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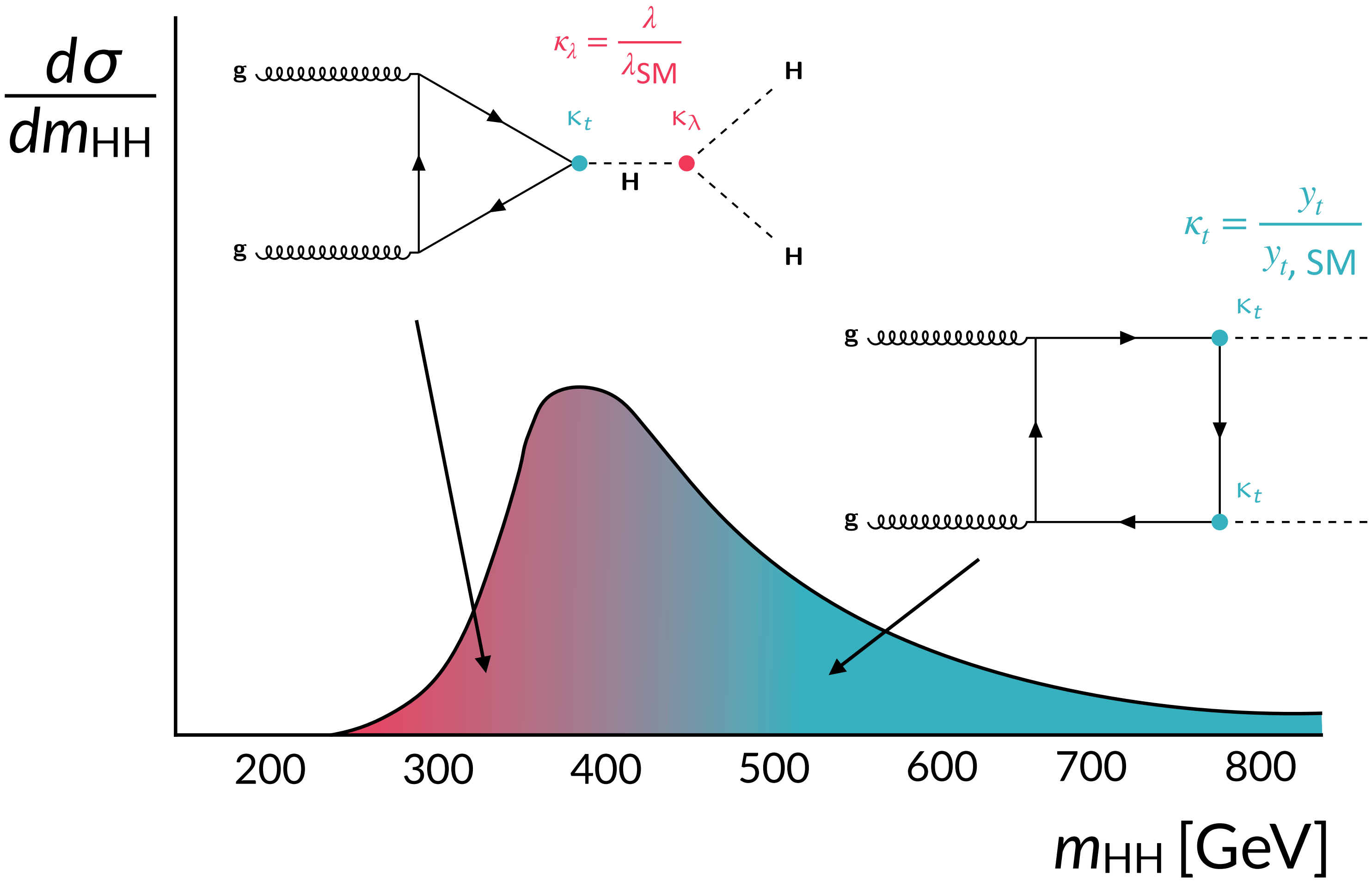
Search results for Higgs boson pair production in the $HH \rightarrow bb\tau\tau$ final state from ATLAS using Run 2 and Run 3 data

Partikeldagarna 2026, Lund
Philipp Rincke, supervised by Stan Lai and Arnaud Ferrari

Di-Higgs (HH) processes offer access to the trilinear self-coupling which we have not yet measured, unlike most other properties



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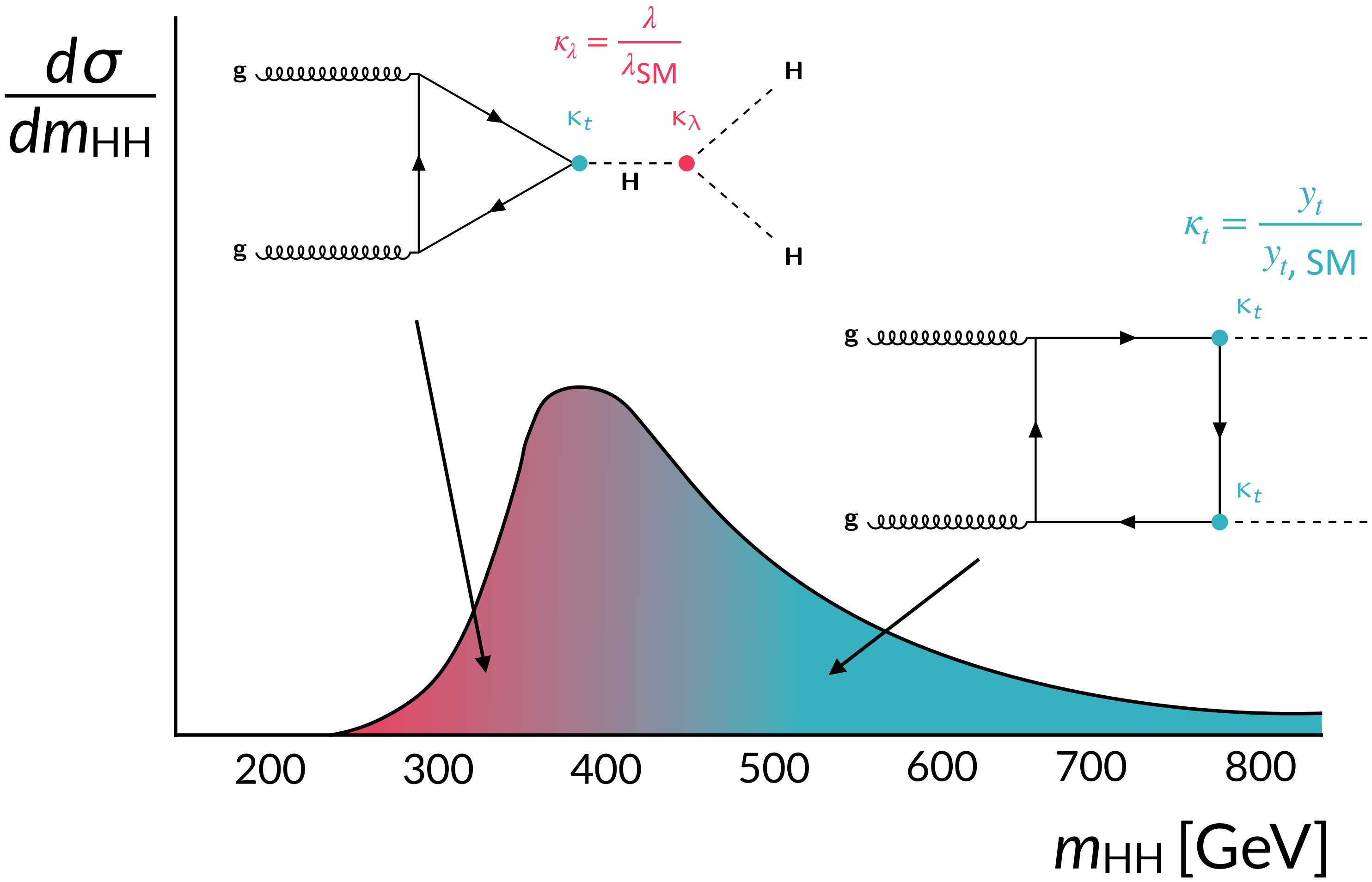

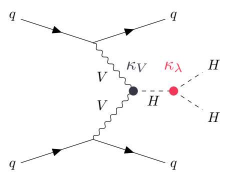

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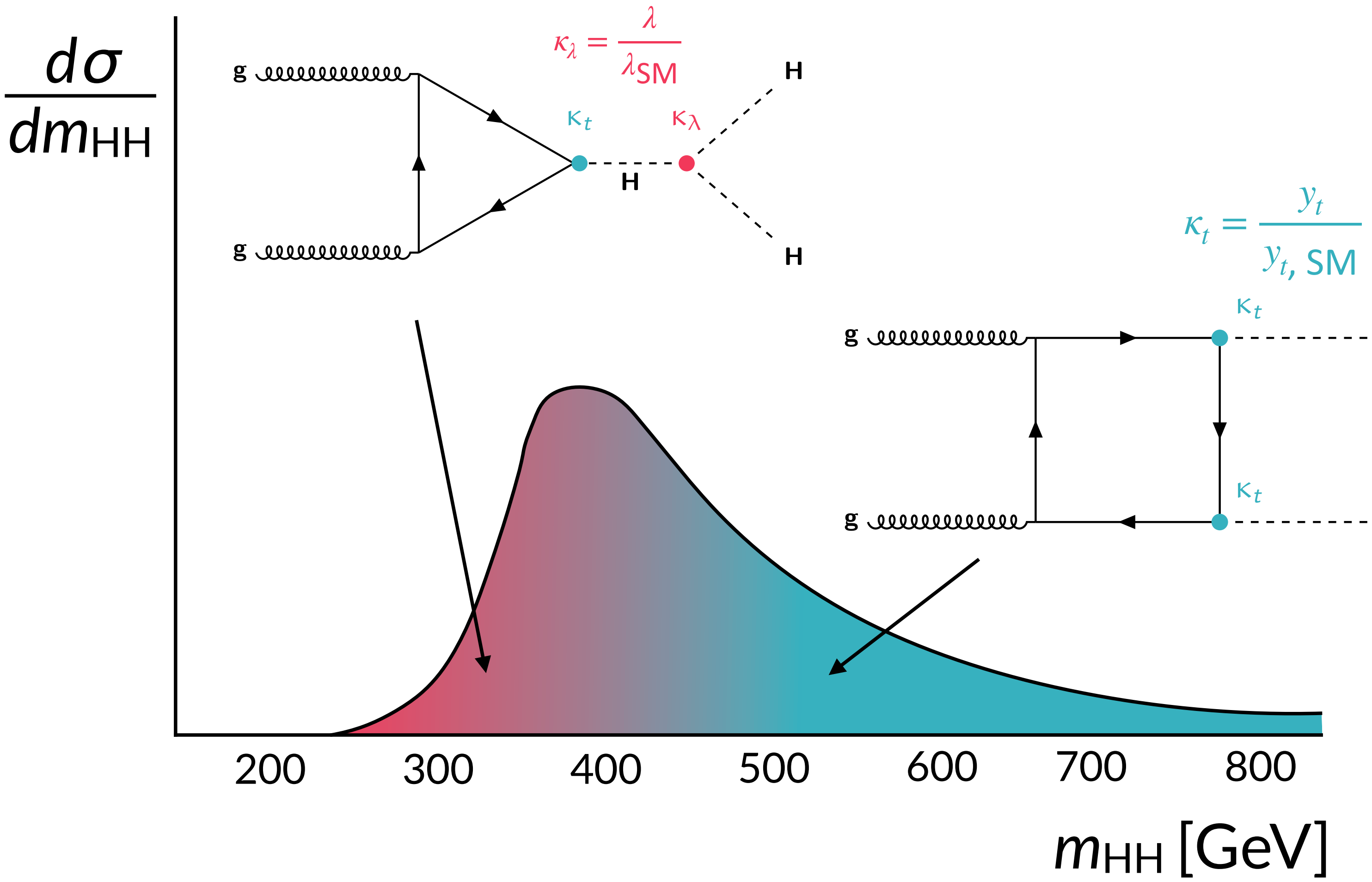

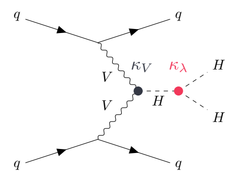

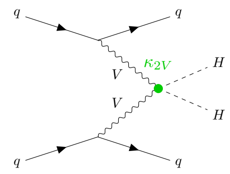

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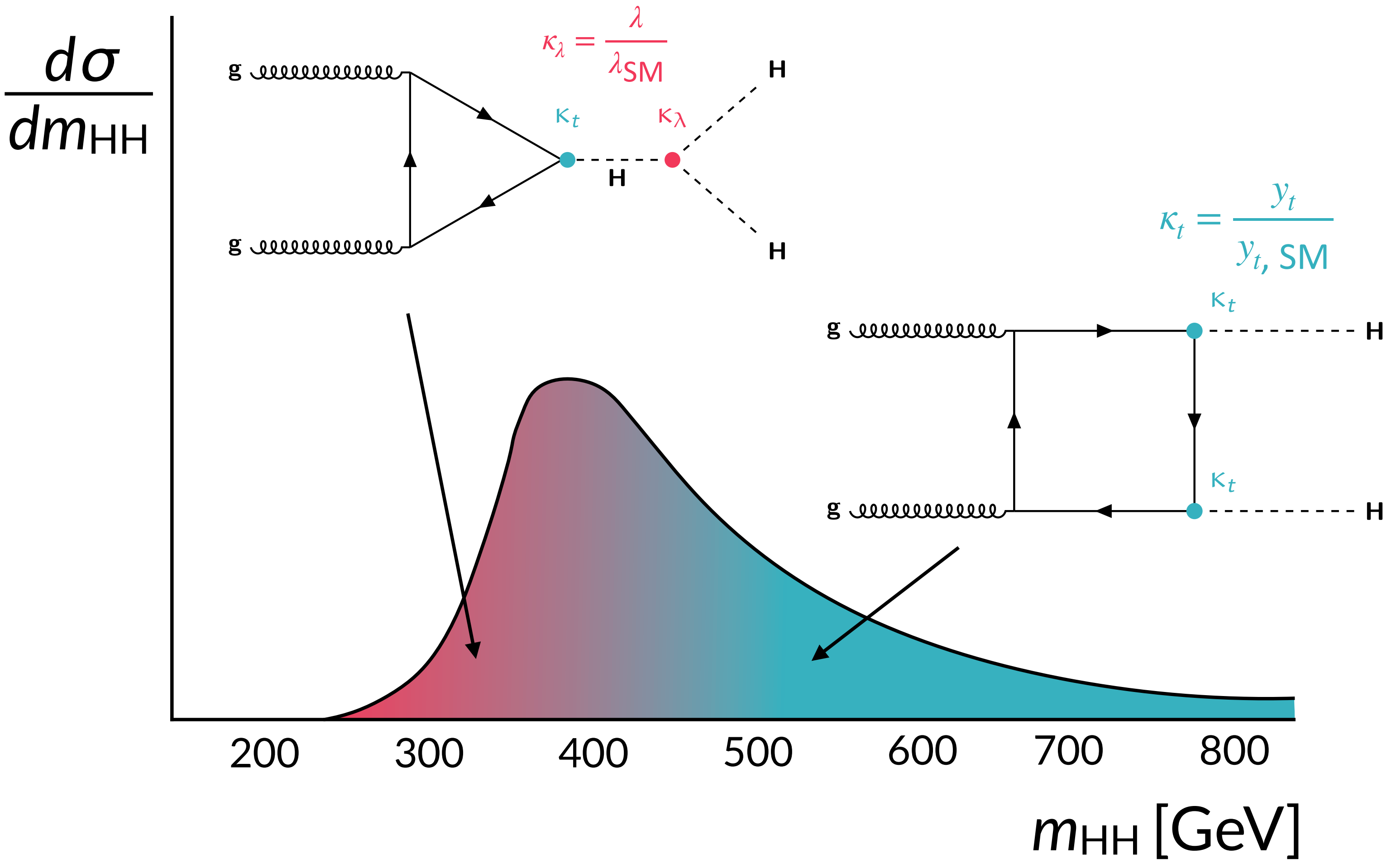

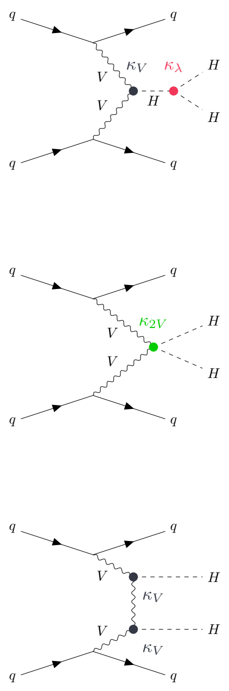

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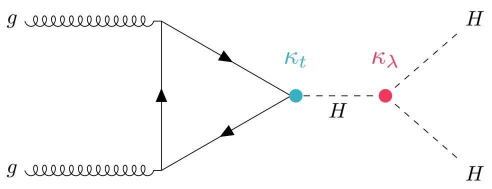
There are many different HH decay channels



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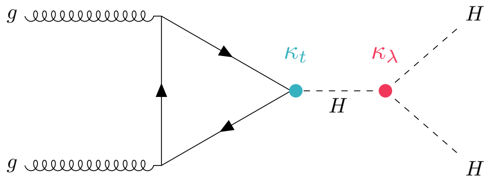

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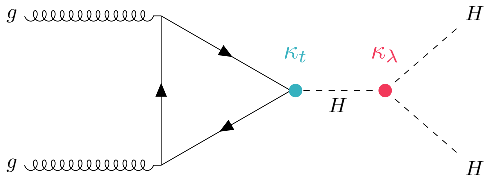

	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

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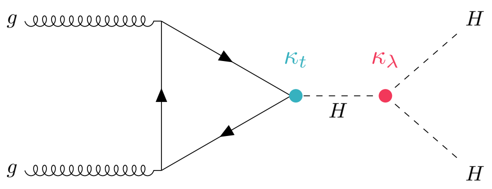

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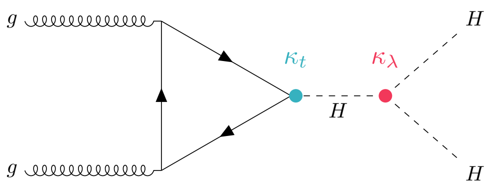

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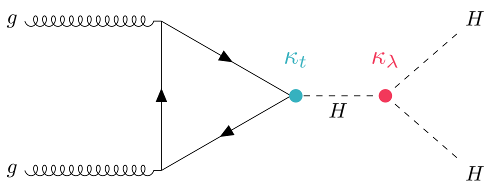

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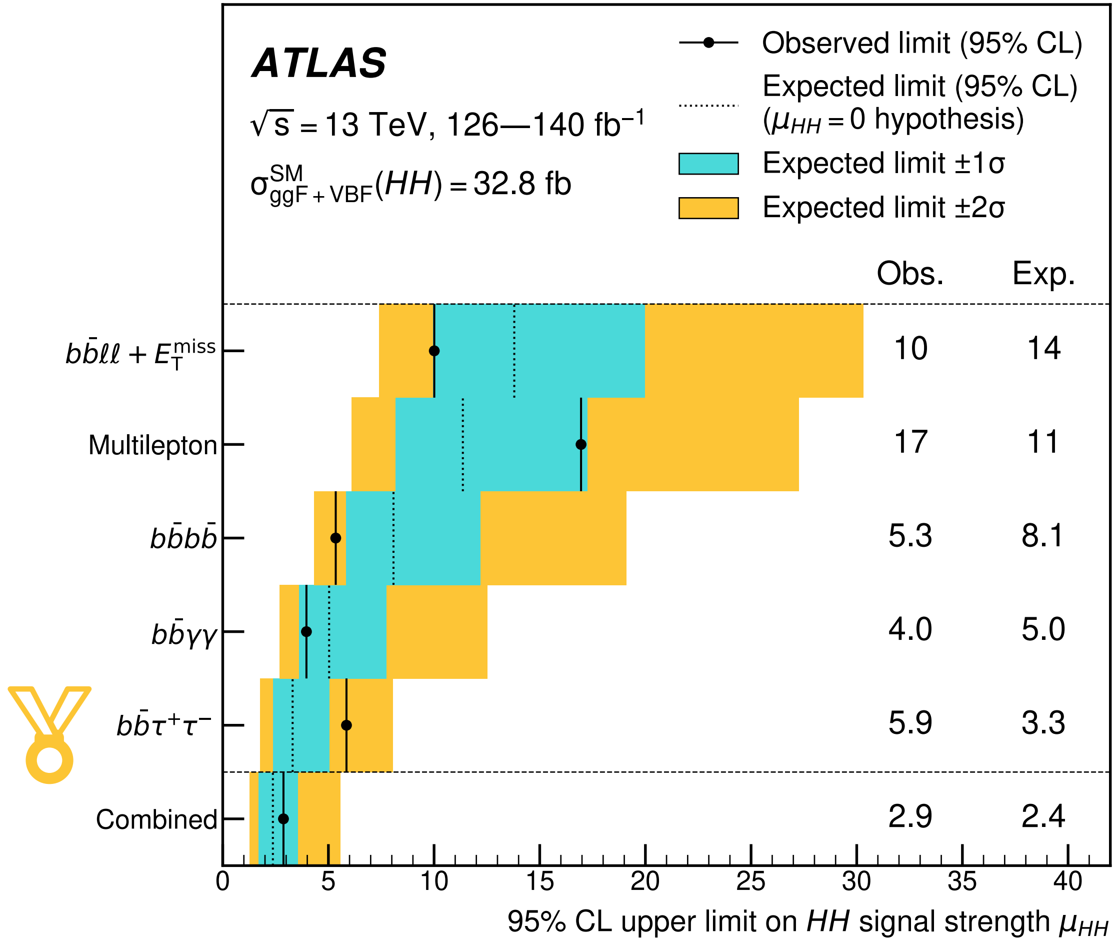

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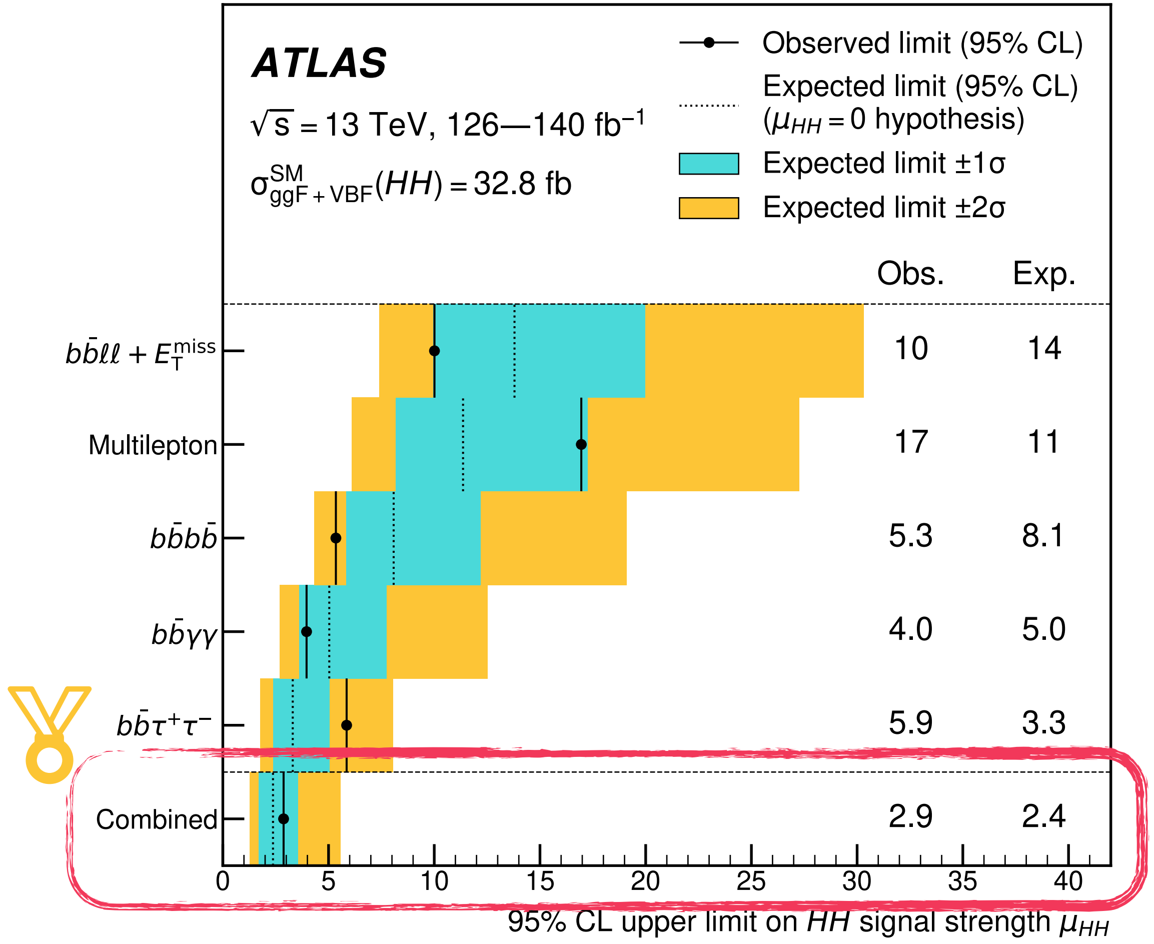

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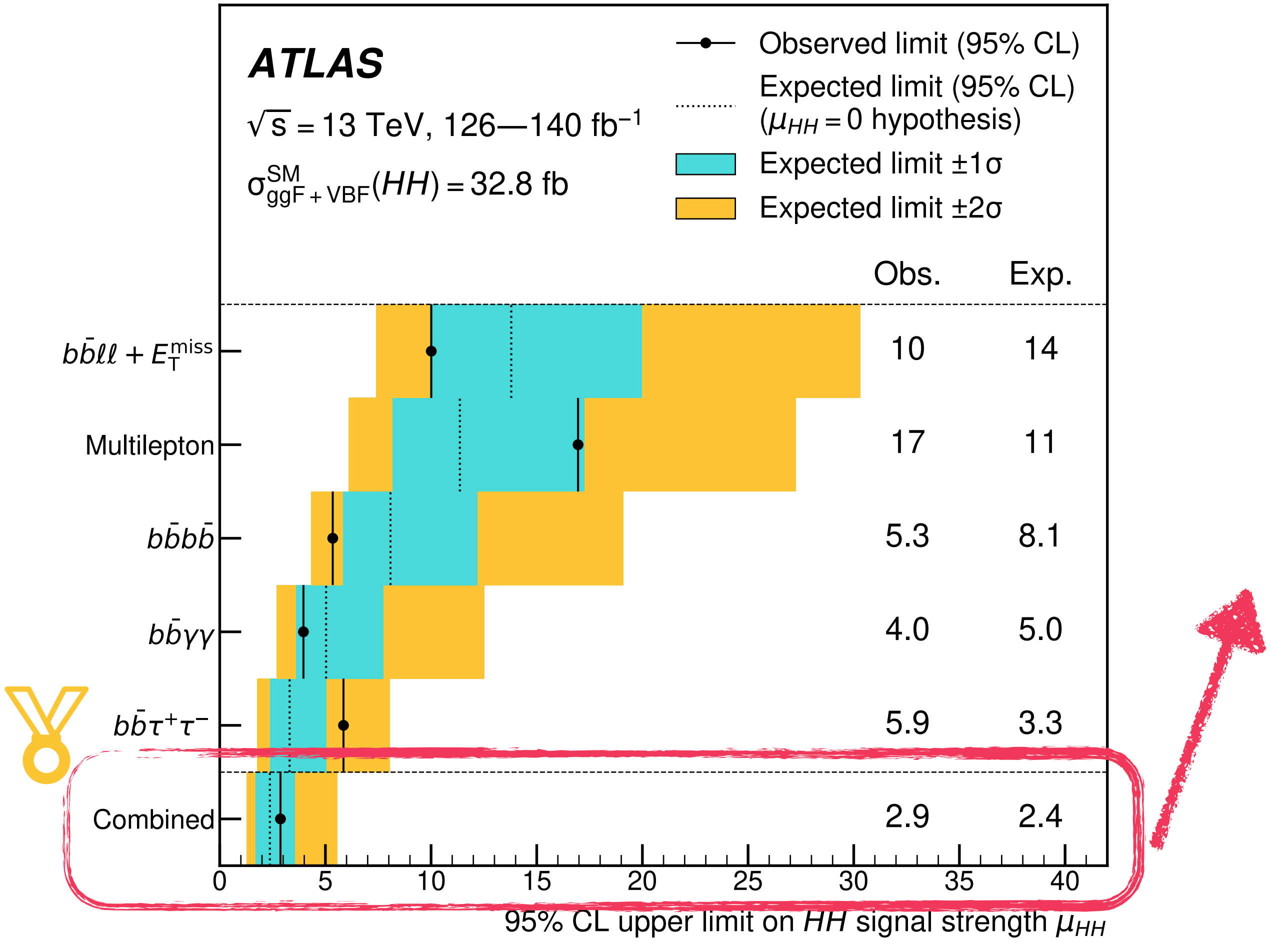

