Search for heavy charged gauge bosons with high p_T lepton in pp collisions at CMS

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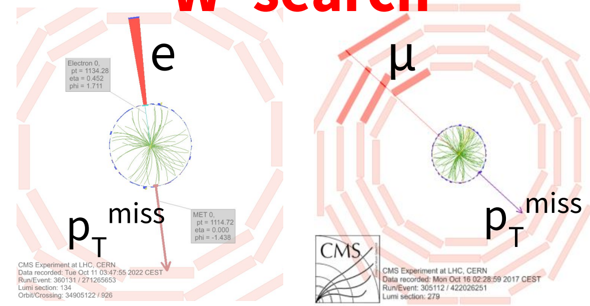
Outline

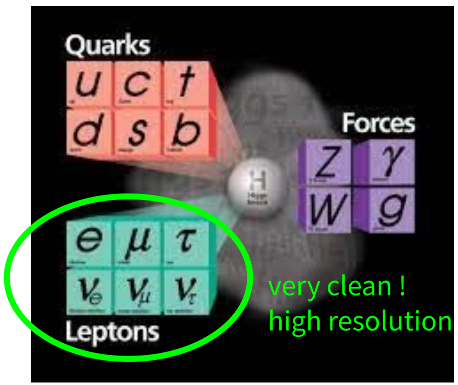
- Search for new physics signals over smoothly-falling background in the **m_T spectrum**
- Results have updated using full Run-2 datasets ($\int Ldt$ = 138 fb^{-1})

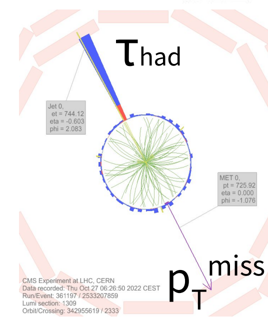
W' search



- **Beyond the Standard Models**
  - predict resonant / non-resonant signals

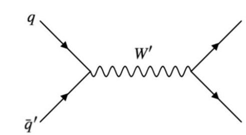
- **Analysis strategies and results**
  - e/μ + p_T^{miss} analysis
  - τ_h + p_T^{miss} analysis





- **Conclusion**

- W' references (@13 TeV with full Run-2)
  - W' → e/μ + p_T^{miss} : JHEP07(2022)067 (CMS), PRD100,052013(2019) (ATLAS)
  - W' → τ_h + p_T^{miss} : 2212.12604 (CMS), PRL120,161802(2018)(ATLAS)
  - W' → q + q' : 2206.09997 (CMS), PRL.125.131801(2020) (ATLAS),
  - W' → t + b : CMS-PAS-B2G-20-012(CMS), ATLAS-CONF-2021-043 (ATLAS)
  - W' → WZ (WH) : PRD.105.032008(2022), 2210.00043 (CMS), EPJC80(2020)1165, PRD102.112008(2020)(ATLAS)
  - W' → VLQ T(B) + t(b) : JHEP09(2022)088 (CMS) … etc



Probing BSMs with $l(e,\mu,\tau_h)$+MET

Resonant Searches

Wide range of BSM models predict

Additional heavy gauge bosons

Spin-1 Heavy 'Charged' Gauge Boson, W'

- **Benchmark SSM**: Sequential Standard Model (e,μ,τ_h)
- **HVT** : Heavy Vector Triplet Model (e,μ)
- **UED** : Universal Extra Dimensions (e,μ)
- **QBH** : Quantum Black Hole (τ_h)
- **RPV SUSY** : R-parity violating Supersymmetry (e,μ)
- **NUGIM** : Non Universal Gauge Interaction Model (τ_h)

NEW

- **HCM** : Higgs Composite Model (e,μ)

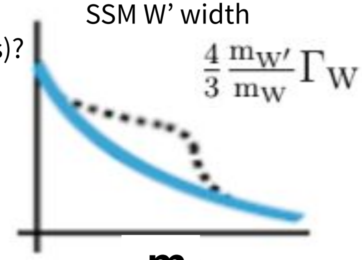
Typical direct signals is **resonances (like ρ)**
Typical indirect signals: **coupling deviation**

extended gauge sector (New heavy bosons)?
Additional scalar states (SUSY)?
Compositeness?

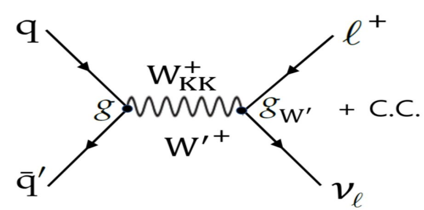
HVT W' width

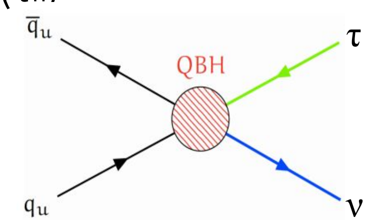
$$\Gamma_{V_\pm \to f\bar{f}'} \simeq 2\Gamma_{V_0 \to f\bar{f}} \simeq N_c[f] \left(\frac{g^2 c_F}{g_V}\right)^2 \frac{M_V}{48\pi}$$

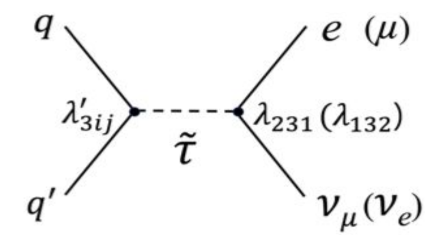
$$\Gamma_{V_\pm \to W_L^\pm Z_L} \simeq \frac{g_V^2 c_H^2 M_V}{192\pi}\left[1+\mathcal{O}(\zeta^2)\right]$$



$$\boxed{M_T = \sqrt{2 p_T^\ell \; p_T^{miss}\left(1-\cos[\Delta\phi(\ell, \vec{p}_T^{miss})]\right)}}$$







Probing BSMs with $l(e,\mu,\tau_h)$+MET

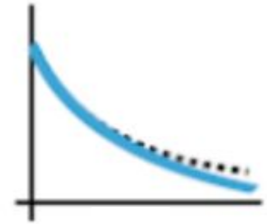
Non-resonant Searches

New physics effect also probed based on the framework of the Effective Field Theory NEW

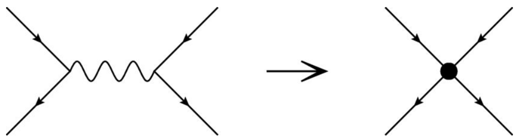
- Oblique *W* and *Y* parameters (e,μ)
- Wilson Coefficient (Coupling parameter) (τ_h)

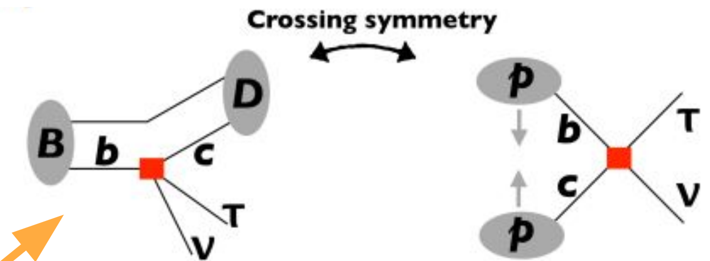
Possible hints of Lepton Flavor Anomalies NEW

- Leptoquarks (LQ) in t-channel (τ_h)


m_T

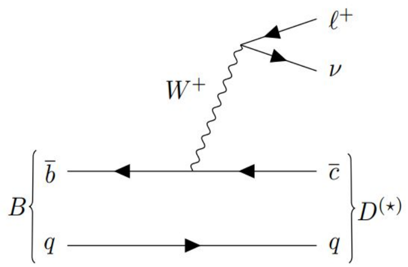
4-fermion contact interaction



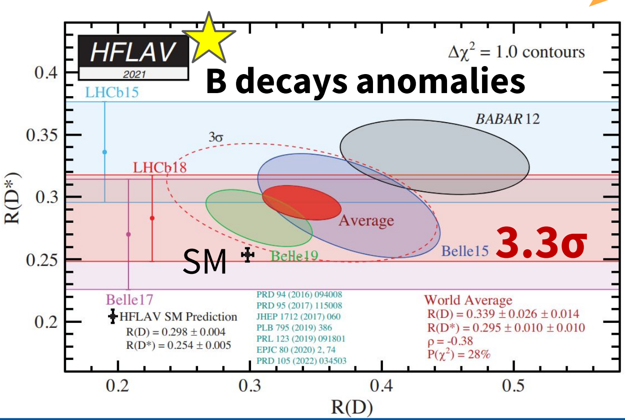


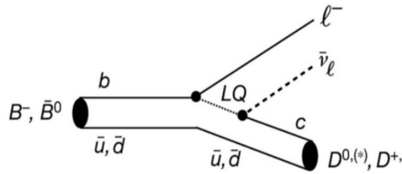
b to c transition

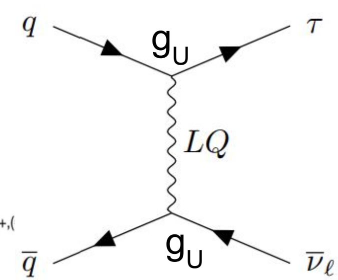
PRL.122(2019)131803



$$R(D^{(\star)}) = \frac{\mathscr{B}(B \to D^{(\star)}\tau\nu)}{\mathscr{B}(B \to D^{(\star)}\ell\nu)} > \text{SM}$$







$\sigma_{LQ\text{-}tch} \propto g^4_U$

Electron/Muon + P_T^{miss} search strategy

electron channel

- **Trigger**
  Single e/γ with p_T > 200 GeV, $|\eta|$ <2.5
- **High-p_T electron ID, ISO**
- Offline electron p_T > 240 GeV

