Search for BSM Physics in High-Mass Diphoton Events at CMS

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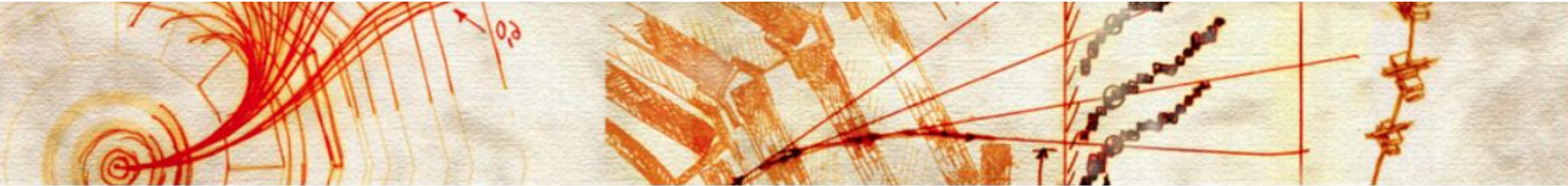


BSM Searches, Why Care?

The Standard Model (SM) has been great!

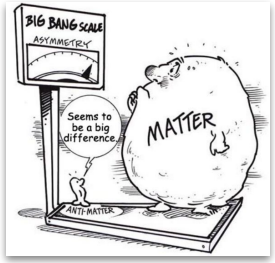
But we are also aware that it's not the ultimate theory..

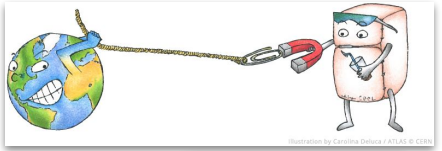
Theoretical concerns:

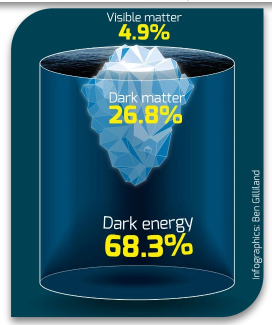
Hierarchy problem, Fine tuning, Why 3 generations?, Unification…

Observational issues:

Baryon asymmetry, Dark matter, Gravity, Neutrino mass…



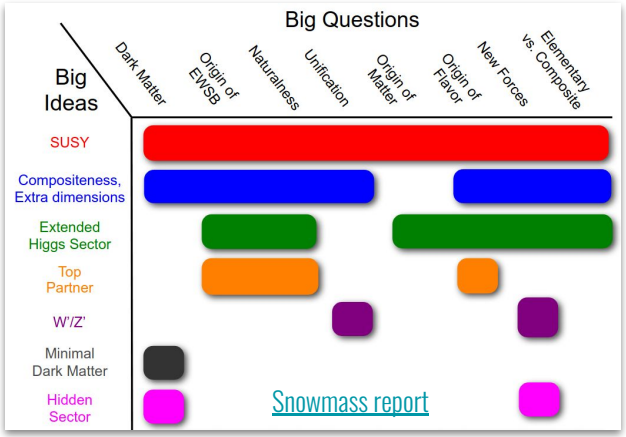




Going Beyond SM is inevitable!

MANY clever ideas from theorists to tackle SM limitations

In most cases, these imply the existence of new fields/particles



BSM Searches, Why Care?

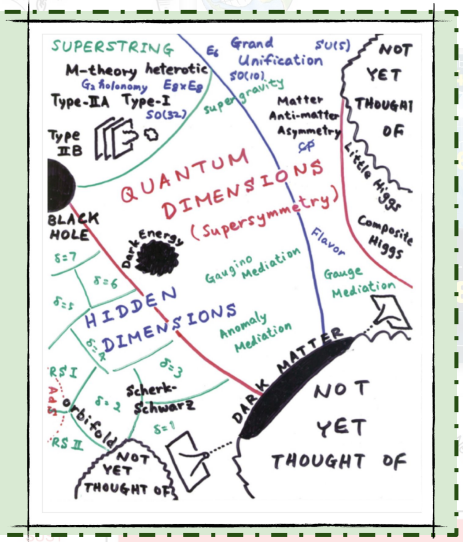
The landscape for BSM scenarios is vast!

