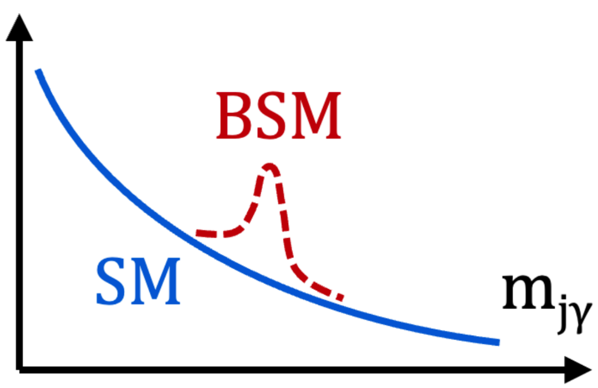
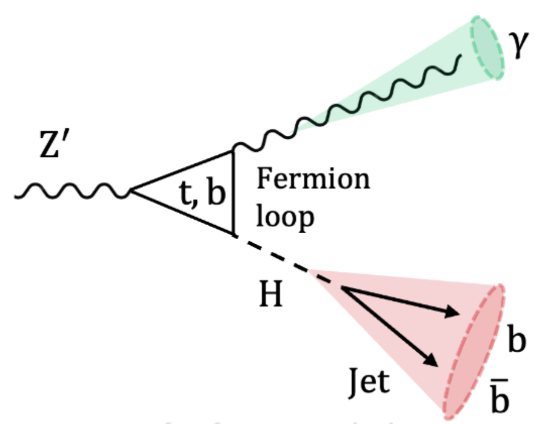
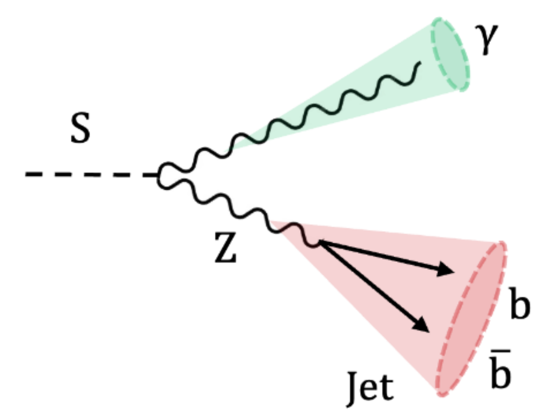
Search for high-mass resonances in H/Z(bb)+γ final state with Run 2 data







CLHCP

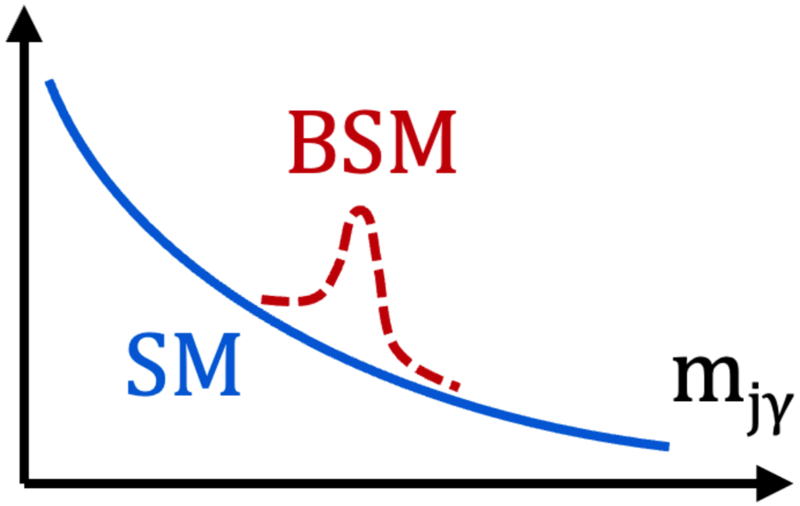
November 1st, 2025

Dawei Fu

on behalf of PKU multiboson group

Motivation & introduction

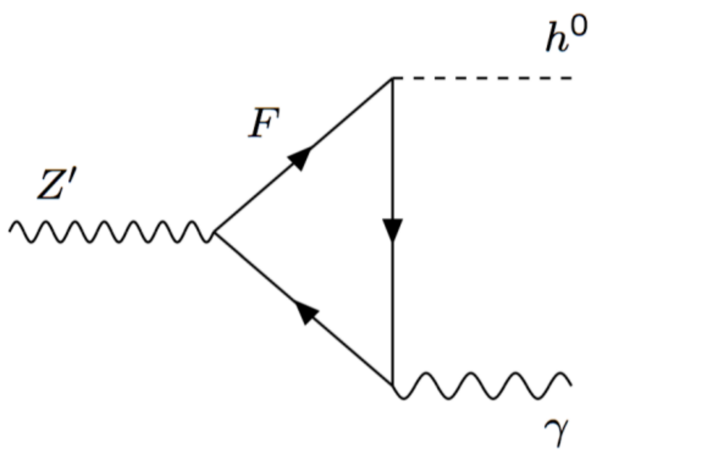
- Many BSM models are constrained by the di-boson resonance search
- Published diboson resonance search in full Run 2:
  - $X \to \gamma\gamma$, VV, HH, VH, Wγ …… except for the Zγ and Hγ
- History of Zγ and Hγ resonance search in CMS
  - X (spin-1)$\to$ H$\gamma \to bb\gamma$, EXO-17-019, [13], with only 2016 data;
  - X (spin-0)$\to$ Z$\gamma \to qq\gamma$, EXO-16-020, with 2015 data (PAS-only);
  - X (spin-0)$\to$ Z$\gamma \to \ell\ell, qq\gamma$, EXO-17-005, with 2016 data;
  - X (spin-0)$\to$ Z$\gamma \to \ell\ell\gamma$, 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



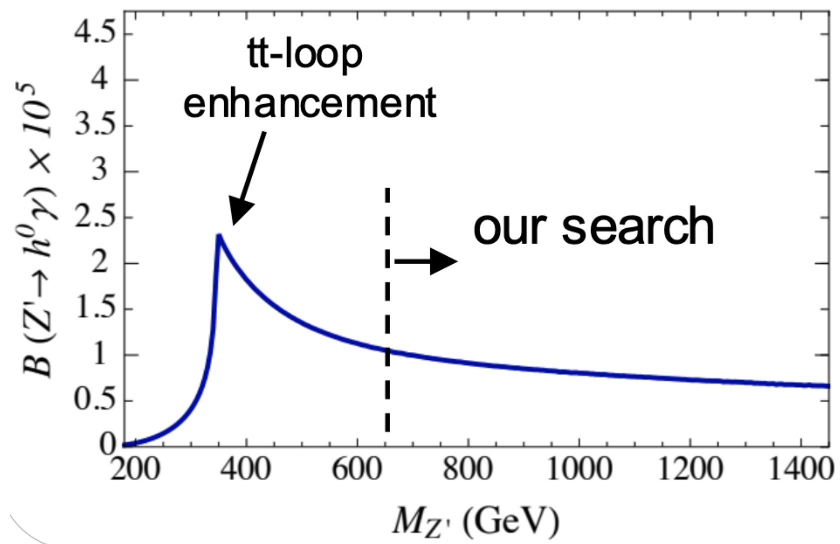
Signal topologies

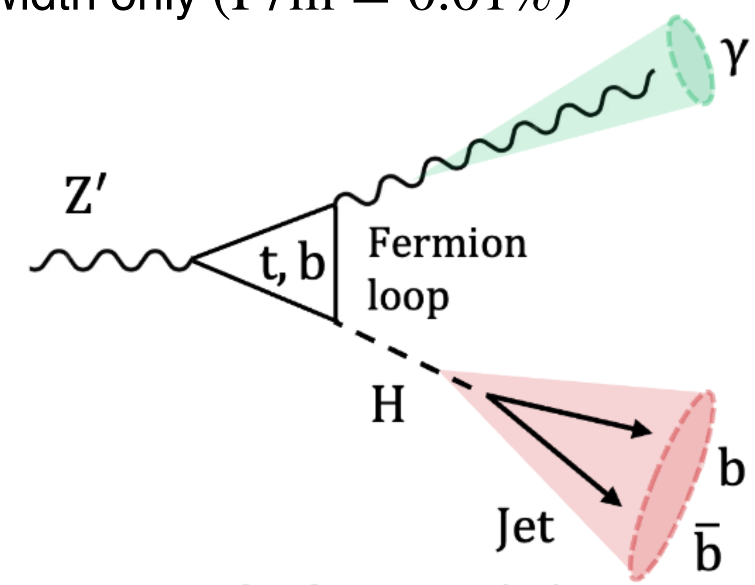
- ➔ Z'(spin-1)→H(bb)+γ:
  - ❖ Benchmark model from [Dobrescu et al. (2017)](#).
  - ❖ Assumption: flavor universal vector coupling of Z' to quarks
  - ❖ Produced via fermion loop

narrow-width only ($\Gamma/\mathrm{m} = 0.01\%$)

