Model-Independent Simplified Limits on Resonances at the LHC

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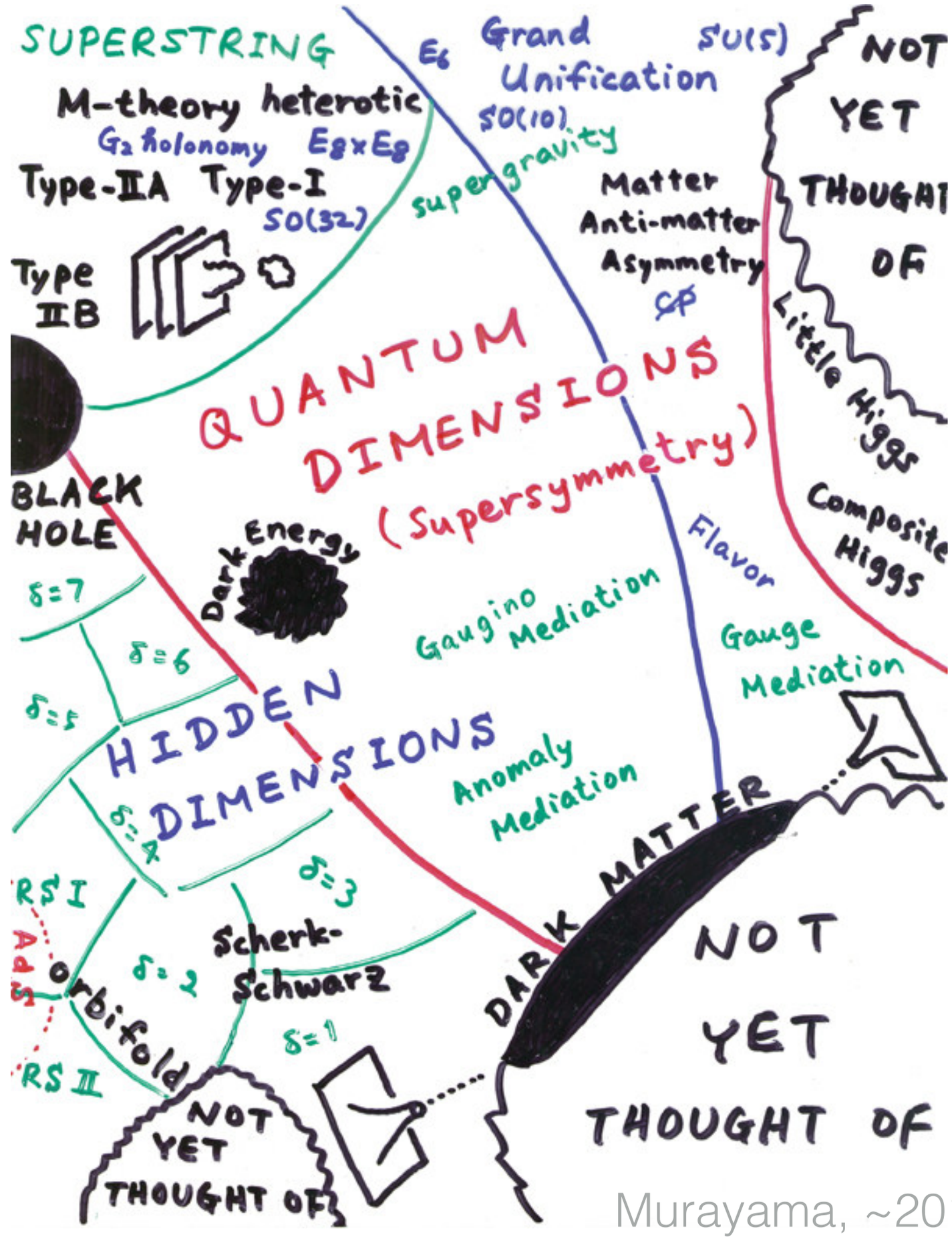
- Resonance searches at LHC
- Traditional “model-independent” Limits
- Simplified Model for s-channel resonances
- Simplified Limits on new resonances
- Applications

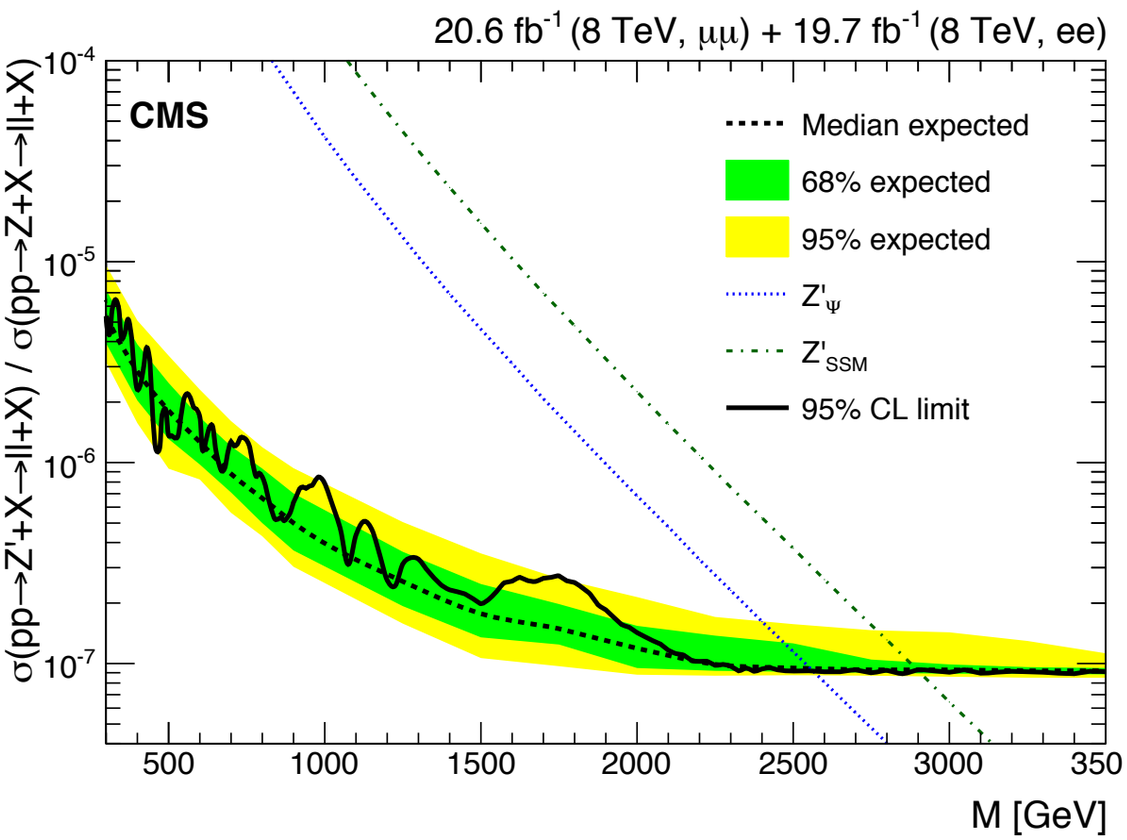
New Physics *typically* implies the existence of new resonances