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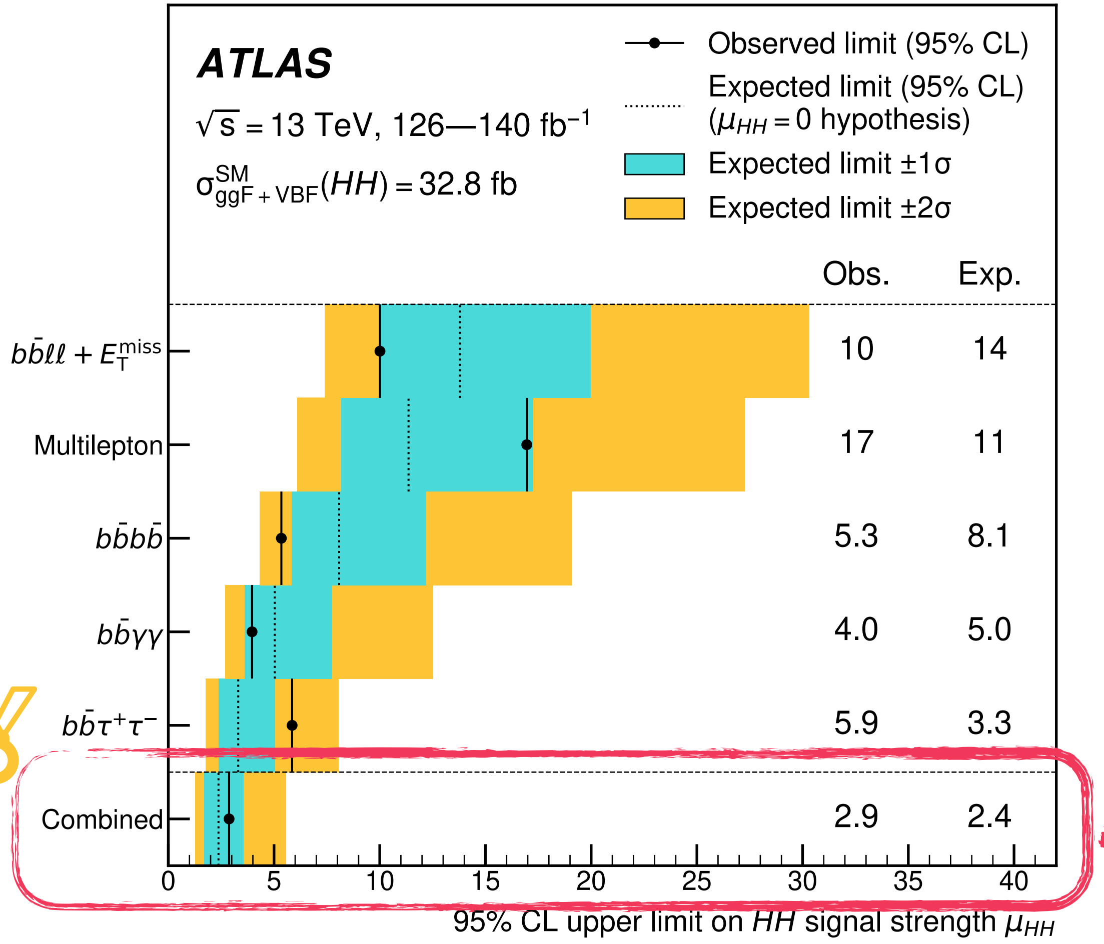

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Combined with CMS: $\mu_{HH} < 2.5$ (1.7 expected)

Phys. Rev. Lett. 10.1103/27s7-2frt

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The $bb\tau\tau$ final state has two main experimental channels, which both depend on the identification of hadronically decaying tau leptons

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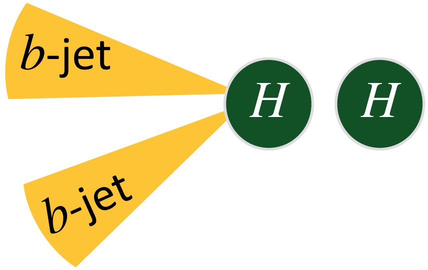

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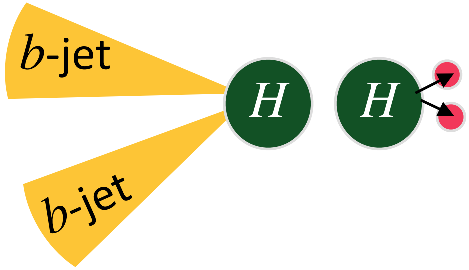

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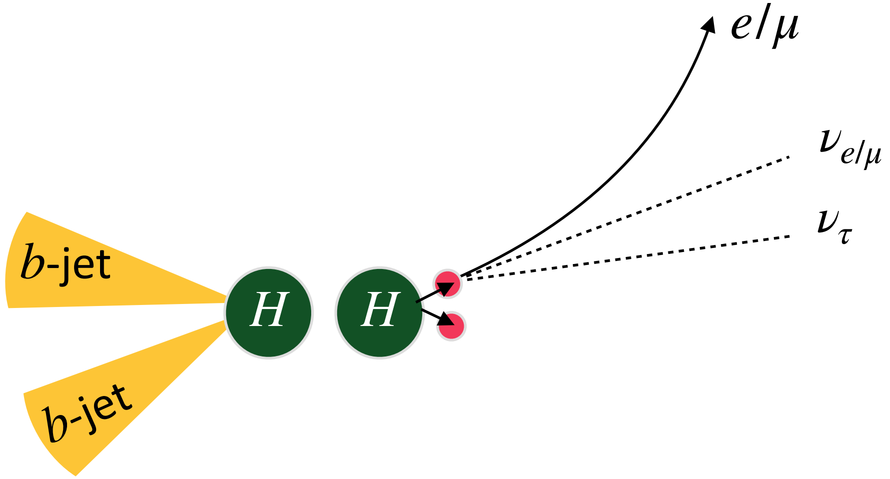

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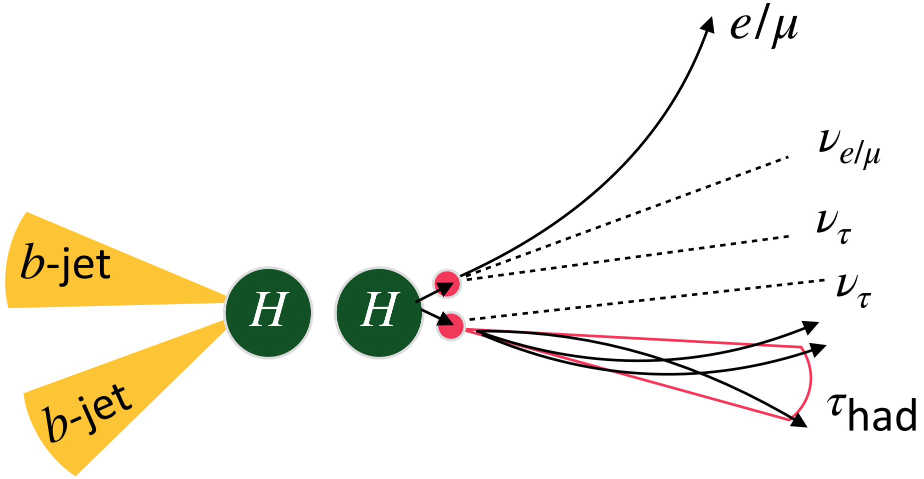

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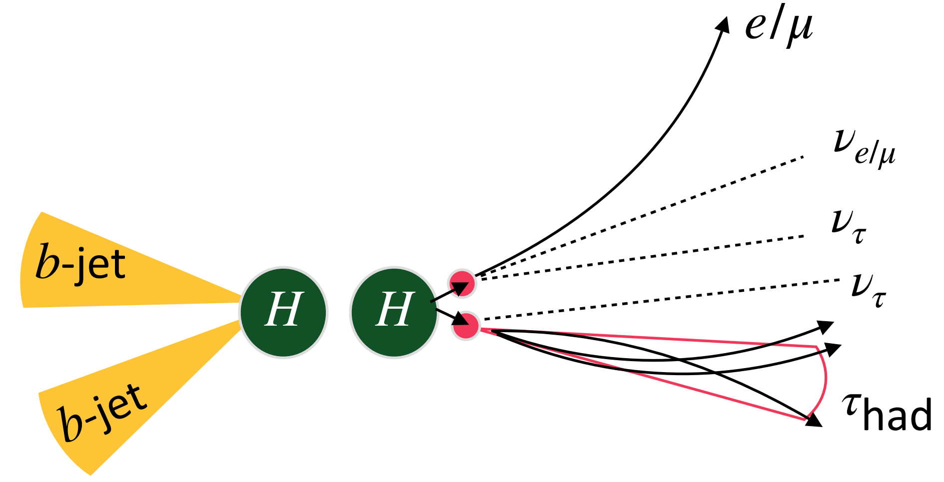

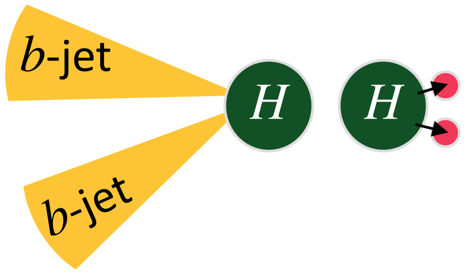

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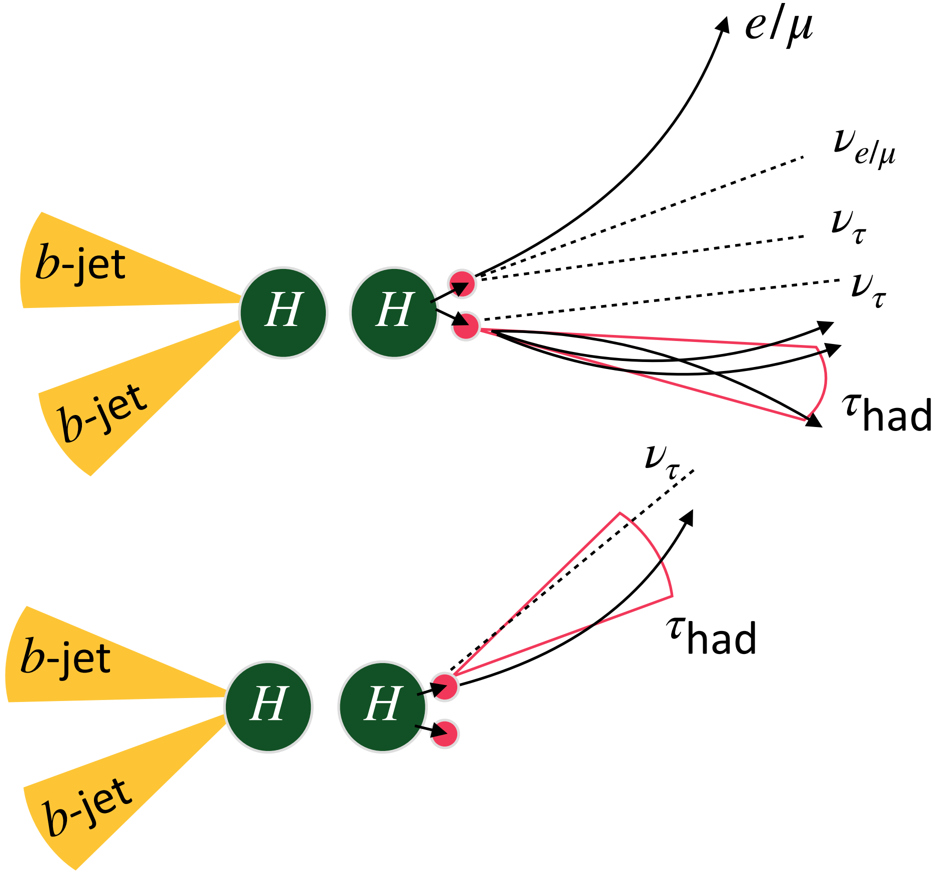

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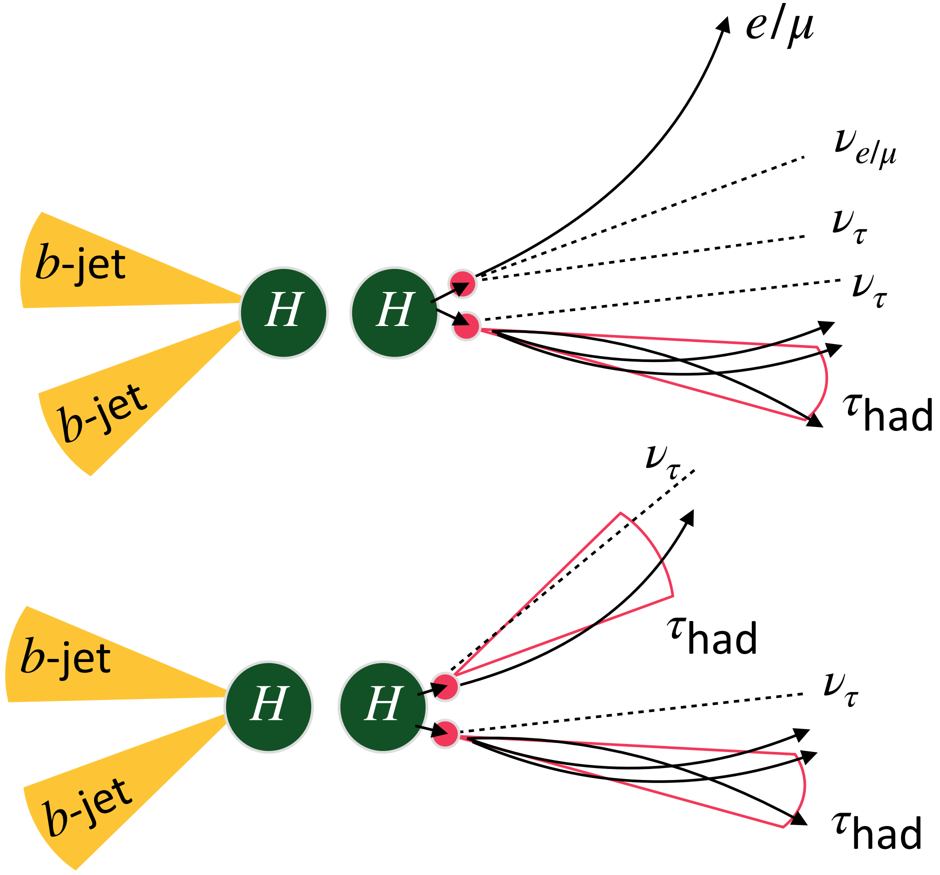

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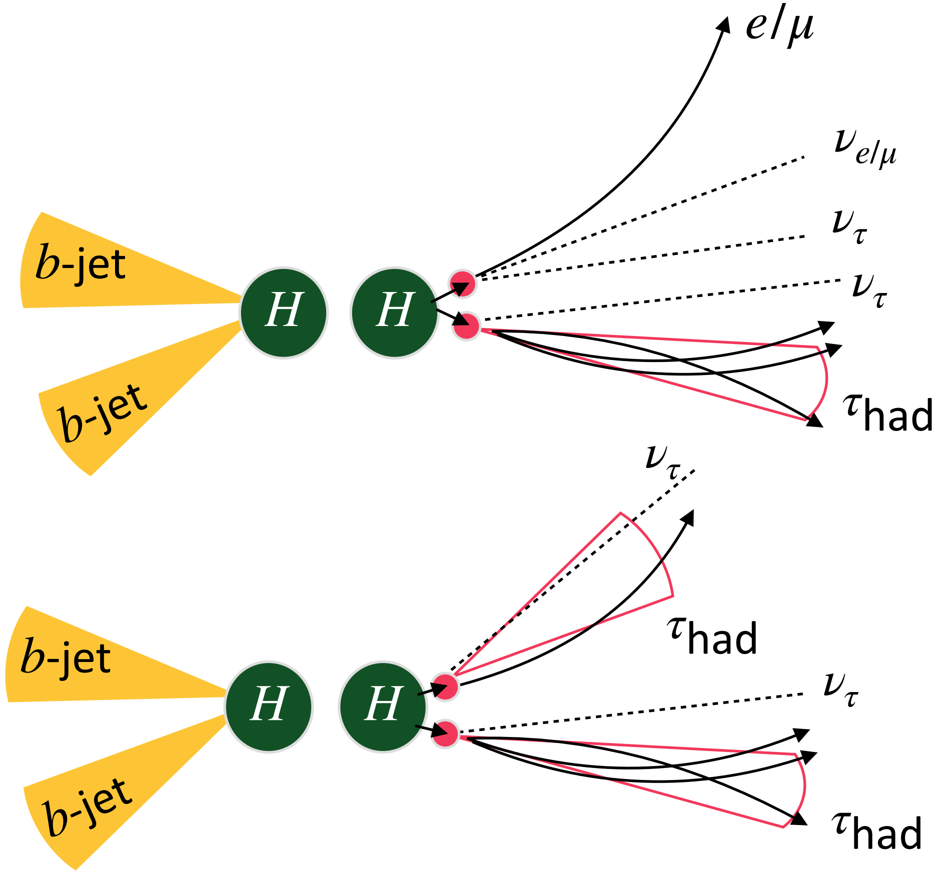

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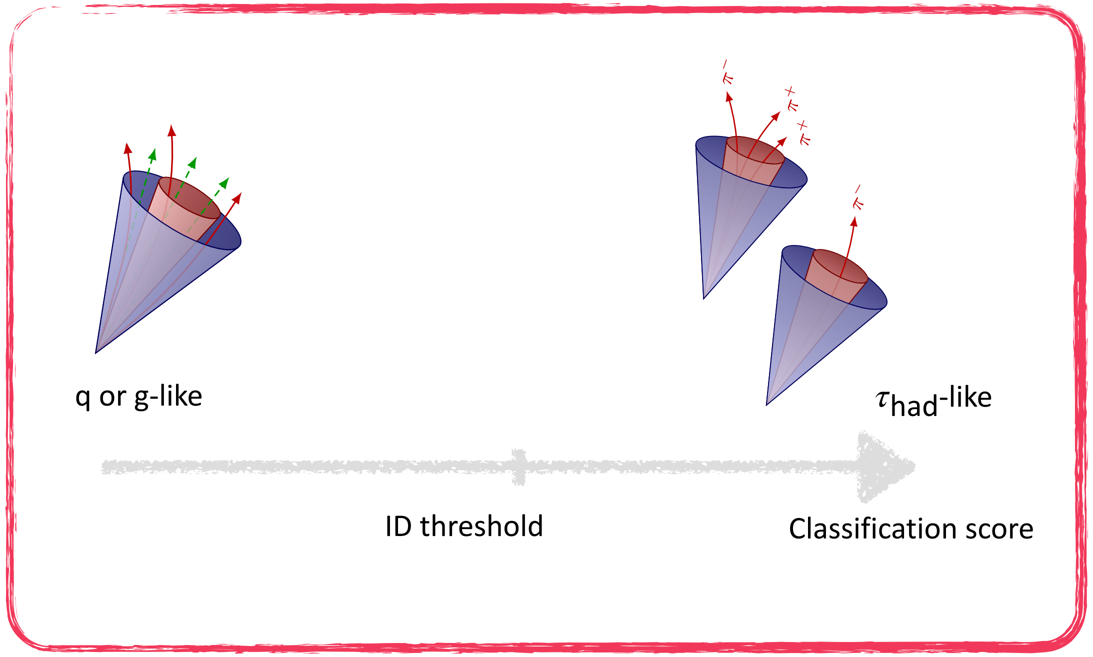

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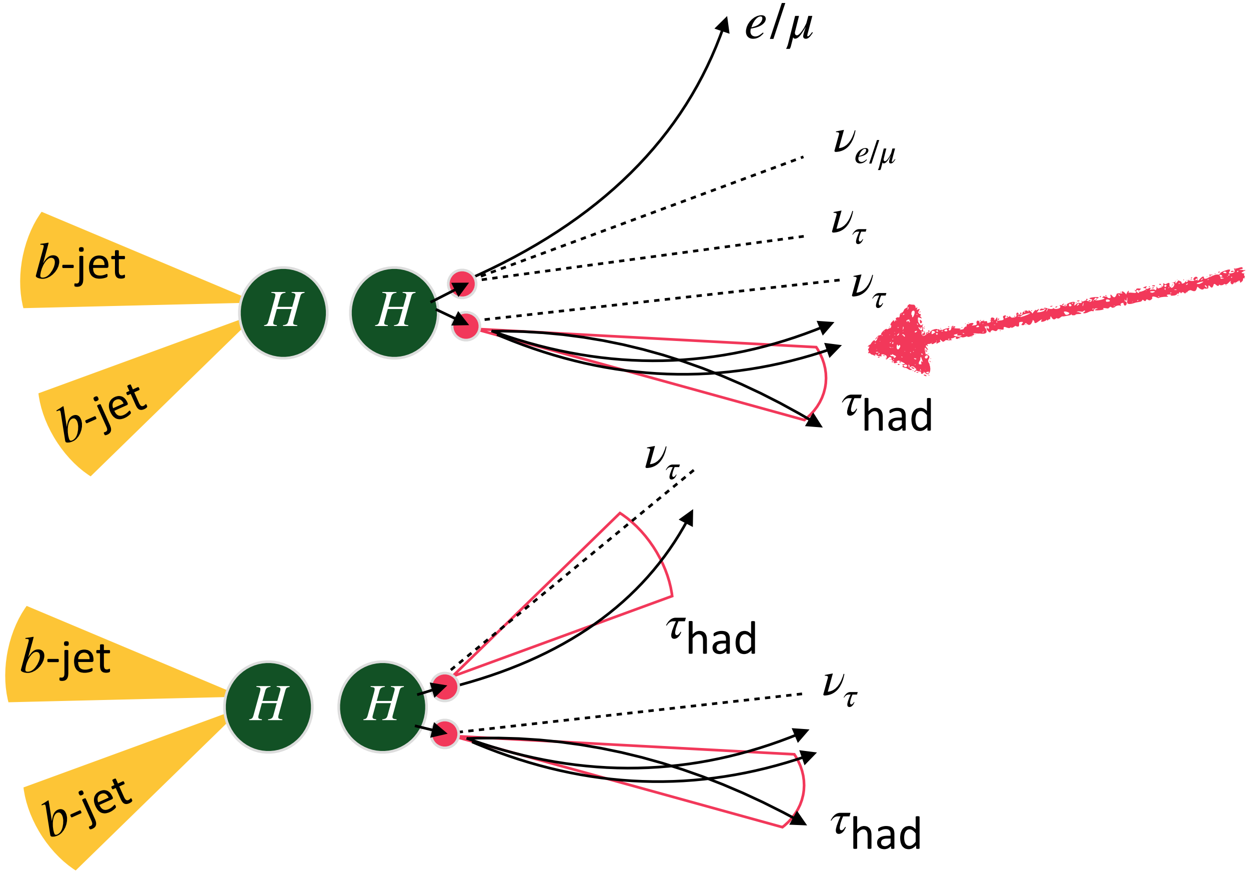

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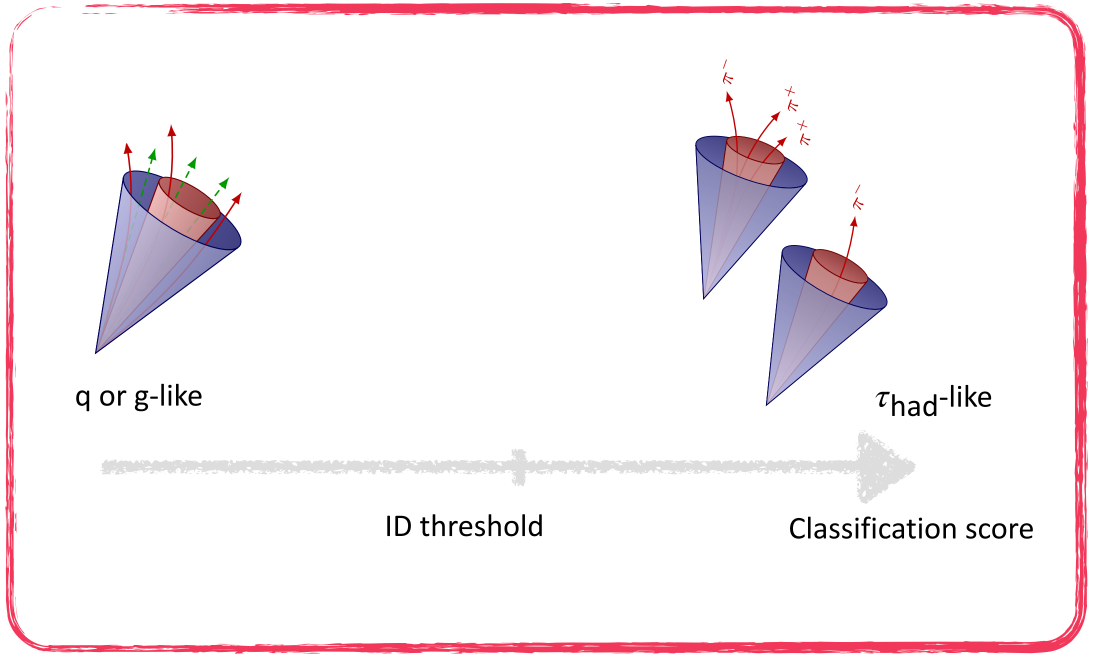

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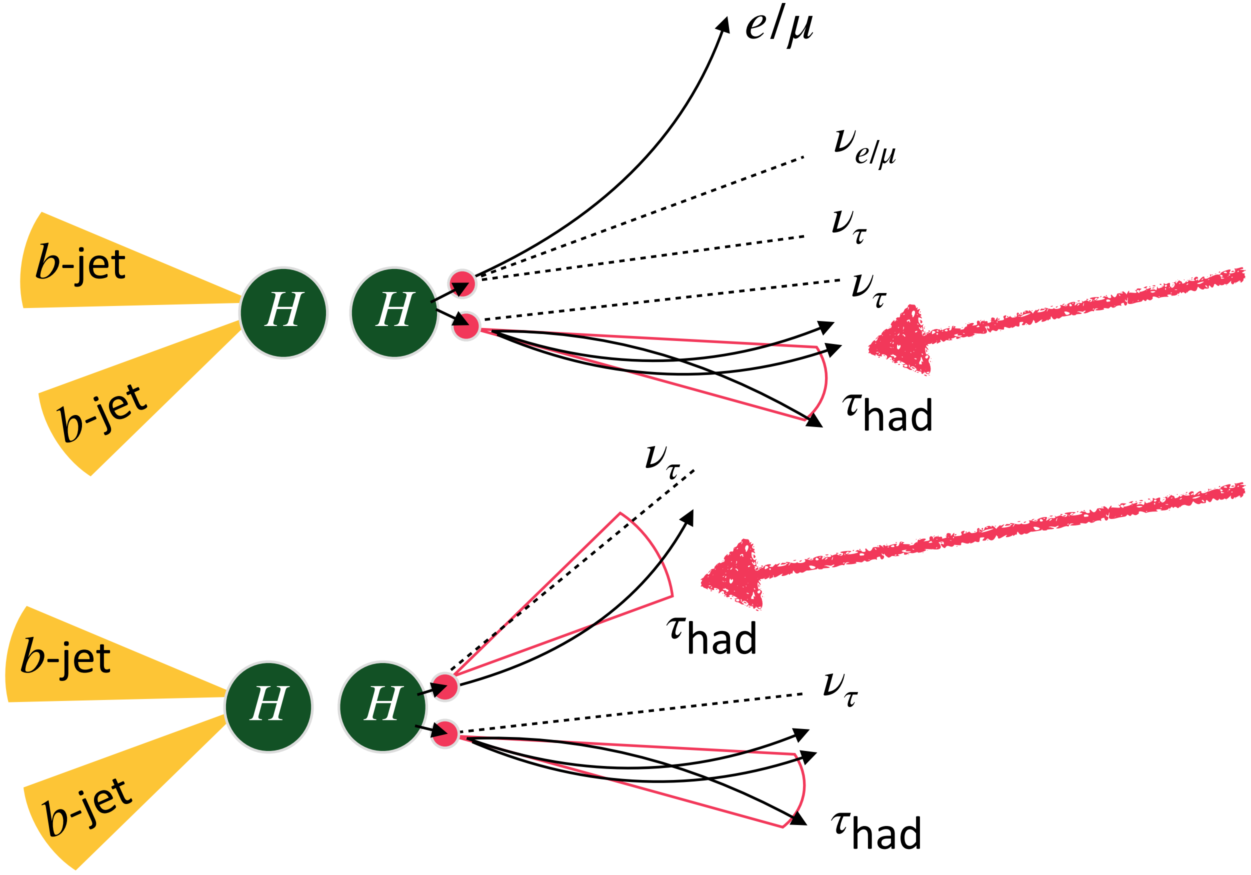

