



Search for Contributions from Higher Order Wilson Operators in the VVV final state and opportunities for Run3 using the scouting dataset

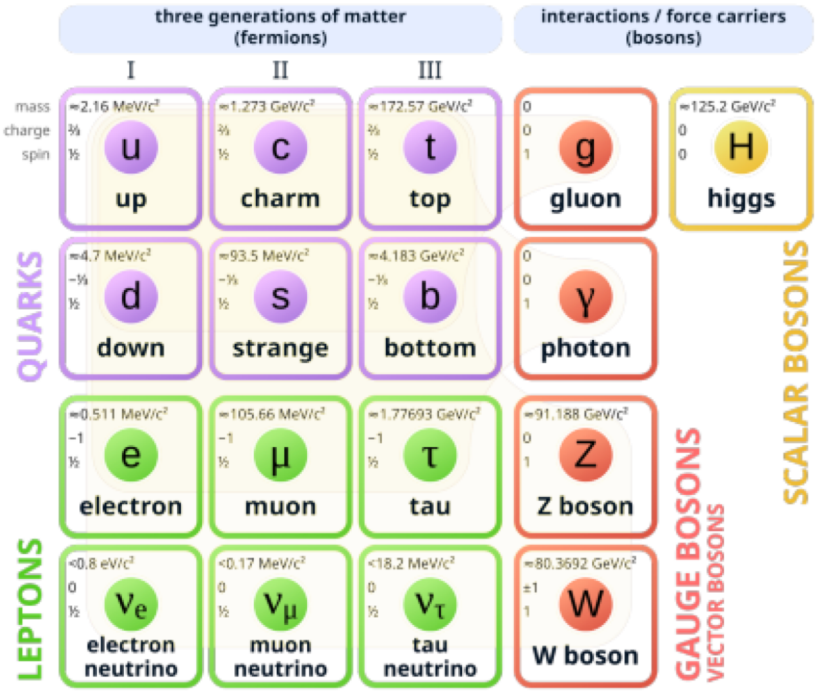
Garyfallia (Lisa) Paspalaki

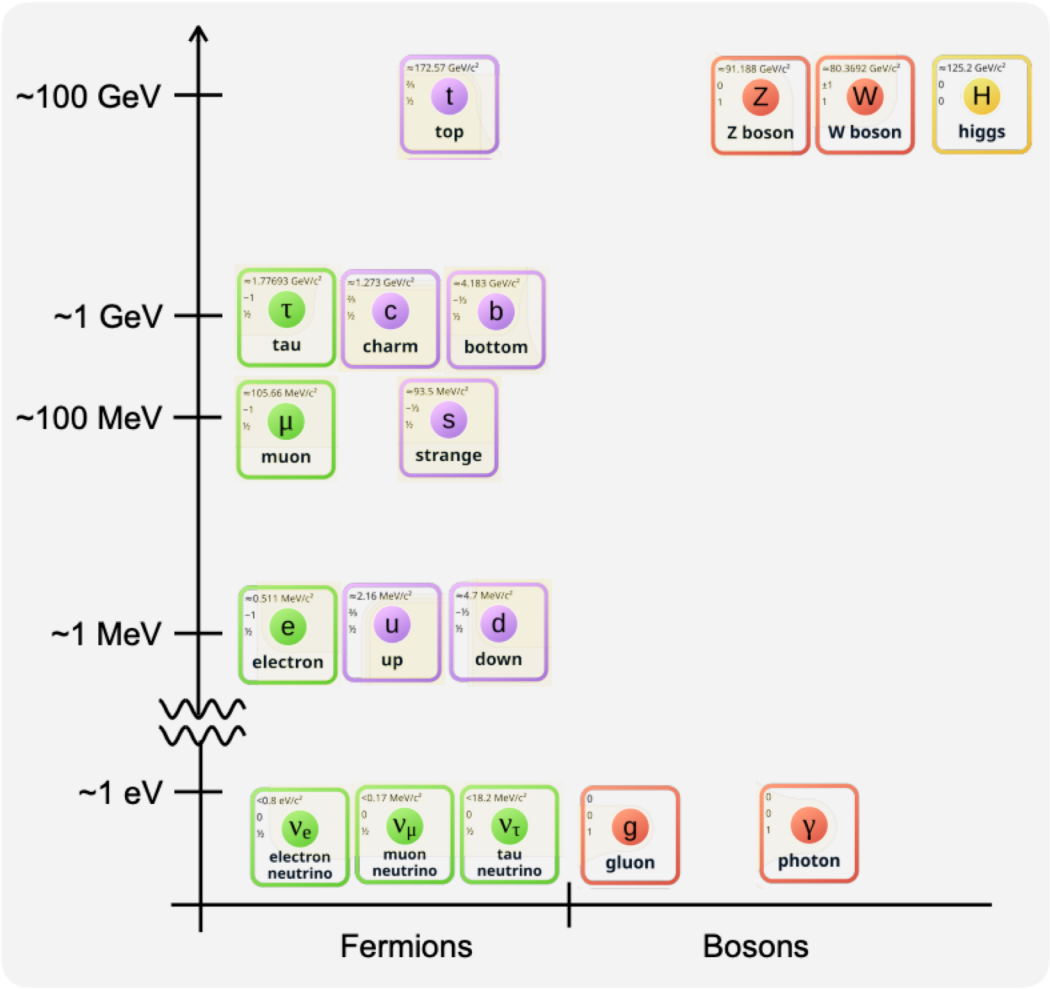
Physics Seminar

16 Oct 2025, Brown university

Motivation

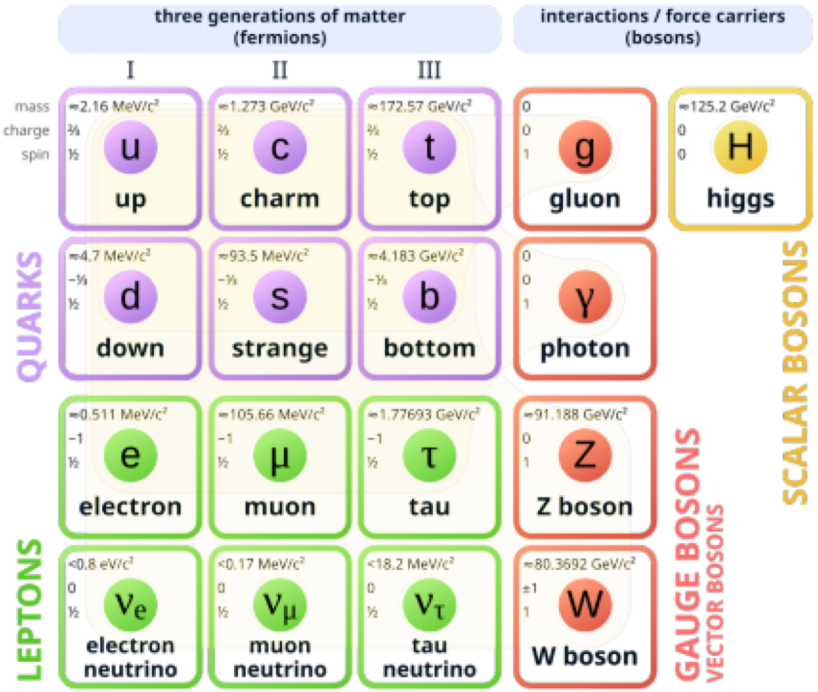
Further study SM ⇒ Search where it breaks down

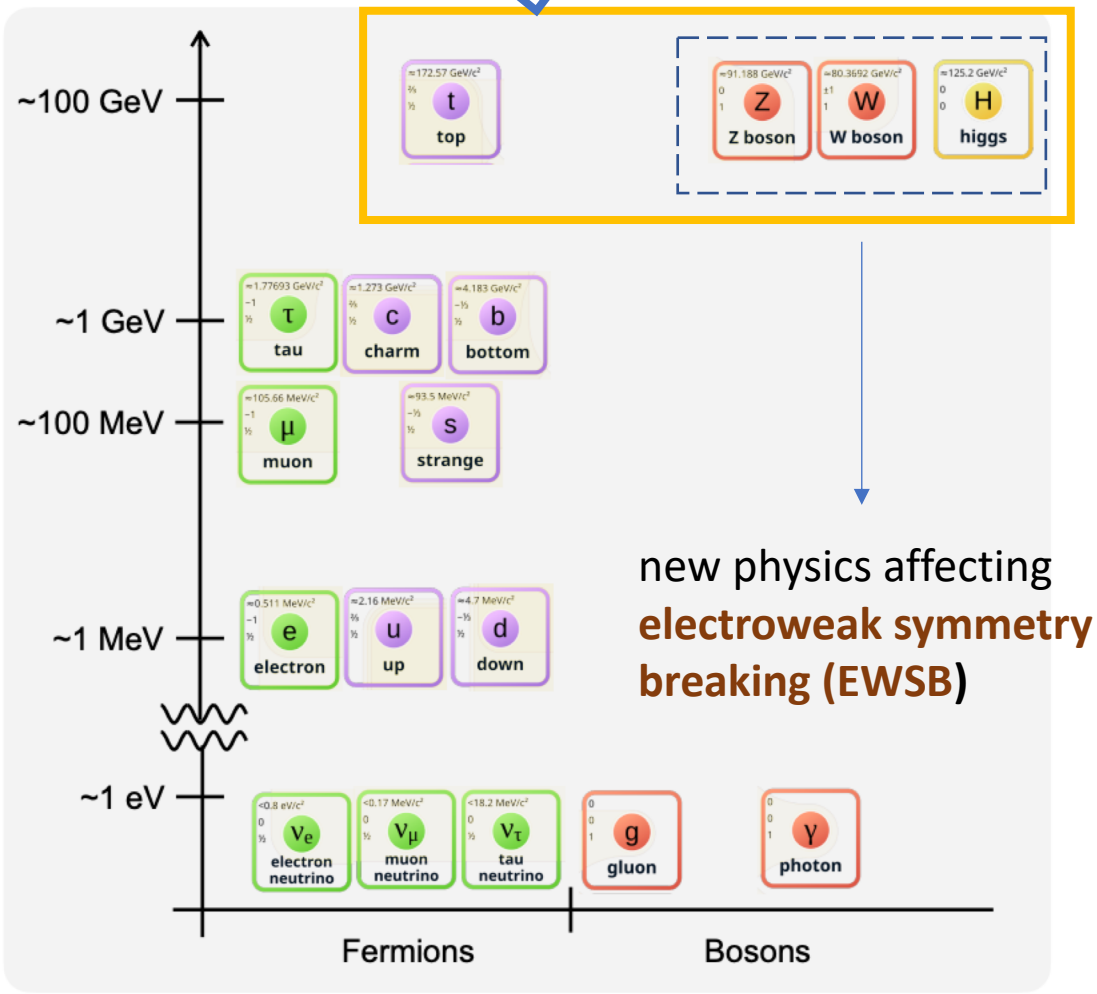




Motivation

Stress-testing the Standard Model where it's weakest: rare, heavy final states

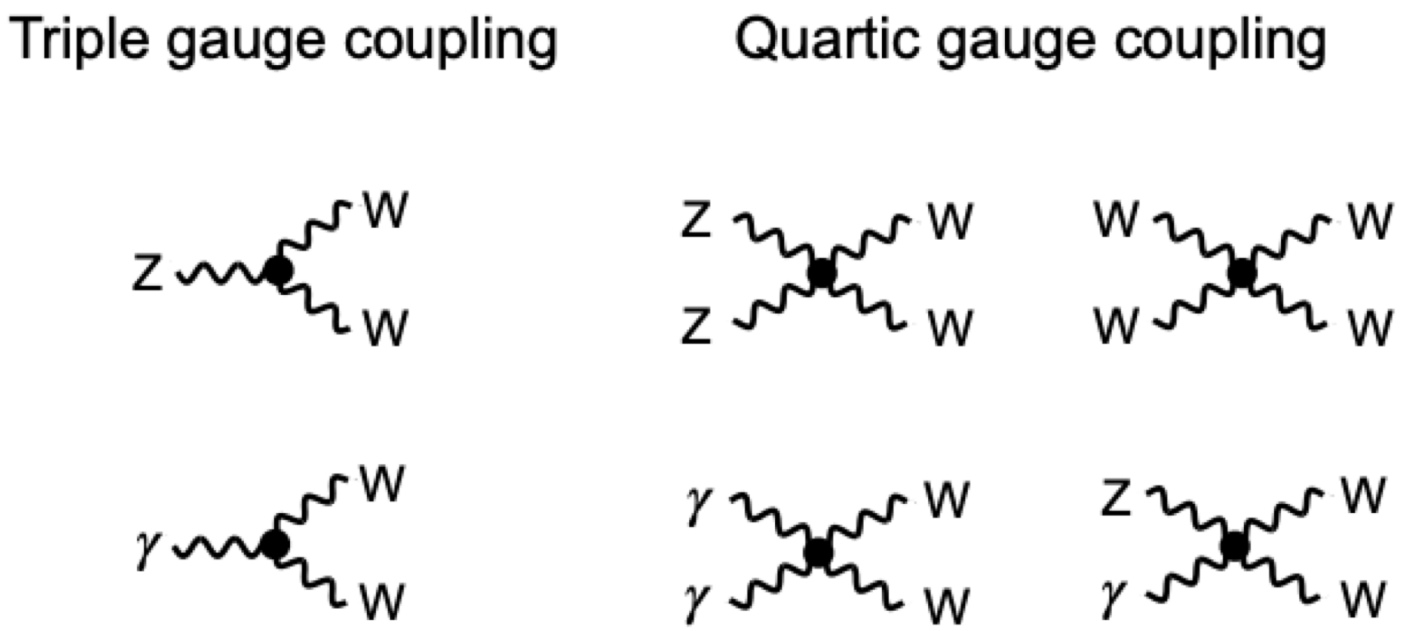




Where to search? Multi boson interactions

Interactions among the electroweak bosons

- **Gauge boson self-interactions** predicted by the SM gauge symmetry
- **Triple Gauge Couplings (TGC)** and **Quartic Gauge Couplings (QGC)** fixed by the SM → deviations signal new physics
- Deviations are parametrized as **anomalous TGCs (aTGC) and QGCS (aQGCs)**



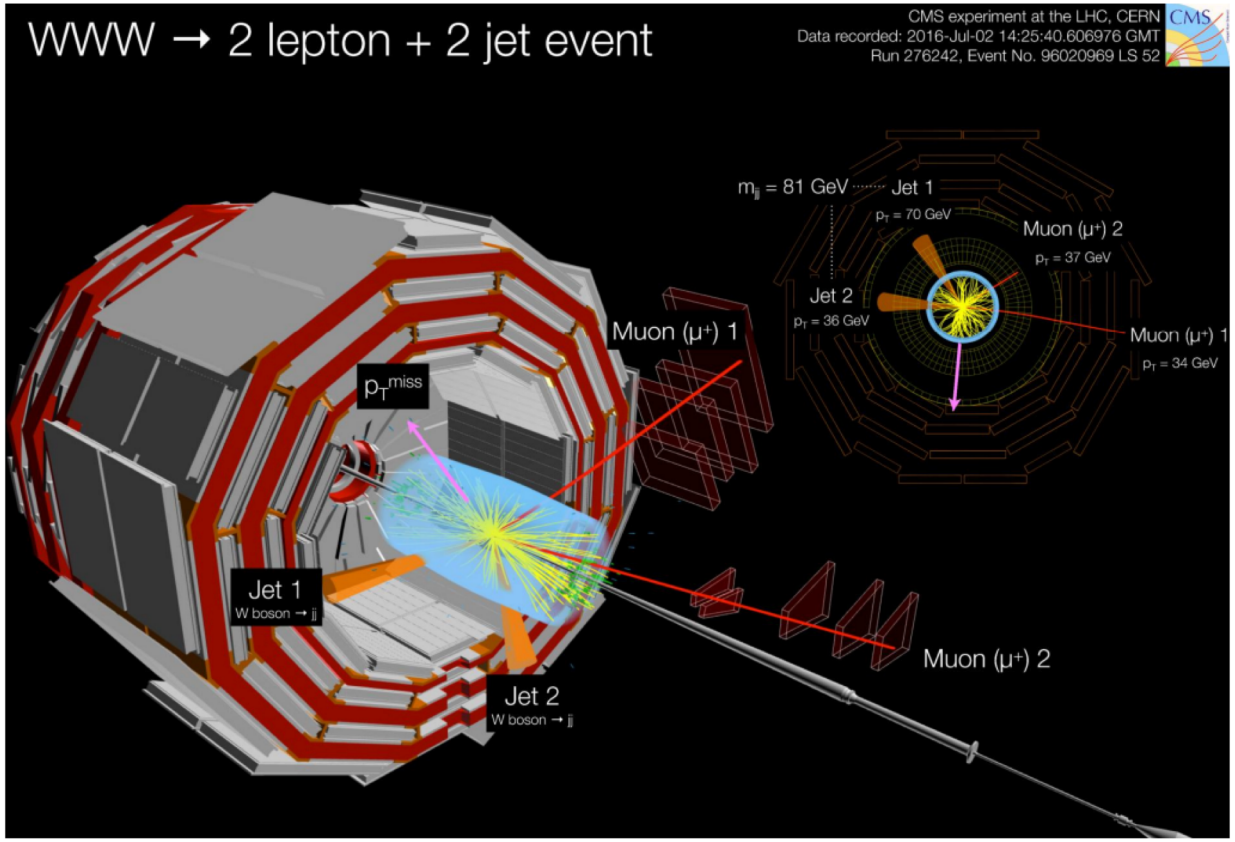
How to probe these interactions and test SM predictions?

Measure multi-boson production processes and constrain anomalous TGCs (aTGC), QGCs (aQGCs)

VVV analyses in CMS and ATLAS

Observation of the production of three massive gauge bosons at 13 TeV by CMS

- **VVV @ 5.7 σ**
- milestone in **SM high energy physics**



Since then:
ATLAS has observed:
WWW @ 8.0σ, VVZ @ 6.4σ, with Run2

CMS:
WWZ **@** 2.4σ with Run2 and early Run3

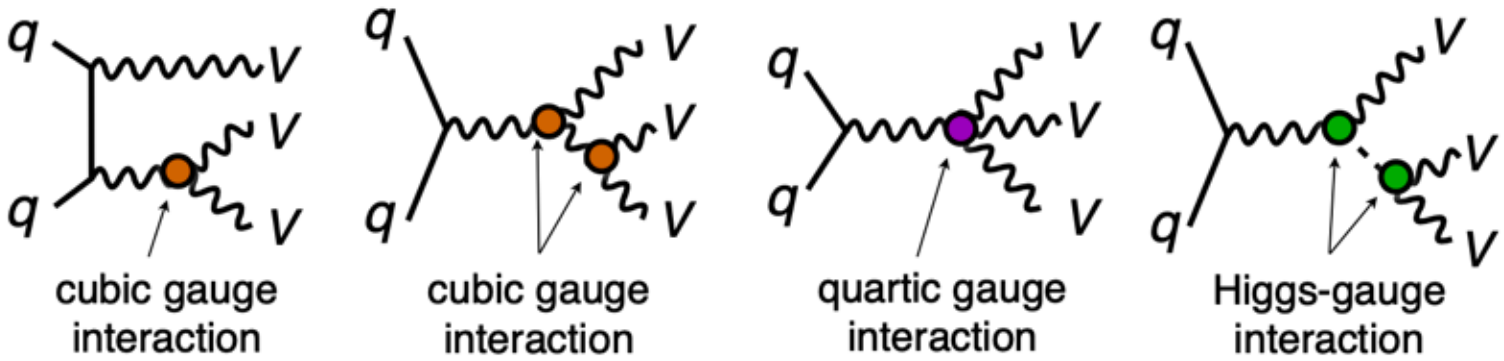
All those efforts exploit the clean signature of leptonic or semi-leptonic channels

VVV EFT in CMS

NEW

New result with VVV interpretation with **dim6** an **dim8** with the full Run2 dataset

First result for ATLAS and CMS for dim6

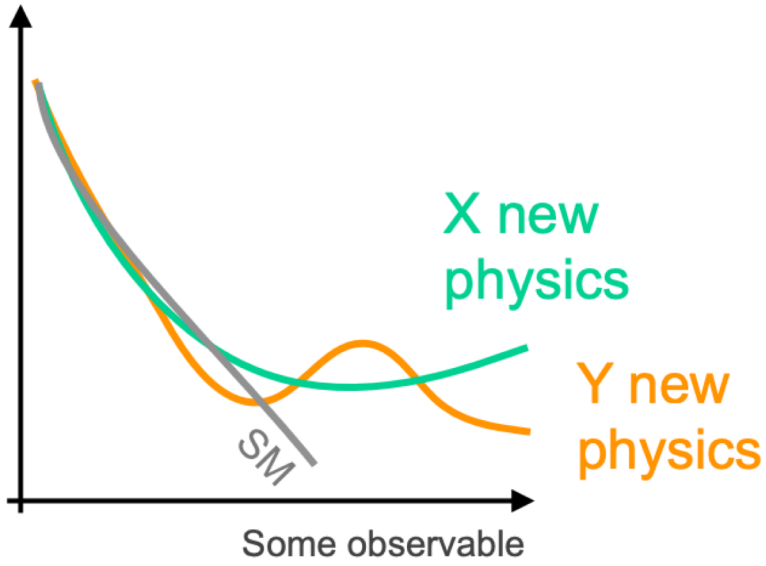


VVV provides access to various couplings

- VVV is rare and has interesting properties, e.g. access to aTGC and aQGC
- **Ideal candidate for an EFT search**.
- Deviations emerge naturally from higher-dimensional operators

Effective Field Theory (EFT)

- New particles may not be light enough to be produced at the LHC
- EFT provides a model independent way to parametrize heavy new physics



Different BSM scenarios described by different WC patterns

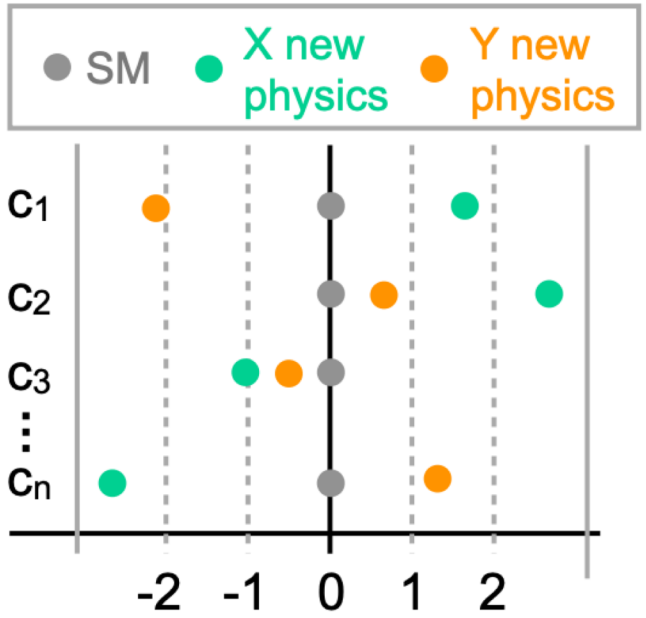


Image credit

Warsaw basis often used to derive set of operators which can be accessed and constrained by analyses

EFT Lagrangian Expansion

New physics at scales beyond what the LHC can directly probe can be approximated by expanding terms **of higher dimensional (d) operators $\mathcal{O}$** consisting of SM fields

Operators are suppressed by powers of the **energy scale Λ,** and the strength is controlled by the **Wilson coefficients c_i**

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i^{(5)}}{\Lambda}\mathcal{O}_{5,i} + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_{6,i} + \sum_i \frac{c_i^{(7)}}{\Lambda^3}\mathcal{O}_{7,i} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_{8,i} + \cdots$$

Lepton number violation

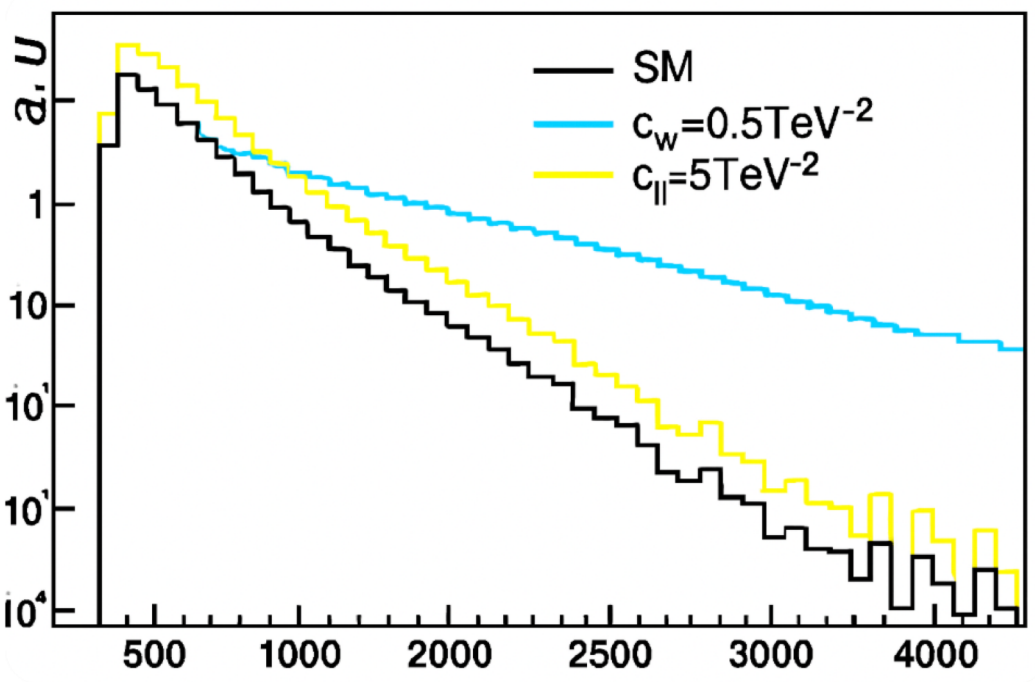
Lepton & Baryon number violation

the coefficients are incorporated as free parameters which allows for the search for heavy new physics in a **model independent way**

Where to look?

