Searches for pair production of charginos and top squarks in final states with two oppositely charged leptons at CMS experiment

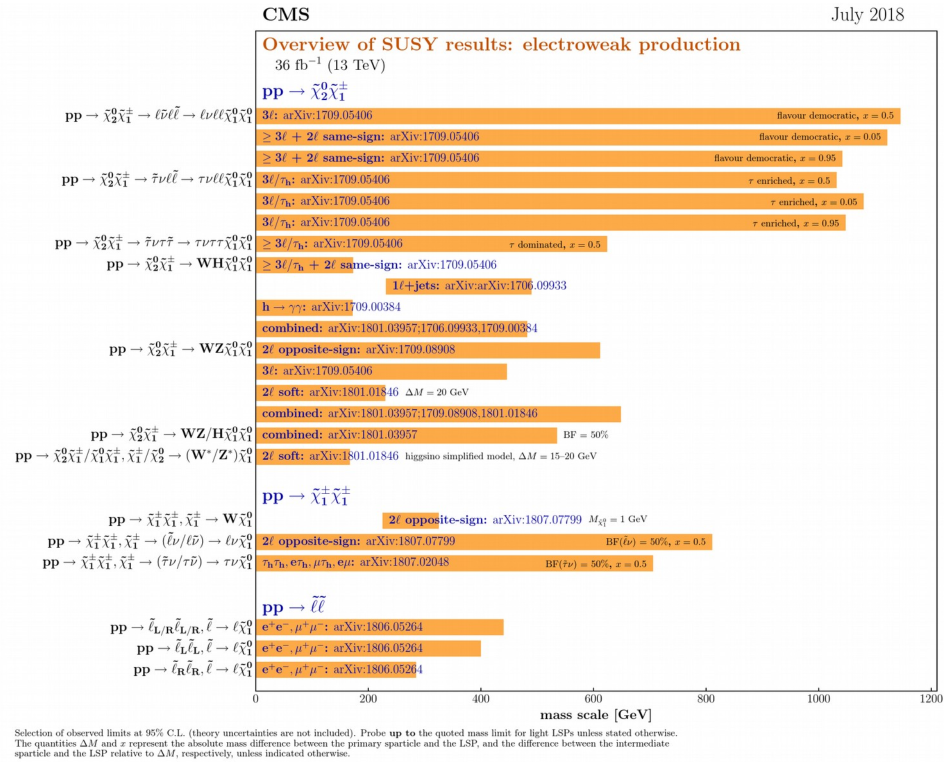
Barbara Chazin
On behalf of CMS collaboration

Talk's Overview

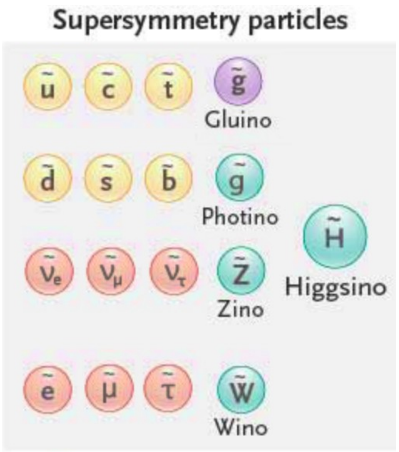
- Introduce two analyses performed by CMS collaboration using an integrated luminosity (L) of 35.9 /fb at $\sqrt{s}$ = 13 TeV
- Describing
  - search strategy
  - Background estimation
  - Systematic and experimental uncertainties
- Showing the global picture of these searches

Motivation

- Supersymmetry (SUSY) can provide solutions to the some open questions of SM
- Still no hints of BSM physics at LHC, … but we are not done yet!



(* See Daniel's talk on Monday)



- CMS has invested a great effort during 2016 and 2017 in finding SUSY but …
- Starting to reach sensitivity to the TeV scale & direct EWK production
- SUSY could be around the corner

Analysis’s Overview

- Two searches for stop and one for chargino pair production with opposite charge dilepton final states and missing transverse momentum using data recorded by CMS in 2016

Previous CMS result

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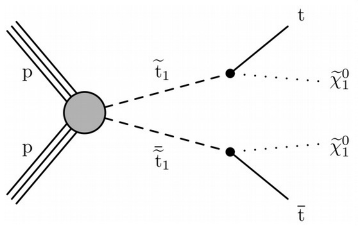
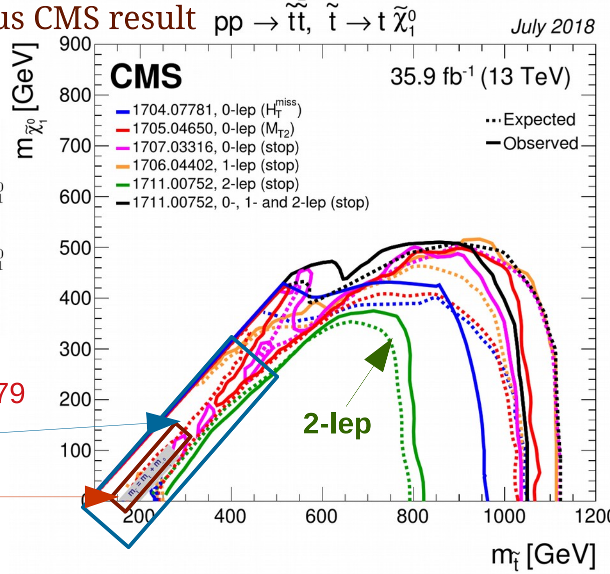




JHEP11(2018)079

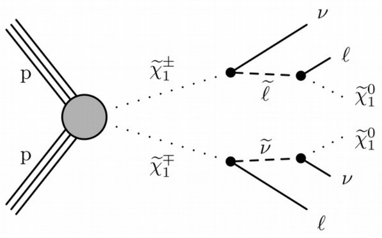
$\tilde{t} \to t^*\tilde{\chi}^0_1$

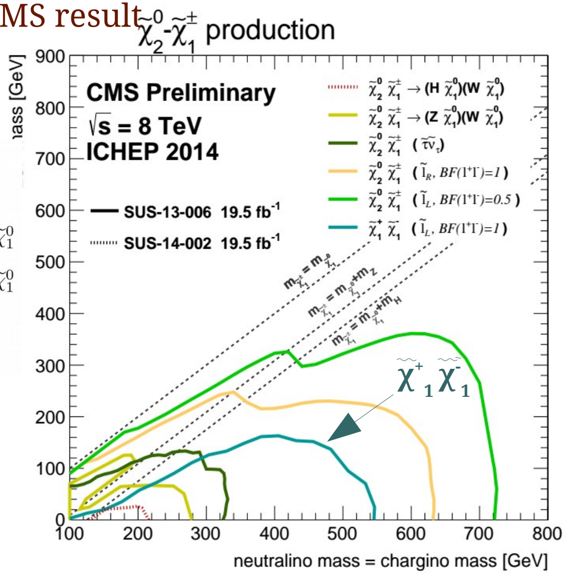
CMS-PAS-SUS-18-003

$\tilde{t} \to t\tilde{\chi}^0_1$

Previous CMS result

SMS:





- The stop searches strategy depends strongly on the mass difference: $\Delta m = m(\tilde{t}) - m(\tilde{\chi}^0_1)$
- Two regions: Three-body decays: $\mathbf{m_W \leq \Delta m \leq m_{top}}$

  Degenerate top and stop: $\mathbf{\Delta m \sim m_{top}}$

- The chargino search studies the whole mass plane

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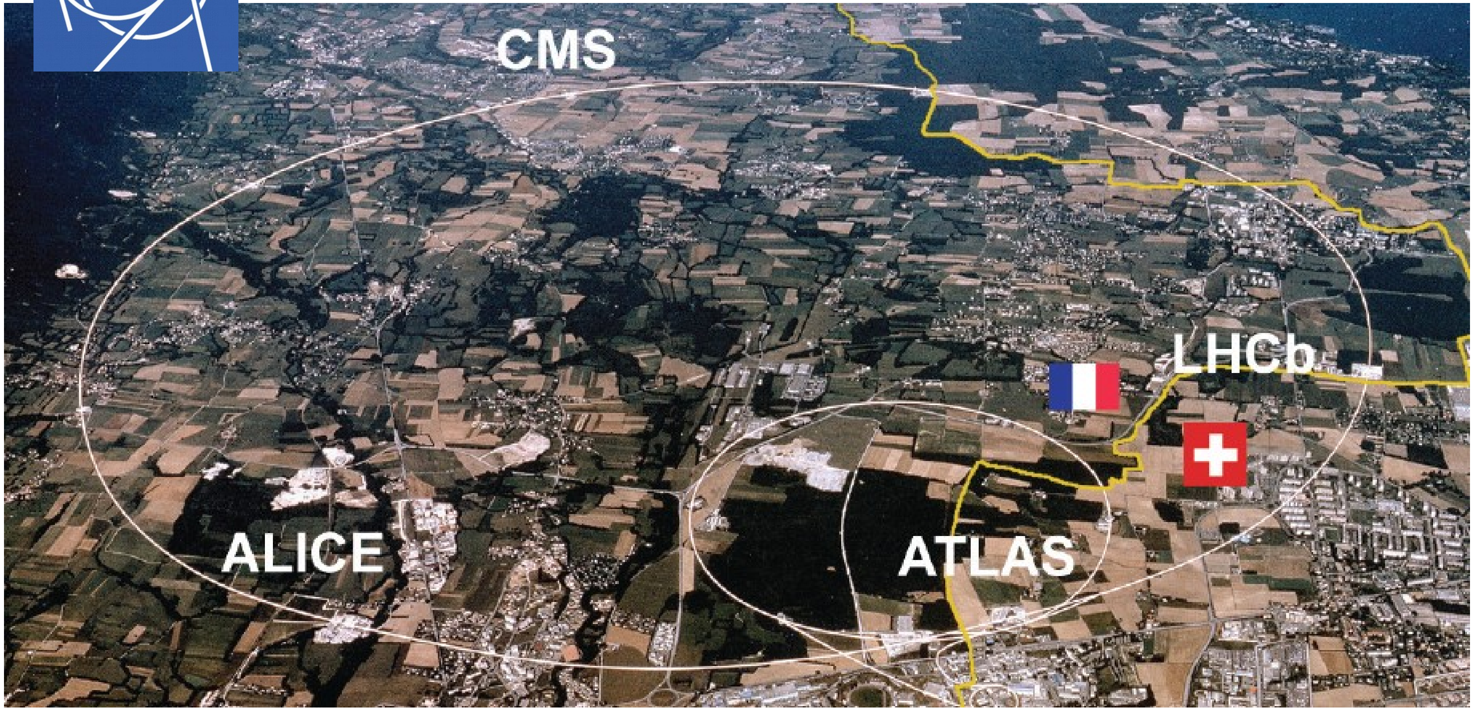
LHC at CERN

Large Hadron Collider (since September of 2008)



Outside:

Long. = 27 Km
> 1000 magnets

Inside:

