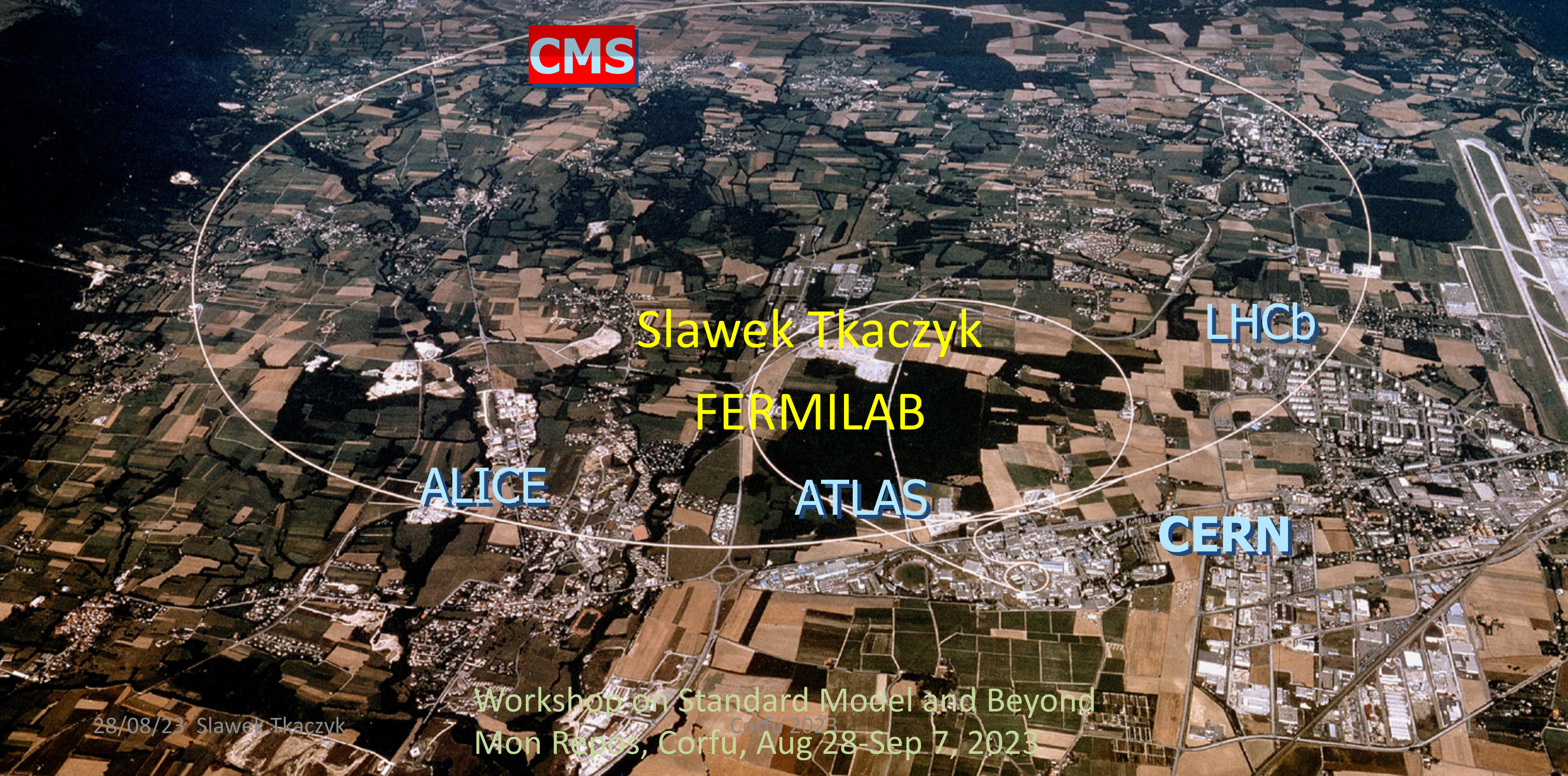
Corfu Summer Institute

Hellenic School and Workshops on Elementary Particle Physics and Gravity

Corfu, Greece

CMS Physics Results in the LHC Runs 2,3



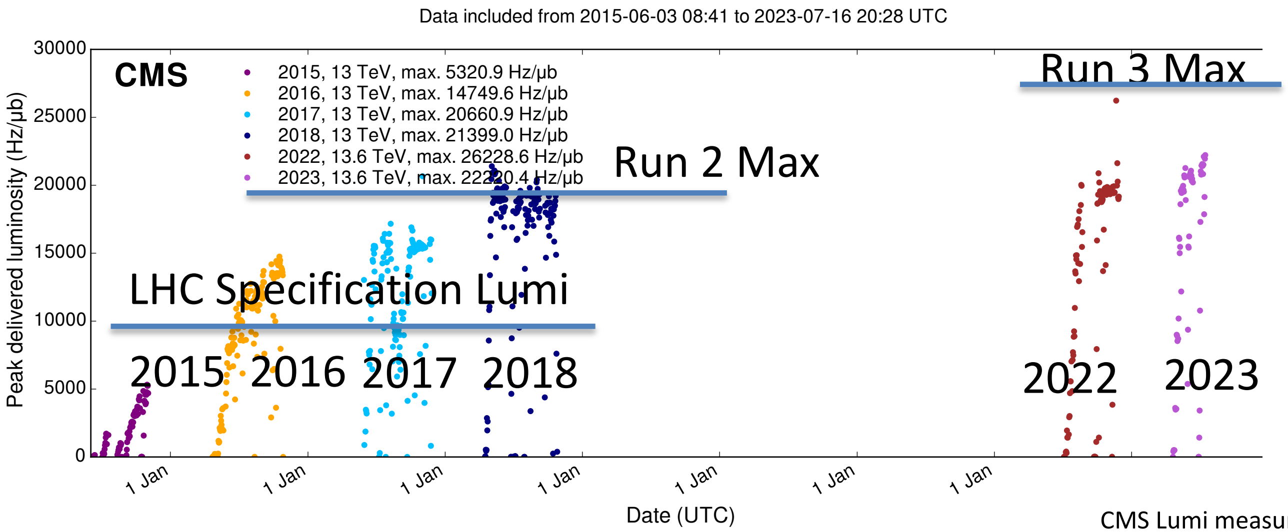
Slawek Tkaczyk

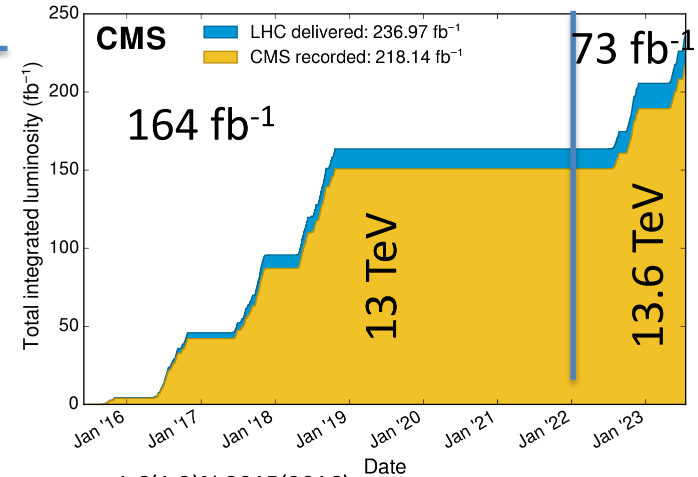
FERMILAB

Workshop on Standard Model and Beyond

Mon Repos, Corfu, Aug 28-Sep 7, 2023

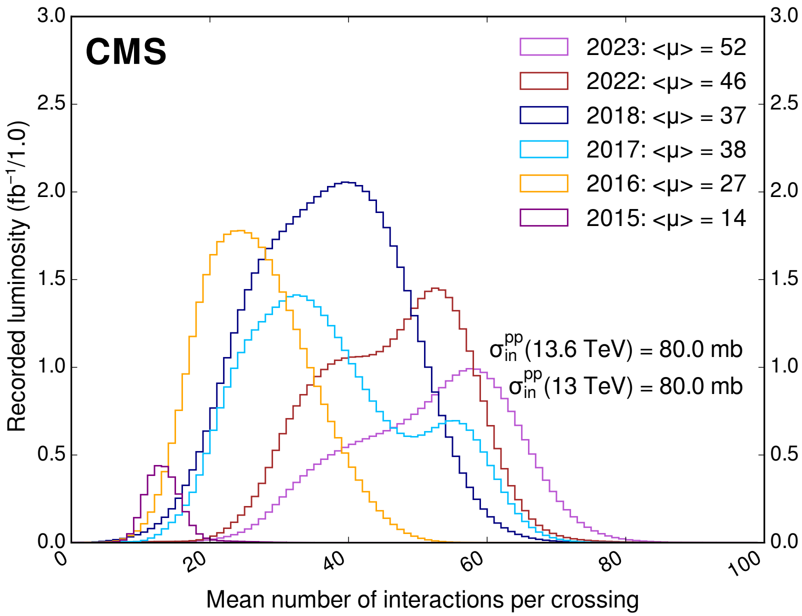
LHC in Run 2,3 (2015-2023)
Highest Energy and Luminosity



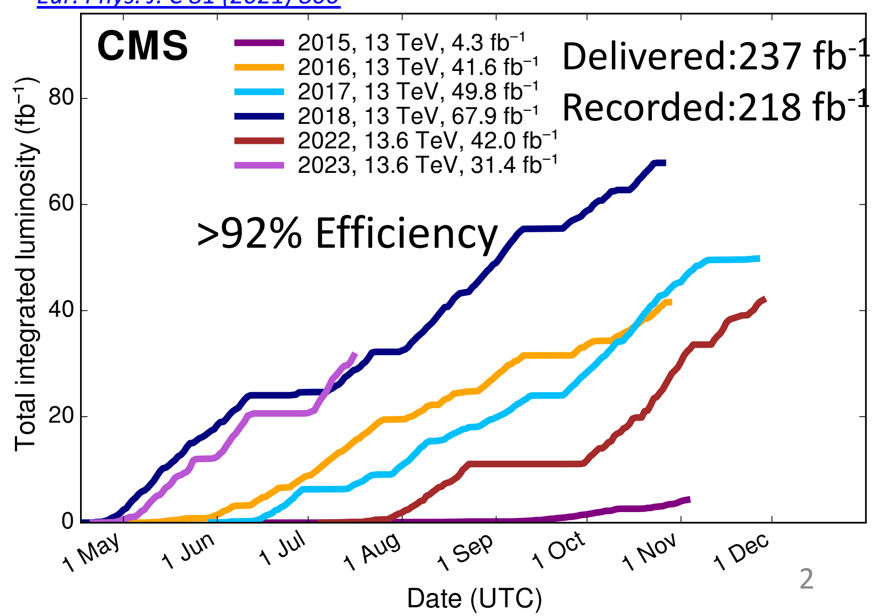


CMS Lumi measurements: 1.6(1.2)% 2015(2016)

Eur. Phys. J. C 81 (2021) 800

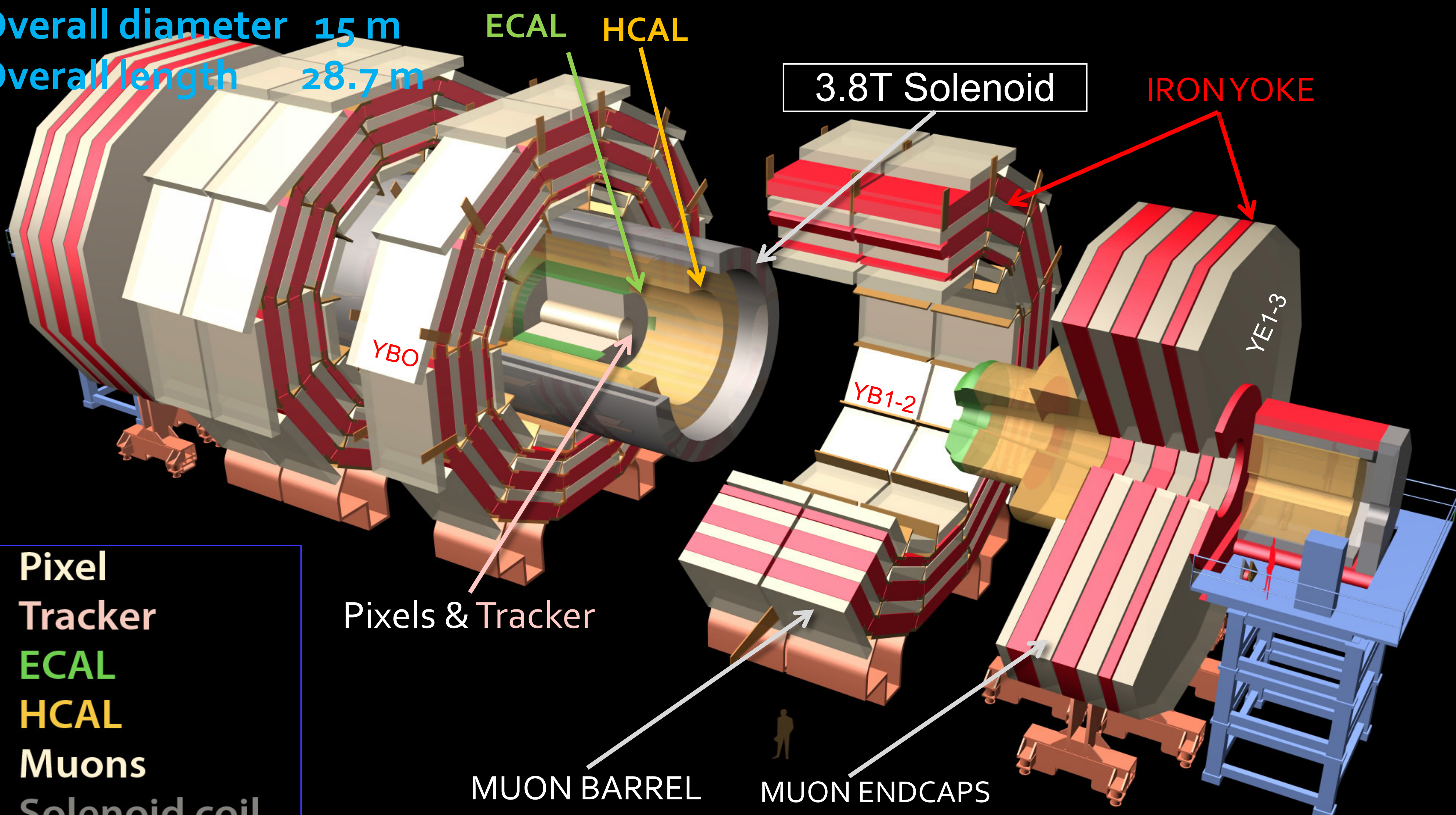


Focus on pp, but…
~150pb^{-1} of **PbPb,pPb**



CMS Detector

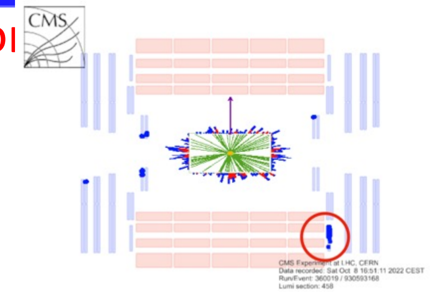
Total weight 14000 t
Overall diameter 15 m
Overall length 28.7 m

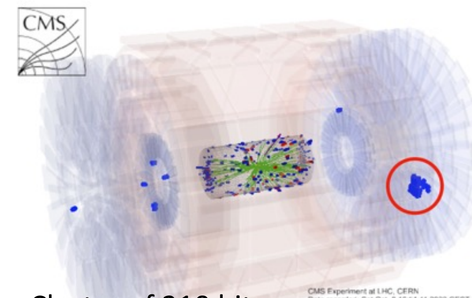


Pixel
Tracker
ECAL
HCAL
Muons
Solenoid coil

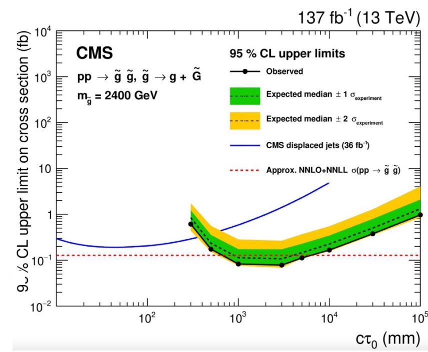
CMS Add-on's for Run 3

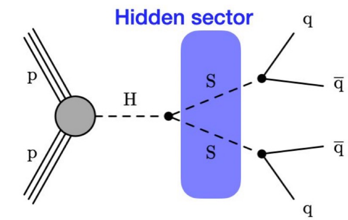
- Many new physics searches enabled by add-o
- Typical Data Rates: 40MHz (pp collisions) → 100kHz (after L1Trigger)→1kHz (tape)
- 1kHz full event size recording limit exceeded:
  - **Data Parking** – events written but offline reconstruction delayed
  - **Data Scouting** – Trigger objects (few kB) read out independent of trigger decisions
- Novel experimental techniques introduced for Run 3
  - Machine learning techniques including DNN
  - High Multiplicity Trigger (HMT) identifying clusters of hits in CSC muons detector
  - New ECAL and HCAL timing triggers for **delayed** and **displaced** LongLivedParticle (**LLP**) jets
- Recent trigger developments included in Run 3 data taking enabled to probe more complex or well motivated models
  - Demonstrators already implemented during Run2 data taking e.g.: PhysRevD.104.012015

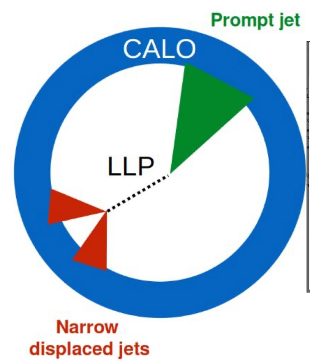


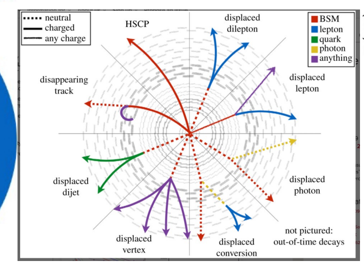


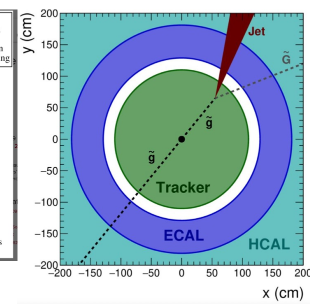
Cluster of 210 hits reconstructed in ME1/3 chamber



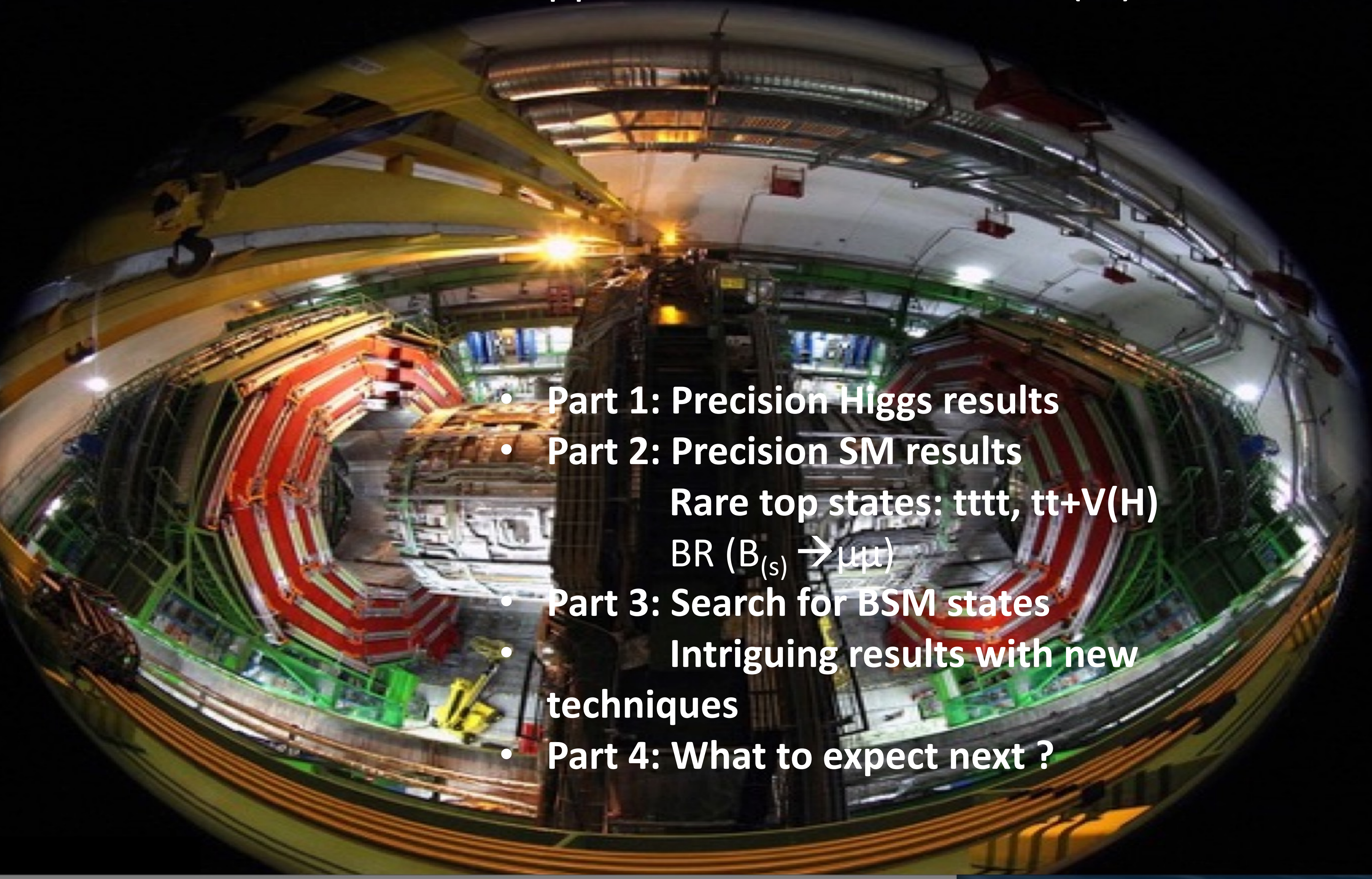








What has CMS seen in the pp Run 2,3 collisions at 13(.6)TeV?



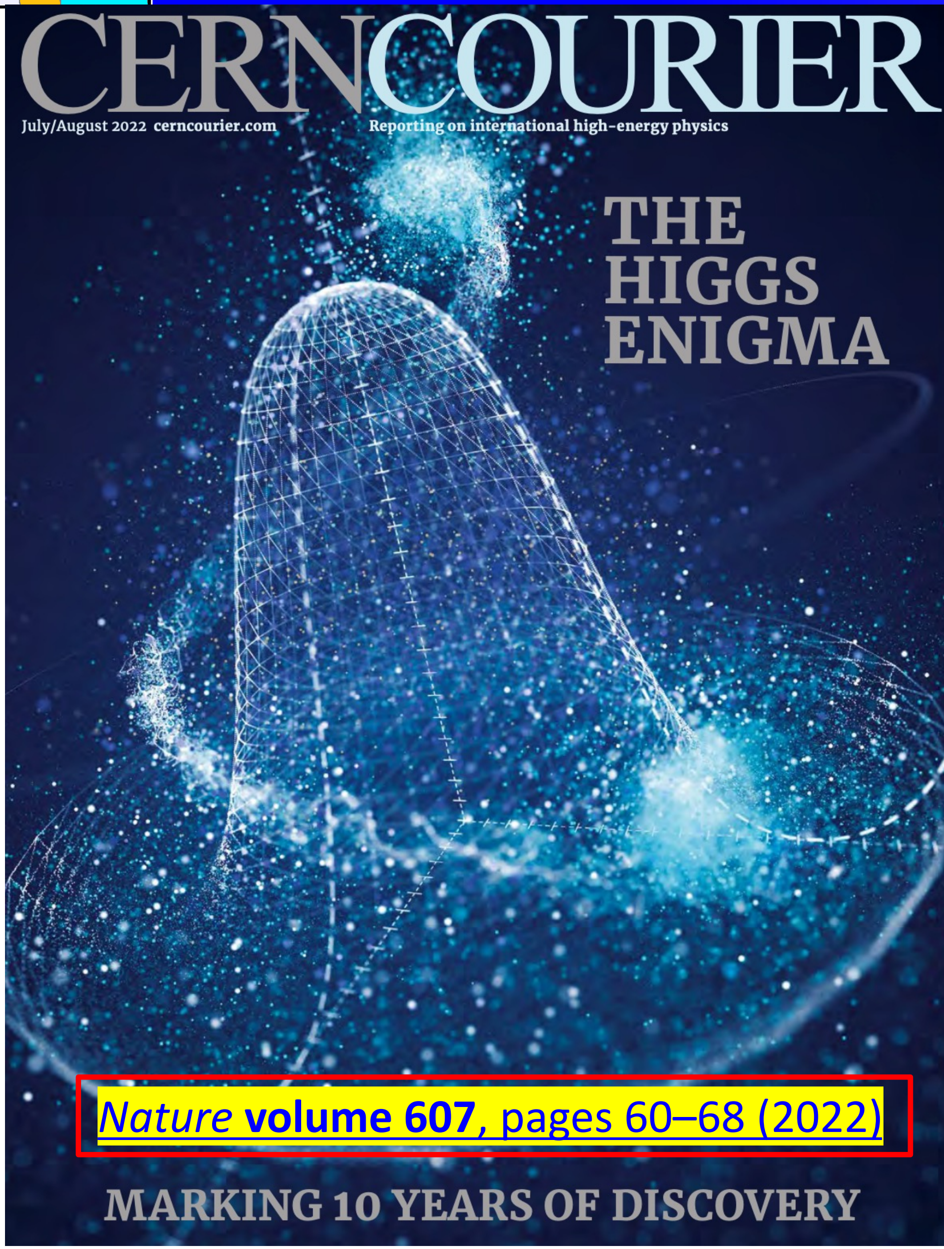
- **Part 1: Precision Higgs results**
- **Part 2: Precision SM results**
  - **Rare top states: tttt, tt+V(H)**
  - BR ($B_{(s)} \rightarrow \mu\mu$)
- **Part 3: Search for BSM states**
  - **Intriguing results with new techniques**
- **Part 4: What to expect next ?**

CMS Measurements from Run 2,3

- Many **new, rare** or **precision** measurements enabled with large Run 2, 3 data sets already collected

- Experimental precision challenges theoretical accuracy
  - M_W, M_{top}, other

Higgs Program



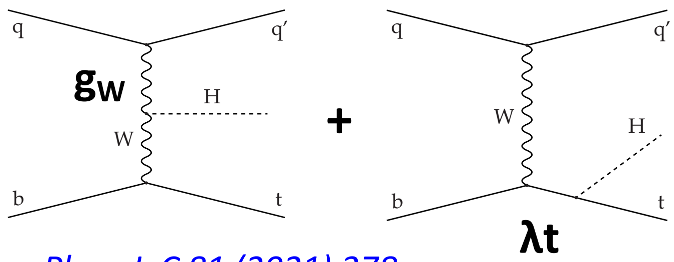
Nature **volume 607**, pages 60–68 (2022)

