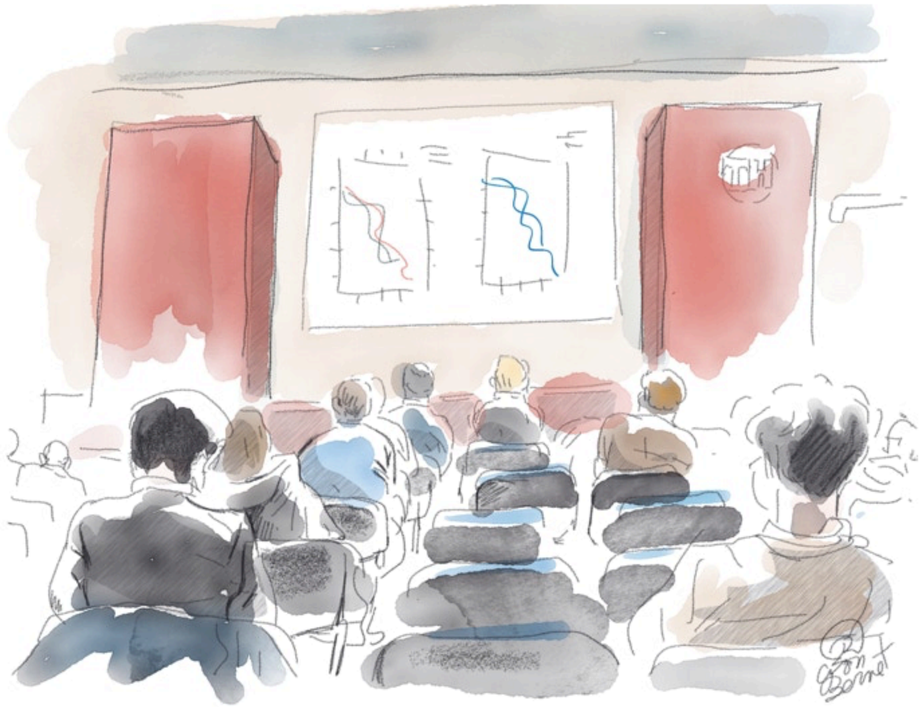
Highlights from the Recontres de Moriond

Zeynep Demiragli (Boston University)



April 22 2022, Wine and Cheese Seminar, Fermilab

Moriond was in person!

Disclaimer 1: I was not there … but …

- Over 140 participants in Moriond EW and over 100 participants in Moriond QCD
- (Was told) great atmosphere & lots of interaction & great skiing conditions

And of course many new results!

Disclaimer 2: CMS alone has over 25 new results!

- Naturally there will be some personal bias on the “more” highlighted results in this presentation.
- When related, tried to bring in the insight from the other side of the ring, ATLAS

Moriond was in person!

Full (**impressive**) list of results that were presented at Moriond (EW/QCD)!

CMS-PAS-SUS-21-007	Search for supersymmetry in final states with a single electron or muon using angular correlations and heavy object tagging in proton-proton collisions at √s= 13 TeV
CMS-PAS-TOP-20-006	Measurement of differential cross sections for the production of top quark pairs and of additional jets in pp collisions at √s= 13 TeV
CMS-PAS-TOP-21-008	Measurement of the top quark pole mass using tt¯¯¯—tt¯+jet events in the dilepton final state at √s= 13 TeV
CMS-PAS-TOP-21-011	Measurement of the cross section of top quark-antiquark pair production in association with a W boson in proton-proton collisions at s√=s= 13 TeV
CMS-PAS-EXO-20-011	Search for a heavy composite Majorana neutrino
CMS-PAS-B2G-20-009	Search for new heavy resonances decaying to WW, WZ, ZZ, WH, or ZH boson pairs in the all-jets final state in proton-proton collisions at s√=s= 13 TeV
CMS-PAS-TOP-21-007	Search for central exclusive production of top quark pairs in proton-proton collisions at s√=s= 13 TeV with tagged protons
CMS-PAS-PRO-21-001	Proton reconstruction with the CMS Precision Proton Spectrometer in Run 2
CMS-PAS-EXO-19-009	A search for new physics in central exclusive production using the missing mass technique with the CMS-TOTEM precision proton spectrometer
CMS-PAS-HIN-21-009	Observation of ττ lepton pair production in ultraperipheral nucleus-nucleus collisions
CMS-PAS-HIG-19-016	Measurement of the Higgs boson inclusive and differential fiducial production cross sections in the diphoton decay channel with pp collisions at √s= 13 TeV with the CMS detector
CMS-PAS-HIG-21-001	Searches for additional Higgs bosons and vector-like leptoquarks in ττfinal states in proton-proton collisions at √s= 13 TeV
CMS-PAS-HIG-20-013	Measurements of properties of the Higgs boson in the W boson pair decay channel in proton-proton collisions at √s= 13 TeV
CMS-PAS-B2G-21-004	Search for pair-produced vector-like leptons in ≥≥ 3b ++ N ττ final states

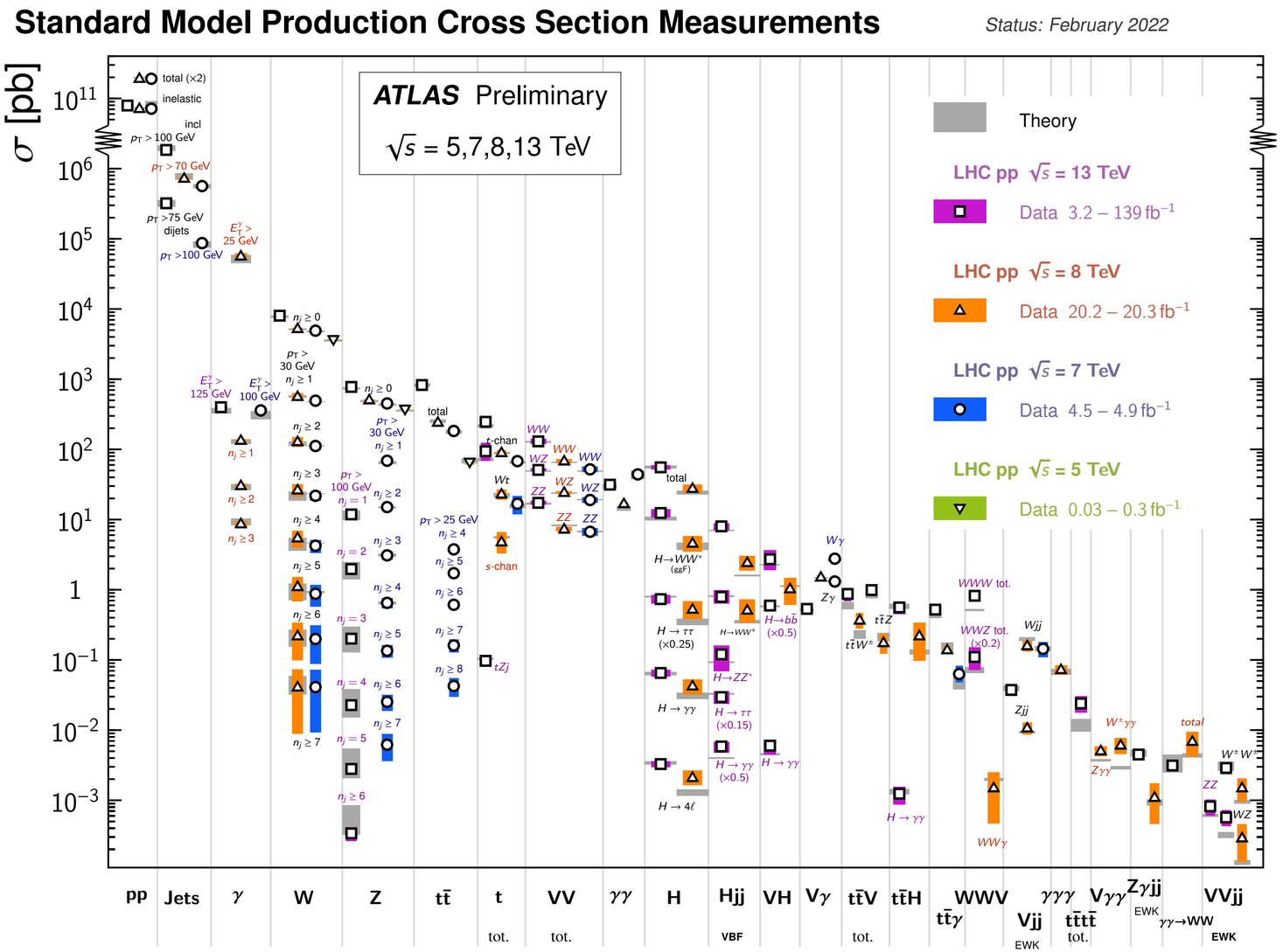
CMS-PAS-HIG-21-010	Search for a charged Higgs boson decaying into a heavy neutral Higgs boson and a W boson in proton-proton collisions at √s= 13 TeV
CMS-PAS-HIG-21-016	Search for exotic Higgs boson decays H →AA→4γ with events containing two merged photons in proton-proton collisions at √s= 13 TeV
CMS-PAS-HIG-21-015	Search for the Higgs boson decay to a pair of electrons in proton-proton collisions at s√=s= 13 TeV
CMS-PAS-HIG-20-016	Search for high mass resonances decaying into W++W−− in the dileptonic final state with 138 fb−1−1 of proton-proton collisions at s√=s= 13 TeV
CMS-PAS-SMP-21-014	Search for exclusive γγ→ WW and γγ→ ZZ production in final states with jets and forward protons
CMS-PAS-SMP-21-013	Observation of WW from double-parton scattering in proton-proton collisions at s√=s= 13 TeV
CMS-PAS-B2G-22-003	Nonresonant pair production of highly energetic Higgs bosons decaying to bottom quarks
CMS-PAS-EXO-21-003	Probing Majorana neutrinos and the Weinberg operator in the same-charge dimuon channel through vector boson fusion processes in proton-proton collisions at √s= 13 TeV
CMS-PAS-EXO-21-010	Search for resonant and non-resonant production of pairs of identical dijet resonances in pp collisions at √s= 13 TeV
CMS-PAS-EXO-20-006	Search for Z' bosons decaying to pairs of heavy Majorana neutrinos in proton-proton collisions at √s= 13 TeV
CMS-PAS-HIG-21-006	Search for CP violation in tt¯H and ttH production in multilepton channels at √s= 13 TeV
CMS-PAS-HIG-20-010	Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two tau leptons in proton-proton collisions at √s= 13 TeV
CMS-PAS-HIG-21-008	Direct search for the standard model Higgs boson decaying to a charm quark-antiquark pair

Standard Model: W & Z Measurements

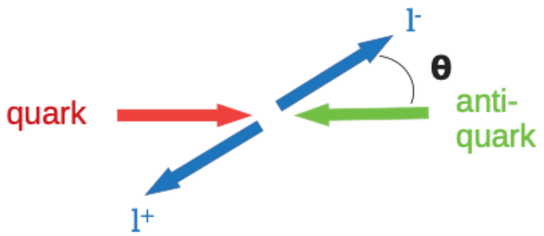
We are sensitive to an ***enormous*** dynamic range of cross sections at the LHC

Vector Bosons processes are very well understood at hadron colliders:

- Probe QCD effects
- Measure EWK parameters, couplings/branching fractions, AFB
- Search for rare decay channels



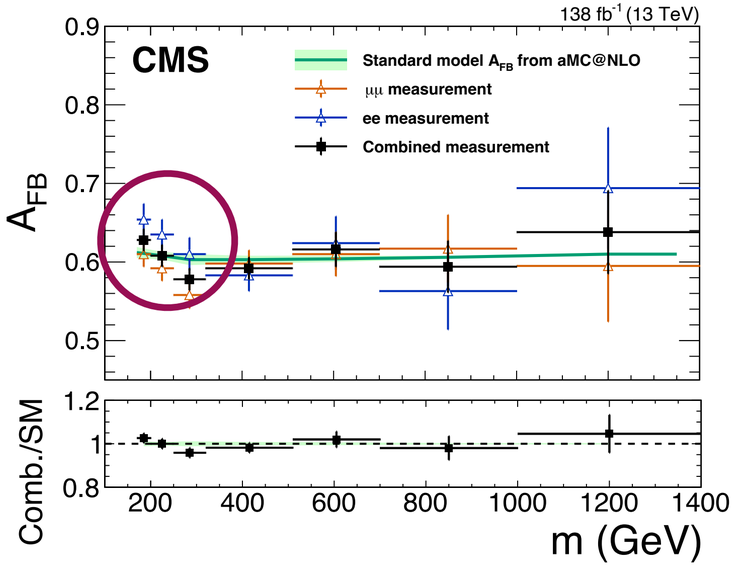
DY forward-backward asymmetry measurements



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

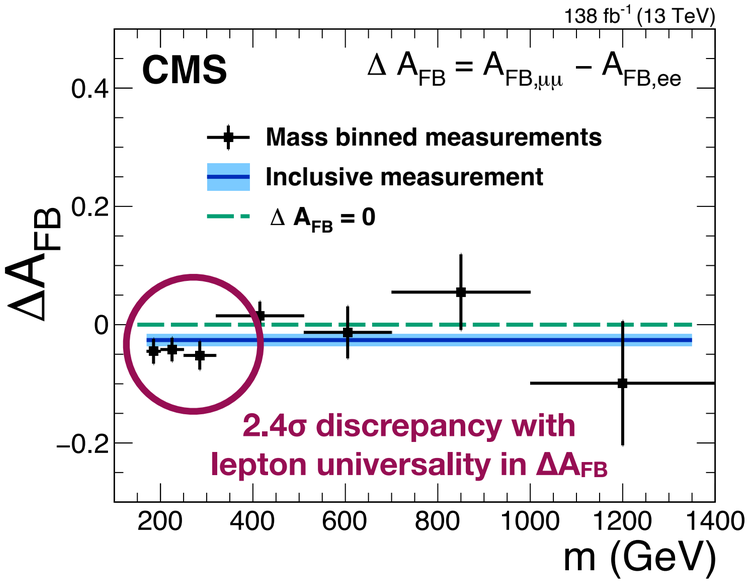
Forward-Backward Asymmetry, **A_{FB}**, compares the angular distribution of the final state lepton with respect to the initial state quark. **SMP-21-002**

N_F= number of events with cos(θ) > 0
N_B = number of events with cos(θ) < 0



Why is it interesting?

- new gauge bosons, quark-lepton compositeness, extra dimensions, vector-like fermions, dark matter models, or leptoquarks
- measuring separately in e and μ gives sensitivity to lepton non-universality.



