


Searches with leptons in the final state @ CMS

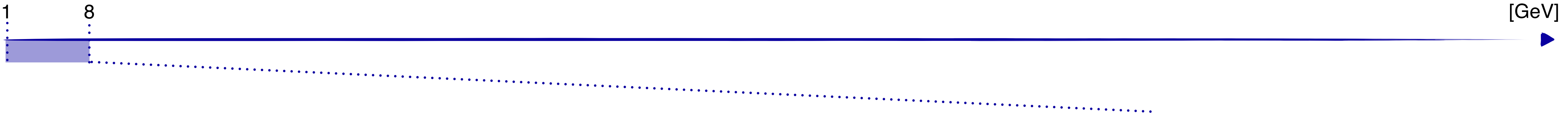
Mattia Campana on behalf of CMS Collaboration

LHCp 2024, 4th June 2024, Boston

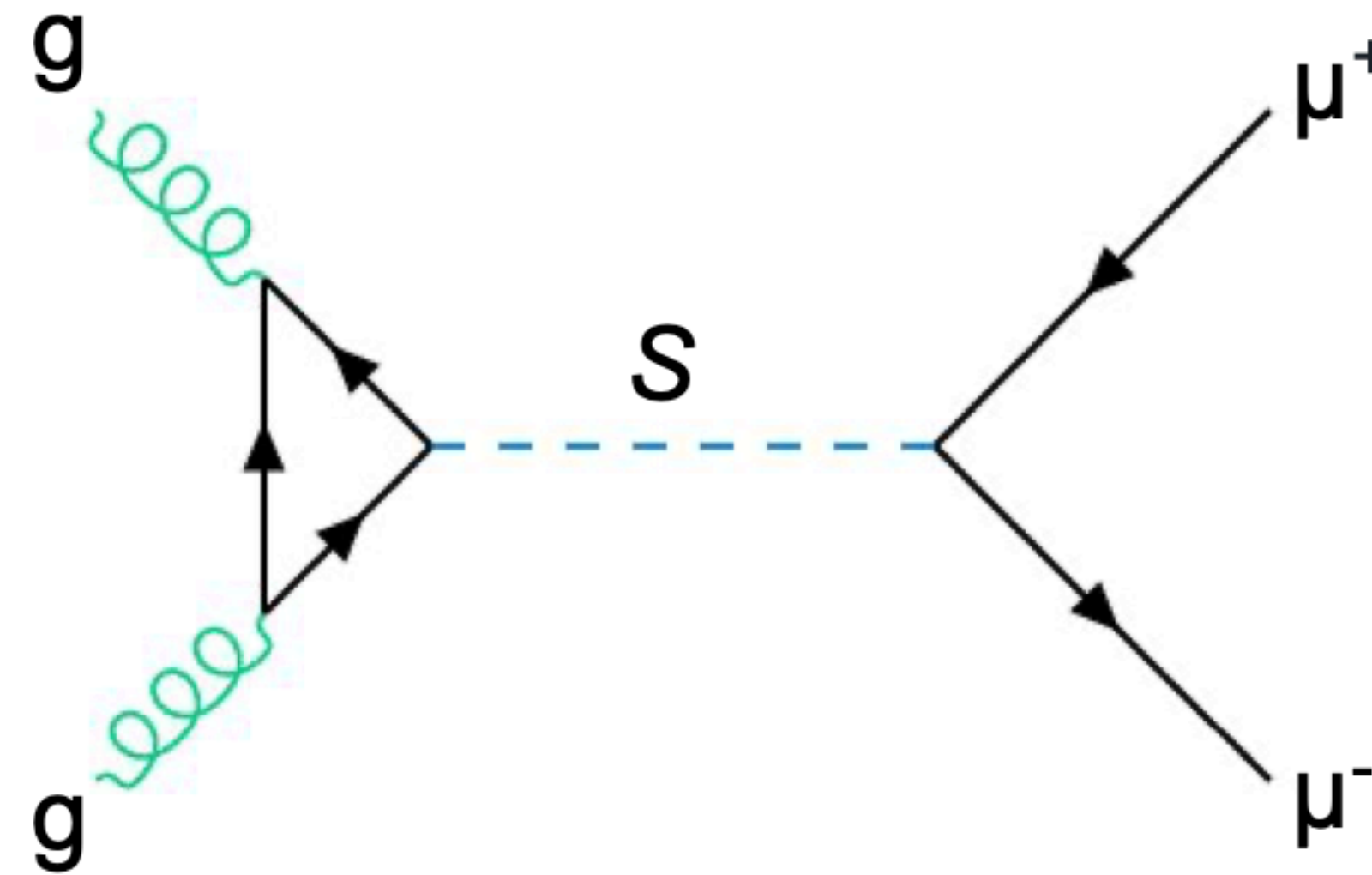
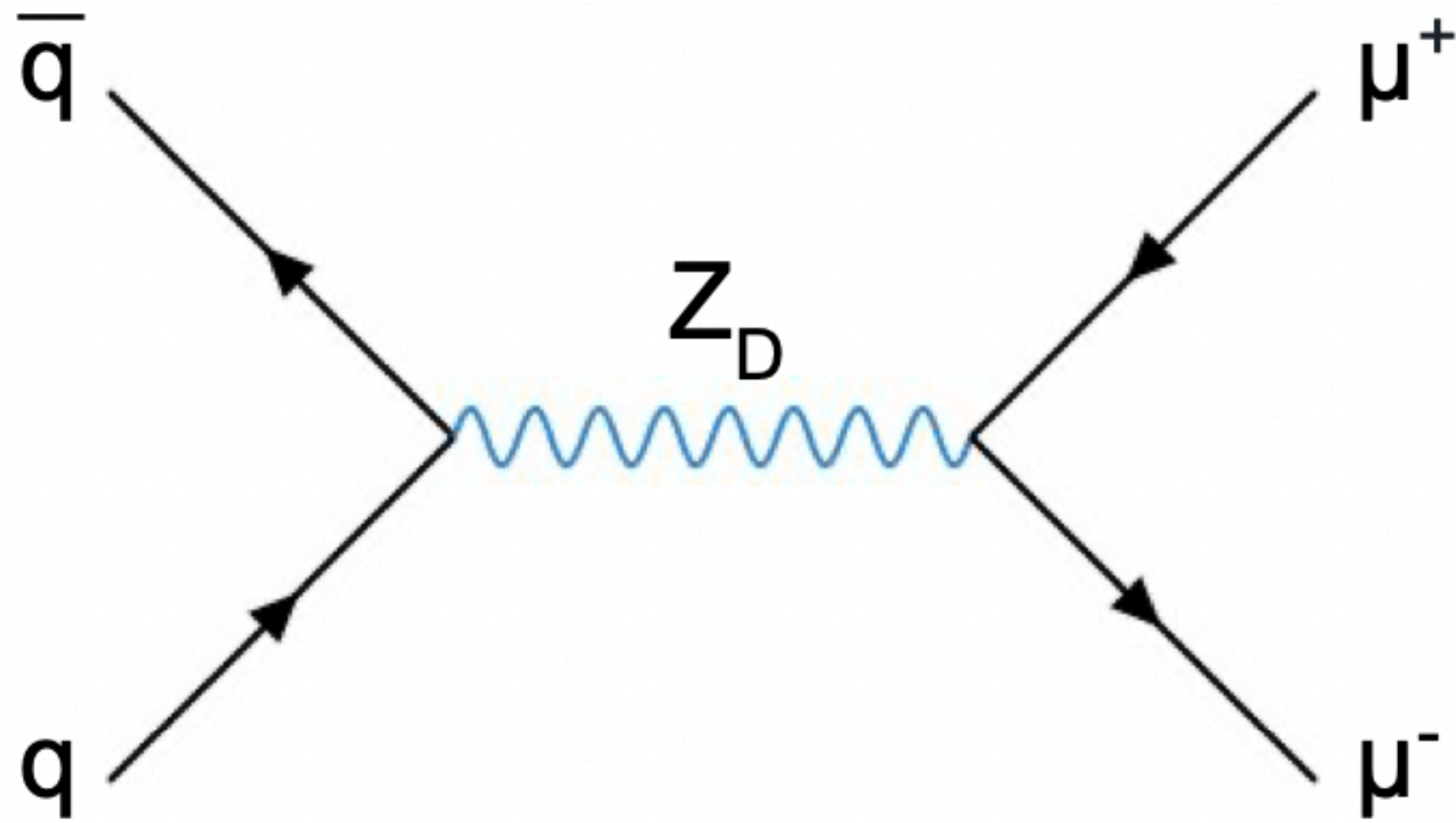
Introduction

- Direct searches for BSM physics remains a key part of the CMS physics program
 - an extensive searches for **NEW Physics** in which **leptons** provide clear signatures
- Many exotic BSM extension from few GeV up to TeV scale
 - Dark Photon & Extended Higgs sector ([10.1007/JHEP12\(2023\)070](https://arxiv.org/abs/10.1007/JHEP12(2023)070))
 - New resonances ([arXiv:2402.11098](https://arxiv.org/abs/2402.11098))
 - Heavy gauge bosons ([CMS-PAS-EXO-21-015](#) & [CMS-PAS-EXO-21-016](#)) 
 - SUSY (recent results covered in [Carlos'](#), [Victor's](#) and [Weijie's](#) talks)
 - ...
- In this talk, the focus is on lately realised or published results
 - full Run-2 (2016-2018) up to 140/fb @ $\sqrt{s} = 13$ TeV
 - New result from for Run-3 @ $\sqrt{s} = 13.6$ TeV in [Anne's](#) and [Raphael's](#) talks

Low mass di-muon with scouting

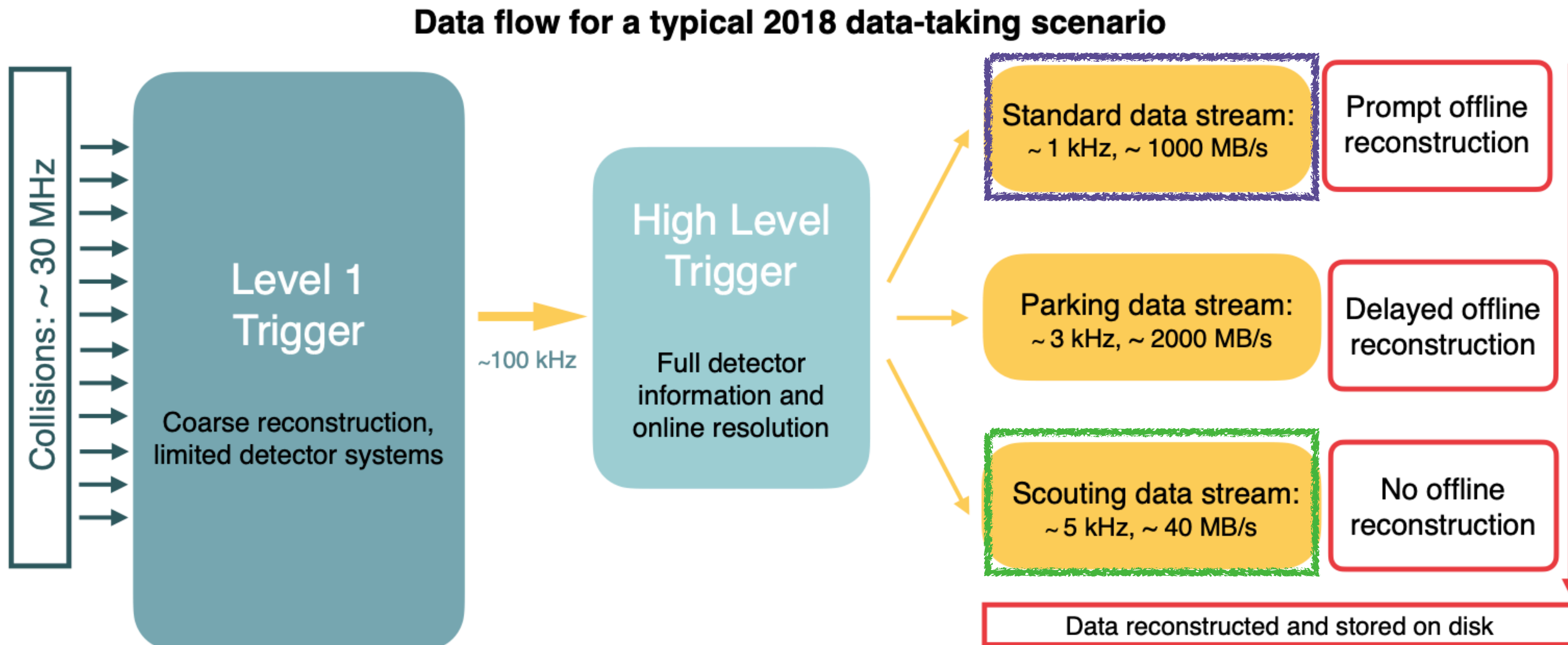


Search for prompt low-mass dimuon resonances with scouting [10.1007/JHEP12\(2023\)070](https://arxiv.org/abs/10.1007/JHEP12(2023)070)



Scouting

- Objects are reconstructed at trigger level to take trigger decision
- We can store the **trigger objects** and use them to do analysis
 - Physics objects saved (PF candidates, Jets, ...) reconstructed at HLT



Traditional muon
triggers

$$p_T > 15 \text{ GeV}$$

Sacrifice event
content to lower
trigger thresholds
(more physics
possibilities)

