TWENTY-FIRST LOMONOSOV CONFERENCE ON ELEMENTARY PARTICLE PHYSICS

August, 24-30, 2023

MOSCOW STATE UNIVERSITY

Overview of the Recent Results of the CMS Experiment

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on behalf of the CMS Collaboration
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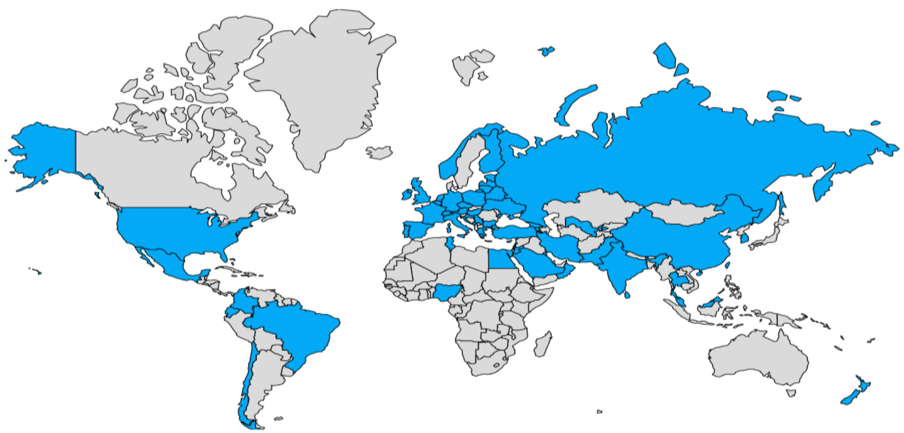
CMS Overview

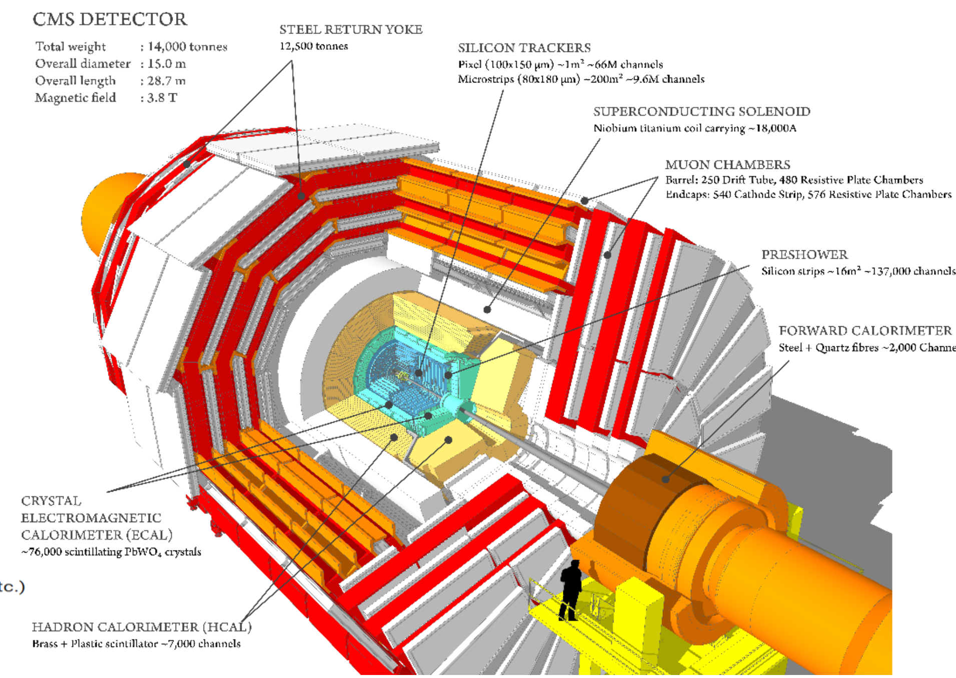
The CMS experiment has members from **255** institutes coming from **57** countries

3401 Physicists (1229 students) | **1118** Engineers | **283** Technicians



The CMS collaboration has around **6385** active people (physicists, engineers, technical, administrative, students, etc.)

2172 Phd Physicists (405 women 1767 men) | **1229** Physics Doctoral Students (324 women 905 men) | **1118** Engineers (152 women 966 men) | **1455** Undergraduates (414 women 1041 men)



https://cms.cern/
https://cms-info.web.cern.ch/

Moscow State University, Moscow, 26 August, 2023

Some Statistics from CMS

This talk are summarized the selected (by me) the recent CMS Results results (the SM, Higgs physics and BSM)

LHCP2023, 22-27 May, Belgrad,
EPS-HEP2023, 21-25 Aug 2023, Hamburg
[Recent CMS Briefings]

Lomonosov2023 talks with the CMS Results

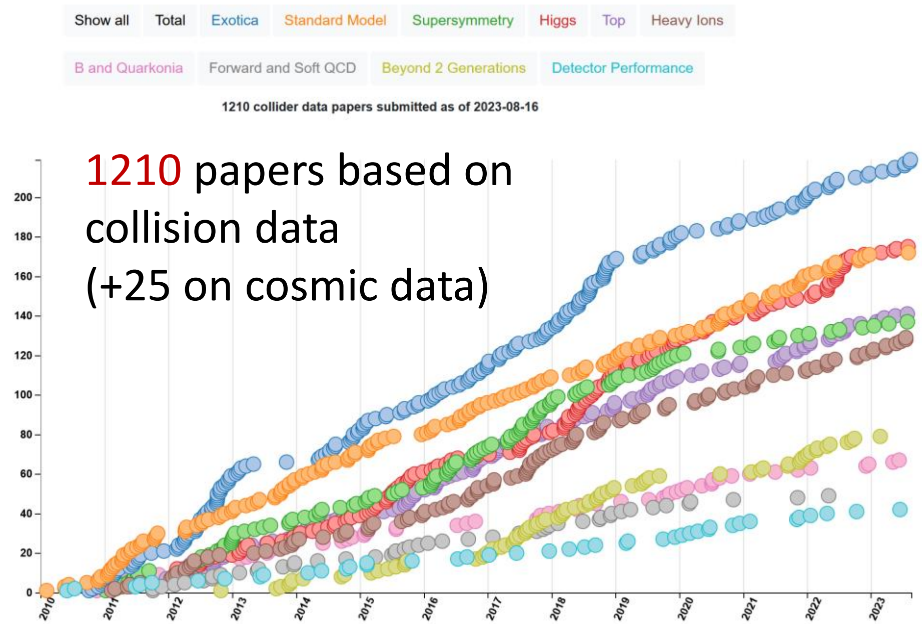
QCD and Heavy Ions
Olga Kodolova, QCD physics with CMS detector
Serguei Petrushanko, Latest results on heavy-ion physics..
D.Myagkov (MSU) Azimuthal anisotropy in Xe–Xe and Pb–Pb collisions..

Standard Model
Nikita Petrov, New resonances in J/psi J/psi mass spectrum at CMS
Kirill Ivanov, CMS results on heavy flavour spectroscopy and production
Ruslan Chistov, Searches for lepton flavour / universality violation at CMS
Maksim Sergeev, Recent CMS results on rare heavy flavour decays
Itana Bubanja, Inclusive production of vector bosons in CMS

Beyond the Standard Model
Maria Savina, Dark Matter Search at the LHC

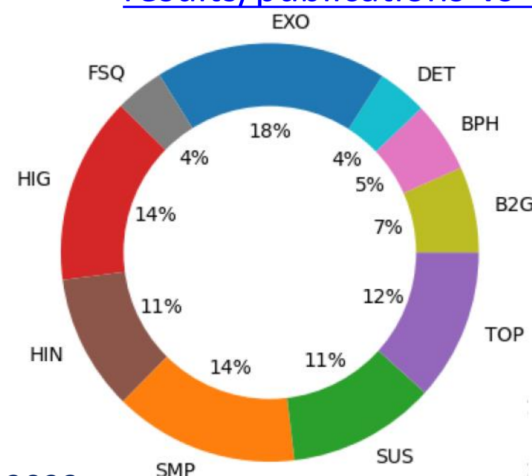
CMS Publications Page
https://cms-results.web.cern.ch/cms-results/public-results/publications/

CMS Public Results (newest)
https://cms-results-search.web.cern.ch/



1210 papers based on collision data (+25 on cosmic data)

http://cern.ch/cms-results/public-results/publications-vs-time/



35% of Standard Model (SMP/FSQ/BPH/TOP)

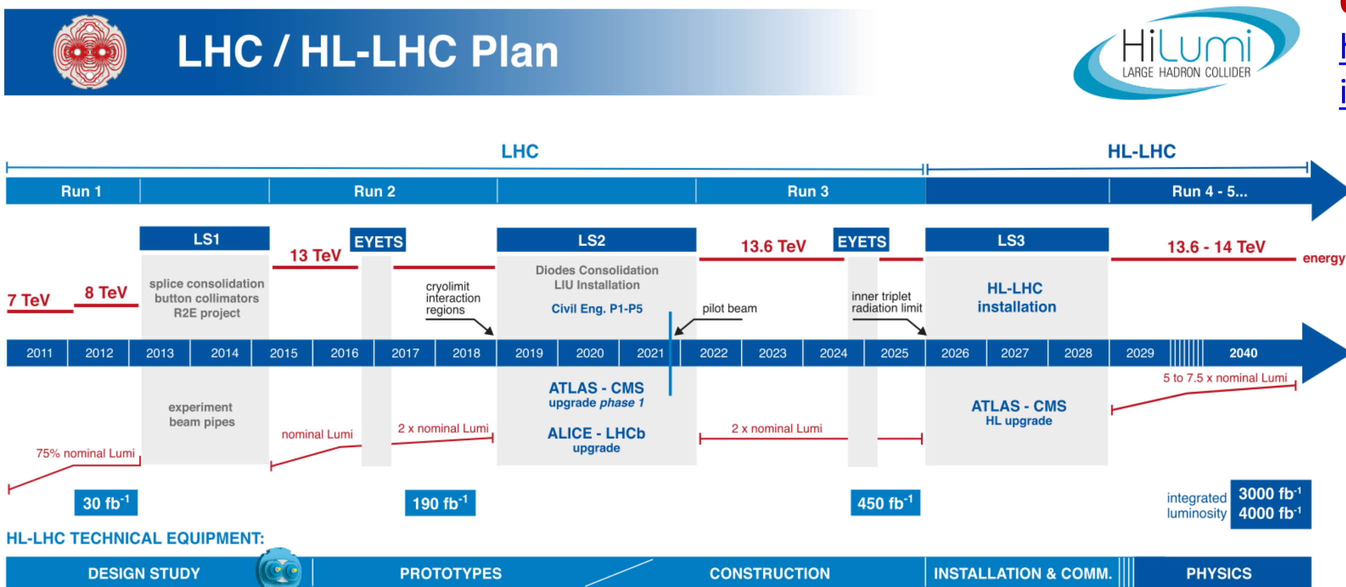
14% of Higgs Physics

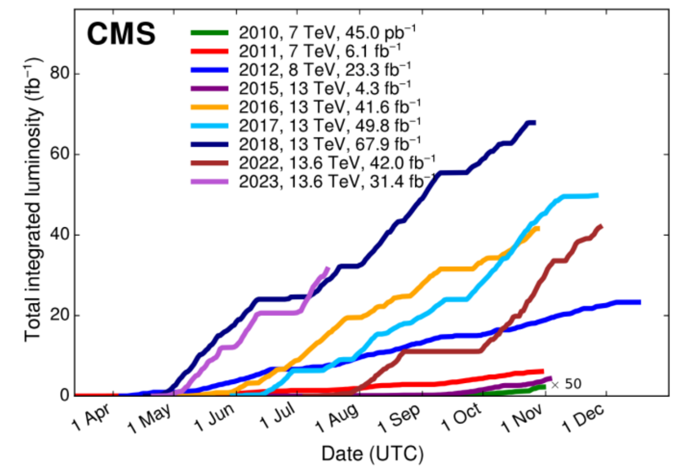
36% of BSM Physics (EXO/B2G/SUSY)

11% of Heavy Ion

LHC Timeline and Data That We Have

CMS Luminosity Information
https://twiki.cern.ch/twiki/bin/view/CMSPublic/LumiPublicResults



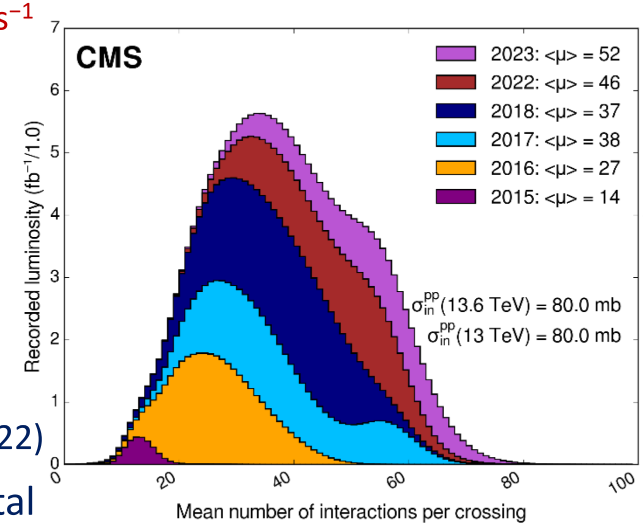


L_{inst} = 2.1×10^{34} $cm^{-2}s^{-1}$

We are here

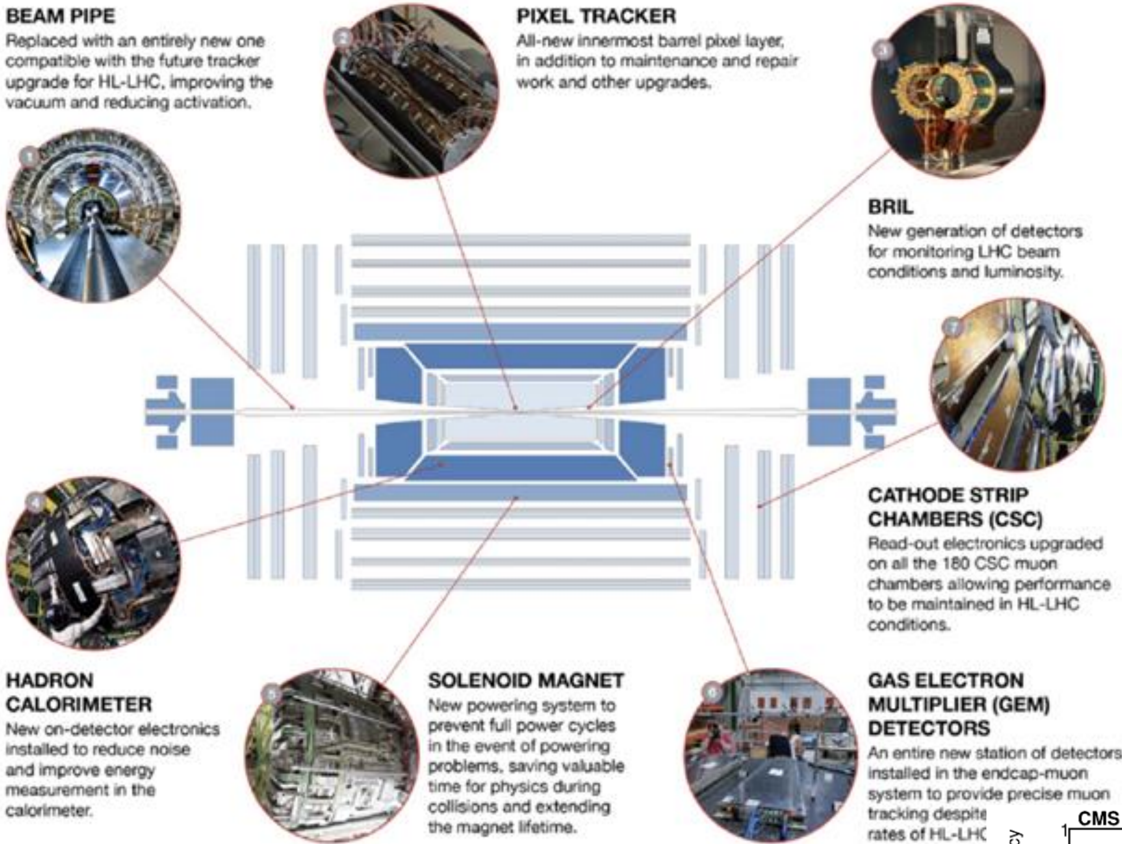
L_{nisyt} = 7.5×10^{34} $cm^{-2}s^{-1}$

- CMS Dataset RUN2
  - ✓ ~163 fb^{-1} of proton-proton collisions @ 13 TeV is delivered
  - ✓ 151.78 fb^{-1} is recorded by CMS (data-taking efficiency ~93%)
- CMS Dataset RUN3
  - ✓ ~73.4 fb^{-1} is already delivered @ 13.6 TeV during the RUN3
  - ✓ 63.7 fb^{-1} is recorded by CMS (data-taking efficiency ~92%)
  - ✓ ~93% of collected data "good for physics" in 2023 (91% in 2022)
  - ✓ number of pp interactions per beam crossing (PU): $\langle\mu\rangle$ = 52 for 2023 (46 for 2022)
- ~260 fb^{-1} it is expected @ 13.6 TeV for the end of the RUN3 (450 fb^{-1}, in total for RUN1/2/3)
- pPb and PbPb Runs (see talk by Serguei Petrushanko)



CMS Data Quality Information
https://twiki.cern.ch/twiki/bin/view/CMSPublic/DataQuality

CMS Detectors in RUN3



Completion of the Phase 1 upgrades and start of the Phase 2 upgrades.

Phase 1: HCAL barrel readout, new barrel inner pixel (layer 1)

Phase 2: First of GEM chambers installed, upgraded CSC electronics for HL-LHC, new beam pipe.

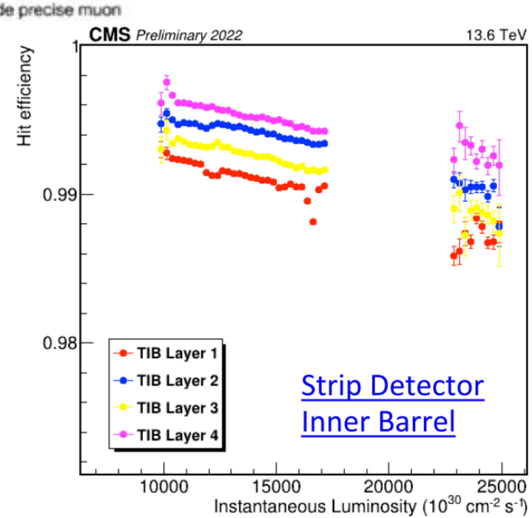
added GPUs to the HLT nodes.

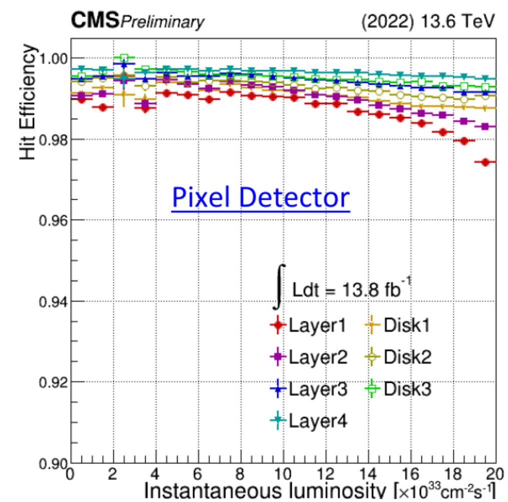
Demonstrator for Phase 2 muon drift tube electronics and Beam Radiation, Instrumentation and Luminosity (BRIL) demonstrators installed.