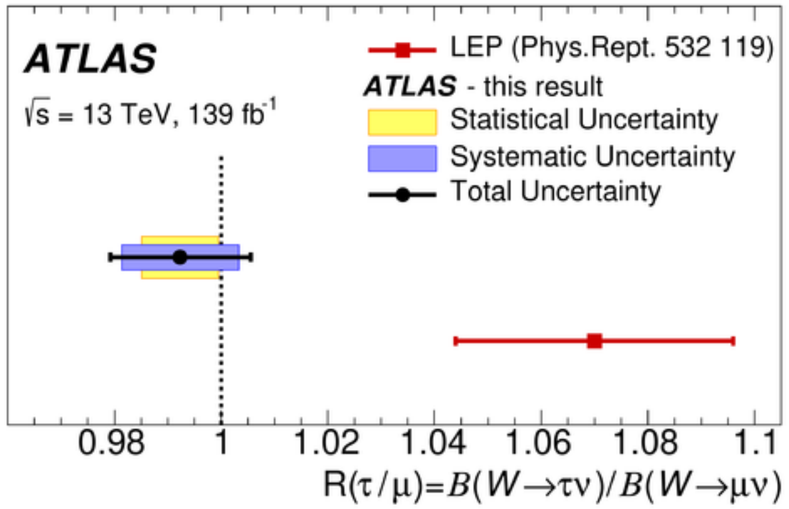
W Branching Fractions - Lepton Flavor Universality

Test of the universality of τ and μ lepton couplings in W-boson decays with ATLAS Nature Physics 21

Unique approach: using di-leptonic top quark pairs:

- One W decaying promptly to μ (or e)
- The other decaying $W \rightarrow \tau\nu_\tau \rightarrow \mu\nu_\mu\nu_\tau\nu_\tau$
  - Using pT and $d\mu_0$ to distinguish the τ decays from the prompt decay

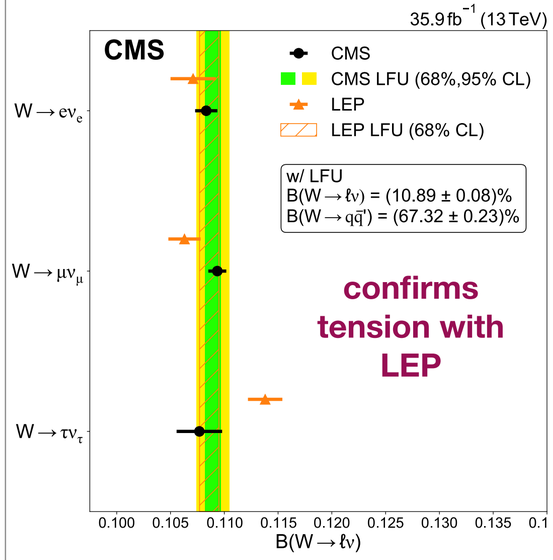
Tension with LEP, and better precision

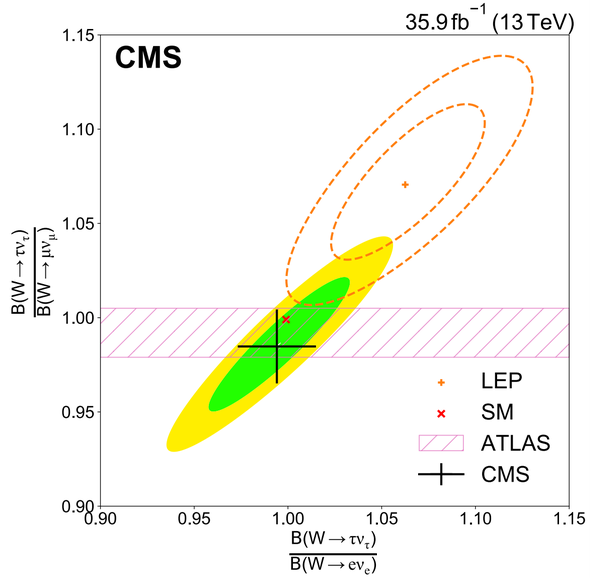


Precision measurement of the W boson decay branching fractions Phys. Rev. D (Editors' Suggestion article)

- All the W BFs (3 leptons and hadrons) and their ratios are measured di-leptonic tt decays (ee, μμ or eμ).
- tW, WW processes are also considered as signal

competitive with ATLAS and consistent with SM

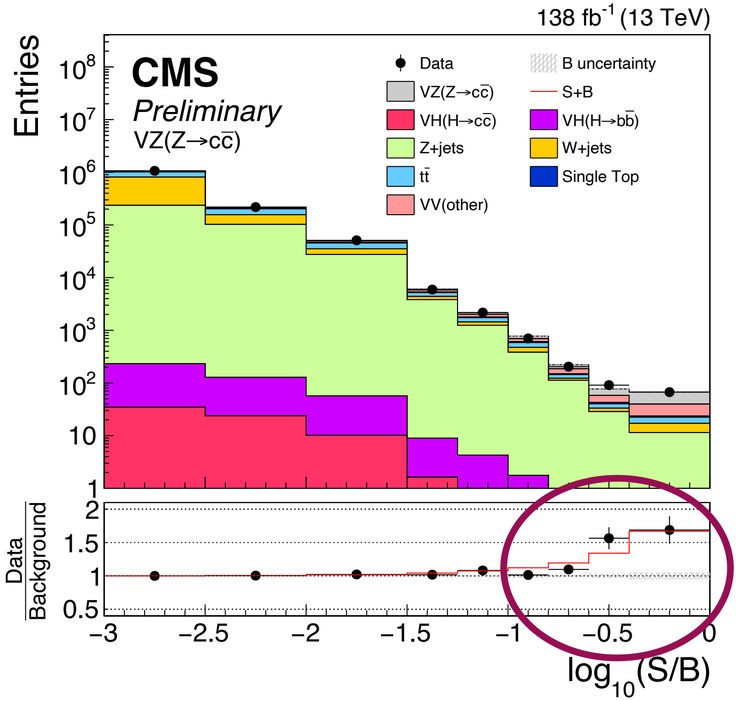




First observation of Z to cc

In attempt to measure H → cc in associated VH production, ended up with the first **observation of Z → cc** at a hadron collider! Analysis validated by first looking for VZ(Z→cc) process **HIG-21-008**

Very challenging measurement: large QCD multijet background and difficulty of identifying charm quark jets in a hadronic environment



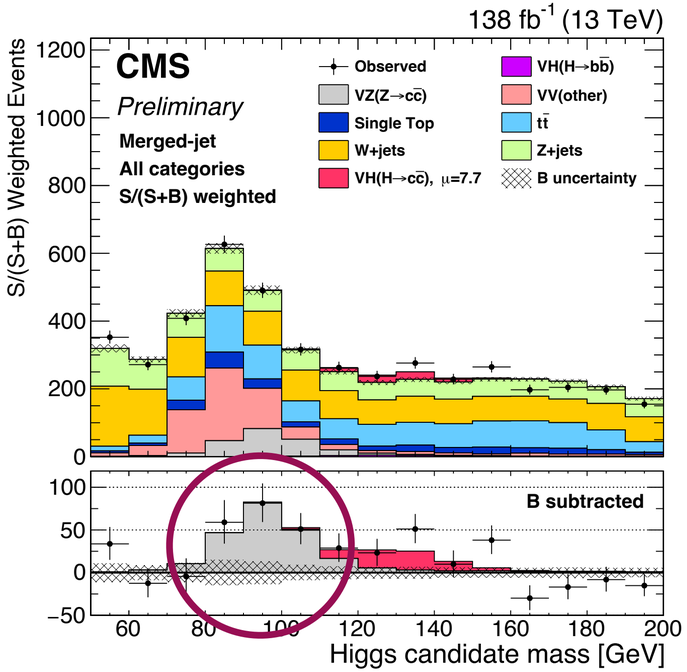
Resolved (2 resolved AK4 jets)

- DeepJet for charm Tagging: Multiclassifier DNN architecture that makes use of CNN and RNN layers
- c-jet energy regression using DNN architecture
- Kinematic fit
- BDT for signal extraction

Merged (1 AK15 jet)

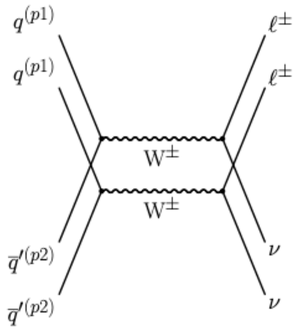
- Particle Net cc-tagger based on a graph neural network (GNN) that treats the jet as an unordered set of particles
- Mass regression on the AK15 jet
- BDT for signal extraction

First observation of Z→cc at (5.7σ)
μ (Z→cc) = 1.01 + 0.23 - 0.21

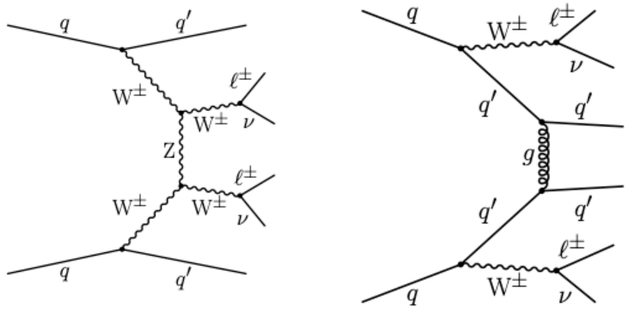


Observation of WW from double-parton scattering

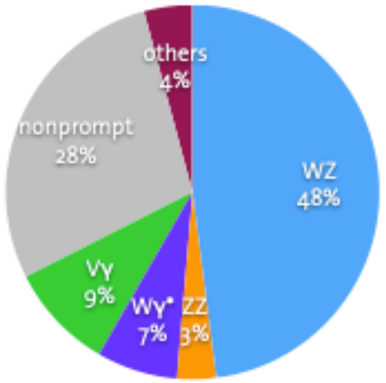
SMP-21-013



DPS W±W± signal



SPS production EW+QCD



Signal & background **discrimination based on BDT classifiers**; trained separately against WZ and fake lepton backgrounds

A lot of interesting physics can be learned from multi parton scattering:

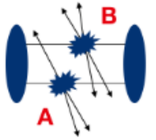
Probes the internal structure of a proton & Provides input for the tuning of MC simulations & Background for SM & BSM processes

Remember: DPS cross section grows strongly with center of mass energy

Observed with **6.7 s.d. (expected: 6.2 s.d.)** production cross section of

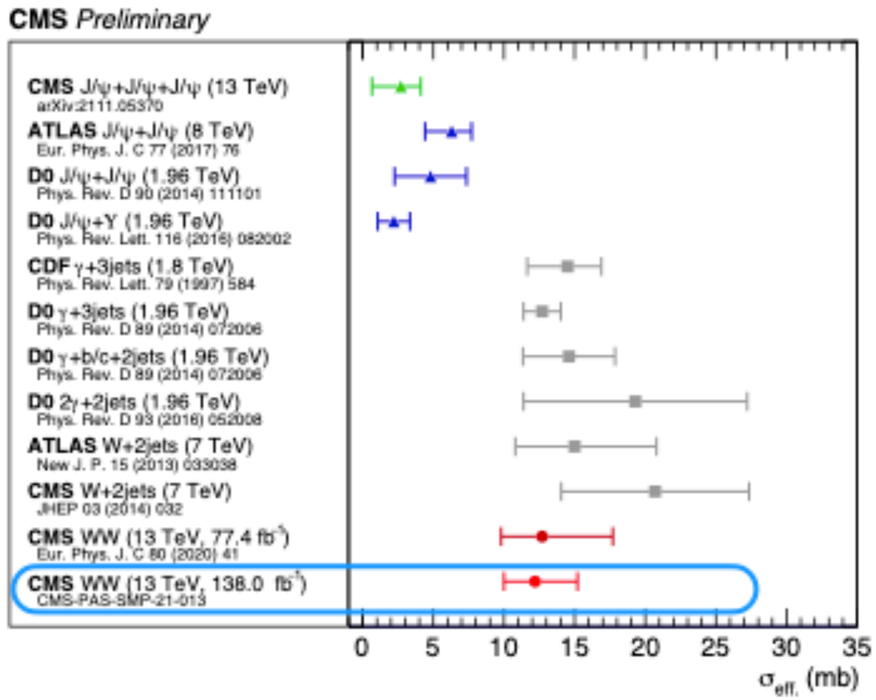
σ_{DPS}^{WW} **= 0.16 ± 0.02 (stat) ± 0.02 (syst) ± 0.02 (model) pb**

expected cross section from pythia: 0.173 pb ± 40% (tune)



$$\sigma_{AB}^{DPS} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

effective cross section σ_{eff} **= 12.16 + 3.0 - 2.2 mb**



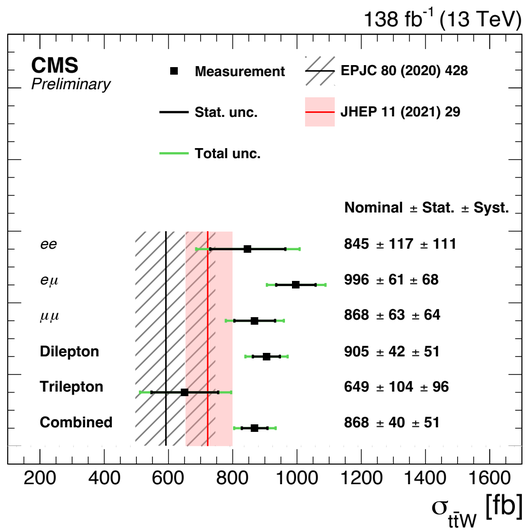
Observation of WWW and Measurement of ttW

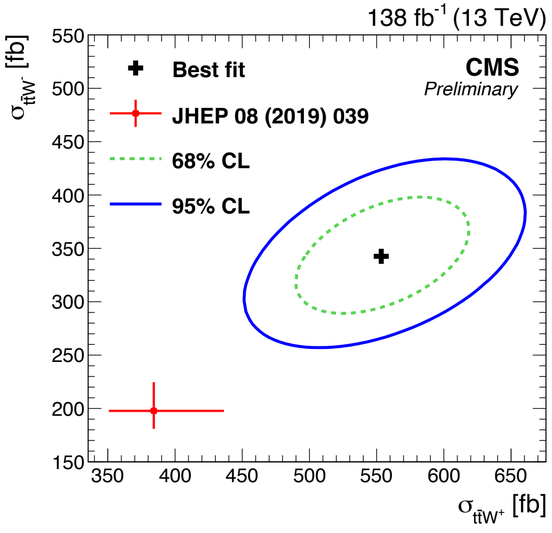
Observation of WWW production in pp collisions at √s=13 TeV with the ATLAS detector STDM-2019-09

- Test of SM gauge boson self-interactions, deviations would hint BSM
- Among the least-understood SM processes given the small production cross-section.
- In this analysis: Considered 2l and 3l final states & Two BDTs used to improve signal to background separation

CMS had before observation of VVV with 3.3 σ in WWW.
PRL 125 (2020) 151802

Fit	$\mu(WWW)$	Significance observed (expected)
$e^{\pm}e^{\pm}$	1.54 ± 0.76	2.2 (1.4) σ
$e^{\pm}\mu^{\pm}$	1.44 ± 0.39	4.1 (3.0) σ
$\mu^{\pm}\mu^{\pm}$	2.23 ± 0.46	5.6 (2.7) σ
2ℓ	1.75 ± 0.30	6.6 (4.0) σ
3ℓ	1.32 ± 0.37	4.8 (3.8) σ
Combined	$\mathbf{1.61 \pm 0.25}$	**8.0 (5.4) σ**



