Latest CMS results @ 13 TeV

Simranjit S. Chhibra (INFN - Bologna)

on behalf of the CMS Collaboration

(Aperitivo scientifico - Bologna, 8 April 2016)

https://agenda.infn.it/conferenceDisplay.py?confId=10726

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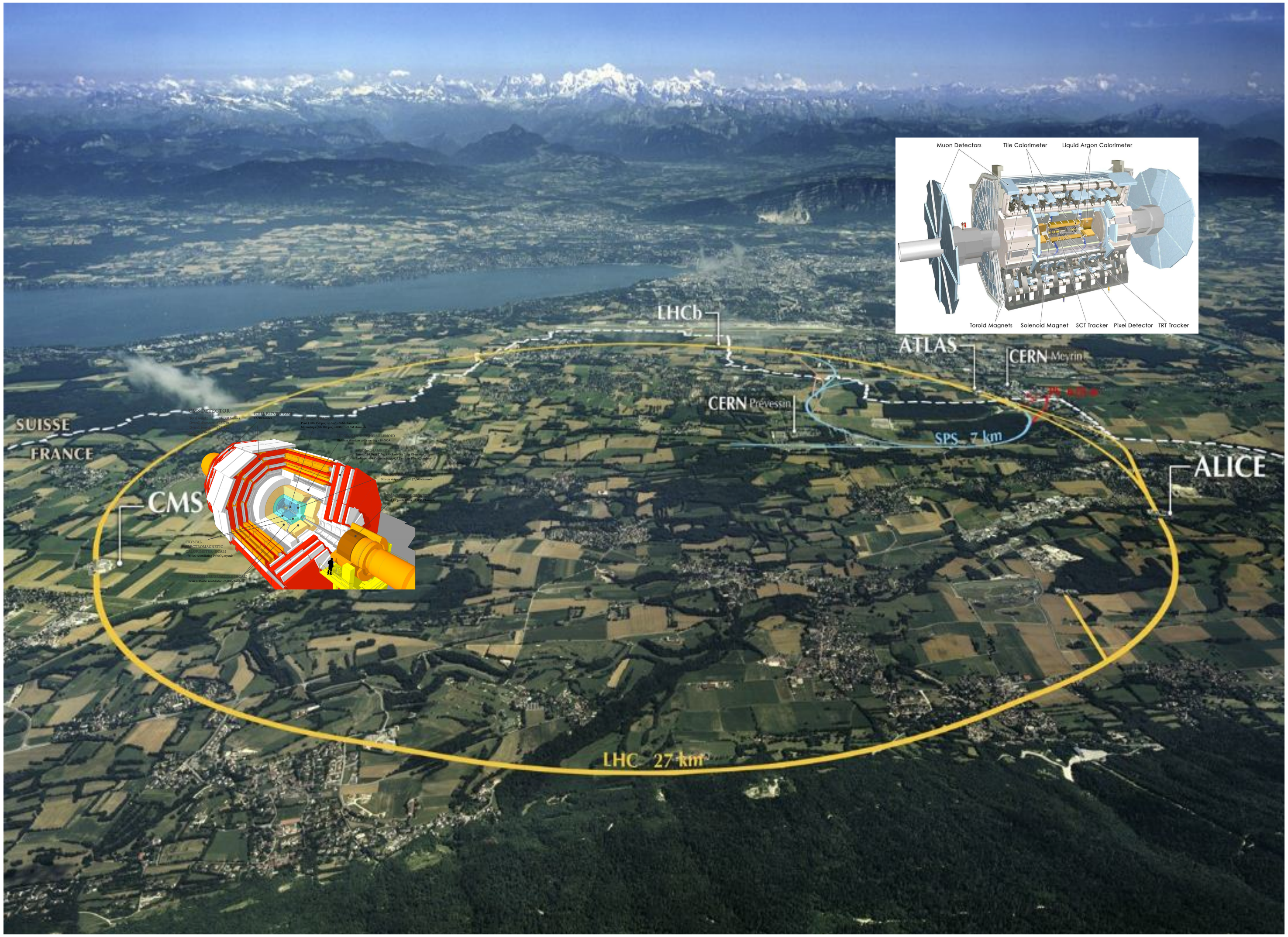
Outline

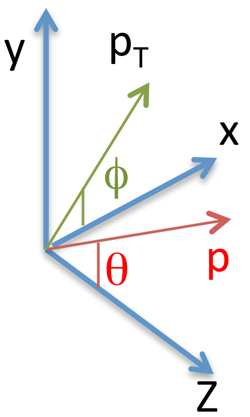
- The CMS experiment
- Introduction to “particle physics” data analysis
- CMS 13 TeV results for
  - diphoton resonance searches: excess @ 750-760 GeV
  - heavy gauge boson searches
  - dark matter searches
  - Higgs boson precision measurements
- Summary/2016 physics plans

The LHC @ CERN

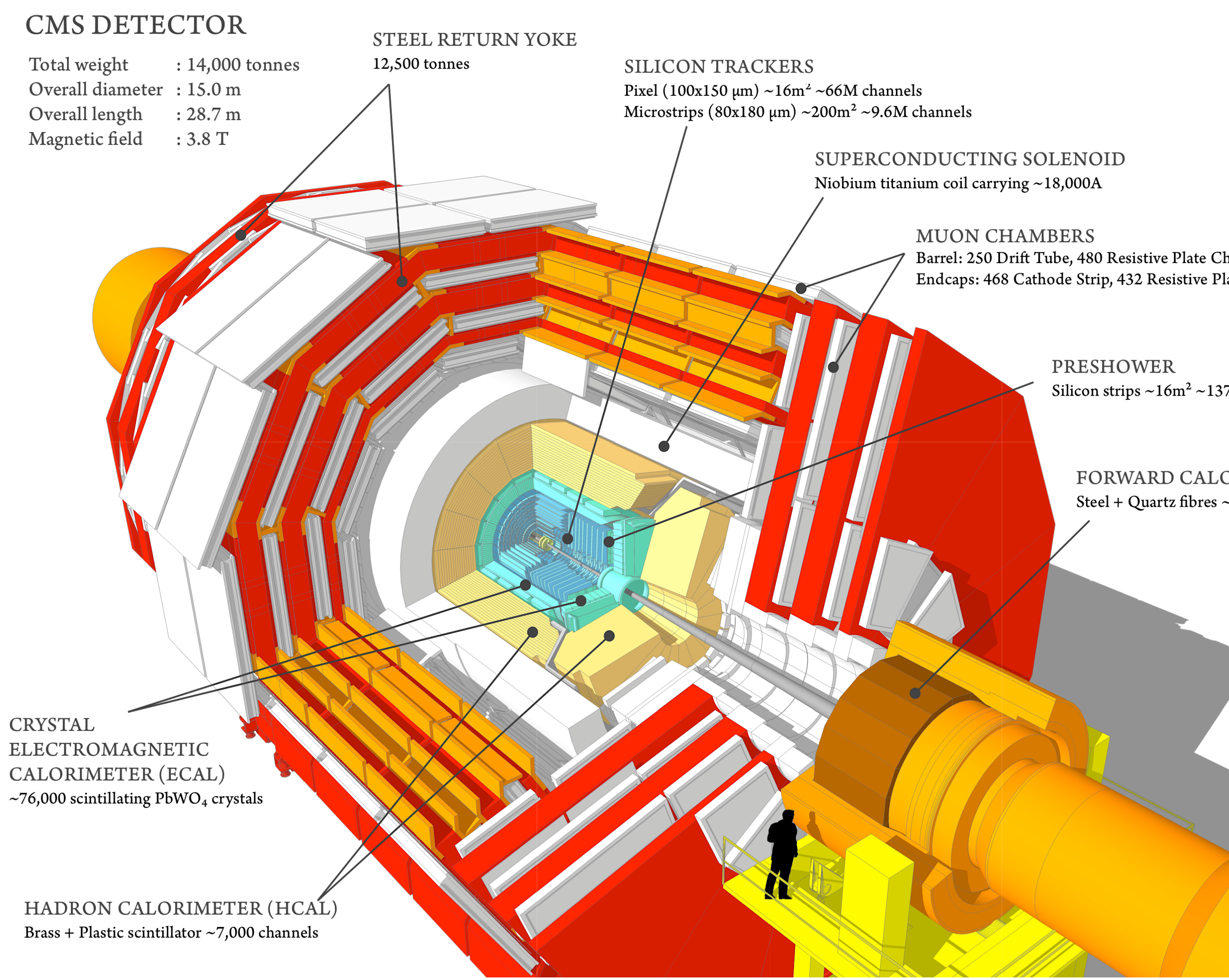


Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

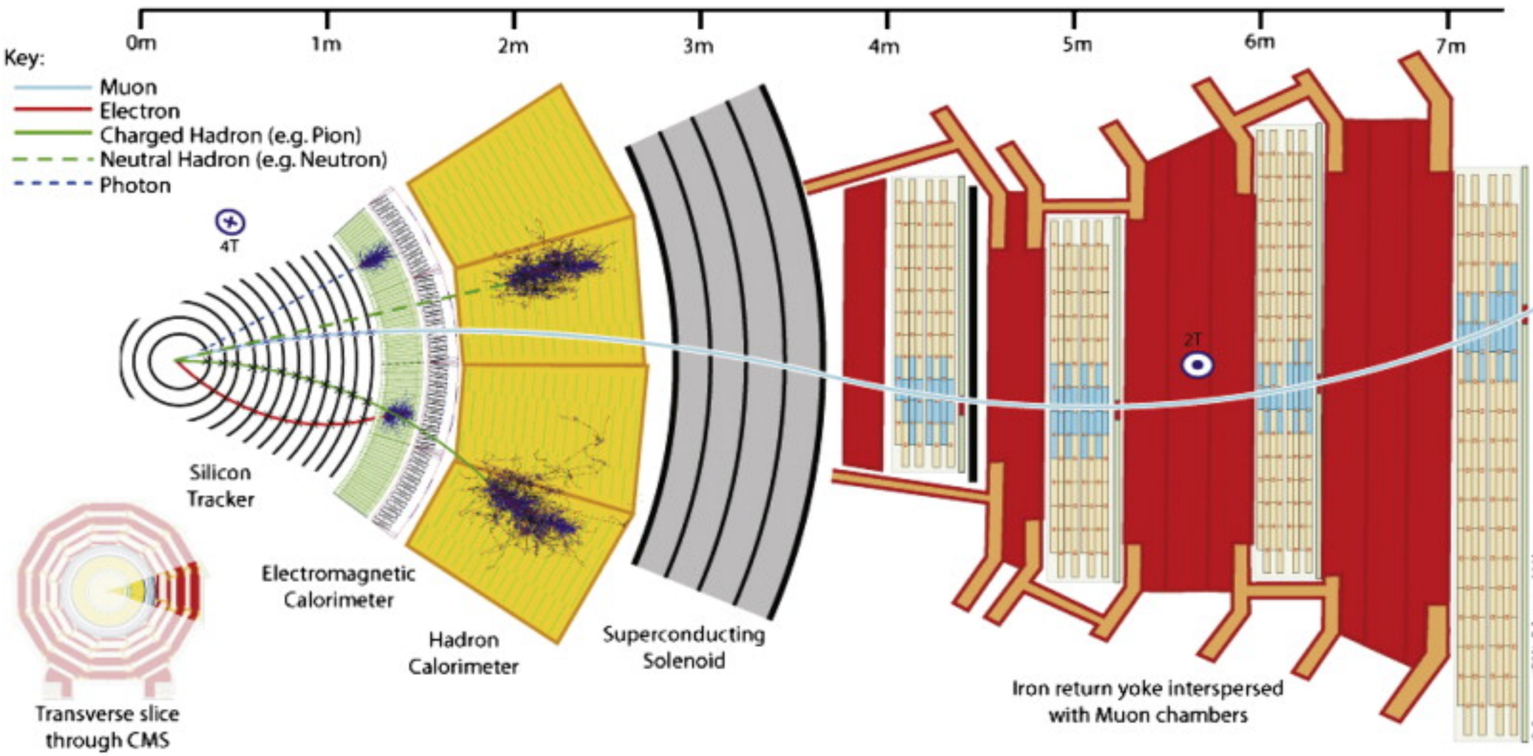
The CMS Experiment



$$\eta = -ln\tan\frac{\theta}{2}$$



Particles' signature in CMS

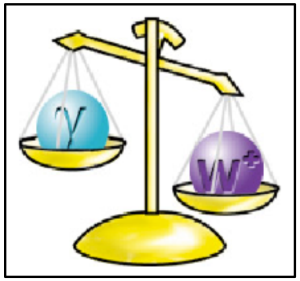


The CMS Collaboration

- 3500 scientists, engineers and students from 193 institutes in 43 countries

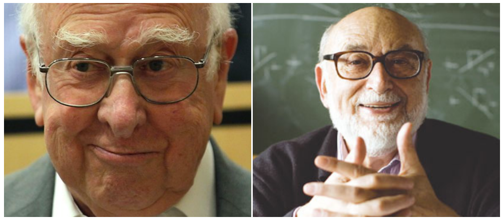
Introduction to particle physics data analysis: real example

- Data analysis is essentially an attempt to make sense of data events on the true basis



Physics problem

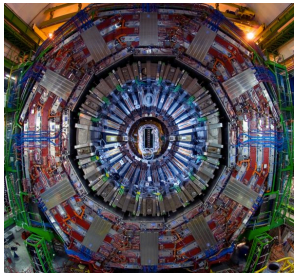
Theoreticians



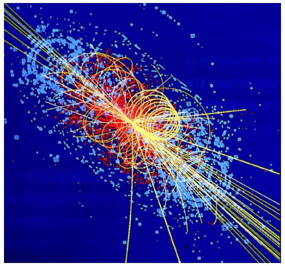
Standard model (SM)

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

Experiment(s)

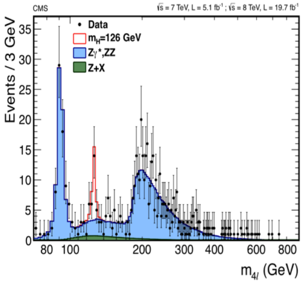


Data events



Data analysis:

Discovery of 125 GeV Higgs



Simulation

Introduction to particle physics data analysis: real example

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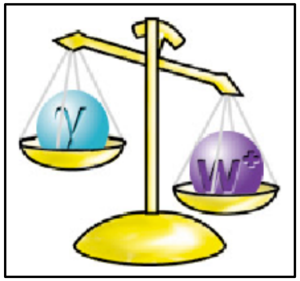
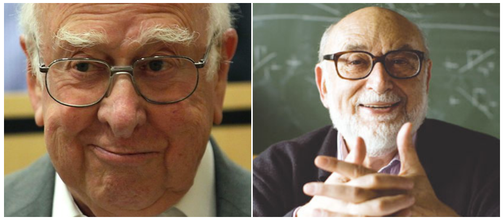


Physics problem

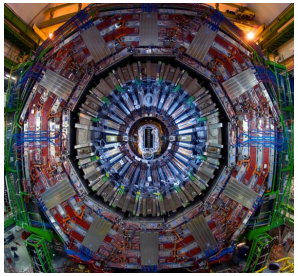
Theoreticians



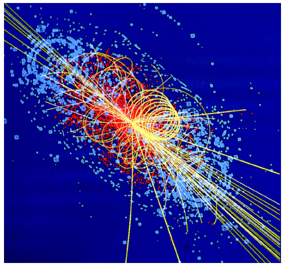
Standard model (SM)

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

Experiment(s)

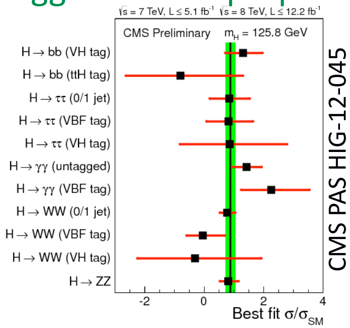


Data events



Data analysis:

Higgs 125 GeV properties



Simulation

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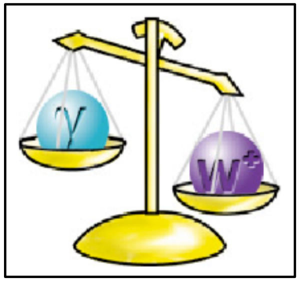
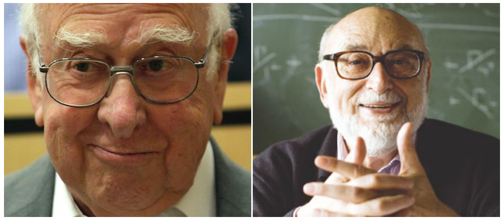


Physics problem

Theoreticians



EW singlet extension of SM

Search for another particle who shares the signal strength, μ, with 125GeV Higgs:

$$\Gamma' = \frac{C'^2}{1 - BR_{new}}\Gamma_{SM}; \quad \mu' = C'^2(1 - BR_{new})$$

