CMS Highlights

JIM OLSEN

CMS DEPUTY SPOKESPERSON

PRINCETON UNIVERSITY

MAY 12, 2021

LHCP 2019 Conference in Puebla

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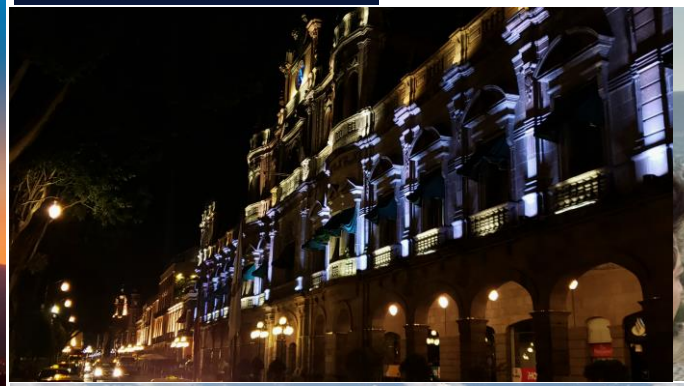
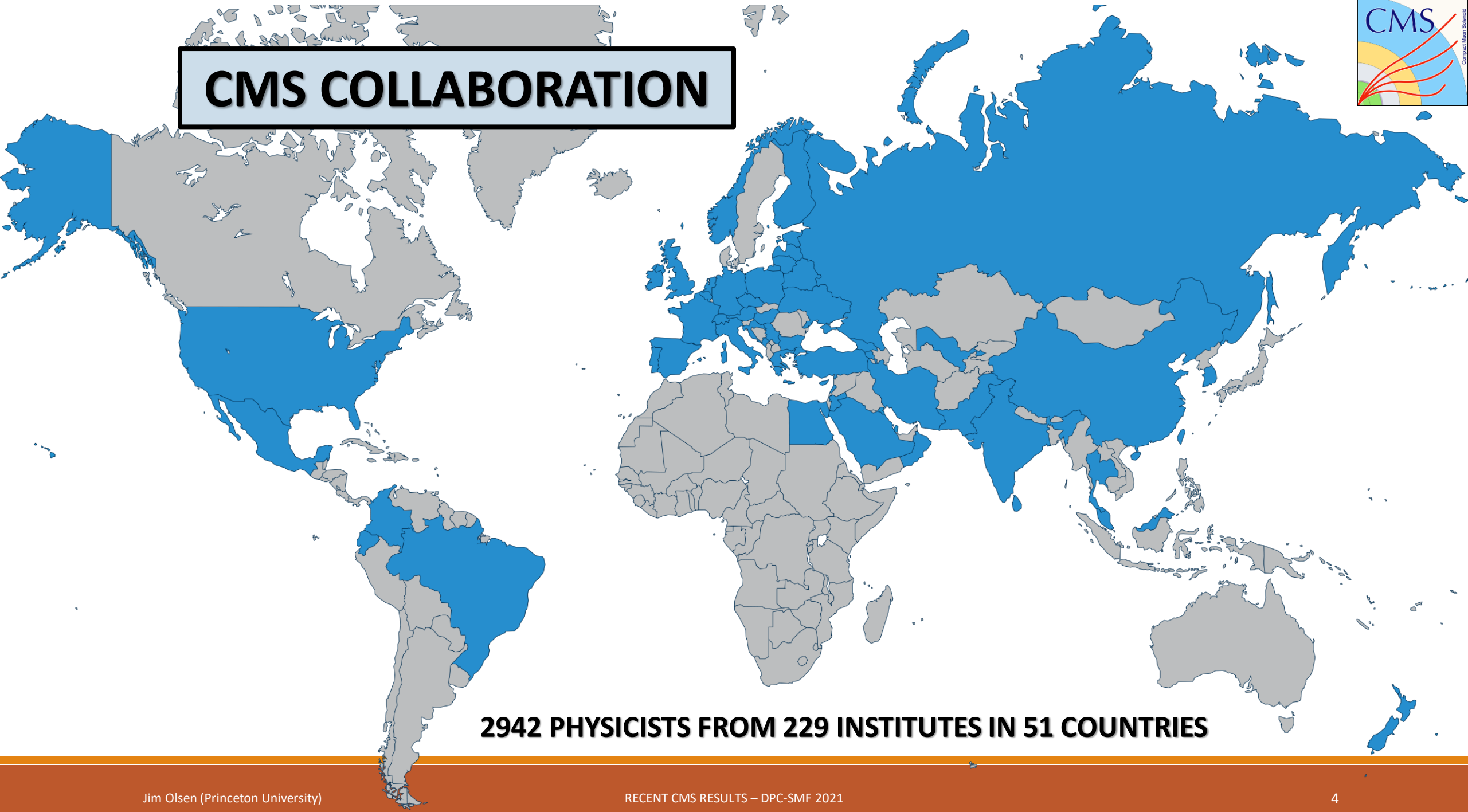


Large Hadron Collider

27 km in circumference colliding protons at (so far) 13 TeV CM energy
Four large detectors test the standard model and search for new physics

CMS COLLABORATION



2942 PHYSICISTS FROM 229 INSTITUTES IN 51 COUNTRIES

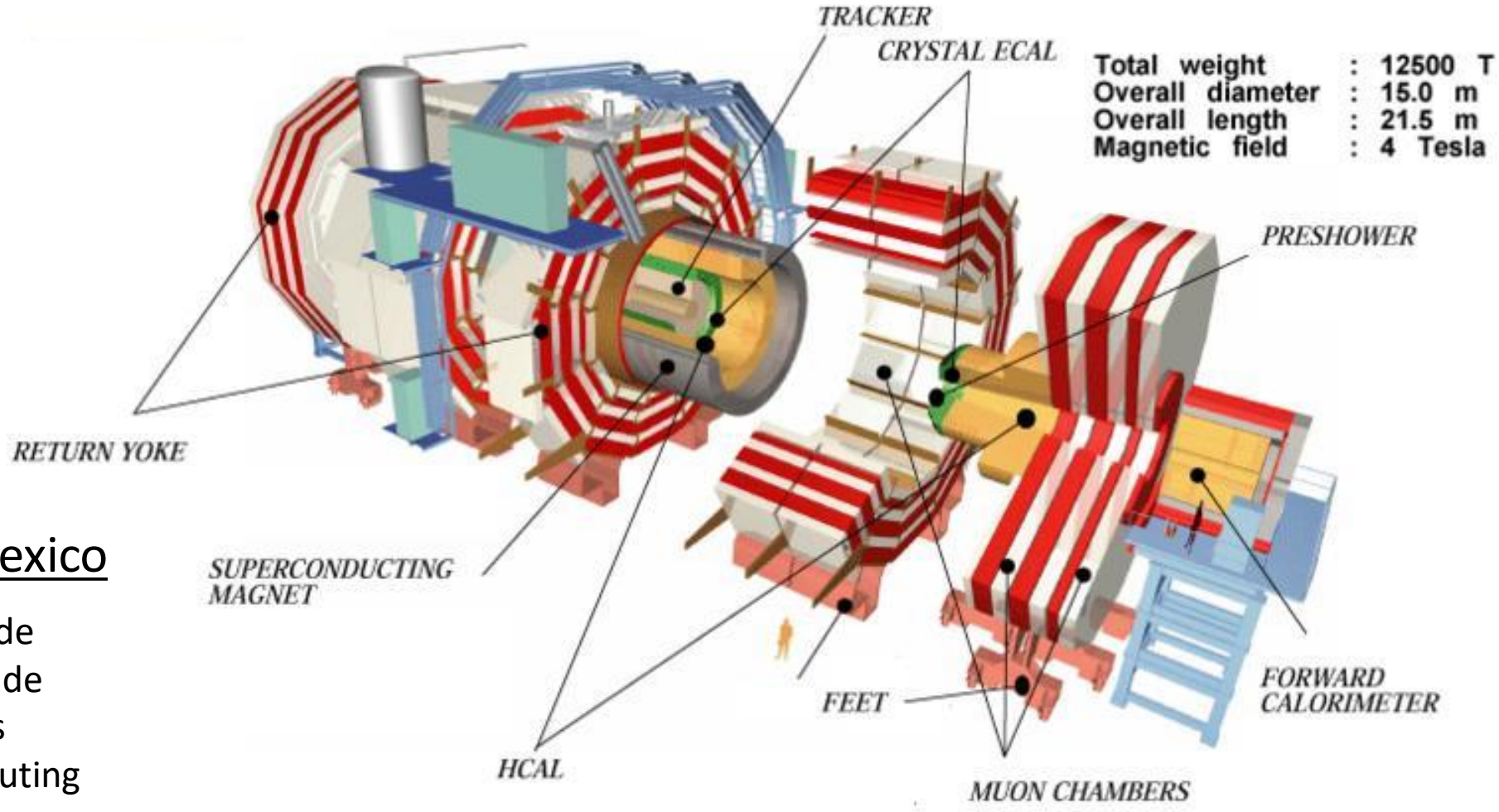
Mexico in CMS

Mexico in CMS since 2005

Five institutes and ~40 collaborators

- **Benemerita Universidad Autonoma de Puebla**
- **Centro de Investigacion y de Estudios Avanzados del IPN**
- **Universidad Autónoma de San Luis Potosí**
- **Universidad Iberoamericana**
- **Universidad de Sonora (UNISON)**

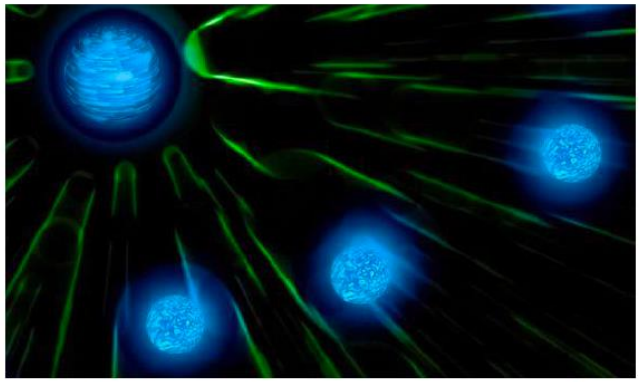
Mexico and the CMS Detector



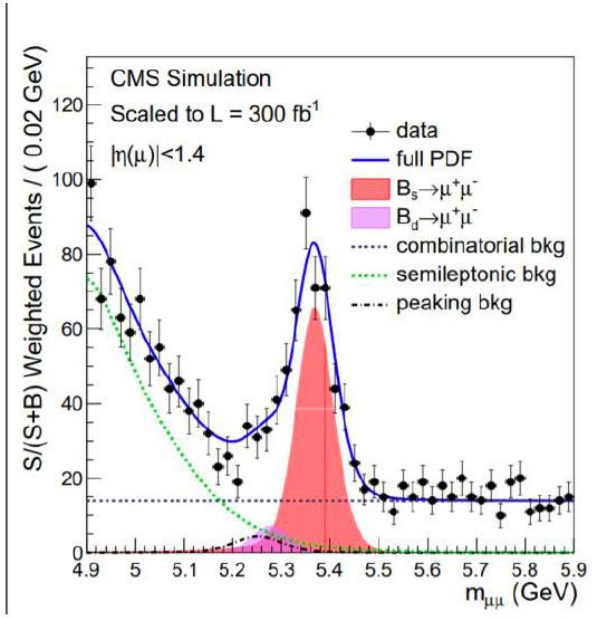
Contributions from Mexico

- RPC muon system upgrade
- Luminosity system upgrade
- Tier 2 computing centers
- High-performance computing and artificial intelligence