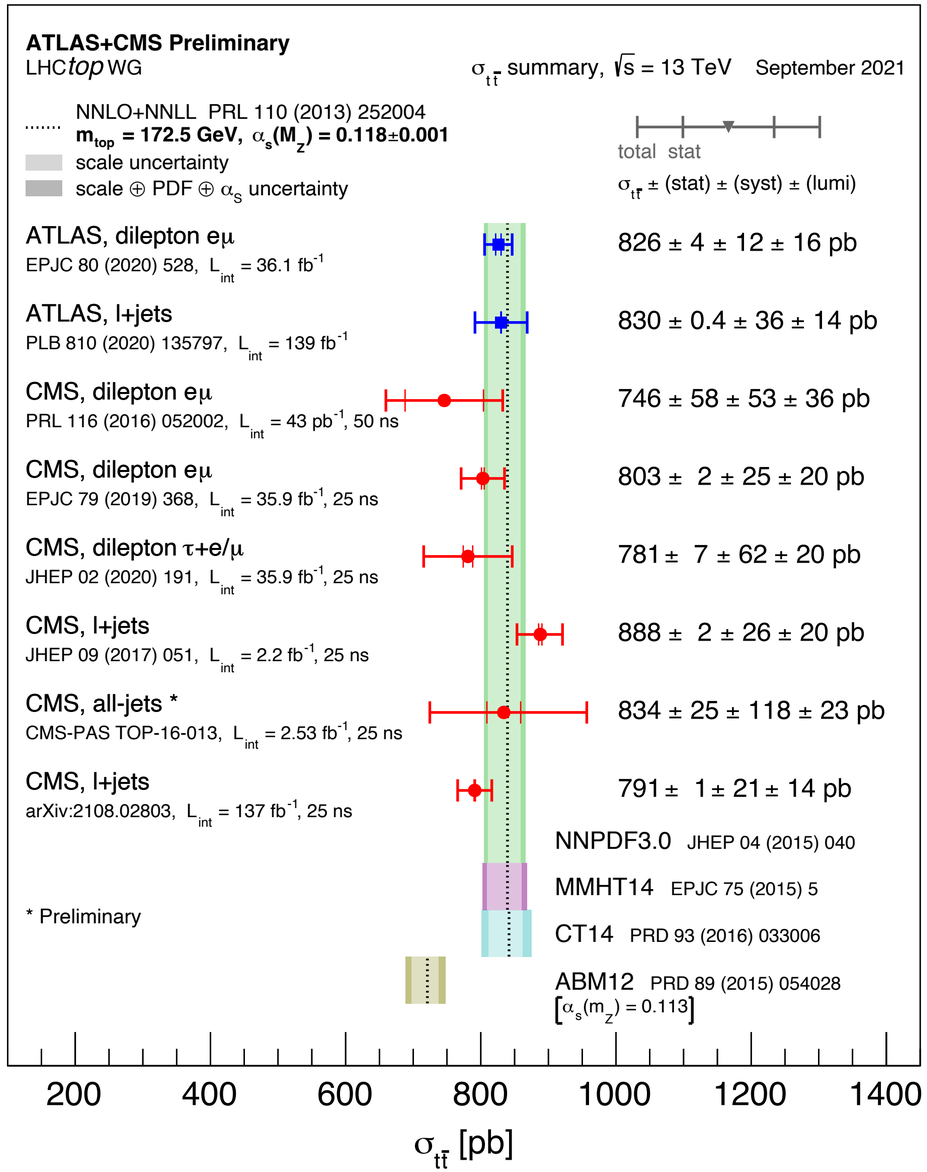


Measurement of the cross section of top quark-antiquark pair production in association with a W boson

TOP-21-011

- t-W scattering sensitive to EWK coupling
- **R ttW+/ ttW- asymmetry (~1.6)** as expected
  Cross-section ~1.5x higher than NLO+NNLL / NLO w. FxFx ME
- One of the important systematics
  - 50% uncertainty is applied on the triboson production, as the main contribution to this background comes from the WWW

Getting precise with Top!



Top quark being the heaviest SM particle (with y_t nearly 1)!

- affects the EW vacuum stability.
- It also decays before hadronisation and spin decorrelation, enabling a direct access to top mass and polarization!

BSM extensions predict:

- Modifications in top quark couplings
- Observation of the top production or decay processes that would nominally be suppressed (or forbidden) in SM

Most precise single inclusive measurement is:

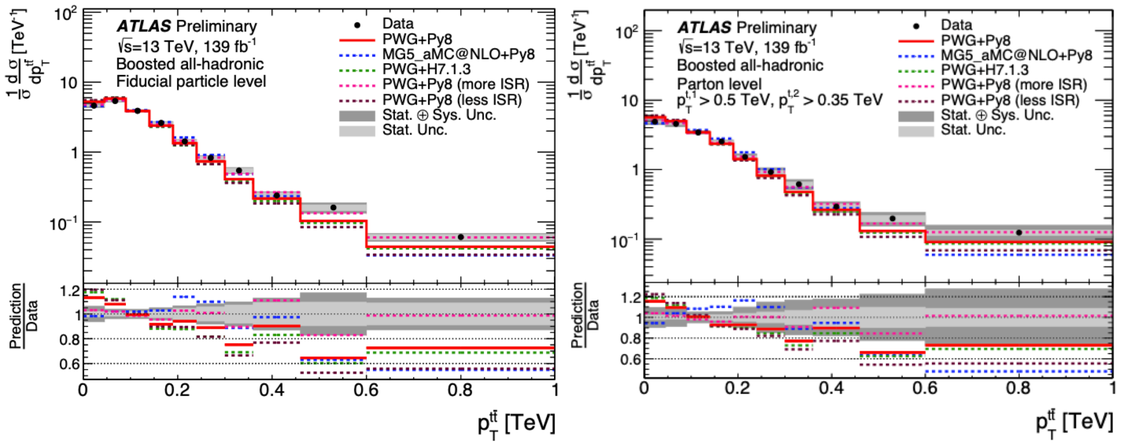
- **$\Delta\sigma / \sigma = 2.4\%$** (from ATLAS)
- **Theory predictions has $\Delta\sigma / \sigma = +4.8/-5.5\%$**

Differential measurements, cross sections in bins of 1,2, or 3 kinematic variables at particle level and/or Parton level are crucial to the LHC program

Getting precise with Top!

Differential tt cross-section measurements using boosted top quarks in the all-hadronic final state
ATLAS-CONF-2021-050

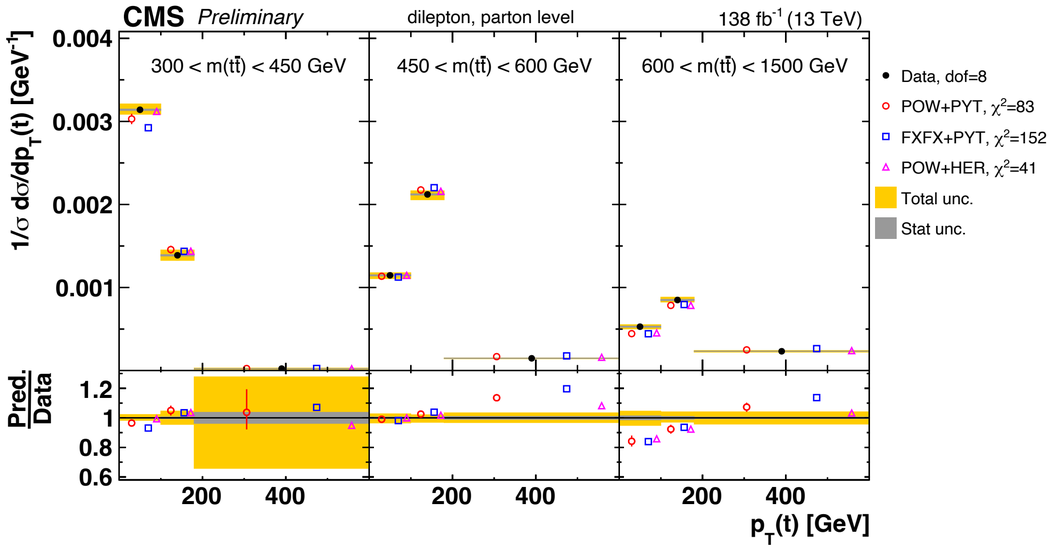
- A focus on highly-boosted top-quark final states probes the QCD ttbar production processes in the TeV scale range
- DNN based top-quark-tagging algorithm
- Differential measurements on particle and on parton level



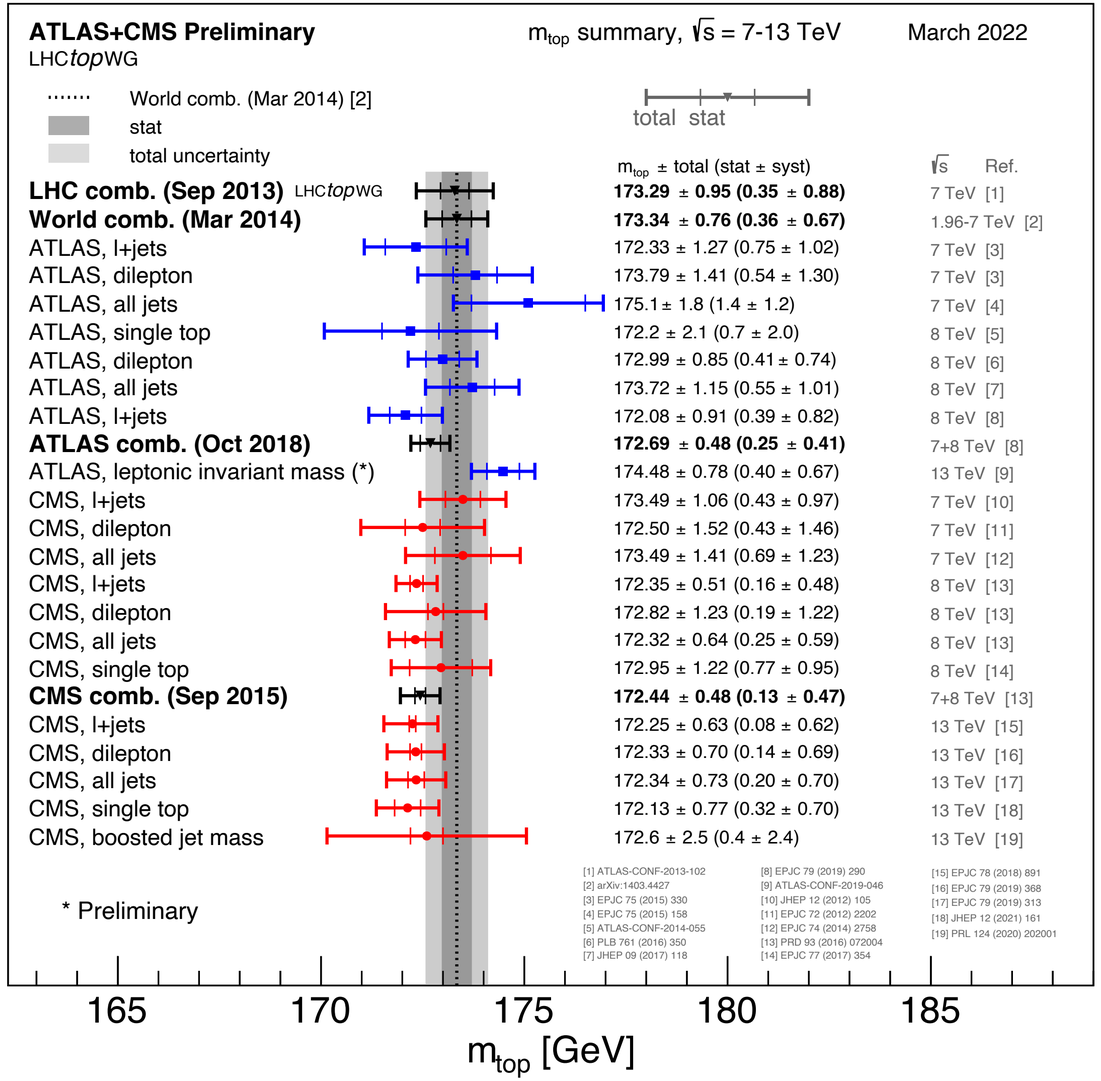
Measurement of differential cross sections for the production of top quark pairs and of additional jets

CMS-TOP-20-006

- Measuring as a function of top and ttbar kinematic observables, their decay products, and the number of additional jets
- Compared to MC with NLO accuracy and also beyond NLO. Largest deviations for multi-differential cross-sections



Top Mass



Direct measurements of the top mass reach a precision of:

m_t = 172.44 ± 0.48 GeV

The direct measurements rely on the reconstruction of the top quark decay products -> Relying on MC

$$m_t^{MC} = m_t^{pole} + \Delta_{MC}\ O(1\ \text{GeV})$$

TOP-21-008

First measurement of **top quark pole mass** using normalized differential cross section of **ttbar+ jet in CMS at 13 TeV**

$$\mathcal{R}(m_t, \rho) = \frac{1}{\sigma_{t\bar{t}+jet}} \frac{d\sigma_{t\bar{t}+jet}}{d\rho}$$

$$\text{with } \rho = \frac{2\,m_0}{m_{t\bar{t}+jet}},\ m_0 = 170\ \text{GeV}$$

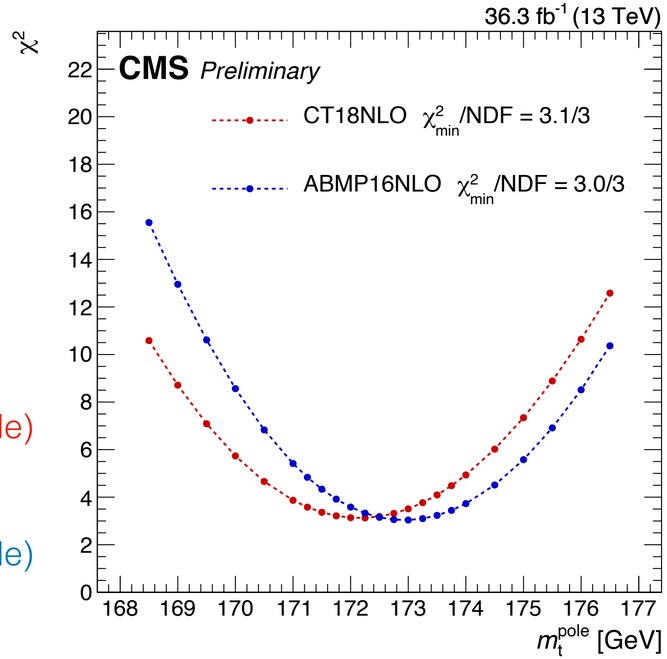
m_t^{pole} =

(CT18NLO)

172.16 ± 1.34 (fit+PDF+extr) $^{+0.50}$ (scale)

(ABMP16NLO)

172.94 ± 1.26 (fit+PDF+extr) $^{+0.51}$ (scale)



The Higgs Boson - 10th year anniversary coming up

2012 - I am born!
2013 - First steps
2014 - Who am I?
2015 - Why am I alone?
2016 - Not afraid of dark!
2017 - Trip to the tau-land
2018 - From top to bottom
2019 - I am getting precise
2020 - Meet 2nd generation
2021 - How broad am I?
2022 - I am charming!

From G. Landsberg

10 new results from HIG @ Moriond!

