Recent highlights from SUSY searches at CMS

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on behalf of the CMS collaboration

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für Bildung
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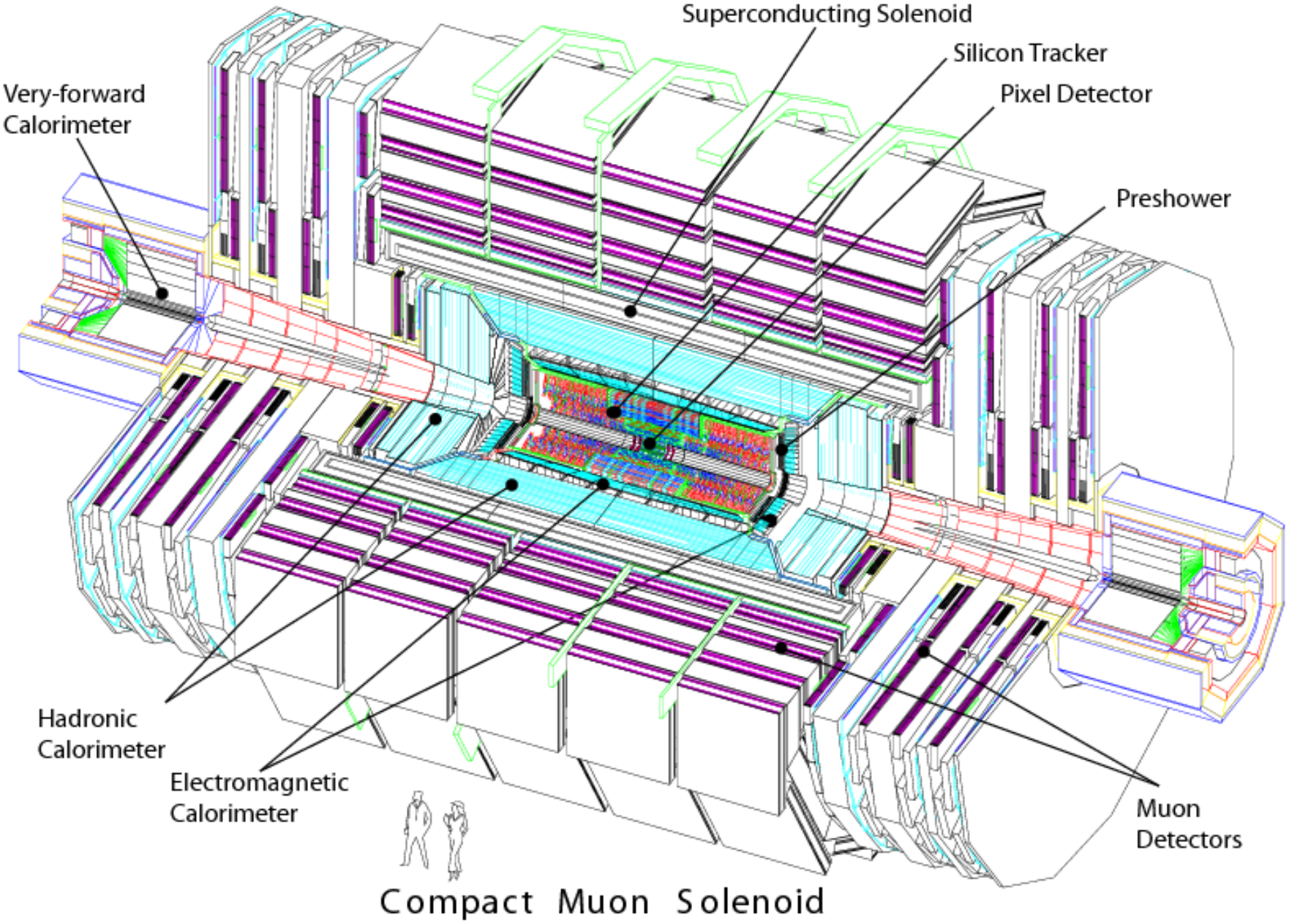
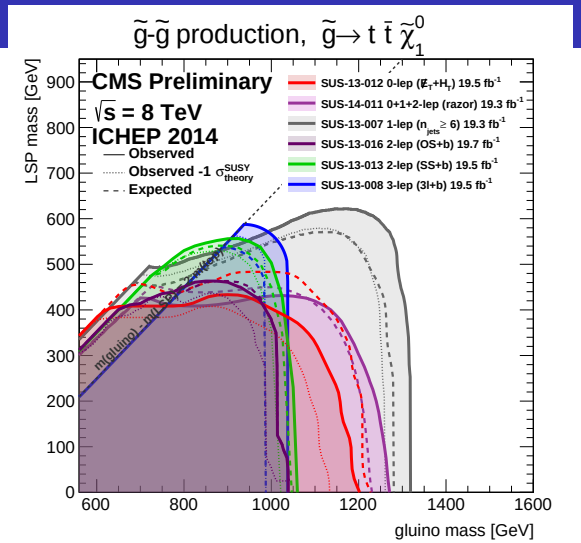
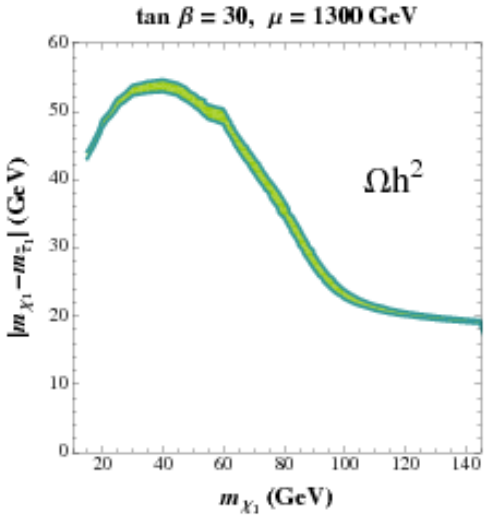
The Compact Muon Solenoid experiment



Motivation

- Supersymmetry is well motivated:
- Possible GUT, radiative Higgs-boson mass corrections, possible dark matter candidate, last possible extension of the Poincarè group...
- But: Already very stringent limits
- But: m_H disfavors large parts of the MSSM





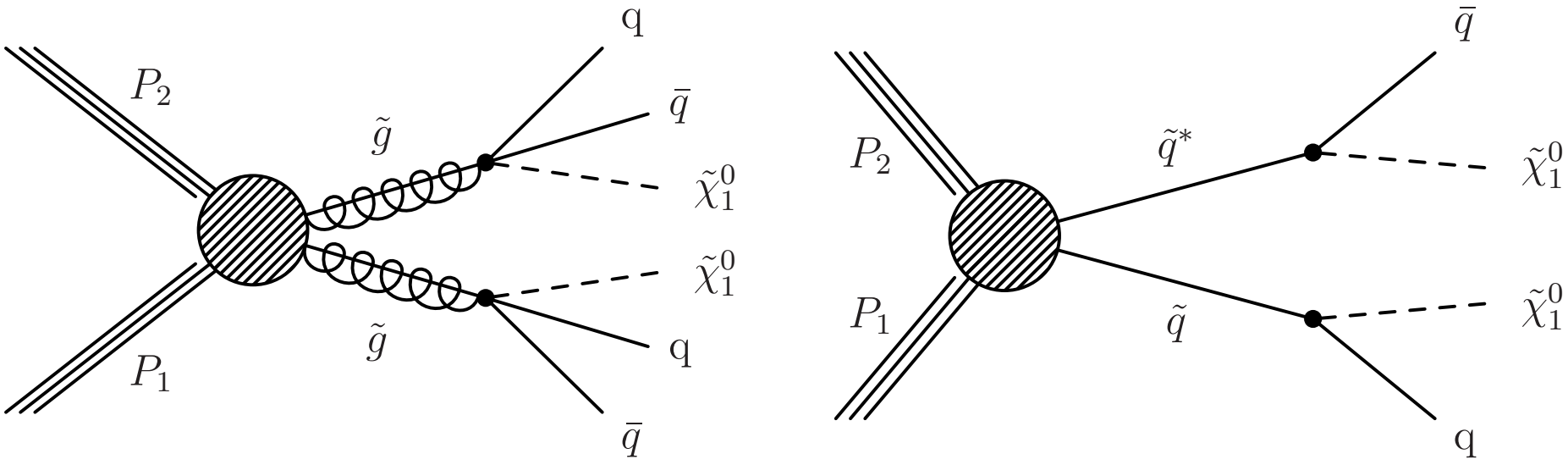
- Radiative corrections can be rescued by "light" third generation squarks (esp. $\tilde{t}$)
- Dark matter relic density motivates search for $\tilde{\tau}$
- Compressed regions of sparticles near mass-degenerate with the LSP gain interest

arXiv:1205.5842

This talk shows excerpts from recent CMS analyses covering a range of sparticles

Generic search with hadronic recoil variable "M_{T2}"