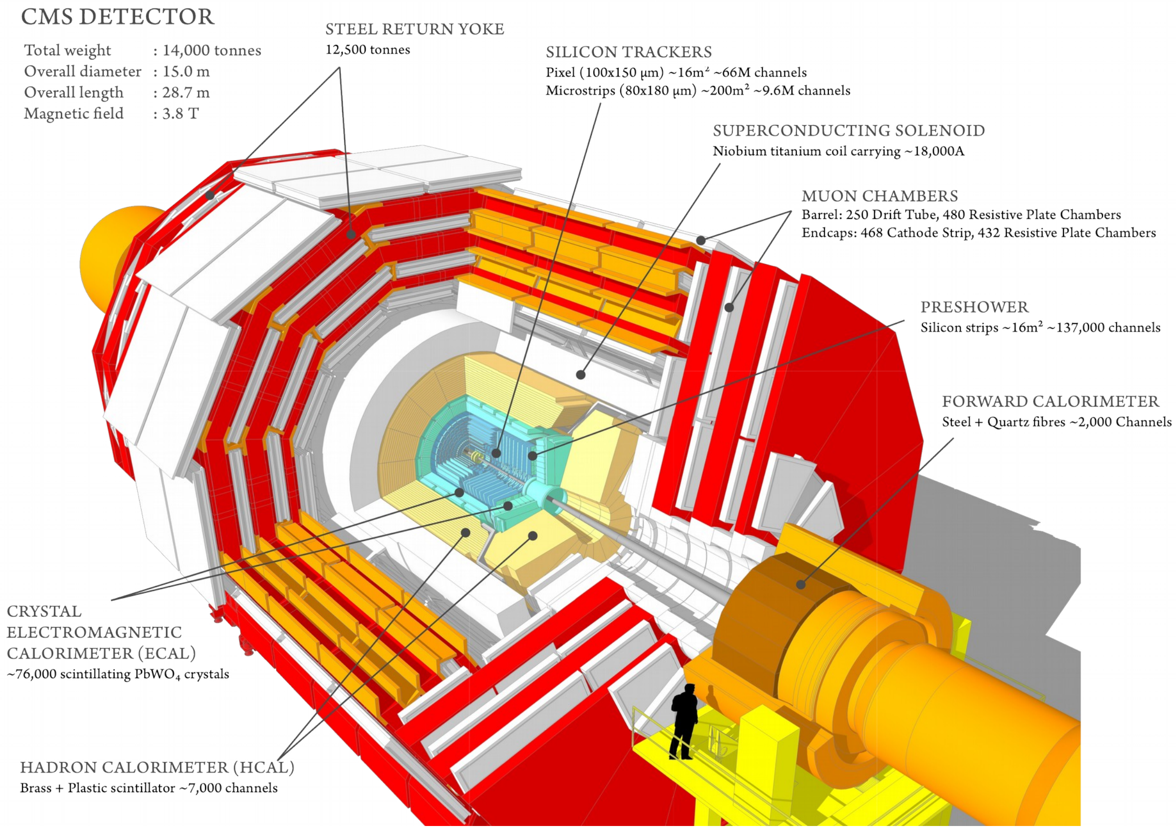
p beams at high energy (6.5 TeV) in ultrahigh vacuum

Experiments in 2016:

p-p collisions
$\sqrt{s}$ = 13TeV

CMS at LHC

Compact Muon Solenoid a general-purpose detector: SM, DM, SUSY,…, Extra Dimensions

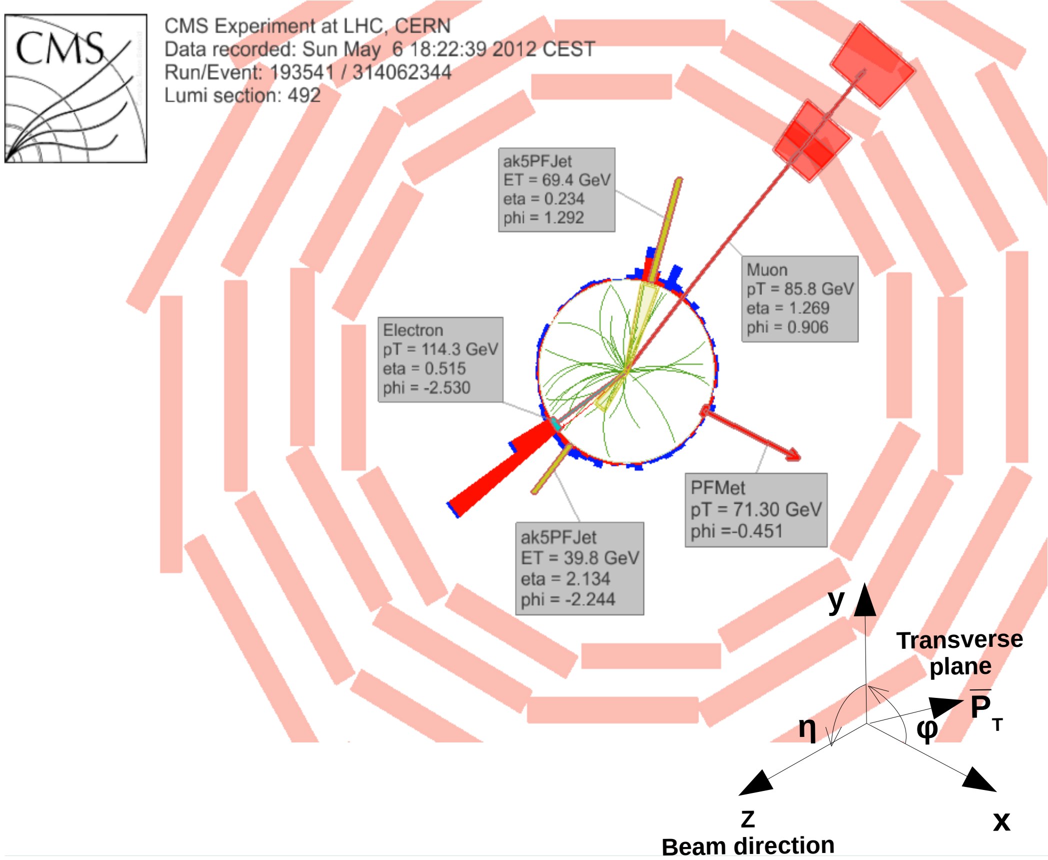


- The CMS detector is built around a huge solenoid magnet (10 ^5 Earth's field)
- The field is confined by a steel "yoke" that forms the bulk of the detector's 14,000-tonne weight.
- The CMS experiment is one of the largest international scientific collaborations in history
  - 4300 people
  - 182 institutions
  - 42 countries

(2014)

Object Selection

- Objects reconstructed by the CMS particle-flow algorithm are electron, muons, charged and neutral hadrons, and photon candidates



Events are selected requiring the presence of two leptons ($e^{\pm}$, $\mu^{\pm}$)

$p_T^1 \geq 25$; $p_T^2 \geq 20$ GeV, $|\eta| \leq 2.4$

Jets are clustered from PF candidates are selected if $p_T \geq 20$ GeV, $|\eta| \leq 2.4$

Jets originating from the hadronization of bottom quarks (b jets) are identified by the CSVv2 algorithm

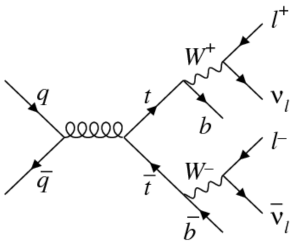
The missing transverse momentum of the event ($\overline{p}_T^{miss}$) :

$$\overline{p}_T^{miss} = - \Sigma \, \overline{p}_T \text{ (allPFcandidates)}$$

Stop Three-body Decay (3-body) Search

Top squark search in the compressed scenario:

- $m_W < \Delta m \leq m_t \rightarrow$ off-shell top quark

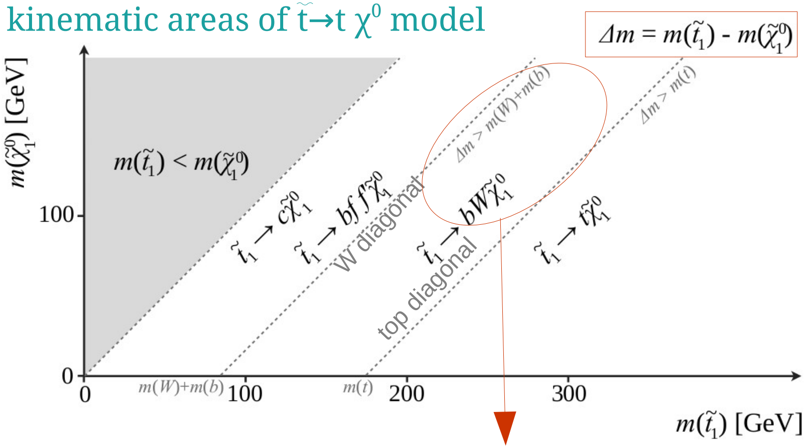


Signatures: b-jets with low p_T, W bosons, and high p_T^{miss}

Main irreducible backgrounds:

WW, tW, $t\bar{t}$ (dileptonic decays)

kinematic areas of $\tilde{t} \rightarrow t\, \chi^0$ model



at intermediate neutralino masses

Specific signal region selection:

* At least 1 b jet → $t\bar{t}$ and WW enriched region; WW almost suppressed; signal models close to top diagonal

* No b jets → WW enriched region, $t\bar{t}$ (tW) decreases its contribution; signal models close to W diagonal

We exploit the transition area between diagonals with different signal regions and define control regions for the main backgrounds.

Chargino Search

Common baseline selection

2 opposite charge leptons (e^+e^-, $e^+\mu^-$, $e^-\mu^+$, $\mu^+\mu^-$) → select dileptonic events

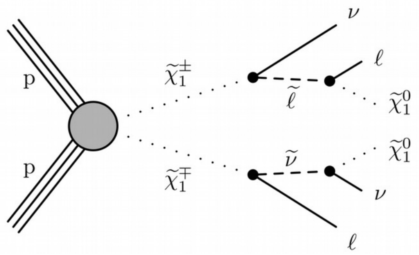
m_{ll} > 20 GeV & $|m_{ll} - m_Z|$ >15 GeV (e^+e^-,$\mu^+\mu^-$) → avoid low masses and Z resonances

p_T^{miss} > 140 GeV → enhance the large missing transverse momentum signatures

Chargino search involves the whole mass plane:

Three generations of leptons are assumed to be degenerated with $m_{slept} = avg(m(\tilde{\chi}^{\pm}_1), m(\tilde{\chi}^0_1))$;

BR ($\tilde{l}$) = BR ($\tilde{\nu}$) =0.5



Main irreducible backgrounds: WW, tW, $t\bar{t}$, ZZ (→2l2ν)

Specific signal region selection:

* At least 1 b jet region → used as control region for top backgrounds

* No b jets split in sub-regions with and without jets → improves the signal sensitivity

Chargino and Stop 3-body Search Strategy

m_{T2} (ll) shape → in bins of p_T^{miss} as discriminant (p_T^{miss} [140,200), [200,300), [300, ...) GeV) ->SRs

$$M_{\mathrm{T2}}(\ell\ell) = \min_{\vec{p}_{\mathrm{T}}^{\mathrm{miss1}}+\vec{p}_{\mathrm{T}}^{\mathrm{miss2}}=\vec{p}_{\mathrm{T}}^{\mathrm{miss}}} \left(\max\left[M_{\mathrm{T}}(\vec{p}_{\mathrm{T}}^{\mathrm{lep1}},\vec{p}_{\mathrm{T}}^{\mathrm{miss1}}), M_{\mathrm{T}}(\vec{p}_{\mathrm{T}}^{\mathrm{lep2}},\vec{p}_{\mathrm{T}}^{\mathrm{miss2}})\right]\right), \quad m_{T2}\text{(ll)} \le m_{mother}$$