L. Silvestris LHCP 2023

From tests in 2022, we gained an understanding of the impact on tracker efficiencies at high instantaneous luminosity

- Strip Tracker shows **linear continuation** at higher luminosities,
- Pixel Layer 1 **well behaved up to design luminosity of 2 x 10^{34}.**





Physics of the Standard Model

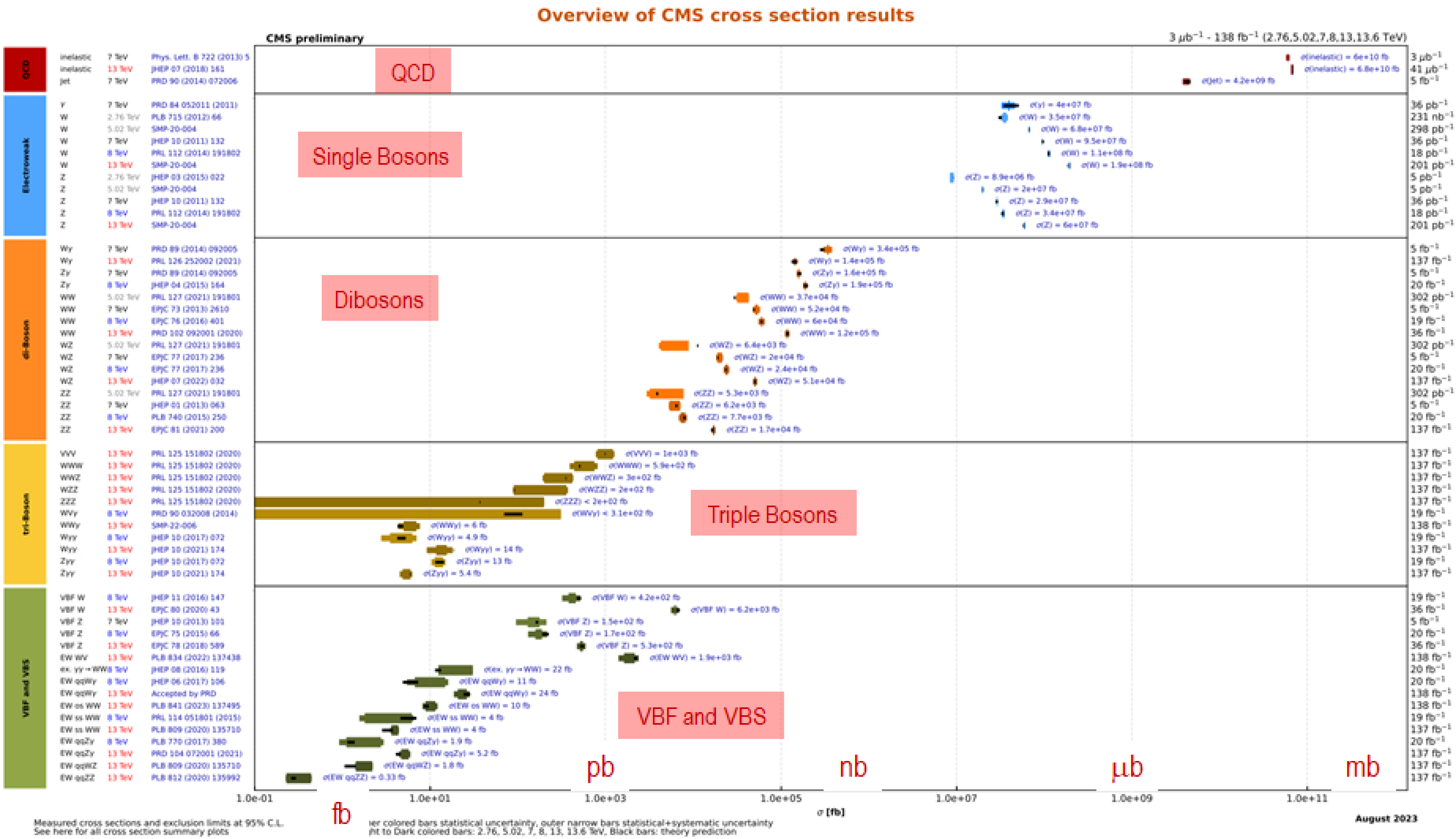
High rate at the LHC

- ✓ Provides statistic to study inclusive and differential distributions
- ✓ Good understanding of the detectors allow for precision measurements
- ✓ Test p-QCD and PDF in different regimes, deviations may indicate presence of new physics, EFT interpretations
- ✓ Developments and testing of new MC generators and techniques

Summary of Standard Model Tests with EWK Bosons

Summaries of CMS cross section measurements
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

plots are updated for Summer 2023 conferences



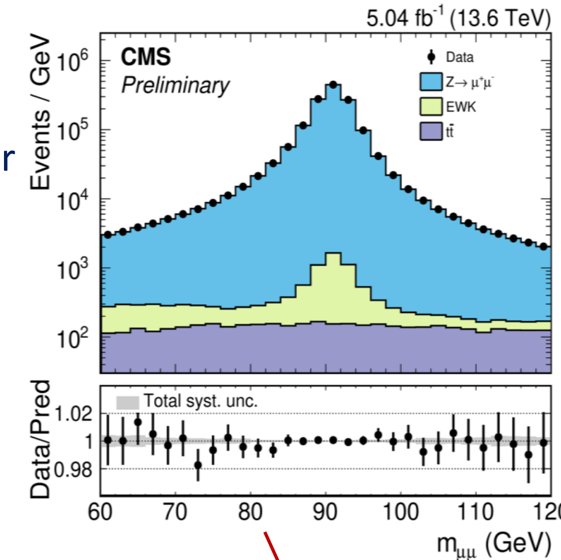
W and Z Production Cross Sections

The first measurement of the Z boson production cross section in proton-proton collisions at 13.6 TeV

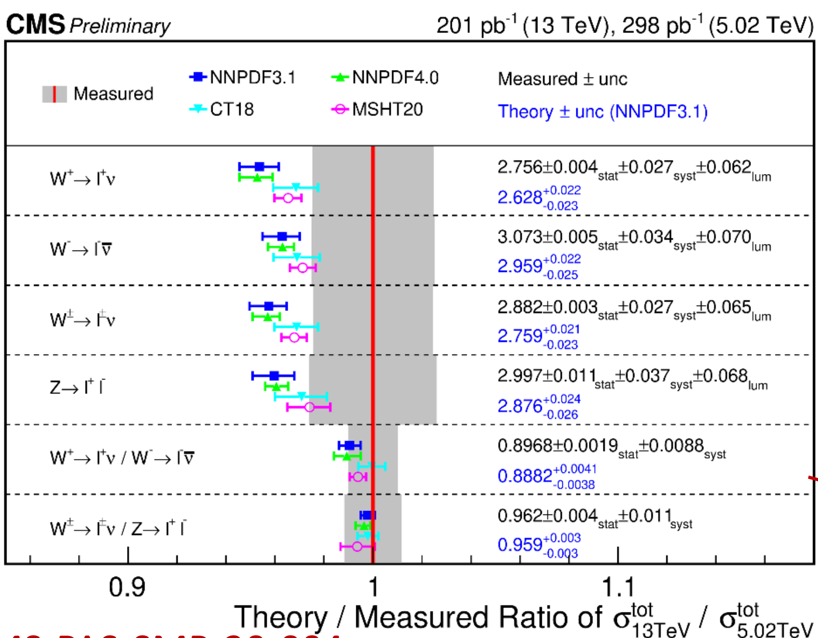
- dimuon final states are studied in data samples collected with the CMS detector corresponding to integrated luminosity of 5.04 ± 0.12 fb^{-1}
- the measured product of the total cross section and branching fraction for the invariant dimuon mass in the range 60 to 120 GeV

$$\sigma_Z(Z\to\mu\mu) = 2.010 \pm 0.001(\text{stat}) \pm 0.018(\text{syst}) \pm 0.046(\text{lumi}) \pm 0.007(\text{theo})\ \text{nb}$$

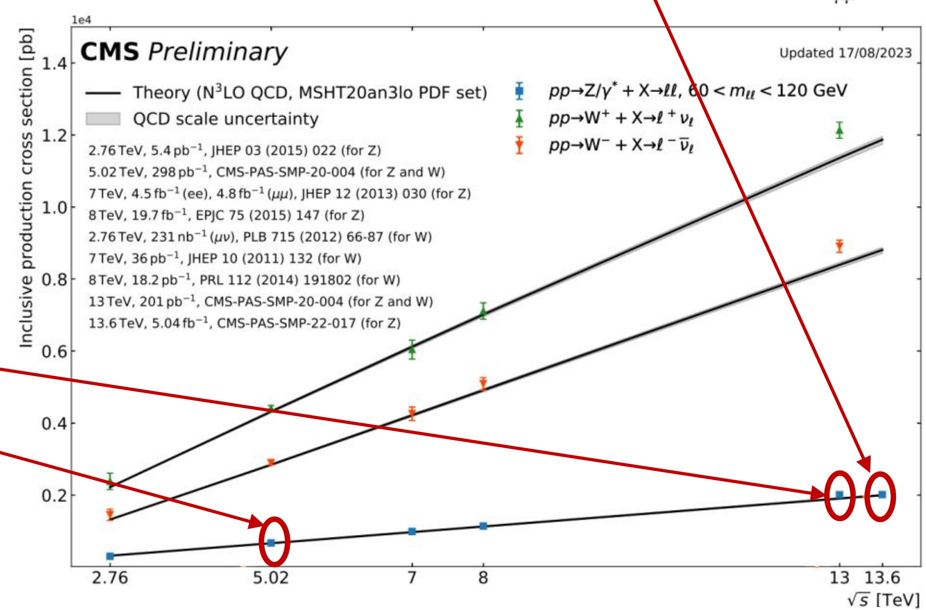
- well in agreement with theoretical calculations. CMS-PAS-SMP-22-017



W and Z cross sections at 5.02 and 13 TeV



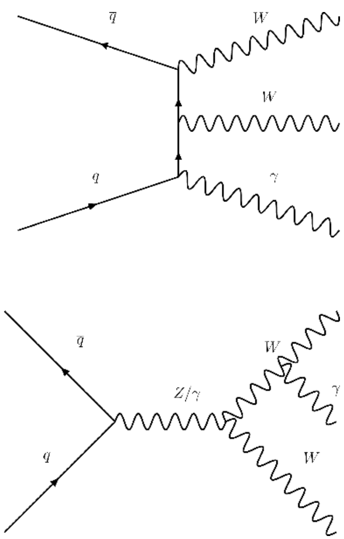
CMS-PAS-SMP-20-004

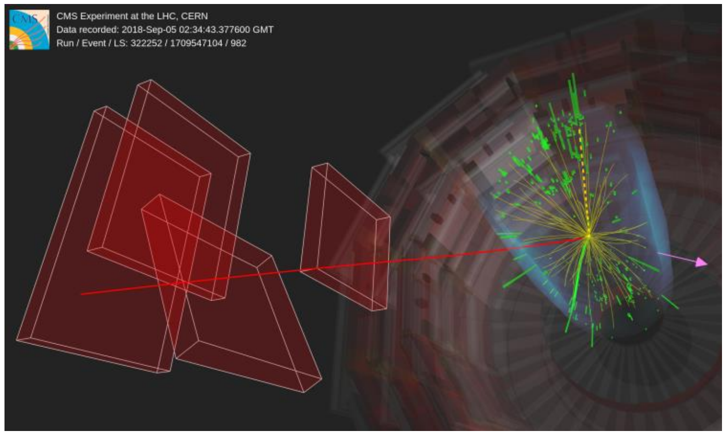


 see talk by Itana Bubanja for details

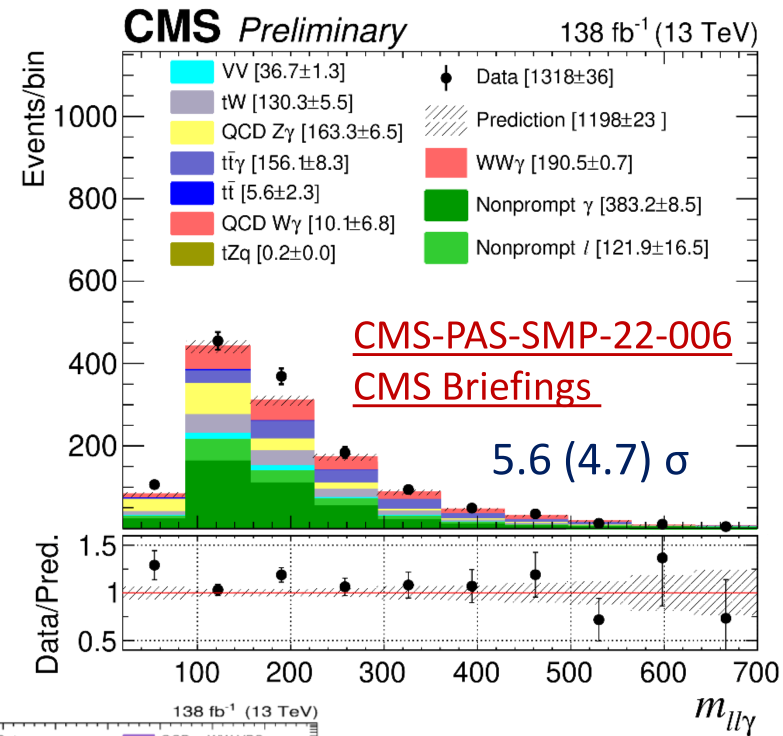
Multi-boson Recent Results

First observation of WWγ production





$\sigma_{WW\gamma}$ = 6.0 ± 1.0(stat) ± 1.0(syst) ± 0.9(theo) fb



CMS-PAS-SMP-22-006

CMS Briefings

5.6 (4.7) σ

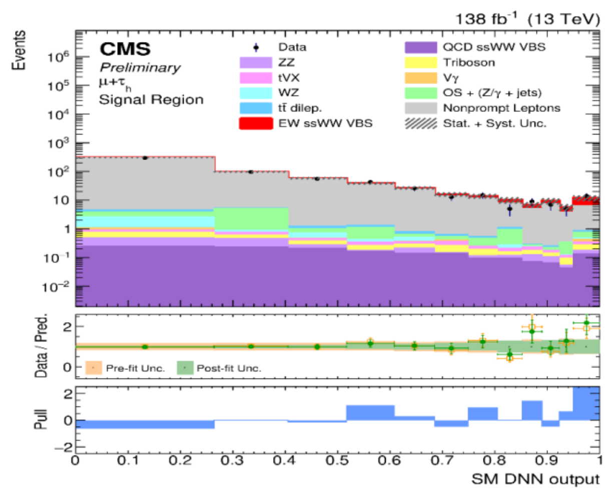
First study of a VBS process (same-sign WW)

The variables used as input to the DNN model are listed below:

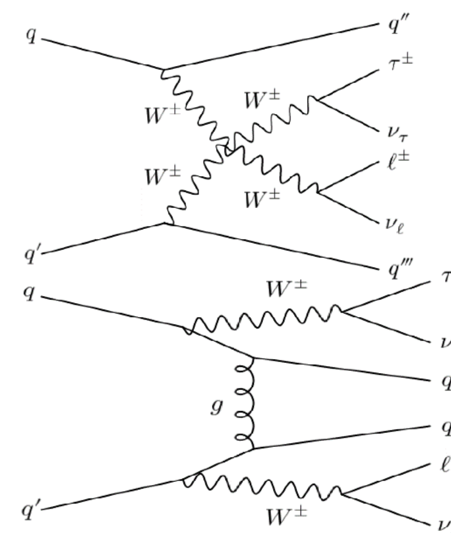
- VBS jet pair invariant mass M_{jj};
- transverse mass $M_T(\ell, \vec{p}_T^{\rm miss})$;
- transverse mass M_{1T};
- transverse mass M_{o1};
- p_T of leading VBS jet;
- p_T of subleading VBS jet;
- p_T of τ_h;
- p_T of ℓ;
- ratio of p_T of the leading track of the jet associated with τ_h to the τ_h p_T.

$\mu_{ssWW} = 1.44^{+0.63}_{-0.56}$

2.7 (1.9) σ



CMS-PAS-SMP-22-008



Summary of HLO Strinjent Tests

Summary of the cross sections standard model particles produced in association with jets

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined

V+jets VV+jets

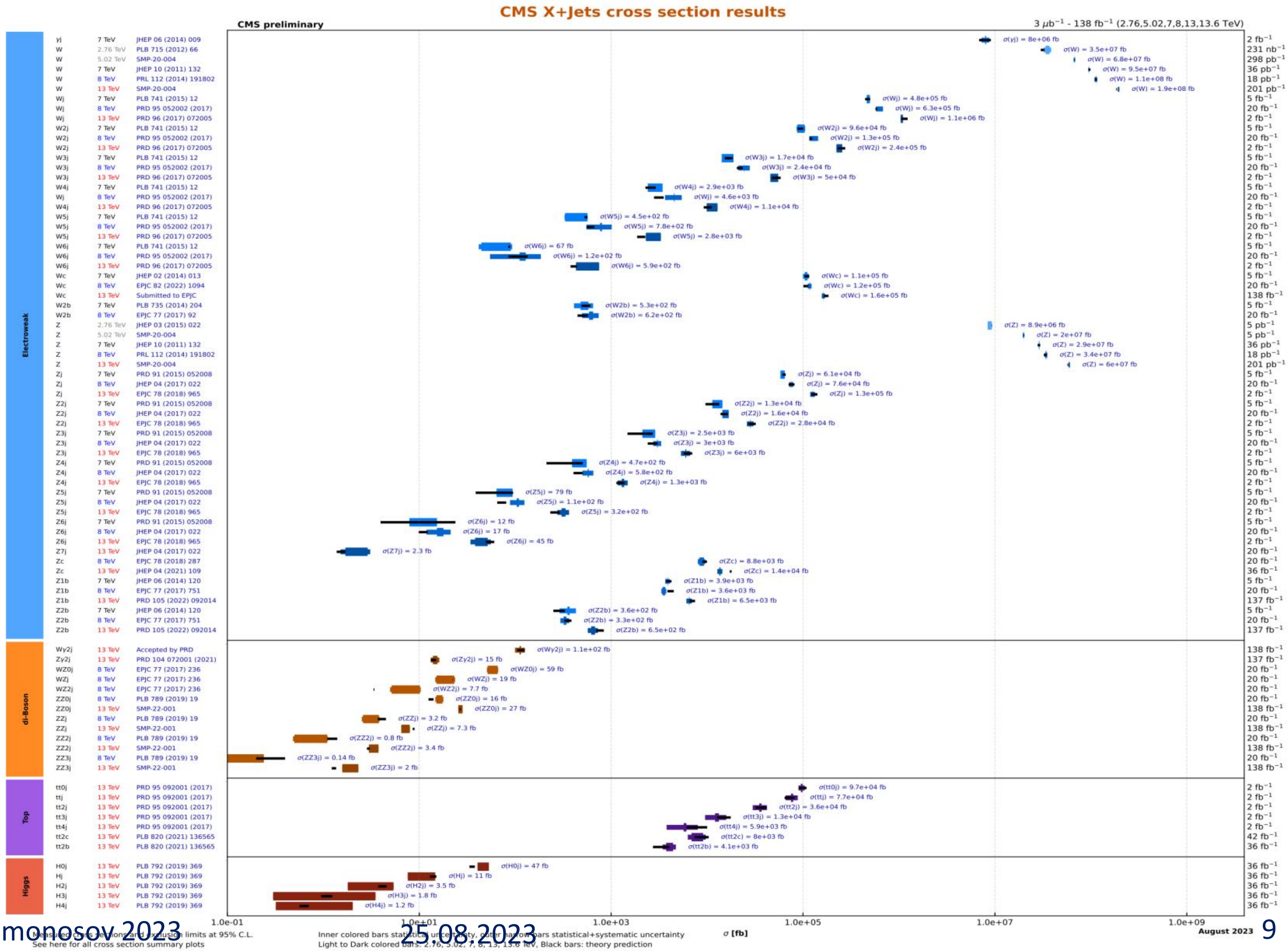
tt + jets

h + jets

up to 4 jets

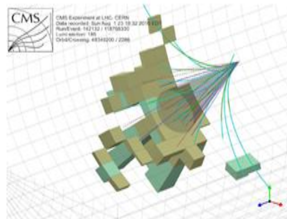
plots are updated for Summer 2023 conferences

Agrees with the standard model prediction!



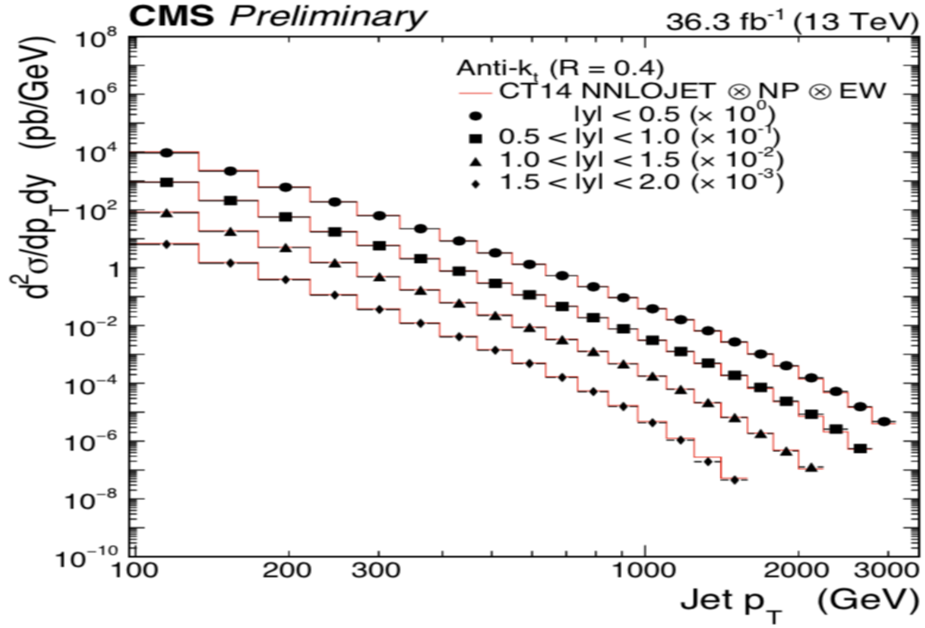
QCD Jets

- ✓ tests of theory
  - pQCD
  - non-perturbative regime
- ✓ parton structure (PDF)
- ✓ measurement of the the running coupling constant
- ✓ etc