2 approaches: *model driven, signature driven*

This Talk:

Searches in high-mass diphoton channel

(blend of 2 approaches..) **JHEP 08 (2024) 215**



Outline

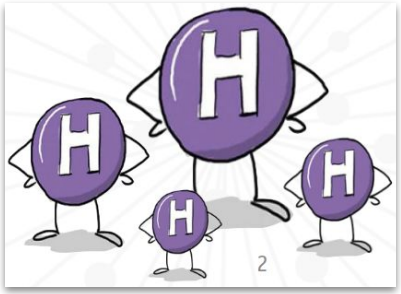
- Introduction & Motivations
- Selections & Categorization
- Resonant Signal & Background Modelling
- Resonant Results
- Non-resonant Signal & Background Modelling
- Non-Resonant Results
- Summary & Outlook

Motivations

Several BSM theories addressing SM limitations predict high-mass states decaying to photon pairs

➢ **Extended Higgs sector**

- BSM Higgs(es), Is the SM Higgs alone?
- **nHDMs** (h, H, A, H+/-), MSSM, etc.



The Higgs or *a* Higgs..?

➢ **Extra dimensions models**: Gravitons

- Addressing the EW Hierarchy problem
- e.g., **Randall-Sundrum (RS) models** (Phys. Rev. Lett. 83, 3370)
  - ★ proposes the existence of extra spatial dimensions
  - ★ **"warped"**: inaccessible to most particles except for gravity ➡ hierarchy!

The Strategy in a Nutshell

What

- Search for new (non-)resonant particles decaying to photon pairs
- Full Run 2 CMS data (138 fb^{-1},13 TeV)

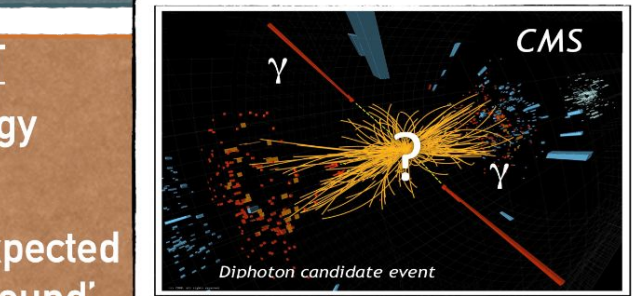
Why

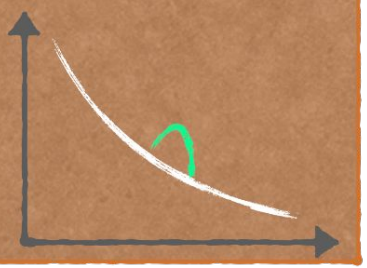
- Intriguing excesses: warrants more investigation
- Diphoton: Clean signal over smooth/well-known bkg

How

I. RESONANT

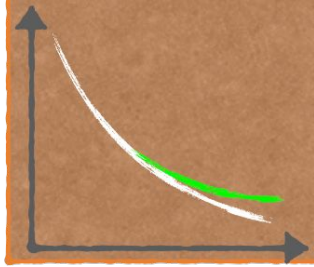
- Classic collider methodology in BSM searches
- Bump hunt: 'Look for unexpected peaks on a smooth background'
- Explore diphoton inv. mass spectra > 500 GeV
- Benchmark signals:
  - Spin-0 BSM Higgs (Γ_X/M_X = 0.014, 1.4, 5.6 %)
  - Spin-2 RS1 gravitons. (k/M_{pl} - 0.01, 0.1, 0.2)





II. NON-RESONANT

- Tightly spaced states →unresolvable as peaks
- Non-reso excess: deviation to the expected slope of the SM bkg
- Benchmark signals:
  - Arkani-Hamed, Dimopoulos, Dvali (ADD), large extra dims, Spin-2 gravitons
  - Clockwork mechanisms



Selections & Categorization

Trigger

Dedicated diphoton trigger (HLT_DoublePhoton60(70))

Event selections

Resonant & Non-resonant searches are *"twin analyses"*

- Share **common** event selections, Different signatures → Different sig/bkg modelling

Photon preselections:

- **Regression** to correct photon raw energy
- **Scale and smearing** corrections
- Shower shape/isolation for prompt photons, CSEV, etc.

