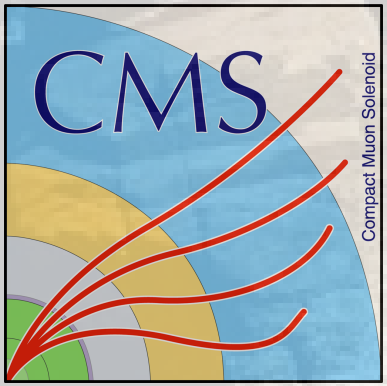
Searches for new resonances in final states with leptons at CMS



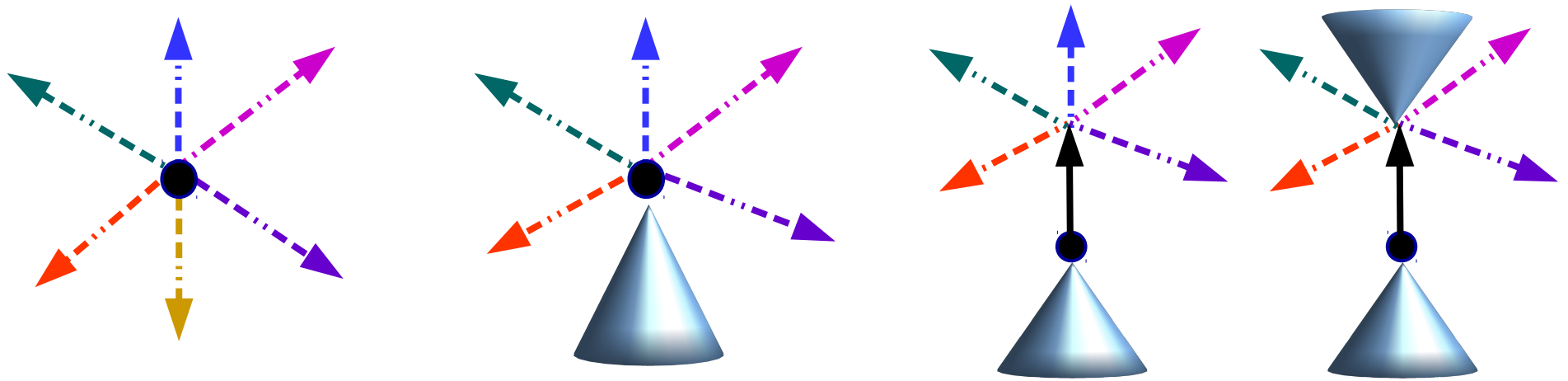
Anshul Kapoor
IISER Pune

on behalf of the CMS Collaboration

25th Rencontres du Vietnam
Windows on the Universe
Qui Nhơn (Vietnam)

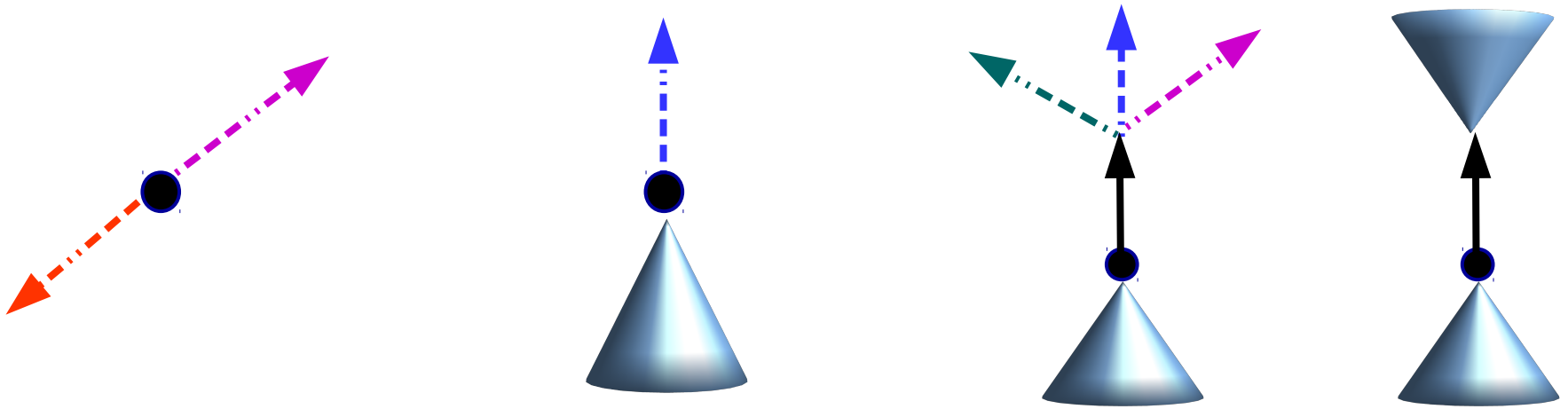
August 8th, 2018

Searching is all about strategy



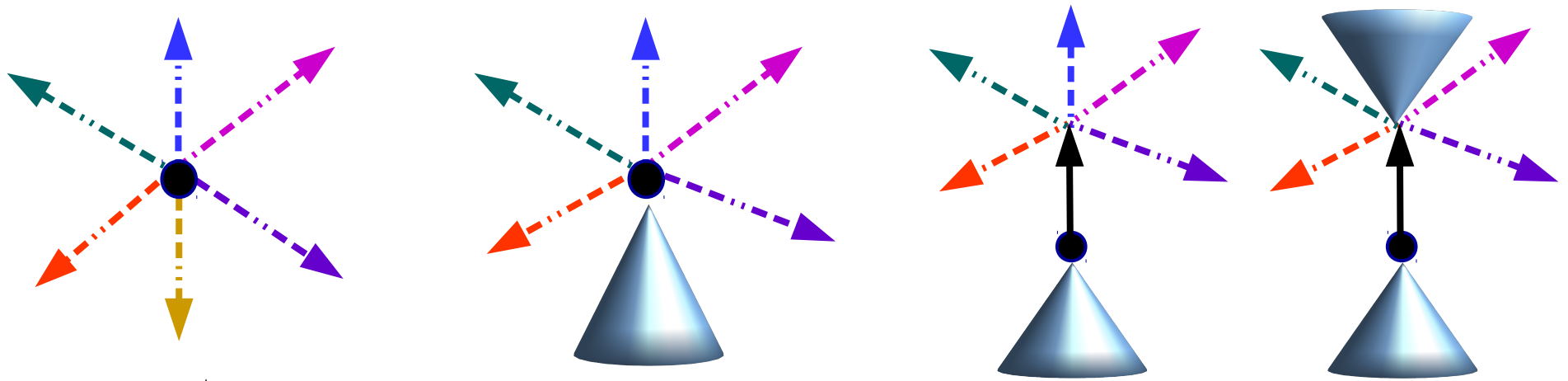
The same particle, when produced, can result in varied topologies based on decay , lifetime, branching ratios etc.

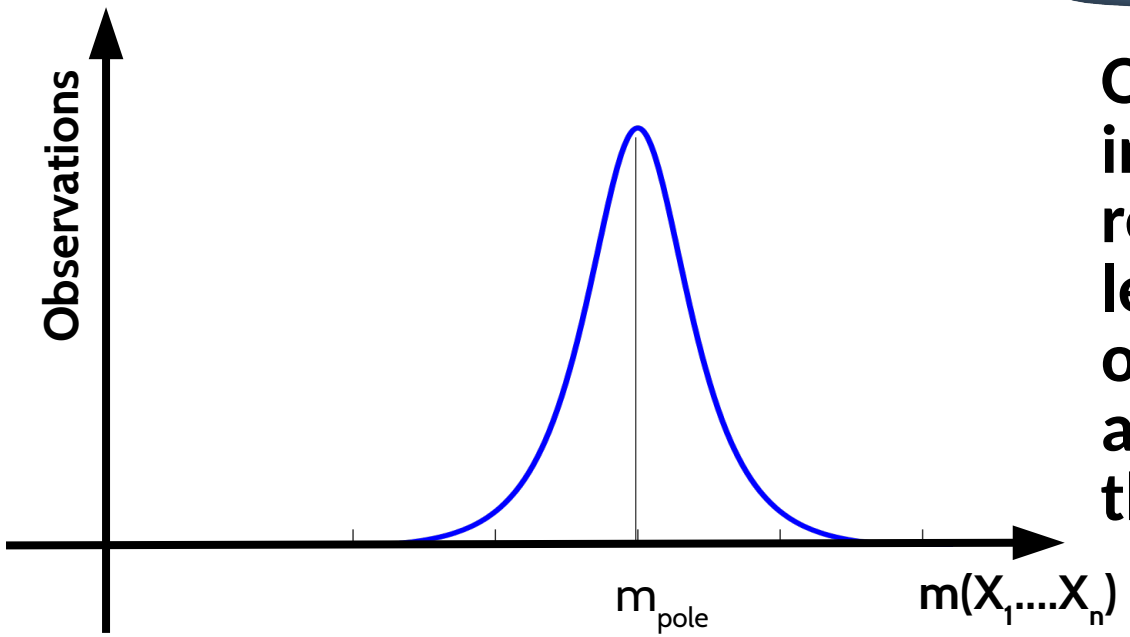
Searching is all about strategy



Depending on physics, background composition, effective cross section and other aspects of interest, one can use different strategies to look for the same particle.

