Report from CMS Data Analysis Group

18/03/2022

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for the CMS data analysis group

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Group

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CMS CB chair

Manfred Jeitler
Senior scientist

Wolfgang Waltenberger
Senior scientist

Dietrich Liko
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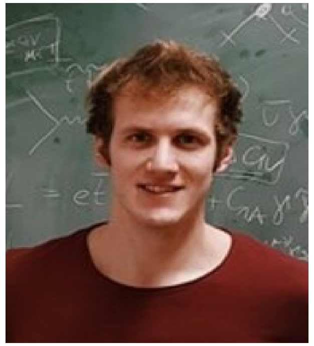


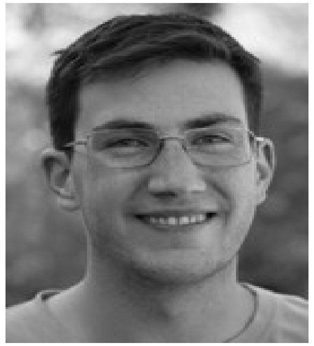
Alberto Escalante del Valle
Post-doc

Suman Chatterjee
Post-doc

Dennis Schwarz
Post-doc

Priya Sajid Hussain
PhD student

Lukas Lechner
Graduated in Nov, 2021



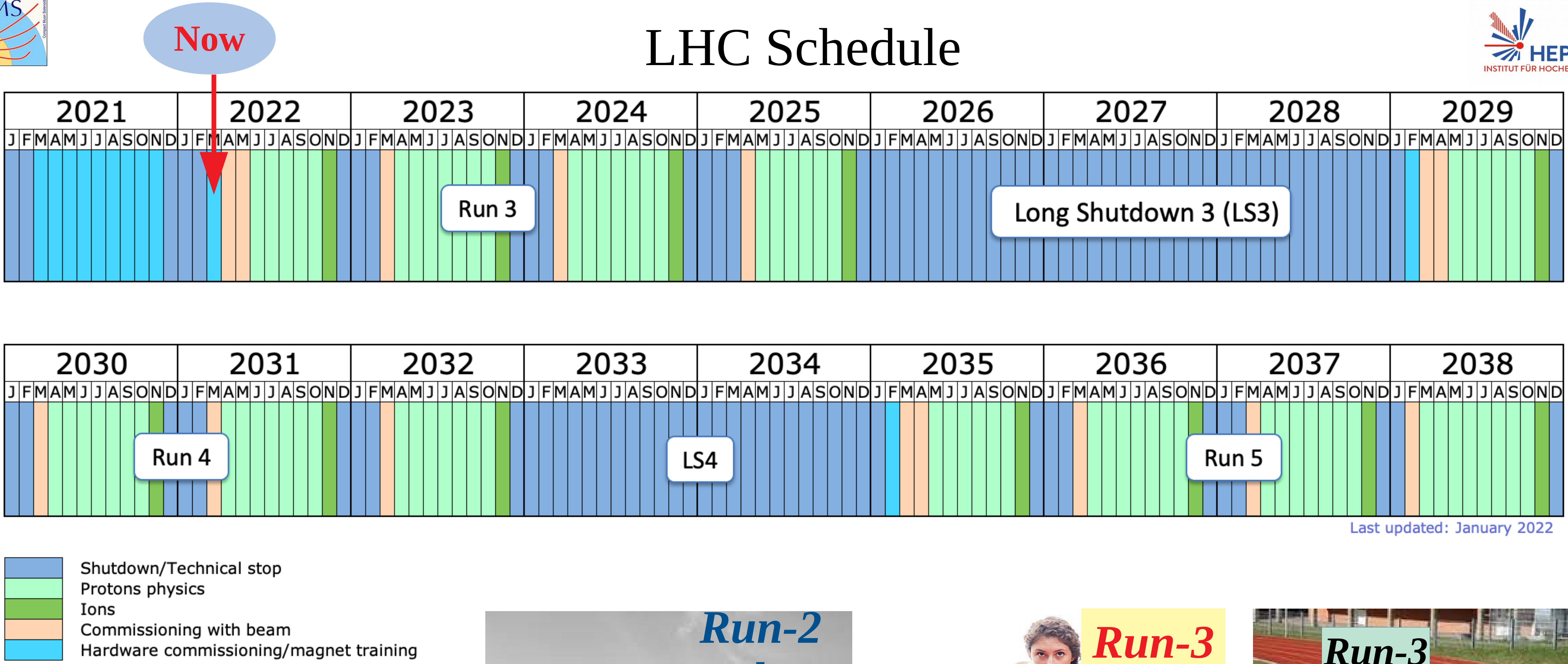
Janik Andrejkovic
Thesis submission in March, 2022

Sebastian Templ
Graduated in Nov, 2021

Mangesh Sonawane
PhD student

Mark Matthewman
PhD student

LHC Schedule



Data delivered by LHC (p-p):

Run 2: 159/fb (CMS recorded 138/fb)
Run 3: ~250/fb (target)

CMS is ready for Run 3

Magnet reached 3.8 T on 11th of March

Finished?

Fresh (re)start?

Brand new ideas?

Group activity

(Direct) searches for new physics

Signatures of supersymmetry
long-lived particles } → New d.o.f. [produced in collision]
↓
SM d.o.f.

Why new physics?

<u>Standard model can't explain</u>

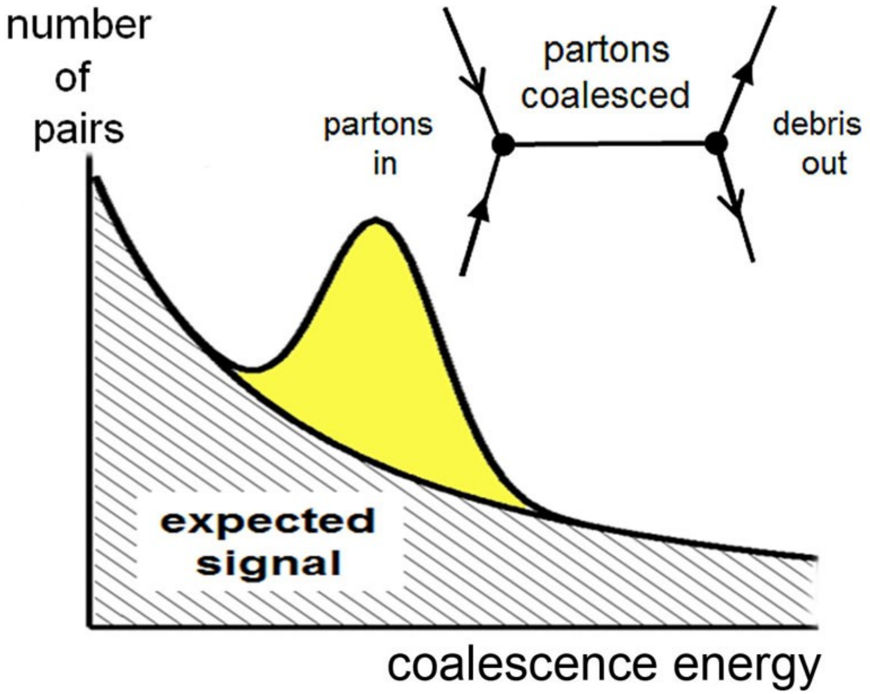
Neutrino mass

Dark matter

Baryon asymmetry in universe

Fine-tuning of Higgs boson mass

…



Group activity

Precision measurements → **Indirect search for new physics**

with

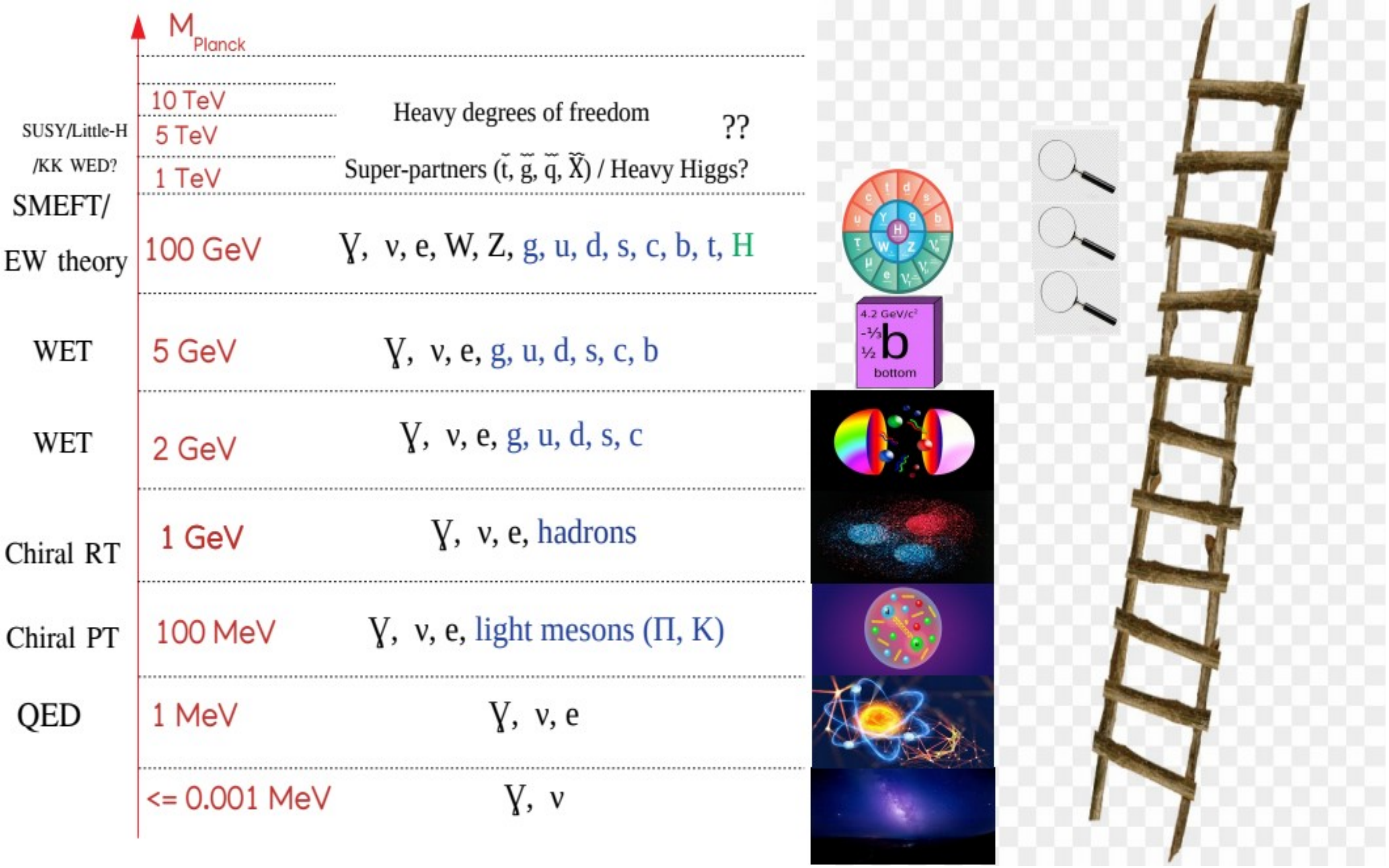
top quark

Higgs boson

(Standard model) effective field theory (SM-EFT)

$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i^{(5)}}{\Lambda}\mathcal{L}_5^i + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{L}_6^i + \ldots$$

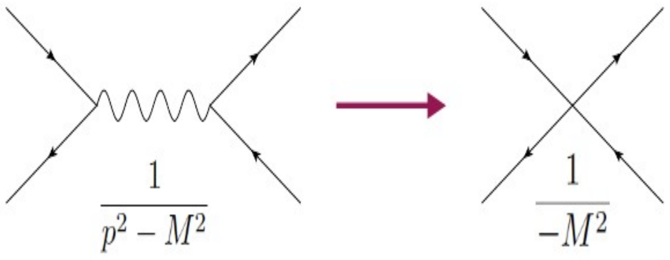
Piece of interest (for now)

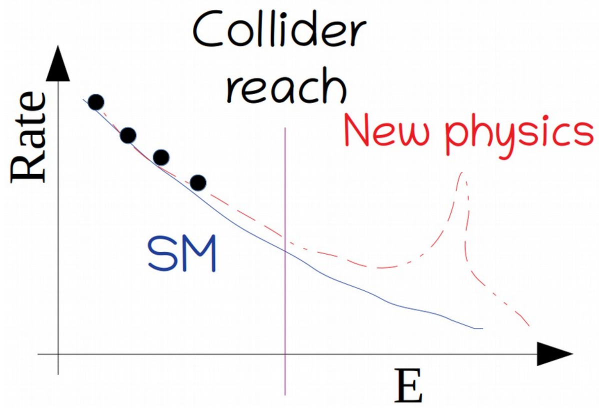


New d.o.f.

↓

Modify SM interactions

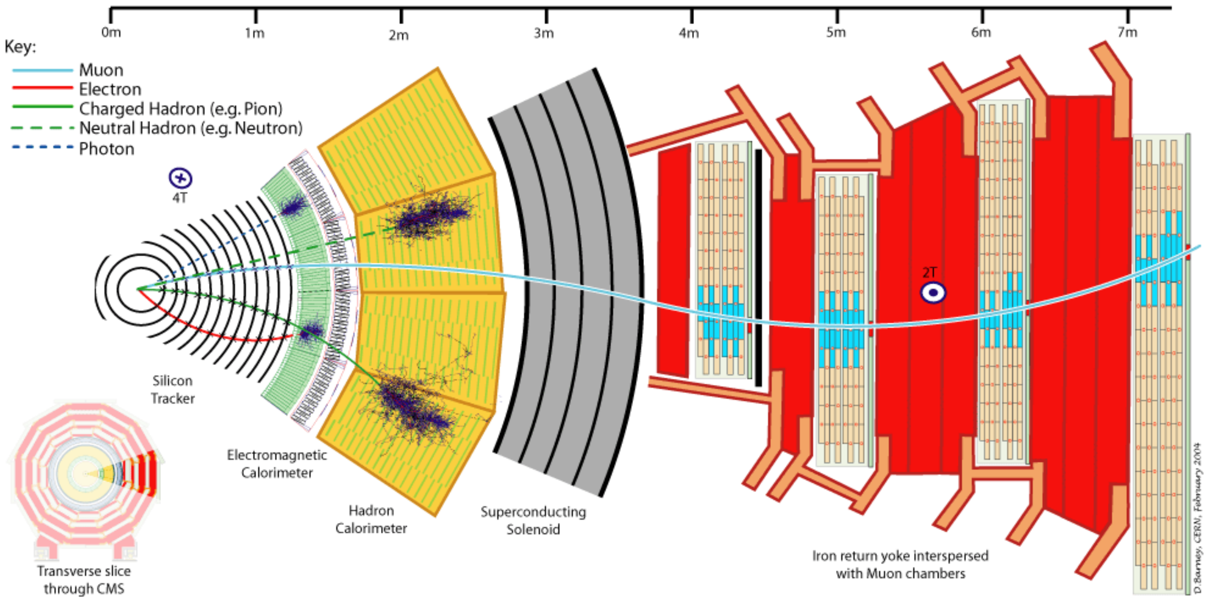




Learning vocabulary

Object reconstruction using particle-flow: JINST12(2017)

Combining information from different sub-detectors in an optimized way



$e^{\pm}$, $\mu^{\pm}$, γ, $h^{\pm}$, h^{0}

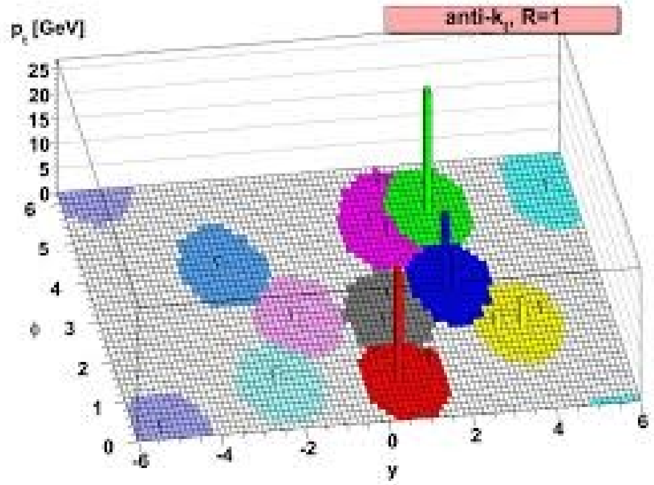
All particle-flow candidates — Input →

Jet reconstruction

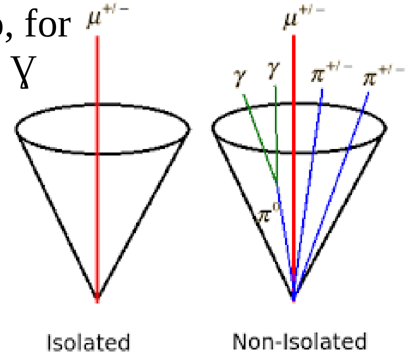
Anti-k_T algorithm

JHEP04(2008) 063

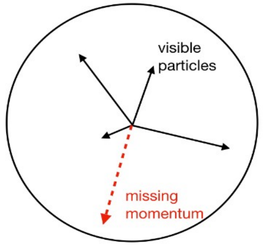
Output → Jets



Also, for e, γ



Often the case for leptons from W, Z, H, τ decay, EWK decays of BSM particles



Missing transverse momentum (MET)

Objects to be quoted in rest of the talk

Muons
+
Electrons
+
Photons
+
(Hadronic) Jets → (Hadronic) Tau (τ_h)

Searches for supersymmetry

Signature of supersymmetry (we look for) @ LHC?

Search for stop quark

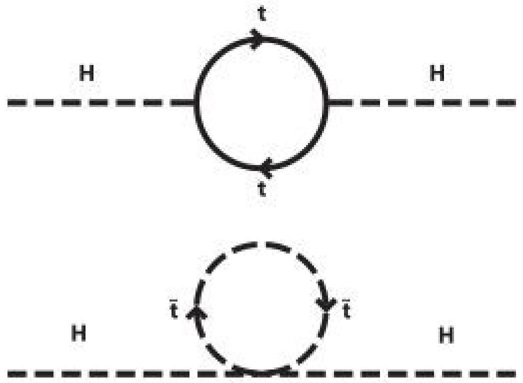
← (Lightest) super-partner of top quark

Likely to be at TeV scale

→ Cancels top quark contribution to correction to m_H

Carries color charge

→ Sizeable production cross section



Search for additional Higgs bosons

Minimal version of SUSY:

2 Higgs doublets → 5 Higgs bosons

More complicated versions of SUSY:

→ Can have more than 5 Higgs bosons

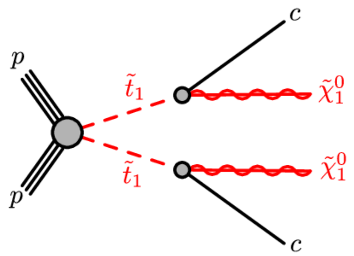
$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \frac{1}{\sqrt{2}}(v_1 + \phi_1^0 + i a_1) \end{pmatrix},$$

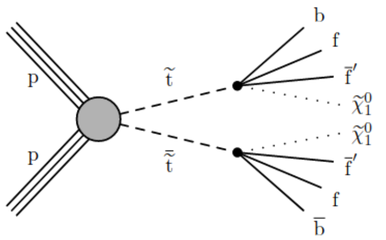
$$\Phi_2 = \begin{pmatrix} \phi_2^+ \\ \frac{1}{\sqrt{2}}(v_2 + \phi_2^0 + i a_2) \end{pmatrix}. \qquad (2)$$

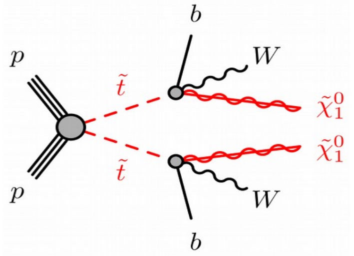
(Don't) Stop searches

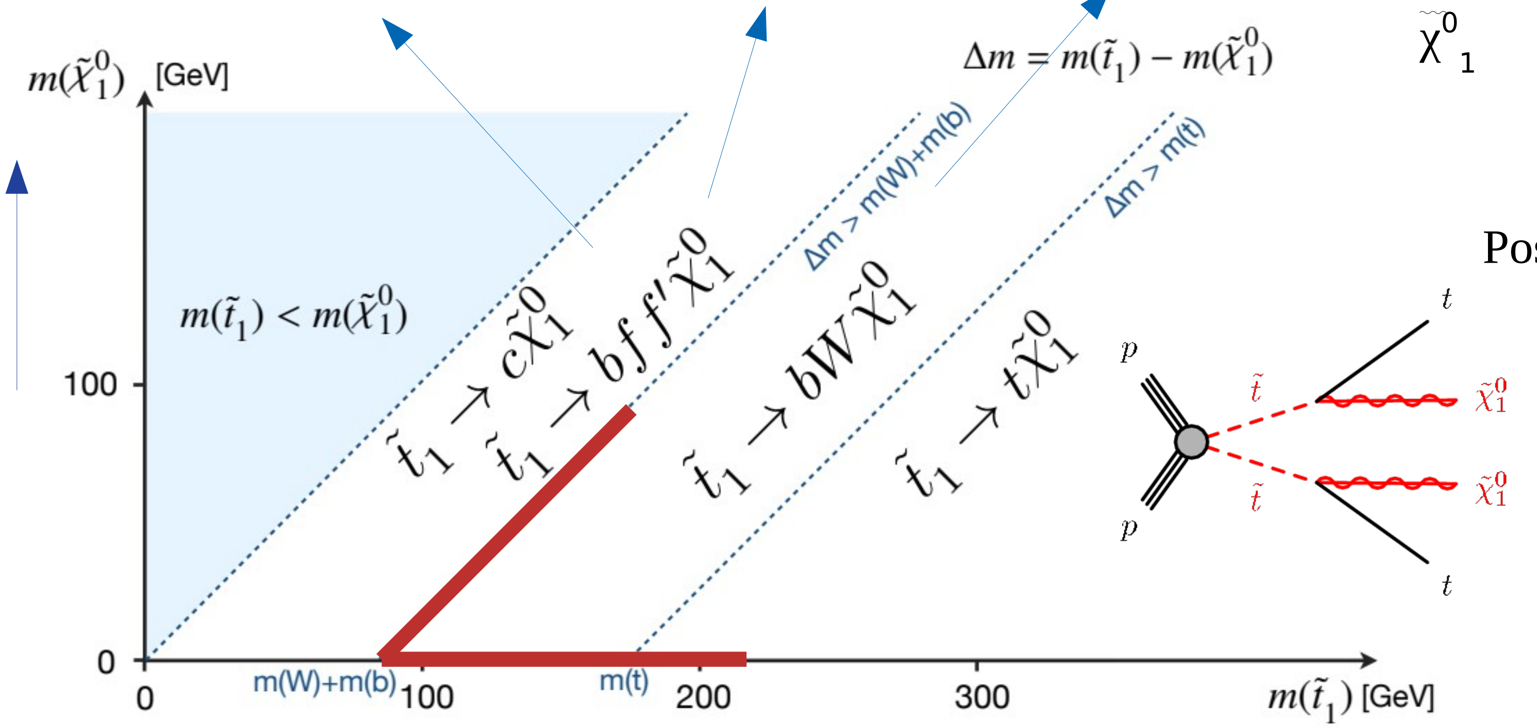
Topologies in stop decay

Small Δm









Decay products soft
small missing energy

$\tilde{\chi}^0_1$ Neutralino: Lightest supersymmetric particle (LSP)
→ stable, if R parity $(-1)^{3(B-L)+2s}$ is conserved

Possible dark matter candidate

Different decay topologies according to stop-neutralino mass splitting (Δm)

JHEP 11 (2014) 118

Decay products have high momentum

Large missing energy

Large Δm

Daniel, Priya, Robert

Stop search in dileptonic final state

Eur. Phy. J. C 81 (2021) 3

<u>Signal signature:</u>

2 opposite sign (OS) leptons

N_{jets} >= 2, $N_{b\ jets}$ >= 1

Missing energy

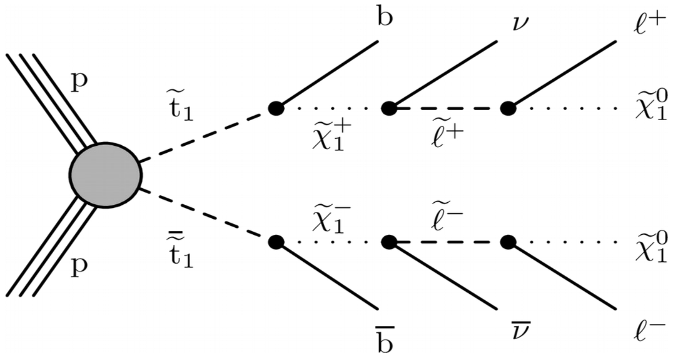
<u>Backgrounds:</u>

ttZ ($Z \rightarrow \nu\nu$)

Drell-Yan + jets

tt (+ jets)

Diboson (WW, WZ, ZZ)



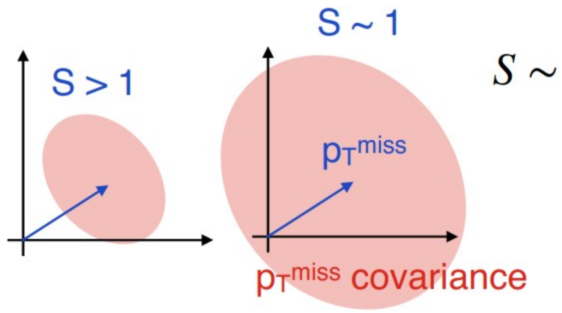
<u>Key observables:</u>

MET significance (S) = $2\ln\left(\frac{\mathcal{L}(\vec{\varepsilon}=\sum\vec{\varepsilon}_i)}{\mathcal{L}(\vec{\varepsilon}=0)}\right)$

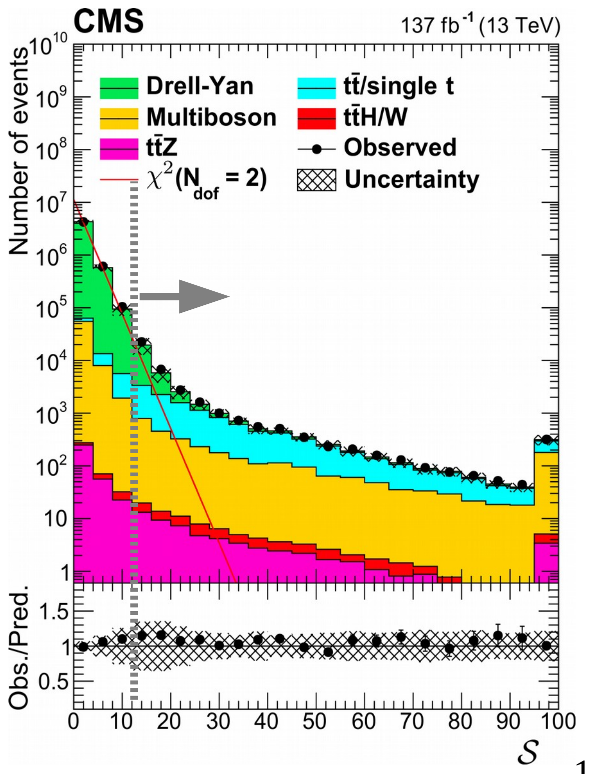
→ Deviation from no-genuine-MET hypothesis

→ Reduced pile up dependence compared to MET

→ Rejects Drell-Yan background



$$S \sim \frac{p_T^{miss\,2}}{\sigma^2_{p_T^{miss}}}$$



Tuning and calibration performed in-house

Daniel, Priya, Robert

Stop search in dileptonic final state

Eur. Phy. J. C 81 (2021) 3

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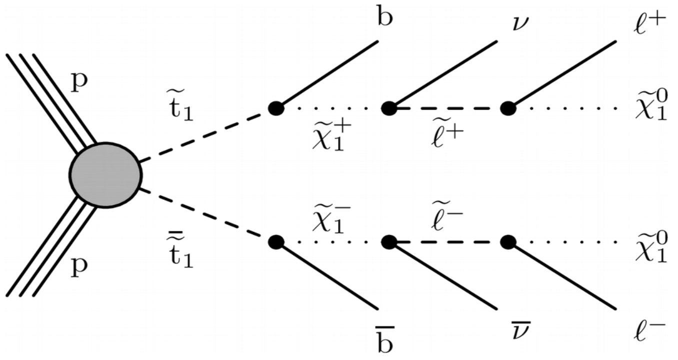


Signal signature:

2 opposite sign (OS) leptons

N_{jets} >= 2, $N_{b\ jets}$ >= 1

Missing energy

Backgrounds:

ttZ (Z → νν)

Drell-Yan + jets

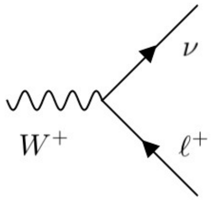
tt (+ jets)

Diboson (WW, WZ, ZZ)

Key observables:

$$m_T^2 = m_l^2 + m_\nu^2 + 2(E_T^l E_T^\nu - \mathbf{p}_T^l \cdot \mathbf{p}_T^\nu)$$

Maximum possible value of m_T : m_W →



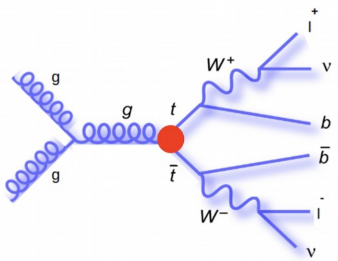
$$M_{T2} = \min_{\vec{p}_T^{\text{miss}1}+\vec{p}_T^{\text{miss}2}=\vec{p}_T^{\text{miss}}} \left(\max\left[M_T(\vec{p}_T^{\text{vis}1},\vec{p}_T^{\text{miss}1}), M_T(\vec{p}_T^{\text{vis}2},\vec{p}_T^{\text{miss}2})\right]\right),$$

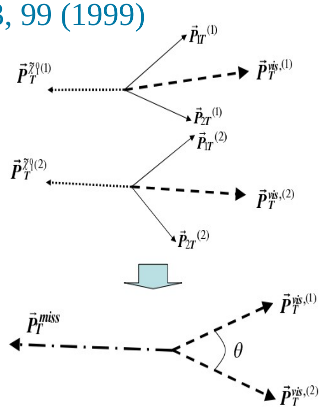
Phys. Lett. B463, 99 (1999)

Generalization of m_T for two similar decay chains with invisible particles

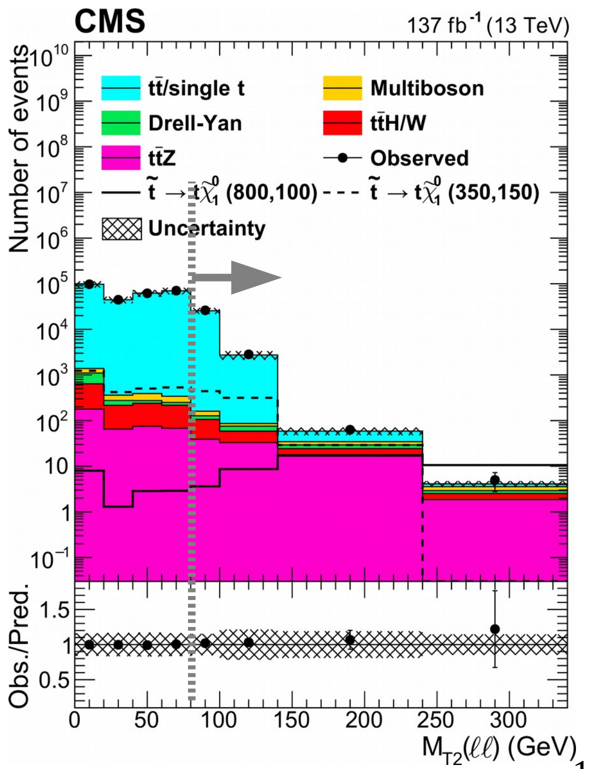
→ M_{T2} has kinematic end point at m_W →

→ Removes tt (+jets) background





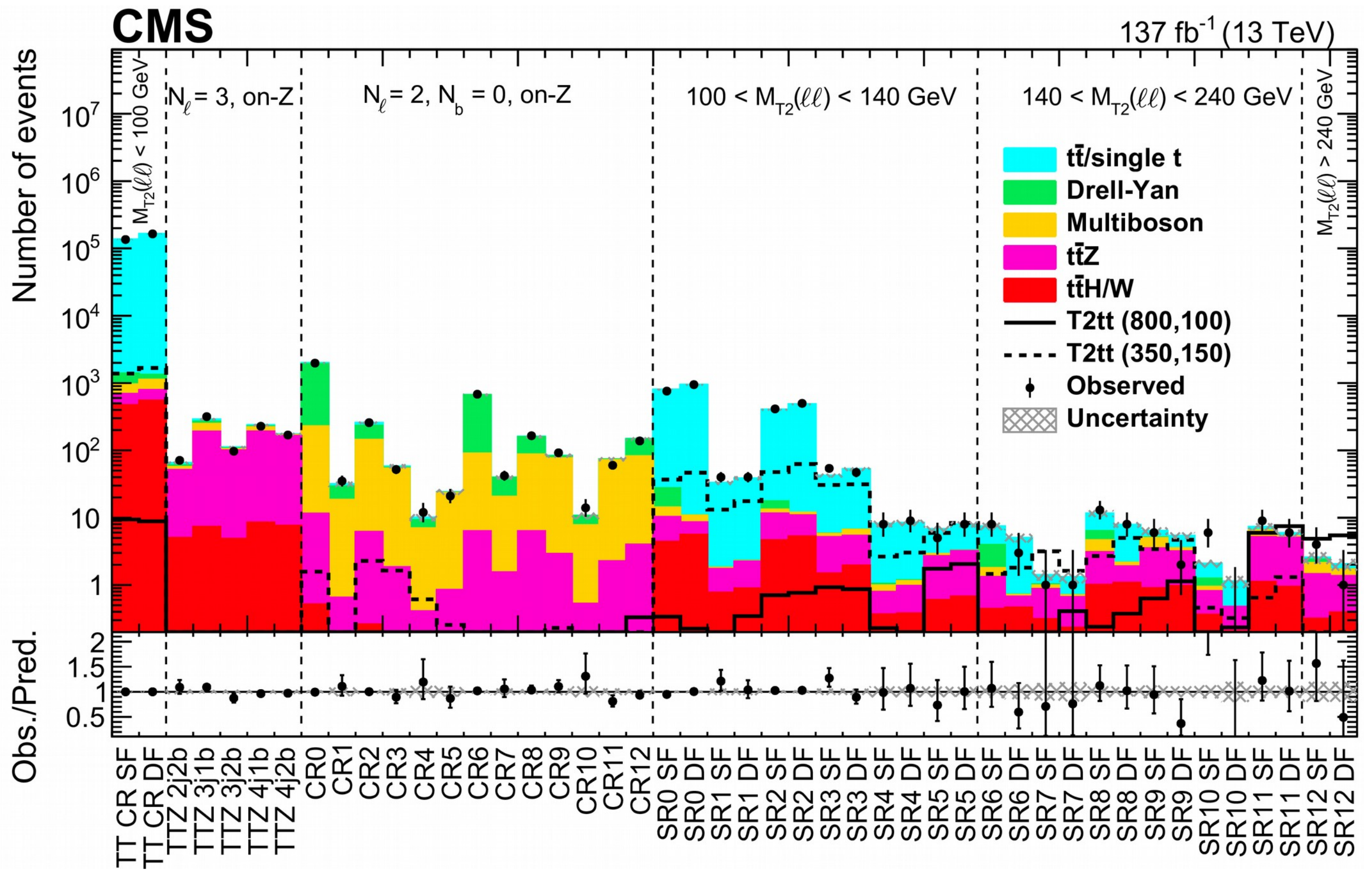
JHEP0802:035,2008

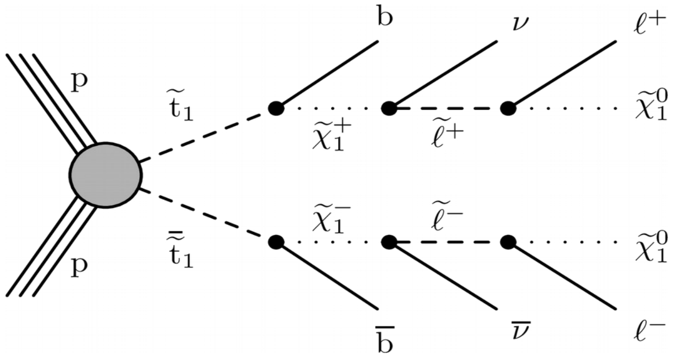


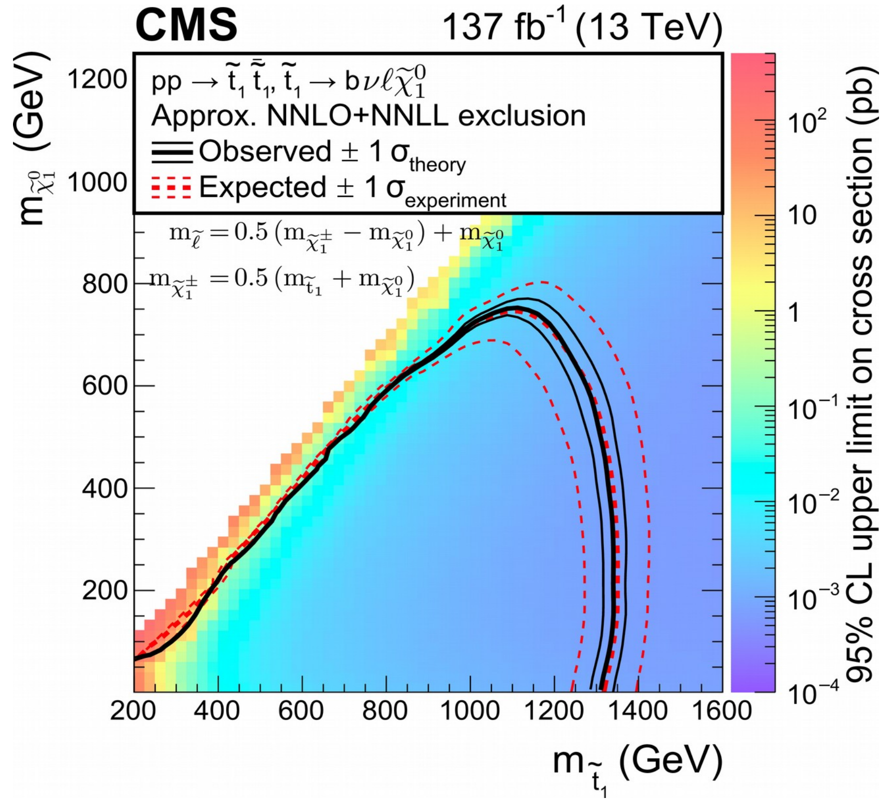
Daniel, Priya, Robert

Stop search in dileptonic final state

Eur. Phy. J. C 81 (2021) 3







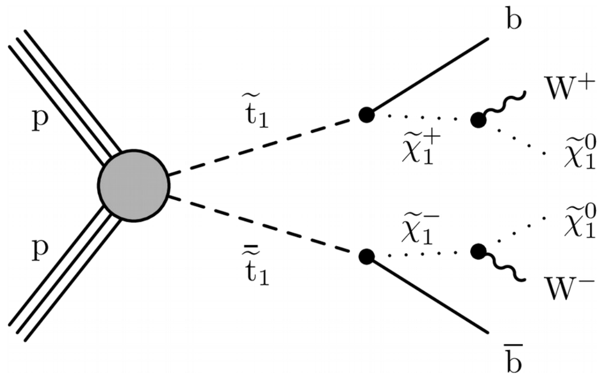
No significant deviation observed in data compared to SM background