Expect enhancement in the tail

Increased normalization



Gen level m_{VVV} in WWW sample at different EFT points

VVV searches so far used only leptonic signatures

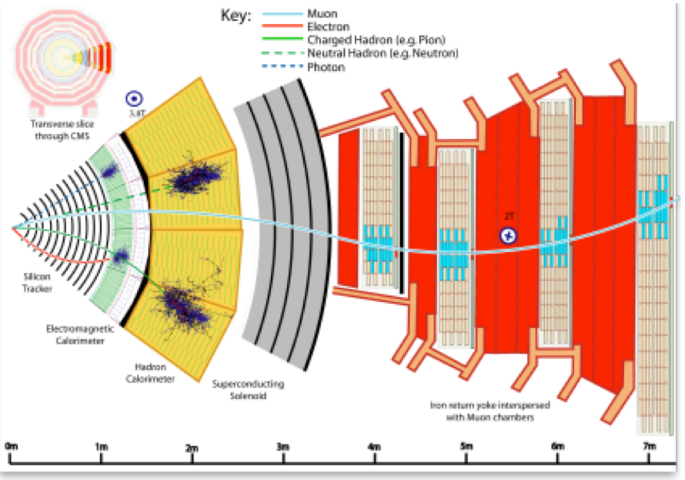
EFT signal is expected at the tails of the distributions

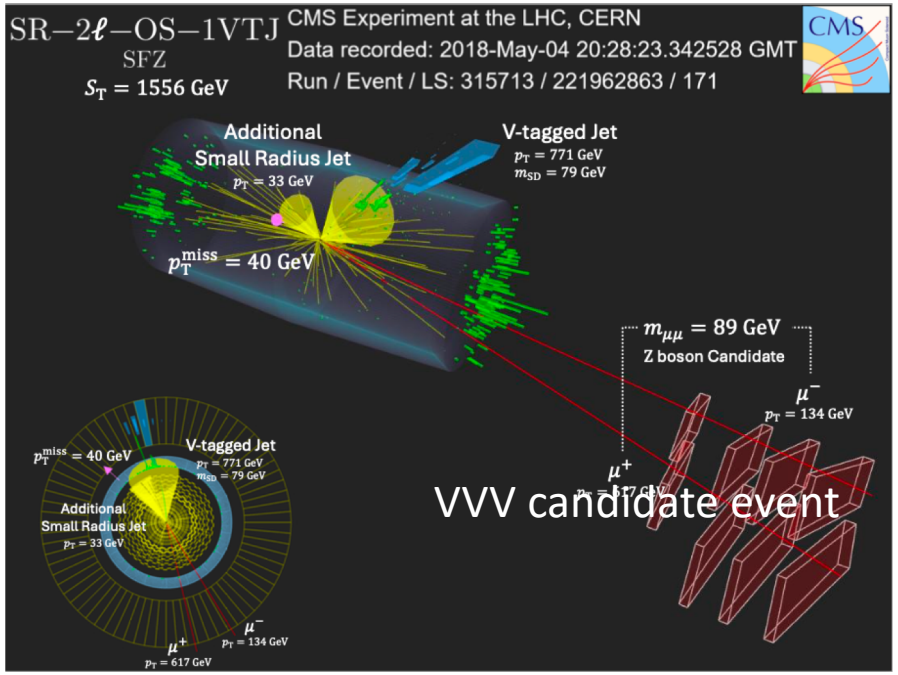
Need to exploit the high-pT regime

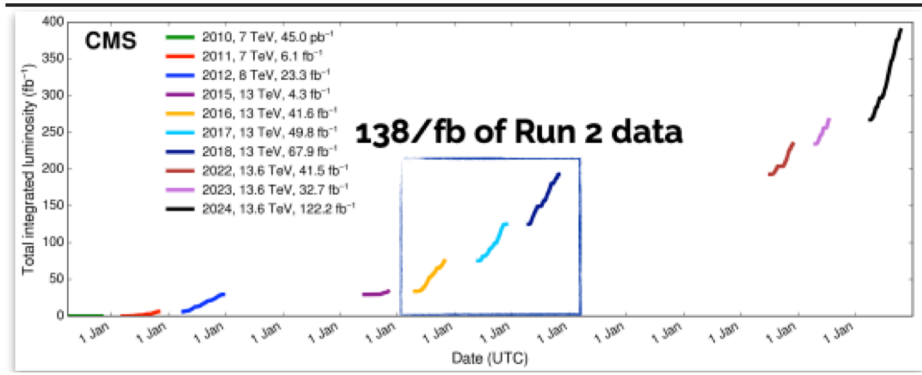
Using hadronic final states with high Lorentz boost jets (**boosted V jets)**:

What tools do we have?

CMS detector







Jet Tagging via Particle Clouds

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Loukas Gouskos†
CERN, CH-1211 Geneva 23, Switzerland

How to represent a jet is at the core of machine learning on jet physics. Inspired by the notion of point clouds, we propose a new approach that considers a jet as an unordered set of its constituent particles, effectively a "particle cloud". Such a particle cloud representation of jets is efficient in incorporating raw information of jets and also explicitly respects the permutation symmetry. Based on the particle cloud representation, we propose ParticleNet, a customized neural network architecture using Dynamic Graph Convolutional Neural Network for jet tagging problems. The ParticleNet architecture achieves state-of-the-art performance on two representative jet tagging benchmarks and is improved significantly over existing methods.

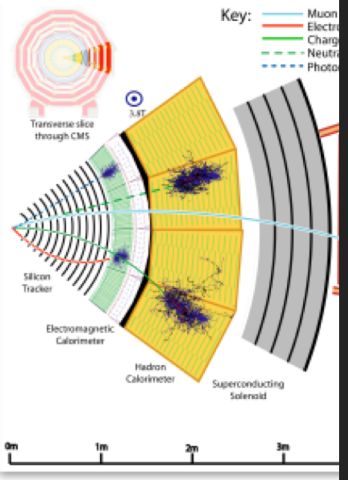
Particle flow reconstruction

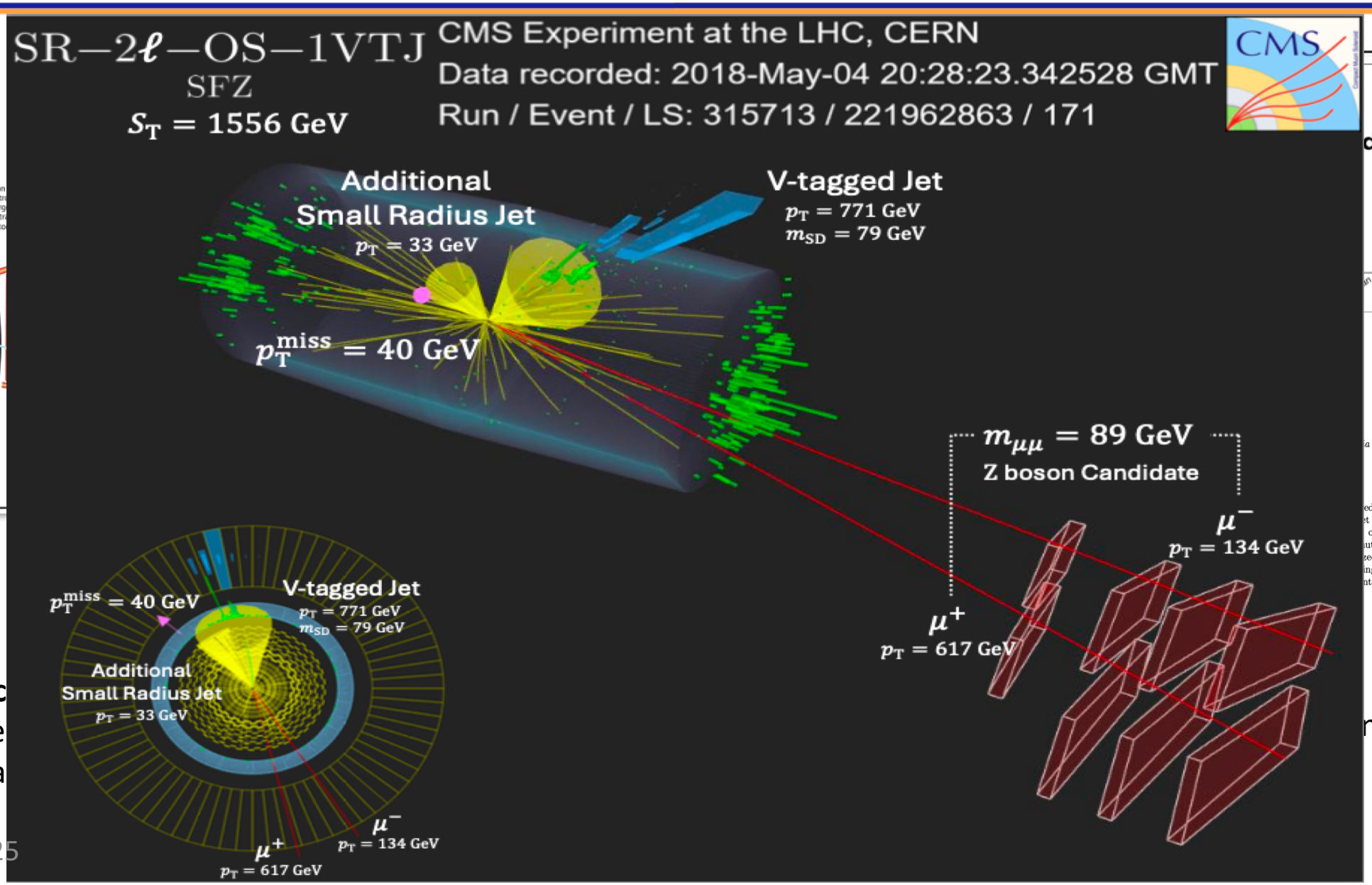
- Excellent energy and momentum resolution
- Combined particle reconstruction with detailed properties

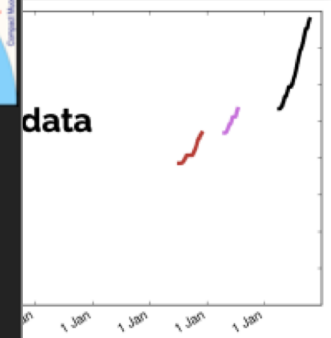
[arX:1902.08570](arX:1902.08570)

Smart usage of physics-oriented Machine learning

What tools do we have?







Particle flow rec

- Excellent ene
- Combined pa
  properties

nted

The physics of boosted Jets

Why are large-radius jets relevant for Physics?

The study of **high-pT regimes** requires reconstructing boosted particles

→ Quark pairs cannot be resolved as single AK4 jets in this regime

→ Clustering particles into a single large-radius jet (e.g. AK8 jet)

Jet tagging: identifying the hard scattering particle that initiates the jet

Example: **heavy resonance tagging (top/W/Z/Higgs)**
The rise of machine learning (ML) has brought lots of new progresses to jet tagging

ParticleNet: GNN model for jet tagging via particle clouds

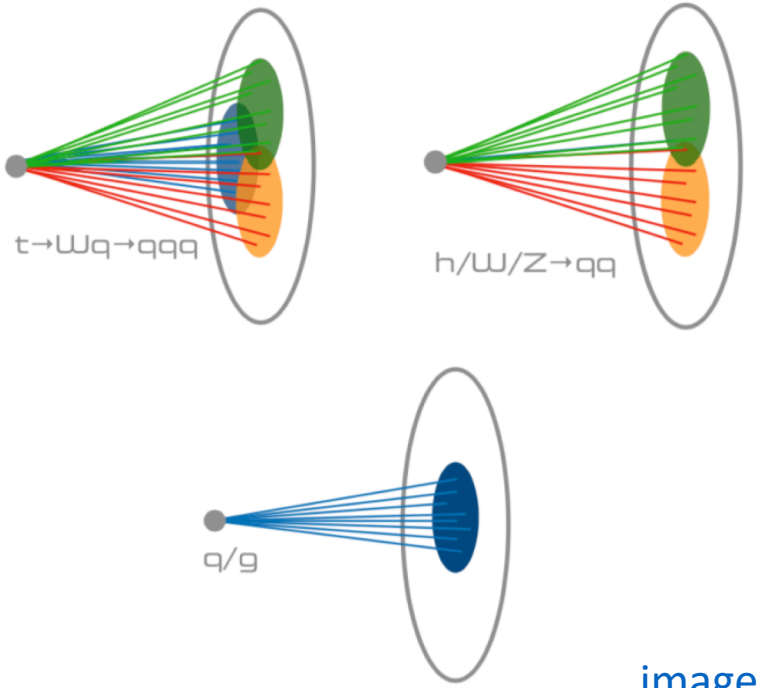
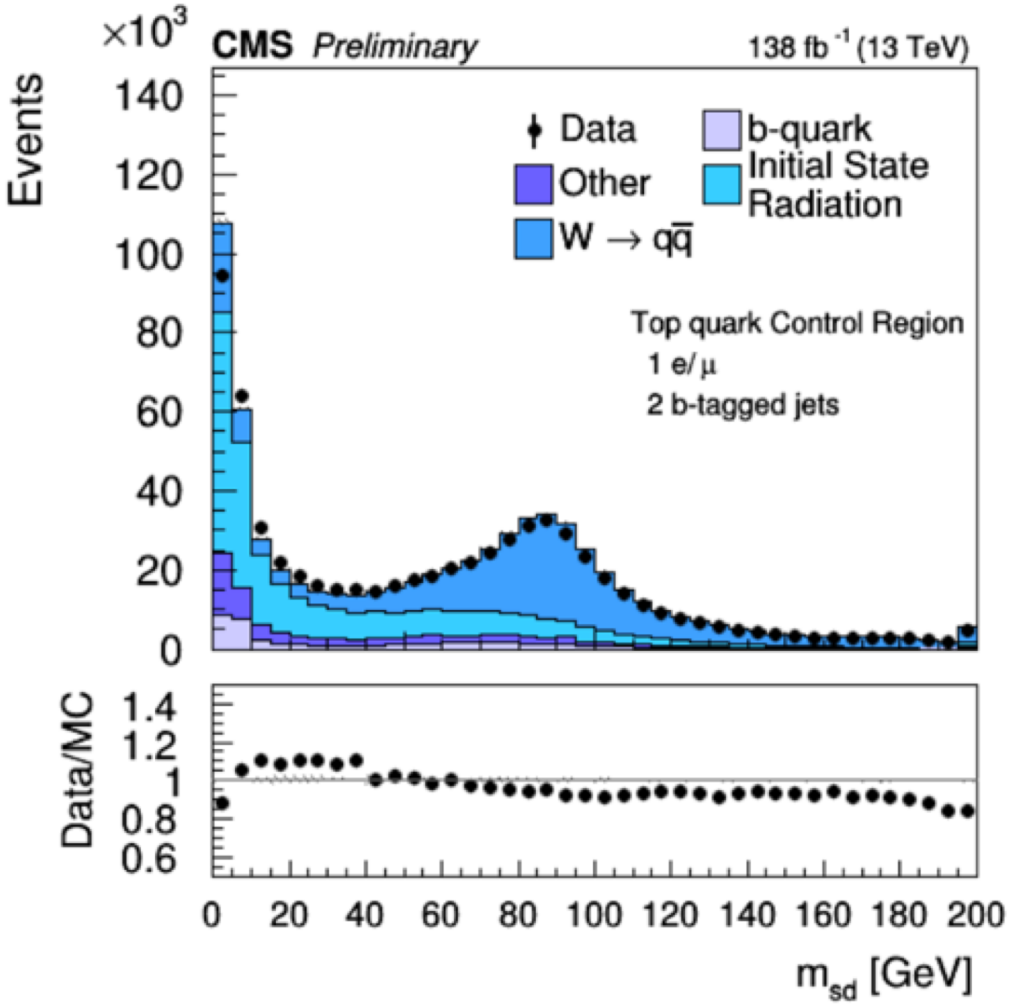


image credit

V tagged Jets



- Large-radius jet collection contains all with pT > 200 GeV
- Jet substructure variables are used to get hadronic V decay

ParticleNet V tagger

- Two prong structure
- Mass decorrelated
- WPs based on different signal and background rejection requirements

Analysis strategy in a nutshell

- Analysis is designed to target **boosted objects** – not sensitive to SM
- Impacts of EFT can manifest as **high $\sqrt{\hat{s}}$ excess** or increased normalization
- Explore **dimension-8** and **dimension-6** operators
- Privately produced samples with “faux-NLO” scheme (LO, LO+1jet)
- Use **8 orthogonal channels** based on lepton multiplicity targeting one or more VVV processes
- **Events are binned by $\sqrt{\hat{s}}$ proxy variable for increase sensitivity**

Dimension 6 and Dimension 8 operators

Dim 8 Eboli basis [PRD 93, 093013]

Operator	Corresponding Wilson Coefficient
Longitudinal operators	
$[(D_\mu\Phi)^\dagger D_\nu\Phi]\times[(D^\mu\Phi)^\dagger D^\nu\Phi]$	$f_{S,0}$
$[(D_\mu\Phi)^\dagger D^\mu\Phi]\times[(D_\nu\Phi)^\dagger D^\nu\Phi]$	$f_{S,1}$
$[(D_\mu\Phi)^\dagger D_\nu\Phi]\times[(D^\nu\Phi)^\dagger D^\mu\Phi]$	$f_{S,2}$
Mixed operators	
$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}]\times[(D_\beta\Phi)^\dagger D^\beta\Phi]$	$f_{M,0}$
$Tr[\hat{W}_{\mu\nu}\hat{W}^{\nu\beta}]\times[(D_\beta\Phi)^\dagger D^\mu\Phi]$	$f_{M,1}$
$[B_{\mu\nu}B^{\mu\nu}]\times[(D_\beta\Phi)^\dagger D^\beta\Phi]$	$f_{M,2}$
$[B_{\mu\nu}B^{\nu\beta}]\times[(D_\beta\Phi)^\dagger D^\mu\Phi]$	$f_{M,3}$
$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}D^\mu\Phi]\times B^{\beta\nu}$	$f_{M,4}$
$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}D^\nu\Phi]\times B^{\beta\mu}+H.c.$	$f_{M,5}$
$[(D_\mu\Phi)^\dagger\hat{W}_{\beta\nu}\hat{W}^{\beta\mu}D^\nu\Phi]$	$f_{M,7}$
Transverse operators	
$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}]\times Tr[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}]$	$f_{T,0}$
$Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}]\times Tr[\hat{W}_{\mu\beta}\hat{W}^{\alpha\nu}]$	$f_{T,1}$
$Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}]\times Tr[\hat{W}_{\beta\nu}\hat{W}^{\nu\alpha}]$	$f_{T,2}$
$Tr[\hat{W}_{\mu\nu}\hat{W}_{\alpha\beta}]\times Tr[\hat{W}^{\alpha\nu}\hat{W}^{\mu\beta}]$	$f_{T,3}$
$Tr[\hat{W}_{\mu\nu}\hat{W}_{\alpha\beta}]\times B^{\alpha\nu}B^{\mu\beta}$	$f_{T,4}$
$Tr[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}]\times B_{\alpha\beta}B^{\alpha\beta}$	$f_{T,5}$
$Tr[\hat{W}_{\alpha\nu}\hat{W}^{\mu\beta}]\times B_{\mu\beta}B^{\alpha\nu}$	$f_{T,6}$
$Tr[\hat{W}_{\alpha\mu}\hat{W}^{\mu\beta}]\times B_{\beta\nu}B^{\nu\alpha}$	$f_{T,7}$
$B_{\mu\nu}B^{\mu\nu}B_{\alpha\beta}B^{\alpha\beta}$	$f_{T,8}$
$B_{\alpha\mu}B^{\mu\beta}B_{\beta\nu}B^{\nu\alpha}$	$f_{T,9}$

Dim 6 Warsaw basis [JHEP 2010, 85]

Operator	Corresponding Wilson Coefficient
Gauge boson self interaction	
$\epsilon^{IJK}W^{I\nu}_{\mu}W^{J\rho}_{\nu}W^{K\mu}_{\rho}$	c_W
$H^\dagger HW_{I\mu\nu}W^{I\mu\nu}$	c_{HW}
$H^\dagger HB_{\mu\nu}B^{\mu\nu}$	c_{HB}
$H^\dagger\tau^I HW^I_{\mu\nu}B^{\mu\nu}$	c_{HWB}
$(H^\dagger H)\Box(H^\dagger H)$	$c_{H\Box}$
$(H^\dagger D_\mu H)*(H^\dagger D^\mu H)$	c_{HDD}
Gauge boson and fermion interaction	
$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$	c_{Hq3}
$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$	c_{Hq1}
$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$	c_{Hu}
$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$	c_{Hd}
$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$	c_{Hl3}
Four fermion interaction	
$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma_\mu l_t)$	c_{ll1}

Analysis channels

Channel label	# leptons	# FatJets	# τ_h	Sensitive to VVV Process	Variable of Interest	
SR-0l-2fj	0	2	0	WWW, WWZ, WZZ, ZZZ	$H_{\mathrm{T,fj}}$	
SR-0l-3fj	0	≥ 3	0	WWW, WWZ, WZZ, ZZZ	$\sum p_{\mathrm{T,fj}}$	
SR-ℓ-2fj	1	≥ 2	0	WWW, WWZ, WZZ	$\mathrm{M_{JJ\ell\nu}}$	
SR-2l-OS-1fj	2	1	0	WWW, WWZ, WZZ, ZZZ	S_{T}	
SR-2l-OS-2fj	2	≥ 2	0	WWZ, WZZ, ZZZ	S_{T}	
SR-2l-SS-1fj	2	≥ 1	0	WWW	S_{T}	
SR-1T-1l-1fj	1	1	1	WWW, WWZ, WZZ, ZZZ	BDT Score and S_{T}	(2D)
SR-1T-2l-0fj	2	0	1	WWW, WZZ	BDT Score and S_{T}	(2D)

8 orthogonal signal regions

Discriminating variable defined to proxy mVVV

ST: scalar sum of P_T o jets and leptons

$m_{\mathrm{jjl\nu}}$: invariant mass of lepton, V-tagged jets and reconstructed neutrino

Background Overview

- Each channel has its own background composition
- **Data driven methods** are used to estimate **the major backgrounds**

channel	Lepton Flavour	Dominant background	Method used	Subdominant background	method
SR-0l-2fj	------	QCD	**ABCD method**	Top	**MC**
SR-0l-3fj		QCD	**ABCD method**	Top	**MC**
SR-l-2fj	combined	W+jets	**CR+ extrapolation**	Top	**CR+ extrapolation**
SR-2l-OS-1fj	eμ	Top	**CR**	WW	**MC**
	ee/μμ off Z	DY	**ABCD method**	WZ	**MC**
	ee/μμ on Z	DY	**ABCD method**	ZZ	**MC**
SR-2l-OS-2fj	combined	DY	**MC**	WZ	**MC**
SR-2l-SS-1fj	combined	Top	**CR+ extrapolation**	WZ	**CR+ extrapolation**
SR-1T-1l-ifj	combined	QCD	**ABCD**	Top	**MC**
SR-1T-2l-0fj	Combined	QCD	**ABCD**	Top	**MC**

Background Overview

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- **Data driven methods** are used to estimate **the major backgrounds**

channel	Lepton Flavour	Dominant background	Method used	Subdominant background	method
SR-0l-2fj		QCD	**ABCD method**	Top	**MC**
SR-0l-3fj	------	QCD	**ABCD method**	Top	**MC**
SR-l-2fj	combined	W+jets	**CR+ extrapolation**	Top	**CR+ extrapolation**
SR-2l-OS-1fj	eμ	Top	**CR**	WW	**MC**
	ee/μμ off Z	DY	**ABCD method**	WZ	**MC**
	ee/μμ on Z	DY	**ABCD method**	ZZ	**MC**
SR-2l-OS-2fj	combined	DY	**MC**	WZ	**MC**
SR-2l-SS-1fj	combined	Top	**CR+ extrapolation**	WZ	**CR+ extrapolation**
SR-1T-1l-ifj	combined	QCD	**ABCD**	Top	**MC**
SR-1T-2l-0fj	Combined	QCD	**ABCD**	Top	**MC**

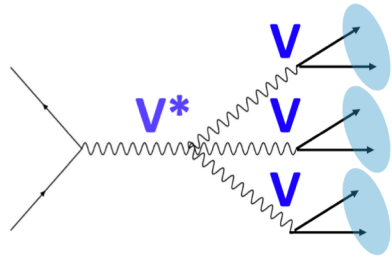
0 lepton channel –3 Fat Jets

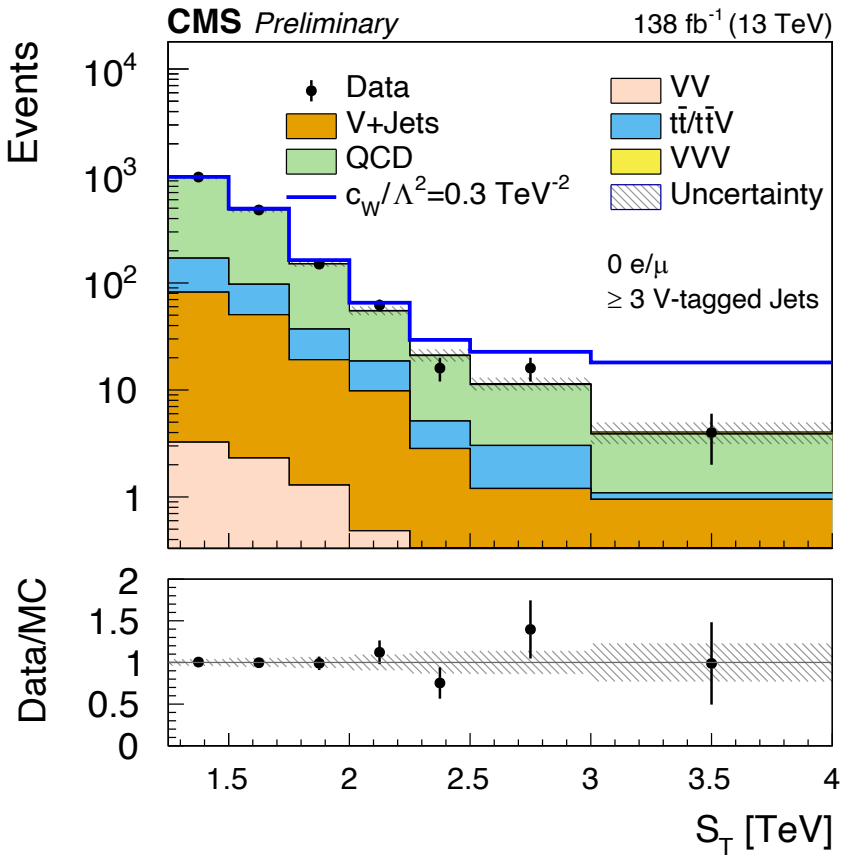
Signal region:

- **exactly 0 leptons e/μ**
- 3 loose V-tagged jets with
- $p_{T,VTJ1}$ > 600GeV, $p_{T,VTJ2,3}$ > 200GeV
- ST > 1.25 TeV
- Spherical cut D_3 < 35GeV

$$D_3 = \sqrt{\sum \left(m_{sd,VTJ} - 85\text{GeV}\right)^2}$$

QCD background is dominant



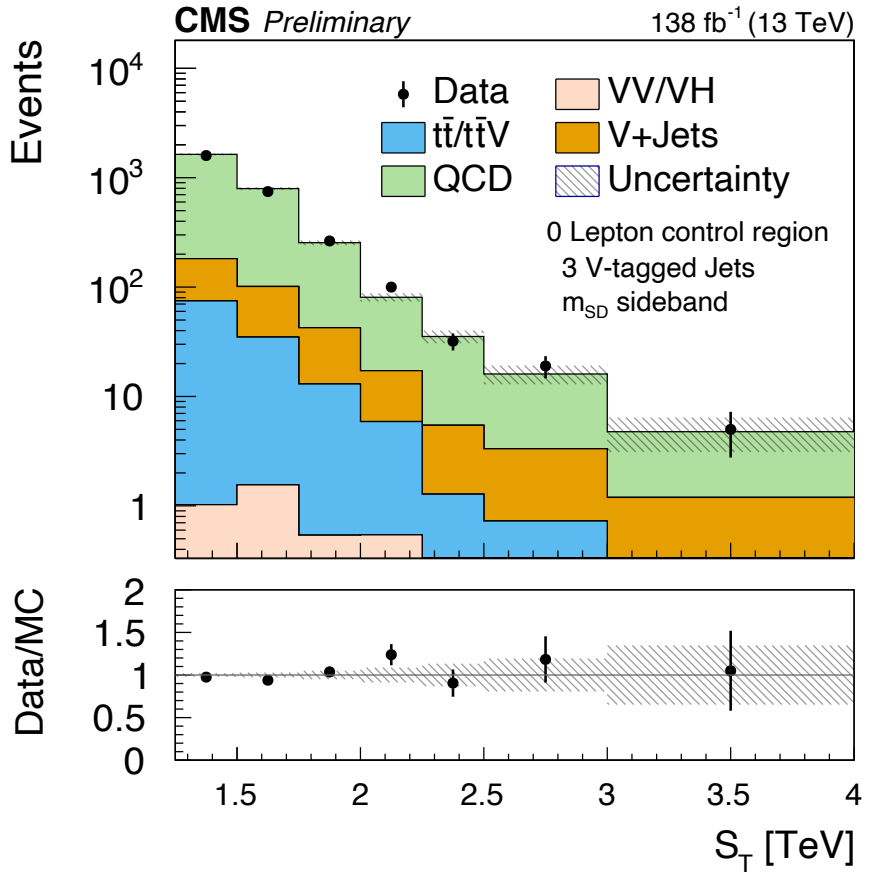


QCD estimation

ABCD method is used to estimate QCD

- Use D3 and pass/fail of the tagger

	All pass tagging	Any fail tagging
$D_3 < 35\text{GeV}$	A	B
$D_3 > 50\text{GeV}$	C	D
$35 < D_3 < 50\text{GeV}$	E	F