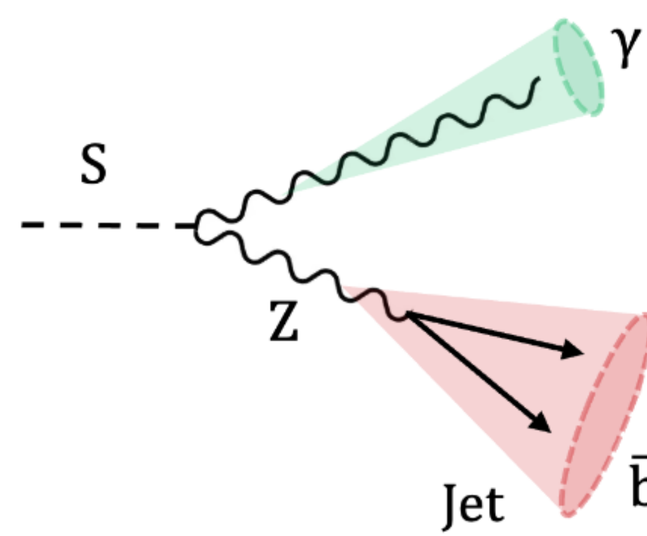


$$\Gamma(Z' \to h^0\gamma) = \frac{c_\gamma^2\, \alpha\, v^2}{1536\pi^4\, m_0^4} M_{Z'}^3 \left(1 - \frac{M_h^2}{M_{Z'}^2}\right)^3$$



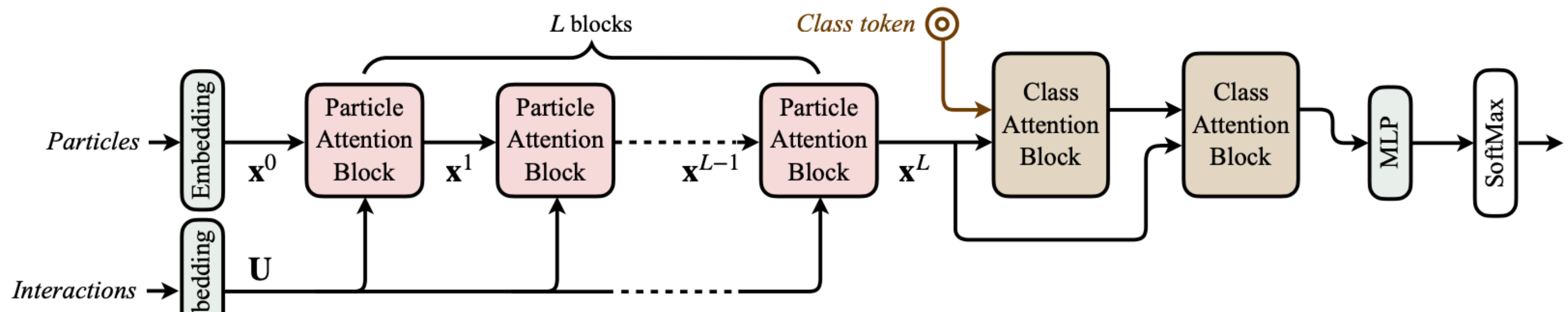


- ➔ S(spin-0)→Z(bb)+γ:
  - ❖ Search for Higgs-like scalar with SM-like couplings
  - ❖ Predicted in many models
    - Technicolor
    - little Higgs models
    - extended Higgs sectors
    - extra spatial dimensions



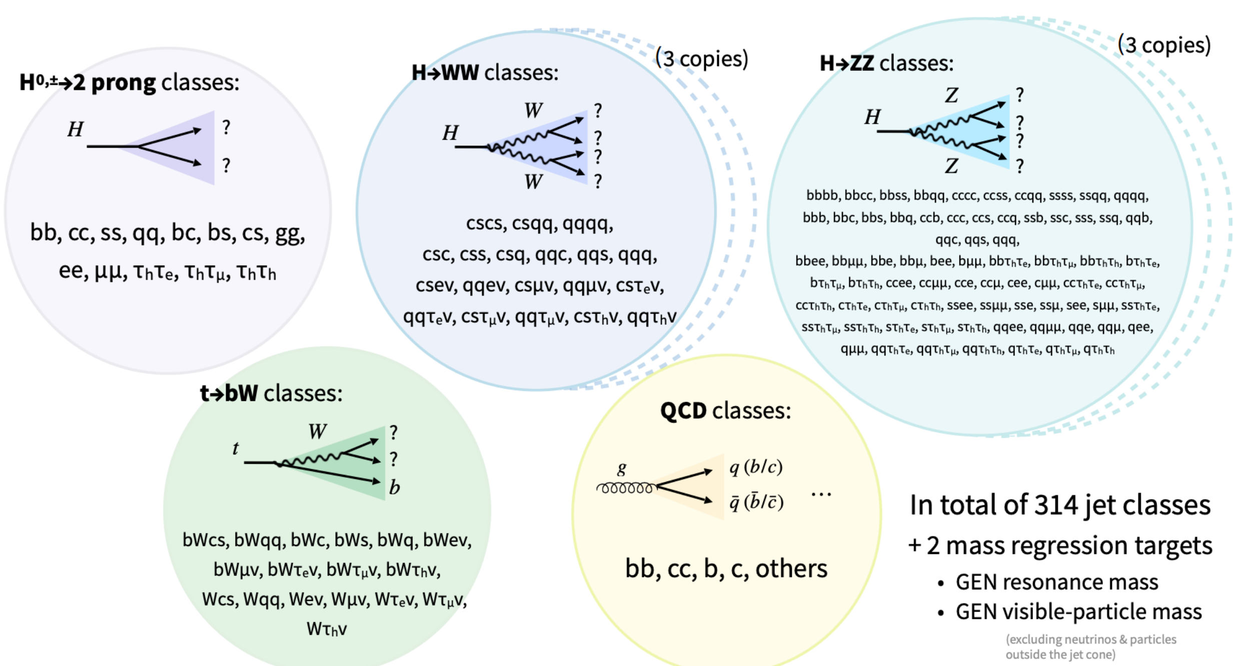
three widths ($\Gamma/\mathrm{m} = 0.014\,\%$, $5.6\,\%$, 10%)

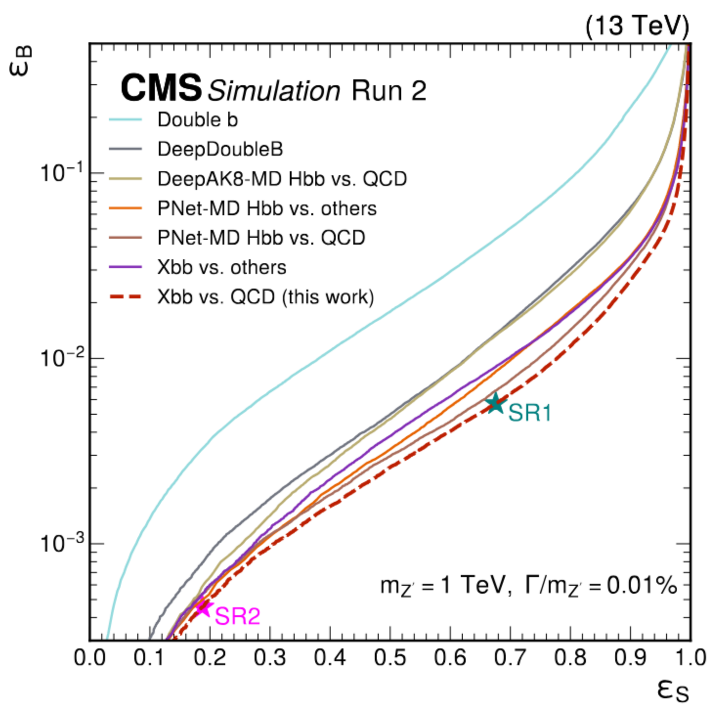
- State-of-the-art ML jet tagger
    - Architeture: based on Particle Transformer (Qu et al., 2022)

