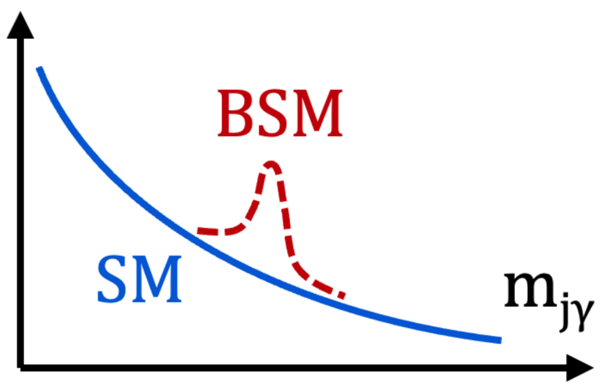
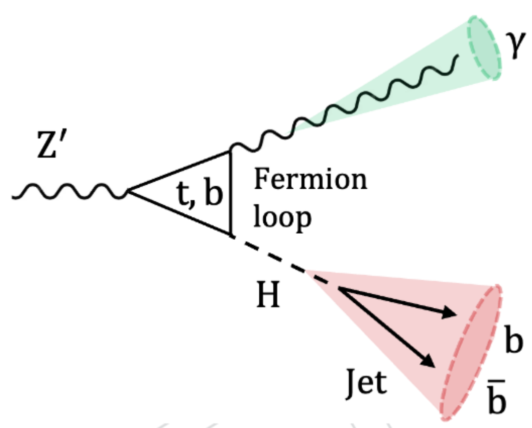
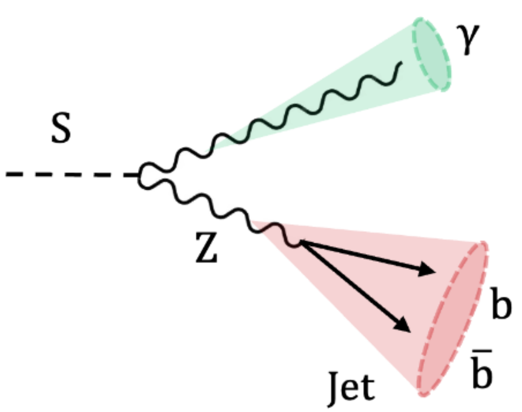
Search for high-mass resonances in H/Z(bb)+γ final state with Run 2 data







LHC理论与实验联合研讨会--新粒子寻找

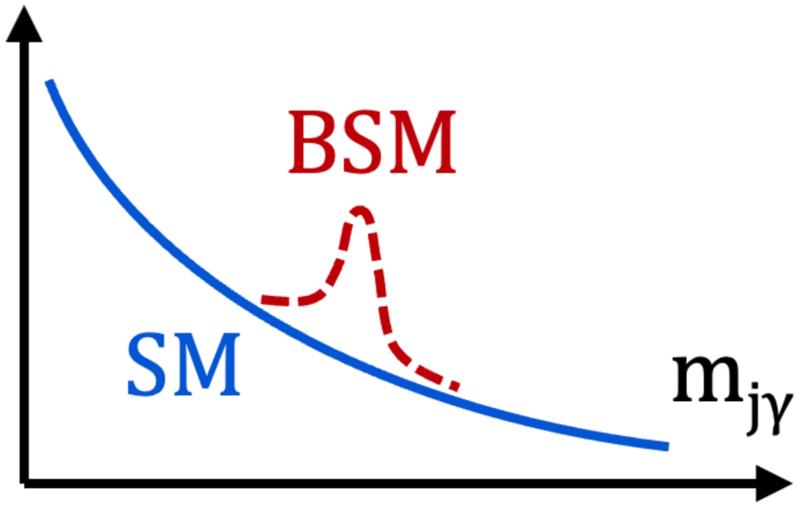
Sep. 13th, 2025

Dawei Fu

on behalf of PKU multiboson group

Motivation & introduction

- ➔ Many BSM models are constrained by the di-boson resonance search
- ➔ Published diboson resonance search in full Run 2:
  - ❖ $X \to \gamma\gamma$, VV, HH, VH, Wγ …… except for the Zγ and Hγ
- ➔ History of Zγ and Hγ resonance search in CMS
  - X (spin-1)$\to$ Hγ $\to b b\gamma$, EXO-17-019, [13], with only 2016 data;
  - X (spin-0)$\to$ Zγ $\to q q\gamma$, EXO-16-020, with 2015 data (PAS-only);
  - X (spin-0)$\to$ Zγ $\to \ell\ell, q q\gamma$, EXO-17-005, with 2016 data;
  - X (spin-0)$\to$ Zγ $\to \ell\ell\gamma$, EXO-16-019, with 2015–2016 and Run 1 data;
- ➔ Strategy preview
  - ❖ Focus on H/Z(bb) channel for the large BRs and the same final state
  - ❖ With the advanced ML jet tagger to enhance sensitivity
  - ❖ Standard di-boson bump hunt

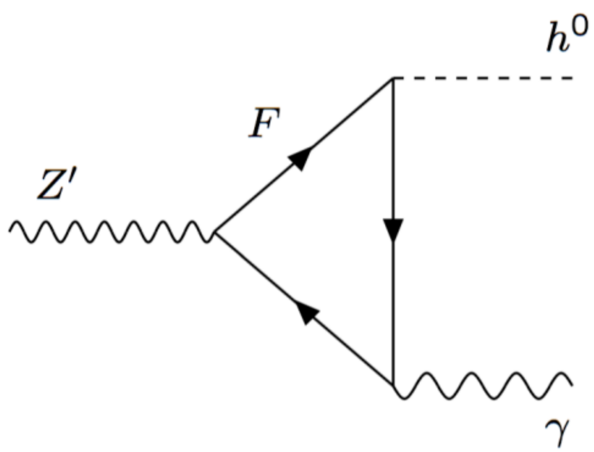


Signal topologies

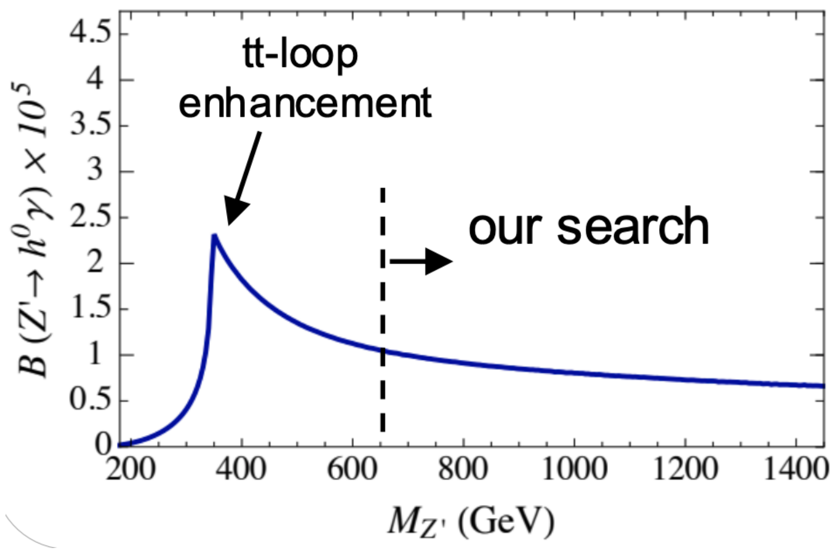
➔ Z'(spin-1)→H(bb)+γ:

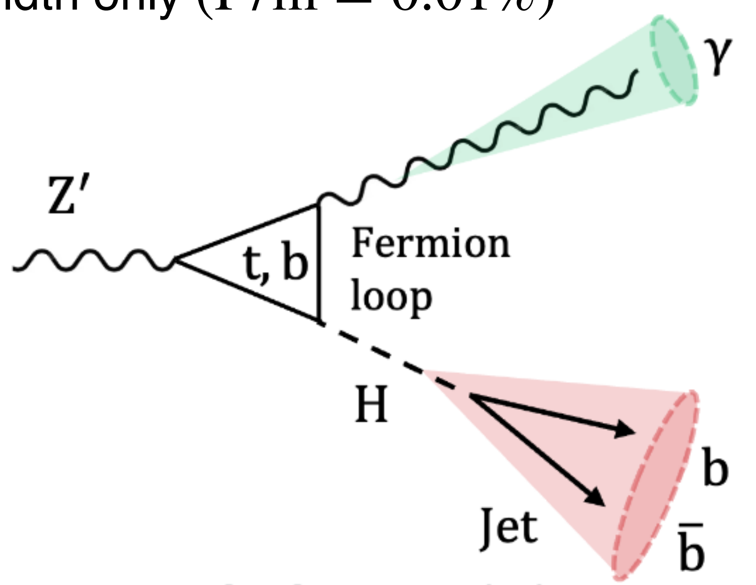
- Benchmark model from Dobrescu et al. (2017).
- Assumption: flavor universal vector coupling of Z' to quarks
- Produced via fermion loop

narrow-width only (Γ/m $= 0.01\%$)



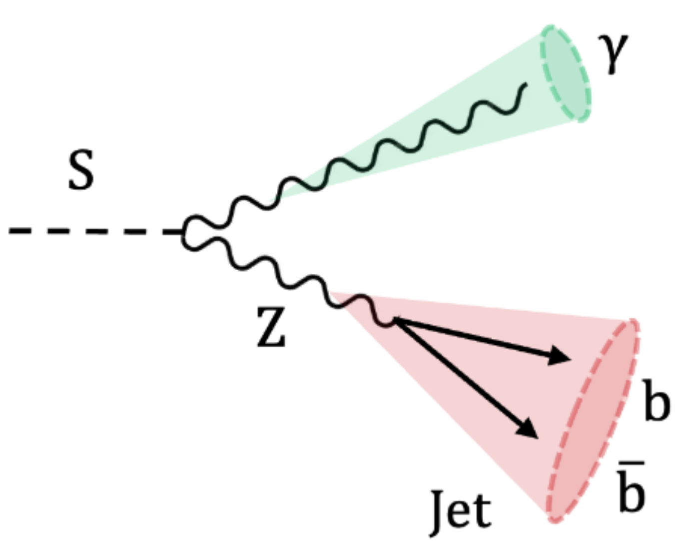
$$\Gamma(Z' \to h^0\gamma) = \frac{c_\gamma^2\,\alpha\,v^2}{1536\pi^4\,m_0^4}\,M_{Z'}^3\left(1-\frac{M_h^2}{M_{Z'}^2}\right)^3$$





