SUSY searches at CMS

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On behalf of the CMS Collaboration

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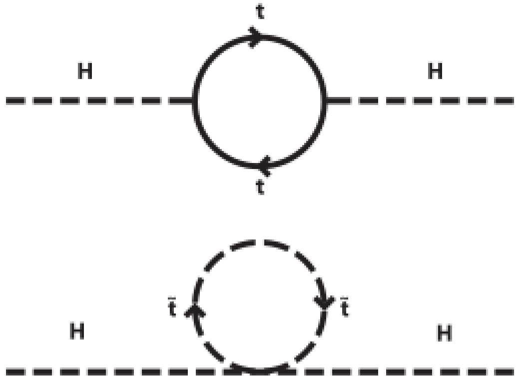
Outline

- Motivations;
- The CMS detector and dataset;
- Analysis strategies;
- SUSY searches at CMS:
  - ➔ Inclusive (hadronic) searches;
  - ➔ Searches in final states with leptons;
  - ➔ Searches in final states with photons;
  - ➔ Searches in final states with Higgs bosons;
- Conclusions and Outlook.

Motivations

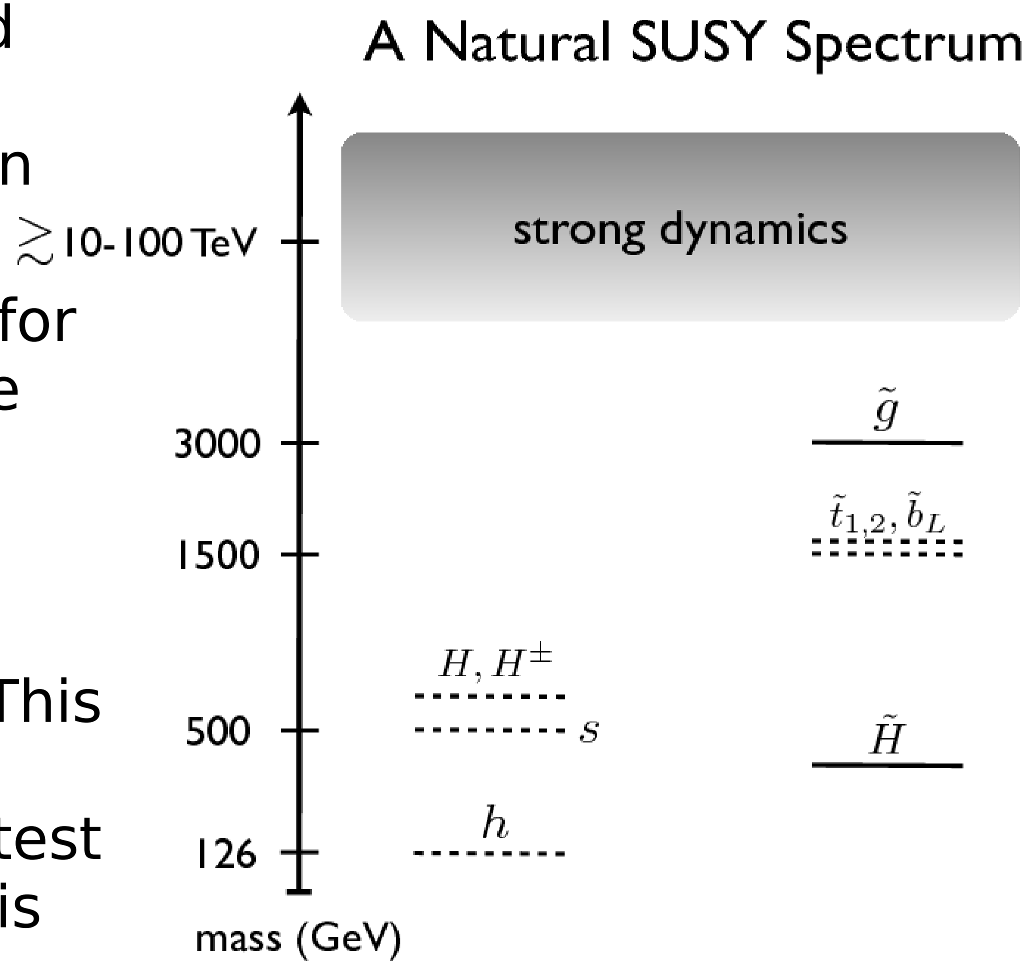
- The strongest motivation for Supersymmetry (SUSY) comes from the need to stabilize the mass of the Higgs boson (the Hierarchy Problem);

- The mass of the Higgs boson receives quadratic radiative corrections from particles at higher energy scales;
- Unless some miraculous fine tuning of the parameters is in place, the mass of the Higgs boson is expected to drift away from ~125.6 GeV;
- SUSY is a symmetry that exchanges fermions with bosons;
- If we postulate that every fermion (boson) has a boson (fermion) partner, the quadratic divergences become logarithmic.

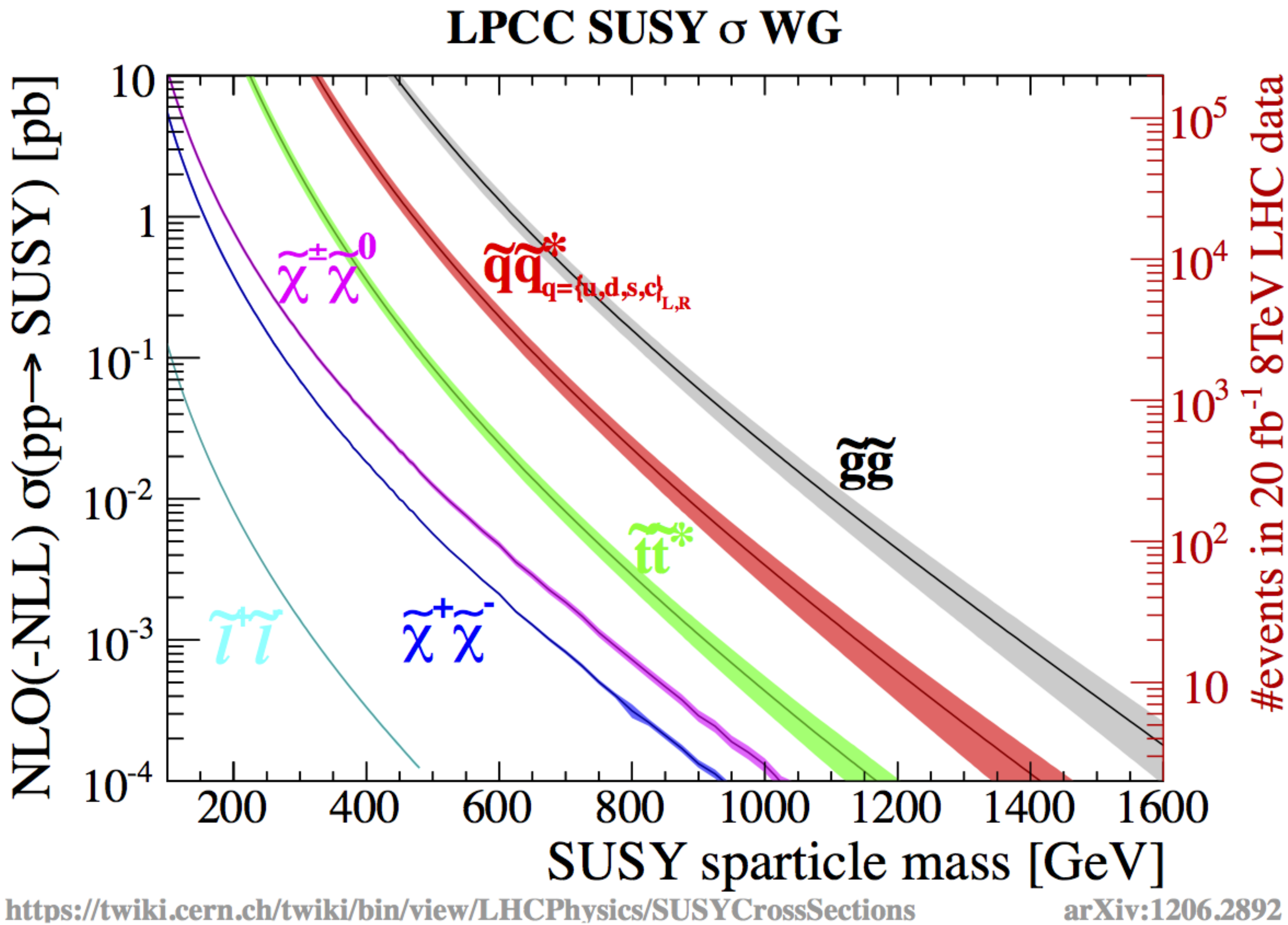


Motivations

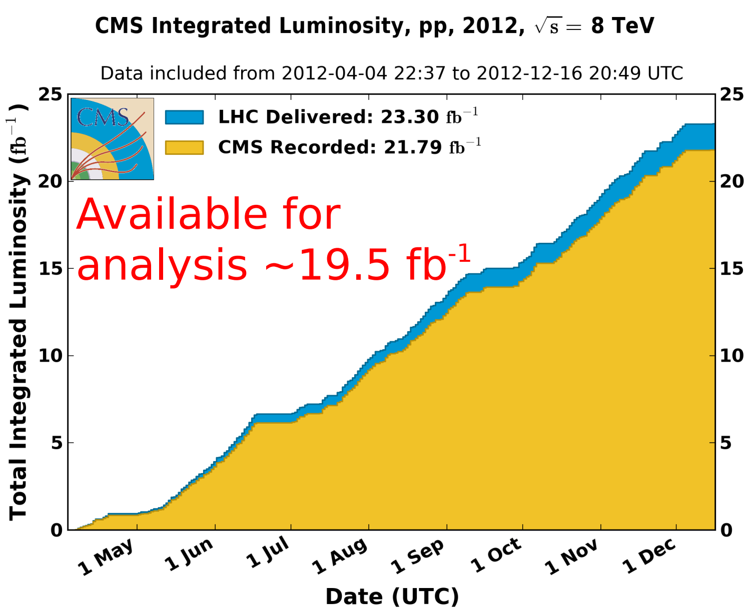
- In order to be “natural” (i.e. to avoid fine tuning), it is required that the mass of the stops is relatively small (not higher than the TeV scale);
- Similar requirements are valid for the mass of the sbottom(s), the higgsinos, and the gluinos;
- Many SUSY realizations also require R-parity conservation. This implies that SUSY particles are produced in pairs, and the lightest supersymmetric particle (LSP) is stable;
- The LSP could be an ideal candidate for the Dark Matter.

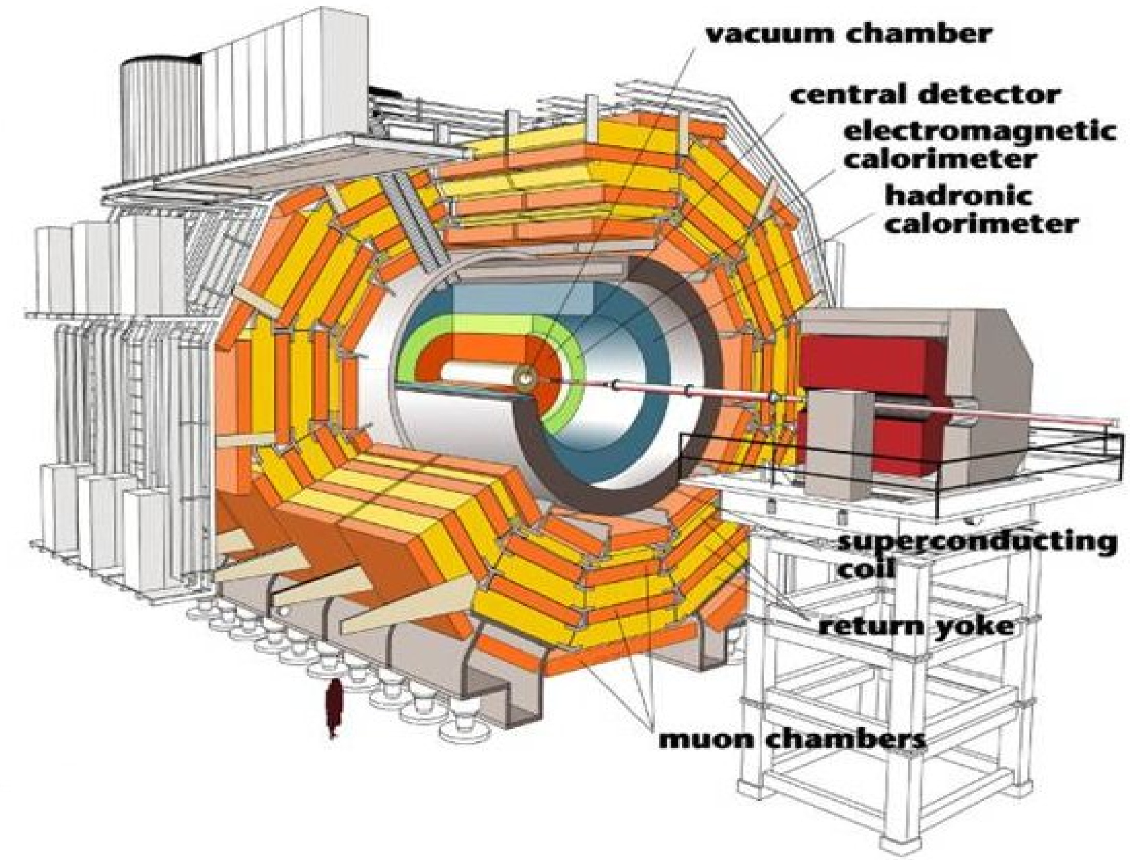


SUSY production at LHC



The CMS Detector at the LHC





General purpose detector, very broad SM physics program (including Higgs)… and a vast array of New Physics searches!