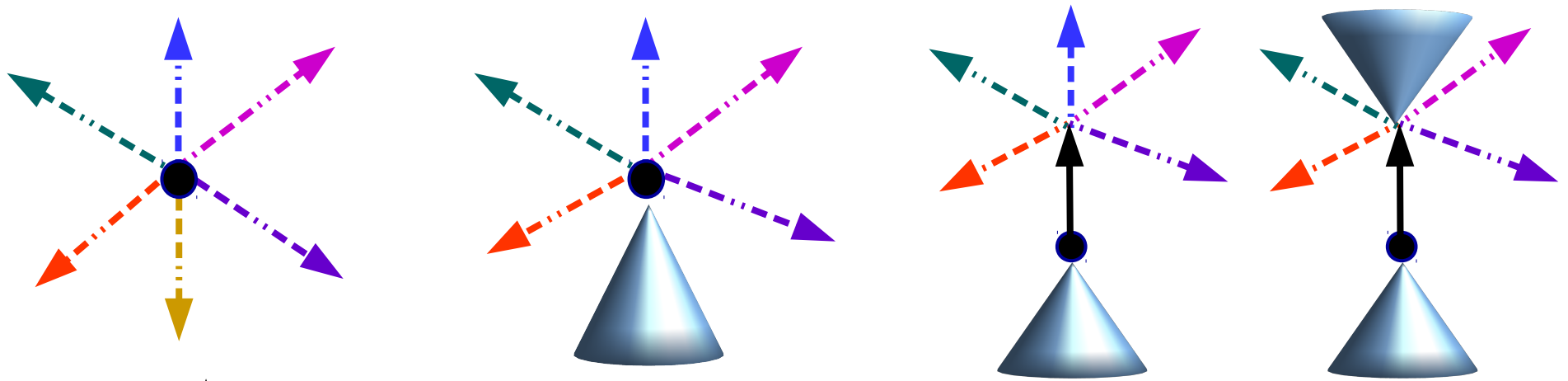
Resonances

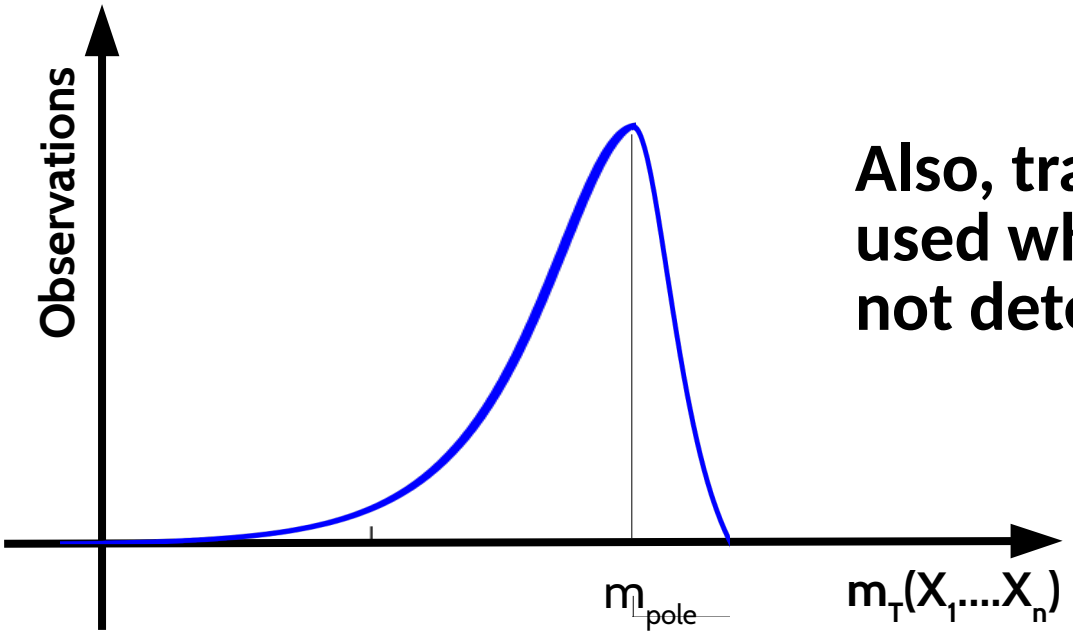




One can also look at the invariant mass of all the resultant particles, leading to observation of preferred production at the on-shell mass of the particle.

Resonances

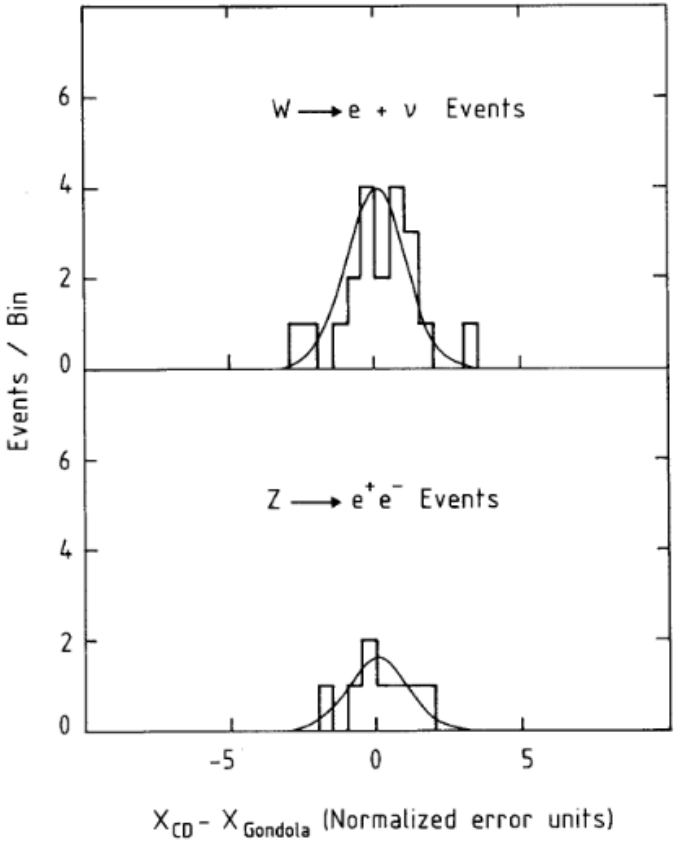




Also, transverse mass can be used when one of the particle is not detected directly.

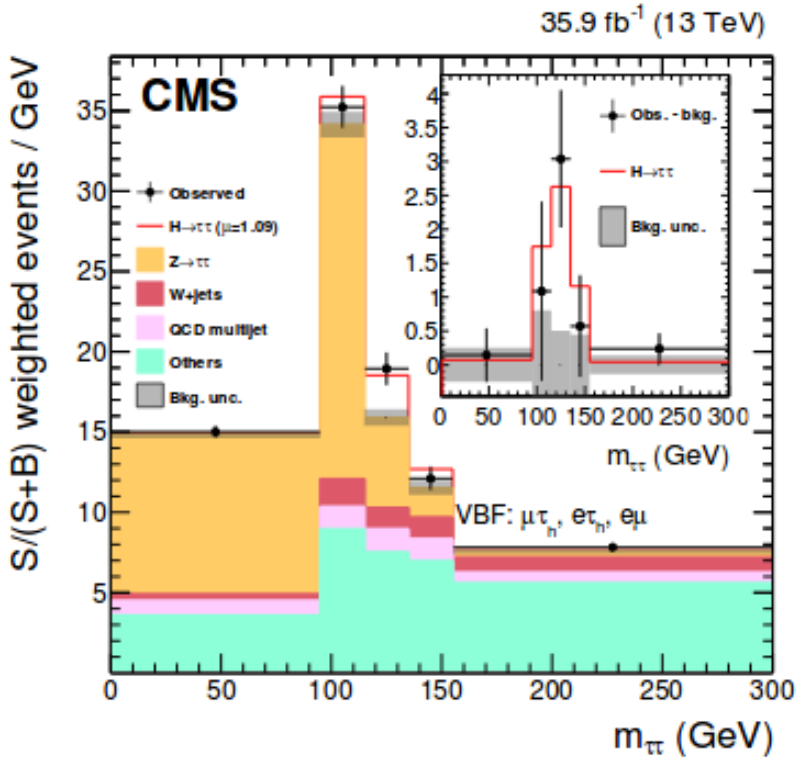
Legacy of 35 years

1983: W and Z
81 GeV, ~nb^{-1}



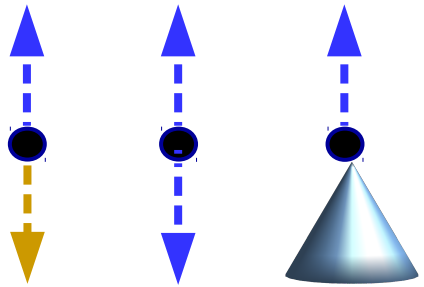
Phys. Lett. B 126 (1983) 398-410
Aug 11 1983

2018: h → τ τ
125 GeV, ~fb^{-1}



Phys.Lett. B779 (2018) 283-316

Searches with leptons



New particles beyond the **standard model(SM)** may show up as resonances at the TeV scale in:

1) Sequential-SM with SM like couplings
2) Models of extra dimensions with KK excitations
3) Grand unified theories

Why leptons ?

- Leptons can be more distinctly spotted.
- Hence leptonic final states are cleaner, when comparing to final states with jets.