➔ S(spin-0)→Z(bb)+γ:

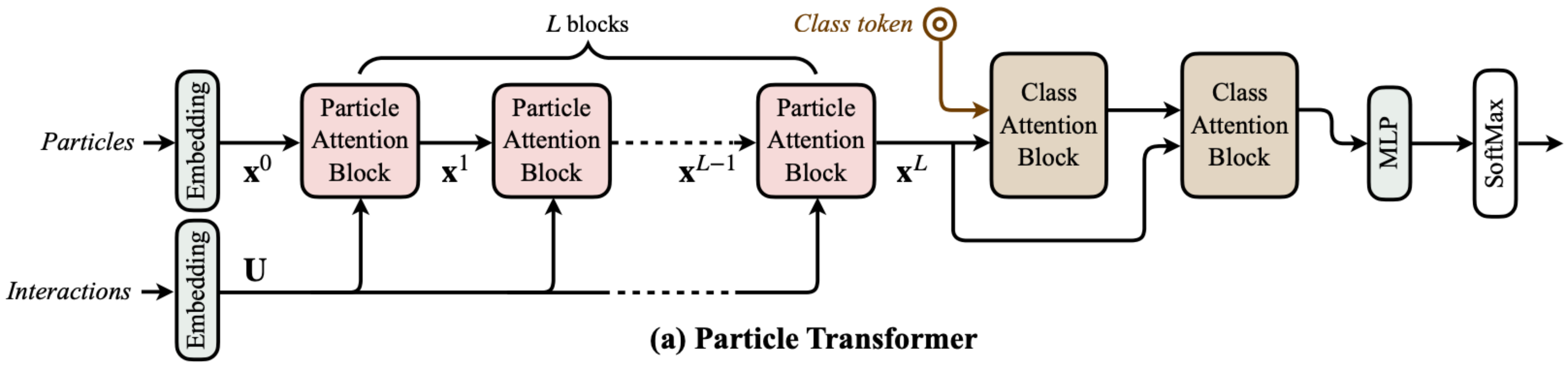
- Search for Higgs-like scalar with SM-like couplings
- Predicted in many models
  - Technicolor
  - little Higgs models
  - extended Higgs sectors
  - extra spatial dimensions



three widths (Γ/m $= 0.014\,\%$, $5.6\,\%$, 10%)

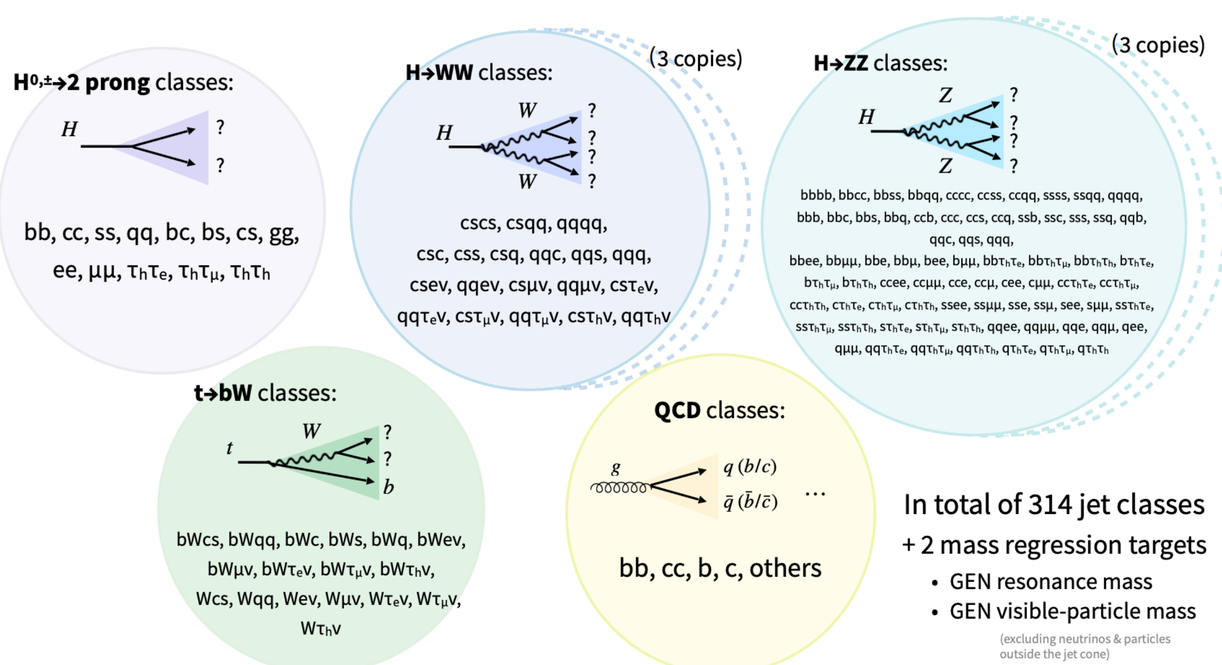
Fat jet tagging

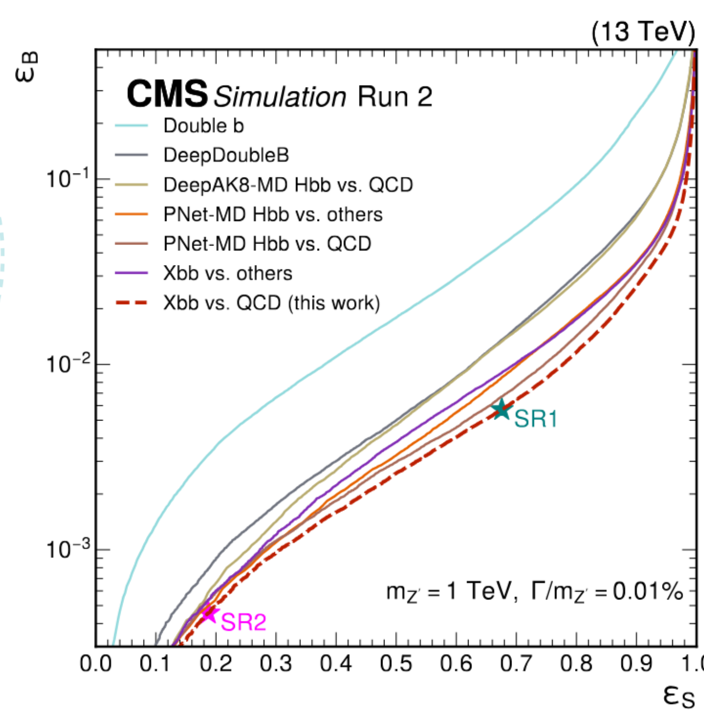
- ➔ State-of-the-art ML jet tagger
  - ❖ Architeture: based on Particle Transformer ([Qu et al., 2022](#))

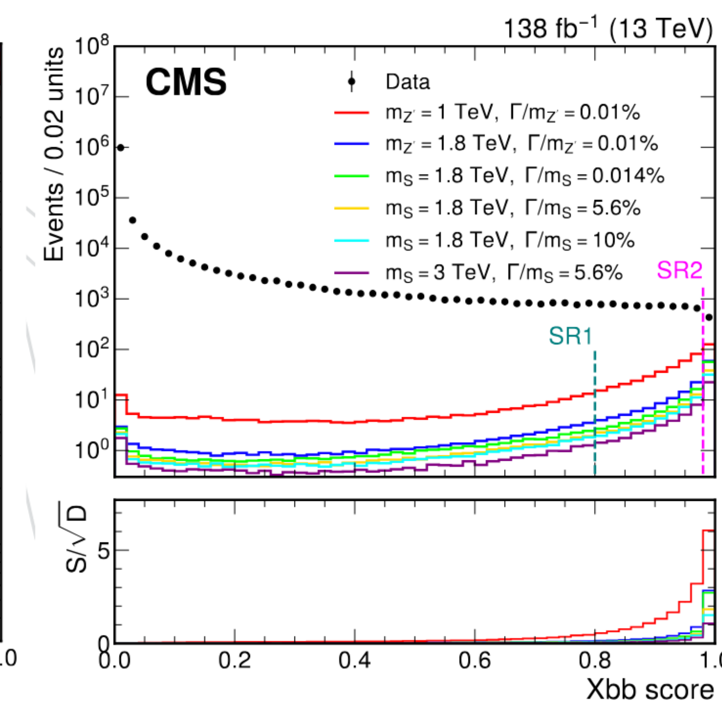


(a) Particle Transformer

- ➔ Implementation in CMS: GloParT (v1: [PAS-JME-25-001](#))
  - ❖ V2 is used in this analysis: Xbb tagger = Hbb vs. QCD for both H and Z jets