Scouting muon
triggers

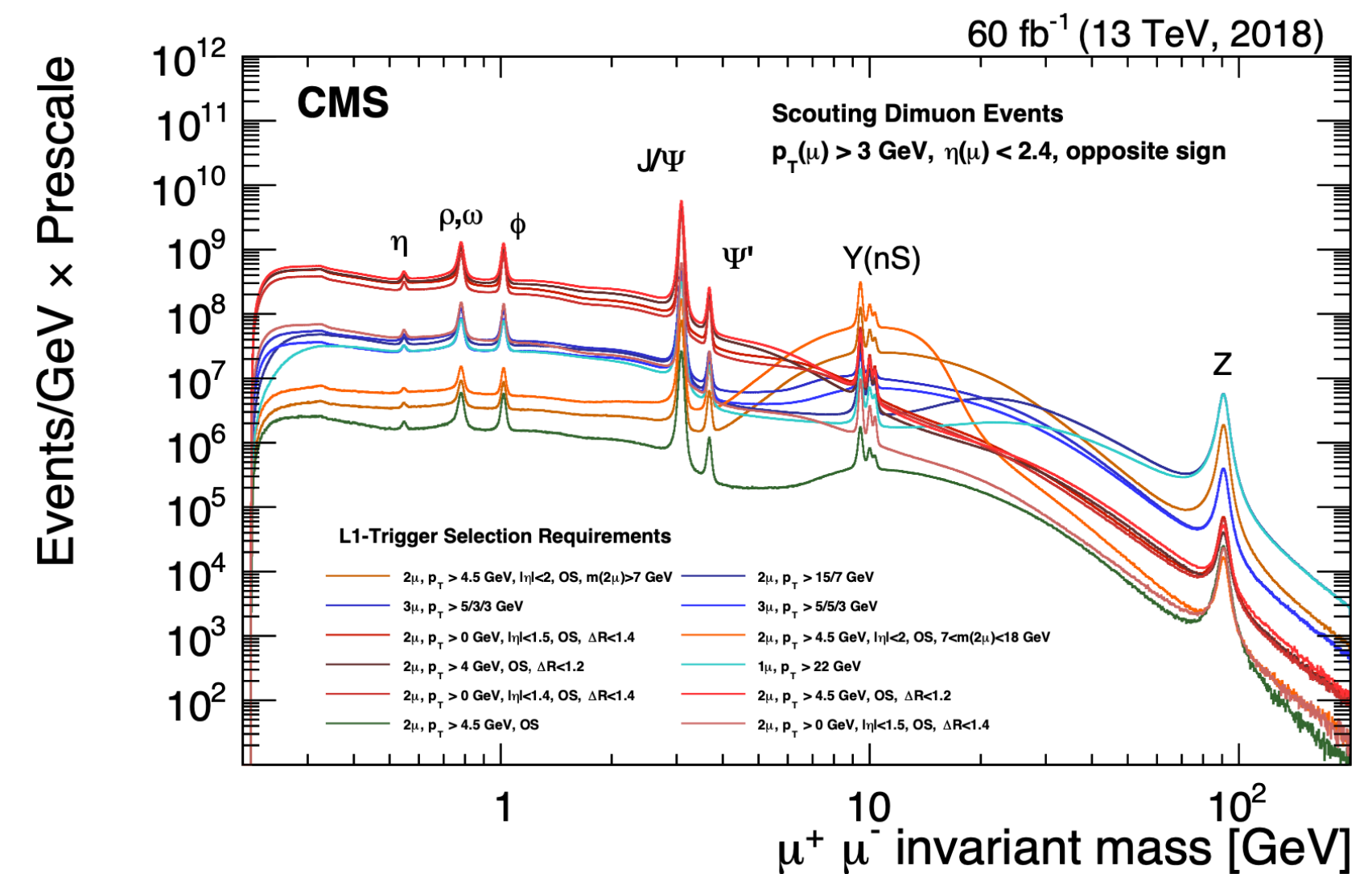
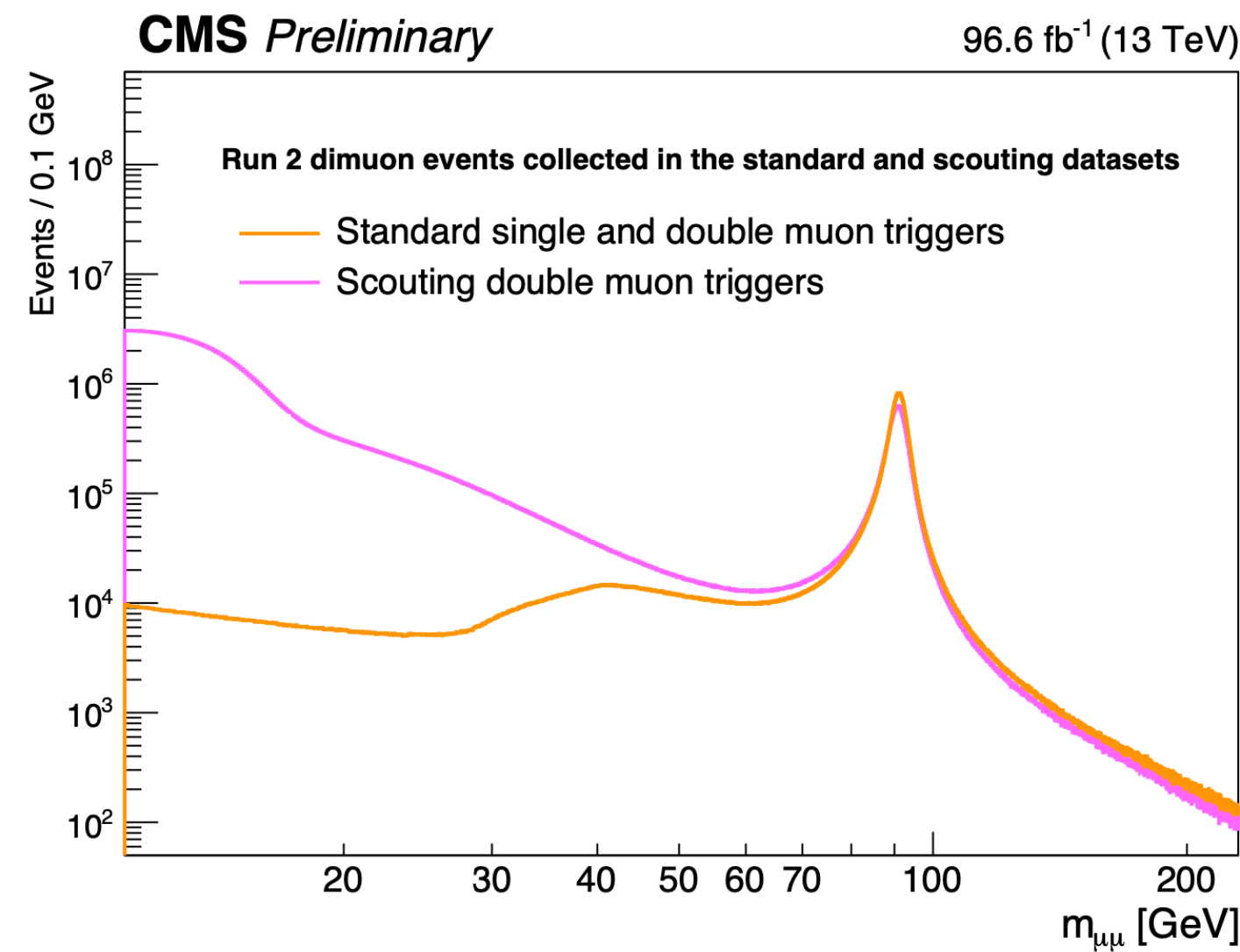
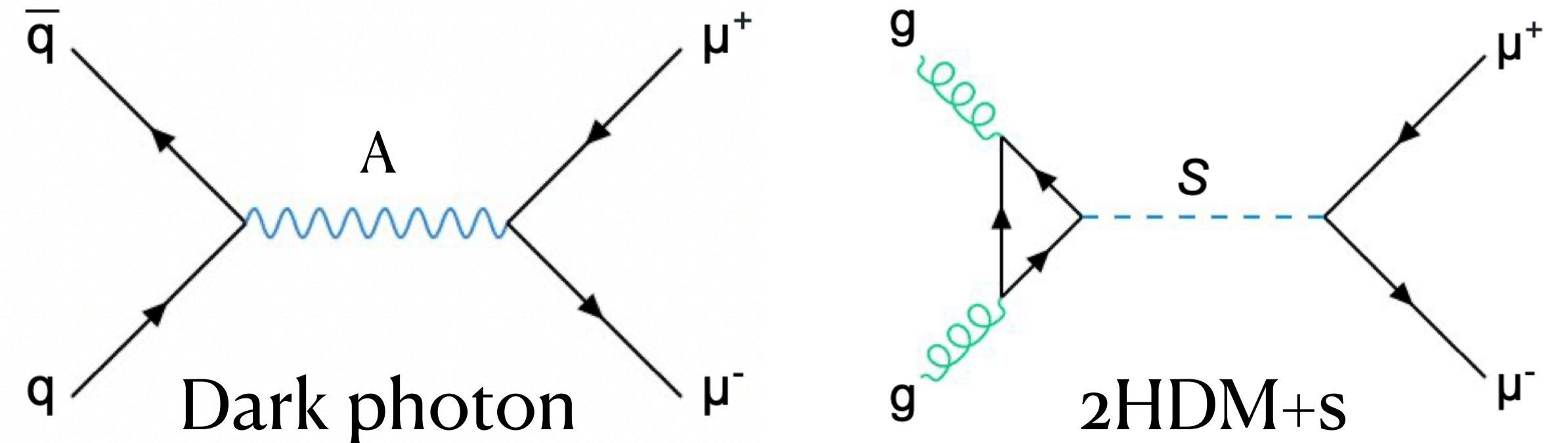
$$p_T > 3 \text{ GeV}$$

$$(m_{\mu\mu} \sim 200 \text{ MeV})$$

[Scouting Paper](#)

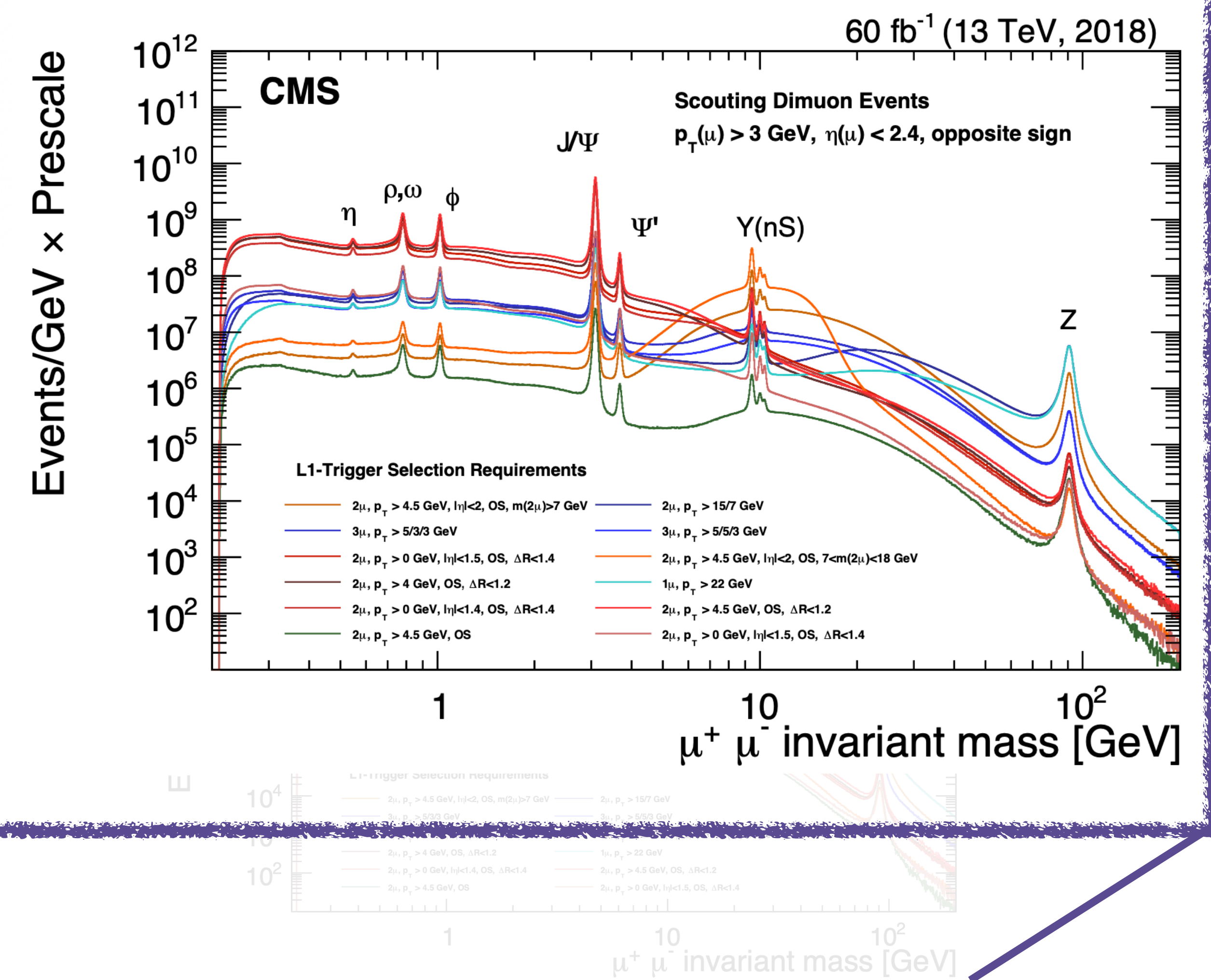
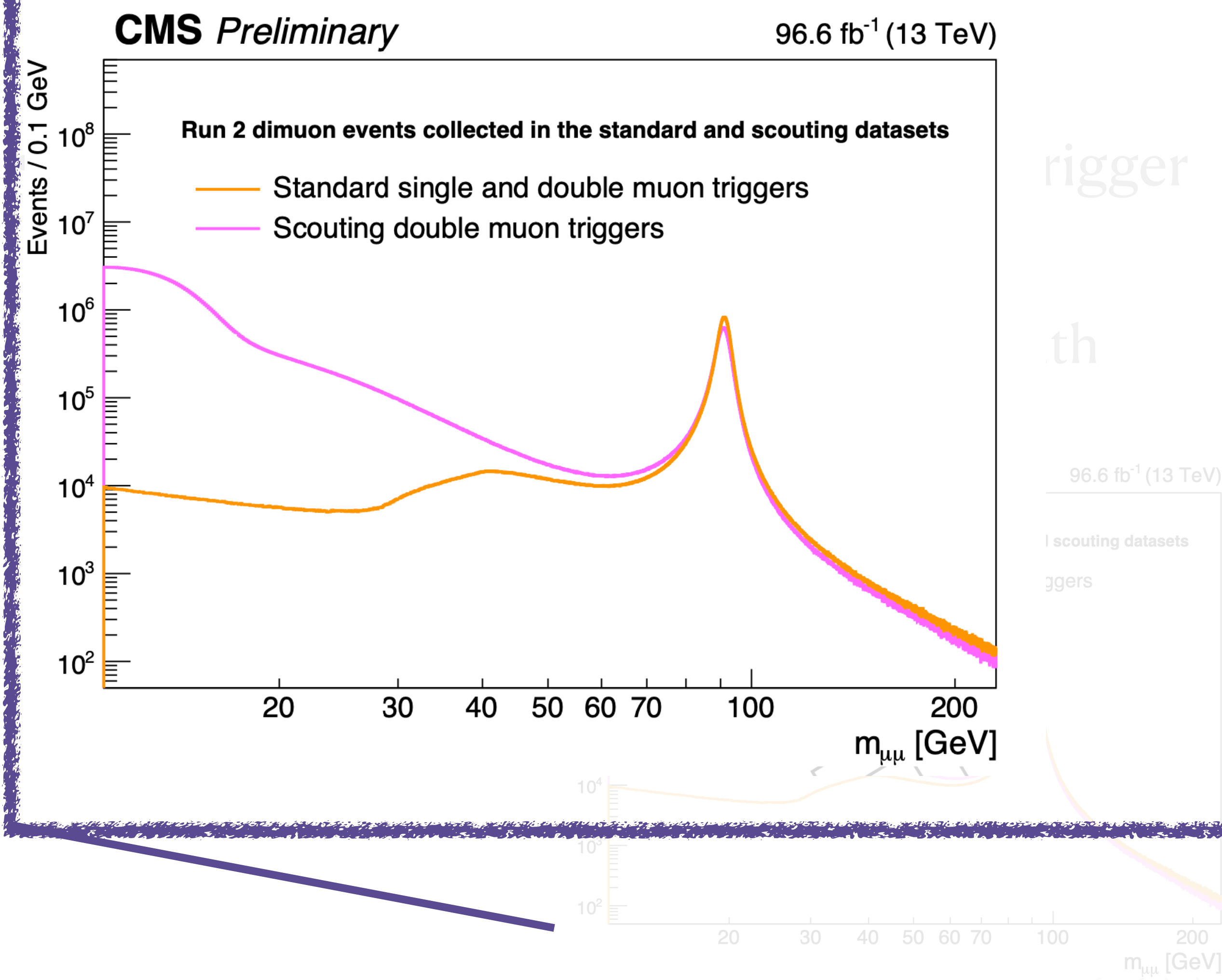
Low mass di-muon with scouting - Model

- Mainly targeting light mediators (short-lived)
- A challenging search with traditional trigger strategies
 - Low-pt objects, very high trigger rate with traditional triggers



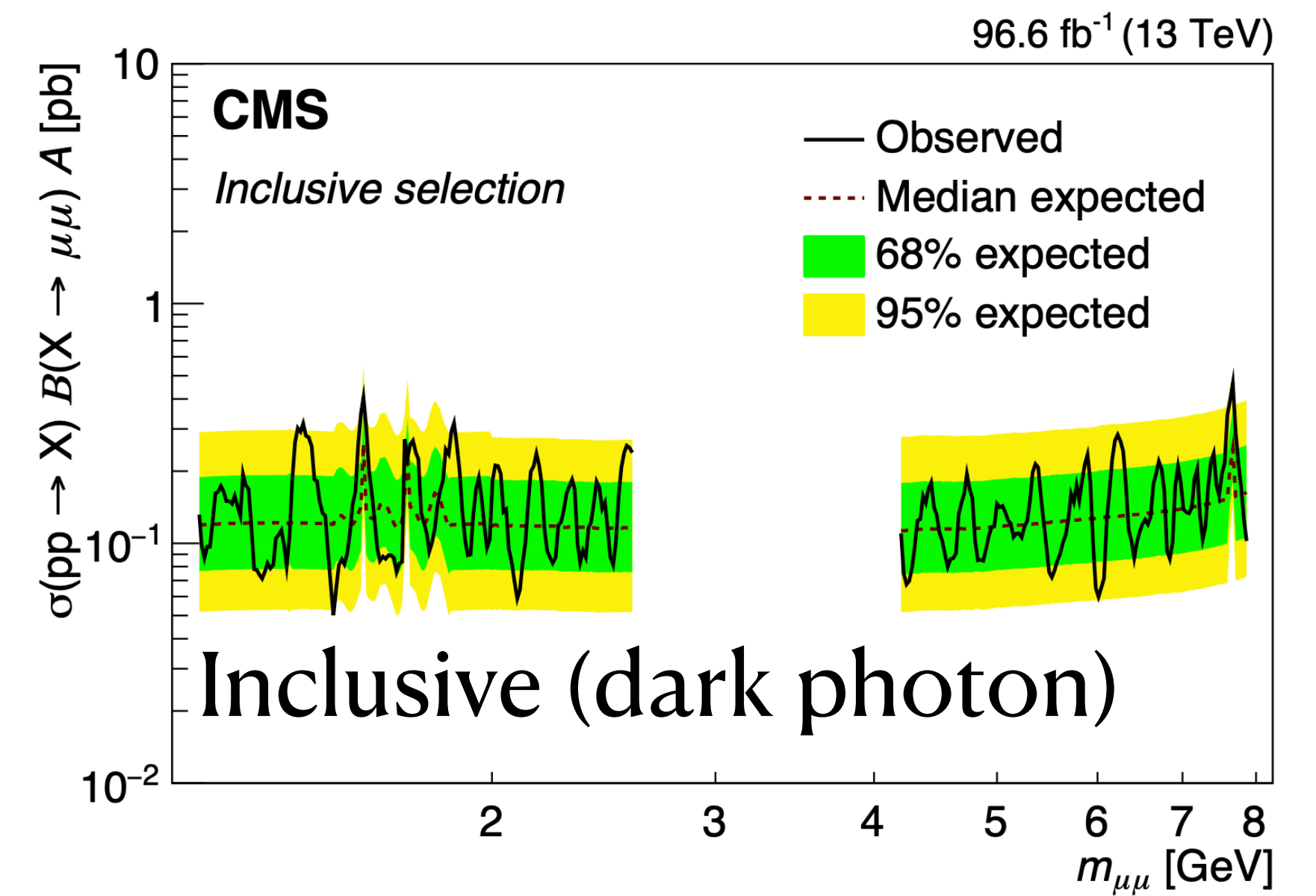
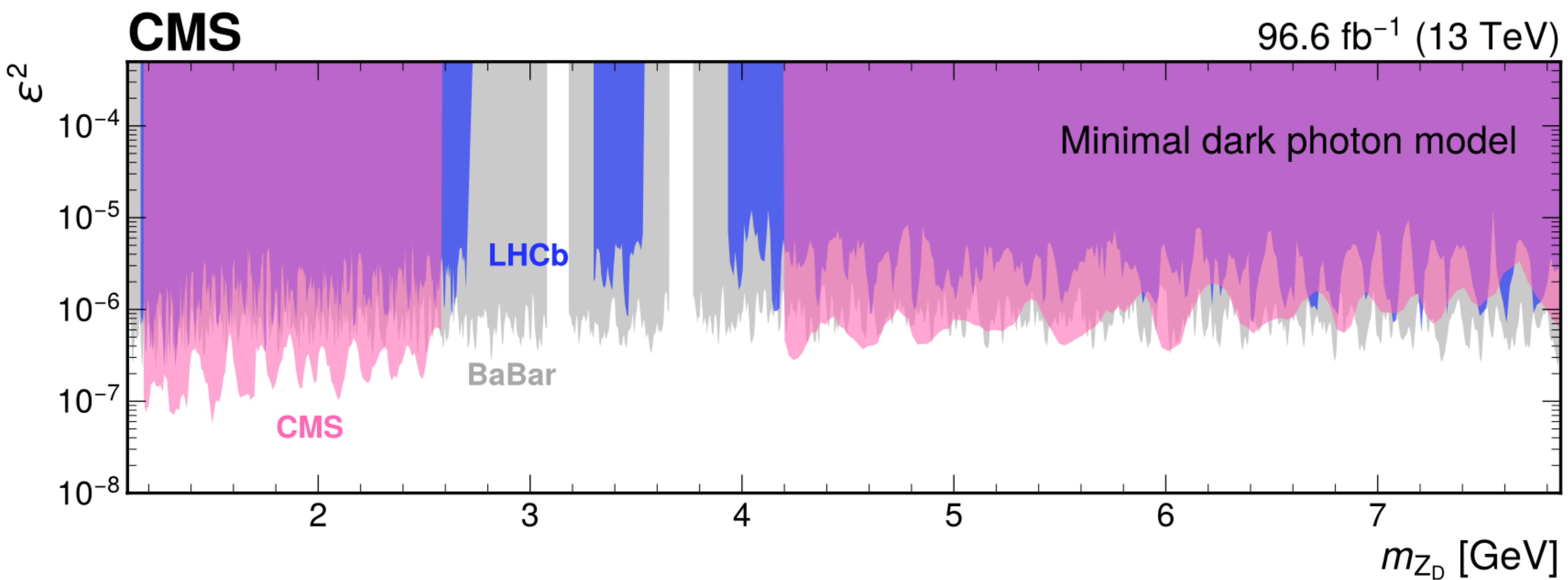
Low mass di-muon with scouting - Scouting Trigger