General idea: quantify hadronic momentum imbalance per event



- Inclusive search with H_T, $\not{E}_T$ and $H_T \times \not{E}_T$ triggers
- Veto on isolated leptons
- Binning in number of jets (N_j) and b-quark tags (N_b)
- Makes use of a transverse mass defintion M_{T2}
- Wide range of sensitivity across various simplified models
- Showing only a small excerpt of possible interpretations

arXiv:1502.04358

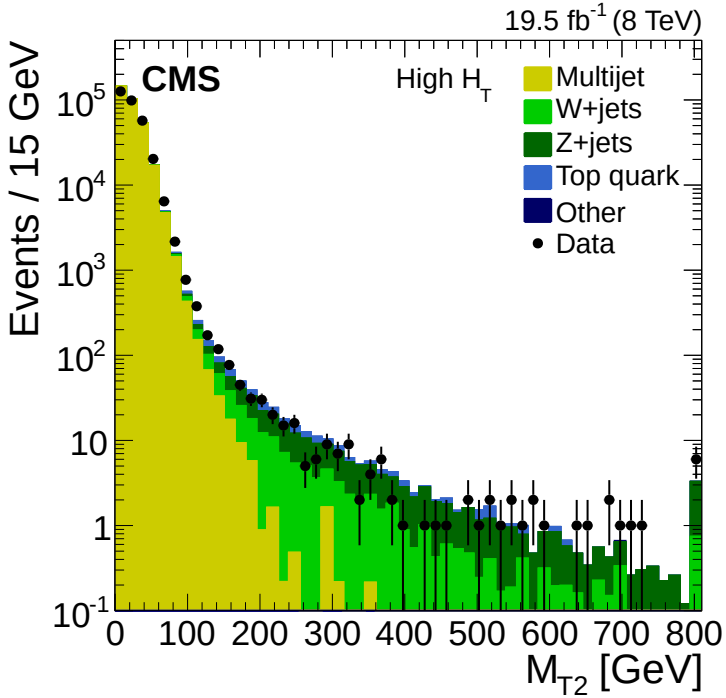
M_{T2} definition

For a single invisible particle in a two-body decay, a transverse mass M_T shows an edge at the mother particle mass

$$(M_T^{(i)})^2 = (m^{\mathrm{vis}(i)})^2 + m_\chi^2 + 2\left(E_T^{\mathrm{vis}(i)} E_T^{\chi(i)} - \vec{p}_T^{\,\mathrm{miss\ vis}(i)} \cdot \vec{p}_T^{\,\mathrm{miss}\ \chi(i)}\right) \quad (1)$$

M_{T2} extends this feature to the case of two LSP leaving the detector

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

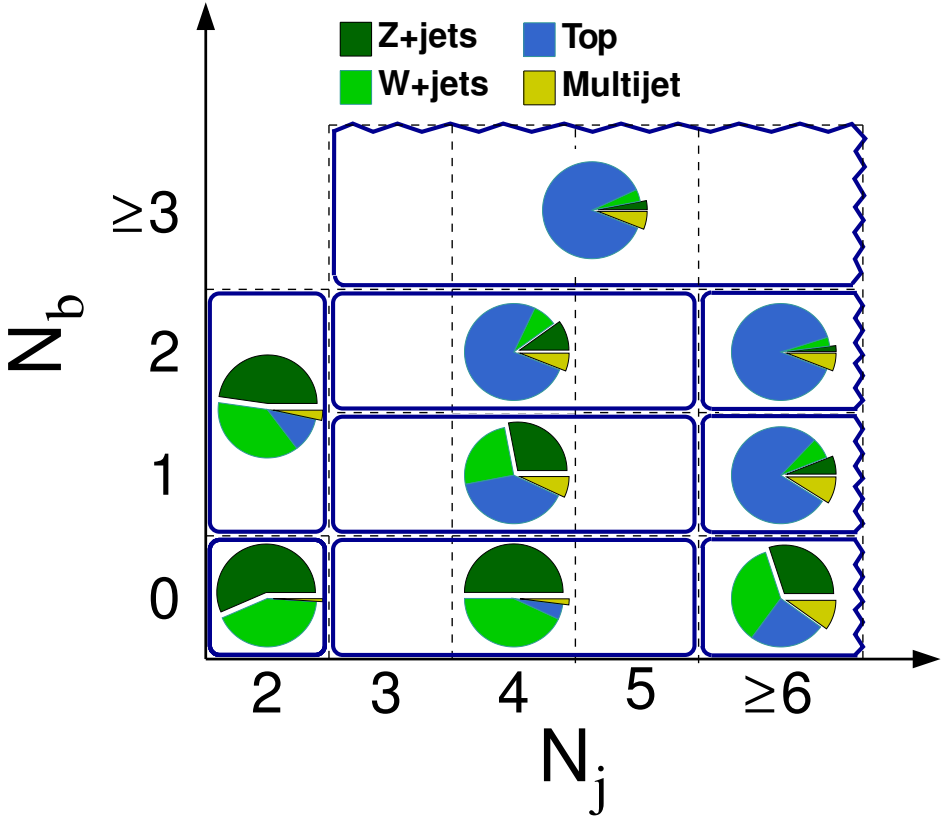


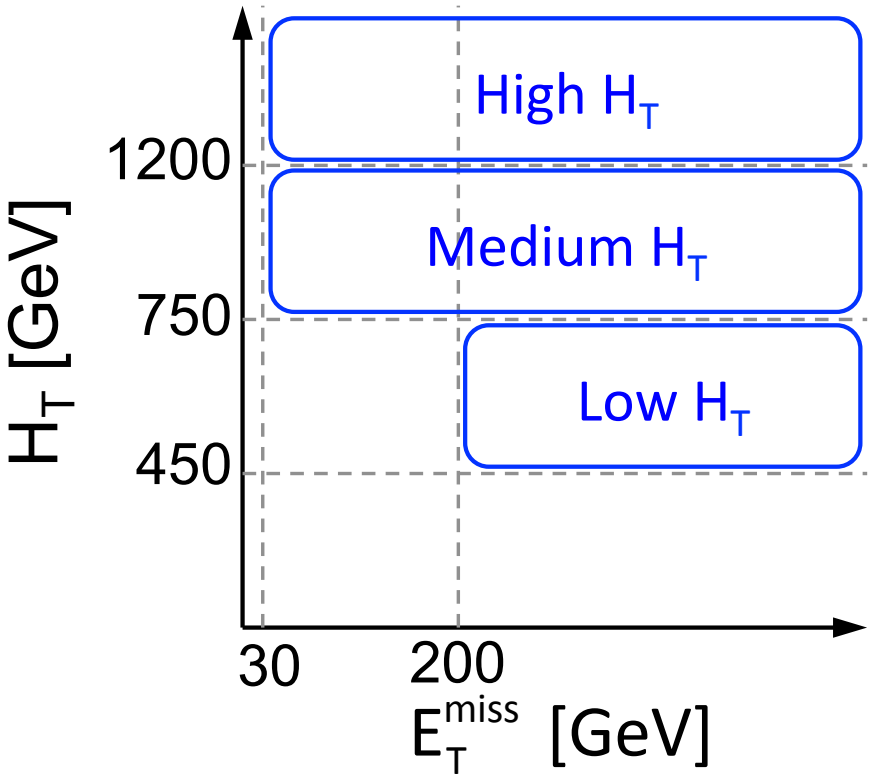
High values of M_{T2} either due to:

- SM: tails of jet energy resolution
- SM: not reconstructed ("lost") leptons
- BSM: R-parity conserving SUSY