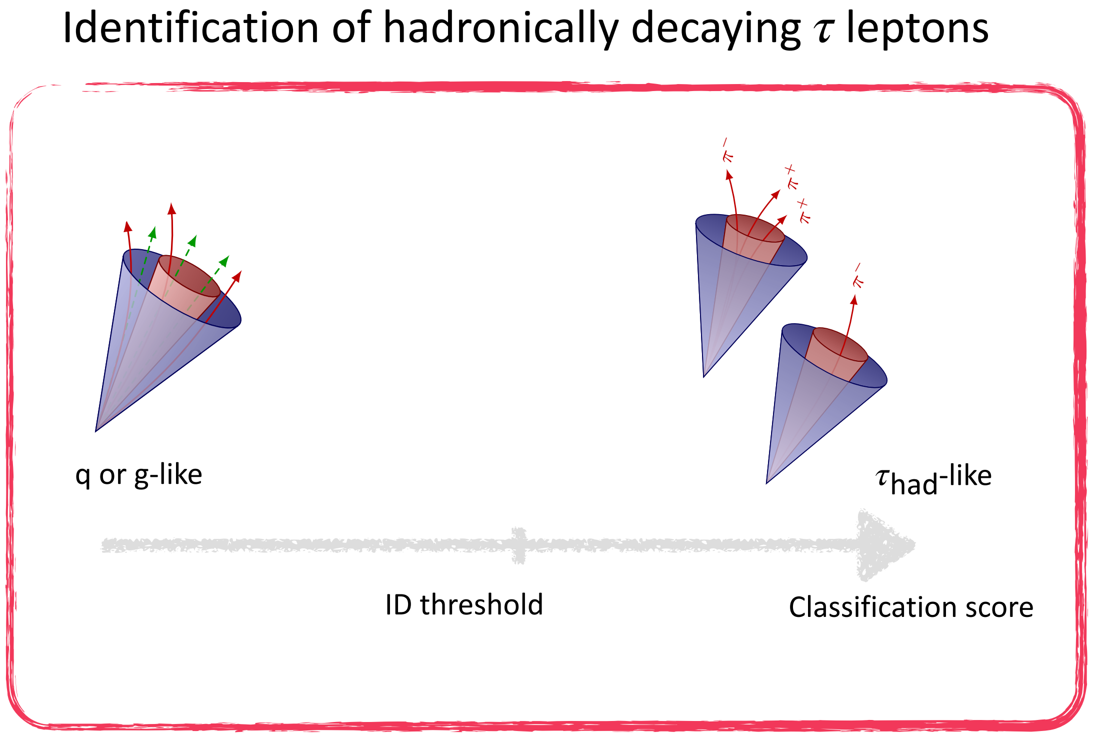

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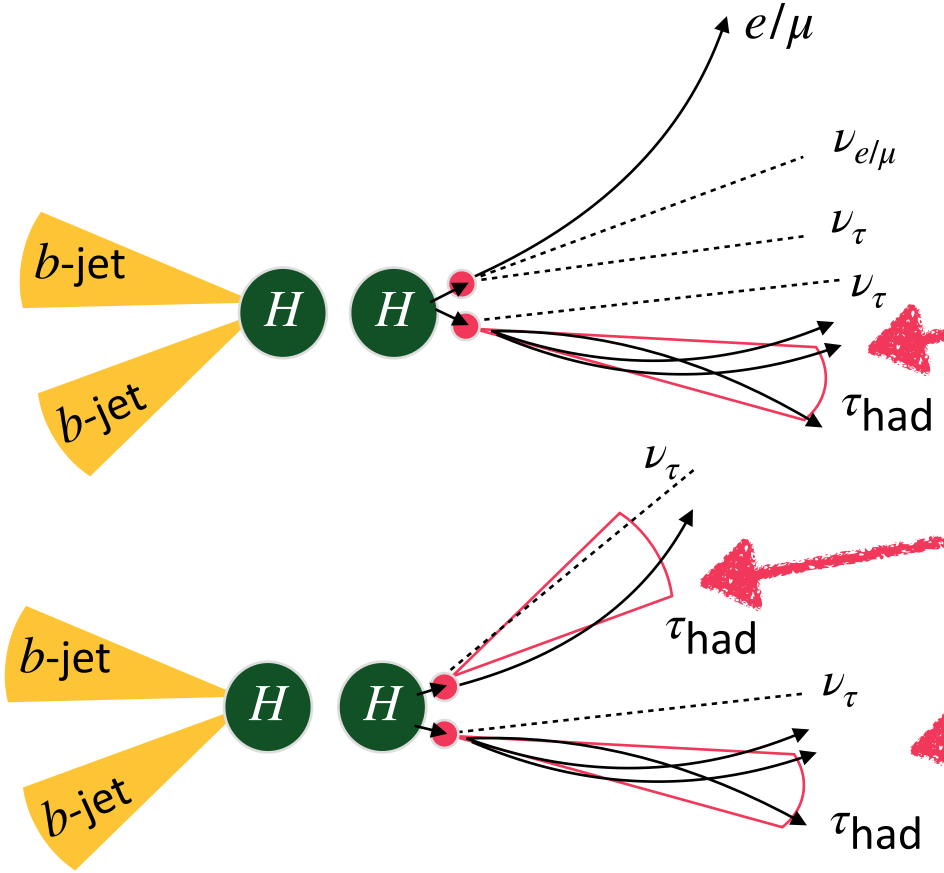

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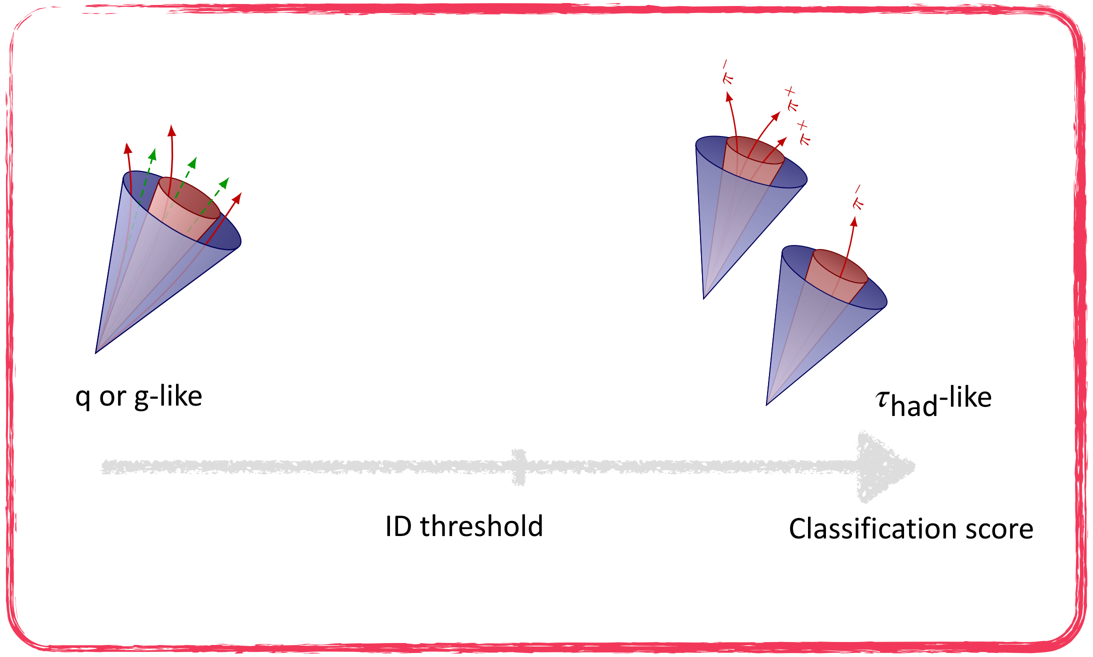

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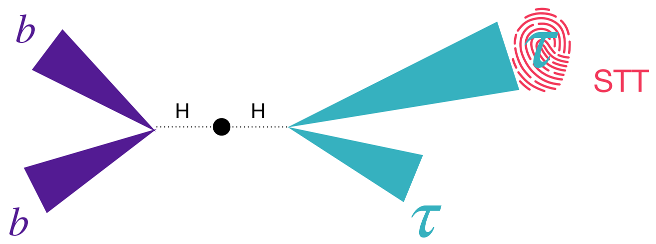
For the $\tau_{\text{had}}\tau_{\text{had}}$ channel, several (complex) triggers are used to select events during data-taking based on object identification and kinematics



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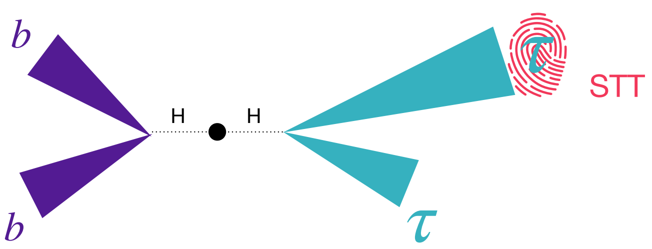

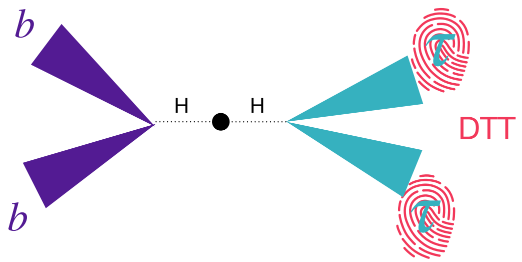

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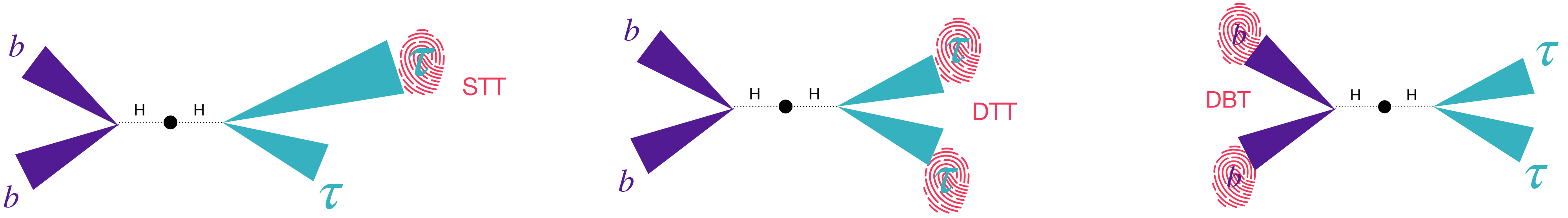

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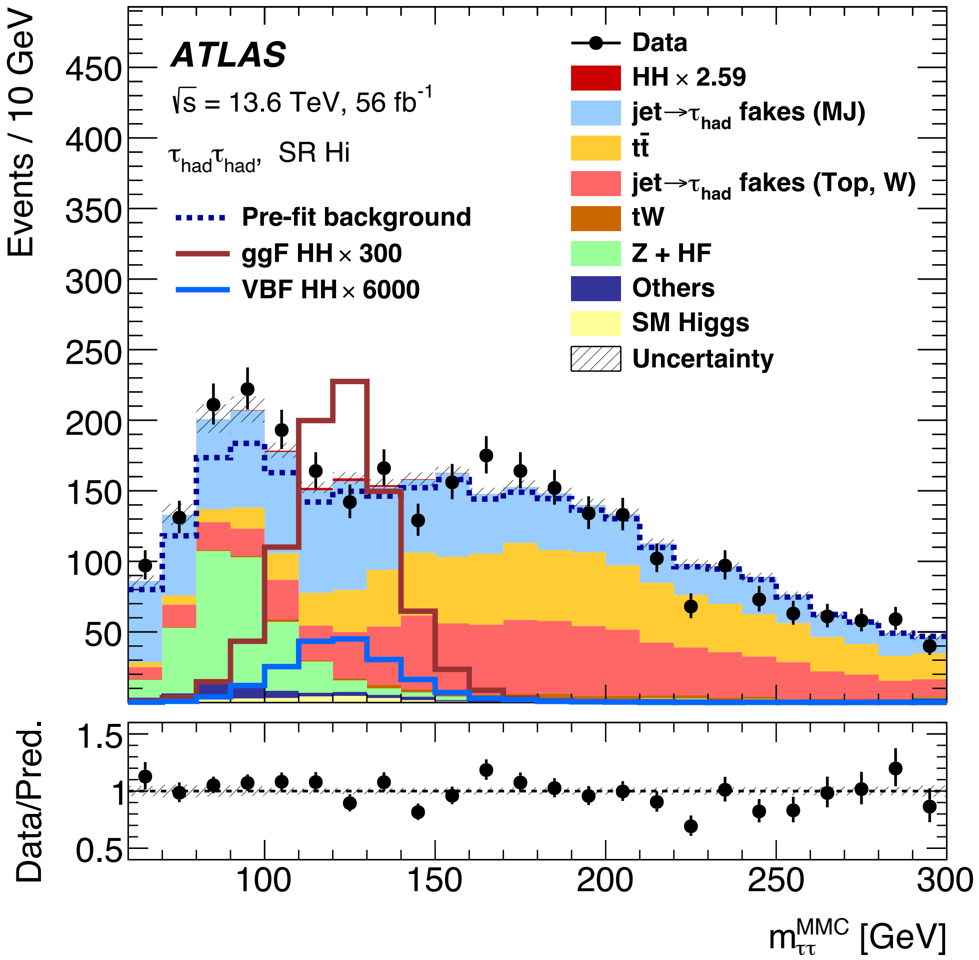
The signal signature is very similar to that from many other processes



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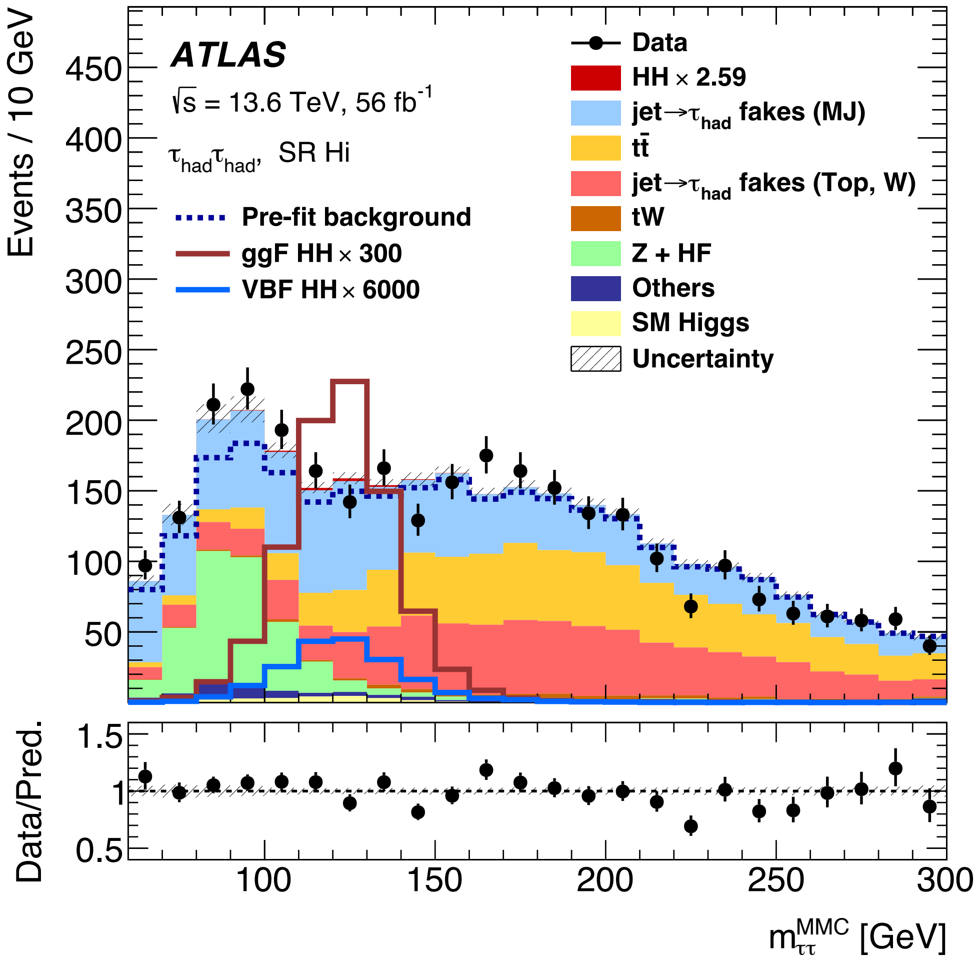

Both channels and runs:

$$\frac{s}{b} = \frac{\mathcal{O}(20)}{\mathcal{O}(200000)}$$

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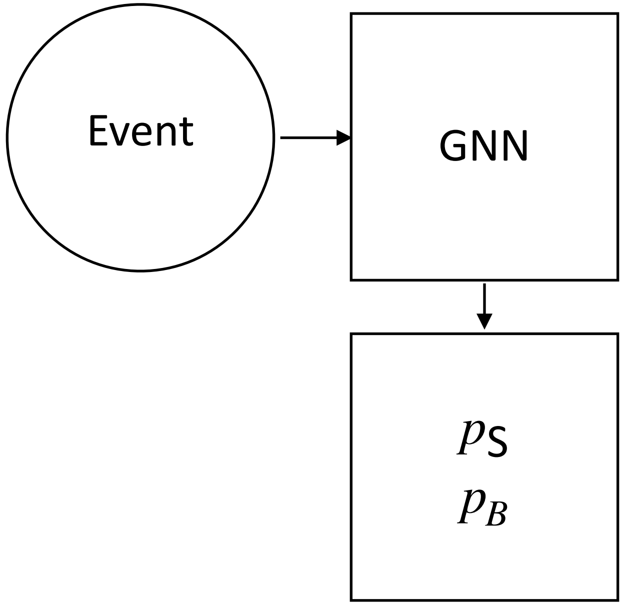
… thus a signal-classifier is used per channel to separate signal from background…



arXiv:2607.26879

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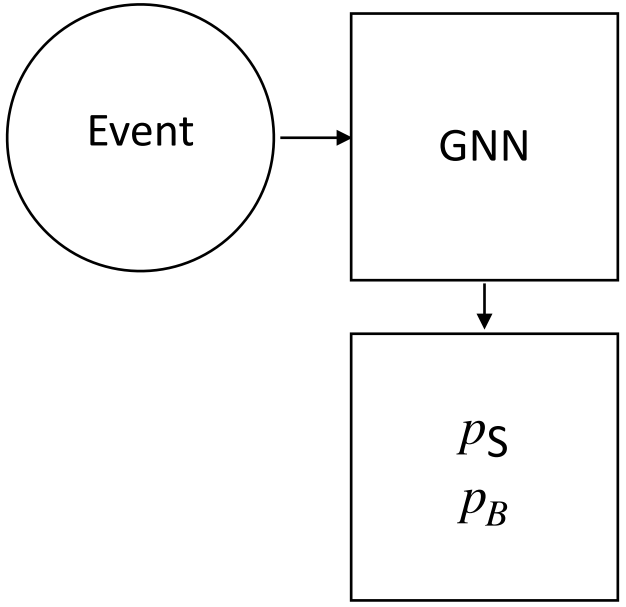

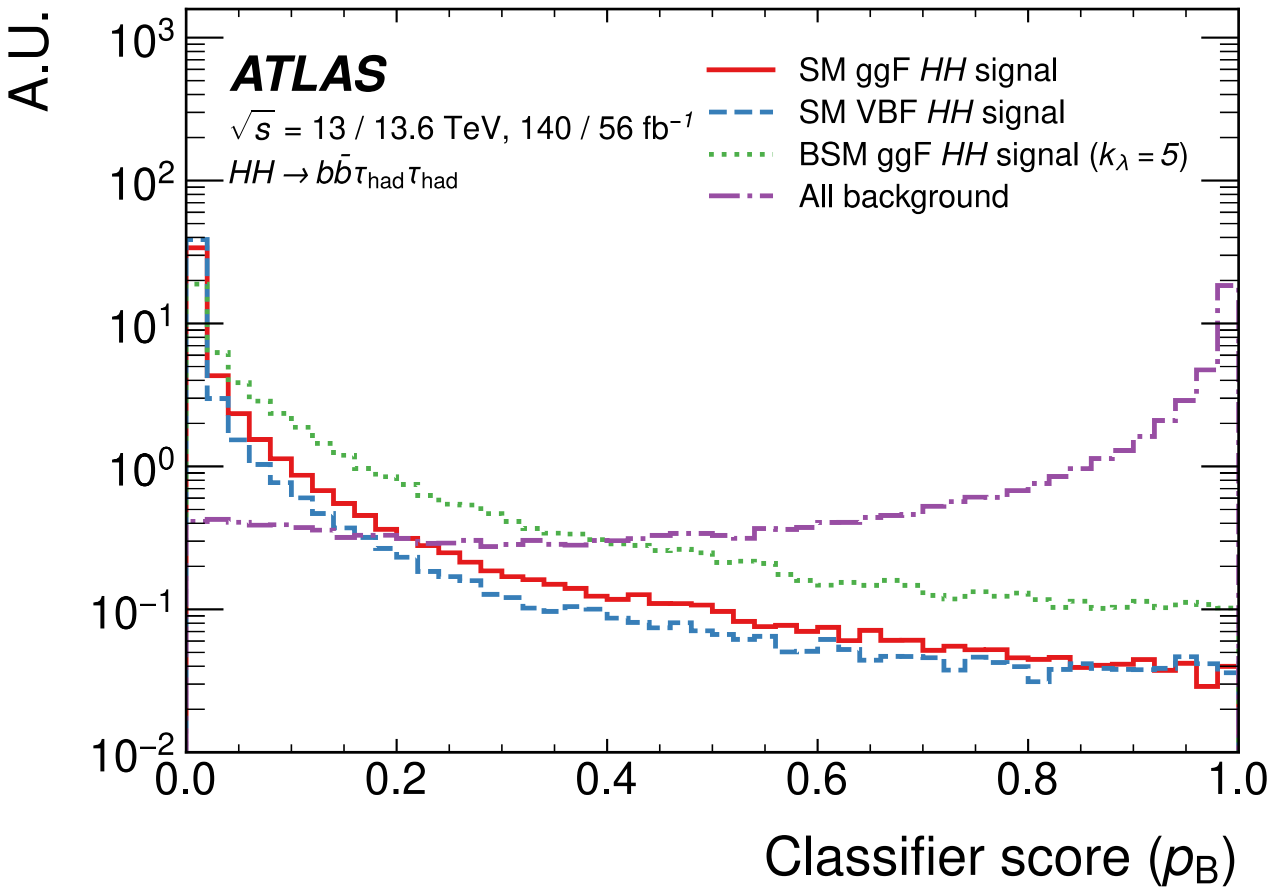

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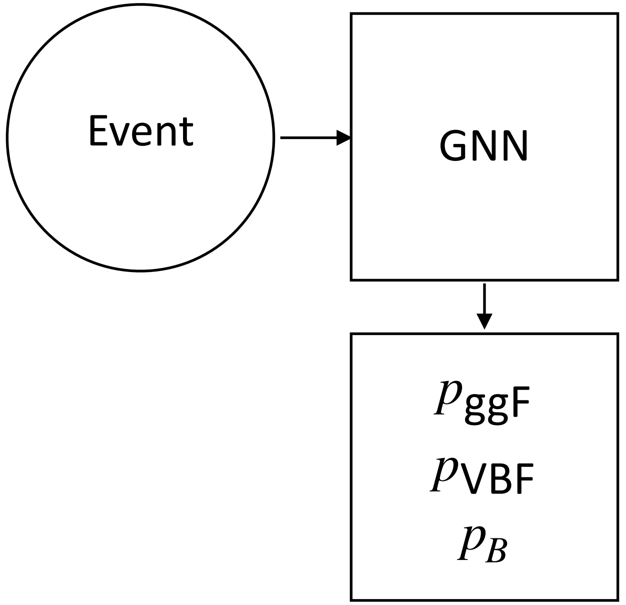
… which is actually a multi-classifier to also separate production modes



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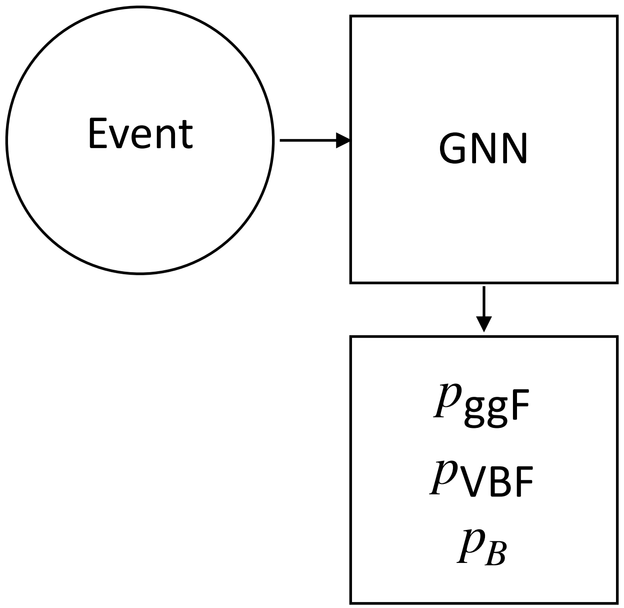

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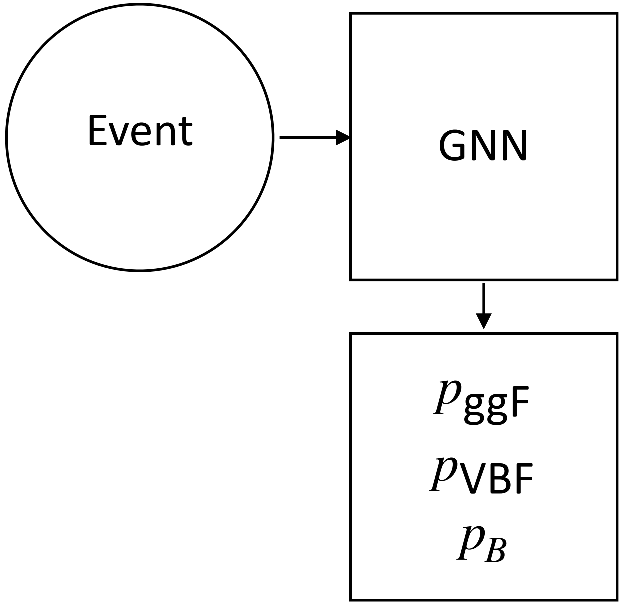

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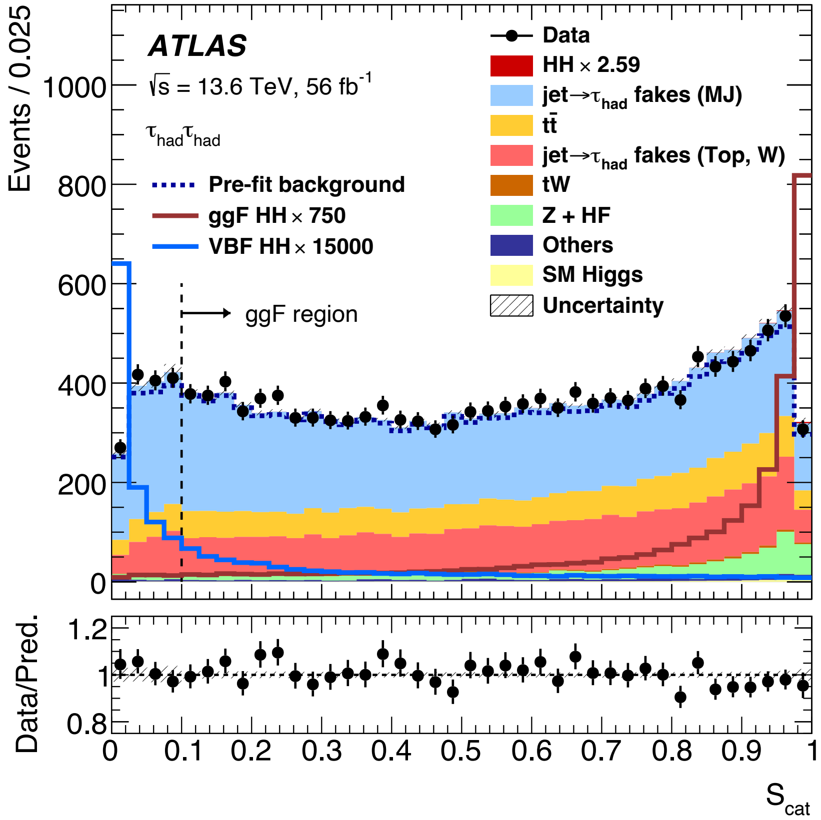

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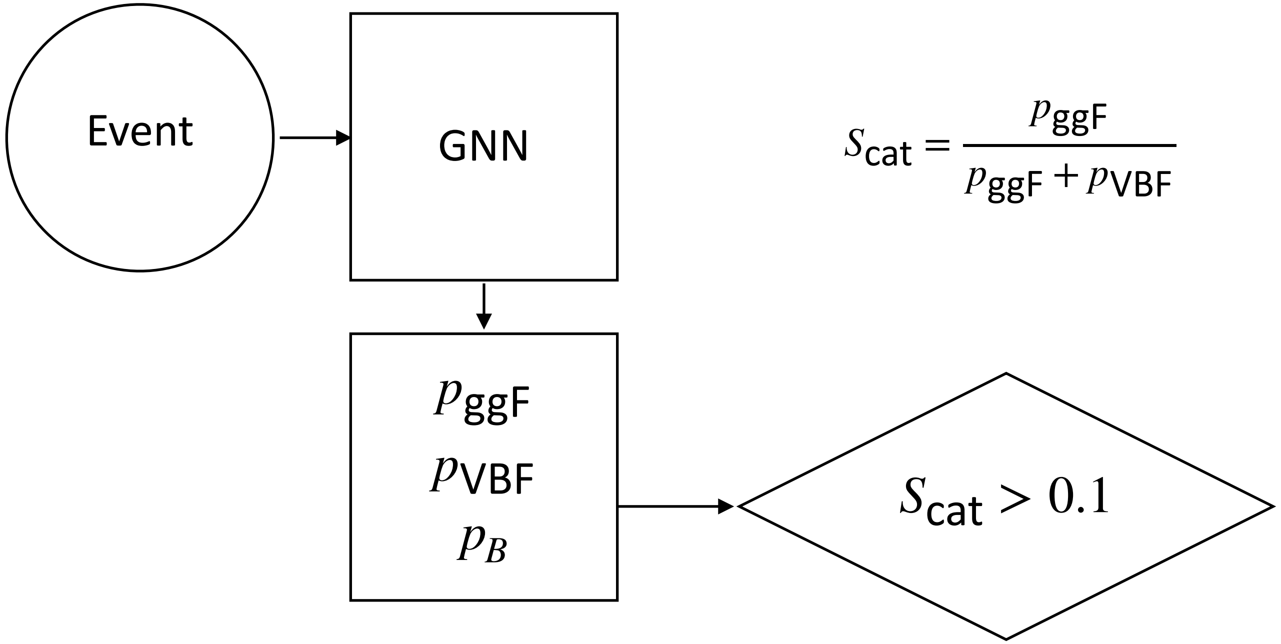