Analysis strategies

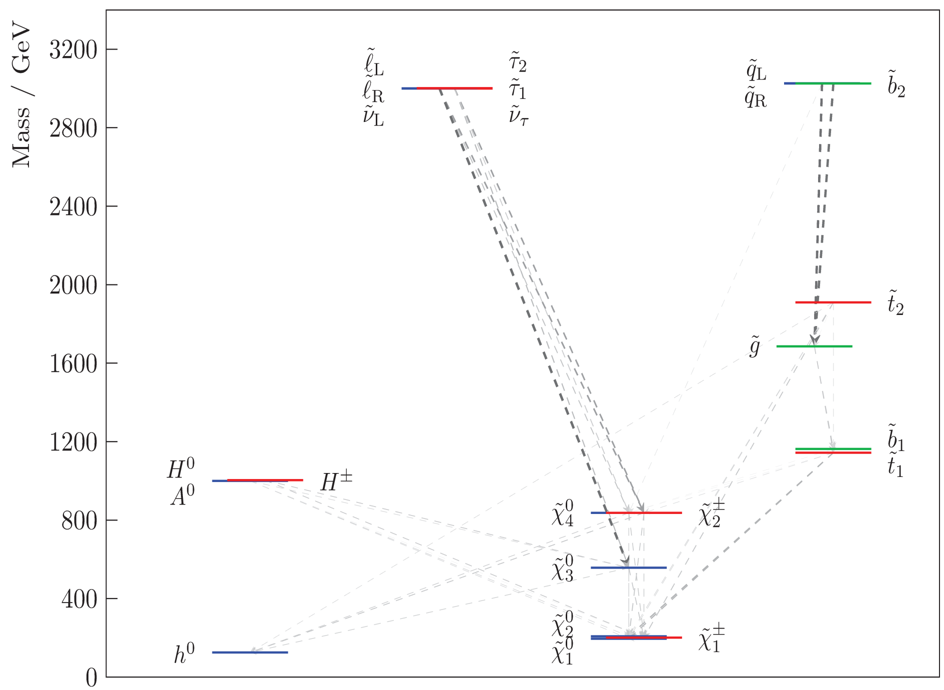
- Today I will focus on R-parity conserving SUSY searches;
- The lightest SUSY particle (LSP) is stable and neutral and the main signature in pp collisions consists in a significant amount of missing transverse energy (MET);
- We often reparameterize MET into alternative variables (M_{T2}, R, …) to exploit particular topologies we are searching for;
- Several sources of SM backgrounds:
  - multijet QCD (with MET arising from jet energy mismeasurements);
  - $t\bar{t}$, single top, W+jet;
  - $Z \rightarrow \nu\nu$ + jets;
  - diboson production;
  - lepton/photon misidentification;
- For the background estimation, we rely as much as possible on background data control samples, often utilizing “transfer factors” taken from the simulation.

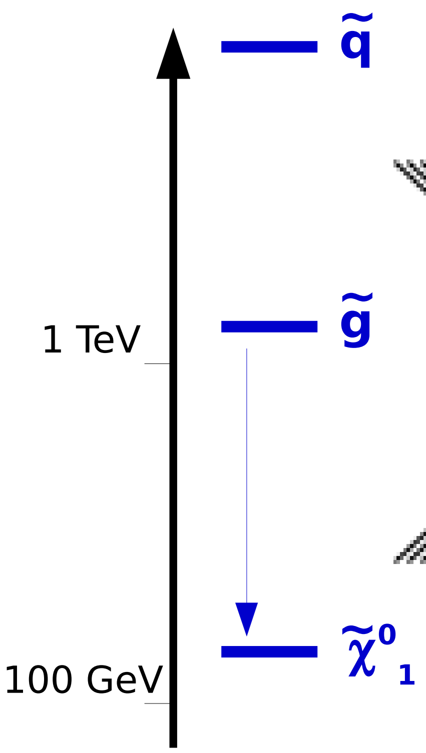
Interpretations

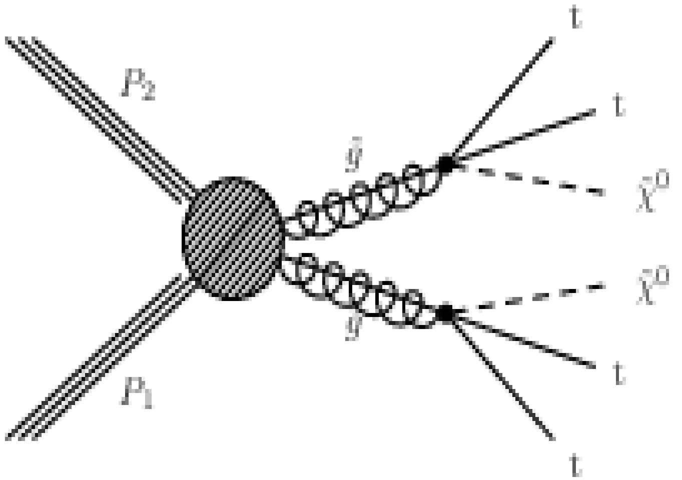
- We interpret the results of our analyses in the context of:

Full Models: (pMSSM, cMSSM, mSugra, ...), the whole SUSY spectrum and all possible decays are considered

Simplified Models (SMS's): focus on very specific decays, strong assumptions are made





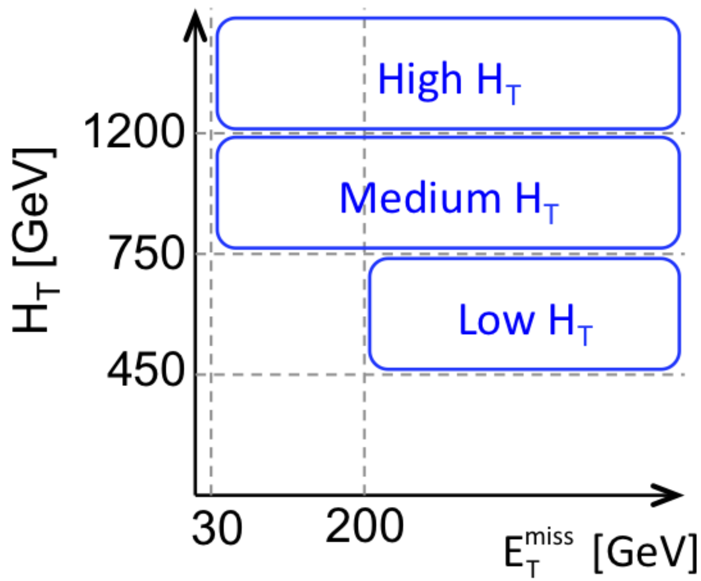


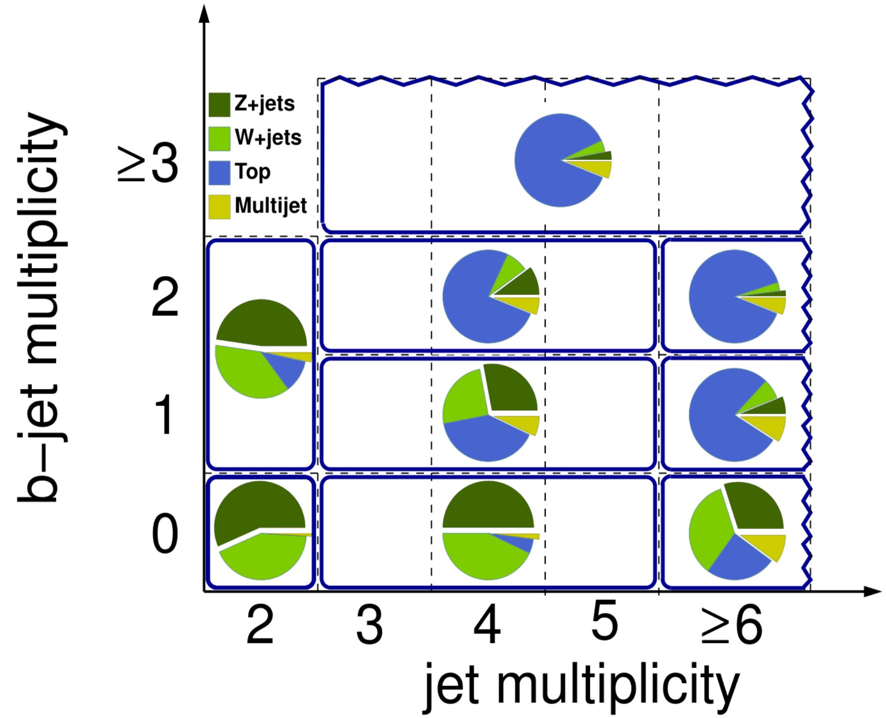
Today I will focus on SMS interpretations.

Inclusive Hadronic searches: M_{T2}

- Target: production of squark pairs and gluinos in fully hadronic final states;
- Many signal regions are defined:

HT: scalar sum of the p_T of the hard jets in the event





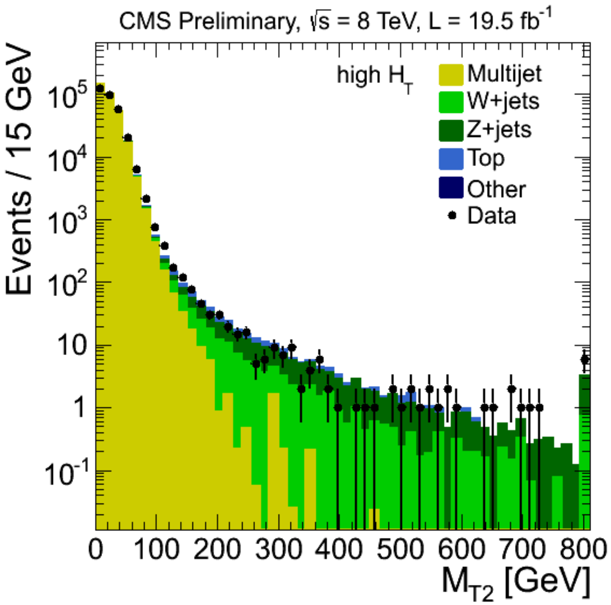
- Main discriminating variable, designed to be robust against jet energy mismeasurements:

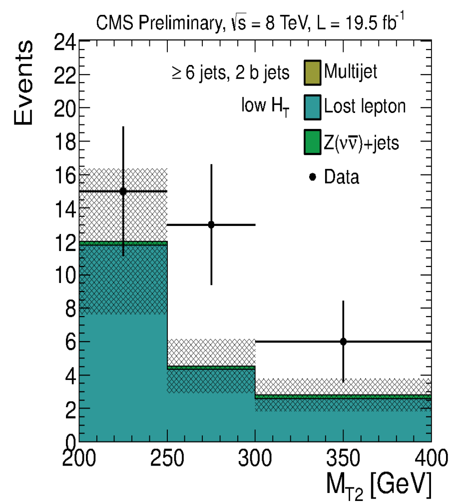
$$M_{T2}(m_{\tilde{\chi}}) = \min_{\vec{p}_T^{\tilde{\chi}(1)} + \vec{p}_T^{\tilde{\chi}(2)} = \vec{p}_T^{\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

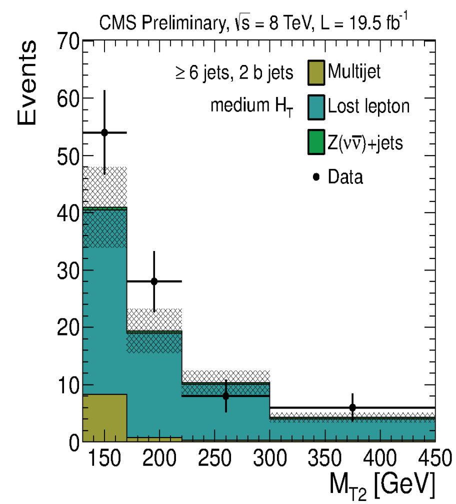
$$(M_T^{(i)})^2 = (m^{\text{vis}(i)})^2 + m_{\tilde{\chi}}^2 + 2\left(E_T^{\text{vis}(i)} E_T^{\tilde{\chi}(i)} - \vec{p}_T^{\text{vis}(i)} \cdot \vec{p}_T^{\tilde{\chi}(i)} \right)$$