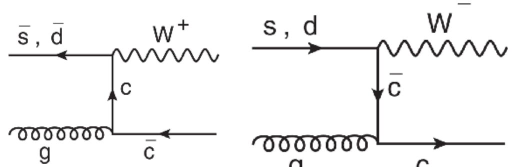


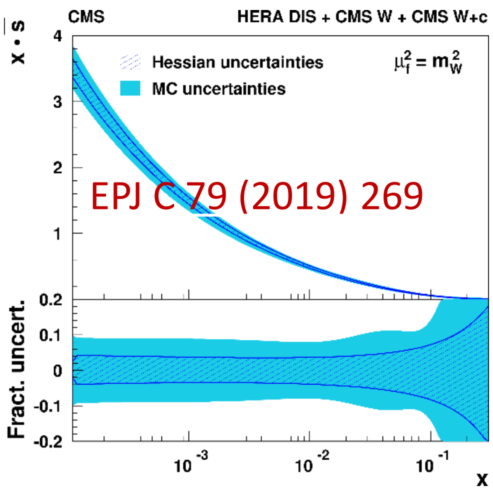
Compared to Powheg + Pythia8, Herwig++

Agreement with NLO is in general better than LO



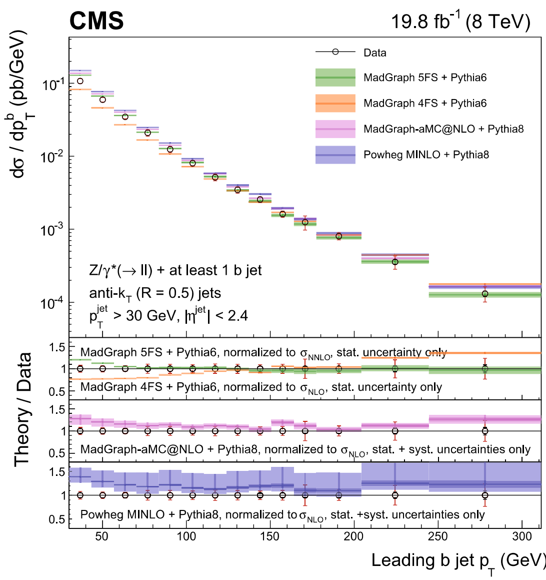
s-quark PDF from W+c

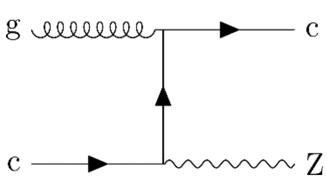


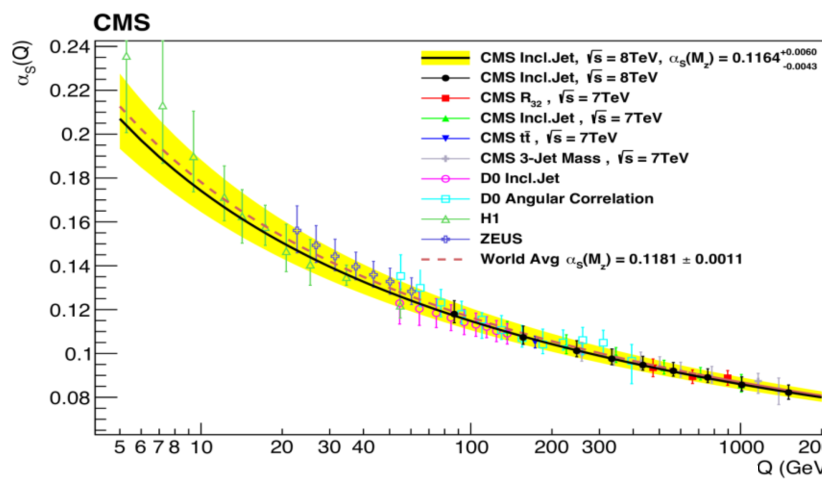


EPJ C 79 (2019) 269

c- and b-quarks PDFs from W+c/Z+c/Z+b







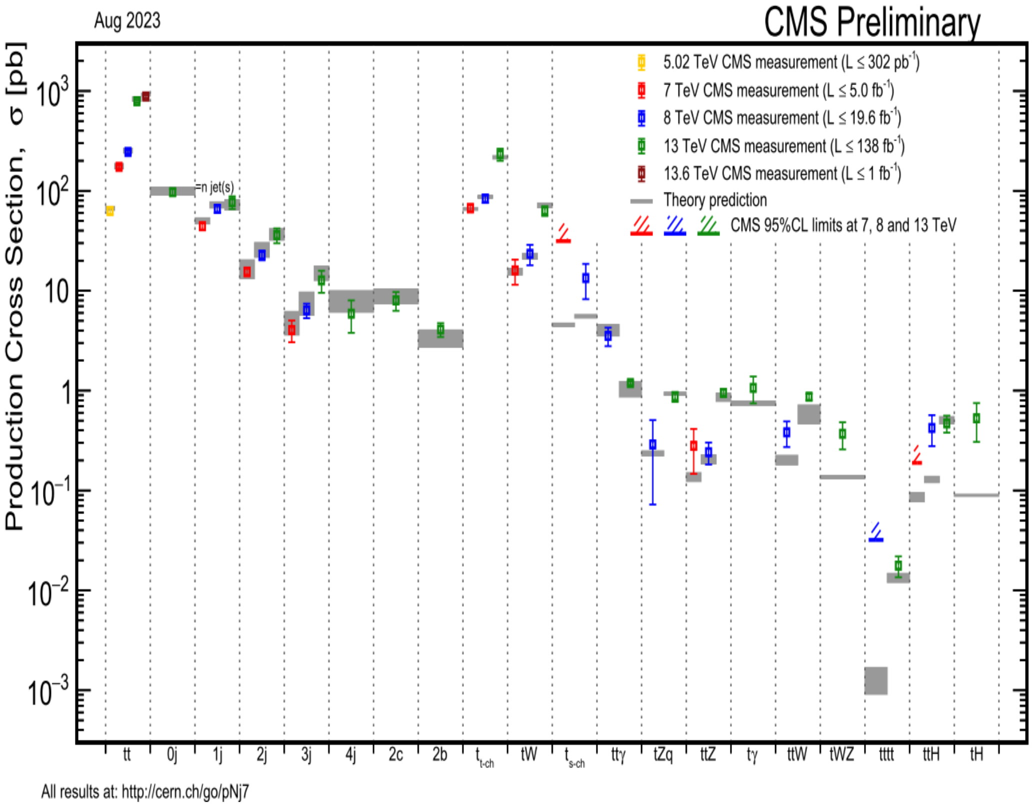
EPJC 78 (2018) 287

JHEP04 (2021) 109

see talk by Olga Kodolova for details

Top Quark Production Cross Section

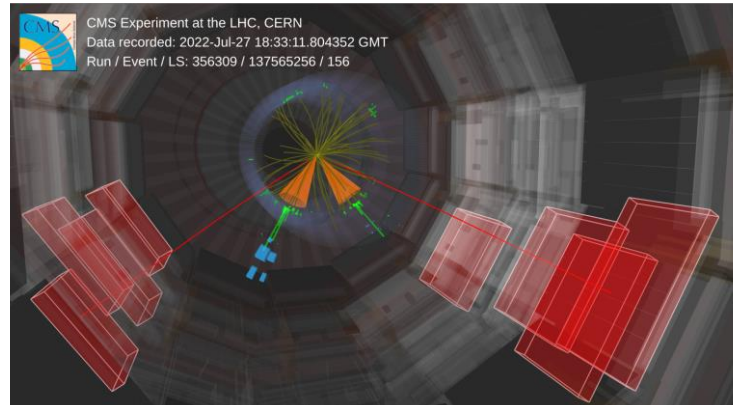
Summary of production cross sections involving top quarks
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined



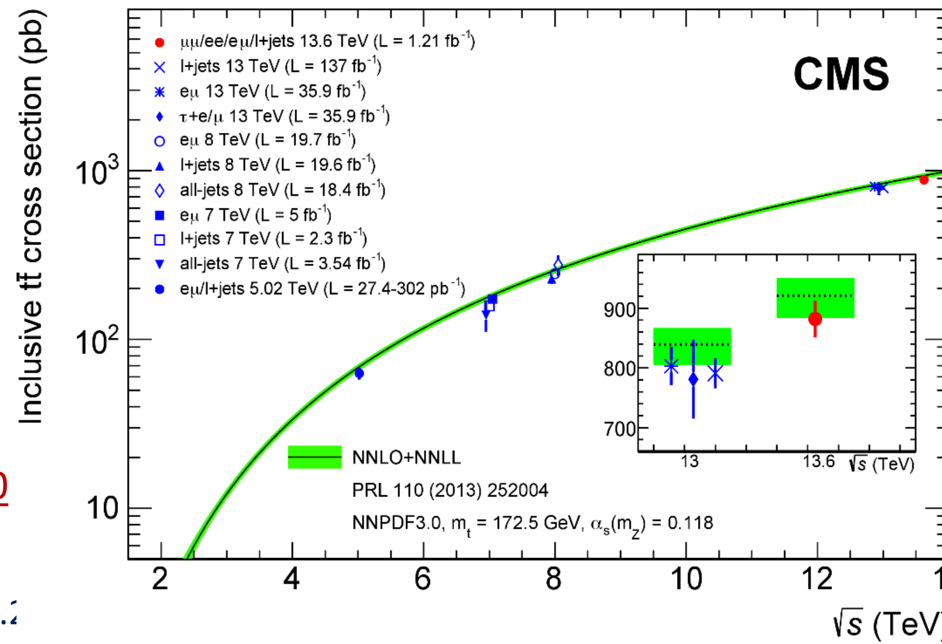
Good agreement with SM prediction

[CMS-PAS-TOP-22-012](CMS-PAS-TOP-22-012)
https://arxiv.org/abs/2303.10680
CMS Briefings

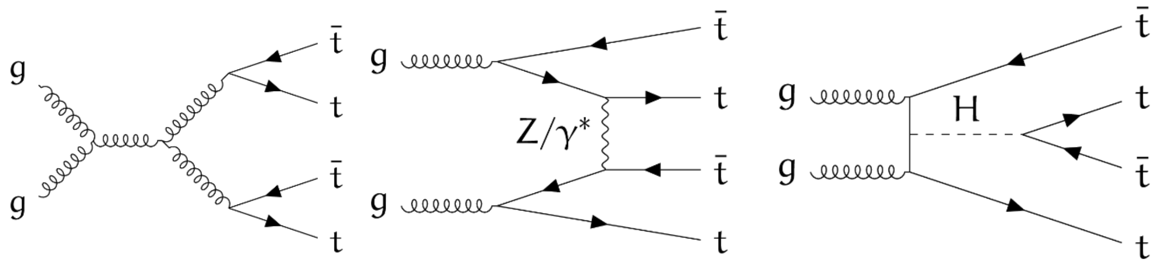
First measurement of the top quark pair production cross section in proton-proton collisions at 13.6 TeV



σ (tt) = 882 ±± 23 (stat+syst) ± 20 (lumi) pb
1.21 fb-1, dilepton and lepton + jets channels

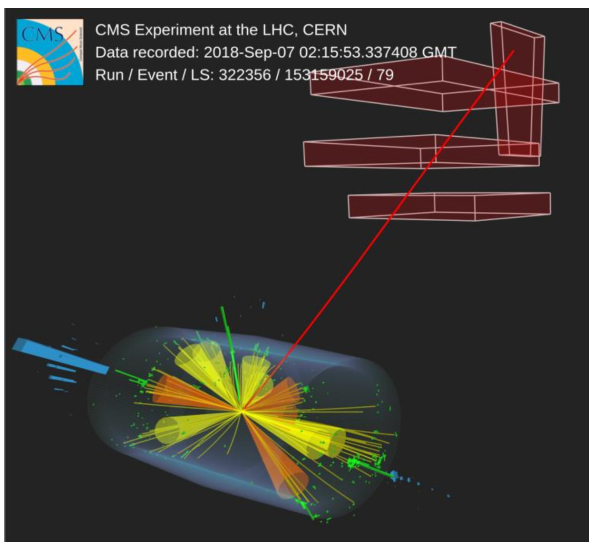


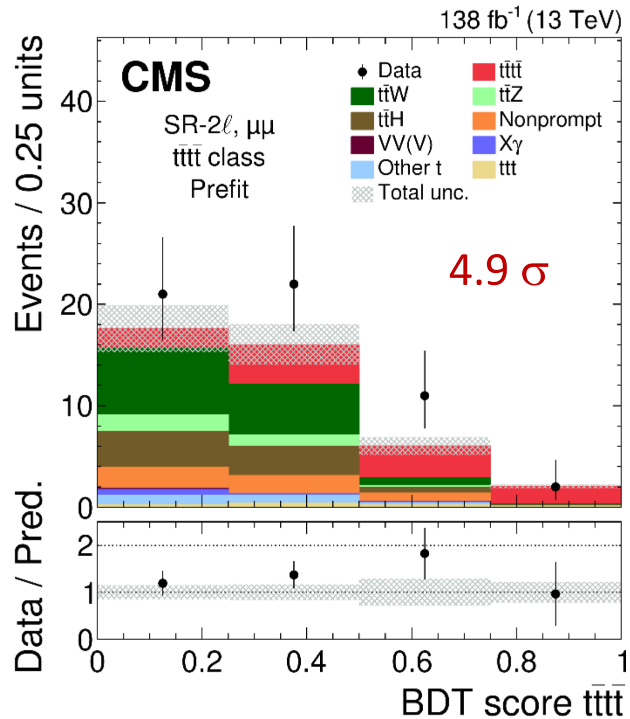
Observation of 4 top quarks production



- two same-sign, three, or four charged leptons (electrons and muons)
- additional jets

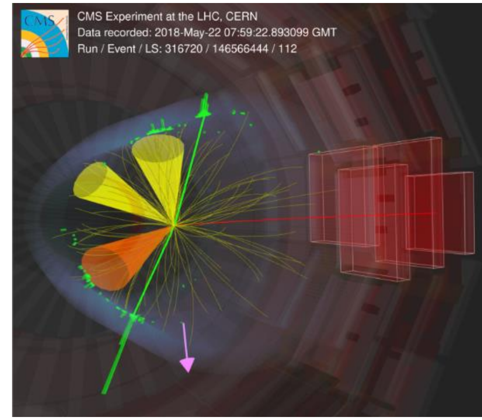
$\sigma_{tttt} = 17.7^{+3.7}_{-3.5}\,(\text{stat})\;^{+2.4}_{-1.9}\,(\text{syst})$ fb

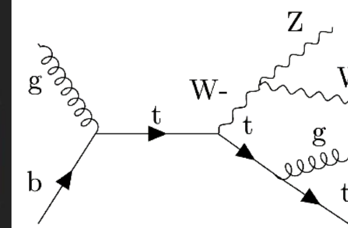




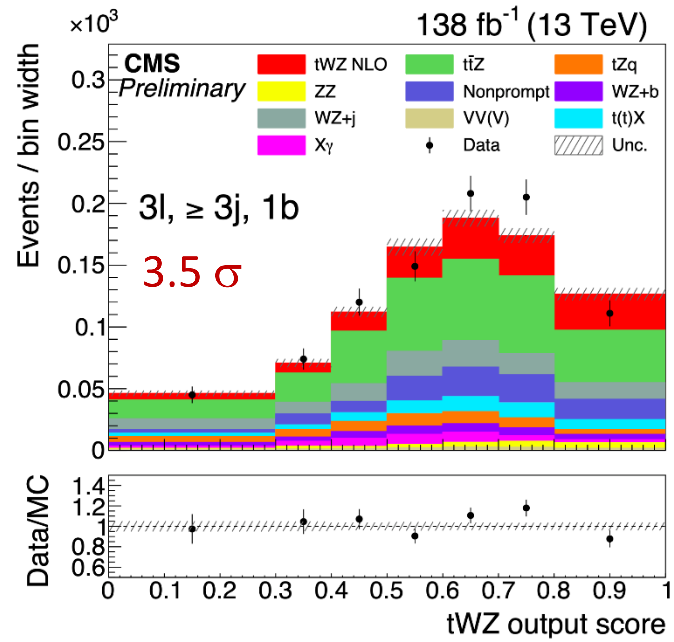
CMS-PAS-TOP-22-013, arXiv:2305.13439, CMS Briefings

First evidence of tWZ production





CMS-PAS-TOP-22-008
CMS Briefings



$\sigma_{tWZ} = 0.37 \pm 0.05(\text{stat}) \pm 0.10(\text{syst})$ fb

Rare Decays and LFUV Tests

Measurement of the dependence of the hadron production fraction ratio f_s/f_u on B meson kinematic variables in proton-proton collisions at $\sqrt{s}$ = 13 TeV

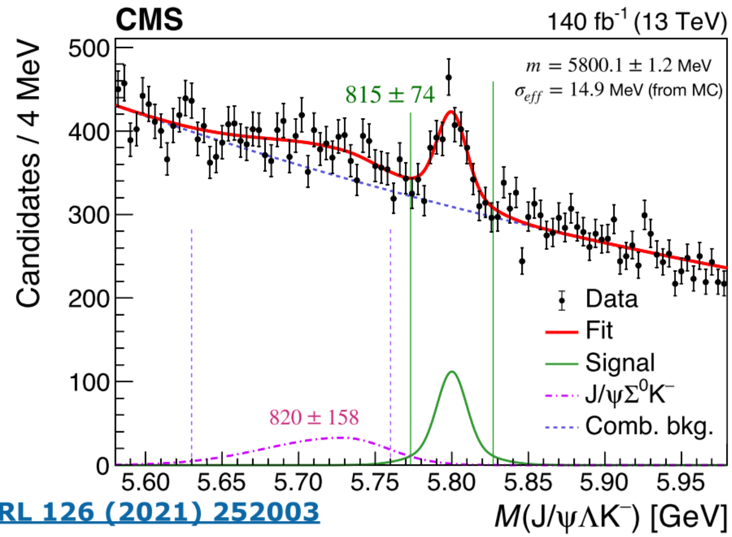
CMS-BPH-21-001, arXiv:2212.02309, **accepted by Phys. Rev. Lett.**

Observation of the $\Lambda_b^0 \to J/\psi\, \Xi^- K^+$ decay

CMS-PAS-BPH-22-002
https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/BPH-22-002/index.html

Observation of a new excited beauty strange baryon decaying to $\Xi_b^- \pi^+ \pi^-$

CMS-BPH-20-004, Phys. Rev. Lett. 126 (2021) 252003



PRL 126 (2021) 252003

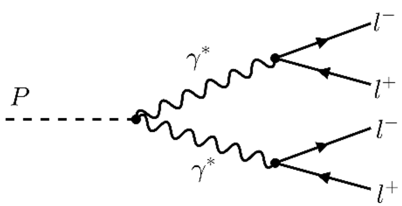
Observation of $B^0 \to \psi(2S) K_S^0 \pi^+ \pi^-$ and $B_s^0 \to \psi(2S) K_S^0$ decays

22) 499

$$R_s = \frac{\mathcal{B}(B_s^0 \to \psi(2S) K_S^0)}{\mathcal{B}(B^0 \to \psi(2S) K_S^0)} =$$

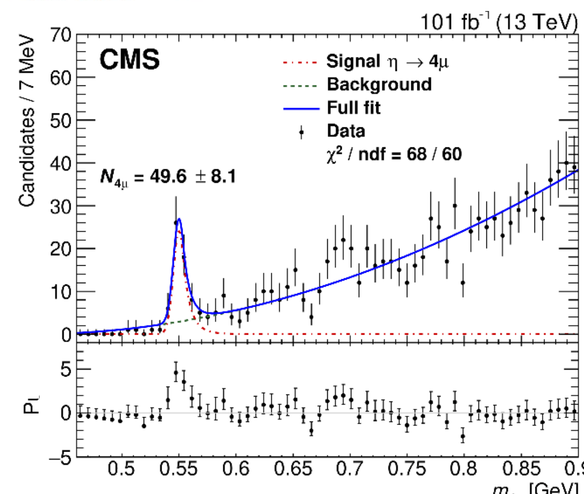
$$= (3.33 \pm 0.69\,(\text{stat}) \pm 0.11\,(\text{syst}) \pm 0.34\,(f_s/f_d)) \times 10^{-2}$$

Observation of the rare decay of the η meson to four muons



arXiv:2305.04904

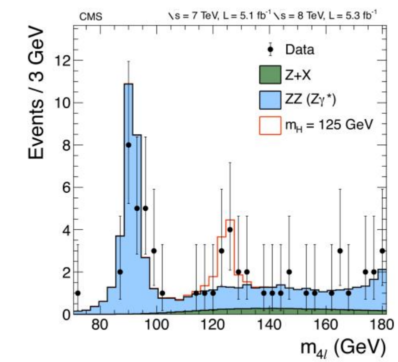
see talks by Nikita Petrov, Kirill Ivanov, Ruslan Chistov, Maksim Sergeev

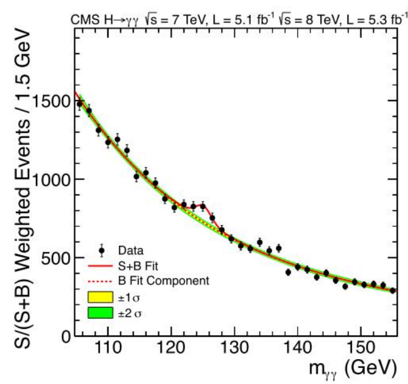


Higgs Physics

From design

to discovery

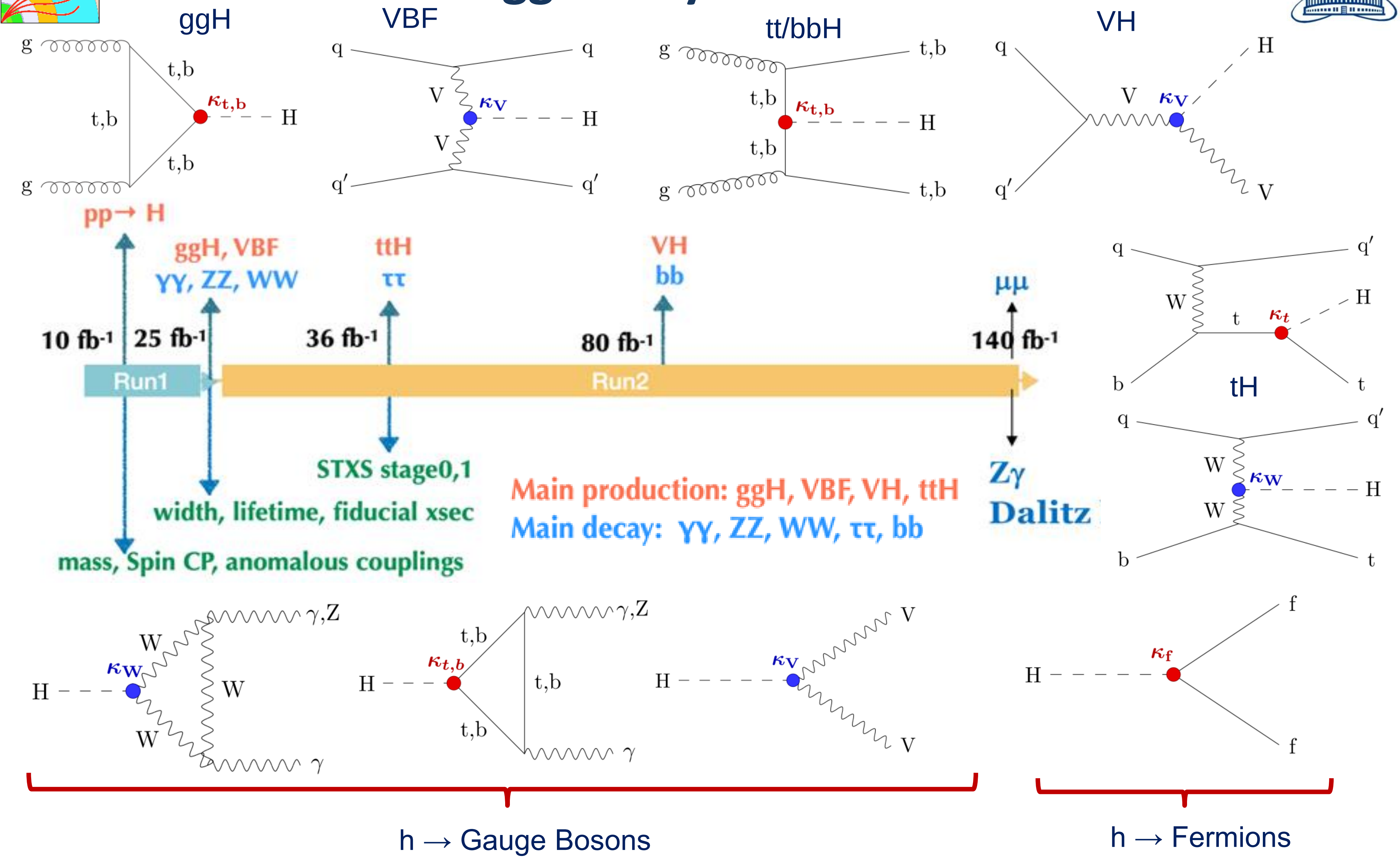




4 July 2012
Higgs announcement at CERN

	Int. Luminosity at 7, 8 TeV	mH [GeV]	Expected [st. dev.]	Observed [st. dev.]
ATLAS	10.7 fb^{-1}	126.0 ± 0.6	4.6	5.0
CMS	10.4 fb^{-1}	125.3 ± 0.6	5.9	4.9

