About the possibility of non-resonance explanation for 750GeV $\gamma\gamma$

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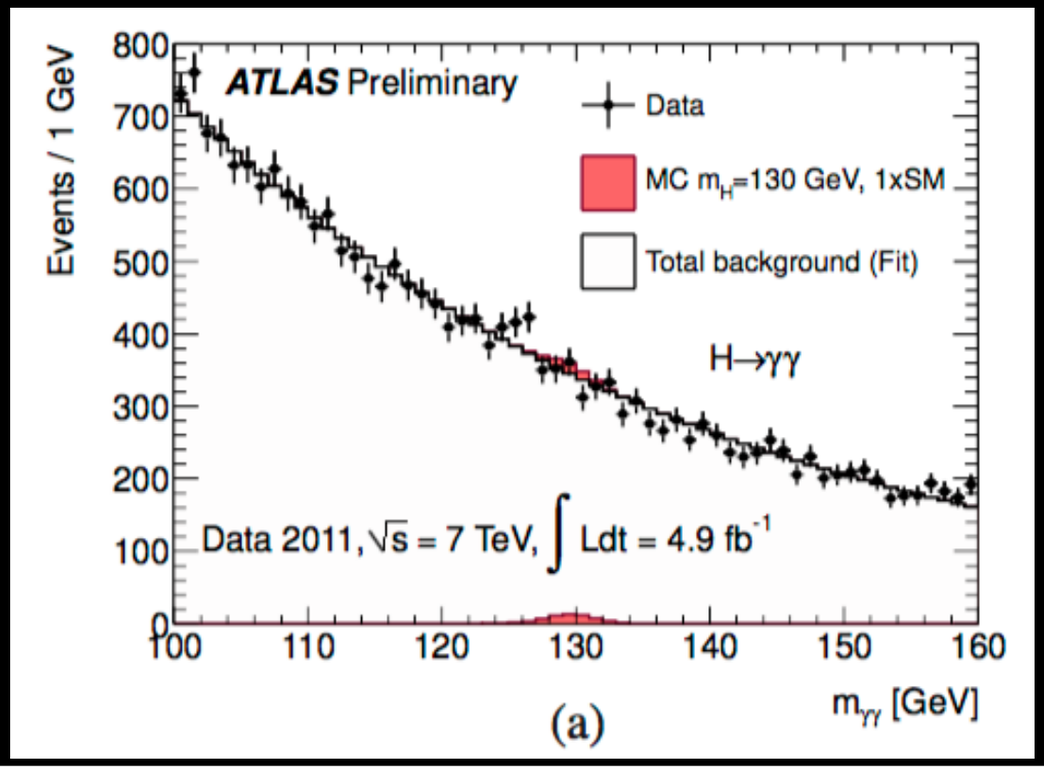
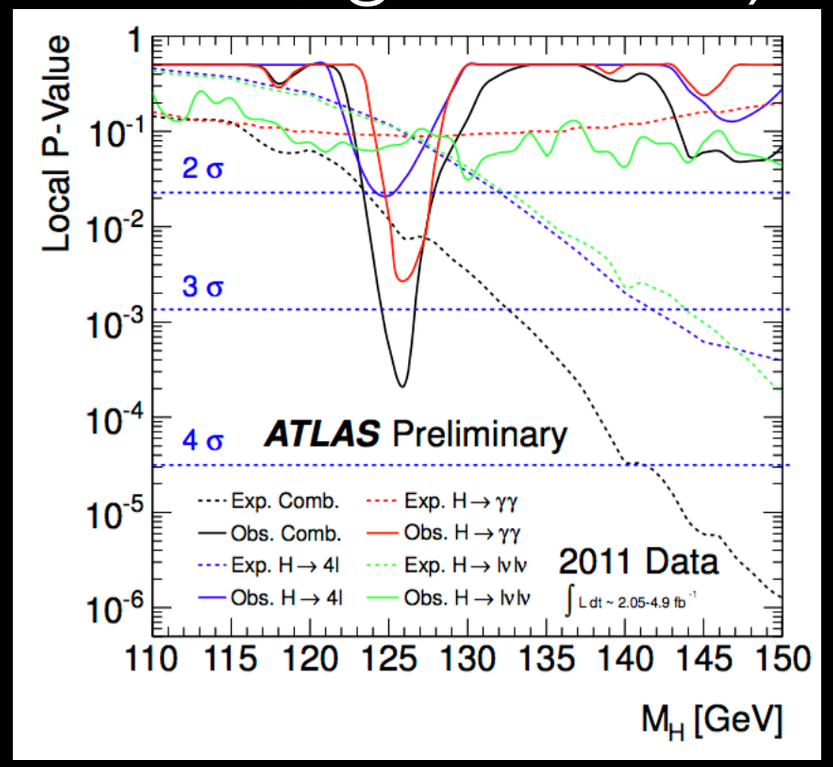
arXiv:1512.06824v2 (PRL 116,151805)

IBS-SNU Joint Workshop on Particle physics

HIGGS 2011

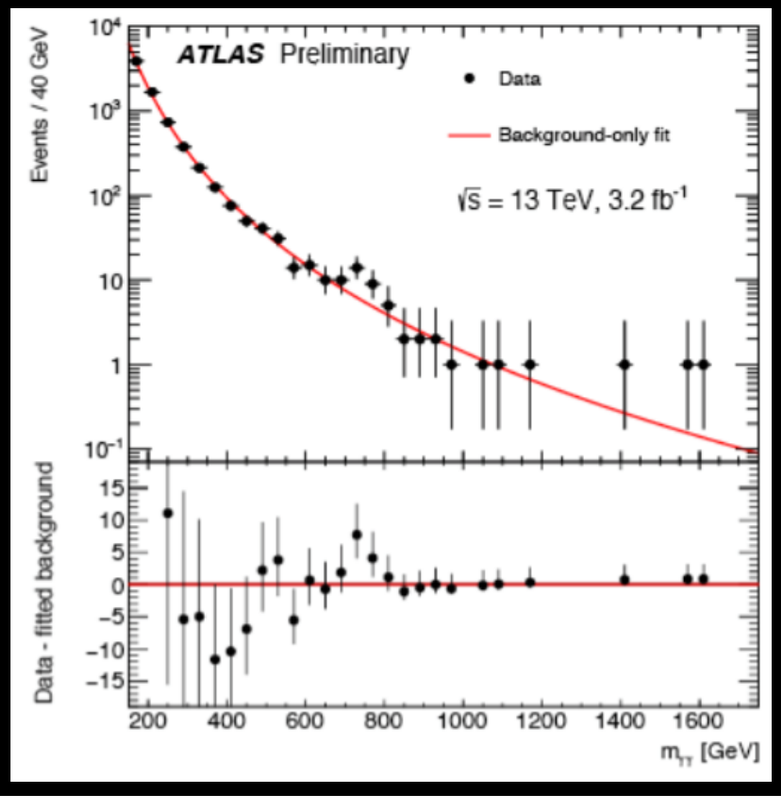
Local significance: 2.8 (combined 3.6, global 2.3)

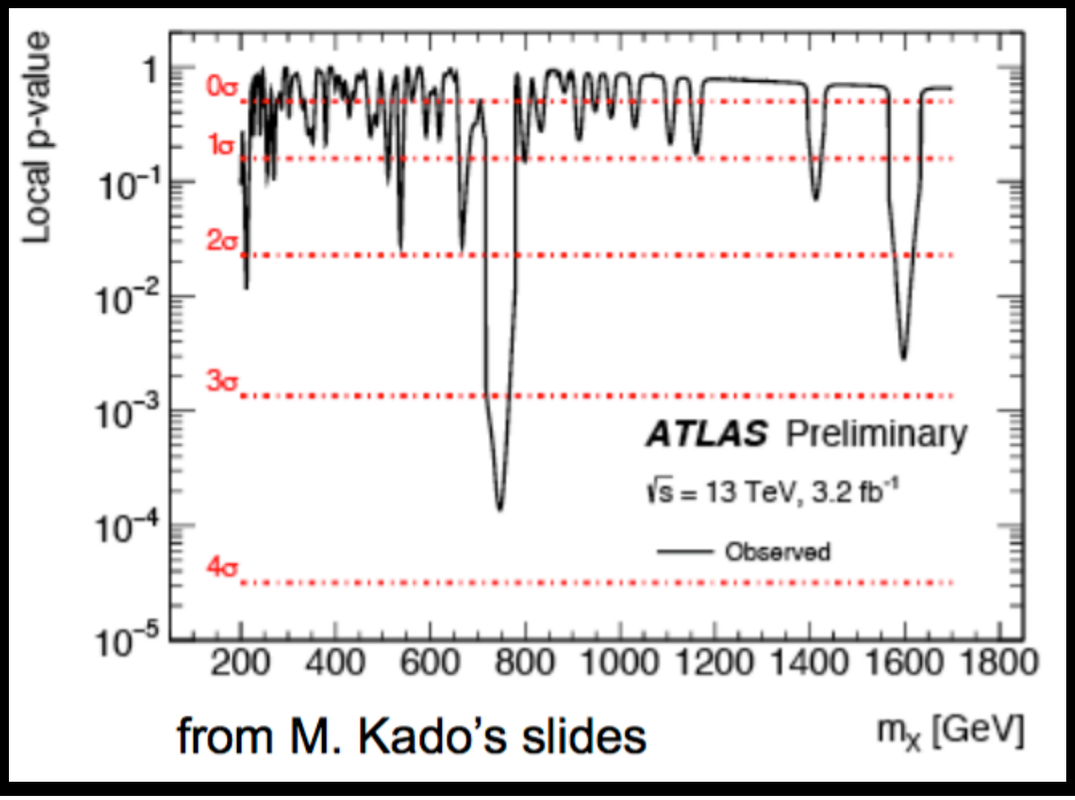




SOMETHING 2016

Local significance: 3.9 (global 2.0)





IDEAS (Recipe) to make a simple model

- Initial parton: (Gluon , heavy flavoured quark, photon)

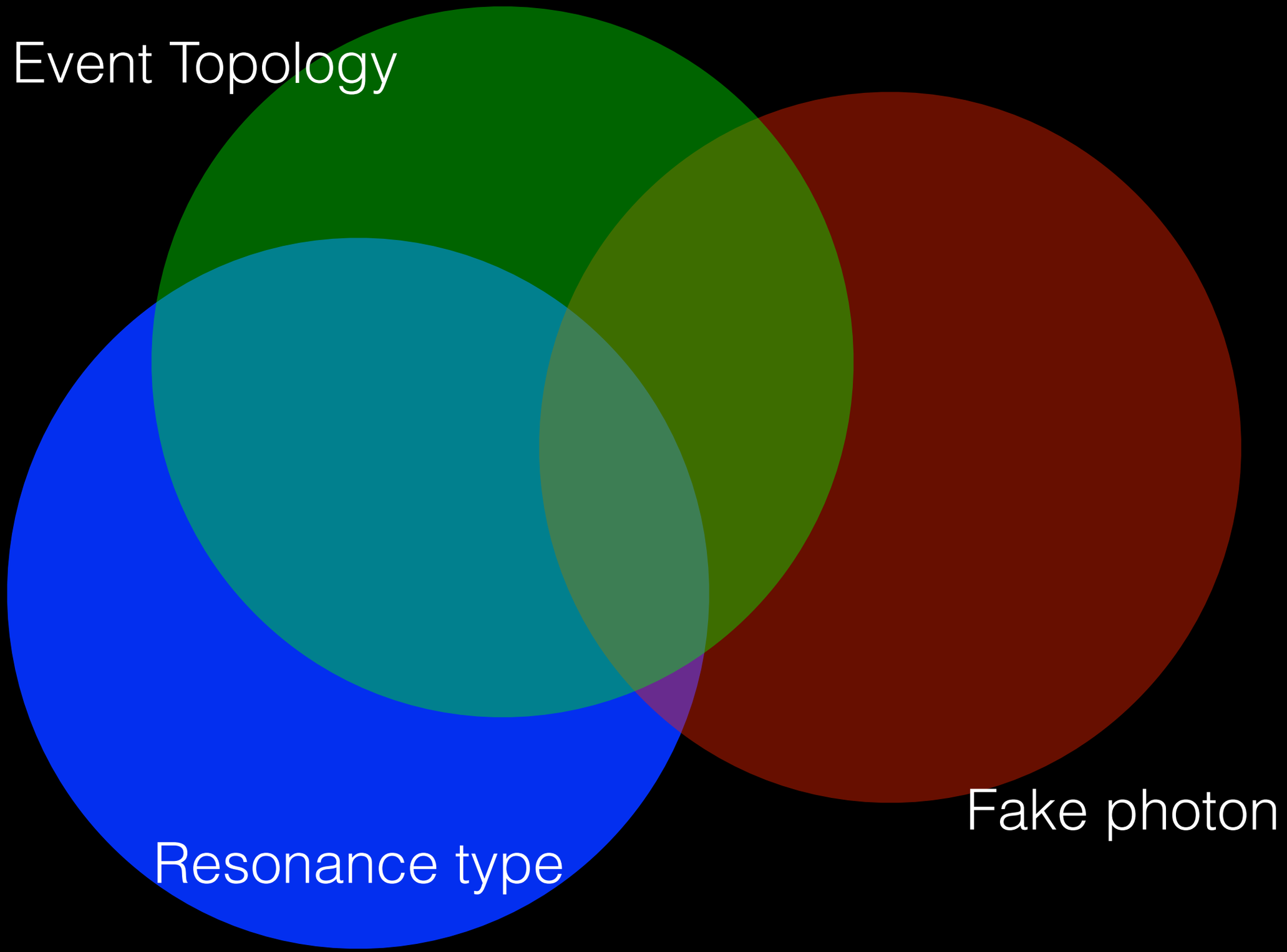
- Resonance type : Spin 0, Spin 2, Bound states