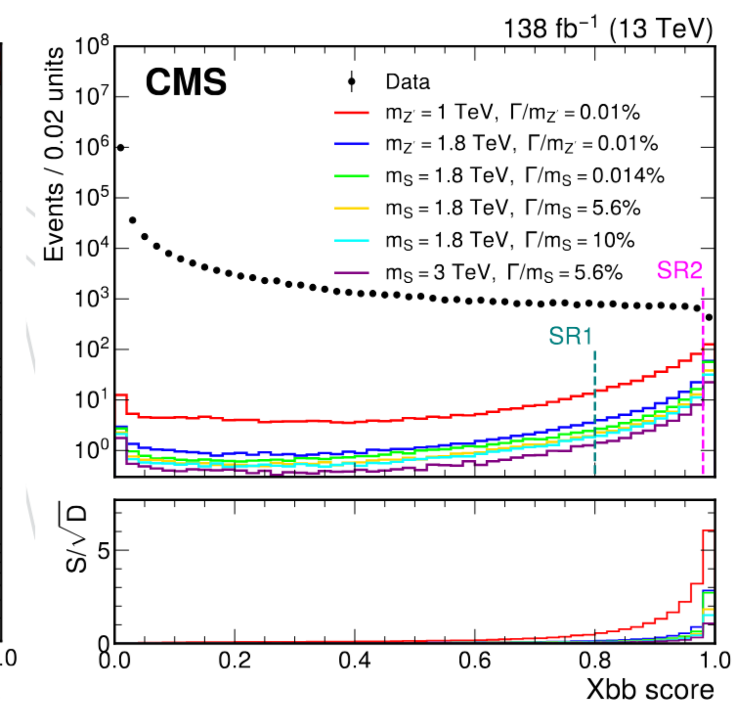


(a) Particle Transformer

- 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

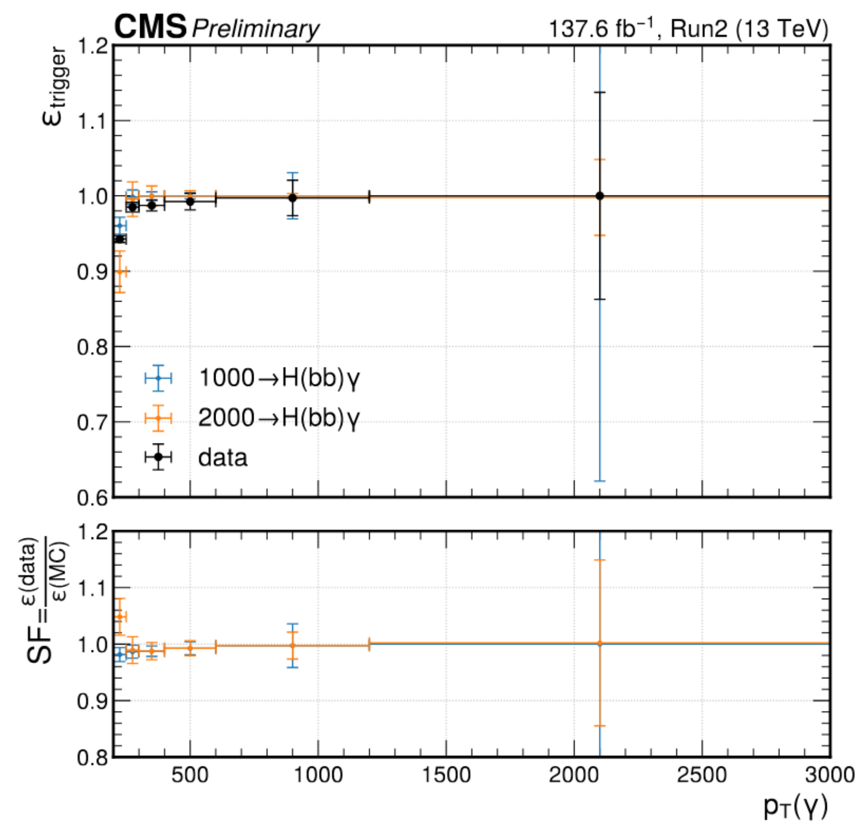






Triggers & datasets

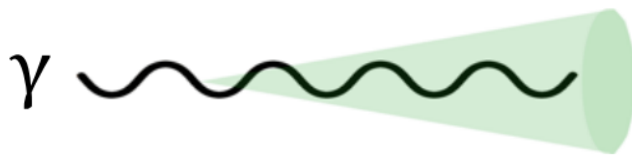
- ➔ Triggers:
  - ❖ 2016: HLT_Photon165_HE10 || HLT_Photon175
  - ❖ 2017 & 2018: HLT_Photon200
- ➔ Data: integrated lumi. = $138\ \mathrm{fb}^{-1}$
  - ❖ 2016 & 2017: SinglePhoton
  - ❖ 2018: EGamma
  - ❖ HLT efficiency: SingleMuon



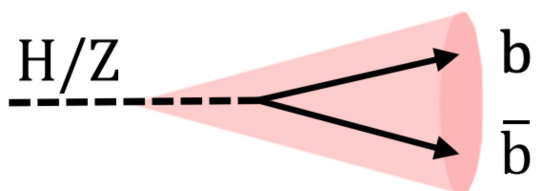
- ➔ Signal MC
  - ❖ Resonance mass points: from 700 to 3500 GeV with 15 points
  - ❖ Spin-1 $Z' \to H\gamma$: generated from the benchmark model and $\Gamma/m = 0.014\,\%$
  - ❖ Spin-0 $S \to Z\gamma$: generated via pythia8 and $\Gamma/m = 0.014\,\%$, $5.6\,\%$, $10\,\%$
- ➔ Background MC
  - ❖ Prompt 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
- ❖ $|\eta_{\gamma}| \in [0,1.4442) \cup (1,556,\ 2.5)$
- ❖ $N_{\gamma} = 1$

➔

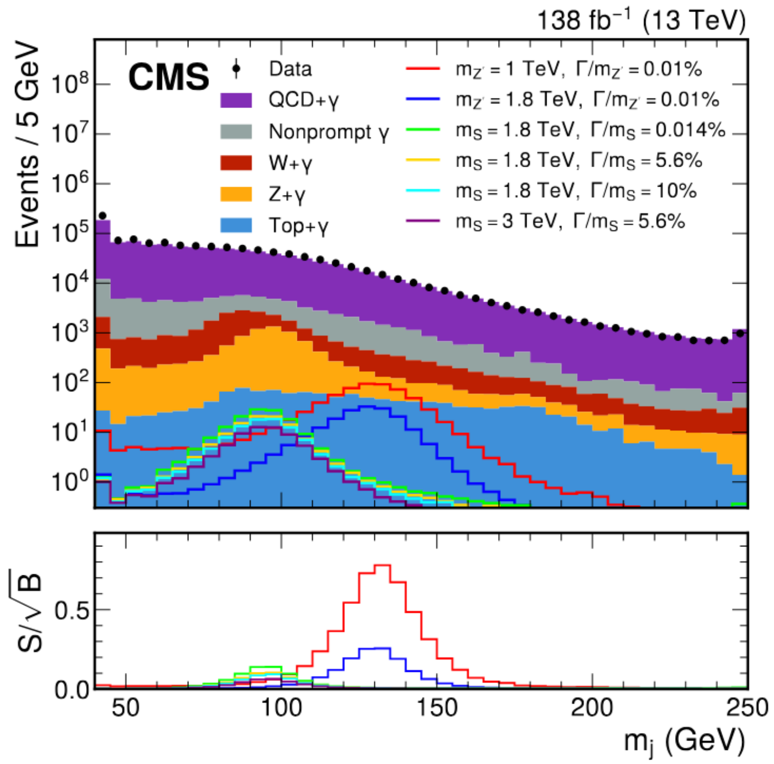
- ❖ $p_T^{j} > 250$ GeV, $|\eta_j| < 2.4$
- ❖ $m_{SD}^{j} > 30$ GeV, $N_j \geq 1$
- ❖ H/Z candidate: leading Xbb score
- ❖ $\Delta R(\gamma, H/Z) > 1.1$