M_{T2}: backgrounds

9×3 **signal region definitions**

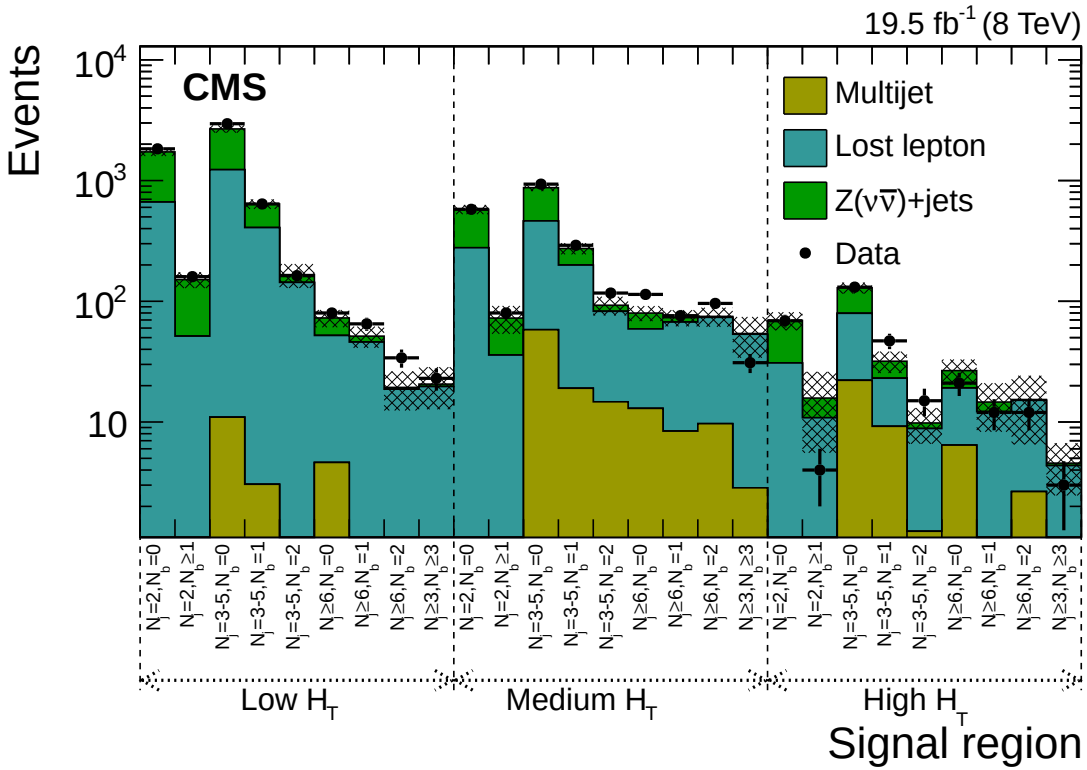


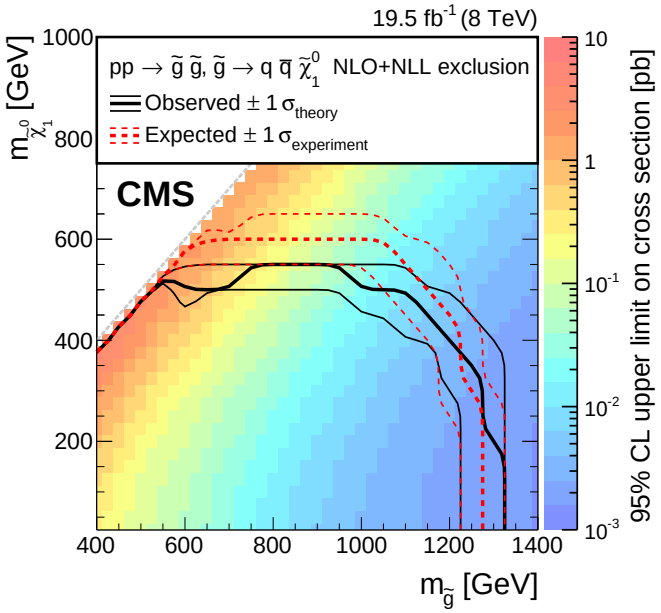


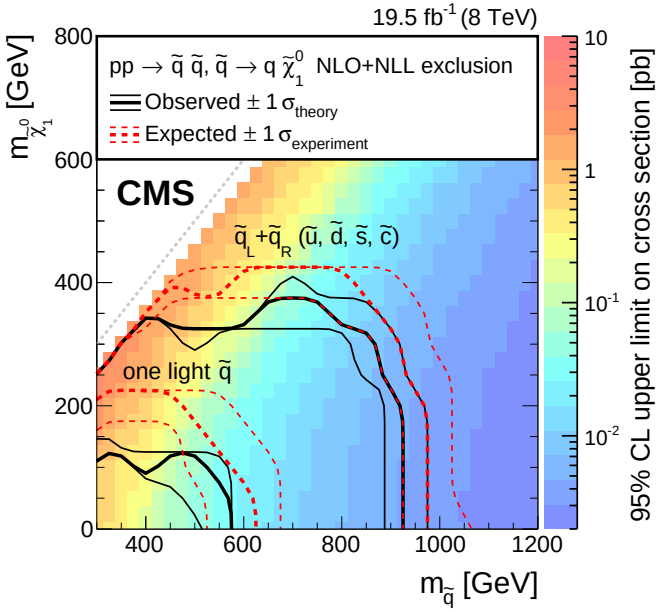
Data-driven background estimations for:

- Multijet: $\Delta\phi_{\min}$ variation between recoil and four leading jets
- leptonic W+jet/$t\bar{t}$: one lepton sidebands
- Z$\rightarrow \nu\bar{\nu}$: Z/$\gamma \rightarrow l\bar{l}$ events, substracting l momenta

M_{T2}: results and interpretation



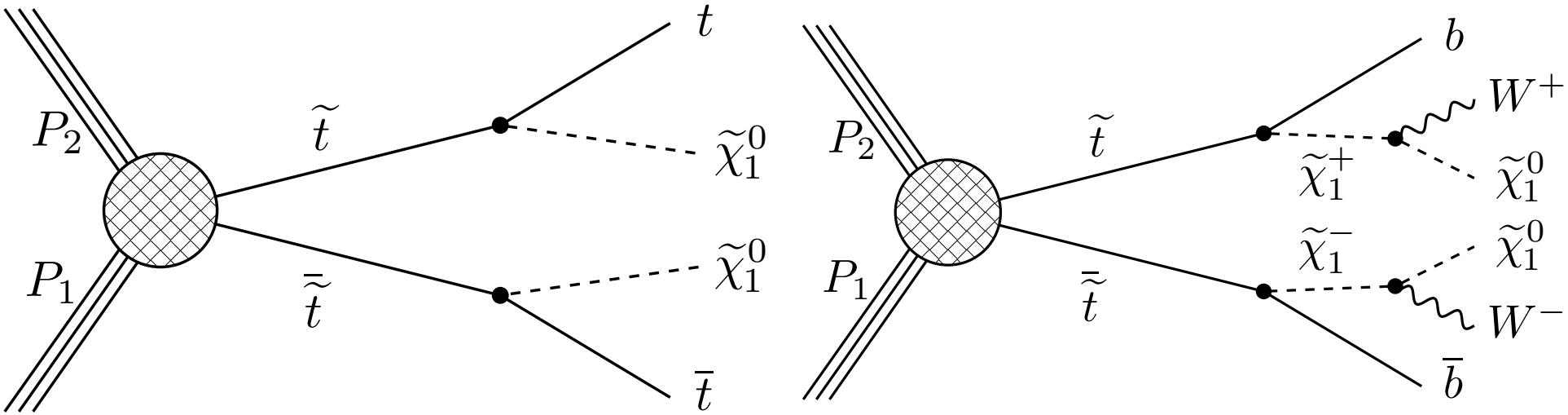




- Results compatible with SM (just an excerpt of various interpretations)
- Other searches are more specialised for third generation sparticles and compressed spectra

Third generation squark search with $\tilde{t}$ tagging

General idea: Large $\Delta(m_{\tilde{t}}, m_{\tilde{\chi}_1^0})$ lorentz-boost top-decay
$\rightarrow$ boosted top tagging