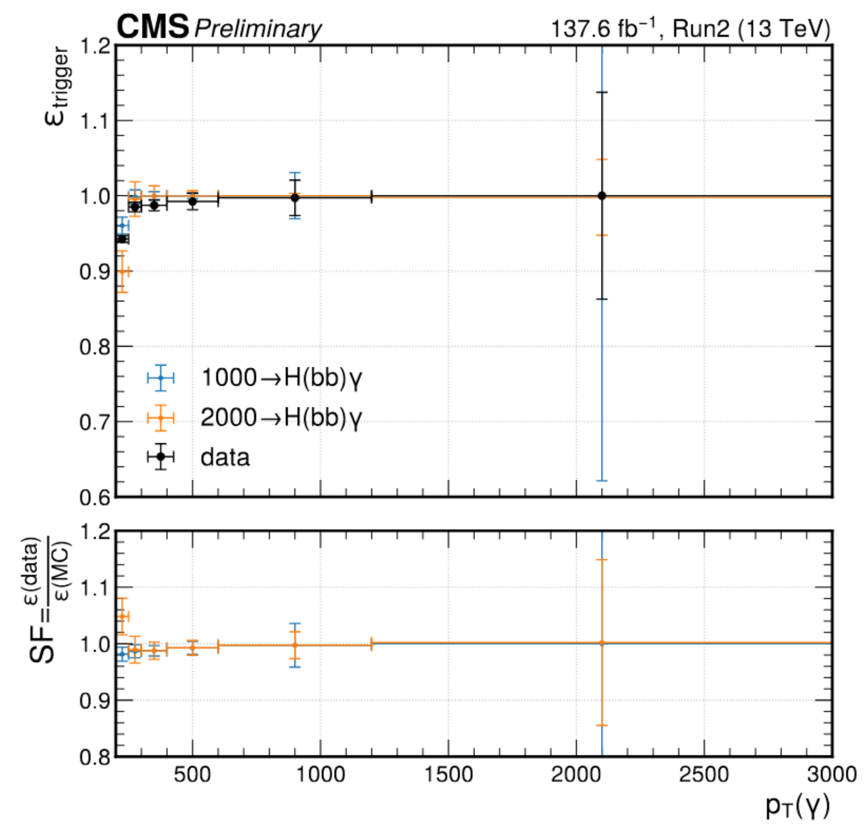






Triggers & datasets

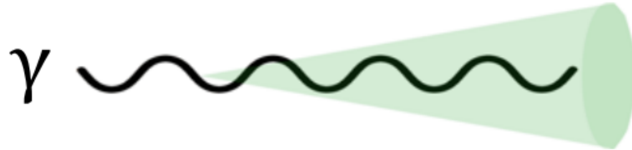
- Triggers:
  - 2016: HLT_Photon165_HE10 || HLT_Photon175
  - 2017 & 2018: HLT_Photon200
- Data: integrated lumi. = $138\ \mathrm{fb}^{-1}$
  - 2016 & 2017: SinglePhoton
  - 2018: EGamma
  - HLT efficiency: SingleMuon



- Signal MC
  - Resonance mass points: from 700 to 3500 GeV with 15 points
  - Spin-1 $\mathrm{Z}' \to \mathrm{H}\gamma$: generated from the benchmark model and $\Gamma/\mathrm{m} = 0.014\,\%$
  - Spin-0 $\mathrm{S} \to \mathrm{Z}\gamma$: generated via pythia8 and $\Gamma/\mathrm{m} = 0.014\,\%\,,\ 5.6\,\%\,,\ 10\,\%$
- Background MC
  - Prompt photon: QCD+γ, Z+γ, W+γ, TT+γ
  - Non-prompt photon: QCD, Z, W, TT, Single Top

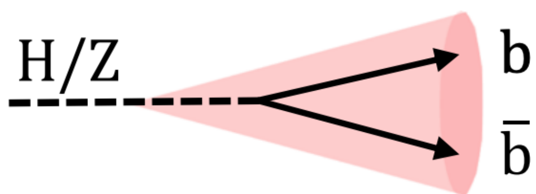
Objects & preselection

→ Photons



- Loose cut-based ID
- Electron veto (CSEV)

→ AK8 jets



- PUPPI, tight Jet ID & tightLeptVeto
- GloParT v2 tagging
- Soft-drop mass for preselection
- Regressed mass for SR binning

→ AK4 jets

- CHS
- DeepJet b tag @ medium WP
- Exclusive b-veto: top rejection

→ Preselection

→

- $p_T^{\gamma} > 225$ GeV
- $|\eta_{\gamma}| \in [0,1.4442) \cup (1,556,\ 2.5)$
- $N_{\gamma} = 1$

→

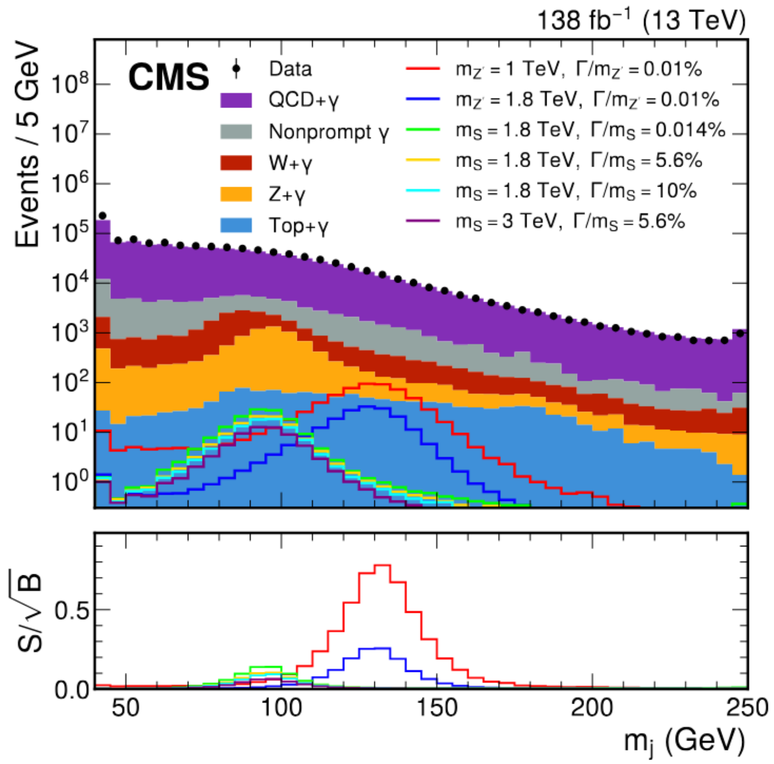
- $p_T^{j} > 250$ GeV, $|\eta_{j}| < 2.4$
- $m_{SD}^{j} > 30$ GeV, $N_{j} \geq 1$
- H/Z candidate: leading Xbb score
- $\Delta R(\gamma, H/Z) > 1.1$

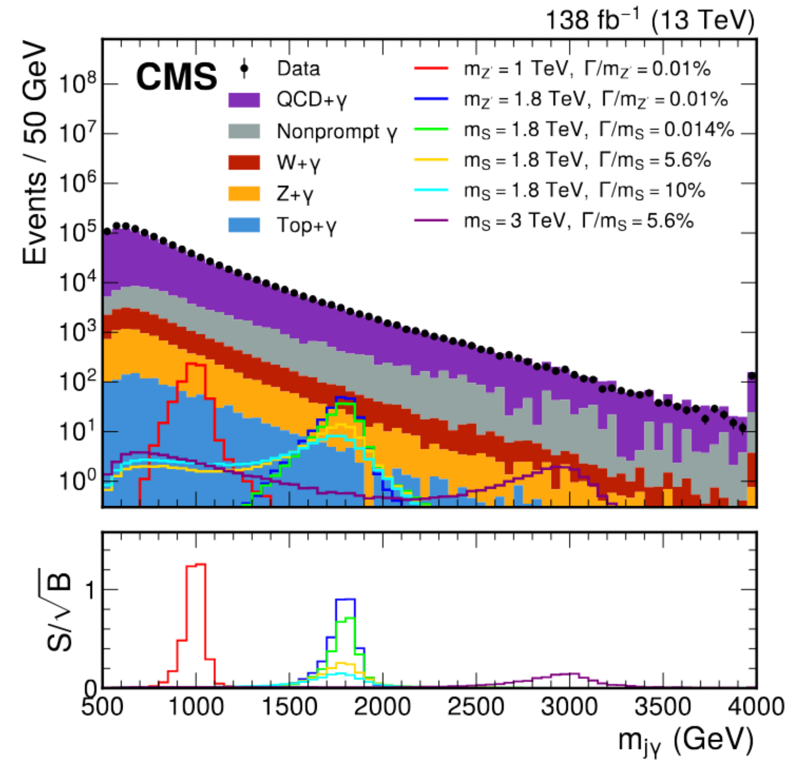
→

- $\Delta R(b, H/Z) > 1.2$
- $N_{b}^{exc.} = 0$

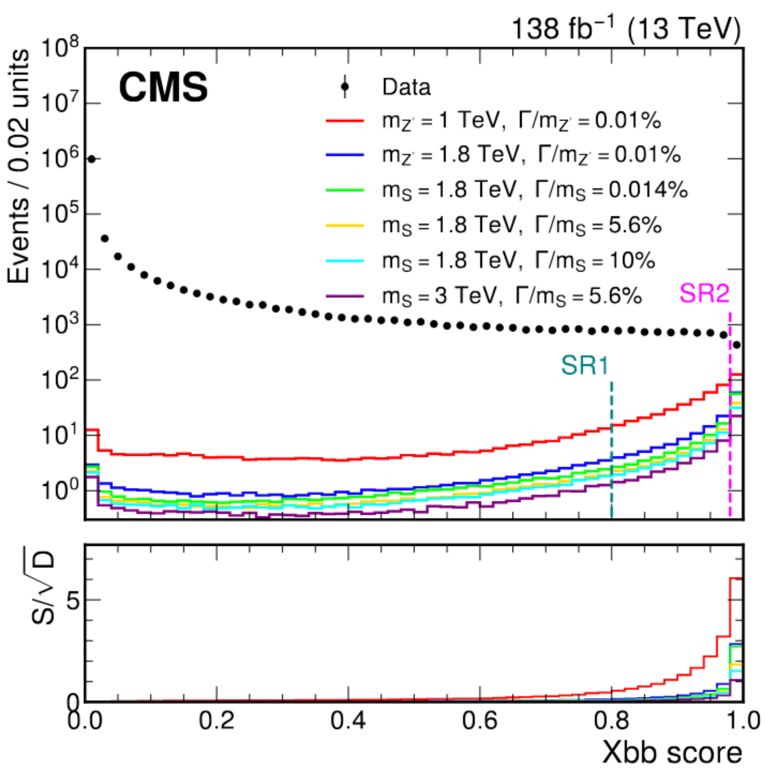
Kinematics at preselection & SR/CR definition