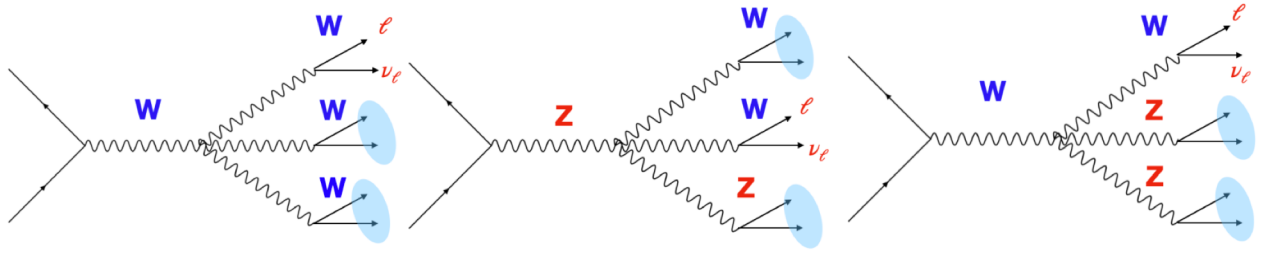
ABCD method to estimate the yields in signal region,

Method is validated in the data

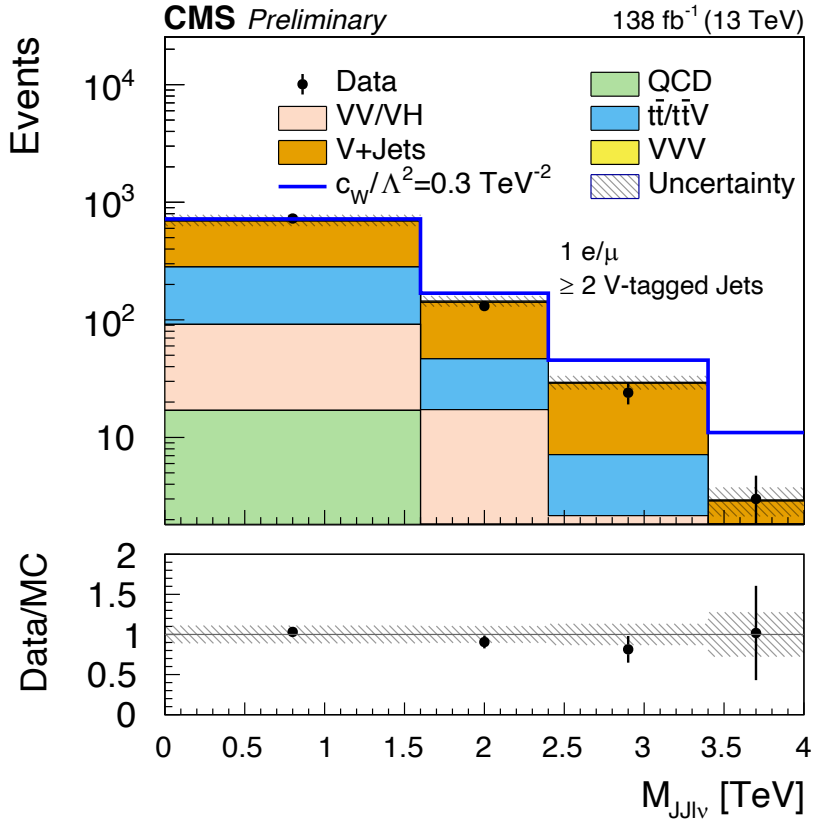
1 lepton channel + 2 FatJets

Signal region

- Exactly 1 e/μ
- 2 loose V-tagged jets with
- $|m_{sd}-85|<20$ GeV
- 0 b-jets

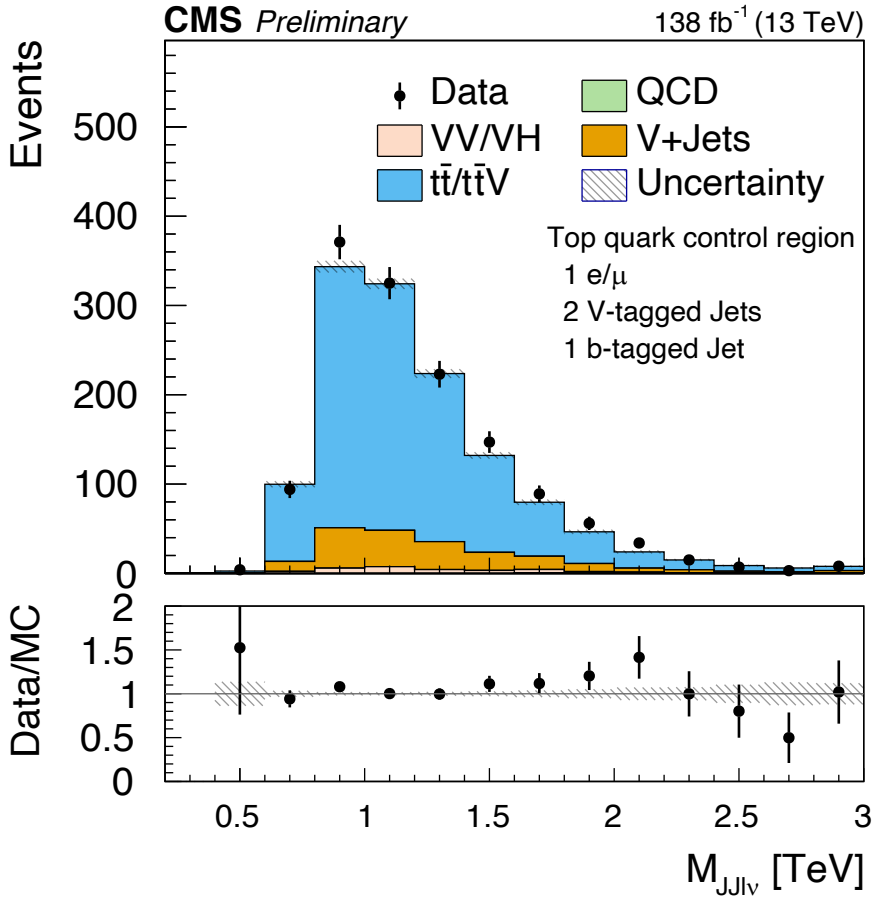


$$mjj\ell\nu = \sqrt{(PVTJ,1 + pVTJ,2 + p\ell + p\nu)^2}$$

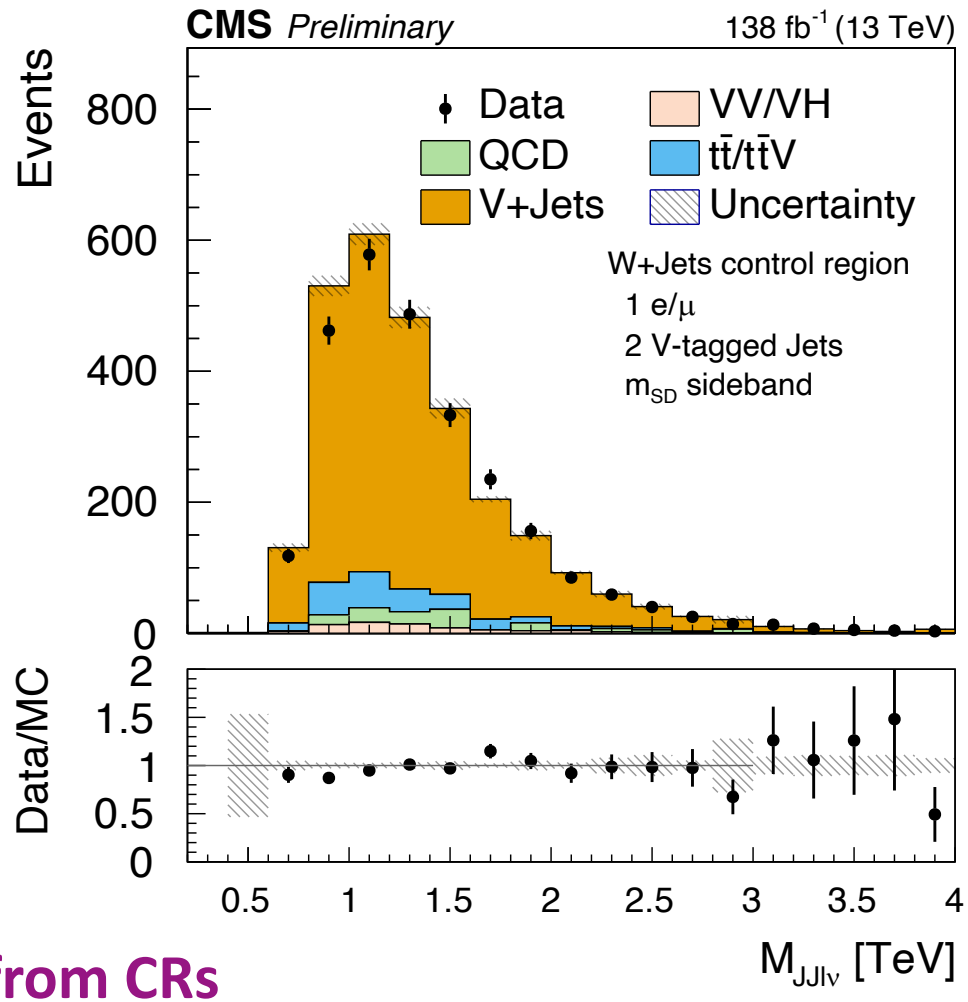


Control Regions

Top CR: flip b the veto



W+jets CR: mSD sideband

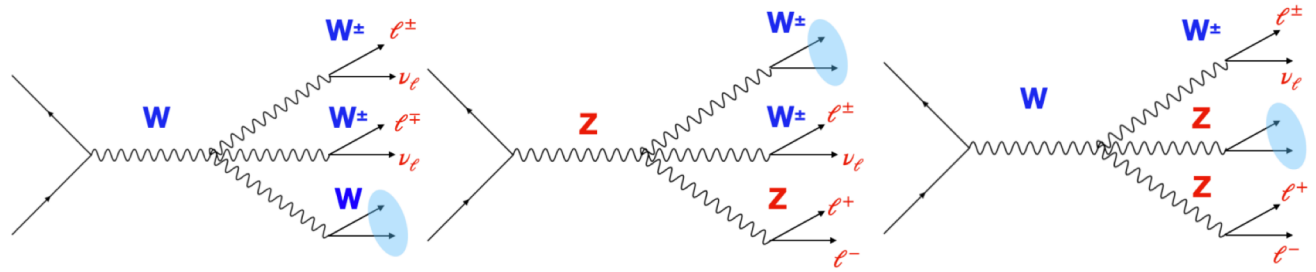


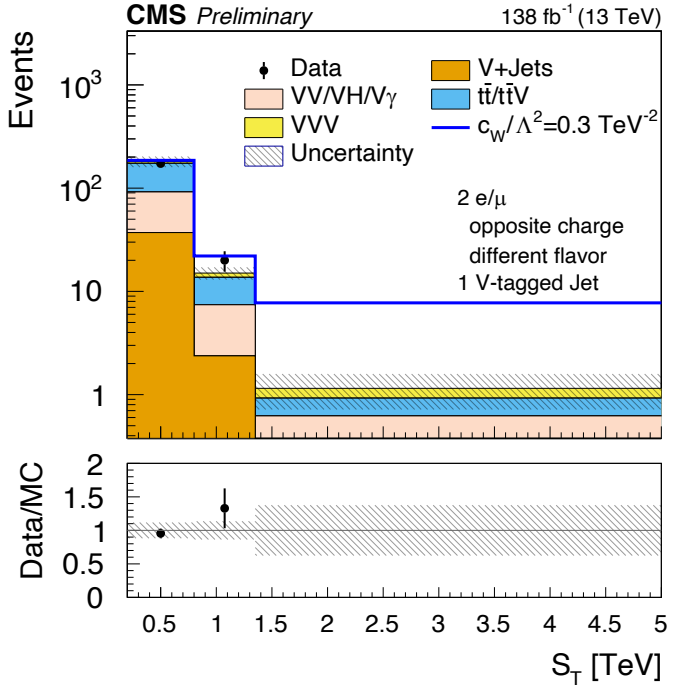
Transfer factors used from CRs

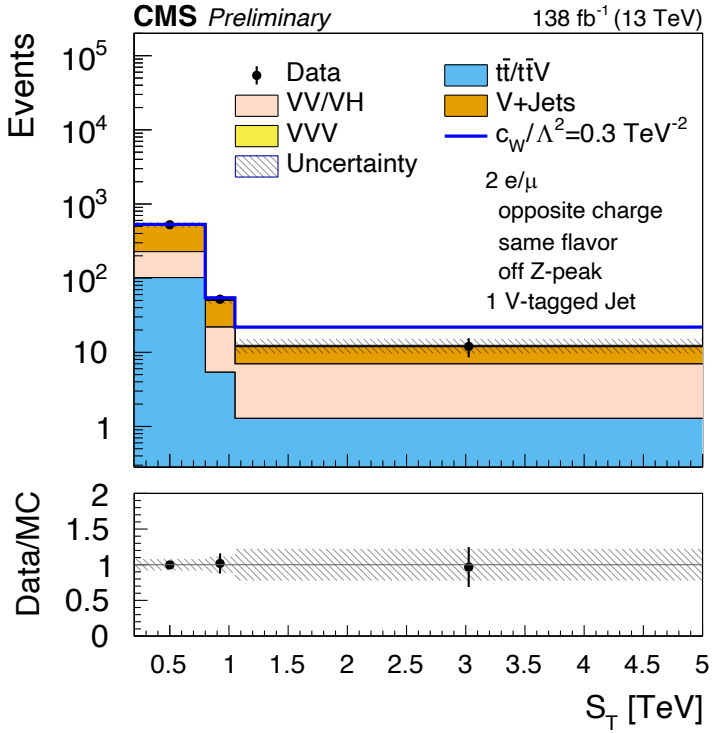
2OS leptons -1FatJet channel

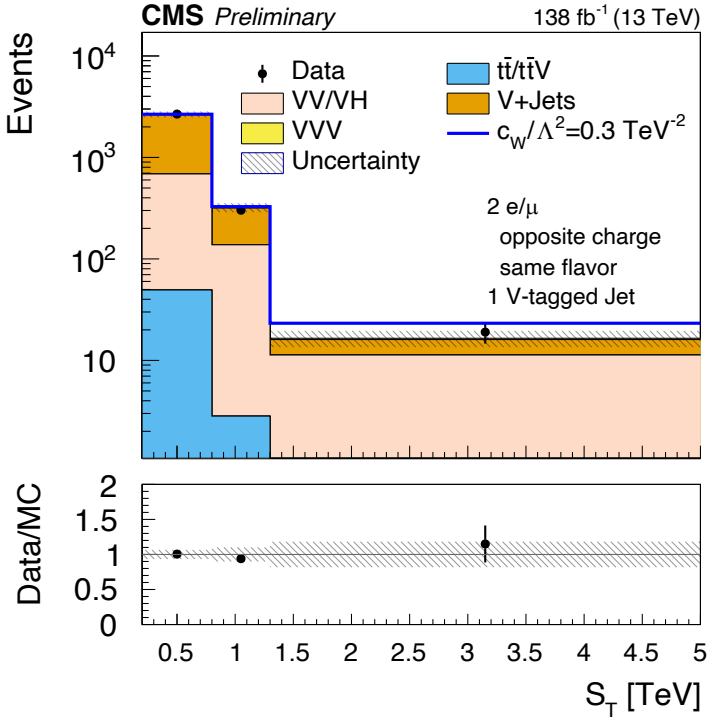
Three signal regions based on different lepton flavor

- opposite sign different flavor
- opposite sign same flavor off Z-peak
- opposite sign same flavor on Z-peak







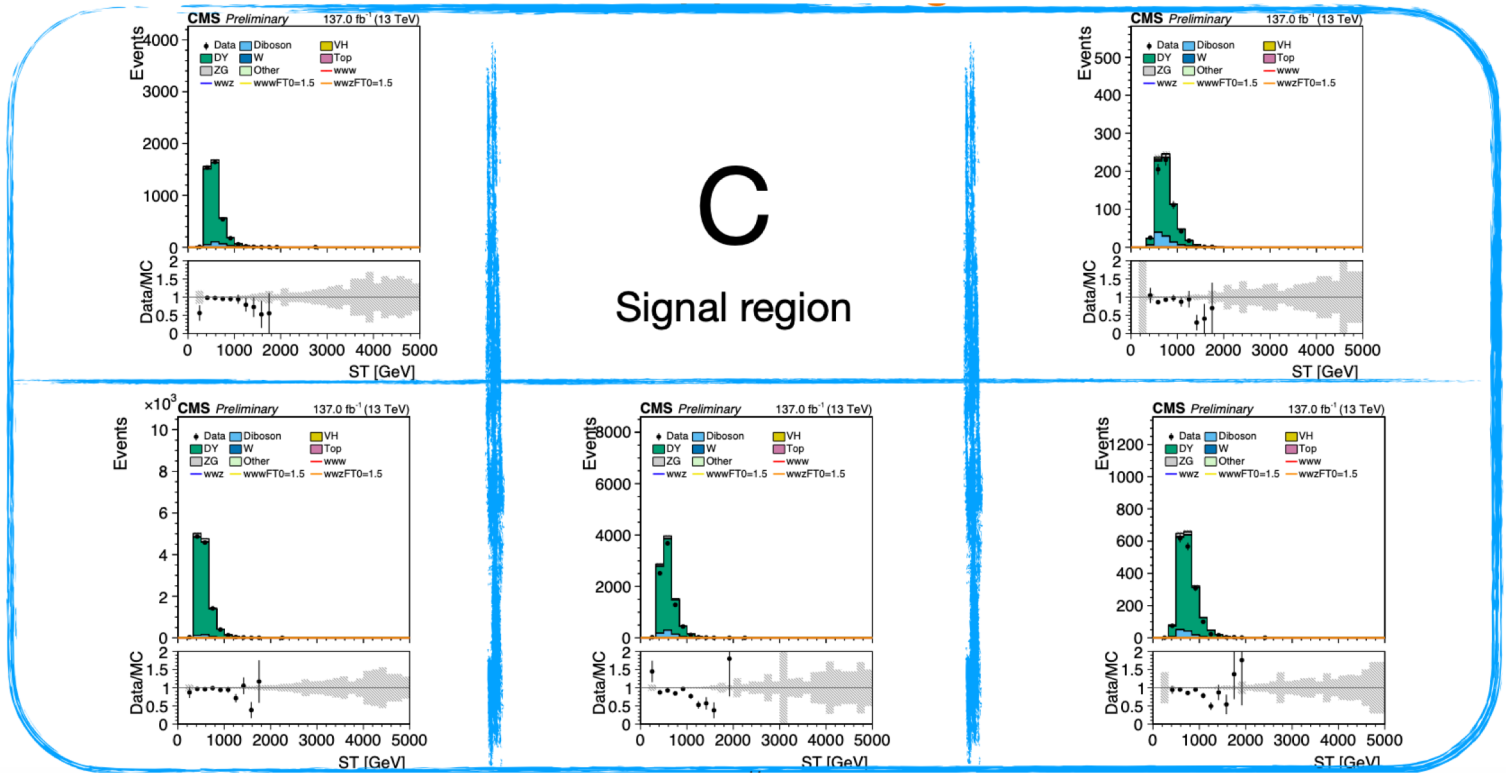


Z+jets background

In Same Flavour channels Z+jets is the dominant background

B Pass tight requirement and $40 < m_{SD} < 65$ GeV	**C** Signal region	**E** Pass tight requirement and $105 < m_{SD} < 130$ GeV
A Fails tight requirement and $40 < m_{SD} < 65$ GeV	**D** Fails tight requirement and $65 < m_{SD} < 105$ GeV	**F** Fails tight requirement and $105 < m_{SD} < 130$ GeV

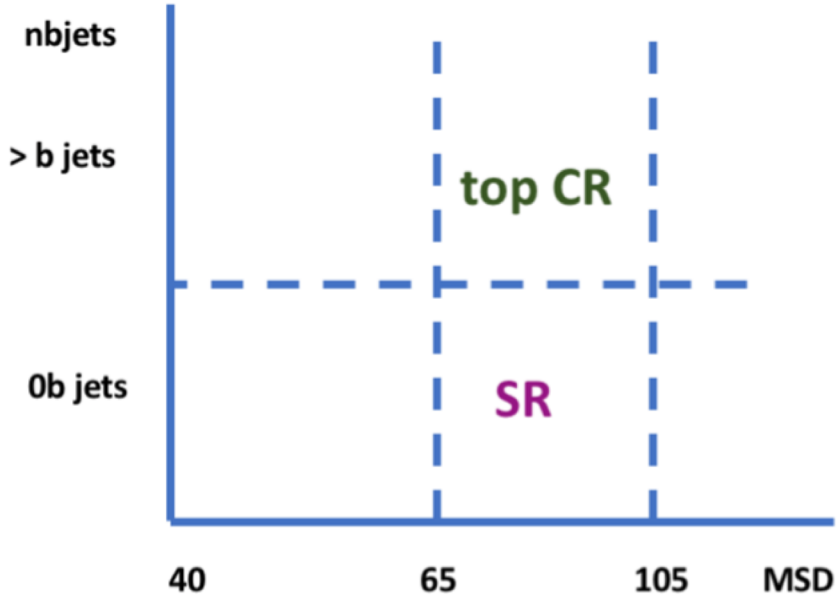
$$N_C = \frac{N_{B+E}^{data-rest} \cdot N_D^{data-rest}}{N_{A+F}^{data-rest}} \quad \text{per } S_T \text{ bin}$$

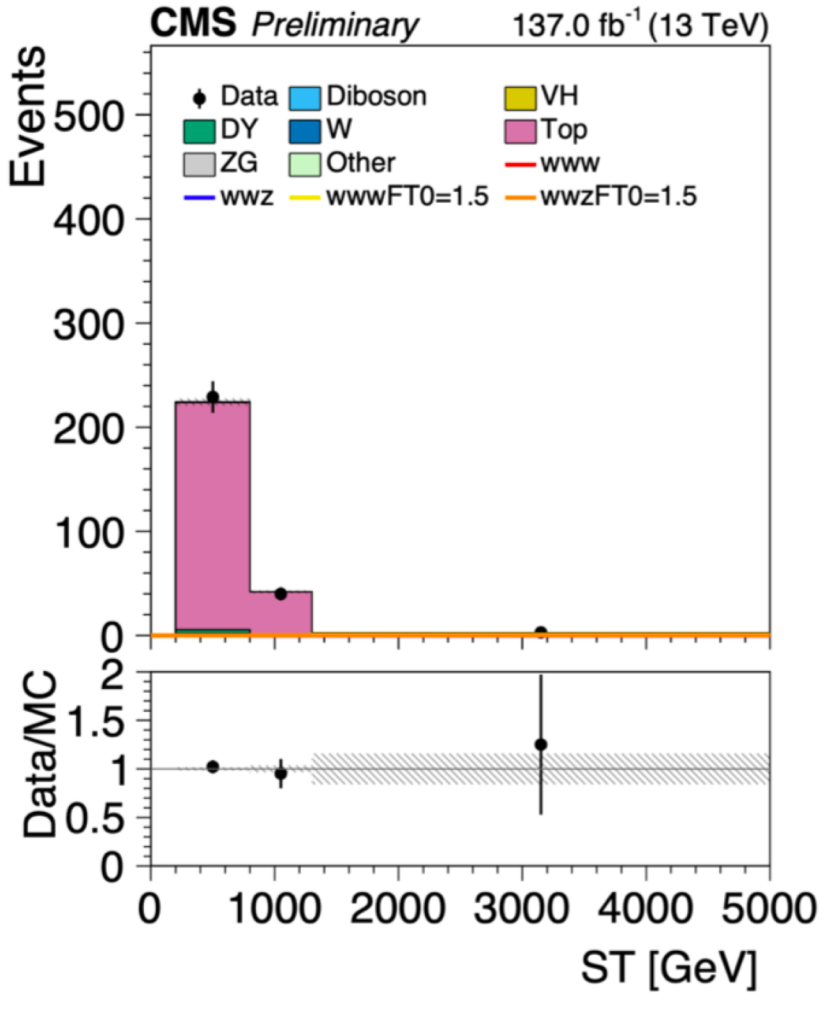


Top background

Top-related processes (dilepton ttbar, single lepton ttbar and ttX) are dominant in the OF channel

flipping b-veto



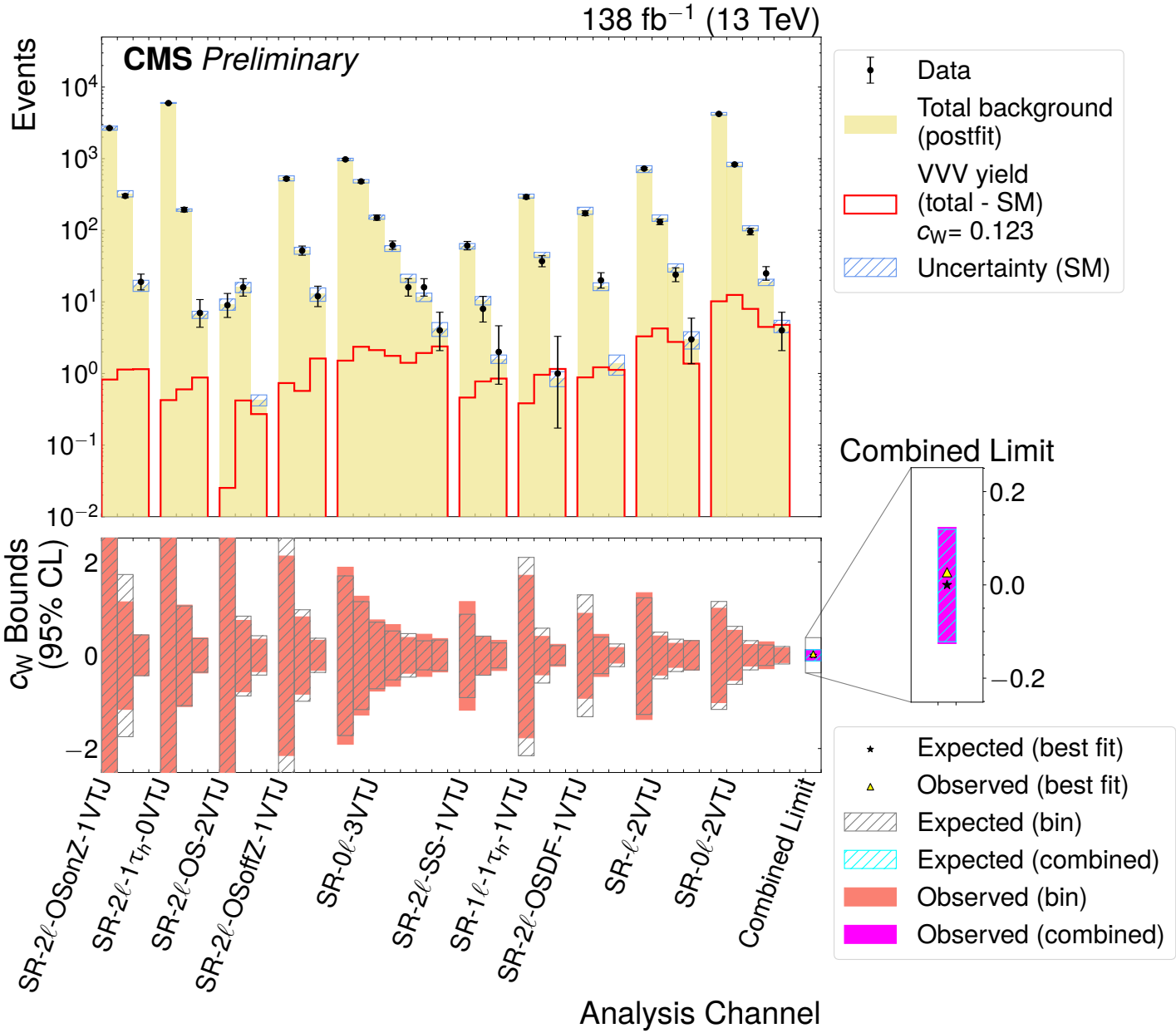


$$N_{bkg,SR} = \frac{N_{bkg,MC}^{SR}}{N_{bkg,MC}^{CR}} \times \left(N_{data}^{CR} - N_{rest,MC}^{CR}\right)$$