- Differential cross sections
- Rare decays or not allowed in SM: LFV H→τe/μe/τμ
- Couplings to vector bosons, quarks and leptons and ttH (H→bb/ττ/γγ)
- HH resonance studies (bb + bb/γγ/ττ)
- Decays to non-SM particles: H→*invisible* or light pseudo- or scalar-particles

Only a couple of newest results shown ; See Reiner Mankel's review of the Higgs in the morning session ;

Higgs Coupling to Top in Run 2

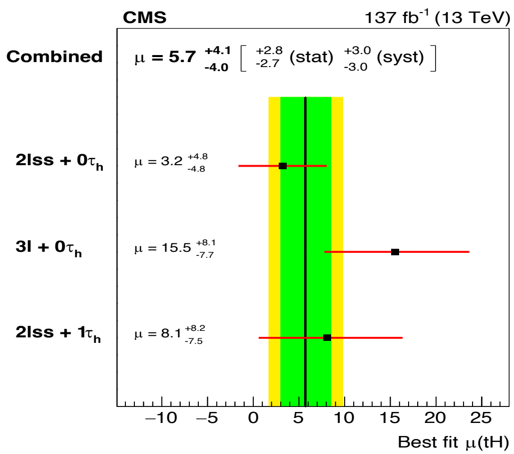
ttH - a direct probe to Top Yukawa **λt** cplg while **tH** - a unique channel to study the relative sign of couplings while

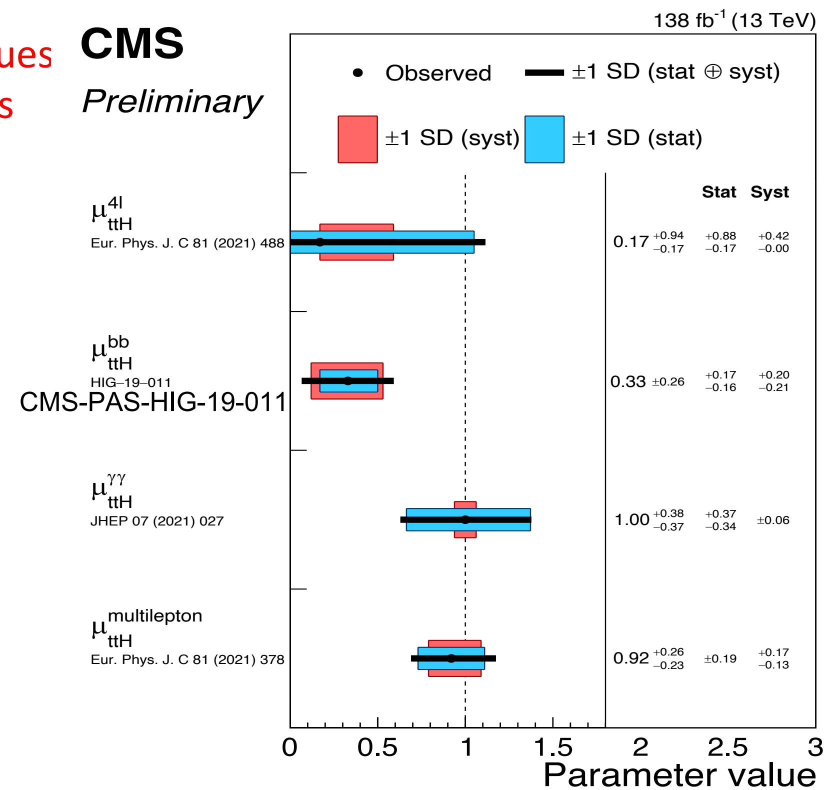


Constructive interference when **λt** and **g_W** have opposite sign → large increase in x-section

- tHV + tHq + ttH with tt decays to multi-ℓ or all-jet final states
- H→WW*,ZZ*,ττ, bb – channels in 10 signatures depending on lepton multiplicity
- MVA, ML and ME techniques to separate ttV and tt+jets backgrounds from signals

[*Eur. Phys. J. C 81 (2021) 378*]





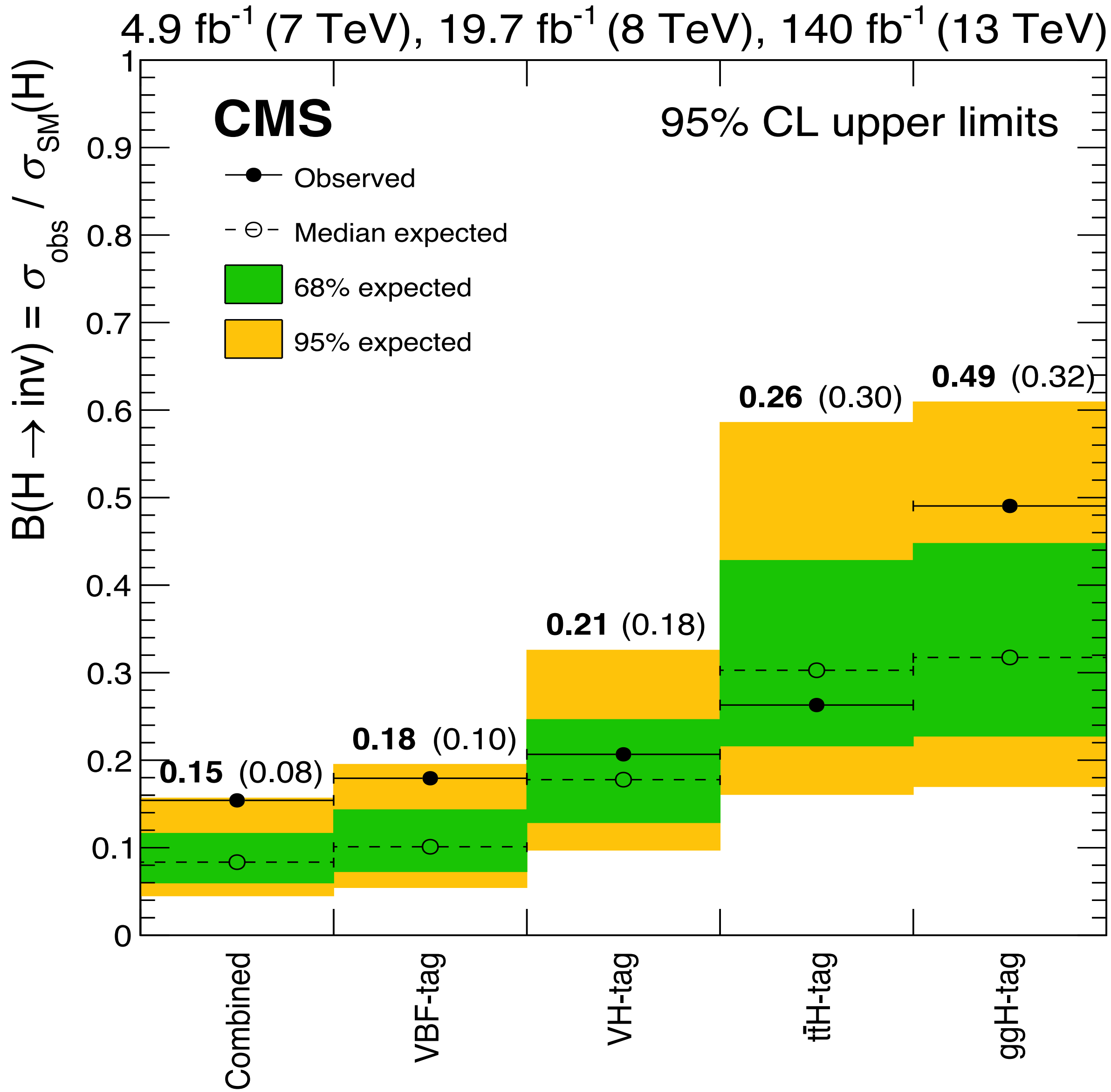
Significance for **tH** with M_h=125 GeV:
Observed: **1.4 σ** Expected: **0.3 σ**

Significance for ttH with M_h=125 GeV:
Observed: **4.7 σ** Expected: 5.2 σ

Higgs Width to Invisible Run 2

CMS-HIG-21-007
sub. Eur. Phys.J.C.
March 2023

Run 1 & 2 combination



No significant excess
of events above the SM

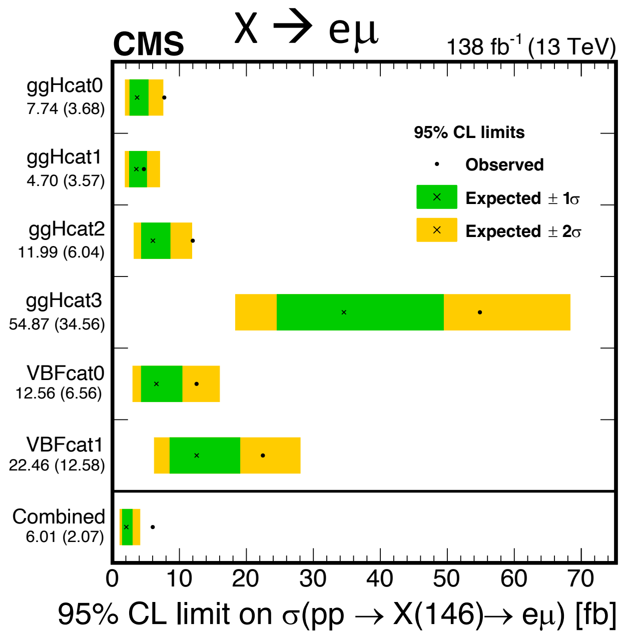
LFV Higgs Decays Run 2

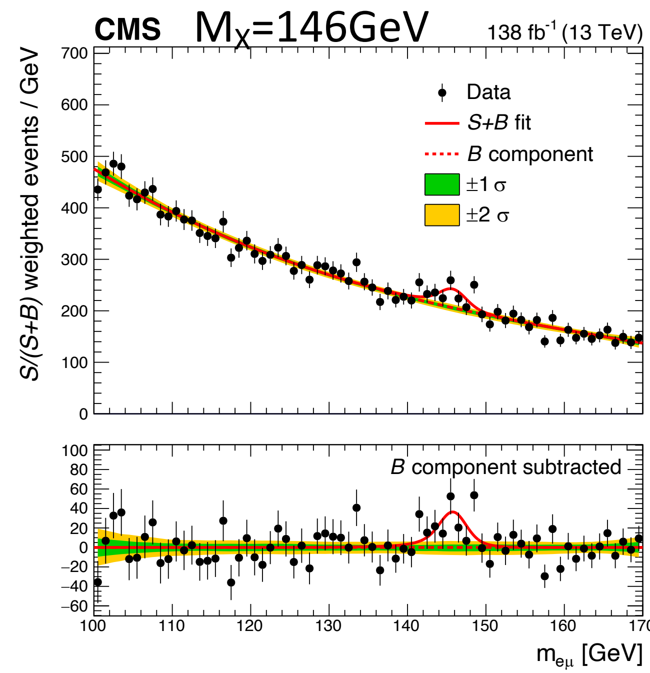
arxiv:2305.18106

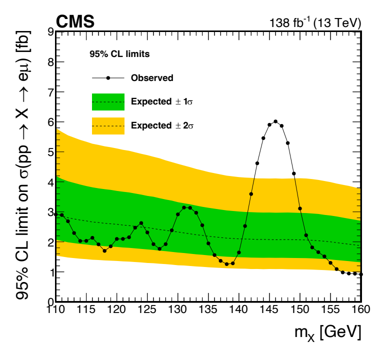
HIG-22-002

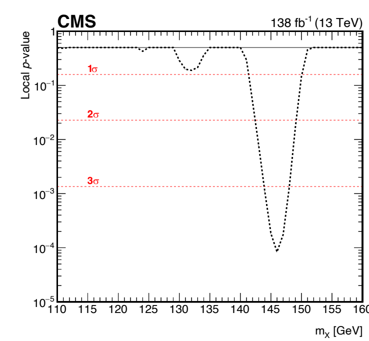
Production of X in the mass range 110-160GeV

- Select one eμ OS pair
- b-jet veto
- VBF and ggF productic
- Divided into subsampl









@M_H=146GeV:

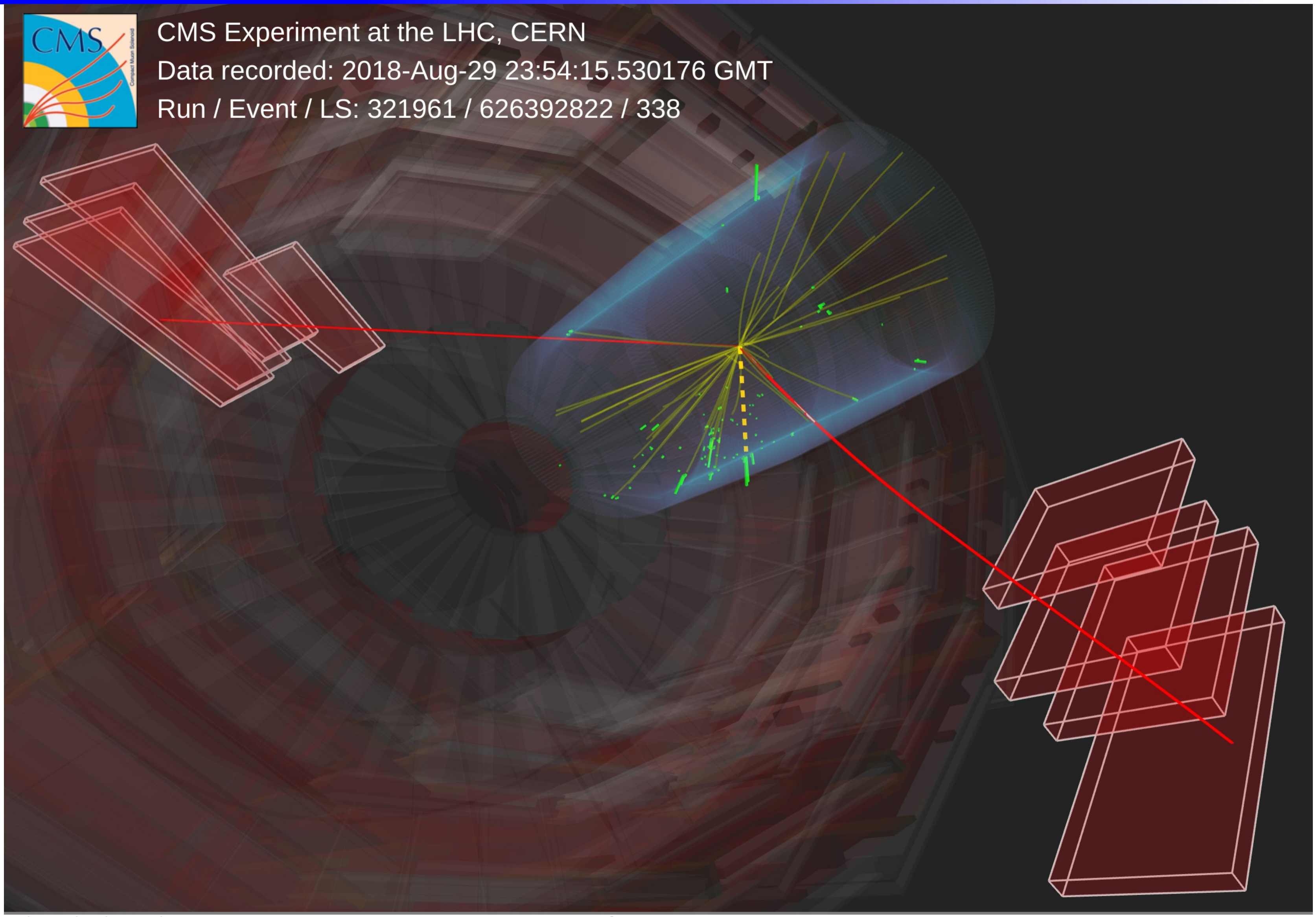
Observed(expected) Upper Limit on x-sec of X→ eμ:

6.0(2.1) fb^{-1} @95% CL

Excess observed: **Global (local)significance: 2.8(3.8)σ**

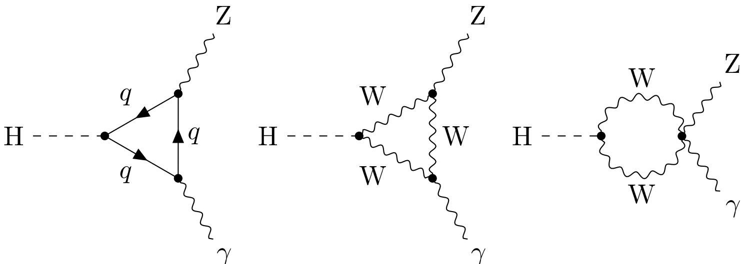
Higgs Decay H → Zγ

JHEP05(2023)233



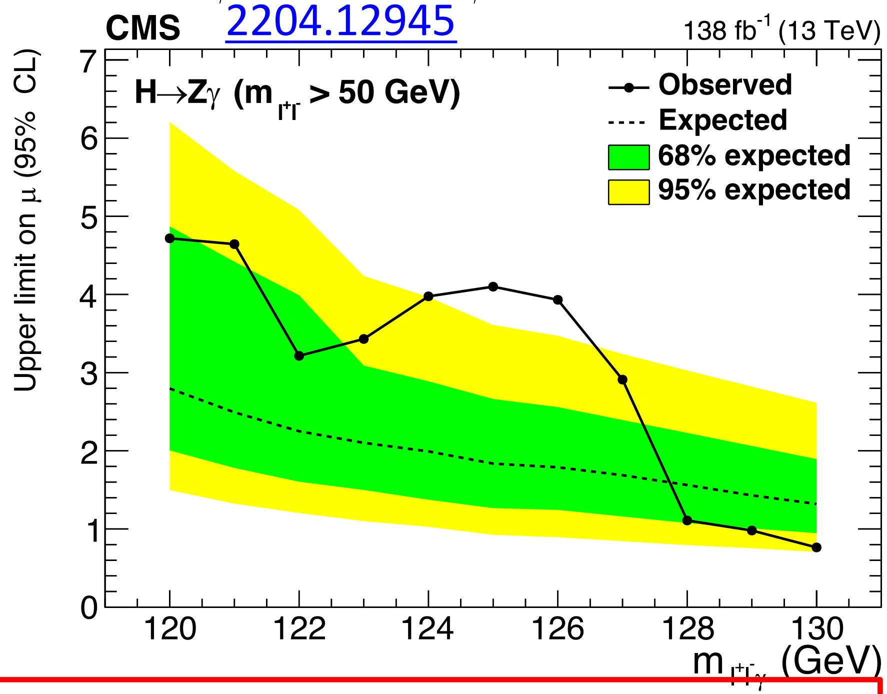
Higgs Decay H → Zγ

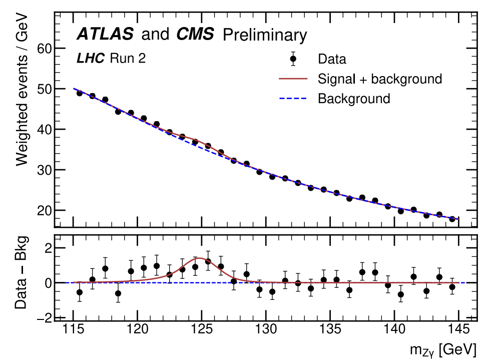
JHEP05(2023)233

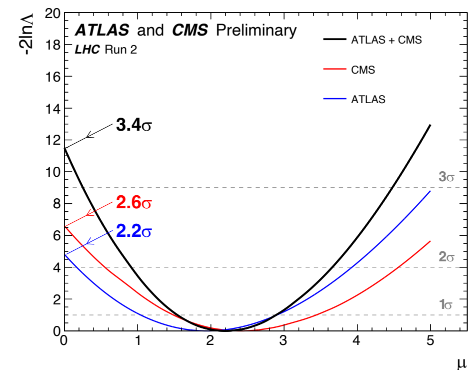


- First example of combined ATLAS and CMS evidence of H → Zγ from previously published results

2204.12945







Signal strength μ for M_h=125.38 GeV: μ=2.4 ±0.9
Observed significance: **2.7** σ
Upper limit on μ: 4.1 Observed 1.8 Expected

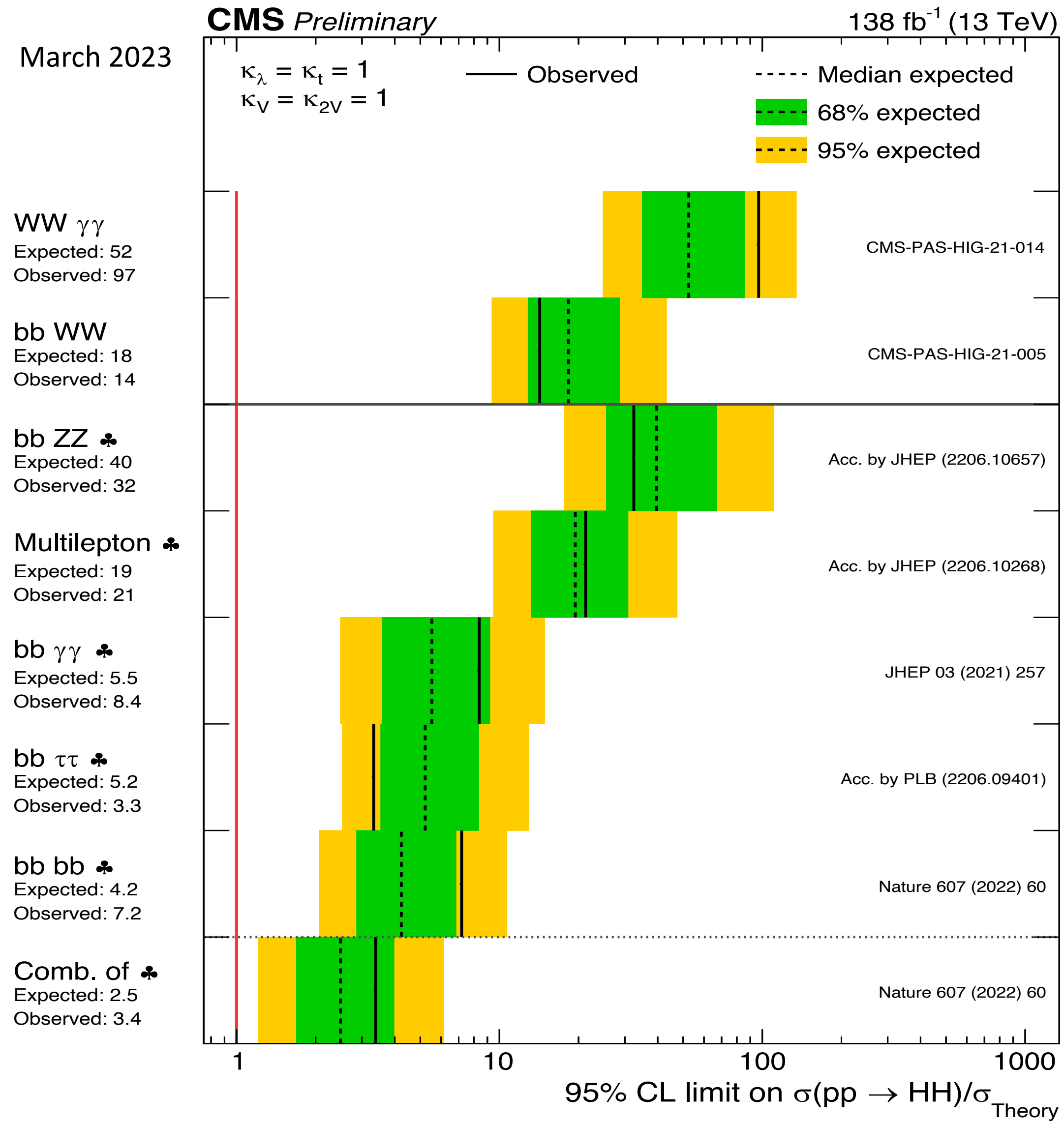
Combined CMS and ATLAS evidence for H → Zγ decay with observed significance: **3.4** σ (expected **1.6** σ)

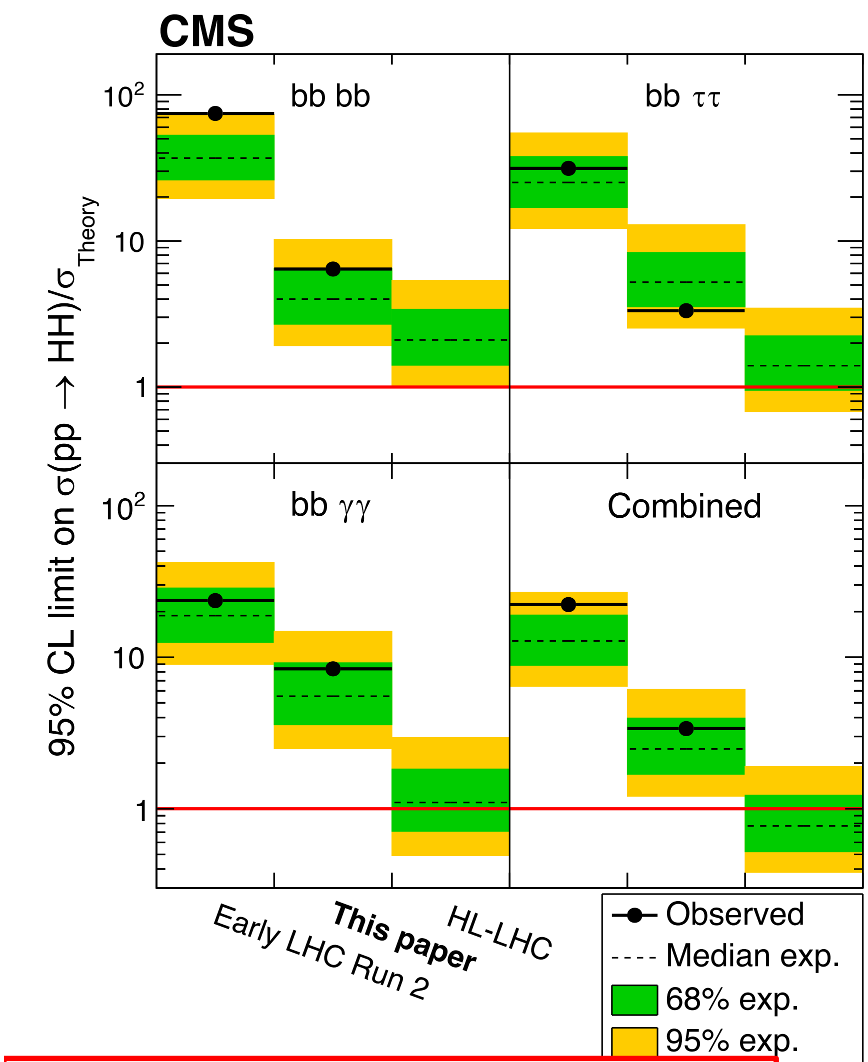
Signal strength: μ=2.2 ±0.7
1.9 σ compatibility with the SM prediction

HH Production Limits Run 2

[Nature 607 (2022) 60-68]

