Third generation SUSY searches in CMS

Eric Chabert
On behalf the CMS collaboration

Last talk on the SUSY 3G

SUSY session on Tuesday:

- Squark/gluino searches in hadronic channels with CMS *(SAKUMA, Tai*)
- pMSSM studies with ATLAS and CMS *(FAWCETT, William James)*

SUSY plenary session this morning:

- Inclusive searches for gluinos and squarks @LHC *(HODGKINSON, Mark)*
- SUSY searches in lepton and photon final states @LHC *(SCHULTE, Jan-Frederik)*
- Third generation SUSY searches at the LHC *(HOPKINS, Walter)*

SUSY plenary session this morning:

- Squark/gluino in leptonic channels with CMS *(LOBANOV, Artur)*

Last talk on the SUSY 3G

I'm the last one ☹
I should have chosen a experiment whose name starts with a A not a C ....

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How could I be original ??

What's in ?

Run I analyses

- Stop searches in 0/1/2 leptons
- Stop search in 2bs+MET
- Stop searches in RPV
- Gluino mediated stop production
- …

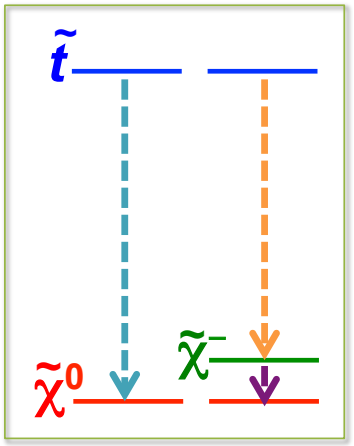
Run II analyses

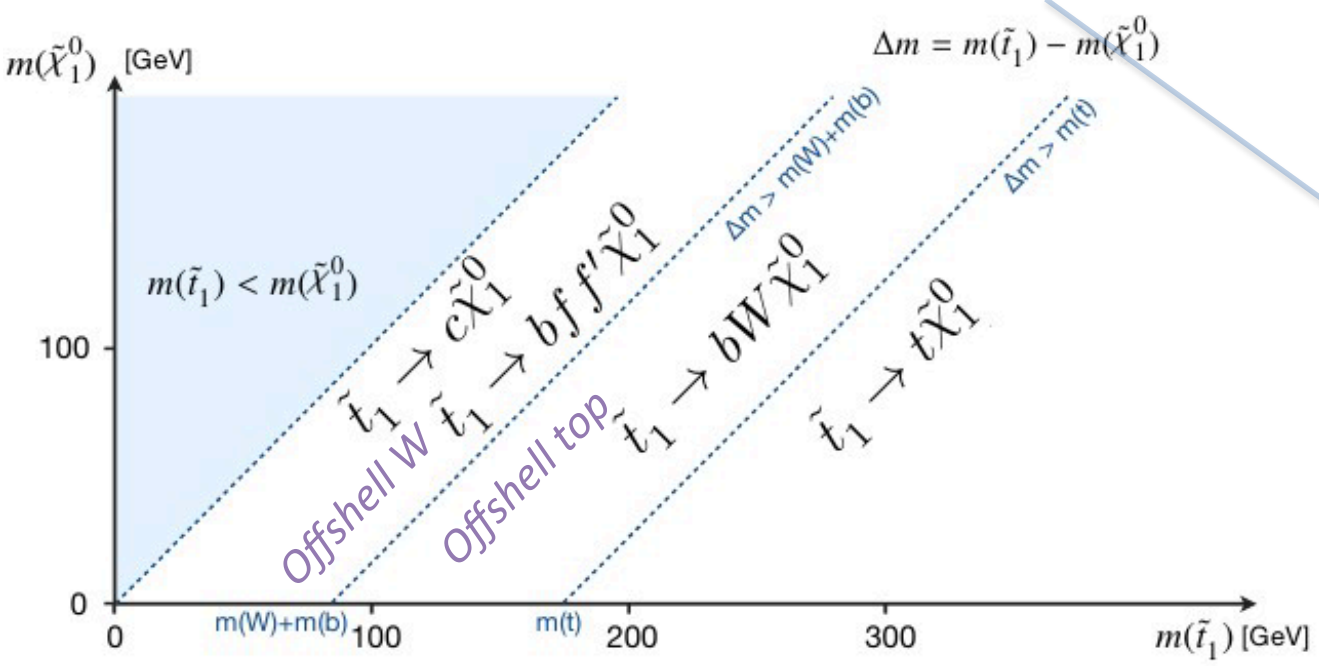
- Stop searches in multi-jets
- Stop searches in l+jets
- Stop search in 2bs+jets
- Sbottom search in 2bs+MET
- Sbottom search in OS -2l
- Gluino mediated stop production search

Physic processes considered

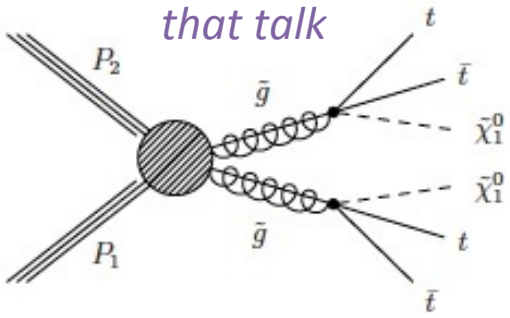
- Consider Simplified Models Spectra with a limited number of sparticles
- Production modes of stop/sbottom
  - Direct pair production
  - *Gluino induced pair production*

Example:



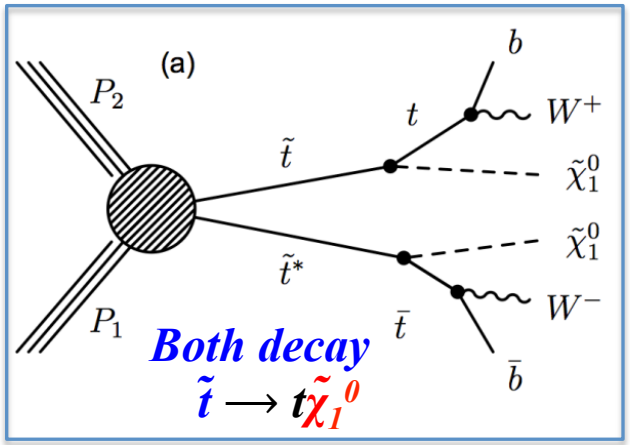


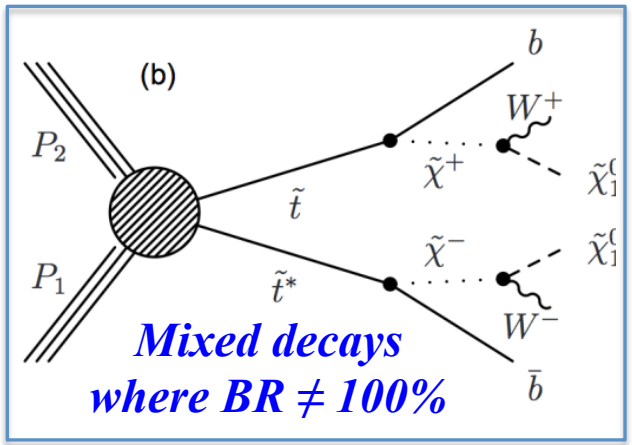
Not described in that talk

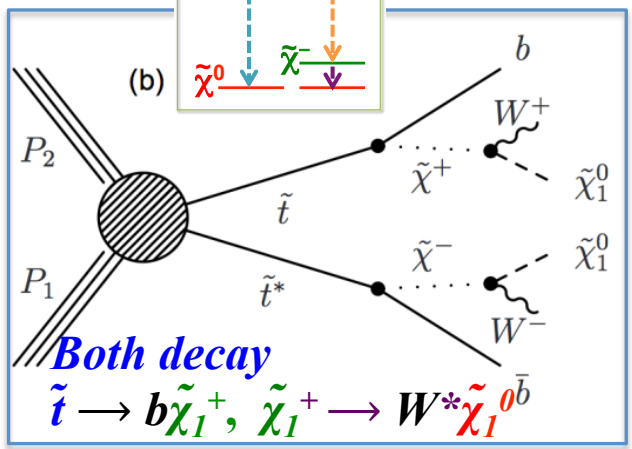


Physic processes considered

➢ Stop searches

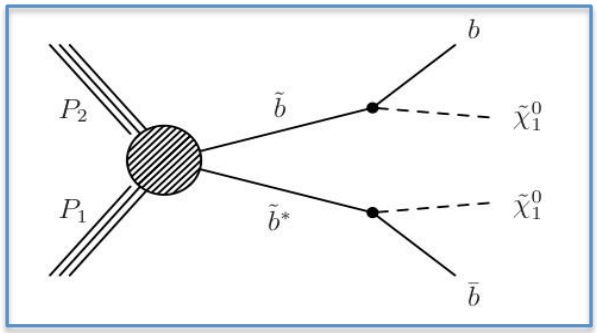


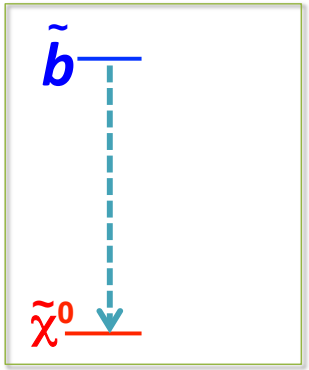




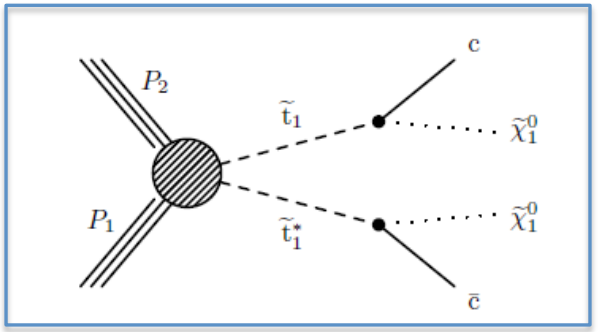
➔ Top decays lead to 3 channels: 0, 1, 2 leptons