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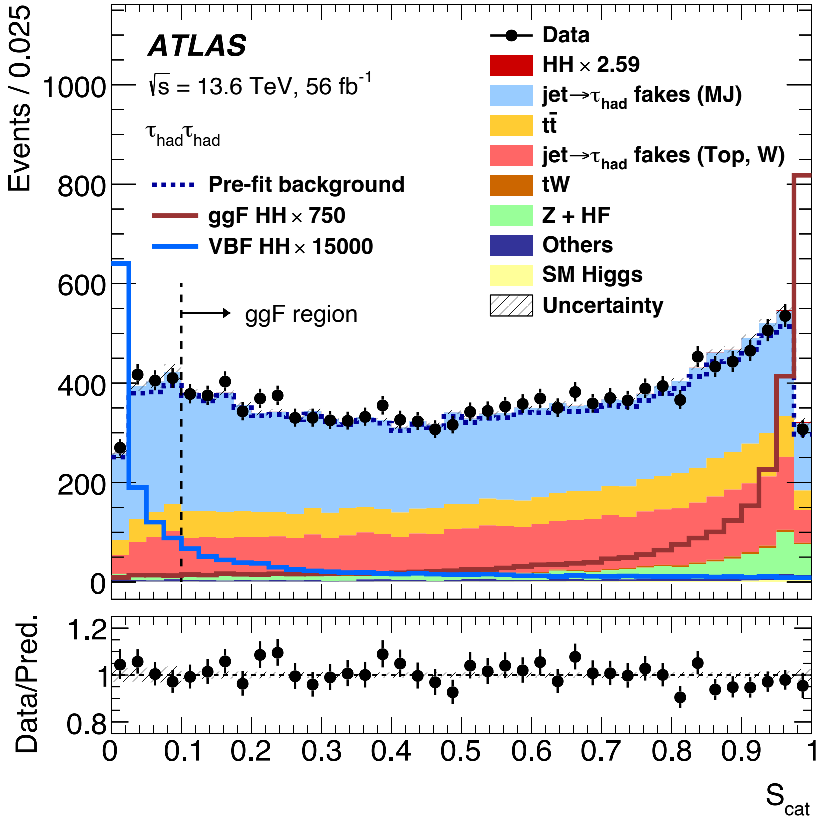

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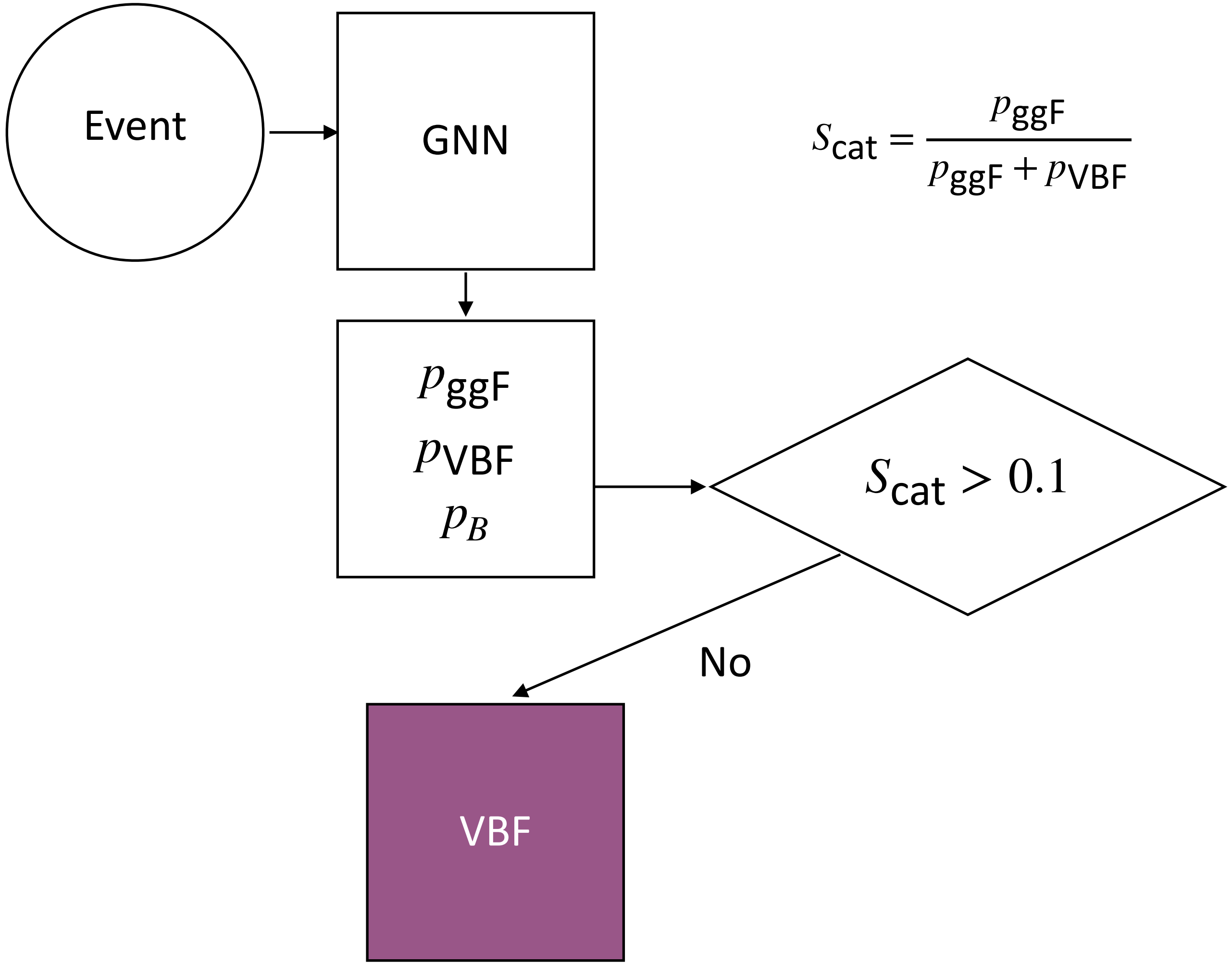

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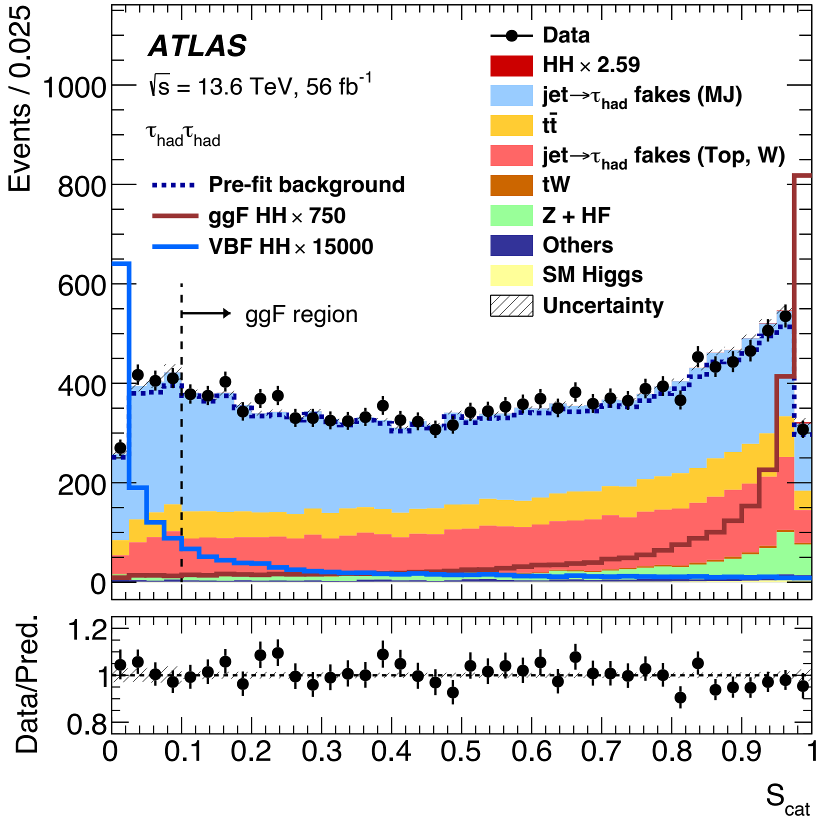

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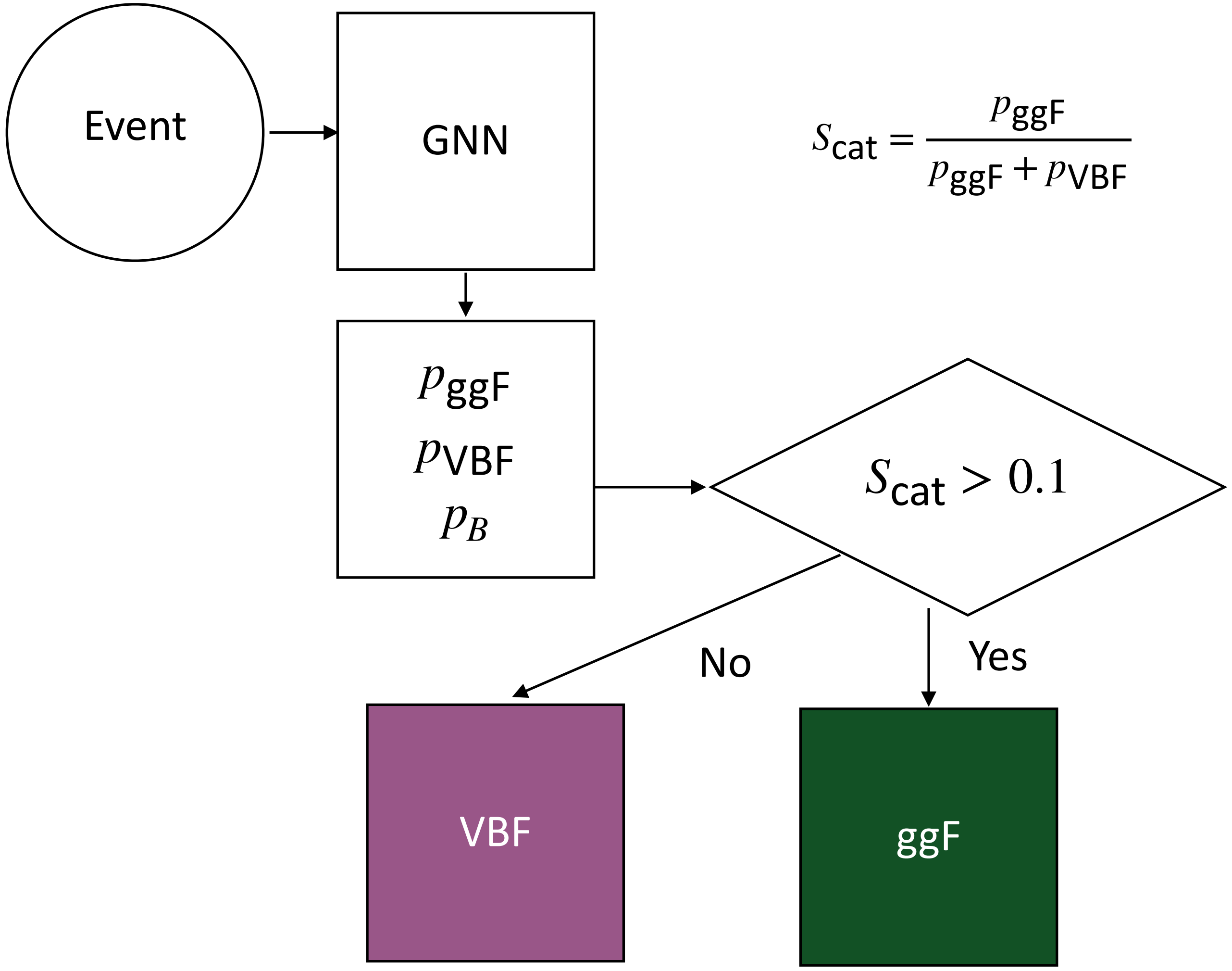

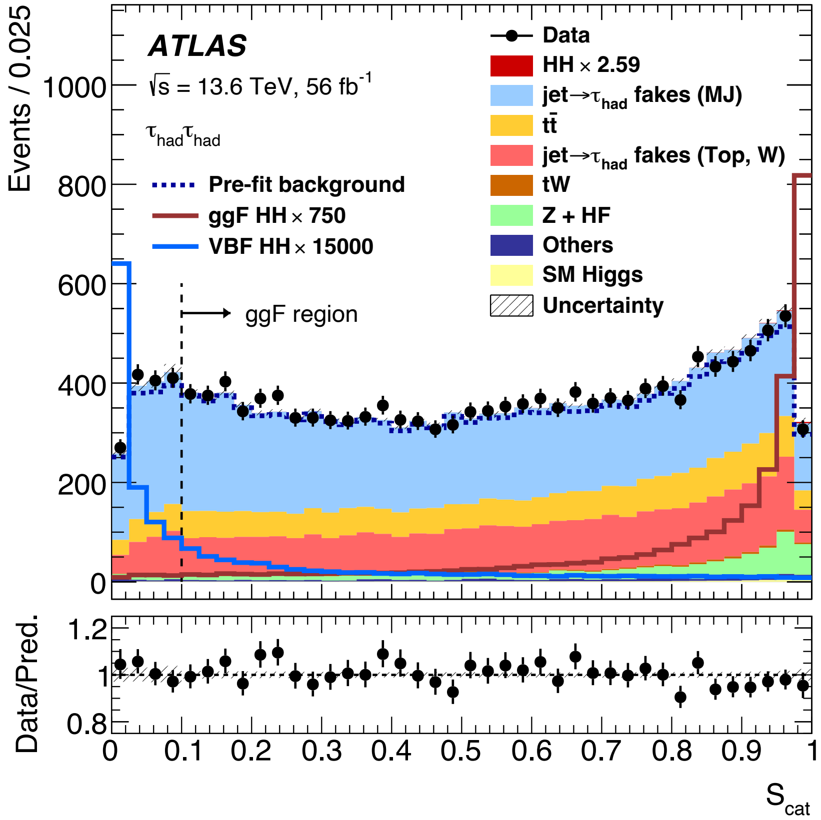

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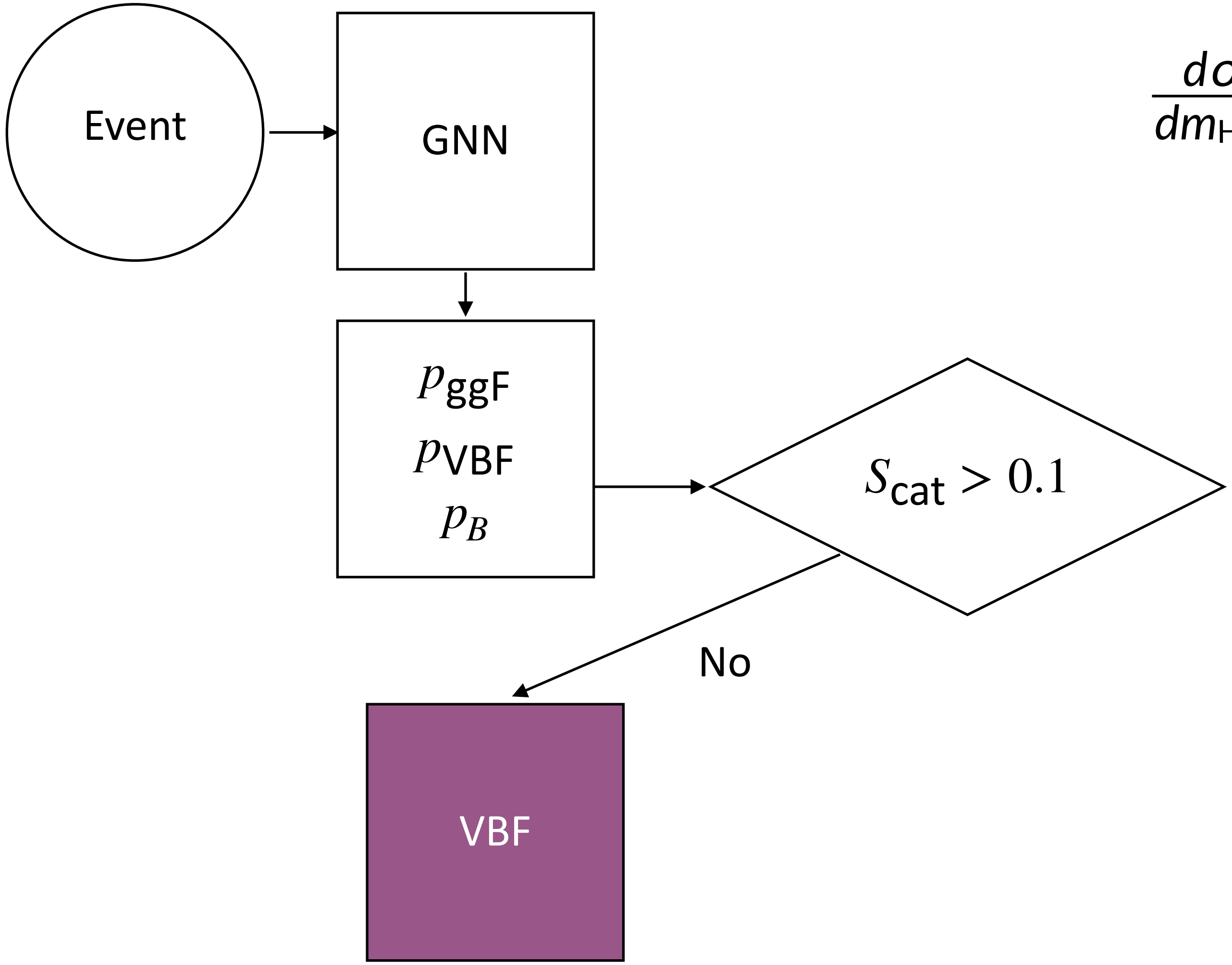
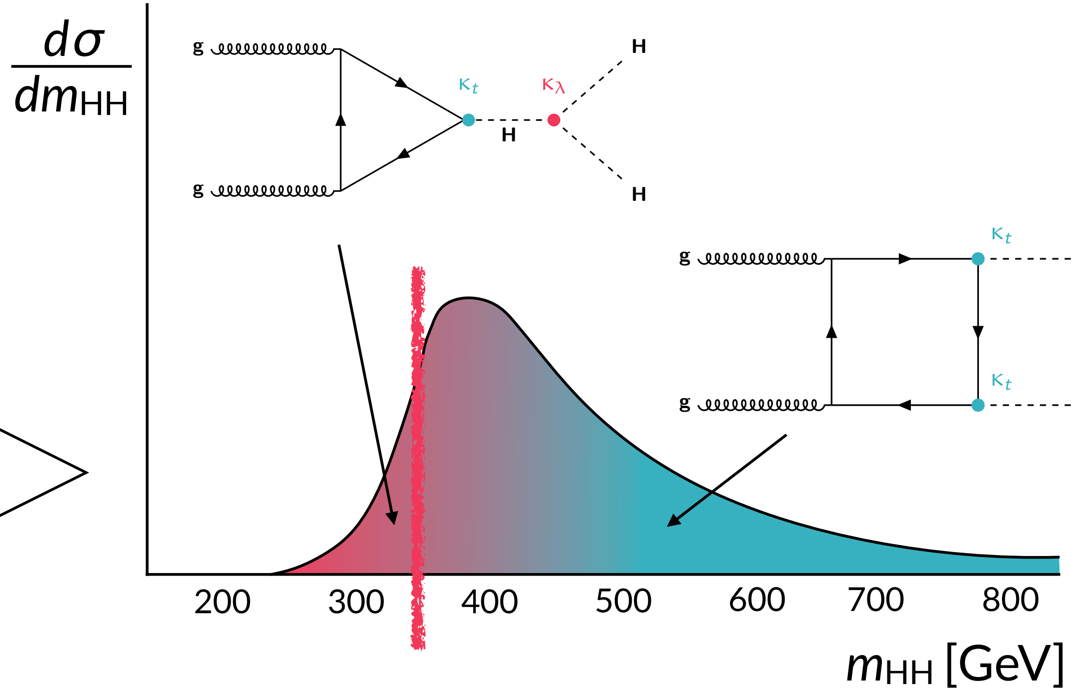
Also, the ggF region is further split to enhance the triangle and box diagrams relative contributions





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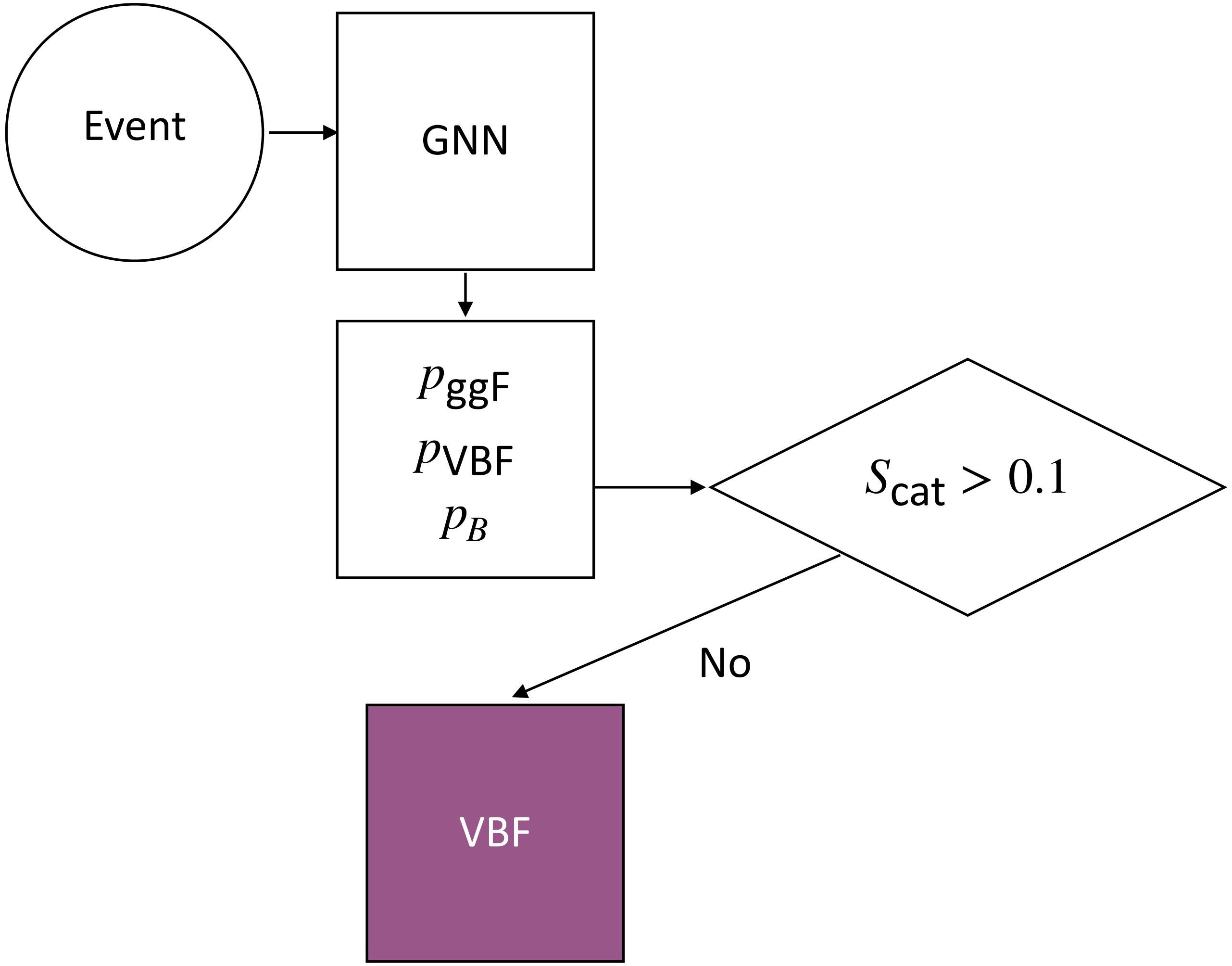

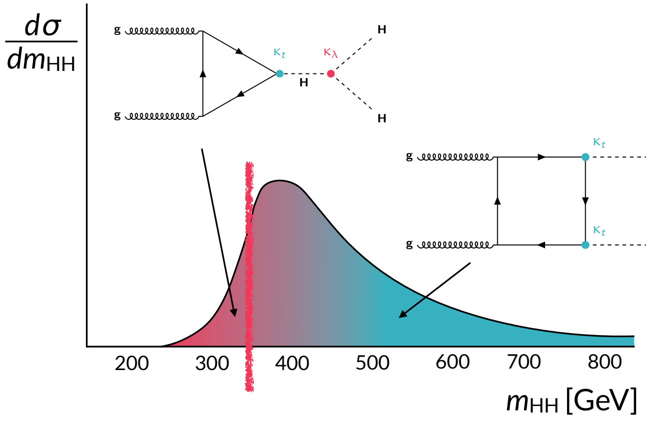

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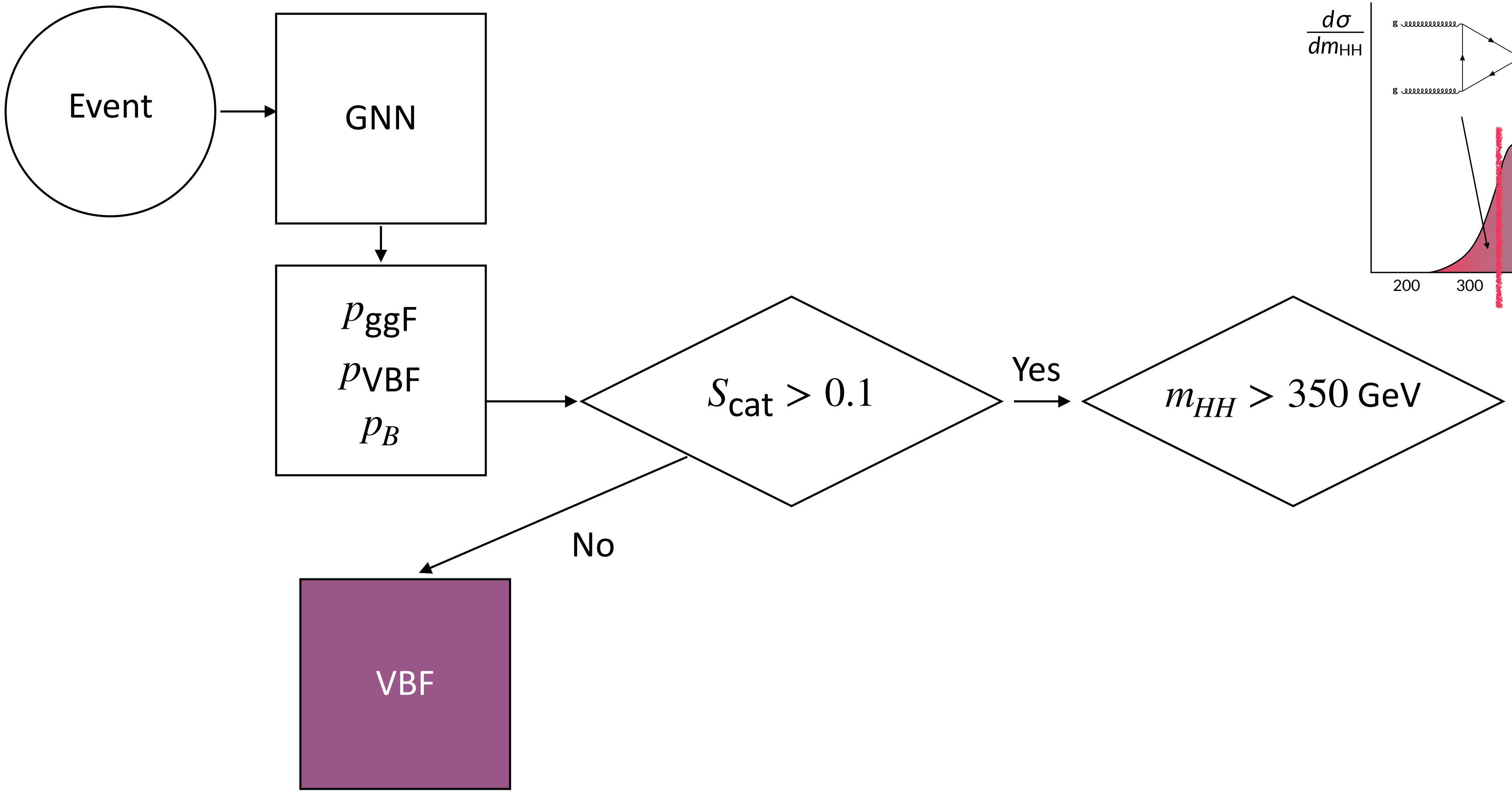

