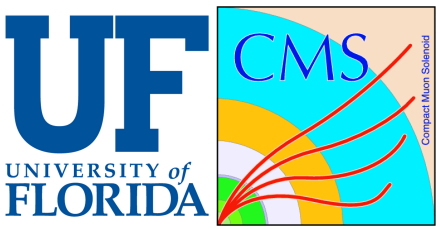
Searches for BSM physics in dilepton, multilepton, and lepton+MET final states at CMS

L. Thomas,
on behalf of the CMS Collaboration

University of Florida

April 13th, 2016



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8 TeV results:

- Search for leptophobic Z' decaying into four leptons in the final state at $\sqrt{s} = 8$ TeV **CMS-PAS-EXO-14-006**

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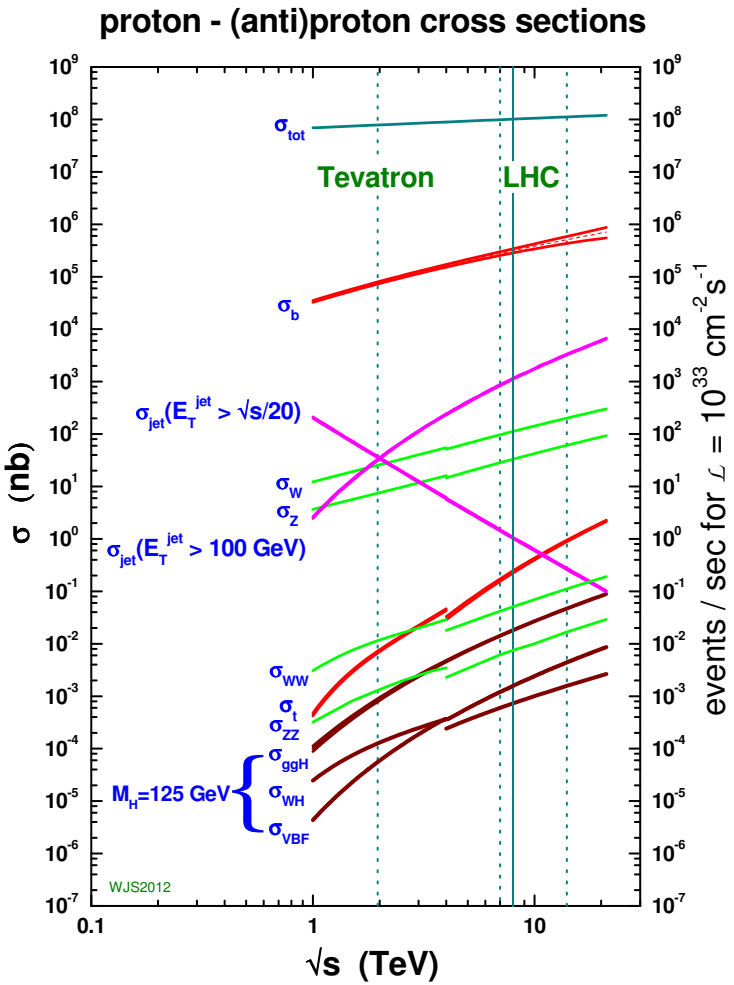

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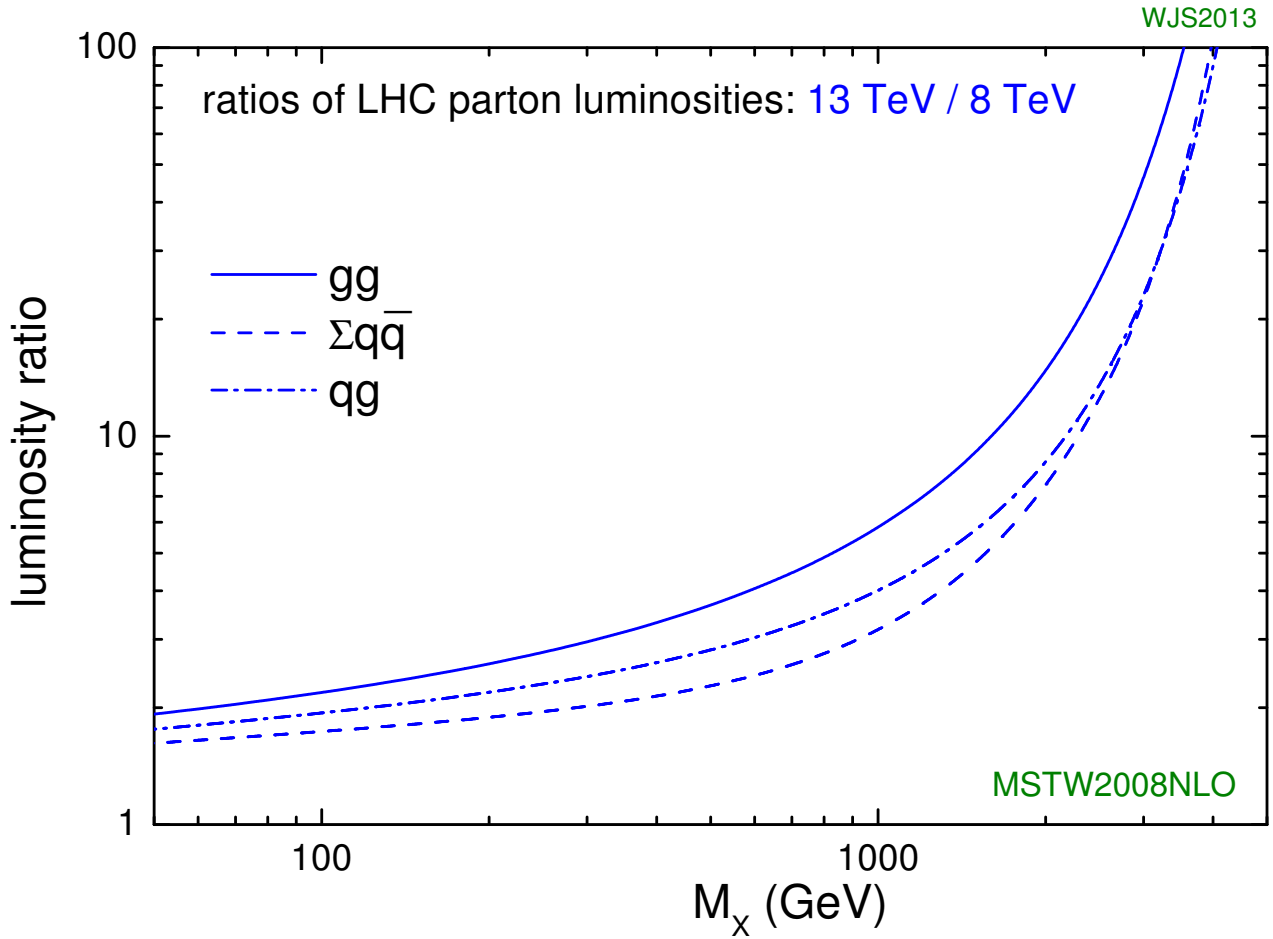

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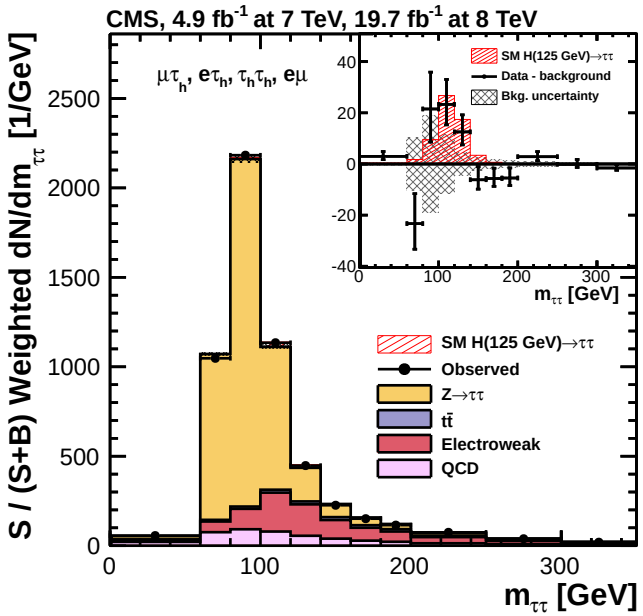

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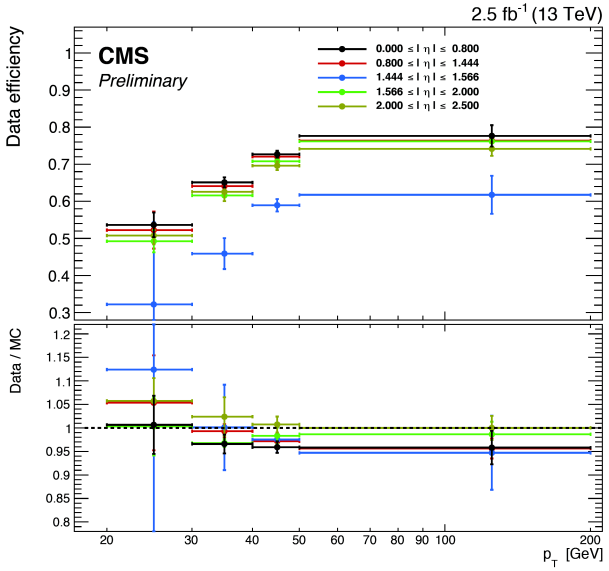

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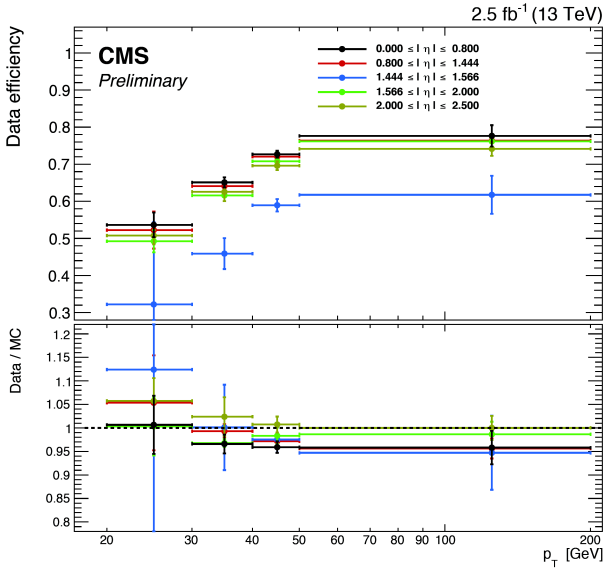

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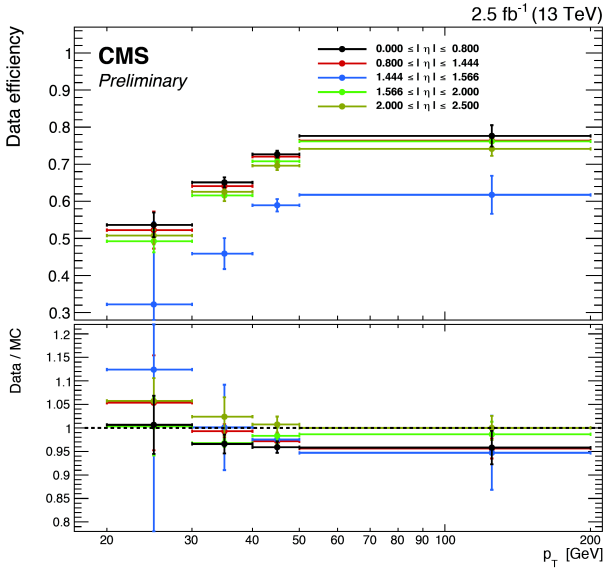

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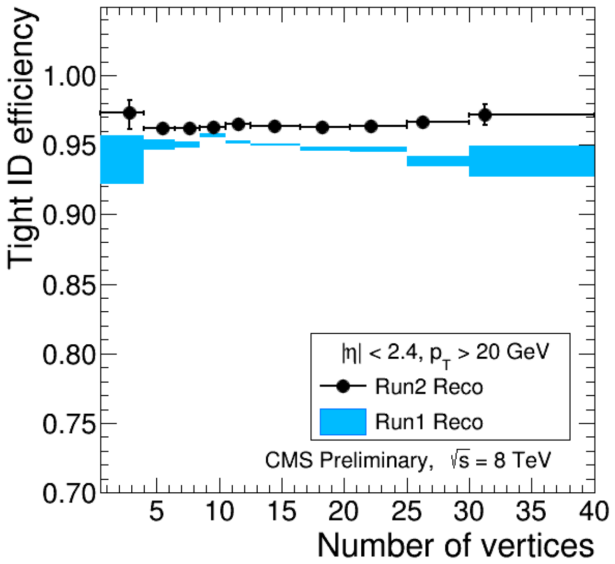

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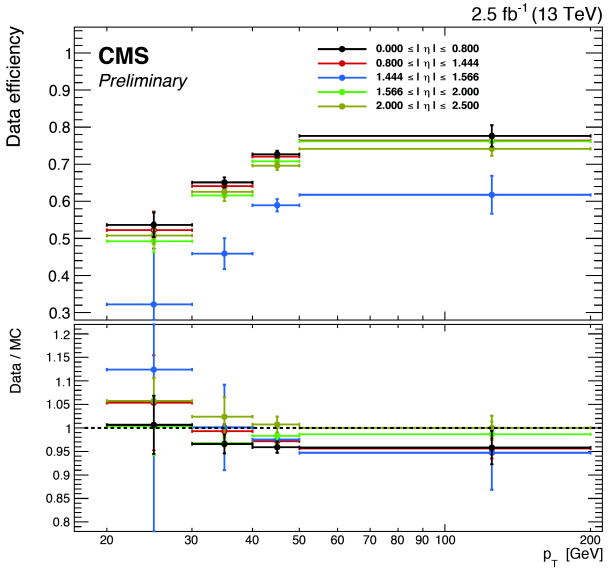

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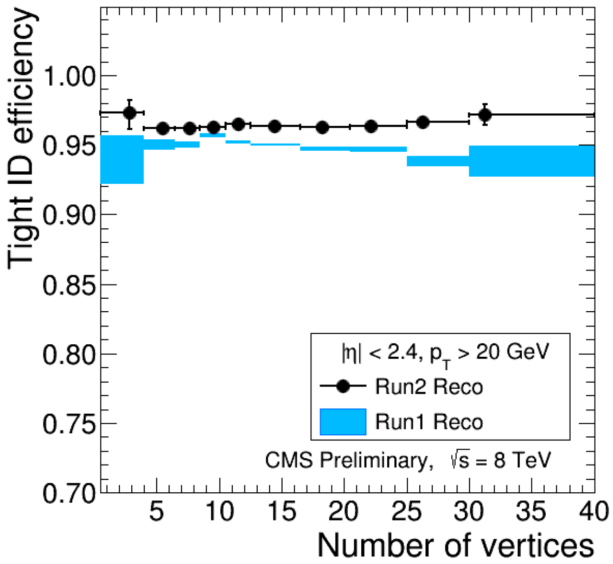

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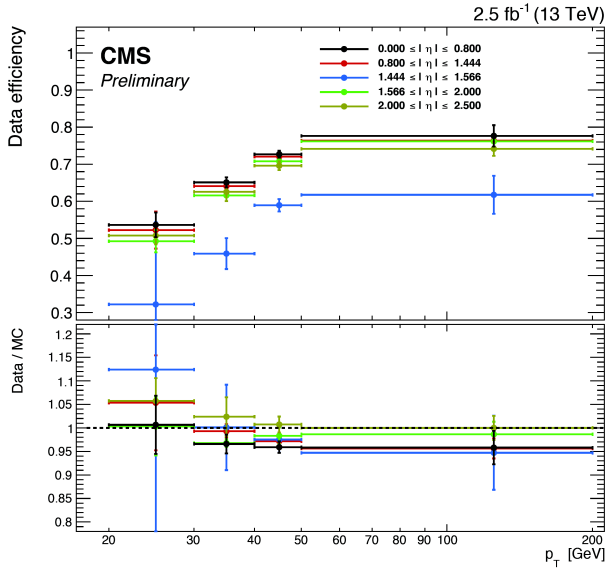

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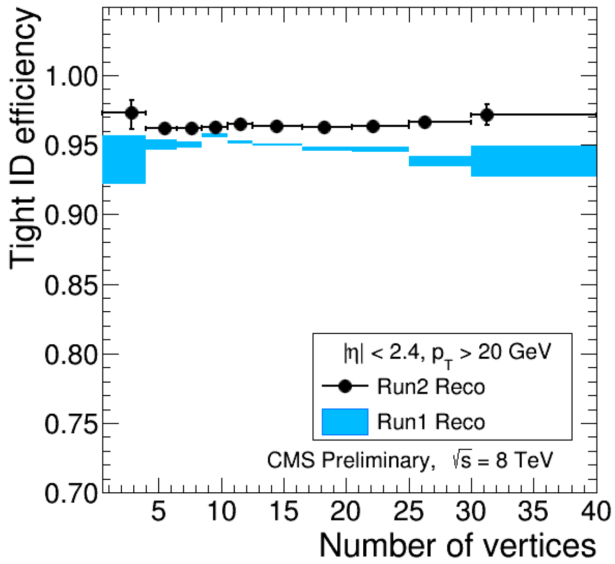
- High p_t features:
  - Dedicate algorithm for p_t measurement
  - $dM_{\mu\mu}/M_{\mu\mu}$ mass dependent: $\approx 4\%$ for $M_{\mu\mu} = 1$ TeV
  - $\approx 95\%$ efficiency per muon for $M_{\mu\mu} > 1$ TeV



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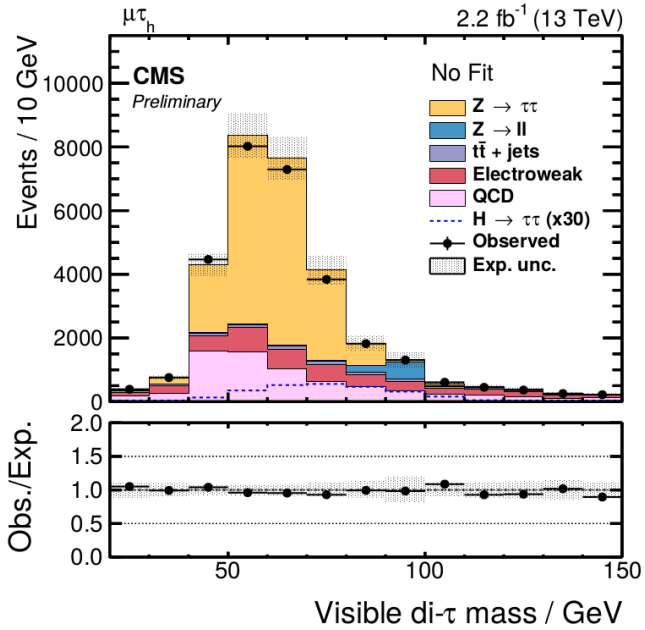

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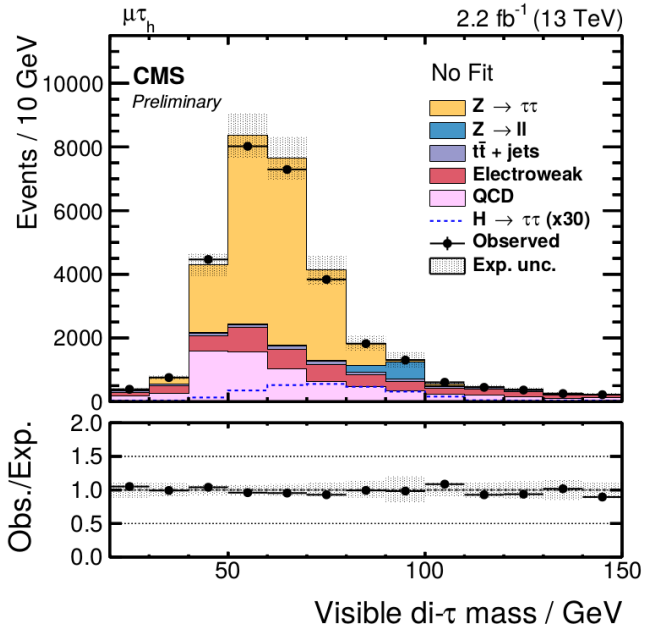