Murayama, ~2010

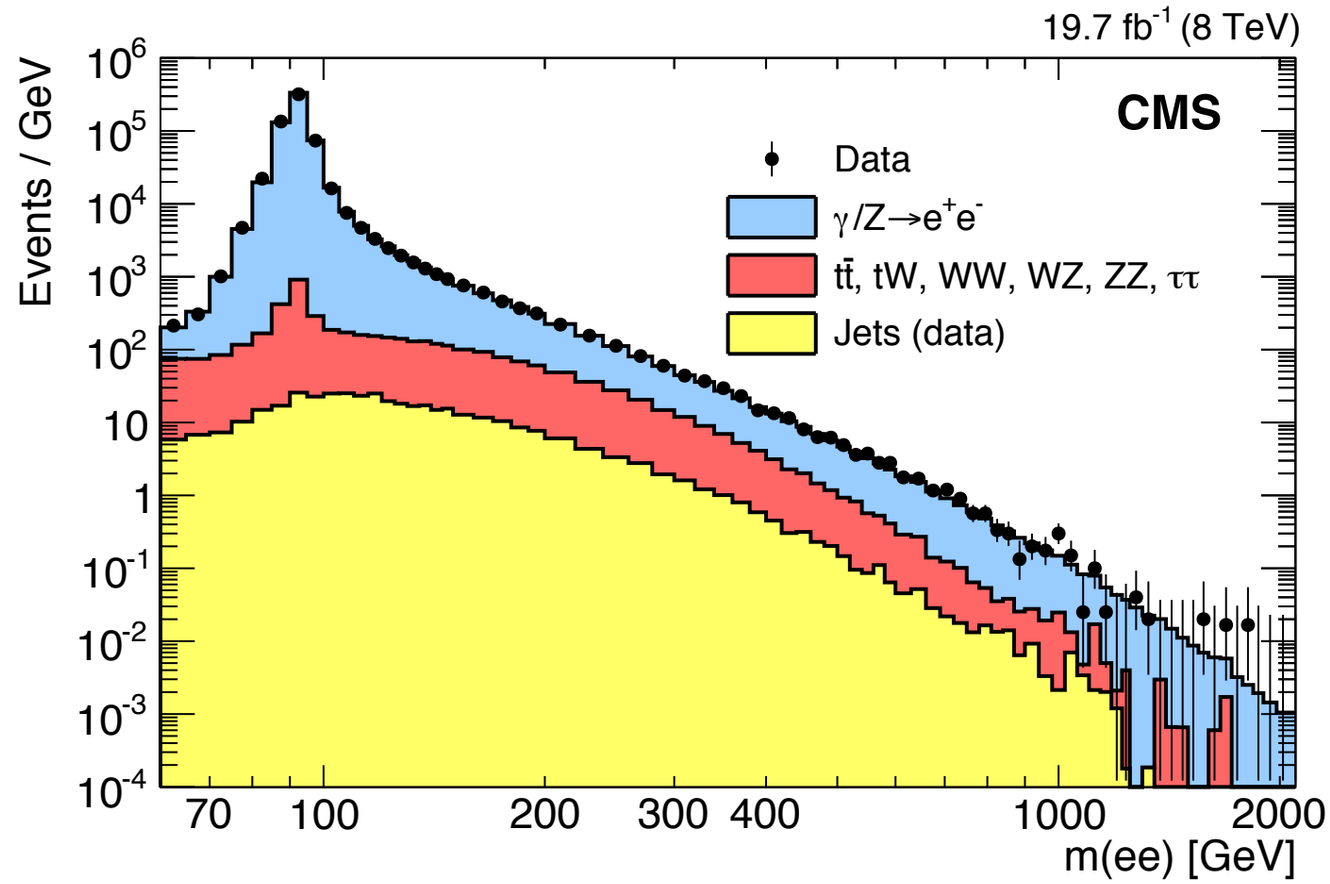
Dilepton Resonance Searches

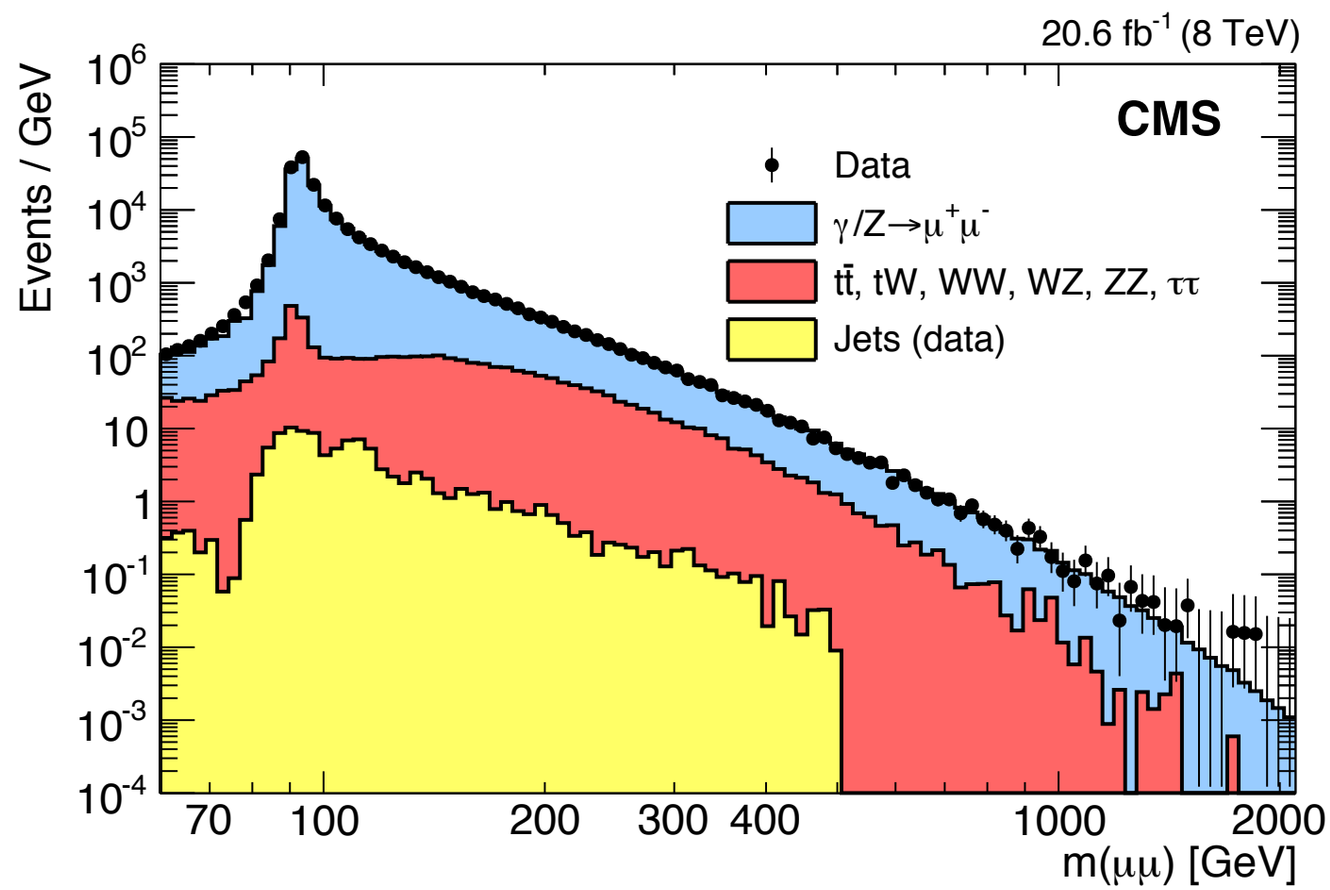
Flavor-independent Z'