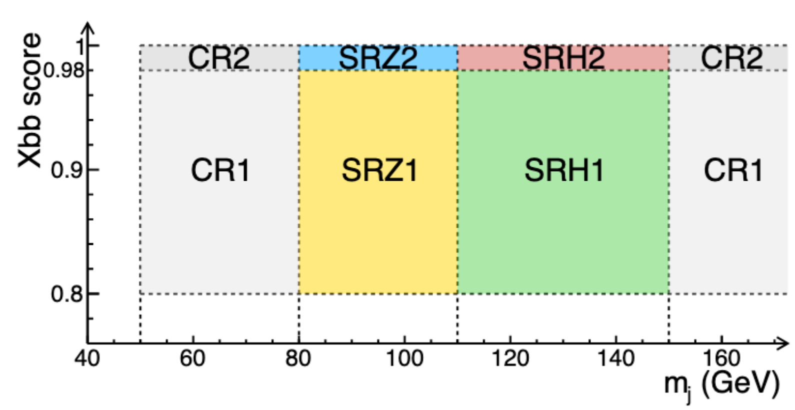
➔ Agreement check on Data/MC at preselection

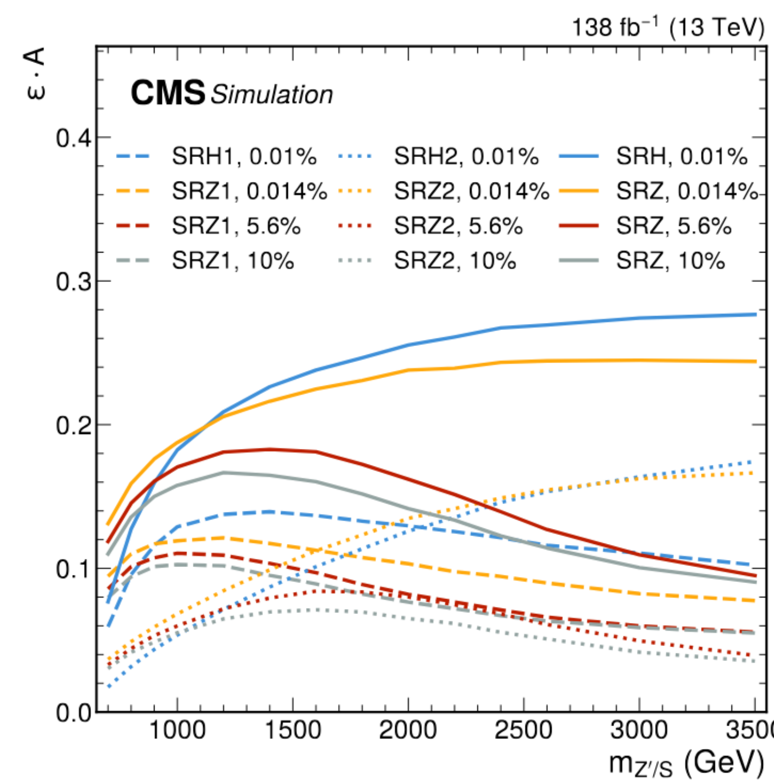




➔ The definition of SR/CR and the acceptance x efficiency of SR







Fitting strategy

- Unbinned parametric fitting on $m_{j\gamma}$ ranging from 650 to 4000 GeV
- Signal modeling
  - Fitted to MC in SR
  - Discrete mass points: from 700 to 3500 GeV with 15 points
  - Parametric funtion: double-sided crystal ball function
  - Singal interpolation on function parameters
  - Systematic uncertainties mainly on signal
- Background modeling
  - Fitted to data in SR
  - Validated with data in CR
  - Discrete profiling with 6 candidate functions
  - The only systematic uncertainty: the function choice as the floating parameter

$$f(m; m_0, \sigma, \alpha_L, n_L, \alpha_R, n_R) = \begin{cases} A_L \cdot \left(B_L - \frac{m-m_0}{\sigma_L}\right)^{-nL}, & \text{for } \frac{m-m_0}{\sigma_L} < -\alpha_L \\ \exp\left(-\frac{1}{2} \cdot \left[\frac{m-m_0}{\sigma_L}\right]^2\right), & \text{for } \frac{m-m_0}{\sigma_L} \leq 0 \\ \exp\left(-\frac{1}{2} \cdot \left[\frac{m-m_0}{\sigma_R}\right]^2\right), & \text{for } \frac{m-m_0}{\sigma_R} \leq \alpha_R \\ A_R \cdot \left(B_R + \frac{m-m_0}{\sigma_R}\right)^{-nR}, & \text{otherwise,} \end{cases}$$

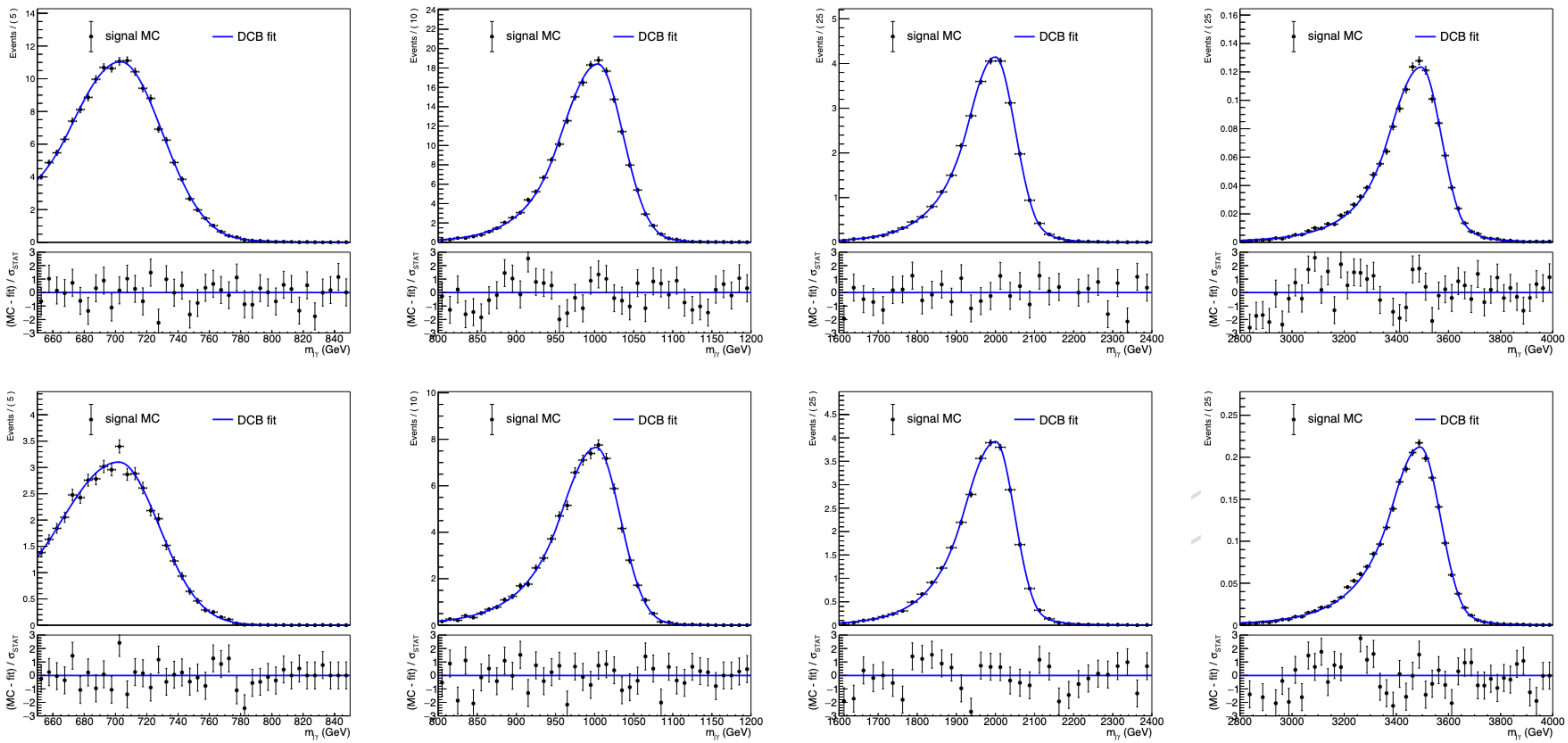
$$A_i = \left(\frac{n_i}{|\alpha_i|}\right)^{ni} \cdot \exp\left(-\frac{|\alpha_i|^2}{2}\right), \quad B_i = \frac{n_i}{|\alpha_i|} - |\alpha_i|.$$

$$\begin{aligned} &\text{dijet2:} && p_0 m^{p_1 + p_2 \log(m)}; \\ &\text{dijet3:} && p_0 m^{p_1 + p_2 \log(m) + p_3 \log^2(m)}; \\ &\text{expow1:} && p_0 m^{p_1}; \\ &\text{expow2:} && p_0 m^{p_1} e^{p_2 m}; \\ &\text{invpow2:} && p_0 (1 + p_1 m)^{p_2}; \\ &\text{invpow3:} && p_0 (1 + p_1 m)^{p_2 + p_3 m}. \end{aligned}$$