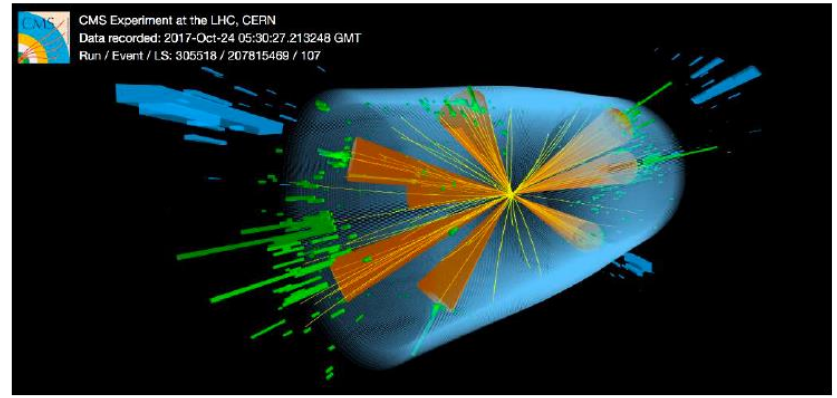
Mexico in CMS Physics Analysis



Search for Dark Matter particles
- dark photons
- dark Higgs bosons

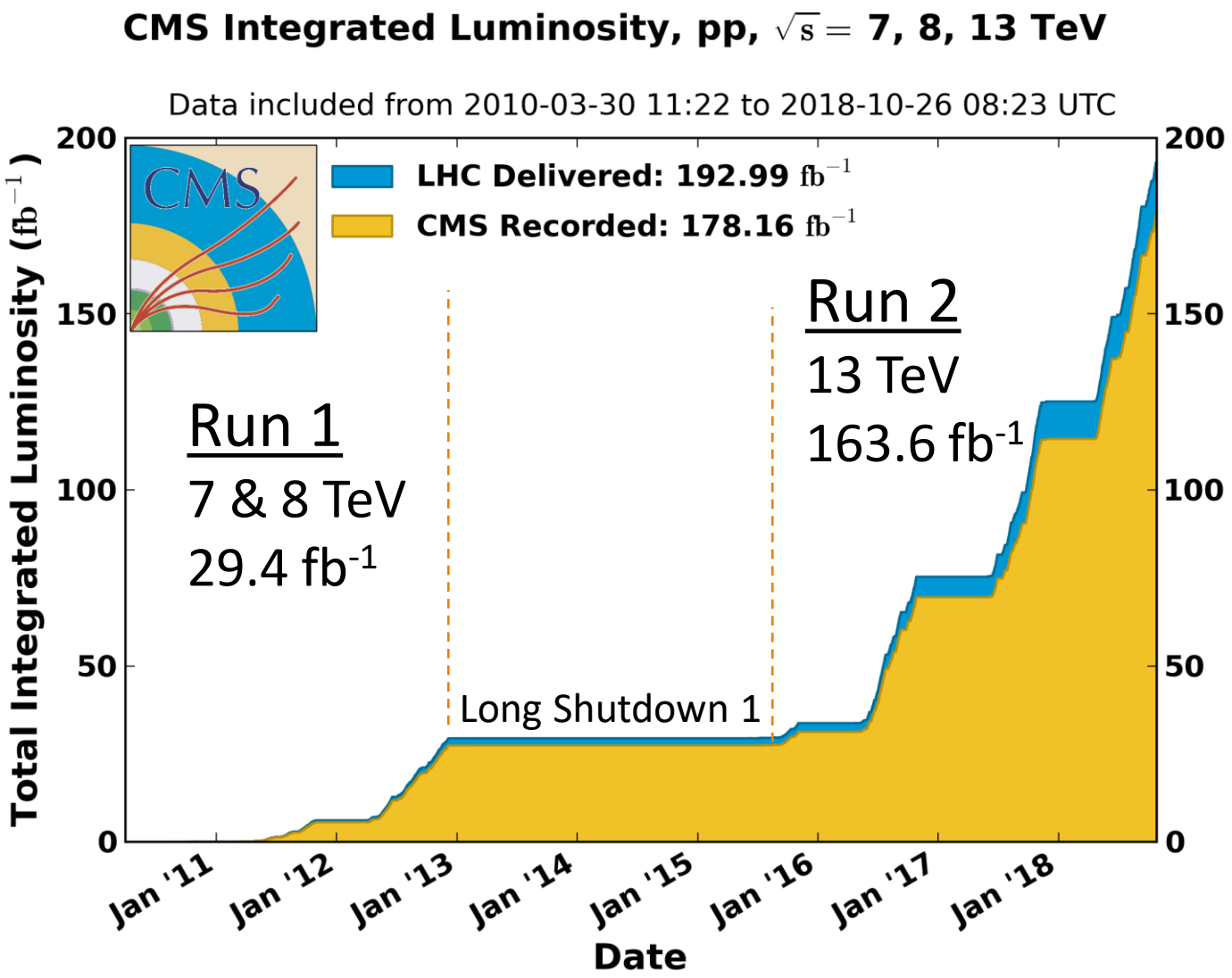


B Physics
- Bc and Bs spectroscopy
- rare B decays



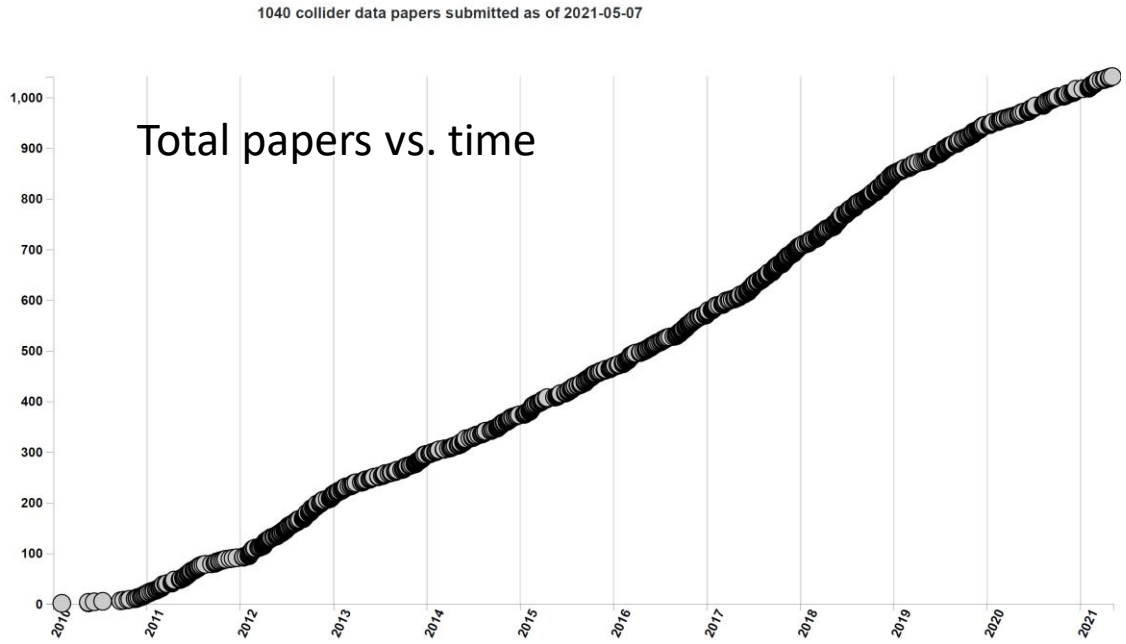
Higgs Physics
- rare tH production
- BSM Higgs bosons

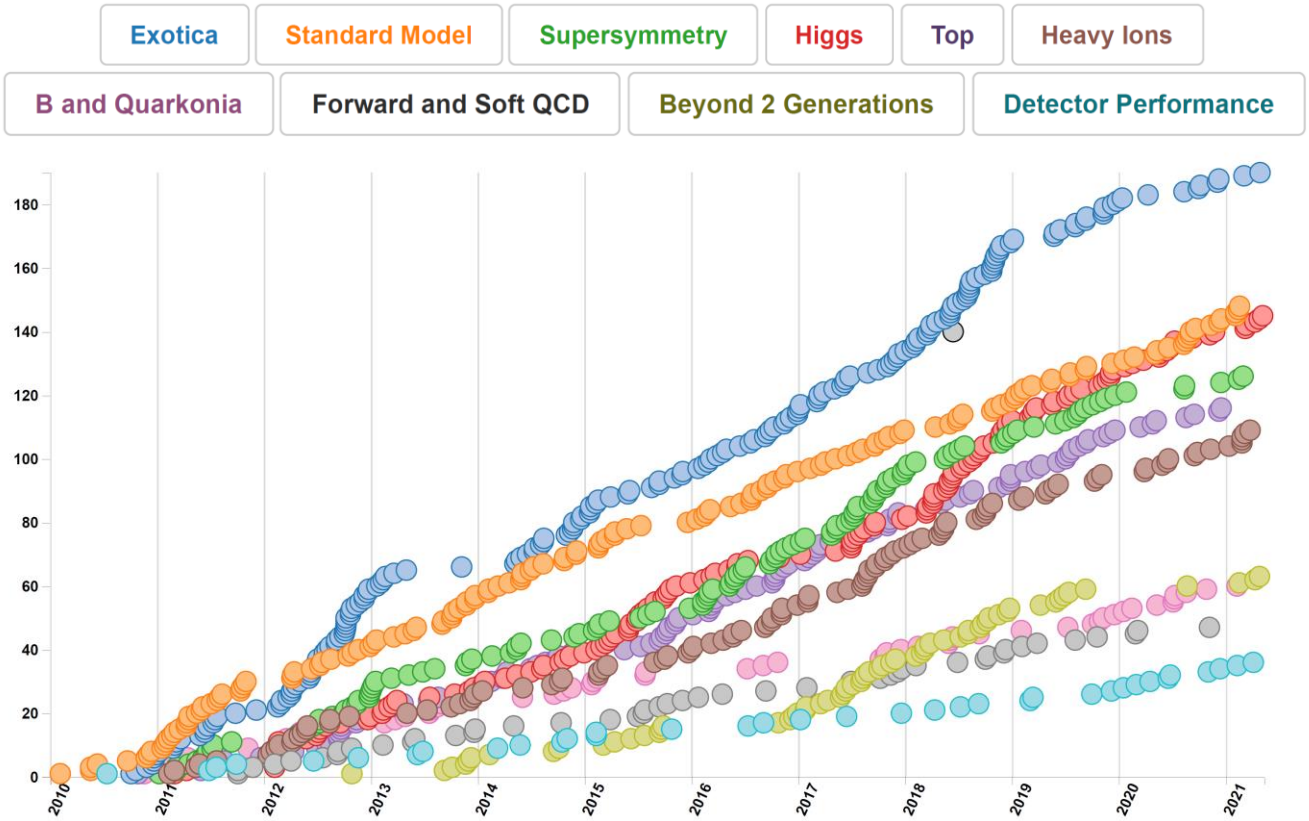
CMS Data: 2010 – 2018



- **Excellent LHC performance**
  - peak luminosity > 2 x 10^{34} cm^{-2} s^{-1}
  - Long Shutdown 2 since late 2018, collisions will return in Spring 2022
  - magnets currently being retrained to reach 14 TeV collision energy
- **Excellent CMS performance**
  - data-taking efficiency > 92%
  - > 1000 published physics papers
  - currently upgrading the detector in preparation for Run 3
  - long-term upgrades underway for the High-Luminosity LHC era

CMS Publications vs. Time

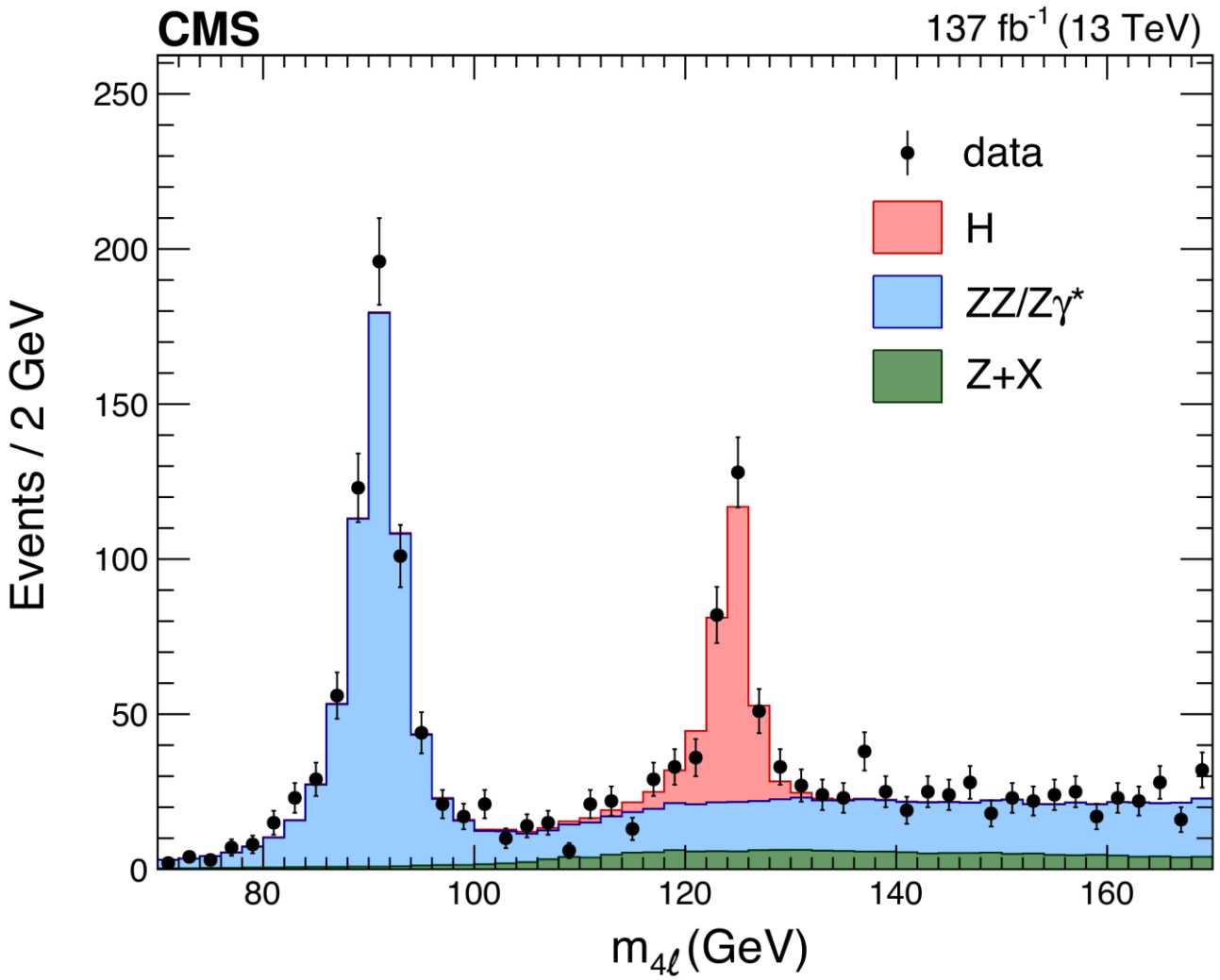




Despite the stress and hardship brought on by the Covid-19 pandemic, CMS physicists have continued to produce new results at historical rates. This is a testament to the resilience and collaborative spirit of the individual members, who continue to work together on exciting physics analyses under difficult circumstances.

Highlights: Higgs Physics

Higgs Overview



Since the first observation in 2012, CMS has been studying the properties of the Higgs boson with increasing precision:

$m_h = 125.46 \pm 0.16$ GeV

Quantum numbers consistent with $J^{PC} = 0^{++}$

Production rates measured in four channels: gluon fusion, VBF, VH, and ttH

Branching fractions measured in 5 + 1 decay channels: $\gamma\gamma$, ZZ^*, WW^*, $\tau^+\tau^-$, $b\bar{b}$, and $(\mu^+\mu^-)$

All measurements are consistent with standard model predictions thus far.

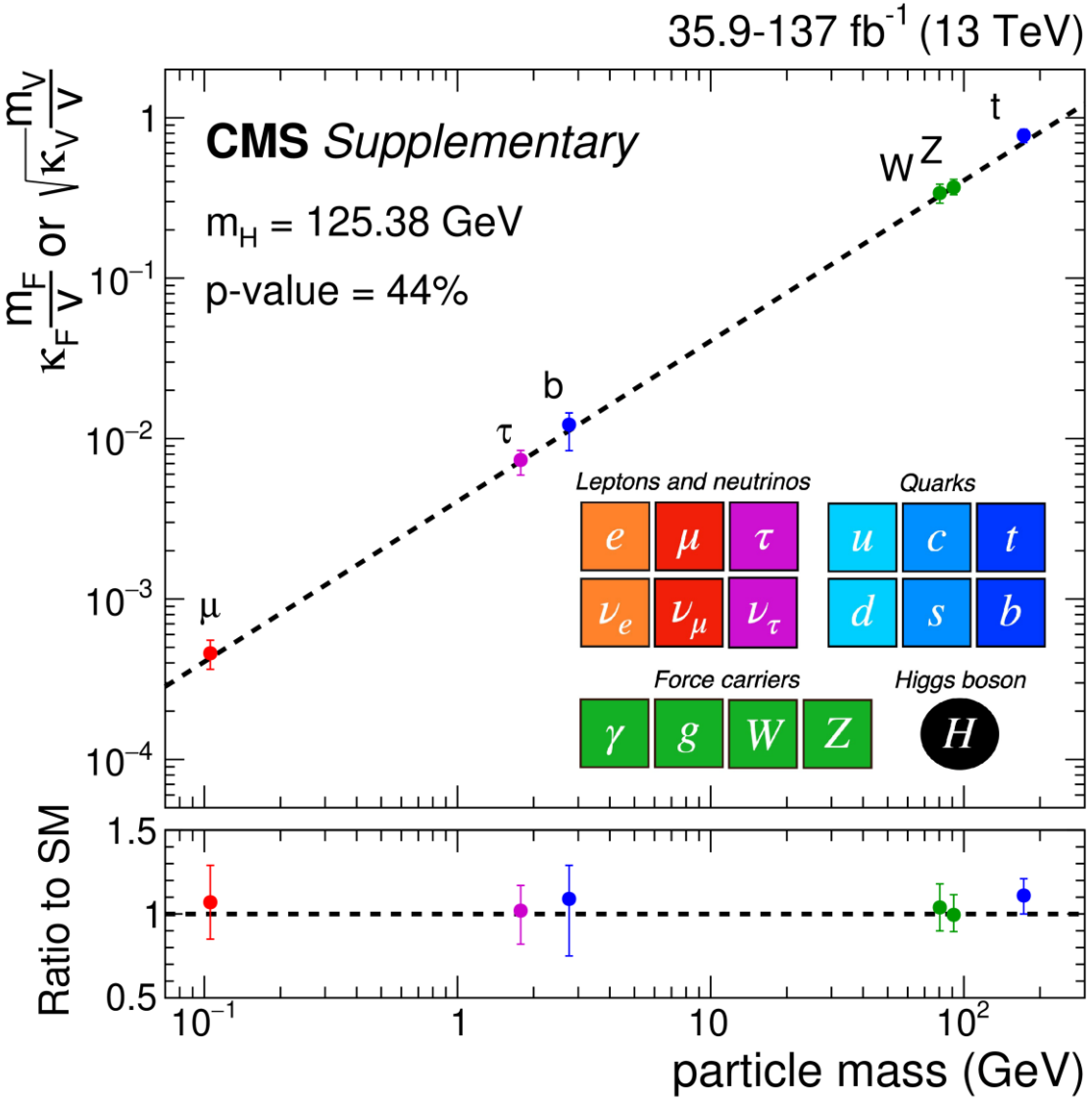
Higgs Couplings

Higgs couplings to standard model particles are determined by the masses

If there is a single Higgs boson that gives mass to all the fundamental particles, all the couplings should be related (and they are →)