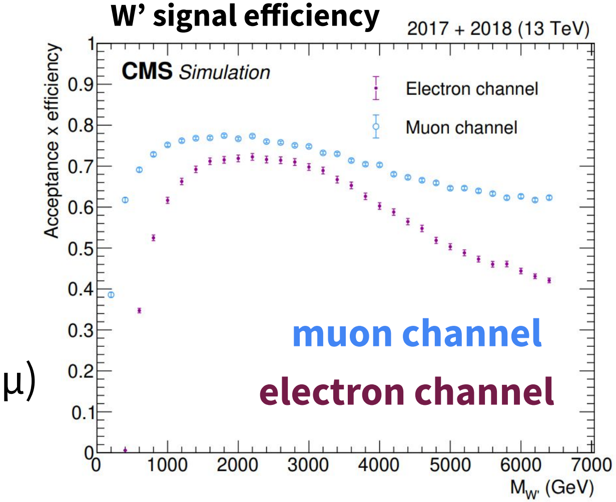
muon channel

- **Trigger**
  Single muon with p_T > 50 GeV, $|\eta|$ <2.4
- **High-p_T muon ID, ISO**
- Offline muon p_T > 53 GeV

Background :
SM W, DY, Top(tt, single top), Diboson(WW, WZ,ZZ), QCD

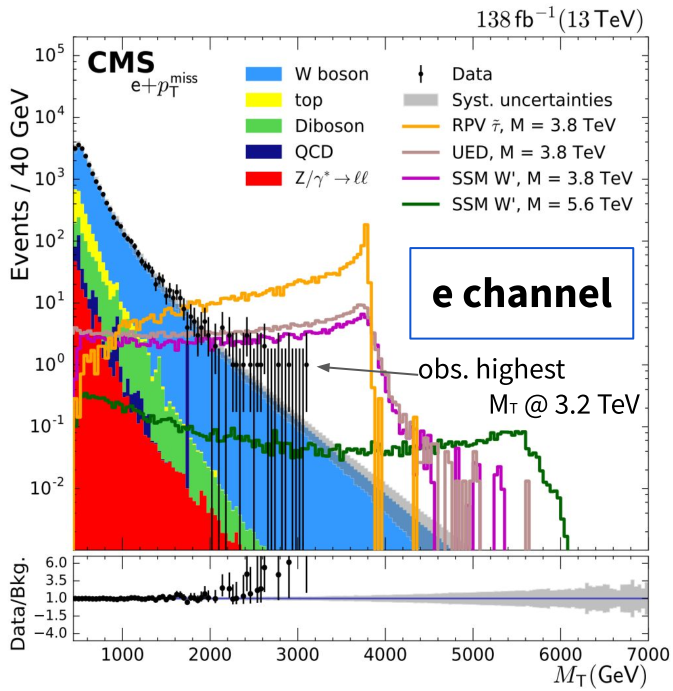
Additional cuts :
Type-1 corrected p_T^{miss}
2nd lepton (p_T >25 GeV) veto to suppress DY
Num. of jets > 6 || leading jet tagged as b veto to suppress tt (μ)

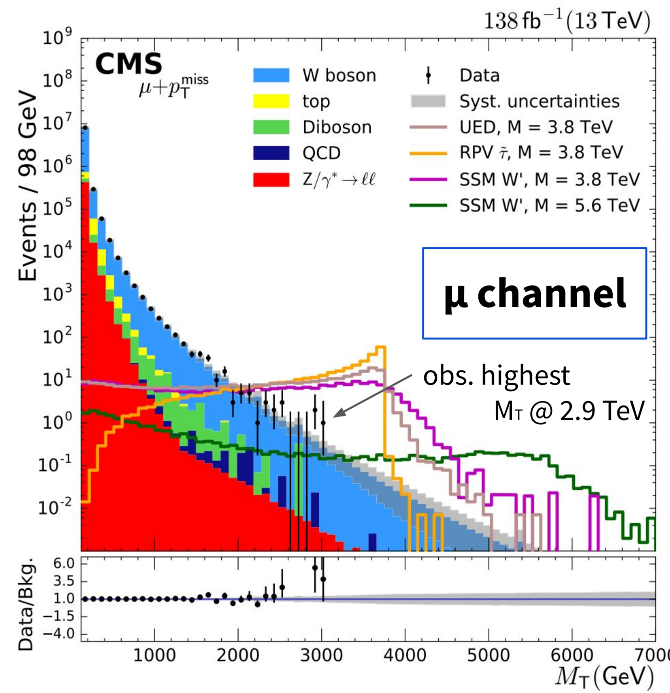
W' signal efficiency



Kinematic cuts :
back-to-back : $\Delta\phi(l, p_T^{miss}) > 2.5$ and Energy balanced : $0.4 < p_T^l / p_T^{miss} < 1.5$

M_T distribution

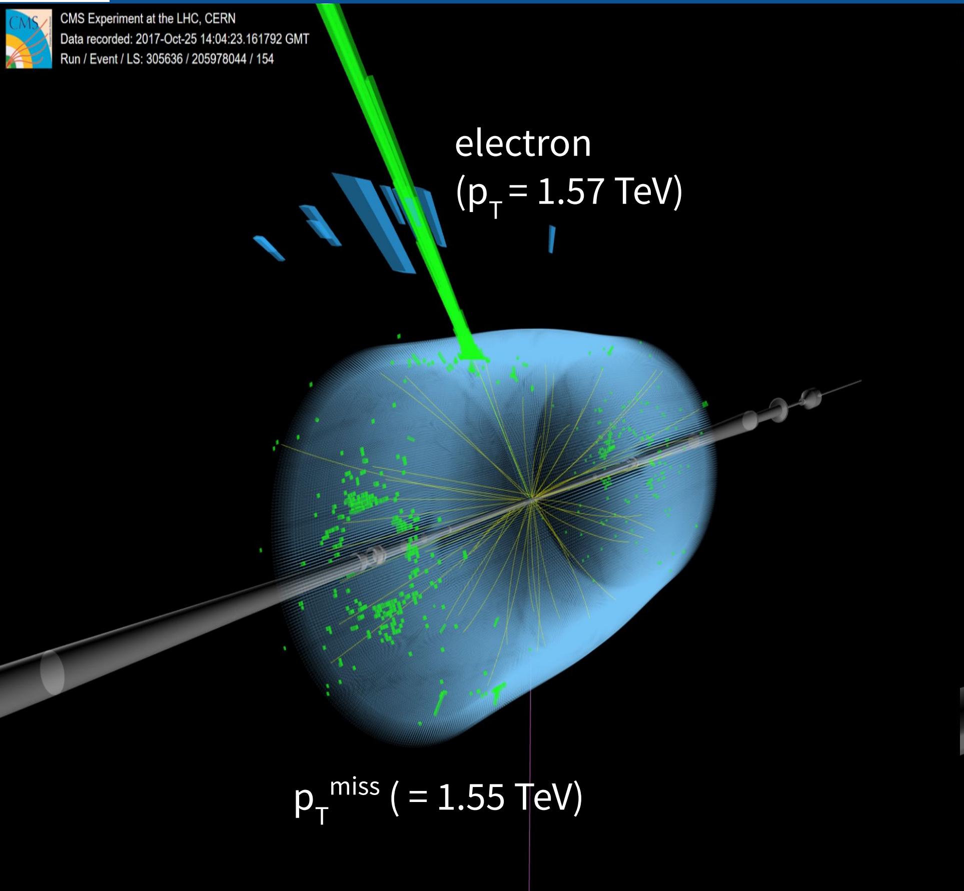




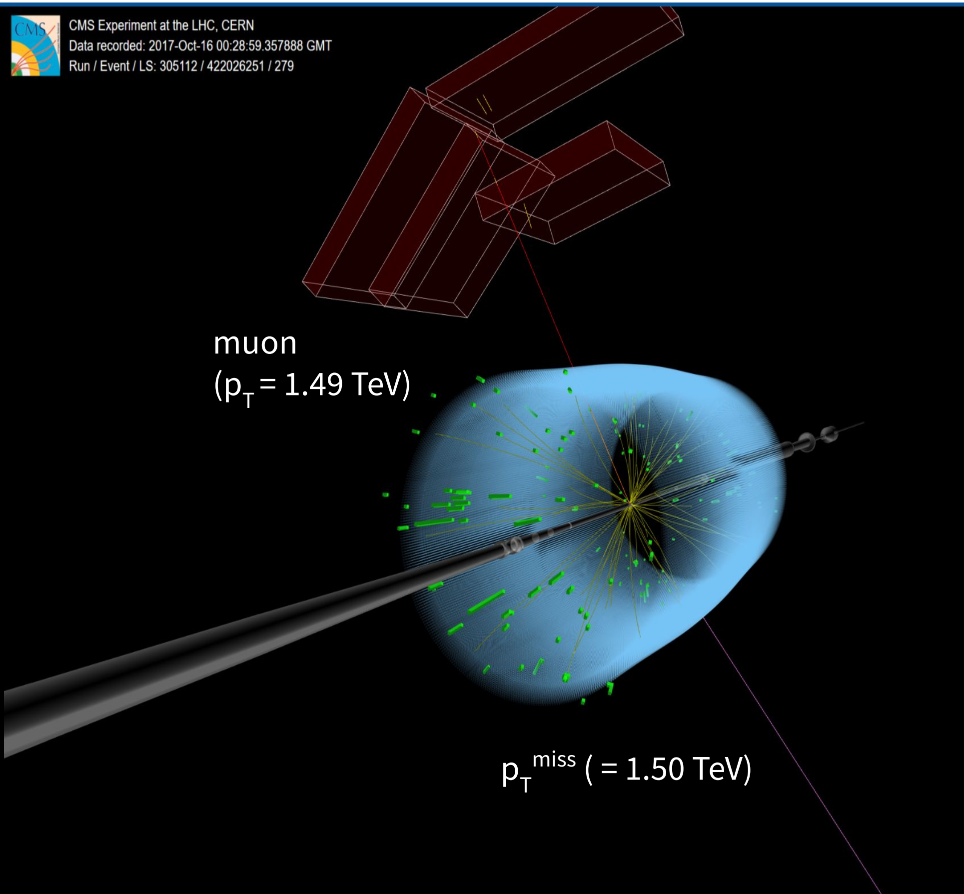
Dominant background is **offshell W** :