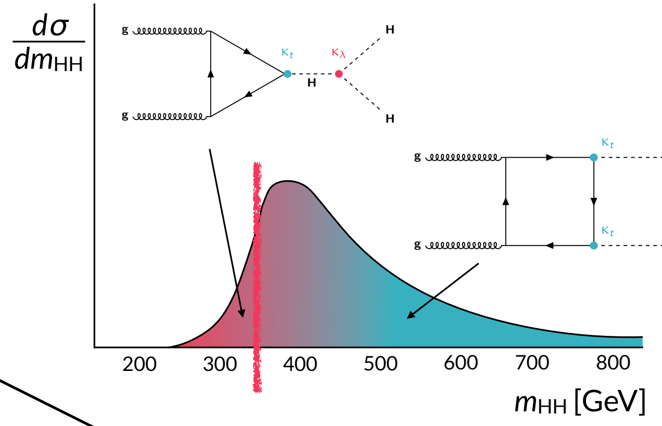

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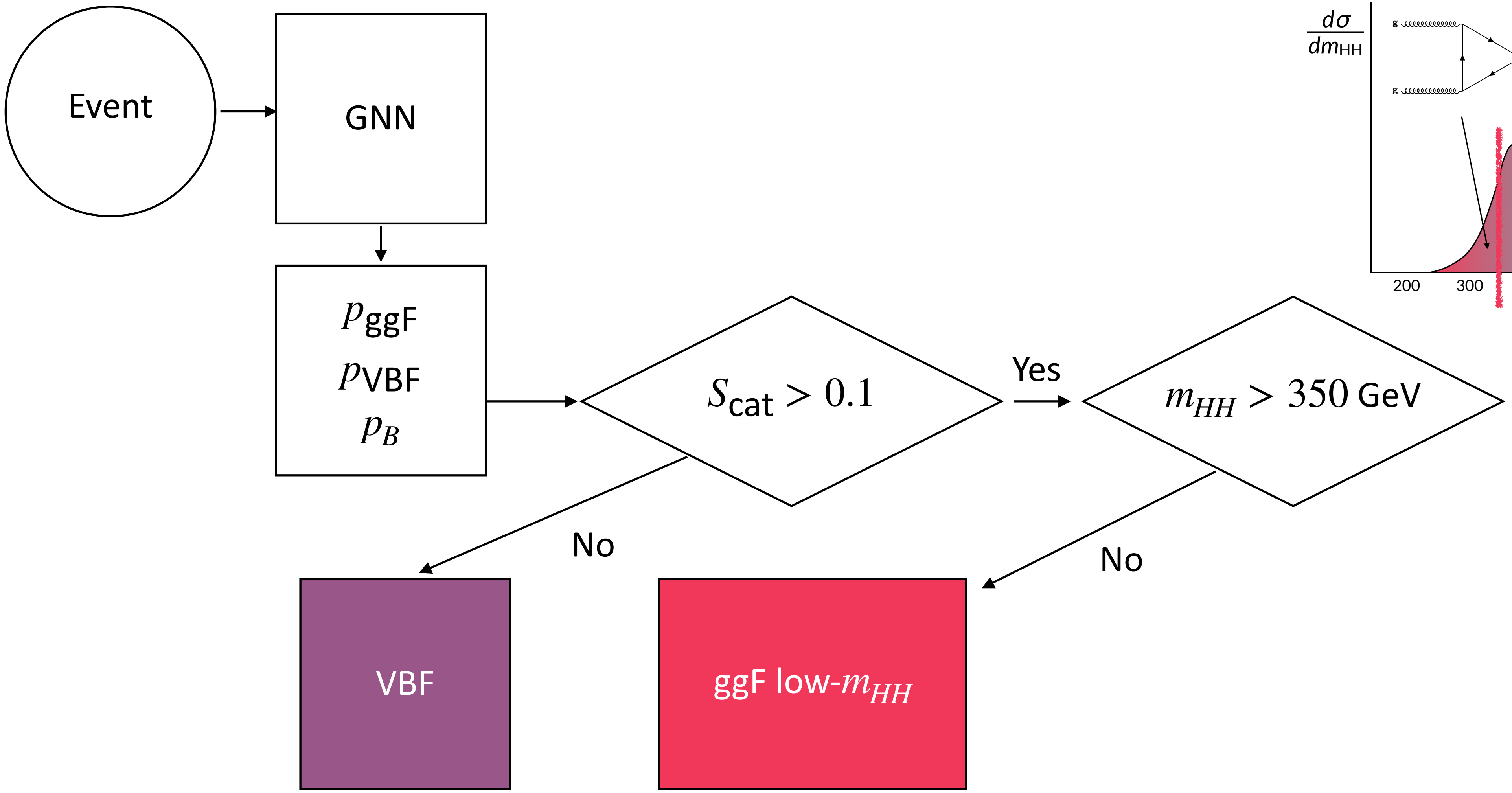

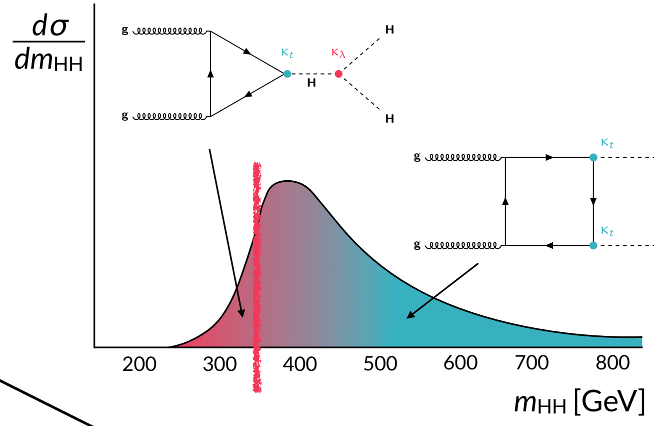

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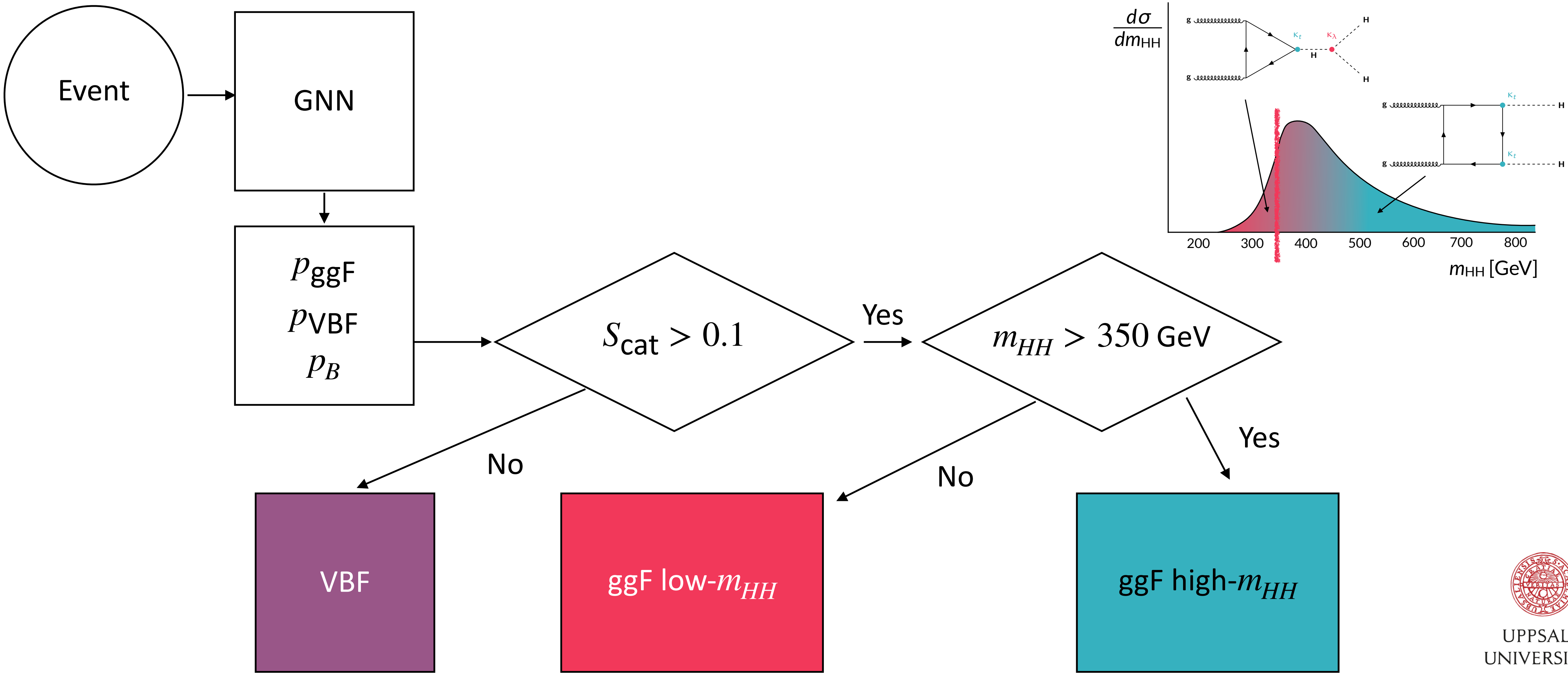

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Also, the ggF region is further split to enhance the triangle and box diagrams relative contributions

Event → GNN → p_{ggF}, p_{VBF}, p_B → $S_{\text{cat}} > 0.1$

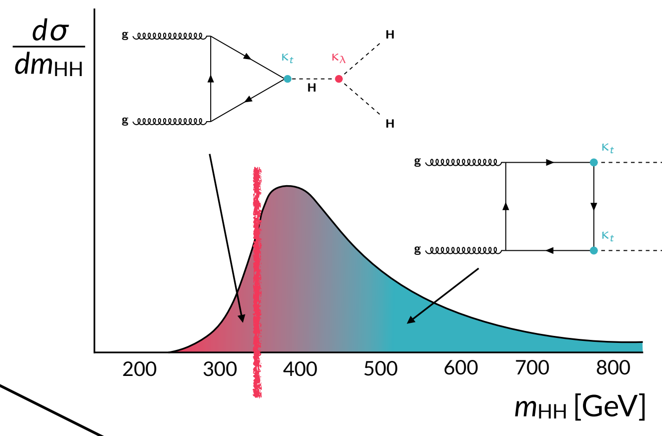
$$S_{\text{S}} = \frac{p_{\text{S}}}{p_{\text{S}} + p_{\text{B}}}$$

$S_{\text{cat}} > 0.1$: No → VBF

$S_{\text{cat}} > 0.1$: Yes → $m_{HH} > 350$ GeV

$m_{HH} > 350$ GeV: No → ggF low-m_{HH}

$m_{HH} > 350$ GeV: Yes → ggF high-m_{HH}



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My work was estimating multijet contributions with jets faking τ_{had} candidates in the $\tau_{\text{had}}\tau_{\text{had}}$ channel

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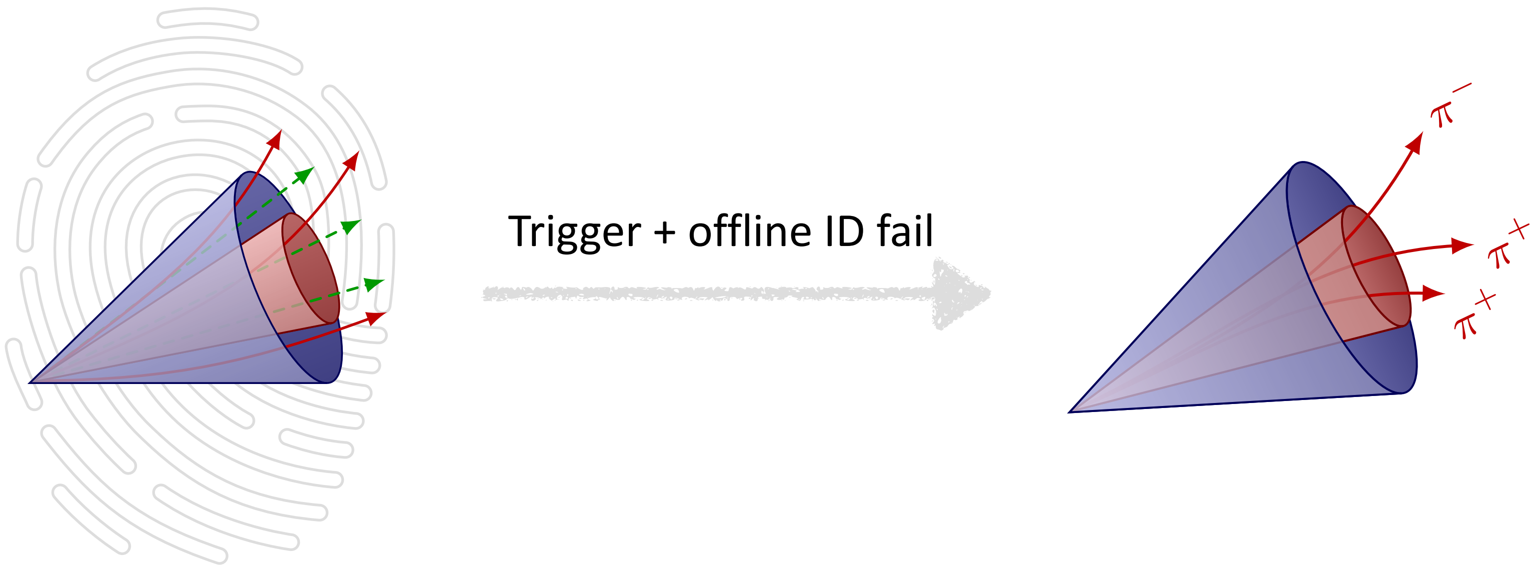

Jets mis-identified as τ_{had}

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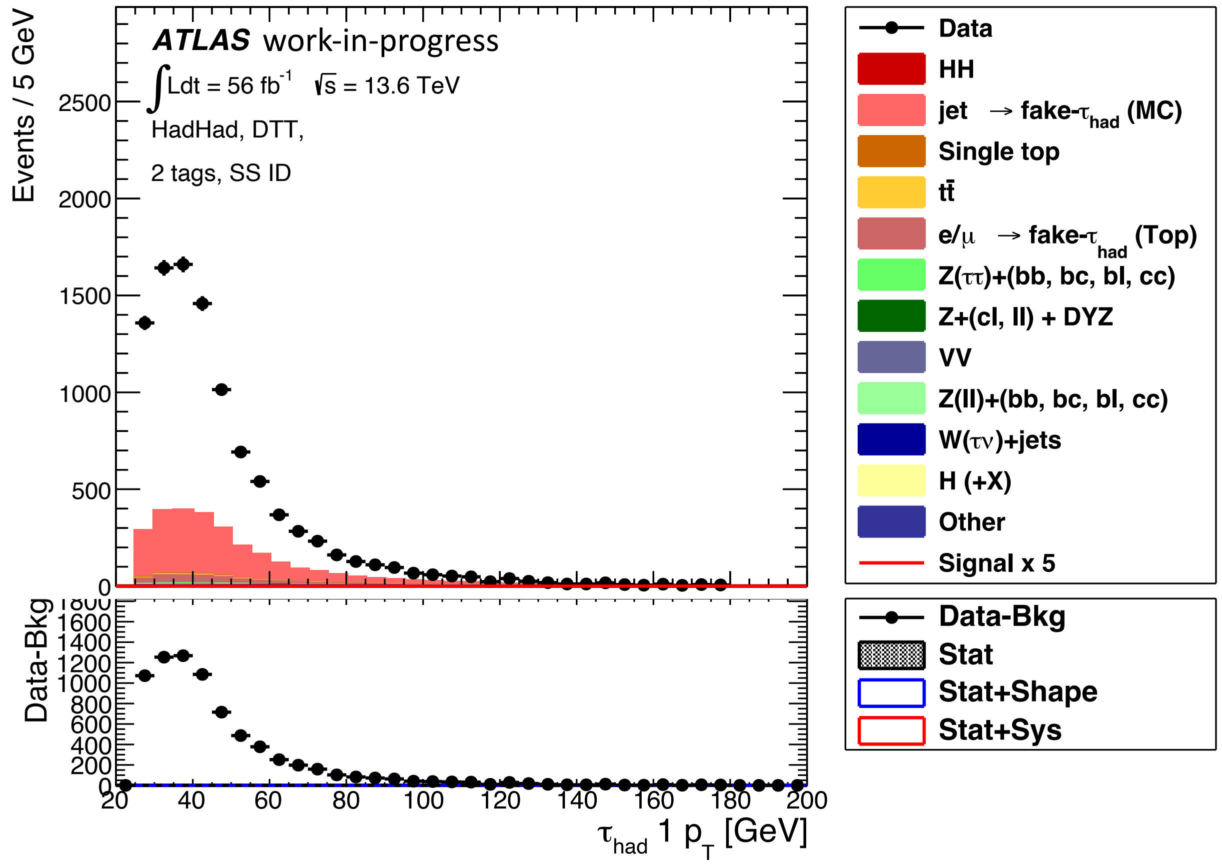
Multijet processes are difficult to model, so a data-driven method is used instead



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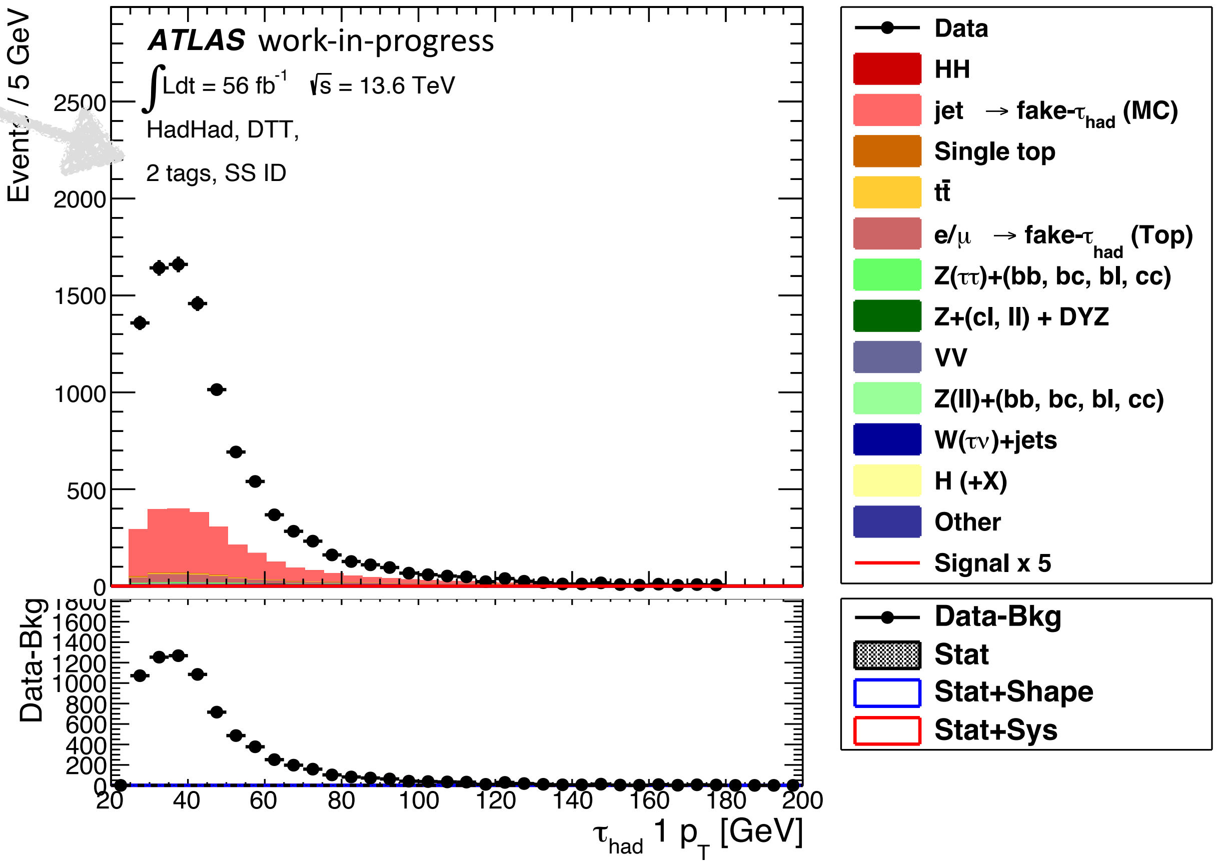
Multijet enriched control region



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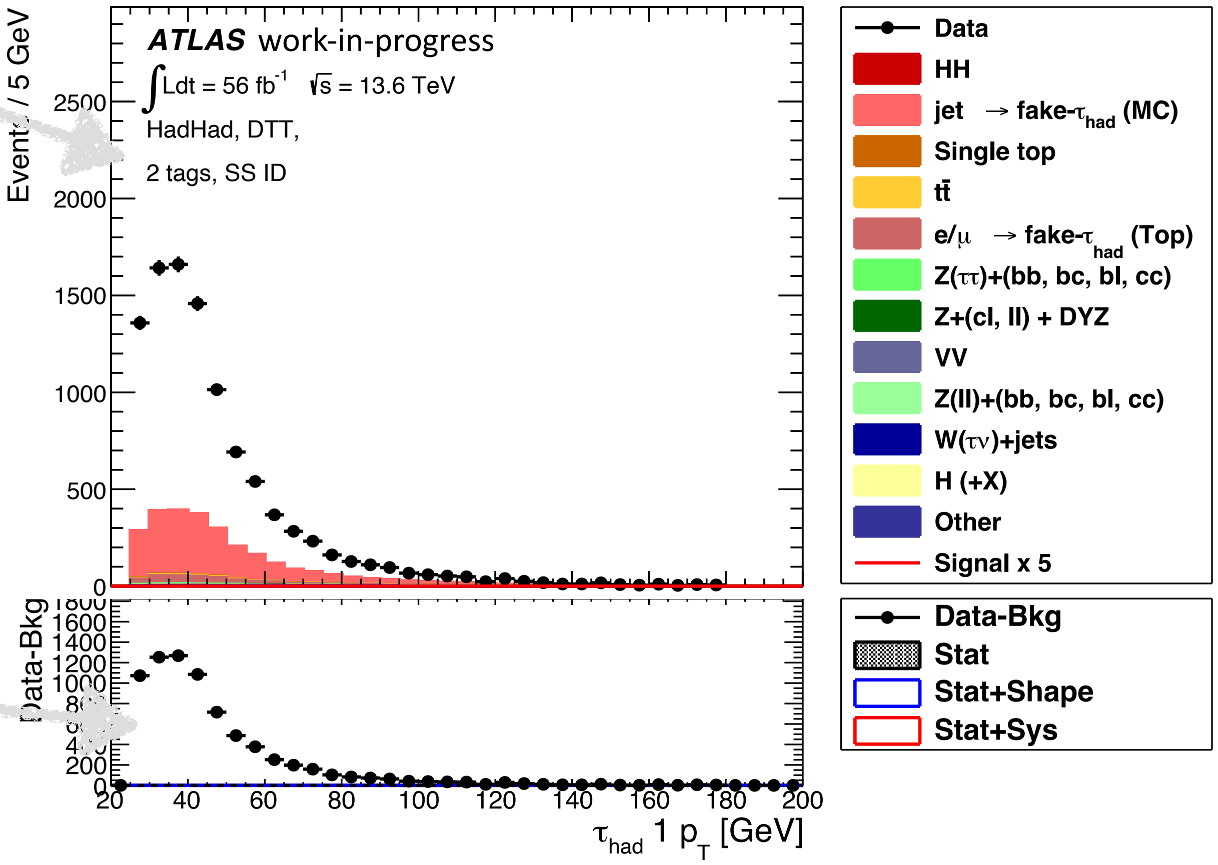

Multijet estimate

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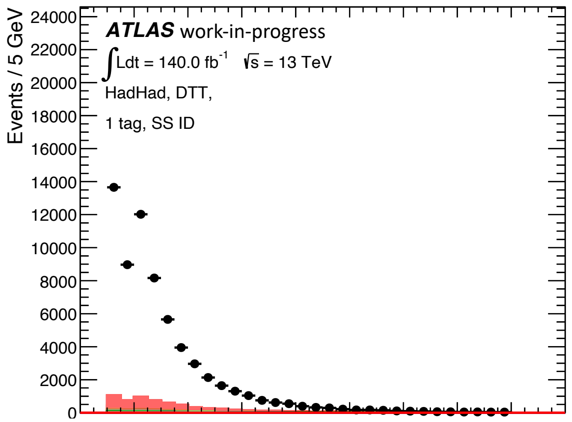
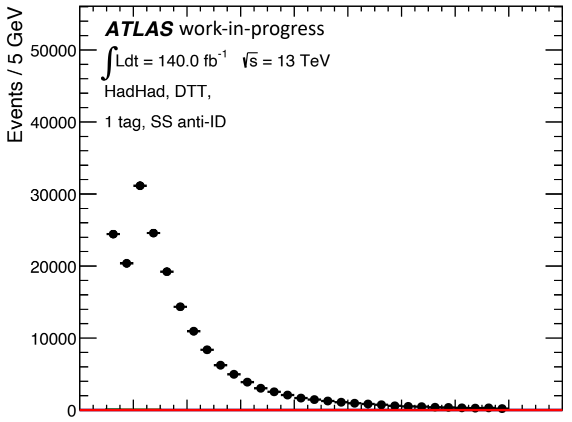
Fake factors are measured as ratio of multijet estimates in ID and anti-ID regions





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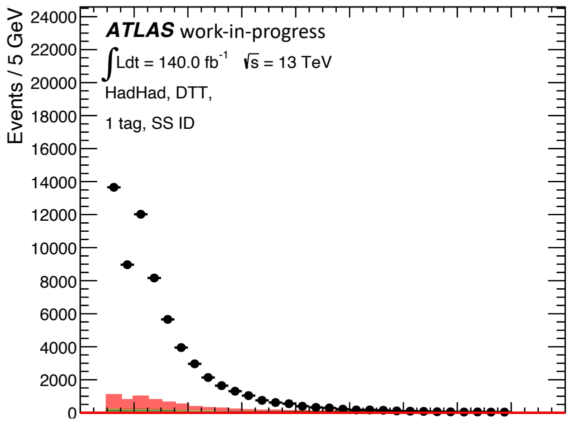

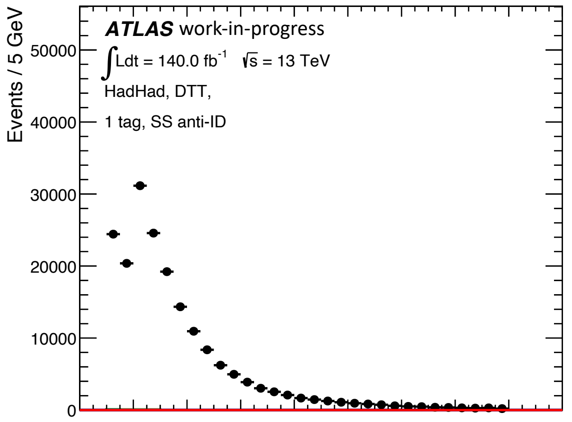

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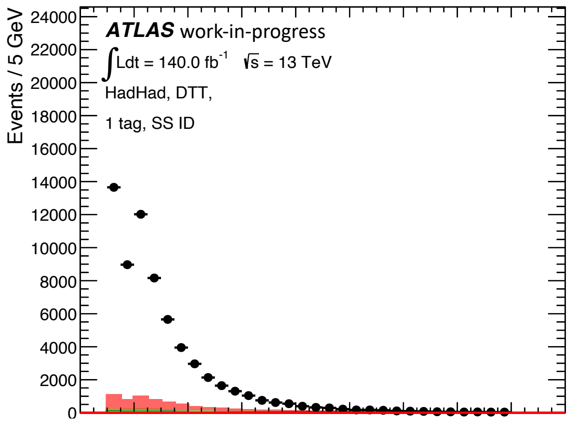