➢ Sbottom searches





Relevant in compressed spectra

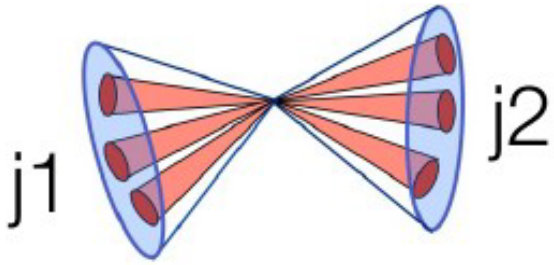


SUS-16-007 Stop searches: fully hadronic

Top p_T OR $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$

High Efficiency **Top Tagging** (HPTT)

Resolved topology

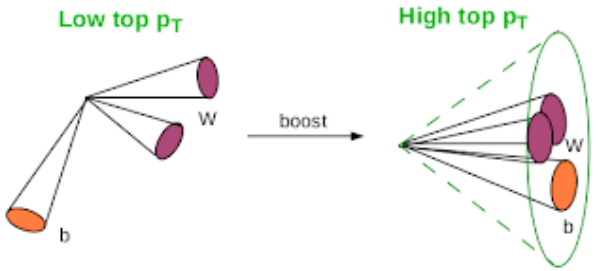


- Use AK4 jets
- Combination of 3 jets with ΔR=1.5
- Constraints on 2- and 3-body masses (W/top)
- Sensitivity to boosted topology:
  1- and 2-jets combination (W/top appearing as a single jet: mass constraints)

Optimized for low Δm, and mixed scenarios with T2tb decays

High Purity **Top Tagging** (HPTT)

Boosted topology



Use Ak8 jets – CMS Top Tagging algo:

- At least 3 subjets
- Jet mass: [140-250] GeV
- MinMass(3 highest p_T subjets)>50 GeV
- p_T>400 GeV

More efficient for T2tt models with medium and large Δm

SUS-16-007

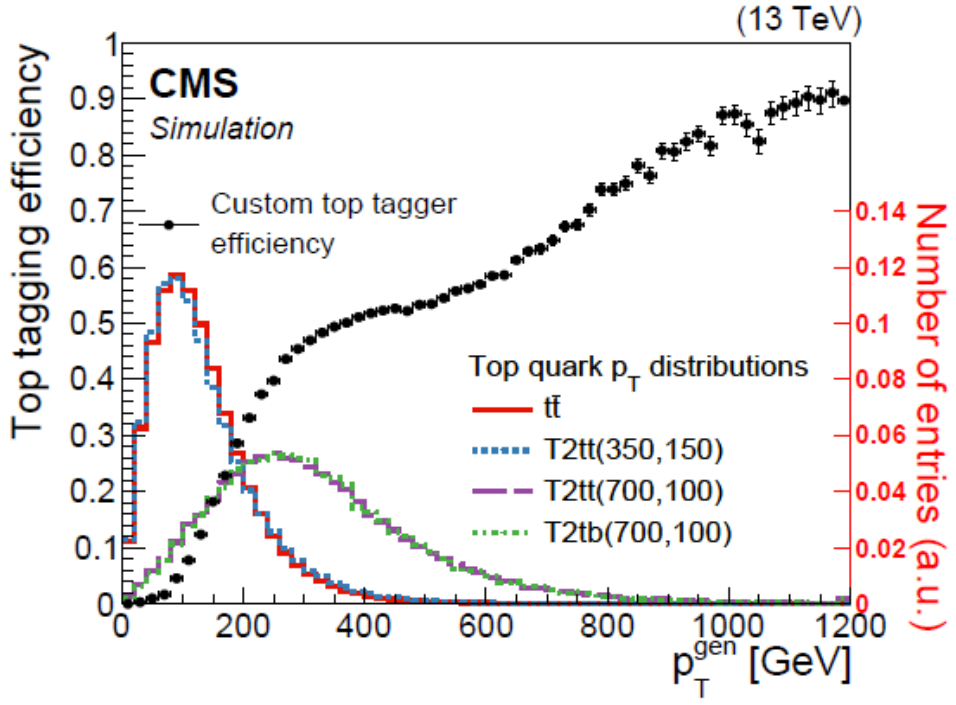
Stop searches: fully hadronic

Top p_T OR $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$

High Efficiency Top Tagging (HPTT)

Performances measured in data

- Tag-and-probe method in tt-1l enriched sample
- MC/Data agreement: flat 5% uncertainty



High Purity Top Tagging (HPTT)

Performances measured in data

- Efficiency measured with tt-1μ enriched sample: 10% uncertainty
- Fake rate measured a Control Sample with H_T>1 TeV & MET>200 GeV:
  - 30% overestimation in MC (corrected)
  - 10% uncertainty

SUS-16-007 Stop searches: fully hadronic

Selection

- $N_j \geq 4$ (5) ($p_T \geq 30$ (20) GeV) [suppress QCD]
- $N_b \geq 1$ ($N_b^l \geq 2$) [suppress EW]
- Isolated Lepton veto ($e/\mu/\tau_h$) [suppress 1l processes]
- Min $\Delta\phi$ (j,MET) > 0.5 (among 3 or 4 leading jets) [suppress QCD]
- MET>200(250) GeV [suppress tt] (+ HT > 500 GeV)

Introduce discriminating variables

$$M_T(b_{1,2}, \not{E}_T) \equiv \mathrm{Min}[M_T(b_1, \not{E}_T), M_T(b_1, \not{E}_T)]$$

End-shape at top mass for tt

$$M_{T2} \equiv \min_{\vec{q}_T^{(1)} + \vec{q}_T^{(2)} = \vec{p}_T^{\,\mathrm{miss}}} [\max\{m_T^2(\vec{p}_T^{(1)}; m_P^{(1)}, \vec{q}_T^{(1)}; m_{\tilde{\chi}_1^0}), m_T^2(\vec{p}_T^{(2)}; m_P^{(2)}, \vec{q}_T^{(2)}; m_{\tilde{\chi}_1^0})\}]$$

$M(\tilde{\chi}_1^0) = 0$

Estimator of stop mass for signal

MET is coming from $\tilde{\chi}_1^0$

SUS-16-007

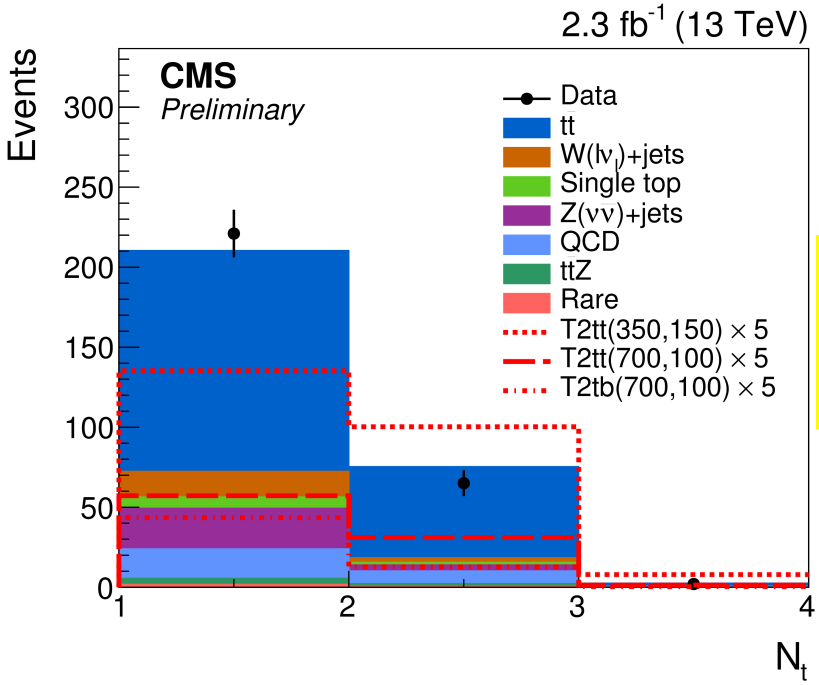
Stop searches: fully hadronic

Top p_T OR $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$

High Efficiency Top Tagging (HPTT)

Binning:

