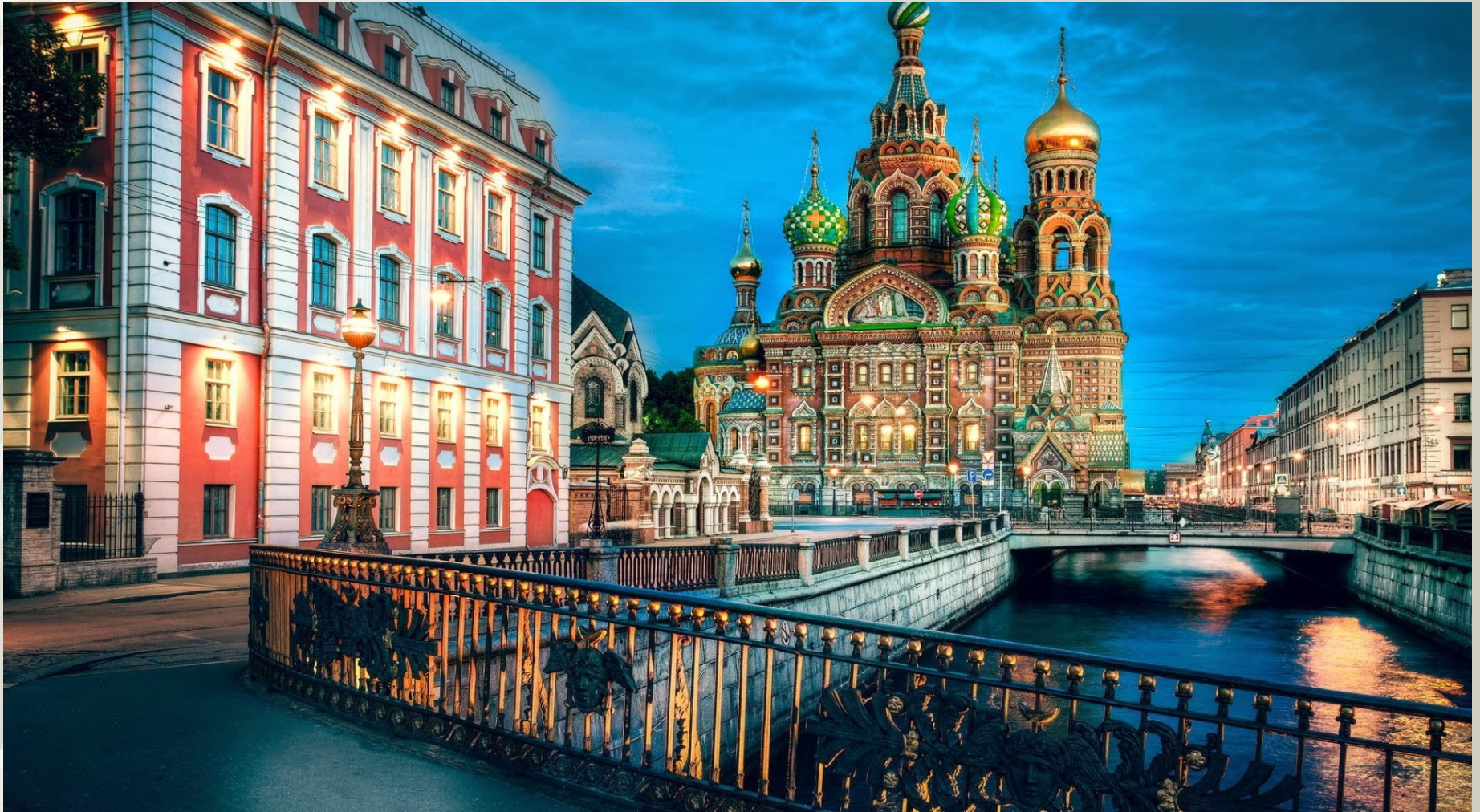


Searches for third generation squarks



Lara Lloret Iglesias
LHCP2015



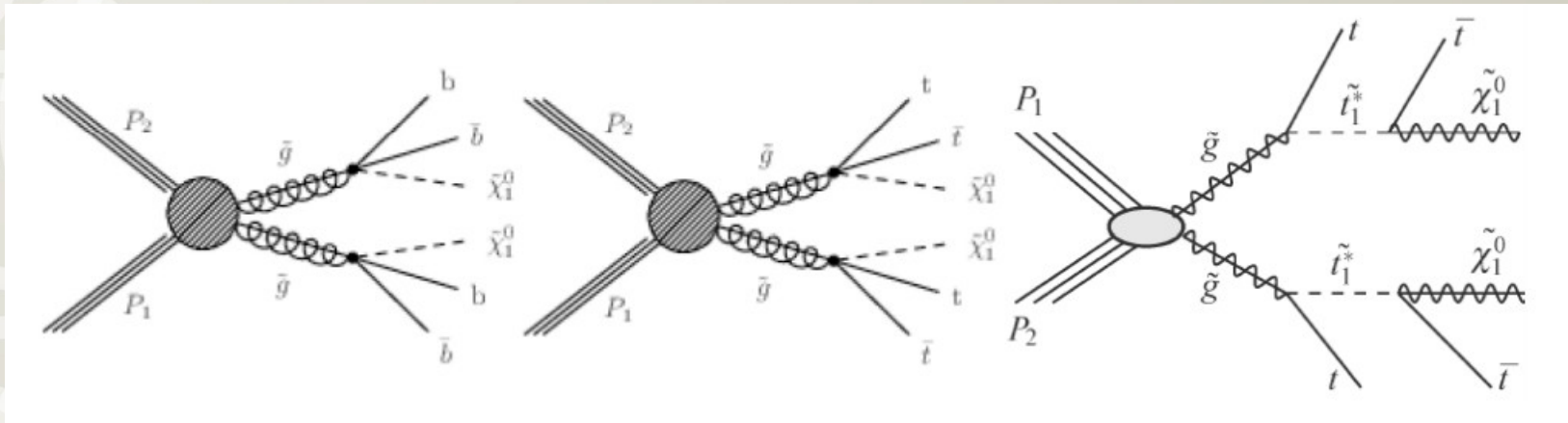
31 Aug-5 Sep 2015, Saint Petersburg

Motivation: third generation

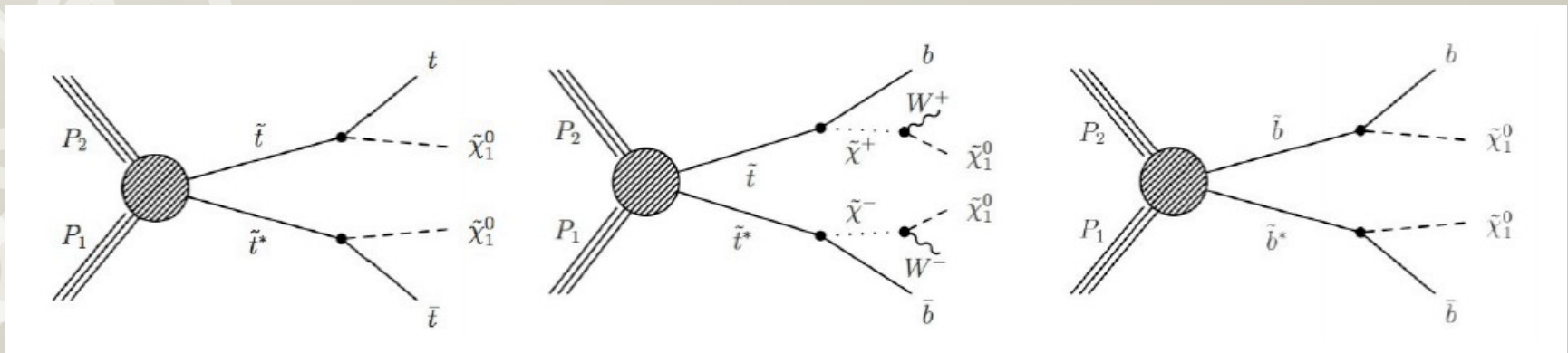
- ✓ There is a large effort in searches for third generation squarks.
- ✓ They **contribute** in Higgs boson mass **loop corrections**.
- ✓ Naturalness of Higgs mass requires top squarks (stops) to be light.
 - 3rd generation squarks **may be accessible at LHC**
- ✓ When **R-parity is conserved**, the number of SUSY particles must be preserved in the decay (assumed in this talk)
- ✓ Simplest squark decay signature: direct decay of **squark to quark + LSP**
 - Lightest supersymmetric particle (LSP) cannot decay
 - Provides nice **dark matter candidate**
 - In this talk, the **LSP is always the lightest neutralino**

Third generation searches

- If gluino mass accessible at 8 TeV then one can search for gluino mediated sbottom/stop pair production. Final state rich in b-jets and tops (large Missing ET and numbers of jets)

