully hadronic inclusive searches

- Large ME_T from neutralinos
- Many jets
- Large energy deposits

- Sensitivity to very different signals through binning in **jet & b-jet** multiplicity



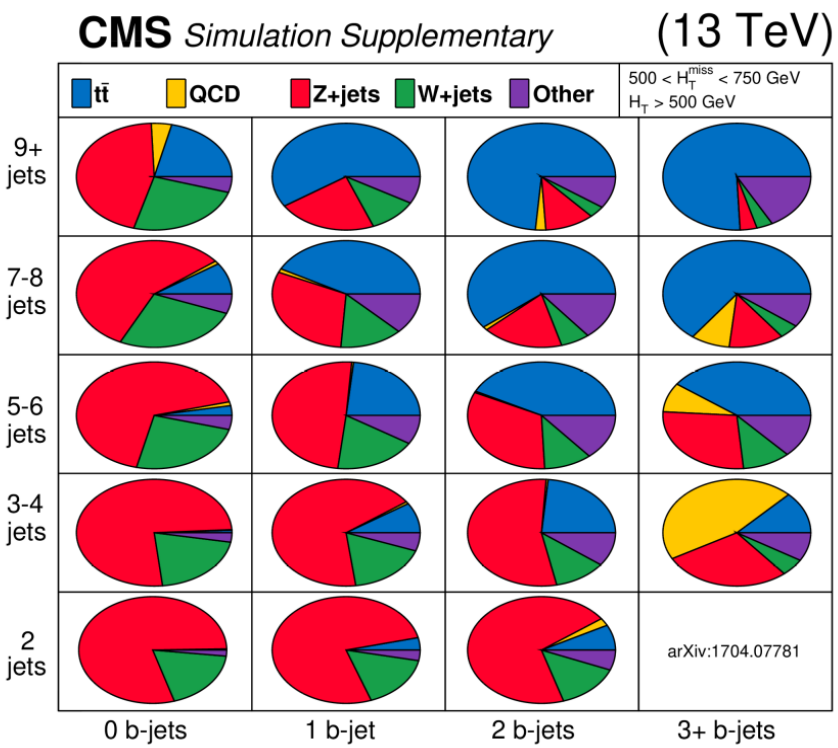
- Binning in $\mathbf{H_T}$ for energy scale sensitivity

$$H_T = \sum_{jets} |\vec{p_T}|$$

- Lepton veto

Main backgrounds

- **QCD multi-jet:**
  - Mis-measurement of a jet leads to imbalanced event → **instrumental ME_T**
- **W-jets & ttbar (Lost lepton):**
  - **ME_T from neutrino** from leptonic W decay
  - Charged lepton not caught by lepton veto because of acceptance, reconstruction or isolation
- **$Z_{\nu\nu}$+jets:**
  - **ME_T from the two neutrinos**



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QCD multijet suppression & Discovery variables

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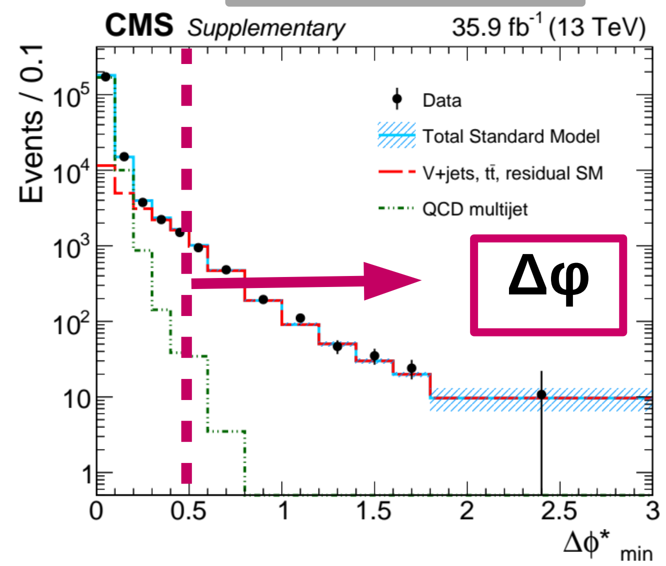
Angle between mismeasured jet and ME_T (H_T^{miss}) is small
→ suppress QCD multijet events

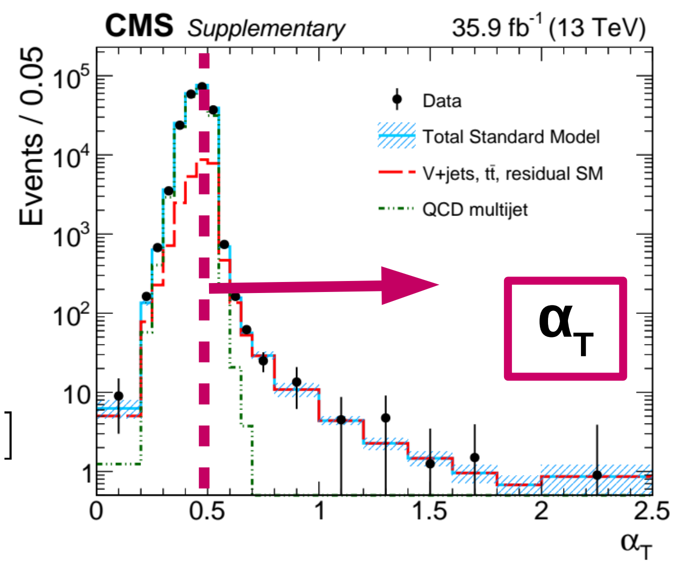
Discovery variables are **ME_T like**
(Tail searches!):

$$\alpha_T = E_T^{j2} / M_T$$

$$\mathrm{H}_T^{miss} = |-\sum_{jets} \vec{p_T}|$$

$$\mathrm{M}_{T2}(m_c) = \min_{\vec{p}_T^{\,c(1)} + \vec{p}_T^{\,c(2)} = \vec{p}_T^{\,miss}} [\max(M_T^{(1)}, M_T^{(2)})]$$

