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Measurement of Triboson Production and aQGCs in CMS

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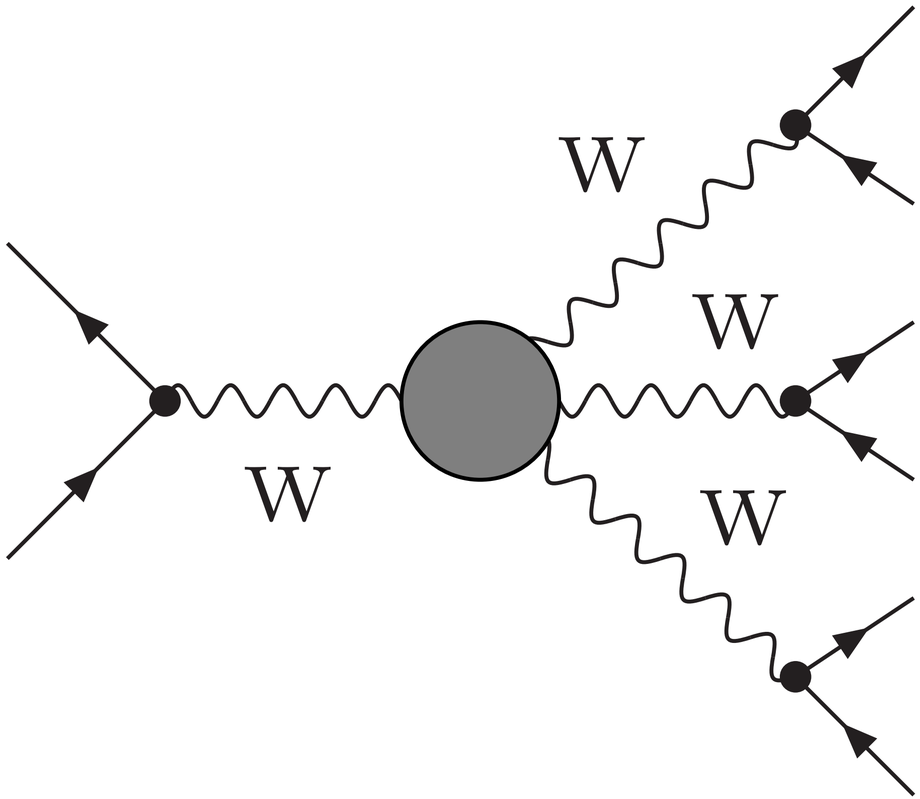
FNAL

August.27.2019
Multiboson Interaction Workshop

Physics motivation for triboson



- Stringently tests of SM Symmetry structure: SU(2)xU(1).
  - Access to quartic couplings
- Extremely rare processes: new physics may manifest themselves easily in these processes

Summary of triboson analyses in CMS

Process	Dataset	Measurement/significance	aQGC
Wγγ/Zγγ (JHEP 10 (2017) 072)	8 TeV/19.7fb-1	2.6/5.9 σ (~ a few fb-1)	Yes
WVγ (PRD 90 (2014) 032008)	8 TeV/19.7fb-1	X	Yes
WWW (PRD 100 (2019) 012004)	13TeV/36 fb-1	1.78/0.6 σ	Yes

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- Channels with photons:
  - No rate loss due to branching fraction
  - First evidence / observations

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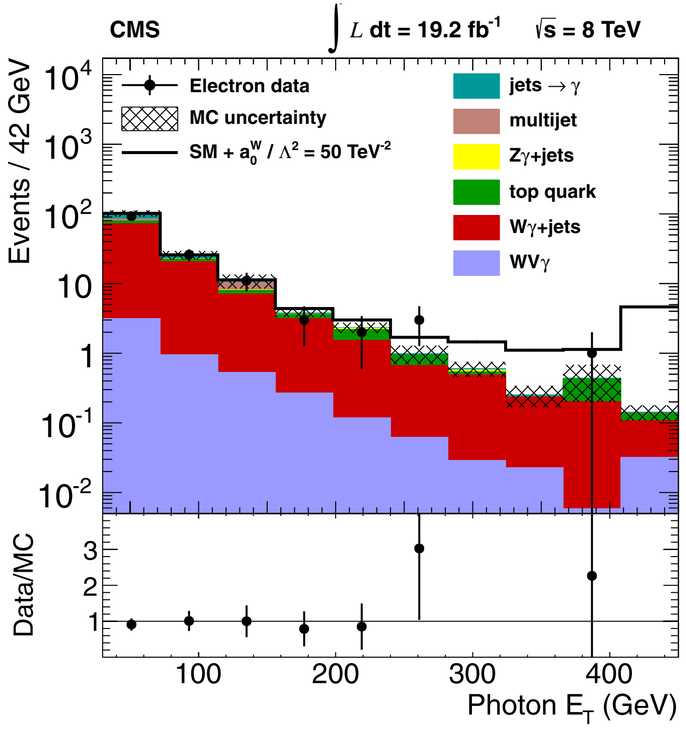
WVγ—>W(lν)V(jj) + γ



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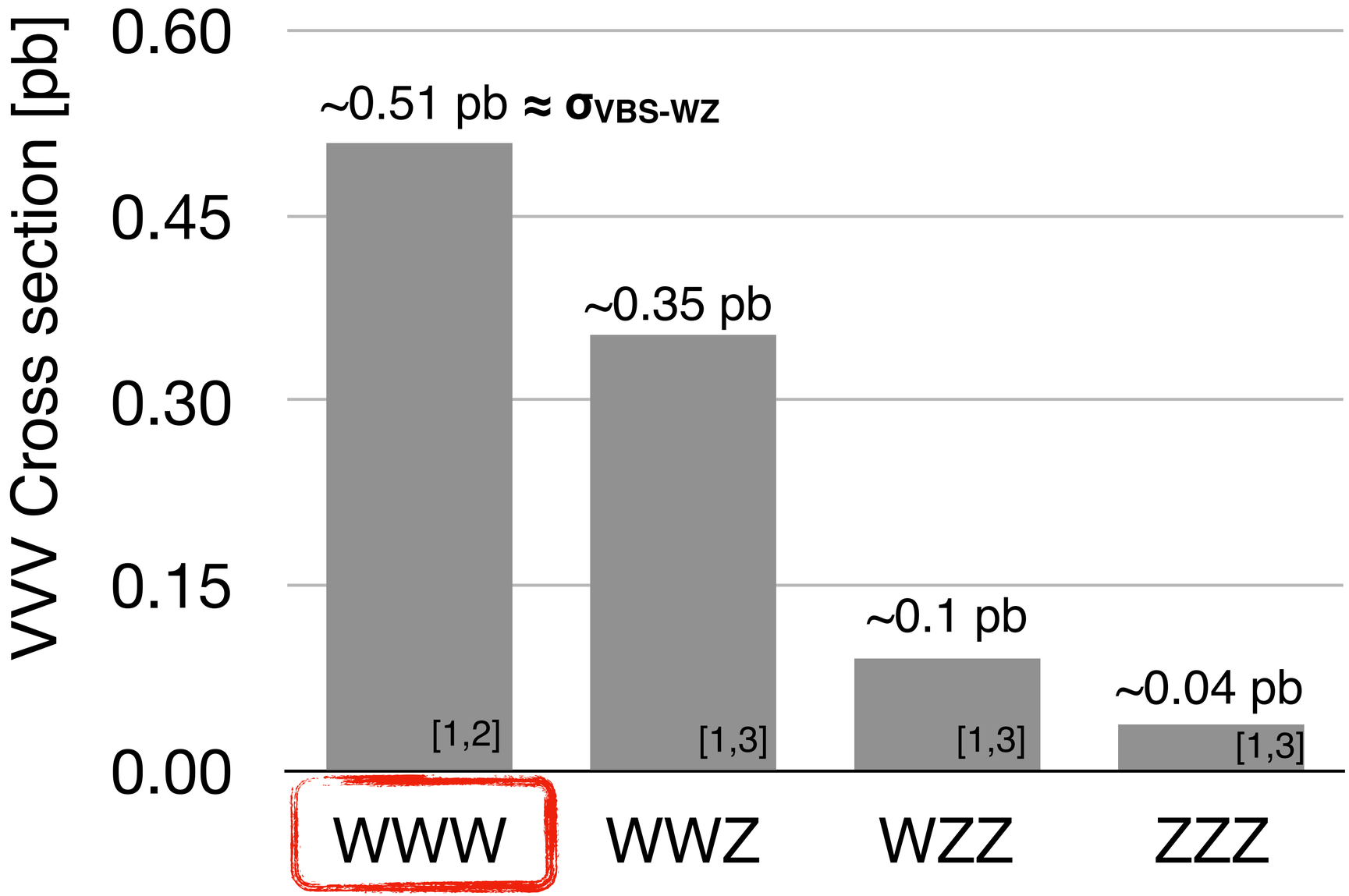
- Today's focus
- First attempt in CMS