Mainly targeting light mediators (short-lived)



Low mass di-muon with scouting - Results

- Limits are set for $m_{\mu\mu}$ in [1.1, 2.6] and [4.2, 7.9] GeV



$X\phi$ family

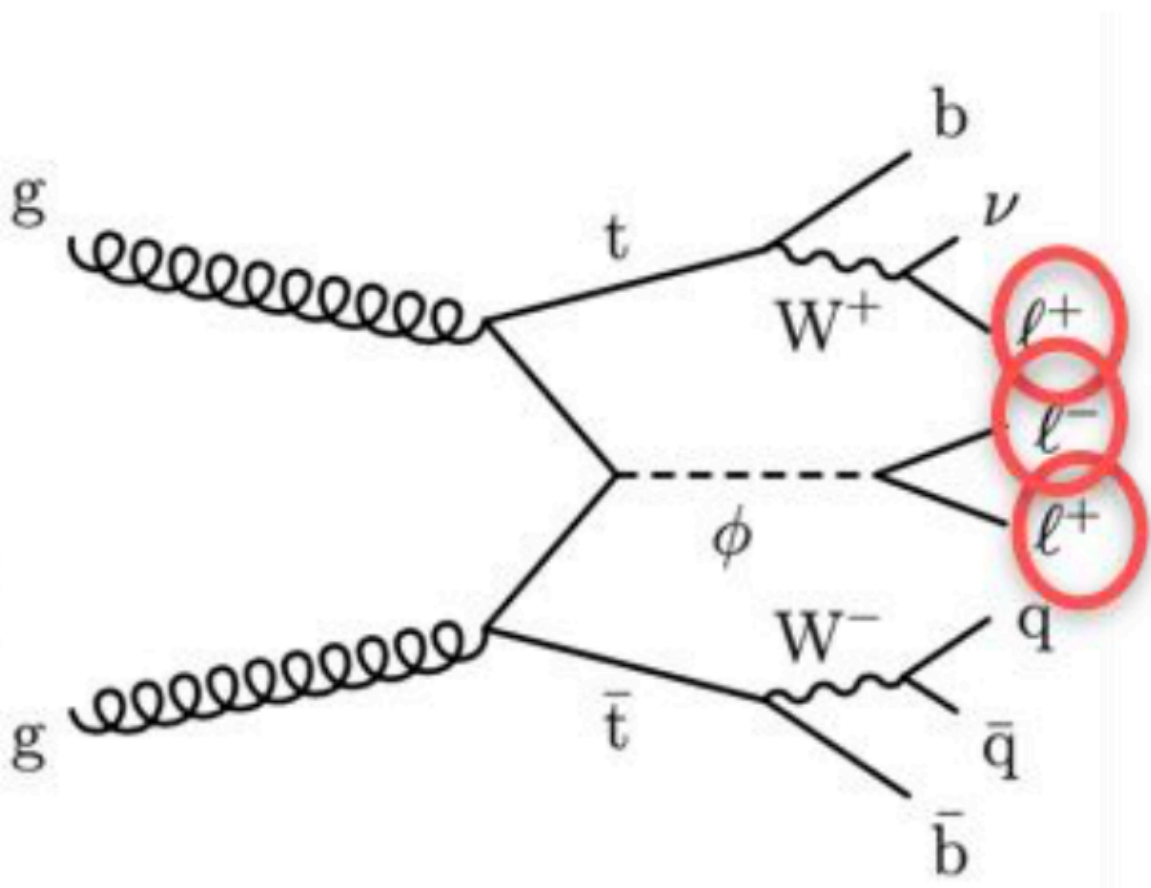


Search for resonant signatures in the multilepton final state

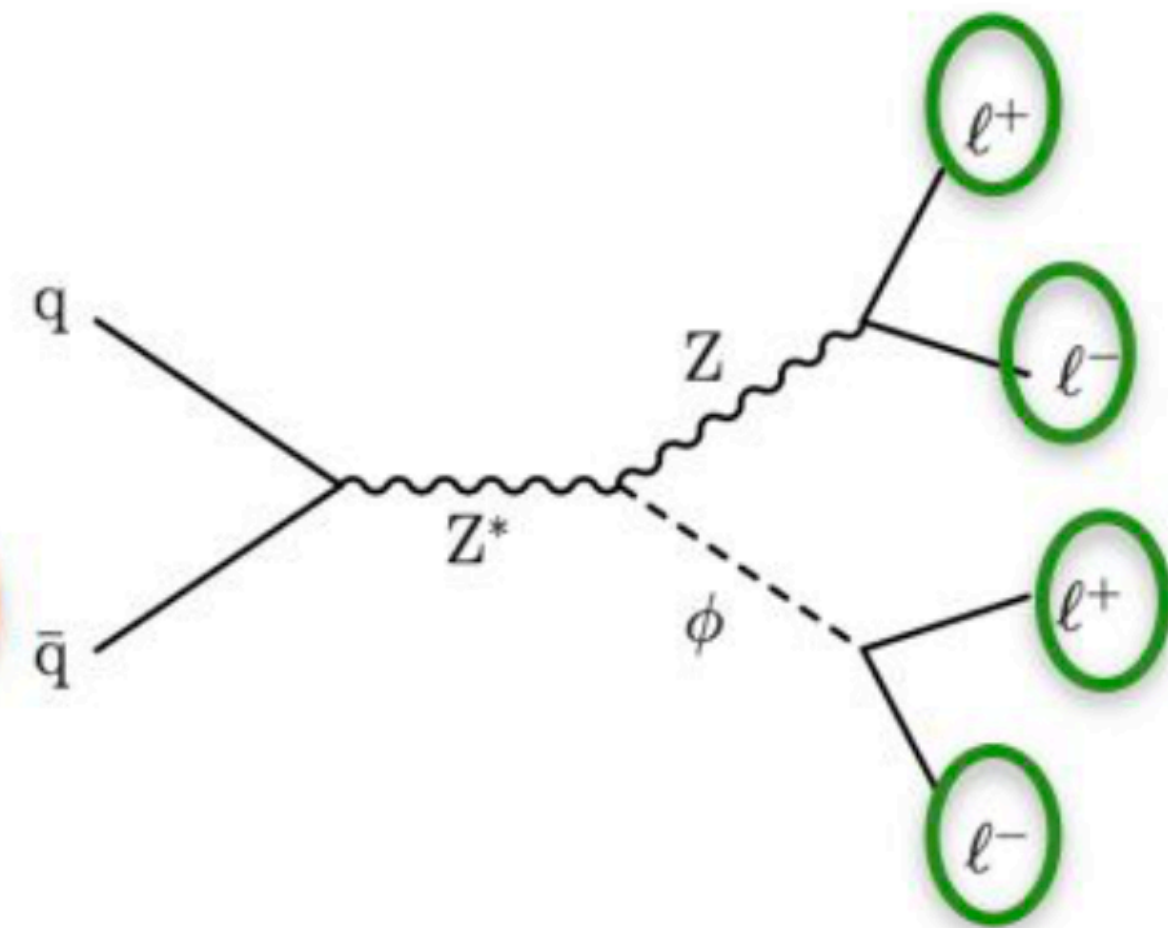
[arXiv:2402.11098](https://arxiv.org/abs/2402.11098)

Sub. to PRD

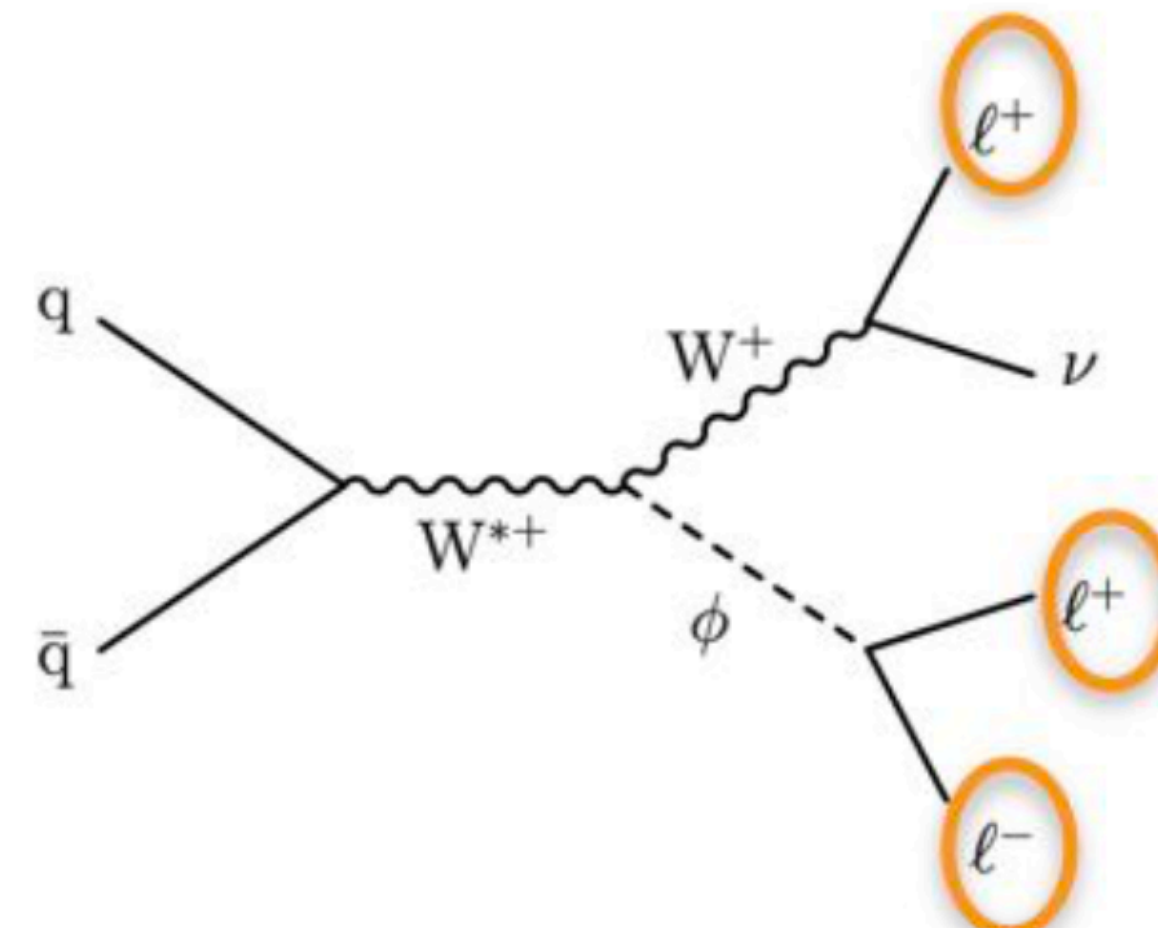
$t\bar{t}\phi$ ($\phi \rightarrow \ell^+\ell^-$)



$Z\phi$ ($\phi \rightarrow \ell^+\ell^-$)



$W\phi$ ($\phi \rightarrow \ell^+\ell^-$)