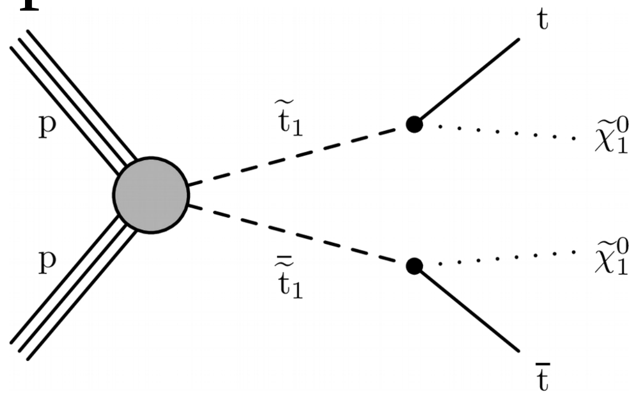
Exclusion limit at 95%:

Stop < 1300 GeV
Neutralino < 750 GeV

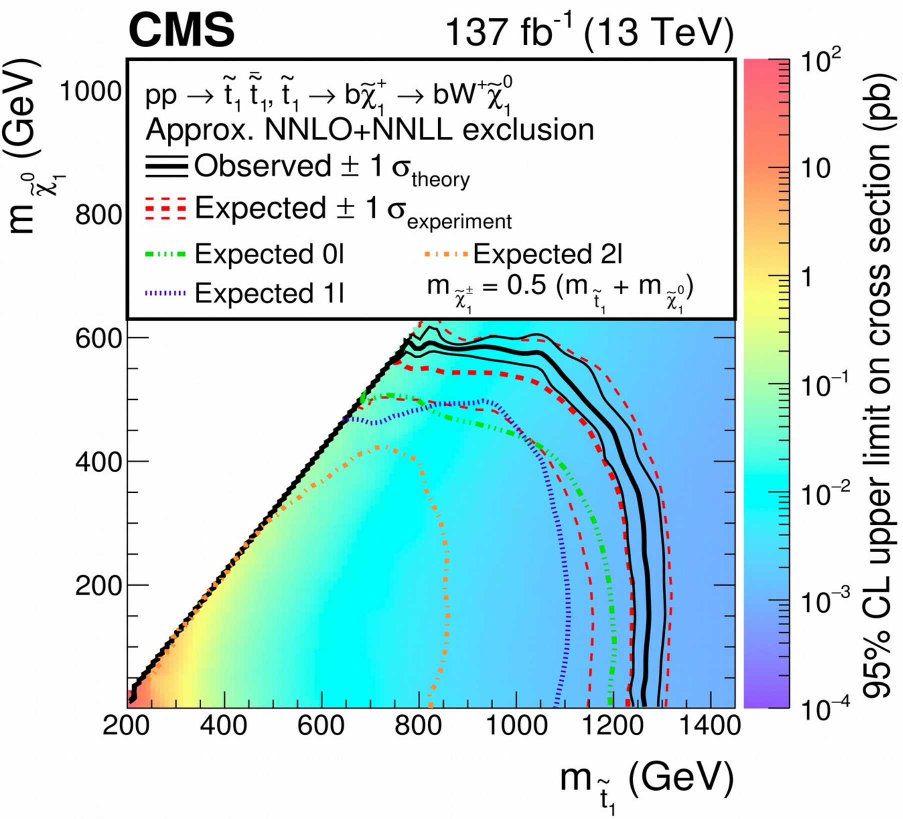
Stop search in dileptonic final state

Eur. Phys. J. C 81 (2021) 970

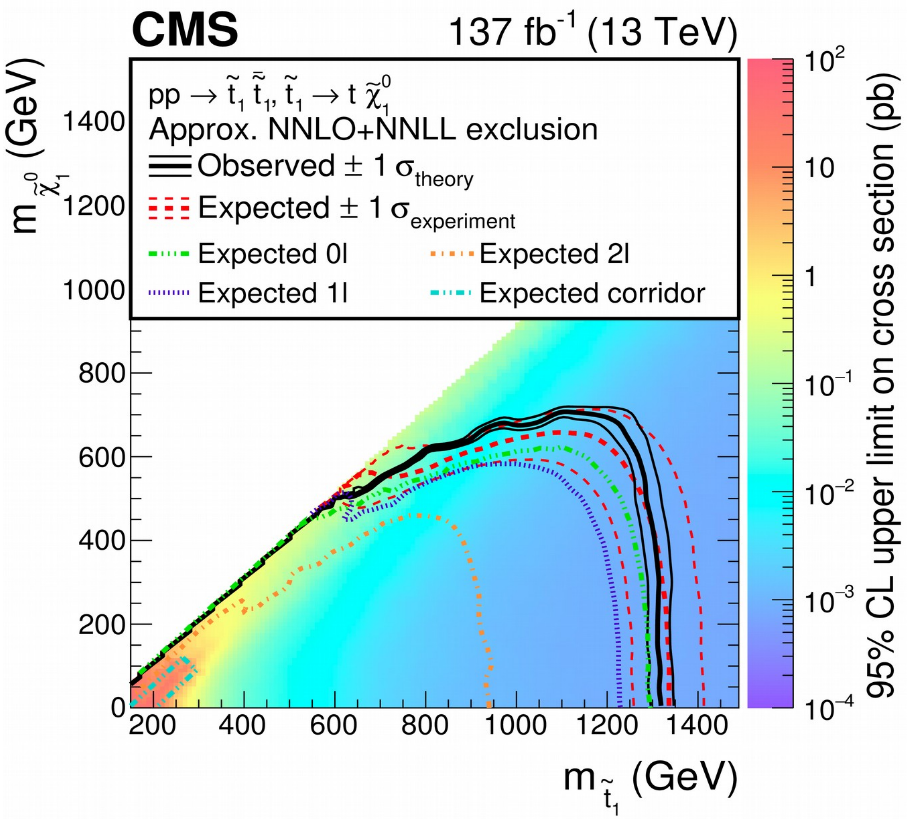




Results used in combination with other final states searching for stop pair production



Exclusion limit at 95%: Stop < 1205 GeV
Neutralino < 575 GeV

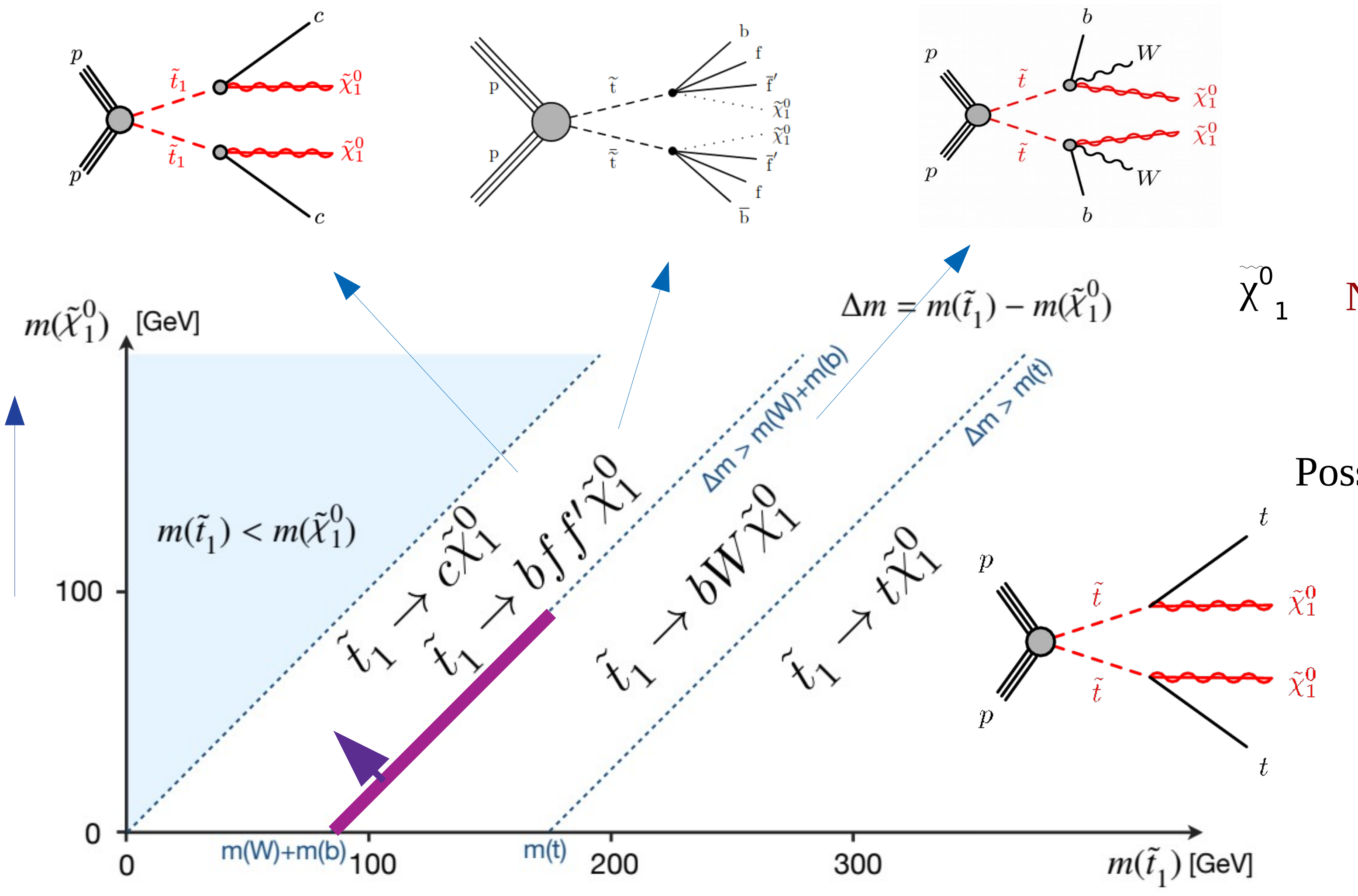


Exclusion limit at 95%: Stop < 1325 GeV
Neutralino < 700 GeV

Topologies in stop decay

Small Δm

Decay products soft
small missing energy



$\tilde{\chi}^0_1$ Neutralino: Lightest supersymmetric particle (LSP)
→ stable, if R parity $(-1)^{3(B-L)+2s}$ is conserved

Possible dark matter candidate

Different decay topologies according to stop-neutralino mass splitting (Δm)

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Large Δm

Decay products have high momentum

Large missing energy

Priya, Janik, Dietrich, Manfred, Ivan,Wolfgang A

Stop search in compressed spectra with soft leptons + jets

Focus on compressed region:

Small stop-neutralino mass gap

Motivation

A stop-LSP co-annihilation scenario for thermal freeze-out possible

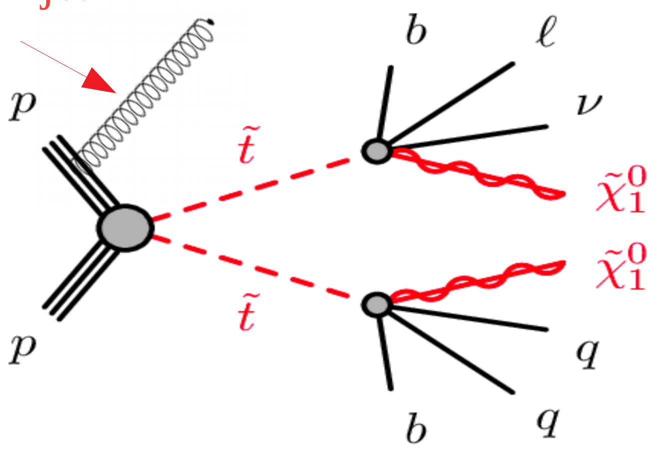
A natural light stop (<1 TeV) still not excluded

→ 4-body decay of stop quark

Signature

→ Final decay products can have too little energy to be detected

Energetic ISR jet



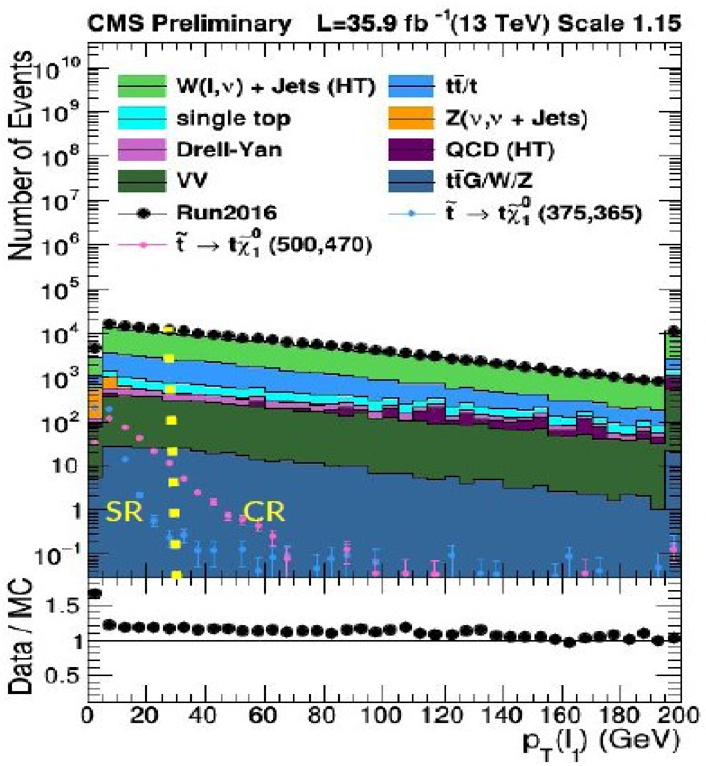
Signature:

At least 1 soft lepton +

No or only soft b jets +

Missing energy +

>=1 energetic jet



Solution:

Require an energetic jet from initial-state radiation (ISR)

→ Stop pair system recoils against ISR jet

→ Decay products more often have large enough energy to be reconstructed

→ Boost gives maximum momentum to most massive particle, here $\tilde{\chi}^0_1$

→ Large missing energy

Lepton is still soft in signal events

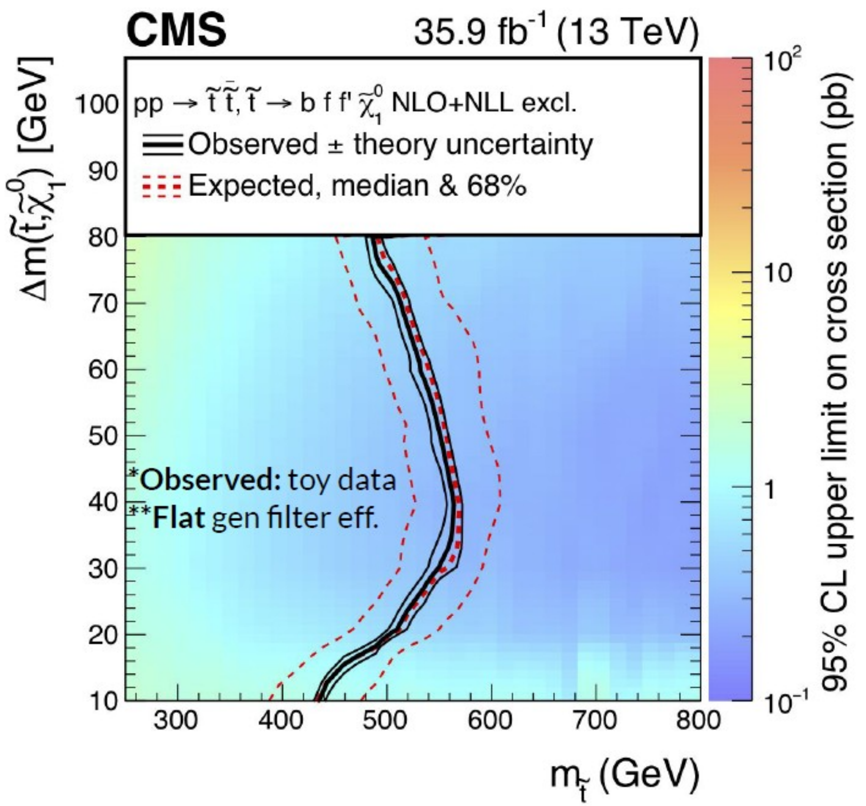
Stop search in compressed spectra with soft leptons + jets

Signal regions: Binned in lepton p_T, m_T, # of soft b jets, combination of hadronic & missing energy

Simulated backgrounds normalized to data in high lepton p_T control regions

Data-driven estimation of multijet background

Sensitivity check performed in comparison to results published using Run 2 (2016 only) data



(Ongoing)

Adapting latest reprocessing of data by CMS

Innovations to increase sensitivity w.r.t. existing results ←

- Signal region optimization
- Dedicated soft b tagging
- New reconstruction for soft electron

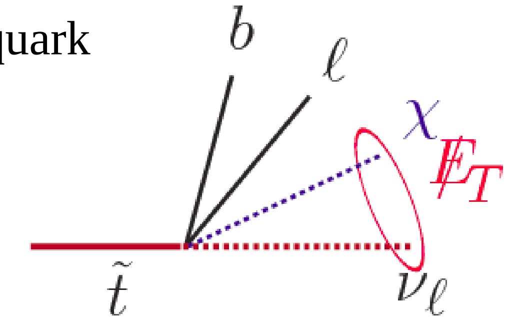
Final results to be derived with full Run-2 data

Priya, Janik, Dietrich, Manfred, Ivan,Wolfgang A

Stop search in compressed spectra with soft leptons + jets

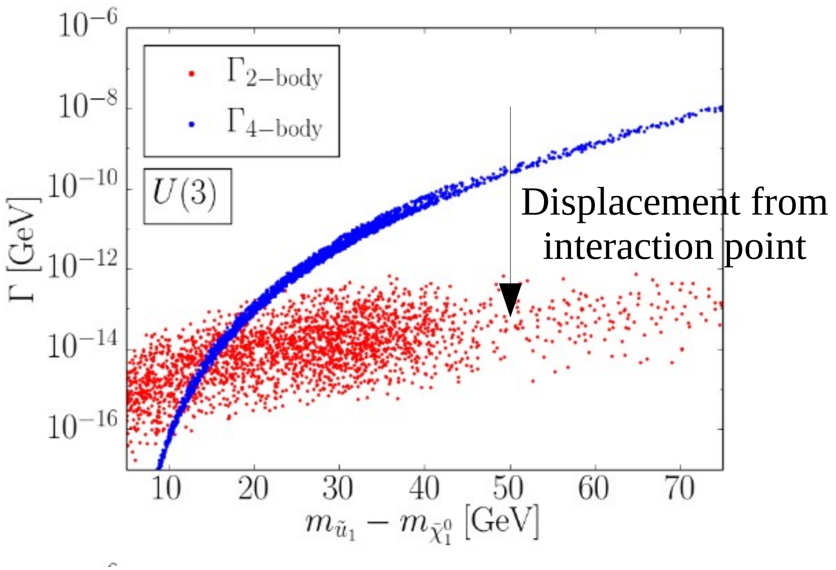
Small mass gaps (Δm < 30 GeV) can lead to long-lived stop quark

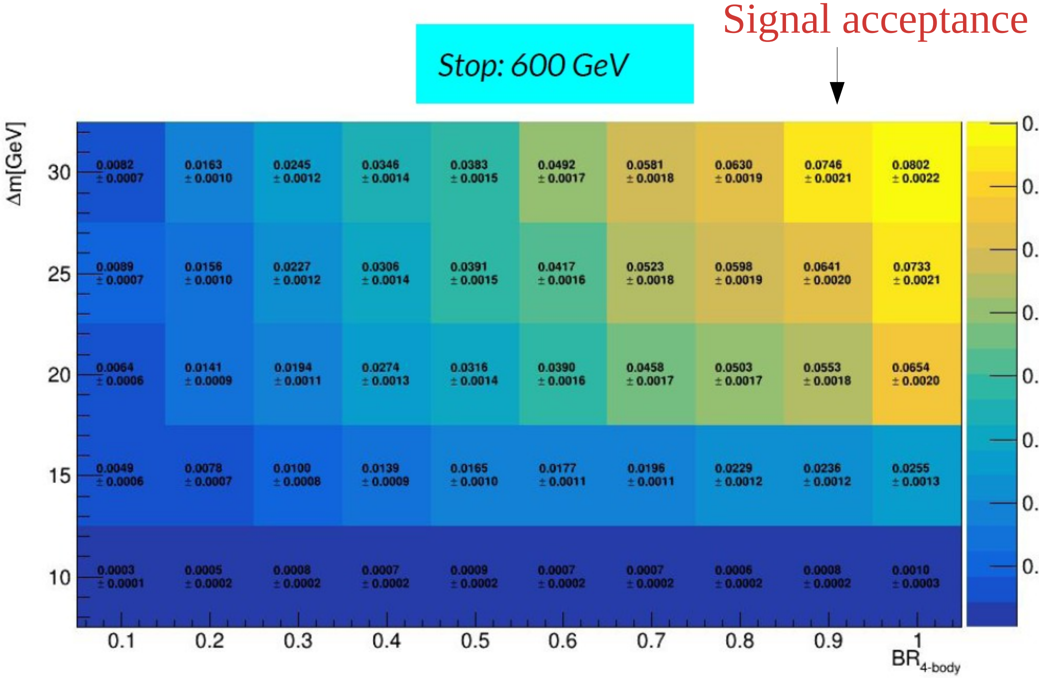
← Ignored in previous LHC measurements

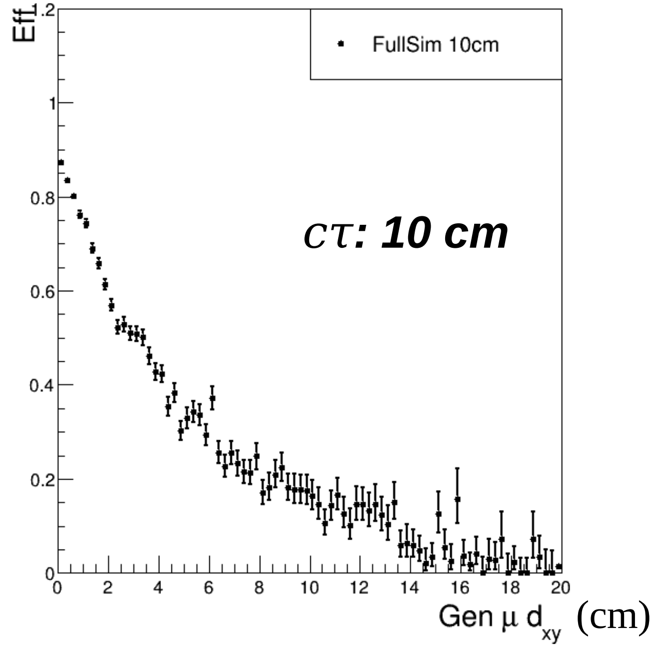


Lepton displaced from interaction point

$$\Gamma_{total} = \Gamma_{4\text{-body}} \times \Delta m / BR_{4\text{-body}}$$







Reconstruction efficiency goes down

Timeline: Winter 2022

Smaller Δm → Larger displacement → Loss in lepton reconstruction efficiency, but offers additional handle to reduce SM background

Larger BR → Larger # of events with 4-body decay → Compensates loss due to lepton reconstruction at small Δm

Benjamin, Max,
Dietrich, Robert

DeepLepton finding displaced muons

Conventional way of (prompt) lepton identification:

Conditions on reconstructed lepton features: Cut-based or MVA-based

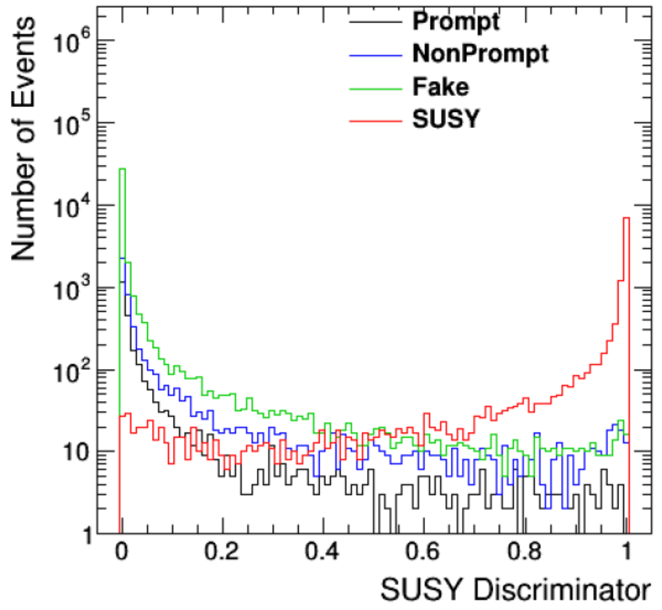
DeepLepton = Deep neural network for lepton identification:

→ DNN without multiple output nodes

→ Use properties of particles & secondary vertices within a cone around lepton ★

More efficient to identify lepton in hadronic environment

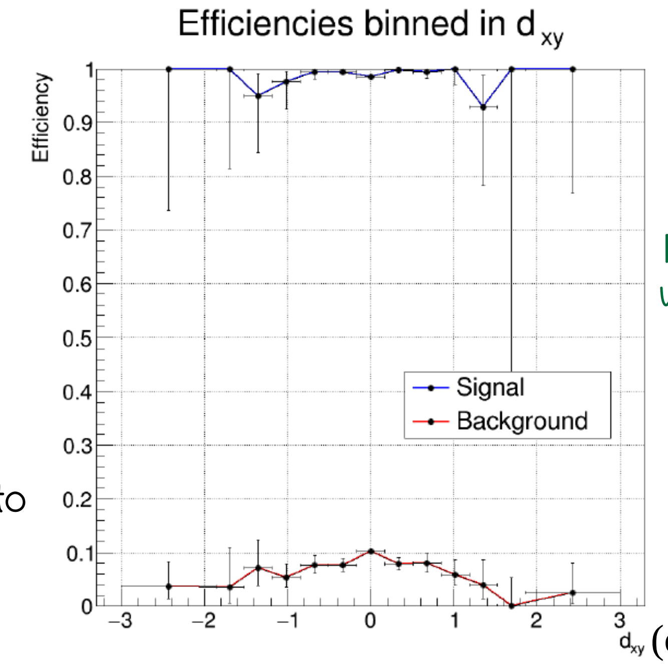
Recover efficiency loss for displaced leptons



Prompt
← from primary interaction

NonPrompt
← from secondary vertices
(e.g., hadron decay)

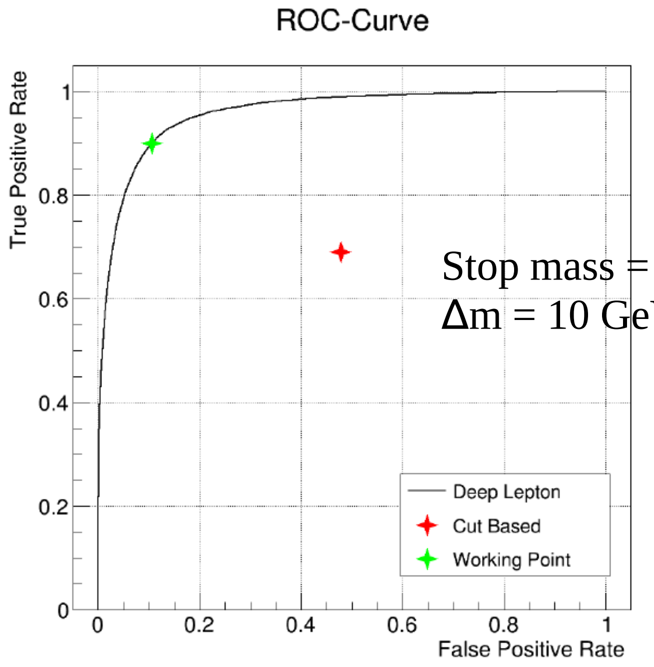
Fake
← Misidentified particle



Efficiency of displaced muons from
stop decay (signal)
stable over impact parameter distance

Prompt + NonPromt + Fake used as background to
displaced muons from SUSY signal →

Performance ↑
w.r.t. standard
method



Stop mass = 250 GeV
Δm = 10 GeV

Searches for heavy Higgs bosons

Search for X→ Y(→bb) H(→WW)

Suman

Theory motivation:

Next-to-minimal supersymmetric extension of SM

2 complex Higgs doublets + 1 complex singlet scalar
→ 3 CP-even (X, Y, h) + 2 CP-odd neutral Higgs bosons + 2 charged Higgs bosons ($H^{\pm}$)

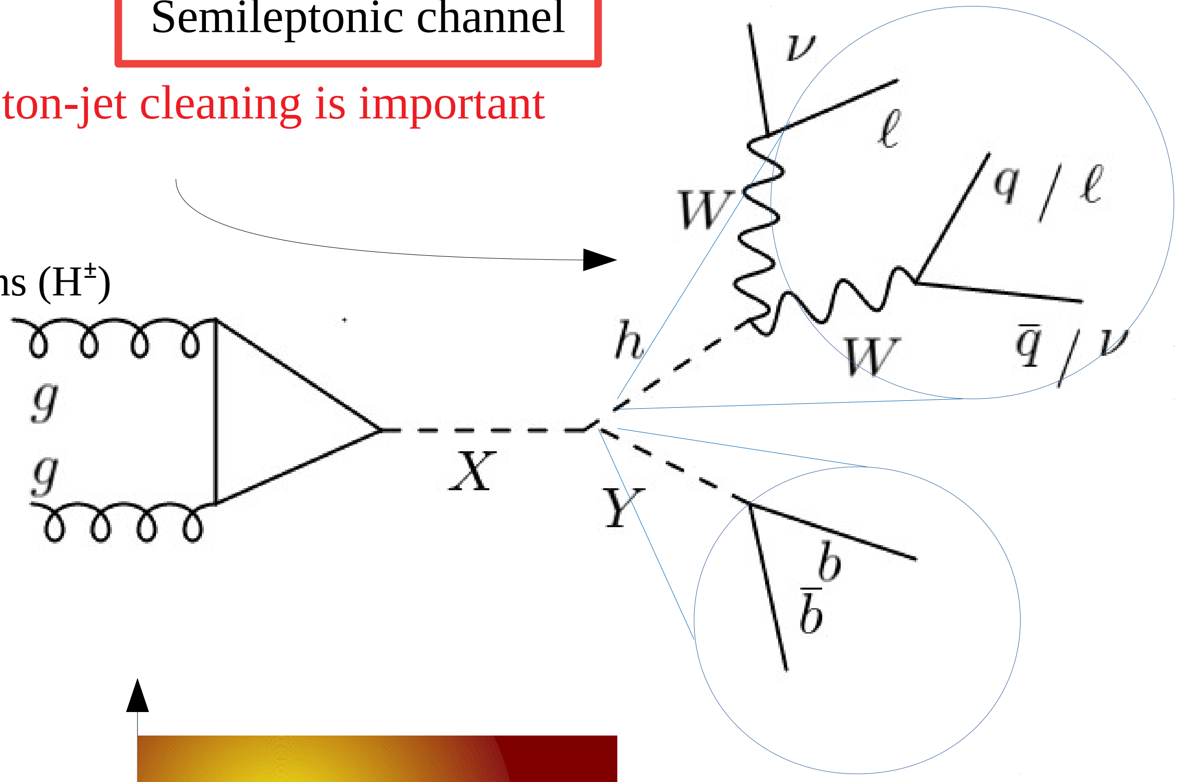
Two-real-singlet-scalar extension of SM (TRSM)

3 CP-even Higgs bosons (X, Y, h)

Focusing on boosted region: $m_X >> m_Y / m_h$

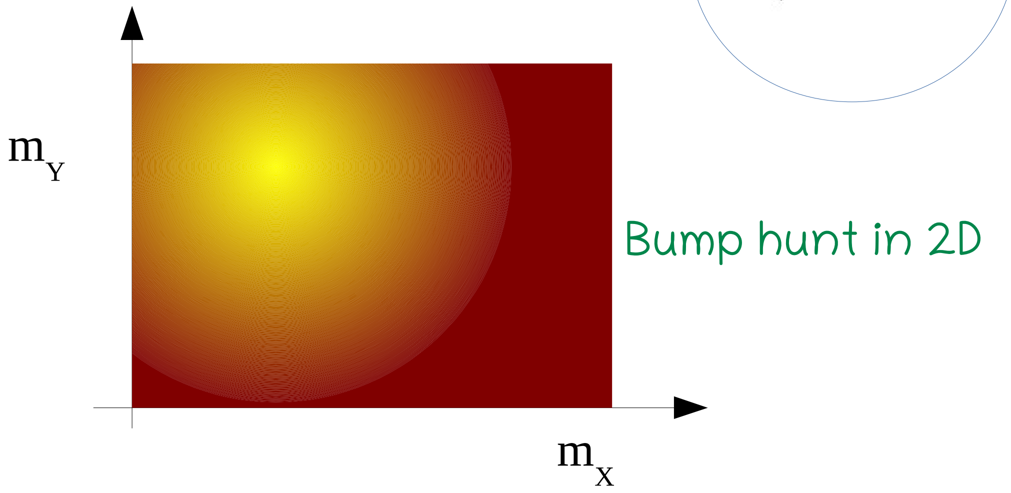
Semileptonic channel

Lepton-jet cleaning is important



Signature:

2 large-area jets (capturing Y→ bb & W→ qq')
+
1 non-isolated lepton (inside the jet from hadronic W)
+
Missing energy



Use of deep neural network to identify Y(→bb) & W(→ qq') initiated jets

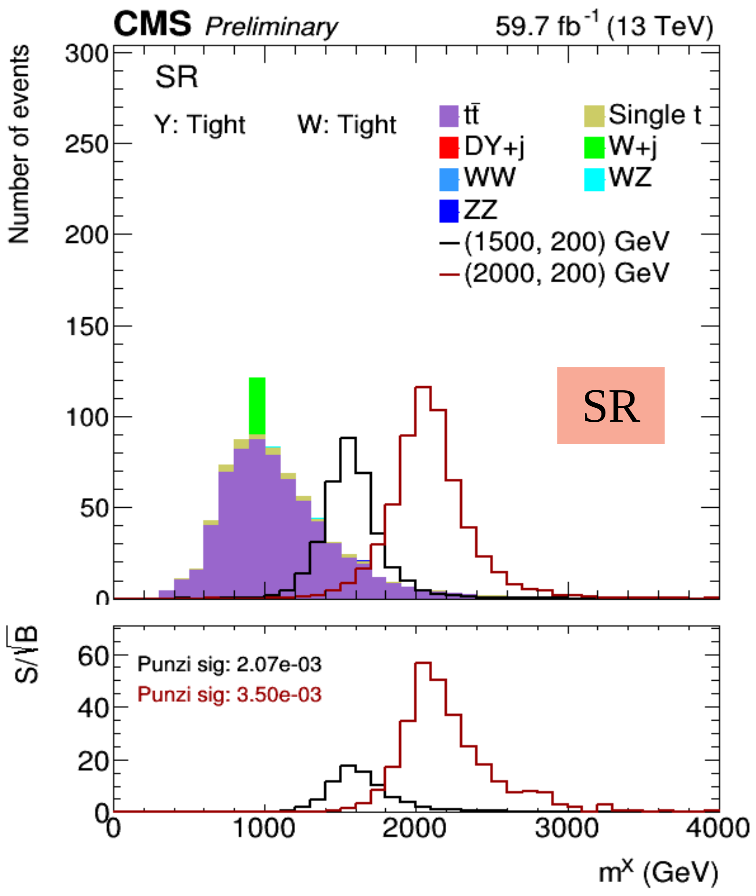
Dileptonic channel will be considered in future