- Resulted being updated with full Run 2 data (137 fb-1)
- CMS Standard Model Publications

VVV production



WWW production in the SM

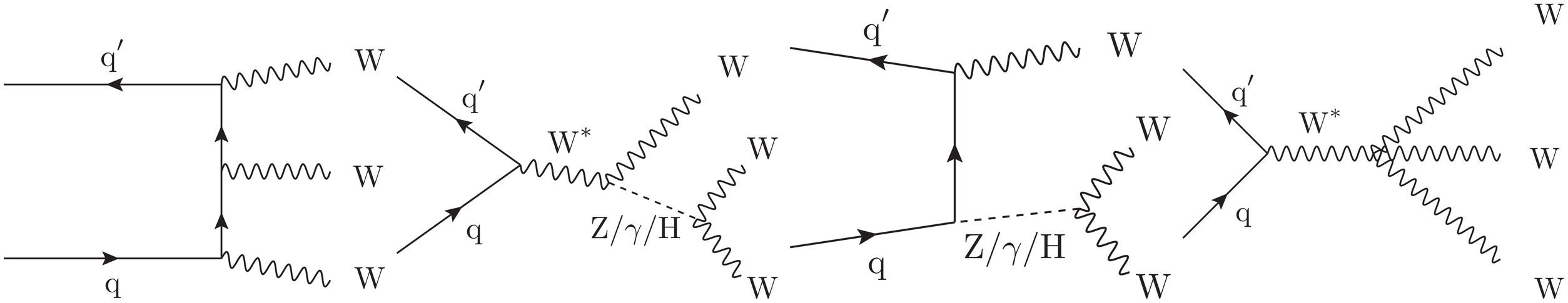
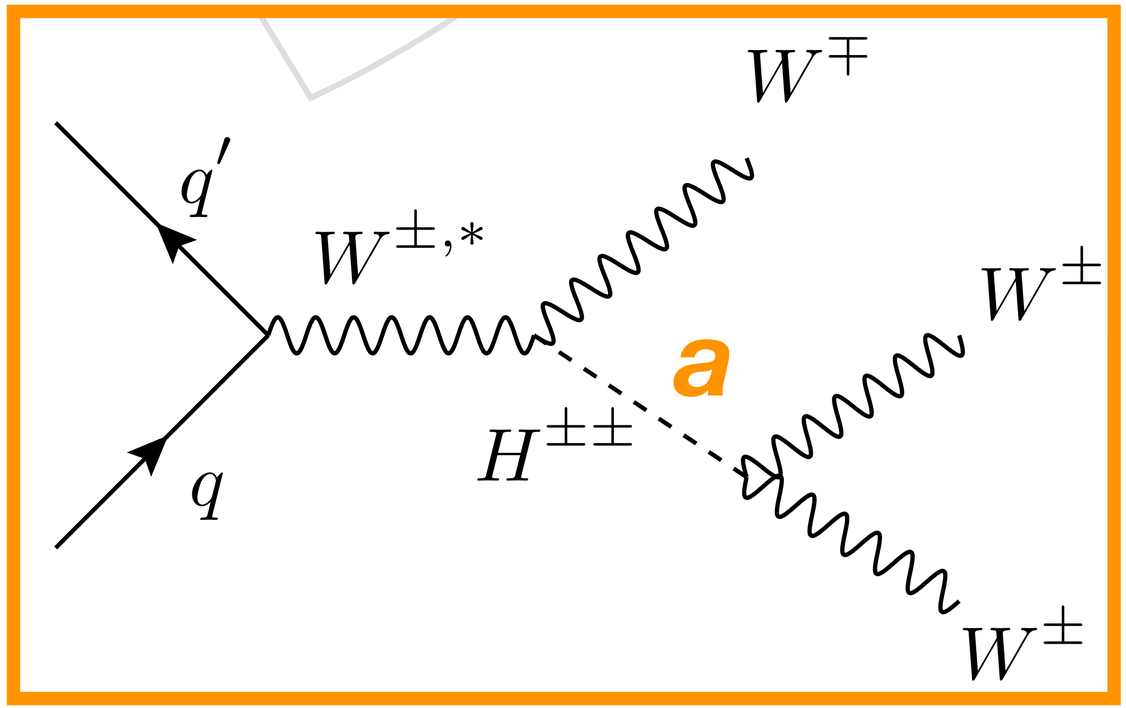
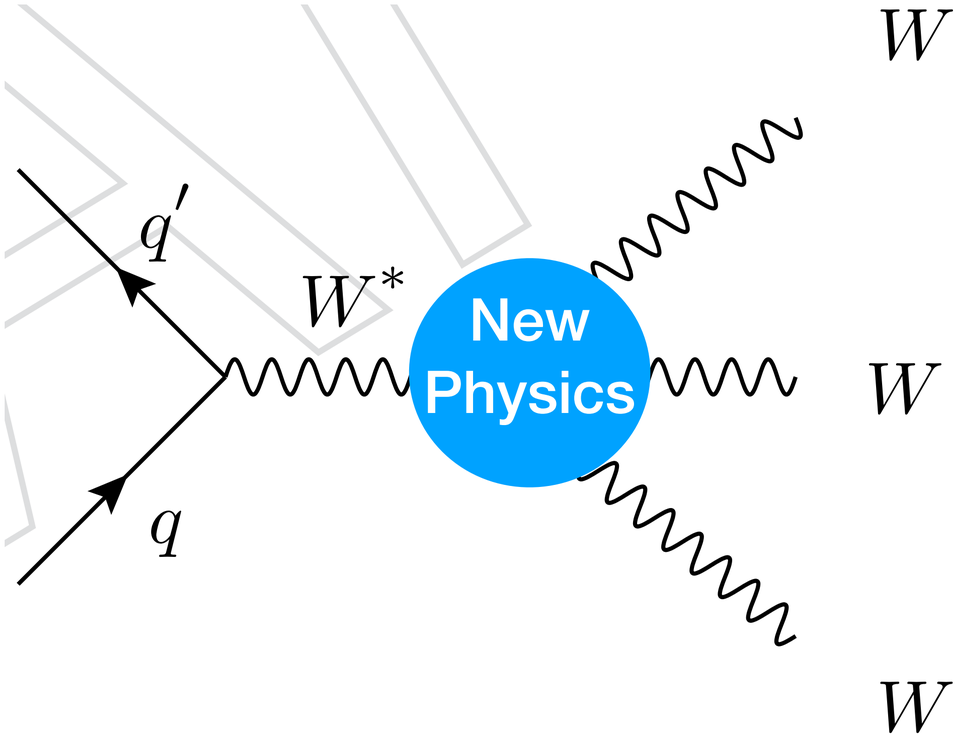


FIG. 1. Tree-level Feynman diagrams for *WWW* production.

Sensitive to BSM contributions





Doubly charged Higgs/axion-like particles, anomalous couplings coming from new physics beyond our kinematic reach