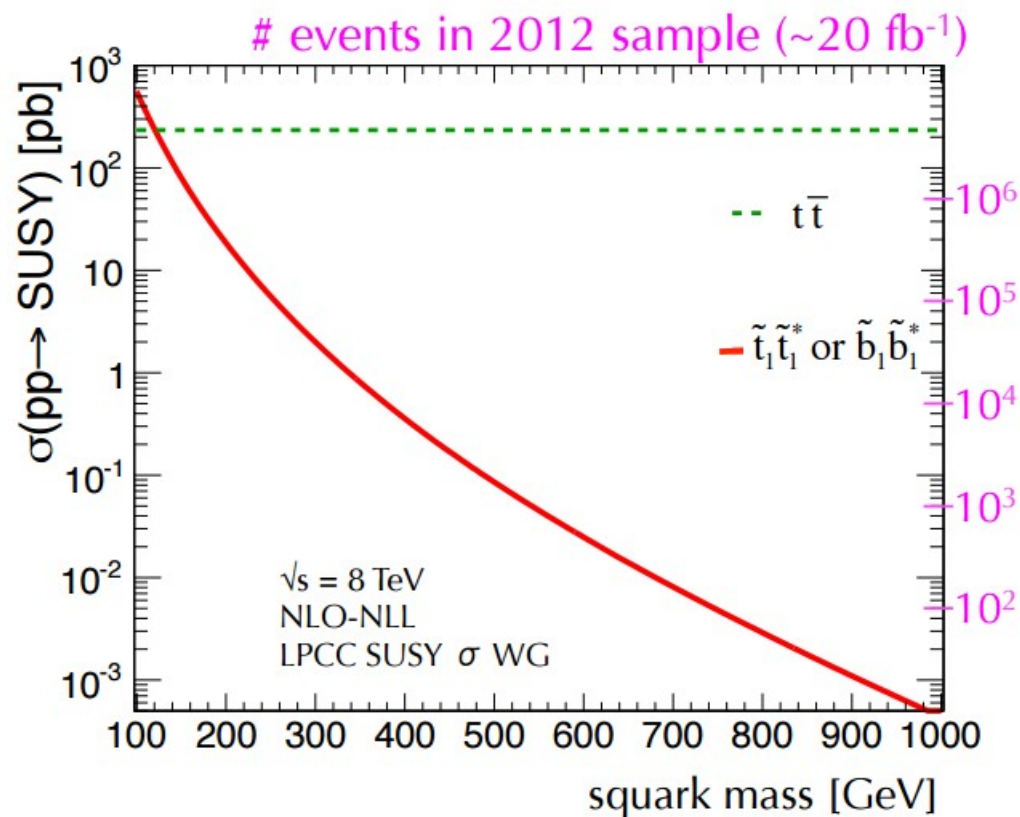
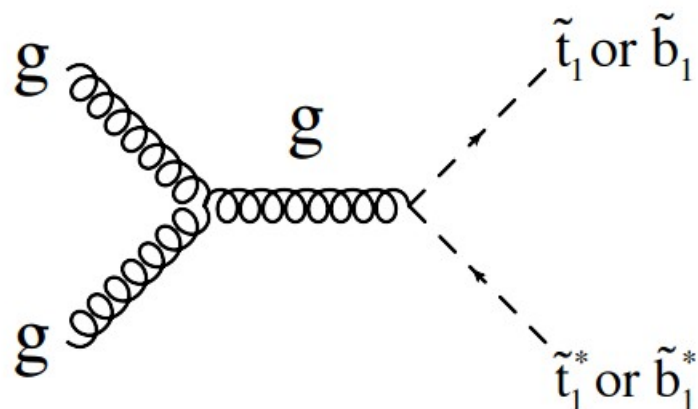


- If gluino mass not accessible at 8 TeV then one can search for direct sbottom/stop pair production. Final state typically $t\bar{t}$ + Missing ET or $b\bar{b}$ + Missing ET → Reach of this talk



Direct production

- ✓ Direct squark pair production by gg fusion or qq annihilation



- ✓ Cross-section rapidly falls with mass

~ 100 events expected in 8 TeV dataset for 700 GeV squarks

- ✓ Cross-section of squark pairs is $\sim 1/6$ of quark pairs with same mass (e.g. $t\bar{t}$)



Direct squark pair production

- **All hadronic MVA**
- **Monojet**
- **One lepton**
 - **Combined with 0 lepton razor**

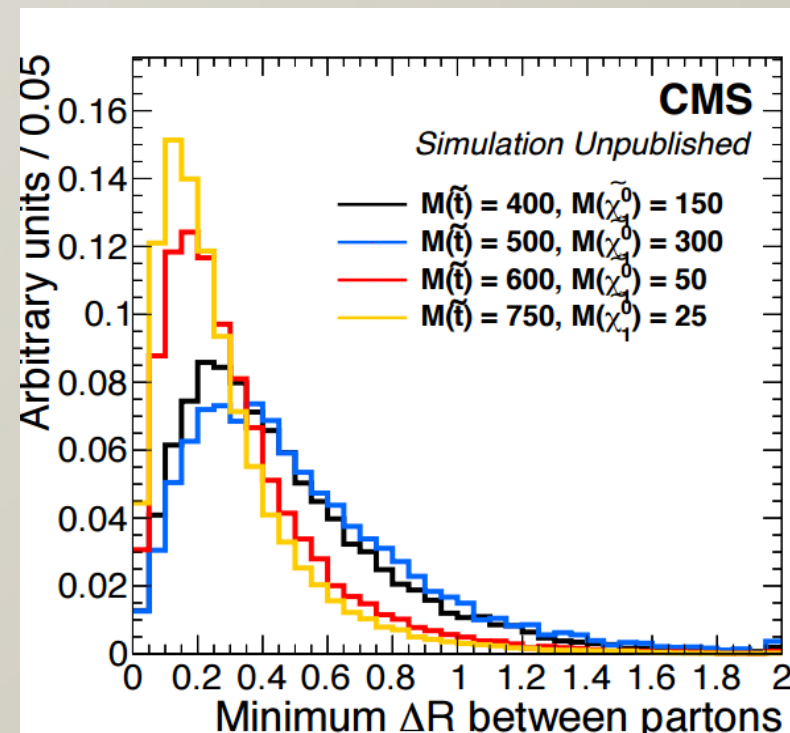
All hadronic MVA

- 1) Clustering jets with the Cambridge/Aachen algorithm with distance metric $R=1$ (fat jets)
- 2) Each fat jet is then considered for division into a pair of subjects
- 3) MVA ‘picky’ metric is then used to determine if it is more appropriate to associate the particles with the two subjects than with the fat jet

CORRAL top pair reconstruction:

- Identify “top candidates”: three jet combinations containing at least one seed (highest pt jets in the event)
- They must pass top candidate MVA
 - W and top invariant masses and the b-tagging discriminator value
- Identify “top **pair** candidates”: pairs of top candidates group \rightarrow six unique jets
 - Choose best pair based on MVA

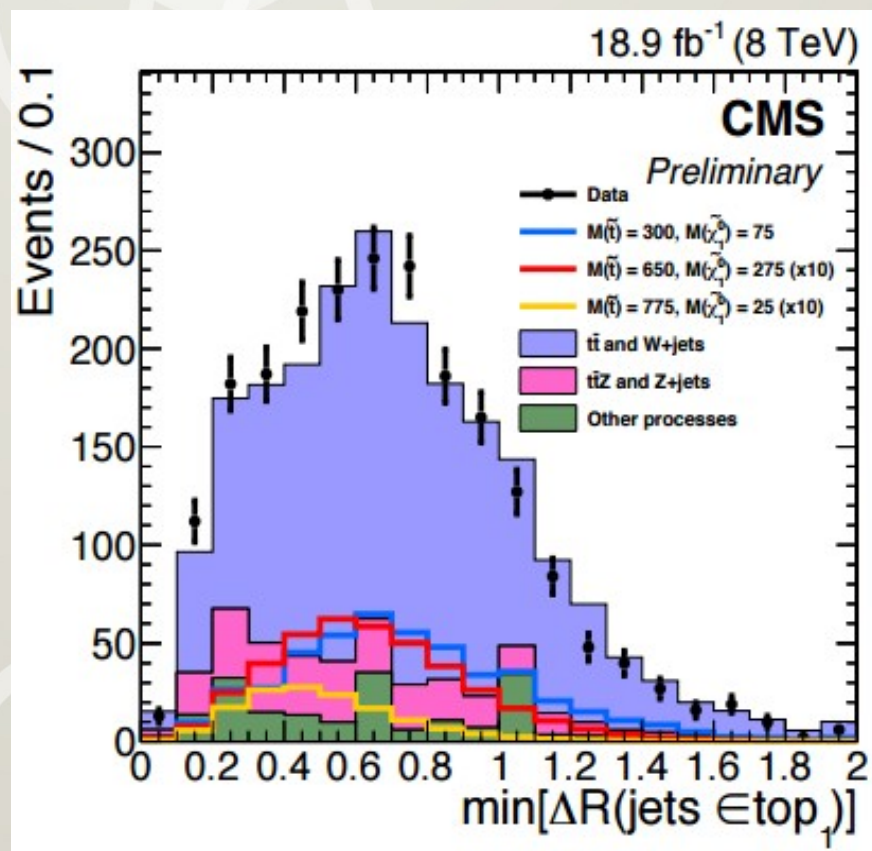
ΔR between partons differs
based on top quark boost



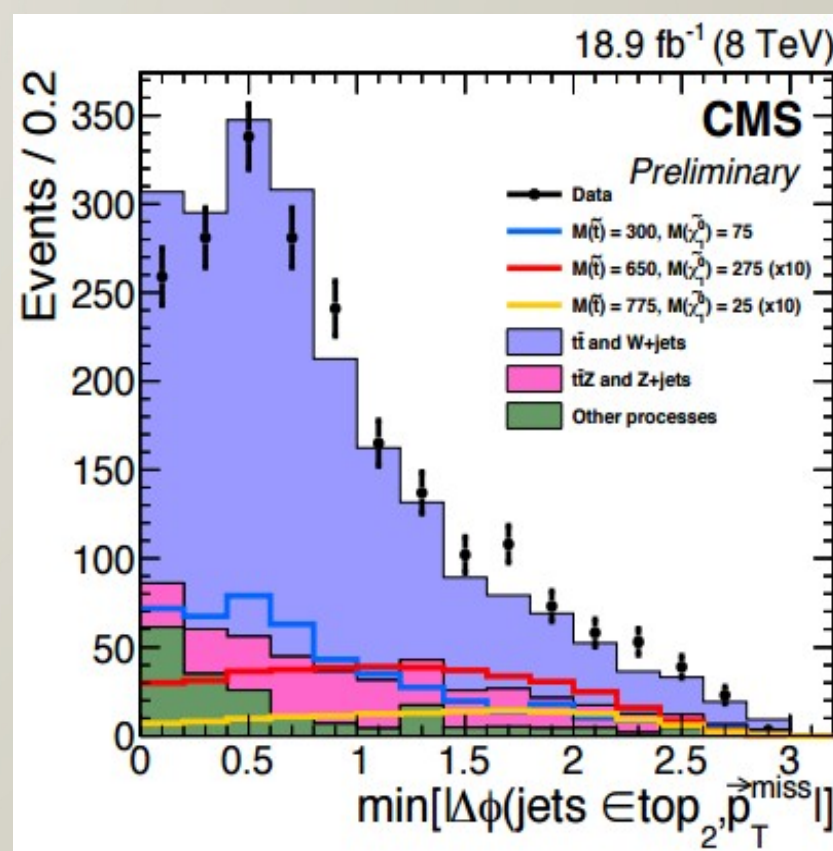
All hadronic MVA

Once the top pairs have been reconstructed: kinematics are used to discriminate signal from background