March 2023





HH Discovery expected at the HL-LHC

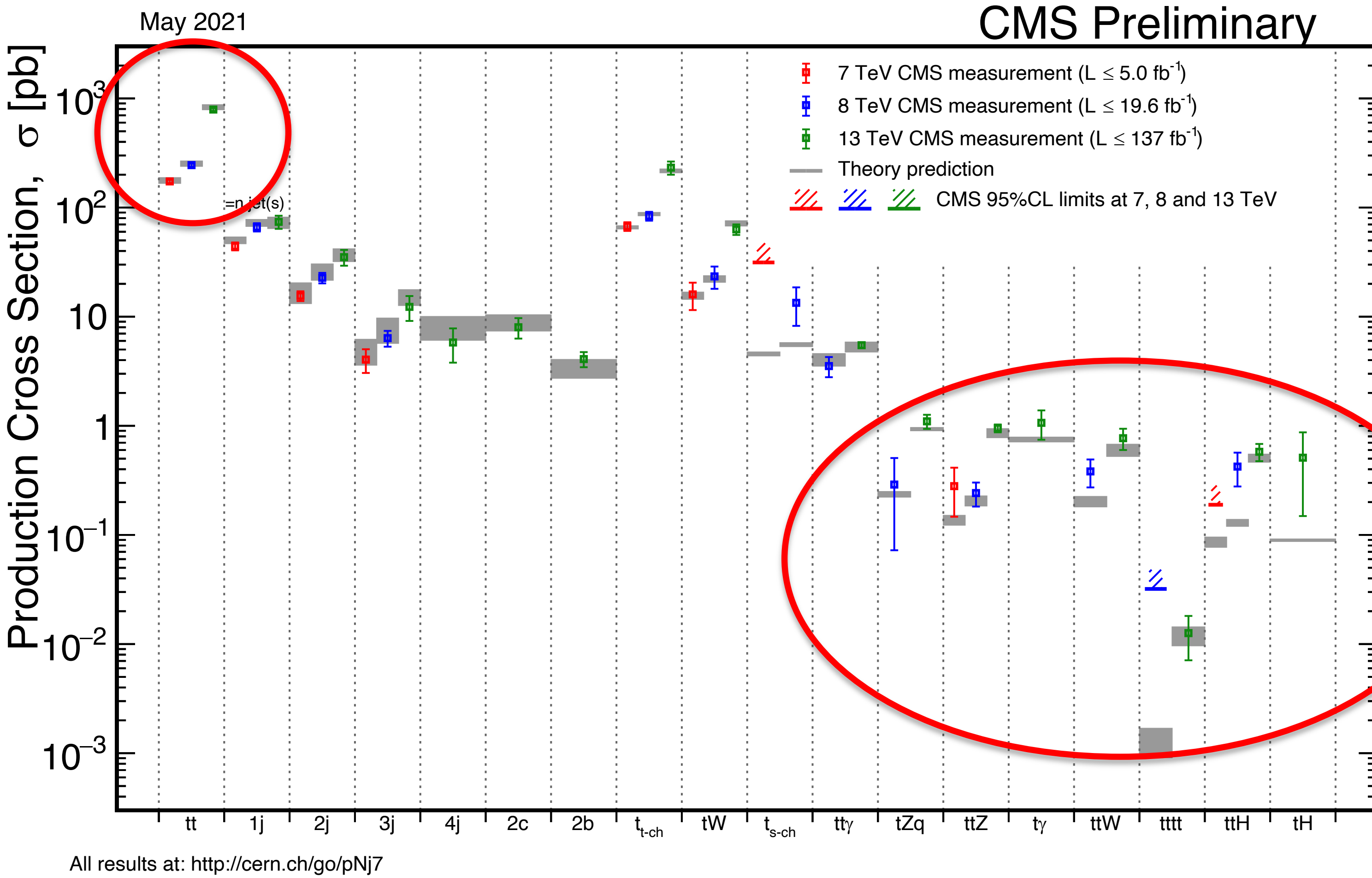
Summary of Higgs Measurements

- Strong limits, below **1**%, on LVF of H→μe, μτ, τe
- Higgs may play a role as a portal to new physics theories ; H→invisible observed (expected) limit of **0.15(0.08)** @95% CL
- HH measurements @HL-LHC

TOP Quark Properties

- TOP Production and Mass

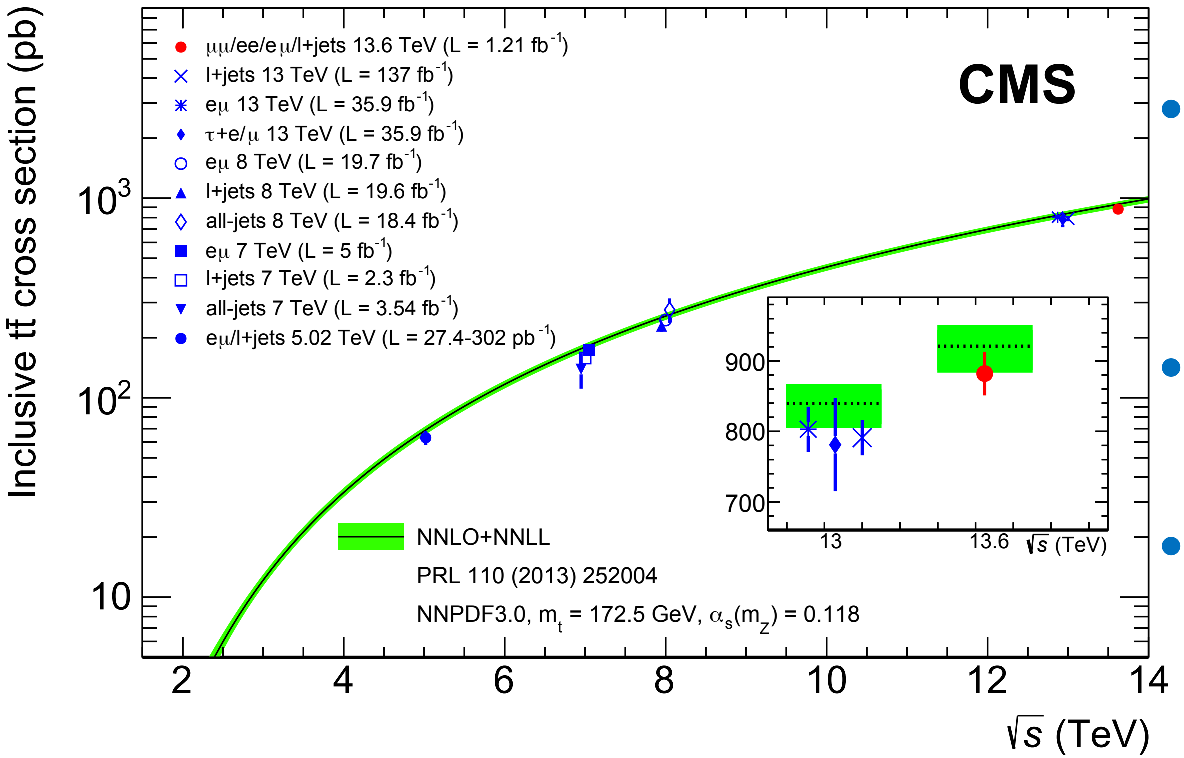
TOP Quark Studies



- TOP Studies with sample sizes of few hundred events produced
- Continuous improvements in precision with increasing data samples

tt^{bar} Production in Run3

CMS_TOP_22_012
subm.to JHEP



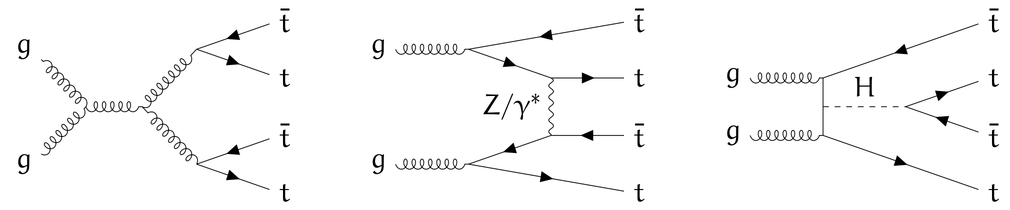
- The first @CMS Run3 measurement at **highest** LHC energy of **13.6TeV**
- Dataset of 1.21 fb^{-1} collected up to Aug 3 2022
- Combined analysis of event categories: ***ℓℓ*** or ***ℓ*** and additional jets

σ_{tt} = 882 ±23(stat.+Syst.)±20(lumi.) pb

σ_{tt}^{theory} = 921 +29/-37(stat.+syst.) pb

Four Top Quark Production

CMS_TOP_22_013
arXiv: 2305.13439

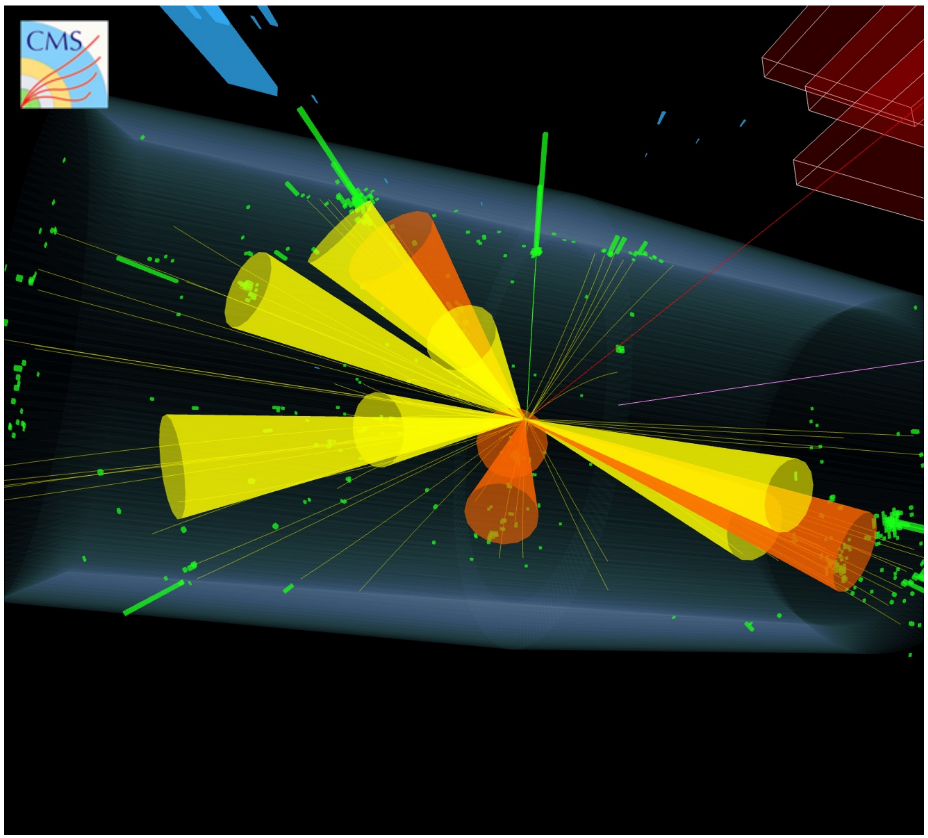


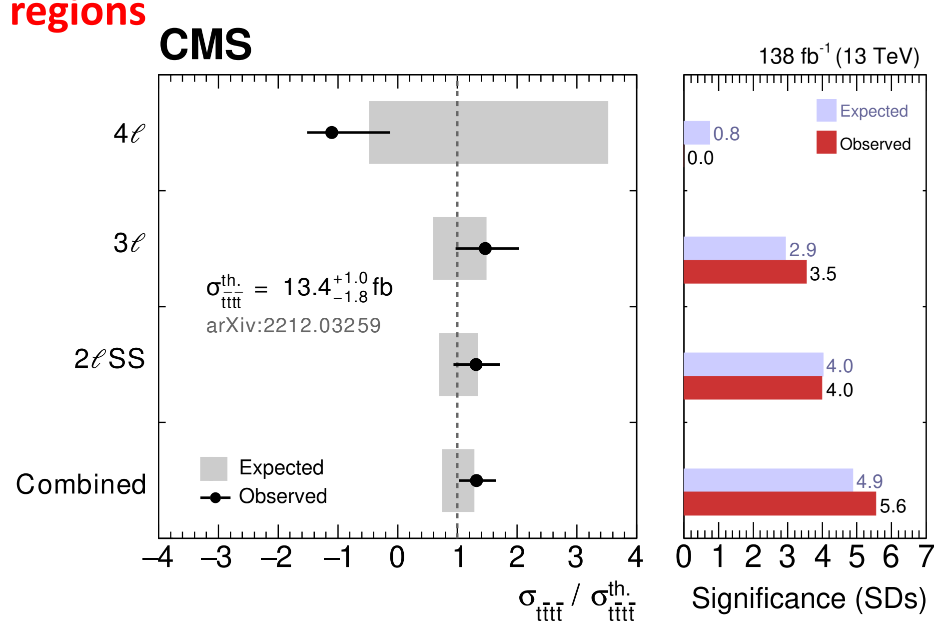
Multileptons with jets channels

Optimised selection with ML techniques

- **MVA in lepton identification**
- **DeepJet for b-tagging**

Likelihood profile fit in Several Signal and Control regions

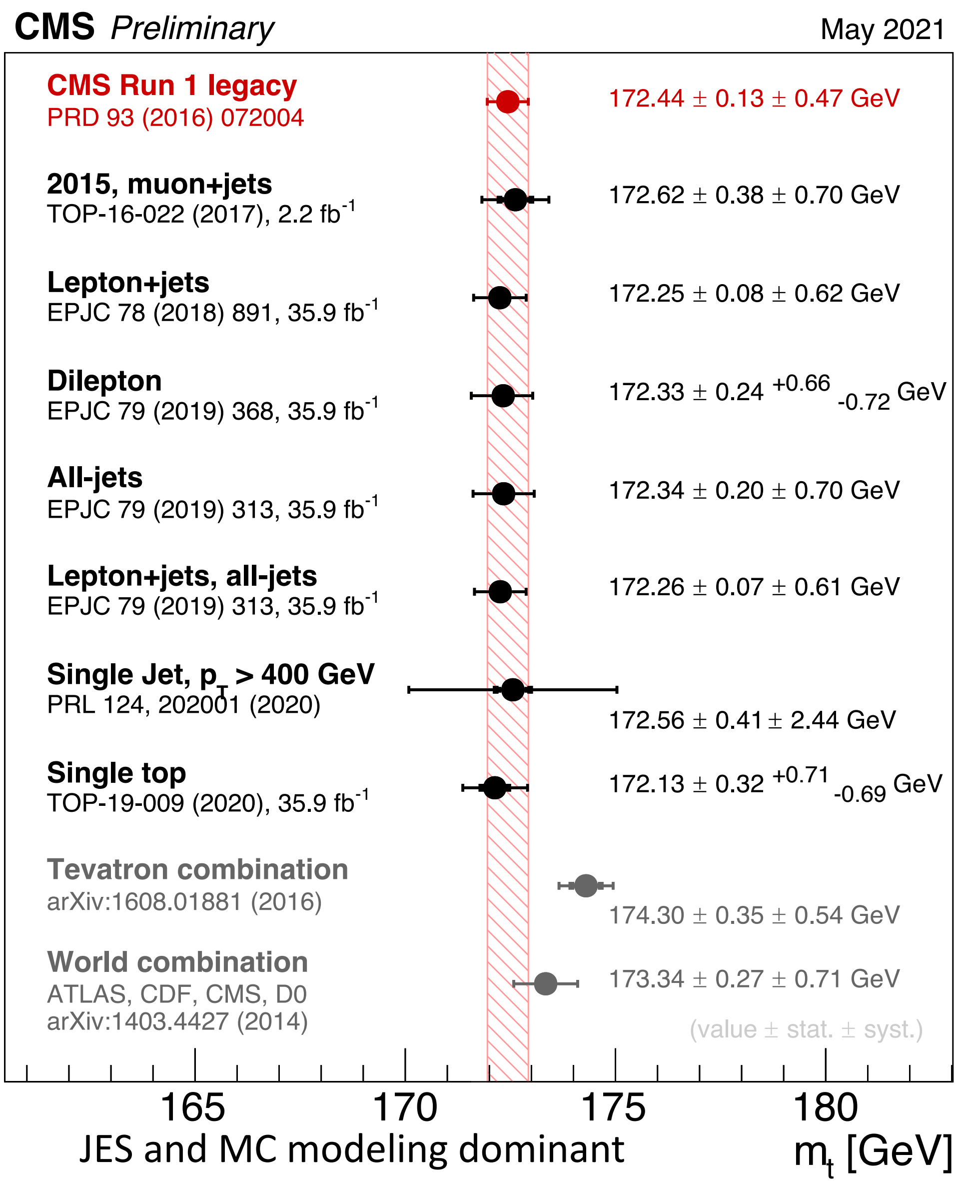




σ_{tttt} = 17.7 ± 3.7(stat.)± 2.3(syst.) fb

σ_{tttt}^{theory} = 13.4 +1.0 / -1.8 fb

TOP Mass Determination Run 2



JES and MC modeling dominant

Early Run 2 analysis !

CMS-PAS-TOP-020-008
Sub. Eur.Phys.J.C
Feb 2023

- Direct measurement with 5d-fit constraining the jet uncertainty from W-peak in the ML fit
- **m_t = 171.77±0.37 GeV**

JHEP07(2023)077

- Measurement from tt-jet cross section
- **m_t^{pole} = 172.94±1.37 GeV**

Eur.Phys.J.C83(2023)560

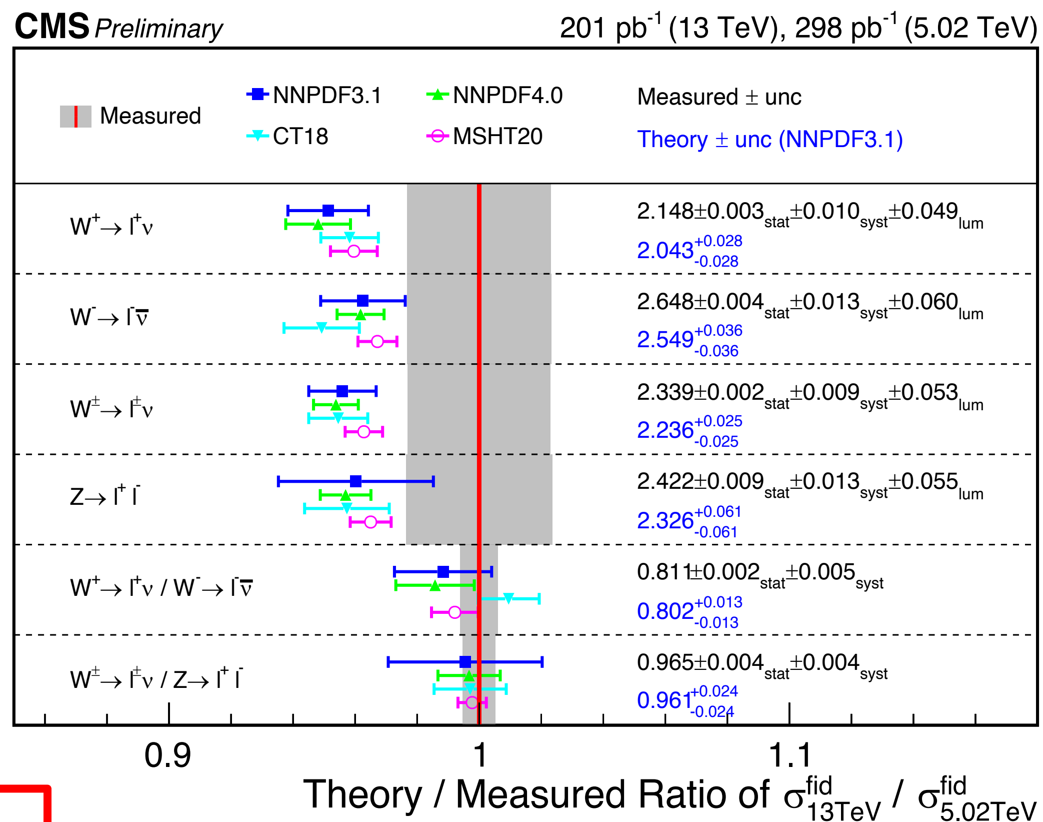
- Measurement of mass distribution and m_t in hadronic decays to boosted jets
- **m_t = 173.06±0.84 GeV**

M_{top} an interesting parameter in the M_W, M_H, M_{top} correlation plot

W,Z Cross Sections @5+@13TeV

CMS-PAS-SMP-20-004

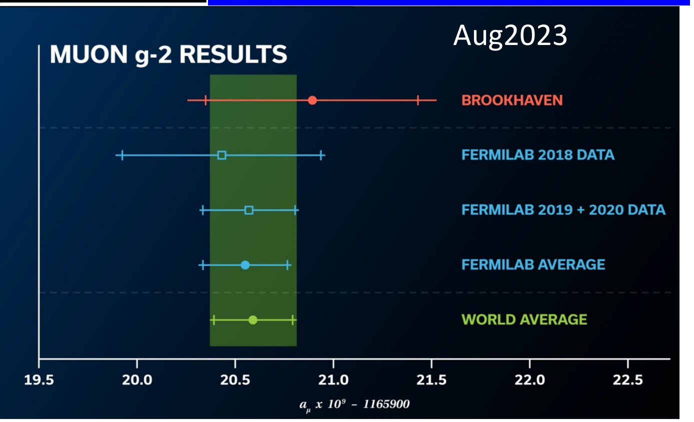
- Dedicated runs with low luminosity taken in 2017 at 5.02 and 13 TeV
- Fiducial cross sections, ratios and double ratios measured
  - Dominated by the lumi uncertainty
- Fiducial region:
  - Z: P_T>25GeV; |η|<2.4; 60<M(ll)<120 GeV
  - W: P_T>25GeV; |η|<2.4; M_T>40GeV;2^{nd} ℓ vetc



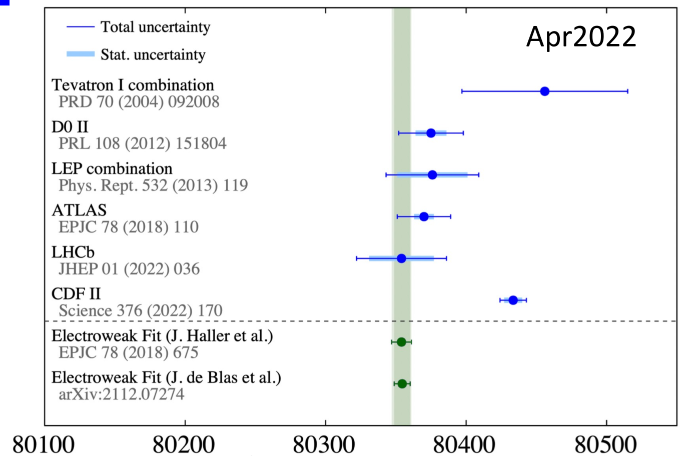
@13TeV results slightly larger than the predictions
Agreement with NNLO calculations

- Beyond Standard Model Physics is around us
  - Dark Matter, Dark Energy
  - Neutrino oscillations
  - M_h~125 GeV

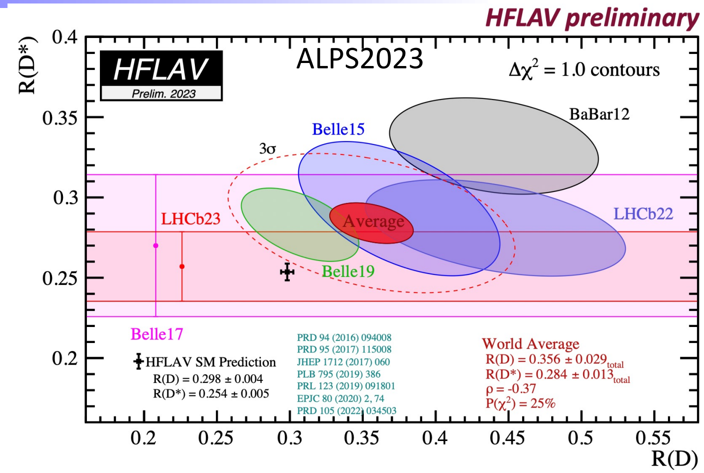
Discrepancies – a Look Outside LHC



5.0σ away from the SM(2020)



7.0σ away from the SM



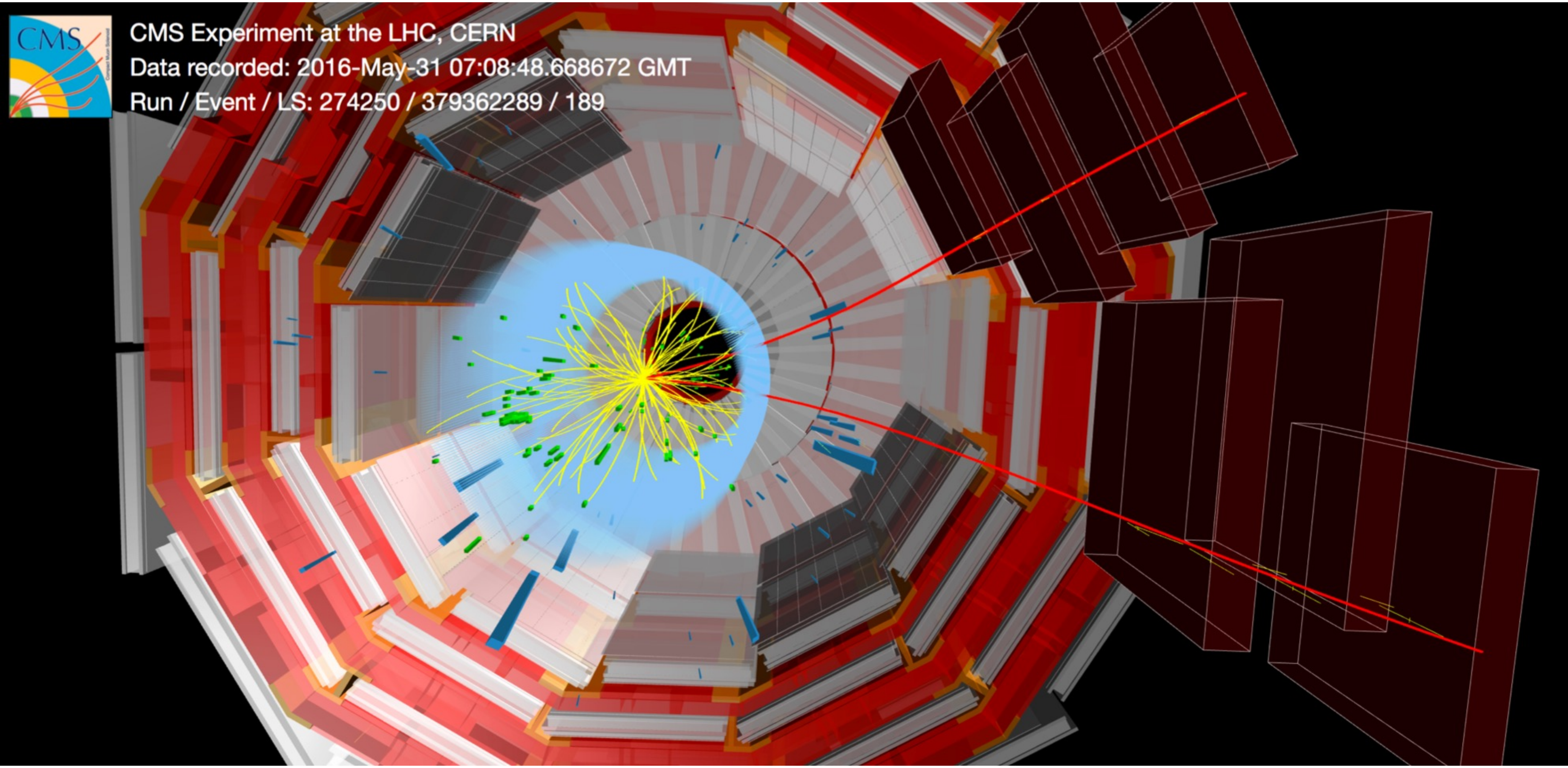
Flavour anomalies decay rates :

b → cντ –– ratios; R_D(D*) @ 3.2σ
b → s ℓ ℓ –– ratios and differential ;
R_K(K*) @ 0.2σ (no anomaly!)