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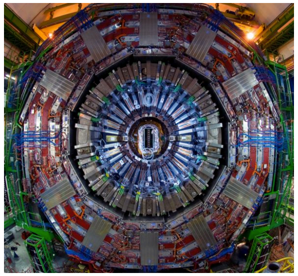
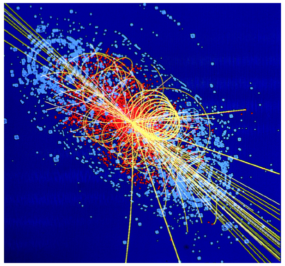
Experiment(s)

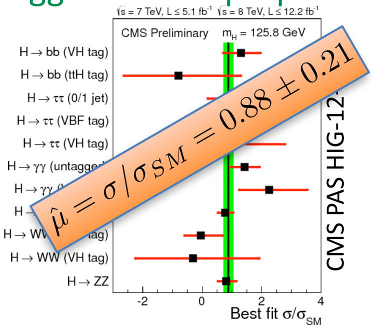


Data events



Data analysis:

Higgs 125 GeV properties



$\hat{\mu} = \sigma/\sigma_{SM} = 0.88 \pm 0.21$

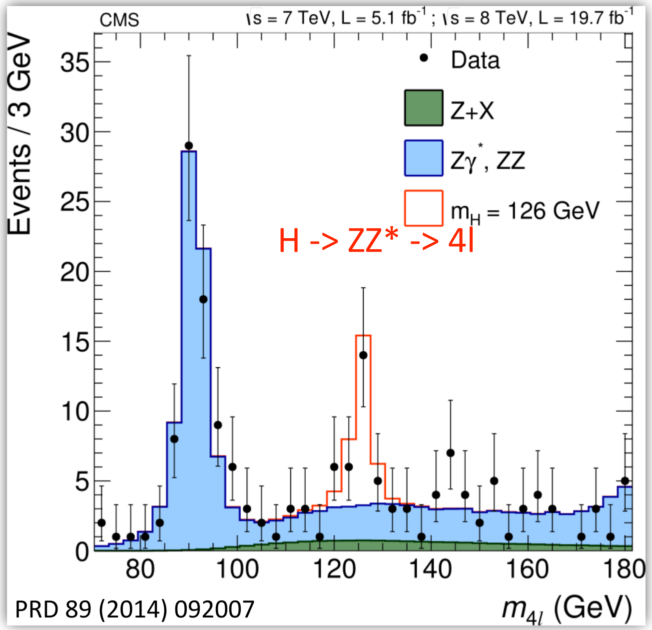
CMS PAS HIG-12-

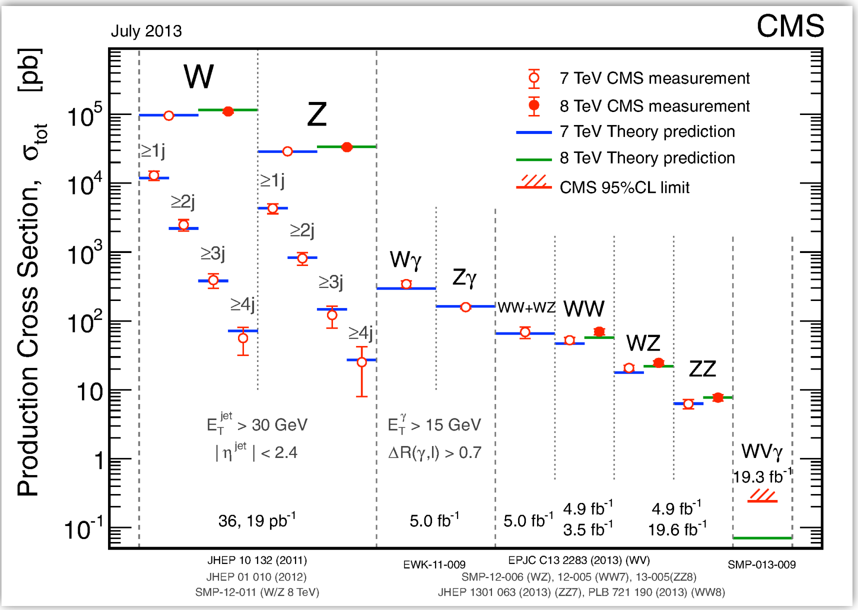
Simulation

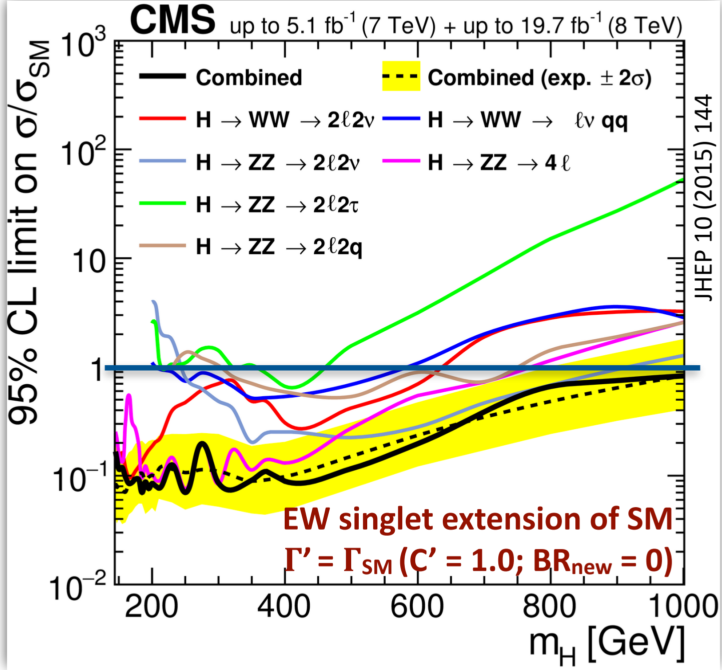
Inputs to the theory

Run1 Legacy Results

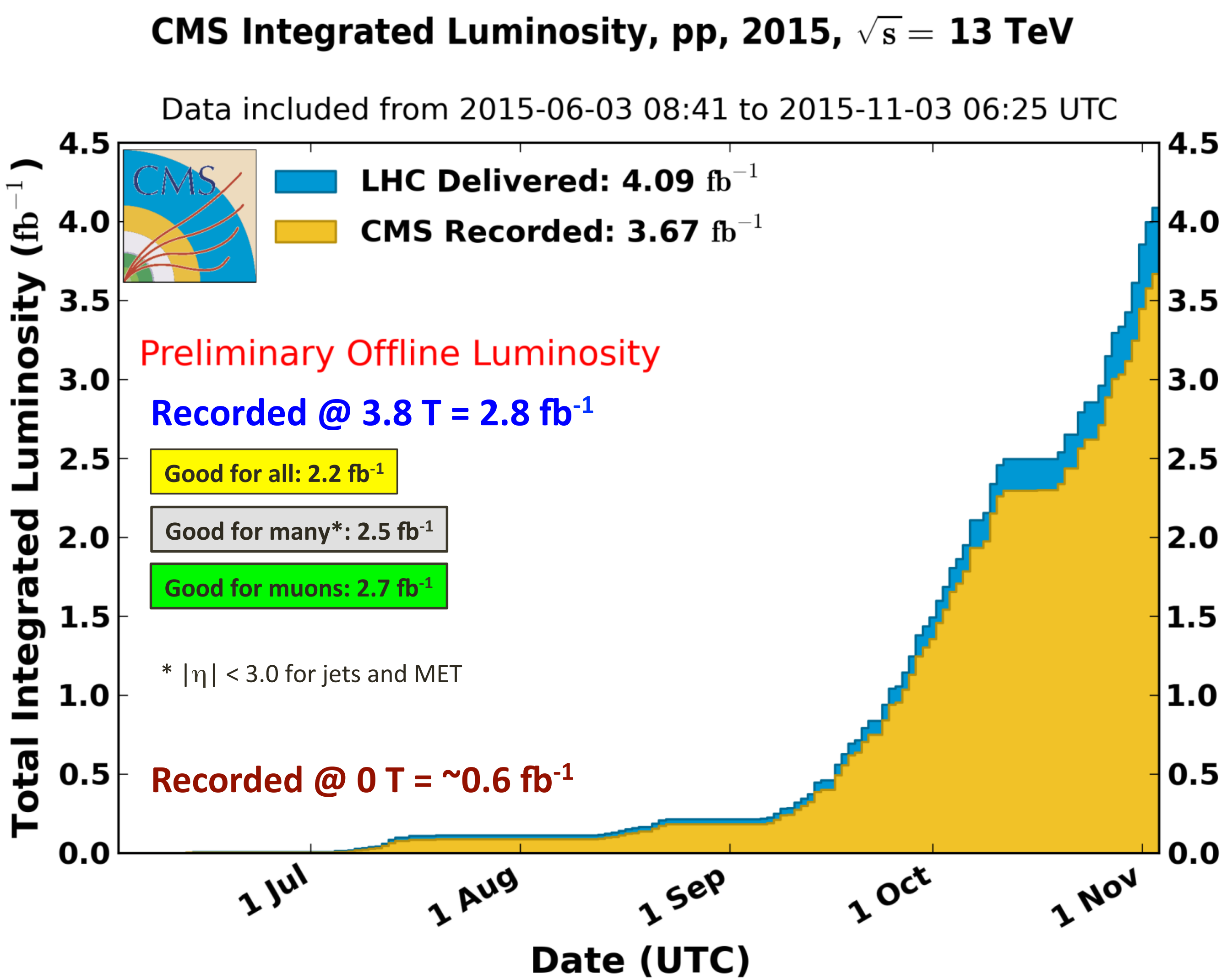
- Run1 data: ~5.5/fb @ 7TeV, ~20/fb @ 8TeV
- Discovery of the Higgs boson of SM
- Many SM parameters measurements
- Many BSM searches, a few bumps



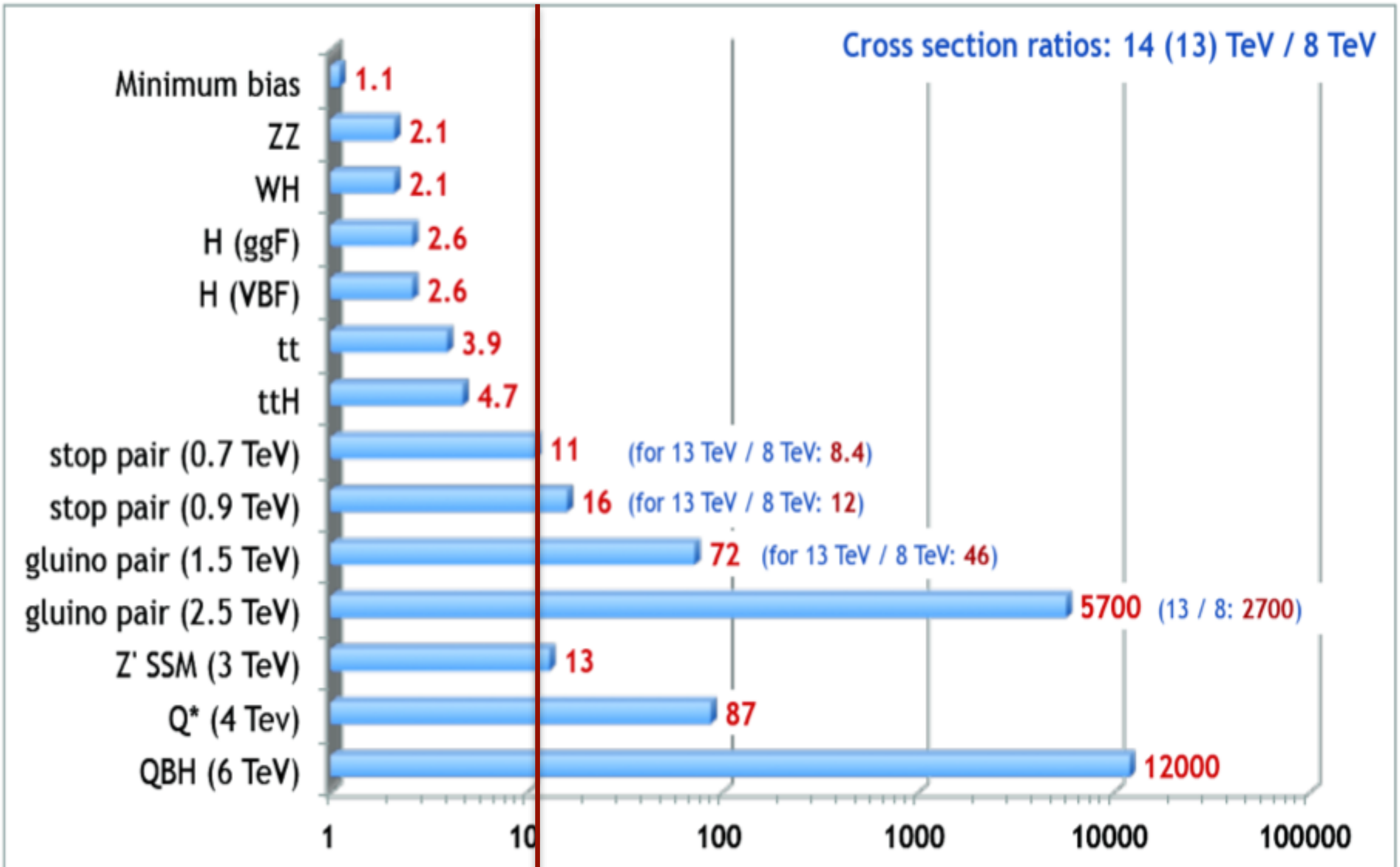




CMS 13 TeV dataset



Increased reach @ 13 TeV



2/fb @ 13TeV = 20/fb @ 8TeV

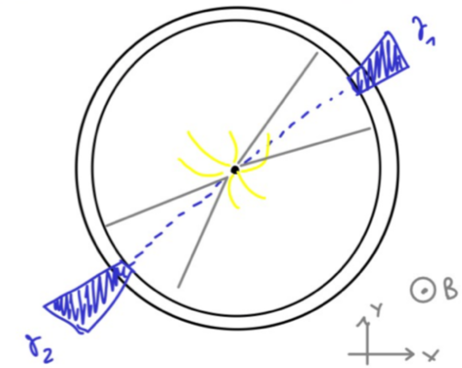
Search for high-mass diphoton resonances

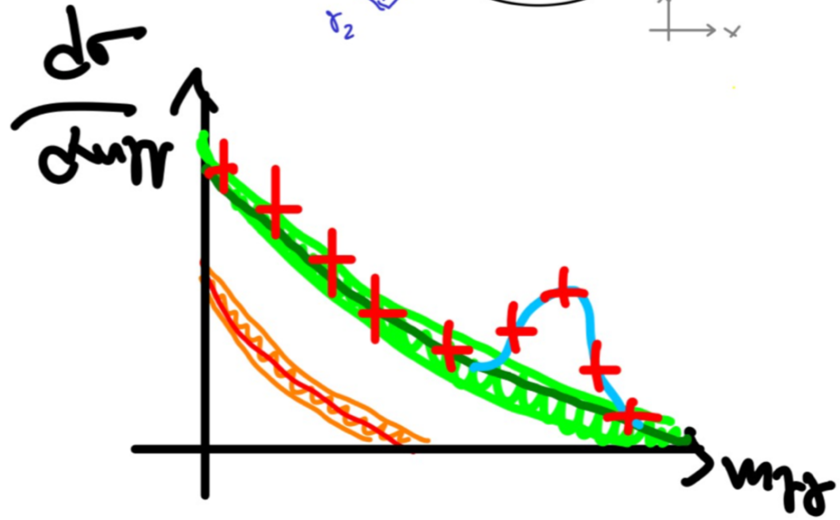
Introduction

- Motivated by several theories beyond the SM:
  - spin-0 SM extensions, spin-2 Randall-Sundrum (RS) model of extra-dimensions (graviton search)
  - 100s of phenomenological papers in arXiv 😅