Tops from signal are collimated

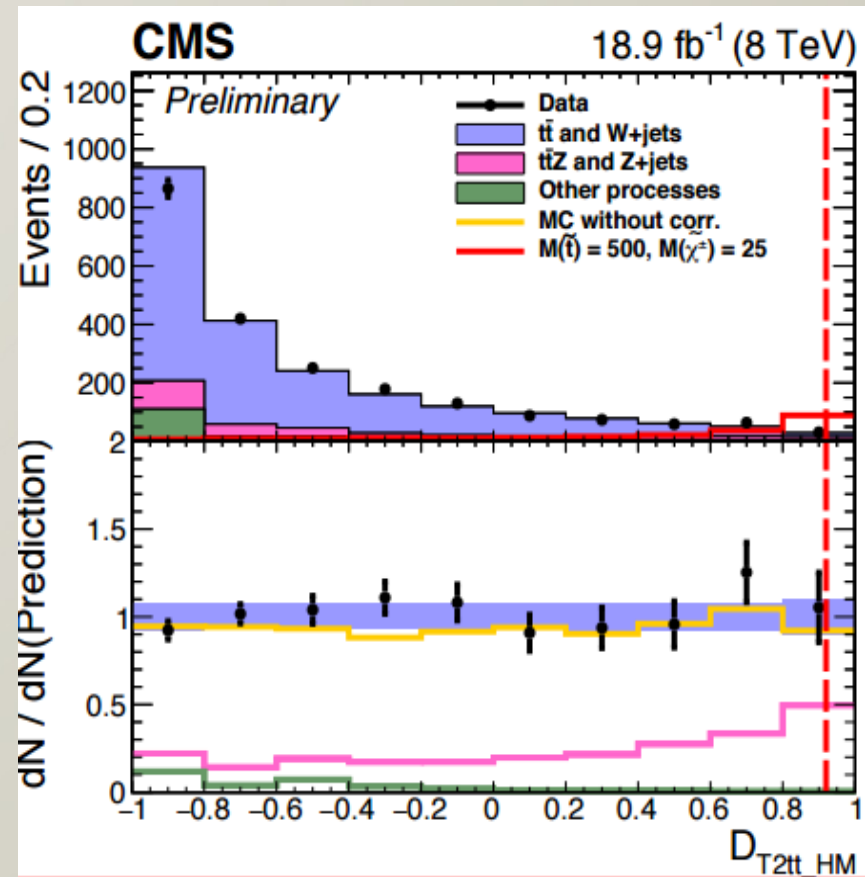
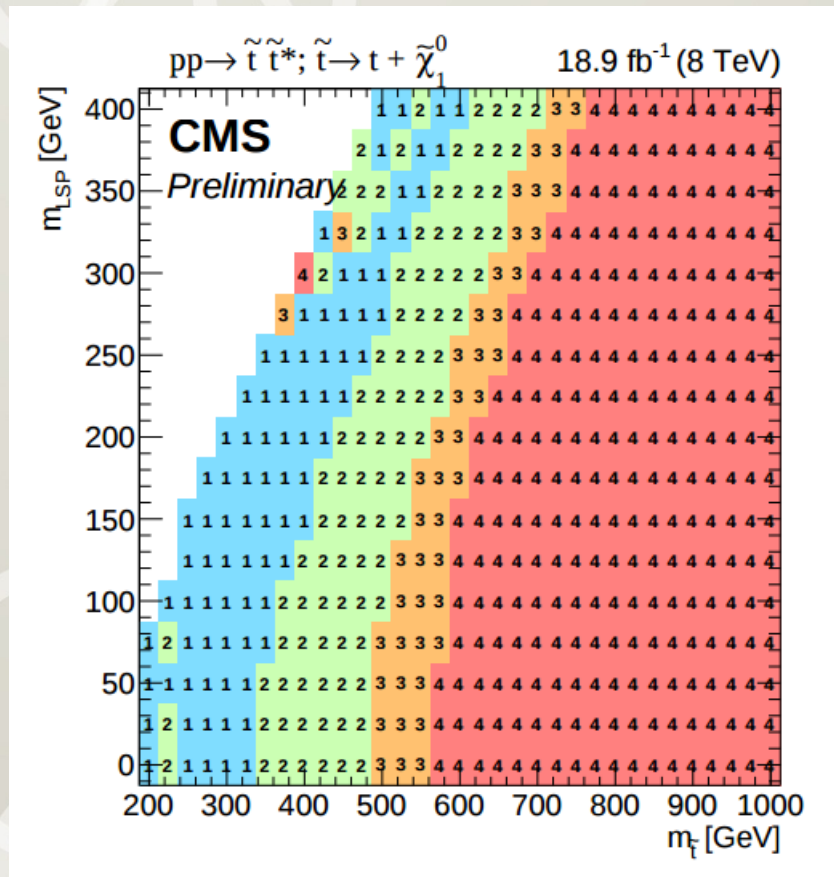


Tops from signal are not angularly correlated with MET



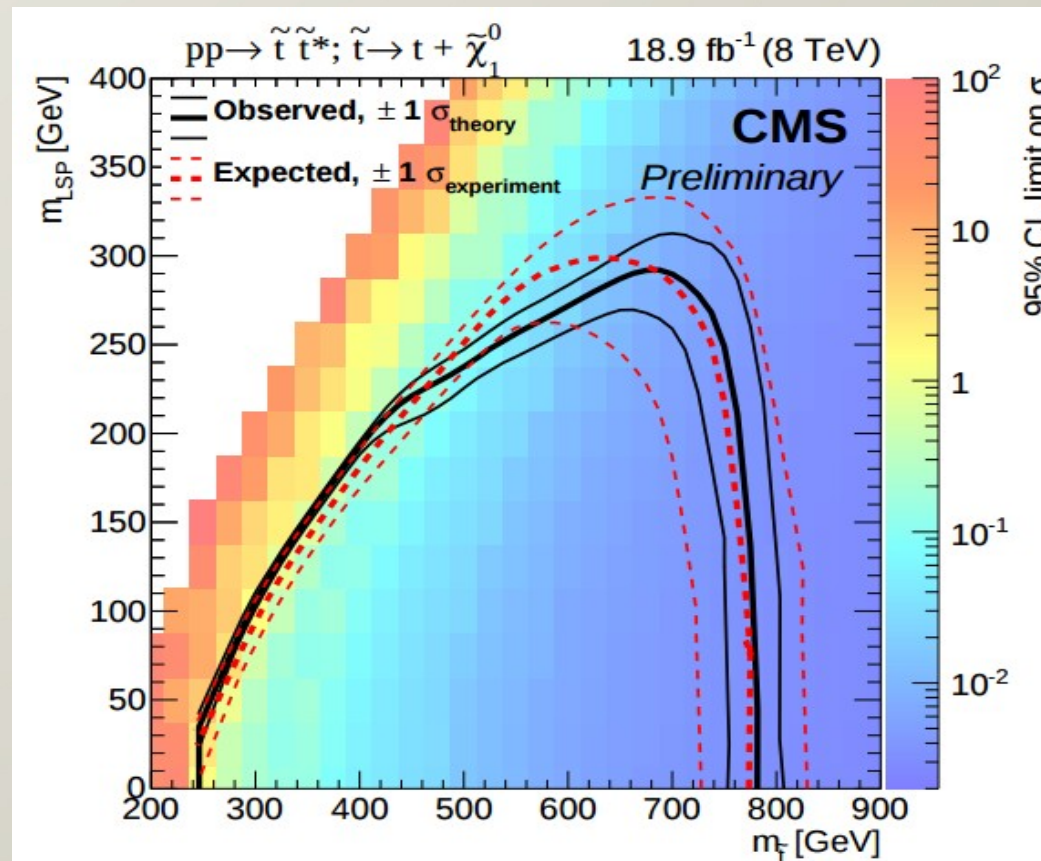
All hadronic MVA

- Four different BDTs optimized for different stop mass phase space:
 - Trained with 24 input variables:** including MET, $m_T(\text{b-tag, MET})$, jet multiplicity, CORRAL top candidate MVA value and more
- MC are corrected using data-driven scale factors for mis-modeling of lepton id efficiency, b-tagging efficiency, jet momentum, and MET