- N_{top}, N_b, MET, M_{T2}
- 37 exclusives search regions

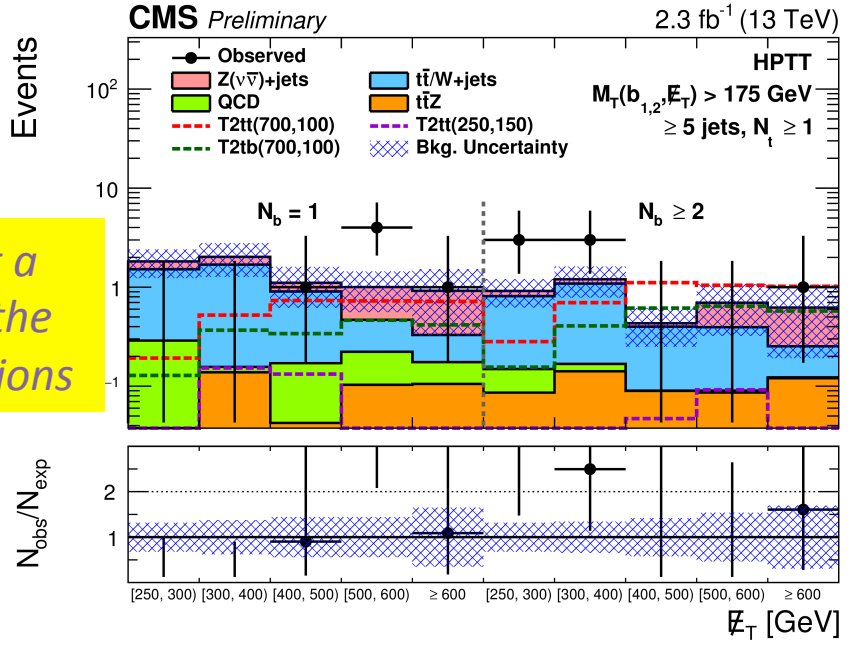


This is just a subset of the Signal regions

High Purity Top Tagging (HPTT)

Binning:

- N_{top}, N_b, N_{jets}, M_T(b,MET)
- 50 exclusives search regions



SUS-16-007 Stop searches: fully hadronic

Generalities:

- Major backgrounds estimated from **orthogonal control regions (CR)**
  - Define to be as **close** as possible to the signal regions (~ same binning)
  - **Integration over some variables** done to increase the statistical power of the estimation when no dependencies are observed
  - Make use of **Transfer Factors** (Control -> Signal region)
- Rare backgrounds taken from simulation
  - **reweighted** to the most accurate x-section and to known mis-modeling of the simulation (ex: PU)
  - all uncertainties (theory – experimental) are taken into account
- Signal is taken from simulation in similar way to the MC background (reweighting + uncertainties)

Background estimation strategy for fully hadronic stop searches

- **Lost lepton background:** from 1l CR. MT < 100 GeV.
- **Z→νν:** Use an enriched 2l CR as well as a γ +jets CR
- **Multi-jet background:** estimated from a CR defined by inverting the cut on Δϕ (jets, MET)
- **ttZ:** from simulation

SUS-16-007

Stop search: one lepton

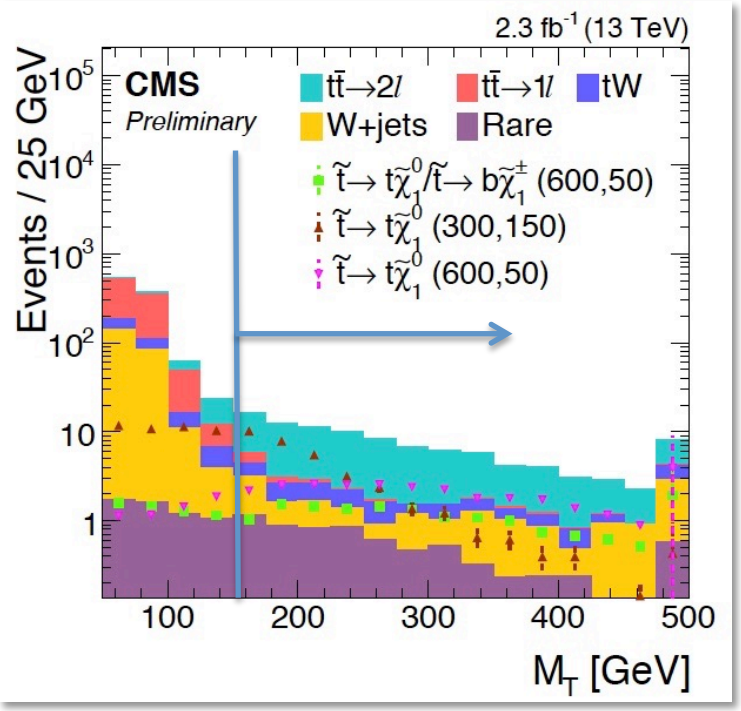
Selection

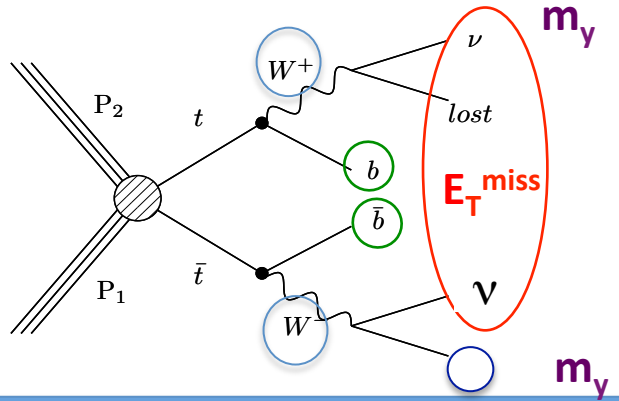
- 1 lepton (e/μ)
- MET > 250 GeV
- At least one b-tagged jet (against EWK)
- M_T > 150 GeV (against W+jets & tt →1l)
- No extra e/μ/τ (against tt → 2l)

Binning

- N_{jet} (2, 3 or ≥ 4 jets)
- MET bins
- MT2W [</> 200 GeV]

$$M_{\mathrm{T2}}^{\mathrm{W}} = \min\{m_y \text{ consistent with } [p_1^2 = 0, (p_1 + p_\ell)^2 = p_2^2 = M_W, \vec{p}_{\mathrm{T}}^{\,1} + \vec{p}_{\mathrm{T}}^{\,2} = \vec{E}_{\mathrm{T}}^{\mathrm{miss}}, (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2,]\}$$

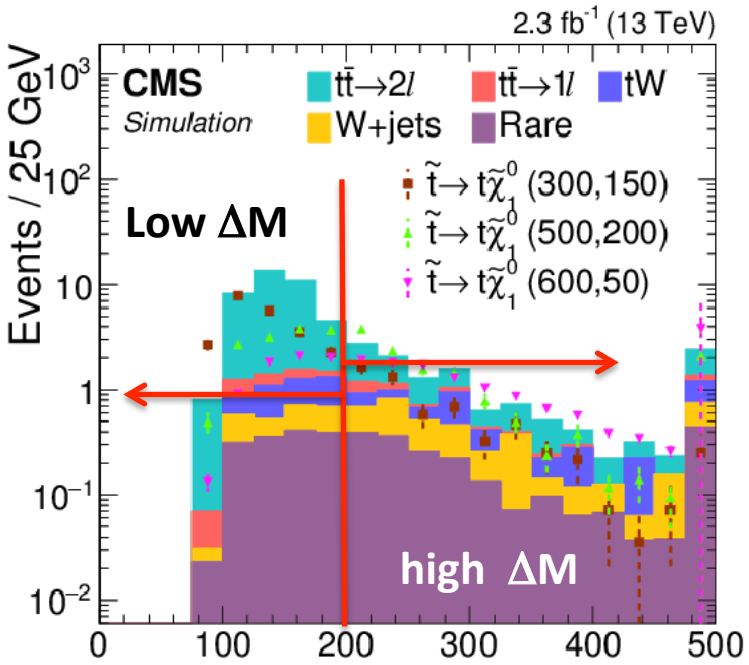




SUS-16-007

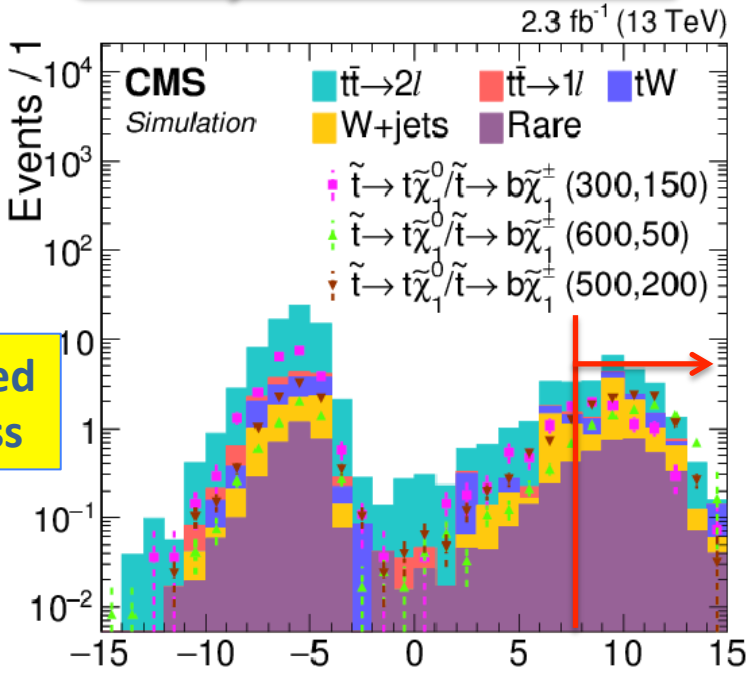
Stop search: one lepton

3- >=4 jets selection



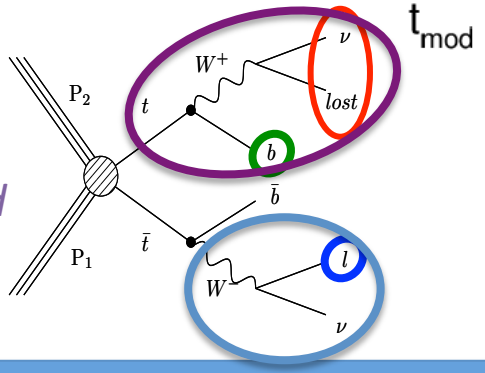
MT2W

2 jets selection



Modified topness

Use t^{mod} instead of MT2W to suppress tt-2l background: X^2 with W^l mass and $top^{lost\ lepton}$ mass