- Several discrepancies from the SM observed: g-2, M_W, flavour anomalies (in R_D)
  - Refinements expected for the SM theory predictions
  - Hints of the Lepton Flavor Universality Violation (LFUV)
- Possible explanations of individual and multiple discrepancies with BSM effects
  - New models proposed to accommodate the effects
  - LFUV can be present in motivated BSMs
  - Focus on suppressed decays in the SM : e.g. $B_s \rightarrow \mu\mu$

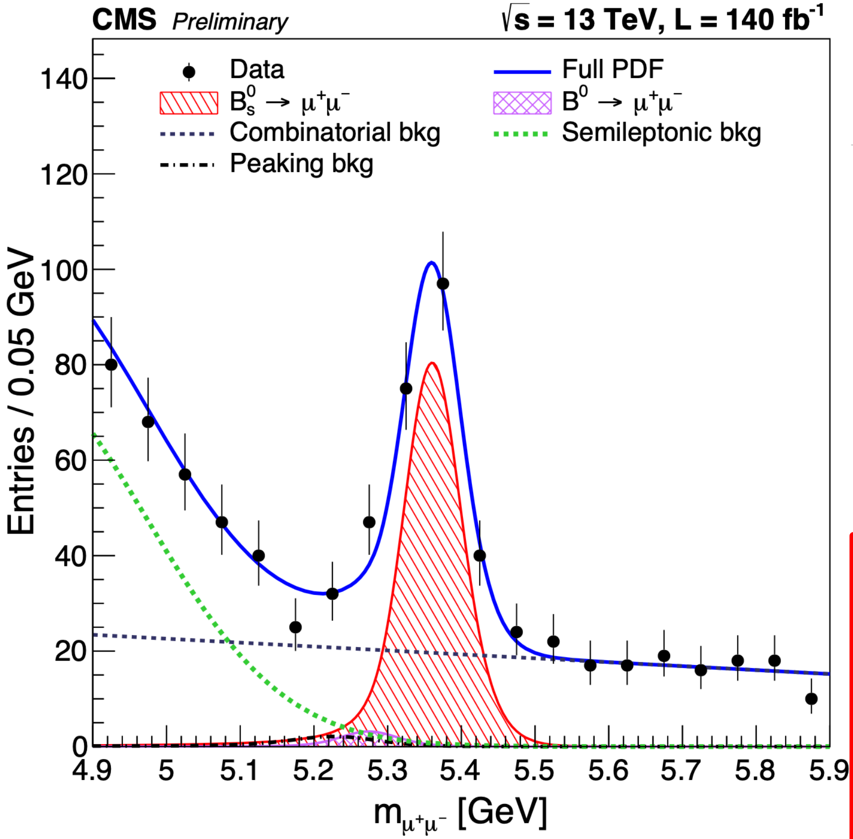
Leading role of LHC physics program !

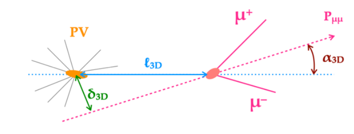
$B_{d(s)} \rightarrow \mu\mu$ Candidate Event



$B_{(s)} \to \mu\mu$ Results in Run 2

CMS-BPH-21-006
Phys.Lett. B 842 (2023) 137955





Summer 2022 $B_{s(d)} \to \mu\mu$ CMS result

- BF normalized using $B \to J/\psi K$ (nominal) and $B_s \to J/\psi\ \Phi$ (alternative)
- New Multivariate Analysis (MVA_B) used to suppress backgrounds
- Fake rates in control samples $K_s \to \pi\pi$ and $\Phi \to KK$
- New MVA based muon identification to improve Kaon decays in flight

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}\ (\text{stat})\ ^{+0.19}_{-0.16}\ (\text{syst})\ ^{+0.14}_{-0.13}\ (f_s/f_u)\right] \times 10^{-9}$$

$$\tau = 1.83\ ^{+0.23}_{-0.20}\ (\text{stat})\ ^{+0.04}_{-0.04}\ (\text{syst})\ \text{ps.}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = \left[0.37^{+0.75}_{-0.67}\ (\text{stat})\ ^{+0.08}_{-0.09}\ (\text{syst})\right] \times 10^{-10}$$

Summer 2020 combination of $B_{(s)} \to \mu\mu$ (ATLAS, CMS and LHCb)

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (2.69\ ^{+0.37}_{-0.35}) \times 10^{-9}$$

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-)_{SM} = (3.66 \pm 0.23) \times 10^{-9}$$

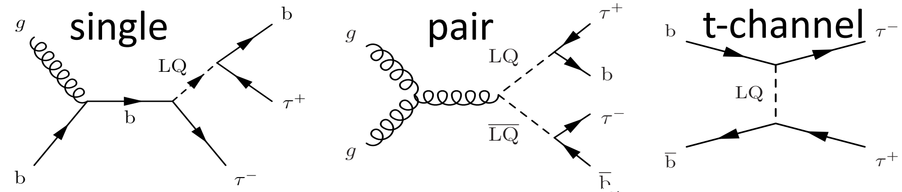
The results are compatible with the SM predictions

Most precise measurement from a single experiment
Expected improvements with addition of Run 3 data !

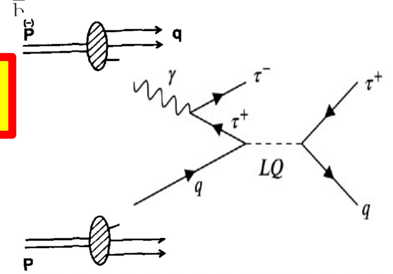
Search for LeptoQuarks

CMS PAS EXO-22-018
2308.06143

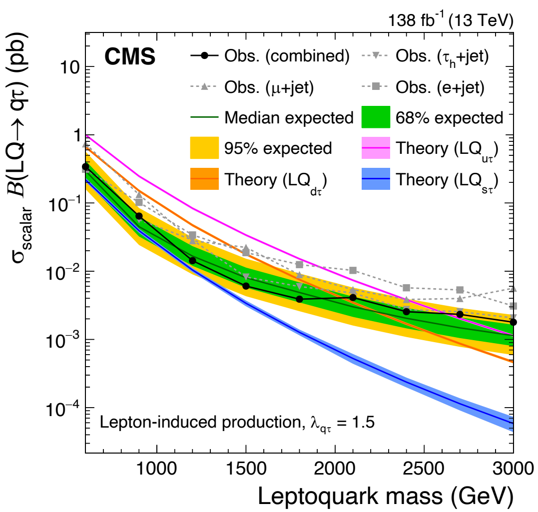
- LQ predicted by many extensions of the SM
- **New Production mechanism** by **colliding quarks** in one proton beam with **leptons** generated by splitting photons radiated of quarks from another proton
- LQ masses up to 3 TeV expected at LHC
- Final State: jet, MET, tau(had, ℓ)

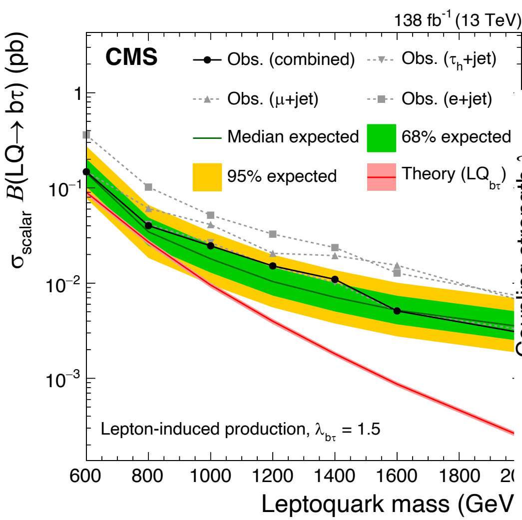


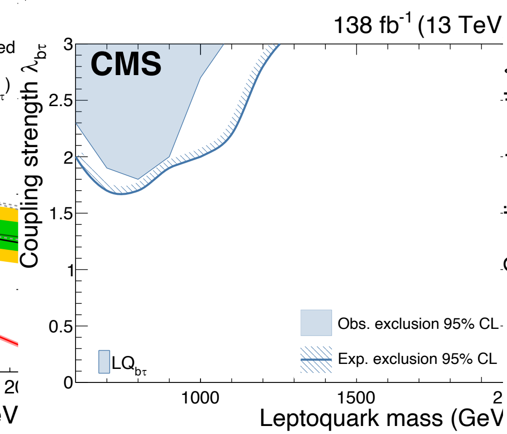
Single in l-q collisions

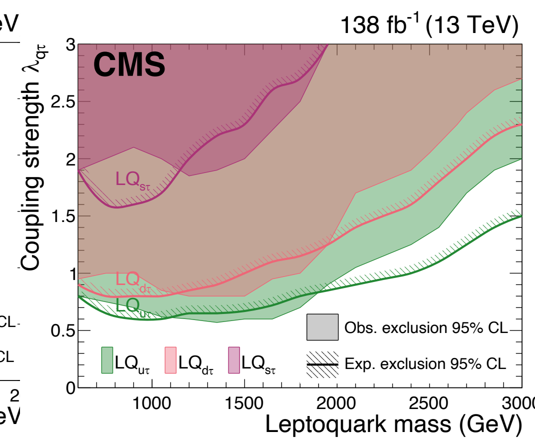


J. Ohnemus, S. Rudaz, T. Walsh, and P. Zerwas. Phys. Lett. B 334, 203 (1994)









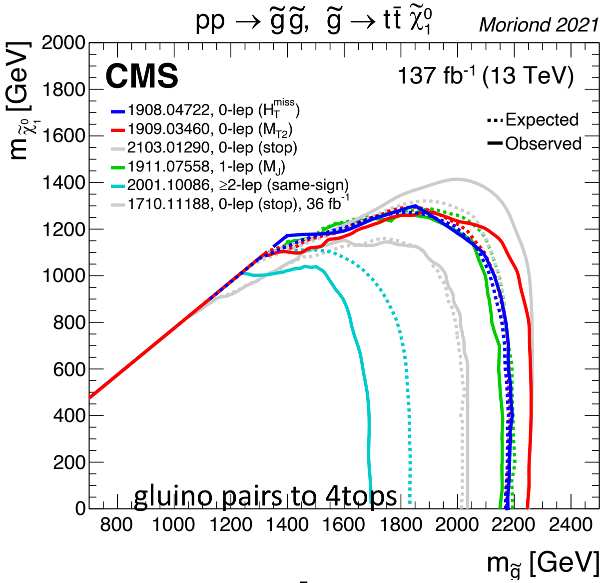
- ULimits on **scalar** LQ coupling strength to light-, b-quarks and τ
- Light-q – τ limits set for the first time (u,d,s)
- b-quark – τ limits compatible with previous results

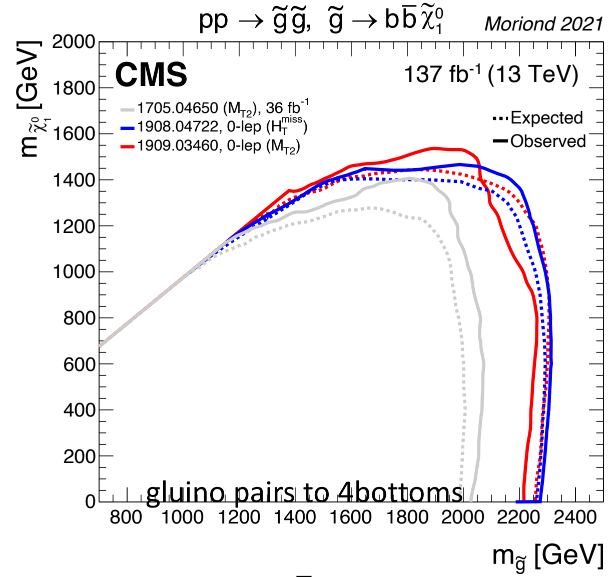
Part 3- Searches for direct production

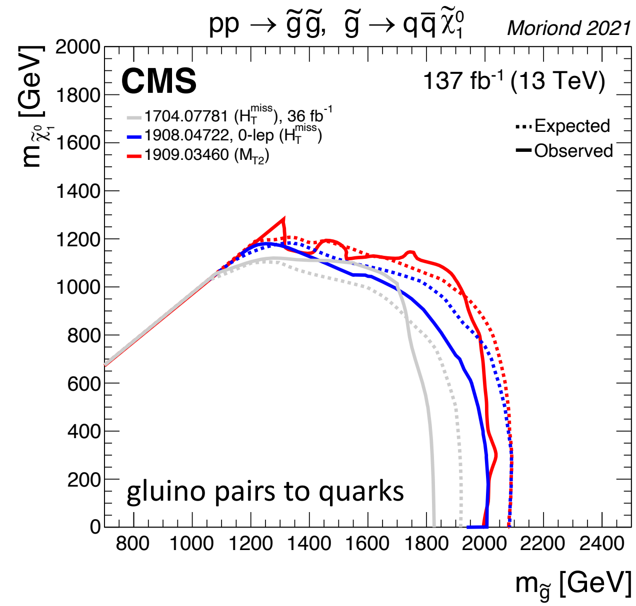
- What else is being seen in Run 2,3 data ?
  - Or else…what have not been seen … yet
- A set of Universal Measurements serving many original phenomenological analysis needs in a variety of models in new regions of parameter spaces
- Examples of such results – selected today:
  - SUSY Phenomenology
  - Search for new higgs particles neutral or charged $H^{+/-}$, H^{++}
  - Di-boson resonances in VV, Vγ, VH, HH channels
  - Z’, W’, LQ, VLL, VLH, excited quarks, resonances in di-jets
- Many improvements observed in existing Run 2,3 results compared to Run 1 using new highly optimized ML techniques and new triggers

Search for colored SUSY in Run 2

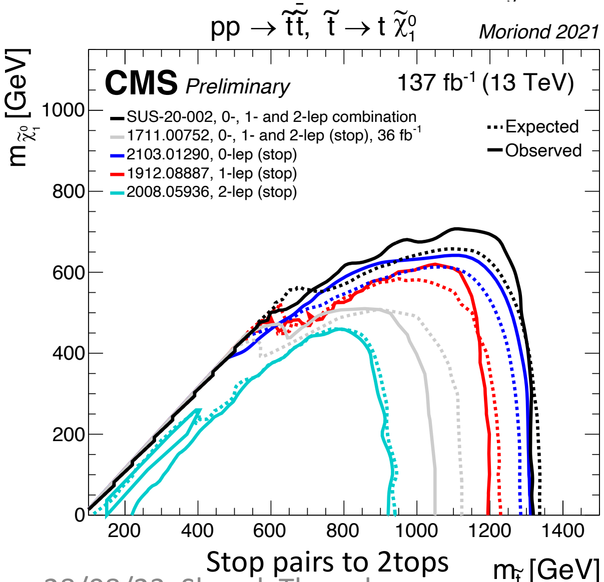
gluinos

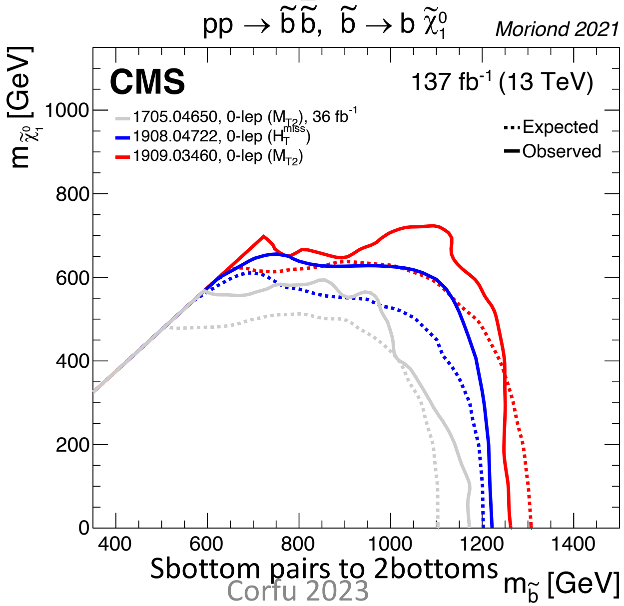


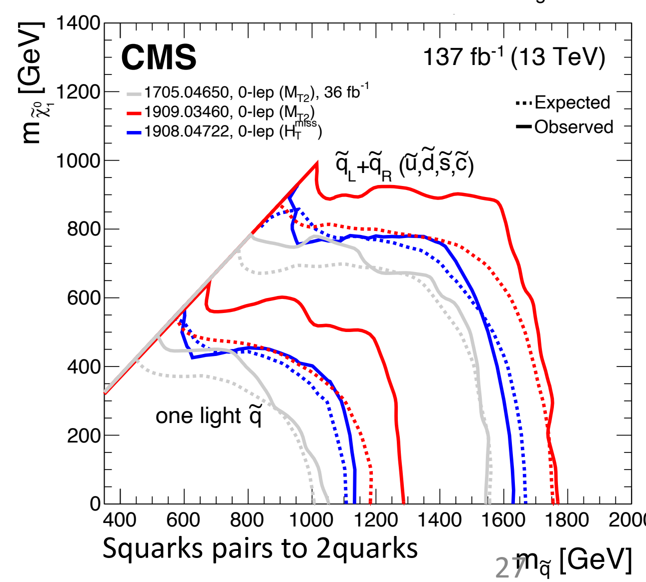




Stop, sbottom, squarks







Search for SUSY EWKinos in Run 2

CMS-PAS-SUS-21-008

Results interpreted in simplified models of chargino-neutralino, neutralino or slepton pair;

Combination of EWK production of winos, binos, higgsinos, sleptons provides additional coverage of the parameter phase space and increases sensitivity in the compressed mass parameter regions

Neutralino, Chargino or mixed Pair

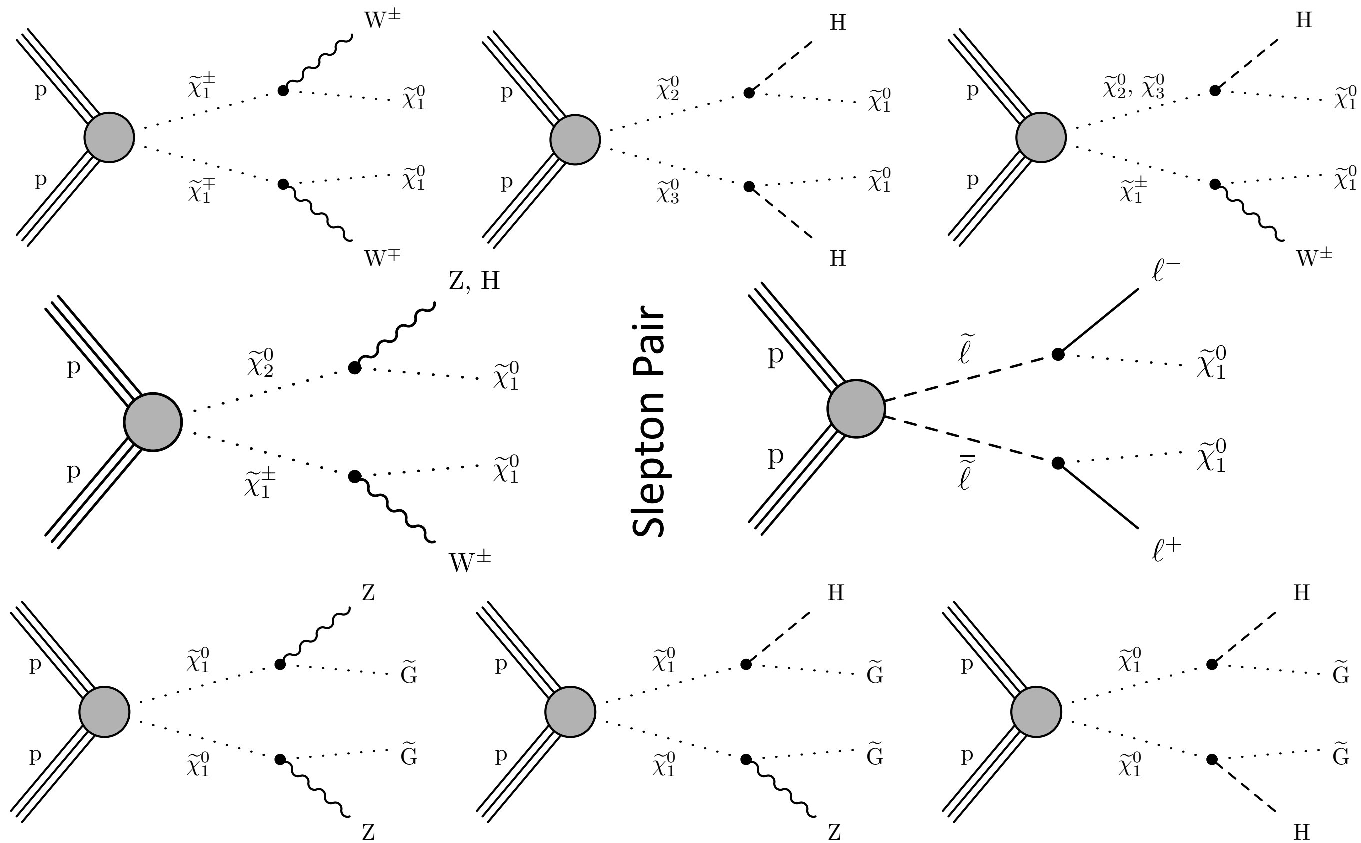
Decays via W/H

Chargino-Neutralino Pair

Decays via WZ, WH or leptons

Neutralino Pair GMSB

Decays via Z/H



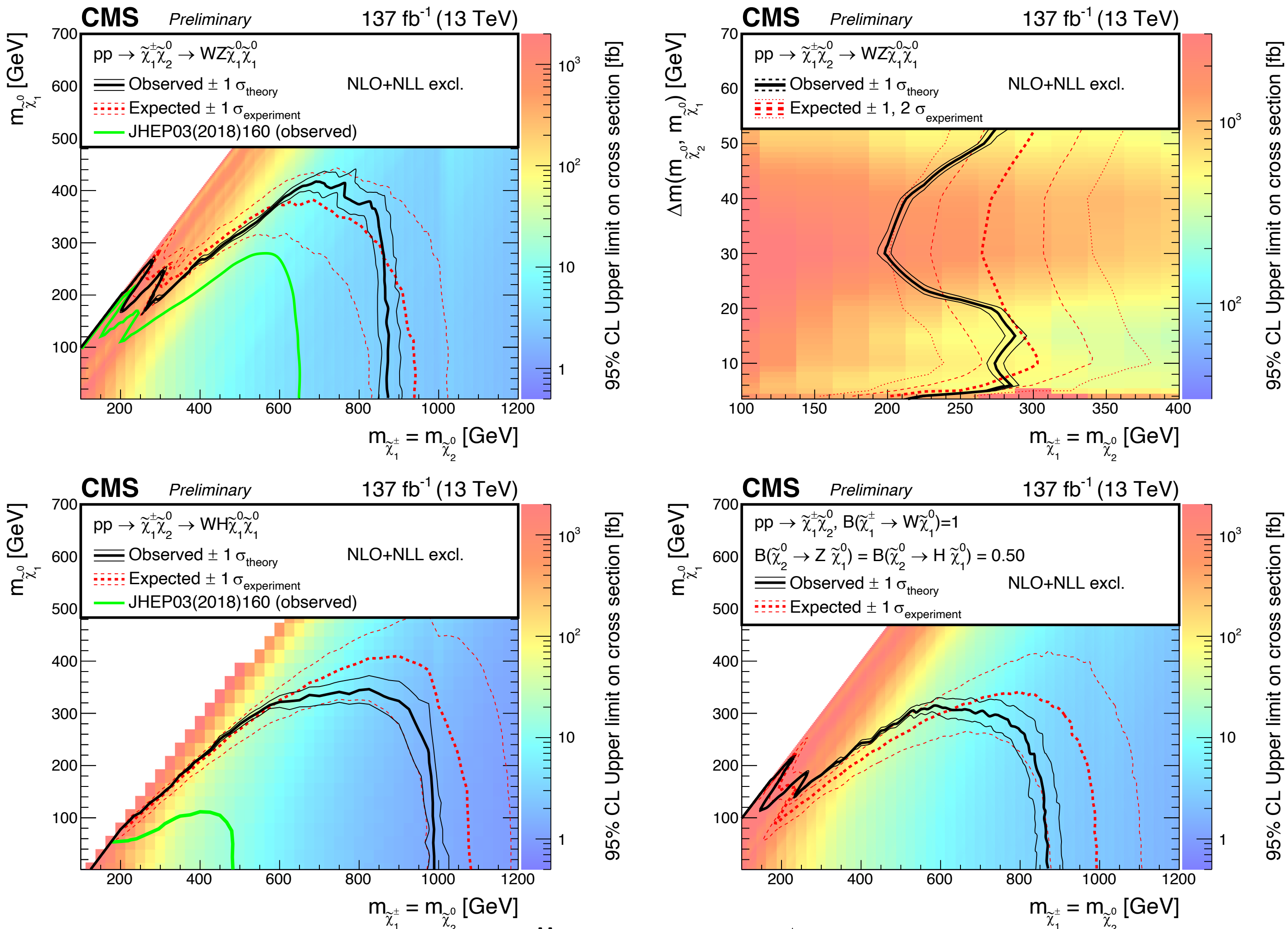
Important to show the combination of results rather than overlaid limits

