Searches for heavy resonances in leptonic final states at CMS in LHC, at $\sqrt{s}$ = 13 TeV

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on behalf of CMS Collaboration

9th International Conference in New Frontiers in Physics (ICNFP)
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CERN CMS GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas cfp CIEMAT física de partículas

Introduction

Many SM extensions predict additional resonances at the TeV energy scale
the identification and measurement of **leptonic resonances** is a critical tool in searching for signatures of new physics: the W, Z and Higgs bosons were discovered using this signature

- ➜ Heavy gauge bosons studied in benchmark models such as SSM, HVT and variation of the coupling respect to the SM doi:10.1103/RevModPhys.81.1199
- ➜ Grand unified theories (GUT): unique G group $E > E_{GUT}$ unifying strong and EWK interactions doi:10.1016/0370-1573(89)90071-9
- ➜ Quantum black holes (QBH): nonthermal objects, that can decay to pairs of particles Phys. Lett. B 668 (2008) 20
- ➜ R-parity violating (RPV) SUSY model with lepton as mediator Phys. Rev. D 86 (2012) 055010
- ➜ Dark Matter JHEP 09 (2009) 078
- ➜ And more…

Additionally, data driven searches interpreted as model independent as possible

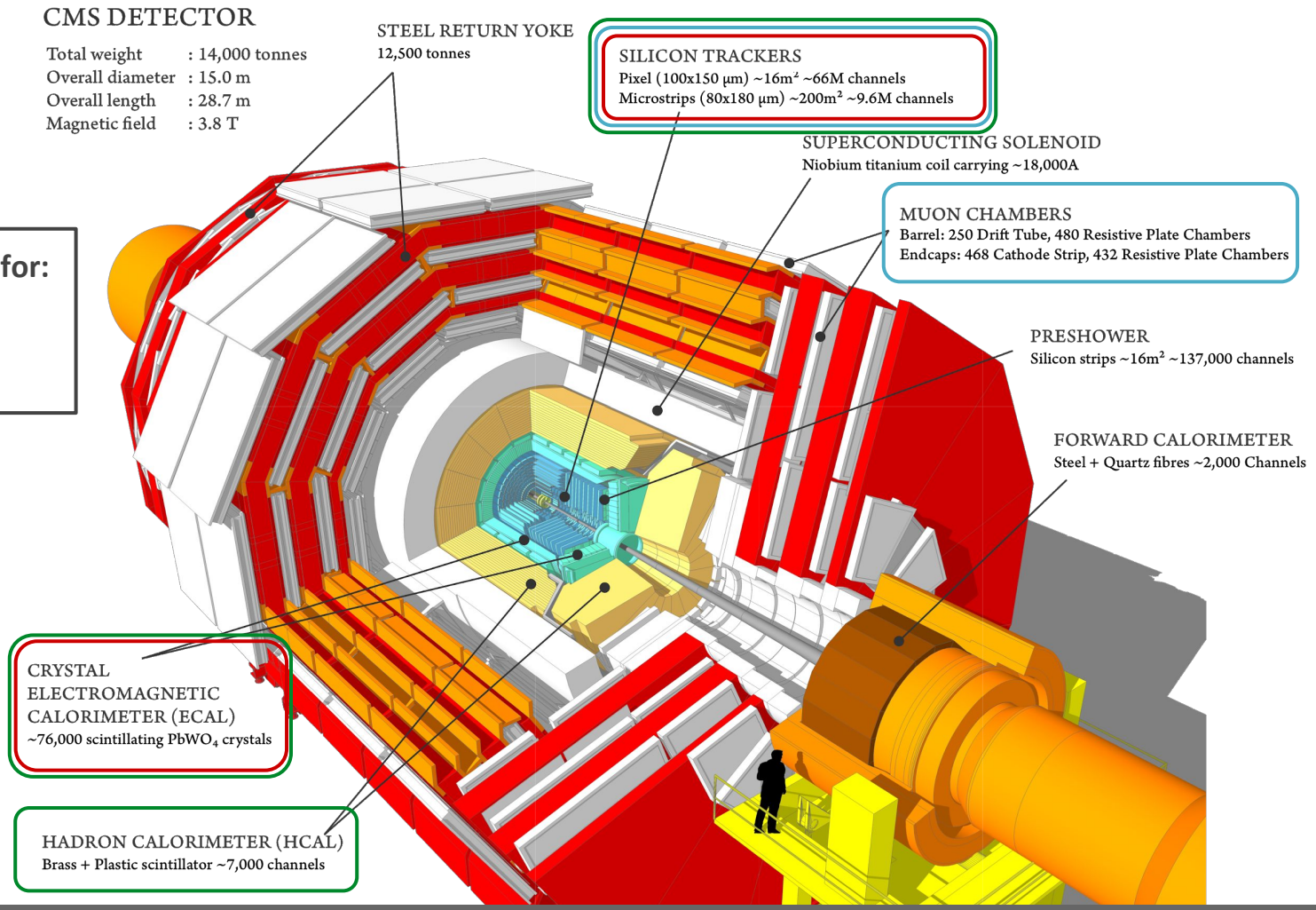
more BSM searches in CMS presented at ICNFP:
7th Sep by Ben Kilminster - Dark Matter searches at CMS
9th Sep by Laurent Thomas - Exotica searches at CMS

CMS experiment at the LHC

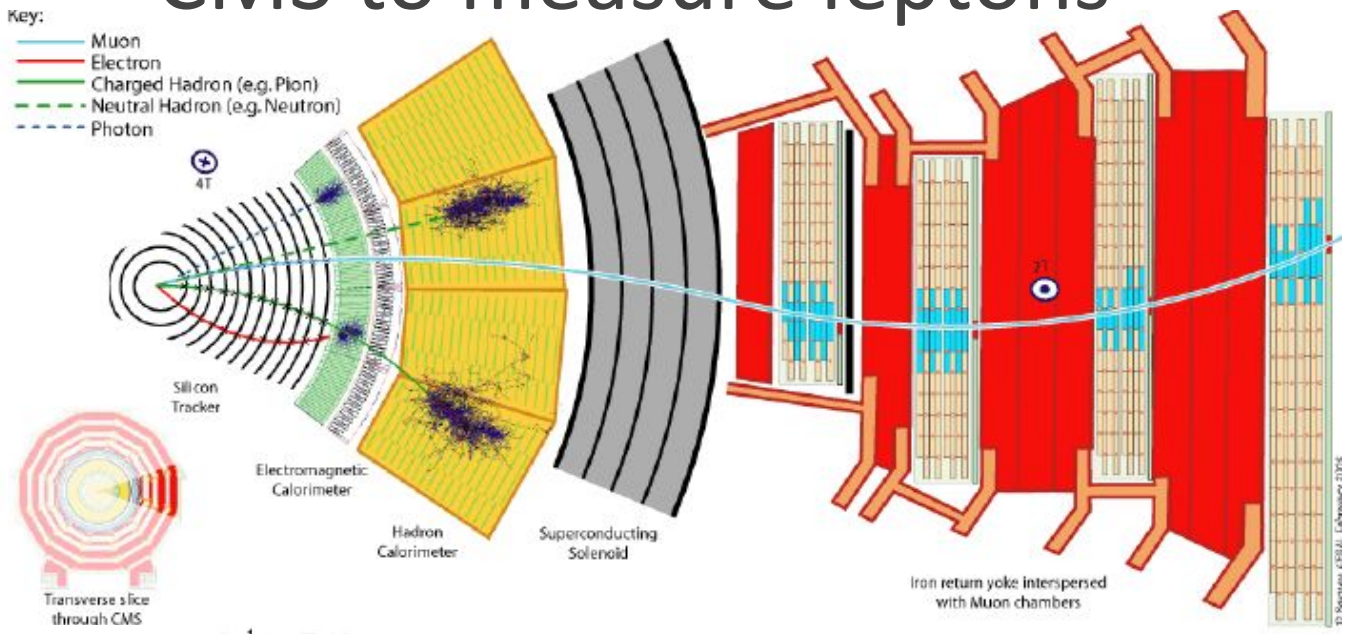
LCH Run II **high statistics and high energy** is a great opportunity for different searches at the **energy frontier**

CMS is an ideal detector to measure leptons with high precision

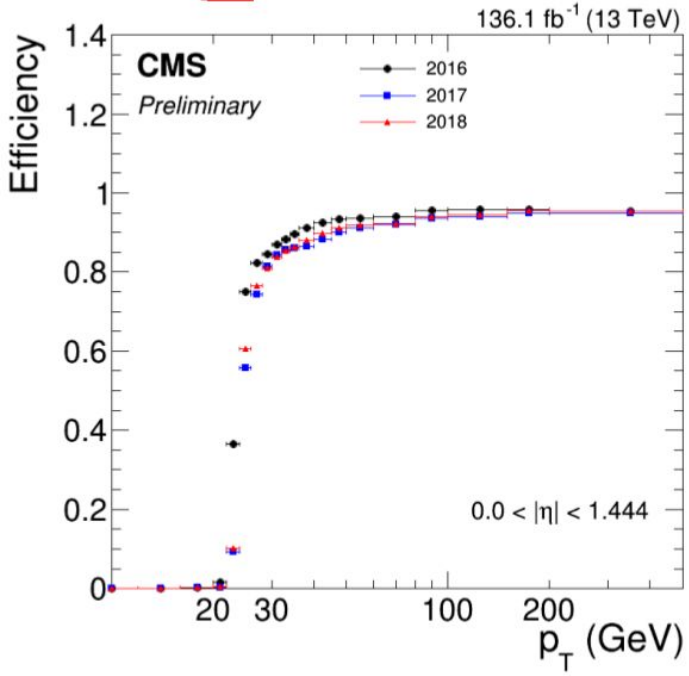
main subdetector for:
- **electron**
- **muon**
- **tau**



CMS to measure leptons



CMS DP-2020/016



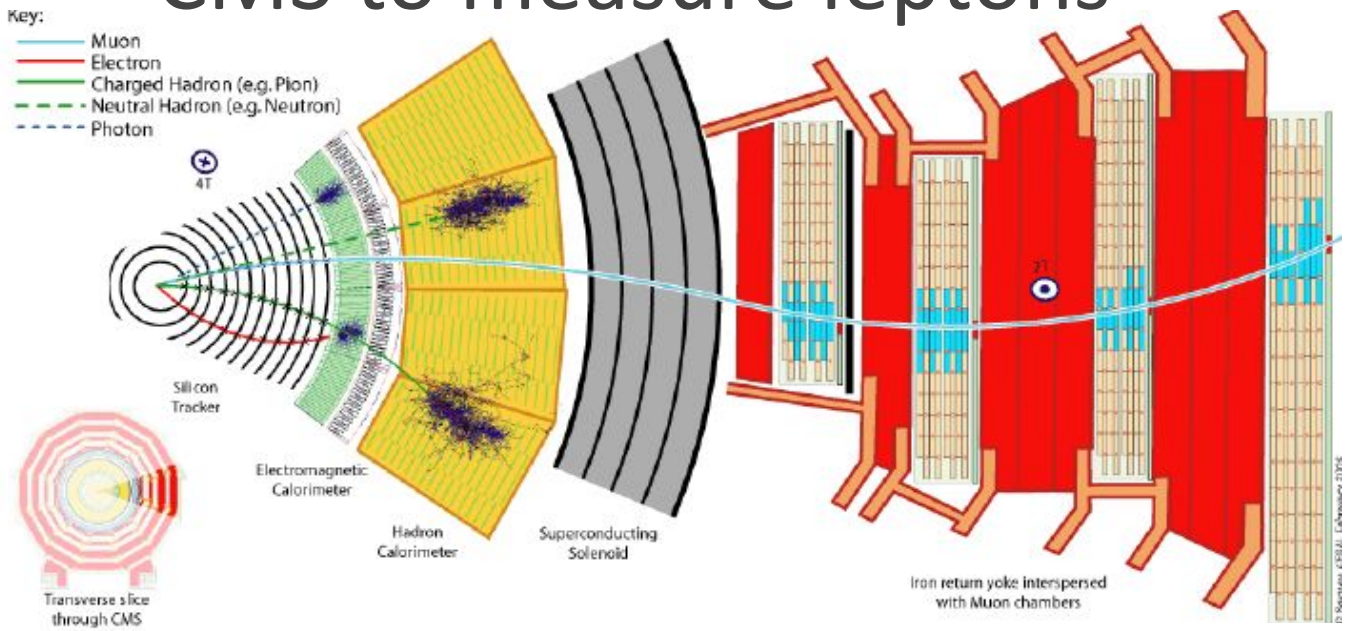
Electrons Si tracker + ECAL, $|\eta| < 2.5$ region.