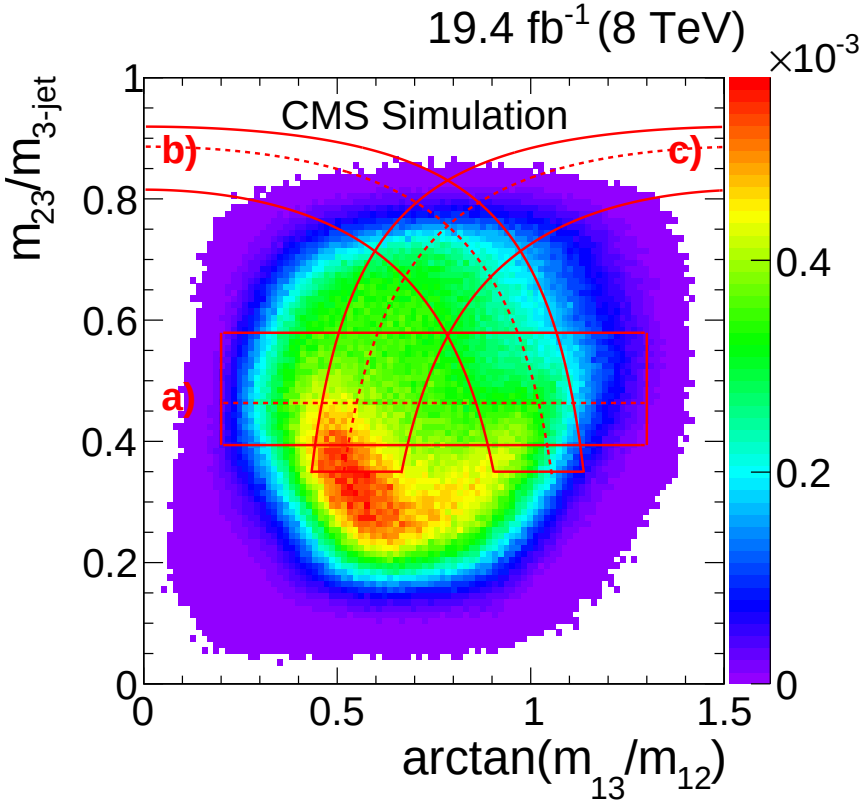


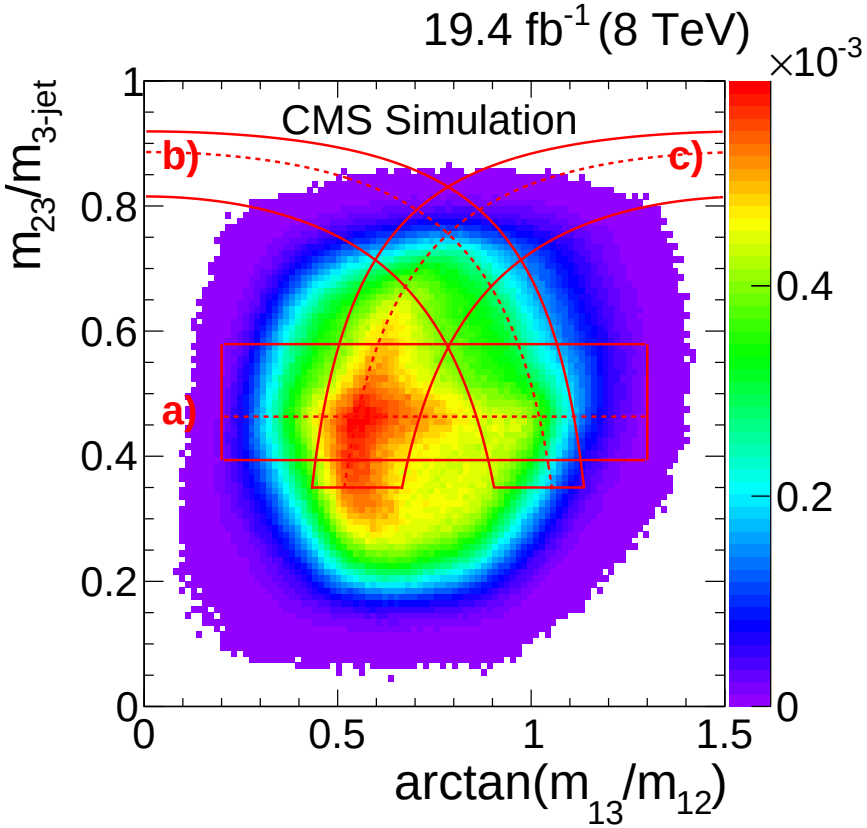
- Requires one fully hadronic boosted top quark to be reconstructed
- In addition, one at least partially reconstructed top quark is required
- Trigger with two jets in $|\eta| < 2.6$ with $p_T > 50$ GeV and $\not{E}_{\mathrm{T}} > 80$ GeV

arXiv:1503.08037

$\tilde{t}$ tagging: backgrounds

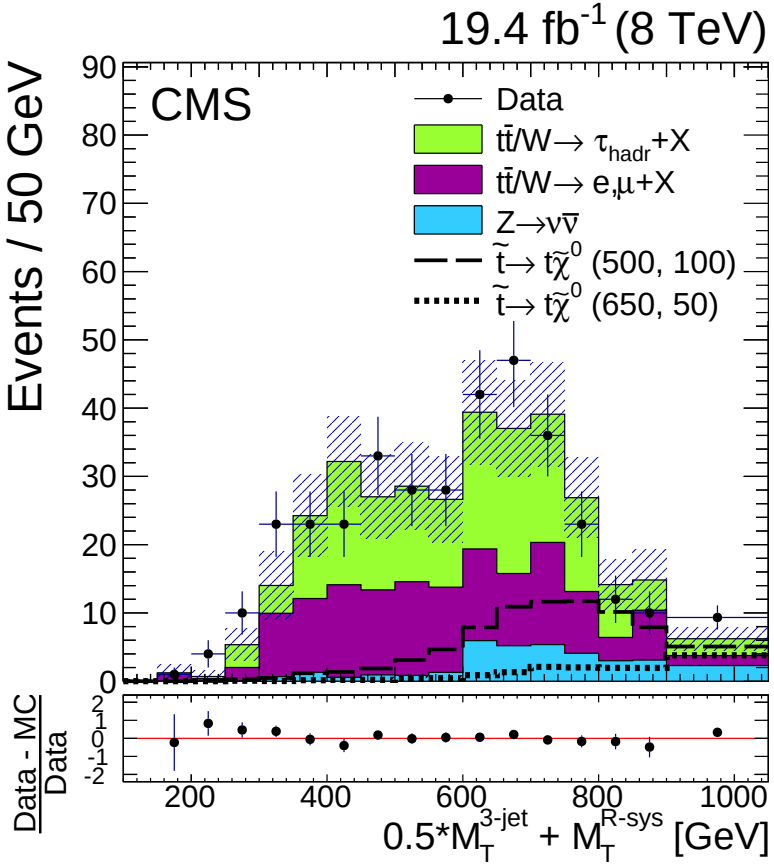
Boosted top tagging allows to differentiate Multijet (left) and $\mathrm{t\bar{t}}$ (right)

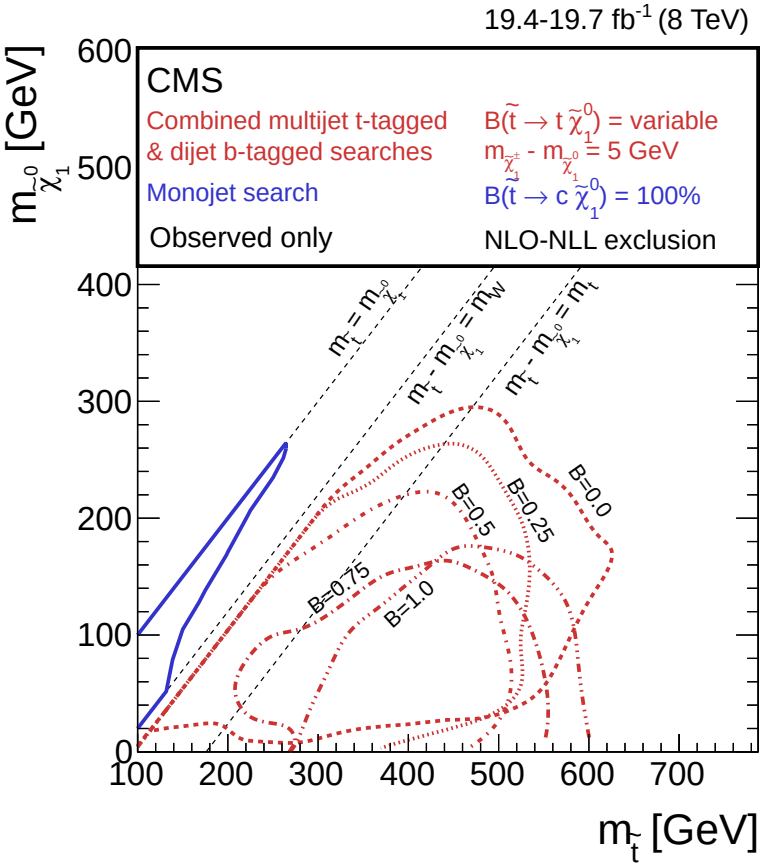




- Additional requirement of $\Delta\phi(\vec{p}_T^{miss}, p_T(\mathrm{jet\ 1\text{-}3}))$ reduces Multijet
- Remaining background: SM top quarks (distinguished by $\mathrm{M_{T2}}$-like variables $\mathrm{M_T^{3\text{-}jet}}$ and $\mathrm{M_T^{R\text{-}sys}}$)

