Search for high-mass resonances @ CMS

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on behalf of the CMS Collaboration

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https://indico.cern.ch/event/489180/

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Motivation

- The Standard Model (SM) is a successful theory supported by many experimental evidences
- Recent discovery of the SM Higgs boson by ATLAS and CMS experiment is one of them

- **SM omissions:** hierarchy problem, absence of gravity, lack of dark matter…

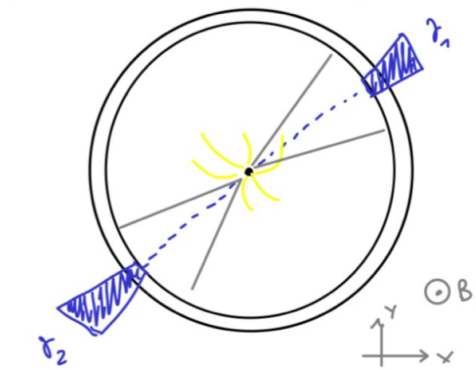
- Many theories beyond the SM address these omissions:
  - Models with extended Higgs sectors
    - e.g. Two-Higgs-Doublet model (2HDM) predicts heavy spin-0 resonance
  - Extra dimensional models
    - e.g. Arkani-Hamed, Dimopoulos and Dvali (ADD) and Randall-Sundrum (RS) models predict heavy spin-2 resonance
  - Superstring-inspired models and Sequential Standard Model (SSM) predict heavy spin-1 gauge bosons, Z'
  - 100s of phenomenological papers in arXiv 😅

Outline

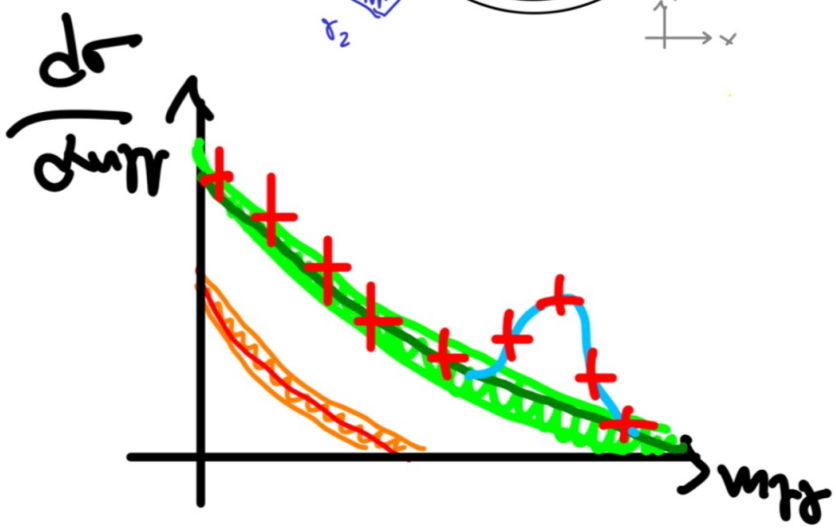
- Diphoton search:
  - 13 TeV: 2.7 /fb (B = 3.8 T) + 0.6 /fb (B = 0 T)
  - 8 TeV: 19.7 /fb
- Dijet search:
  - 13 TeV: 2.4 /fb
- Dijet search @ low mass:
  - 8 TeV: 18.8 /fb
- Dilepton search:
  - 13 TeV: 2.8(2.6) /fb for muons(electrons)

Diphoton search

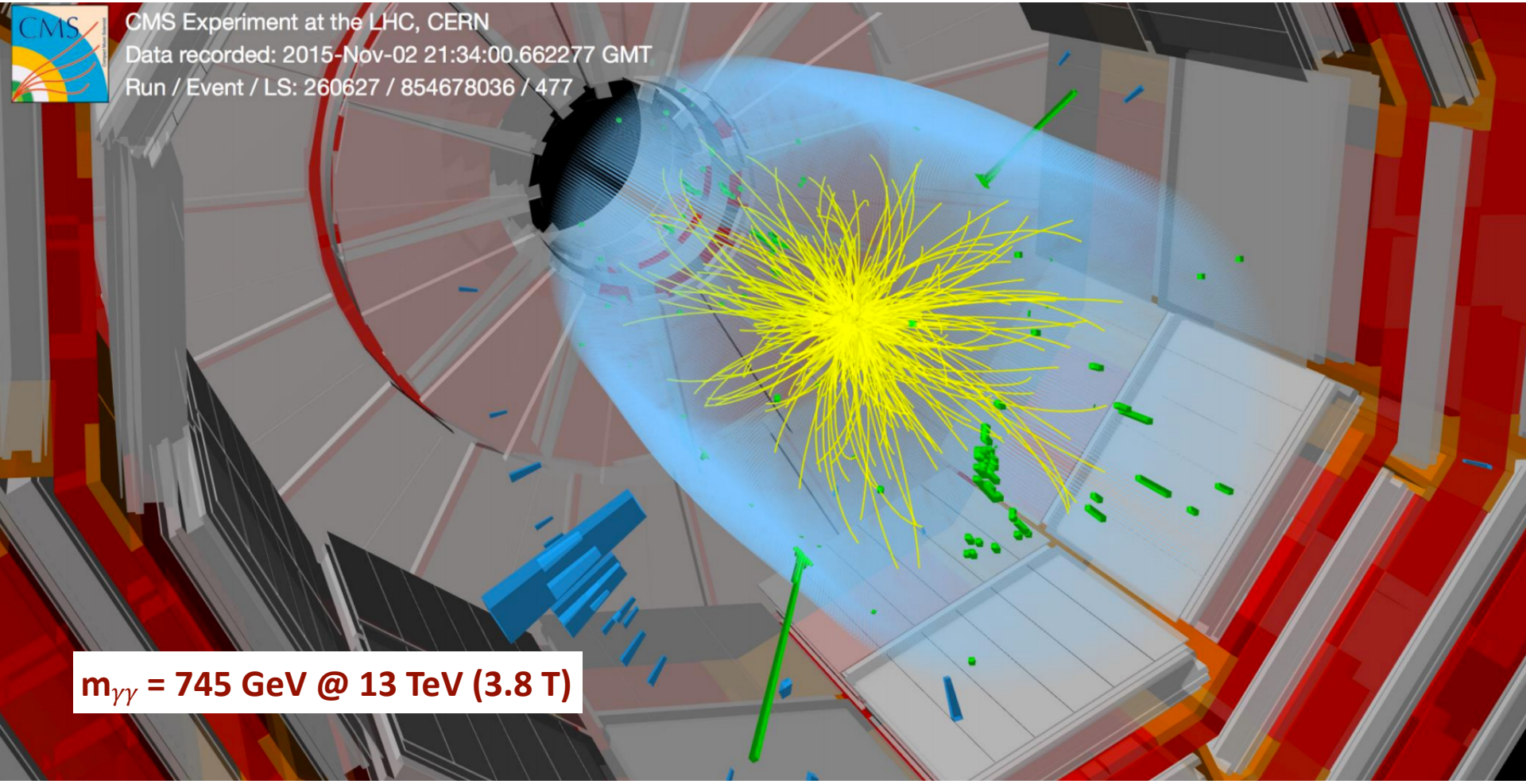
- Signal: two well isolated high-p_T photons reconstructed as high energy deposits in EM calorimeter
- Backgrounds: irreducible $\gamma\gamma$ and reducible γ +jets and dijet



- Strategy: search for localised excess of events in the $m_{\gamma\gamma}$ spectrum in data, from 500 GeV to 4.5 TeV
- Four categories: barrel-barrel (EBEB) and barrel-endcap (EBEE) for B = 3.8 and 0 T
- Three width scenarios:
  - $\Gamma/m_{\gamma\gamma}$ = 1.4e-4(narrow), 1.4e-2(wide) and 5.6e-2(wider)