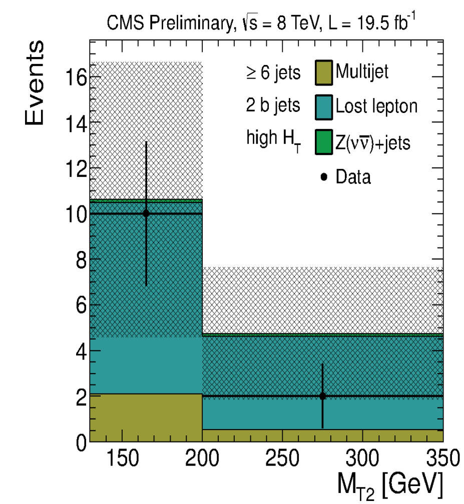
CMS-SUS-13-019

Inclusive Hadronic searches: M_{T2}



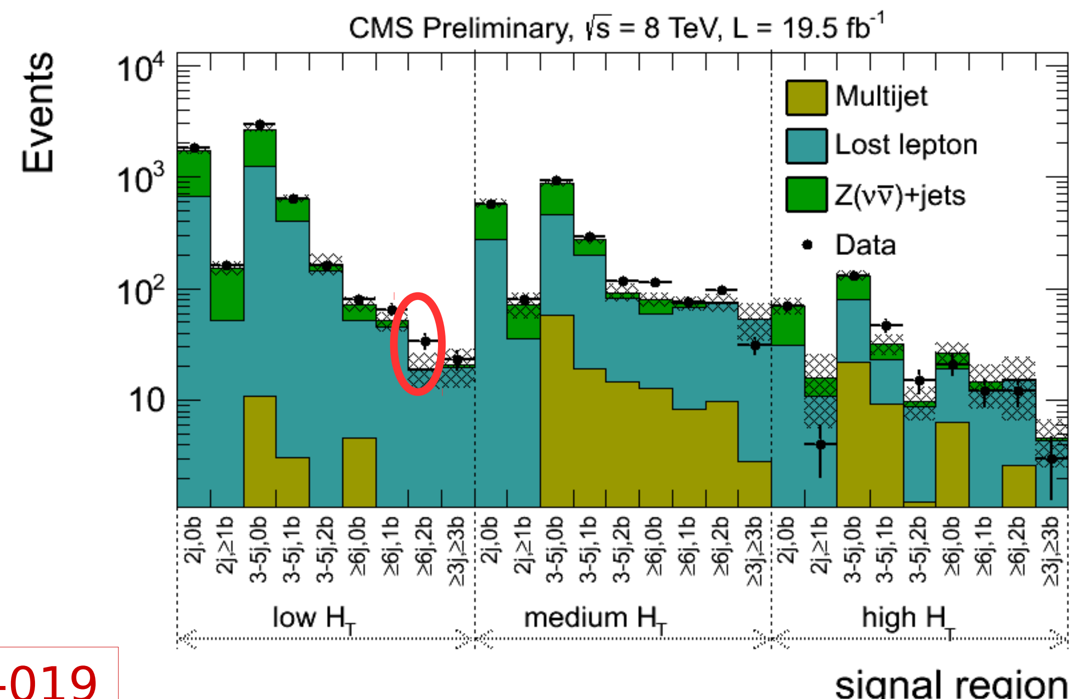






In general good agreement between data and background predictions is found.

A small excess observed in the $N_{jet} \geq 6$, $N_{b\text{-}jet} = 2$, low HT region is likely due to an under-fluctuation in the background control sample.



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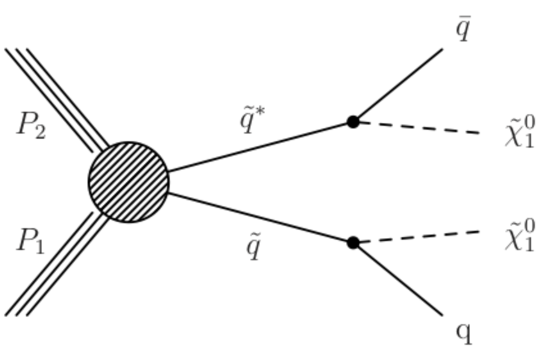
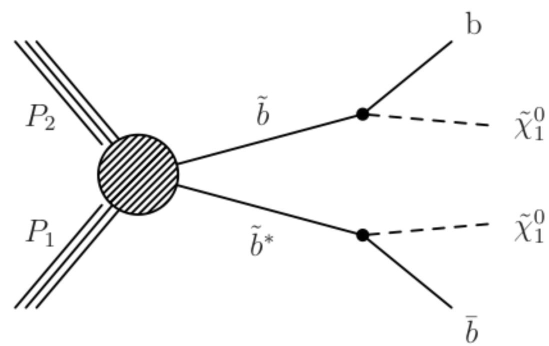
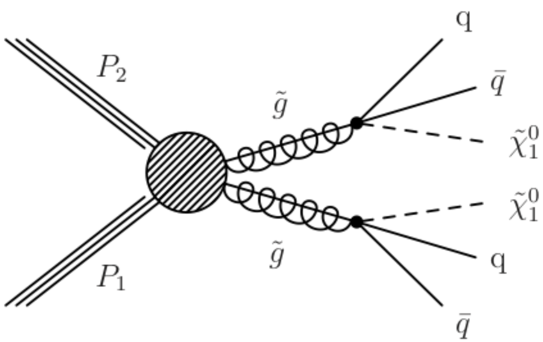
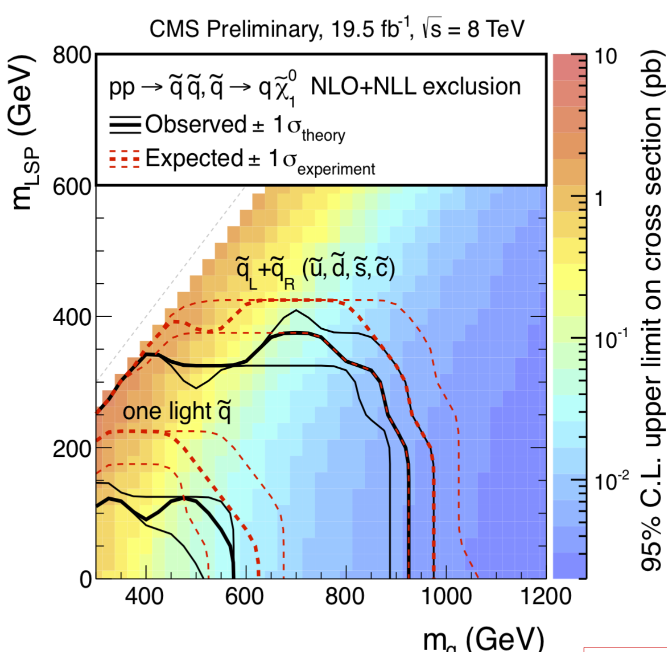
Inclusive Hadronic searches: M_{T2}

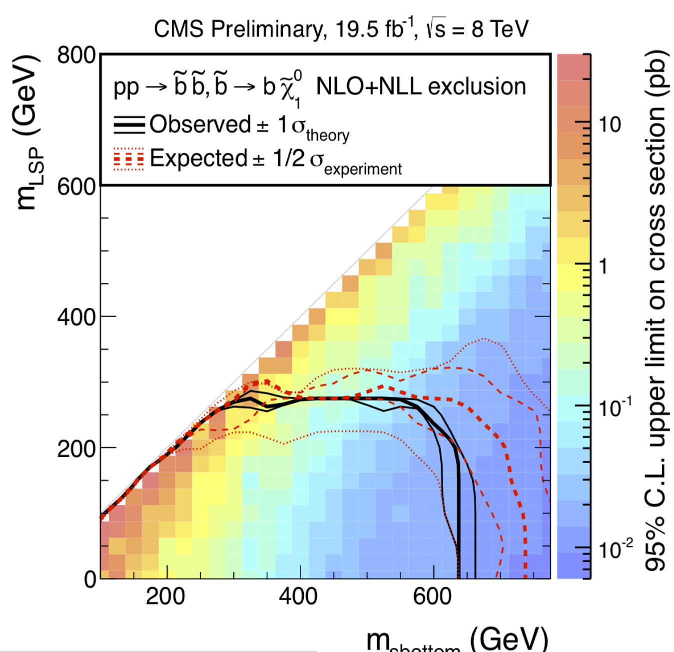
For the interpretation, only the signal regions expected to be sensitive to the signature under study are used:

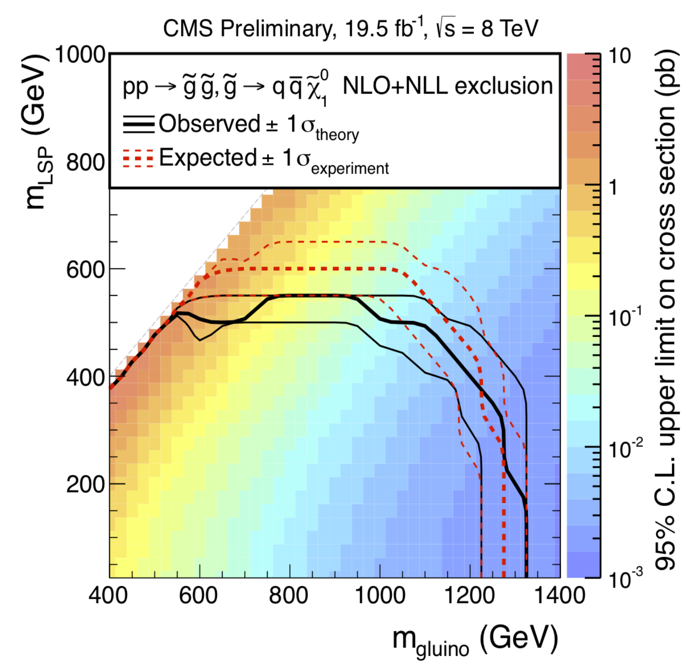












CMS-SUS-13-019

Search for direct $\tilde{b}$ production

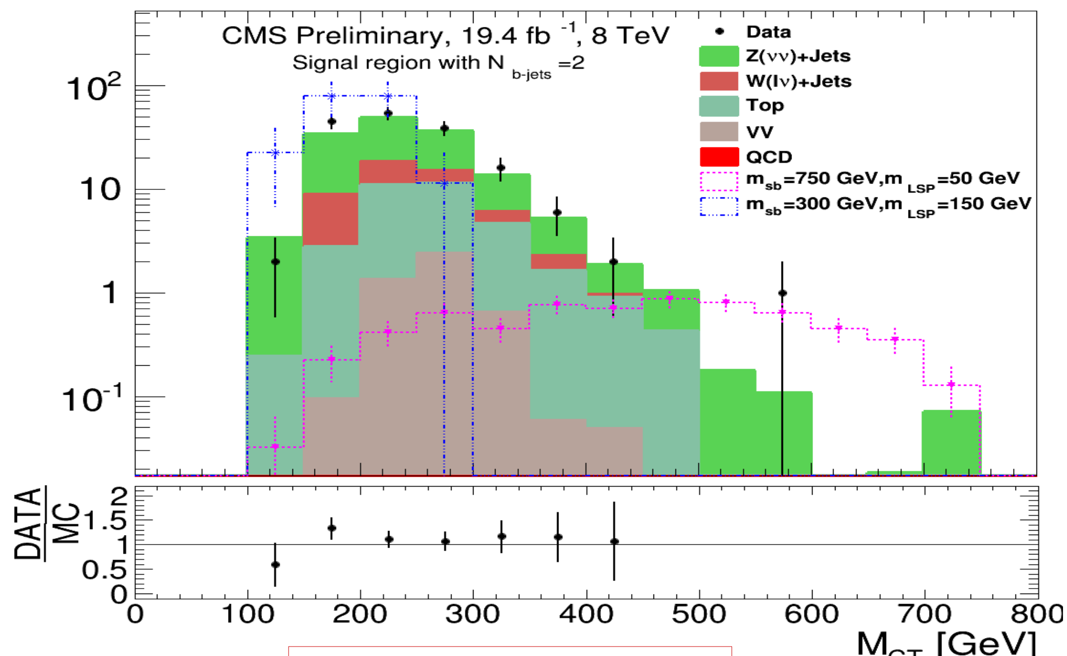
- Target: direct sbottom pair production;
- Main discriminating variable:

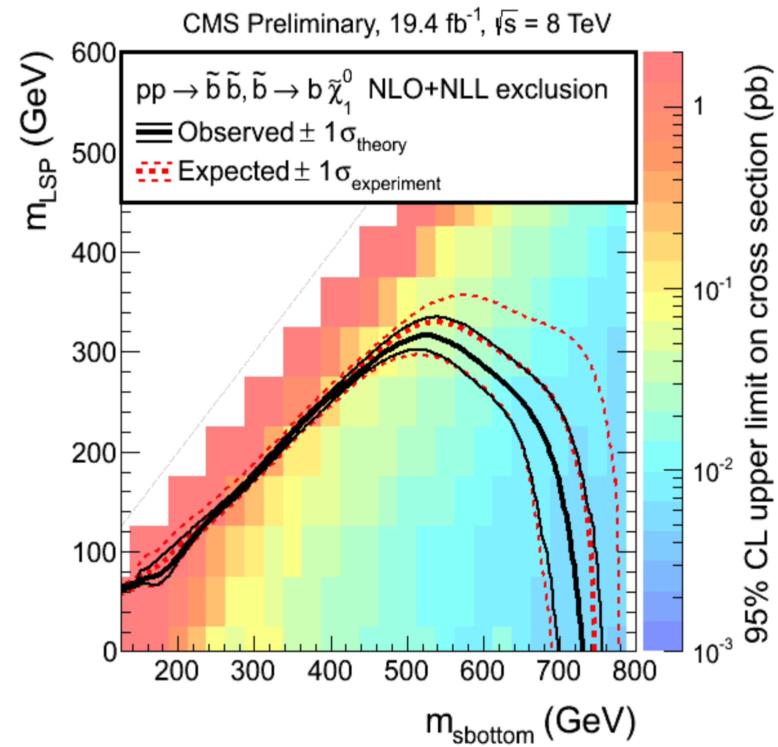
$$M_{CT}^2(J_1, J_2) = [E_T(J_1) + E_T(J_2)]^2 - [\mathbf{p_T}(J_1) - \mathbf{p_T}(J_2)]^2 = 2p_T(J_1)p_T(J_2)(1 + \cos\Delta\phi(J_1, J_2))$$

- Dominant backgrounds: $Z(\nu\nu)$+jets, $W(l\nu)$+jets, $t\bar{t}$, estimated from single μ data.