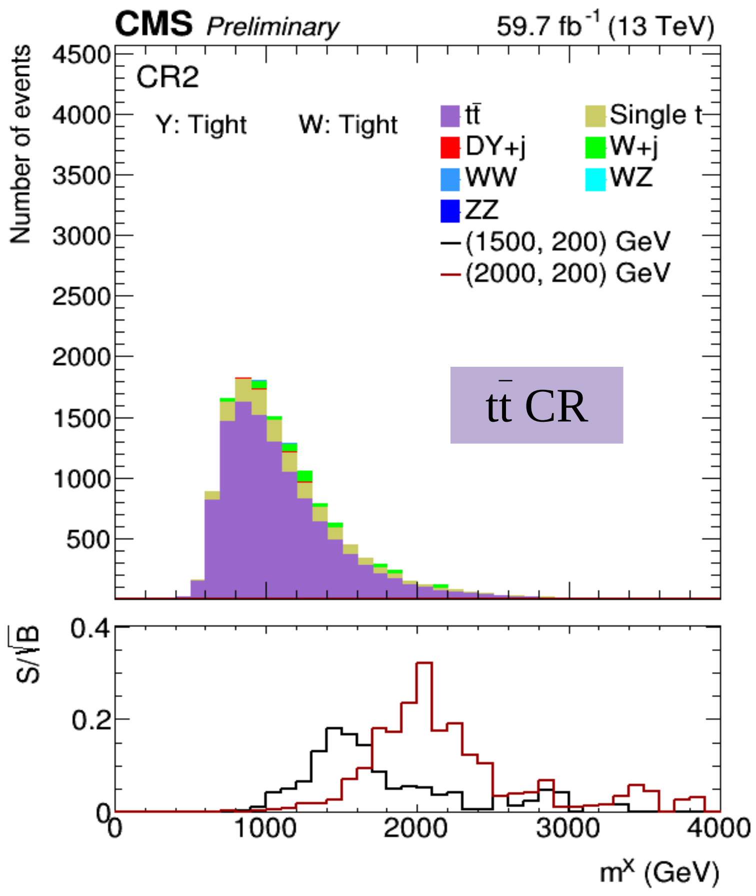
Suman

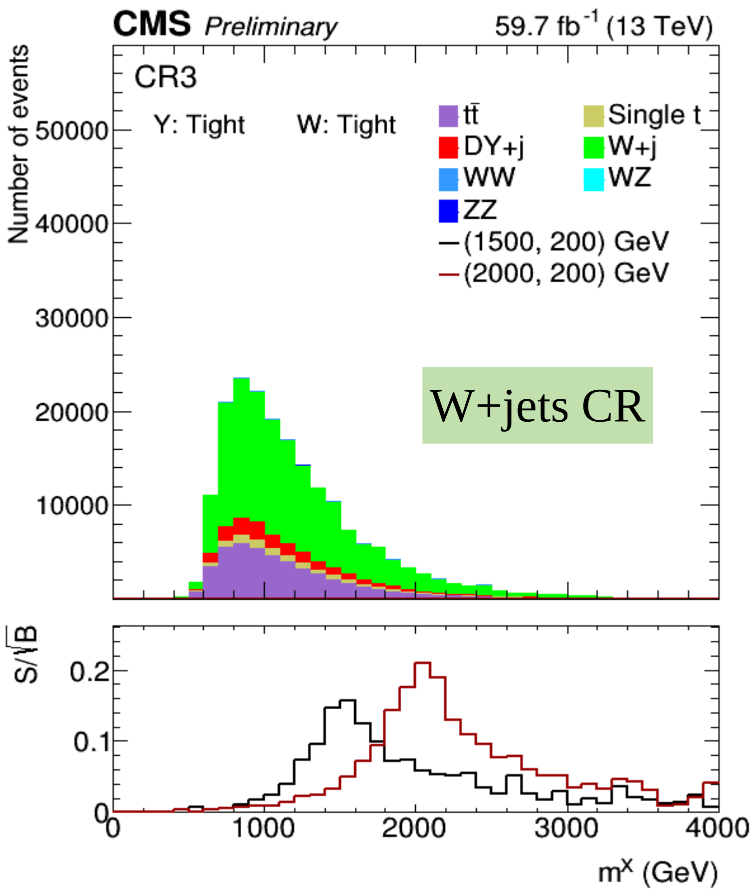
Search for X→ Y(→bb) H(→WW)

Semileptonic channel

Signal region (SR) and control regions (enriched with background processes) already defined







<u>Next steps:</u> Background estimation strategy & preliminary sensitivity results

Timeline:
Moriond EWK 2023

Searches for long-lived particles

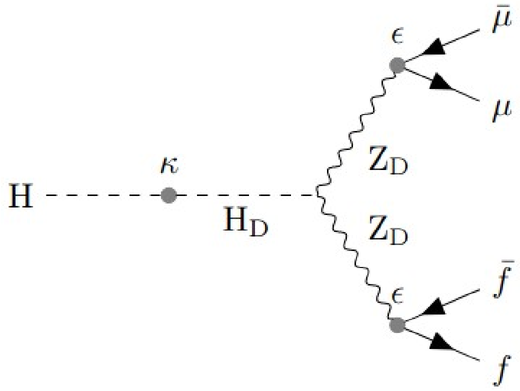
Mangesh, Sebastian
Alberto, Ivan

Search for displaced dimuons

Theory motivation:

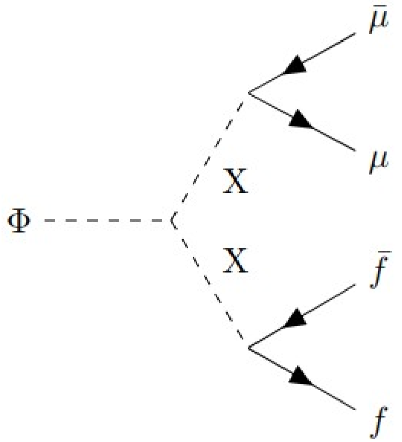
Dark photon model:

SM Higgs boson mixes with dark Higgs
→ Decays to dark photons: long-lived for small ϵ



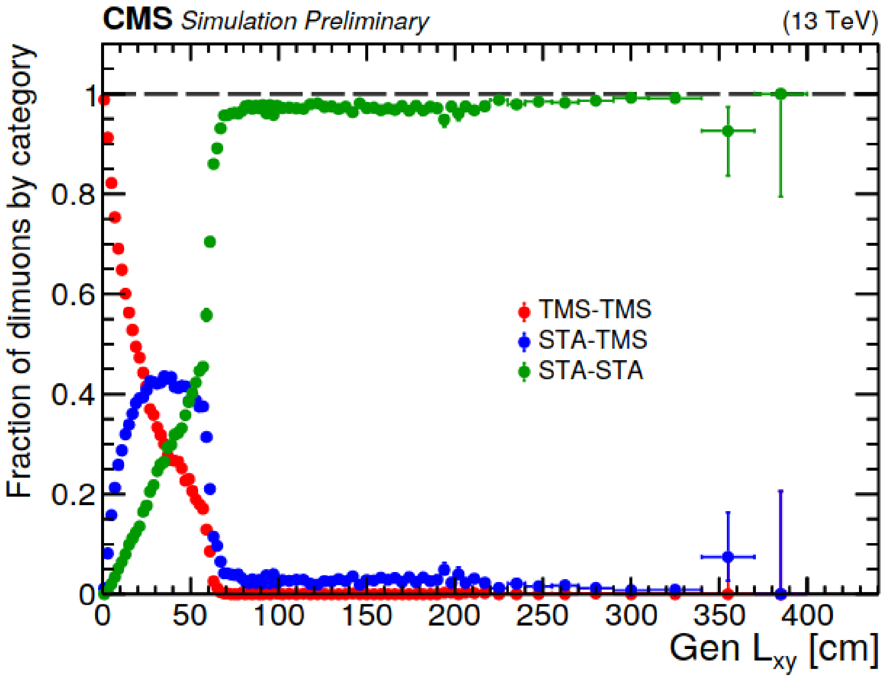
BSM Higgs model:

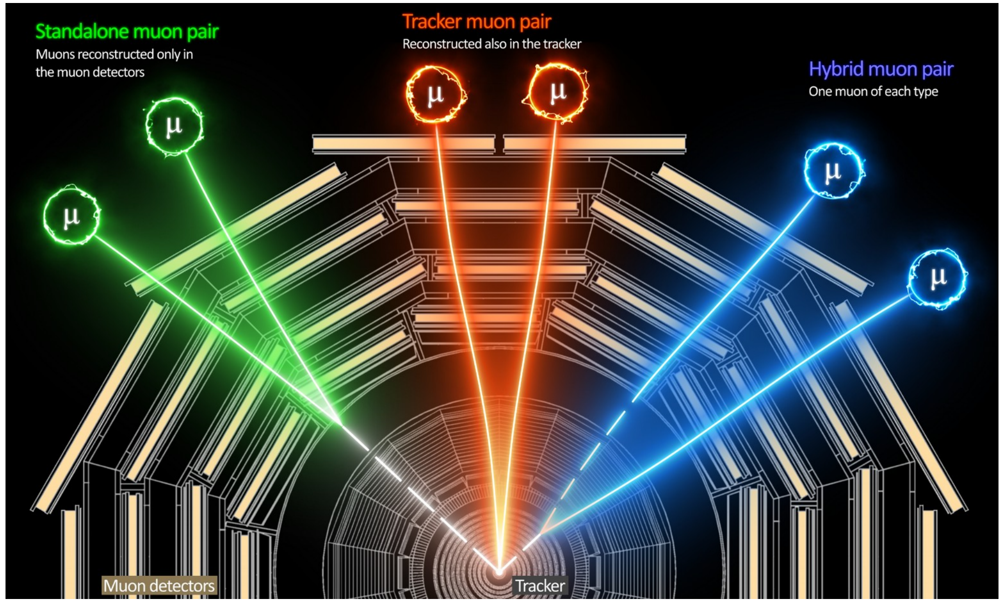
Heavy scalar (Φ) decays to lighter scalars X
→ Long-lived X decays to fermion pair



TMS: Muons reconstructed using tracker + muon system

STA: Stand-alone muon reconstruction with muon chamber





Mangesh, Sebastian
Alberto, Ivan

Search for displaced dimuons

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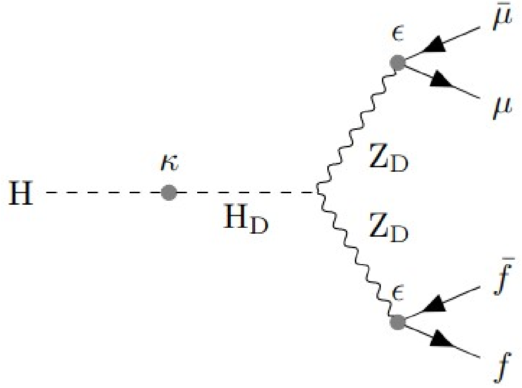

BSM Higgs model:

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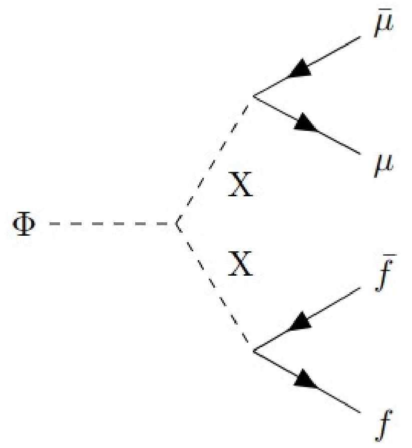
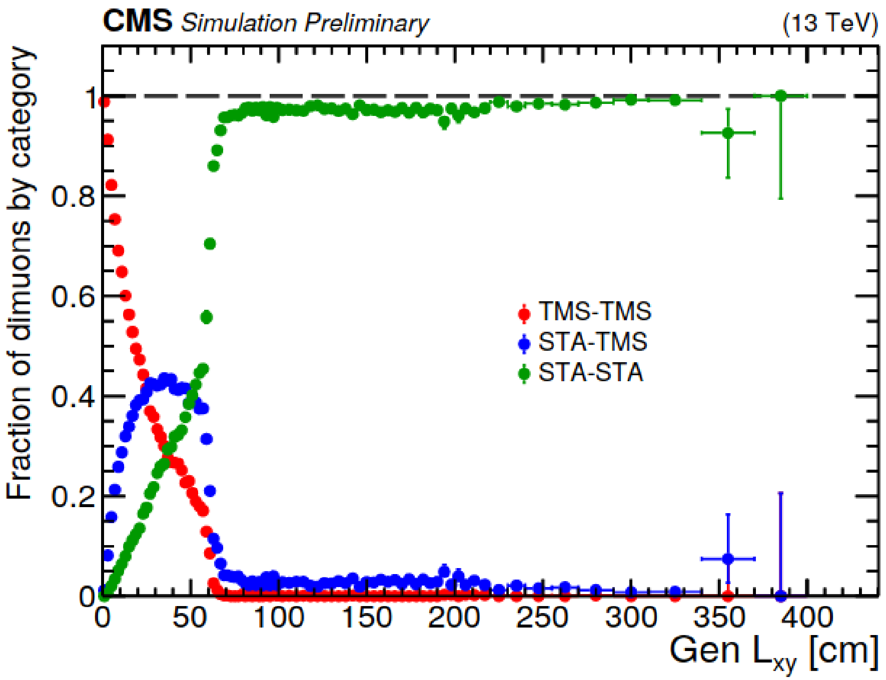
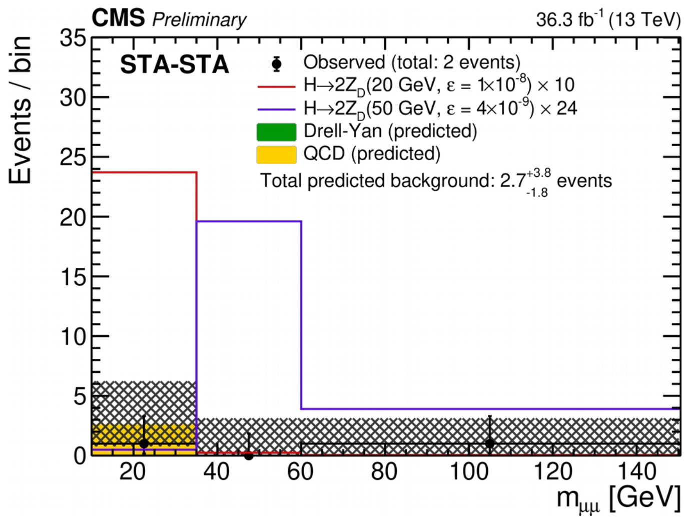


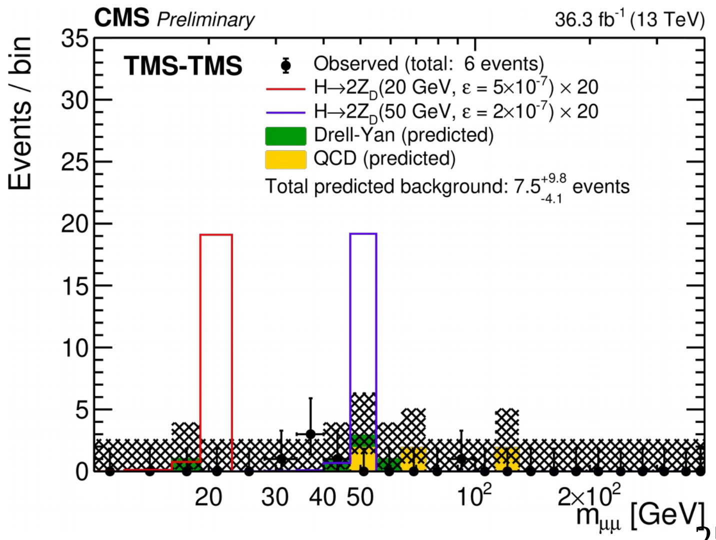
TMS: Muons reconstructed using tracker + muon system

STA: Stand-alone muon reconstruction with muon chamber

All backgrounds estimated from data





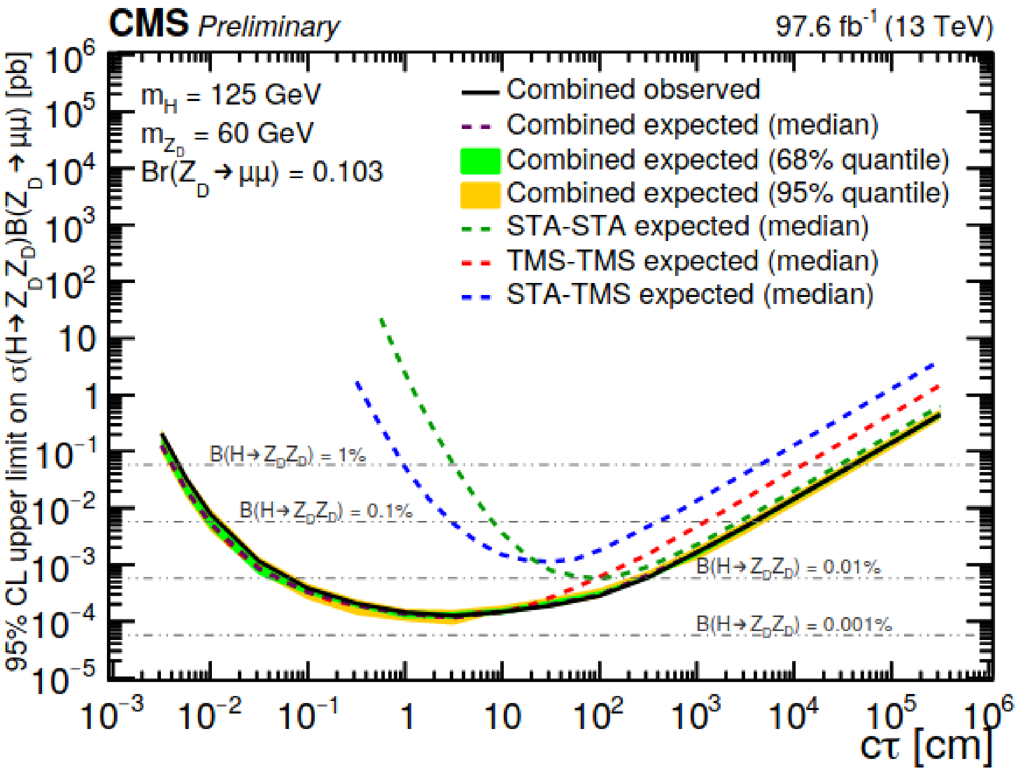


Data consistent with estimated background :(

Mangesh, Sebastian
Alberto, Ivan

Search for displaced dimuons

CMS-PAS-EXO-21-006



Sensitivity dominated by:

TMS-TMS category at low cτ

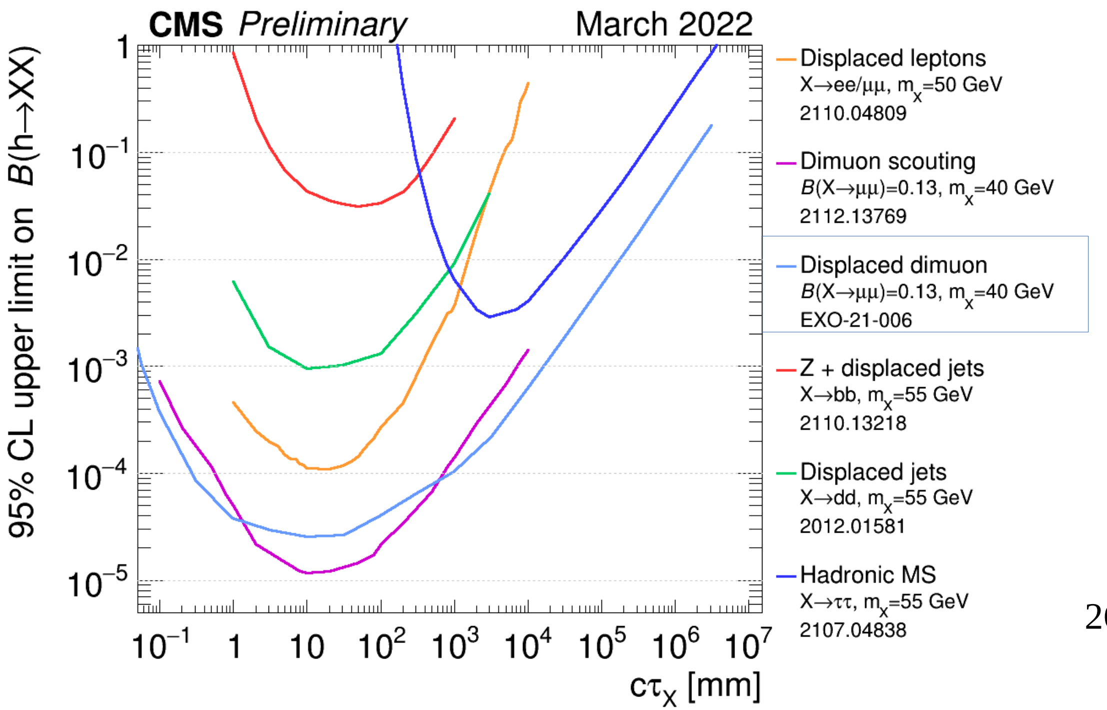
STA-STA category at high cτ

Results presented in Lepton-Photon 2022 & highlighted in Moriond EWK

← Constraints on dark photon model

EXO summary plots

Constraints also placed on BSM Higgs model [Φ→ X(→2u) X(→2f)] →

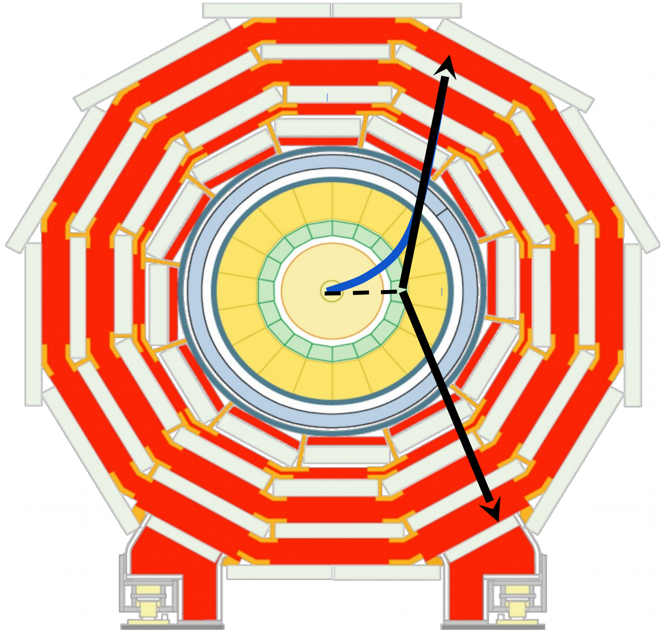


Most stringent limits on Higgs rare decays

at cτ < 0.05 & > 20 cm for for SM Higgs boson
& at all cτ for heavier Higgs bosons

Timeline:
Paper by LHCP 2022
Ramping up for Run 3

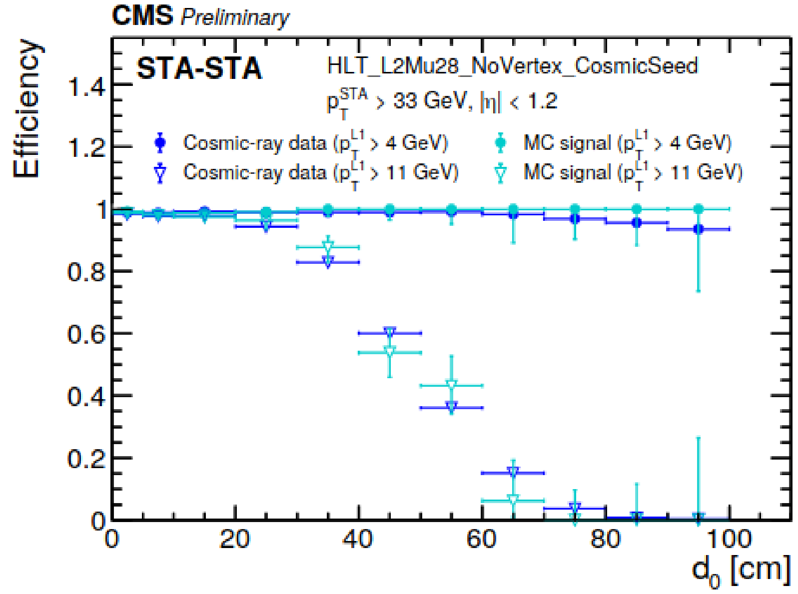
New triggers for displaced dimuon search in Run 3



Beam spot constraint at L1 trigger

↓

Lower efficiency for L1 muon trigger efficiency for larger displacement



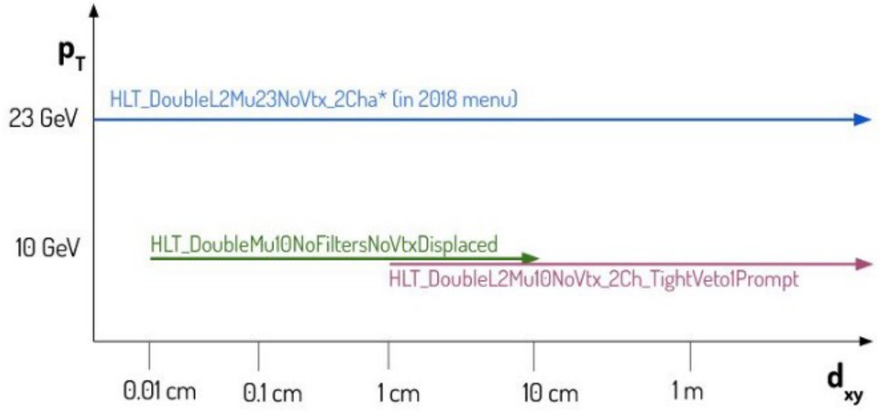
For Run 3

New L1 trigger algorithms removes beam spot constraint

→ Provides ‘unconstrained’ p_T and impact parameter (IP)

3x signal efficiency in signal region compared to Run 2 analysis!

New HLT paths for Run 3 in preparation!



Group is leading the efforts to develop hardware and software based displaced dimuon triggers in CMS

[More details in trigger report]

Measurements and searches in τ final states

Janik, Martin (Wolfgang A)

Terminated in close collaboration with R. Wolf (KIT)

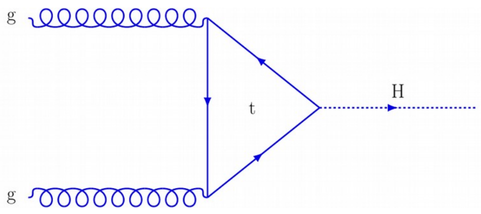
Higgs boson decaying to τ leptons

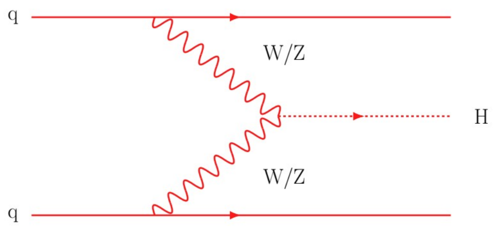
CMS-PAS-HIG-19-10

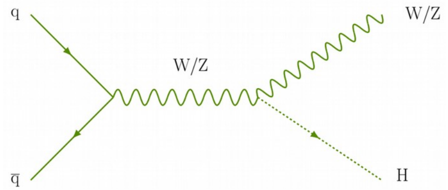
H → ττ

Decay mode used for the first direct observation of Higgs boson coupling to fermions!! Phys. Lett. B 779 (2018) 283

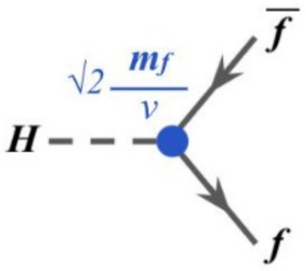
Production (targeted)

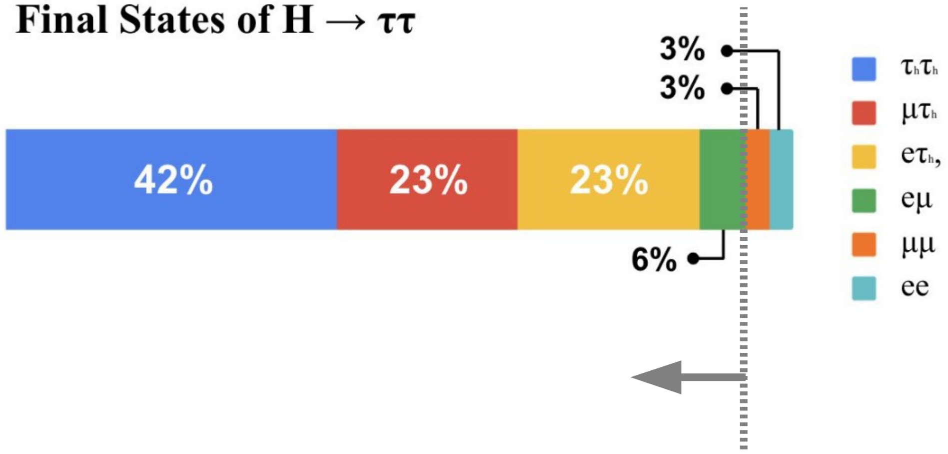






Decay



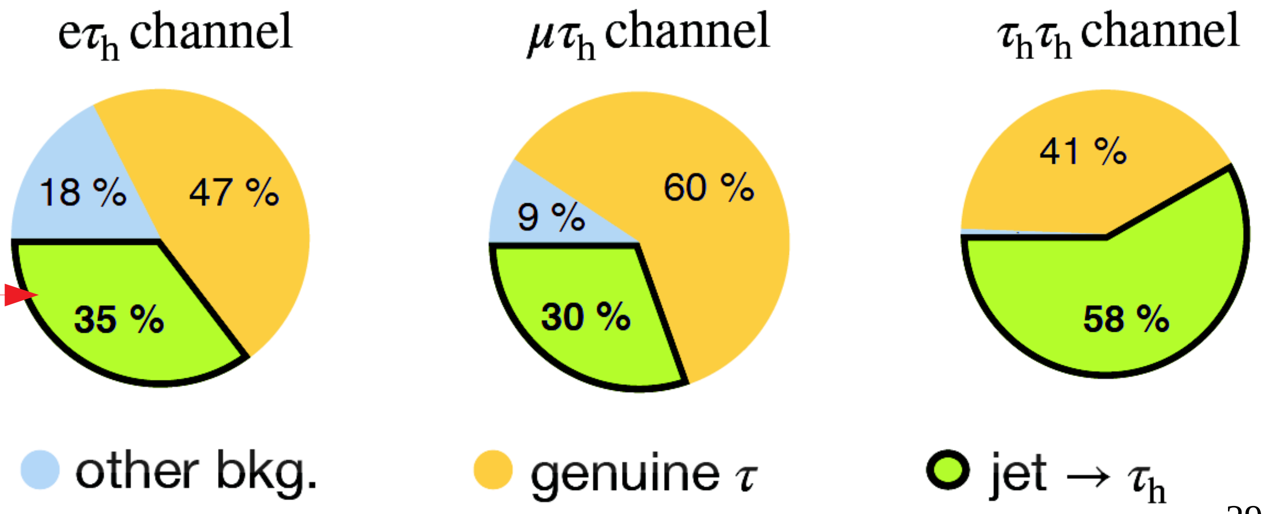


τ_h identification:

Using DNN-based algorithm

Jet faking as τ_h is an important background!

Estimation from simulation not reliable



(Numbers for collisions in 2018)

Jet → τ fake background in H → ττ

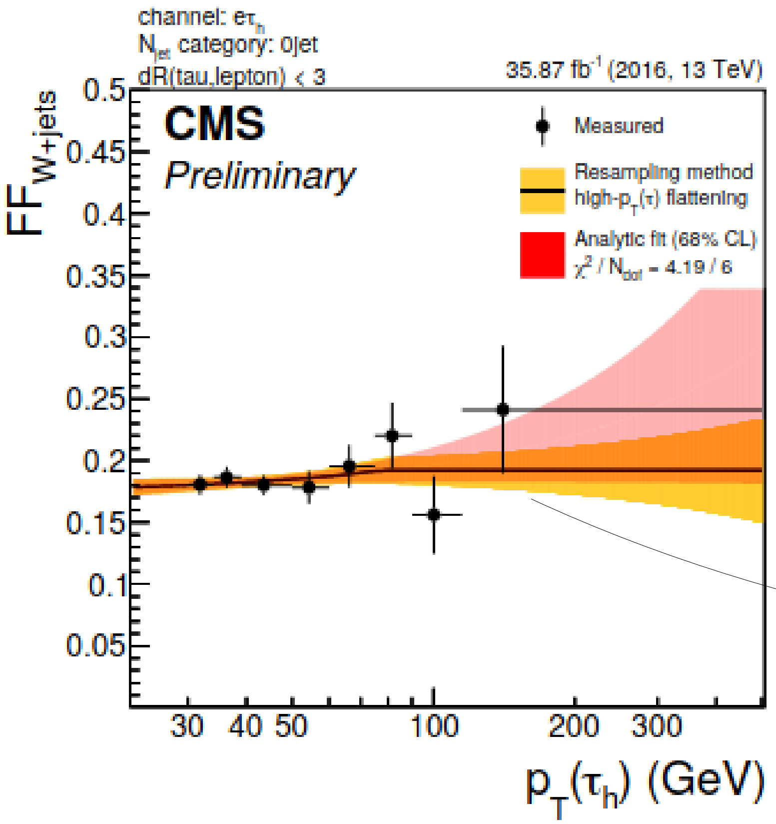
CMS-PAS-HIG-19-10

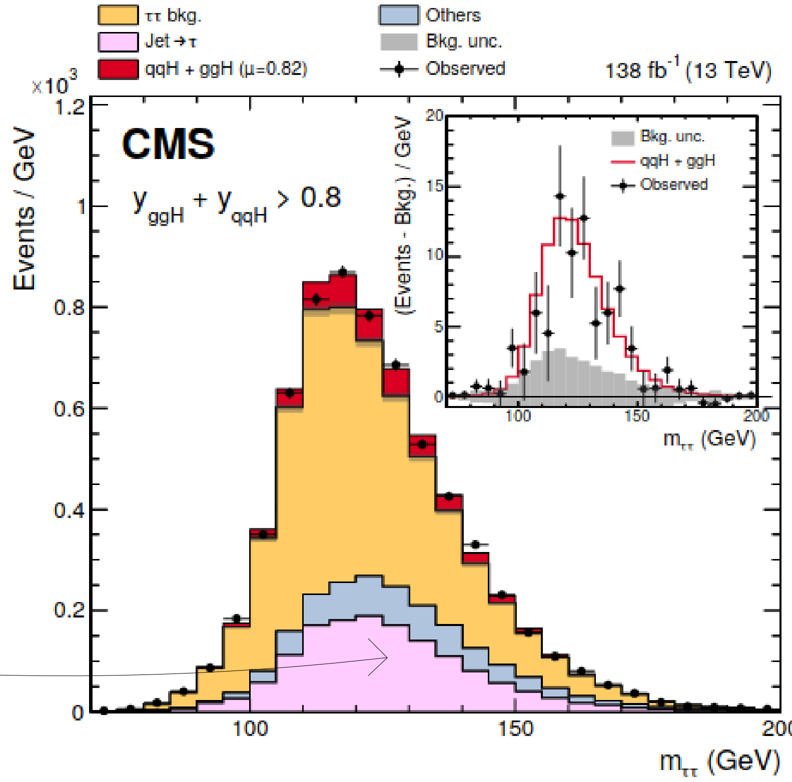
Terminated in close collaboration with R. Wolf (KIT)

Derive a *'fake factor'* = # of τ's passing a tight condtion (T) / # of τ's passing a loose cond. (L) & failing the tight cond.

in different control regions enriched in different bkg events

*Corrections applied to capture differences between signal & control regions





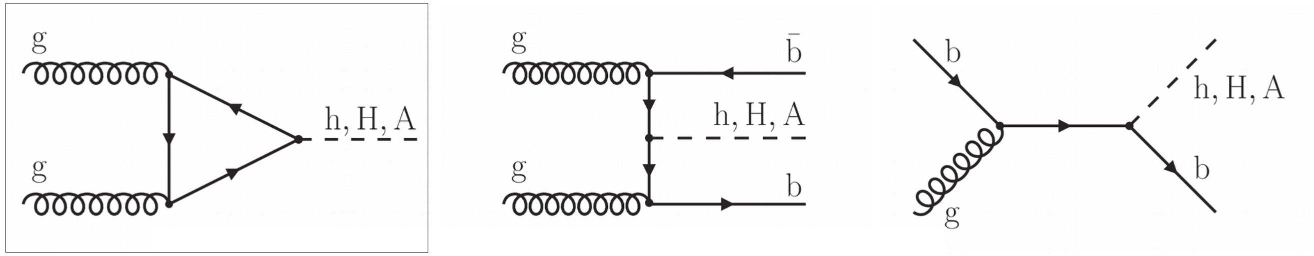
Observed Higgs boson signal compatible with SM at 95% confidence interval

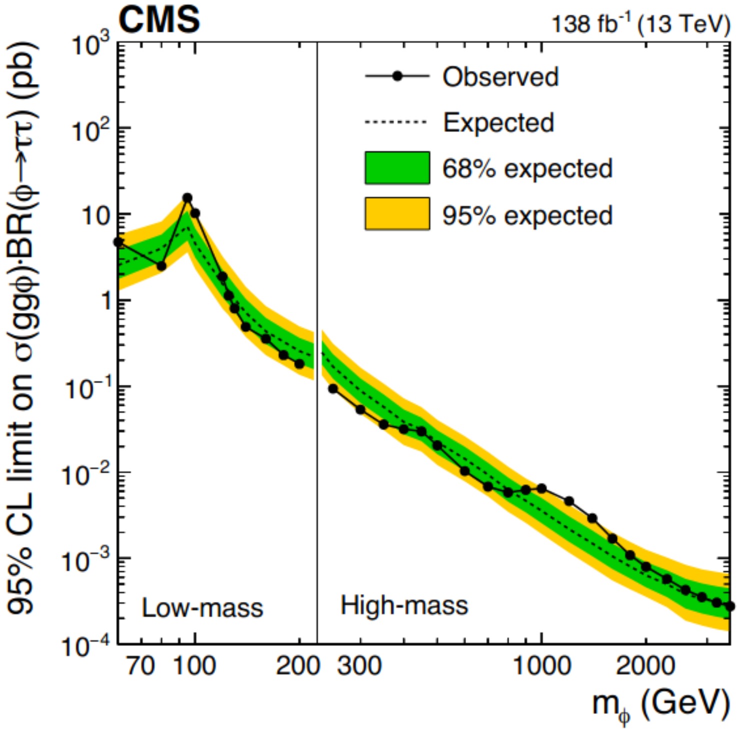
Jet → τ fake background in BSM searches

Fake factor technology re-used in searches for

Janik, Suman

BSM H → ττ CMS-PAS-HIG-21-001



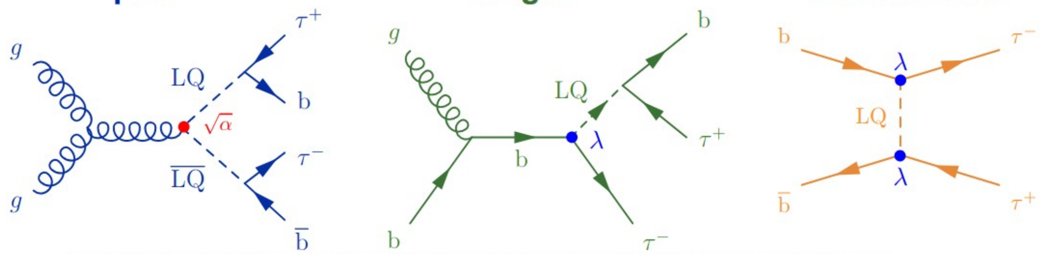


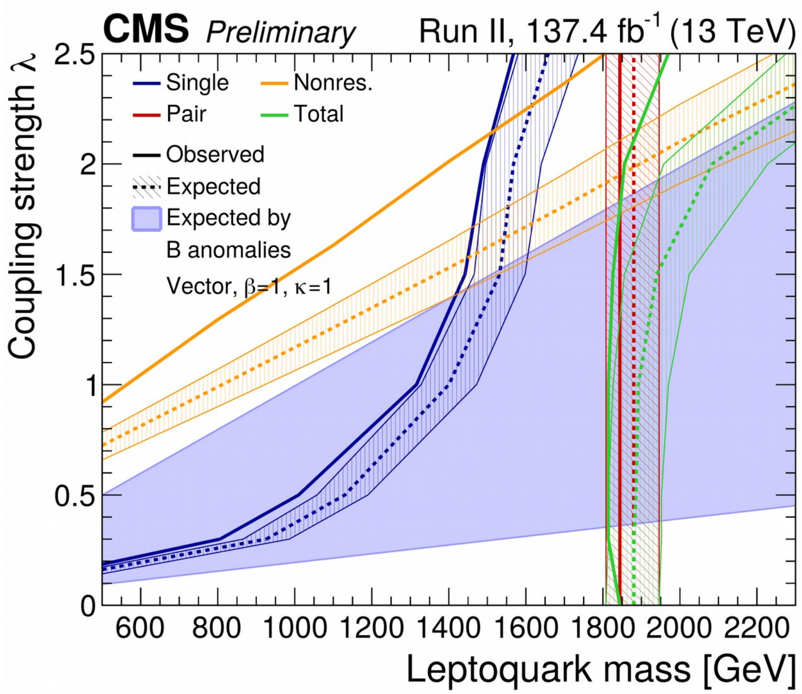
@ 100 GeV local (global) significance for ggΦ = 3.1 (2.7) σ
@ 1200 GeV local (global) significance for ggΦ = 2.8 (2.4) σ

