

Nikhef



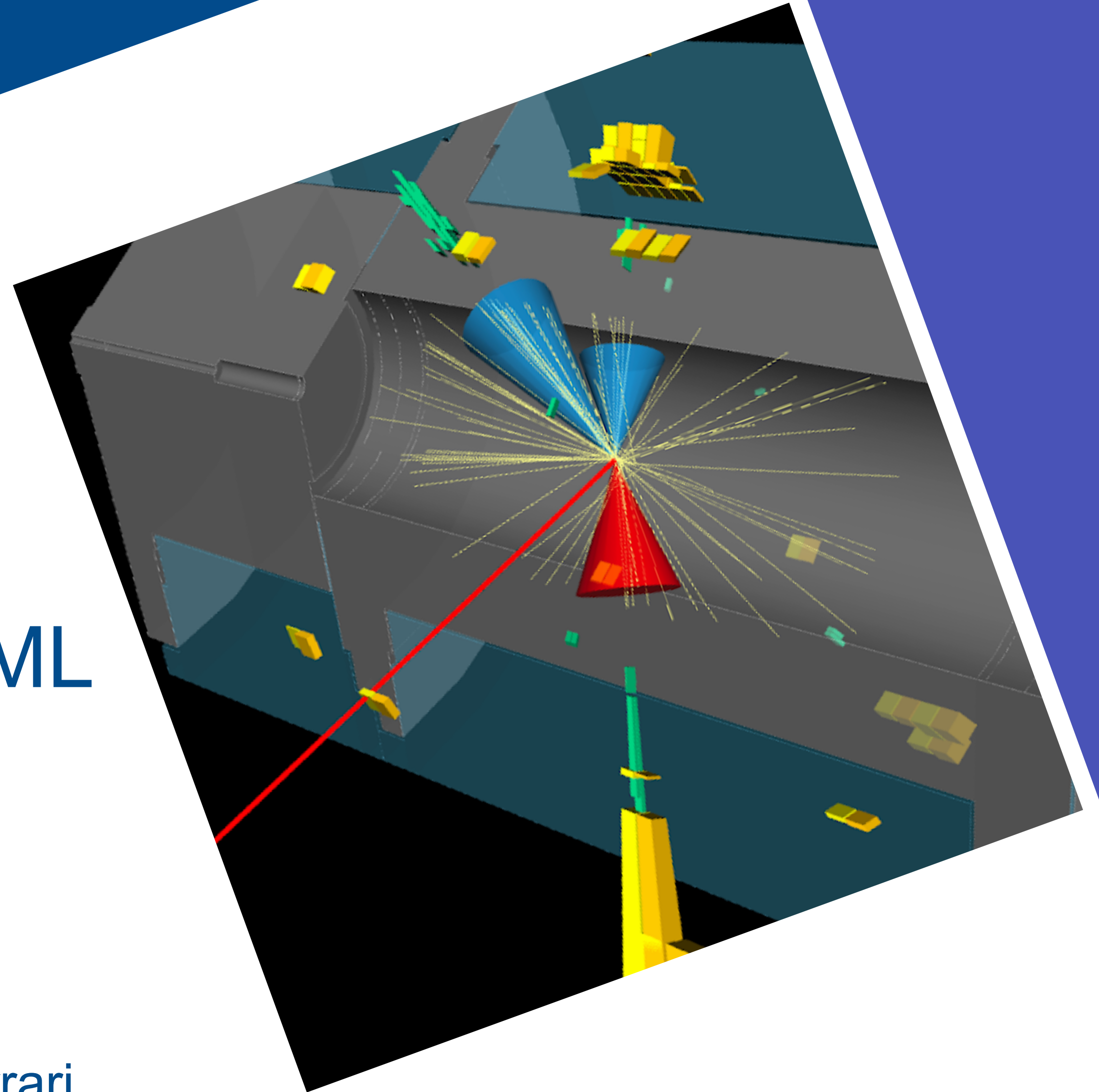
ATLAS
EXPERIMENT

UNIVERSITY
OF TWENTE.

$H(bb)H(\tau\tau)$ & Advanced ML At ATLAS

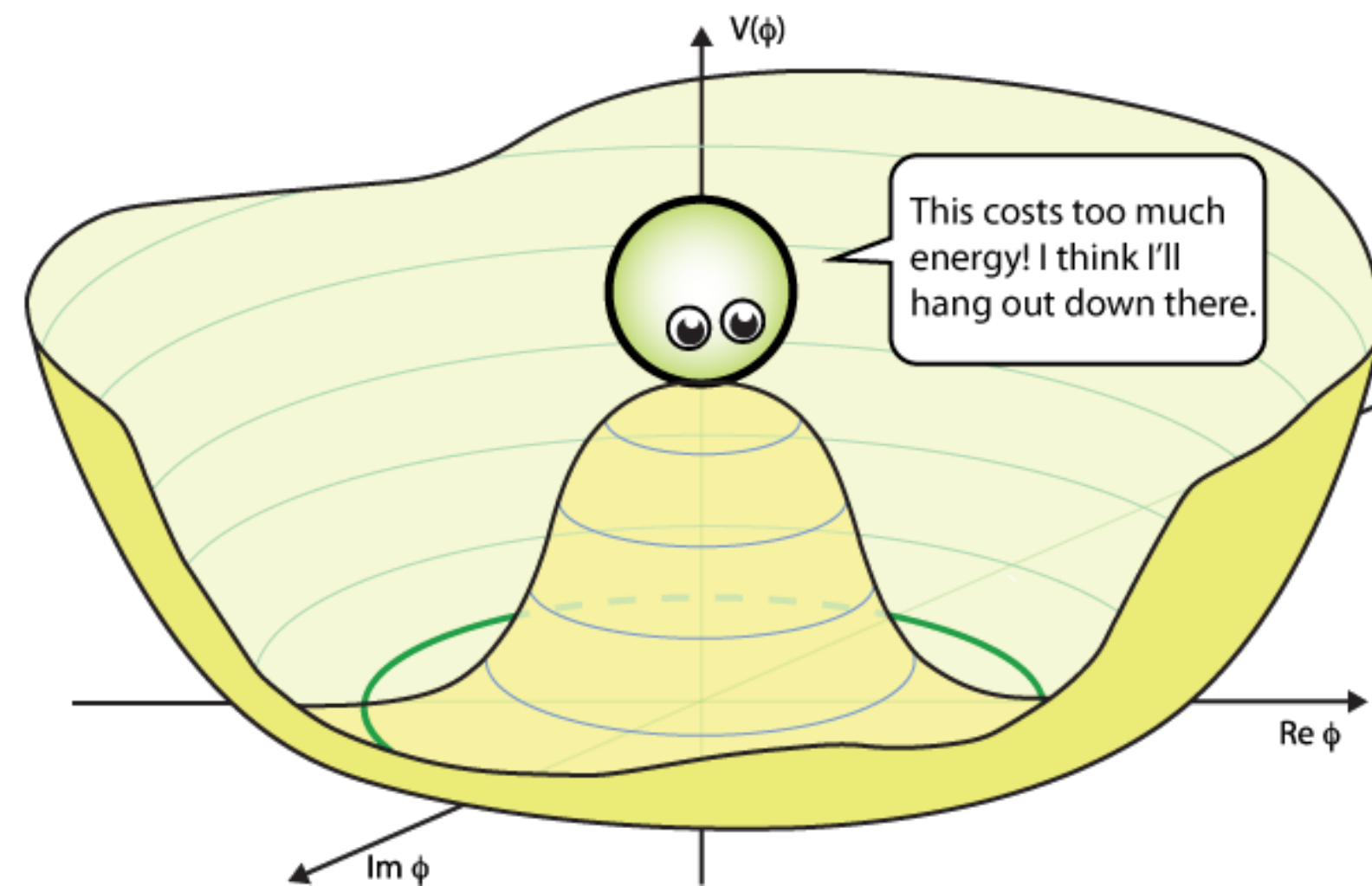
Osama Karkout

Supervised by Tristan du Pree and Pamela Ferrari



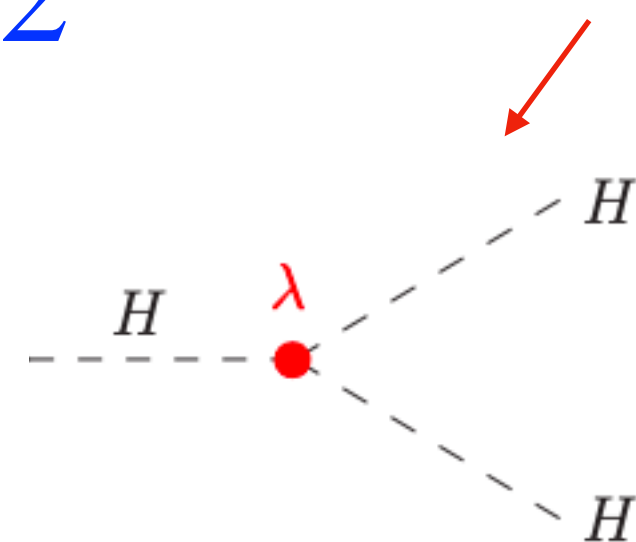
When lights are off, Higgs is on!

Vacuum expectation value = 246 GeV. Why not 0 like everything else?



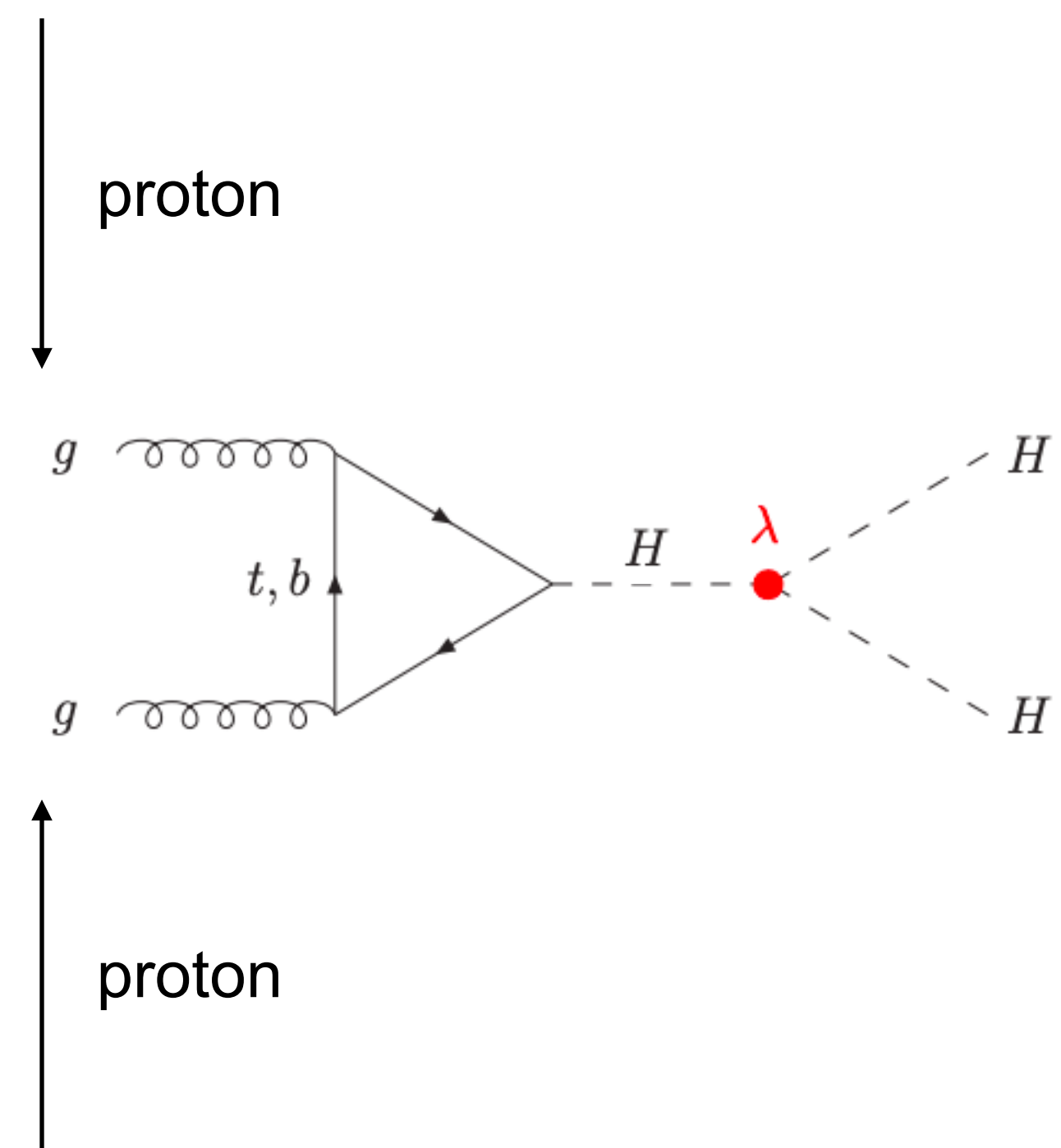
Explanation:
Higgs potential in SM = Simplest Model
probably wrong or incomplete
But falsifiable!

$$V(H) = \frac{1}{2}m^2H^2 + \underbrace{\lambda v H^3 + \lambda H^4}_{\text{red}}$$

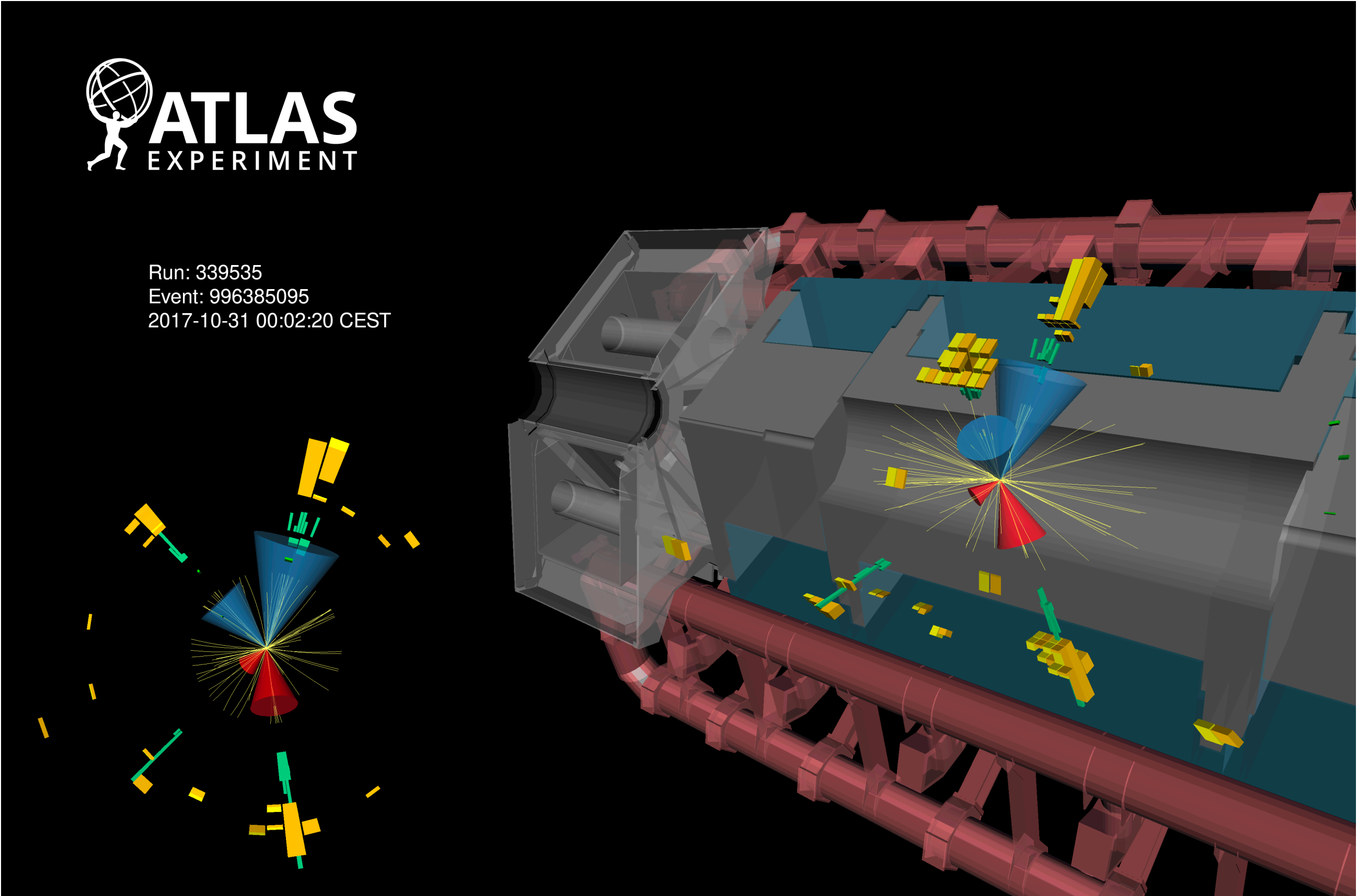


$\lambda \neq 0?$

Search for one Higgs decaying to two ($H \rightarrow HH$)