Selection:

- exactly 2 jets with $p_T > 70$ GeV;
- $\Delta\phi(j_1,j_2) < 2.5$;
- at least one of the jets is a b-jet;
- HT > 250 GeV, MET > 175 GeV, MT (j_2,MET) > 200 GeV.



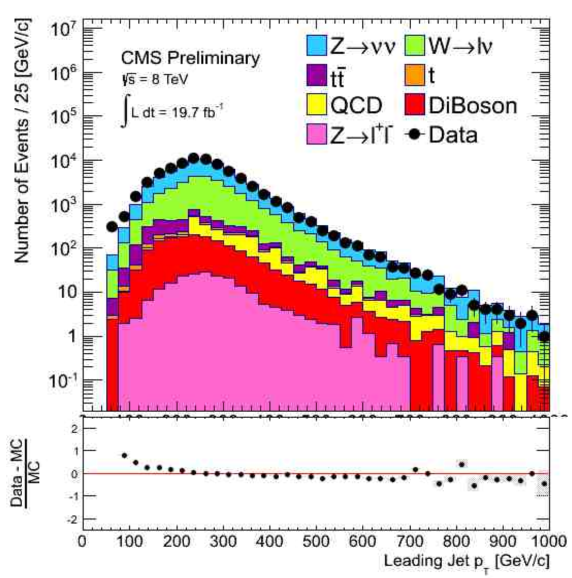


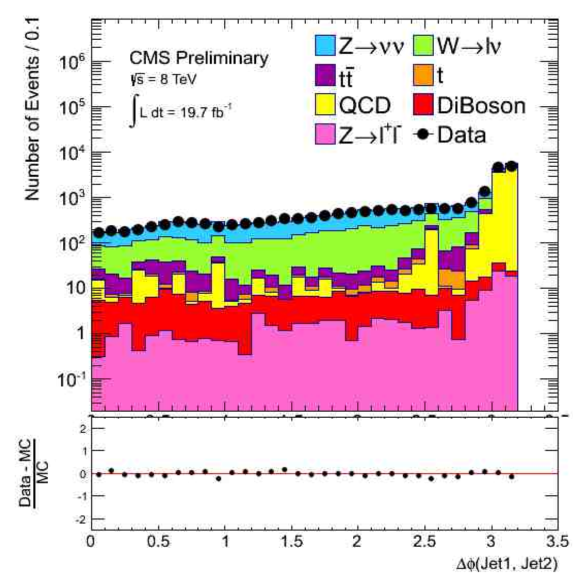
CMS-SUS-13-018

Search for monojet $\tilde{t} \to c\,\tilde{\chi}^0_1$

- Target: direct stop pair production. Very compressed scenario: $10 < m_{stop} - m_{LSP} < 80$ GeV, so $\tilde{t} \to c\,\tilde{\chi}^0_1$;
- The decay products of the stop will be very soft;
- "Invisible decay" recoiling against an ISR jet (monojet signature);
- Dominant backgrounds:
  - Z(νν)+jets, estimated using $Z \to \mu\mu$ data;
  - W(lν)+jets, estimated with the "lost lepton" method on single μ data;
- The correct modeling of the ISR is crucial and our simulation is validated against some SM processes (Z+jets, $t\bar{t}$, …).

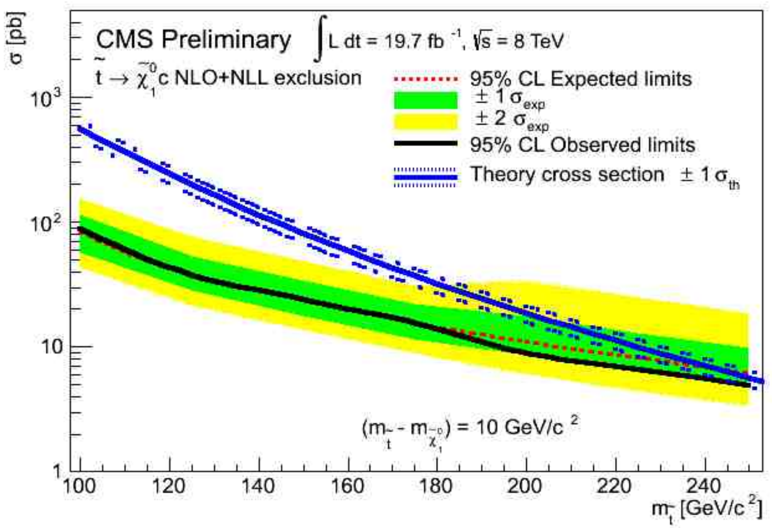
CMS-SUS-13-009

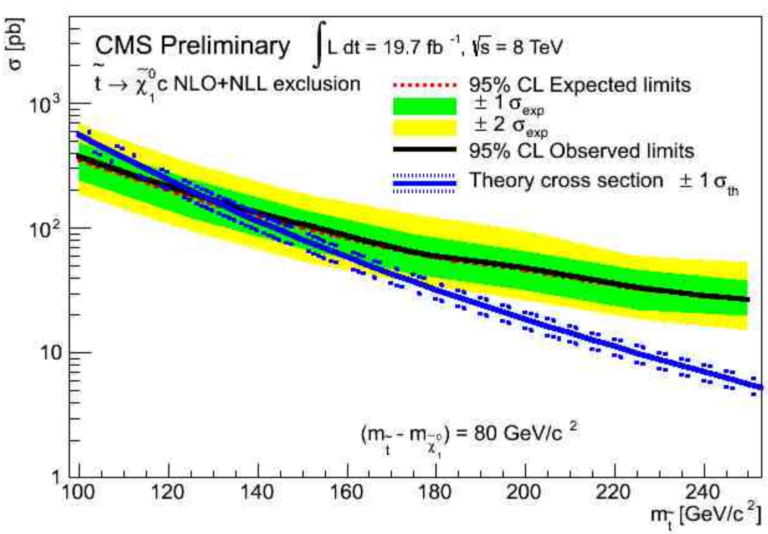




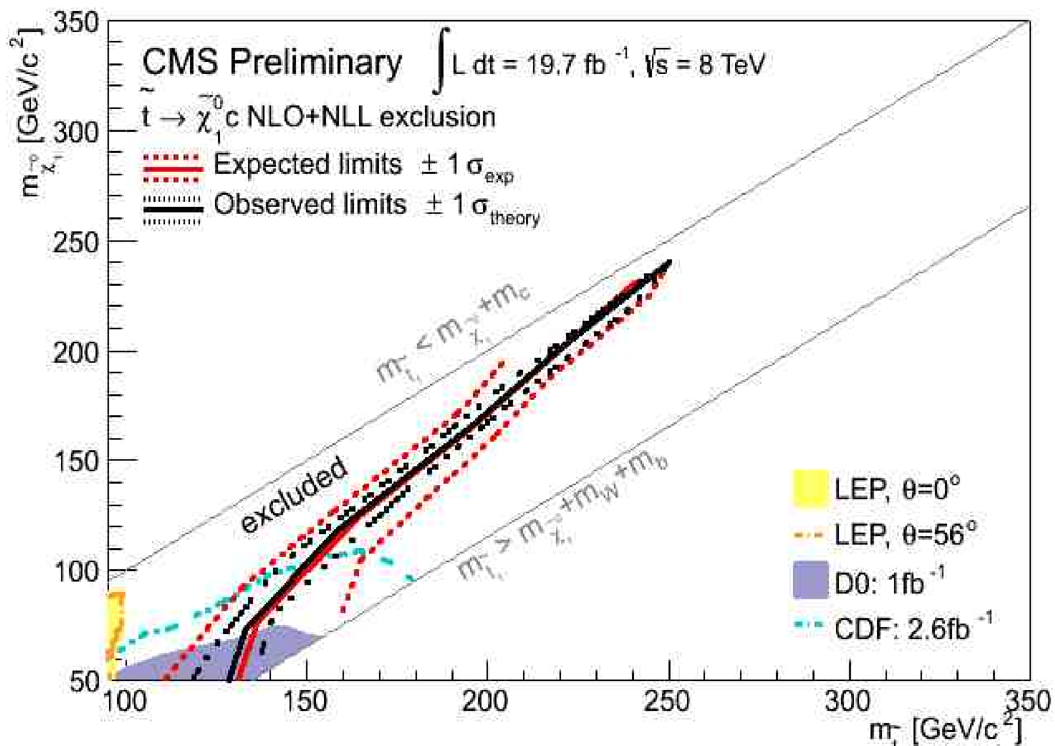
Search for monojet $\tilde{t} \to c\,\tilde{\chi}^0_1$

- No significant excess is seen over the predicted SM background;





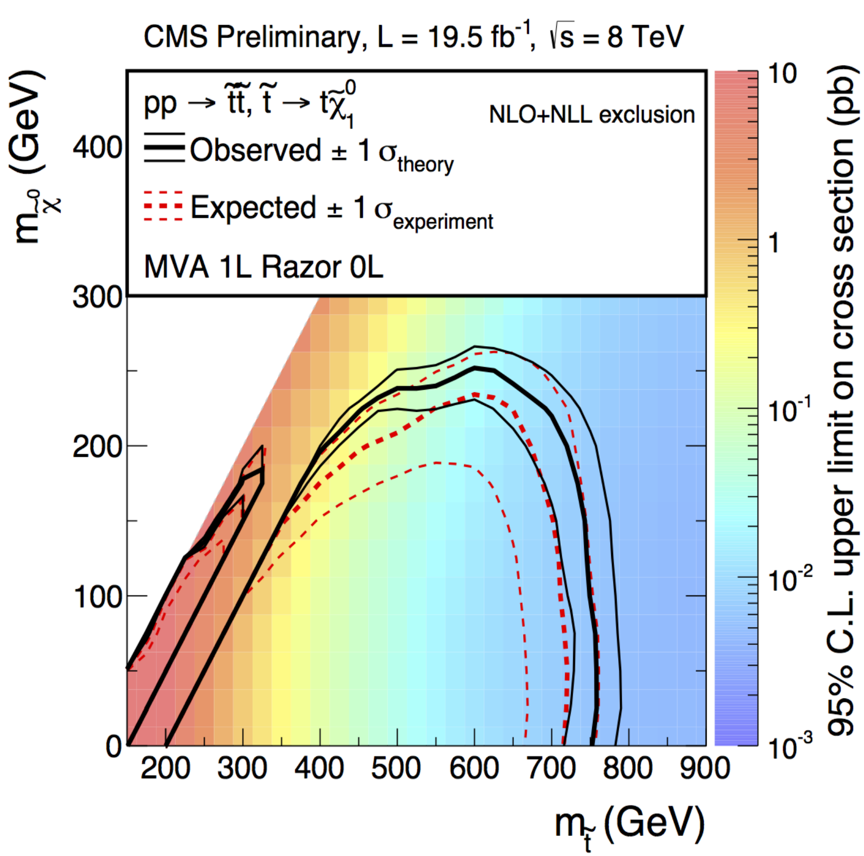
- The acceptance is higher for higher stop mass and lower mass splitting (the events are more monojet-like).



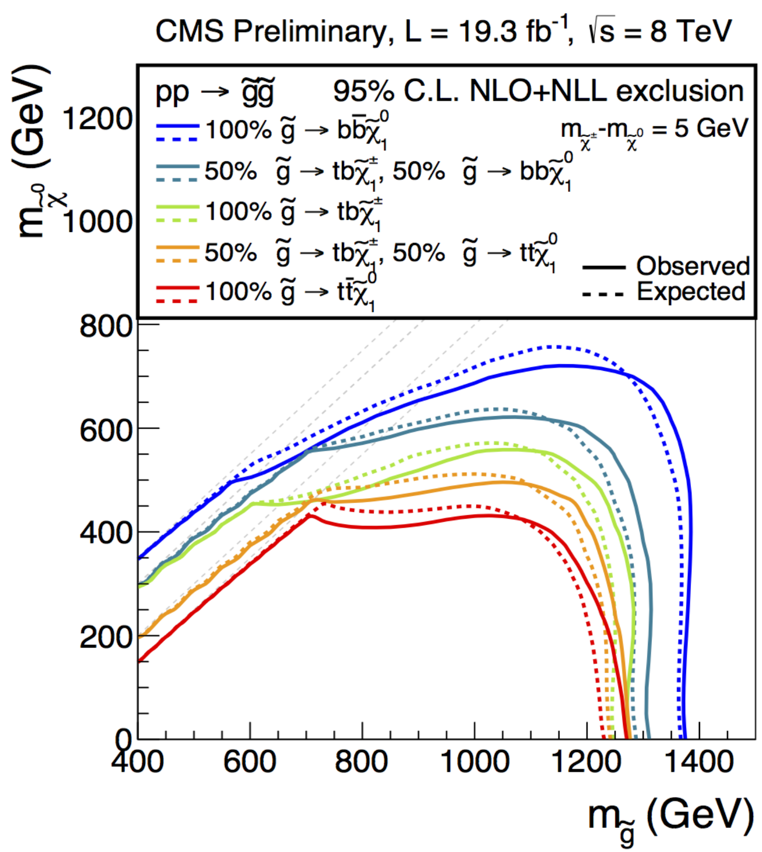
CMS-SUS-13-009

Other squark and gluino searches

More results on direct stop production and gluino pair production:



Combination of the single lepton MVA analysis (CMS-SUS-13-011), with Razor fully hadronic (CMS-SUS-13-004).



Gluino pair production limits, with gluinos decaying to different mixtures of b/t quarks.