- Event Topology: Simple resonance
  “One step” resonance

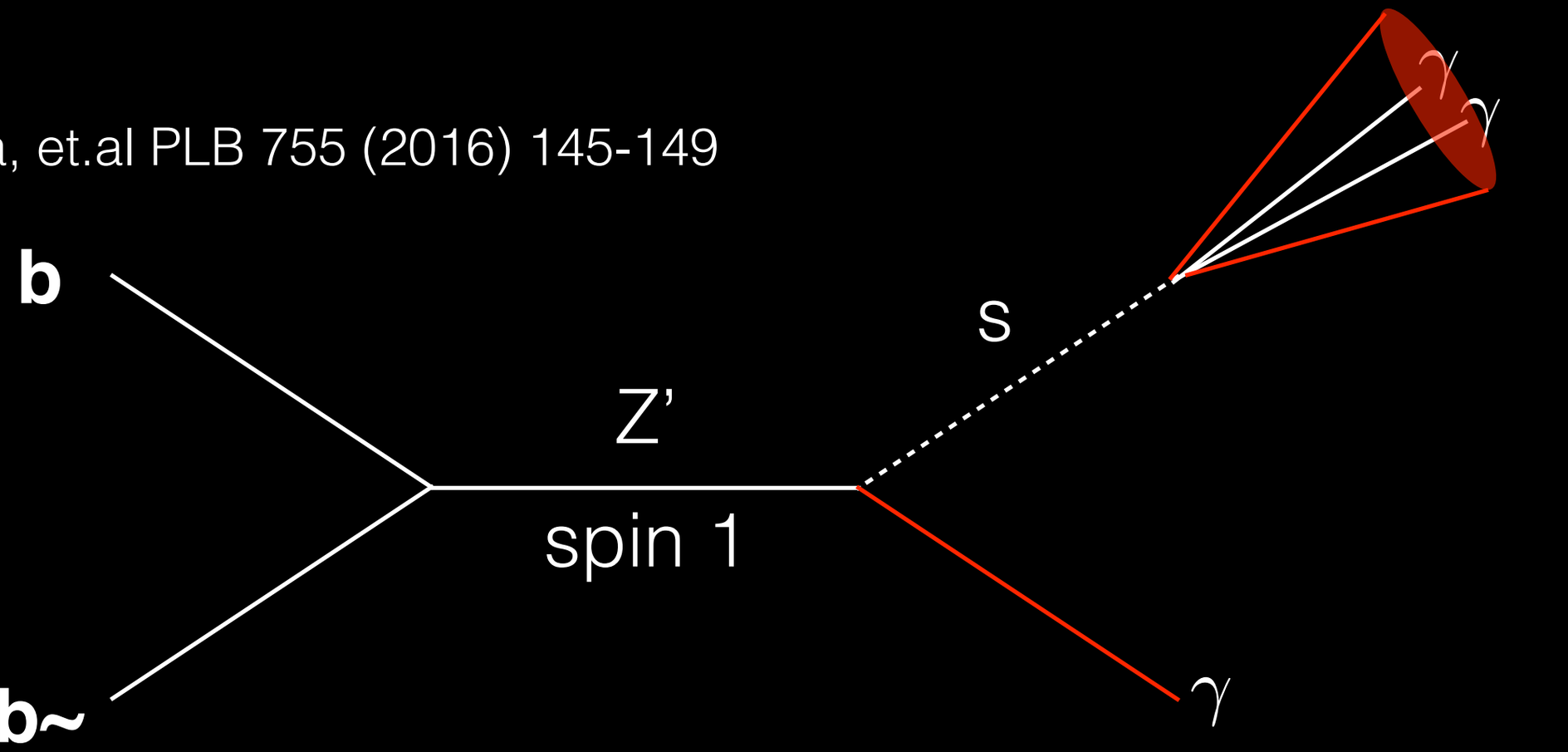
- Fake photon: photon-jet
  Displaced electron-jet

Combine ingredients

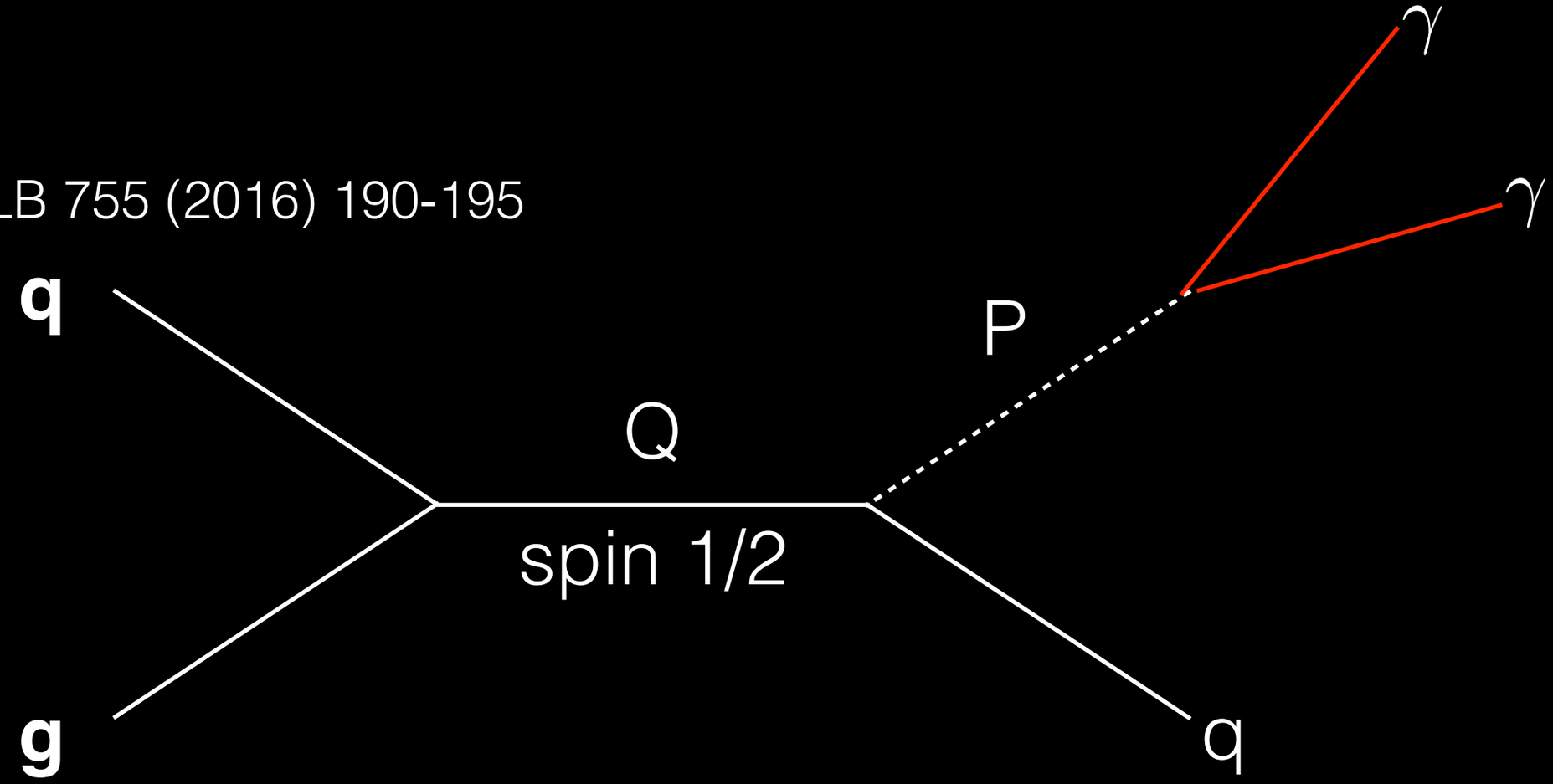
Event Topology



Mikael Chala, et.al PLB 755 (2016) 145-149



Jihn E. Kim PLB 755 (2016) 190-195



Have we missed something?

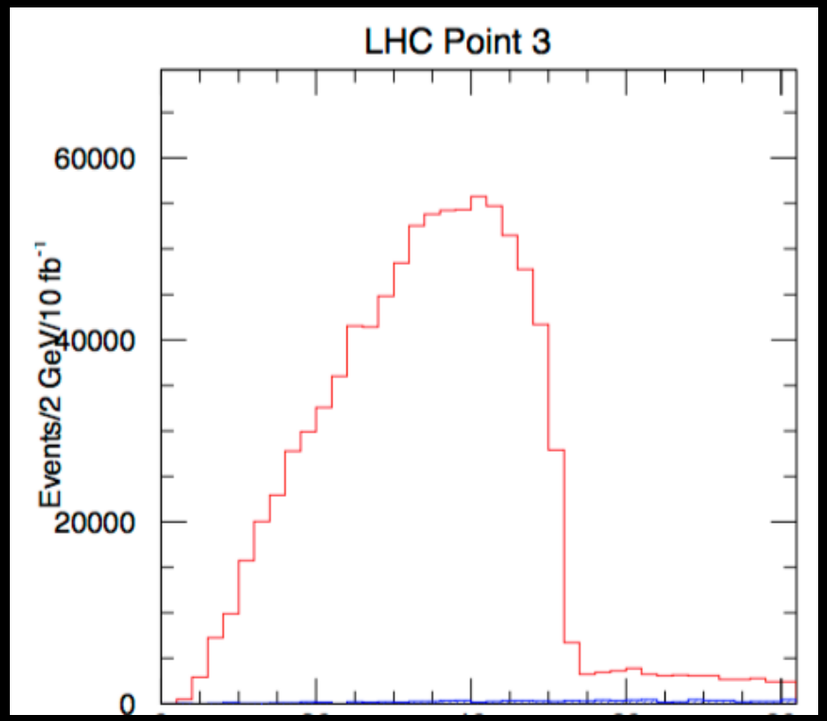
- To be model-independent way, we will do bottom- up approach (“simplified model”)
- Two photons + “non-photonic” particles (χ)
- We will focus on the **wide-width** case (not easy to get with resonance scenario)

$$\sigma(pp \to S \to \gamma\gamma) \sim c_{gg} \frac{1}{M_S} \frac{\Gamma_{gg}\Gamma_{\gamma\gamma}}{\Gamma}$$

