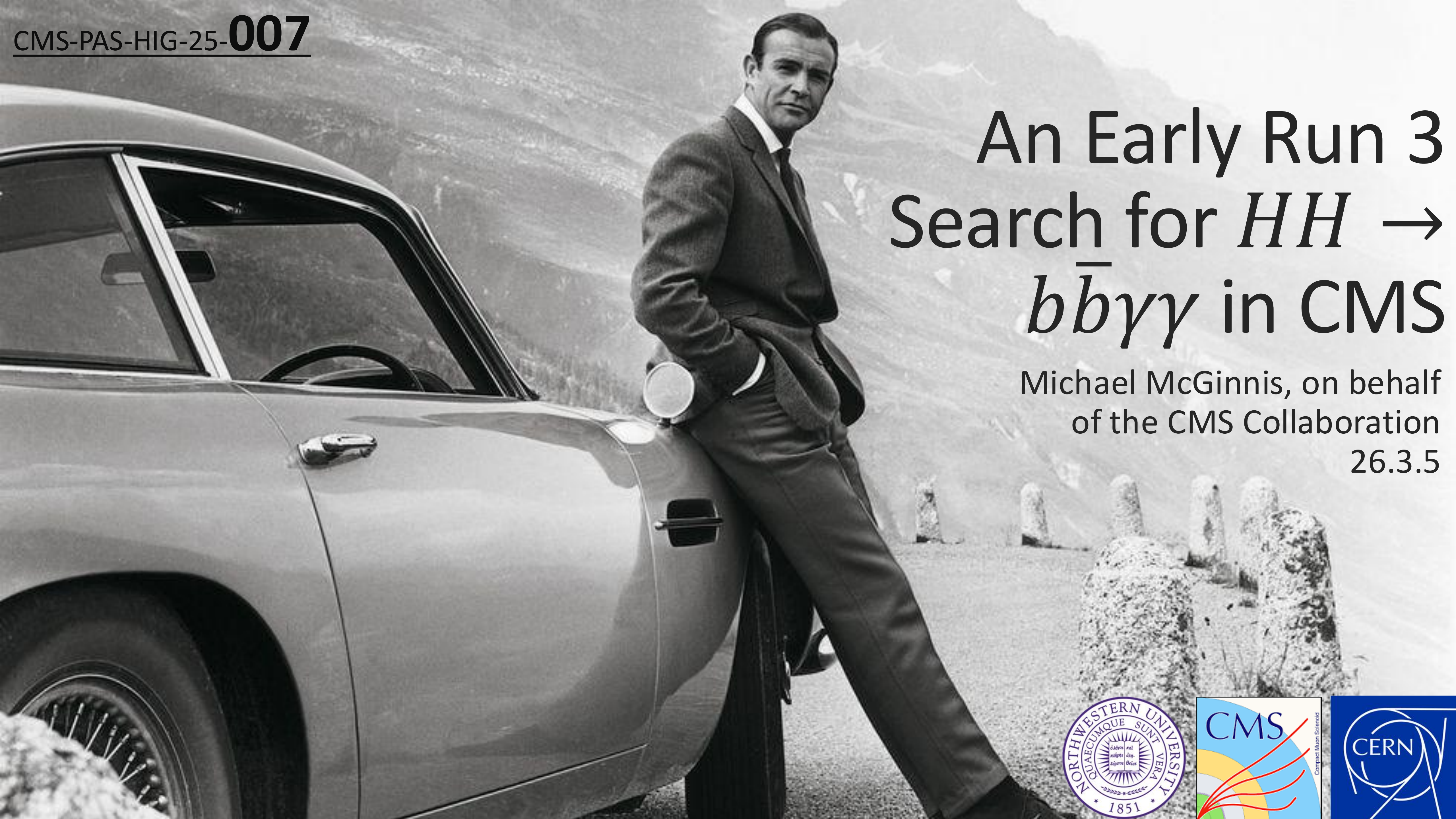
CMS-PAS-HIG-25-**007**



An Early Run 3 Search for $HH \rightarrow b\bar{b}\gamma\gamma$ in CMS

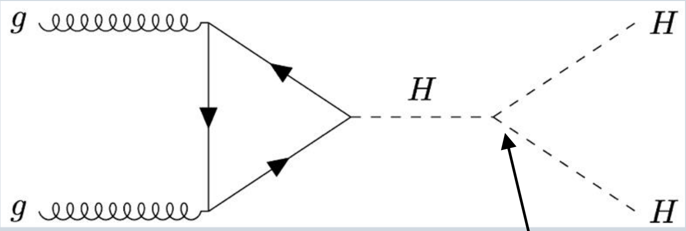
Michael McGinnis, on behalf of the CMS Collaboration

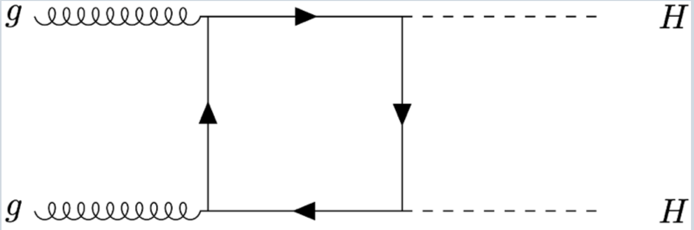
26.3.5

$pp \rightarrow HH \rightarrow b\bar{b}\gamma\gamma$

Higgs-boson self-coupling determines shape of the Higgs potential, yet to be measured.

- Focus of this analysis is the ggF mode
- XS @ 13.6 TeV: 34.13 fb





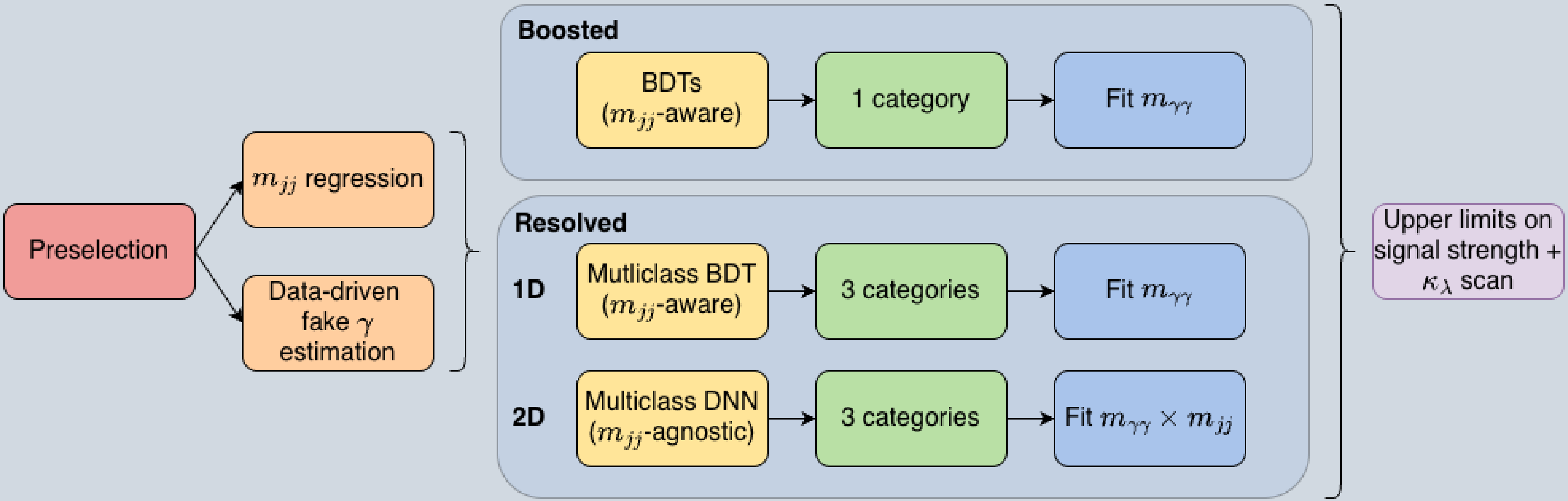
Trilinear self-coupling: $\kappa_\lambda = \frac{measured}{SM}$

- **Since $\lambda \propto \sigma_{HH}^2$, can measure self coupling via HH cross-section**

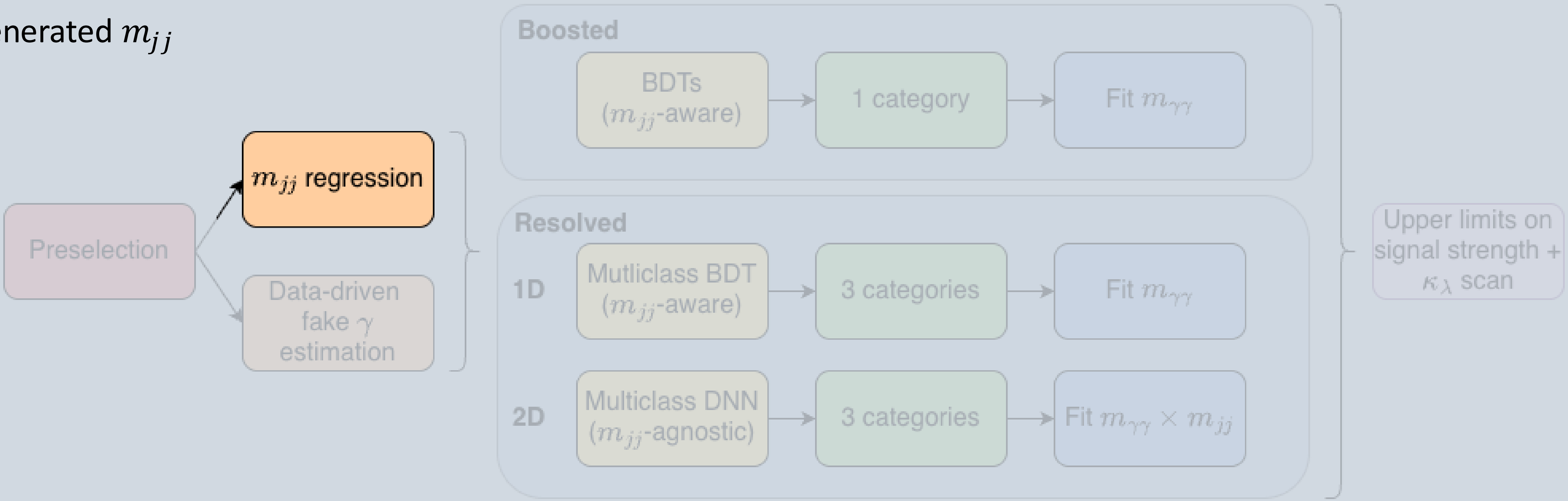
	$b\bar{b}$	WW	$\tau\bar{\tau}$	ZZ	$\gamma\gamma$
$b\bar{b}$	34%				
WW	25%	4.6%			
$\tau\bar{\tau}$	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
$\gamma\gamma$	0.26%	0.10%	0.028%	0.012%	0.0005%