CMS-SUS-14-011

Kinematic edge in OS dileptons

- Target: ewkino decay chains, such as $\tilde{\chi}^0_2 \rightarrow l\tilde{l} \rightarrow l^+l^-\tilde{\chi}^0_1$;
- The invariant mass of the dilepton pair would have a “triangular shape” with a sharp kinematic endpoint;
- We require two isolated leptons with $p_T > 20$ GeV, at least 2 jets, and MET > 100 GeV;
- Two signal regions:

  a) both leptons are central: $|\eta| < 1.4$;

  b) at least one lepton in the forward region $1.6 < |\eta| < 2.4$;
- Two search strategies:

  1) Kinematic fit in the region $20 < m_{ll} < 300$ GeV using a triangular signal shape convoluted with a Gaussian:

$$\mathcal{P}_S(m_{\ell\ell}) = \frac{1}{\sqrt{2\pi\sigma_{\ell\ell}}} \int_0^{m_{\ell\ell}^{edge}} y \cdot \exp\left(-\frac{(m_{\ell\ell}-y)^2}{2\sigma_{\ell\ell}^2}\right) dy.$$

  2) Cut and count analysis in the region $20 < m_{ll} < 70$ GeV.

CMS-SUS-12-019 – PAS will be available soon

Kinematic edge in OS dileptons

- Fit analysis:

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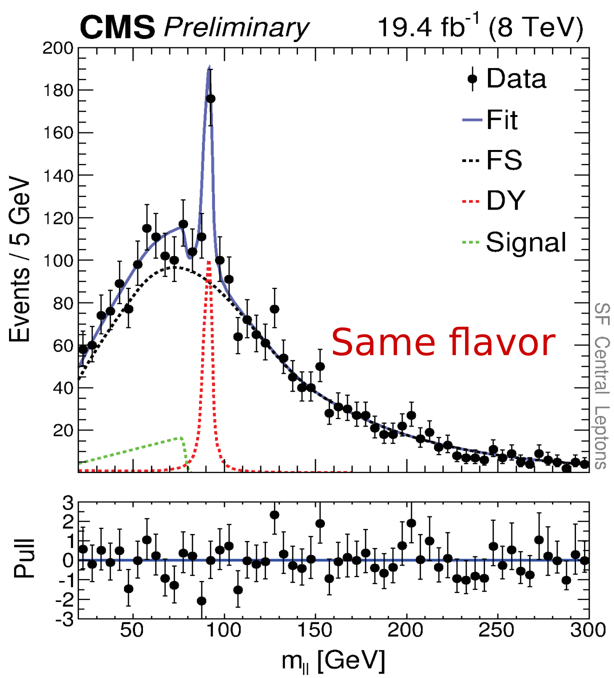
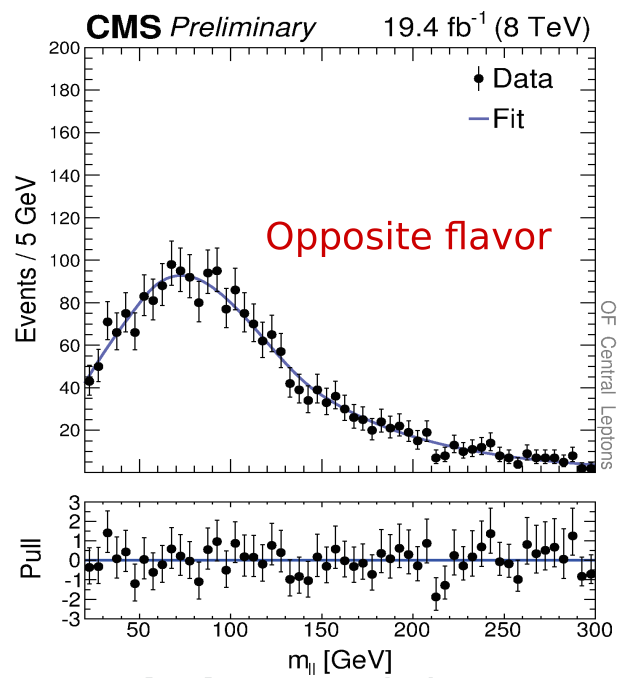
Central region:





	Central	Forward
Drell–Yan	158 ± 23	71 ± 15
Flav. Sym. [OF]	2270 ± 44	745 ± 25
$R_{SF/OF}$	1.03	1.02
Signal events	126 ± 41	22 ± 20
$m_{\ell\ell}^{edge}$ [GeV]	78.7 ± 1.4	
Local Significance [σ]	2.4	

- The two regions (central and forward) are fitted simultaneously, the only parameter in common is the position of the edge;
- The quoted significance does not include the "Look Elsewhere Effect".

Kinematic edge in OS dileptons

- Cut and count analysis:

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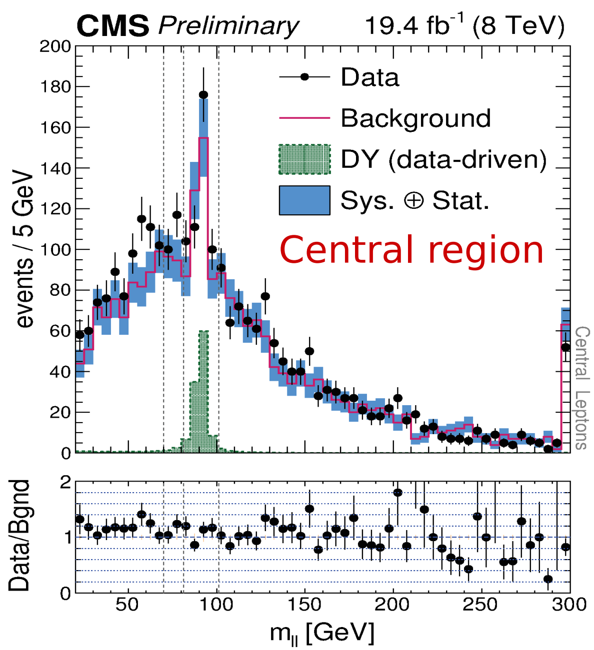
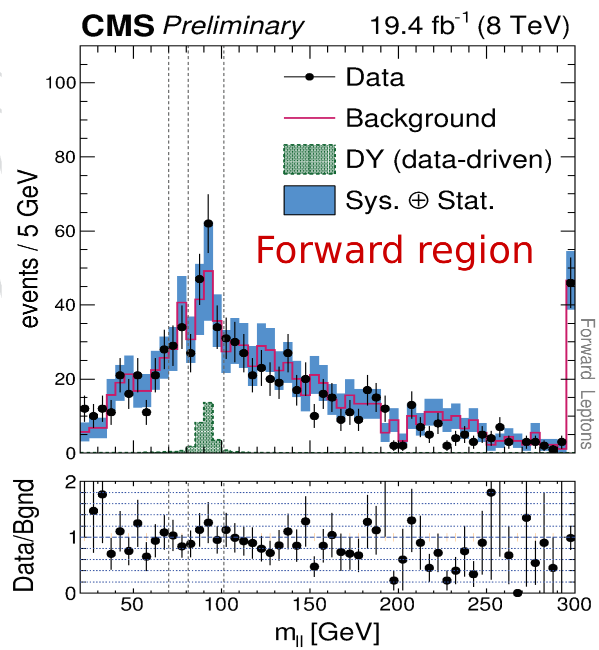




The signal is searched for in the region $20 < m_{ll} < 70$ GeV.

	Central	Forward
Observed [SF]	860	163
Flav. Sym. [OF]	$722 \pm 27 \pm 29$	$155 \pm 13 \pm 10$
Drell–Yan	8.2 ± 2.6	1.7 ± 1.4
Total estimates	730 ± 40	157 ± 16
Observed – Estimated	130^{+48}_{-49}	6^{+20}_{-21}
Significance [σ]	2.6	0.3

- The two analysis strategies give compatible results (also considering alternative background estimation techniques);
- The small excess we observe in the central region is not statistically significant.

Diphoton search with Razor

CMS-SUS-14-008 – PAS will be available soon

- Target: a variety of SUSY scenarios involving the decay of heavy squarks or gluinos, with photons in the final state;
- We select two isolated photons with $p_T > 30, 22$ GeV, $|\eta| < 2.5$;
- We require at least one jet with $p_T > 40$ GeV, $|\eta| < 2.5$, and $\Delta R > 0.5$ from each candidate photon;
- The Razor variables are defined as:

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

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

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

- For a generic event, physics objects are merged into two “megajets”. The combination that minimizes the quadratic sum of the invariant masses of the megajets is chosen.

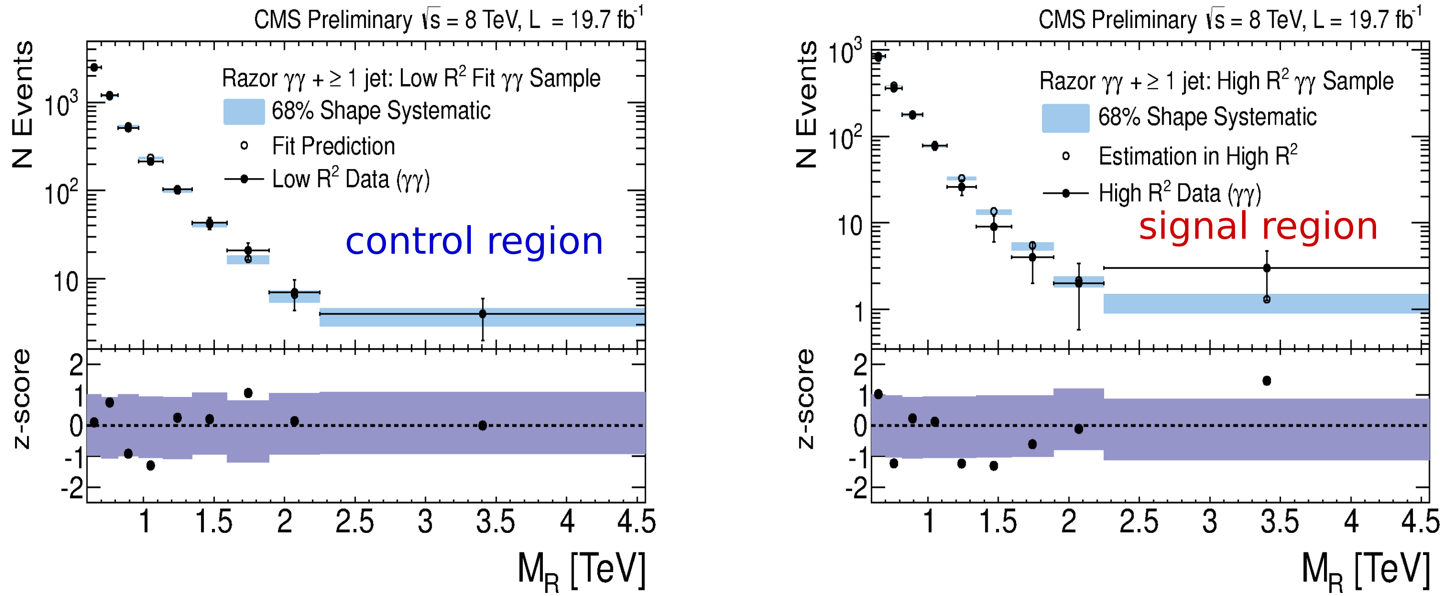
Diphoton search with Razor

CMS-SUS-14-008 – PAS will be available soon

- We define:
  - a signal region, with $M_R > 600$ GeV, $R^2 > 0.002$;
  - a control region, with $M_R > 600$ GeV, $0.001 < R^2 < 0.002$;
- We fit for the background in the control region (signal contamination is negligibly small), using the function:

$$P(M_R) \propto e^{-k(M_R - M_R^0)^{\frac{1}{n}}}$$

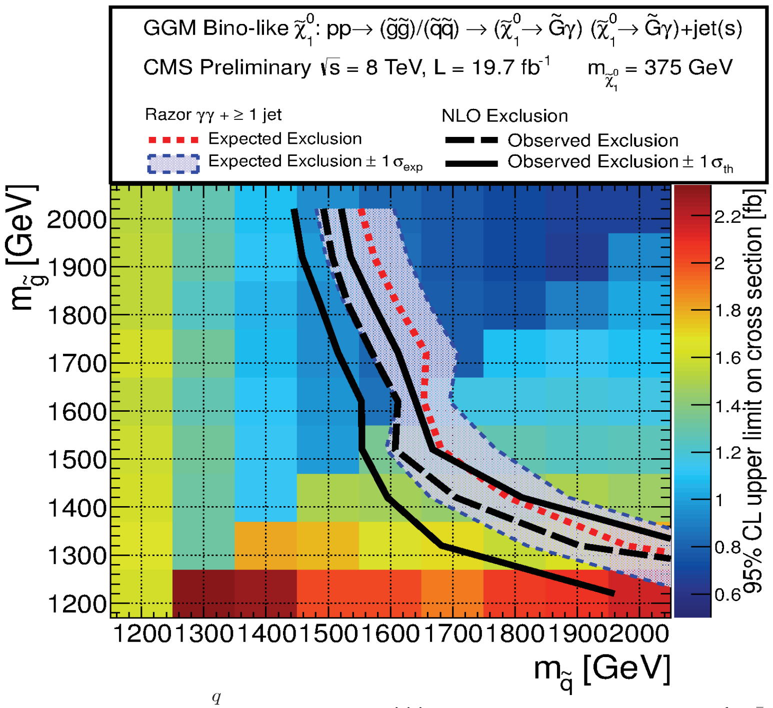
- From the results of this fit we predict the background in the signal region;
- No significant excess is observed.