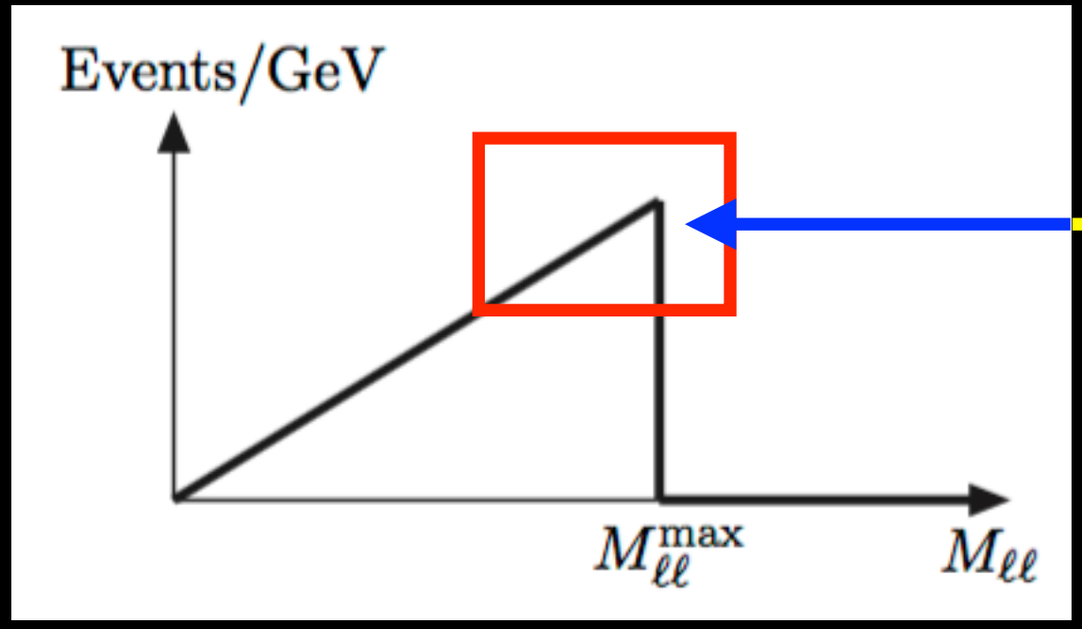
A large width requires “BIG”-couplings

e.g.) Minho Son, Alfredo Urbano arXiv:1512.08307

A classic SUSY di-lepton example



$$\tilde{N}_2 \to \ell\tilde{\ell} \to \ell\ell\tilde{N}_1$$



It looks like the **WIDE PEAK** :)

- We consider **all possible** cases of the diphoton+ Xs

All possible cases with two photon +X

- We focus on the two photons + Non photonic particles
- There would be lots of cases to give two photon+MET

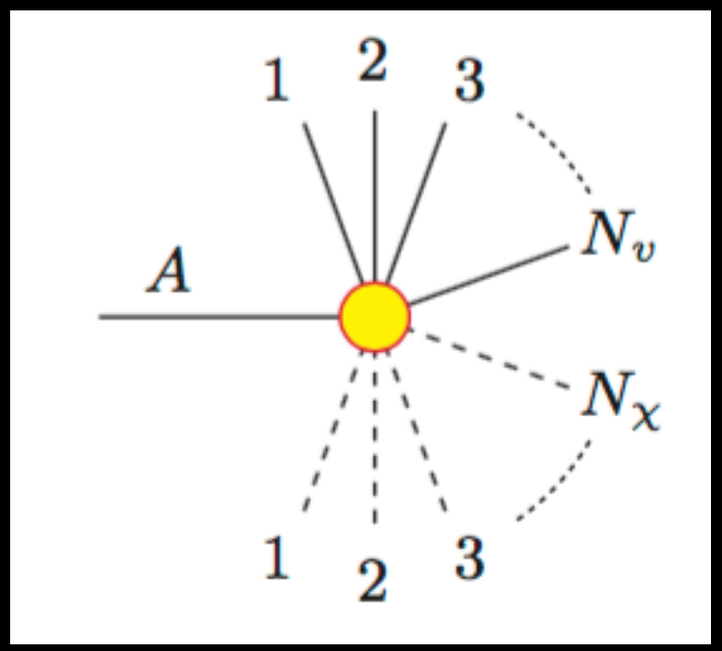
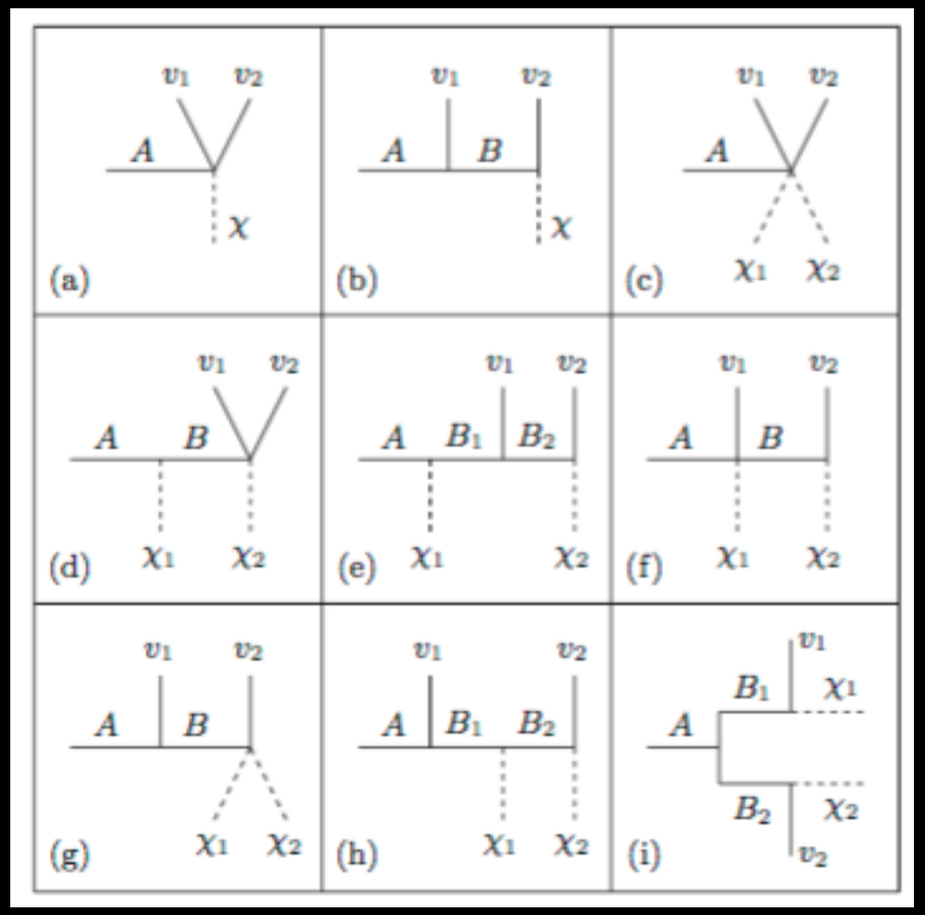


TABLE I. The number of inequivalent event topologies as a function of $1 \leq N_v \leq 4$ and $1 \leq N_\chi \leq 5$.

	N_χ				
N_v	1	2	3	4	5
1	1	2	4	8	16
2	2	7	20	55	142
3	4	20	78	270	860
4	8	55	270	1138	4294

All possible cases with two photon +X

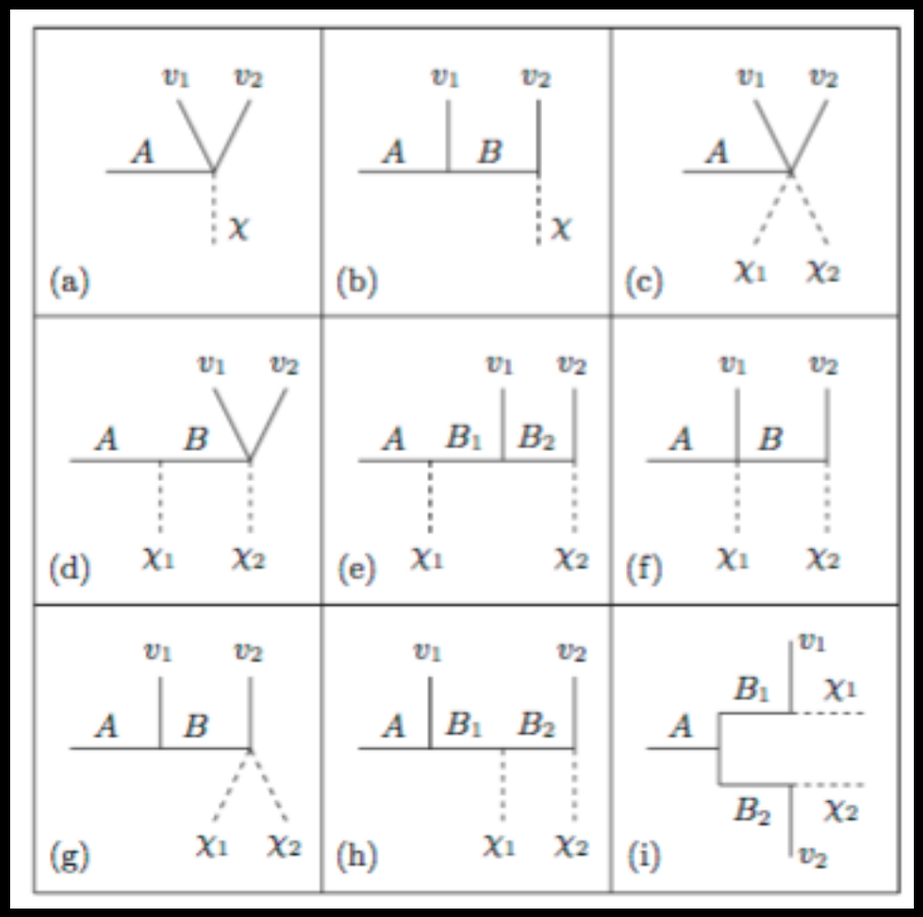


MP, Won Sang Cho, Doojin Kim, K. Matchev
PRL 112, 211801 (2014)

- The nine cases with two photons+ up to two Non-photonic particles.