Interpretation for third generation squark masses



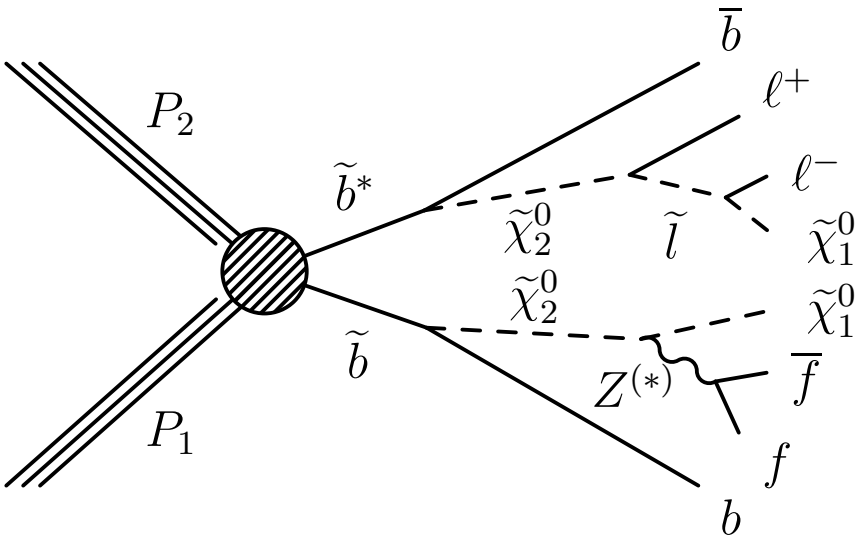


- Results compatible with SM
- Limits set for variable branching ratios of $\tilde{t} \to t\tilde{\chi}_1^0$ (B=1.0) and $\tilde{t} \to b\tilde{\chi}_1^{\pm}$ (B=0.0)

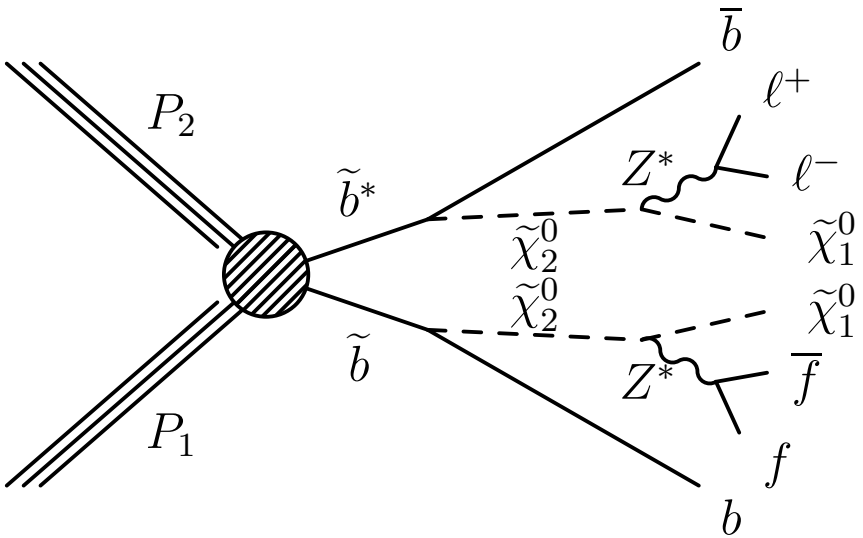
Di-lepton mass edge, jets and $\not{E}_T$ search

General idea: kinematic edge of opposite sign same flavour leptons generated by SUSY decay chain