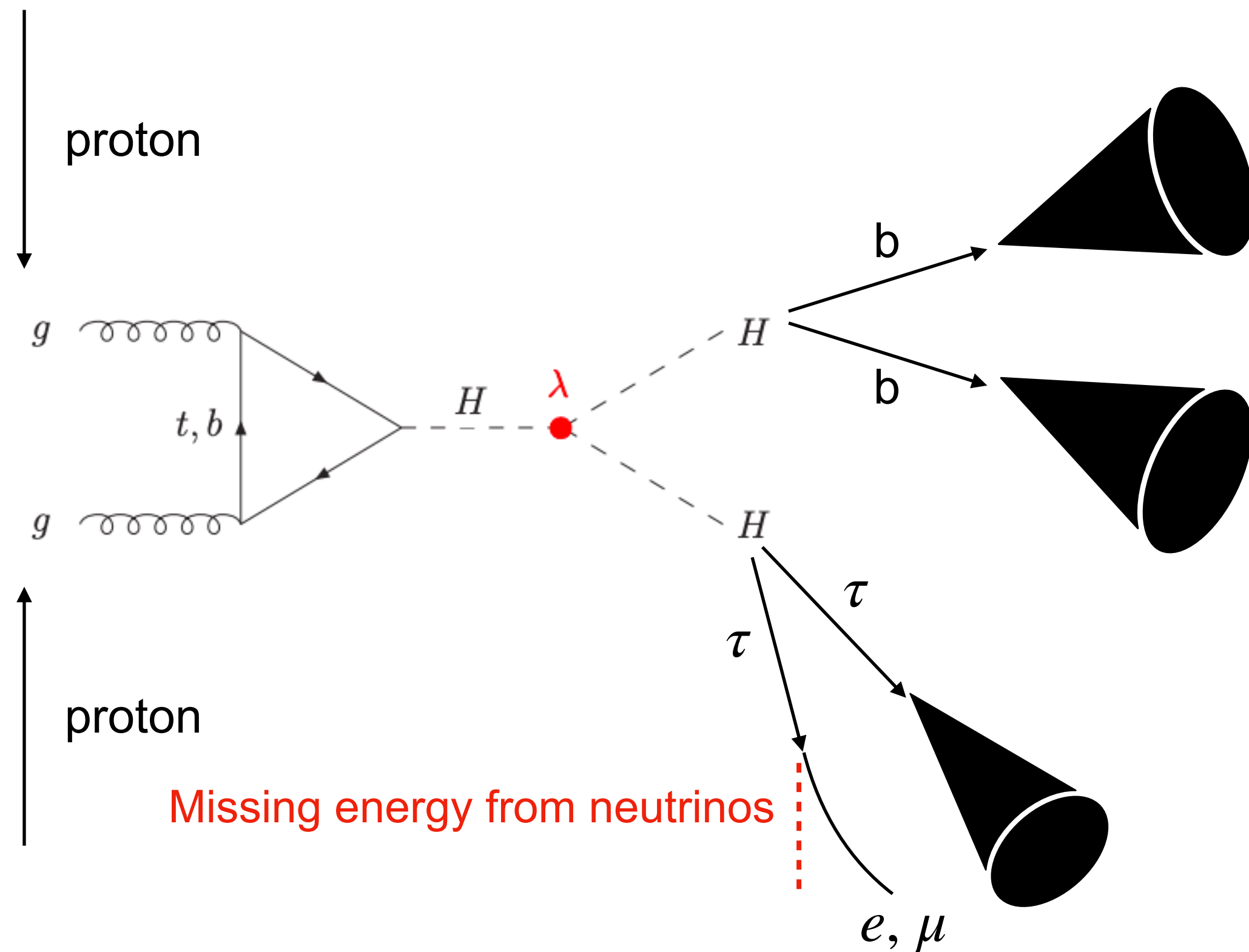


ATLAS run-2 data: predict \sim 5000 events



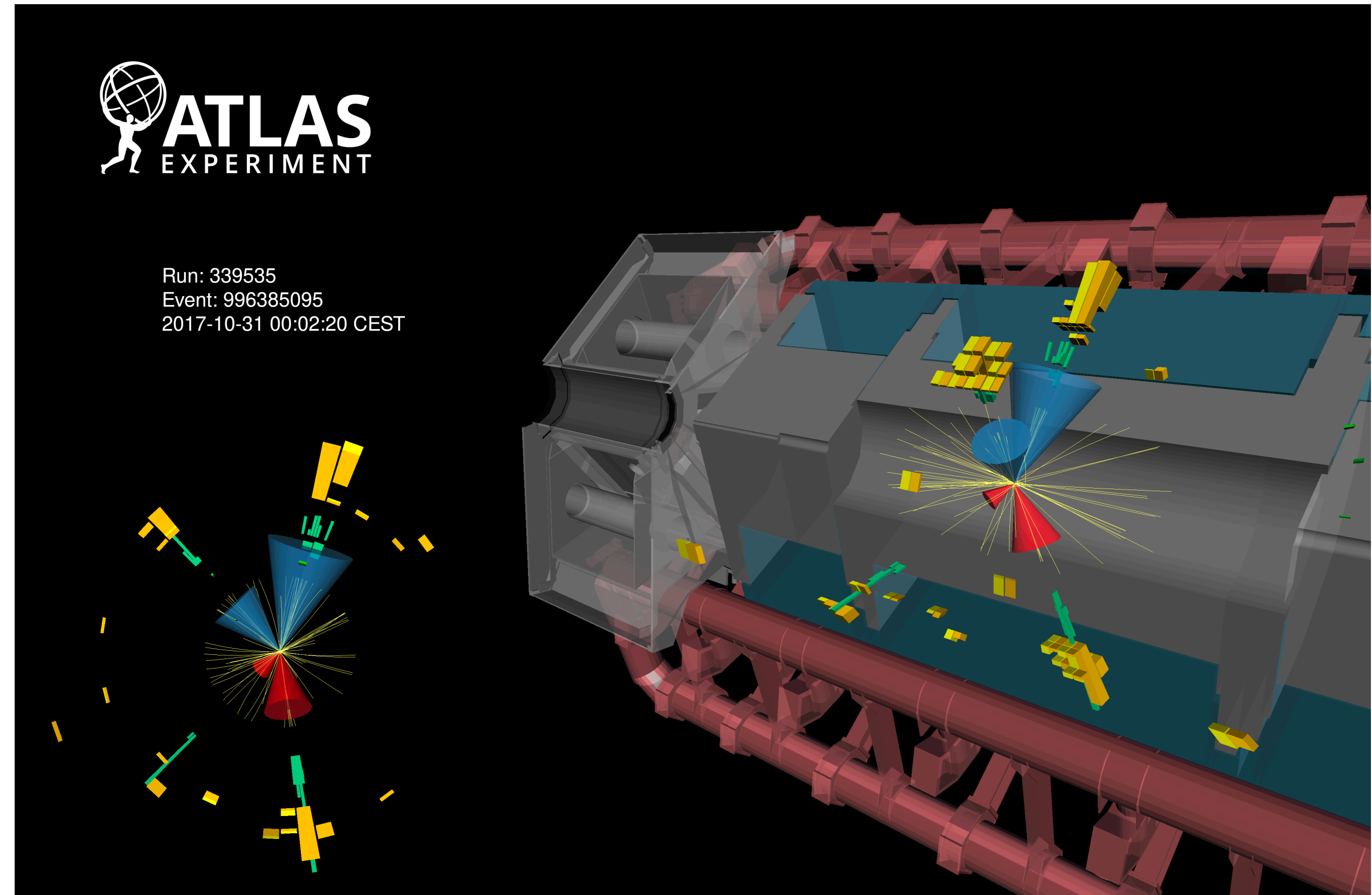
Can do statistics $\wedge_ \wedge$

$H \rightarrow HH \rightarrow bb\tau\tau$ event



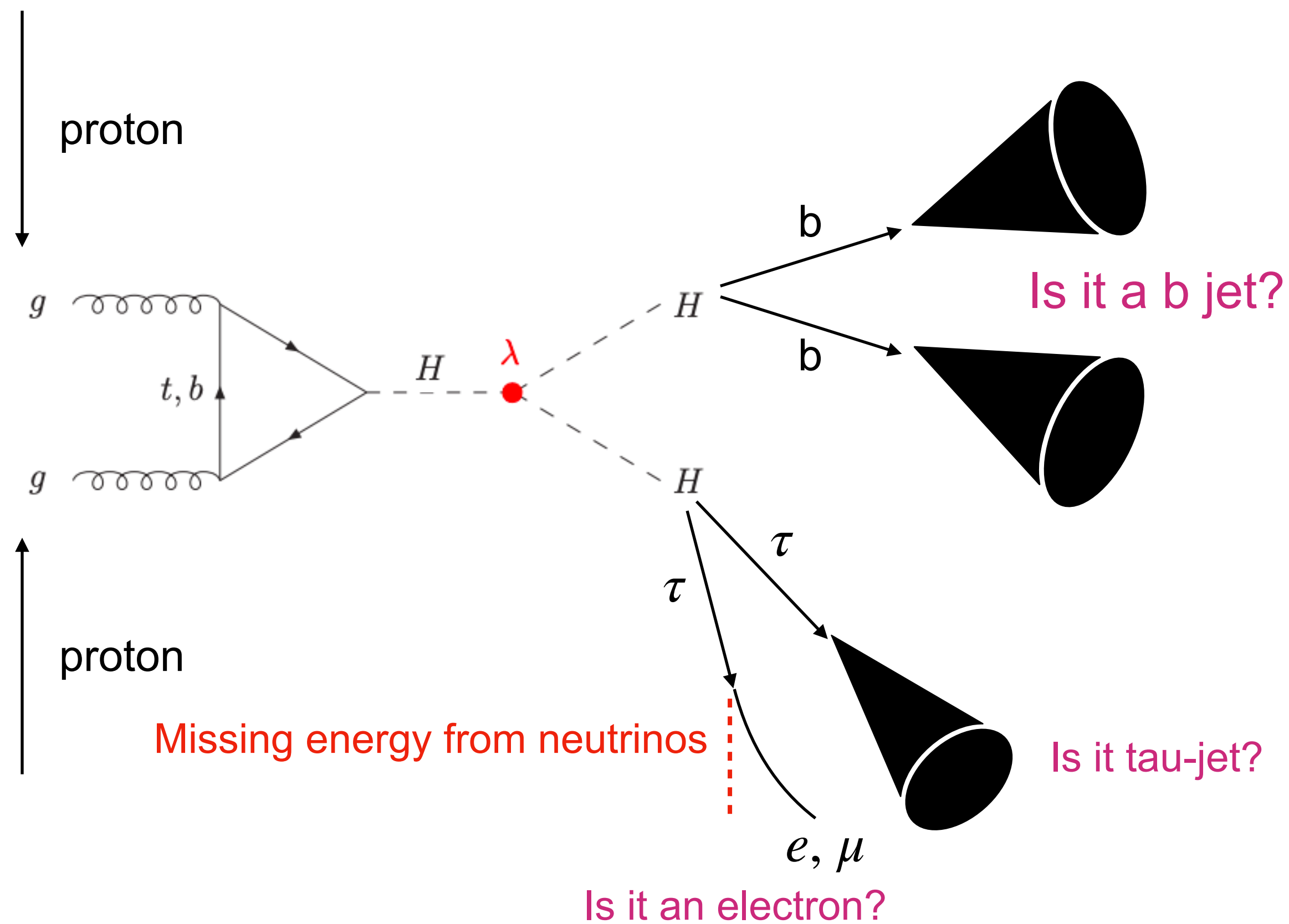
$$BR(HH \rightarrow bb\tau\tau) \approx 7 \%$$

~ 300 events

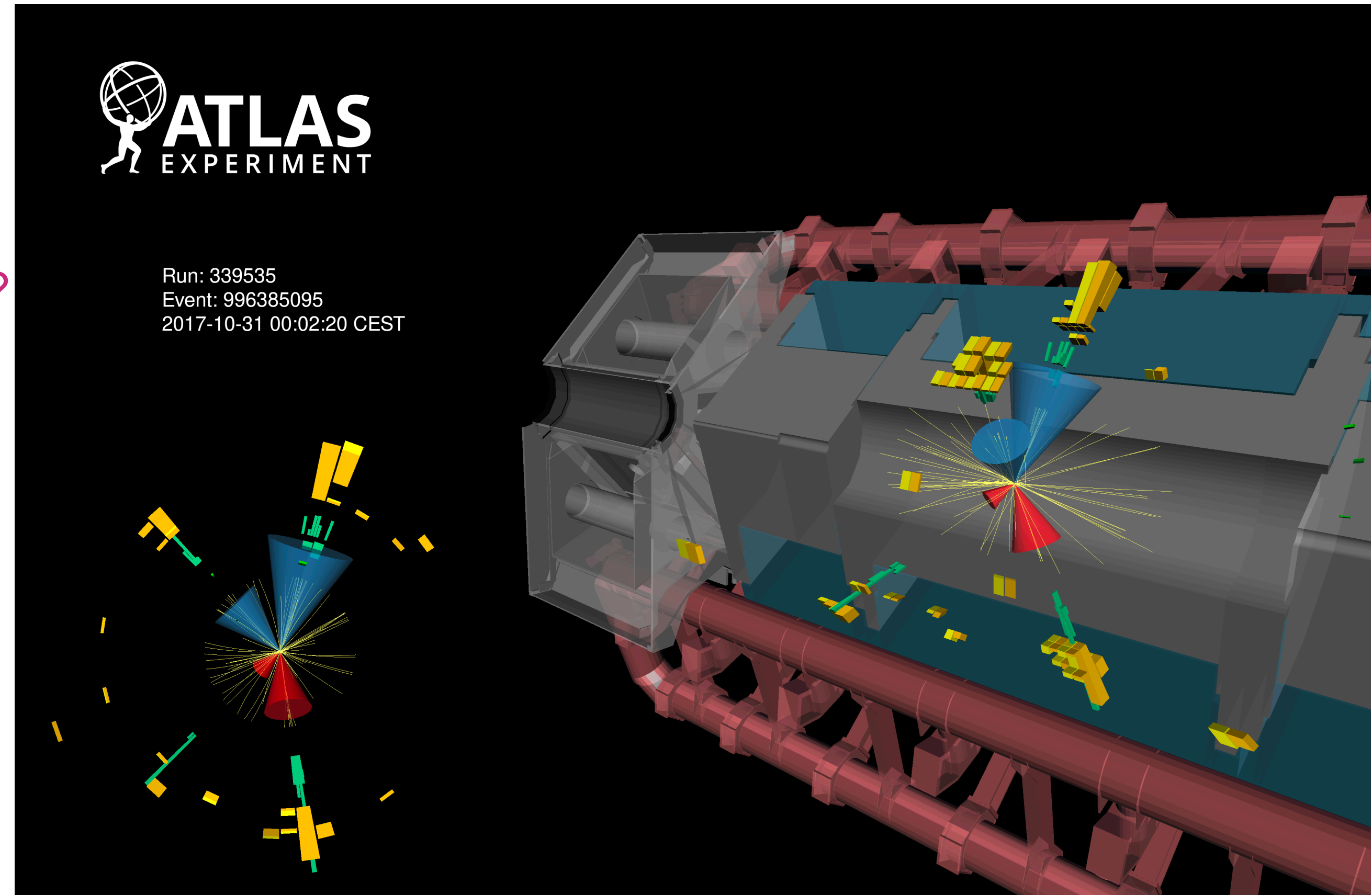


Can do some statistics...

$HH \rightarrow bb\tau\tau$ objects



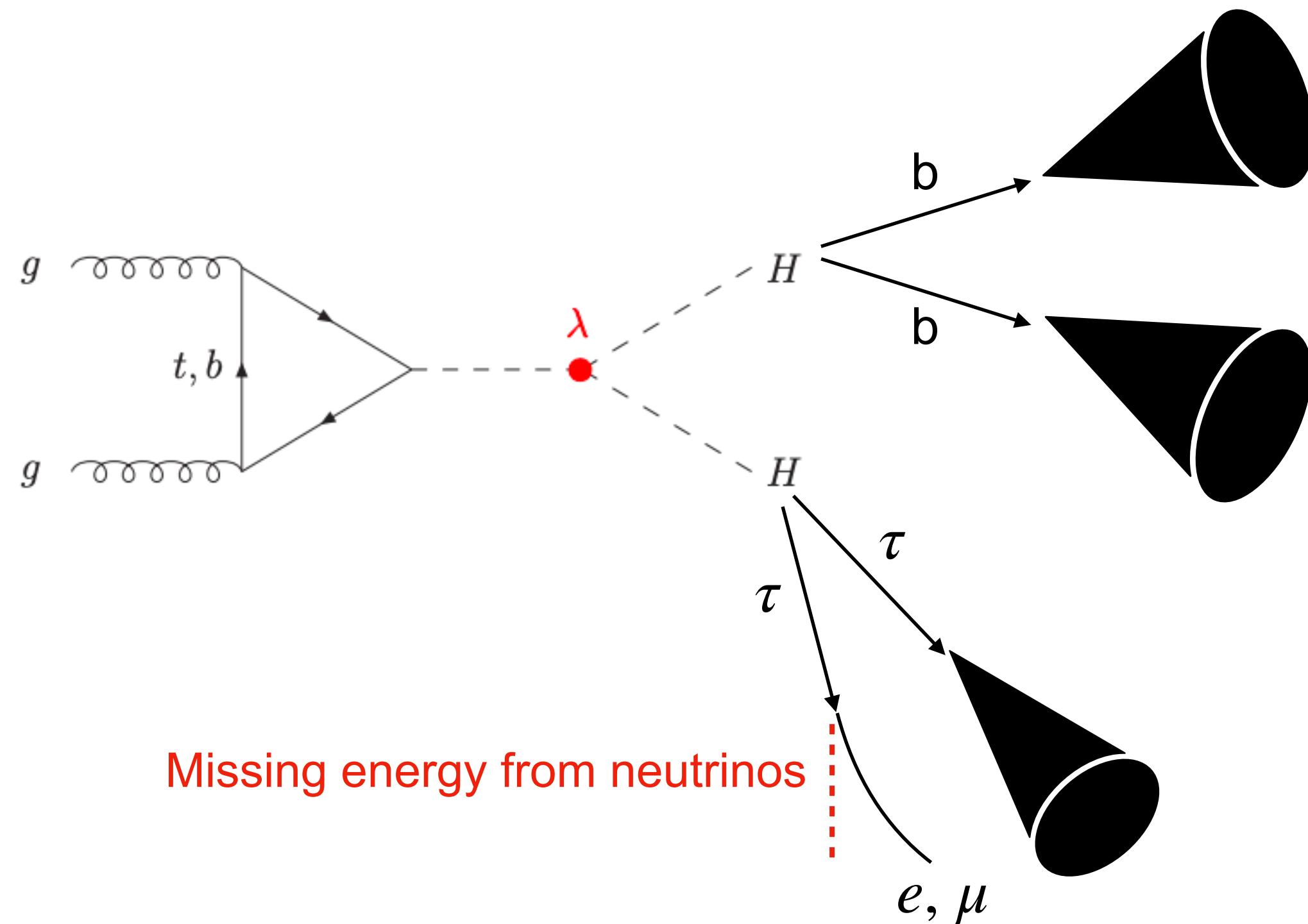
+ quality cuts
+ Trigger



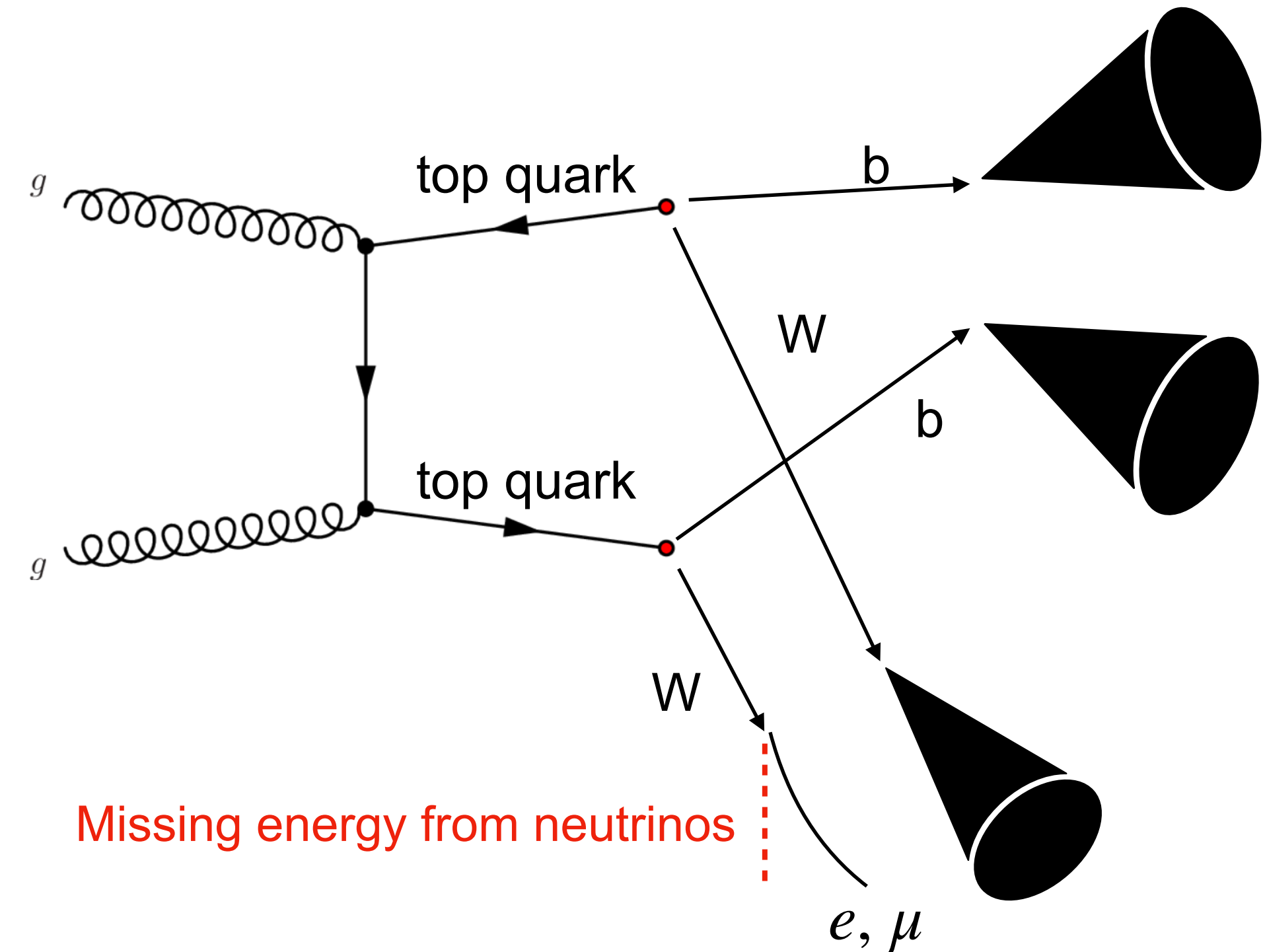
~ 10 events :(

No background? :.)

$HH \rightarrow bb\tau\tau$ signal VS background



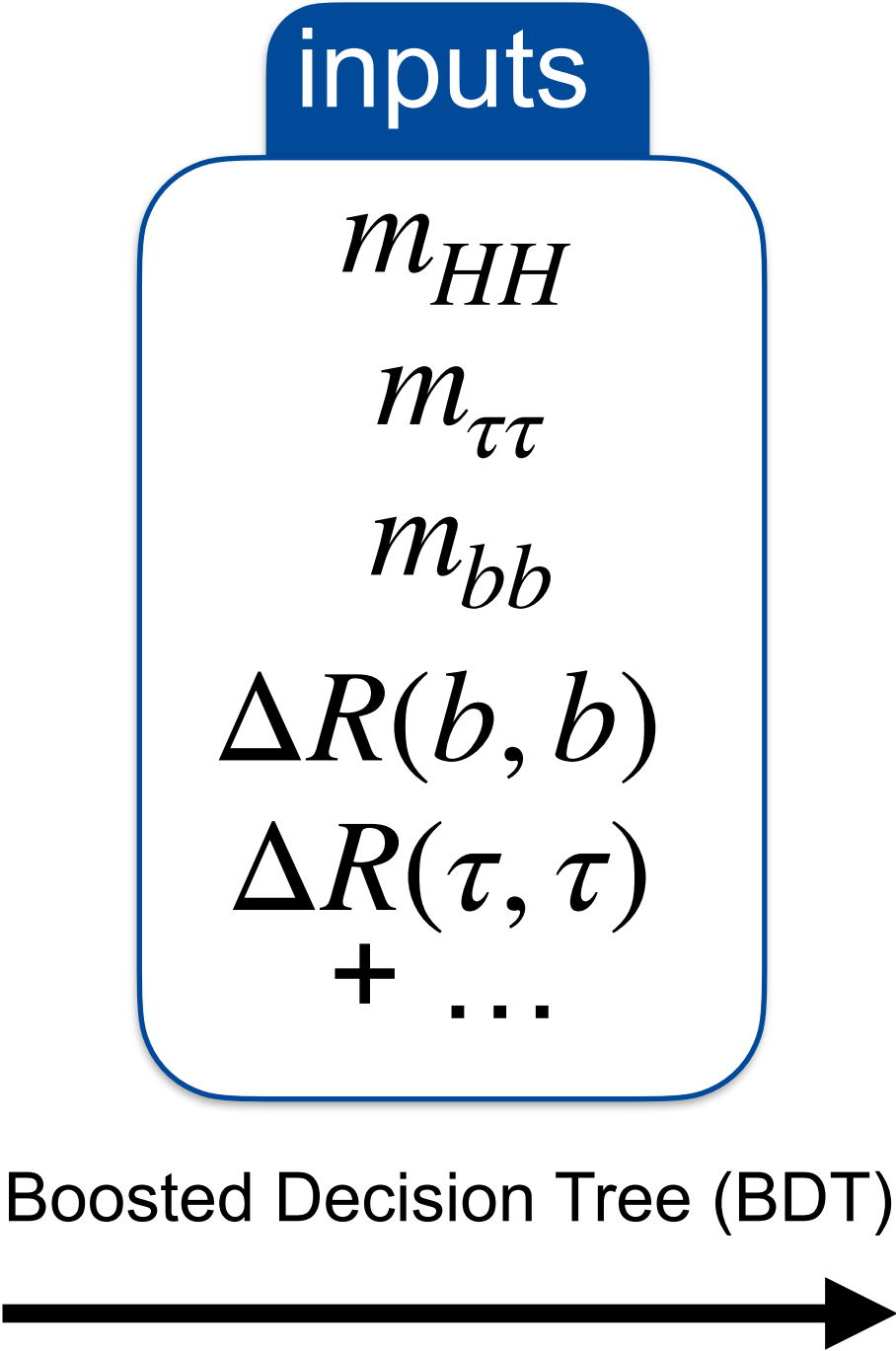
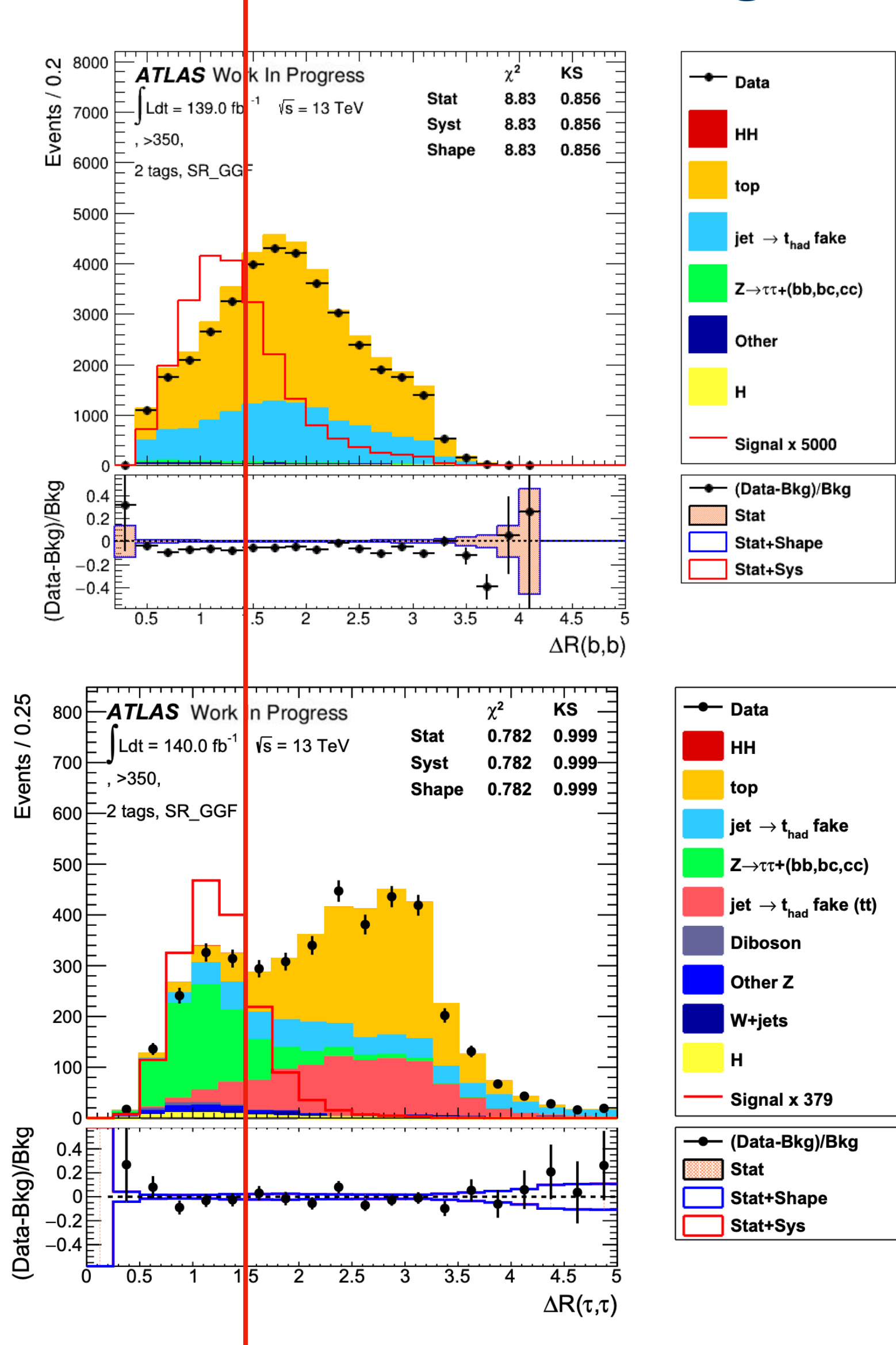
~ 10 signal events