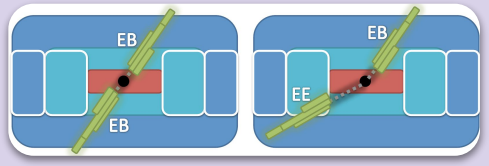
Diphoton selections

- Two photons passing **dedicated Photon ID** with pT > 125 GeV
- $m_{\gamma\gamma}$ = 500 to 3000 GeV
- $\Delta R_{\gamma\gamma} > 0.45$

Event categorisation

EBEB: both photons in Ecal barrel

EBEE: one photon in Ecal barrel, other in endcap region



Resonant Signal & Background Modelling

Bkg:

- Data driven modeling
- Fit Mgg by functional forms to data,
- Best-fit function from discrete profiling scan

Sig:

- Horizontal template morphing scheme,
- Inter/extrapolate Mgg shapes

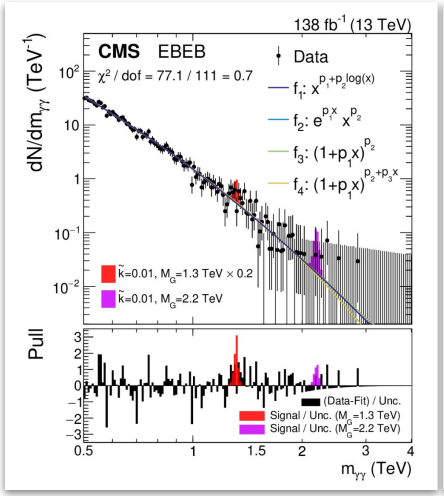
- Offshell production dominates in the ggH process at high mass

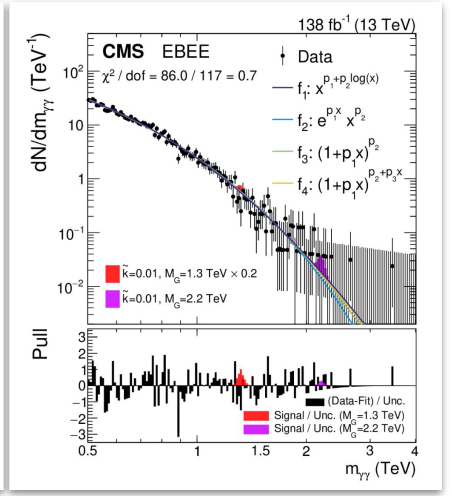
Fiducial region:

Remove low-mass tail in ggF spin-0 signal

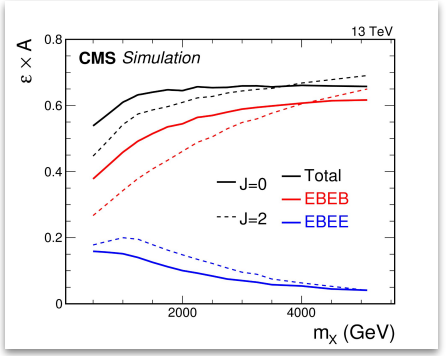
$$\frac{|Mass_{gen} - Mass_X|}{Mass_X} < 20\%$$

Bkg fits





Signal Normalization:
computed as: [ε×A] = [evt. selection eff. × detector acceptance]