Charged Resonances

1) W' → lυ
10.1007/JHEP06(2018)128

2) W' → τυ
arXiv:1807.11421

6) Multileptons
CMS-PAS-EXO-18-005

Neutral Resonances

3) Z' → ll
10.1007/JHEP06(2018)120

4) Z' → ee
CMS-PAS-EXO-18-006

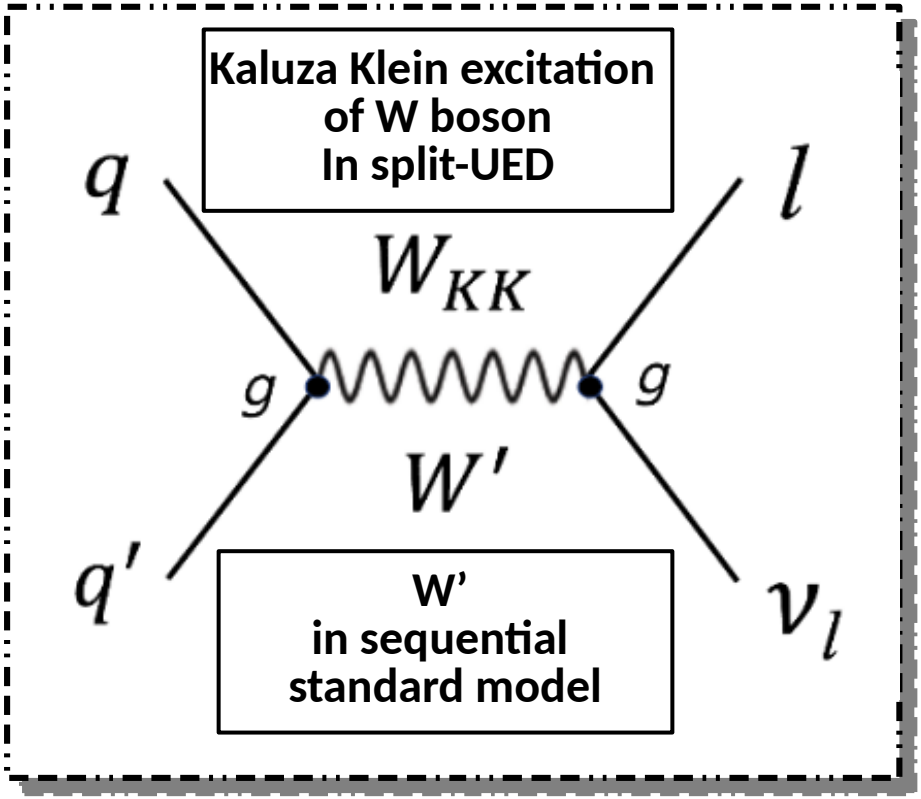
5) X → eμ
10.1007/JHEP04(2018)073

W' → lυ

JHEP 06 (2018) 128

- **W'→ lυ :**
  ~36 fb^{-1} **(2016)** data
- Channels: **W'→ eυ**, **W'→ μυ**

  Dominant background
  W→lυ
  Other backgrounds
  tt̄, tW, WW, WZ, Z/γ*
- **Search for bumps in M_T distribution**



$$M_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell} \; p_{\mathrm{T}}^{\mathrm{miss}} \left(1 - \cos[\Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})]\right)}$$

W’ → lυ

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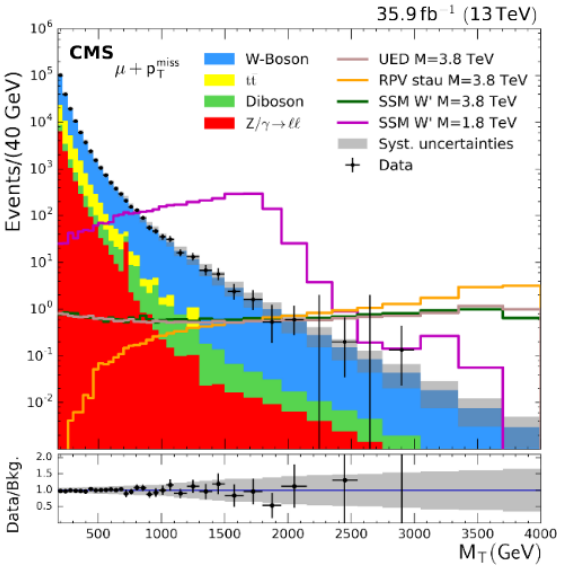
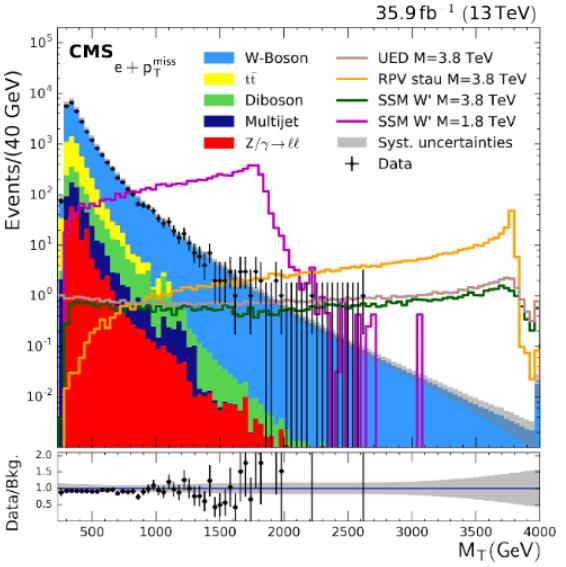
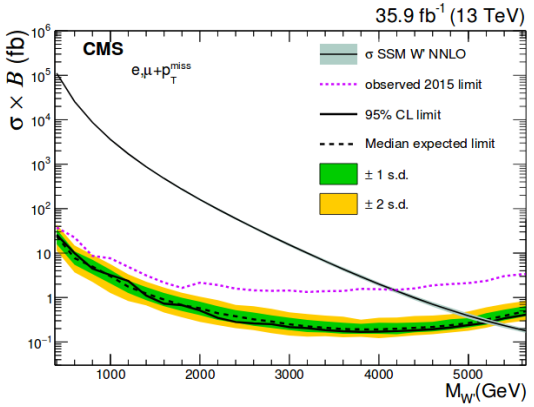
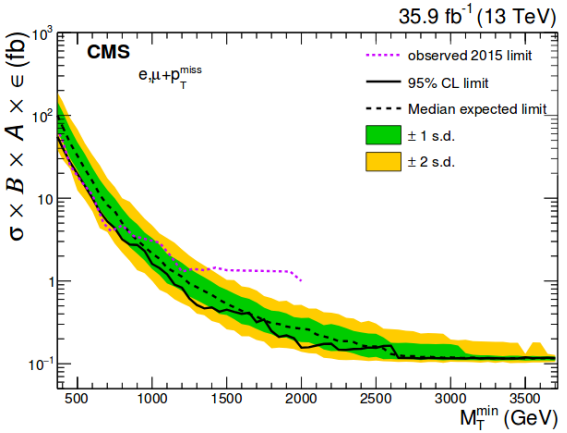
- **W’→ eυ** : e p_T > 130 GeV, p_T^{miss} > 150 GeV
  W’→ μυ : μ p_T > 53 GeV
  $\Delta\Phi(p_T^{\tau}, p_T^{miss})$>2.5 (back-to-back requirement)
  0.4< p_T/p_T^{miss} <1.5

No observed excess above SM
Lower limits placed on mass of the **W’** :
$m(W'_{SSM})$> 5.2 TeV
Model independent limits as a function of minimum M_T for X→lυ





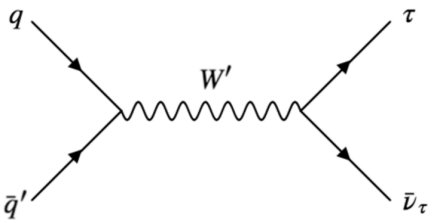


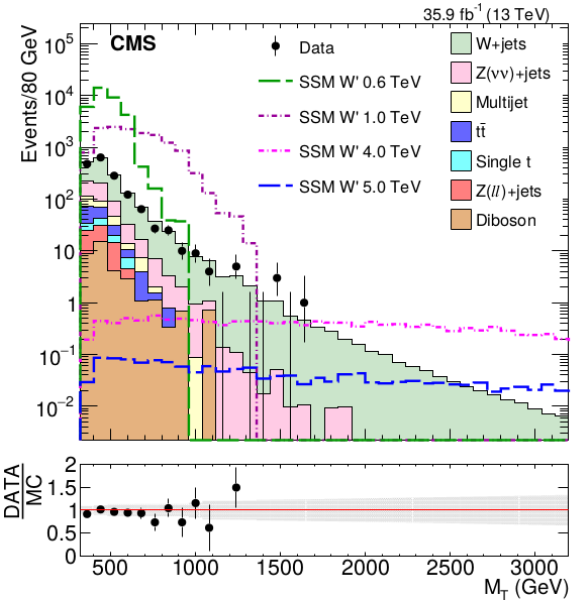


W' → τν

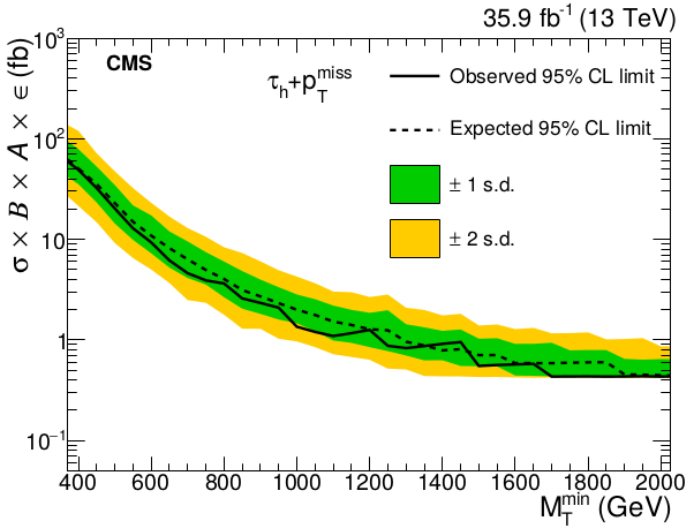
arXiv:1807.11421 (submited to PLB)