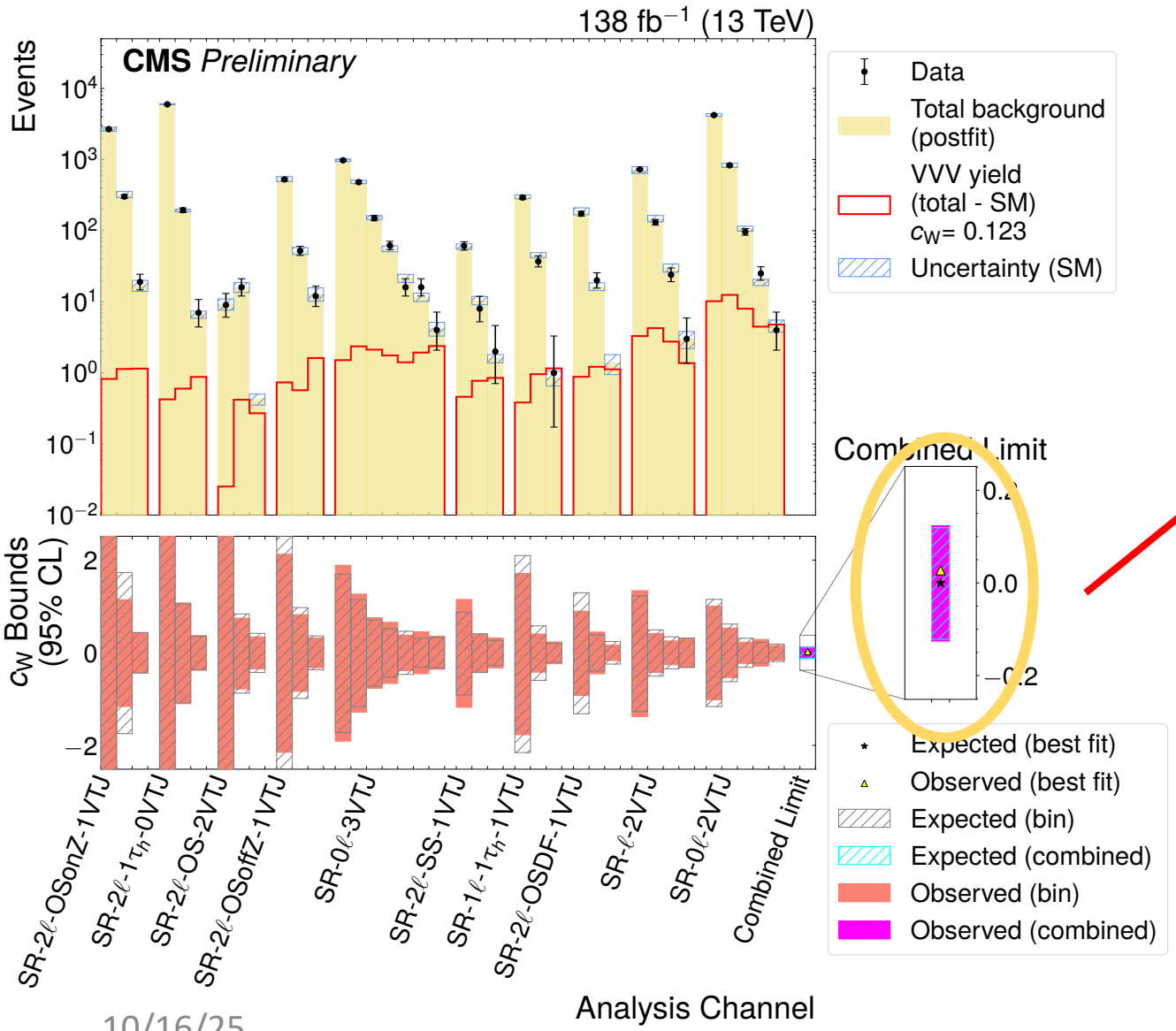
Results

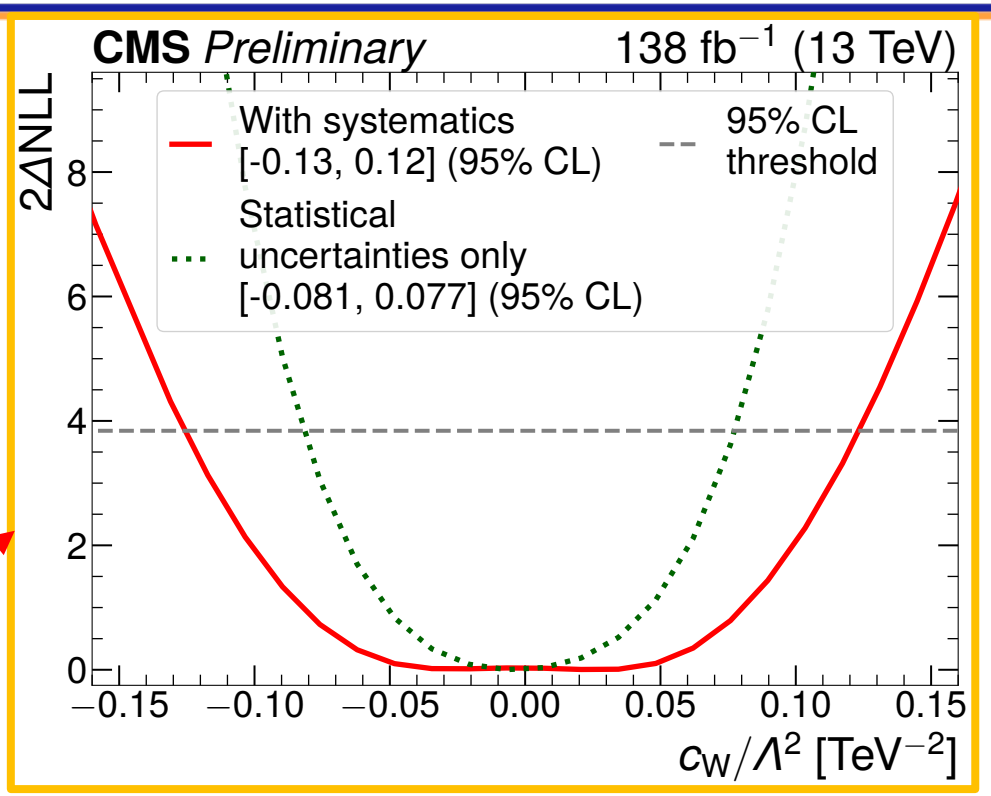
summary of the yields in all SRs and the associated bin-wise limits on c_W

- **orange bar**: the observed bin-wise 95% CL limits on c_W
- **mangenta bar**: full combination limit on c_W



Results





Stringiest bounds in Cw operator
[-0.13,0.12]

Results on EFT limits

dim6

Wilson coefficient	Freeze other WCs 95% bounds $[^{-2}]$ Observed	Freeze other WCs 95% bounds $[^{-2}]$ Expected	Profile other WCs 95% bounds $[^{-2}]$ Observed	Profile other WCs 95% bounds $[^{-2}]$ Expected
c_w/Λ^2	$[-0.13, 0.12]$	$[-0.12, 0.12]$	$[-0.11, 0.11]$	$[-0.13, 0.13]$
c_{Hq3}/Λ^2	$[-0.24, 0.21]$	$[-0.23, 0.20]$	$[-0.40, 0.29]$	$[-0.30, 0.26]$
c_{Hq1}/Λ^2	$[-0.34, 0.34]$	$[-0.32, 0.32]$	$[-0.39, 0.40]$	$[-0.35, 0.34]$
c_{Hqu}/Λ^2	$[-0.60, 0.59]$	$[-0.61, 0.59]$	$[-0.84, 0.67]$	$[-0.75, 0.73]$
c_{Hqd}/Λ^2	$[-0.79, 0.79]$	$[-0.79, 0.79]$	$[-0.75, 0.93]$	$[-0.87, 0.89]$
c_{HW}/Λ^2	$[-1.60, 1.55]$	$[-1.63, 1.55]$	$[-1.97, 3.0]$	$[-2.1, 2.4]$
c_{HWB}/Λ^2	$[-5.2, 5.0]$	$[-5.5, 5.2]$	$[-7.2, 9.2]$	$[-7.8, 7.7]$
c_{Hl3}/Λ^2	$[-3.7, 1.16] \cup [9.1, 17]$	$[-3.4, 15]$	$[-16, 29]$	$[-12, 26]$
c_{HB}/Λ^2	$[-11, 11]$	$[-12, 12]$	$[-8.3, 8.6]$	$[-13, 13]$
c_{ll1}/Λ^2	$[-32, -13] \cup [-9.1, 10]$	$[-30, 6.9]$	$[-48, 26]$	$[-44, 22]$
c_H/Λ^2	$[-76, 69]$	$[-69, 61]$	$[-74, 75]$	$[-61, 60]$
c_{HDD}/Λ^2	$[-114, 71]$	$[-108, 68]$	$[-116, 67]$	$[-125, 74]$

First dim6 limits on VVV process

- Good sensitivity in many operators
- Results are compatible with the SM
- **Stringiest bounds in Cw operator**

dim8

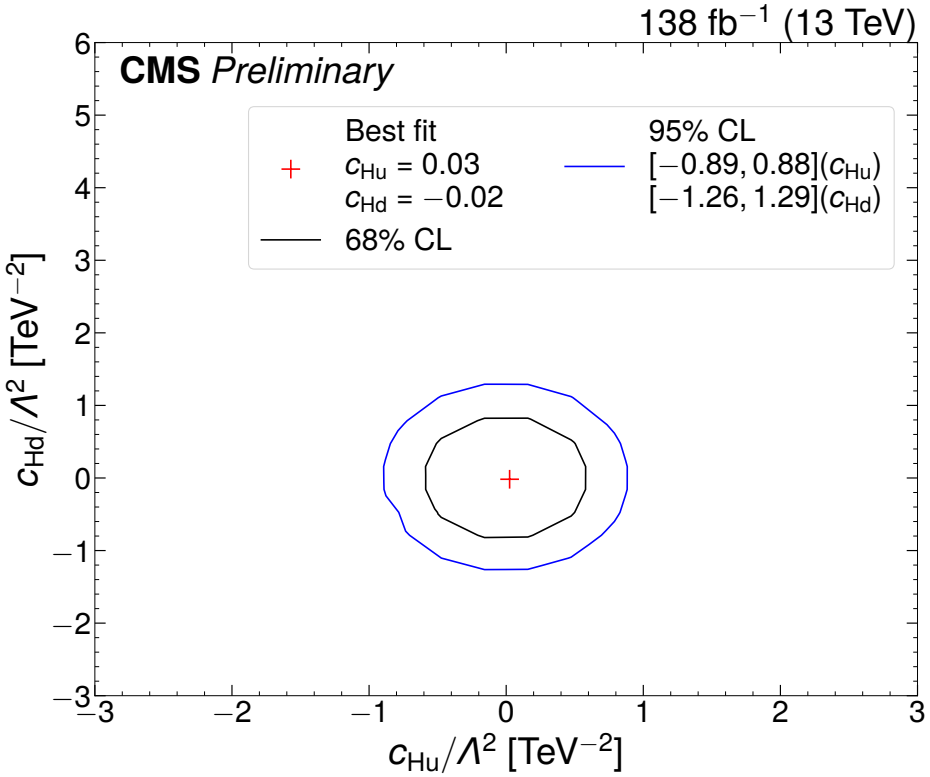
Wilson coefficient	95% CL Bounds $[^{-4}]$ Observed	95% CL Bounds $[^{-4}]$ Expected	Measurement $[^{-4}]$ Observed
$f_{T,0}/\Lambda^4$	$[-0.57, 0.63]$	$[-0.48, 0.54]$	$-0.05^{+0.34}_{-0.28}$
$f_{T,1}/\Lambda^4$	$[-0.63, 0.70]$	$[-0.54, 0.62]$	$0.05^{+0.26}_{-0.41}$
$f_{T,3}/\Lambda^4$	$[-1.22, 1.32]$	$[-1.04, 1.18]$	$0.10^{+0.48}_{-0.82}$
$f_{T,2}/\Lambda^4$	$[-1.29, 1.39]$	$[-1.10, 1.24]$	$0.10^{+0.50}_{-0.85}$
$f_{M,0}/\Lambda^4$	$[-3.8, 4.0]$	$[-2.8, 3.2]$	$-0.4^{+2.9}_{-1.76}$
$f_{T,5}/\Lambda^4$	$[-4.0, 3.9]$	$[-3.1, 3.0]$	$0.0^{+2.6}_{-2.7}$
$f_{T,6}/\Lambda^4$	$[-4.9, 4.8]$	$[-3.8, 3.7]$	$0.0^{+3.2}_{-3.3}$
$f_{M,1}/\Lambda^4$	$[-6.7, 6.4]$	$[-5.0, 5.1]$	$-1.0^{+4.7}_{-3.0}$
$f_{T,4}/\Lambda^4$	$[-9.2, 9.0]$	$[-7.1, 7.0]$	$0.0^{+6.0}_{-6.0}$
$f_{T,7}/\Lambda^4$	$[-10, 10]$	$[-7.9, 7.7]$	$0.1^{+6.8}_{-7.1}$
$f_{M,7}/\Lambda^4$	$[-10, 11]$	$[-8.4, 9.2]$	$-1.0^{+6.7}_{-4.4}$
$f_{M,5}/\Lambda^4$	$[-11, 11]$	$[-9.0, 9.0]$	$0.0^{+7.3}_{-7.0}$
$f_{T,8}/\Lambda^4$	$[-11, 12]$	$[-7.3, 7.3]$	$5^{+3.1}_{-13}$
$f_{M,4}/\Lambda^4$	$[-13, 13]$	$[-11, 11]$	$0.0^{+8.7}_{-8.4}$
$f_{M,2}/\Lambda^4$	$[-14, 14]$	$[-11, 11]$	$0.0^{+9.7}_{-9.7}$
$f_{T,9}/\Lambda^4$	$[-22, 23]$	$[-14, 14]$	$11^{+5.0}_{-27}$
$f_{M,3}/\Lambda^4$	$[-23, 23]$	$[-18, 18]$	0^{+16}_{-15}
$f_{S,1}/\Lambda^4$	$[-26, 26]$	$[-24, 25]$	-2^{+16}_{-13}
$f_{S,0}/\Lambda^4$	$[-38, 38]$	$[-35, 35]$	-2^{+22}_{-20}
$f_{S,2}/\Lambda^4$	$[-38, 39]$	$[-36, 36]$	-2^{+22}_{-20}

Compatible with the SM

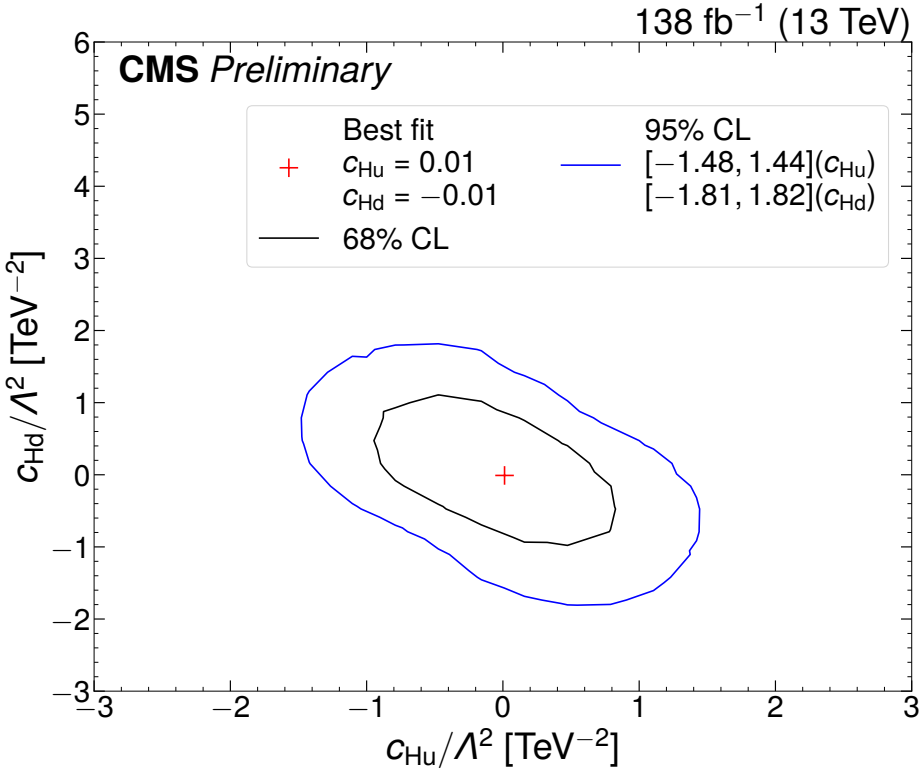
Good sensitivity on FT0 operator

2D scan

2D contours

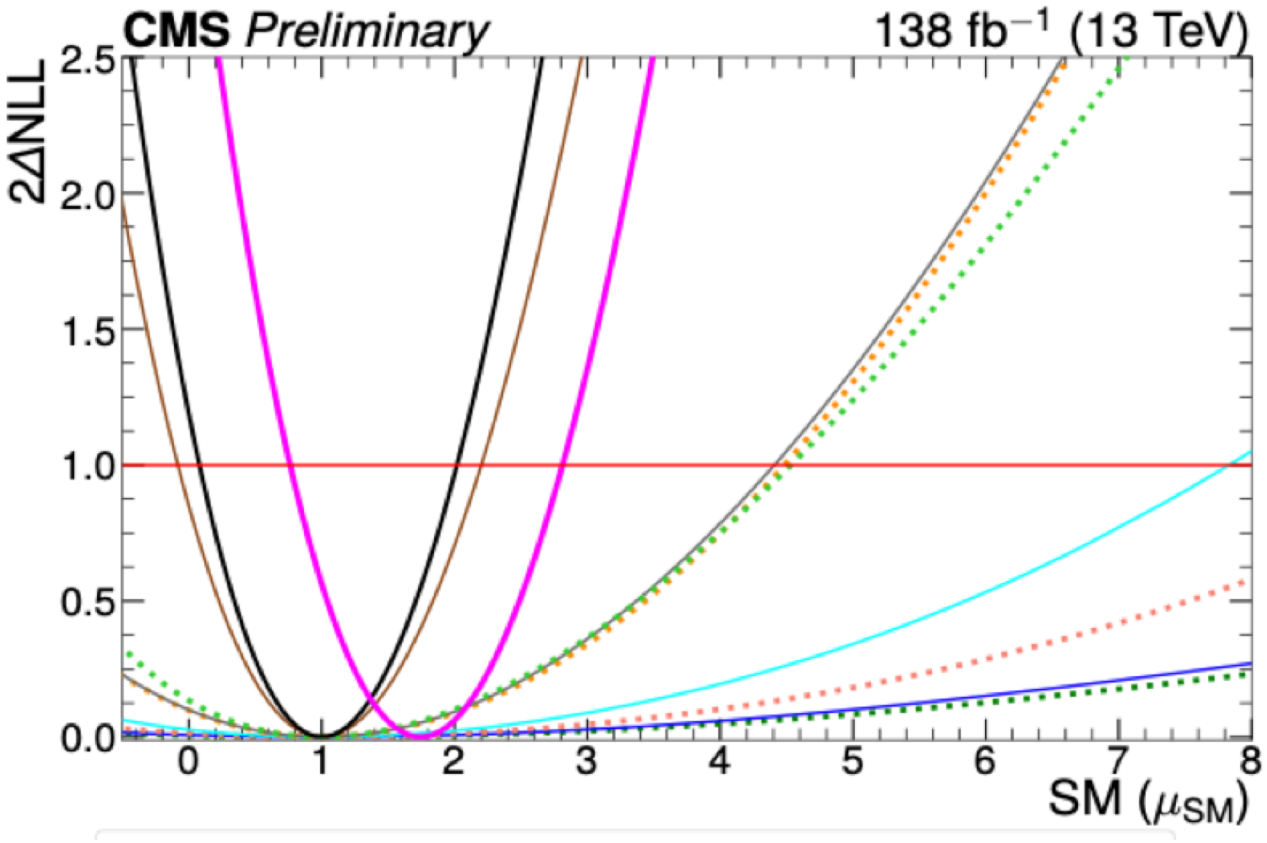


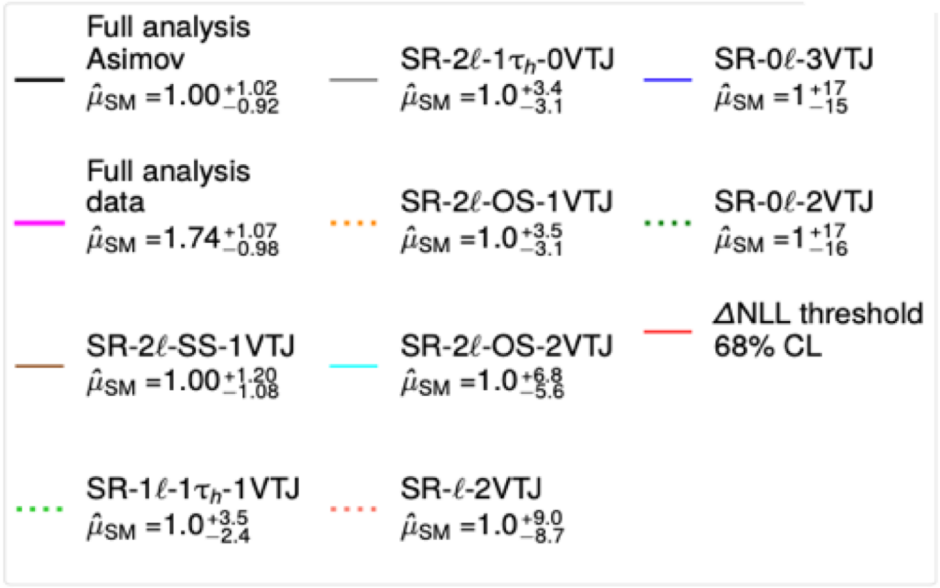
Freezing:
all other operators are fixed in the SM value



Profiling:
or other operators are allowed to float in the fit

Sensitivity of the SM

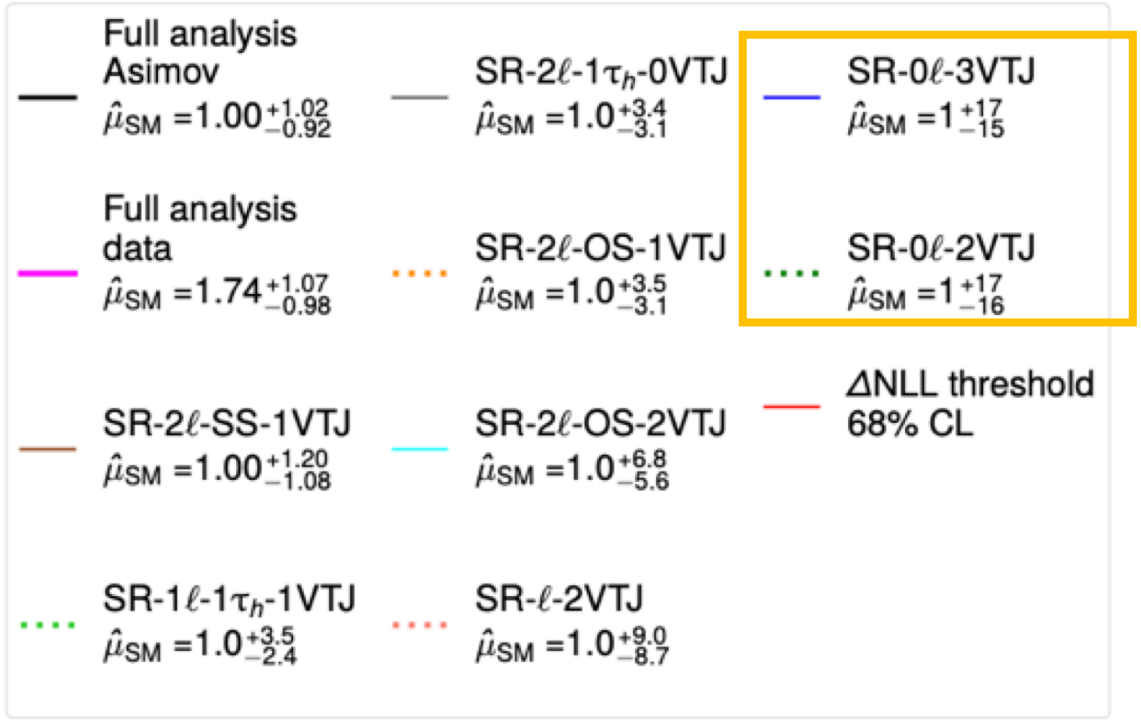




Not sensitive to the SM

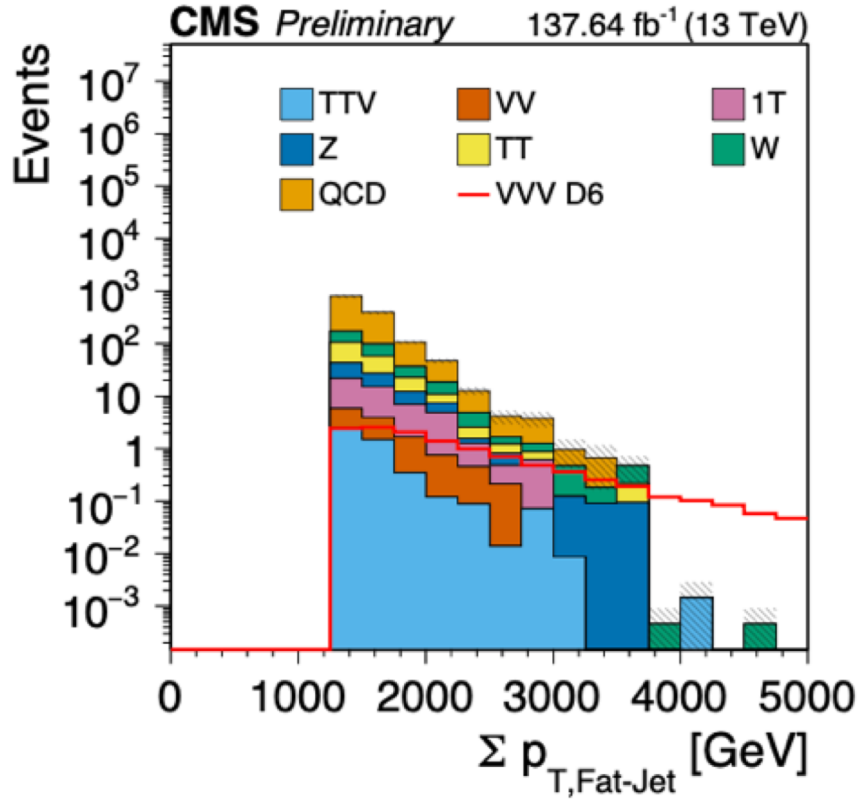
Sensitivity of the SM

SM sensitivity



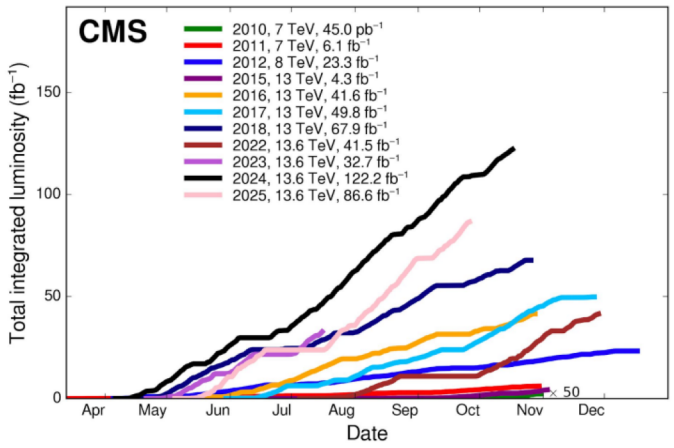
All-hadronic SM VVV production has **not been observed** yet