- What do we need to consider ?
  1. Choose the rather **NARROW** width :)
  2. Sum of photon-pt

Choosing Narrow Width

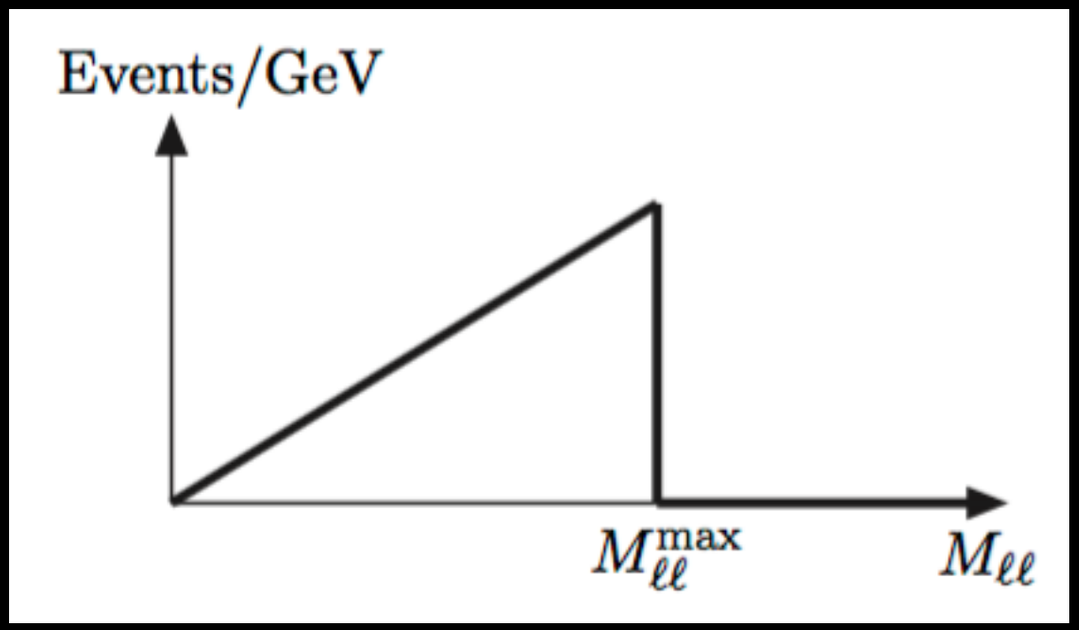


- The phase space of 9 diagrams can be categorised by

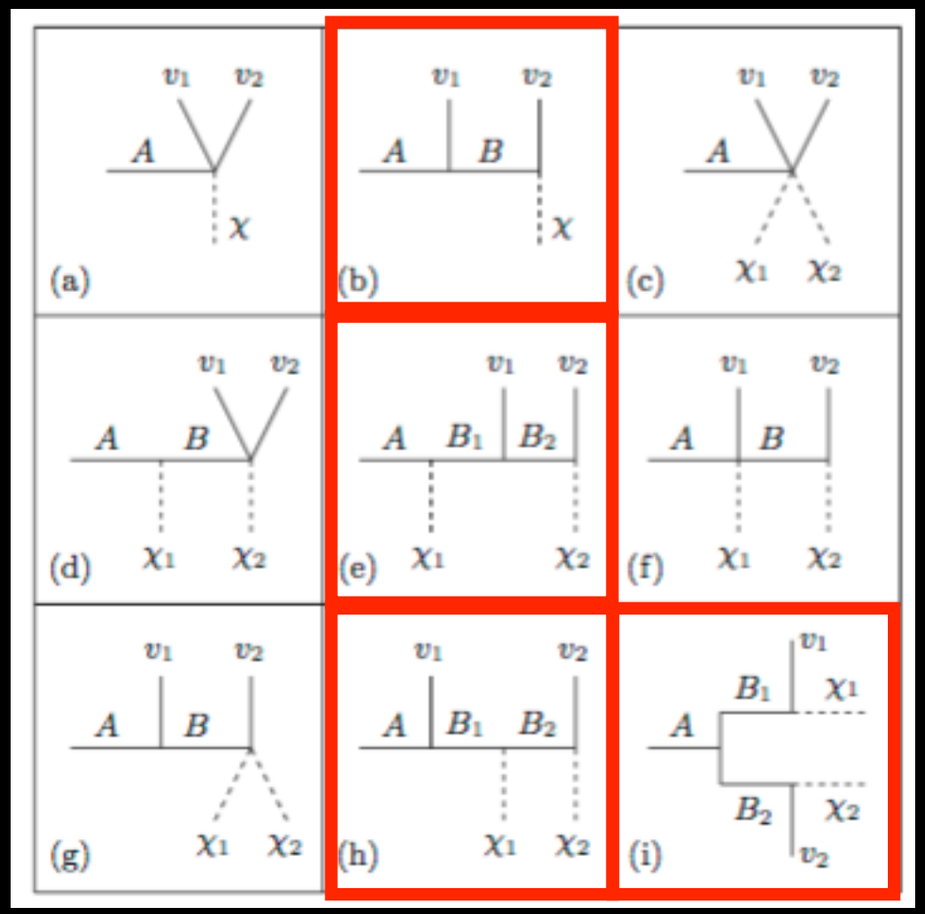
  1. **P/E**: The Relative position of P (peak) to the E (Endpoint).

  2. **R_2** : (Curvature around a peak, the related one with "**width**")

$$R_2 \equiv -\left(\frac{m^2}{f(m)}\frac{\mathrm{d}^2 f(m)}{\mathrm{d}m^2}\right)_{m=P}$$



Choosing Narrow Width



MP, Won Sang Cho, Doojin Kim, K. Matchev
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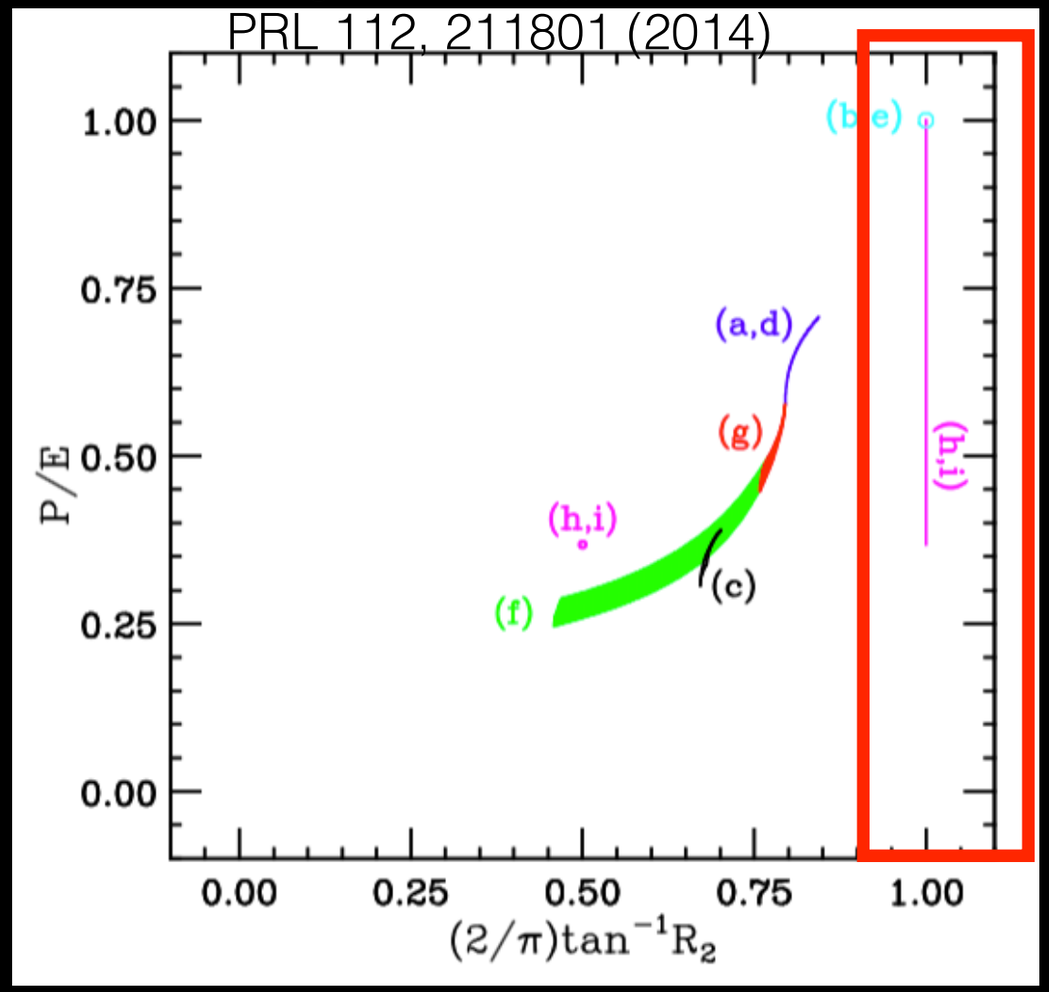
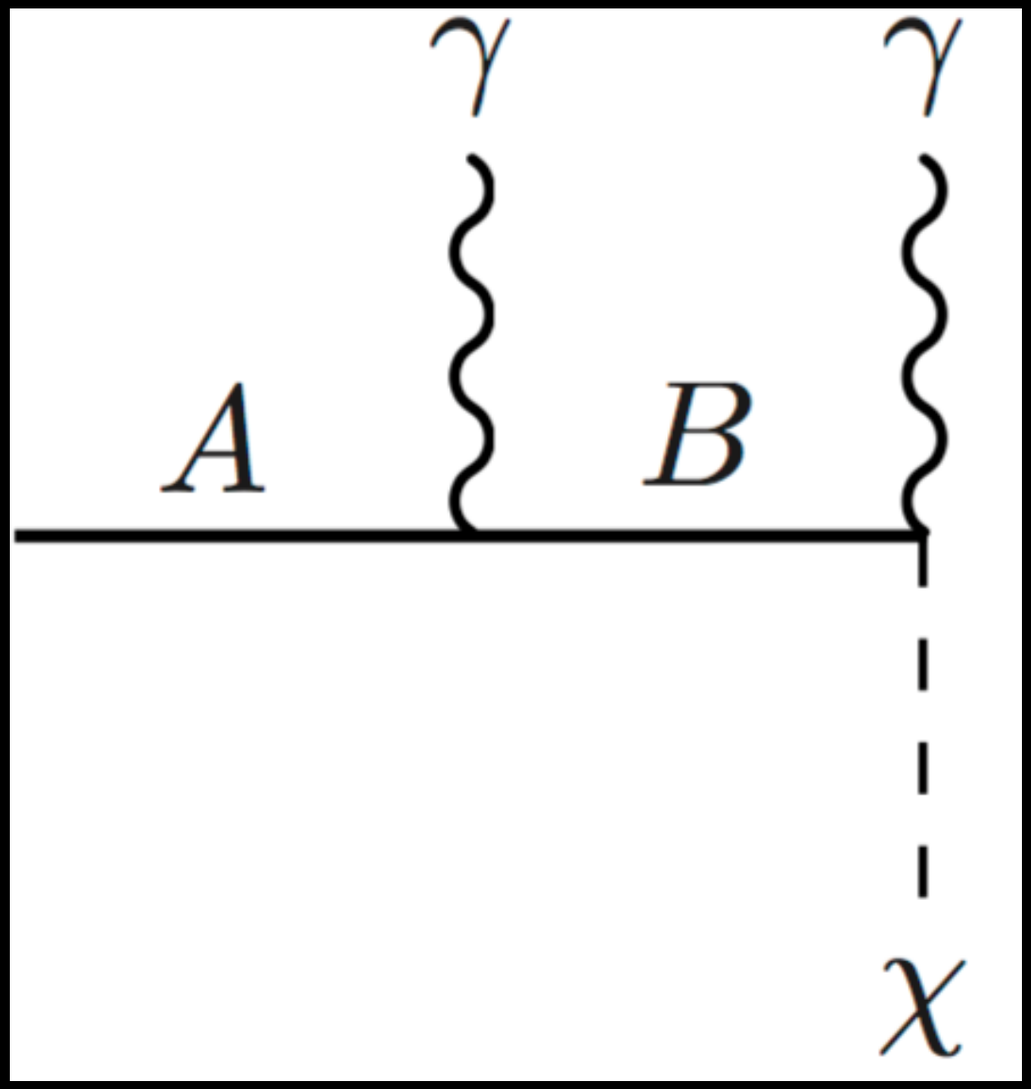


- (b) & (e): 2-Step cascade decay
- (h) : A cascade with an invisible between two photons,
  We call “Sandwich” topology
- (i) : “Antler” topology

2-step cascade



$$f(m) \sim m$$

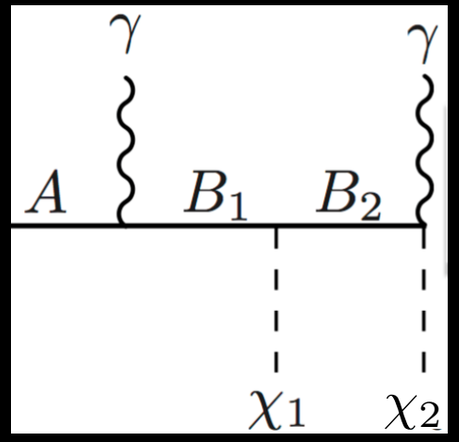
$$E = \sqrt{(M_A^2 - M_B^2)(M_B^2 - M_\chi^2)/M_B^2}$$