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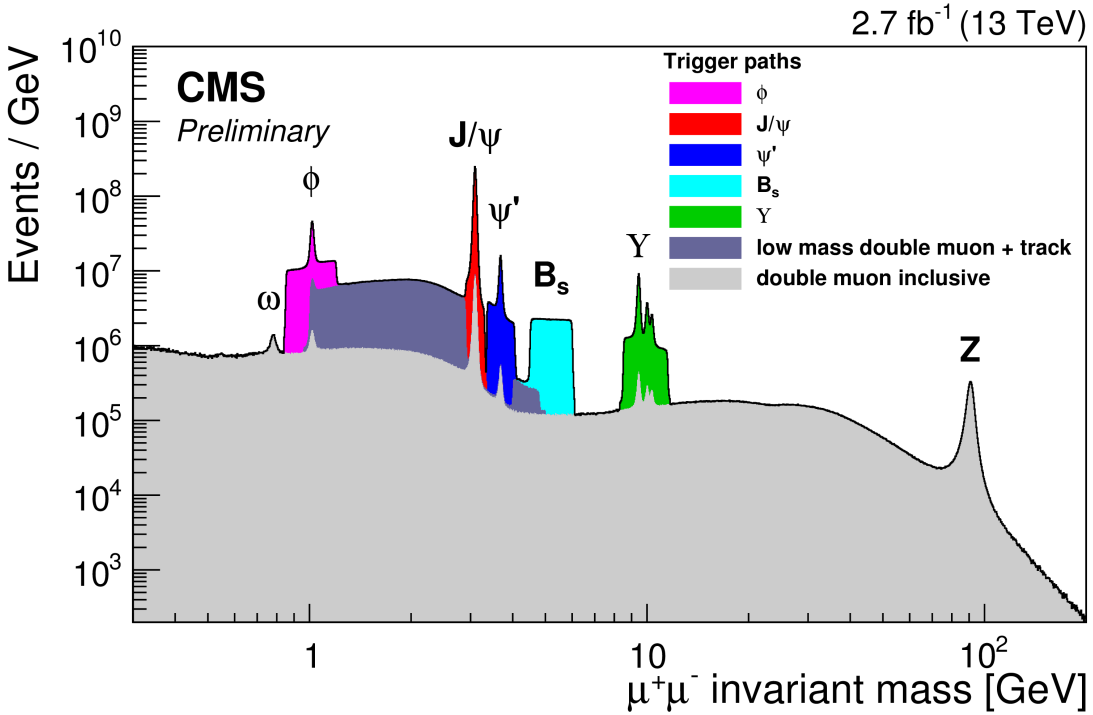

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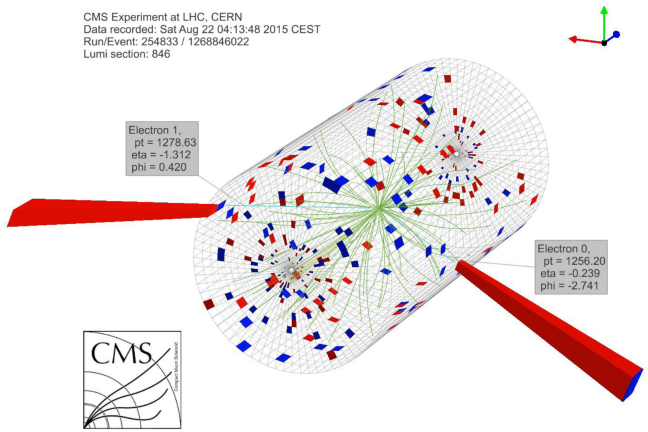
Early surprise:

- Dielectron event with $M_{ee} = 2.9$ TeV observed after 60 pb^{-1} of data collected only.



	electron 0	electron 1
E_T	1260 GeV	1280 GeV
η	-0.24	-1.31
ϕ	-2.74 rad	0.42 rad
charge	-1	+1
mass	2.91 TeV	
$\cos\theta^*_{CS}$	-0.49	
y	-0.78	

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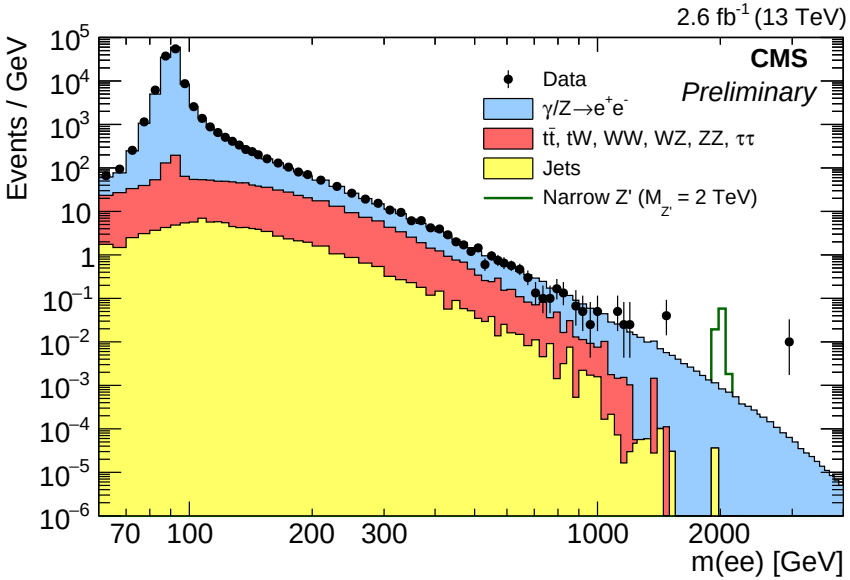

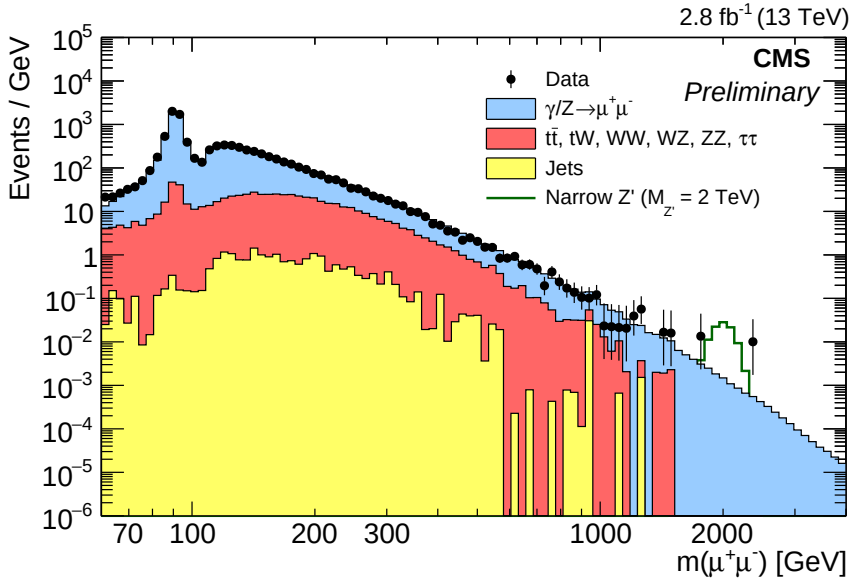

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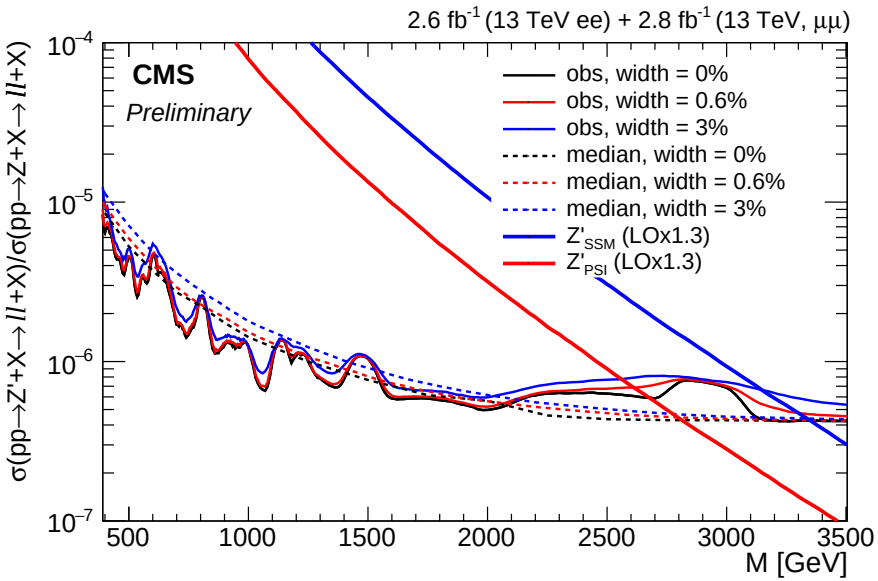

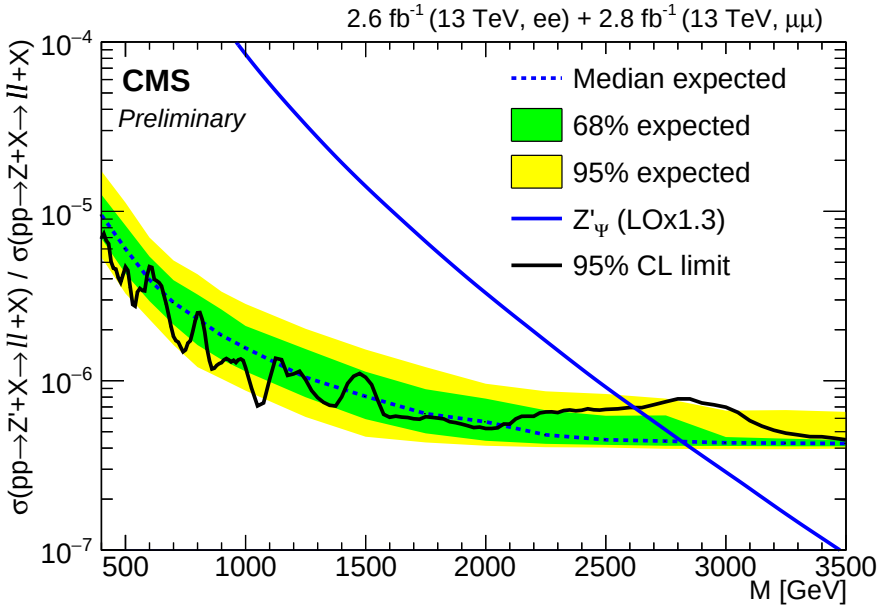

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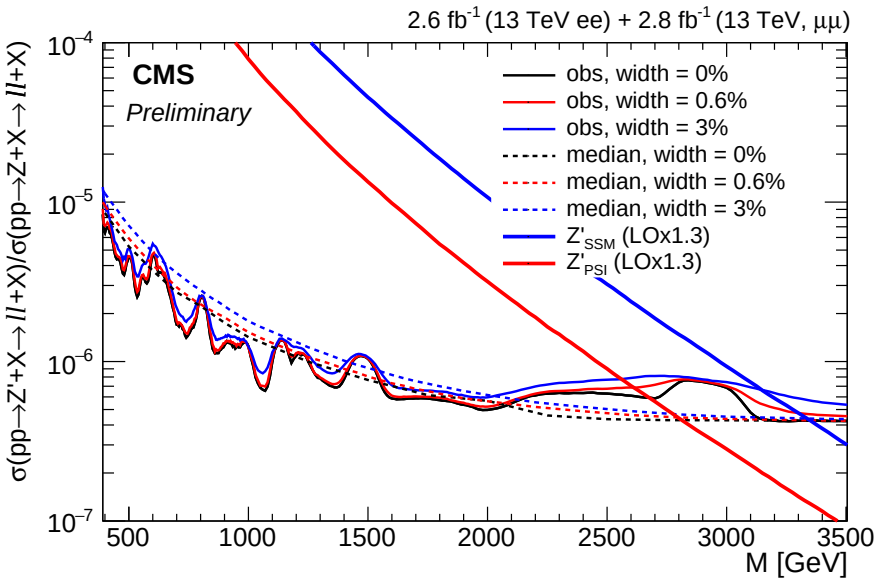

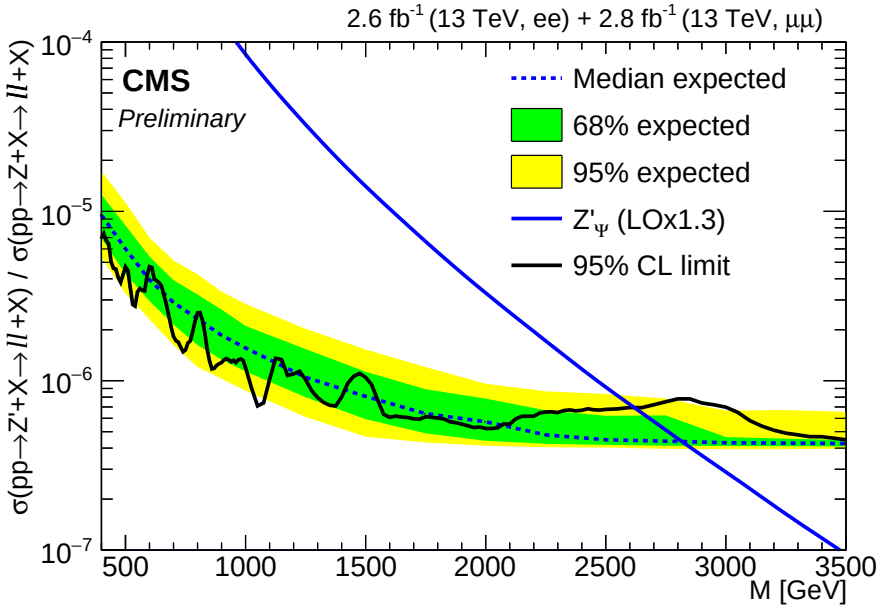

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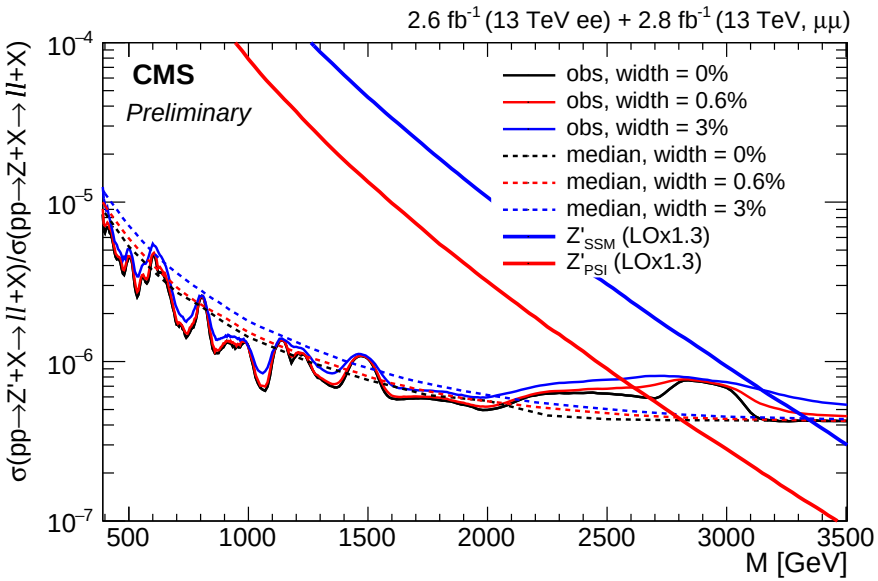

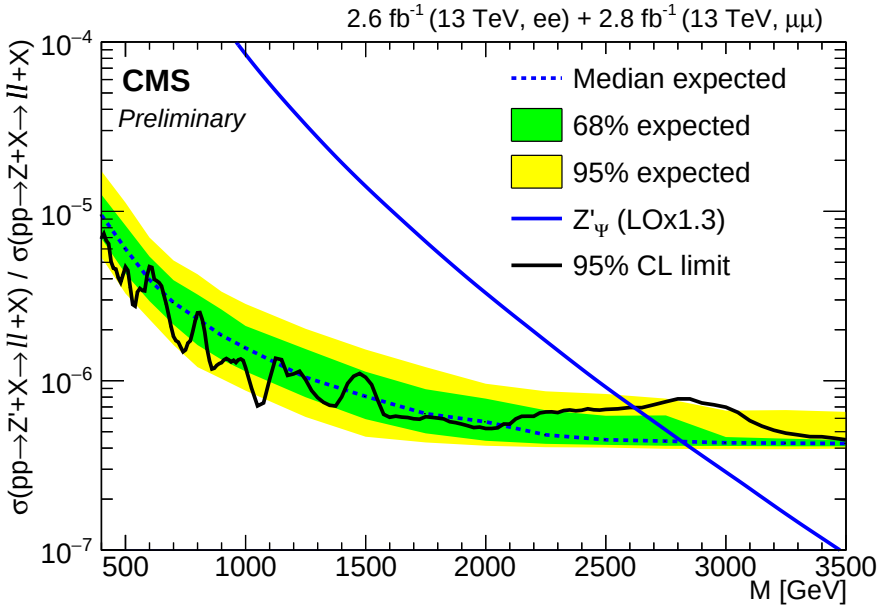

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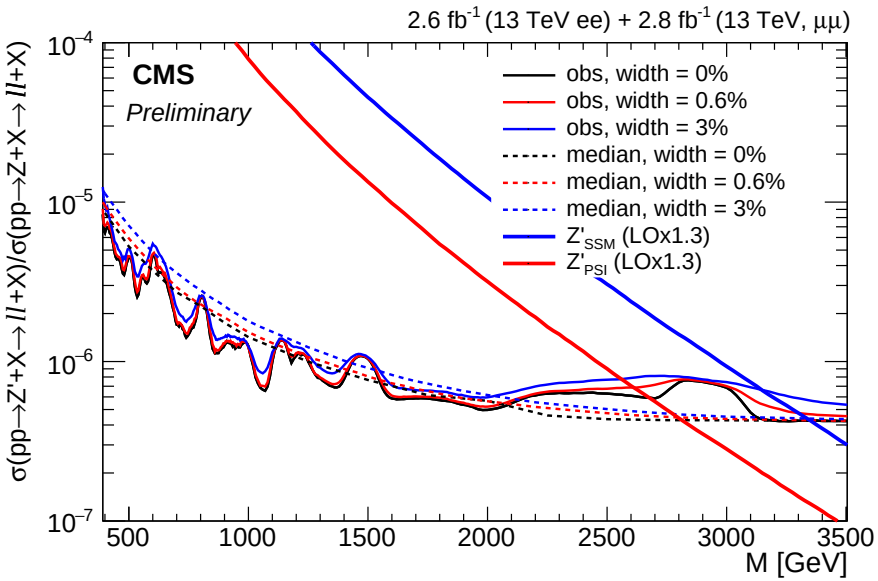