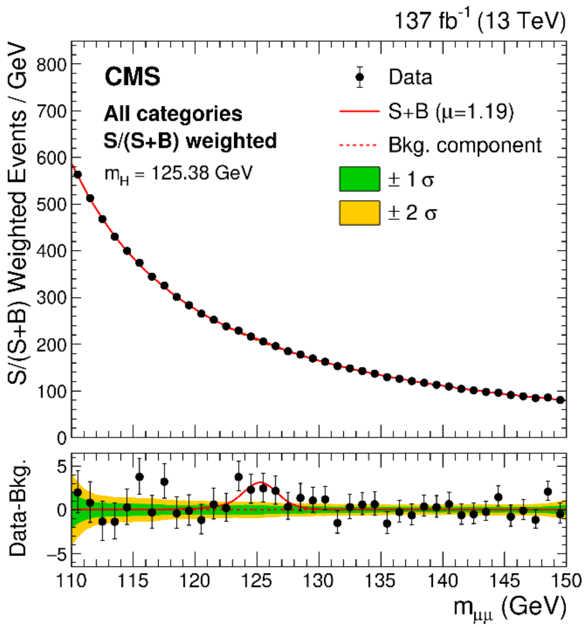
Higgs Story at the LHC



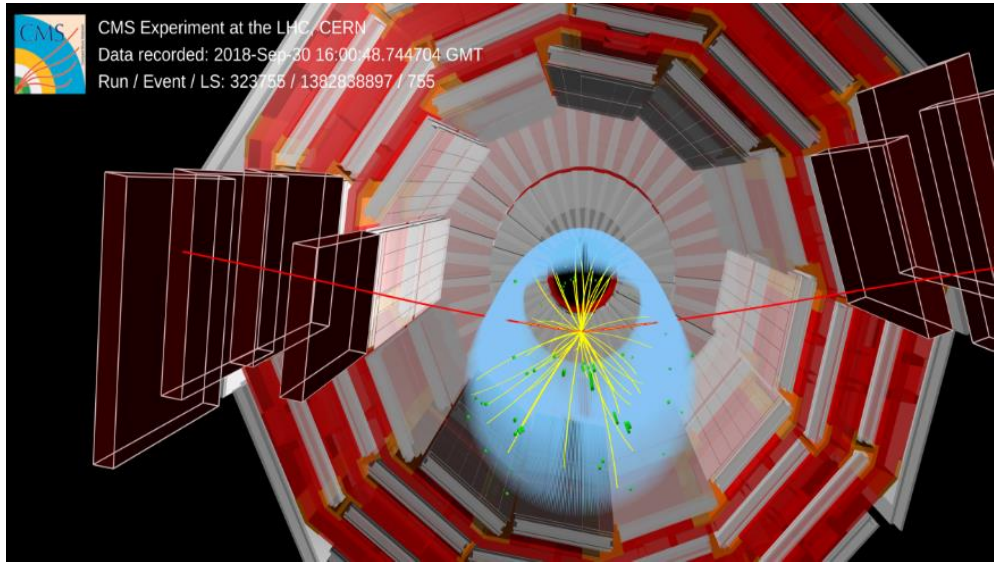
Rare Higgs Decay h → $\mu\mu$

First evidence of the coupling of the Higgs boson with fermions of the second generation

JHEP 01 (2021) 148

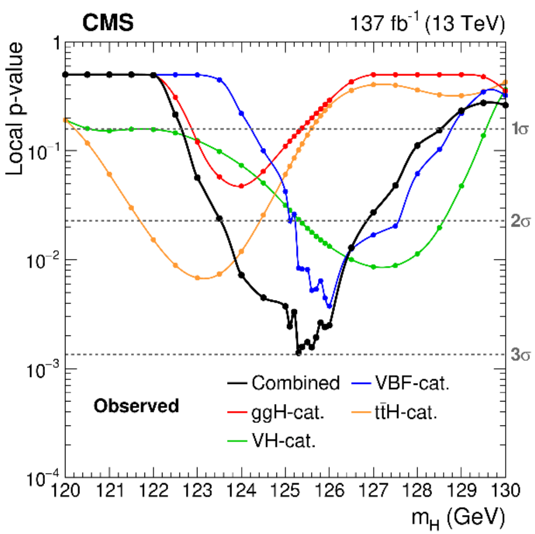


H → $\mu\mu$ candidate in gluon fusion channel, m_H = 125.46 ± 1.13 GeV



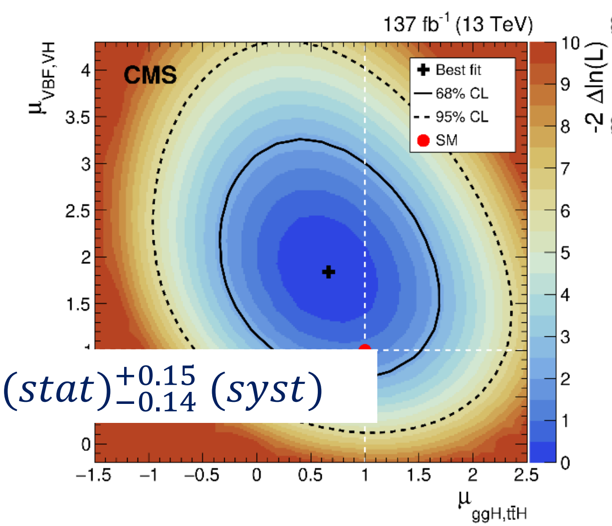
targets
ggH, VBF , VH, ttH
best sensitivity

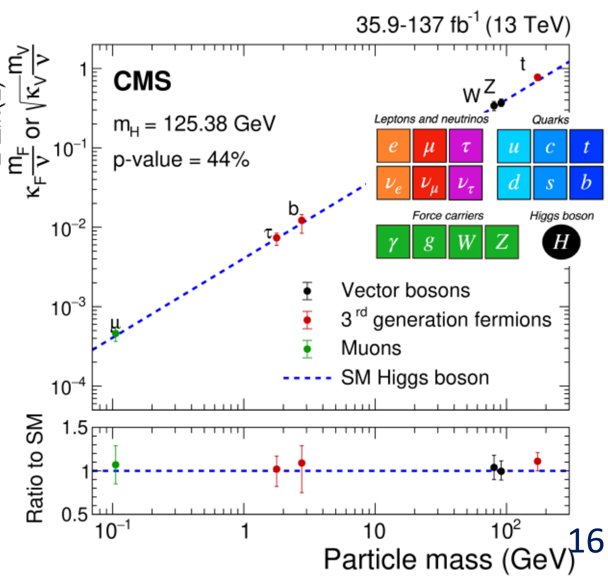
Drell-Yan background considerably reduced by VBF topology requirement (two forward jets)



Obs. (exp.) significance is 3.0σ (2.5σ).

$$\mu = 1.19^{+0.40}_{-0.39}\,(stat)^{+0.15}_{-0.14}\,(syst)$$





ov 2023

Rare Higgs Decays $h \to Z\gamma$//VBF $h \to bb$/$h \to e\mu$/$h \to cc$

Florencia Canelli

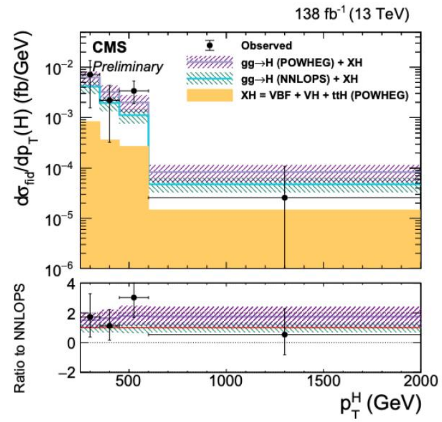
EPS-HEP Conference
August 22, 2023

Evidence of H→ Zɣ decays ***CMS-PAS-HIG-23-002***
CMS + ATLAS combined evidence: observed 3.4σ (expected 1.6σ)

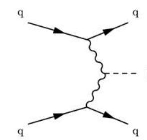
Search for lepton flavor violating H→ eμ decays
In 110 – 160 GeV mass region of a eμ pair
Observed (expected) upper limit on BR is 4.4 (4.7) × 10^{-5} at 95% CL
Most stringent limit from direct searches ***CMS-PAS-HIG-22-002***

Measure highly Lorentz-boosted H→ττ events
Using dedicated algorithms to resolve overlapping τ_s the signal with p_T^H > 250 GeV is observed (expected) 3.5 (2.2) σ

CMS-PAS-HIG-21-017

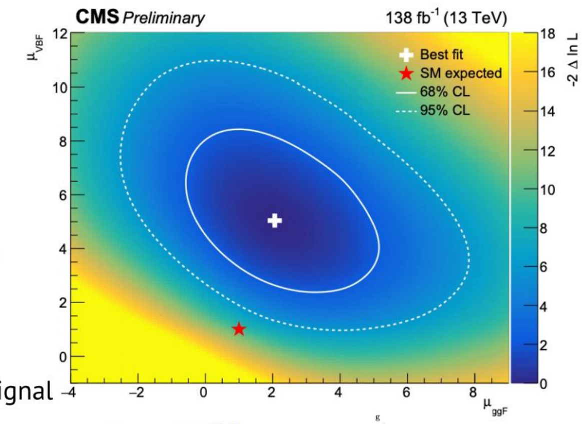


Measure VBF and ggF production simultaneously with H→bb
Using boosted Higgs decays since the relative contribution to Higgs cross-section from ggF decreases with p_T^H



μ_{VBF}=5.0$^{+2.1}_{-1.8}$

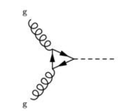
3.0 σ (0.9σ)



The observed signal strengths and corresponding observed (expected) significances

μ_{ggF}= 2.1$^{+1.9}_{-1.7}$

1.2 σ (0.9 σ)



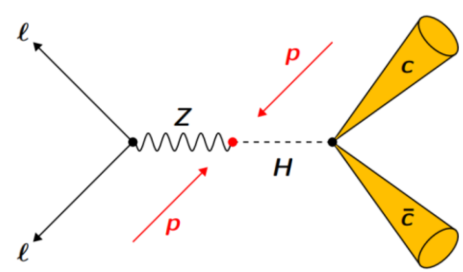
CMS-PAS-HIG-21-020

Probes and searches seen today:

- $H \to cc$: most stringent limits on κ_c to date
- $H \to \mu\mu$: 3.0 std dev evidence of the decay
- $H \to ZJ/\Psi$ and $H \to J/\Psi J/\Psi, \Upsilon\Upsilon$: clean 4ℓ final state and upper limits on $\mathcal{B}$
- $H \to Z\gamma$: CMS+ATLAS combination showing evidence of 3.4 std dev
- $H\gamma$ production: limits on all $\kappa_u, \kappa_d, \kappa_s, \kappa_c$
- **In general, no significant discrepancy w.r.t. the SM prediction until now**

Higgs decays and high p_T are particularly sensitive to BSM ➔ these results provide an important step forward in the exploration of the Higgs boson and its interactions

H decay to cc [Phys. Rev. Lett. 131 (2023) 061801, 041801]



Upper limits on $\mathcal{B}$ set at 95% CL:

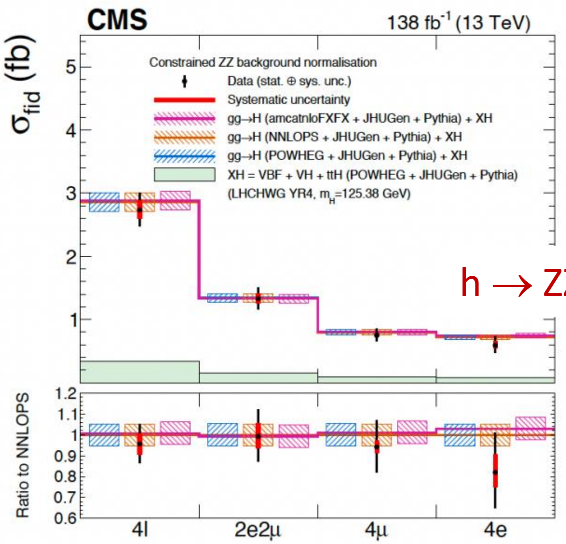
- $\mu_{VH(H\to cc)} = 14$ $(7.6^{+3.4}_{-2.3})$ the SM prediction
- $1.1 < |\kappa_c| < 5.5$ $(|\kappa_c| < 3.4)$
- **Most stringent constraint on κ_c to date**

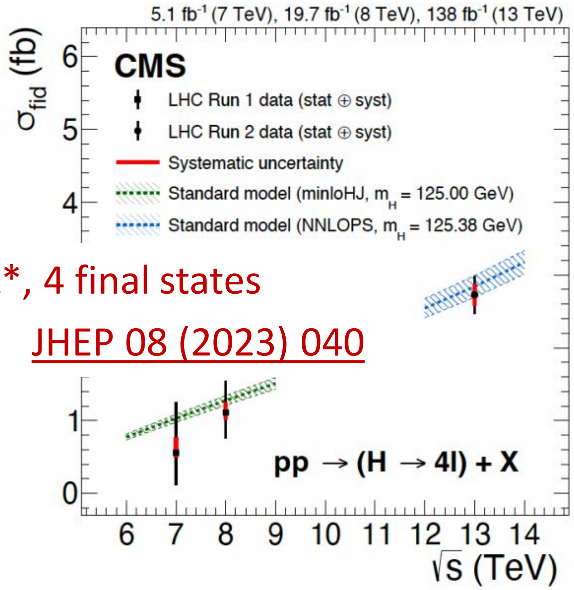
R. Ardino EPS-HEP 2023

Higgs Inclusive and Differential Cross Sections

Unfold signal yields to cross sections

Differential cross sections





h → ZZ*, 4 final states

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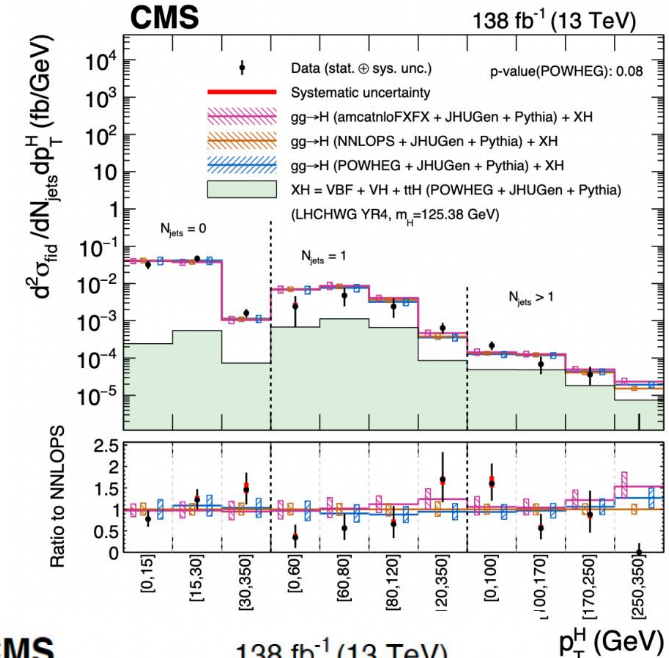

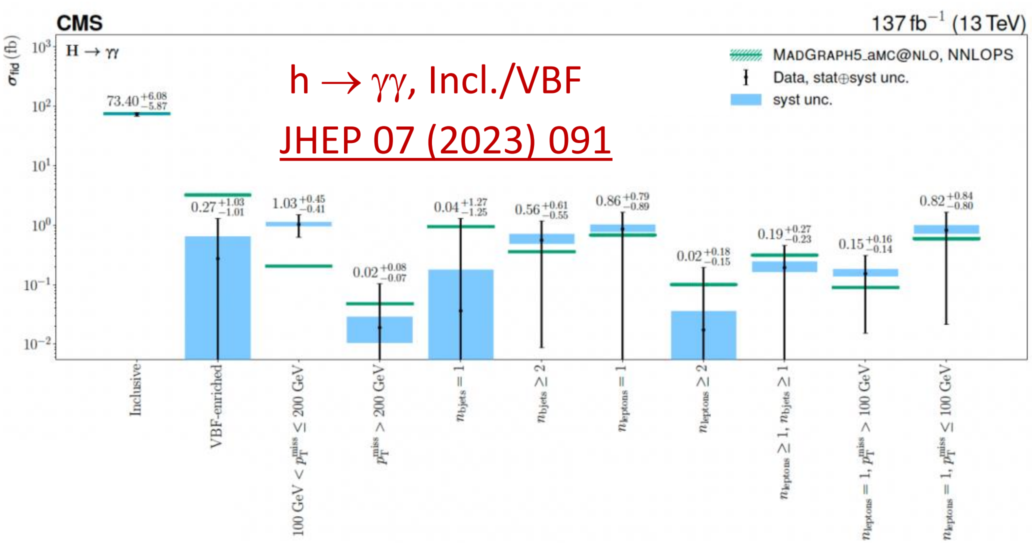

h → γγ, Incl./VBF

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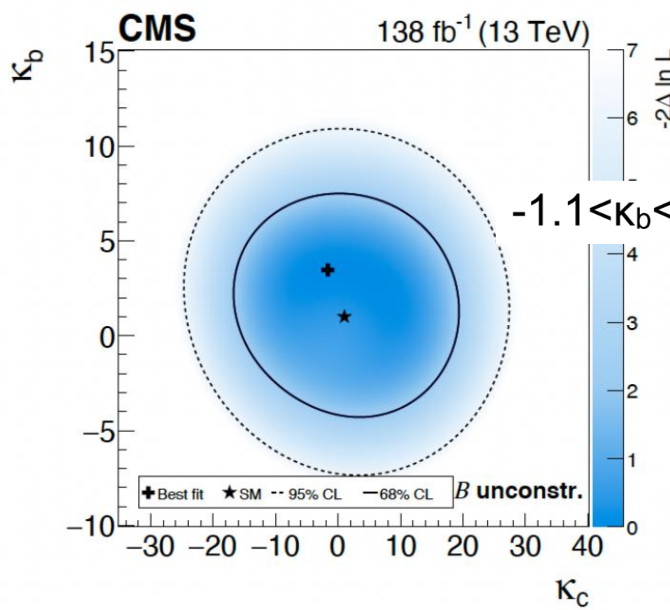
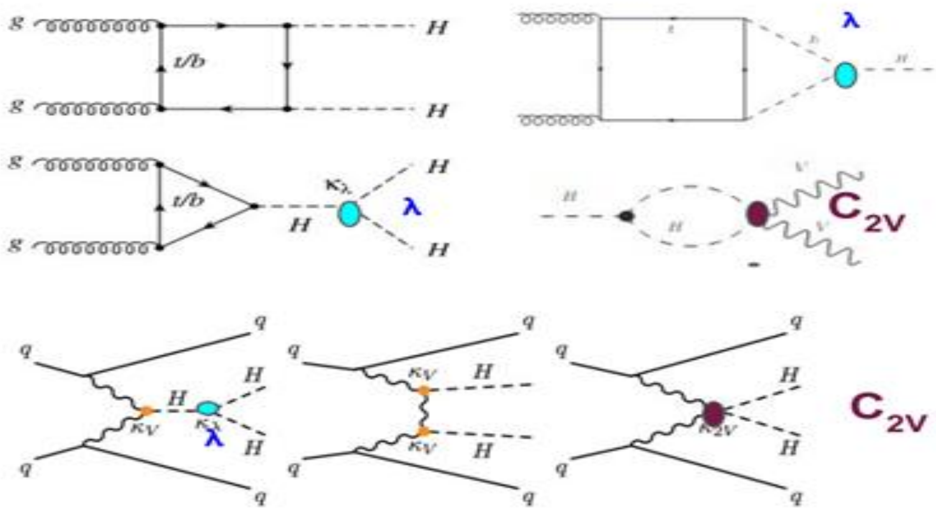
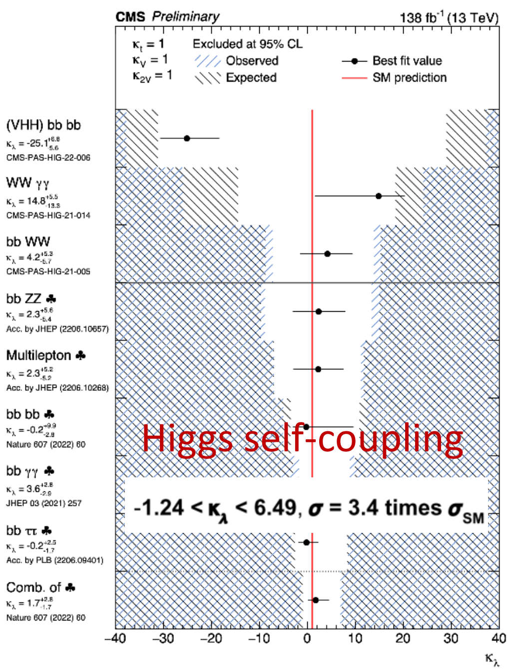


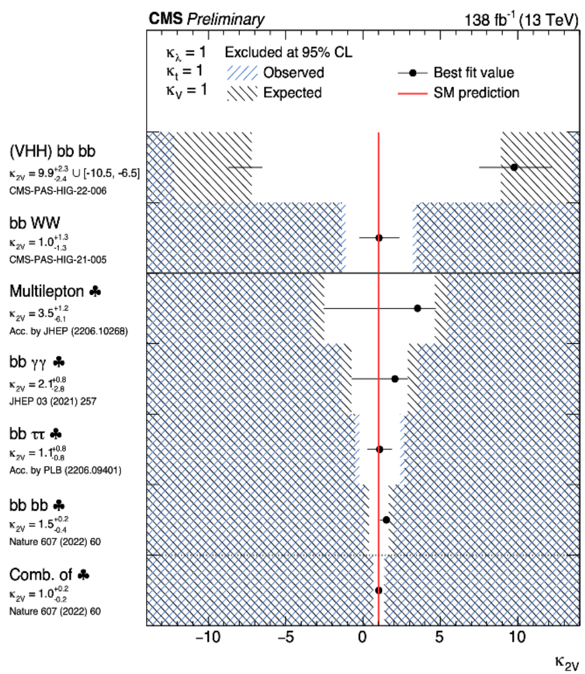
$-1.1<\kappa_b<1.1$; $-5.3<\kappa_c<5.2$