- The famous triangular shape : One parameter, E

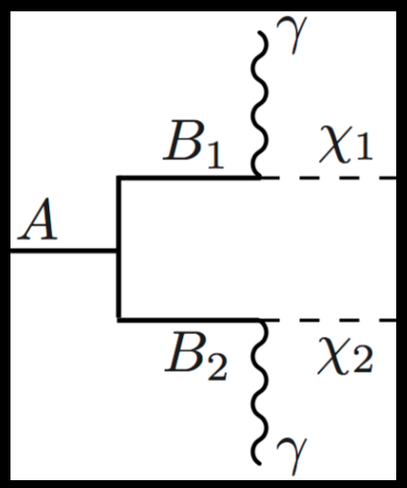
Sandwich and Antler

- The phase space structure of Sandwich and of Antler are the **same** ! (Only two parameters, eta and E)

$$f(m) \sim \begin{cases} \eta\, m\,, & 0 \le m \le e^{-\eta} E, \\ m \ln(E/m)\,, & e^{-\eta} E \le m \le E, \end{cases}$$

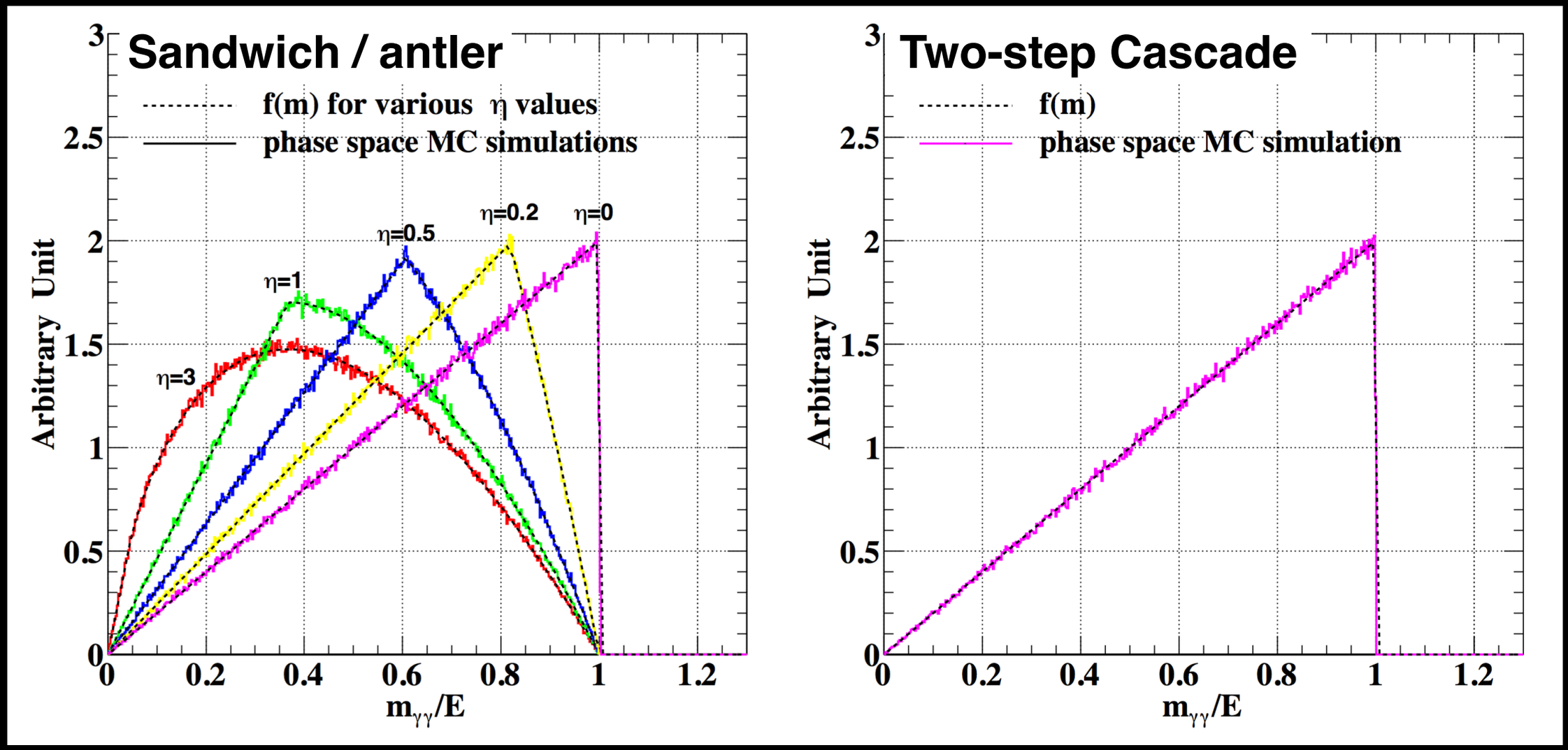


$$\begin{aligned} E &= \sqrt{e^{\eta}(M_A^2 - M_{B_1}^2)(M_{B_2}^2 - M_{\chi_2}^2)/(M_{B_1} M_{B_2})}\,, \\ \eta &= \cosh^{-1}\left[(M_{B_1}^2 + M_{B_2}^2 - M_{\chi_1}^2)/(2 M_{B_1} M_{B_2})\right]. \end{aligned}$$



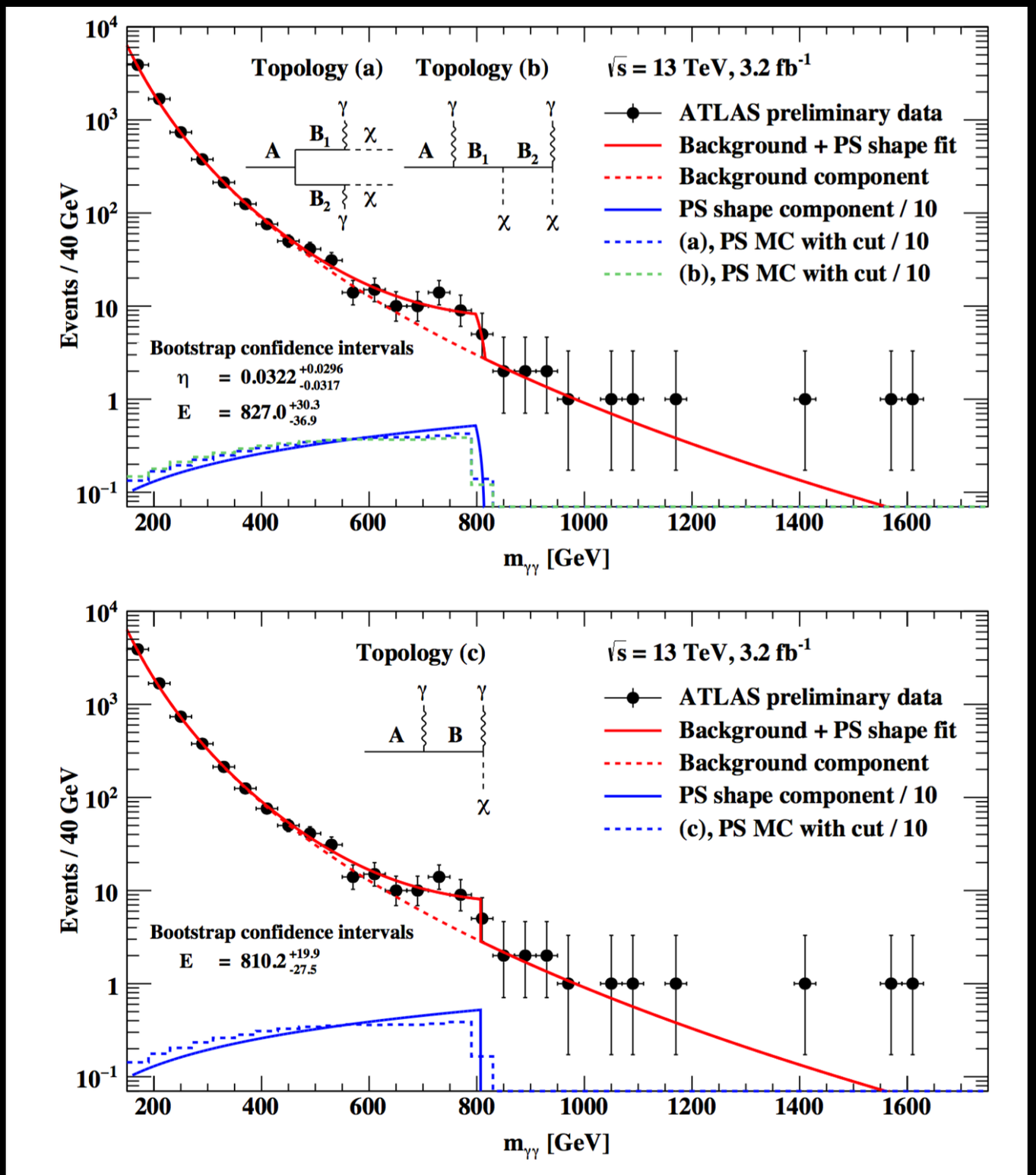
$$\begin{aligned} E &= \sqrt{e^{\eta}(M_{B_1}^2 - M_{\chi_1}^2)(M_{B_2}^2 - M_{\chi_2}^2)/(M_{B_1} M_{B_2})}\,, \\ \eta &= \cosh^{-1}\left[(M_A^2 - M_{B_1}^2 - M_{B_2}^2)/(2 M_{B_1} M_{B_2})\right]. \end{aligned}$$

Invariant mass shape



- Phase space invariant mass shape depends only on two (or one) parameters, that would be good news…

How good are they ?



- We use the ATLAS background function.
- For fit, we also use the theoretical (phase space) functions of the invariant mass distribution.
- Effects from the selection cuts: dotted lines