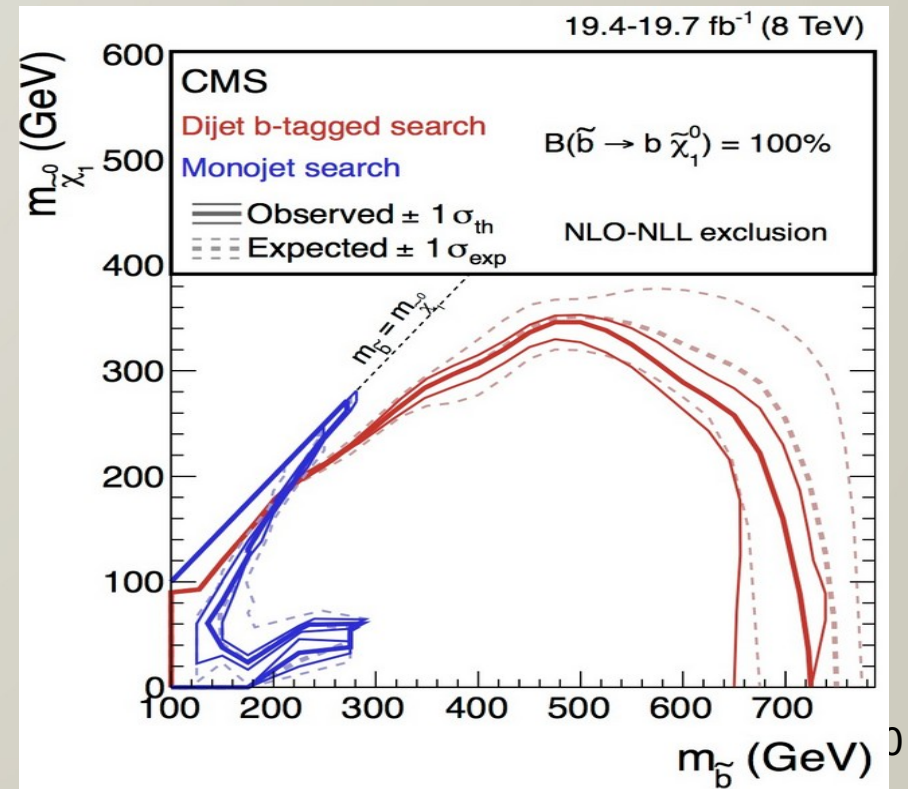
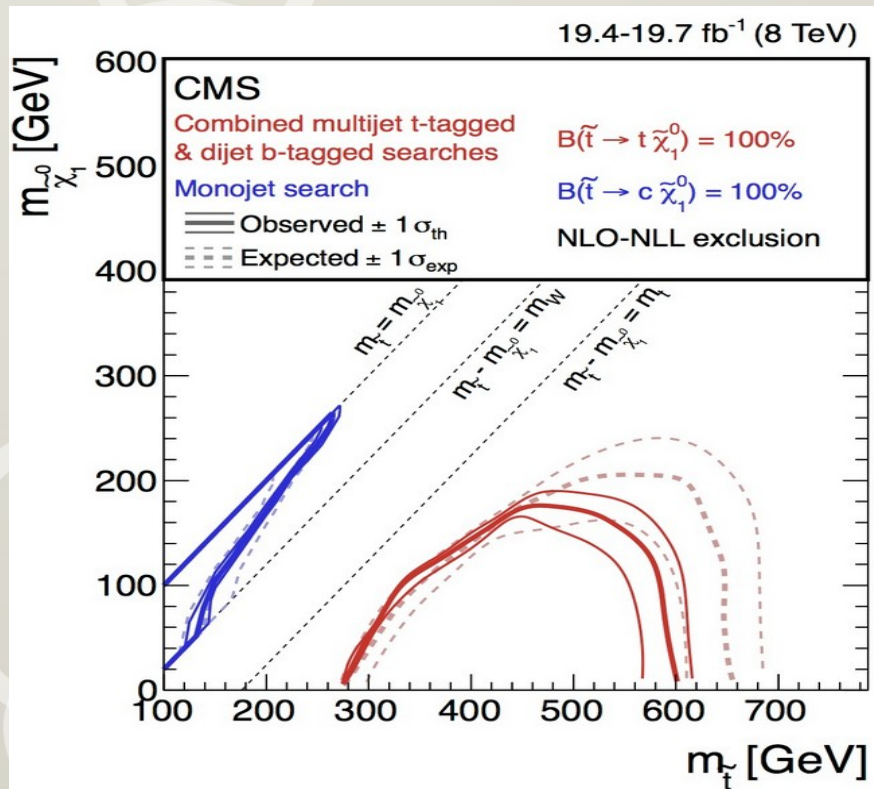
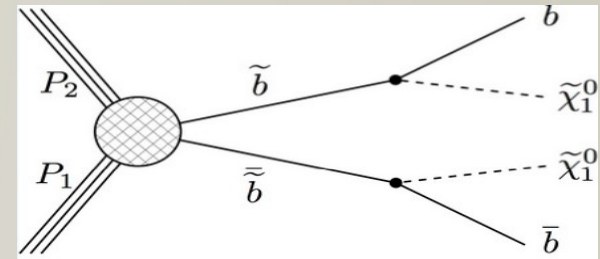
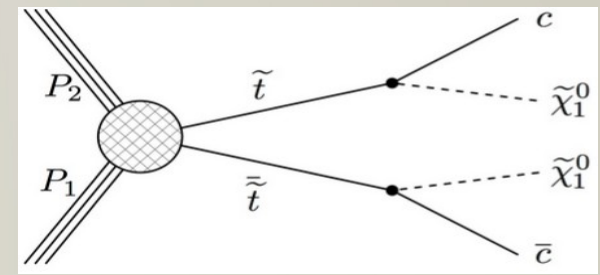
All hadronic MVA

- Models with the top squark decaying via an on-shell top quark:
 - excluded for top squark masses up to 775 GeV and for neutralino masses below 200 GeV.
- Models with an intermediate chargino are excluded in some scenarios for top squark masses up to 650 GeV.



Monojet

- **For stop:** dominant mode $\tilde{t} \rightarrow c\tilde{\chi}_1^0$
- **For sbottom:** dominant mode $\tilde{b} \rightarrow b\tilde{\chi}_1^0$
- Single high p_T ISR jet recoiling against the LSP
- Main backgrounds due to $Z(\nu\nu)$ +jets and $W(l\nu)$ processes \rightarrow estimated from μ +jets data control samples



1 lepton stop MVA

Two decay modes: T2tt and T2bw ($x=0.25, 0.50, 0.75$)

- **Baseline selection:**

$$m_{\tilde{\chi}_1^\pm} = x \cdot m_{\tilde{\tau}} + (1 - x) \cdot m_{\tilde{\chi}_1^0}$$
- 1 high p_T isolated e/μ : $p_T > 25$ (30) GeV for e/μ
- $n_{\text{Jets}} \geq 4$ (30 GeV) at least one b-tagged
- $\text{MET} > 100$ GeV
- ✓ **Select events with $M_T > 120$ GeV**
- Several signal regions defined with a cut-based or MVA approach (~ 40 % improvement)
- ✓ **Estimate backgrounds from MC**
 - Derive corrections/uncertainties in control regions

SELECTION CRITERIA	exactly 1 ℓ	> 1 ℓ
0 b-tags	CR-0b: W+jets Validate W+jets M_T tail	---
≥ 1 b-tags	SIGNAL REGION	CR-2ℓ: $tt \rightarrow \ell\ell$ CR-ℓt: $tt \rightarrow \ell + \text{isolated trk} / \tau_{\text{had}}$ Validate physics modeling and detector effects

1 lepton stop MVA

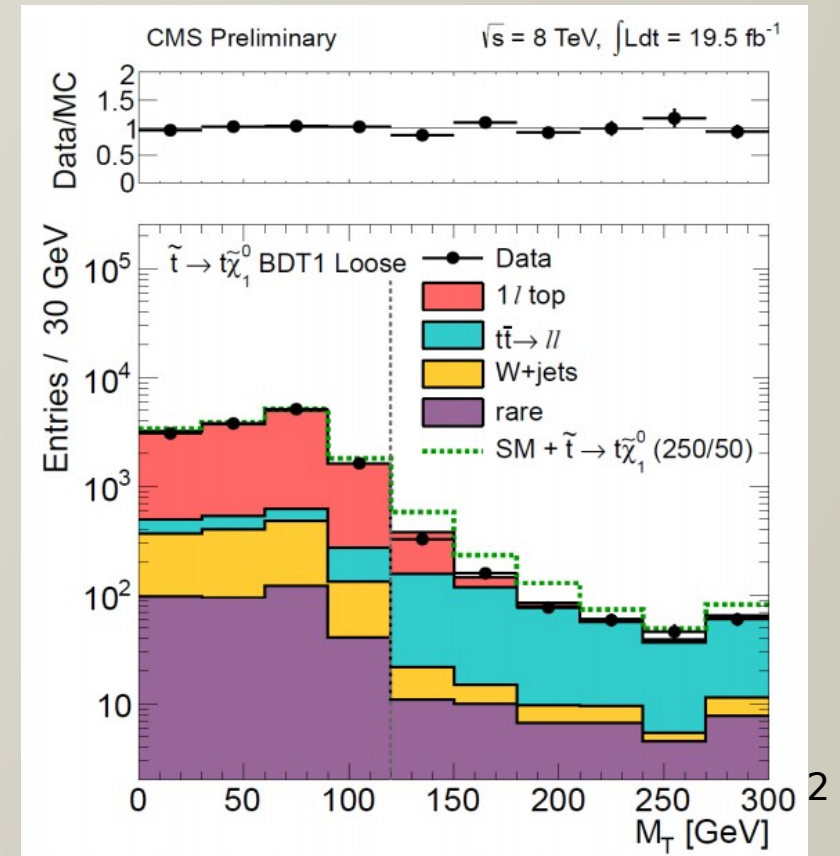
For each control region:

- 1) Normalize MC to data in M_T peak region \rightarrow reduce uncertainties from $\sigma(t\bar{t})$, luminosity, ...
- 2) Extrapolate to large M_T
- 3) Derive corrections and uncertainties on the “peak-to-tail” ratios

$$N_{\text{pred}} = N_{\text{MC}} \left(\frac{\text{data}}{\text{MC}} \right)_{\text{peak}} \left(\frac{\text{data}}{\text{MC}} \right)_R$$

\uparrow Predicted bkg in signal region
 \uparrow “raw” MC prediction in signal region
 \uparrow M_T peak normalization
 \uparrow Data/MC correction