Leptoquark

Janik, Ivan, Wolfgang A

Can explain deviation from LFU in b→ sll & b→clν transitions





Constraining regions in parameter space allowed by theory fit to flavor physics data [by Isidori group]

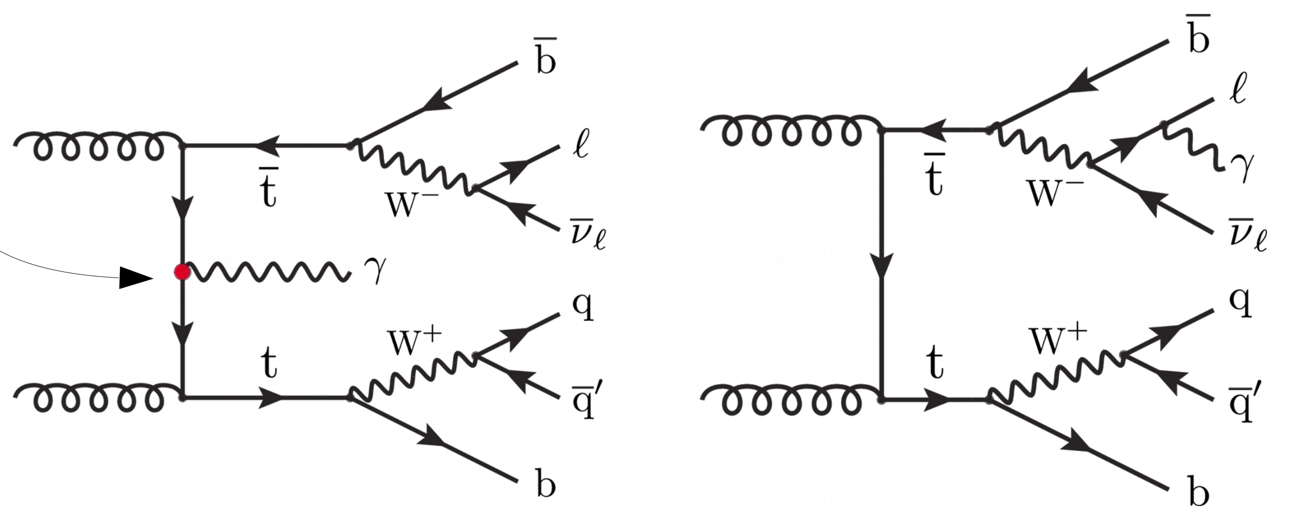
Precision measurements with top quarks (& effective field theory interpretation)

Lukas, Robert

Measurement of σ(ttγ) in ℓ+jets final state

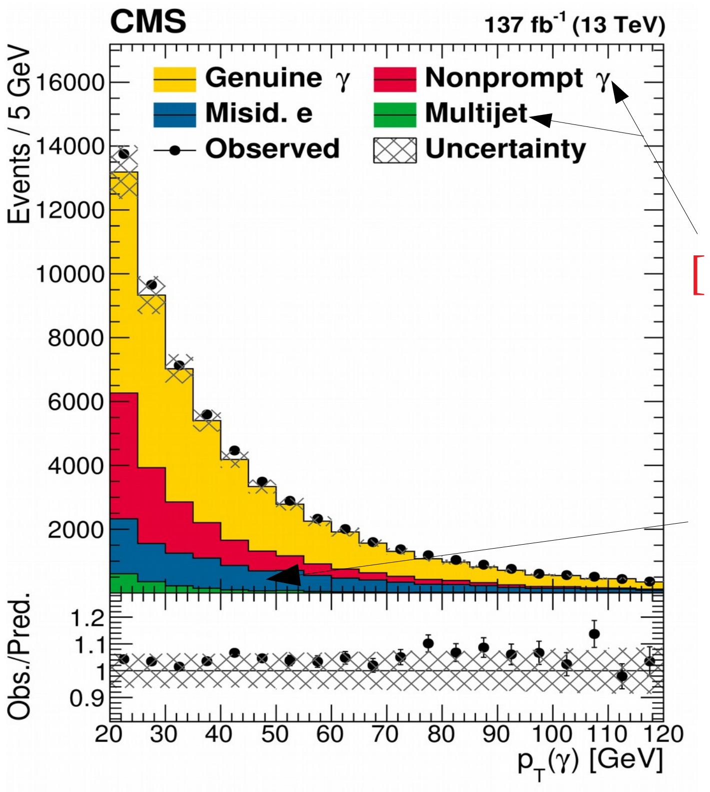
JHEP 12 (2021) 180

Direct measurement of top quark coupling to photon



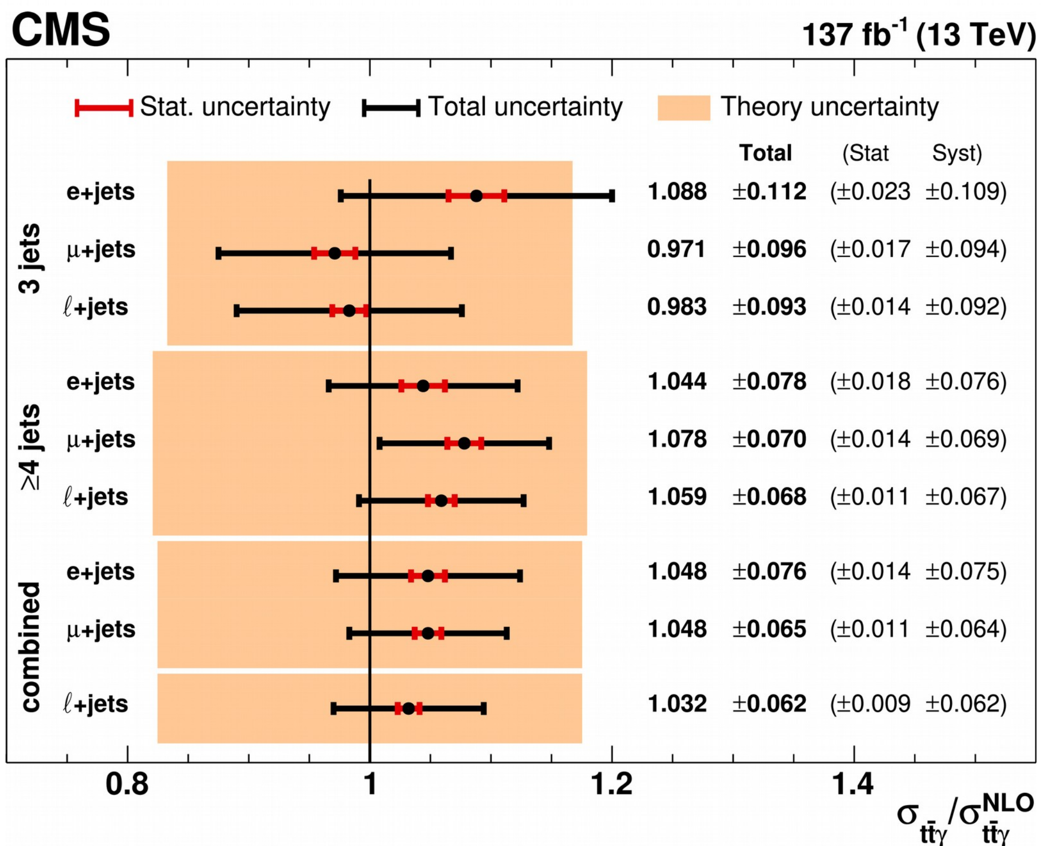
Signature:

1 isolated γ +1 isolated electron/muon
+
>=1 b-tagged jets+ >=3 jets



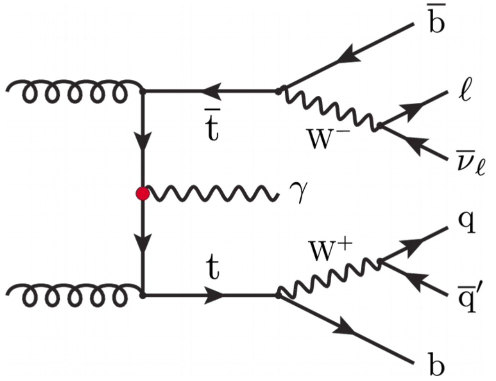
Entirely measured from data
[using shower shape variables]
[relaxing isolation criterion]

Simulation
+
data-based correction derived in Z(→ee)+jets control region



EFT interpretation of σ(ttγ) in ℓ+jets final state

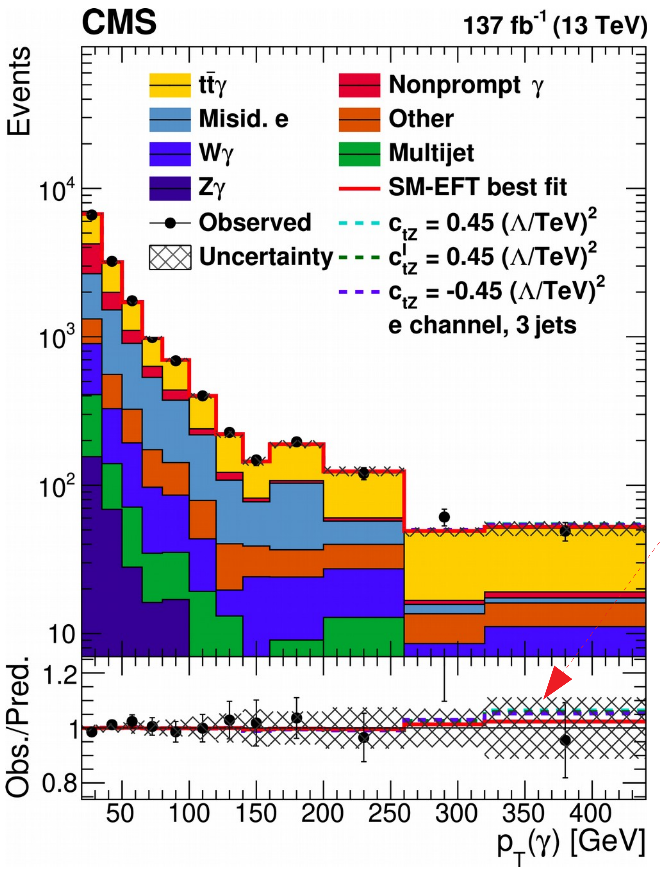
JHEP 12 (2021) 180



t-γ coupling modified by dim-6 dipole operators

$$O_{uW}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} \tau^I u_j)\, \tilde{\varphi} W^I_{\mu\nu}$$

$$O_{uB}^{(ij)} = (\bar{q}_i \sigma^{\mu\nu} u_j) \quad \tilde{\varphi} B_{\mu\nu}$$



Induce electroweak dipole moment of top quark & predict harder photon p_T spectrum

Probe of top quark compositeness

$$c_{tZ} = \mathrm{Re}\left(-\sin\theta_W C_{uB}^{(33)} + \cos\theta_W C_{uW}^{(33)}\right),$$

$$c^I_{tZ} = \mathrm{Im}\left(-\sin\theta_W C_{uB}^{(33)} + \cos\theta_W C_{uW}^{(33)}\right),$$

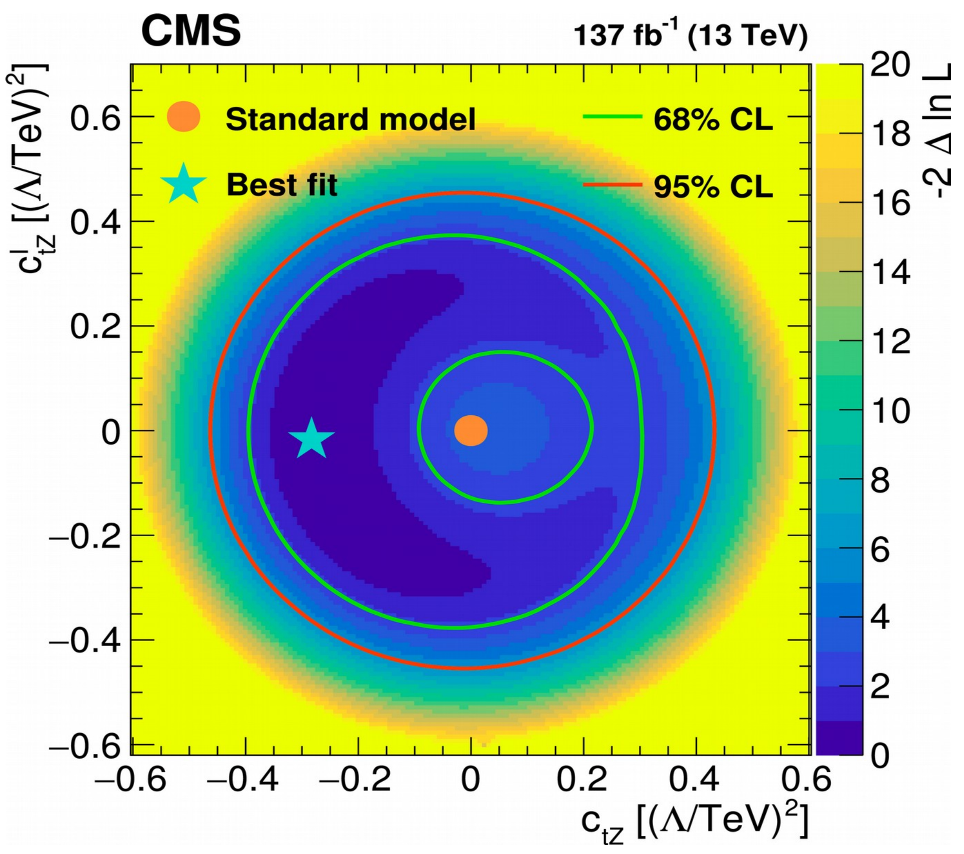
$$c_{t\gamma} = \mathrm{Re}\left(\cos\theta_W C_{uB}^{(33)} + \sin\theta_W C_{uW}^{(33)}\right),$$

$$c^I_{t\gamma} = \mathrm{Im}\left(\cos\theta_W C_{uB}^{(33)} + \sin\theta_W C_{uW}^{(33)}\right),$$

$$C_{uW}^{(33)} = 0$$

Ensures SM Wtb vertex

Constraints placed on 2-D plane of EFT coefficients



Lukas, Robert

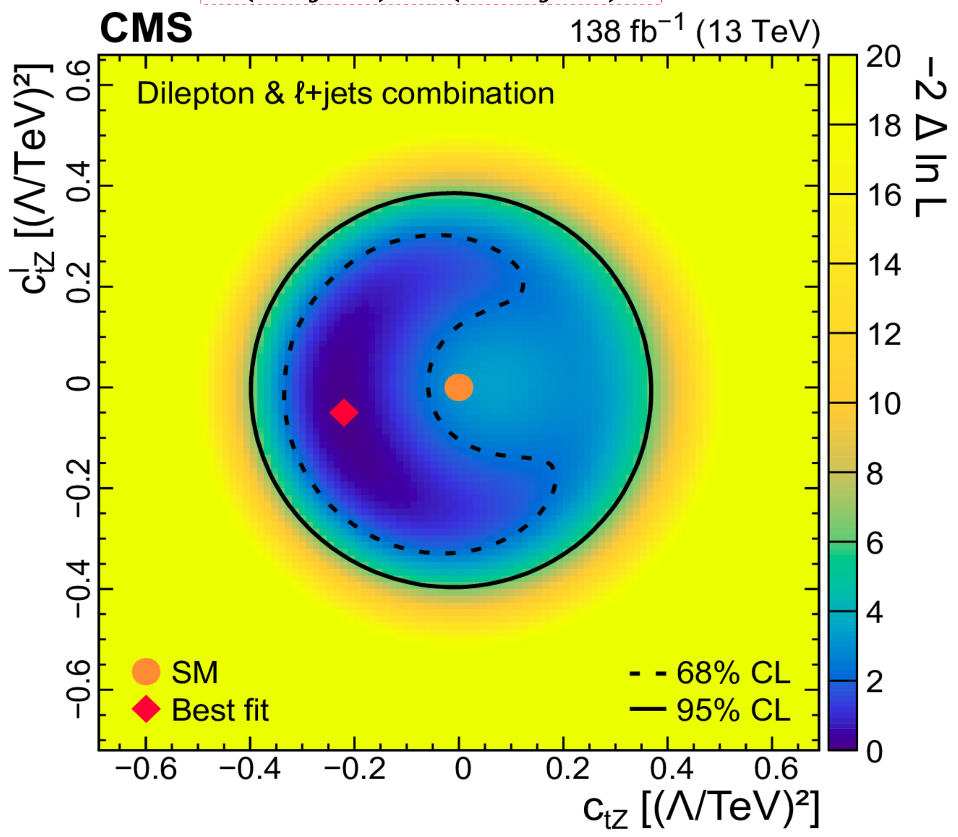
EFT interpretation of σ(ttγ)

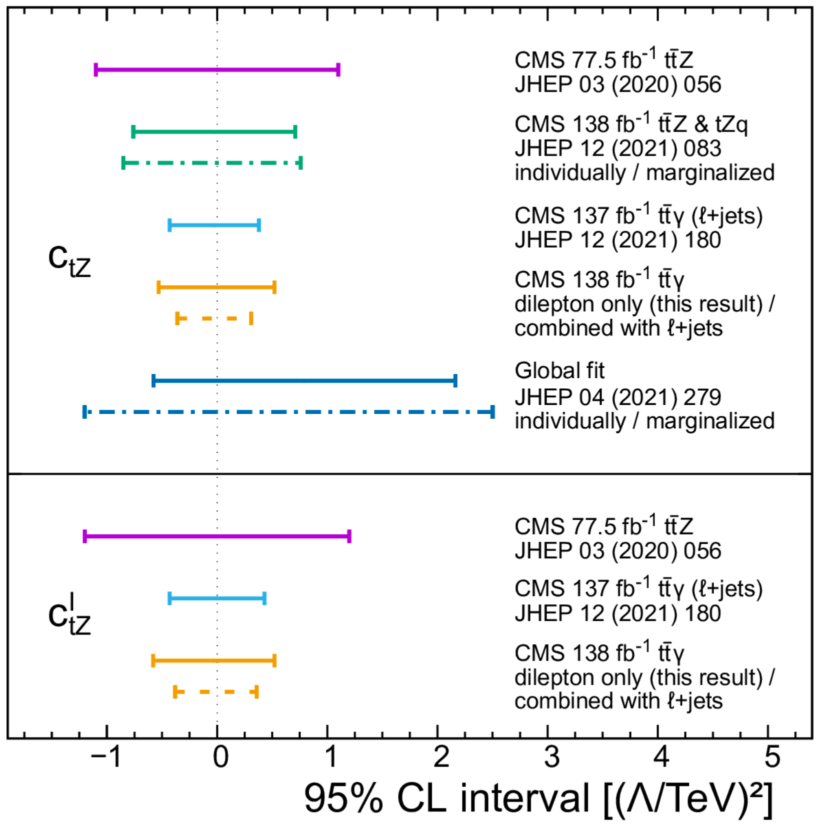
arXiv: 2201.07301

Submitted to JHEP

Results combined with similar analysis in di-leptonic final state

(l+jets) + (2l+jets)





Combined results dominated by l+jets analysis

→ Most stringent constraints on top quark magnetic dipole operators from ATLAS and CMS measurements

Flavor structure of vector couplings in SMEFT

Target: Measure flavor structure of vector coupling operators at dim-6

Hints of violation of lepton flavor universality from flavor factories & (g-2)

→ Is flavor universality respected in quark sector (modulo Yukawa int.) at D-6?

$$\mathcal{O}^{(1)}_{Hq} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{q}\gamma^\mu q \qquad \mathcal{O}_{Hu} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{u}_R\gamma^\mu u_R$$

$$\mathcal{O}^{(3)}_{Hq} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q}\sigma^a\gamma^\mu q \qquad \mathcal{O}_{Hd} = iH^\dagger \overleftrightarrow{D}_\mu H \bar{d}_R\gamma^\mu d_R$$

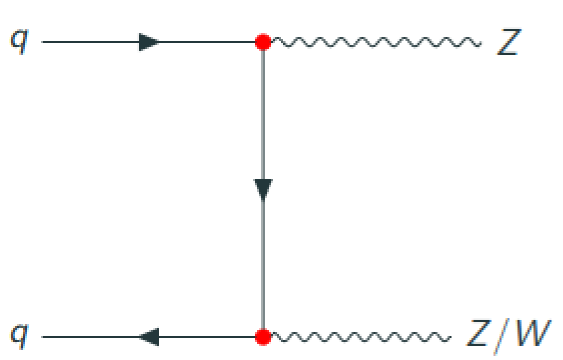
(w/ left-handed quarks) (w/ right-handed quarks)

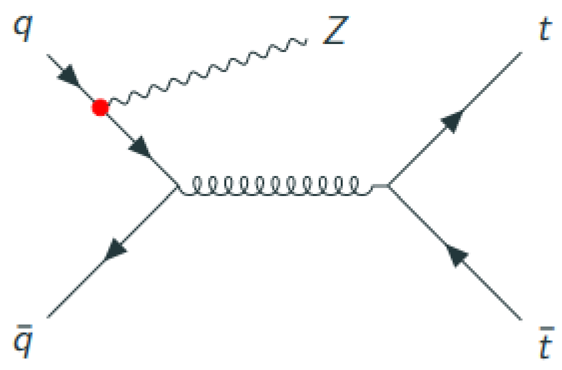
	$C^{(1)}_{\phi q}$	$C^{(3)}_{\phi q}$
ii	a	a
33	$a + by_t^2$	$a + by_t^2$

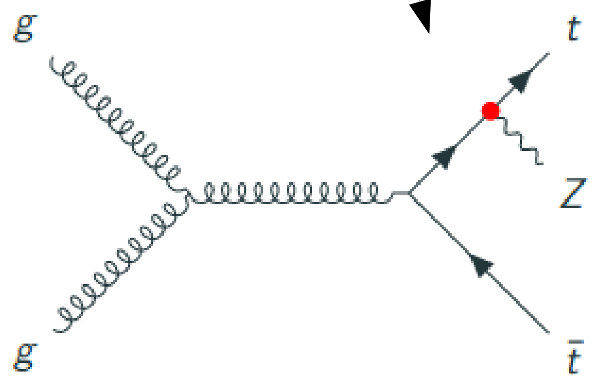
arXiv: 2101.07273

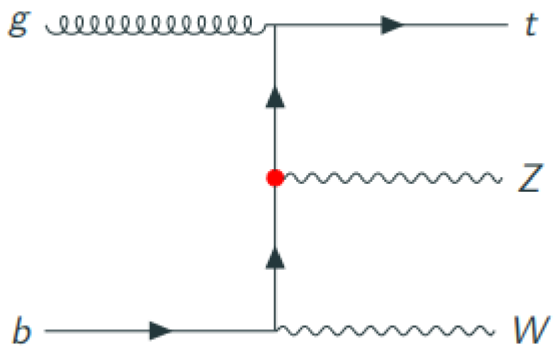
Probe light quark couplings in diboson & ttZ productions

Measure top quark couplings in tWZ & ttZ productions





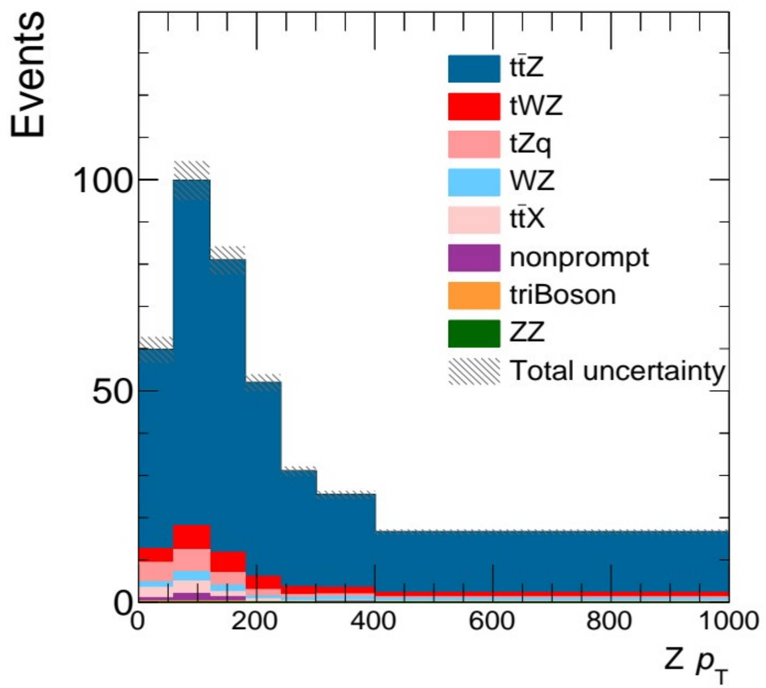




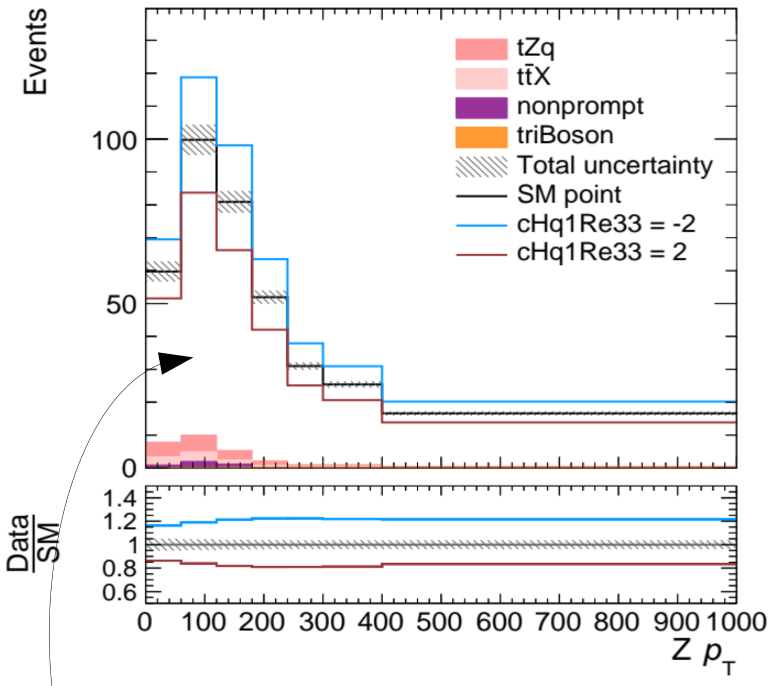
Flavor structure of vector couplings in SMEFT

Fiducial regions defined by conditions on reconstructed objects (independent of EFT hypothesis)

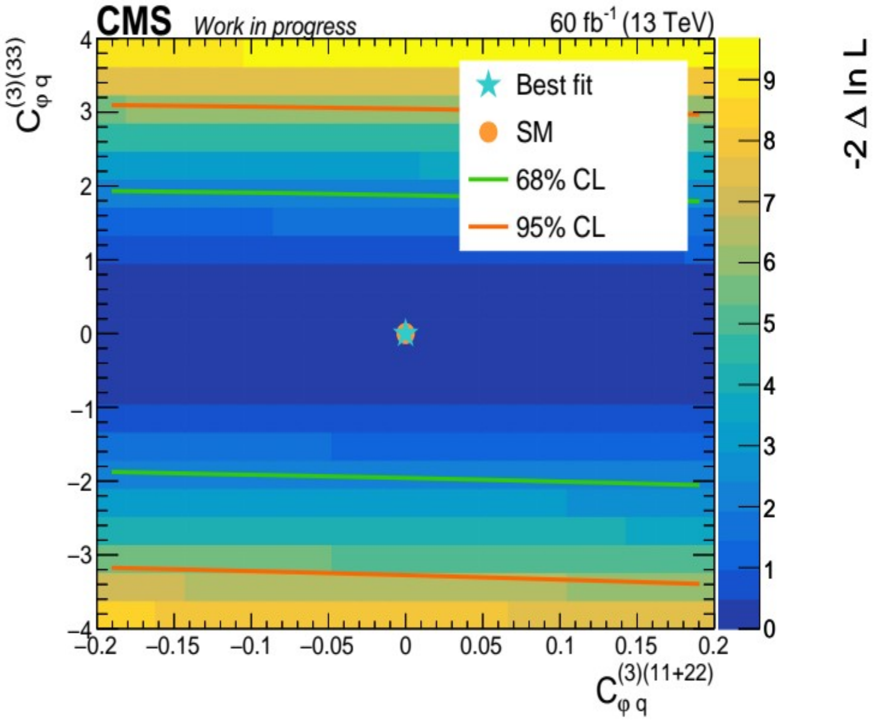
ttZ region



Pure ttZ region



Simultaneous EFT for ttZ, WZ, ZZ



Constrains heavy-quark operators

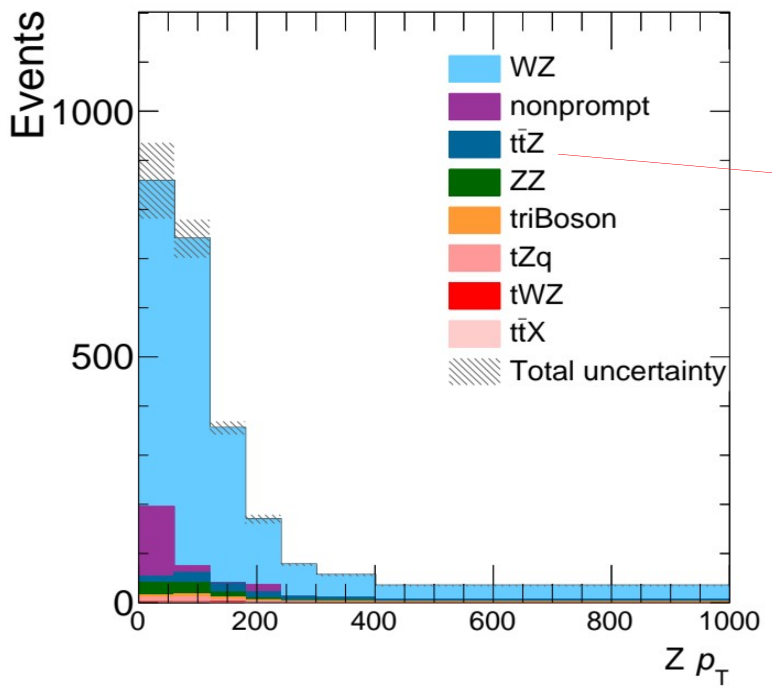
ttZ +WZ + ZZ + tWZ

Dennis, Robert

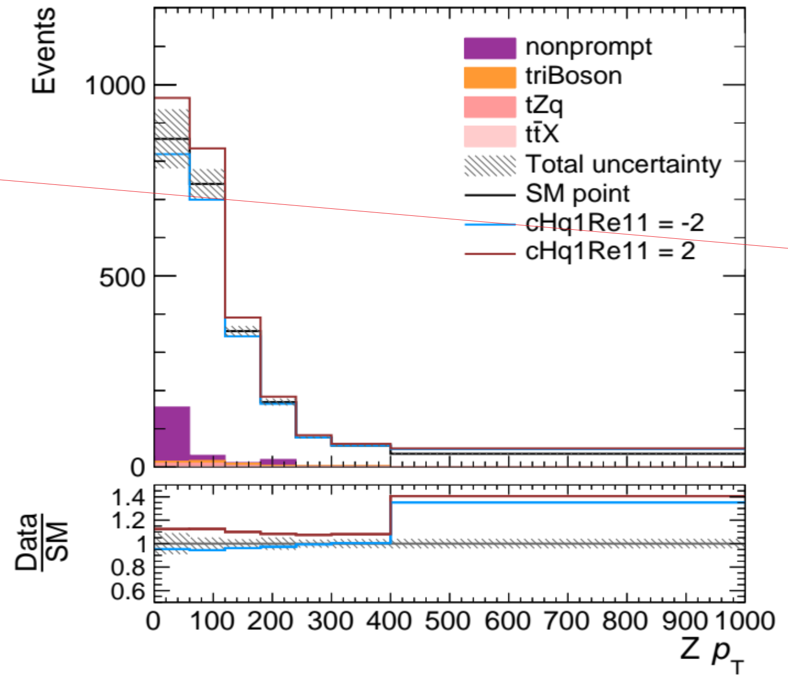
Flavor structure of vector couplings in SMEFT

Fiducial regions defined by conditions on reconstructed objects (independent of EFT hypothesis)

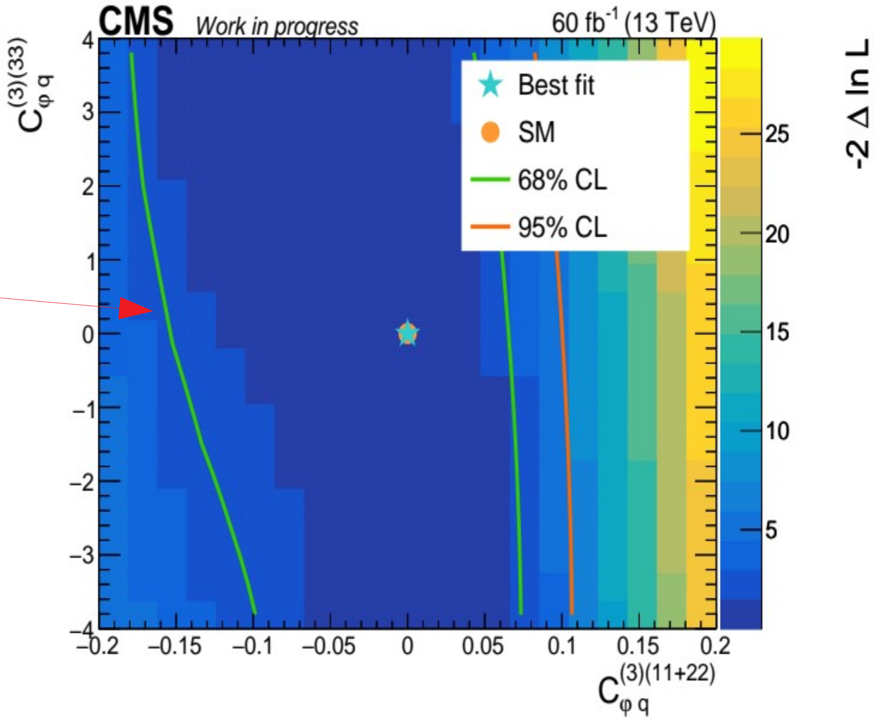
WZ region



Pure WZ region



Simultaneous EFT for ttZ, WZ, ZZ



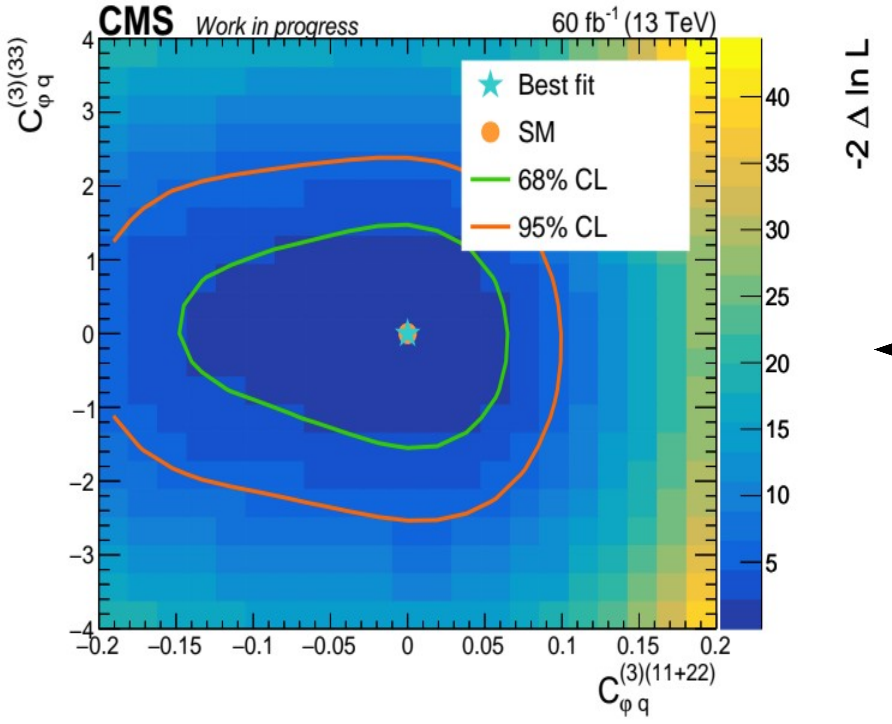
Constrains light-quark operators

Similar results in ZZ region

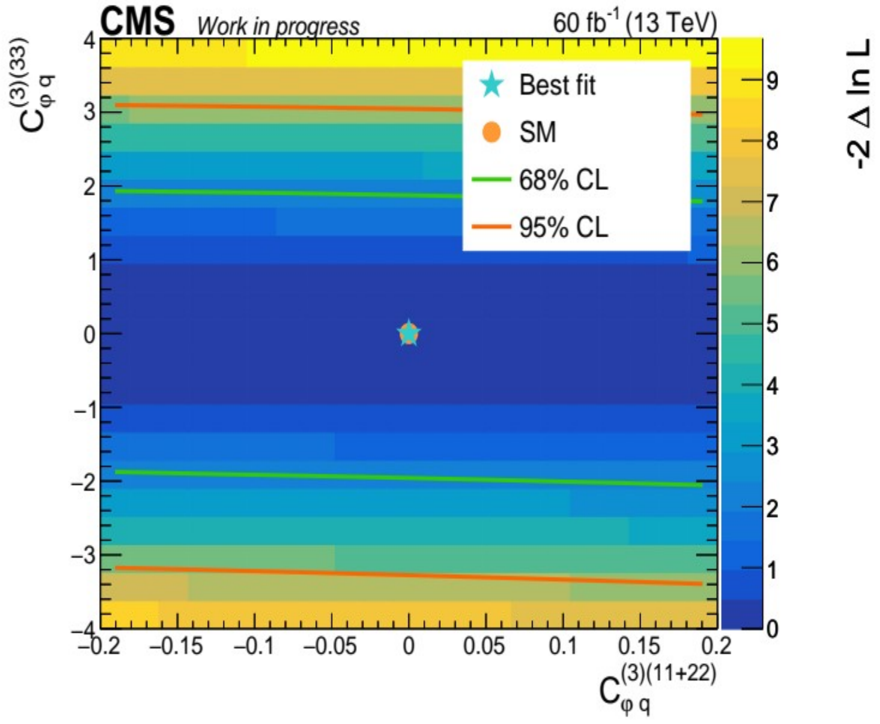
Effect of small ttZ contamination in WZ region