➜ mass resolution of dielectron event: 1.8% for m > 800 GeV

➜ momentum resolution in Z boson decay from 1.7 to 4.5%

➜ the identification efficiency is ~ 85 - 95 %

CMS to measure leptons



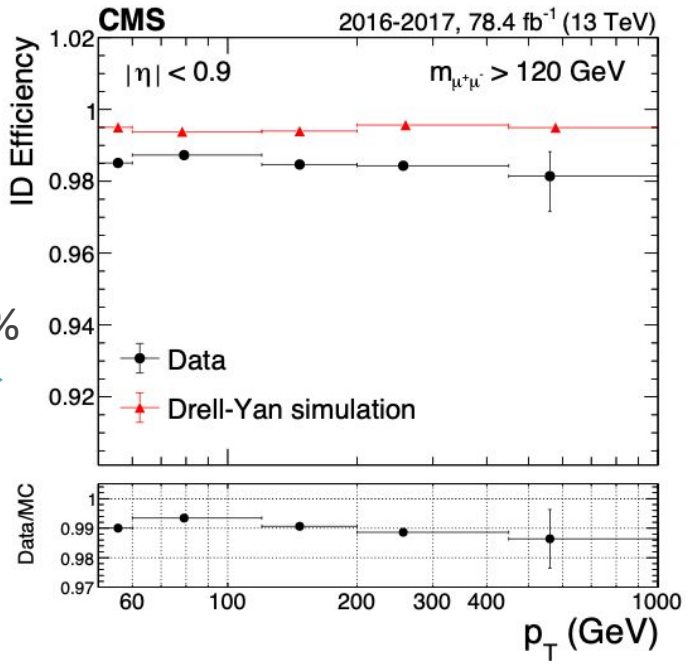
Muons $|\eta| < 2.4$ region

$p_T < 200$ GeV: tracker, with pT resolution of ~1%,

$p_T > 200$ GeV: tracker + muon system (DT, RPC, CSC) with a pT resolution < 4% in the Barrel, the alignment is critical

➜ dimuon mass resolution at Z peak goes from ~1 to 2 GeV

➜ High p_T muons have a high identification efficiency: ~ 99%



CMS has released a dedicated paper about high p_T muons

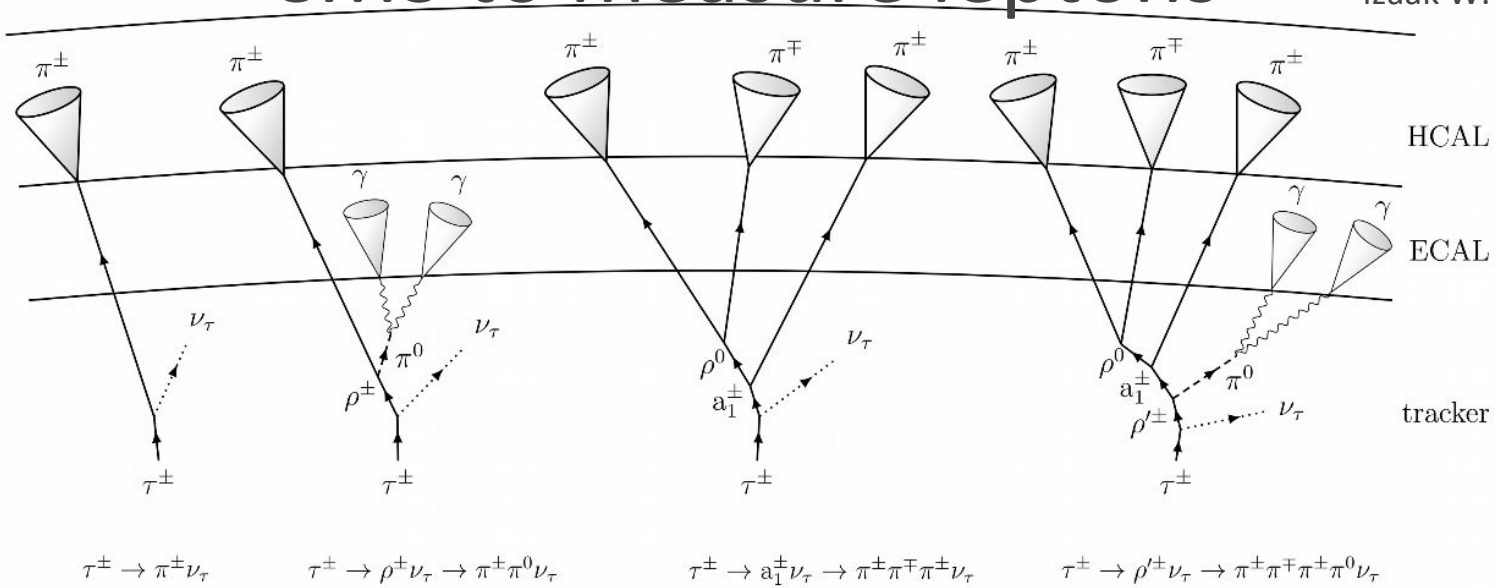
doi:10.1088/1748-0221/15/02/P02027

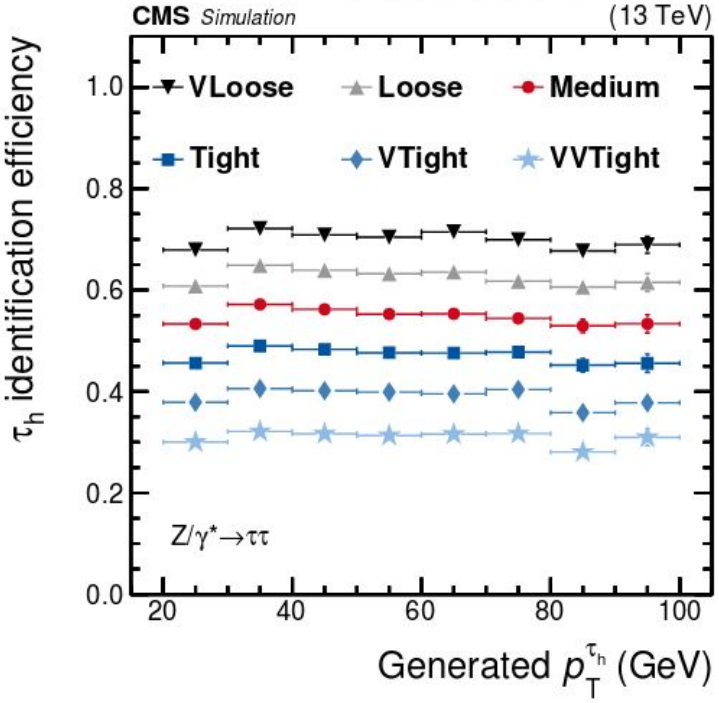
and a physics briefing on high p_T muon reconstruction

http://cms.cern/news/enhancing-muon-compact-muon-solenoid

CMS to measure leptons

image credits to Izaak W. Neutelings



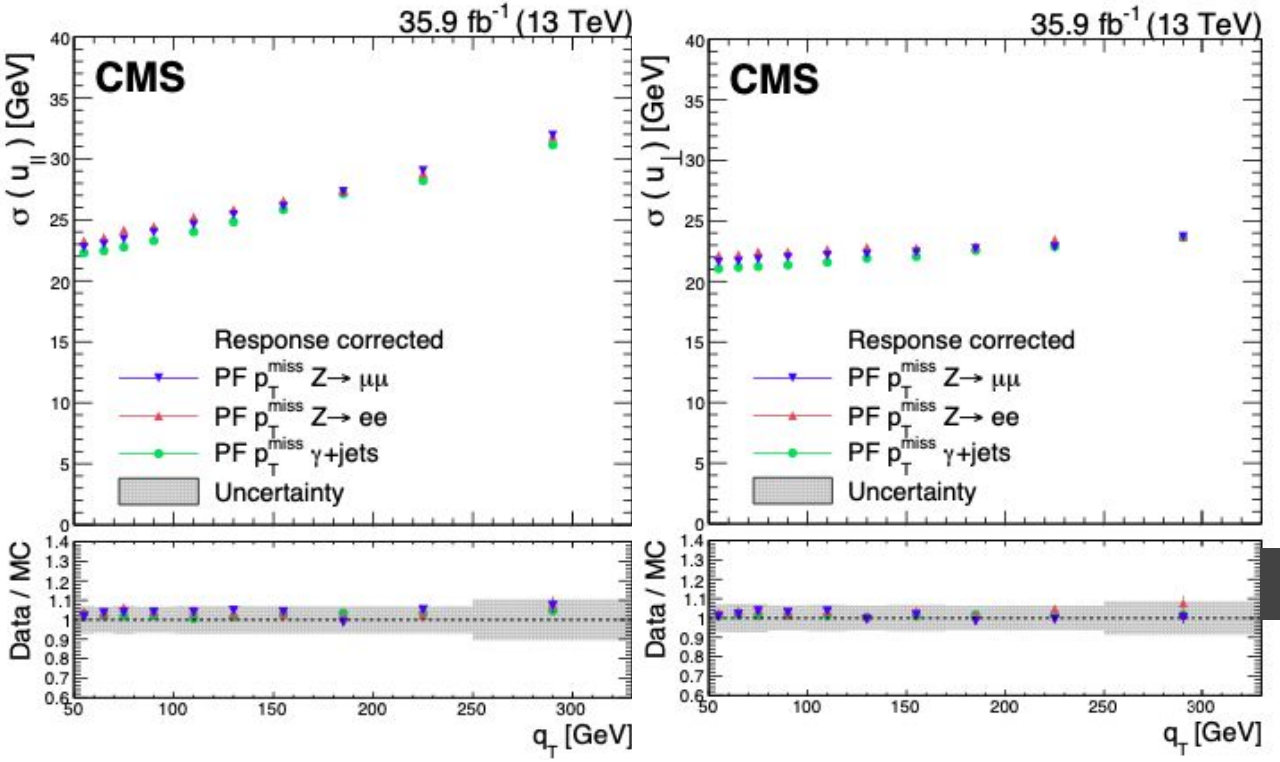


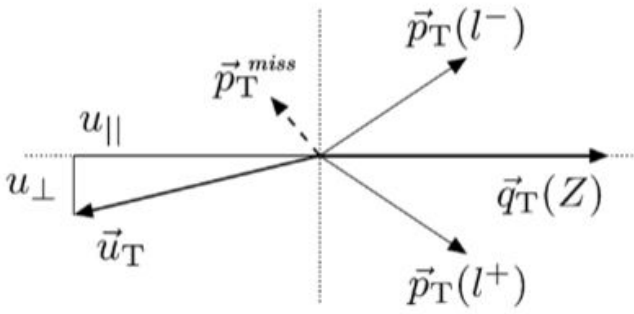
doi:10.1088/1748-0221/13/10/P10005

Tau candidates are reconstructed by considering 4 hadronic decay modes

identification efficiency of ~50 - 60 % with a probability for quark and gluon jets, electrons, and muons to be misidentified as τ lepton of ~10^{-2}-10^{-3}