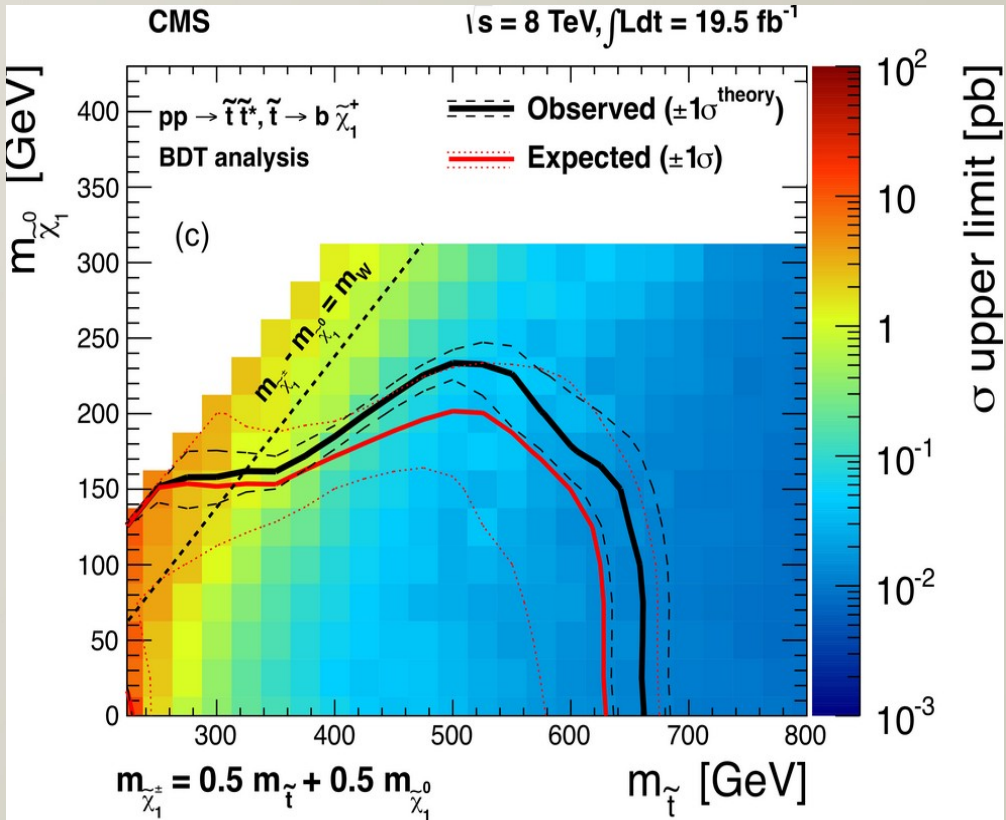
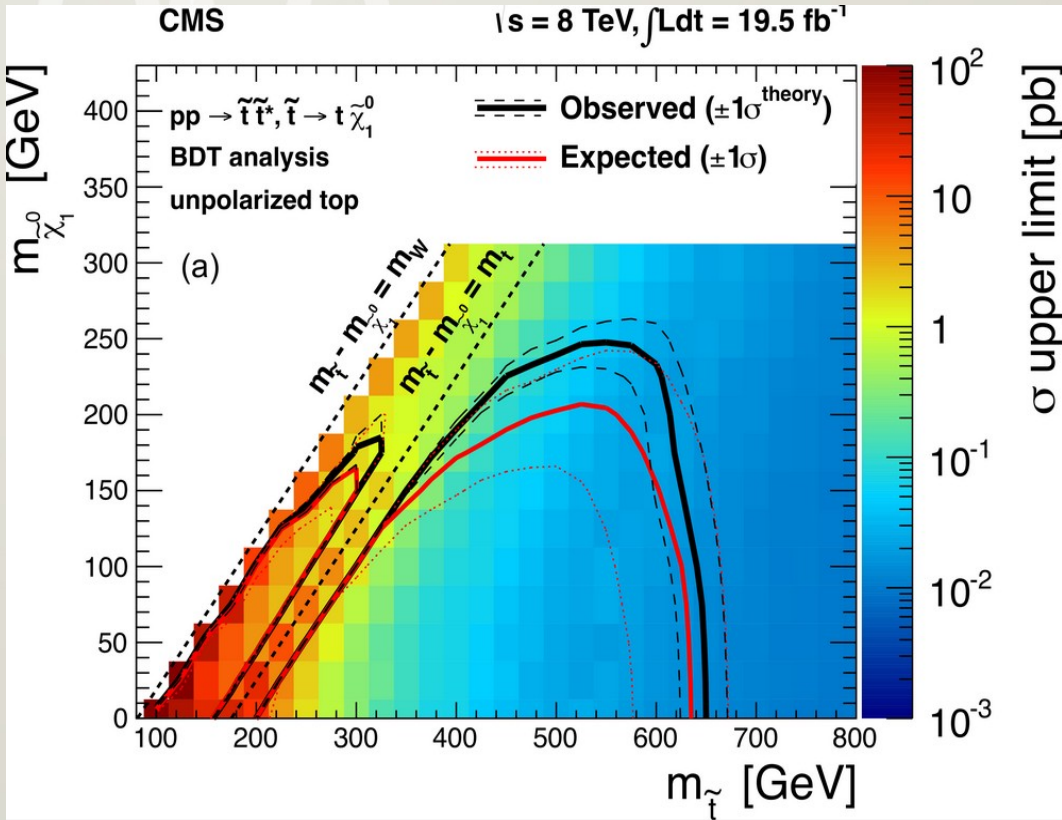
Data consistent with background prediction
 \rightarrow **no evidence for top-squark**



1 lepton stop MVA

t2tt

t2bW



Limits testing top squarks masses up to 650 GeV and neutralinos masses up to 250 GeV, depending on the model

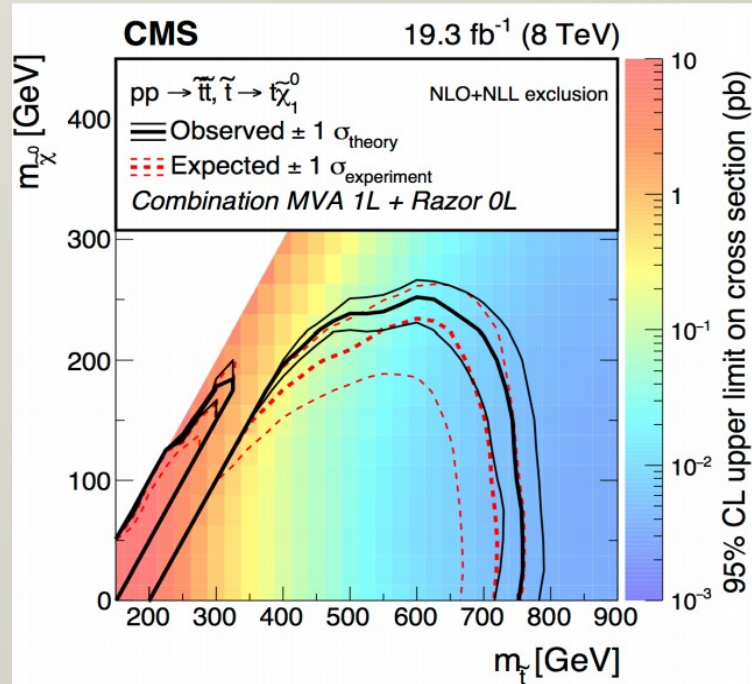
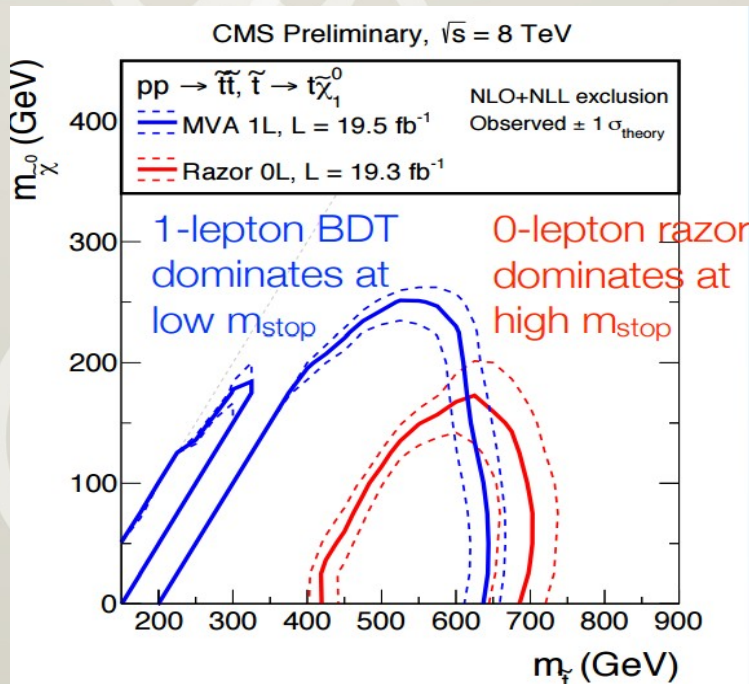
1 lepton stop MVA + 0 lepton razor

The razor variables are defined in the context of pair production of heavy particles each decaying to a visible system of particles and a weakly interacting particle.

$$M_R \equiv \sqrt{(|\vec{p}(j_1)| + |\vec{p}(j_2)|)^2 - (p_z(j_1) + p_z(j_2))^2} \quad \text{and} \quad R \equiv \frac{M_T^R}{M_R}$$

$$M_T^R \equiv \sqrt{\frac{E_T^{\text{miss}}(p_T(j_1) + p_T(j_2)) - \vec{E}_T^{\text{miss}} \cdot (\vec{p}_T(j_1) + \vec{p}_T(j_2))}{2}}$$

- M_T^R is expected to have a **kinematic endpoint** at the mass of the new heavy particle
- R variable is a measure of **how well the missing transverse momentum is aligned with respect to the visible momentum.**