- **W' → τν**
  ~36 fb^{-1} **(2016)** data
- **τ** p_T > 80 GeV, p_T^{miss} > 200 GeV
  $\Delta\Phi(p_T\tau, p_T^{miss})$>2.4 (back-to-back requirement)
  0.7< p_T/p_T^{miss} <1.3
- Dominant background : **W+jets**
- Search in M_T





No observed excess above SM
Excluded: m(W'$_{SSM}$) >4.0 TeV
Model independent limits as a function of minimum M_T for a X→ τν

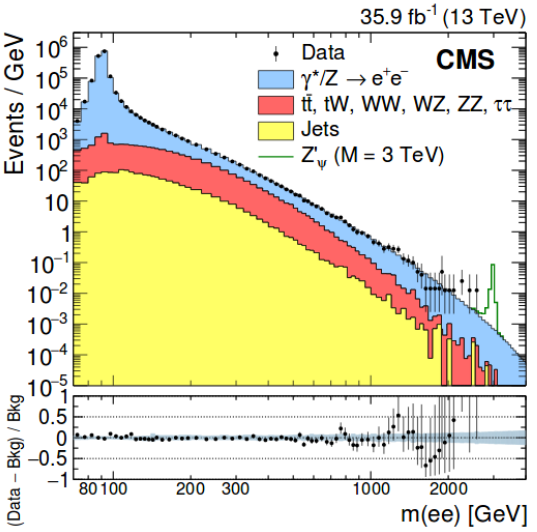


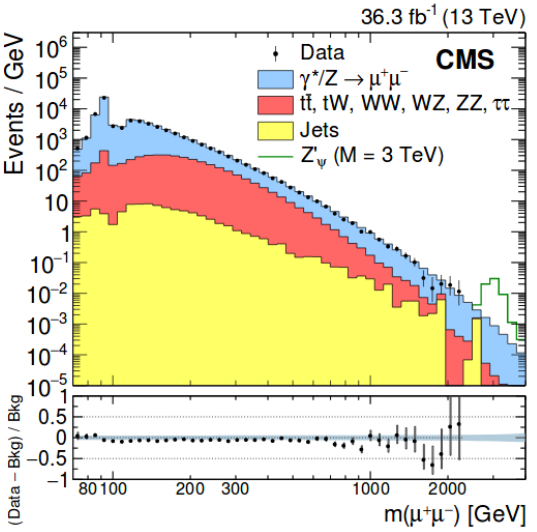
Z' → ll

JHEP 06 (2018) 120

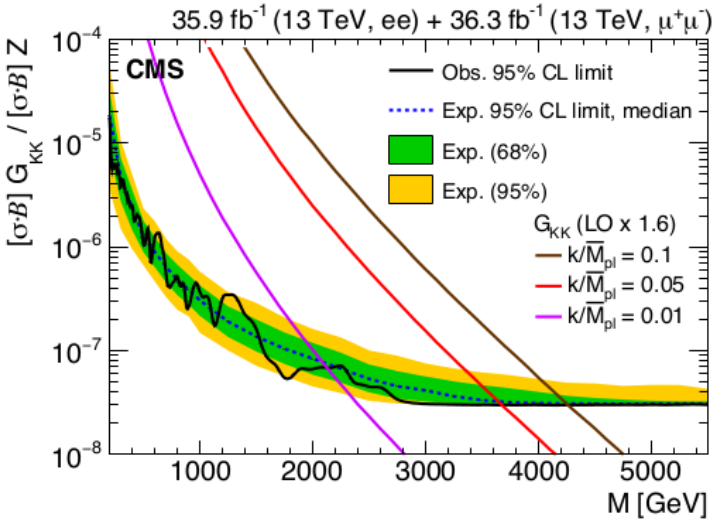
- **Looking for Z like SSM boson**
- **Z'→ll** :
  ~36 fb^{-1} **(2016)** data
- Channels:
  Z'→ ee, **Z'→ μμ**

  Dominant background : **Z/γ***
  Other backgrounds : **tt̄, tW, WW, WZ, ZZ, τ τ**





Excluded:
Spin-1 : m(Z'$_\psi$)> 3.9 TeV, m(Z'$_{SSM}$)> 4.5 TeV
Spin-2 : k/M$_{Pl}$ =0.01: m>2.10 TeV
k/M$_{Pl}$ =0.05: m>3.65 TeV
k/M$_{Pl}$ =0.1: m>4.25 TeV



Z' → ee

CMS PAS EXO-18-006

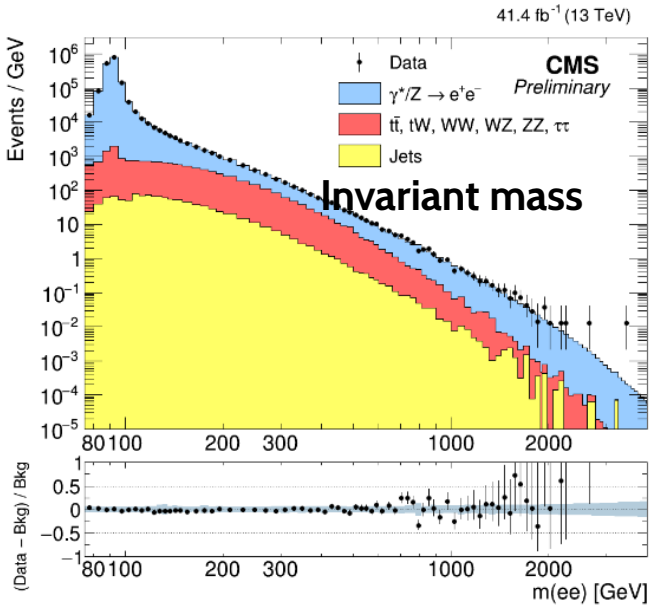
- **Z'→ee** :
  ~41 fb^{-1} **(2017)** data

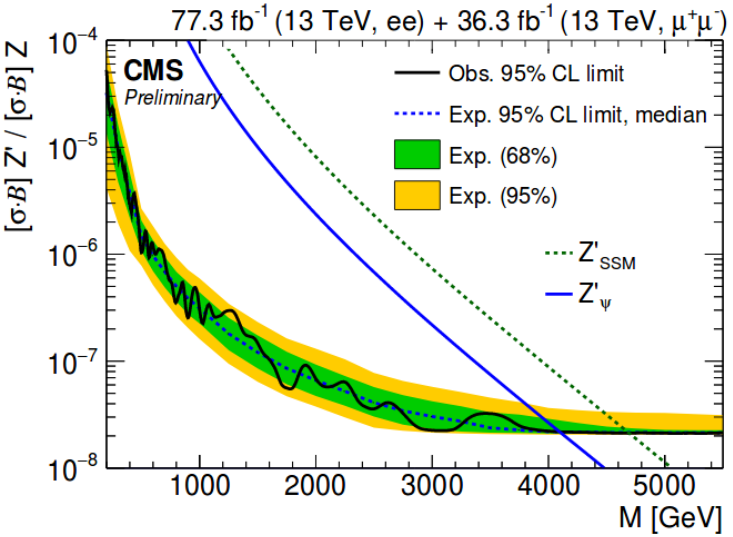
  P_T > 35 GeV for both electrons
  No opposite sign requirement due to high charge misidentification backgrounds for TeV electrons

  Dominant background : **Z/γ***
  Other backgrounds : **tt̄, tW, WW, WZ, ZZ**

- Statistically combined with
  Z'->ll : ~36 fb^{-1} **(2016)** data

Excluded
Spin-1 :
m(Z'$_\psi$) > 4.1 TeV, m(Z'$_{SSM}$) > 4.7 TeV

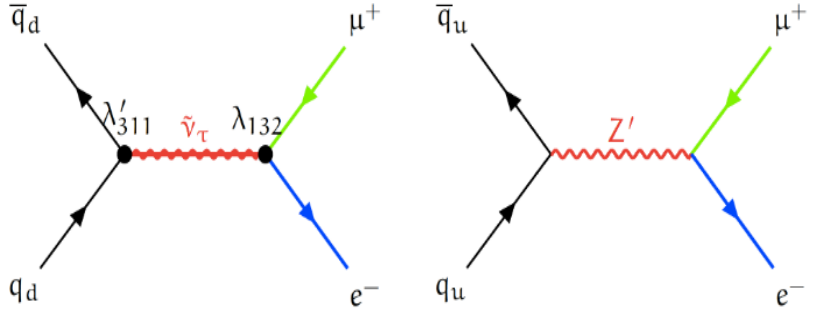




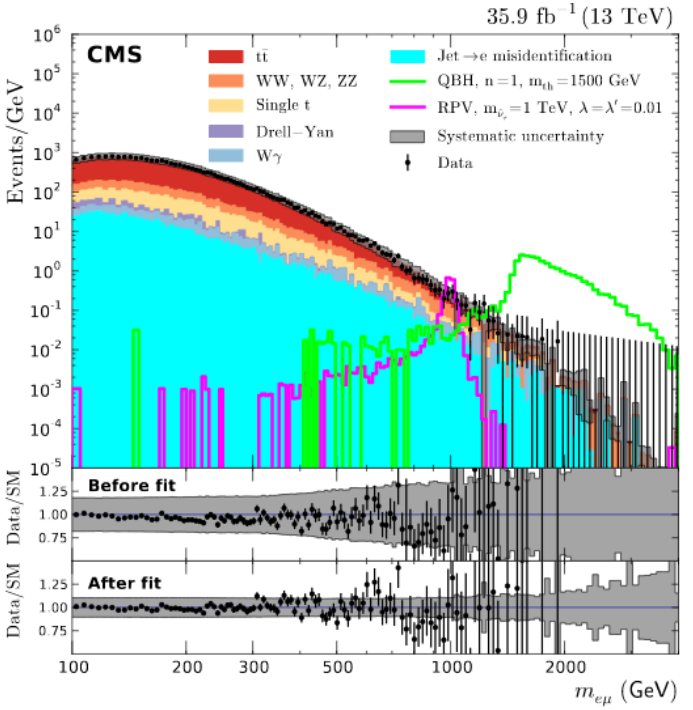
X → eμ

JHEP 04 (2018) 073

- **X → eμ**
  ~36 fb^{-1} (2016) data



- Model Independent search for heavy resonances with flavor violating decays
- p_T >35 GeV for electron
  p_T >53 GeV for muon
  p_T^{miss} >50 GeV, $M_{e\mu}$ > 200 GeV
- Backgrounds : **$t\bar{t}$, tW, WW, WZ**