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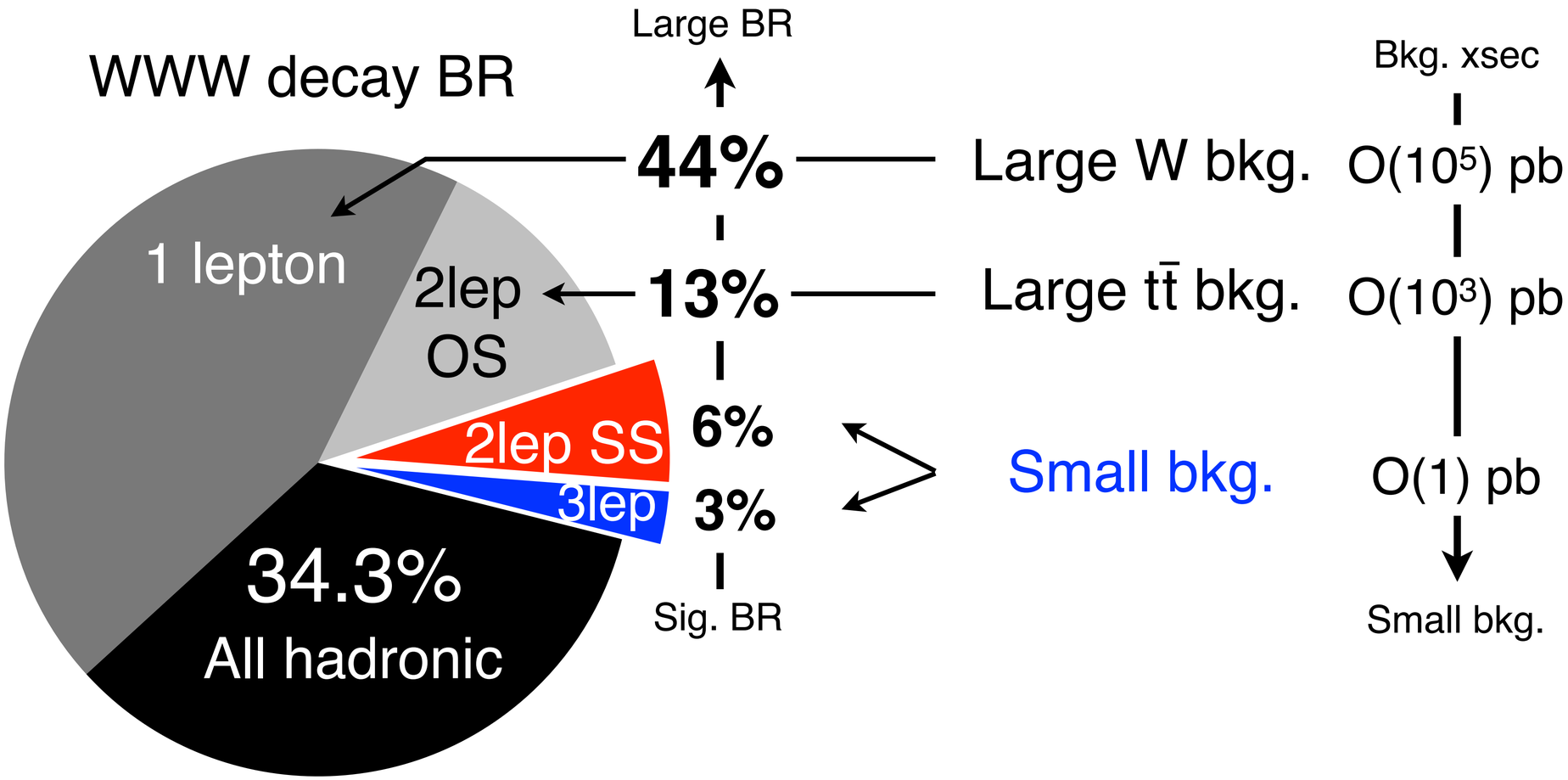
WWW: the "measurable" part is small...



Target same-sign 2 lepton and 3 lepton final state **:< 10 % of the total**

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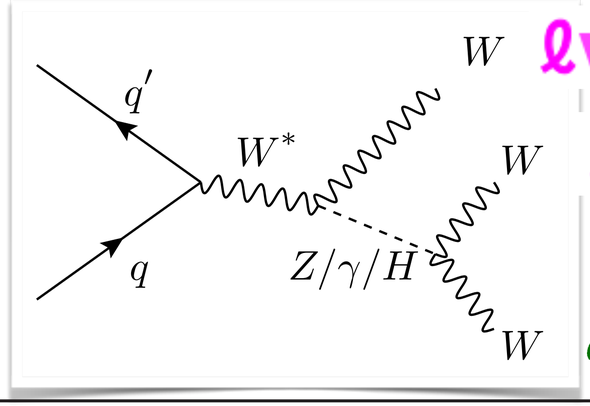
Same-sign selection



lν
lν
qq

Split by lepton flavor

Variable	$e^\pm e^\pm$	$e^\pm \mu^\pm$	$\mu^\pm \mu^\pm$
Signal leptons	2 tight same-sign leptons with $p_T > 25$ GeV		
Additional leptons	No additional rejection lepton		
Isolated tracks	No (additional) isolated tracks		
Jets	At least two jets with $p_T > 30$ GeV, $\|\eta\| < 2.5$		
b-tagged jets	No b-tagged jet		
m_{jj} (dijet mass of jets closest in ΔR)	$65 < m_{jj} < 95$ GeV (m_{jj} -in) OR $\|m_{jj} - 80\ \text{GeV}\| \geq 15$ GeV (m_{jj} -out)		
m_{JJ} (dijet mass of leading jets)	<400 GeV		
$\Delta\eta$ of two leading jets	<1.5		
p_T^{miss}	>60 GeV	>60 GeV	>60 GeV if m_{jj} -out
$m_{\ell\ell}$	>40 GeV	>30 GeV	>40 GeV
$m_{\ell\ell}$	$\|m_{\ell\ell} - m_Z\| > 10$ GeV	...	...
m_T^{max}	>90 GeV	...	...

veto top backgrounds

Tag hadronically decaying W

Veto Vector bosons scattering

neutrinos

reject low mass resonants

against charge flip

reject WZ(3 lepton)

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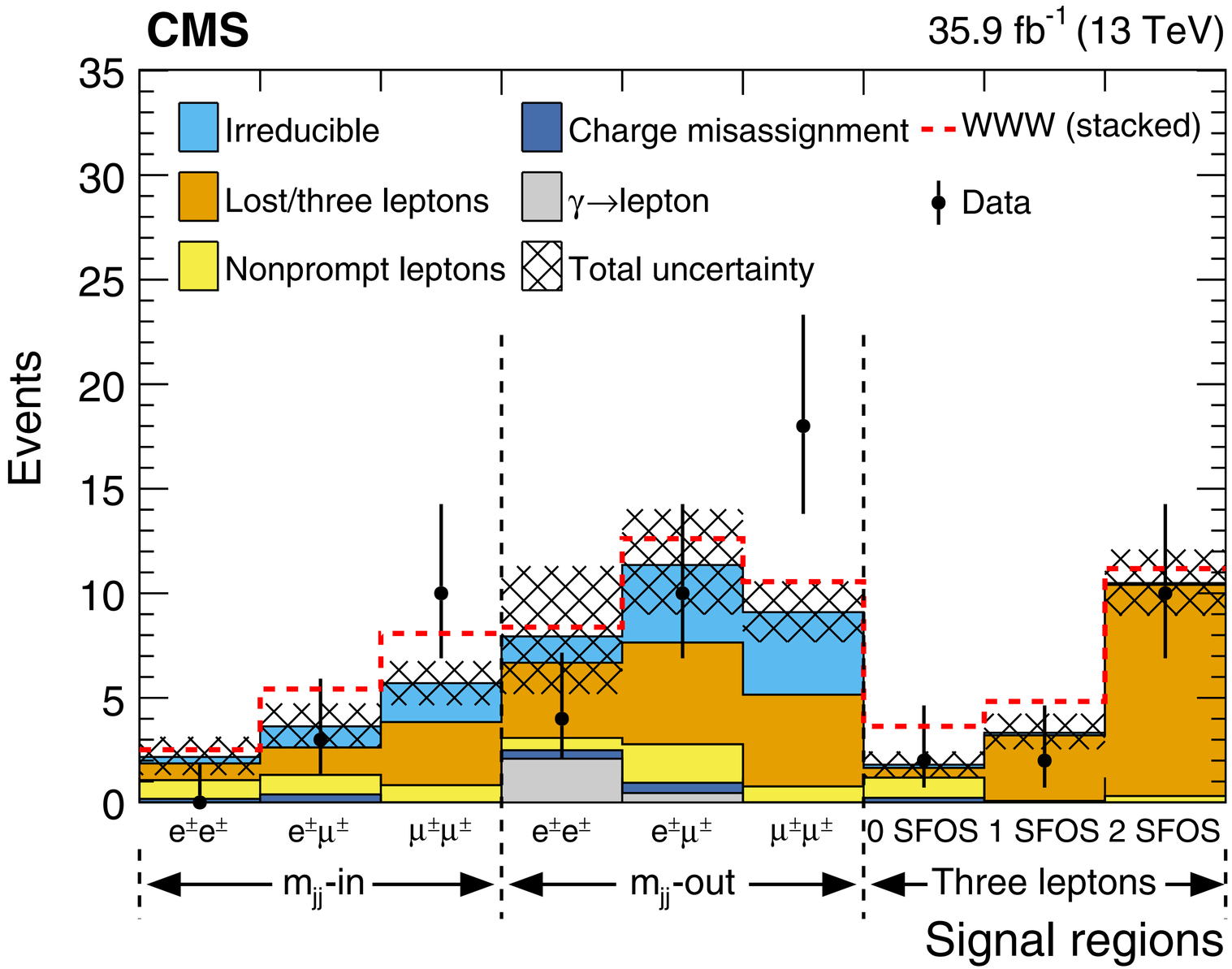
Three lepton selection