CMS-PAS-HIG-19-016	Measurement of the Higgs boson inclusive and differential fiducial production cross sections in the diphoton decay channel with pp collisions at $\sqrt{s} = 13$ TeV with the CMS detector
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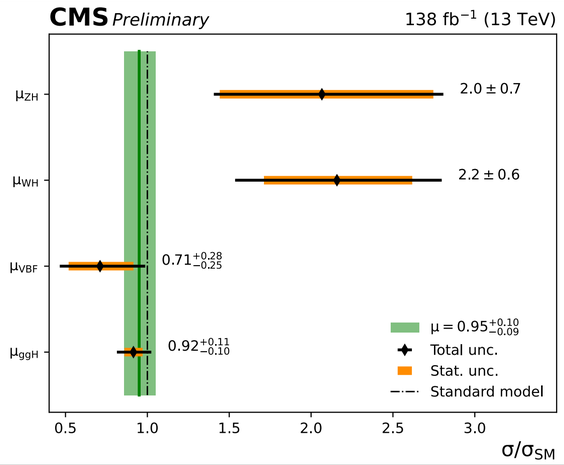
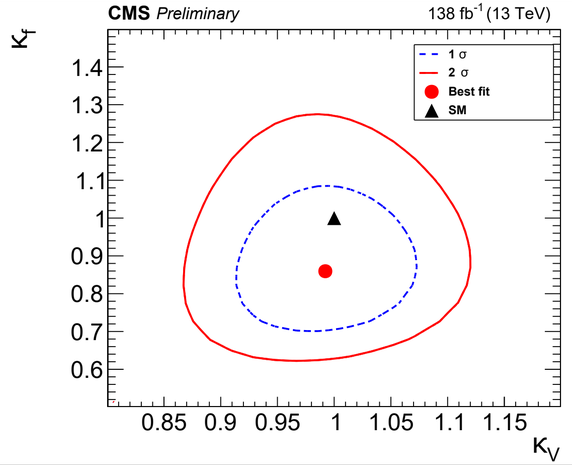
CMS-PAS-HIG-21-008	Direct search for the standard model Higgs boson decaying to a charm quark-antiquark pair

Differential Higgs Measurements

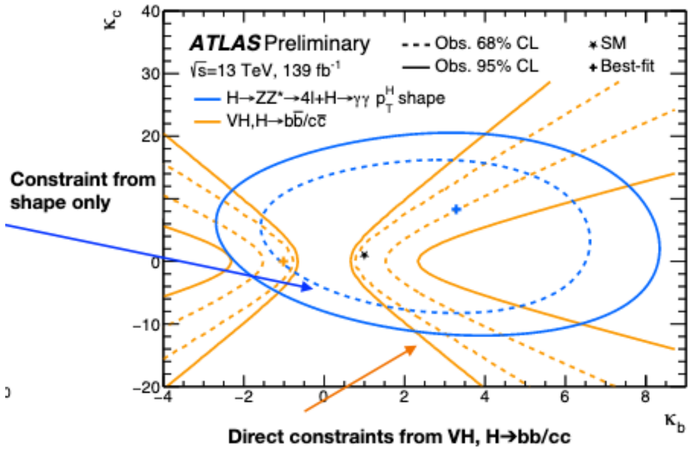
Measurements of properties of the Higgs boson in the W boson pair decay channel HIG-20-013

Targeting ggH, VBF, VH (hadronic) and VH(leptonic) production and final states with 2-4 leptons
Results on inclusive and differential cross sections, as well as coupling modifiers of the Higgs to vector bosons and fermions.





Combined measurement of the total and differential cross sections in the H→γγ and the H→ZZ→4ℓ
ATLAS-CONF-2022-002



Measurement of the Higgs boson inclusive and differential fiducial production cross sections in the diphoton decay channel HIG-19-016:

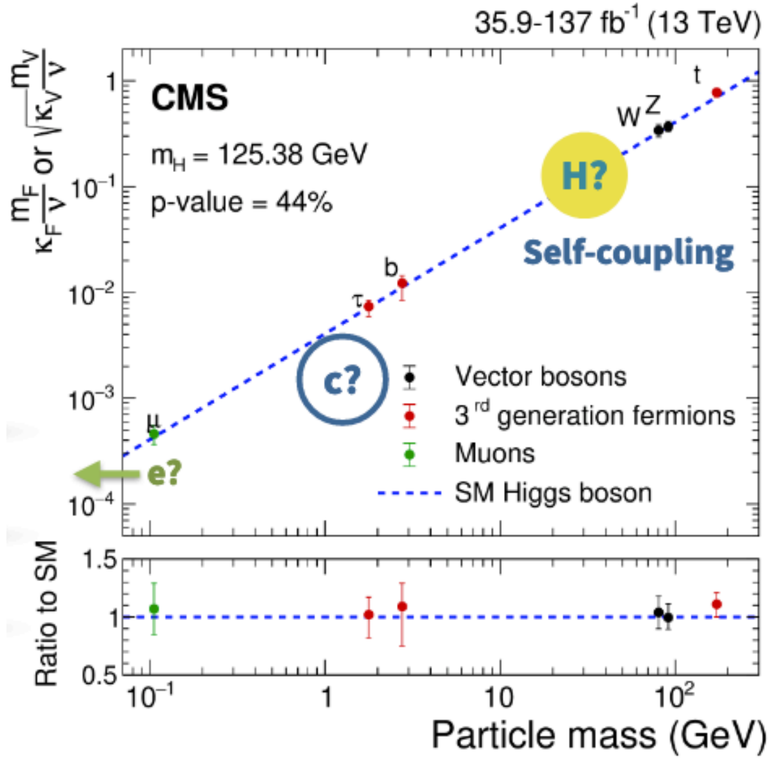
Differential fiducial and double-differential cross section measurements of large range of variables including measurements of new variables such as angular observables

The inclusive fiducial cross section is measured to be

$$\sigma_{\text{fid}} = 73.40^{+5.4}_{-5.3}\ (\text{stat})\ ^{+2.4}_{-2.2}\ (\text{syst})\ \text{fb},$$

Consistent with expectation of 75.44 ± 4.1 fb

Rare Higgs Processes

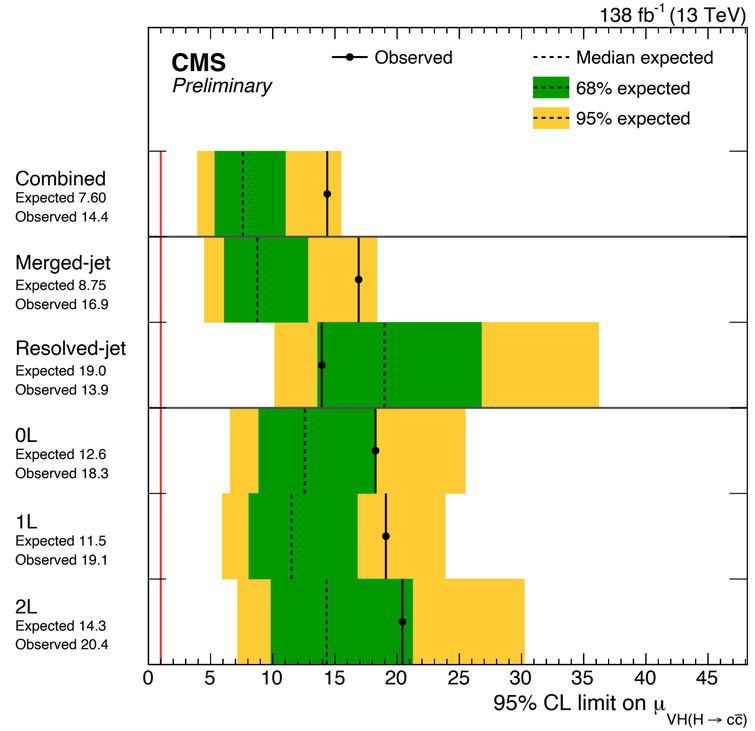


Direct search for the standard model Higgs boson decaying to a charm quark-antiquark pair HIG-21-008

Searching for H to cc in associated VH production. The search has a resolved and a boosted category. New ML based c and cc tagging algorithms, fitting jet mass in categories based on kinematic BDT and H→cc tagging score, new jet mass regressions

Expected 7.6 x SM

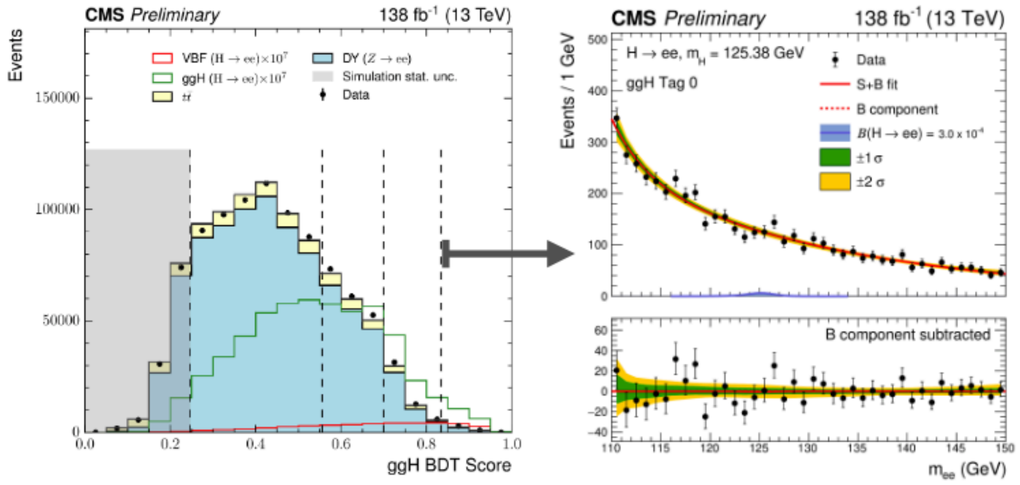
1.1 < | κ_c | < 5.5 obs (| κ_c | < 3.4 exp)



Search for the Higgs boson decay to a pair of electrons HIG-21-015

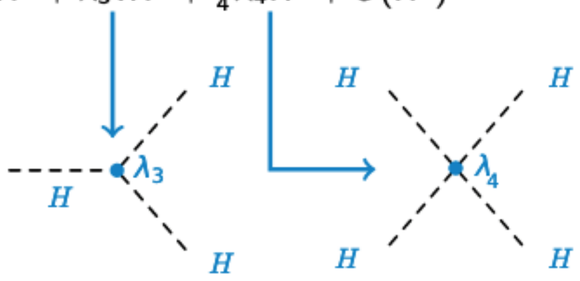
Considers 4 categories with gluon fusion production, and 2 categories with VBF production. Final approach is a fit to m(ee) distribution

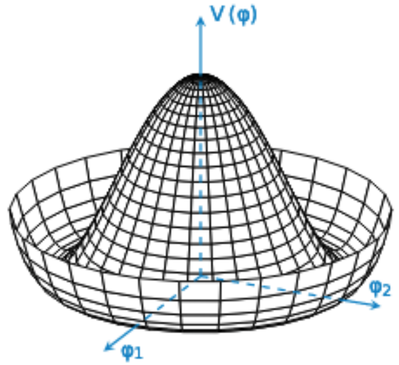
Most stringent limits to date on B(H to ee) 3.0×10⁻⁴ (SM 5x10⁻⁹)



Double Higgs Production

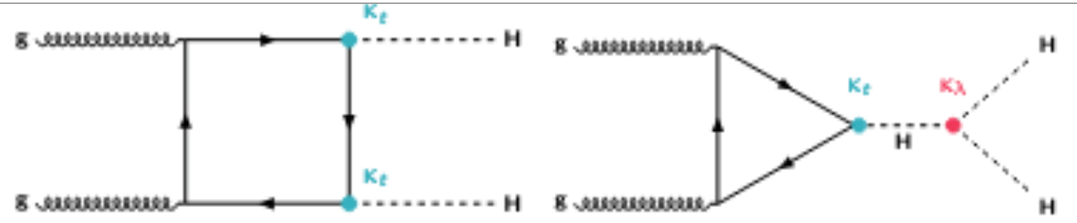
$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 v H^3 + \frac{1}{4}\lambda_4 H^4 + O(H^5)$$





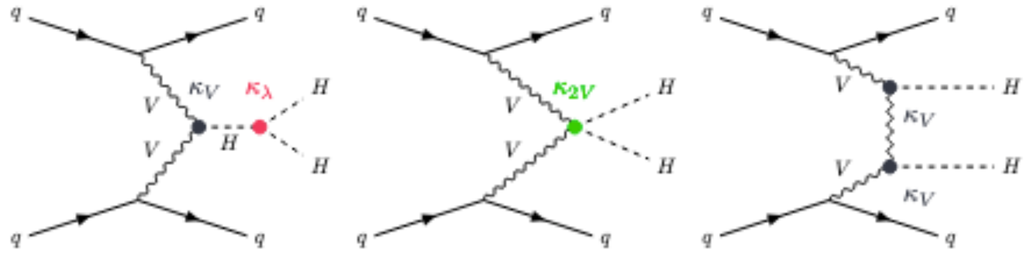
The trilinear coupling λ_3 is directly accessible through Higgs boson pair production

While the HH xsec is too small, non resonant searches can be sensitive to BSM physics!



sensitive to trilinear self-coupling and its variation, $\kappa_\lambda = \lambda_3/\lambda_{SM}$

sensitive to κ_λ and to quartic VVHH coupling (κ_{2V})

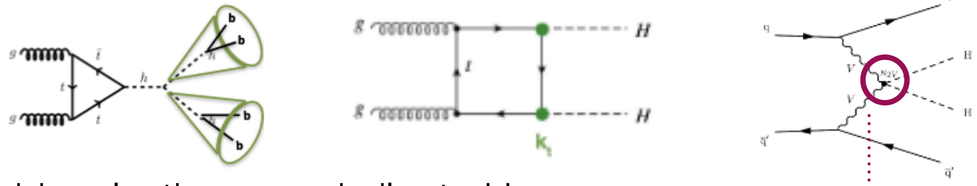


		$\sigma_{HH}/\sigma_{HH}^{SM}$ 95% CL			κ_λ 95% CL	
		Obs.	Exp.	Improvement wrt. 36 fb^{-1} tot. (w/o lumi)	Obs.	Exp.
$HH \to bb\gamma\gamma$	ATLAS	4.2	5.7	×4.6 (2.3)	[-1.5, 6.7]	[-2.4, 7.7]
	CMS	7.7	5.2	×3.6 (1.9)	[-3.3, 8.5]	[-2.5, 8.2]
$HH \to bb\tau\tau$	ATLAS	4.7	3.9	×3.8 (2)	[-2.4, 9.2]	[-2.0, 9.0]
	CMS	3.3	5.2	×4.8 (2.5)	[-1.8, 8.8]	[-3.0, 9.9]
$HH \to bbbb$	ATLAS	–	–	–	–	–
	CMS	3.9	7.8	×4.7 (2.4)	[-2.3, 9.4]	[-5.0, 12.0]
boosted	CMS	9.9	5.1	-	[-9.9, 16.9]	[-5.1, 12.1]
$HH \to bbZZ$	ATLAS	–	–	–	–	–
	CMS	30	37	–	[-9.0, 14.0]	[-10.5, 15.5]
Multilepton	ATLAS	–	–	–	–	–
	CMS	21.8	19.6	–	[-7.0, 11.7]	[-7.0, 11.2]
Combination ($bb\gamma\gamma$+$bb\tau\tau$)	ATLAS	3.1	3.1	×3.2 (1.6)[a]	[-1.0, 6.6]	[-1.2, 7.2]
	CMS	–	–	–	–	–

Double Higgs Production

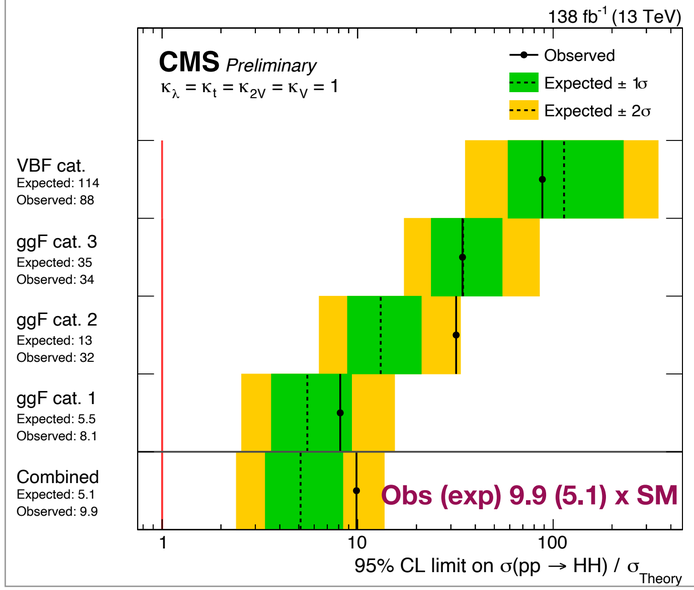
Nonresonant pair production of highly energetic Higgs bosons decaying to bottom quarks B2G-22-003