Drowning in background $O(10^5)$

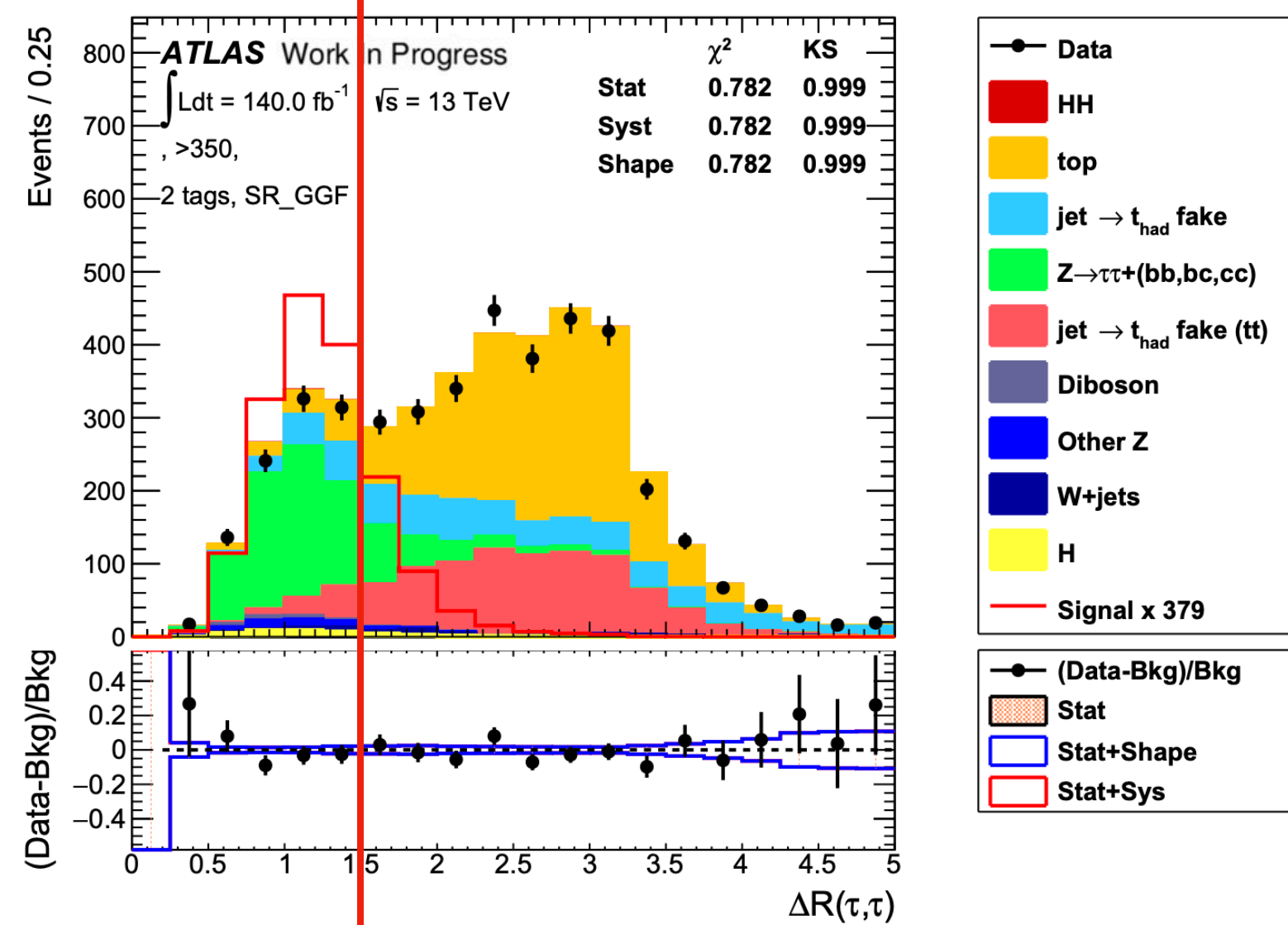
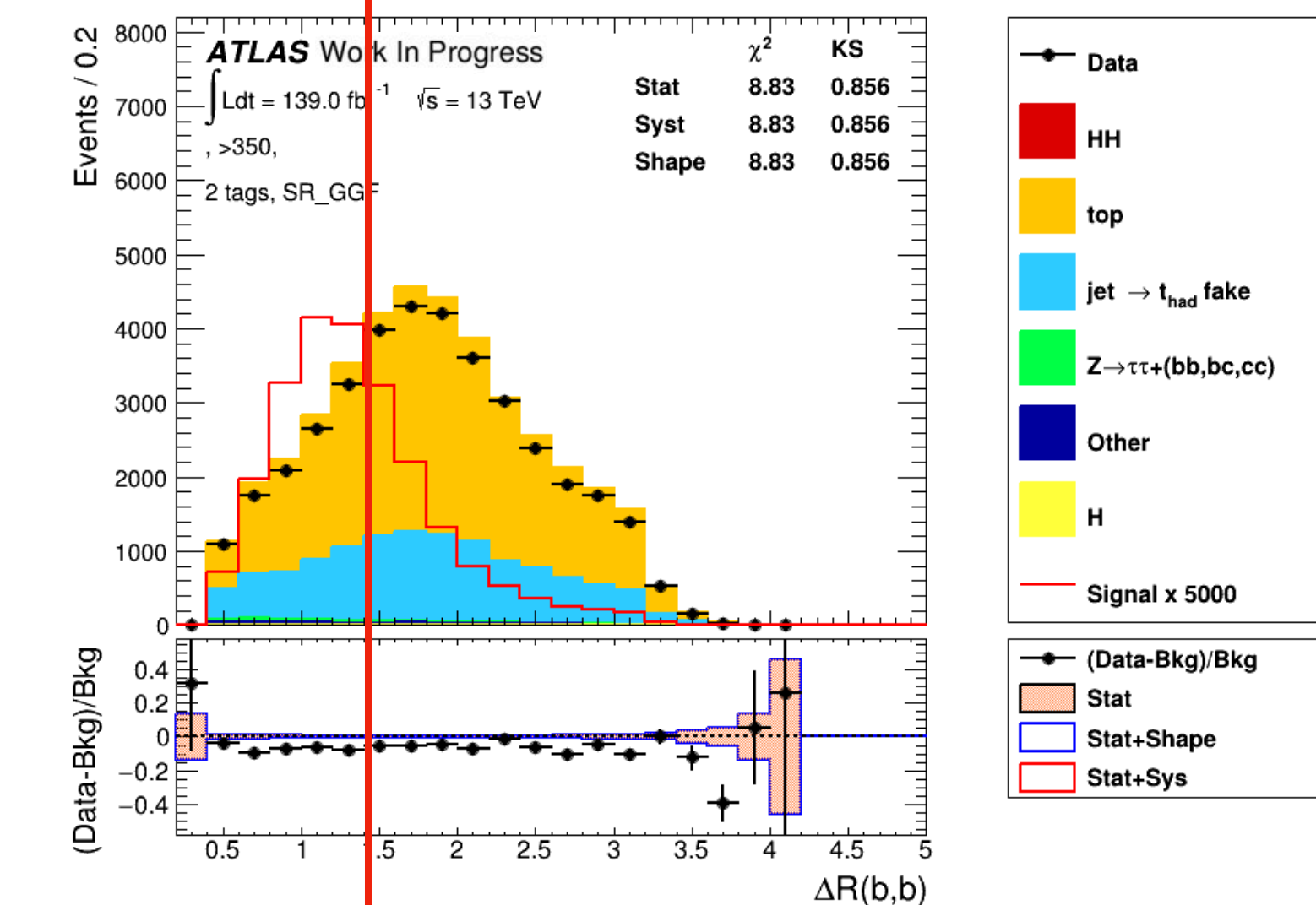
How can you separate them?

$HH \rightarrow bb\tau\tau$ signal VS background

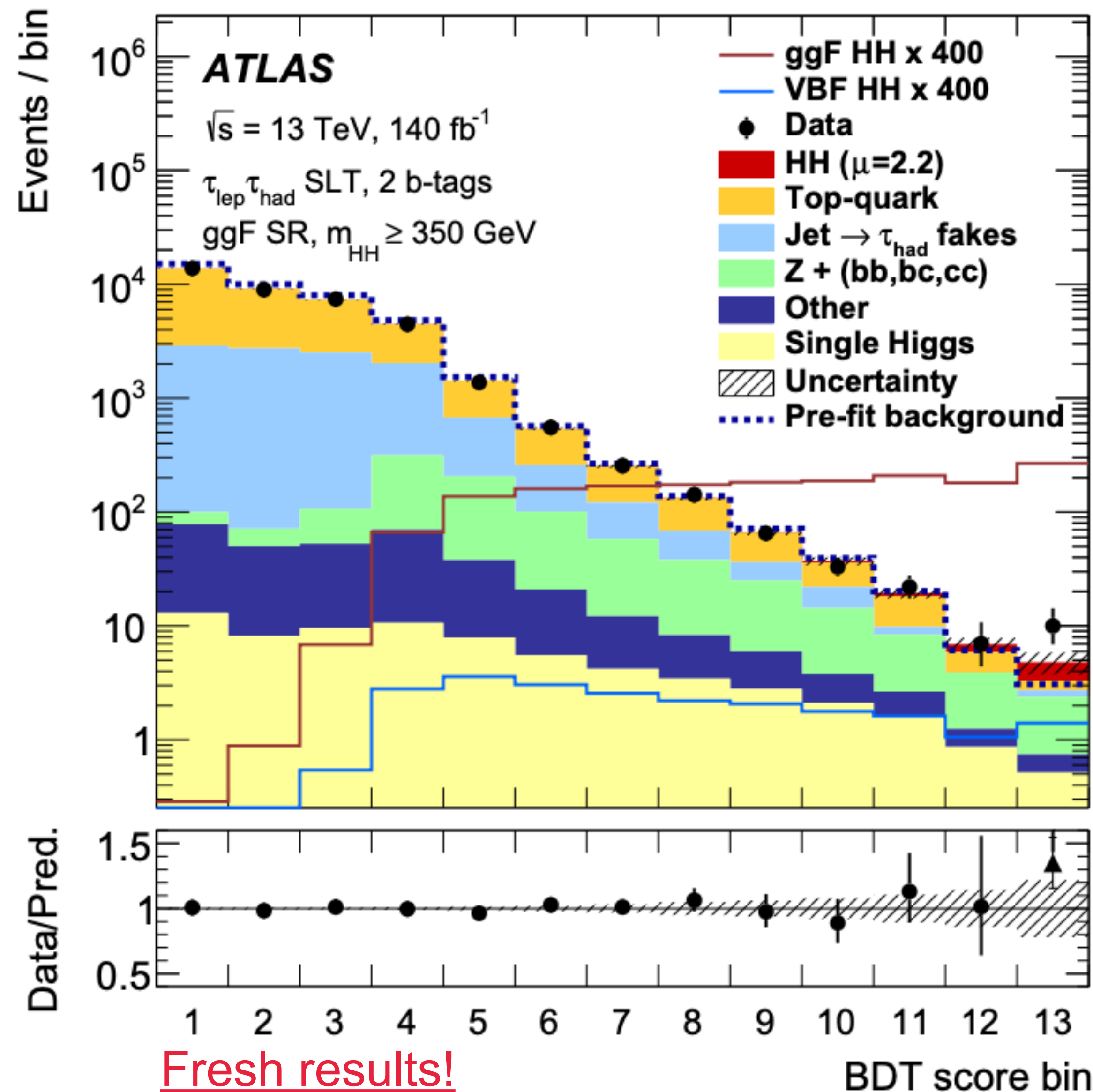


$HH \rightarrow bb\tau\tau$ signal VS background

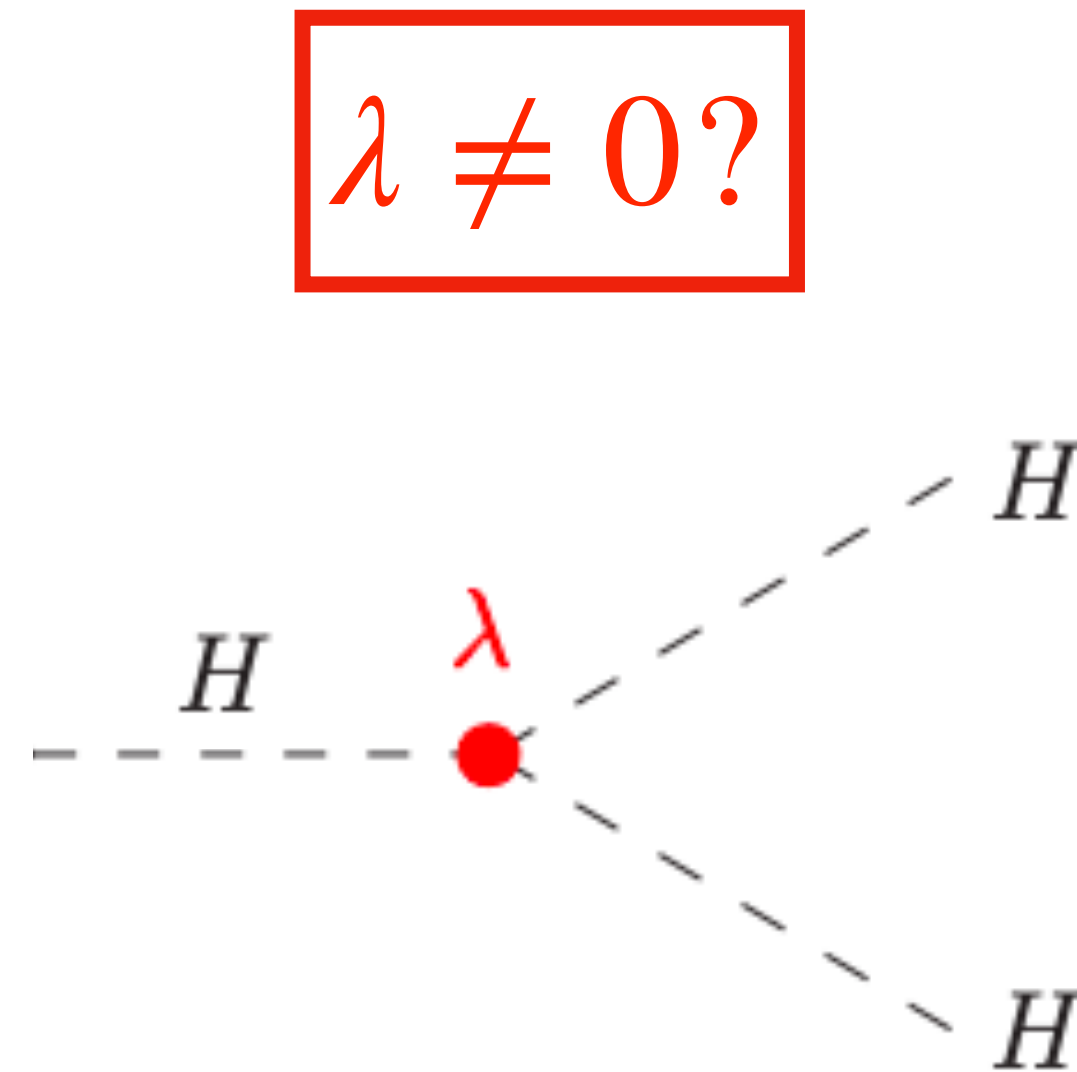
signal strength $\mu_{HH} = \sigma_{obs}/\sigma_{SM} = 2.2 \pm 1.7$



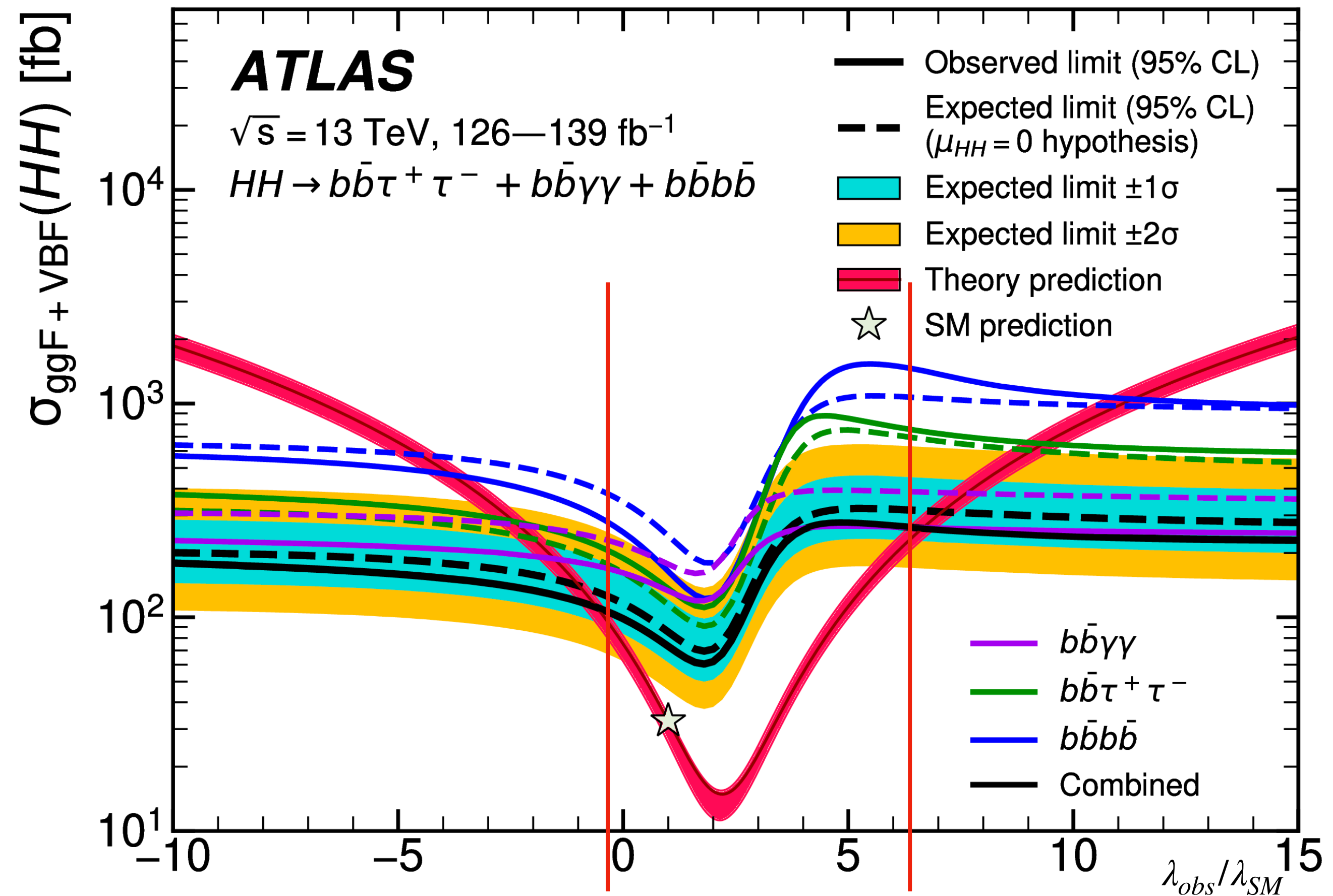
Boosted Decision Tree (BDT)



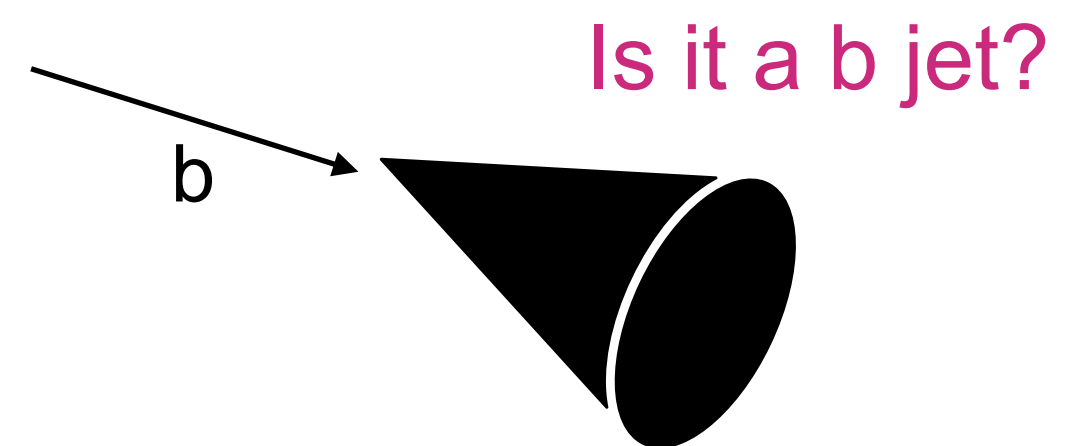
HH analyses combined: so close! How will we do better?



$\lambda \neq 0?$



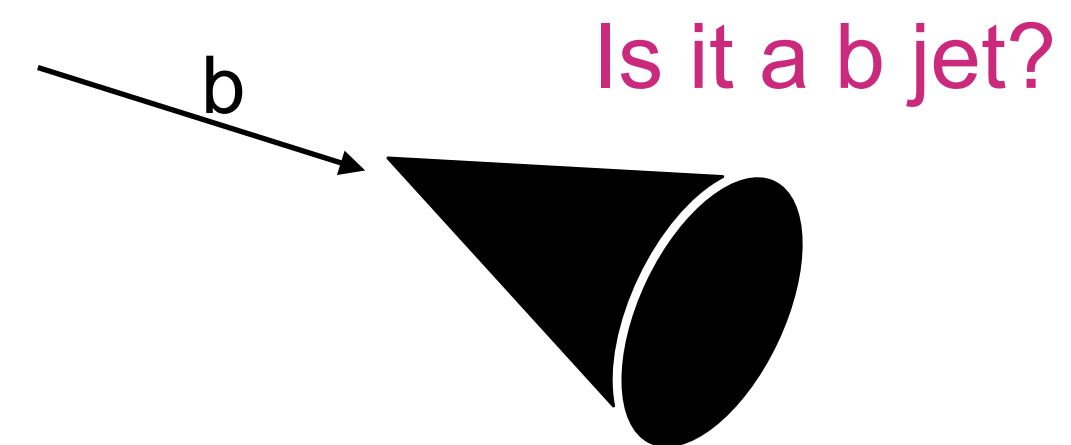
$$-0.4 < \frac{\lambda_{\text{obs}}}{\lambda_{\text{SM}}} < 6.3$$



Is it a b-jet?