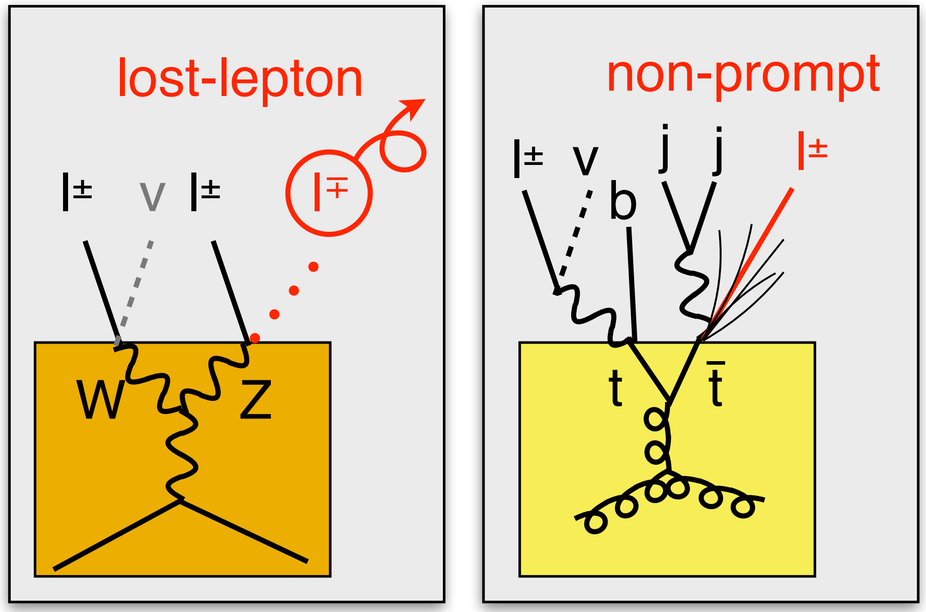
categorized by number of same-flavor opposite sign pairs

Variable	0 SFOS	1 SFOS	2 SFOS
Signal leptons		3 tight leptons with $p_{\mathrm{T}} > 25/20/20$ GeV and charge sum $= \pm 1$e	
Additional leptons		No additional rejection lepton	
Jets		At most one jet with $p_{\mathrm{T}} > 30$ GeV, $\lvert\eta\rvert < 5$	
b-tagged jets		No b-tagged jets	
$p_{\mathrm{T}}(\ell\ell\ell)$	...	>60 GeV	>60 GeV
$\Delta\phi(\vec{p}_{\mathrm{T}}(\ell\ell\ell), \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$		>2.5	
$p_{\mathrm{T}}^{\mathrm{miss}}$	>30 GeV	>45 GeV	>55 GeV
${m_{\mathrm{T}}}^{\mathrm{max}}$	>90 GeV	...	...
$m_{\mathrm{T}}^{\mathrm{3rd}}$	...	>90 GeV	...
SF lepton mass	>20 GeV	...	...
Dielectron mass	$\lvert m_{ee} - m_Z\rvert > 15$ GeV	...	...
m_{SFOS}	...	$\lvert m_{\mathrm{SFOS}} - m_Z\rvert > 20$ GeV and $m_{\mathrm{SFOS}} > 20$ GeV	$\lvert m_{\mathrm{SFOS}} - m_Z\rvert > 20$ GeV and $m_{\mathrm{SFOS}} > 20$ GeV
$m_{\ell\ell\ell}$		$\lvert m_{\ell\ell\ell} - m_Z\rvert > 10$ GeV	

Dominating background : 3L WZ

Backgrounds overview





- 2-lepton channel (same-charge)
  - WZ→3ℓ w/ a lost lepton
  - tt̄→1ℓ + non-prompt lepton
  - W±W± / tt̄W
- 3-lepton channel
  - WZ→3ℓ
  - tt̄→2ℓ + non-prompt lepton

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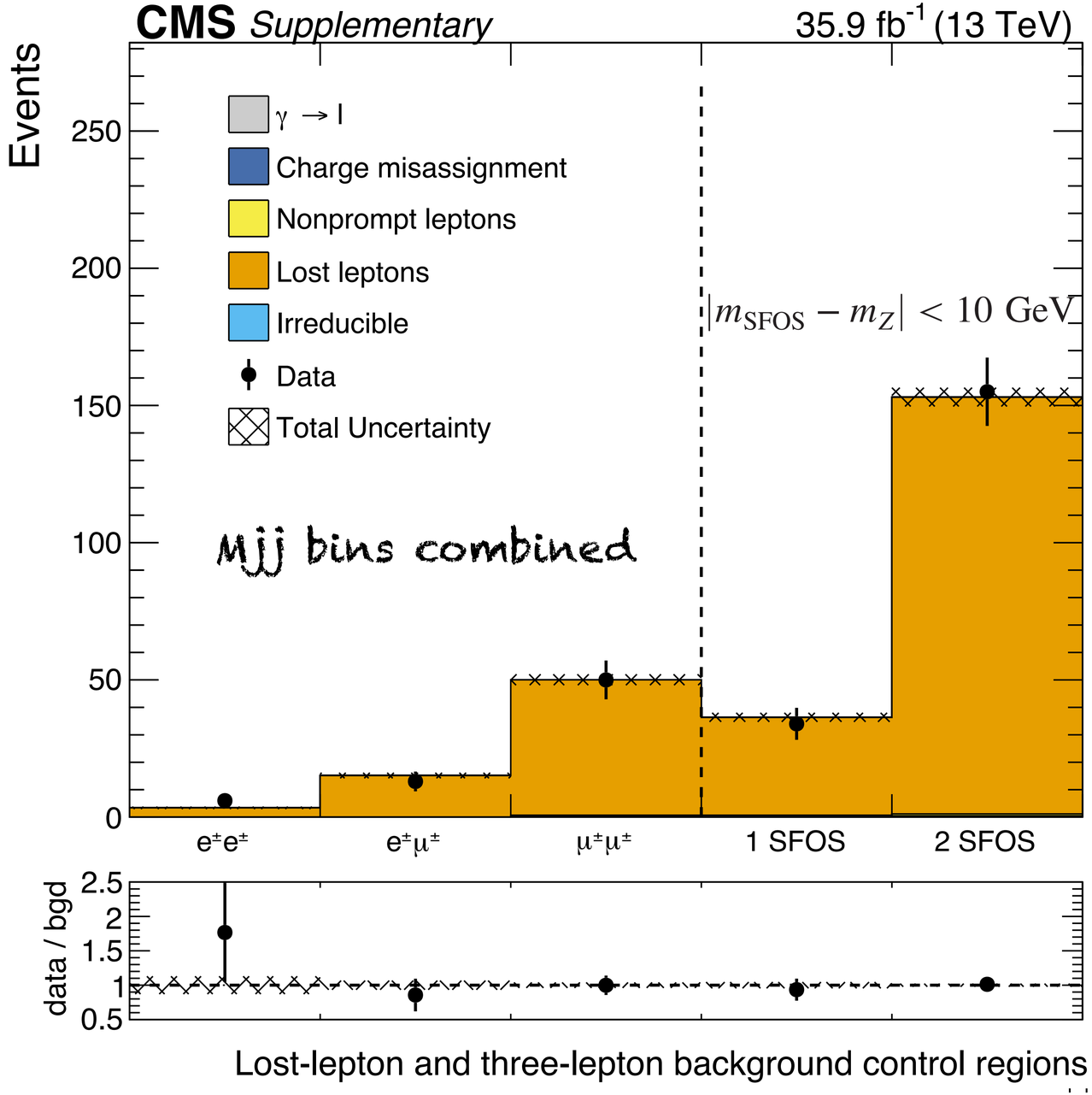
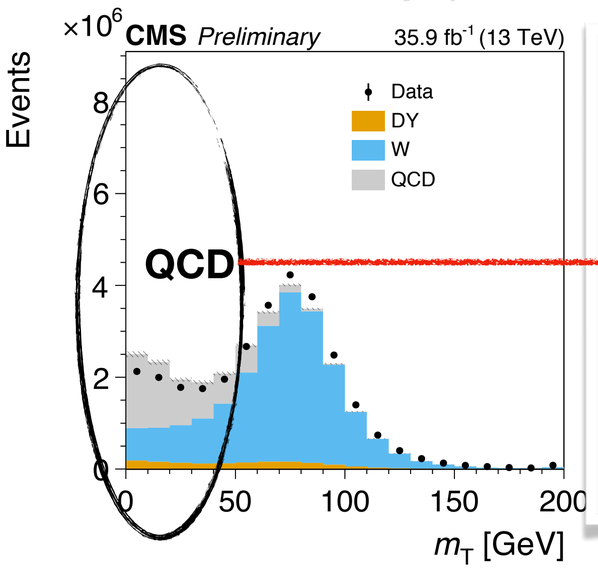
Backgrounds: WZ