- 0 lepton channels show even less sensitivity
- Offline pT cut of 600 GeV
- **Impossible due to trigger high HT cut!!**



What tools do we have? Scouting + ML = new reach

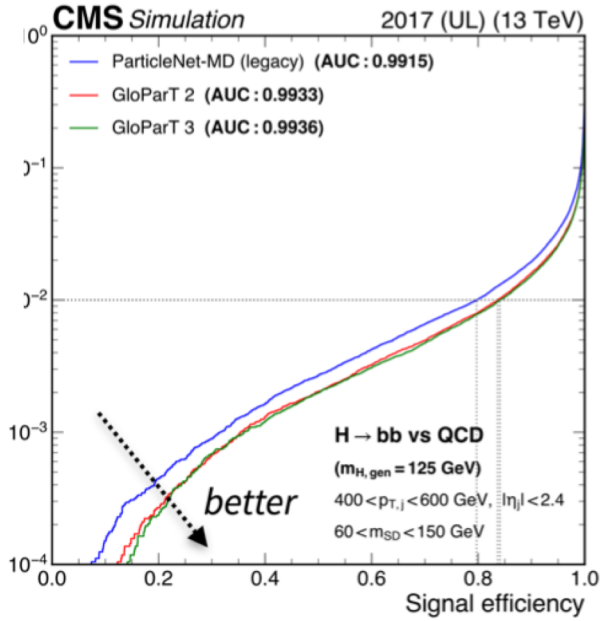
Run3 data
+Run2 (?)



which data stream:
data scouting



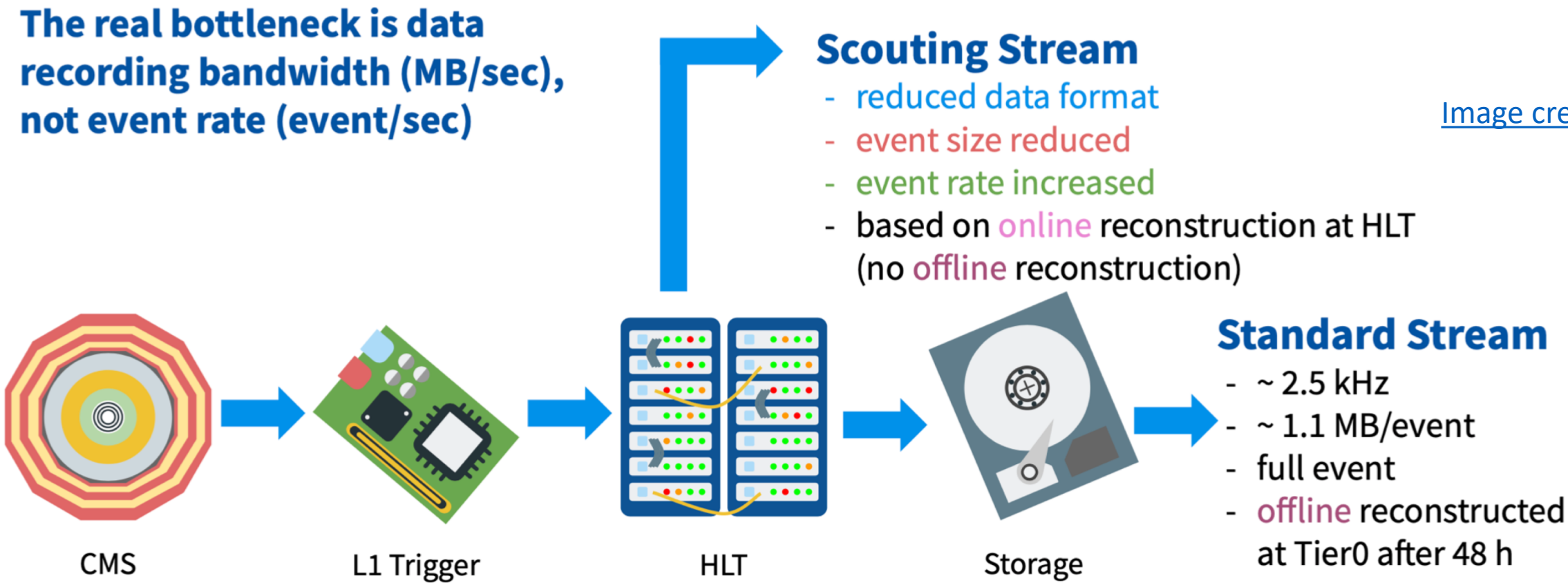
+ better tagger than Run2 (GloParT)



“Triggerless” analyses become possible

HLT Scouting

Online reconstruction → Store reduced particle information → Lower trigger threshold

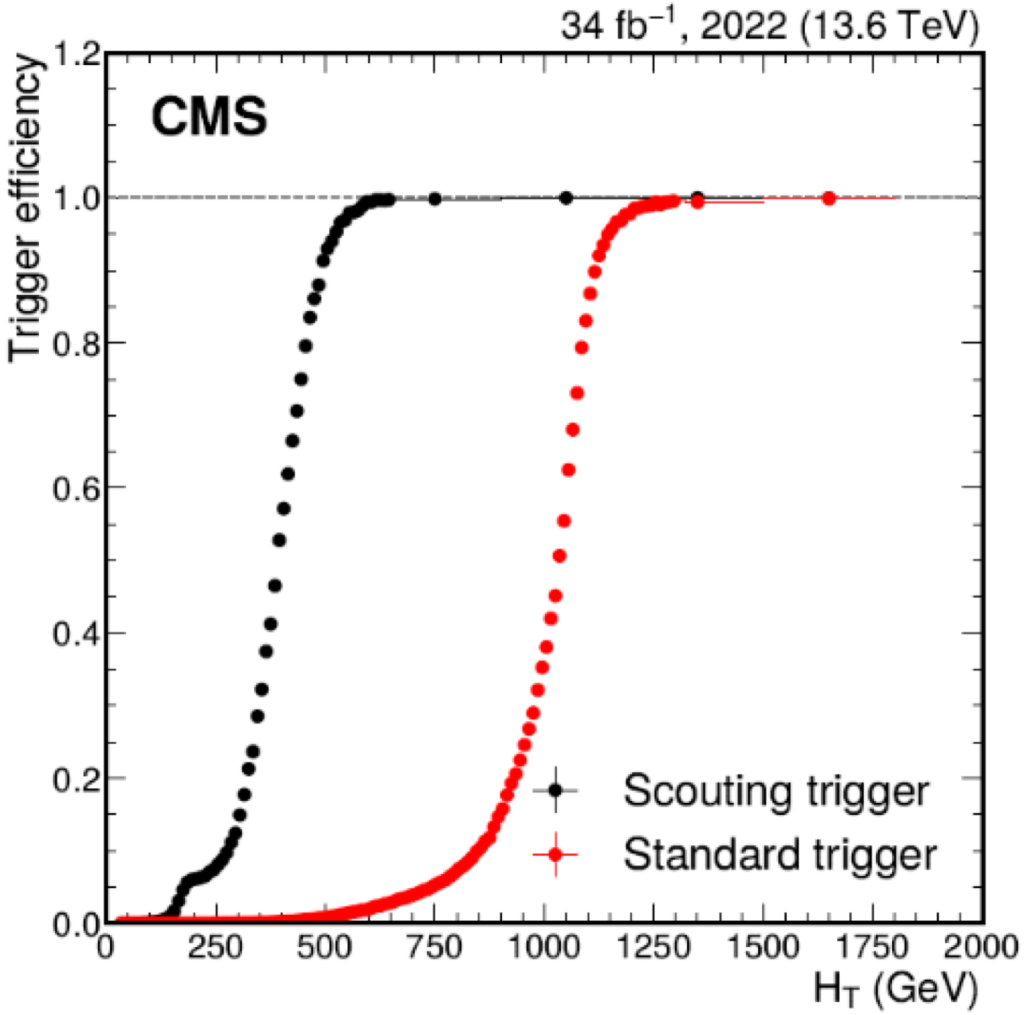


HLT Scouting in Run3

arxiv

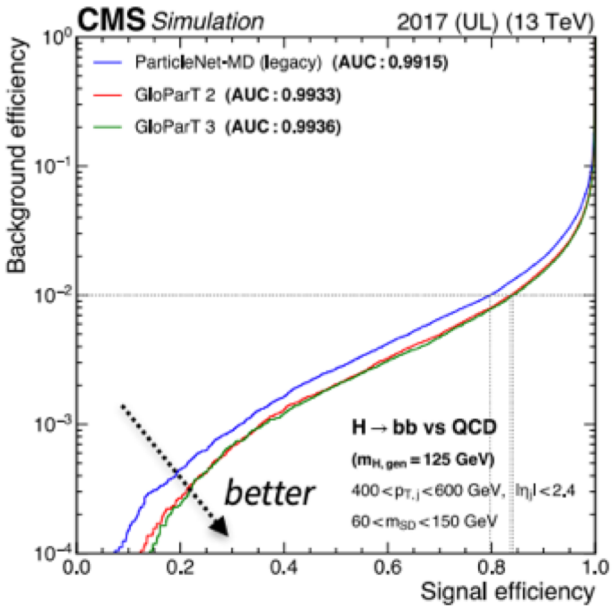
CMS scouting program is expanding for Run3

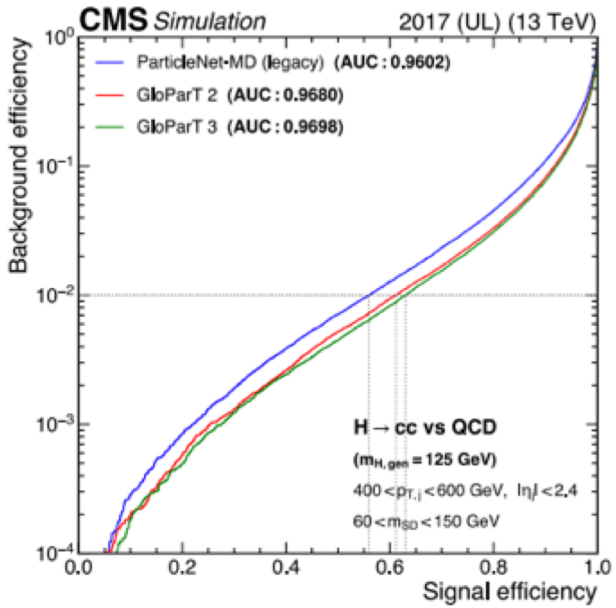
- Includes almost all physics objects
- Possibility of offline post-processing (jet re-clustering and tagging)
- Dedicated path for each objects: **scouting JetHT trigger**
- Much lower jet trigger threshold→ Sufficient data for searching
- Full tracking → good jet energy resolution

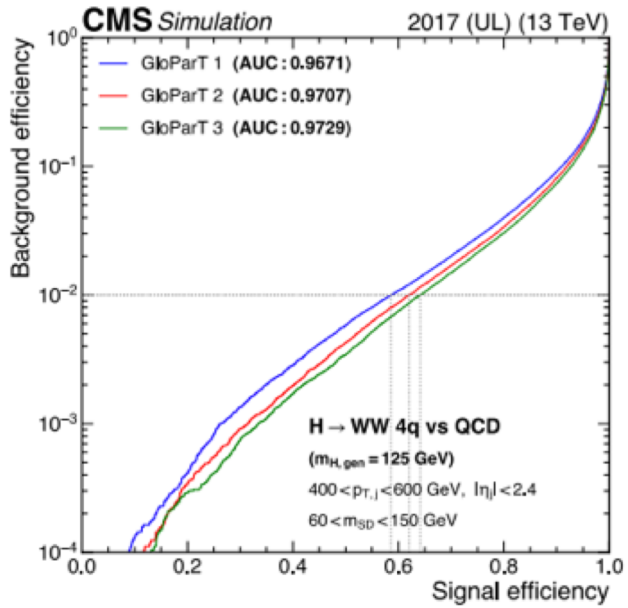


Global Particle Transformer-GloParT

- **transformer-based neural network** architecture developed for **jet tagging**
- Latest AK8 jet tagging in CMS
- **improvement** compared to other taggers (PartilceNet-MD)
- Application in di-Higgs/multi-V/top related analyses



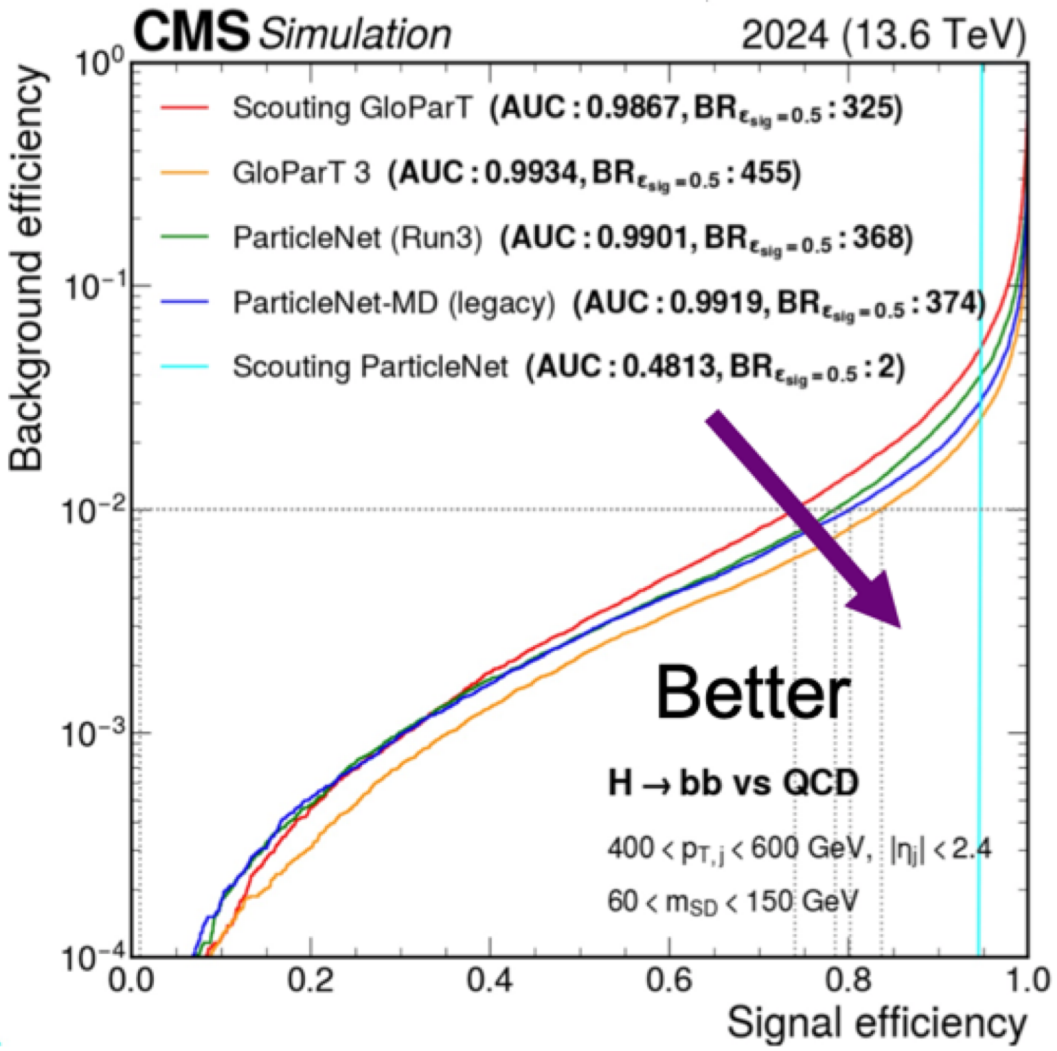




x1.5-2 better background rejection compared to early baselines

How to combine?

WORK in Progress

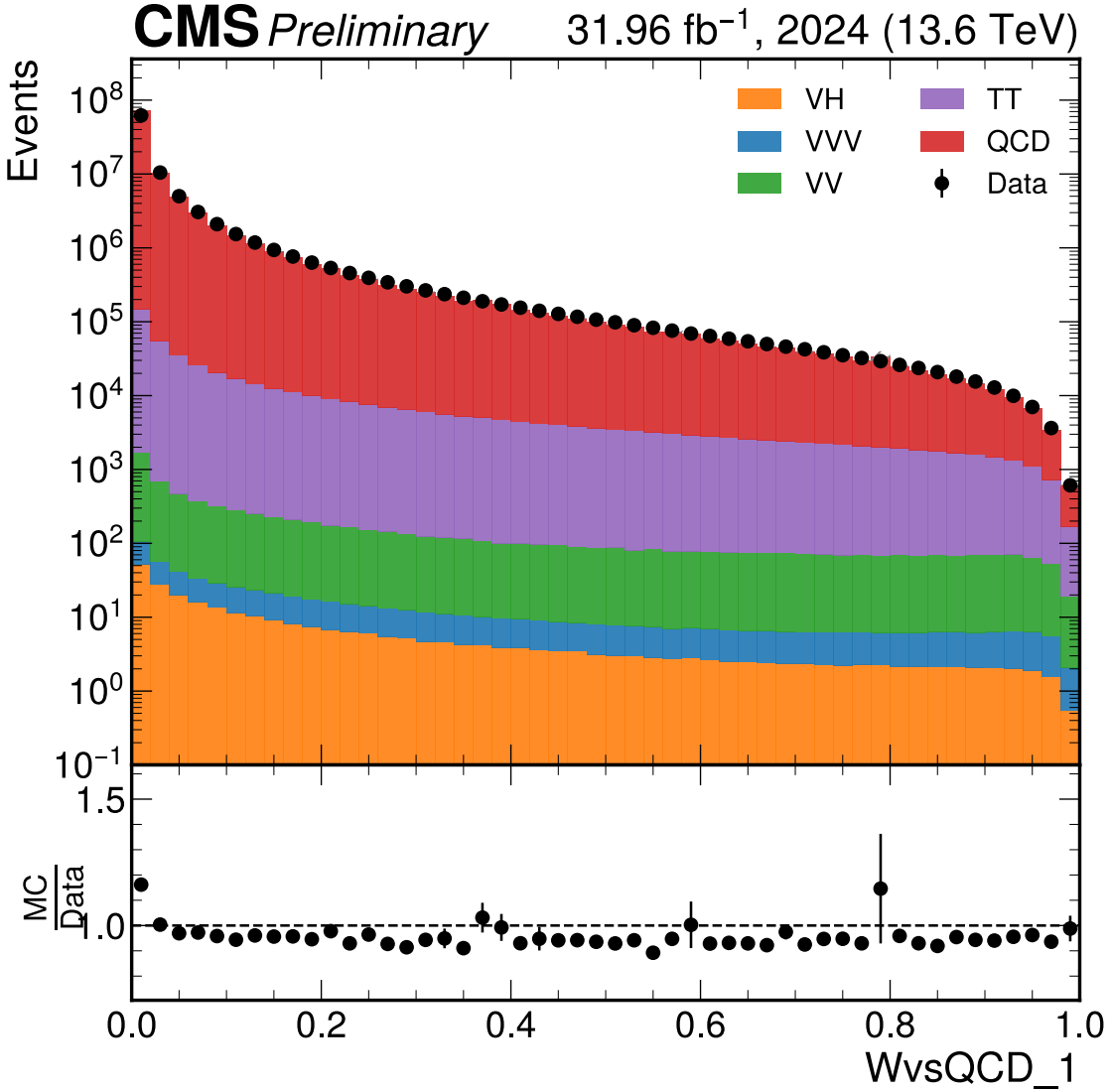


- **Retrain** and **fine tune** GloParT with scouting inputs: **Scouting GloParT**
- **Scouting Glo-ParT** has the advantage **of low trigger threshold** while maintaining **high tagging performance**
- Similar performance as GloParT, better than ParticleNet
- Scouting VVV was the starting point, but scouting GloParT can be used in other physic cases

Data – MC Validation

WORK in Progress

Region with 2 AK8 jets



Scouting Glo-ParT WvsQCD for 1st AK8 jet

Good agreement

Preselection region with events with 2 AK8

Summary - Outlook

- EFT search was presented in VVV final state with the full Run2 dataset
- we set bounds on 32 effective field theory operators
- **First bounds on dimension-6** operators in triboson processes
- Stringent bounds on some operators, cW
- New opportunities were presented with the use of **scouting dataset** and the **Glo-ParT tagger**
- Ongoing work to establish signal and control regions and to estimate the sensitivity – stay tuned!

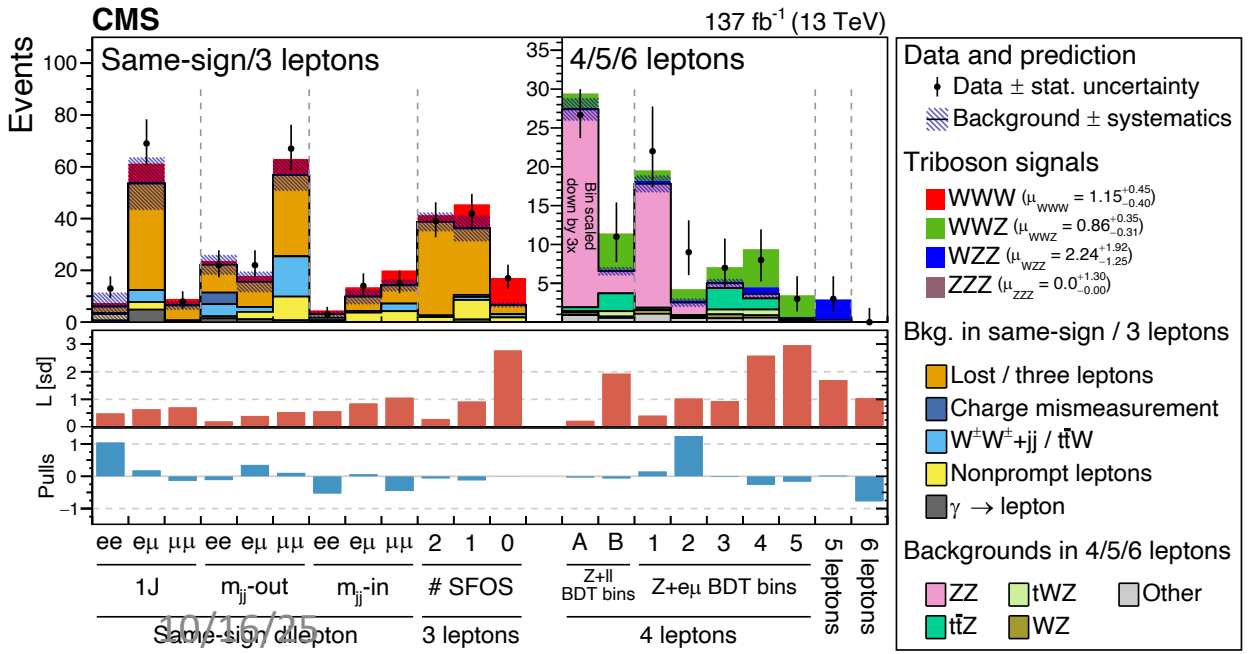
These efforts also tie directly into the broader HL-LHC program — **improving our understanding of electroweak interactions** at multi-TeV scales and **preparing for the precision era of SMEFT global analyses.**

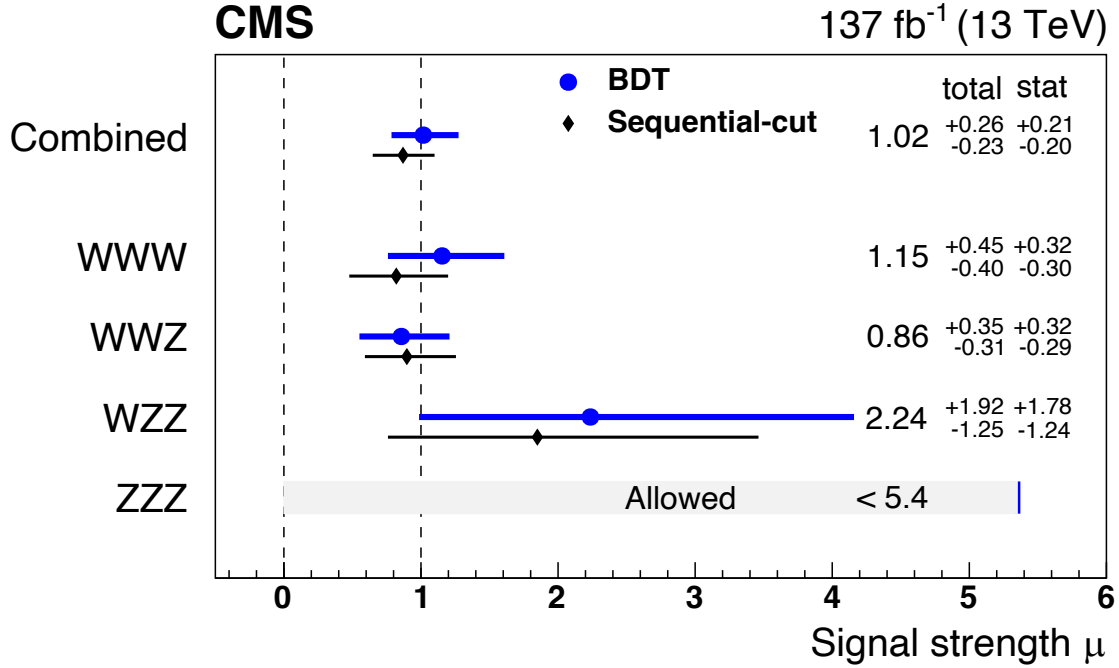
Back up

VVV analyses in CMS

Observation of the production of three massive gauge bosons at 13 TeV (arXiv:2006.11191)