- W background estimated by MC (apply NNLO QCD + NLO EW K factor)
- Mass dependent uncertainty (5-20 %)
- PDF uncertainties dominate at high mT (40% beyond 2.0 TeV, from NNPDF3.1)

Highest M_T event display (2016 - 2018)



highest M_T (3.1 TeV) in 2017-10-25



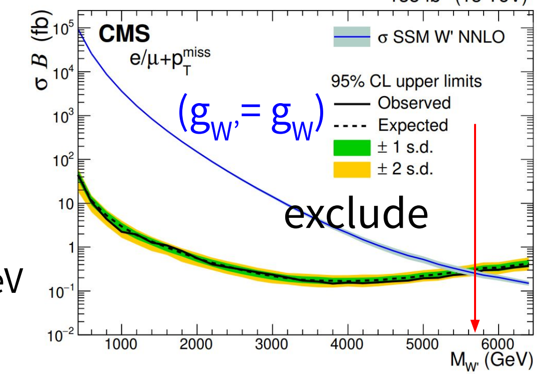
highest M_T (2.9 TeV) in 2017-10-16

Results of the resonant searches

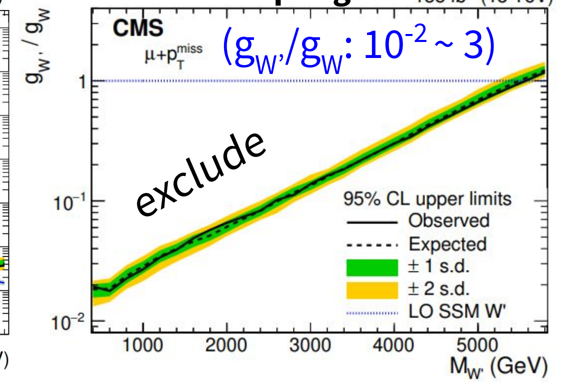
Observed (expected) Limits @ 95%CL

- **SSM W' benchmark** mass Limit
  ⇒ $\mathbf{M_{W'} < 5.7\ (5.6)\ TeV}$ excluded (e+μ)
- **SSM W' Coupling** Limit
  ⇒ $g_{W'}/g_{SM} > 0.027\ (0.029)$ excluded $M_{W'} = 1$ TeV
- **Split-UED** Limit (W^2_{KK})
  R (Radius of ED), $M(W^2_{KK}) \propto 1/R$
  μ (a bulk mass parameter) : 0.05~10 TeV
  ⇒ $1/R < 2.8\ (2.7)$ TeV excluded at $\mu = 2$ TeV
- **RPV SUSY scalar τ** Limit
  λ'_{3ij}(production coupling) : 0.05 ~ 0.5
  λ_{231}, λ_{132}(decay coupling) : 10^{-3} ~ 0.5
  ⇒ $\lambda_{231} > 3.7\ (4.6)\ \times 10^{-3}$ for e channel,
  $\lambda_{132} > 4.7\ (4.7)\ \times 10^{-3}$ for μ channel
  excluded when $M_{stau} = 1$ TeV, $\lambda'_{3ij} = 0.5$

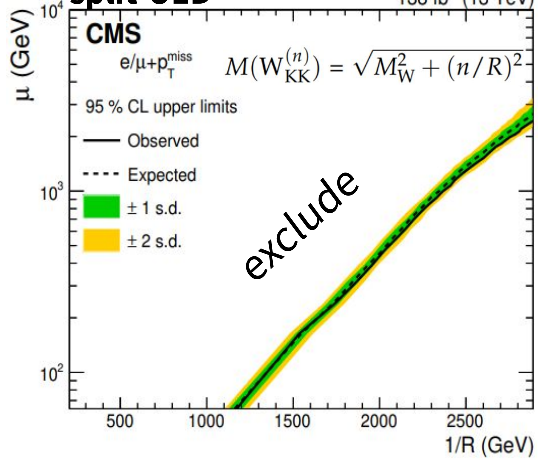
SSM W' benchmark



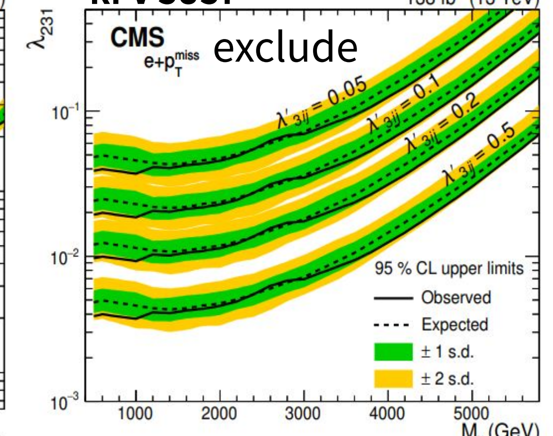
SSM W' Coupling



split-UED

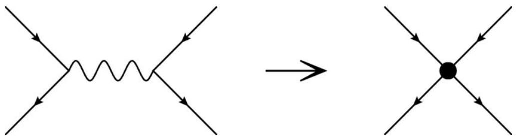


RPV SUSY



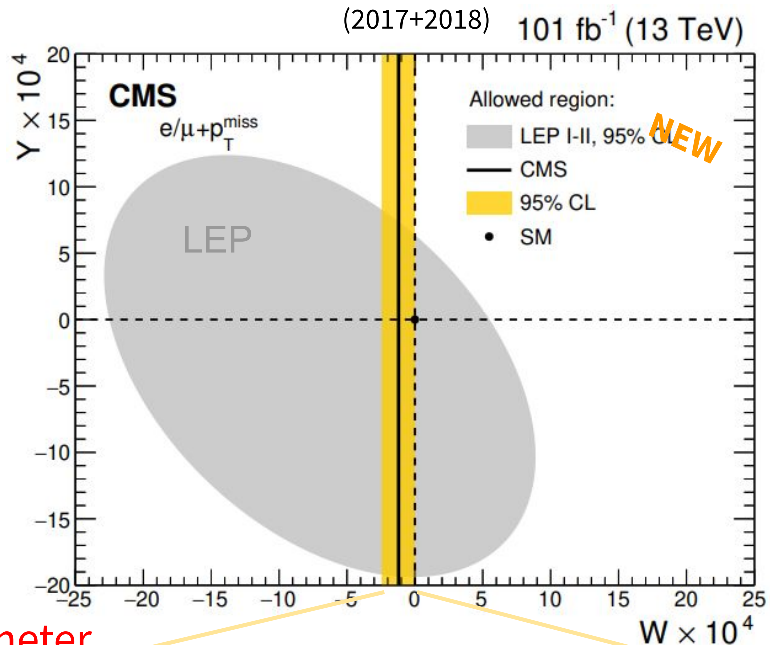
Result of EFT approach : oblique W

4-fermion contact interaction



$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \boxed{\frac{W\,(q^2 - m_W^2)}{m_W^2}}\right)^2$$

SM EWK deviation weight $\propto q^4$



W oblique parameter

$$W = -1.2^{+0.5}_{-0.6} \times 10^{-4}$$

Gray-shaded area : Previous constraint from LEP experiment

PLB772(2017)210
JHEP02(2016)086

These are the first results using LHC dataset in $\ell\nu$ channel!

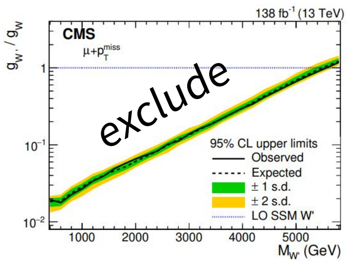
Result of Higgs Compositeness

Constraint on **Higgs** measurement

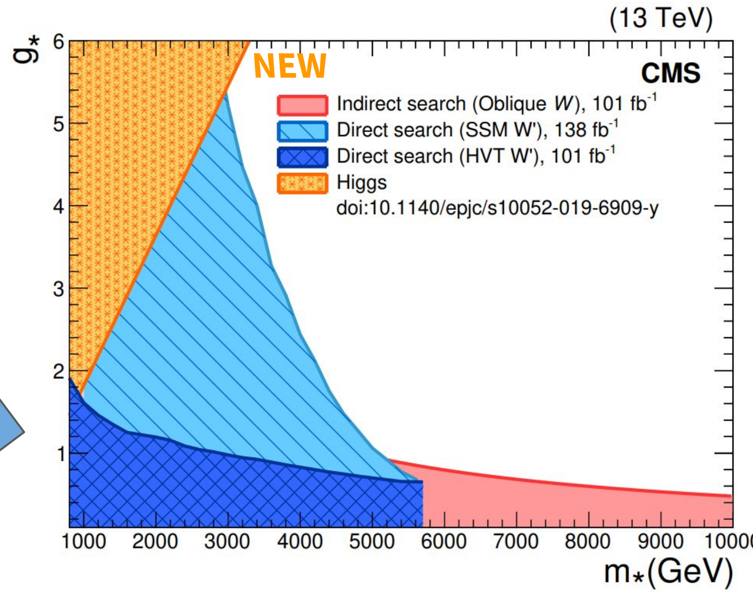
$\Delta\mu_H < 0.20$ at 95% CL

Direct Search

coupling limits (SSM) (HVT)



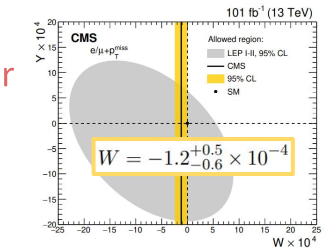
Strongly-Interacting Light Higgs(SILH) framework



extended to 10 TeV scale

Indirect Search

EFT *W* parameter



Set new constraints on composite Higgs model parameter (m*-g*) with 3 different ways.