New in 2020, first evidence for Higgs boson decays to 2nd generation particles: $h \to \mu^+\mu^-$

Next target: $h \to c\bar{c}$

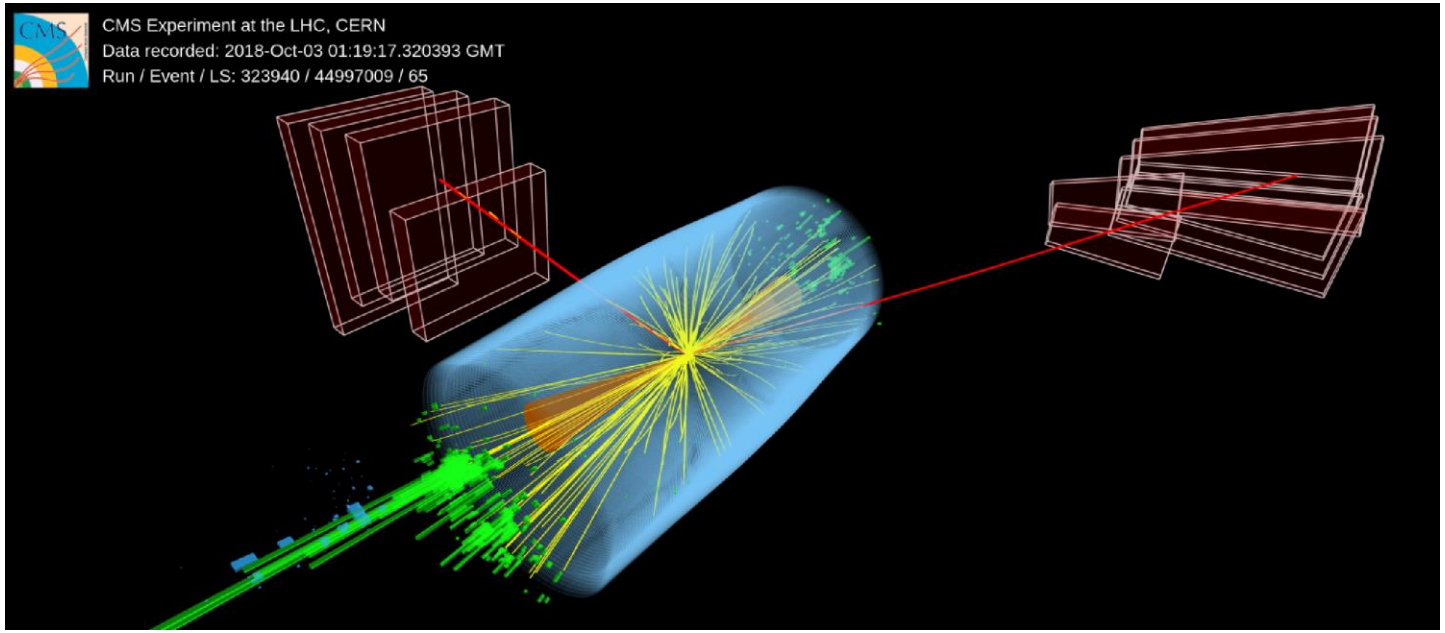


Higgs decay to Muons

- Rare decay with BF $\approx 2 \times 10^{-4}$
  - Large, irreducible dimuon background
- Ratio of measured / expected rate (μ) consistent with SM:

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

Observed (expected) significance @ 125.38 GeV = 3.0 (2.5)σ



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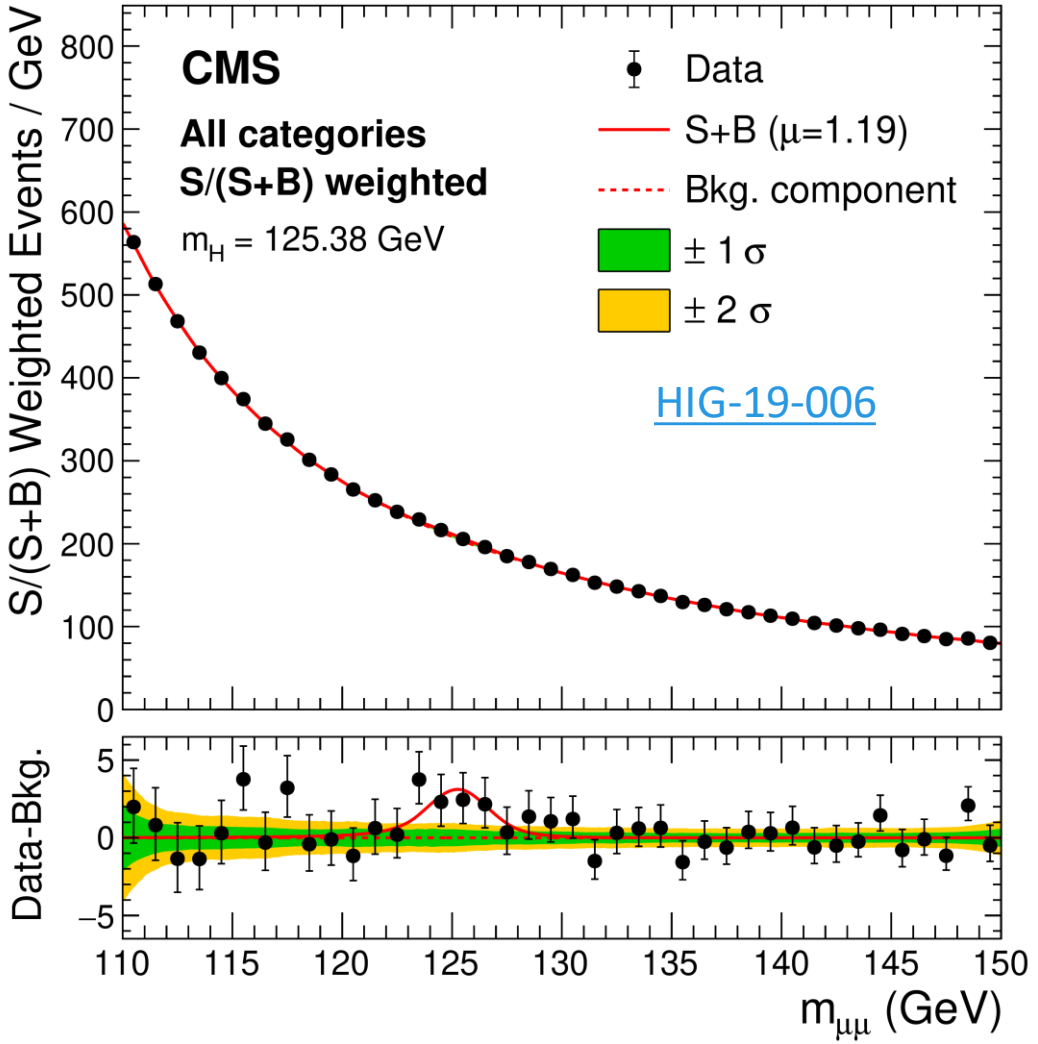
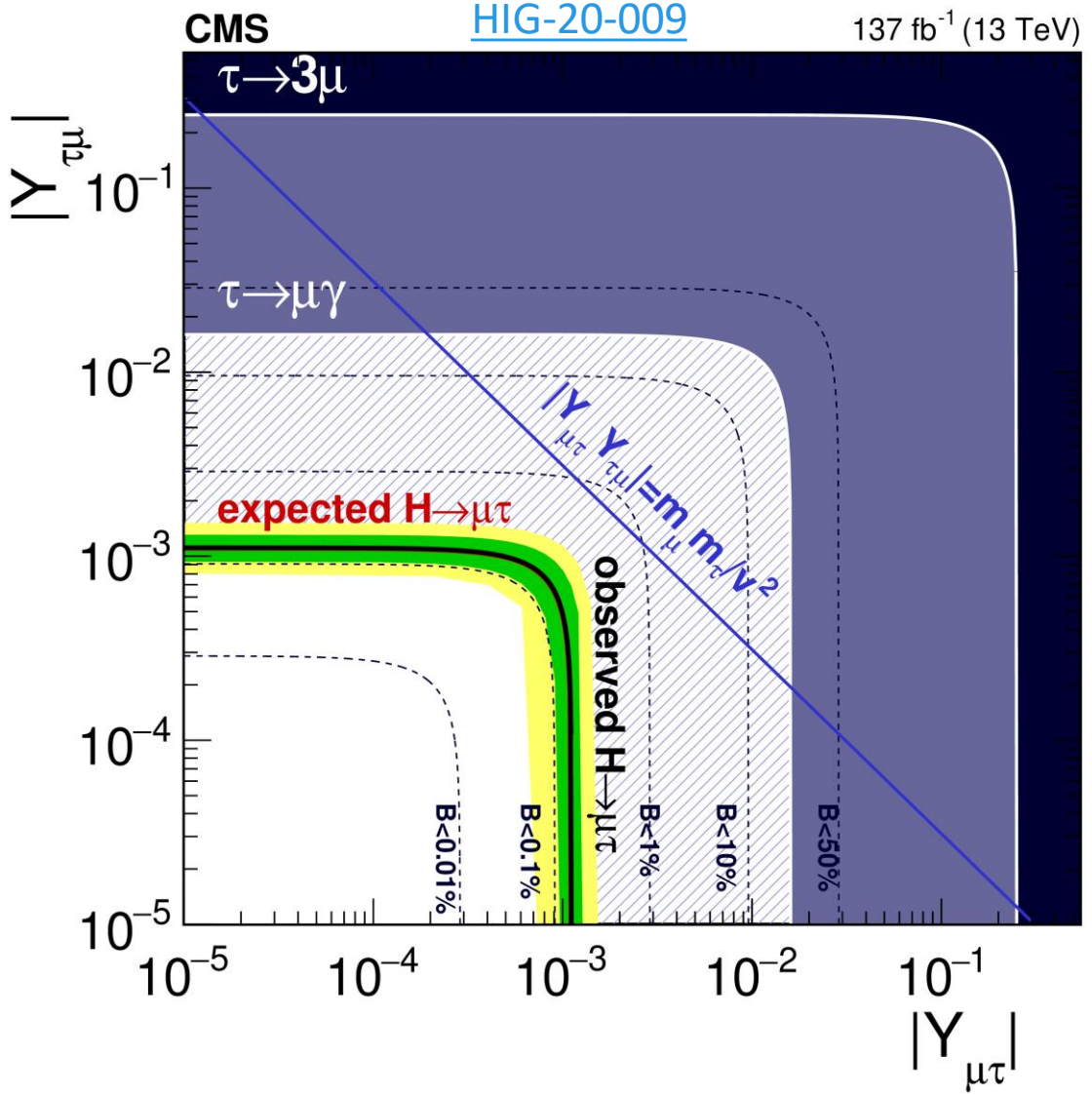
137 fb^{-1} (13 TeV)



HIG-19-006

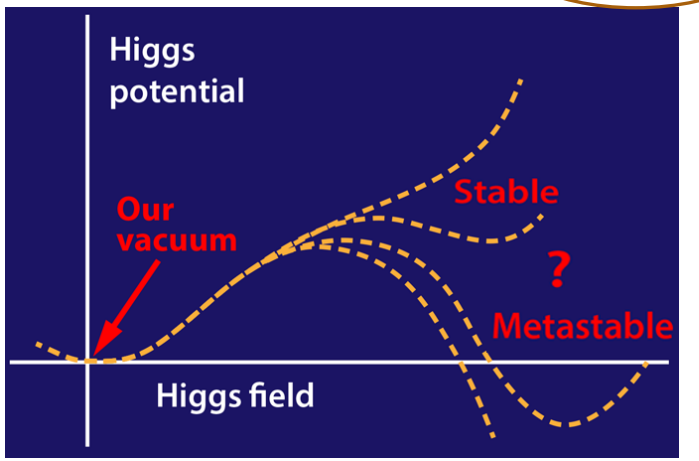
Lepton-Flavor-Violating Higgs Decays

- Higgs discovery opened new windows on the search for physics beyond the standard model (BSM)
- CMS has searched for lepton flavor violation in Higgs decays to $\mu\tau$ and $e\tau$
- Observed limits on the Yukawa couplings are approaching 10^{-3}, more stringent than constraints from e.g. searches for $\tau \rightarrow 3\mu$, $\mu\gamma$, and lepton magnetic moment measurements



Di-Higgs Production and the Higgs Potential

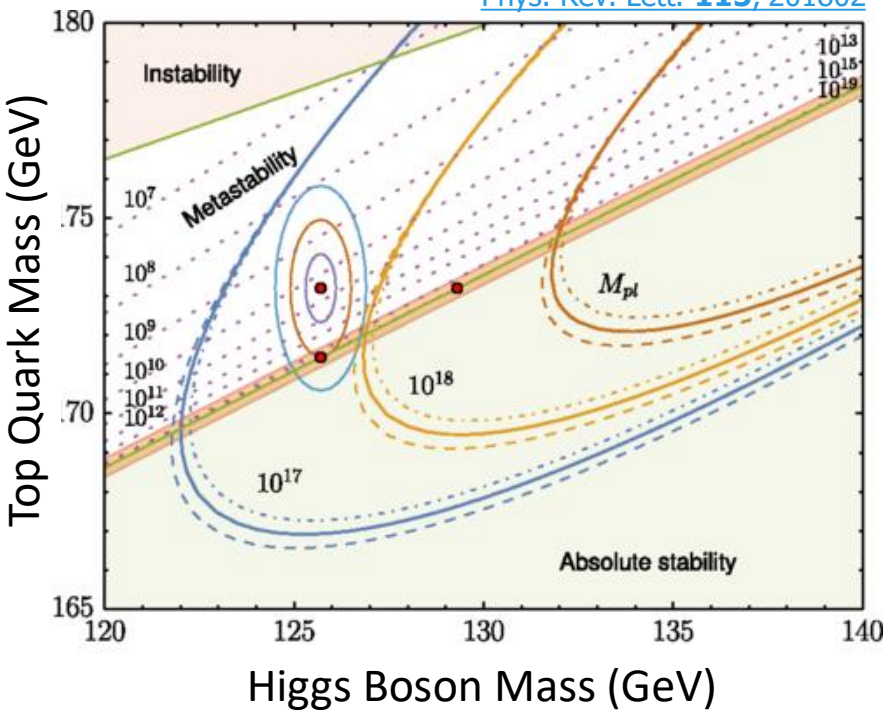
$$V(\Phi) = -\mu^2 \Phi^\dagger \Phi + \lambda \left(\Phi^\dagger \Phi\right)^2$$



link

Di-Higgs production directly probes the structure of the Higgs potential, which has consequences for the stability of the vacuum

Phys. Rev. Lett. **115**, 201802



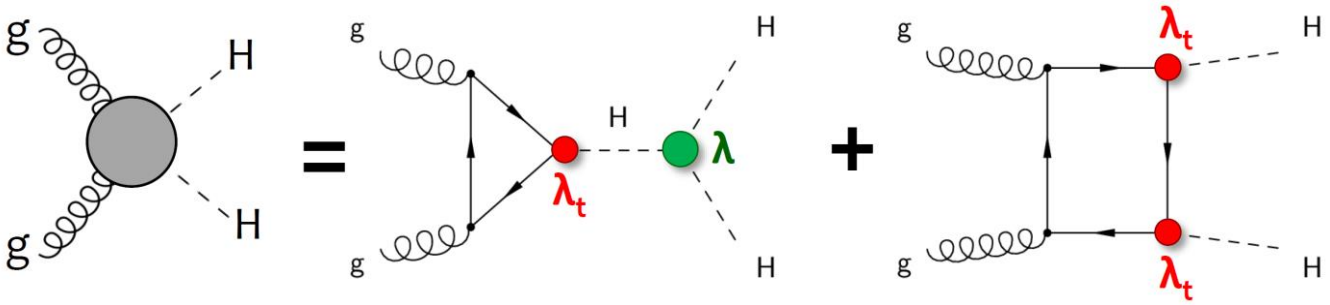
The structure of the Higgs potential impacts a wide range of hot topics in physics:

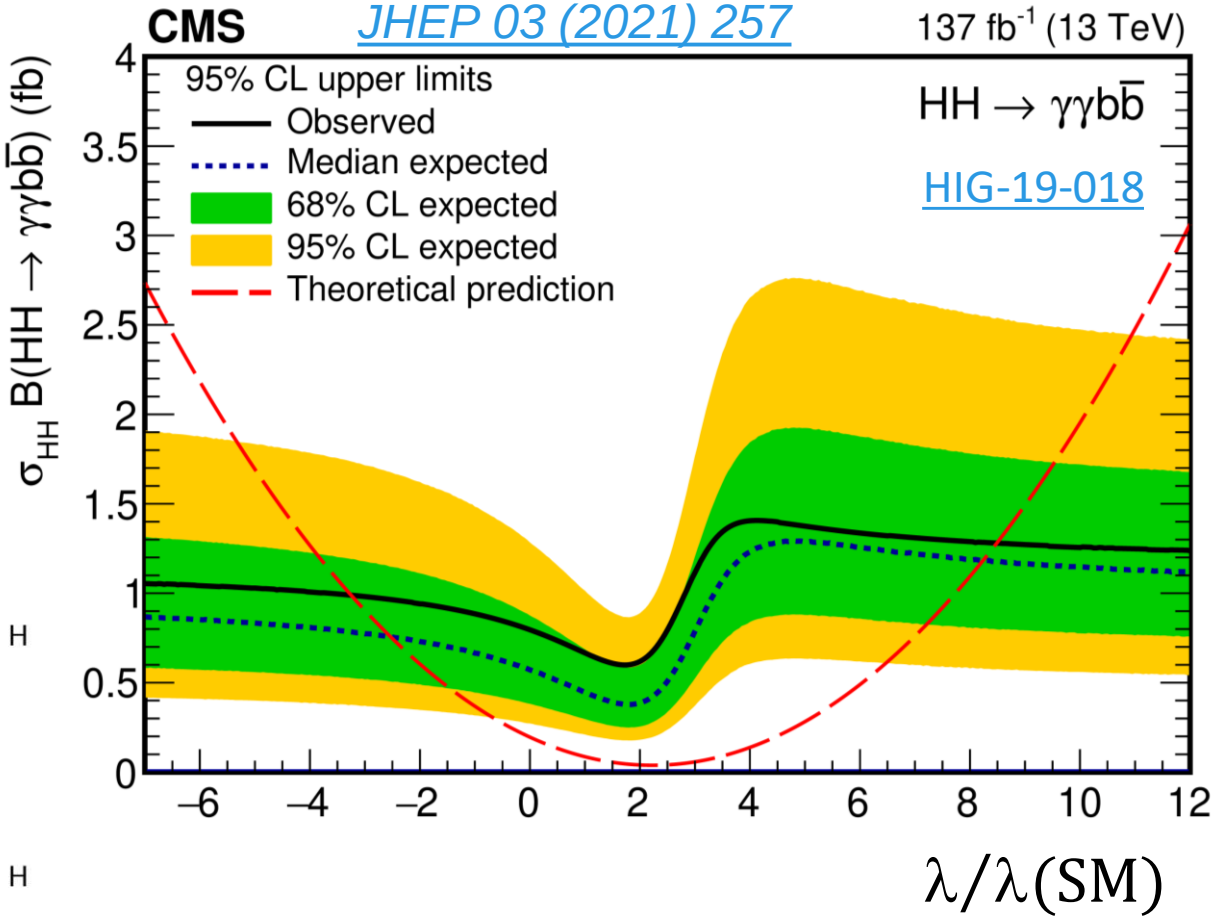
- dark matter, cosmological constant, hierarchy problem, baryon asymmetry, gravity…

Di-Higgs Production is a Primary Target for HL-LHC!

Recent Results on Di-Higgs Production

- Gluon fusion dominates HH production at the LHC, sensitive to H-top coupling (λ_t) and Higgs self-coupling (λ)
- Most searches require $H \rightarrow b\bar{b}$ for one Higgs boson due to the large BF
- Recent result searching for the $\gamma\gamma b\bar{b}$ final state: $-3.3 < \lambda/\lambda_{SM} < 8.5$





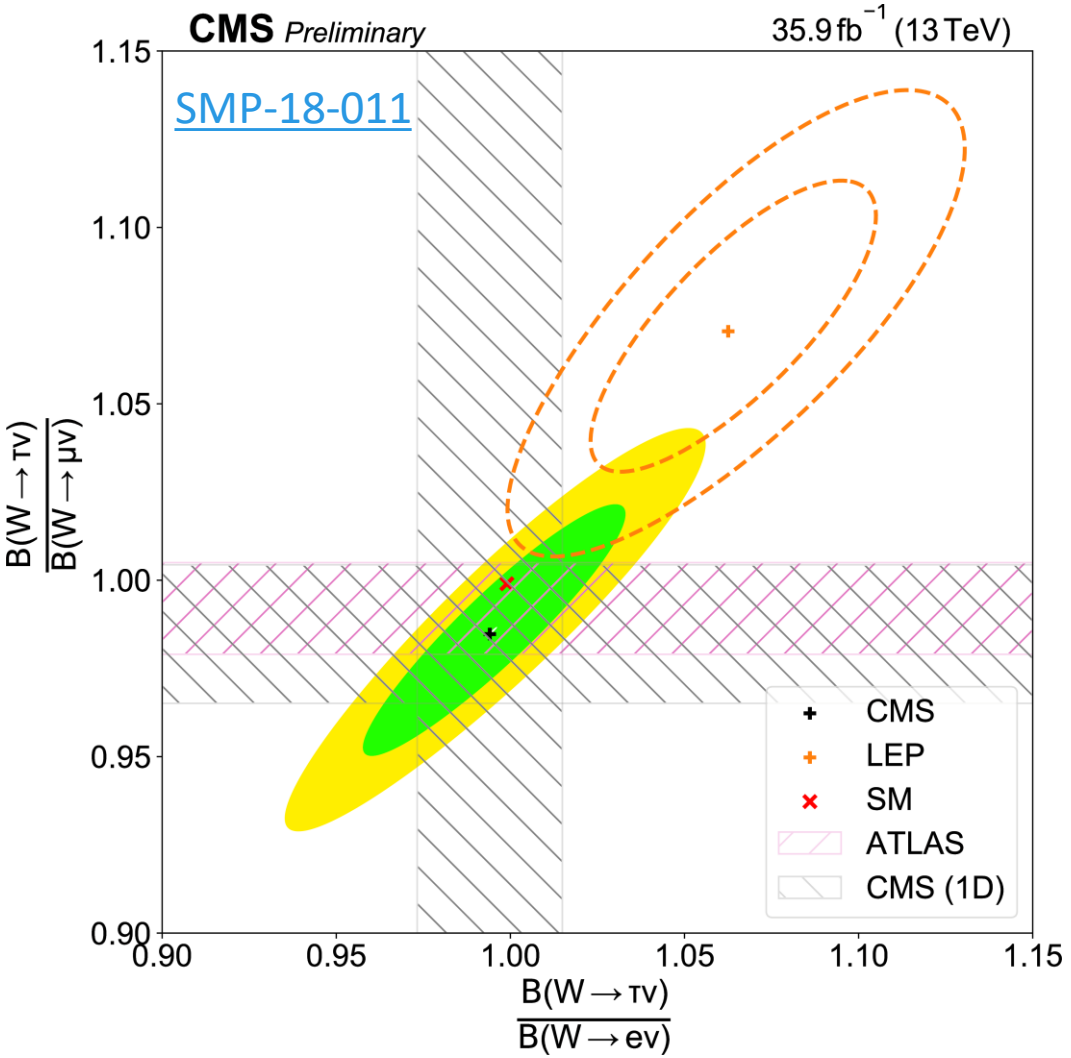
Highlights: Standard Model Physics

Measurement of W Branching Fractions

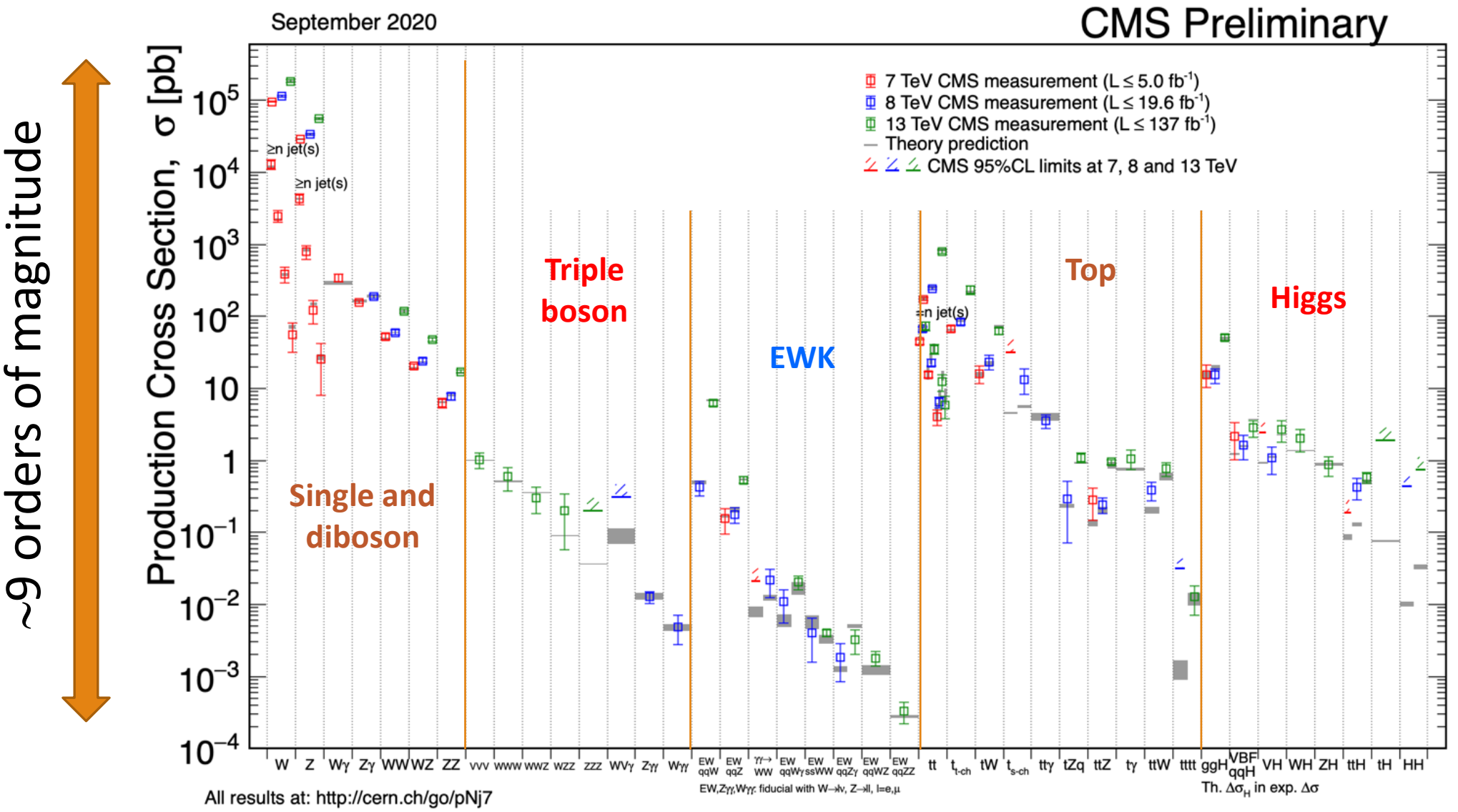
- Recent results from LHCb imply potential deviations from lepton universality (LU)
- Run 2 data allows for precision measurements of W leptonic branching fractions, which are sensitive probes of LU
- CMS precision improves on LEP results

	CMS	LEP
$\mathcal{B}(\mathrm{W} \to \mathrm{e}\bar{\nu}_\mathrm{e})$	$(10.83 \pm 0.01 \pm 0.10)\%$	$(10.71 \pm 0.14 \pm 0.07)\ \%$
$\mathcal{B}(\mathrm{W} \to \mu\bar{\nu}_\mu)$	$(10.94 \pm 0.01 \pm 0.08)\%$	$(10.63 \pm 0.13 \pm 0.07)\ \%$
$\mathcal{B}(\mathrm{W} \to \tau\bar{\nu}_\tau)$	$(10.77 \pm 0.05 \pm 0.21)\%$	$(11.38 \pm 0.17 \pm 0.11)\ \%$
$\mathcal{B}(\mathrm{W} \to \mathrm{h})$	$(67.46 \pm 0.04 \pm 0.28)\%$	–
with LU		
$\mathcal{B}(\mathrm{W} \to \ell\bar{\nu})$	$(10.89 \pm 0.01 \pm 0.08)\%$	$(10.86 \pm 0.06 \pm 0.09)\%$
$\mathcal{B}(\mathrm{W} \to \mathrm{h})$	$(67.32 \pm 0.02 \pm 0.23)\%$	$(67.41 \pm 0.18 \pm 0.20)\%$

Derived assuming $B_e = B_\mu \neq B_\tau$

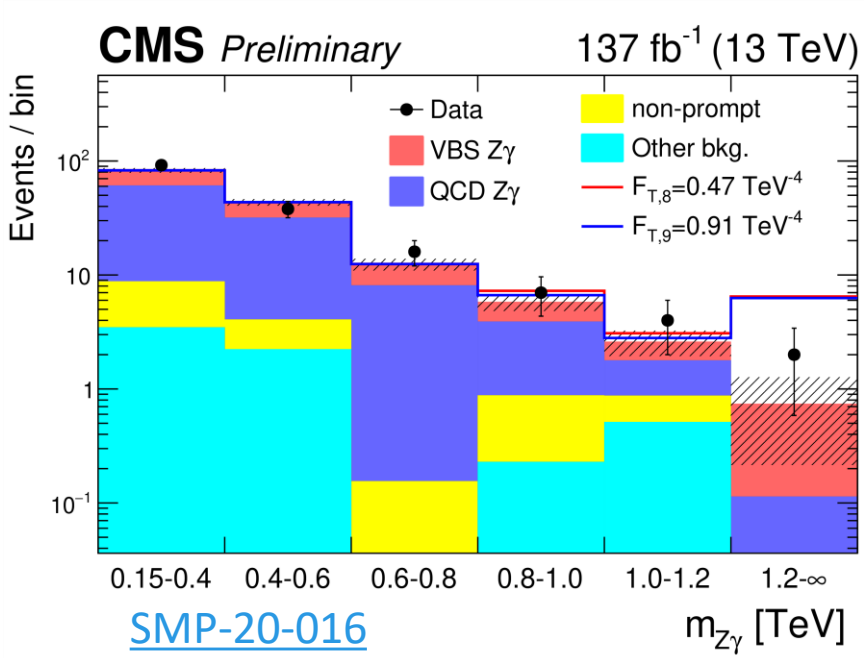


Standard Model Production @ CMS



W and Z Production with Photons

- Wγ and Zγ production is a complementary method of constraining anomalous triple gauge couplings
- Run 2 data allows to probe the region of very high photon momentum and Vγ mass