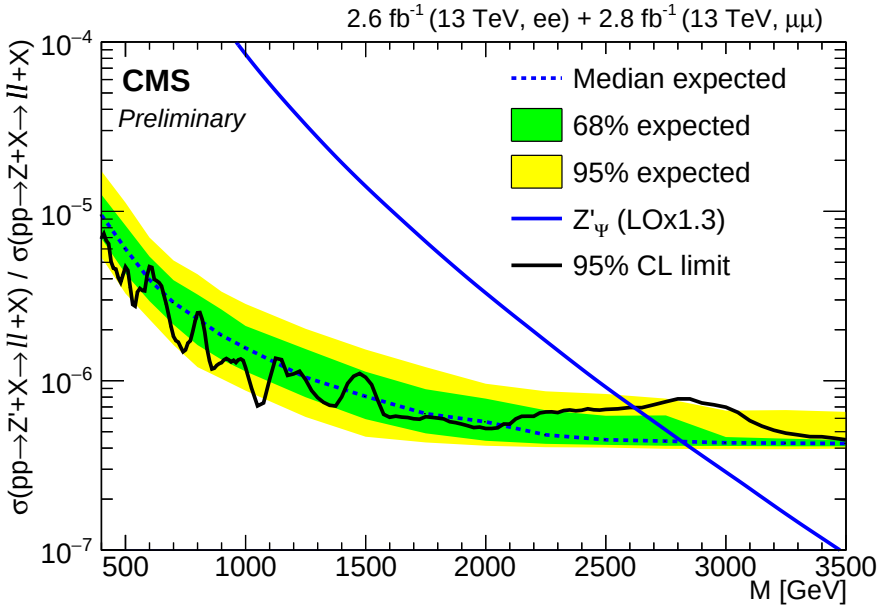

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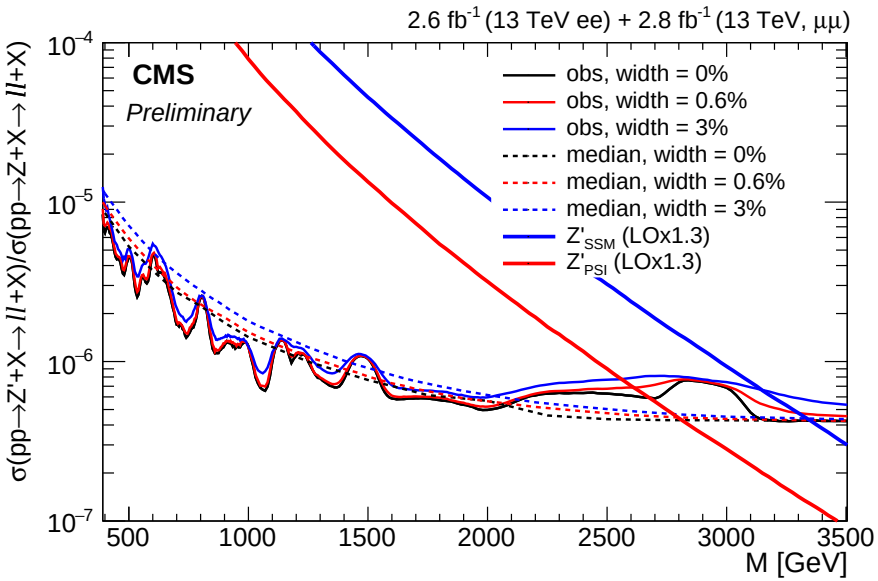

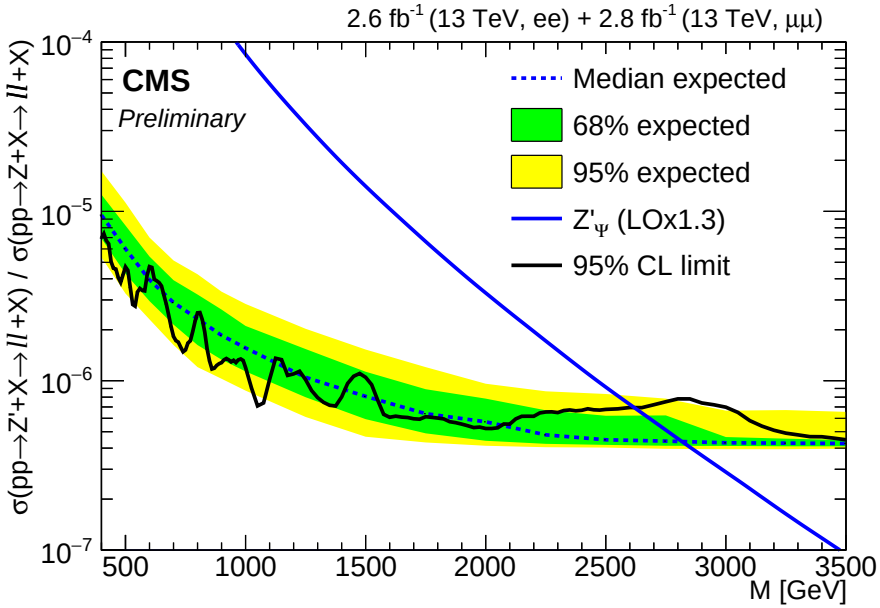

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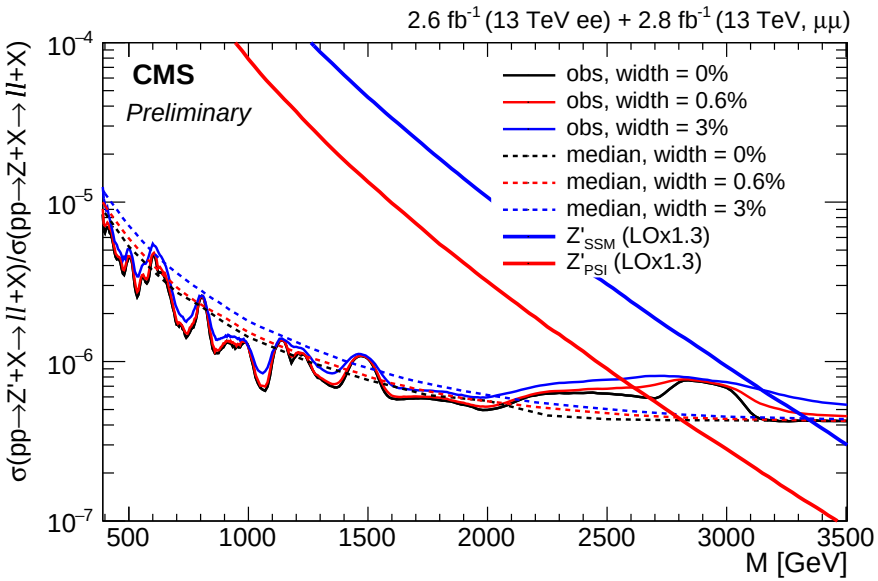

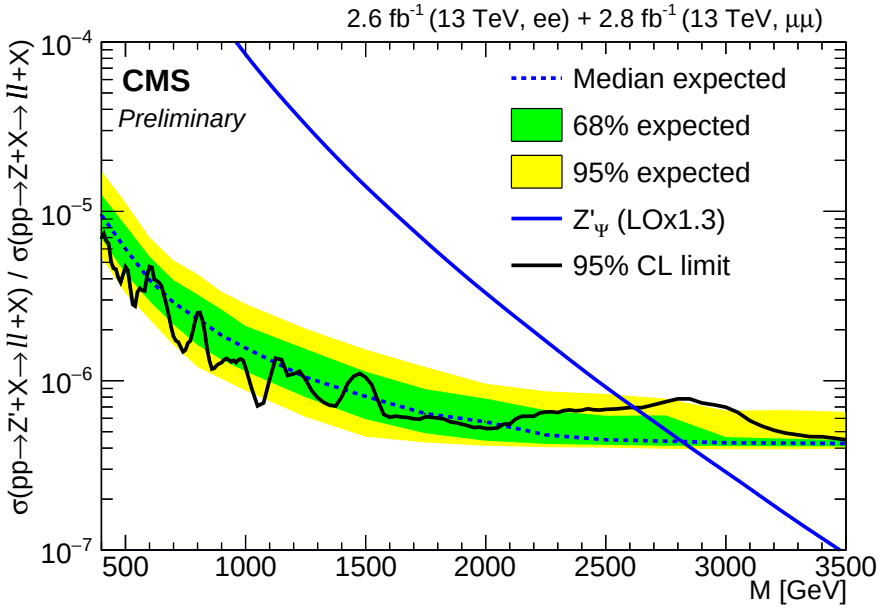

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$$M_T = \sqrt{2 p_t^l E_T^{miss} (1 - \cos \Delta\phi(\vec{p}_t^{\,l}, \vec{p}_T^{\,miss}))}$$

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Search strategy:

- Search based on the lepton+missing E_T transverse mass distribution:

$$M_T = \sqrt{2 p_t^l E_T^{miss} (1 - \cos \Delta\phi(\vec{p}_t^{\,l}, \vec{p}_T^{\,miss}))}$$

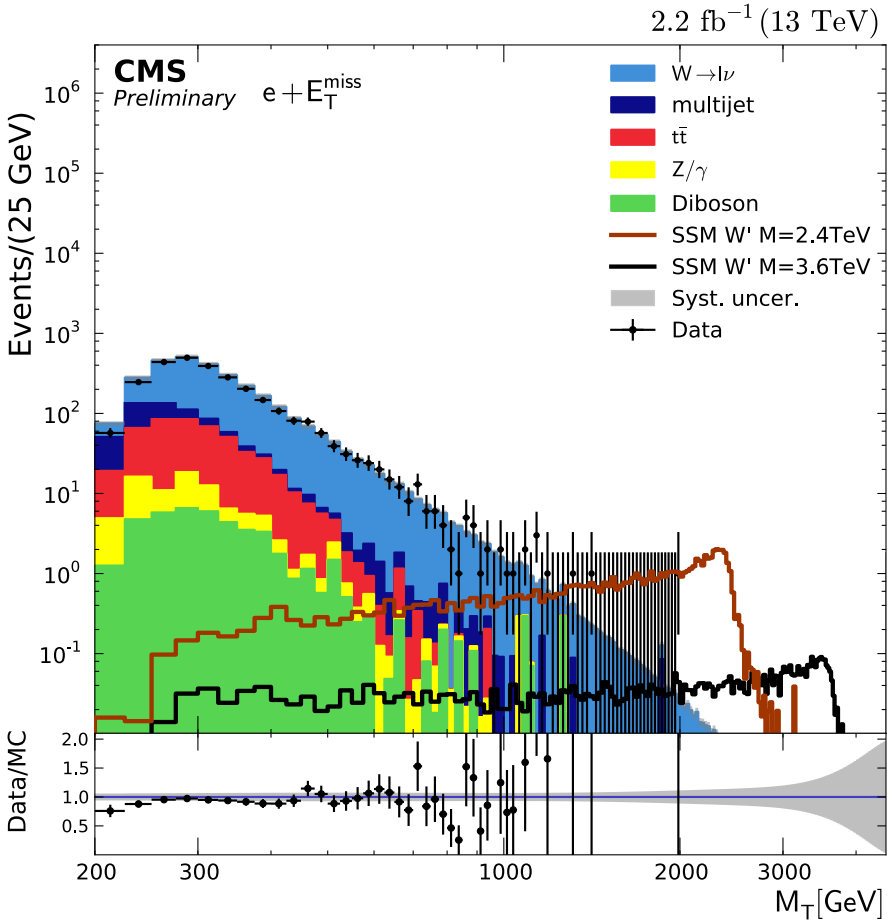
Event selection:

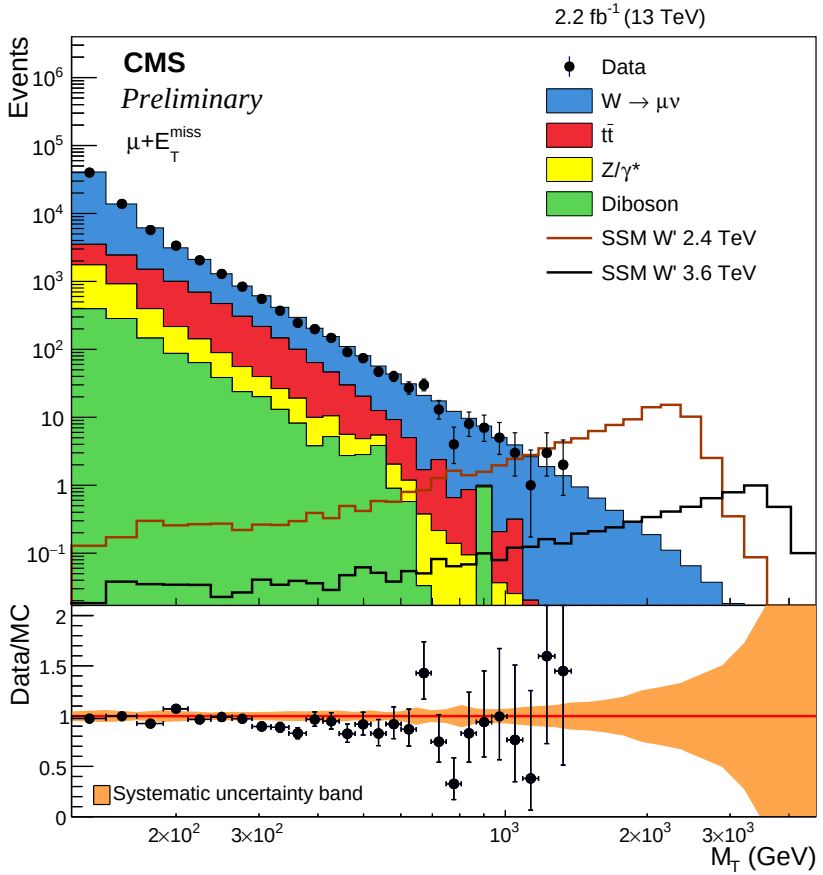
- One isolated high p_t lepton: $> 130/53$ GeV (e/μ)
- $\vec{p}_t^{\,l}$ /missing E_T balance: $0.4 < p_t^l / E_T^{miss} < 1.5$ and $|\Delta\phi(\vec{p}_t^{\,l}, \vec{p}_T^{\,miss})| > 2.5$
- Veto on additional leptons with $p_t > 35/25$ (e/μ).

Search for SSM W' production, in the e/μ + MET final state (2)

Search for SSM W' production, in the e/μ + MET final state (2)

M_T spectra:





Search for SSM W' production, in the e/μ + MET final state (3)

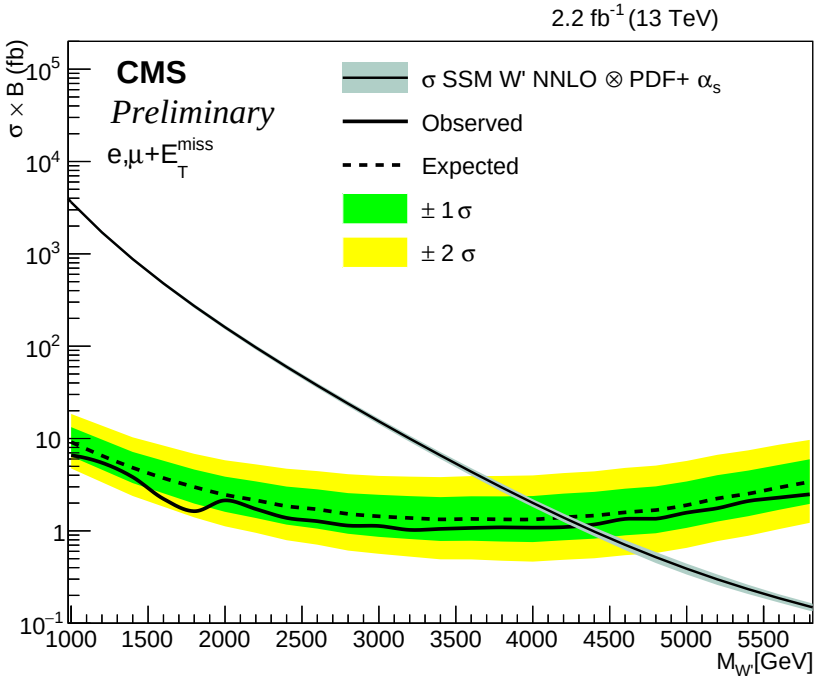
Search for SSM W' production, in the e/μ + MET final state (3)

Interpretations

Search for SSM W' production, in the e/μ + MET final state (3)

Interpretations

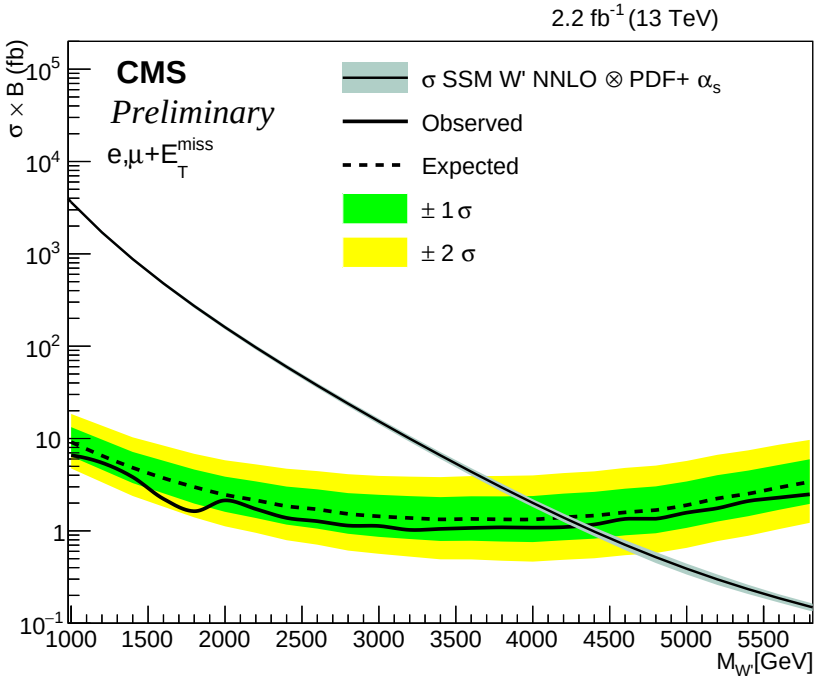
- Limits set using the full shape of the W'_{SSM} distribution due to large tail at low M_T (jacobian peak + offshell contribution).



Search for SSM W' production, in the e/μ + MET final state (3)

Interpretations

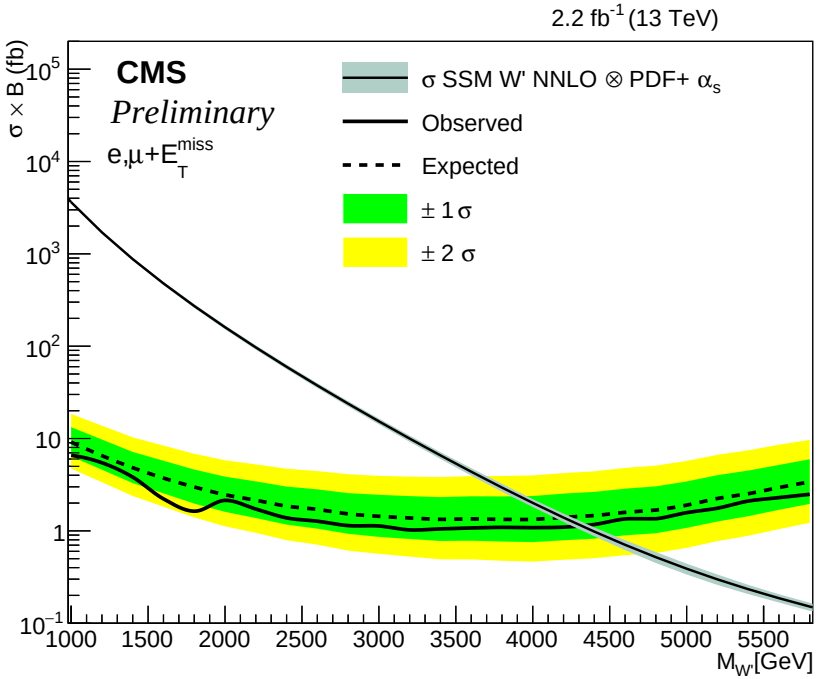
- Limits set using the full shape of the W'_{SSM} distribution due to large tail at low M_T (jacobian peak + offshell contribution).
- Signal acc. $\times$ eff. $\approx$ 75% for M = 3 TeV.