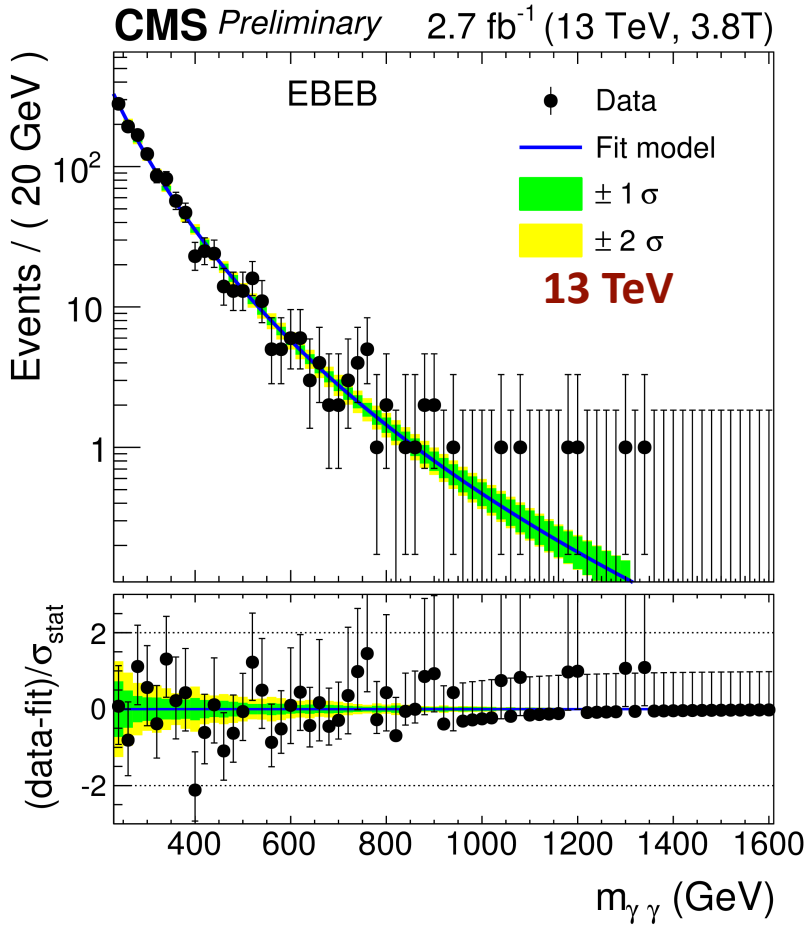


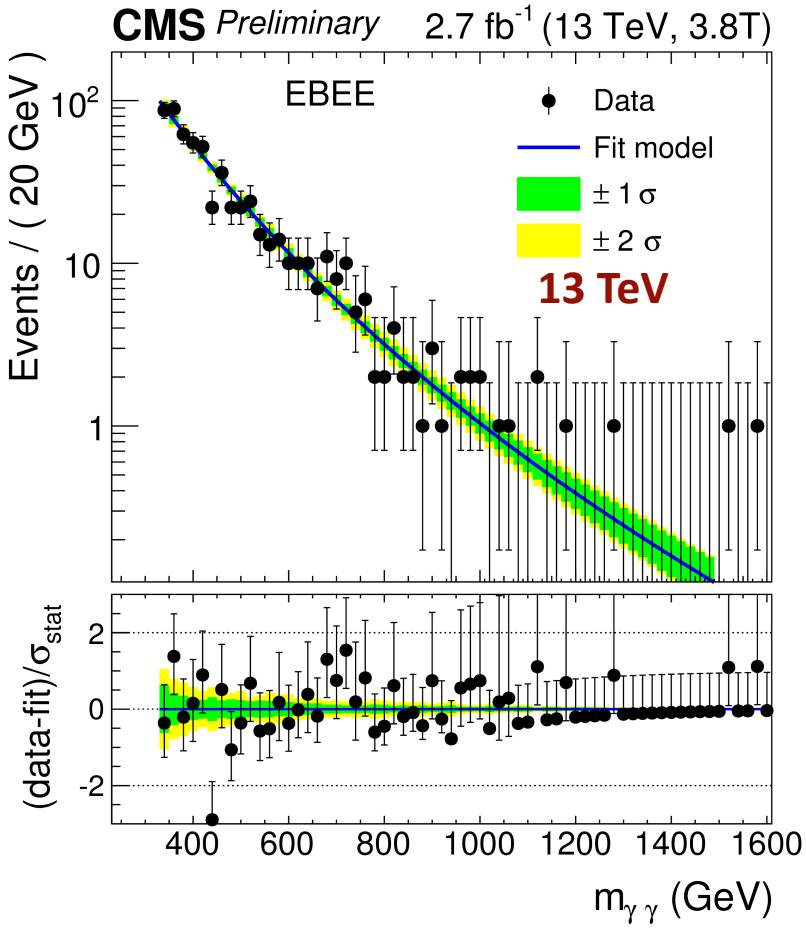
Diphoton event



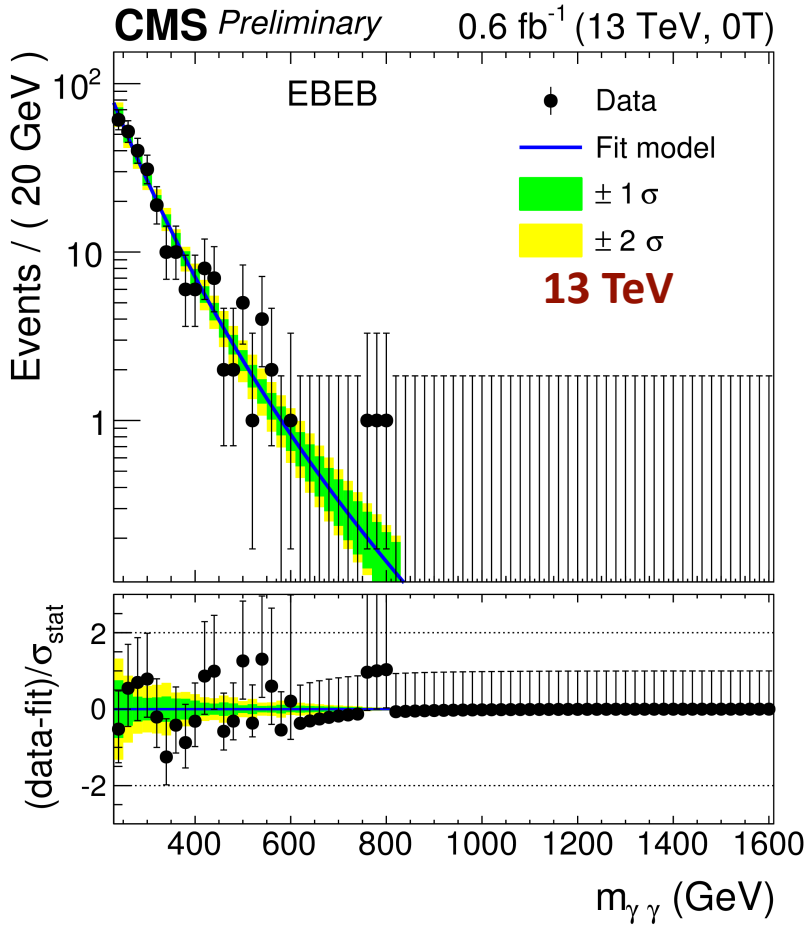
$m_{\gamma\gamma}$ = 745 GeV @ 13 TeV (3.8 T)

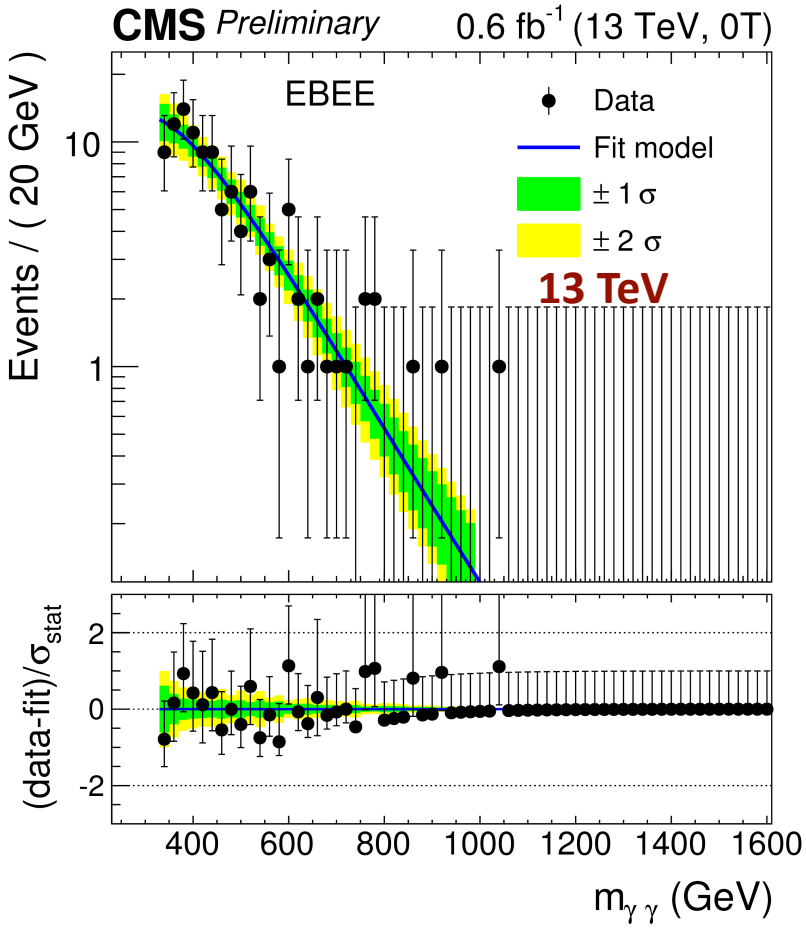
$m_{\gamma\gamma}$ spectrum (B = 3.8 T)



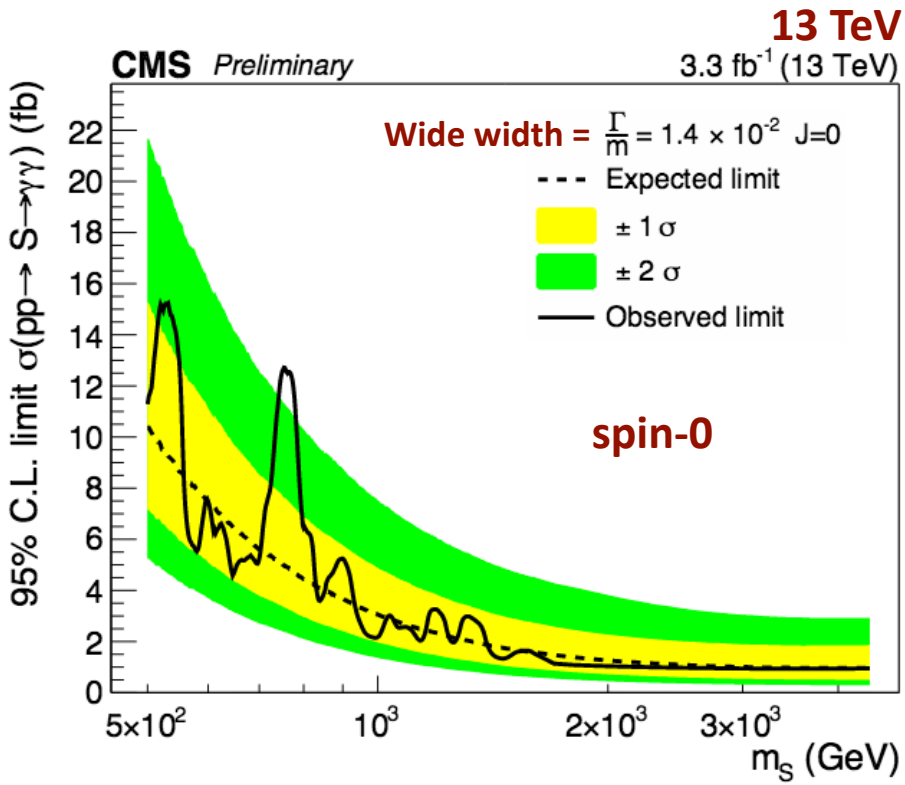


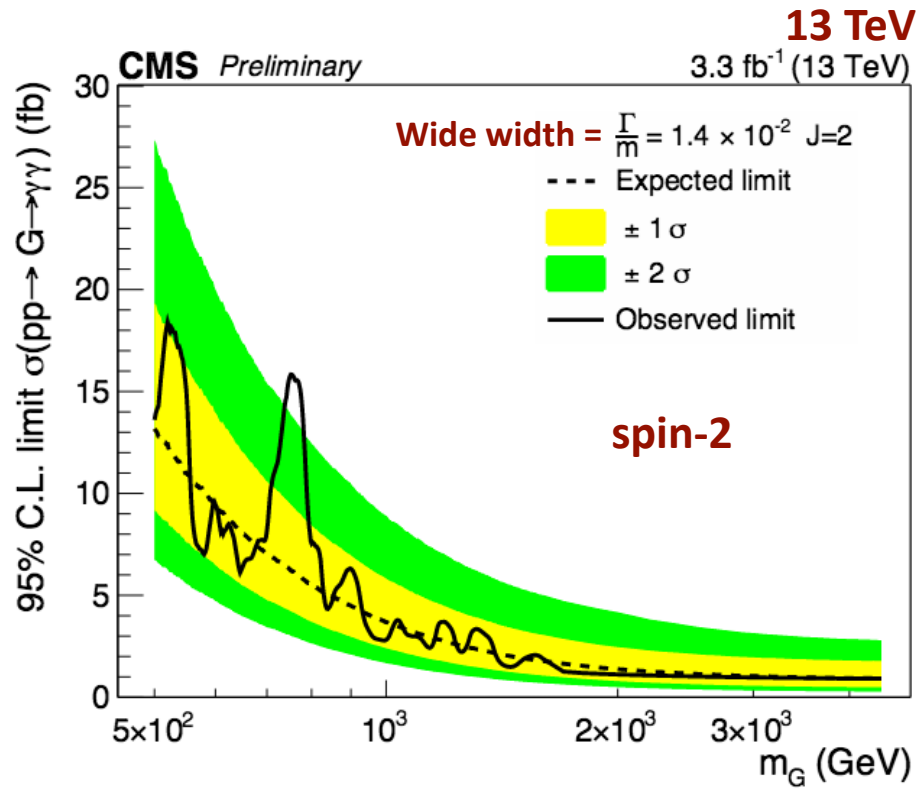
$m_{\gamma\gamma}$ spectrum (B = 0 T)





Upper limits (B = 3.8 T + 0 T)