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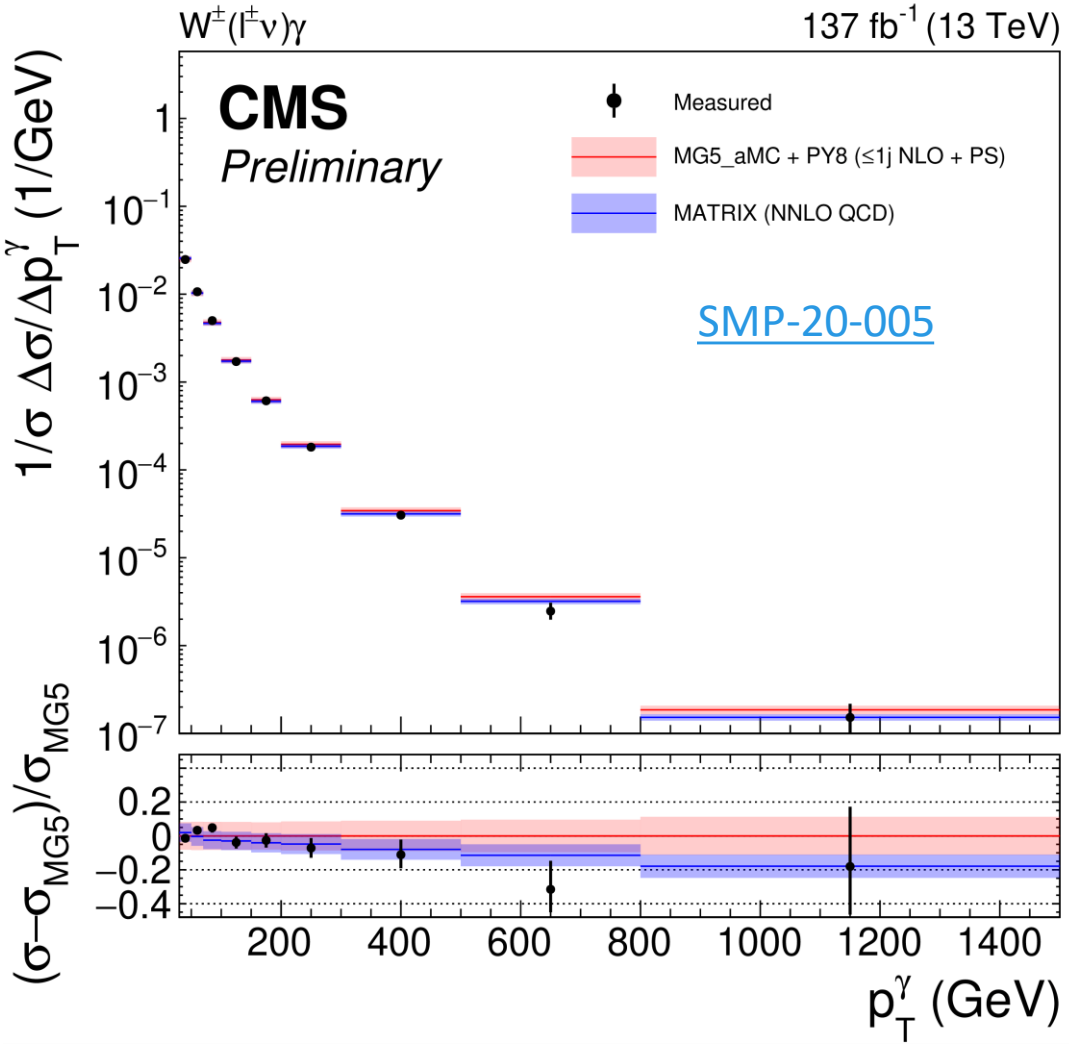
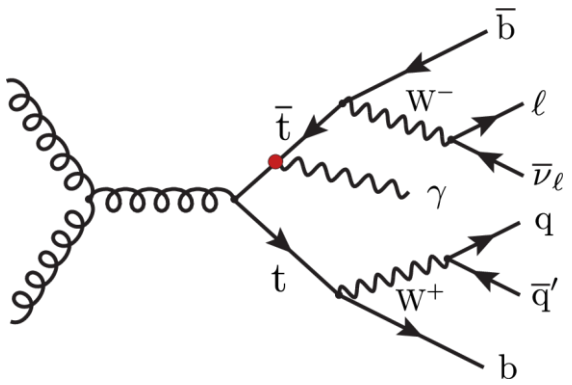
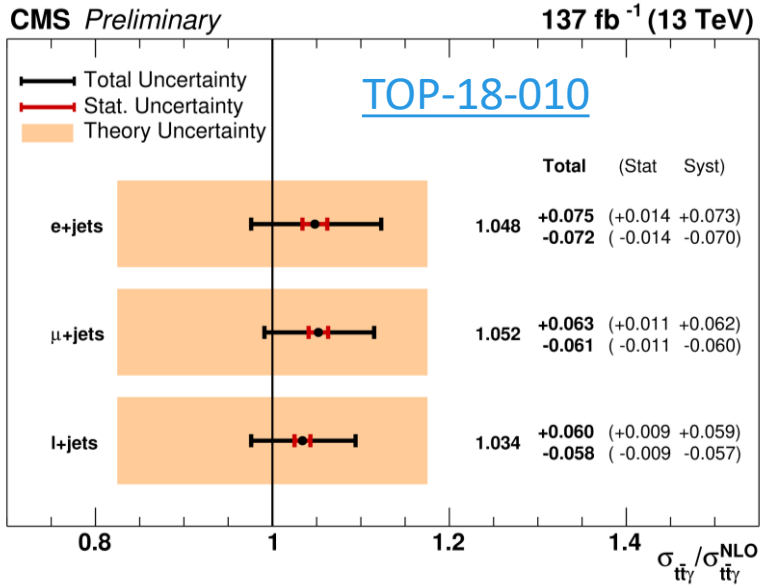


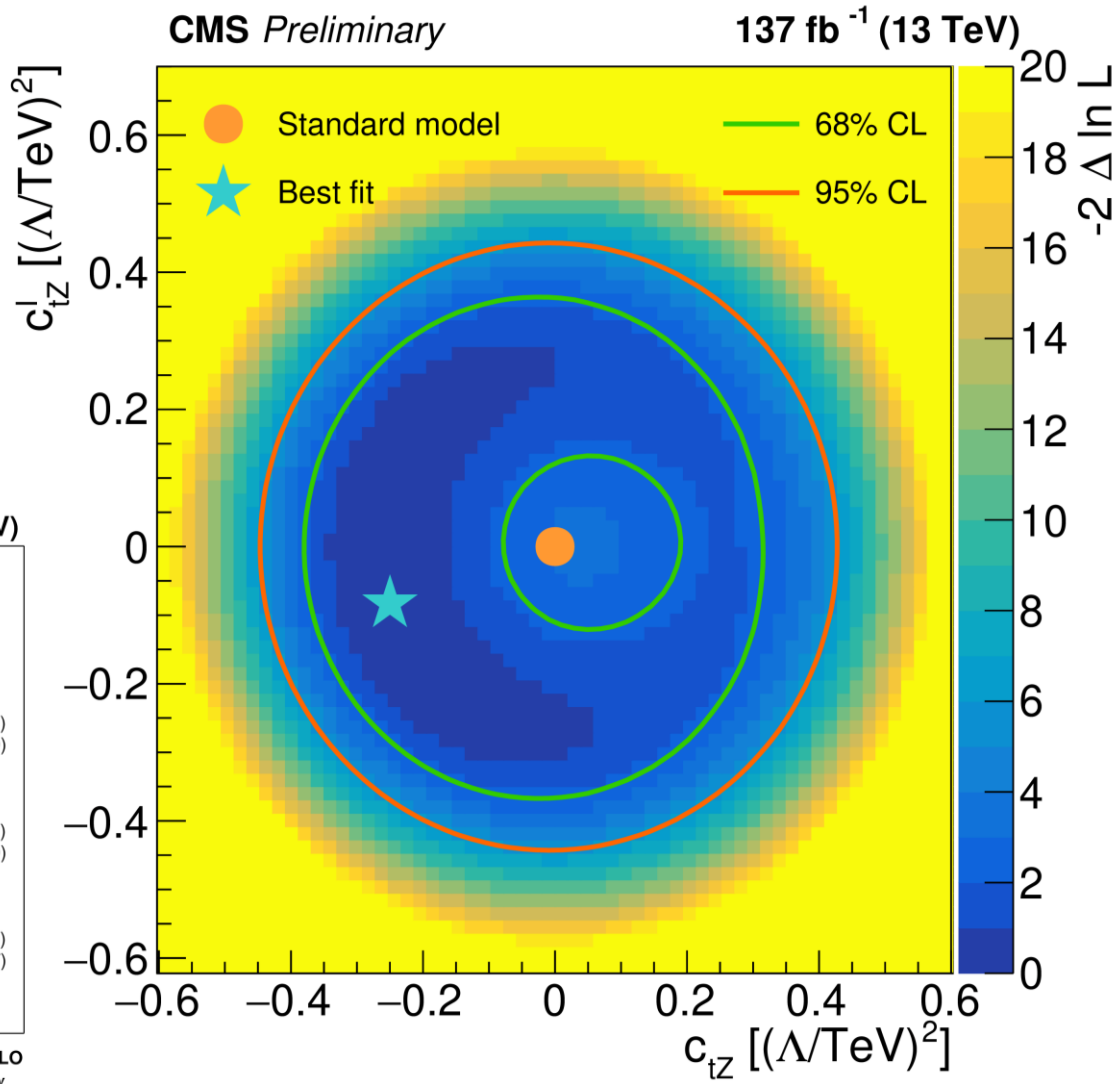
SMP-20-005

Top Quark Production with Photons

- Anomalous top-quark couplings are predicted in many models beyond the SM
- Run 2 data allows the measurement of rare top-quark processes, including $t\bar{t}\gamma$
- Data interpreted in the context of SMEFT





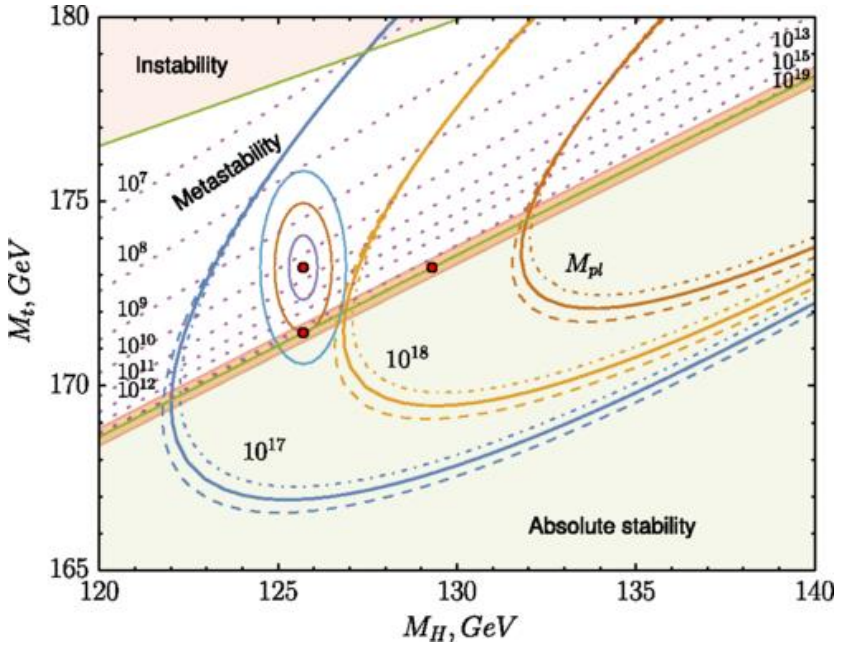


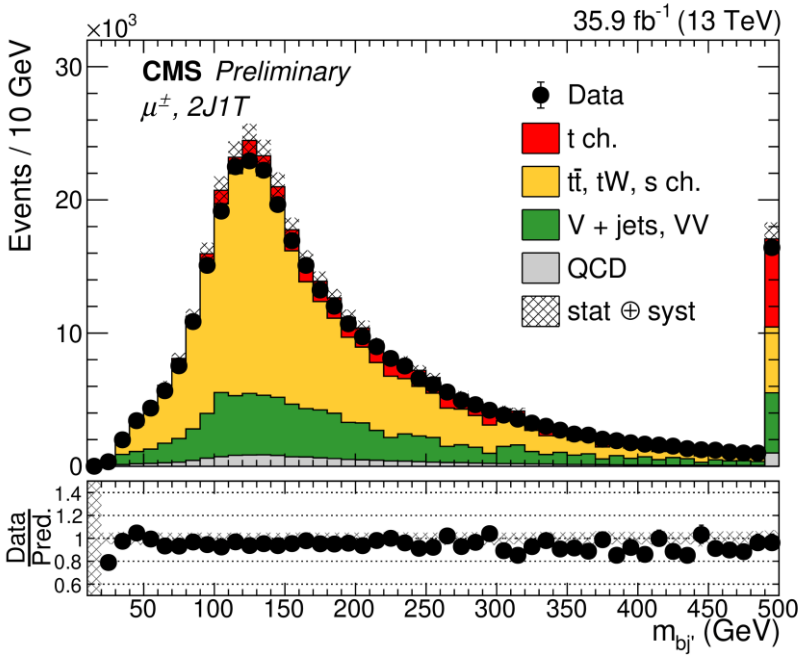
Top Quark Mass in Single Top Events

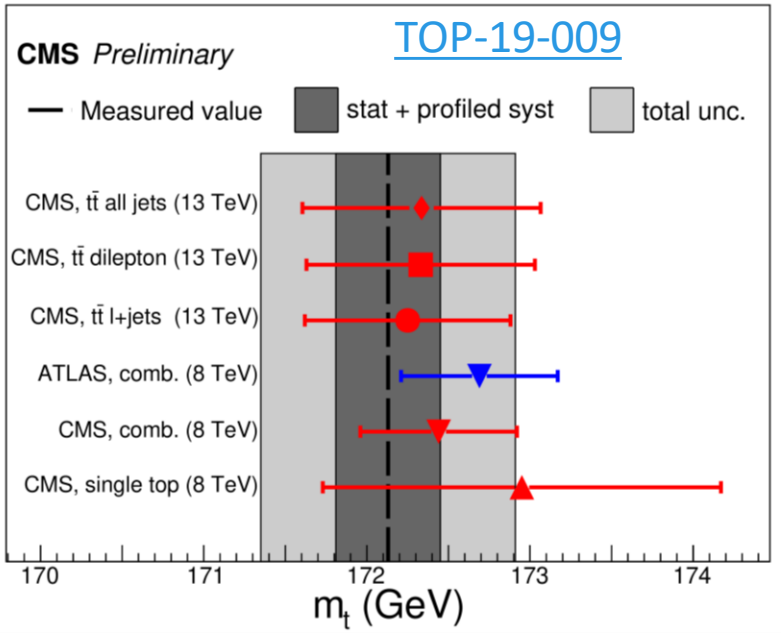
- Due to its large mass, the top quark plays a special role in the SM
- Important to measure the top quark mass in as many ways as possible to reduce systematic uncertainties
- Single top events (pp $\rightarrow$ tW) provide a complementary approach