Mass range (GeV)	$m_{e\mu}<500$	$500<m_{e\mu}<1000$	$1000<m_{e\mu}<1500$	$m_{e\mu}>1500$
Jet→e misidentification	3601	82.8	2.92	0.849
Wγ	2462	56.2	2.76	0.562
Drell-Yan	2638	5.31	0.343	0.0145
Single t	9930	141	2.81	0.178
WW, WZ, ZZ	11126	239	13.0	2.03
$t\bar{t}$	96754	971	18.5	1.01
Total background	126513	1495	40.3	4.64
Systematic uncertainty	23495	420	13.5	1.28
Data	123150	1426	41	4

SM BACKGROUND → Total background

OBSERVATION → Data

X → eμ

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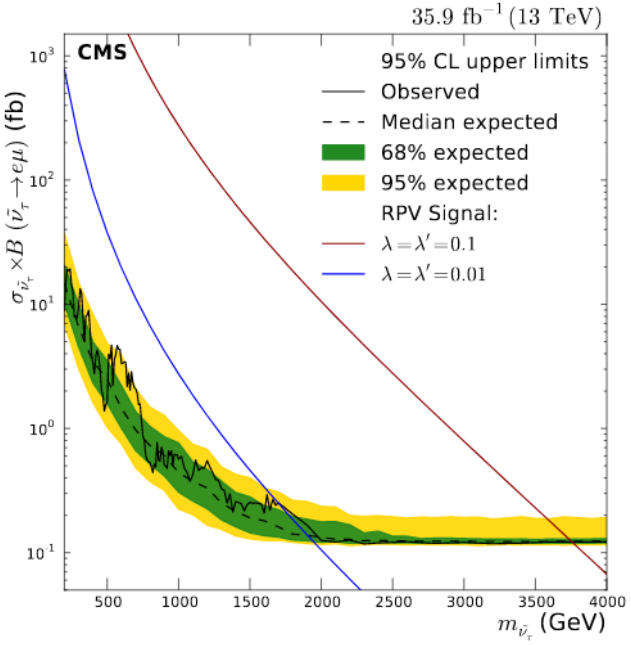
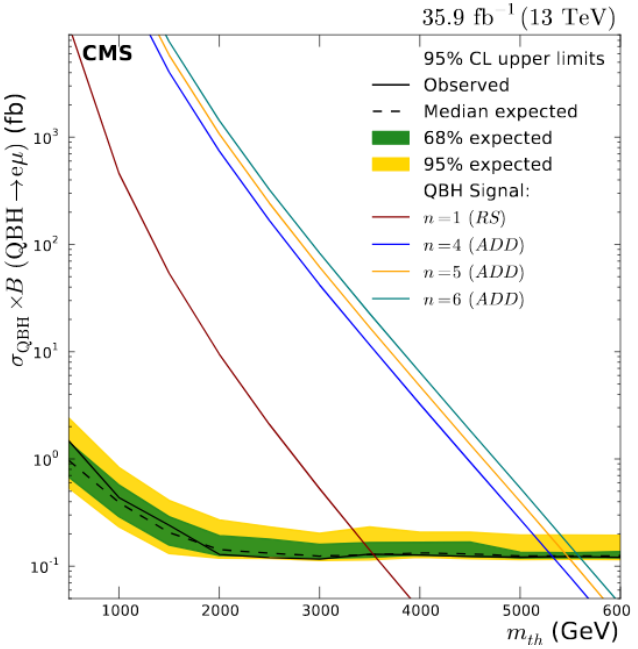
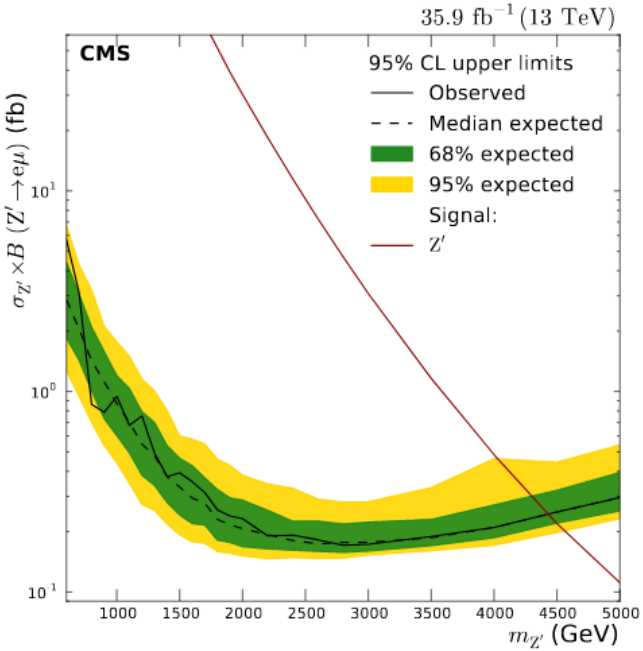
RPV SUSY



QBH



Z'



Excluded
λ',λ=0.01 m(ν_τ) >1.7 TeV
λ',λ=0.1 m(ν_τ) >3.8 TeV

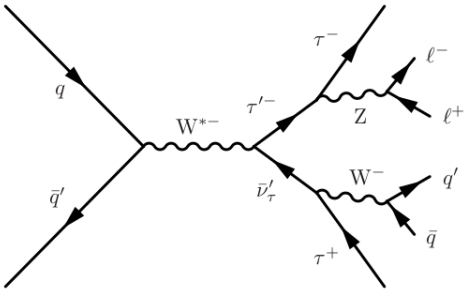
N=1, m_{QBH}>3.6 TeV
N=4,5,6 :
m_{QBH}>5.3, 5.5, 5,6 TeV

m(Z') > 4.4 TeV

Multileptons

CMS-PAS-EXO-18-005

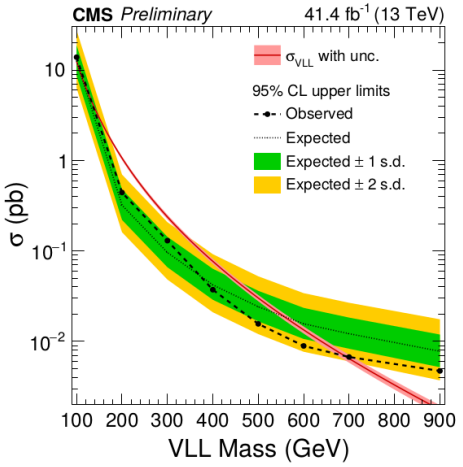
- **Search for vector like leptons**
  ~41 fb^{-1} **(2017)** data

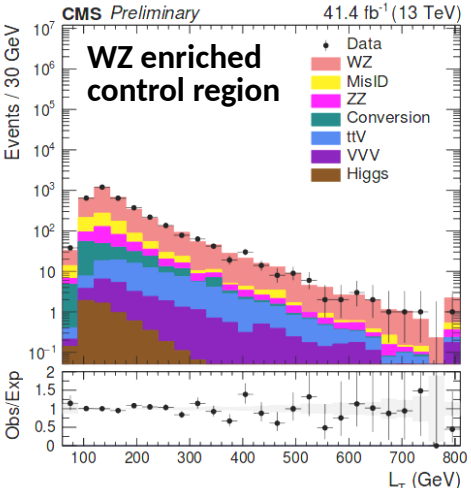


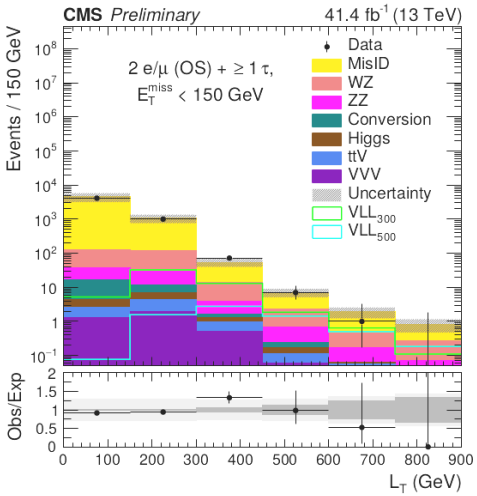
- VLLs couple to SM τaus

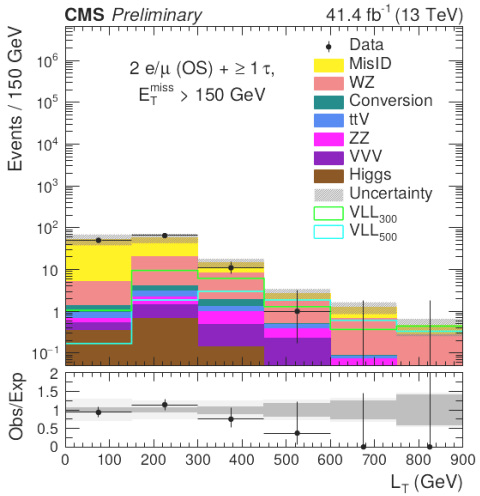
- **Channels** : **3 e/μ, ≥4 e/μ, 2 e/μ+τ**
  Backgrounds :
  Z/γ*+jets, WZ, ttZ, ZZ, WW, Higgs