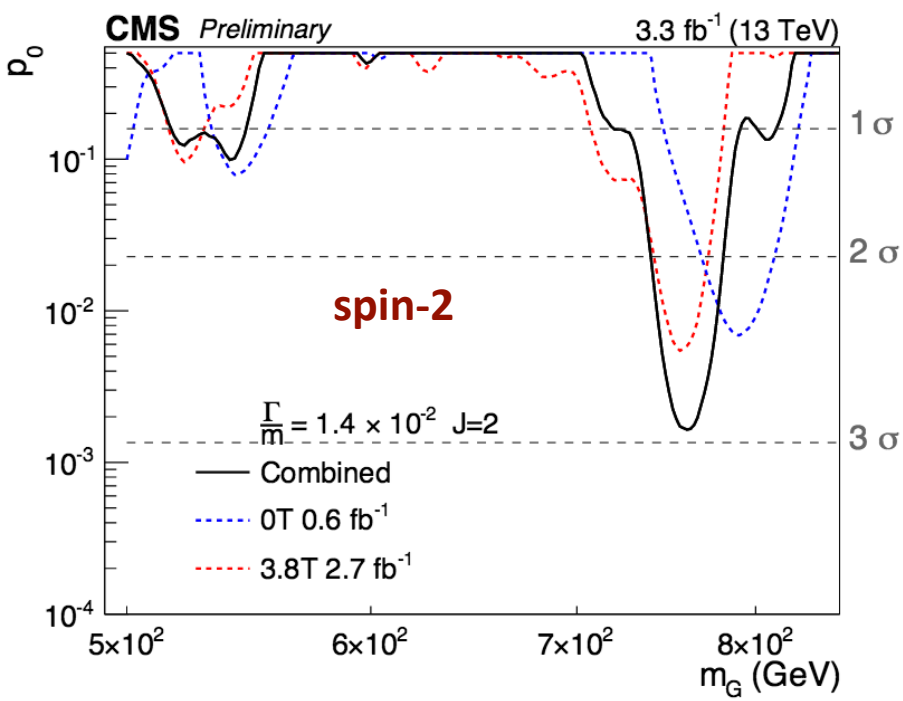
p-values

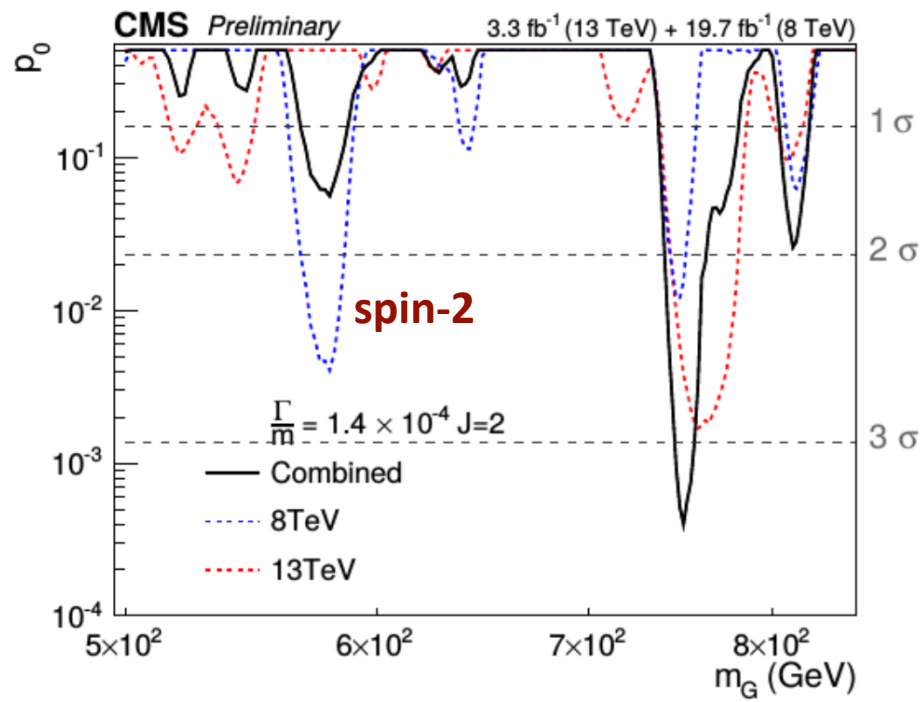
13 TeV:

- @ m_X = 760 GeV for wide width scenario
- Local significance: 2.9σ
- Global significance (LEE from 0.5 to 3.5 TeV) < 1σ

13 + 8 TeV:

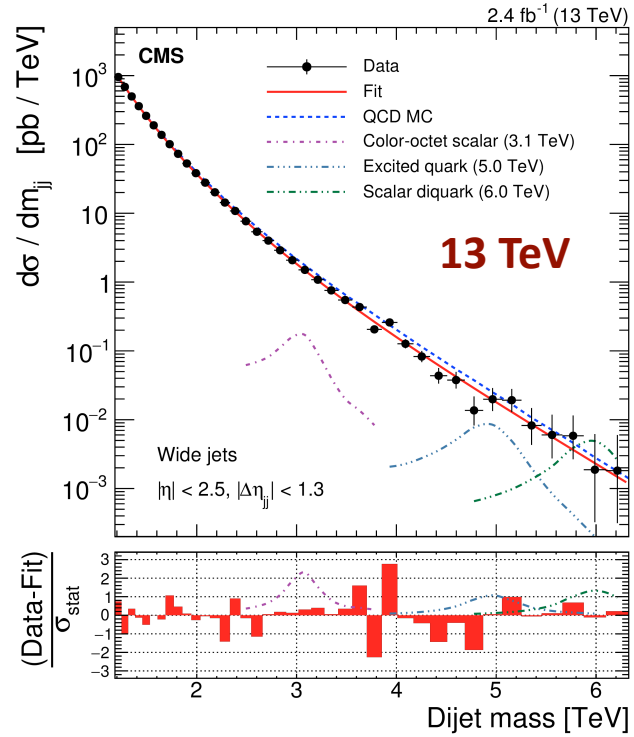
- @ m_X = 750 GeV for wider width scenario
- Local significance: 3.4σ
- Global significance (LEE from 0.5 to 3.5 TeV) = 1.6σ

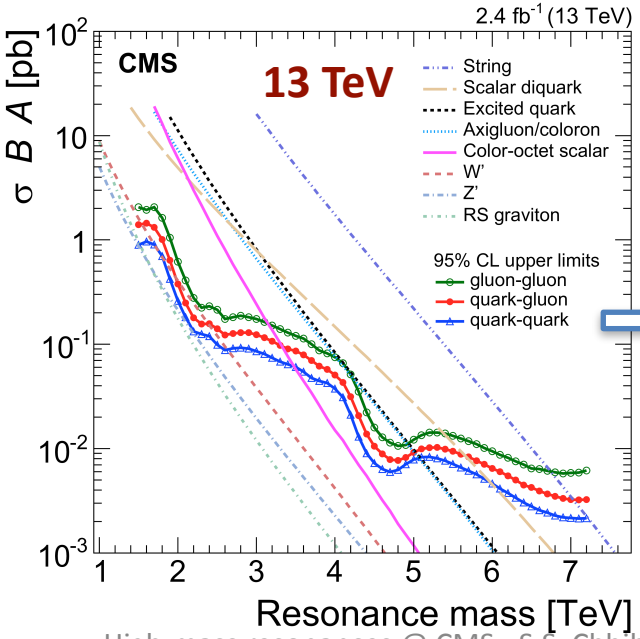


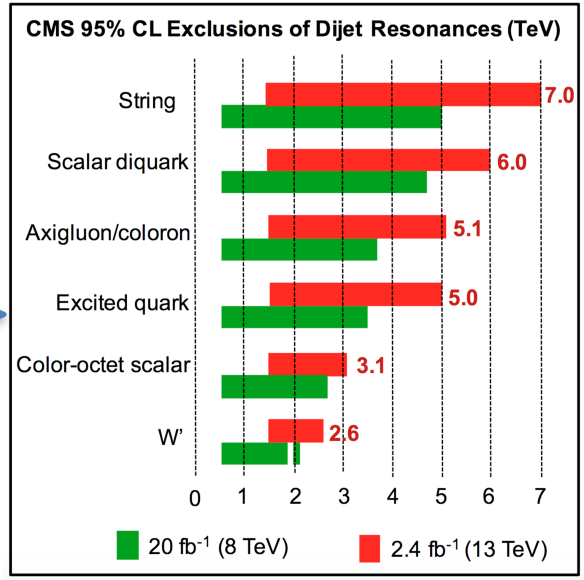


Dijet search

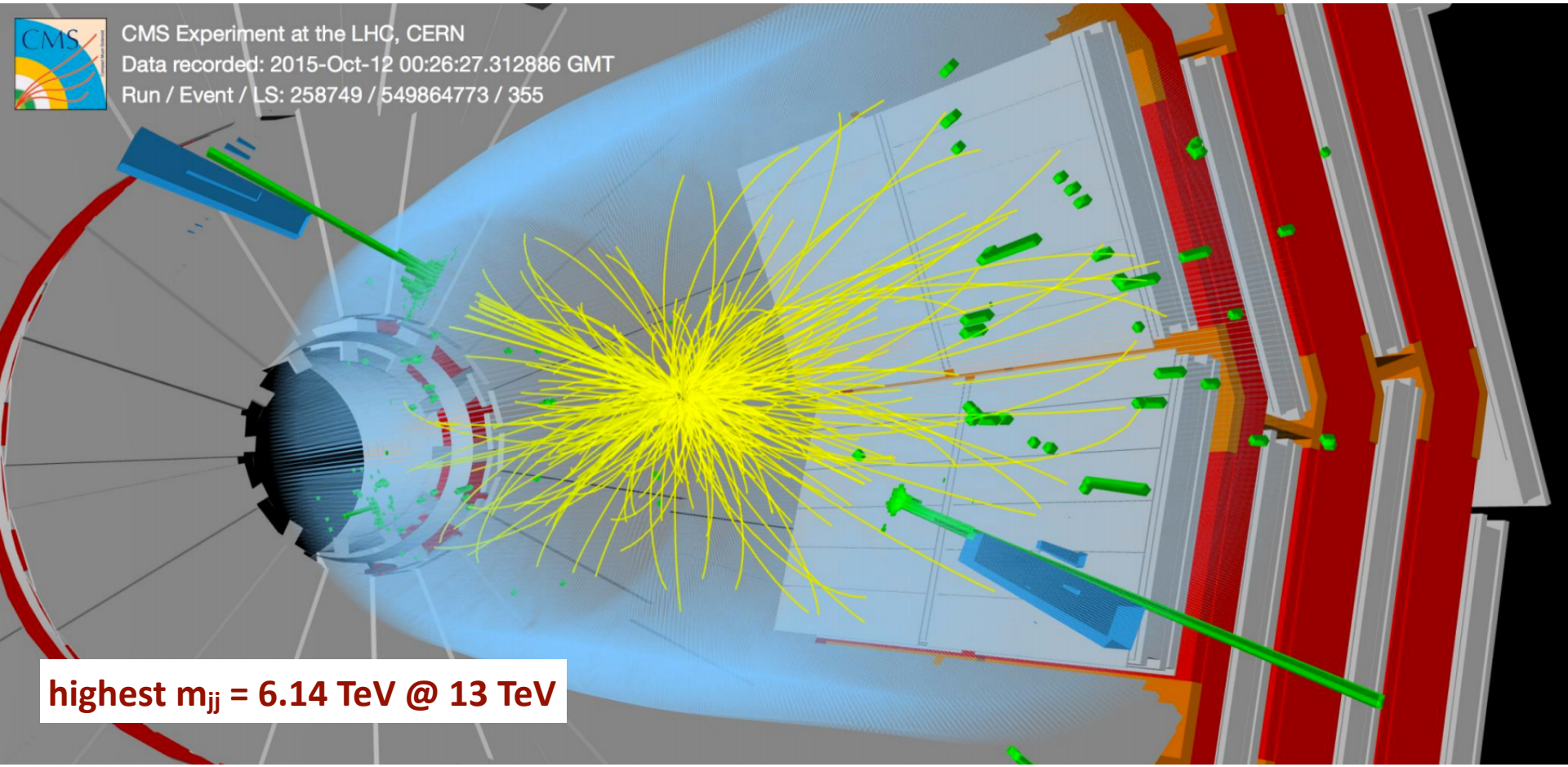
- Signature of two high-p_T (leading) jets with very low background at high-mass: $\Sigma_{jet}P_T(jet) > 800$ GeV (or a jet with $p_T > 500$ GeV)
- Backgrounds: irreducible dijet, reducible lepton+jets
- Strategy: search for localised excess in m_{jj} spectrum, from 1.5 to 7 TeV
- Highest mass events: 6.14 TeV