Search for SSM W' production, in the e/μ + MET final state (3)

Interpretations

- Limits set using the full shape of the W'_{SSM} distribution due to large tail at low M_T (jacobian peak + offshell contribution).
- Signal acc. $\times$ eff. $\approx$ 75% for M = 3 TeV.
- Main systematics : acceptance $\times$ efficiency (3-8%), muon momentum scale (10-20% at p_t = 1 TeV), luminosity (2.7%)



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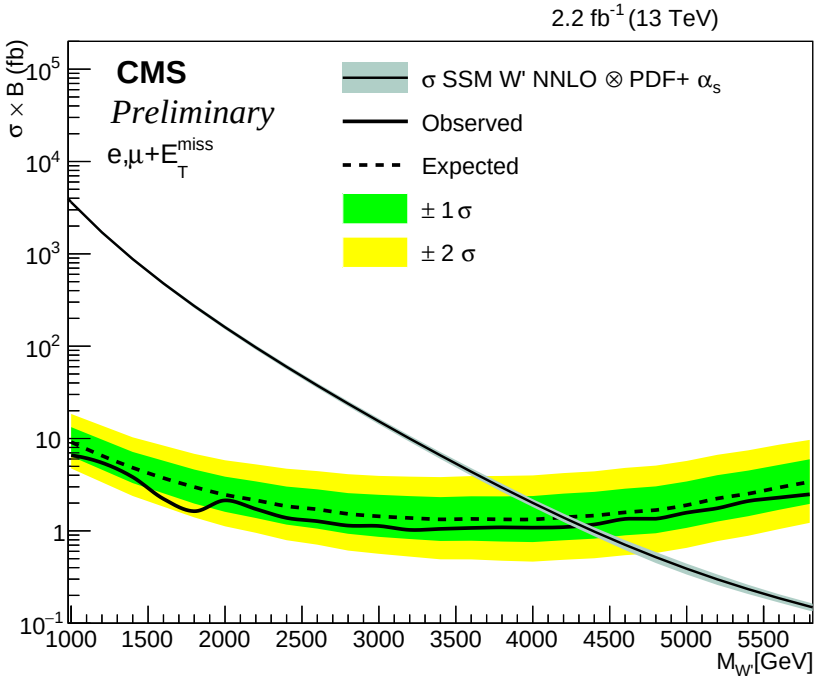
- W'_{SSM} excluded below 4.4 TeV



Search for SSM W' production, in the τ + MET final state

Search for SSM W' production, in the τ + MET final state

Search strategy:

Search for SSM W' production, in the τ + MET final state

Search strategy:

- Similar to e/μ + MET

Search for SSM W' production, in the τ + MET final state

Search strategy:

- Similar to e/μ + MET
- M_T distribution even more spread due to the presence of two neutrinos

Search for SSM W' production, in the τ + MET final state

Search strategy:

- Similar to e/μ + MET
- M_T distribution even more spread due to the presence of two neutrinos
- Slightly different kinematic cuts.

Search for SSM W' production, in the τ + MET final state

Search strategy:

- Similar to e/μ + MET
- M_T distribution even more spread due to the presence of two neutrinos
- Slightly different kinematic cuts.

Event selection:

- One isolated high p_t hadronic tau: > 80 GeV
- $\vec{p}_t^{\,l}$ /missing E_T balance: $0.7 < p_t^l / E_T^{miss} < 1.3$ and $|\Delta\phi(\vec{p}_t^{\,l}, \vec{p}_T^{\,miss})| > 2.4$

Search for SSM W' production, in the τ + MET final state

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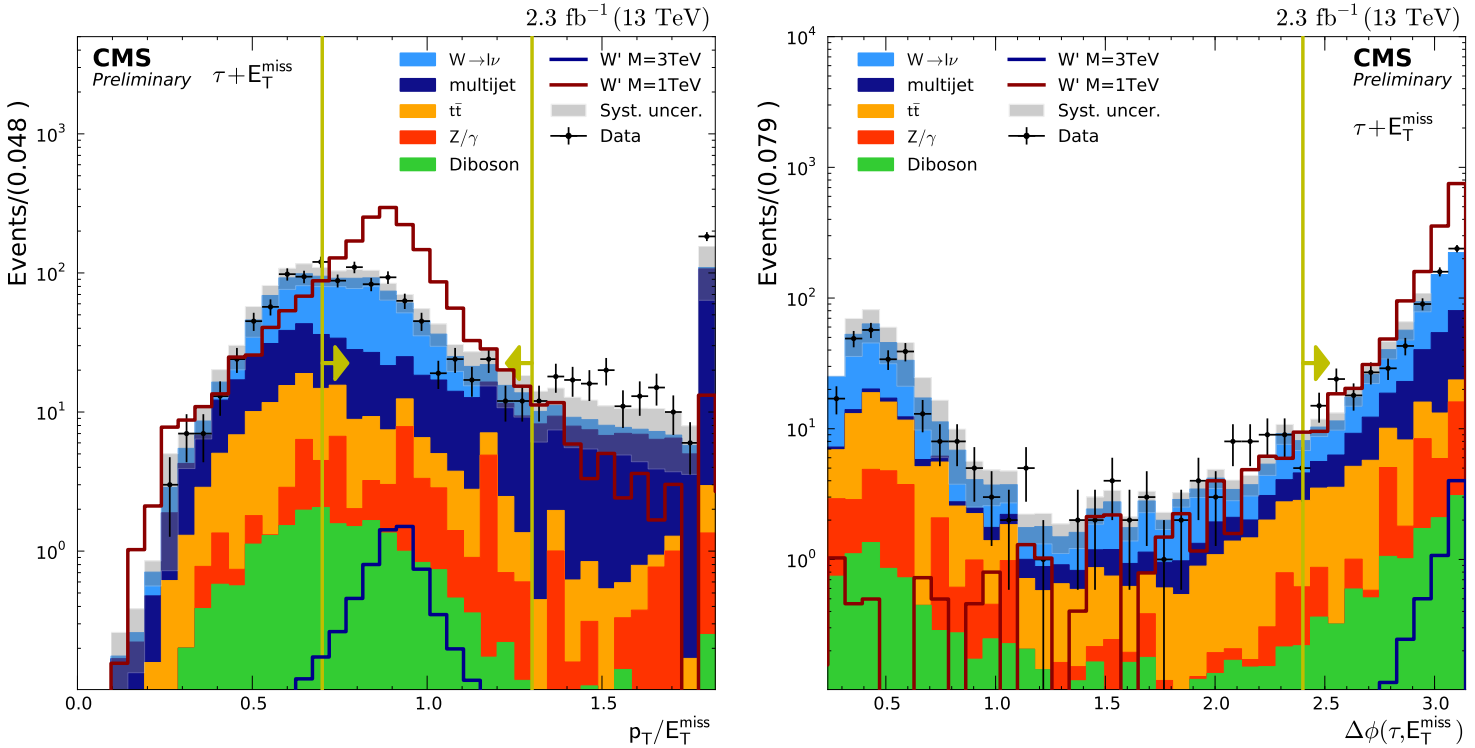

Search for SSM W' production, in the τ + MET final state (2)

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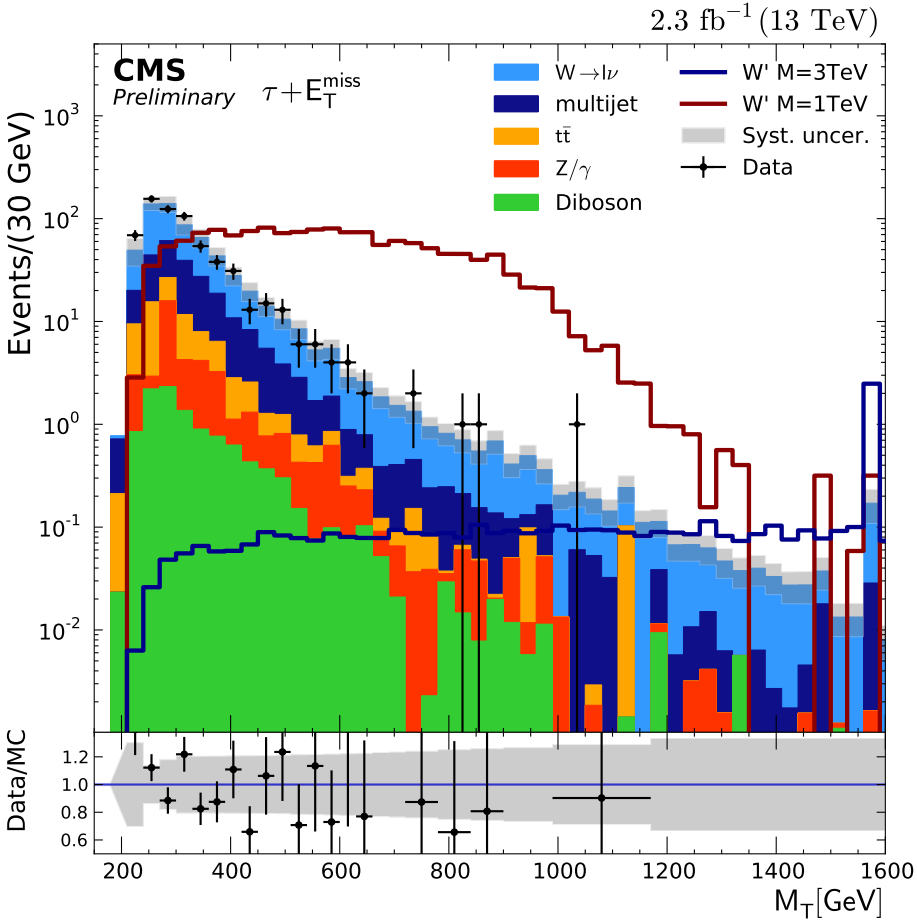

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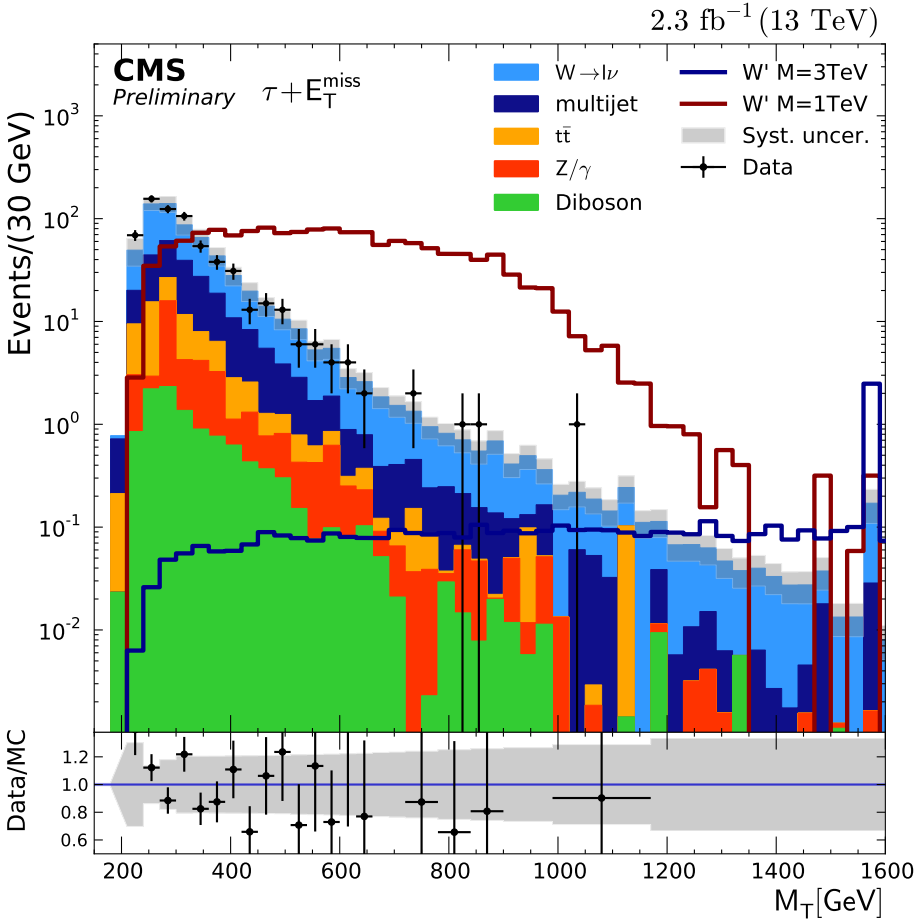

Contribution from fakes from QCD much larger than in e/μ channels

Search for SSM W' production, in the τ + MET final state (3)

Search for SSM W' production, in the τ + MET final state (3)

Interpretations

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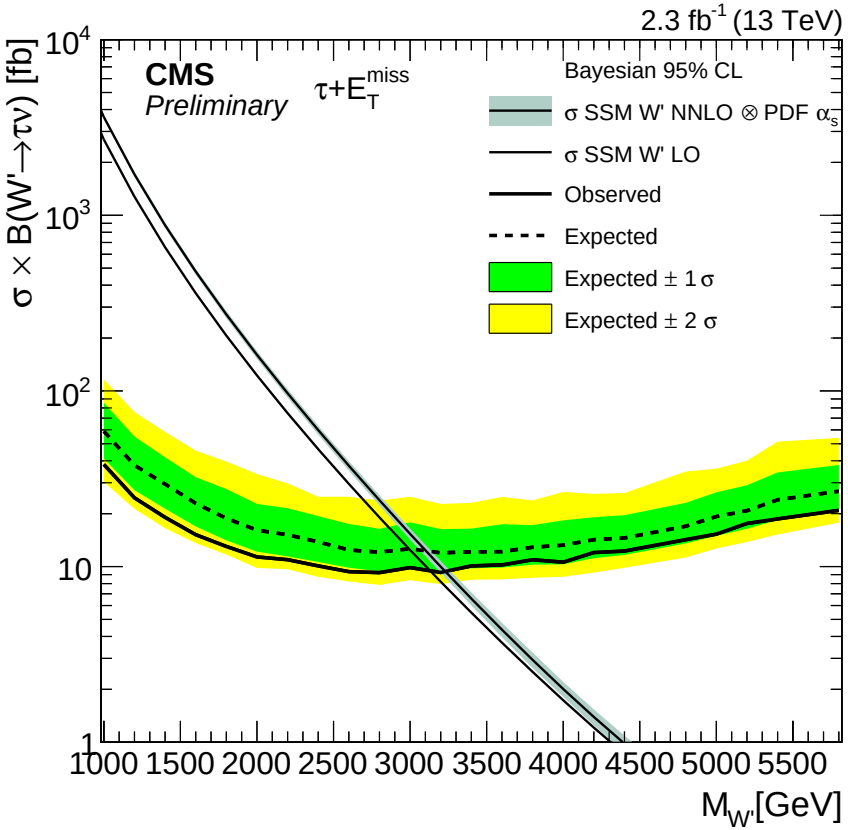
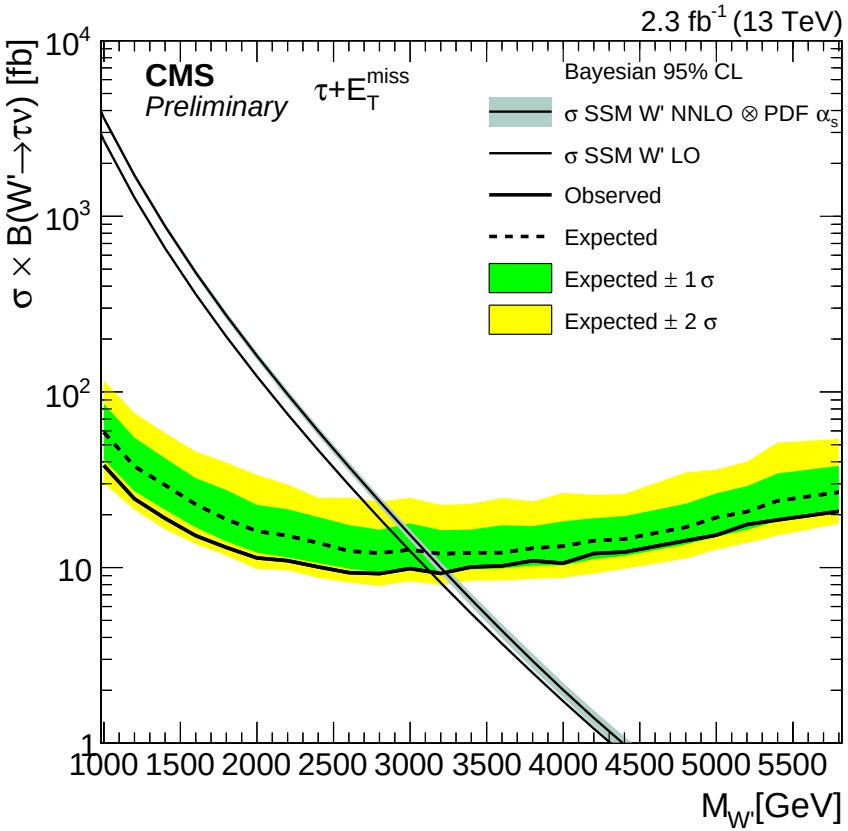


Search for SSM W' production, in the τ + MET final state (3)

Interpretations

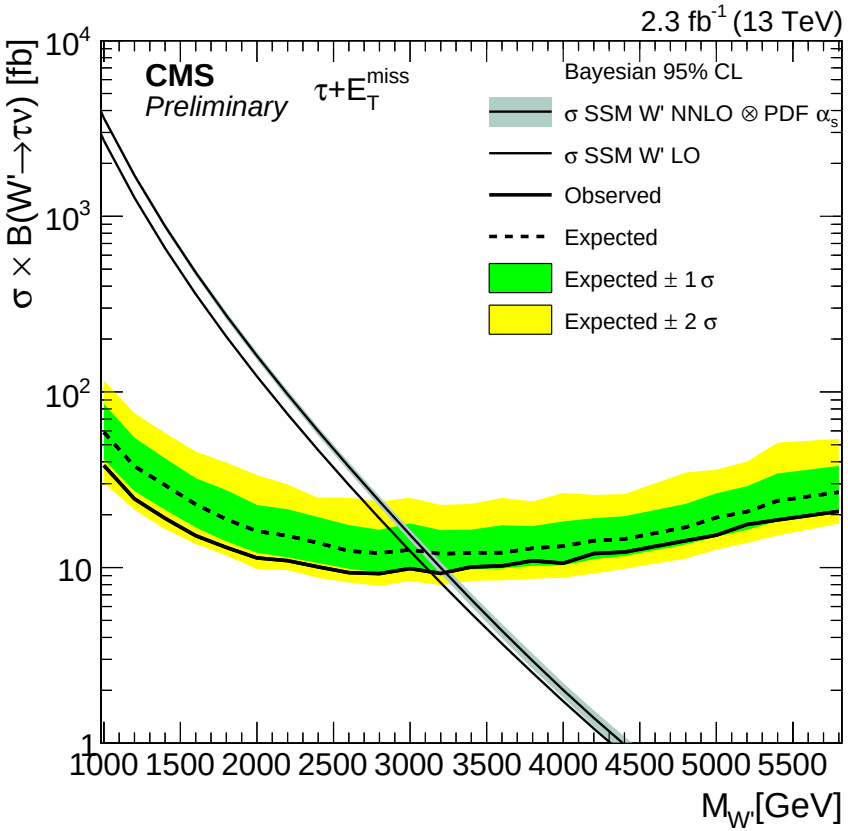
- Limits set using the full shape of the W'_{SSM} distribution due to large tail at low M_T.
- Signal acc. $\times$ eff. $\approx$ 23% for M = 3 TeV.