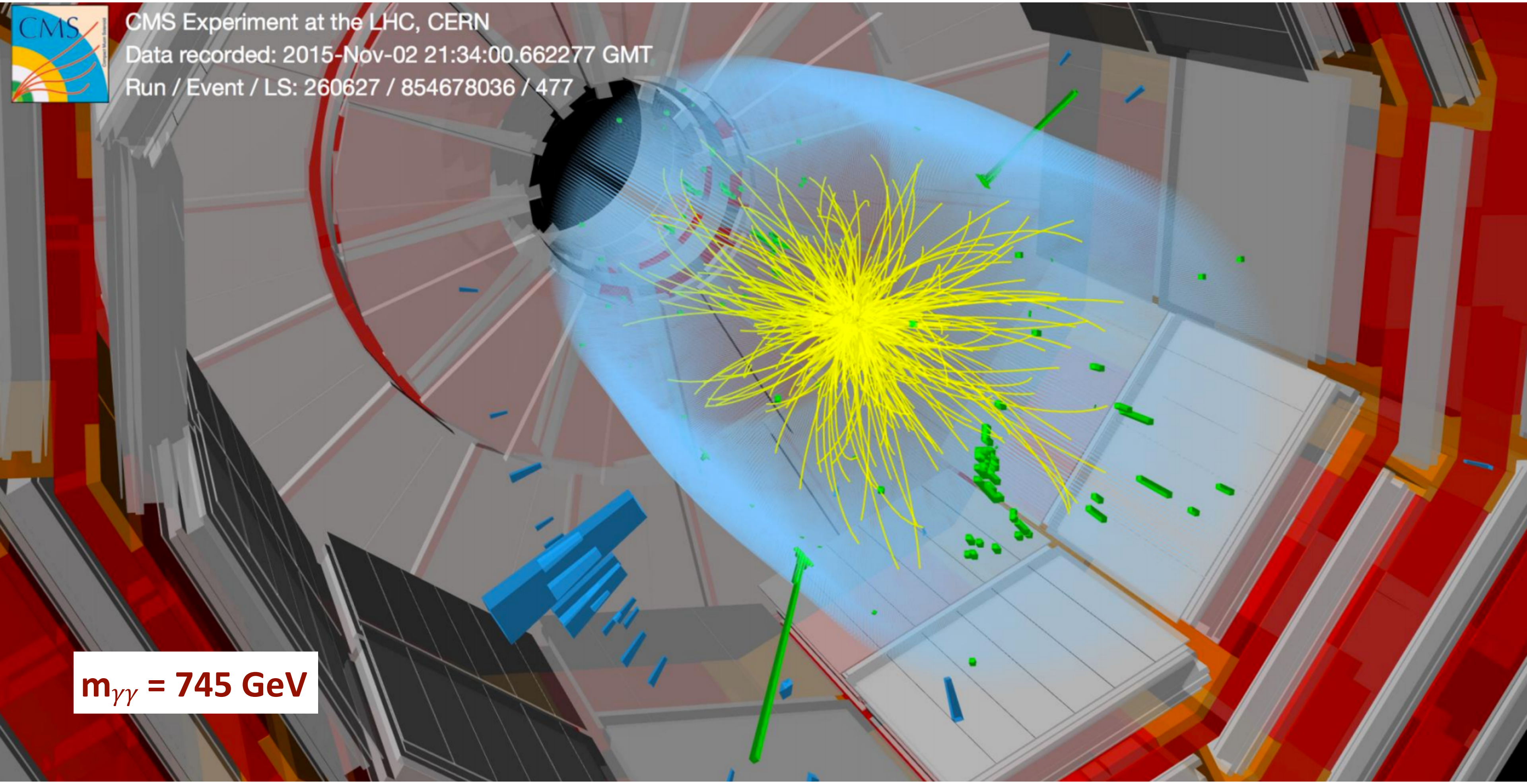
- Two high-pT photons:
  - reconstructed as high energy deposits in EM calorimeter
  - isolated: no additional activities in the direction of the two photon candidates
- Backgrounds: irreducible $\gamma\gamma$ and reducible γj and jj

- Search for localised excess of events in the diphoton invariant mass spectrum, from 500 GeV to 4.5 TeV
- Three width scenarios: $\Gamma/m_{\gamma\gamma}$ = 1.4e-4 (narrow), 1.4e-2 and 5.6e-2 (wider)



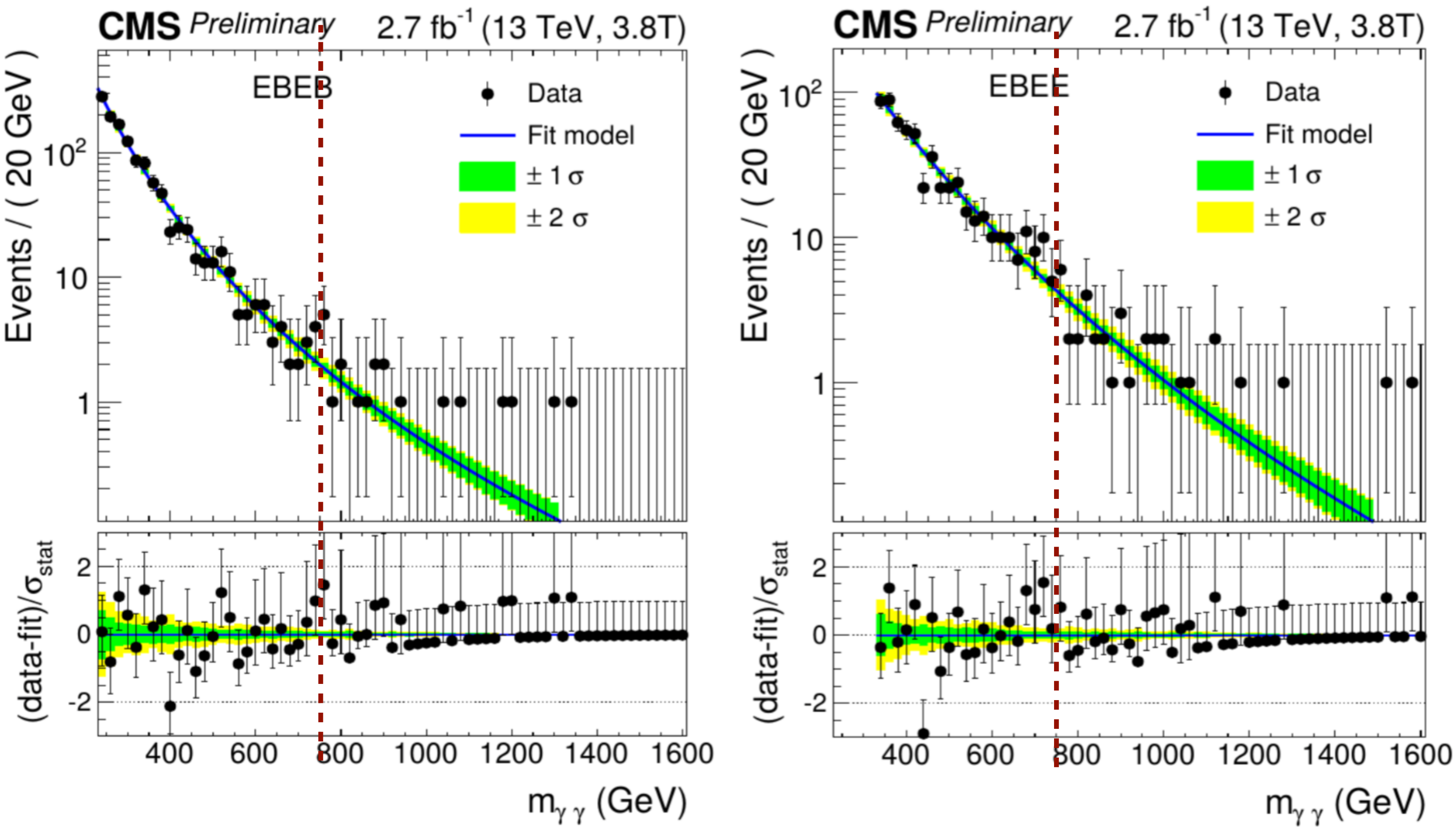


Diphoton event

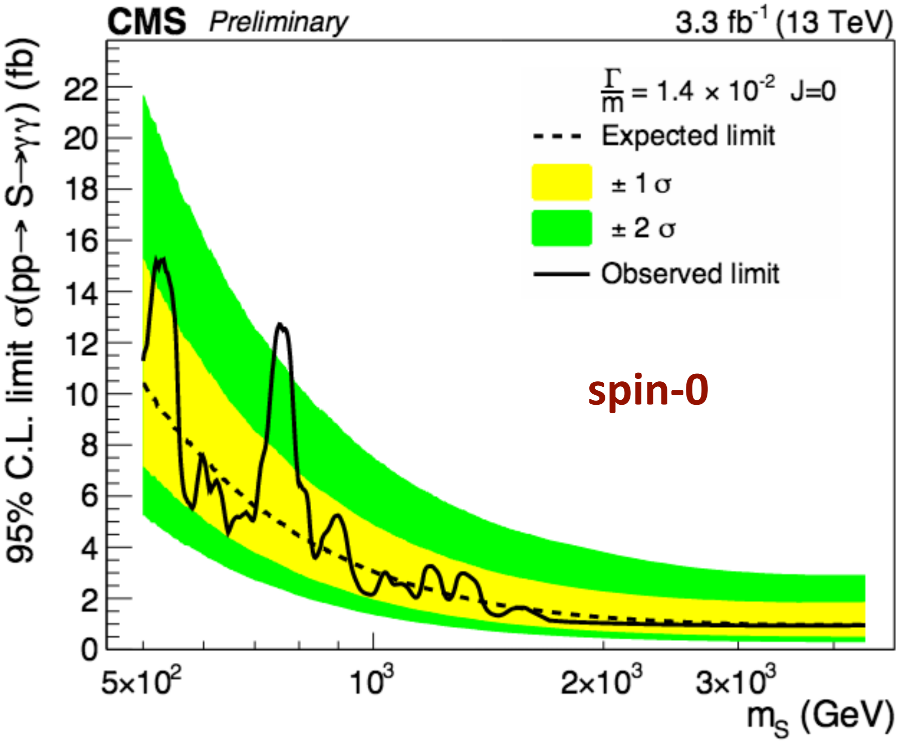


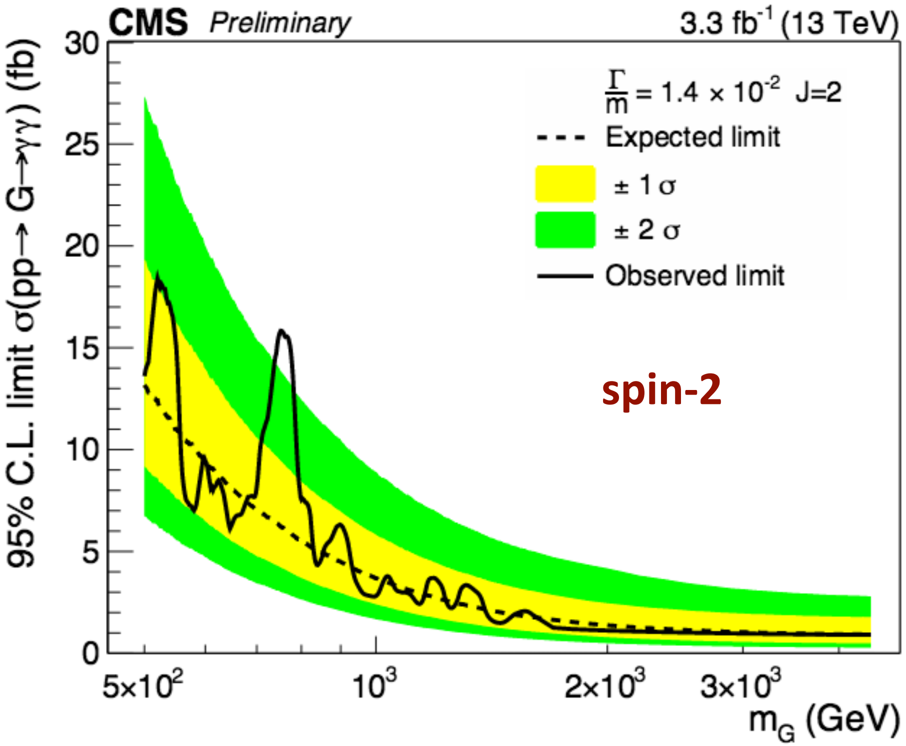
Diphoton invariant mass spectrum

- Analysis is performed in two categories: barrel-barrel (EB-EB) and barrel-endcap (EB-EE) to increase the sensitivity



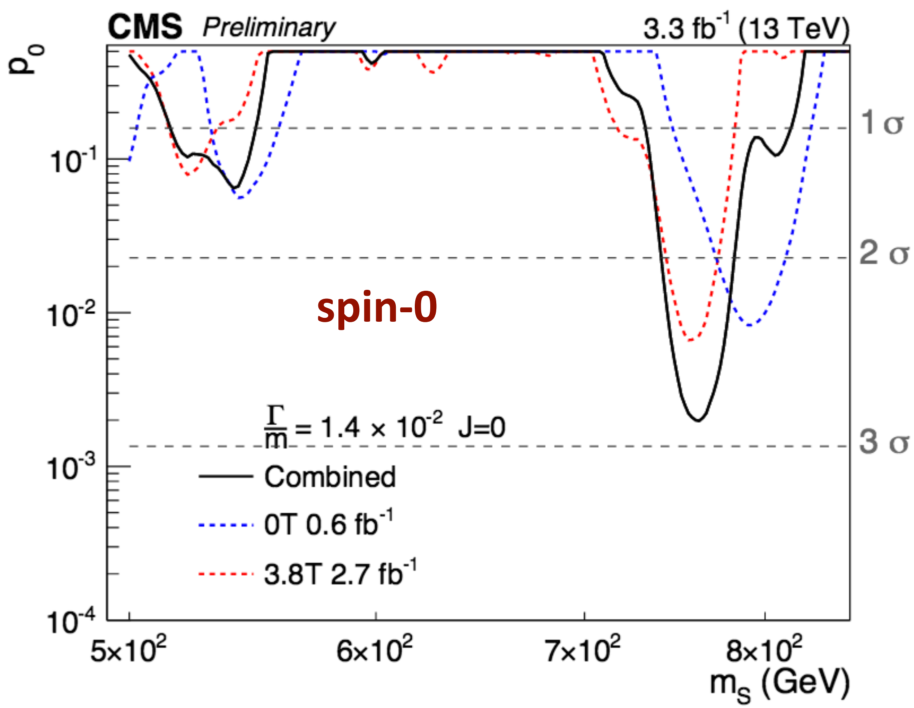
Upper limits

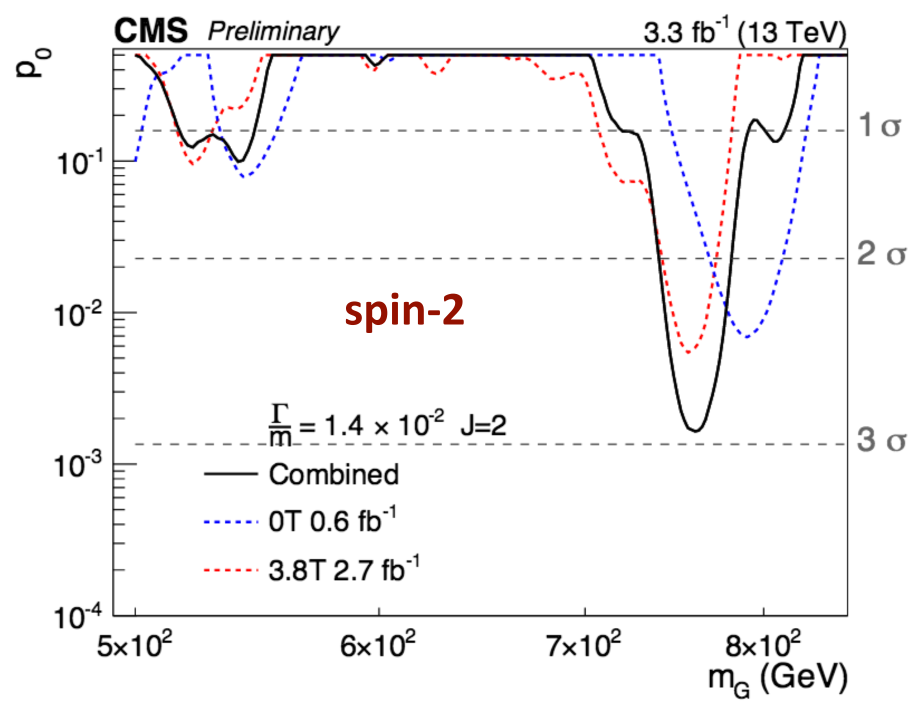




p-values

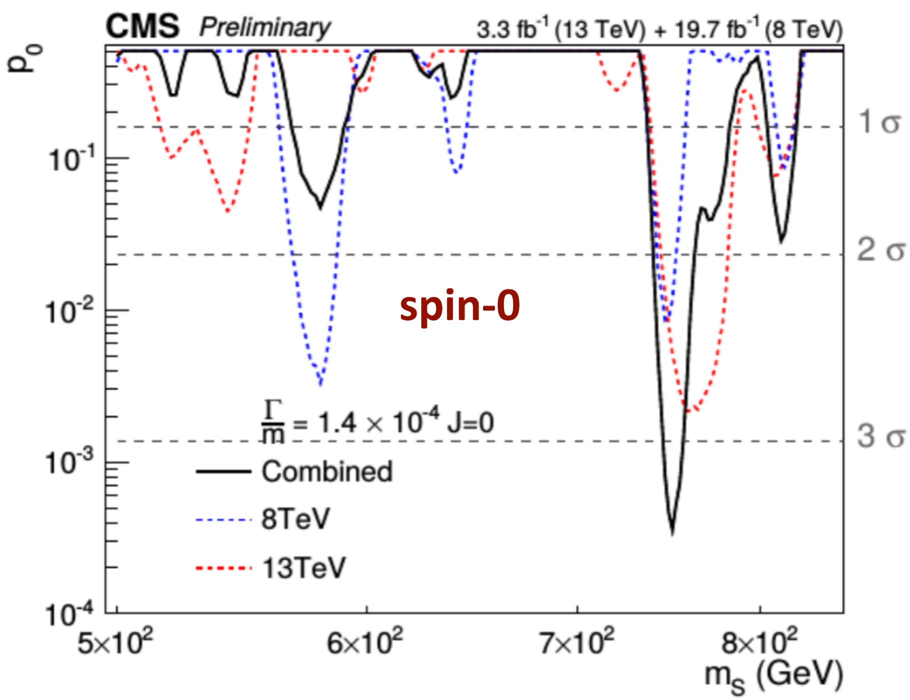
- Largest excess is observed for m_X = 760 GeV and for width = 1.4e-2
- Local significance: 2.8σ for spin-0 and 2.9σ for spin-2
- Global significance < 1σ