Signal modeling: $Z' \rightarrow H\gamma$

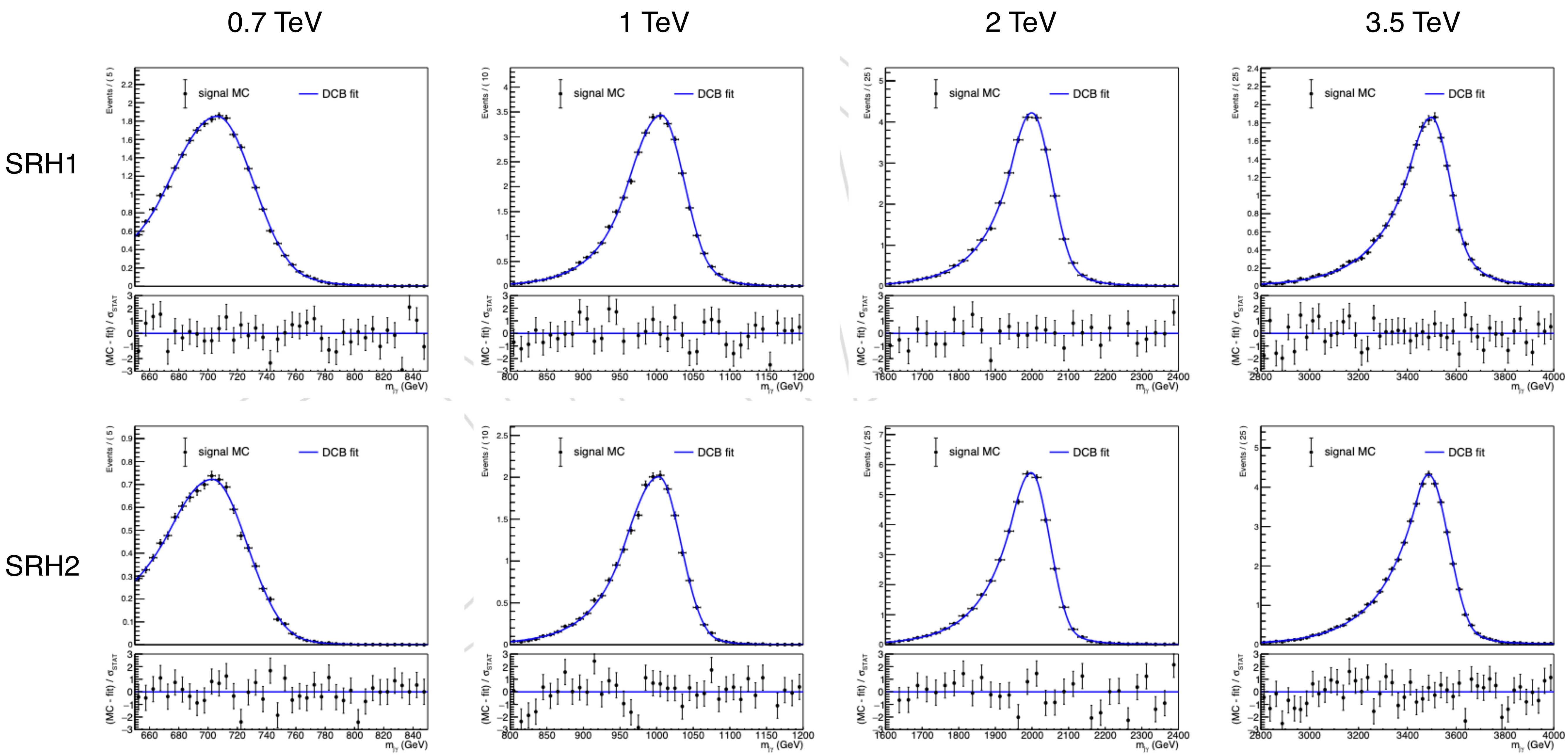
➔ Signal width $\Gamma/m = 0.01\ \%$

	0.7 TeV	1 TeV	2 TeV	3.5 TeV
SRH1				
SRH2				



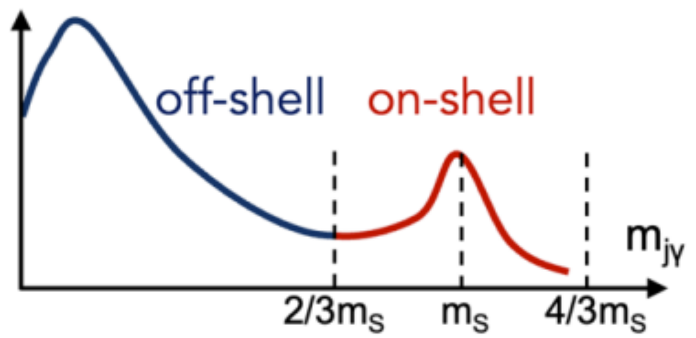
Signal modeling: $S \to Z\gamma$

➔ Signal width $\Gamma/\mathrm{m} = 0.014\,\%$



Signal modeling: $S \rightarrow Z\gamma$

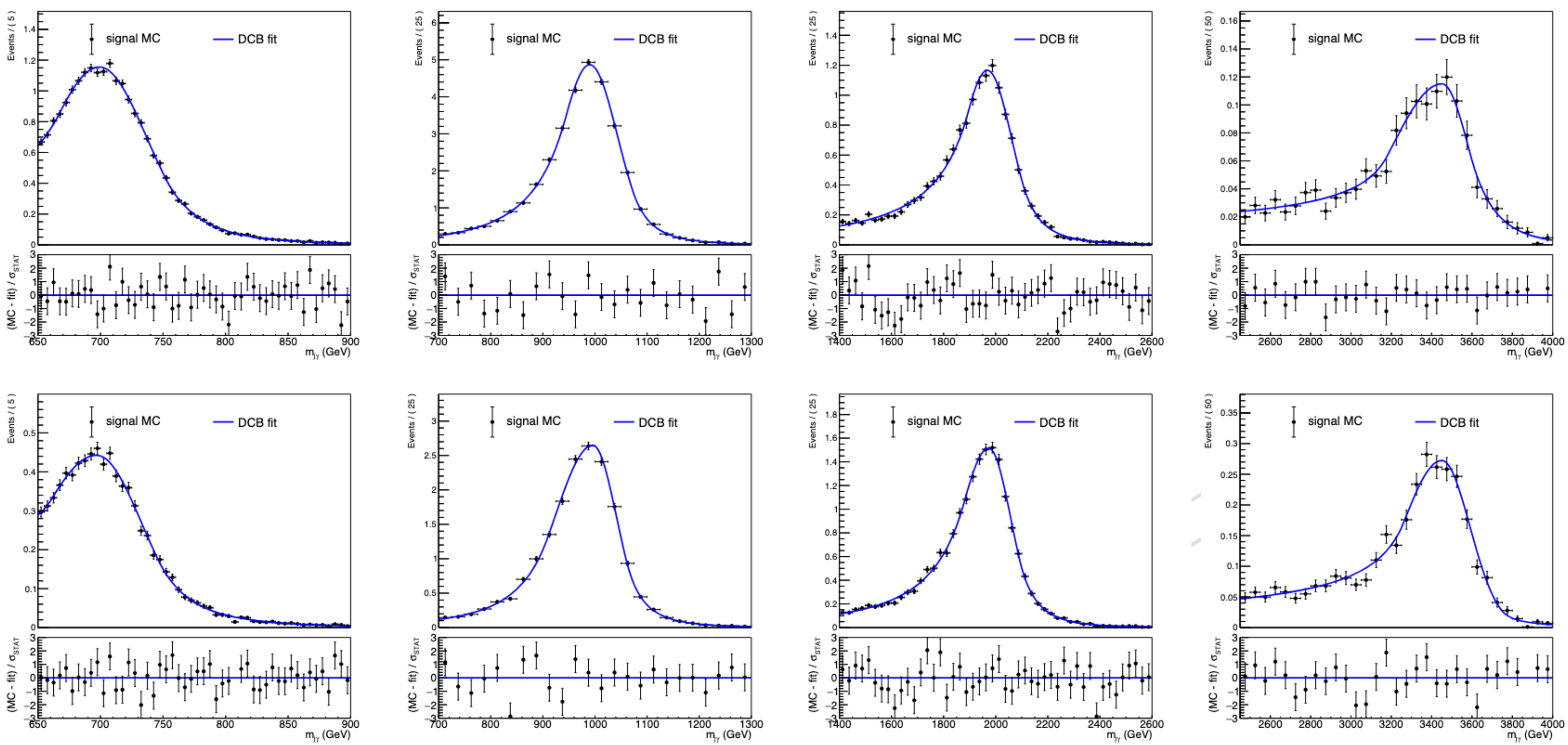
➔ Signal width $\Gamma/\mathrm{m} = 5.6\,\%$