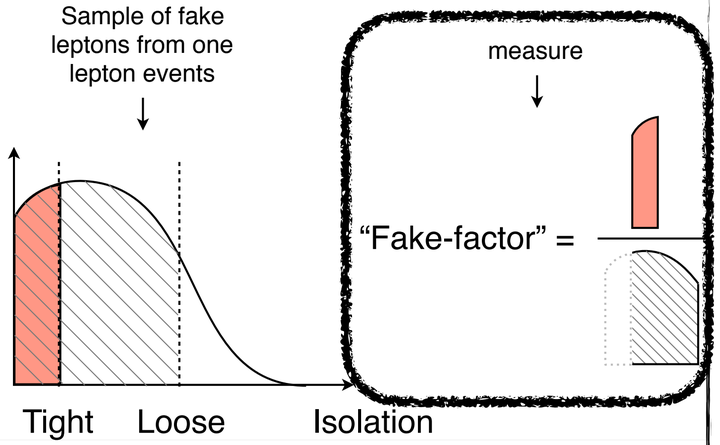
Lost-lepton and three-lepton background control regions

- Lost lepton/3L: WZ, ttV with 3 real leptons -> dominating
  - 30% to 90%
- Control region in data: three lepton events.
- Extrapolated to the signal region with transfer factor measured in simulation

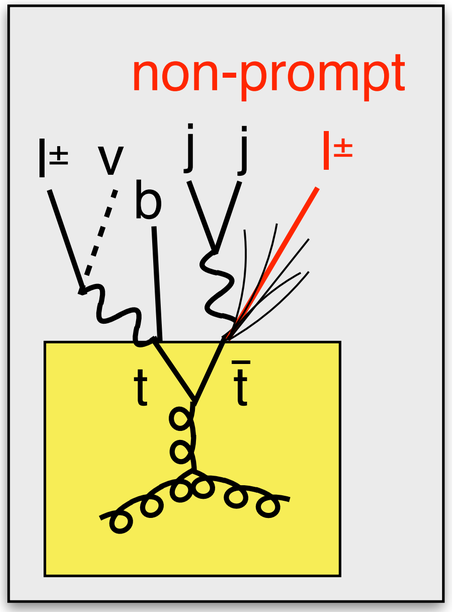
Estimate Non-prompt leptons



❶ Measure "fake-factor" from one lepton data events

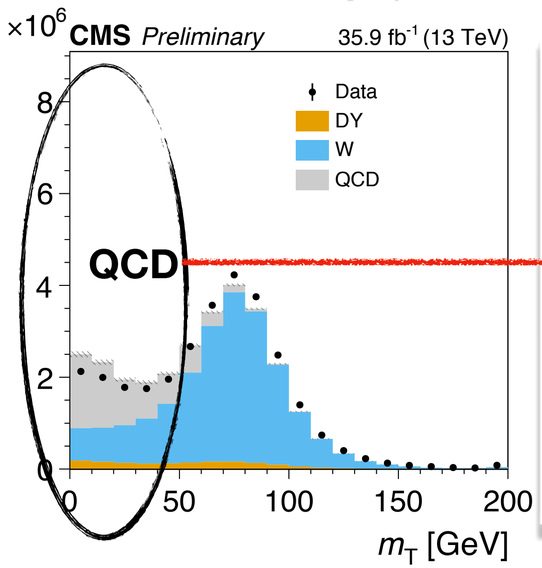


Single lepton triggered events



- Non-prompt Lepton faked by hadronic jets (1L W+Jets, ttbar)
  - most challenging, poorly modeled in MC, needs full data-driven estimate
  - Step1: QCD enriched enriched region-> tight-to-loose

Estimate Non-prompt leptons



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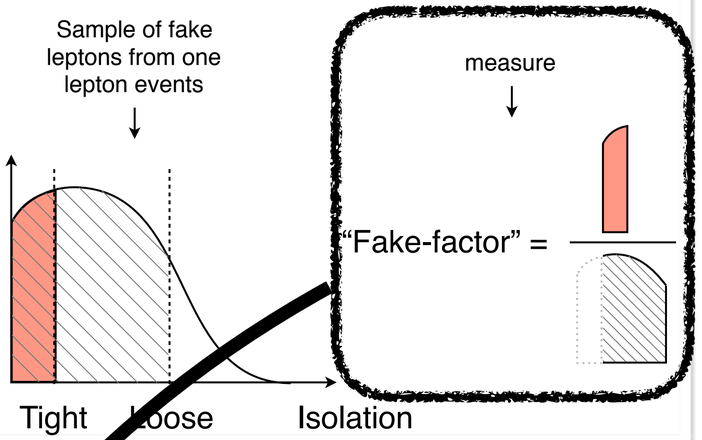
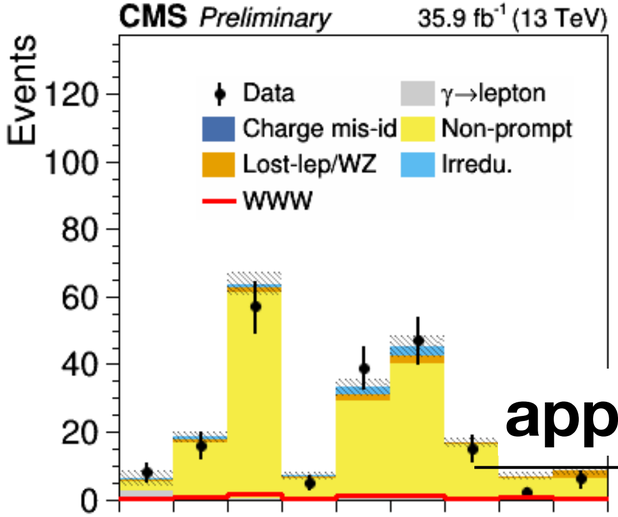
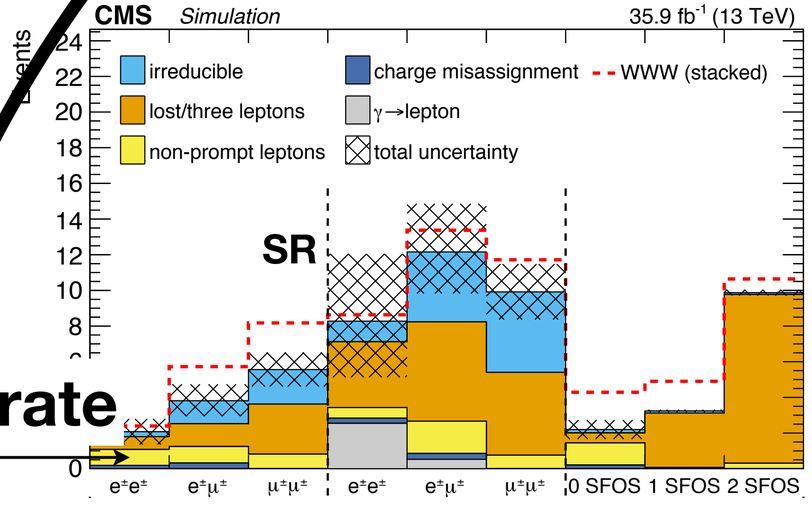


- Step 2: Tight-to-loose ratio applied to signal regions (2 lepton events)