These are the first results using LHC dataset in $\ell\nu$ channel!

Composite Higgs Limit

⇒ $m_* \leq 3$ TeV excluded in SSM

⇒ $m_* \leq 1$ TeV excluded in HVT model

$\tau + P_T^{miss}$ search strategy

- **Trigger**
  Single τ with $p_T > 180$ GeV, $|\eta| < 2.1$
  OR with $p_T^{miss} > 120$ GeV
- **DeepTAU ID** Tight Working Point (vs. jet/e/μ)
- Offline tau $p_T > 190$ GeV and $p_T^{miss} > 200$ GeV

Decay mode	Resonance	$\mathcal{B}$ (%)
Leptonic decays		35.2
$\tau^- \to e^- \overline{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \overline{\nu}_\mu \nu_\tau$		17.4
Hadronic decays		64.8
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	25.9
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other		3.3

Background

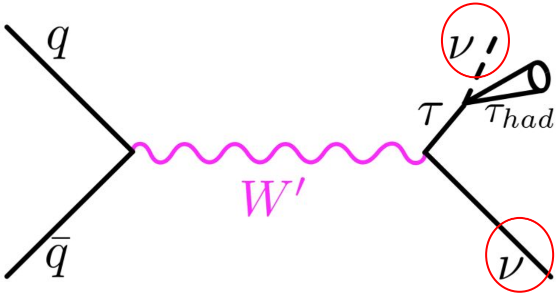
Simulation : SM W+jets, DY+jets, Top(tt, single top), Diboson(WW, WZ,ZZ)

Data-driven : Mis-identification of jets → τ_{had} (Mostly from the multijet QCD) ABCD method

Additional cuts :

Type-1 corrected p_T^{miss}

Vetoing additional electron, muon (loose ID $p_T > 20$ GeV)



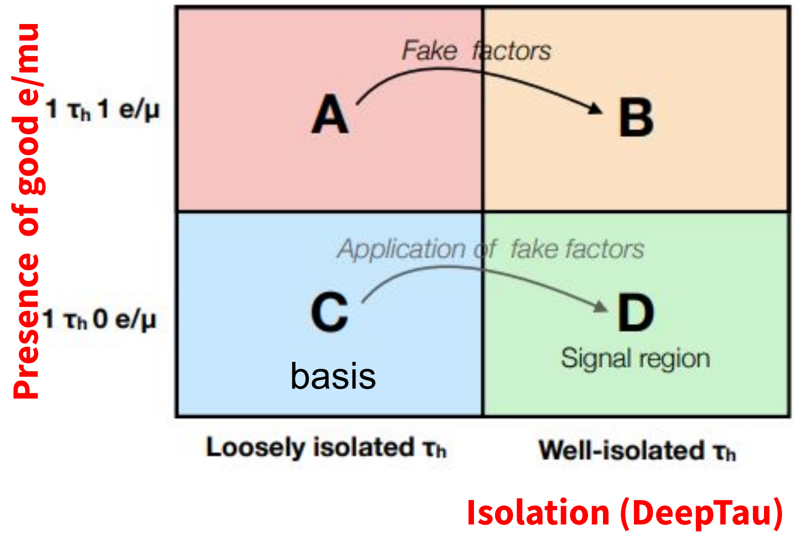
Kinematic cuts :

back-to-back : $\Delta\phi(\tau, p_T^{miss}) > \cancel{2.5}\ 2.4$ and Energy balanced : $\cancel{0.4}\ 0.7 < p^{\tau}_T / p_T^{miss} < 1.3$

high p_T Tau fake estimation

ABCD method is used with 4 orthogonal event categories :

- Fake tau shape is obtained in C by subtracting MC with genuine tau from data
- Fake Rate (FR) obtained in B / A, to determine the normalization in the D



Signal Region D (Well-isolated τh)

Signal Region D' (for High-p_T validation region) :

- $p^{\tau h}_T/p_T^{miss} > 1.5$ and other cuts are identical to D

Control Region C (Loosely-isolated region) :

- τh fail the DeepTau Tight WP but pass the DeepTau VVVLoose WP τh vs. jets and other cuts are identical to D

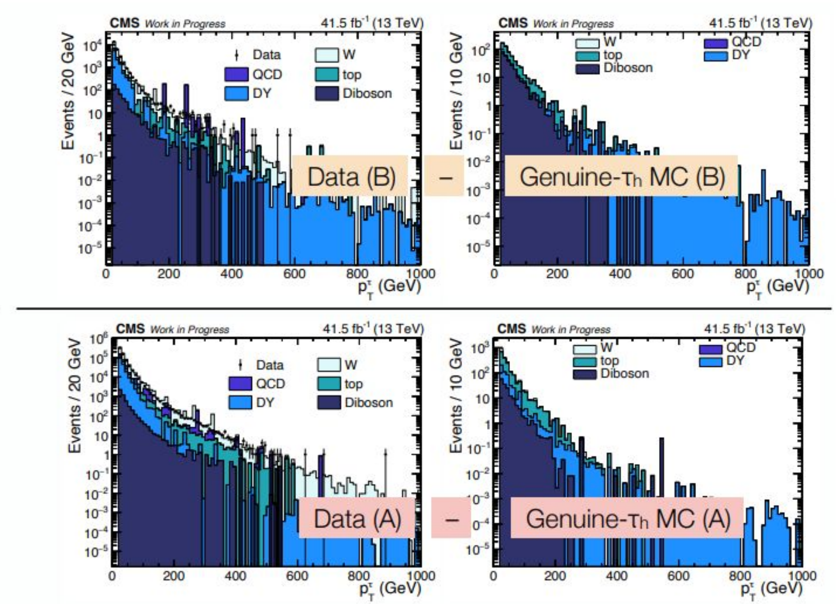
Control Region A and B (Single-lepton sideband regions) :

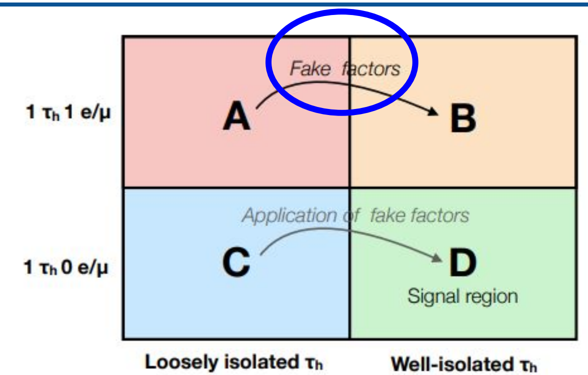
- One well-identified/isolated **e (or μ) is required** (p_T > 40 (53) GeV, same charge as τh) and other cuts are identical to C and D

Picture made by Santeri Laurila @cern

How to measure Fack Factor

Fake Rate (FR) =





Apply the FR on an event basis to **region C** and normalize by removing Genuine true τh from MC from A and B sideband region

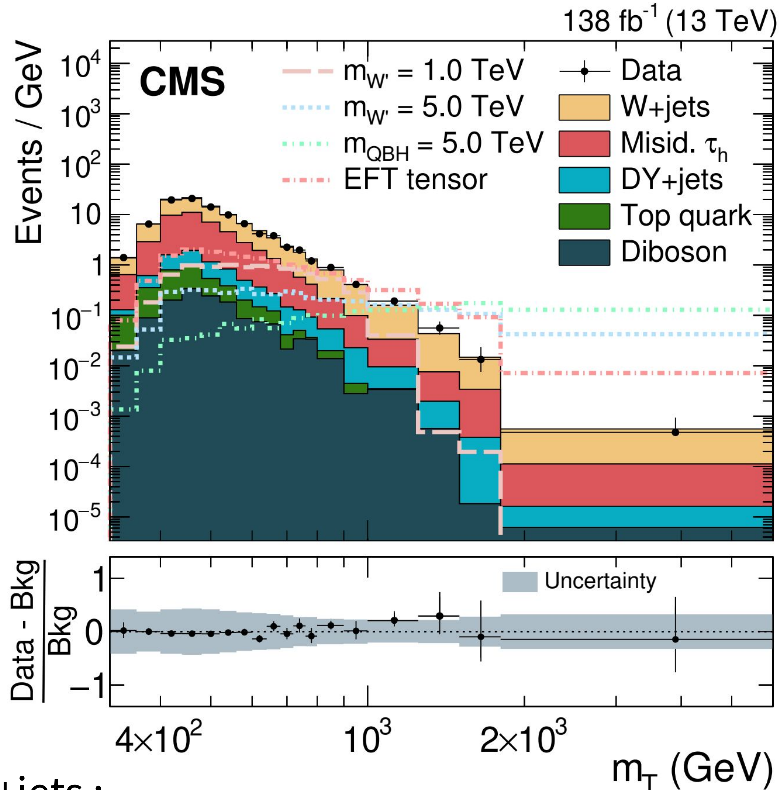
- High Probability for **a jet → fake an energetic τh** (p_T=100–200 GeV) 32 %, (p_T > 200 GeV) 69 %
- A jet is easier to fake **1-prong τh ($h^\pm$)** τh (p_T=100–200 GeV) 17 %, (p_T > 200 GeV) 37 %