Flavor structure of vector couplings in SMEFT

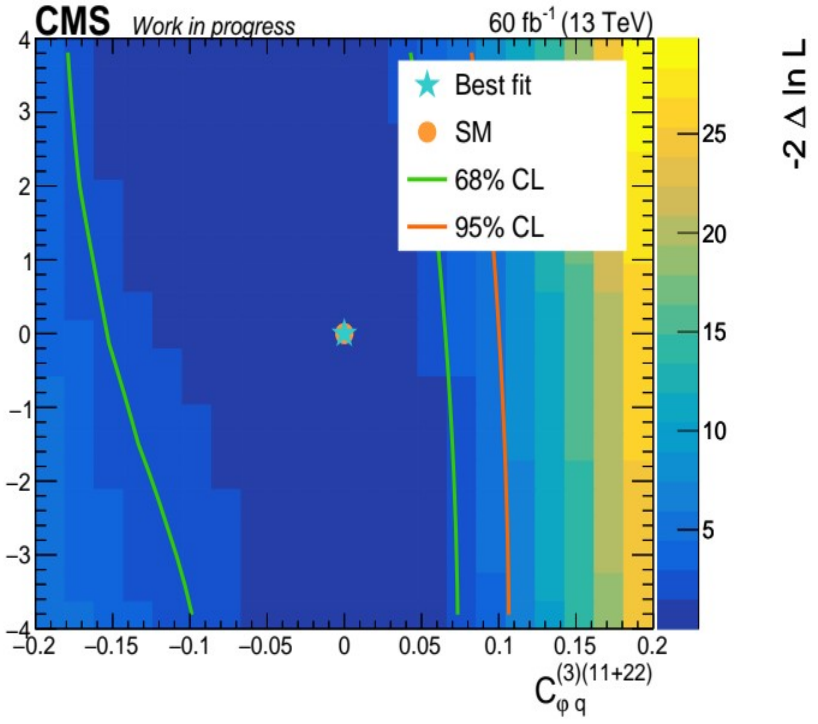
ttZ+WZ regions



ttZ region



WZ region



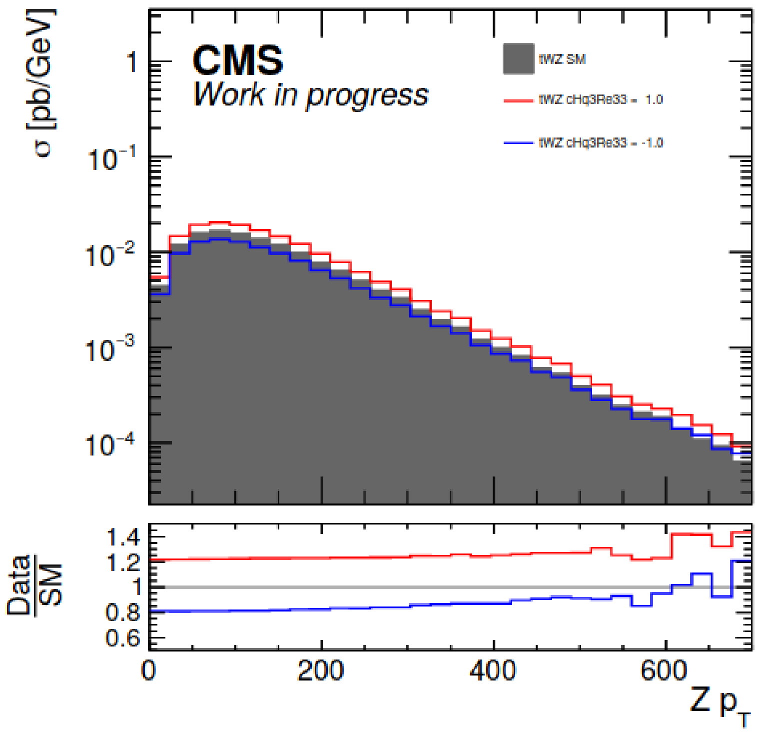
Together constrain light & heavy quark couplings

Dennis, Robert

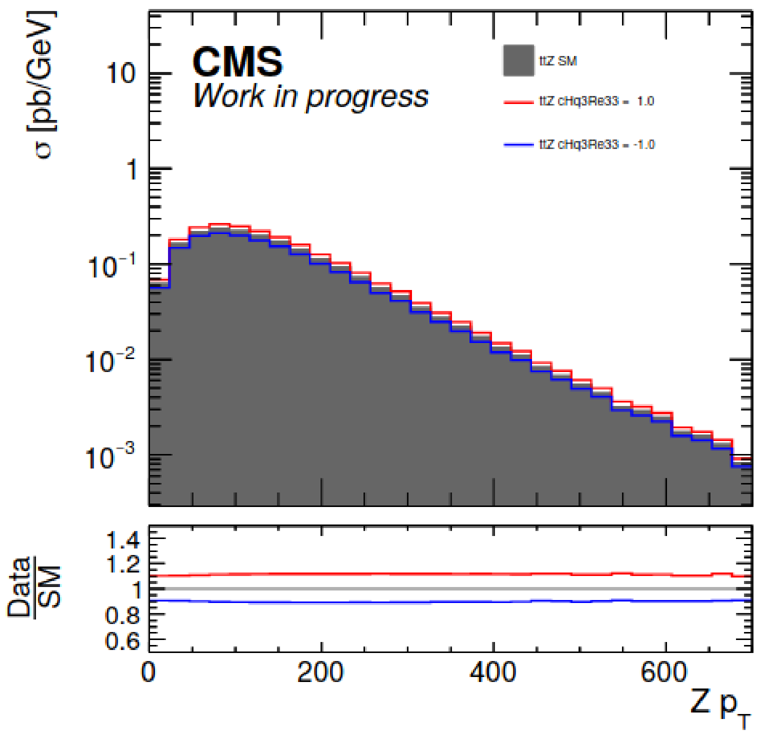
Flavor structure of vector couplings in SMEFT

The tWZ process boosts sensitivity to third generation coupling

tWZ



$t\bar{t}Z$



$\sigma_{tWZ} << \sigma_{ttZ}$ → much lower statistics for tWZ (not yet observed!)

Difficult to gain additional sensitivity from tWZ in LHC Run-2

Still larger impact of EFT operators makes it an important baseline for LHC Run-3 & HL-LHC

Timeline:
Winter 2022 (Run 2 analysis)
Plan to continue in Run 3

Mass measurement of jets from boosted top quarks

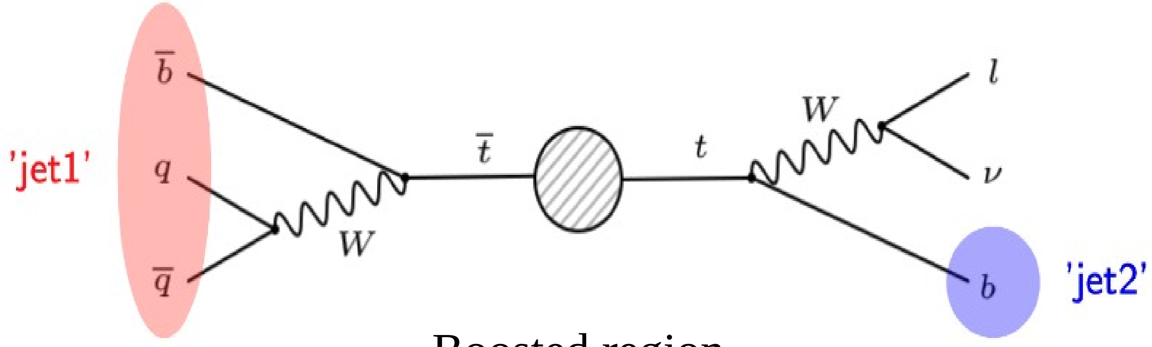
Event sample:

t (→ b j j) t (→ b l ν) production

Top quarks with large p_T → Decay products merged into a single large-area jet

Cons: Smaller statistics

Pros: Reduction of uncertainty from color reconnection



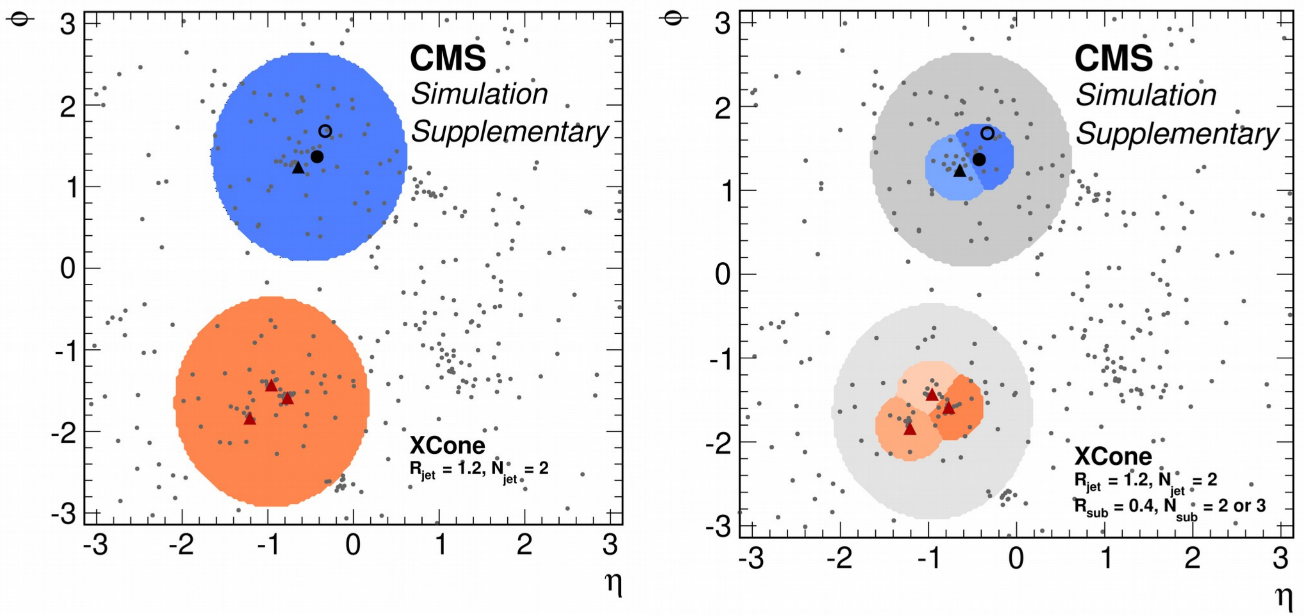
Boosted region

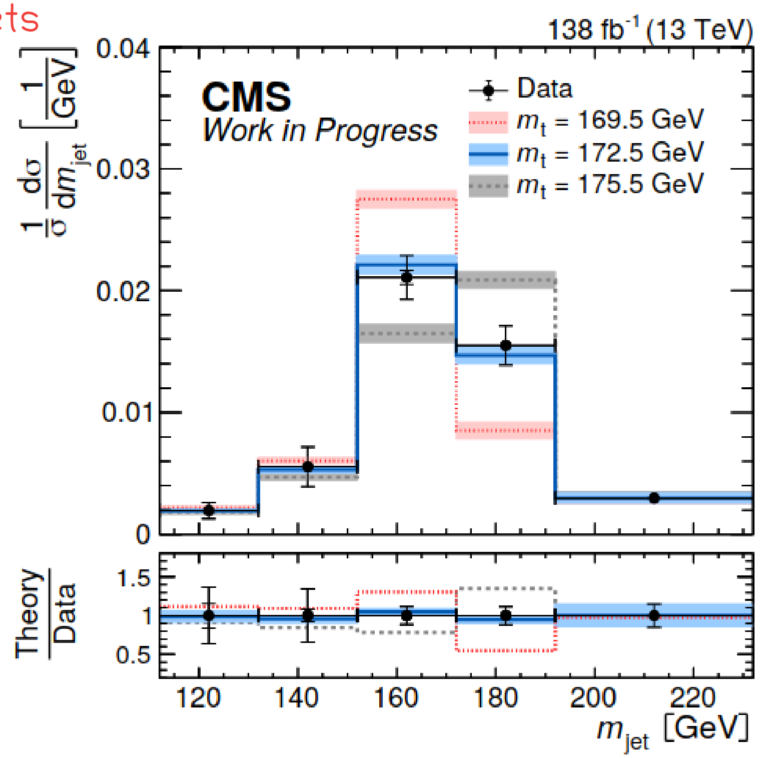
Jet reconstruction using XCone algorithm JHEP 11 (2015) 072

→ 2 circular large jets, each with 3 subjets

Large jet mass = Invariant mass of 3 subjets

Dedicated calibration reduces systematic uncertainty compared to previous measurement using 2016 data





Mass measurement of jets from boosted top quarks

New ideas from theorists (J. Holguin, I. Moult, A. Pathak, M. Procura)

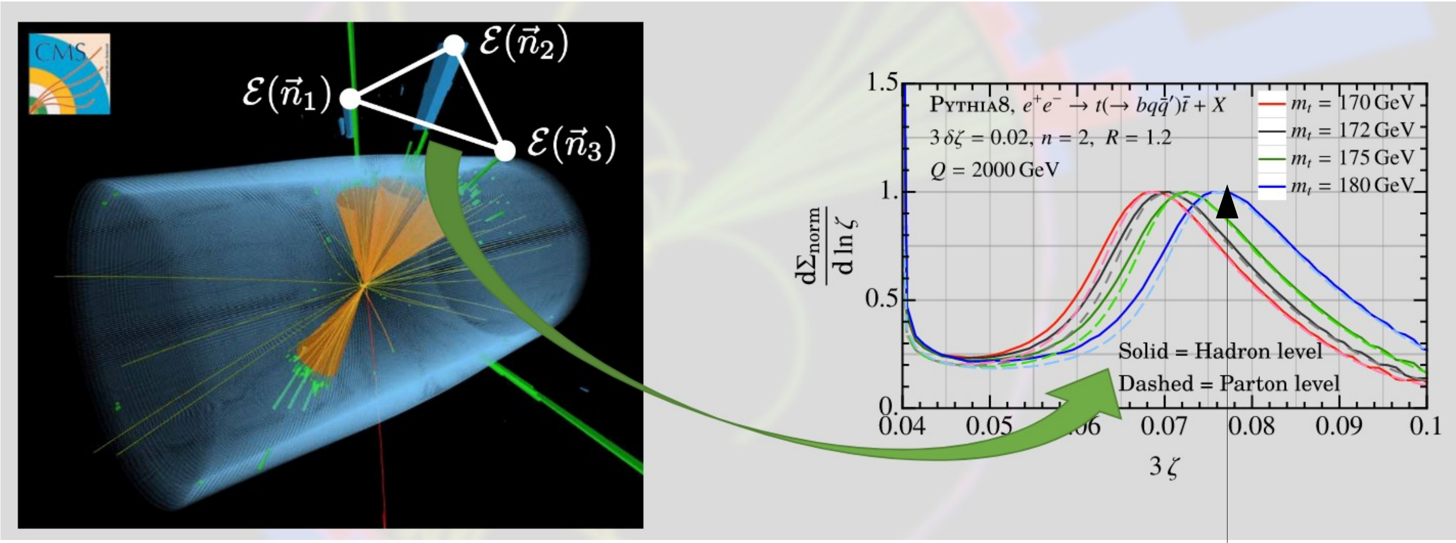
Measurement of top quark pole mass using energy weighted correlators

Why?

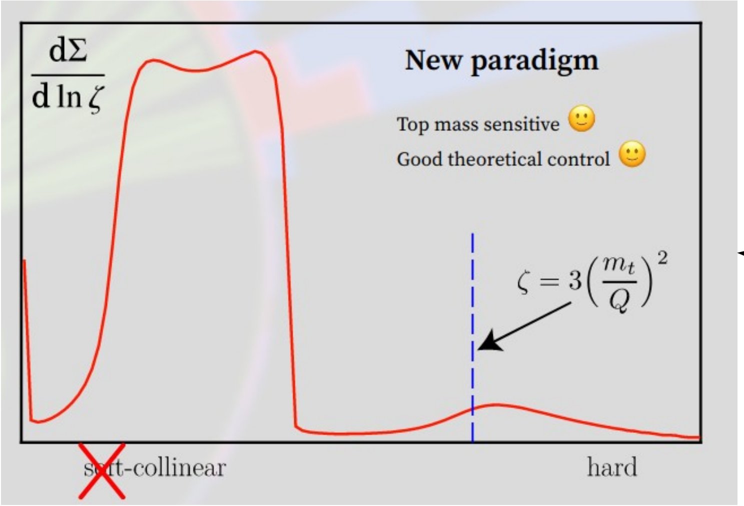
arXiv: 2201.08393

Direct mass measurement in experiment → MC mass

Determining pole mass from MC mass: theoretical uncertainty of 1 GeV



$$\zeta^{(pp)}_{\mathrm{peak}} \approx 3m_t^2/p_{T,t}^2$$



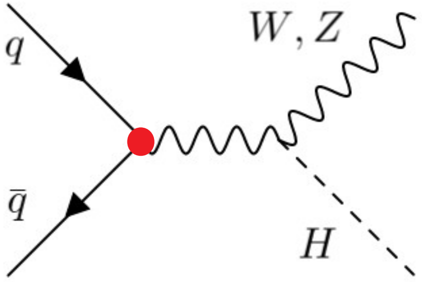
Access to the region → Sensitive to top mass
→ Theoretically clean

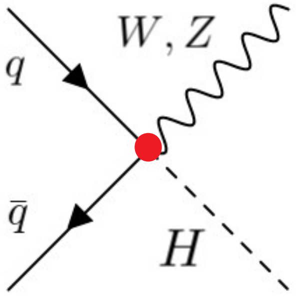
Advertisement for a M.Sc. student

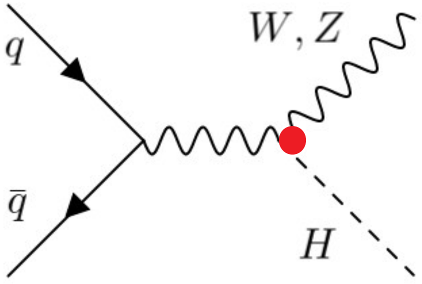
Effective field theory interpretation in Higgs boson measurements

Suman, Robert

Illuminating SMEFT with Higgs radiation







$$\mathcal{O}^{(3)}_{Hq} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q} \sigma^a \gamma^\mu q$$

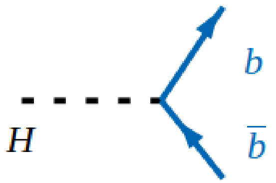
$$\mathcal{O}_{HW} = |H|^2 W_{\mu\nu} W^{\mu\nu}$$

$$\mathcal{O}_{H\tilde{W}} = |H|^2 W^a_{\mu\nu} \tilde{W}^{a\mu\nu}$$

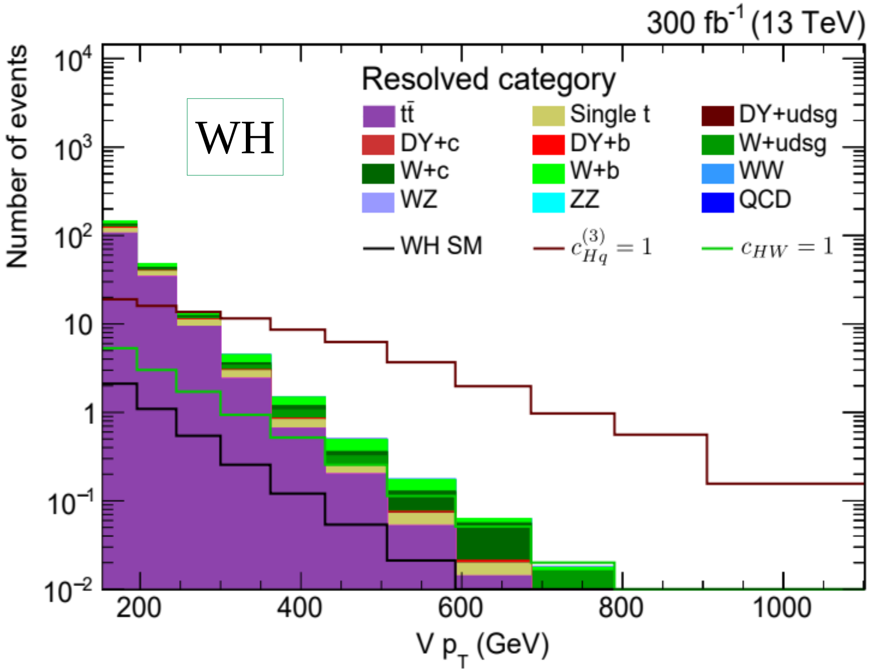
Accessible only @LHC

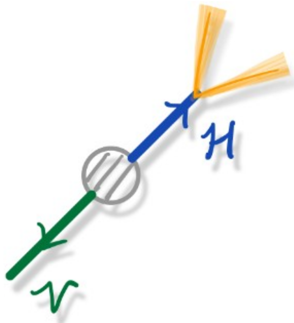
Final states considered

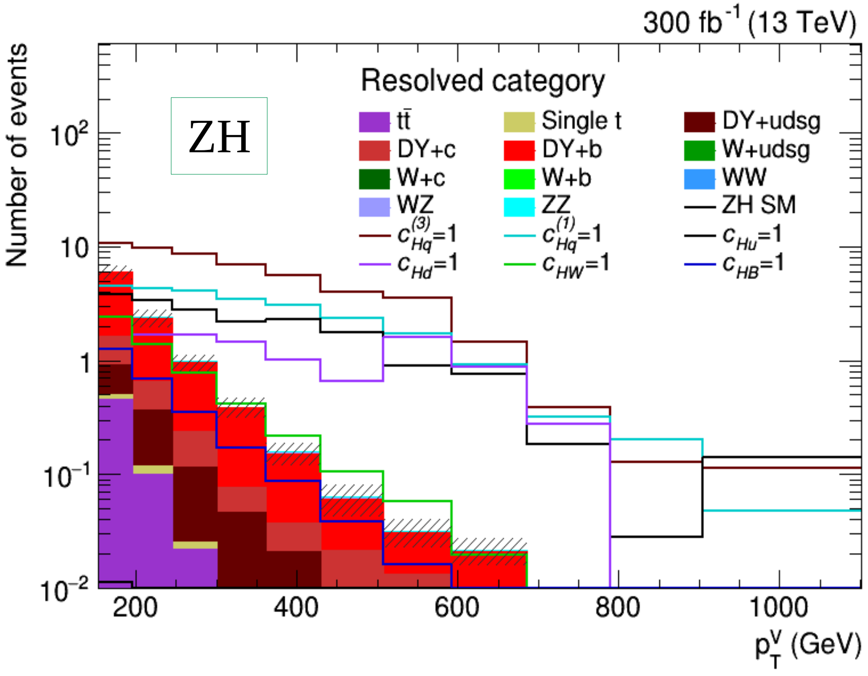
$W^\pm(\to lep.), Z(\to lep.)$



VH signal separated from bkg using DNN





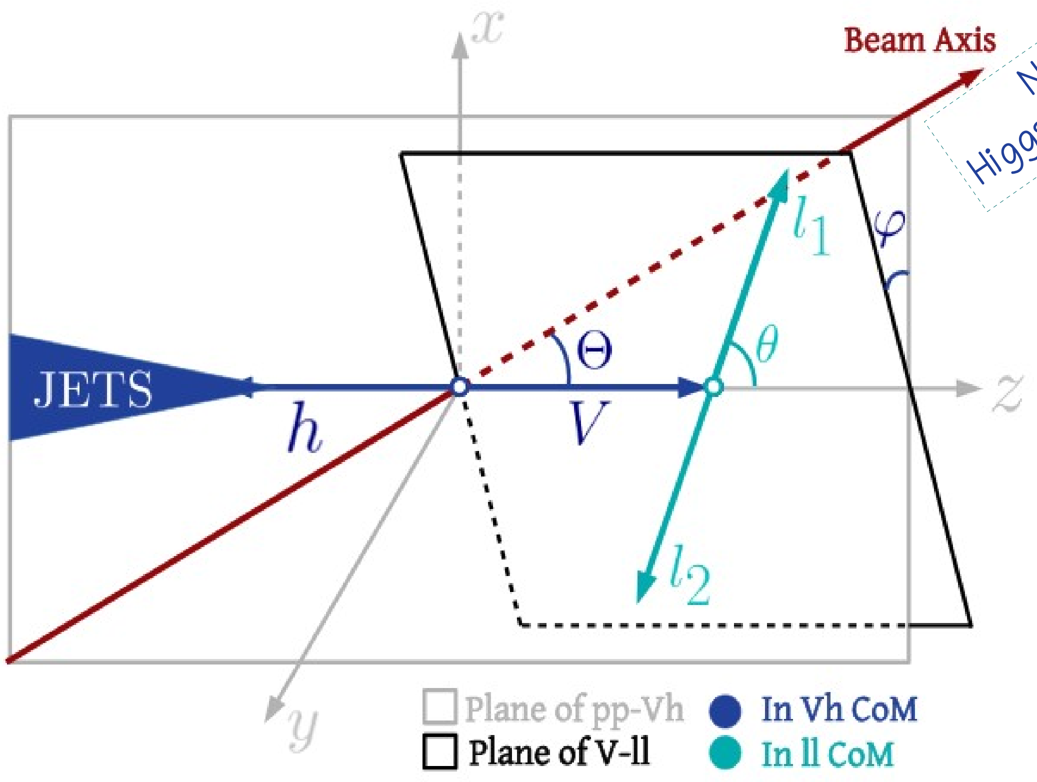


EFT effects grow with energy

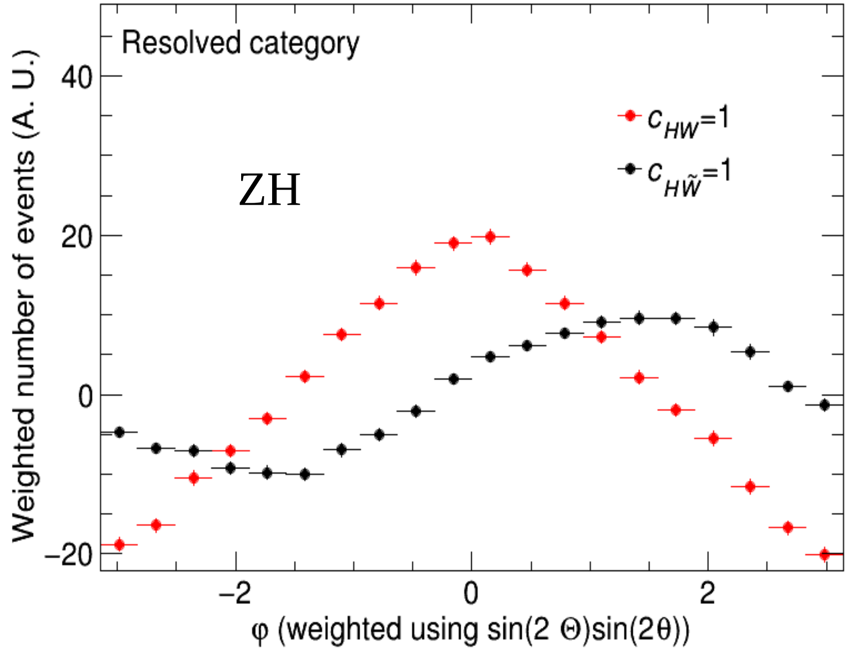
Illuminating SMEFT with Higgs radiation

Use of multi-dimensional event information:

Angles in V & V+H C.O.M. frames



Not yet considered in Higgs analyses in ATLAS & CMS



Extract additional features of SMEFT operators

+

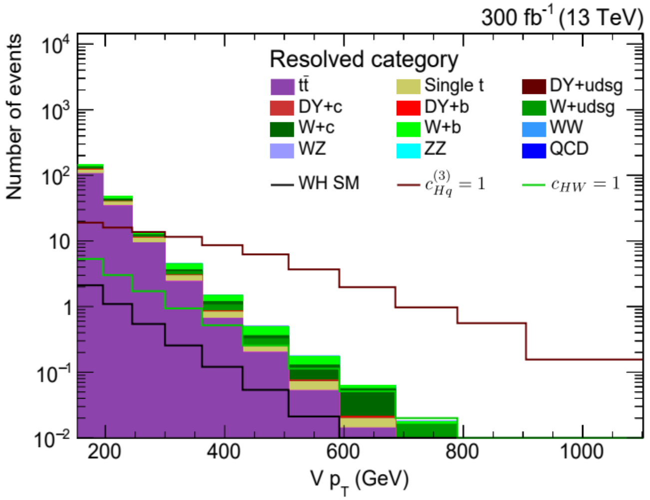
Introduces CP-sensitivity (lost in cross section measurements)

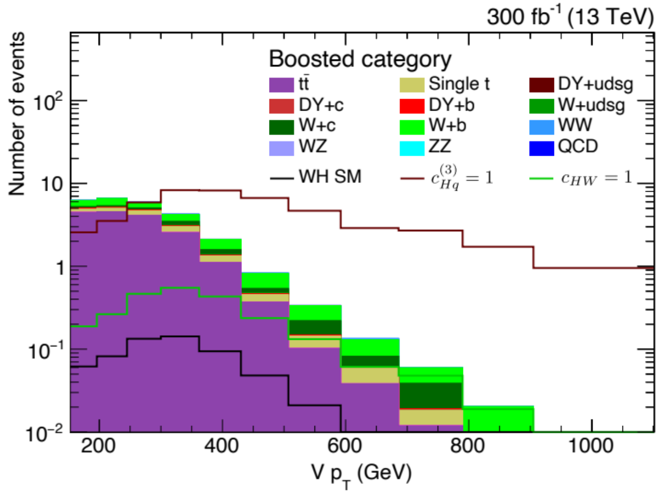
Nice separation of CP-even & -odd operators' effects

Suman, Robert

Illuminating SMEFT with Higgs radiation

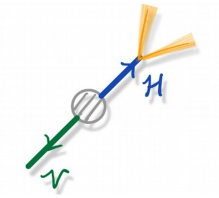
Preliminary sensitivity results obtained for Run-2 + Run-3 integrated luminosity (~300 fb-1)



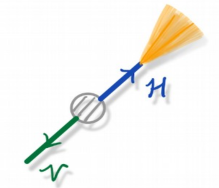


Resolved cat. [WH]
Resolved cat. (ϕ bins) [WH]
Resolved+boosted cat. (ϕ bins) [WH]
Resolved+boosted cat. (ϕ bins) [WH+ZH]

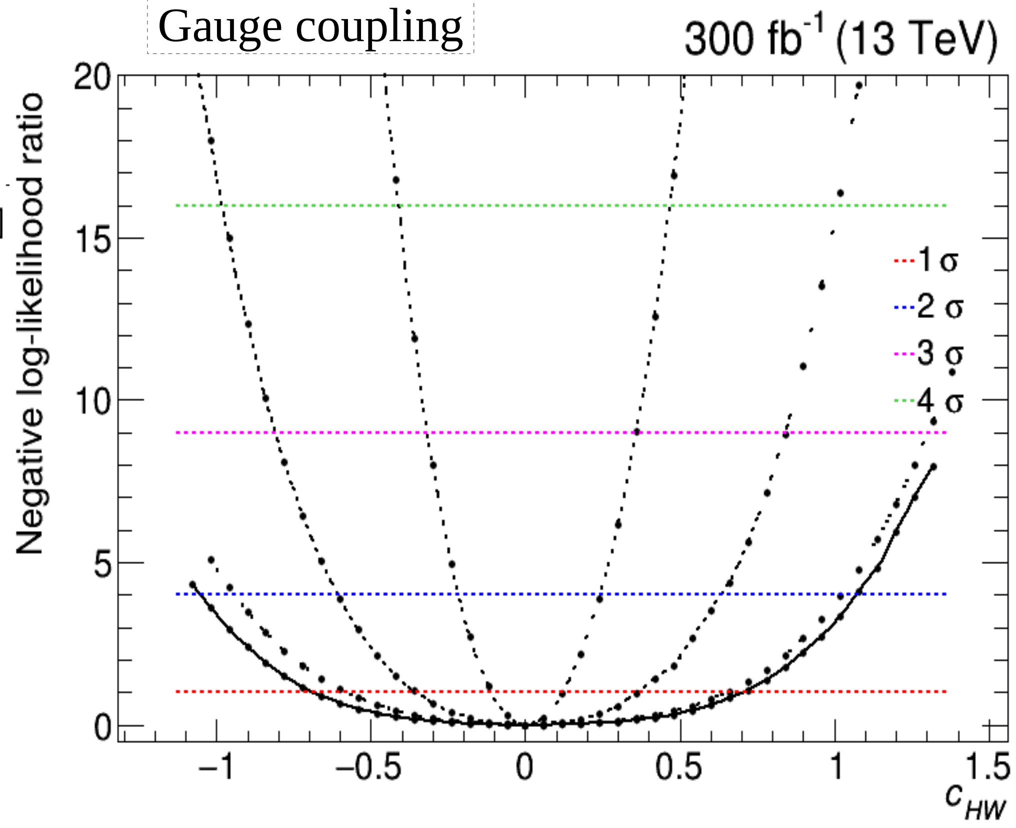
Resolved category:



Boosted category:



Gauge coupling



$$\mathcal{O}_{HW} = |H|^2 W_{\mu\nu} W^{\mu\nu}$$

Cross section growth with energy → EFT effects can be probed to a high precision

Large gain in sensitivity combining WH and ZH signals

Timeline:
Winter 2022 (Run 2 analysis)
Plan to continue in Run 3

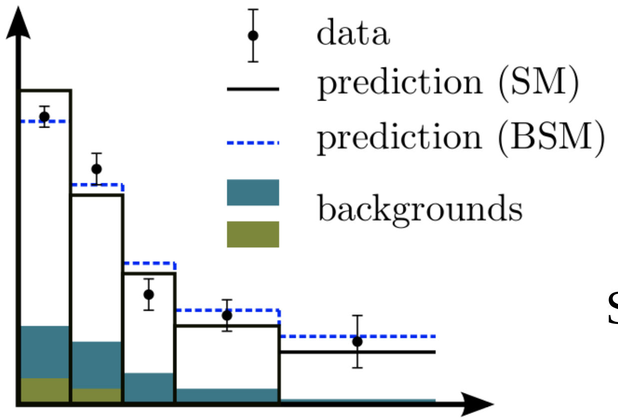
Machine learning to probe effective field theory

Niki, Stefan, Dennis, Suman, Robert

Boosted information tree (BIT) for EFT analysis

HEPHY INSTITUT FÜR HOCHENERGIEPHYSIK

arXiv 2107.10859



Two hypotheses:
SM & BSM (EFT)

EFT prediction:

$|\mathcal{M}|^2 = |\mathcal{M}_{SM} + \mathcal{M}_{BSM}|^2$

$|\mathcal{M}|^2 = |\mathcal{M}_{SM}|^2 + 2 * \mathrm{Re}\,(\mathcal{M}_{SM}\,\mathcal{M}_{BSM}) + |\mathcal{M}_{BSM}|^2$

Pure SM — SM-BSM interference — Pure BSM

$\mathcal{M}_{BSM} = c/\Lambda^2(\,..)$

$\theta = c/\Lambda^2$

$\sigma = \sigma_{SM} + \theta\sigma_{SM\text{-}BSM} + \theta^2\sigma_{BSM\text{-}only}$

After including BSM, cross section is a polynomial in θ

Goal: Design MVA as optimized EFT parameter (θ) estimator

Neyman-Pearson Lemma:

Log likelihood ratio (R) is the most powerful test statistic => Knowing R → Maximum information about SM-BSM differences

$$L(\boldsymbol{x}|\boldsymbol{\theta}) = \mathrm{P}_{\mathcal{L}\sigma(\boldsymbol{\theta})}(N) \times \prod_{i=1}^{N} p(\boldsymbol{x}_i|\boldsymbol{\theta}) = \frac{e^{-\mathcal{L}\sigma(\boldsymbol{\theta})}}{N!} \times \prod_{i=1}^{N} \mathcal{L}\sigma(\boldsymbol{\theta})p(\boldsymbol{x}_i|\boldsymbol{\theta})$$

$$\log\frac{L(\boldsymbol{x}|\boldsymbol{\theta}_1)}{L(\boldsymbol{x}|\boldsymbol{\theta}_0)} = -\mathcal{L}\left(\sigma(\boldsymbol{\theta}_1) - \sigma(\boldsymbol{\theta}_0)\right) + \sum_{i=1}^{N}\log\underbrace{\frac{\sigma(\boldsymbol{\theta}_1)\,p(\boldsymbol{x}|\boldsymbol{\theta}_1)}{\sigma(\boldsymbol{\theta}_0)\,p(\boldsymbol{x}|\boldsymbol{\theta}_0)}}_{R(\boldsymbol{x}|\boldsymbol{\theta}_1,\boldsymbol{\theta}_0)}$$