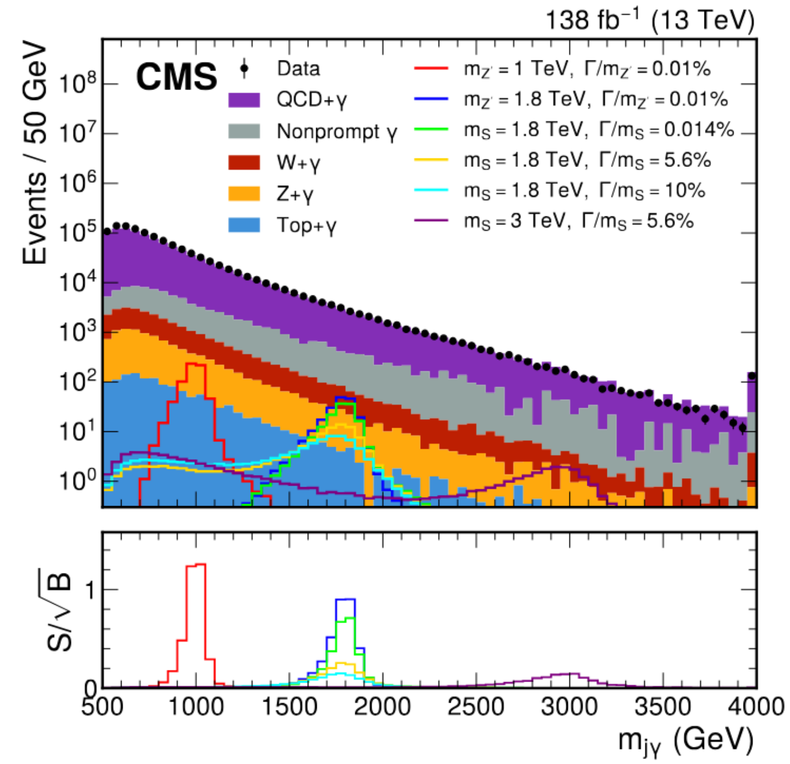
➔

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

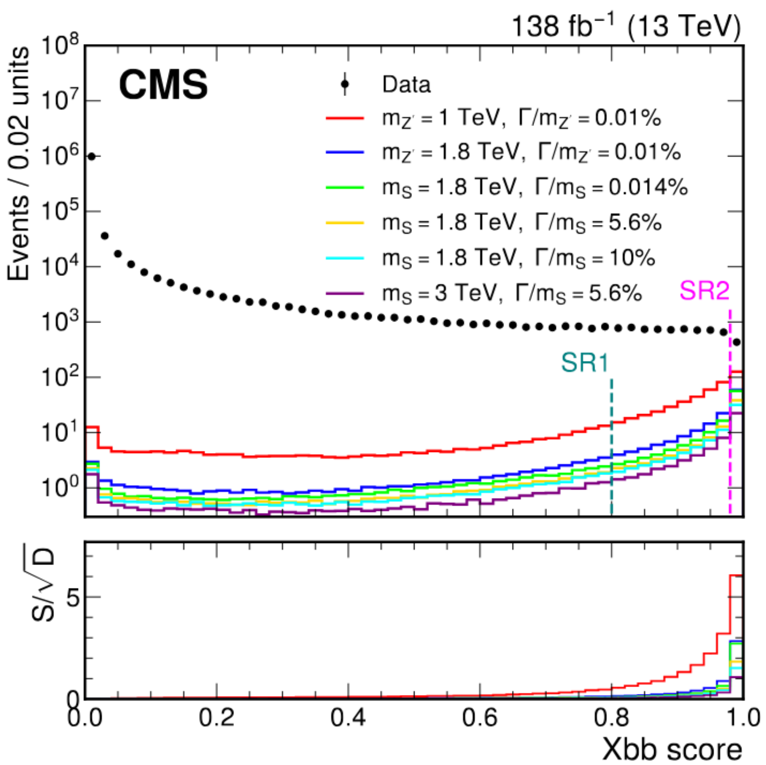
Kinematics at preselection & SR/CR definition

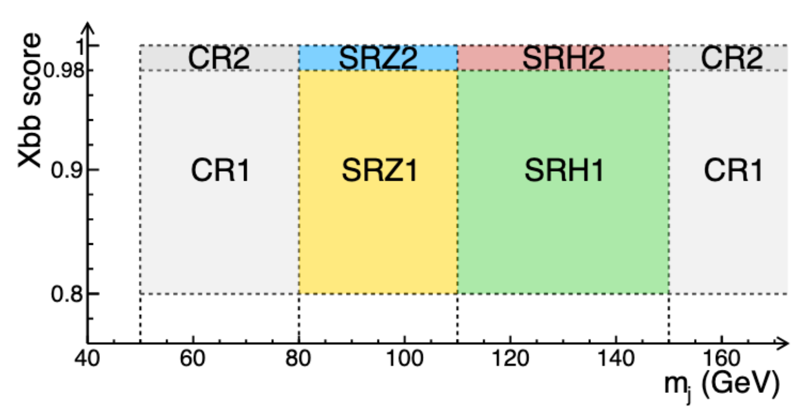
➔ Agreement check on Data/MC at preselection