FR (2018) for $p^{\tau h}_T$ range and τh decay mode

2018

p_T^τ range (GeV)	τ DM	FR Ele	FR Muon	FR e/mu Combined	FR high pt-ratio region
100 – 200	$h^\pm$	$0.17^{+0.02}_{-0.01}$	$0.16^{+0.02}_{-0.02}$	$0.17^{+0.01}_{-0.02}$	-
100 – 200	$h^\pm\pi^0$	$0.09^{+0.00}_{-0.01}$	$0.08^{+0.00}_{-0.01}$	$0.08^{+0.01}_{-0.00}$	-
100 – 200	$h^\pm h^\mp h^\pm$	$0.05^{+0.01}_{-0.00}$	$0.05^{+0.00}_{-0.01}$	$0.05^{+0.00}_{-0.00}$	-
100 – 200	$h^\pm h^\mp h^\pm\pi^0$	$0.03^{+0.00}_{-0.01}$	$0.01^{+0.01}_{-0.00}$	$0.02^{+0.00}_{-0.00}$	-
> 200	$h^\pm$	$0.43^{+0.10}_{-0.09}$	$0.31^{+0.08}_{-0.06}$	$0.37^{+0.06}_{-0.06}$	$0.38^{+0.10}_{-0.07}$
> 200	$h^\pm\pi^0$	$0.23^{+0.03}_{-0.02}$	$0.17^{+0.02}_{-0.02}$	$0.20^{+0.02}_{-0.02}$	$0.15^{+0.04}_{-0.03}$
> 200	$h^\pm h^\mp h^\pm$	$0.07^{+0.01}_{-0.01}$	$0.07^{+0.02}_{-0.01}$	$0.07^{+0.01}_{-0.01}$	$0.06^{+0.03}_{-0.02}$
> 200	$h^\pm h^\mp h^\pm\pi^0$	$0.05^{+0.01}_{-0.01}$	$0.06^{+0.01}_{-0.01}$	$0.05^{+0.01}_{-0.01}$	$0.07^{+0.02}_{-0.03}$

M_T distribution



Dominant background is W+jets :

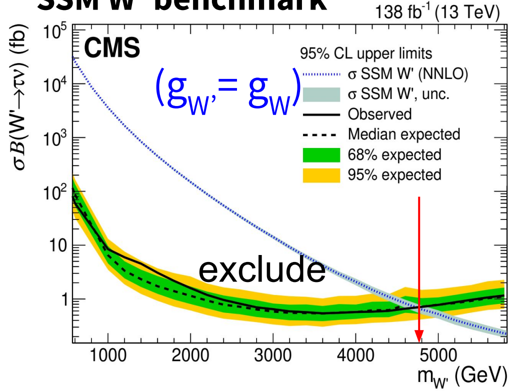
- W+jets background estimated by MC (apply NNLO QCD + NLO EW K factor)
- Mass dependent K factor uncertainty (5-20 %)
- Dominant error : PDF uncertainties (from NNPDF3.1) at high m_T (50% over 1.8 TeV)

Results of the resonant searches

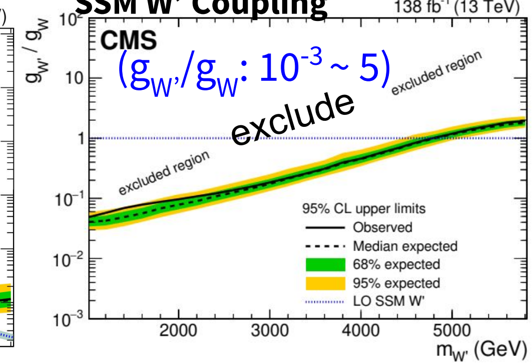
Observed (expected) Limits @ 95% CL

- **SSM W' benchmark** mass Limit
  $\Rightarrow M_{W'} < 4.8\ (4.8)$ TeV excluded
- **SSM W' Coupling** Limit
  $\Rightarrow g_{W'}/g_{SM} > 0.05\ (0.05)$ excluded $M_{W'} = 1$ TeV
- **Quantum Black Holes (QBH) Limit**
  $\Rightarrow M_{QBH} < 6.6\ (6.6)$ TeV excluded
- **Non-Universal Gauge Interaction Model (NUGIM)** Limit
  $\Rightarrow M_{W'} < 4.8\ (4.8)$ TeV excluded @ $\cot(\theta_E)=1$
  $\Rightarrow M_{W'} < 2.2\ (2.4)$ TeV excluded @ $\cot(\theta_E)=5.5$

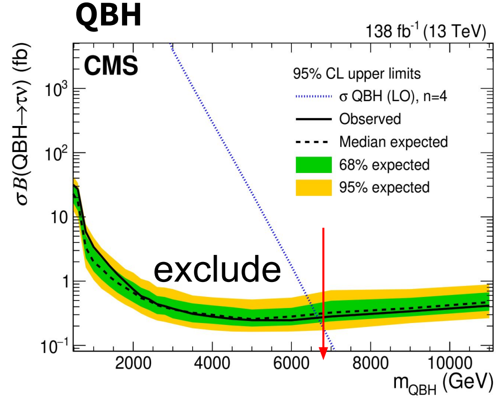
SSM W' benchmark



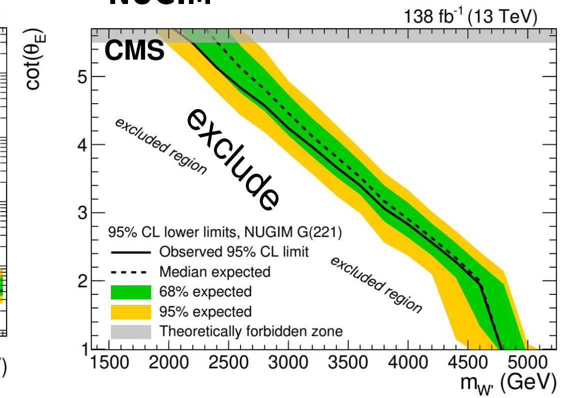
SSM W' Coupling



QBH



NUGIM



Mixing angle $\cot(\theta_E)=1$ corresponds to SSM, $\cot(\theta_E) > 5.5$ forbidden (gray)

Enhanced BR for decays into 3rd generation fermions.

Results of the non-resonant searches

Observed (expected) Limits @ 95% CL

- **EFT approach**

  Wilson Coefficient for $b \to c$ transition

  Vector ($\varepsilon^{cb}L$), Scalar ($\varepsilon^{cb}SL$), Tensor ($\varepsilon^{cb}T$)

  $\Rightarrow \varepsilon^{cb}_{L} > 0.32$ (0.27) excluded

  $\Rightarrow \varepsilon^{cb}_{S} > 0.51$ (0.41) excluded

  $\Rightarrow \varepsilon^{cb}_{T} > 0.27$ (0.22) excluded (most stringent)

- **Leptoquark (LQ) in t-channel**

- **LQ democratic flavor**

  $\Rightarrow M_{LQ} < 5.9$ (6.7) TeV @ $g_U = 1.0$

- **LQ Best-fit LH**

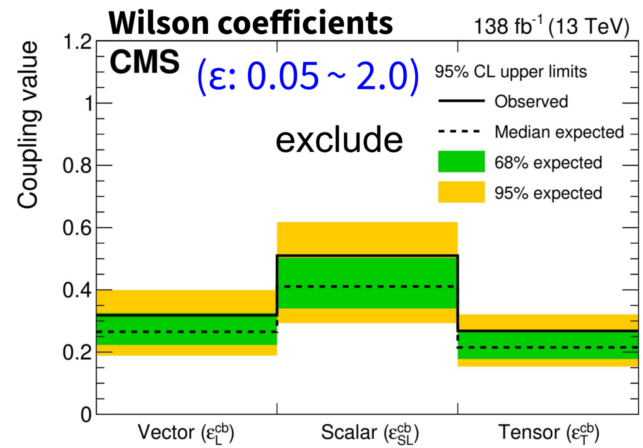
  $\Rightarrow M_{LQ} < 0.21$ (0.15) TeV @ $g_U = 1.0$

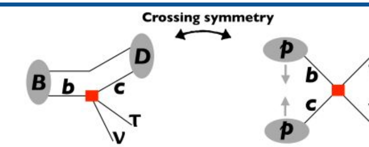
  $\Rightarrow M_{LQ} < 1.5$ (1.8) TeV @ $g_U = 2.5$

- **LQ Best-fit LH+RH**

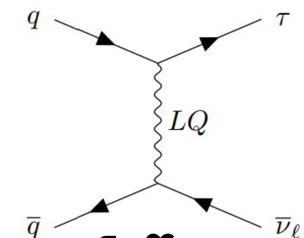
  $\Rightarrow M_{LQ} < 0.52$ (0.65) TeV @ $g_U = 1.0$