Dijet event

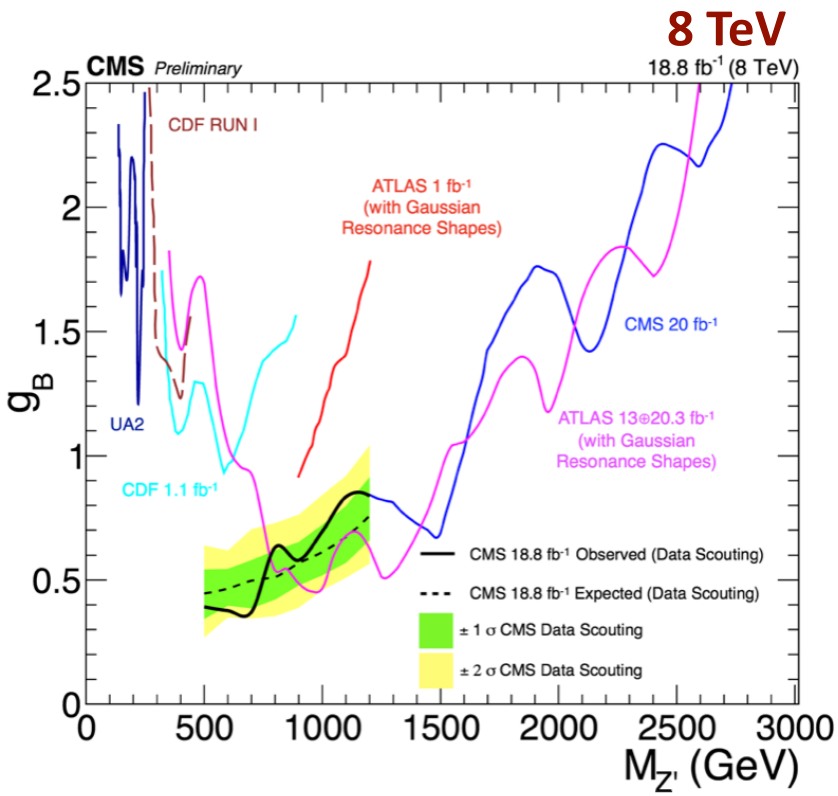


highest m_{jj} = 6.14 TeV @ 13 TeV

Dijet search @ low mass

- Data Scouting: a dedicated algorithm with trigger which filters the events if $\Sigma_{jet}E_T(jet) > 250$ GeV
  - Only kinematics of trigger level reco. jets are stored then
  - Fits to the CMS data storage capabilities: 1kHz
  - Allows to perform the dijet resonance search at low masses

- No evidence for signal has been found
- Search is being performed @ 13 TeV

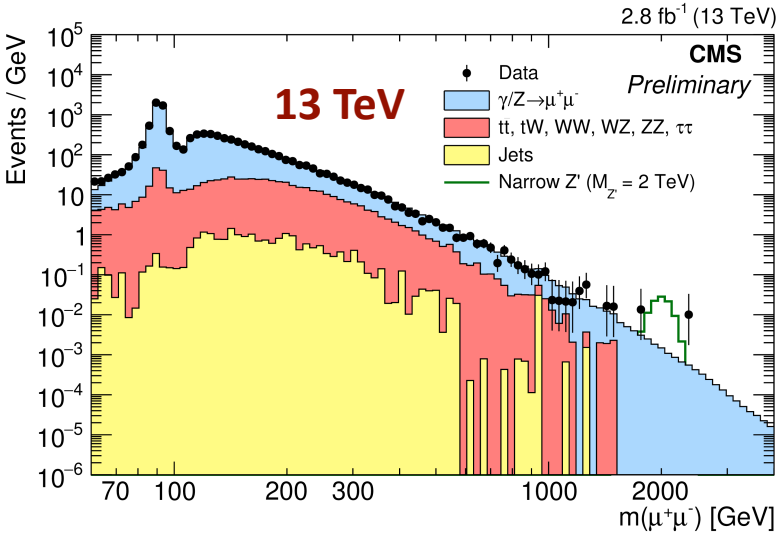


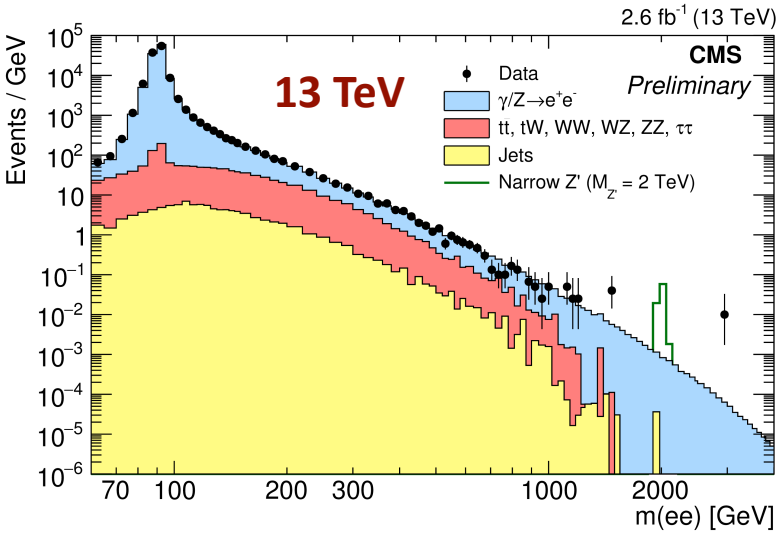
Search for Z' -> $\mu^+\mu^-$ or e^+e^-

- Signal: clean signature of two same flavour high-p_T leptons with very low background at high-mass
- Backgrounds: irreducible Z/γ* and reducible ttbar, tW and diboson

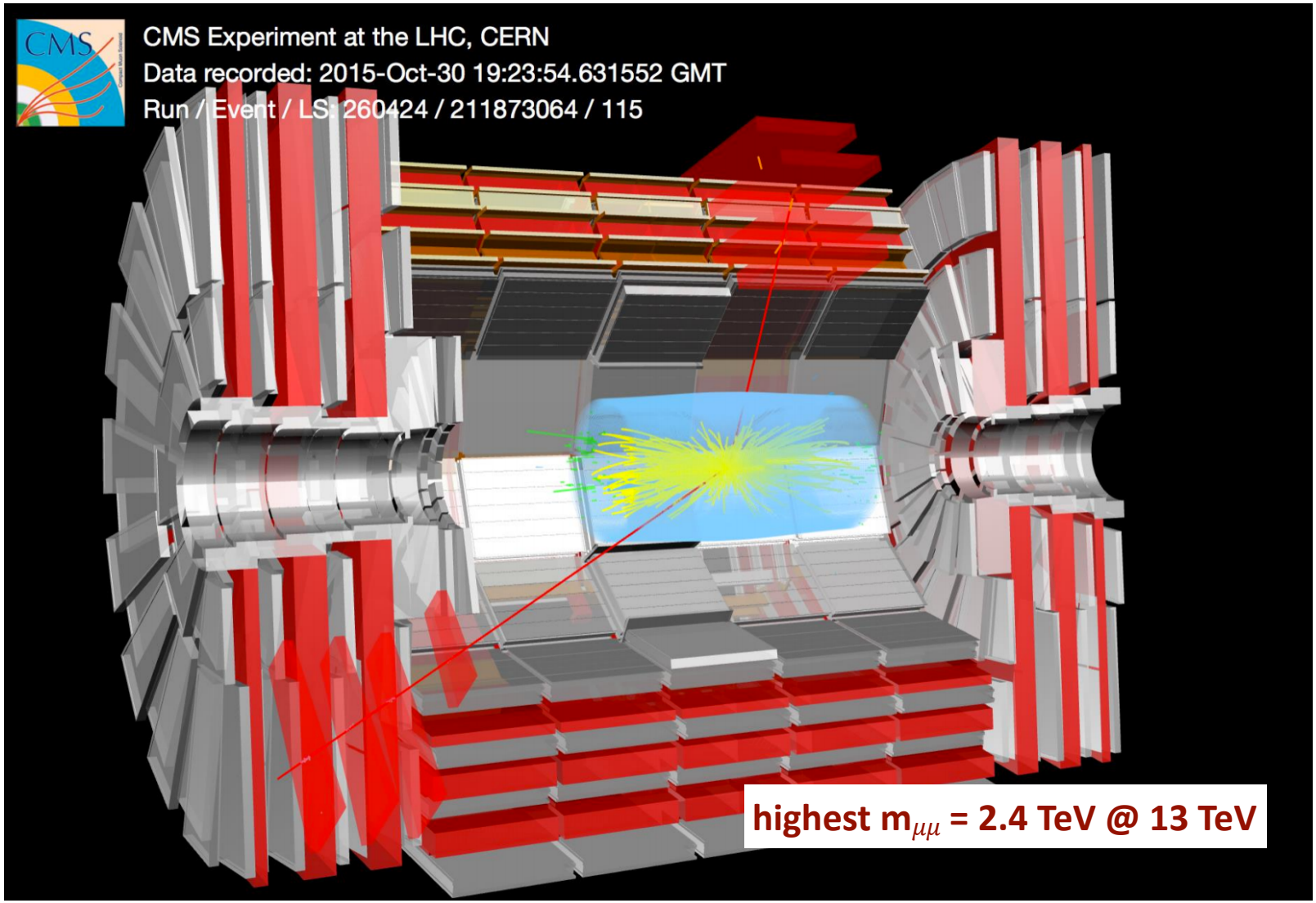
- Strategy: search for localised excess in m_{ll} spectrum, up to 5 TeV
- Three width scenarios: 0%, 0.6% (Z'_{ψ}) and 3% (Z'_{SSM})

- Highest mass events:
  - Muon - 2.4 TeV
  - Electron - 2.9 TeV
- Probability to observe at least one dielectron event with mass > 2.8 TeV is 3.6%