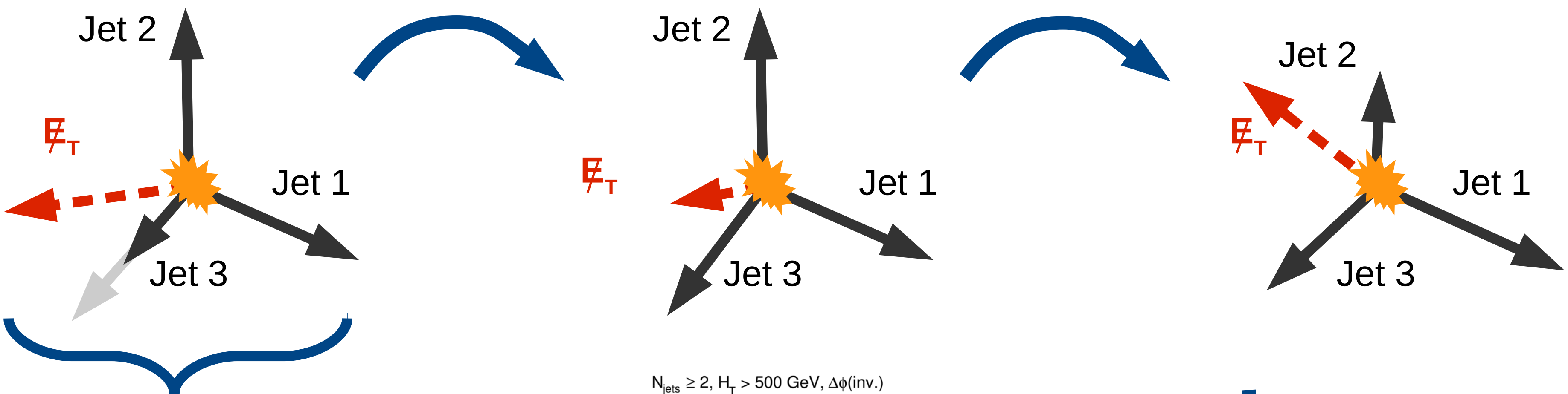




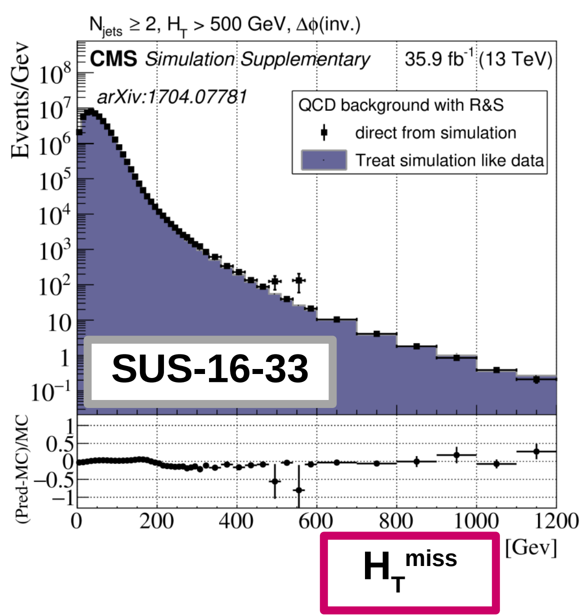
QCD Estimate: Rebalance and Smear

Rebalance jets to true hard scatter event with $ME_T \approx 0$

Smear jets according to response

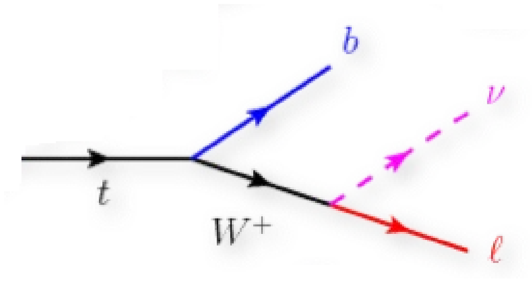


QCD multi-jet events have no intrinsic ME_T, only **instrumental ME_T** due to detector response that depends on η & p_T of jets

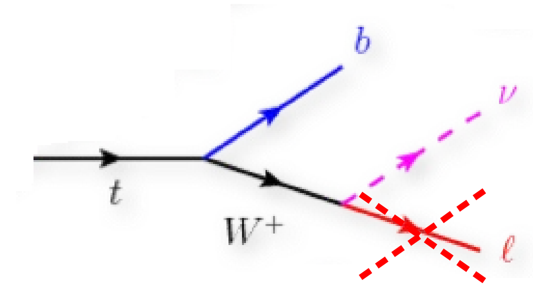


Good agreement with out of the box simulation

Lost Lepton estimate

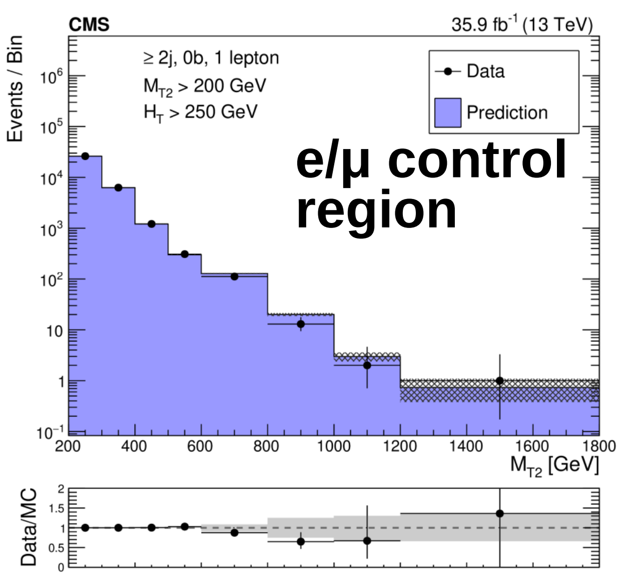


Probability to lose it (from MC)



Single lepton (e/μ) control region

0 lepton signal region



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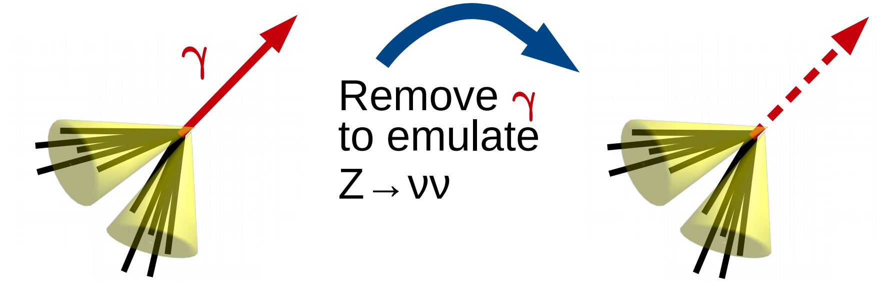
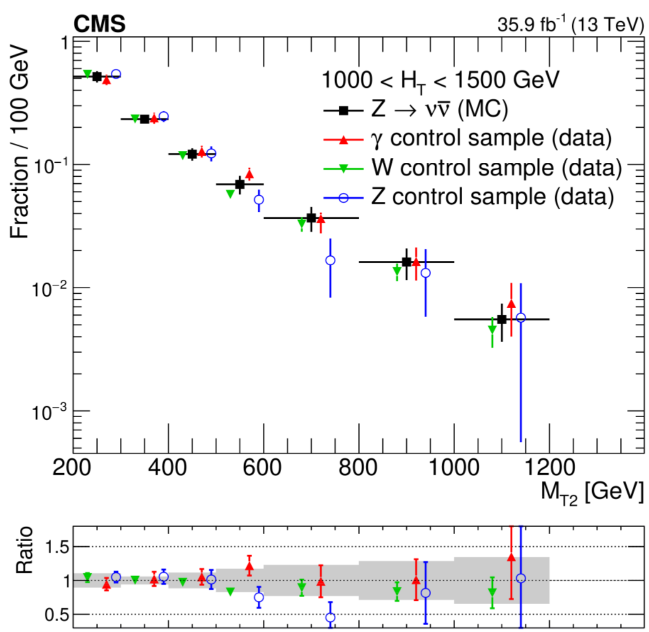
- Charged lepton not seen because of
  - Acceptance of detector
  - Reconstruction/ID
  - Non-isolation
- **Suppress with efficient lepton veto**