Steps:

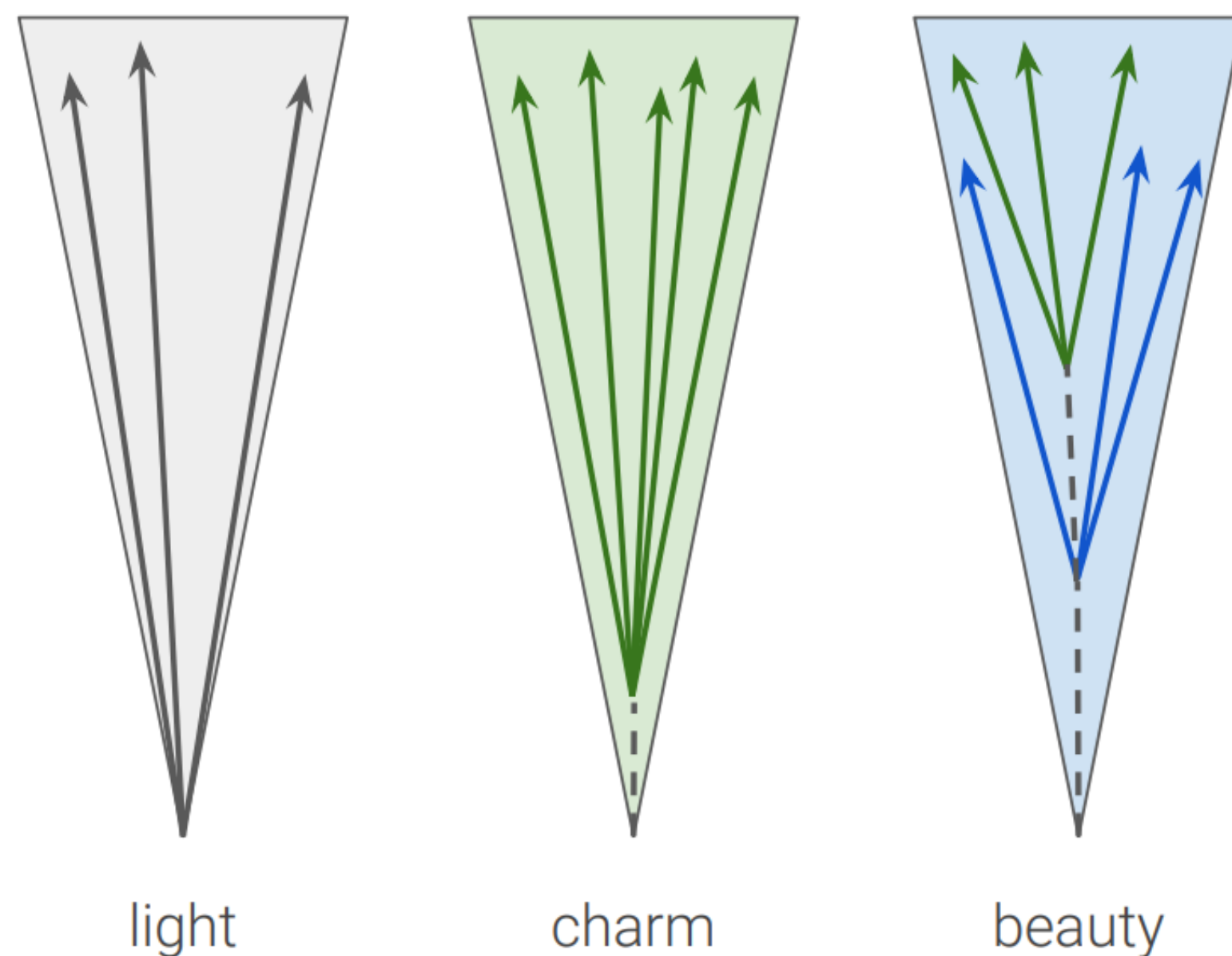
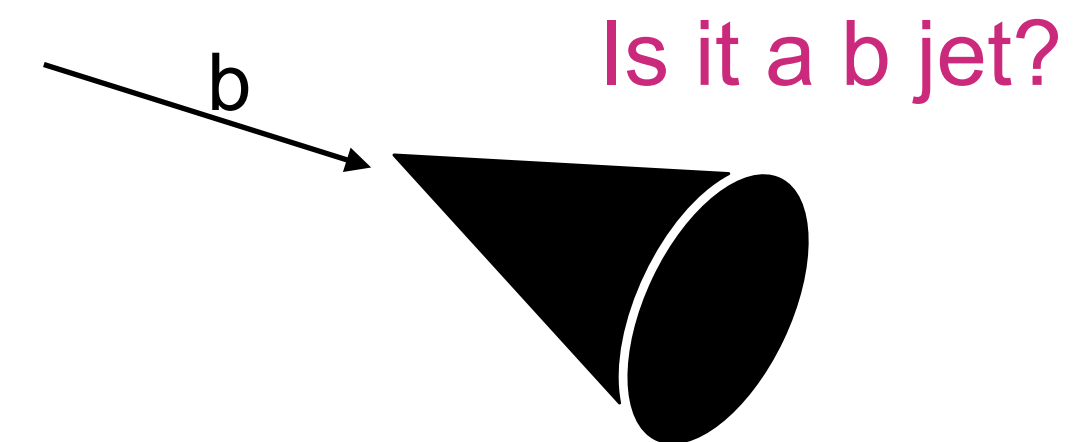
1. Reconstruction: remove noise and keep what's relevant
2. Calibration: correct momentum and energy
3. Identification (flavour tagging): what particle made the jet?



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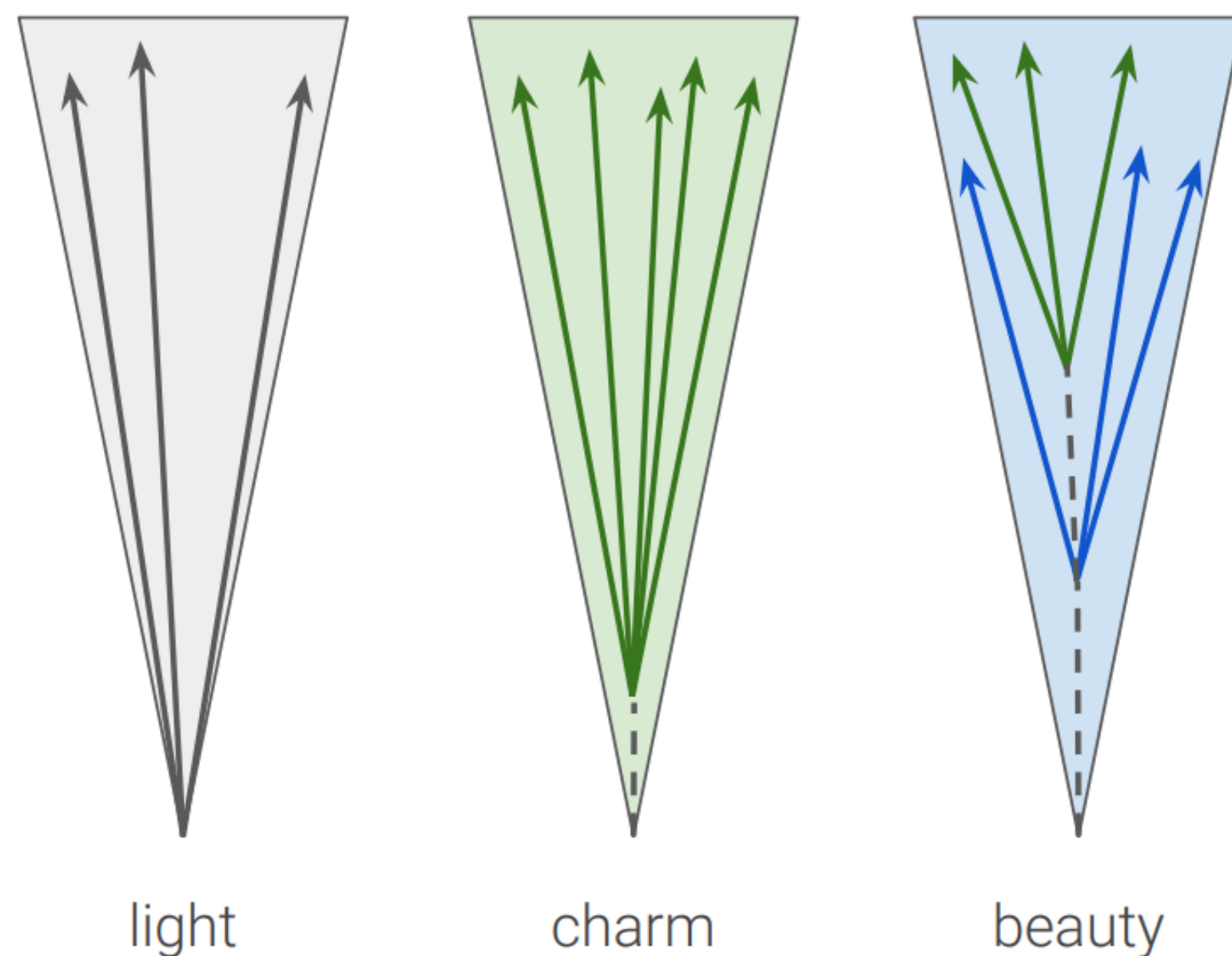
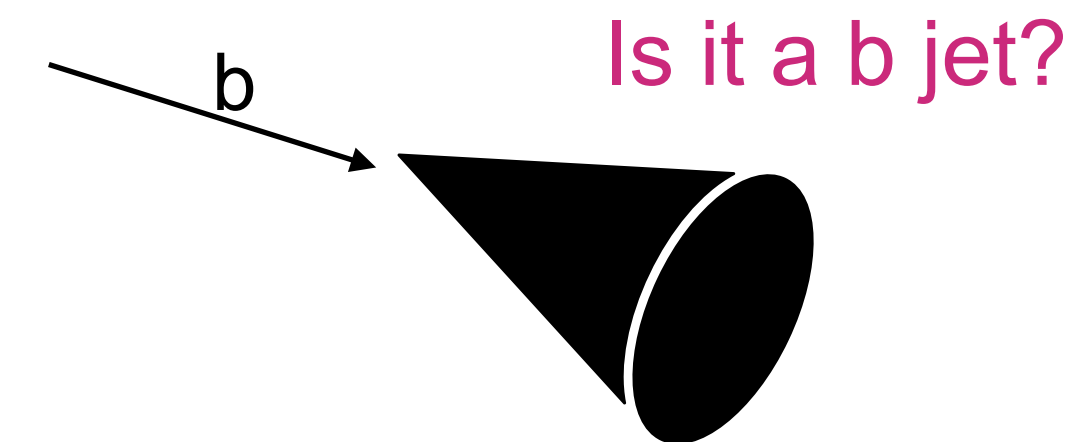


*light = not heavy quarks and gluons

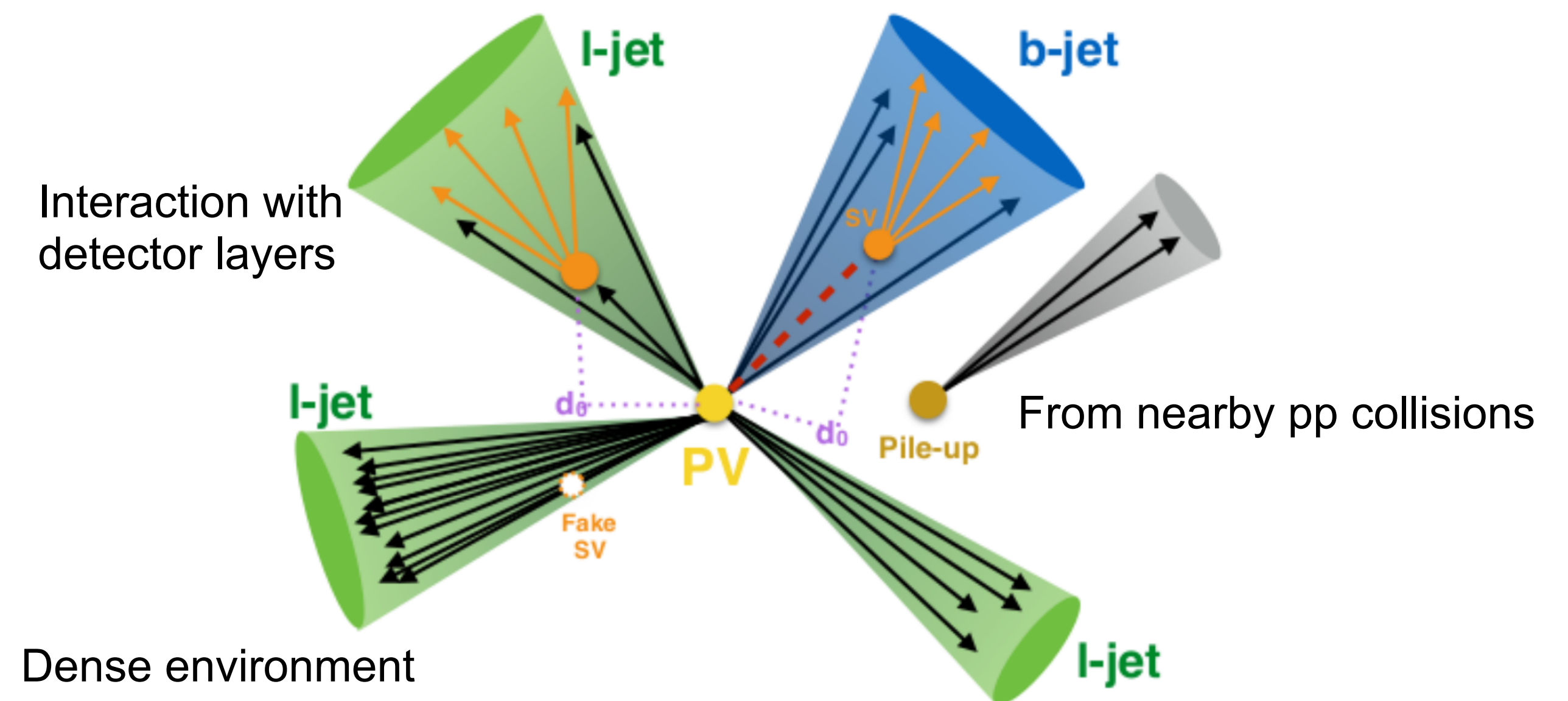
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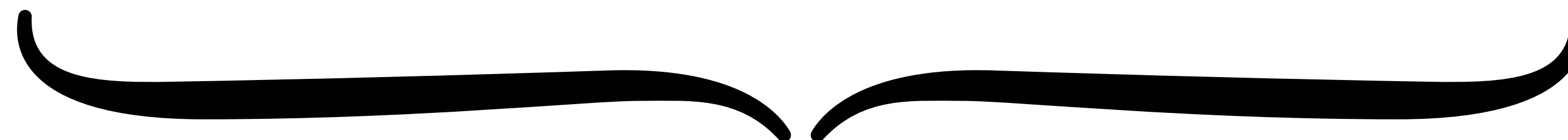
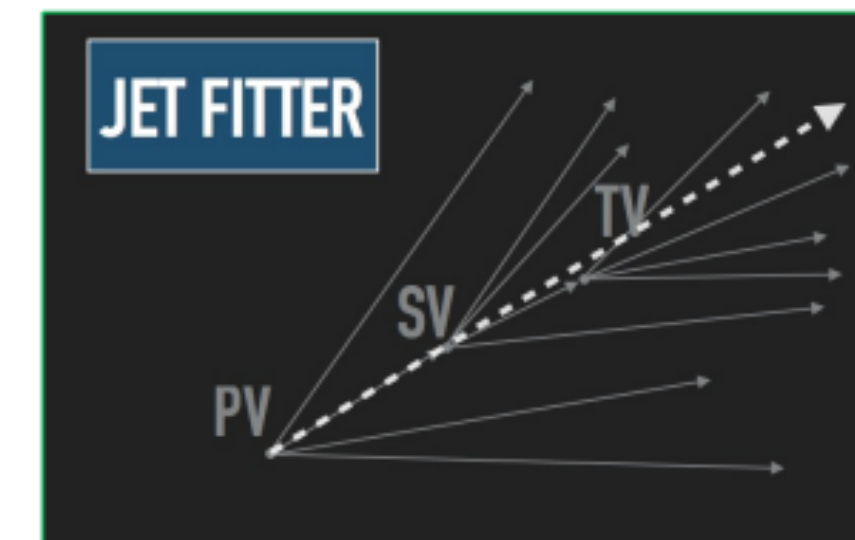
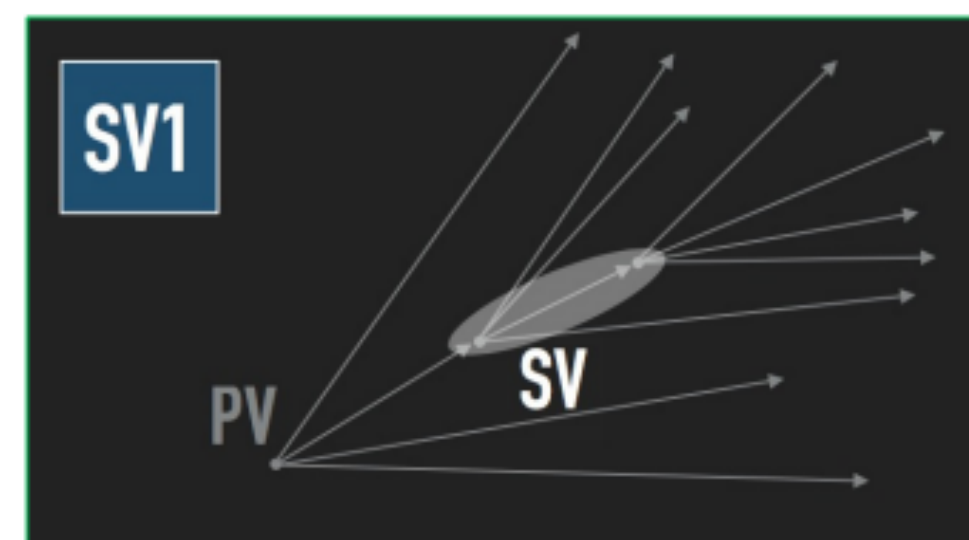
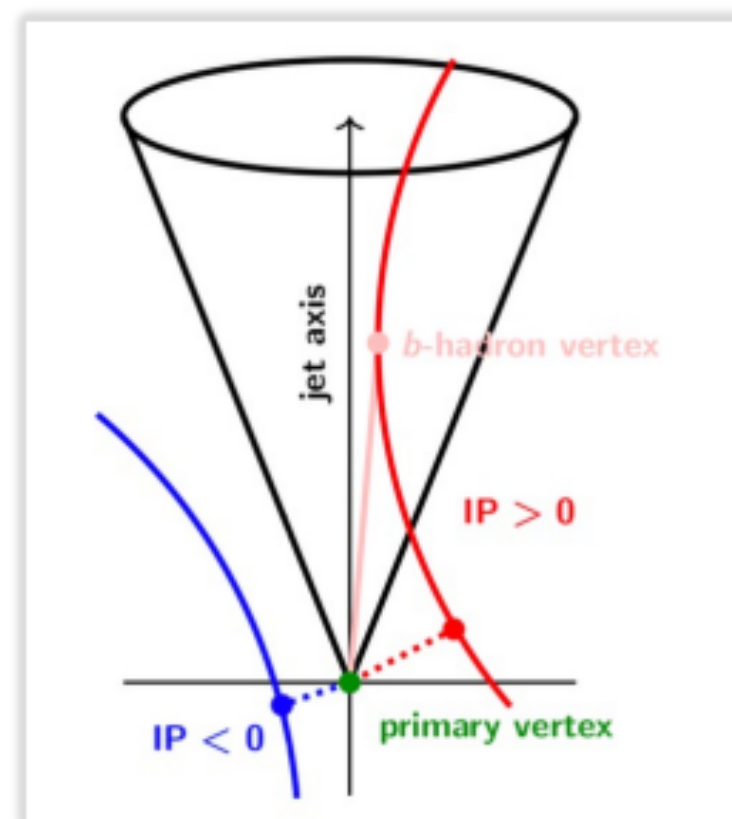
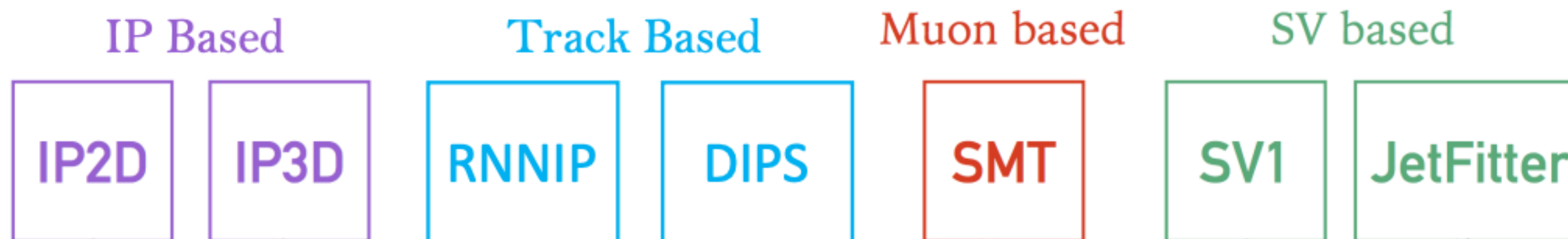


*PV = Primary Vertex
*SV = Secondary Vertex

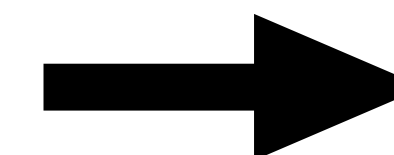
Is it a b-jet? old answer

1. Tailored algorithms with assumptions about what b jets look like
2. Combine their information as inputs to a feed-forward deep neural network

*PV = Primary Vertex
*SV = Secondary Vertex
*IP = Impact Parameter



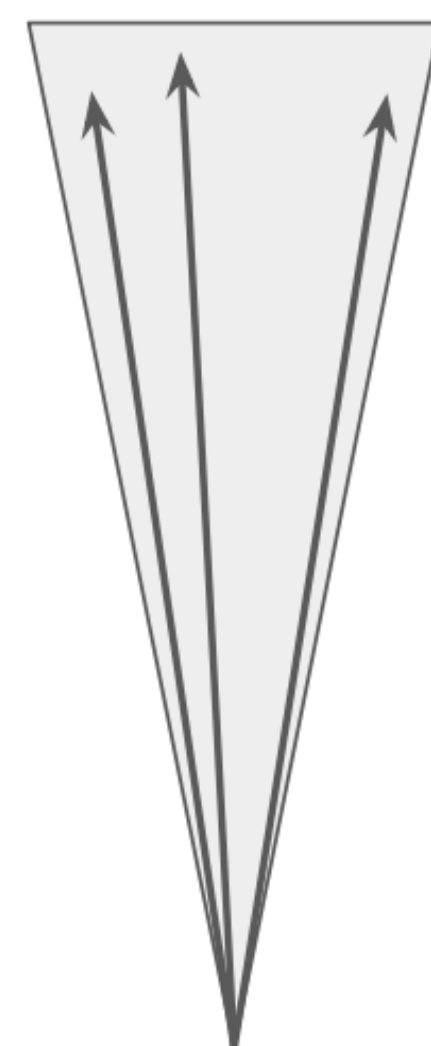
Deep NN (DL1r)