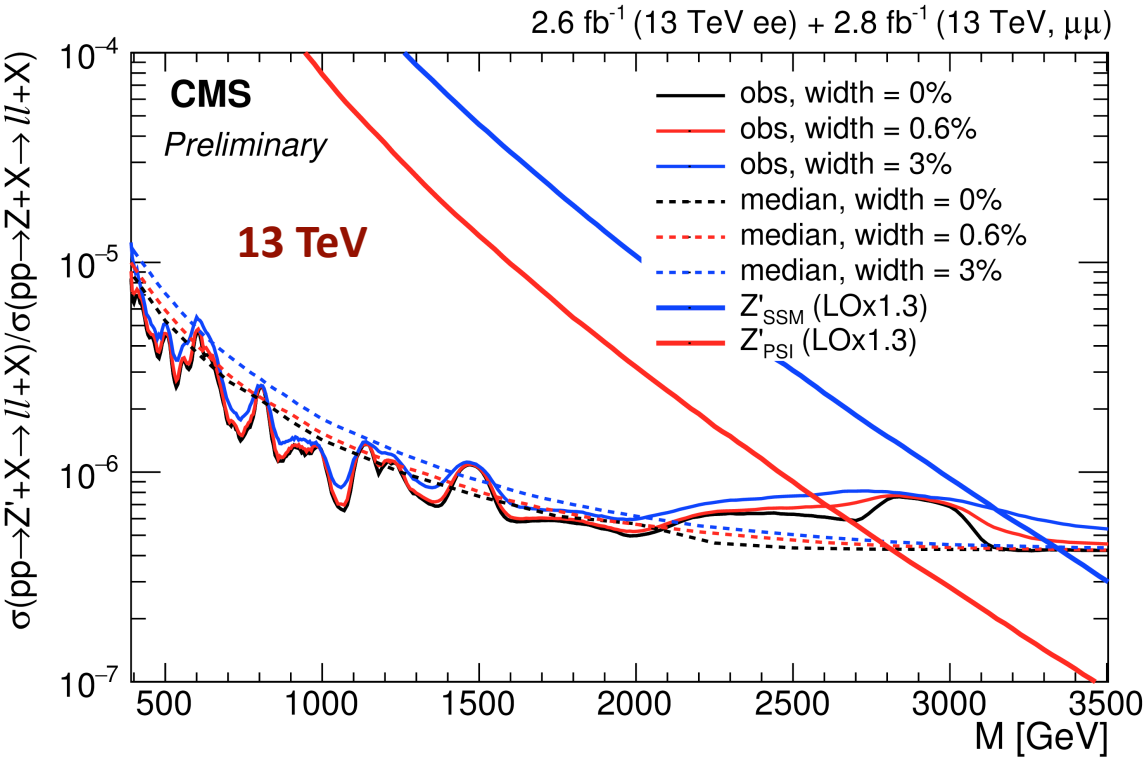
Dimuon event



highest $m_{\mu\mu}$ = 2.4 TeV @ 13 TeV

Upper limits

- **13 TeV:** Z'_{SSM} < 3.15 TeV and Z'_{ψ} < 2.6 TeV are excluded
- **8TeV:** Z'_{SSM} < 2.9 TeV and Z'_{ψ} < 2.57 TeV are surpassed



Summary

- Search for high-mass resonances have been performed by CMS using 13 and 8 TeV datasets, and results have been presented today

- An excess of events has been observed in $m_{\gamma\gamma}$ spectrum over the SM backgrounds continuum, around 750-760 GeV
  - Local significance @ 13 TeV + 8 TeV: 3.4σ
  - Global significance @ 13 TeV + 8 TeV = 1.6σ

- Same excess has been investigated in dijet channel using the data collected @ 8 TeV by so-called "data-scouting" algorithm
  - No any excess has been observed

- No excess has been observed in dilepton resonance searches
  - Exclusion @ 13 TeV: Z'_{SSM} of mass below 3.15 TeV and Z'_{ψ} of mass below 2.6 TeV are excluded

Summary

- Search for high-mass reso MS using 13 and 8 TeV datasets, and results have
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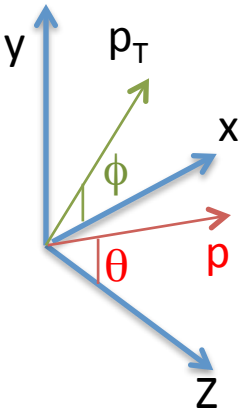
  - Local significance @ 1
  - Global significance @
- Same excess has been inv data collected @ 8 TeV by so-called "data-scouting"
  - No any excess has be
- No excess has been obser s
  - Exclusion @ 13 TeV: Z ψ of mass below 2.6 TeV are excluded

Bibliography

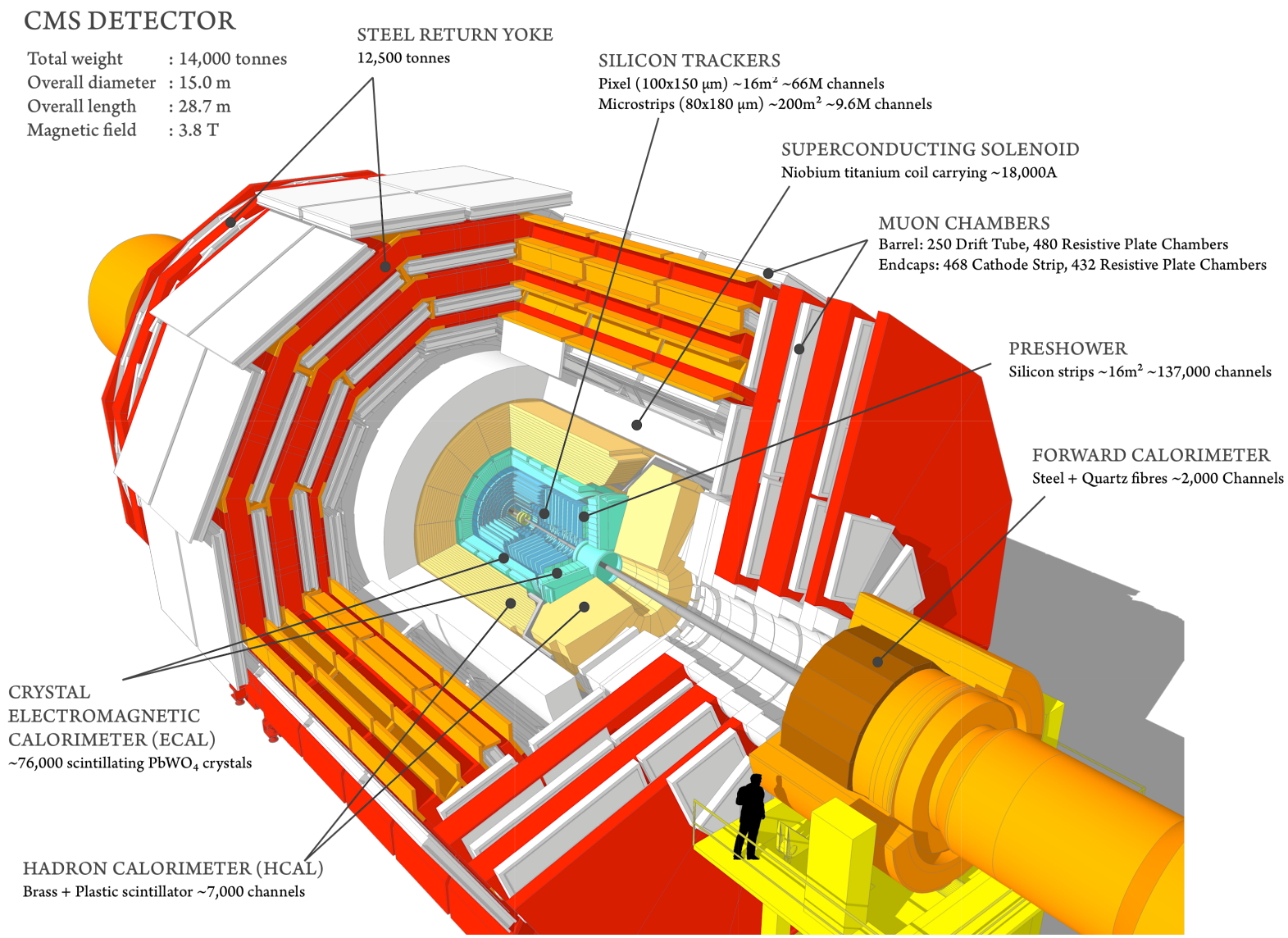
- **CMS PAS EXO-16-018:** “Search for new physics in high mass diphoton events in 3.3 /fb of proton-proton collisions at √s = 13 TeV and combined interpretation of searches at 8 TeV and 13 TeV”
- **CMS PAS EXO-15-001:** “Search for narrow resonances decaying to dijets in proton-proton collisions at √s = 13 TeV”
- **CMS PAS EXO-14-005:** “Search for resonance decaying to dijet final states at √s = 8 TeV with scouting data”
- **CMS PAS EXO-15-005:** “Search for a narrow resonance produced in 13 TeV pp collisions decaying to electron pair or muon pair final states”
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO