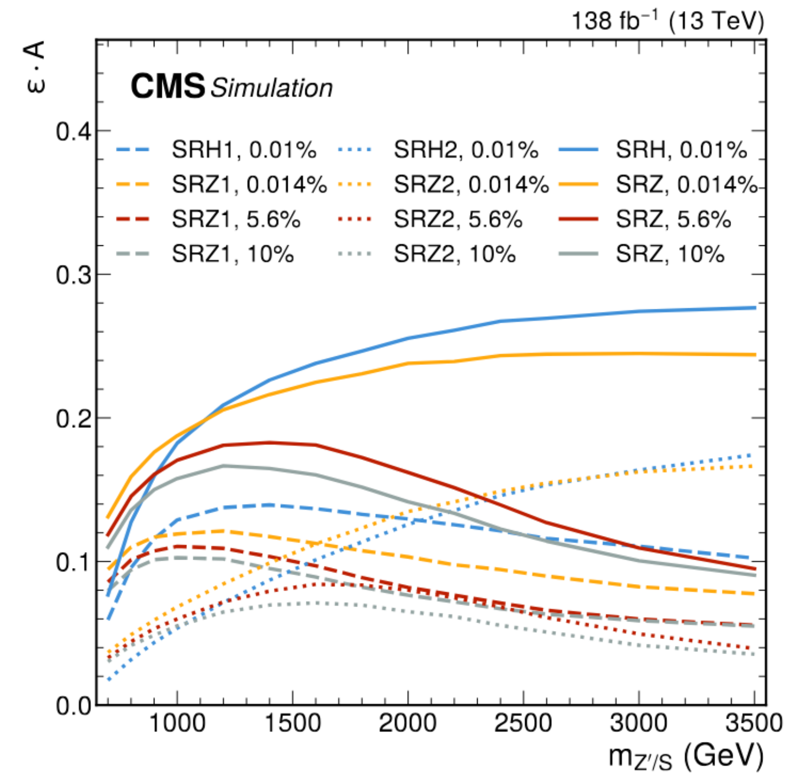




➔ The definition of SR/CR and the acceptance x efficiency of SR







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

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

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

- 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

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

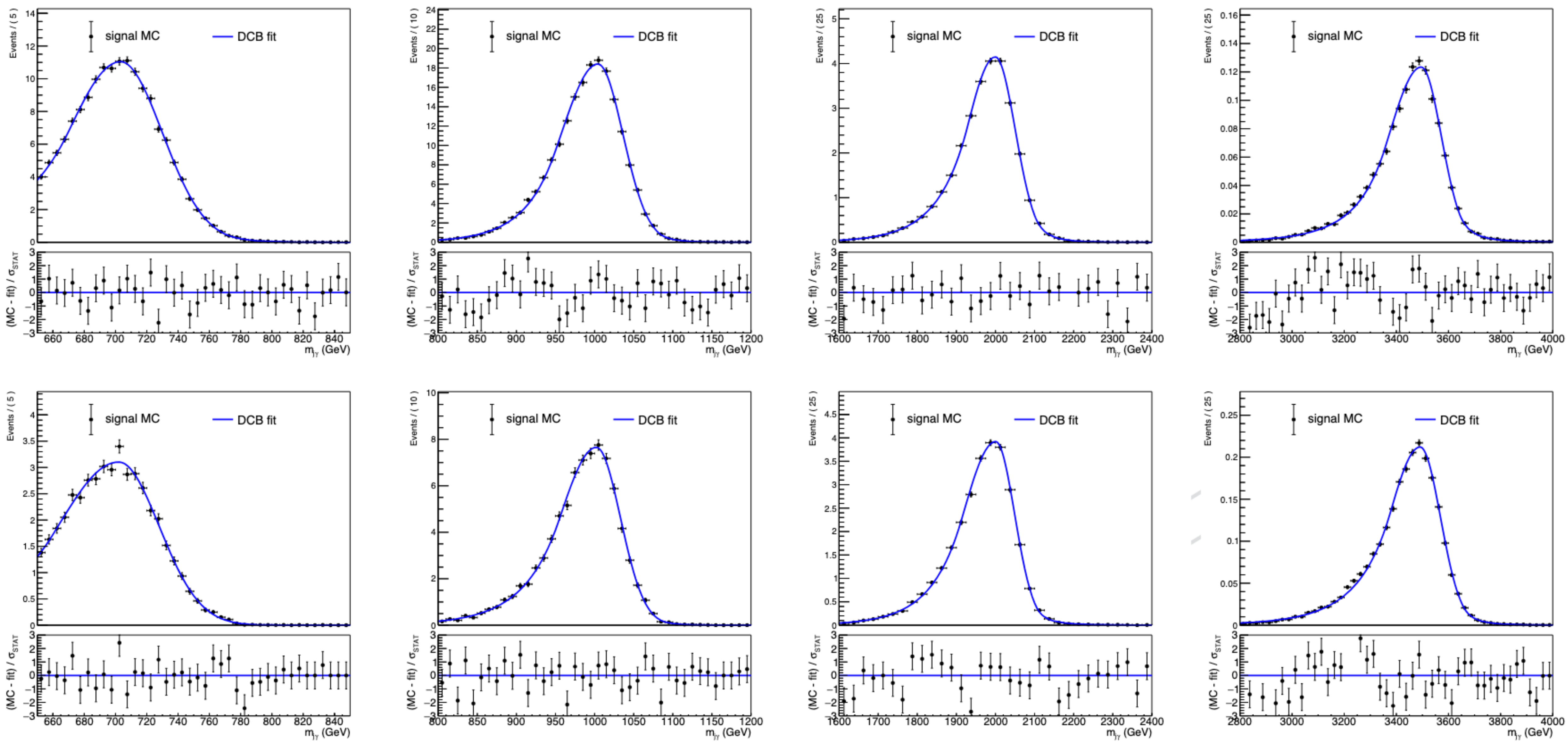
Signal modeling: $Z' \to H\gamma$

➔ Signal width $\Gamma/m = 0.01\ \%$

0.7 TeV | 1 TeV | 2 TeV | 3.5 TeV

SRH1

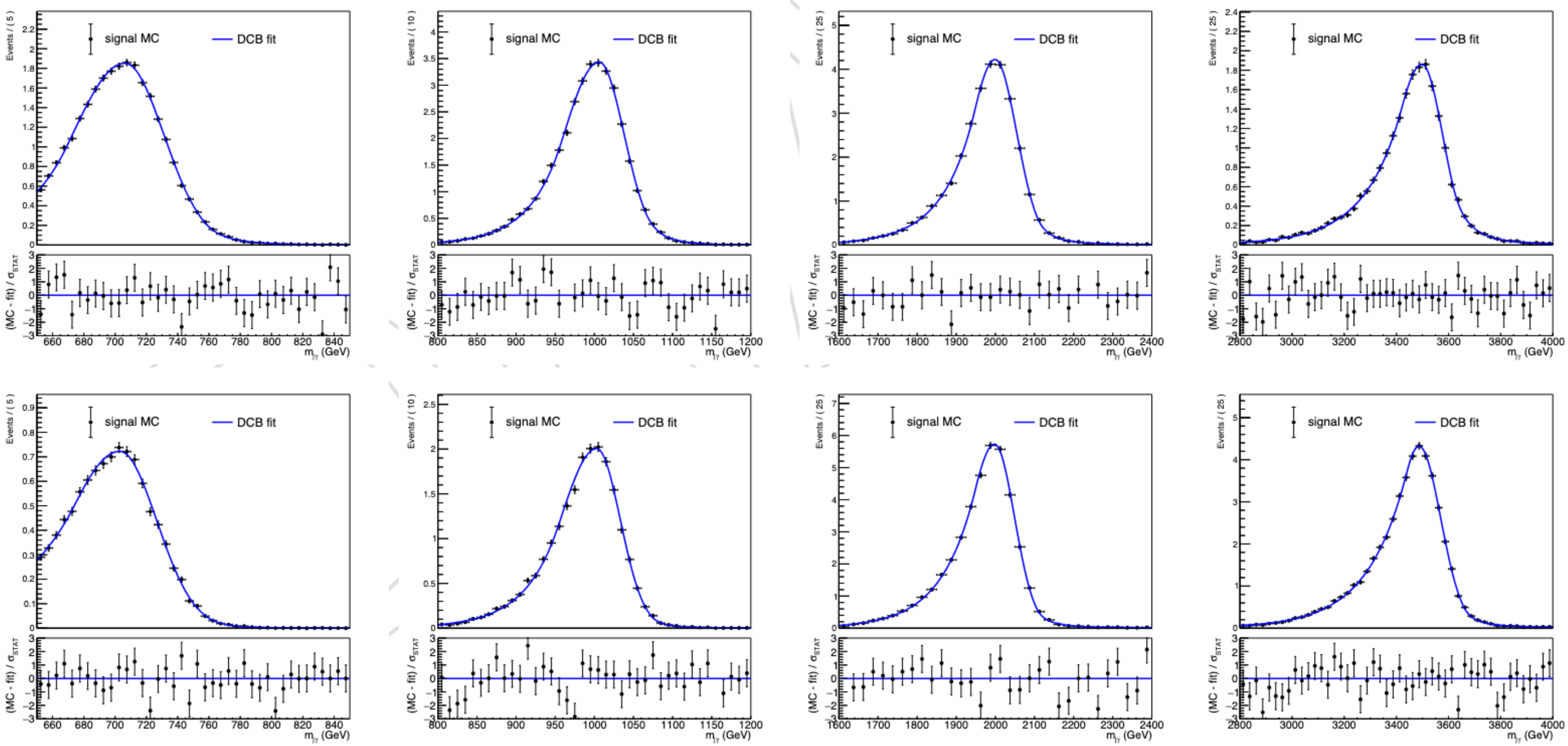
SRH2



Signal modeling: $S \rightarrow Z\gamma$

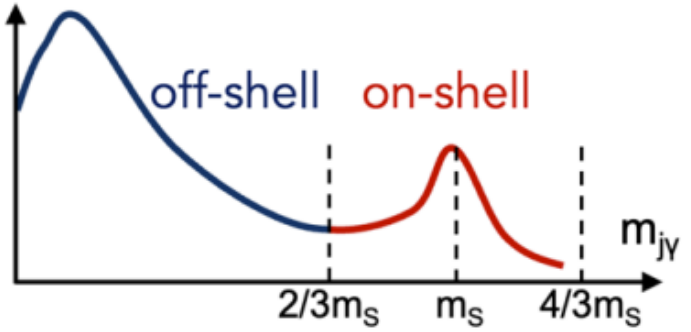
➔ Signal width $\Gamma/\mathrm{m} = 0.014\,\%$