Search in two production modes: gluon and vector boson fusion

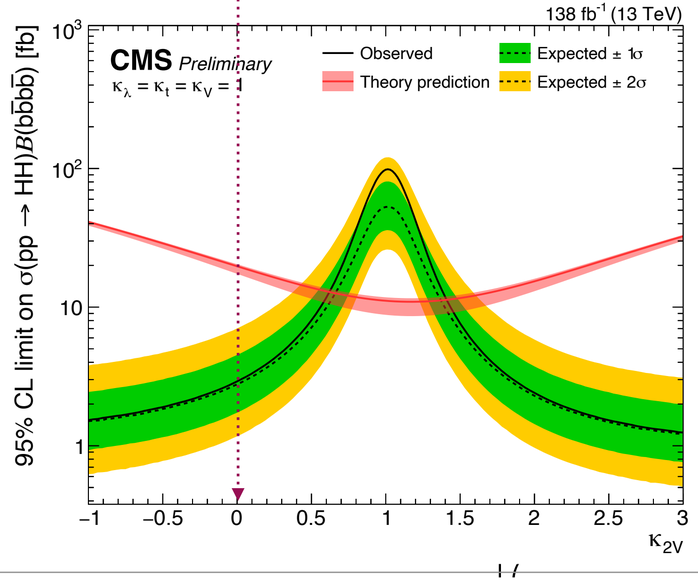


H→bb selection very similar to H→cc

- ParticleNet tagging of H→bb jets & ParticleNet-based mass regression



κ2V = 0 excluded (6.3σ)

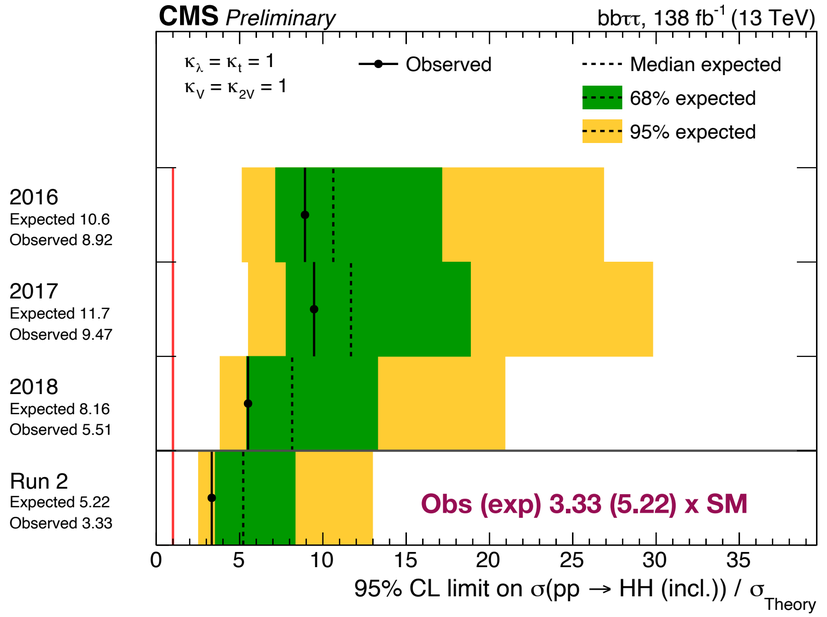


Search for nonresonant Higgs boson pair production in final states with two bottom quarks and two tau leptons HIG-20-010

Search in two production modes: gluon and vector boson fusion.

- Using l+τ+VBF ττ trigger paths
- ML for b and tau objects

=> all leading to x2 better sensitivity (over statistical)

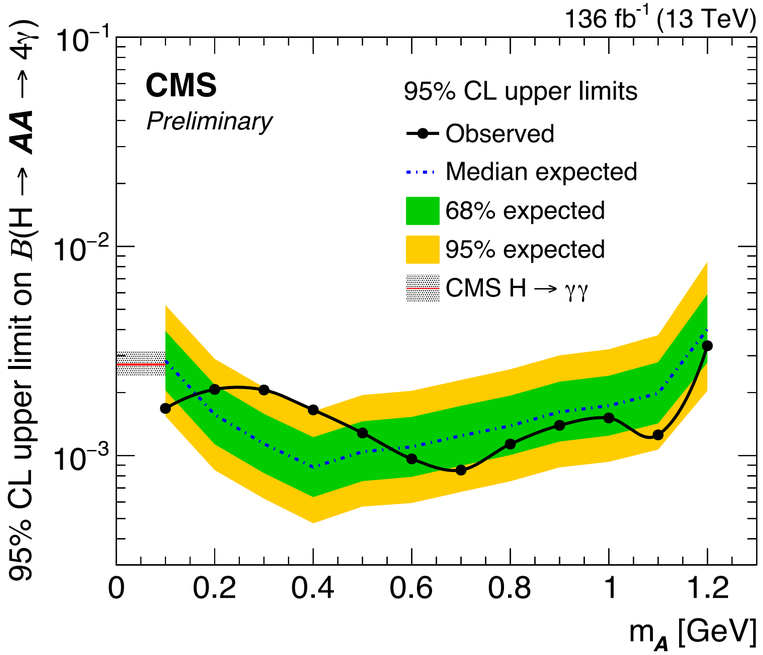


Exotic Higgs

Search for exotic Higgs boson decays H to AA to 4 photons with events containing two merged photons HIG-21-016

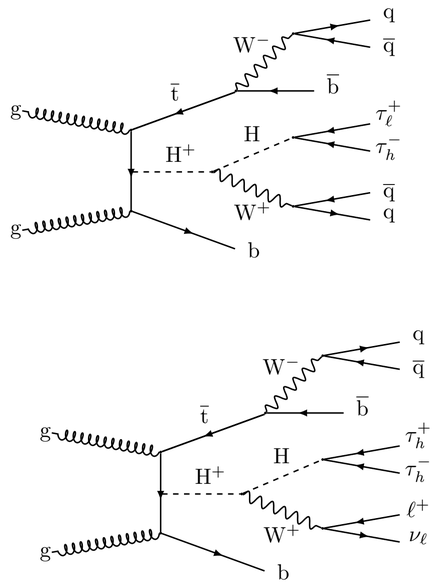
The hypothetical particle A is a low-mass, boosted scalar decaying promptly to two highly merged photons, mis-reconstructed as a single photon-like object.

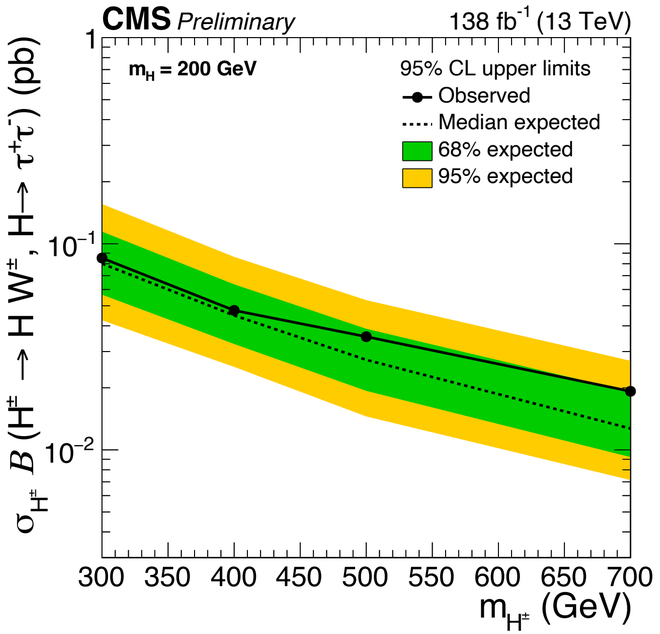
Buried under the SM H->diphoton :)



Search for a charged Higgs boson decaying into a heavy neutral Higgs boson and a W boson HIG-21-010

analysis targets the H boson decay into a pair of tau leptons with at least one of them decaying hadronically and with an additional electron or muon present in the event



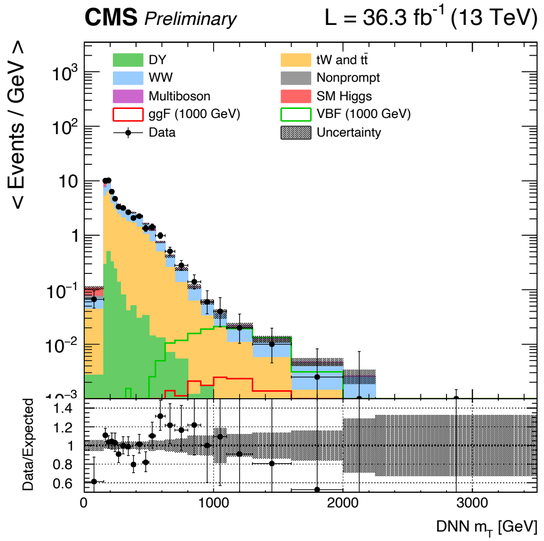


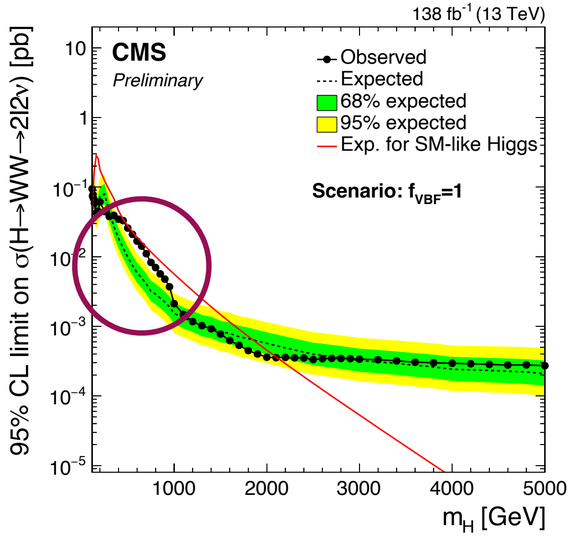
Exotic Higgs - with excesses (!)

Search for high mass resonances decaying into WW in the dileptonic final state HIG-20-016

analysis considers the fully leptonic final state (eμ, μμ, ee) mass range from 115 GeV to 5 TeV, utilizing DNN based mass regression. Both the gluon and vector-boson-fusion signal production processes are considered

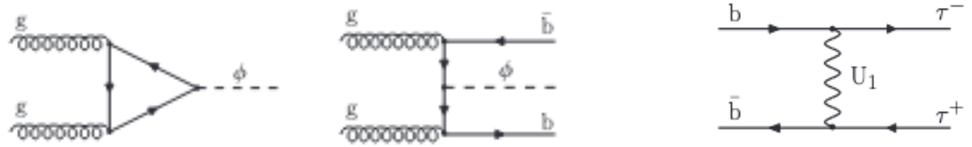
Excess in the VBF category at around 650 GeV: 3.8σ local, 2.6σ global



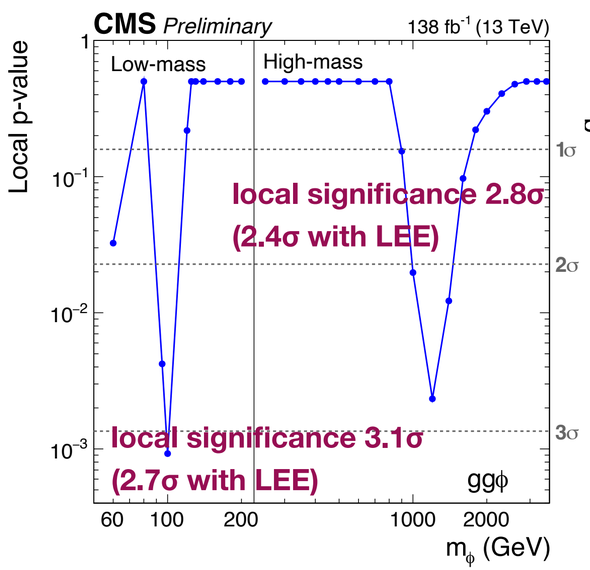


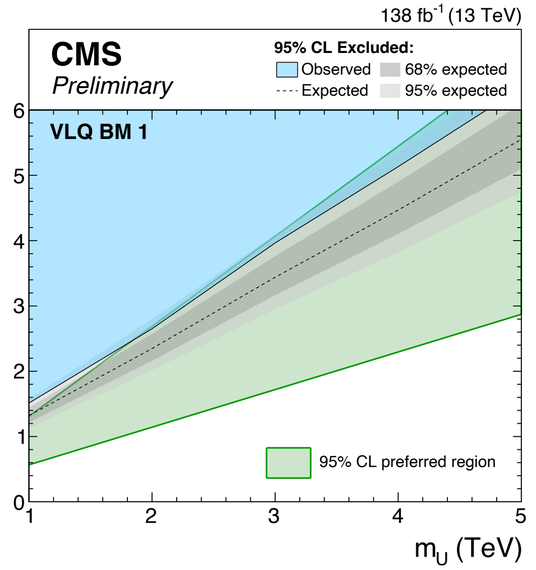
Searches for additional Higgs bosons and vector-like leptoquarks in ττ final states HIG-21-001

Analysis strategy is to fit m(ττ) in various categories:
4 ττ final states (τhτh, μτh, eτh, eμ) & b-tag/no b-tag categories



sensitive to a portion of the parameter space that can explain the B-physics anomalies





CERNCOURIER

CMS

Dijet excess intrigues at CMS

The Standard Model (SM) has been extremely successful in describing the behaviour of elementary particles. Nevertheless, conundrums such as the nature of dark matter and the cosmological matter–antimatter asymmetry strongly suggest that the theory is incomplete. Hence, the SM is widely viewed as an effective low-energy limit of a more fundamental underlying theory that must be modified to describe particles and their interactions at higher energies.

A powerful way to discover new particles expected from physics beyond the SM is to search for high-mass dijet or multi-jet resonances, as these are expected to have large production cross-sections at hadron colliders. These searches look for a pair of jets originating from a pair of quarks or gluons, coming from the decay of a new particle "X" and appearing as a narrow bump in the invariant dijet-mass distribution. Since the energy scale of new physics is most likely high, it is natural to expect these new particles to be massive.

CMS and ATLAS have performed a suite of single-dijet-resonance searches. The next step is to look for new identi-cal-mass particles "X" that are produced in pairs, with (resonant mode) or without (non-resonant mode) a new intermedi-ate, heavier particle "Y" being produced and decaying to pairs of X. Such processes would yield two dijet resonances and four jets in the final state: the dijet mass would correspond to particle X and the four-jet mass to particle Y. The CMS experiment was also motivated to search for Y → XX → four jets by a candidate event recorded in 2017, which was presented by a previous CMS search for dijet resonances (figure 1). This spectacular event has four high-transverse-momentum jets forming two dijet pairs, each with an invariant mass of 1.9 TeV and a four-jet invariant mass of 8 TeV.