Search for SUSY EWKinos in Run 2

Chargino-Neutralino Pair decay to WZ, WH + LSP

Uncompressed

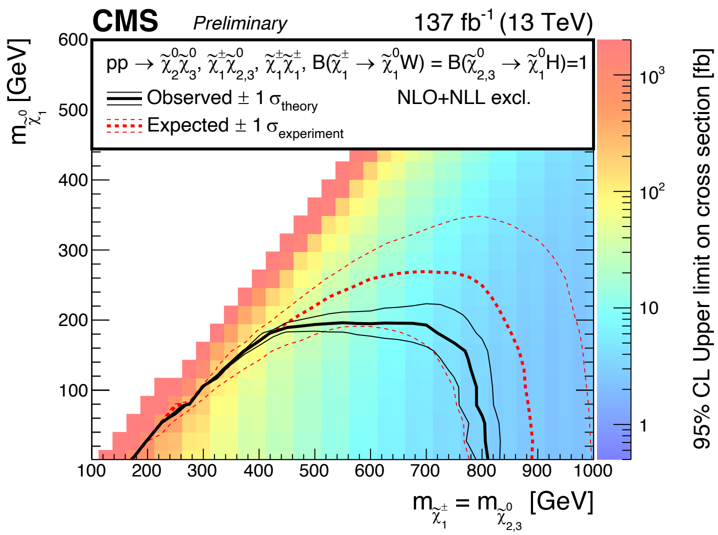
Compressed



Small excess near ΔM ~40MeV

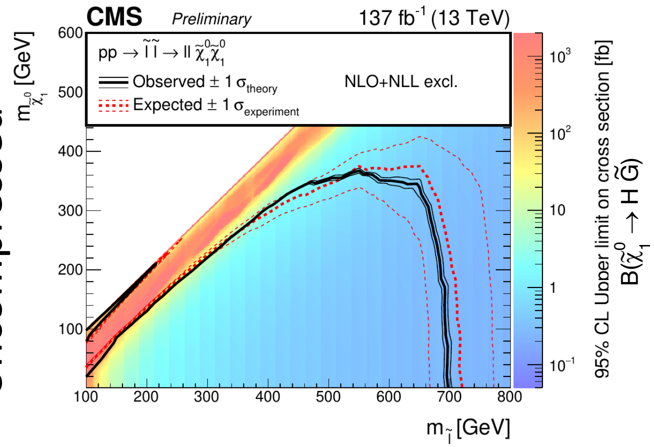
Search for SUSY EWKinos in Run 2

Neutralino, Chargino
or Mixed Pair
WW, HH, WH + LSP

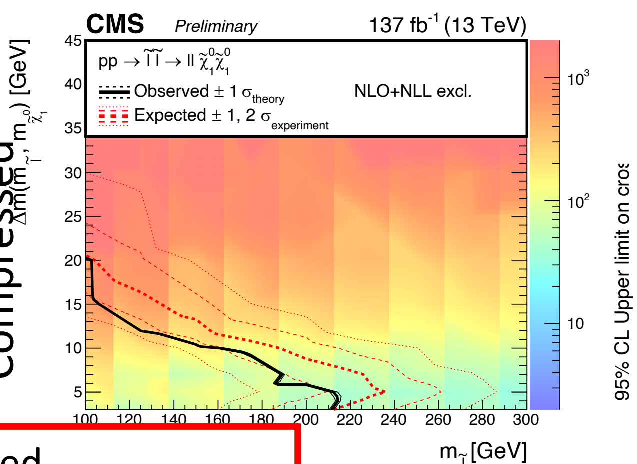


Slepton Pair

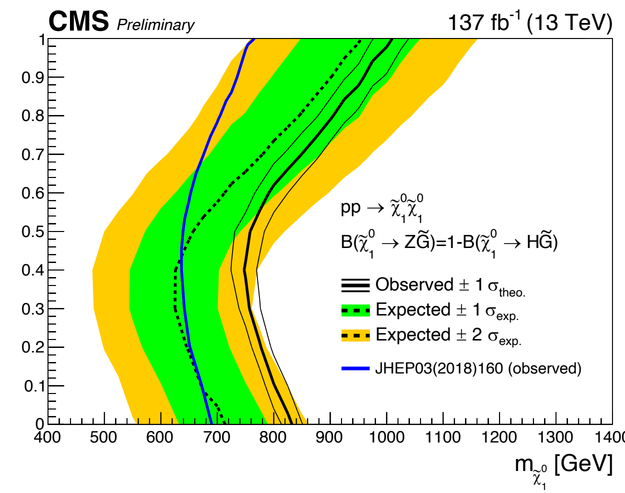
Uncompressed



Compressed



Neutralino Pair in GMSB



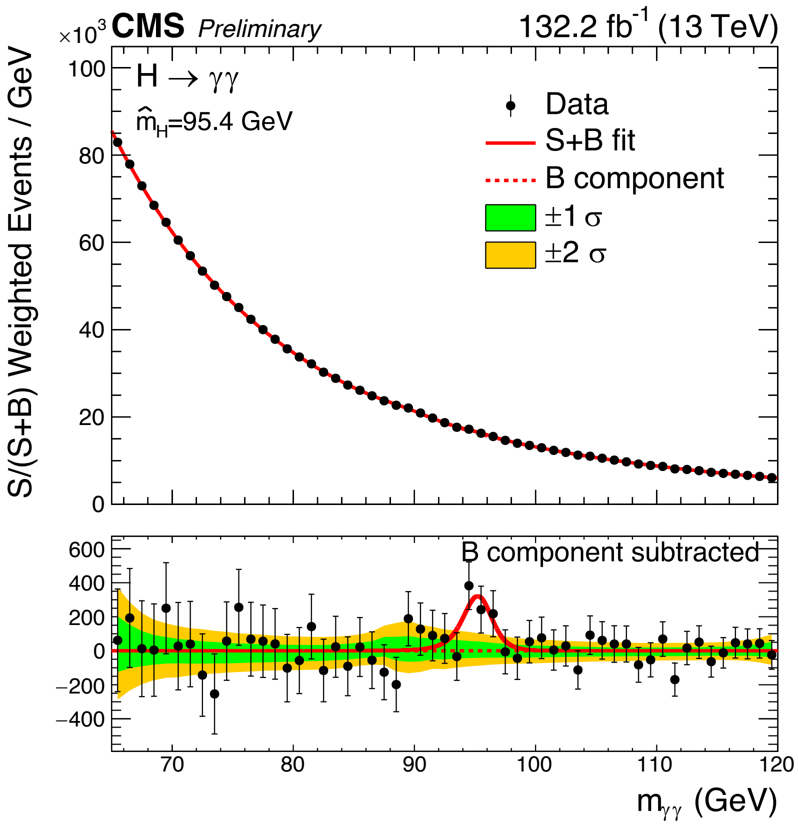
Minimal Mass Splitting between Charginos and Neutralinos in GMSB
Approximation by neutralinos production with light Gravitino (LSP) and neutral Z, H bosons
Exclusion limits in terms of Br(χ_1^0->(Z,H) G)

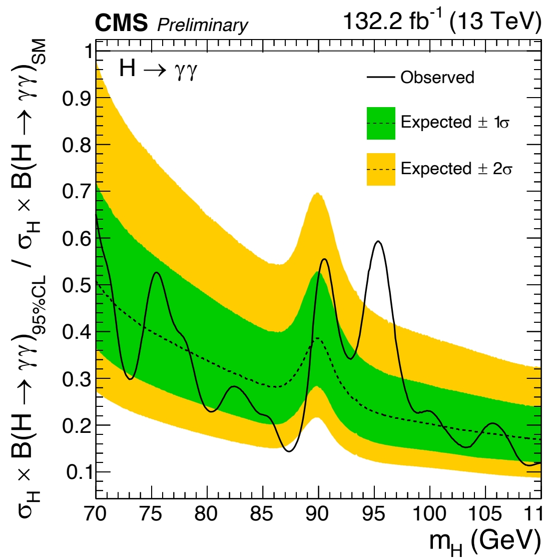
No significant deviation from the SM observed
Improved limits 100-500 GeV compared to previous results

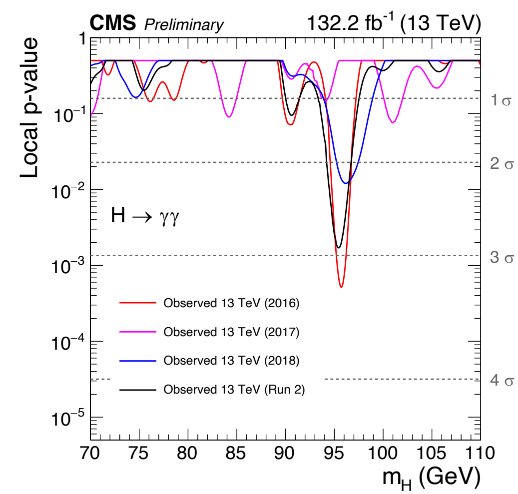
Search for Light H → γγ

CMS-PAS-HIG-020-002

Search for light H → γγ decays below H(125)





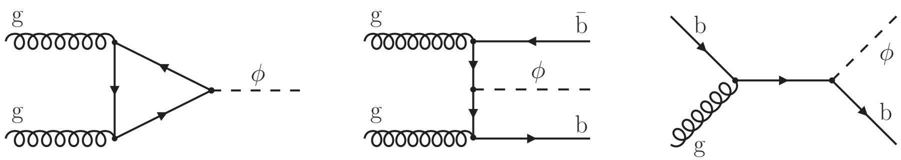


Data compatible with background-only-hypothesis
Observed Upper Limit on σ x BF : from 73 to 15 fb-1
Largest deviation M=94.5 GeV w/ Local (Global) 2.9(1.3)σ

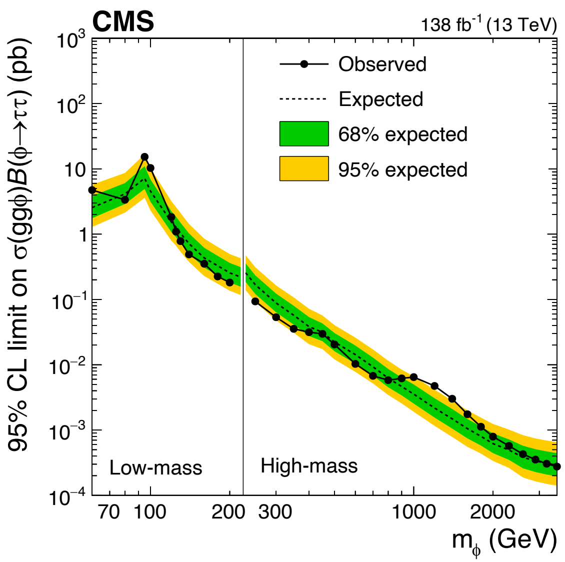
Search for neutral higgs ϕ

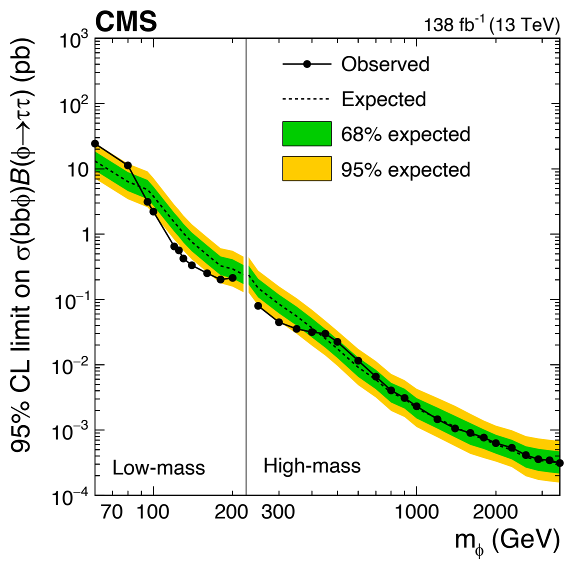
JHEP07(2023)073

Neutral higgs ϕ in ggF or in association with b-quark(s)



$\phi \rightarrow \tau\tau$ in lepton or hadron decays





Limits set [60 - 3500 GeV] ranging from 10pb to 0.3fb
e.g. two excesses in ggϕ at 0.1 and 1.2 TeV with ~3σ

In MSSM scenarios M_h^{125} & $M_{h,\,EFT}^{125}$ additional Higgs bosons with masses below 350 GeV excluded

Search for Heavy Higgs to WW decays

CMS-PAS-HIG-020-016

ggF and VBF production considered
Fully leptonic final states (ee, μμ, eμ)

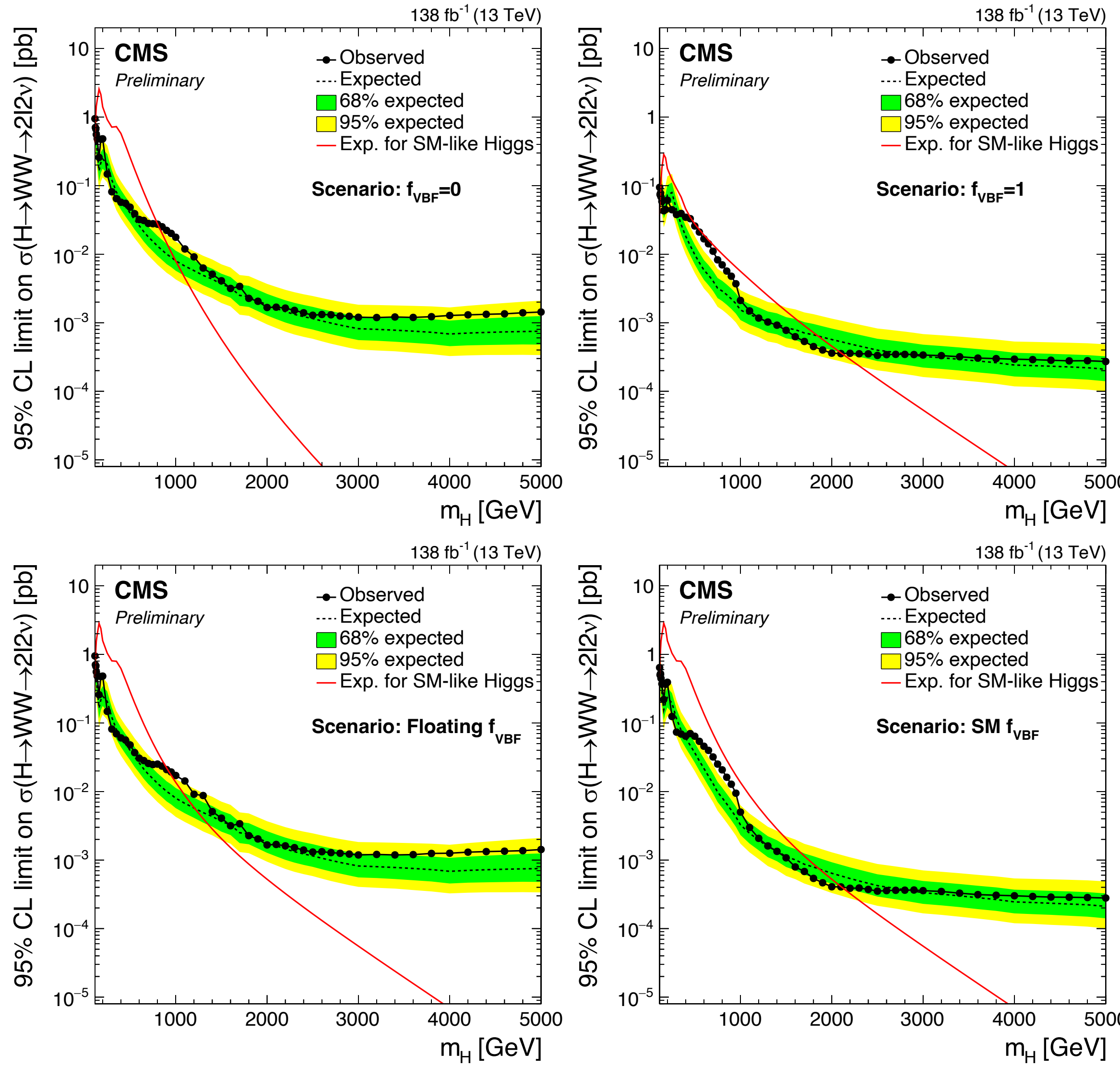
New analysis techniques implemented
Various width hypothesis considered

Heavy higgs excluded up to 2100TeV @95% CL depending on the production model

Upward fluctuation observed in data over the expected background

Signal hypothesis at mass of 650 GeV with highest global significance of 2.6σ for VBF production only

Additional exclusion limits obtained on MSSM and 2HDM scenarios



Search for charged Higgs

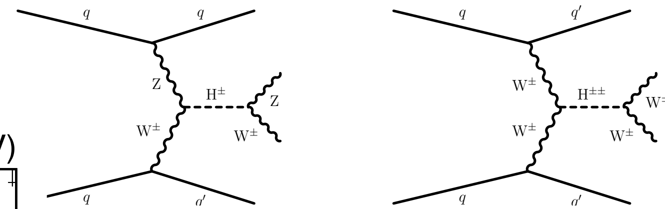
CMS HIG-20-017

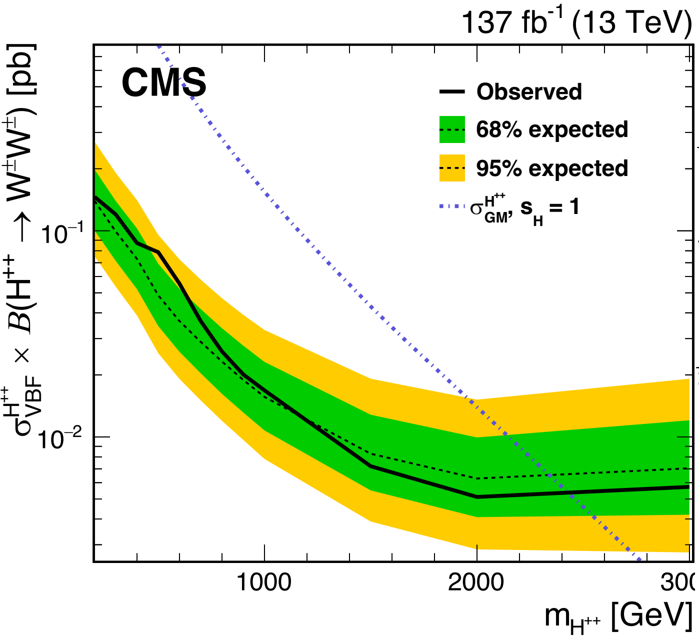
Eur. Phys. J. C 81 (2021) 723

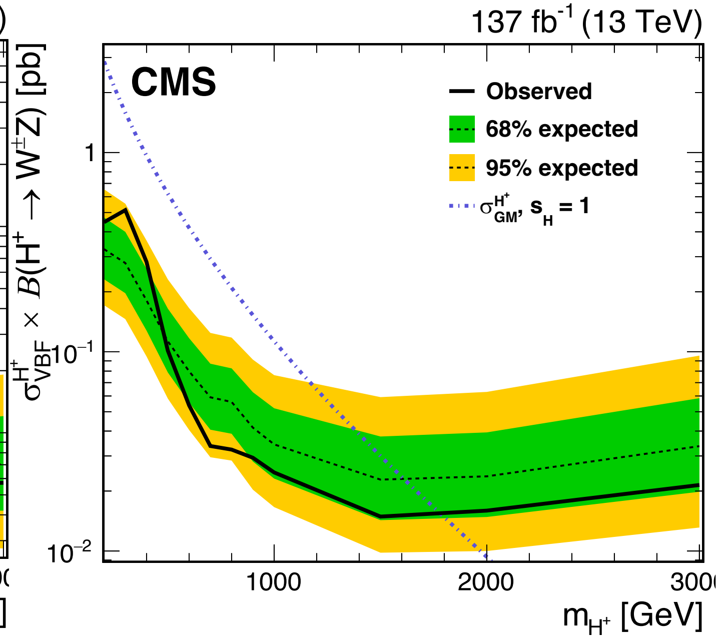
VBF production of charged Higgs: $H_5(H^+, H^{++})$ – degenerated in mass@LO

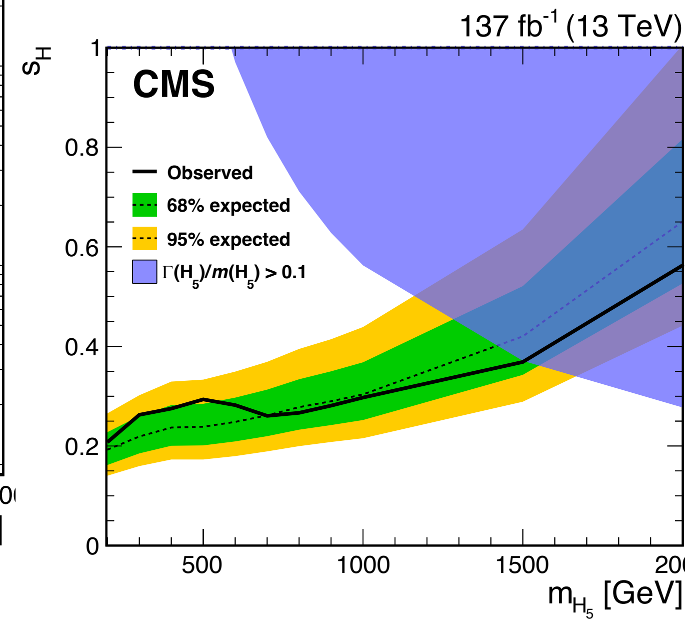
Leptonic decays of VV and VBS selection

Interpretation using **Georgi-Machacek** model with additional triplets









Most stringent limits on production **of GM charged higgses to** date

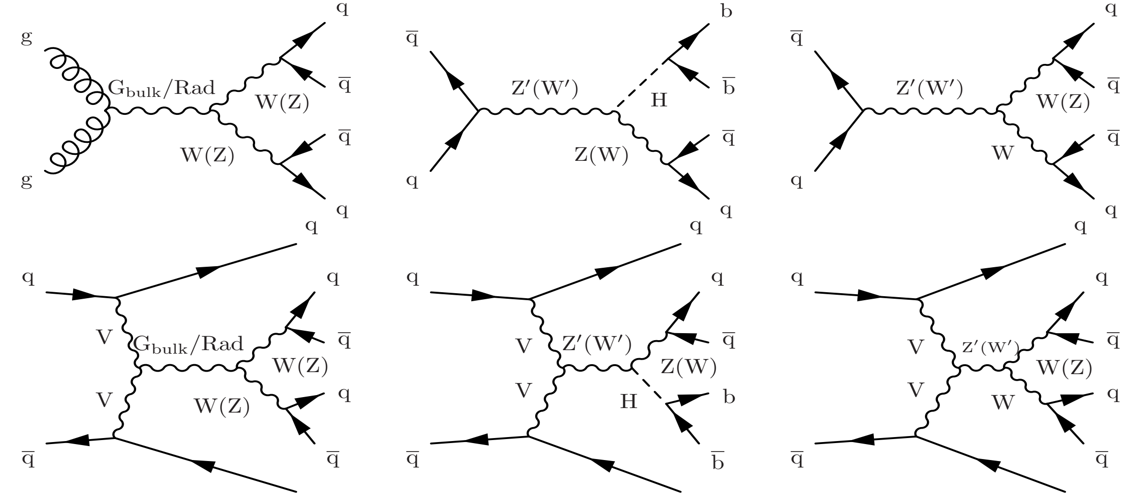
GM particles as a resolution of tensions in EWK fits with new CDF m_W e.g.Ellis et al. arXiv:2204.05260 - list tree-level single field extensions that include EFT dim-6 operators providing a better fit than SM alone among them 2.9TeV Ξ– triplet

Exclusion of model parameter S_H for masses 200-1500GeV: 0.2-0.35@95%CL

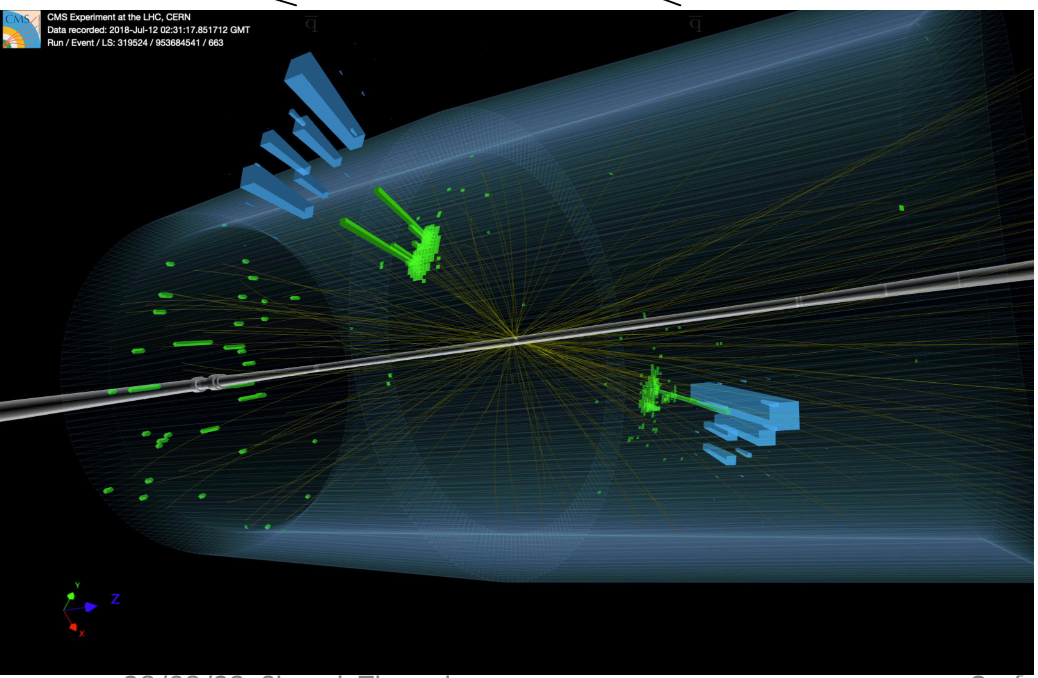
Search for VV,VH All-Hadronic Resonance

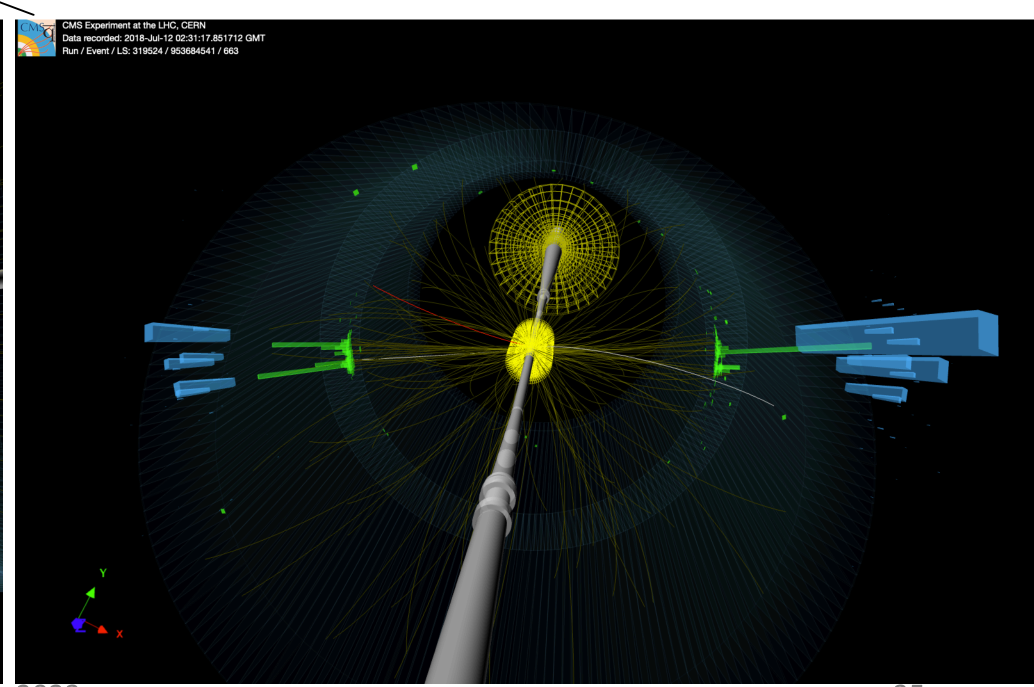
CMS PAS B2G-20-009

Phys. Let. B 844 (2023) 137813



Bosons highly boosted reconstructed as 1 super-jet with new ML algorithm



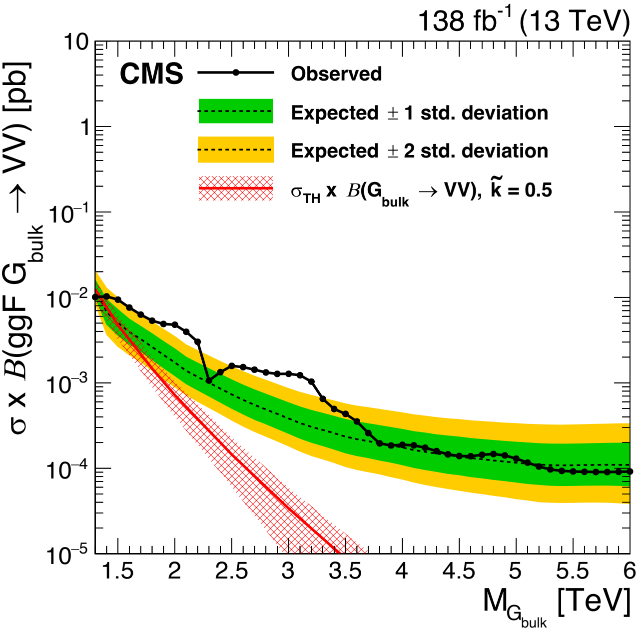


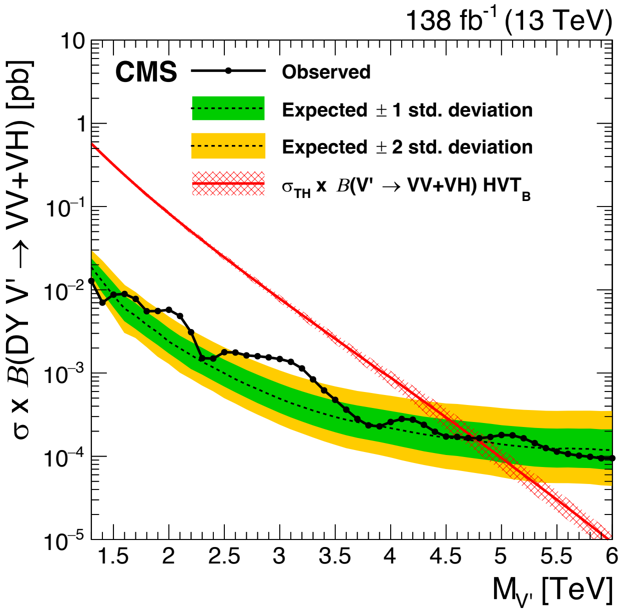
Search for VV,VH All-Hadronic Resonance

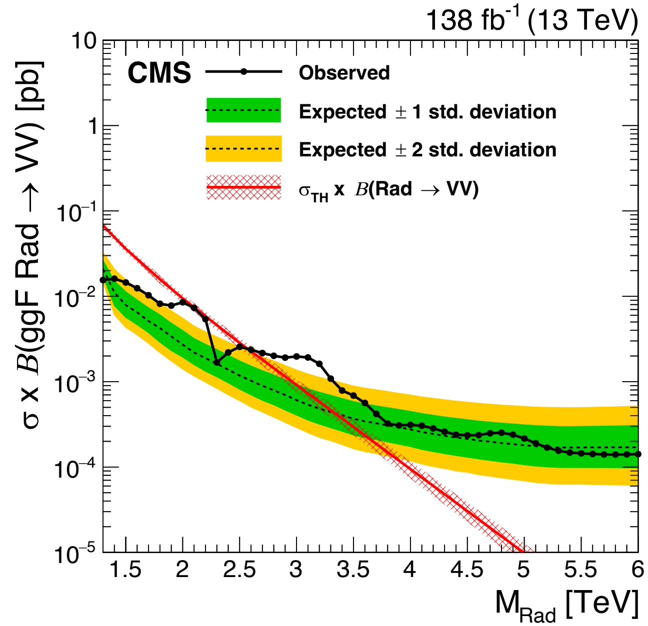
CMS PAS B2G-20-009
Phys. Let. B 844 (2023) 137813