$\chi\phi$ family - Model

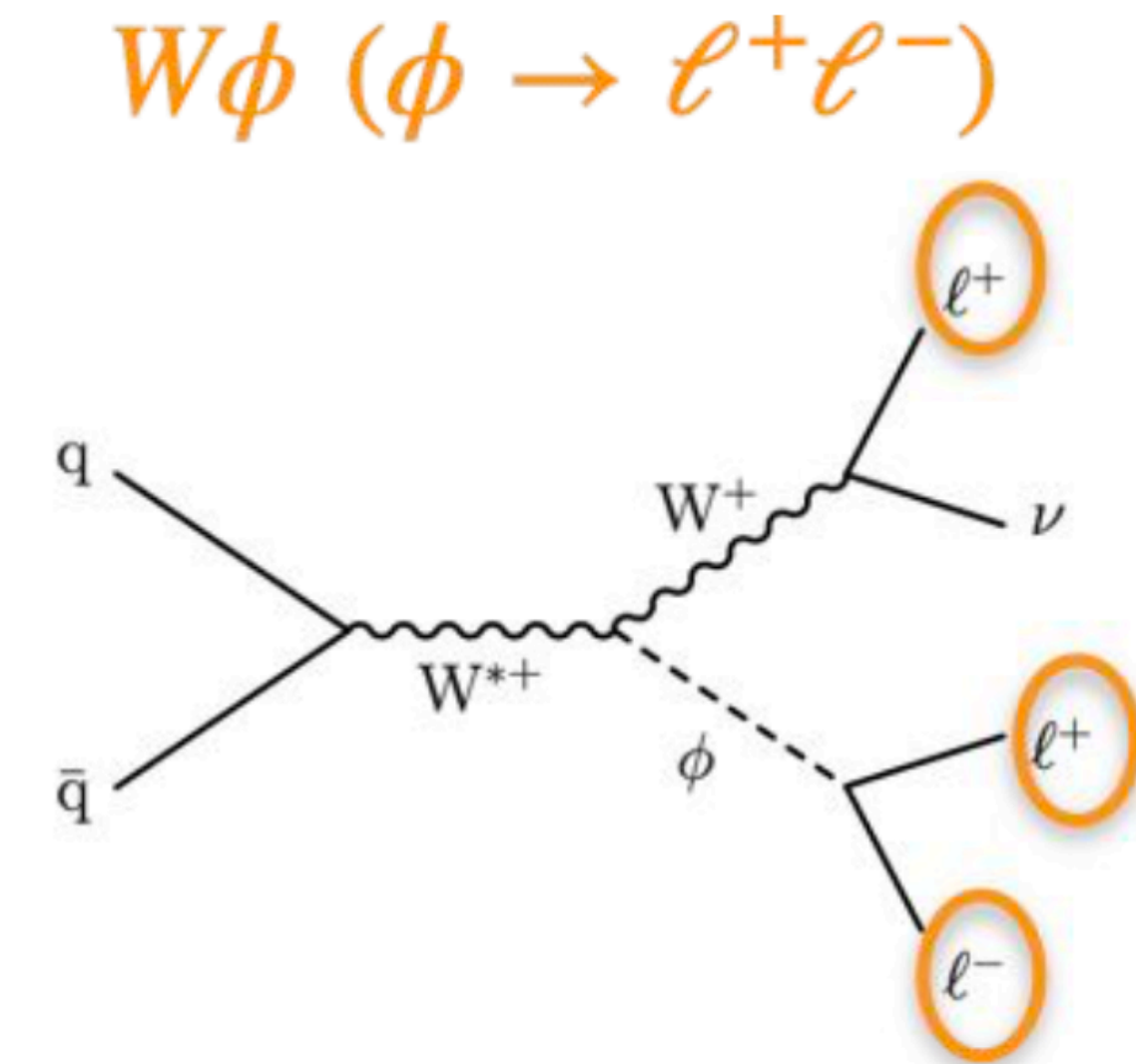
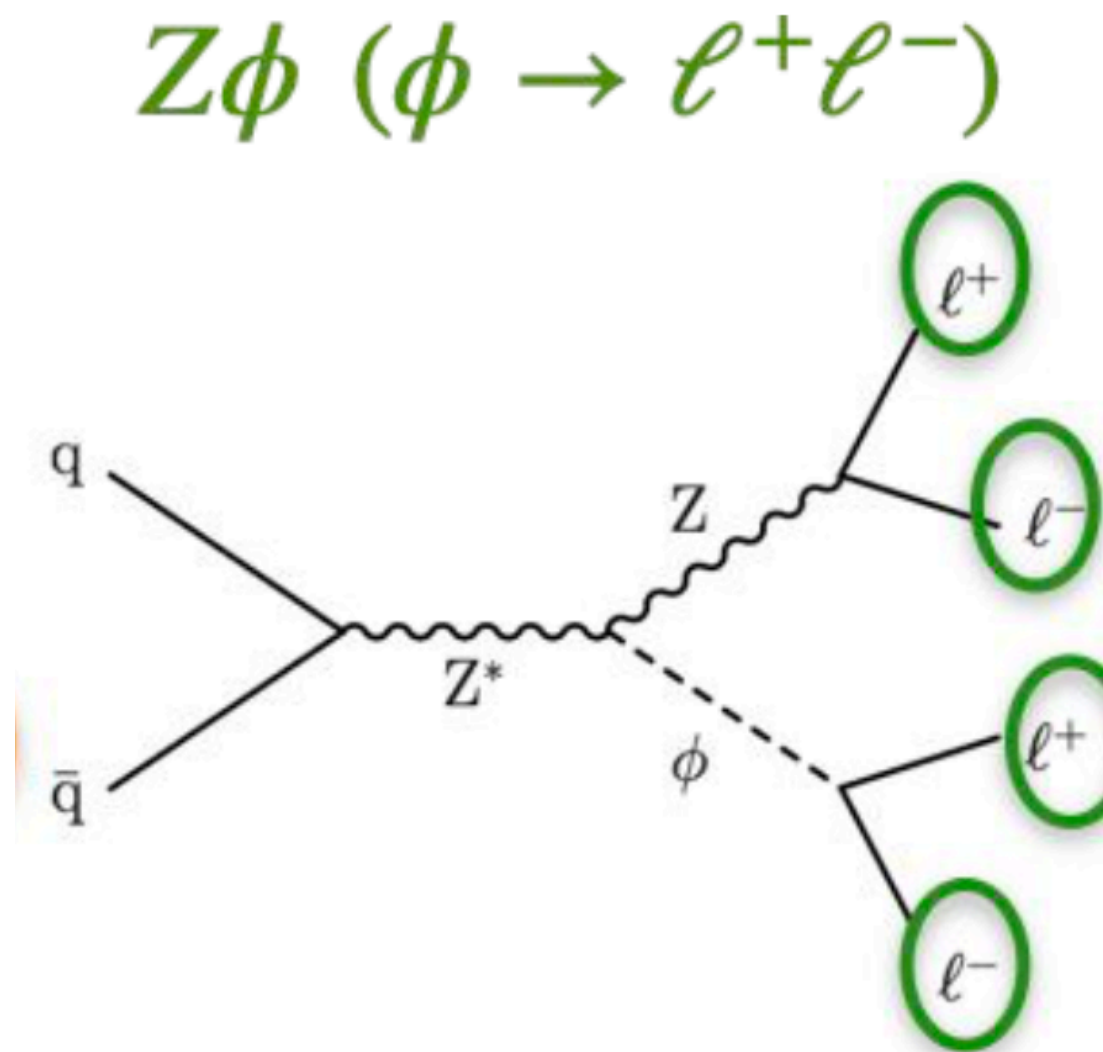
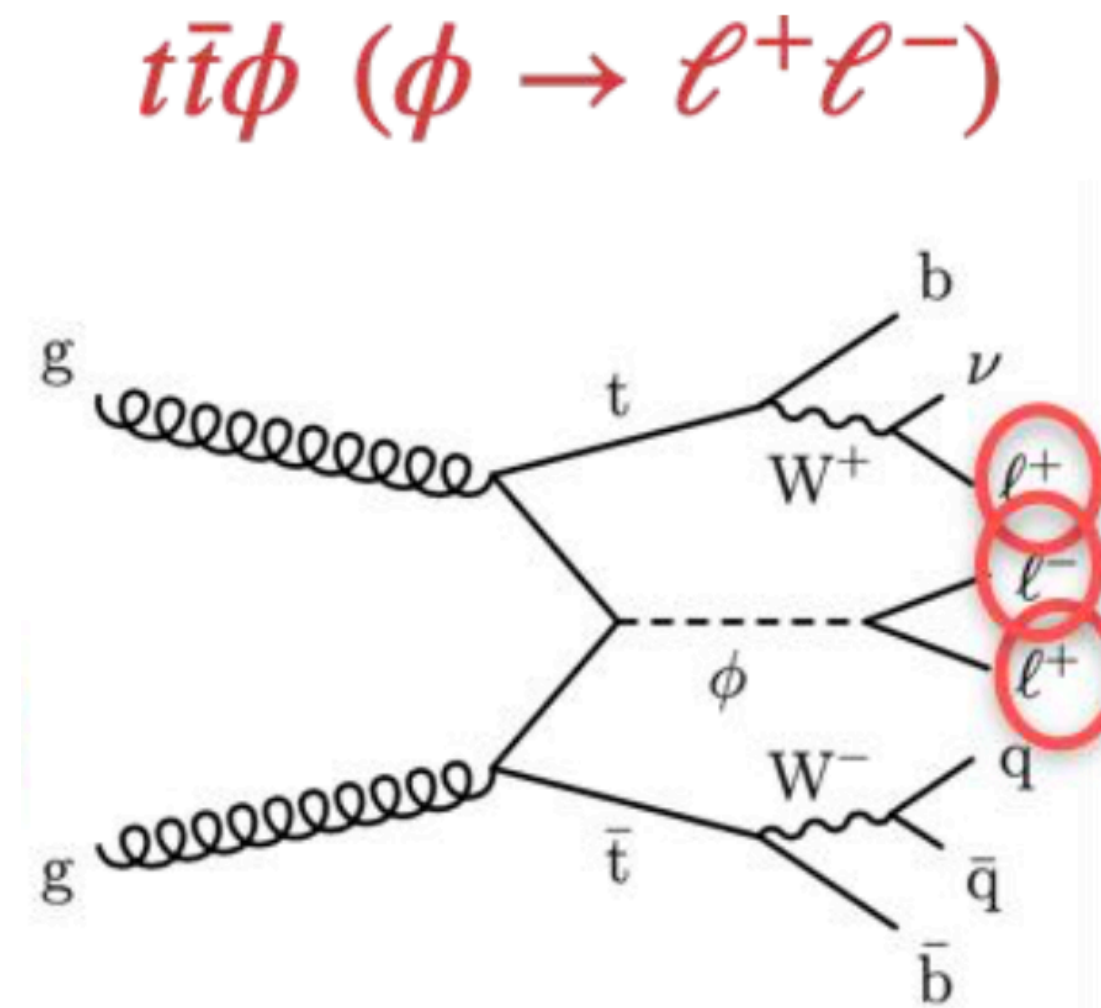
- Search for resonant signature of ϕ boson in multilepton events
- ϕ is produced in association with $t\bar{t}$ pair or W/Z bosons
 - Scalar(S), pseudoscalar (PS) and Higgs-like (H) coupling scenarios are probed

For S/ PS : $\sigma(W\phi/Z\phi) \sim \Lambda^{-2}$
 $\sigma(tt\phi) \sim g_{s/ps}^2$

For Higgs-like: $\sigma(W\phi/Z\phi) \sim \sin^2 \theta$
 Λ effective coupling mass scale,
 θ mixing angle, g Yukawa coupling to top quark

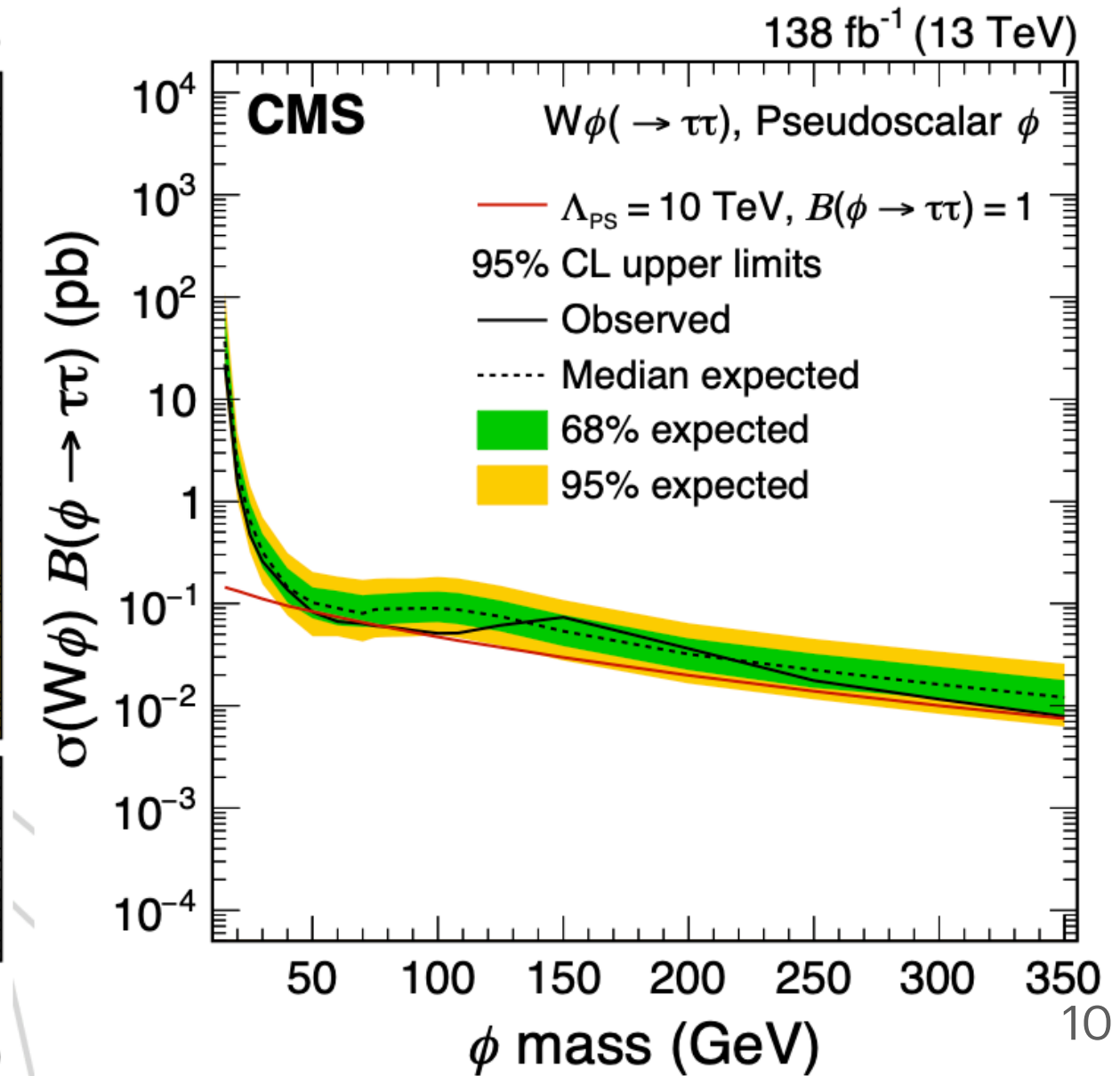
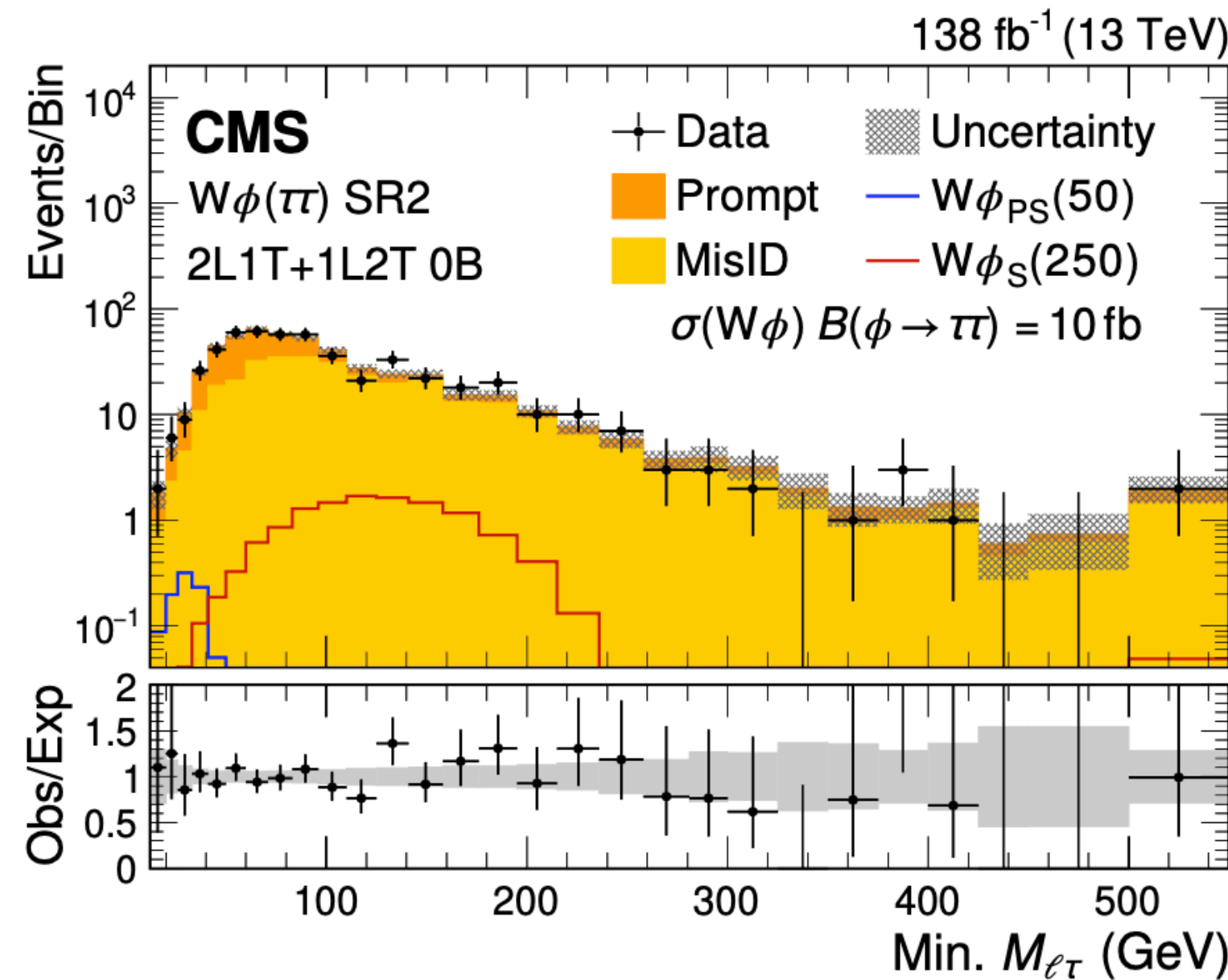
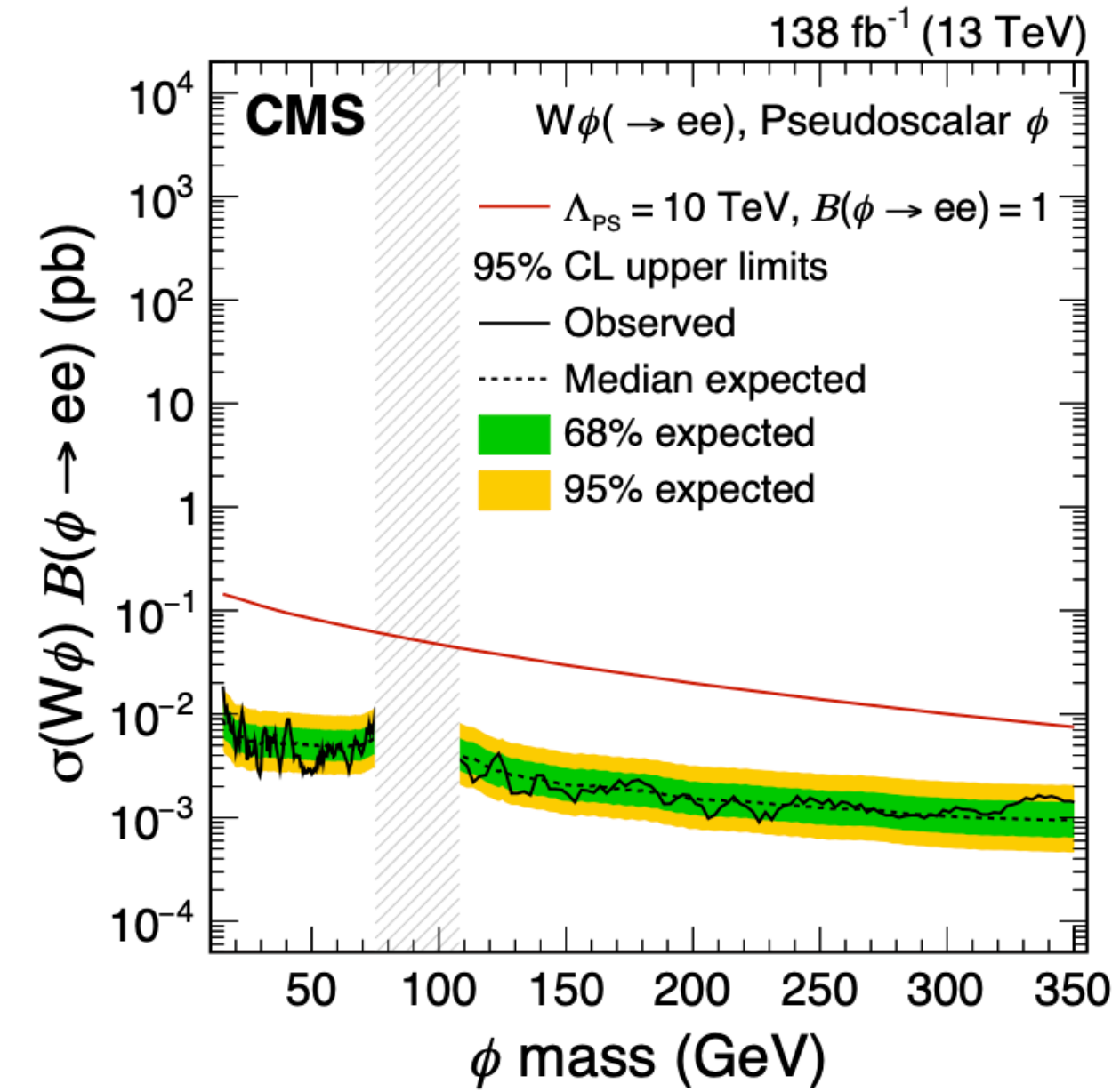
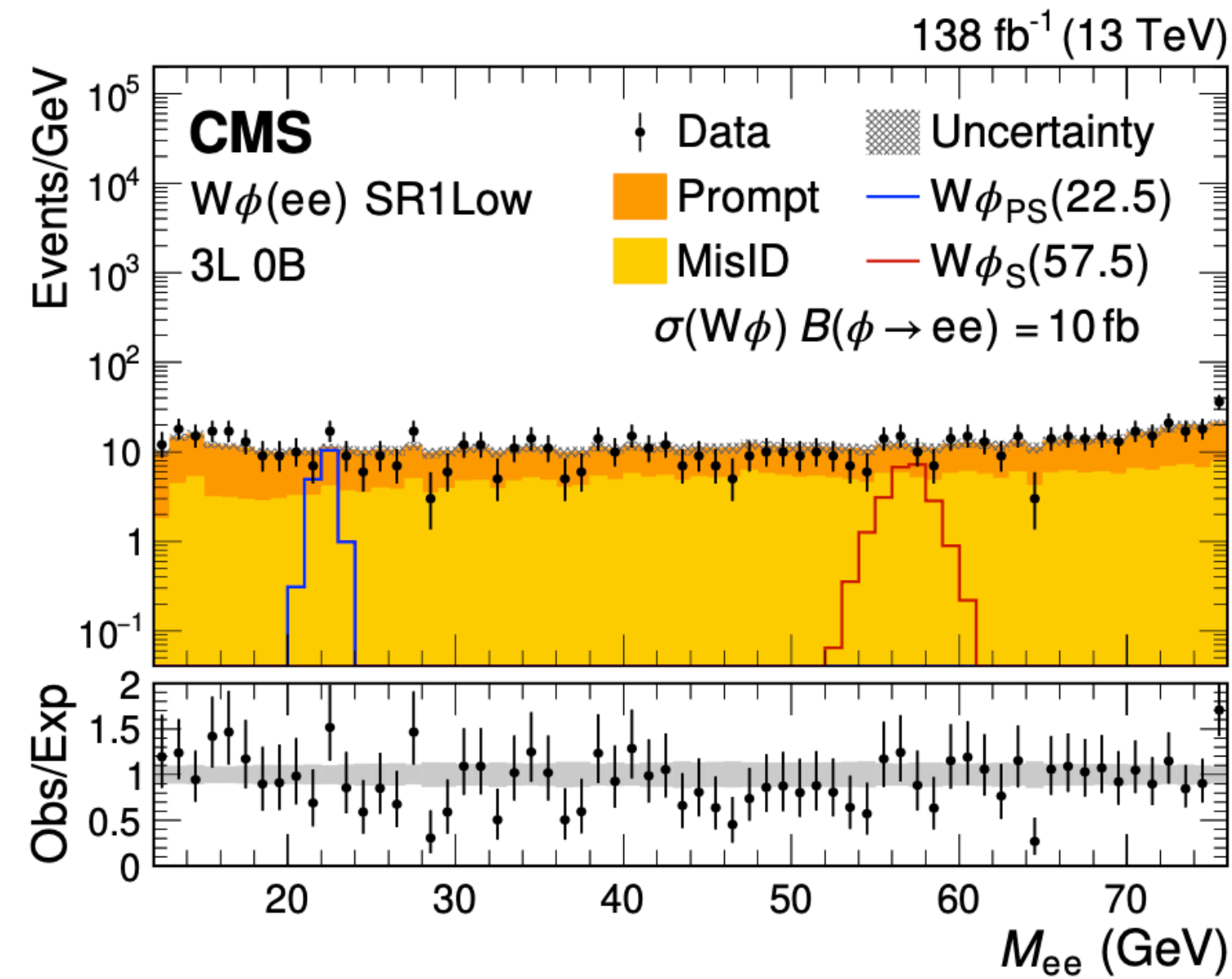
- Complementary signatures:

- 0 / 1+ b-jets,
- low/high ST,
- 3 or 4 leptons,
- with/without MET



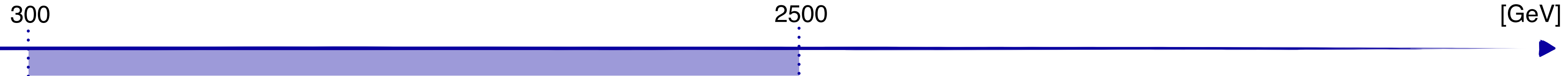
$X\phi$ family - Results

- Resonant $X\phi \rightarrow ee/\mu\mu$
 - Dilepton mass is the final discriminator distribution
 - ϕ mass is probed in the mass range of 15-76 GeV and 106-366 GeV (Z mass window excluded)
- Semiseronant $X\phi \rightarrow \tau\tau$
 - Mass spectra are defined depending on the flavor of leptons used to reconstruct the ϕ mass
 - two τ_h leptons $\rightarrow M_{\tau\tau}$, light lepton + $\tau_h \rightarrow M_{l\tau}$, two light lepton $\rightarrow M_{ll}$
- $W\phi$, $Z\phi$ and $tt\phi \rightarrow \tau\tau$ are the first direct constraints on an extension of the SM with light boson in leptonic decay channels and this mass range.

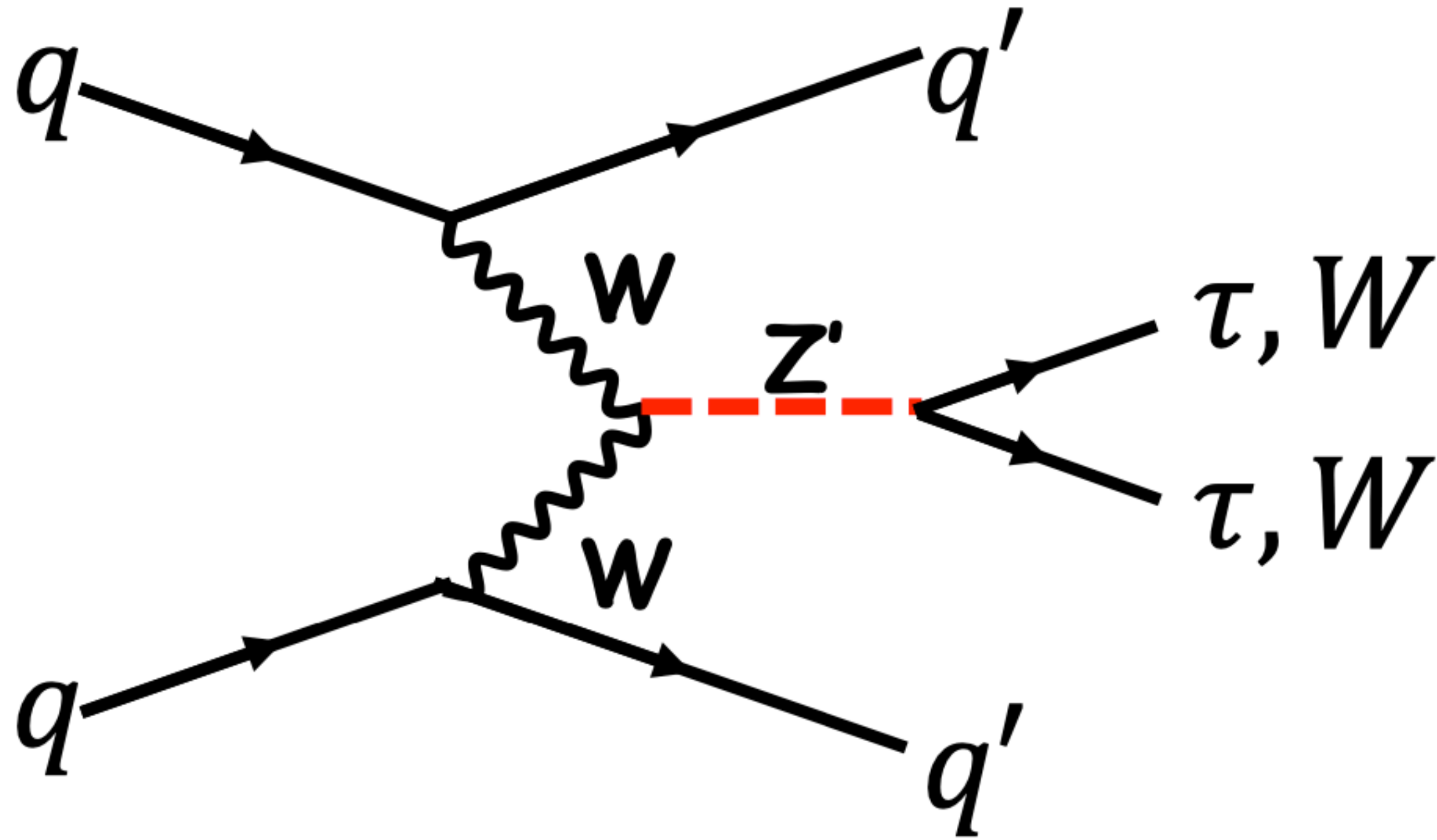


NEW

VBF Z' ($WW/\tau\tau$)



Search for VBF Zprime to tautau (WW)



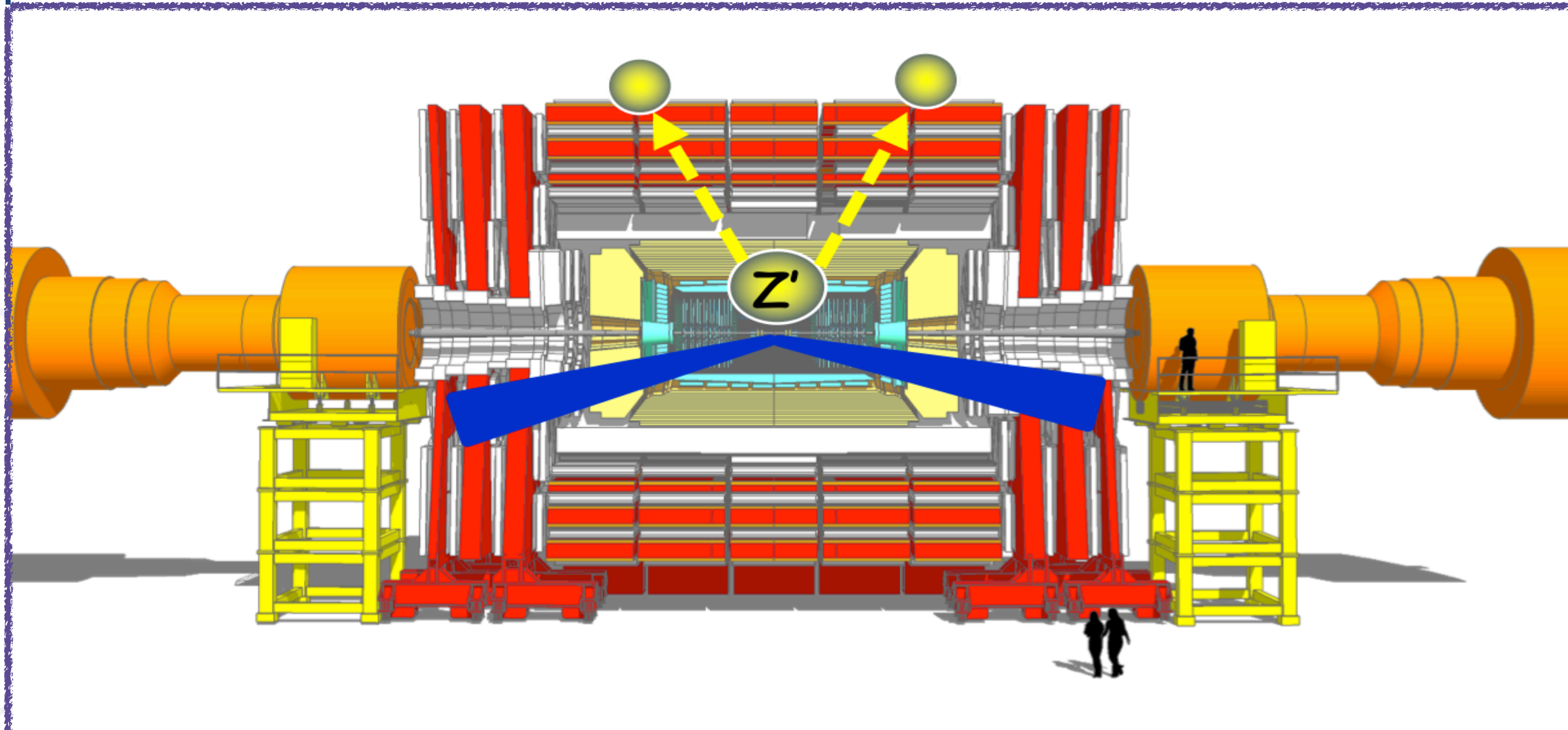
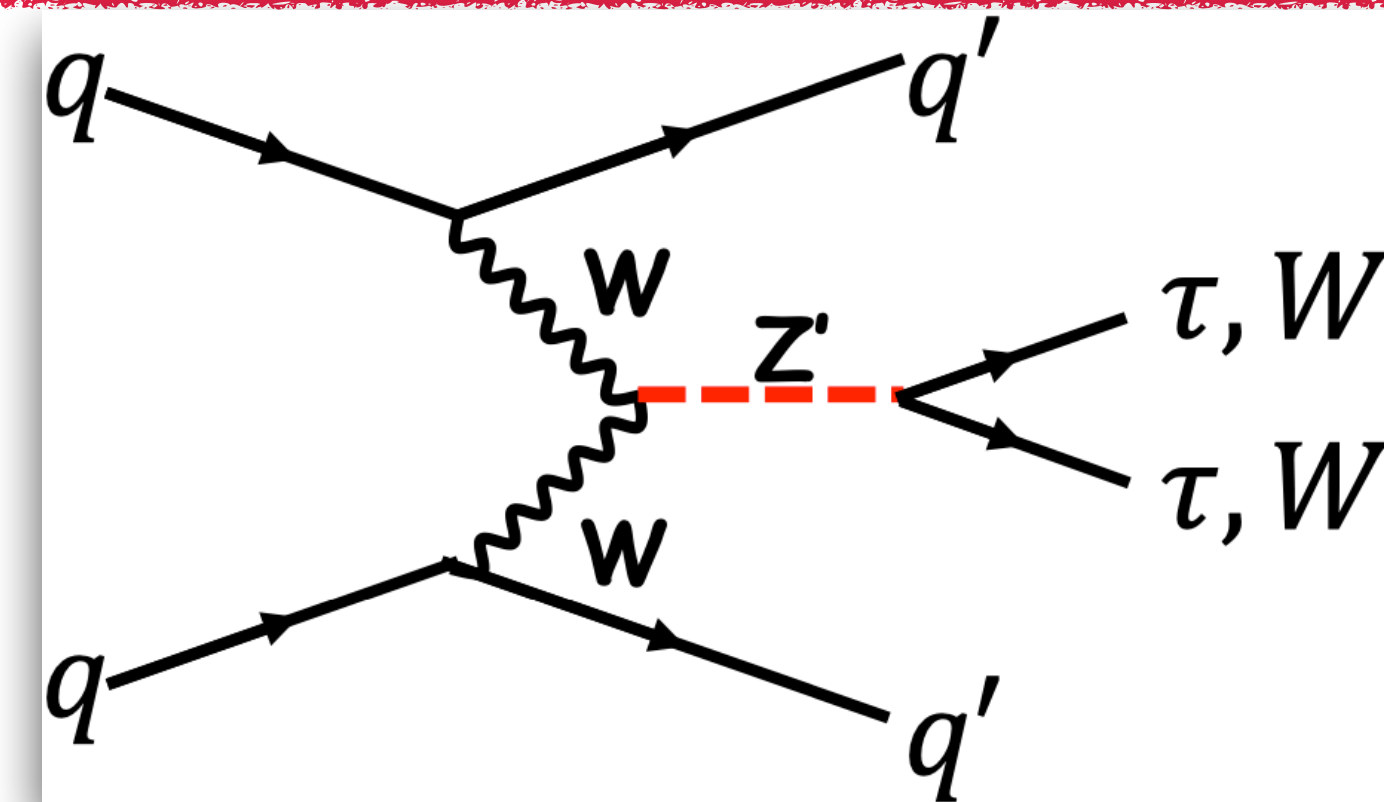
Other result with τ lepton in the final state in [Carlos' talk](#)