- **5.7 σ**
- milestone in **SM high energy physics:** stringent test of SM in the EWK sector
- observation was achieved in the fully leptonic channel



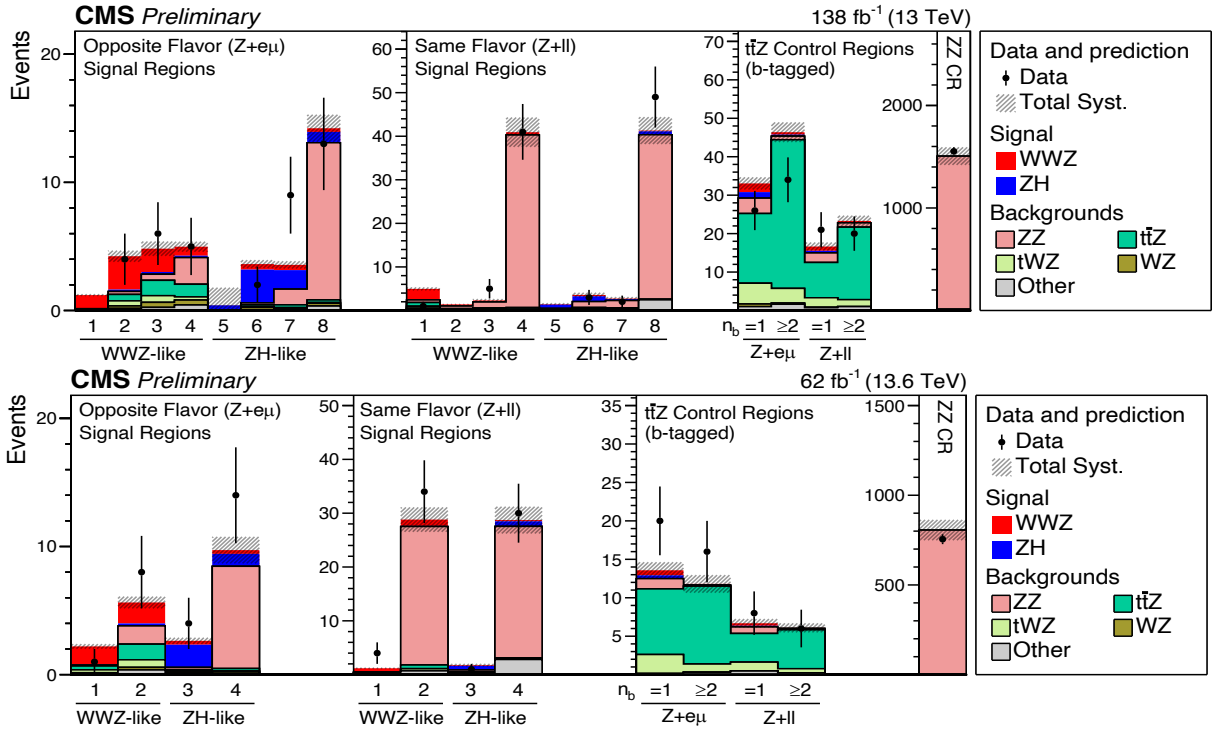


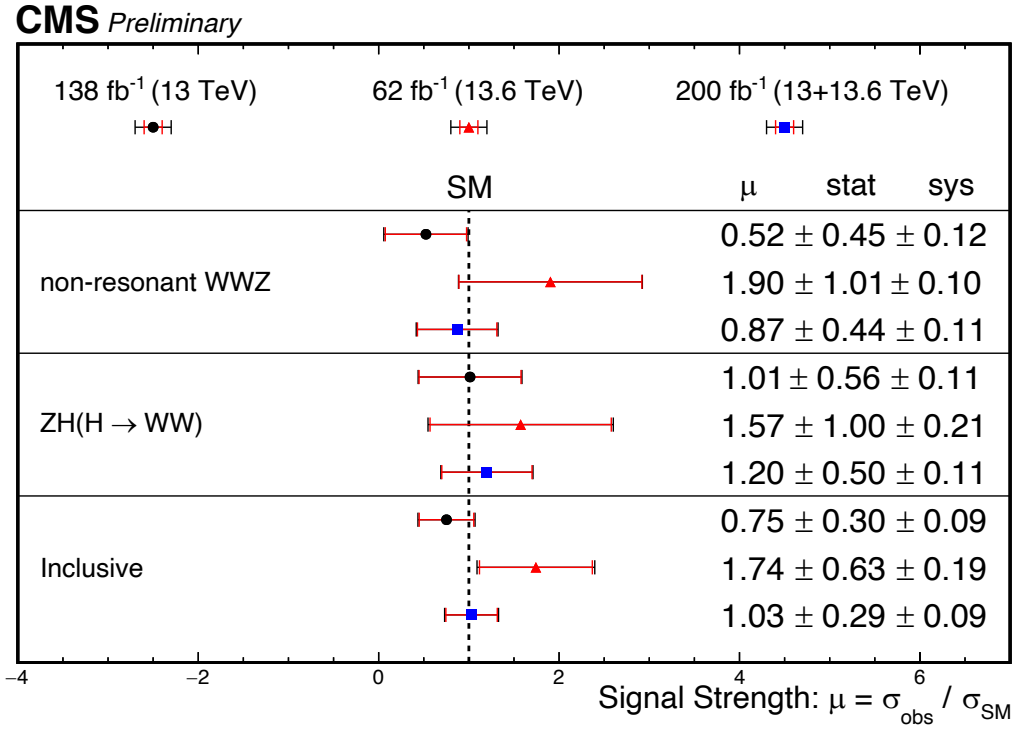
VVV analyses is CMS

[CMS-PAS-SMP-24-015]

- **First simultaneous measurement of WWZ and ZH**
- First measurement of any triboson process at 13.6 TeV
- WWZ : **significance 2.4 σ**

Era	Total	WWZ	ZH
Run 2	2.9 (4.4)	1.3 (3.1)	2.0 (2.6)
Run 3	3.8 (2.5)	2.5 (1.3)	2.5 (1.7)
Total	4.5 (5.0)	2.4 (3.3)	3.1 (3.1)





EFT search in VVZ production

arXiv:2412.15123

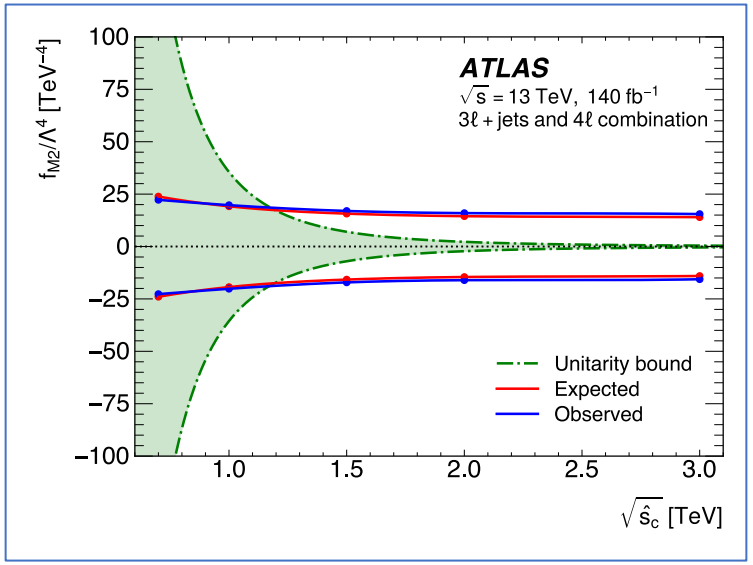
VVZ was observed with significance 6.4σ

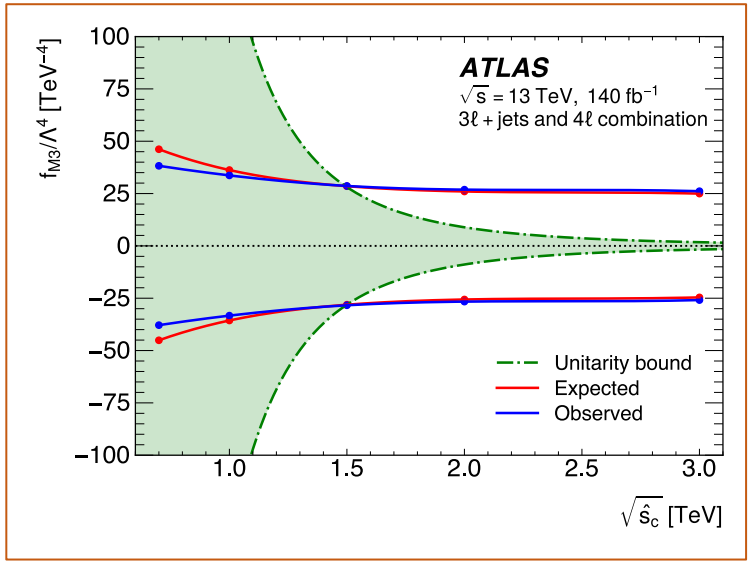
EFT interpretation of the results in the content of **Dim-8 operators** discriminants optimized to enhance the sensitivity to EFT contributions to the SM processes

Observed (expected) 95% CL limits on Wilson coefficients (TeV^{-4})			
Coefficient	3ℓ	4ℓ	Combination
f_{M2}/Λ^4	$[-15, 15]$ $([-17, 17])$	$[-23, 23]$ $([-18, 18])$	$[-15, 15]$ $([-14, 14])$
f_{M3}/Λ^4	$[-25, 25]$ $([-29, 30])$	$[-39, 40]$ $([-31, 31])$	$[-26, 26]$ $([-25, 25])$
f_{M4}/Λ^4	$[-13, 14]$ $([-16, 16])$	$[-17, 17]$ $([-16, 16])$	$[-11, 11]$ $([-13, 13])$
f_{M5}/Λ^4	$[-11, 11]$ $([-13, 13])$	$[-12, 12]$ $([-13, 13])$	$[-8.5, 8.7]$ $([-10, 10])$

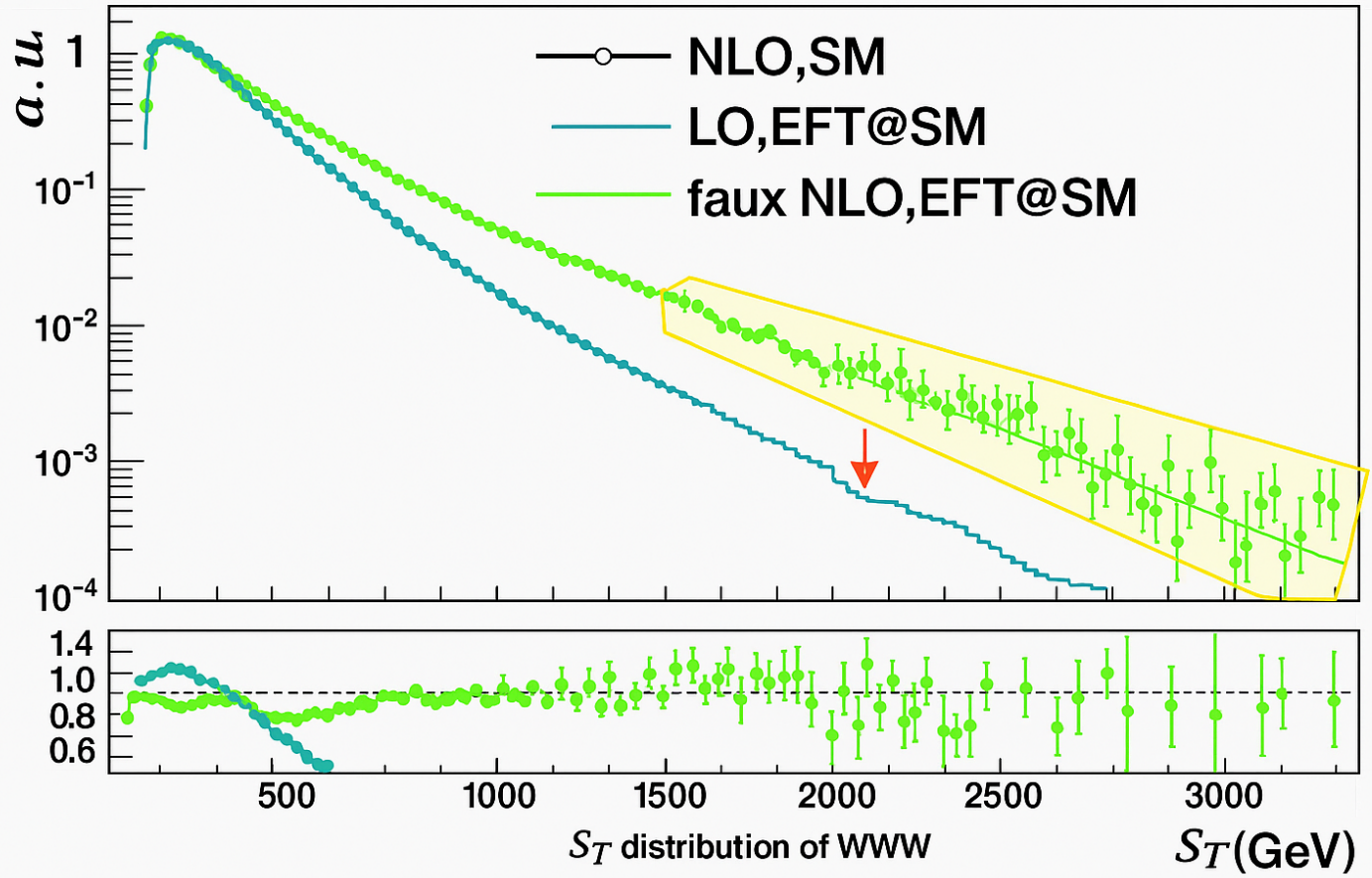
Clipping method to provide limits avoiding unitarity violation at high $\sqrt{\hat{s}}$

Coefficient	Expected limit [TeV^{-4}]	Exp. $\sqrt{\hat{s}_c}$ [TeV]	Observed limit [TeV^{-4}]	Obs. $\sqrt{\hat{s}_c}$ [TeV]
f_{M2}/Λ^4	$[-18, 17]$	1.2	$[-19, 19]$	1.2
f_{M3}/Λ^4	$[-28, 29]$	1.5	$[-28, 29]$	1.5
f_{M4}/Λ^4	$[-14, 14]$	1.6	$[-12, 12]$	1.7
f_{M5}/Λ^4	$[-11, 11]$	2.1	$[-9.1, 9.3]$	2.2





VVV + ≥1 parton EFT sample



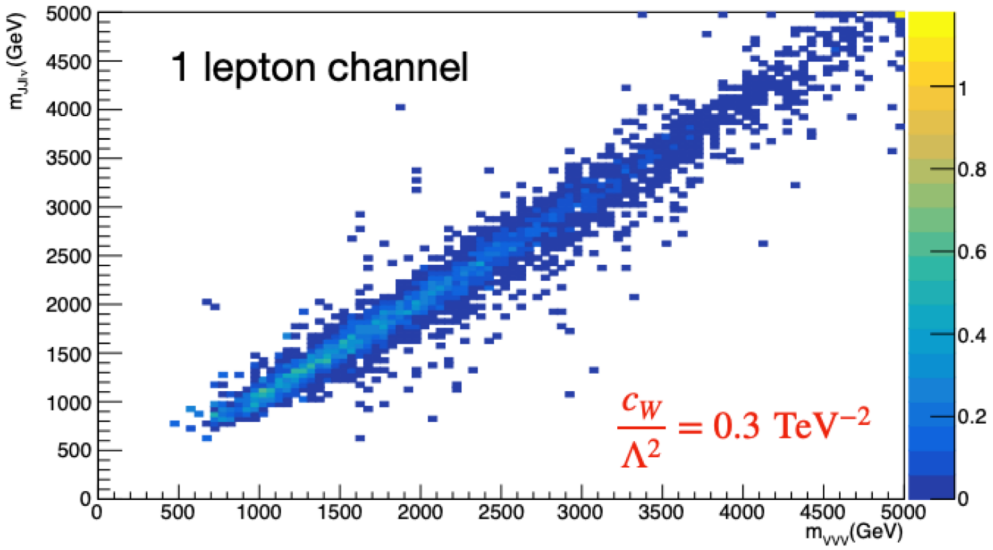
Challenge: LO EFT sample @ SM at tail vastly different from NLO SM

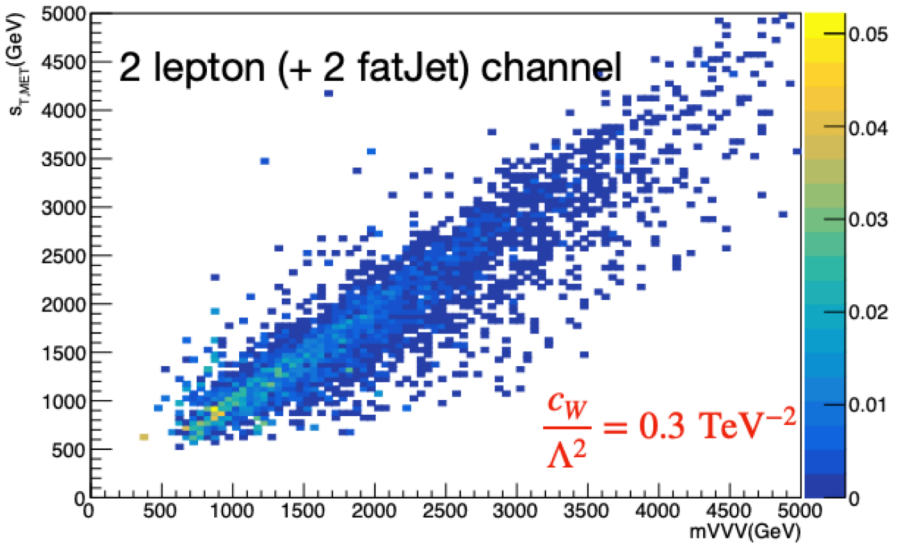
Privately produced samples with "faux-NLO" scheme (LO, LO+1jet)

VVV + ≥ 1 parton EFT sample @ SM agrees well with NLO SM

Variable of Interest

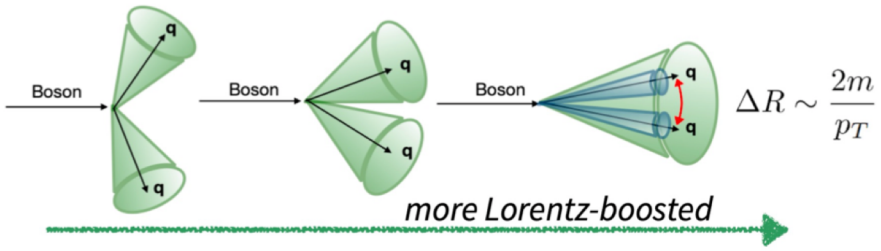
- Variable of interest constructed to be a proxy for the of the process
- Depends on channel topology
- correlation between generator-level and reconstructed variable of interest

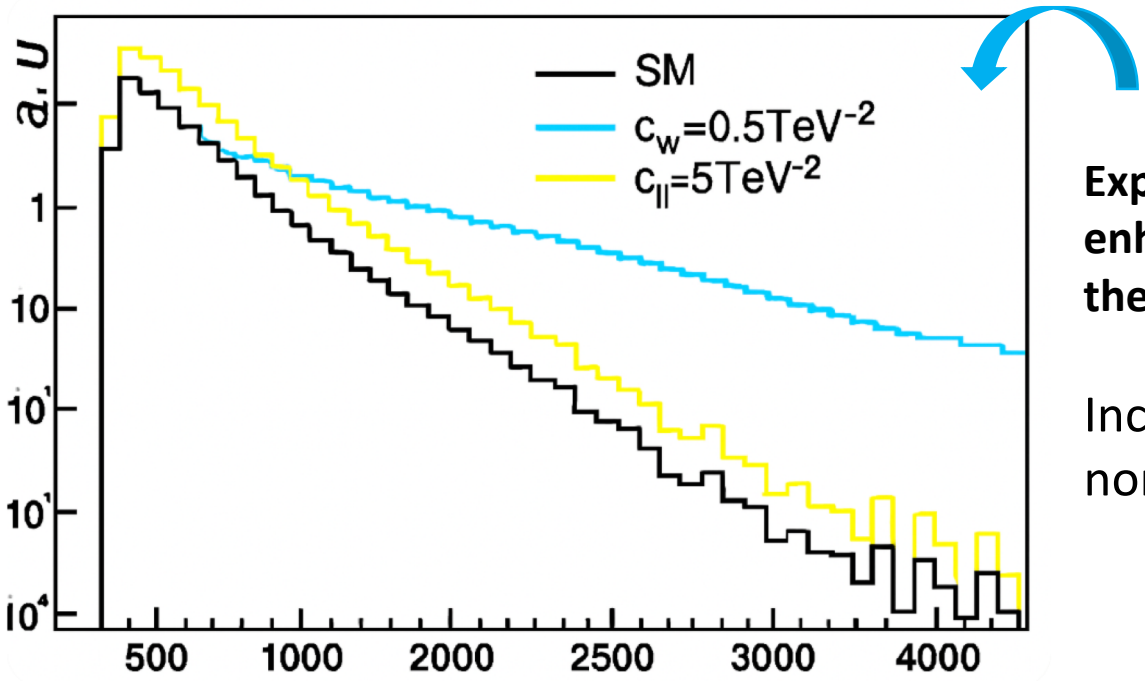




Boosted Topologies

- VVV searches so far used only leptonic signatures
- Using hadronic final states and **boosted jets (V tagged jet)**: More sensitive to **couplings beyond SM**





Expect enhancement in the tail

Increased normalization

Gen level m_{VVV} in WWW sample at different EFT points

Multi-boson Measurements

Test the SM at TeV scale:

Differential cross-section:

- measurement in validation of current models

Vector boson scattering/fusion (VBS/F):

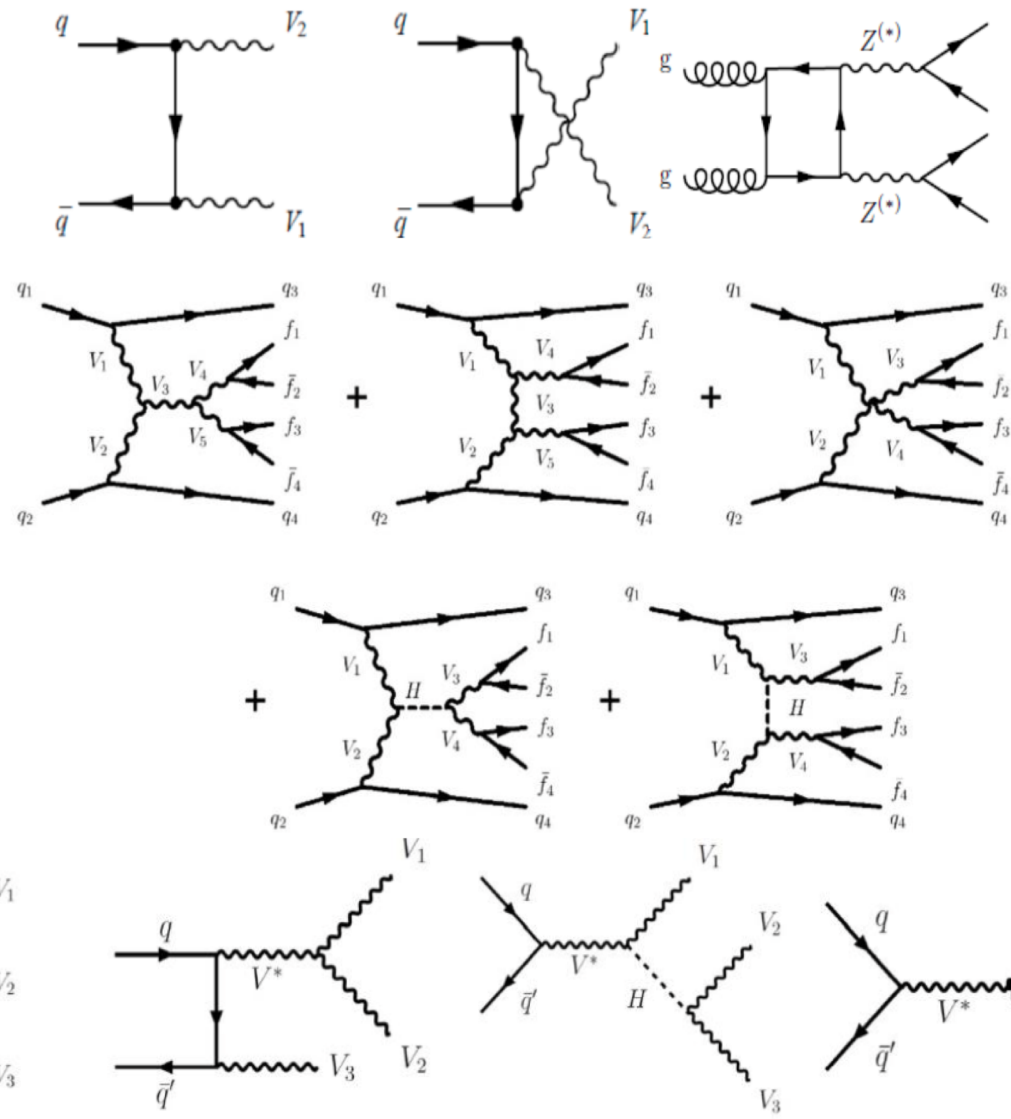
- processes **probe the mechanism of electroweak symmetry breaking**

Triple/Quatric Gauge Couplings (T/QGC):