Search for SSM W' production, in the τ + MET final state (3)

Interpretations

- Limits set using the full shape of the W'_{SSM} distribution due to large tail at low M_T.
- Signal acc. $\times$ eff. $\approx$ 23% for M = 3 TeV.
- Main systematics : acceptance $\times$ efficiency ($\approx$ 25% at 1 TeV), tau momentum scale (3%), luminosity (4.6%), fake uncertainty (50%)



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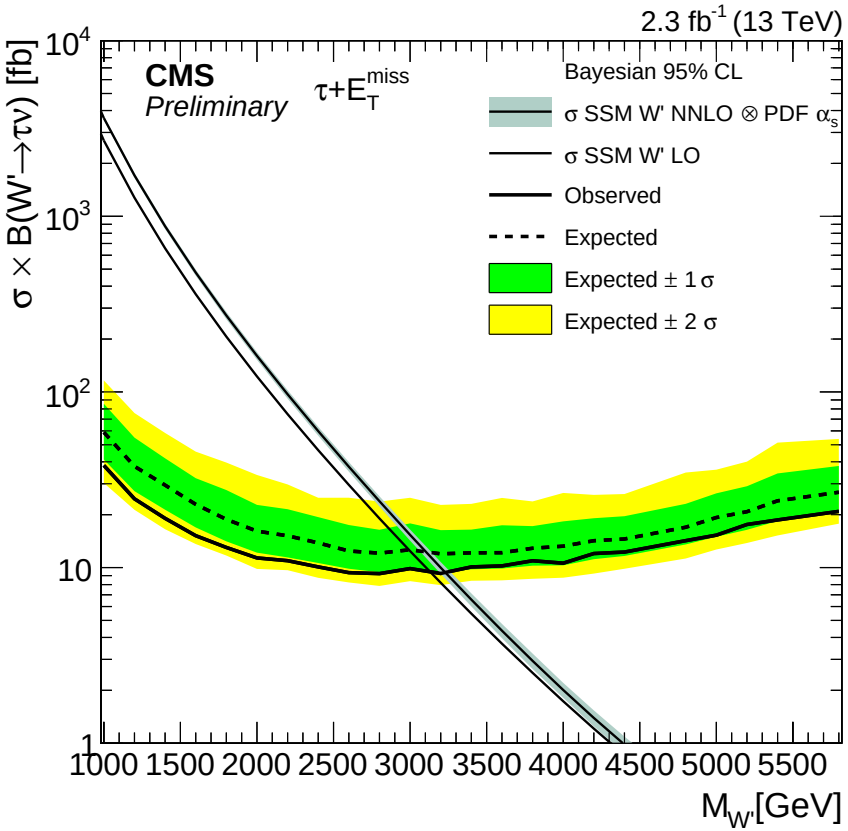

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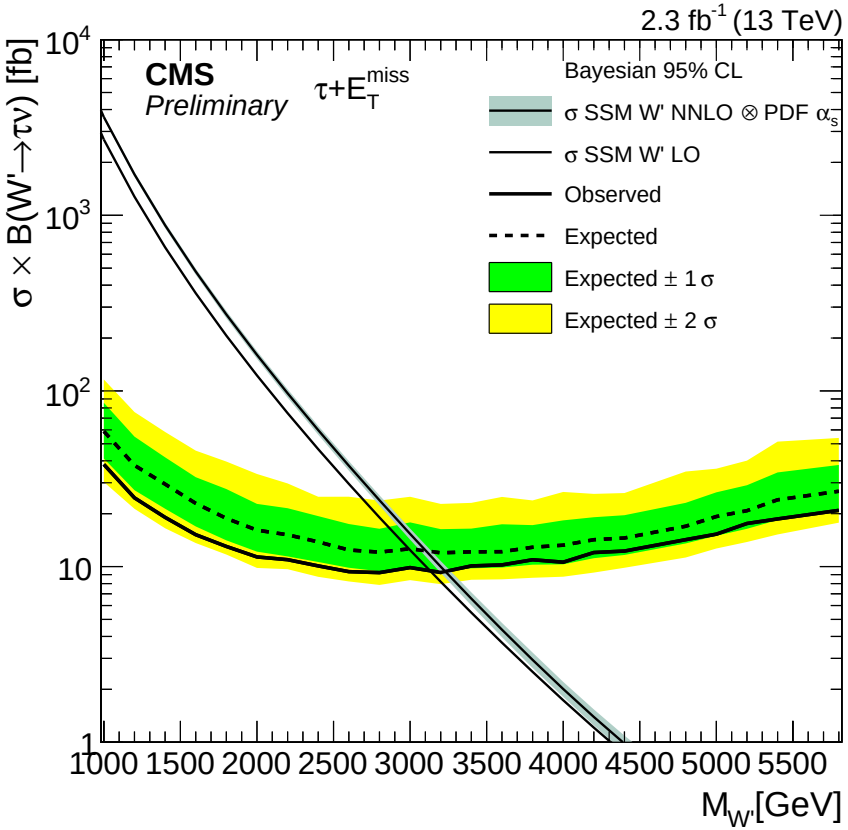
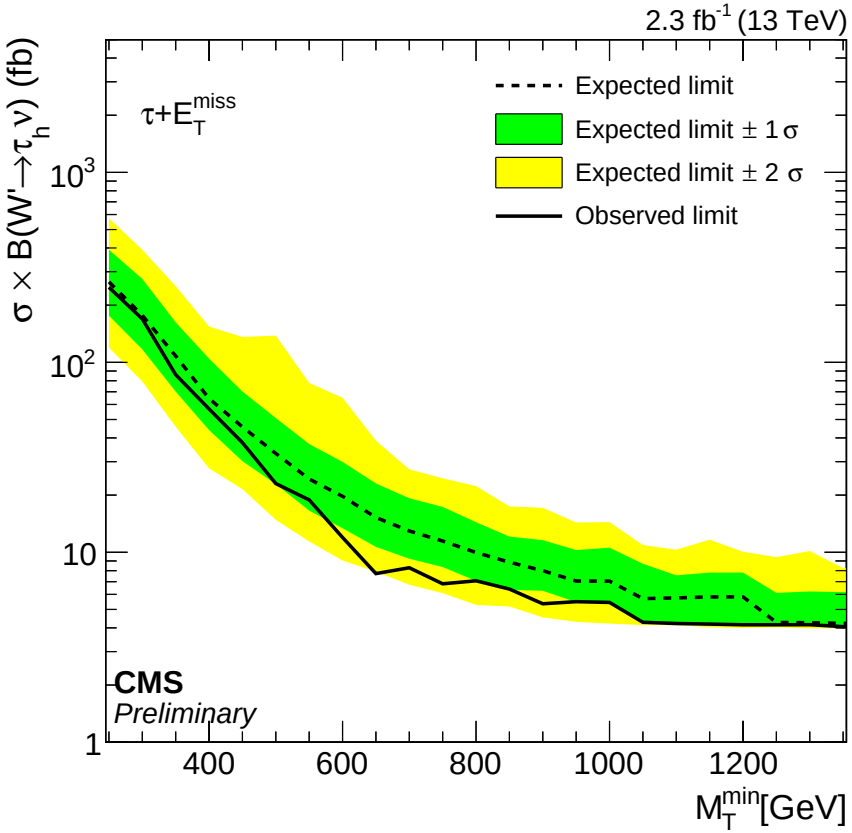
- W'_{SSM} excluded below 3.3 TeV
- Model independent limits for $M_T >$ given threshold also set





Search for Type-III Seesaw heavy fermions in the multilepton final state

Signal targeted

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- Type-III Seesaw model explains neutrino masses by introducing massive charged ($\Sigma^{\pm}$) and neutral (Σ^{0}) fermion partners.

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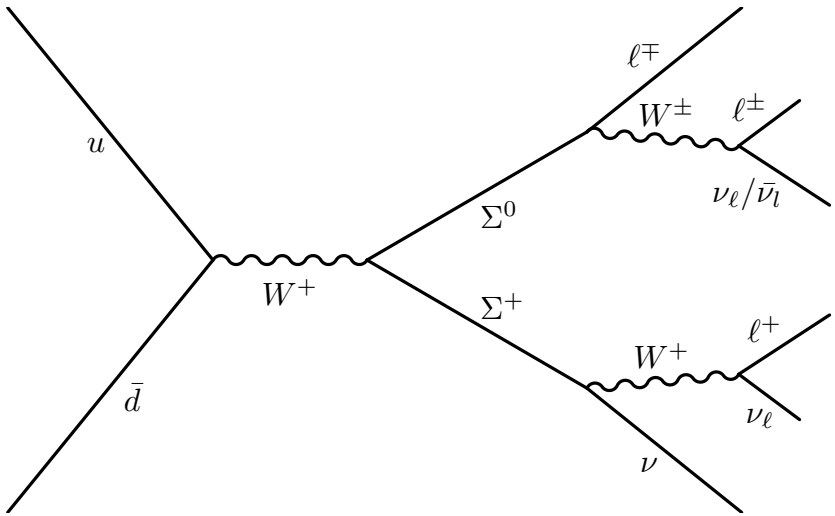
- Their decay can lead to final state with $\geq$ 3 charged leptons.



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- Type-III Seesaw model explains neutrino masses by introducing massive charged ($\Sigma^{\pm}$) and neutral (Σ^{0}) fermion partners.
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Search strategy: define various regions to separate signal from background

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Search strategy: define various regions to separate signal from background

- Classify events according to the number of leptons, of opposite sign same flavour pairs (OSSF), and the lower mass(es) (M_{low}^{OSSF}).

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- Bin events in $L_T + E_T^{miss} = \Sigma_i p_t^l(i) + E_T^{miss}$

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Event selection:

- Three isolated leptons (e/μ): $p_t >$ 20-15-10 GeV
- Veto events if any pair satisfies M_{OSSF} <12 GeV or if $81 < M_{3l,SF} < 101$ GeV and an associated OSSF pair with $M_{OSSF} < 101$ GeV is found

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- $L_T + E_T^{miss} > 350$ GeV.

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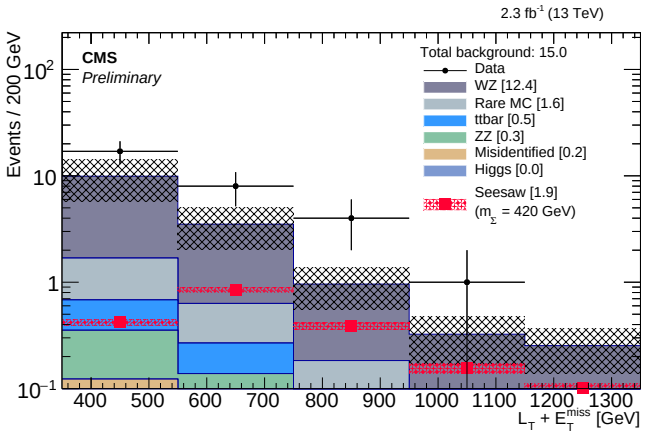
- $L_T + E_T^{miss} > 350$ GeV.
- Signal regions:

Signal regions	# leptons	# OSSF pairs	M_{OSSF} (GeV)
A	=3	≥ 1	≥ 1 pair $\in (81, 101)$
B	=3	≥ 1	lowest M_{OSSF} >101
C	=3	=0	/
D	=4	≥ 1	/

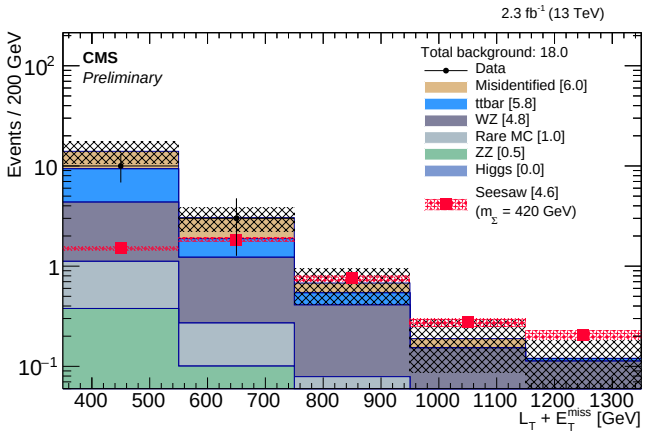
Search for Type-III Seesaw heavy fermions in the multilepton final state (2)

Search for Type-III Seesaw heavy fermions in the multilepton final state (2)

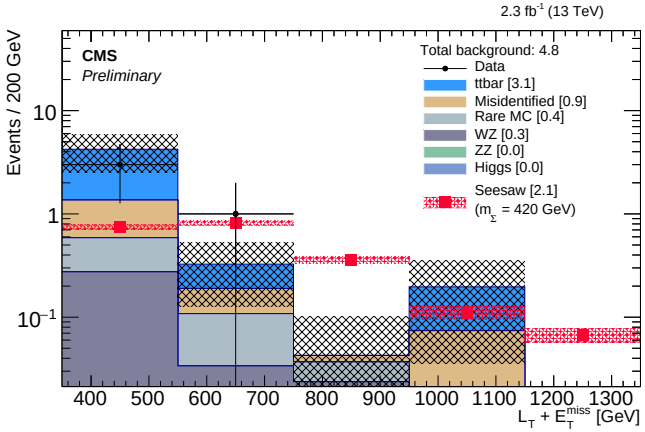
$L_T + E_T^{miss}$ spectra:



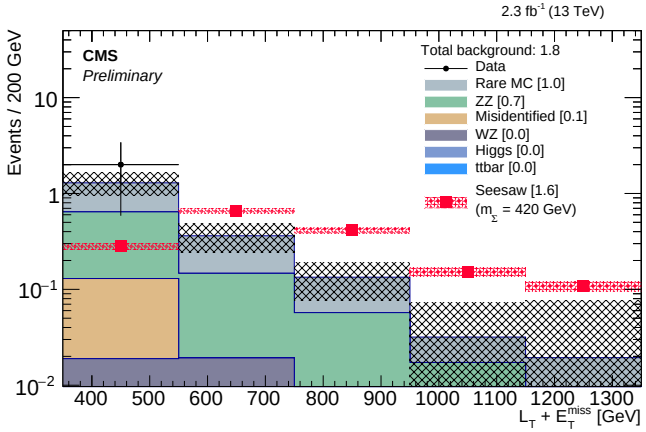
Signal region A



Signal region B



Signal region C



Signal region D

Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

Interpretations

Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

Interpretations

- Limits set using the 20 bins together.

Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

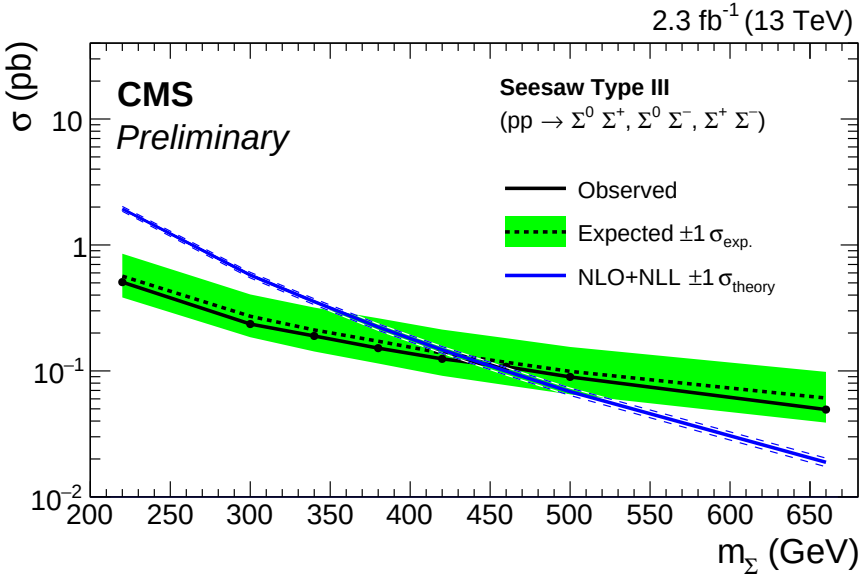
Interpretations

- Limits set using the 20 bins together.
- Main systematics : WZ normalization (50%), $t\bar{t}/Z$+jets data driven estimates (14-50%).

Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

Interpretations

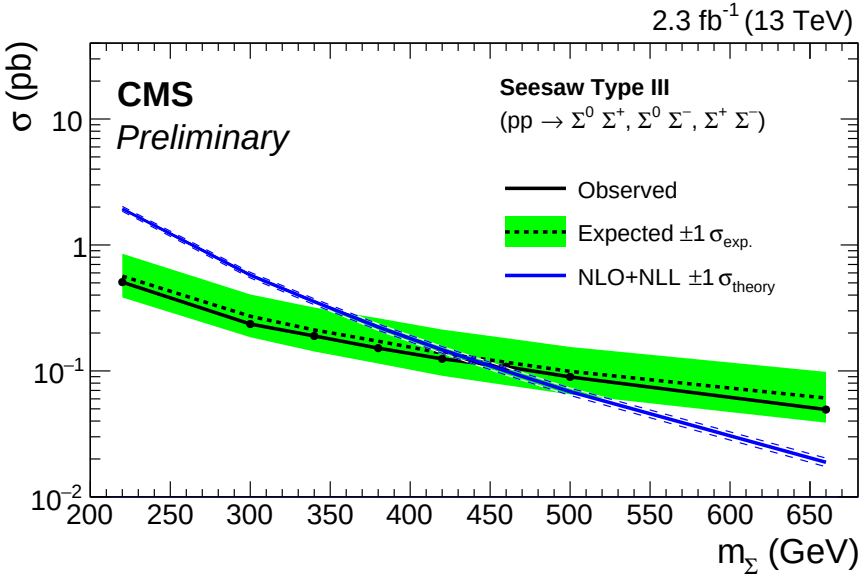
- Limits set using the 20 bins together.
- Main systematics : WZ normalization (50%), $t\bar{t}/Z$+jets data driven estimates (14-50%).
- Σ excluded below 440 GeV .



Search for Type-III Seesaw heavy fermions in the multilepton final state (3)

Interpretations

- Limits set using the 20 bins together.
- Main systematics : WZ normalization (50%), $t\bar{t}/Z$+jets data driven estimates (14-50%).
- Σ excluded below 440 GeV .
- Better limits than in Run 1 due to signal cross sections ($\approx$3 $\times$ higher than at 8 TeV) and new search strategy.



Search for leptophobic Z' decaying into four leptons in the final state

Search for leptophobic Z' decaying into four leptons in the final state

Signal targeted

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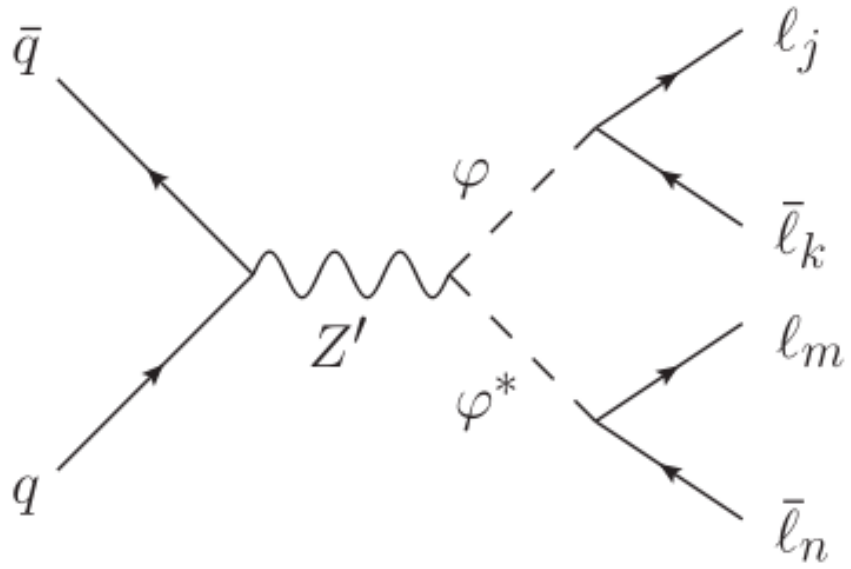
Signal targeted

- Generic search for resonances decaying into 4 leptons: $X \to \phi\phi^* \to l_1\bar{l}_2 l_3\bar{l}_4$, as generic as possible.



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Search strategy

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Search strategy

- Bump hunting in the 4 lepton invariant mass spectrum.

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Search strategy

- Bump hunting in the 4 lepton invariant mass spectrum.
- Both Lepton Flavour conservation (LFC) and violation (LFV) considered (i.e. $eee\mu$ and $e\mu\mu\mu$ final states included).

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Event selection:

- Four isolated leptons (e/μ): $p_t >$ 45-45-30-30 GeV

Search for leptophobic Z' decaying into four leptons in the final state

Signal targeted

- Generic search for resonances decaying into 4 leptons: $X \to \phi\phi^* \to l_1\bar{l}_2 l_3\bar{l}_4$, as generic as possible.

Search strategy

- Bump hunting in the 4 lepton invariant mass spectrum.
- Both Lepton Flavour conservation (LFC) and violation (LFV) considered (i.e. $eee\mu$ and $e\mu\mu\mu$ final states included).
- No mass constraint except $M_\phi \neq M_Z$ in LFC case.
- Channel extremely clean. (first background: ZZ or $t\bar{t}$)

Event selection:

- Four isolated leptons (e/μ): $p_t >$ 45-45-30-30 GeV
- Possible overlap of leptons due to boosted configuration
  $\to$ dedicate lepton reconstruction, removal of footprint of neighbour leptons in isolation computation.