Top Mass in Single Top

$m_t = 172.12 \pm 0.77$ GeV

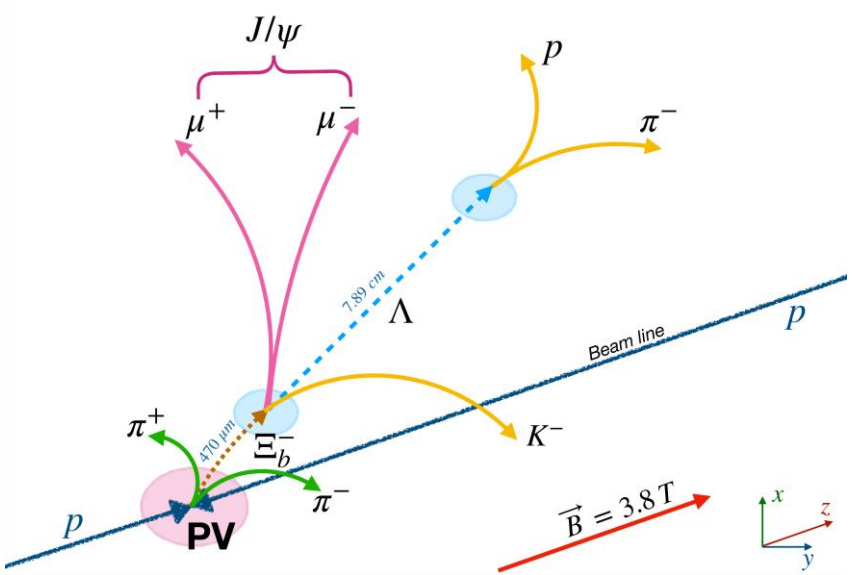


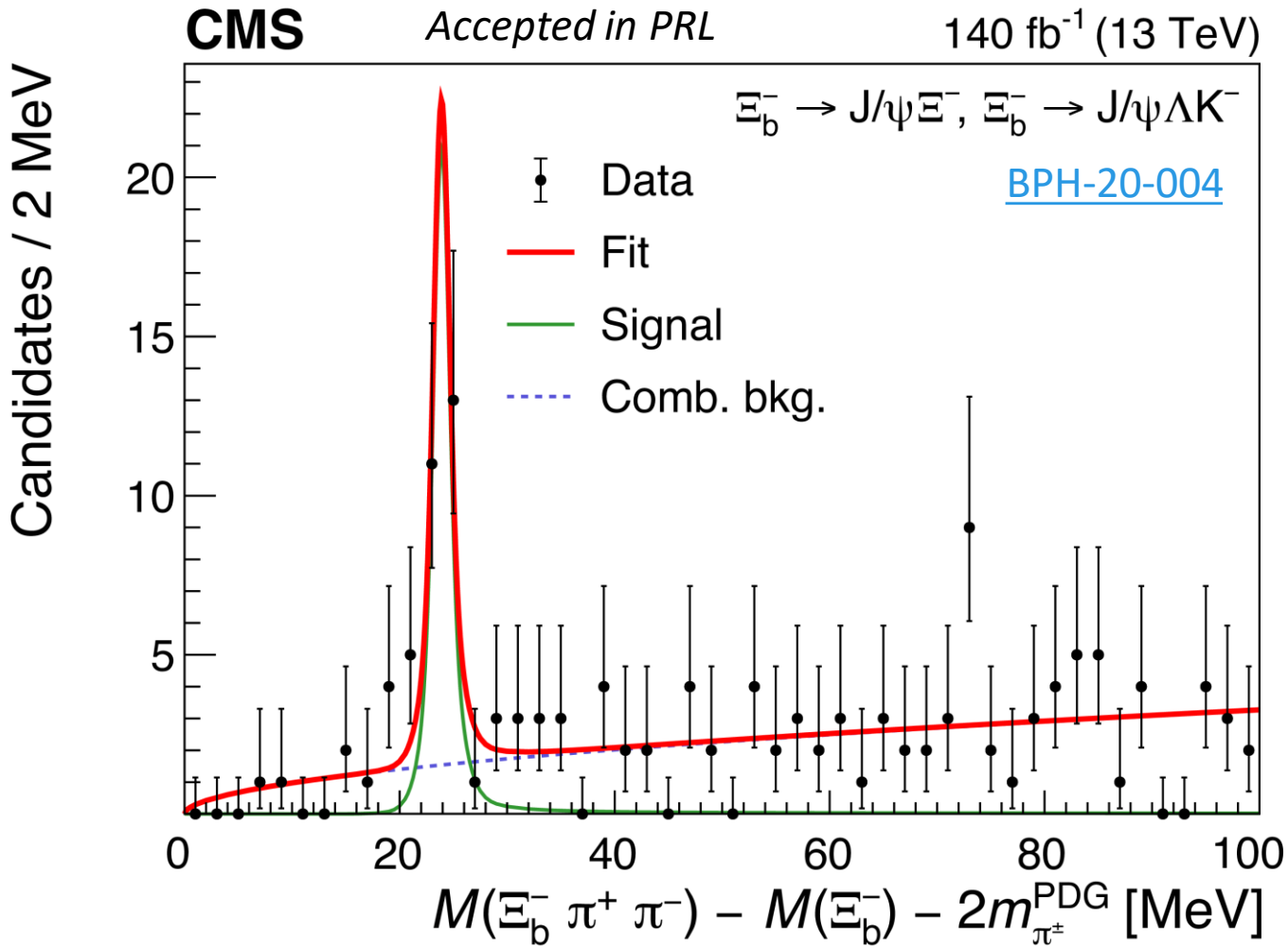




A New Particle: $\Xi_b(6100)$

- CMS and ATLAS are also active in the area of B physics, complementing LHCb
- Due to its large solenoidal field (3.8 T) and excellent tracker, CMS is able to search for high-mass B meson states
- Recent observation of an excited Ξ_b



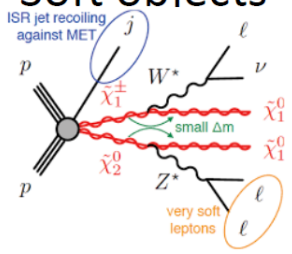


Highlights: Beyond Standard Model

Many ways to search for BSM @ LHC

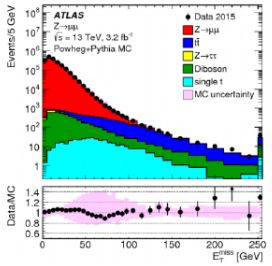
Soft objects

SUSY 2019



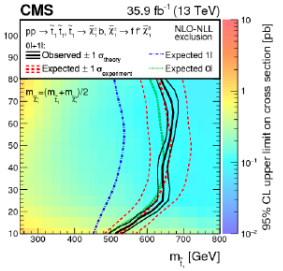
Search in tails of distributions

arXiv:1802.08168



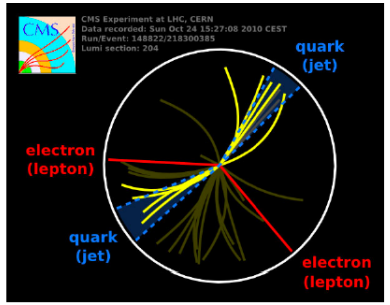
Compressed mass spectra

arXiv:1805.05784



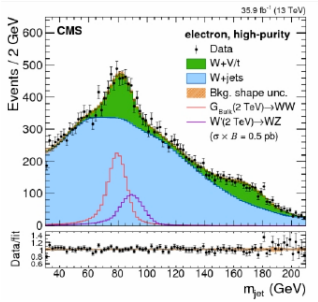
Leptoquarks

Fermilab news at work



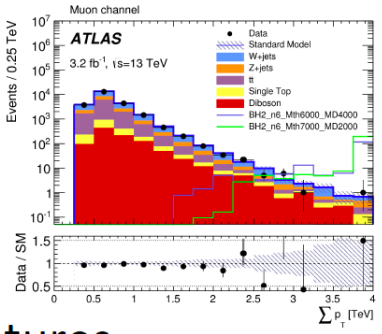
New heavy resonances

arXiv:1802.09407



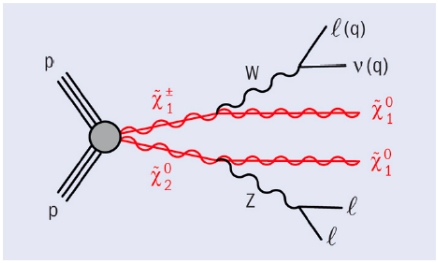
Extra dimensions

arXiv:1606.02265



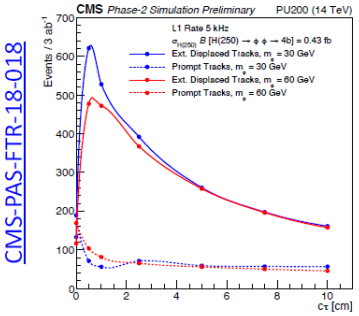
Electroweak Supersymmetry (SUSY)

CERN Courier



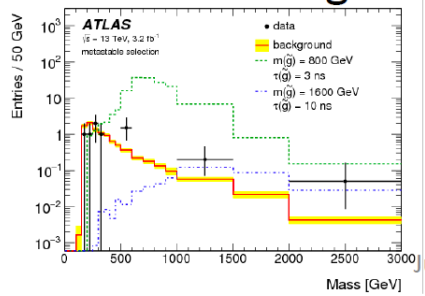
Displaced objects

CMS-PAS-FTR-18-018



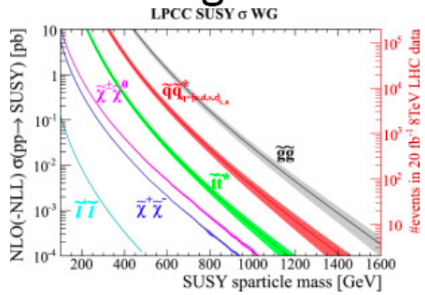
Unconventional signatures

arXiv:1604.04520



Strong SUSY

Rev in Physics 2019



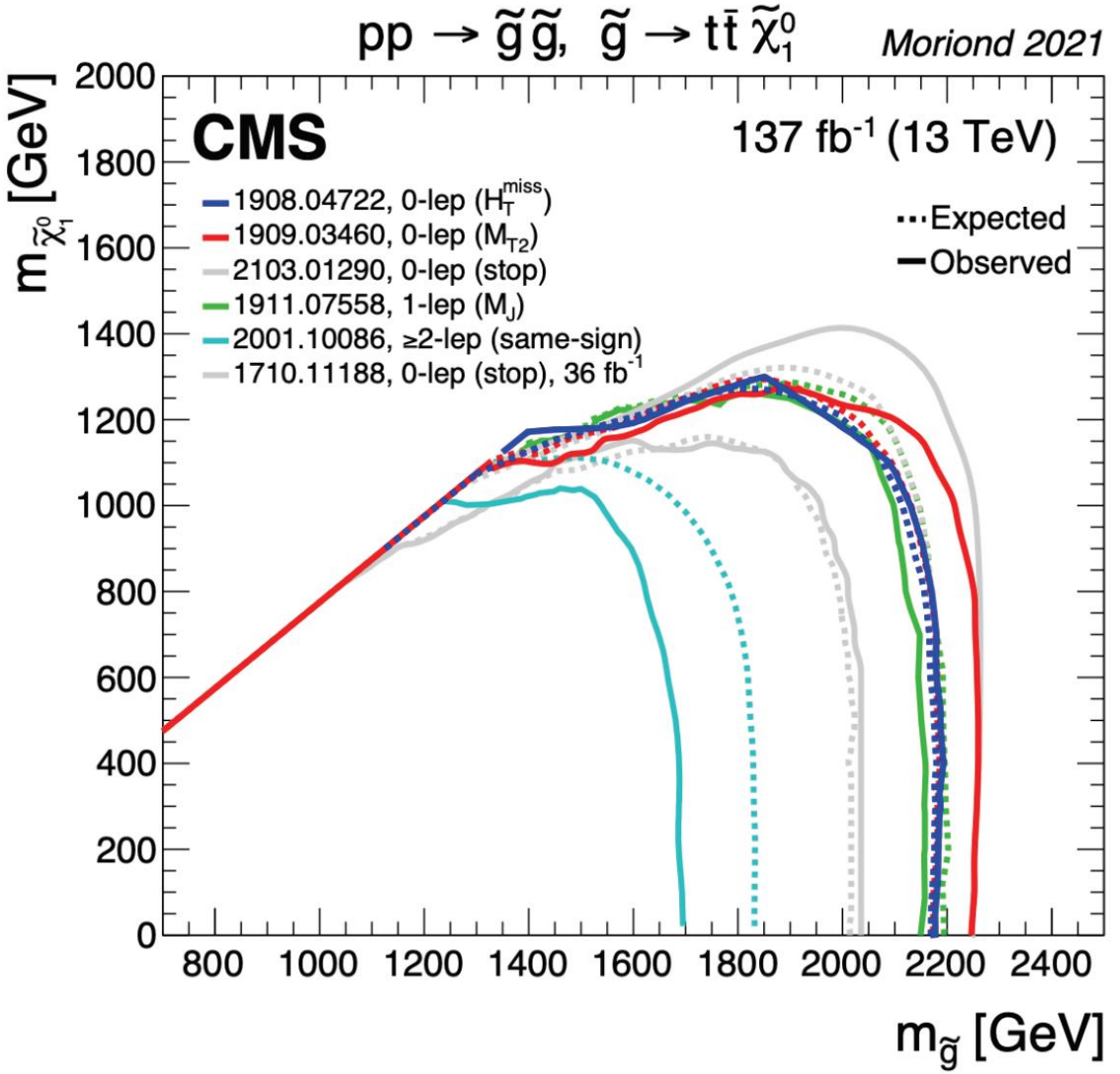
and more!