Additional material

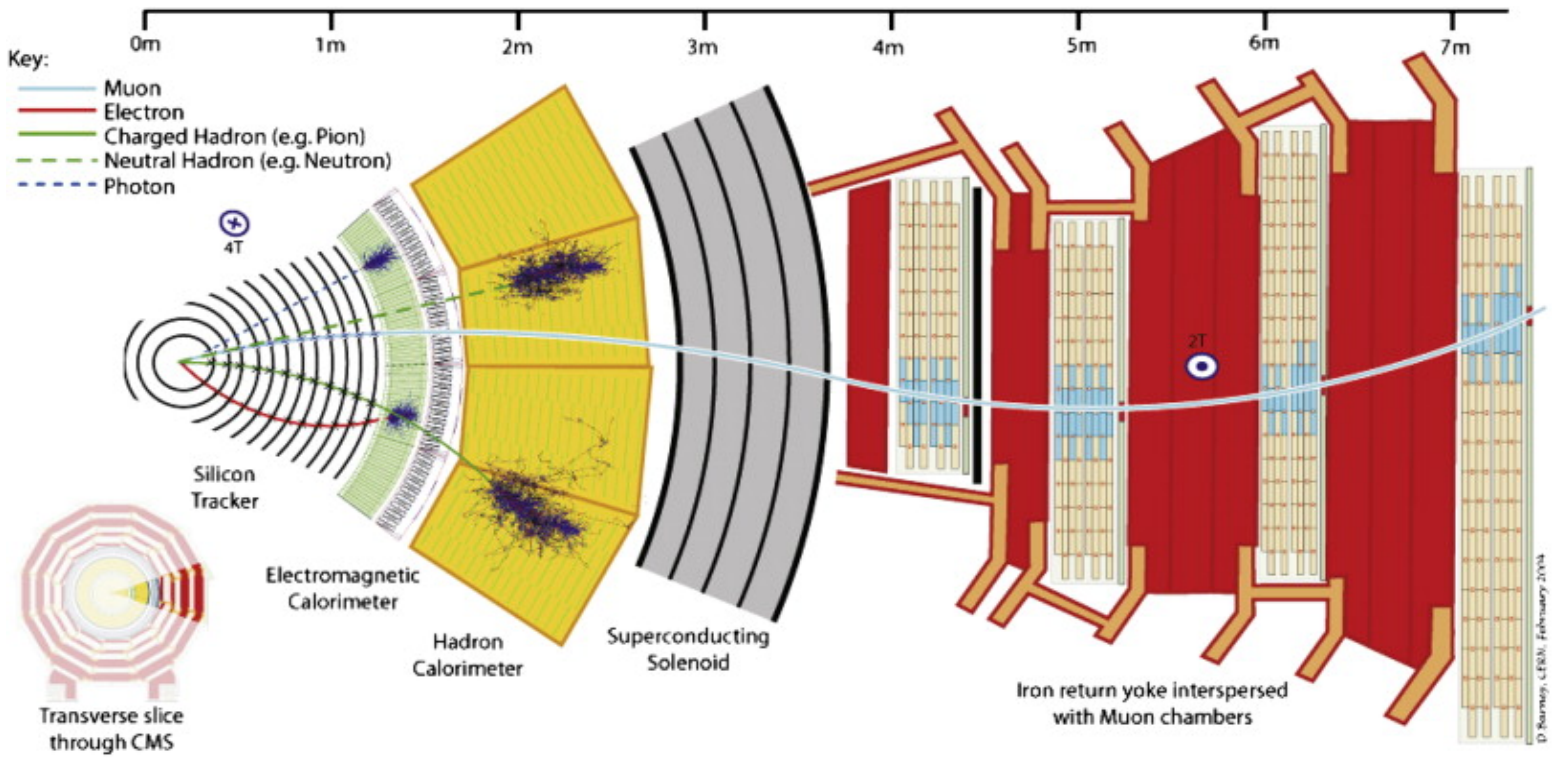
The CMS Experiment



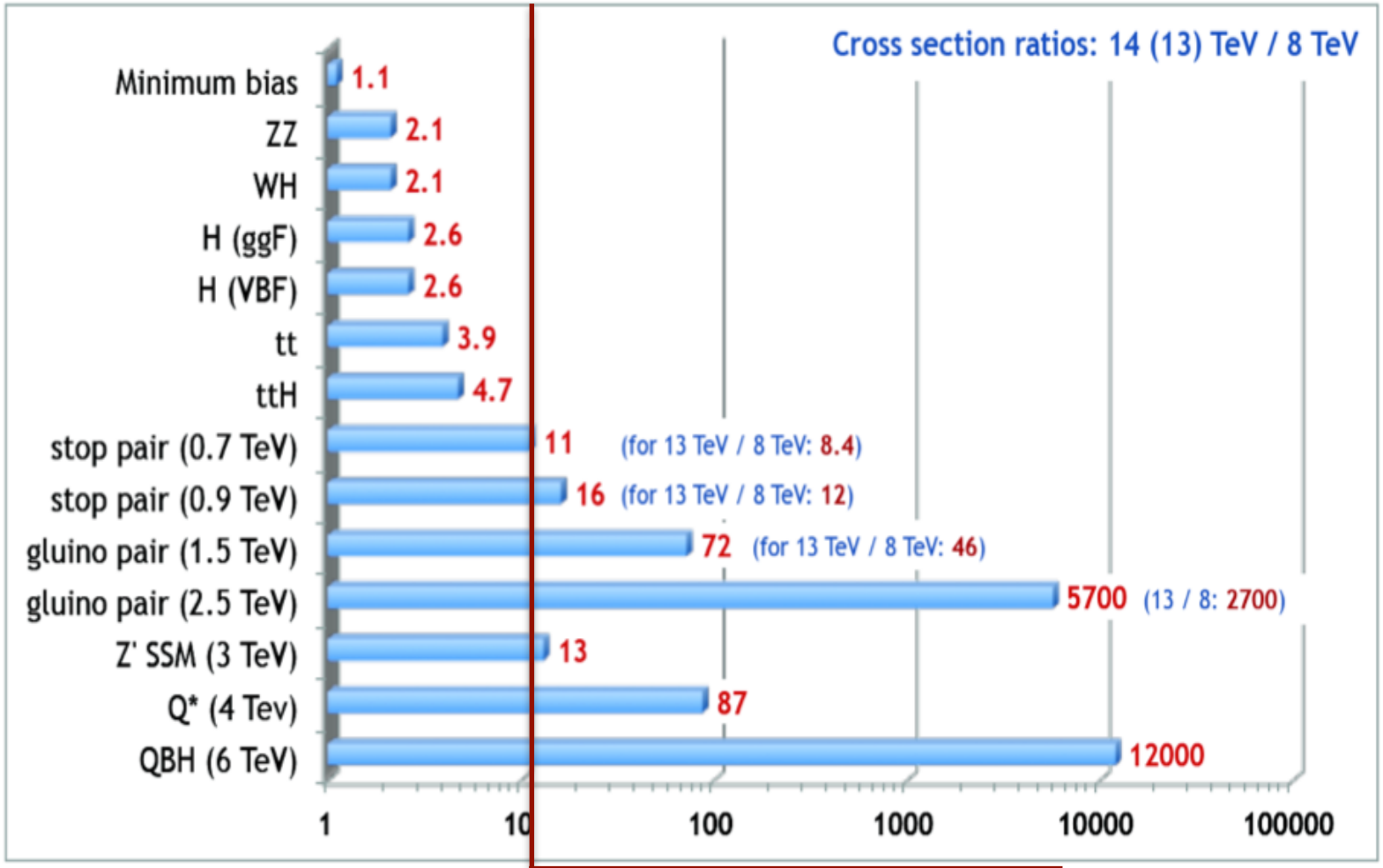
$$\eta = -ln \tan \frac{\theta}{2}$$



Particles' signature in CMS



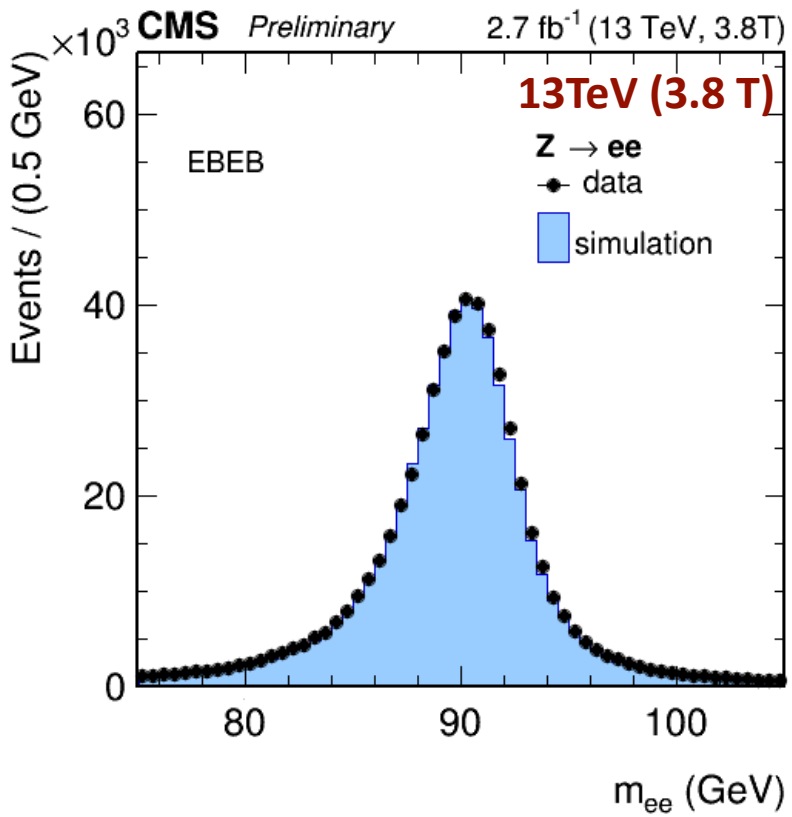
Increased reach @ 13 TeV

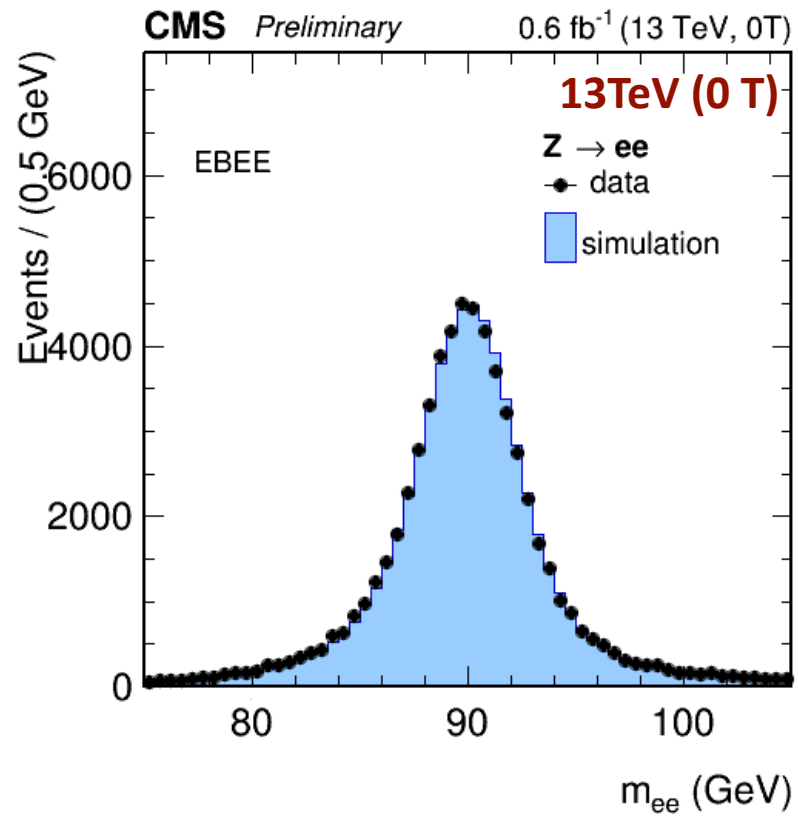


2/fb @ 13TeV = 20/fb @ 8TeV

Energy scale and resolution calibration

- Obtained by using Z->ee events: adjusting simultaneously the energy and resolution as a function of pseudo-rapidity and shape of the energy cluster in EM calorimeter
  - Energy scale corrections: 0.5(1.5)% for B = 3.8(0) T
  - Gaussian smearing for energy resolution: 0.8-1.5% and 2-2.5% for barrel and endcaps respectively, for both B = 3.8 and 0 T