Search for leptophobic Z' decaying into four leptons in the final state

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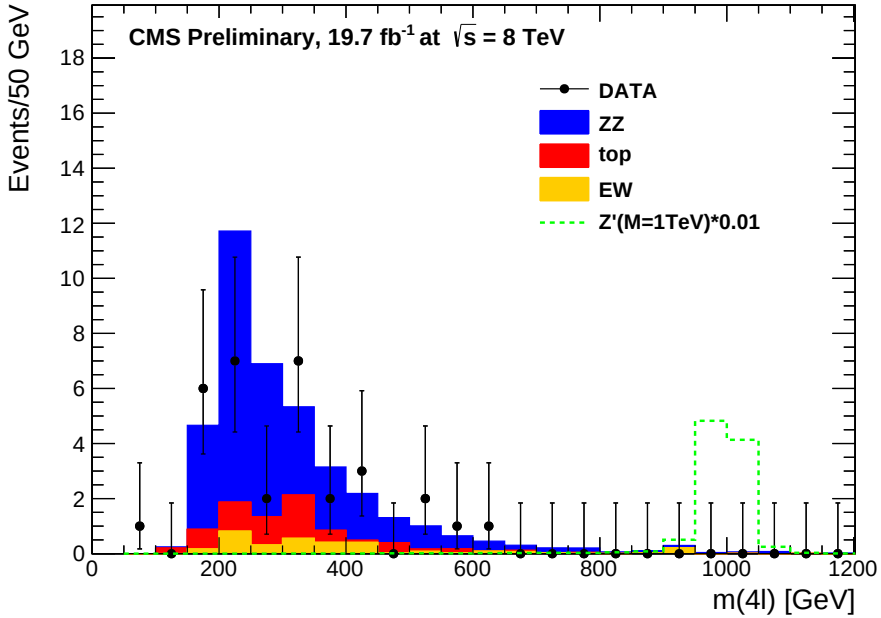
Search for leptophobic Z' decaying into four leptons in the final state (2)

Search for leptophobic Z' decaying into four leptons in the final state (2)

M_{4l} spectra and yields:



Channel	100 GeV $< M <$ 1 TeV					$M >$ 1 TeV	
	N_{obs}	SM backgrounds				N_{obs}	N_{tot}
		N_{ZZ}	N_{top}	N_{EW}	N_{tot}		
$Z' \to \mu\mu\mu\mu$	3	4.9 ± 0.3	0.9 ± 0.5	—	5.9 ± 0.6	0	—
$Z' \to \mu\mu\mu e$	6	0.4 ± 0.1	1.3 ± 0.6	1.2 ± 0.3	2.9 ± 0.7	0	—
$Z' \to \mu\mu ee$	12	9.3 ± 0.4	3.0 ± 1.5	1.2 ± 0.3	13.5 ± 1.6	0	0.1 ± 0.1
$Z' \to \mu eee$	2	0.2 ± 0.1	0.4 ± 0.1	0.6 ± 0.2	1.2 ± 0.2	0	0.1 ± 0.1
$Z' \to eeee$	9	15.0 ± 0.5	0.2 ± 0.1	0.2 ± 0.1	15.4 ± 0.5	0	0.2 ± 0.1
combination	32	29.9 ± 0.7	5.7 ± 1.9	3.3 ± 0.5	38.9 ± 2.1	0	0.4 ± 0.2

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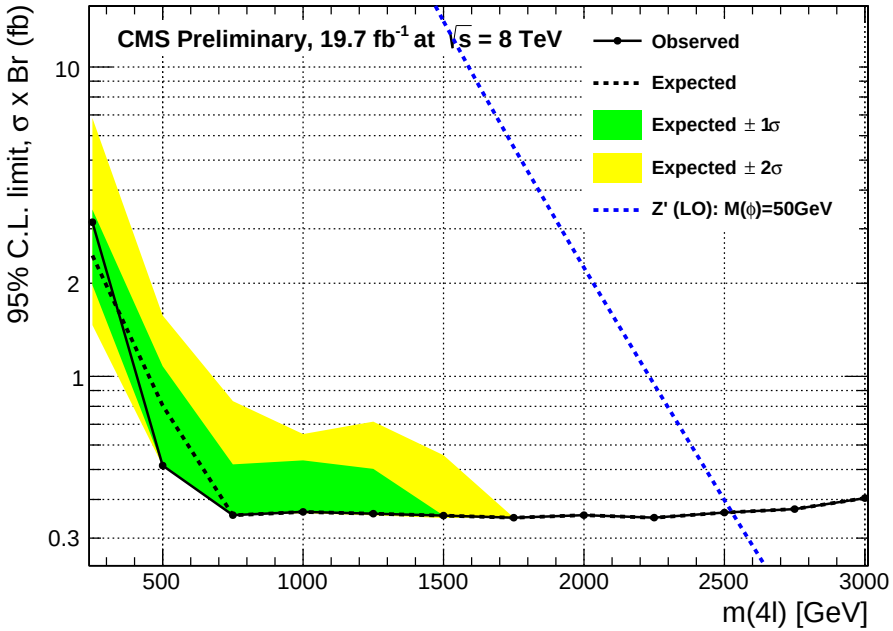

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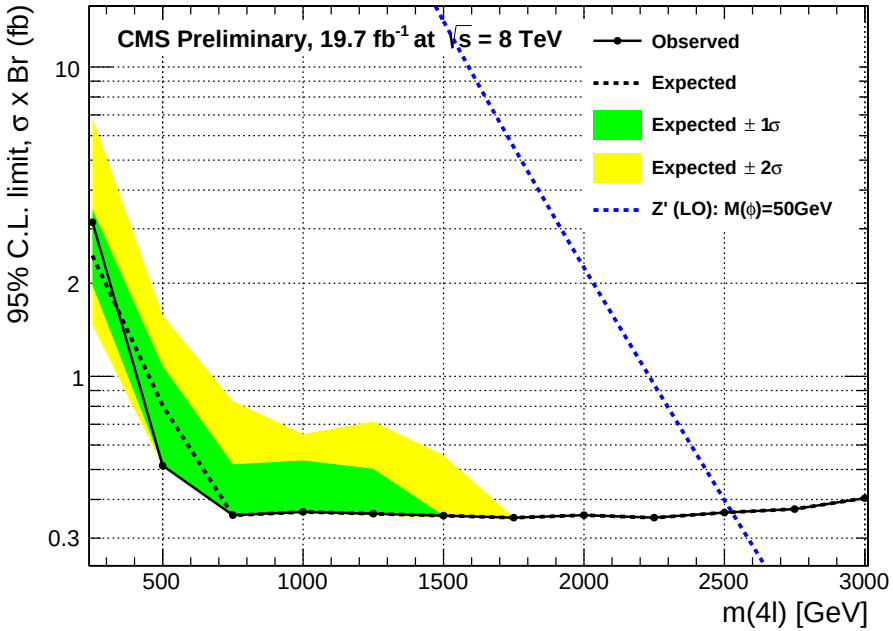
- Model independent limits for the whole mass range also computed



Channel	$\mathcal{L}$ (fb^{-1})	ϵ_i	$\sigma_i^{4l\ fid} \cdot Br_i$ (fb)
$eeee$	19.7 ± 0.5	0.45 ± 0.10	0.38
μeee		0.47 ± 0.10	0.37
$\mu\mu ee$		0.51 ± 0.10	0.34
$\mu\mu\mu e$		0.52 ± 0.10	0.34
$\mu\mu\mu\mu$		0.55 ± 0.10	0.32

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Stay tuned !

Analyses not covered

Many more recent results if jets/photons added to the final state.
To mention only 13 TeV results:

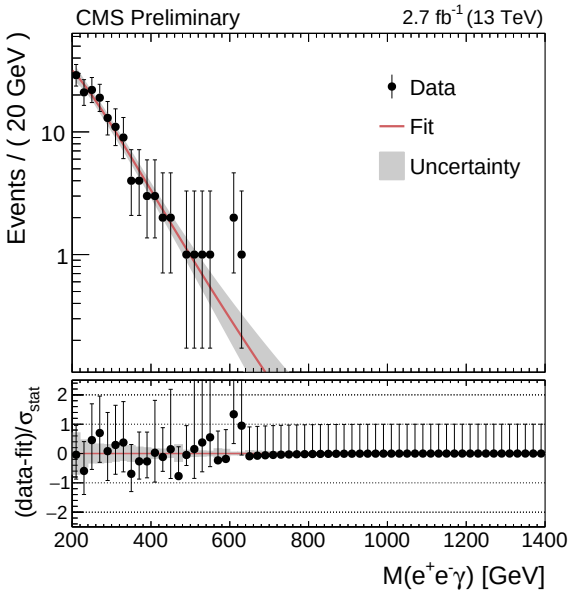
- Search for high-mass resonances in $Z\gamma \to e^+e^-\gamma/\mu^+\mu^-\gamma$ final states in proton-proton collisions at $\sqrt{s}$= 13 TeV CMS-PAS-EXO-16-019
- Search for pair-production of second-generation scalar leptoquarks in pp collisions at $\sqrt{s}$= 13 TeV with the CMS detector CMS-PAS-EXO-16-007
- Search for massive resonances decaying into pairs of boosted W and Z bosons at $\sqrt{s}$= 13 TeV CMS-PAS-EXO-15-002
- Search for new physics in final states with two opposite-sign same-flavor leptons, jets and E_T^{miss} in pp collisions at $\sqrt{s}$= 13 TeV CMS-PAS-SUS-15-011
- Search for supersymmetry in events with one lepton in proton-proton collisions at $\sqrt{s}$= 13 TeV with the CMS experiment CMS-PAS-SUS-15-006
- Search for SUSY with multileptons in 13 TeV data CMS-PAS-SUS-16-003
- Search for direct top squark pair production in the single lepton final state at $\sqrt{s}$= 13 TeV CMS-PAS-SUS-16-002
- Search for SUSY in same-sign dilepton events at $\sqrt{s}$= 13 TeV CMS-PAS-SUS-15-008
- Search for supersymmetry in pp collisions at $\sqrt{s}$= 13 TeV in the single-lepton final state using the sum of masses of large radius jets CMS-PAS-SUS-15-007
- Search for single production of a vector-like T quark decaying to a Higgs boson and a leptonically decaying top quark CMS-PAS-B2G-15-008
- Search for WW in semileptonic final states: low mass extension CMS-PAS-B2G-16-004
- Search for heavy resonances decaying into a vector boson and a Higgs boson in the (ll, $l\nu$, $\nu\nu$) bb final state CMS-PAS-B2G-16-003
- Search for pair production of vector-like T quarks in the lepton plus jets final state CMS-PAS-B2G-16-002
- Search for $t\bar{t}$ resonances in boosted semileptonic final states in pp collisions at $\sqrt{s}$= 13 TeV CMS-PAS-B2G-15-002
- Search for W' boson resonances decaying into a top quark and a bottom quark in the leptonic final state at $\sqrt{s}$= 13 TeV CMS-PAS-B2G-15-004
- Search for top quark partners with charge 5/3 at $\sqrt{s}$= 13 TeV CMS-PAS-B2G-15-006

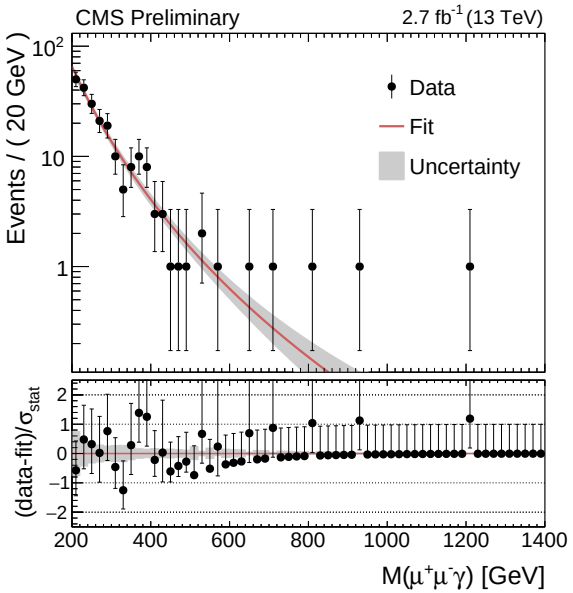
Some of them in back up if you are interested.

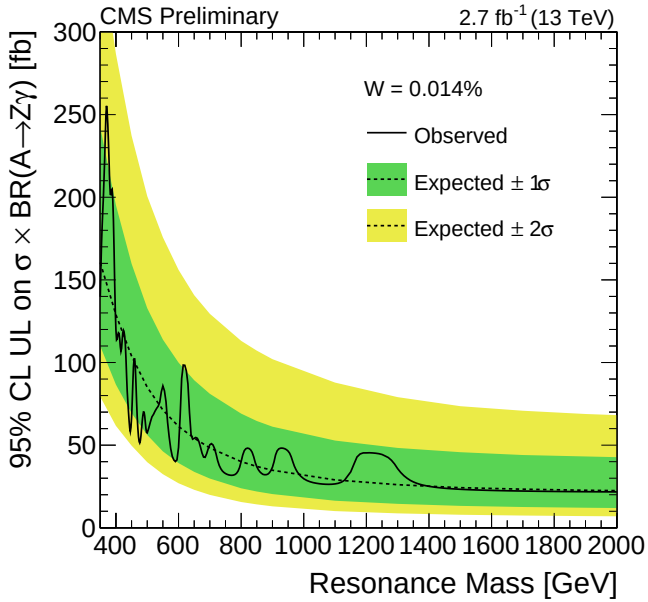
http://cms-results.web.cern.ch/cms-results/public-results/publications/

Search for high-mass resonances in $Z\gamma \to e^+e^-\gamma/\mu^+\mu^-\gamma$ final states in proton-proton collisions at $\sqrt{s}$= 13 TeV

- 2 OSSF leptons (p_t >25/20 GeV), 1 isolated photon (p_t >40 GeV $\Delta R > 0.4$ from leptons)
- $p_{t,\gamma} > 0.266 \times M_{Z/\gamma}$
- Main background: Standard Model $Z\gamma$.
- Limits set on narrow / finite widths.







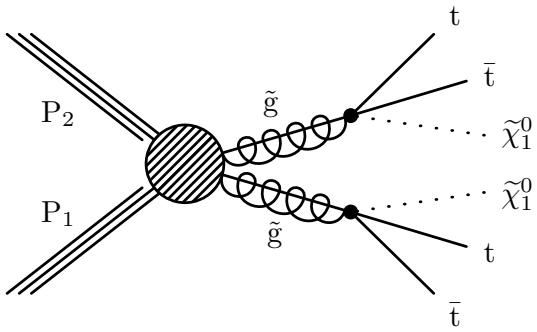
Search for SUSY with multileptons in 13 TeV data

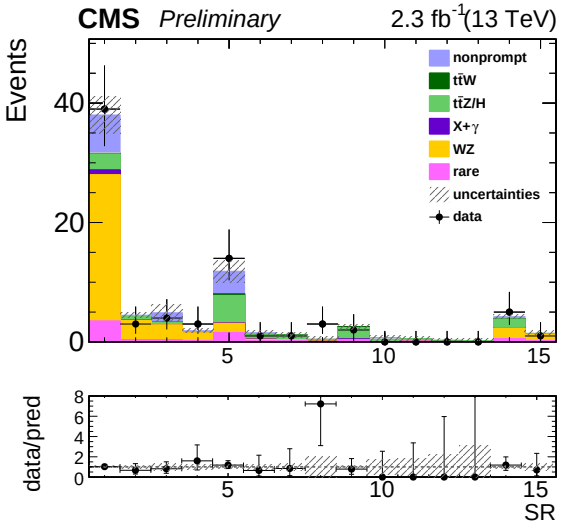
Event selection:

- 3 light leptons (p_t >20/15/10 GeV)
- $\geq$ 2 jets (p_t >30 GeV)
- $E_T^{miss} > 50$ GeV
- Veto on events with l pairs from B hadron decays.

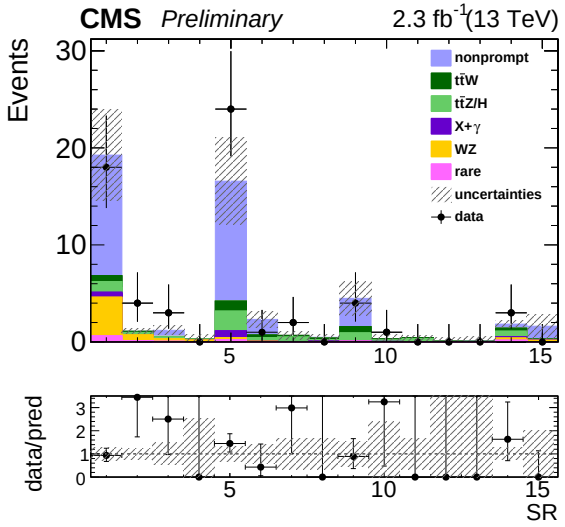
Various signal regions built from #jets, # b-jets, $H_T = \Sigma_j p_{t,j}$, E_T^{miss}, presence/absence of OSSF compatible with onshell Z.

Limits set on various gluinos/squarks decay scenarios.





On Z signal regions



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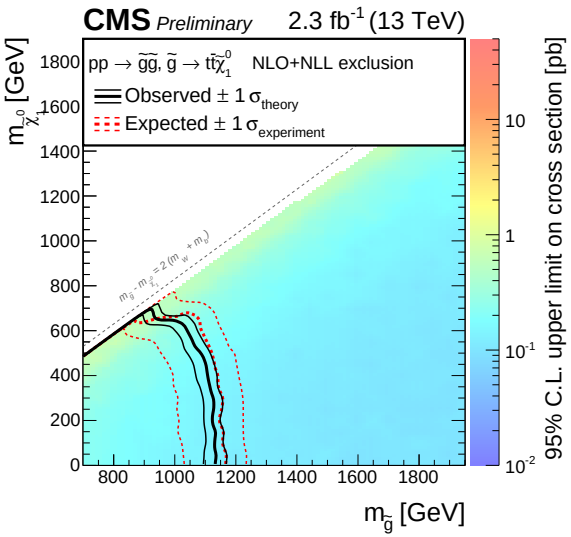
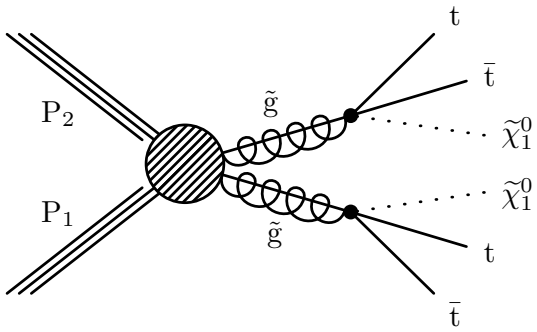


Limit on T1tttt

Search for SUSY in same-sign dilepton events at $\sqrt{s}$= 13 TeV

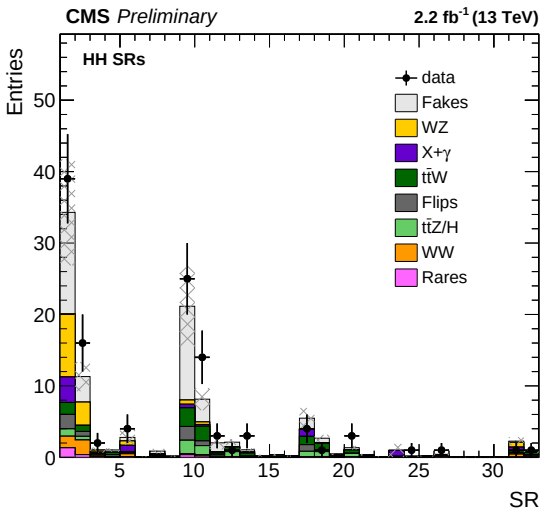
Event selection:

- 2 Same sign light leptons $p_{t,l}$ >15(e) or 10(μ) GeV.
- $\geq$ 2 jets (p_t >40 GeV)
- $E_T^{miss} > 50$ GeV
- Veto on events with l pairs from B hadron decays/Z.

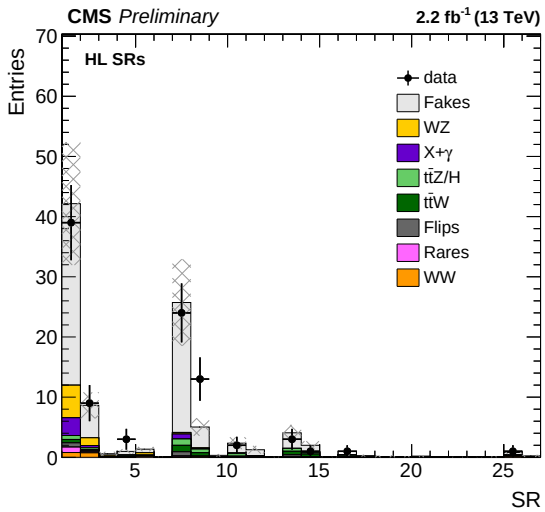


Various signal regions built from #jets, # b-jets, $H_T = \Sigma_j p_{t,j}$, E_T^{miss}, #l with$p_{t,l} > 25$ GeV

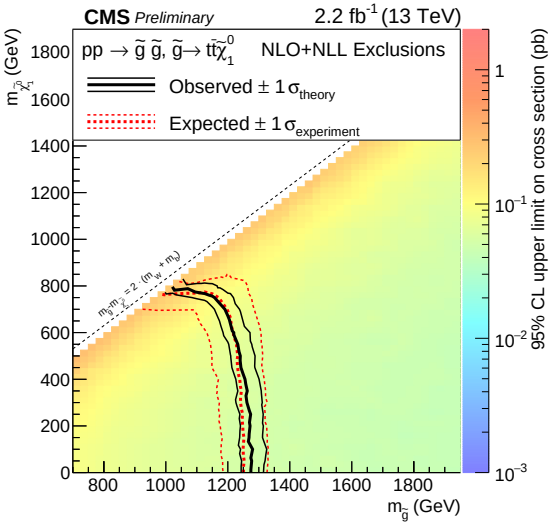
Limits set on various gluinos/squarks decay scenarios.