Limits: 2.5-3 TeV

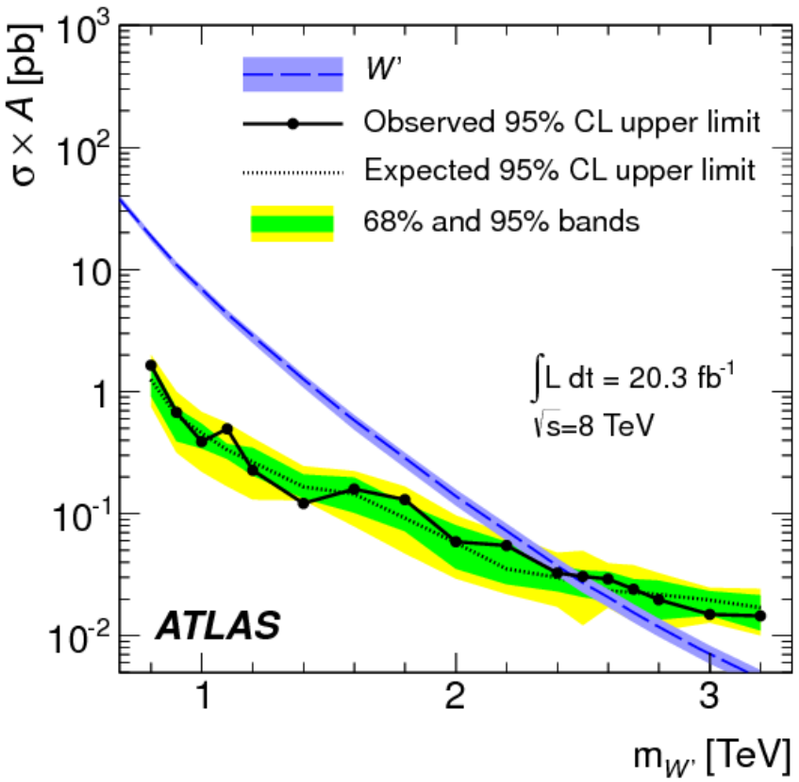
CMS EXO-12-061

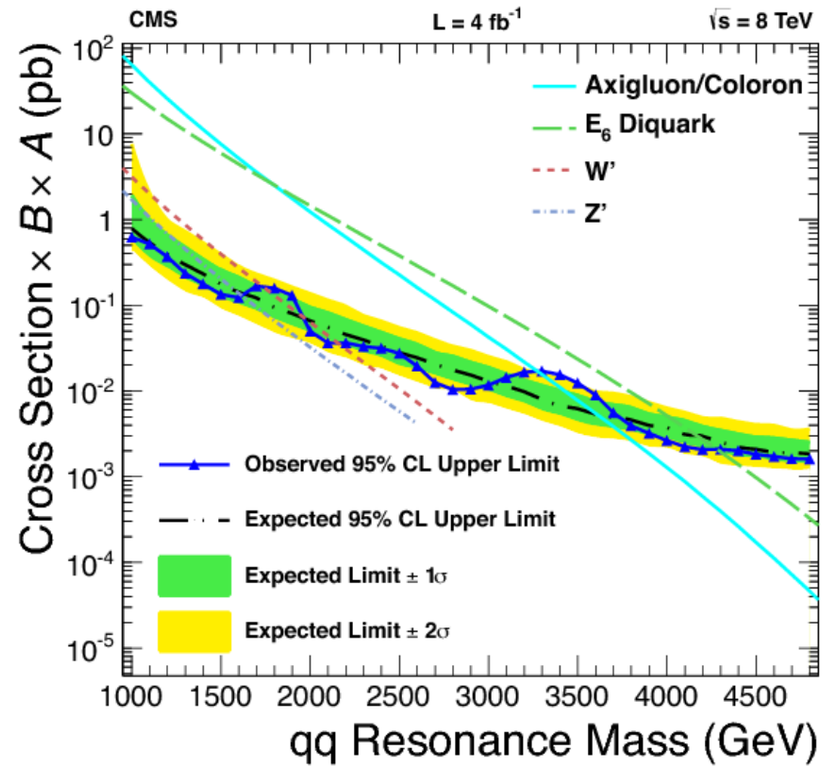


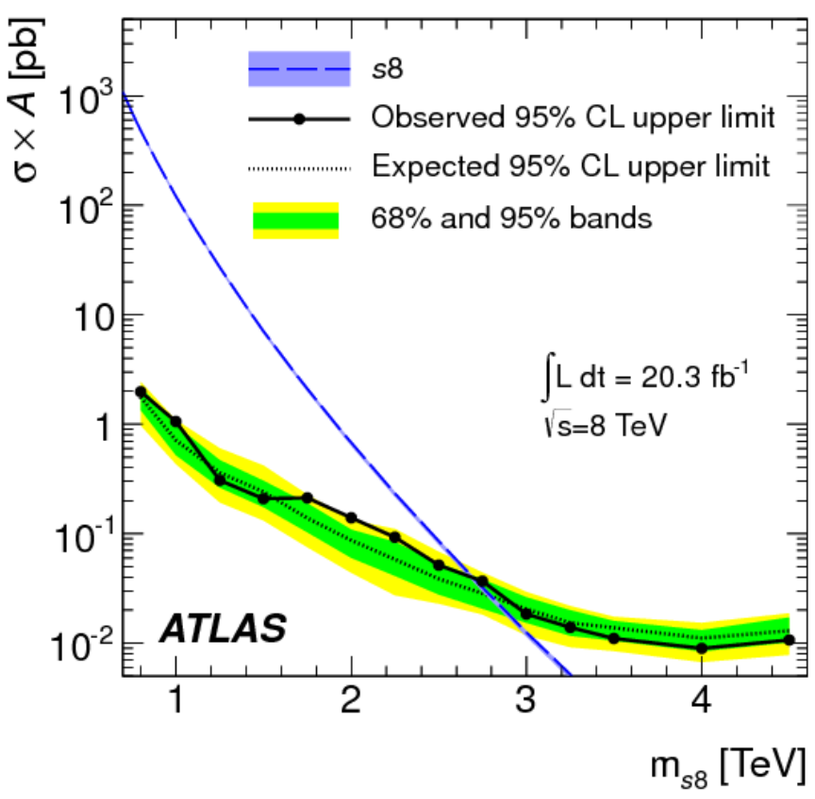


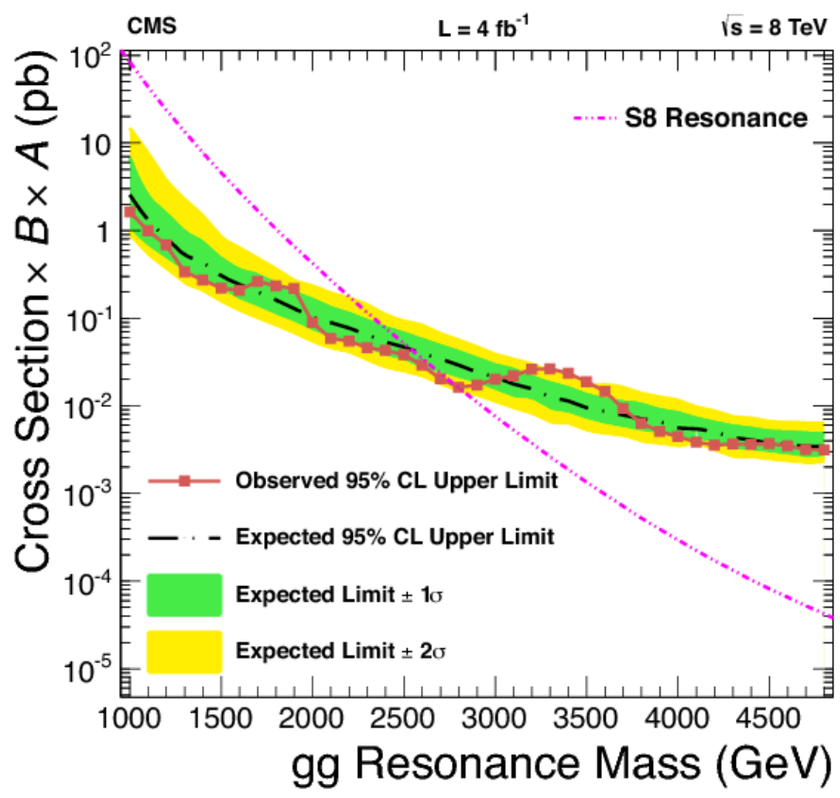
Dijet Resonance Searches

ATLAS CERN-PH-EP-2014-147
CMS EXO-12-016

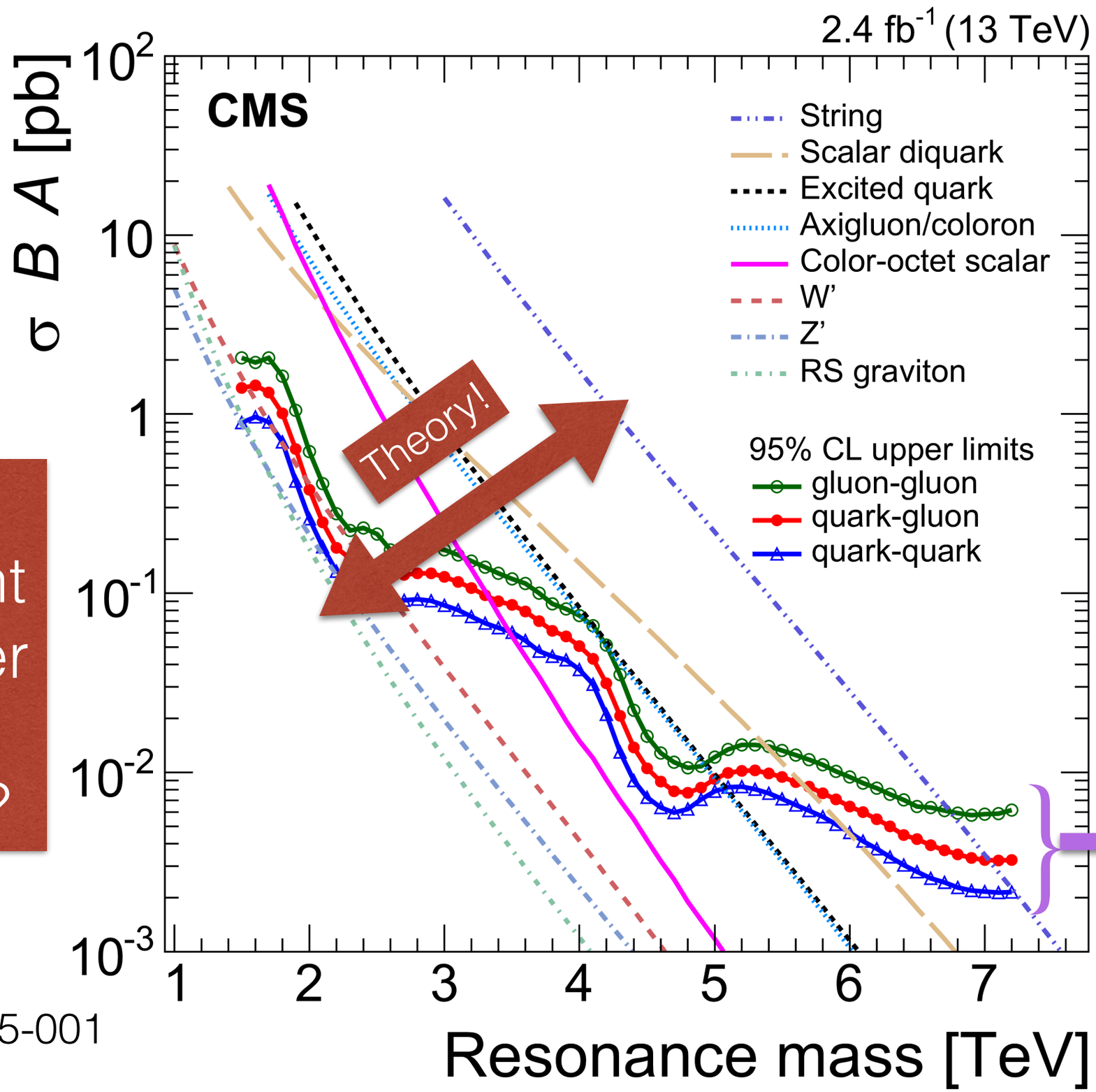








Conventional "Model-Independent" (dijet) Limits

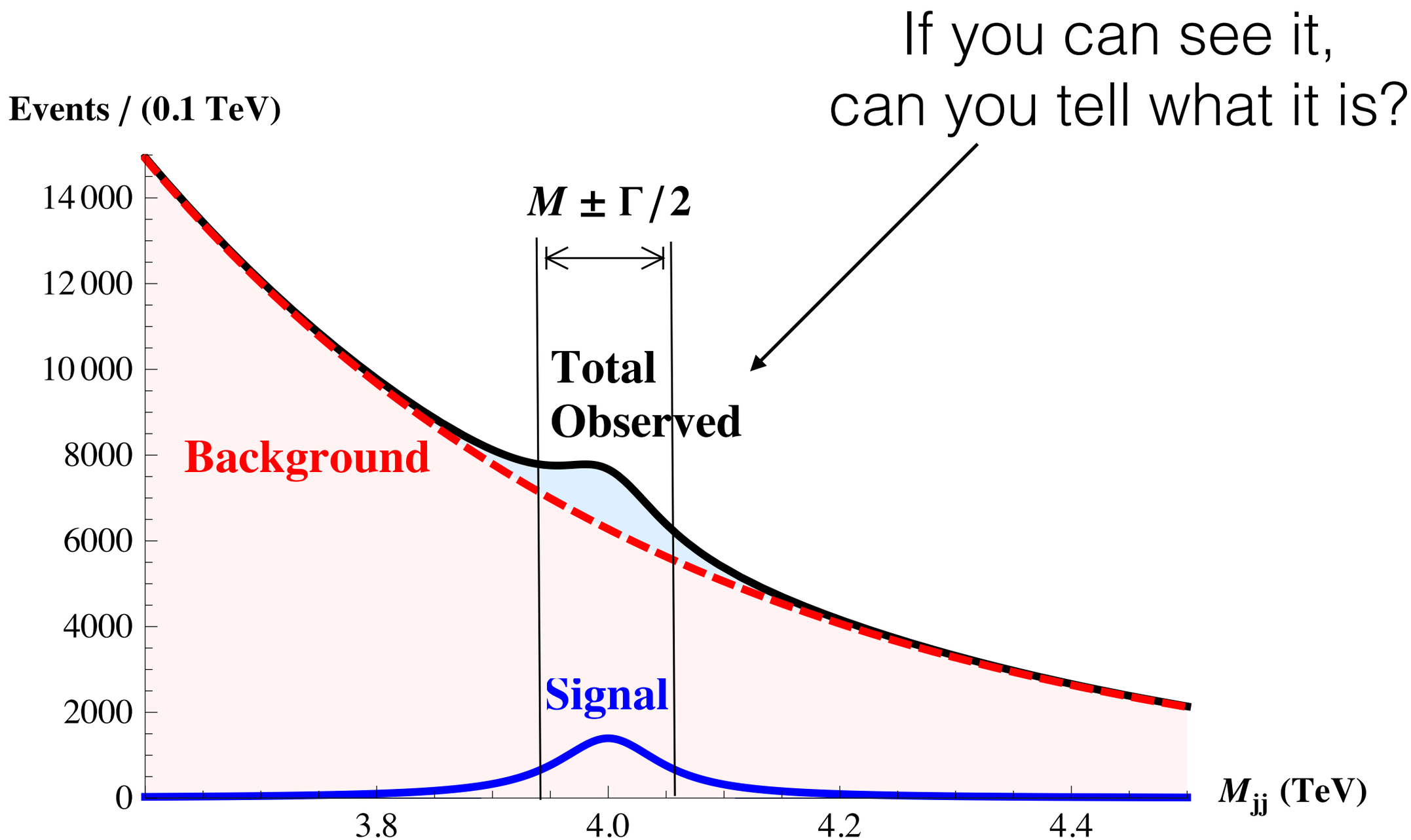


Can we represent a broader class of models?

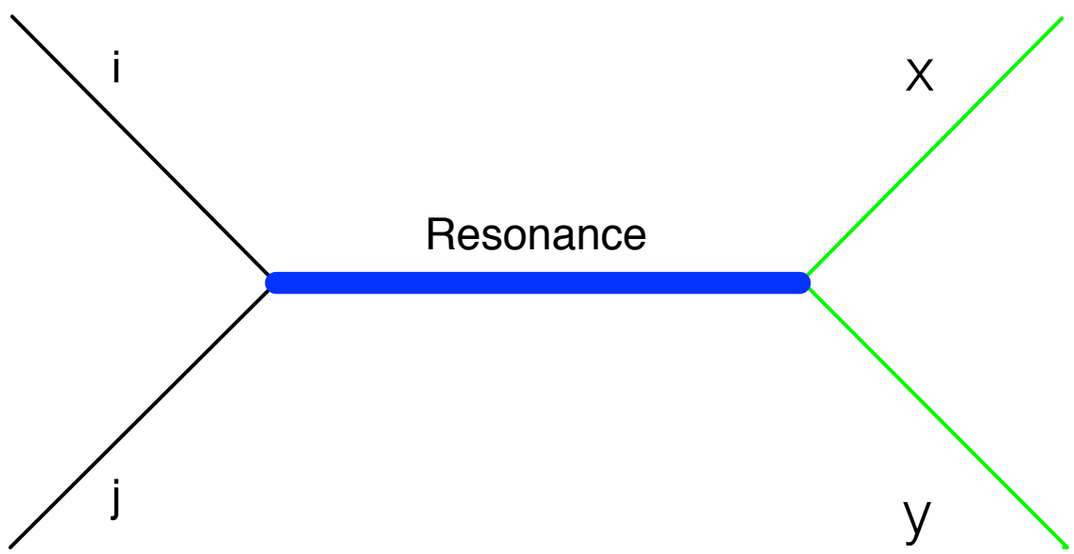
dijet characteristics

CMS EXO-15-001

s-channel Resonance



Simplified s-channel Model



i,j = u,d,g,γ,W,Z

x,y = j,t,b,g,γ,W,Z,h

Resonance Characteristics	Corresponding Observables
couplings	BR, σ * BR
mass, width	$d\sigma/dm_{ab}$
spin	$d\sigma/d\cos\theta_{ab}$
x,y (each channel)	flavor tagging; jet substructure
i,j	event properties

NB: If x,y can be light quarks,
t-channel process may be relevant

Narrow Width Approximation

$$\sigma_R(pp \to x + y) = \int_{s_{min}}^{s_{max}} d\hat{s}\, \hat{\sigma}(\hat{s}) \cdot \left[\frac{dL^{ij}}{d\hat{s}}\right]$$

$$\hat{\sigma}_{ij\to R\to xy}(\hat{s}) = 16\pi(1+\delta_{ij}) \cdot \mathcal{N} \cdot \frac{\Gamma(R \to i+j) \cdot \Gamma(R \to x+y)}{(\hat{s} - m_R^2)^2 + m_R^2 \Gamma_R^2}\,, \quad \boxed{\mathcal{N} = \frac{N_{S_R}}{N_{S_i} N_{S_j}} \cdot \frac{C_R}{C_i C_j}}$$

$$\frac{1}{(\hat{s} - m_R^2)^2 + m_R^2 \Gamma_R^2} \approx \frac{\pi}{m_R \Gamma_R} \delta(\hat{s} - m_R^2)$$

$$\boxed{\sigma_R(pp \to x + y) = 16\pi^2 \cdot \mathcal{N} \cdot \frac{\Gamma_R}{m_R} \cdot (1+\delta_{ij}) BR(R \to ij) \cdot BR(R \to xy) \left[\frac{1}{s}\frac{dL^{ij}}{d\tau}\right]_{\tau = \frac{m_R^2}{s}}}$$

(Note: Can be corrected for K-factor(s) & Acceptance)

Chivukula, Ittisamai, Mohan, EHS 1607.05525

Branching Ratios

$$\sigma_R(pp \to x + y) = 16\pi^2 \cdot \mathcal{N} \cdot \frac{\Gamma_R}{m_R} \cdot (1 + \delta_{ij}) BR(R \to ij) \cdot BR(R \to xy) \left[\frac{1}{s} \frac{dL^{ij}}{d\tau} \right]_{\tau = \frac{m_R^2}{s}}$$

Simplest case: one relevant incoming / outgoing state

$$BR(R \to i + j)(1 + \delta_{ij}) \cdot BR(R \to x + y) = \frac{\sigma_R^{xy}}{16\pi^2 \mathcal{N} \frac{\Gamma_R}{m_R} \left[\frac{1}{s} \frac{dL^{ij}}{d\tau} \right]_{\tau = \frac{m_R^2}{s}}}$$

$$\left.\begin{array}{ll} \leq 1/4 & (ij \to R \to xy) \\ \leq 1 & (ij \to R \to ij) \\ \\ \leq 1/2 & (ii \to R \to xy) \\ \leq 2 & (ii \to R \to ii) \end{array}\right\}$$

Upper bound shows which classes of models are viable.