slepton edge



fixed edge

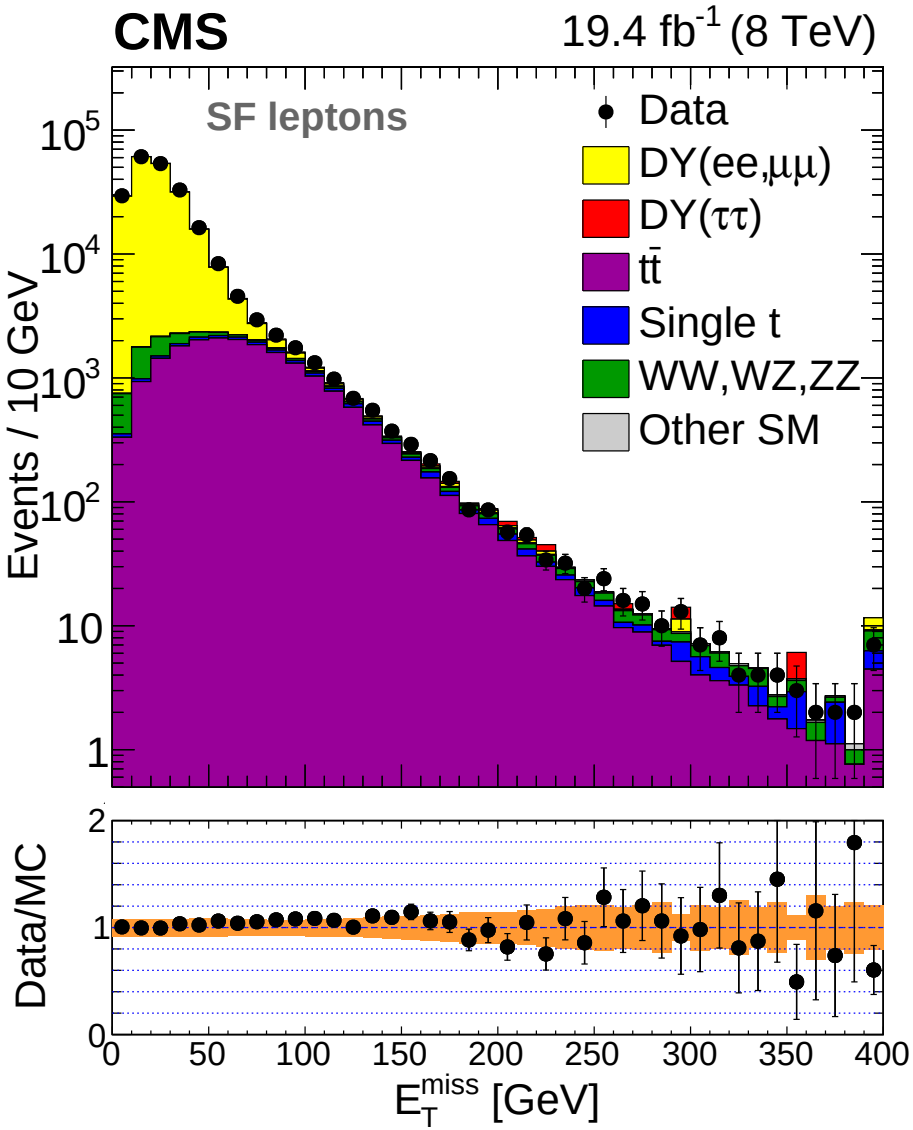


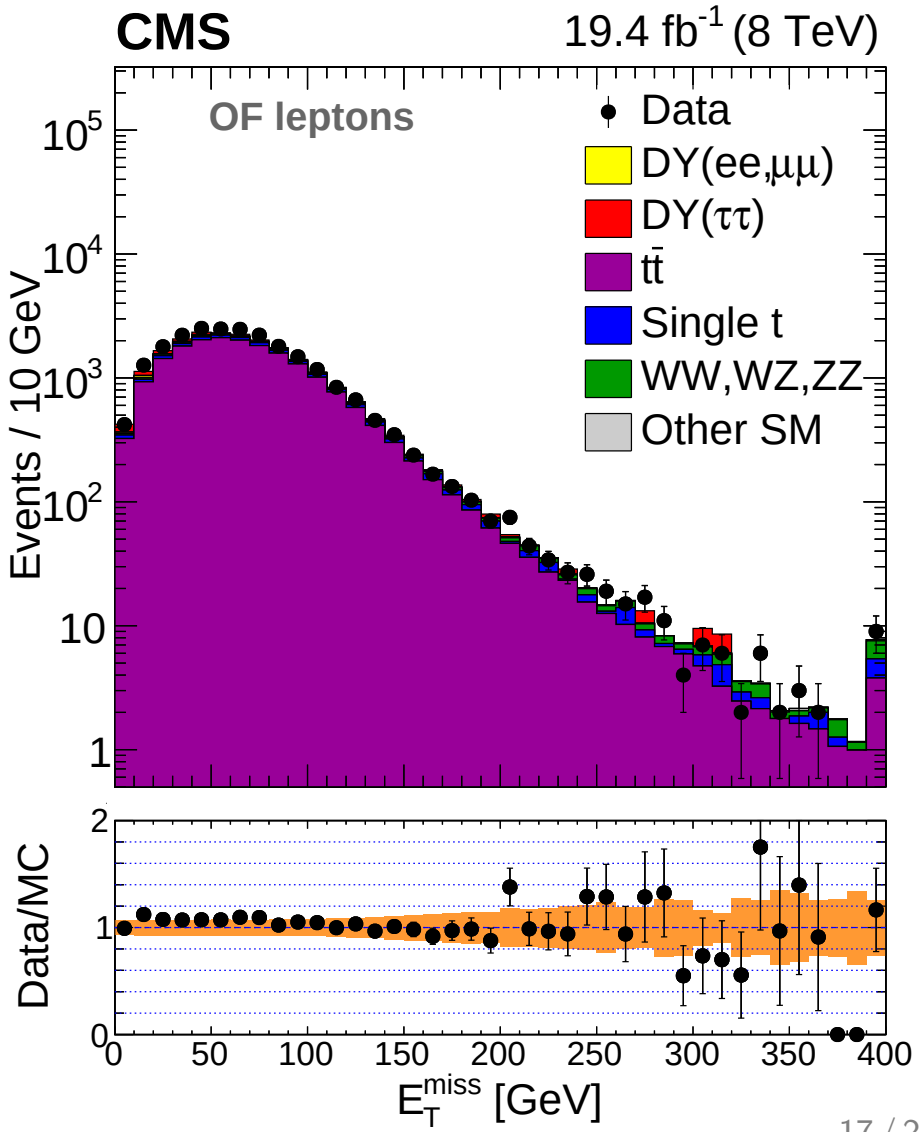
- Uses dedicated di-lepton triggers
- Assumes mass-degenerate $\tilde{e}$ and $\tilde{\mu}$

arXiv:1502.06031

Search regions and background estimation

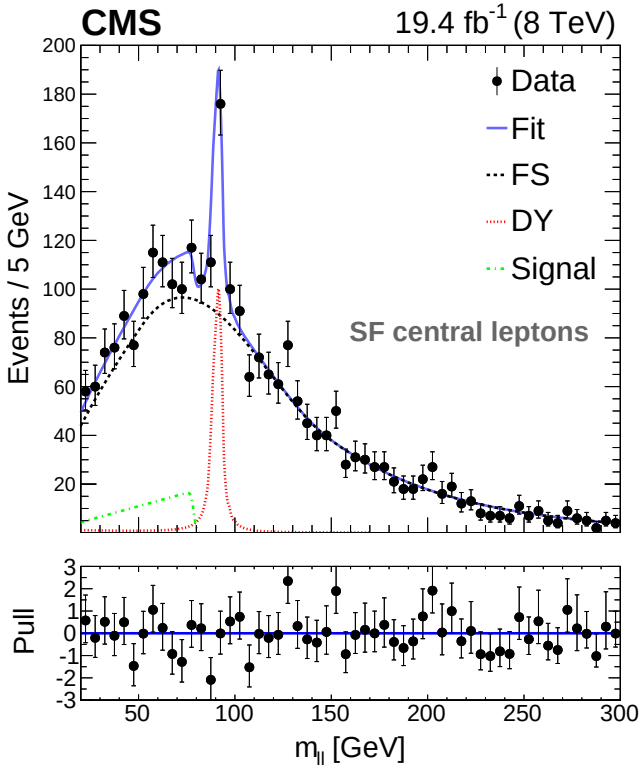
Distinction between flavor symmetric (FS) and flavor asymmetric (FA) backgrounds allows subtraction of $t\bar{t}$:

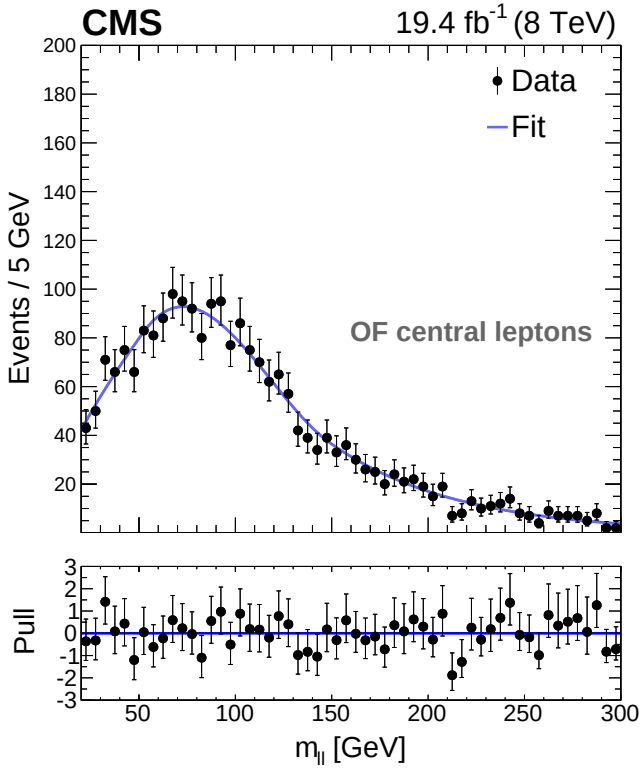




Di-lepton fit

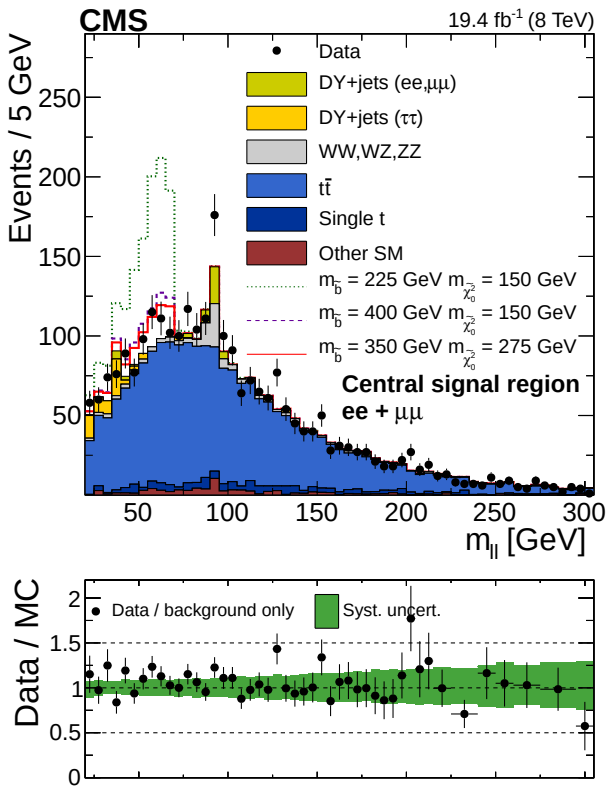
[low-mass, on-Z, high-mass] $\times$ [central($|\eta_{\rm lep}| < 1.4$), forward($1.6 < |\eta_{\rm lep}| < 2.4$)] =**6 signal regions**