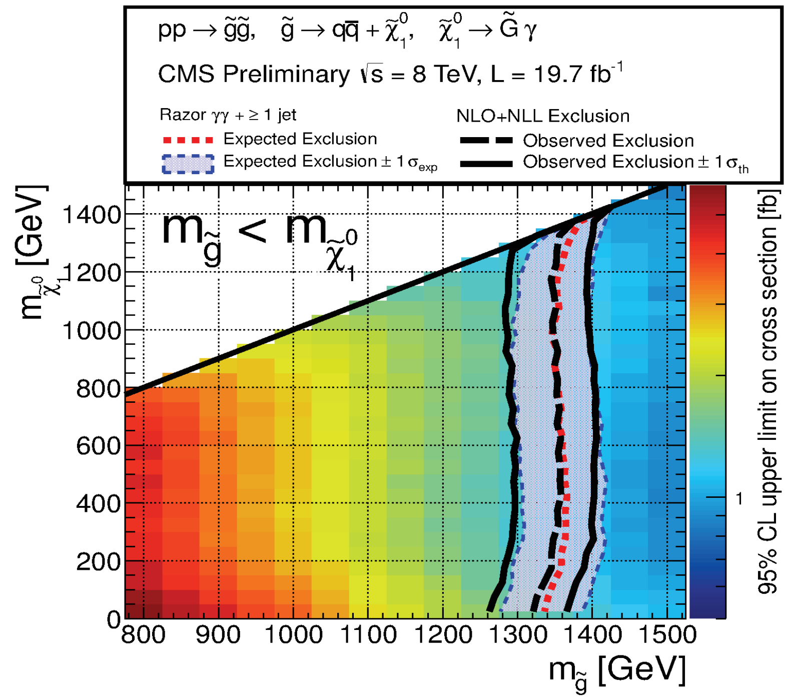


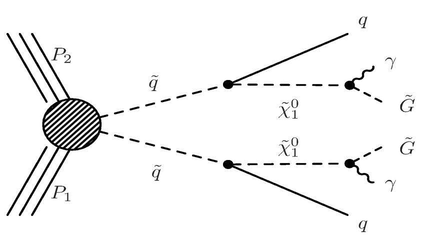
Diphoton search with Razor

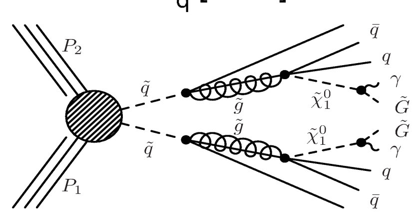
CMS-SUS-14-008 – PAS will be available soon

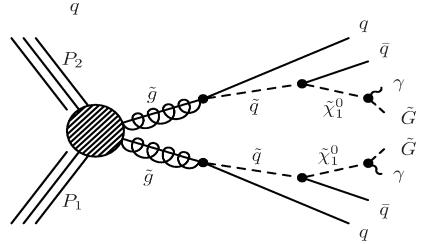
General Gauge Mediation (GGM) scenario

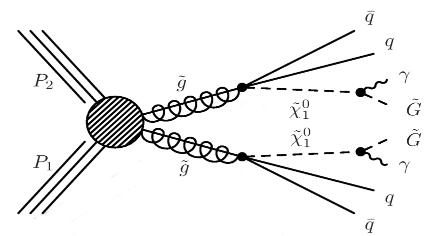






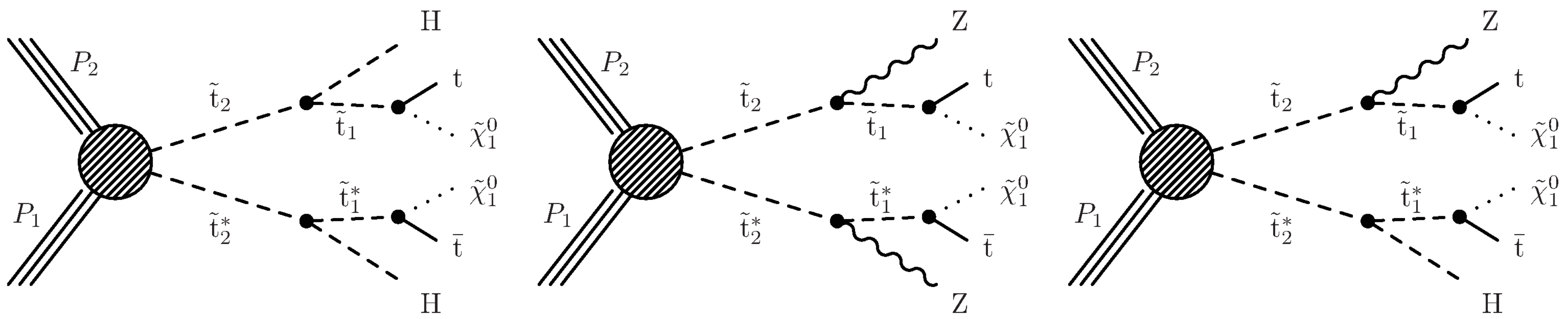






h/Z from stop decays

- Target: stop pair production in the region $m(\tilde{t}) - m(\tilde{\chi}^0{}_1) \sim m(t)$;
- Higgs bosons or Z's can be produced in the stop decays:



- A signal is searched for in three channels:

  a) 1 lepton or 2 OS leptons, and at least 3 b-jets;

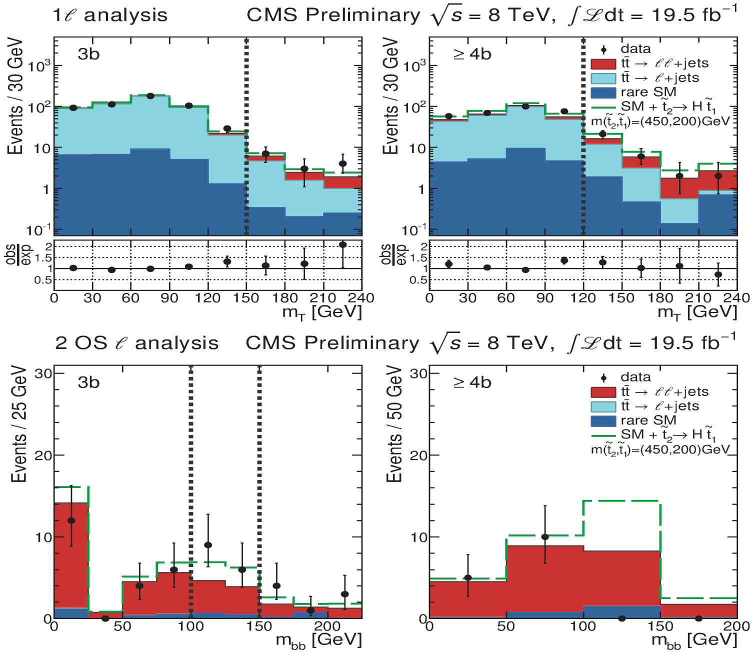
  b) 2 SS leptons and at least one b-jet;

  c) at least 3 leptons and at least one b-jet;
- Dominant backgrounds from $t\bar{t}$ and VV production, reduced with further requirements on number of jets, $m_T(l,\text{MET})$, … .

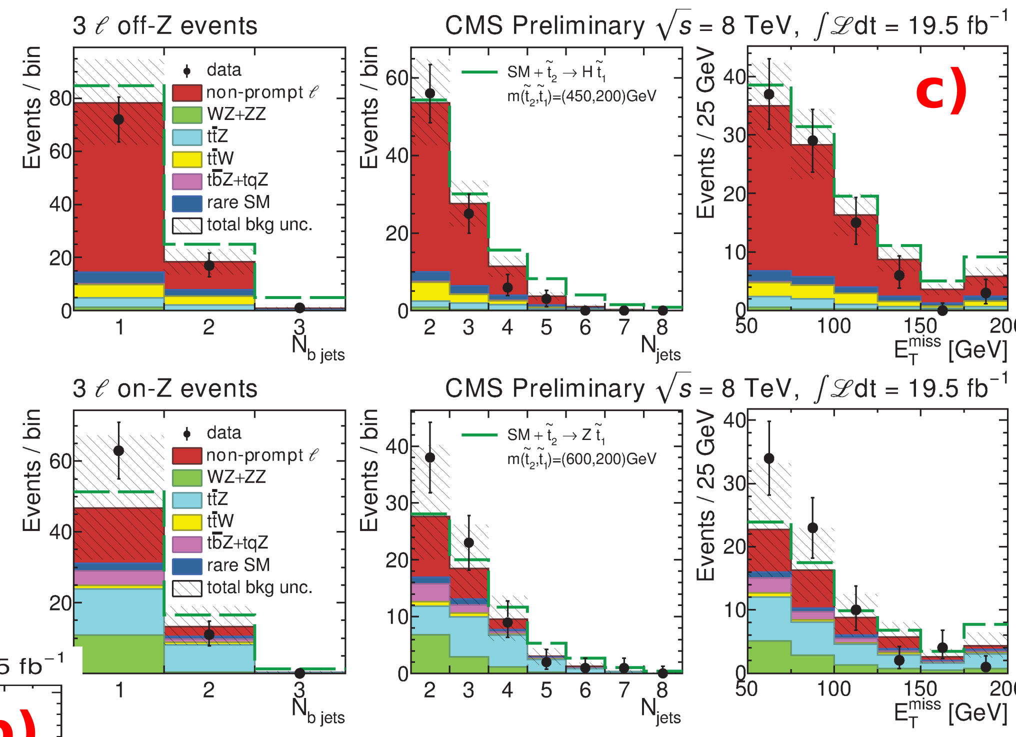
CMS-SUS-13-024 – accepted by PLB

h/Z from stop decays

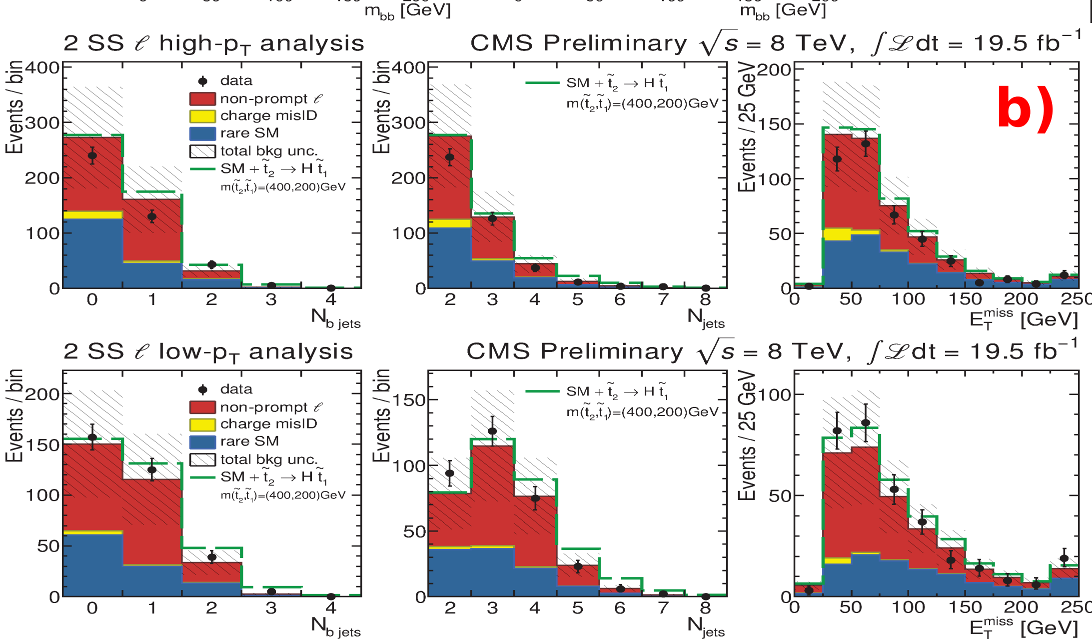
a)



c)



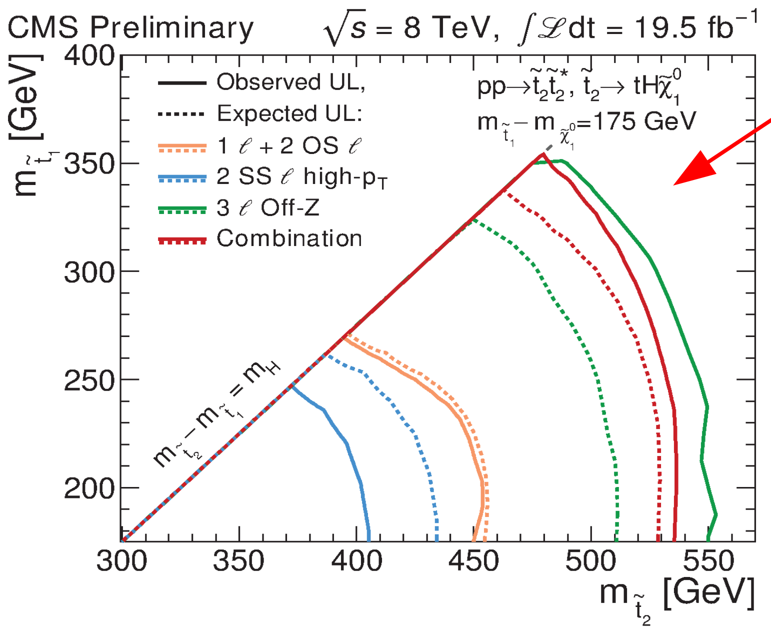
b)