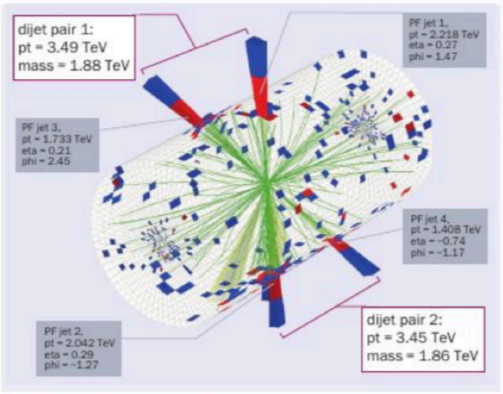


Fig. 1. *Display of the highest mass event with a four-jet mass of 8 TeV, in which each pair of jets has a dijet mass of 1.9 TeV.*

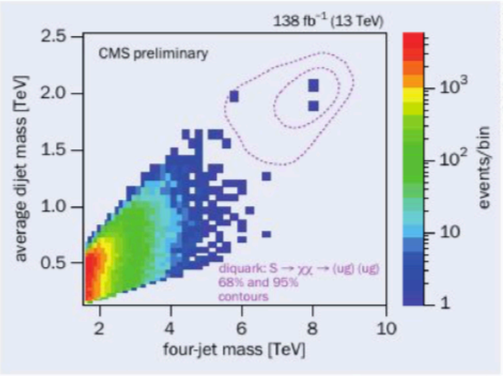


Fig. 2. *Number of events observed (colour scale) within bins of the four-jet mass and the average mass of the two dijets. Purple ellipses show the 1 and 2σ resolution contours, respectively, from a signal simulation of a four-jet resonance (Y), with a mass of 8.4 TeV, decaying to a pair of dijet resonances (XX), each with a mass of 2.1 TeV.*

The CMS collaboration recently found another very similar event in a new search optimised for this specific Y → XX → four-jet topology. These events could origi-nate from quantum-chromodynamics processes, but those are expected to be extremely rare (figure 2). The two can-didate events are clearly visible at high masses and distinct from all the rest. Also shown in the figure (in purple) is a simulation of a possible new-physics signal – a diquark decaying to vector-like quarks – with a four-jet mass of 8.4 TeV and a dijet mass of 2.1 TeV, which very nicely describes these two candidates.

The hypothesis that these events originate from the SM at the observed X and Y masses is disfavoured with a local significance of 3.9σ. Taking into account the full range of possible X and Y mass values, the compatibility of the observation with the SM expectation leads to a global significance of 1.6σ.

The upcoming LHC Run 3 and future High-Luminosity LHC runs will be cru-cial in telling us whether these events are statistical fluctuations of the SM expectation, or the first signs of yet another groundbreaking discovery at the LHC.

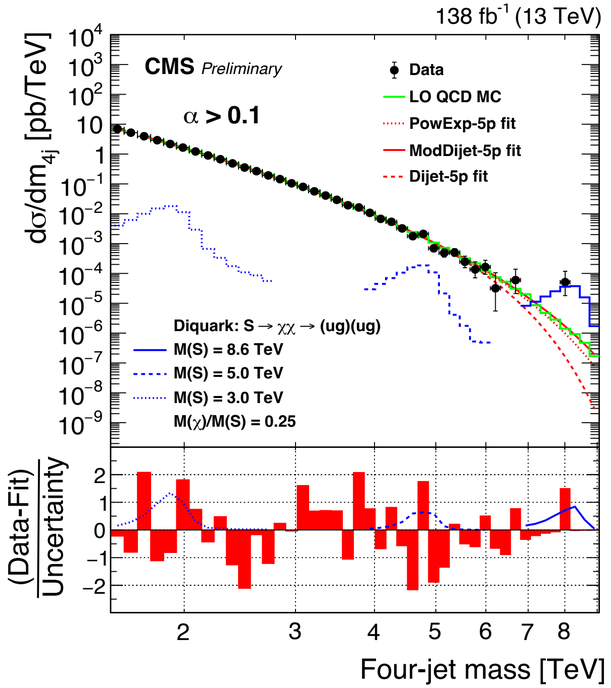
Further reading

CMS Collab. 2022 CMS-PAS-EXO-21-010.

Search for resonant and non-resonant production of pairs of identical dijet resonances EXO-21-010

Data-driven search for pairs of dijet resonances in final states with at least four jets:

- Resonant: Two events on the tail of the distributions, with a four-jet mass of 8 TeV and an average dijet mass of 2 TeV. **Local (Global) significance: 3.9 σ (1.6 σ)**
- Non-resonant: Excess at average dijet mass of 0.95 TeV, **Local (Global) significance: 3.6 σ (2.5 σ)**

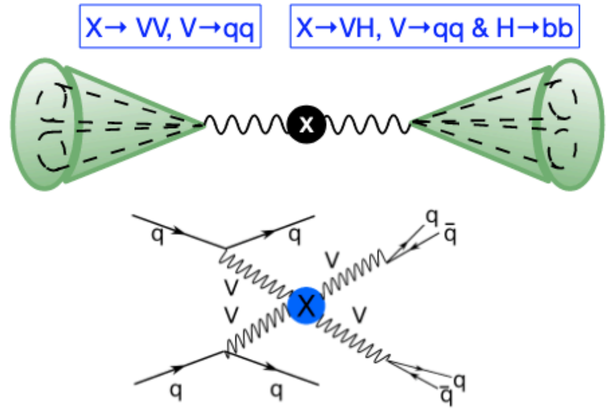


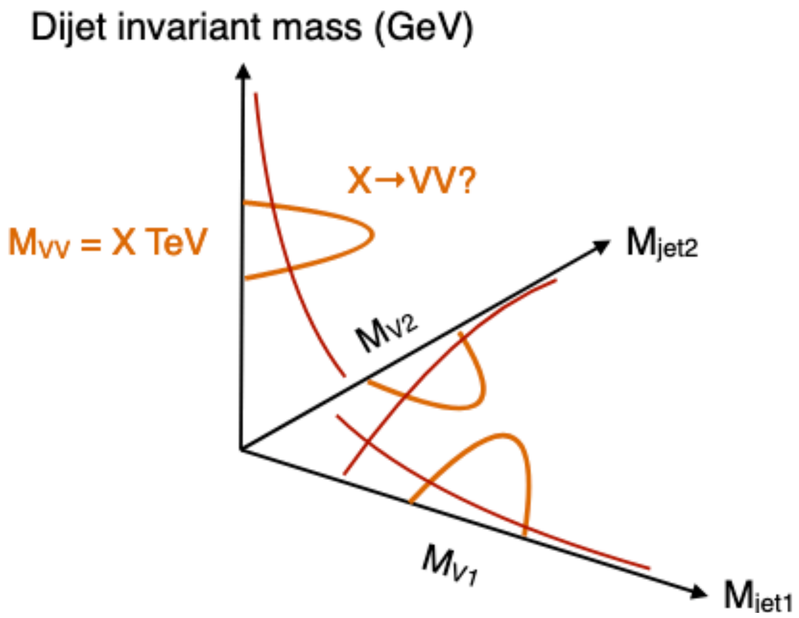
First ~ **30/fb (70/fb)** of Run 3 data could lead to **"evidence" for resonant (non-resonant)** signal at 8 TeV (1 TeV)

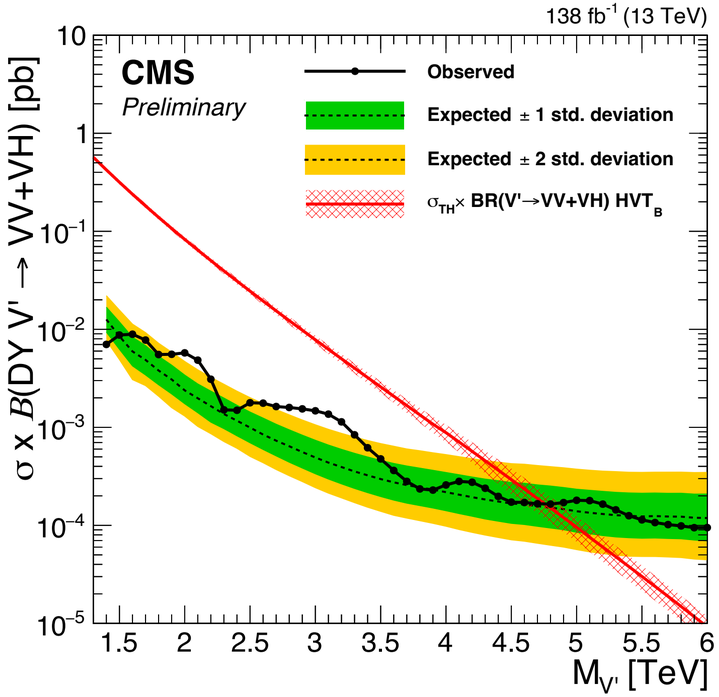
Beyond the Standard Model: Heavy Resonance

Search for new heavy resonances decaying to WW, WZ, ZZ, WH, or ZH boson pairs in the all-jets final state B2G-20-009

- Using 2 large cone jets (resonance decay products), and 2 small cone jets (VBF tags)
- Tag the jets with ML algorithms to distinguish from QCD







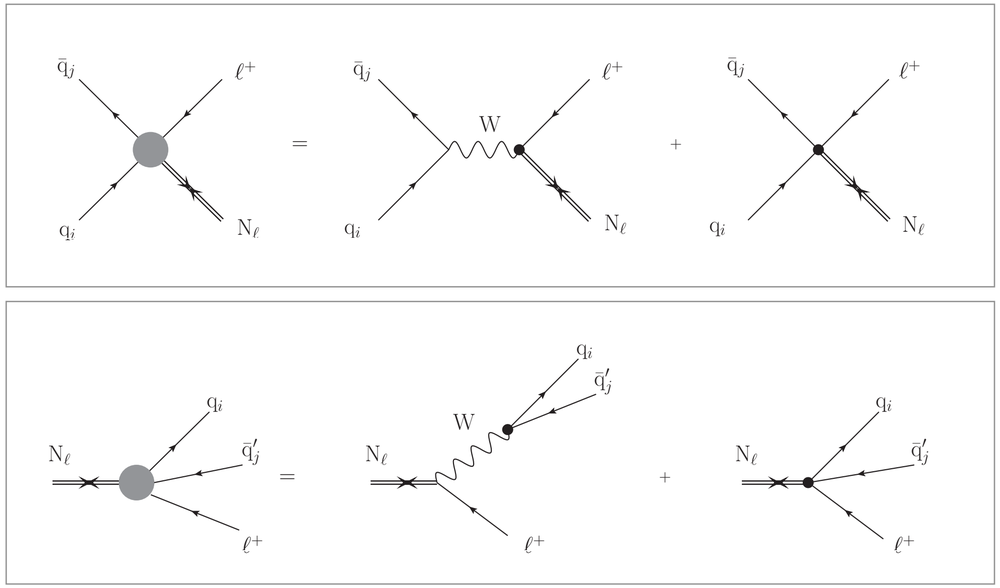
2 excesses in VV decay modes only:

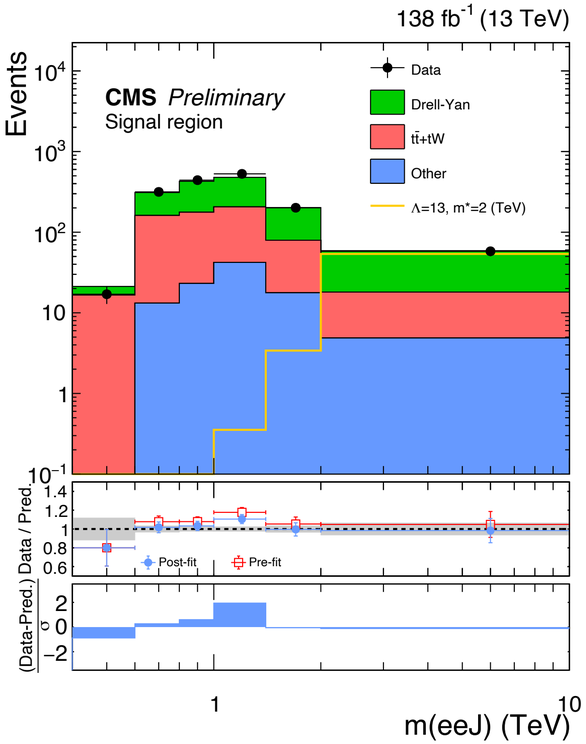
Local significant: 3.6 σ
Global significance: 2.3 σ

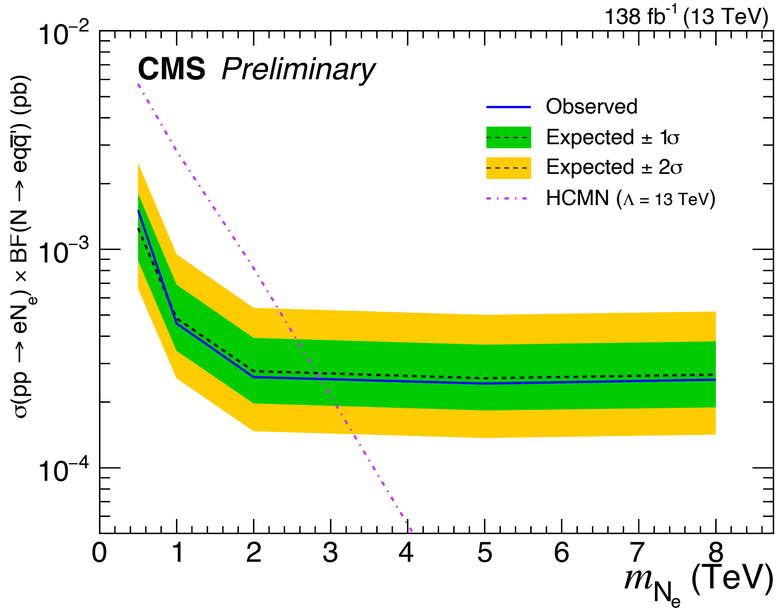
Beyond the Standard Model

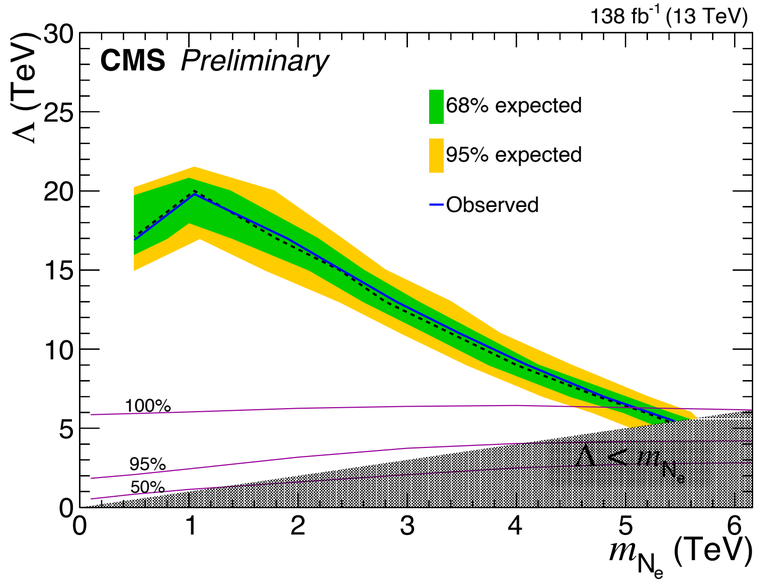
Search for a heavy composite Majorana neutrino EXO-20-011

Excited states of quarks and leptons with masses lower than compositeness scale with effective interactions via gauge or contact interactions