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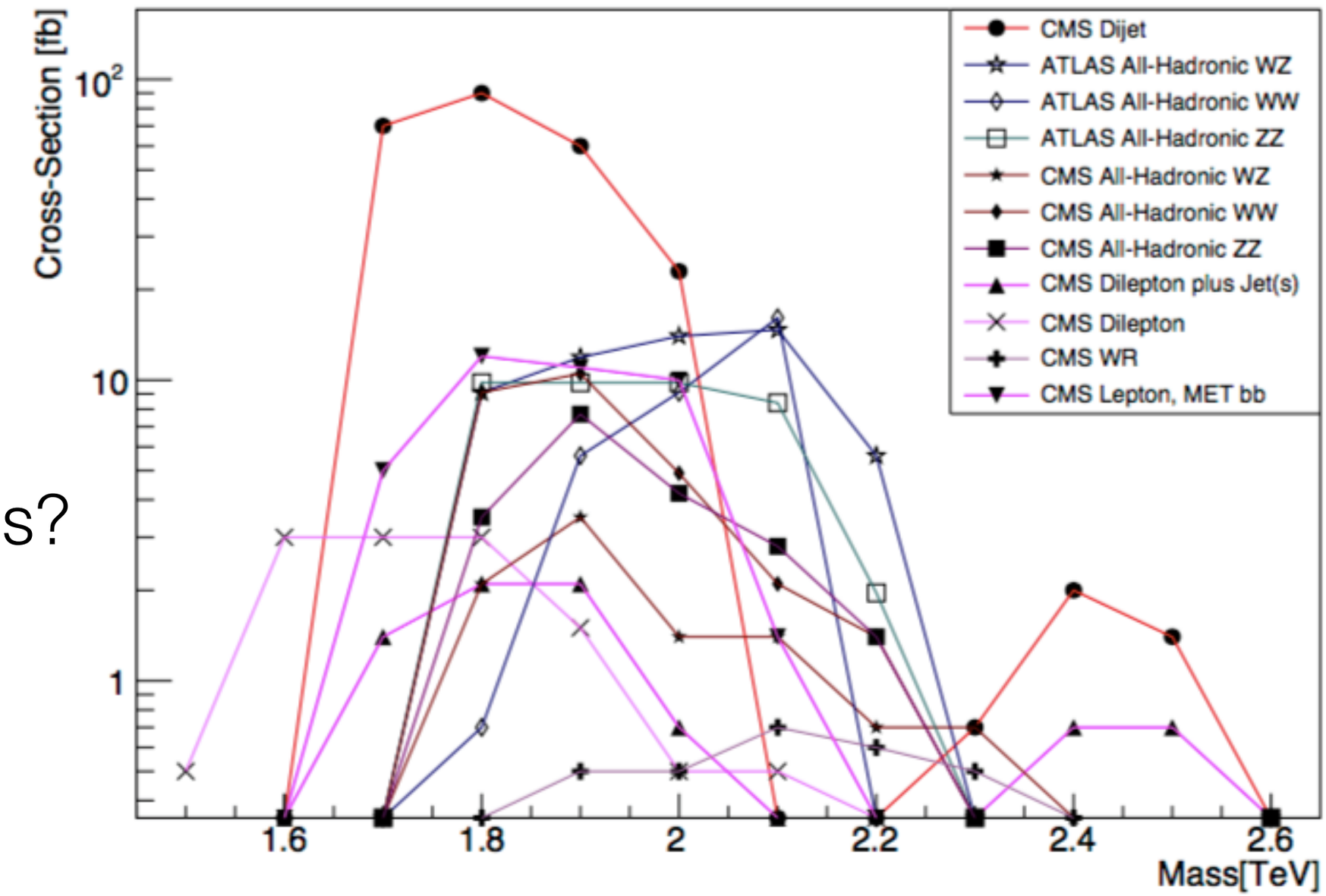
DiBoson Excess 2015

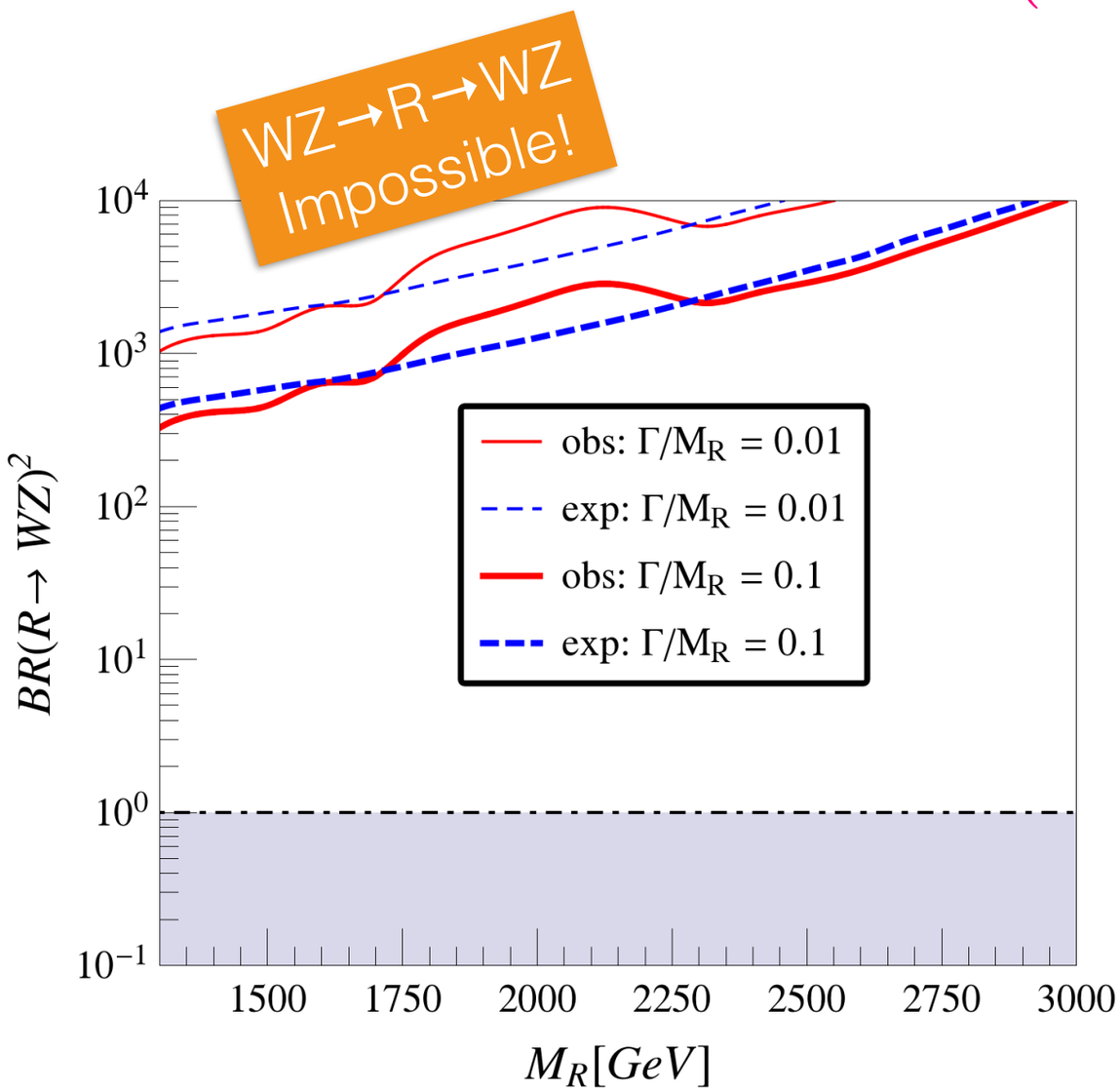
1-100 fb
“WZ” excess?