March 22, 2021 Juliette Alimena 3

Talk by J. Alimena @ Moriond EWK 2021

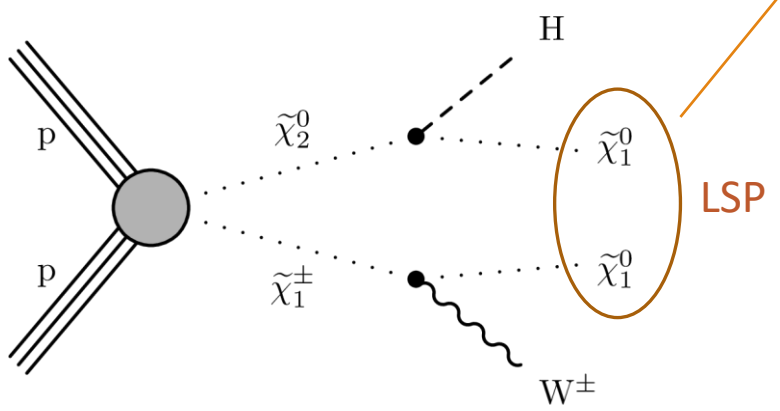
Status of Supersymmetry (SUSY)

- Extensive (but not exhaustive) searches for SUSY @ LHC for more than a decade, leading to stringent mass constraints
- Absence of any signal has generated a variety of responses:
  - SUSY is dead
  - SUSY is unnatural
  - SUSY is heavy
  - SUSY is just around the corner!
- Recent focus on electroweak production and searching in difficult-to-reach places (stop corridor)

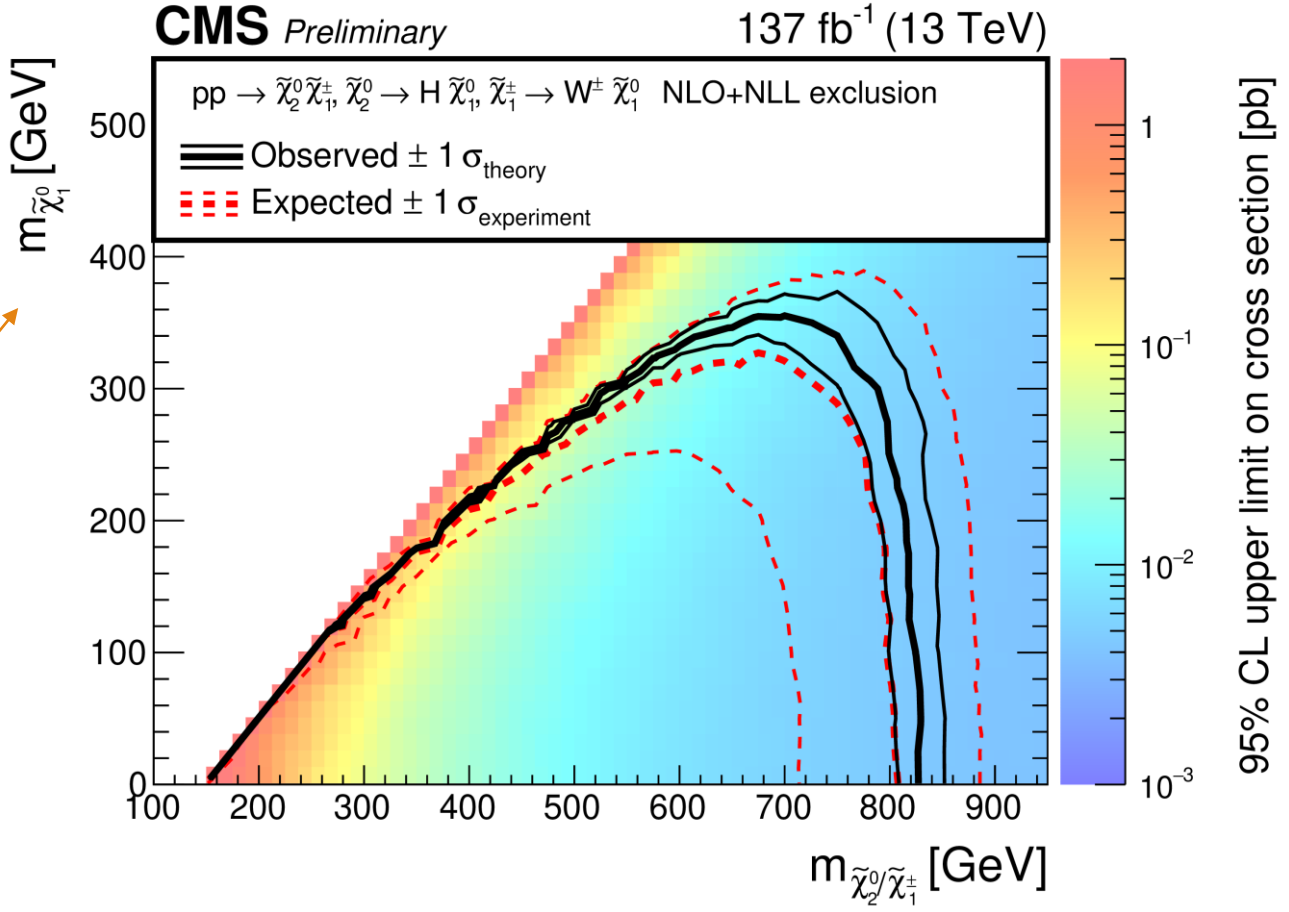


Search for Electroweak SUSY

- Smaller cross sections, but many ways to search (e.g. using Higgs)
- Signature of large missing energy (LSP), leptons and W/Z/H
- Mass limits are approaching the TeV scale, which will further strain natural SUSY interpretations

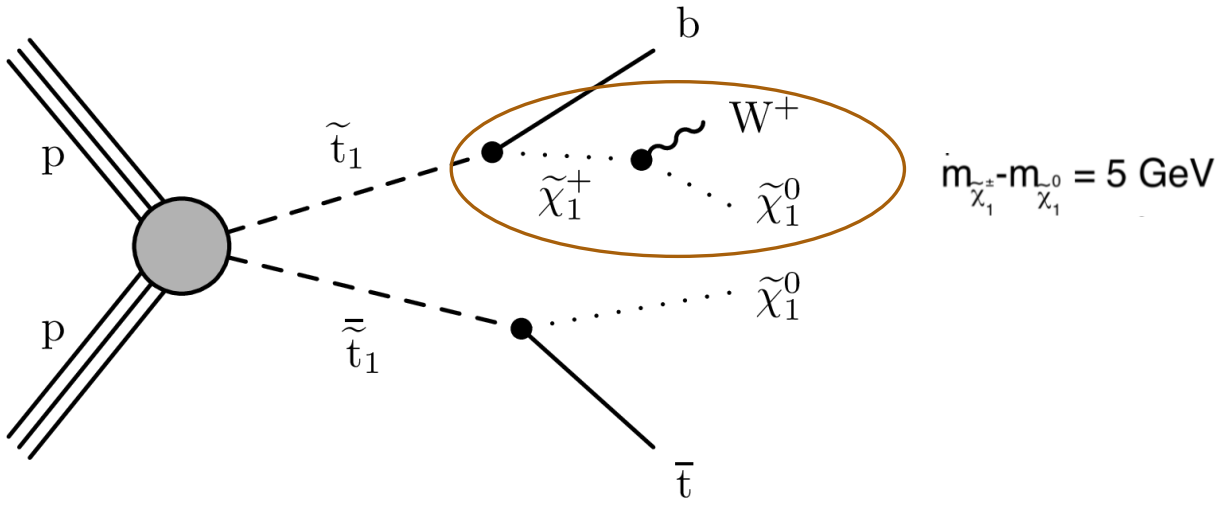


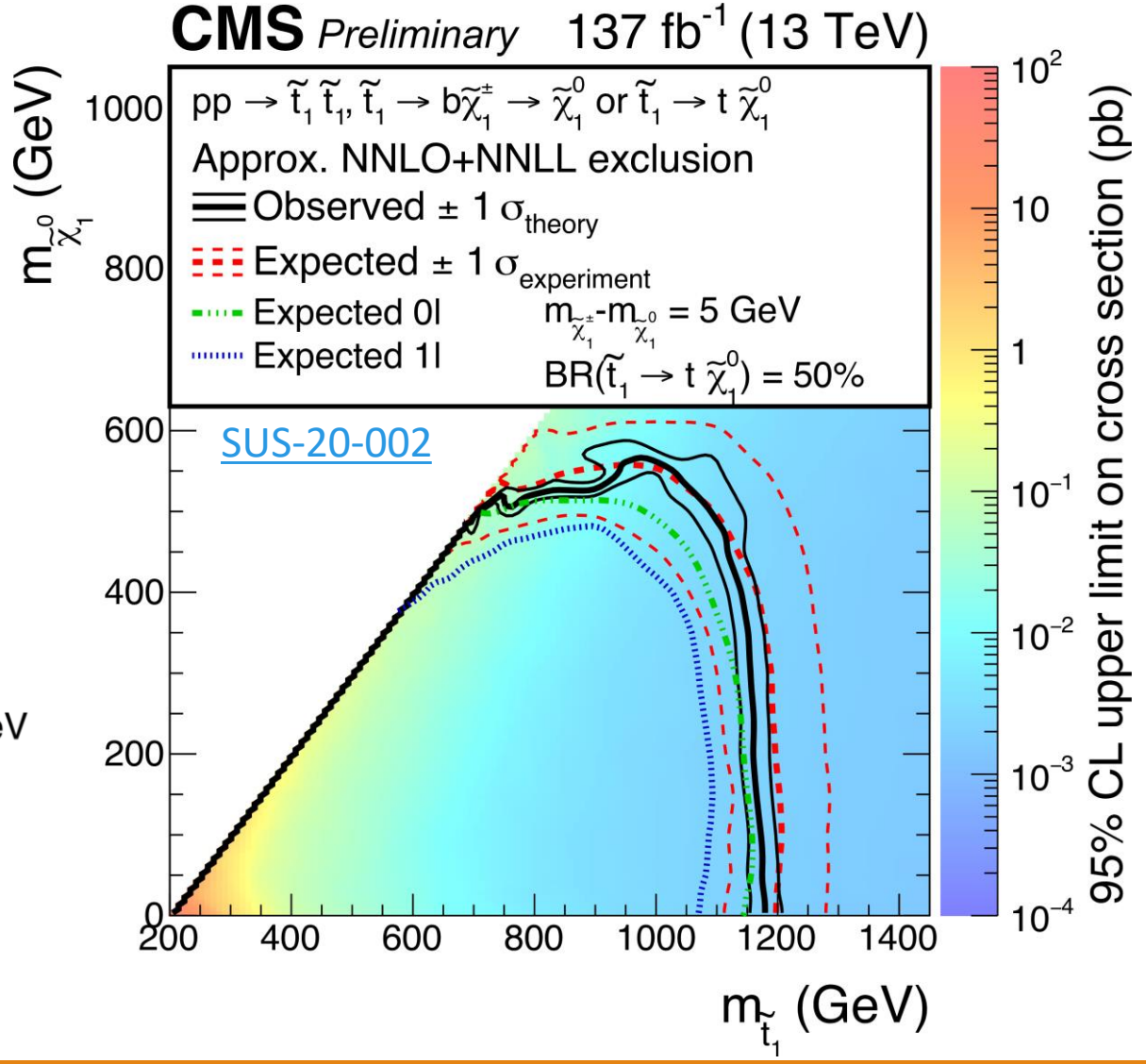
SUS-20-003



Top Squark in Compressed Spectra

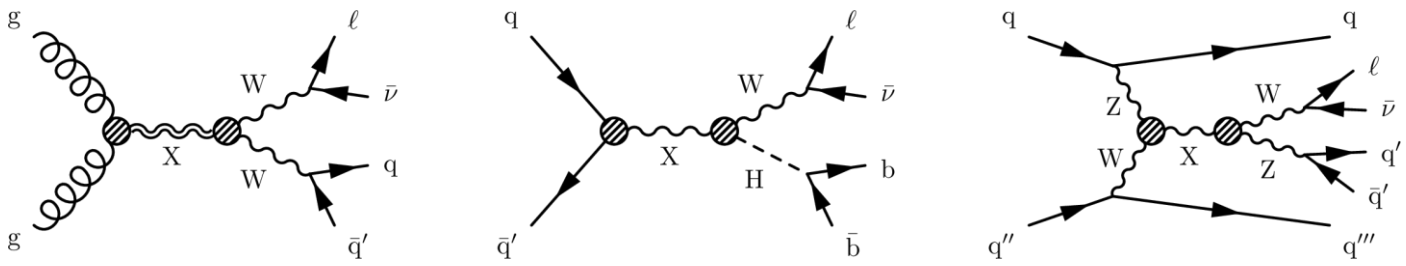
- Compressed spectra where SUSY mass differences are small (~ GeV)
- Soft final-state particles, need dedicated searches
- Large Run 2 data set opening previously unexplored regions

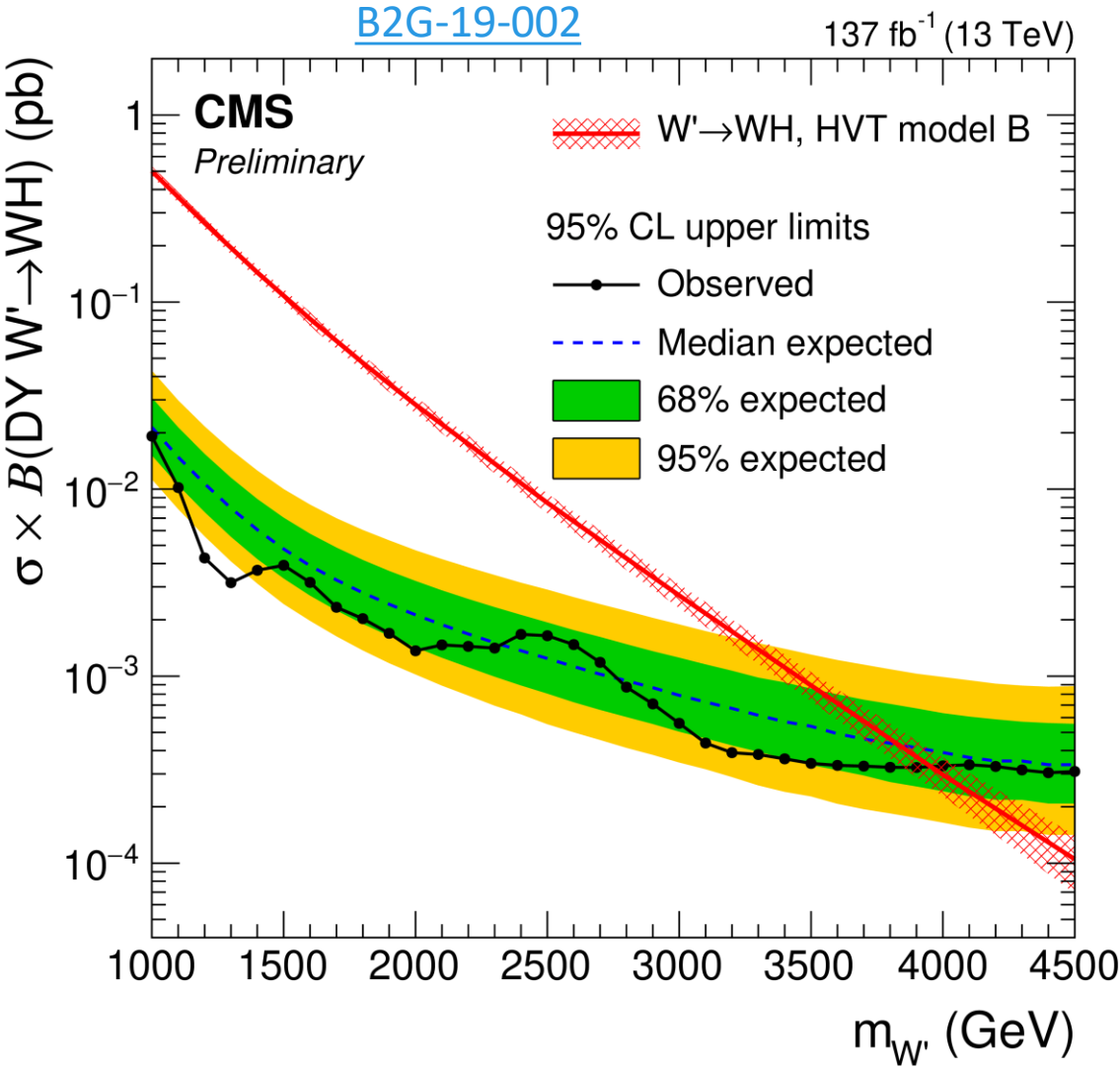




Search for Heavy Resonances

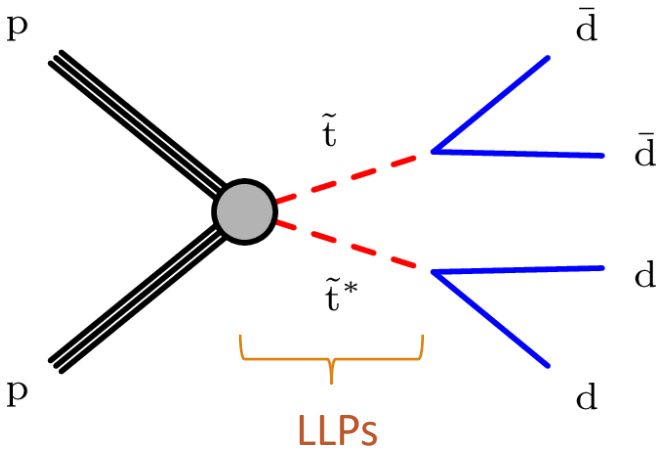
- Unique feature of LHC: unprecedented energy facilitates direct production and detection of heavy (TeV) particles in the lab
- Searches for resonant di-boson production are powerful tools, including final states with Higgs bosons
- Limits are now reaching 4 TeV!