CMS to measure leptons





10.1088/1748-0221/14/07/P07004

neutrinos and other undetectable particles create p_T imbalance (p_T^{miss})

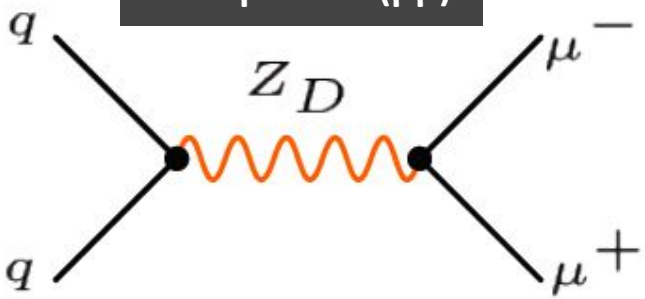
resolution of $u_{||}$ and $u_\perp$ components of the hadronic recoil goes from 22 to 32 GeV

The p_T^{miss} response ($u_{||}$ / q_T) reaches 1 for boson p_T > 100 GeV,
deviations from unity indicate imperfect calibration of the hadronic energy scale

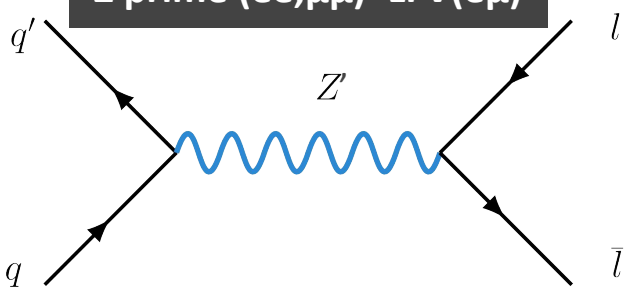
outline

in this presentation, most recent results in resonances decaying leptonically:

dark photon (μμ)



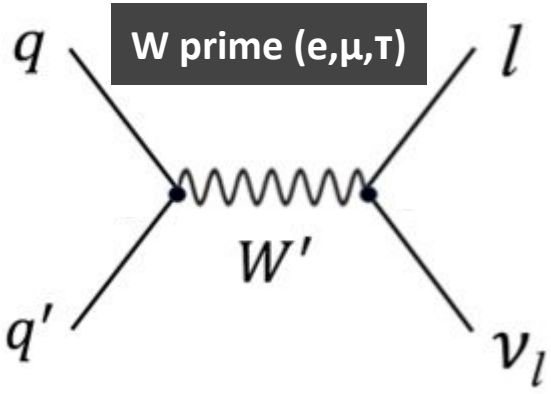
Z prime (ee,μμ)+LFV(eμ)



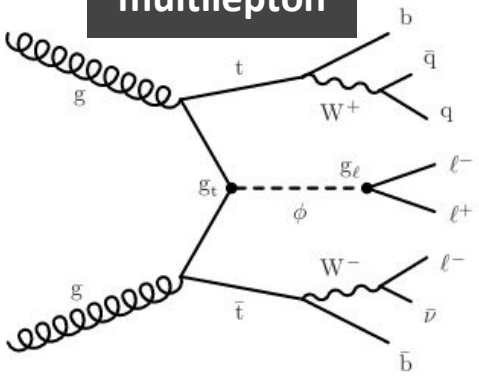
200 400 6000

mass scale (GeV)

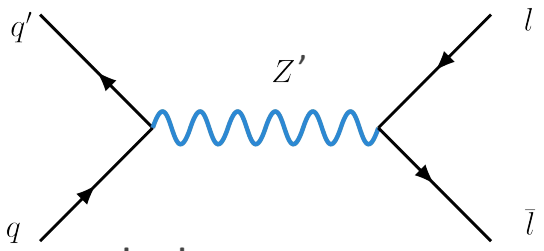
W prime (e,μ,τ)



multilepton



other:



Z' → l^+l^- (l=e,μ)

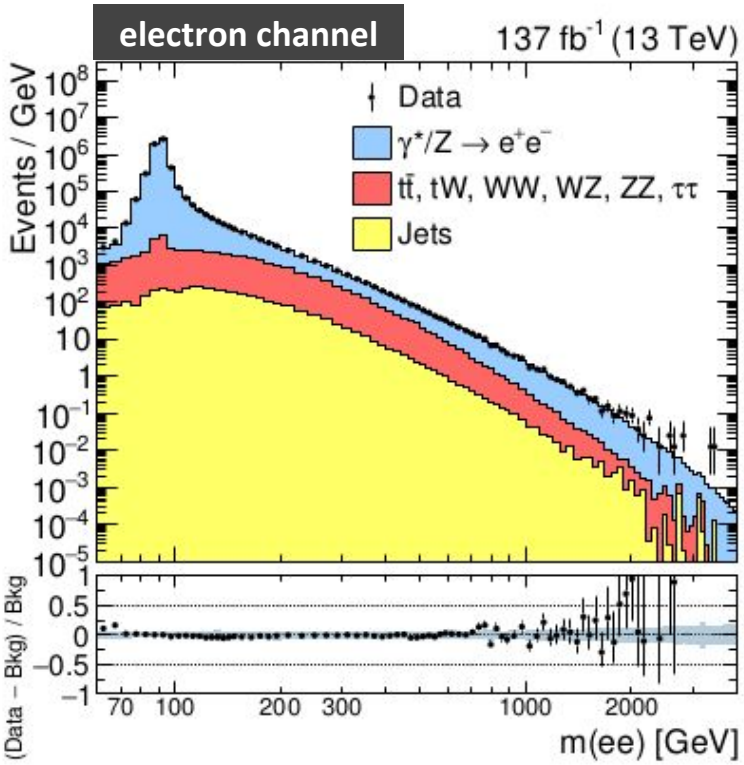
CMS-PAS-EXO-19-019

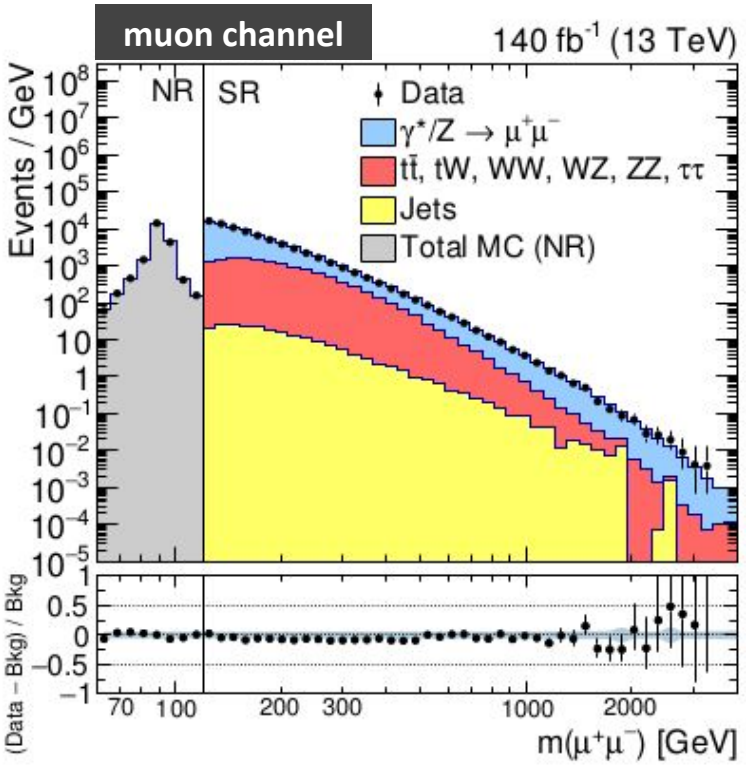
$L = 137\ fb^{-1}$

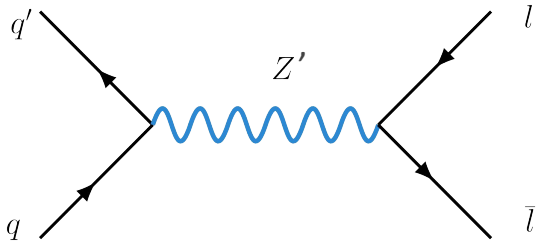
search targeting high mass resonances decaying to **two muons or two electrons**

strategy:

- ➜ MC background normalised to the Z peak to reduce systematics
- ➜ jet background estimated from data
- ➜ selection: electrons (muons) of p_T>35 (53) GeV and isolated
- ➜ main background: SM Z leptonic, top quark, dibosons
- ➜ discriminant variable: **di-lepton invariant mass**