$Z \rightarrow \nu\nu$ Estimate

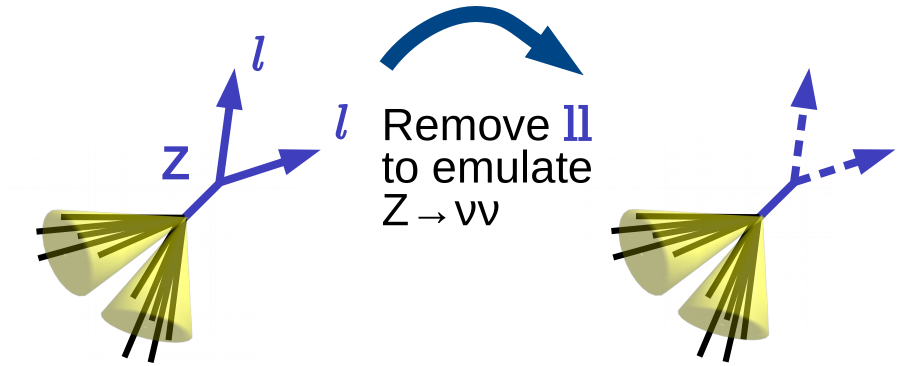


SUS-16-36



γ+jets

- High stats control region
- Large systematic uncertainties due to fragmentation photons & theoretical uncertainty on Z/γ ratio



$Z \rightarrow ll$

- Lower stats, now possible with 40 fb^{-1}
- Lower uncertainties (same process)
- Account for Top contamination in same flavor with **eμ data control region**

Selected results: good agreement with SM

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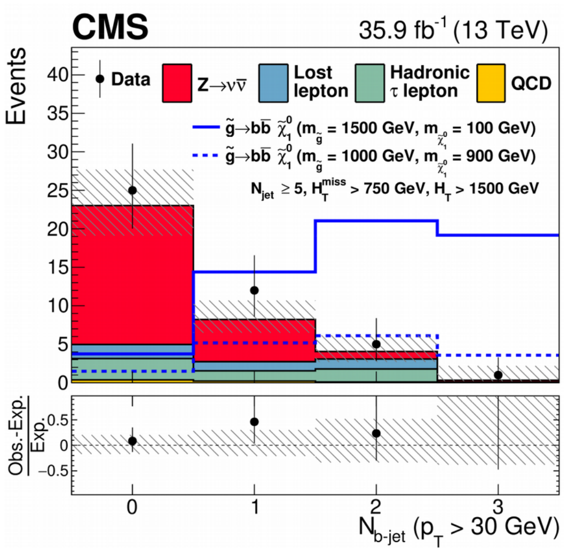
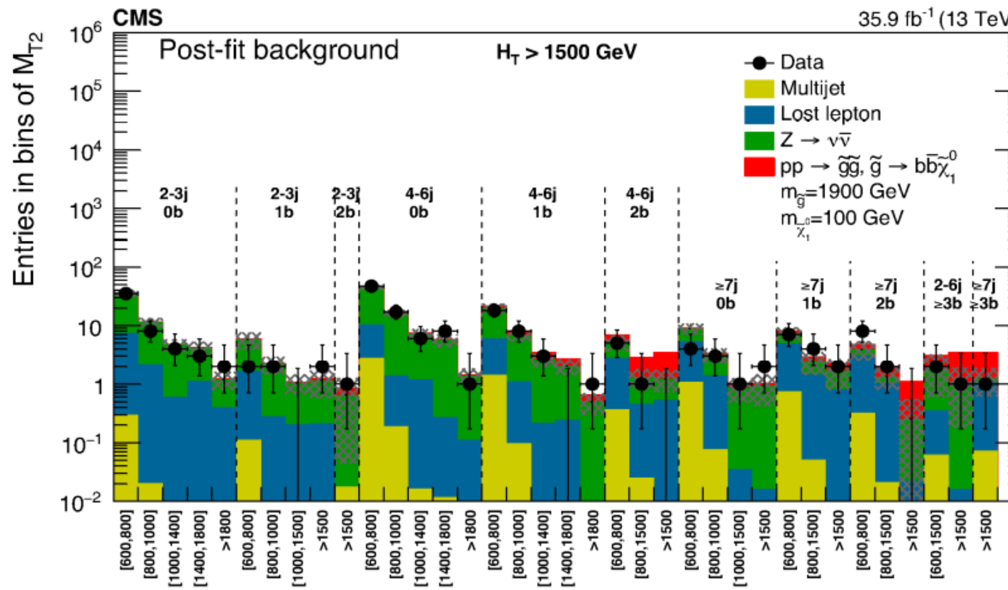
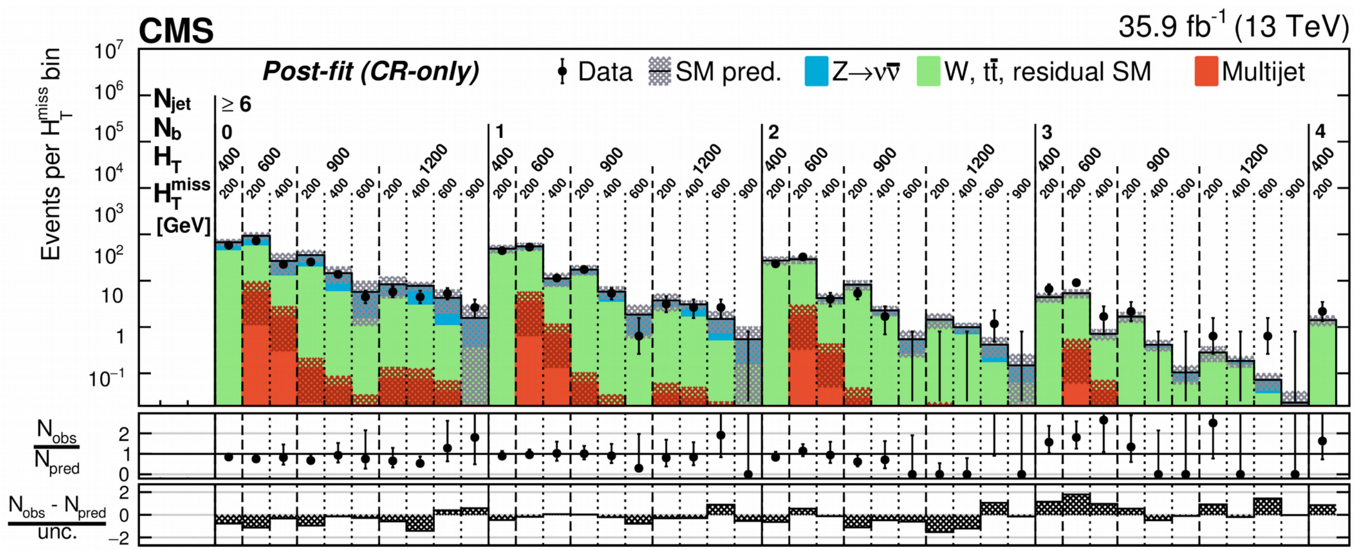