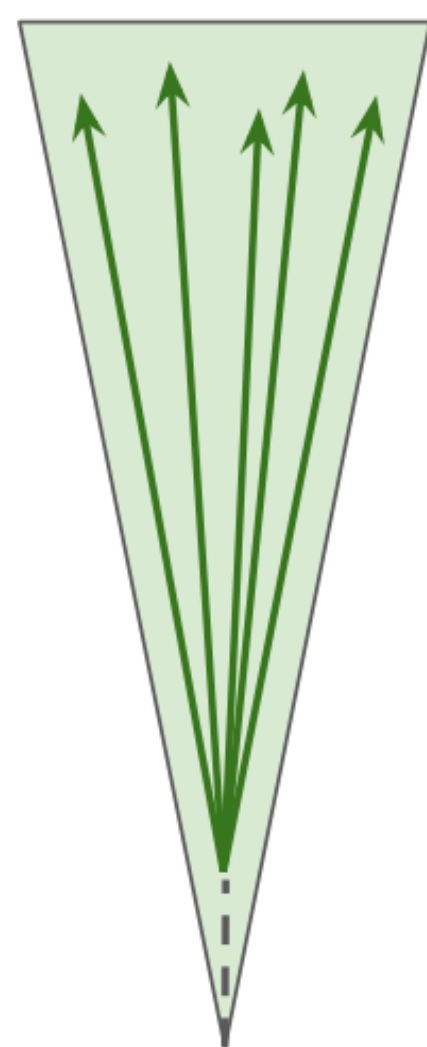
Classification {l, c, b} jets

Is it a b-jet? old vs new

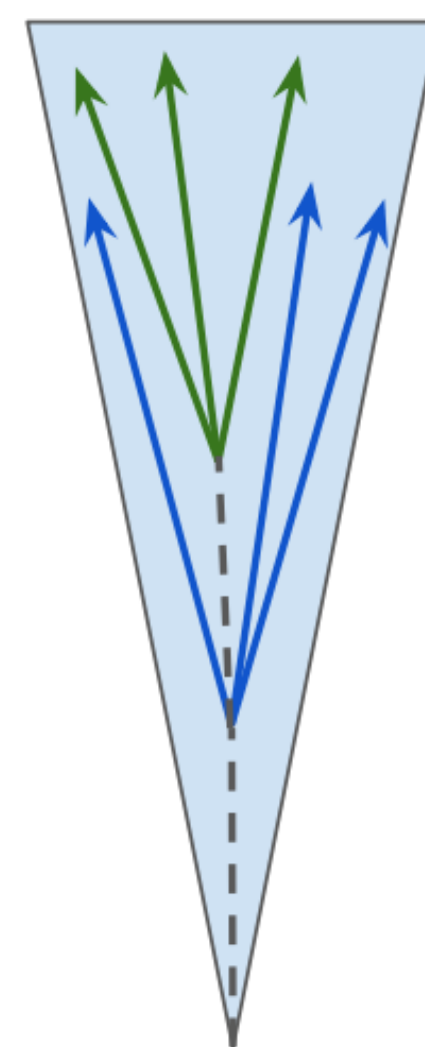
Train on Jet variables and associated tracks directly!
much more information to unpack, more correlations to access



light



charm



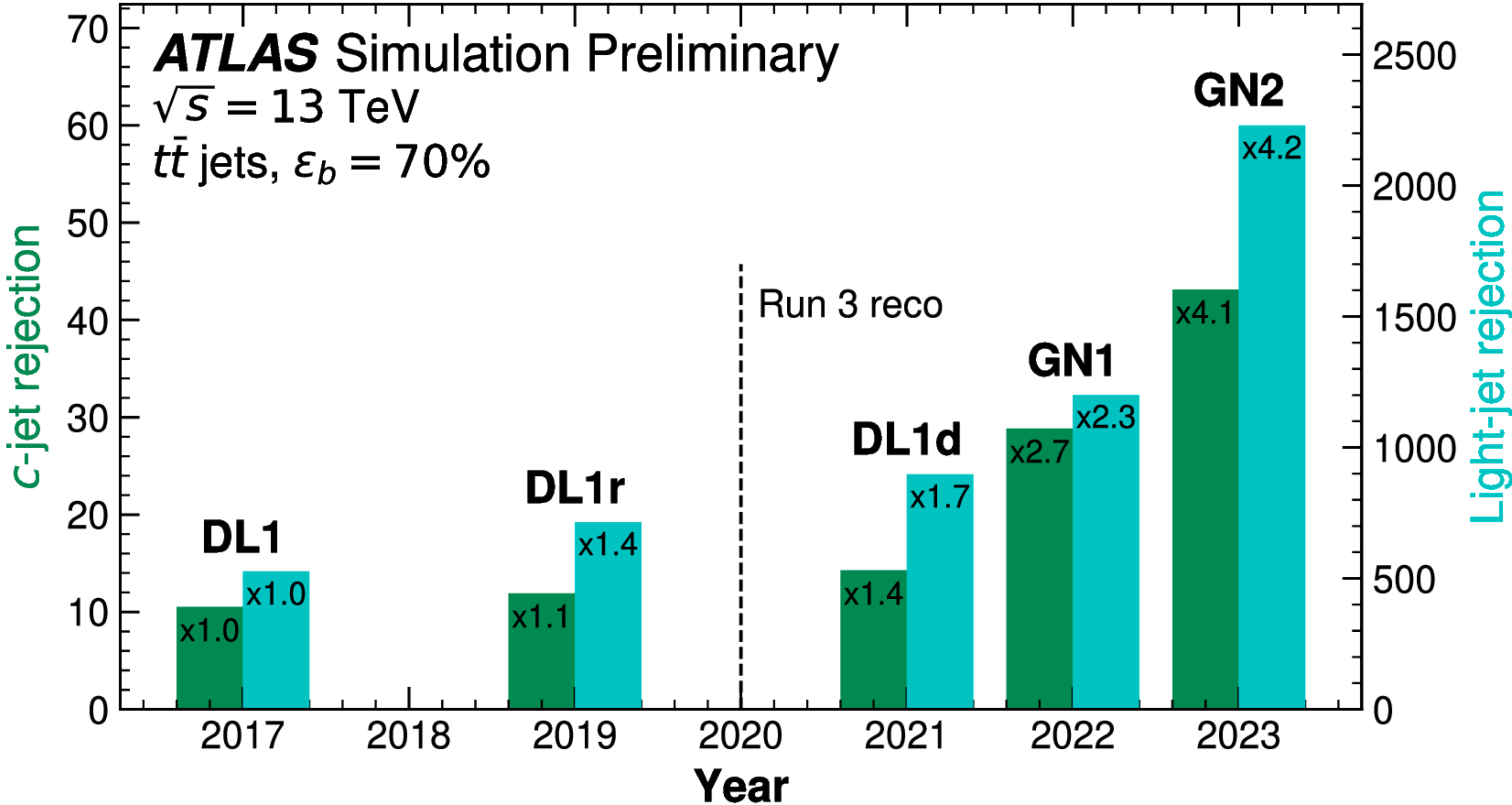
beauty



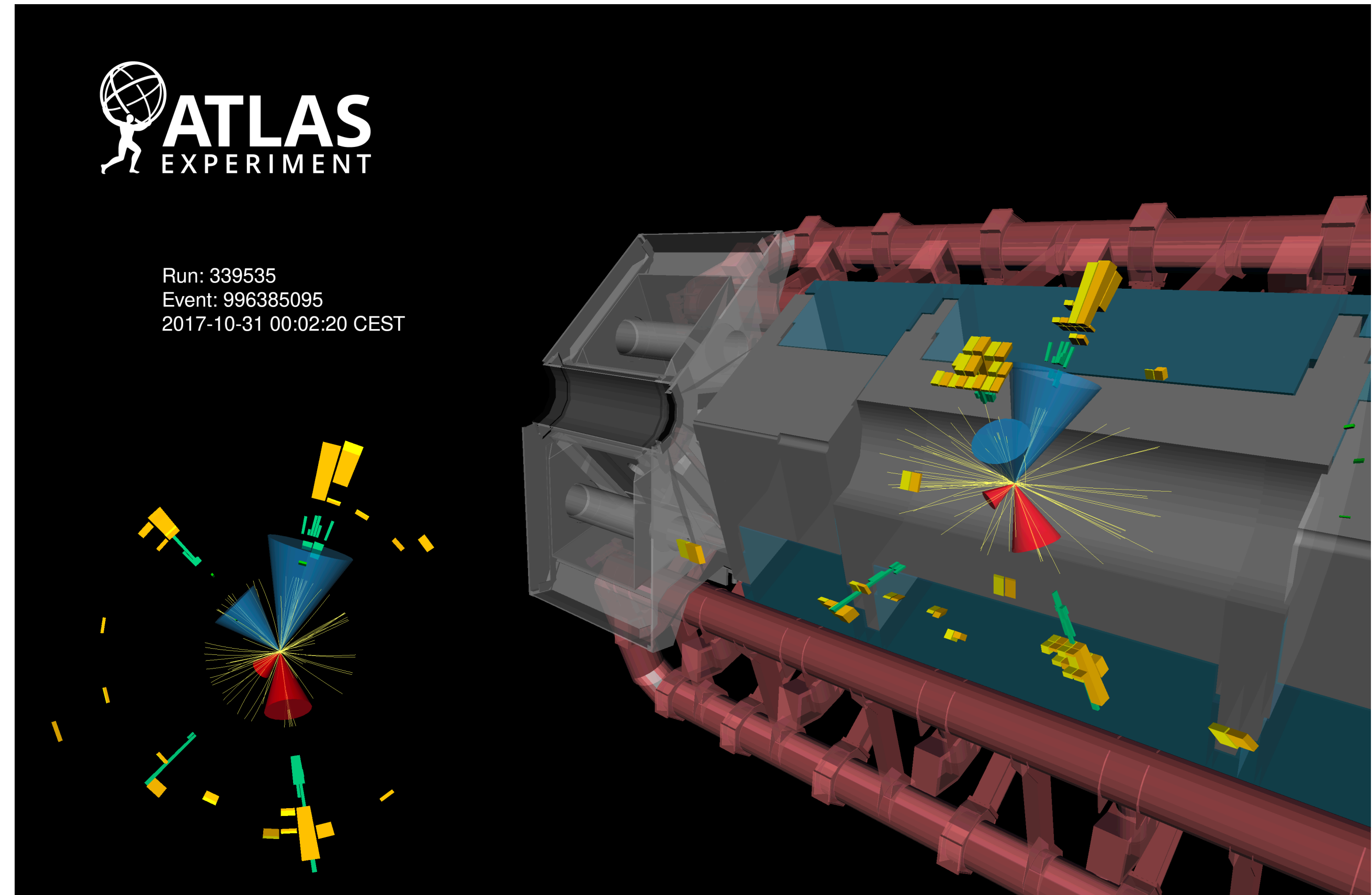
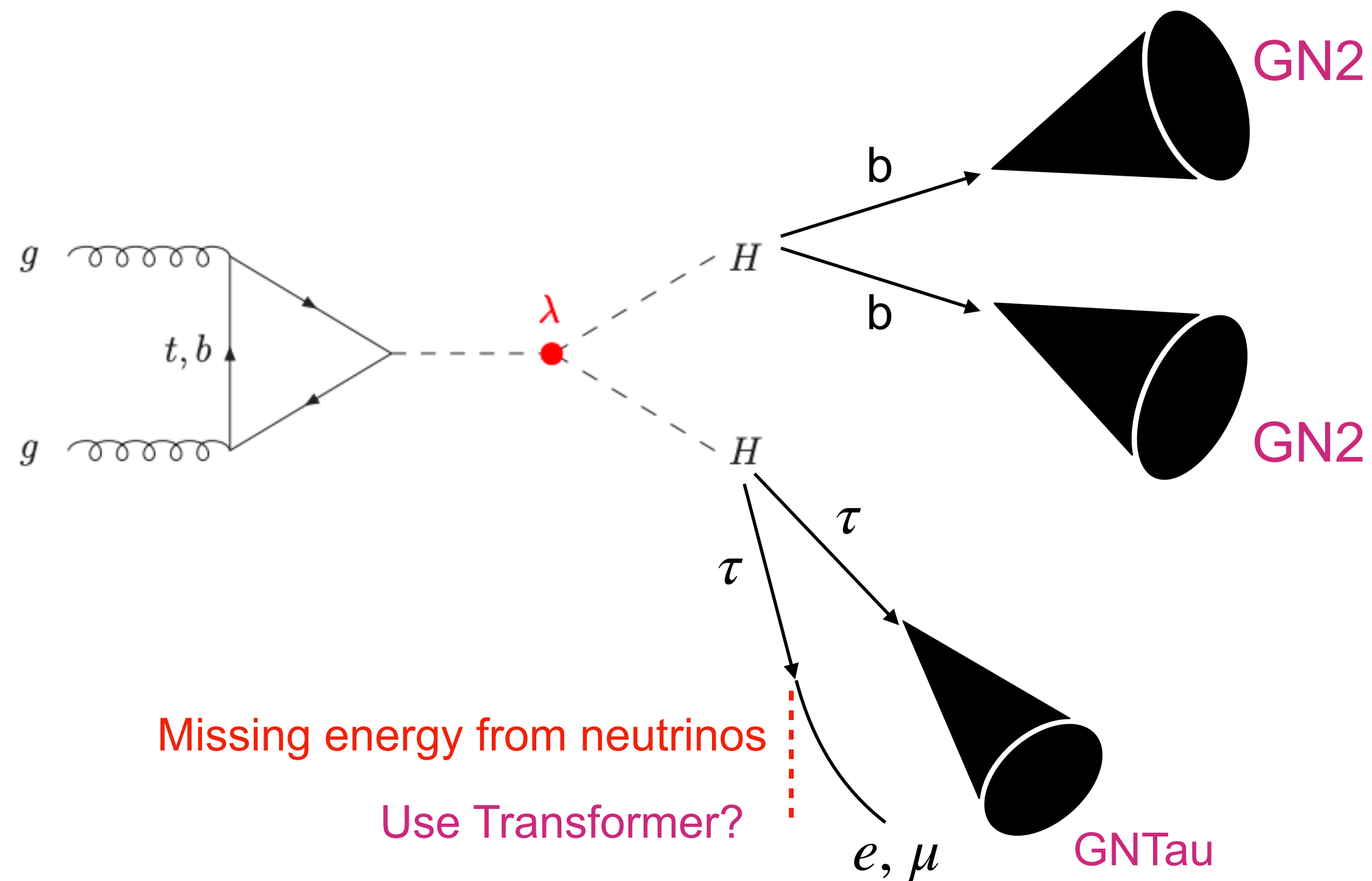
**Graph NN +
Multihead Attention
(GN2)**

Classification into {l, c, b} jets

Is it a b-jet? old vs new



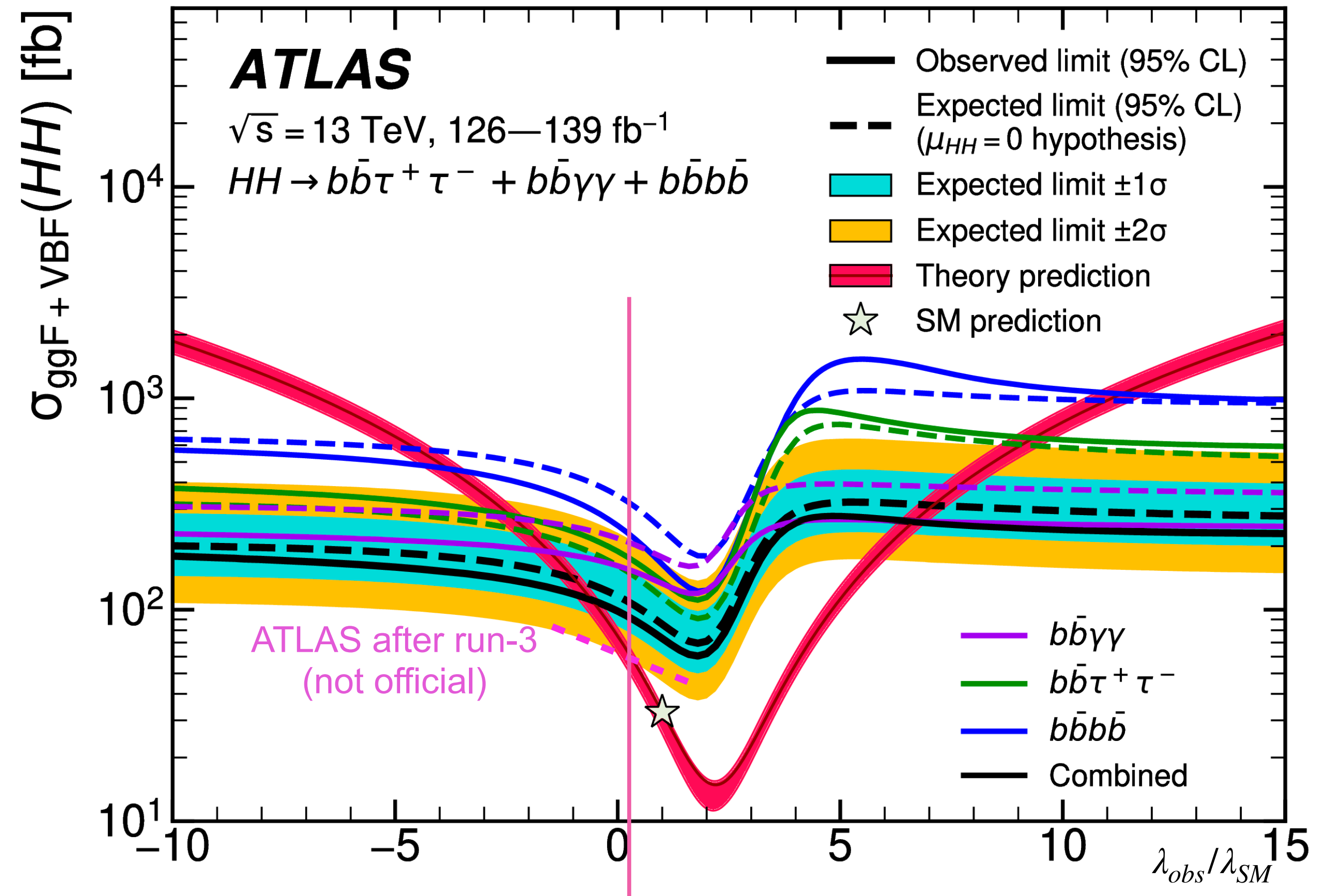
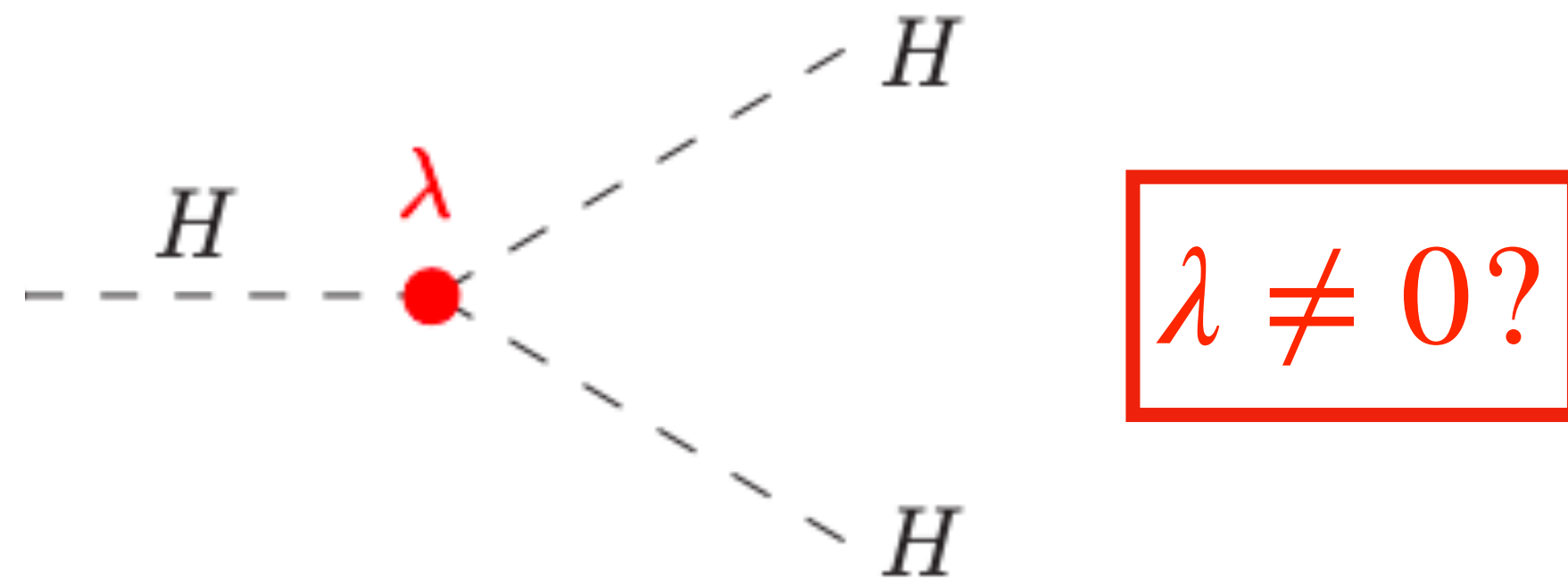
Run-3: Transformer everything



+ Transformer to separate signal events from background events!

HH run-3 projection!

- Include run3 data
 - Use GN2
 - Better triggers
 - Even without better analysis techniques!
- => Significance x2
=> upper limit almost halved



I think...