$$\epsilon_{cut} \times \sigma \simeq 15.80\text{fb}$$

$$(\epsilon_{cut} \times \sigma_{\text{resonance}} \simeq 6 - 10\text{fb})$$

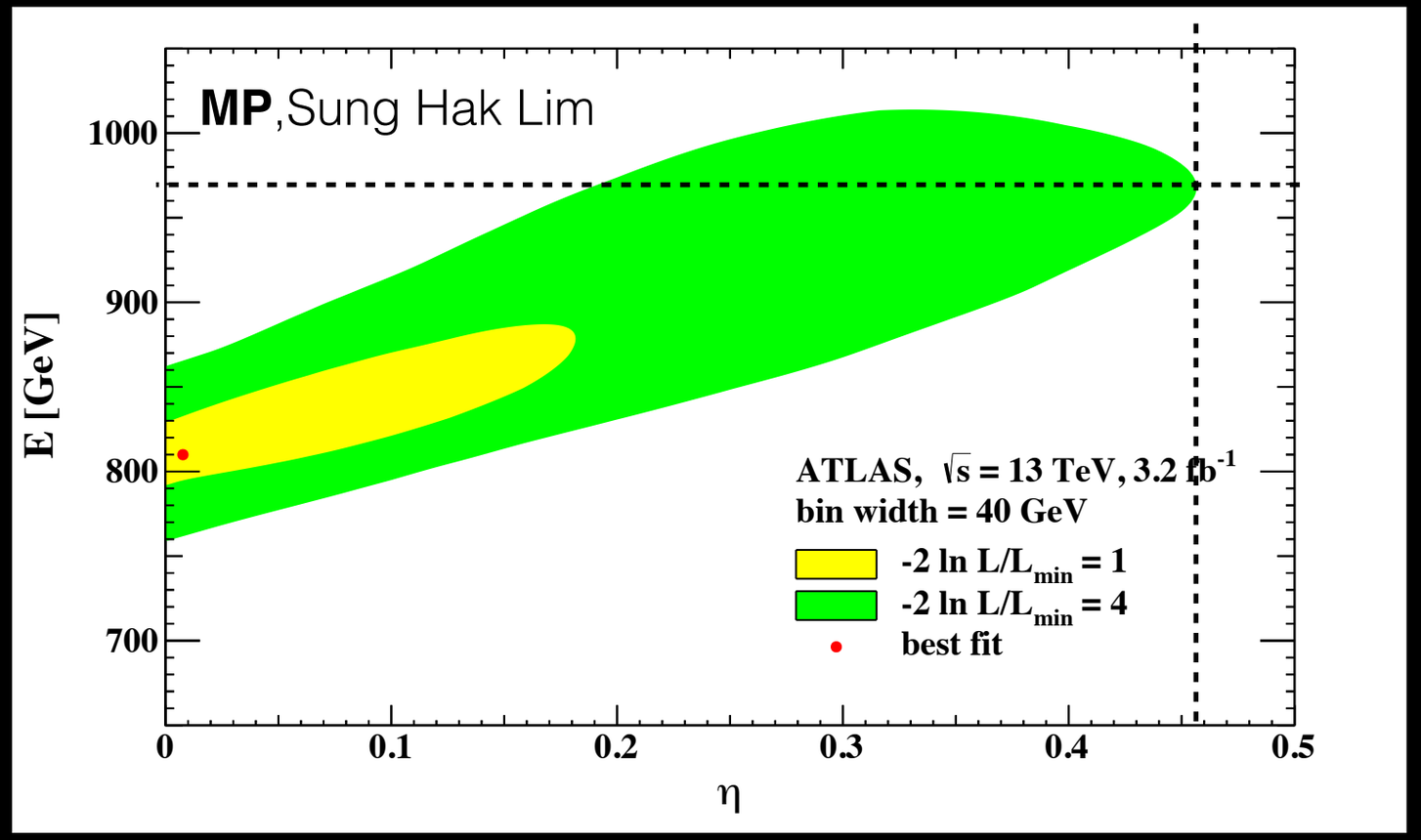
Effects from Decay widths of A, Bs

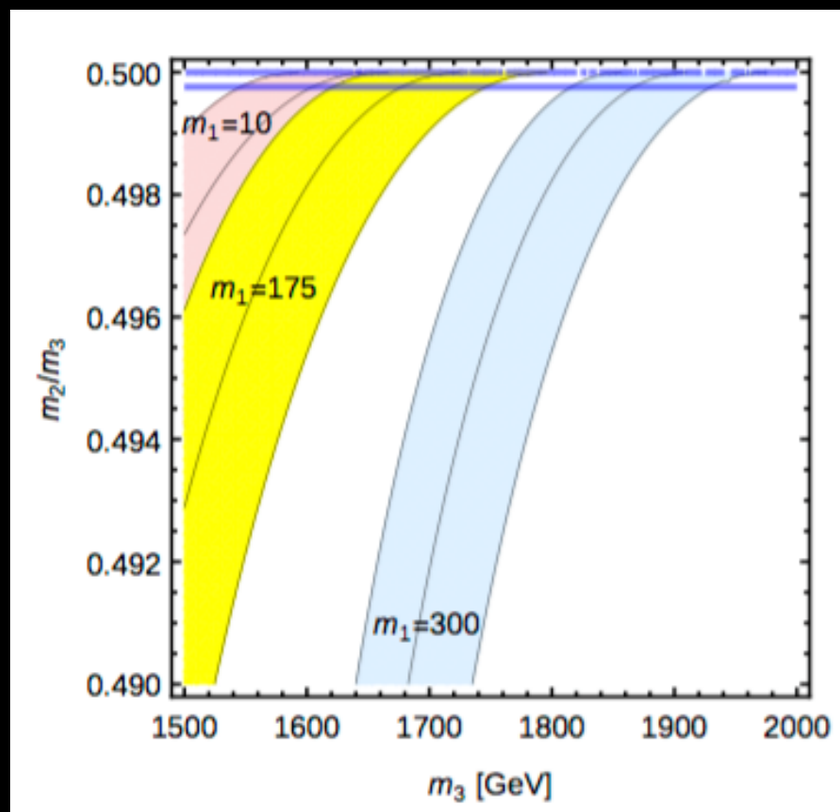
$$E = \sqrt{e^{\eta}(M_{B_1}^2 - M_{\chi_1}^2)(M_{B_2}^2 - M_{\chi_2}^2)/(M_{B_1}M_{B_2})}\,,$$
$$\eta = \cosh^{-1}\left[(M_A^2 - M_{B_1}^2 - M_{B_2}^2)/(2M_{B_1}M_{B_2})\right].$$

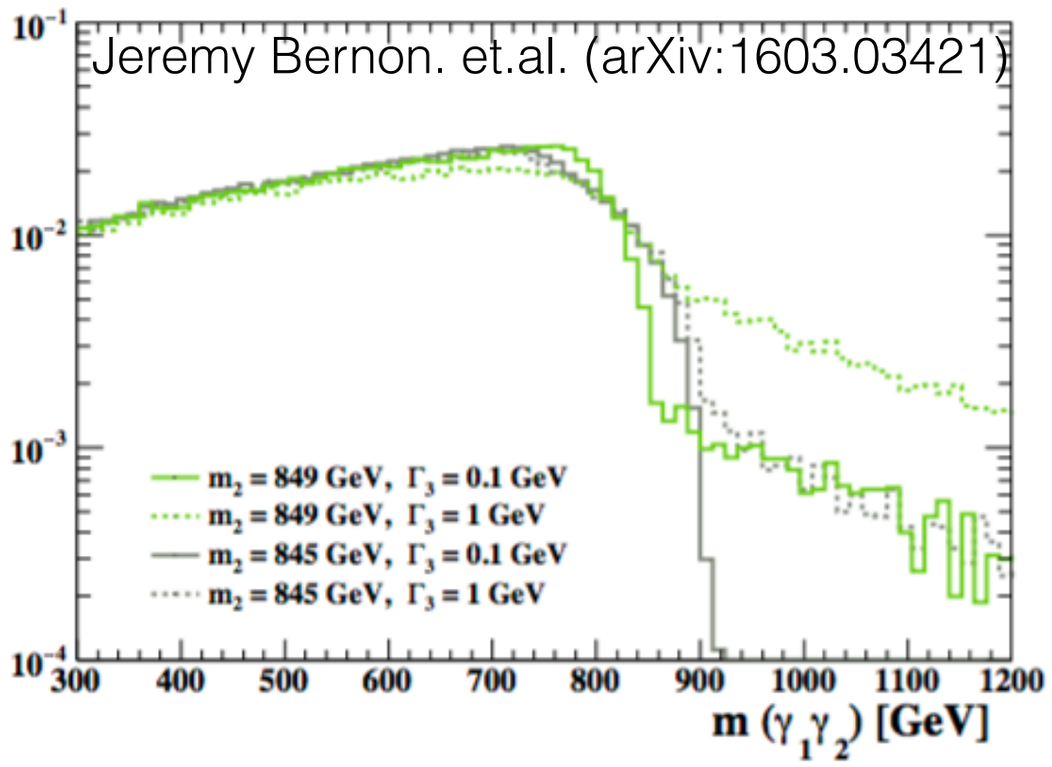
$$\frac{m_B}{m_A}\left(=\frac{m_2}{m_3}\right) \simeq 0.487$$

$$m_B \simeq 828.3\mathrm{GeV}$$

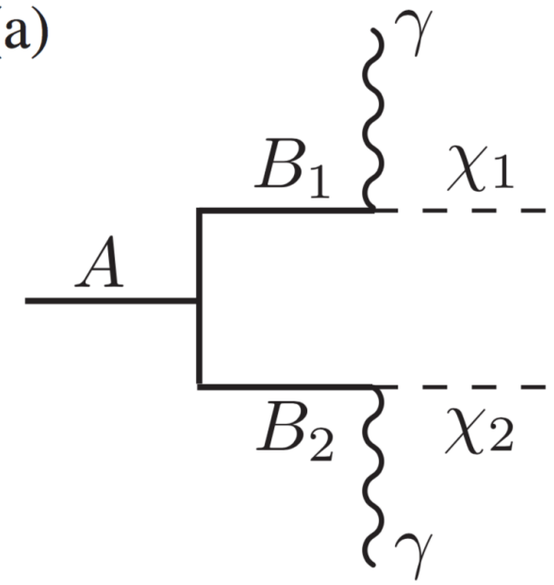
$$(m_A = 1,700\mathrm{GeV})$$

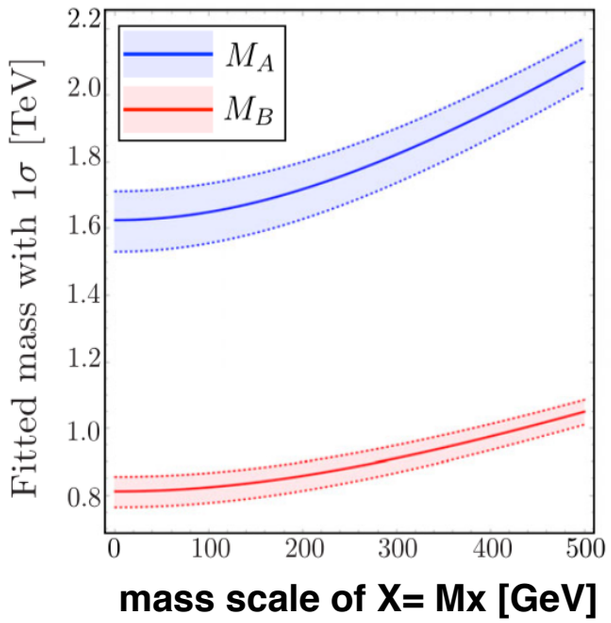


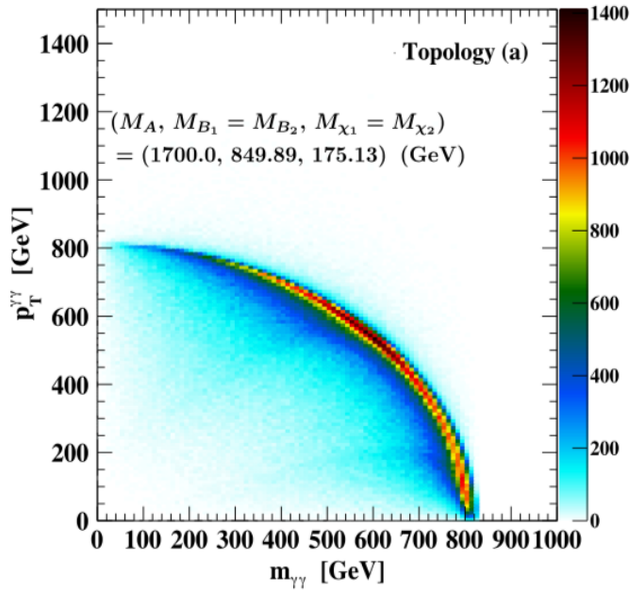




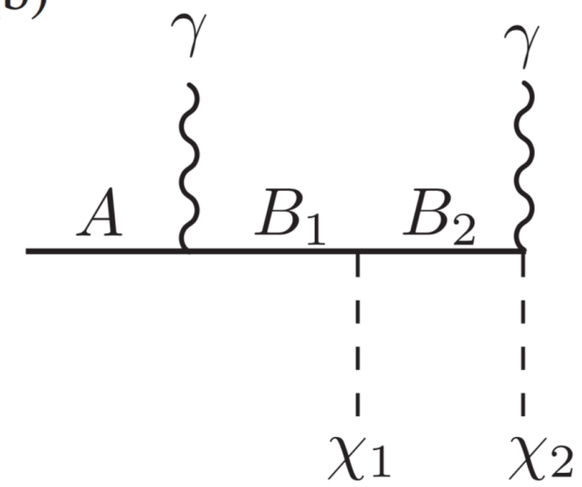
(a)