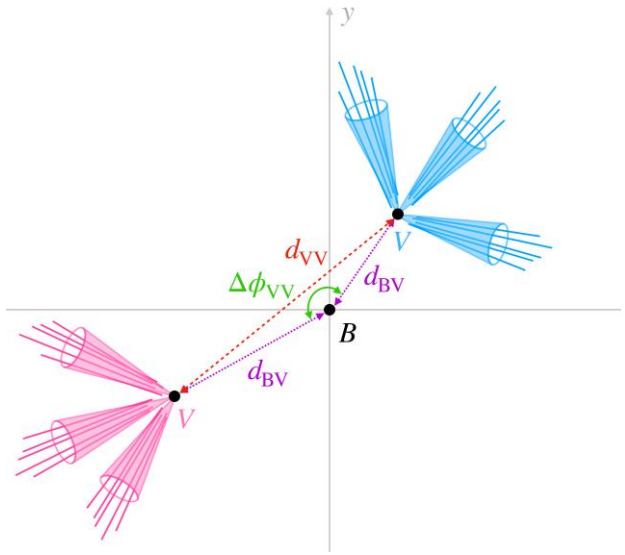




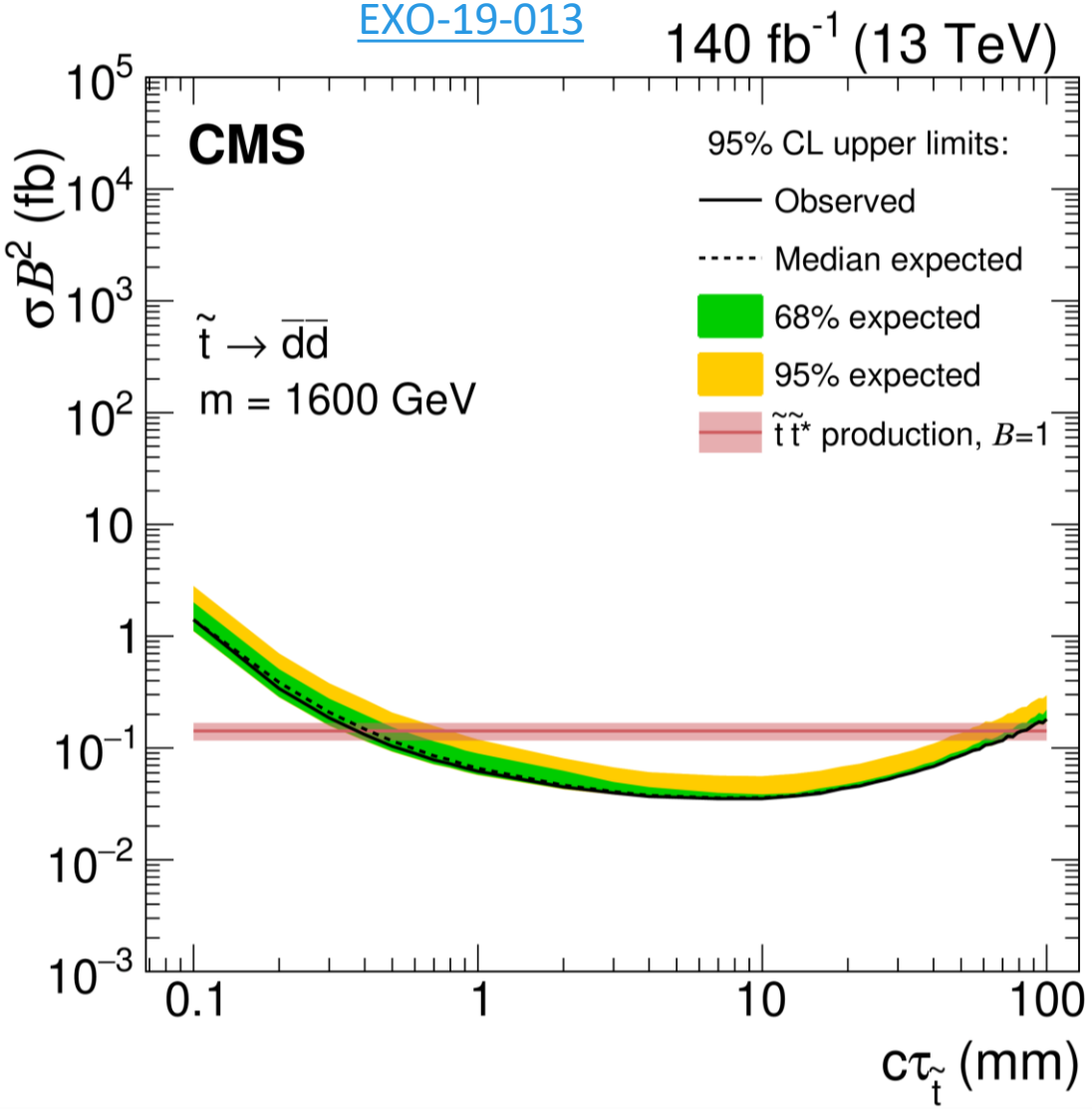
Search for Long-lived Particles

- Many BSM models predict long-lived particles (LLPs) that would appear in CMS as objects displaced from the beam line
- Improved background suppression techniques allow for sensitivity across many orders of magnitude in lifetime

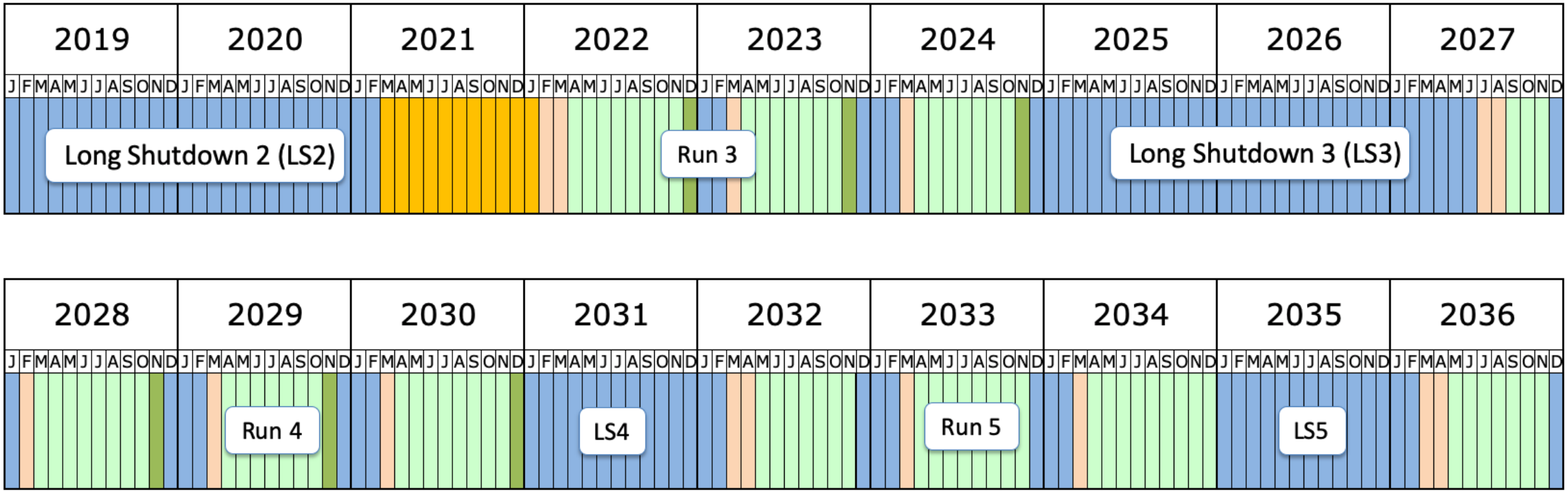




EXO-19-013



LHC Schedule



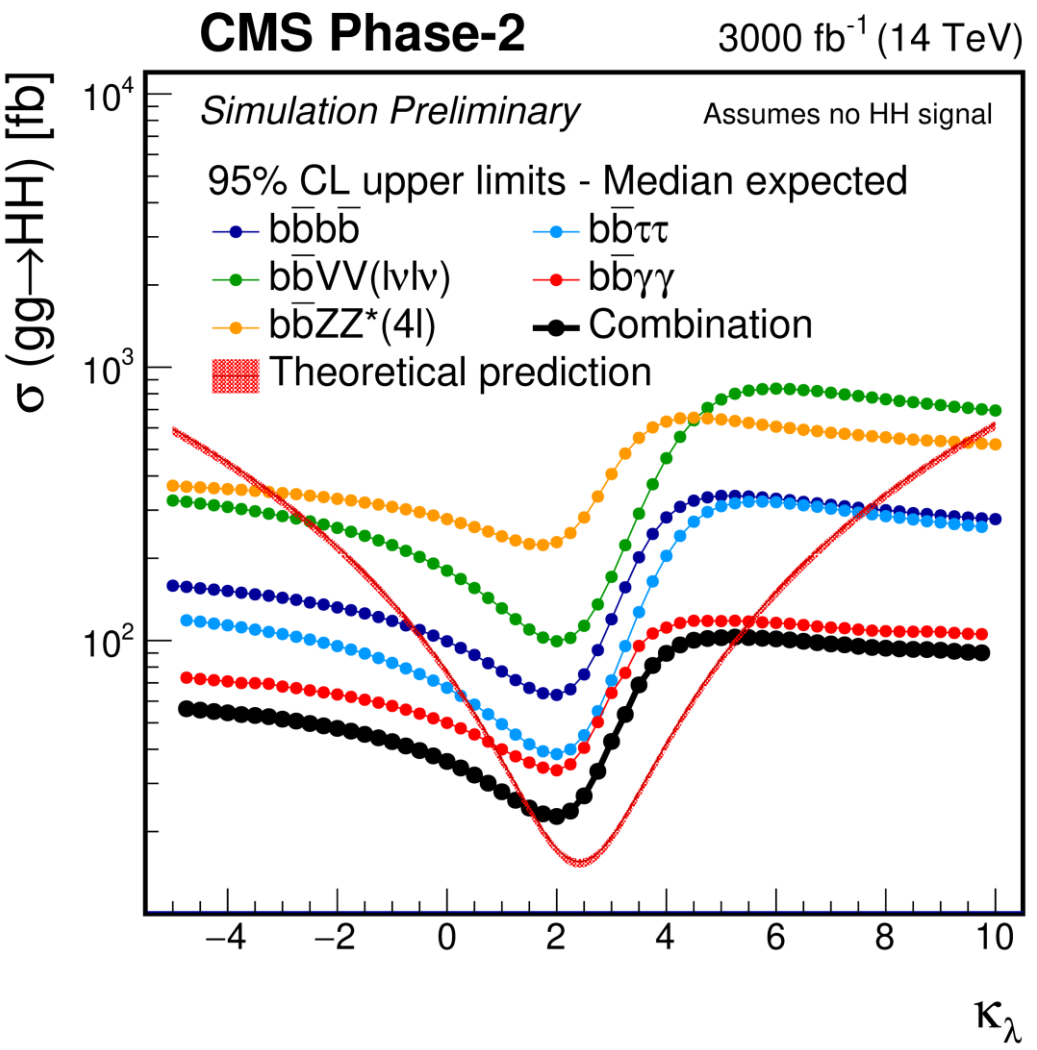
Run 3 begins in Spring 2022 and should add ~300fb^{-1} of pp collision data

High-Luminosity LHC era begins in ~2027 and will eventually provide a total of 3000fb^{-1} (roughly 200x current data)

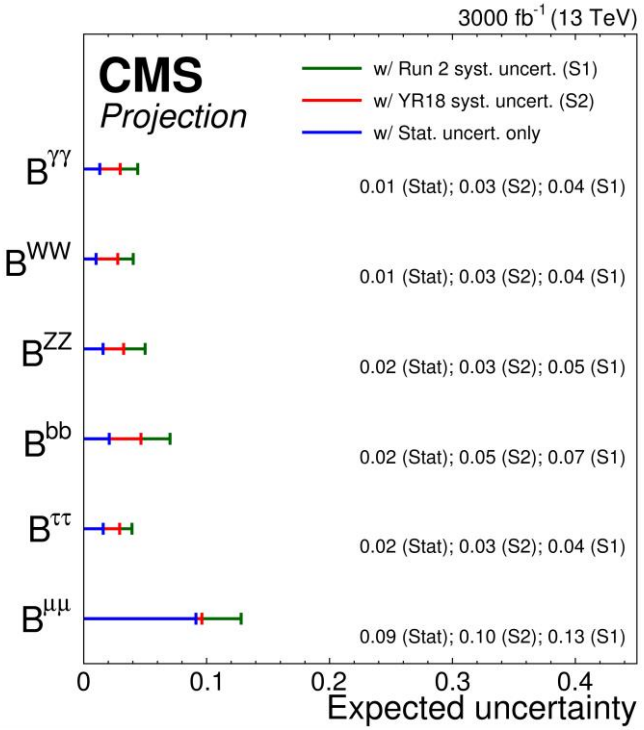
Future Higgs Prospects with 3000fb^{-1}

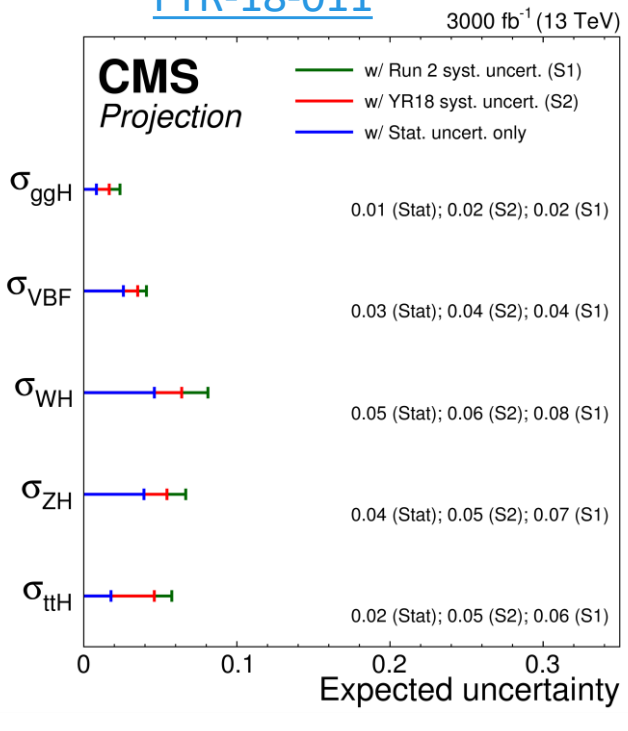
- CMS will measure Higgs cross sections and branching fractions at the % level
- Expected significance for di-Higgs production is > 2.5σ, while the constraint on λ/λ_{SM} would be improved substantially in the absence of signal

FTR-18-019



FTR-18-011





Summary

- It is a great time to be an LHC physicist!
  - LHC results impact a wide range of hot topics in physics, now and in the future
- LHC and CMS performing well and preparing for Run 3 in 2022
- Mexico is fully engaged in the CMS experiment and providing important contributions to the detector and physics analysis
- The High-Luminosity LHC era will provide an unprecedented dataset that will be used to further characterize the SM and expand the search for new particles and interactions