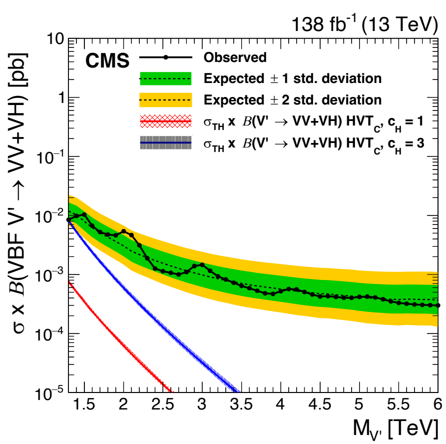
Models: Gravitons, heavy spin-1 bosons (W', Z') and spin-0 radions

Decay channels: Bosons highly boosted reconstructed as 1 super-jet with a new algorithm









Limit on G_{bulk} mass
G_{bulk} 1.4 TeV at 95%CL

Mild excesses observed @2.1&2.9TeV with **3.6σ(2.3σ)** local (global) significance

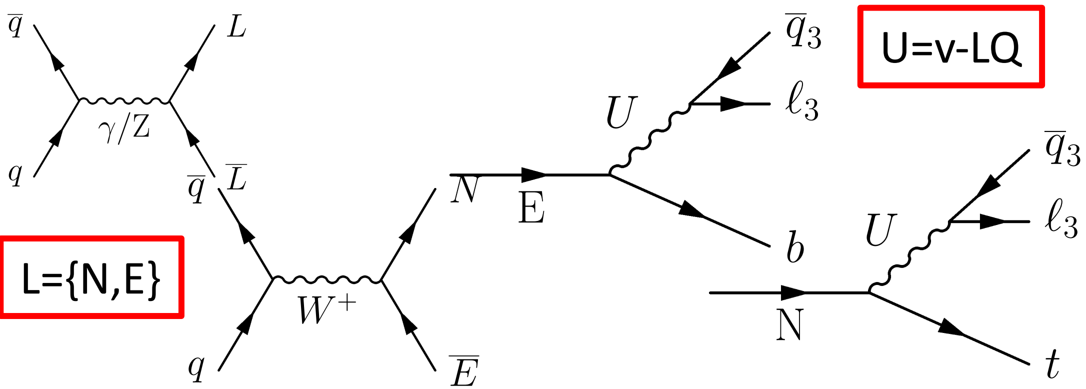
Limits on Radion mass:
Rad: 2.7 TeV at 95%CL

Limits on the Heavy Vector Triplet "B"-type model: V': 4.8 TeV at 95%CL
HVT C-type: Upper Limit on x-section and branching ratio at 0.1fb

Search for Vector Like Leptons

CMS-PAS-B2G-021-004
acc. PL B

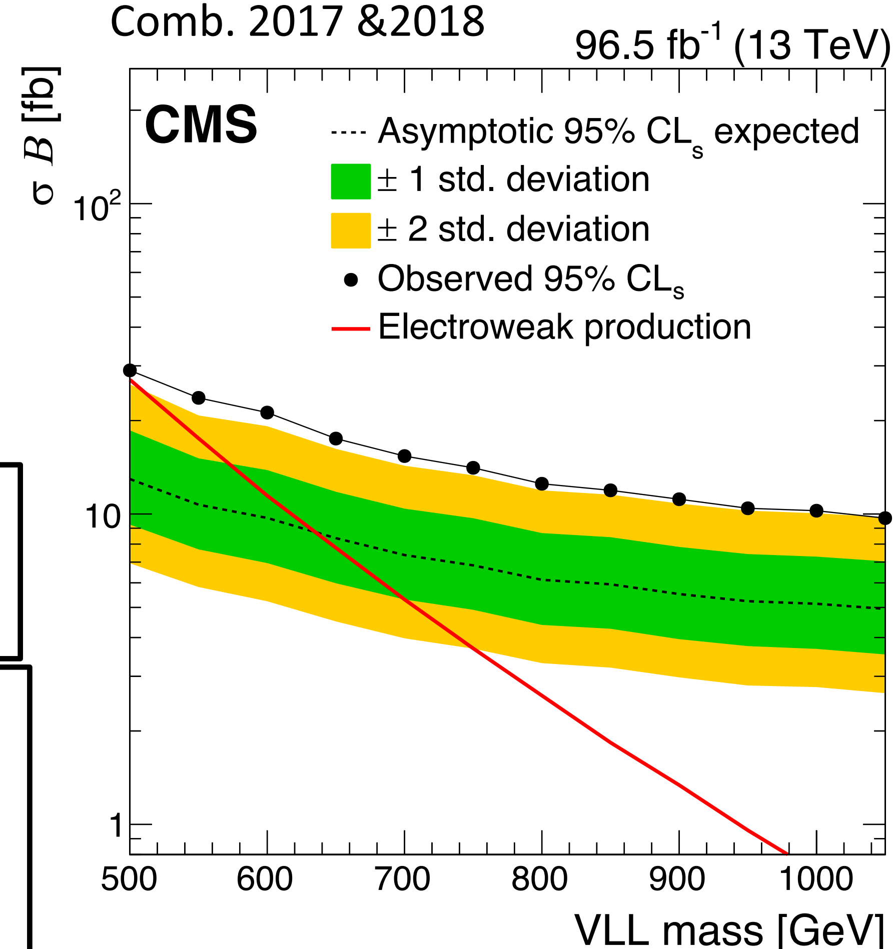
Vector Like–Leptons from 4321 UV-complete model
Potential to explain B-physics results tensions with SM
SU(4) brings VLF pair produced or coupled to LQ



Final states with more than 3 b-jets and a pair of 3rd gen ($\tau\nu$, $\tau\tau$, $\nu\nu$) in the final state
Graph-NN used to discriminate particles in multi-jet events

Expected exclusion of VLL masses below 640 GeV
Observed: small excess in the data !
Observed excess consistent with presence of VLL's e.g. at mass of 600 GeV at the level **2.8σ** over the background only hypothesis

Comb. 2017 &2018

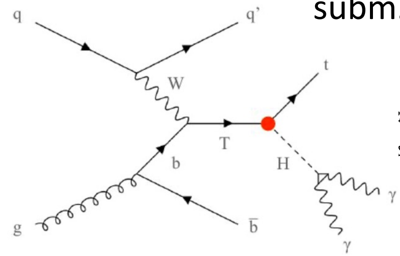


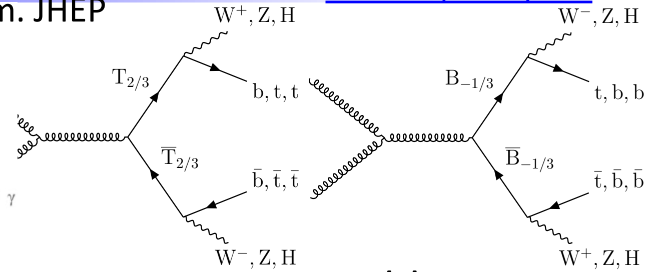
Search for Vector Like Quarks

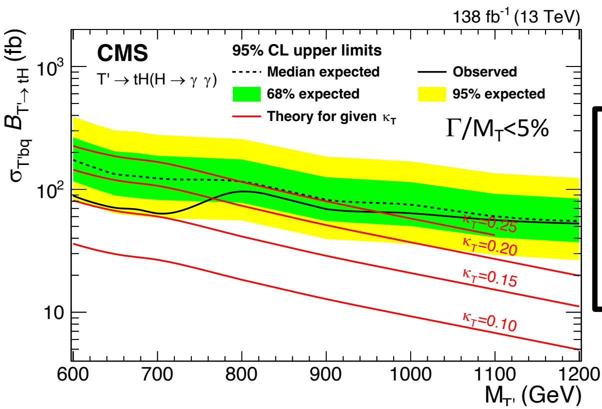
CMS-B2G-021-007
subm. JHEP

CMS-B2G-020-011
JHEP07(2023)020

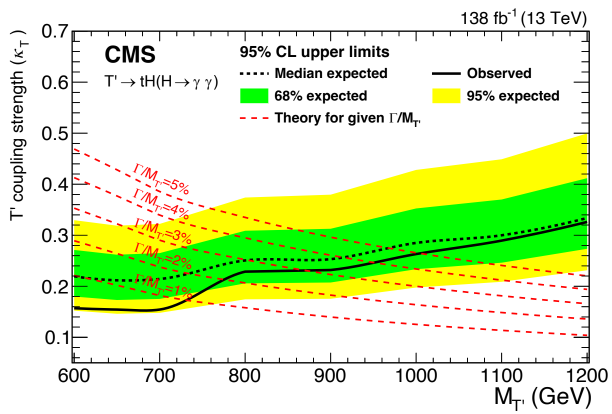
Vector-Like Quarks are in many models and affect quantum loop corrections to Higgs mass ;
VLQ pair and in single production with resonance of t/b quarks with bosons







hadronic and leptonic decay modes of the top quark;
MVA with 3 separately optimized BDTs

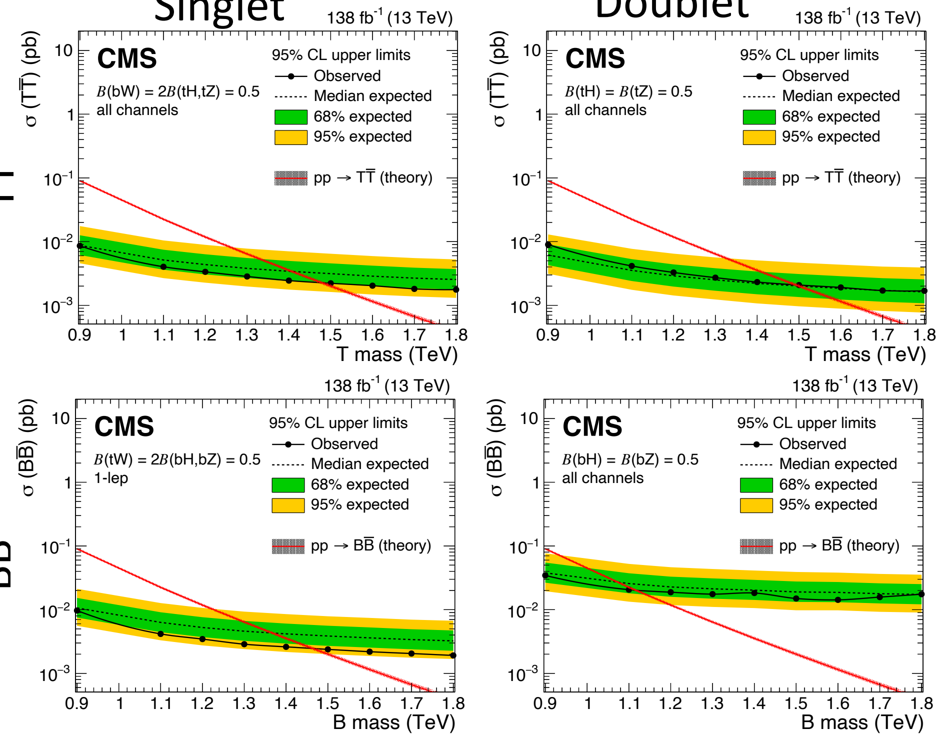


Singlet

Doublet

TT

BB

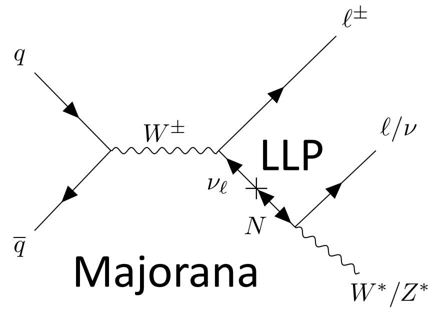


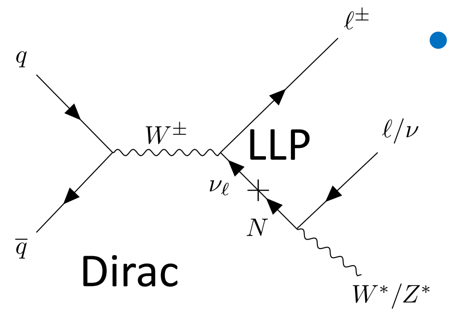
Exclusion of VLQ below 960 GeV@95%CL with κ_T=0.25 and Γ/M_T<5%

Exclusion@95%CL of:
T_{VLQ} below 1.54TeV B_{VLQ} below 1.56 TeV (Br)

Search for Heavy Neutral Lepton - HNL

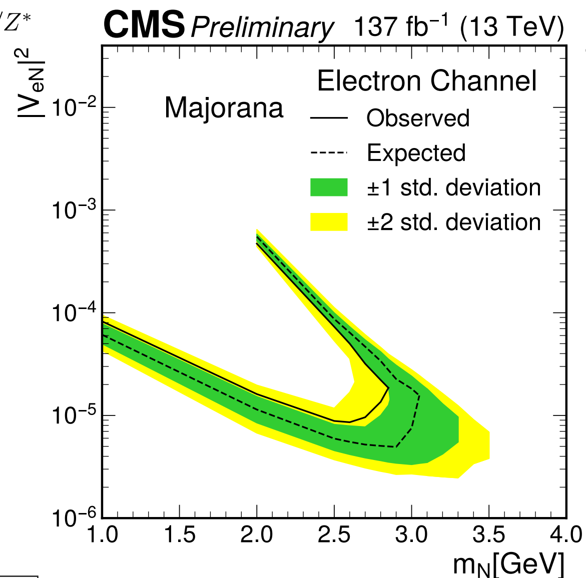
CMS PAS EXO-22-017

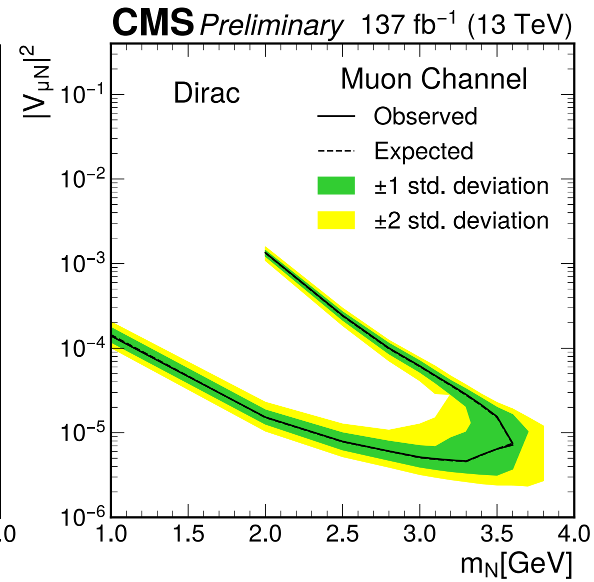




- Signature: prompt lepton (ℓ^+) and **displaced lepton (LLP)** and **W/Z boson**

- SM and Hidden/Dark Sector connected by a portal
  - Neutrino mixes with a SM neutrino and serves as the portal to SM
  - Long lifetime enough to fly a meter away
- New Techniques to Probe more complex but well motivated models
  - Displaced muon trigger using clusters of hits in muon detectors only
- HNL with mass <10Gev and τ < 1m





Coupling	HNL type	m_N (GeV)	Excluded range at 95% CL
$\|V_{Ne}\|^2$	Majorana	2.6	8.6×10^{-6}–5.0×10^{-5}
$\|V_{N\mu}\|^2$	Majorana	2.8	5.0×10^{-6}–3.9×10^{-5}
$\|V_{N\tau}\|^2$	Majorana	1.8	2.5×10^{-4}–1.8×10^{-3}
$\|V_{Ne}\|^2$	Dirac	2.8	8.9×10^{-6}–7.5×10^{-5}
$\|V_{N\mu}\|^2$	Dirac	3.3	4.6×10^{-6}–2.8×10^{-5}
$\|V_{N\tau}\|^2$	Dirac	1.8	3.1×10^{-4}–5.9×10^{-3}

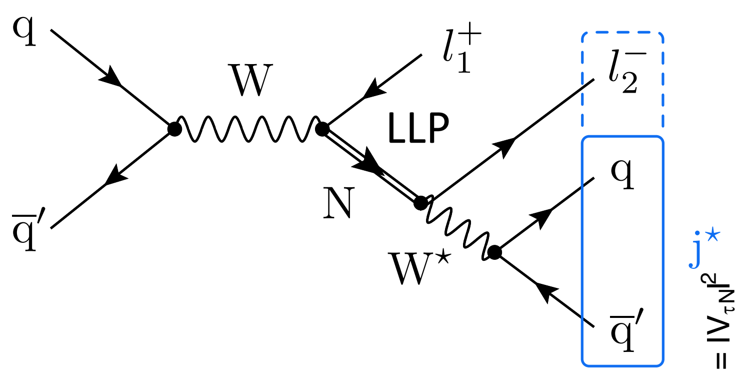
-- Sensitivity to three lepton couplings for Dirac and Majorana Neutrinos

-- No deviations from the SM expectations observed

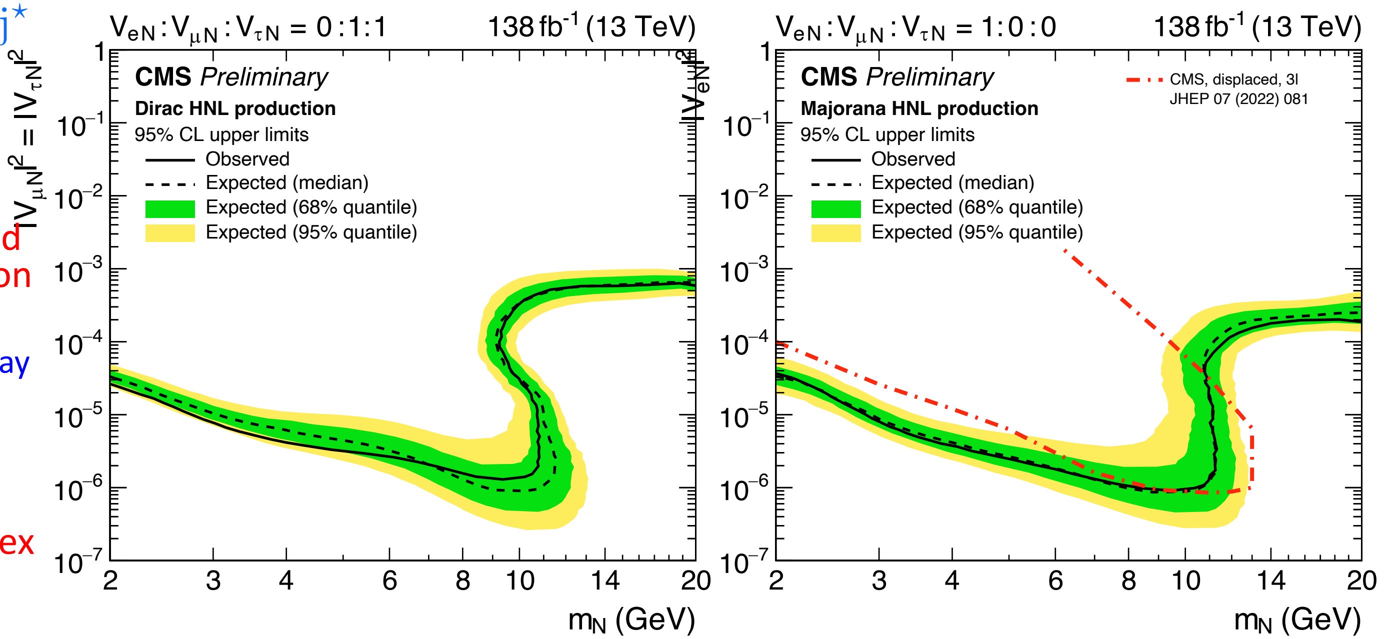
-- Most stringent observed limits of $|V_{lN}|^2$ for Majorana and Dirac type HNL in the mass range of 2.1-3.0 (1.9-3.3) GeV, reaching squared mixing parameter values as low as 8.6(4.6) × 10^{-6} in the e (μ) channel

Search for Heavy Neutral Lepton

CMS PAS EXO-21-013



- Signature: prompt lepton (ℓ_1^+) and **displaced lepton and a jet**

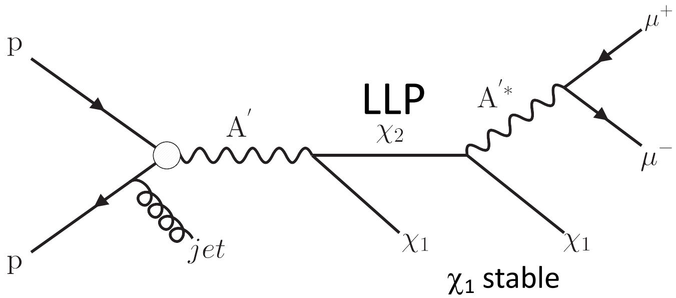


- SM and Hidden/Dark Sector connected by a portal with a Heavy Neutral Lepton
  - HNL serves as the portal to SM
  - Long lifetime enough to fly meters away
- Coupling scenarios involving all three lepton generations
- New Techniques to Probe more complex but well motivated models
  - DNN tagger for displaced jets

- Sensitivity to three lepton couplings for Dirac and Majorana Neutrinos
- The best limit on the coupling strength obtained for pure muon coupling scenarios excluding values of $|V\mu N|^2 > 5\ (4) \times 10{-}7$ for Dirac (Majorana) HNLs with a mass of 10 GeV at 95% CL

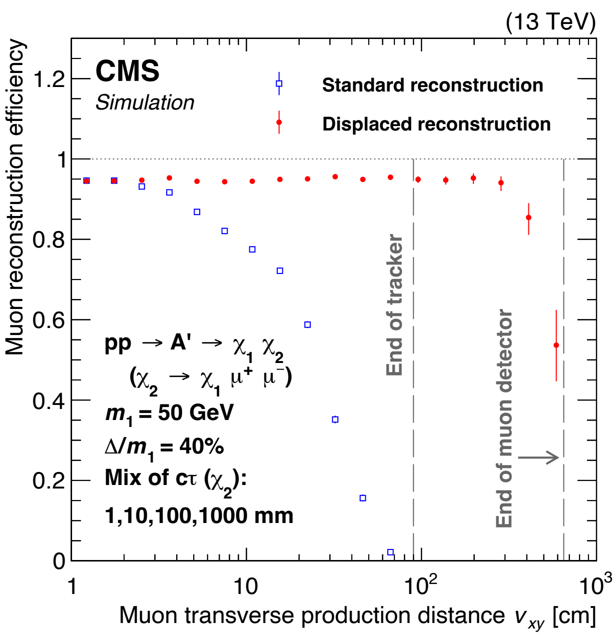
Inelastic Dark Matter

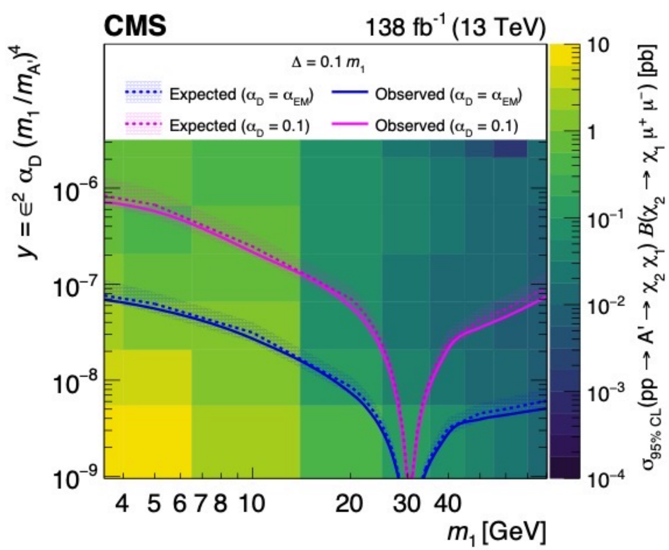
[CMS-EXO-20-010]

