CMS Recent Results and Prospects

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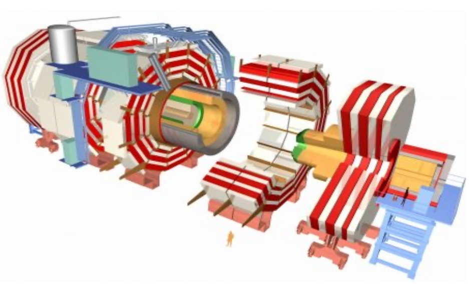
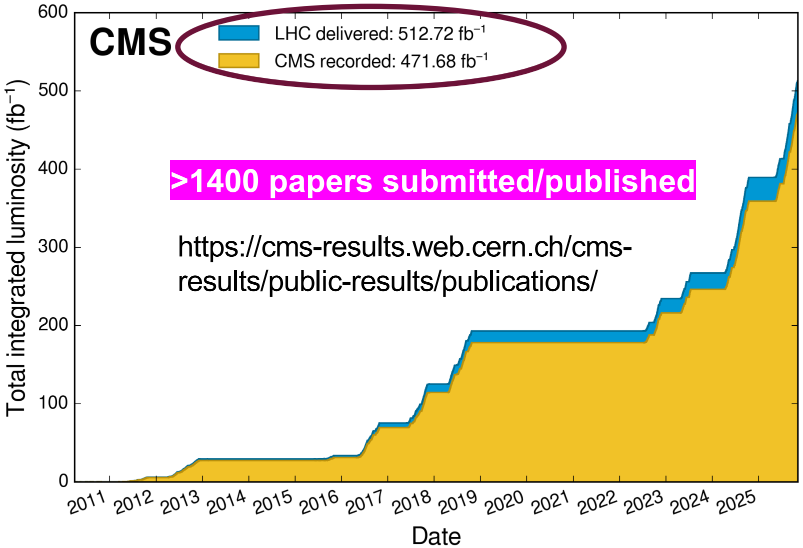
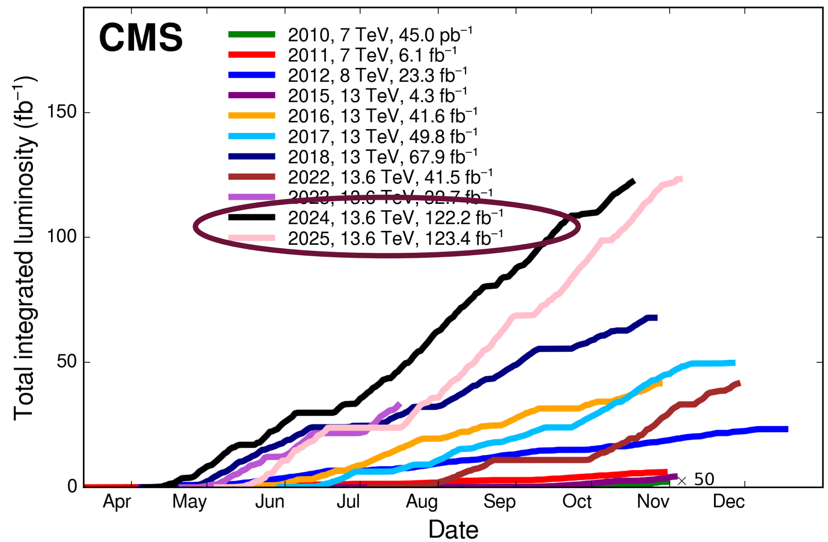
- ✓Status of LHC
- ✓Recent physics results (what we have learned so far)
  - SM results: Higgs, W/Z/QCD, top, B-mesons
  - BSM searches: SUSY, LLPs, BHs, Sphalerons
- ✓Future prospects (3000fb^{-1} data, HL-LHC scenario)
- ✓Summary

India-JINR Workshop on Particle, Nuclear, Neutrino Physics and Astrophysics

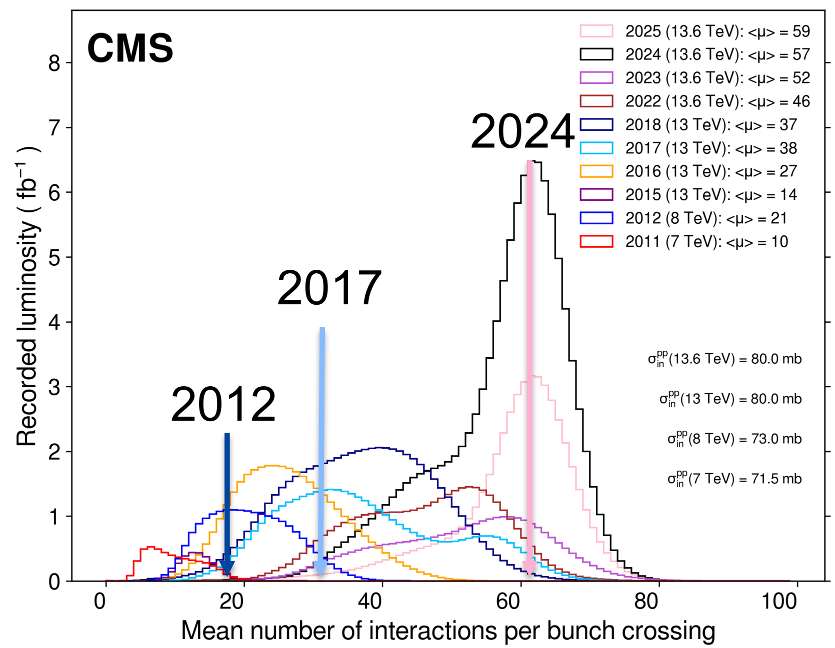


LHC and CMS performance

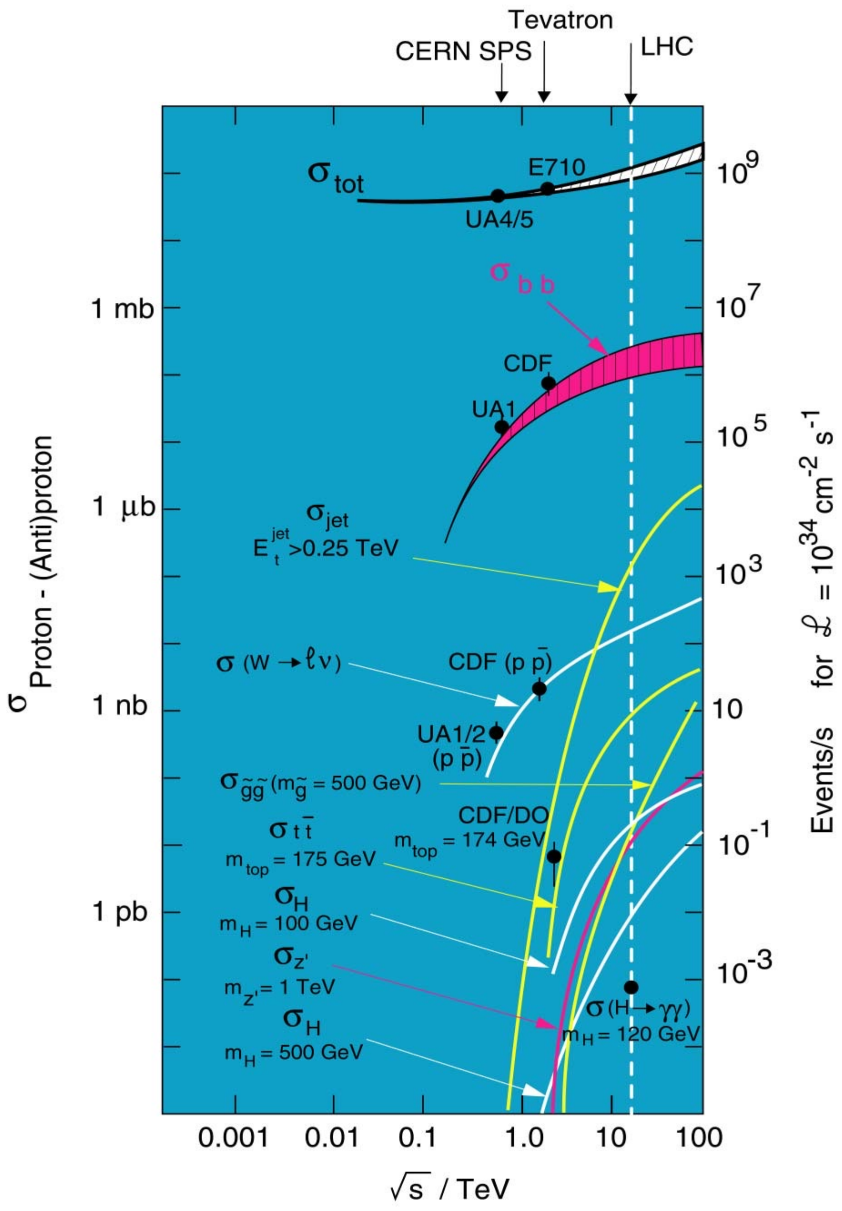


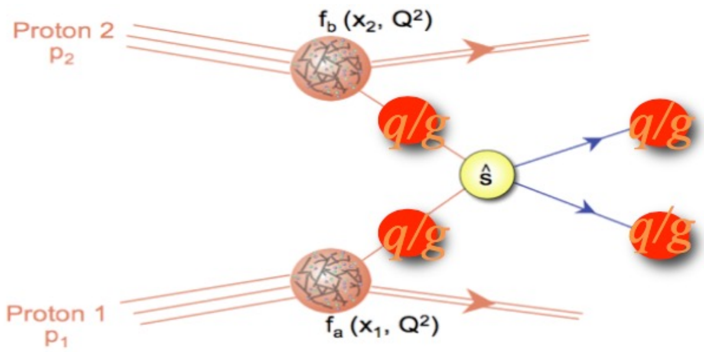


- ✓ The LHC has provided > 500 fb^{-1} data
  out of which CMS recorded ~92% of it.
  >50% of our total data collected in last 2-yrs.
- ✓ The detectors have been performing very well.
  > 98 - 99% active channels during run
- ✓ Currently, LHC center of mass energy is
  13.6 TeV. Allows us more interesting events
  (as no of events =σ x Luminosity)
- ✓ Final goal is to get ~4000 fb^{-1} data. Requires
  upgrade in accelerator (detectors need
  upgrade to survive high beam intensity)



Physics production cross section with LHC





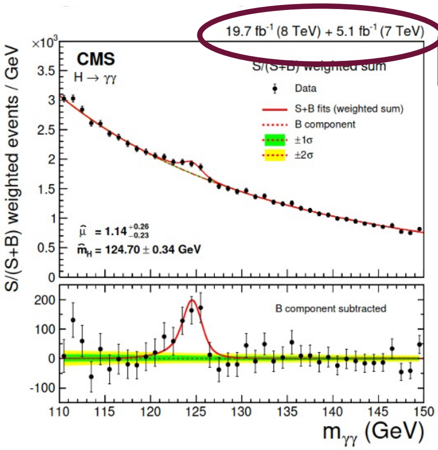
The current production cross-section for interesting physics events goes up significantly [some cases by several order of magnitude higher compared to Tevatron or even LHC@7 or 8 TeV]

Production cross-section is important, but the decay mode is equally crucial .

We carry out range of physics studies such as W/Z, Higgs, top-quark, flavor physics, QCD etc. (SM); SUSY, LLP, LQ, Dark Photons, T, W'/Z', BH etc(BSM).

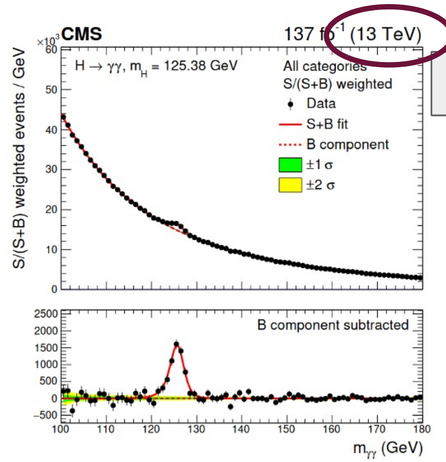
I will cover few selected results

Triumphs in Higgs sector



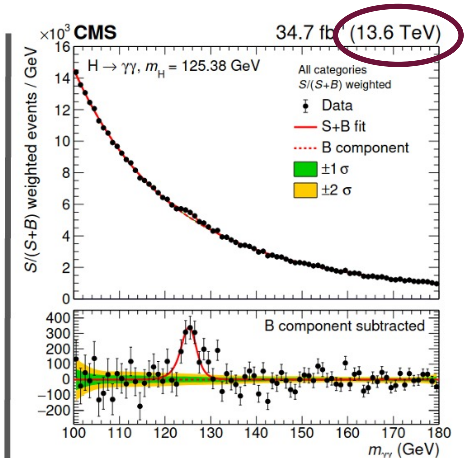
7+8 TeV

RUN 1 (2011-12)

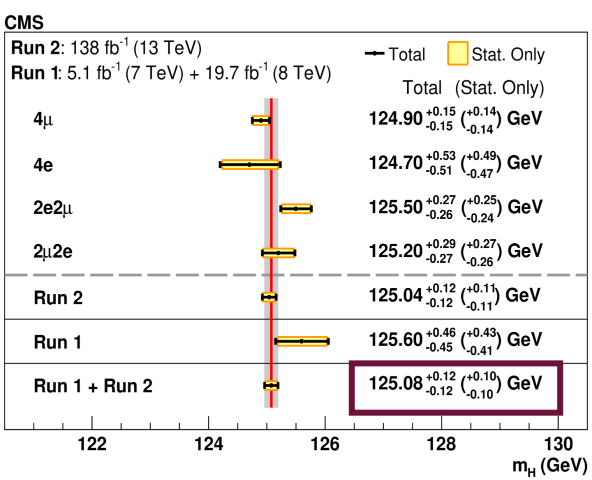


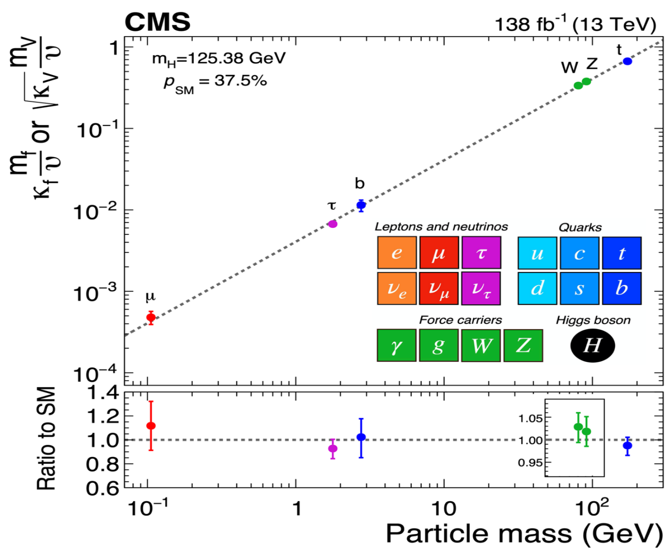
13 TeV

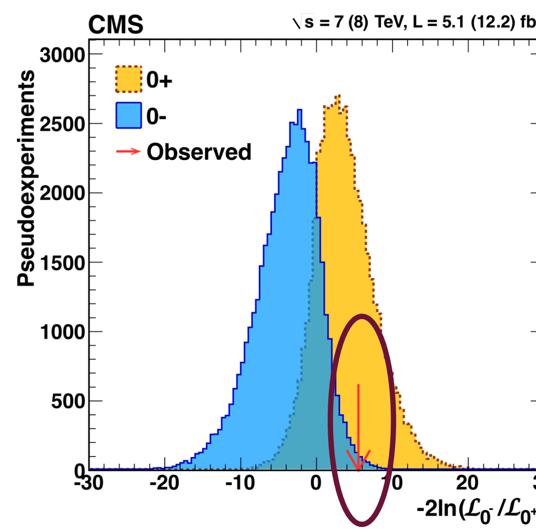
RUN 2 (2016-18)



RUN 3 (2022-26)







- ✓ Higgs discovery has been one of the spectacular successes of SM
- ✓ CMS have been pursuing for the precision measurement of its properties such as mass, width, coupling to fermions, spin, parity, etc.

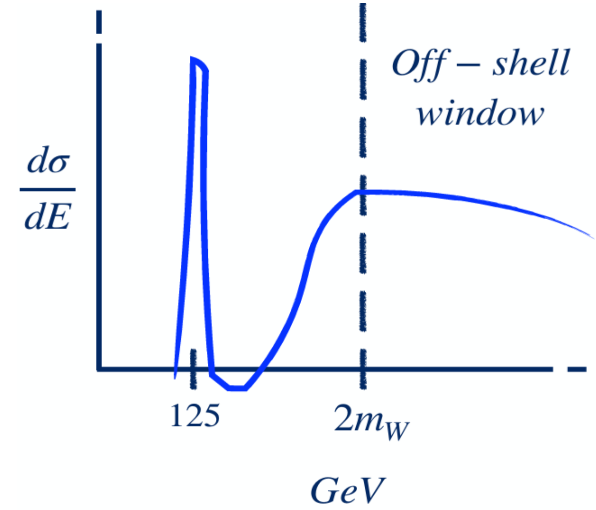
Γ_H using off-shell WW→ 2ℓ 2ν mode

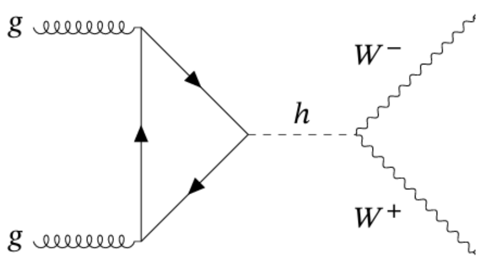
$$\sigma \propto \frac{g_p^2 g_d^2}{(p^2 - m^2) + m\Gamma_H} \sim \frac{g_p^2 g_d^2}{m\Gamma_H}$$

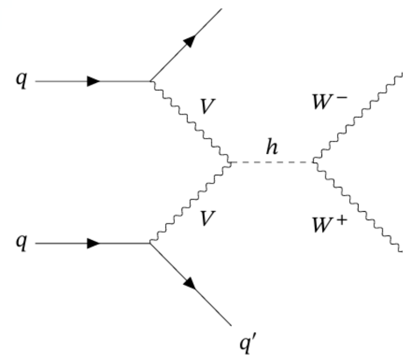
$$\mu_{on-shell} \propto \sigma_{on-shell} \propto \frac{g_p^2 g_d^2}{\Gamma_H}$$

$$\Gamma_H \propto \frac{\mu_{off-shell}}{\mu_{on-shell}} = r$$

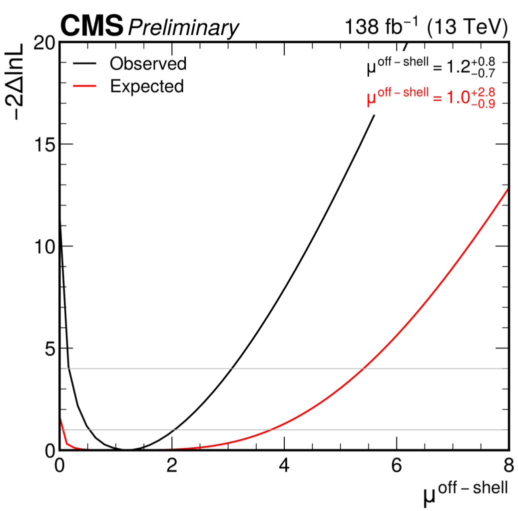
$$\mu_{off-shell} \propto \sigma_{off-shell} = g_p^2 g_d^2$$