Abundance from $H \rightarrow b\bar{b}$

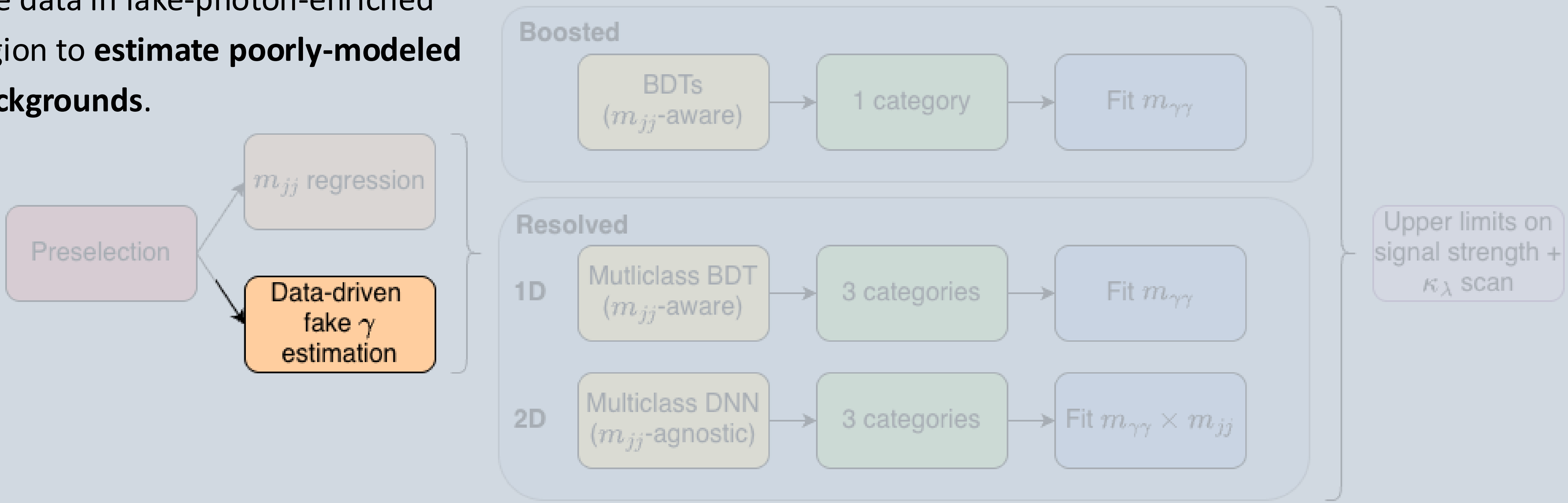
Excellent $m_{\gamma\gamma}$ resolution, fully reconstructible, simpler triggers


Preselection
m_{jj} regression
Data-driven fake γ estimation
Boosted
BDTs (m_{jj}-aware)
1 category
Fit $m_{\gamma\gamma}$
Resolved
1D
Mutliclass BDT (m_{jj}-aware)
3 categories
Fit $m_{\gamma\gamma}$
2D
Multiclass DNN (m_{jj}-agnostic)
3 categories
Fit $m_{\gamma\gamma} \times m_{jj}$
Upper limits on signal strength + κ_λ scan

DNN trained on signal to **improve m_{jj} resolution**, targeting scaling term between reconstructed and generated m_{jj}

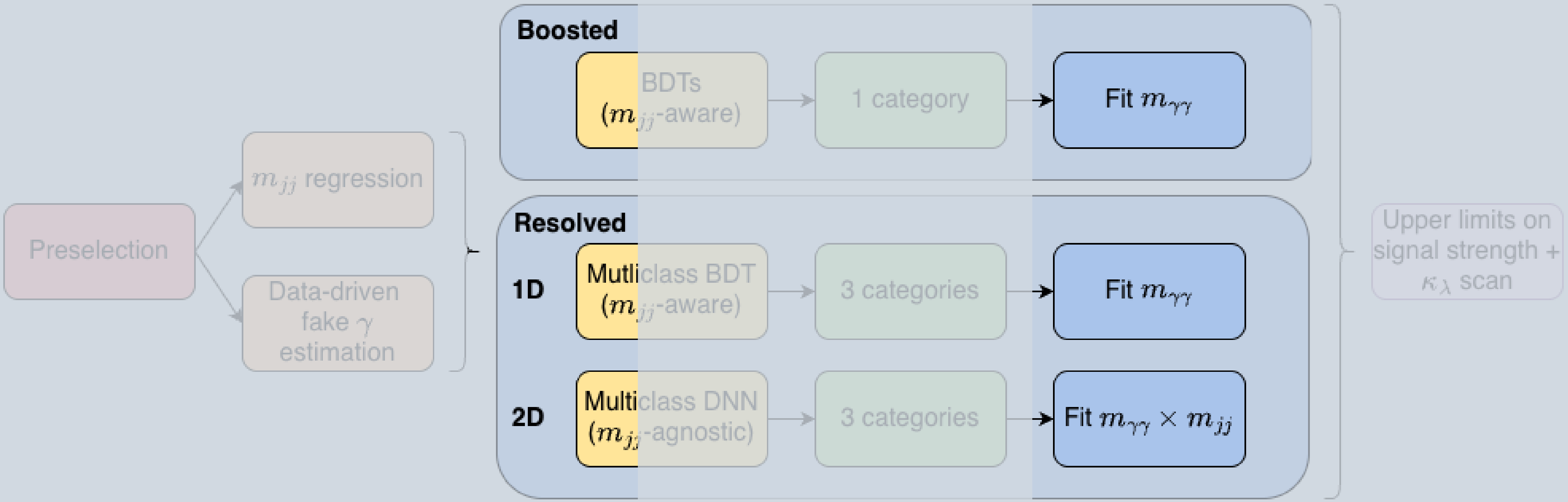


Use data in fake-photon-enriched region to **estimate poorly-modeled backgrounds**.



Novel w.r.t. to previous CMS HH results.

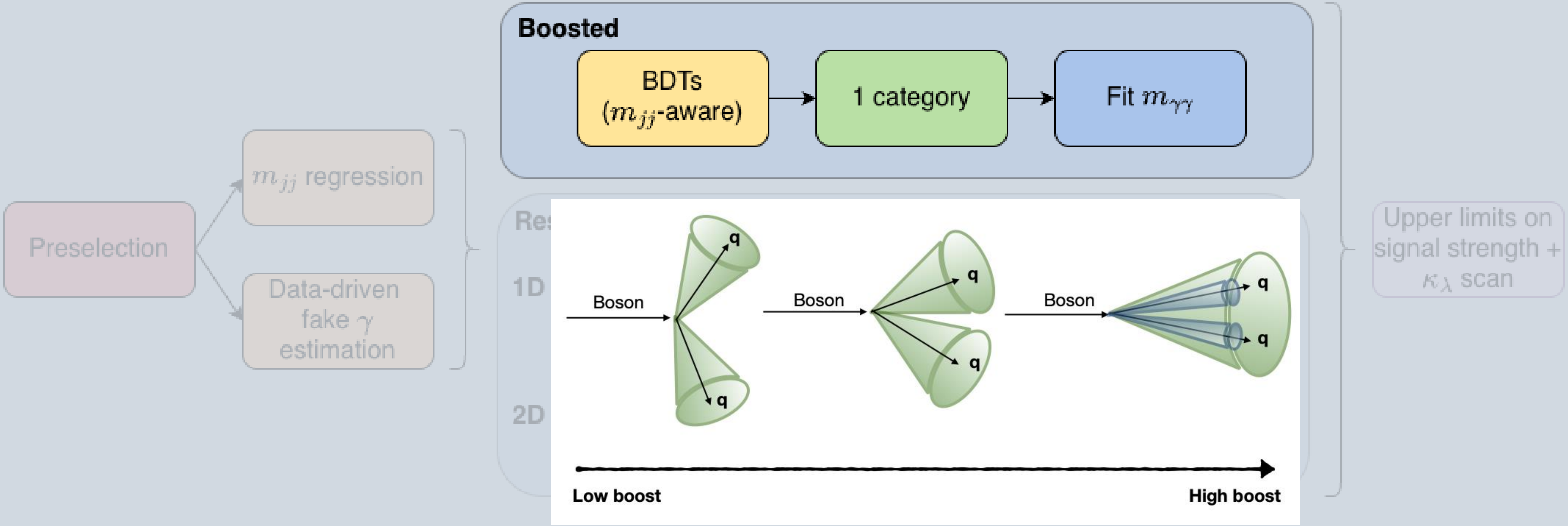
Boosted category combined with each 1D & 2D for results.