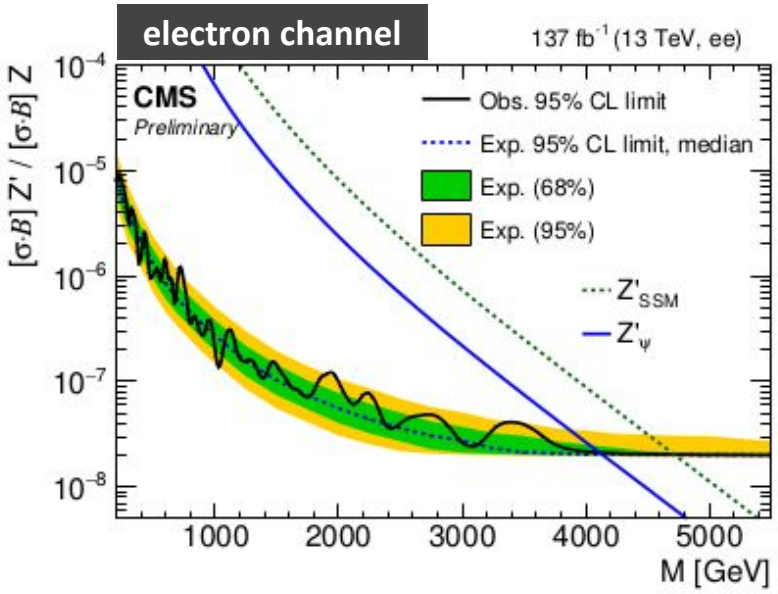


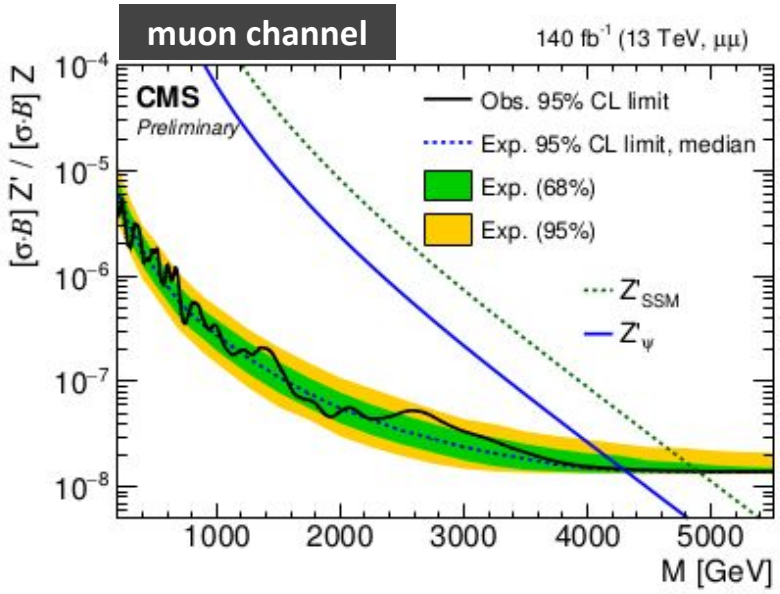


$Z' \rightarrow l^+l^-$ (l=e,μ)

CMS-PAS-EXO-19-019

$L = 137\ fb^{-1}$





results: no significant deviation from SM found

main uncertainty source: theo.: PDFs + exp.: selection eff (e), mass resolution (μ)

interpretations: SSM with SM-like couplings to SM fermions (Z'_{SSM}) and GUT model, super string inspired, based on the E6 gauge group (Z'_{ψ})

mass range explored: (200-5500) GeV

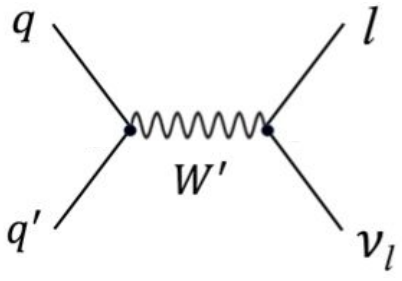
signal efficiency ~ 0.85

limits at 95% CL, e+μ ch: Z'_{SSM} mass< 5.15 (exp. 5.14) TeV, Z'_{ψ} mass < 4.56 (exp.4.55) TeV

non-resonant interpretations coming soon

~ 1 TeV improvement wrt the 2016 data limit

10.1007/JHEP06(2018)120



$W' \rightarrow p_T^{miss} + l(e,\mu,\tau)$

e,μ: 10.1007/JHEP06(2018)128
T: 10.1016/j.physletb.2019.01.06

$L = 35.9\ fb^{-1}$

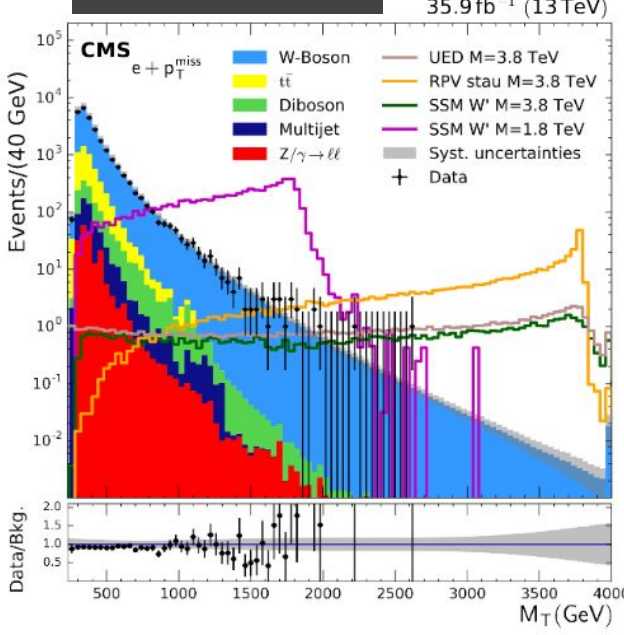
search targeting high mass W' boson decaying to one lepton (electron, muon or tau) and p_T^{miss}

selection: one electron (muon)[tau] with p_T> 130 (53)[50] GeV, with a back to back topology between the lepton and the p_T^{miss} and vetoing two lepton events

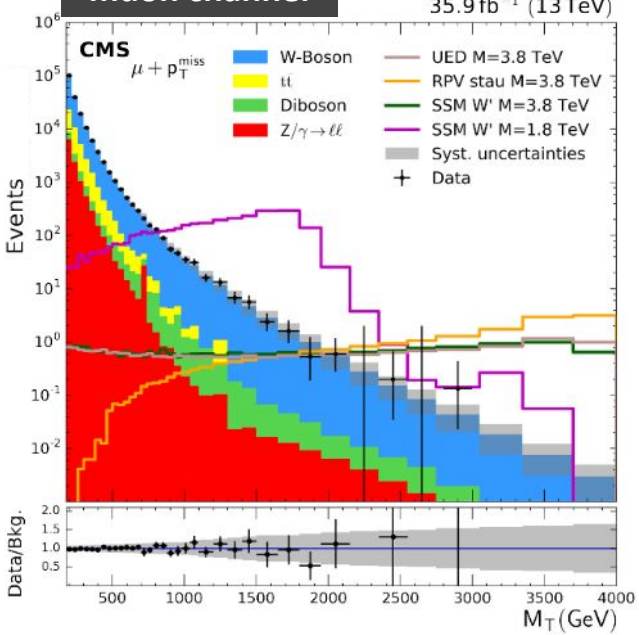
main background: SM W leptonic, top quark, dibosons and DY

non-resonant discriminant variable: mass (**l+p_T^{miss}**) $M_T = \sqrt{2p_T^{\ell}\ p_T^{miss}(1-\cos[\Delta\phi(\ell,\vec{p}_T^{miss})])}$

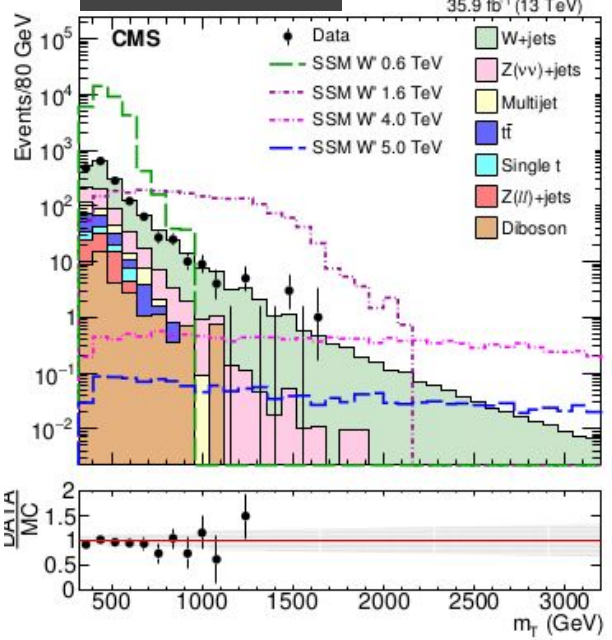
electron channel



muon channel



tau channel



$W' \rightarrow p_T^{miss} + l(e,\mu,\tau)$

$L = 35.9\ fb^{-1}$

e,μ: 10.1007/JHEP06(2018)128

τ: 10.1016/j.physletb.2019.01.06

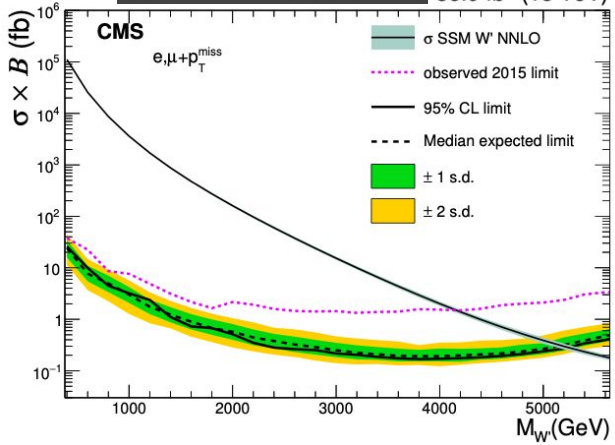
main uncert. source: theo.: PDFs + exp.: p_T^{miss} scale (e ch.), muon p_T scale (μ ch.), τ ID (τ ch.)

signal eff ~0.70 (e,μ) ~0.45 (τ)

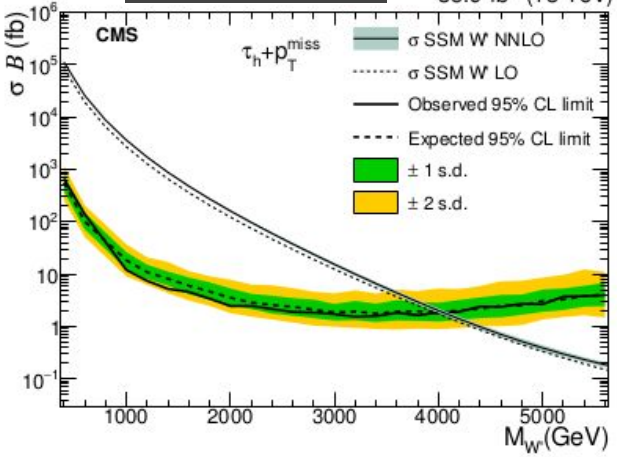
mass range (400-5600) GeV

SSM W'

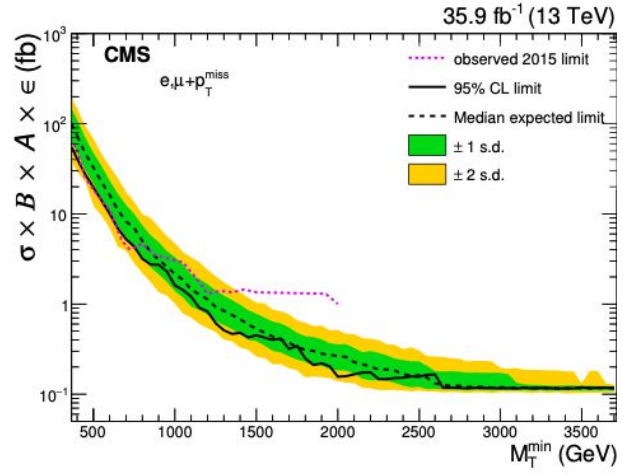
e+μ channel

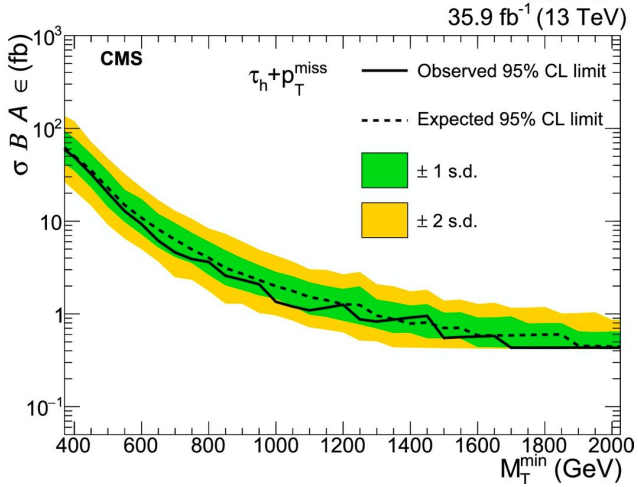


tau channel



model independent





SSM W' limits at 95% CL:

$M_{W'} < 5.2$ TeV
(exp. 5.2 TeV)(e+μ ch.)