SUS-16-002

Stop search: one lepton

2 jets

Soft /invisible decay

Small $\Delta M(\tilde{\chi}_1^+, \tilde{\chi}_1^0)$

3 jets

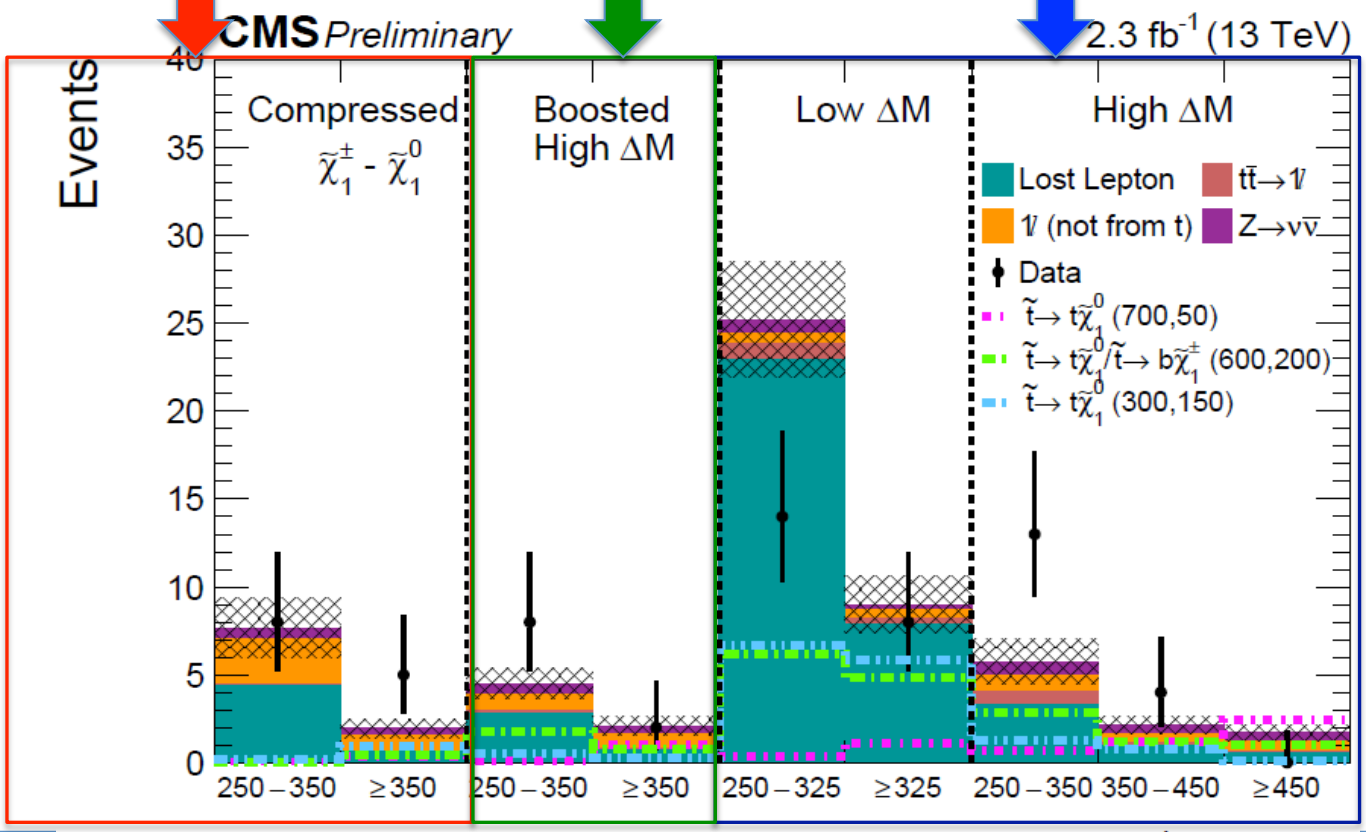
Boosted hadronic W

V.Large $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$

≥ 4 jets

MT2W used to discriminate

Small and high $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$



SUS-16-007

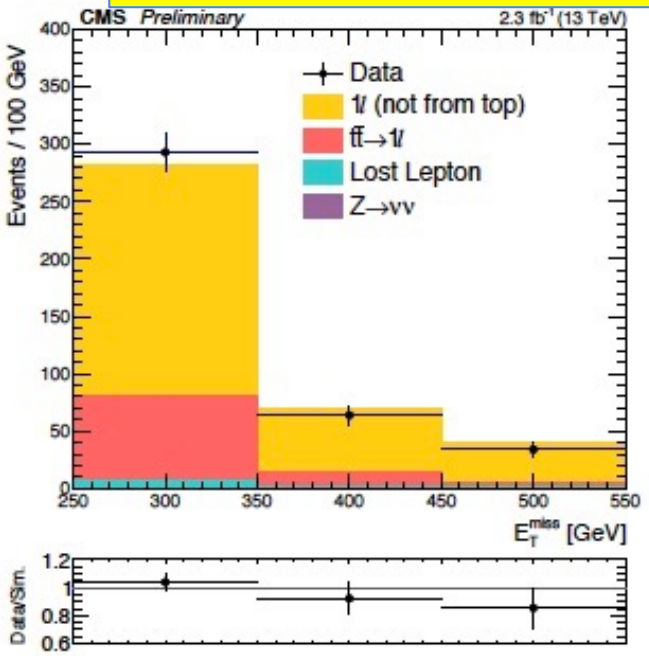
Stop search: one lepton

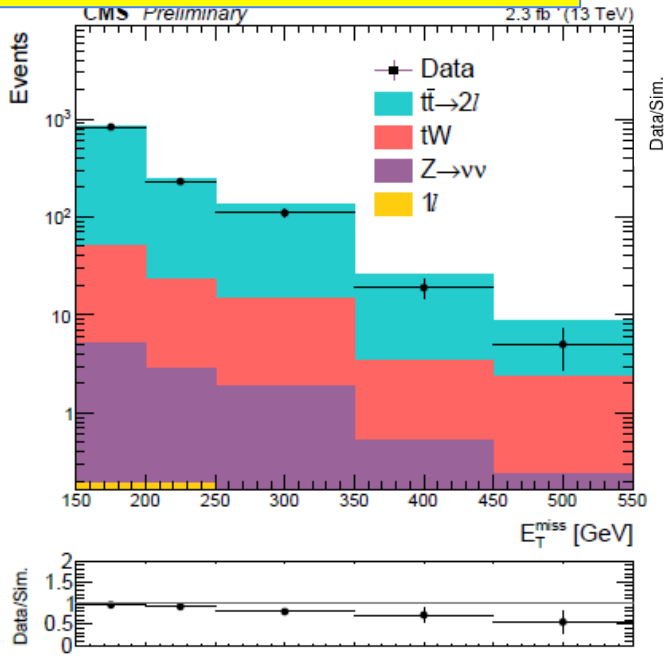
Background estimation

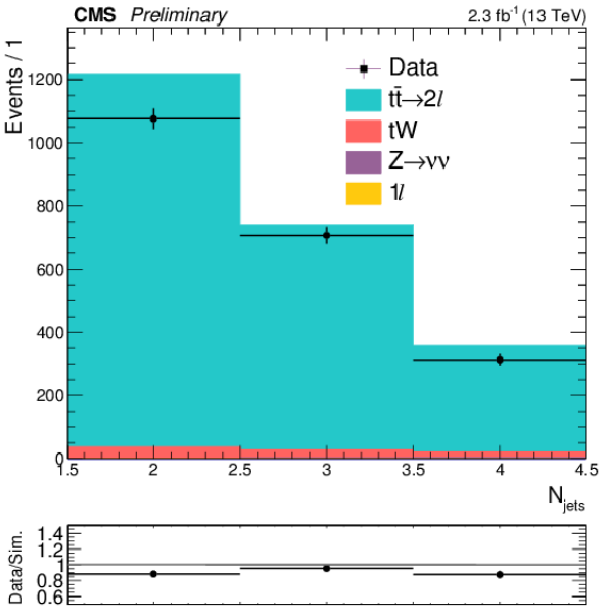
- **Lost lepton**: taken from a 2l CR
- **W+Jets**: estimated from 0 b-tag CR
- **Minor backgrounds**: from simulation