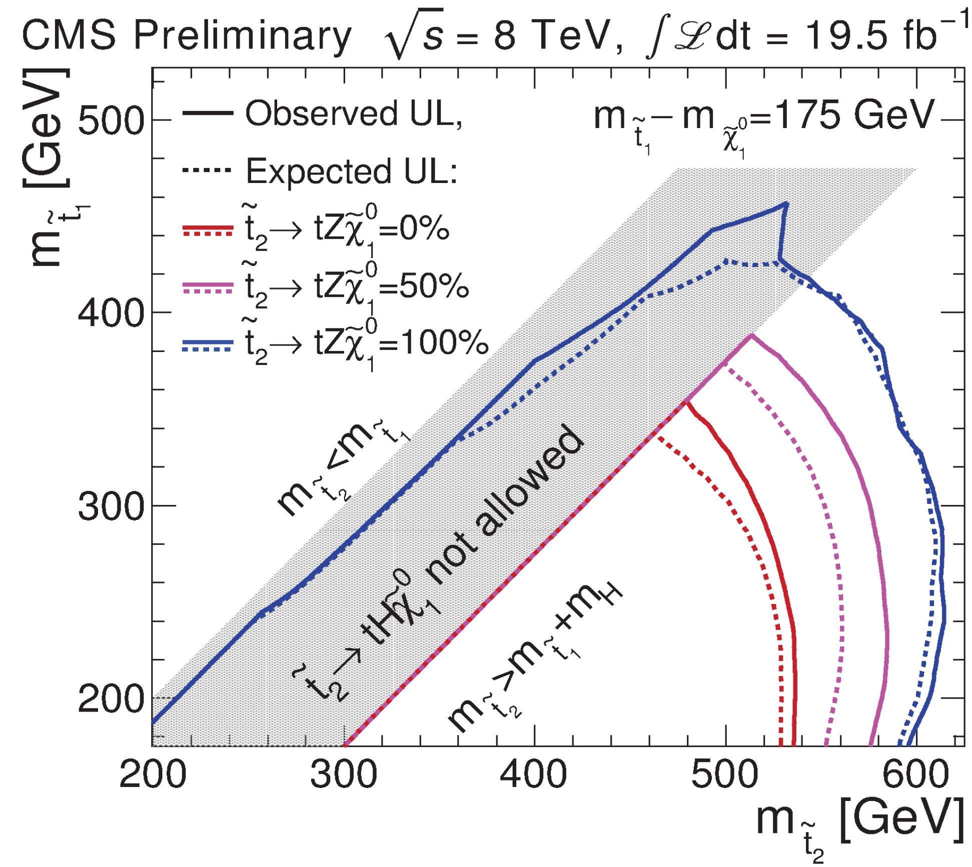
Observed yields are consistent with background predictions

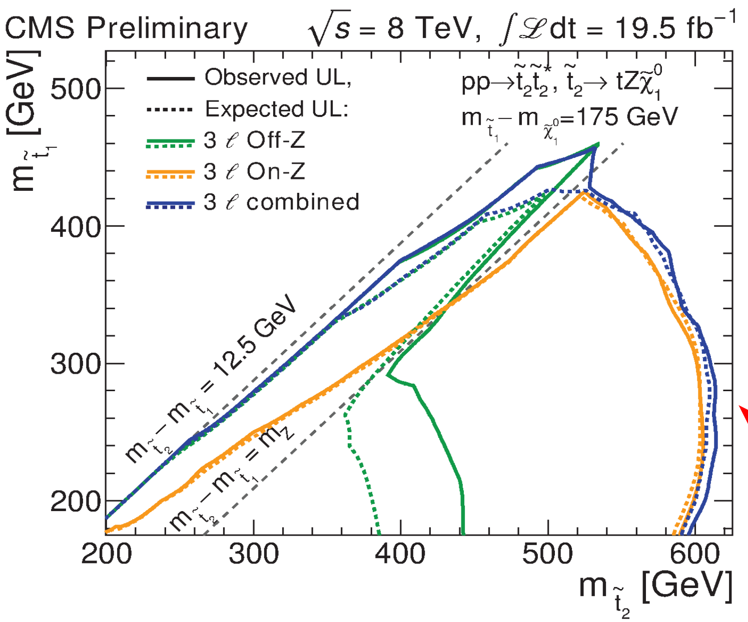
CMS-SUS-13-024 – accepted by PLB

h/Z from stop decays



$\tilde{t}_2 \rightarrow t\,H\,\tilde{\chi}^0_1$



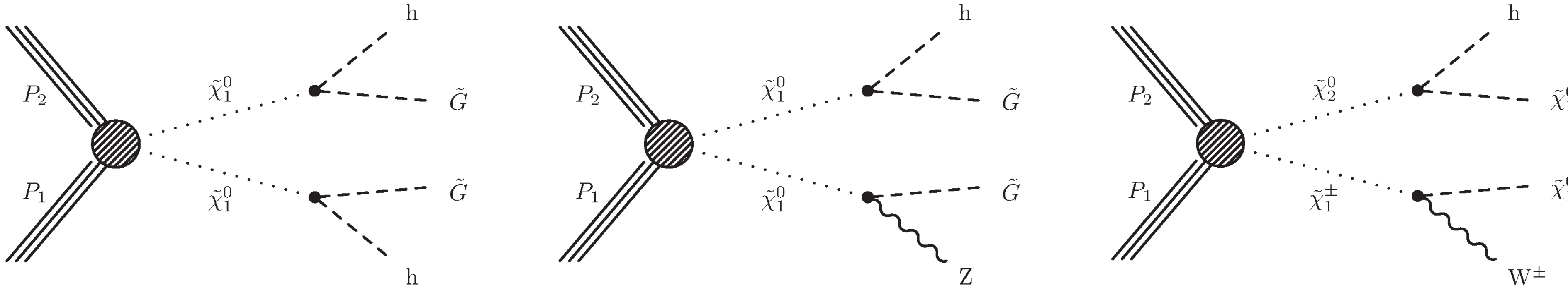


$\tilde{t}_2 \rightarrow t\,Z\,\tilde{\chi}^0_1$

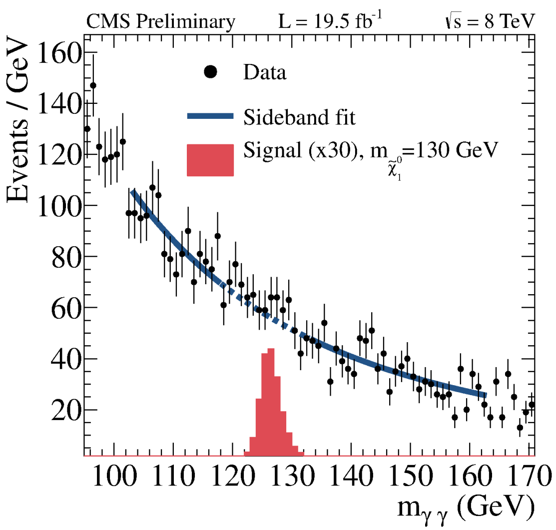
CMS-SUS-13-024 – accepted by PLB

h/Z/W from ewkino decays

- Target: ewkino pair production, with decays to h, Z, and W:

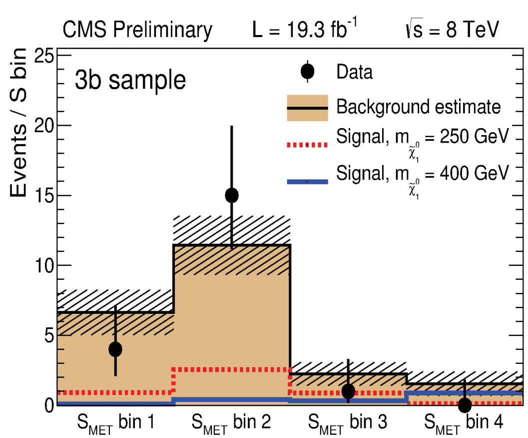


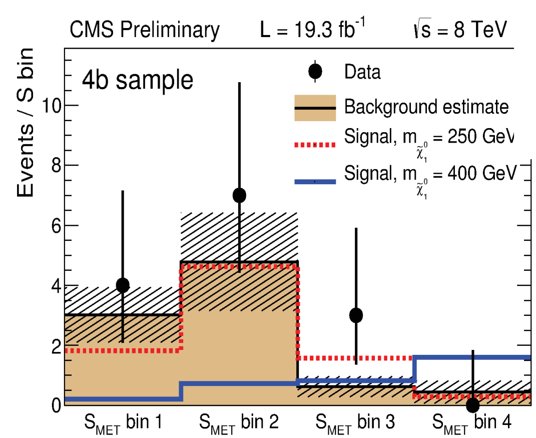
- Different channels are considered:
  - hh: bb bb, γγ bb, γγ WW/ZZ/ττ;
  - hZ: γγ jj, γγ ee/μμ/ττ, bb ee/μμ;
  - hW: γγ jj, γγ *l*ν;