~ 1 TeV improvement wrt the 2015 data limit in e+μ
10.1016/j.physletb.2017.04.043

$M_{W'} < 4.0$ TeV
(exp. 4.0 TeV) (τ ch.)

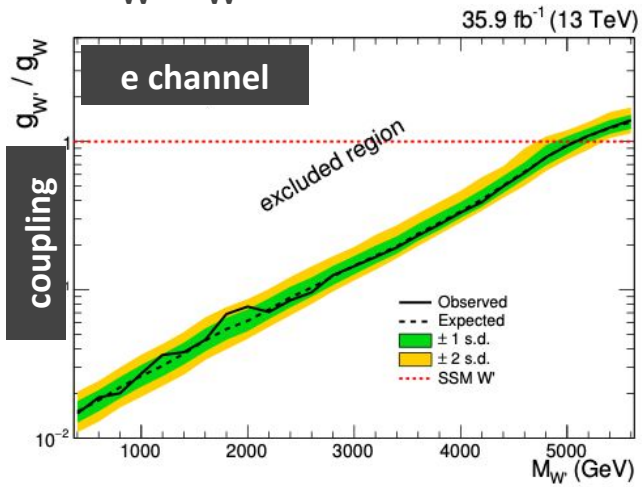
τ previous limit: 2.7 TeV
(19.7 fb^{-1} , $\sqrt{s}$ = 8 TeV)
10.1016/j.physletb.2016.02.002

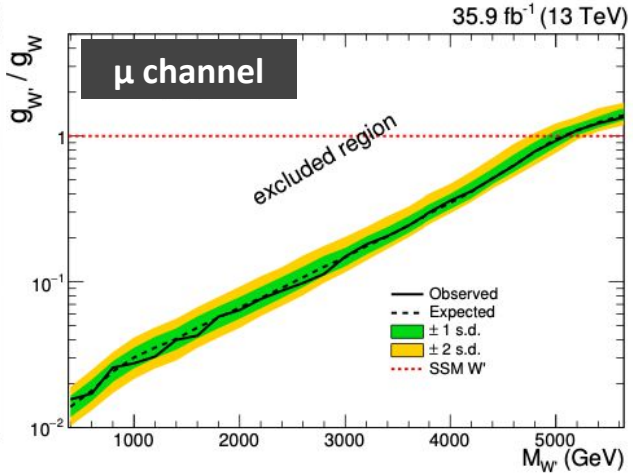
$W' \rightarrow p_T^{miss} + l(e,\mu,\tau)$

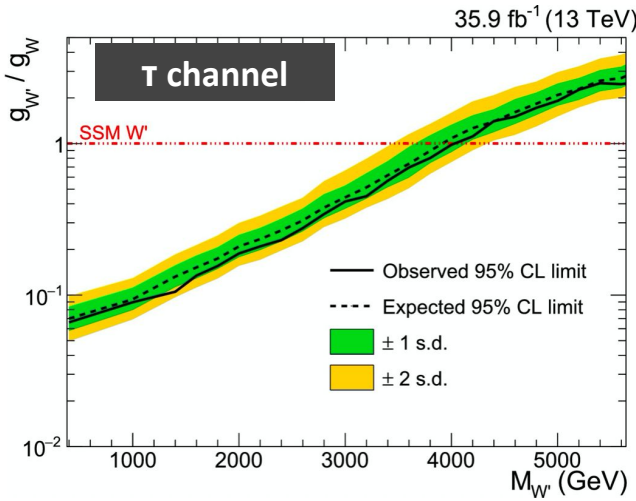
e,μ: 10.1007/JHEP06(2018)128

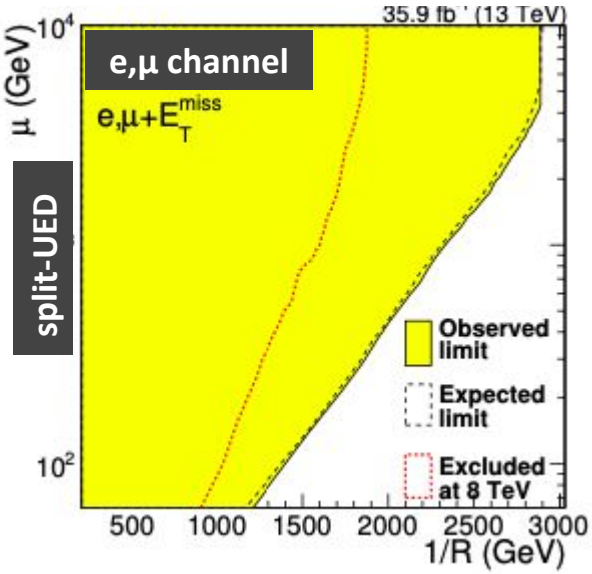
τ: 10.1016/j.physletb.2019.01.06

$g_{W'}/g_W$ values down to 2×10^{-2} (e,μ) , 7×10^{-2} (τ) are excluded for low masses:



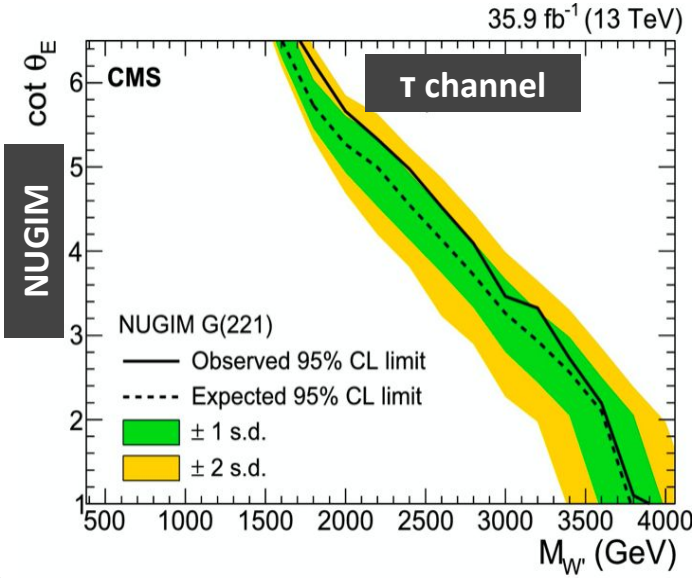




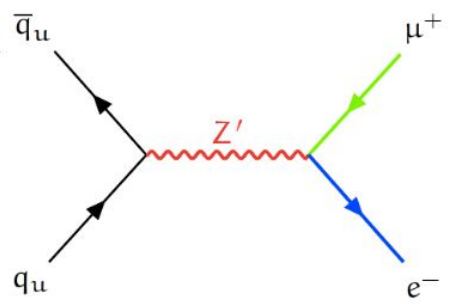


2.9 TeV of 1/R of the extra dimension in split-UED

Nonuniversal gauge interaction models (NUGIMs): W' mass from 1.7 to 3.9 TeV



update: 137fb^{-1} soon (~3 times more statistics), including new interpretations



LFV: Z' ⟶ e + μ

10.1007/JHEP04(2018)073

$L = 35.9\ fb^{-1}$

selection:

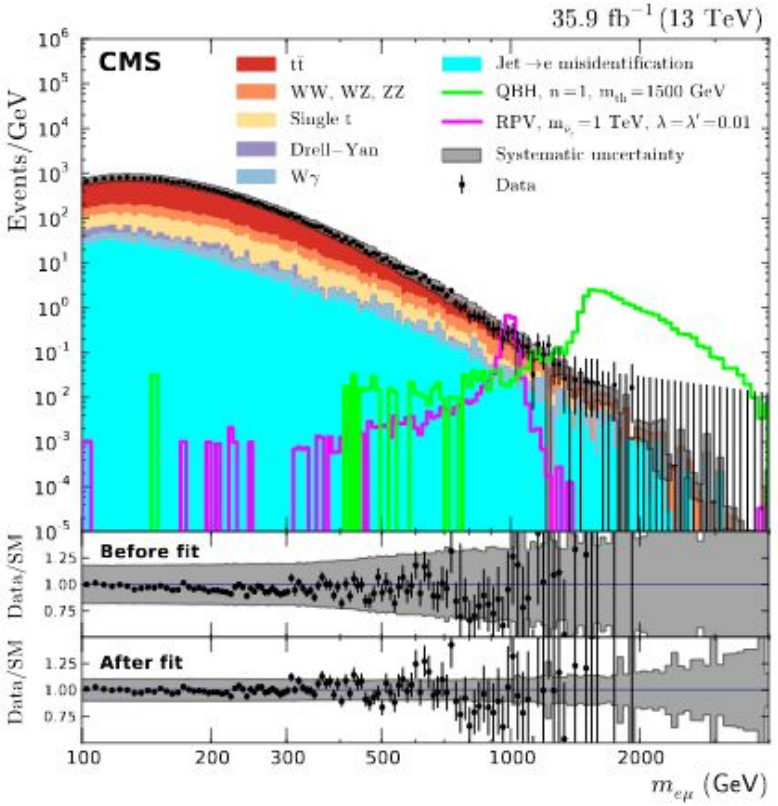
isolated electron (E_T > 35 GeV)
+ isolated muon (p_T > 53 GeV)

not opposite charge required to keep it unaffected by lepton charge misID

high energetic muons can produce bremsstrahlung and lead to fake electron candidates ⇒ veto these events

main background: ttbar process (in red)

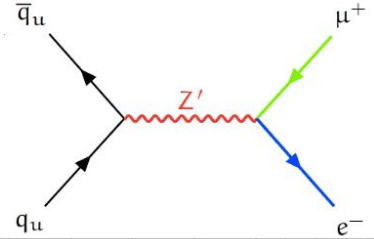
discriminating variable: **e+μ invariant mass**