NEW

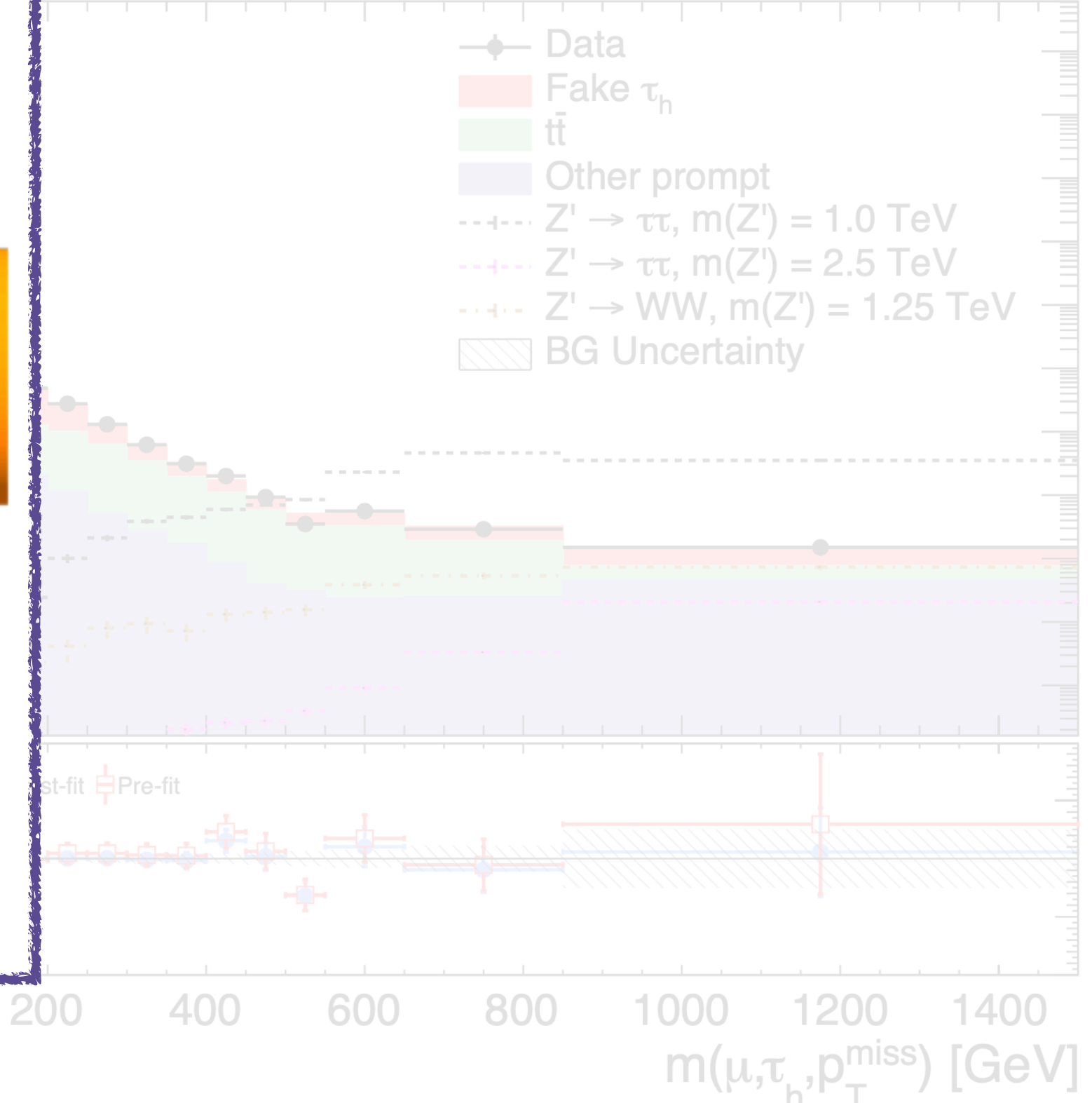
VBF Z' (WW/ $\tau\tau$) - Model

- Search in the $e\mu$, $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states, with emphasis on 3rd generation

- VBF topology -> require a pair of well separated & in the opposite plane ($|\Delta\eta_{jj}| > 4.2$ & $|\eta_1\eta_2| < 0$) jets with high mass ($m_{jj} > 500$ GeV)



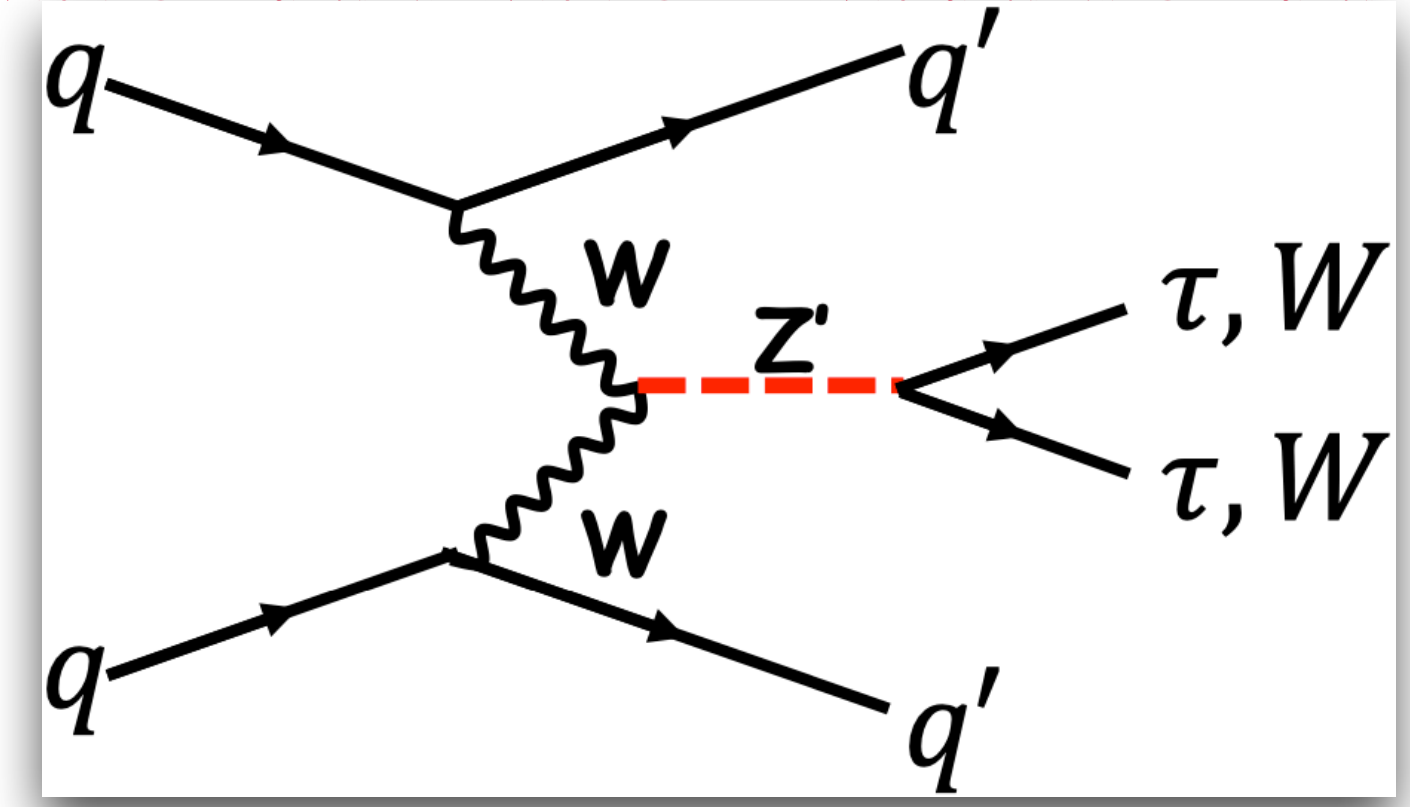
MS Preliminary Run 2, 138 fb⁻¹ (13 TeV)



NEW

VBF Z' (WW/ττ) - M_{Z'}

- Search in the eμ, eτ_h, μτ_h, and τ_hτ_h final states, with emphasis on 3rd generation
- VBF topology -> require a pair of well separated & in the opposite plane ($|\Delta\eta_{jj}| > 4.2$ & $|\eta_1\eta_2| < 0$) jets with high mass ($m_{jj} > 500$ GeV)
- Boost to the Z' => p_T^{miss} from τ decay is collinear with Z'

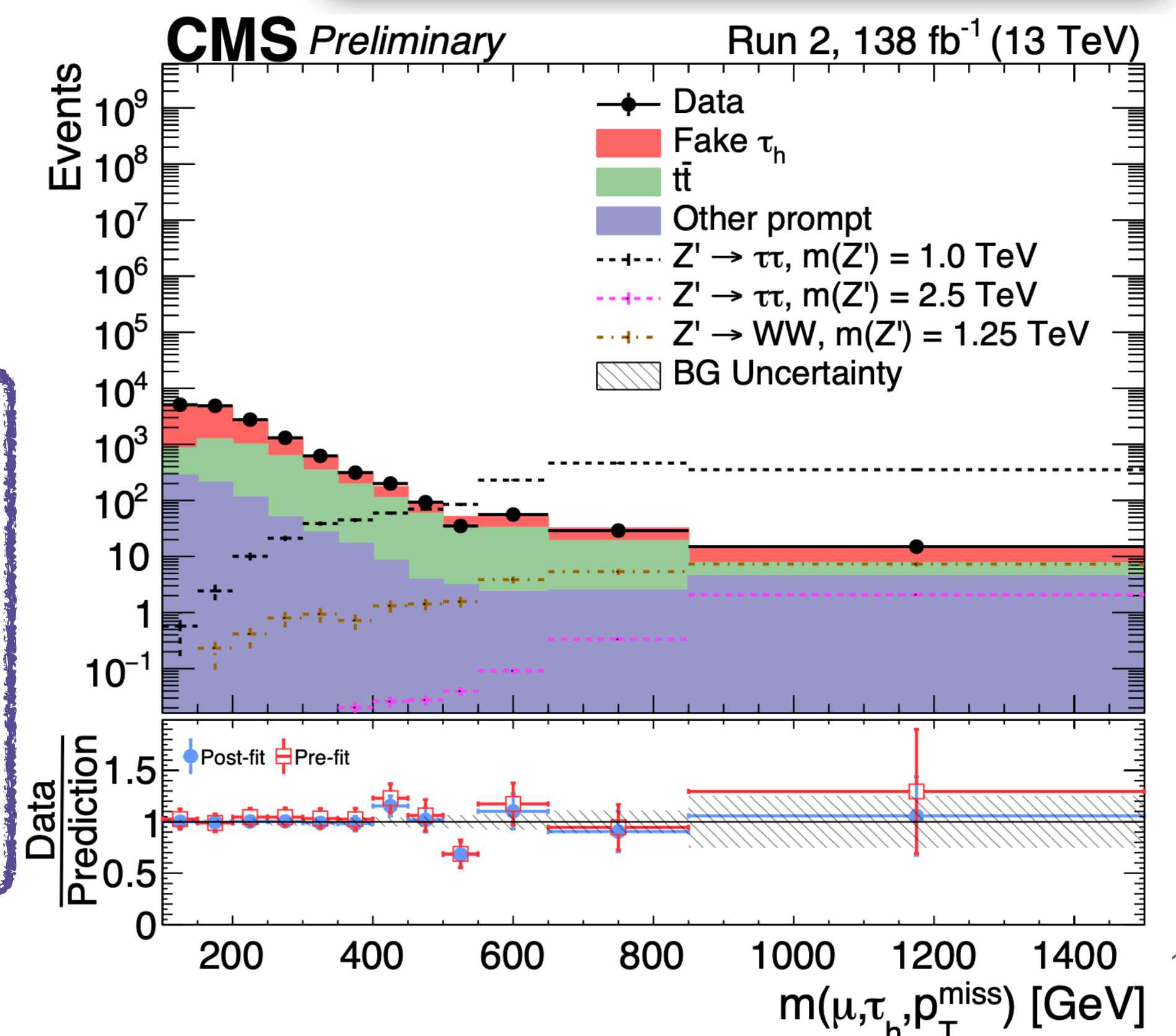


$$m_{Z'}^{reco} = \sqrt{(E_{\ell_1} + E_{\ell_2} + p_T^{miss})^2 - (\vec{p}_{\ell_1} + \vec{p}_{\ell_2} + \vec{p}_T^{miss})^2}$$

Background estimation:

Non-prompt background estimated by loose-tight method from sidebands

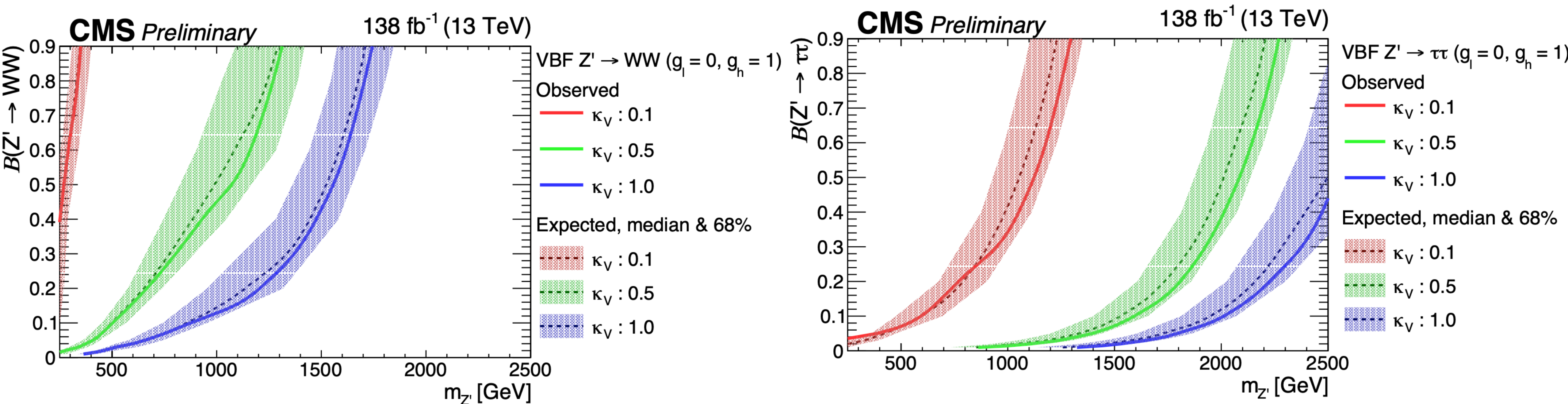
Prompt background estimated by MC and normalized from data



NEW

VBF Z' (WW/ $\tau\tau$) - Results

- Interpretation relies on the Sequential Standard Model and four independent parameters:
 - Z' couplings to 1st+2nd (g_l) and 3rd (g_h) generations
 - Coupling to W (κ_V)
 - Z' mass ($m_{Z'}$)
- First interpretations of VBF produced Z' at the LHC