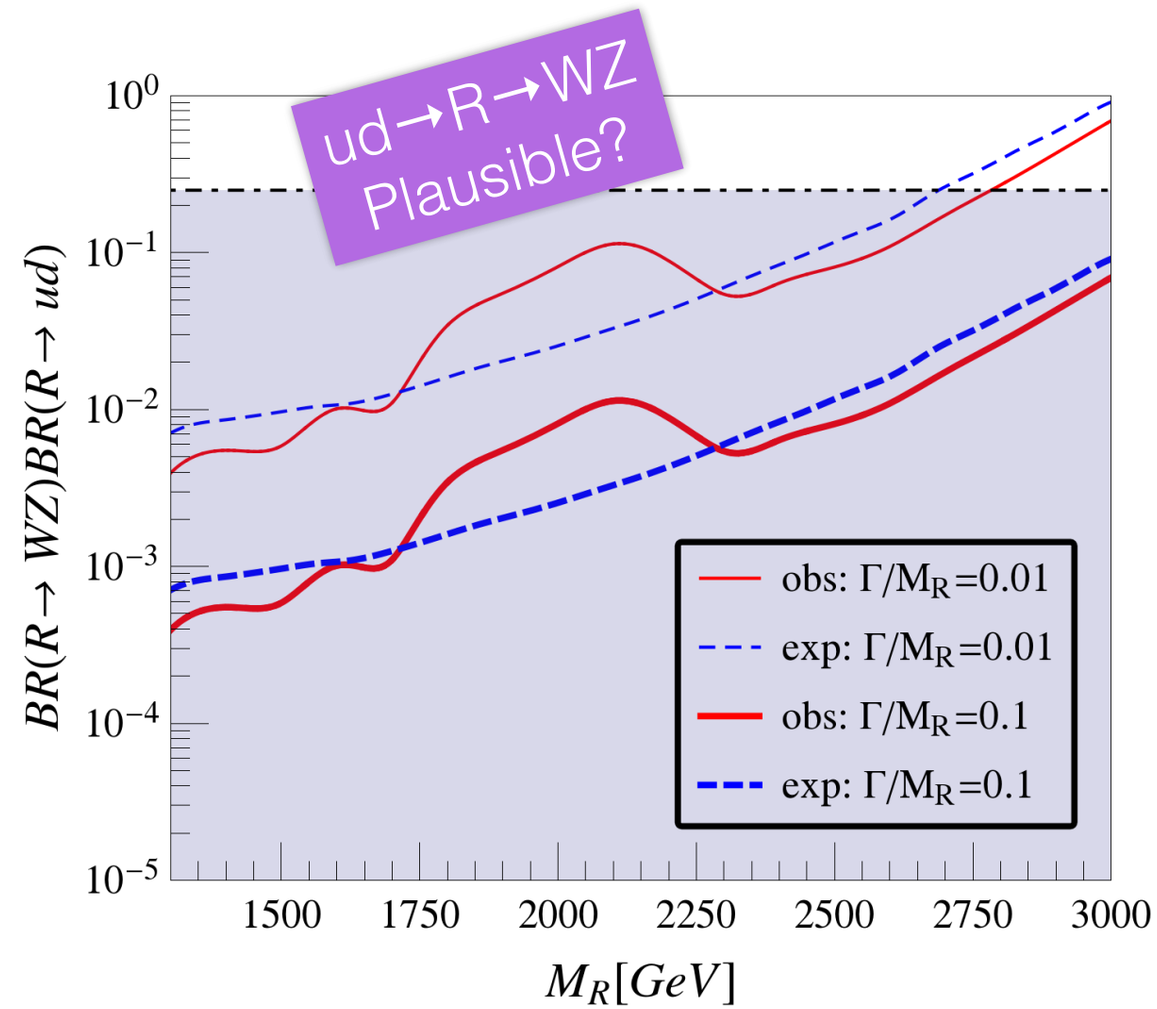


Les Houches 2015 - arXiv:1512.04537

DiBoson Vector Resonances

$$BR(R \to ij)(1+\delta_{ij})\, BR(R \to xy)$$





Differences in PDF sizes and energy dependence produce differing values, shapes of constraint curves.

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Better Variable: ζ

$$\sigma_R(pp \to x + y) = 16\pi^2 \cdot \mathcal{N} \cdot \frac{\Gamma_R}{m_R} \cdot (1 + \delta_{ij}) BR(R \to ij) \cdot BR(R \to xy) \left[\frac{1}{s} \frac{dL^{ij}}{d\tau} \right]_{\tau = \frac{m_R^2}{s}}$$

Simplest case: one relevant incoming / outgoing state

$$\zeta \equiv (1 + \delta_{ij}) BR(R \to i + j) \cdot BR(R \to x + y) \cdot \frac{\Gamma_R}{m_R}$$

$$= \frac{\sigma_R^{XY}}{16\pi^2 \cdot \mathcal{N} \times \left[\left[\frac{1}{s} \frac{dL^{ij}}{d\tau} \right]_{\tau = \frac{m_R^2}{s}} \right]}$$

- Collapses different widths onto a single curve
- For upper bound, use $\Gamma/M \sim 0.1$

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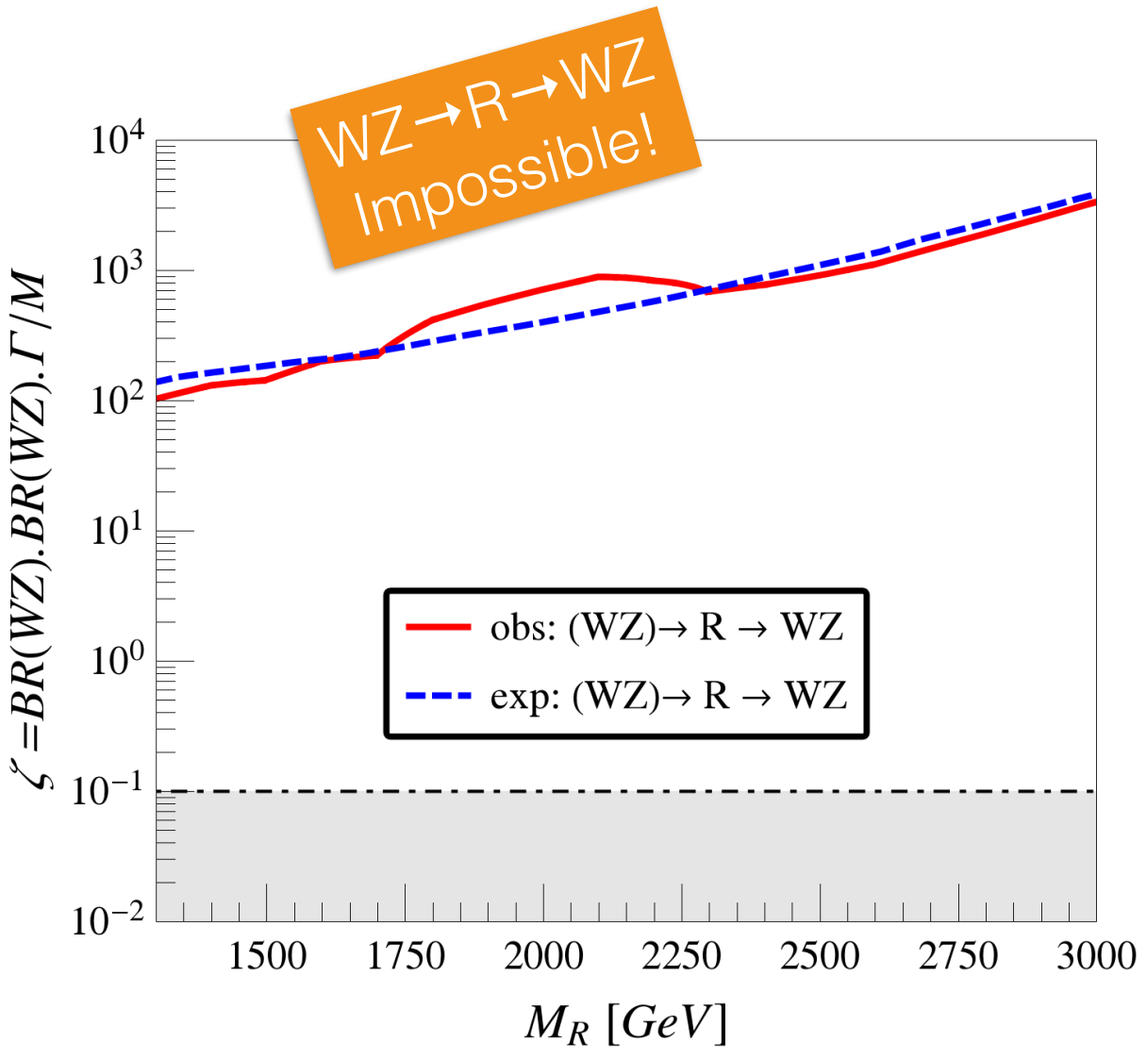
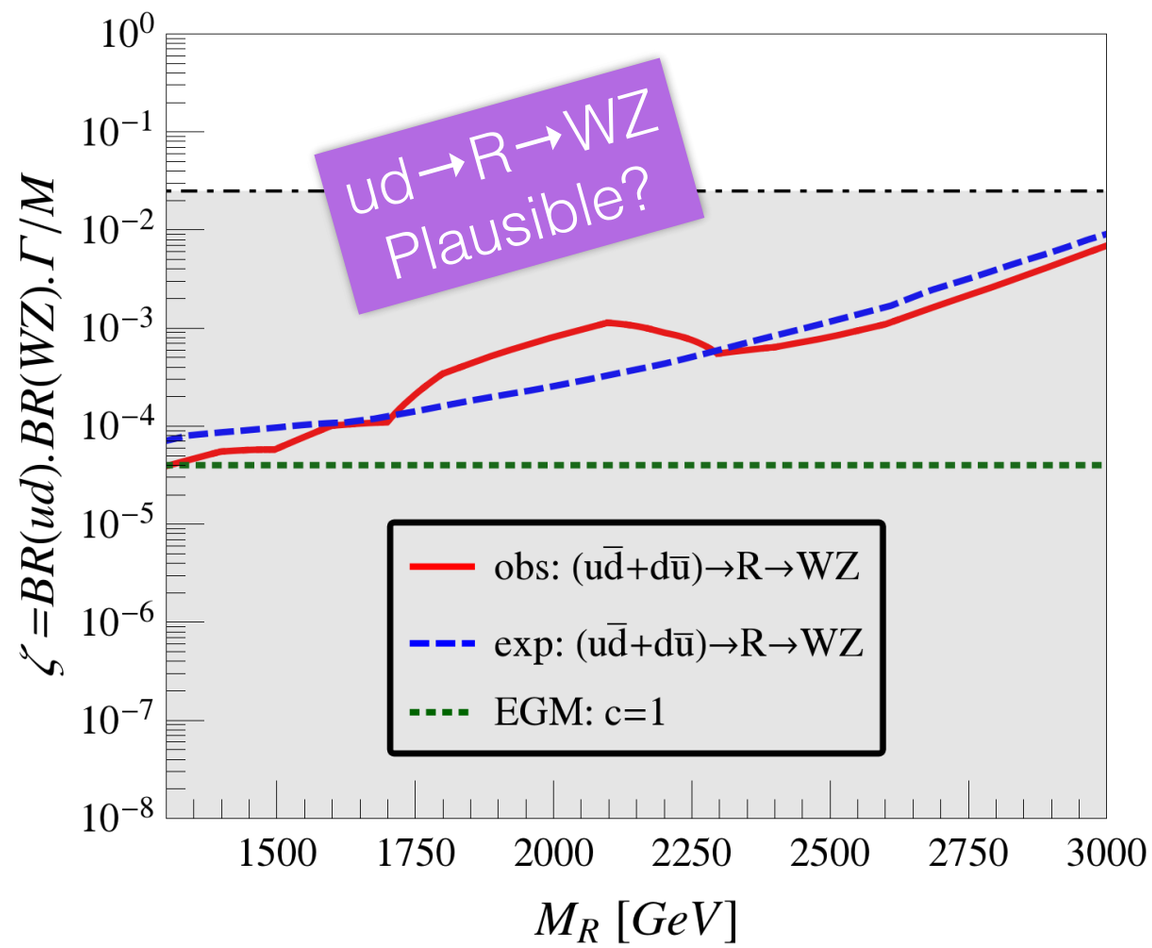
DiBoson Vector Resonances