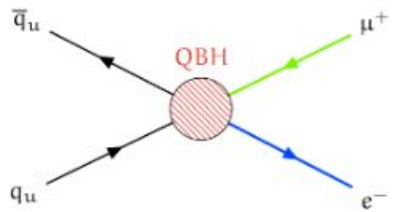


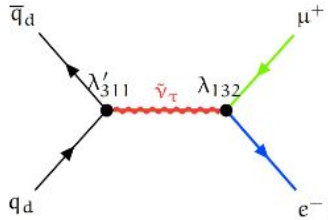
LFV: Z’ ⟶ e + μ

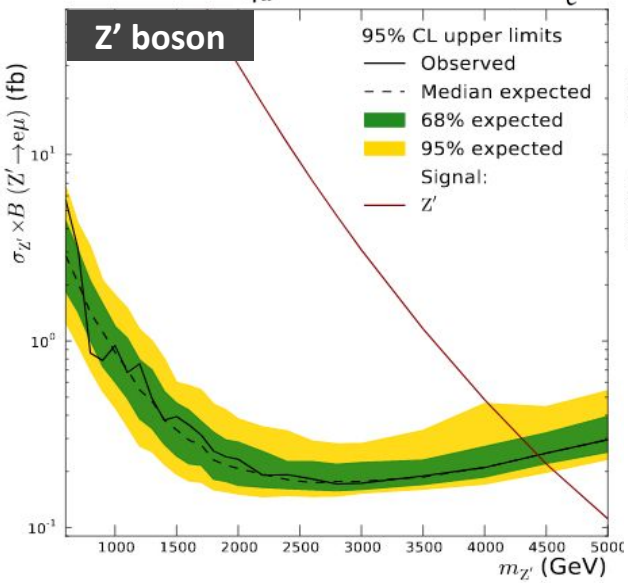
$L = 35.9\ fb^{-1}$

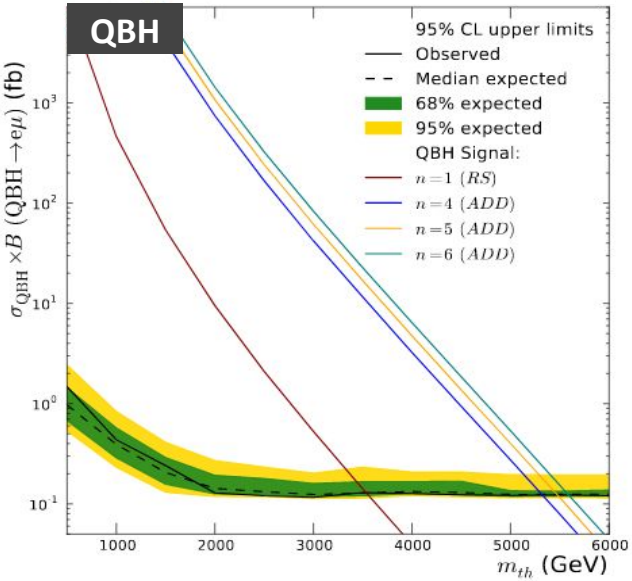
10.1007/JHEP04(2018)073

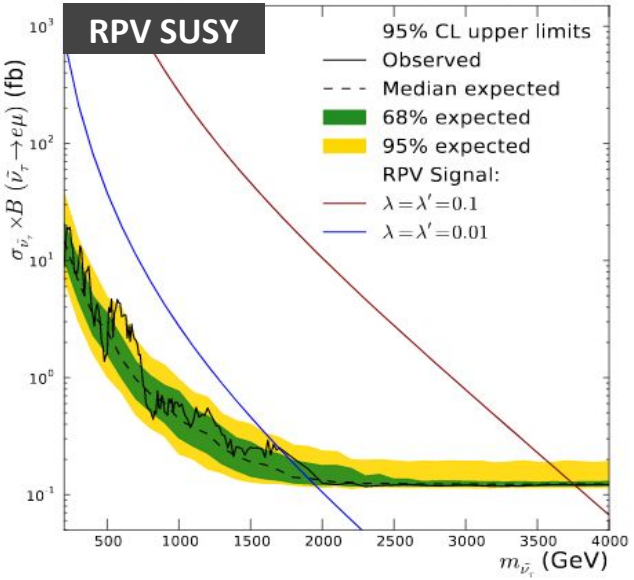












results: no significant deviation from SM found

interpretations: LFV Z′ boson, Quantum Black Hole (QBH) in a model with extra dimensions and τ sneutrino in an RPV SUSY model

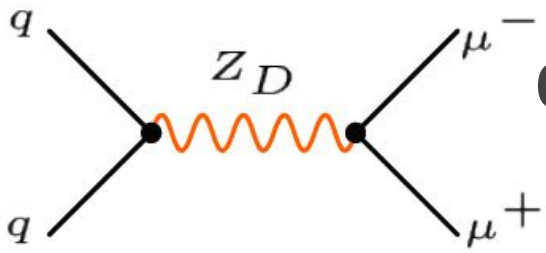
signal efficiency: ~0.7, **limits** at 95% CL:

➜ LFV Z′ mass of 4.4 TeV (exp. 4.4 TeV)

➜QBH lower mass limits are found between 3.6 and 5.6 TeV

➜RPV SUSY is excluded for masses below 1.7 TeV, for couplings $\lambda_{132} = \lambda_{231} = \lambda'_{311} = 0.01$

previous limits improved by ~ 1 TeV
Eur. Phys. J. C76 2016 317



dark photon ($\mu^+\mu^-$)

Phys. Rev. Lett. 124 (2020) 131802

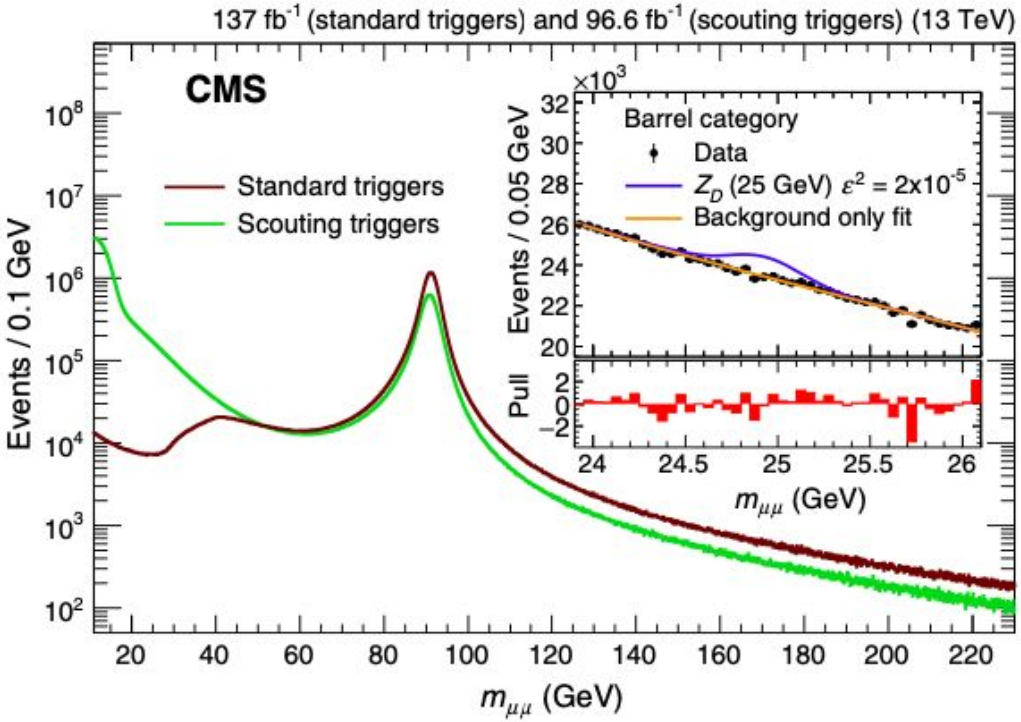
$L = 137\ fb^{-1}$

search for a low mass resonance decaying to a pair of muons

selection: muon1 p_T > 20 GeV + muon2 p_T > 10 GeV

mix of the standard and a special scouting dataset used:

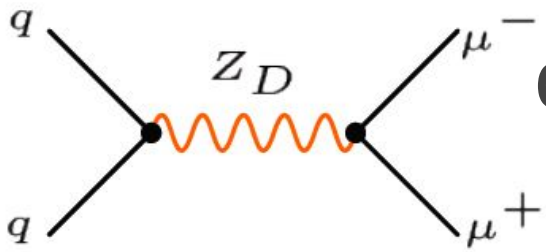
- ➜ **m = (11.5-45.0) GeV:** 96.6 fb^{-1} of data scouting = specific triggers + low p_T + less info
- ➜ **m = (45.0-200.0) GeV:** full Run-2 dataset of 137 fb^{-1}



background estimated from data fit

main uncertainty source: extraction of a possible signal in the background fit

discriminant variable: **invariant di-muon mass**



dark photon ($\mu^+\mu^-$)

Phys. Rev. Lett. 124 (2020) 131802

$L = 137\ fb^{-1}$

results: no significant deviation from SM found

interpretation: Dark Photon (Z_D), described by the variables:

m_{ZD} = Dark Photon mass

ε = kinetic mixing coefficient, it determines the degree of mixing and the strength of the coupling of Z_D to SM particles (photons and Z bosons)

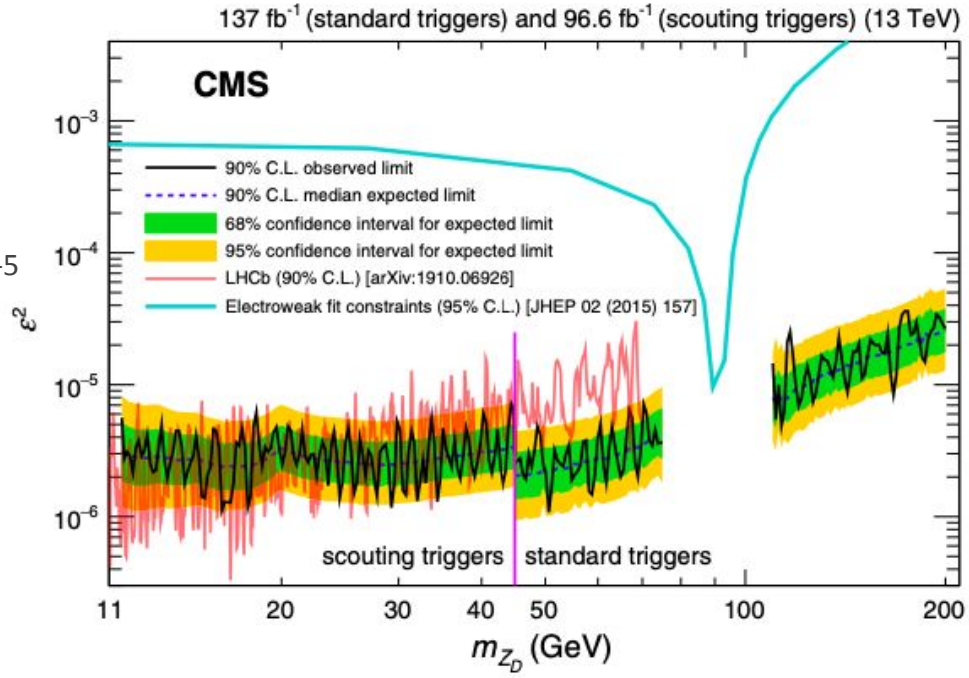
signal efficiency: ~0.40

limits at 95% CL in ε^2 :

➜ m_{ZD} = (11.5-45.0) GeV: 2 x 10^{-6}

➜ m_{ZD} = (45.0-200.0) GeV: 2 x 10^{-6}- 2 x 10^{-5}

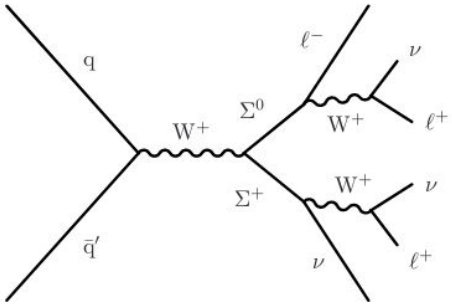
most stringent constraints on dark photon to date!