0.7 TeV | 1 TeV | 2 TeV | 3.5 TeV

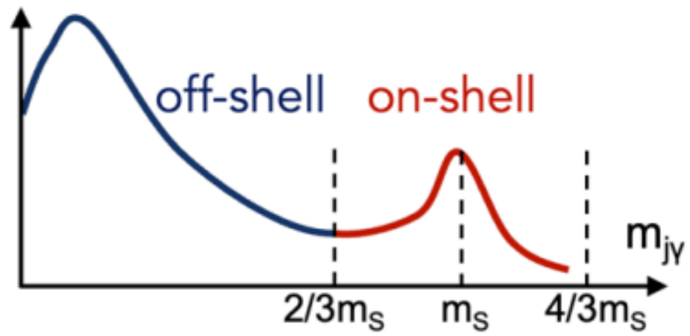
SRH1

SRH2



Signal modeling: $S \rightarrow Z\gamma$

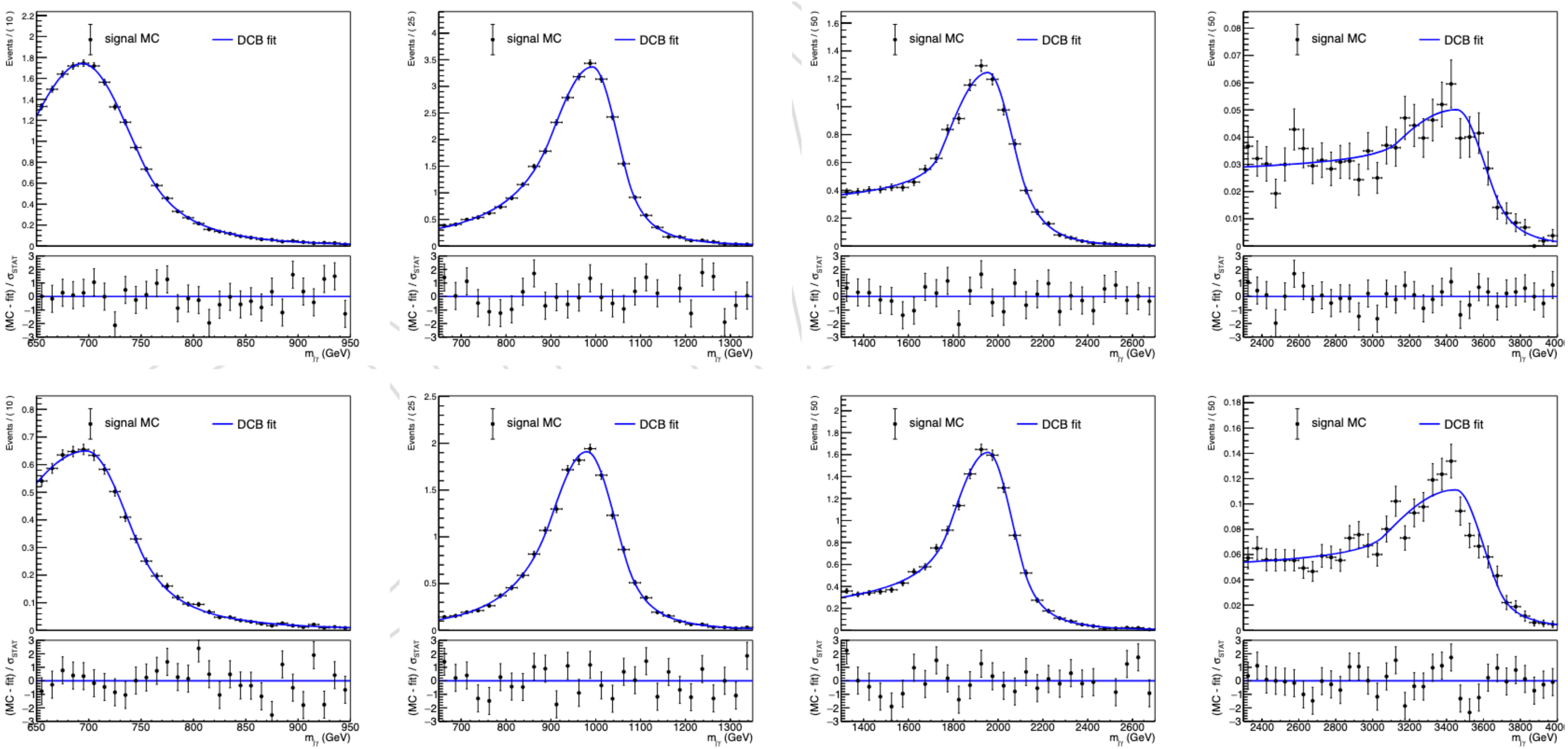
➔ Signal width $\Gamma/m = 10\,\%$



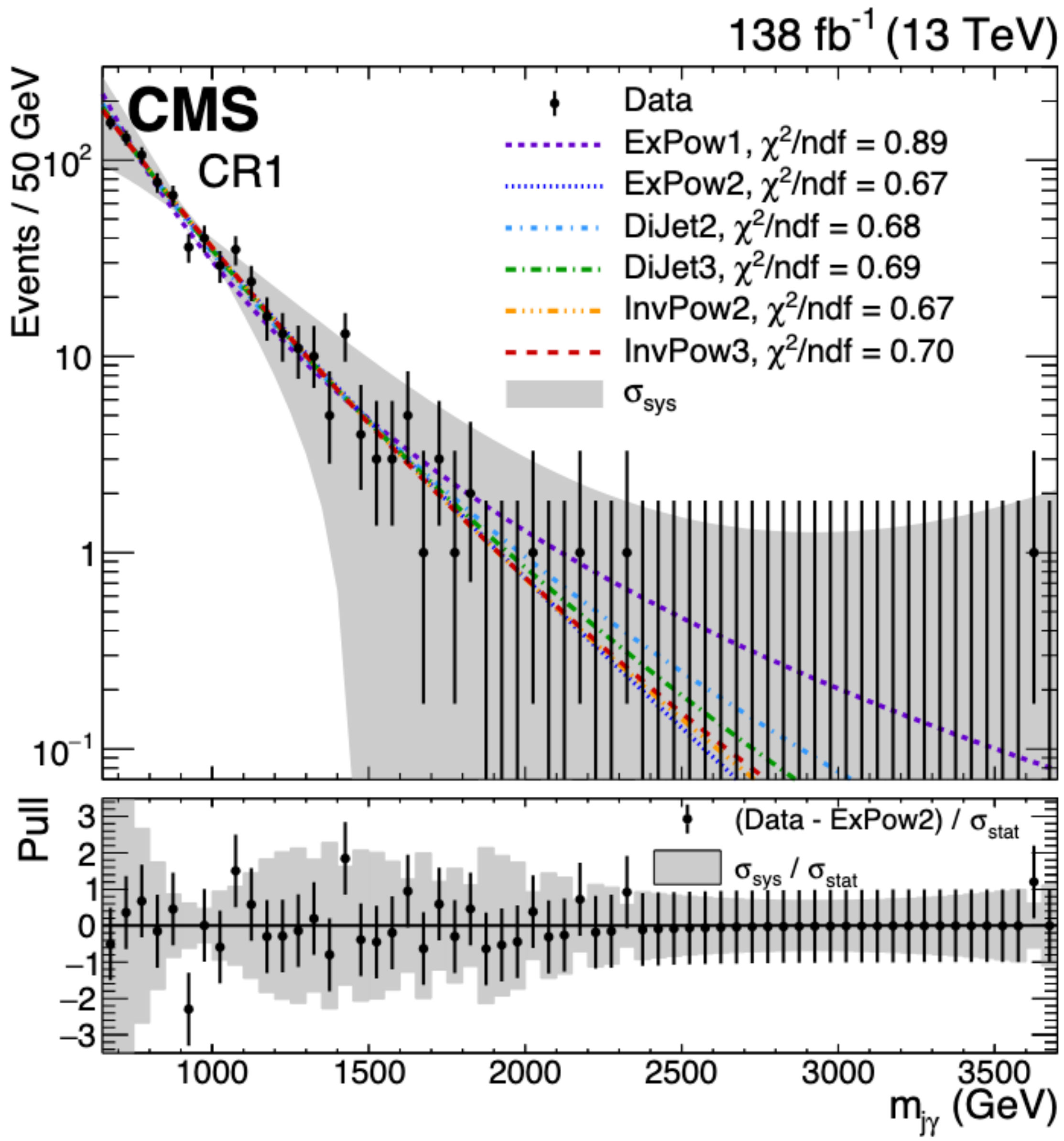
0.7 TeV | 1 TeV | 2 TeV | 3.5 TeV

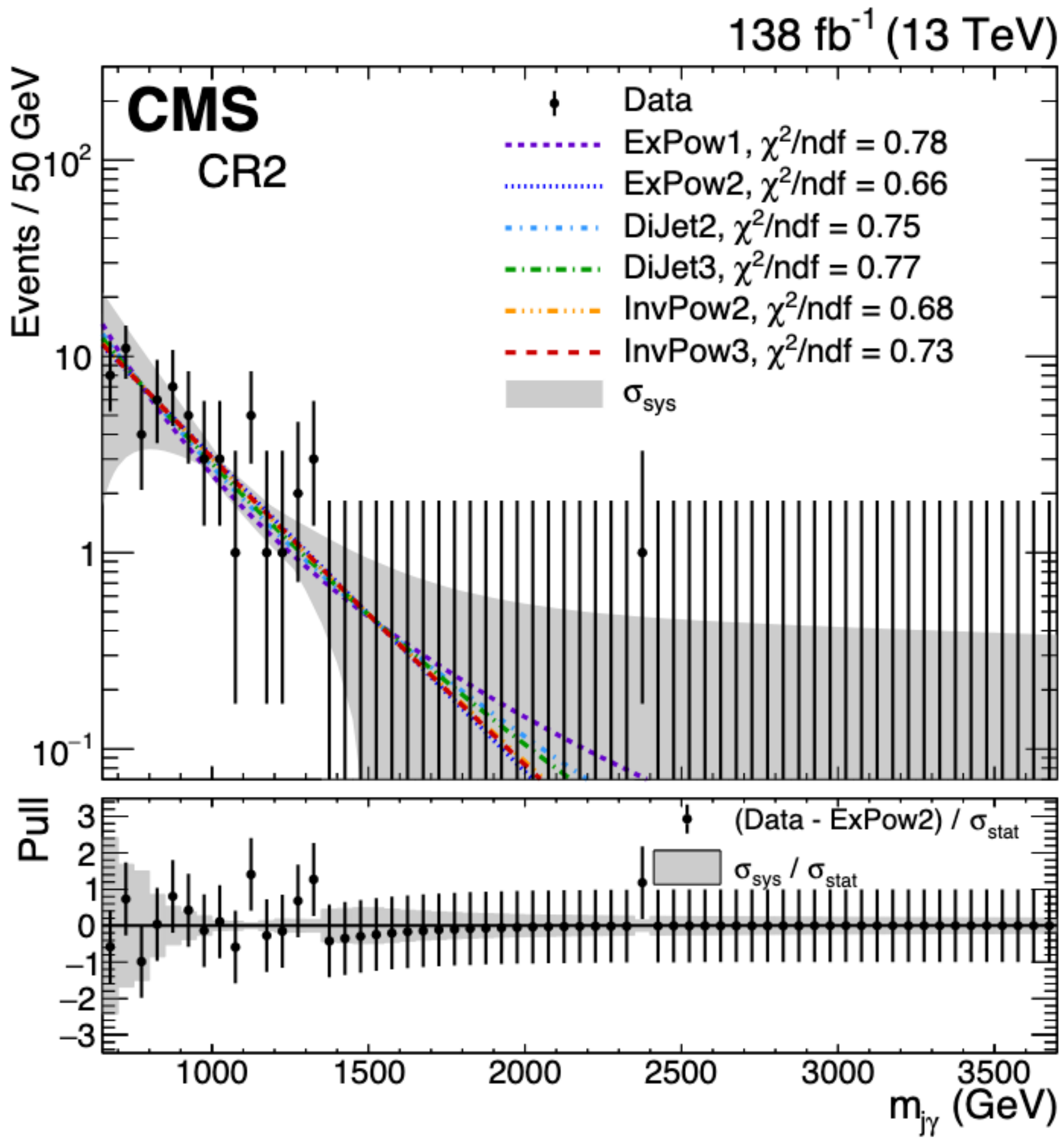
SRH1

SRH2



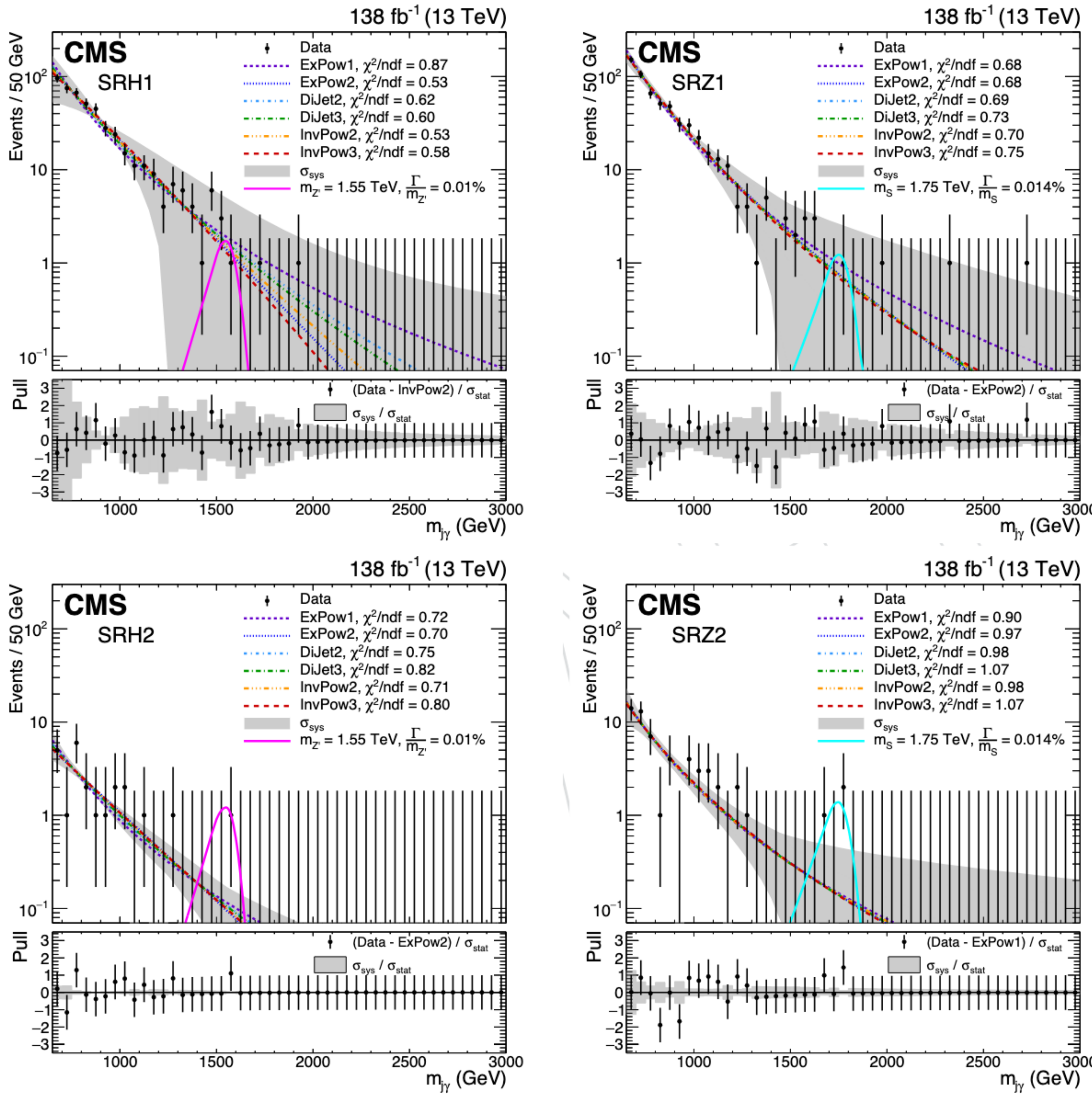
Background modeling: validation in CR





Background modeling: SR

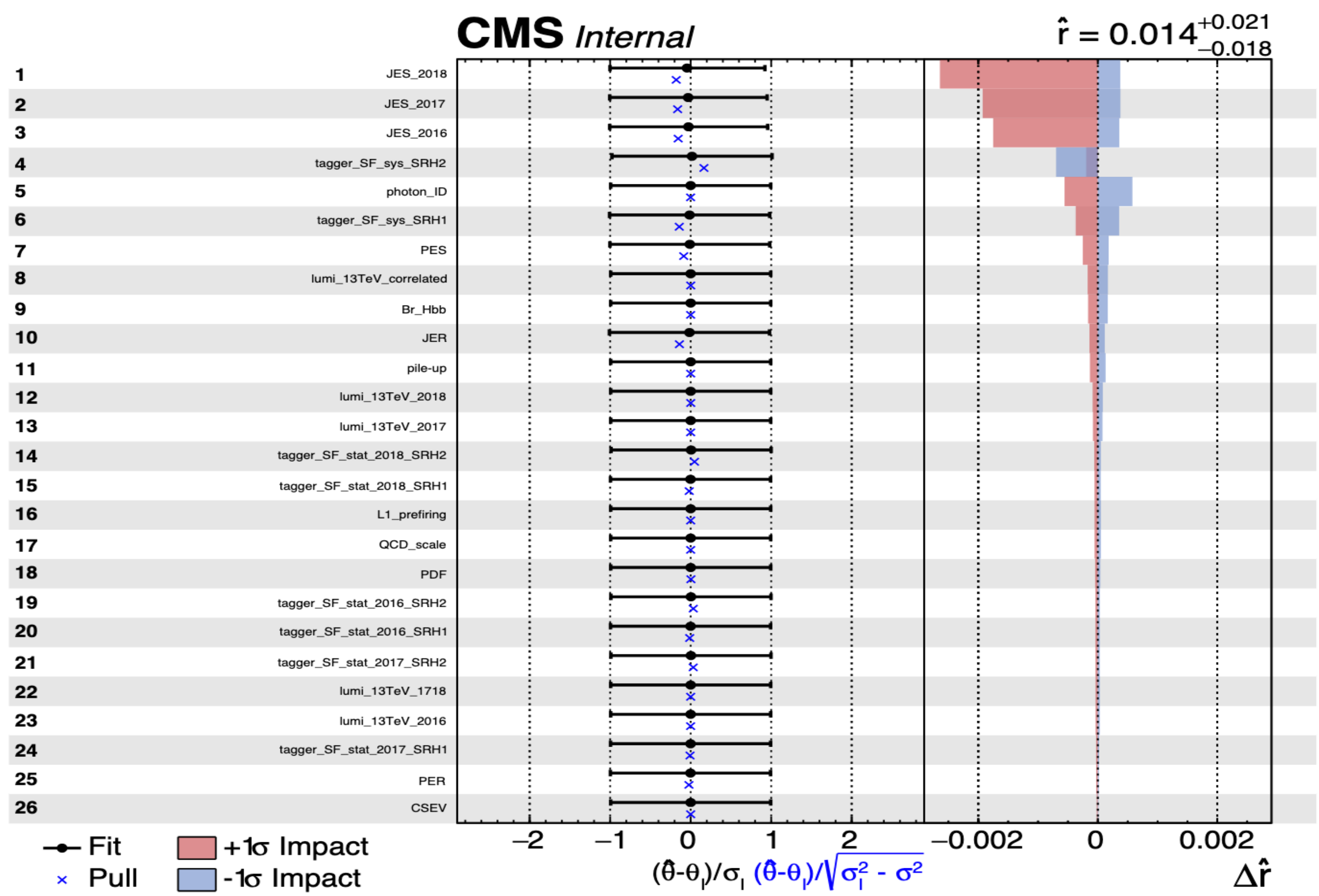
➔ Signals with the largest significances are shown



Systematic uncertainties

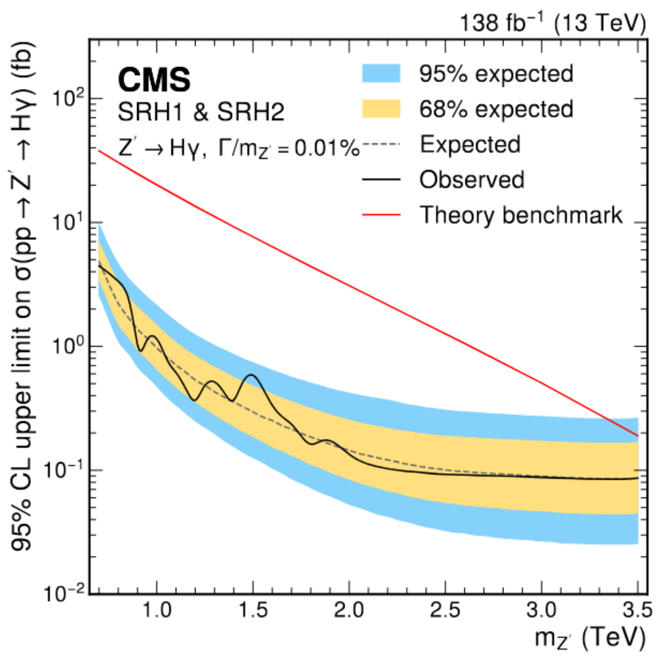
Uncertainty source	*B* or *S*	Effect on	Magnitude	Number of NPs & correlations
Background function choice	*B*	Shape	-	1 per SR, uncorr. across SRs
Photon ID SFs	*S*	Rate	4.4%	1, correlated across all SRs
Trigger selection SFs	*S*	Rate	1%	1, correlated across all SRs
Integrated luminosity	*S*	Rate	1.6%	1, correlated across all SRs
PU reweighting	*S*	Rate	1%	1, correlated across all SRs
PDFs	*S*	Rate	0.3–5.0%	1, correlated across all SRs *
μ_R and μ_F scales	*S*	Rate	0.2–1.2%	1, correlated across all SRs *
Xbb tagger SF systematic	*S*	Rate	3–7%	2, uncorr. across SRs *
Xbb tagger SF statistical	*S*	Rate	<4%	6, uncorr. across years and SRs *
JES	*S*	Shape	0.7–4.0% on peak center	1, per data-taking year *
JER	*S*	Shape	0.5–4.0% on peak width	1, correlated across SRs *
PES	*S*	Shape	0.3–0.7% on peak center	1, correlated across SRs
PER	*S*	Shape	0.3–0.8% on peak width	1, correlated across SRs