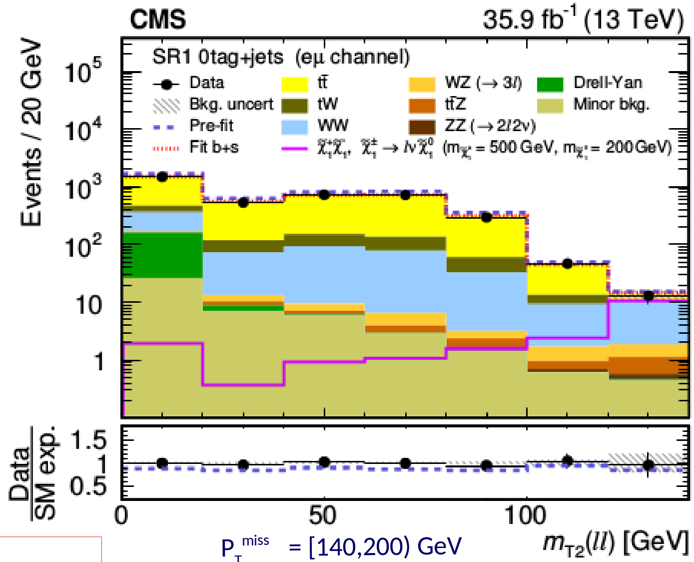
$$m_T^2 = m_\ell^2 + m_\nu^2 + 2(E_T^\ell E_T^\nu - \mathbf{p}_T^\ell \cdot \mathbf{p}_T^\nu), \quad m_T \le m_{mother}$$

Dominant backgrounds from ttbar, tW and WW production

For these backgrounds, leptons and undetected particles come from W bosons decay

The m_{T2}(ll) observable will therefore present a kinematic endpoint at the W boson mass

Signal events do not present such a feature due to additional contributions of neutralinos to the p_T^{miss}



P_T^{miss} = [140,200) GeV

To set the upper limits on the signal cross section:
Perform a simultaneous binned likelihood fit of m_{T2}(ll) shape in all signal and control regions for the ee, μμ, eμ

Background Estimation and Systematics

Chargino and Stop 3-body

Main backgrounds: ttbar, tW and WW

- Keep under control the tails (detector resolution effects!)
  - study m_{T2}(ll) shape in validation regions:
    p_T^{miss} in [100, 140) GeV, p_T^{miss} ≥ 140 GeV
  - study the contribution of events with non-prompt leptons
- Normalization is determined by the fit

Secondary backgrounds:
Z+jets, $t\bar{t}$Z, ZZ(→2l2v), and WZ(→ 3l1v)

- Normalization estimates in control regions
  → Scale Factors (*SF*)

Minor backgrounds: VVV, $t\bar{t}$W, HWW

- Normalized to the theoretical cross section and integrated luminosity

Source of uncertainty	SM processes	
	Change in yields	Change in $m_{T2}(\ell\ell)$ shape
Integrated luminosity	2.5%	—
Trigger	2%	—
Lepton ident./isolation	4–5%	<1%
Jet energy scale	1–6%	3–15%
Unclustered energy	1–2%	2–16%
b tagging	<3%	<2%
Renorm./fact. scales	1–10%	1–6%
PDFs	1–5%	2–8%
$t\bar{t}$Z normalization	<1%	<9%
WZ normalization	<1%	<1%
ZZ normalization	<1%	<5%
Drell–Yan normalization	<4%	1–11%
$m_{T2}(\ell\ell)$ shape (top quark)	—	4–18%
$m_{T2}(\ell\ell)$ shape (WW)	—	1–15%
ZZ *K* factors	—	<3%
$m_{T2}(\ell\ell)$ shape (Drell–Yan)	—	1–13%
Nonprompt leptons	<1%	<4%
$t\bar{t}$ p_T reweighting	1–4%	1–8%

range of the systematic uncertainties effect on the predicted yields for SM processes and the m_{T2} (ll) shape across all signal regions before the fit.

Degenerate Stop Search

Top squark search in the compressed scenario:

- $\Delta m \sim m_t$ → very compressed region

  Main irreducible background

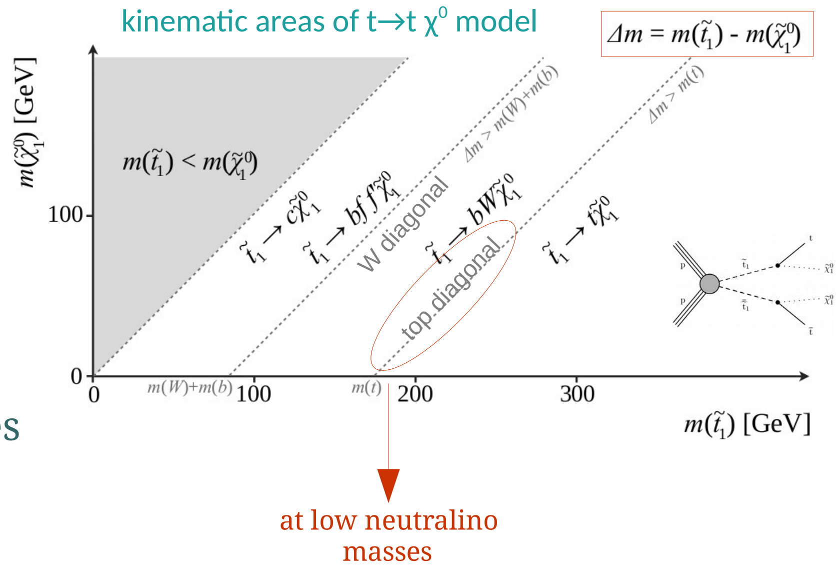
  tW, $t\bar{t}$ (dileptonic decays)

  $m(\tilde{t}) \approx m_t$ → signal reproduces top kinematics

  Sensitivity comes from a precise estimate of the $t\bar{t}$ in MC simulation, exploiting the small uncertainties in the cross section

  $m(\tilde{t}) > m_t$ → Signal kinematic slightly differs from $t\bar{t}$

  Sensitivity comes from massive LSP gives additional p_T^{miss} using the m_{T2} (ll) to signal extraction



Specific signal region selection:

* 2 opposite charge leptons ($e^+\mu^-$, $e^-\mu^+$) , m_{ll} > 20 GeV , nº jets ≥ 2

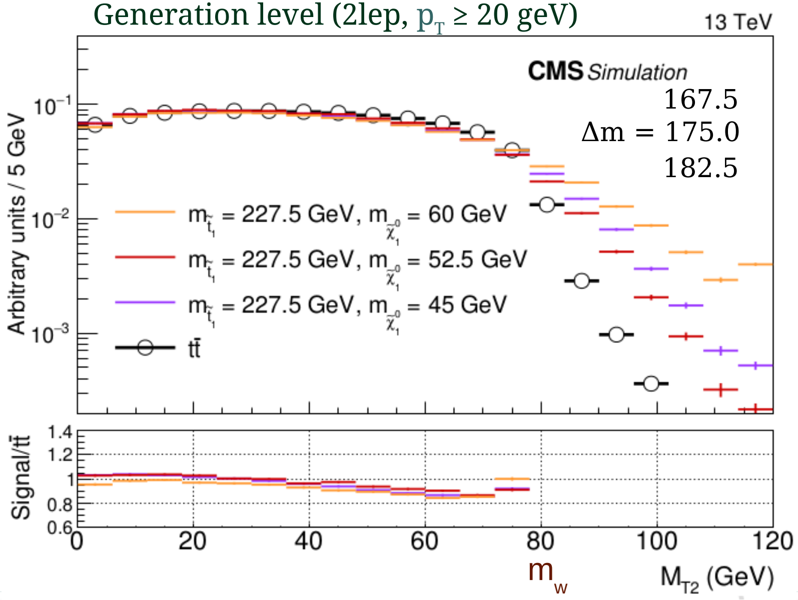
* At least 1 b jet → $t\bar{t}$ enriched region increase the signal to background ratio

Degenerate Stop Search Strategy

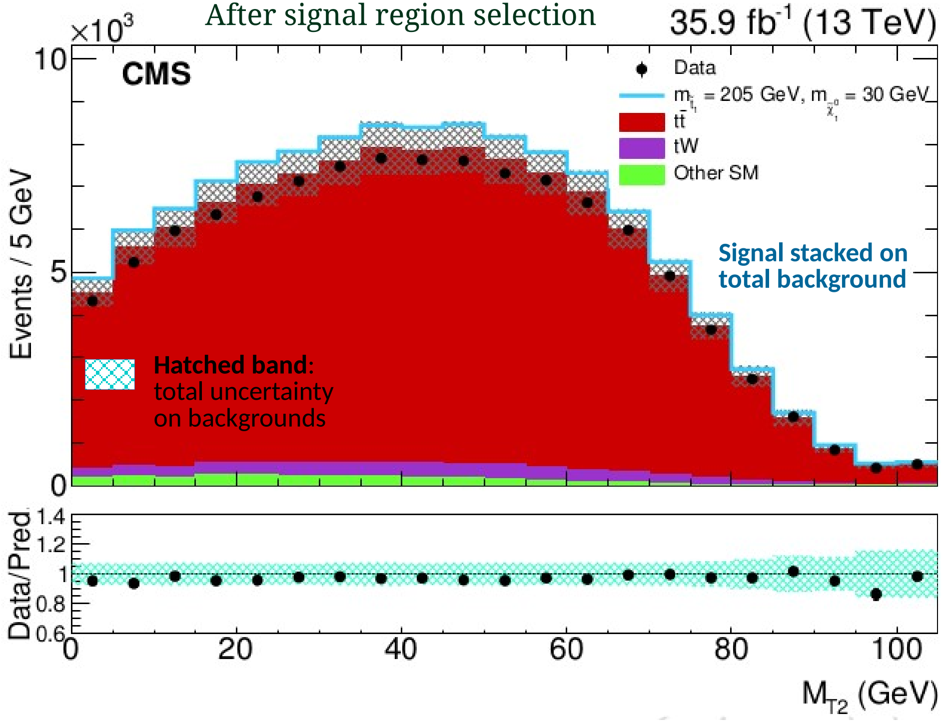
- For small $\tilde{t}_1$ masses, the precise measurement of $t\bar{t}$ cross section and the accurately modeling of kinematic variables can be exploited to distinguish signal to background

- For higher $\tilde{t}_1$ masses, the presence of extra p_T^{miss} can be exploited using as main discriminator variable the $m_{T2}(ll)$

Generation level (2lep, $p_T \geq 20$ geV)



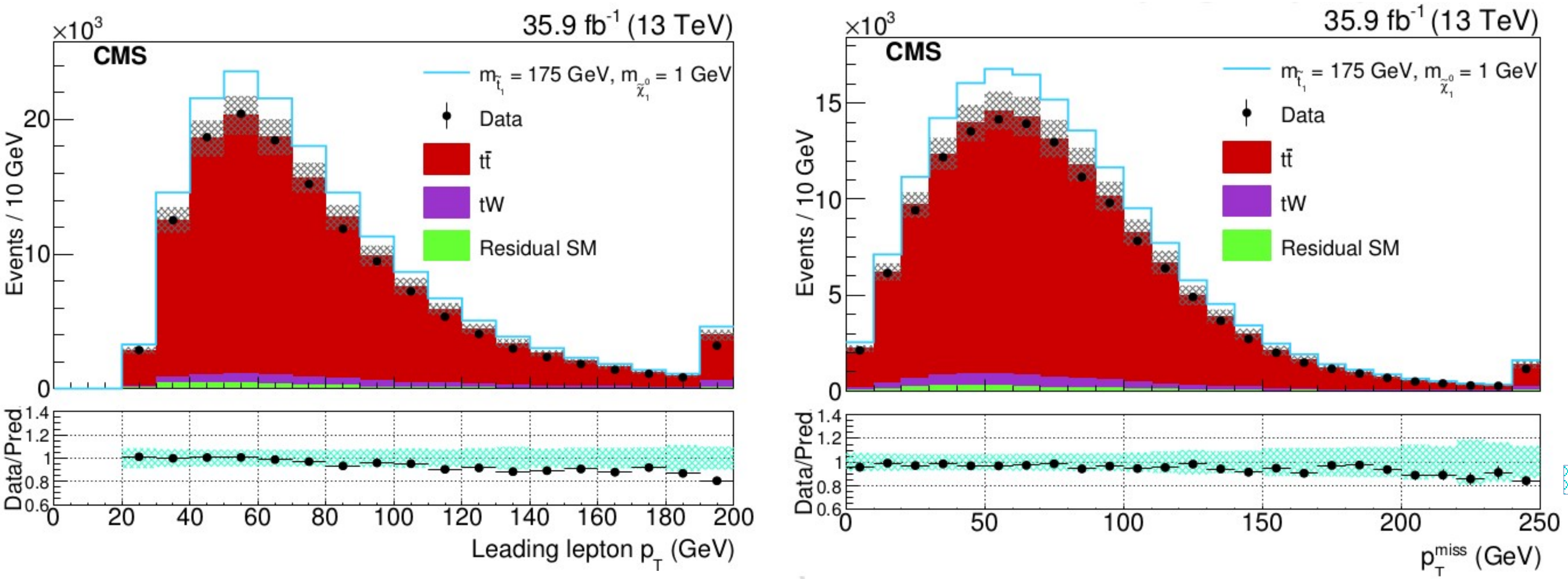
After signal region selection



Signal is expected as an excess in $t\bar{t}$ prediction

Degenerate Stop Background Estimation

Some observables to construct the m_{T2} (ll) variable → good agreement Data/SMprediction