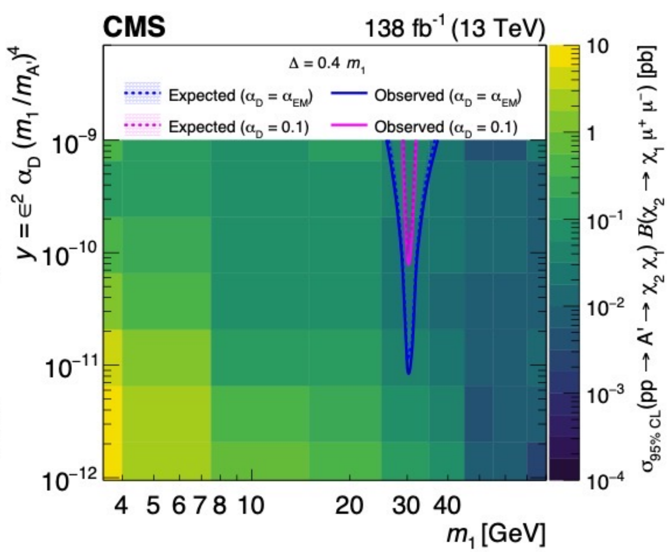


Signature: 2 almost collinear displaced low momentum muons, MET recoiling against an ISR jet

- IDM with 2 DM(χ1, χ2) compressed states with increased lifetime and a dark photon A
- New Techniques to Probe more complex but well motivated Dark Matter models
  - Displaced muon reconstruction
- SM and Dark Sector connected by a portal
  - Dark photon A serves as the portal to SM







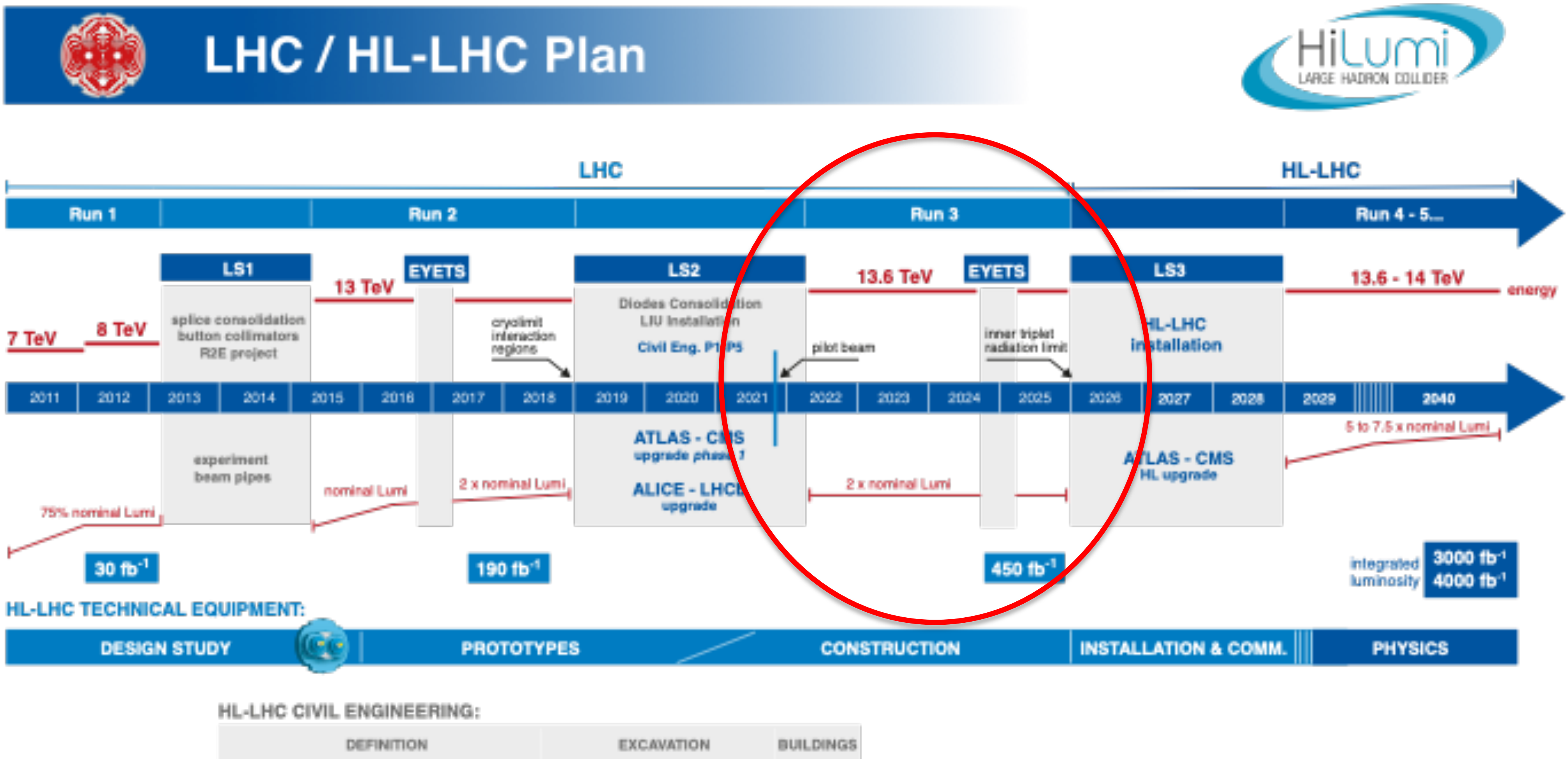
y-interaction strength; m_1-light DM mass ; M_A=3m_l ; mass splitting Δ=m2-m1; ε-kinetic mixing param. between A and SM hypercharge ; α_D coupling strength of the U(1)$_D$ in the dark sector

Regions above the curves excluded

No excess observed over the SM expectations
First search for inelastic dark matter and expands sensitivity to m_1 above 10GeV

Part 4 – What is next ?

Beyond Run 2 and 3



CONCLUSIONS

- Many precise and important measurements from Runs 2&3 already available:
  - Higgs boson, Top quark and Gauge boson measurements
  - Direct searches for new physics
- No signs of physics beyond standard model yet, but Run 2&3 analyses continue and combination of datasets imminent
- Improved limits on new particles often in new regions of parameter space
  - Results can be used to further constrain the model building !
- The well known open questions still remain! Plenty of work to do !

CORFU2023

- Many more new and interesting results from Run 2,3 which I had no time to discuss : focus on full data sets and newest results

- Other talks at this conference extend the coverage:
  - Mon 28.08 – 10:30 – Rainer Mankel – “Higgs Physics in Atlas and CMS” (CMS)
  - Tue 29.08 – 13:00 – Elvira Rossi – “SM (QCD+EWK) in Atlas and CMS” (Atlas)
  - Wed 30.08 – 12:00 – Otila Anamaria Ducu – “SUSY in Atlas and CMS” (Atlas)
  - Wed 30.08 – 09:00 – Jun Guo– “Exotics and BSM (non-SUSY non-DM) in Atlas and CMS” (Atlas)
  - Wed 30.00 – 12:30 – Bisnupriya Sahu – “Dark Matter in Atlas and CMS”(CMS)
  - Fri 03.09 – 12:30 – Markus Cristinziani– “Top Physics in Atlas and CMS” (Atlas)

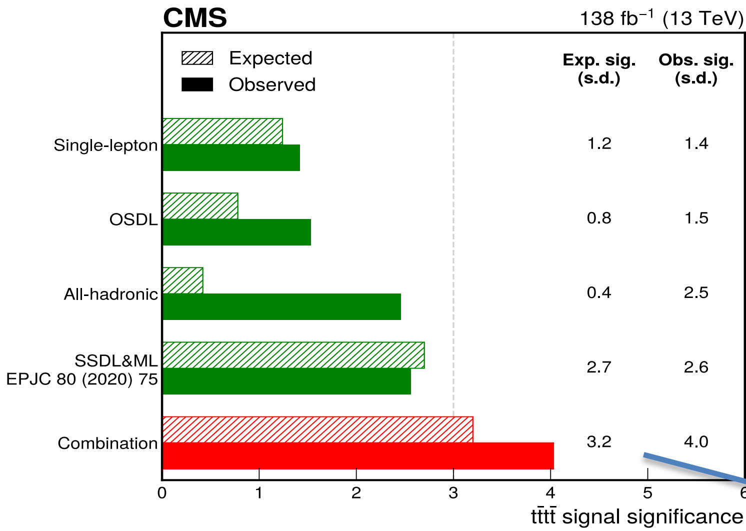
- More information about CMS publications on CMS twiki
  - CMS Preliminary Public Results ±

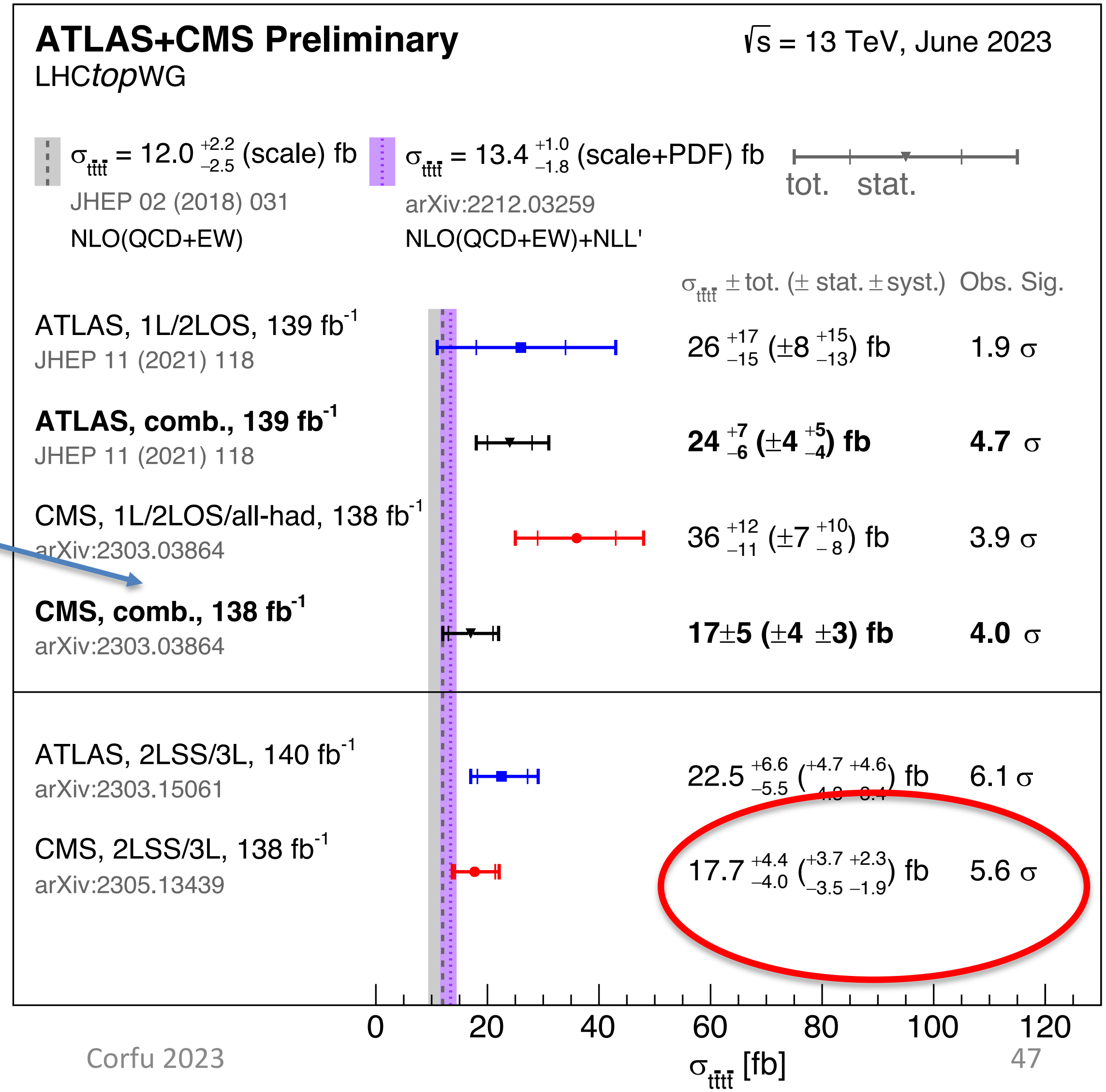
Additional Slides

FOUR Top Quark Production

Phys.Lett.B 844, Sep 2023, 138076

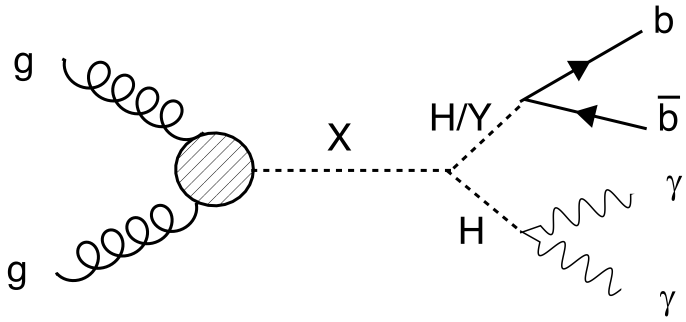
LHCPhysics/LHCTopWGSummaryPlots

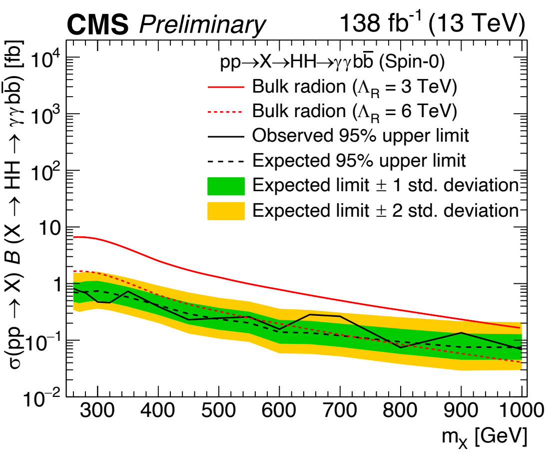


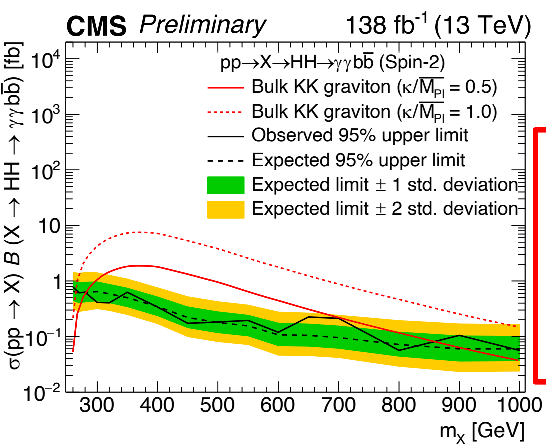


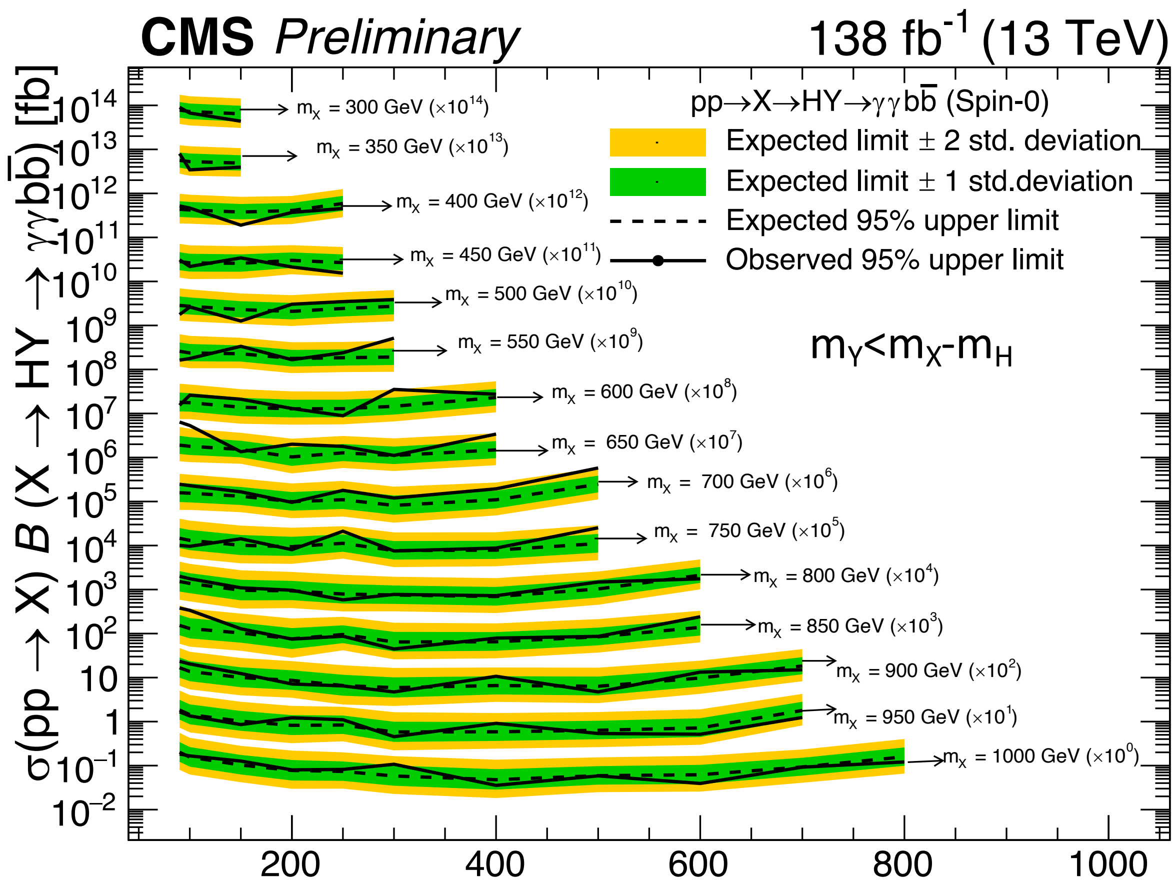
Search for X → H/Y(bb)H(γγ)

CMS-PAS-HIG-021-011







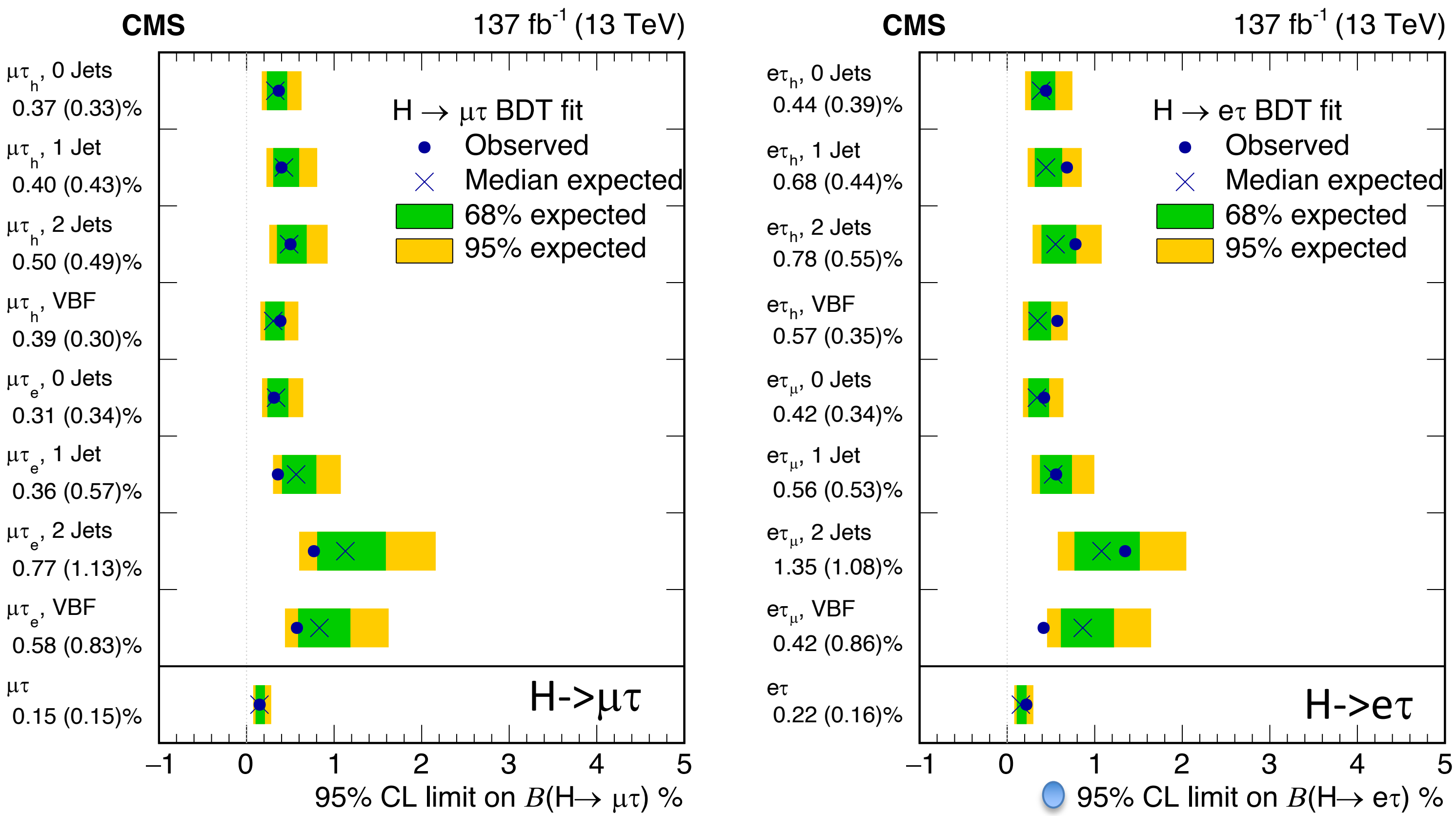


Overall agreement with the SM
Data compatible with background-only-hypothesis

Largest deviation M_X=650GeV and M_Y=90GeV w/ Local (Global)3.8σ(2.8σ)

LFV Higgs Decays Run 2

Phys. Rev. D 104 (2021) 032013



	Observed (expected) upper limits (%)	Best fit branching fractions (%)	Yukawa coupling constraints
$H \to \mu\tau$	<0.15 (0.15)	0.00 ± 0.07	$< 1.11\,(1.10) \times 10^{-3}$
$H \to e\tau$	<0.22 (0.16)	0.08 ± 0.08	$< 1.35\,(1.14) \times 10^{-3}$

No excess observed in Run 2 data

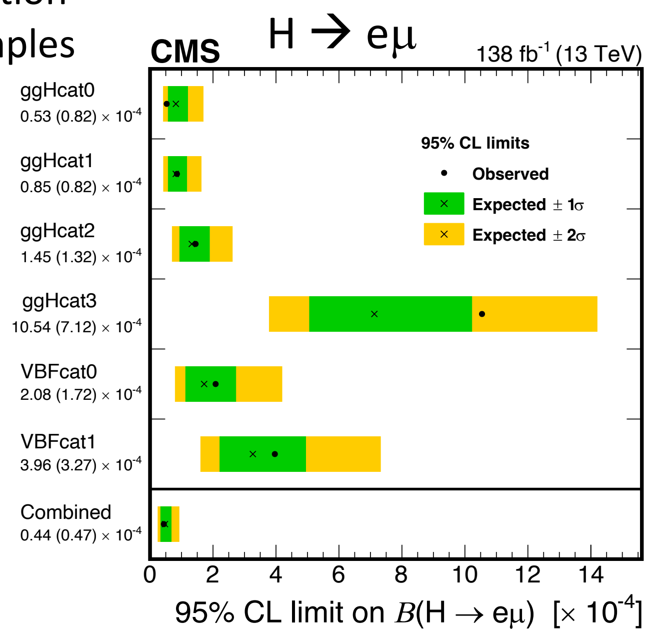
LFV Higgs Decays Run 2

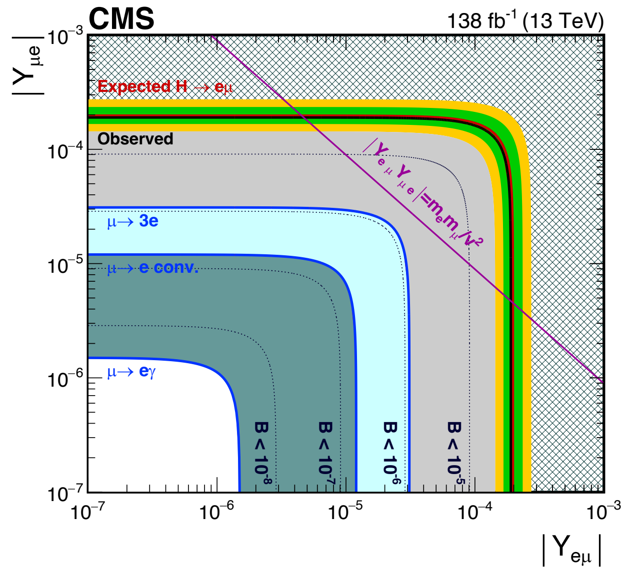
arxiv:2305.18106

HIG-22-002

Production of X in the mass range 110-160GeV

Select one eμ OS pair
b-jet veto
VBF and ggF production
Divided into subsamples



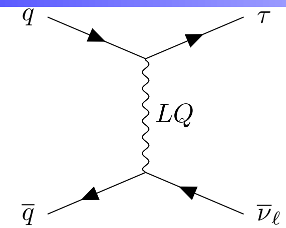


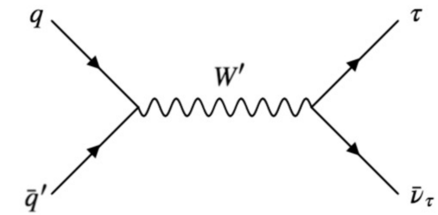
@M_H=125GeV: Observed(expected) Upper Limit on BF of H→ eμ:
4.4(4.7) x 10^{-5} @95% CL
Yukawa Coupling: < 1.9(2.0) x 10^{-4} @95% CL