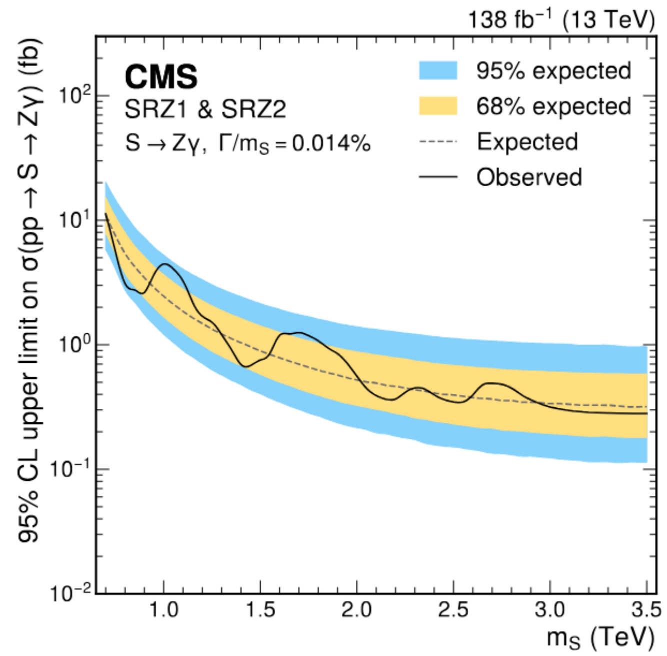
$Z'(1\ \mathrm{TeV}) \rightarrow H\gamma$

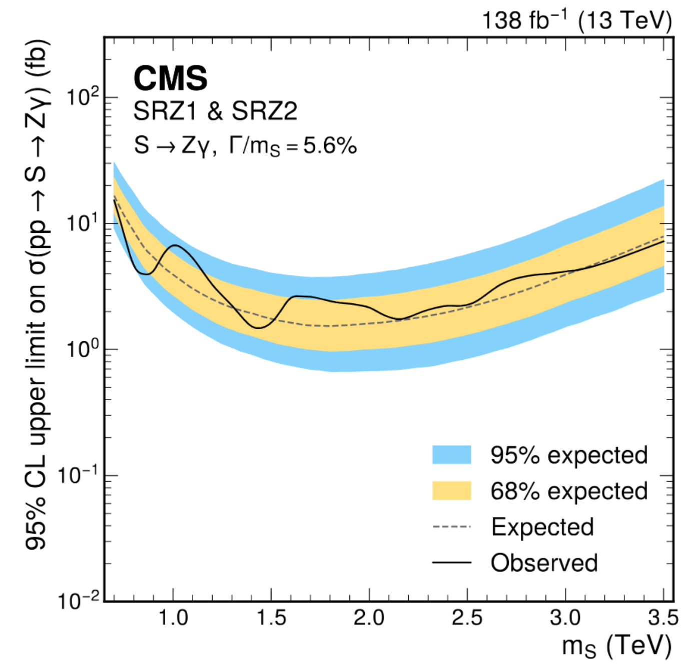


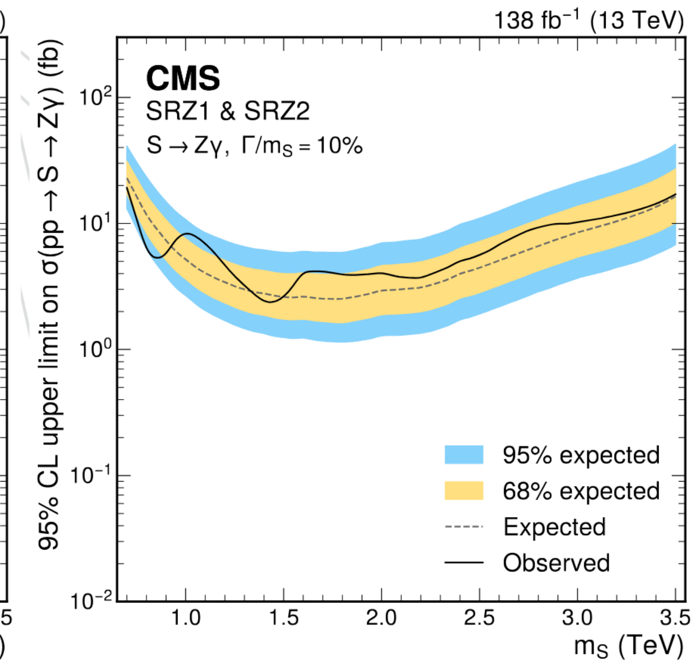
Results & interpretation

➔ Upper limits at 95% CL on $\sigma \cdot \mathrm{BR}$ under Asymptotic statistical method



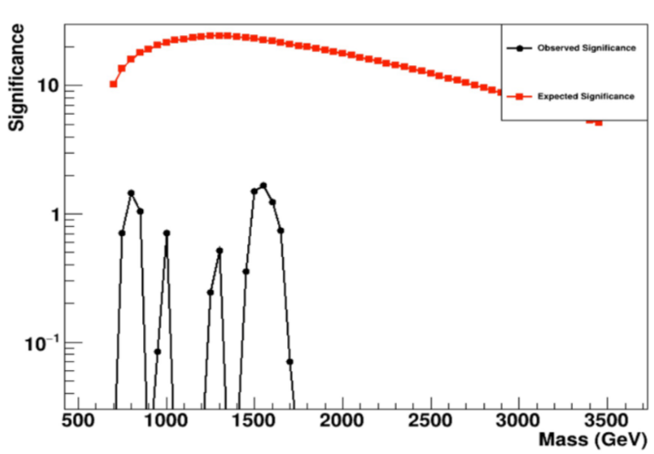


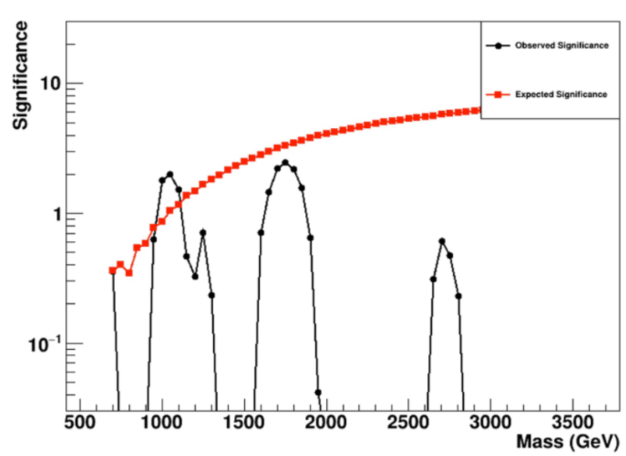


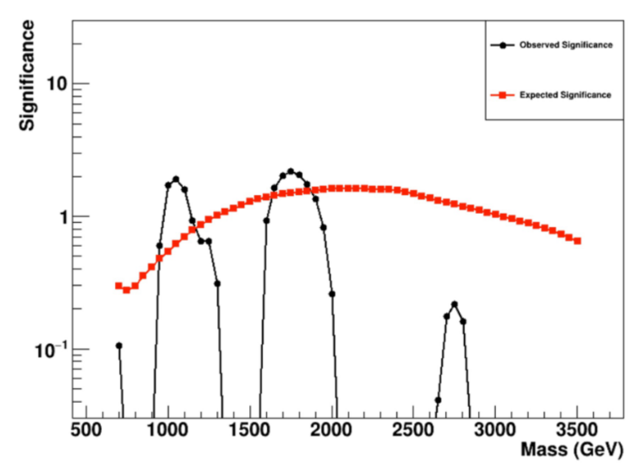


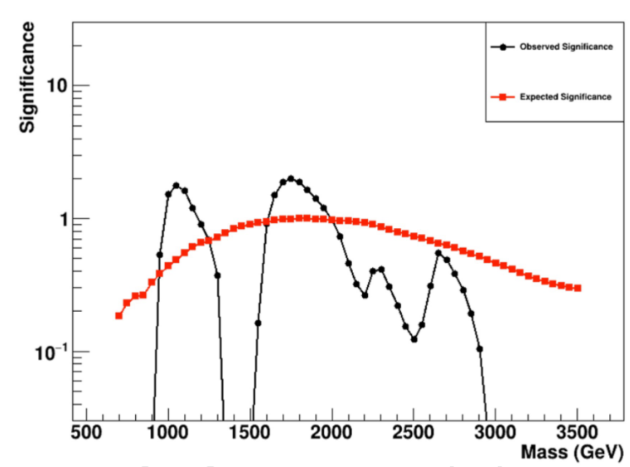
➔ Local significance

Observed significance
Expected significance









Summary & prospect

- ➔ Perfromed the search for diboson resonance $\mathrm{X} \rightarrow \mathrm{H/Z}\gamma$ with Run-2 data
  - ❖ Both the spin-1 (model-dependent) and spin-0 (model-independent) resonances are considered
  - ❖ With the same final states of $\gamma + \mathrm{j(bb)}$
  - ❖ Adopted the same tagger for both H(bb) and Z(bb); outperformed the previous ones and greatly increase the sensitivity
  - ❖ Discrete profiling as a flexible background modeling and tractable for systematics
  - ❖ Set the most stringent limits up to date on $\sigma \cdot \mathrm{BR}$ for both channels

- ➔ Prospect on the resonance search
  - ❖ Towards Run 3 and HL-LHC
    - Higher energy will broaden the upper bound of the search scope
    - High luminosity will enhance the sensitivity in the statistics-dominated (high-purity) regions
  - ❖ Towards AI era
    - The successful jet tagger $\rightarrow$ the powerful event tagger?
    - Achieve SOTA at the known channels + generalized to the unknown channels?