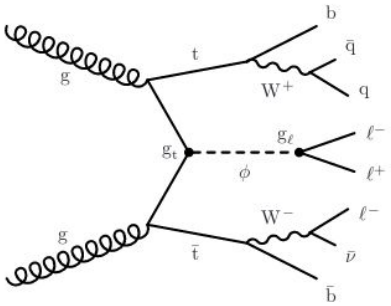


multilepton

JHEP 03 (2020) 051

$L = 137\ fb^{-1}$





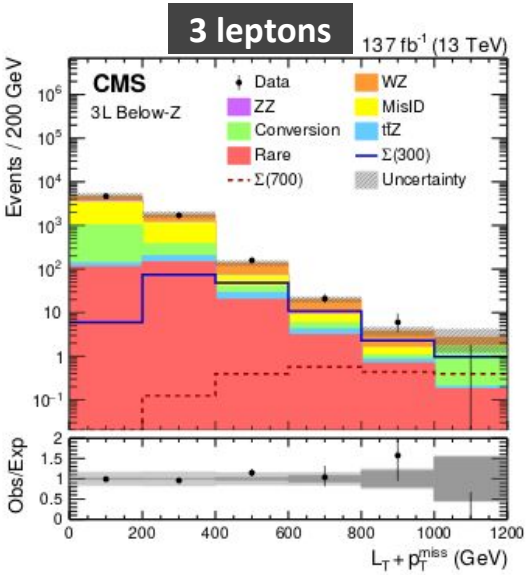
search for new physics in events with three or more electrons or muons in final state.

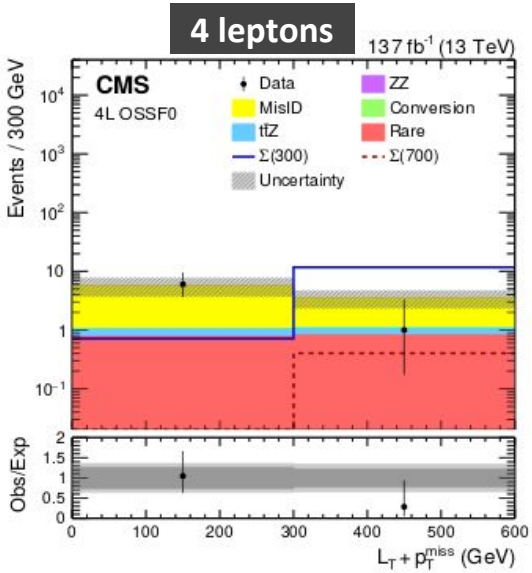
pre-selection: at least one electron (p_T >35 GeV) and one muon (p_T > 26 GeV)

vetos:

➜ events containing a same-flavor lepton pair with invariant mass below 12 GeV

➜ 3L events with an opposite-sign-same flavor (OSSF) pair with m < 76 GeV when the trilepton mass is within a Z boson mass window



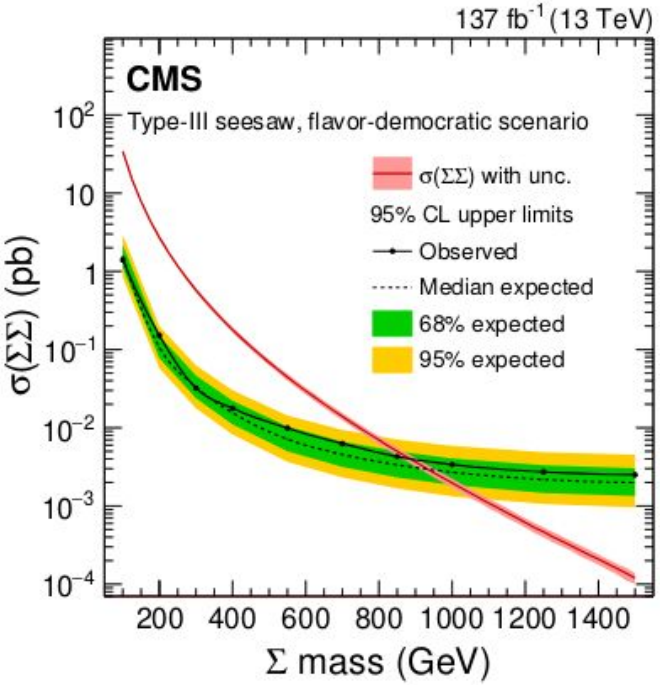


events classified to different signal regions based on lepton flavour, number (3 or 4), charge and inv. mass

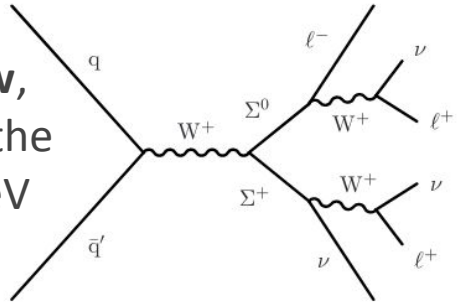
multilepton

JHEP 03 (2020) 051

$L = 137\ fb^{-1}$



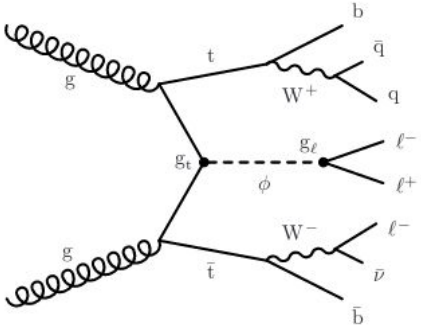
heavy fermions of the type-III seesaw, non-resonant excesses in the tails of the transverse mass: limit mass of 880 GeV at 95% CL (exp. 930 GeV)



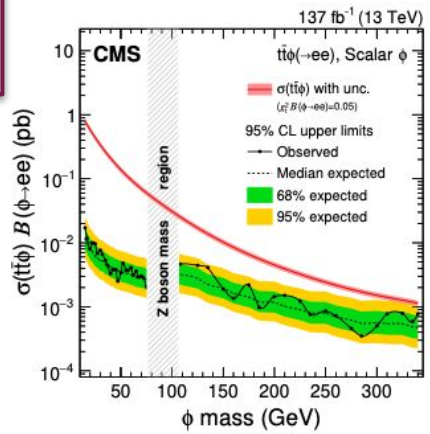
the most restrictive limit to date

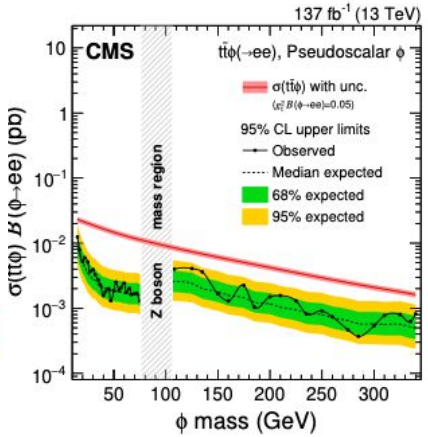
Φ new light scalar (pseudoscalar) boson with a pair of top quarks, models: extended Higgs, SUSY and dark sector extensions

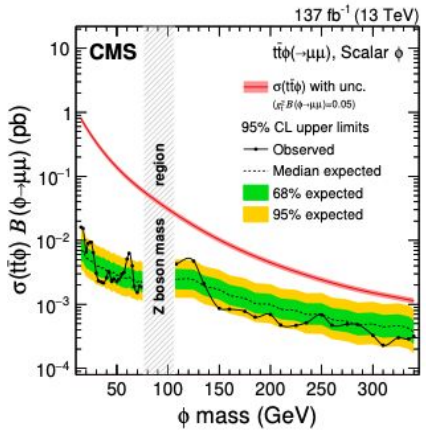
Φ BF of 0.004 (0.03) and 0.04 (0.03) excluded for masses 15-75 GeV and 108-340 GeV

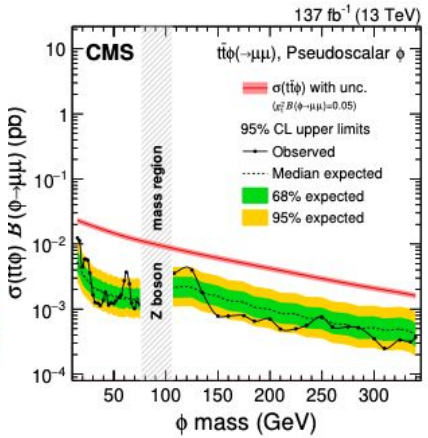


first limits in these channels



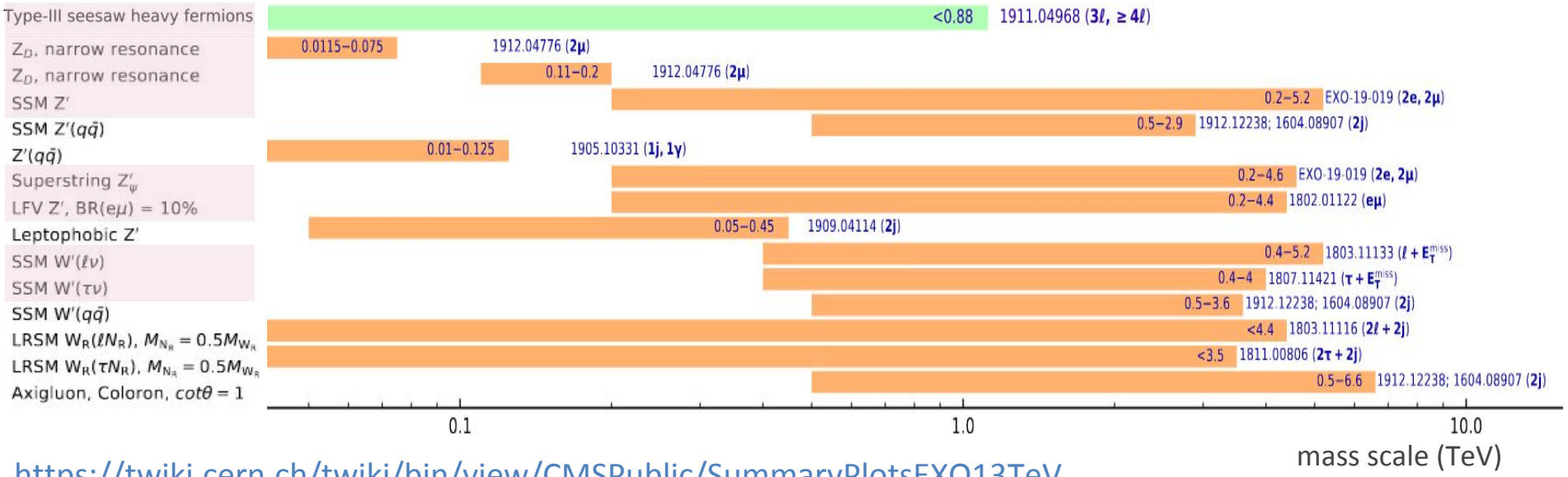






summary

presented today



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV

- ➜ several analyses in searches for heavy resonances with leptonic final states at CMS presented
- ➜ no significant deviation from SM found
- ➜ more results to be released soon