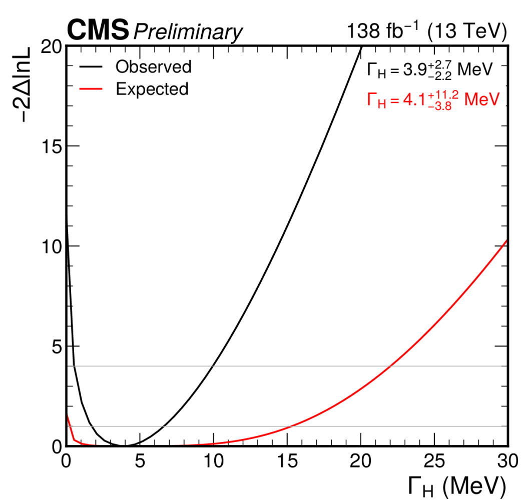






Parameter	c.v.	Observed 68% CL	Observed 95% CL	Expected 68% CL	Expected 95% CL
$\mu_{\text{on-shell}}$	1.25	1.09, 1.44	0.94, 1.65	0.85, 1.18	0.72, 1.38
$\mu_{\text{ggF}}^{\text{off-shell}}$	1.19	0.48, 2.15	< 3.40	< 4.31	< 6.21
$\mu_{\text{VBF}}^{\text{off-shell}}$	1.25	0.16, 3.09	< 5.59	< 6.41	< 11.2
$\mu^{\text{off-shell}}$	1.21	0.53, 2.05	0.17, 3.08	0.06, 3.75	< 5.4
Γ_H (MeV)	3.91	1.72, 6.61	0.54, 9.94	0.25, 15.3	< 22.0





$$\Gamma_H = 3.9^{+2.7}_{-2.2}\,\text{MeV}$$ @68% CL

Improvement w.r.t Run-1 WW result
Consistent with SM prediction: 4.1 MeV

$$\mu_{\text{off-shell}} = 1.2^{+0.8}_{-0.7}$$

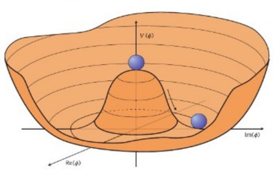
Consistent with SM expectation to be 1

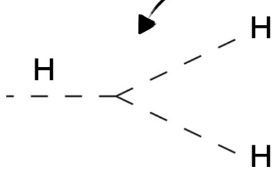
CMS-PAS-HIG-24-011

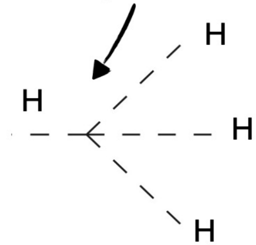
HH and HHH poduction

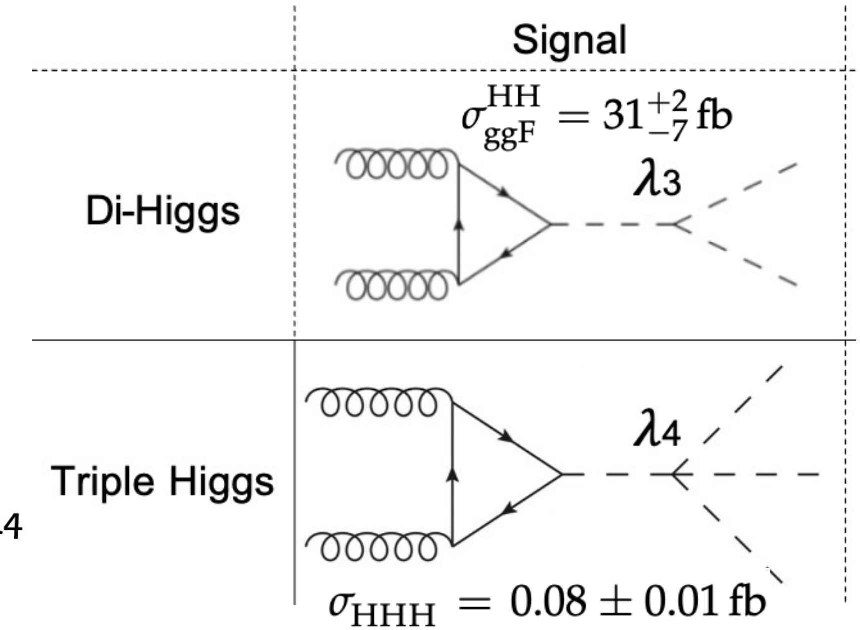
- ✓ Higgs self coupling: One of the most important properties not measured yet
  - In SM: Higgs potential directly responsible for masses of particles
  - Trilinear coupling: responsible for HH production (sensitive to λ_3)
  - Quartic coupling: responsible for HHH production (sensitive to λ_3 and λ_4)
- ✓ Full determination of Higgs potential only possible through combined measurements

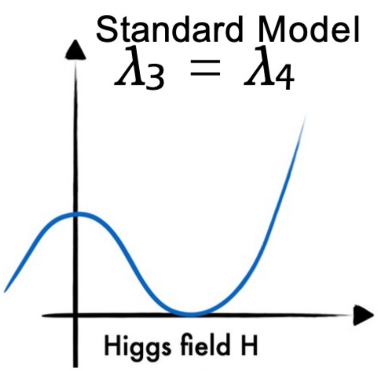
$$V(H) = \frac{1}{2}m_H^2 H^2 + \lambda_3 v H^3 + \frac{1}{4}\lambda_4 H^4$$

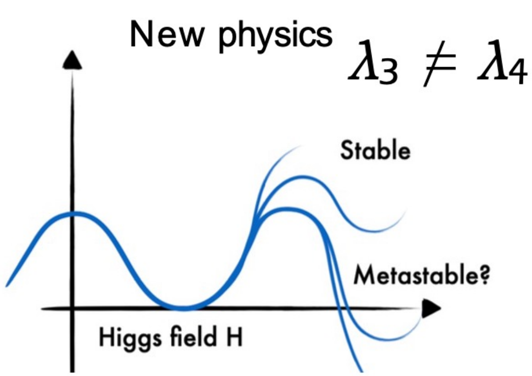


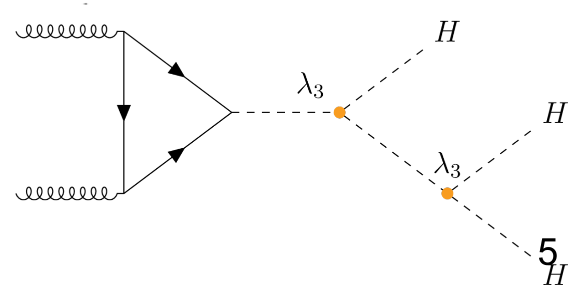




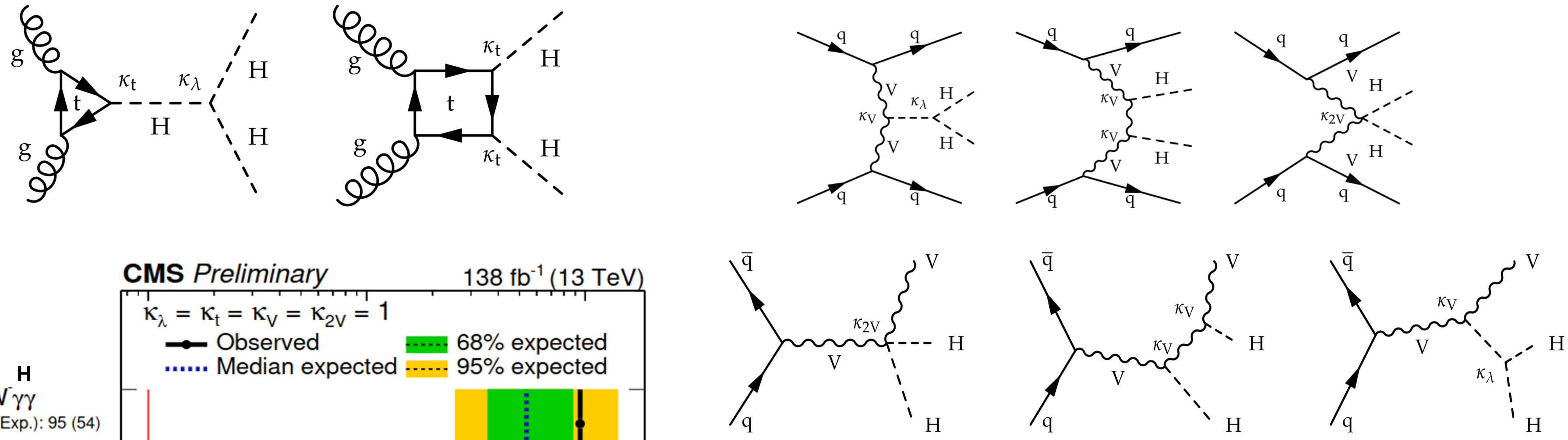


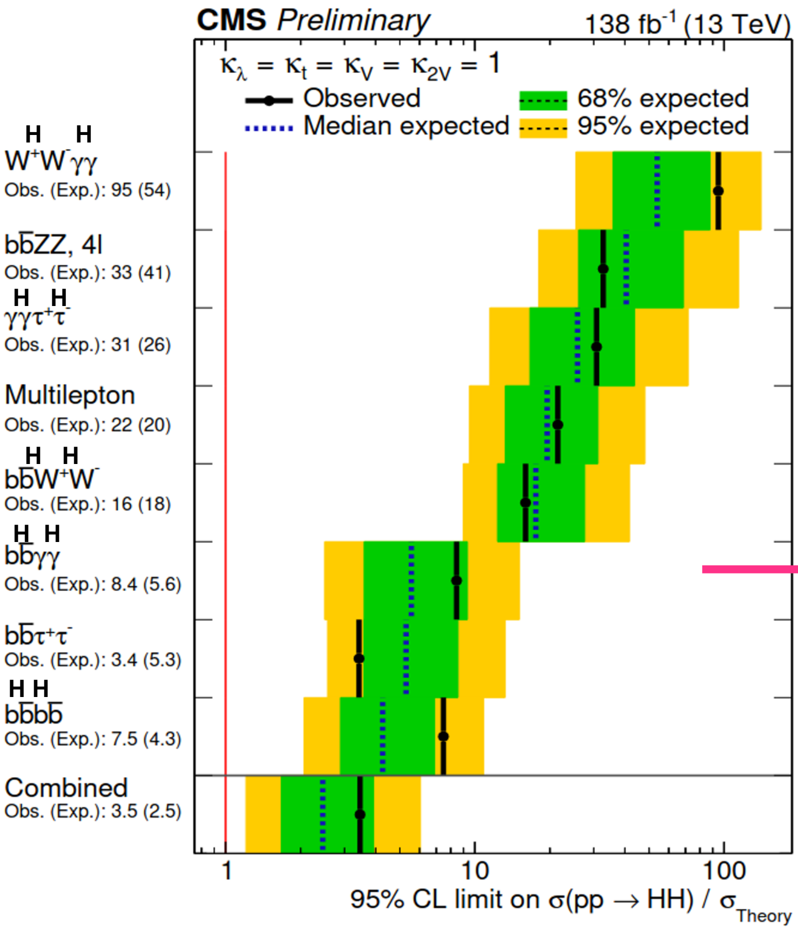


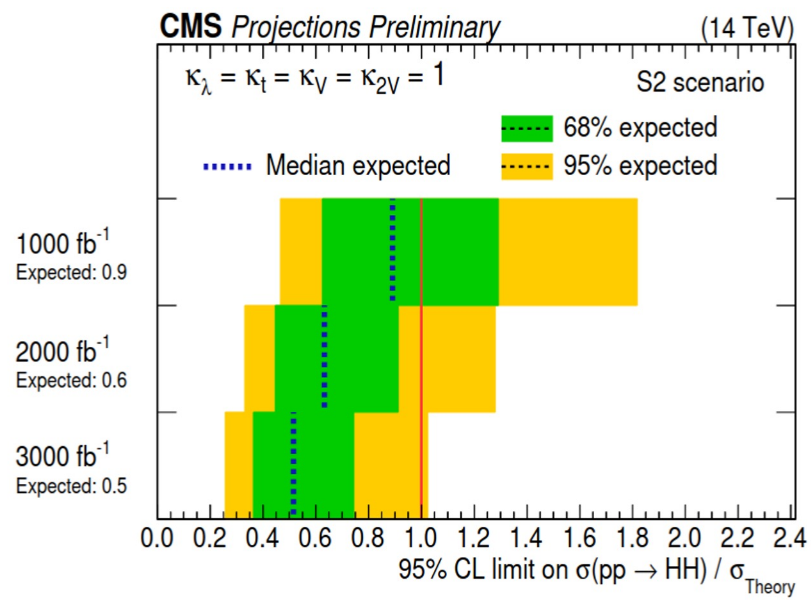




Di-Higgs (HH) production





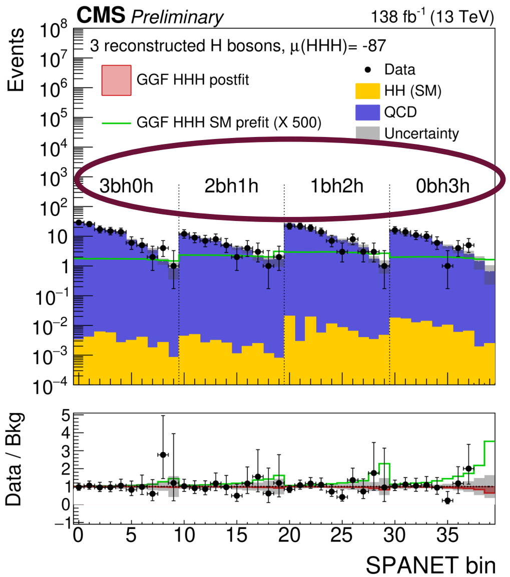


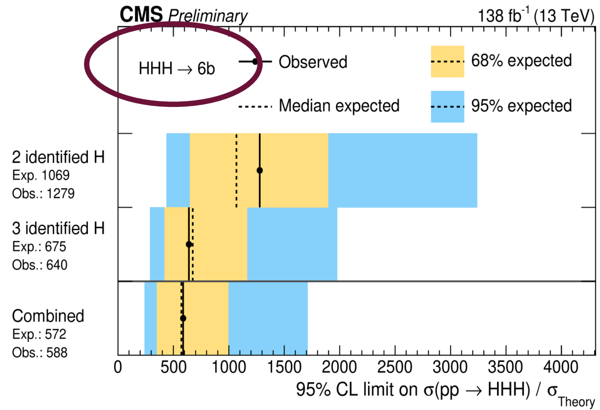
Current upper limit on HH production ~3 x SM prediction

CMS-PAS-HIG-20-011

Triple-Higgs (HHH) production

✓ H->bb has largest rate of ~60% (resolved or boosted jets)





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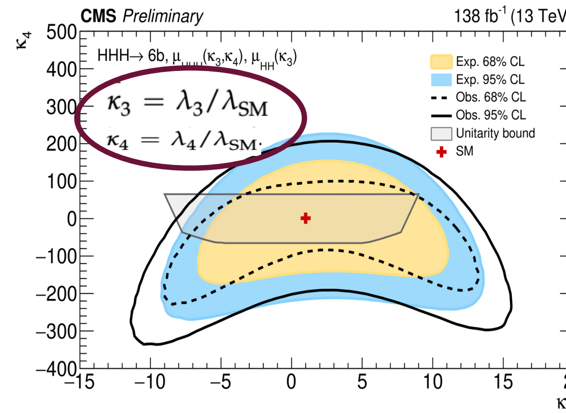

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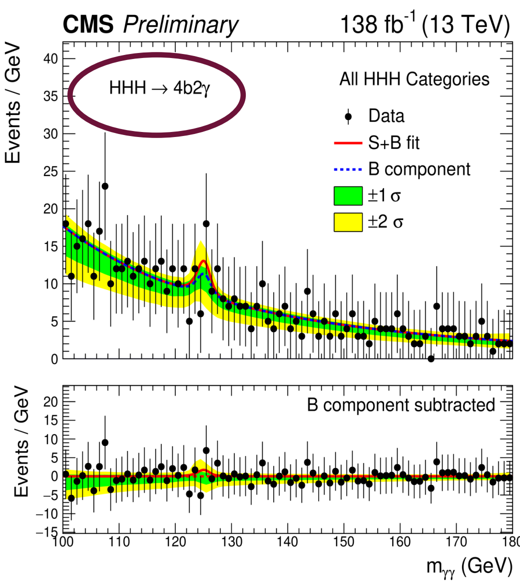
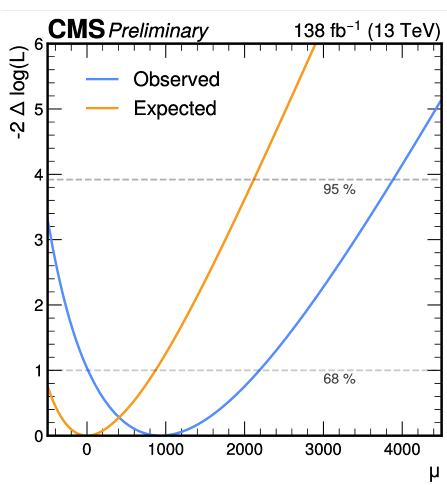
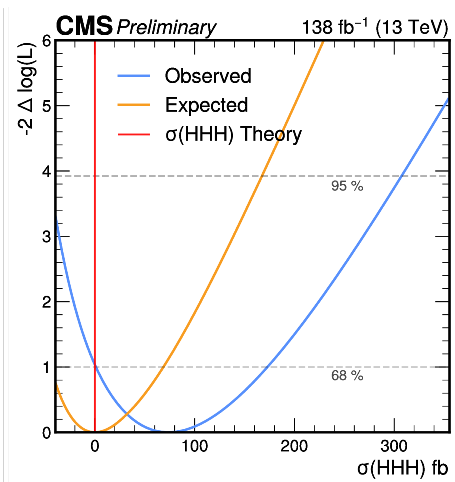
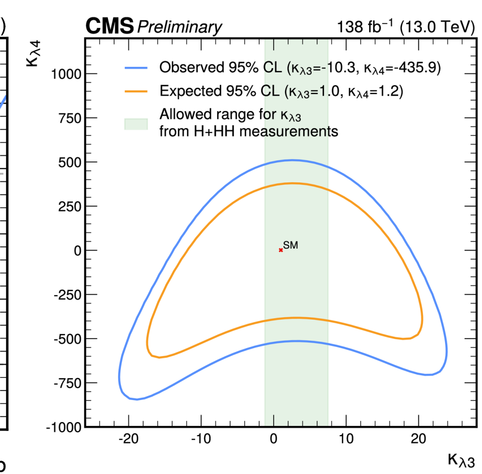


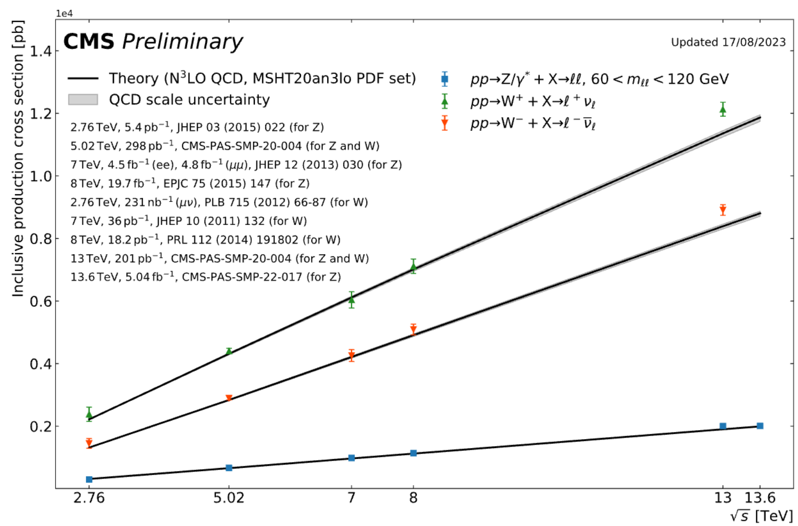


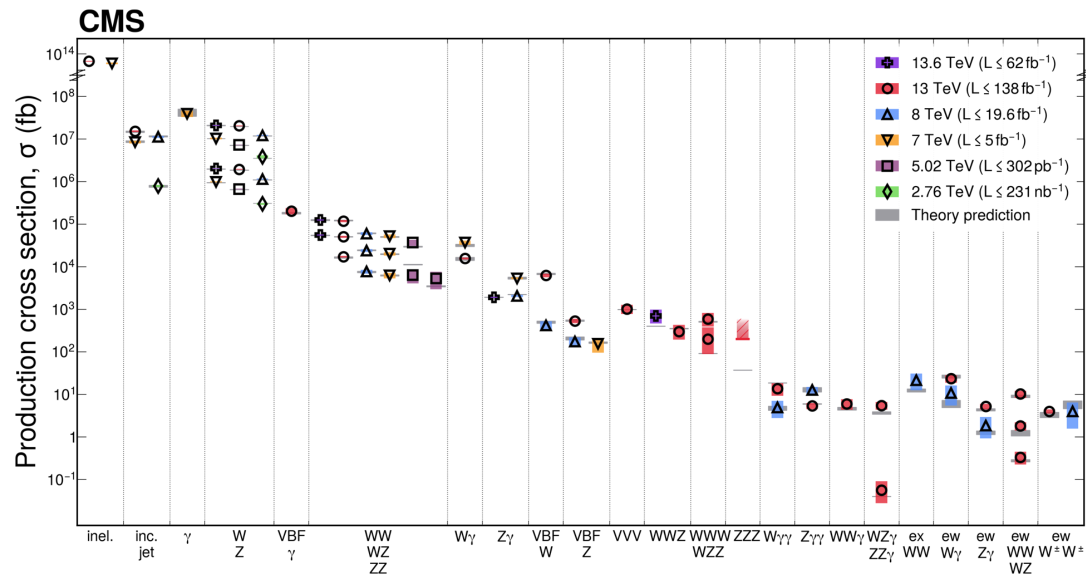


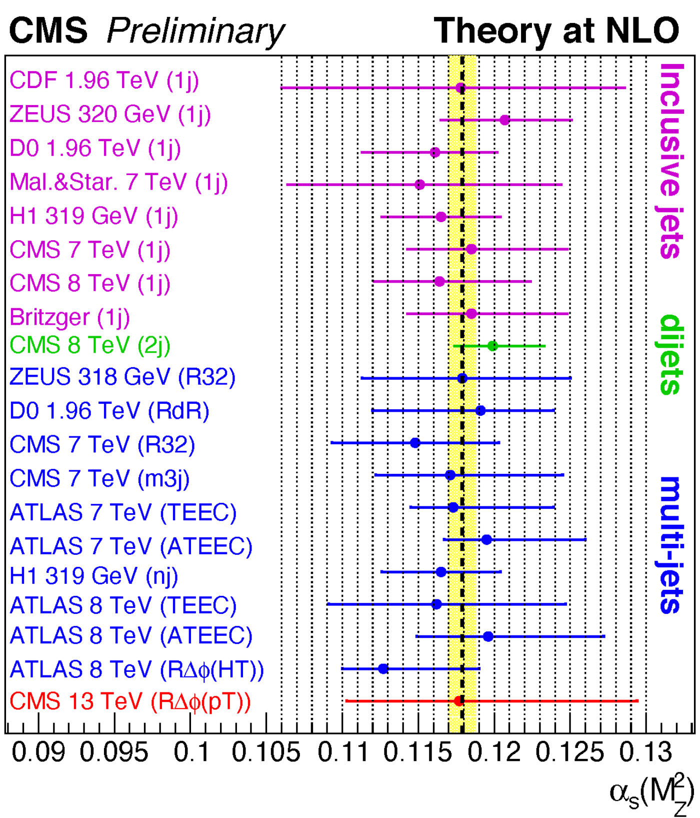


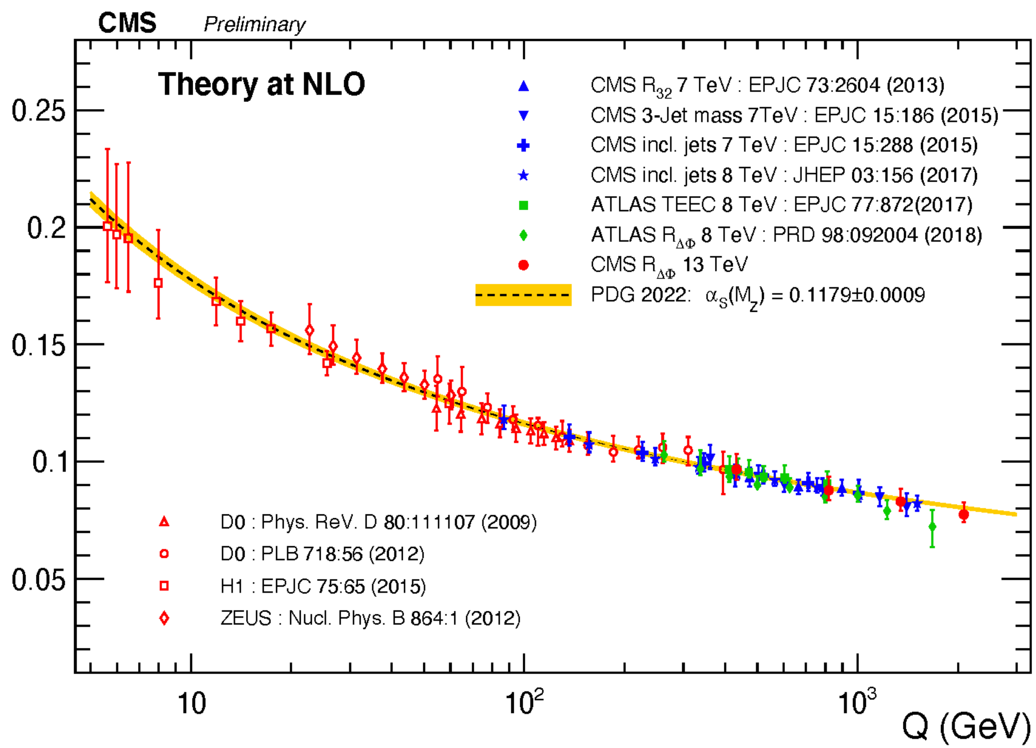
✓ Observation of HH, HHH will still be challenging with HL-LHC