Combination improves the constraint on the top-squark mass from 650 to 730 GeV

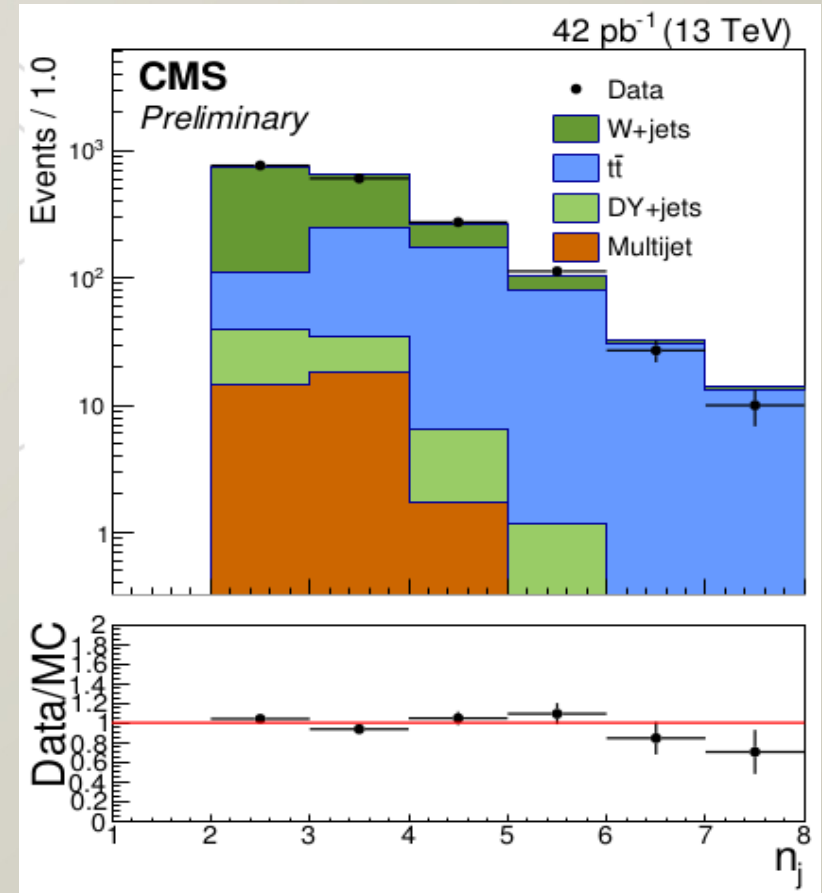
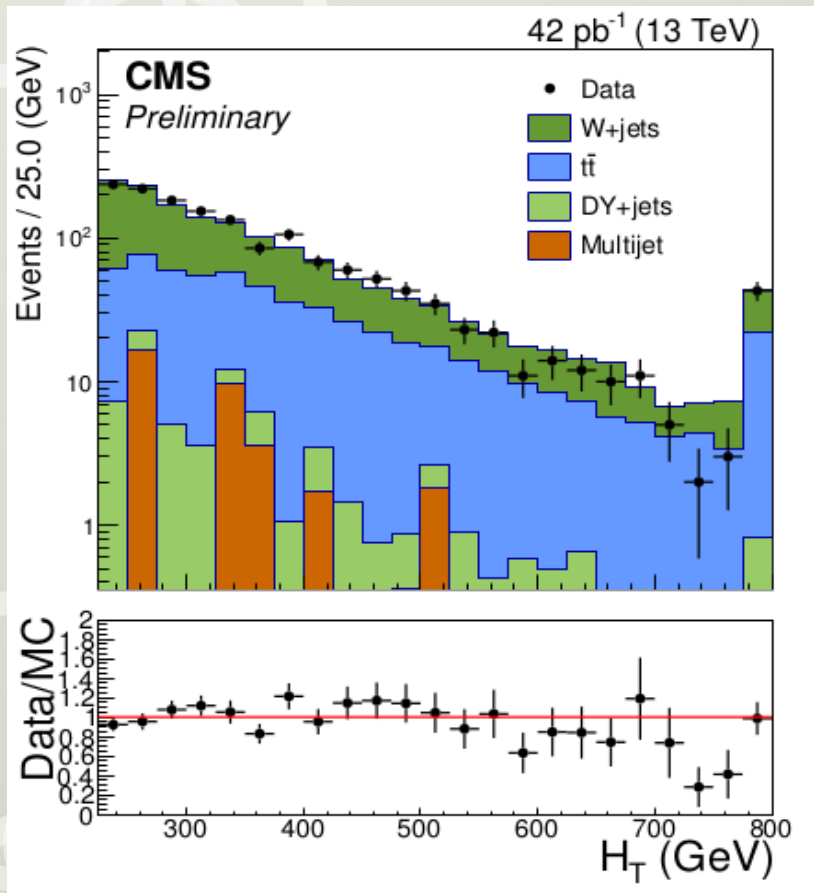


Some plots at 13 TeV

Key variables commissioning

CMS_DP2015_035

- Exactly one isolated muon with $p_T > 30$ GeV and $|\eta| < 2.1$
- Good agreement for both HT and number of jets

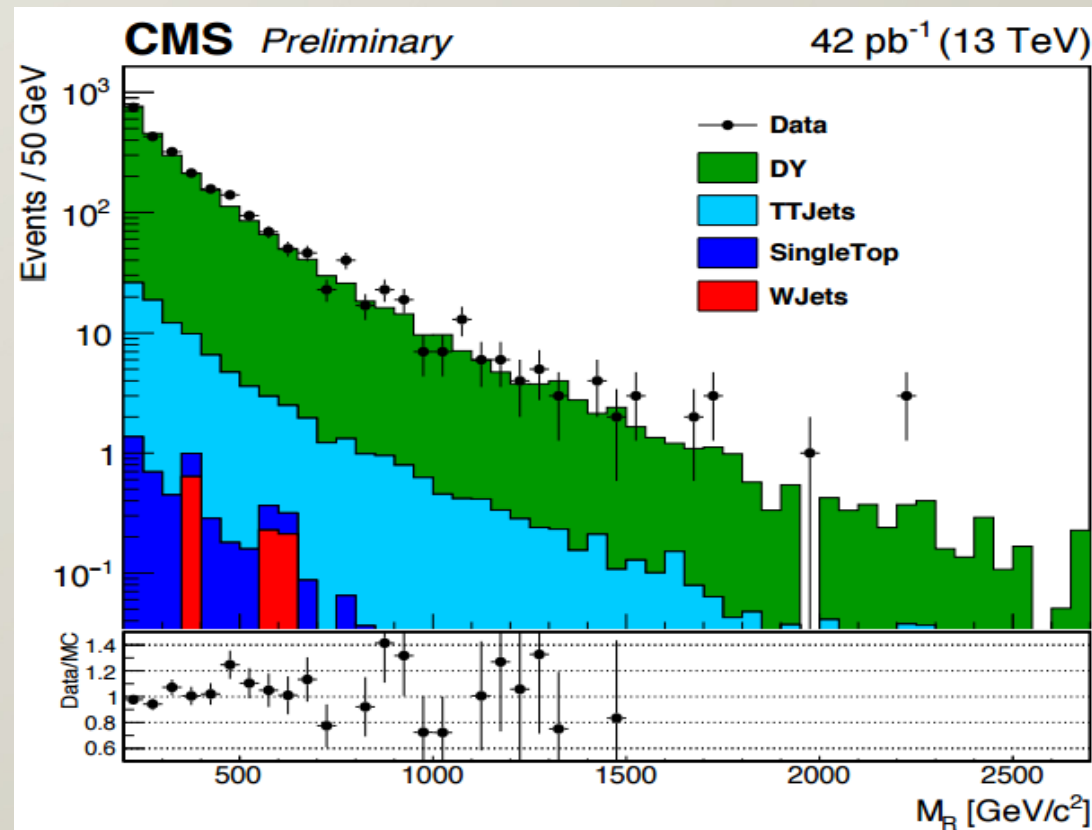


Key variables commissioning

CMS_DP2015_035

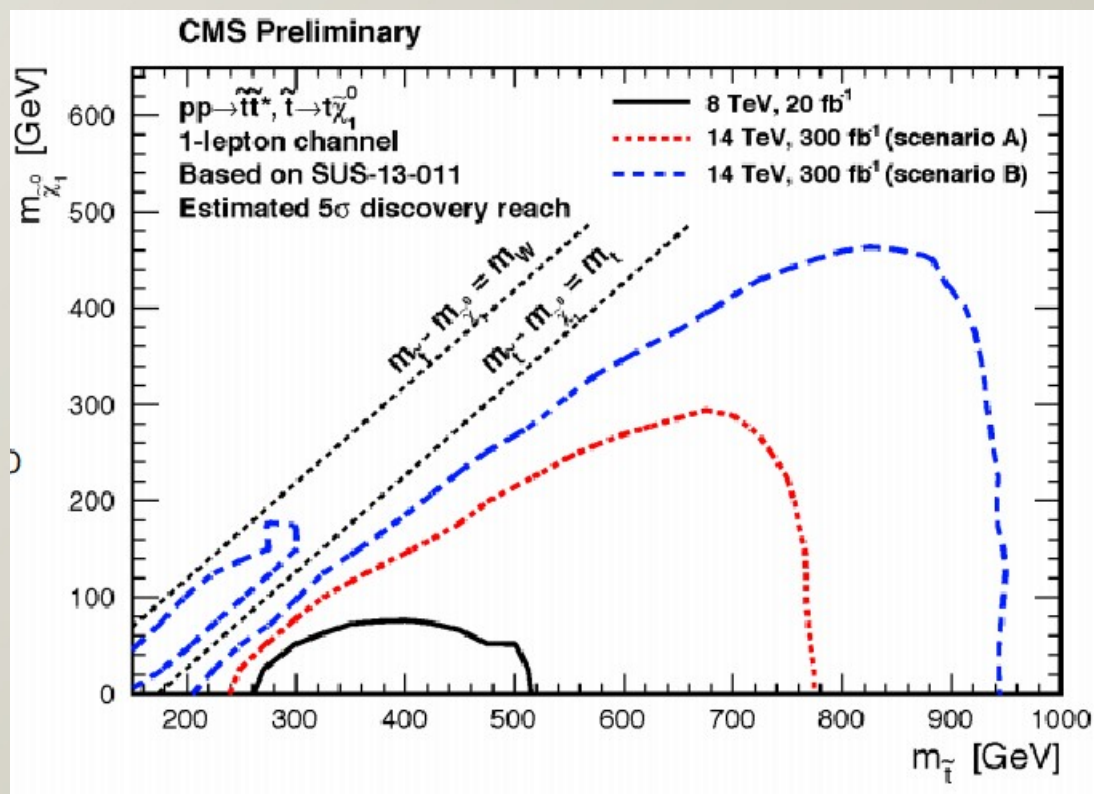
- Checking razor variable distributions in data and uncorrected MC in early 13 TeV data
- M_R variable in a dilepton sample with lepton $p_t > 25$