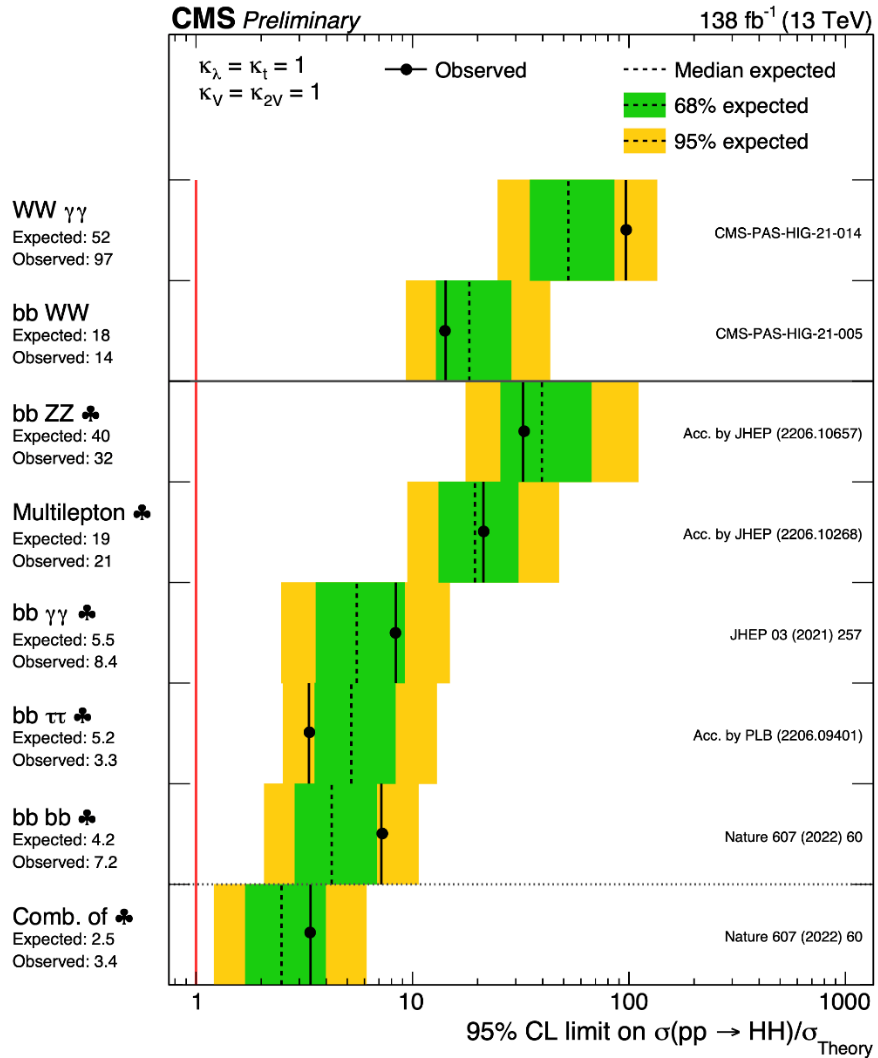
no significant deviation from SM predictions

Search for pair-production of Higgs









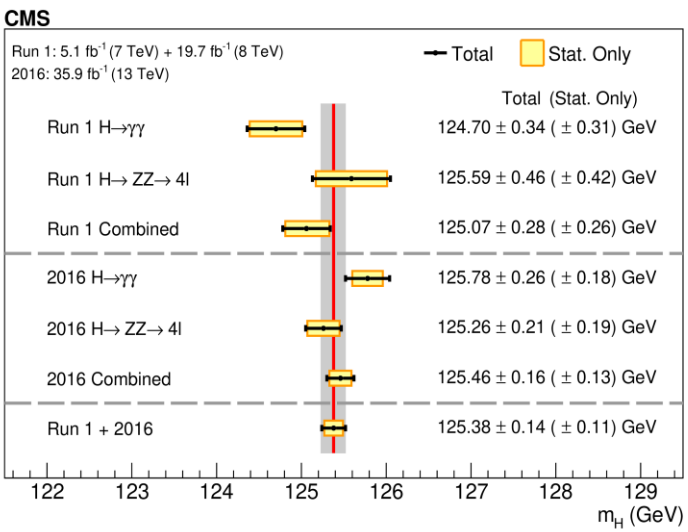
Nature 607 (2022) 60-68

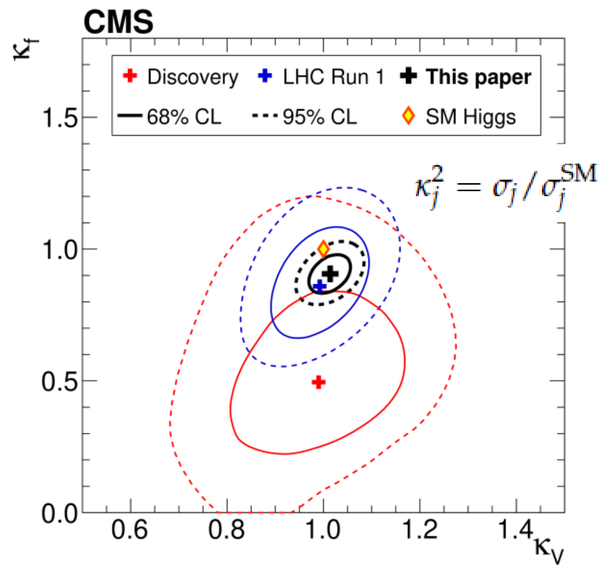
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryResultsHIG

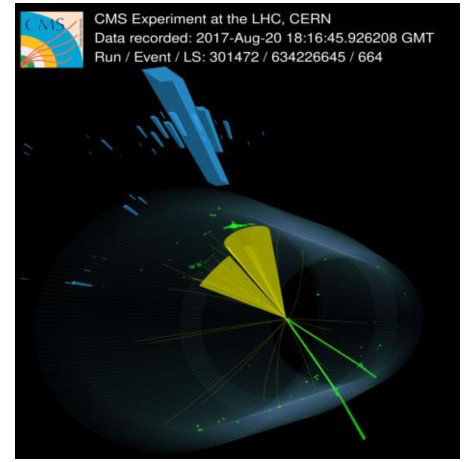
Higgs Portrait after 10 Years

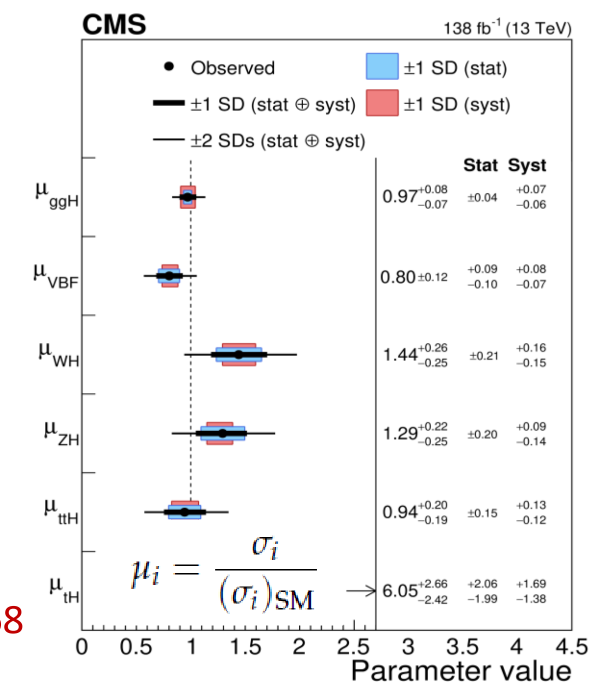
During Run 2 of the LHC the experimental collaborations started to employ the combined data for precision measurements of Higgs properties (mass, width, couplings, CP, rare decays)

- All main production mechanisms are observed, including h → bbar, ttH, VH
- Mass of Higgs boson m_h is measured with an accuracy of 0.1% (!)







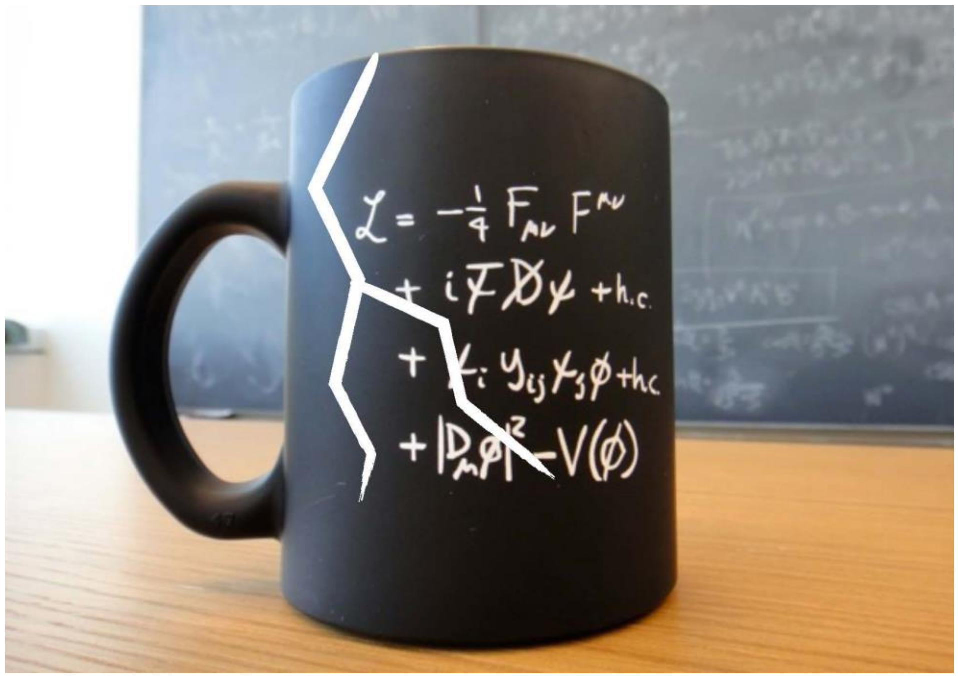


- Precisions of cross section and branching ratio measurements in combined channel are down to 8.5% level
- We have ~6-30% accuracy for measurements of couplings
- The absolute value of a width $\Gamma_H = 3.2^{+2.4}_{-1.7}$ MeV is getting closer to the SM expectations (4.1 MeV). We still need to improve an accuracy.
- Spin, parity, differential distributions do not contradict the SM

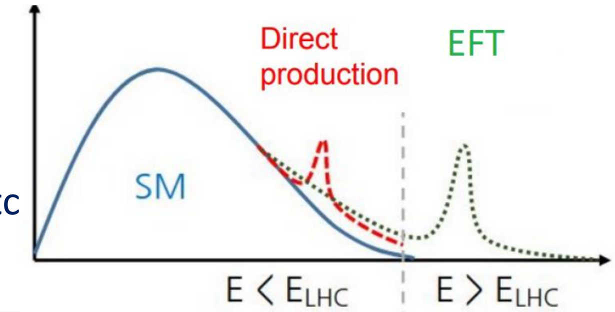
Nature 607 (2022) 60-68

No SM violations are observed

Physics beyond the SM



BSM Analyses in the CMS Collaboration



- Direct Searches for the Physics Beyond the SM
  - ✓ Conventional Signals, such as new resonances in dileptons/diphotons/dijets spectra or non-resonant signals, combinations of physics objects (leptons/photons/jets) and MET/ b/t-jets tags, high-multiplicity events, etc

SUSY

Extra Dimensions

Extended Gauge Sector

LQ/CI/Excited Fermions/B3G

  - ✓ on-conventional Signals, for example displaced vertices/leptons/lepton-jets/dileptons from Long-Lived Particles or emerging jets/leptons from boosted heavy objects, $m \ll p_T$ (i.e. high-p_T Z/W/h_{125} bosons)

Long-Lived Particles (Dark Matter/Non-standard SUSY/Neutrino Masses/etc)

Extended Higgs and Dark Matter Sectors

- BSM-Higgs Physics
  - ✓ Searches for the new Higgs states (from extended Higgs sector including SUSY)
  - ✓ Probes for the New Physics with h_{125} (Higgs as a tool for new discovery)

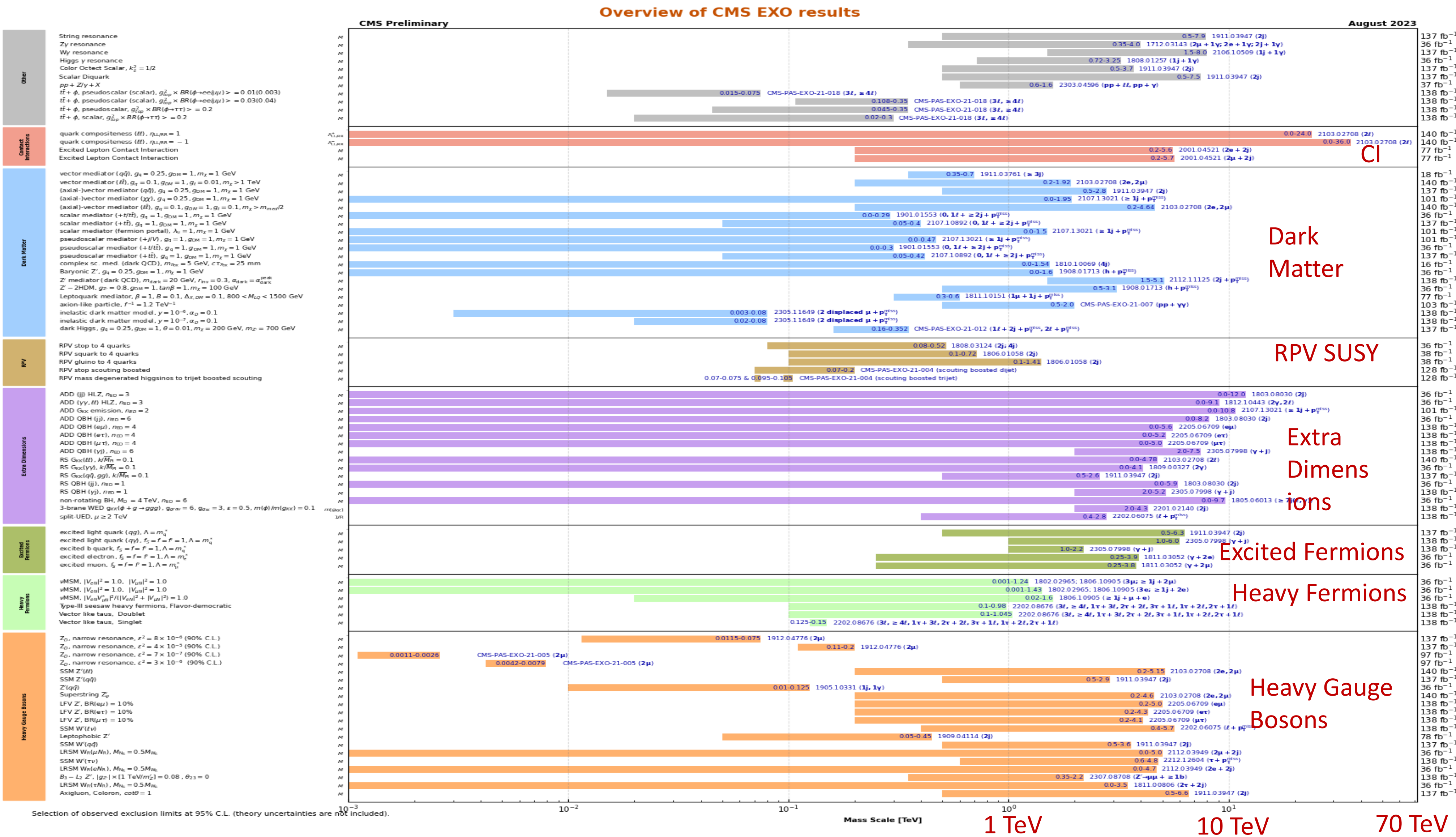
Extra Higgses, Dark Matter, Flavour Universality Violation

- Check for discrepancies with data and search for new physics via Effective Field Theory

$$L = L_{SM}^{(4)} + \sum_i \frac{c_i^{(5)}}{\Lambda_i} O_i^{(5)} + \sum_i \frac{c_i^{(6)}}{\Lambda_i^2} O_i^{(6)} + \dots$$

- Precision Tests of SM
  - ✓ Measurements of the W/Z, Drell-Yan (+ n jets) x-sections and angular characteristics
  - ✓ Search for rare decays of B-mesons
  - ✓ Observations of other rare process in top sector within SM (Wtb couplings, CP violating top quark couplings, flavor-changing neutral current interactions of the t-quark and h_{125})

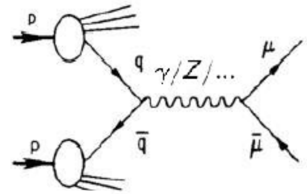
Direct Search for BSM: Conventional Signals



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SummaryPlotsEXO13TeV

Searches for Heavy Resonances

New Physics ($Z'/Z_{KK}/G_{KK}$) contributions to SM processes



$$R_\sigma = \frac{\sigma(pp \to Z' + X \to l^+l^- + X)}{\sigma(pp \to Z^0 + X \to l^+l^- + X)}$$

Dileptons, full RUN2 data

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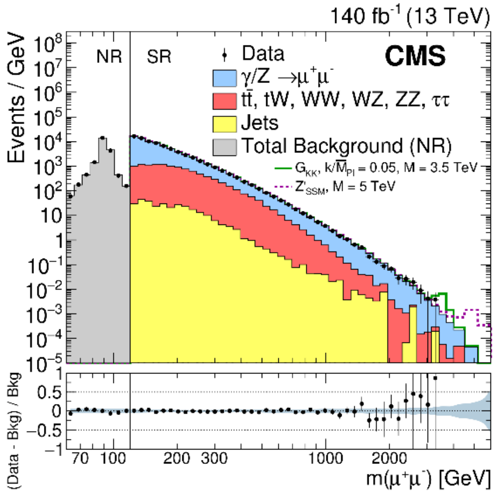
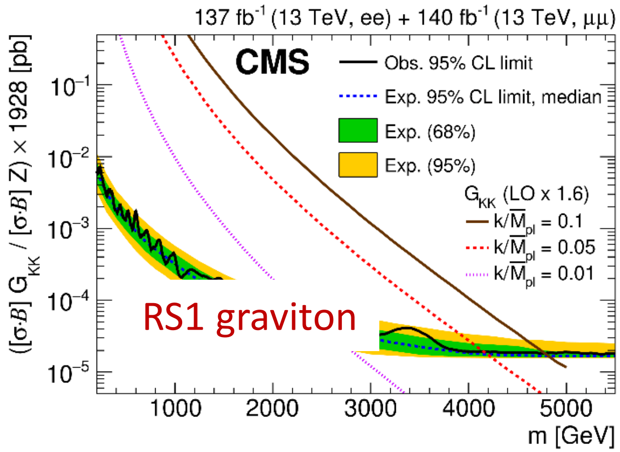
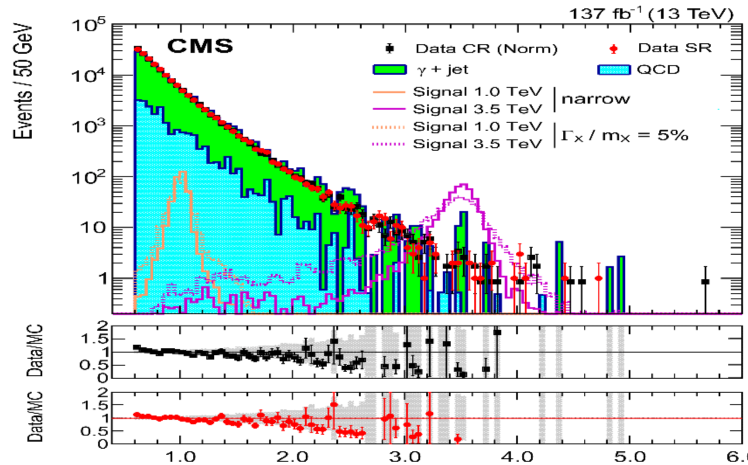
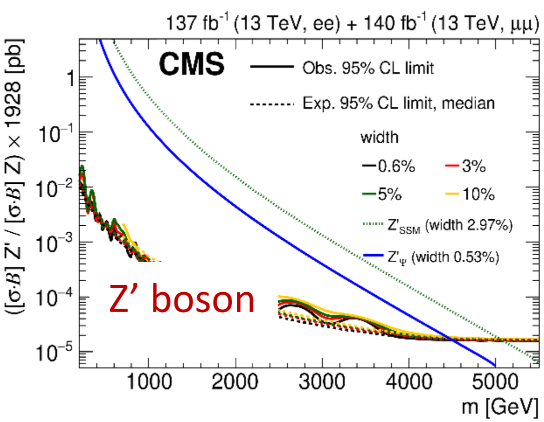