MET distribution in CR

W+j enriched **tt-2l enriched**



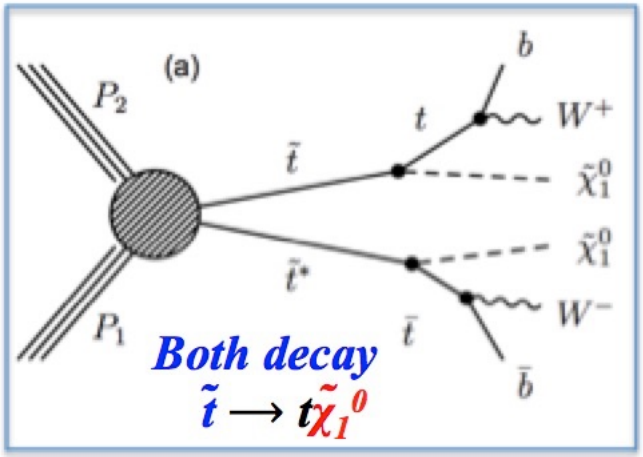


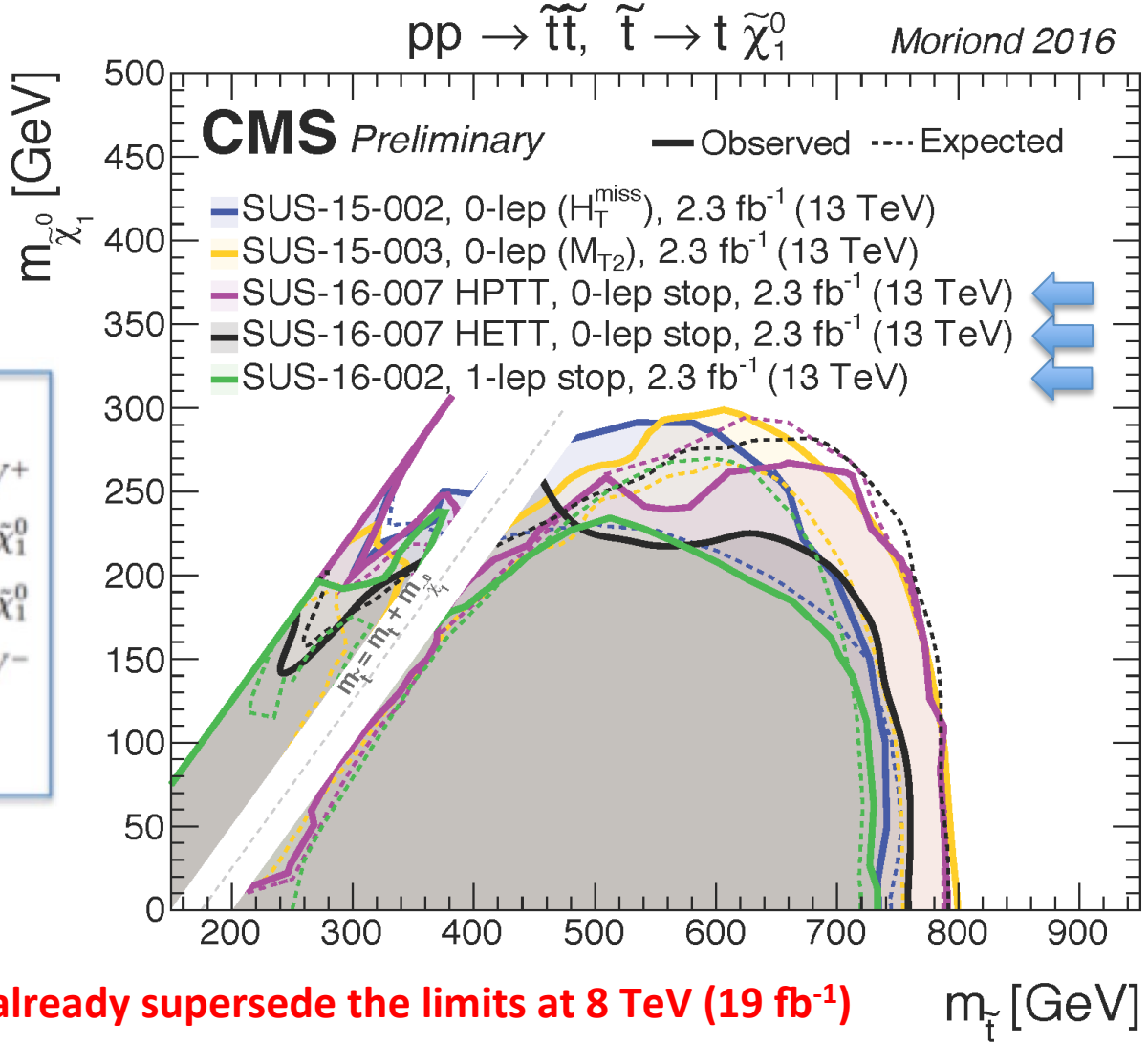


Njet distribution in an enchriched tt-2l CR

Stop searches: Combination

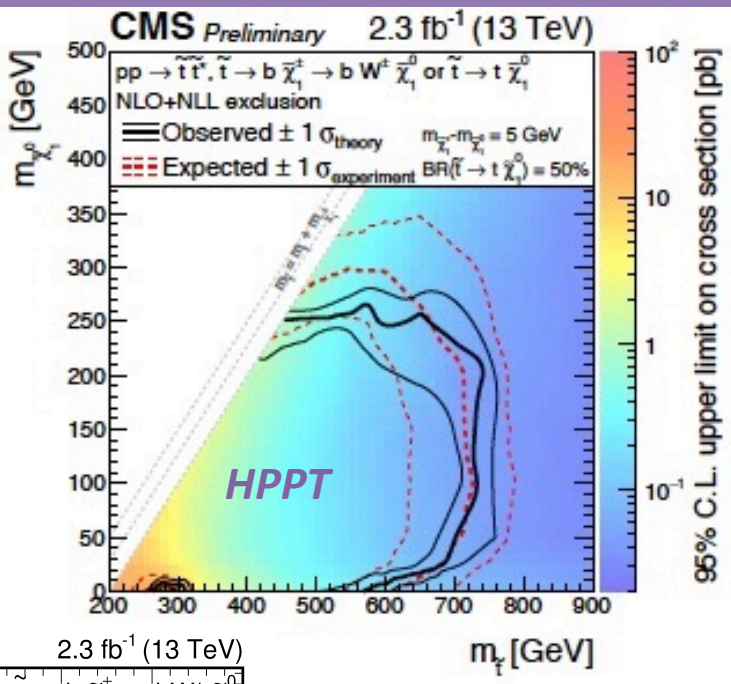
BR=100%

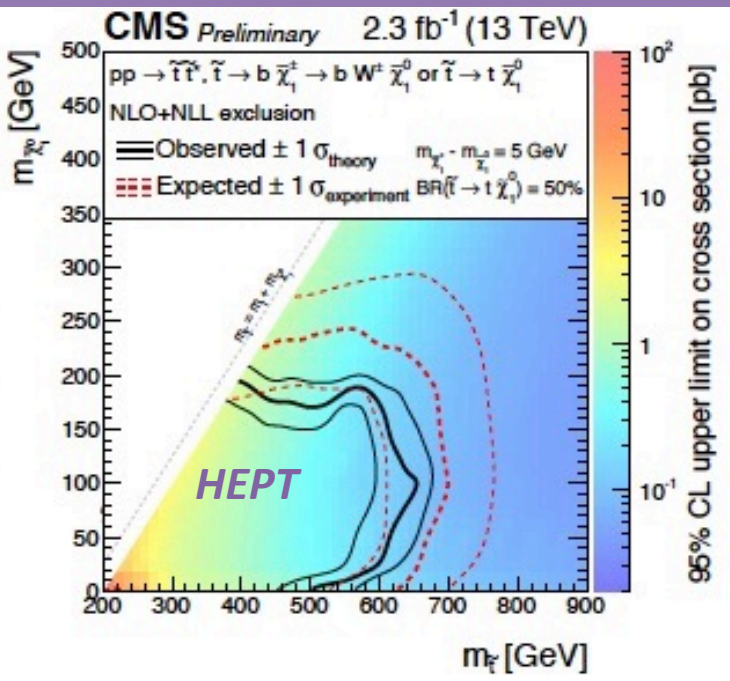


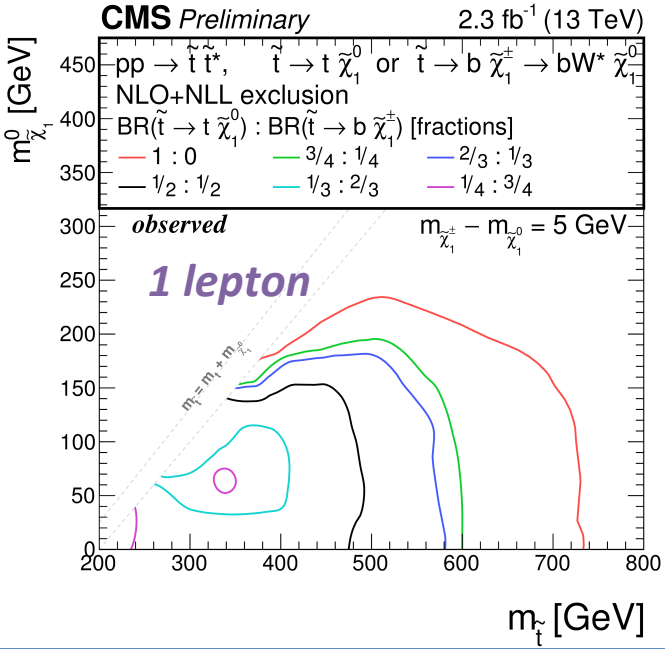


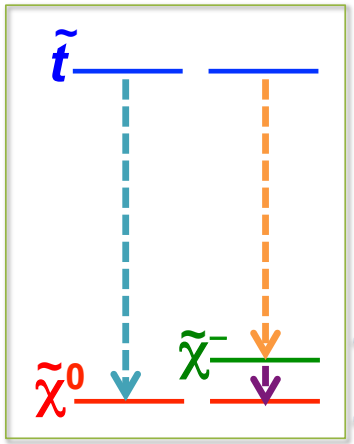
First 13 TeV results (2.3 fb^{-1}) already supersede the limits at 8 TeV (19 fb^{-1})

Assume BR= 50 % for both channels

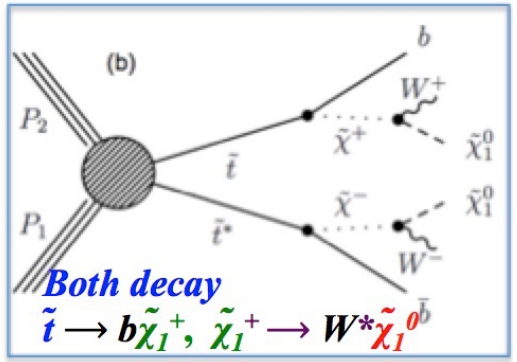








$\Delta M(\tilde{\chi}_1^+, \tilde{\chi}_1^0)$ =5 GeV



SUS-16-001

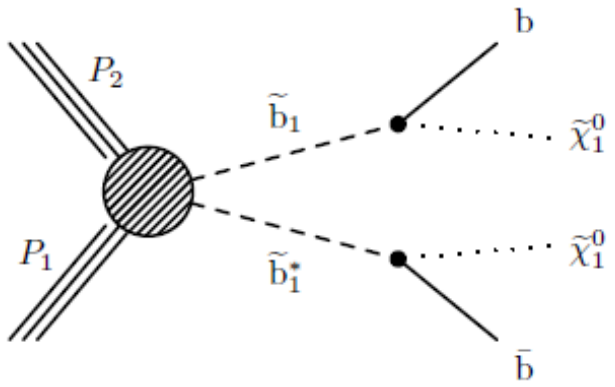
Sbottom search