Hatched band: total uncertainty

Background contributions

ttbar ≈ 94% → Normalized to NLO+NNLL cross section and *L*

tW ≈ 4%

Others (DY, dibosons,ttV) ≈ 1% } Normalized to the theoretical cross section and *L*

Non-prompt leptons ≈ 1 % } Normalization estimates in $e^{\pm}\mu^{\pm}$ control region *SF*= 1.2 ±0.1

Degenerate Stop Systematics

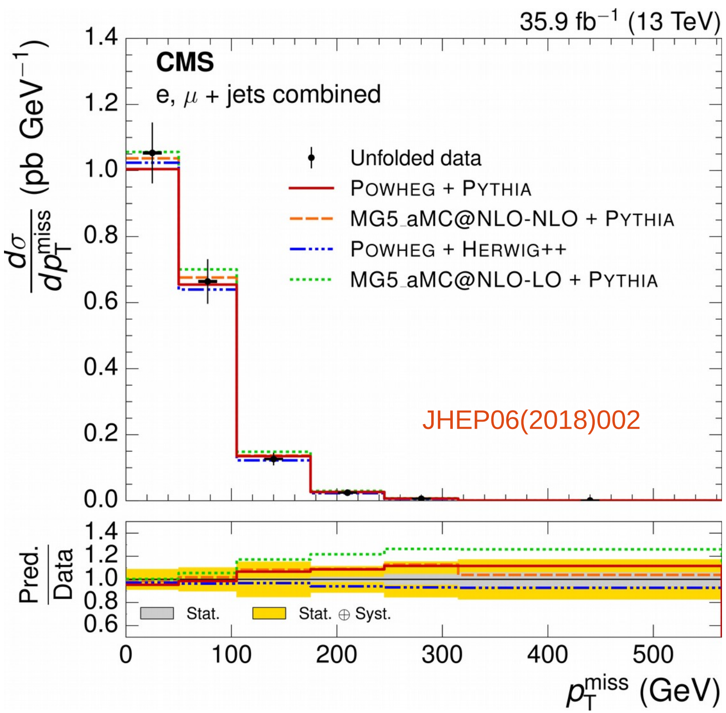
$t\bar{t}$ Modelling uncertainties

- An accurate estimation of the $t\bar{t}$ background takes into account the effect of varying the main theoretical parameters within their uncertainties. The big challenge of this analysis

Source	Range (%)
ME/PS matching (h_{damp})	0.3 – 2
Initial state radiation	0.5 – 1
Final state radiation	0.6 – 1.2
Color reconnection	≈ 1.5
ME scales	0.3 – 1
PDF	≈ 0.6
Top mass (acceptance)	≈ 1
Top p_T reweighting	0.1 – 0.5
Underlying event	≈ 0.8

ME ~ Matrix element
PS ~ parton shower

Treated as shape uncertainties. The ranges correspond to variations of the uncertainty along the $m_{T2}(ll)$ distribution.



Normalized p_T^{miss} differential $t\bar{t}$ cross section compared to different $t\bar{t}$ simulations

Degenerate Stop Systematics

Experimental uncertainties

Treated as correlated among all m_{T2}(ll)bins.

The numbers represent typical values for the uncertainties on signal and $t\bar{t}$ yields or ranges of these uncertainties in different m_{T2} (ll) bins and different signal samples

Source	Range for $t\bar{t}$ and signal (%)
Muon efficiencies	≈1.4
Electron efficiencies	≈1.5
Trigger efficiency	≈0.6
Lepton energy scale	0.5 – 2
Jet energy scale	1.5 – 3.0
Jet energy resolution	0.3 – 3.5
b-tagging efficiency	1.2 – 2.0
Mistagging efficiency	0.2 – 0.6
Unclustered p_T^{miss}	0.5 – 1.5
Pileup	0.5 – 3.5

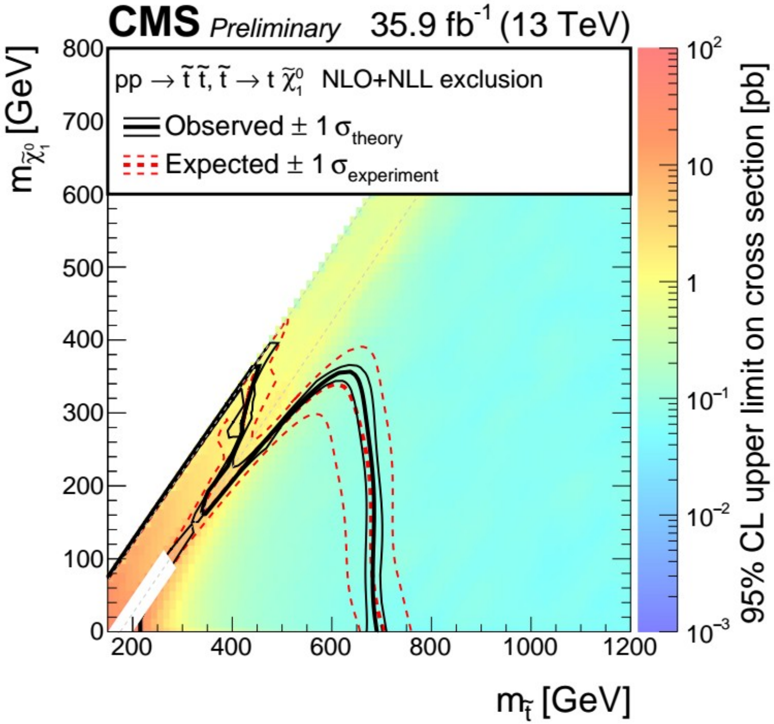
Normalization uncertainties

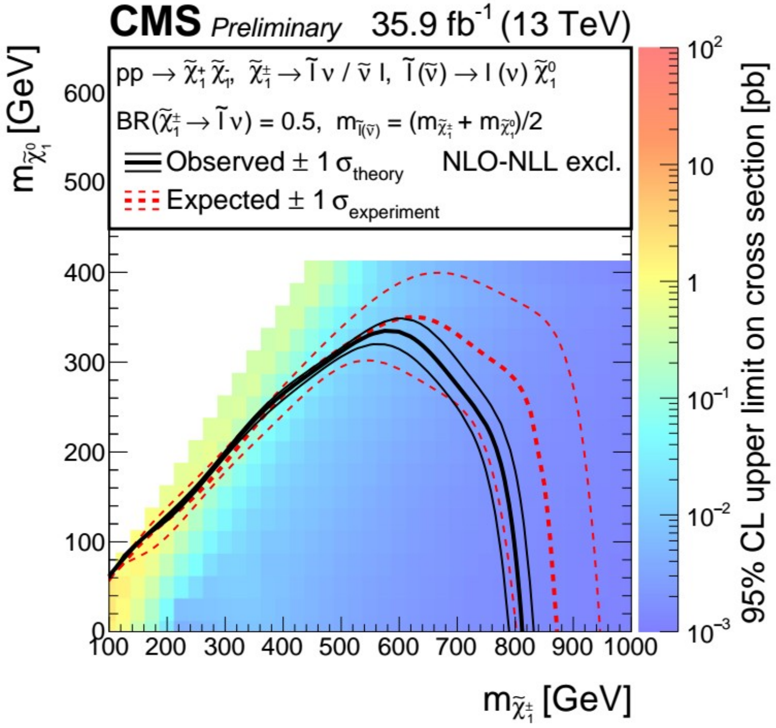
DY	15%	
tW, dibosons, $t\bar{t}V$	30%	
Non-prompt leptons	30%	
Signal	15 %	→ according predicted cross section uncertainties
Renorm./fact. Scales	<1.0%	→ on each m_{T2} (ll) bin
Lumi	2.6%	

Three-body decays and Chargino Results

arXiv:1807.07799, JHEP11(2018)079

Observed limits extend up 420 (360) GeV for top squark (neutralino) masses in the region $m_W \leq \Delta m \leq m_{top}$, and up to 800 GeV for chargino masses