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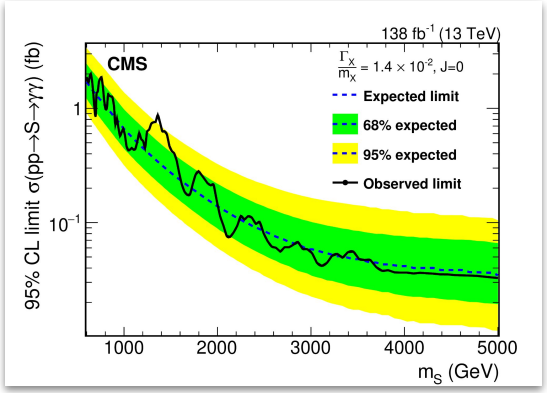
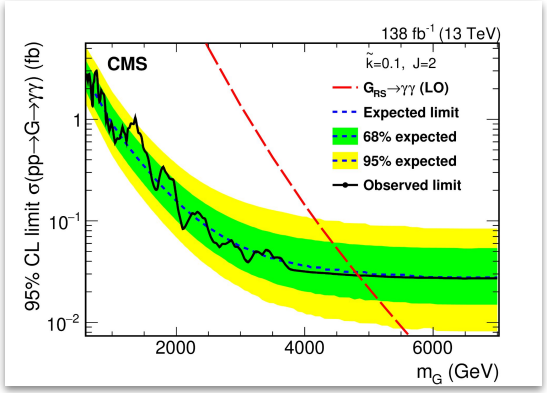
Resonant Results

Upper Limits set on the cross-section for BSM Higgs & RS1 Graviton → $\gamma\gamma$

- within fiducial acceptance
- total 6 sig categories: (BB + BE) x (3yrs)
- **higher mass exclusion** wrt ATLAS result
  - CMS: 4.8 TeV
  - ATLAS: 4.5 TeV (JHEP 10 (2023) 079)





Local p-value scanned in both resonance mass and width

- Largest deviation found at **M_x = 1320 GeV**, (Γ/M = 5.6 x 10^{-2})
  - Local significance: **2.58σ**
  - Global significance: **0.8σ** (LEE)

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Non-resonant Sig/Bkg Modelling

ADD signals generated at LO together with the SM diphoton process to account for interference effects

- **Parametrized by**: UV cutoff parameter for the virtual graviton exchange process and number of extra dimensions

Clockwork: reinterpretation of the ADD signals

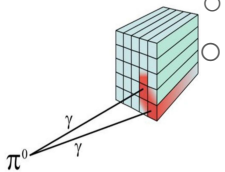
$$\sigma_{\text{total}} = \sigma_{\text{SM}} + \frac{\mathcal{F}}{M_S^4}\sigma_{\text{int}} + \frac{\mathcal{F}^2}{M_S^8}\sigma_{\text{ADD}}$$

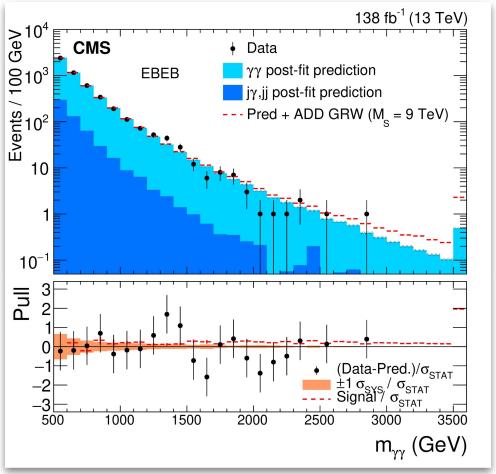
Conventions

$$\mathcal{F} = \begin{cases} 1 & \text{(GRW)}, \\ \log\left(\frac{M_S^2}{\hat{s}}\right), & \text{if } n_{\text{ED}} = 2 \\ \frac{2}{n_{\text{ED}}-2}, & \text{if } n_{\text{ED}} > 2 \end{cases} \text{(HLZ)} \quad \pm\frac{2}{\pi} \text{ (Hewett)}$$

2 sources of backgrounds:

- **Real SM diphoton**
  - Dominant & Irreducible
  - Generated with Sherpa & NNLO K-factor from MCFM
- **Jet misidentified as photon**
  - Primarily γ+j events ($\pi^0/\eta \to \gamma\gamma$), reducible
  - **Strategy**: Measure `Fake Rate`, a relative rate b/w types of jet fragmentation. Then use it as a transfer function to get expected Fake contribution to background