Novel w.r.t. to previous CMS HH results: 1D & 2D in same paper

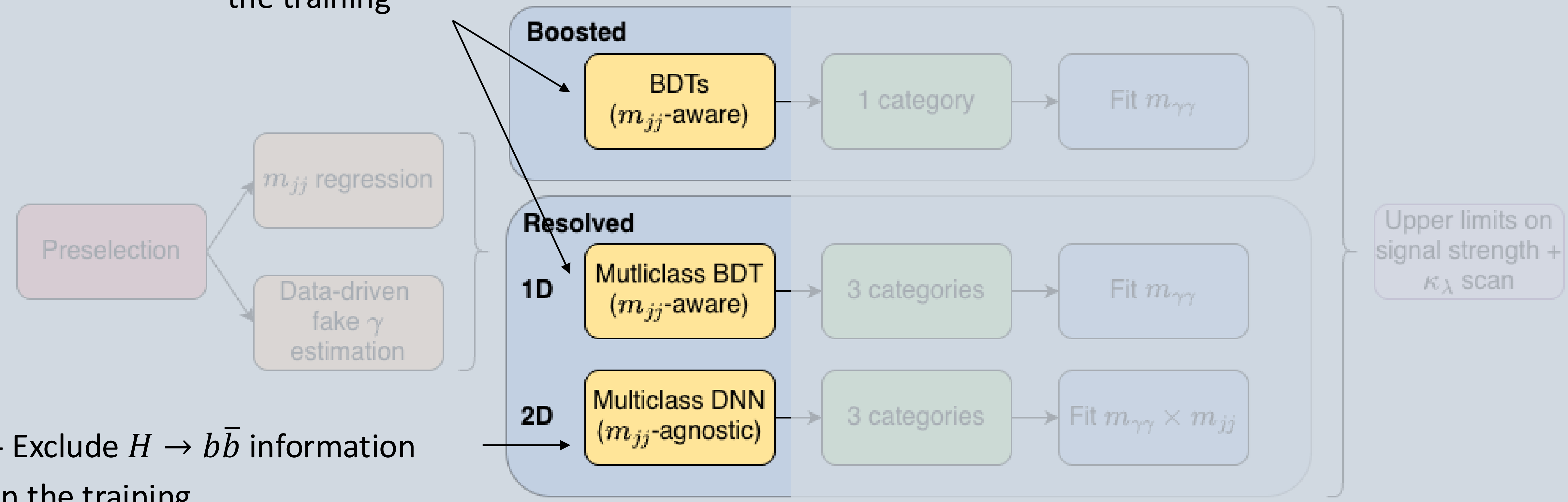
Target high p_T $H \rightarrow b\bar{b}$: less isolated jets, **High signal-to-background**.

-Jets reconstructed with larger radius parameter (0.4 vs 0.8)



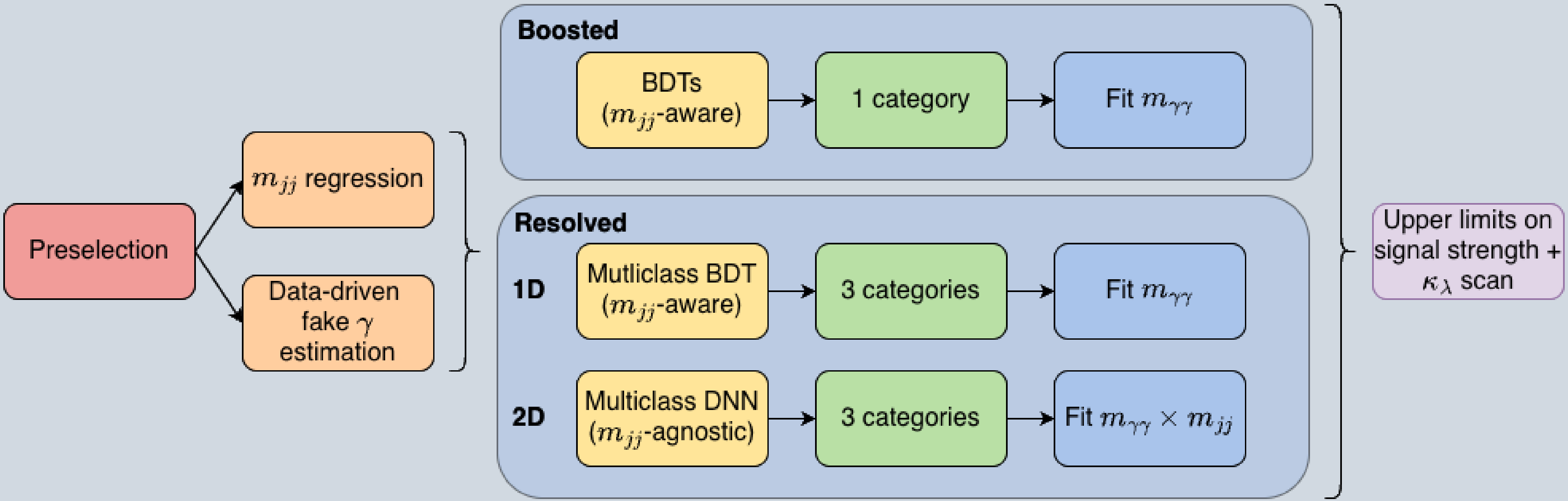
ML techniques to **discriminate signal and backgrounds**

Use $H \rightarrow b\bar{b}$ information in the training



- Exclude $H \rightarrow b\bar{b}$ information in the training.

Account for sculpting with bias uncertainty (see later slide)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3 categories
Fit $m_{\gamma\gamma} \times m_{jj}$
Upper limits on signal strength + κ_λ scan

Signal, Resonant Backgrounds Fitting

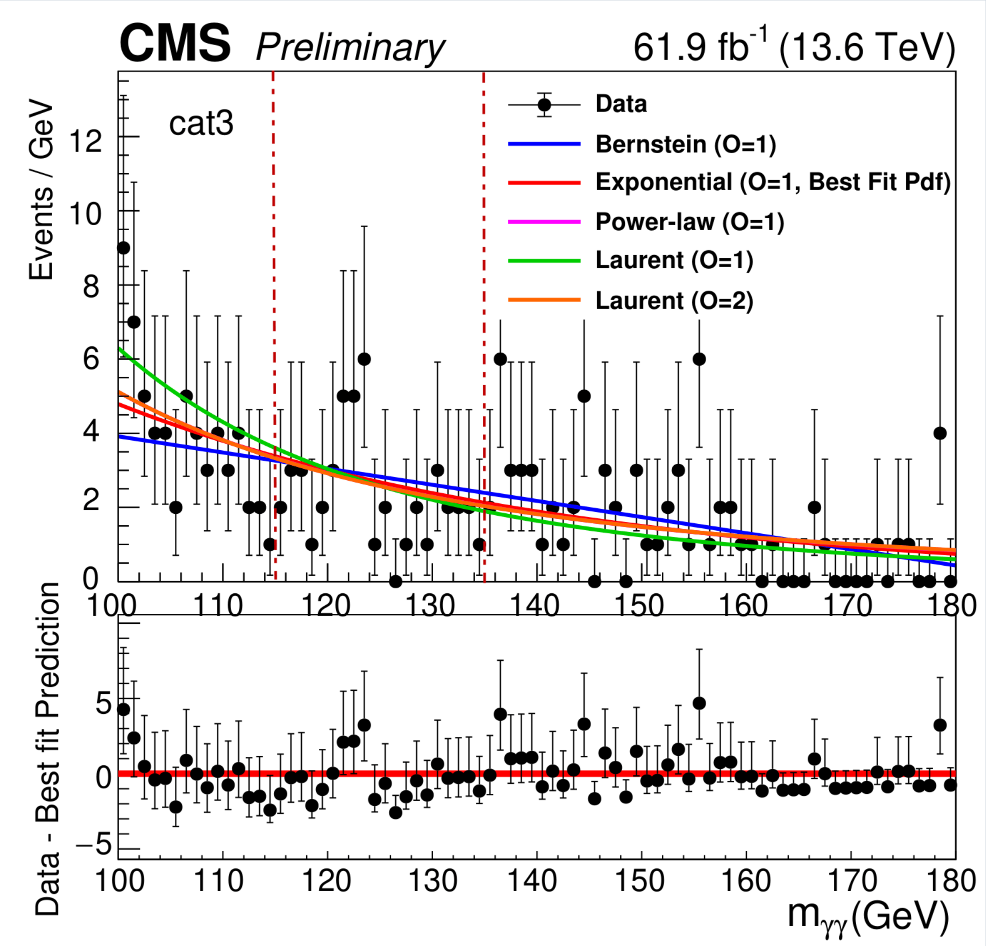
- Resonant backgrounds: $\mathrm{H} \rightarrow \gamma\gamma$ + jets

	1D	2D ($m_{\gamma\gamma}$)	2D (m_{jj})	Boosted
Sum of Gaussians	Signal VH+ttH+ggH+VBFH	Signal	Signal	
Double Crystal Ball		VH, ttH, ggH+VBFH	VH, ttH	Signal, VH, ttH, ggH+VBFH

- When using a sum of Gaussians, minimize $\chi^2/n(dof)$
- Combining backgrounds to reduce impact of statistical fluctuations
  - 1D: all backgrounds
  - 2D, boosted: ggH+VBFH
- 2D m_{jj} fit of ggH+VBFH: best fit series of functions, discrete profiling method