→ fake estimates in signal region

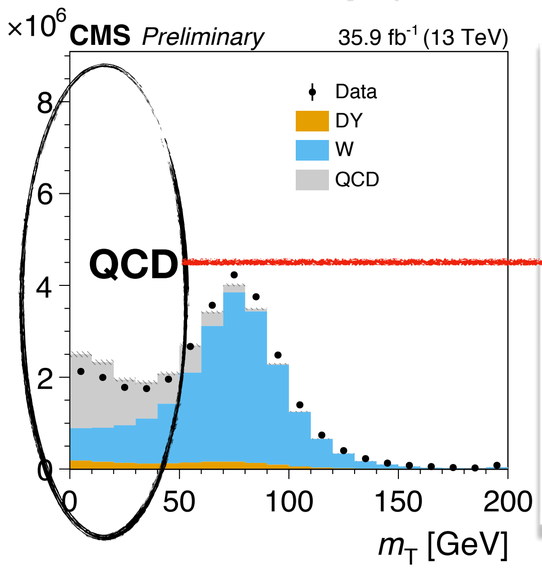


apply fake rate



Tight+loose Signal bins

Estimate Non-prompt leptons



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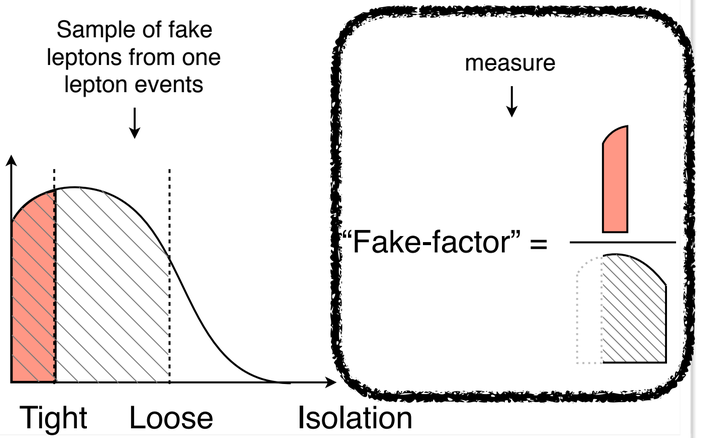
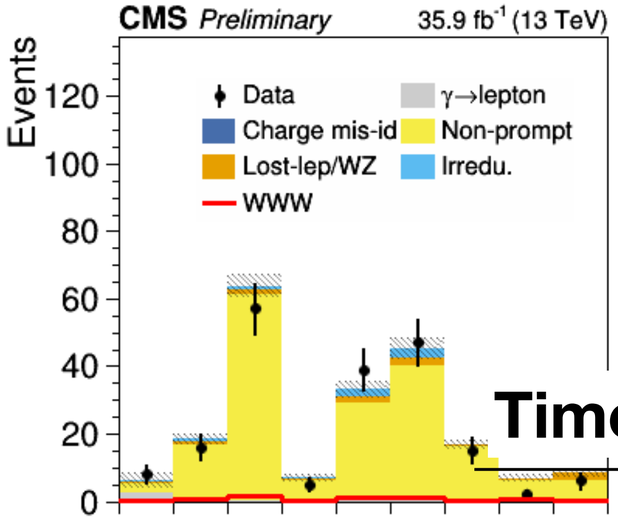
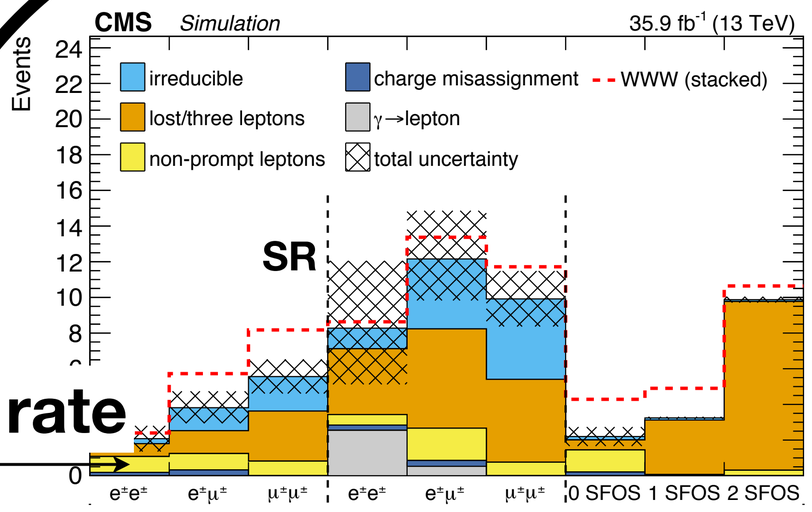




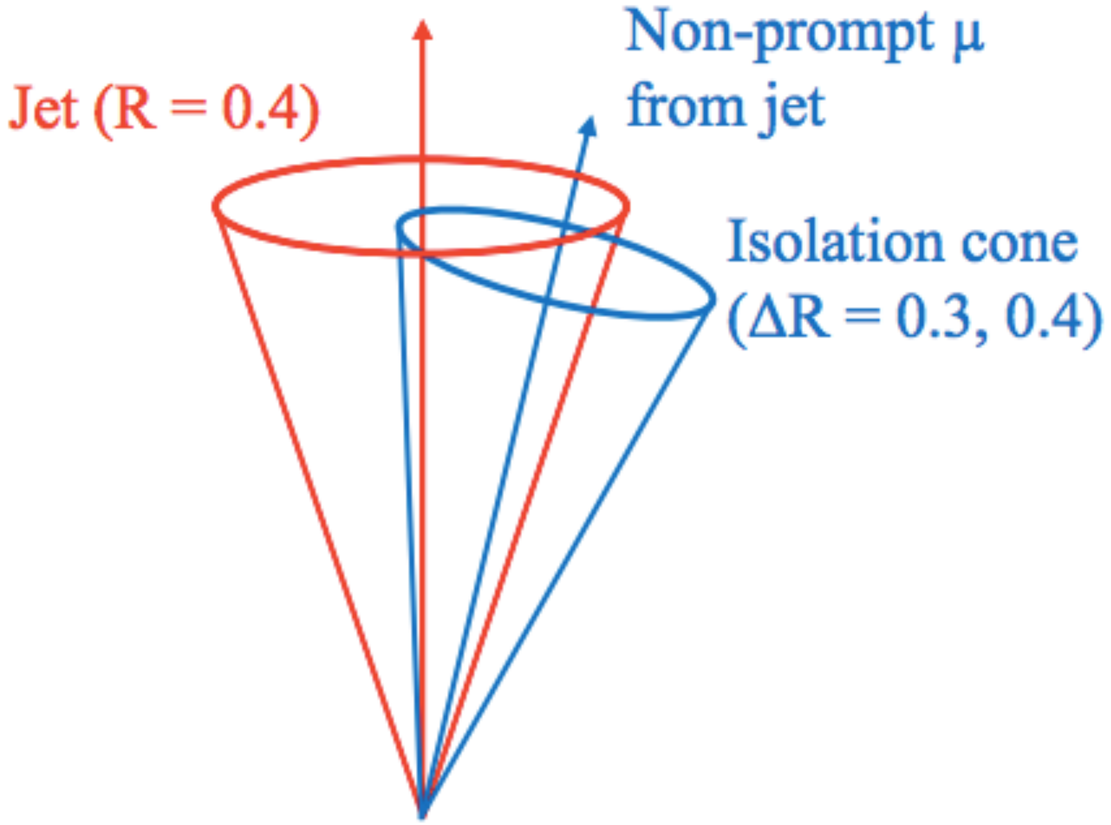
Tight+loose Signal bins

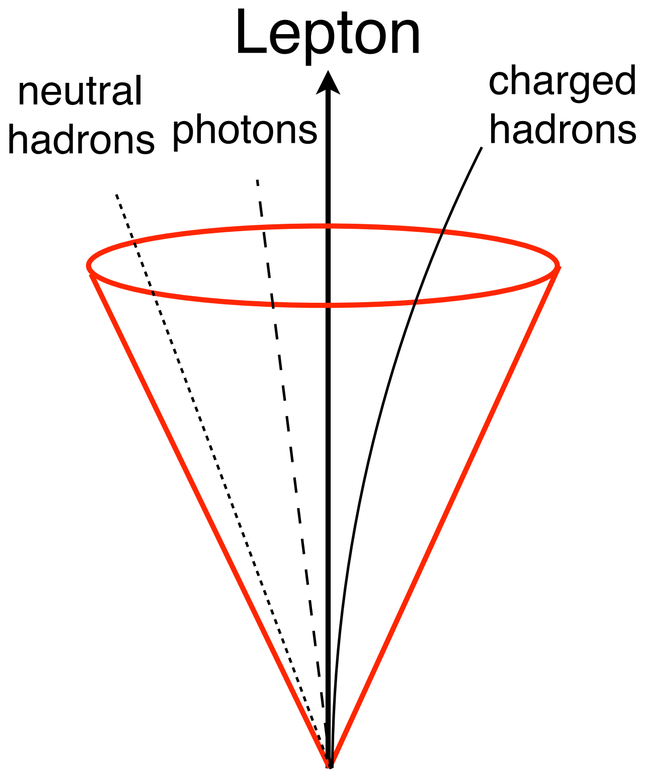
Times fake rate



- Large systematic uncertainties associated (50%-100%)
  - MC closure. Fake rate measurement statistics...
  - Need to suppress it as much as possible

Reject Non-prompt leptons with isolation





$$\text{Iso}_{\text{Rel}} = \frac{\Sigma\text{PF cand's } P_T \text{ in the cone} - \text{PU}}{\text{Lepton } P_T}$$