- **Background estimation:**
  Z/γ*+jets : Data driven method
  WZ, ttZ, ZZ, WW etc : Simulation









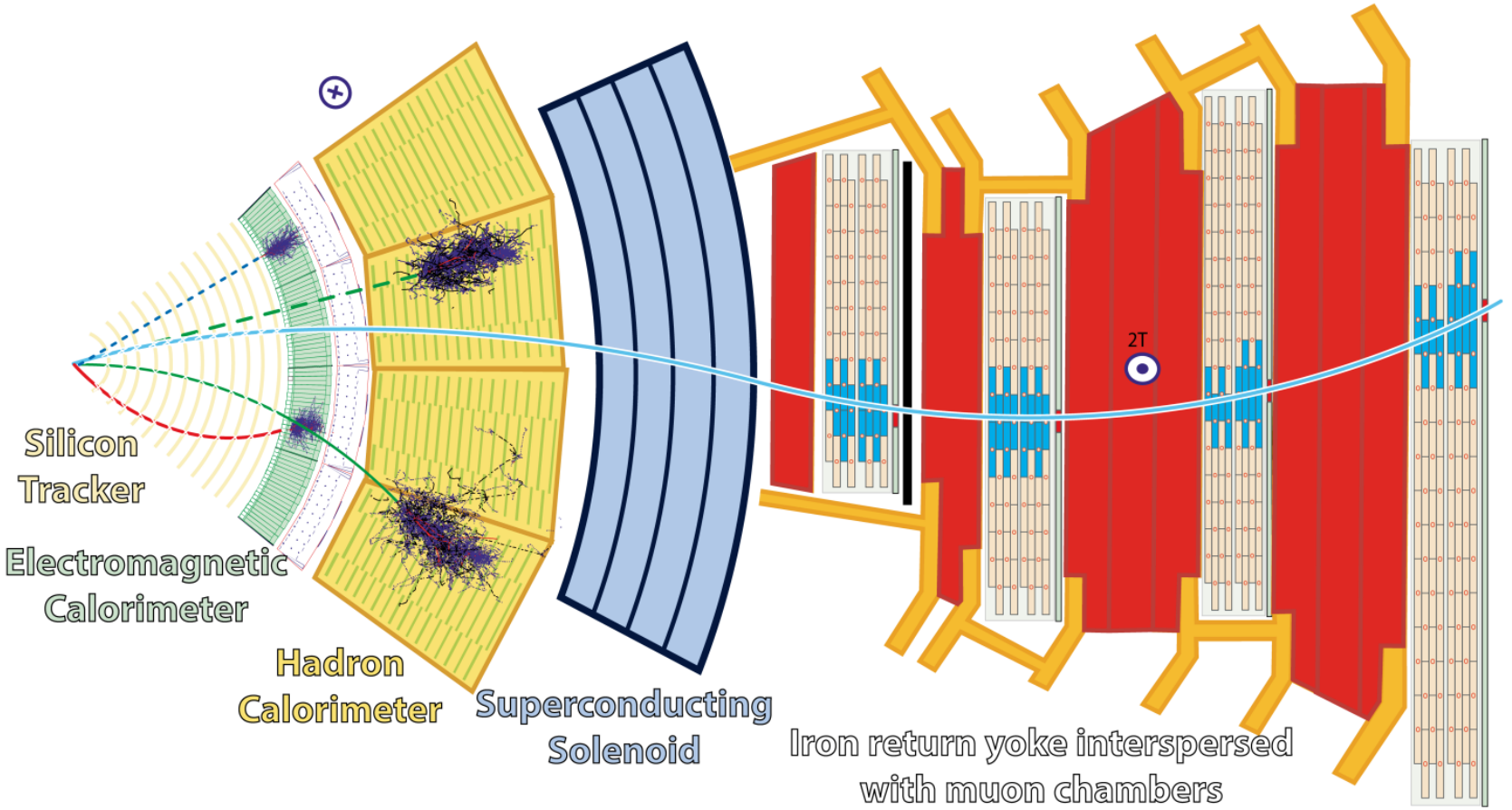
Excluded: 130<m_{VLL}<690 GeV

Summary

- **CMS collaboration** has been extensively looking for new physics in leptonic final states using the data collected in **2016** and **2017**
- New particles beyond the **standard model(SM)** may show up as resonances at the **TeV scale**
- Analyses searching for **W'_{SSM}**, **Z'_{SSM}**, **Quantum Black Holes**, **R-Parity Violating SUSY**, **Vector Like Leptons** exploiting leptonic resonances were presented.
- **No significant excess above SM** has been observed and lower limits have been placed on the mass of these resonances / new particles.

BACKUP

CMS


Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with muon chambers
2T
Muon
Electron
Charged hadron (e.g. pion)
Neutral hadron (e.g. neutron)
Photon

W' → lν

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	$M_T > 1$ TeV	$M_T > 2$ TeV	$M_T > 3$ TeV	$M_T > 4$ TeV
Electron data	200	2	0	0
Sum of SM backgrounds	213 ± 28	5.00 ± 0.96	0.260 ± 0.077	0.0163 ± 0.0078
SSM W′ M = 1.8 TeV	5040 ± 770	25.9 ± 5.8	0.43 ± 0.44	0 ± 0
M = 2.4 TeV	1180 ± 200	560 ± 100	1.14 ± 0.44	0 ± 0
M = 3.8 TeV	53 ± 13	40 ± 11	23.9 ± 8.4	0.44 ± 0.25
M = 4.2 TeV	23.3 ± 7.3	17.6 ± 6.5	11.8 ± 5.4	3.4 ± 2.2
Muon data	208	4	0	0
Sum of SM backgrounds	217 ± 20	6.0 ± 1.2	0.27 ± 0.21	0.02 ± 0.02
SSM W′ M = 1.8 TeV	5345 ± 530	96 ± 14	2.5 ± 1.2	0 ± 0
M = 2.4 TeV	1282 ± 120	577 ± 85	2.4 ± 1.2	0.10 ± 0.05
M = 3.8 TeV	57 ± 6	42 ± 6	24 ± 12	2 ± 1
M = 4.2 TeV	25 ± 3	19 ± 3	12 ± 6	3.6 ± 1.8

W' → lν

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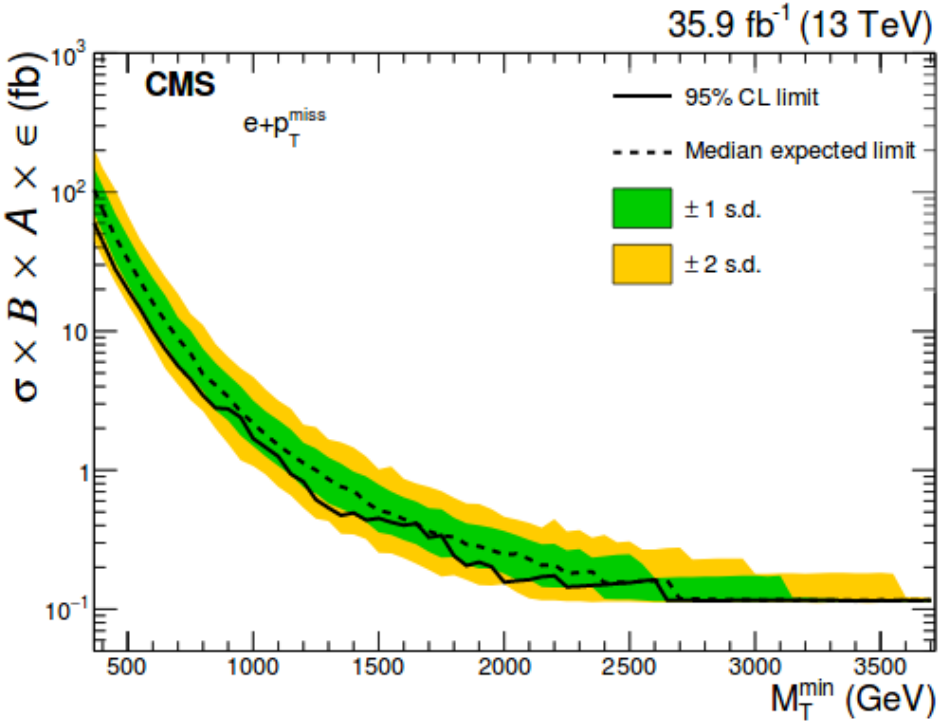