Nonresonant Backgrounds Fitting

- $n\gamma$+jets backgrounds (no $\mathrm{H} \to \gamma\gamma$)
  - Fit data in mass sidebands due to poor modeling of nonresonant backgrounds
  - 1D & 2D (both $m_{\gamma\gamma}$ and m_{jj})
- Find best fit for different orders of several families of functions, minimizing $\chi^2/n(dof)$
- Uncertainty accounting for choice of functional form via discrete profiling method

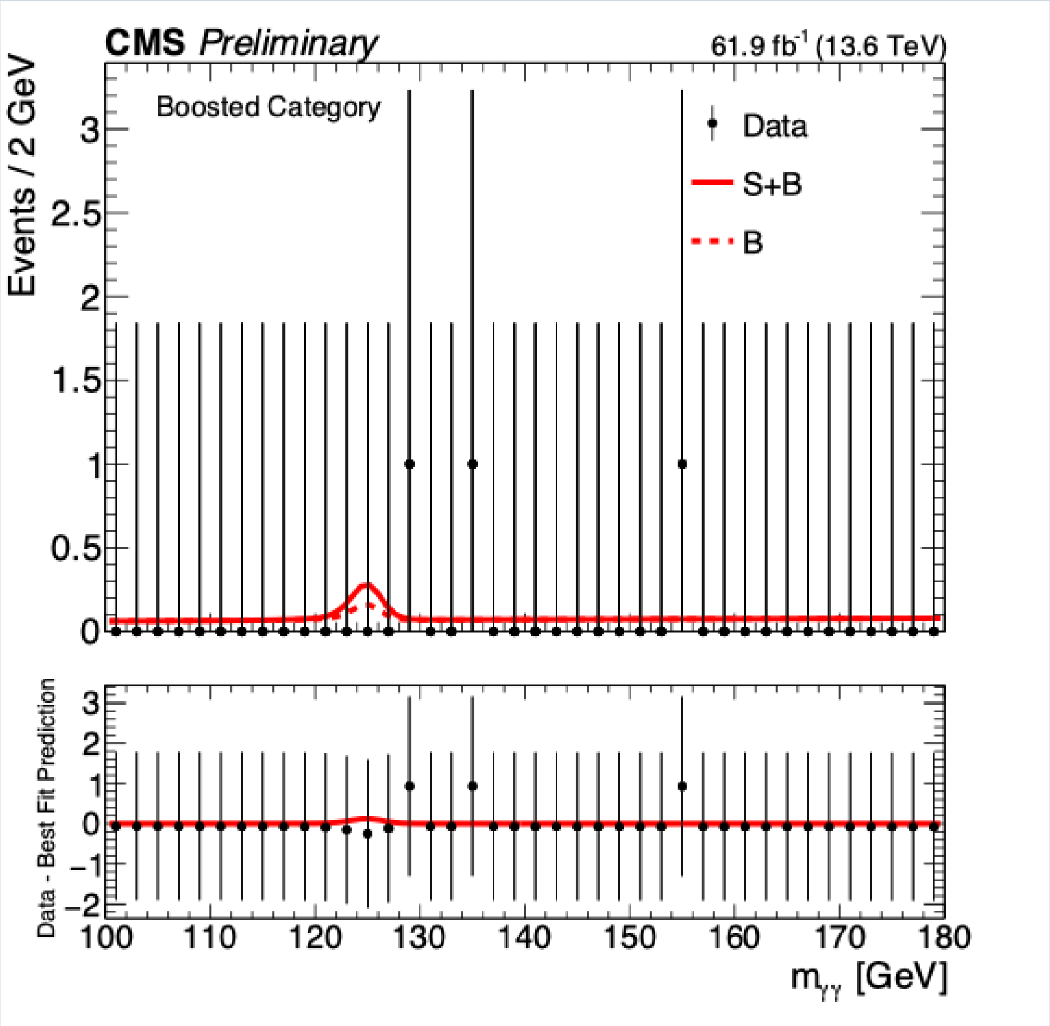


$m_{\gamma\gamma}$ blinded region in dashed lines

Systematic Uncertainties

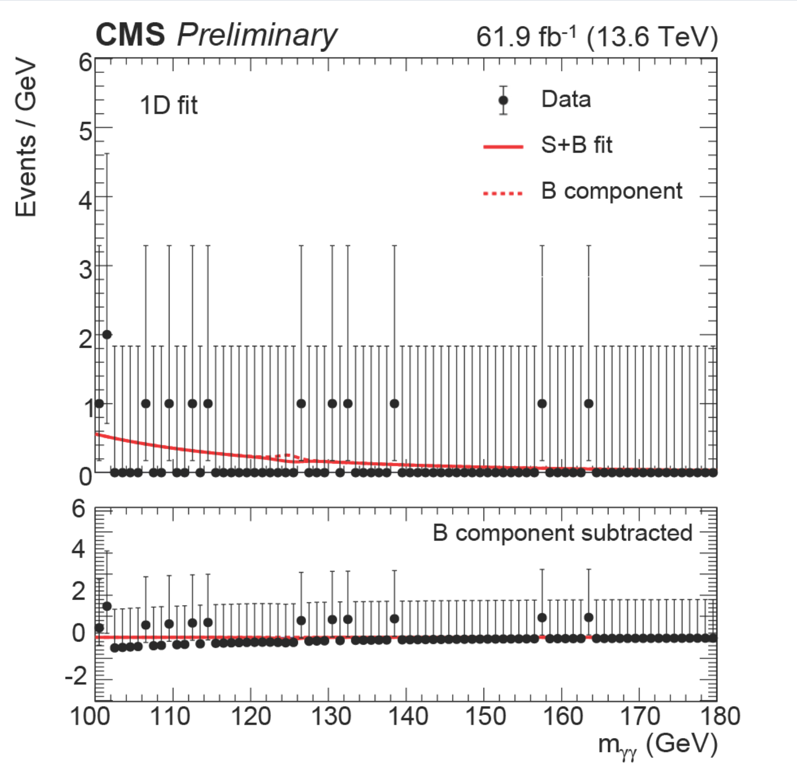
Uncertainty source	uncertainty Size	1D fit	2D fit	boosted
b tagging	6–9%	norm	norm	norm
Trigger efficiency	1–2%	norm	norm	norm
Preselection efficiency	1–2%	norm	norm	norm
Electron veto efficiency	1–2%	norm	norm	norm
Pileup	1–4%	norm	norm	norm
Luminosity	1.4%	norm	norm	norm
Photon energy scale	$< 10\%$	shape	shape	shape
Photon energy resolution	$< 10\%$	shape	shape	shape
Jet energy scale	4–9%	norm	shape	norm
Jet energy resolution	1–4%	norm	shape	norm
Higgs boson branching ratio	2 %	norm	norm	norm
ggH, VH, VBF H cross section	1–4%	norm	norm	norm
$t\bar{t}H$ cross section	9%	norm	norm	norm
PDF	1–3%	norm	norm	norm
α_S	1–3%	norm	norm	norm
HH theory cross section	23%	norm	norm	norm
bbH modeling	50%	norm	norm	norm
Bias uncertainty	3–30%	–	norm	–
MC statistics	1–20%	norm	norm	norm