$$\zeta \equiv BR(R \to ij)(1+\delta_{ij})\, BR(R \to xy)\, \Gamma/M$$





Extended Gauge Model cannot explain excess

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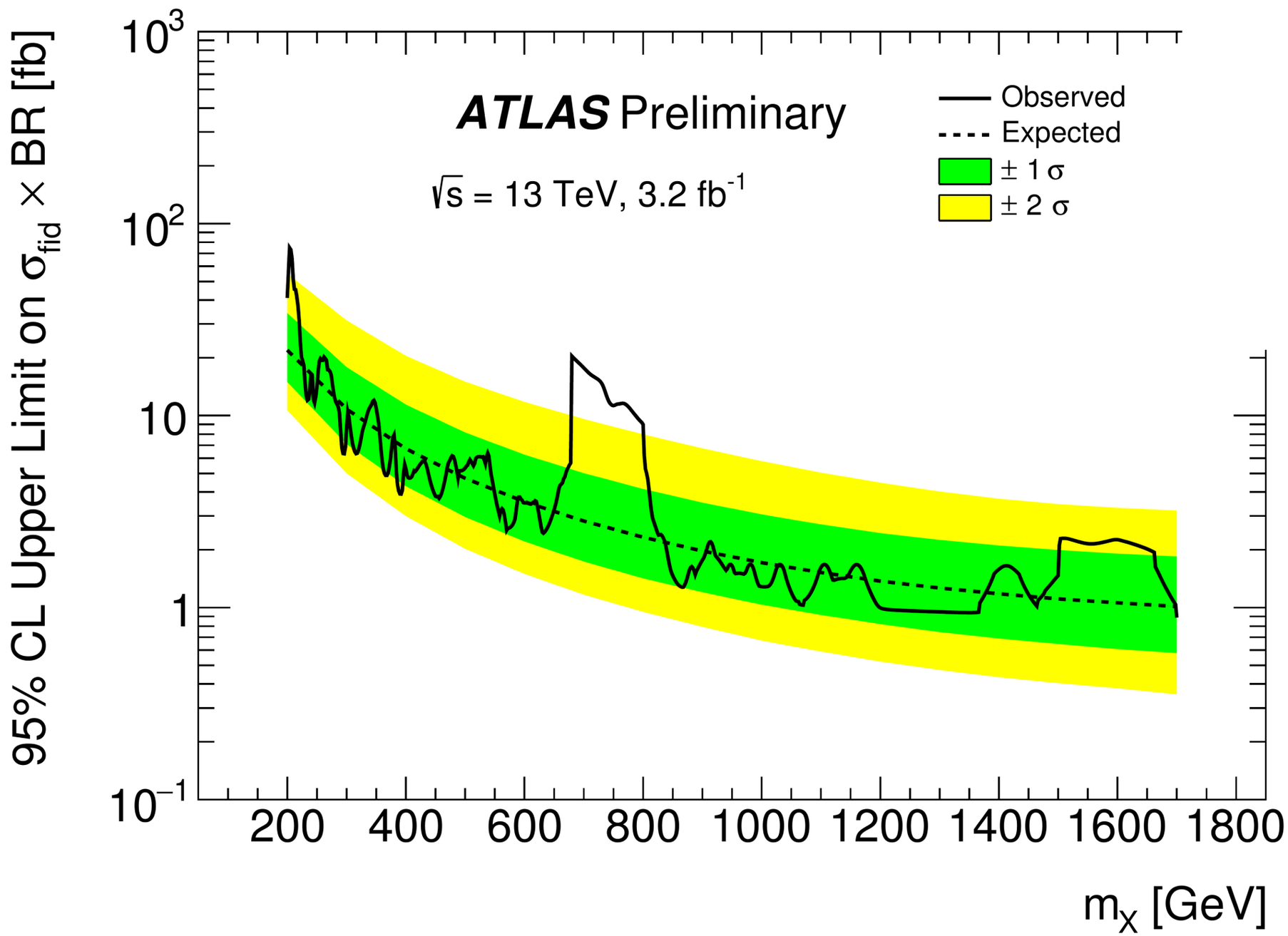
Diphoton Resonance 2015



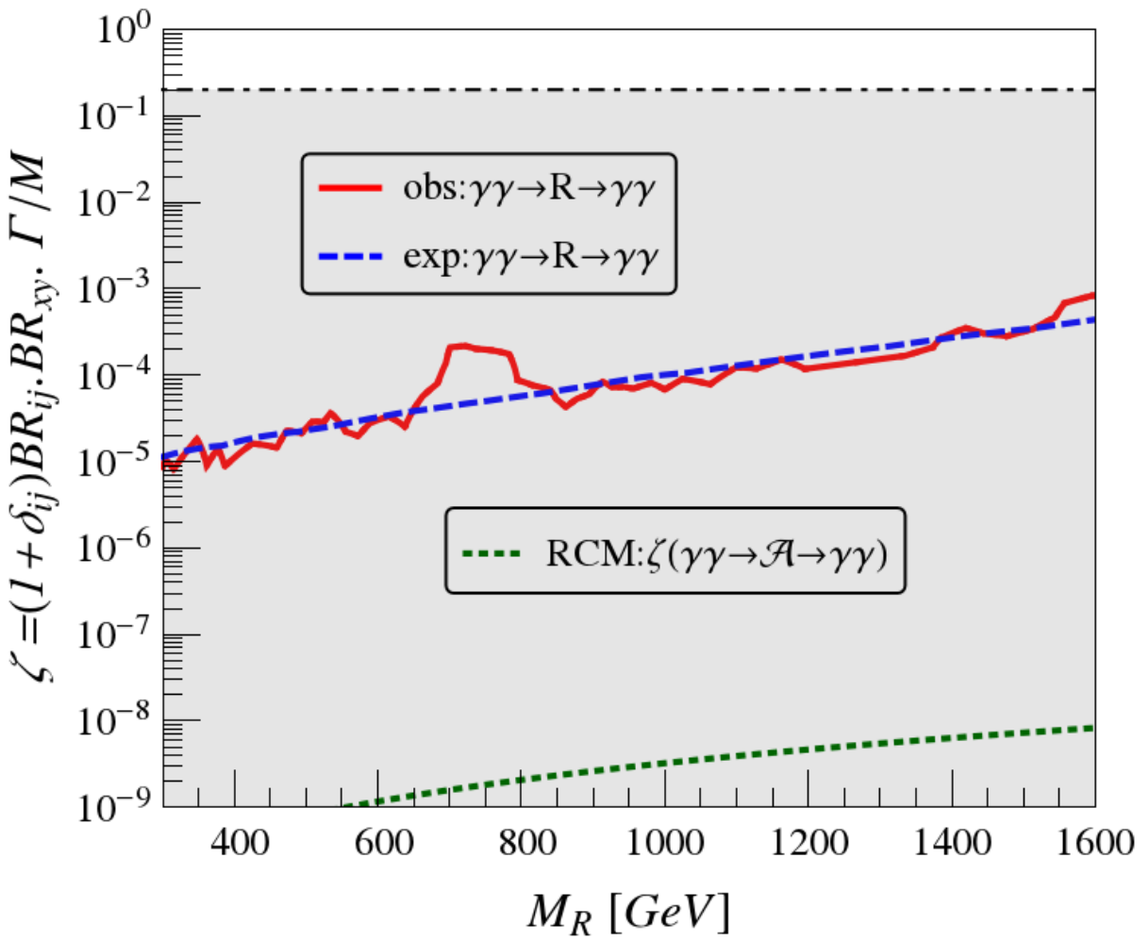
ATLAS-CONF-2015-081

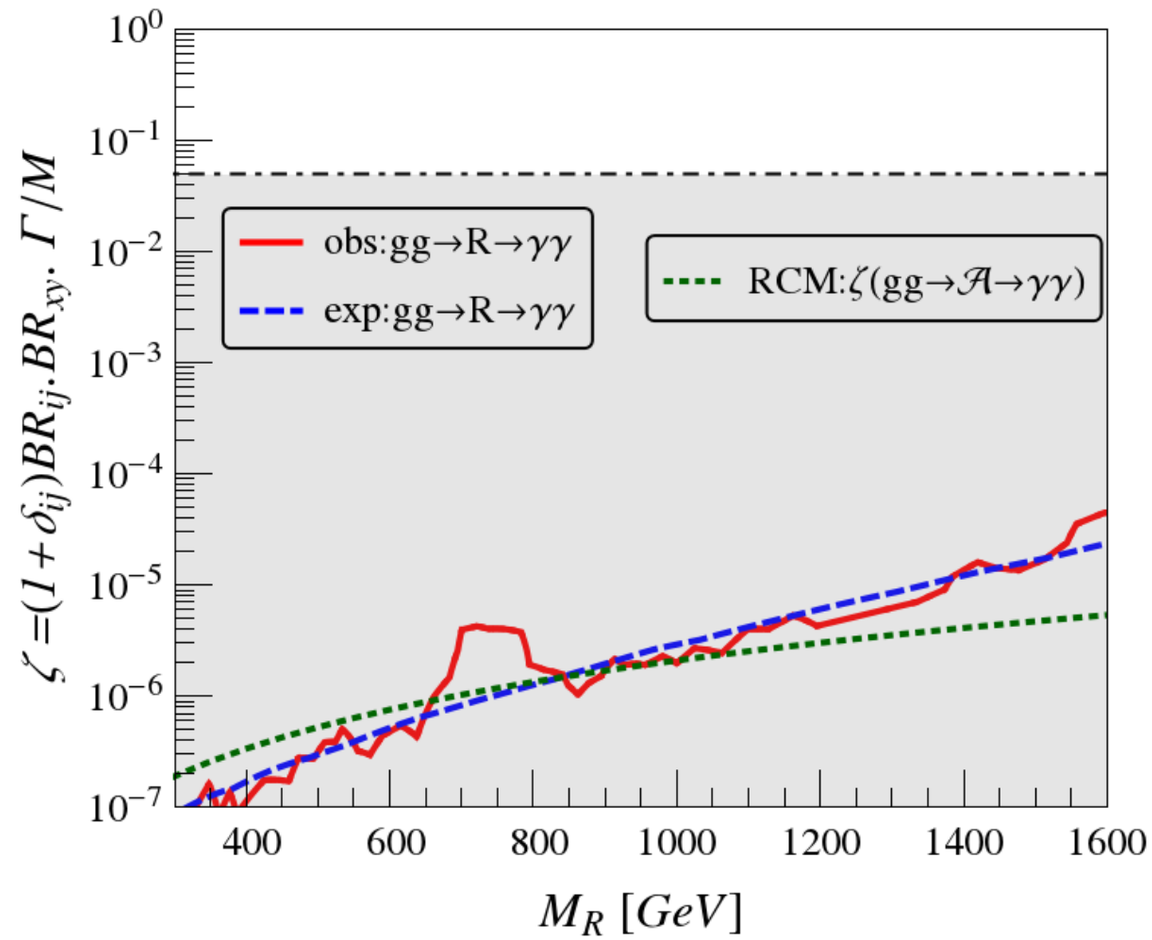
Simplified Limits on Scalar Diphoton Resonances: ***Diphoton Production***

$$\sigma_R(pp \to \gamma\gamma) = 32\pi^2 \cdot \left(\frac{1}{4}\right) \cdot \frac{\Gamma_R}{m_R} \cdot BR(R \to \gamma\gamma)^2 \cdot \left[\frac{1}{s}\frac{dL^{\gamma\gamma}}{d\tau}\right]_{\tau=\frac{m_R^2}{s}}$$

To be **consistent** with observed signal a scalar *produced* through photon fusion (since BR<1), needs $\Gamma/M > 3 \times 10^{-4}$