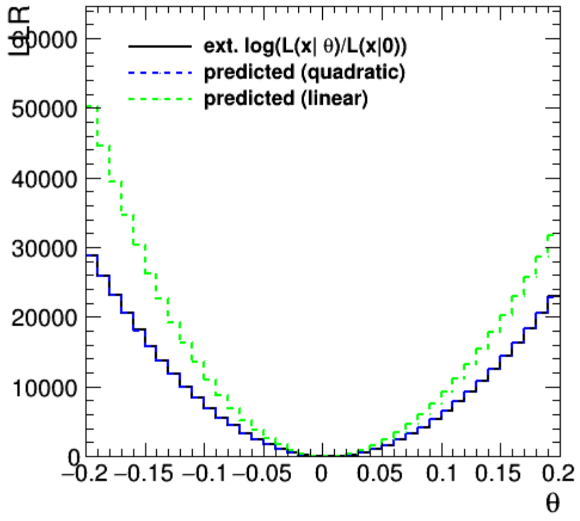
$$R(\boldsymbol{x}|\boldsymbol{\theta}_1,\boldsymbol{\theta}_0) = \frac{\sigma(\boldsymbol{\theta}_1)\,p(\boldsymbol{x}|\boldsymbol{\theta}_1)}{\sigma(\boldsymbol{\theta}_0)\,p(\boldsymbol{x}|\boldsymbol{\theta}_0)} = \frac{\mathrm{d}\sigma_{\boldsymbol{\theta}_1}(\boldsymbol{x})}{\mathrm{d}\boldsymbol{x}} \Big/ \frac{\mathrm{d}\sigma_{\boldsymbol{\theta}_0}(\boldsymbol{x})}{\mathrm{d}\boldsymbol{x}}$$

$$= 1 + (\theta_1-\theta_0)_a t_a(\boldsymbol{x}) + \frac{1}{2}(\theta_1-\theta_0)_a(\theta_1-\theta_0)_b s_{ab}(\boldsymbol{x})$$

Quadratic function in θ

$$p(\boldsymbol{x}|\boldsymbol{\theta}) = \frac{1}{\sigma(\boldsymbol{\theta})}\frac{\mathrm{d}\sigma_{\boldsymbol{\theta}}(\boldsymbol{x})}{\mathrm{d}\boldsymbol{x}}$$

$$t_a(\boldsymbol{x}) = \frac{\partial}{\partial\theta_a}\log p(\boldsymbol{x}|\boldsymbol{\theta})$$



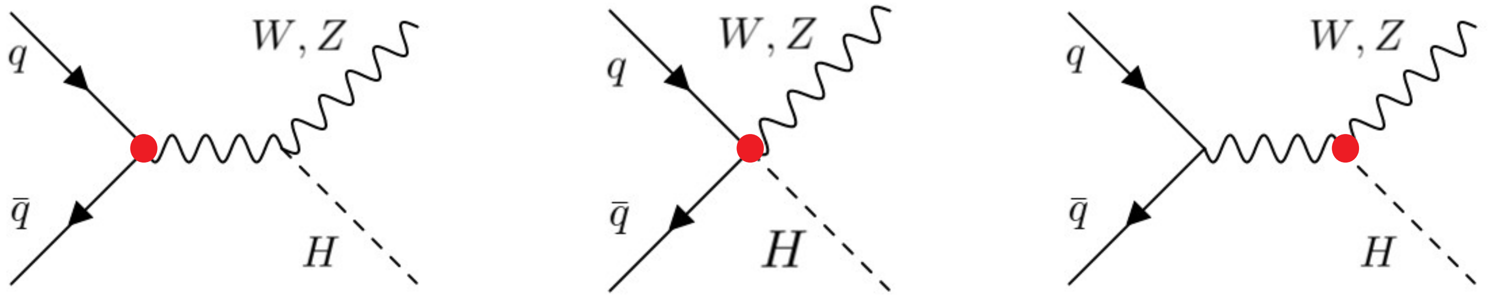
Achieved via tree boosting

Learning terms in R at each order → Compute Likelihood

Stefan, Dennis, Suman, Robert

BIT for EFT analysis in VH

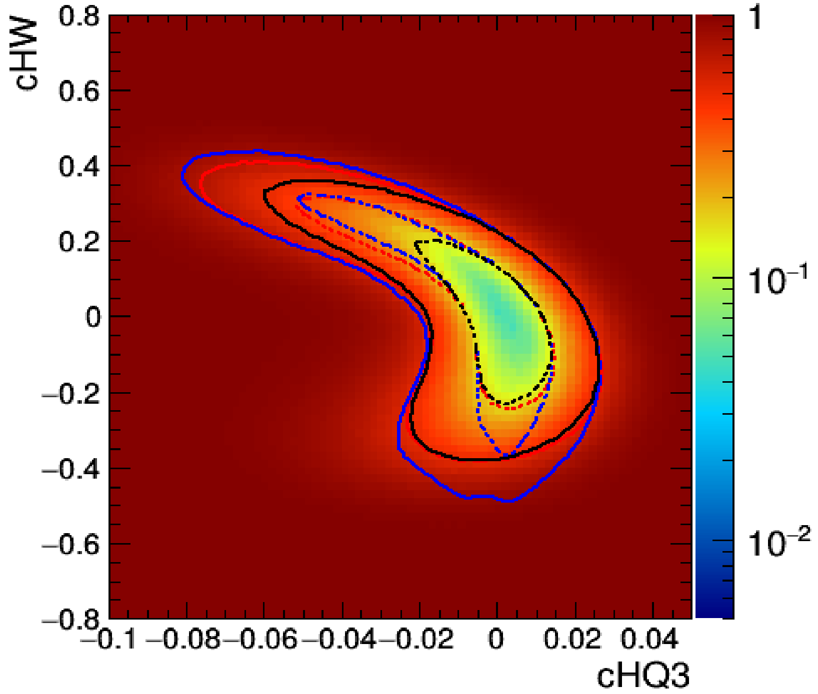
Draft in preparation



$$\mathcal{O}_{Hq}^{(3)} = iH^\dagger \sigma^a \overleftrightarrow{D}_\mu H \bar{q} \sigma^a \gamma^\mu q$$

$$\mathcal{O}_{HW} = |H|^2 W_{\mu\nu} W^{\mu\nu}$$

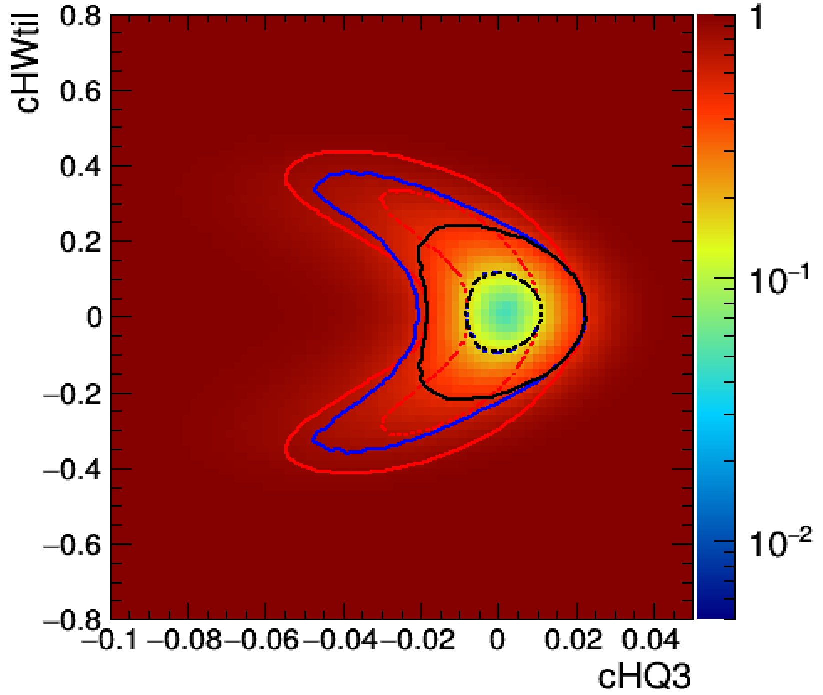
$$\mathcal{O}_{H\tilde{W}} = |H|^2 W^a_{\mu\nu} \tilde{W}^{a\mu\nu}$$



Significant improvement
in constraining power
from linear to quadratic terms

Learning linear term in R
Learning quadratic term in R
Total

68% CL interval
95% CL interval



Interpreting data:

From observation to physics models

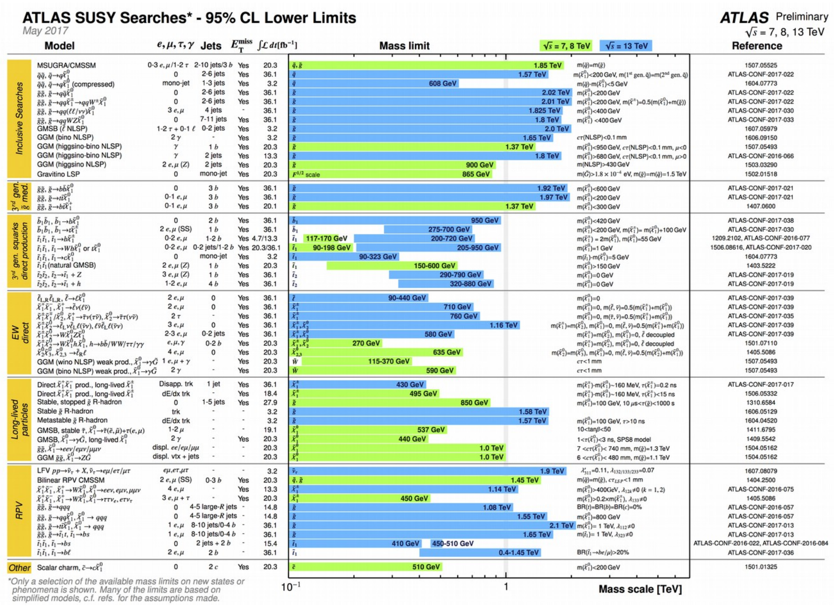
Wolfgang W

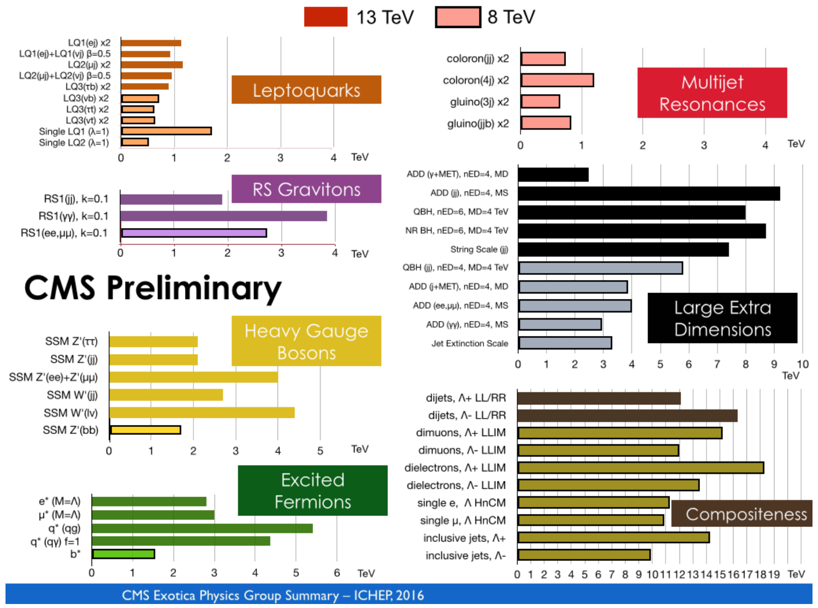
Interpretation

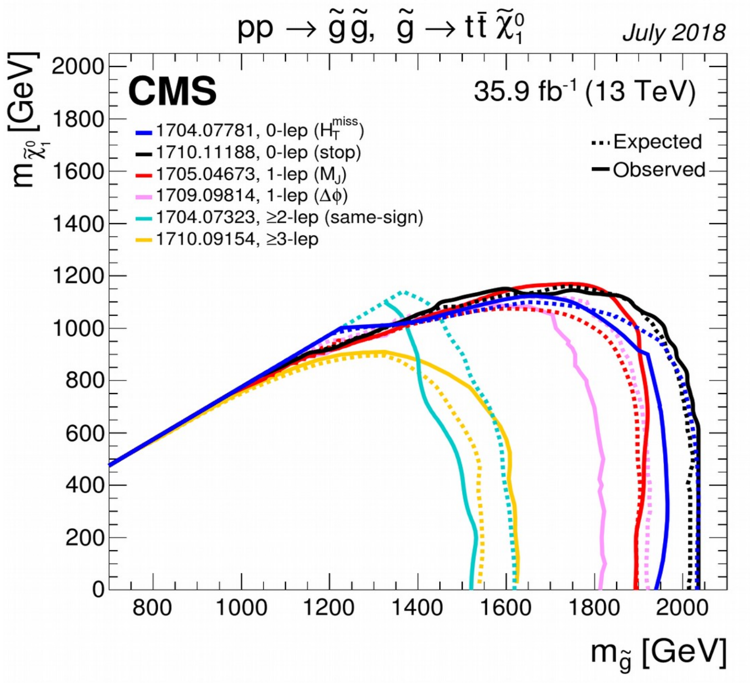
What do data tell us?

Is SUSY dead?

What is the big picture? (UV completion)







Interpretation

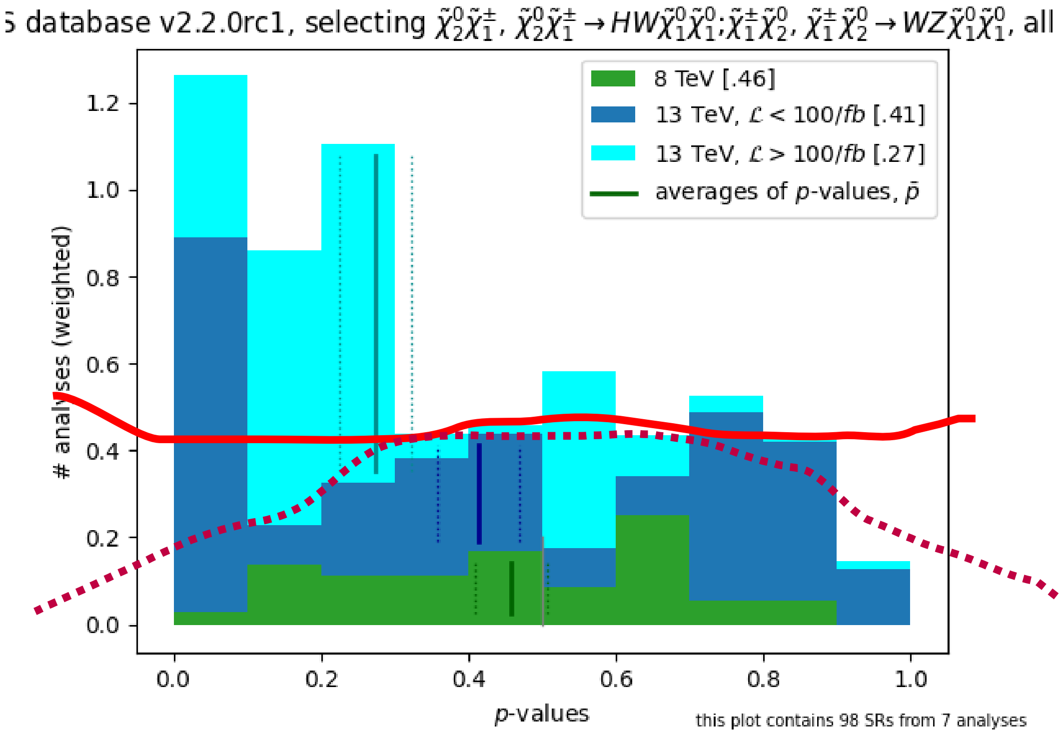
SmodelS: Tool developed by W. Waltenberger et al to interpret LHC results in terms of simplified models

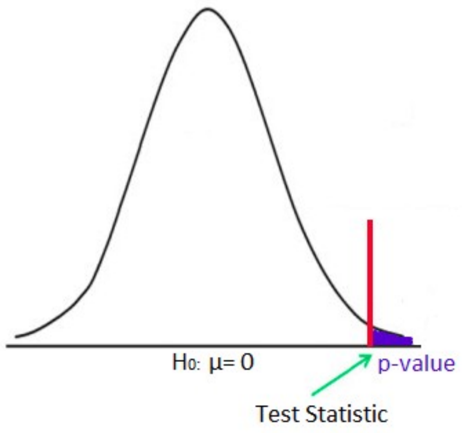
SModelS 2.2.0 about to be released.

Most important new features: statistical combinations, and a larger database update.

Flat red line:
Uniform distribution corresponding to the hypothesis that no new physics is in the database (null hypothesis).

Red dashed line:
Distribution, if we account for the conservatism of the analysts





Meta-statistics of the SModelS database, selecting chargino and neutralino production(decaying to W's, Z's, and Higgs bosons)

Interpretation

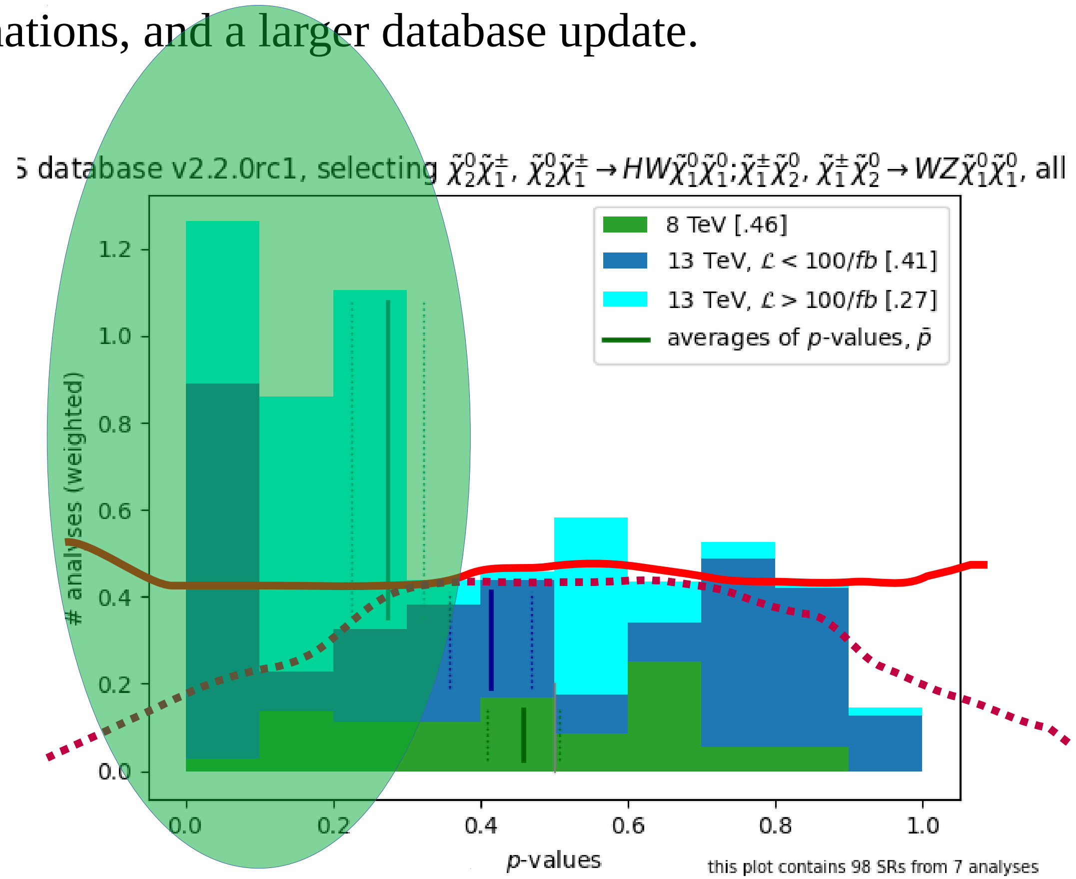
SmodelS: Tool developed by W. Waltenberger et al to interpret LHC results in terms of simplified models

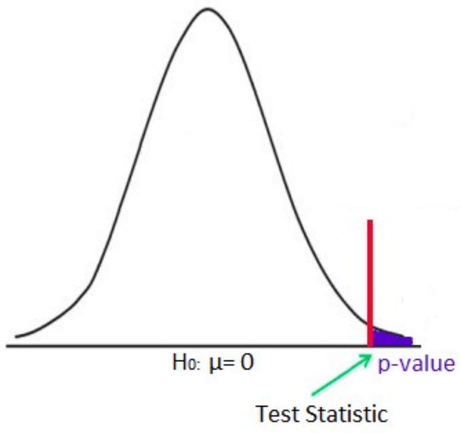
SModelS 2.2.0 about to be released.

SUSY is not Dead (yet)

Most important new features: statistical combinations, and a larger database update.

Selection bias?
Random fluke?
A mistake?
New physics?

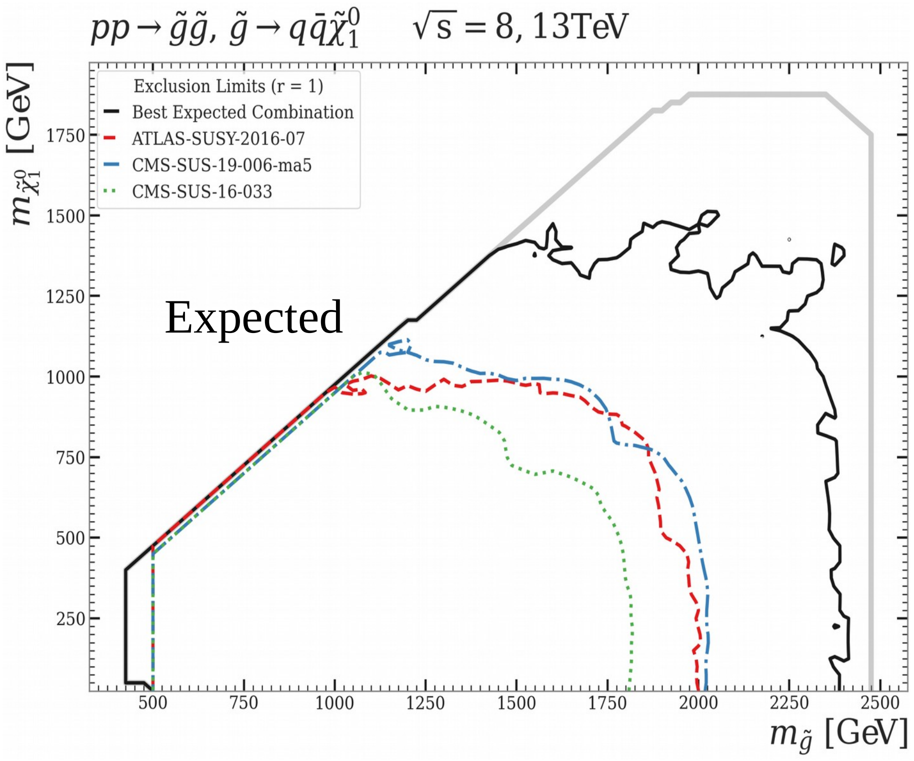


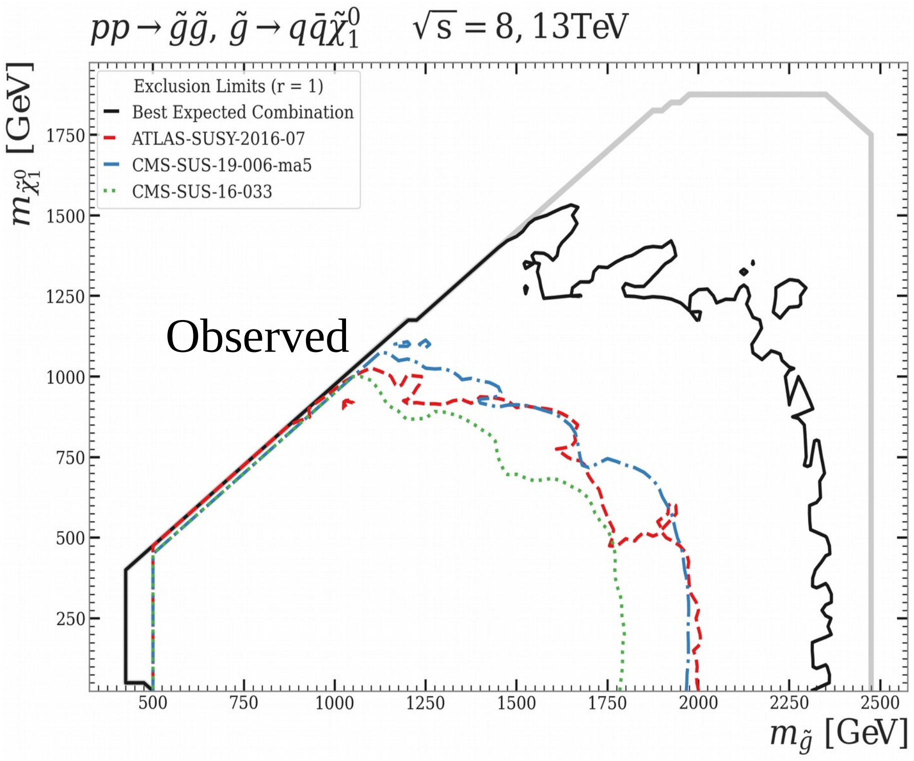


Meta-statistics of the SModelS database, selecting chargino and neutralino production(decaying to W's, Z's, and Higgs bosons)

Interpretation

Idea: perform large-scale combinations of results in SModelS database that are approximately uncorrelated. Identify most sensitive combinations.





Combination adds additional exclusion power

"**TACO collaboration**": Collaboration with members from MadAnalysis5, Contur/Rivet, and Gambit!

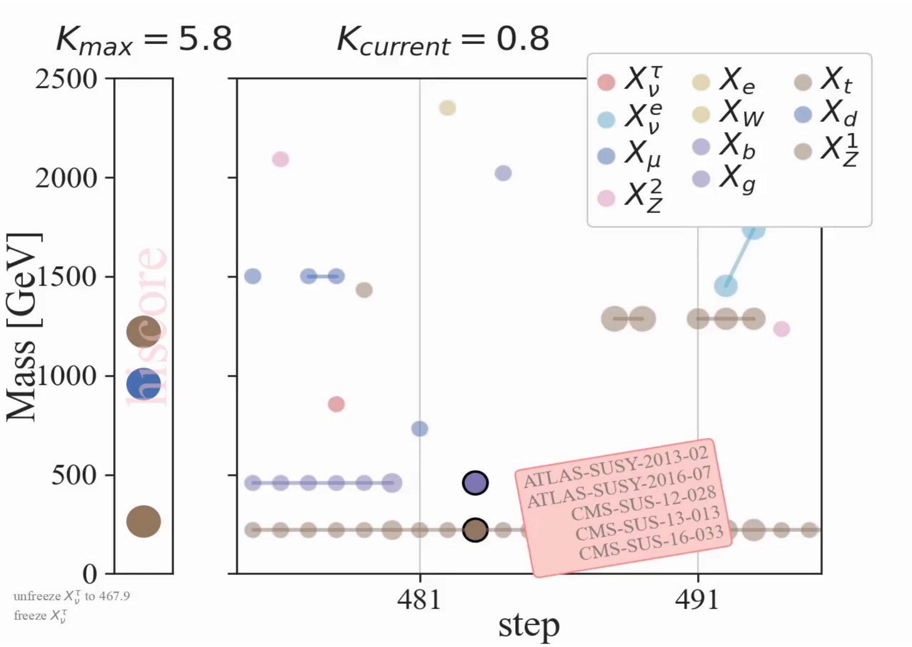
Discussions about larger combinations between searches and measurements

Interpretation

Idea:

Learn – non-differentiably – precursor theories (“protomodels”) to the Next Standard Model (NSM) from the published results.

LHC Data → Simplified models results → Protomodels → NSM Lagrangian



Identify potential dispersed signal in a bayesian MCMC walk

← The machine is inventing and improving models

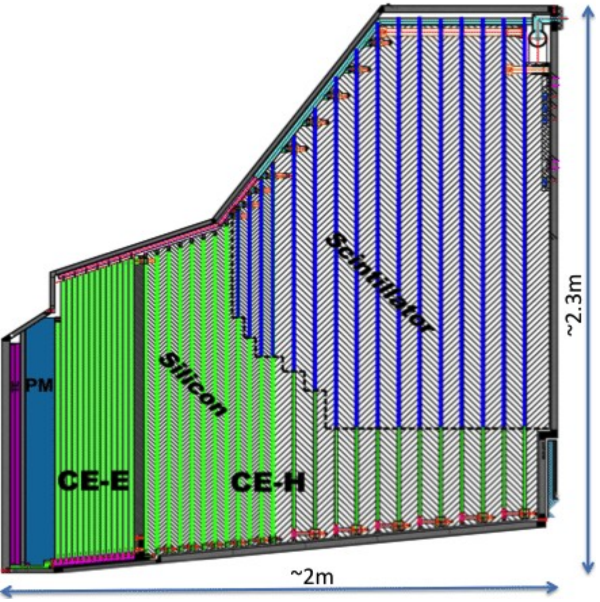
JHEP 2021, 207 (2021)

French-Austrian bilateral grant, one PhD, one PostDoc

https://smodels.github.io/protomodels/

Particle shower reconstruction in high multiplicity environment @ CMS

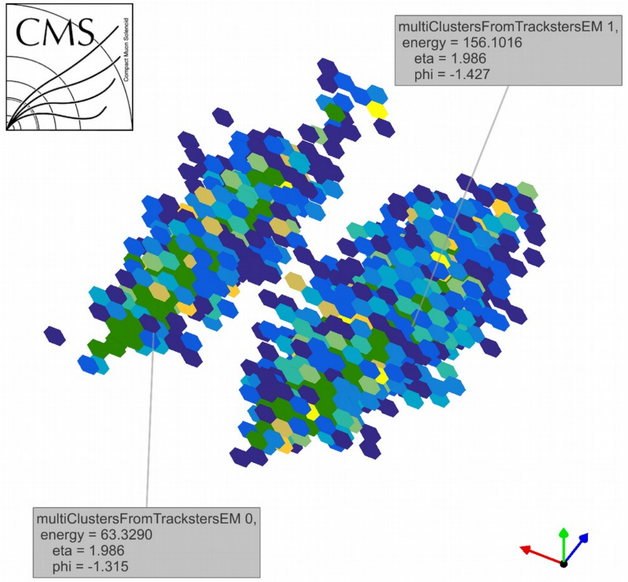
Mark, Wolfgang W



HL-LHC and Phase 2 upgrade

- HL-LHC will provide an increase in instantaneous luminosity (5 - 7.5x)
- Phase 2 upgrade of CMS detectors and software necessary for high luminosity environment (PU ~ 200)
- High granularity calorimeter (HGcal) offers unprecedented lateral and longitudinal granularity and precision timing capabilities

Covered in Moritz's talk

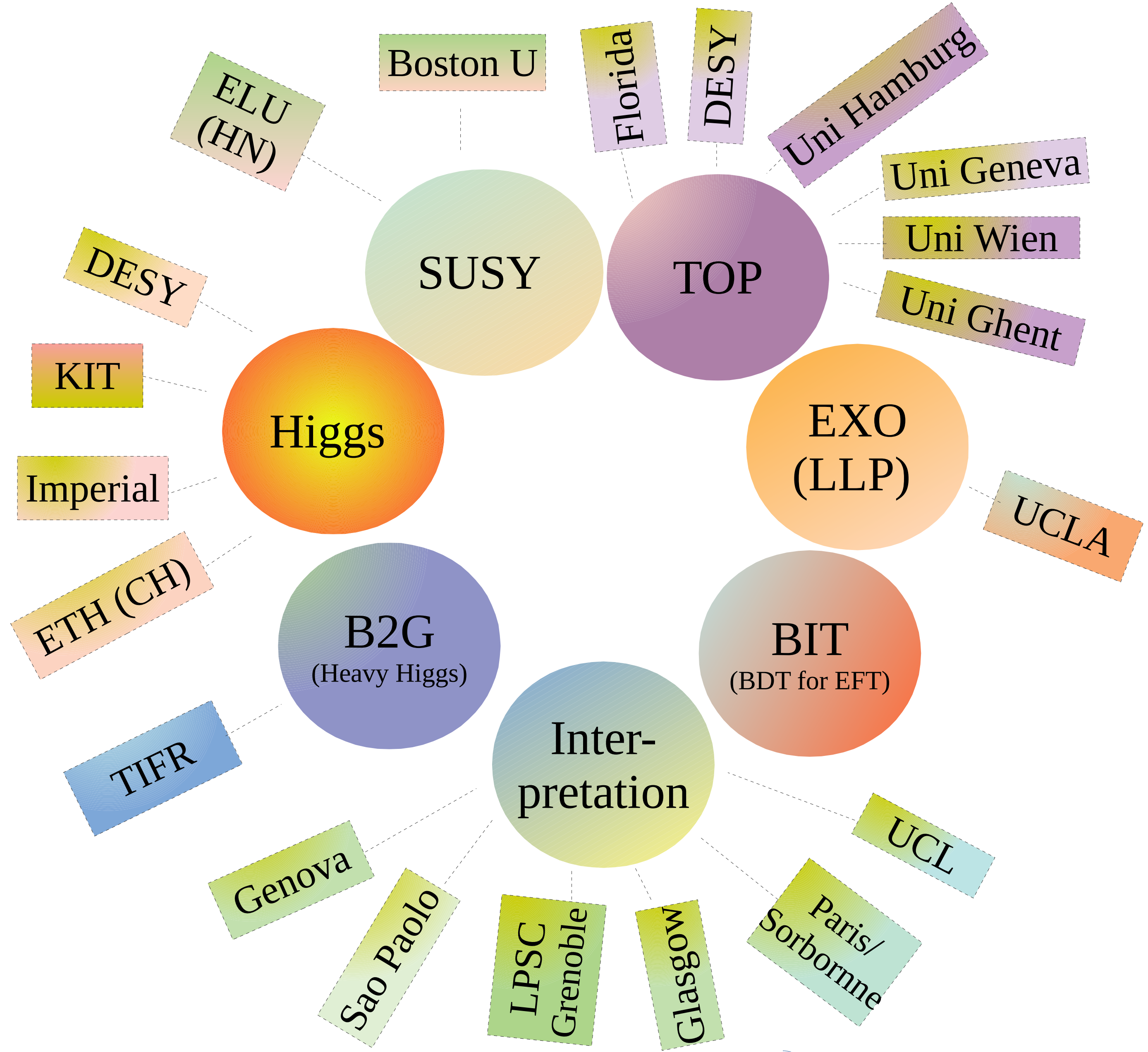


PhD Project

- Implement Kalman Filter and Smoother (KF) algorithms for the purpose of muon reconstruction in the HGcal software
- Energy regression and particle identification (PID) using hex-shaped convolutional neural networks (CNNs) to mirror the shape of the HGcal silicon sensors

Supervisors: Wolfgang Waltenberger, Erica Brondolin, Marco Rovere
PhD Student: Mark Matthewman

Collaboration & Responsibilities



Ongoing

Claudia	Collaboration board	Chair

Finished in 2021

Robert	TOP mass & properties	L3 convener
Alberto	EXO Non-hadronic	L3 convener
Sebastian	L1 Trigger menu	L3 convener

Target in 2022

PAG = Physics Analysis Group

Robert	TOP PAG	L2 convener
Alberto	EXO PAG	L2 convener

EPR Tasks

Performed by members in context of
Trigger group (rate monitoring)
Tracker group (HGcal sensor test)
Shifts @P5

New potential collaboration: T. Corbett (SM-EFT), A. Broggio (ttX calculation) } Senior post-docs hired by Univ. Wien with 6 yrs contracts (starting in Autumn 2022)

External funding

(Recently) finished

R. Schöfbeck TOP/BSM 1 PhD (Lukas)
FWF Standalone

C. Wulz & M. Jeitler EXO/LLP 1 PhD (Sebastian)
FWF-DKPI

Sum
(onging + approved within last 2 yrs):

HEPHY-only: 830K EUR
All: 1.6M EUR

Ongoing

R. Schöfbeck TOP/SM/BSM 1 PD (Dennis)
FWF Standalone till April, 2025 ~310k EUR

A. Escalante EXO/LLP 1 PD (Alberto)+1 PhD (Mangesh)
FWF Standalone till Nov, 2023 ~395k EUR

C. Wulz & M. Jeitler SUSY/Compressed 1 PhD (Priya)
FWF-DKPI till May, 2022 ~125k EUR

W. Waltenberger ML/HGcal 1 PhD (Mark)
Austrian Doctoral student programme till Feb, 2025 ~120k EUR

Approved

R. Schöfbeck (w/ D. Dobur, F. Riva) TOP 2 PhDs
FWF Trilateral till Aug, 2026 ~325k EUR

W. Waltenberger (w/ S. Kraml) ML/BSM 1 PhD — application open
FWF Bilateral till Jan, 2026 ~200k EUR

R. Schöfbeck ML/GEN 1 PhD — application open
Austrian Doctoral student programme 3 yrs ~120k EUR

R. Schöfbeck & C. Wulz ML/GEN 1 PhD + 1 PD / 2 PhDs
Cosmic matters: Particles and interaction (O-B1 + O-B3)

Submitted

S. Chatterjee HIggs/BSM 1 PhD
FWF Standalone

In preparation

I. Mikulec EXO/LLP

W. Adam SUSY/Flavor physics

Conference talks & seminars

Conference talks

2022

R. Schöfbeck	Invited plenary	at DIS
M. Sonawane	YSF talk	at Moriond EWK
A. Escalante	Parallel talk	at Lepton-photon

2021

D. Schwarz	Plenary talk	at TOP	arXiv:2112.01297
R. Schöfbeck	Parallel talk	at EPS-HEP	PoS (EPS-HEP2021) 490
S. Chatterjee	Parallel talk	at EPS-HEP	PoS EPS-HEP2021 (2022) 365
C. Wulz	Parallel talk	at LHCP	PoS LHCP2021 (2021) 009
S. Chatterjee	Poster	at LHCP	PoS LHCP2021 (2021) 207
L. Lechner	Parallel talk	at LHC TOP WG meeting	
L. Lechner	YSF talk	at Moriond EWK	
W. Waltenberger	Invited talk	at Reinterpretation workshop	

2020

S. Chatterjee	Invited talk	at DAE-BRNS
M. Zarucki	Parallel talk	at LHCP
M. Jeitler	Plenary talk	at INSTR

Invited seminars

2022

W. Waltenberger	at Institut für Weltraumforschung, Graz
R. Schöfbeck	at University of Birmingham

2021

A. Escalante	at Hunting SUSY @LHC, ICTS Bangalore
W. Waltenberger	at Hunting SUSY @LHC, ICTS Bangalore

2020

A. Escalante	at CIEMAT, Spain

Invited lectures

2021

W. Waltenberger	at Uni Graz

2020

W. Waltenberger	at Uni Wien
W. Waltenberger	at MCNet Machine Learning School

Summary of works in last 2 years

Within CMS Collaboration

- Papers Published since 2020

Search for top squarks using dilepton final states	**Eur. Phy. J. C 81 (2021) 3**
Combination of top squark searches	**Eur. Phy. J. C 81 (2021) 970**
Measurement of ttγ cross sections in the single-lepton channel + EFT interpretation	**JHEP 12 (2021) 180**

- Papers in Journal Review

Measurement of tγ cross sections measurement in di-lepton channel + combination with single-lepton channel	**arXiv: 2201.07301**

- PAS public + Paper in preparation

Search for long-lived particles decaying to dimuons	**CMS-PAS-EXO-21-006**
SM Higgs boson decaying to pair of τ leptons	**CMS-PAS-HIG-19-010**
Search BSM Higgs boson decaying pair of τ leptons	**CMS-PAS-HIG-21-001**

- Ongoing

	Timeline
Search for top squarks in compressed region using semileptonic final states	Winter 2022
Illuminating SMEFT with Higgs radiation	Winter 2022
Flavor structure of SMEFT operators in ttZ, Diboson, tWZ	Winter 2022
Search for X→Yh in bbWW (leptonic) final state	Spring 2023
Preparing for search for long-lived particles decaying to dimuons in LHC Run-3	Winter 2023

Summary of work in last 2 years

Outside CMS Collaboration

- Papers Published since 2020

Status of searches for electroweak-scale supersymmetry after LHC Run 2	**Int.J.Mod.Phys.A 37 (2022) 02, 2130022**
Artificial Proto-Modelling: Building Precursors of a Next Standard Model from Simplified Model Results	**JHEP 03 (2021) 207**
A SModelS interface for pyhf likelihoods	**Comput.Phys.Commun. 264 (2021) 107909**
SModelS Database Update v1.2.3	**LHEP 2020 (2020) 158**
Constraining the Higgs boson valence contribution in the proton	**Phys. Rev. D 101, 114018 (2020)**

- Papers in Journal Review

Constraining new physics with SModelS version 2	**arXiv: 2112.00769**
Tree boosting for learning EFT parameters	**arXiv:2107.10859**

Summary of work in last 2 years

Outside CMS Collaboration

- Papers Published since 2020

Status of searches for electroweak-scale supersymmetry after LHC Run 2 — **Int.J.Mod.Phys.A 37 (2022) 02, 2130022**

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- Papers in Journal Review

Constraining new physics with SModelS version 2 — **arXiv: 2112.00769**

Tree boosting for learning EFT parameters — **arXiv:2107.10859**

Ďakujem + धन्यवाद

Extra material??