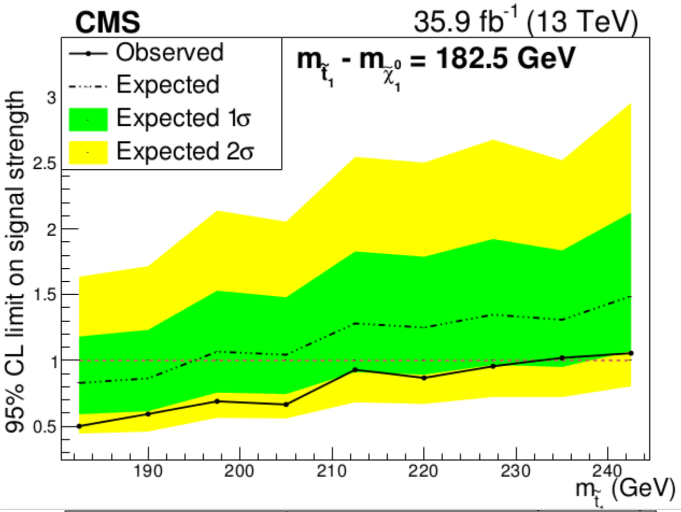
Degenerate Stop Results

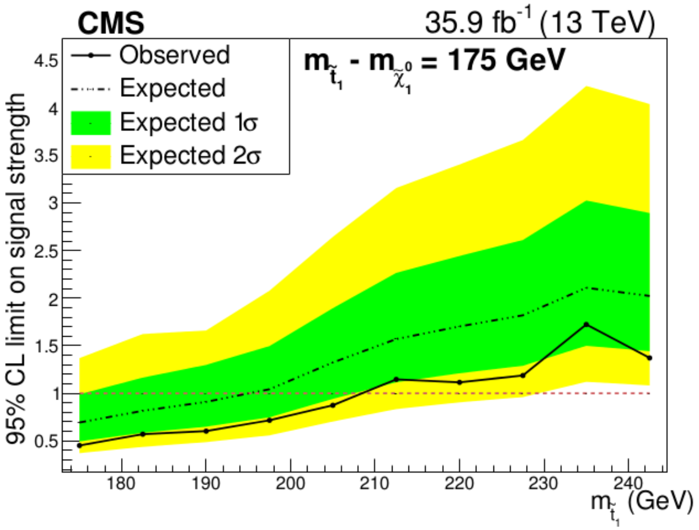
CMS-PAS-SUS-18-003

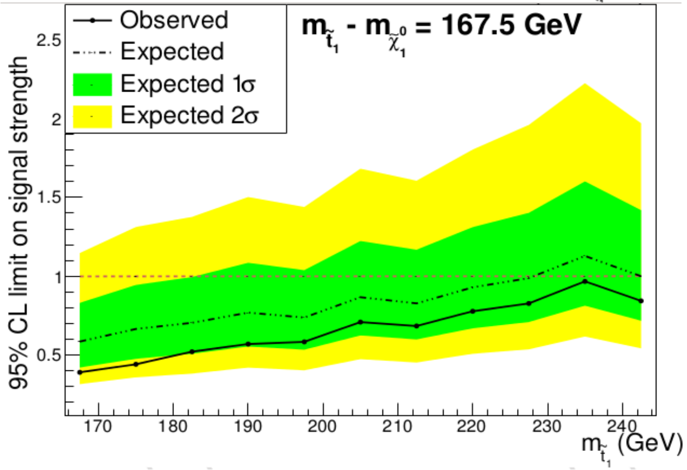
- Top squark excluded for masses up to

  210 GeV in models with $\Delta m = m_{top}$

  240 GeV in models with $\Delta m = m_{top} \pm 7.5$ GeV

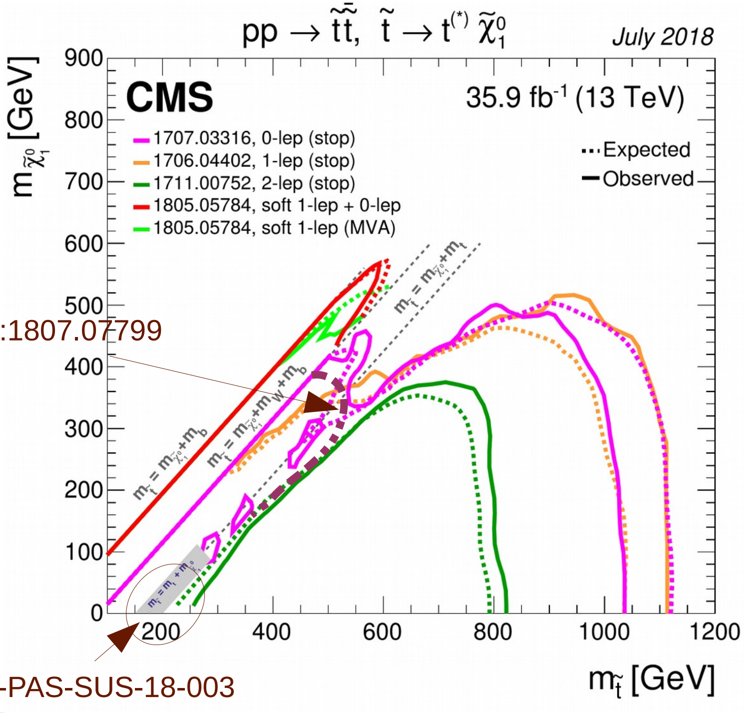






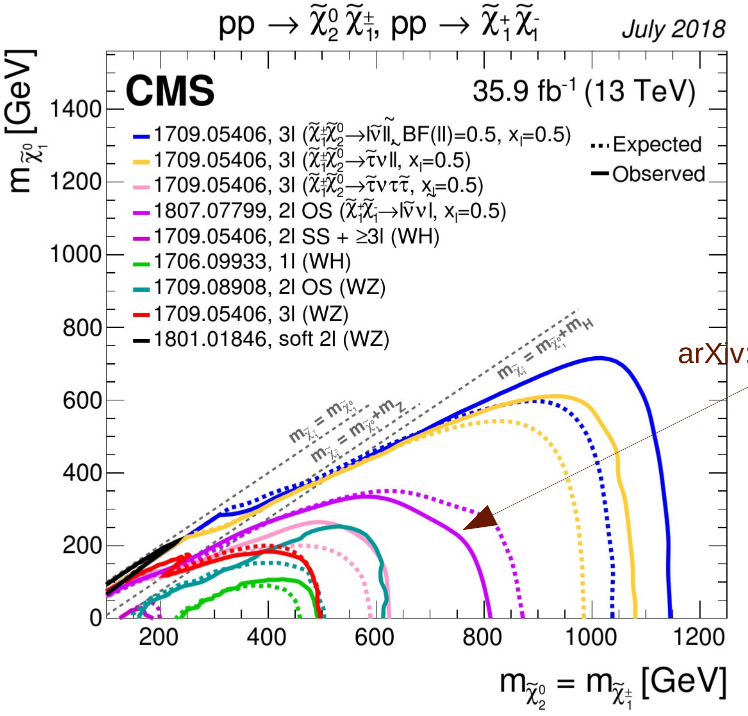
Stop 3-body and Chargino CMS Results

- Summary of mass limits of top squark pair production via an intermediate virtual top quark (left) and chargino pair production and chargino second neutralino production (right) in various final states



arXiv:1807.07799

CMS-PAS-SUS-18-003



arXiv:1807.07799

Conclusions

- Searches for top squark and chargino pair production in final states with two leptons using 2016 LHC data have been presented:

    Latest searches focusing into phase space corners and other decay modes

    No sign for new physics observed over SM backgrounds

- CMS experiment has excluded top squark and chargino masses below to 1.2 TeV and LSP neutralino mass below to 0.8 TeV

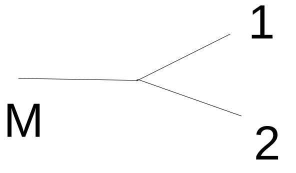
- New and upgraded searches are expected with full RunII LHC data (4-5 time increase of luminosity ~ 150 /fb)

Thanks for your attention

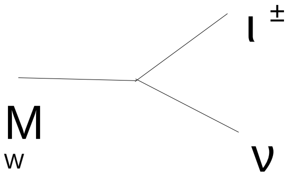
Backup

Analysis Strategy

Invariant mass from a decay: $M^2 = (E_1 + E_2)^2 - \|\mathbf{p}_1 + \mathbf{p}_2\|^2 = m_1^2 + m_2^2 + 2\,(E_1 E_2 - \mathbf{p}_1 \cdot \mathbf{p}_2)$



Invariant transverse mass from a decay at LHC: Example W boson decay



$$m_T^2 = m_\ell^2 + m_\nu^2 + 2(E_T^\ell E_T^\nu - \mathbf{p}_T^\ell \cdot \mathbf{p}_T^\nu)$$

At LHC:

- The ν is invisible and massless
- The lepton mass is negligible

$$m_T^2 = 2(E_T^e \not{E}_T - \mathbf{p}_T^e \cdot \not{\mathbf{p}}_T)\ ,\ \not{E}_T^2 \equiv \not{\mathbf{p}}_T^2$$

$$\longrightarrow\ M_T = \sqrt{2E_\ell E_T^{\text{miss}}\,[1 - \cos(\Delta\phi)]}$$

$$\boxed{m_T^2 \leq m_W^2}$$

Analysis Strategy

M_{T2} (ll) variable from a decay:

- To generalize the transverse mass to a system with two particles of the same mass, each decaying semi-invisibly, we have to decompose the measured P_T^{miss} into a sum of two missing transverse momentum vectors according to $\boxed{\mathbf{p}_T^{miss} = \mathbf{p}_{T1}^{miss} + \mathbf{p}_{T2}^{miss}}$

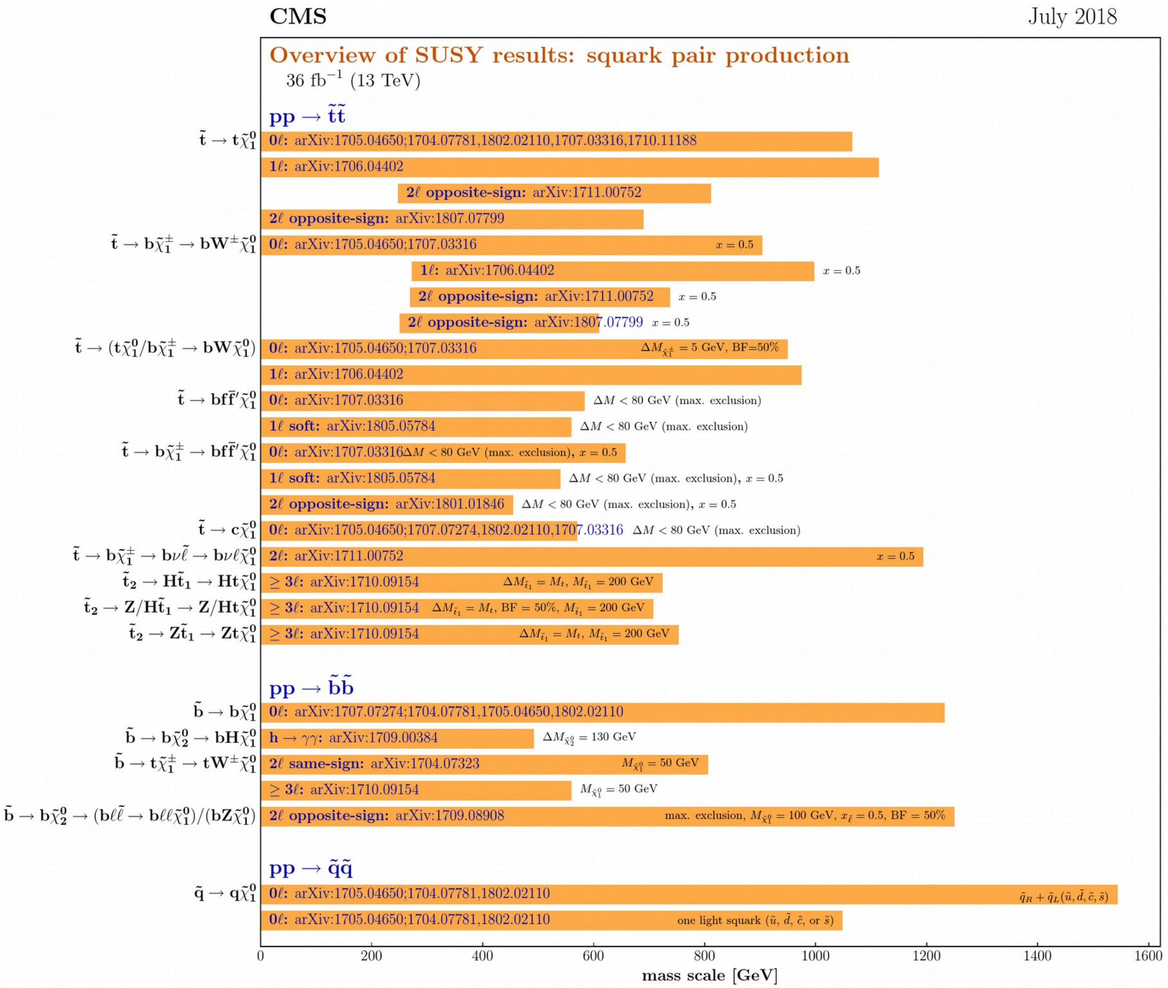
- Since the correct division of the P_T^{miss} into two components is not known, a useful method is to minimize the maximum of the two transverse masses formed under all possible combinations satisfying $\mathbf{p}_T^{miss} = \mathbf{p}_{T1}^{miss} + \mathbf{p}_{T2}^{miss}$

- We explore the parameter space of all possible hypothetical neutrino momenta that satisfy the $\mathbf{p}_T^{miss} = \mathbf{p}_{T1}^{miss} + \mathbf{p}_{T2}^{miss}$ and for each point in this parameter space we calculate M_T for each half of the event and report the maximum of the two. We take the M_{T2} (ll) value for the event to be the minimum of the larger M_T values for each such point.