backup

$Z' \rightarrow \tau + \tau$

10.1007/JHEP02(2017)048

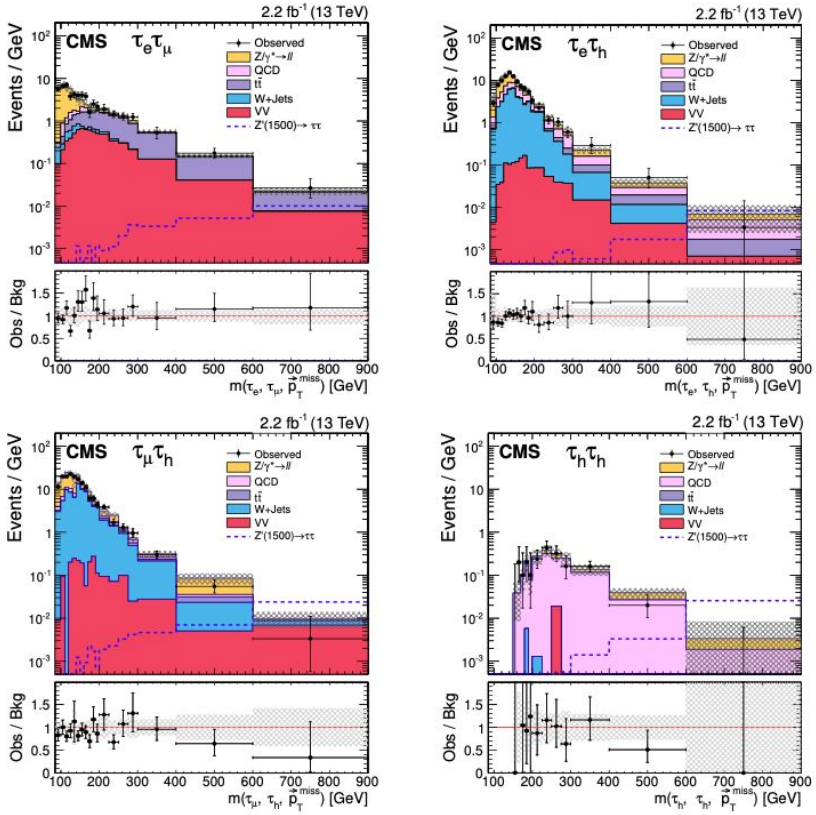
luminosity = 2.2 fb^{-1}

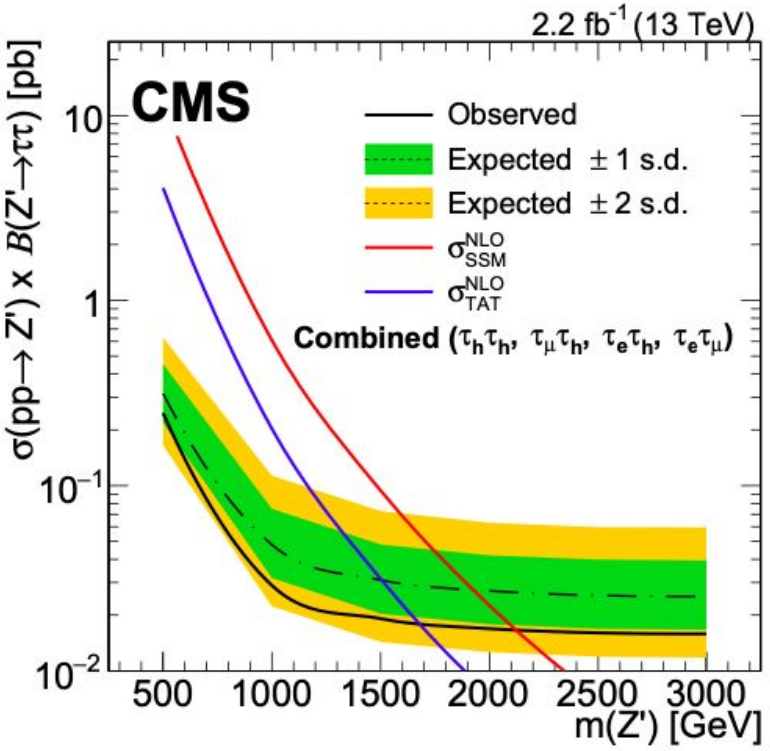
$\sqrt{s}$ = 13 TeV

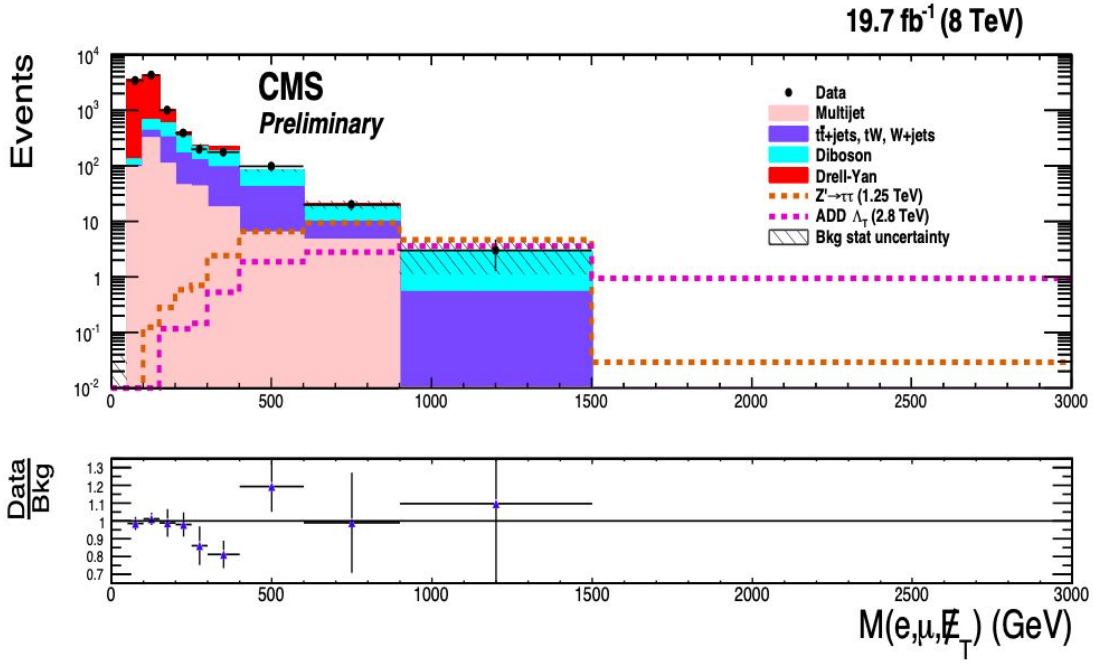
tau-lepton pairs decaying into leptons (electron or muon) or hadrons, the discriminant variable is the invariant mass between the taus and the missing energy:

$$m(\tau_1, \tau_2, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}) = \sqrt{(E_{\tau_1} + E_{\tau_2} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - (\vec{p}_{\tau_1} + \vec{p}_{\tau_2} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}})^2}$$

The presence of SSM Z′ bosons decaying to a tau pair is excluded for Z′ masses below 2.1 TeV







luminosity = 19.7 fb^{-1}

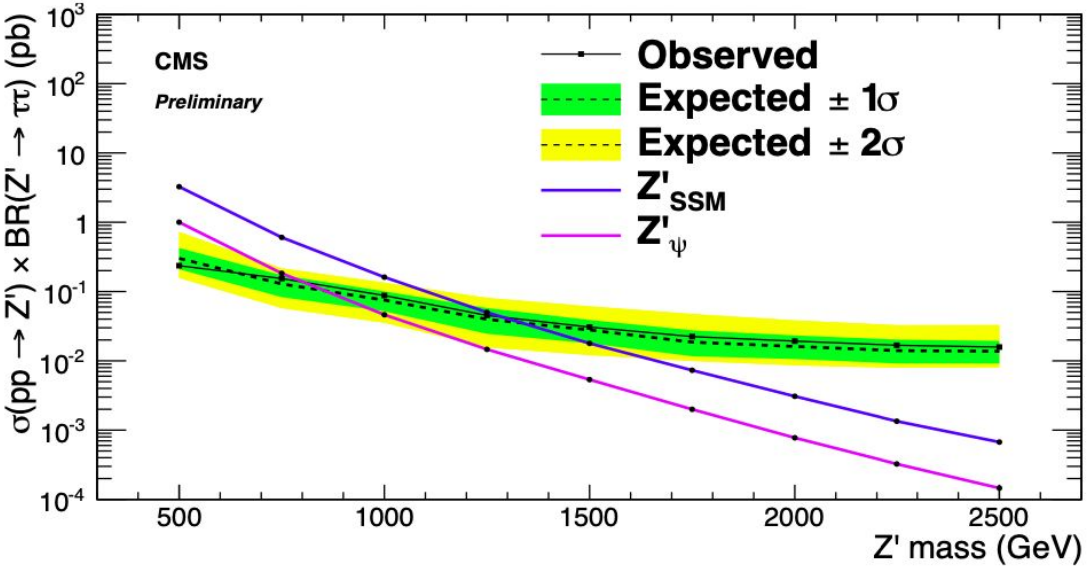
$\sqrt{s}$ = 8 TeV

$$Z' \longrightarrow \tau + \tau$$

tau-lepton pairs decaying into final states with an electron and a muon

ditau pairs are constructed by pairing electrons and muons of opposite charge that do not overlap ($\Delta R > 0.3$).

$$M(\mu, e, \not{E}_T) = \sqrt{(E_\mu + E_e + \not{E}_T)^2 - (\vec{p_\mu} + \vec{p_e} + \vec{\not{E}_T})^2}.$$



Z'_{SSM} and Z'_{ψ} have been excluded at 95% CL with masses below 1300 GeV and 810 GeV respectively.