Triumph in SM W/Z/QCD sector

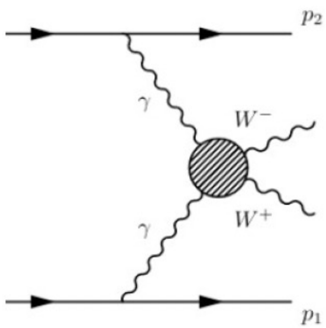








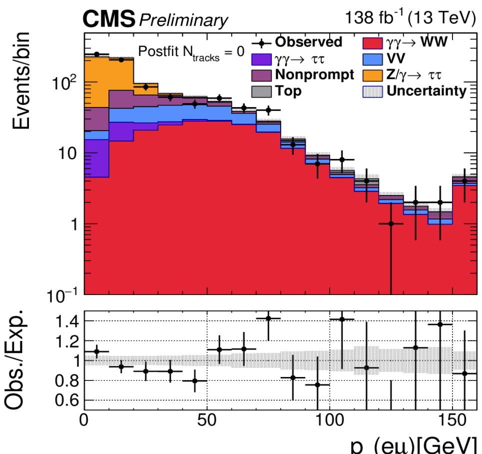
$\gamma\gamma \rightarrow$ WW cross section

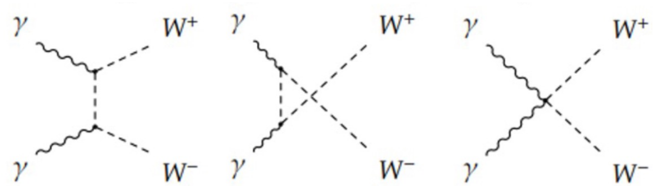


- Provides a pure electroweak environment $\sigma(\gamma\gamma) \propto \log^3(\sqrt{s})$
- In SM the process proceeds via trilinear and quartic interaction
- Signal: WW -> $e\nu_e\,\mu\nu_\mu$ (opposite sign leptons)
- Signal selection is based on detector activity around production vertex of W bosons (no other tracks attached to $e\mu$ vertex)

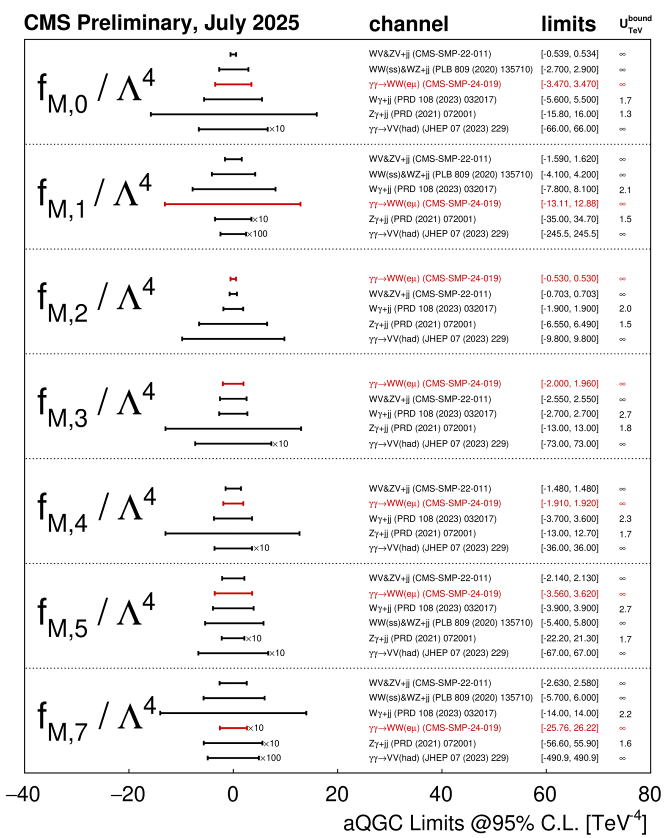
$$\mathcal{L}_{WW\gamma} = -ie\{(\partial^\mu W^\nu - \partial^\nu W^\mu)W^\dagger_\mu A_\nu - (\partial^\mu W^{\nu\dagger} - \partial^\nu W^{\mu\dagger})W_\mu A_\nu + W_\mu W^\dagger_\nu(\partial^\mu A^\nu - \partial^\nu A^\mu)\}$$

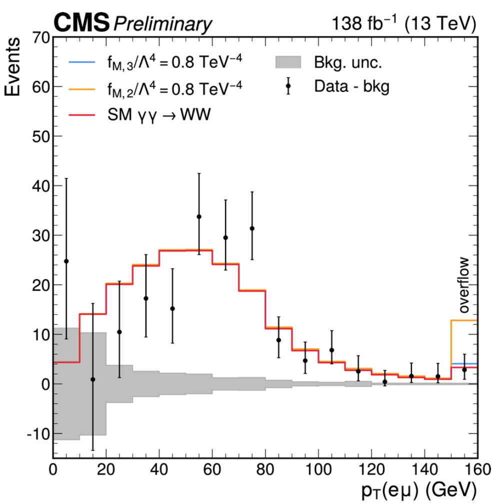
$$\mathcal{L}_{WW\gamma\gamma} = -e^2(W^\dagger_\mu W^\mu A_\nu A^\nu - W^\dagger_\mu A^\mu W_\nu A^\nu)$$





In signal region (no of track =0) and control region (1<ntrk<5) excellent data-MC agreement





Measured inclusive cross-section: 659 ± 80 fb , SM: 631 fb

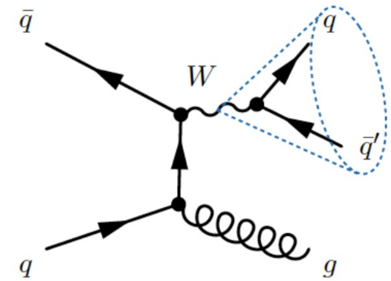
Fiducial cross-section: 4.1 ± 0.5 fb

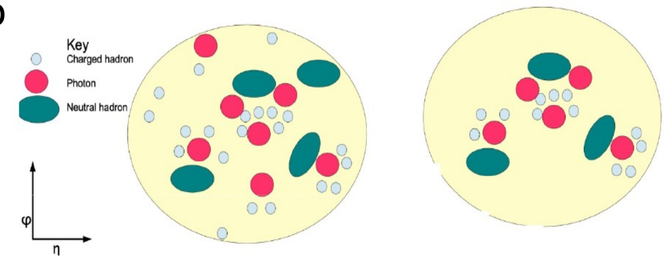
Stringent constraints on dim-8 operators in EFT approach

CMS-PAS-SMP-24-019

Jet mass distributions and W mass

- Cross section measurement of W(qq) + jets
  - At high momentum P_T> 650GeV
  - Double-differential in jet P_T and jet mass
- W(qq) object from wide ΔR=0.8 jet
  - Substructure tagged for 2-prong with particleNeT algo
    -> to suppress QCD background
  - Mass from jet groomed with softdrop algorithm
    -> Suppresses soft and wide-angle emissions
- Unfolding to both particle level jet P_T and mass
- Sensitive to W mass -> turn into measurement
- First measurement at a hadron collider of **W-mass in all-jet final state, m(W)= 80.77 ± 0. 57 GeV**





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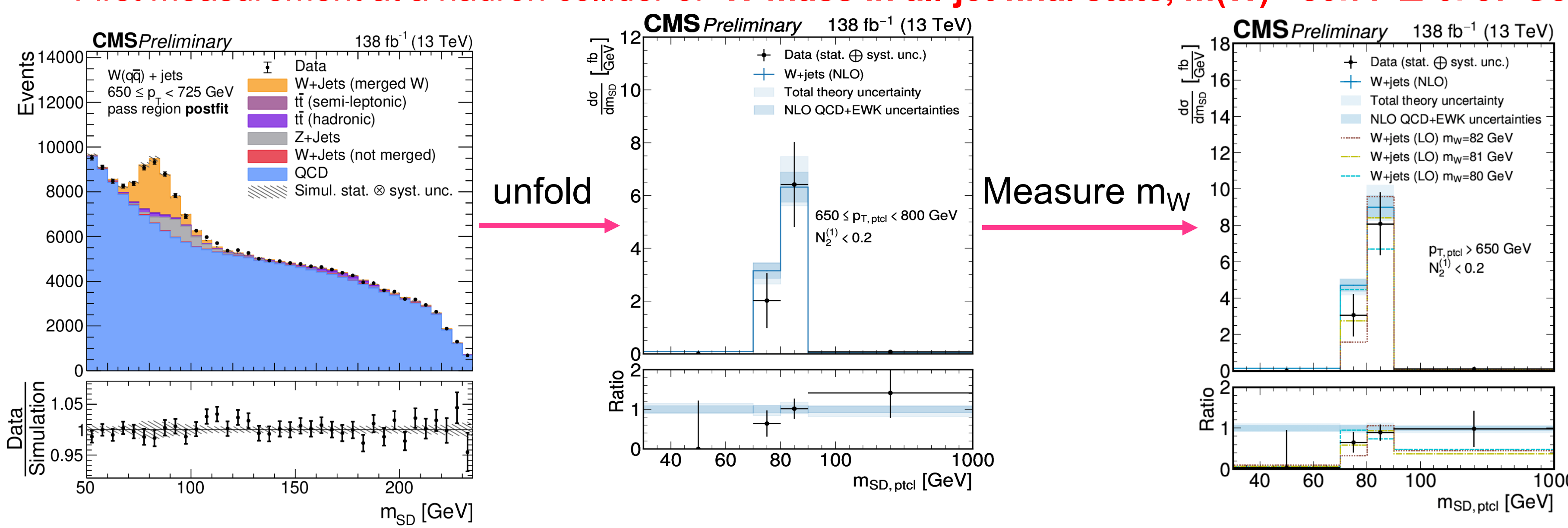
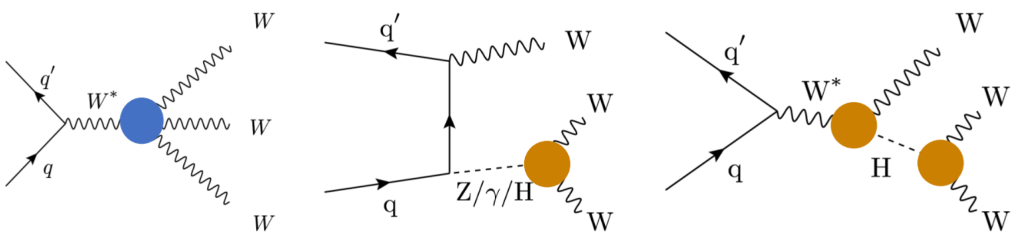


New Physics in triple boson production

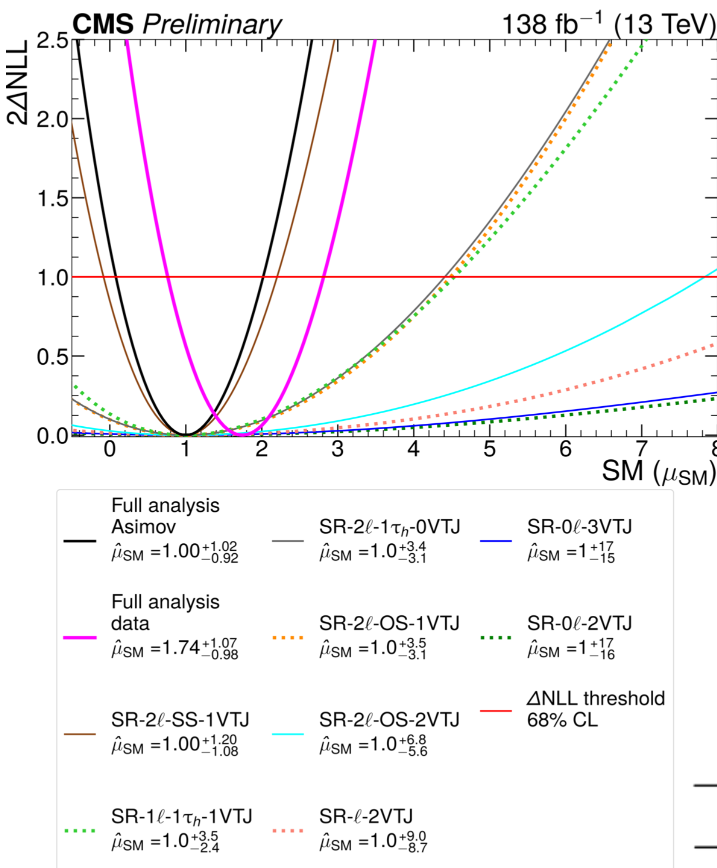
- ✓ Three massive VVV boson production is a rare process -> observed earlier by CMS & ATLAS
- ✓ Sensitive to TGC, QGC, Higgs gauge coupling -> focus on EFT interpretation of VVV
- ✓ The analysis is BSM search driven

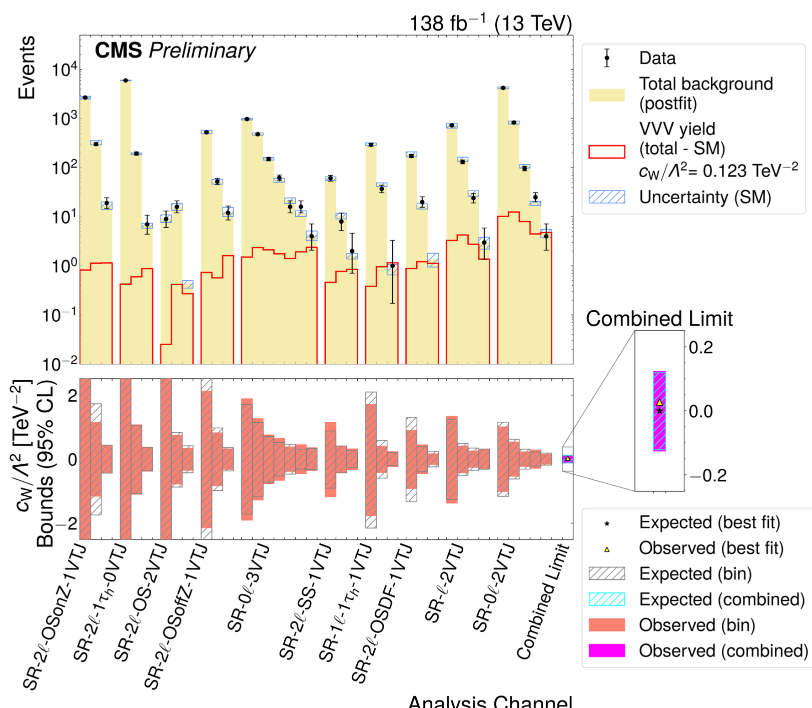


This search includes:
WWW, WWZ, WZZ, ZZZ
(boosted region: P_T>200 GeV)

zero in SM

$$L = L_{SM} + \sum_{\text{dim}-6} \frac{c_i}{\Lambda^2}\mathcal{O}_i + \sum_{\text{dim}-8} \frac{f_j}{\Lambda^4}\mathcal{O}_j.$$



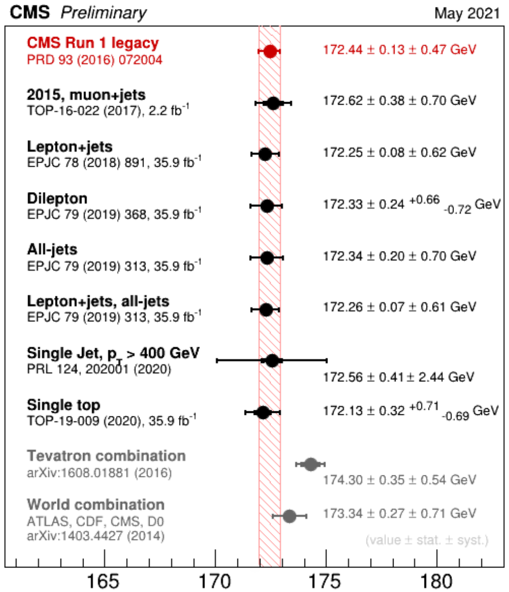


$$-0.13 < c_W/\Lambda^2 < 0.12\ \text{TeV}^{-2}$$

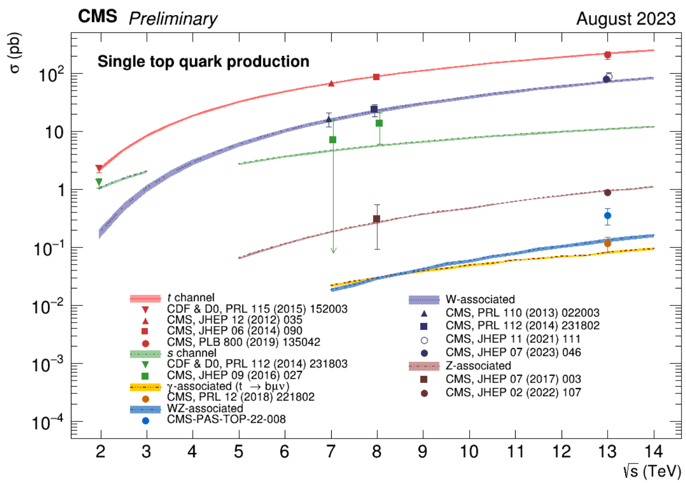
$$-0.24 < c_{Hq3}/\Lambda^2 < 0.21\ \text{TeV}^{-2}.$$