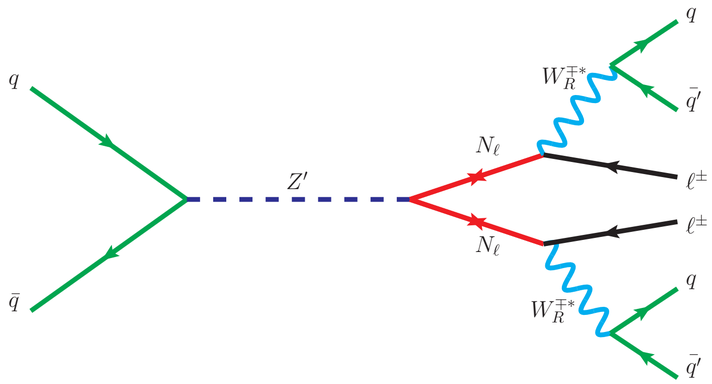


Performed separately on ee/mm channels using same sign leptons + Require 1 large cone jet (agnostic to the effective interactions). And fit on m(lljj)

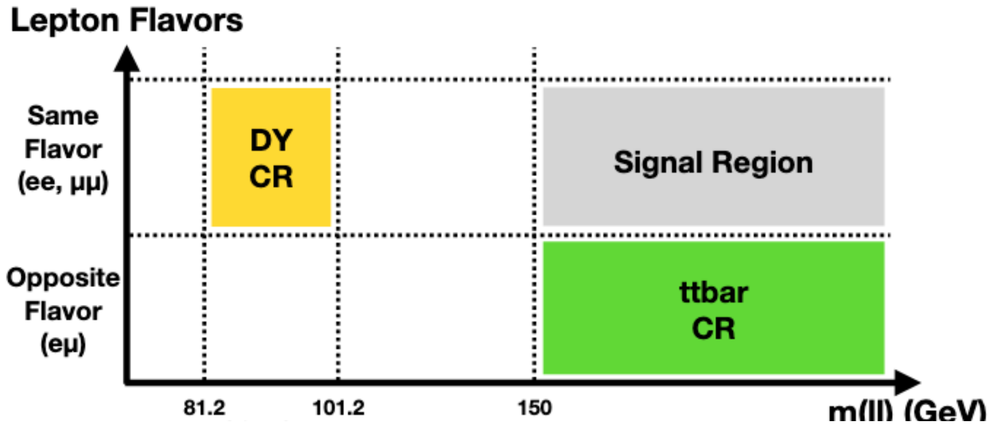
Beyond the Standard Model - HNL

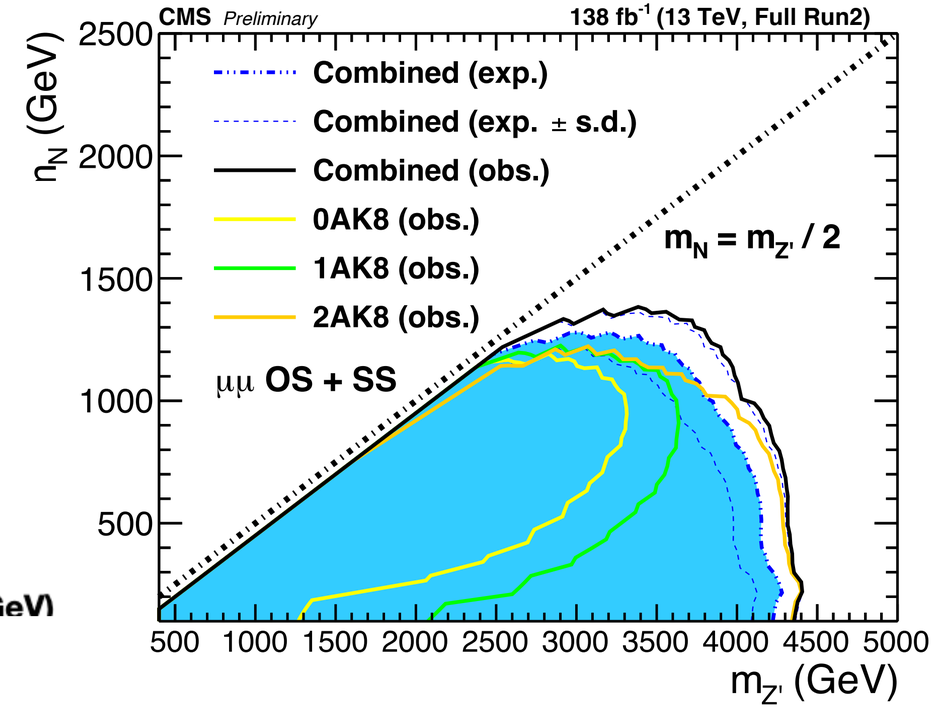
Search for Z' bosons decaying to pairs of heavy Majorana neutrinos EXO-20-006

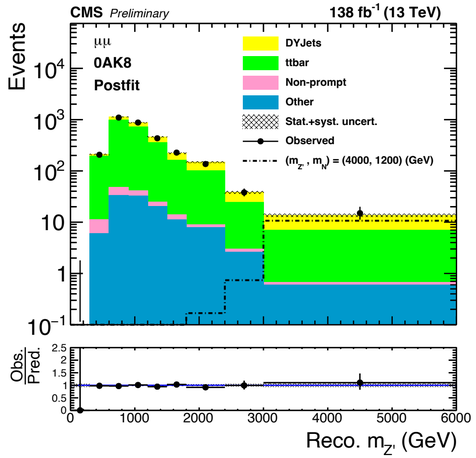
LRSM: Z', $W_R^{+/-}$, N_l
Performed in electron and muon channels
Probing both resolved and boosted topologies

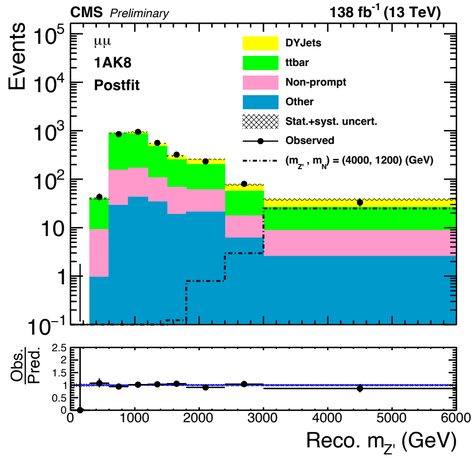


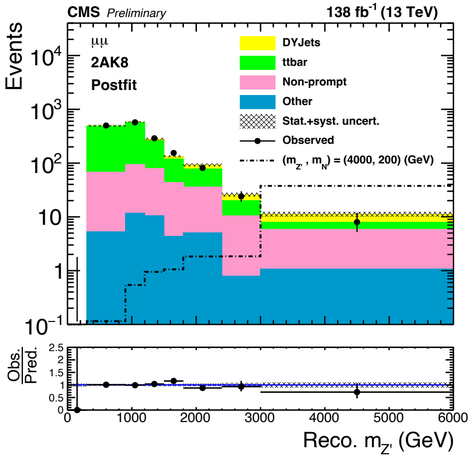
SR	N(AK8 jet)	N(tight leptons)	N(AK4 jet)
SR1 (0AK8)	$= 0$	$= 2$	≥ 4
SR2 (1AK8)	$= 1$	≥ 1	≥ 2
SR3 (2AK8)	≥ 2	—	—







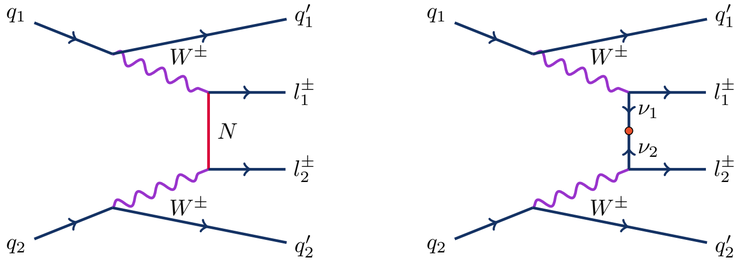


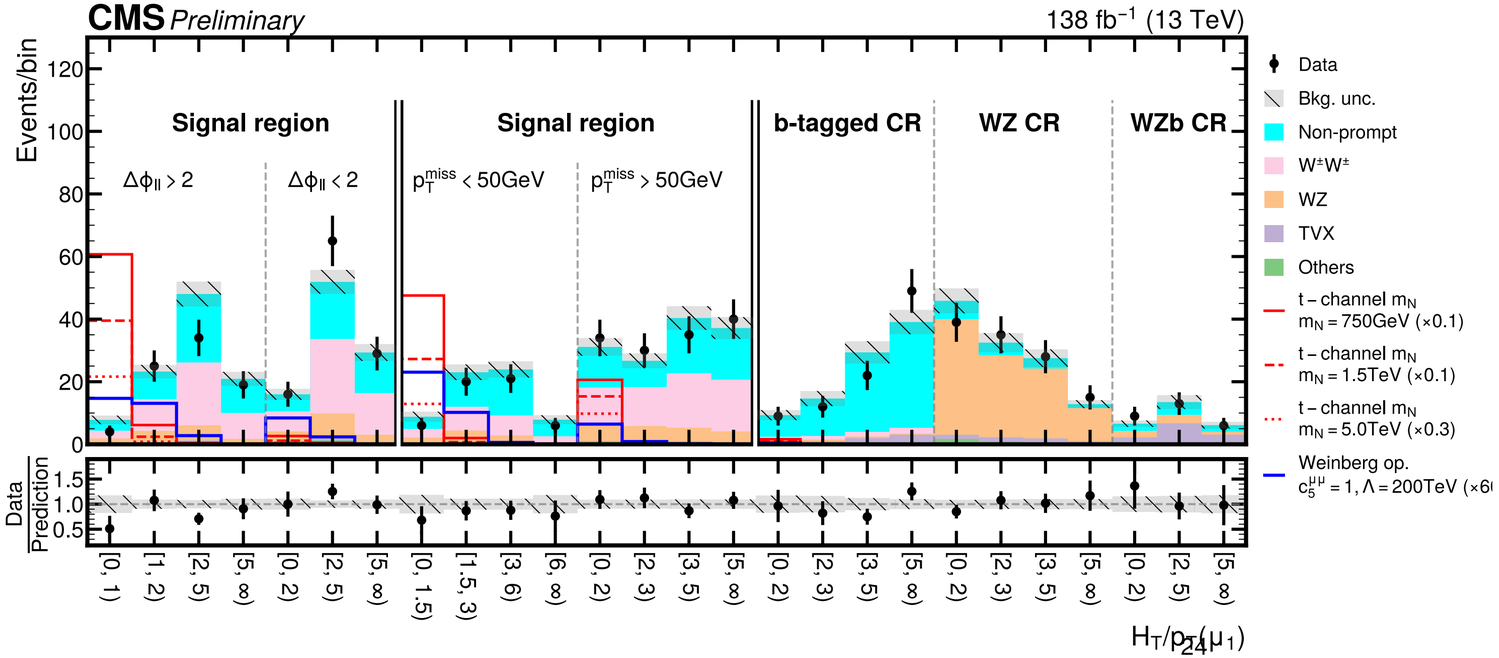


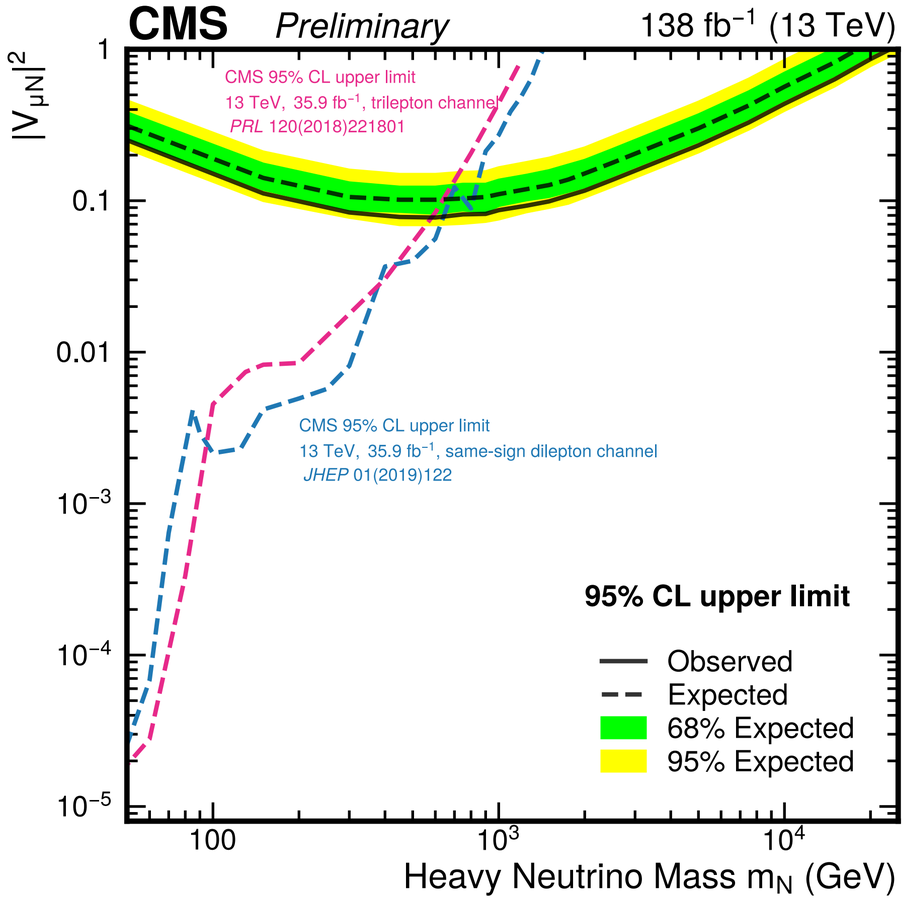
Beyond the Standard Model - HNL

Probing Majorana neutrinos and the Weinberg operator in the same-charge dimuon channel through vector boson fusion processes EXO-21-003

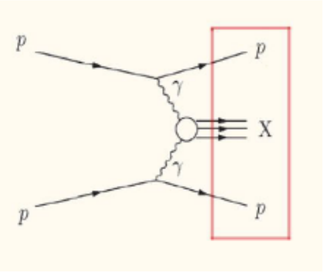
VBF t-channel production of heavy neutrinos to enhance the sensitivity at higher mass region.