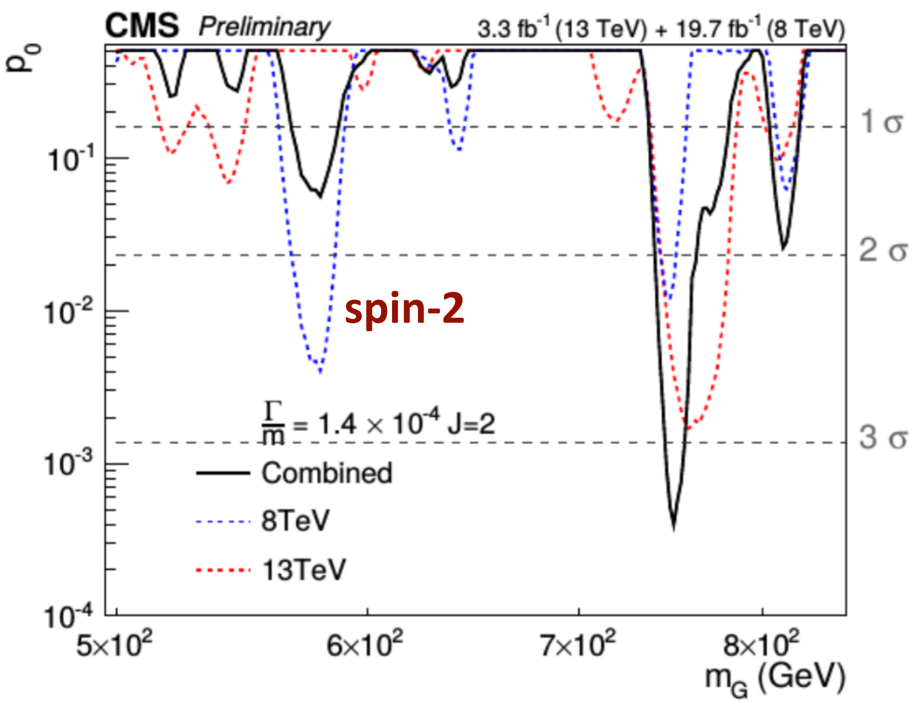




p-values (13 TeV + 8 TeV)

- Largest excess is observed for m_X = 750 GeV and for width = 1.4e-4)
- Local significance: 3.4σ for spin-0 and spin-2
- Global significance = 1.6σ

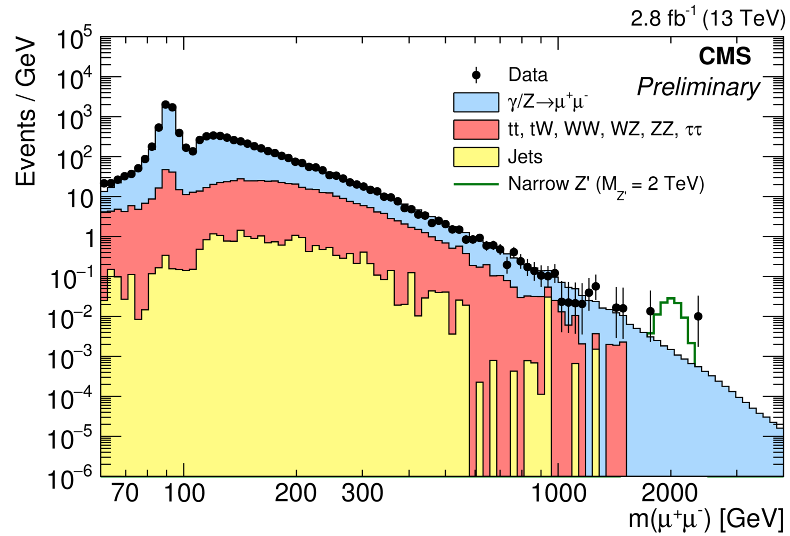


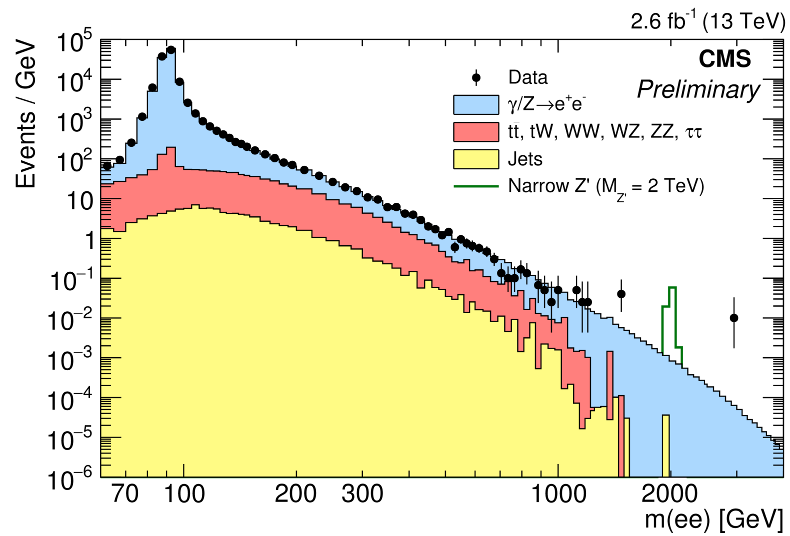


Search for heavy gauge bosons

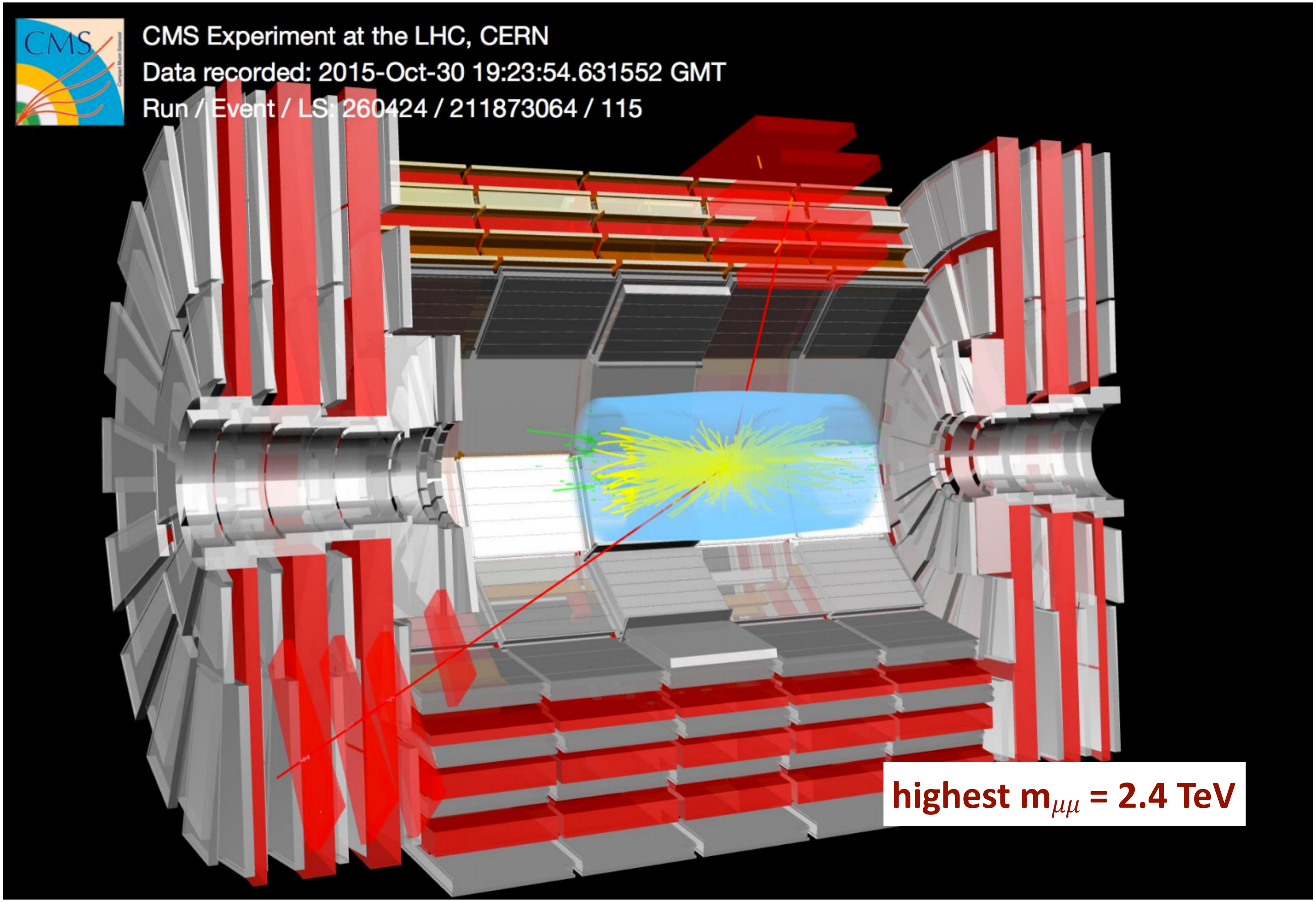
Z' -> $\mu^+\mu^-$ or e^+e^-

- Heavy gauge boson, Z', decaying to a pair of leptons
    - spin-0 sequential standard model (Z'_{SSM}) and super-string inspired Z'_{ψ} models
- Clean signature of two same flavour lepton candidates with very low background at high-mass
- Search for localised excess in dilepton invariant mass spectrum, up to 5TeV
- Highest mass events:
    - Muon - 2.4 TeV
    - Electron - 2.9 TeV
- p-value to observe at least one event in the range m(ee) > 2.8 TeV is 3.6% (> 2σ)



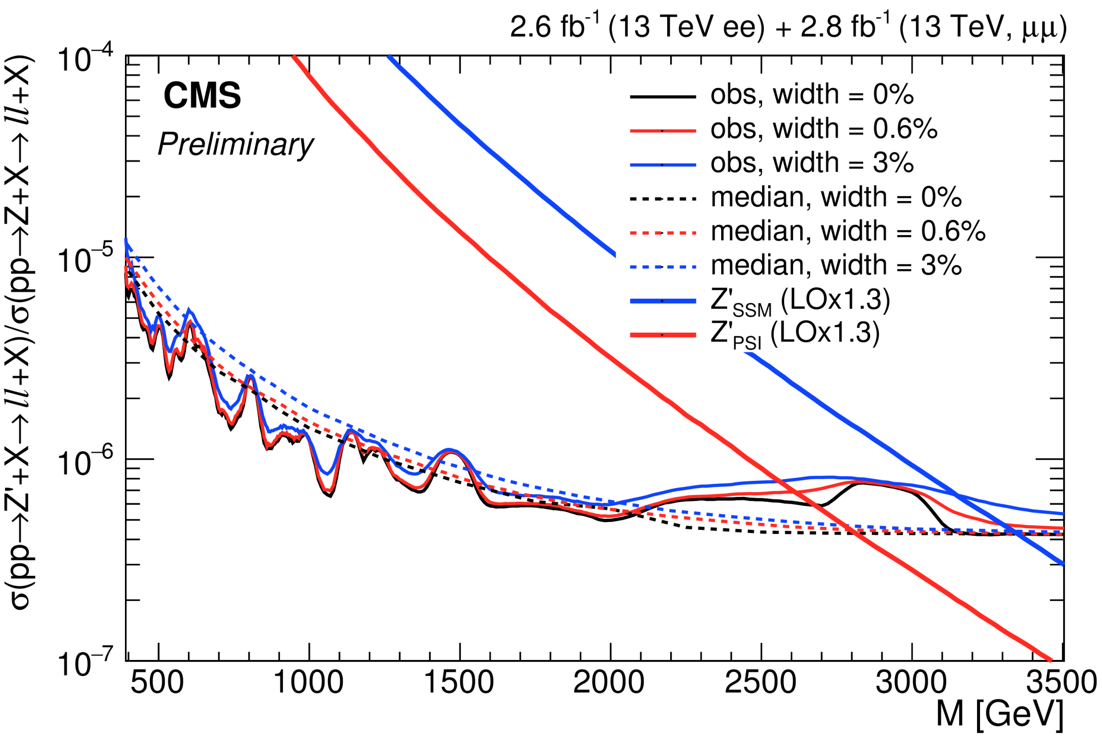


Dimuon event

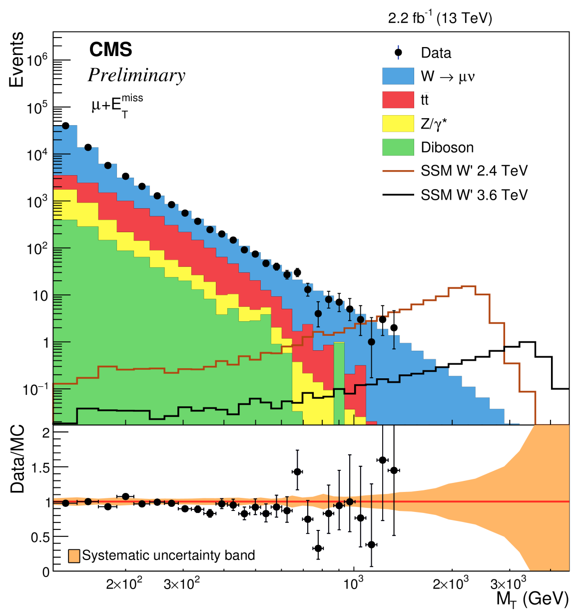


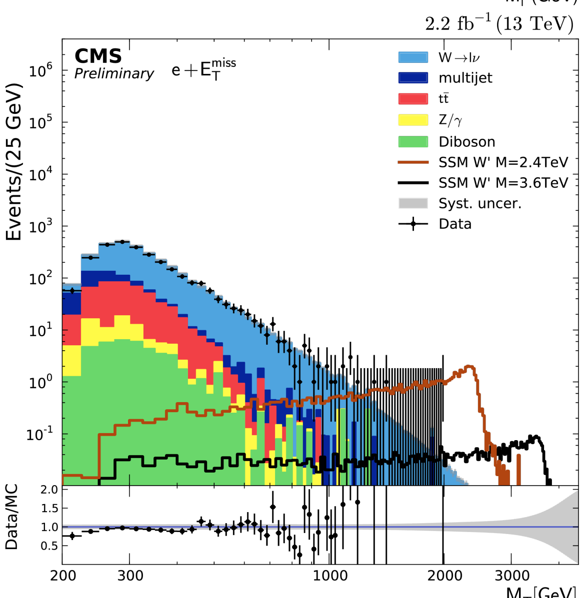
Upper limits

- Three width scenarios: 0%, 0.6%(Z'_{SSM}) and 3%(Z'_{ψ})
- Z'_{SSM} of mass below 3.15 TeV and Z'_{ψ} of mass below 2.6 TeV are excluded

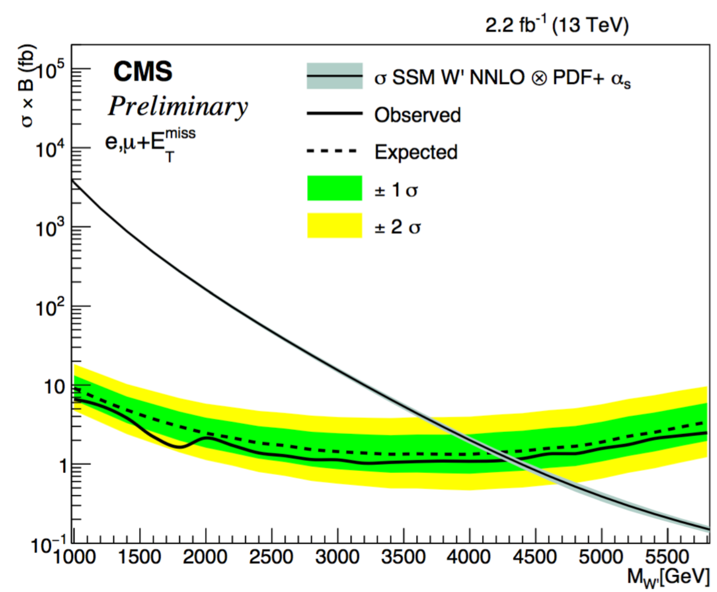


W' -> $\mu\nu_\mu$ or $e\nu_e$

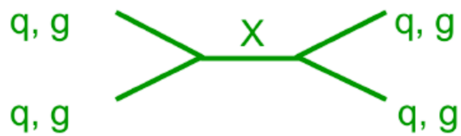




- Heavy gauge boson, W', decaying to a lepton + missing E_T
  - spin-0 sequential standard model (W'_{SSM})
- Highest mass events:
  - Muon - 1.3 TeV
  - Electron - 2 TeV
- W'_{SSM} of mass below 4.4 TeV is excluded