  $\Rightarrow M_{LQ} < 2.5$ (3.0) TeV @ $g_U = 2.5$



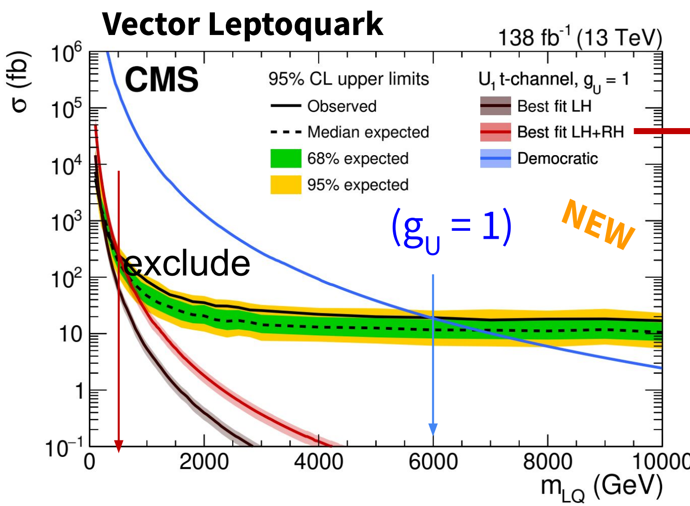


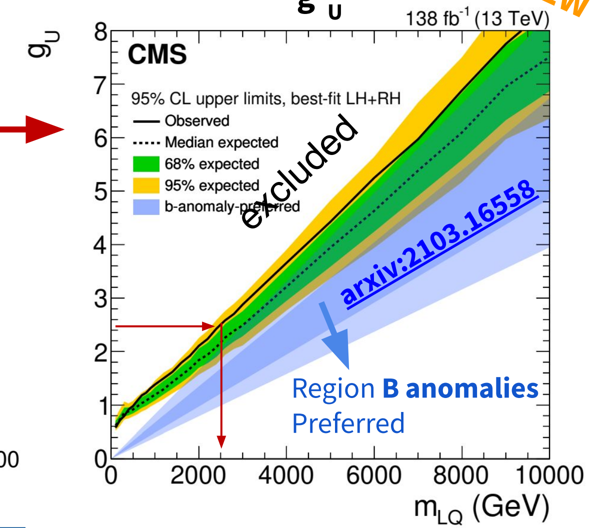
PRD.(2016)94.094012



$\sigma_{LQ} \propto g^4_U$

NEW





Conclusion

- We explore new physics phenomena in lepton(e/μ/τ) + p_T^{miss} final state with 13 TeV full Run 2 dataset (138 fb^{-1}).
- Focus on the high mass regions, but also the low coupling realms
- No obvious sign for BSM physics have shown up yet.
- 95% CL Limits in various BSM models have been derived.

- For Run-3 with new com energy 13.6 TeV, searches is going on (in early stage), improving upon new reconstruction techniques/new search strategies like charge asymmetry, flavor ratio study ..etc , in the hope to get some signal or clear deviation from SM.

Thank you for your attention.

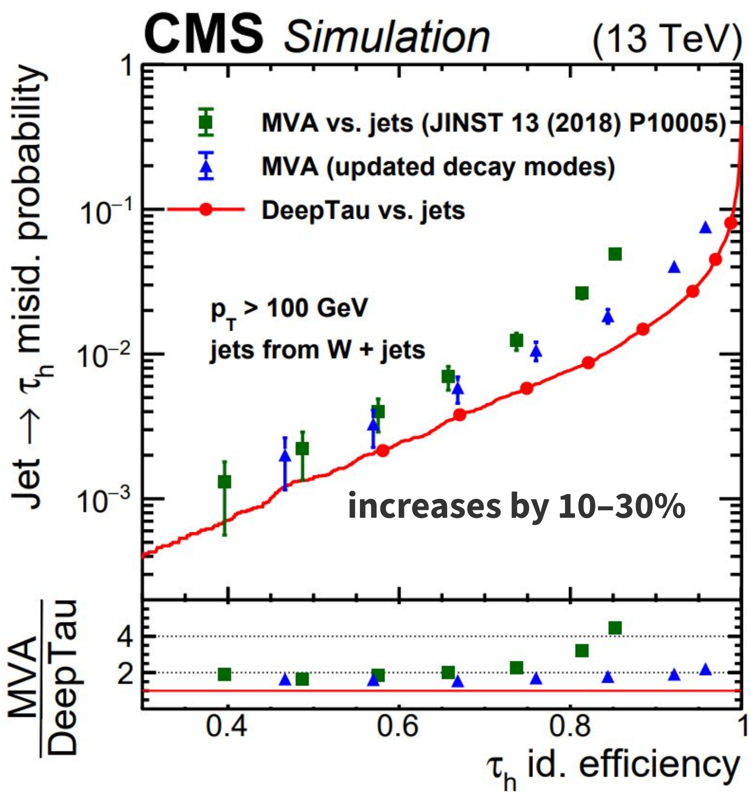
backup

References for BSM theories

- **Sequential Standard Model (e,μ,τ)**
  - Phys. Rev. D 11 711 (1975) 2558, Z. Phys. C 45 (1989) 109
- **Heavy Vector Triplet Model (e,μ)**
  - JHEP 09 (2014) 060
- **Non Universal Gauge Interaction Model (τ)**
  - arxiv:1408.0914
- **Universal Extra Dimensions (e,μ)**
  - Phys. Rev. D 64 (2001) 035002, JHEP 09 730 (2009) 078, JHEP 728 04 (2010) 081
- **R-parity violating Supersymmetry (e,μ)**
  - Phys. Lett. B 76 (1978) 575, Phys. Rev. D 86 (2012) 055010
- **Quantum Black Hole (τ)**
  - J.Phys.G37:105108,2010
- **Higgs Composite Model (e,μ)**
  - JHEP 06 (2007) 045, JHEP 07 (2015) 100
- **Effective Field Theory :** Oblique *W* and *Y* parameters (e,μ)
  - Phys. Rev. 764 D 46 (1992) 381, Phys. Lett. B 772 (2017) 210
- **Effective Field Theory :** Wilson Coefficient (Coupling parameter) (τ)
  - Phys. Rev. Lett. 122, 131803 (2019), Eur.Phys.J C 77 (2017) no.8, 536
- **Leptoquarks (LQ) in t-channel (τ)**
  - JHEP 08 (2021) 050

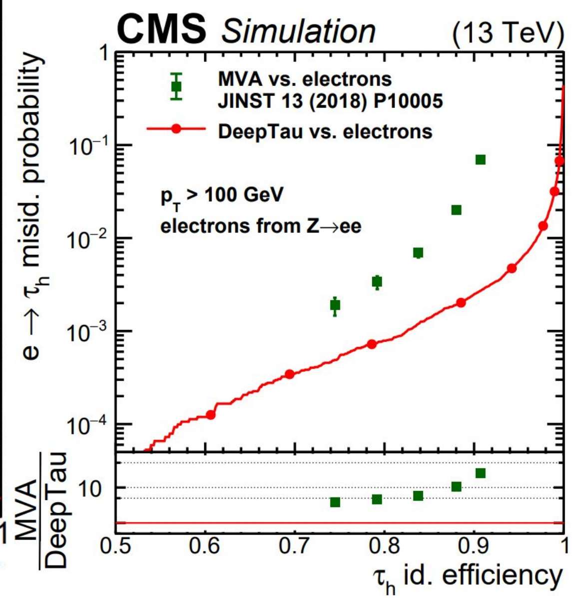
Hadronic tau identification (DeepTAU)

DeepTau vs. jets

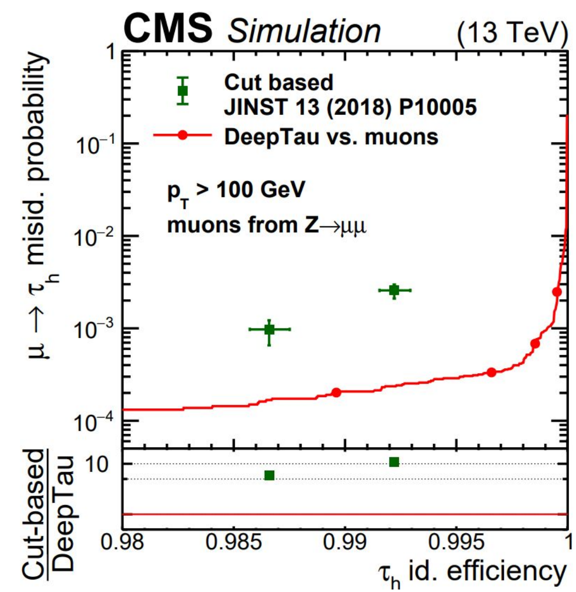


The identification efficiency of genuine τ_h candidates ($p_T > 100$ GeV) provided by the chosen identification method in this analysis is approximately 75%, while the probability of a jet being misidentified as a τ lepton is less than 0.7%. Differences between data and simulation arising