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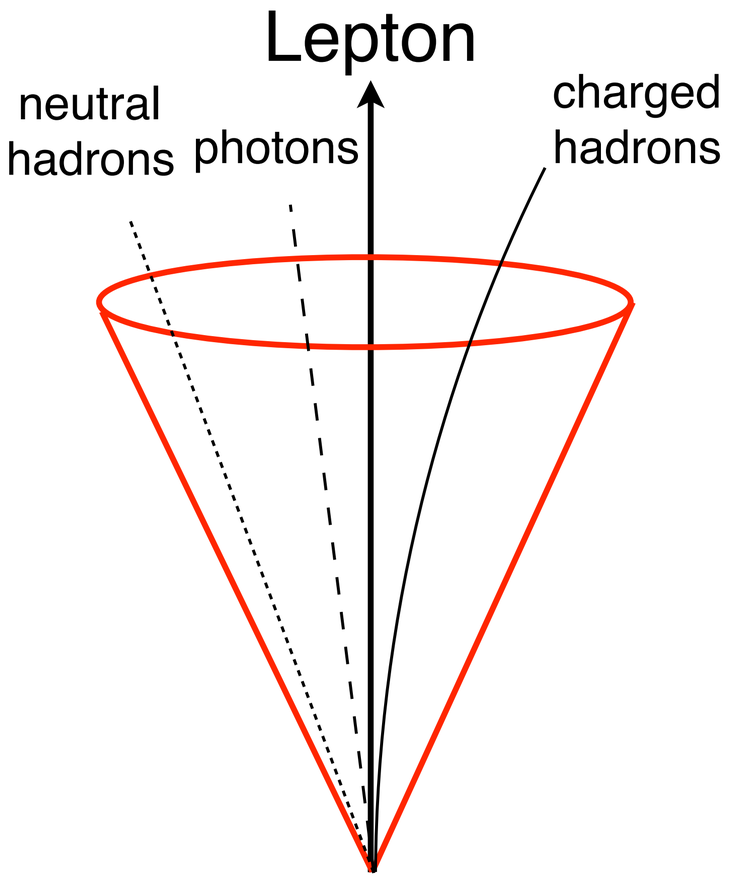
Modified isolation definition



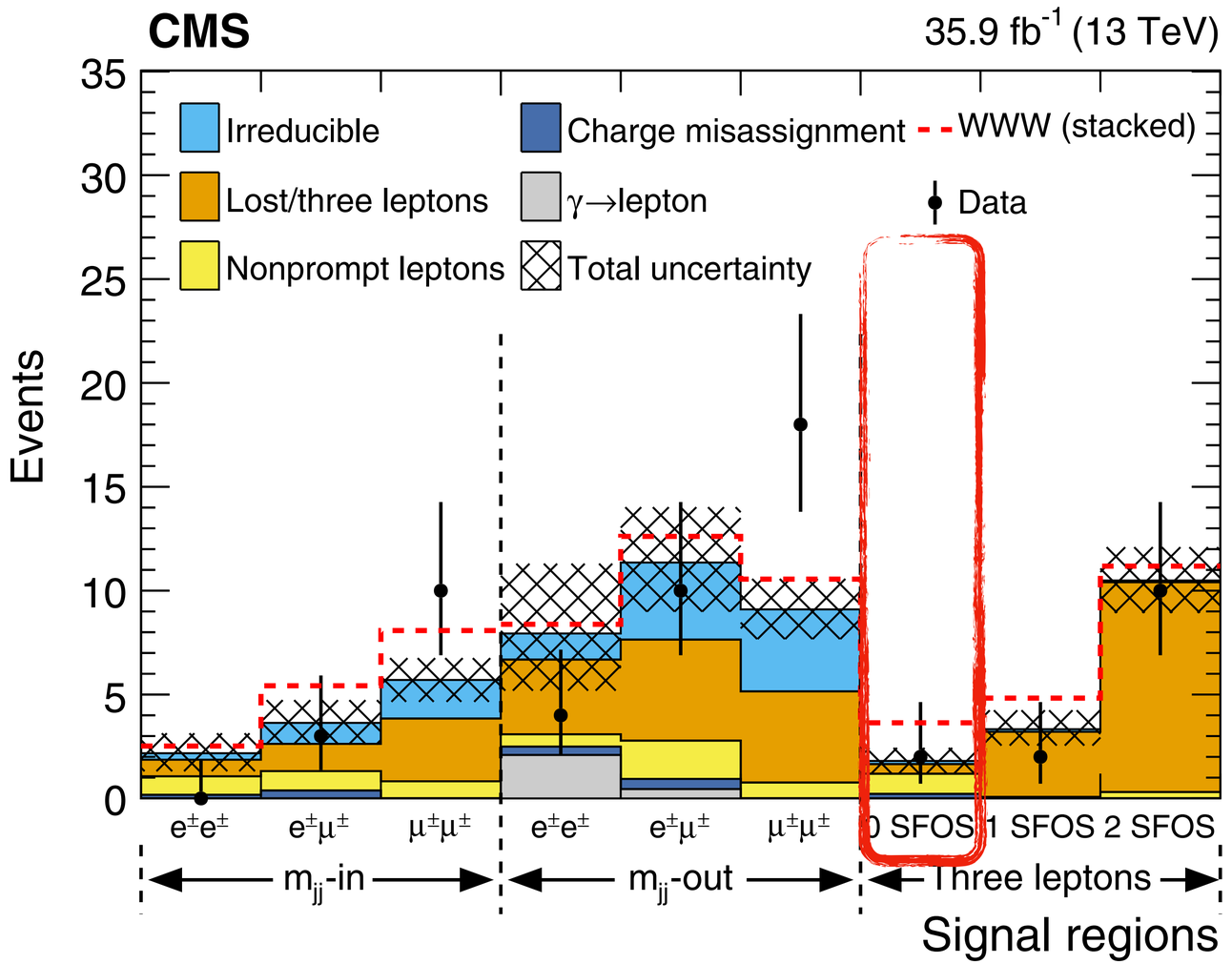
$$\text{Iso}_{\text{Rel}} = \frac{\Sigma \text{PF cand's } P_T \text{ in the cone} - \text{PU}}{\text{Lepton } P_T}$$

- Smaller cone-size: 0.4→0.3
- Add lepton candidates to Isolation calculation improves rejection: heavy flavor decay (B→D→2 leptons + X), one of the leptons is selected as our good lepton.

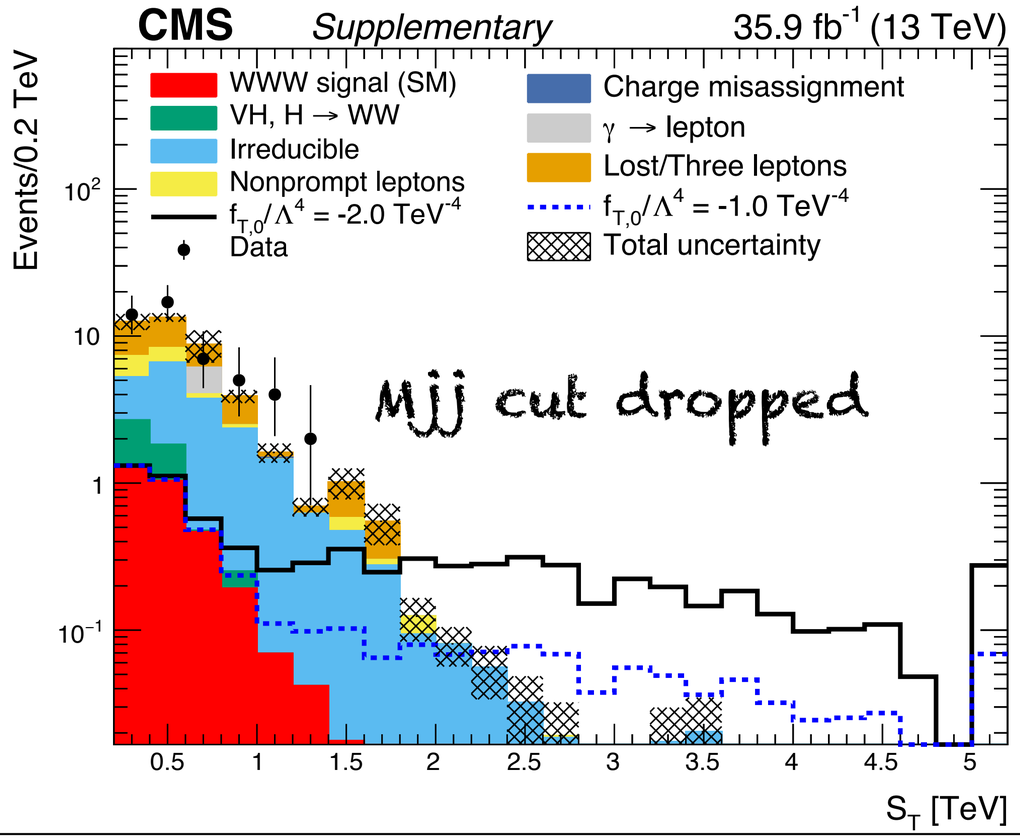
3.5 X background rejection for muons compared to CMS official recommendations