List of physics analysis summaries

CMS-PAS-SUS-19-011

CMS-PAS-SUS-20-002

CMS-PAS-HIG-19-010

CMS-PAS-TOP-18-010

CMS-PAS-TOP-21-004

CMS-PAS-EXO-21-006

CMS-PAS-HIG-21-001

Weinberg operator

Only possible operator to write at d=5

$$\mathcal{L}_5 = \frac{C_5^{\ell\ell'}}{\Lambda}\left[\Phi\cdot\overline{L}_\ell^c\right]\left[L_{\ell'}\cdot\Phi\right] + \text{H.c.}$$

Violates lepton number conservation (that's okay!)

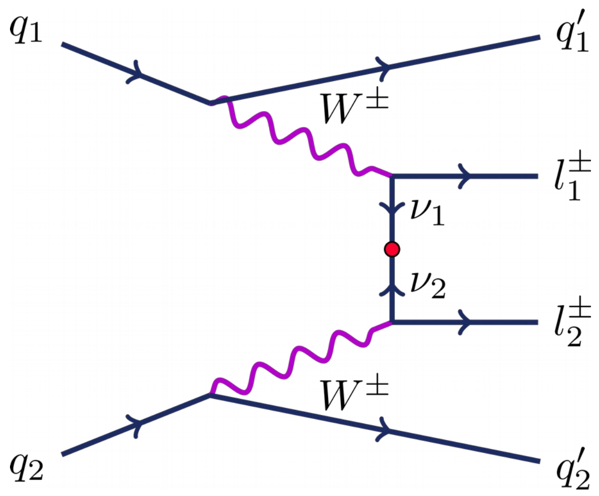
Generates Majorana neutrino massses :) → Λ/ c ~ 10^{14} GeV

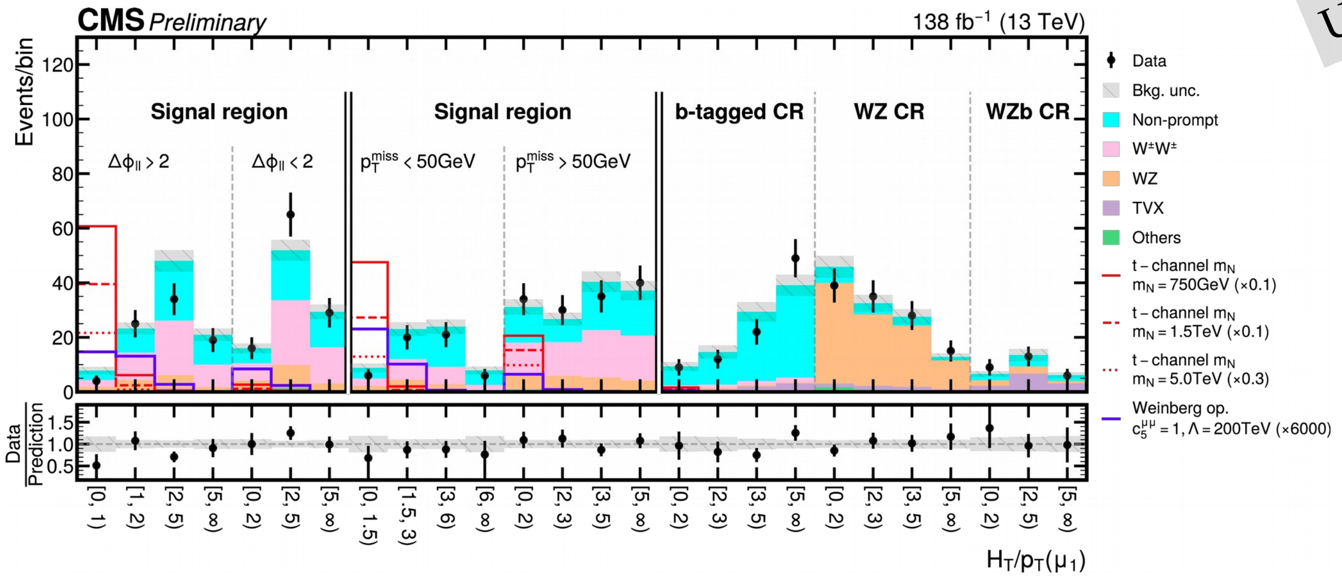
Energy scale expected to be very high
→ Operator can be ignored for LHC physics

Unless c is too small!

Still probed at LHC using same-sign WW scattering

CMS-PAS-EXO-21-003





In summary, this note presents the first search for TeV mass scale Majorana neutrinos and a first probe of the Weinberg operator at the LHC. Vector boson fusion processes resulting in a dimuon final state are studied. The results agree with the predictions from the standard model, and upper limits are set on the model parameters accordingly. For heavy Majorana neutrinos, upper limits on $|V_{\mu N}|^2$ are set for the mass range 750 GeV $< m_N <$ 25 TeV, which is a significant improvement compared to previous searches at the LHC. The highest mass exclusion at $|V_{\mu N}|^2 = 1$ is around 23.30 TeV. For the Weinberg operator, the observed (expected) 95% confidence level upper limit on the effective $\mu\mu$ Majorana mass is $|m_{\mu\mu}| = 10.84$ (12.84) GeV. This is the first time such constraints have been obtained for this process.

Big questions for Higgs boson

- Does Higgs boson have structure inside?

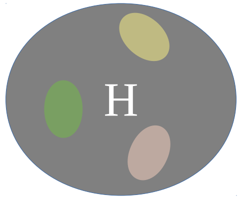
If yes, possible to generate form factor-like operators

→ Yukawa-type ~ $|H|^2 (\overline{\Psi}_L H \Psi_R) / \Lambda^2$

→ Higgs self-interaction-type ~ $(\partial_\mu |H|^2)^2 / \Lambda^2$

LHC-HXSWG-2019-006

Giudice, Grojean, Pomarol, Rattazzi (2007)



- Stability of SM vacuum?

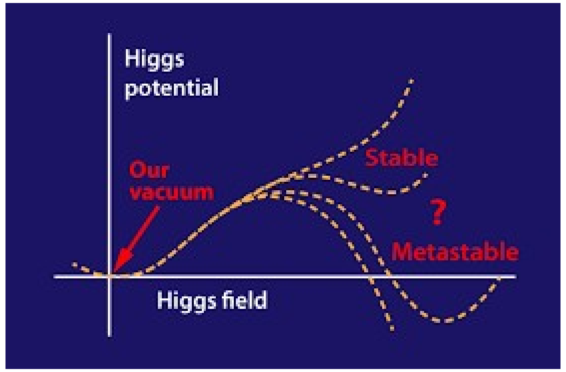
Higher dimensional operators can change Yukawa couplings

→ Appear in RG running of Higgs quartic

→ Determine stability of the universe

$$\mu \frac{d\lambda_i}{d\mu} = \beta_{\lambda_i}(\lambda_j)$$

$$V(\varphi) = -m^2\varphi^2 + \lambda\varphi^4$$

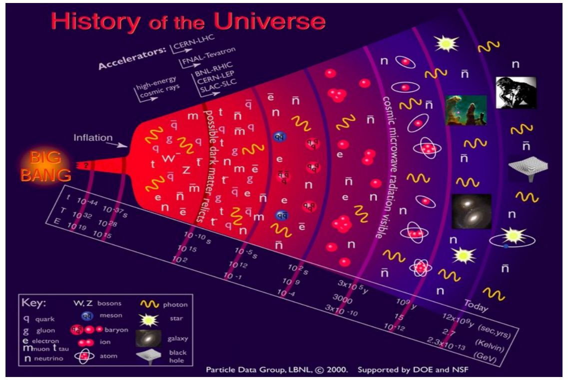


- Is Higgs boson responsible for matter formation?

CP violation in SM not sufficient to explain baryon asymmetry of universe

16 dimension-6 CP-odd operators involving Higgs boson (assuming $U(3)^5$ flavor symmetry)

→ Possible to cause additional sources of CP-violation



Priya, Janik, Dietrich, Manfred, Ivan, Wolfgang A

Stop search in compressed spectra with soft leptons & b jets

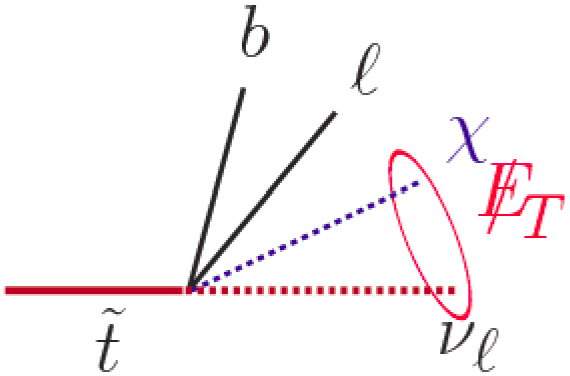
Stop can be long-lived for Δm < 30 GeV ← Ignored in previous LHC measurements

$\Delta E \, \Delta t \sim \hbar$

Small mass gaps

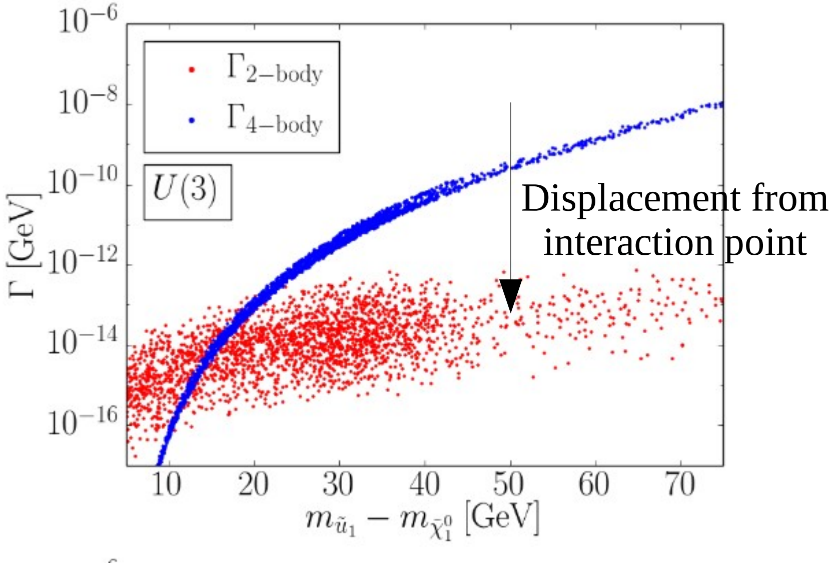
→ Long-lived stop quark

$\Gamma_{total} = \Gamma_{4\text{-body}} \times \Delta m / BR_{4\text{-body}}$



Lepton displaced from interaction point

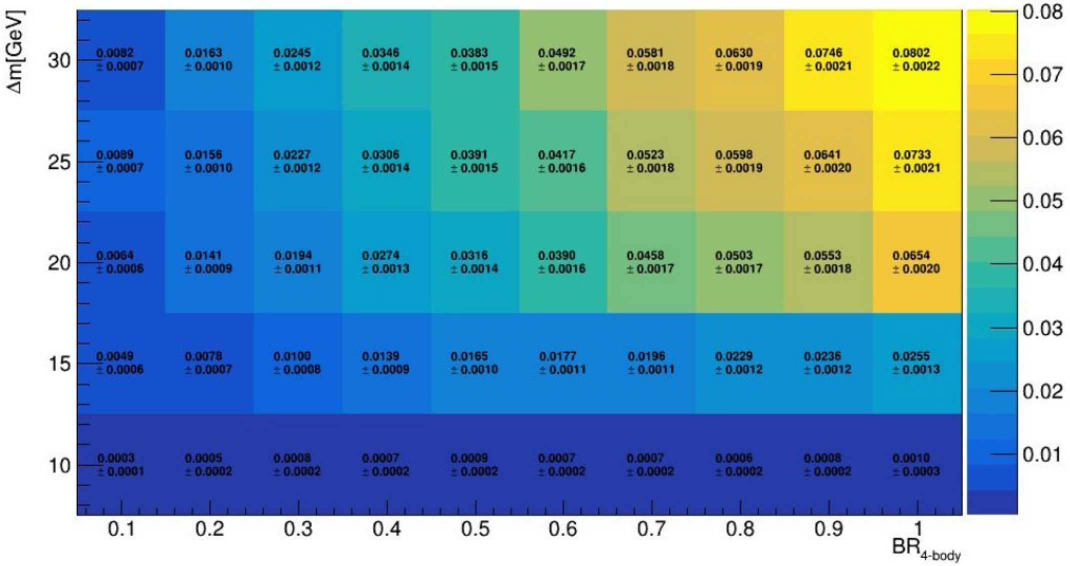
→ Additional handle to reduce SM background

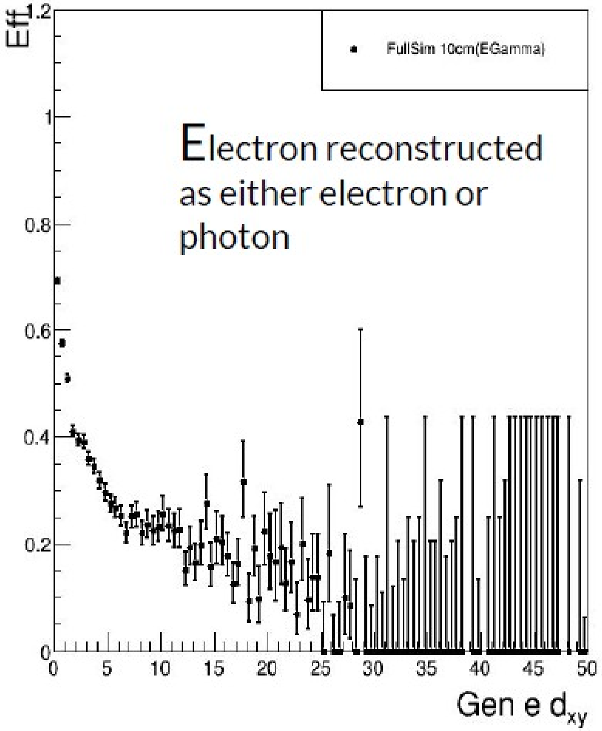


Displacement from interaction point

Signal acceptance

Stop: 600 GeV





Reconstruction efficiency goes down

Timeline: Winter 2022

Smaller Δm → Larger displacement → Loss in lepton reconstruction efficiency

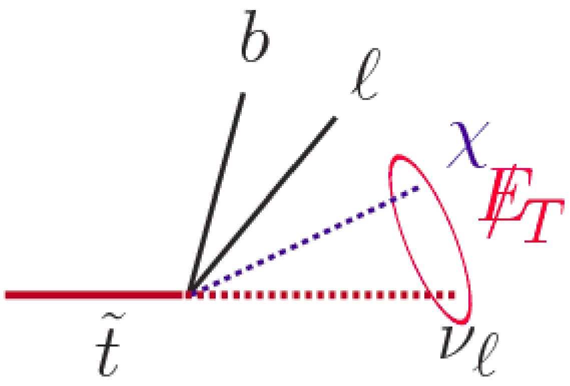
Larger BR → Larger # of events with 4-body decay → Compensates loss due to lepton reconstruction

Priya, Janik, Dietrich, Manfred, Ivan,Wolfgang A

Stop search in compressed spectra with soft leptons + jets

Small mass gaps (Δm < 30 GeV) can lead to long-lived stc

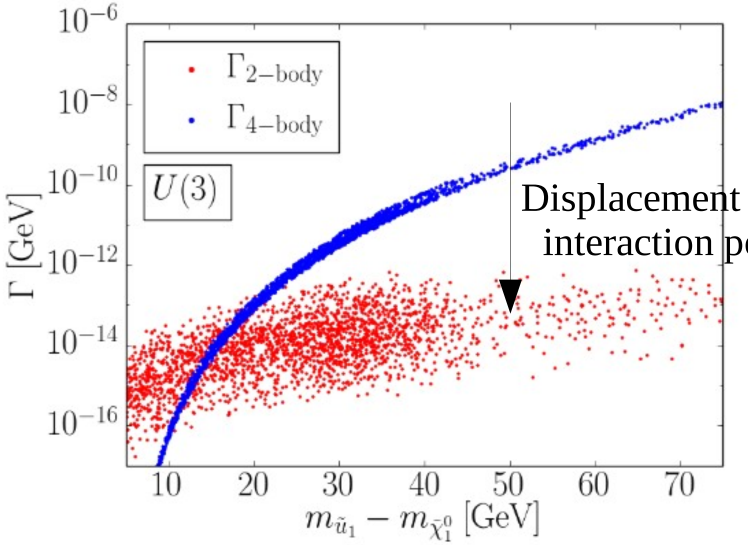
← Ignored in previous LHC measurements

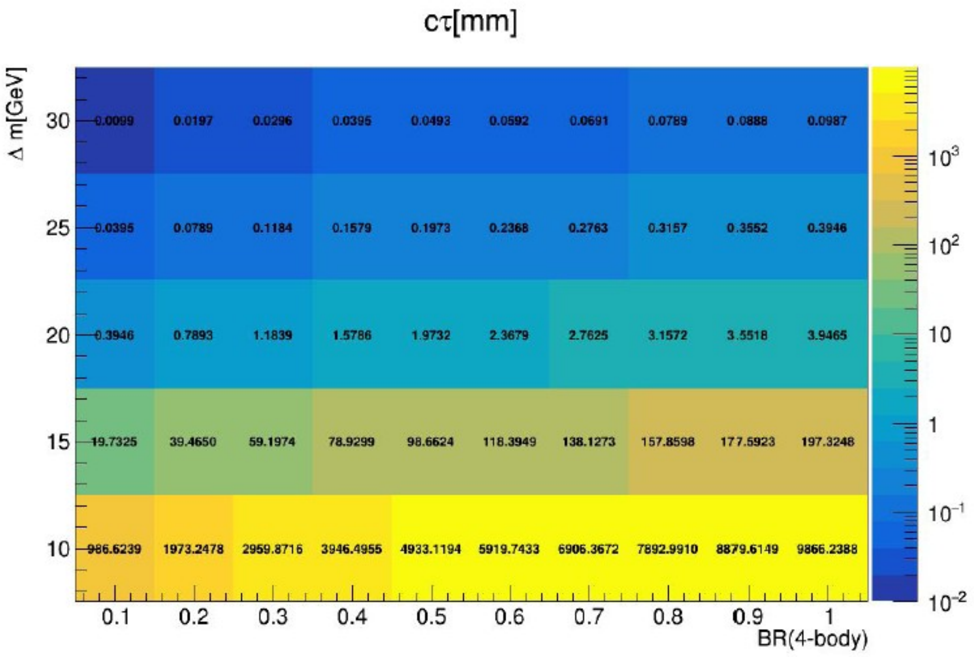


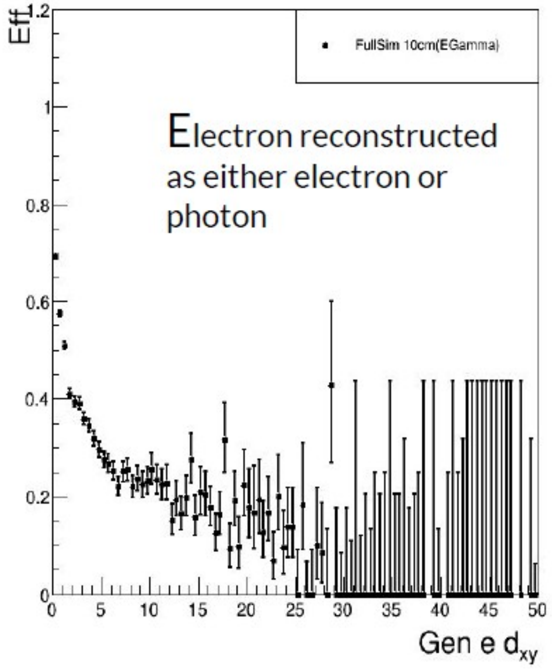
Lepton displaced from interaction point

→ Additional handle to reduce SM background

$\Gamma_{total} = \Gamma_{4\text{-body}} \times \Delta m / BR_{4\text{-body}}$



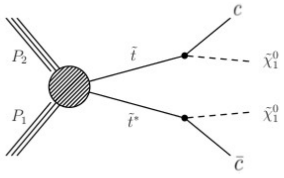




Reconstruction efficiency goes down

Timeline: Winter 2022

$c\tau = (\hbar * c)/\Gamma_{total}$



FCNC process

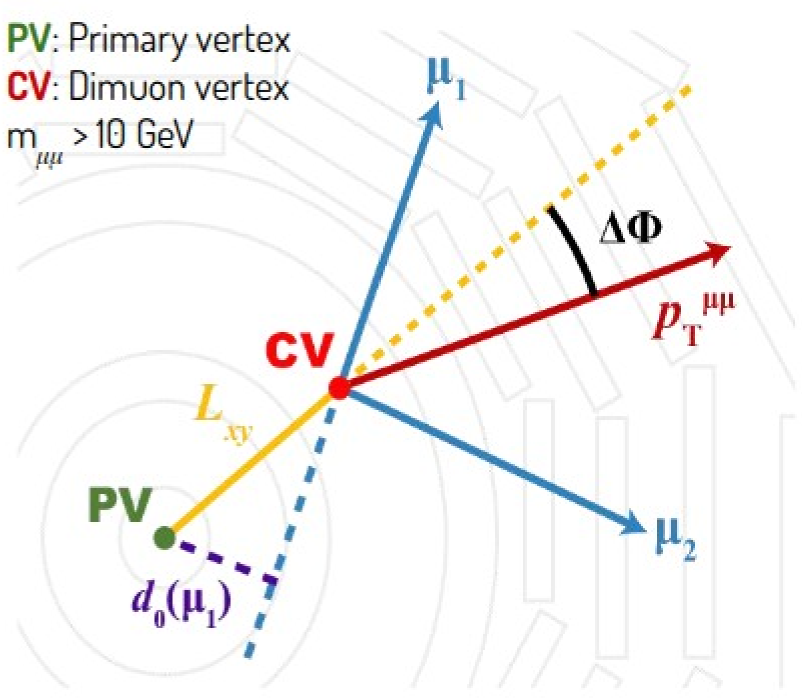
Highly model-dependent

Can be suppressed from flavor constraints

Mangesh, Sebastian
Alberto, Ivan

Search for displaced dimuons

CMS-PAS-EXO-21-006



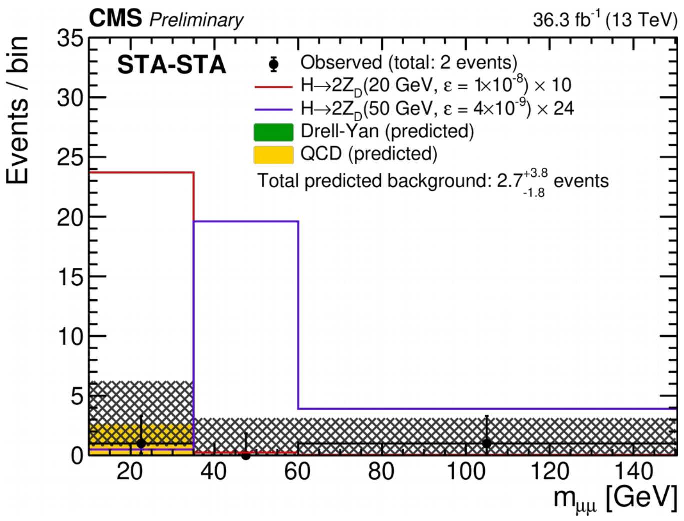
Signal Region

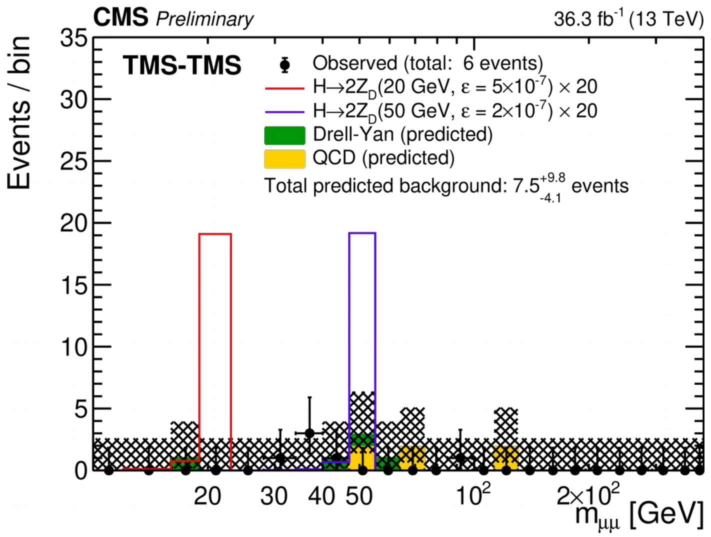
	$L_{xy}/\sigma(L_{xy})$	$\min(d_{xy}/\sigma(d_{xy}))$	Main handles to suppress background
TMS-TMS	> 6	In [6, 10, >20] intervals.	TMS muon isolation and vertex χ^2
STA-TMS	> 3	> 6	Associate STA to TMS muons and TMS muon isolation.
STA-STA	> 6	No requirement	Associate STA to TMS muons and dimuon quality.

$m_{\mu\mu}$ > 10 GeV
$|\Delta\Phi| < \pi/4$

All backgrounds estimated from data using regions not overlapping with signal region

signal region → optimized for each category separately





<u>Key variables:</u>

Transverse decay length (L_{xy}), collinearity angle ($\Delta\Phi$), transverse impact parameter d_{xy} & d_{xy} significance

Search for excess of events in search regions with very low bkg

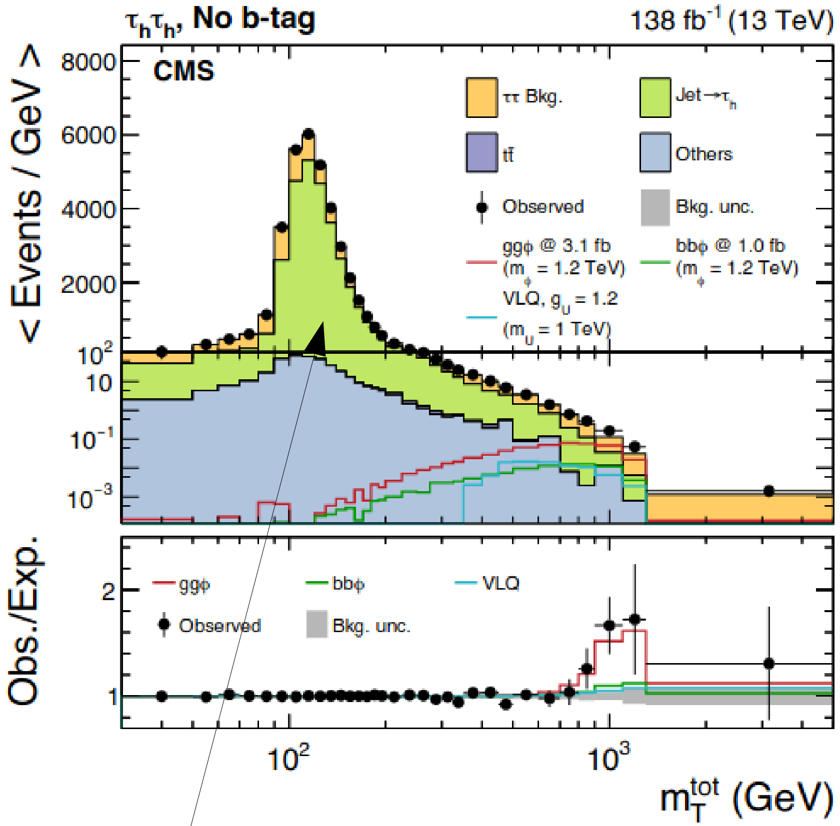
(difference in bin sizes between categories ← detector resolution)

Data consistent with estimated background :(

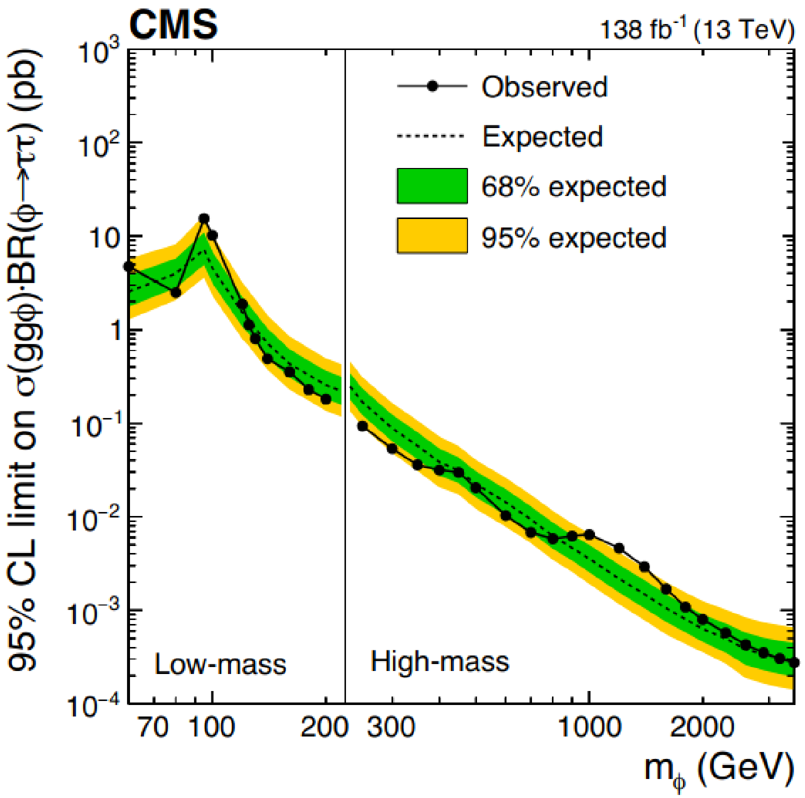
Jet → τ fake background for BSM H → ττ search

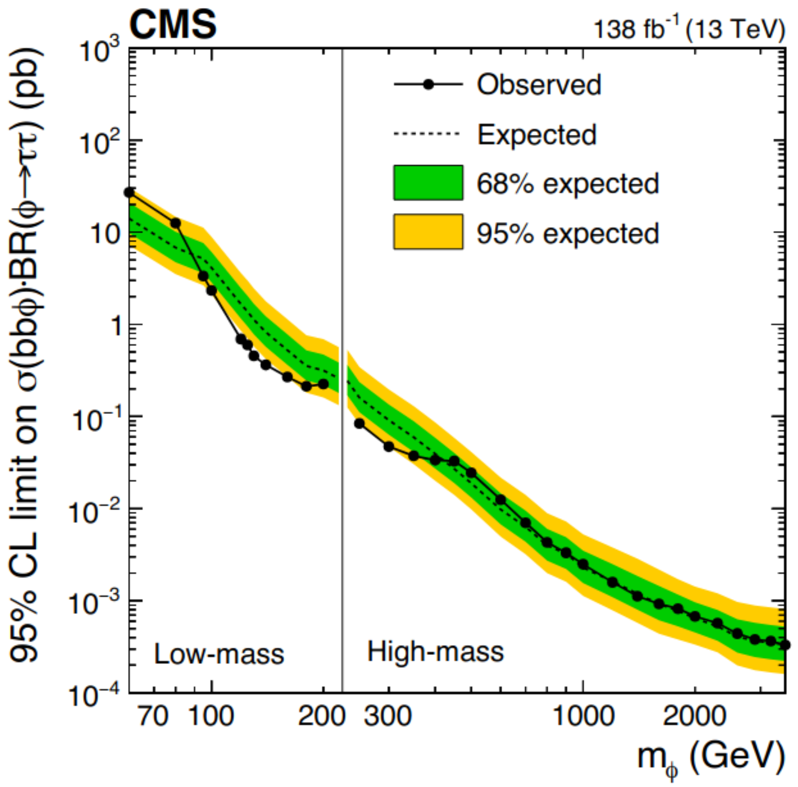
Timeline:
PAS by Moriond EWK (2022)
Paper by ICHEP (2022)

Fake factor technology re-used for BSM H → ττ search



Measured from data using jet → τ fake factor





@ 100 GeV local (global) significance for ggΦ = 3.1 (2.7) σ
@ 1200 GeV local (global) significance for ggΦ = 2.8 (2.4) σ

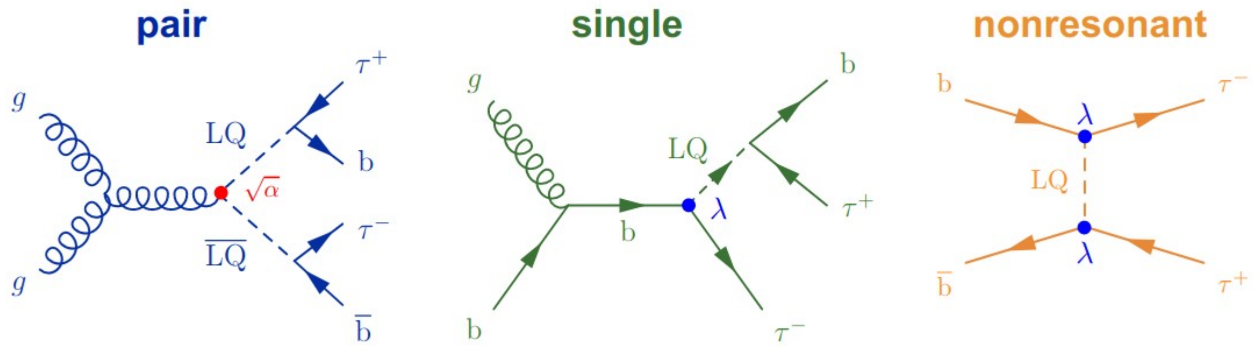
No excesses are observed for bbΦ production (→ inconsistent with MSSM prediction)

Jet → τ fake background for leptoquark search

Jet → τ fake factors also used in search for of leptoquark (LQ) production

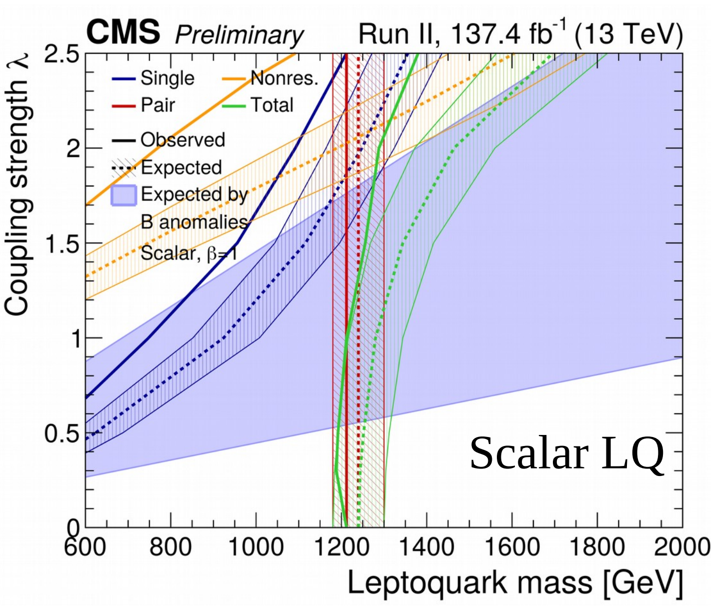
CMS-EXO-19-016

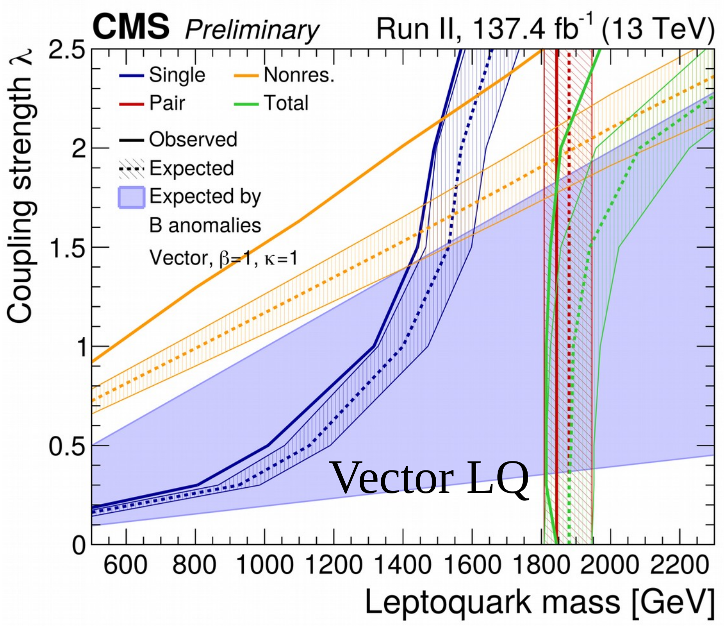
LQ → Explains deviations from lepton flavor universality observed in both b → sll & b → clν transtions