DeepTau vs. electron

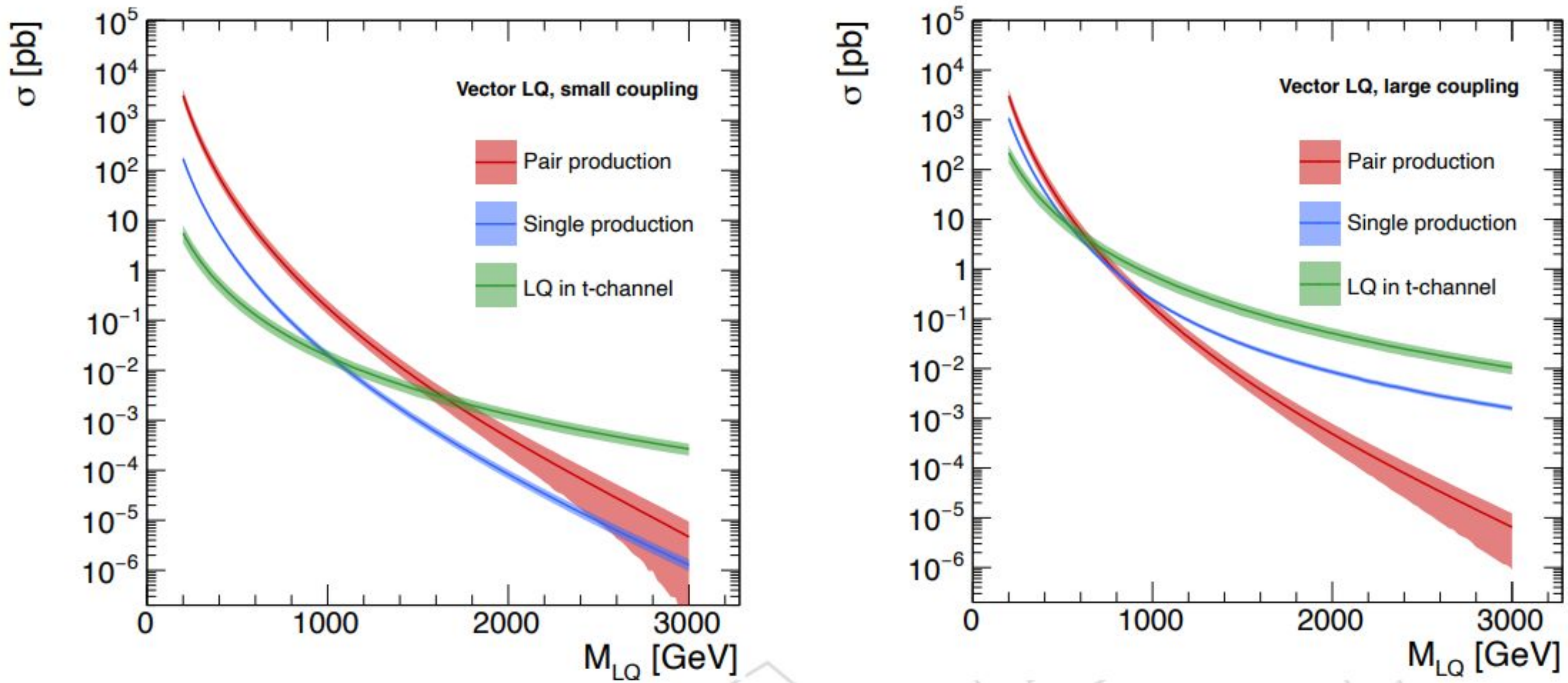


DeepTau vs. muon



Mis-rate (eff for q & g jets to pass different tau id discriminators)
vs. the eff for genuine τh .

LQ Prod. Cross section (Pair, Single, t-ch)

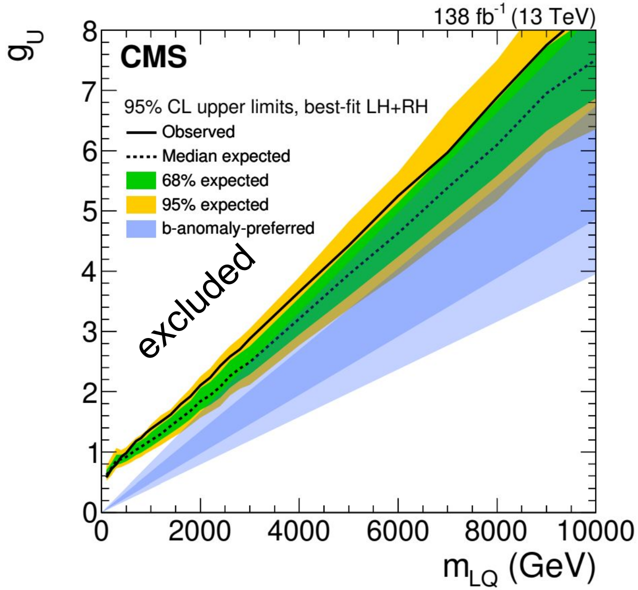


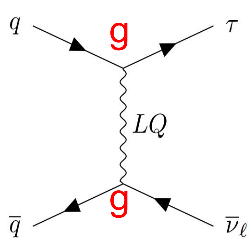
- **LQ pair production** via QCD relies only on LQ mass.
- **For LQ single production**, initial state PDF is important and depends on LQ mass. And the cross section is proportional to the square of the coupling.
- The cross section of **t-channel** is proportional to the 4th power of the coupling.

LQ in the t-channel ($\tau\nu$, $\tau\tau$)

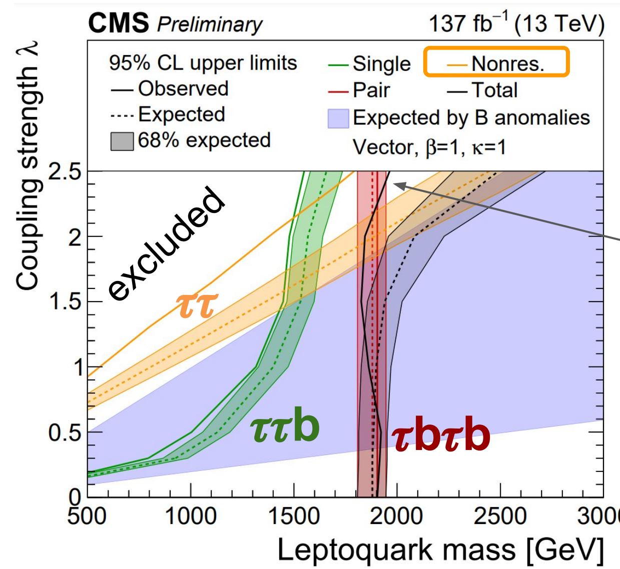
t-channel (non-resonant) production
has higher sensitivity towards high coupling strengths

Bonus

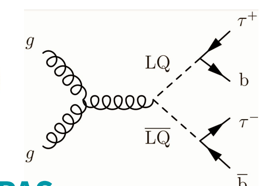


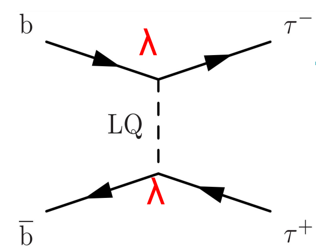


[CMS-EXO-21-009]

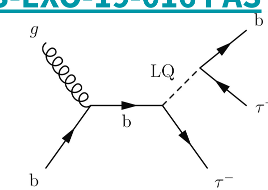


Mild excess (3.4σ) at m_{LQ}=2 TeV, coupling = 2.5



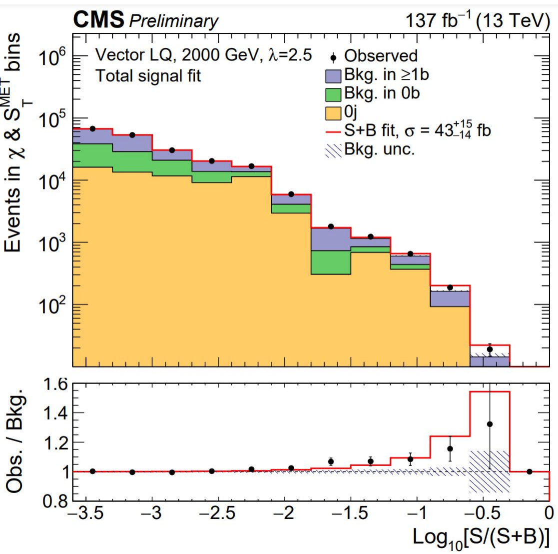


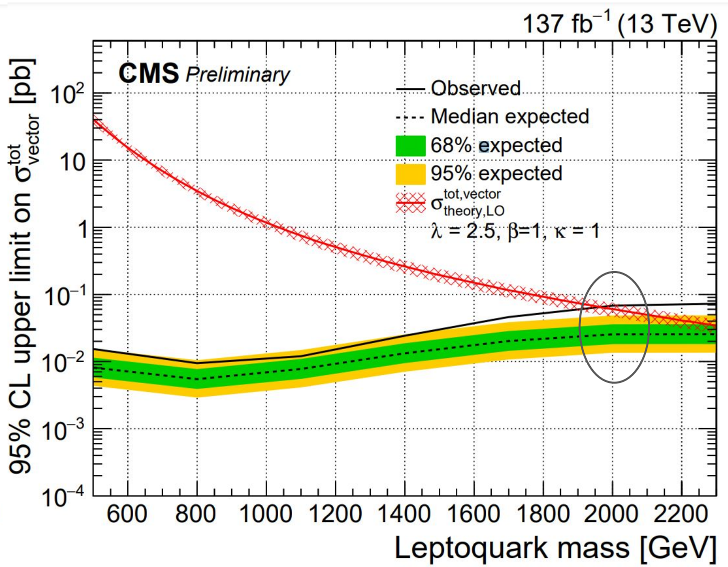
[CMS-EXO-19-016 PAS]