CMS-PAS-SMP-24-017

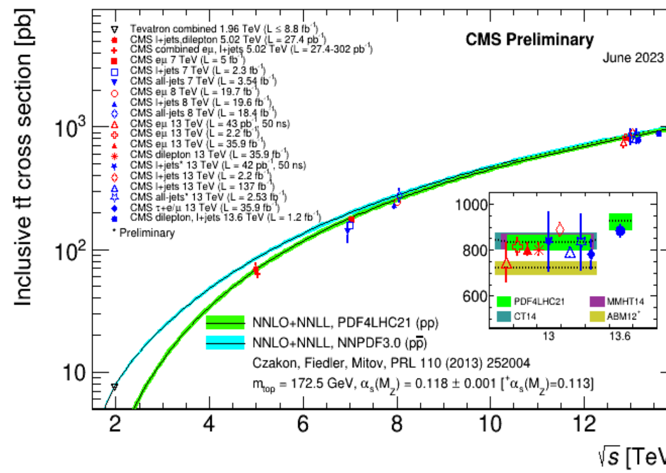
Triumphs in top-quark sector



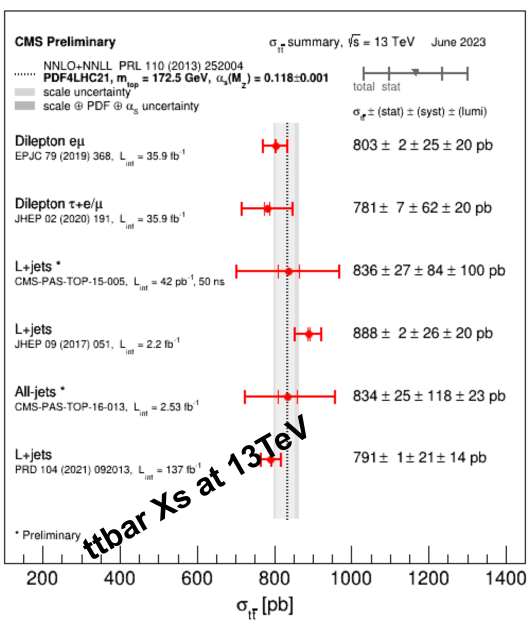
top-quark mass



single top production cross section

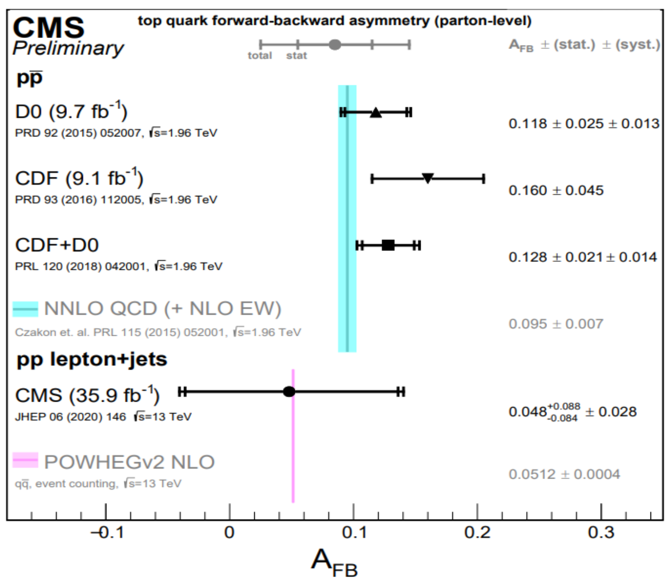


ttbar Xs as function of COM energy

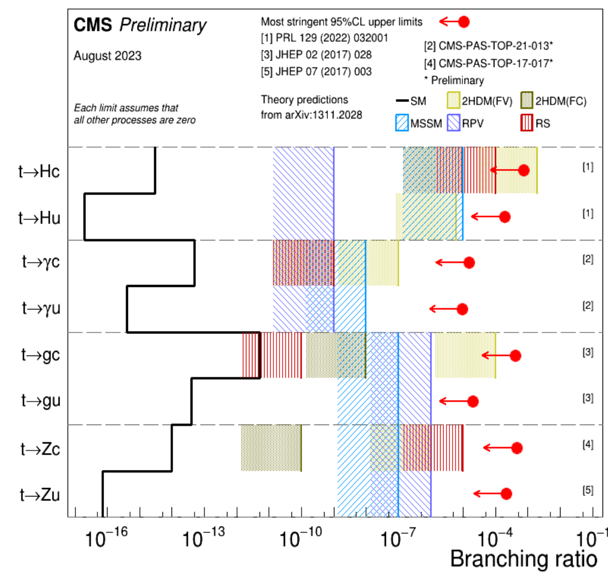


ttbar Xs at 13TeV

top-antitop forward backward asymmetry

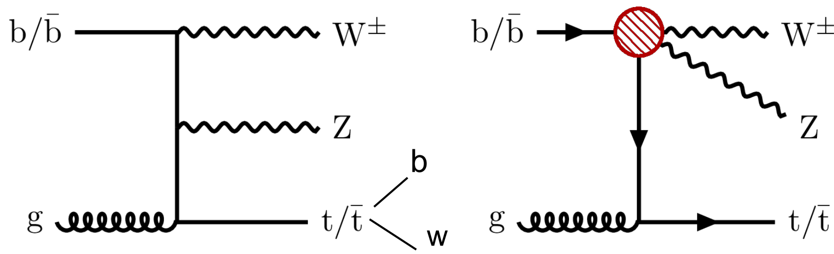


top FCNC decays



Rare top production via tWZ process

- Provides access of EW coupling to top quark. Allows stringent test of gauge structure of SM.
- Events with 3 and 4 lepton final states with jets and missing P_T (final state: bWWZ, Z->opposite sign same flavor leptons, one of the W-> lepton/jets)
- Very small production cross section, 136 ± 10 fb @13TeV and 147.8 ± 10 fb @13.6TeV
- Challenging background ttZ and WZ+jets
- Simultaneous fit to multiple analysis regions
- **σ_{tWZ} = 248 ± 52 fb (13 TeV), 244 ± 74 fb (13.6 TeV)**
- **5.8σ observed significance (3.5σ expected)**
- First observation of tWZ (Run2 and Run3 data)



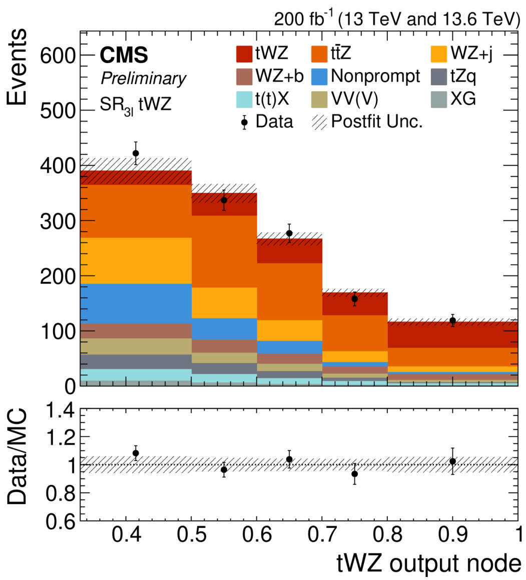
Semi-leptonic tWZ

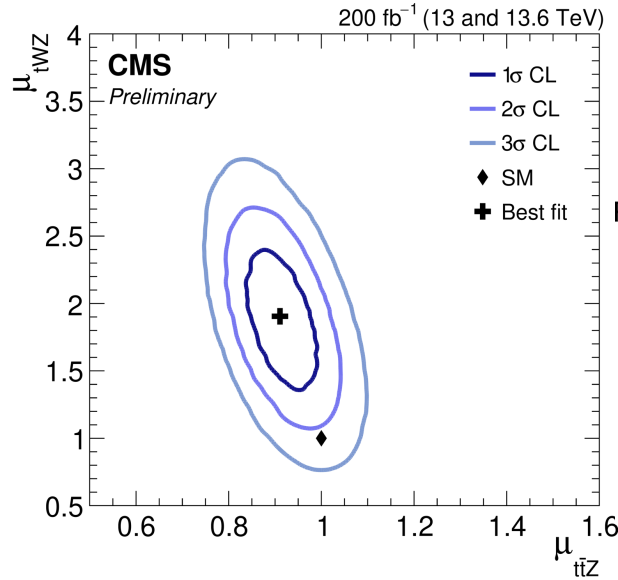
- At least 2 jets
- At least 1 b-jet
- Exactly 3 leptons
- |m(ll)-m(Z)| < 15 GeV

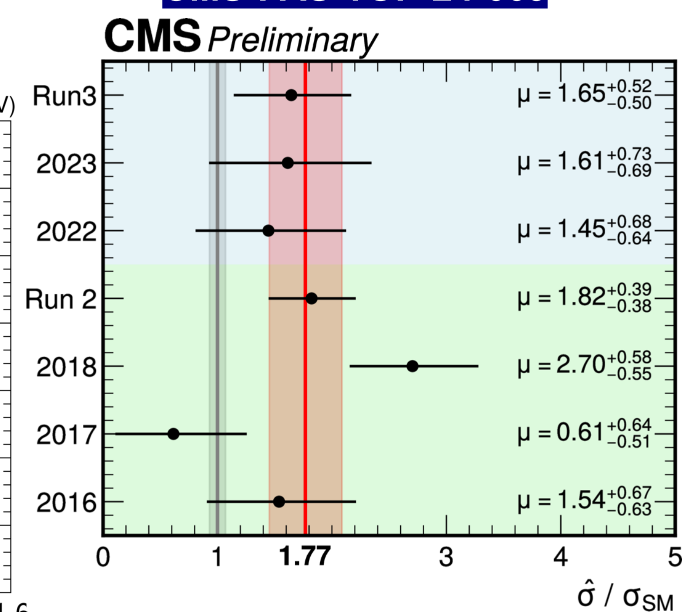
Fully-leptonic tWZ

- At least 1 jet
- At least 1 b-jet
- Exactly 4 leptons
- |m(ll)-m(Z)| < 15 GeV

CMS-PAS-TOP-24-009

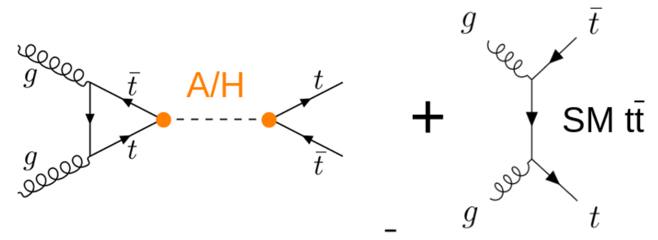




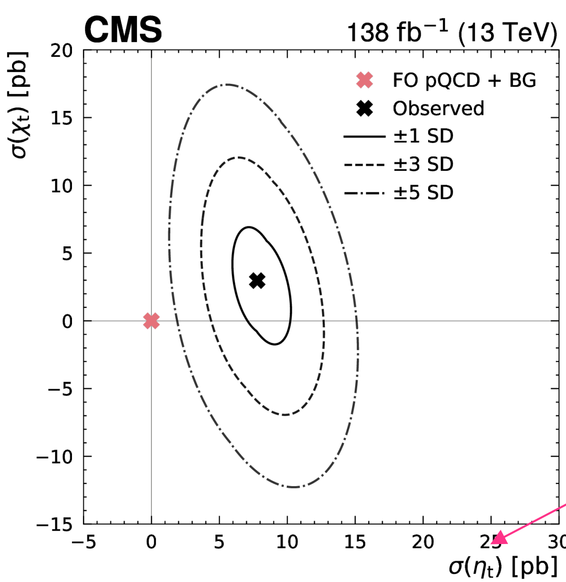


Observation of pseudoscalar (toponium) to top pair

- ttbar pair don't form bound state due to short lifetime, but NRQCD predicts bound state enhancement at tt threshold (toponium color singlet bound state)
- Final states: two leptons and at least two jets
- Signal extracted with 3D likelihood fit to m_{ttbar}, C_{hel}, C_{han} (C_{hel}, C_{han} are angular variables of leptons w.r.t parent ttbar)

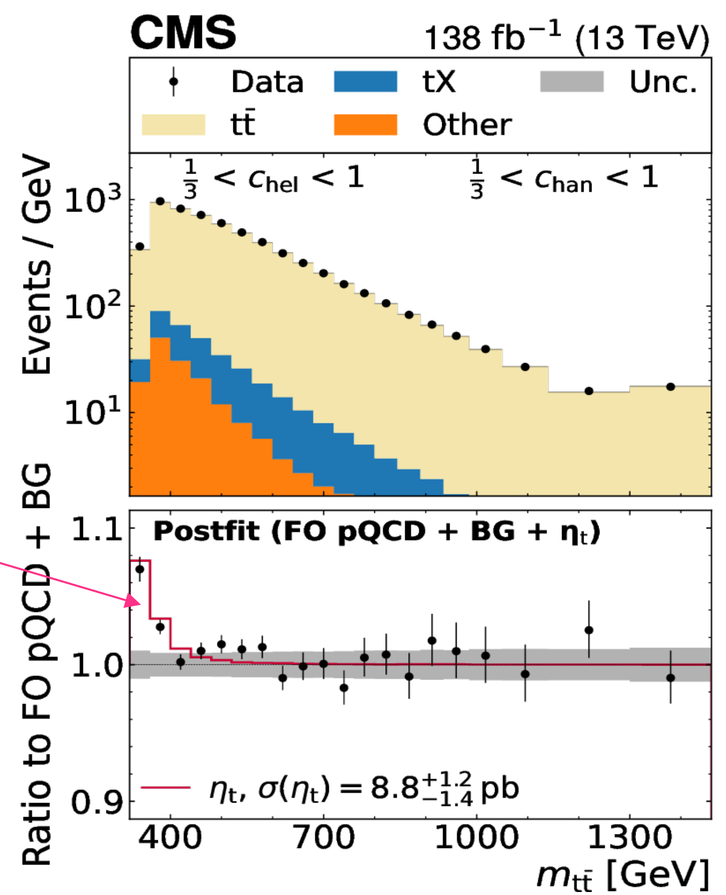


Rep. Prog. Phys 88 (2025) 087801



To determine the spin and CP structure, both pseudo-scalar (η_t) and scalar (χ_t) components are included.

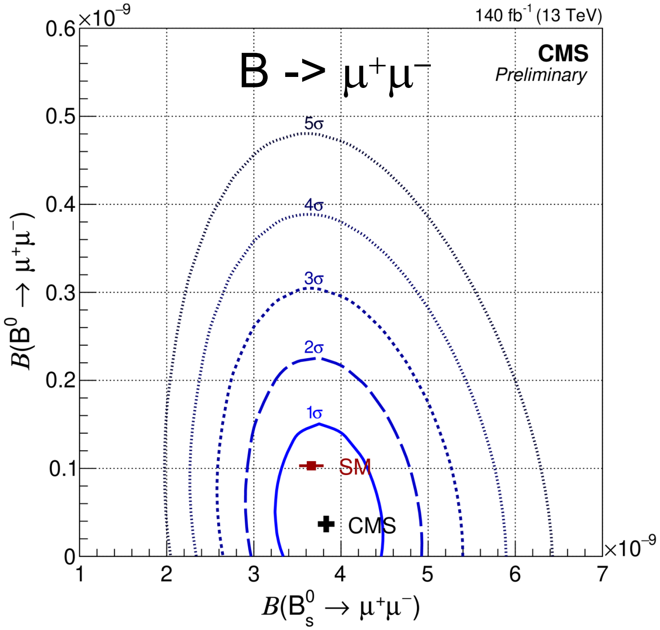
Excess compatible with pseudo-scalar hypothesis (more than 5σ signal sig)

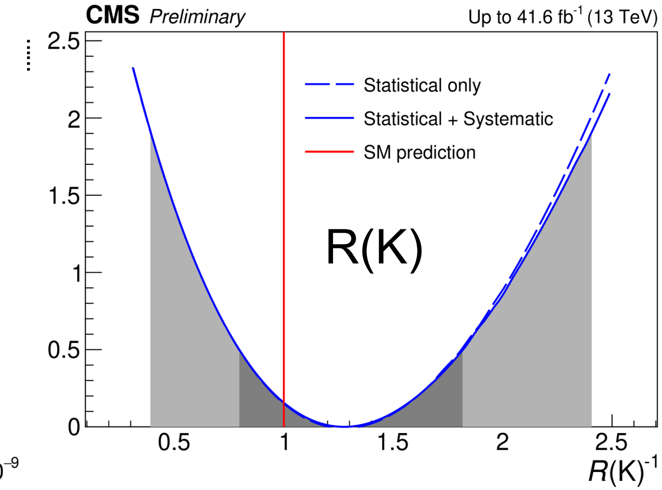


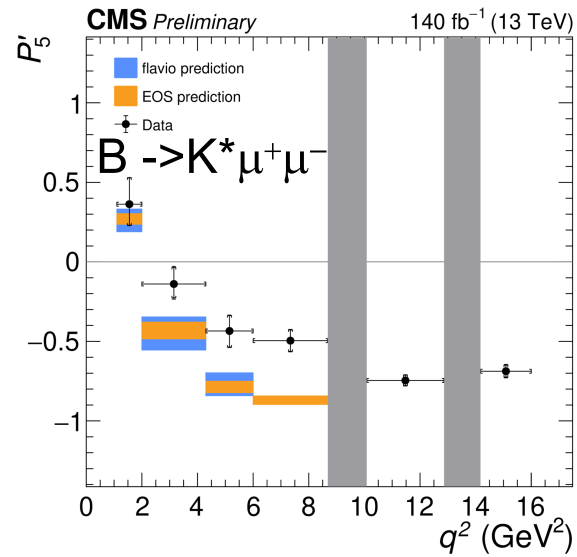
The result is compatible with formation of Pseudo-scalar state (η_t) with cross section:

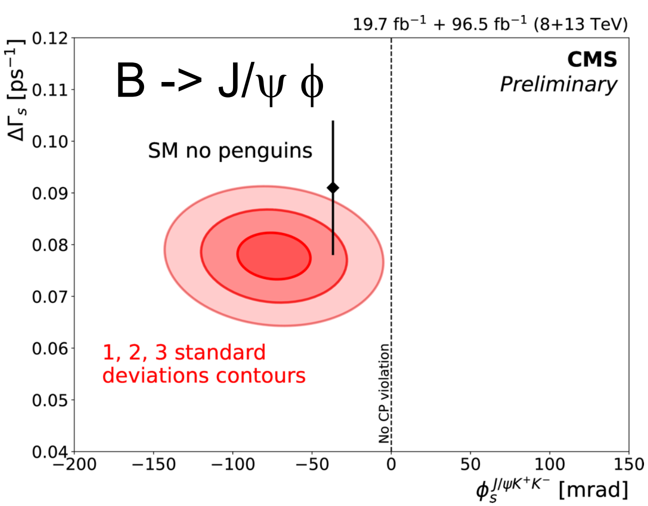
$$\sigma(\eta_t) = 8.8 \pm 0.5\,(\text{stat})\,^{+1.1}_{-1.3}\,(\text{syst})\,\text{pb} = 8.8\,^{+1.2}_{-1.4}\,\text{pb}$$

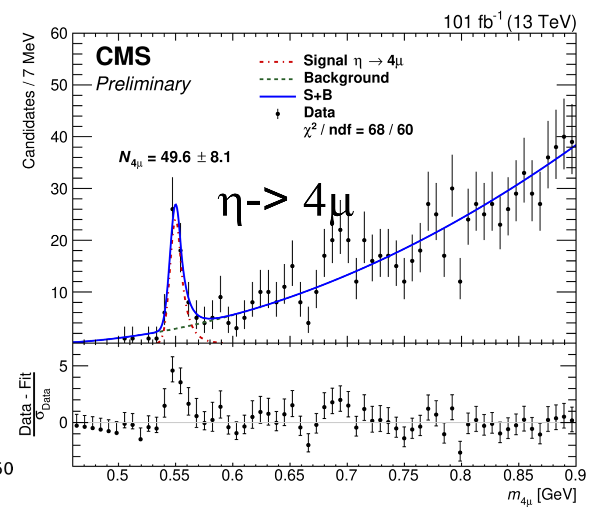
Triumphs in B-meson-sector

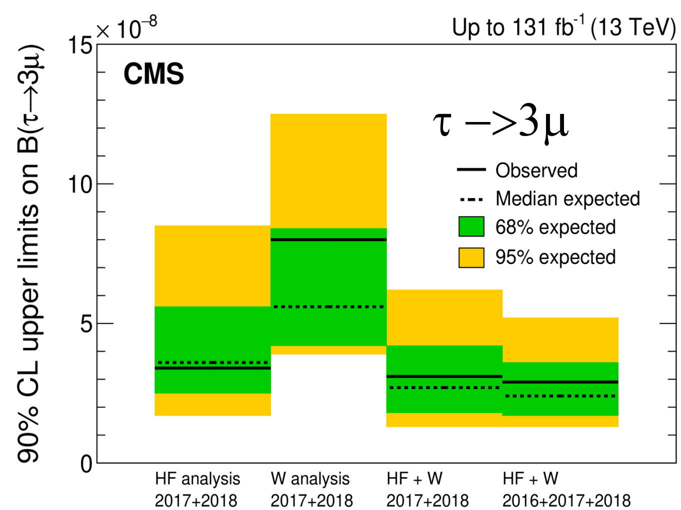








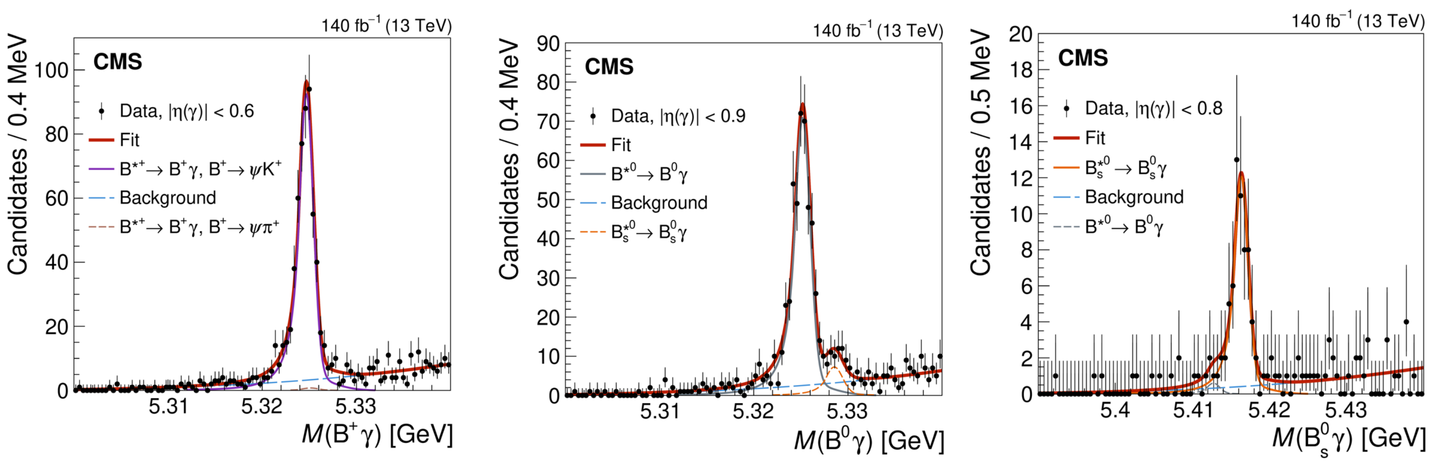




Exclusive B* reconstruction

- First exclusive reconstruction of excited vector B meson states: B^{*+}, B^{*0}, B_s^{*0}
  -> Main challenge is low-energy photon (40-50 MeV) from $B^* \to B\gamma$
- Low energy photons are reconstructed through conversions into e^+e^- pairs
  -> Small angular separation
  -> conversion vertex at least 1.5cm away from beam axis
  -> Two tracks to originate from same vertex with zero invariant mass
- To improve resolution, the $B\gamma$ invariant mass is evaluated using

$$M(B\gamma) = m(B\gamma) - m(B) + M_B^{PDG}$$

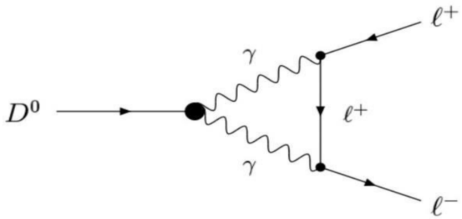


$$\Delta m(B^{*+}) \equiv m(B^{*+}) - m(B^+) \quad 45.277 \pm 0.039 \pm 0.027\,\text{MeV}$$
$$\Delta m(B^{*0}) \equiv m(B^{*0}) - m(B^0) \quad 45.471 \pm 0.056 \pm 0.028\,\text{MeV}$$
$$\Delta m(B_s^{*0}) \equiv m(B_s^{*0}) - m(B_s^0) \quad 49.407 \pm 0.132 \pm 0.041\,\text{MeV}$$

arXiv: 2508.05820 (submitted to PRL)