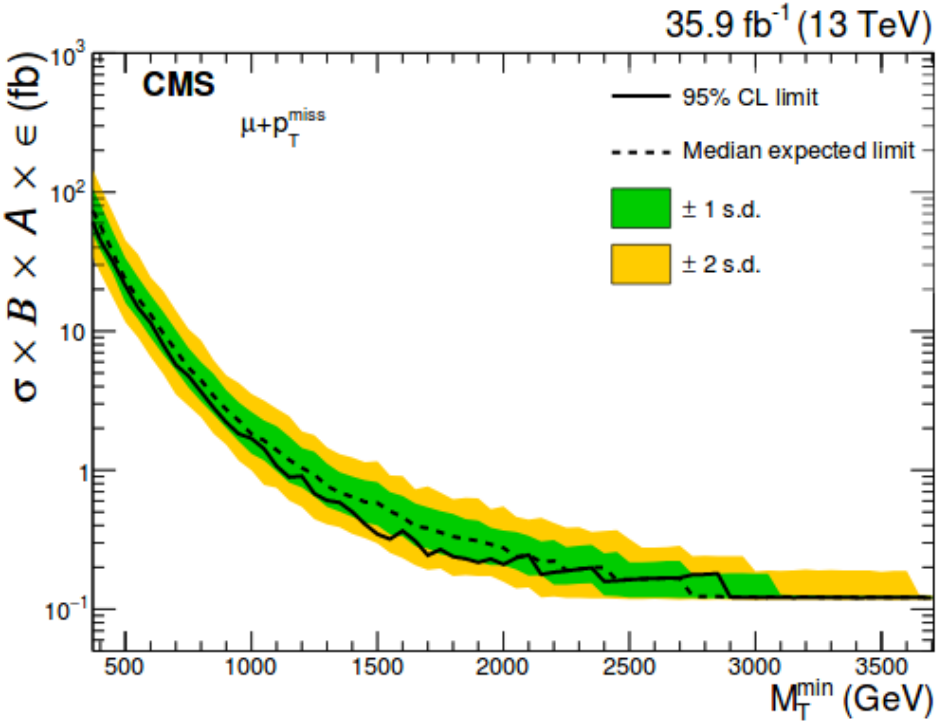

W' → lν

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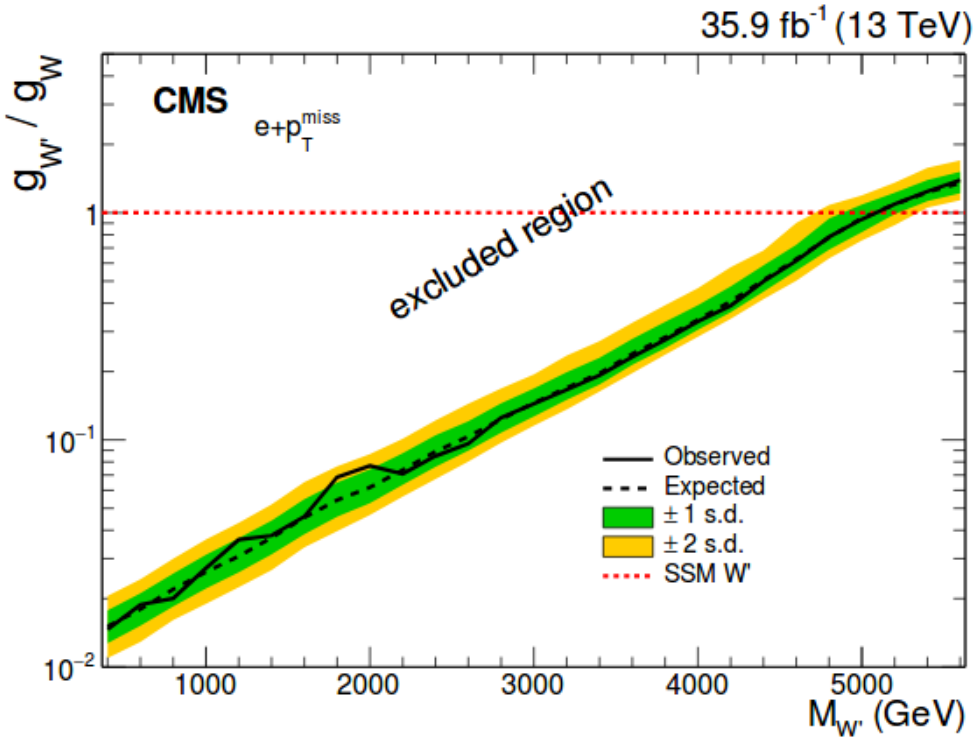
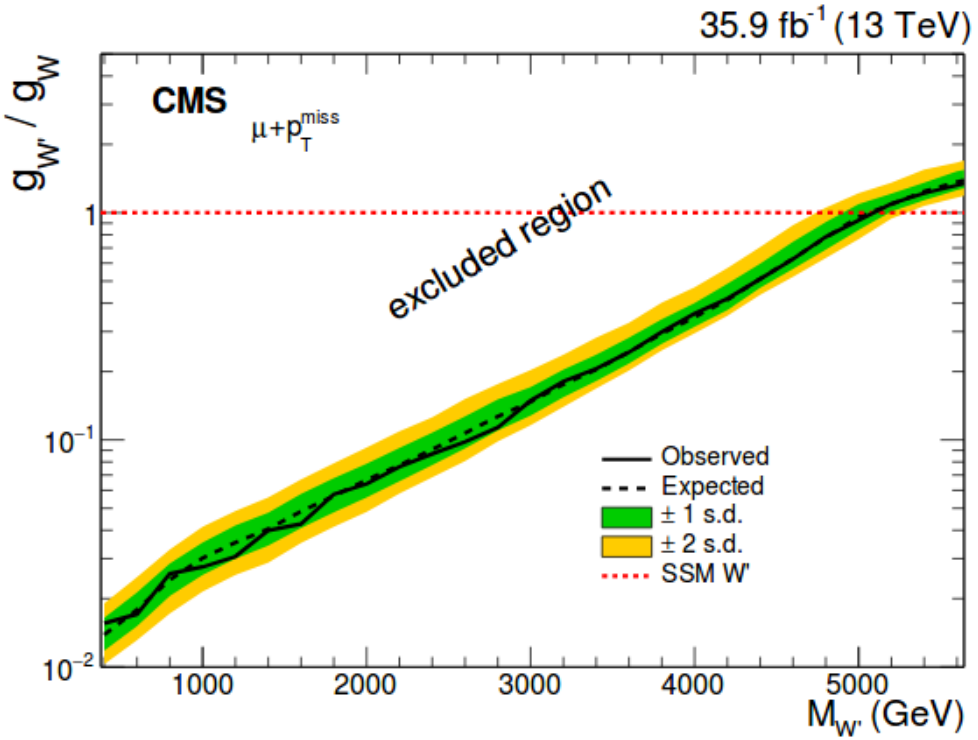
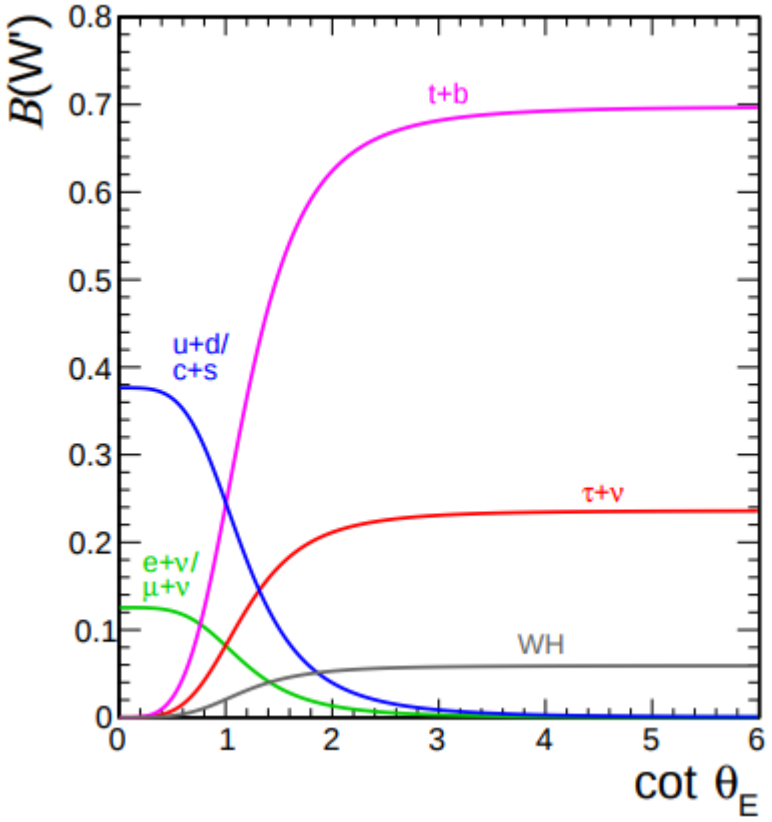
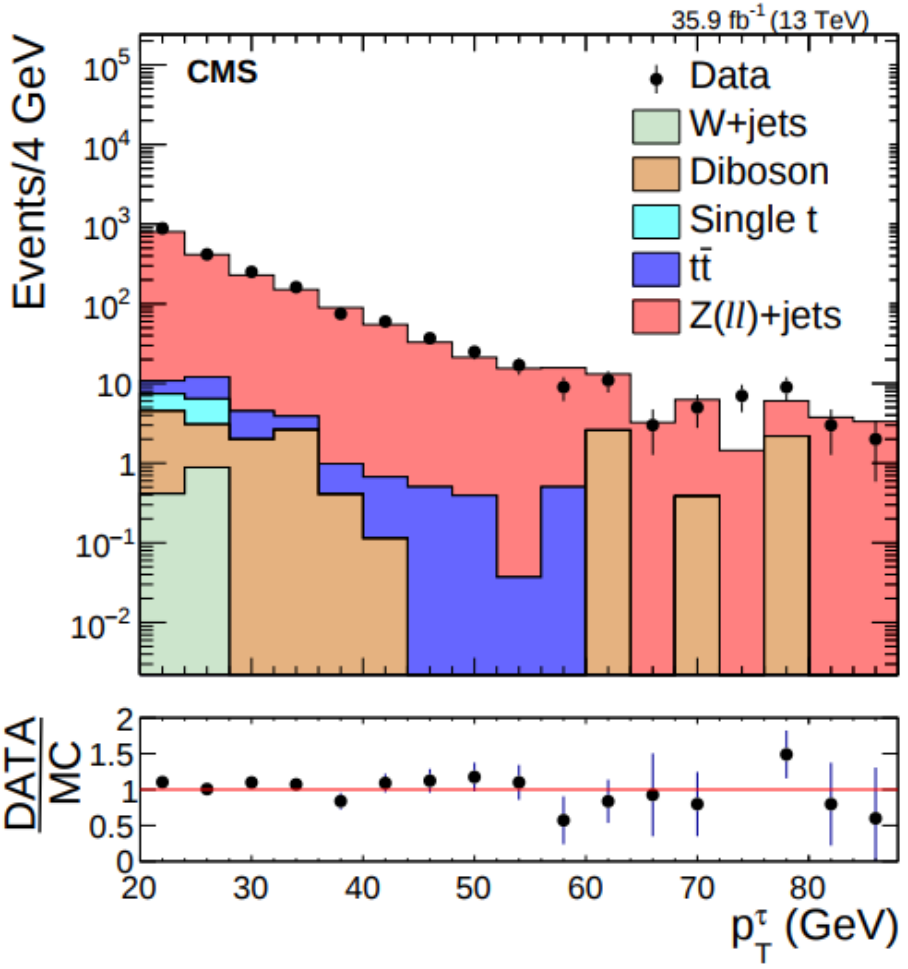