hZ/hW → γγjj

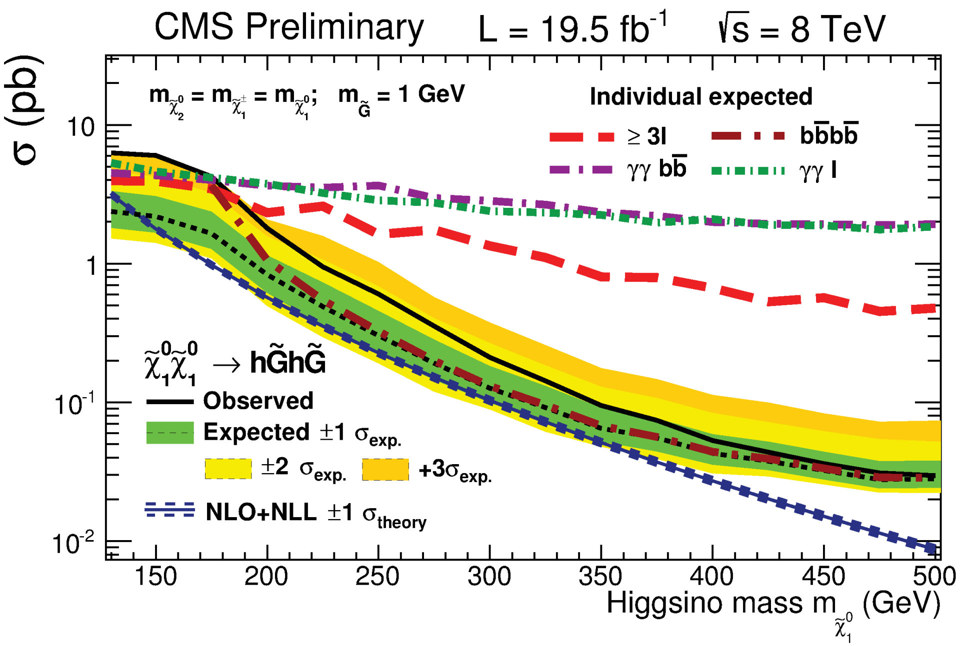
hh → bbbb

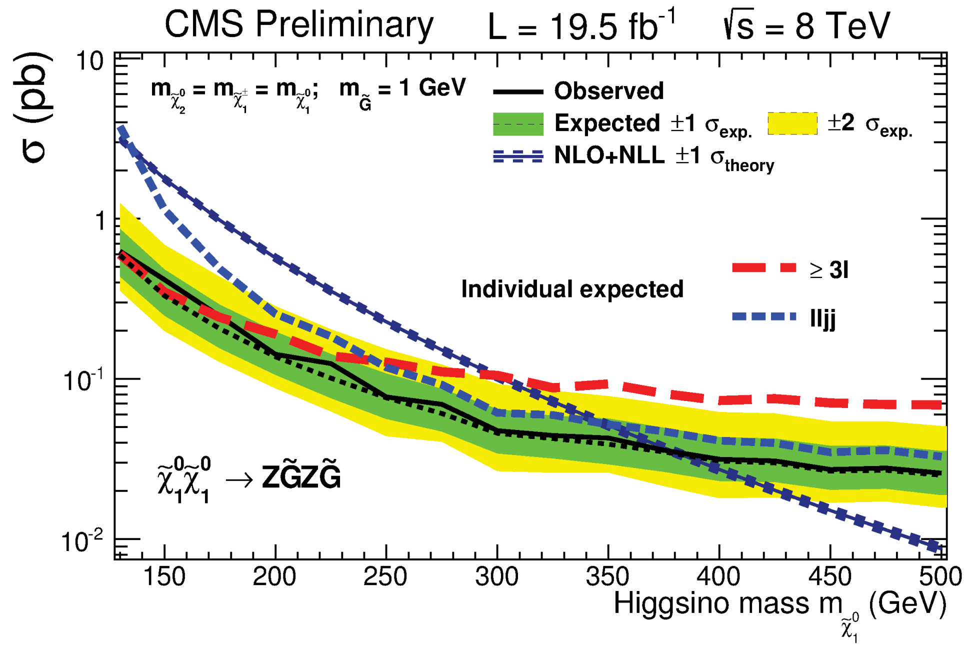


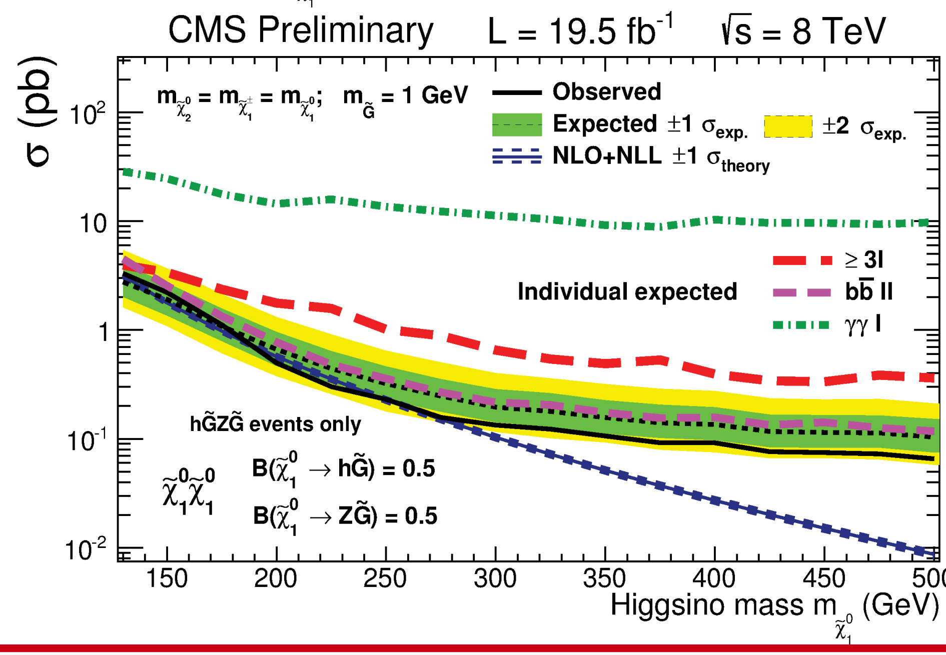


CMS-SUS-14-002

h/Z/W from ewkino decays

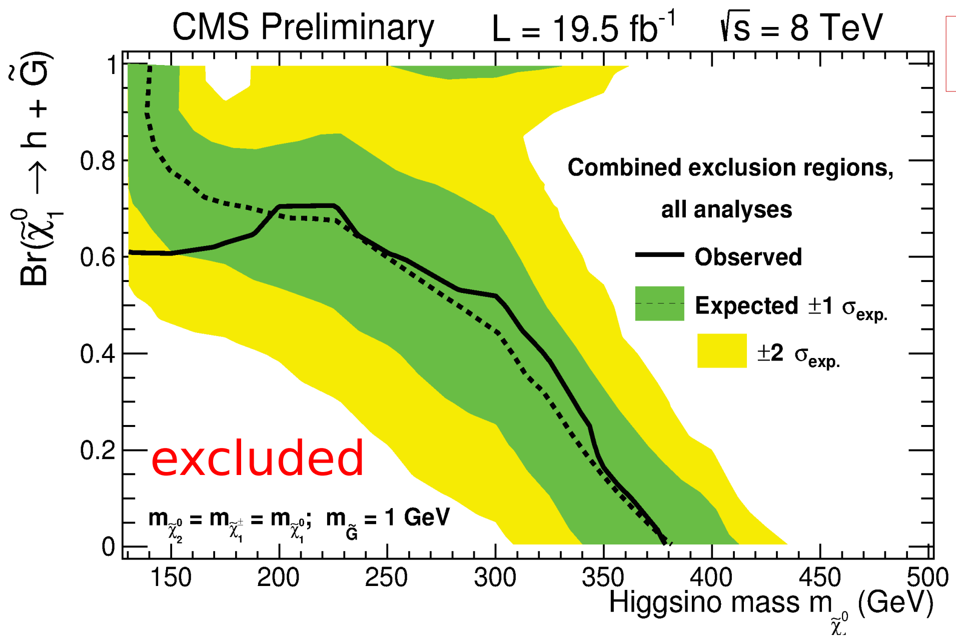




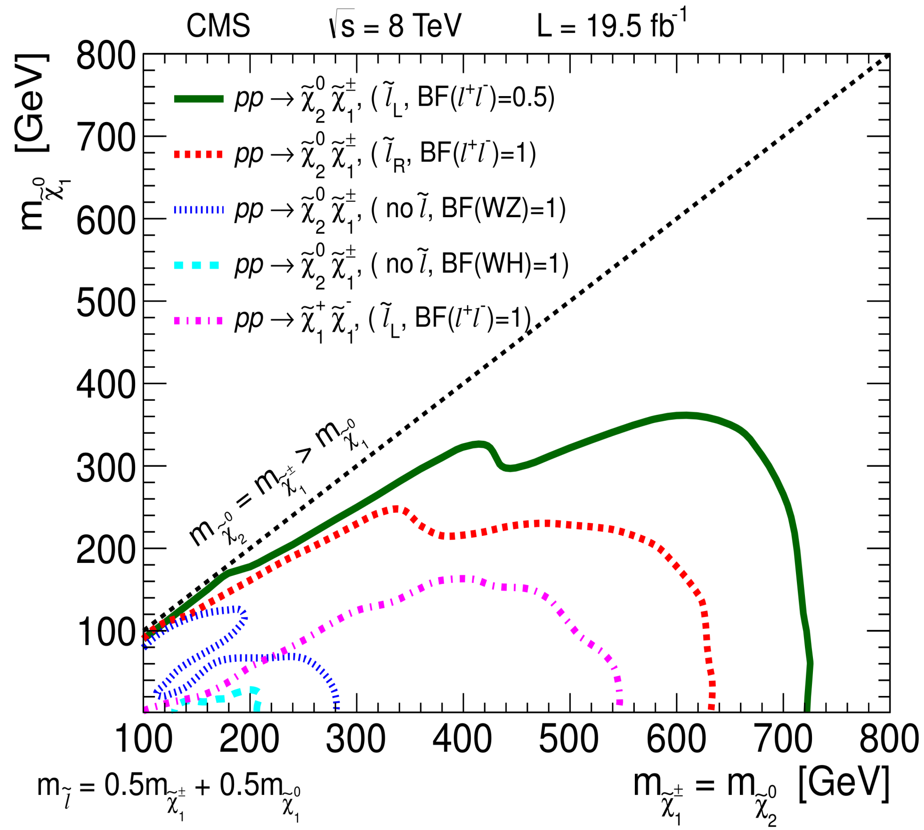


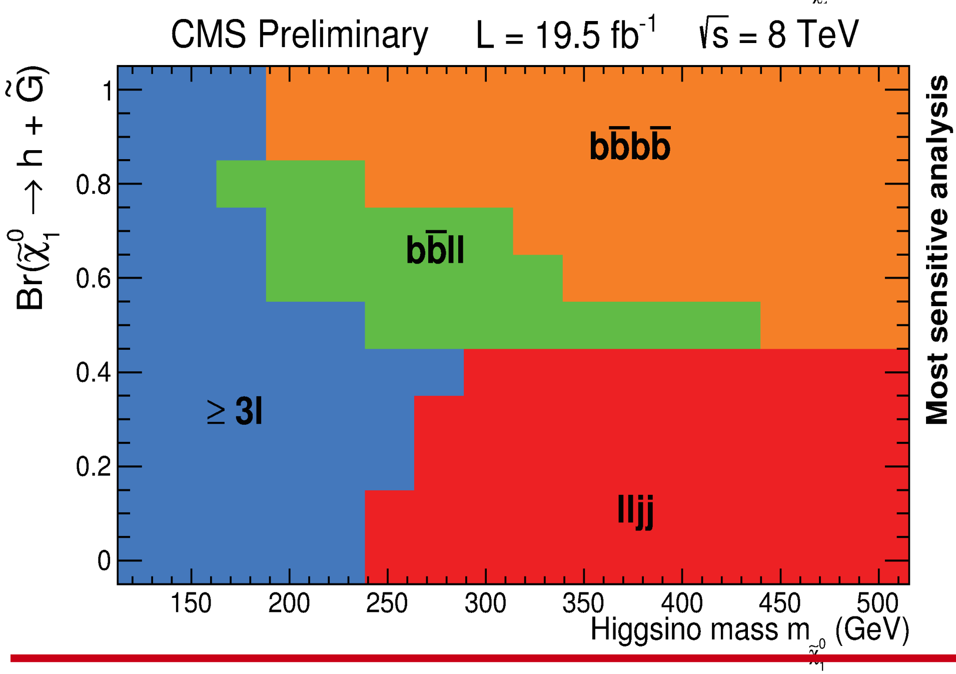
CMS-SUS-14-002

h/Z/W from ewkino decays



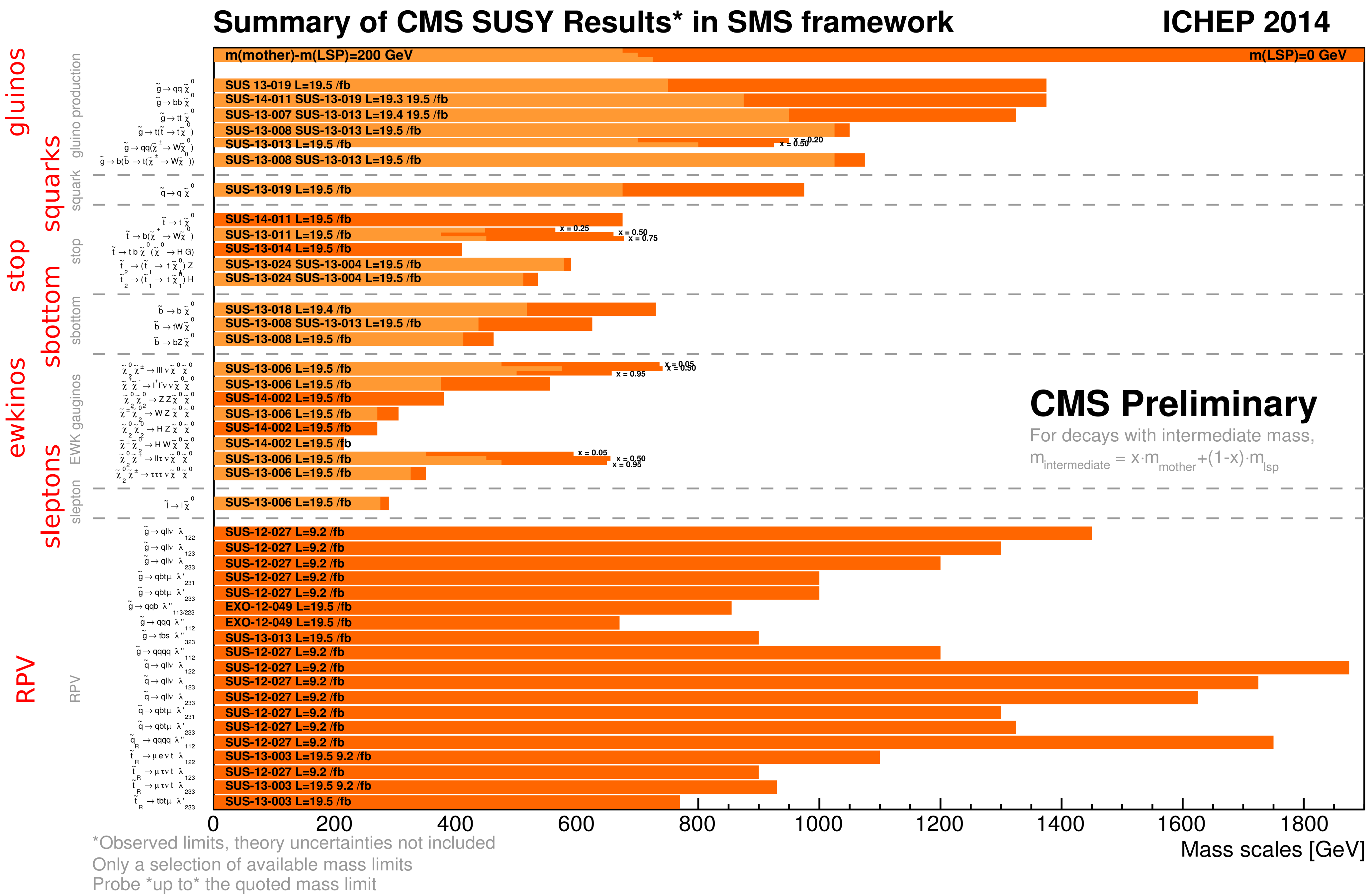
CMS-SUS-14-002





arXiv:1405.7570 [hep-ex]
submitted to EPJC

Summary


Summary of CMS SUSY Results* in SMS framework
ICHEP 2014
gluinos
squarks
stop
sbottom
ewkinos
sleptons
RPV
gluino production
squark
stop
sbottom
EWK gauginos
slepton
RPV
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
SUS 13-019 L=19.5 /fb
SUS-14-011 SUS-13-019 L=19.3 19.5 /fb
SUS-13-007 SUS-13-013 L=19.4 19.5 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-013 L=19.5 /fb
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SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-12-027 L=9.2 /fb
SUS-13-003 L=19.5 9.2 /fb
SUS-13-003 L=19.5 /fb
CMS Preliminary
For decays with intermediate mass,
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$
0
200
400
600
800
1000
1200
1400
1600
1800
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

Conclusions

- We performed a vast program of SUSY searches, unfortunately we didn't catch any signal yet...
- This is just a glimpse of the SUSY searches performed at CMS, for more results and interpretations, please visit:

  https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
- More results will come as we continue to squeeze some more physics out of the Run1 dataset...;
- ... and the focus is shifting towards the imminent start of Run2, scheduled for next Spring, when the collision energy will be raised to 13 TeV;
- The substantial increase in energy will open a large chunk of phase-space for the next round of searches;
- Stay tuned!