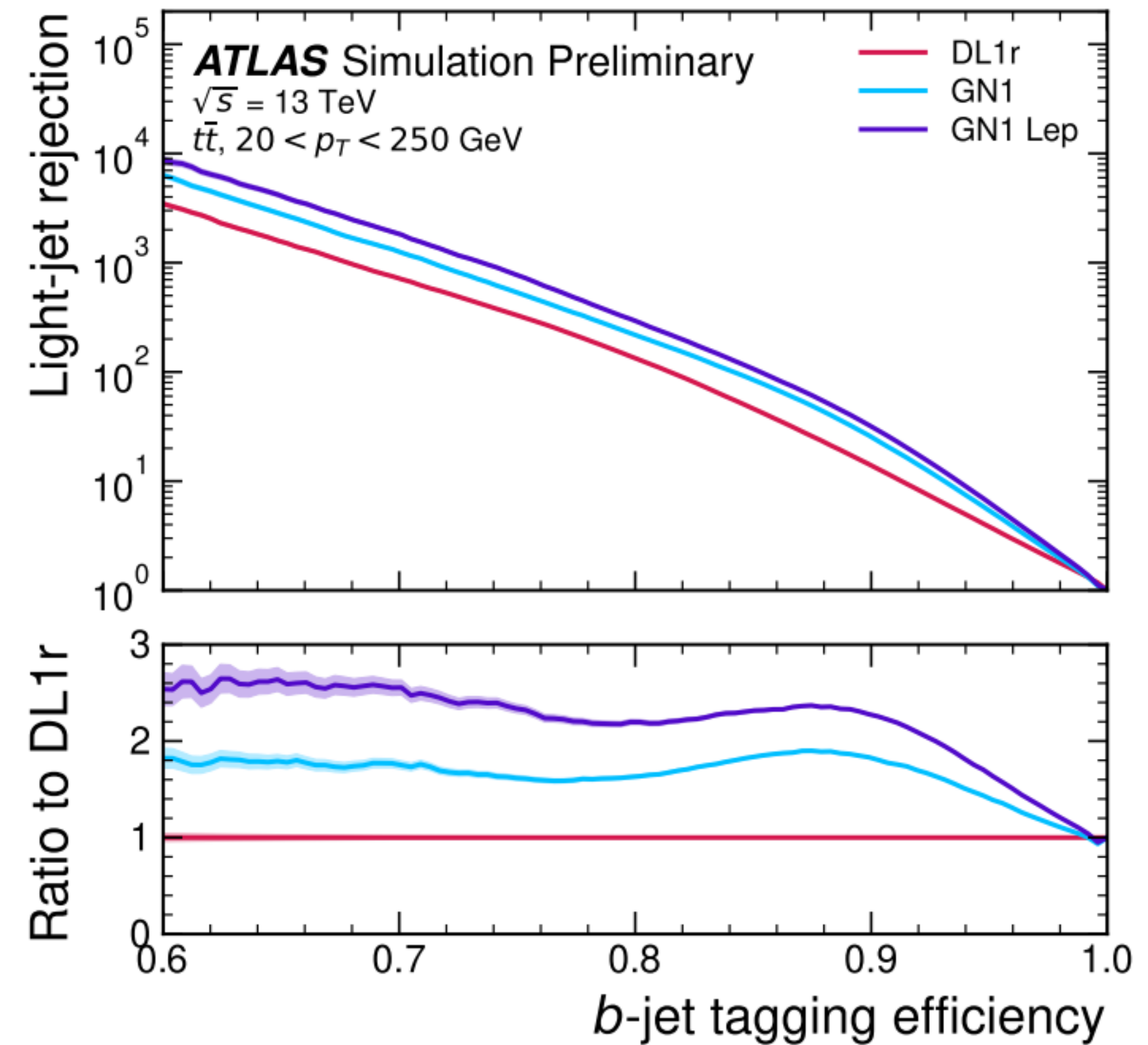
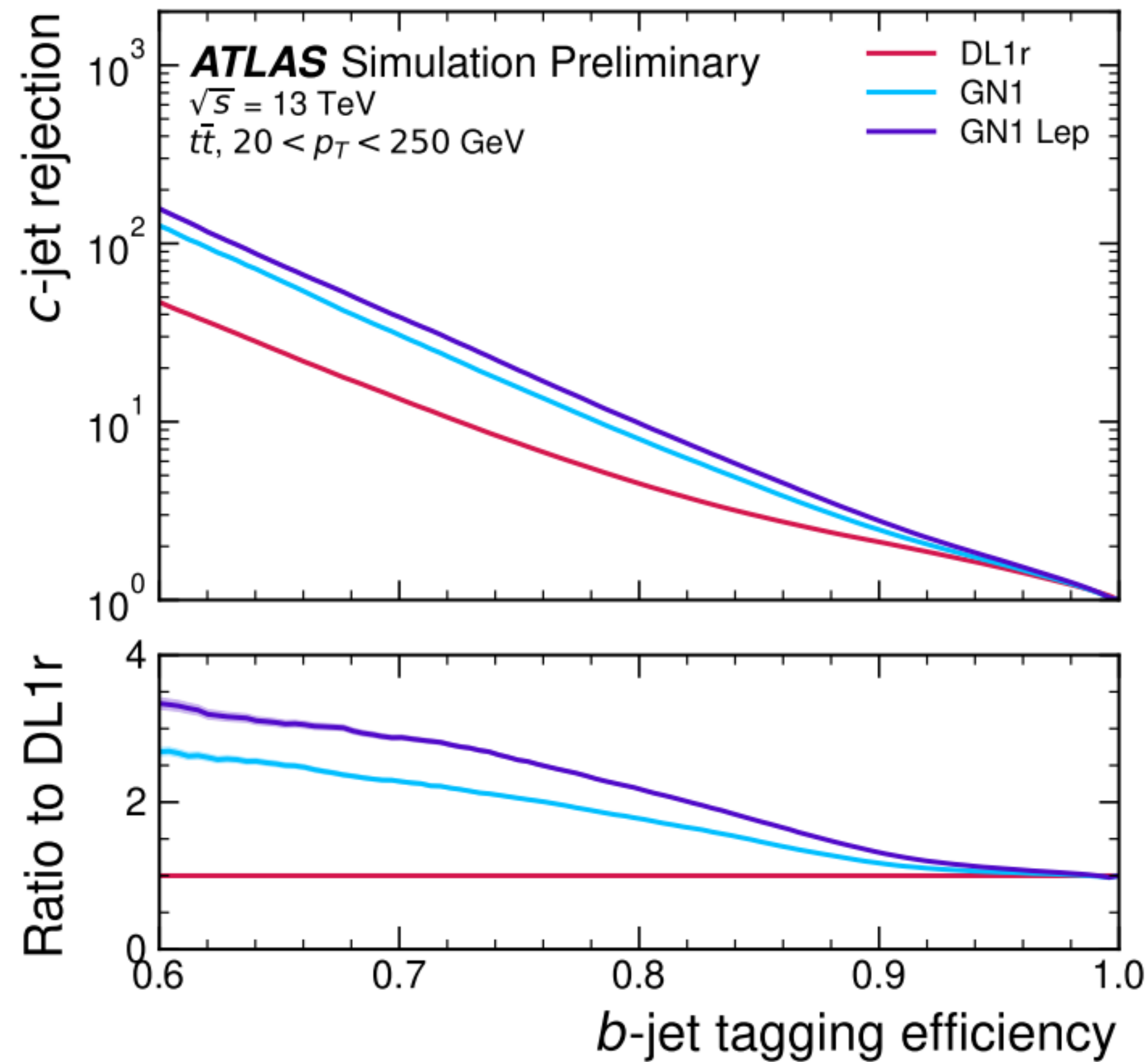
We will see Higgs splitting for the first time!
 If not! SM is in trouble :D

$$0 < \frac{\lambda_{obs}}{\lambda_{SM}}$$

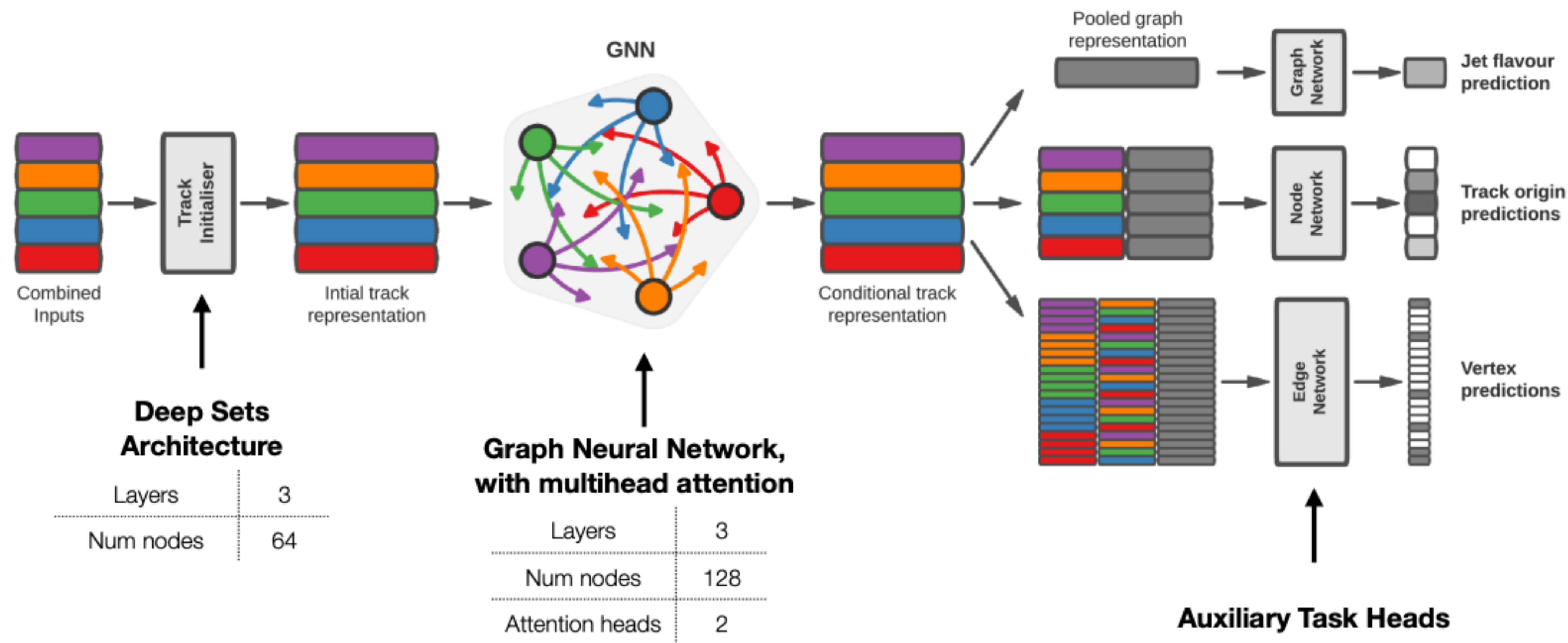
Back up



Back up

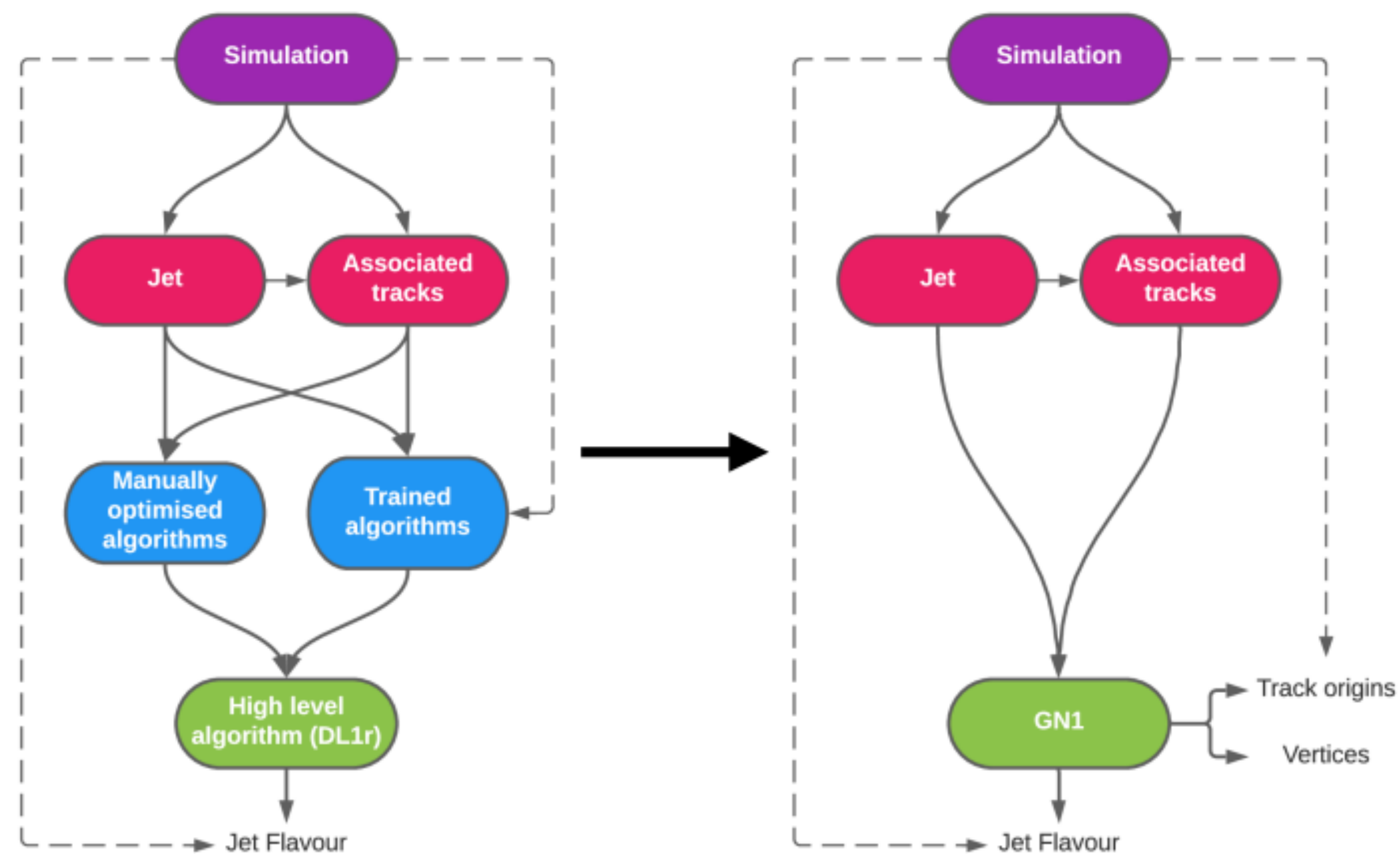


Is it a b-jet? GN1 architecture

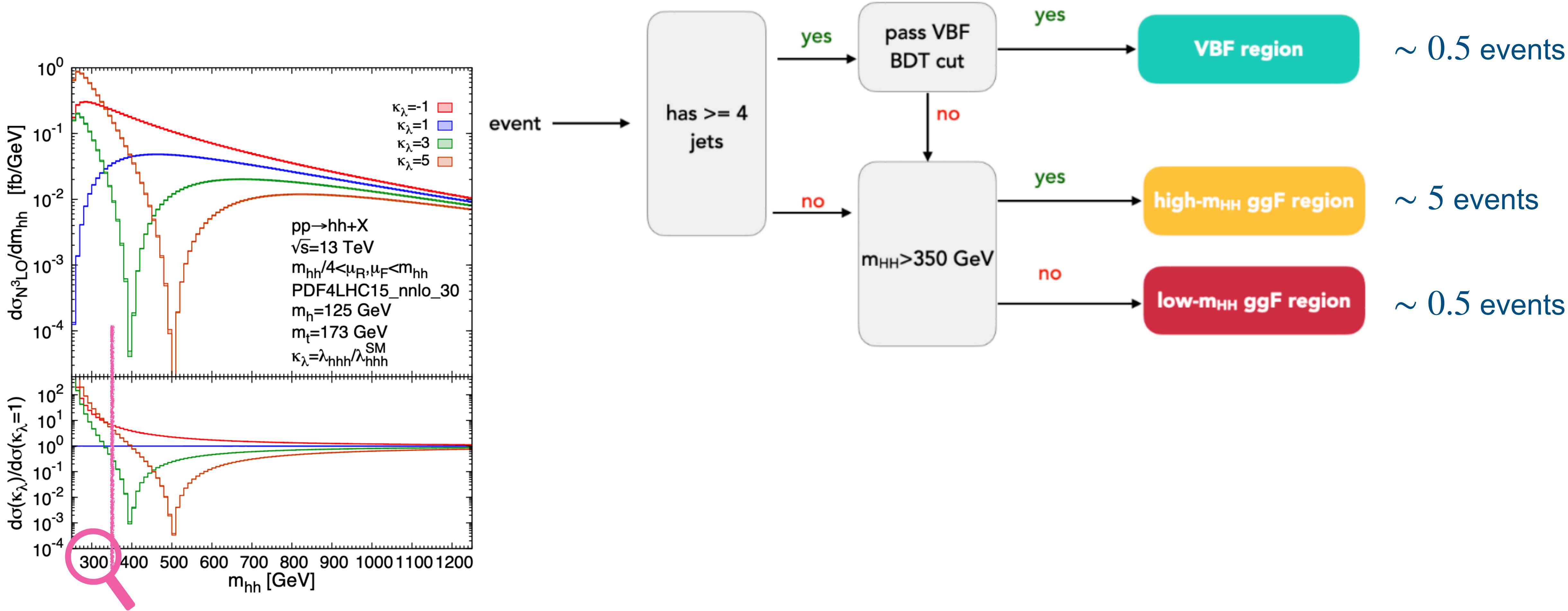


Is it a b-jet? old vs new

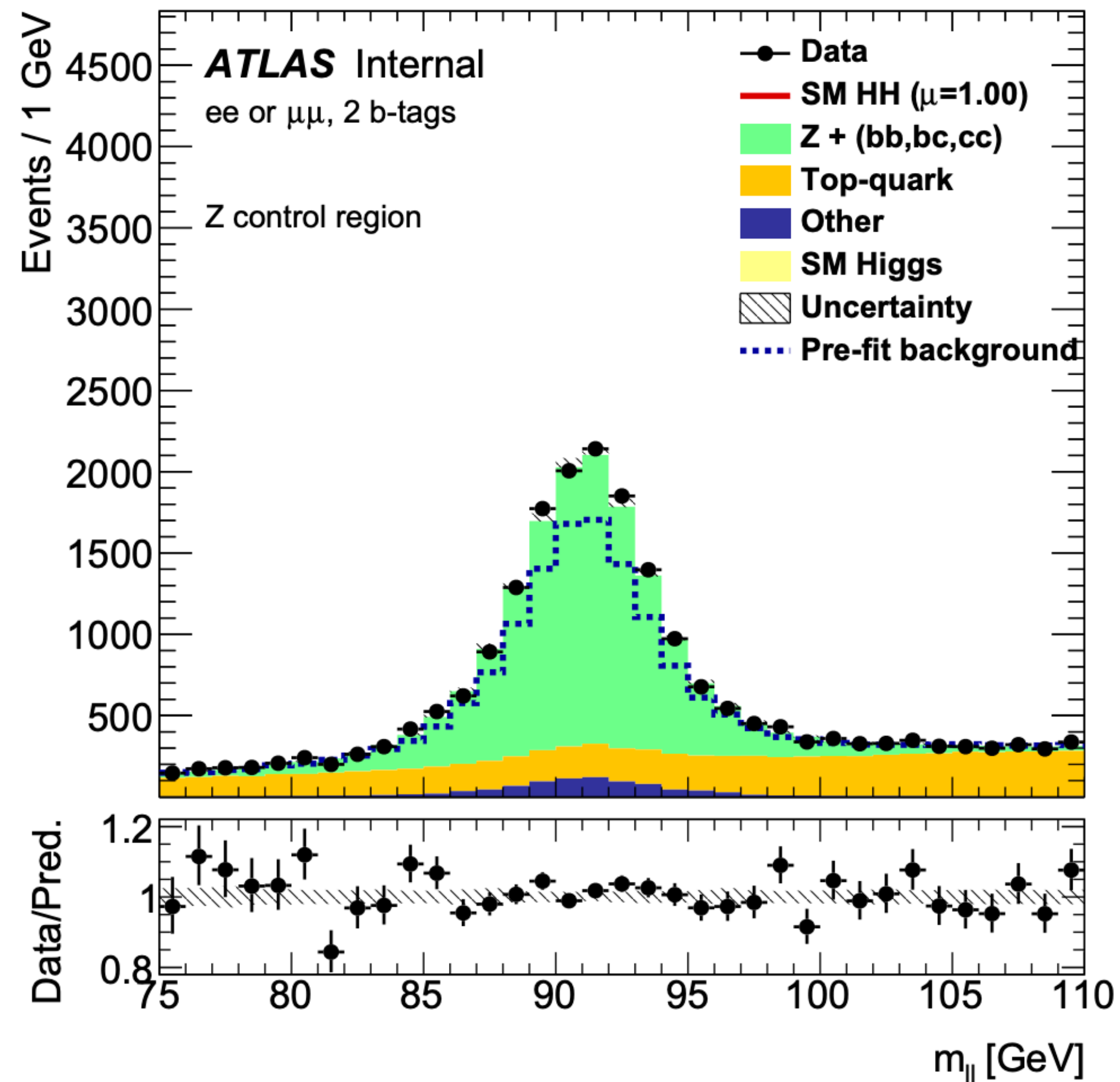
Train on Jet variables and associated tracks directly!
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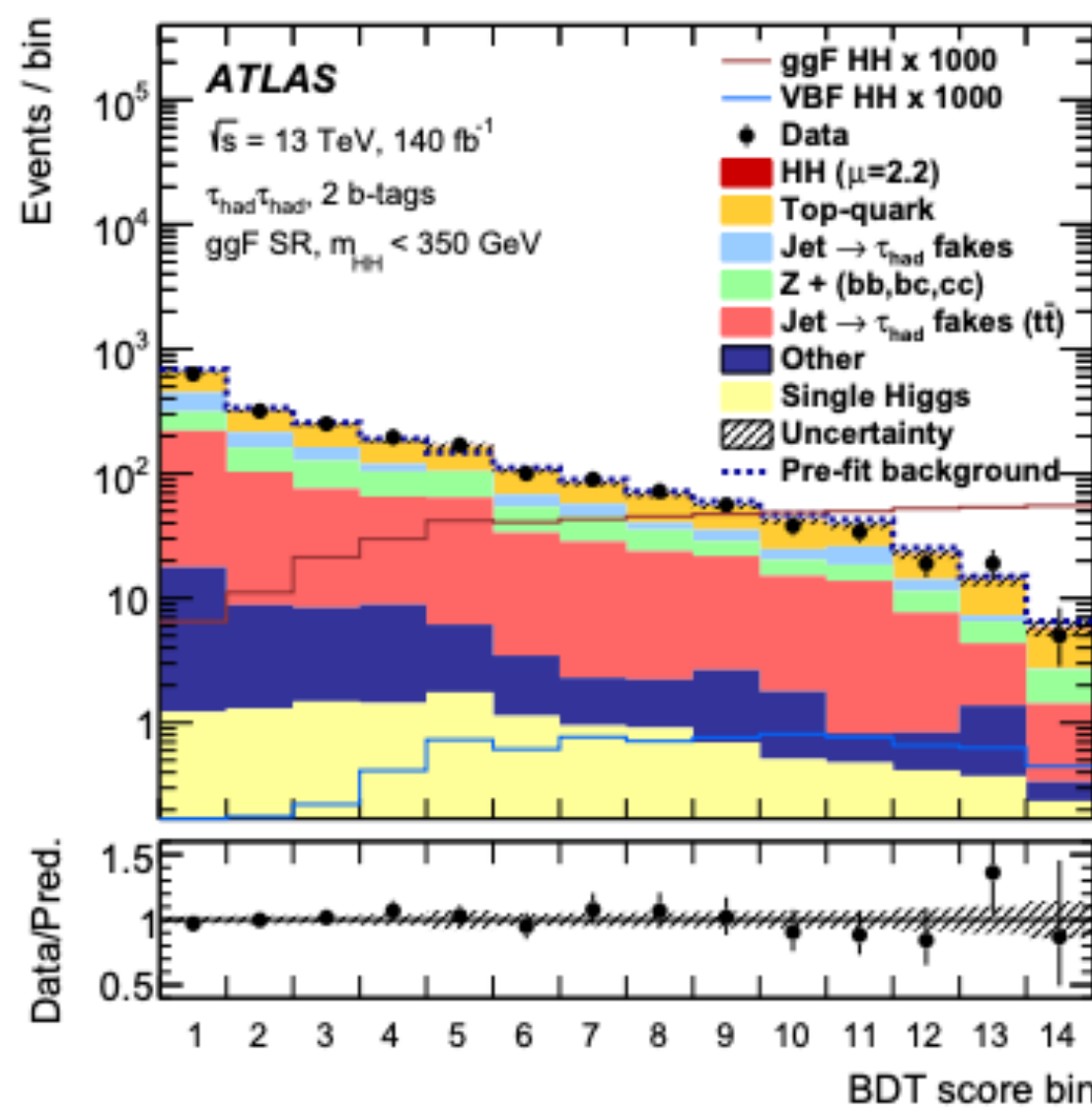
$HH \rightarrow bb\tau\tau$ at ATLAS: event categorisation