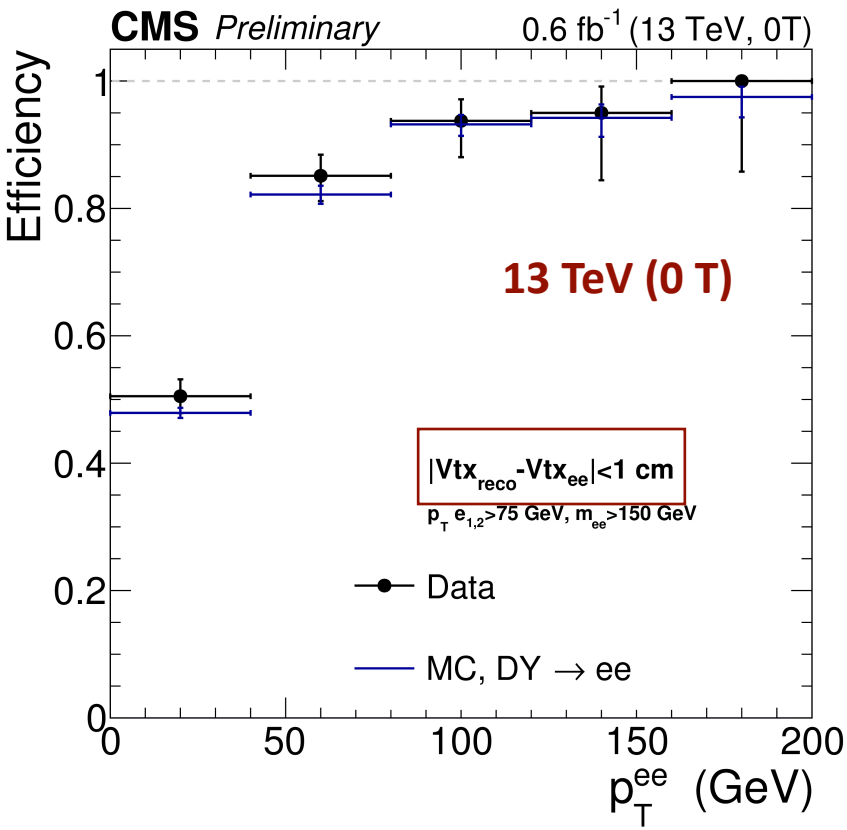


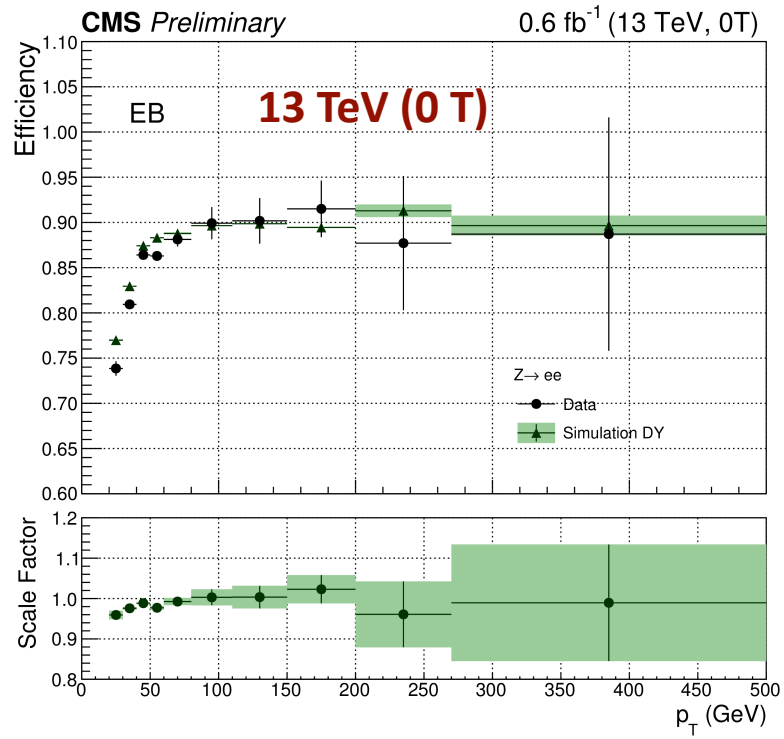


Vertex and photon identification

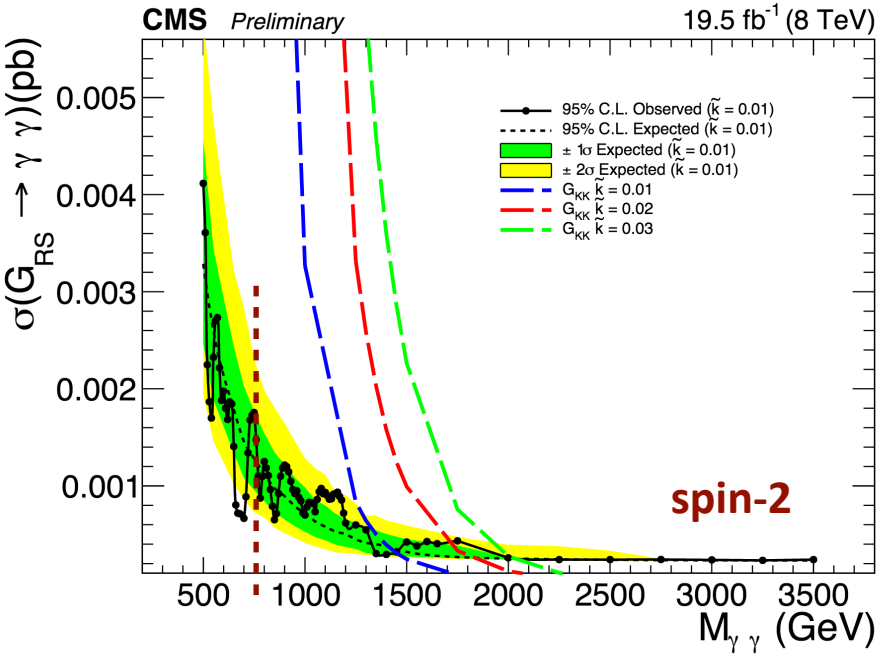
- Vertex identification:
  - For B = 3.8 T: based on BDT (using recoil and track p_T) trained for H->$\gamma\gamma$
  - For B = 0 T: based on track-counting
  - 90(60)% correct assignment for B = 3.8(0) T

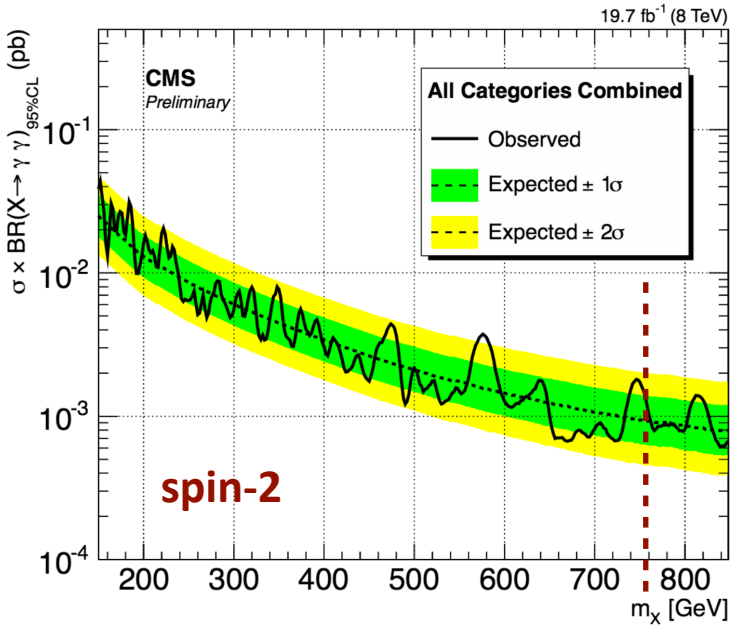
- Photon identification:
  - Obtained by using Z->ee events
  - Efficiency: ~ 90% per photon in both barrel and endcaps



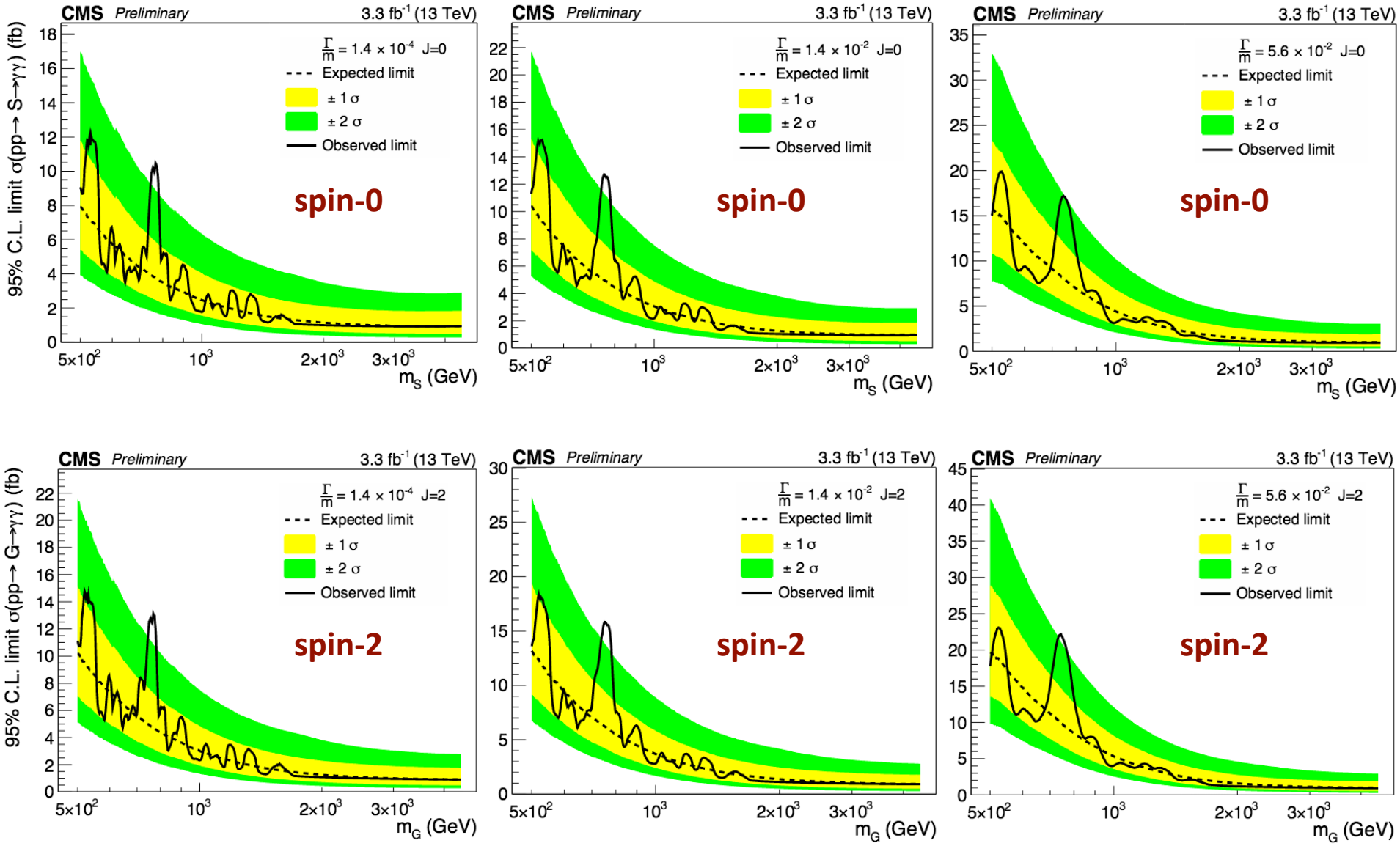


Upper limits for diphoton search @ 8TeV



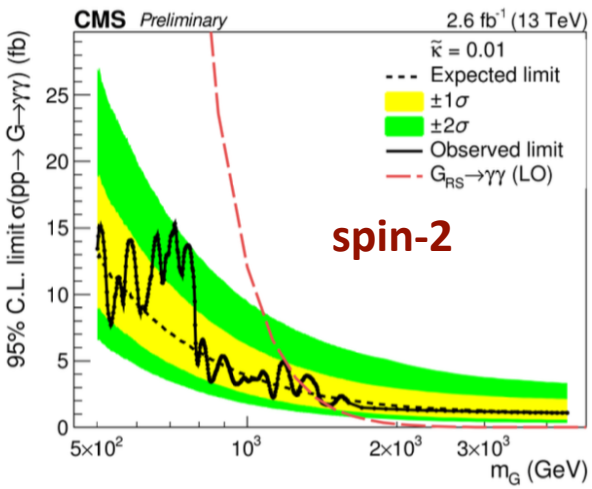


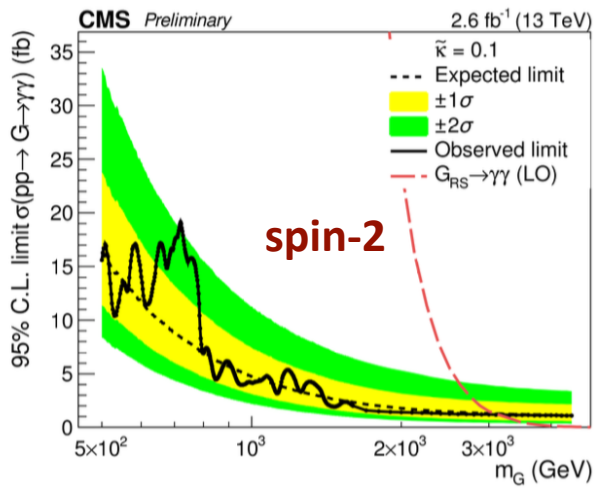
Diphoton upper limits for different widths (B = 3.8T + 0T)