Good agreement : DY and tt dominated



Outlook for 13 TeV

- Discovery reach in stop mass will reach to 800 GeV in a conservative scenario
- Crucial region for testing naturalness and whether SUSY has a role in Electroweak symmetry breaking
- Naturalness prefers m_{stop} lighter than 700 GeV
- Higgs mass of ~ 125 GeV prefers m_{stop} heavier than 300 GeV



Conclusions

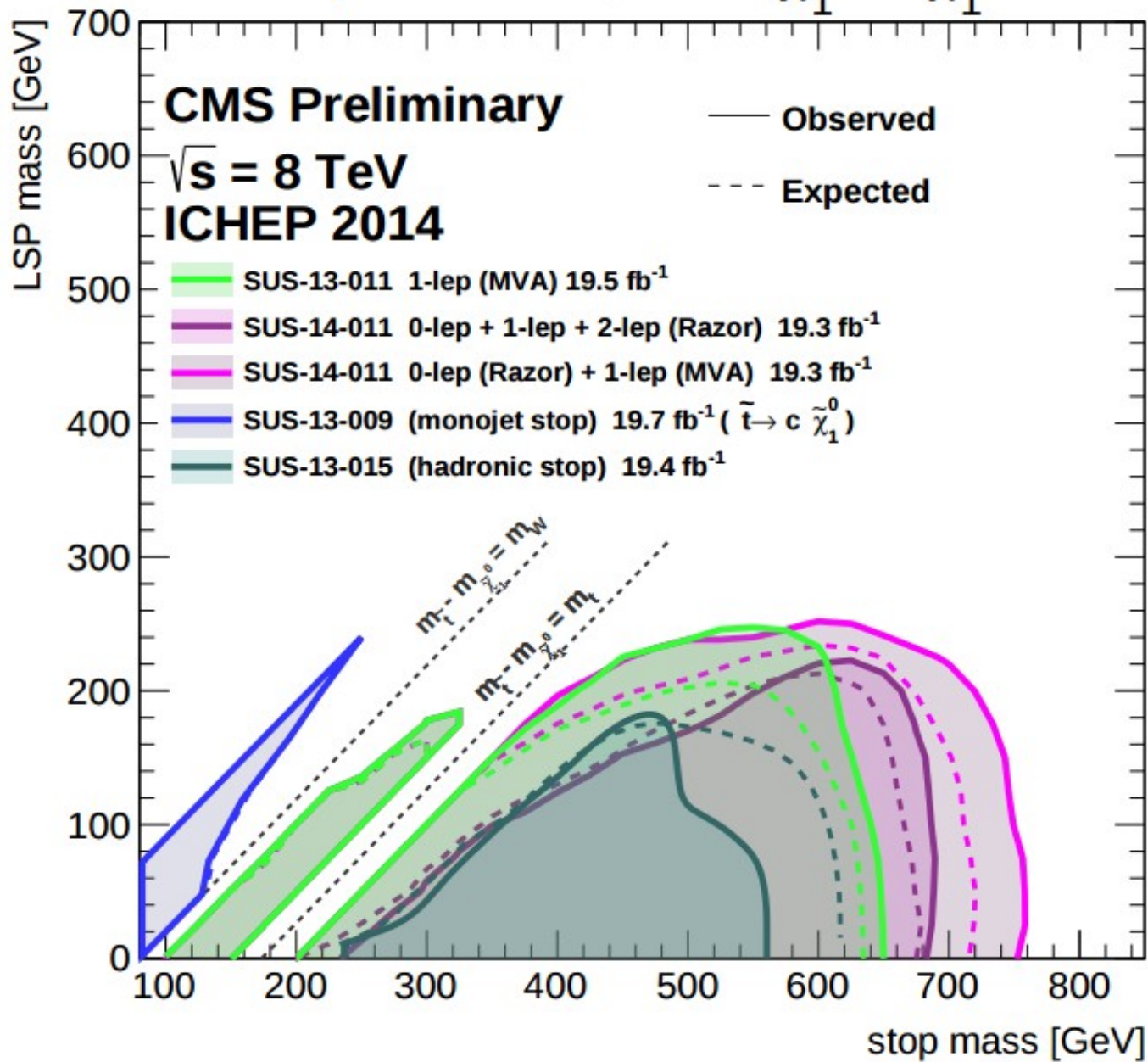
- **The CMS SUSY search program at 8 TeV has been produced**
 - **Stringent limits on many “natural” SUSY scenarios:**
 - **775 GeV for stop mass**
 - **Compressed region (stop to charm + LSP) covered by monojet search**
- **Key variables for the 13 TeV have been commissioned**

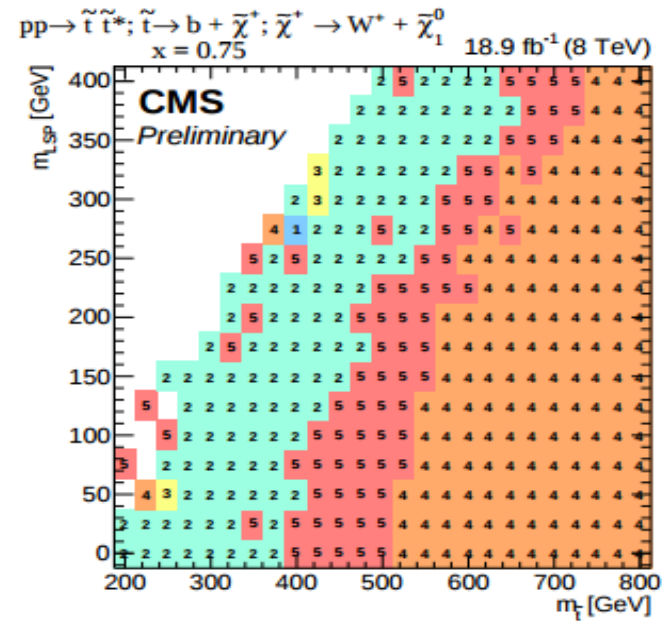
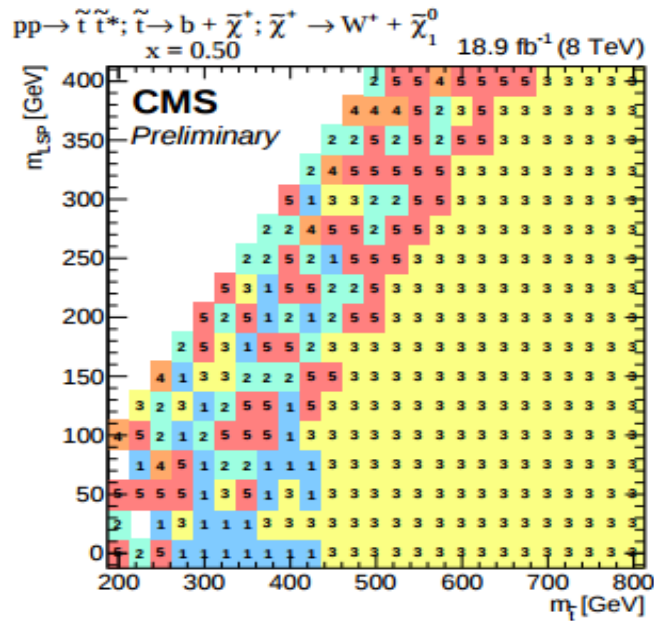
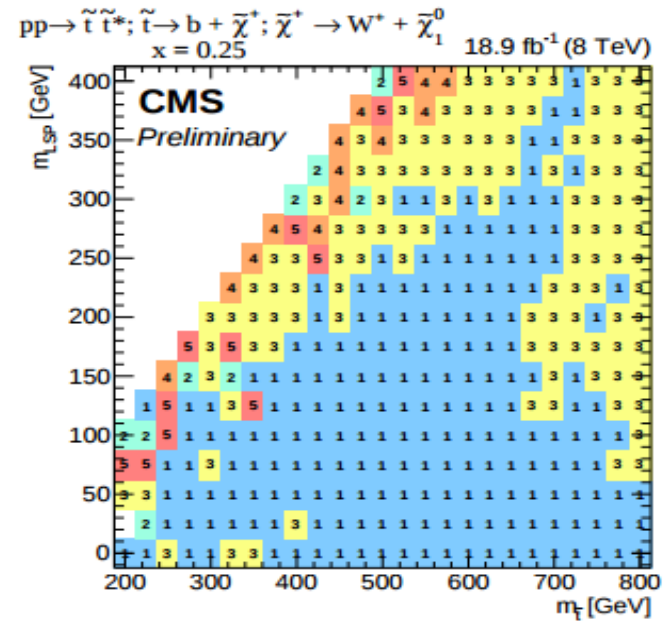
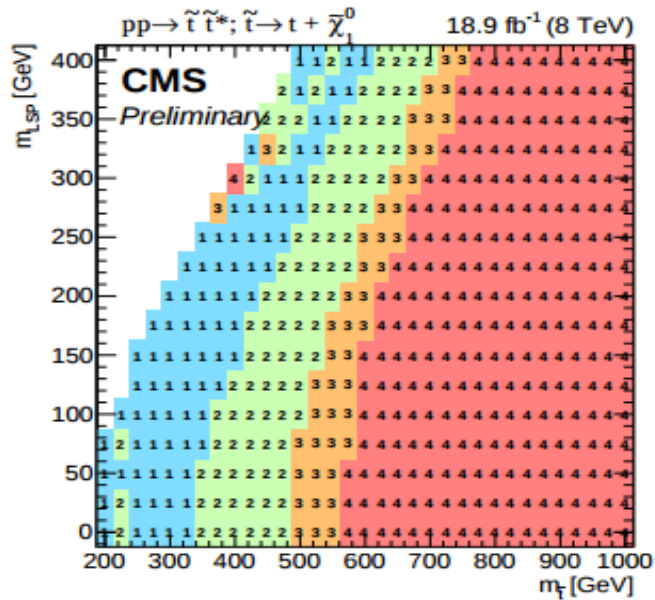
Stay tuned: 13 TeV can hide surprises!