- **Selection:** veto ℓ or isolated track, **two or three jets** with p_T>50 GeV, MET>250 GeV (MET trigger), $\Delta\phi(j_{123},MET)$> 0.4

Non-compressed

Selection:

- $p_T(j1)$>100 GeV, $p_T(j2)$>75 GeV
- both are **b-tagged**,
- H_T>200 GeV, m_{CT}>250 GeV



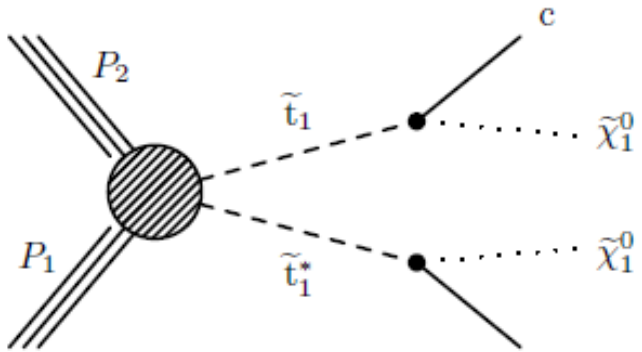
Compressed

Selection:

- $p_T(j1)$>250 GeV - NOT b-tagged

➔**Require a ISR jet to boost the system**

- $p_T(j2)$>60 GeV, **b-tagged**
- $\Delta\phi(j1,MET)$>2.3



Sensitive to small $\Delta M(\tilde{t}, \tilde{\chi}_1^0)$

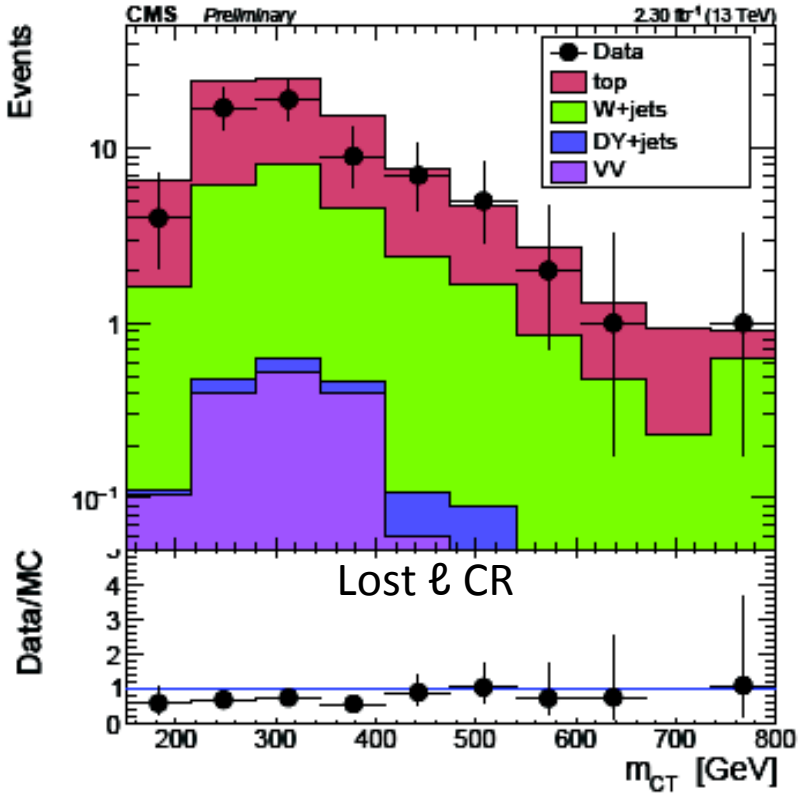
SUS-16-001

Sbottom search

Non-compressed

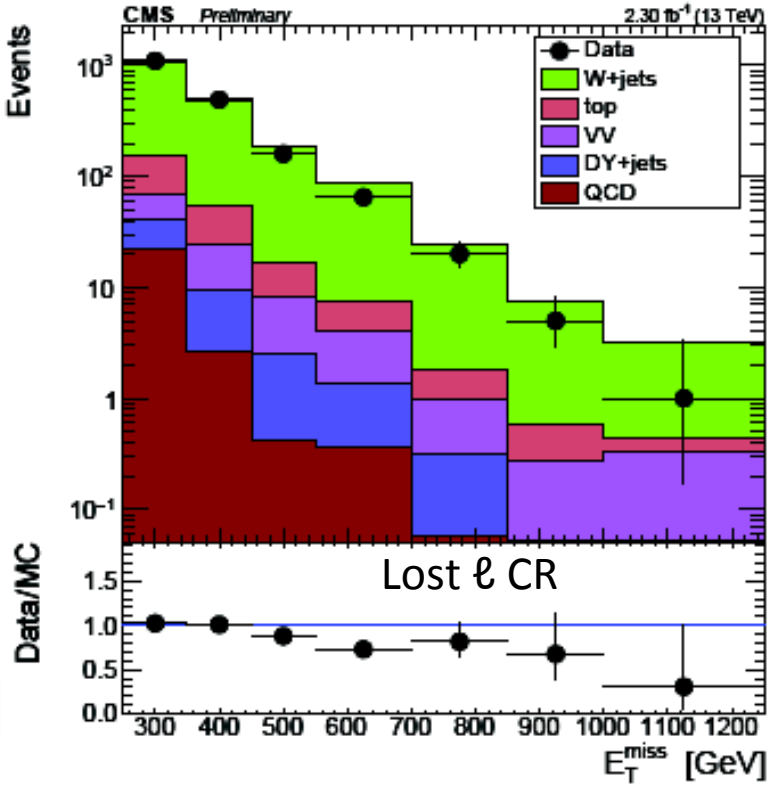
Binning: H_T and m_{CT}

$$m_{CT}^2(j_1, j_2) = [E_T(j_1) + E_T(j_2)]^2 - [p_T(j_1) - p_T(j_2)]^2$$
$$= 2p_T(j_1)p_T(j_2)(1 + \cos\Delta\phi(j_1, j_2)),$$