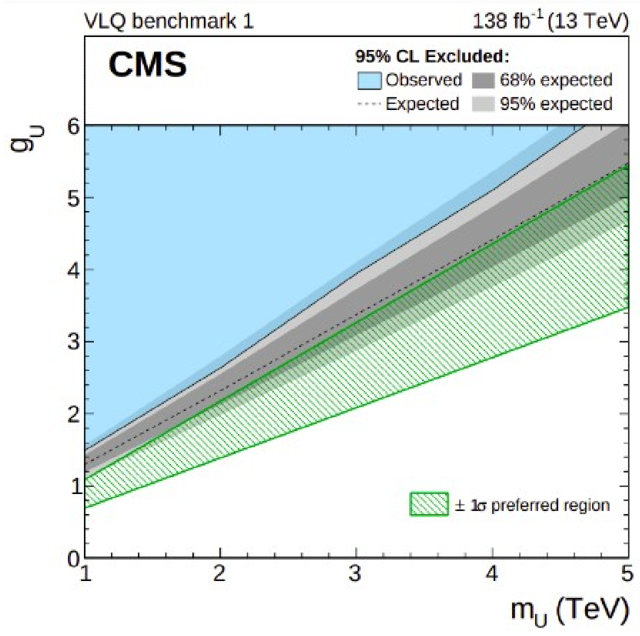


BSM H → ττ search is sensitive to nonresonant production of LQ

→ Extends sensitivity to large vector LQ masses





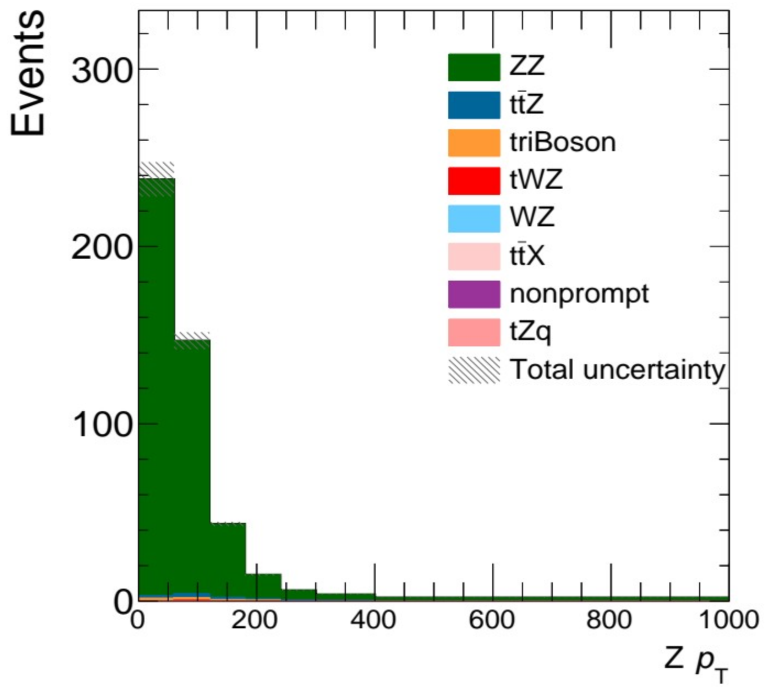


Constraining regions in parameter space allowed by theory fit to flavor physics data [by Isidori group]

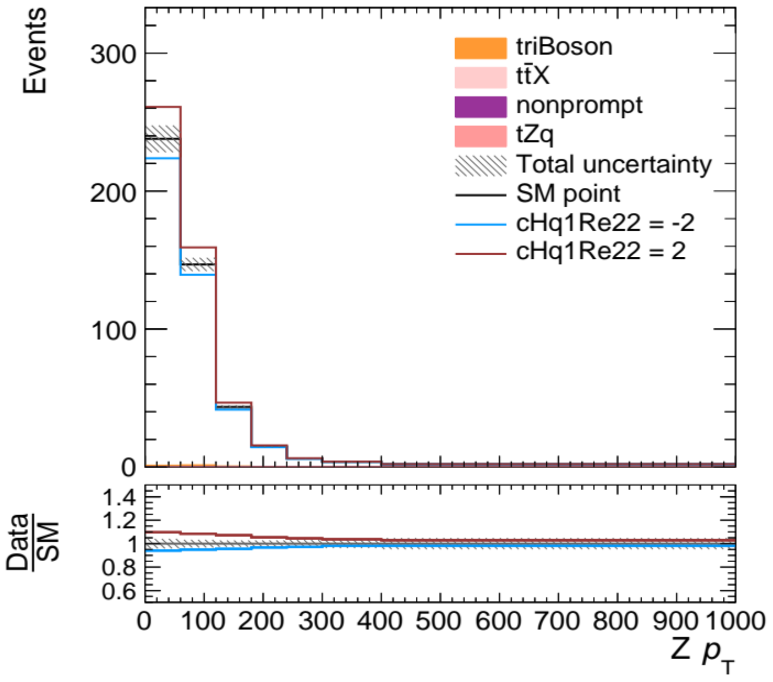
Flavor structure of vector couplings in SMEFT

Fiducial regions defined by conditions on reconstructed objects (independent of EFT hypothesis)

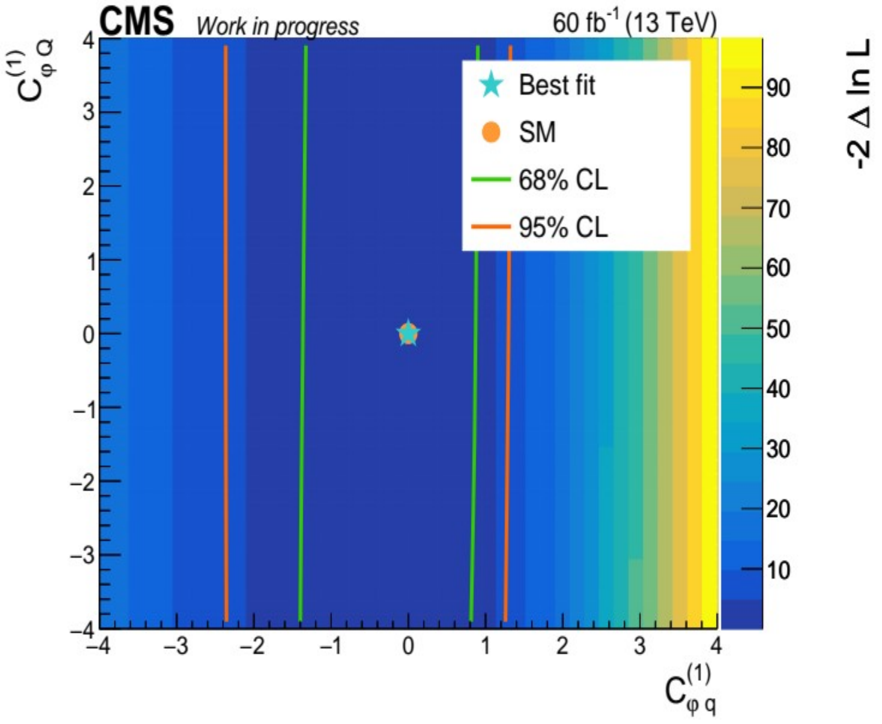
ZZ region



Pure ZZ region



Simultaneous EFT for ttZ, WZ, ZZ



Constrain only light-quark operators

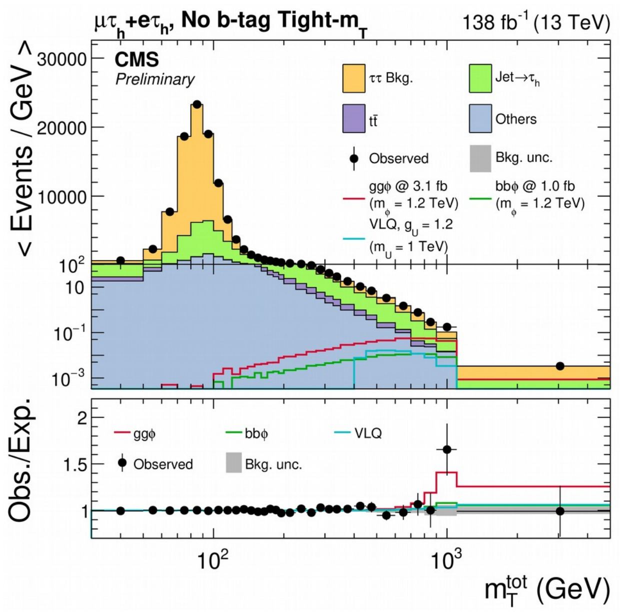
Jet → τ fake background for BSM H→ττ search

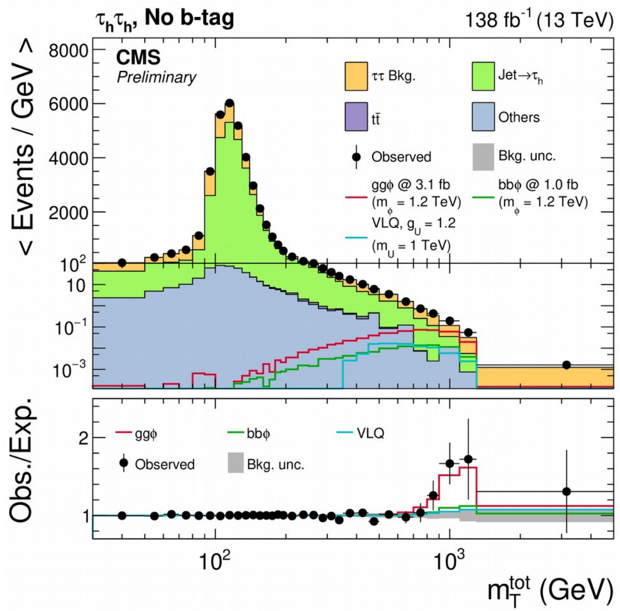
Fake factor technology re-used in searches for

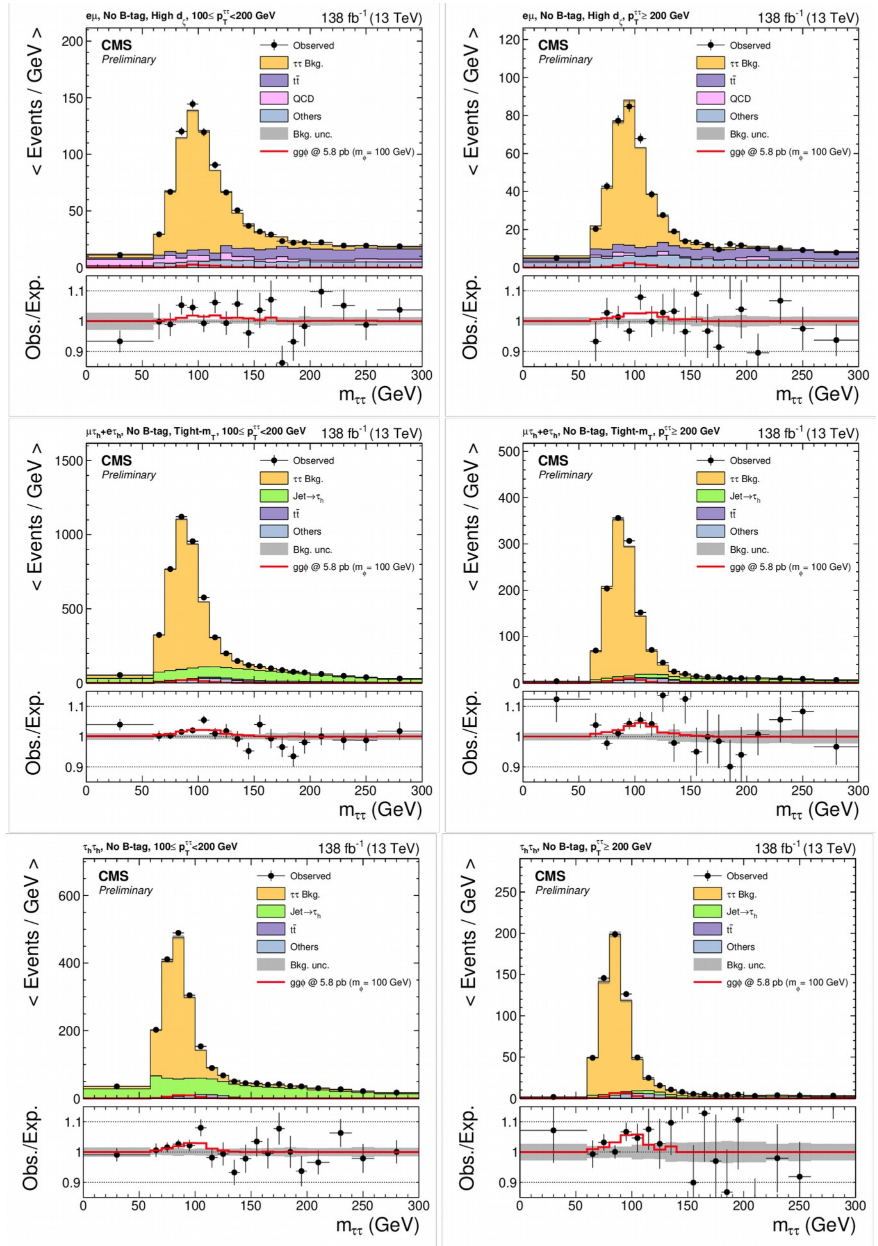
Janik, Suman

BSM H→ττ

CMS-PAS-HIG-21-001





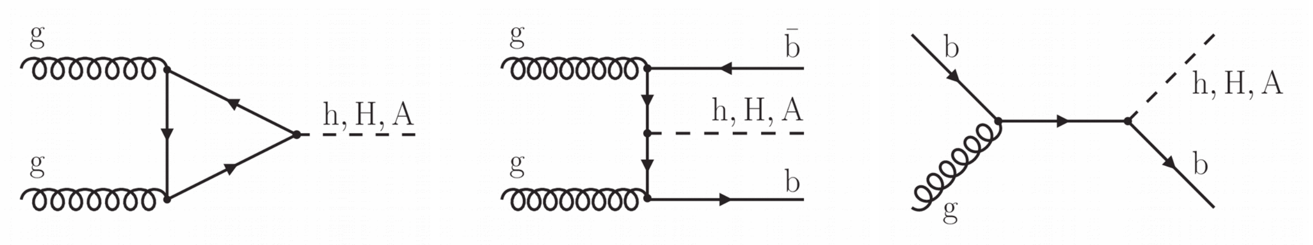


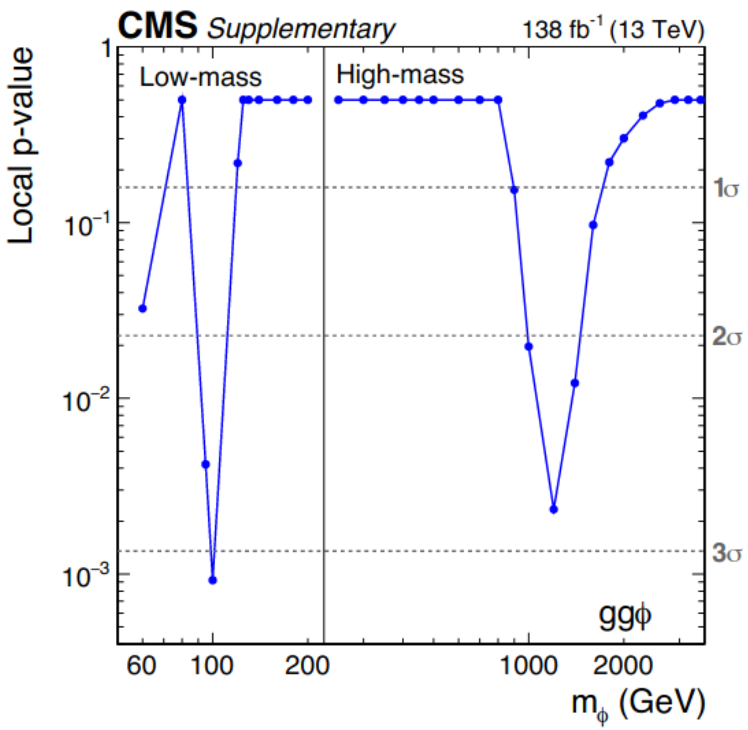
Jet → τ fake background for BSM H→ττ search

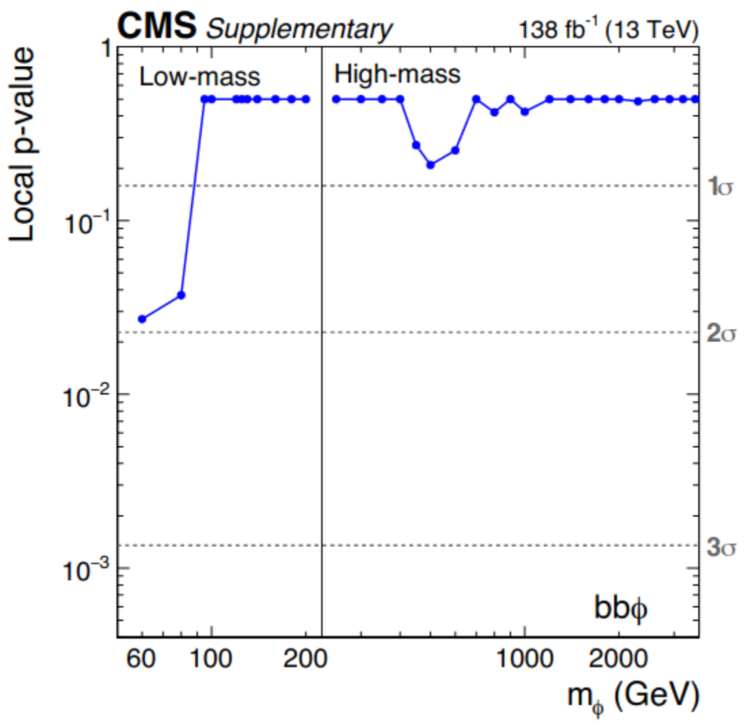
Fake factor technology re-used in searches for

Janik, Suman

BSM H→ττ CMS-PAS-HIG-21-001

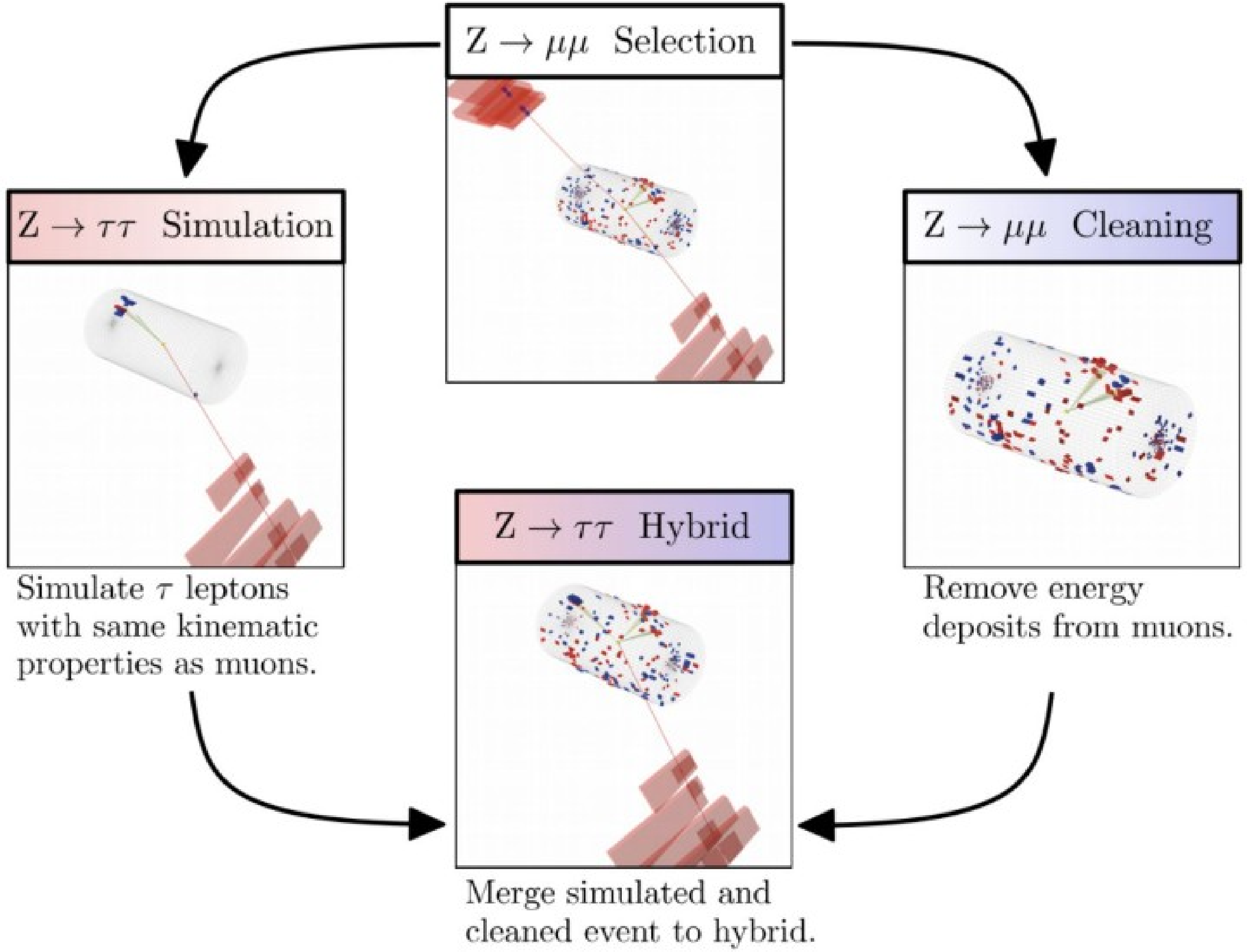






@ 100 GeV local (global) significance for ggΦ = 3.1 (2.7) σ
@ 1200 GeV local (global) significance for ggΦ = 2.8 (2.4) σ

Embedding method



- Estimate all **backgrounds with two real τ**
- Select di-muon events from data, remove muon hits
- Muons are replaced by simulated taus with the same kinematics
- Advantages
  - Decent description of jet and underlying event
  - Less systematic uncertainties
- Used in HIG-18-032

Stolen from D. Kim's talk

Dark matter & compressed stop

$$\Omega_{\rm CDM}h^2 \approx \frac{3\times 10^{-27}{\rm cm}^3{\rm s}^{-1}}{\langle\sigma v\rangle}$$

$$\langle\sigma_{\rm eff}v\rangle = \sum_{ij}\langle\sigma_{ij}v_{ij}\rangle\frac{n_i^{\rm eq}}{n^{\rm eq}}\frac{n_j^{\rm eq}}{n^{\rm eq}}$$

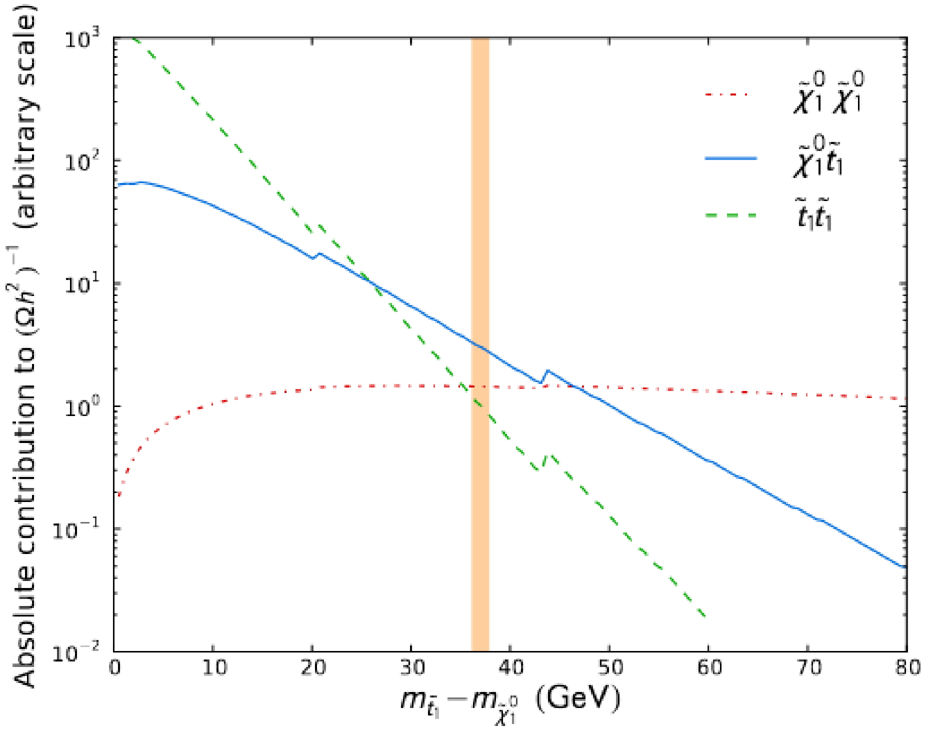
$$r_i\, r_j \equiv \frac{n_i^{\rm eq}}{n^{\rm eq}}\frac{n_j^{\rm eq}}{n^{\rm eq}}$$

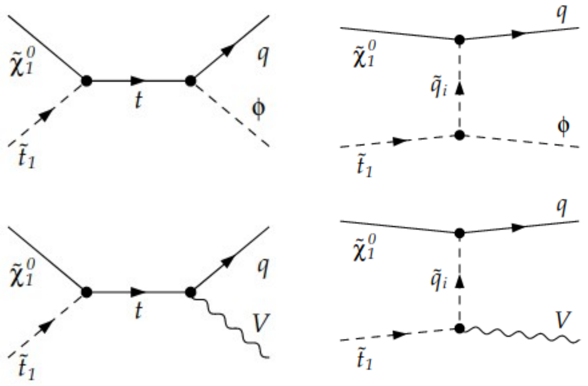
$$r_1\, r_1 \sim 1,$$

$$r_1\, r_2 \sim \frac{g_2}{g_1}\left(\frac{m_2}{m_1}\right)^{3/2} e^{-(m_2-m_1)/T},$$

$$r_2\, r_2 \sim \left(\frac{g_2}{g_1}\right)^2\left(\frac{m_2}{m_1}\right)^3 e^{-2(m_2-m_1)/T}.$$

Plot stolen from Quentin’s thesis





$m_2 = m_{stop}$ & $m_1 = m_{LSP}$

$T \sim m_{LSP}/20$

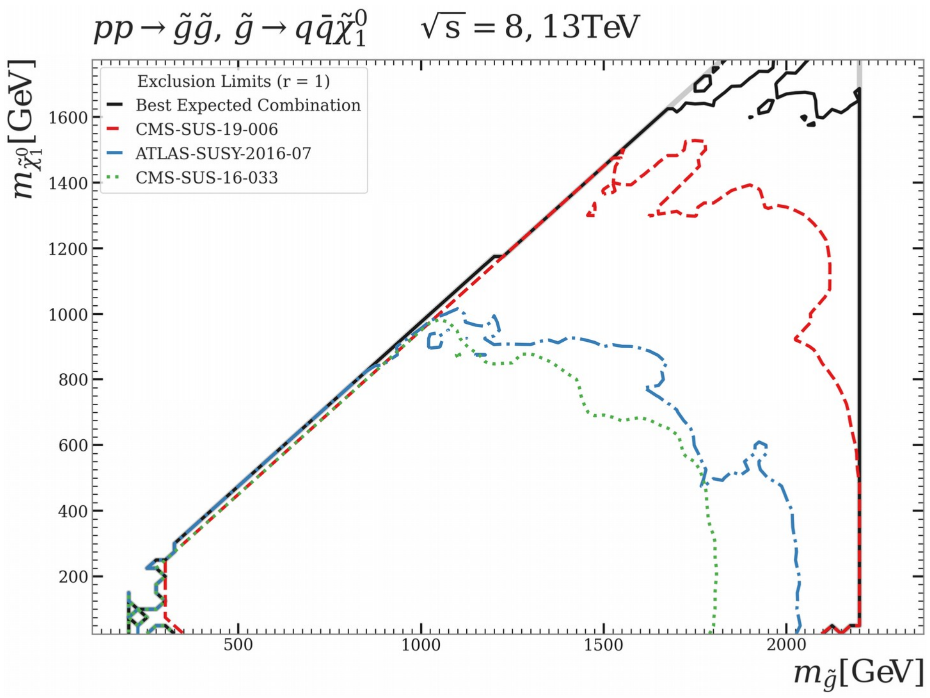
Stop-LSP coannihilation ~ $\exp(-20(m_{stop} - m_{LSP}) / m_{LSP})$

Stop-stop annihilation ~ $\exp(-40(m_{stop} - m_{LSP}) / m_{LSP})$

Wolfgang W

Interpretation

Idea: perform large-scale combinations of results in SModelS database that are approximately uncorrelated. Identify most sensitive combinations.



Show how exclusion lines are better

"**TACO collaboration**": Collaboration with members from MadAnalysis5, Contur/Rivet, and Gambit!

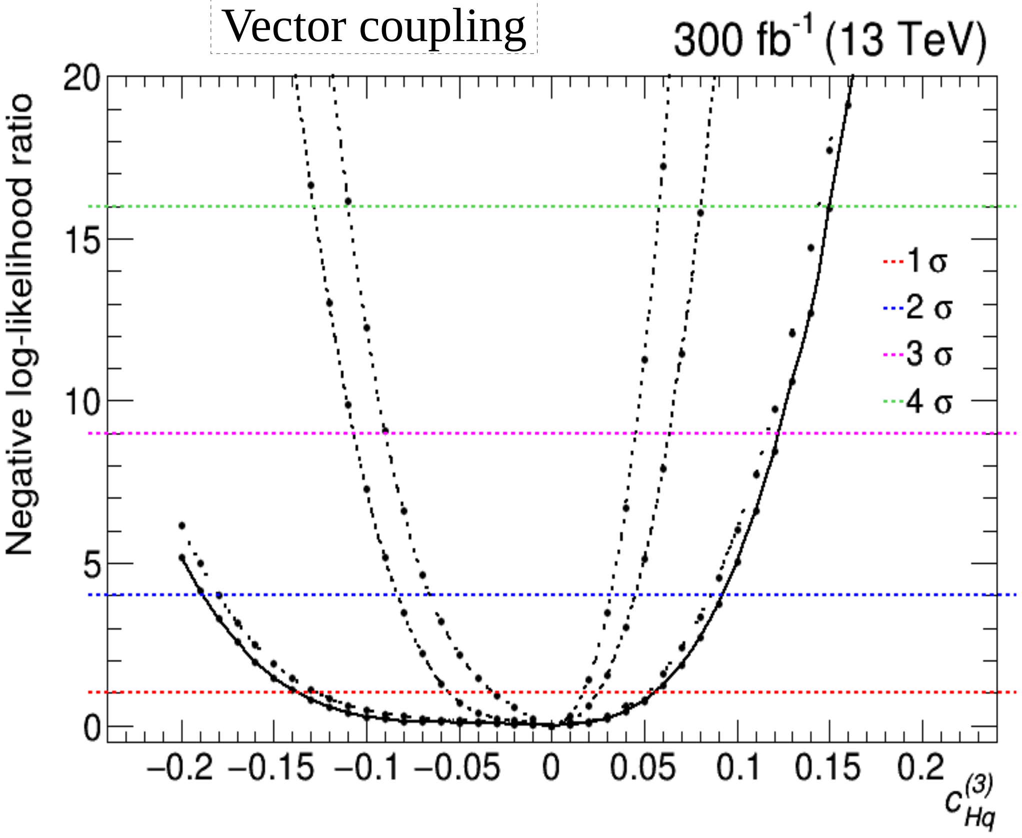
Discussions about larger combinations between searches and measurements

Suman, Robert

Illuminating SMEFT with Higgs radiation

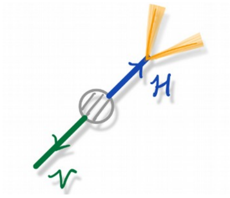
Preliminary sensitivity results obtained for Run-2 + Run-3 integrated luminosity (~300 fb-1)

Vector coupling

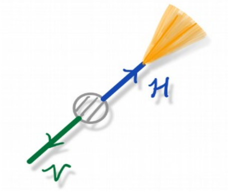


$$\mathcal{O}_{Hq}^{(3)} = iH^{\dagger}\sigma^{a}\overleftrightarrow{D}_{\mu}H\bar{q}\sigma^{a}\gamma^{\mu}q$$

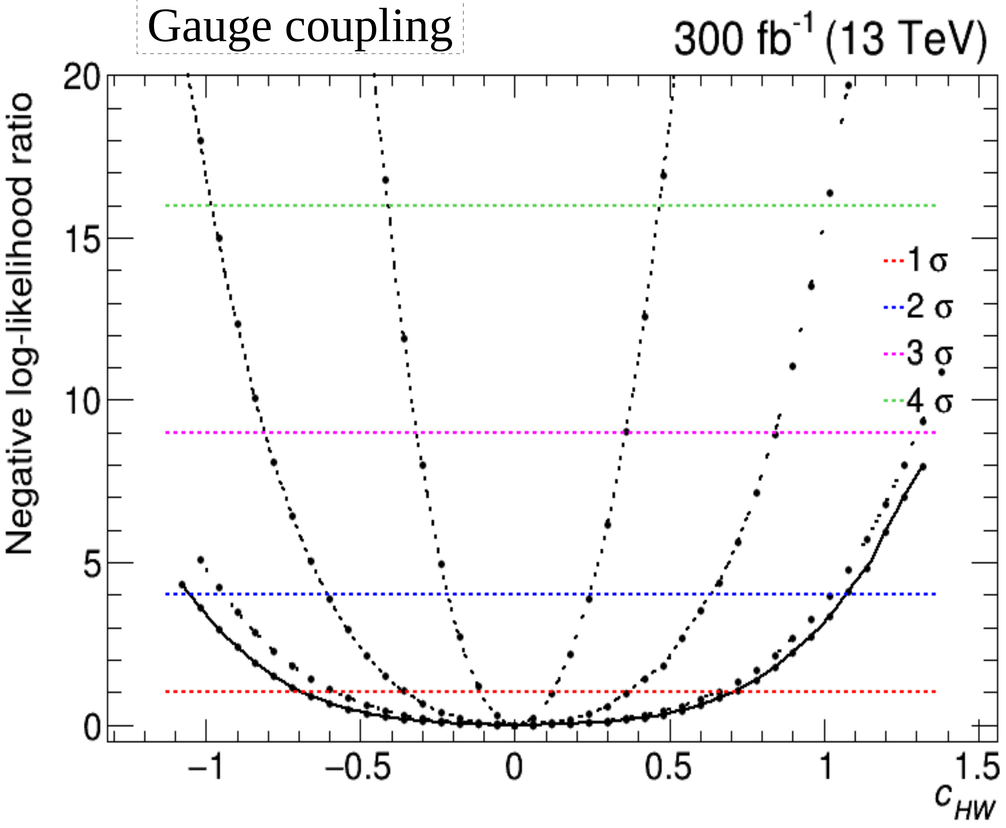
Resolved category:



Boosted category:



Gauge coupling



$$\mathcal{O}_{HW} = |H|^{2}W_{\mu\nu}W^{\mu\nu}$$

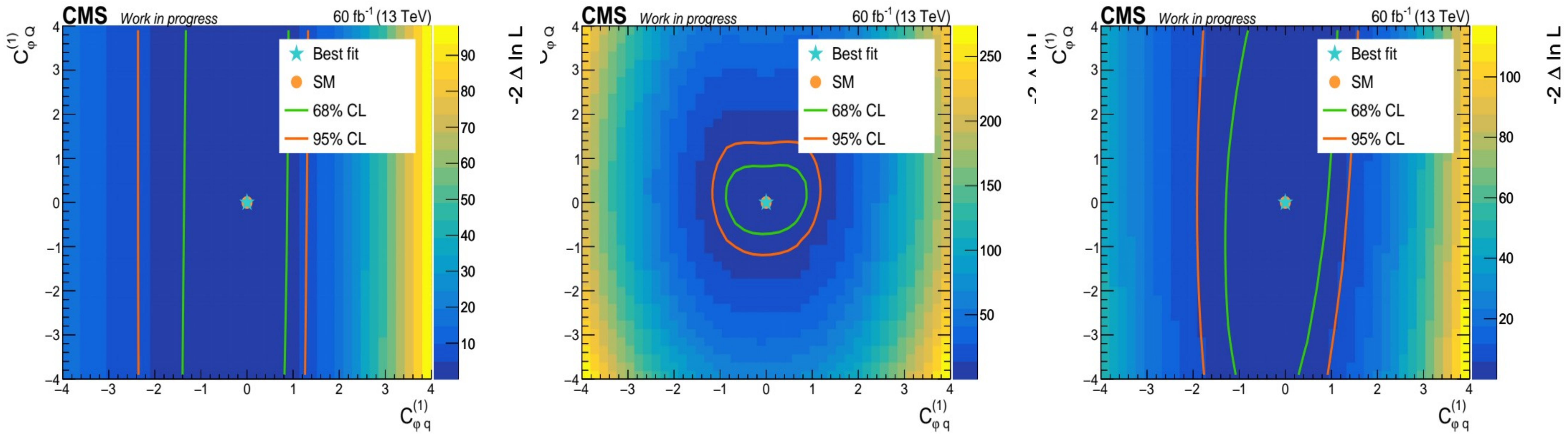
Large cross section growth with energy → EFT effects can be probed to a high precision

Timeline:
Winter 2022 (Run 2 analysis)
Plan to continue in Run 3

Dennis, Robert

Flavor structure of vector couplings in SMEFT

ZZ region **ttZ region** **WZ region**



Together constrain light & heavy quark couplings