~order of magnitude improvement in precision than the previous measurements

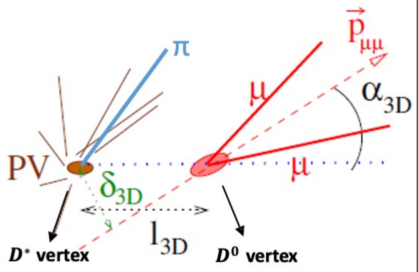
Rare charm decay $D^0 \to \mu^+\mu^-$



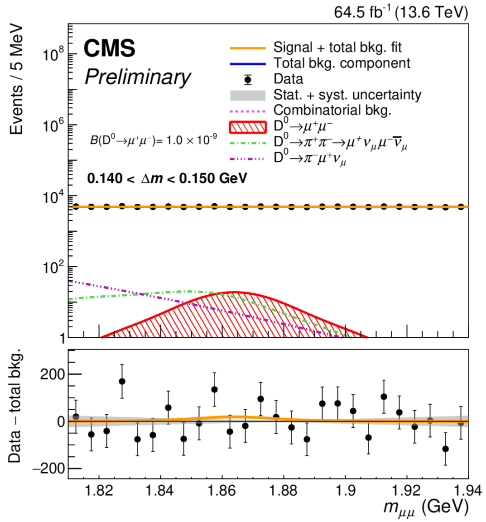
- ✓ Compared to "b → s" (B_s meson decays, ~10^{-9}), rare charm decays mediated by "c → u" transition, are not explored much.
  - SM Prediction: BF($D^0 \to \mu\mu$) > ~3×10^{-13} (Long distance)

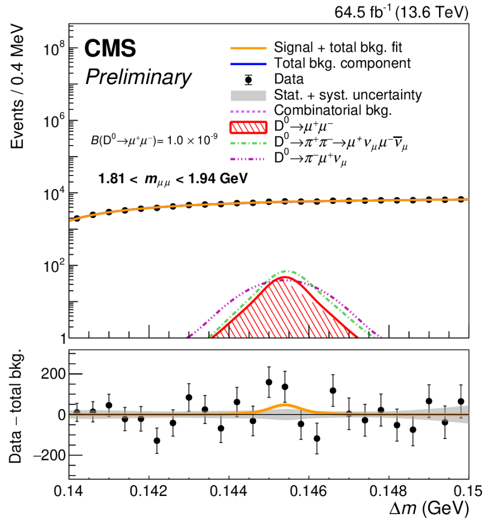
    PRD 66 (2002) 014009
  - Most stringent experimental BF < 3.5×10^{-9} at 95% CL from LHCb,

PRL 131, 041804, which is 4 orders of magnitude larger than SM prediction



- ✓ Look for $D^0 \to \mu^+\mu^-$ through cascade decay of $D^{*+} \to D^0\pi^+$
- ✓ The extra soft pion reduces the background by orders of magnitude
- ✓ Signal yield extracted with 2D fit to: $D^0(\mu^+\mu^-)$ mass and Δm ($m_{D^{*+}} - m_{D^0}$)





$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \mathcal{B}(D^0 \to \pi^+\pi^-)\frac{N_{D^0\to\mu^+\mu^-}}{N_{D^0\to\pi^+\pi^-}}\frac{\varepsilon_{D^0\to\pi^+\pi^-}}{\varepsilon_{D^0\to\mu^+\mu^-}}$$

No significant excess over background expectation is found

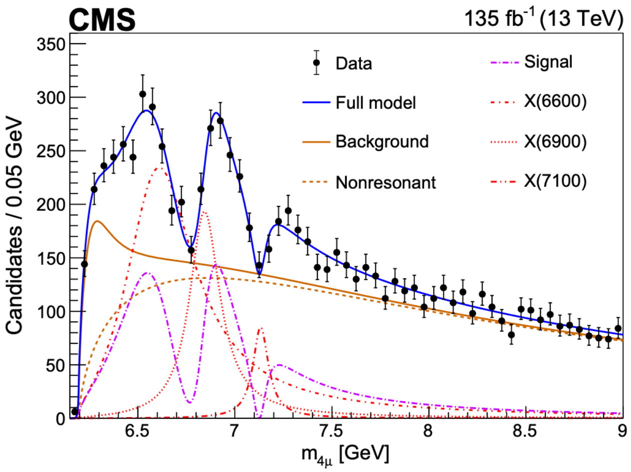
$\mathcal{B}(D^0 \to \mu^+\mu^-) < 2.6 \times 10^{-9}$ at 95% CL

30% improvement over the previous limit

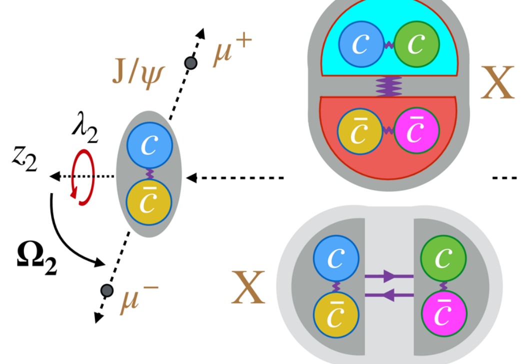
PRL 135 (2025) 151803)

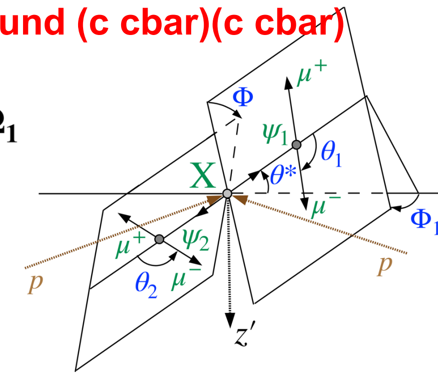
Spin and Parity of all-charm tatraquark

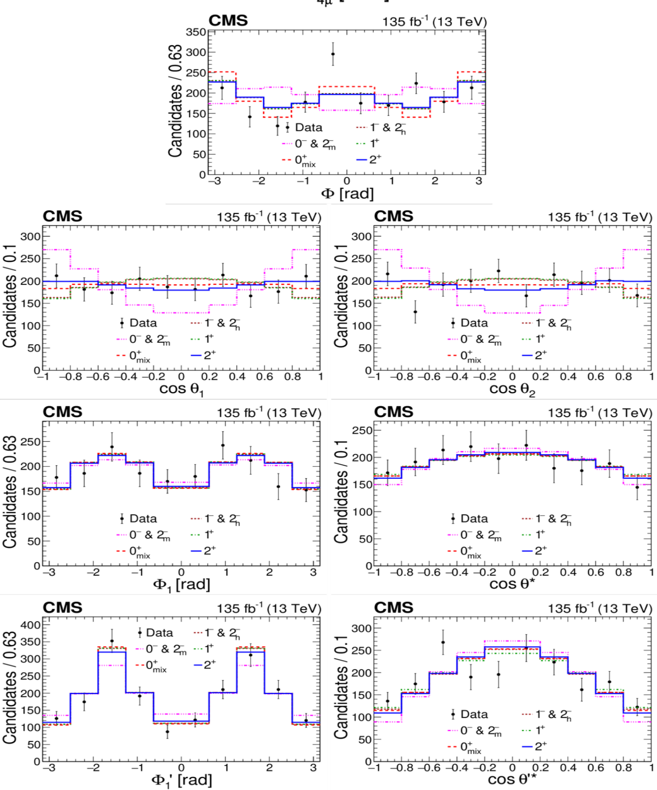
✓ Although several Baryons and Mesons are seen, the observation of tetra-quark and penta-quark are recent development (starting 2003). Needs detail study of their internal structure.

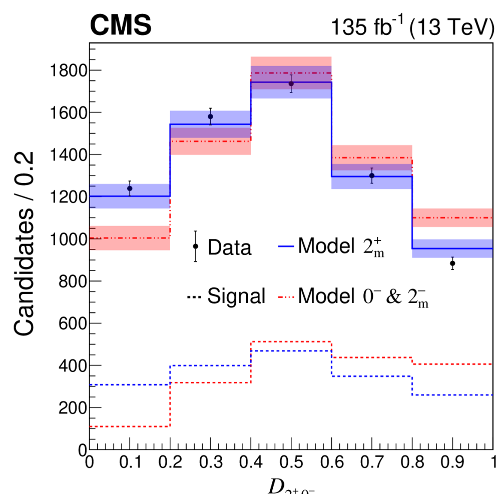


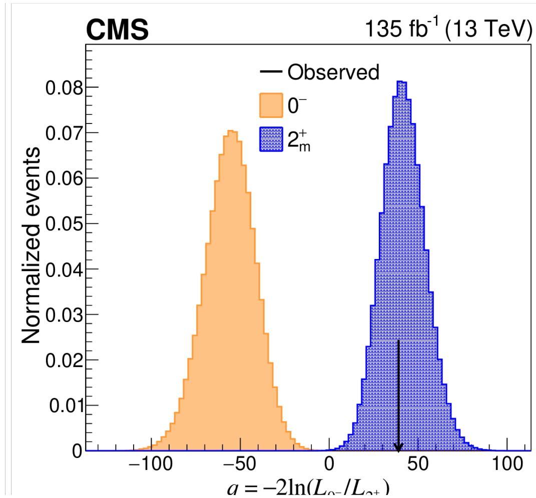
Tightly bound (cc)(cbar-cbar)
Or loosely bound (c cbar)(c cbar)











J^{PC}	Models J_i^P	Contributing amplitudes
0^{-+}	0^-	$A_{++} = -A_{--}$
0^{++}	0_m^+ and 0_h^+	$A_{++} = A_{--}$ and A_{00}
1^{-+}	1^-	$A_{+0} = -A_{0+} = A_{-0} = -A_{0-}$
1^{++}	1^+	$A_{+0} = -A_{0+} = -A_{-0} = A_{0-}$
2^{-+}	2_m^- and 2_h^-	$A_{++} = -A_{--}$ and $A_{+0} = A_{0+} = -A_{-0} = -A_{0-}$
2^{++}	2_m^+	$A_{++} = A_{--}$, A_{00}, $A_{+0} = A_{0+} = A_{-0} = A_{0-}$, and $A_{+-} = A_{-+}$

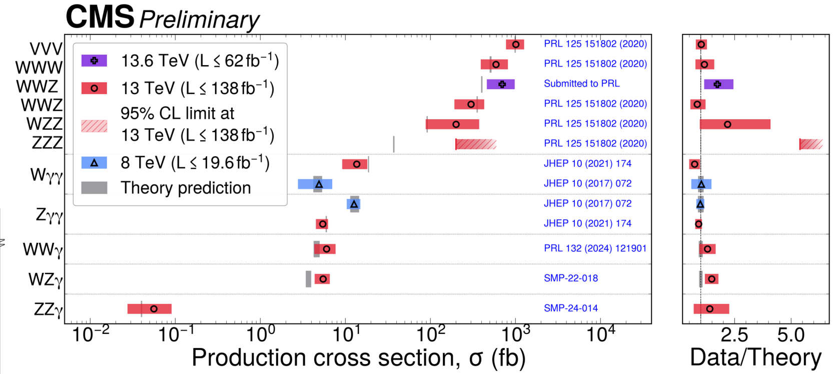
J^{PC} =2 $^{++}$ favored

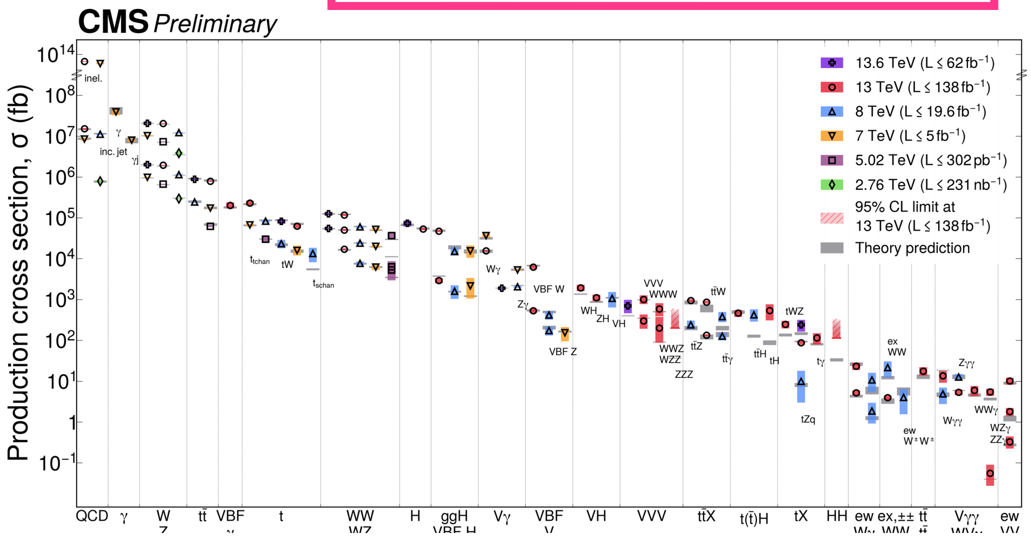
CMS-PAS-SMP-24-017
Accepted by Nature

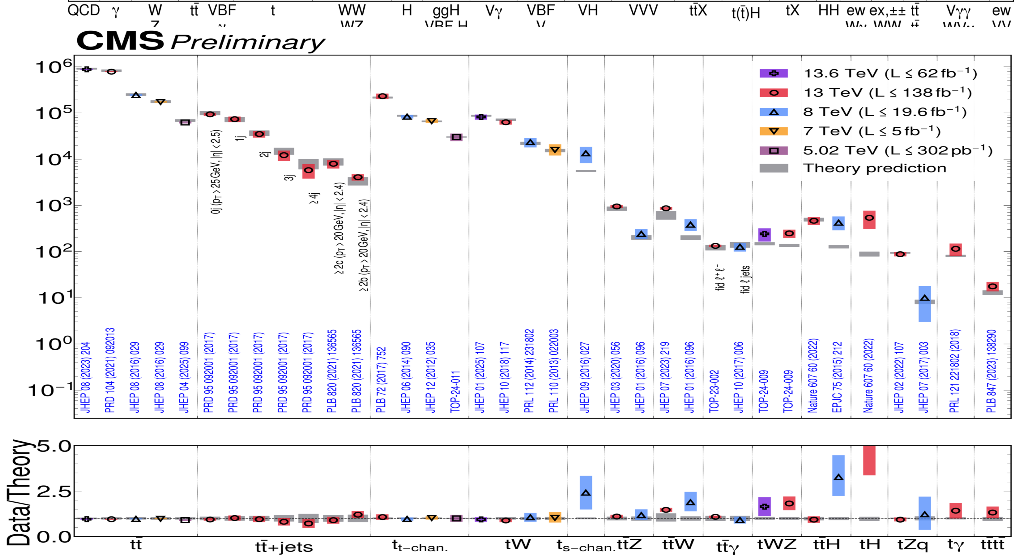
SM as a successful model

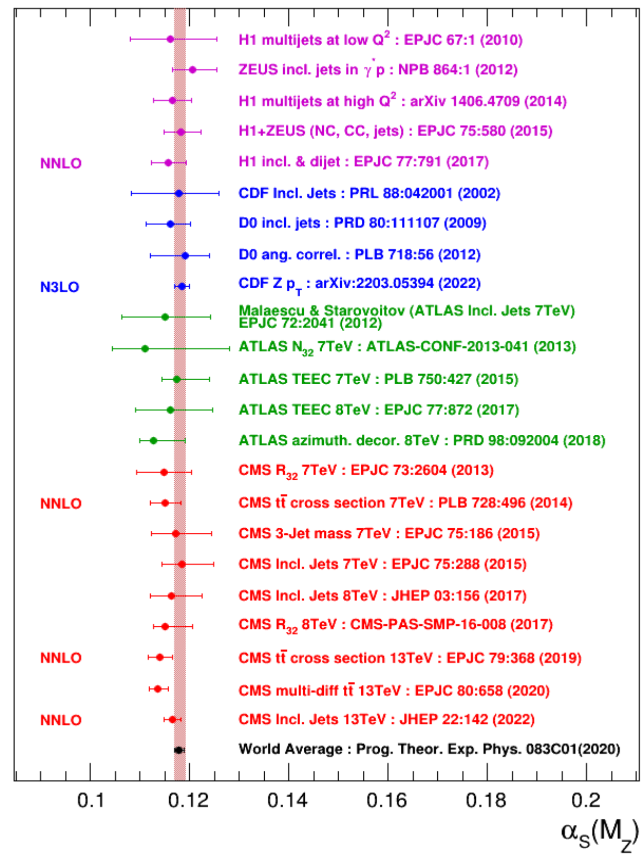
SM Lagrangian:

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi} \not{D} \psi + h.c. + \bar{\psi}_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$



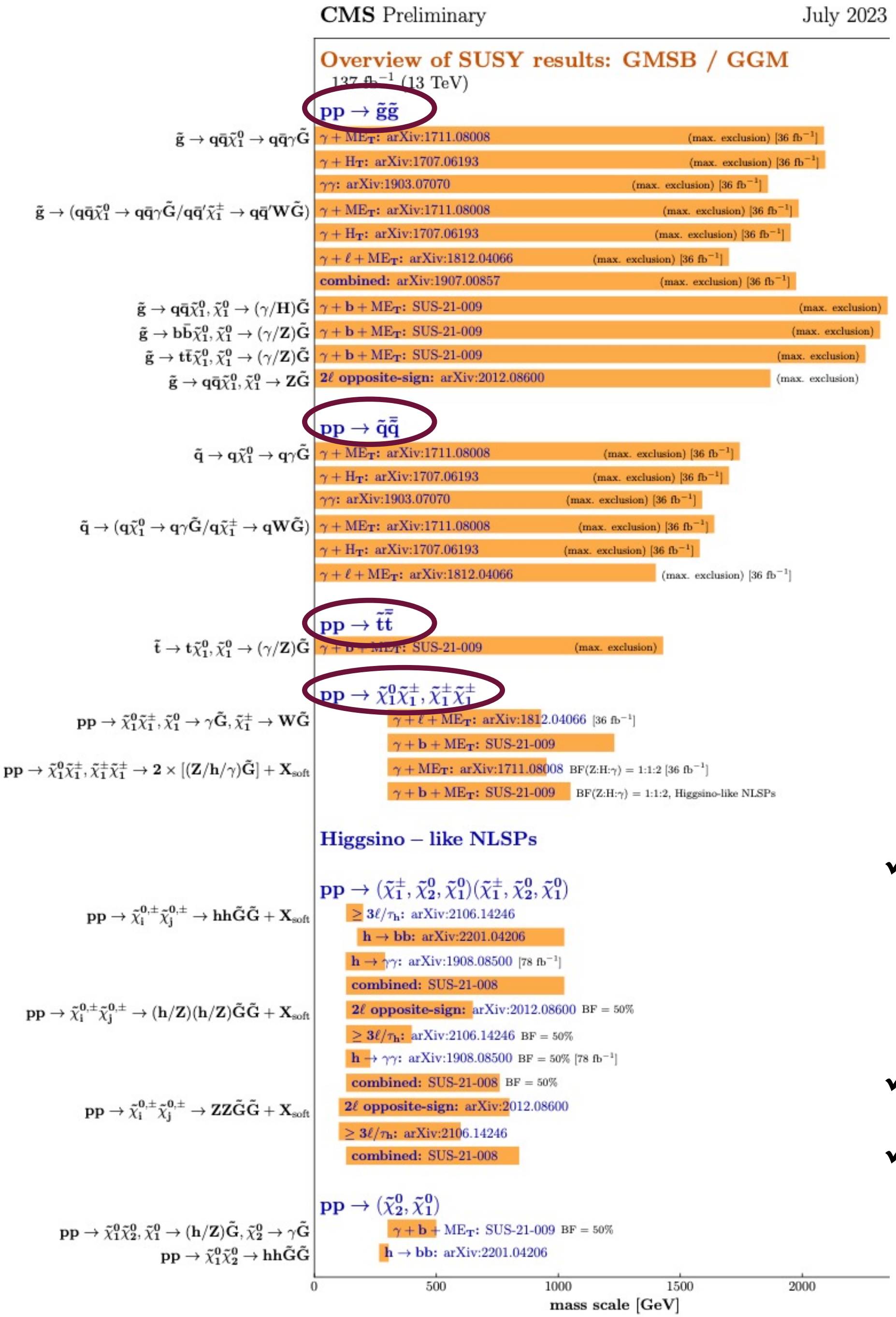


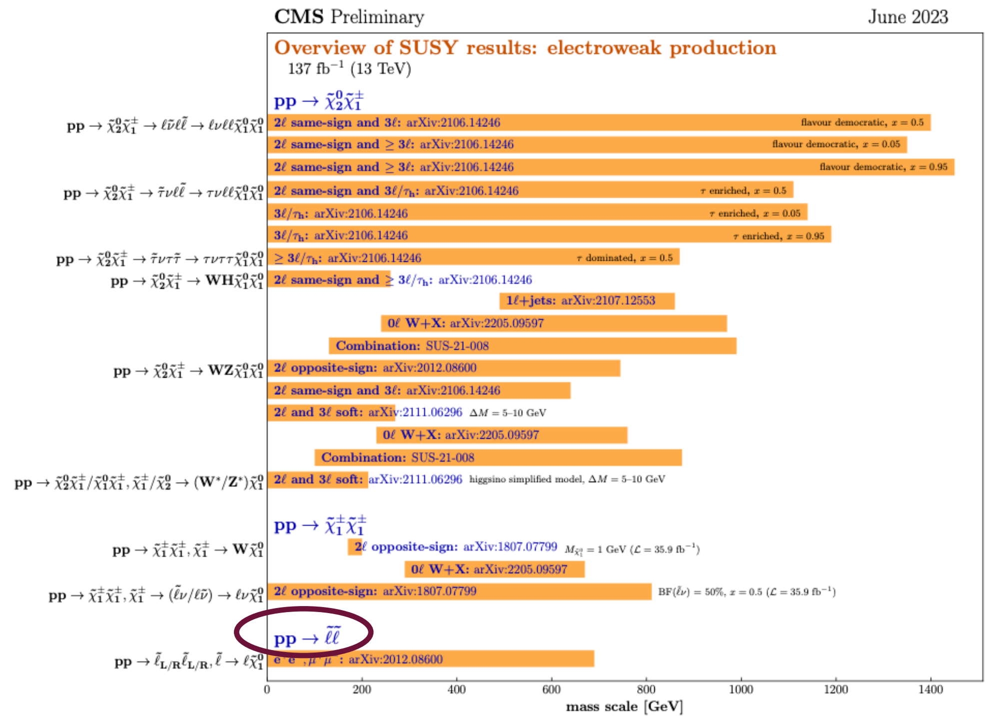




- Standard Model (SM) is tested over last several decades at per-mil level
- However, the searches for BSM physics is one of the primary aims of LHC as well (SUSY, LLPs, etc)