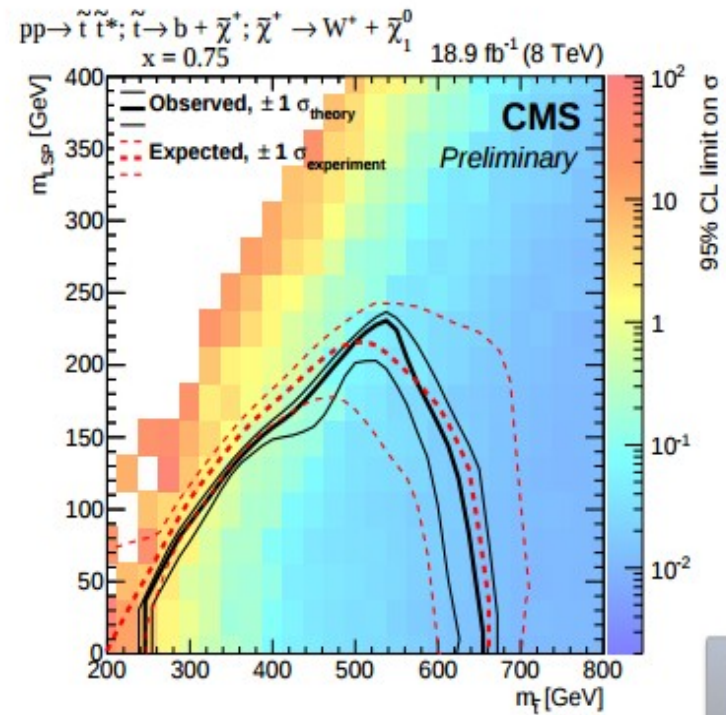
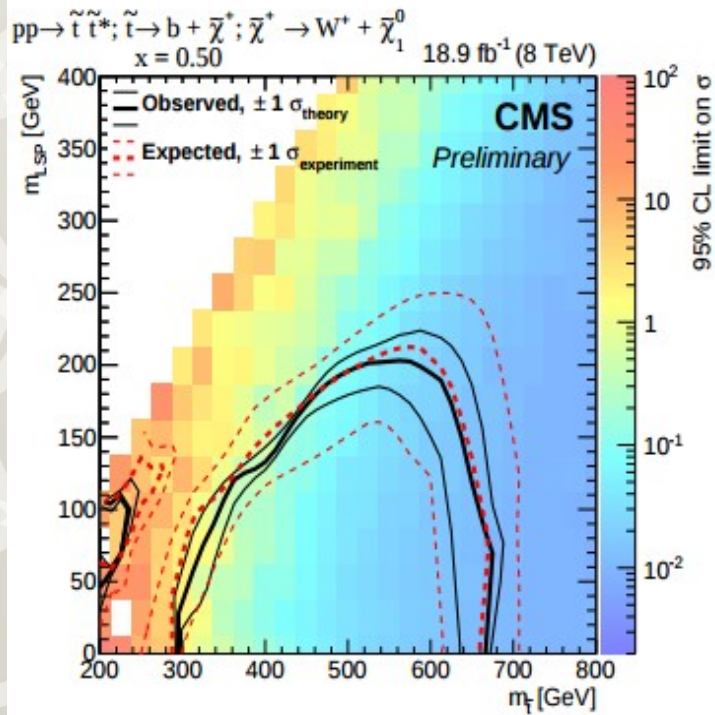
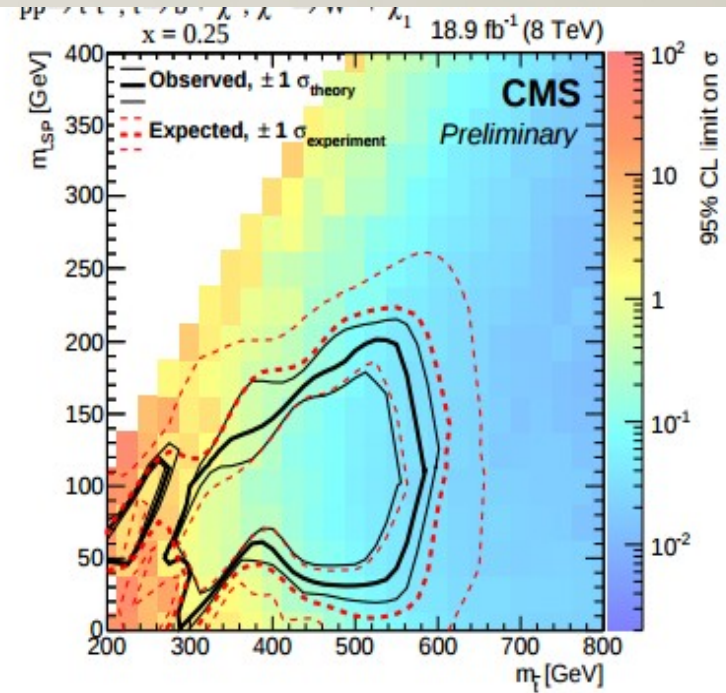
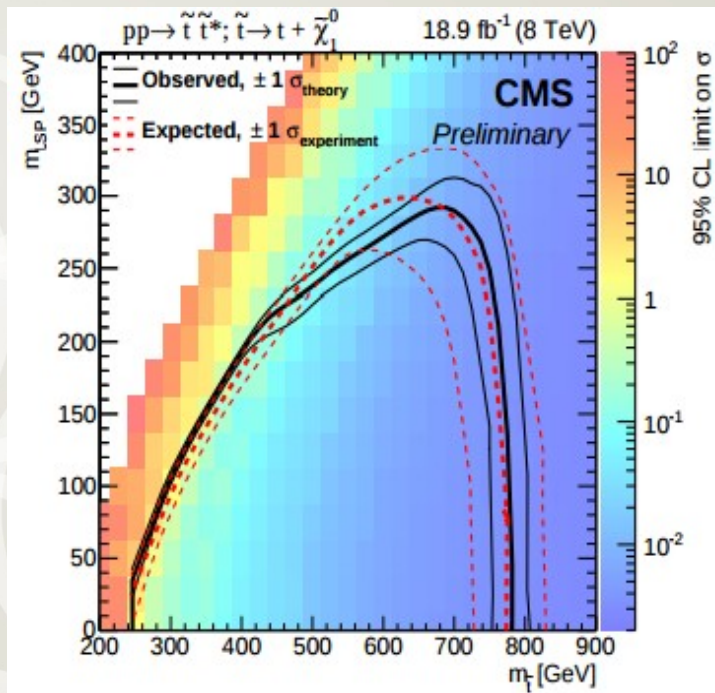


Backup

$\tilde{t}\tilde{t}$ production, $\tilde{t} \rightarrow t \tilde{\chi}_1^0 / c \tilde{\chi}_1^0$







All hadronic MVA

Systematics source	Magnitude (%)
b-tagging	5% - 10%
JES	5% - 20%
JER	< 5%
ISR	1%-20%
PDF	1%-15%
Luminosity	2.6%
CORRAL FastSim (T2tt)	1%-20%
CORRAL dependence on PS (T2tt)	5%
CORRAL reconstruction (T2tt)	5%

1 lepton MVA

$\tilde{t} \rightarrow t\tilde{\chi}_1^0$						
Sample	BDT1-Loose	BDT1-Tight	BDT2	BDT3	BDT4	BDT5
M_T -peak data and MC (stat.)	1.0	2.1	2.7	5.3	8.7	3.0
$t\bar{t} \rightarrow \ell\ell$ N_{jets} modeling	1.7	1.6	1.6	1.1	0.4	1.7
$t\bar{t} \rightarrow \ell\ell$ (CR- ℓt and CR- 2ℓ tests)	4.0	8.2	11.0	12.5	7.2	13.8
2nd lepton veto	1.5	1.4	1.4	0.9	0.3	1.4
$t\bar{t} \rightarrow \ell\ell$ (stat.)	1.1	2.8	3.4	7.0	7.4	3.3
W + jets cross section	1.6	2.2	2.8	1.7	2.7	2.2
W + jets (stat.)	1.1	1.9	2.0	4.6	10.8	5.2
W + jets SF uncertainty	8.3	7.7	6.8	8.1	9.7	8.6
$1 - \ell$ top (stat.)	0.4	0.8	0.8	1.4	4.4	1.2
$1 - \ell$ top tail-to-peak ratio	9.0	11.4	12.4	19.6	28.5	9.1
Rare processes cross section	1.8	3.0	4.0	8.1	15.7	0.7
Total	13.4	17.1	19.3	27.8	38.4	20.2