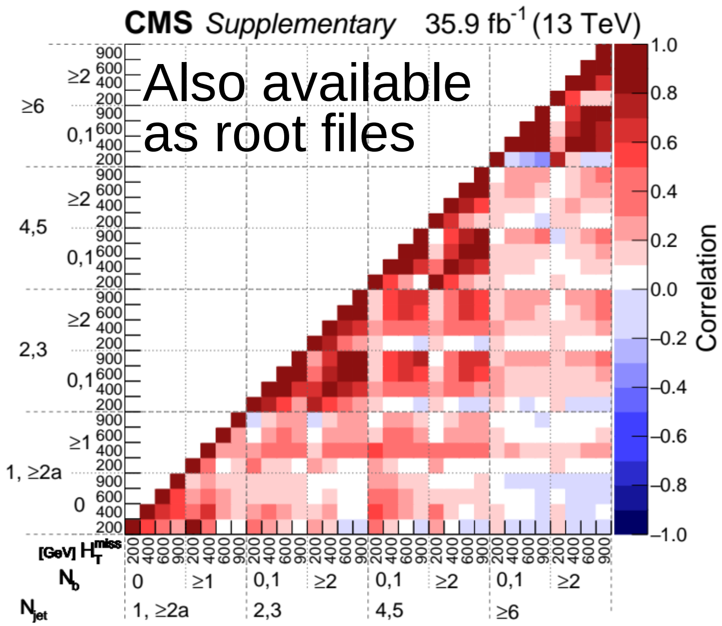
SUS-16-36

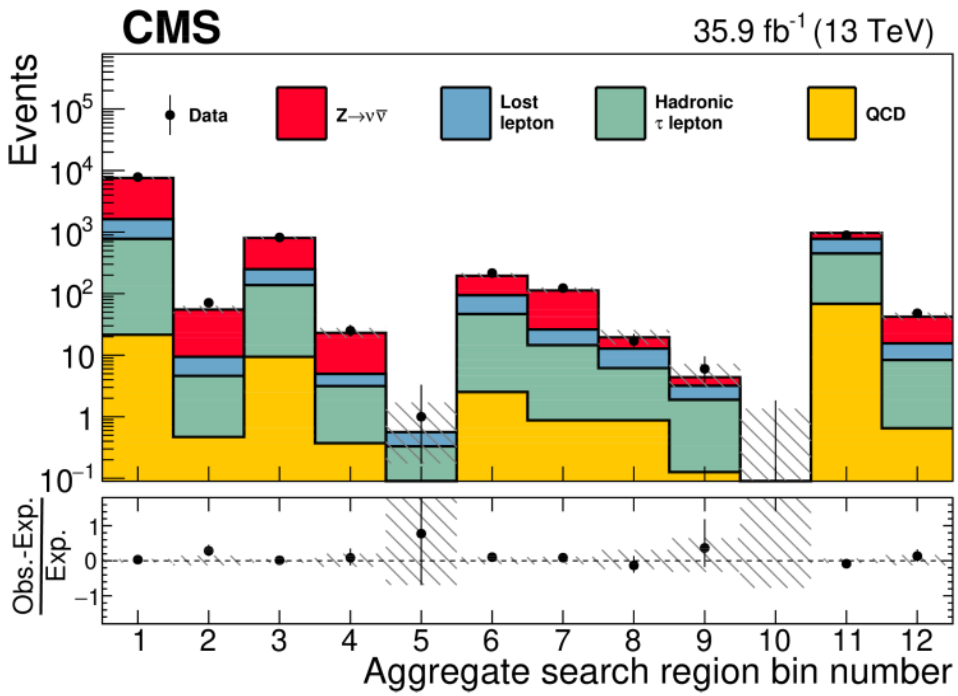


SUS-16-38



Aggregate signal regions & covariance matrix for easier reinterpretation





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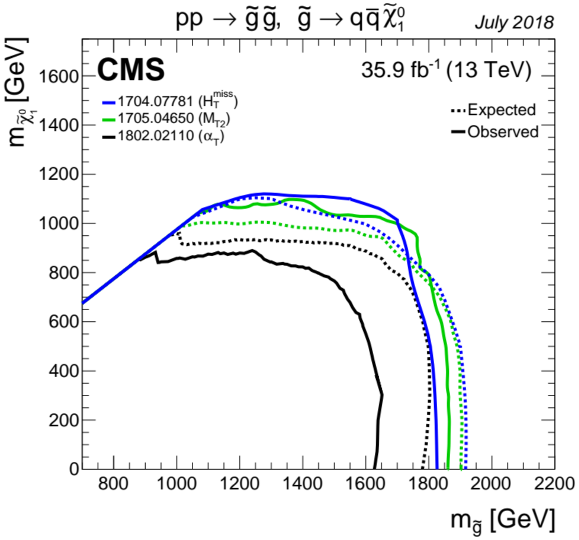
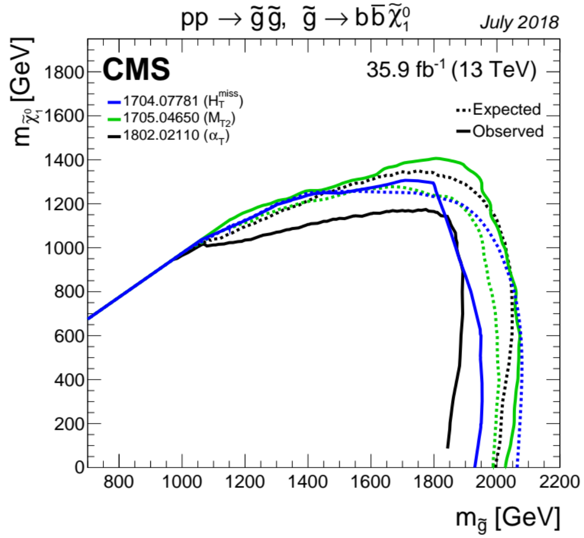
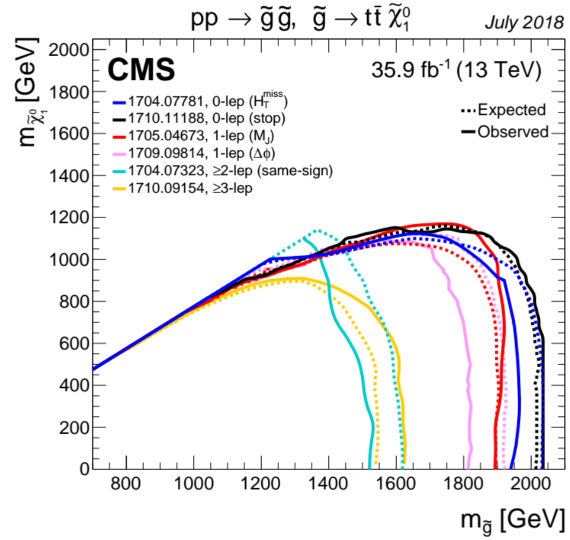
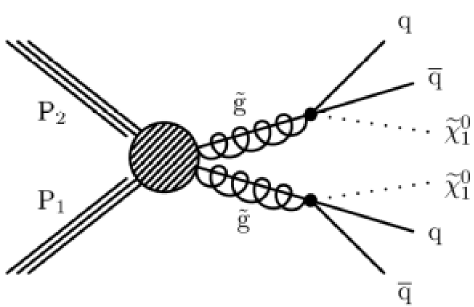
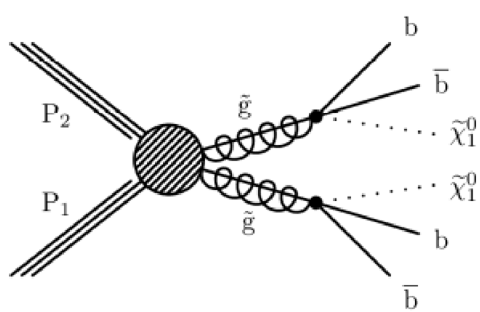
Exclusion Limits – Gluino production