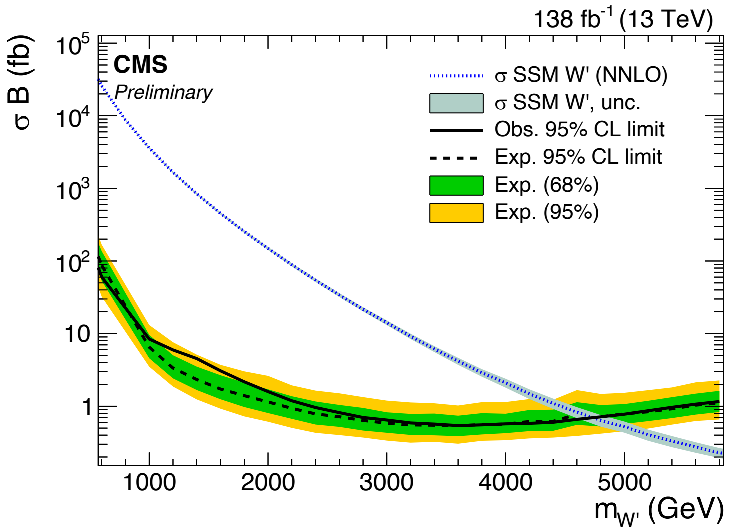
Search for 3rd-Gen LeptoQuarks

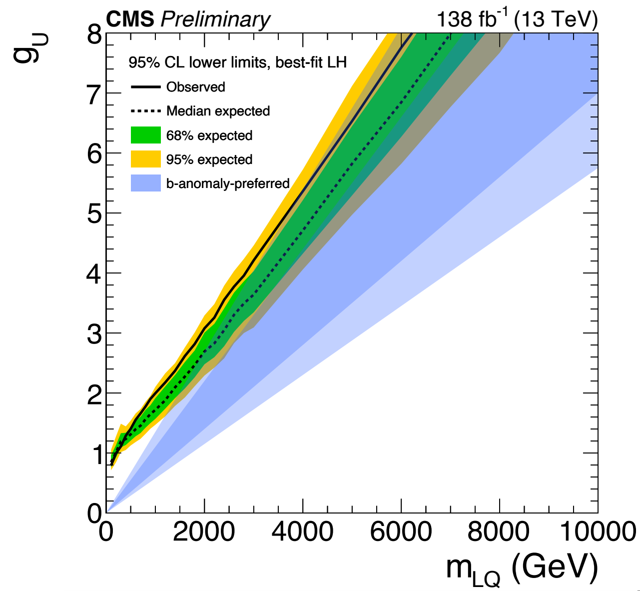
CMS-PAS-EXO-21-009
2212.12604 acc. JHEP

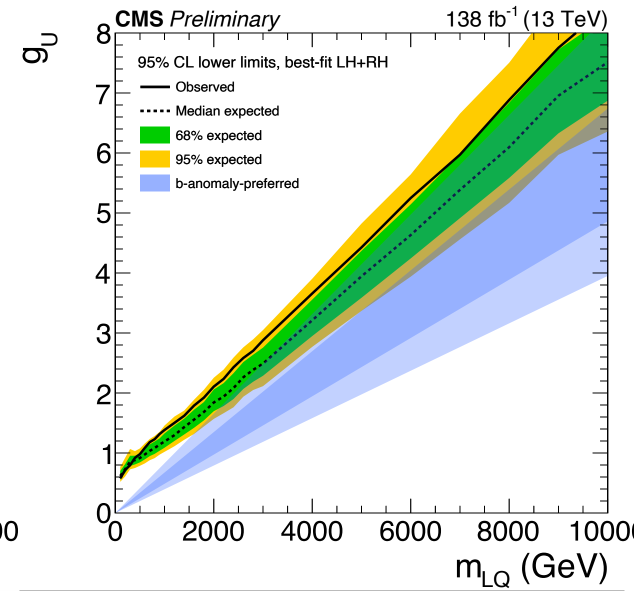
t-channel LQ exchange with τν in the final state and typical channel for W' search

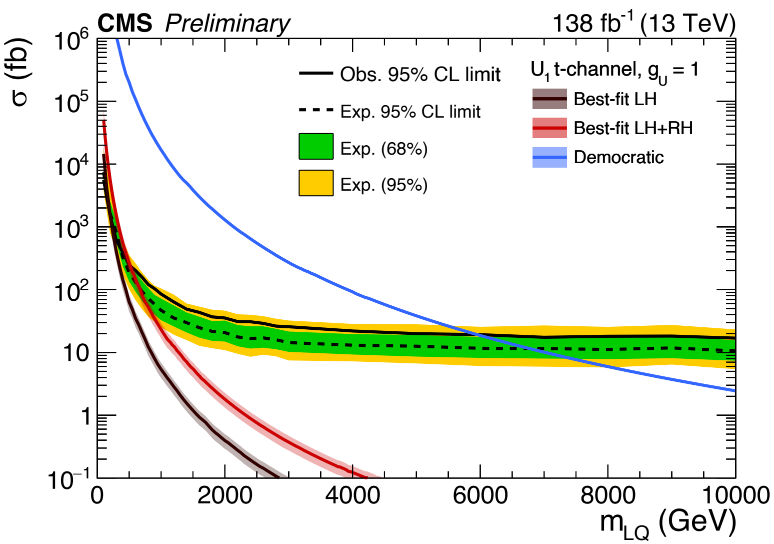










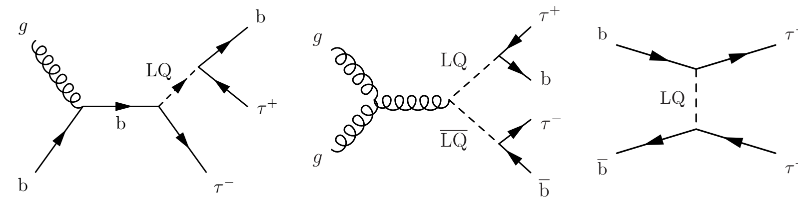


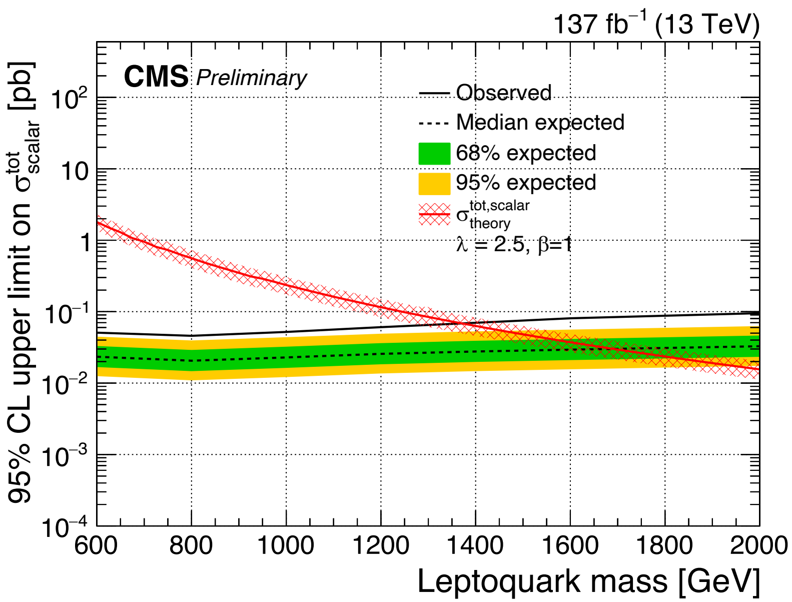
Excluded: QBH below 6.6TeV, W' below 4.6 TeV
First UL set on LQ x-sec in t-channel
Limits set on g_U coupling strength to quark and τ lepton as a function of its mass :
"e.g. excluded portion of the parameter space that can explain **b physics anomalies " – no R_K anomaly**

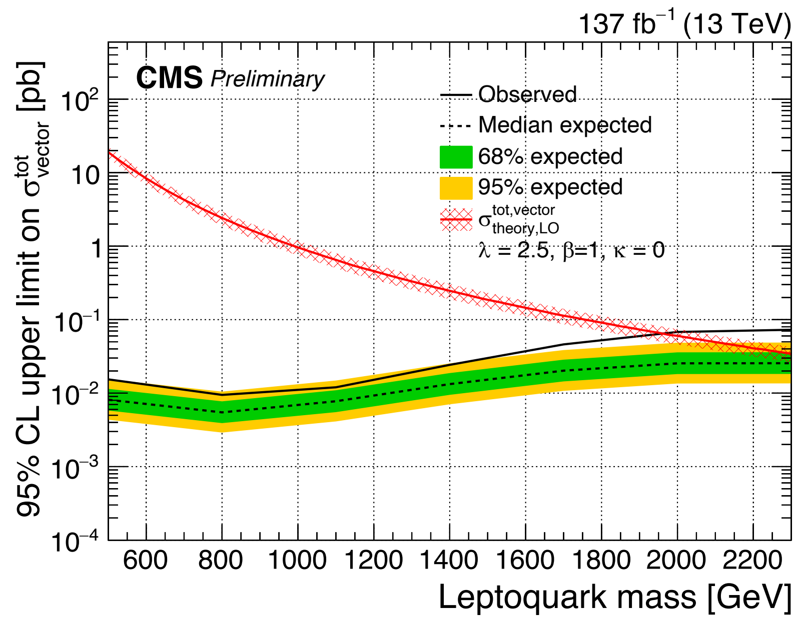
Search for 3rd-Gen LeptoQuarks

CMS-PAS-EXO-19-016

3rd gen. LQ with a pair of ττ and b-quark in the final state
LQ predicted by many extensions of the SM







95%CL Limits set on LQ coupled to b-quark and τ lepton with LQ masses excluded :

LQ^{scalar}— below 1.22 (1.31)TeV with λ=1(λ=2.5)

LQ^{vector} – below 1.50(1.82)TeV for κ=0(1) and λ=1

LQ^{vector} – below 1.73(1.88)TeV for κ=0(1) and λ=2.5

For LQ mass of 2TeV and λ=2.5 an excess of **~2.8σ** observed in the t-channel LQ exchange

Search for SUSY EWKinos in Run 2

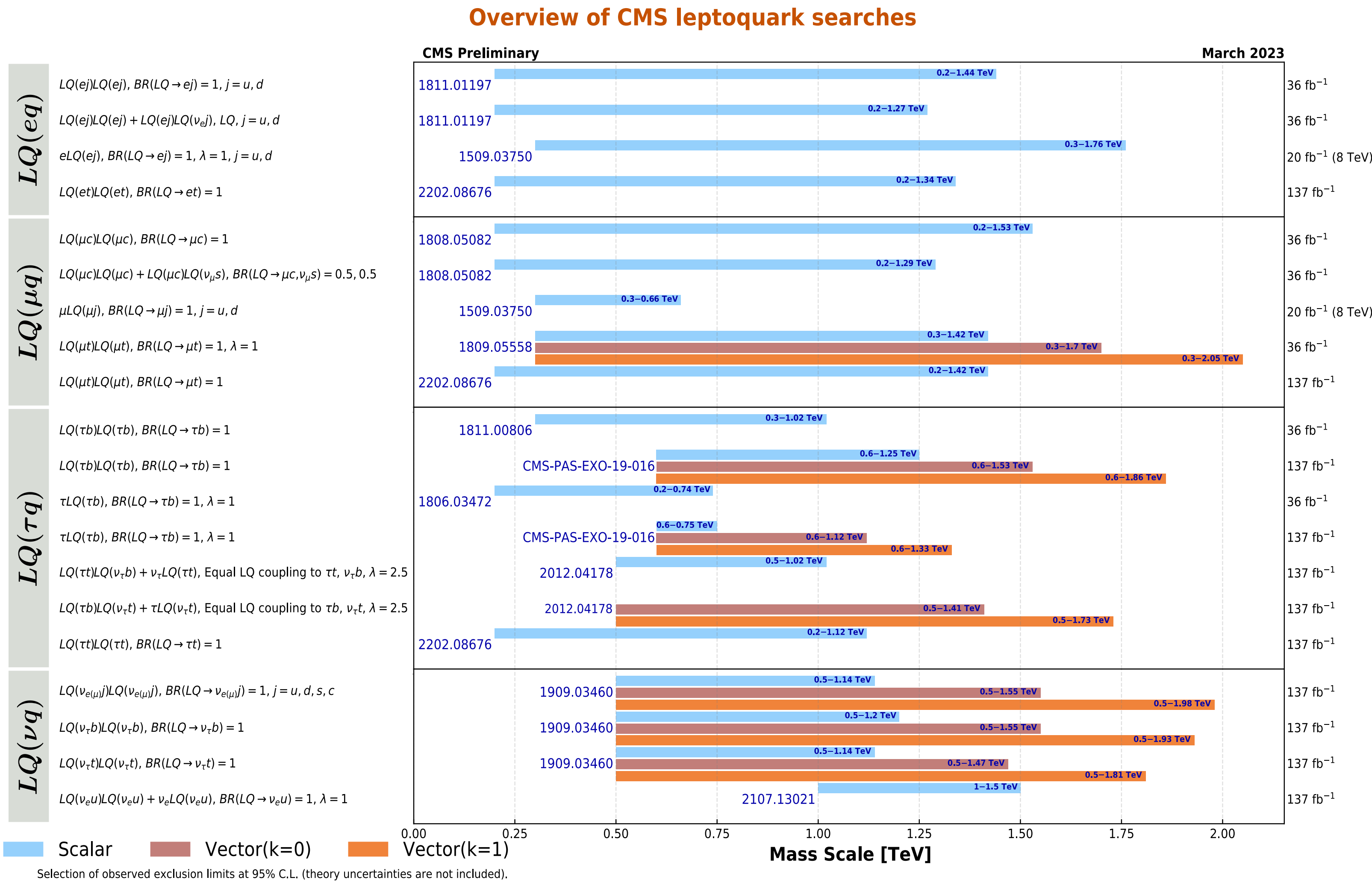
Combination of EWK production of: winos, binos, higgsinos and sleptons

	gaugino		GMSB			higgsino-bino			sleptons
Search	WZ	WH	ZZ	HZ	HH	WW	HH	WH	$\ell^+\ell^-$
$2/3\ell$ soft [17]	all								2ℓ soft
2ℓ on-Z [15]	EW		EW	EW					
2ℓ non-res. [15]									Slepton
$\geq 3\ell$ [18]	SS, A(NN)	SS, A–F	all	all	all			SS, A–F	
1ℓ2b [16]		all						all	
4b [19]					all		3-b, 4-b, 2-bb		
Hadr. WX [20]	all	b-tag				b-veto		b-tag	

[15] JHEP04(2021)123
[16] JHEP10(2021)045
[17] JHEP04(2022)091
[18] JHEP04(2022)147
[19]JHEP05(2022)014
[20] PL B842(2023)137460

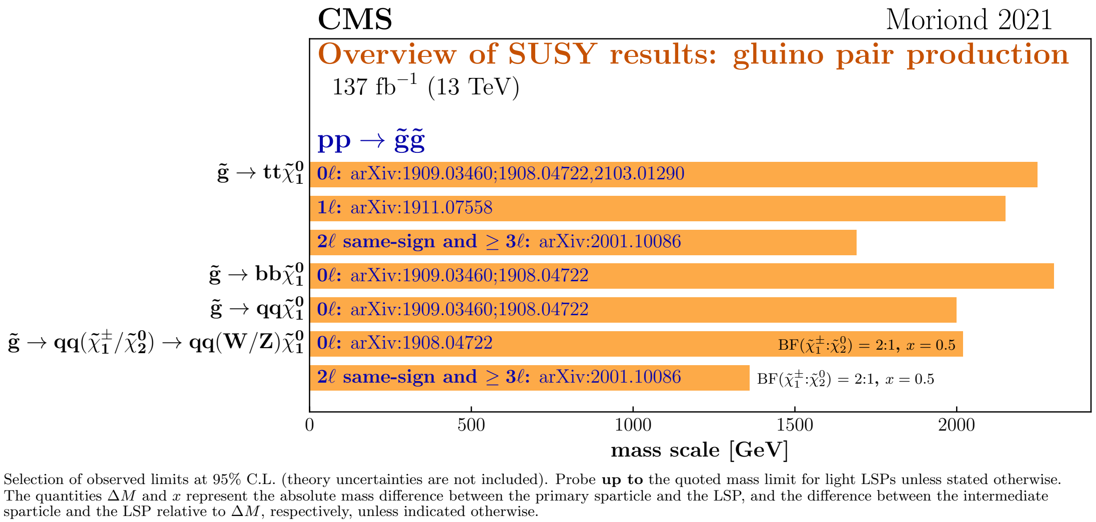
Combination provides additional coverage of the parameter phase space and increases sensitivity in the compressed mass parameter regions

Summary of LQ Searches

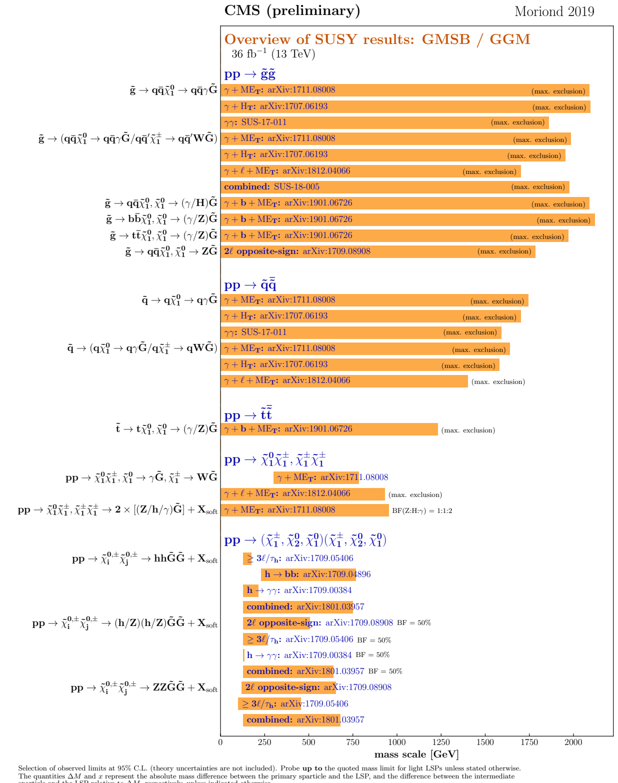


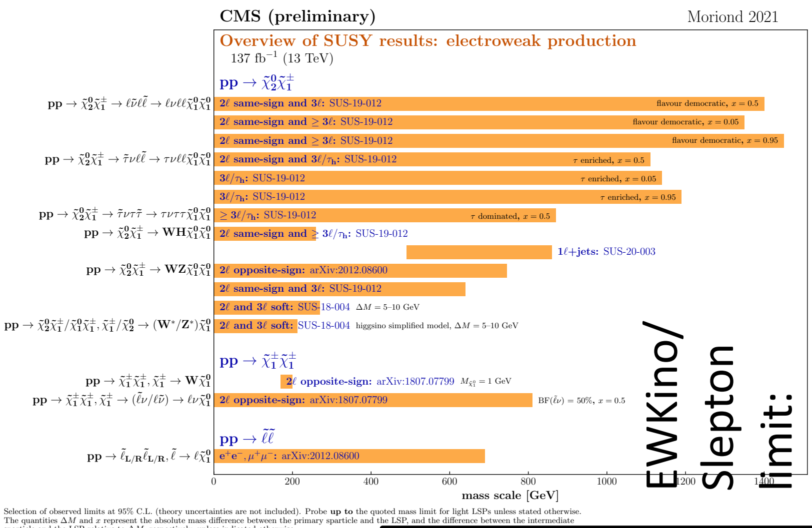
CMS LQ 2023

SUSY Searches Summary

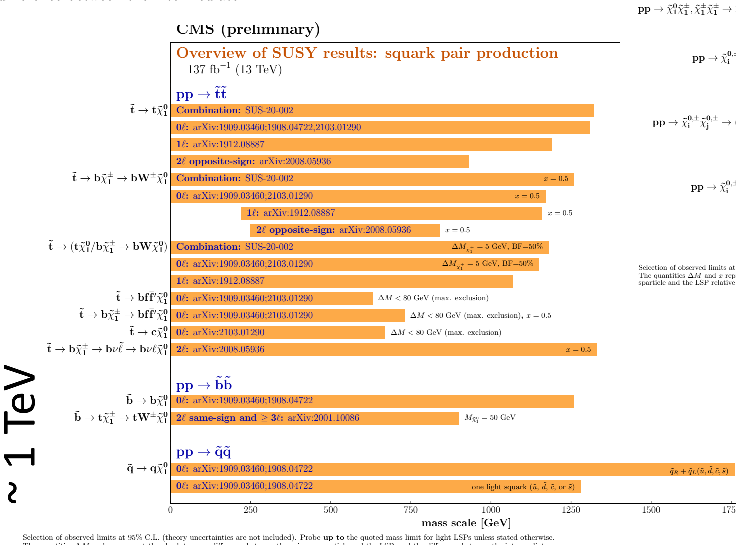


Gluino limit: ~2 TeV





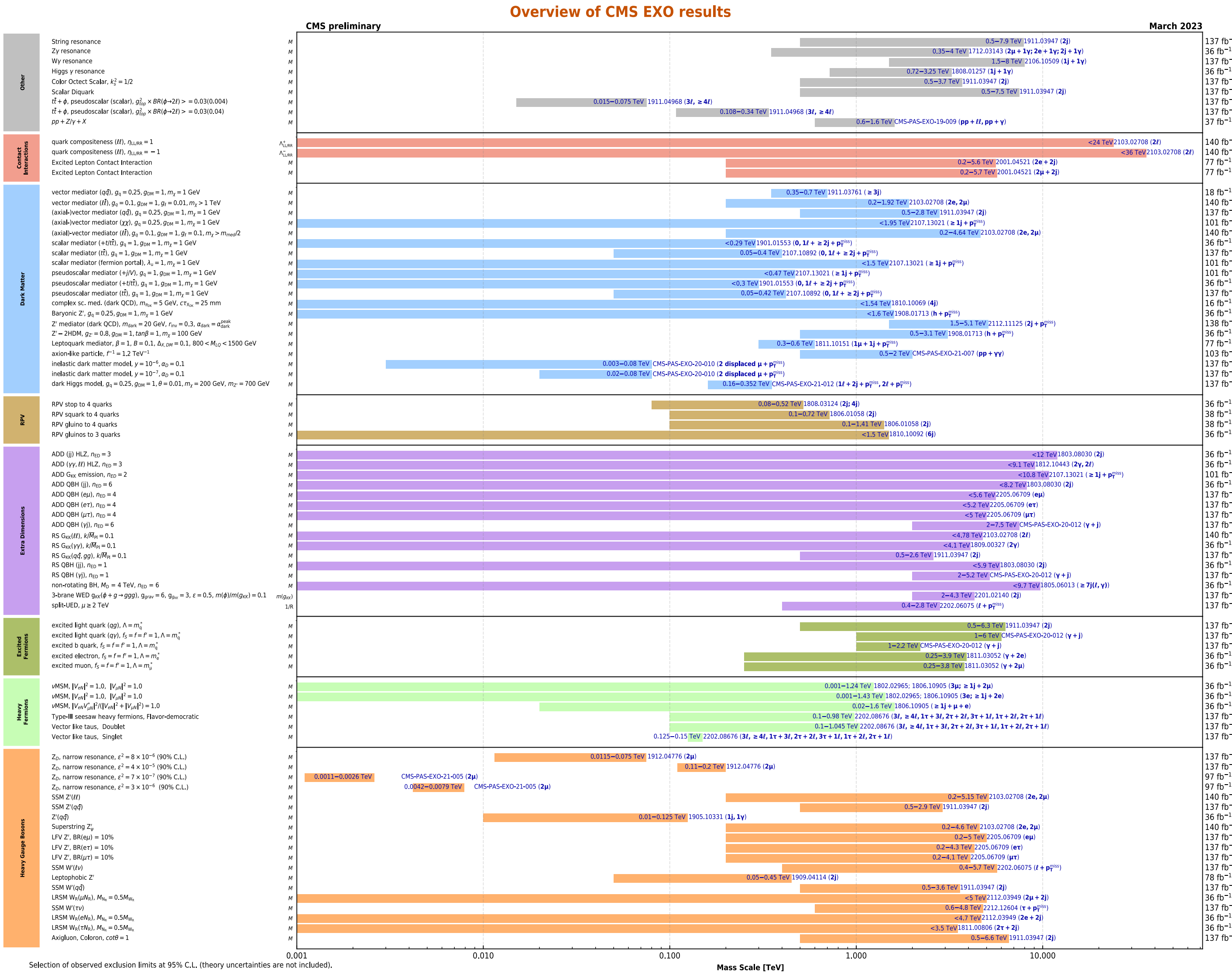
EWKino/Slepton limit: ~ 1 TeV



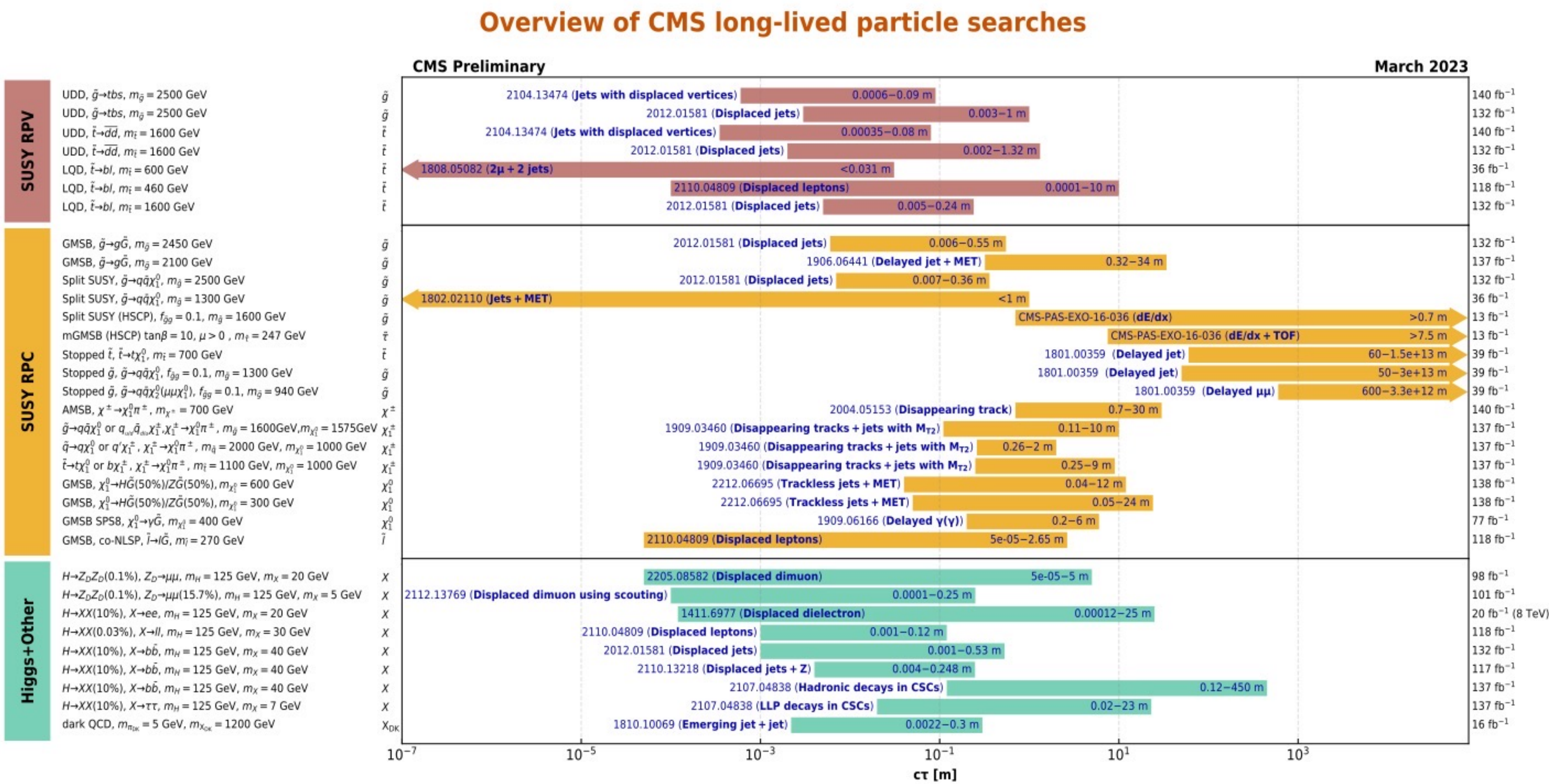
Sbottom/Stop limit: ~1.2 TeV

No sign of SUSY found at the LHC Run 2
continue probing the TeV scale using Simplified models

Summary of Exotic Searches



Summary of Exotic Searches LLP



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.