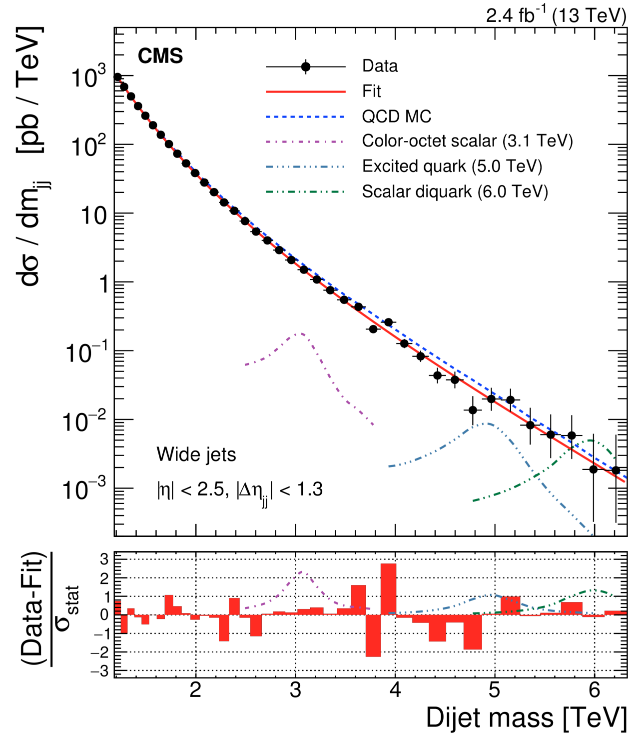
Dijet search

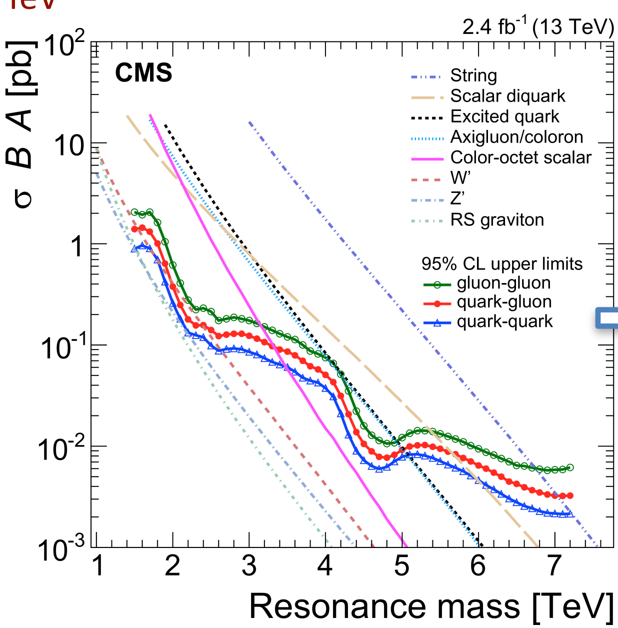


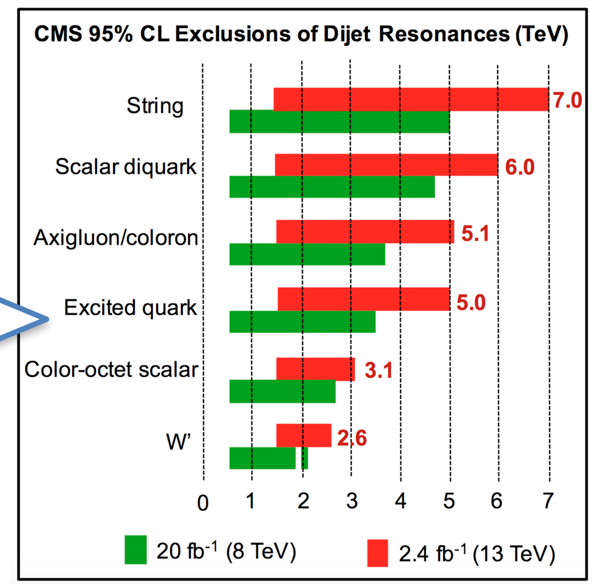
- Motivated by string resonances, spin-0 diquarks, axigluons and colorons, excited quarks, color-octet scalar and W's models

- Signature of two high-p_T (leading) jet candidates with very low background at high-mass: $\Sigma_{jet} P_T(jet) > 800$ GeV (or a jet with $p_T > 500$ GeV)
- Backgrounds: irreducible dijet, reducible lepton + jets
- Search for localised excess in dijet invariant mass spectrum, from 1.5 to 7TeV

- Highest mass events: 6.14 TeV







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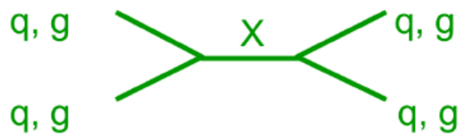
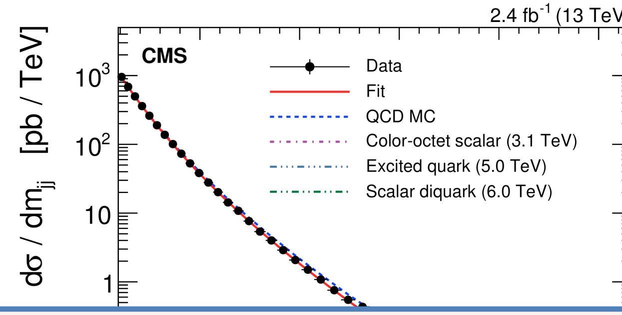




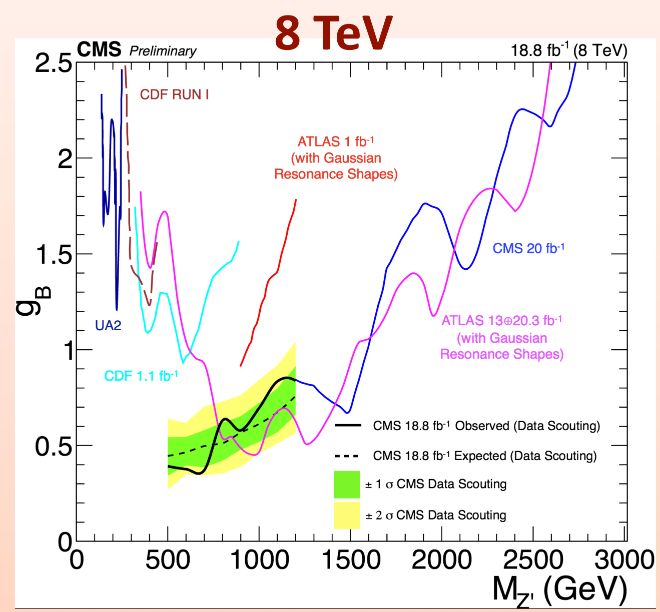
- Motivated by string resonances, spin-0 diquarks, axigluons and colorons, excited quarks, color-octet scalar and W's models

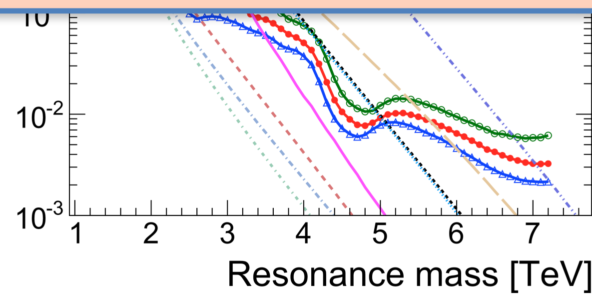
- Sig
  ba
  50
- Ba
- Se
  1.5
- Hig

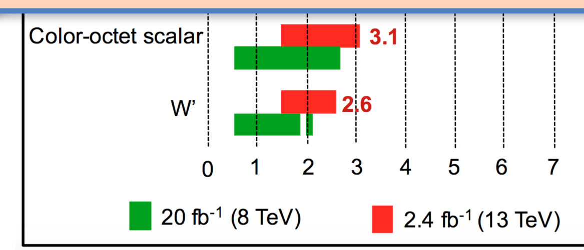
Dijet search (m_{jj} < 1 TeV)

- Data Scouting: a dedicated trigger which filters the events if $\Sigma_{jet}E_T(jet) > 250$ GeV
  - Only a part of event content, kinematics of trigger level reco. jets, is stored then
  - Fits to the CMS storage capabilities
  - Allows to perform the dijet resonance search at low masses
- 13 TeV results are not public yet

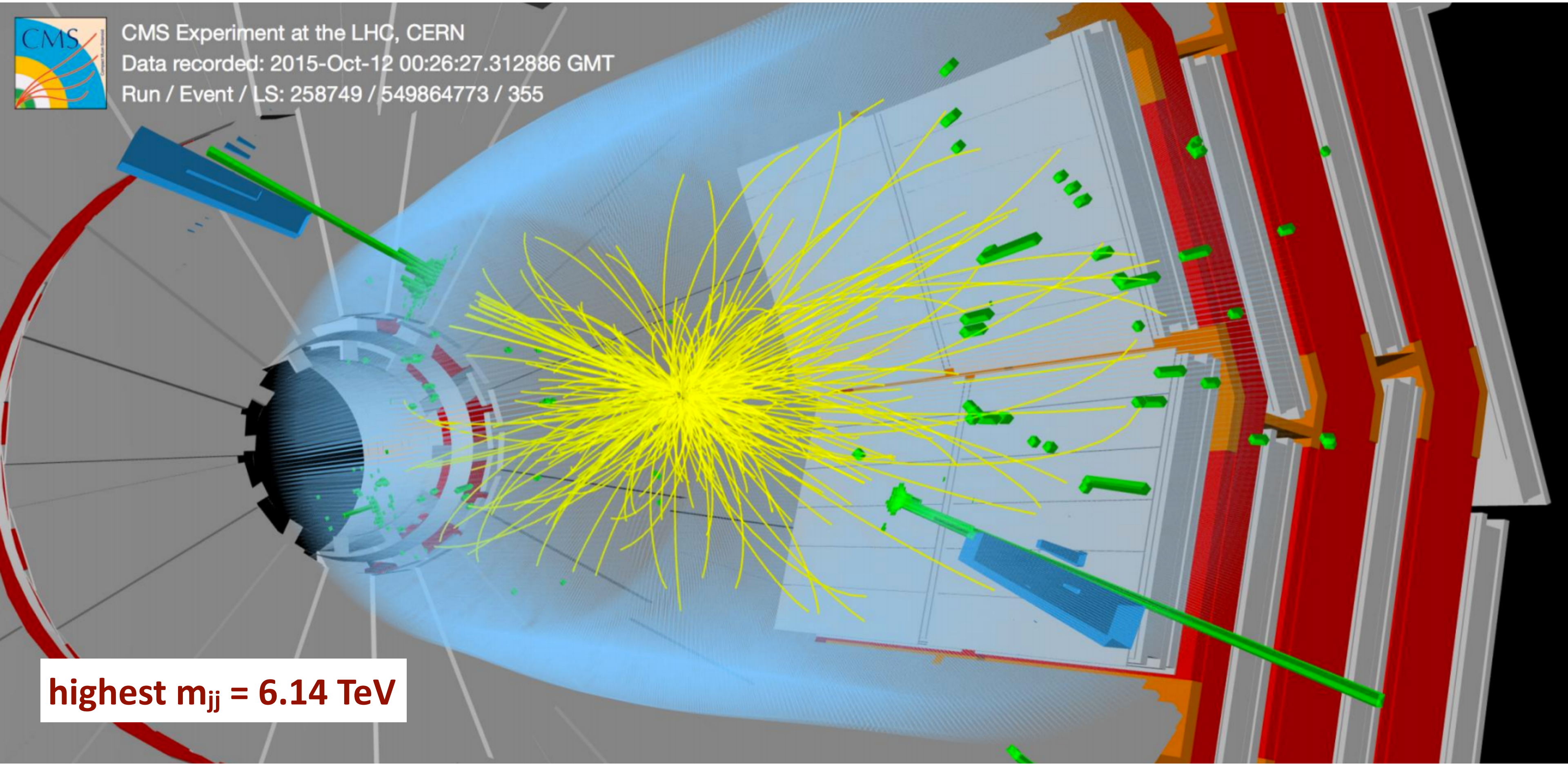
8 TeV







Dijet event @ 13 TeV

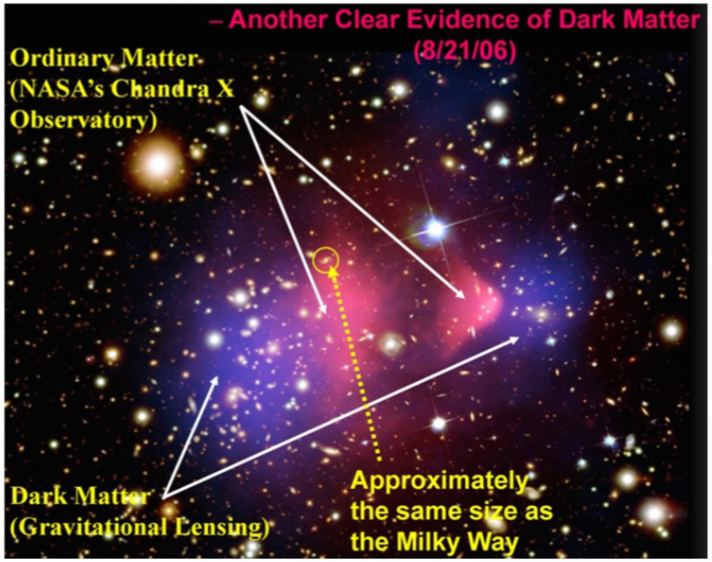


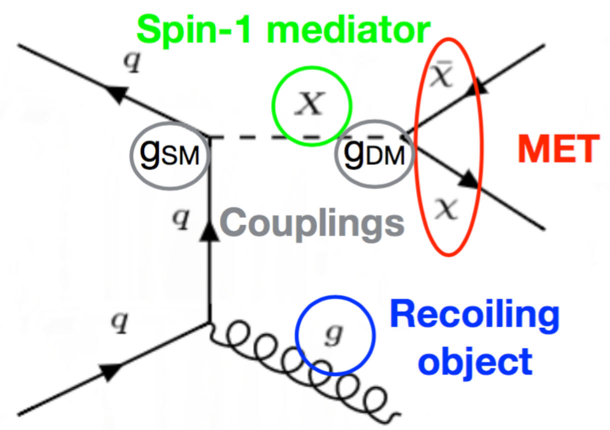
Search for dark matter

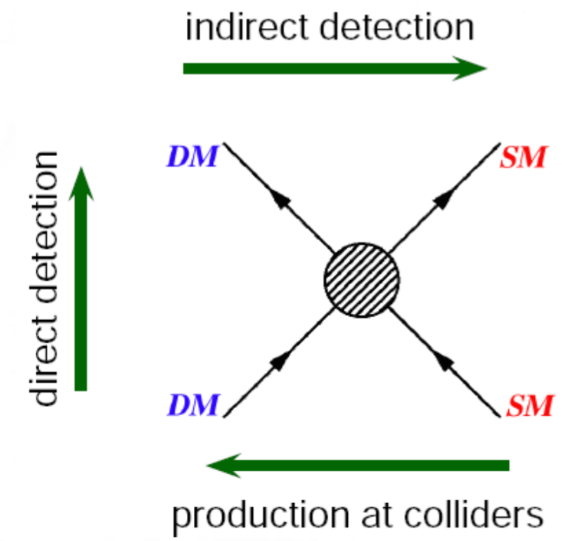
Introduction

- Cosmological observations prove that around 85% of matter component of Universe is composed of dark matter (DM)
- Currently the most popular candidate is a weakly interacting massive particle (WIMP), i.e. a particle with weak interactions and masses roughly above the proton mass