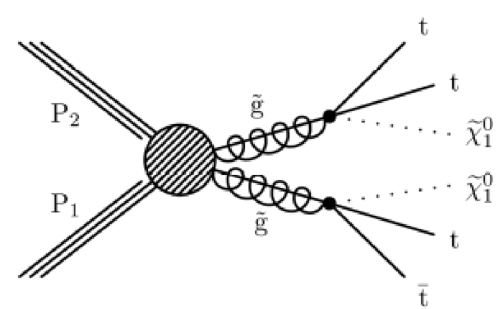






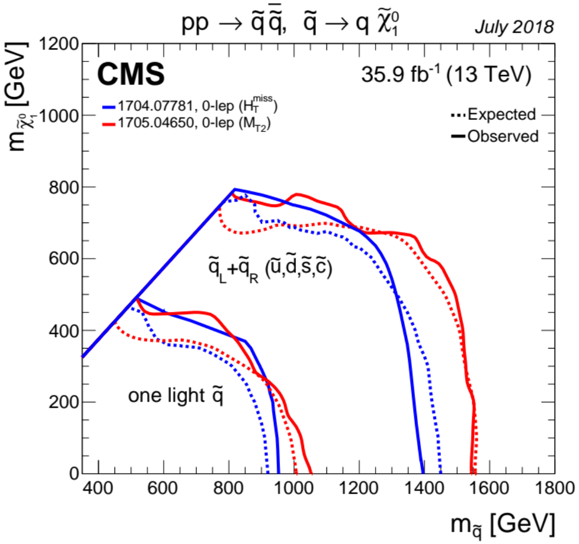


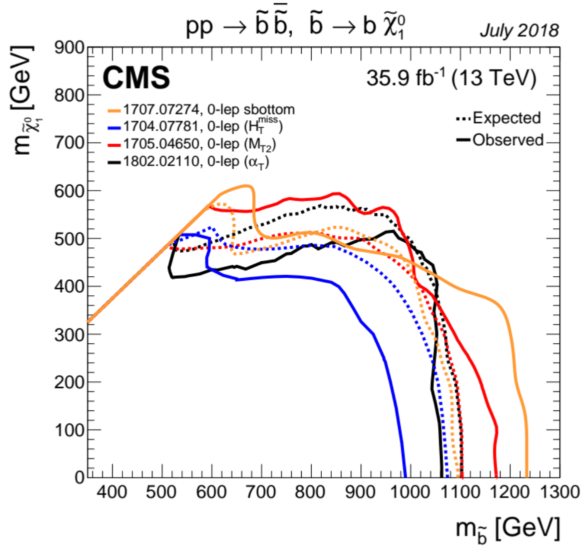


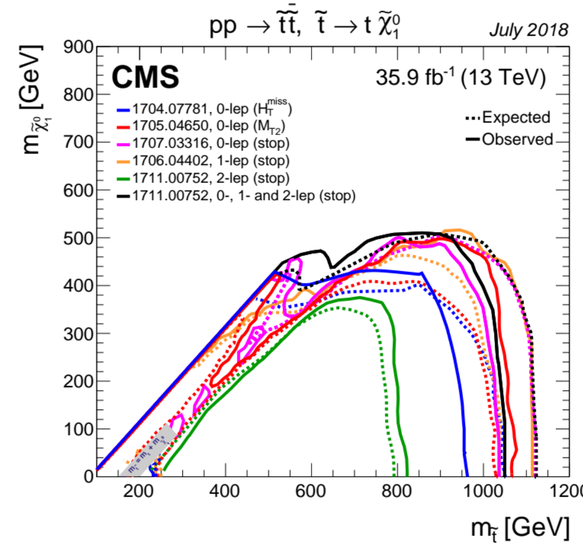


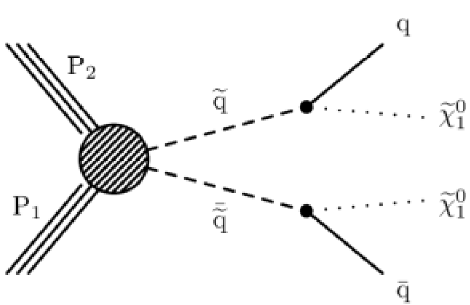
- Similar reach for the analyses
- Hadronic analyses have similar reach as leptonic channels
- Extended reach up to about 2 TeV along gluino mass

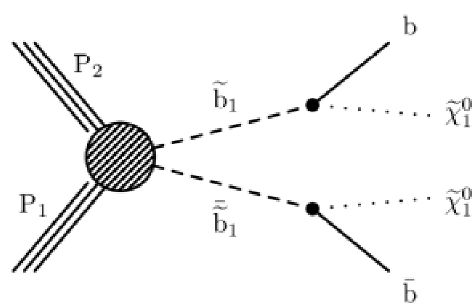
Exclusion Limits – Direct squark production

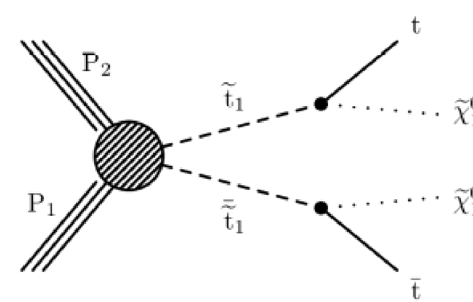












- Similar reach for H_T^{miss} and M_{T2} analyses
- Have similar reach as leptonic channels for stop production
- Extended reach by about 1TeV along squark mass