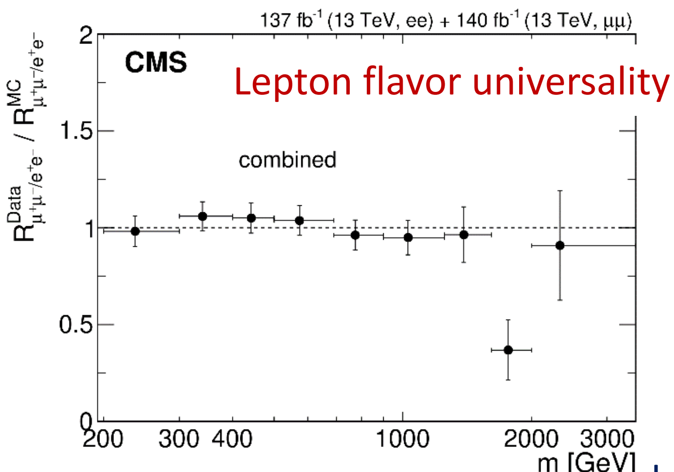


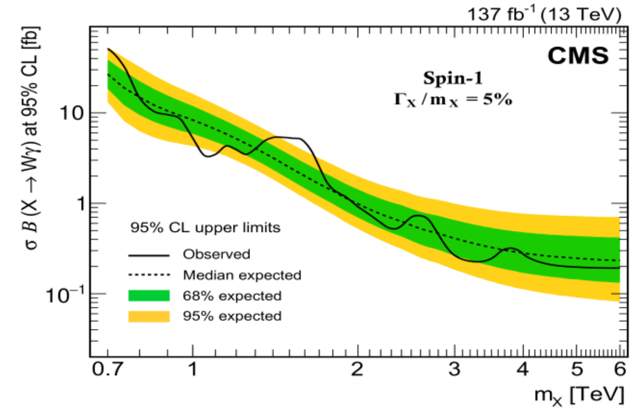
Wγ, full RUN2 data

PLB 826 (2022) 136888







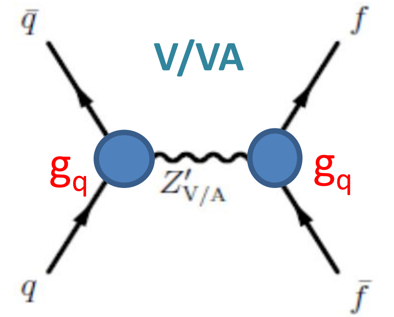


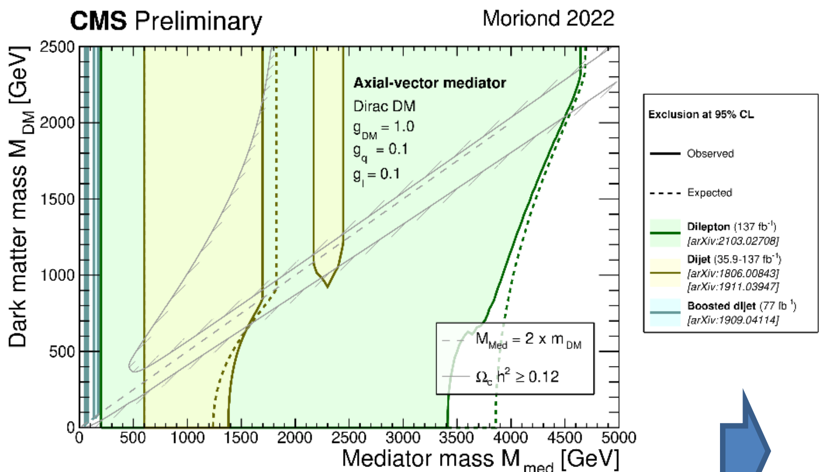
benchmark heavy scalar (vector) triplet bosons with masses between 0.75 (1.15) and 1.40 (1.36) TeV are excluded at 95% CL

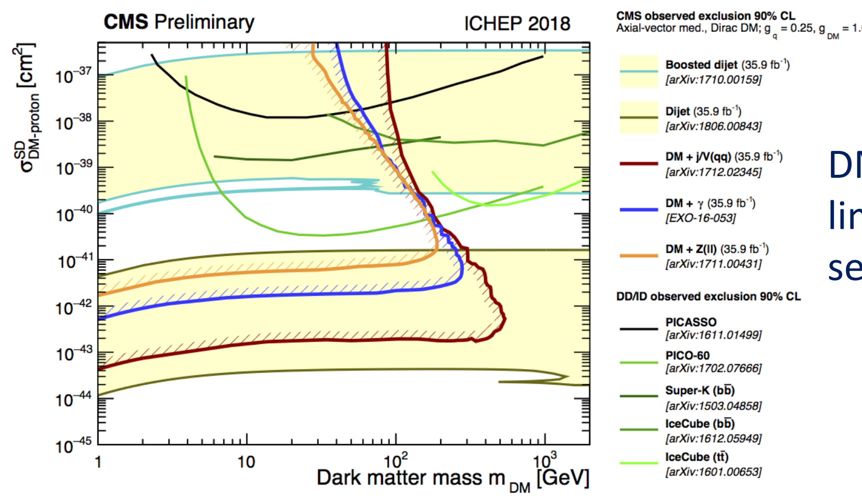
Example of Dark Matter Searches in Dijets+Dileptons

We consider a model that assumes the existence of a single DM particle that interacts with the SM particles through a spin-1 mediator, which can be either a vector or axial-vector boson.

- vector mediator with small couplings to leptons, $g_{DM} = 1.0$, $g_q = 0.1$, $g_l = 0.01$
- axial-vector mediator with equal couplings to quark and leptons: $g_{DM} = 1.0$, $g_q = g_l = 0.1$

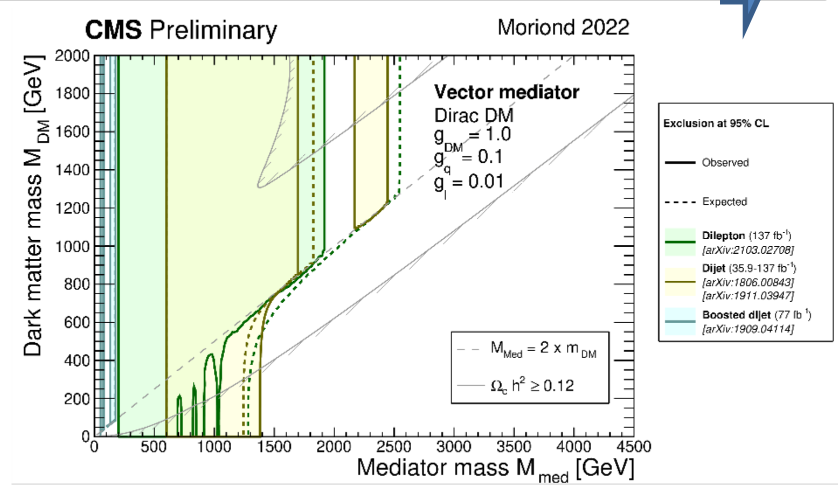




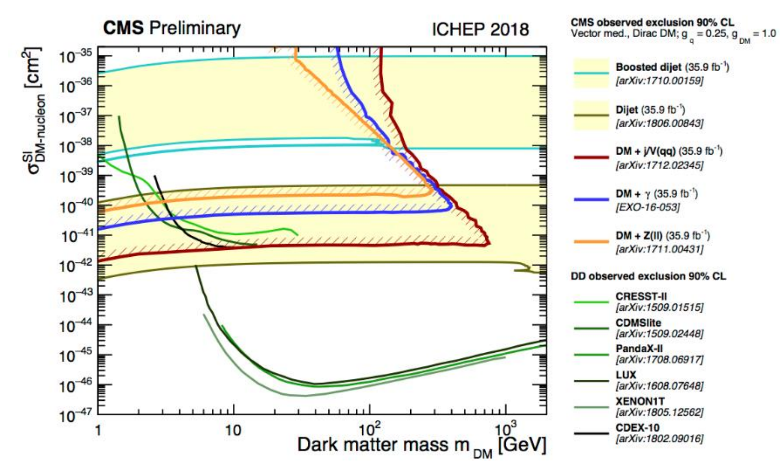


η_{Med}, g_{DM}, g_l, g_q

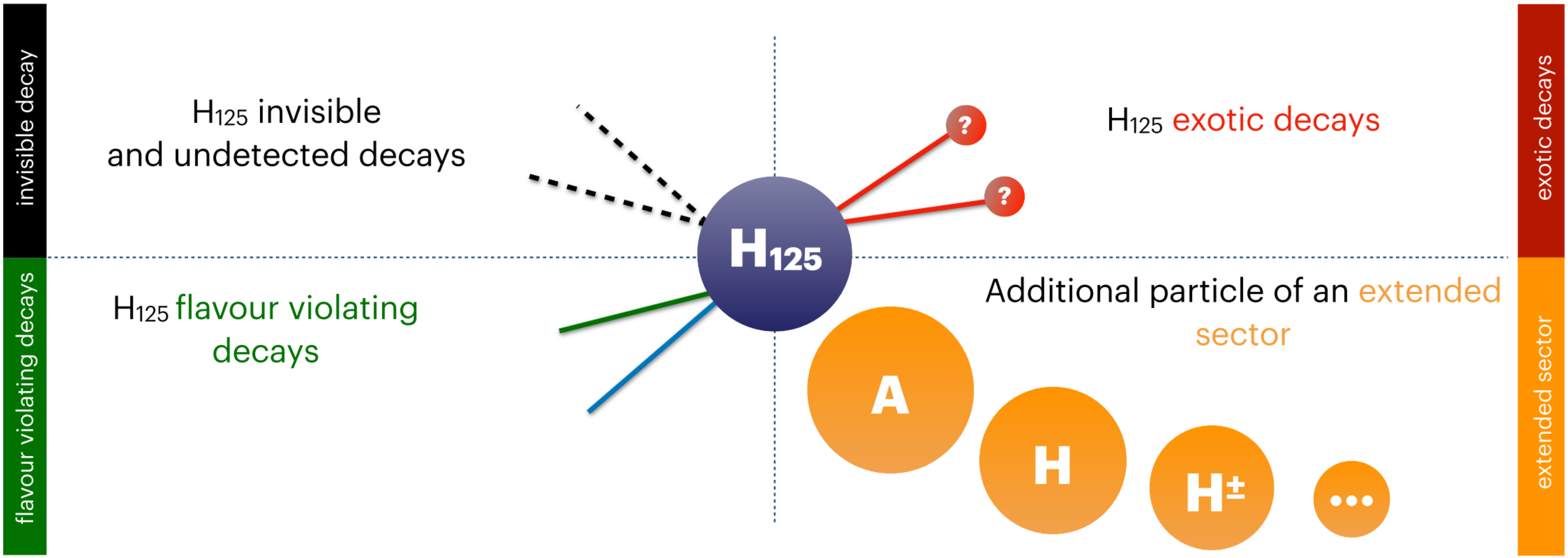
DM-nucleon upper limits on the cross section



see talk by Maria Savina for details



Higgs Boson as a Tool to Search for the New Physics



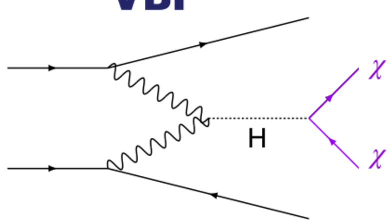
Higgs Invisible Decays

The expected in SM h_{125} the branching fraction $h_{125} \rightarrow$ inv $\mathcal{B}(h_{125} \rightarrow ZZ^{*} \rightarrow 4\nu) = 0.12\%$

Several BSM scenarios predict anomalous and sizeable values, $\mathcal{B}$ is significantly enhanced

- a simple extension of the SM to provide a Dark Matter (DM) candidate and are able to predict the observed relic DM density vis s-channel $\chi\chi \rightarrow f\bar{f}$

VBF



Strategy

2 jets with large angular separation $\Delta\eta_{jj}$ and large invariant mass m_{jj}

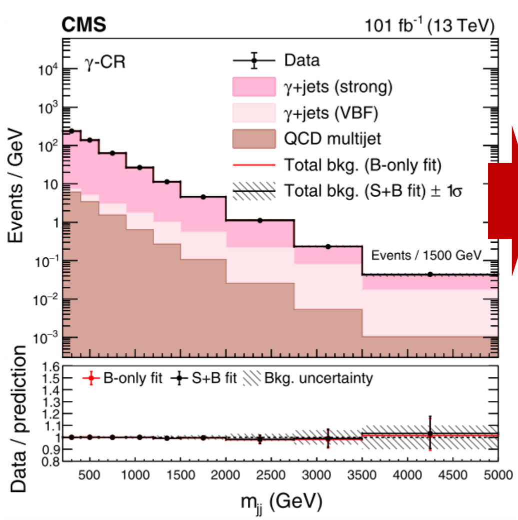
Veto on other objects (leptons/photons)

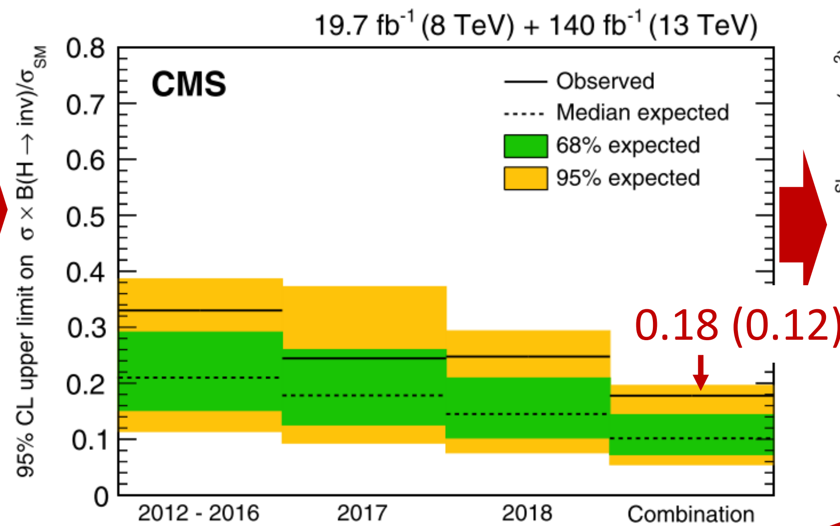
High missing transverse momentum (trigger constraint) → reject QCD

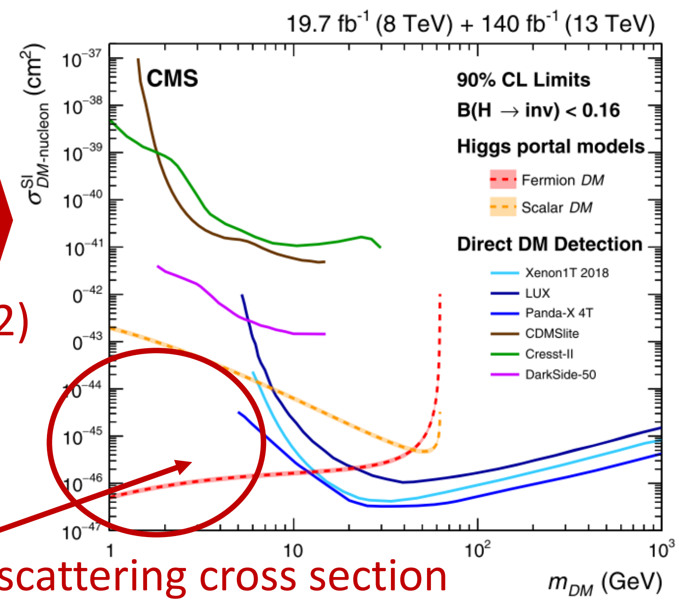
Low $|\Delta\phi_{jj}|$ → reject QCD

⇒ Main remaining backgrounds: $Z(\nu\nu)$ + jets and $W(l\nu)$ + jets (strong and VBF productions)

PRD 105 (2022) 092007







Low-mass region in the spin-independent dark-matter-nucleon scattering cross section

Lepton Flavour Violation Higgs Decays (1)

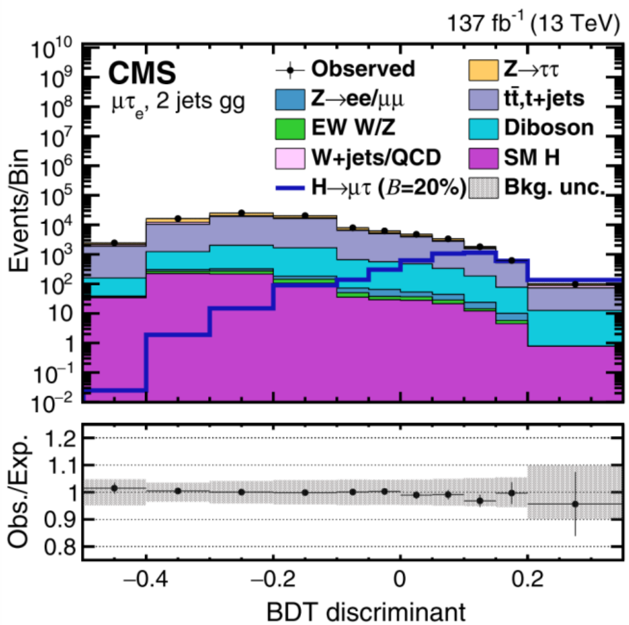
The decays $H \to e\mu/\mu\tau/e\tau$ trough the LFV Yukawa couplings arising in two Higgs doublet models, extra dimensions, models with flavor symmetries, models of compositeness, etc

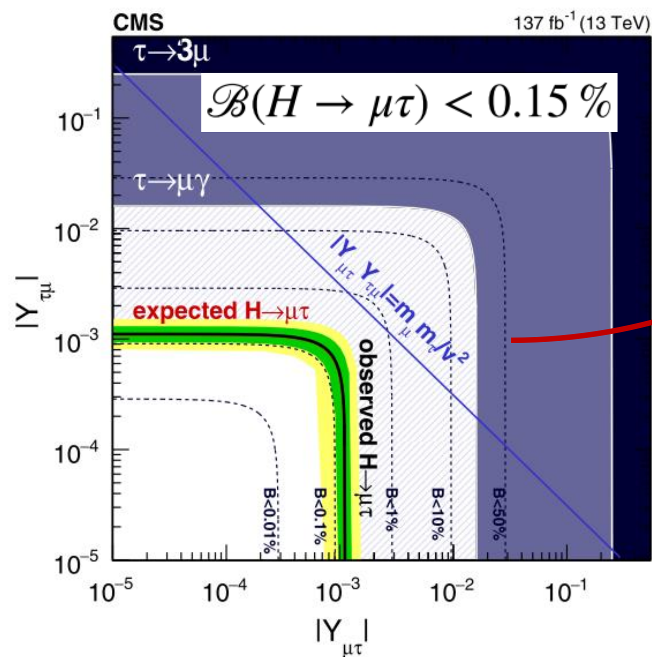
- to verify h_{125} hypothesis, $m_{ll} = m_{h_{125}}$ (type 1)
- to search for new higgs states, $m_{ll} \neq m_{h_{125}} \Rightarrow$ broad invariant mass region (type 2)

type 1, ggH, VBF

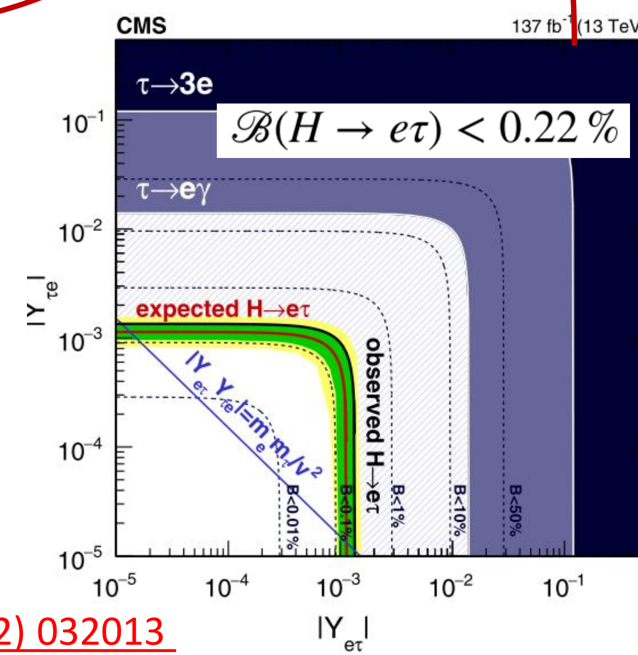
$$\Gamma(\mathrm{H} \to \ell^\alpha \ell^\beta) = \frac{m_\mathrm{H}}{8\pi}\left(|Y_{\ell^\beta \ell^\alpha}|^2 + |Y_{\ell^\alpha \ell^\beta}|^2\right)$$

$$\mathcal{B}(\mathrm{H} \to \ell^\alpha \ell^\beta) = \frac{\Gamma(\mathrm{H} \to \ell^\alpha \ell^\beta)}{\Gamma(\mathrm{H} \to \ell^\alpha \ell^\beta) + \Gamma_\mathrm{SM}}$$





$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ & Y_{\mu\mu} & Y_{\mu\tau} \\ & & Y_{\tau\tau} \end{pmatrix}$$



Channels: $e\tau_h$, $e\tau_\mu$, $\mu\tau_h$, $\mu\tau_e$

Jet categories: 0j, 1j, 2j (ggH), VBF

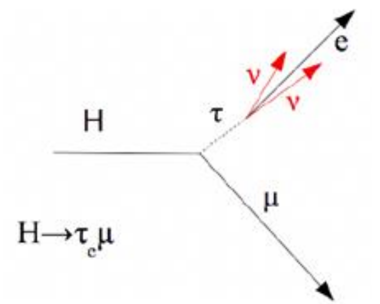
BDTs to discriminate signal

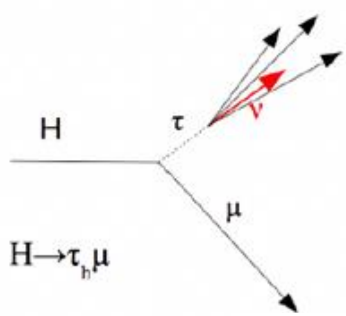
Joint fit to BDT outputs

Lepton Flavour Violation Higgs Decays (2)