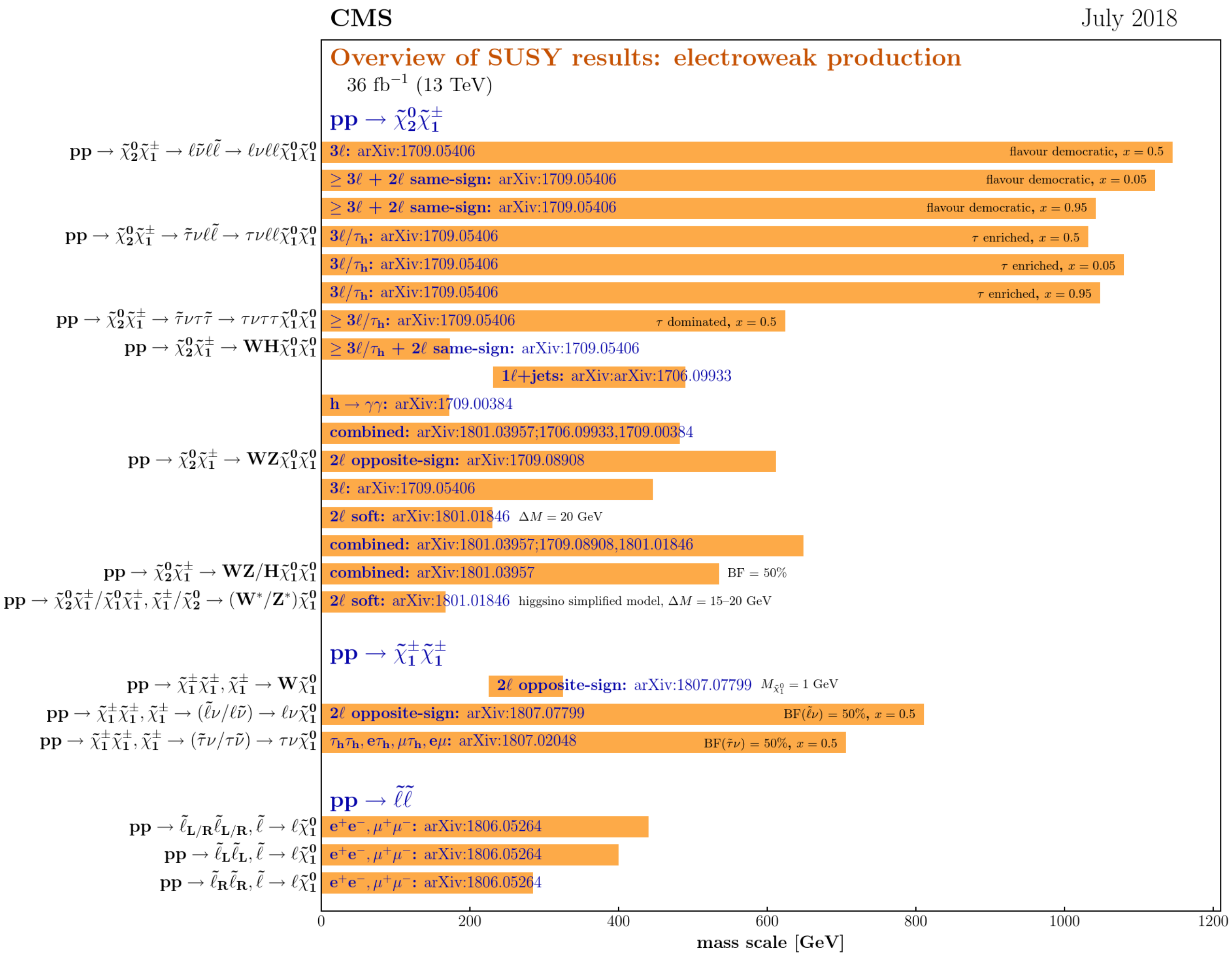
$$M_{T2}^2(ll) = \min_{\mathbf{p}_{T1}^{miss}+\mathbf{p}_{T2}^{miss}=\mathbf{p}_T^{miss}} \left(\max\left[M_T^2(\mathbf{p}_T^{\ell 1}, \mathbf{p}_{T1}^{miss}), M_T^2(\mathbf{p}_T^{\ell 2}, \mathbf{p}_{T2}^{miss})\right]\right) \quad , \quad \boxed{M_{T2}\,(ll) \leq m_{mother}}$$

- The P_T^{miss} and M_{T2} variables exhibit a strong correlation up to MT2ll values of the order of the W boson mass, becoming largely uncorrelated at higher MET values

Bisection method. The algorithm has been implemented in c++ by the authors



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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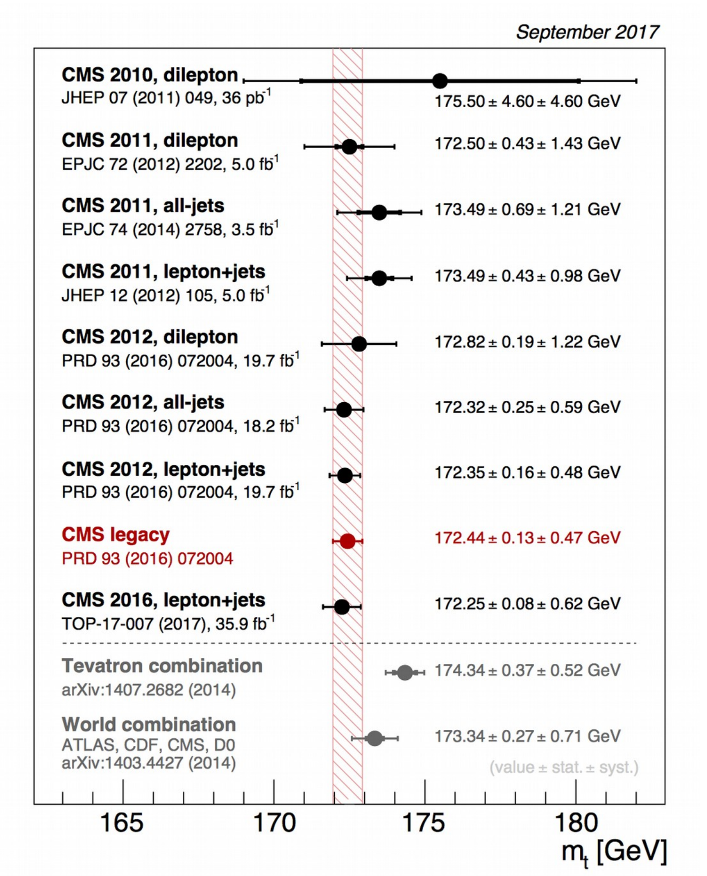
Degenerate Stop search

Documentation from CMS-PAS-SUS-18-003

Summary of top measurements



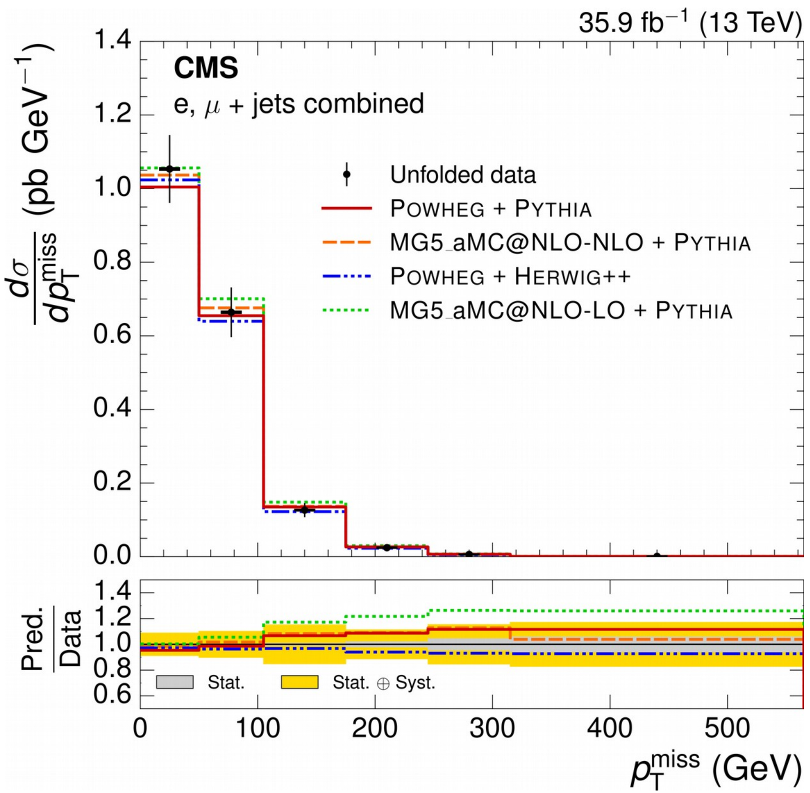
Summary of Run-I CMS mtop measurements and their combination.

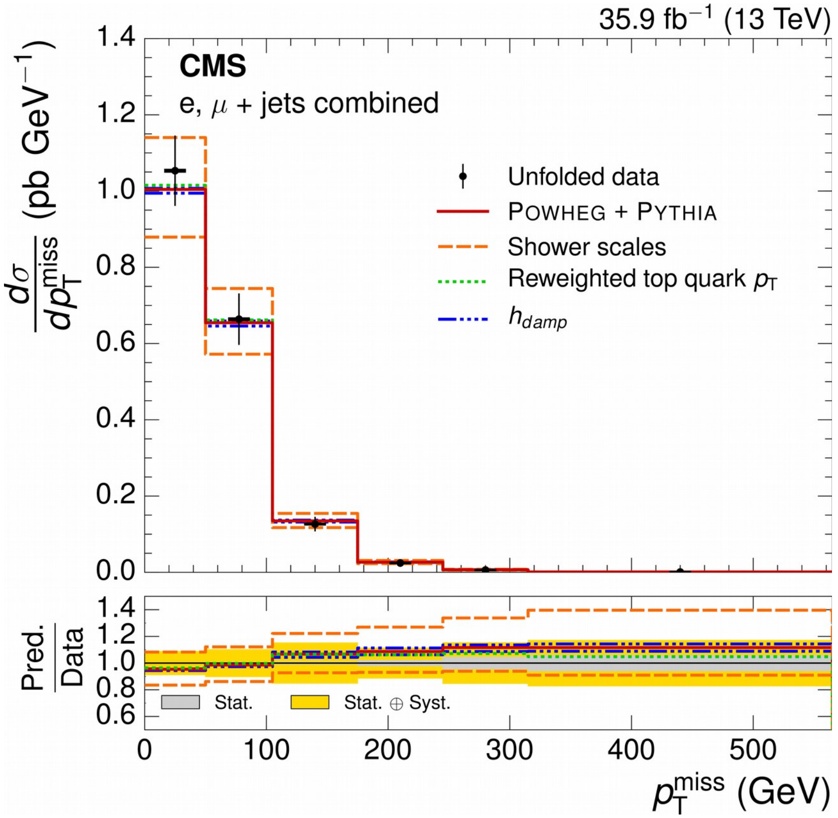
This is figure 12 in the paper CMS TOP-14-022 - arXiv:1509.04044

Simulated tt samples $xs_{top} = 832_{-29}^{+20}$(scale) ± 35(PDF+$\alpha_S$) pb with m_{top} = 172.5 GeV

Normalized p_T^{miss} differential $t\bar{t}$ cross sections

JHEP06(2018)002





Normalized p_T^{miss} differential tt cross sections, compared to different tt simulations in the left plots, and compared to the POWHEG+PYTHIA8 simulation after varying the shower scales, and hdamp parameter, within their uncertainties in the right plots. The vertical bars on the data represent the statistical and systematic uncertainties added in quadrature. The lower plots show the ratio of the predictions to the data.