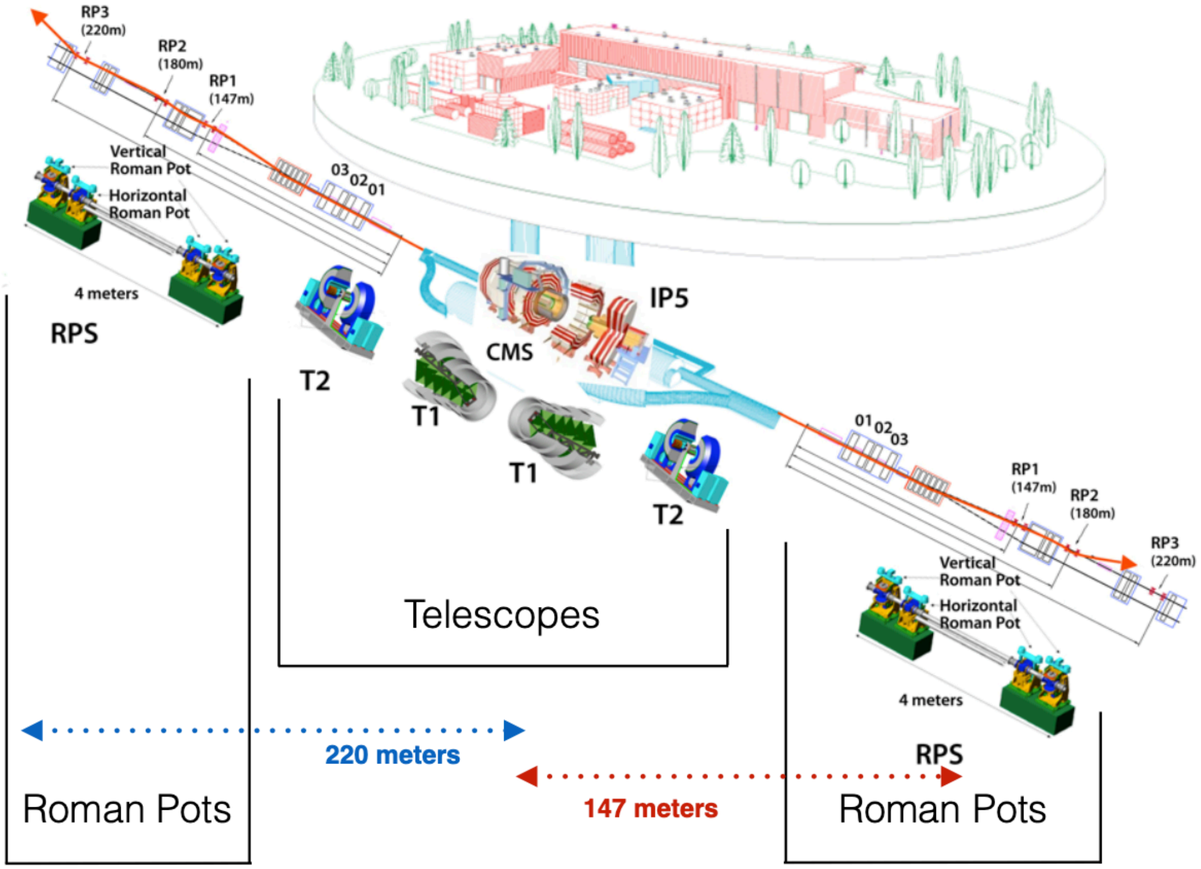






Precision Proton Spectrometer





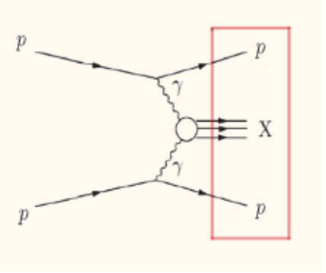
TOTEM experiment is designed to take **precise measurements** of protons as they emerge from collisions **at small angles.**

This region is known as the '**forward**' direction and is **inaccessible**

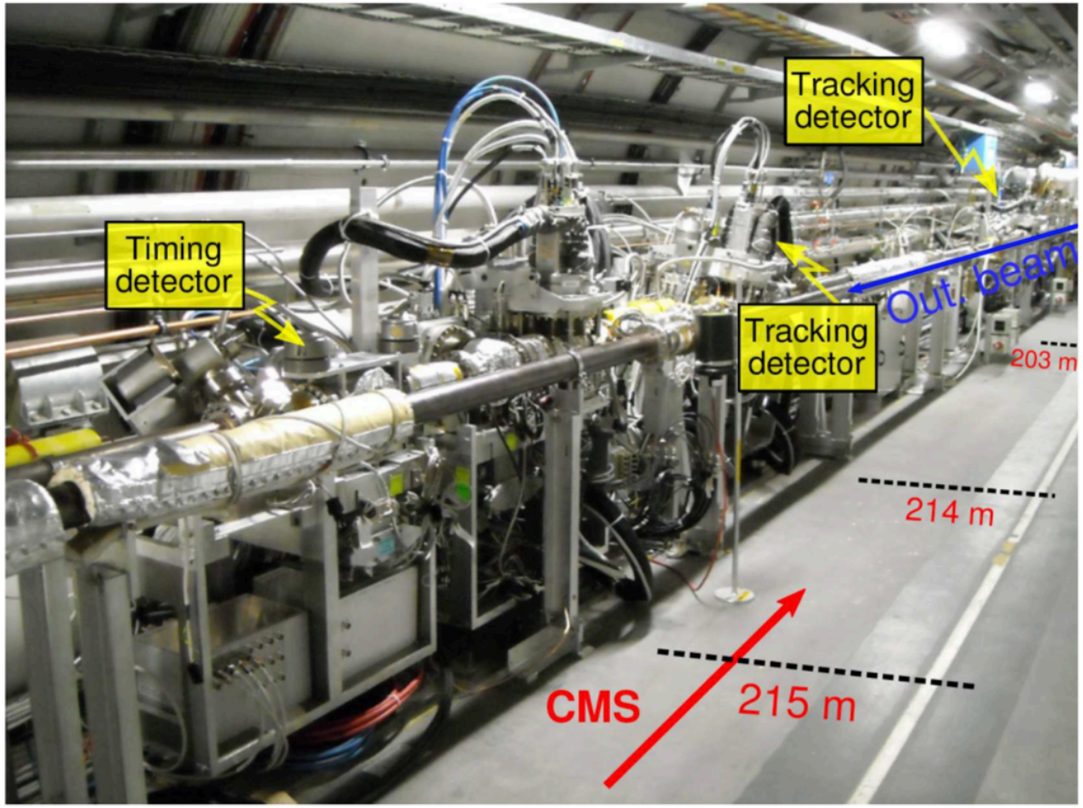
TOTEM and CMS collaborations have coordinated the use of their detectors to **perform combined measurements**

the main measured variable is ξ -- fractional momentum loss of forward proton

Precision Proton Spectrometer



CT-PPS is a magnetic spectrometer that uses the LHC magnets and detector stations, to bend protons to measure their trajectories. **It is fully integrated into CMS DAQ + Reconstruction Software**



<u>Proton tag advantages:</u>

- closure of event kinematics (full 13 TeV energy reconstructed)
- effective background rejection

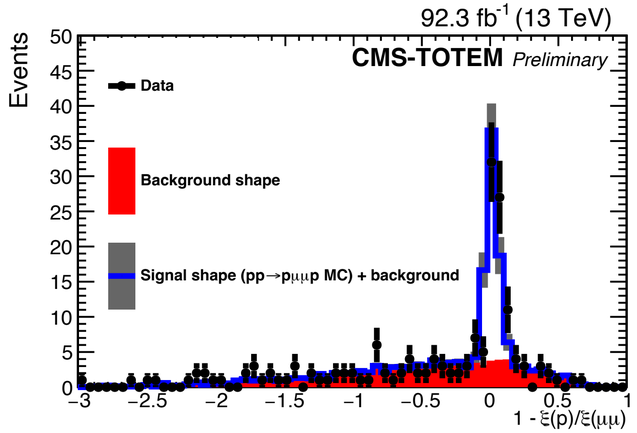
<u>Opportunity to access a variety of topics:</u>

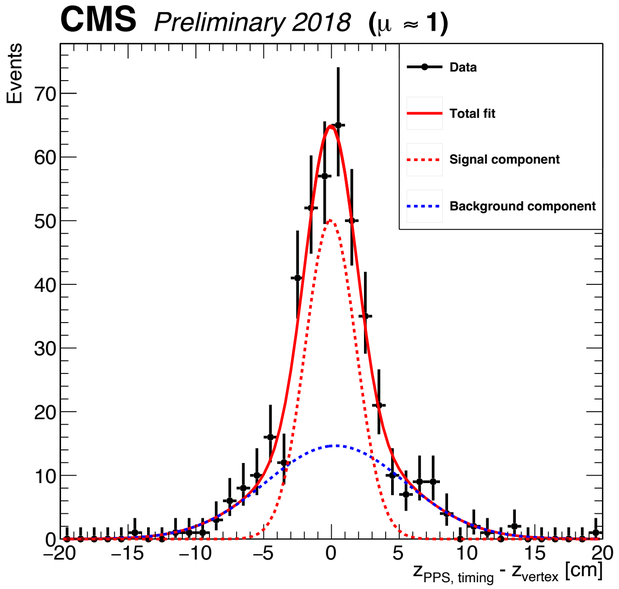
- anomalous couplings with high sensitivity
- new resonances in very clean final state
- rare SM processes

Precision Proton Spectrometer

The Precision Proton Spectrometer of the CMS experiment collected more than 100 fb–1 of data in Run 2.

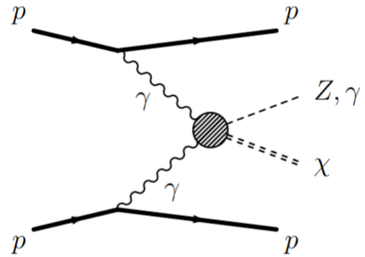
Proton reconstruction with the CMS Precision Proton Spectrometer in Run 2 PRO-21-001





A search for new physics in central exclusive production using the missing mass technique with the CMS-TOTEM precision proton spectrometer EXO-19-009

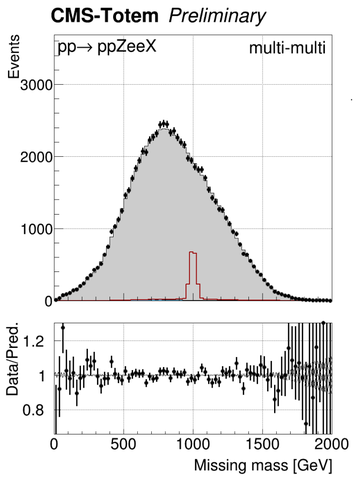
A generic search for production of a Z boson or a photon with an additional unspecified massive particle X in proton-tagged events

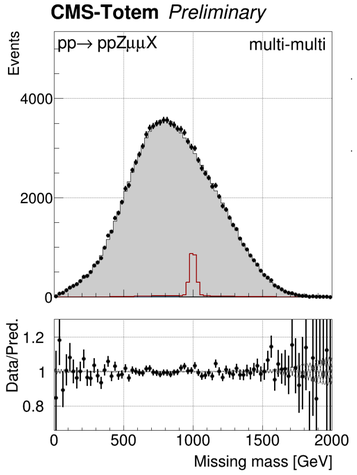


Main variable of interest is the so-called **missing mass**: first use of this technique at the LHC.

Excellent proton momentum reconstruction of PPS allows to search for missing mass signatures at high invariant mass

$$m^2_{\text{miss}} = \left[(P^{\text{in}}_{p_1} + P^{\text{in}}_{p_2}) - (P_V + P^{\text{out}}_{p_1} + P^{\text{out}}_{p_2}) \right]^2$$



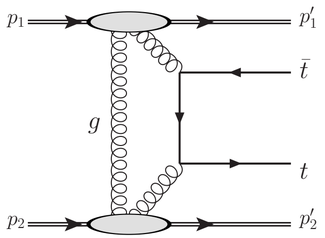


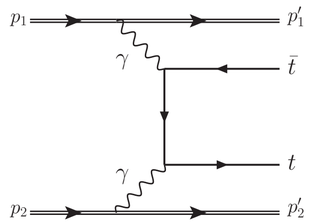
Precision Proton Spectrometer

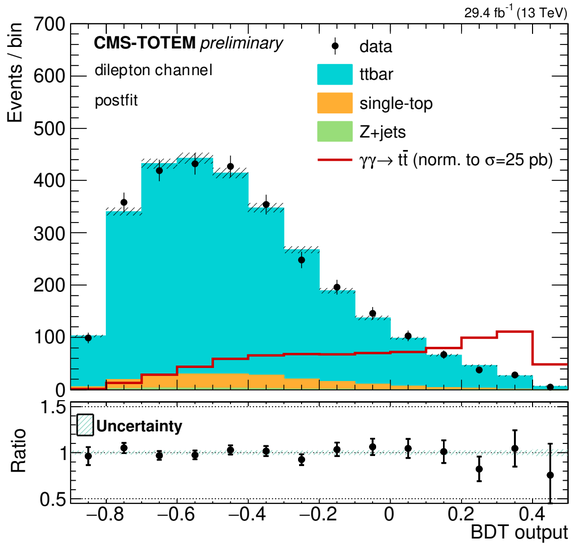
Search for central exclusive production of top quark pairs TOP-21-007

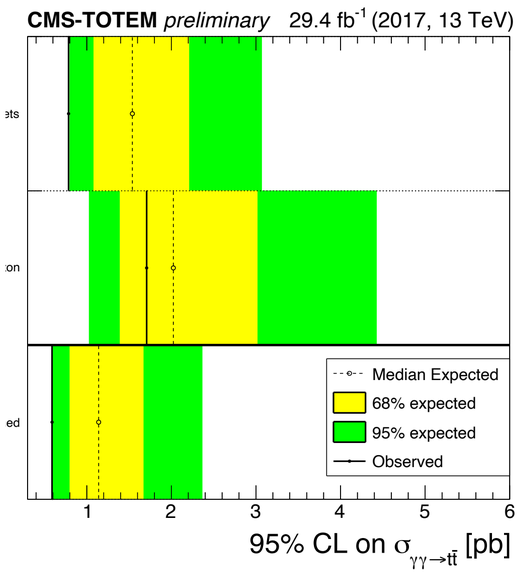
Sensitive to top photon couplings. Very low cross-section!

Observed (expected) limit 0.59 pb (1.14 pb +1.2 –0.6)



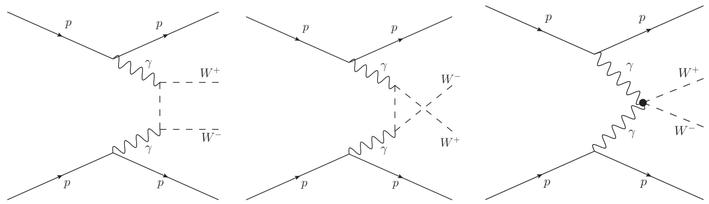


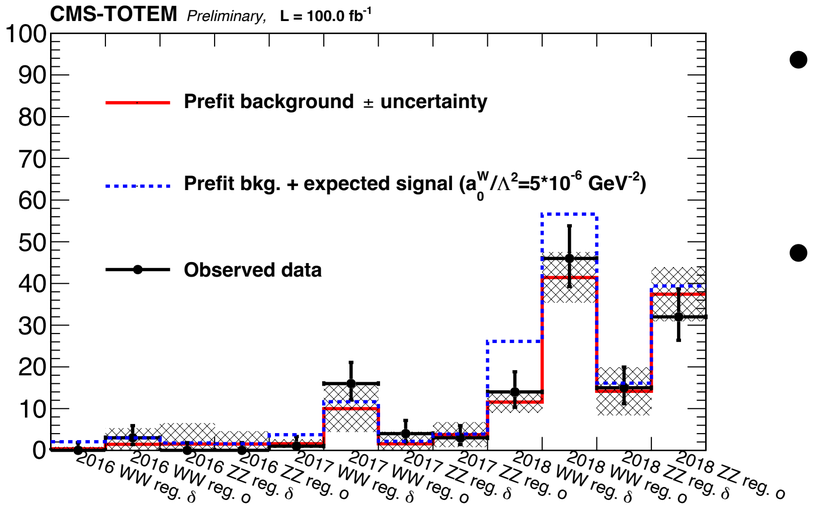




Search for exclusive γγ→WW and γγ→ZZ production in final states with jets and forward protons SMP-21-014

Due to extremely high inclusive QCD background, process can be accessed only with proton tagging





- aQGC and EFT interpretations
- also amended jet trigger thresholds for SM WW targeting Run3

Conclusions

A lot of data, very sophisticated analysis strategies, many excesses :)

Something real?

A lot of analysis in pipeline based on Run 2 and many *new* ideas to explore in early Run 3

Back up