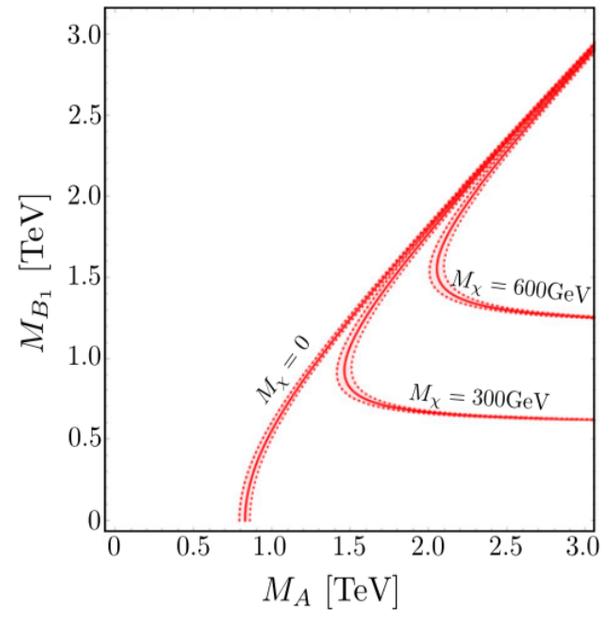

γ
B_1
χ_1
A
B_2
χ_2
γ

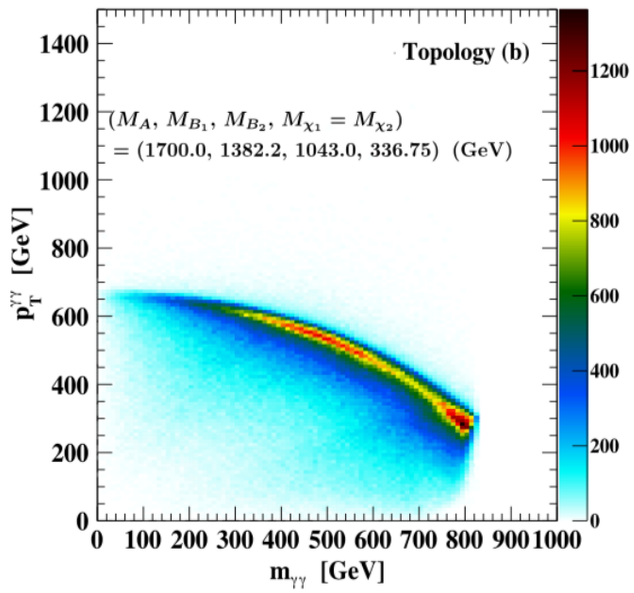

M_A
M_B
Fitted mass with 1σ [TeV]
mass scale of X= Mx [GeV]


Topology (a)
$(M_A, M_{B_1} = M_{B_2}, M_{\chi_1} = M_{\chi_2})$
$= (1700.0, 849.89, 175.13)$ (GeV)
$p_T^{\gamma\gamma}$ [GeV]
$m_{\gamma\gamma}$ [GeV]

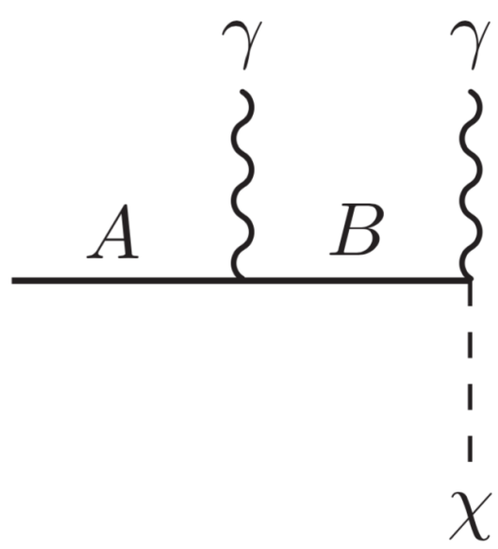
(b)

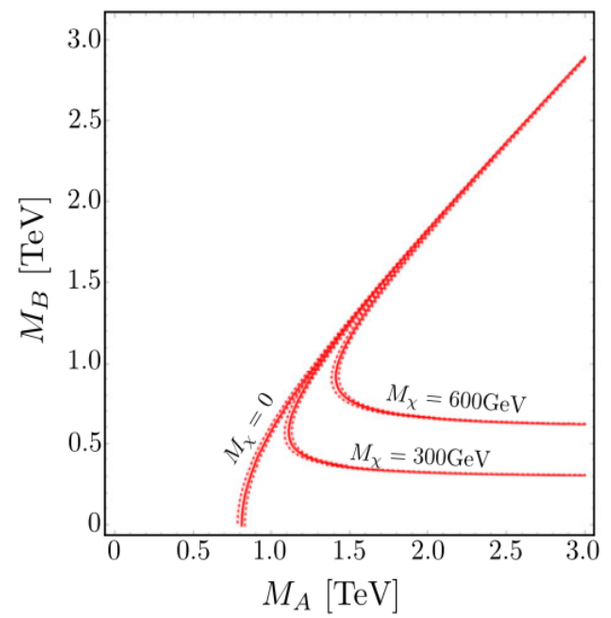

γ
γ
A
B_1
B_2
χ_1
χ_2

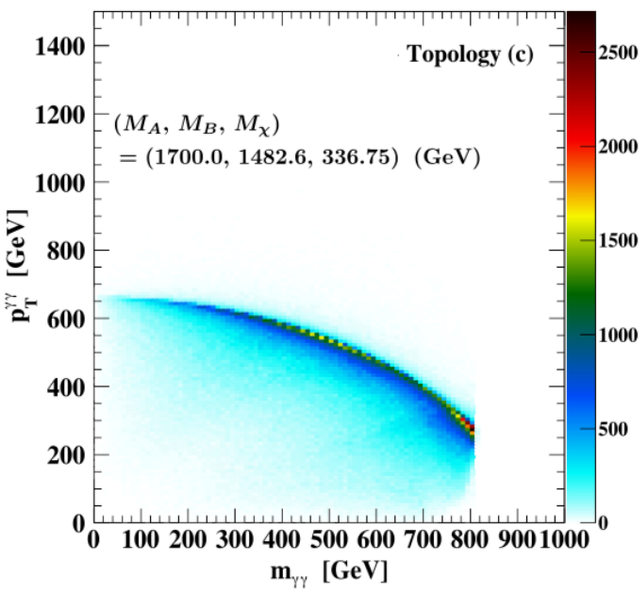

M_{B_1} [TeV]
M_A [TeV]
$M_\chi = 0$
$M_\chi = 600$GeV
$M_\chi = 300$GeV


Topology (b)
$(M_A, M_{B_1}, M_{B_2}, M_{\chi_1} = M_{\chi_2})$
$= (1700.0, 1382.2, 1043.0, 336.75)$ (GeV)
$p_T^{\gamma\gamma}$ [GeV]
$m_{\gamma\gamma}$ [GeV]

(c)