Table 3: Number of expected and observed events after the selection with $M_{T2} > 0$ and $M_{T2} > 90\,\text{GeV}$. The quoted uncertainties reflect both the statistical and systematic contributions.

Process	with $M_{T2} > 0$ GeV	with $M_{T2} > 90$ GeV
$t\bar{t}$	$102\,400 \pm 7400$	1680 ± 260
tW	4700 ± 1400	92 ± 32
Nonprompt leptons	1330 ± 400	30 ± 11
DY + $t\bar{t}$V+ Dibosons	570 ± 100	19 ± 6
Total Background	$109\,000 \pm 7600$	1821 ± 260
Signal: $m_{\tilde{t}_1} = 175.0$ GeV, $m_{\tilde{\chi}_1^0} = 1.0$ GeV	$16\,400 \pm 2500$	276 ± 53
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}_1^0} = 22.5$ GeV	8070 ± 1240	232 ± 41
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}_1^0} = 30.0$ GeV	7830 ± 1200	157 ± 27
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}_1^0} = 37.5$ GeV	6140 ± 650	262 ± 45
Signal: $m_{\tilde{t}_1} = 242.5$ GeV, $m_{\tilde{\chi}_1^0} = 67.5$ GeV	3550 ± 540	106 ± 19
Data	105 893	1694

Stop 3-body and Chargino search

Documentation from JHEP11(2018)079

Analysis signal regions

Variable	Selection
Lepton flavor	e^+e^-, $\mu^+\mu^-$, $e^\pm\ \mu^\mp$
Leading lepton	$p_T \geq 25\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
Trailing lepton	$p_T \geq 20\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
Third lepton veto	$p_T \geq 15\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
$m_{\ell\ell}$	$\geq 20\,\text{GeV}$
$\lvert m_{\ell\ell} - m_Z\rvert$	$>15\,\text{GeV}$ only for ee and $\mu\mu$ events
p_T^{miss}	$\geq 140\,\text{GeV}$

Table 1. Definition of the baseline selection used in the searches for chargino and top squark pair production.

	$SR1^{0jet}_{0tag}$	$SR1^{jets}_{0tag}$	$CR1_{tags}$	$SR2^{0jet}_{0tag}$	$SR2^{jets}_{0tag}$	$CR2_{tags}$	$SR3_{0tag}$	$CR3_{tags}$
p_T^{miss} [GeV]	140–200	140–200	140–200	200–300	200–300	200–300	$\geq$300	$\geq$300
$N_{b\ jets}$	0	0	$\geq$1	0	0	$\geq$1	0	$\geq$1
N_{jets}	0	$\geq$1	$\geq$1	0	$\geq$1	$\geq$1	$\geq$0	$\geq$1
Channels	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF
$m_{T2}(\ell\ell)$	0–20, 20–40, 40–60, 60–80, 80–100, 100–120, $\geq$120 GeV							

Table 2. Definition of the SRs for the chargino search as a function of the p_T^{miss} value, the b-jet multiplicity and jet multiplicity. Also shown are the CRs with b-tagged jets used for the normalization of the $t\bar{t}$ and tW backgrounds. Each of the regions is further divided in seven $m_{T2}(\ell\ell)$ bins as described in the last row.

	$SR1_{0tag}$	$SR1_{tags}$	$SR2_{0tag}$	$SR2_{tags}$	$SR3^{ISR}_{0tag}$	$SR3^{ISR}_{tag}$
p_T^{miss} [GeV]	140–200	140–200	200–300	200–300	$\geq$300	$\geq$300
$N_{b\ jets}$	0	$\geq$1	0	$\geq$1	0	$\geq$1
N_{jets}	$\geq$0	$\geq$1	$\geq$0	$\geq$1	$\geq$1	$\geq$2
ISR jets	$\geq$0	$\geq$0	$\geq$0	$\geq$0	$\geq$1	$\geq$1
Channels	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF	SF, DF
$m_{T2}(\ell\ell)$	0–20, 20–40, 40–60, 60–80, 80–100, 100–120, $\geq$120 GeV					

Table 3. Definition of the SRs for top squark production search as a function of the p_T^{miss} value, the b-jet multiplicity and the ISR jet requirement. Each of the regions is further divided in seven $m_{T2}(\ell\ell)$ bins as described in the last row.

Shape validation regions

- study $M_{T2}(ll)$ shape in validation regions:

P_T^{miss} in [100, 140) GeV → + nbjet ≥ 1 → ttbar enriched
→ + nbjet = 0 → ttbar + WW enriched

Good agreement Data/MC

P_T^{miss} ≥ 140 GeV : WZ → 3l1ν in Z window to mimic WW→ 2l + 2ν → Good agreement Data/MC

Based on the statistical precision of the MC in the CR's derived shape uncertainty

- study the contribution of events with non-prompt leptons:

Contribution < 1% of each expected background across all SR's
At high values of MT2 and P_T^{miss} it becomes 20% for $t\bar{t}$

Modeling of shows good agreement Data/MC in a CR with same sign leptons and at least 1 bjet

Based on the observed agreement with data a scale factor is derived SF = 1.08 ± 0.21

Control regions

Z+jets, $t\bar{t}Z$, ZZ(→2l2v), and WZ(→ 3l1v)

$t\bar{t}Z$ → 2l + 2 bjets + P_T^{miss} => **3leptons** + P_T^{miss} **> 140 GeV** + nbjet ≥ 1

WZ → 3l + P_T^{miss} => **3leptons** + P_T^{miss} **> 140 GeV** + nbjet = 0

ZZ → 2l + P_T^{miss} => **studied ZZ** → 4l => **4leptons** + Z windows + P_T^{miss} **> 140 GeV** + nbjet = 0 + $\begin{cases} \text{njet} > 0 \\ \text{njet} \geq 0 \end{cases}$

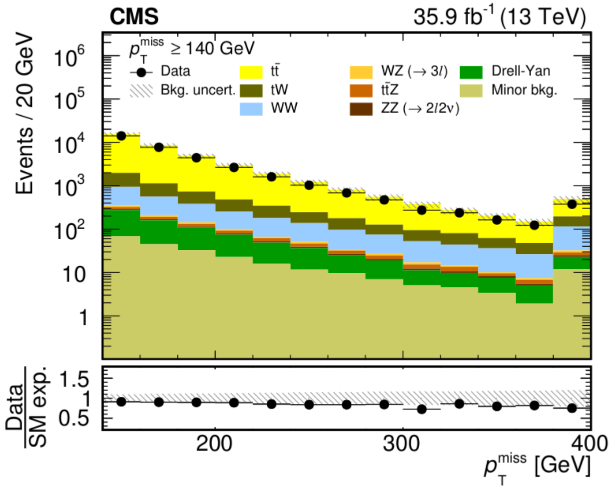
Z+jets → 2l + jets => **Z boson selection** + **100 <** P_T^{miss} **< 140 GeV**

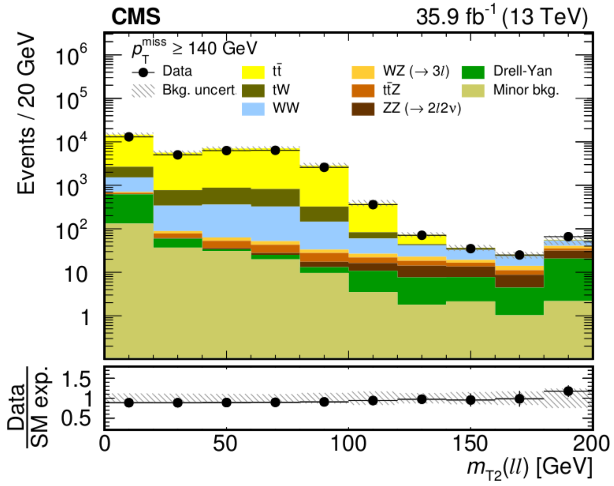
Derived normalization ~32% and shape ~5-50% uncertainties

Process	Scale factors		
	$N_{\text{jets}} = 0$ (a)	$N_{\text{jets}} > 0$ (a)	$N_{\text{jets}} \geq 0$ (b)
$t\bar{t}Z$	1.44 ± 0.36	1.44 ± 0.36	1.44 ± 0.36
WZ	0.97 ± 0.09	0.97 ± 0.09	0.97 ± 0.09
ZZ	0.74 ± 0.19	1.21 ± 0.17	1.05 ± 0.12

Table 4. Summary of the normalization scale factors for $t\bar{t}Z$, WZ, and ZZ backgrounds in the SRs used for the chargino (a) and top squark (b) searches. Uncertainties include the statistical uncertainties of data and simulated event samples, and the systematic uncertainties on the number of expected events from the residual processes in the CRs.