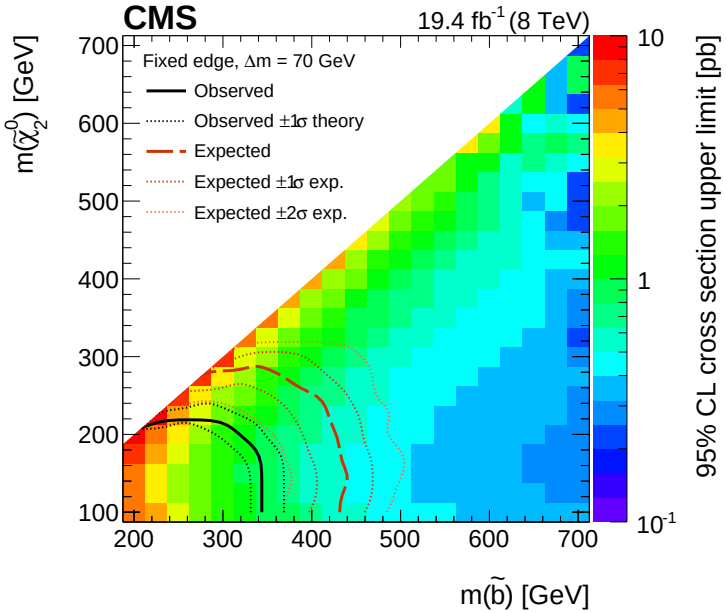


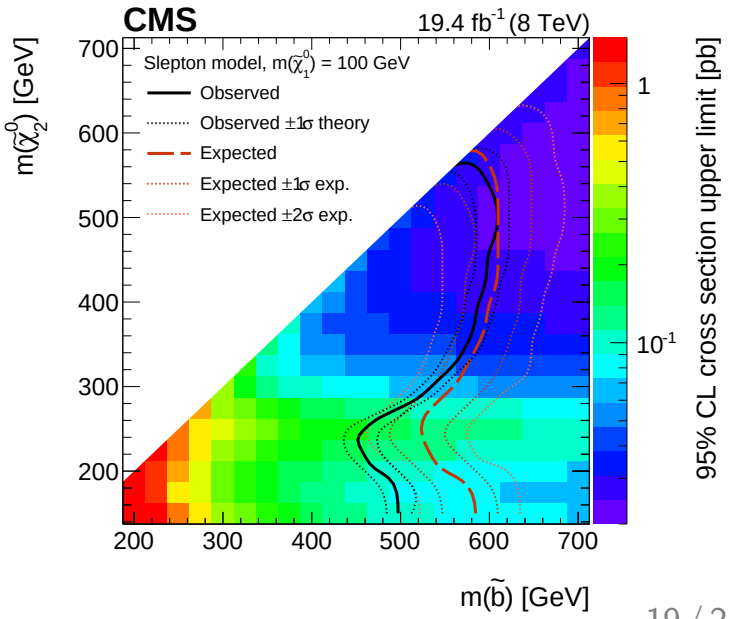


- Contains flavour symmetric, DY and kinematic edge components

Kinematic edge results and interpretation



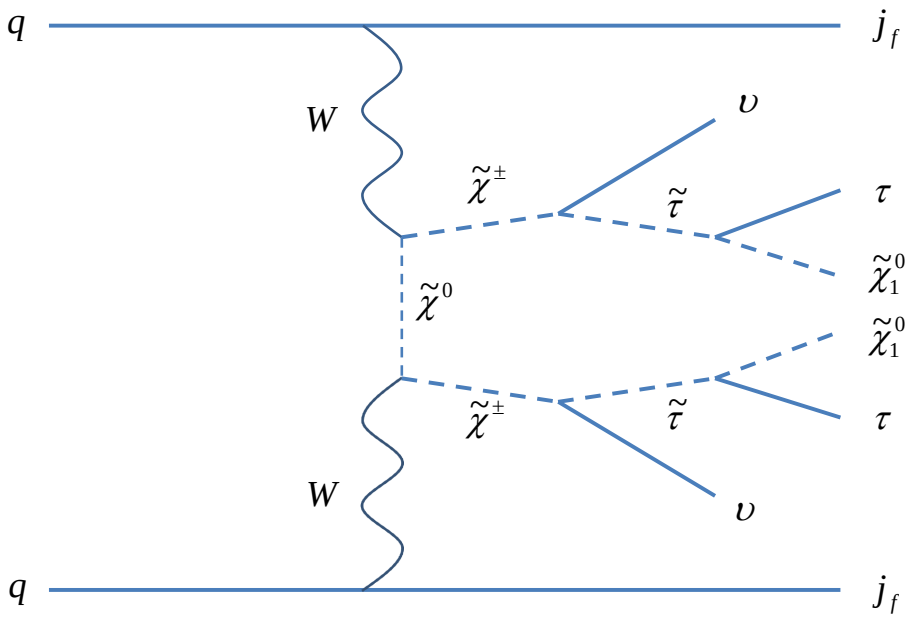


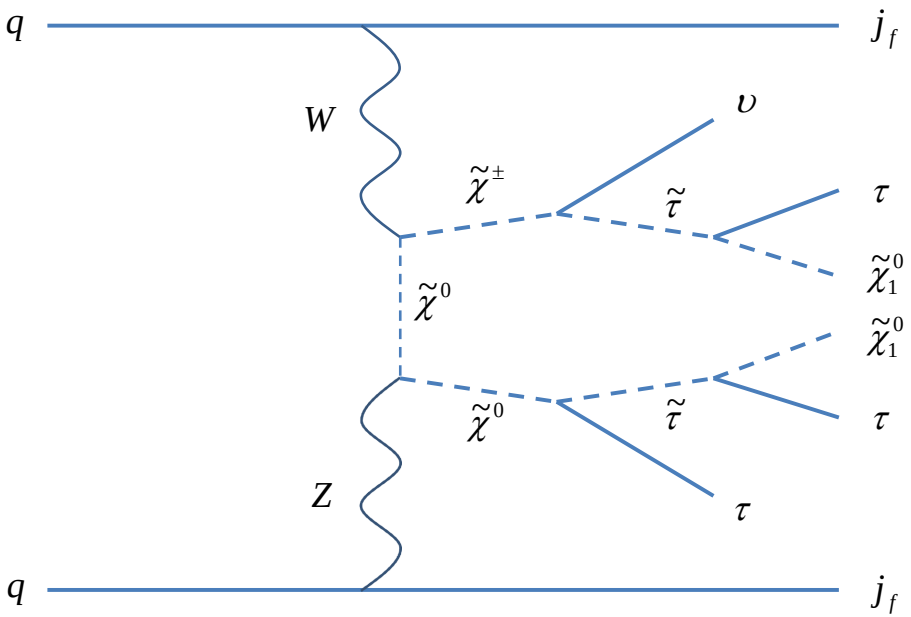


- No evidence for a statistically significant signal is observed.
- The maximum deviation from the null hypothesis is at the level of 2.6 σ within $20 < m_{ll} < 70$ GeV

Search for compressed spectra SUSY with VBF tag

General idea: access compressed spectrum $\tilde{\tau}$ SUSY by tagging vector boson fusion (VBF) jets





- VBF production (just two example diagrams) yields two high p_{T} jets in opposite hemispheres of the detector with large separation in η
- Search performed in opposite sign (OS) and like sign (LS) $\mu\mu$, $\mathrm{e}\mu$, $\mu\tau_{\mathrm{h}}$ and $\tau_{\mathrm{h}}\tau_{\mathrm{h}}$ channels

CMS-PAS-SUS-14-005

Background estimation strategy

VBF topology not well-modeled in simulation $\rightarrow$ all main backgrounds data-driven

- single-μ trigger or di-τ_{had} trigger
- b-tag veto to reduce $\mathrm{t\bar{t}}$
- Two central, isolated leptons
- Mass of VBF jets $>$ 250 GeV, varying $\not{E}_{\mathrm{T}}$ requirements

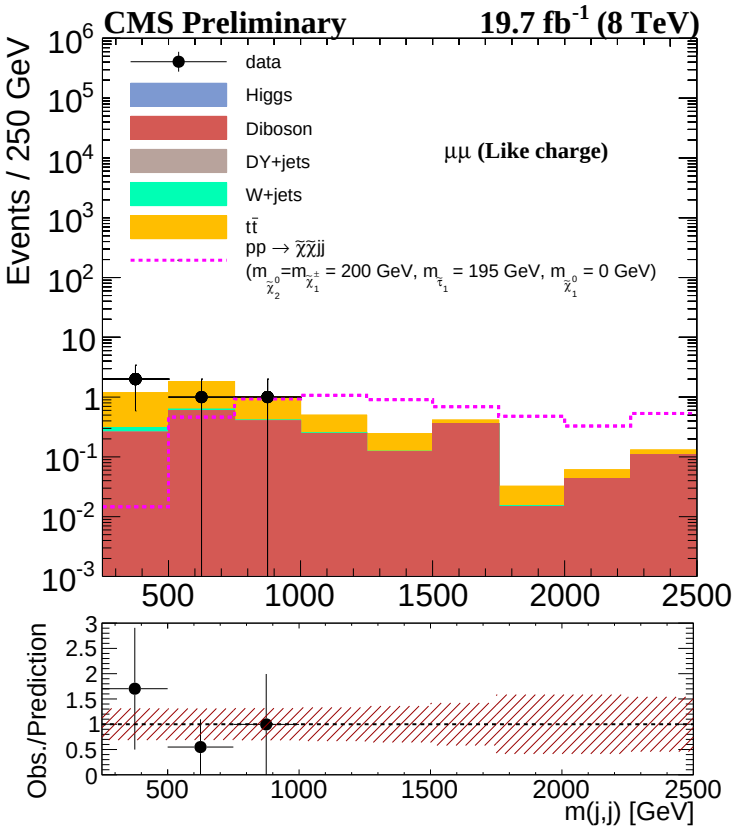
Backgrounds vary with OS (left) or LS (right) and lepton flavor requirements (stat. unc. only):