The first direct search for LFV $H \to \mu\tau/e\tau$ decays for an Extra Higgs mass in the range $200\ GeV < m_H <$ 900 GeV (neutral heavy Higgs boson)

type 2, ggH, τ lepton decay products are highly boosted

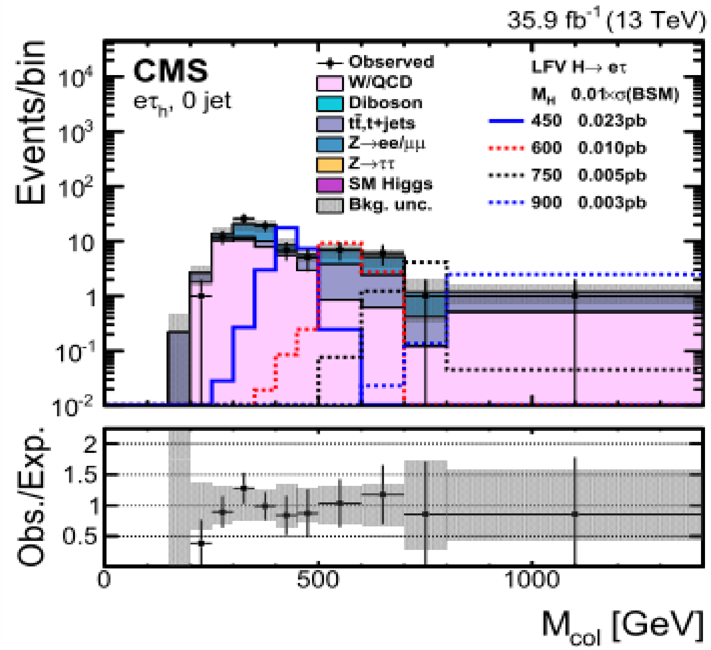


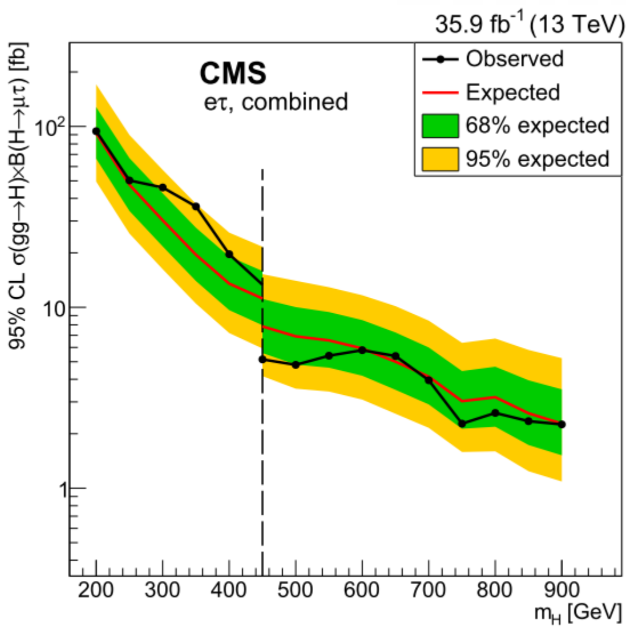


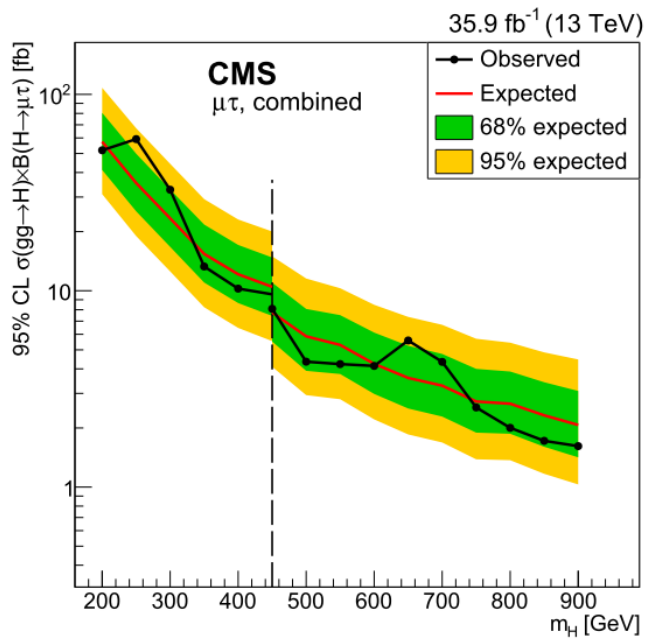
$$x_\tau^{vis} = p_T^{\vec{\tau}^{vis}} / (p_T^{\vec{\tau}^{vis}} + p_T^{\nu, est})$$

$$M_{col} = M_{vis} / \sqrt{x_\tau^{vis}}$$

$\varepsilon_\tau \approx 70\%$ (DNN)







The observed (expected) upper limits (95% CL) is

μτ: 51.9 (57.4) fb to 1.6 (2.1) fb

eτ: 94.1 (91.6) fb to 2.3 (2.3) fb

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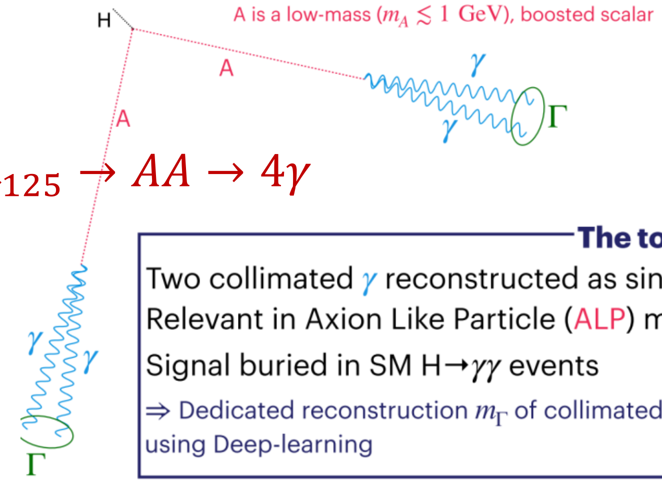
Searches for Low-Mass BSM Higgses/DM in h_{125} Decays

If $m_H > 2m_X$, some BSM scenarios allow Higgs bosons decays via one or two hypothetical on-shell new (pseudo)scalar(s) decaying to a pair of SM particles.



$h_{125} \to AA \to 4\gamma$

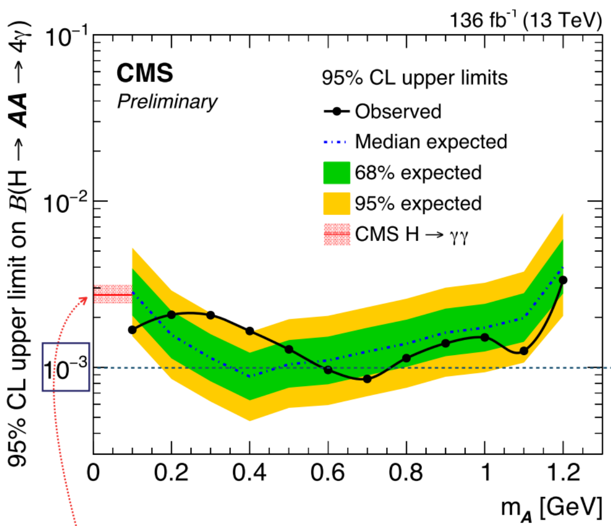
The topology

Two collimated γ reconstructed as single Γ

Relevant in Axion Like Particle (ALP) model

Signal buried in SM H→$\gamma\gamma$ events

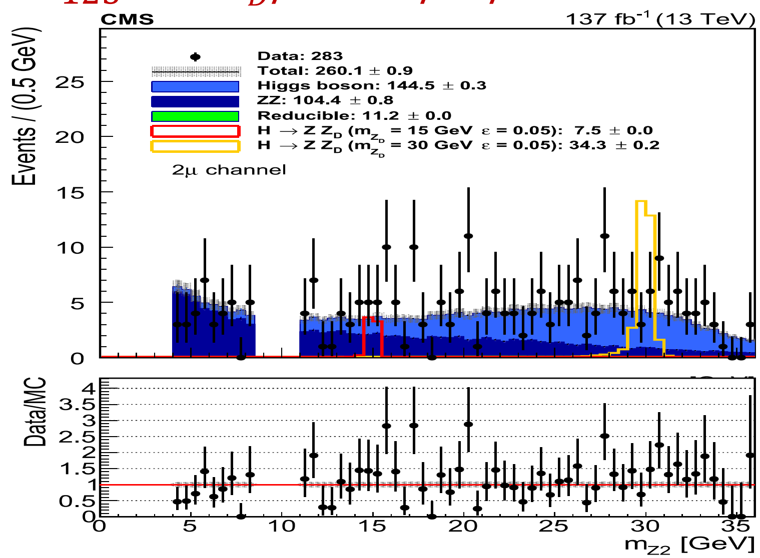
⇒ Dedicated reconstruction m_Γ of collimated di-γ using Deep-learning

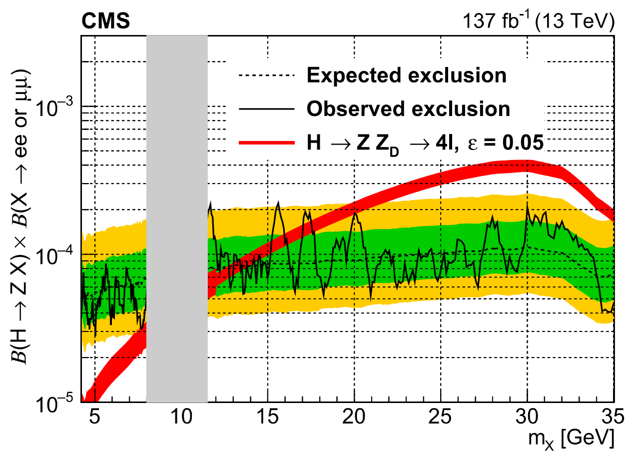


Upper bound provided by SM $H \to \gamma\gamma$

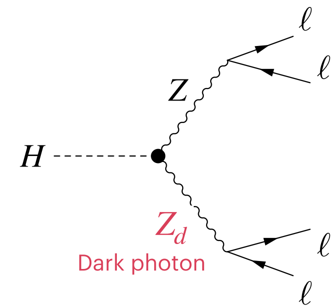
CMS PAS HIG-21-016

$h_{125} \to ZZ_D/ZDZD/ss/aa$

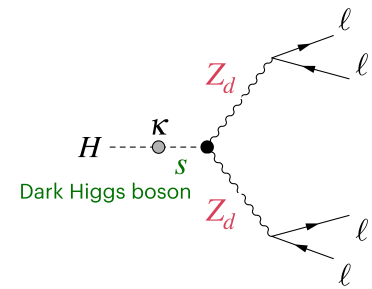




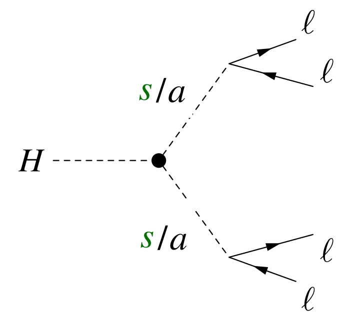
EPJ C 82 (2022) 290



U(1) gauge theory mixes with SM hypercharge



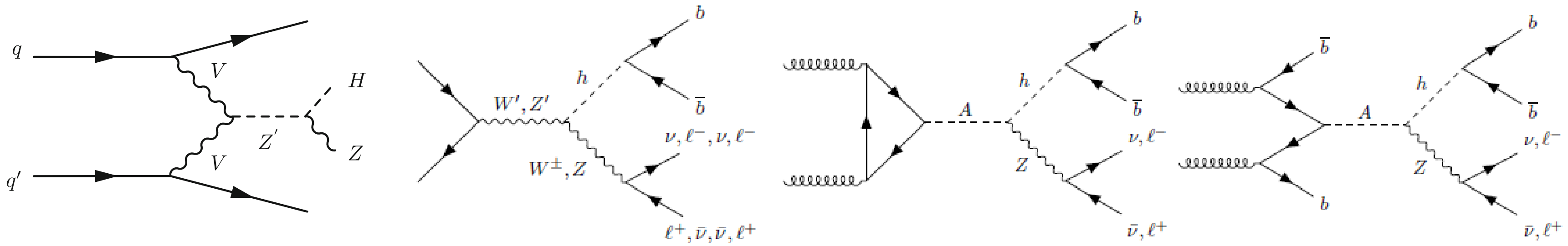
U (1) is broken by a hidden-sector Higgs mechanism



Extended Higgs sector ex. 2HDM, 2HDM+

BSM Higgs/V' in Decays into h_{125}(+X)

If $m_H < 2m_X$, the finals states are possible with h_{125} and SM gauge bosons

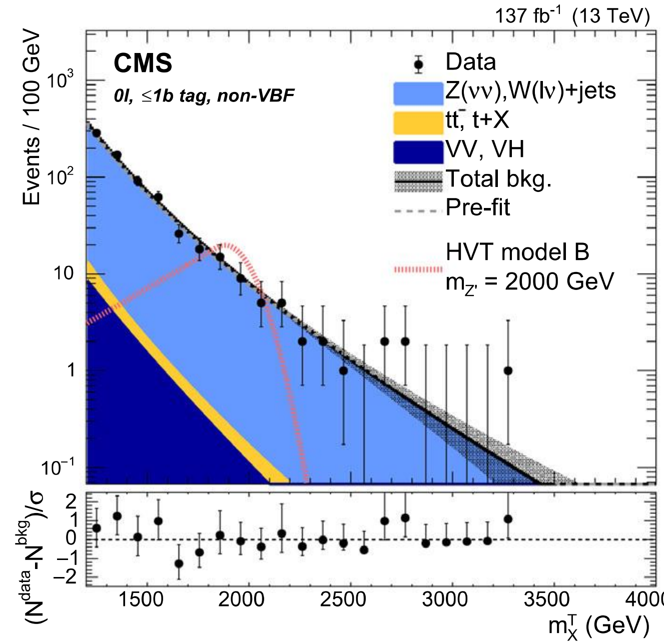


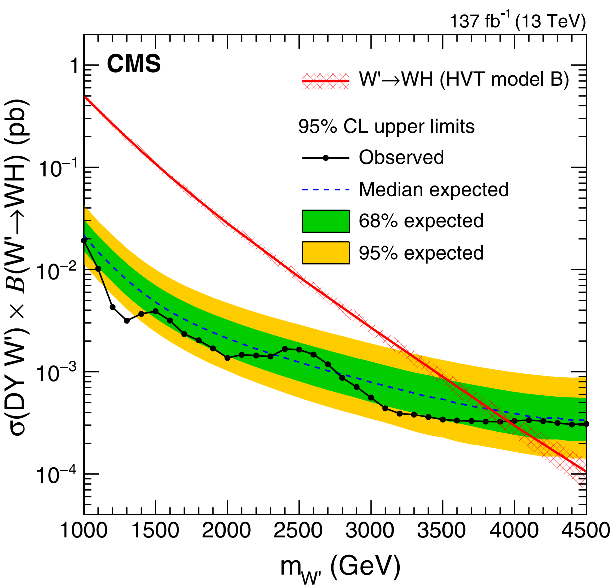
Strategy

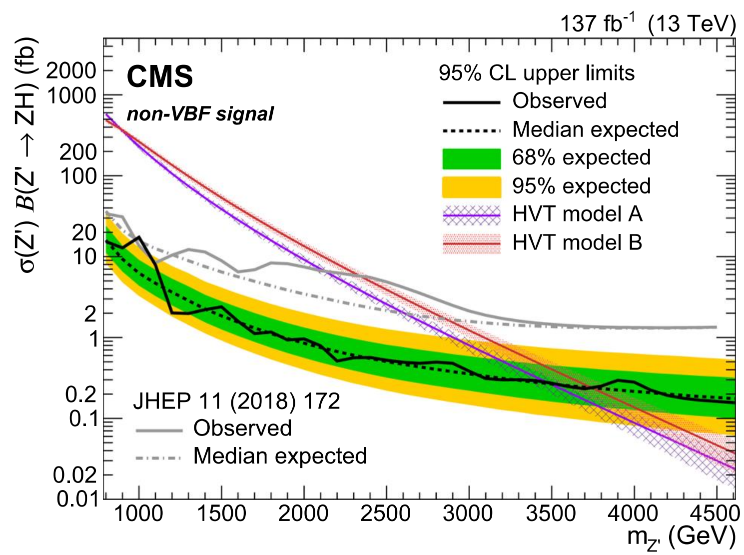
0-, 1-, and 2-lepton channels

b-tag jet categories (merged and resolved)

Fit either $m_{T,VH}$ or m_{VH}

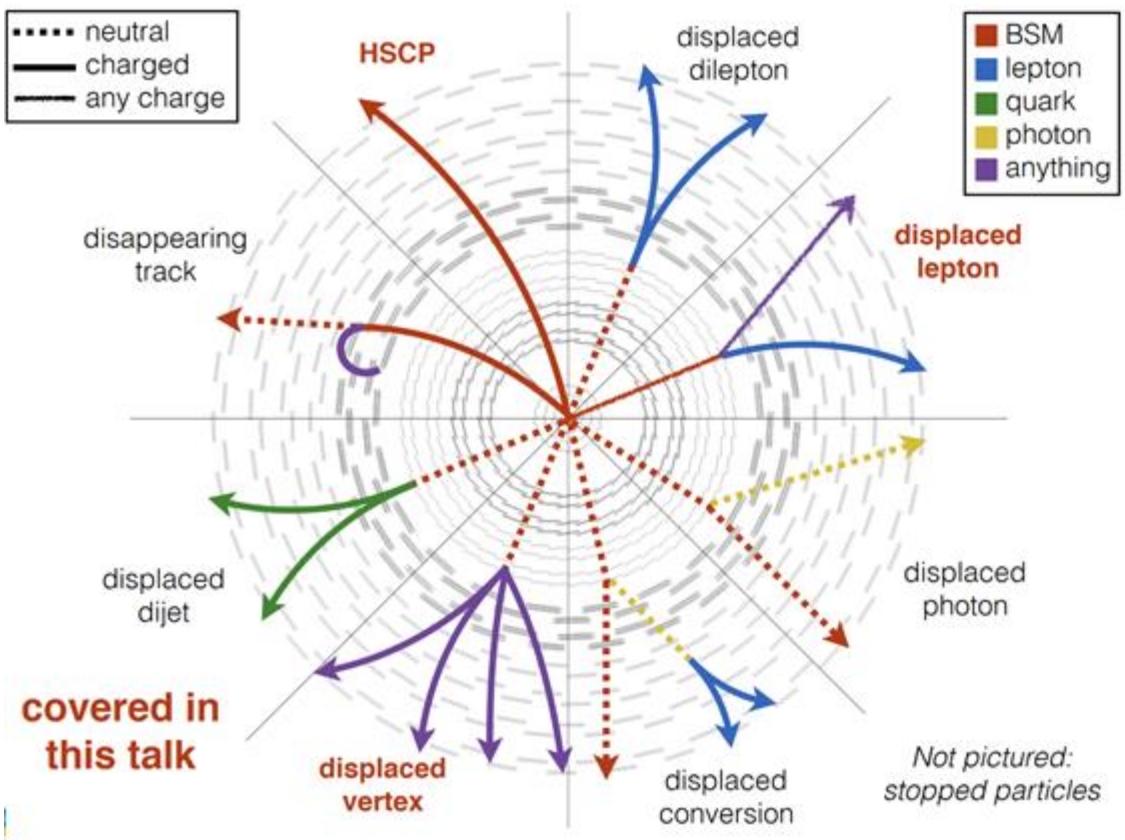


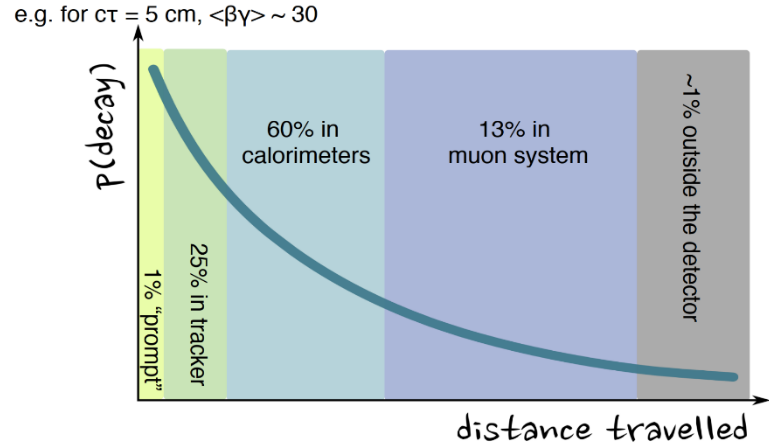




PRD 105 (2022) 032008
EPJ C 81 (2021) 688

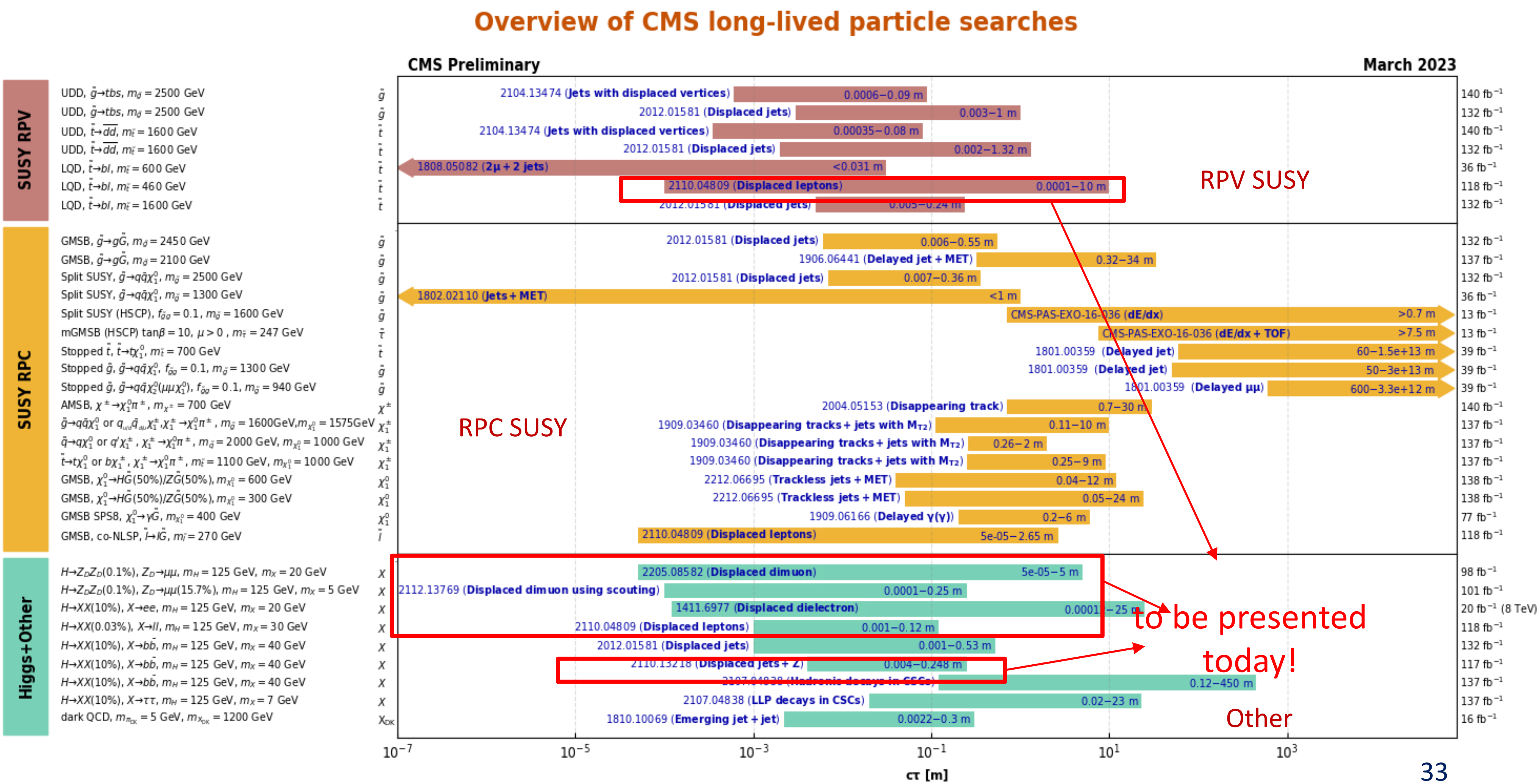
Direct Search for BSM: LLP Non-conventional Signals





- a proper lifetime $c\tau_0$ is greater than or comparable to the characteristic size of the (sub)detectors
- small $c\tau_0$ that comparable to the inner tracker size, no displaced tracks → "standard" prompt decay
- intermediate $c\tau_0$ → LLP
- very large/infinite large $c\tau_0$ → stable particles, "standard" MET signatures

Overview of CMS Exotica LLP Searches



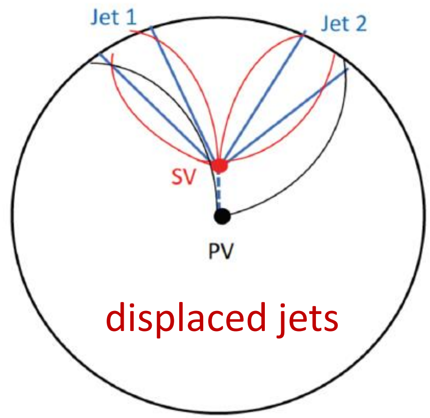
Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included). The y-axis tick labels indicate the studied long-lived particle.