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Non-Resonant Results

Set limits in ADD & clockwork models

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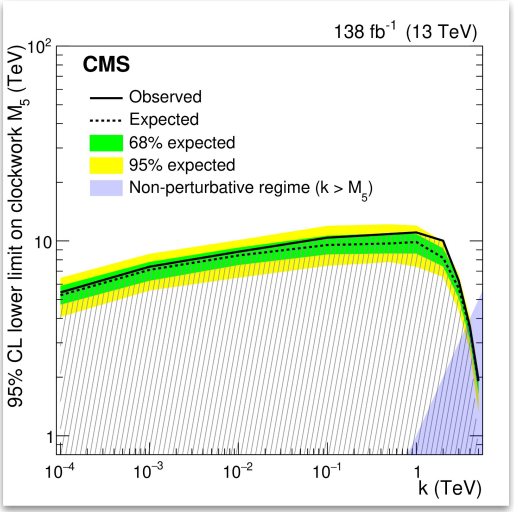
ADD Exclusion limits on the **Ms : 7.1 - 11.1 TeV** (depending on model convention)

Signal:	GRW	Hewett		HLZ				
		negative	positive	$n_{ED} = 3$	$n_{ED} = 4$	$n_{ED} = 5$	$n_{ED} = 6$	$n_{ED} = 7$
Expected:	$8.7^{+0.7}_{-0.6}$	$7.3^{+0.3}_{-0.3}$	$7.8^{+0.6}_{-0.5}$	$10.3^{+0.8}_{-0.7}$	$8.7^{+0.7}_{-0.6}$	$7.9^{+0.6}_{-0.5}$	$7.3^{+0.6}_{-0.5}$	$6.9^{+0.6}_{-0.5}$
Observed:	9.3	7.1	8.3	11.1	9.3	8.4	7.8	7.4

Clockwork exclusion limits set on 2D M5-k space

- Excluded M5 values below 8 TeV for k between 0.2 GeV and 2.0 TeV
- Comparable sensitivity with ATLAS (JHEP 10 (2023) 079)



Summary

- Presented recent CMS Searches for new physics performed in high mass diphoton events from p-p collisions at 13 TeV
- Both Resonant and Non-resonant signals were probed

Outlook

To new beginnings..

CMS:

Largest excess: **1320 GeV**

2.58σ local, 0.77σ global

ATLAS:

Largest excess: **~684 GeV**

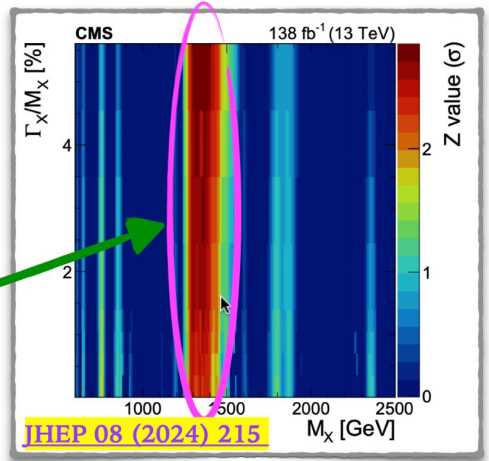
Spin-0 (NWA), Spin-2 (k/MPl = 0.01)

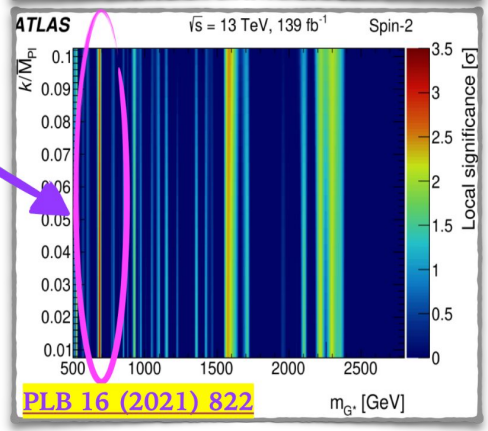
3.29σ local, 1.30(1.36)σ global: Spin-0(Spin-2)

Analysis ongoing, Several improvements in consideration!

Look at Run 3 data

Run 2 re-search





Thank You!

*<u>Acknowledgement</u>: some info adopted directly from (pre-)approval talks, thanks to presenters!