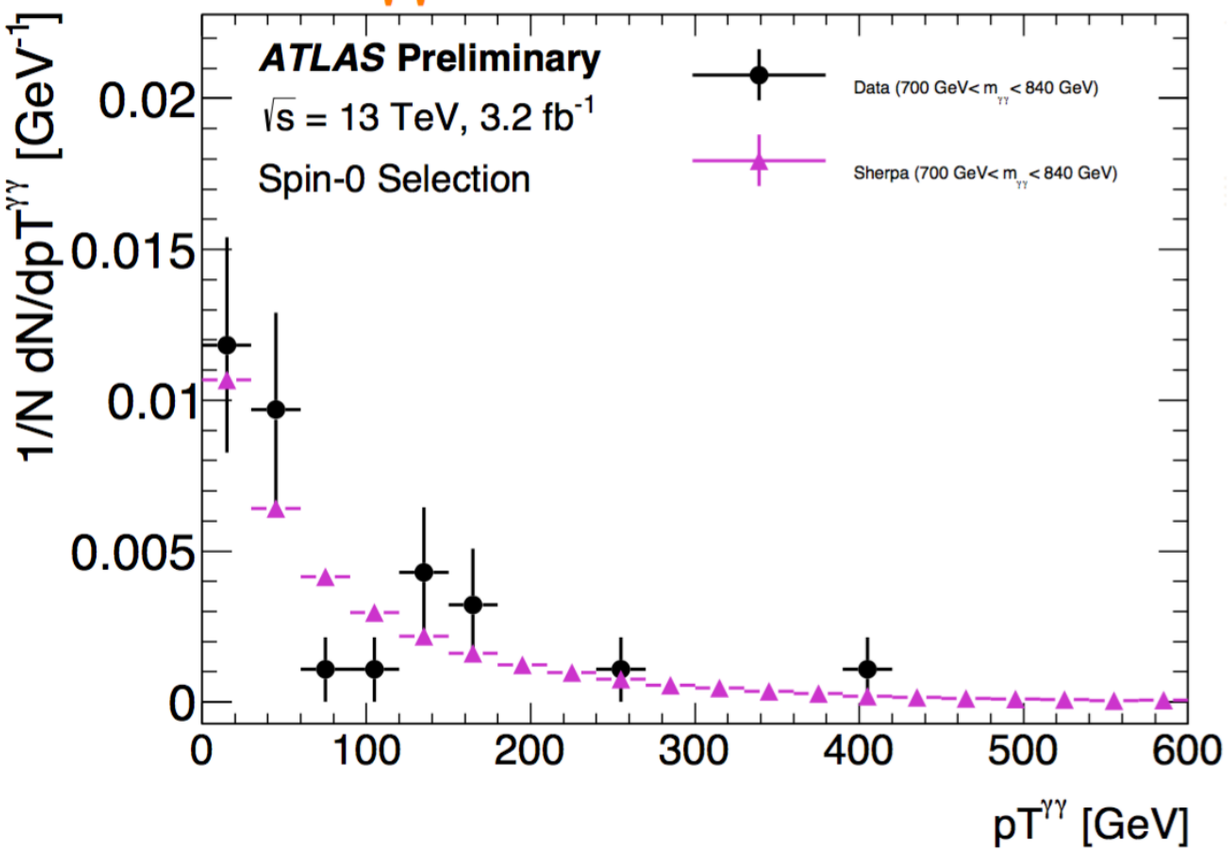

γ
γ
A
B
χ


M_B [TeV]
M_A [TeV]
$M_\chi = 0$
$M_\chi = 600$GeV
$M_\chi = 300$GeV

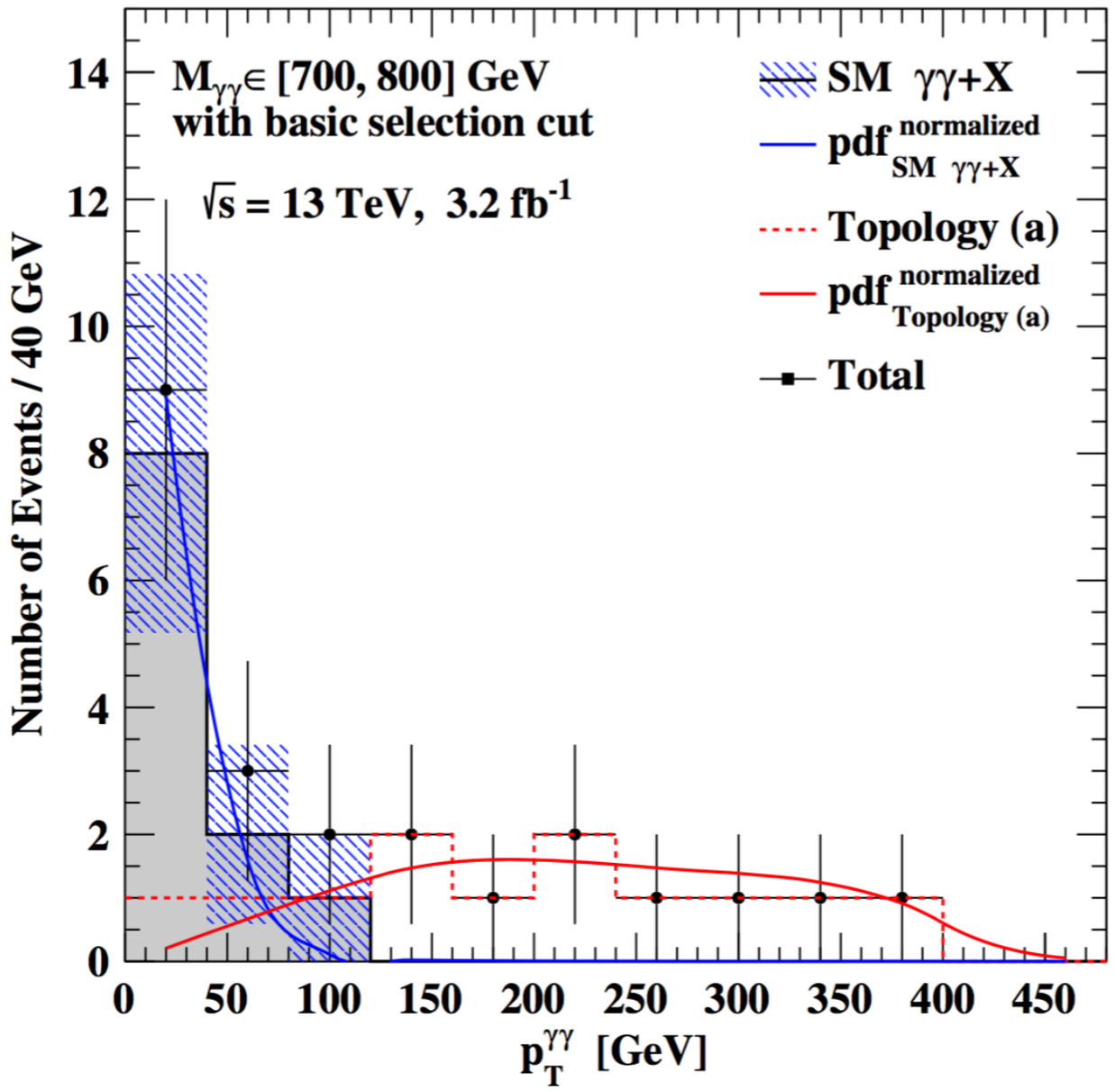

Topology (c)
(M_A, M_B, M_χ)
$= (1700.0, 1482.6, 336.75)$ (GeV)
$p_T^{\gamma\gamma}$ [GeV]
$m_{\gamma\gamma}$ [GeV]

Consistency check for antler topology

$m_{\gamma\gamma}$ = [700-840] GeV

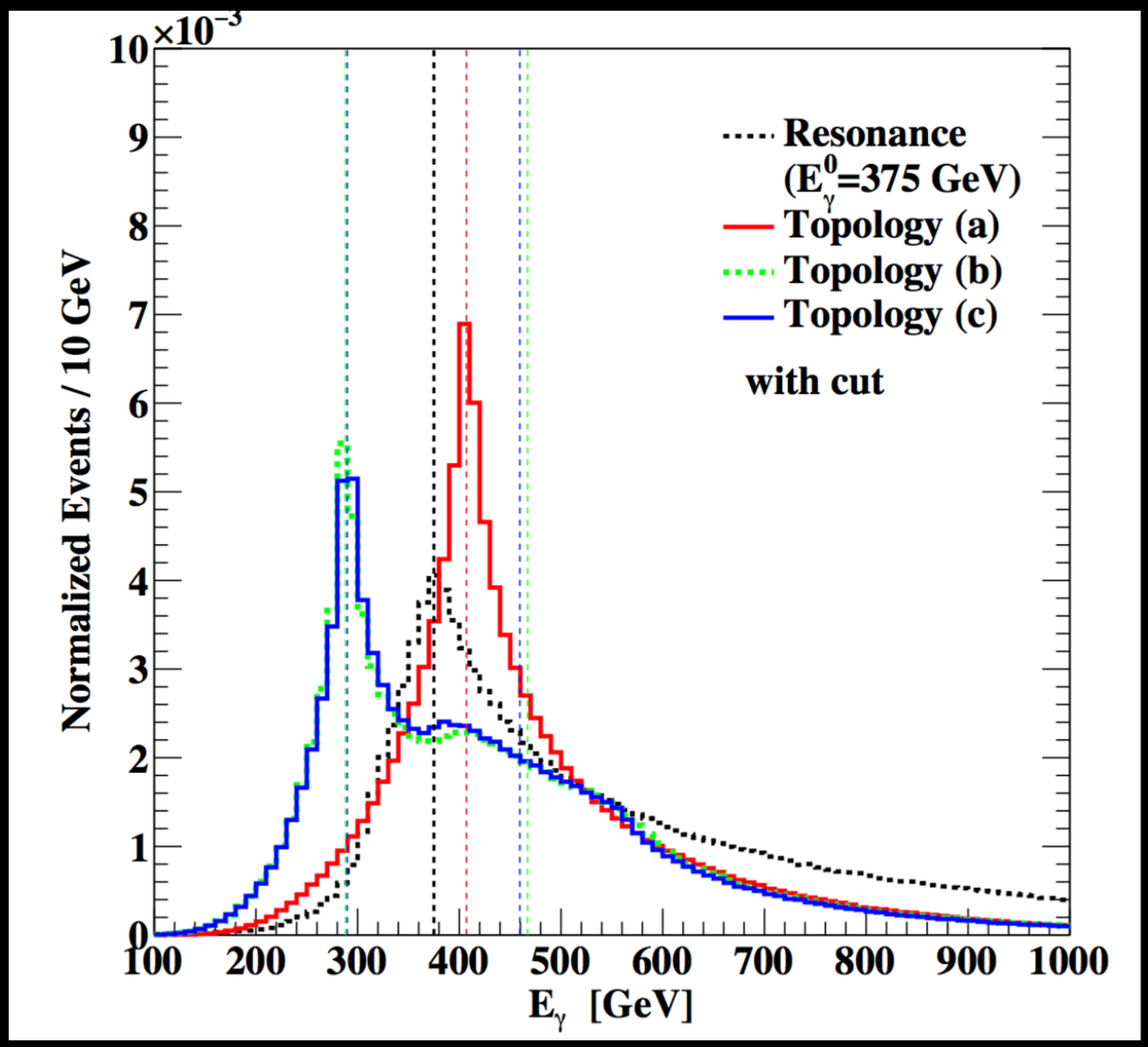


>> P_T(rr) from new released data after Moriond 2016



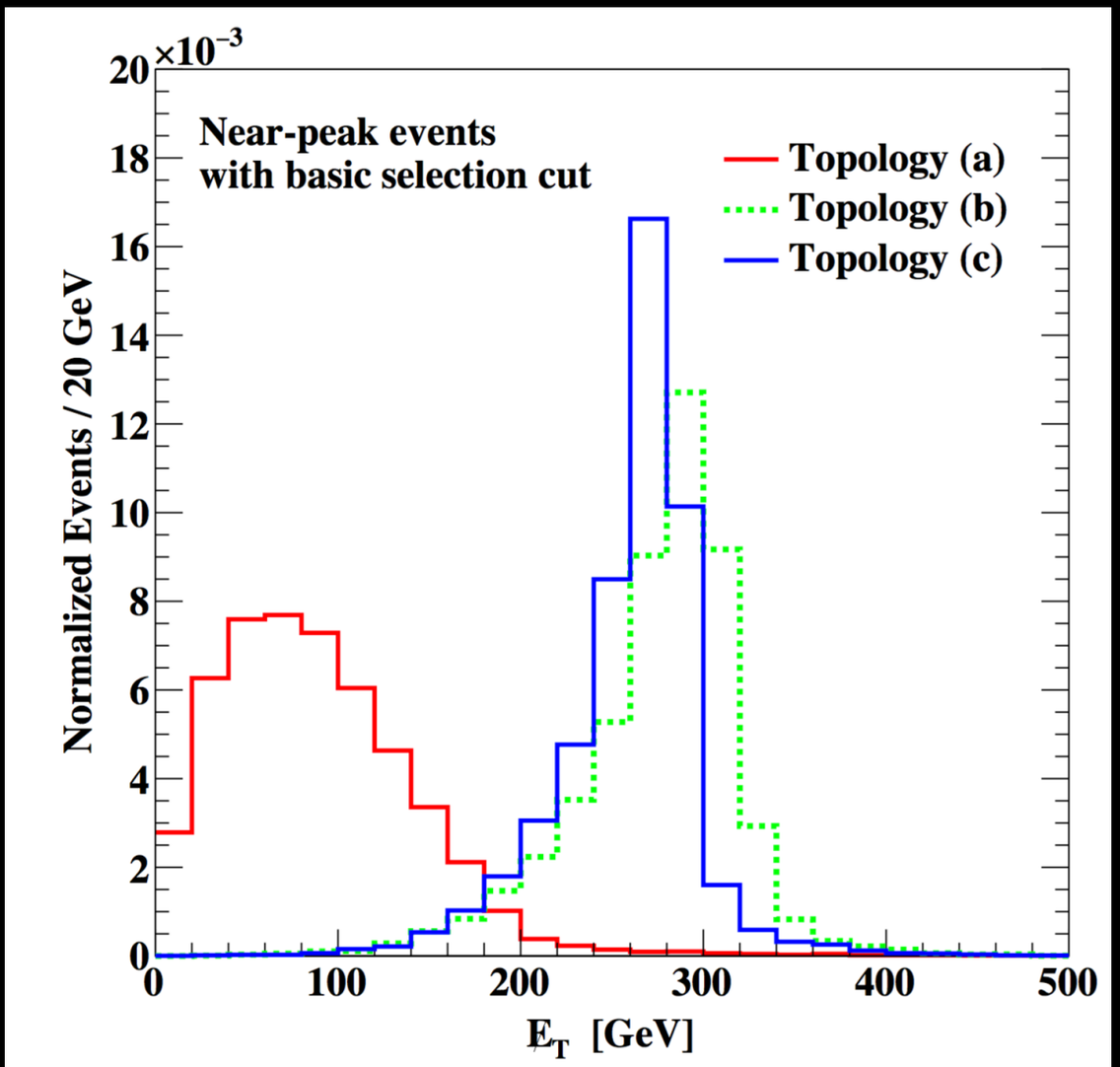
Simulated P_T(rr) (Antler) <<

Can we say something?



- Photon energy spectrum can be the discriminator.
- All of cases look like to come from **a single resonance**. (with low statistics)

What happen to the MET?



- MET distribution near the peak position.
- Antler [here (a)] is preferable.
- MET distribution is only sensitive to the kinematics than spin / coupling structure.

Effects from spin assignment, coupling structure

- Unlike MET (transverse variable), the shape of an invariant mass depends on the spin assignment.

Two-Step cascade

$$f_S(m) \sim m(d_1 + d_2 t + d_3 t^2) \text{ for } 0 \le m \le E\,,$$

Antler / Sandwich

$$f_S(m) \sim \begin{cases} m(c_1 + c_2 t + c_3 t^2)\,, & 0 \le m \le e^{-\eta} E, \\ m[c_4 + c_5 t + c_6 t^2 & \\ +(c_7 + c_8 t + c_9 t^2)\ln t]\,, & e^{-\eta} E \le m \le E. \end{cases}$$

- For the antler case, **S -F - F** (Scalar- Fermion - Fermion) has a phase space shape.

Conclusion

- By focusing on phase space structure, we can cover **whole possibilities** of non-resonance scenario (with some invisible particles) for wide width (~45GeV)

- With pt sum of two photons,
  an antler topology is more preferable.
  (for any spin / coupling structure)

- Dynamics (Physics) can be added on this antler topology scenario.

- χ can bring about the **tension** between our set-up and upcoming summer LHC results.