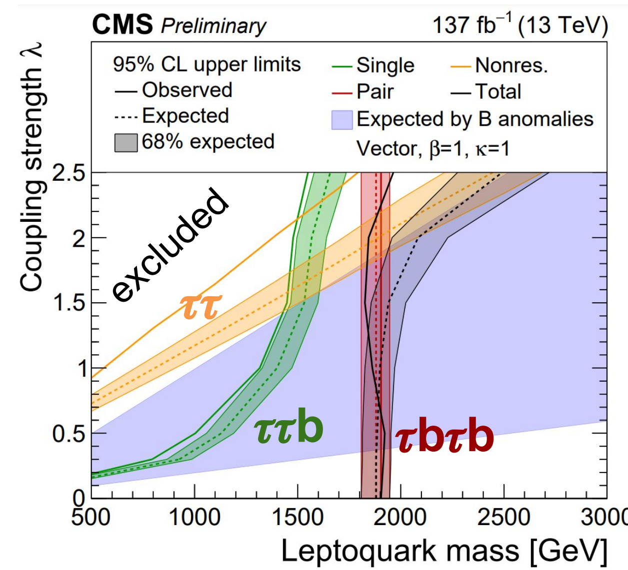


3rd-gen LQ coupling to a τ and a b quark

Please find details at CMS-EXO-19-016 PAS



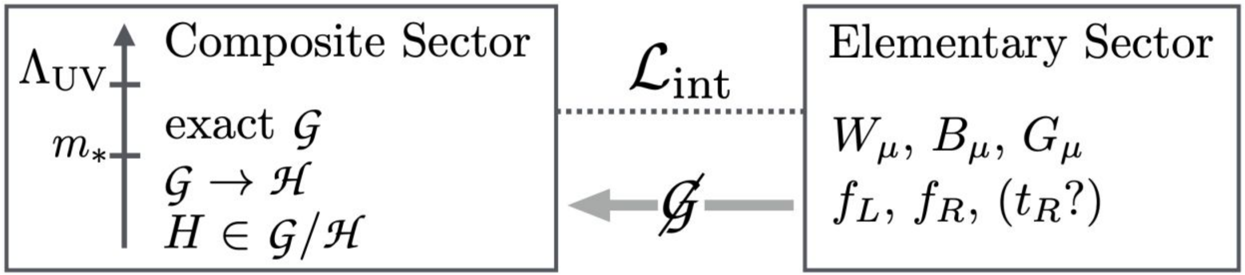


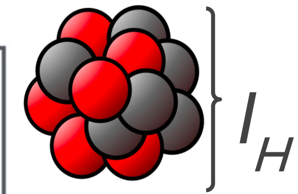


For a representative LQ mass of 2 TeV and a coupling strength of 2.5,
an excess with a significance of **3.4σ** above the SM expectation is observed in the data.

Higgs composite model

The basic structure of the composite Higgs scenario



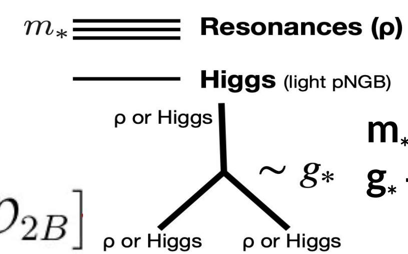


[arxiv:1506.01961](https://arxiv.org/abs/1506.01961)

JHEP06(2007)045

- ➔ Composite sector + Elementary sector (SM quarks, leptons, gauge bosons, no Higgs)
- ➔ Higgs boson = pseudo Nambu-Goldstone boson of broken symmetry
- ➔ It allows Higgs boson to be considerably lighter than confinement scale confinement scale m_*
- ➔ If EWSB effects small (m_* would be ~1 TeV or above)

Predicted new particles!
Additional heavy vector bosons from composite sector dynamics (analogs of **ρ** meson in QCD) and scalars



$m_* \simeq 1 / l_H$
$g_* \in [1, 4\pi]$

$$\mathcal{L}^{d=6}_{universal} = c_H \frac{g_*^2}{m_*^2} \mathcal{O}_H + \frac{1}{g_*^2 m_*^2}\left[c_{2W} g^2 \mathcal{O}_{2W} + c_{2B} g'^2 \mathcal{O}_{2B}\right]$$

scaling all Higgs couplings by a common factor

4-fermion contact interactions, W', Z' resonances

Interplay between indirect and direct search

m∗ : the mass scale of the new spectrum of composite resonances
g∗ : the coupling associated to the new interaction

Important interplay between direct searches for new particles and indirect constraints from precise Higgs measurements and EW parameter.

Direct search for W' in SSM and HVT models

$$g_{W'} = \frac{g^2}{g_*}$$

Indirect constraint on Higgs measurement

$$\Delta\mu_H = \frac{{g_*}^2 v^2}{m_*^2}$$

Indirect constraint on oblique *W* parameter

$$g_*{}^2 = \frac{g^2 M_W^2}{W m_*^2}$$

JHEP06(2007)045

Composite Higgs induces deviations in measurements of the Higgs couplings to SM bosons and fermions)

EPJC79(2019)421

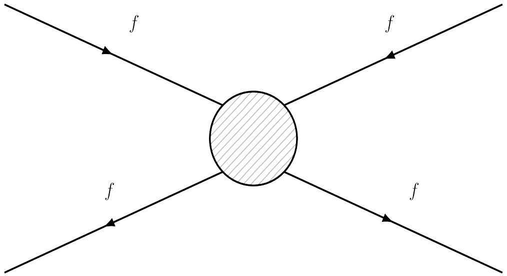
$$\Delta\mu_H < 0.20 \text{ at } 95\% \text{ CL}$$

EFT : oblique W Y parameter

Universal new physics effect in 4-fermion contact interaction

- Universal new physics effects in **4 fermion contact interactions** can be described by the oblique EW parameters ***S, T, W*** **and** ***Y***.
- *W* and *Y* parameters effects ∝ $\sqrt{s}$ = LHC is ideal to test new physics !

- **Idea:** The effect of the new terms in 4-fermion contact interactions is the **modification of propagators** of the SM EWK gauge bosons $P_{W,Y}$, and the relative deviations wrt the SM given by the weight :



$$\frac{g^2 W}{m_W^2}, \frac{g^2 Y}{m_W^2} \rightarrow \frac{coupling^2}{scale^2}$$

New physics

SM

$$\left|\frac{P_W}{P_W^{(0)}}\right|^2 = \left(1 + \frac{(2t^2-1)W}{1-t^2} + \frac{t^2 Y}{1-t^2} - \frac{W\,(q^2 - m_W^2)}{m_W^2}\right)^2$$

quadratic dependence of the new physics deviations with the hard collision energy

t^2 = tangent squared of SM weak mixing angle ~ 0.3

- SM W MC samples are reweighted to this weight with the W-parameter
- A fit between data and reweighted MC BG (dependent on W) yields the W value that makes the BG best reproduce data, constraining the W parameter.

high pt lepton ID Run2

High-p_T electron ID, ISO for Run-2

Variable	Barrel	Endcap
E_T	> 35 GeV	> 35 GeV
η range	$\eta_{sc} < 1.4442$	$1.566 < \eta_{sc} < 2.5$
isEcalDriven	=1	=1
$\Delta\eta_{in}^{seed}$	< 0.004	< 0.006
$\Delta\varphi_{in}$	< 0.06	< 0.06
H/E	<1/E + 0.05	< 5/E + 0.05
full 5x5 $\sigma_{i\eta i\eta}$	n/a	<0.03
full 5x5 E^{2x5}/E^{5x5}	>0.94 OR E^{1x5}/E^{5x5} > 0.83	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et +0.28*rho	<2.5 +0.28*rho for Et<50 else
		<2.5+0.03*(Et-50) +0.28*rho
Track Isol: Trk Pt	<5	<5
Inner Layer Lost Hits	<=1	<=1
dxy	<0.02	<0.05

*Ref. for electron ID (Run-2)
JINST 16 (2021) P05014

High-p_T muon ID for Run-2

The candidate is reconstructed as a Global Muon
At least one muon-chamber hit included in the global-muon track fit or in the TuneP fit
Muon segments in at least two muon stations This implies that the muon is also an arbitrated tracker muon, see SWGuideTrackerMuons
The p_T relative error of the muon best track is less than 30%
Its tracker track has transverse impact parameter d_{xy} < 2 mm w.r.t. the primary vertex
The longitudinal distance of the tracker track wrt. the primary vertex is d_z < 5 mm
Number of pixel hits > 0
Cut on number of tracker layers with hits >5

*Ref. for muon ID (Run-2)
JINST 15 P02027

Run-2 Publication

- **Publication of Run-2 Analysis**

e/μ + MET

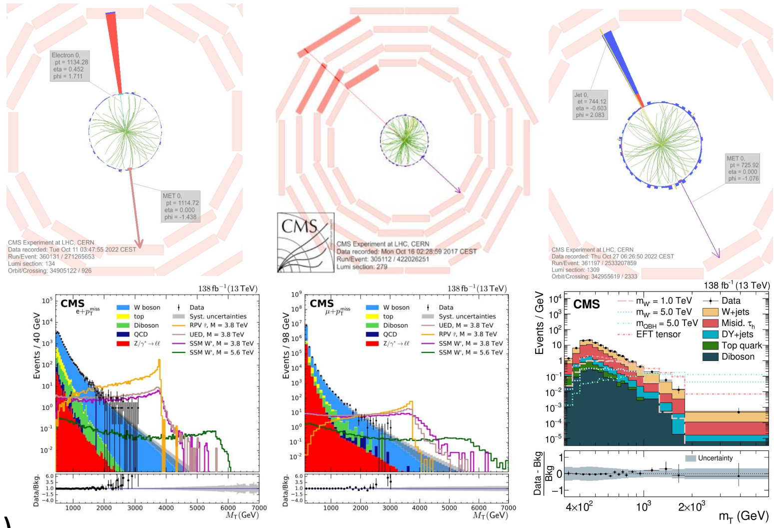
CMS: EXO-16-033, JHEP06(2018)128(2016)
EXO-19-017, JHEP07(2022)067(2016-2018)

ATLAS: EPJC78(2018)401 (2015-2016)
PRD100,052013(2019)(2015-2018)

τ_h + MET

CMS: EXO-17-008, PLB792(2019)107(2016)
EXO-21-009, 2212.12604 Submitted to JHEP(2016-2018)

ATLAS PRL120,161802(2018)(2015-2016)



Main discriminator : Transverse mass

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