NEW

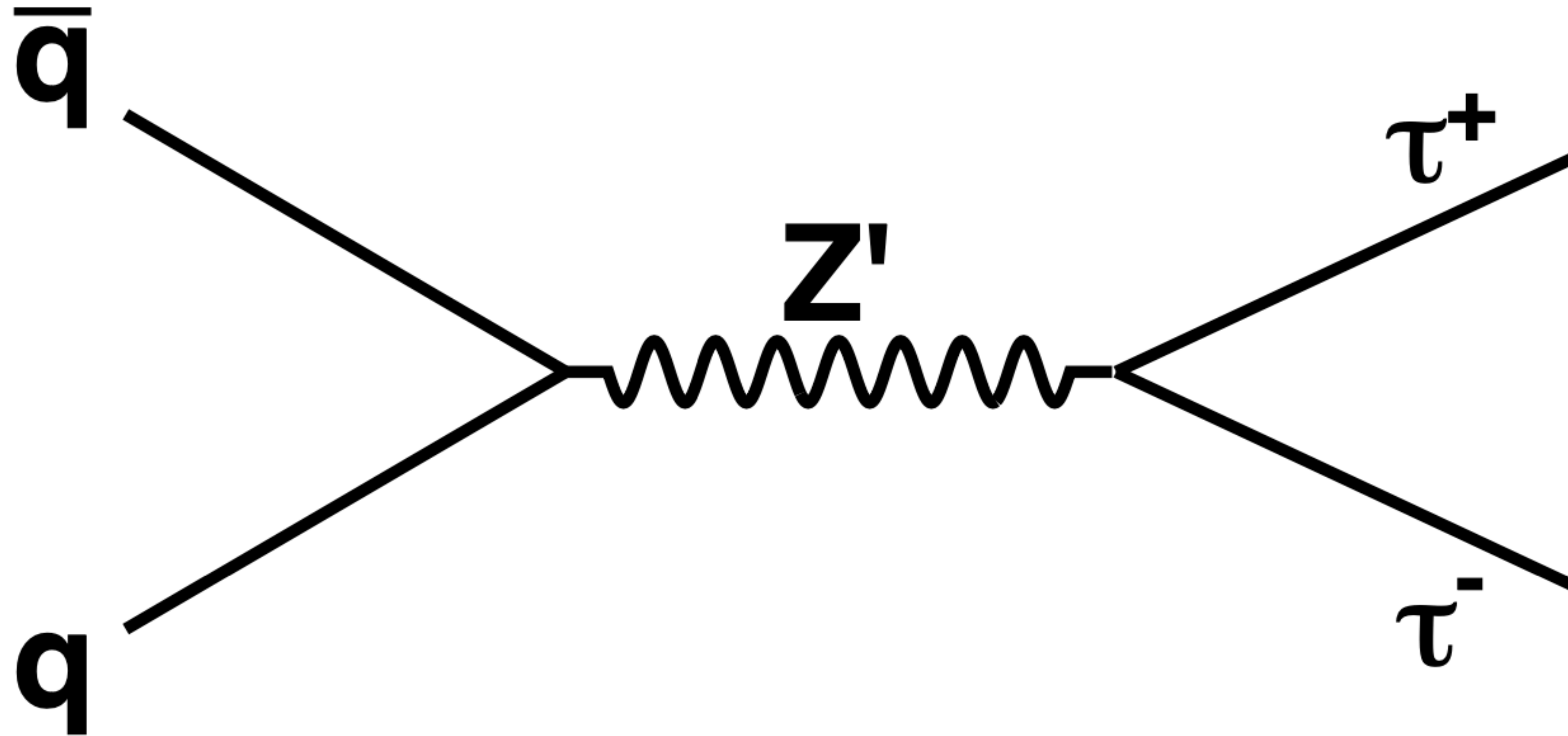
$$Z' \rightarrow \tau\tau$$

400

4000

[GeV]

Search for Heavy Neutral Resonances Decaying to Tau Lepton Pairs

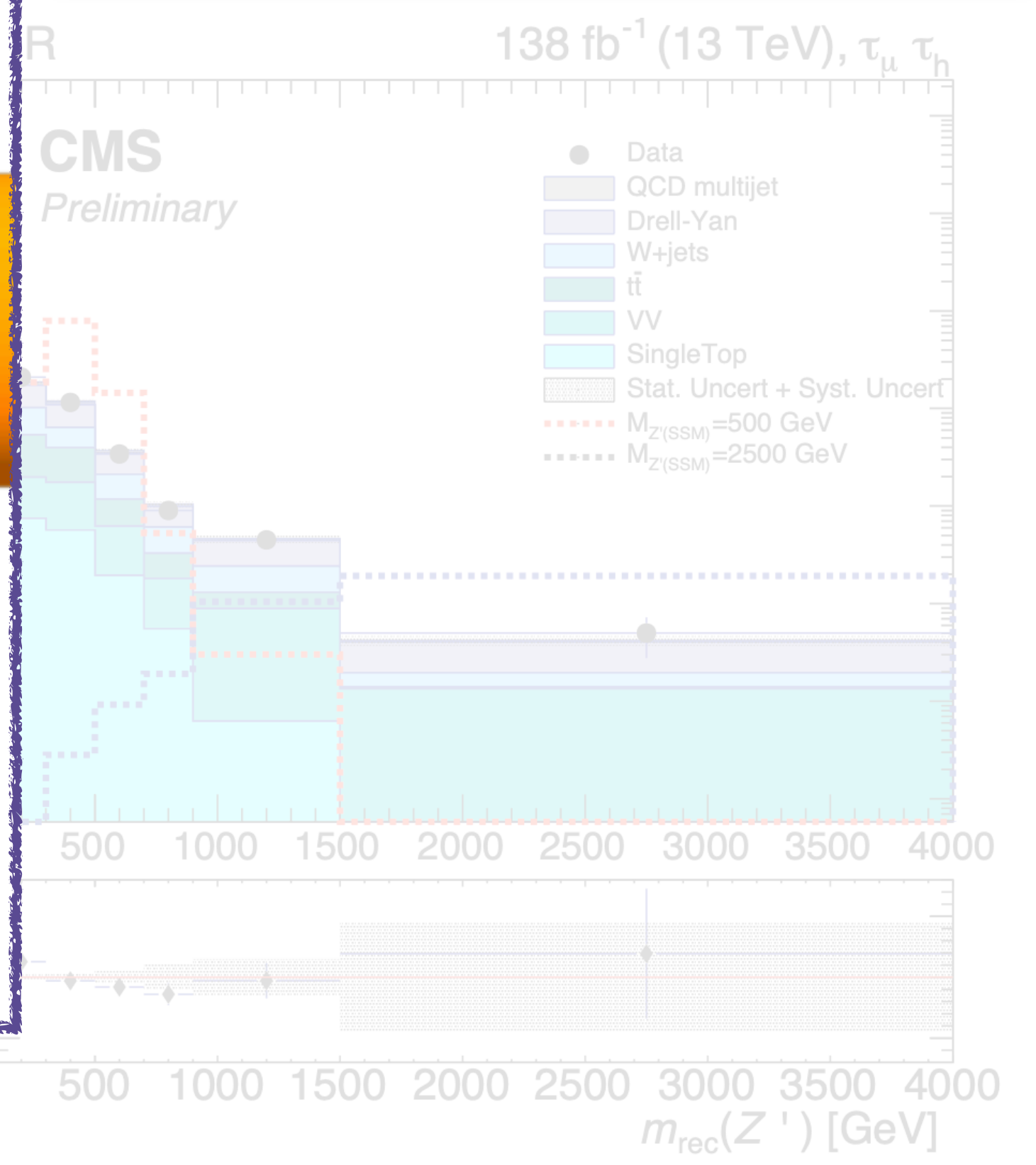
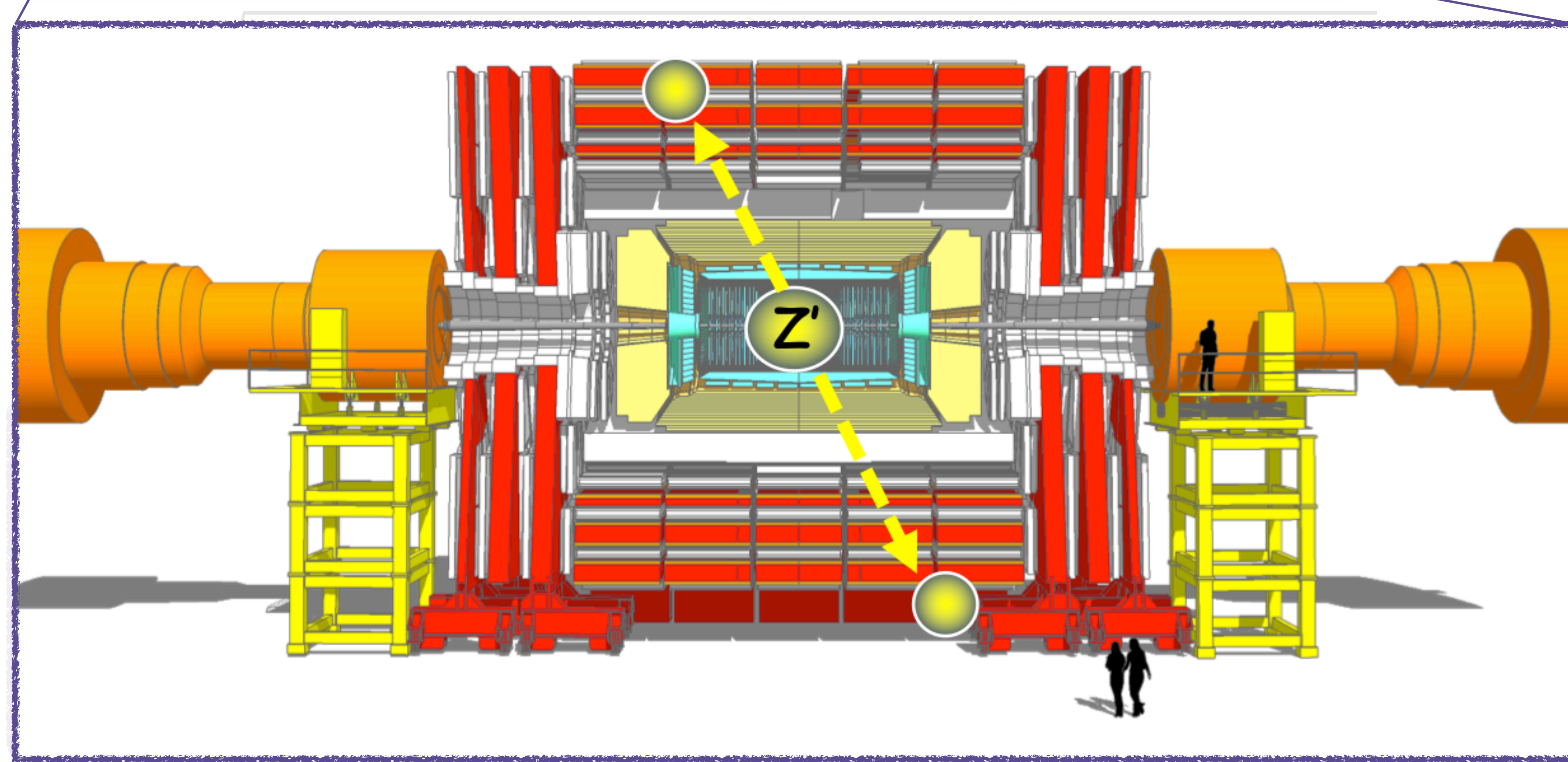
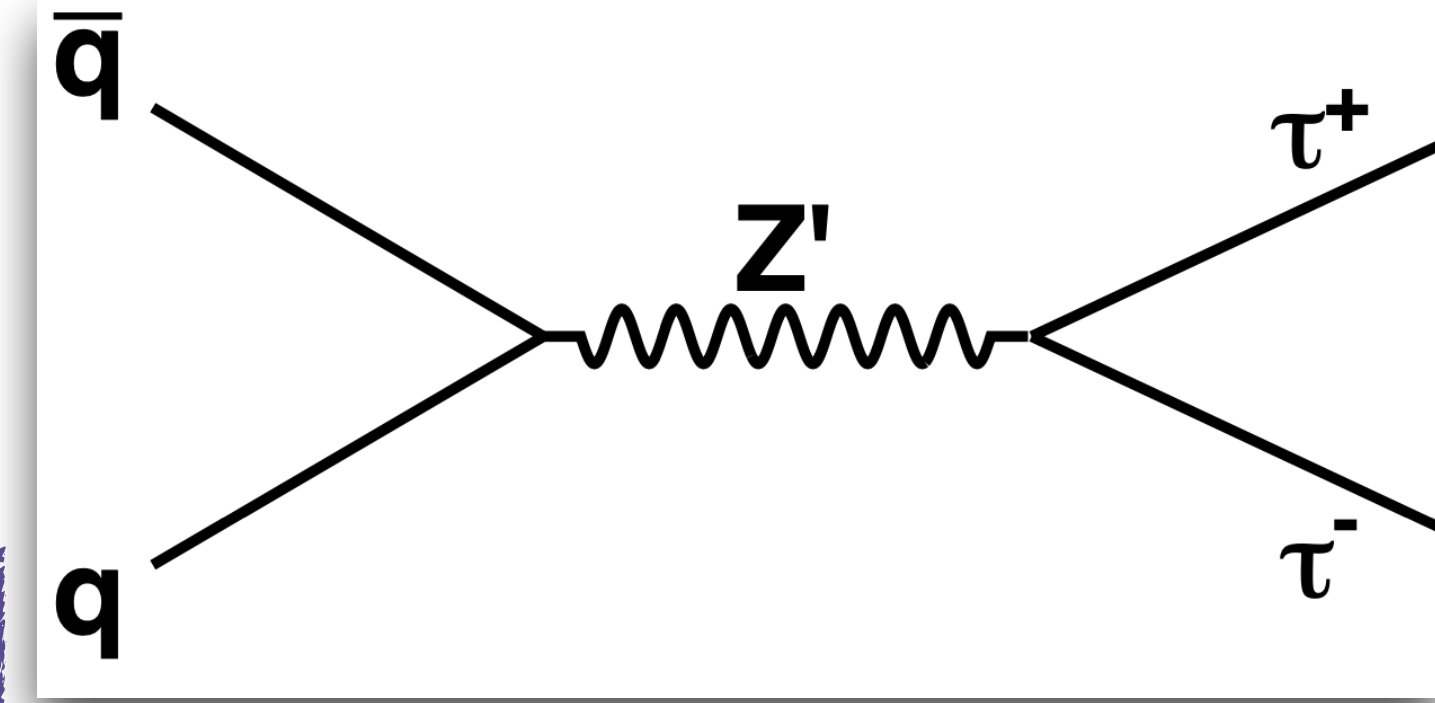


Other result
with τ lepton
in the final
state in
[Carlos' talk](#)

NEW

$Z' \rightarrow \tau\tau$ - Model

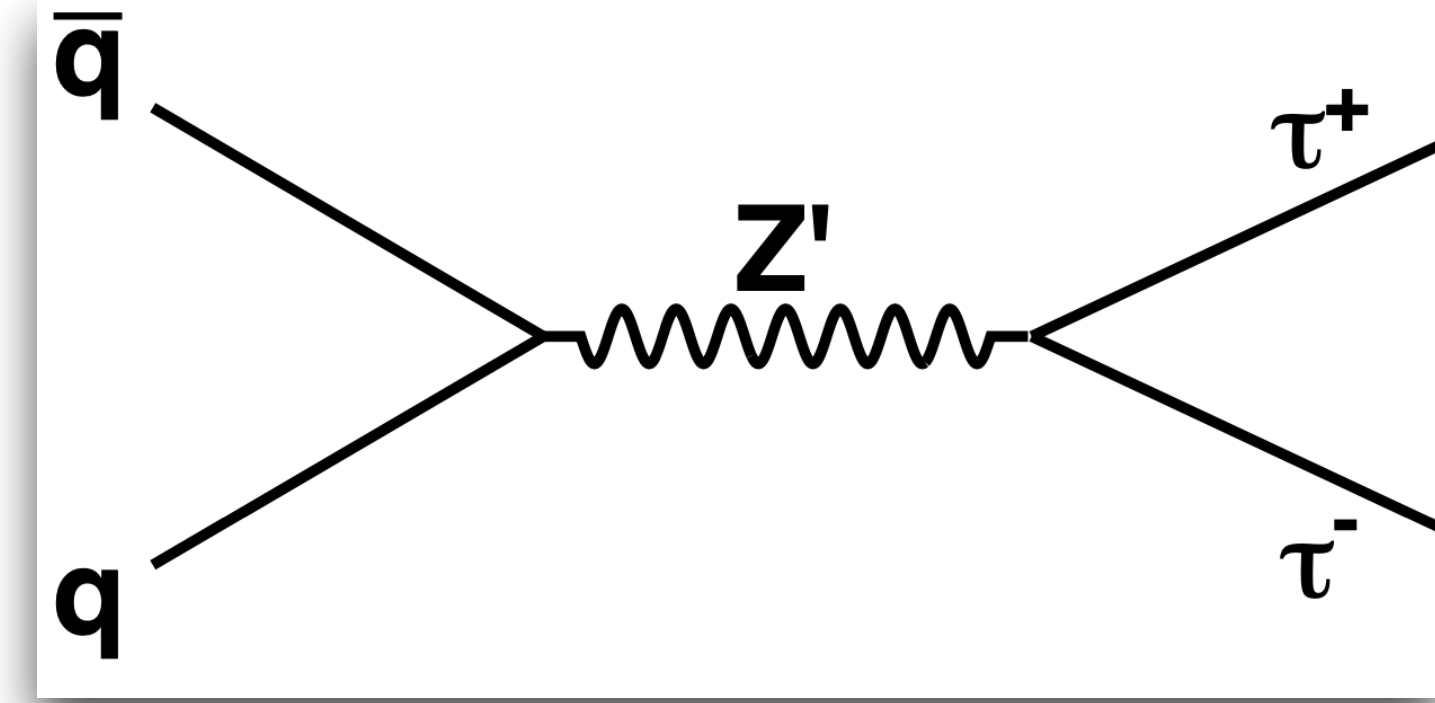
- Search in the $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states
- Z' not boosted \rightarrow high $M_{Z'}$ two back to back τ