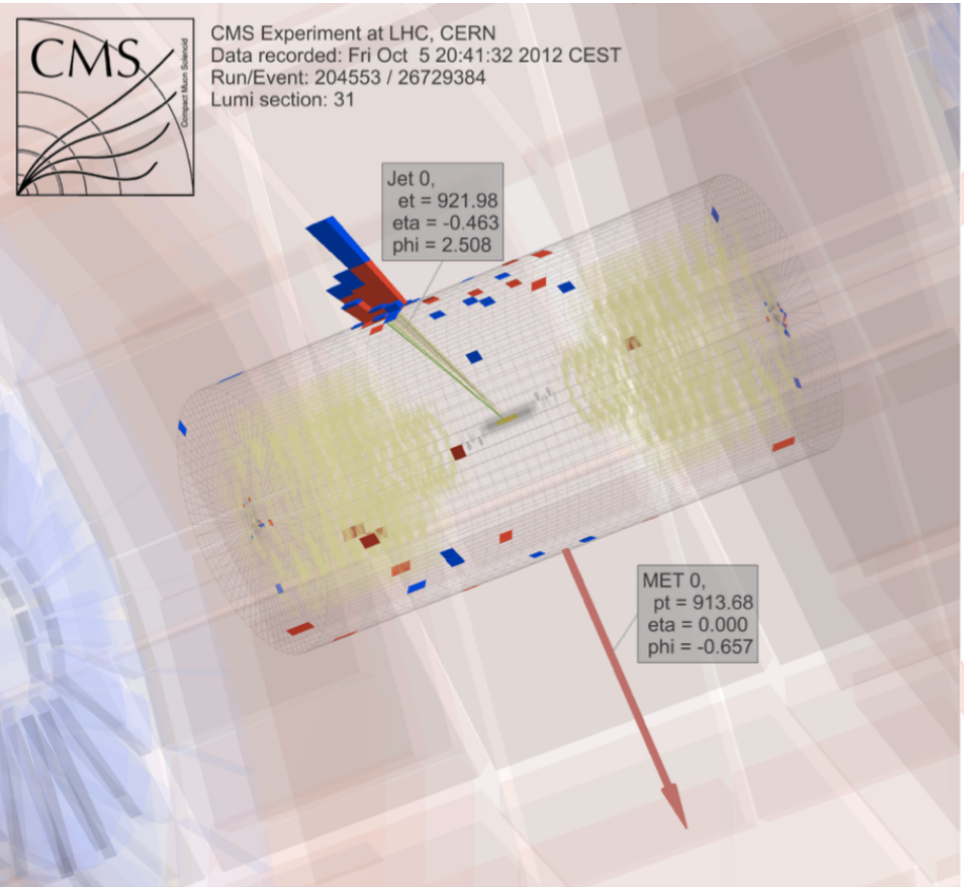
- Dark matter detection at colliders: produce DM particles by colliding SM particles at high energy

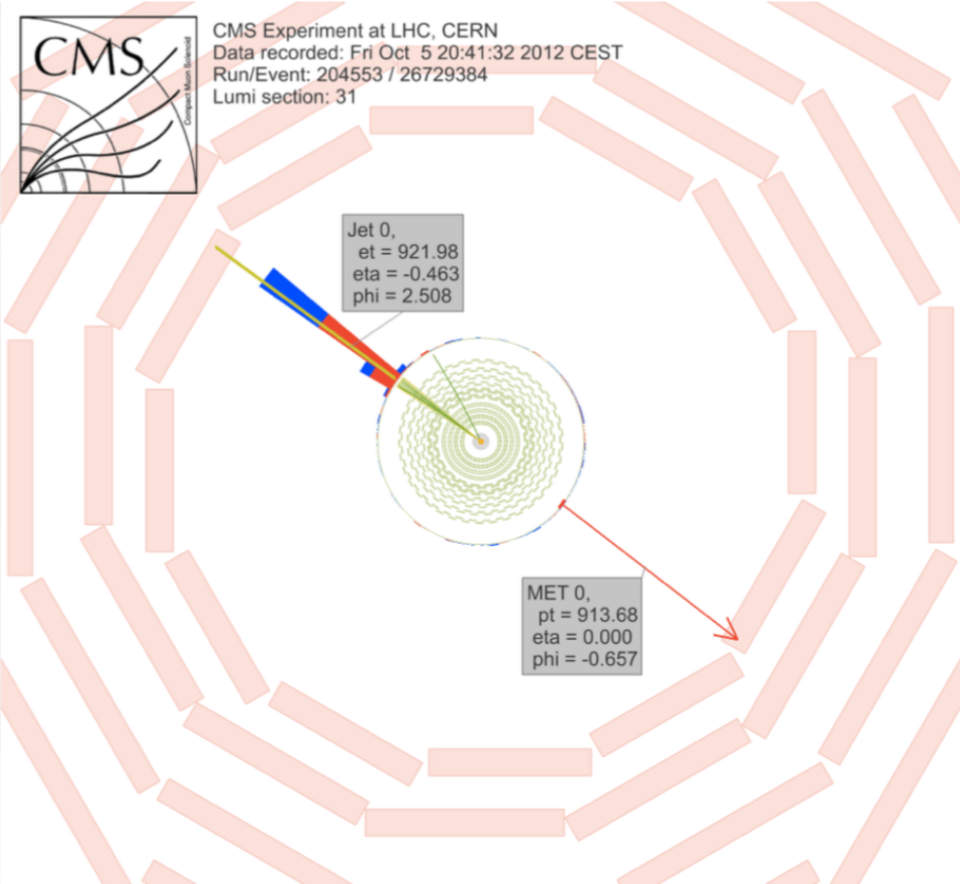






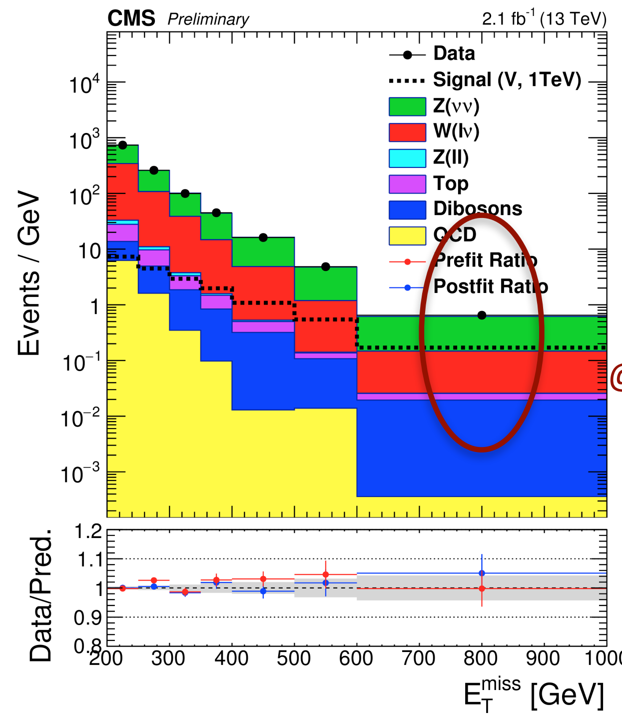
jet(s) + large missing E_T event



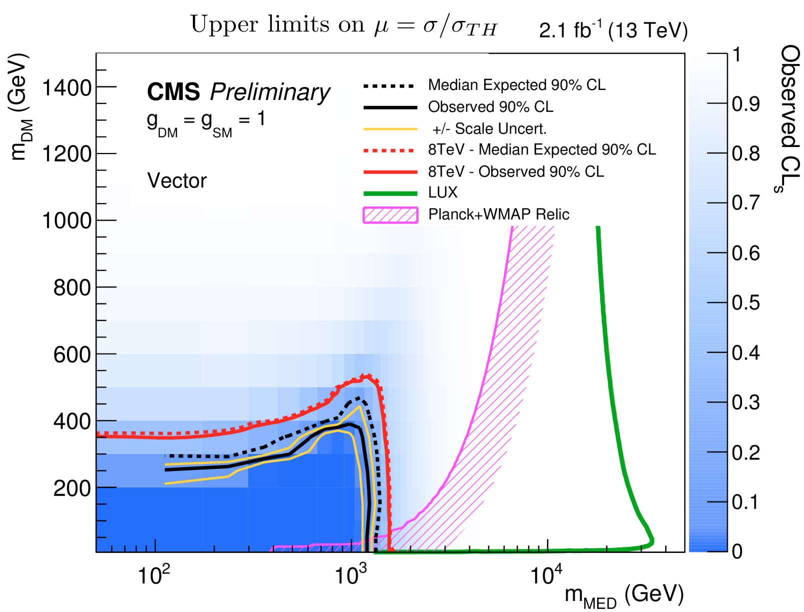


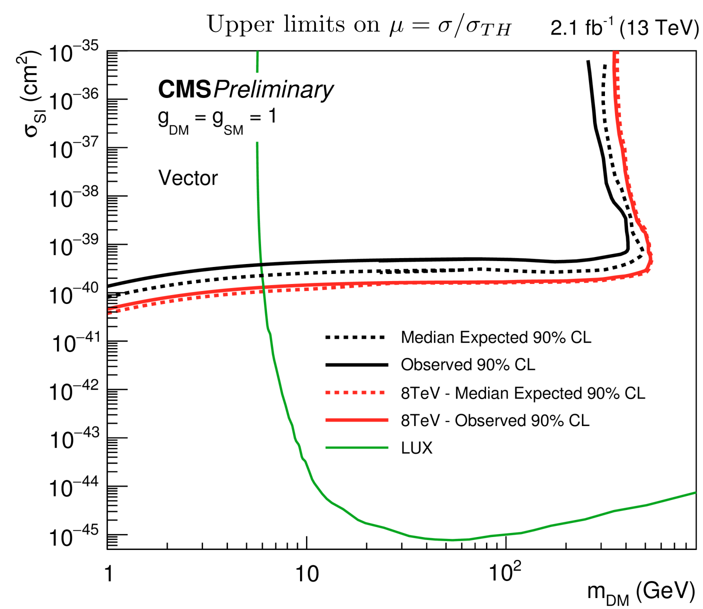
jet(s) + large missing E_T

- Invisible DM particles escape detection: tag events using recoiling object(s) and missing E_T
- Results are interpreted in terms of simplified models: described by mediator and DM mass