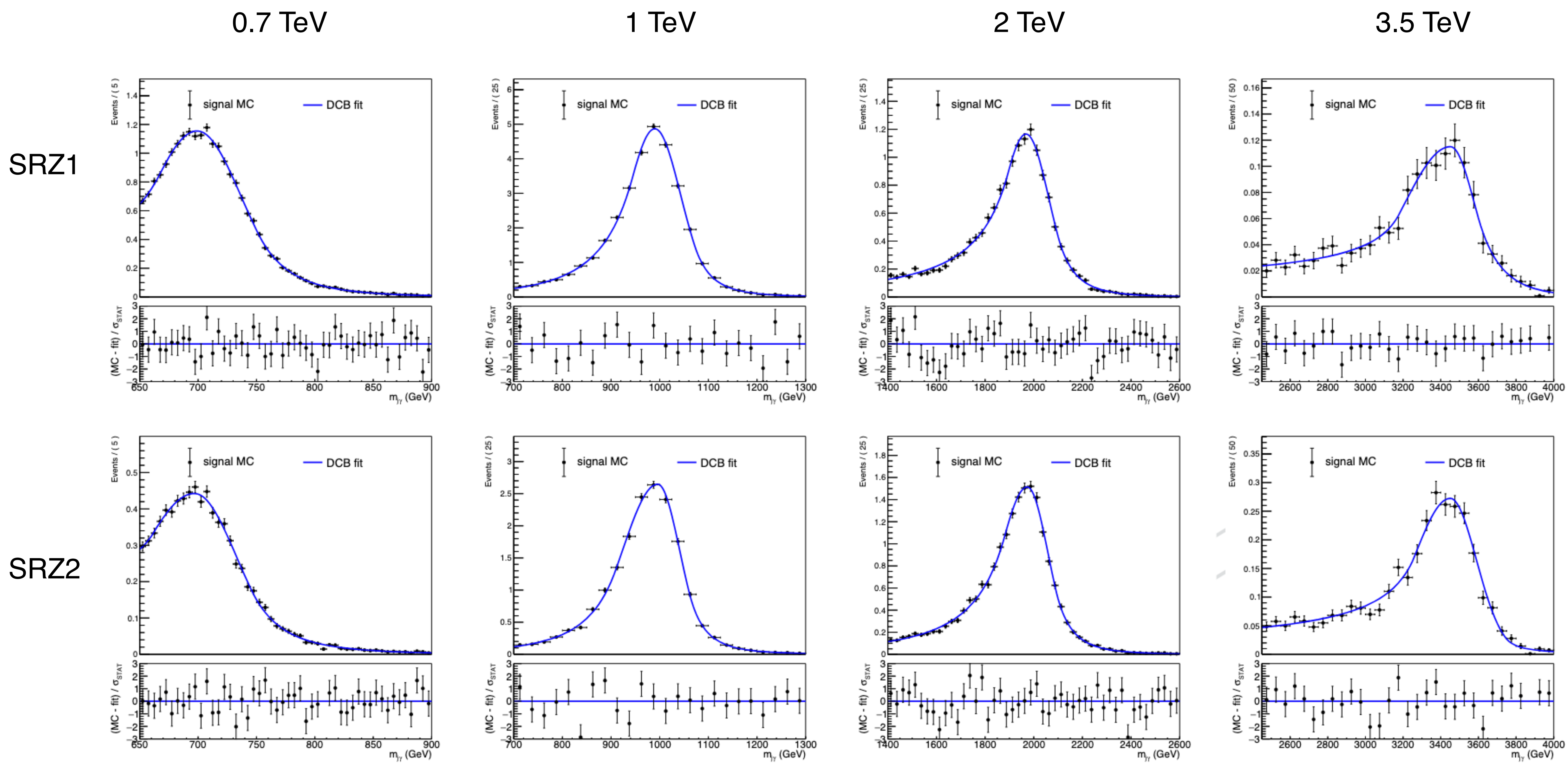
	0.7 TeV	1 TeV	2 TeV	3.5 TeV
SRZ1				
SRZ2				



Signal modeling: $S \to Z\gamma$

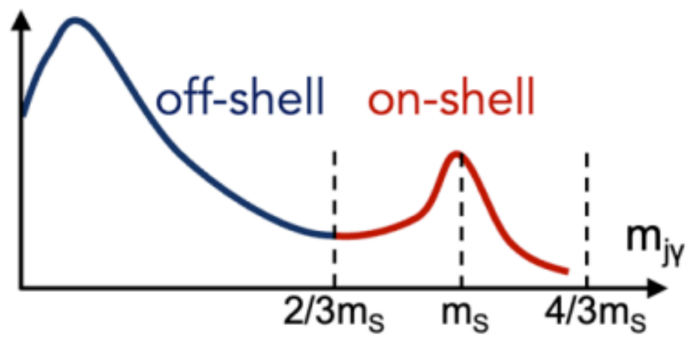
➔ Signal width $\Gamma/m = 5.6\,\%$





Signal modeling: $S \to Z\gamma$

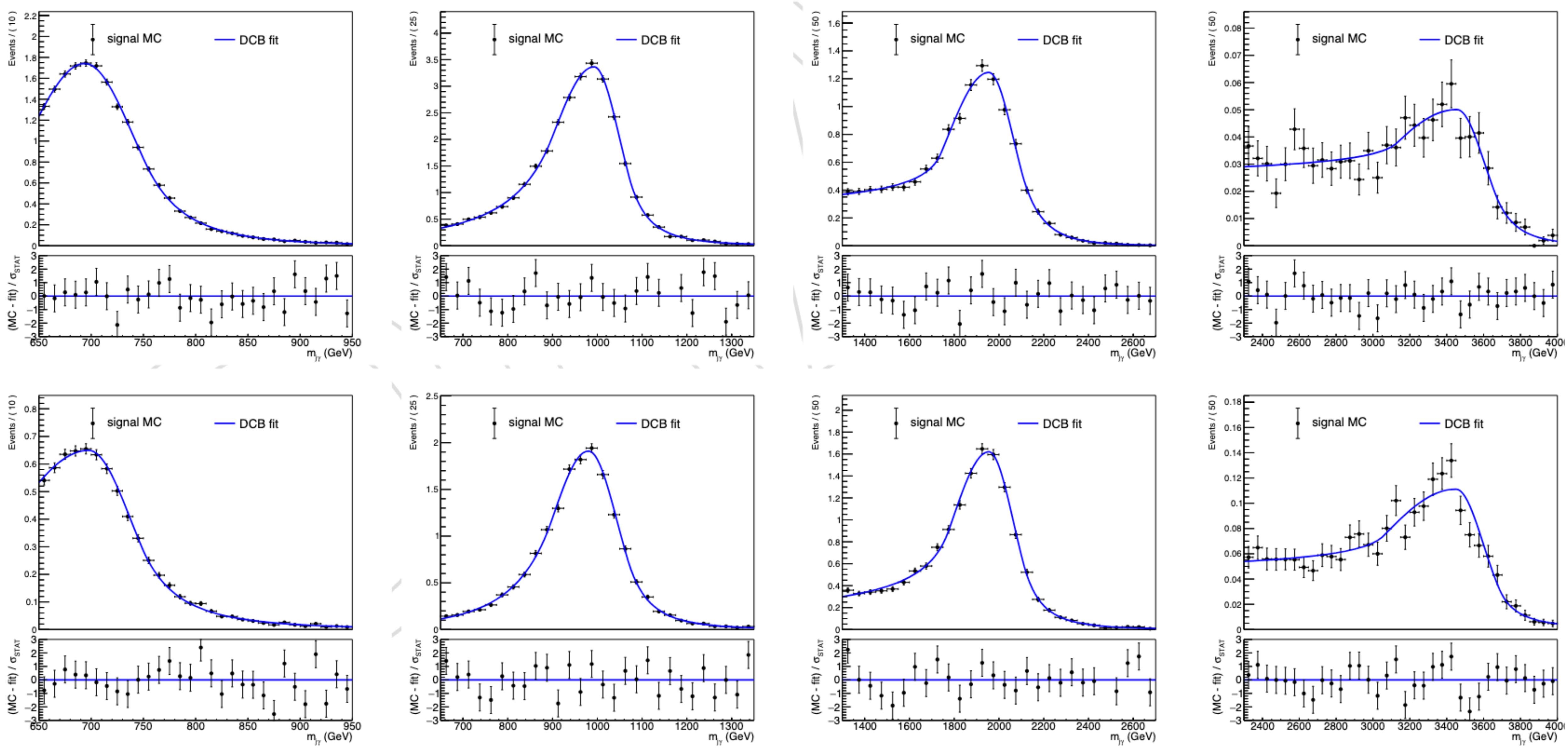
➔ Signal width $\Gamma/\mathrm{m} = 10\,\%$