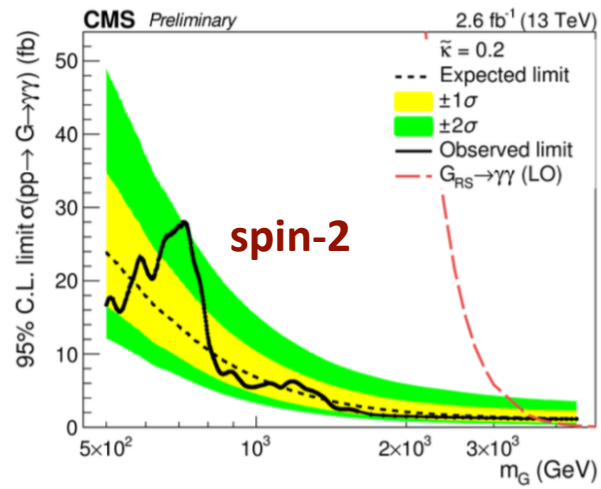


Diphoton upper limits (B = 3.8T)

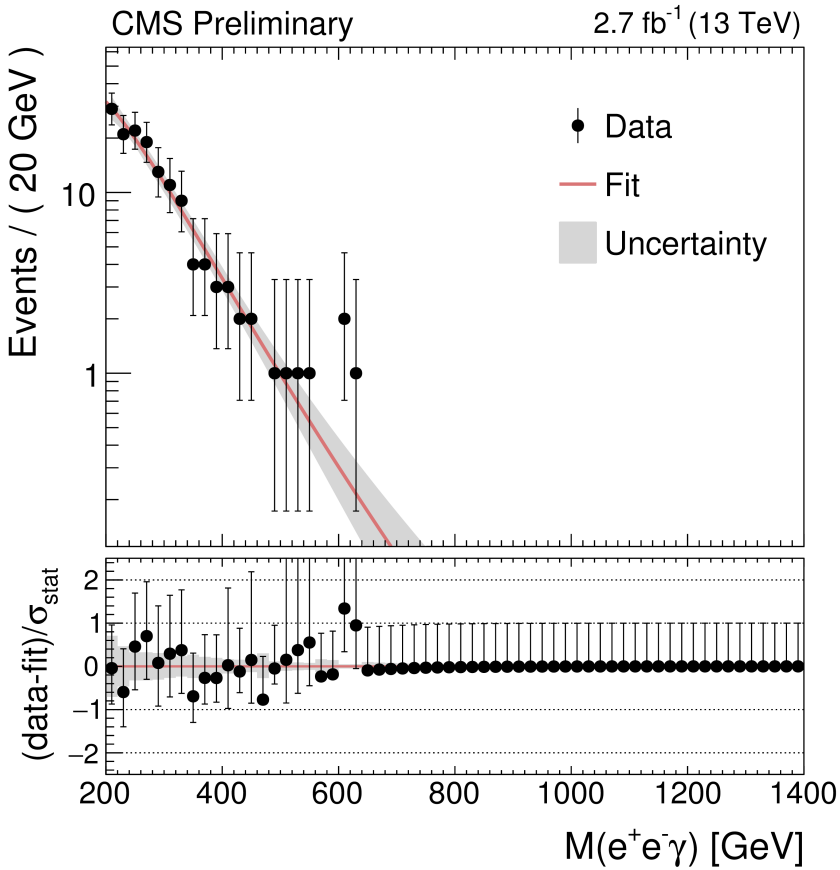
- RS graviton of mass below 1.3, 3.1 and 3.8 TeV are excluded for $\Gamma/m_{\gamma\gamma}$ = 1.4e-4, 1.4e-2 and 5.6e-2 respectively

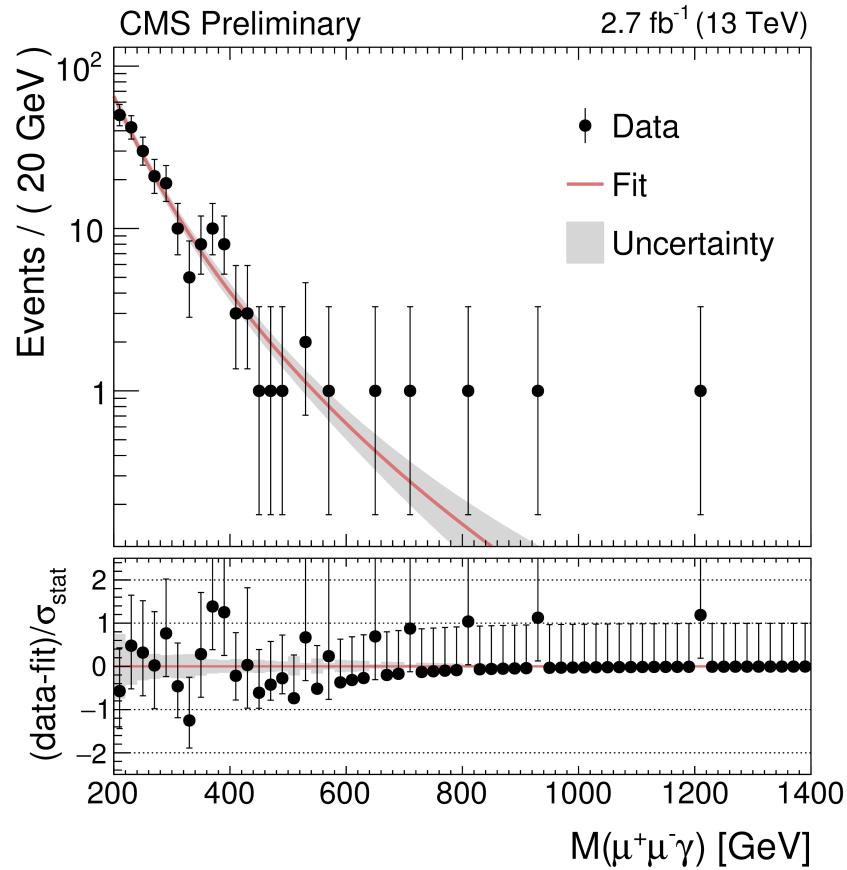




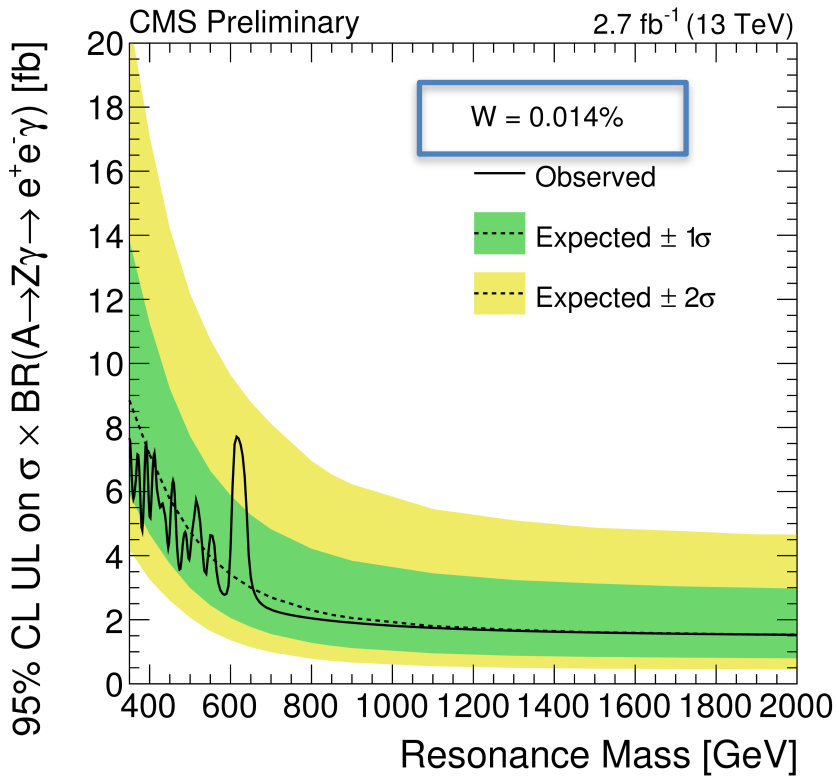


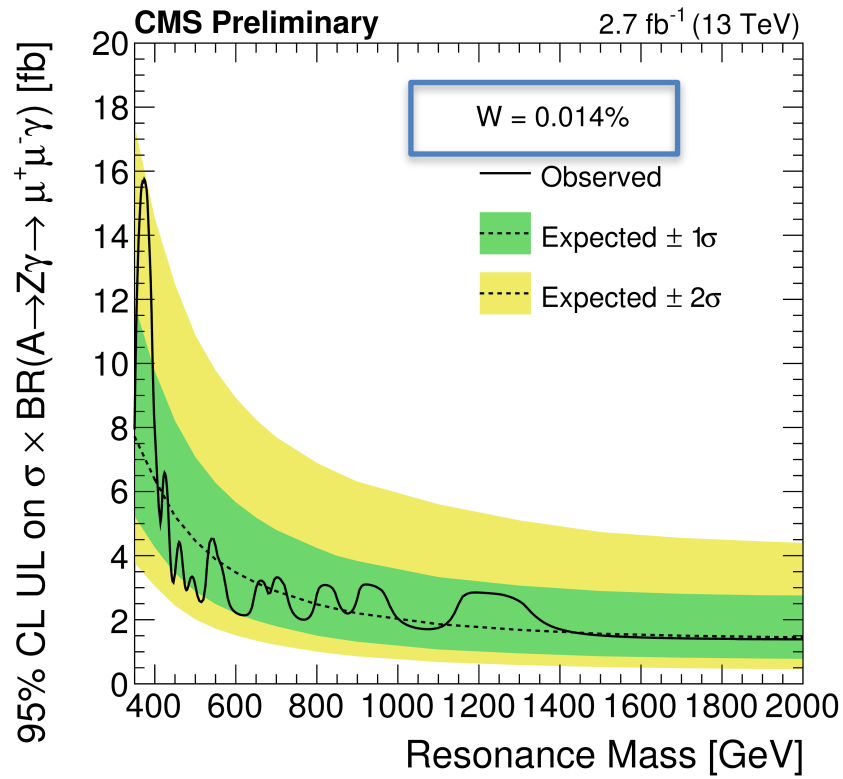
$Z\gamma$ invariant mass spectrum





Upper limits for $Z\gamma$





Statistical analysis

Upper limits

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

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

p-value

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

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

signal parameters

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