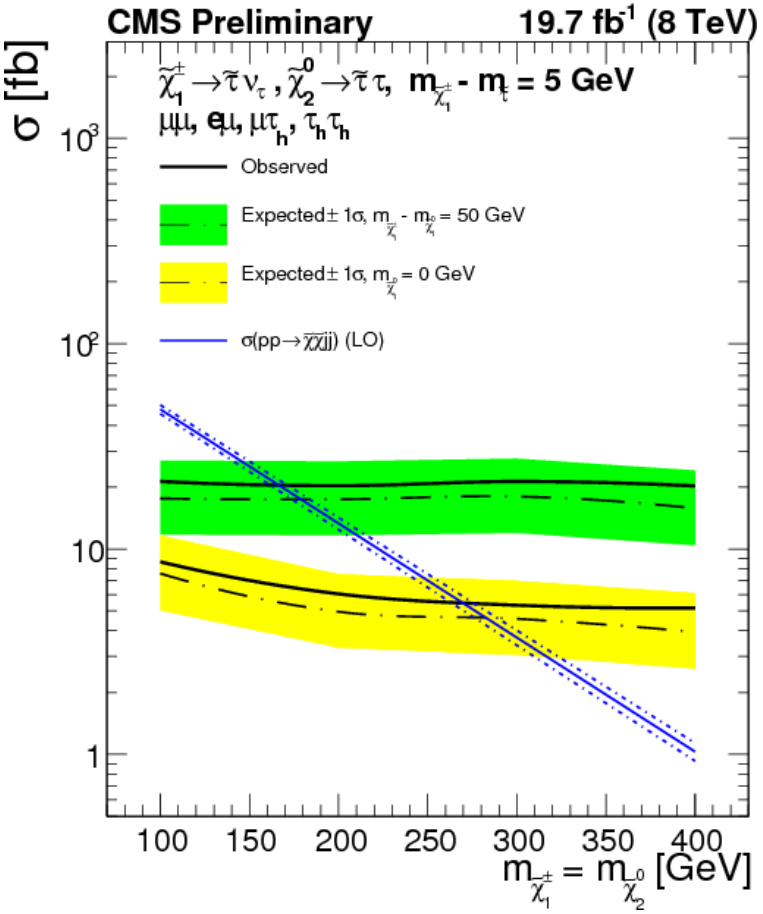
Process	$\mu^{\pm}\mu^{\mp}jj$	$e^{\pm}\mu^{\mp}jj$	$\mu^{\pm}\tau_h^{\mp}jj$	$\tau_h^{\pm}\tau_h^{\mp}jj$
DY + jets	4.3 ± 1.7	$3.7\pm^{2.1}_{1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.01	$4.2\pm^{3.3}_{2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0\pm^{2.3}_{2.4}$	11.7 ± 2.8	–
QCD	–	–	–	6.3 ± 1.8
Higgs	1.0 ± 0.1	1.1 ± 0.5	–	1.1 ± 0.1
VBF Z	–	–	–	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1\pm^{4.6}_{4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

Process	$\mu^{\pm}\mu^{\pm}jj$	$e^{\pm}\mu^{\pm}jj$	$\mu^{\pm}\tau_h^{\pm}jj$	$\tau_h^{\pm}\tau_h^{\pm}jj$
DY + jets	< 0.01	$0\pm^{1.7}_{0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0\pm^{3.0}_{0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9\pm^{0.4}_{0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5\pm^{0.7}_{0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	–	–	–	< 0.1
QCD	–	–	–	7.6 ± 0.9
Higgs	–	–	–	< 0.01
Total	5.4 ± 0.3	$5.4\pm^{3.5}_{0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9

- Data-driven estimations by ABCD methods with inversion of VBF requirements, lepton isolation, b-quark veto, requiring 3 leptons or a transverse mass window

Interpretation with light $\tilde{\tau}$ for compressed spectra and light LSP





- Especially like sign channels have high signal to background ratios
- Results compatible with SM, limits have been set for compressed (green) and large mass gap (yellow) scenarios

Summary

- No conclusive sign of SUSY yet
- Strong exclusion limits on colored sector
- Compressed scenarios, third generation sparticles and electroweak sector pose challenges that are being tackled by new techniques (boosted top tagging, VBF tagging)
- The experience with new techniques will be beneficial for Run 2, but old inclusive search techniques are still needed

All of the CMS SUSY results can be found at:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Backup

M_{T2} event selection

- $H_{\mathrm{T}} = \sum_{\text{jets } p_T > 50 \text{ GeV}} p_T(\text{jet})$
- either $H_{\mathrm{T}} > 750$ GeV for H_{T} trigger, or $H_{\mathrm{T}} > 450$ GeV and $\not{E}_{\mathrm{T}} > 200$ GeV for $\not{E}_{\mathrm{T}} \times H_{\mathrm{T}}$ or $\not{E}_{\mathrm{T}}$ triggers
- veto on e and μ within $|\eta| < 2.4$ and with $p_T > 10$ GeV (exclusion of $1.442 < |\eta| < 1.566$ for electrons), isolation within $\Delta R < 0.3$ (0.15 for e, 0.20 for μ)
- ak5PF+CHS jets, loose jet ID, $p_T > 20$ GeV in $|\eta| < 2.4$
- at least two jets with $p_T > 100$ GeV
- $\Delta\phi_{\min}(\vec{p}_{\mathrm{T}}^{\mathrm{miss}} \cdot \mathrm{jet}_{1..4} > 0.3$
- b-tagging with Combined Secondary Vertex algorithm (medium)
- veto on one- or three-pronged τ, $p_T > 20$ GeV in $|\eta| < 2.3$ with loose isolation (in $\Delta R < 0.5$ less than 2 GeV after pileup substraction)

$\tilde{t}$ tagging event selection

- trigger with two jets in $|\eta| < 2.6$ with $p_T > 50$ GeV and $\not{E}_{\mathrm{T}} > 80$ GeV
- no isolated e or μ with $p_T > 5$ GeV
- at least five jets with $p_T > 30$ GeV in $|\eta| < 2.4$ with two leading jets with $p_T > 70$ GeV and the next two subleading jets with $p_T > 50$ GeV
- at least one b-tagged jet
- $\Delta\phi(\vec{p}_T^{\,\mathrm{jet}}, \vec{p}_T^{\,\mathrm{miss}} > [0.5, 0.5, 0.3]$ for the three leading jets
- Boosted top algorithm refereces: arXiv:0806.0848, arXiv:1006.2833 and arXiv:1205.5816

boosted top M_{T} variables

$$(M_{\mathrm{T}}^{\text{3-jet}})^2 = (m^{\text{3-jet}} + 2(p_{\mathrm{T}}^{\text{3-jet}} p_{\mathrm{T}}^{\mathrm{miss}} \cos \Delta\phi)) \tag{3}$$

For $M_{\mathrm{T}}^{\text{R-sys}}$, the 3-jet variables are replaced with the partial top-quark decay products in the remnant system (R-sys)

Di-lepton mass edge event selection

- oppositely charged lepton pair $e^{\pm}e^{\mp}$, $e^{\pm}\mu^{\mp}$ or $\mu^{\pm}\mu^{\mp}$ (all dedicated di-lepton triggers) with $p_T^{lepton} > 20$ GeV in $|\eta| < 1.4$ (central) or $1.6|\eta| < 2.4$ (forward) and with isolation in $\Delta R < 0.3$ to be < 0.15 after pileup substraction
- choose the two leptons with largest transverse momentum
- ak5PF+CHS jets with $p_T > 40$ GeV in $|\eta| < 3.0$ with a separation of $\Delta R > 0.4$ from selected leptons
- definition of $20 < m_{ll} < 70$ GeV low-mass, $81 < m_{ll} < 101$ GeV on-Z and $m_{ll} > 120$ GeV high-mass regions

VBF tagging event selection

- single muon trigger for $\mu\mu jj$, $e\mu jj$ and $\mu\tau_{\mathrm{had}}jj$ channels requiring $p_T^{\mu} > 30$ GeV and $\not{E}_{\mathrm{T}} > 75$ GeV
- di-τ_{had} trigger for $\tau_{\mathrm{had}}\tau_{\mathrm{had}}jj$ channels requiring $p_T^{\tau_{\mathrm{had}}} > 45$ GeV and $\not{E}_{\mathrm{T}} > 30$ GeV
- veto on b-tagged jets with $p_T > 20$ GeV isolated from leptons with $\Delta R > 0.3$
- VBF selection with two ak5PF+CHS jets with $p_T > 50$ GeV in $|\eta| < 5.0$ passing $\Delta\eta > 4.2$, $\mathrm{sign}(\eta_1 \cdot \eta_2 < 0)$ and $m_{jj} > 250$ GeV