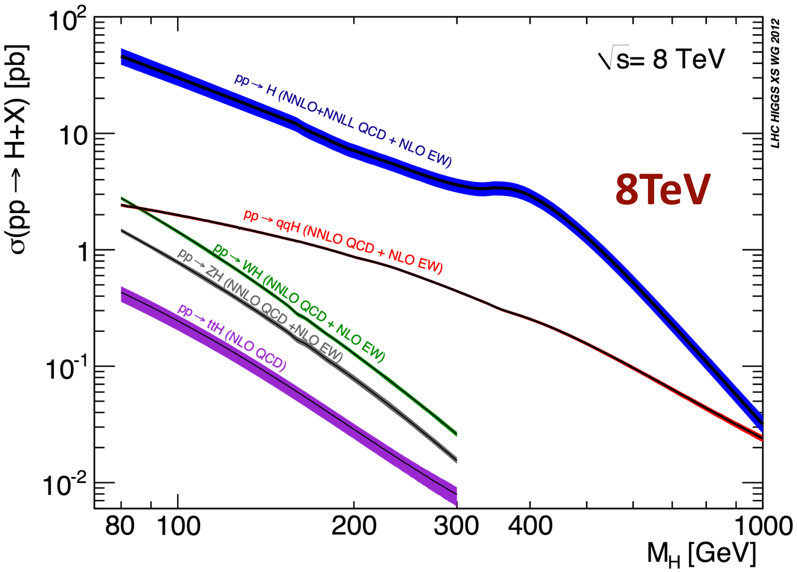
signal peaks @ high miss. E_T

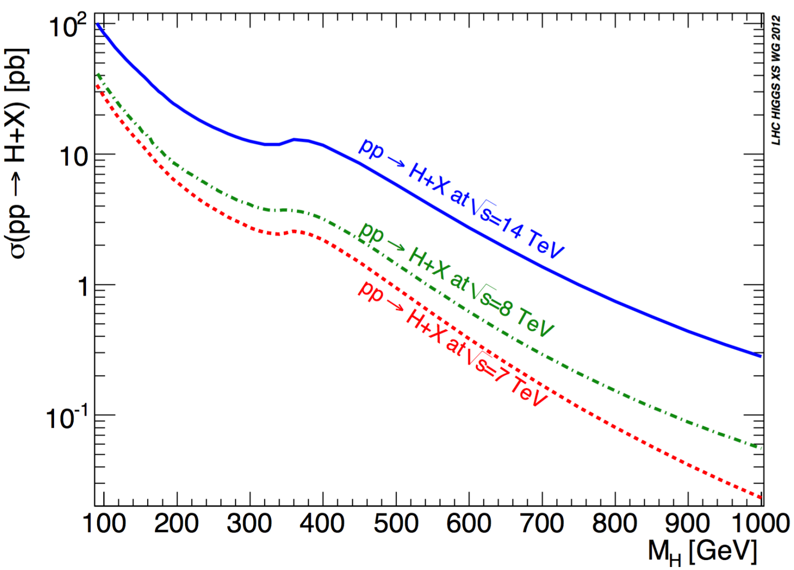




Higgs boson precision measurements

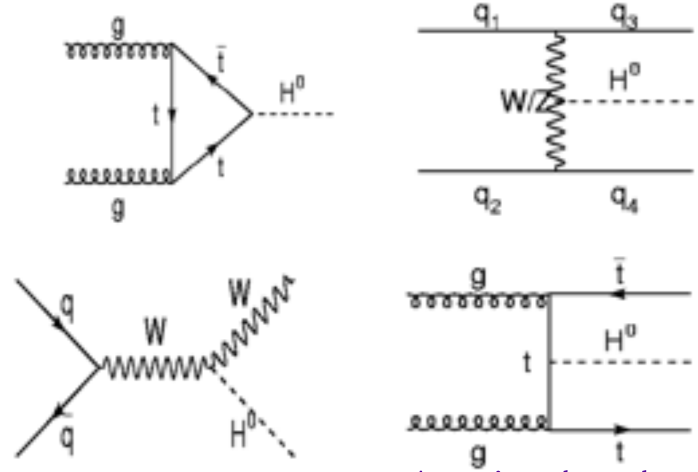
Higgs at LHC





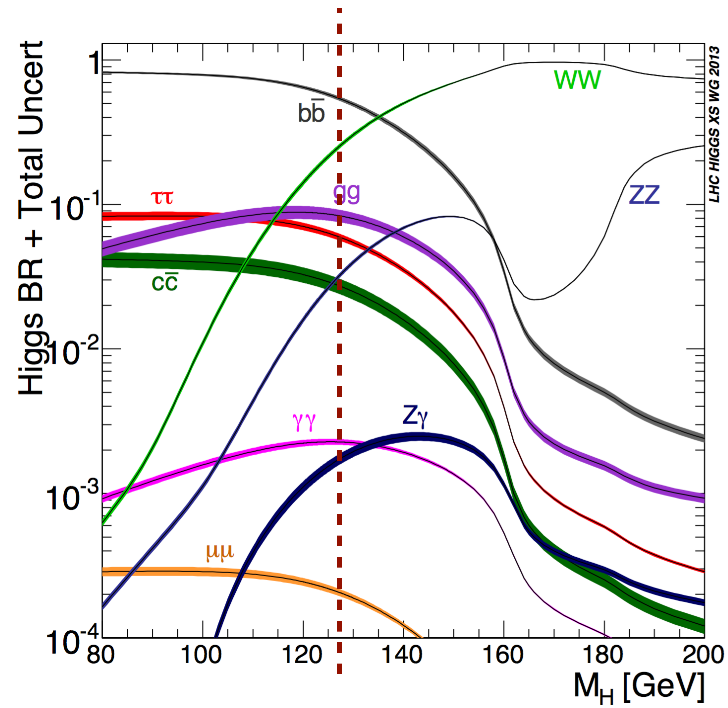
Gluon fusion: gg→H

Vector Boson fusion: qq→H



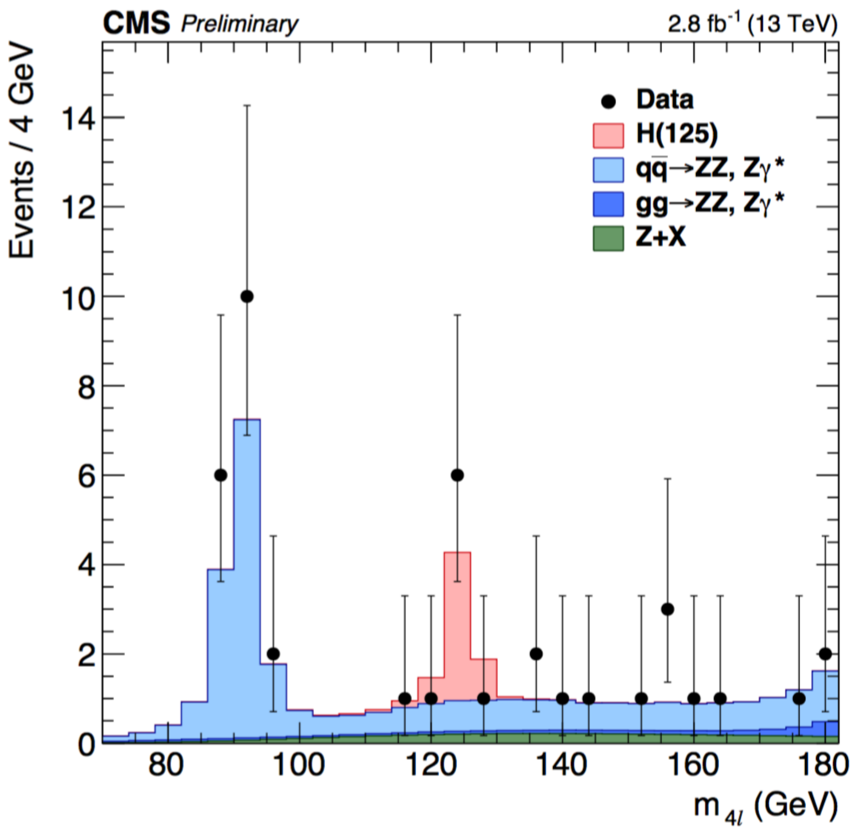
Associated production: WH, ZH

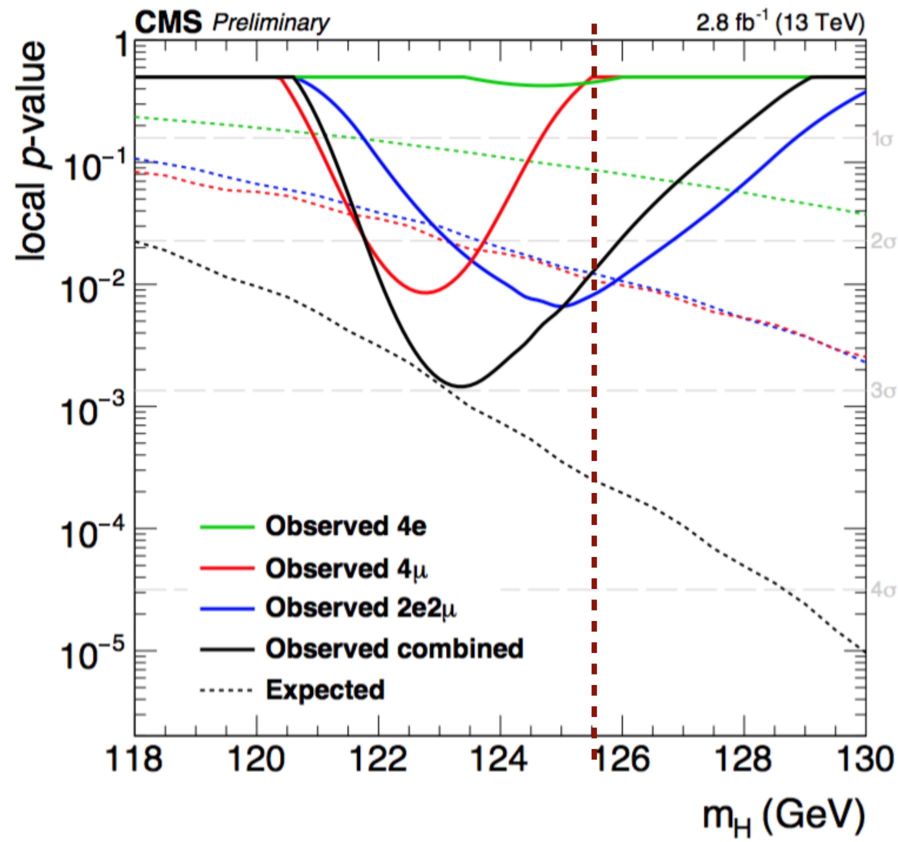
Associated production with heavy quarks: ttbarH



Higgs -> ZZ* -> 4l

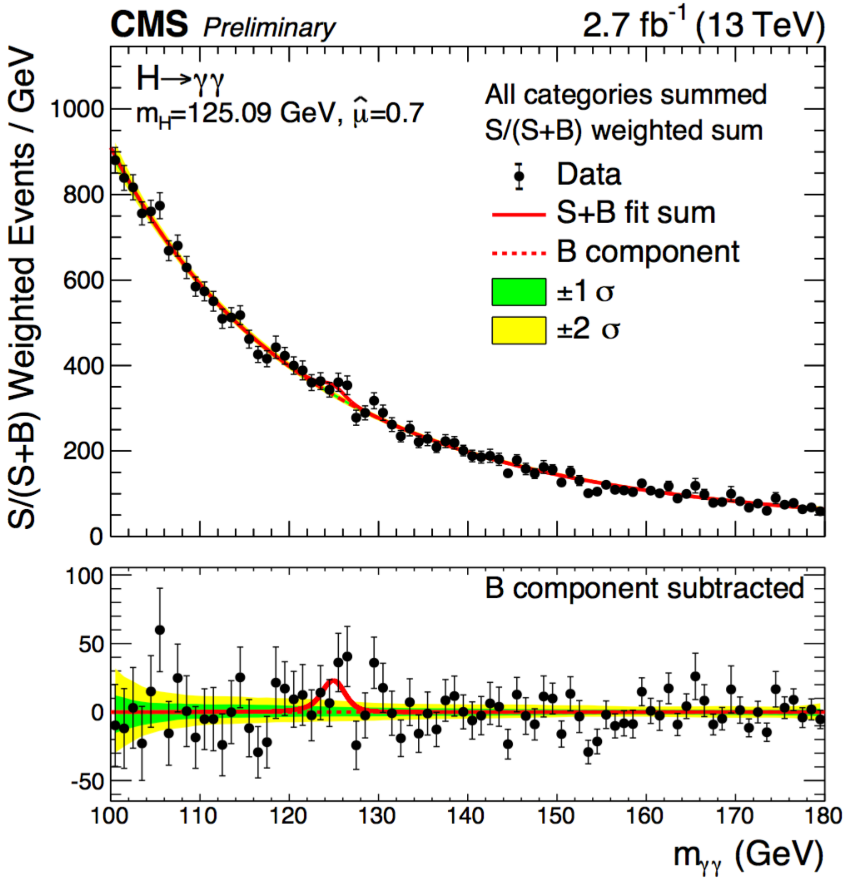
- Local significance for m_H = 125.09 GeV:
  - observed: 2.5σ (6.5σ for Run1 @ 125GeV)
  - expected: 3.4σ (6.3σ for Run1 @ 125GeV)

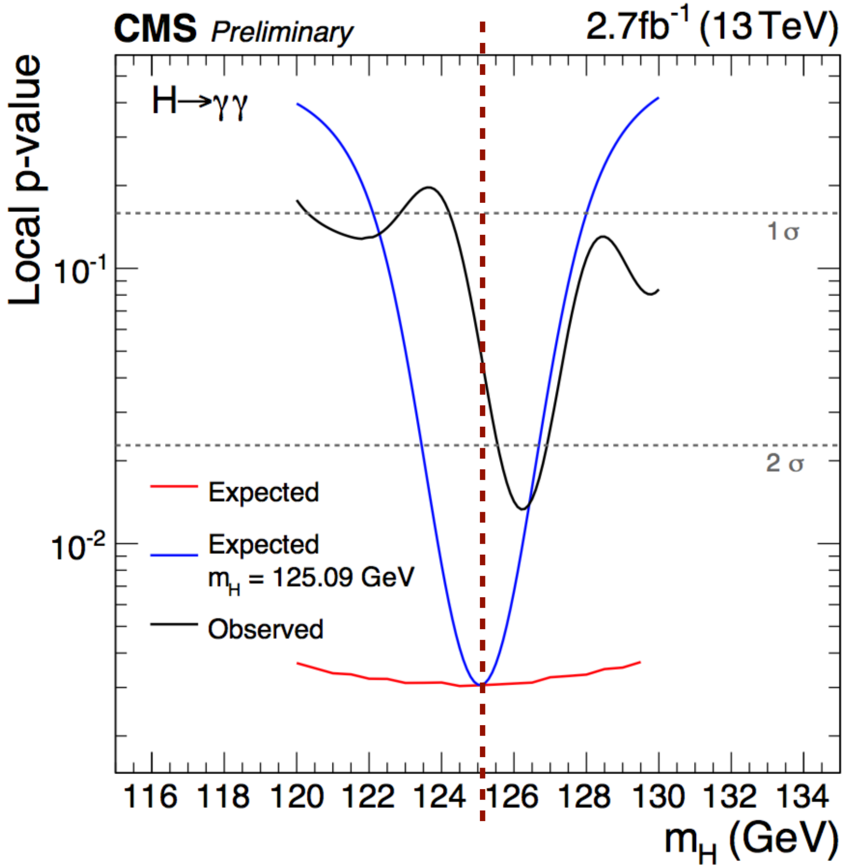




Higgs -> $\gamma\gamma$

- Local significance for m_H = 125.09 GeV:
  - observed: 1.7σ (5.6σ for Run1 @ 125GeV)
  - expected: 2.7σ (5.3σ for Run1 @ 125GeV)





Higgs properties measurements

$H(125.09\ \mathrm{GeV}) \to ZZ$:

$\hat{\mu} = \sigma/\sigma_{SM} = 0.82^{+0.57}_{-0.43}$

$\hat{\mu}_{\mathrm{ggH,t\bar{t}H}} = 0.95^{+0.64}_{-0.49}$

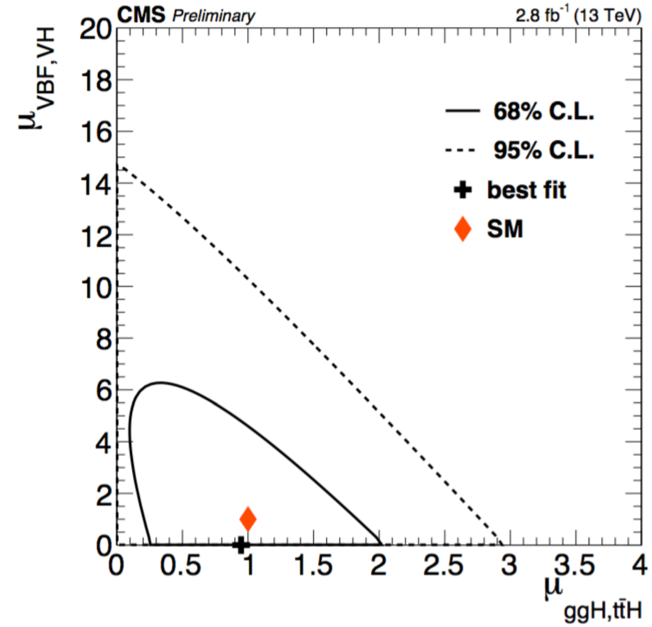
$\hat{\mu}_{\mathrm{VBF,VH}} = 0.0^{+2.5}_{-0.0}$

$H(125.09\ \mathrm{GeV}) \to \gamma\gamma$:

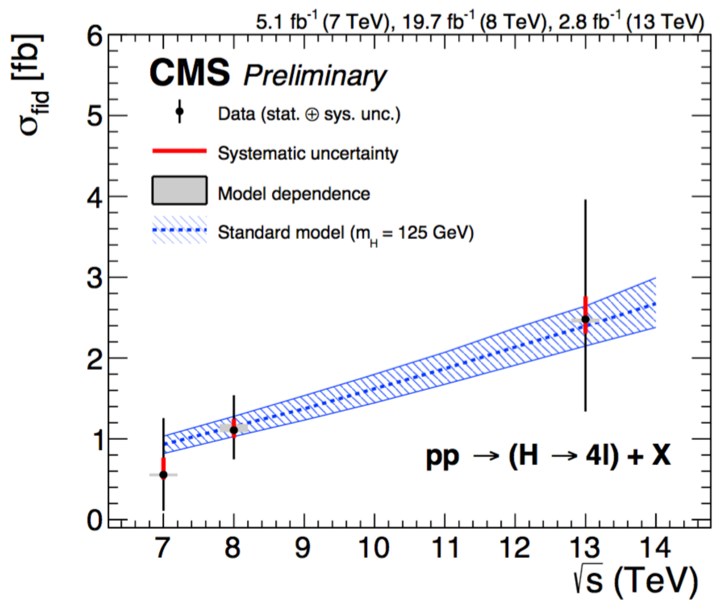
$\hat{\mu} = \sigma/\sigma_{SM} = 0.69^{+0.47}_{-0.42}$

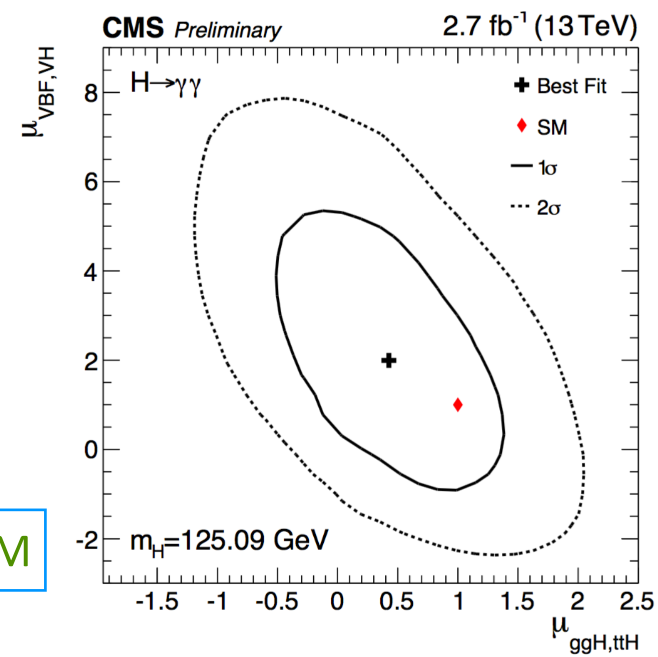
$\hat{\mu}_{\mathrm{ggH,t\bar{t}H}} = 0.43^{+0.59}_{-0.63}$

$\hat{\mu}_{\mathrm{VBF,VH}} = 1.98^{+2.14}_{-1.98}$



$$\sigma_{fid} = 2.48^{+1.48}_{-1.14}(\mathrm{stat.} \oplus \mathrm{sys.})^{+0.01}_{-0.04}(\mathrm{model\ dep.})$$





Results are consistent with the SM

Summary/2016 physics plans

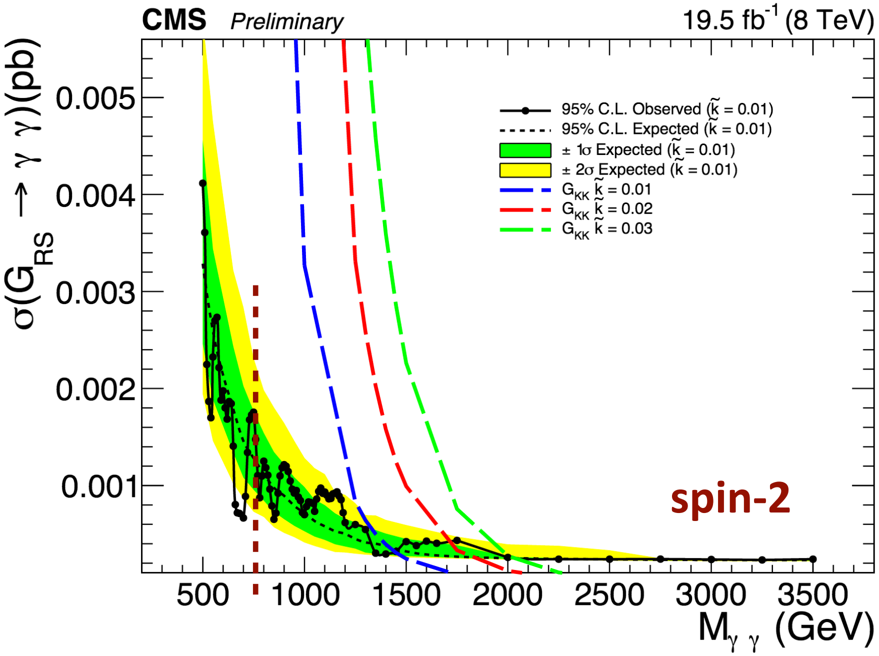
- A large number of interesting results have been produced by CMS @ 13 TeV, and a few of them have been presented today
- An excess has been observed in diphoton resonance searches, around 750-760 GeV
- Dijet resonance search is being performed using the data collected by “data-scouting” algorithm@ 13 TeV
- It is an exiting possibility at CMS to investigate this excess further, using new data that will be collected in 2016
- Other possible decay channels such as $Z\gamma$, ZZ etc. will also join this marathon
- No any excess has been observed in any of the other BSM high-mass resonance searches, and exclusion limits have been set
    - Searches will continue using 2016 data
- Exclusion limits has been set on the dark matter masses
    - Search will continue using 2016 data
- Higgs boson precision measurements have been performed and results are found in agreement with SM
    - Measurements will continue using 2016 data