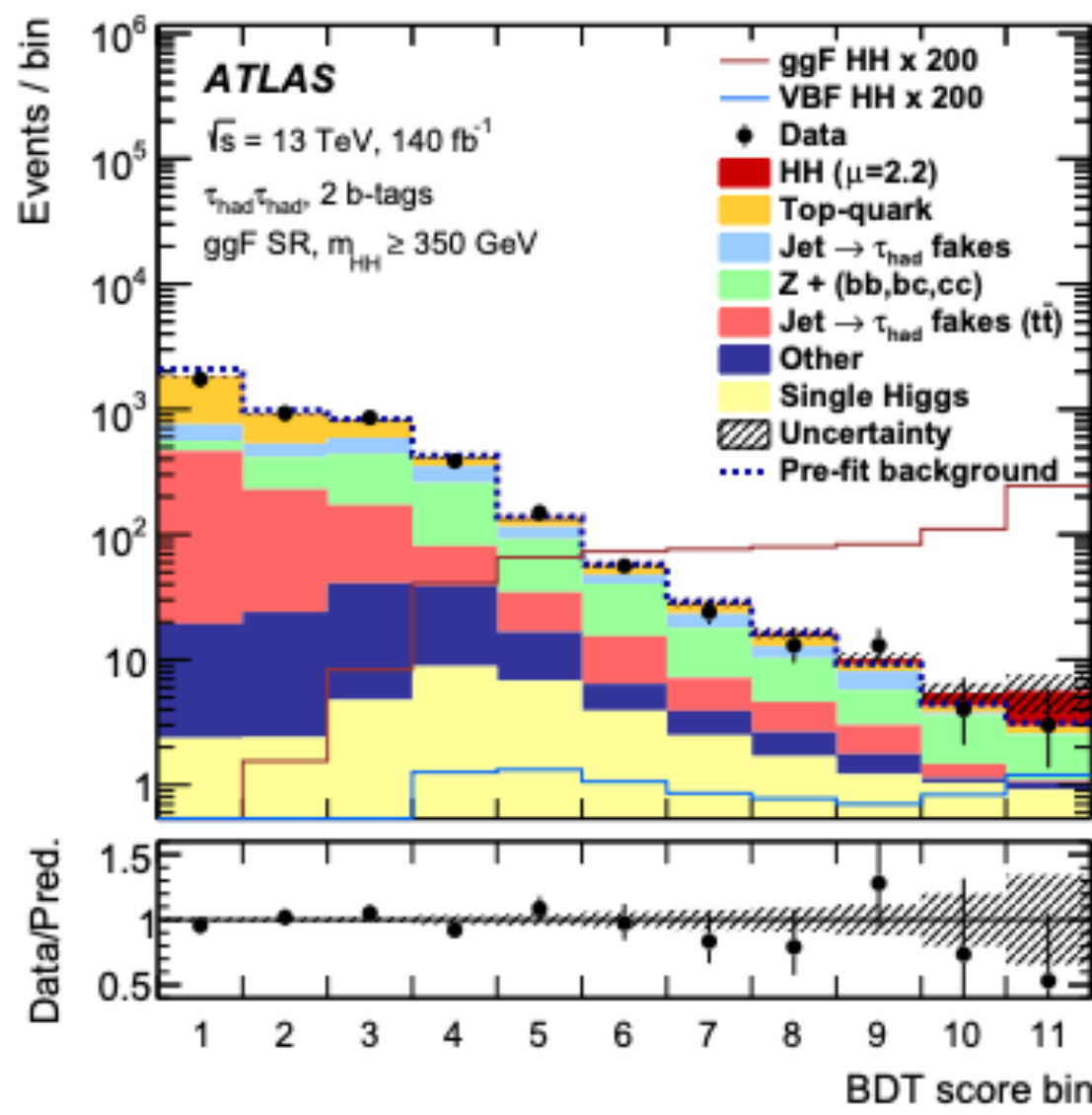
$HH \rightarrow bb\tau\tau$ something is wrong: Z+HF norm is off.



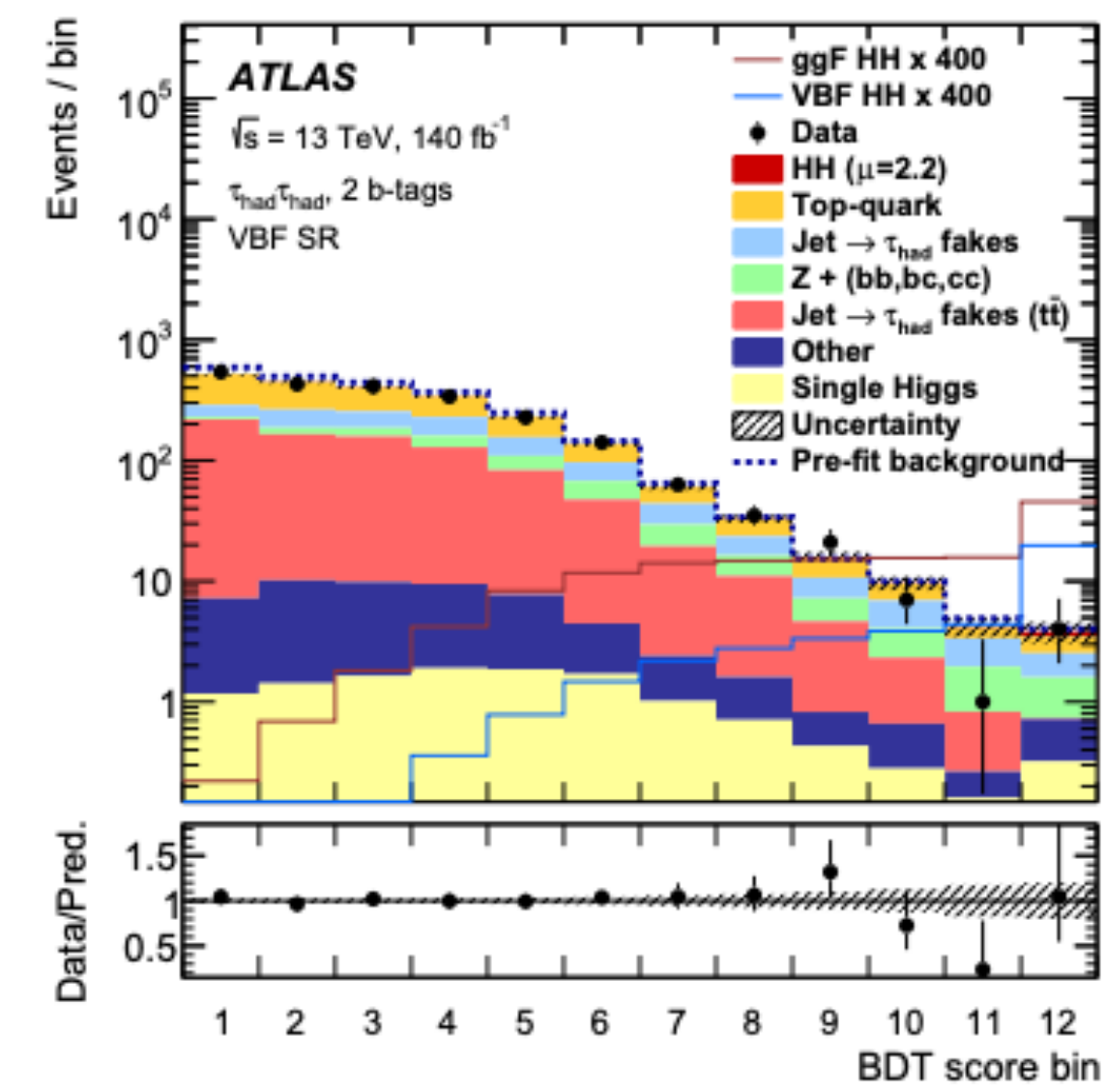
- Events selected with $bb\ell\ell$ trigger selection using single-lepton and di-lepton triggers (see Section 3.1 of Ref. [72]);
- Exactly two muons or two electrons with opposite-sign charges;
- Exactly two b -tagged jets (using DL1r tagger and 77% working point);
- $75 \text{ GeV} < m_{\ell\ell} < 110 \text{ GeV}$ (select Z mass peak);
- $m_{bb} < 40 \text{ GeV}$ or $m_{bb} > 210 \text{ GeV}$ (to veto Higgs mass peak and to ensure orthogonality to $bb\ell\ell$ signal region);
- leading b -jet $p_T > 45 \text{ GeV}$;
- lepton $p_T > 40 \text{ GeV}$.



(a)

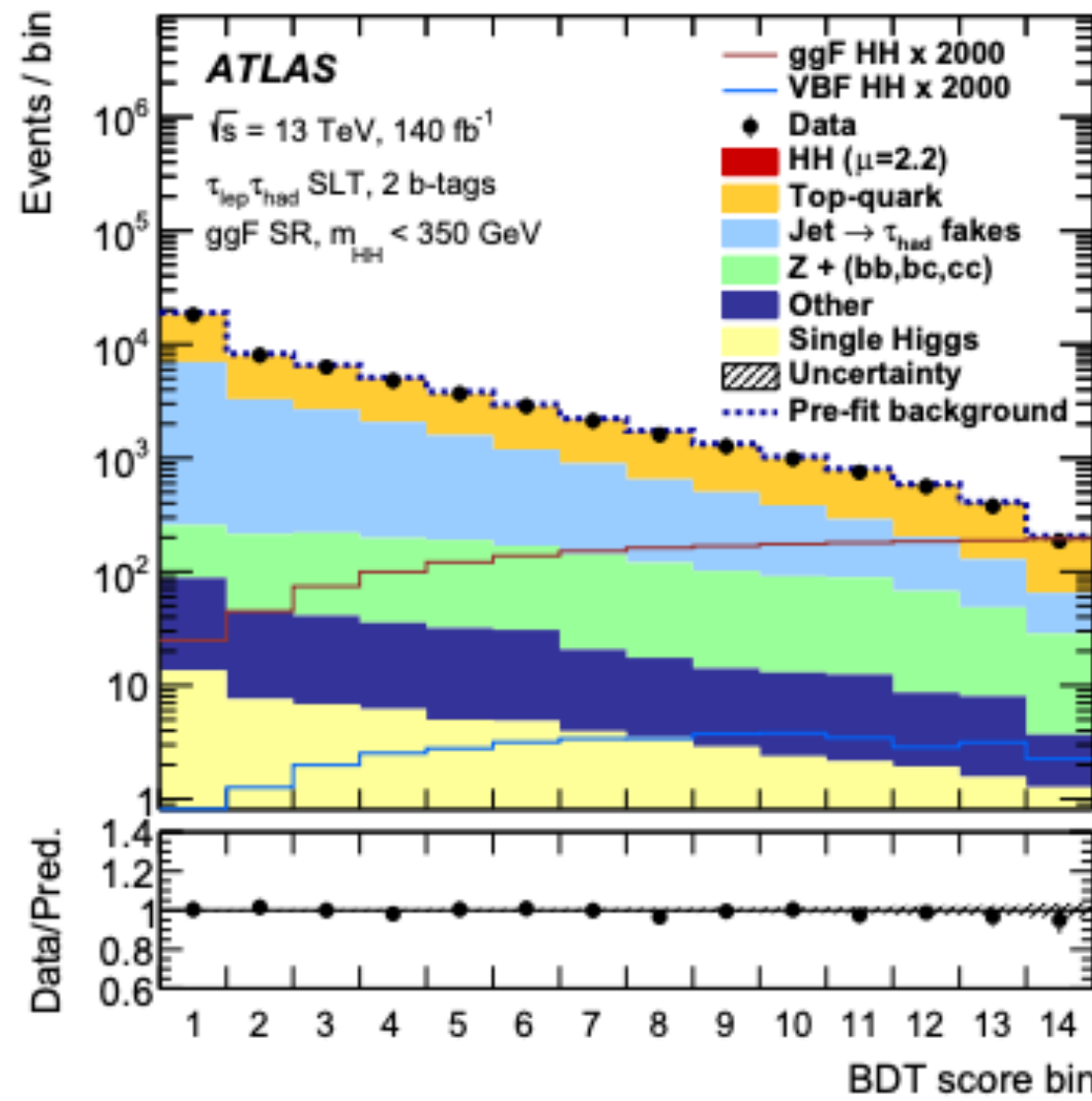


(b)

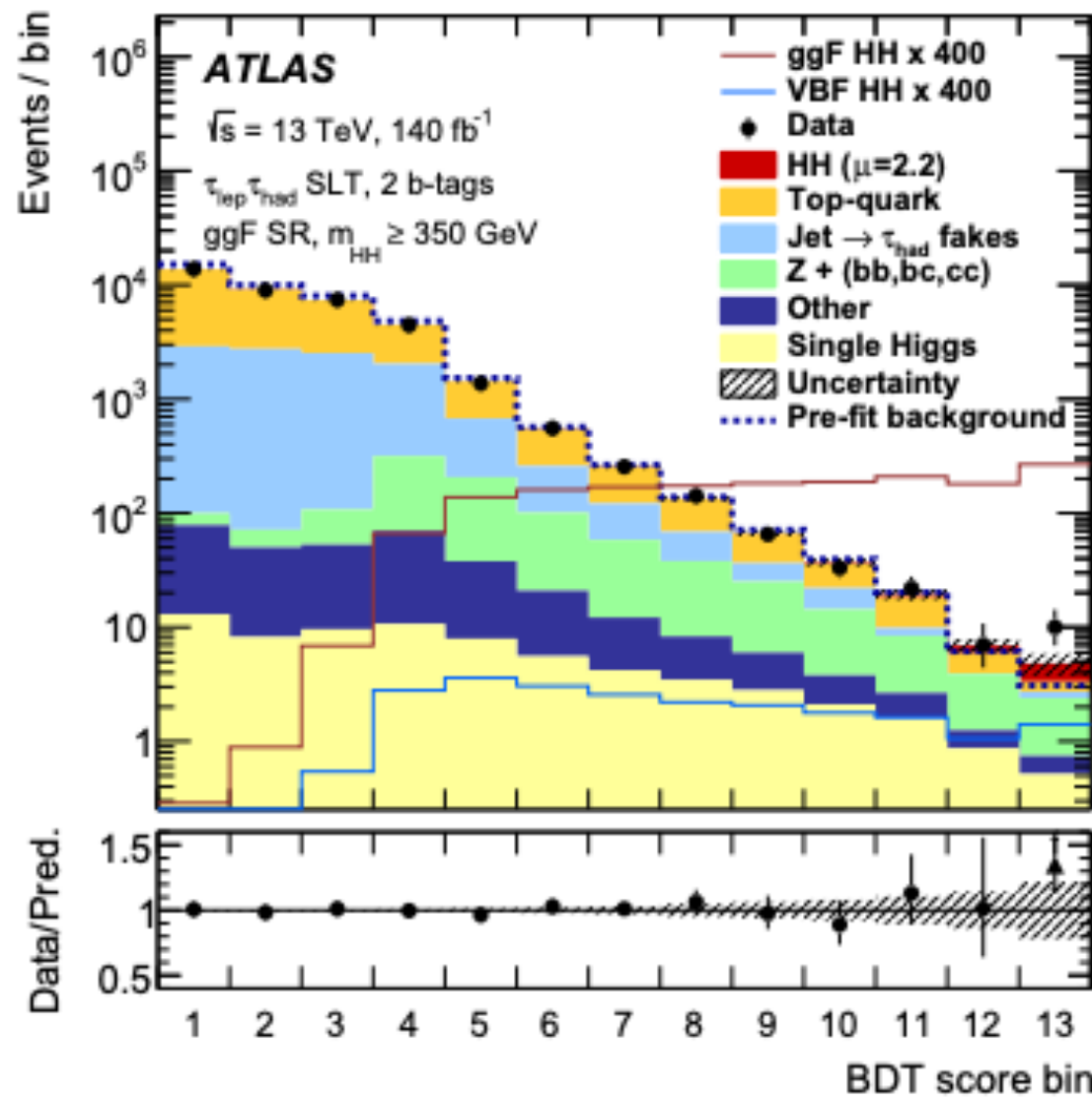


(c)

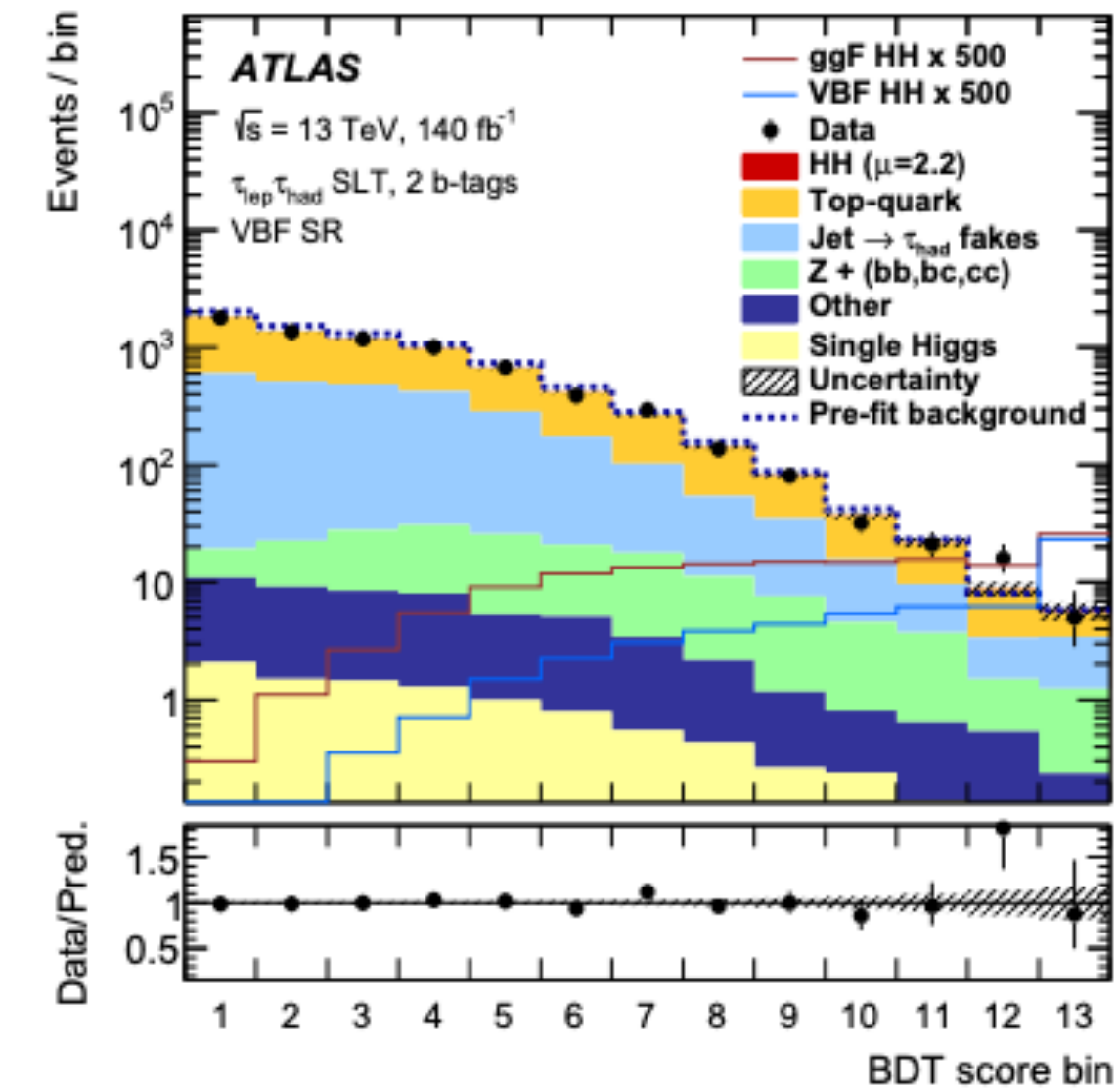
Fresh results!



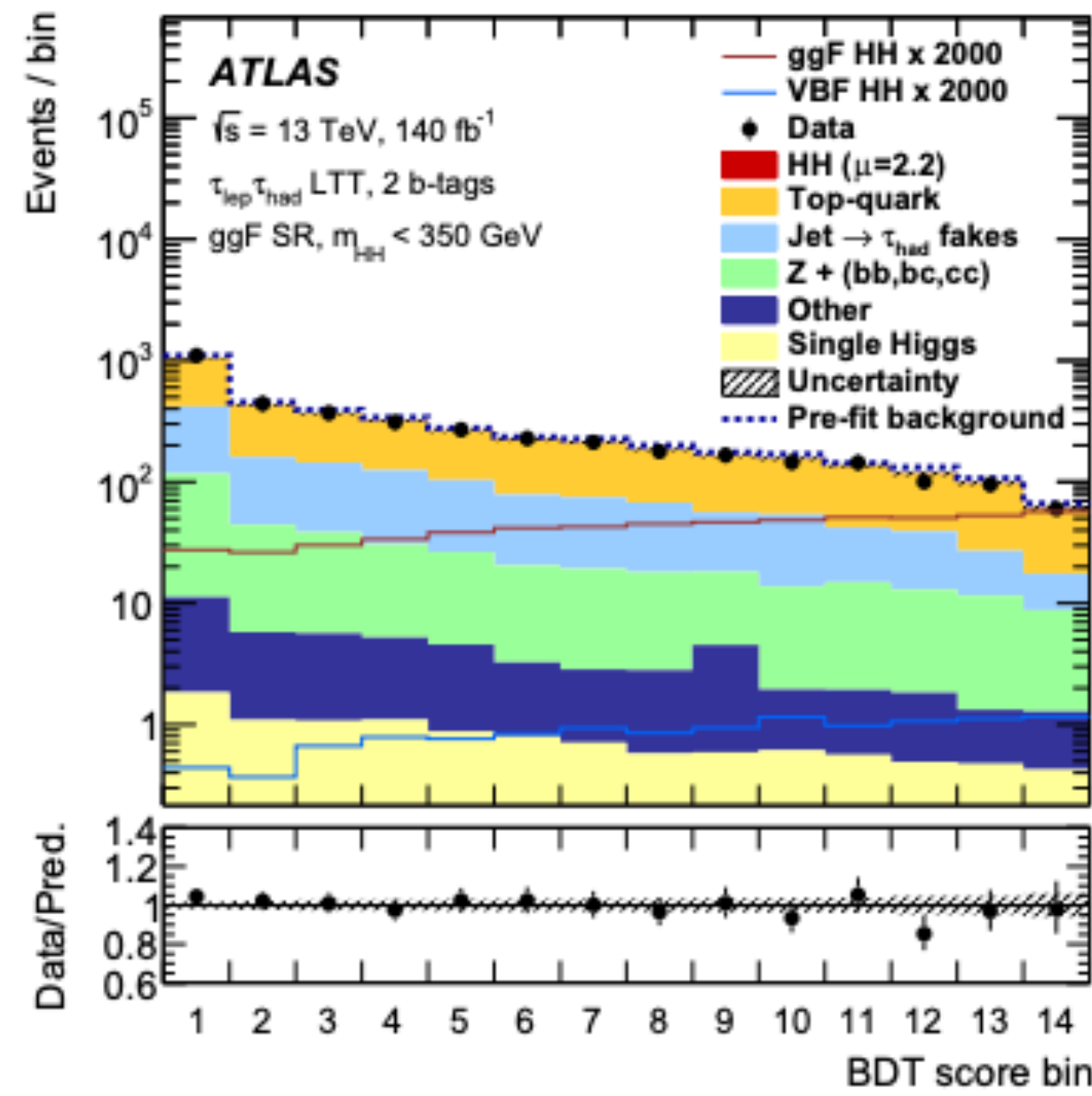
(d)