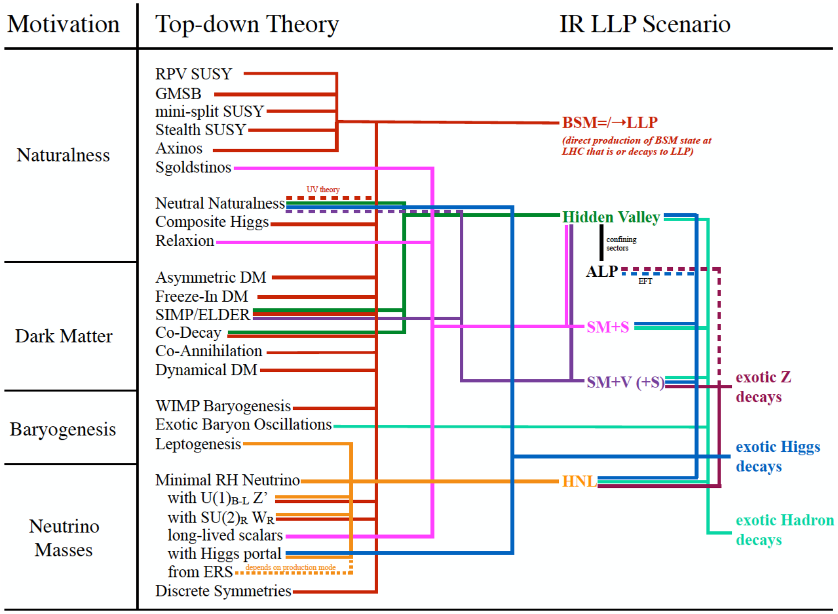
Going beyond SM (SUSY searches)

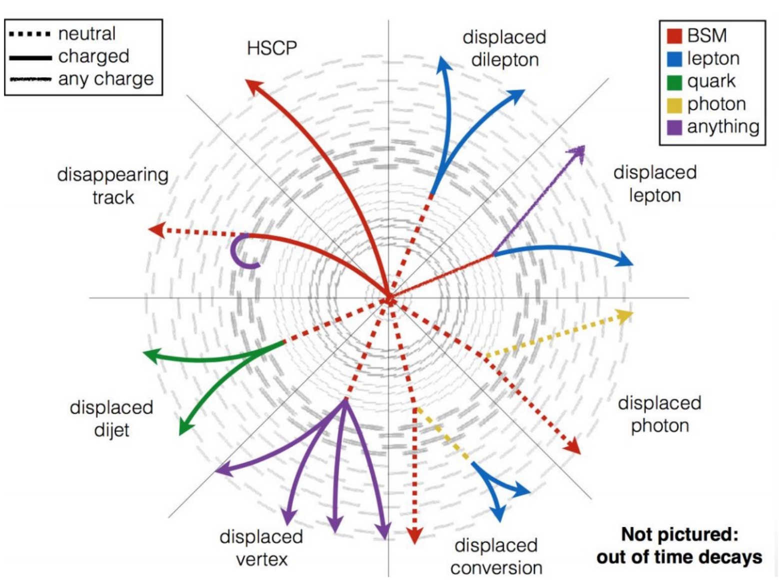




- ✓ Several search modes (involving gluinos, squarks, stop, chargino, neutralino, sleptons) have been explored using LHC data over last decade.
- ✓ No hints for SUSY
- ✓ The exclusion limit, for some cases, is as big as 2TeV or even more

BSM search through LLPs



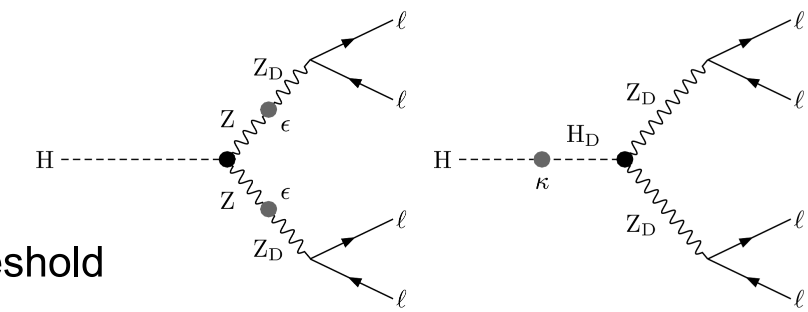


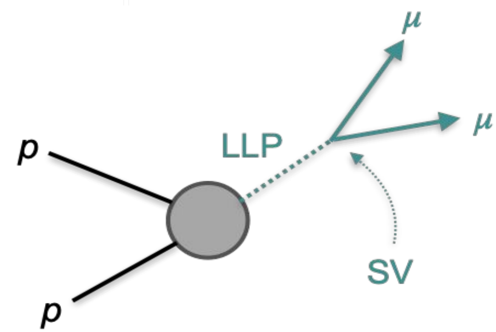
- ✓ Several BSM theories try to explain hierarchy problem, dark matter, baryogenesis, non-zero neutrino masses, etc.

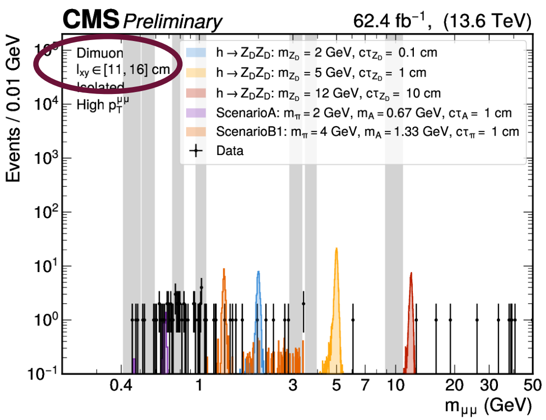
  => No BSM found till date
- ✓ Most BSM searches focus on heavy states that promptly decay to high energy visible particles such as jets, leptons, photons etc.
- ✓ A generic and much less explored alternative is that BSM shows up as new Long Lived Particles (LLPs) decaying to SM particle at some macroscopic distance away from production points.
- ✓ Several such displaced signatures (shown on the left figure) are being searched at LHC
- ✓ The lifetime of the LLPs are in general free parameters of the model (can live up to 10^7m).

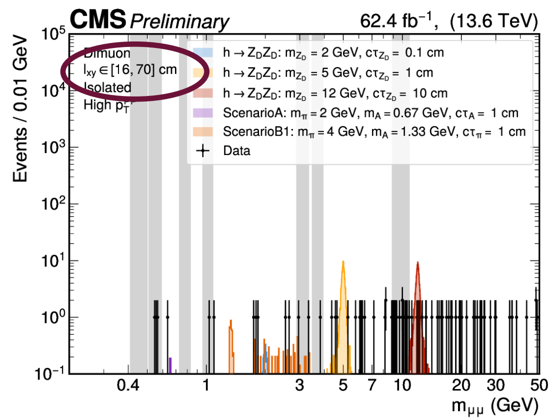
LLPs decaying to two muons

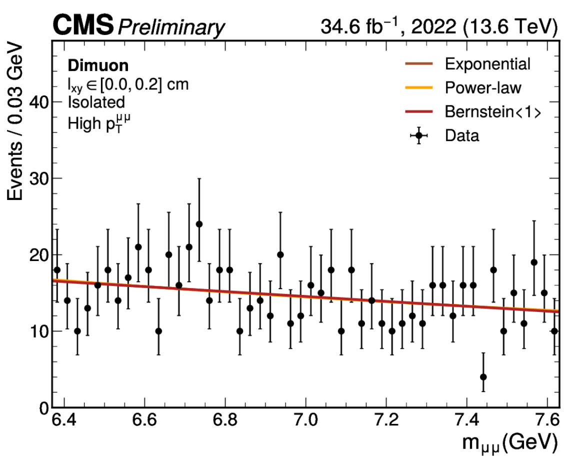
- Dark photons Z_D decaying to pairs of muons
- Assume Z_D is long lived -> Displaced vertex
    Either produced via kinetic Z-Z_D mixing
    or via decays of a mixed dark Higgs boson
- Dedicated dimuon trigger with low momentum threshold
- Fit around each signal hypothesis to test for signal







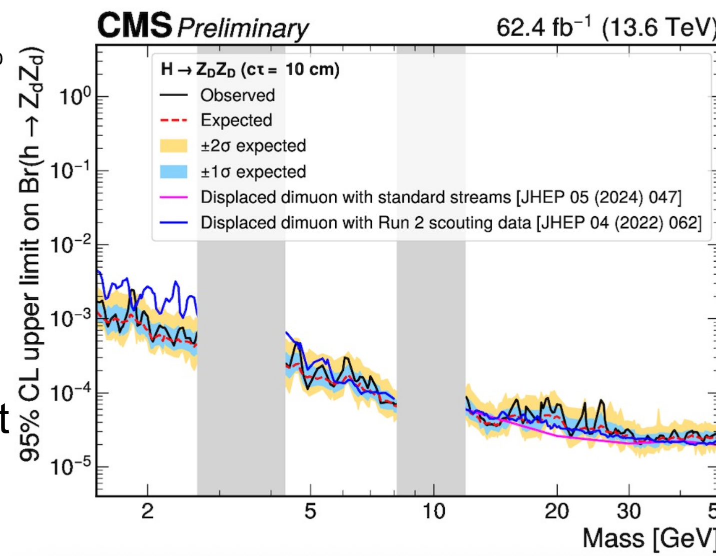




No significant excess in the dimuon invariant mass.

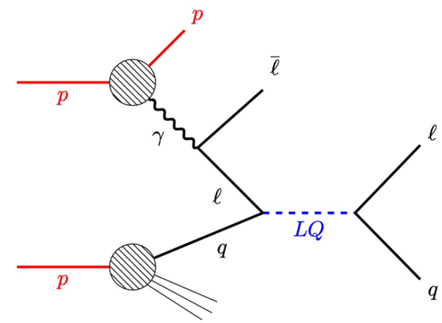
Most stringent limits at low masses and large displacement

CMS-PAS-EXO-24-016

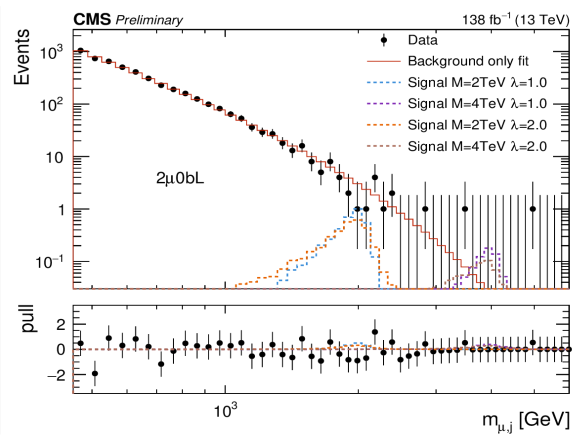


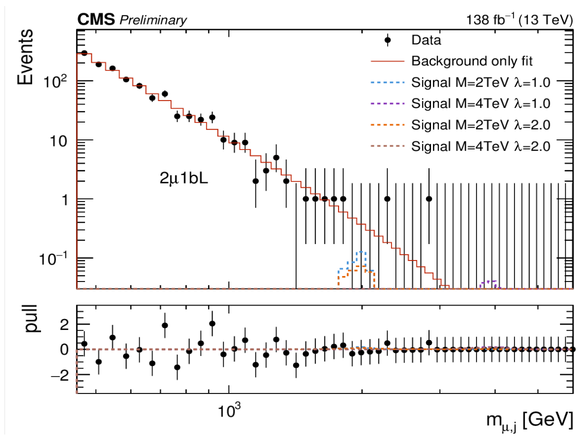
Scalar for lepto-quark (LQ) via muon-quark scattering

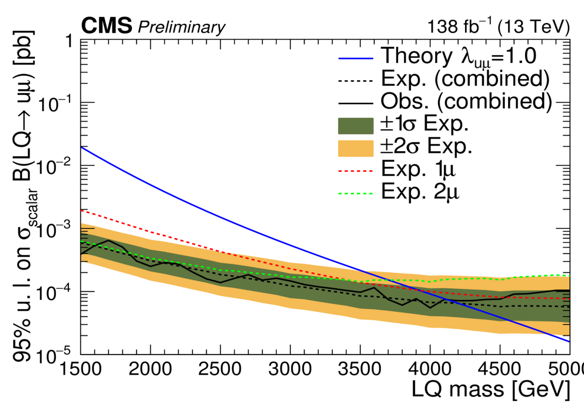
- LQs are foreseen in many BSM models: GUT, SUSY, RPV, etc
- 1st (eq), 2nd (μq), 3rd (τq) generation of LQs
- In LHC LQs can be produced in different modes, however, here we considered lepton induced production
- Final state: High P_T lepton and a jet from LQ, with a second same flavor lepton from photon
- light-quark mass: 1.5-3.6TeV, λ: 0.2-0.6 excluded
- b-quark mass: >1.8 TeV, λ: >1 excluded

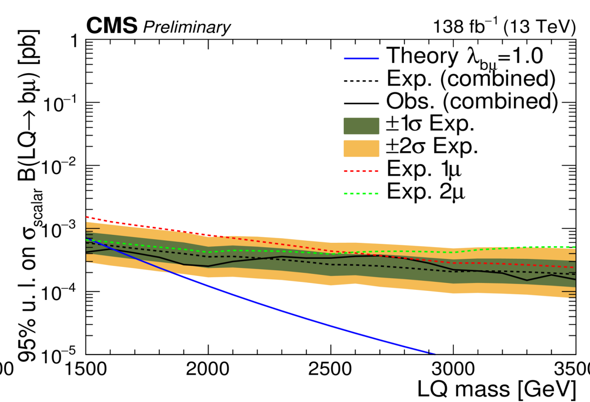


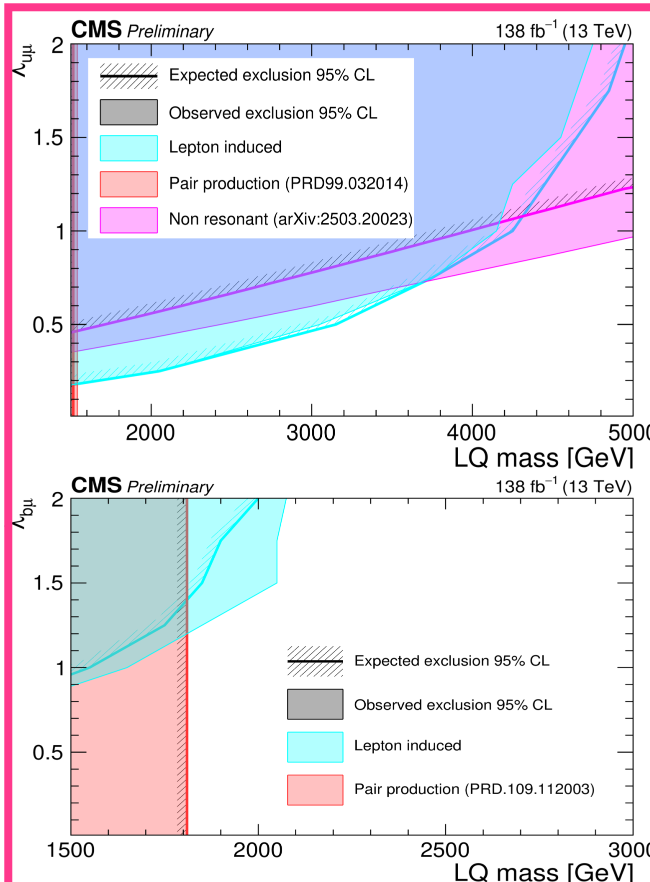
CMS-PAS-EXO-24-005











Search for Microscopic BH and Sphalerons

✓ Extra dimensions theory provides solutions to Hierarchy problems

-> Predicts microscopic Blackholes $M_{pl}^2 \sim M_D^{n+2} R^n$ *R* is size of each extra dimensions

When n is large M_D ~ TeV (within reach of LHC) -> decay to high multiplicity jets and leptons

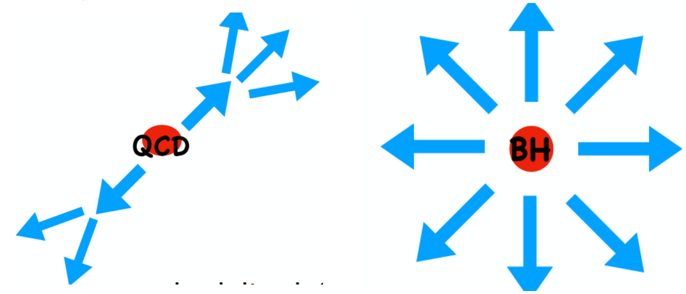
✓ Sphaleron gives solutions to baryon asymmetry by B and L violation

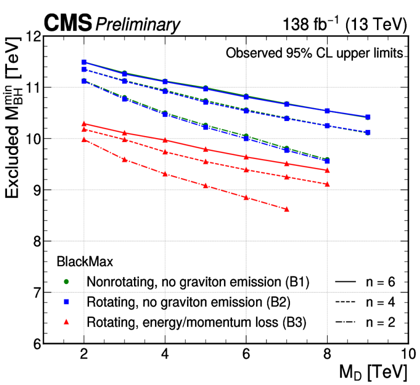
- Decay to 12 fermions, either all matter or all anti-matter
- One lepton from each generation, three quarks from each generation

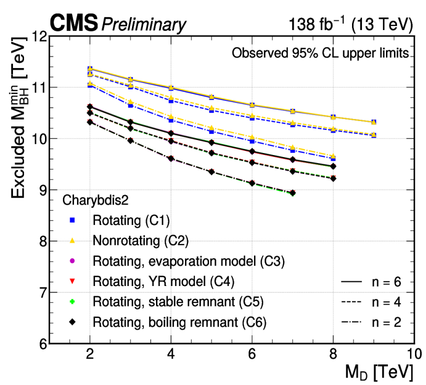
l1q1q1q1 l2q2q2q2 l3q3q3q3, e.g. e uud μ ccs τ ttb

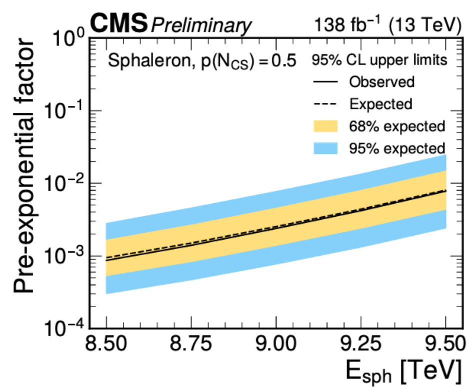
✓ The most important variable to look $S_T = \left(\sum_{i=1}^{N} p_{T,i}\right) + p_T^{miss}$

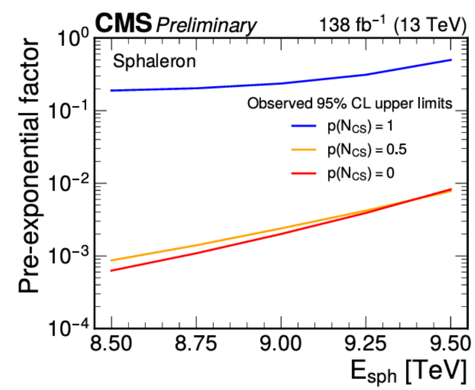
✓ Also look for sphericity of the event:









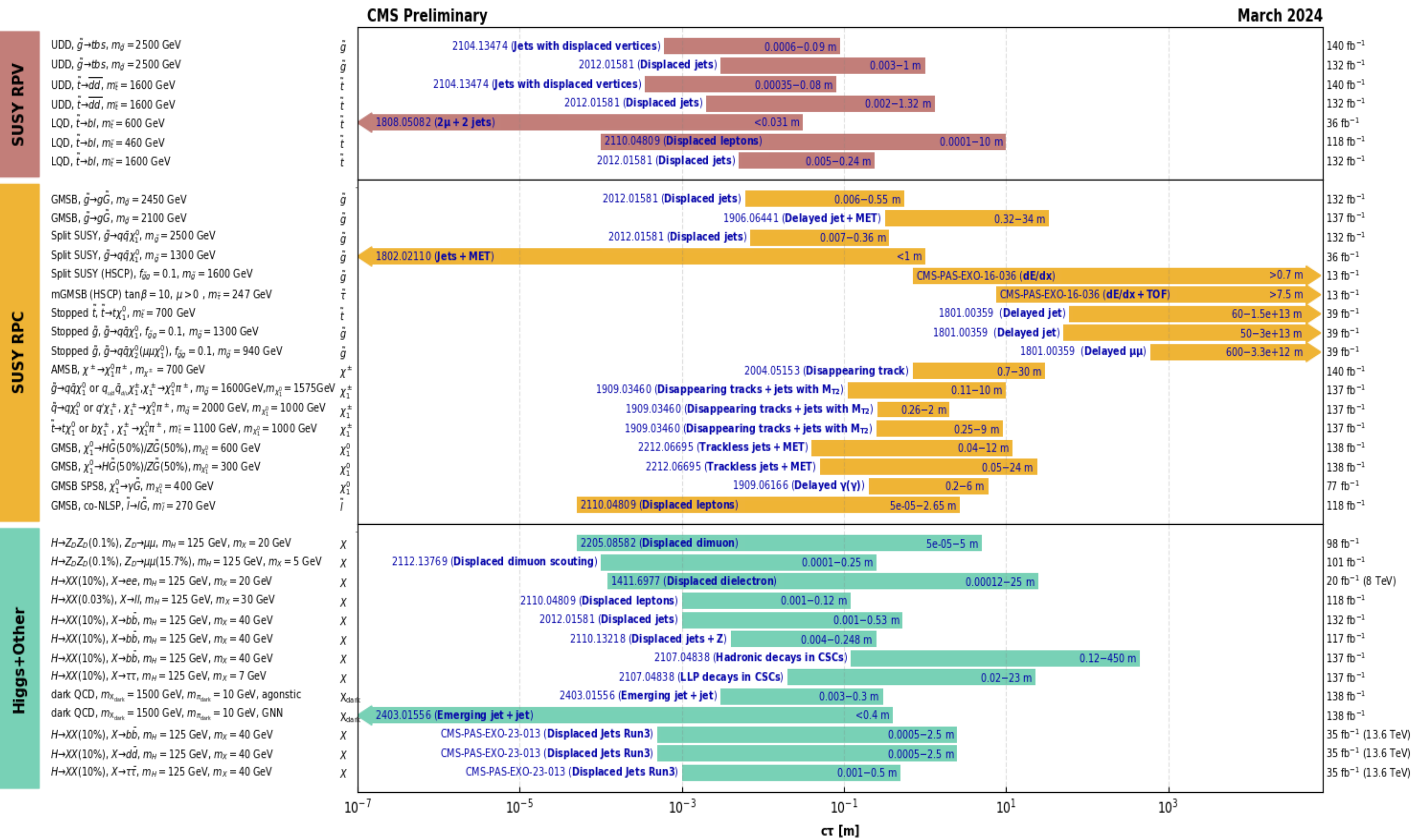


✓ No excess seen over the background expectation

✓ Excludes blackholes with masses below 9-11.4 TeV

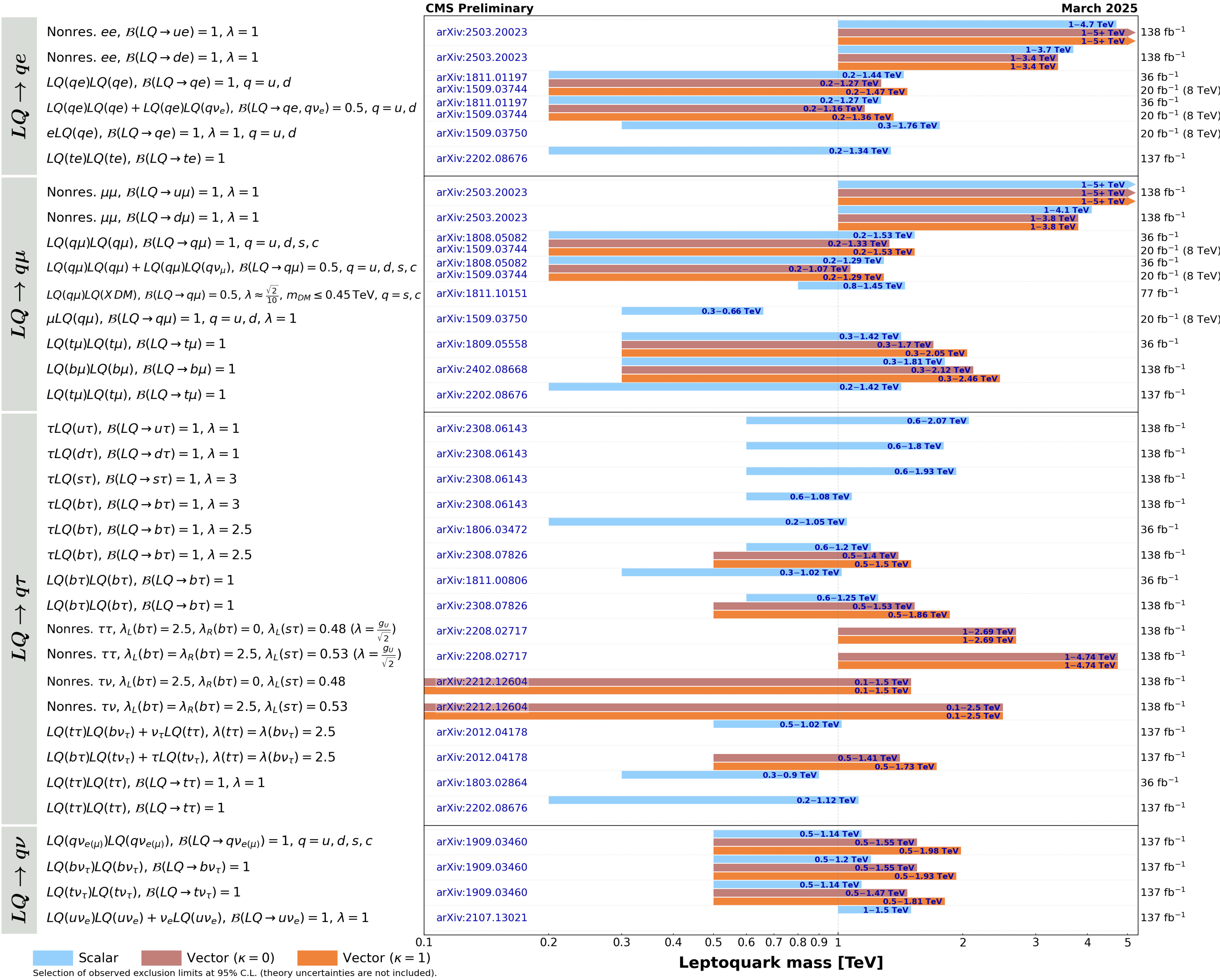
CMS-PAS-EXO-24-028

LLP search summary from CMS

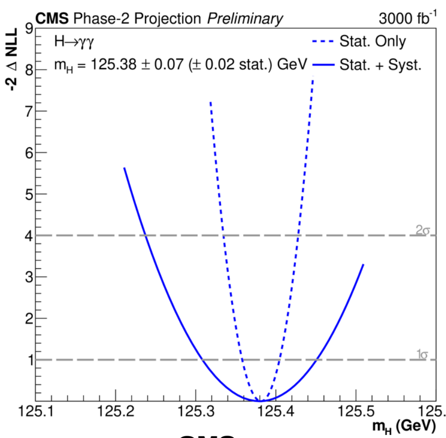


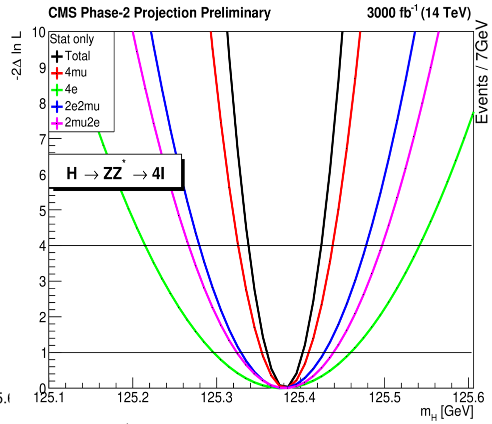
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

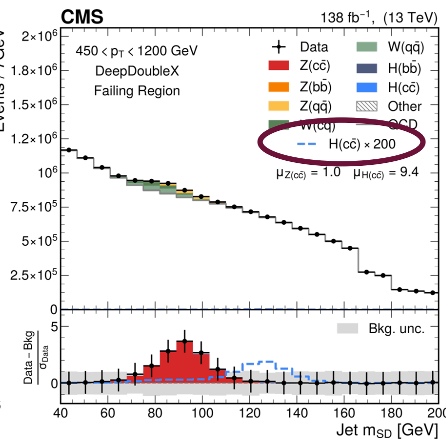
LQ search summary from CMS

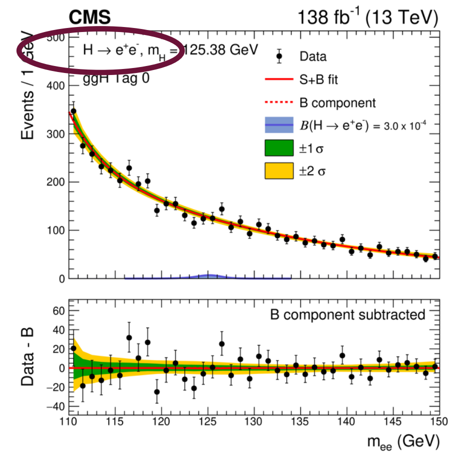


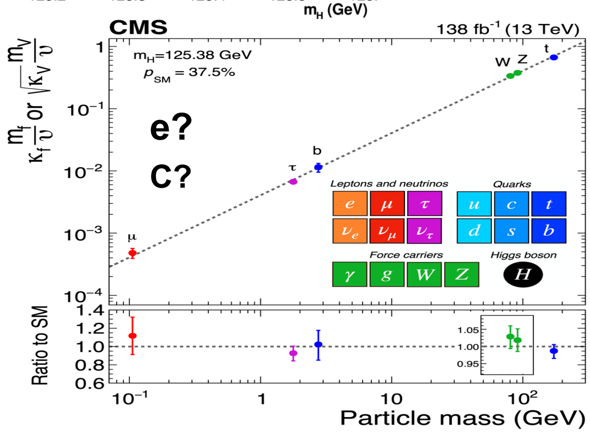
SM measurements with HL-LHC (3 ab^{-1})



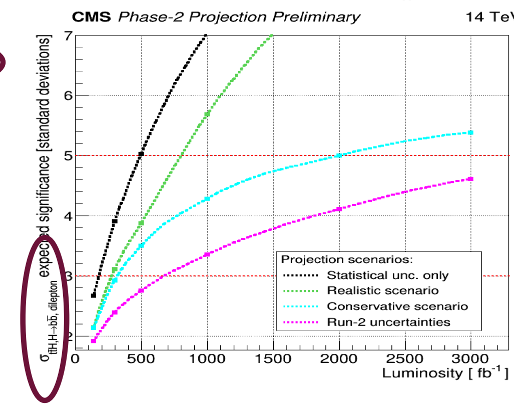


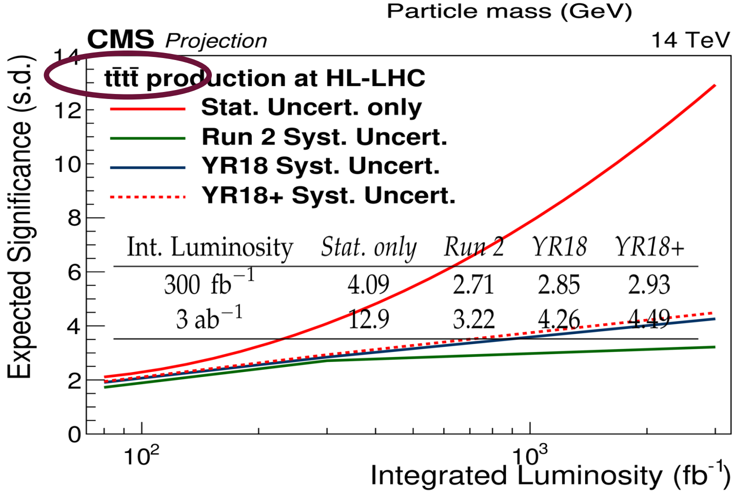


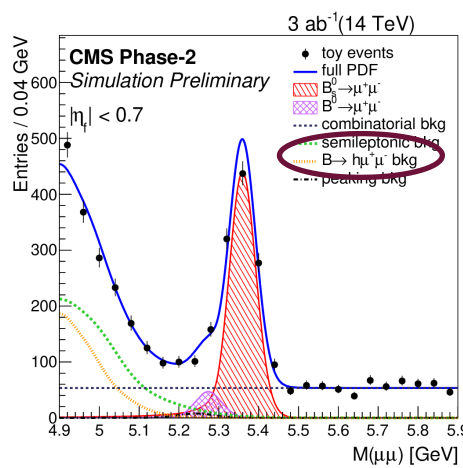


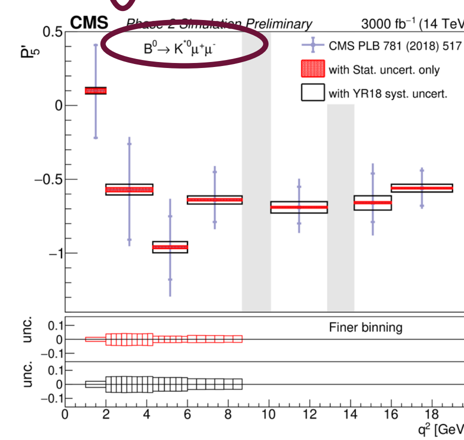


Channel	Significance Stat. + syst.	Significance Stat. only	95% CL limit on $\sigma_{HH}/\sigma_{HH}^{SM}$ Stat. + syst.	95% CL limit on $\sigma_{HH}/\sigma_{HH}^{SM}$ Stat. only
bbbb	0.95	1.2	2.1	1.6
$bb\tau\tau$	1.4	1.6	1.4	1.3
$bbWW(\ell\nu\ell\nu)$	0.56	0.59	3.5	3.3
$bb\gamma\gamma$	1.8	1.8	1.1	1.1
$bbZZ(\ell\ell\ell\ell)$	0.37	0.37	6.6	6.5
Combination	2.6	2.8	0.77	0.71

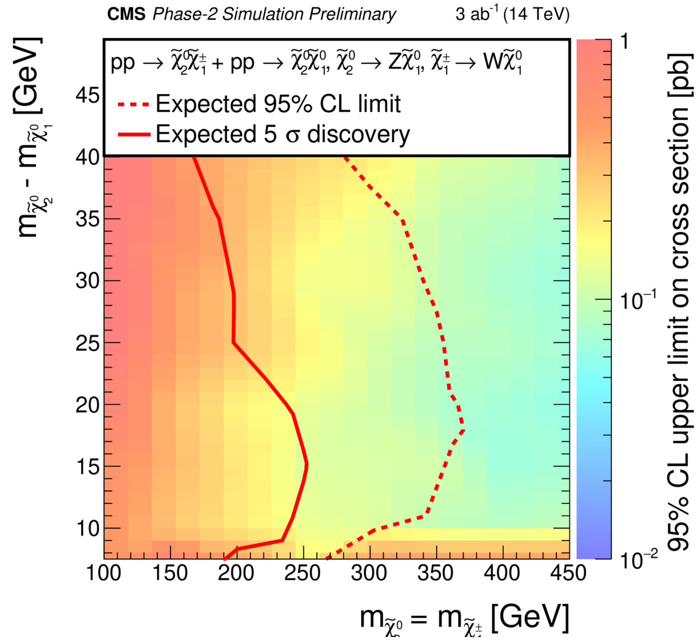


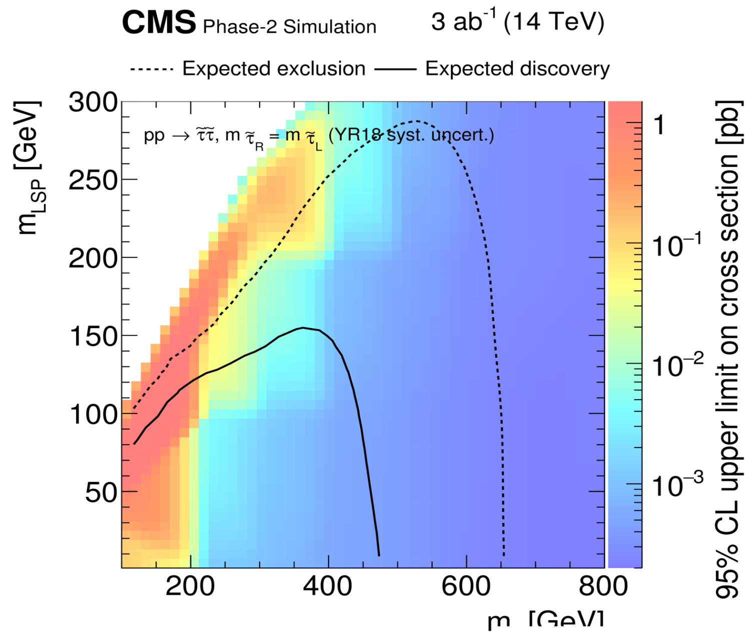


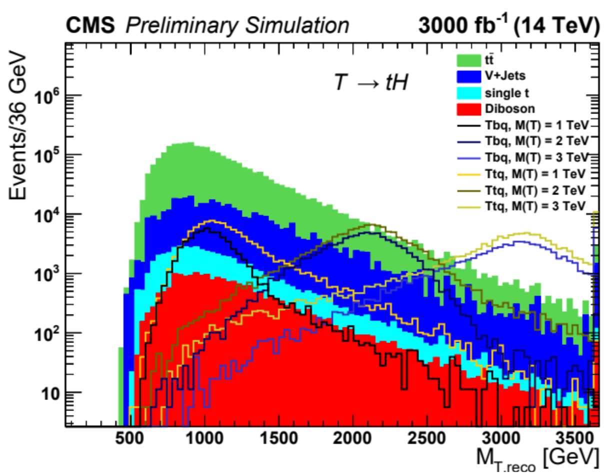


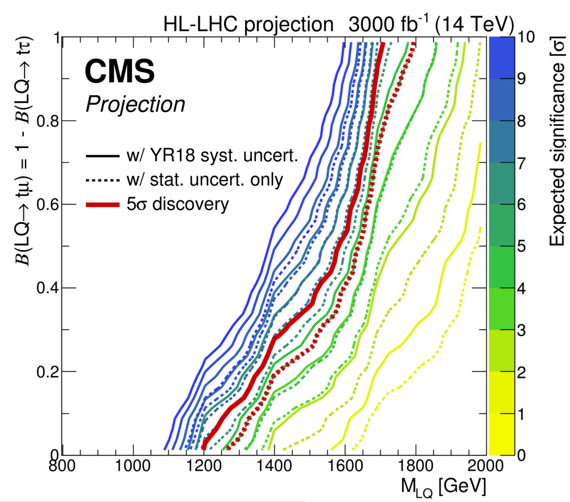


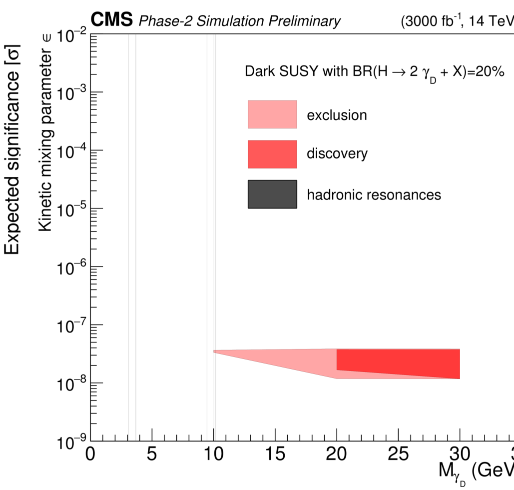
BSM measurements with HL-LHC (3 ab^{-1})

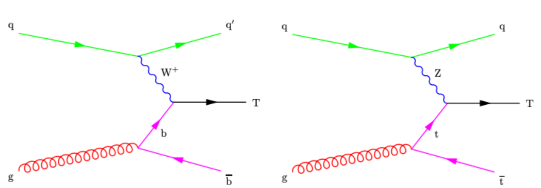












Mass (GeV)	Expected cross section upper limit (fb)	
	Tbq (LH)	Ttq (RH)
1000	85.9	54.7
1500	28.4	20.3
2000	12.8	9.06
2500	7.20	4.64
3000	4.69	4.69

Summary

- LHC has provided greater insight and understanding of Standard Model of Particle Physics.
- We re-established several SM predictions in top, b-flavor W/Z, flavor sector, etc, with greater precision.
- Higgs discovery (and measurement of its properties) is a tremendous success of LHC.
- No BSM found till date.
- The future plan for LHC is to run with more intense beam (~5 x instantaneous luminosity)
- This HL-LHC condition (with higher beam intensity and center-of-mass energy) will provides us with better physics potential for further precision tests in all SM sector and BSM searches.
- However, the HL-LHC beam intensity will create harsher environment for our detectors.
- Major upgrades for CMS featuring finer granularity, new technologies and new capabilities, is planned during 2026-2030.
- Eventually, we will have ~3000 fb^{-1} data (x 6-7 what we have now) to be collected by 2040.
- Look forward to wonderful years ahead with HL-LHC.