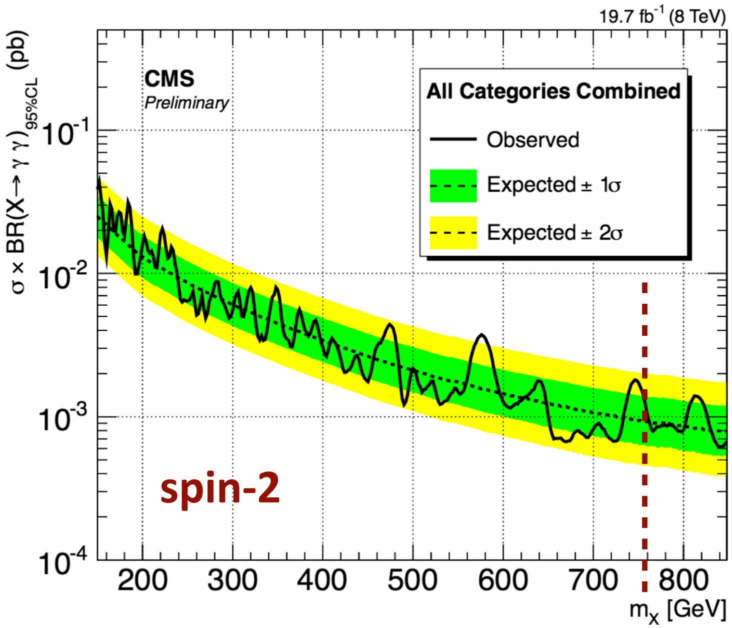
Additional material

The CMS Collaboration

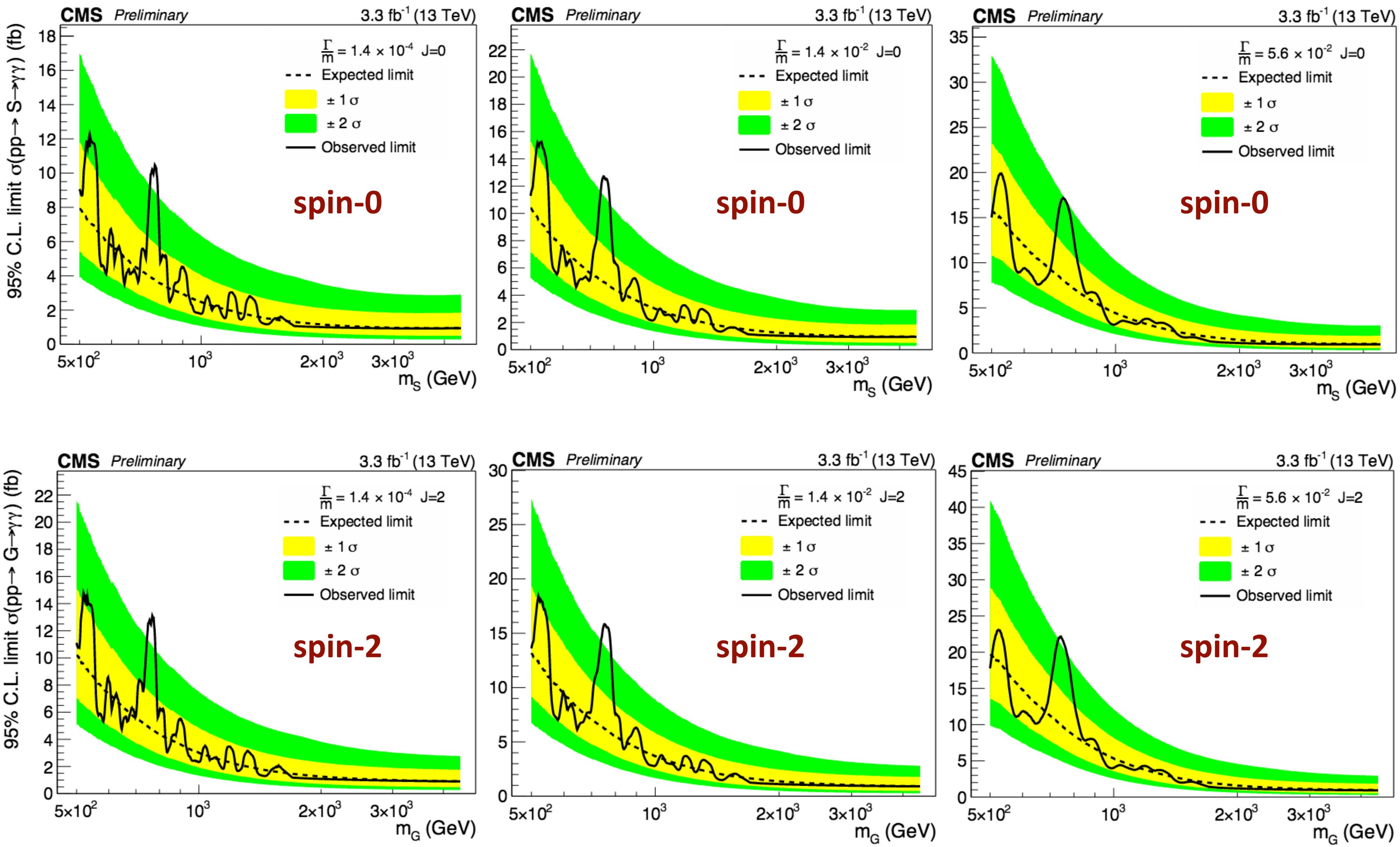
- 3500 scientists, engineers and students from 193 institutes in 43 countries

Upper limits for diphoton search @ 8TeV



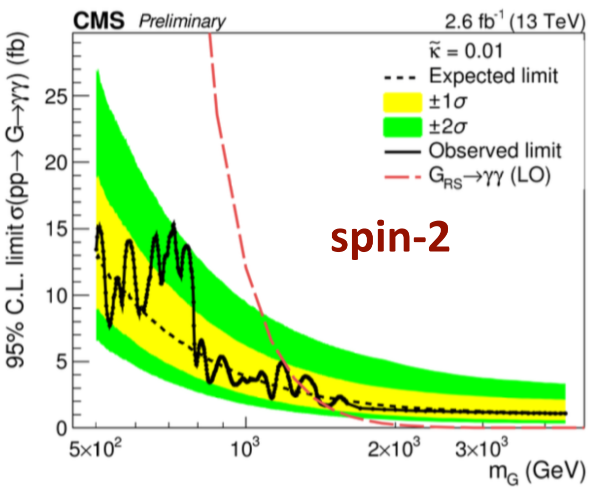


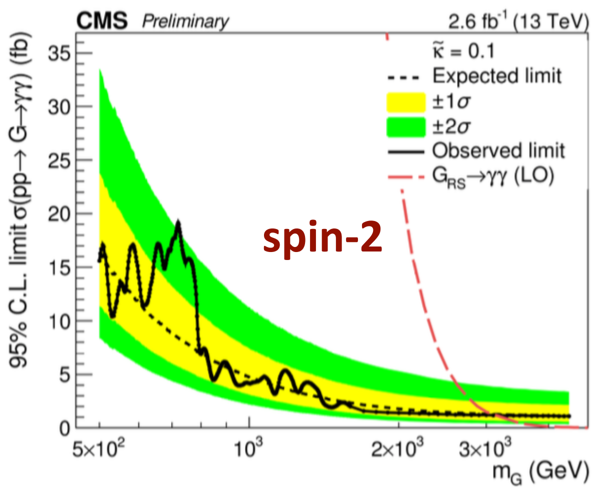
Diphoton upper limits for different widths (B = 3.8T + 0T)

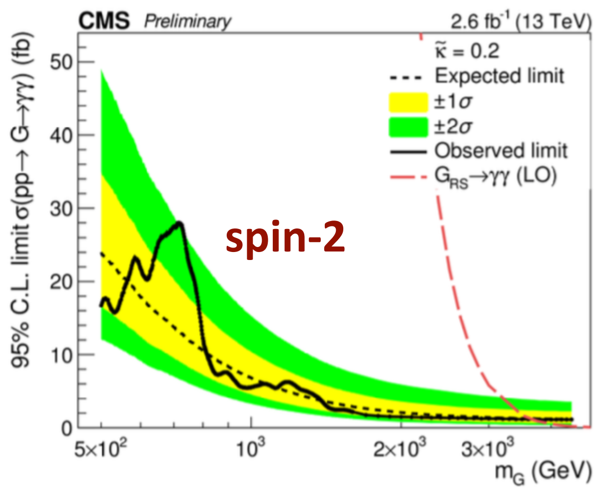


Diphoton upper limits (B = 3.8T)

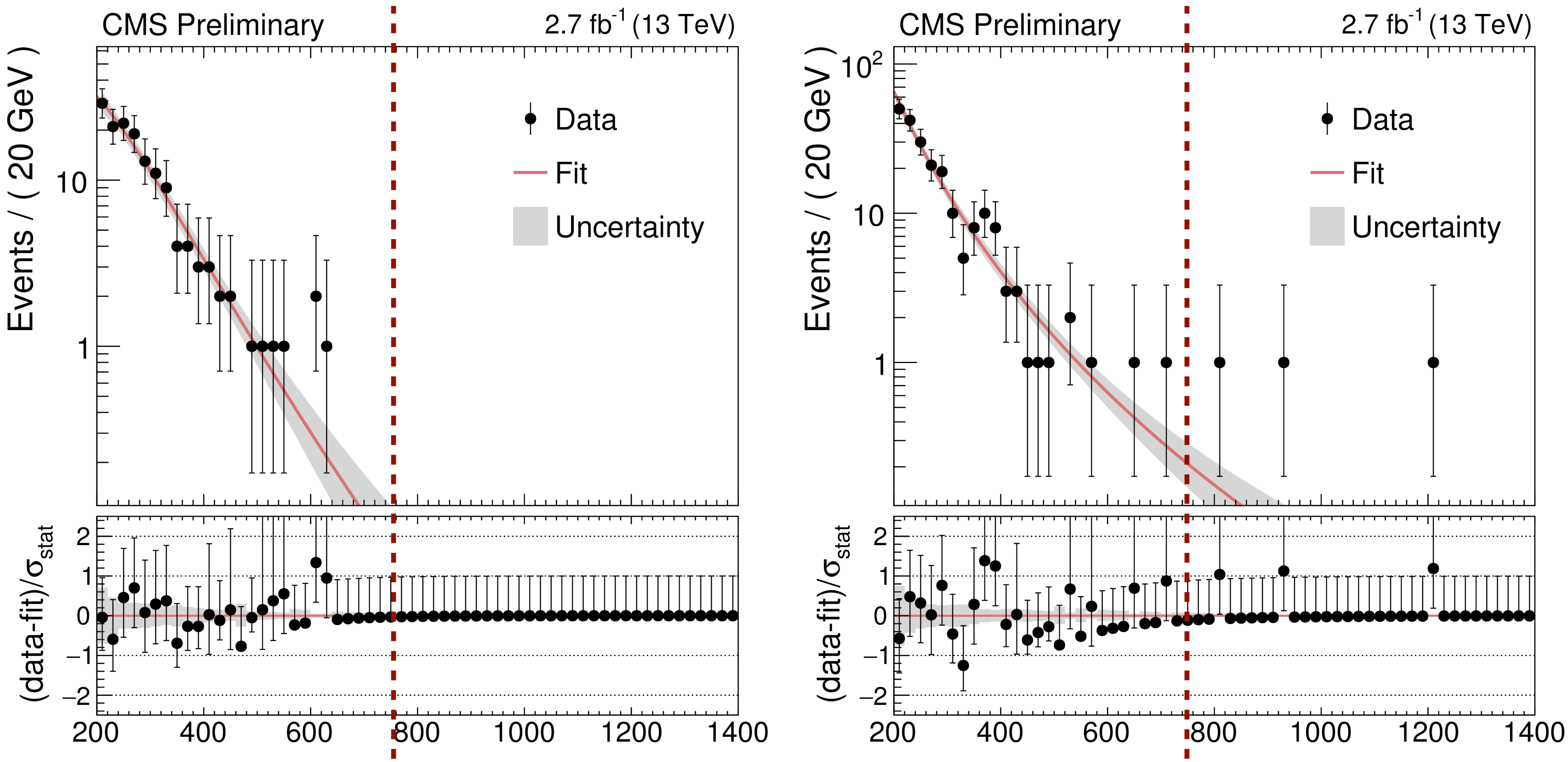
- RS graviton of mass below 1.3, 3.1 and 3.8 TeV are excluded for $\Gamma/m_{\gamma\gamma}$ = 1.4e-4, 1.4e-2 and 5.6e-2 respectively



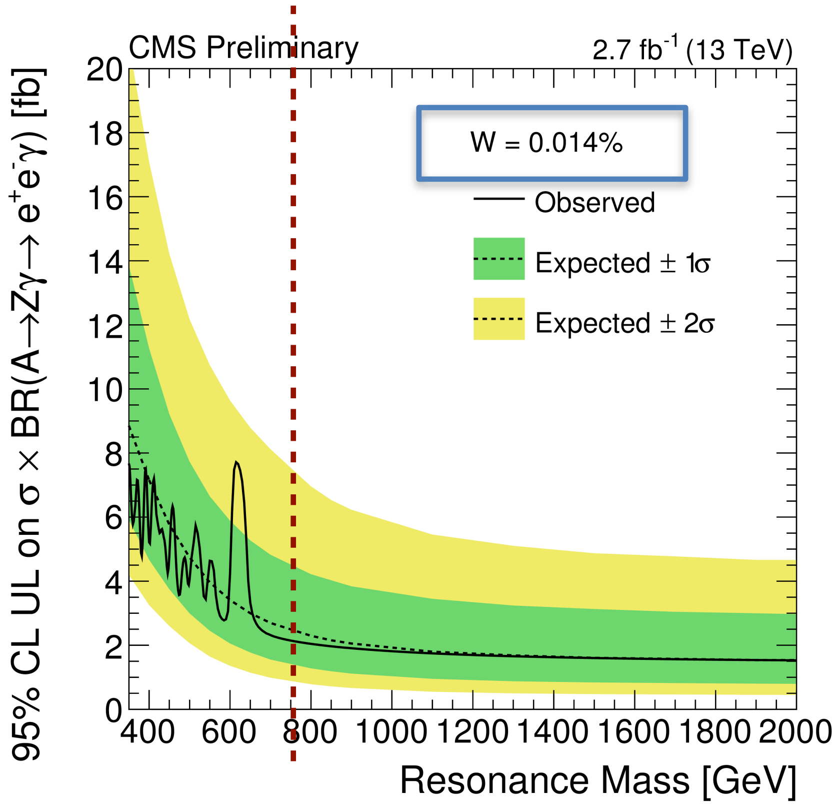


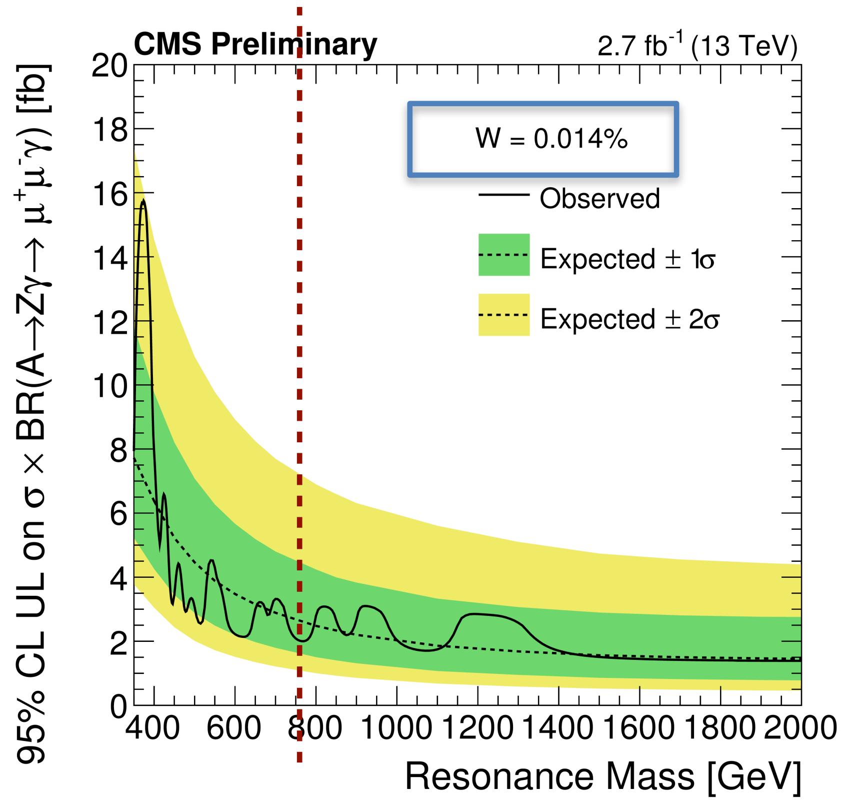


Zγ invariant mass spectrum



Upper limits for Zγ





Statistical analysis

Upper limits

$$q_\mu = -2\ln\frac{\mathcal{L}(\mathrm{obs}\,|\,\mu\cdot s+b,\,\hat{\theta}_\mu)}{\mathcal{L}(\mathrm{obs}\,|\,\hat{\mu}\cdot s+b,\,\hat{\theta})}$$

$$\mathrm{CL_s} = \frac{\mathrm{P}(q_\mu \geq q_\mu^{\mathrm{obs}}\,|\,\mu\cdot s+b)}{\mathrm{P}(q_\mu \geq q_\mu^{\mathrm{obs}}\,|\,b)} \leq \alpha$$

p-value

$$q_0 = -2\ln\frac{\mathcal{L}(\mathrm{data}\,|\,b,\,\hat{\theta}_0)}{\mathcal{L}(\mathrm{data}\,|\,\hat{\mu}\cdot s+b,\,\hat{\theta})},\ \text{with } \hat{\mu} > 0$$

$$p_0 = \mathrm{P}(q_0 \geq q_0^{obs}\,|\,\mathrm{b})$$

signal parameters

$$q(a) = -2\Delta\ln\mathcal{L} = -2\ln\frac{\mathcal{L}(\mathrm{data}\,|\,s(a)+b,\,\hat{\theta}_a)}{\mathcal{L}(\mathrm{data}\,|\,s(\hat{a})+b,\,\hat{\theta})}$$