Exclusion Limits – Split SUSY

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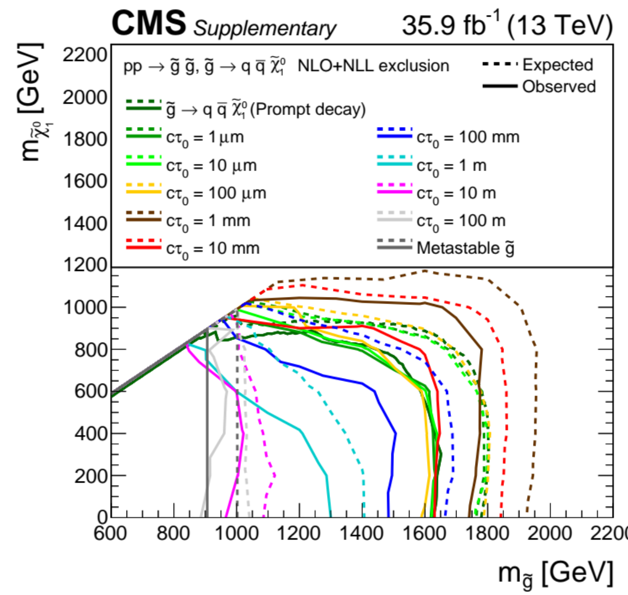
- Split SUSY: all but the fermionic superpartners are assumed to be heavy
  - → highly virtual squark states
  - → suppressed gluino decay
  - → displaced vertices
  - → significant ME_T

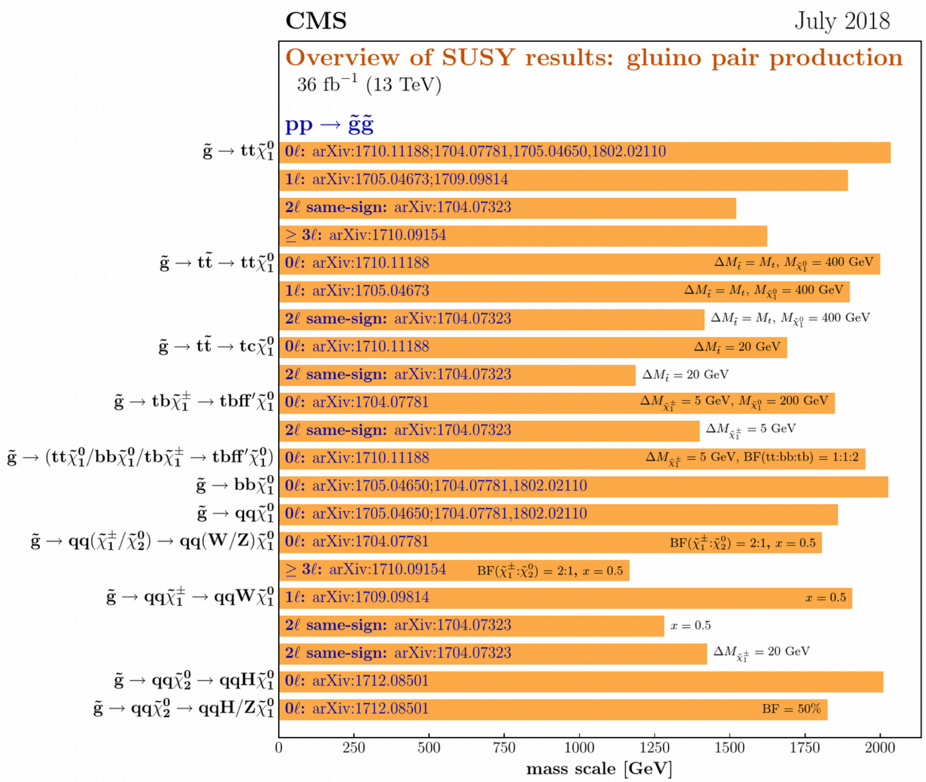


- For τ_0 > 1ps: gluino hadronizes into bound colorless singlet state (R-hadron) until it decays to a quark-antiquark pair and a neutralino

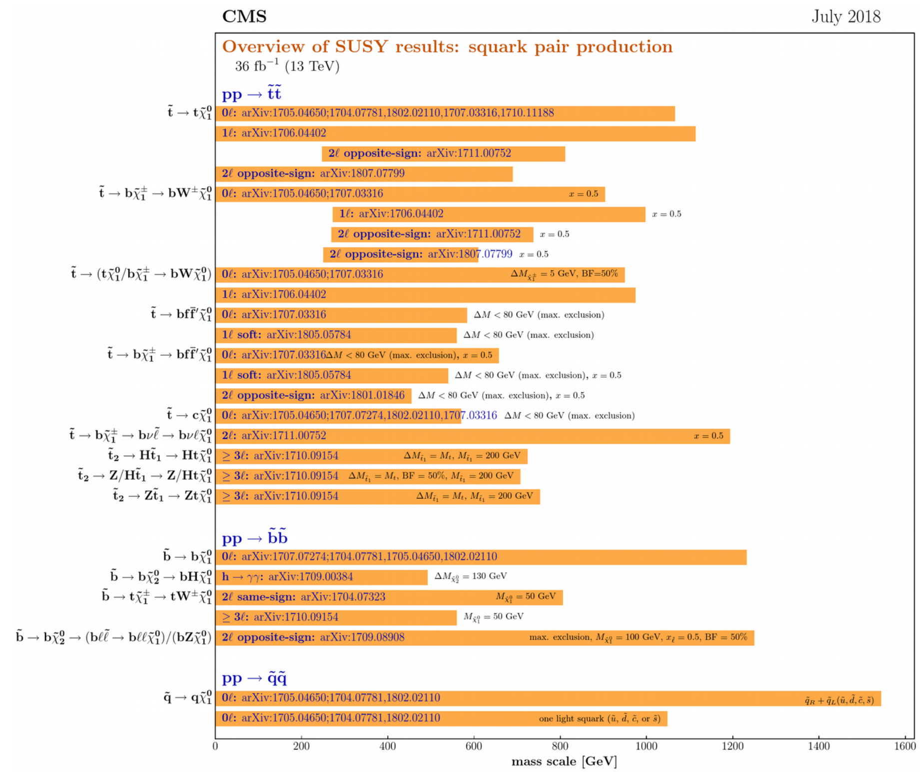
- Models probed from 1µm to 100m and metastable gluinos with $c\tau_0 = 10^{18}$ mm which are leaving CMS without being detected

Conclusions

- Showed results of 3 fully hadronic inclusive searches for SUSY with 35.9 fb^{-1} collected by the CMS detector
- Probed the direct squark and gluino production at the energy frontier
- Probed split SUSY models with decay lengths in the range of $10^{-3} < c\tau_0 < 10^5$ mm
- No significant excess over background predictions:
  → Exclude masses up to about 2 TeV for gluinos and 1 TeV for squarks with three independent approaches



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.