W' → τν

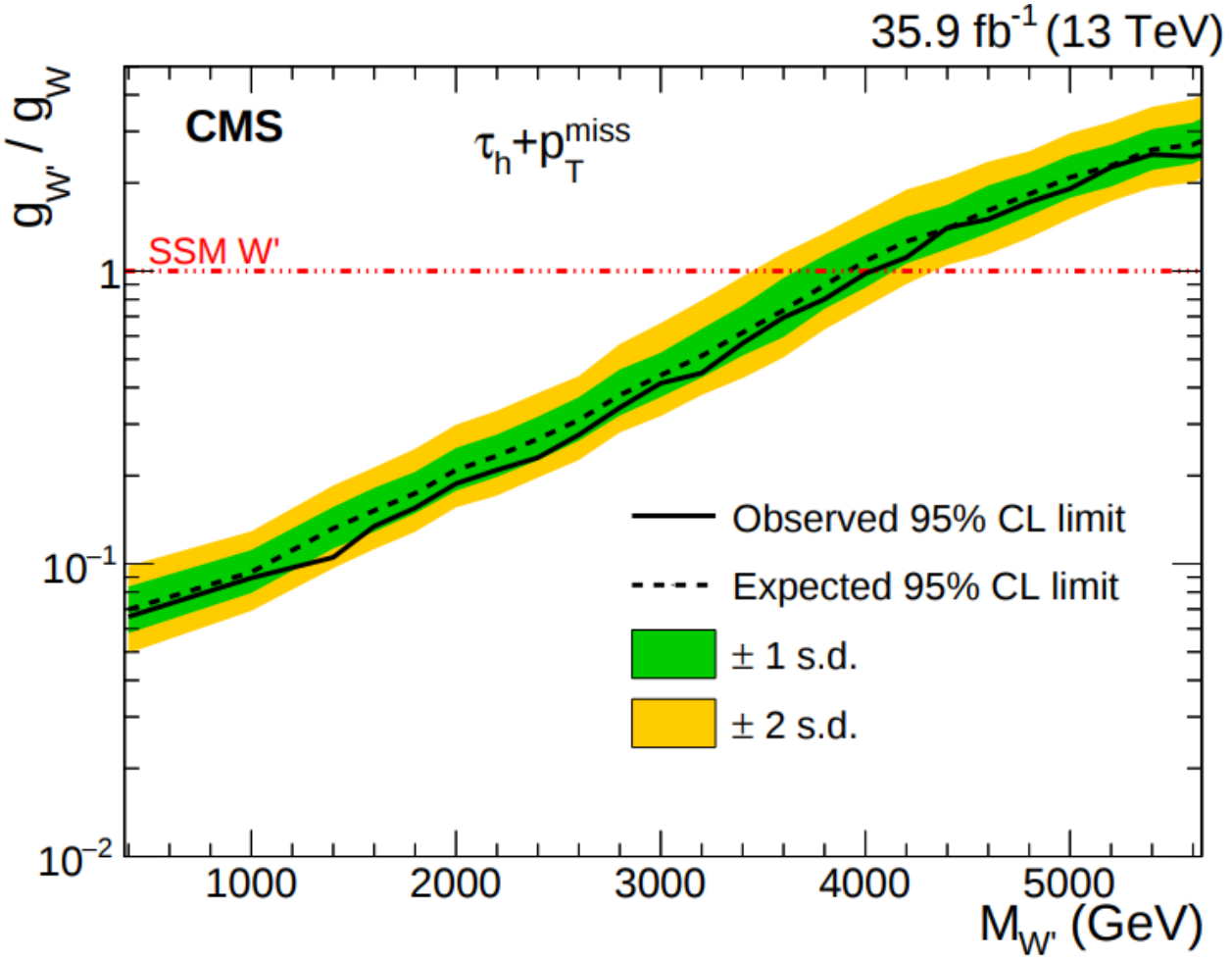
arXiv:1807.11421 (submited to PLB)





W' → τν

arXiv:1807.11421 (submited to PLB)



Z' → ll

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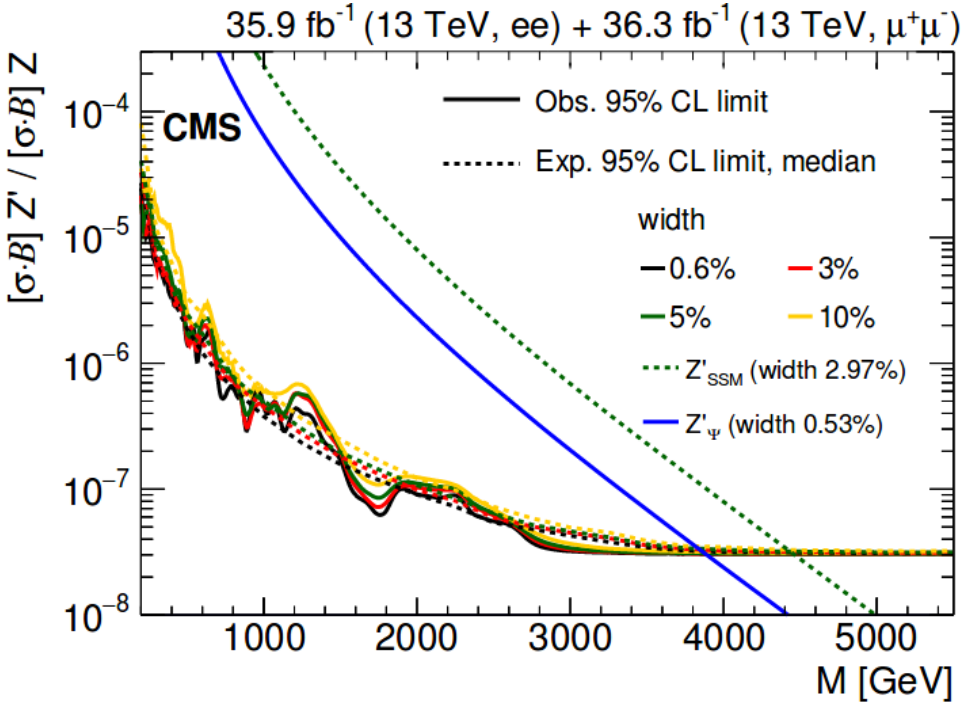

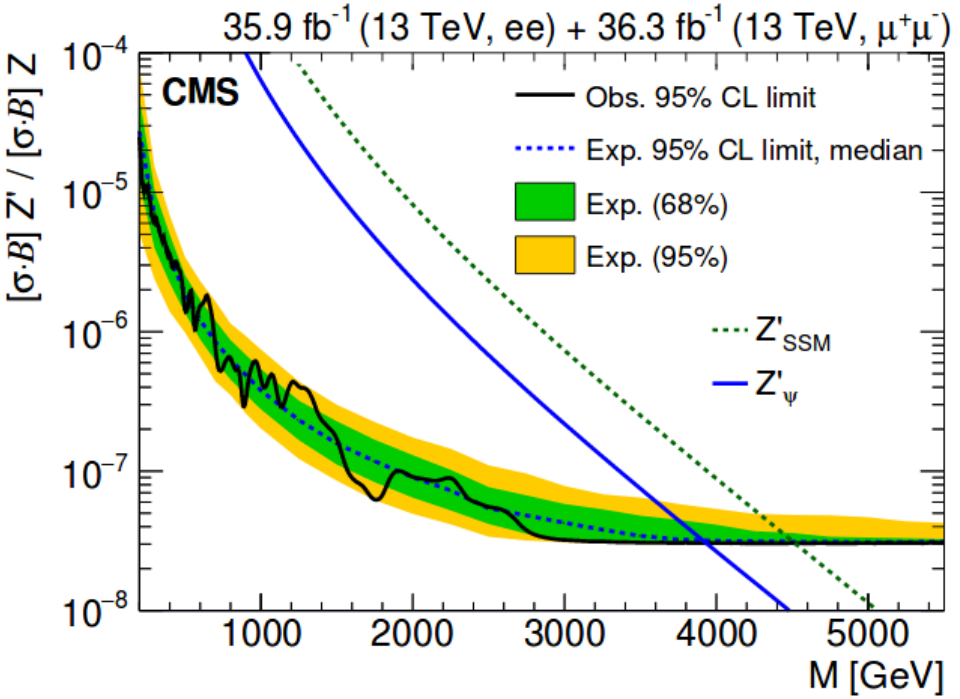

Low mass Z’ → μμ

CMS PAS EXO-18-006

- **Z->Z’μμ->μμμμ :**
  ~77 fb^{-1} **(2017) + (2016)** data

- Muon p_T > 20,10 GeV for leading 2 muons
  The muon pair farthest from SM Z boson mass is the Z’ candidate