Signal + Background Fits: Boosted

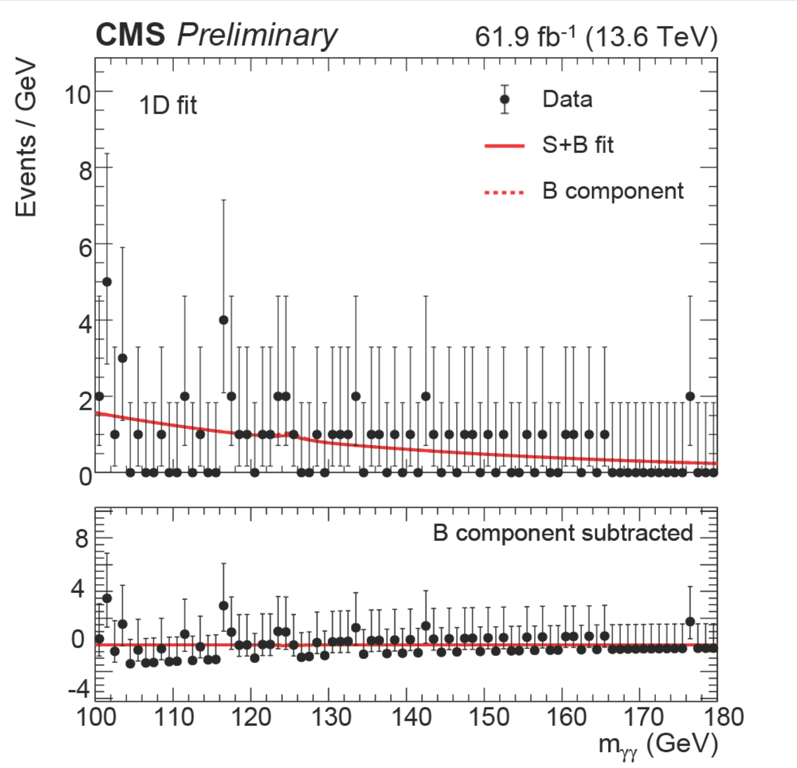


Signal + Background Fits: 1D

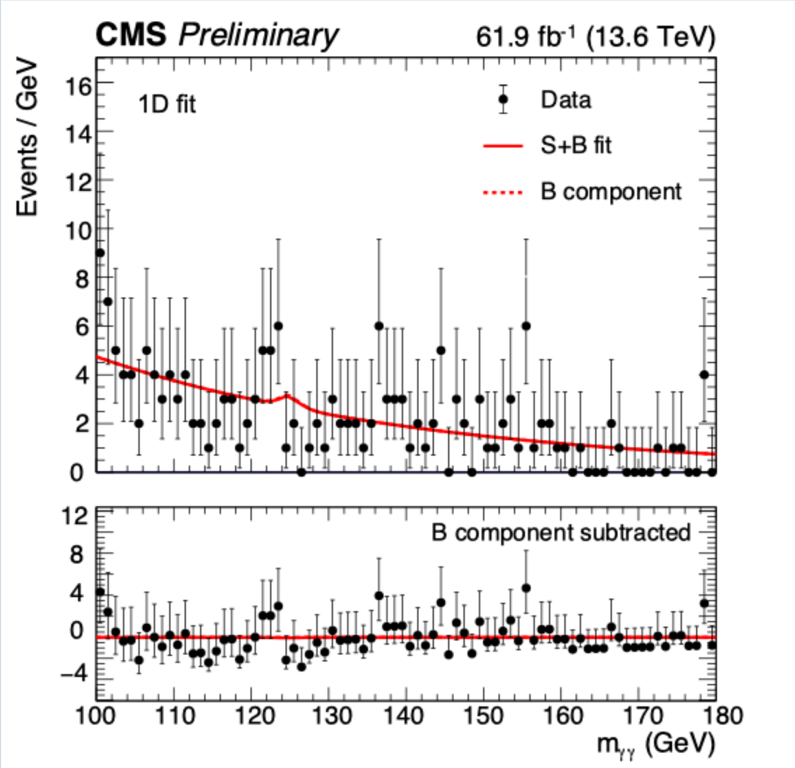
Cat 1



Cat 2



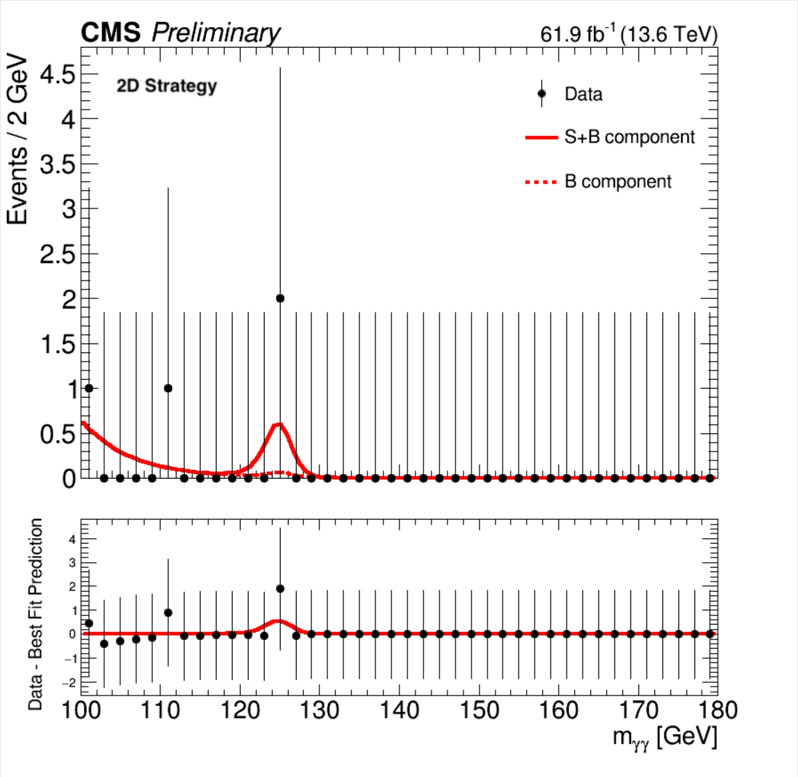
Cat 3



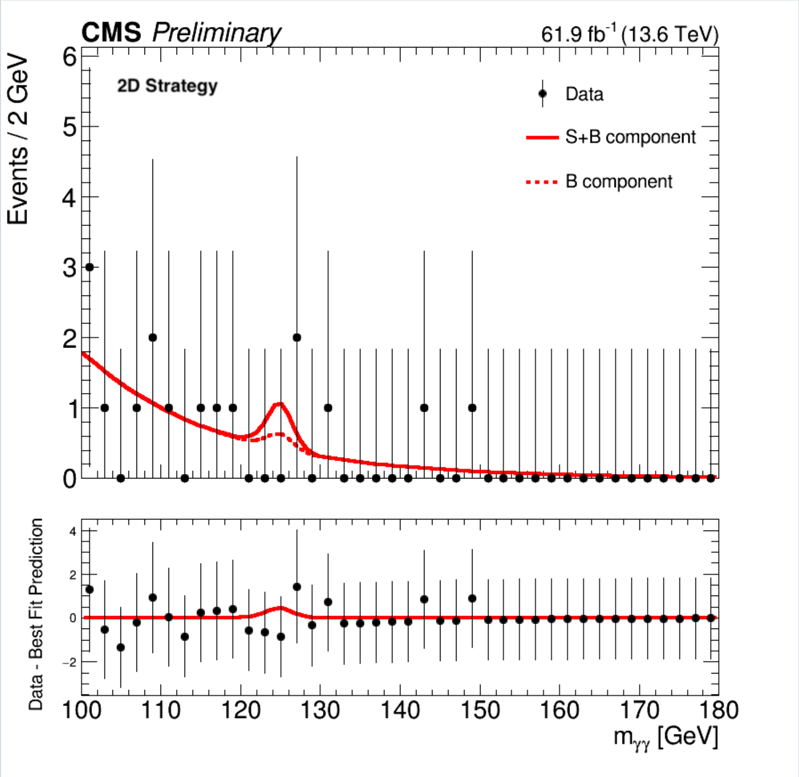
- Most → least sensitive

Signal + Background Fits: 2D $m_{\gamma\gamma}$

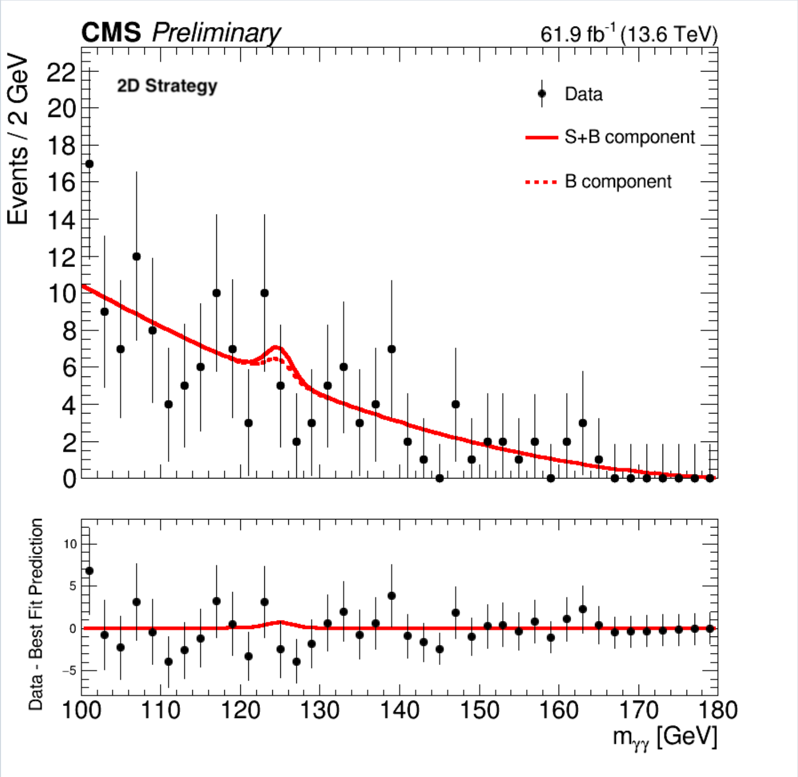
Cat 1



Cat 2



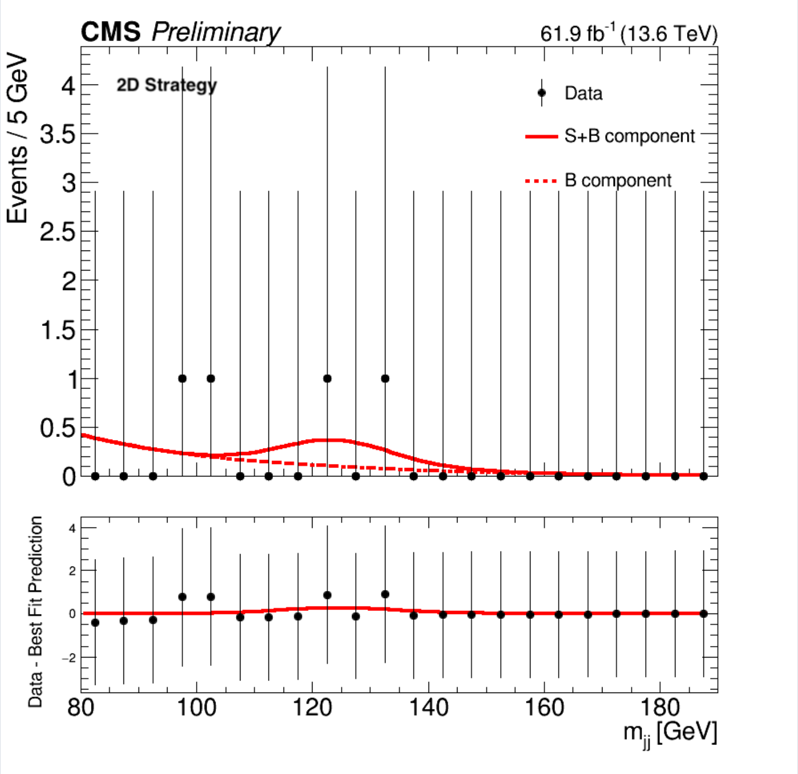
Cat 3



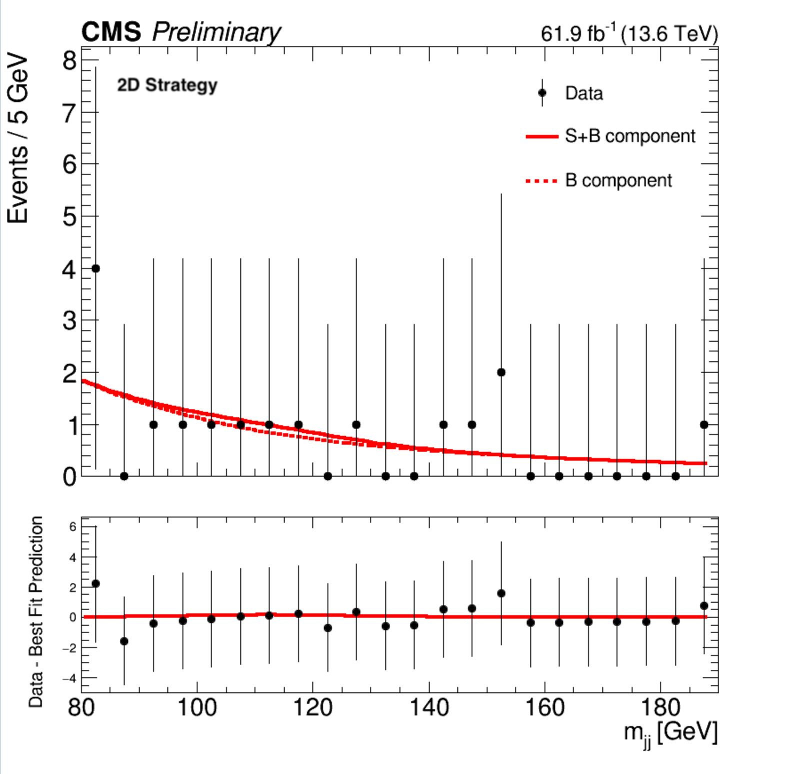
- Most → least sensitive

Signal + Background Fits: 2D m_{jj}

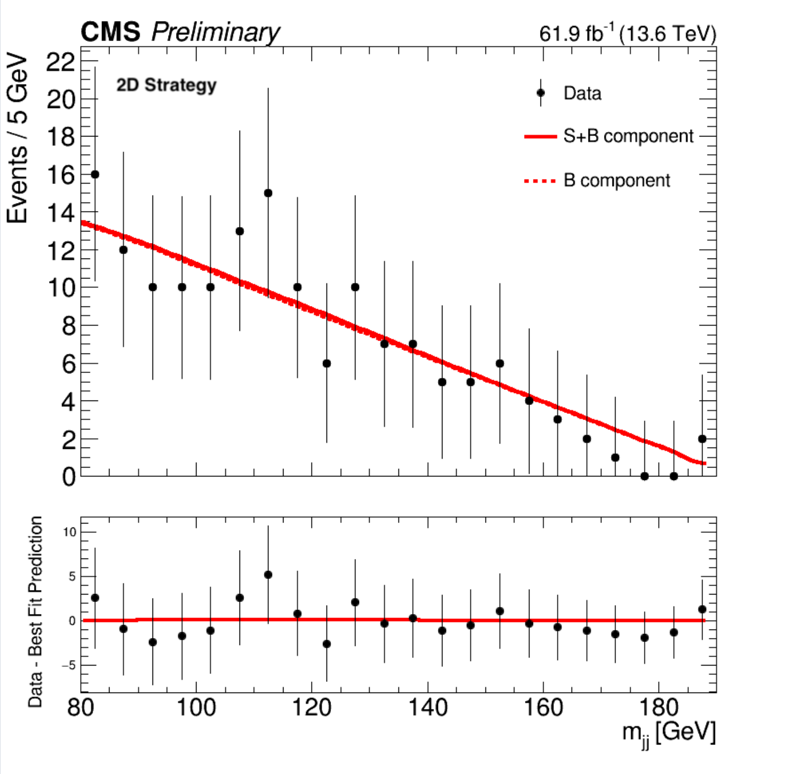
Cat 1



Cat 2

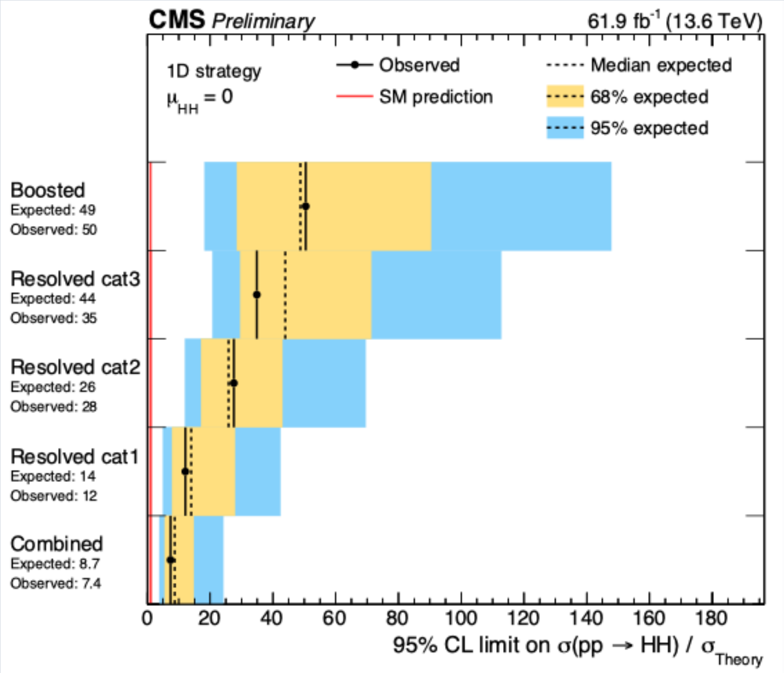