Thank you for listening !

Standard model lagrangian

$$\mathcal{L} = \binom{\text{Kinetic terms of}}{\text{gauge bosons}} + \binom{\text{Kinetic term}}{\text{of Higgs}} + \binom{\text{Kinetic terms}}{\text{of fermions}} + \binom{\text{Yukawa}}{\text{terms}} - \binom{\text{Higgs}}{\text{potential}}$$

$$= \underbrace{\frac{1}{2}\left(\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu}) + \mathrm{Tr}(W_{\mu\nu}W^{\mu\nu}) + B_{\mu\nu}B^{\mu\nu}\right)}_{\text{Kinetic terms of gauge bosons}} + \underbrace{\frac{1}{2}|D_\mu \phi|^2}_{\text{Kinetic term of Higgs}}$$

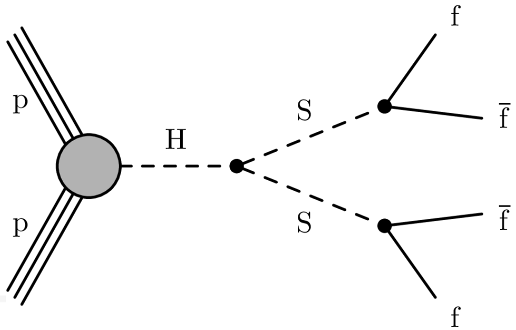
$$+ \underbrace{i\bar{l}_L \not{D} l_L + i\bar{l}_R \not{D} l_R + i\bar{q}^a_L \not{D} q_{La} + i\bar{u}^a_R \not{D} u_{Ra} + i\bar{d}^a_R \not{D} d_{Ra}}_{\text{Kinetic terms of fermions}}$$

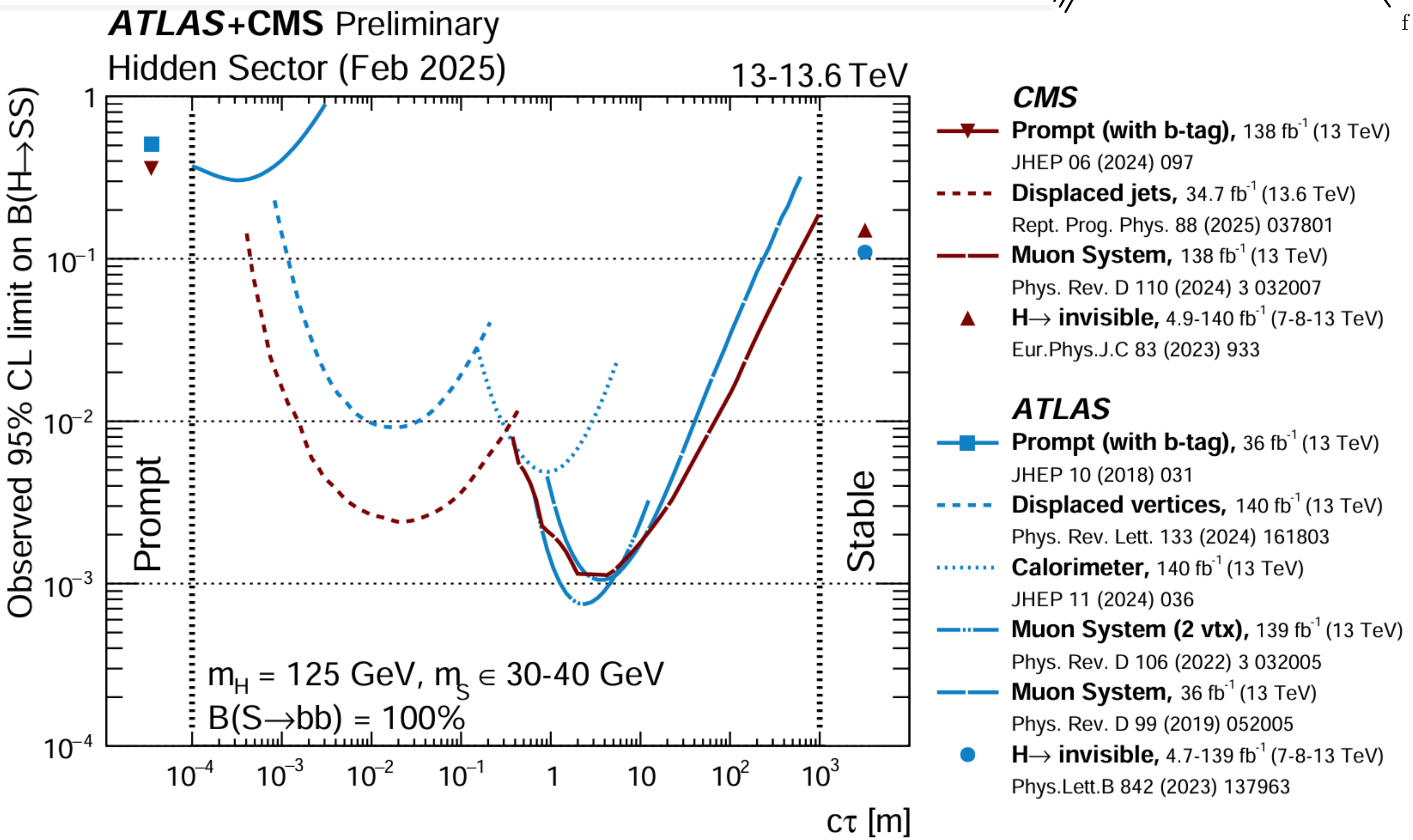
$$+ \underbrace{\left(y_d \bar{q}^a_L \phi d_{Ra} + y_u \bar{q}^a_L \tilde{\phi} u_{Ra} + y_l \bar{l}^a_L \phi l_{Ra} + \text{ conjugate}\right)}_{\text{Yukawa terms}} - \underbrace{V(\phi)}_{\text{Higgs potential}}$$

y_d, y_u, and y_l are coupling constants

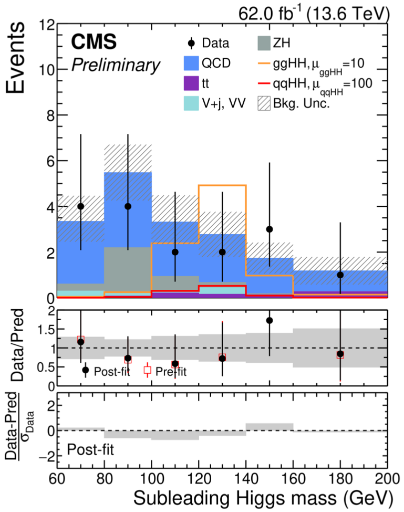
Low mass LLP via di-jet final state

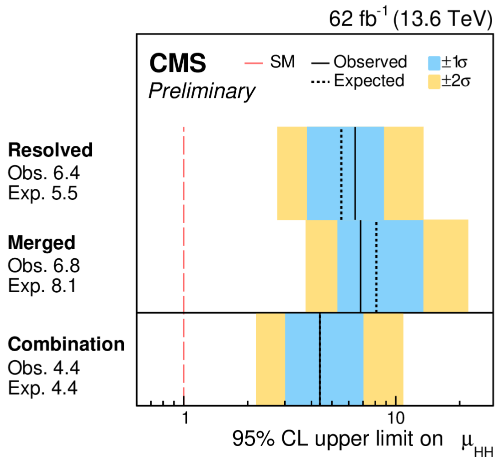
- Decay of 125 GeV Higgs (H) to two long lived neutral scalars(S) -> pair of SM fermions (quark pairs or tau lepton pairs)
- Look for di-jets with displaced vertex, reconstructed using the displaced trackers associated with jets

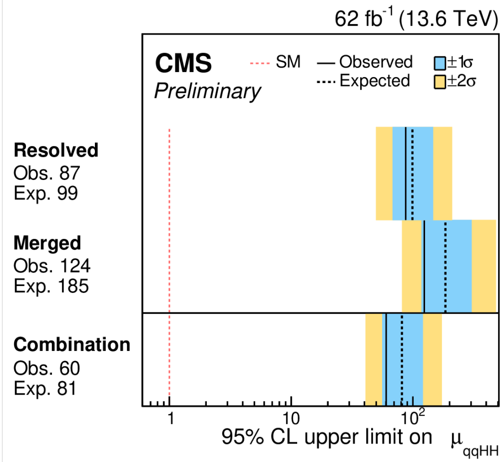


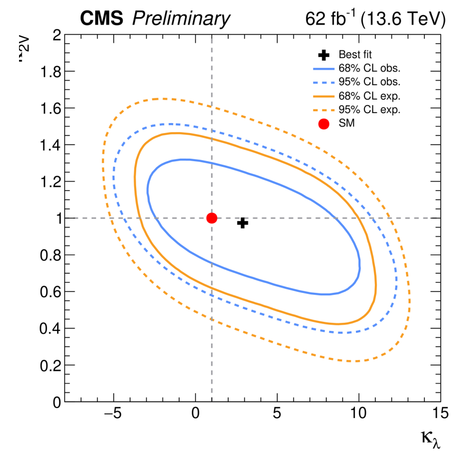


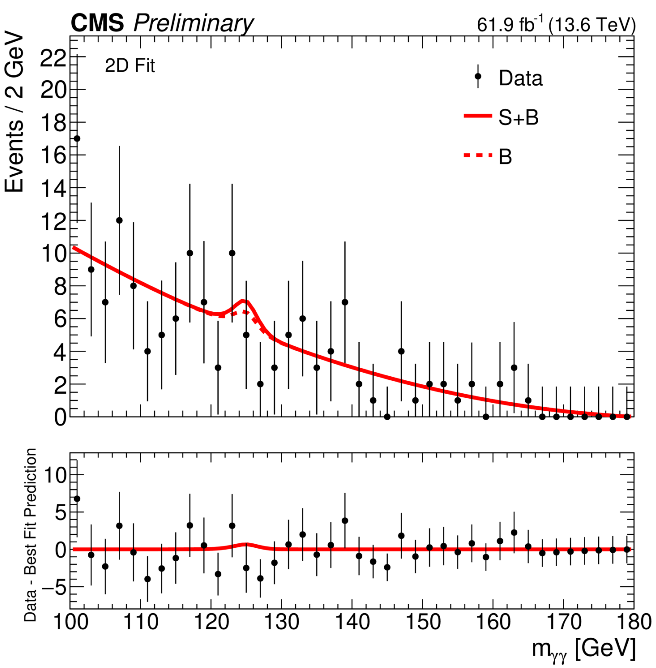
Di-Higgs (HH) to 4b/bbγγ

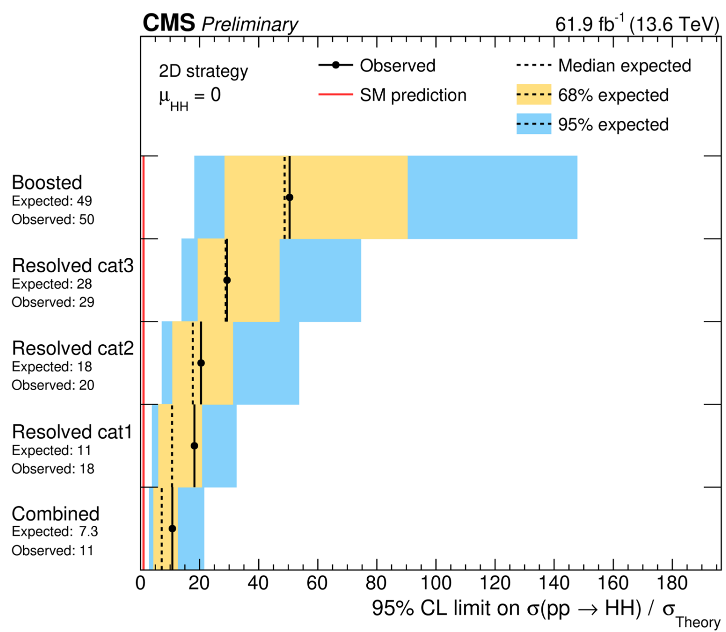


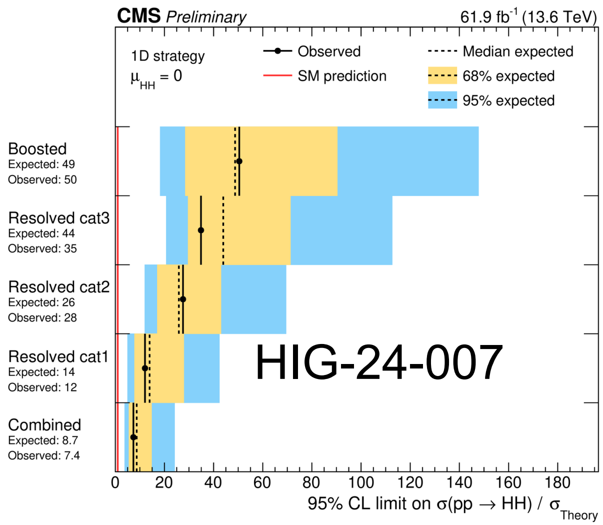


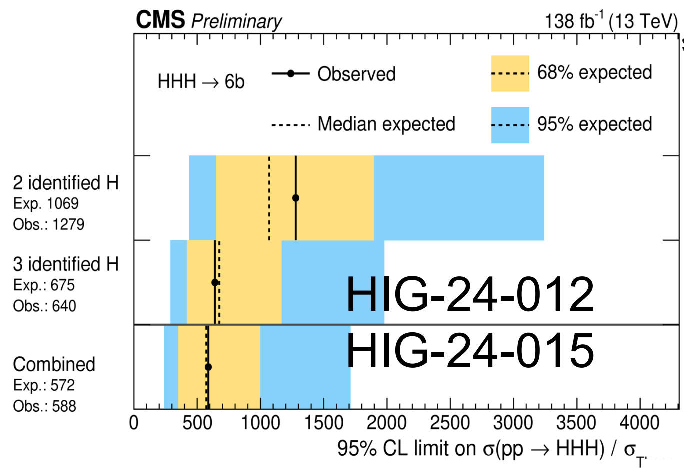


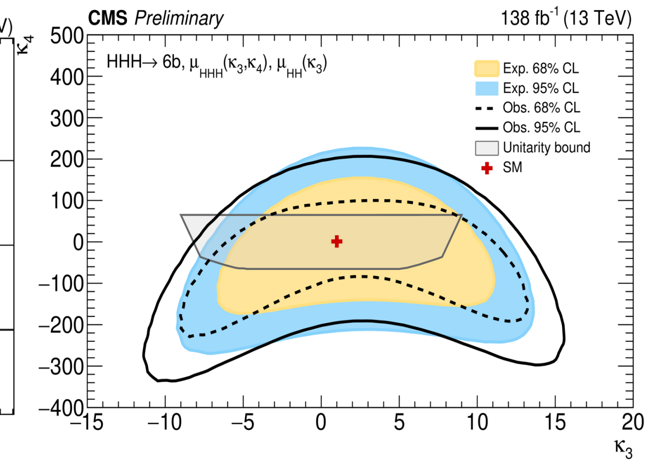




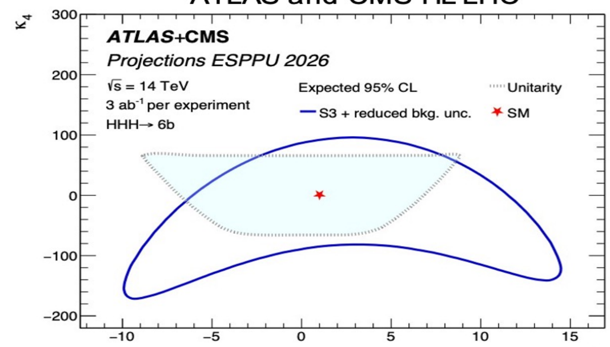


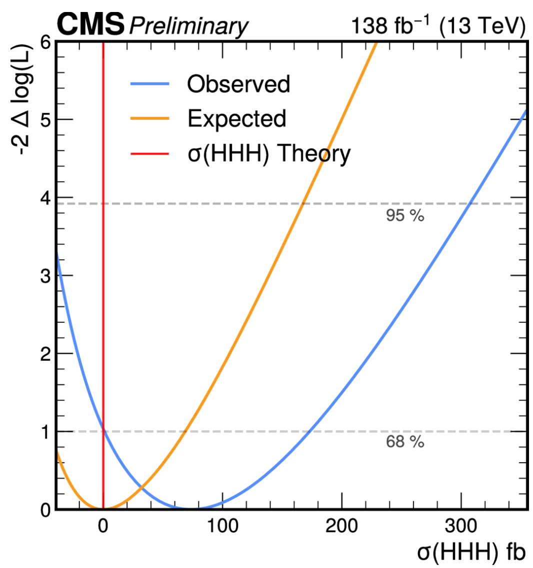


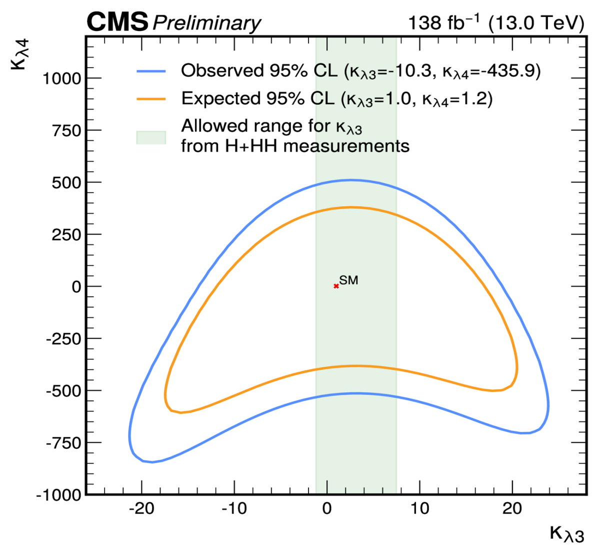




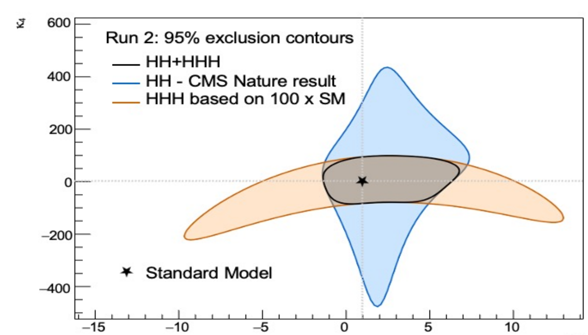
ATLAS and CMS HL-LHC







Run 3 goals:
Combined HH and HHH measurement



B-physics expectations with HL-LHC

Experiment Assumed data sample	**ATLAS** 20.3-99.7 fb^{-1}	**CMS** 116-140 fb^{-1}	**LHCb** 2-9 fb^{-1}	**Belle II** 364-1075 fb^{-1}
Leptonic B decays				
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ $[10^{-9}]$	$^{+0.8}_{-0.7}$ [none-none-none]	0.45 [none-none-none]	0.48 [none-none-none-none]	—
$\mathcal{B}(B^0 \to \mu^+\mu^-)$ $[10^{-10}]$	$< 2.1^*$ [none-none-none]	< 1.5 [none-none-none]	0.79 [none-none-none-none]	—
$\tau_{\text{eff}}(B_s^0 \to \mu^+\mu^-)$ [ps]	$^{+0.45}_{-0.18}$ [none-none-none]	0.23 [none-none-none]	0.29 [none-none-none-none]	—
Flavour-changing neutral current $b \to s\ell\ell$ decays				
$P_5'(B^0 \to K^{*0}\mu^+\mu^-)$ $[10^{-3}]$ †	390 [none-none-none]	100 [none-none-none]	111 [none-none-none-none]	—
Lepton flavour violation in τ decays				
$\mathcal{B}(\tau^+ \to \mu^+\gamma)$ $[10^{-8}]$	—	—	—	< 7.5 [none-none]
$\mathcal{B}(\tau^+ \to \mu^+\mu^+\mu^-)$ $[10^{-8}]$	< 37.6 [none-none-none]	< 2.9 [none-none-none]	< 4.6 [none-none-none-none]	< 1.8 [none-none]

† The sensitivity for the P_5' variable is quoted for the range $q^2 \in [4.0, 6.0]$ GeV^2 for ATLAS and LHCb and $q^2 \in [4.3, 6.0]$ GeV^2 for CMS.

Experiment Assumed data sample	**ATLAS** 3000 fb^{-1}	**CMS** 3000 fb^{-1}	**LHCb** 300 fb^{-1}	**Belle II** 50 ab^{-1}
Leptonic B decays				
$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ $[10^{-9}]$	$(0.33 - 0.40)$	0.22	0.16	—
$\mathcal{B}(B^0 \to \mu^+\mu^-)$ $[10^{-10}]$	$(0.32 - 0.48)$	0.12	0.12	—
$\tau_{\text{eff}}(B_s^0 \to \mu^+\mu^-)$ [ps]	$^{+(0.07-0.11)}_{-(0.05-0.08)}$	0.05	0.05	—
Flavour-changing neutral current $b \to s\ell\ell$ decays				
$P_5'(B^0 \to K^{*0}\mu^+\mu^-)$ $[10^{-3}]$ †	$(47 - 82)$	23	12	—
Lepton flavour violation in τ decays				
$\mathcal{B}(\tau^+ \to \mu^+\gamma)$ $[10^{-8}]$	—	—	—	< 0.7
$\mathcal{B}(\tau^+ \to \mu^+\mu^+\mu^-)$ $[10^{-8}]$	$< (0.13 - 0.64)$	< 0.39	< 0.26	$< (0.02 - 0.17)$

† The sensitivity for the P_5' variable is quoted for the range $q^2 \in [4.0, 6.0]$ GeV^2 for ATLAS and LHCb and $q^2 \in [4.3, 6.0]$ GeV^2 for CMS.