Observables

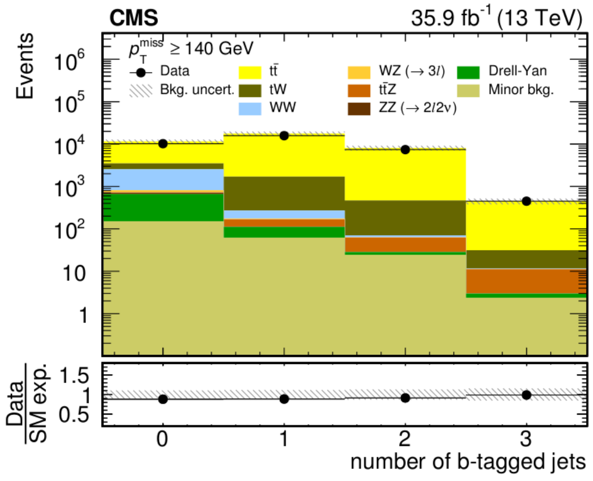


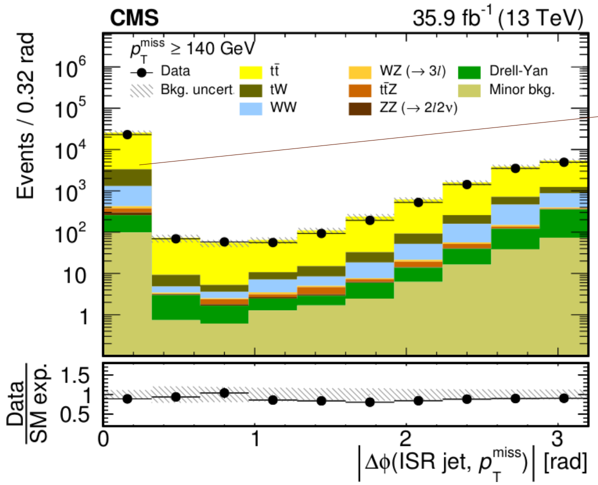


Observables used to define the SR's with

Good agreement data/mc

Hatched band:
total uncertainty





events missing this requirements are shown in the first bin

ISR jet :
leading jet, required not to be b-tagged, $P_T > 150$ GeV

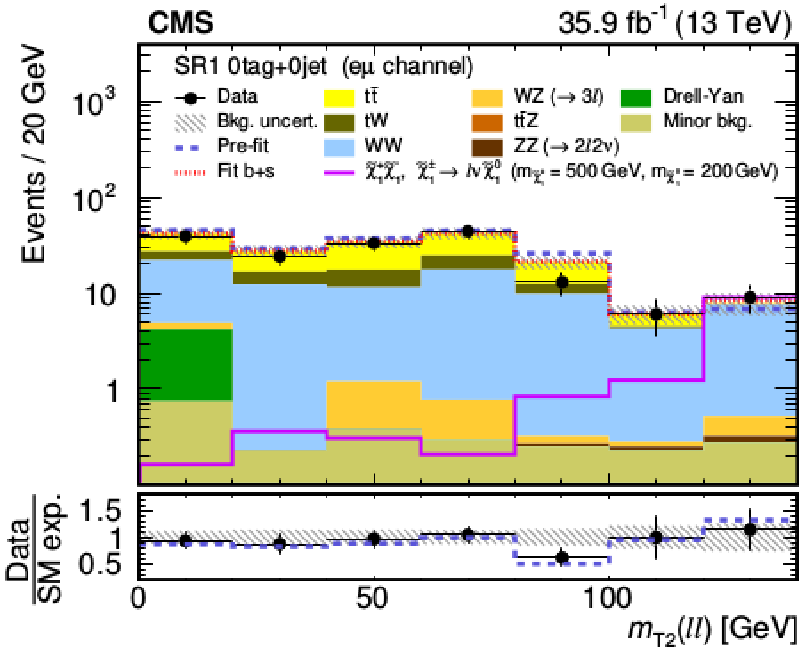
Systematic uncertainties on signal

Source of uncertainty	$\widetilde{\chi}_1^{\pm} \to \widetilde{\ell}\nu(\ell\widetilde{\nu}) \to \ell\nu\widetilde{\chi}_1^0$ ($m_{\widetilde{\chi}_1^{\pm}} = 500\,\text{GeV}$, $m_{\widetilde{\chi}_1^0} = 200\,\text{GeV}$)		$\widetilde{\mathrm{t}}_1 \to \mathrm{t}\widetilde{\chi}_1^0$ ($m_{\widetilde{\mathrm{t}}_1} = 350\,\text{GeV}$, $m_{\widetilde{\chi}_1^0} = 225\,\text{GeV}$)	
	Yields	$m_{\mathrm{T2}}(\ell\ell)$ shape	Yields	$m_{\mathrm{T2}}(\ell\ell)$ shape
Integrated luminosity	2.5%	—	2.5%	—
Trigger	2%	—	2%	—
Lepton ident./isolation	4–5%	<1%	4–5%	<1%
Jet energy scale	1–3%	3–11%	1–4%	2–14%
Unclustered energy	1–2%	8–13%	1–2%	2–7%
b tagging	<1%	<1%	1–3%	<1%
Renorm./fact. scales	1–3%	1–3%	1–3%	1–3%
Lept. id./iso. (FastSim)	4%	<1%	4%	<1%
b tagging (FastSim)	<1%	<1%	<1%	<1%
$\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}$ (FastSim)	1–4%	7–28%	1–6%	6–20%
Pileup (FastSim)	1–6%	4–9%	2–4%	2–14%
ISR reweighting	1–2%	1–6%	2–8%	1–6%

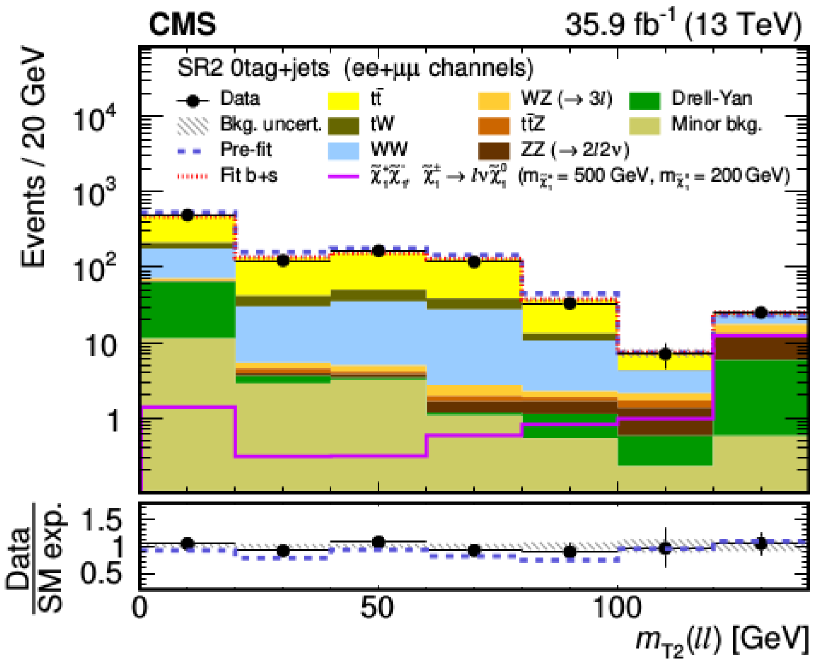
Table 6. Same as in table 5 for two representative signal points, one for chargino pair production and one for top squark pair production.

Representative distributions after the fit

$\chi^+ \chi^- \rightarrow \nu \, \tilde{l} \, (\tilde{\nu} l) + \tilde{\nu} l \, (\nu \, \tilde{l}) \rightarrow \nu l \, \chi^0_1 + \nu l \chi^0_1$



SR1 → P_T^{miss} = [140, 200) GeV

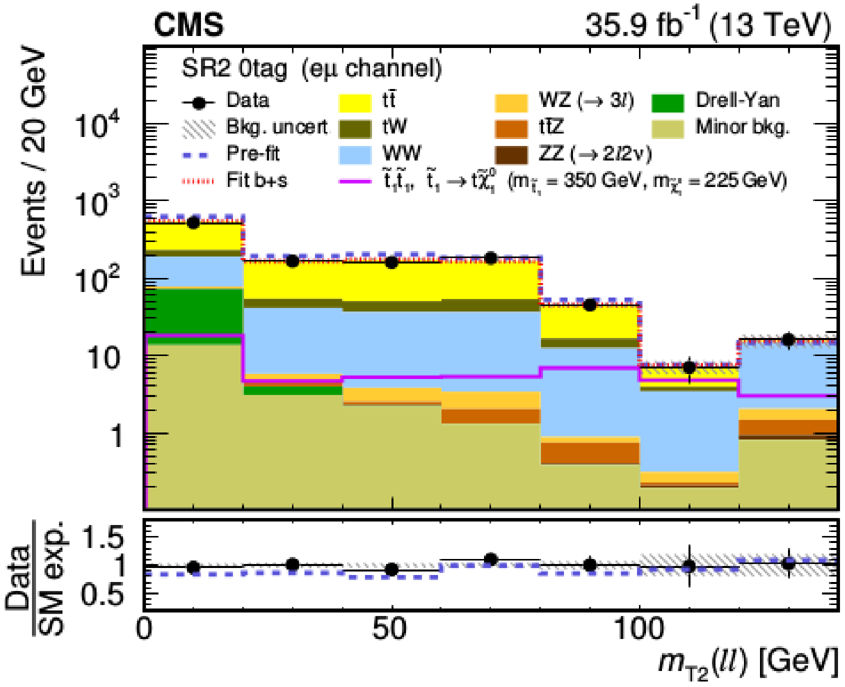


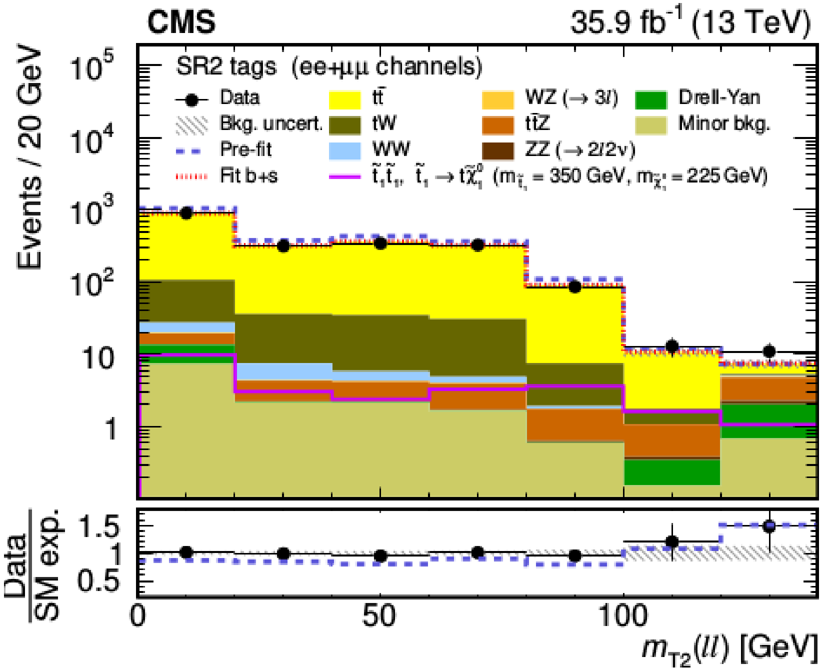
SR2 → P_T^{miss} = [200, 300) GeV

- **Hatched band**: total uncertainty *after the fit*
- **Err** σ_D / MC
- **Hatched band** $1 \pm \sigma_{MC}$ / MC

Representative distributions after the fit

$\tilde{t}\bar{\tilde{t}} \rightarrow t\bar{t}+\tilde{\chi}^0\tilde{\chi}^0 \rightarrow bW^+ + \bar{b}W^- + \tilde{\chi}^0\tilde{\chi}^0 \rightarrow b\bar{b} + l_1^+\nu_1 + l_2^- \nu_2 + \tilde{\chi}^0\tilde{\chi}^0$



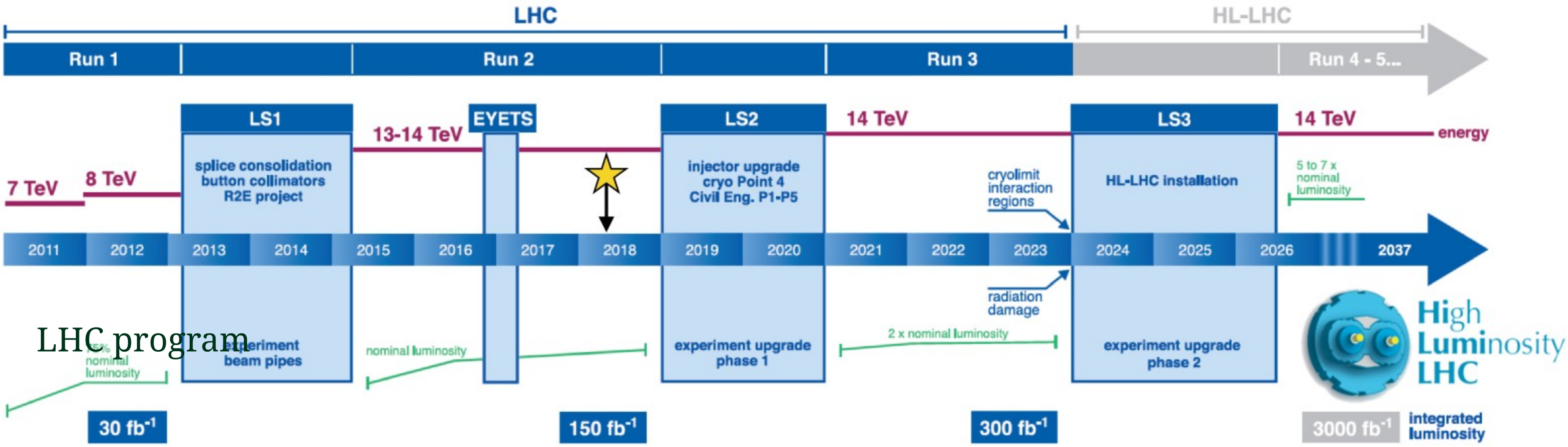


- **Hatched band**: total uncertainty *after the fit*

- **Err** σ_D / MC
- **Hatched band** $1 \pm \sigma_{MC}$ / MC

SR2 → P_T^{miss} = [200, 300) GeV

LHC program



LHC program