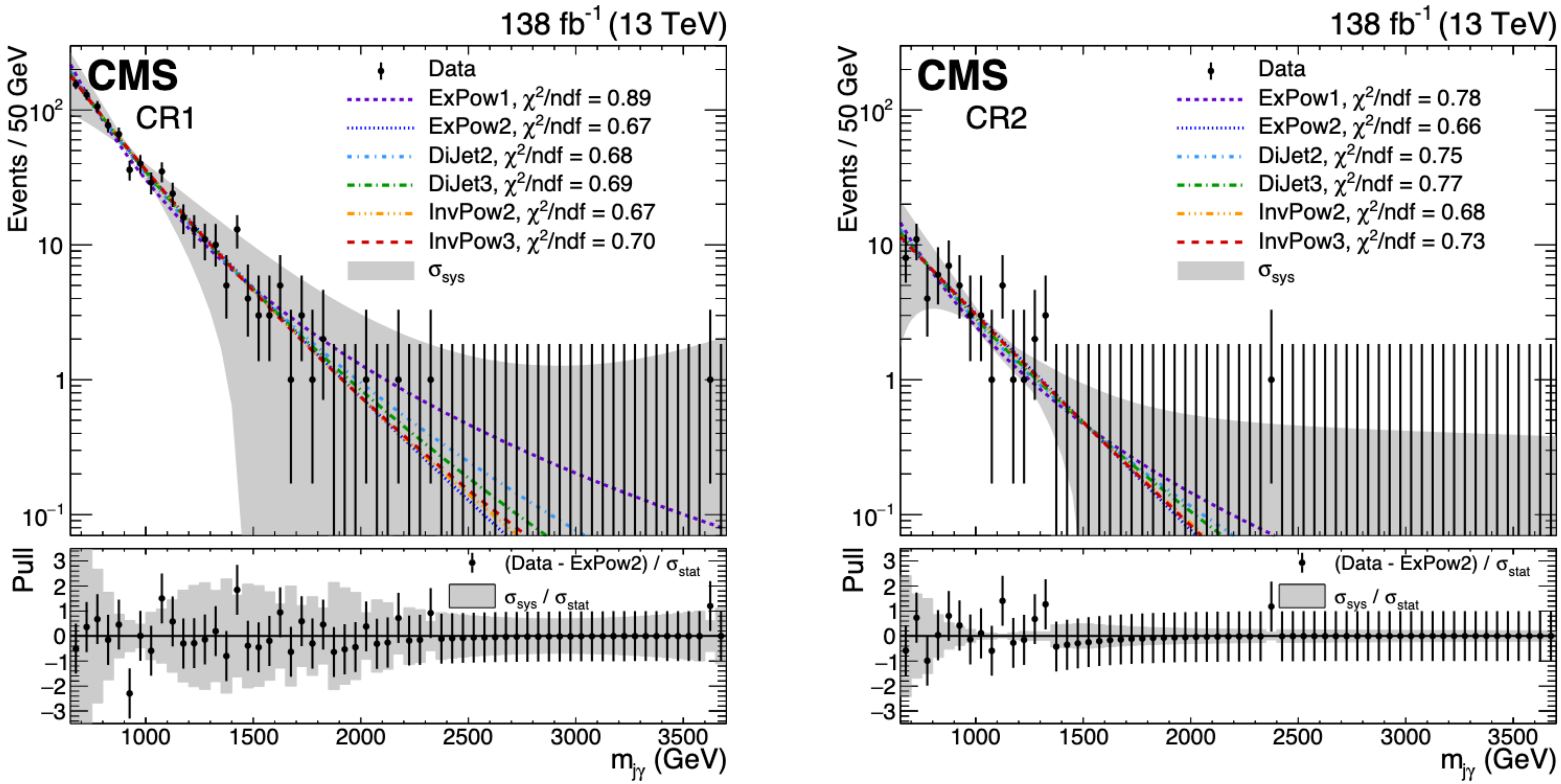
0.7 TeV | 1 TeV | 2 TeV | 3.5 TeV

SRZ1

SRZ2

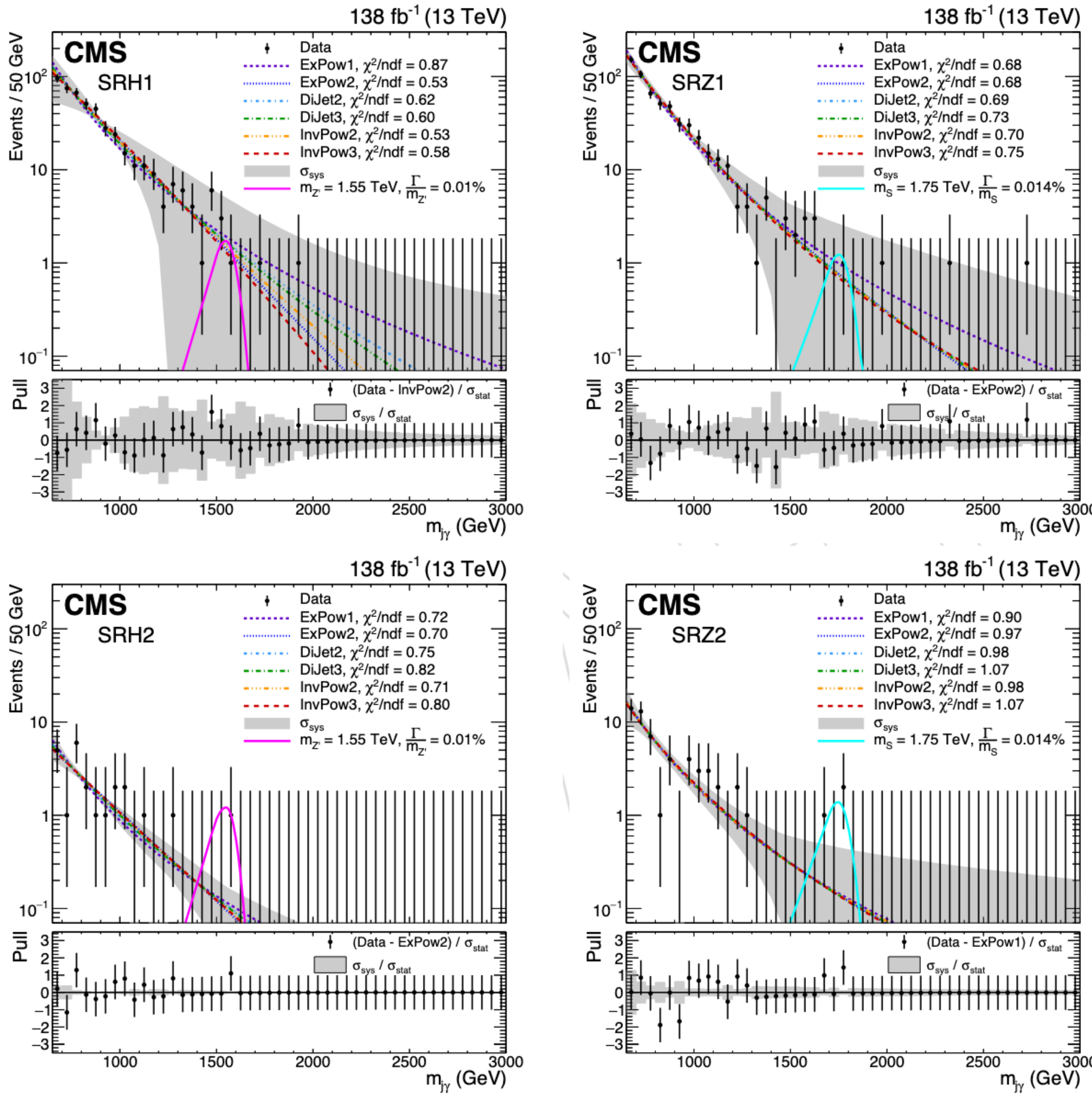


Background modeling: validation in CR



Background modeling: SR

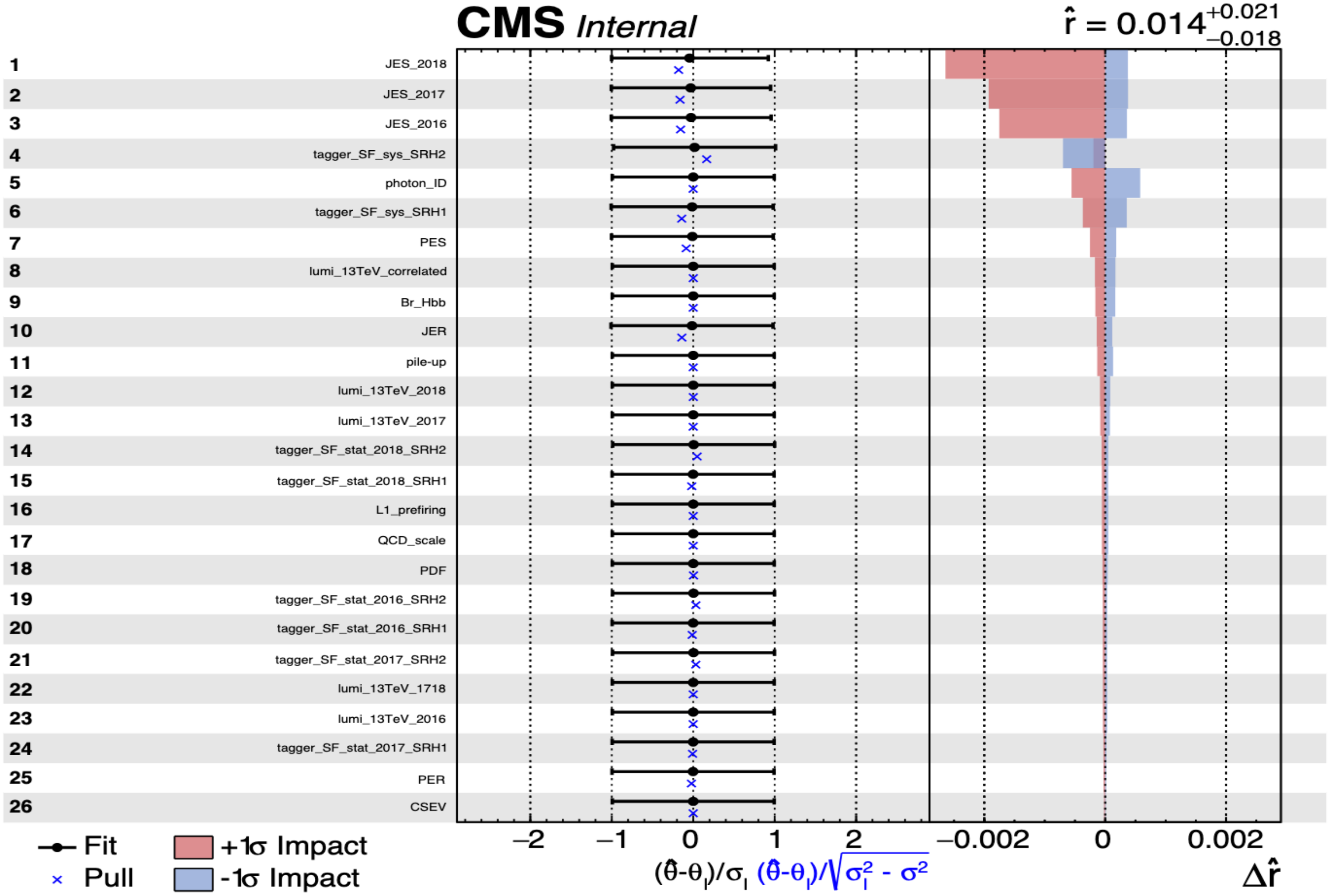
➔ Signals with the largest significances are shown



Systematic uncertainties

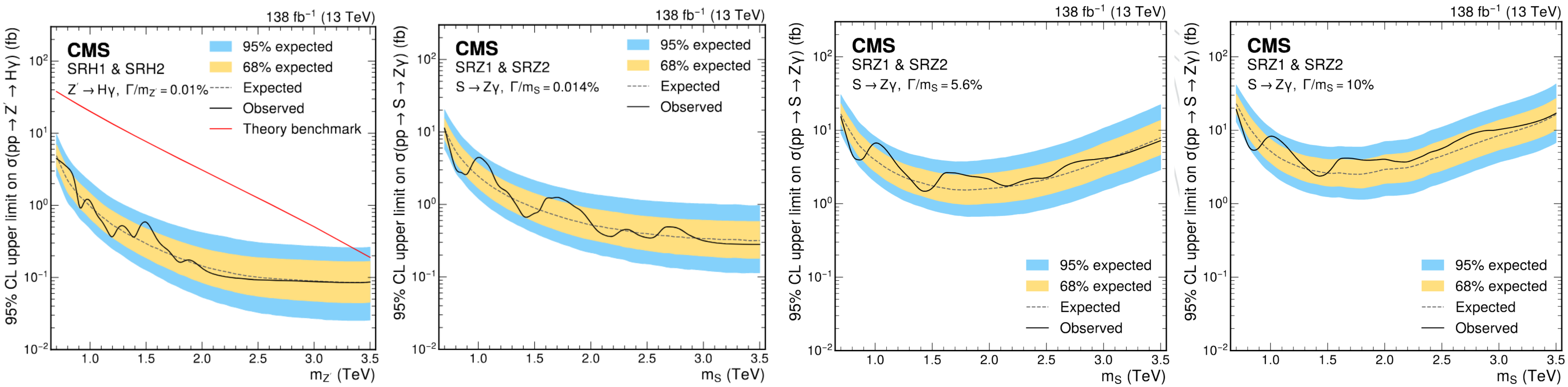
Uncertainty source	B or S	Effect on	Magnitude	Number of NPs & correlations
Background function choice	B	Shape	-	1 per SR, uncorr. across SRs
Photon ID SFs	S	Rate	4.4%	1, correlated across all SRs