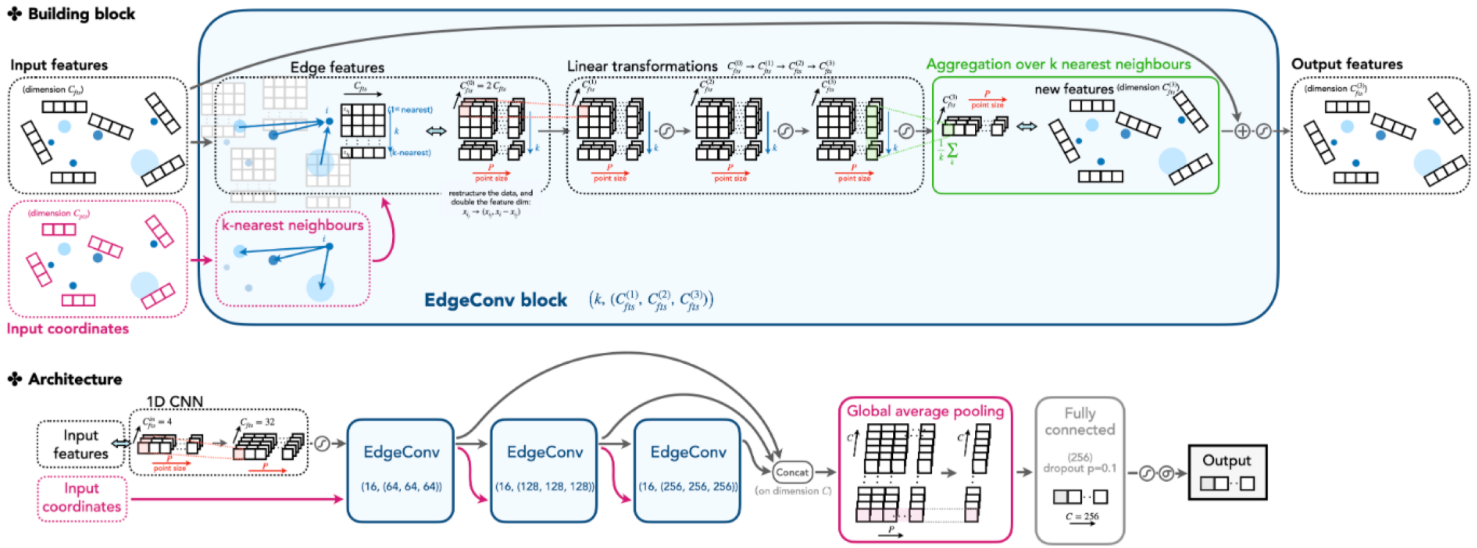
- search for anomalous couplings
- sensitive to new physics

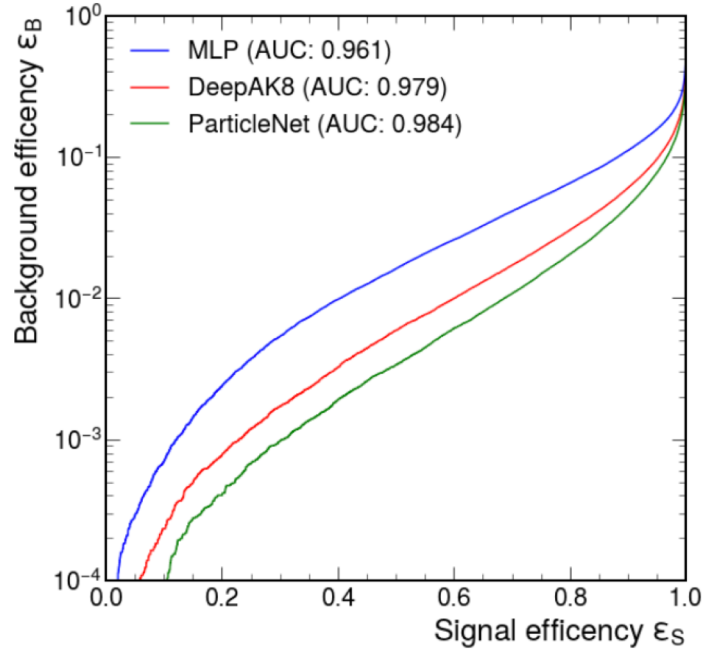
EFT interpretation:

$$\mathcal{L}_{\text{SMEFT}} \approx \mathcal{L}_{\text{SM}}^{(4)} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \sum_j \frac{c_j^{(8)}}{\Lambda^4} O_j^{(8)}$$



ParticleNet-MD

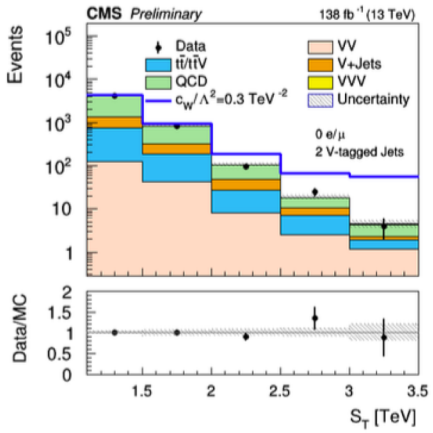




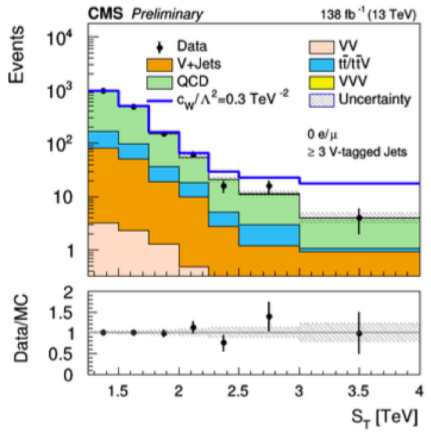
DP2020_002

ParticleNet-MD: A mass-decorrelated particle identification algorithm designed for identifying two-prong hadronic decays of highly Lorentz-boosted particles (e.g., X→bb, X→cc, X→qq). To achieve mass independence, the training uses a dedicated simulated sample containing Lorentz-boosted spin-o particles (X) with a flat mass spectrum between 15 to 250 GeV and subsequently decaying to a pair of quarks (X→bb, X→cc, X→qq) as the signal sample, and the QCD multijet sample as the background sample. Jets from the signal and background samples are also reweighted to yield flat distributions in both p_T and m_{SD} for the training. The same inputs and network architecture as the ParticleNet algorithm are used.

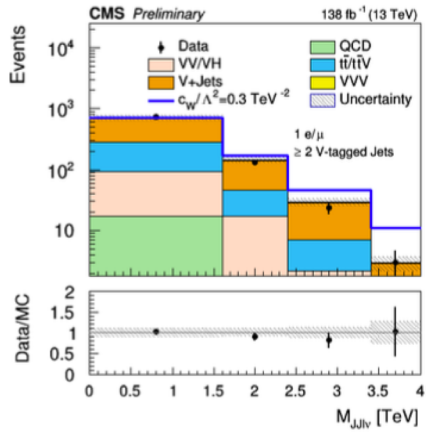
Signal region yields



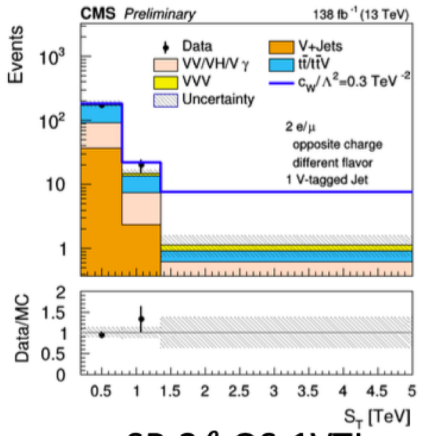
SR-0ℓ-2VTJ



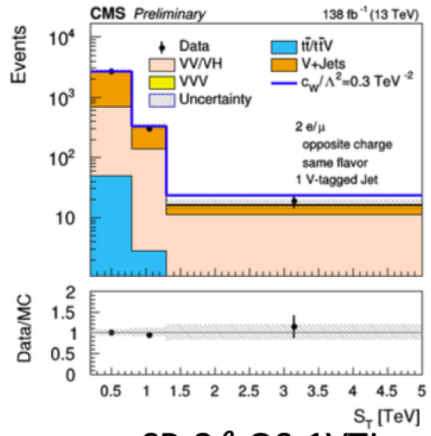
SR-0ℓ-3VTJ



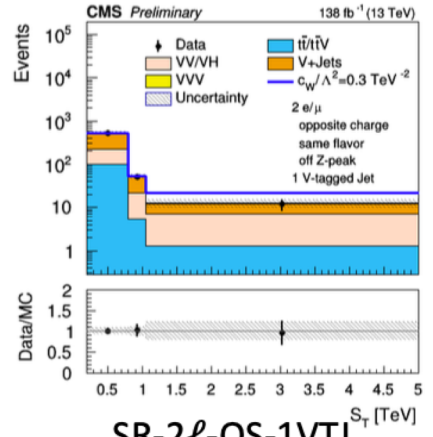
SR-1ℓ-2VTJ



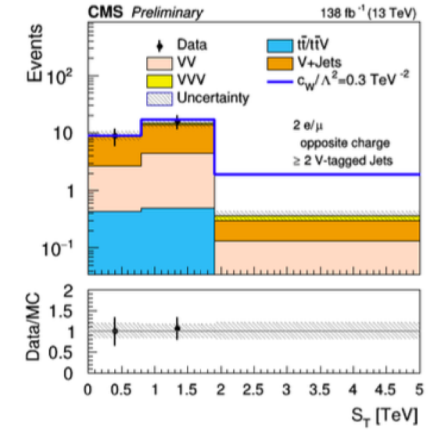
SR-2ℓ-OS-1VTJ different flavor



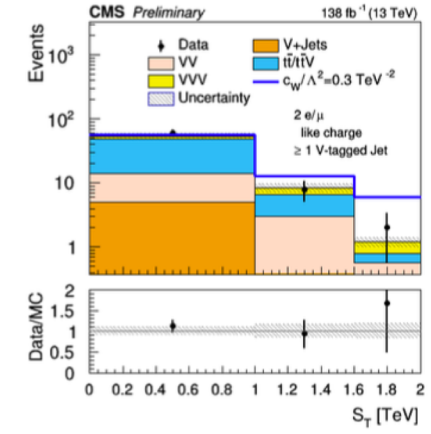
SR-2ℓ-OS-1VTJ same flavor Z



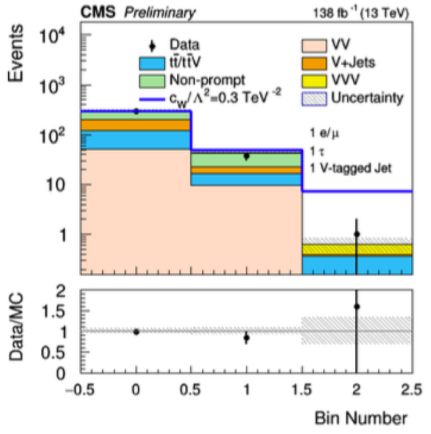
SR-2ℓ-OS-1VTJ same flavor off Z



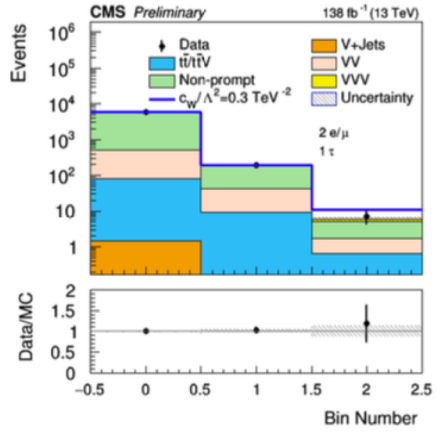
SR-2ℓ-OS-2VTJ



SR-2ℓ-SS-1VTJ



SR-1ℓ-1τ_h-1VTJ



SR-2ℓ-1τ_h-0VTJ

Systematic Uncertainties

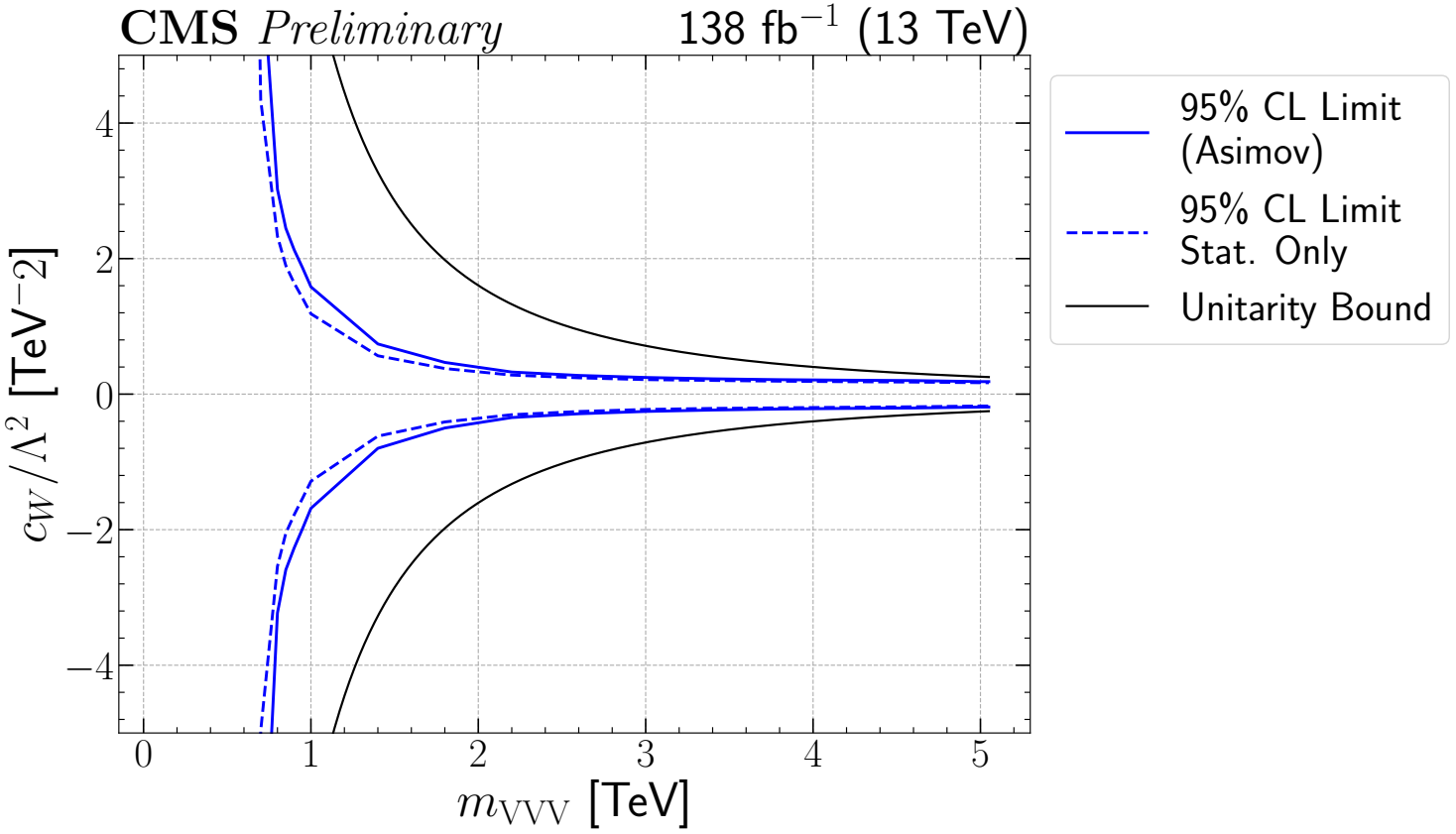
Source	Correlation between channels	POG Recommended	Uncertainty on $c_W = 0.3$ (last bin)
Luminosity	Fully-correlated across all channels	✓	1.6%
Pile-up weight	Fully-correlated across all channels	✓	~1%
Prefire weight	Fully-correlated across all channels	✓	~0.5%
Trigger weight	Fully-correlated across all channels with same trigger set	✓	~1-5%
e/μ SF	50% correlated across all channels(except 0 lepton)	✓	~2%/~0.3%
τ SF	Fully-correlated across all τ channels	✓	~0.6%
b-tag SF	Fully-correlated across all channels	✓	~3%
FatJet SF	Fully-correlated across all channels and WPs	"true" FatJet SF from POG "fake" FatJet SF approved by POG	6-10%
JES	Fully-correlated across all channels	✓	~1-4%
JER	Fully-correlated across all channels	✓	~1%
QCD scale	Fully-correlated across all channels	✓	~10%
PDF	Fully-correlated across all channels	✓	~20%
α_S	Fully-correlated across all channels	✓	~1%

Clipping for dim6 dim8 operators

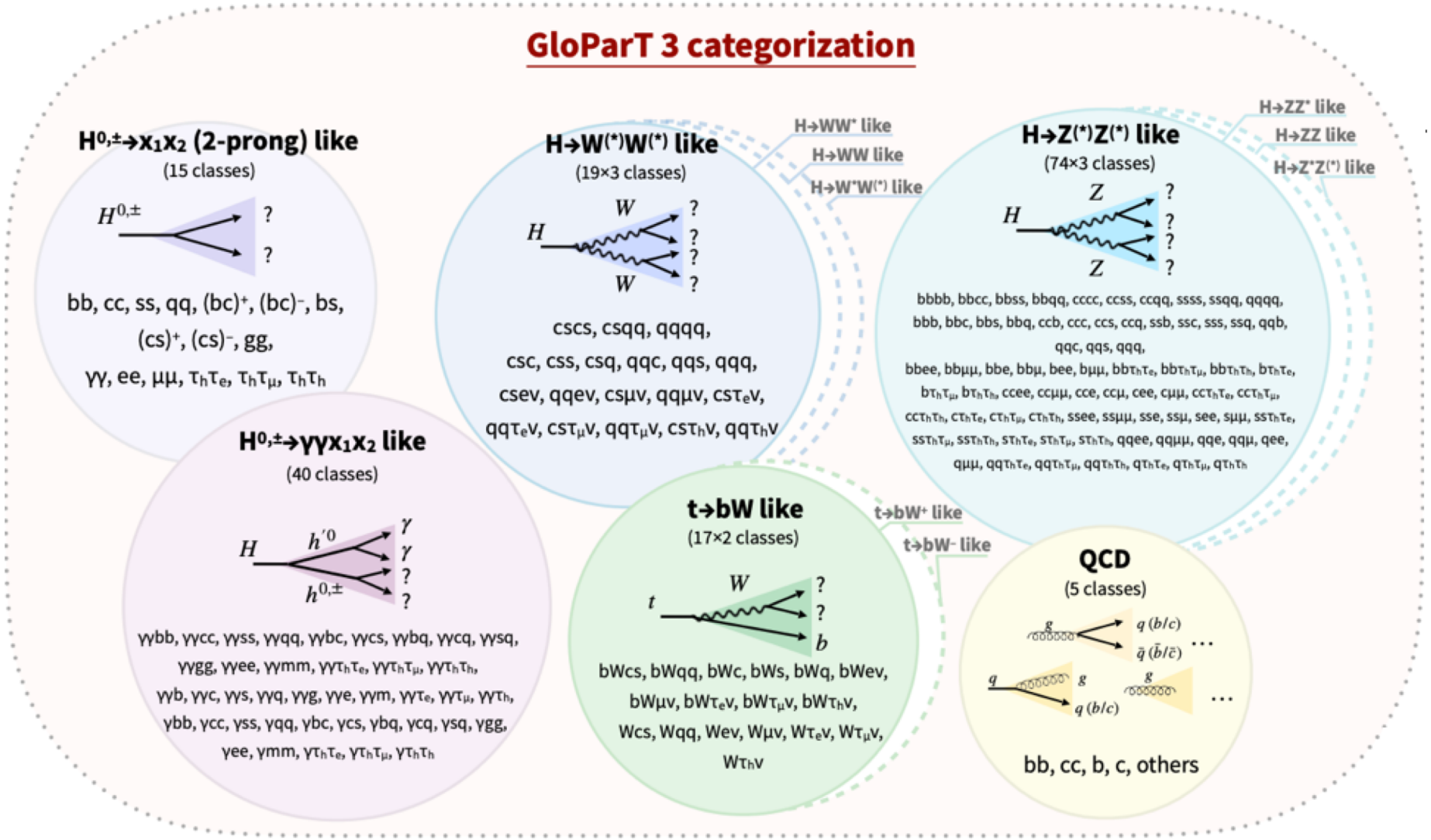
WORK in Progress

- unitarity bounds from theoretical calculation: PhysRevD.101.113003, arXiv:2309.14079
- **blue curves** are generated by imposing a hard cut-off in **generator level mVVV**
- imposing this cut-off and inspecting where(/whether) our experimental limits ever obey unitarity (**black lines**)

Obey the unitarity constrain



GloParTv3

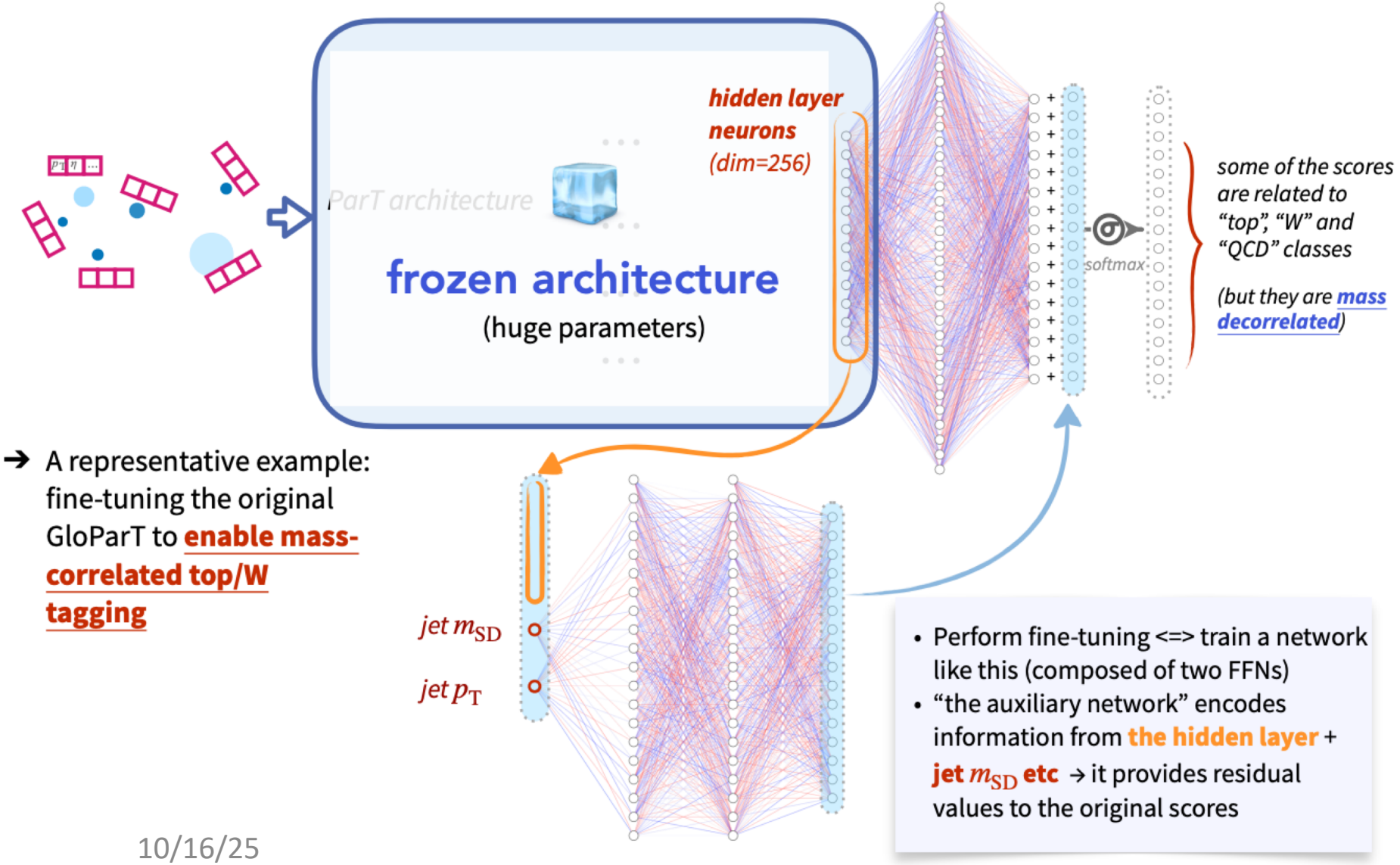


GloParTv3 has 750 raw output nodes (374 final states!)