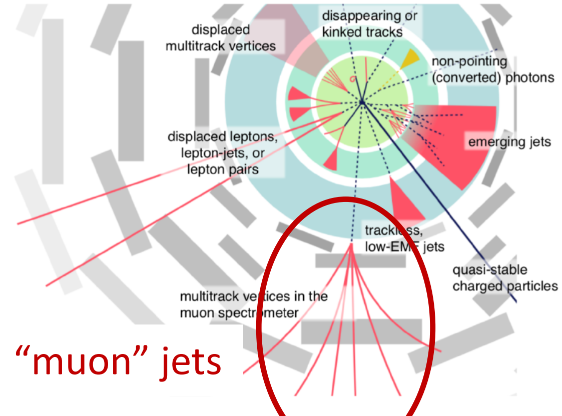
More results:

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/LLP.html

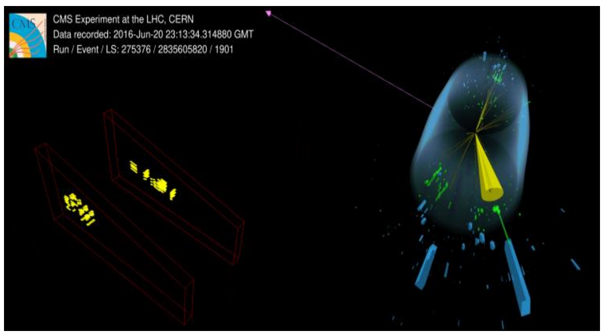
Displaced Jets

- the dark sector particles continue traveling for a long time and traverse several meters (Long-Lived Particles) before tunneling back into our visible universe (quarks or leptons)
- the Higgs is likely to be one of the candidates for a messenger role

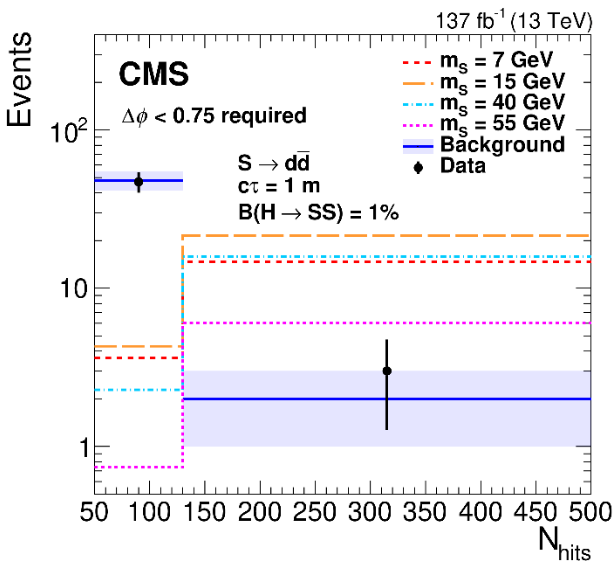




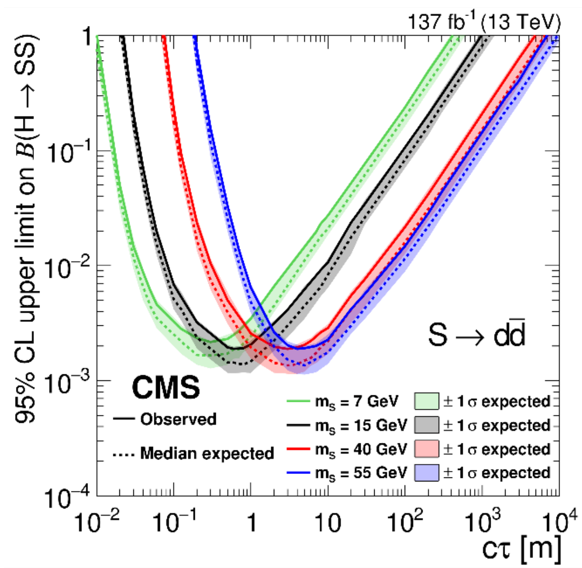
Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider, arXiv:1903.04497

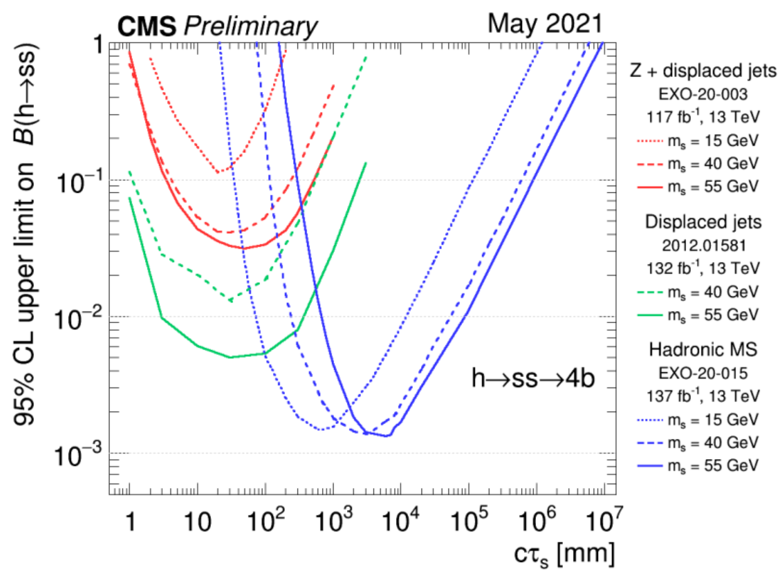


$$h \to SS \to 4l \text{ or } 4q$$



23





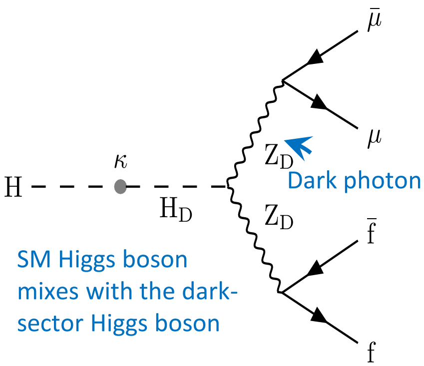
PRL 127 (2021) 261804
CMS Physics Briefings

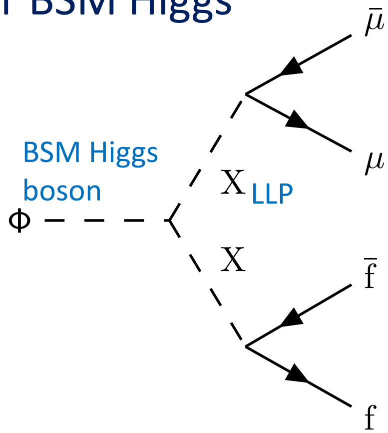
This exciting tool opens up a new program of searches for LLP in a wide variety of theoretical models

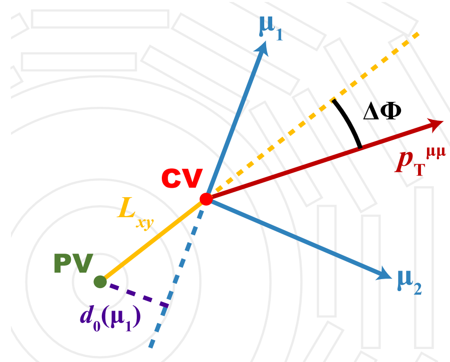
Displaced Dimuons

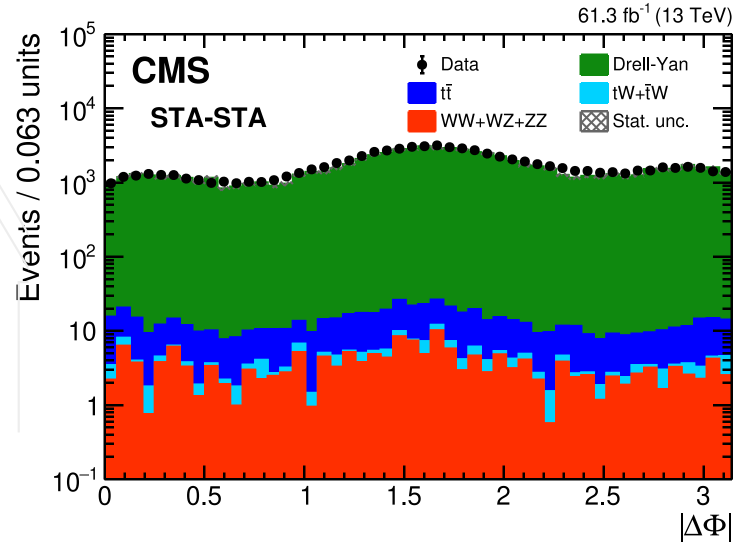
arXiv:2205.08582

Dark photon and Scalar BSM Higgs



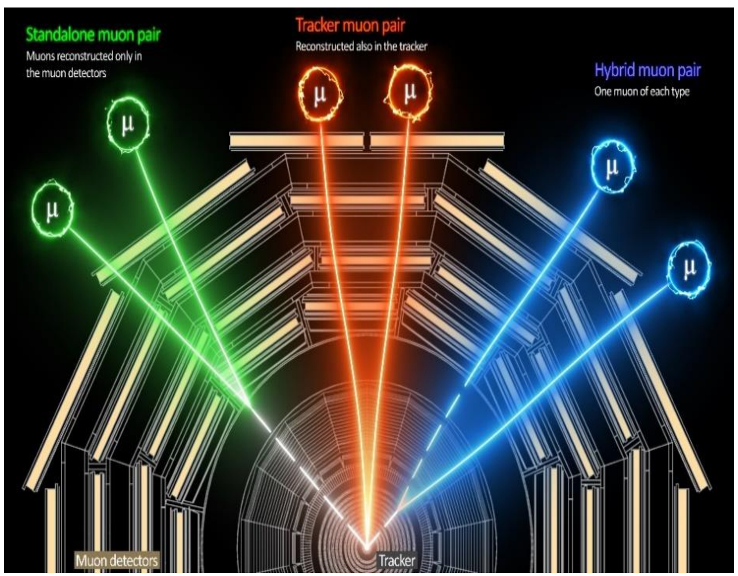


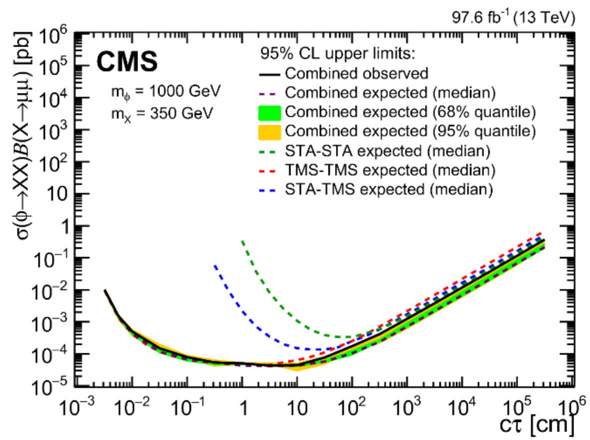


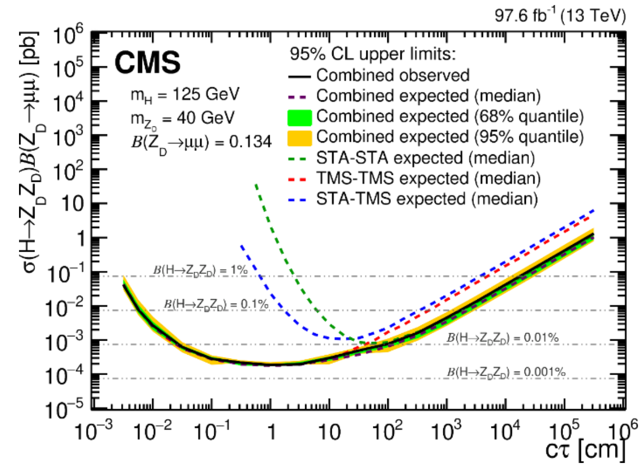


Three categories of events:

STA-STA, TMS-TMS, and STA-TMS

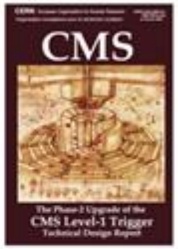




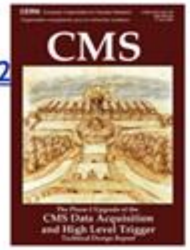


No significant excess of events above the standard model background is observed. The results are interpreted as limits on the parameters of a these two models

The CMS Phase 2 Upgrade

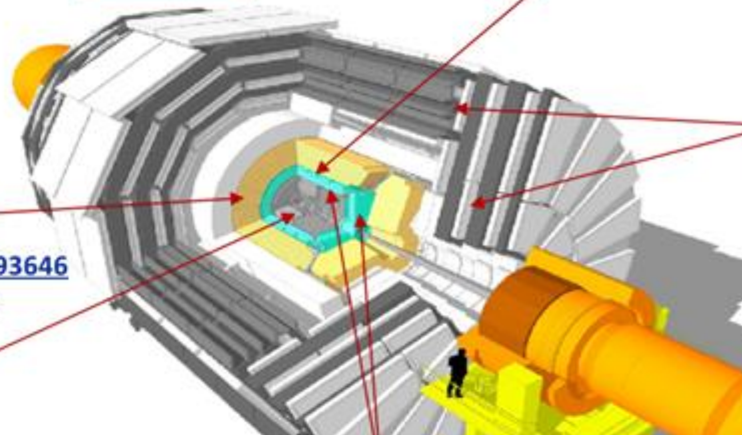


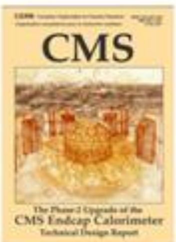
L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

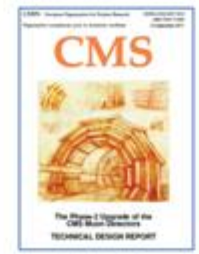
Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MH with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards



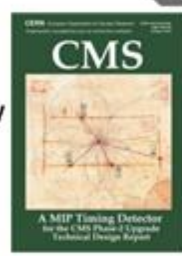


Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η ≃ 3



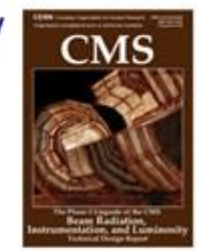
Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to η ≃ 3.8



MIP Timing Detector
https://cds.cern.ch/record/2667167

Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors



Summary

Extensive searches for the New Physics are performed with CMS experiment on RUN1 and RUN2 data

- 582 papers with RUN1 data and 627 papers with RUN2 data
- 1 paper with RUN3

CMS titles

- 599 "Search"
- 48 "Observation"
- 21 "Evidence"
- 333 "Measurement"
- 42 "Study"

The tricks of the RUN2/RUN3 are (procedure was updated during LS2 and will be improved further)

- Higgs boson is intensively involved in searches
- Non-conventional signals

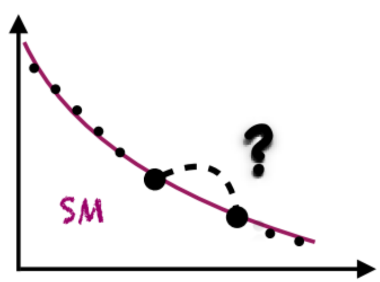
Many new analyses made public

- for Summer Conferences, http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/CMS/index.html
- Physics Briefings at: https://cms.cern/tags/physics-briefing

Phase 2 Upgrades

- excellent progress in all projects
- all Technical Design Reports prepared
- more physics projections for HL-LHC starting to appear

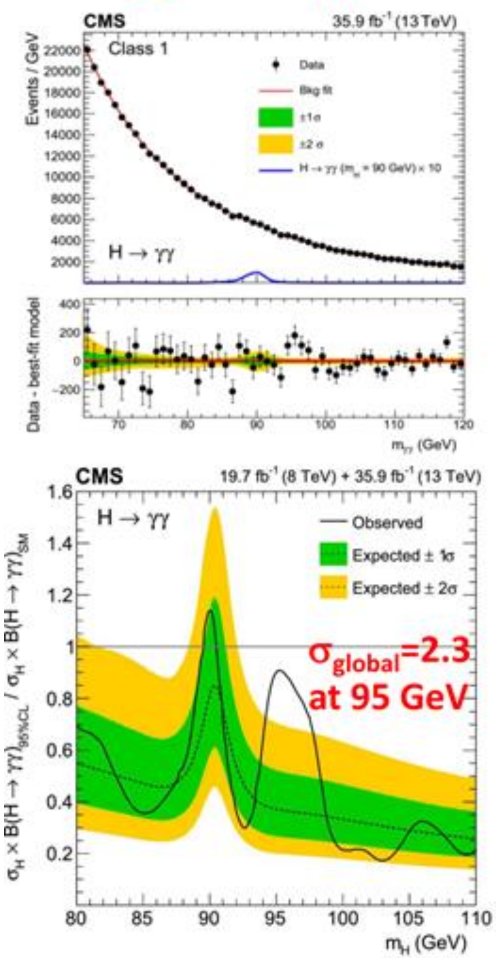
we are looking forward to



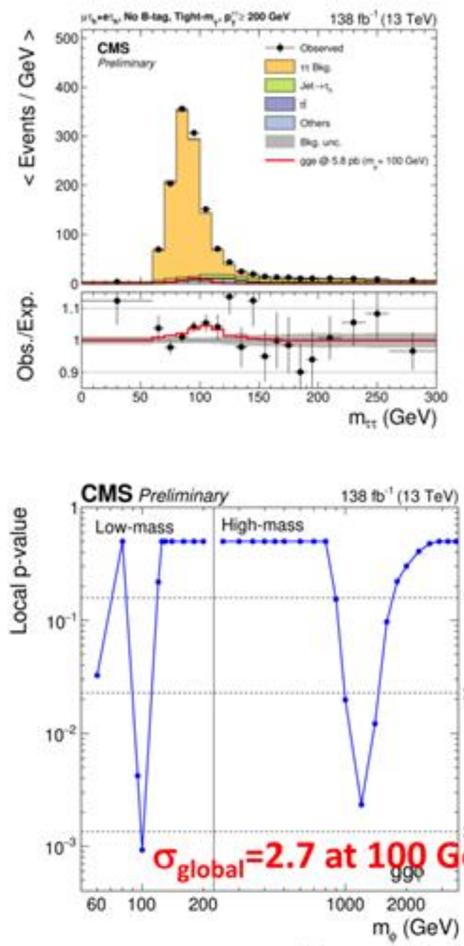
THANK YOU FOR YOUR ATTENTION!

Some Selected Excitements

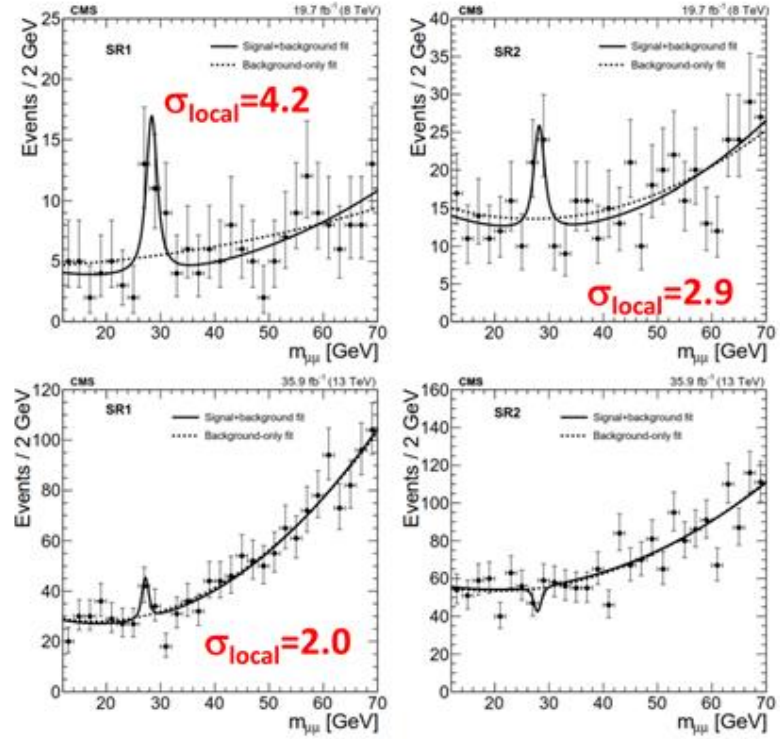
- Light X→γγ



- Light X→ττ



- Light X→μμ



A. Nikitenko

RUN3 is a perfect judge for these challenges!