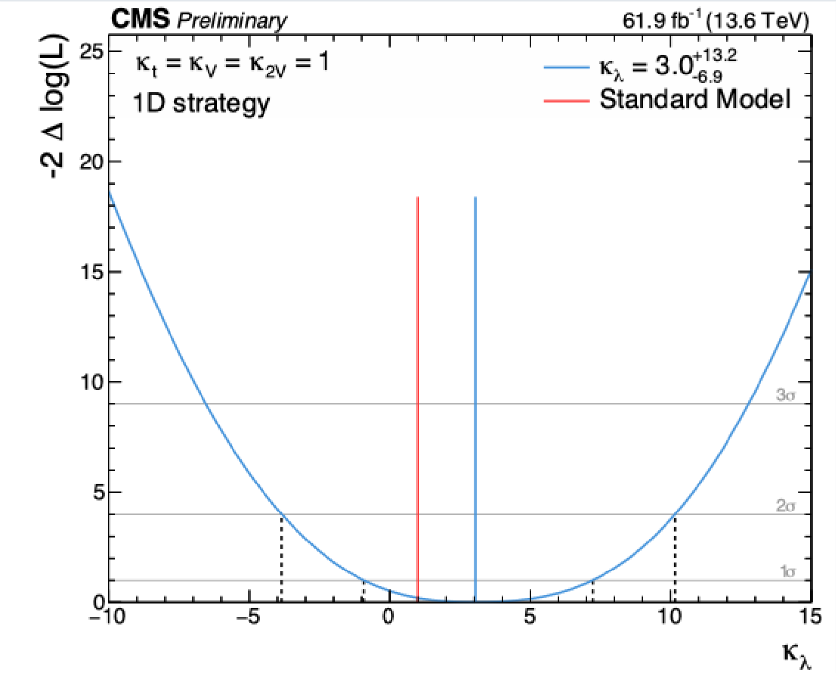
Cat 3

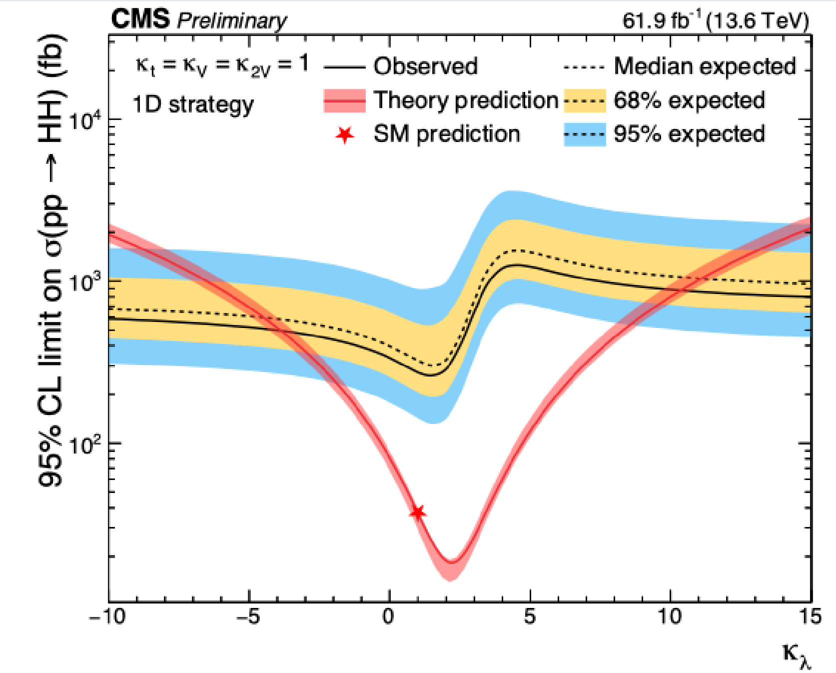


- Most → least sensitive

Results: 1D





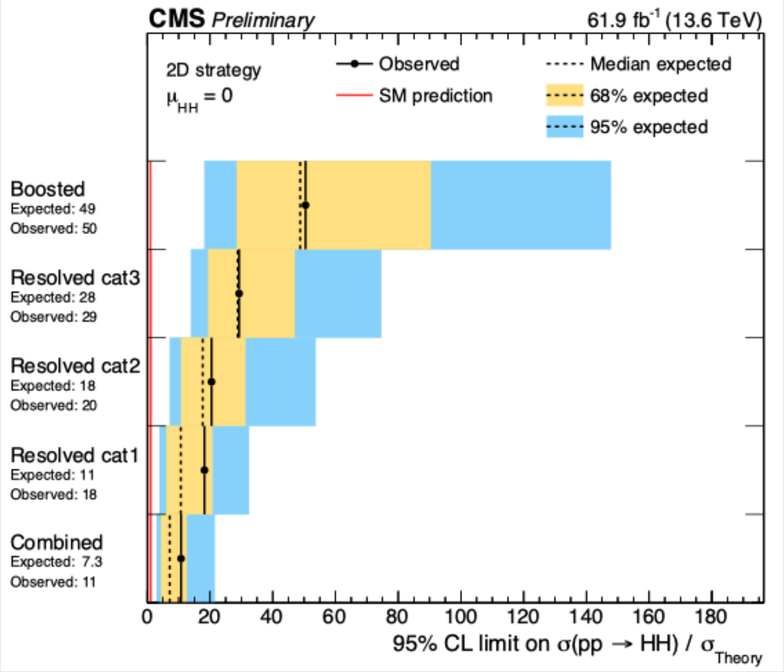


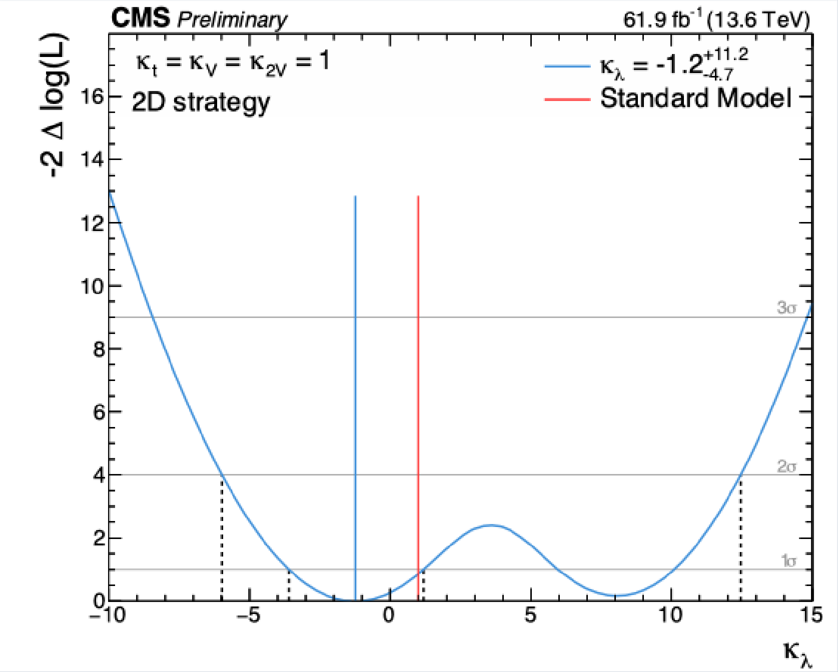
Observed (expected) UL:
$7.4\ (8.7)\ \times\ SM$

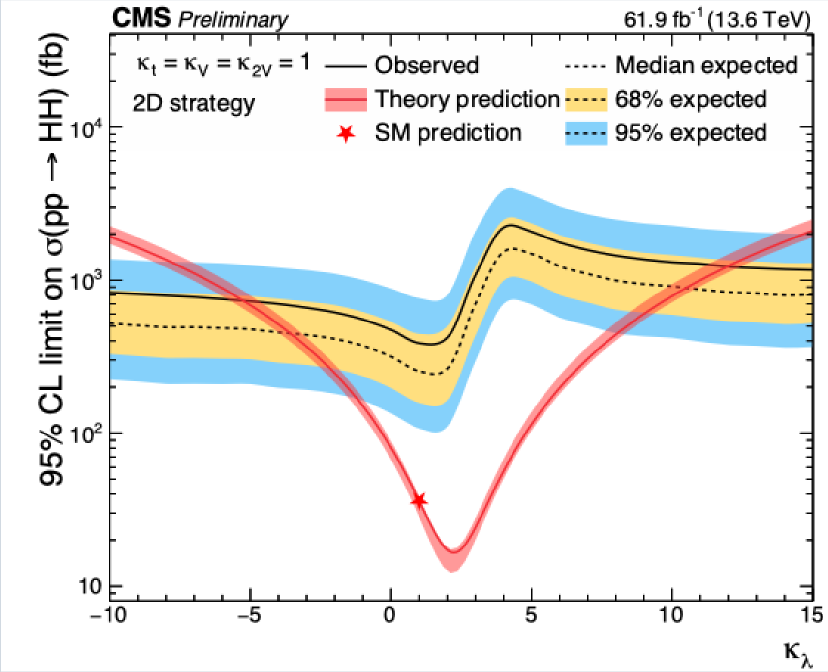
- κ_λ constraints:
  - $-3.9 < \kappa_\lambda < 10.4$ (observed)
  - $-4.5 < \kappa_\lambda < 11.1$ (expected)

(Assuming other couplings are SM)

Results: 2D







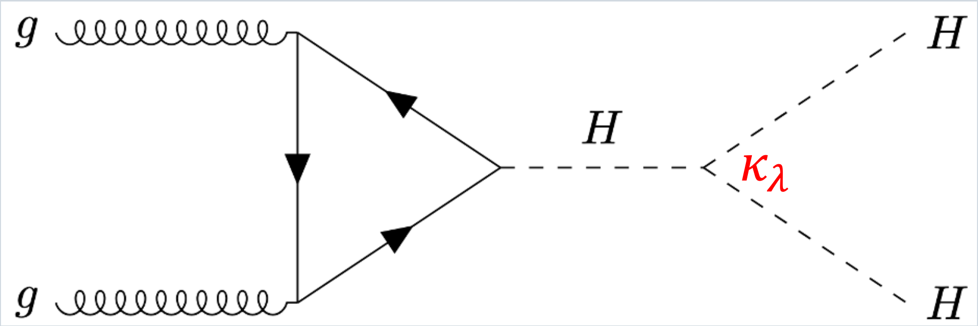
Observed (expected) UL:
$11.0\ (7.3)\ \times\ SM$

- κ_λ constraints:
  - $-5 < \kappa_\lambda < 12.0$ (observed)
  - $-3.6 < \kappa_\lambda < 10.5$ (expected)

(Assuming other couplings are SM)

Summary

- Searched for $HH \to b\bar{b}\gamma\gamma$ with data collected by CMS in 2022 and 2023 (61.9 fb^{-1}) at 13.6 TeV
- Observed (expected) 95 % CL upper limits on $\sigma(pp \to HH) \times \mathcal{B}(HH \to b\bar{b}\gamma\gamma)$
  - **1D: $\mathbf{7.4\ (8.7)\ \times\ SM}$**
  - **2D: $\mathbf{11.0\ (7.3)\ \times\ SM}$**
- Constraints on the effective Higgs-boson self coupling modifier κ_λ
  - **1D: $\mathbf{-3.9 < \kappa_\lambda < 10.4}$**
  - **2D: $\mathbf{-5 < \kappa_\lambda < 12}$**
  - (Assuming other couplings are SM)



- **Look ahead to future results!**

Thank you!