Compressed

Binning: $N_{b\text{-jets}}$, MET

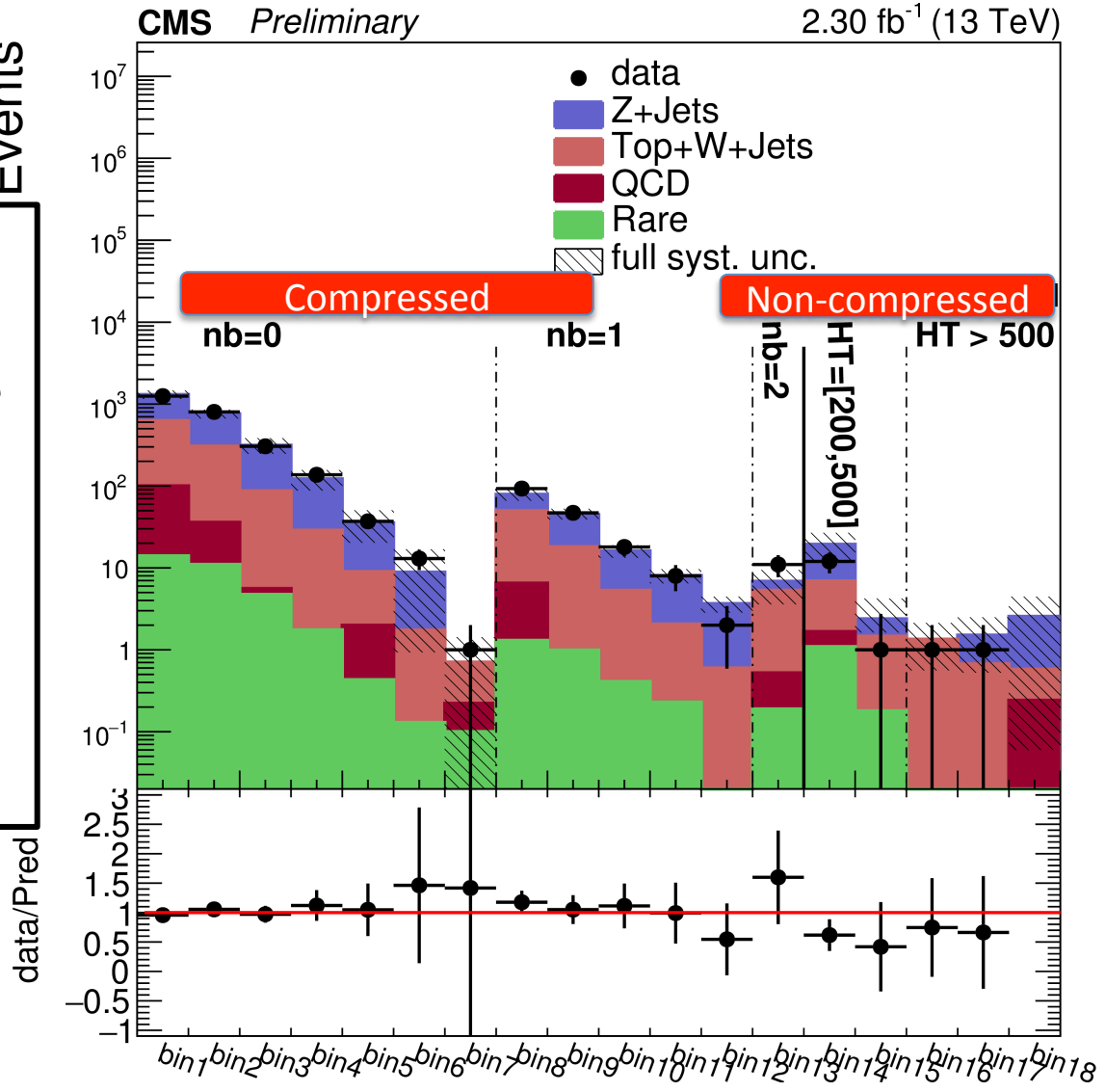


SUS-16-001

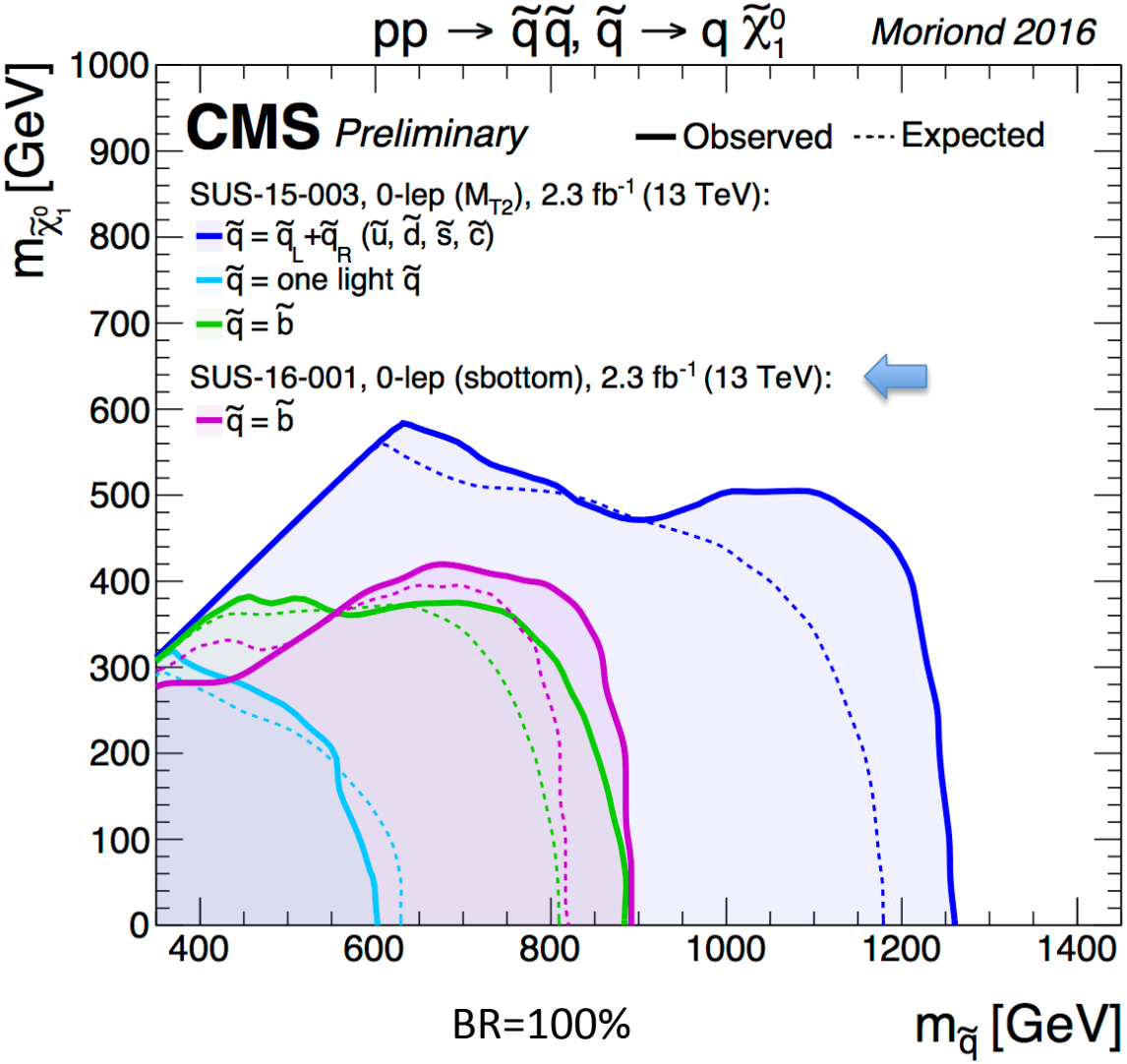
Sbottom search

Main backgrounds estimation:

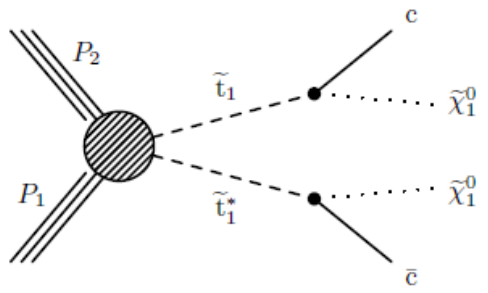
- **Z➔νν:**
  from a Z➔ μμ enriched sample
  μ's are removed to recompute all the kinematic variables
- **Lost lepton backgrounds**:
  from a enriched e/μ single control sample
- **QCD multijets:**
  from control region defined by the inversion of the Δϕ(j,MET) cut and at lower MET values