Diphoton Scalar Resonances





in photon fusion, Renormalizable Coloron Model* cannot explain excess

in gluon fusion, Renormalizable Coloron Model* is consistent with excess

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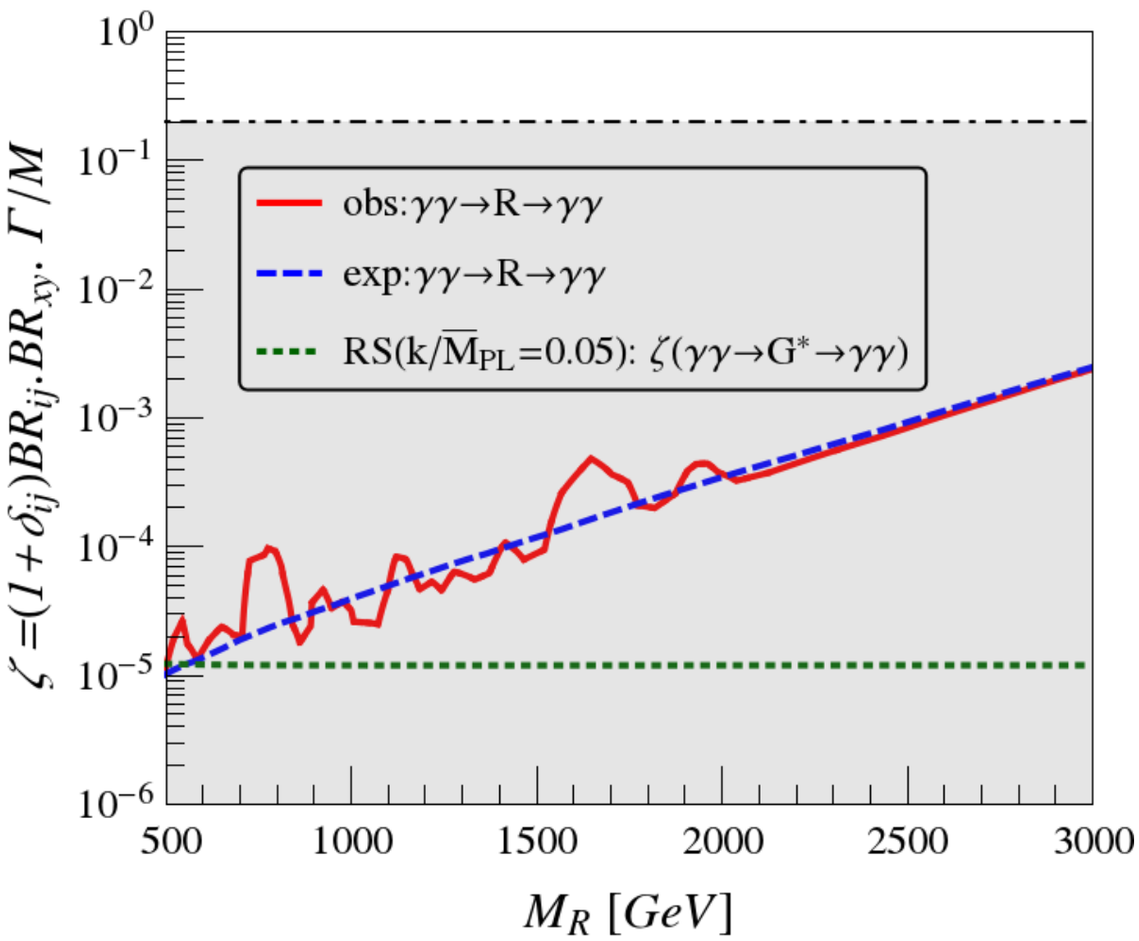
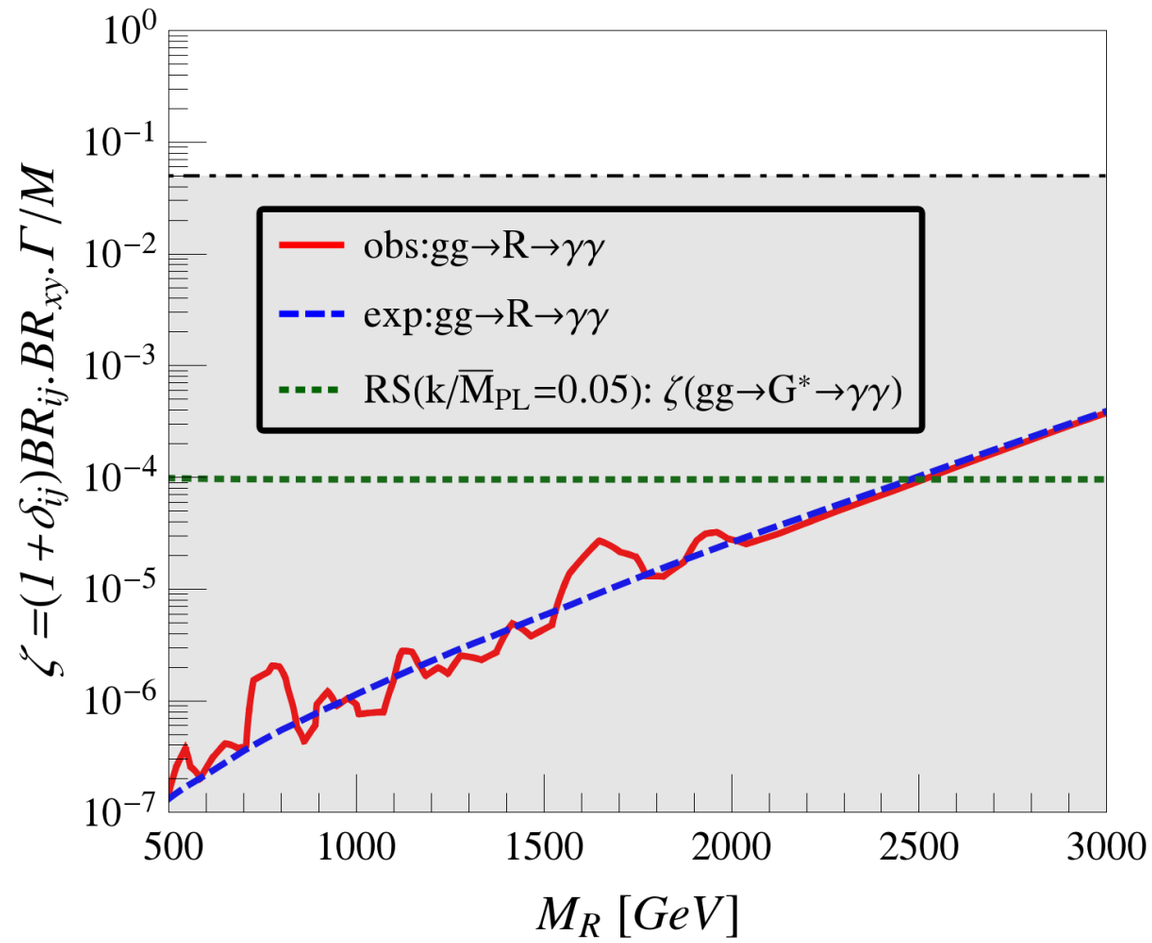
*RCM: Chivukula, Farzinnia, Mohan, EHS 1604.02157

Diphoton Spin-2 Resonances



in photon fusion, RS Graviton (at 0.05) **cannot explain excess**



RS Graviton (at 0.05) **below 2.5 TeV excluded**

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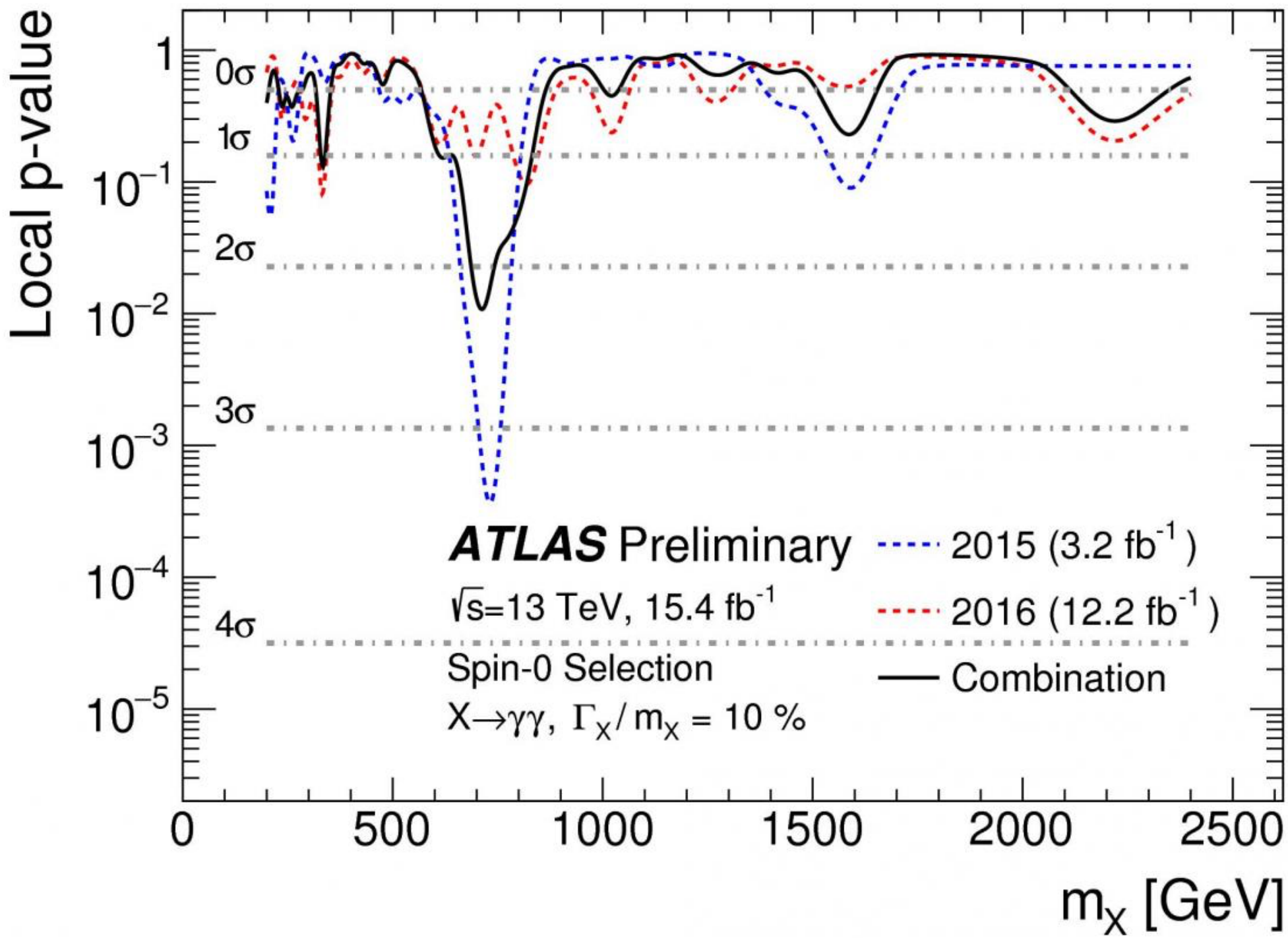
RS: Bijnens et al. hep-ph/0101316

~~Diphoton Resonance~~ 2016



Extension to Multiple Production and Decay Modes

Easy to evaluate for any model class or model

$$\zeta \equiv \left[\sum_{i'j'}(1+\delta_{i'j'})BR(R\to i'+j')\right]\cdot\left(\sum_{xy\in XY} BR(R\to x+y)\right)\cdot\frac{\Gamma_R}{m_R}$$

$$= \frac{\sigma_R^{XY}}{16\pi^2\cdot\mathcal{N}\times\left[\sum_{ij}\omega_{ij}\left[\frac{1}{s}\frac{dL^{ij}}{d\tau}\right]_{\tau=\frac{m_R^2}{s}}\right]}$$

Reporting experimental limits in this format simplifies comparison with theory

weighting factor

$$\omega_{ij} \equiv \frac{(1+\delta_{ij})BR(R\to i+j)}{\sum_{i'j'}(1+\delta_{i'j'})BR(R\to i'+j')}$$