- trained as a mass decorrelated model

[Image credit]

fine-tuning solution for top/W tagging



➔ A representative example: fine-tuning the original GloParT to **enable mass-correlated top/W tagging**

- Perform fine-tuning <=> train a network like this (composed of two FFNs)
- "the auxiliary network" encodes information from **the hidden layer** + **jet m_{SD} etc** → it provides residual values to the original scores

From Congiao's talk in CMS week

How to combine

Tagger:
Jet Tagging Glo-ParT

Data stream
Scouting Dataset

- **Re-train** a special version of Glo-ParT using scouting PF candidate features

- **Fine-tune** this model on a scouting Ak8 jet dataset

(still on the full RECO AK8 jet dataset)

- Lower jet trigger threshold
- Limited PF candidates features



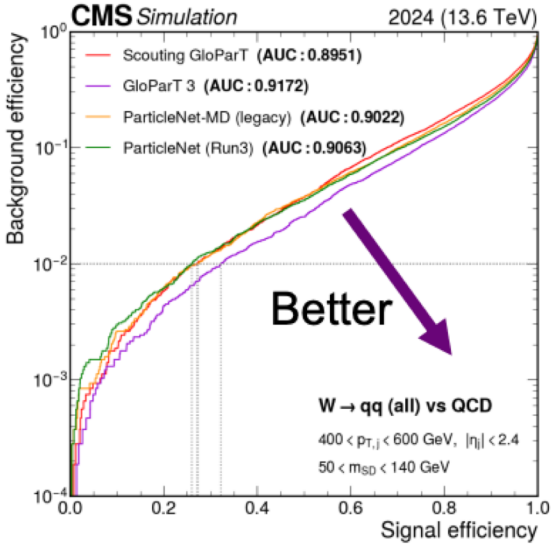
Scouting Glo-ParT

Performance for W(qq) and Z(qq) scores

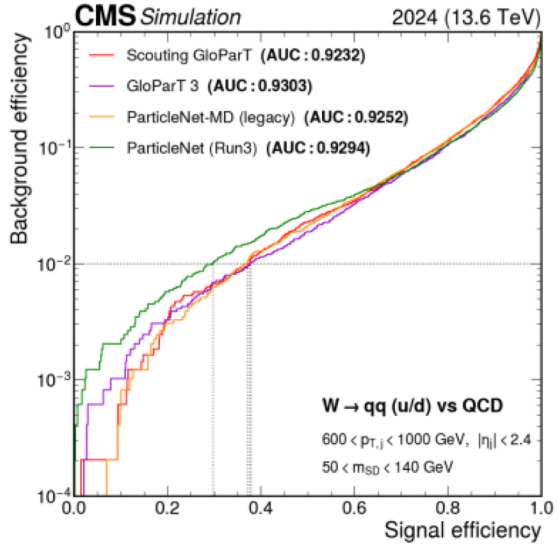
Similar performance with GloParT

- GloParT 3, ParticleNet (Run3/legacy): **full RECO inputs**
- Scouting GloParT: **Scouting inputs**

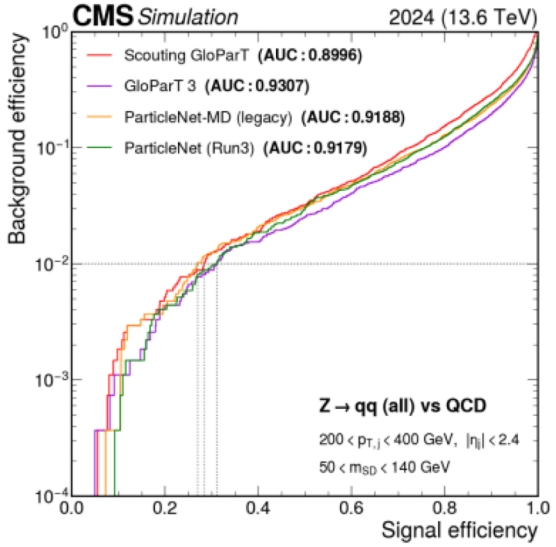
$$\text{score} = \frac{\text{score}_{\text{sig}}}{\text{score}_{\text{sig}} + \text{score}_{\text{bkg}}}$$



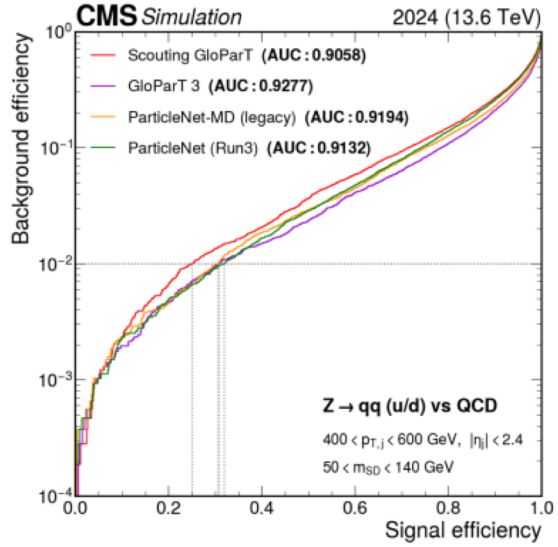
400-600 GeV



600-1000 GeV



200-400 GeV

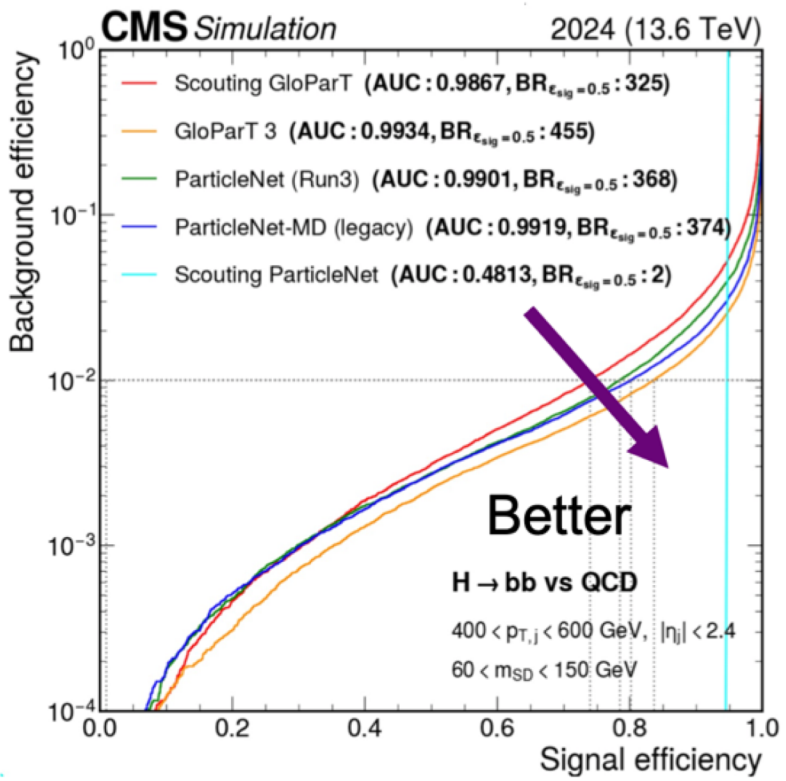


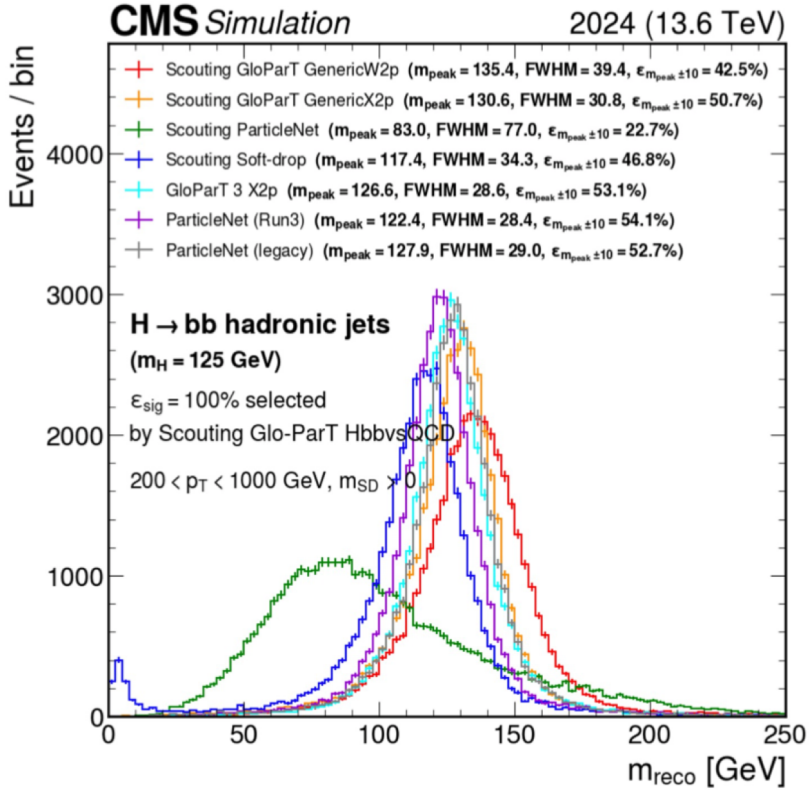
400-600 GeV

Scouting GloParT in Run3

Performance similar to GloParT

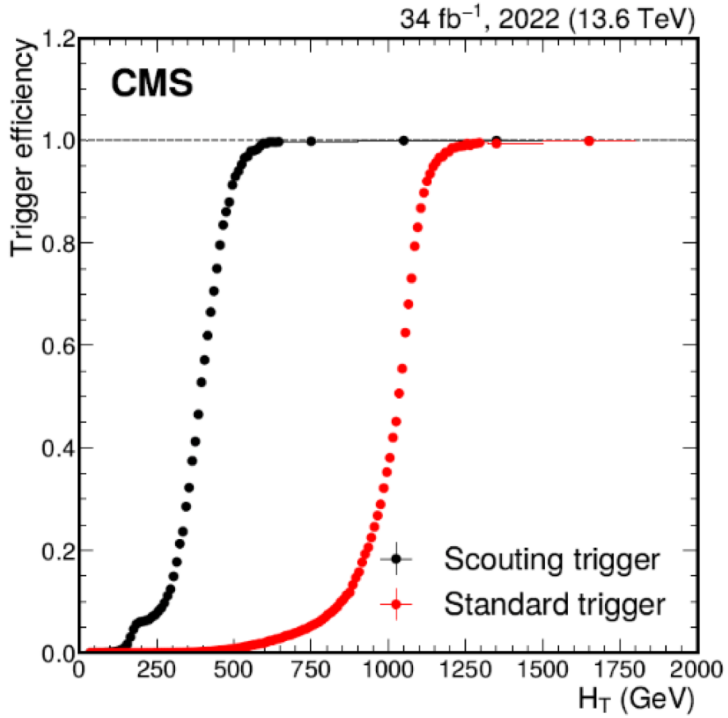
- Tagging: AUC 5% worse than GloParT3
- Mass regression: resolution <10% worse than Glo-ParT3



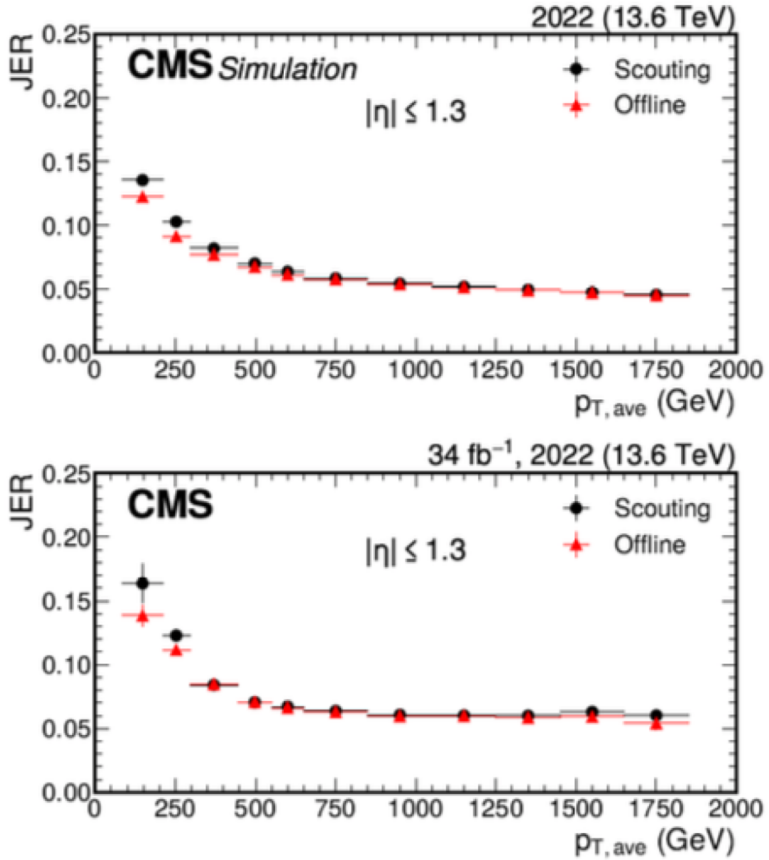


HLT scouting in Run3

- Much lower jet trigger threshold→ Sufficient data for searching
- More PF candidate information→ Enable offline jet cluster, jet tagging, etc.
- Full tracking → Better PF, jet resolutions



Scouting and standard jet trigger efficiency

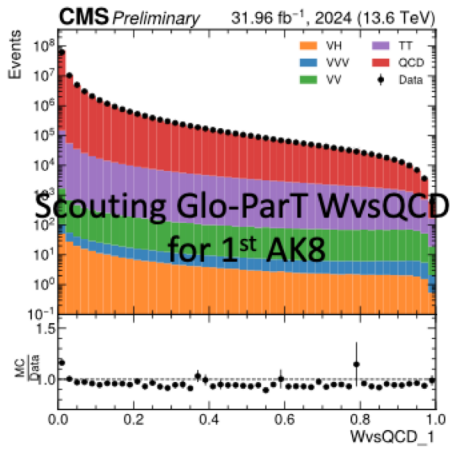


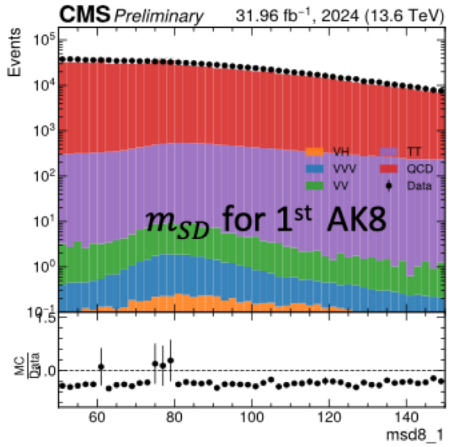
Scouting and standard jet energy resolution

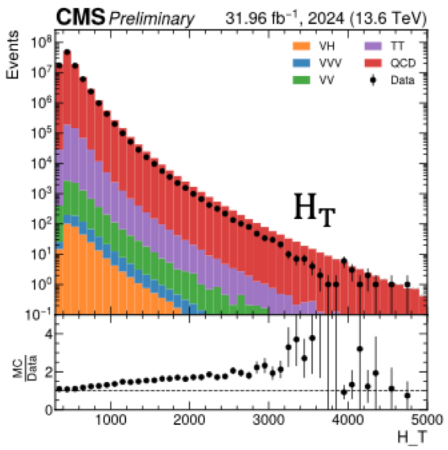
CMS-EXO-23-007

Data – MC Validation

Region with 2 AK8 jets



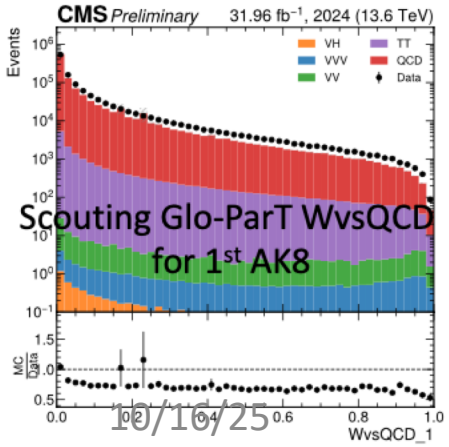


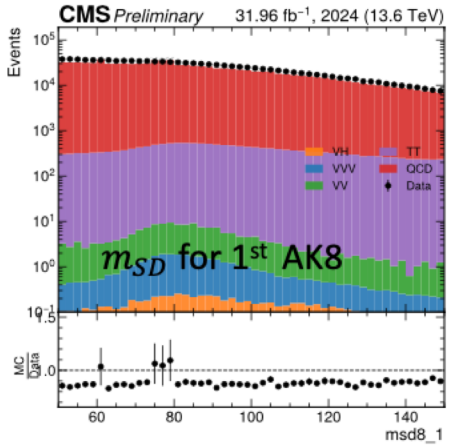


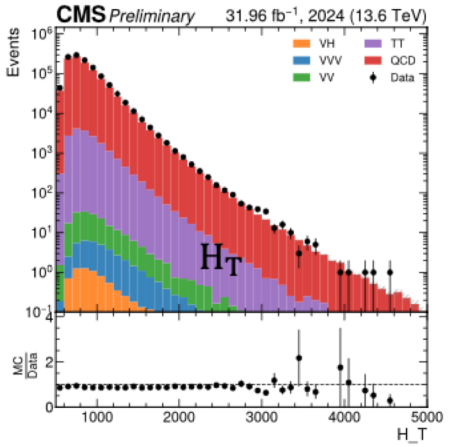
Good agreement

Preselection region with events with 2 AK8 jets and 3 or more AK8 jets

Region with ≥ 3 AK8 jets







Ongoing work to establish signal And control regions and to estimate the sensitivity.

Results on dim6

Wilson coefficient	Freeze other WCs 95% bounds $[^{-2}]$ Observed	Freeze other WCs 95% bounds $[^{-2}]$ Expected	Profile other WCs 95% bounds $[^{-2}]$ Observed	Profile other WCs 95% bounds $[^{-2}]$ Expected
c_w/Λ^2	$[-0.13, 0.12]$	$[-0.12, 0.12]$	$[-0.11, 0.11]$	$[-0.13, 0.13]$
c_{Hq3}/Λ^2	$[-0.24, 0.21]$	$[-0.23, 0.20]$	$[-0.40, 0.29]$	$[-0.30, 0.26]$
c_{Hq1}/Λ^2	$[-0.34, 0.34]$	$[-0.32, 0.32]$	$[-0.39, 0.40]$	$[-0.35, 0.34]$
c_{Hqu}/Λ^2	$[-0.60, 0.59]$	$[-0.61, 0.59]$	$[-0.84, 0.67]$	$[-0.75, 0.73]$
c_{Hqd}/Λ^2	$[-0.79, 0.79]$	$[-0.79, 0.79]$	$[-0.75, 0.93]$	$[-0.87, 0.89]$
c_{HW}/Λ^2	$[-1.60, 1.55]$	$[-1.63, 1.55]$	$[-1.97, 3.0]$	$[-2.1, 2.4]$
c_{HWB}/Λ^2	$[-5.2, 5.0]$	$[-5.5, 5.2]$	$[-7.2, 9.2]$	$[-7.8, 7.7]$
c_{Hl3}/Λ^2	$[-3.7, 1.16] \cup [9.1, 17]$	$[-3.4, 15]$	$[-16, 29]$	$[-12, 26]$
c_{HB}/Λ^2	$[-11, 11]$	$[-12, 12]$	$[-8.3, 8.6]$	$[-13, 13]$
c_{ll1}/Λ^2	$[-32, -13] \cup [-9.1, 10]$	$[-30, 6.9]$	$[-48, 26]$	$[-44, 22]$
c_H/Λ^2	$[-76, 69]$	$[-69, 61]$	$[-74, 75]$	$[-61, 60]$
c_{HDD}/Λ^2	$[-114, 71]$	$[-108, 68]$	$[-116, 67]$	$[-125, 74]$

First dim6 limits on VVV process

- Good sensitivity in many operators
- Results are compatible with the SM
- **Stringiest bounds in Cw operator**

Wilson coefficient	Freeze other WCs Measurement $[^{-2}]$ Observed	Profile other WCs Measurement $[^{-2}]$ Observed
c_w/Λ^2	$0.03^{+0.053}_{-0.11}$	$0.001^{+0.056}_{-0.054}$
c_{Hq3}/Λ^2	$0.05^{+0.085}_{-0.21}$	$-0.14^{+0.31}_{-0.12}$
c_{Hq1}/Λ^2	$0.10^{+0.12}_{-0.33}$	$-0.17^{+0.13}_{-0.10}$ or $0.19^{+0.099}_{-0.15}$
c_{Hqu}/Λ^2	$0.09^{+0.29}_{-0.47}$	$-0.02^{+0.32}_{-0.42}$
c_{Hqd}/Λ^2	$0.10^{+0.39}_{-0.59}$	$0.01^{+0.46}_{-0.36}$
c_{HW}/Λ^2	$0.17^{+0.84}_{-1.22}$	$0.52^{+1.17}_{-1.58}$
c_{HWB}/Λ^2	$0.5^{+2.7}_{-3.8}$	$1.6^{+3.7}_{-4.4}$
c_{Hl3}/Λ^2	$14.4^{+0.87}_{-2.7}$	$-5.9^{+5.0}_{-3.5}$ or $16.1^{+5.5}_{-7.3}$
c_{HB}/Λ^2	$0.7^{+6.4}_{-7.8}$	$0.7^{+3.7}_{-4.8}$
c_{ll1}/Λ^2	$-25.4^{+4.2}_{-3.7}$ or $5.1^{+1.58}_{-5.8}$	$-36^{+14}_{-6.3}$ or $12^{+7.5}_{-11}$
c_H/Λ^2	29^{+23}_{-85}	32^{+23}_{-87}
c_{HDD}/Λ^2	-58^{+104}_{-32}	3^{+38}_{-77}

Results on dim8

Wilson coefficient	95% CL Bounds $[^{-4}]$		Measurement $[^{-4}]$
	Observed	Expected	Observed
$f_{T,0}/\Lambda^4$	$[-0.57, 0.63]$	$[-0.48, 0.54]$	$-0.05^{+0.34}_{-0.28}$
$f_{T,1}/\Lambda^4$	$[-0.63, 0.70]$	$[-0.54, 0.62]$	$0.05^{+0.26}_{-0.41}$
$f_{T,3}/\Lambda^4$	$[-1.22, 1.32]$	$[-1.04, 1.18]$	$0.10^{+0.48}_{-0.82}$
$f_{T,2}/\Lambda^4$	$[-1.29, 1.39]$	$[-1.10, 1.24]$	$0.10^{+0.50}_{-0.85}$
$f_{M,0}/\Lambda^4$	$[-3.8, 4.0]$	$[-2.8, 3.2]$	$-0.4^{+2.9}_{-1.76}$
$f_{T,5}/\Lambda^4$	$[-4.0, 3.9]$	$[-3.1, 3.0]$	$0.0^{+2.6}_{-2.7}$
$f_{T,6}/\Lambda^4$	$[-4.9, 4.8]$	$[-3.8, 3.7]$	$0.0^{+3.2}_{-3.3}$
$f_{M,1}/\Lambda^4$	$[-6.7, 6.4]$	$[-5.0, 5.1]$	$-1.0^{+4.7}_{-3.0}$
$f_{T,4}/\Lambda^4$	$[-9.2, 9.0]$	$[-7.1, 7.0]$	$0.0^{+6.0}_{-6.0}$
$f_{T,7}/\Lambda^4$	$[-10, 10]$	$[-7.9, 7.7]$	$0.1^{+6.8}_{-7.1}$
$f_{M,7}/\Lambda^4$	$[-10, 11]$	$[-8.4, 9.2]$	$-1.0^{+6.7}_{-4.4}$
$f_{M,5}/\Lambda^4$	$[-11, 11]$	$[-9.0, 9.0]$	$0.0^{+7.3}_{-7.0}$
$f_{T,8}/\Lambda^4$	$[-11, 12]$	$[-7.3, 7.3]$	$5^{+3.1}_{-13}$
$f_{M,4}/\Lambda^4$	$[-13, 13]$	$[-11, 11]$	$0.0^{+8.7}_{-8.4}$
$f_{M,2}/\Lambda^4$	$[-14, 14]$	$[-11, 11]$	$0.0^{+9.7}_{-9.7}$
$f_{T,9}/\Lambda^4$	$[-22, 23]$	$[-14, 14]$	$11^{+5.0}_{-27}$
$f_{M,3}/\Lambda^4$	$[-23, 23]$	$[-18, 18]$	0^{+16}_{-15}
$f_{S,1}/\Lambda^4$	$[-26, 26]$	$[-24, 25]$	-2^{+16}_{-13}
$f_{S,0}/\Lambda^4$	$[-38, 38]$	$[-35, 35]$	-2^{+22}_{-20}
$f_{S,2}/\Lambda^4$	$[-38, 39]$	$[-36, 36]$	-2^{+22}_{-20}

Compatible with the SM

Good sensitivity on FT0 operator

SMEFT analyses on VBS + Diboson ref

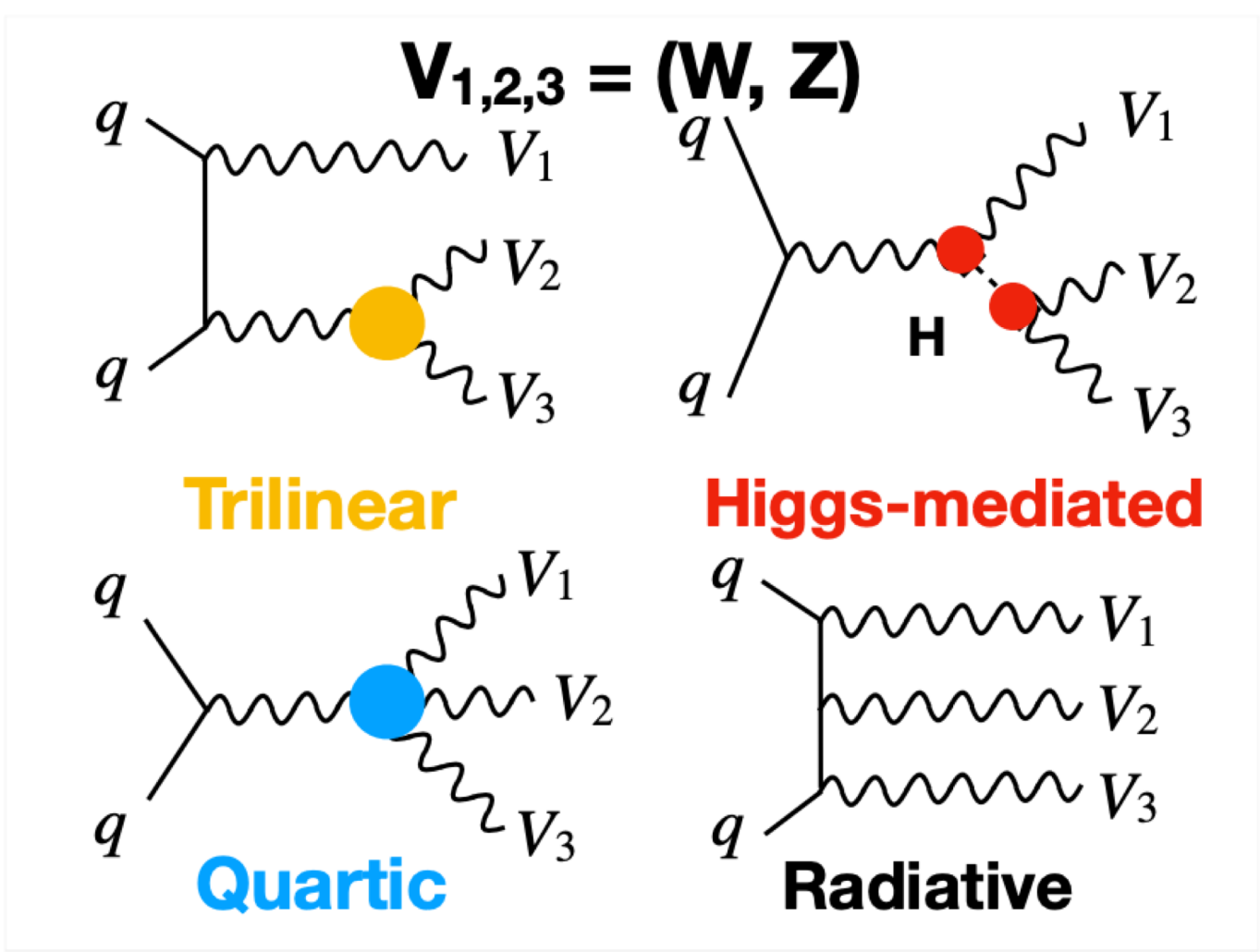
Class	Coefficient	VBS + diboson (marginalised)	VBS + diboson (individual)	Diboson-only (marginalised)
Purely bosonic	$\bar{c}_W$	[−0.13, 0.14]	[−0.001, 0.13]	[−0.20, 0.11]
(CP-even)	$\bar{c}_{\varphi W}$	[−0.55, 1.4]	[−0.048, 0.91]	[−0.97, 2.1]
	$\bar{c}_{\varphi B}$	[−11, 8.8]	[−0.62, 0.69]	–
	$\bar{c}_{\varphi WB}$	[−0.13, 0.44]	[−0.050, 0.071]	[−0.20, 0.44]
	$\bar{c}_{\varphi D}$	[−0.93, 0.32]	[−0.21, 0.08]	[−1.09, 0.26]
Purely bosonic	$\bar{c}_{\widetilde{W}}$	[−0.35, 0.57]	[−0.008, 0.46]	[−0.63, 0.85]
(CP-odd)	$\bar{c}_{\varphi \widetilde{W}}$	[−2.9, 1.8]	[−0.49, 0.93]	[−4.9, 1.3]
	$\bar{c}_{\varphi \widetilde{W} B}$	[−1.4, 1.8]	[−0.49, 0.69]	[−1.3, 2.4]
	$\bar{c}_{\varphi \widetilde{B}}$	[−19, 23]	[−1.2, 1.4]	–

"We consider all **available measurements of VBS fiducial cross-sections and differential distributions from ATLAS and CMS**, in most cases based on the full Run II luminosity, and use them to constrain 16 independent directions in the dimension-six EFT parameter space"

ATLAS WZ analysis arxiv

c contributions. Only one Wilson coefficient is permitted to vary from zero at a time.

	Cut-off value on m_{WZ} [GeV]		
	1000	1500	no cut-off
c_W/Λ^2 [TeV $^{-2}$]	[-0.236, 0.208]	[-0.143, 0.130]	[-0.103, 0.095]
$c_{Hq}^{(3)}/\Lambda^2$ [TeV $^{-2}$]	[-0.286, 0.119]	[-0.195, 0.086]	[-0.145, 0.074]


$V_{1,2,3}$ = (W, Z)
q
q
V_1
V_2
V_3
Trilinear
q
q
V_1
V_2
V_3
H
Higgs-mediated
q
q
V_1
V_2
V_3
Quartic
q
q
V_1
V_2
V_3
Radiative