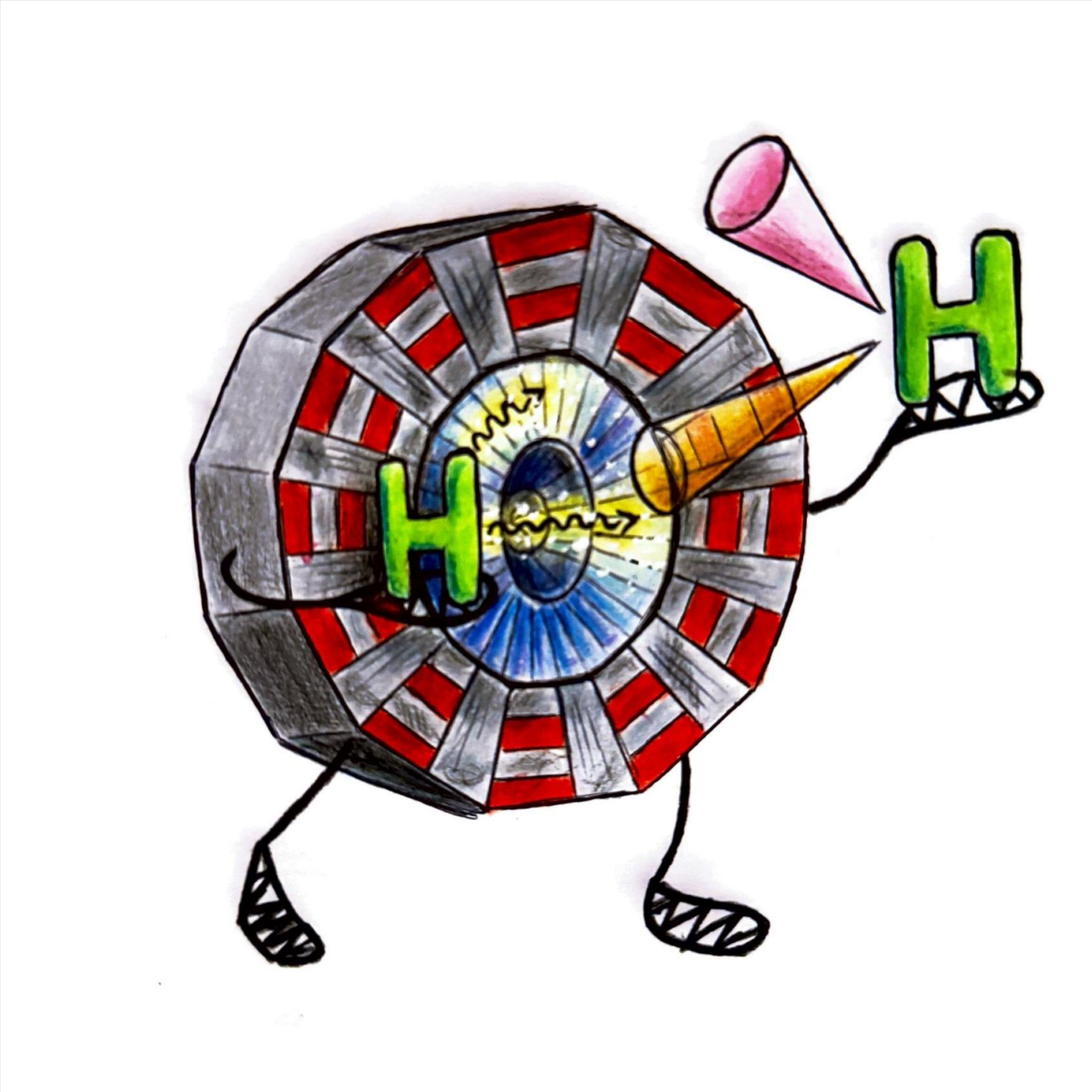
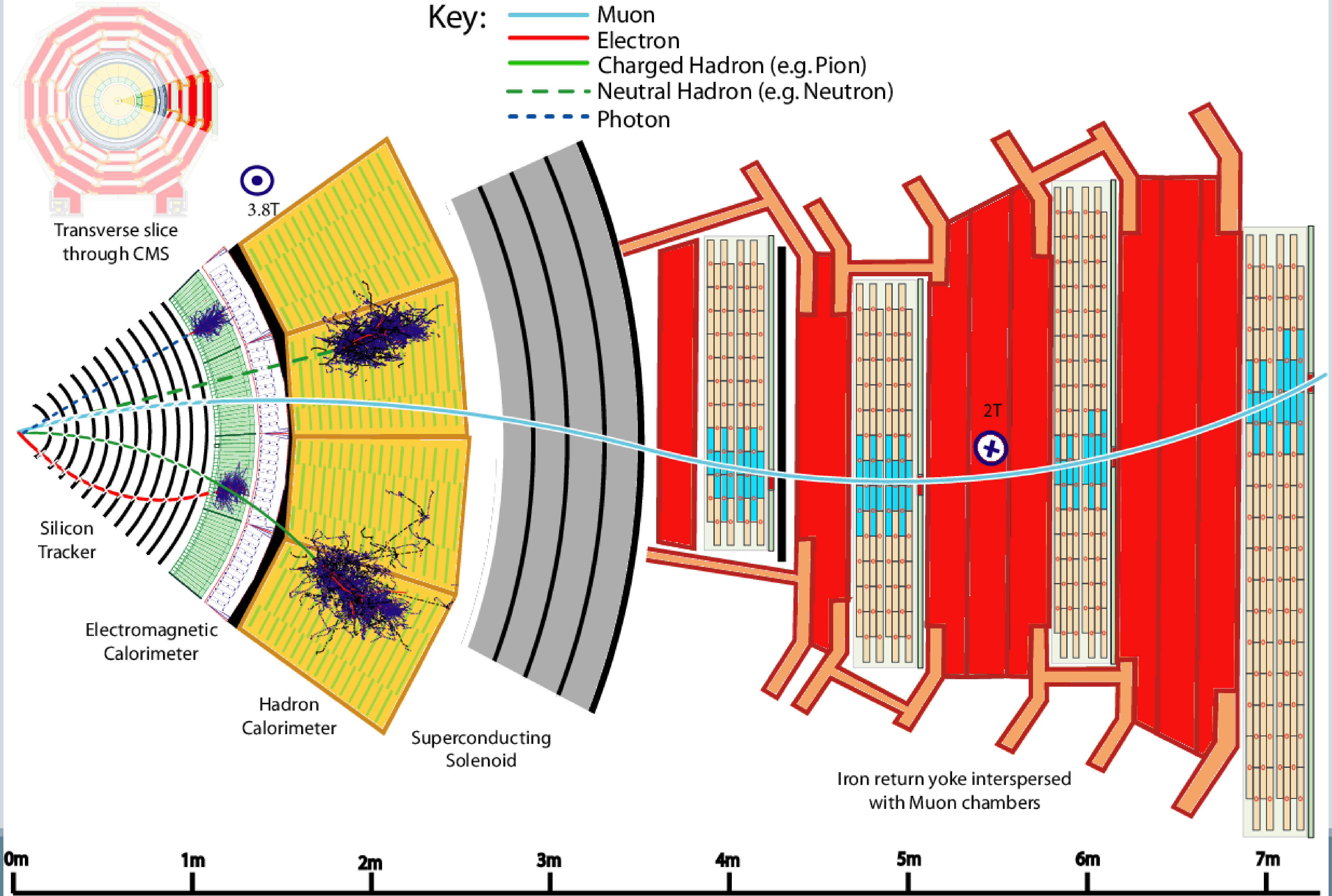


Image Credit: Marta Tornago

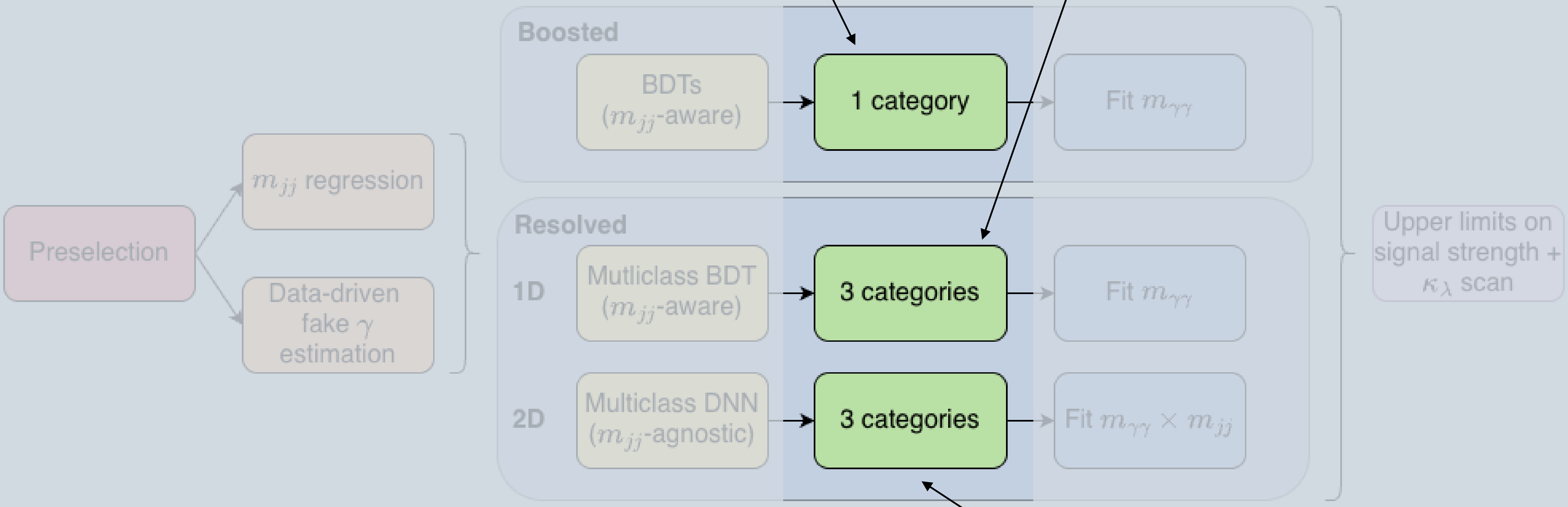

Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
Transverse slice through CMS
3.8T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0m
1m
2m
3m
4m
5m
6m
7m

Preselection

- $H \to \gamma\gamma$ ("default")
  - $p_T(\gamma_{1,2}) > 35, 25\ GeV$
  - MVA ID score used to select prompt photons
  - $H \to \gamma\gamma$ candidate composed of photons with highest sum of p_T
- $H \to b\bar{b}$
  - Resolved (AK 4)
    - $p_T(j) > 20\ GeV$
    - $|\eta| < 2.5$
    - $dR(j, \gamma) > 0.4$
    - $H \to b\bar{b}$ candidate composed of jets with highest sum of b tagging scores with m_{jj} in [70, 190] GeV
  - Boosted (AK 8)
    - $p_T(j) > 250\ GeV$
    - $|\eta| < 2.5$
    - At least 2 subjets, not too unbalanced to keep two prongs

Scan significance, cutting on BDT score

Scan significance, cutting on metric composed of BDT scores



Bayesian optimization on class scores