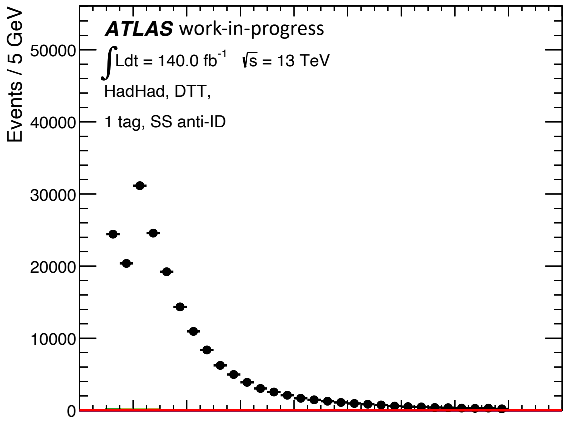

Sliced by trigger, η, year, number of tracks

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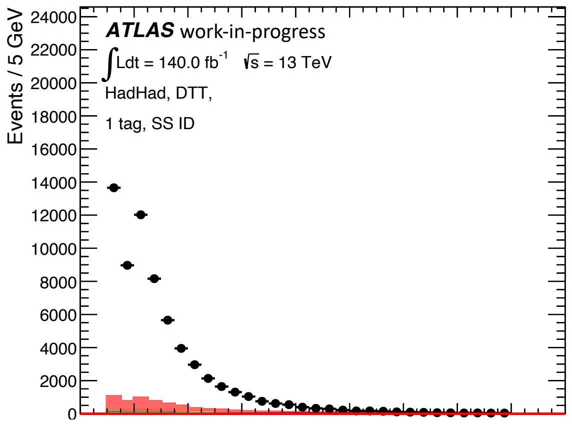

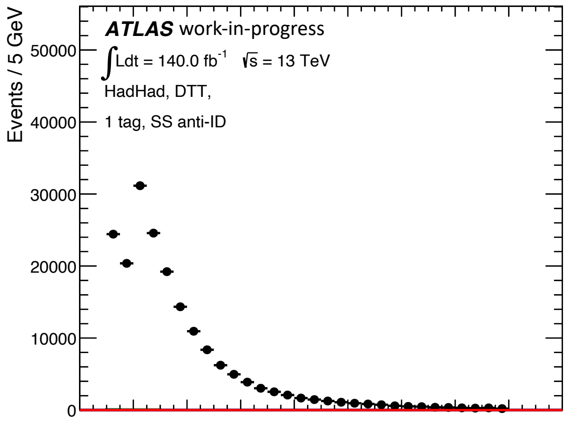

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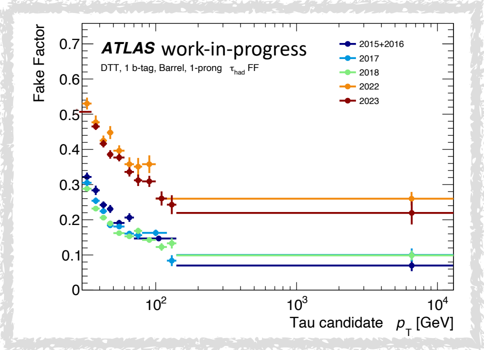

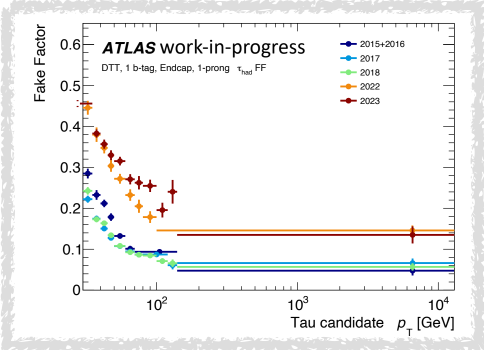

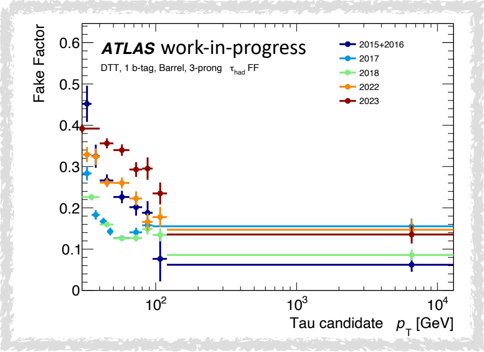

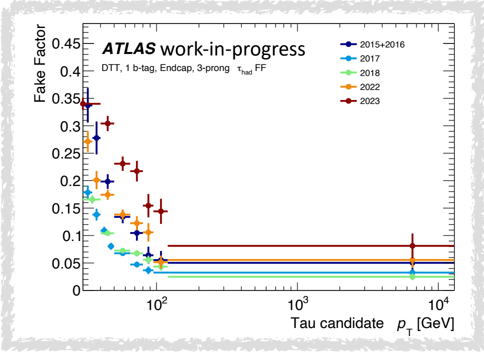

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Fake factors are applied to events in anti-ID regions to estimate the multijet background in the validation and signal regions

arXiv:2607.26879

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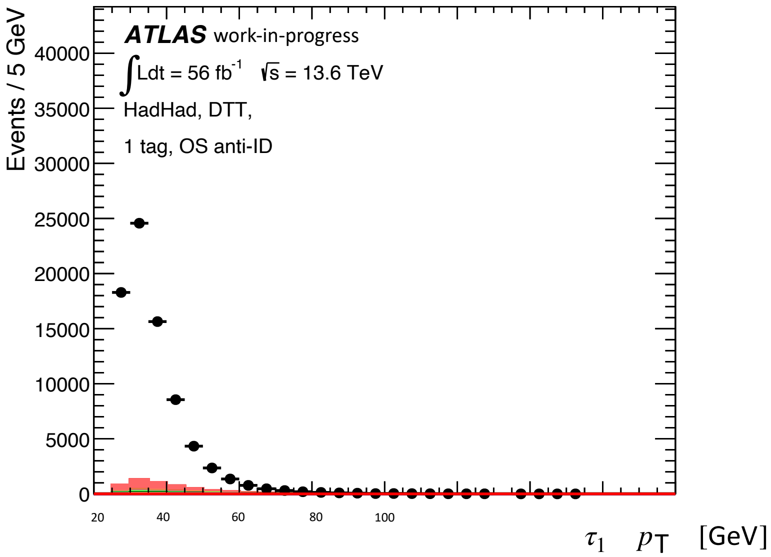

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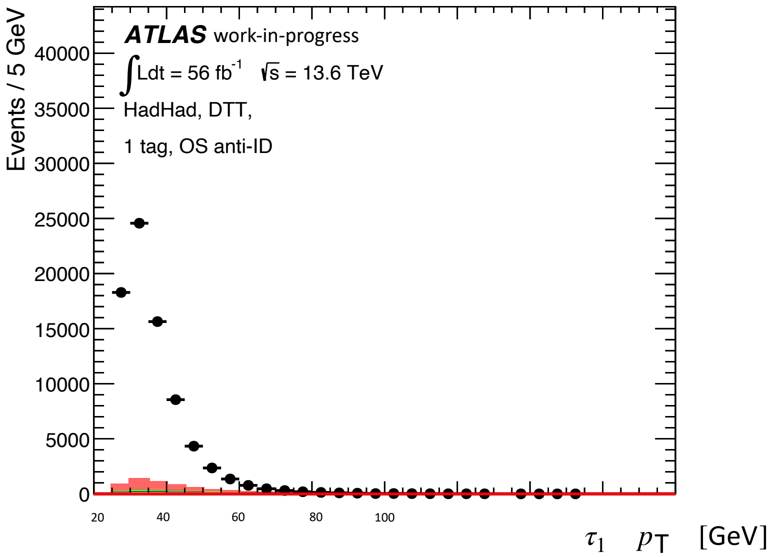

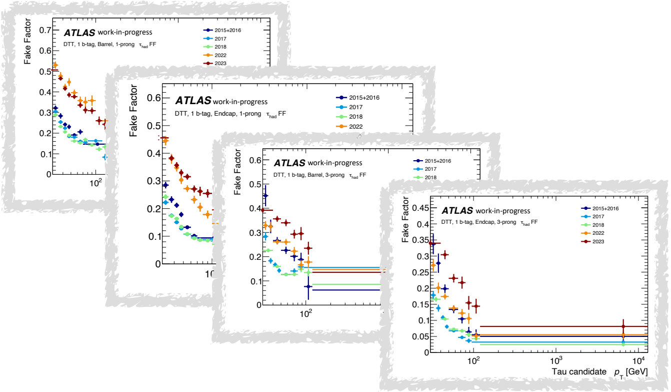

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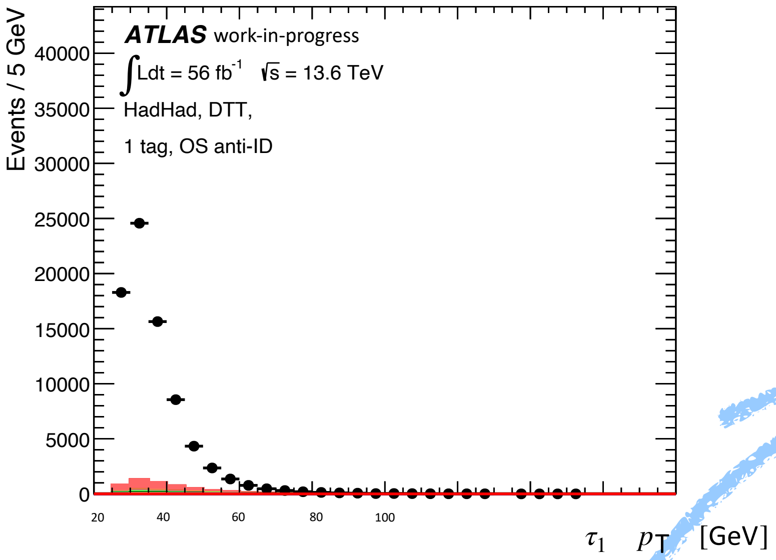

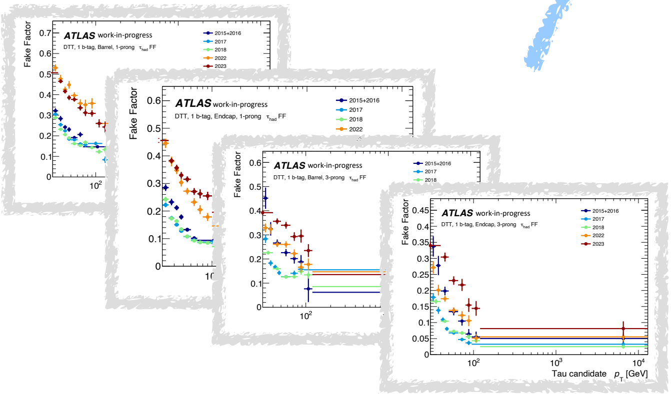

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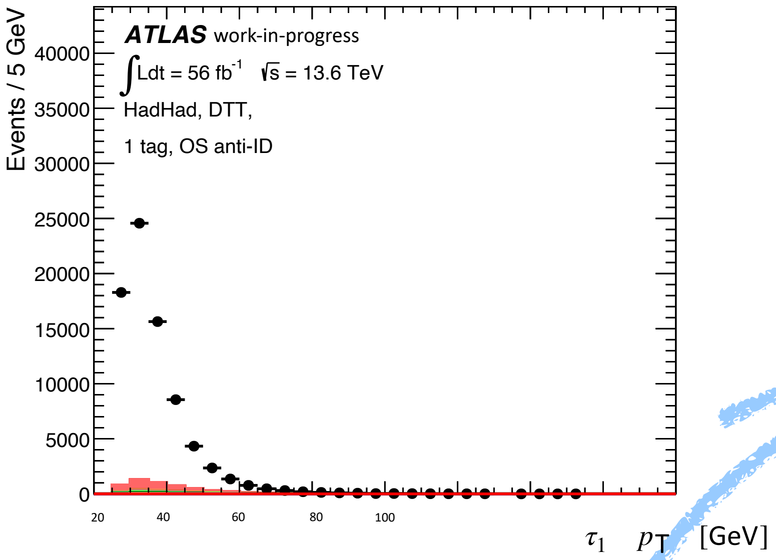

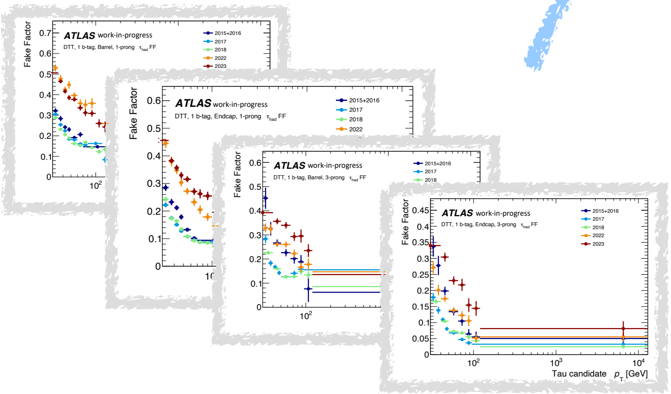

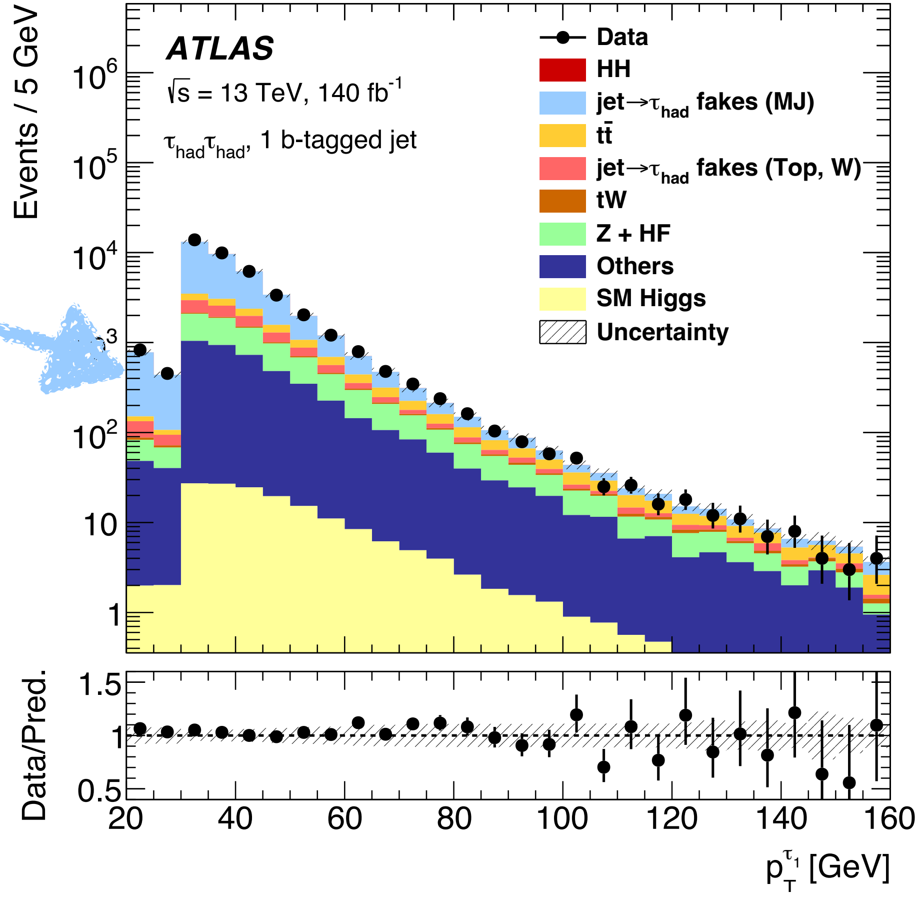

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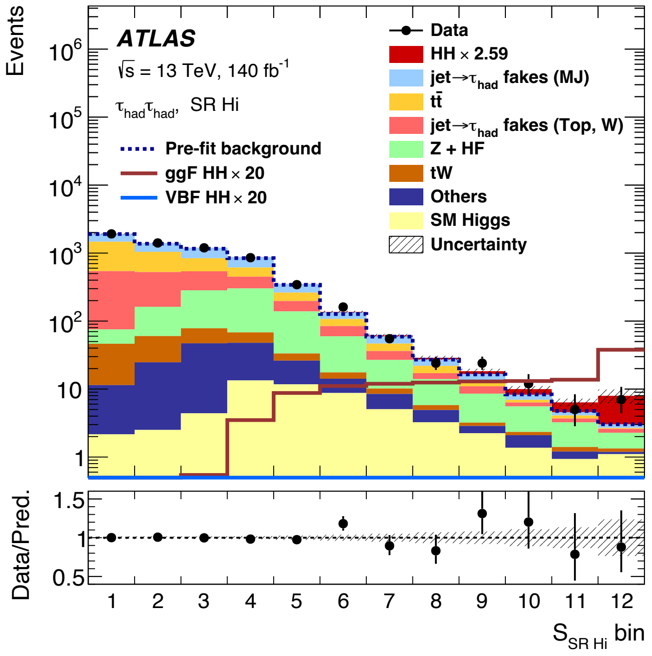
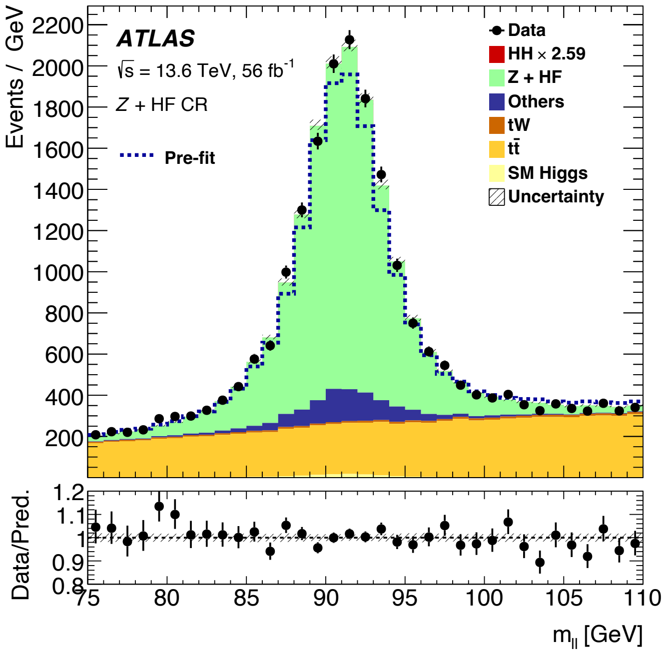
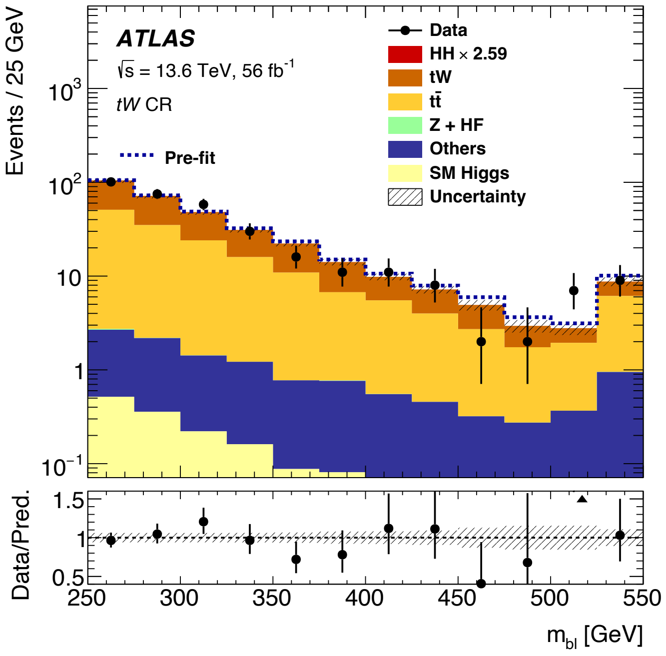
The signal strength is derived by a profile likelihood fit with some floating background normalization factors







$$\hat{\mu} = 2.6^{+1.4}_{-1.0}$$

arXiv:2607.26879

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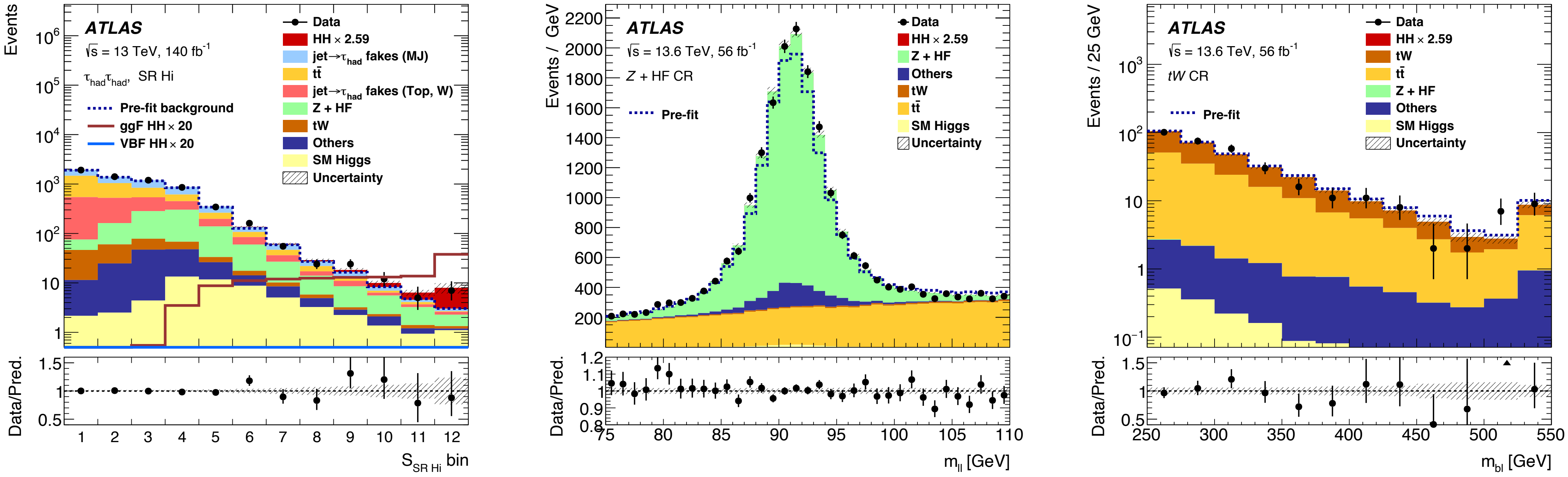

$$\hat{\mu} = 2.6^{+1.4}_{-1.0}$$

95 % CL:

$\mu < 5.3$ (expected: 2.4 bkg only, 2.8 SM)

arXiv:2607.26879

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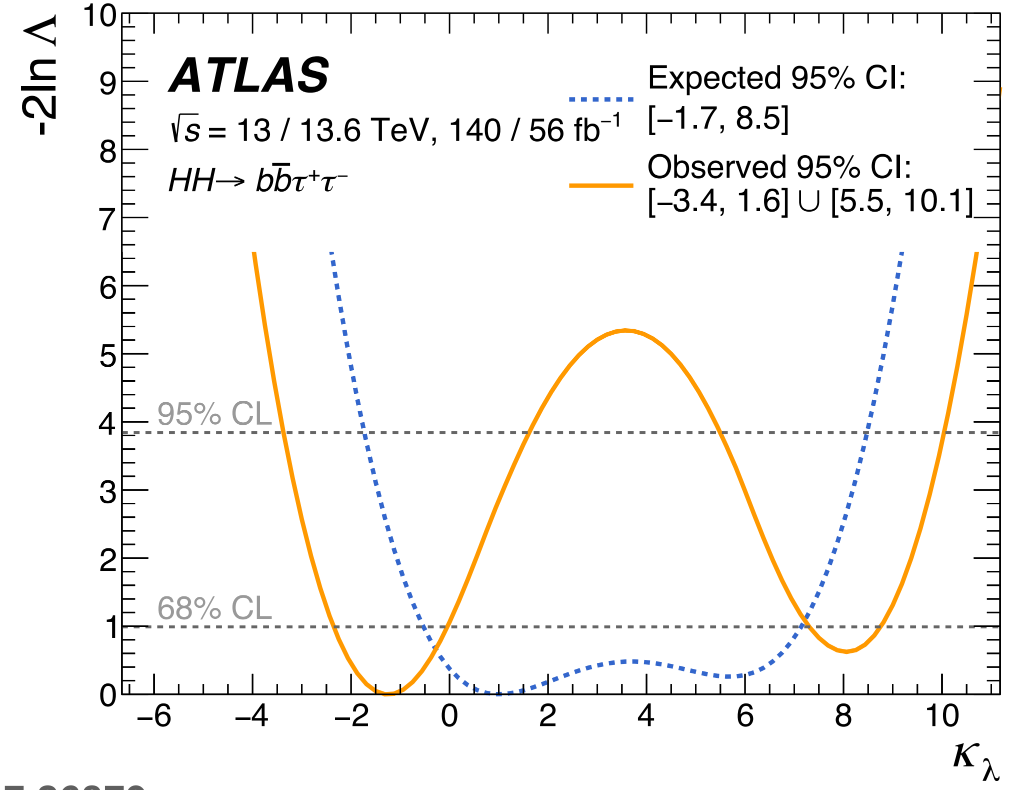
Similarly, the Higgs confidence interval is derived, with the double minima caused by the degeneracy of the production cross as a function in κ_λ

$$\kappa_{2V} = 1$$



arXiv:2607.26879

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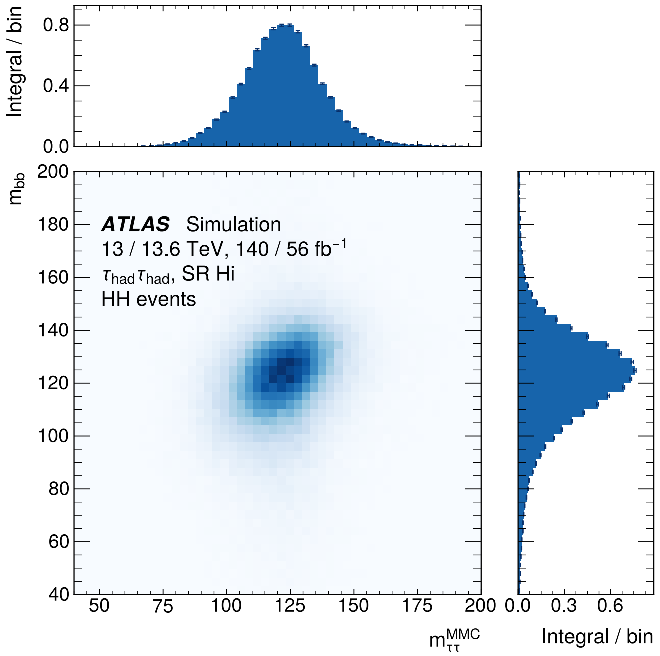
The analysis design is validated by repurposing it as a search for the most signal-like backgrounds $ZZ/ZH \to bb\tau\tau$

arXiv:2607.26879



HH

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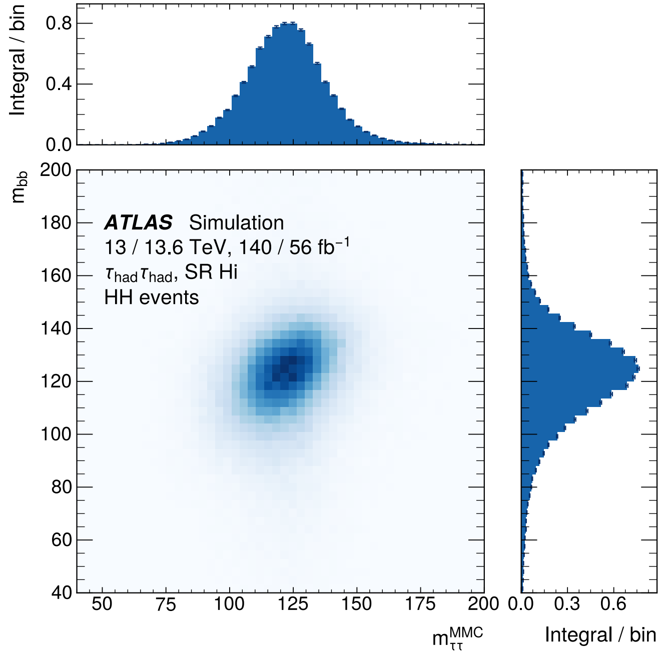
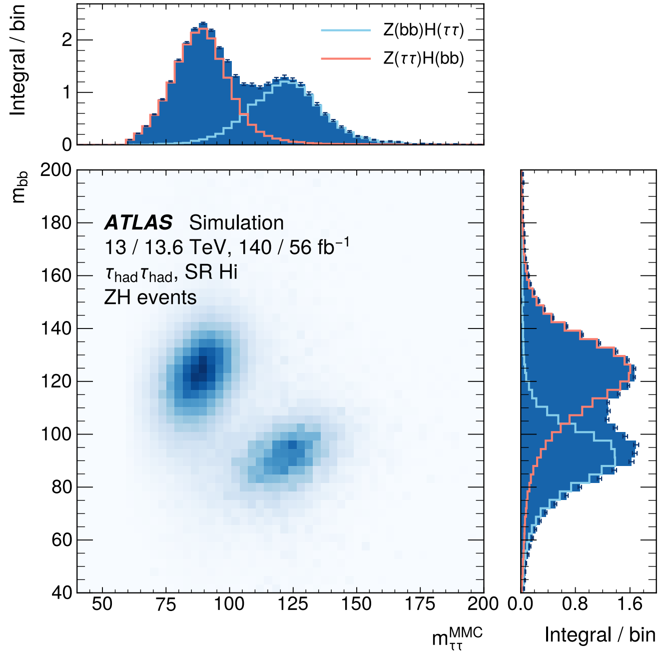
arXiv:2607.26879