Trigger selection SFs	S	Rate	1%	1, correlated across all SRs
Integrated luminosity	S	Rate	1.6%	1, correlated 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

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



Results & interpretation

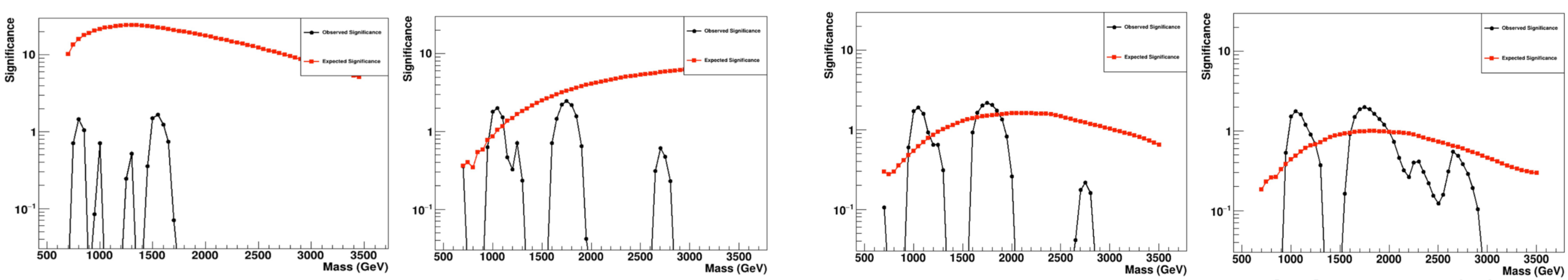
➔ Upper limits at 95% CL on $\sigma \cdot \mathrm{BR}$ under Asymptotic statistical method



➔ Local significance

Observed significance

Expected significance



Summary & prospect

- Perfromed the search for diboson resonance $\mathrm{X} \to \mathrm{H/Z}\gamma$ 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?