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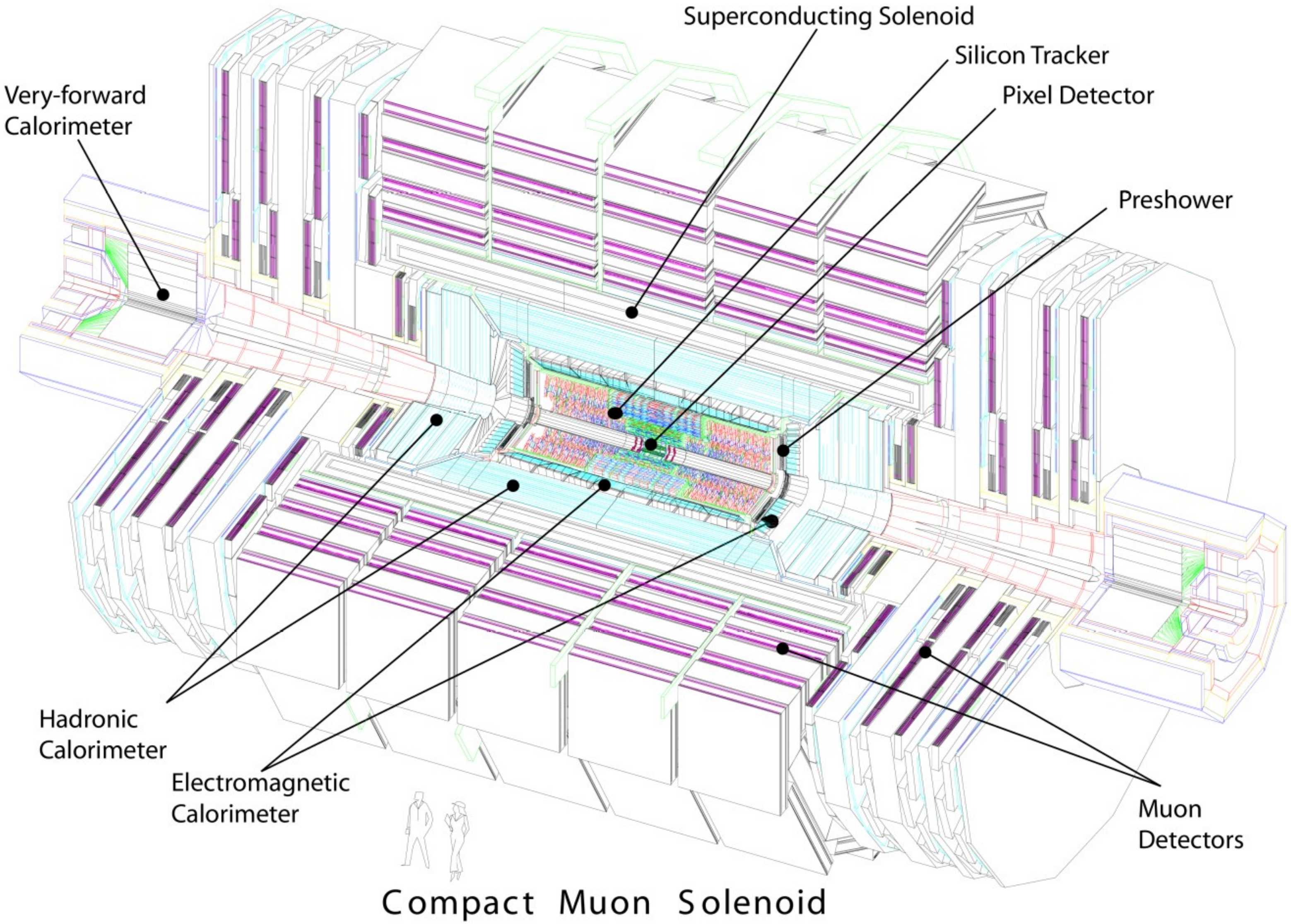
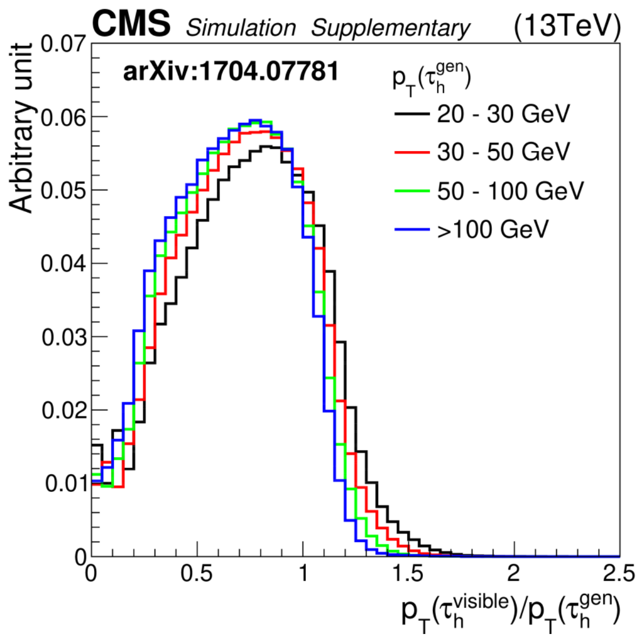
BACK UP

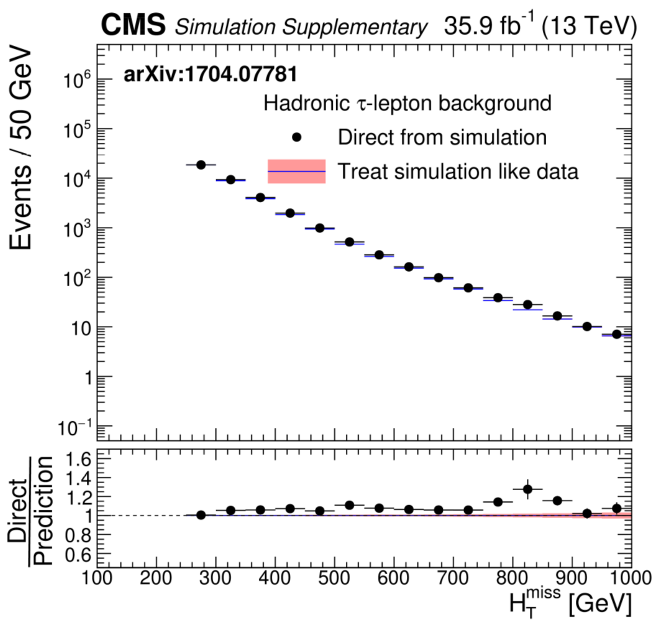
The CMS detector



Special estimate of hadronic Tau decays for H_T^{miss} analysis

- Single μ control region in data
- Smear μ p_T with τ_h response function
- Recompute event kinematics