HH



ZH yield = 4.9 x HH yield

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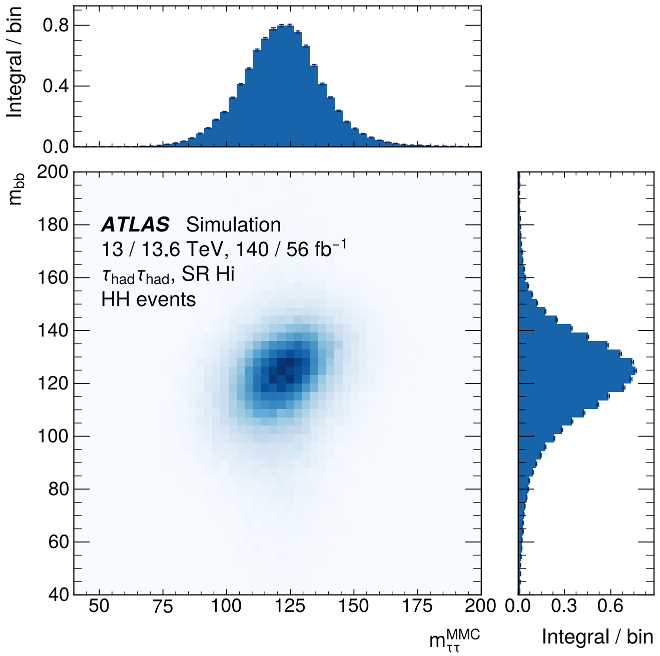

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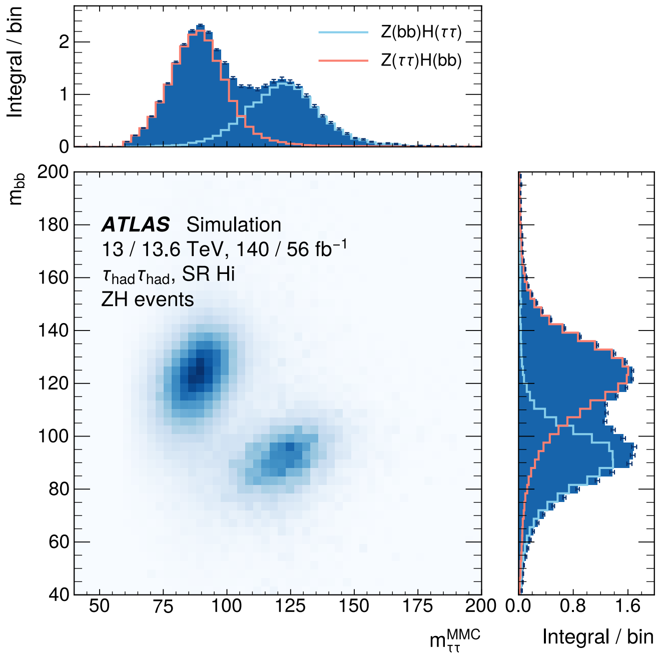
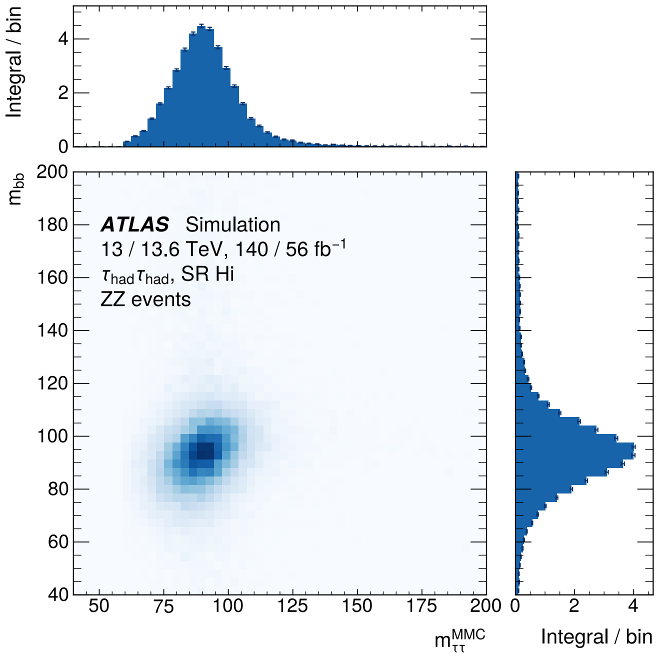


ZH yield = 4.9 x *HH* yield



ZZ yield = 10 x *HH* yield

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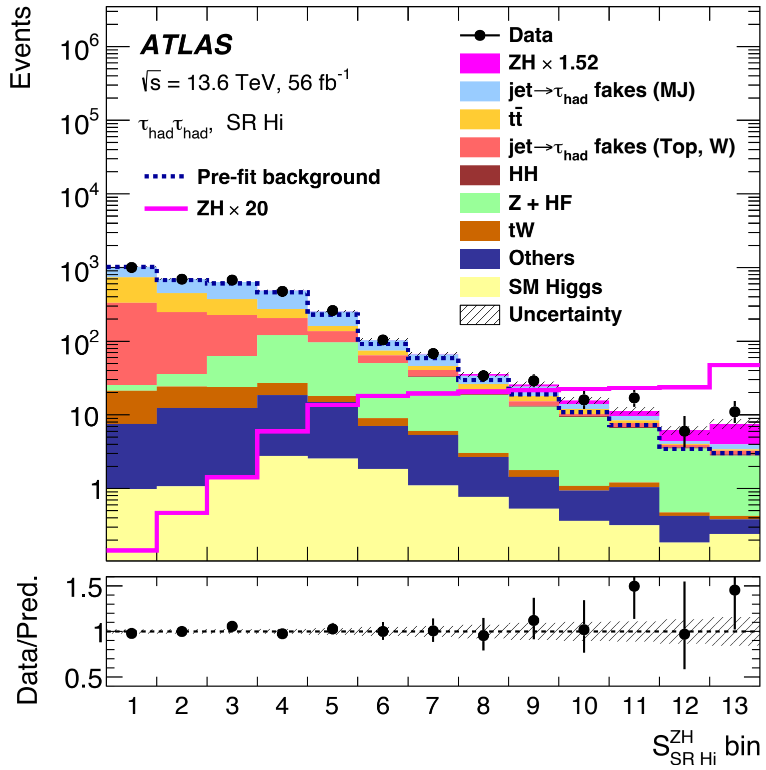
By only replacing the signal classifier, the analysis design can be validated by measuring ZH and ZZ in the $bb\tau\tau$ final states

arXiv:2607.26879



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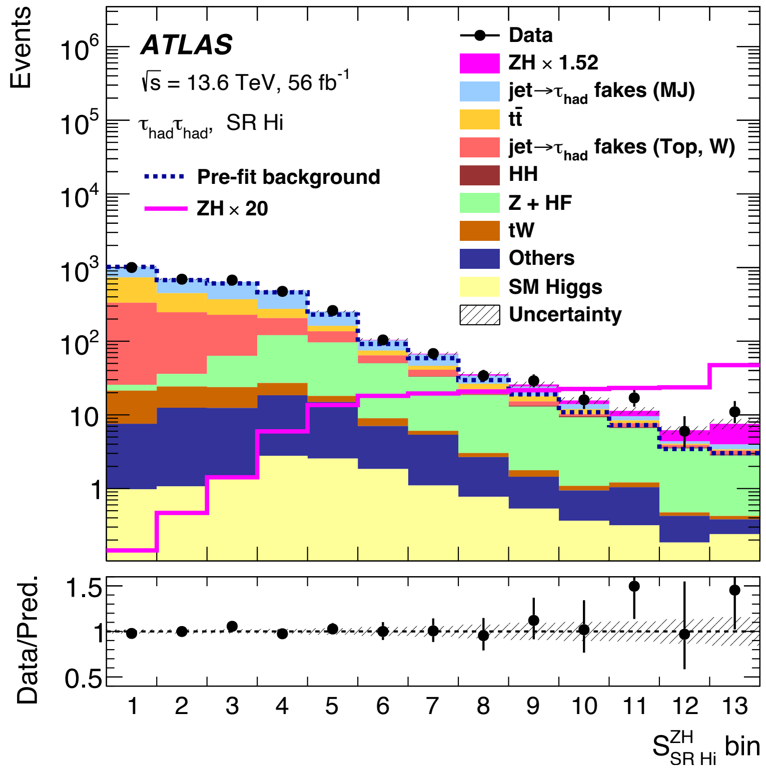

Observed 3.5 σ

Expected 2.4 σ

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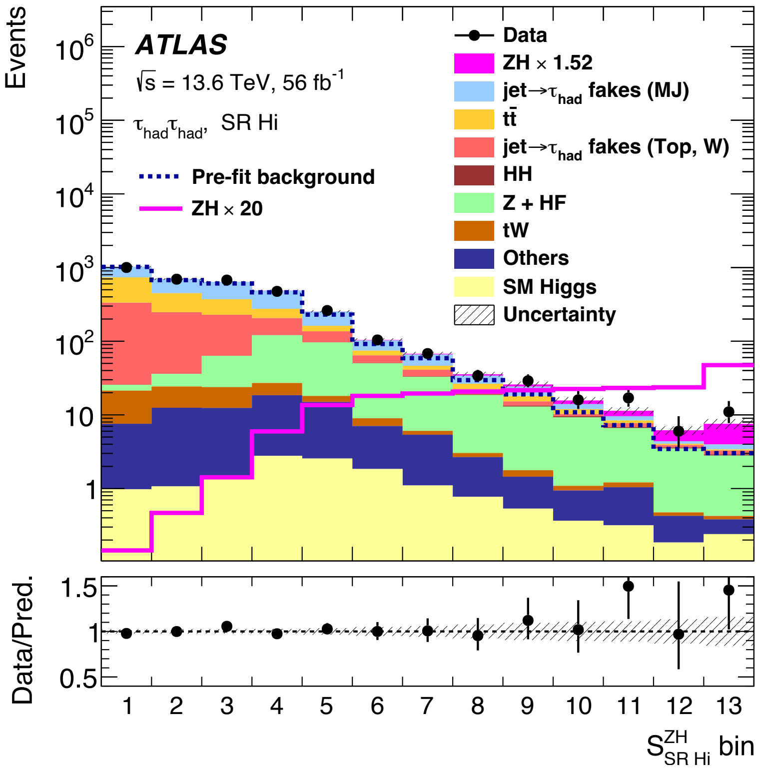

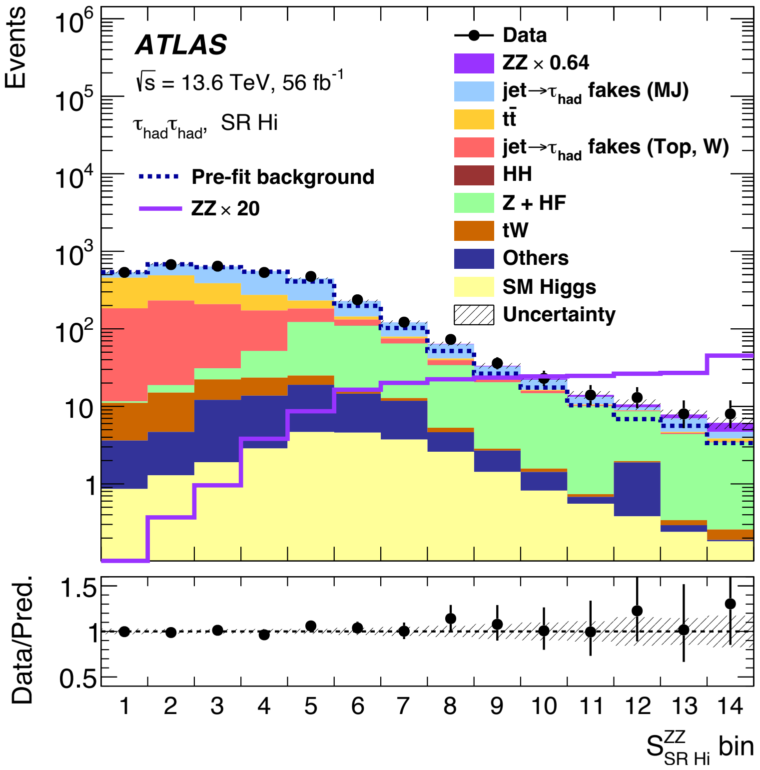

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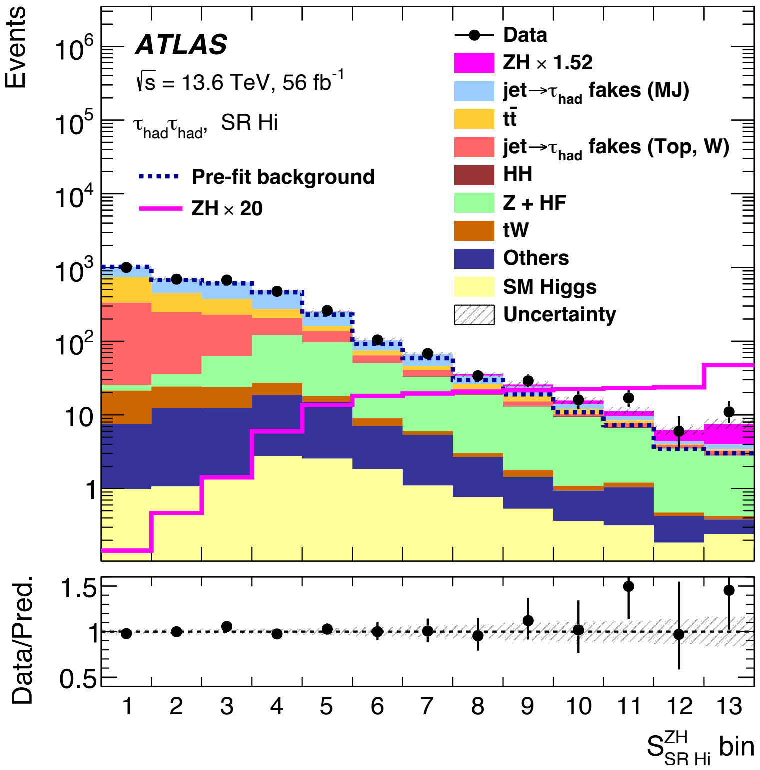

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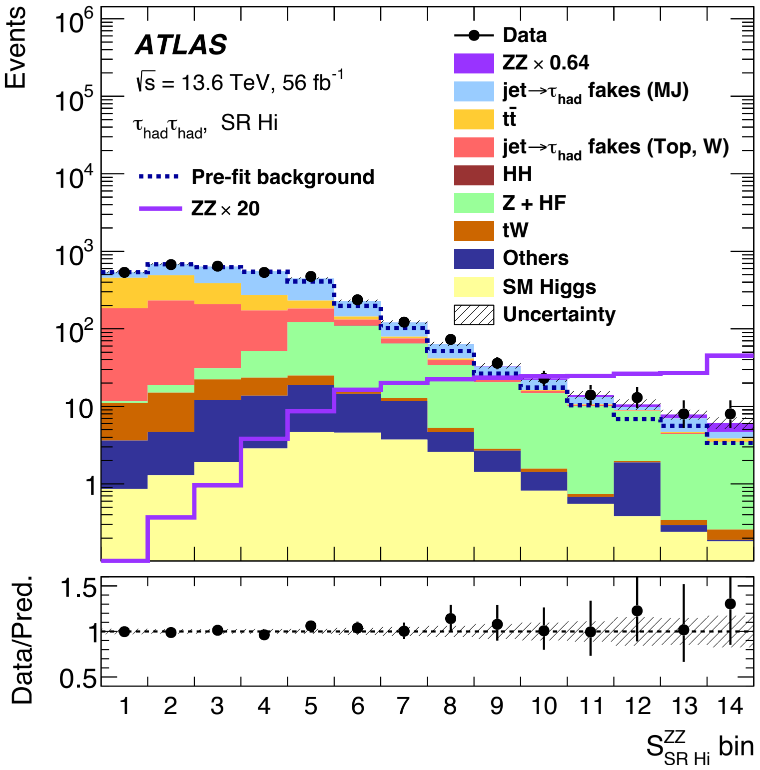

Observed 1.8 σ
Expected 2.7 σ

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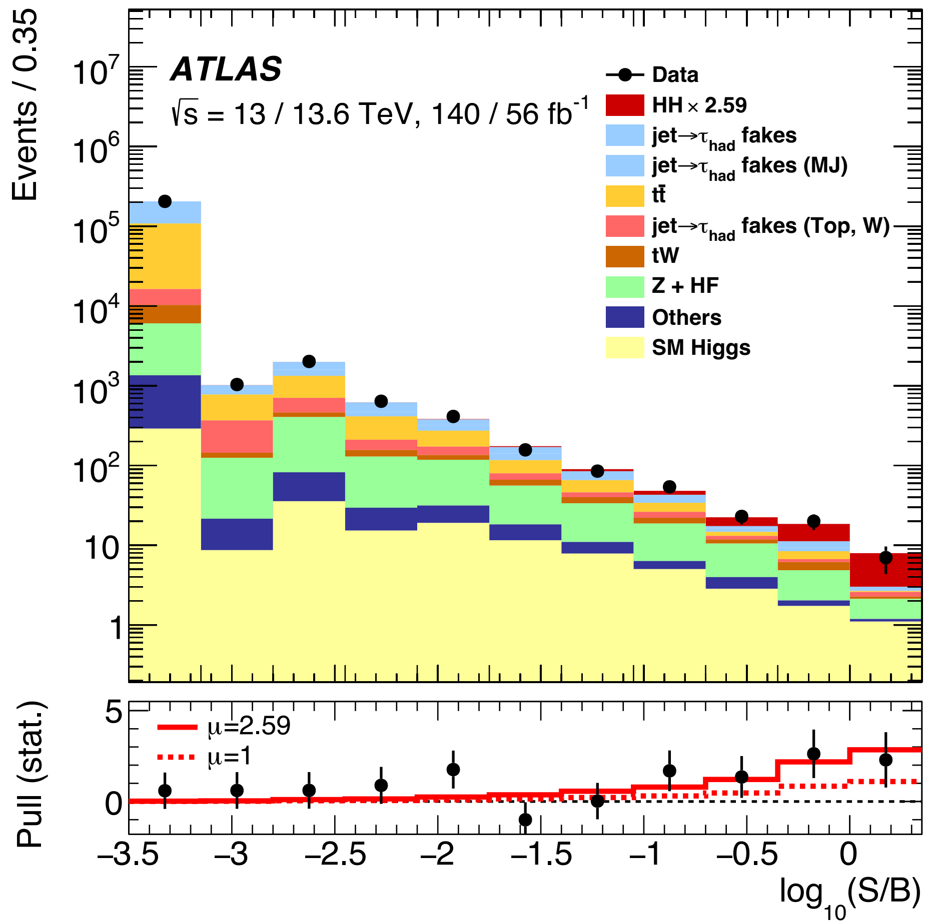
Summary

- Analysis strategy for $HH \rightarrow bb\tau\tau$
- Data-driven multijet estimation
- $\hat{\mu} = 2.6$ with 2.6 σ significance to background-only, 1.6 σ to SM



arXiv:2607.26879

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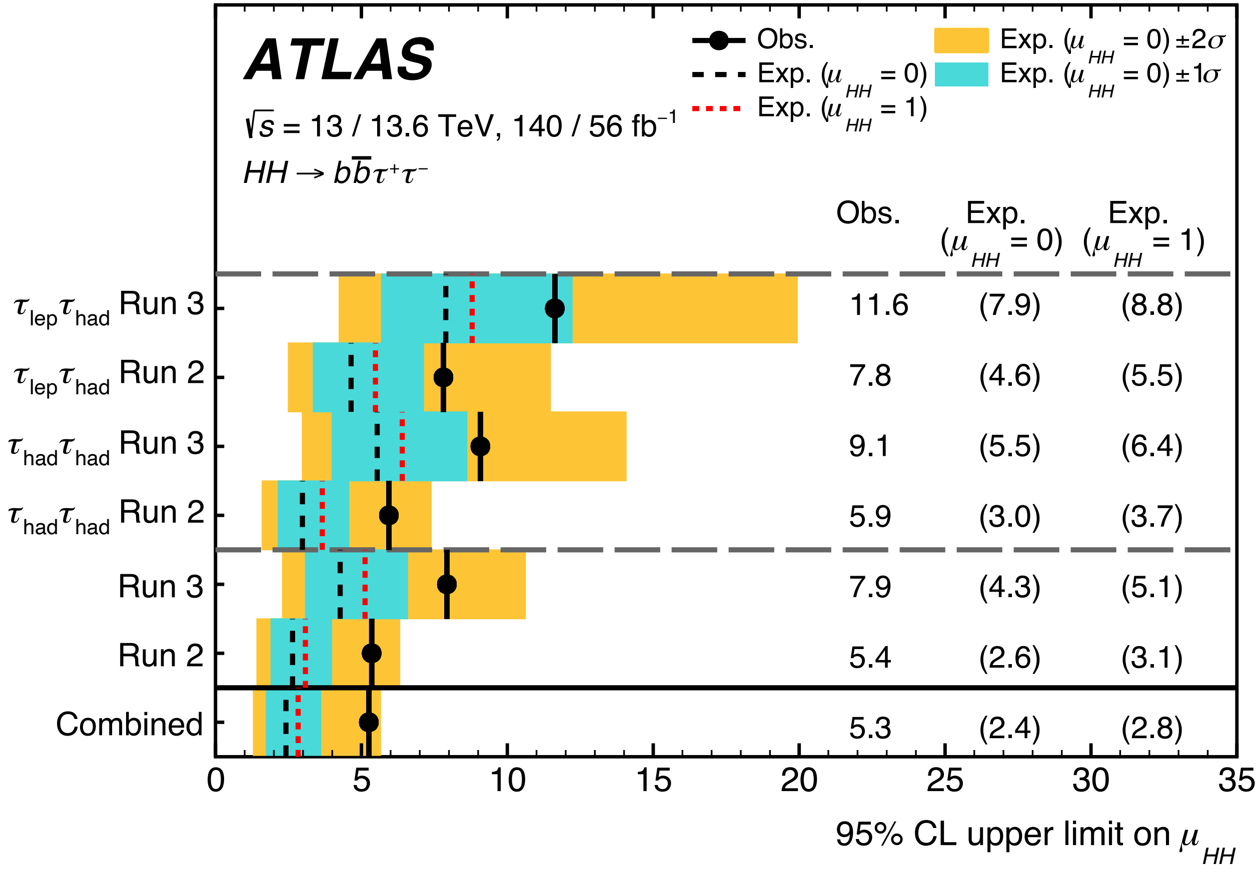
Bonus slides

Signal strength 95 % CL upper limits



arXiv:2607.26879

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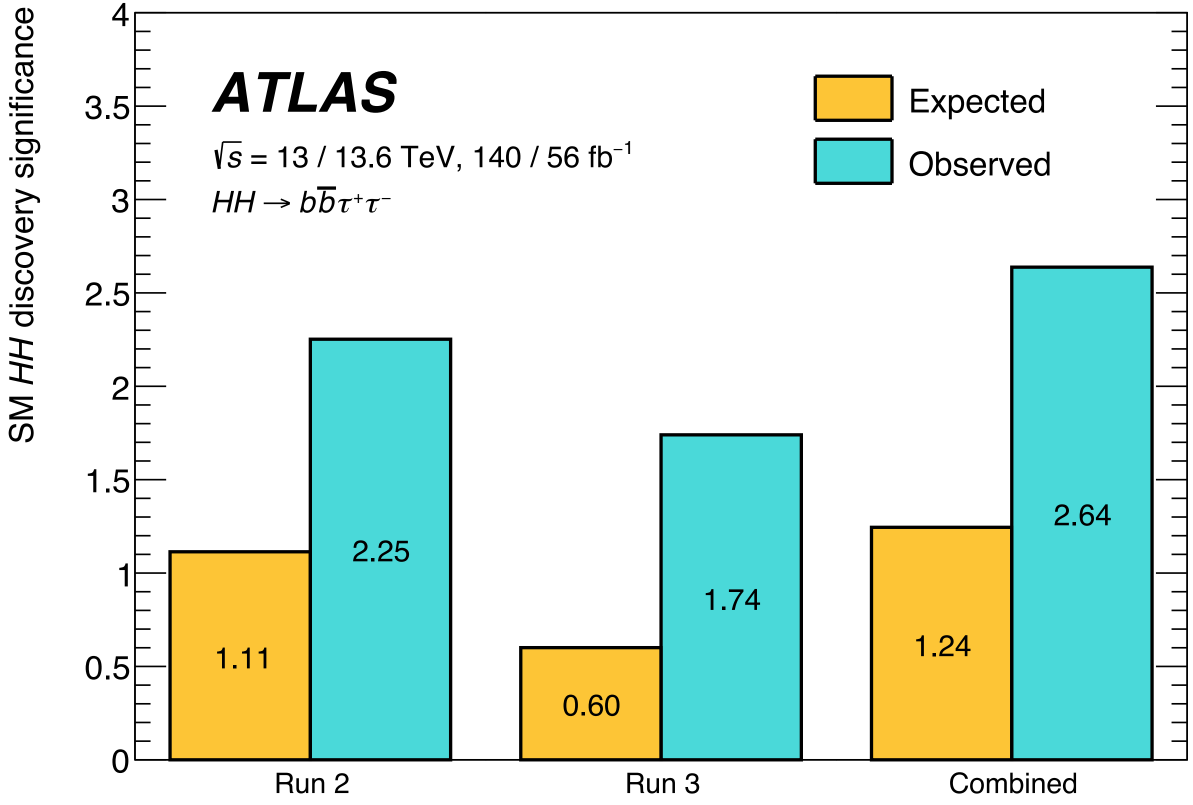
Additional Run 3 alone leads to 18 % improvement on expected significance, but actual improvement is 65 %!



arXiv:2607.26879

ATLAS+CMS
1.1 observed, 1.3 expected

Improvement with respect to arXiv: 2404.12660

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Systematic uncertainties

- Statistics-limited
- Leading systematic uncertainties are signal and background Higgs modeling