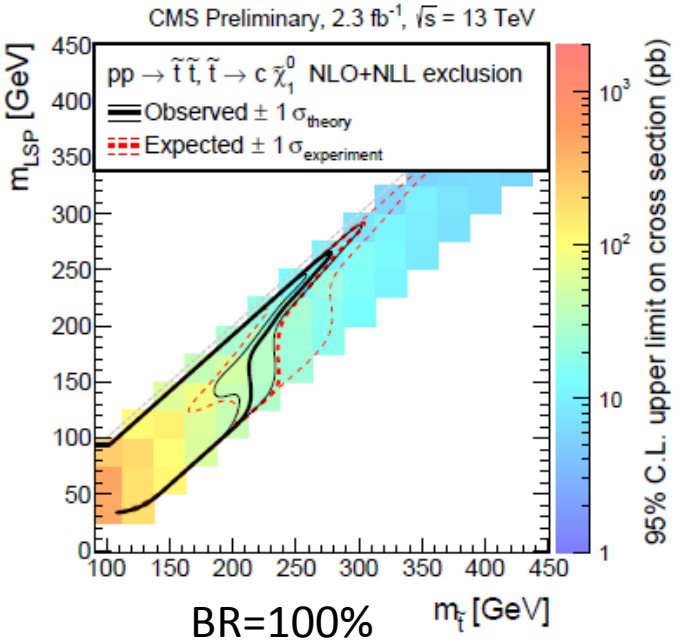


Sbottom searches: exclusion limits



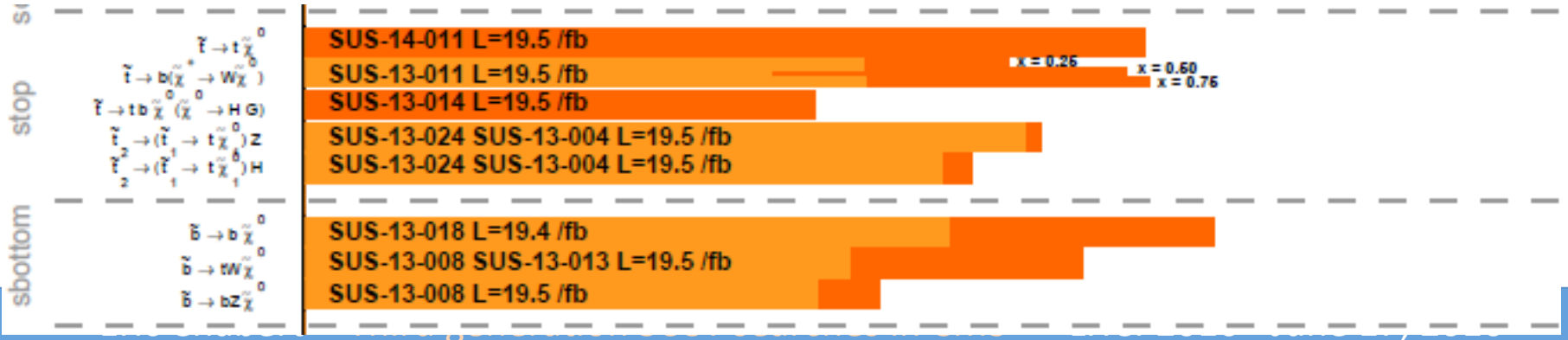
Stop limit interpretation





Conclusion

- Targeted searches for third generation squarks
  - Covering **broad range of signatures** with dedicated tools
  - Use **dedicated approaches** to cover the different kinematics (compressed, moderate, boosted): top-taggers, specific variables
- No evidence yet, results interpreted in terms of limits in SMS
- Stop searches with 2015 data beginning to surpass 8 TeV limits $m_{stop} > 800$ GeV for low m_{LSP}
- Run2 will boost the reach
  - Focus on compressed scenarios, and $\Delta m \approx mt$
  - Work on isolation, boosted objects, high pileup
  - Expand interpretations



Future …

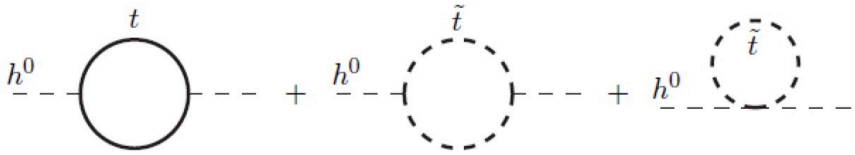
Diversity is the keyword

we don't know where the SUSY could be (if…) and we should try to cover as much possibilities as we can

Backup

Physics motivation

- Partial cancelation of the top quark radiative corrections to the Higgs mass ➔ natural SUSY models

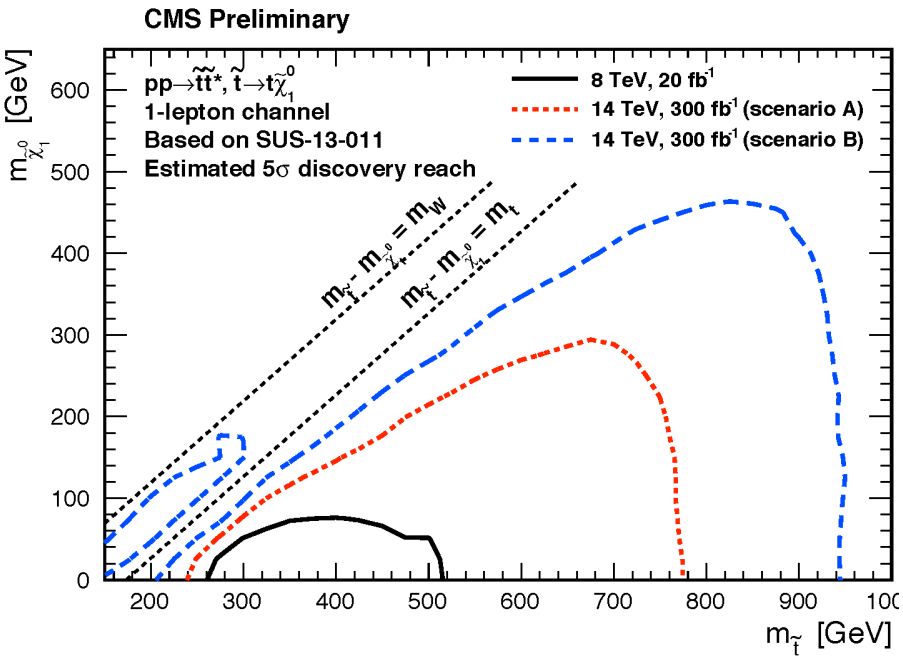


  - Stop expected to be "light"
  - IF lowest color-charged SUSY particle ➔highest cross-section

- Link with Dark Matter (DM)
  - In RP-conserved models, LSP is stable. In most of the models it is the neutralino (WIMP candidate)
  - Stop-neutralino co-annihilation could contribute to the relic DM density: favors low mass difference

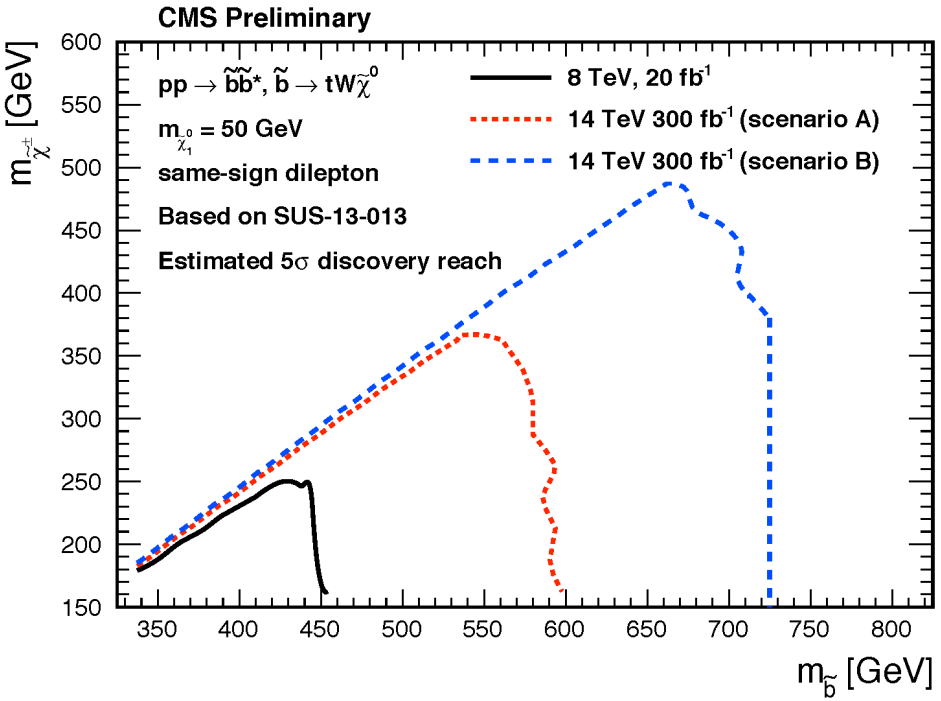
Perspectives

- As a reminder, these are some simple extrapolation made for Snowmass



Stop discovery potential

Sbottom discovery potential



Material

- Latest results: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- Covered analysis:
  - SUS-16-001
  - SUS-16-002
  - SUS-16-007

Simulation

- Generations
  - MADGRAPH5: tt, W+jets, Z+jets, gamma+jets [with NNPDF3.0]
  - POWHEGv1.0:
  - MAGRAPH5_AMC@NLO: single top, ttZ, ttW
- PDF: NNPDF3.0
- PS+Hadronization: PYTHIA8.1
- Simulation: GEANT4 based
- Cross-section normalization: (N)NLO+NLL (when possible)
- Monte-Carlo correction
  - Lepton efficiencies (estimated from Z+jets) [param: kinematics]
  - B-tagging efficiencies (di-jets+tt) [param: kinematics & flavor]
  - PileUp reweighing [data/MC ratios]

Stop search: 8/13 TeV comparison