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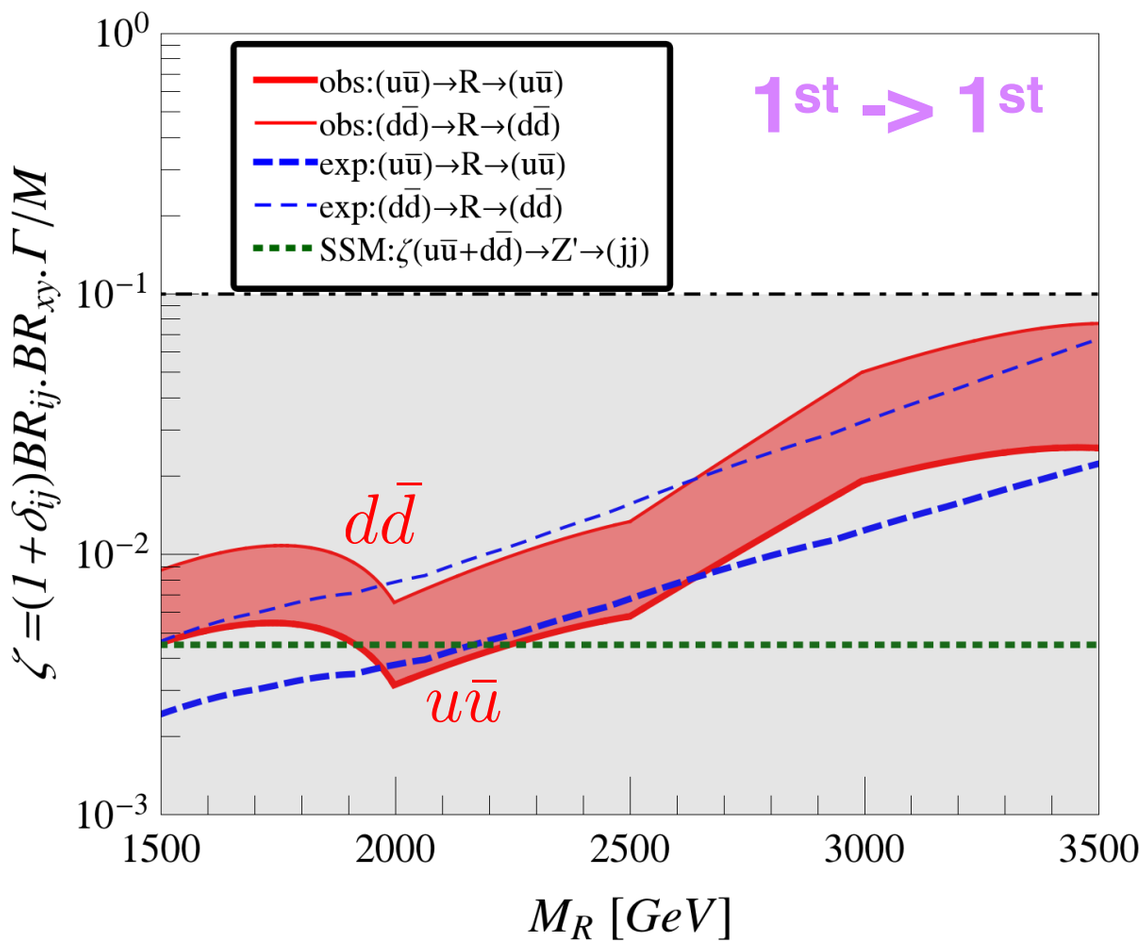
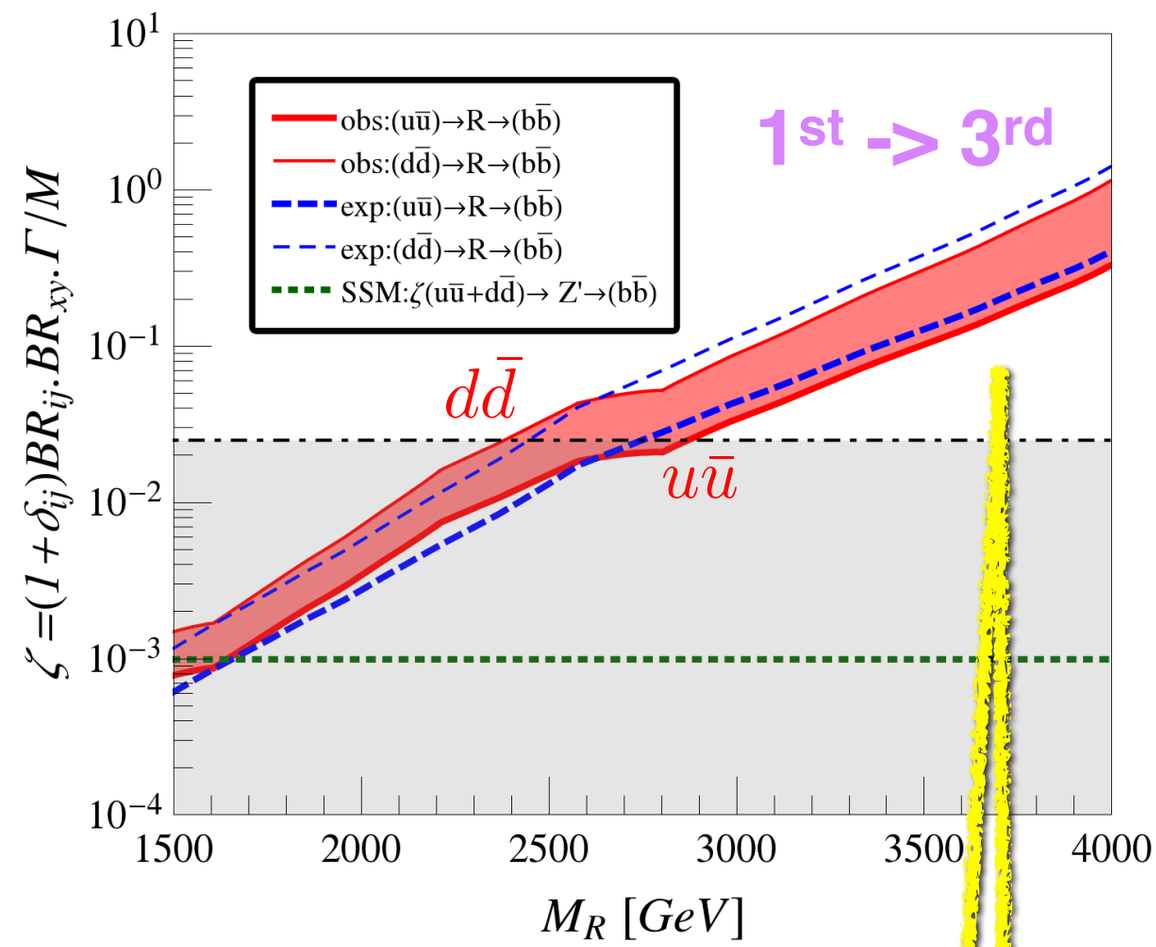
Leptophobic Vector Resonance in Dijets





band indicates range between Resonance (R) coupling only to up-type and only to down-type quarks

Sequential SM Z'

data not constraining high-mass region

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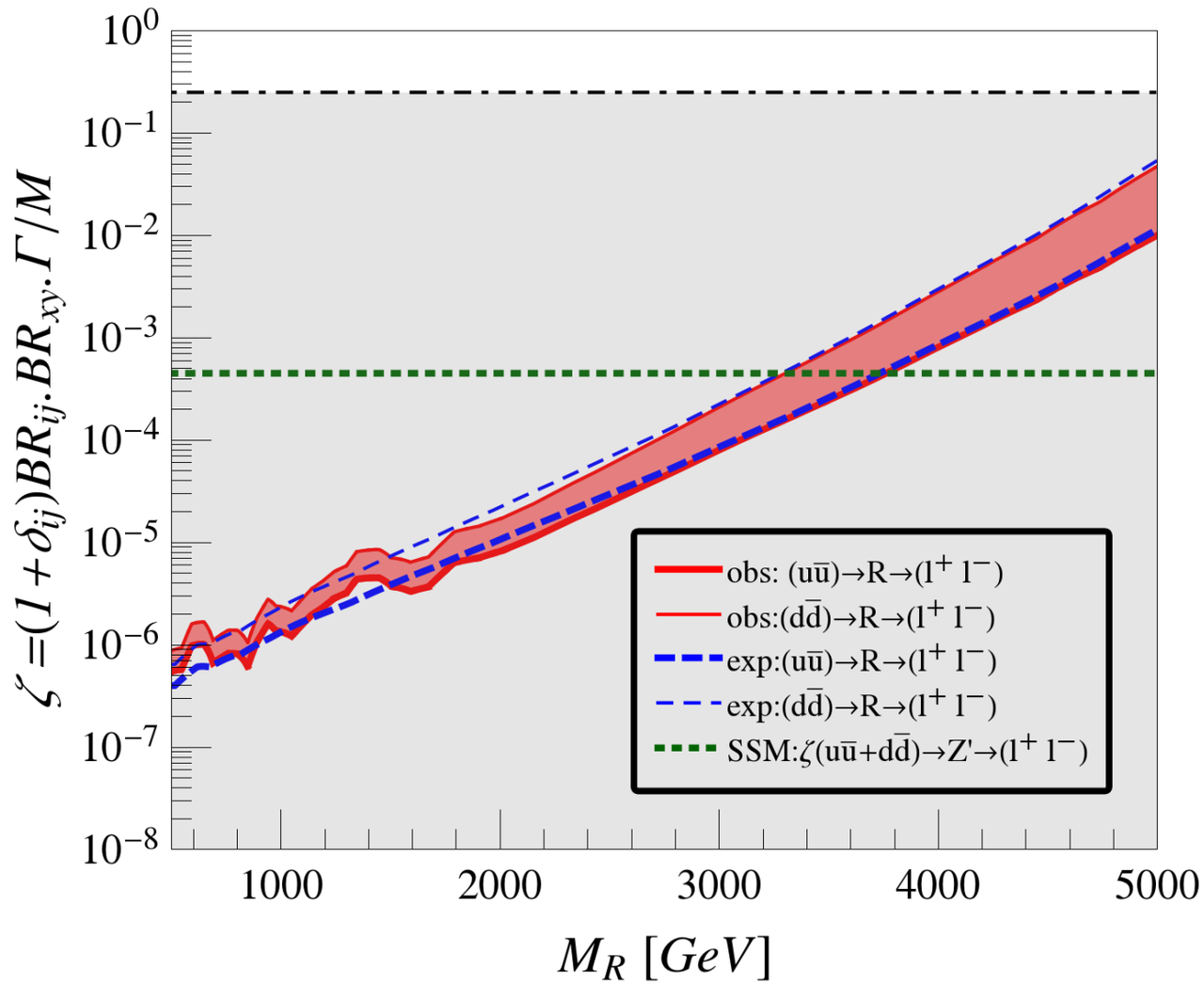
Vector Resonance in Dilepton Channel



band indicates range between Resonance (R) coupling only to up-type and only to down-type quarks

In the dilepton channel, Sequential SM Z' is excluded below ~3.5 TeV

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Conclusions

A simplified resonance model based on the narrow width approximation yields

Simplified Limits:

model-independent bounds on

$\zeta = BR_i \, BR_f \, \Gamma/M$

for different production mechanisms.

Benefits of the Simplified Limits approach:

- focus on model classes ⇔ production mechanisms
- straightforward to identify
  - exclusion limits on BSM resonances
  - whether data is constraining a given channel
  - if a class of models is relevant for a given excess
  - if a specific instance of that class is consistent with an observed excess
- ζ derives directly from model parameters

If the LHC experiments report results in terms of ζ, as well as in terms of σ*BR, **it will speed and deepen our understanding of new findings.**