$p_{t,l1}$ >25 GeV
$p_{t,l2}$ >25 GeV



$p_{t,l1}$ >25 GeV
$p_{t,l2} \in$(10/15,25) GeV

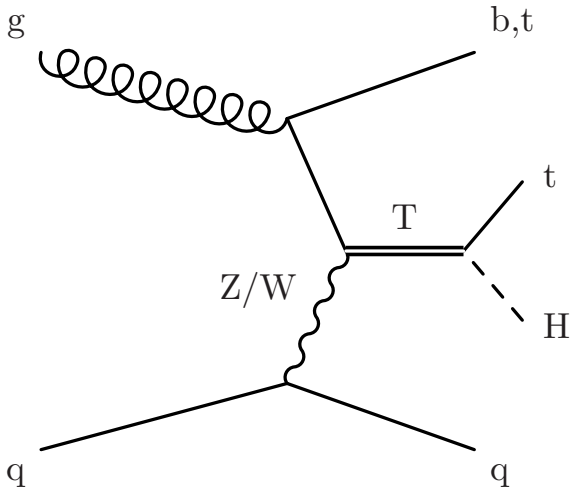


Limit on T1tttt

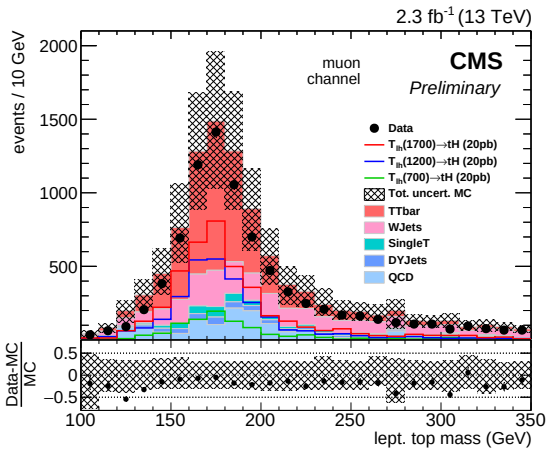
Search for single production of a vector-like T quark decaying to a Higgs boson and a leptonically decaying top quark

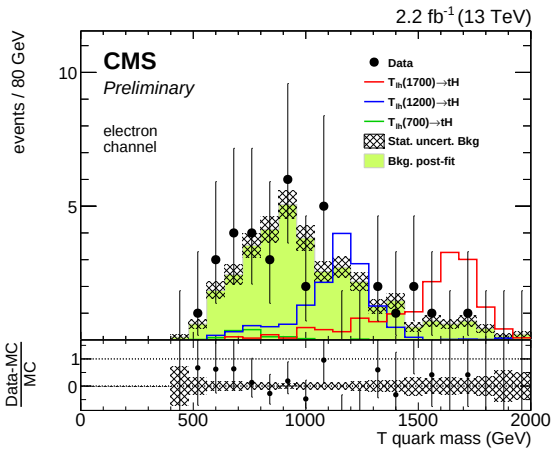
Event selection:

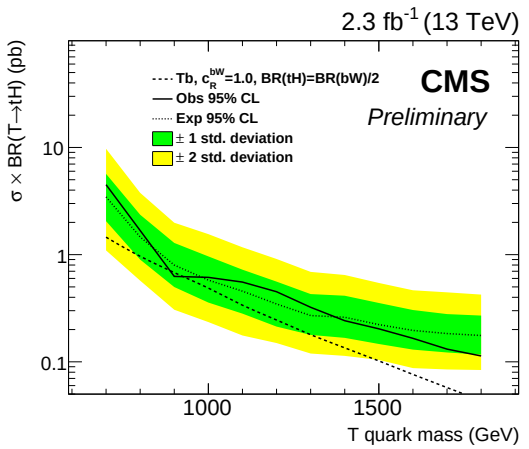
- 1 lepton with $p_t > 50$ GeV(e) or 47 GeV(μ)
- 2 central jets with p_t >250/100 GeV(e) or 70/50 GeV(μ)
- $\Sigma_i p_t^l(i) + \Sigma_i p_t^j(i) + E_T^{miss}$ >400 GeV
- 1 forward jet with $p_t > 30$ GeV.
- 1 H-tagged jet made of 2 b-tagged subjets with 90 $< M_{jj} <$ 160



Analysis using a discriminator based on the observed Higgs and top masses and on $\Delta R(t, H)$.
Limits set on left/right-handed T from tH mass distribution.



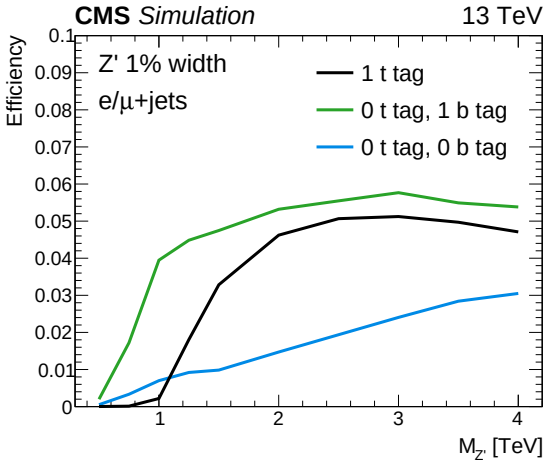




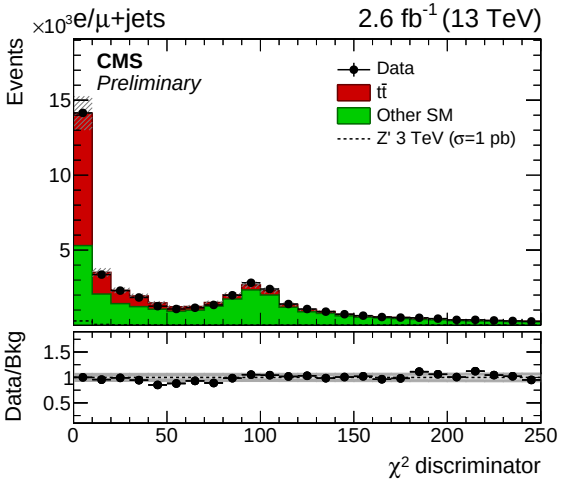
Search for $t\bar{t}$ resonances in boosted semileptonic final states in pp collisions at $\sqrt{s}$= 13 TeV

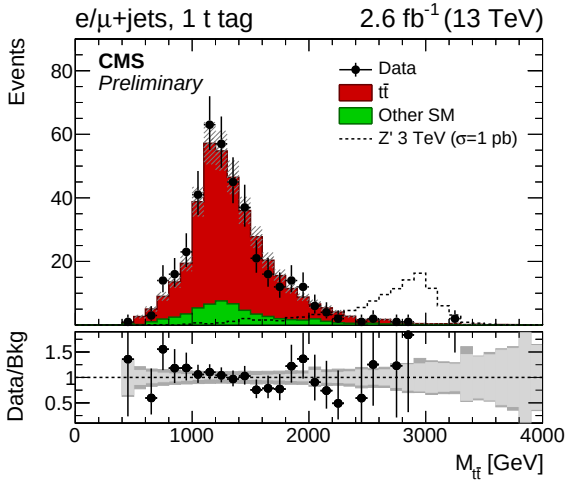
Event selection:

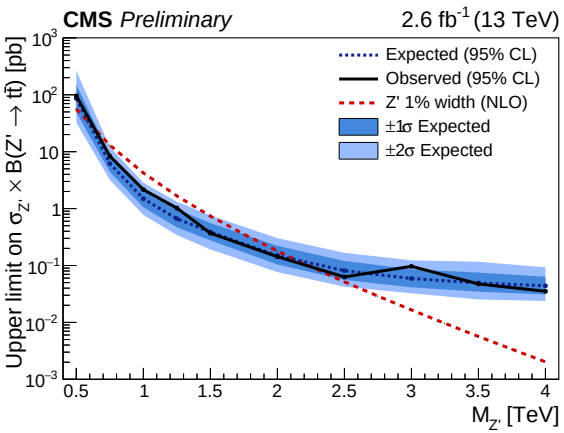
- 1 lepton with $p_t > 50$ GeV
- 2 central jets with p_t >250/70 GeV(e) or 150/50 GeV(μ)
- E_T^{miss} >120 GeV e) or
  E_T^{miss} >50 GeV and $E_T^{miss} + p_{t,l}$ >150 GeV(μ)
- Events separated according to # t-tagged and b-tagged jets



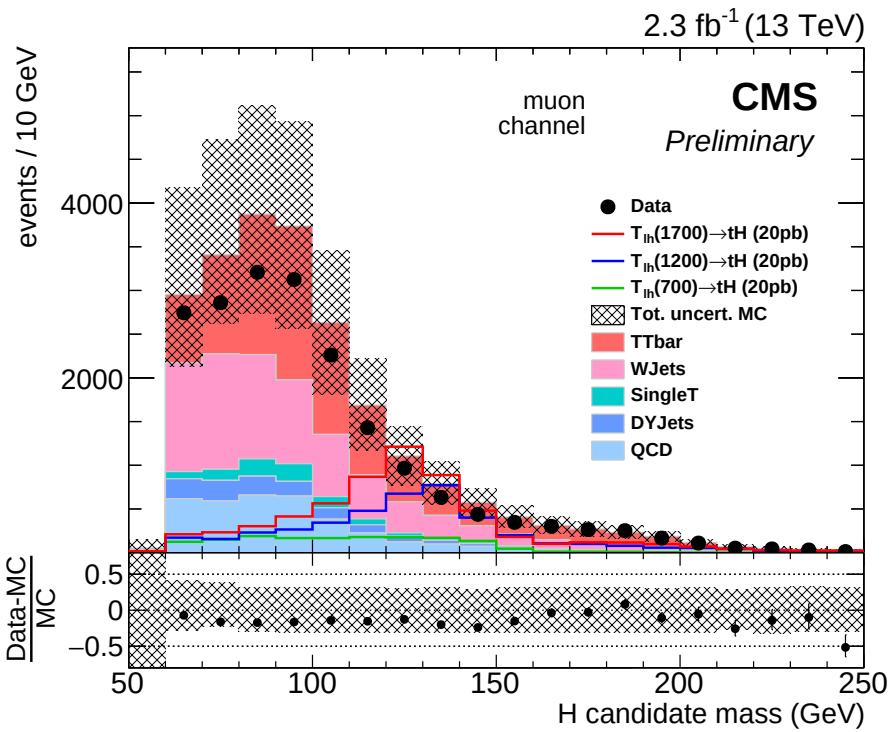
Analysis using a discriminator based on the observed hadronic and leptonic reconstructed top masses.
Limits set on e.g. Z'_{SSM} from $t\bar{t}$ mass distribution.



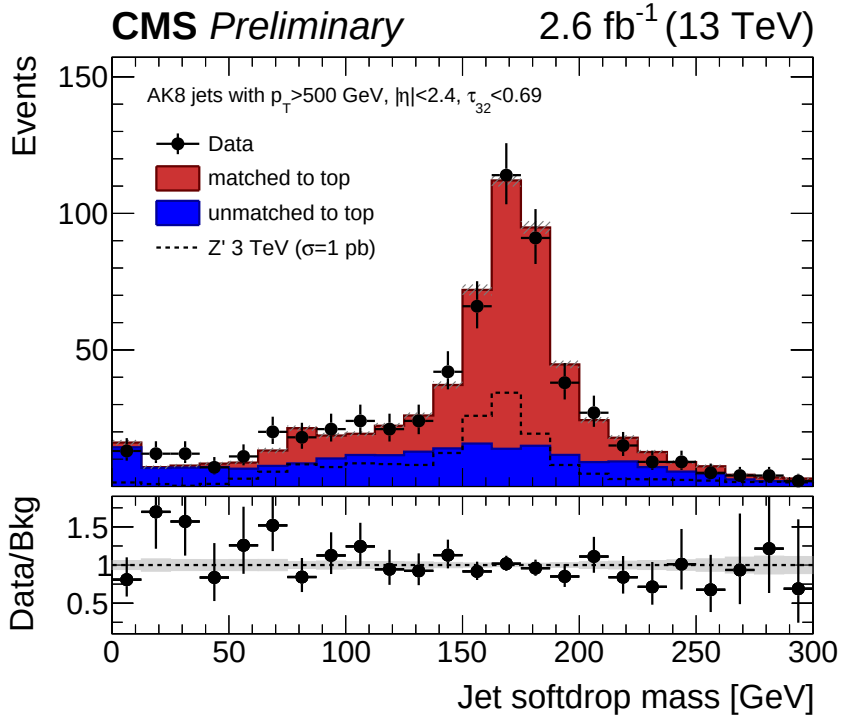




Hadronic top/Higgs mass in searches with Higgs/top in final states

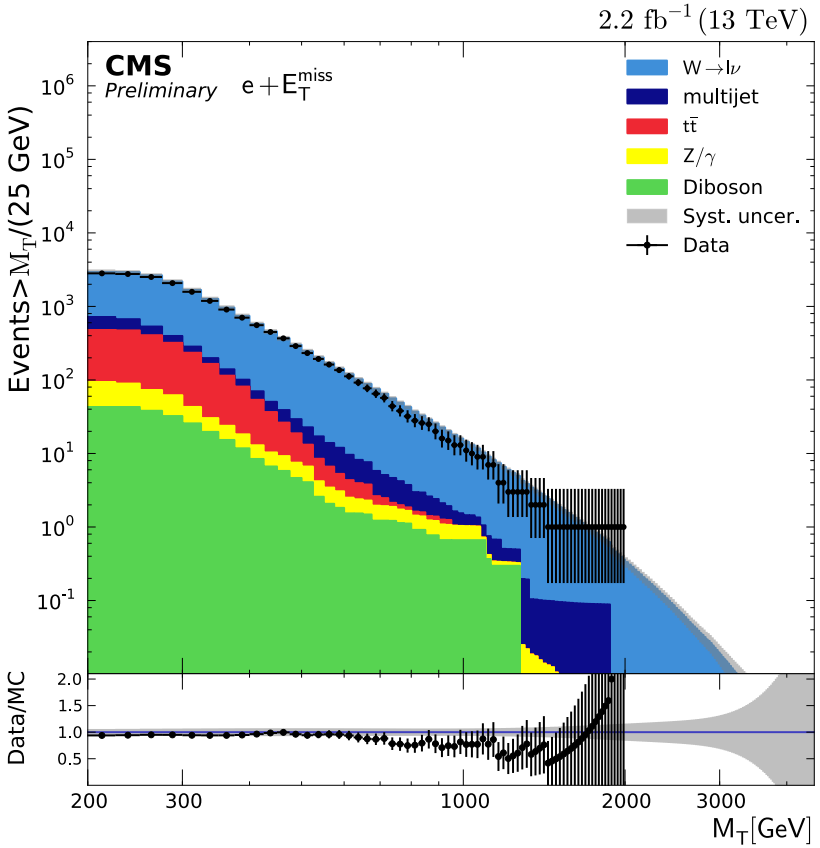


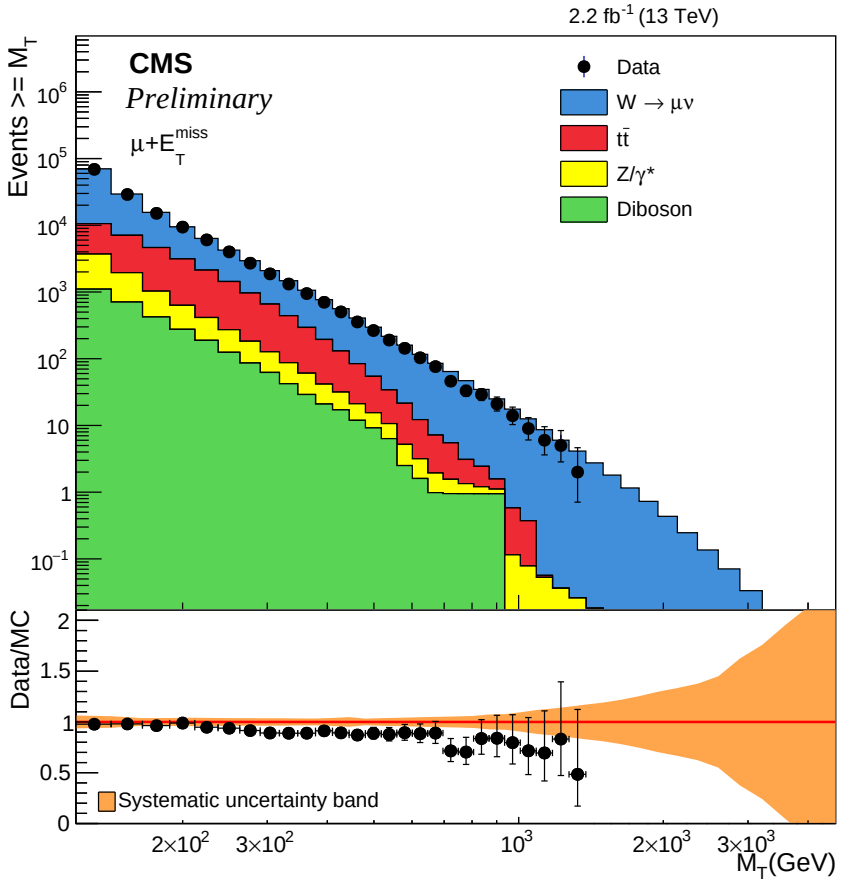
B2G-15-008



B2G-15-002

Cumulative M_T spectra:

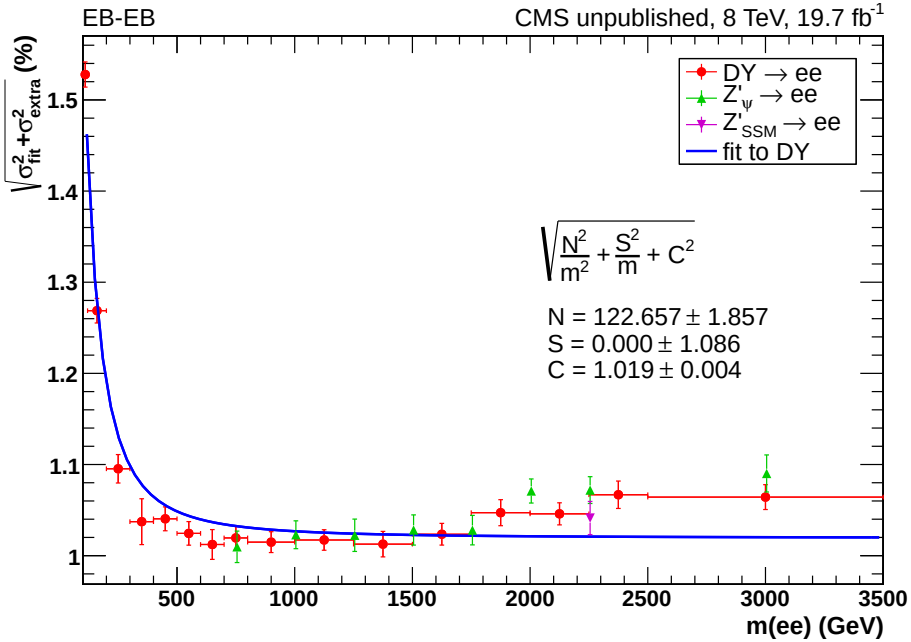


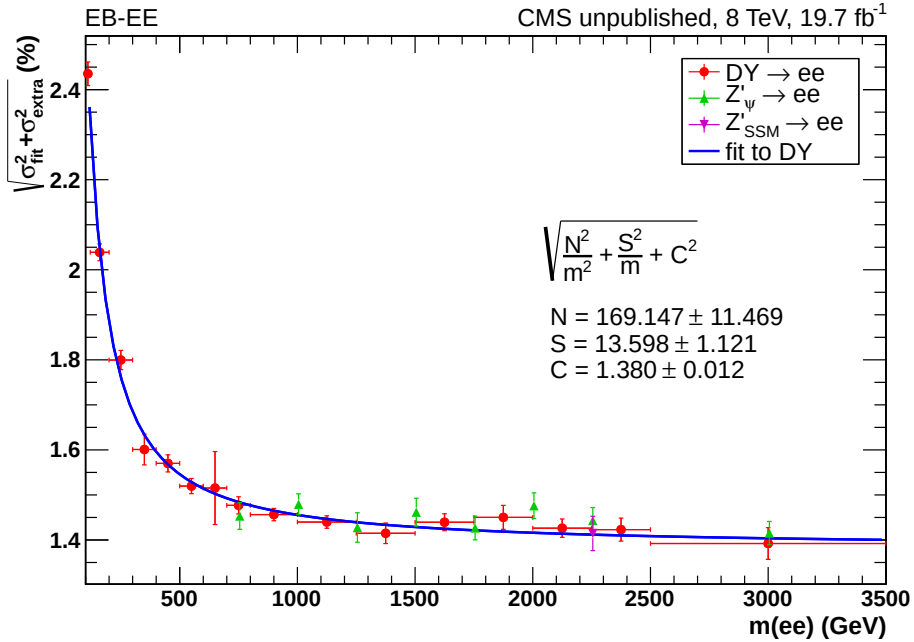


Systematics uncertainties

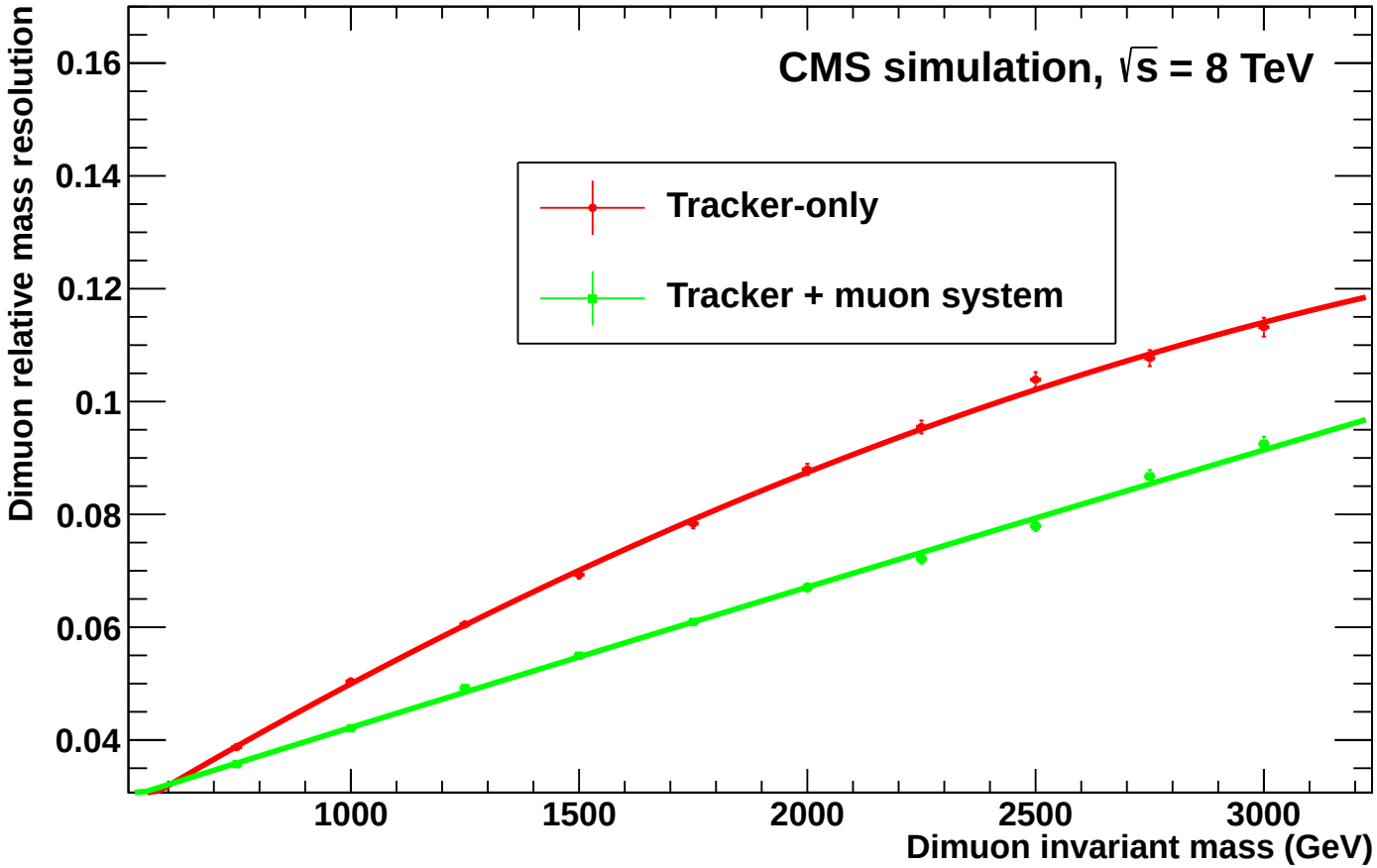
Source of uncertainty	Magnitude	Impact on background/signal estimate in channel with no OSSF pair	OSSF pair above-Z	OSSF pair on-Z
WZ normalization	50 %	13 %	2.8 %	41 %
ZZ normalization	16 %	0.1 %	0.5 %	0.4 %
Integrated luminosity	2.7 %	0.6 %	0.2 %	0.3 %
Lepton ID and isolation	3 %	3 %	3 %	3 %
$E_{\mathrm{T}}^{\mathrm{miss}}$ resolution/smearing	50 %	4.1 %	6.3 %	0.6 %
Pile-up reweighting	5 %	1.5 %	0.3 %	1.3 %
$\mathrm{t\bar{t}}$ misidentification rate	50 %	21 %	11 %	1.8 %
Z + jets background	14 %	9.2 %	1.1 %	1.0 %
Rare MC cross section	50 %	11 %	2.7 %	5.2 %
Signal cross section	10 %	10 %	10 %	10 %
Background (for comparison)		0.3 events	3.0 events	3.5 events
Signal ($m_{\Sigma} = 420$ GeV, for comparison)		0.8 events	1.8 events	0.8 events

Run 1 dielectron resolution

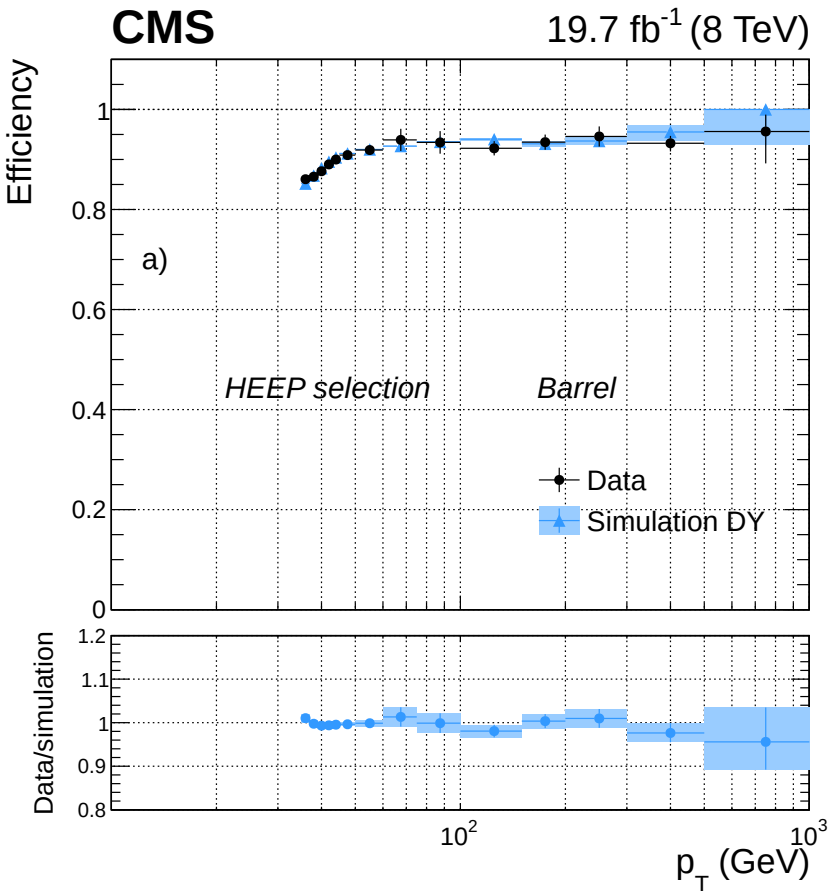


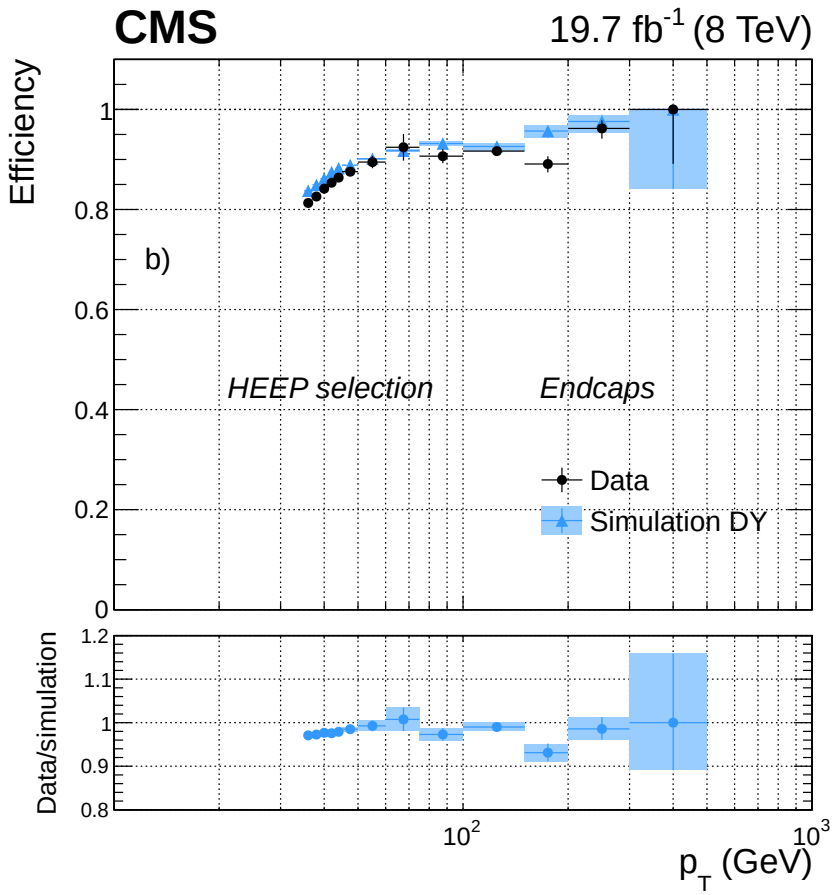


Run 1 dimuon resolution

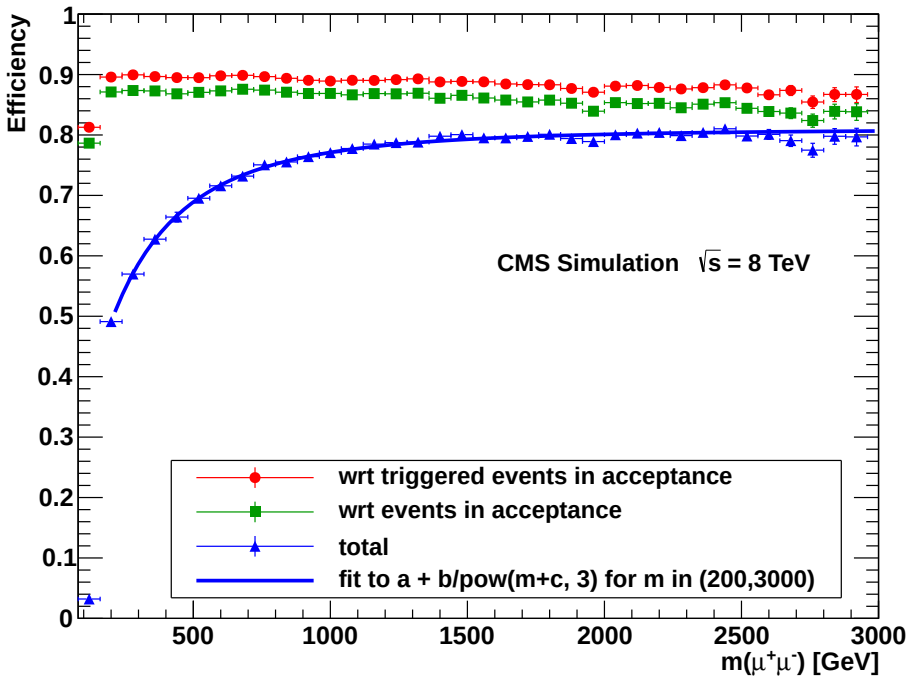


Run 1 electron efficiency



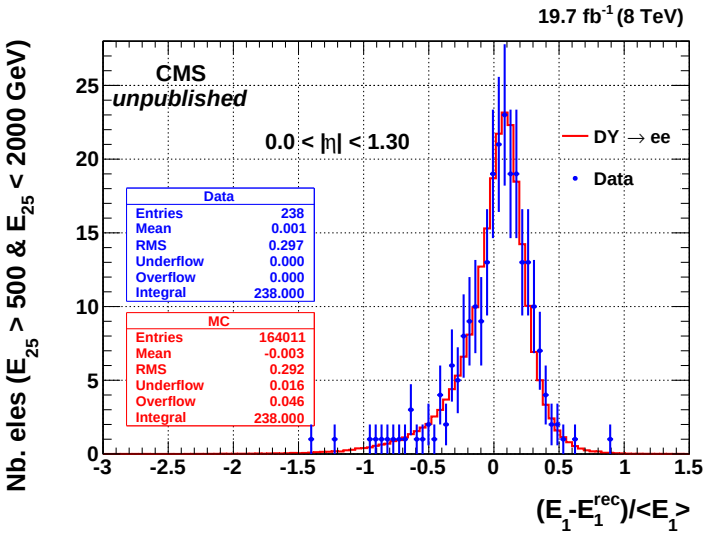


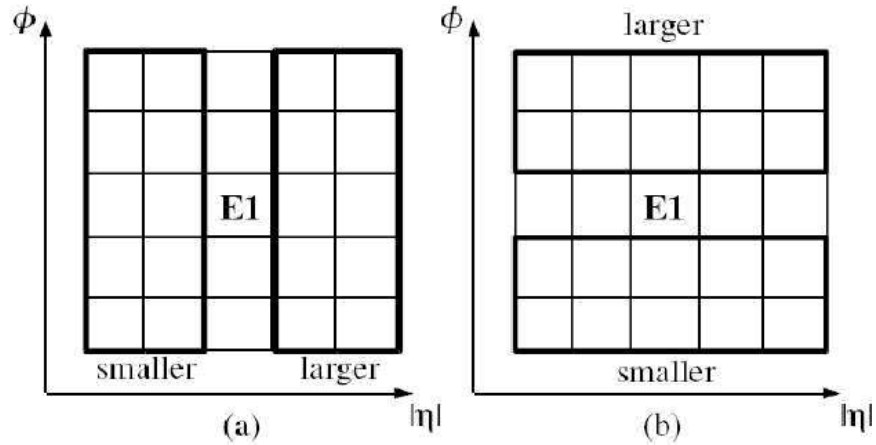
Run 1 muon efficiency



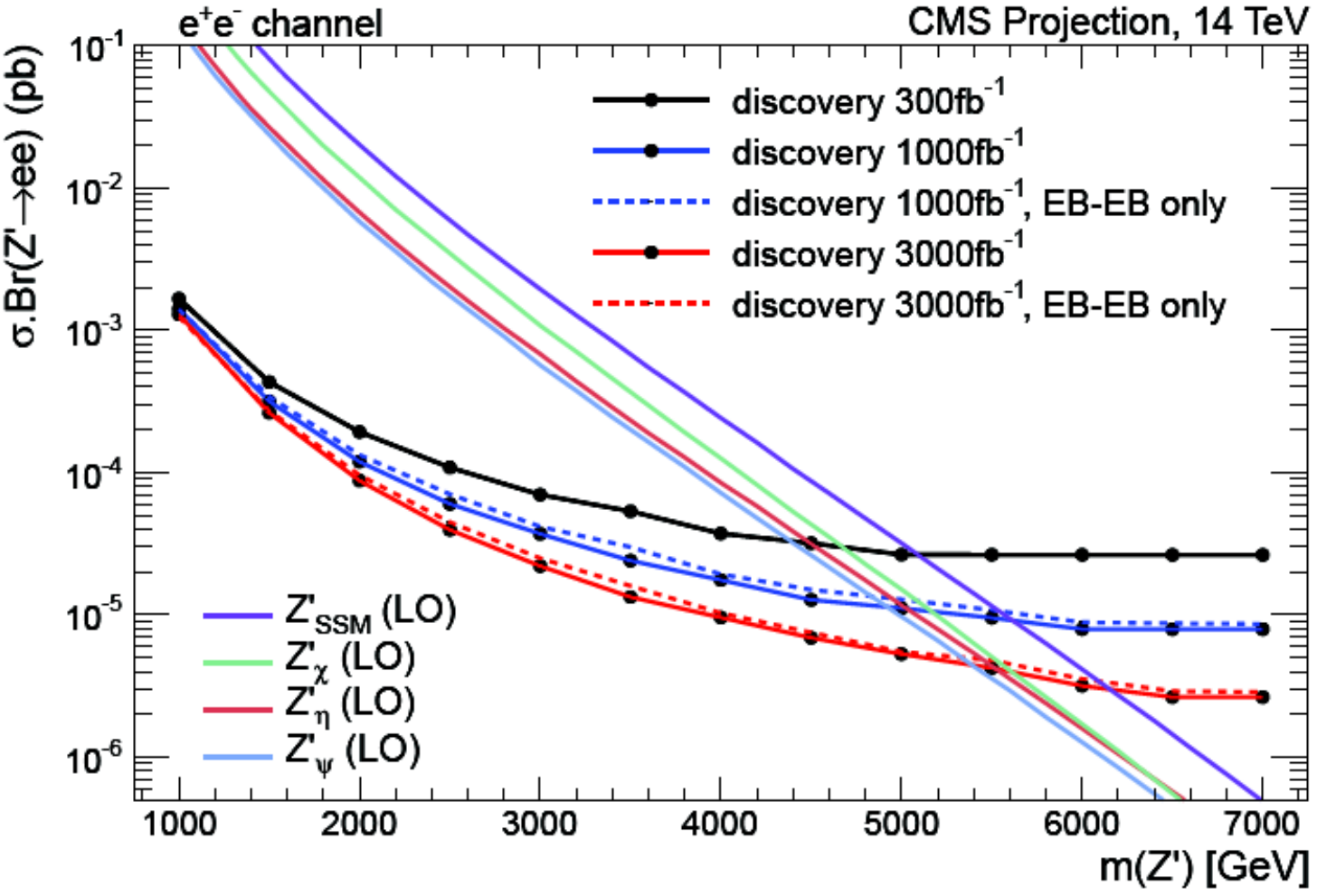
Run 1 high energy electron checks

- Check calorimeter response by estimating the highest energetic cell energy (E_1) from the surrounding ones.





Prospects


e+e- channel
CMS Projection, 14 TeV
σ.Br(Z'→ee) (pb)
discovery 300fb-1
discovery 1000fb-1
discovery 1000fb-1, EB-EB only
discovery 3000fb-1
discovery 3000fb-1, EB-EB only
Z'SSM (LO)
Z'χ (LO)
Z'η (LO)
Z'ψ (LO)
m(Z') [GeV]