Source of uncertainty	$\sigma_{\mu_{HH}}$
Total	1.20
Statistical	0.91
Systematic	0.76
Experimental uncertainties	0.20
Electron and muon	0.01
τ_{had}	0.13
$E_{\text{T}}^{\text{miss}}$	0.03
Jet	0.14
Flavour tagging	0.04
Pile-up	0.01
Luminosity	0.03
Modelling uncertainties	0.71
Background template statistical	0.21
HH	0.54
ZH	0.02
ZZ	<0.01
Other SM Higgs	0.25
Z+jets	0.07
tW	0.21
Top	0.12
jet $\rightarrow \tau_{\text{had}}$ fakes	0.07
Others	0.01

arXiv:2607.26879

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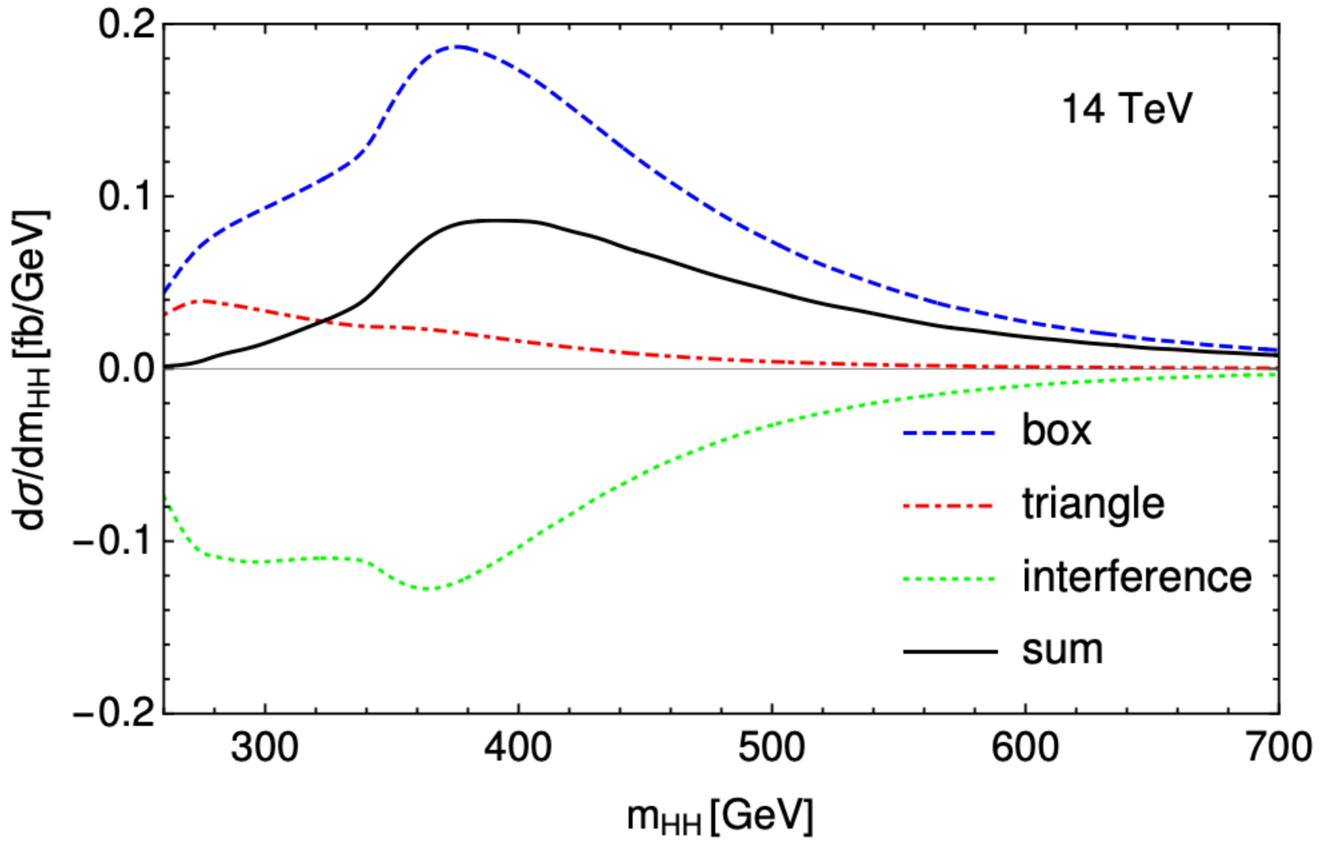
Matrix elements squared for m_{HH}



arXiv:1910.00012

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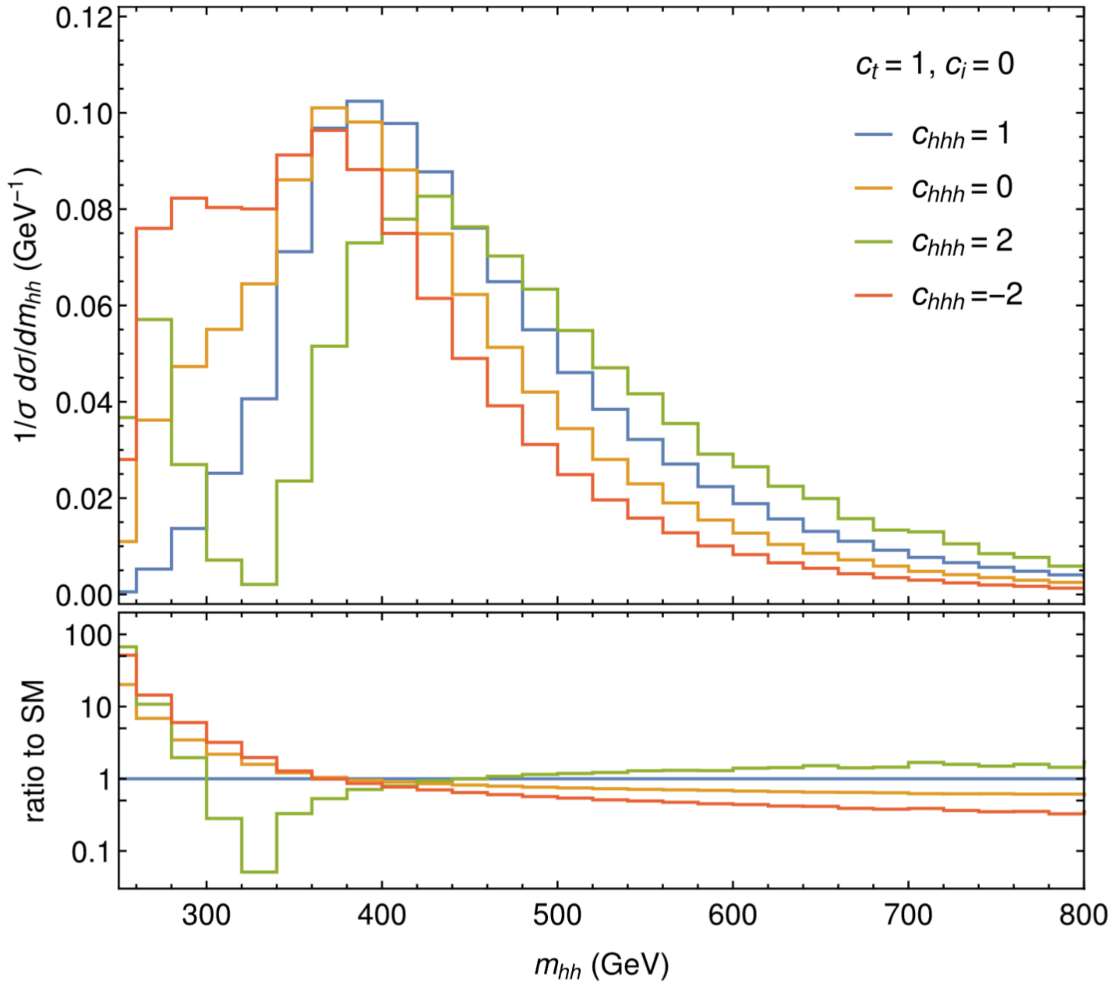
Thus, the actual value of κ_λ impacts these kinematics, too …



arXiv:1910.00012

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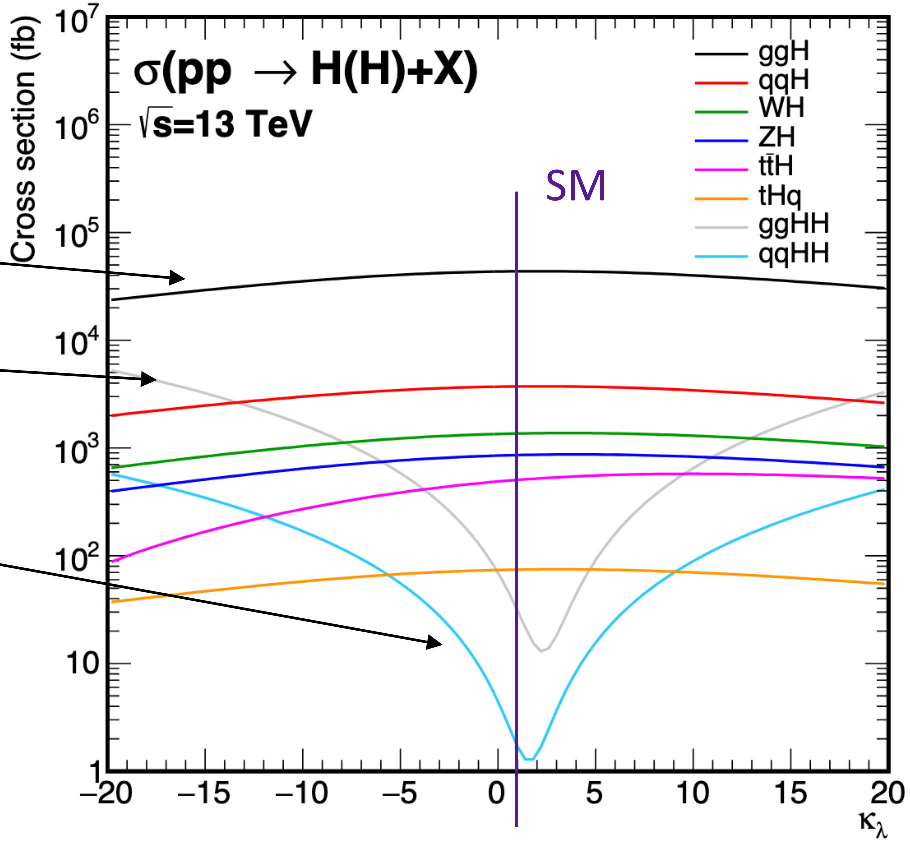
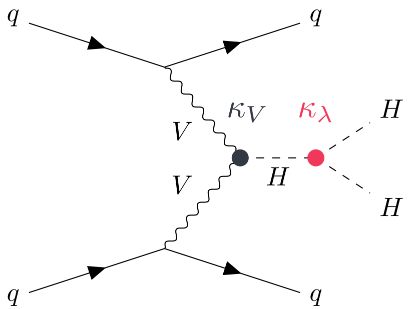
… as well as the HH production cross-sections

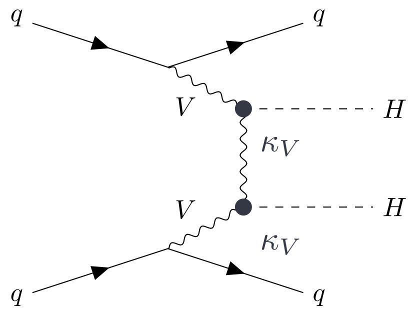
ggF single Higgs

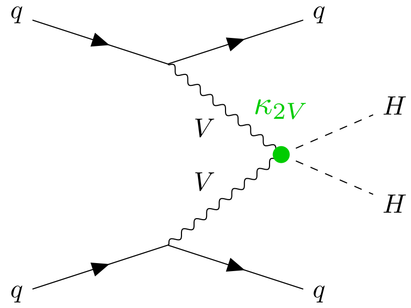
ggF di-Higgs

VBF di-Higgs









LHCWG-2022-002

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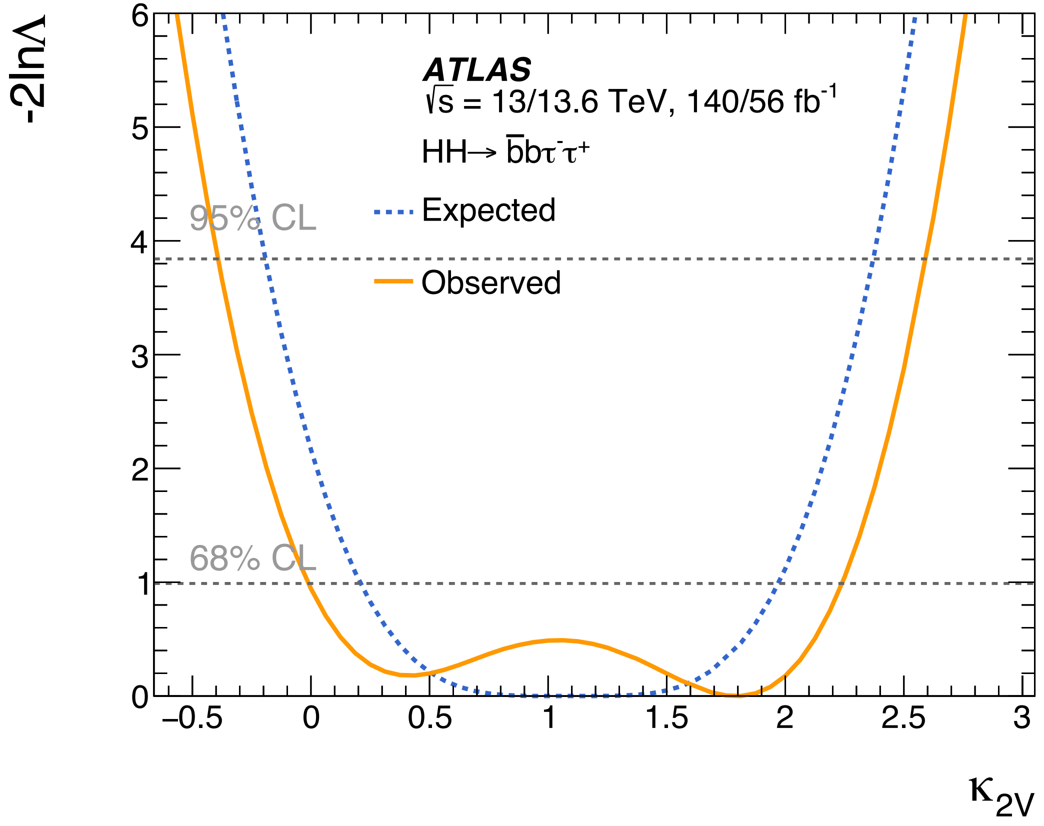
The same procedure is applied to get the confidence interval of κ_{2V} while assuming $\kappa_\lambda = 1$



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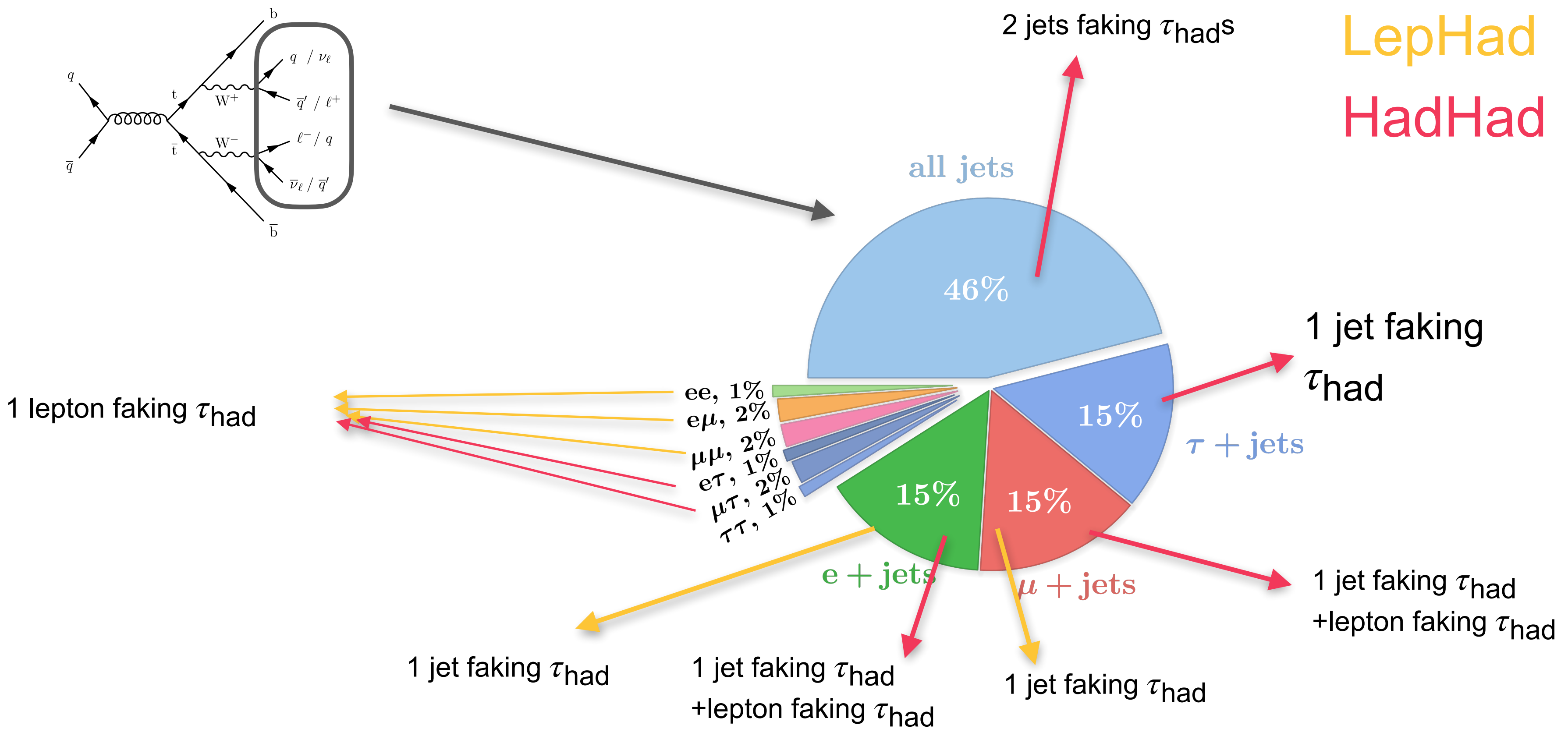
But, the dominant source of background in both channels is $t\bar{t}$



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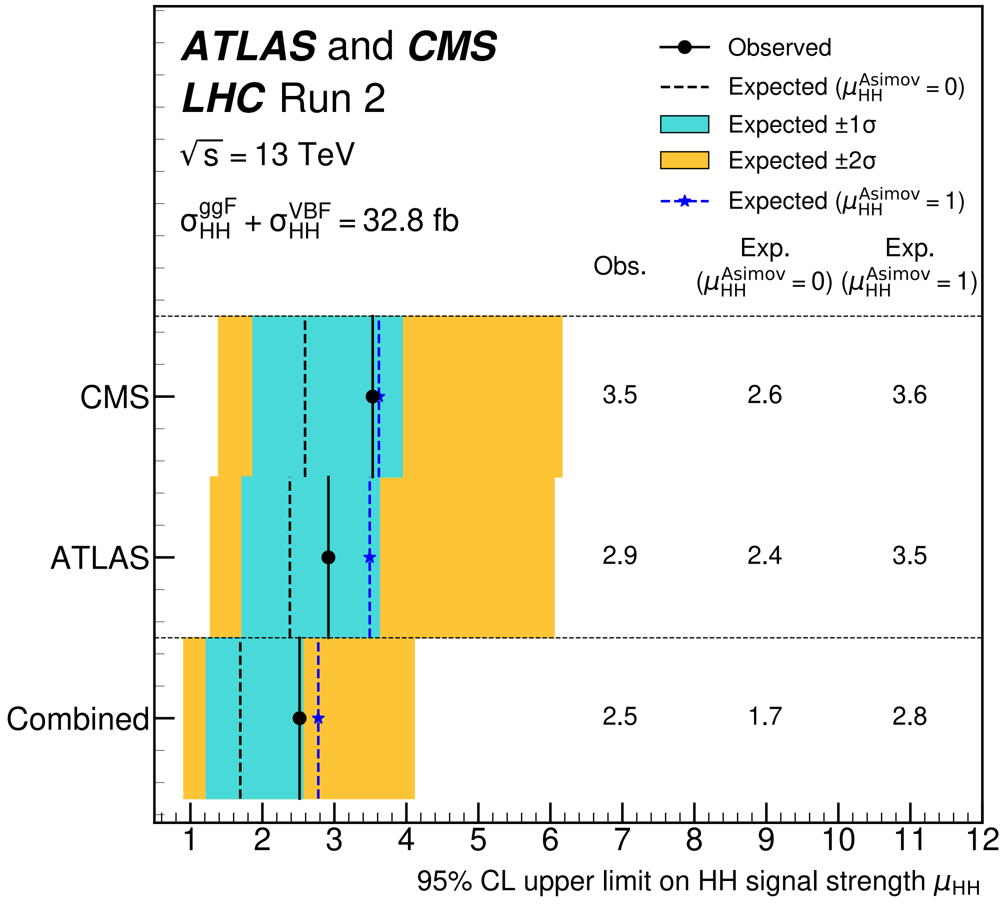
And the most sensitive result is currently achieved by the ATLAS+CMS Run 2 combination



arXiv:2602.23991

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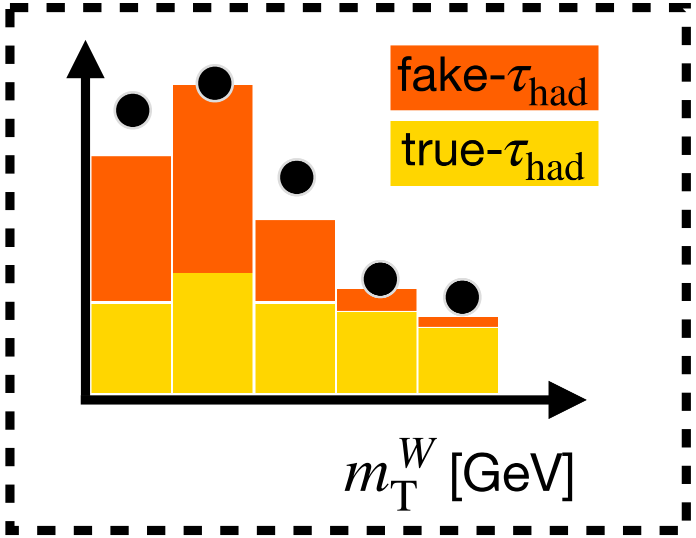
Scale factors are measured in a variable sensitive to fake-τ_{had} in a CR to improve $t\bar{t}$ modeling with jets faking τ_{had} candidates

$bb\tau^{\pm}_{\text{had}}\mu^{\mp}$ CR



Fit

Scale Factor for this bin

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MVA score rebinding

- MVA score bins are merged from high to low until these conditions are fulfilled:
  - $10\frac{n_s}{N_s} + 5\frac{n_b}{N_b} > 1$ (limits number of bins)
  - Low MC stat uncertainty < 20 % (reasonable background modeling)
  - At least 3 expected background events (very likely we observe a data event)

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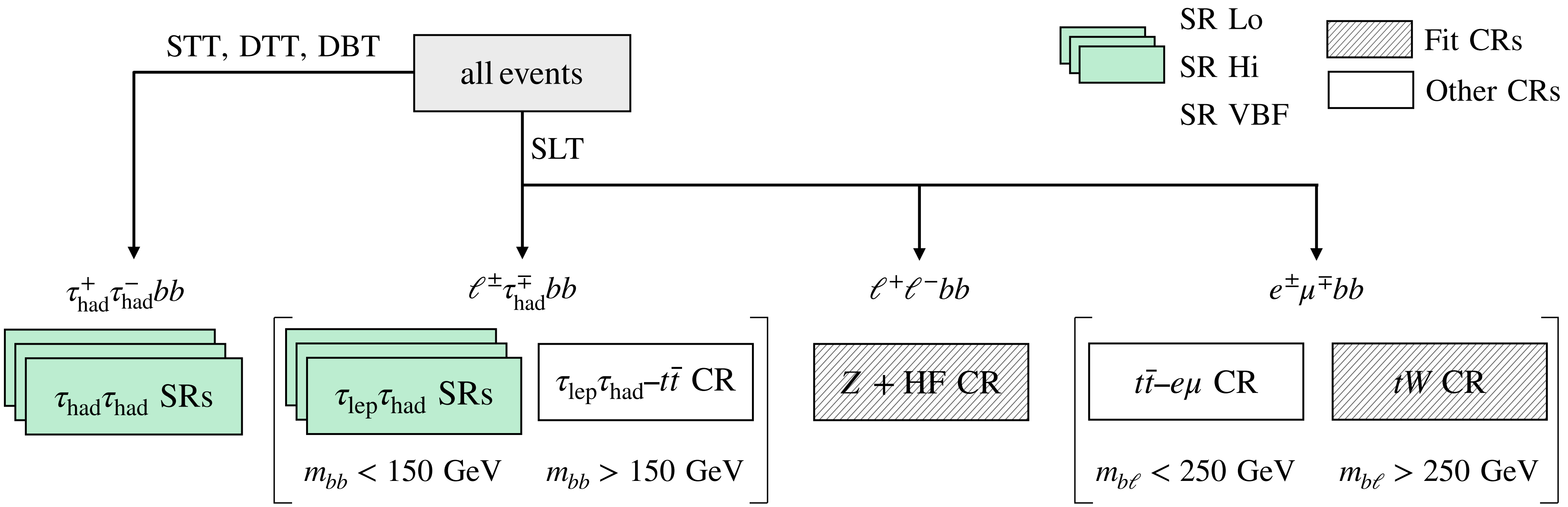
Analysis region overview



arXiv:2607.26879

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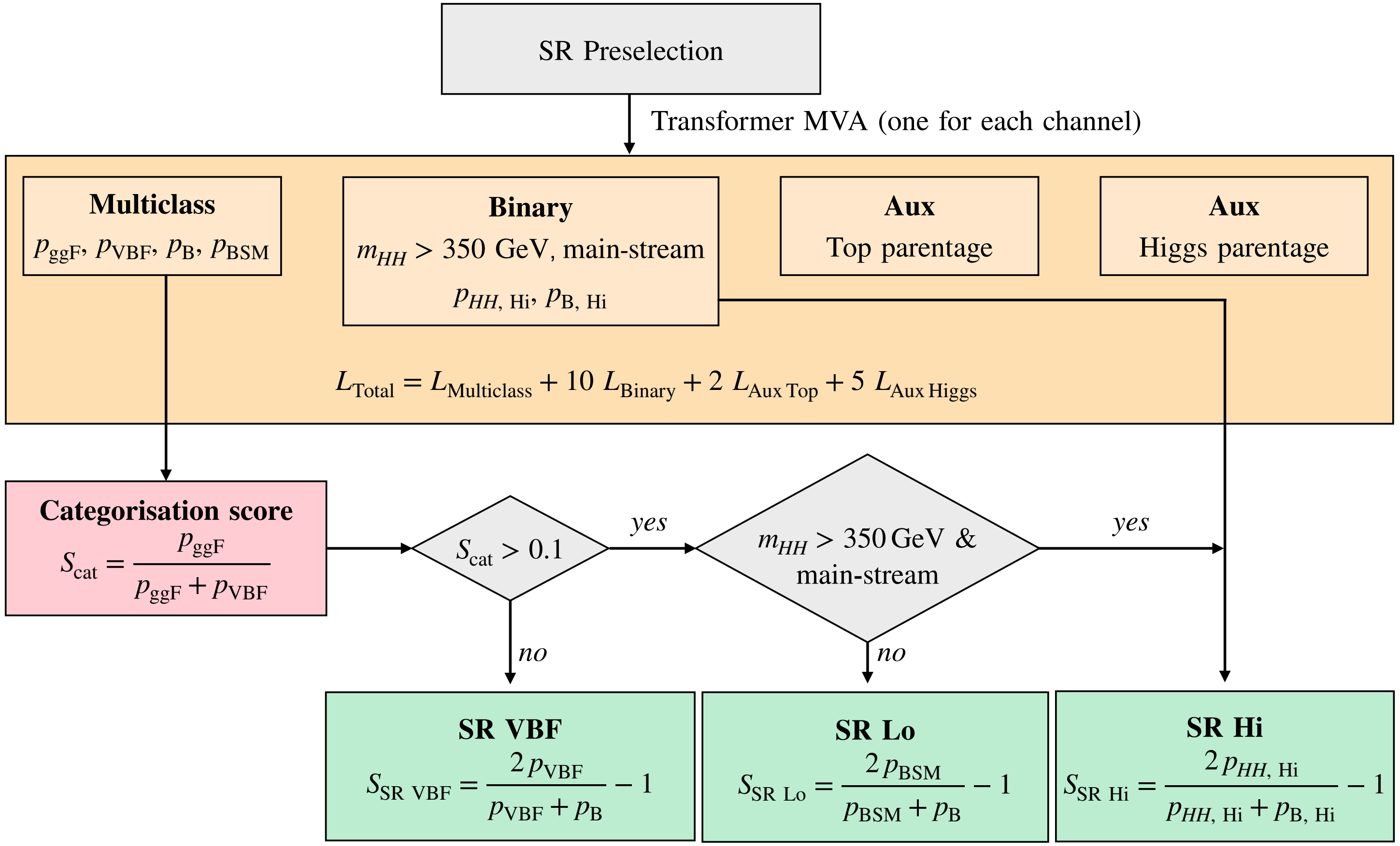
Full MVA transformer



arXiv:2607.26879

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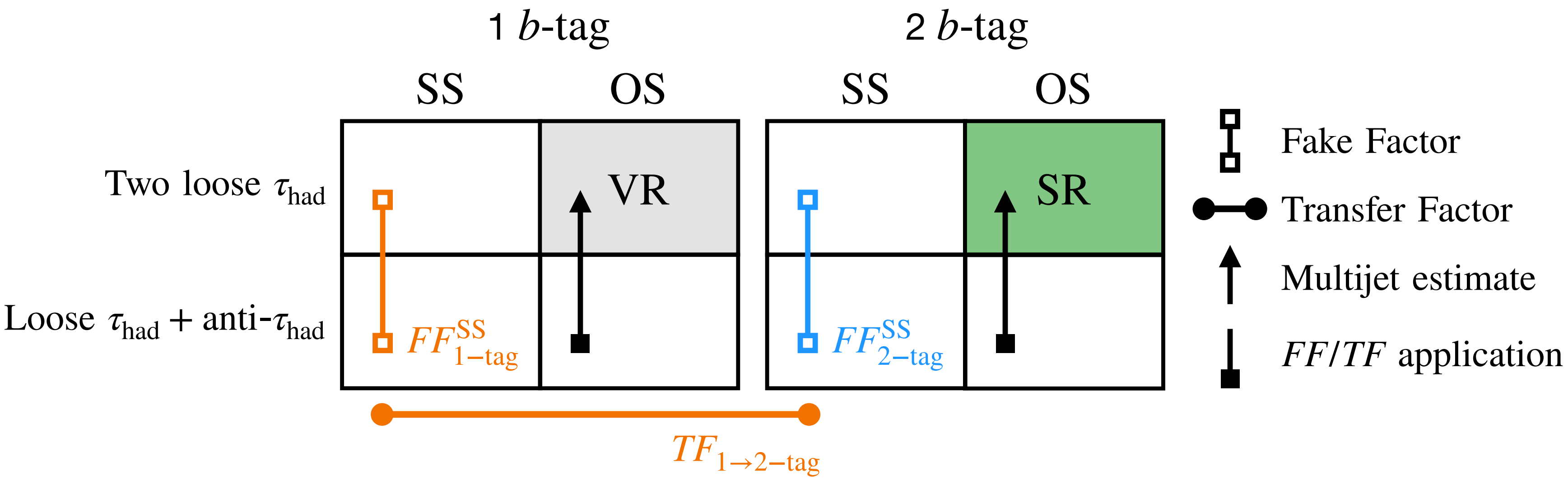
Detailed FF schematic



STTD/DTT : $FF^{\text{SS, STT/DTT}}_{1-\text{tag}} \cdot TF_{1\to2-\text{tag}} \cdot \{e^{\text{Data}-\text{MC}}_{2-\text{tag, OS}-\text{AntiID, STT/DTT}, i}\}$

DBT : $FF^{\text{SS, DBT}}_{2-\text{tag}} \cdot \{e^{\text{Data}-\text{MC}}_{2-\text{tag, OS}-\text{AntiID, DBT}, i}\}$

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