NEW

$Z' \rightarrow \tau\tau - M_{Z'}$

- Search in the $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states
 - Z' not boosted \rightarrow high $M_{Z'}$ two back to back τ

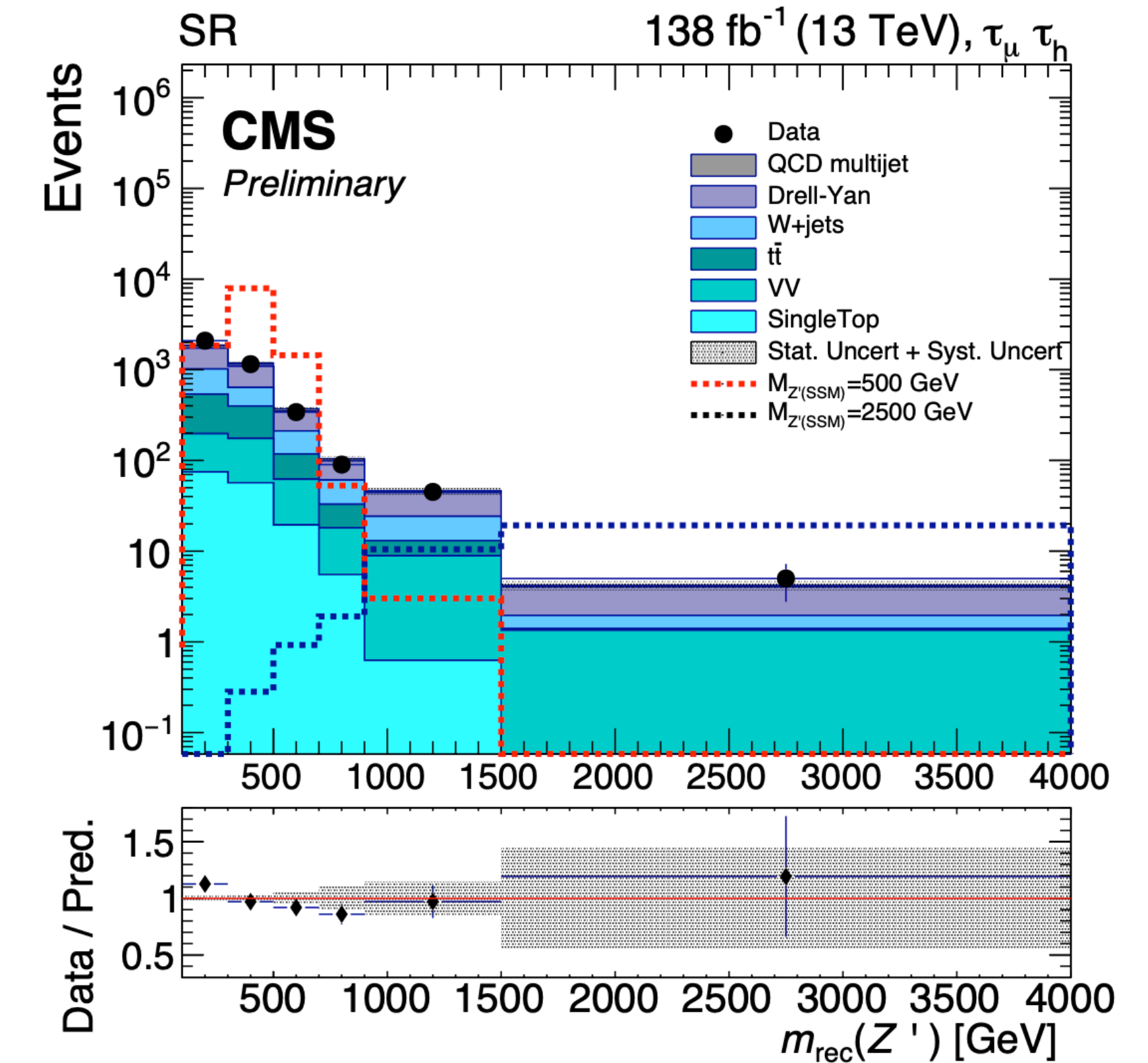


$$m_{Z'}^{reco} = \sqrt{(E_1^{\tau vis} + E_2^{\tau vis} + |p^{Z' miss}|)^2 - |p_1^{\tau vis} + p_2^{\tau vis} + p^{Z' miss}|^2}$$

$$p^{Z' miss} = (-(\vec{p}_{1T}^{\tau vis} + \vec{p}_{2T}^{\tau vis}), 0)$$

Background estimation:

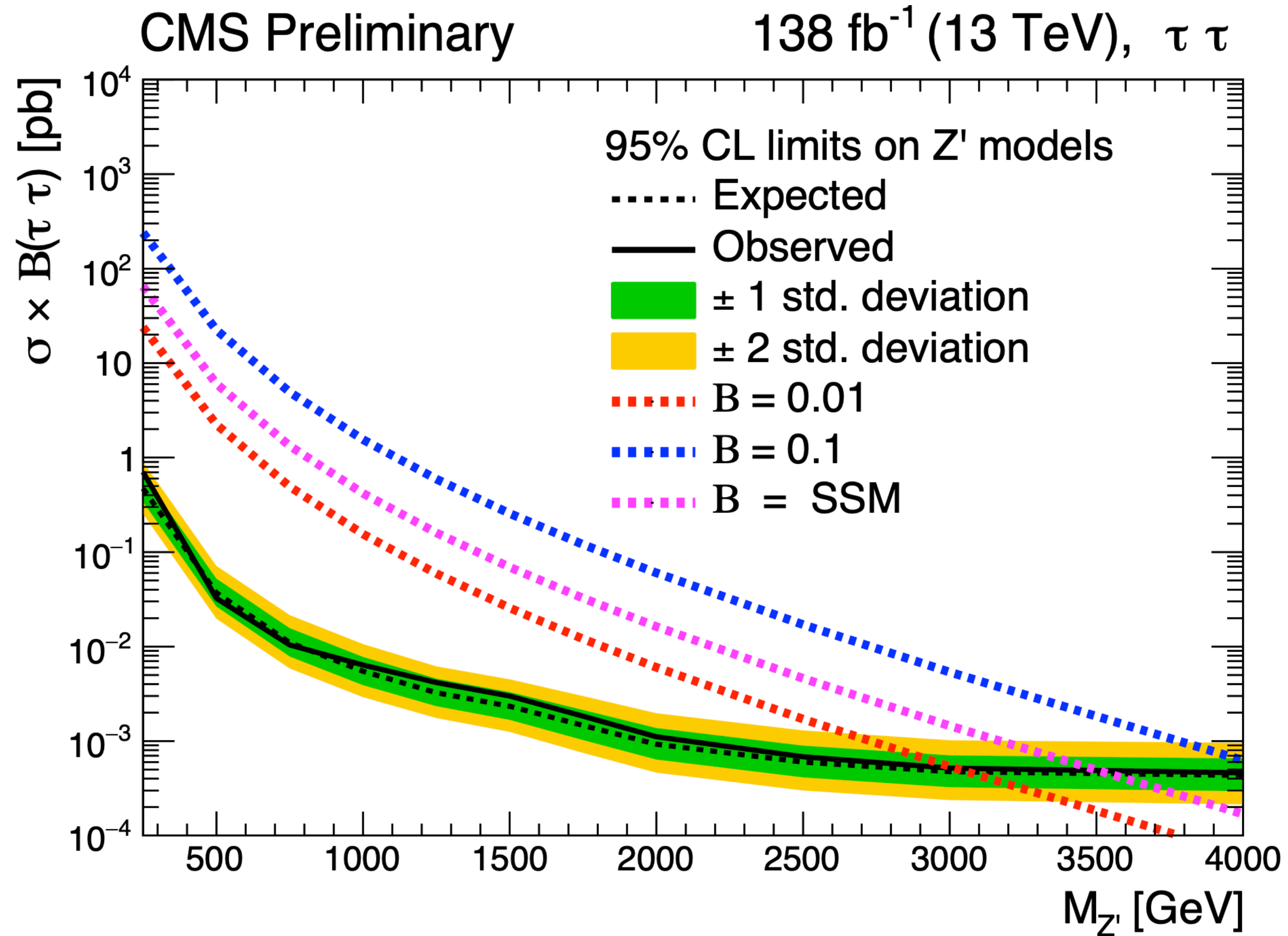
DY,W,tt estimated by MC and normalized from data
 QCD estimated with ABCD method



NEW

$Z' \rightarrow \tau\tau$ - Results

- Interpretation relies on Sequential Standard Model-like interpretation:
- Limits in mass range from 400 GeV to 4 TeV
- Most stringent limits for $Z' \rightarrow \tau\tau$



Summary

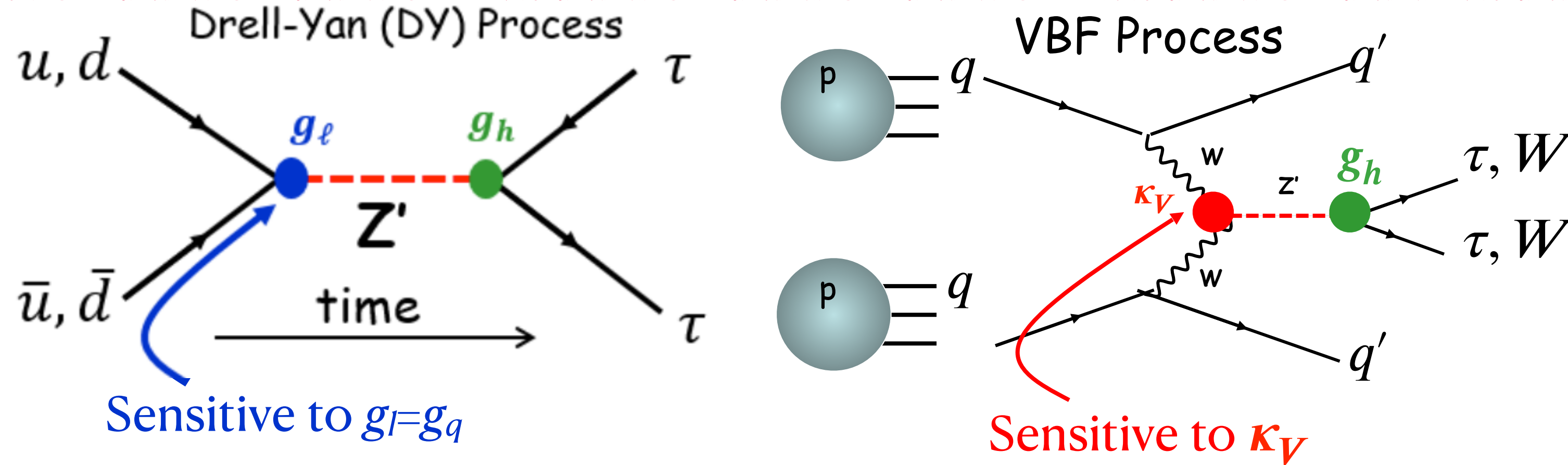
- CMS performed many resonant and non-resonant searches beyond Standard Model with leptons in the final state
 - Only some publications were discussed today. Full list of publications can be found [Exotica Publications page](#) and preliminary results [Recent Exotica Preliminary Results](#).
- 3 New results with τ in final state
 - [CMS-PAS-EXO-21-015](#) & [CMS-PAS-EXO-21-016](#) this talk
 - [CMS-PAS-EXO-22-007](#) in [Carlos'](#) talk
- Run3 is bringing: more data, new triggers, analysis techniques
 - Two results in [Anne's](#) and [Raphael's](#) talk
- Stay tuned for new results



NEW

Backup

DY $Z' \rightarrow \tau\tau$ vs. VBF Z' Complementarity



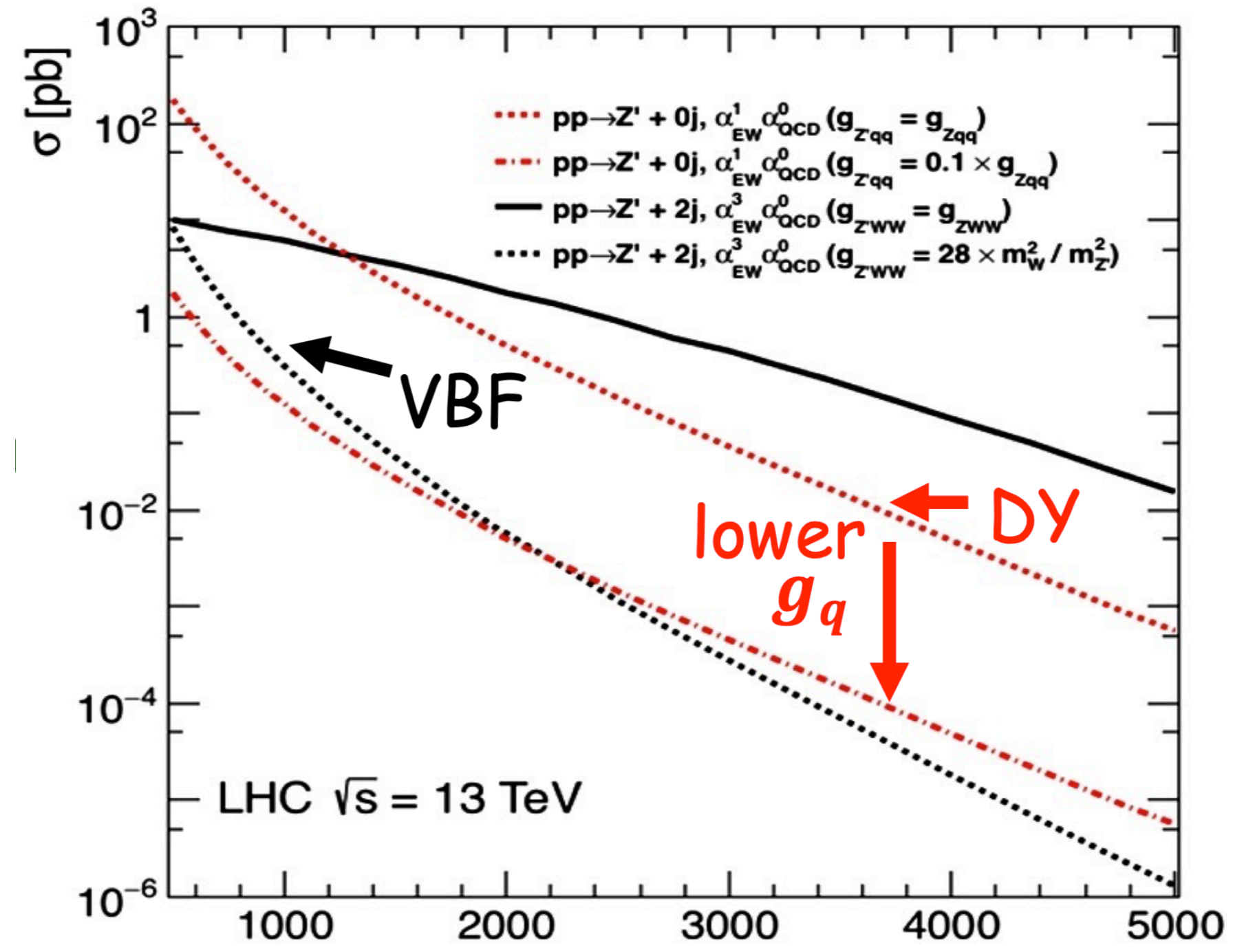
Simplified Model Definitions:

$$g_{Z'ff}^{1st,2nd} = g_\ell \times g_{Zff}^{1st,2nd}$$

$$g_{Z'ff}^{3rd} = g_h \times g_{Zff}^{3rd}$$

$$g_{Z'VV} = \kappa_V \times g_{Z'VV}^{max}$$

- DY $Z' \rightarrow \tau^+\tau^-$ search in events with **no jets from vector boson fusion (VBF) processes** ($|\Delta\eta(j_1, j_2)| > 3.8$ and $m(j_1, j_2) > 500$ GeV), ensuring **mutually exclusive with** $Z' \rightarrow \tau^+\tau^-$ and $WW(e\mu)$ searches in VBF processes. Possible to investigate Z' in parameter space of $g_{Z'qq}$, $g_{Z'\tau\tau}$, $g_{Z'ww}$
- When g_q is suppressed, existing bounds on $m(Z')$ from DY searches are weak (below 400 GeV, see [1])
- VBF Z' process has similar or larger cross section compared to DY when g_q is small [2]



DY $Z' \rightarrow \tau\tau$ vs. VBF Z' Complementarity - Results

- VBF Z' provides the best sensitivity when g_q is less than 0.3 [2]
- Investigating Z' in parameter space of $g_{Z'qq}$, $g_{Z'\tau\tau}$, $g_{Z'WW}$