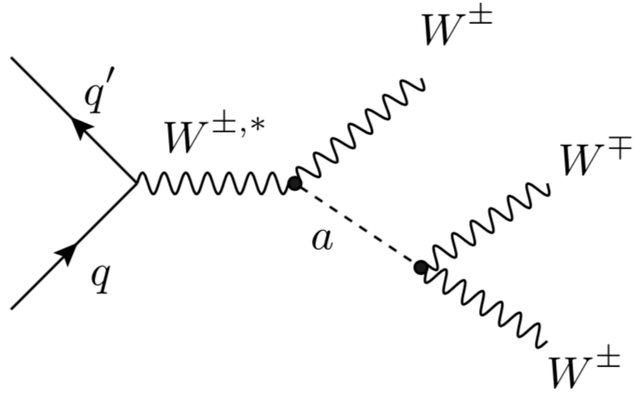
SM Results

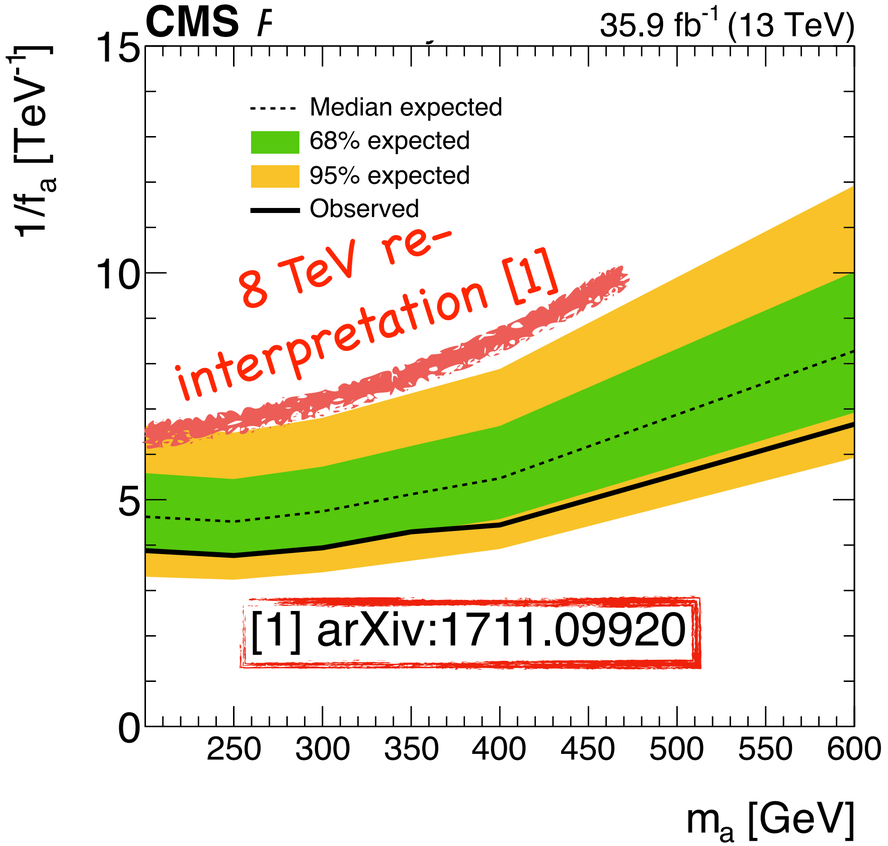
- 1.78 σ (expected)/0.6 σ observed with 2016 dataset
  - Analysis statistically limited, with luminosity scaling:
    - 2016+2017(~80fb-1): SS 1.7σ, 3 L: 1.9 σ
      - Comparable to ATLAS
    - Run 2 (137 fb-1): ~3.7 σ



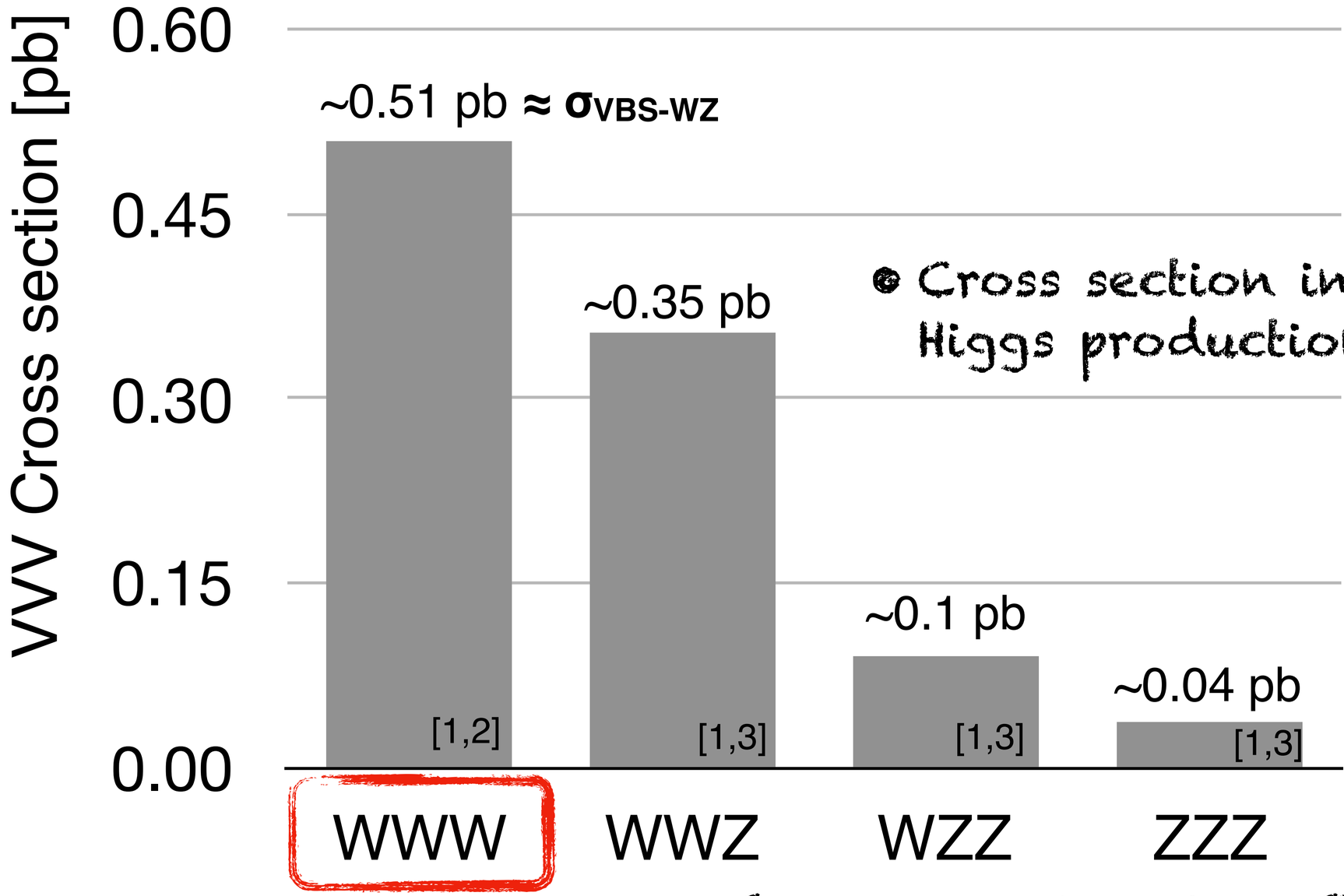
BSM results: aQGC and Axion-like particles







Anomalous coupling	Allowed range (TeV^{-4})	
	Expected	Observed
$f_{T,0}/\Lambda^4$	[-1.3, 1.3]	[-1.2, 1.2]
$f_{T,1}/\Lambda^4$	[-3.7, 3.7]	[-3.3, 3.3]
$f_{T,2}/\Lambda^4$	[-3.0, 2.9]	[-2.7, 2.6]



- Cross section includes Higgs production

- Access to more channels with full Run 2 data (137 fb-1)

- Stay tuned!

- LHC Run 2 data provides unprecedented opportunities for studying tri-boson processes.
  - First attempt to measure WWW with CMS 2016 data.
  - Full Run 2 results in pipeline. Possibilities to include signatures with jets.
- We've collected only 5% of the LHC data. New opportunities to study multi bosons with incoming LHC /HL-LHC datasets:

— Precision measurements. Higgs mediated vs non-Higgs mediated

Thanks!