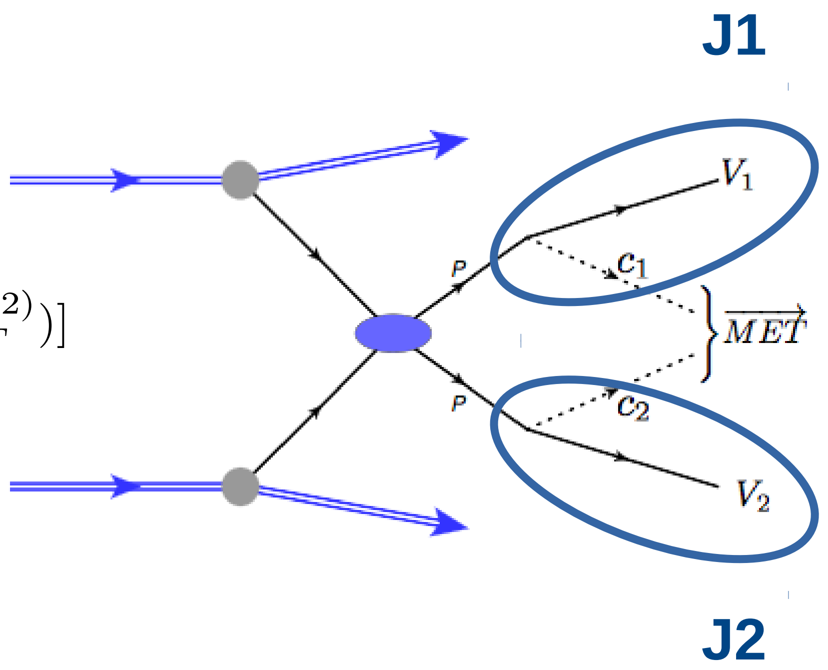


The M_{T2} Variable

- M_{T2} is a generalized ME_T like variable for decays with 2 unobserved particles

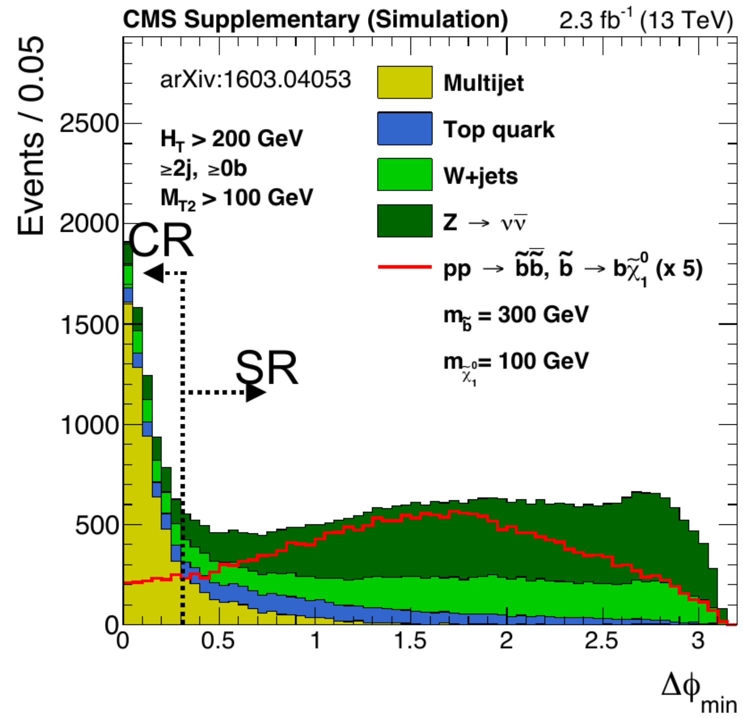
$$M_{T2}(m_c) = \min_{\vec{p}_T^{\,c(1)}+\vec{p}_T^{\,c(2)}=\vec{p}_T^{\,miss}} [\max(M_T^{(1)}, M_T^{(2)})]$$

- Split visible part of event into 2 hemispheres (pseudojets) for calculation of M_{T2}



Approximative formula:
$(M_{T2})^2 \sim p_T(J1) \cdot p_T(J2) \cdot (1+\cos\varphi_{12})$

QCD background estimate via delta Phi



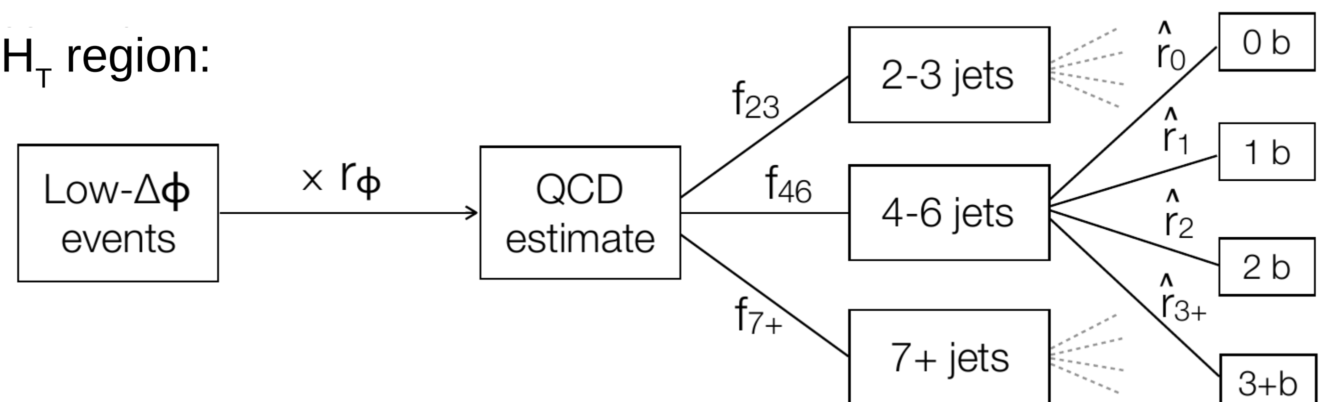
- Invert $\Delta\varphi(ME_T$, jets) cut

$$r_\phi = \frac{N(\Delta\phi_{min}(jets, E_T^{miss}) > 0.3)}{N(\Delta\phi_{min}(jets, E_T^{miss}) < 0.3)}$$

- Fit r_φ at low M_{T2} & extrapolate to signal region inclusively in each H_T region
  - → Then split among N_j/N_b with data based transfer factors
- N_{CR} coming from signal triggers

$$N_{QCD}^{SR} = N^{CR}(H_T, M_{T2}) \cdot r_\phi(M_{T2}) \cdot f_j(H_T) \cdot r_b(N_j)$$

In each H_T region:



Aggregate signal regions

M_{T2} @12.9 fb^{-1}

Signal	Expected limit [fb] (full analysis)	Expected limit [fb] (best aggregated region)
$pp \to \tilde{g}\tilde{g}, \tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ ($m_{\tilde{g}} = 1700\,\mathrm{GeV}$, $m_{\tilde{\chi}_1^0} = 0\,\mathrm{GeV}$)	1.80	3.84
$pp \to \tilde{g}\tilde{g}, \tilde{g} \to b\bar{b}\tilde{\chi}_1^0$ ($m_{\tilde{g}} = 1000\,\mathrm{GeV}$, $m_{\tilde{\chi}_1^0} = 950\,\mathrm{GeV}$)	234	498

Full analysis give significantly better limits than the **best aggregate region**