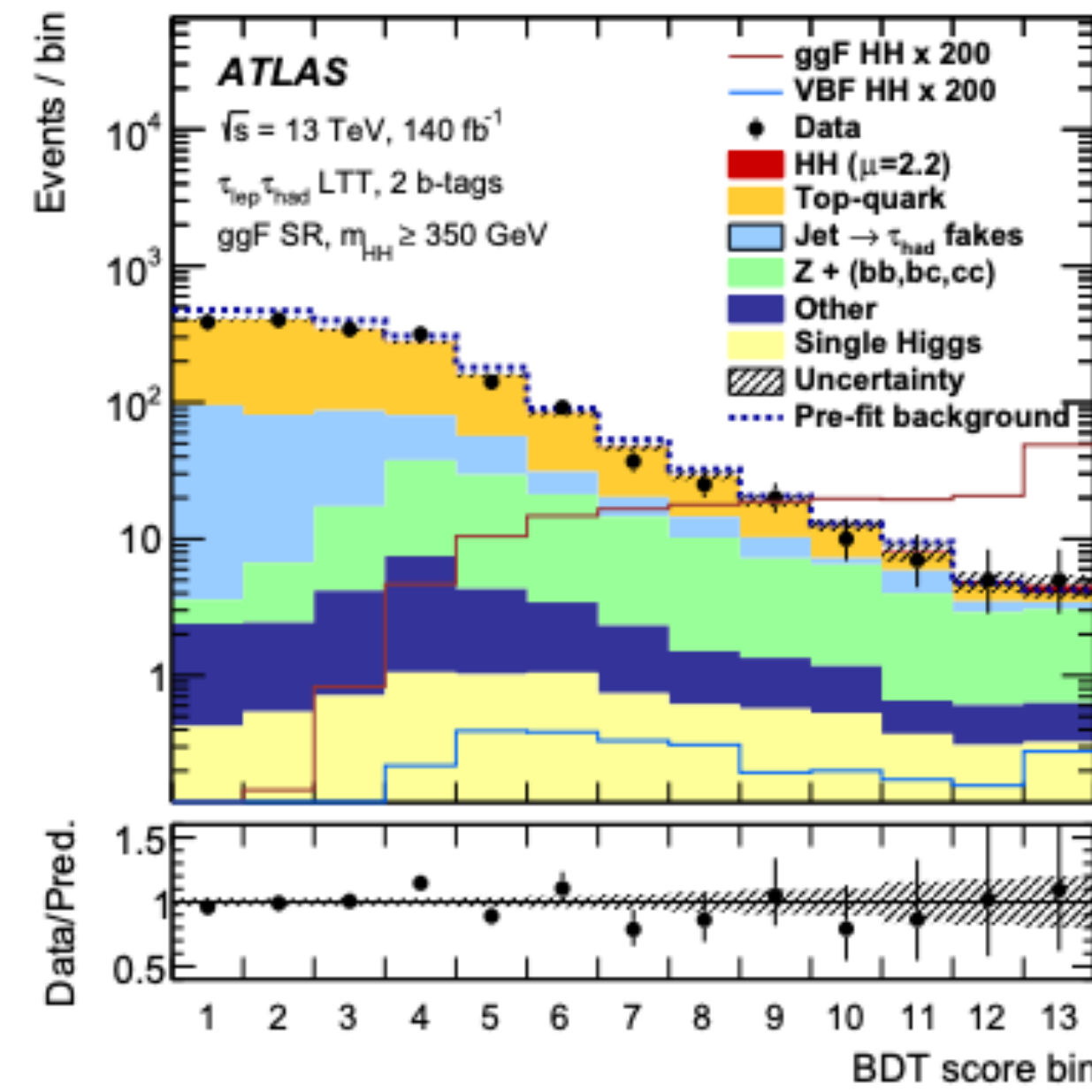
(e)



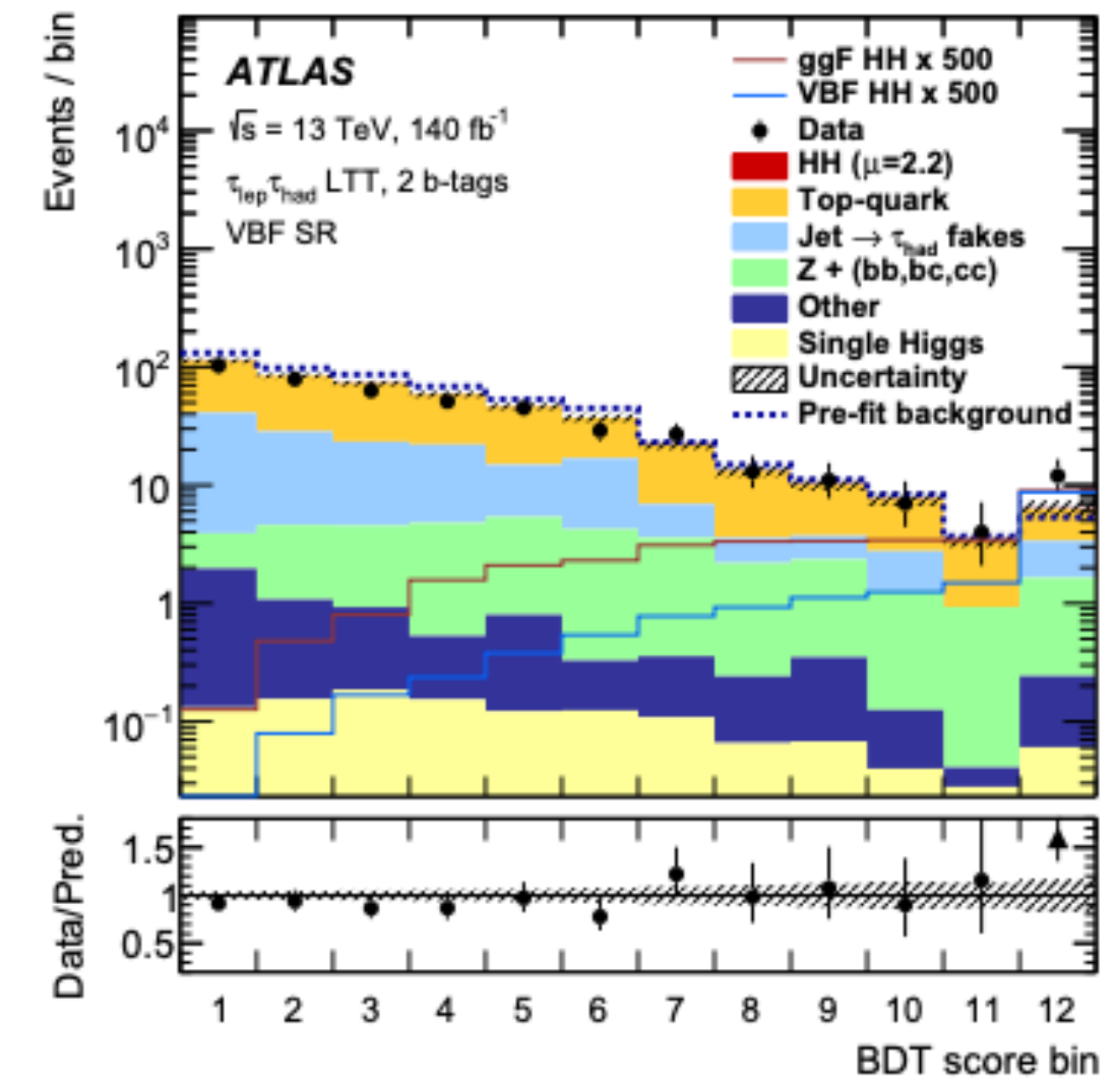
(f)



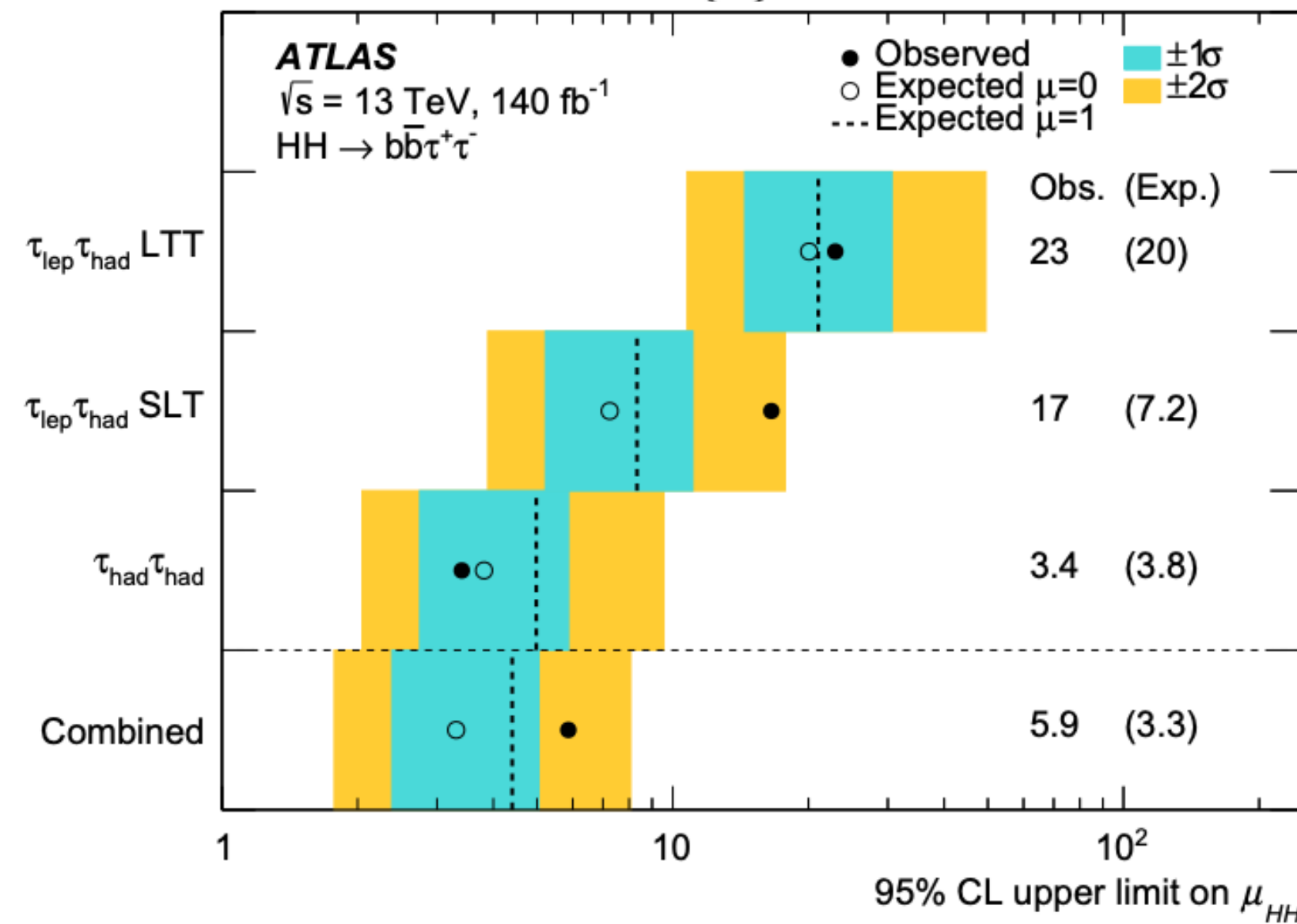
(g)



(h)



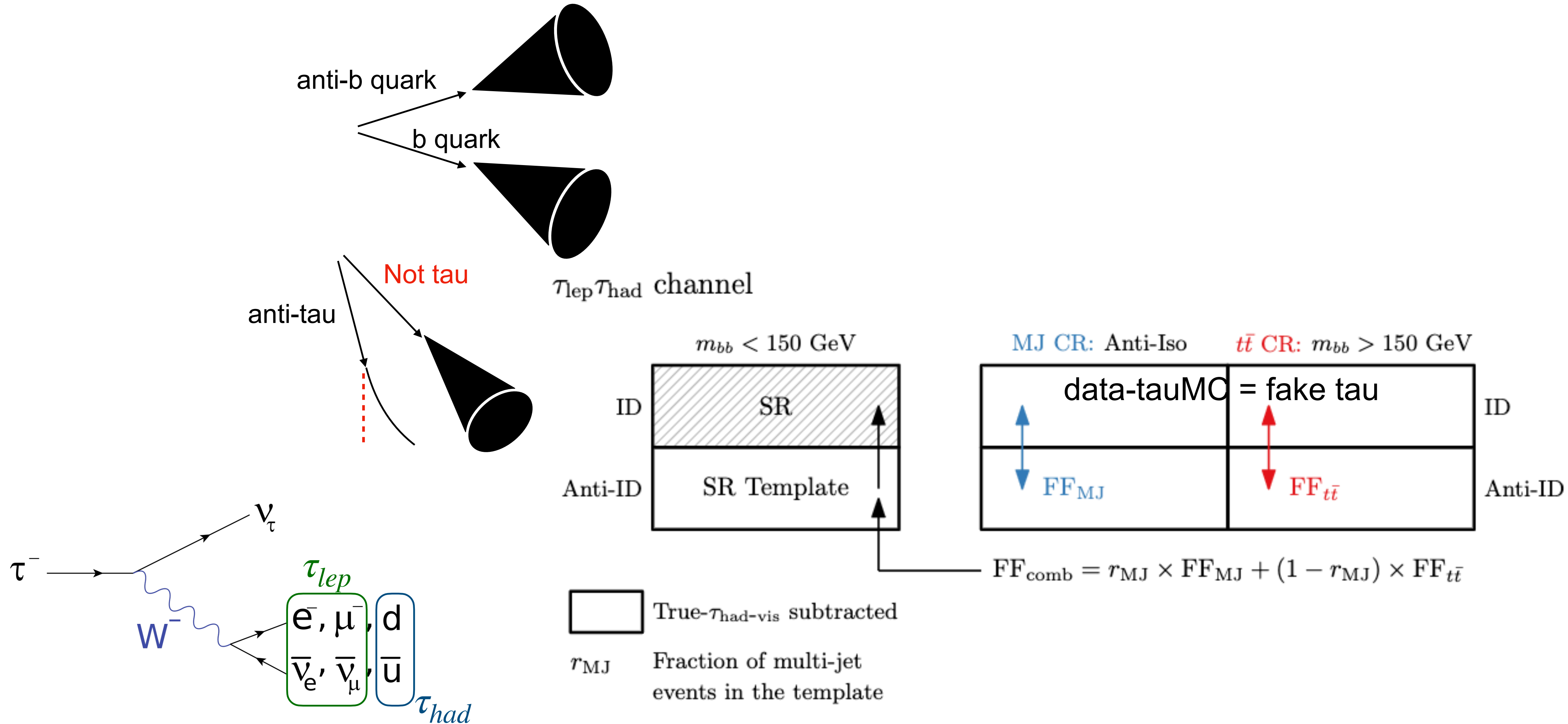
(i)



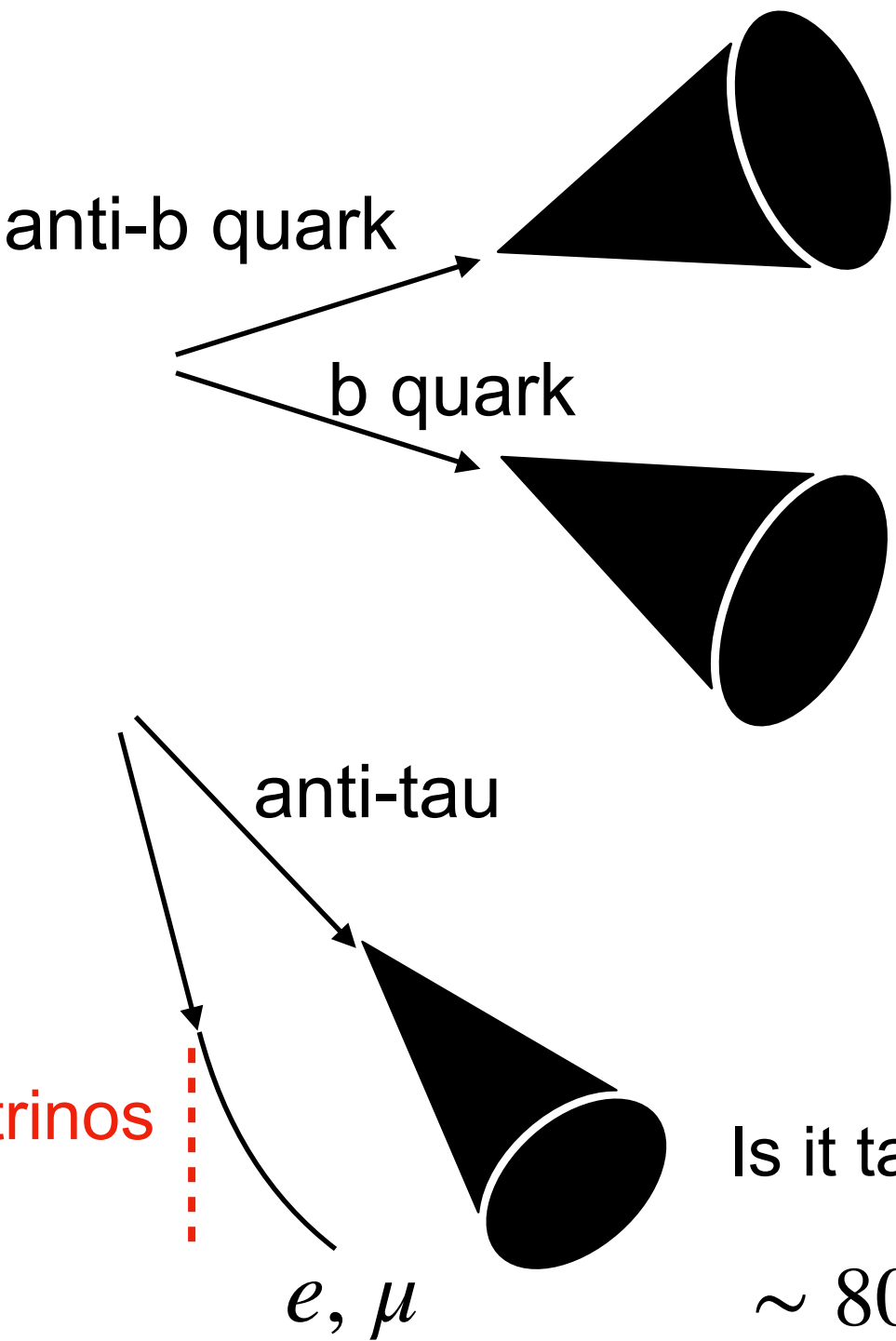
Fresh results!

$HH \rightarrow bb\tau\tau$ fake tau-had

ID: $\tau_{had-vis}$ passed RNN 'loose' WP
Anti-ID: $\tau_{had-vis}$ failed RNN 'loose' WP & RNN score > 0.01
 $\tau_{had-vis}$: reconstructed τ_{had} candidate with BDT on track vars.

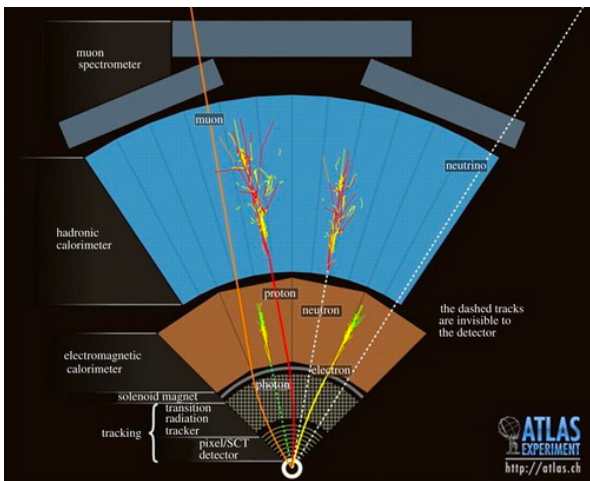


$HH \rightarrow bb\tau\tau$ event and objects



Is it b-jet? DL1r (deep learning algorithm)

b-tagging cut: 77% are accepted

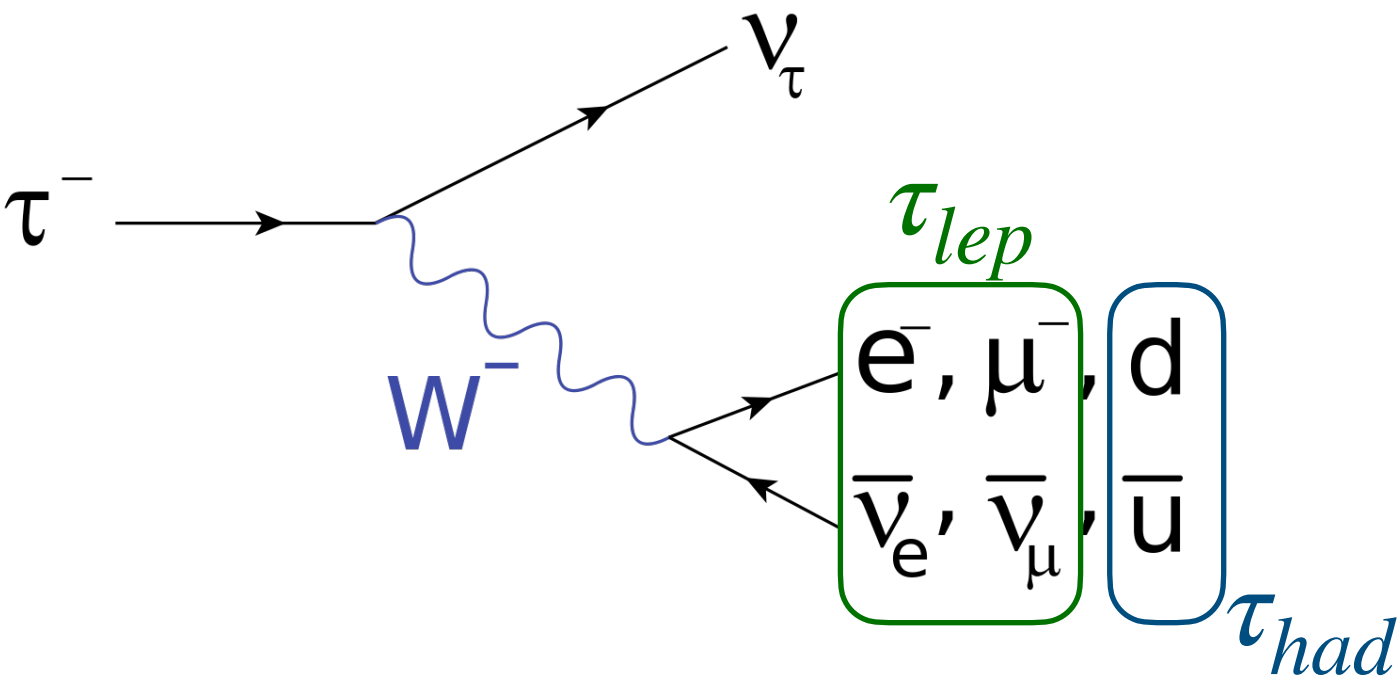


- + cuts for quality of objects (p_T, η)
- + Triggers: (STT, DTT, SLT, LTT)
- + cuts to reduce background:
 $m_{\tau\tau} > 60 \text{ GeV}, m_{bb} < 150 \text{ GeV}$

Missing energy from neutrinos

Is it tau-jet? $\sim 80 \%$ tau jets are accepted

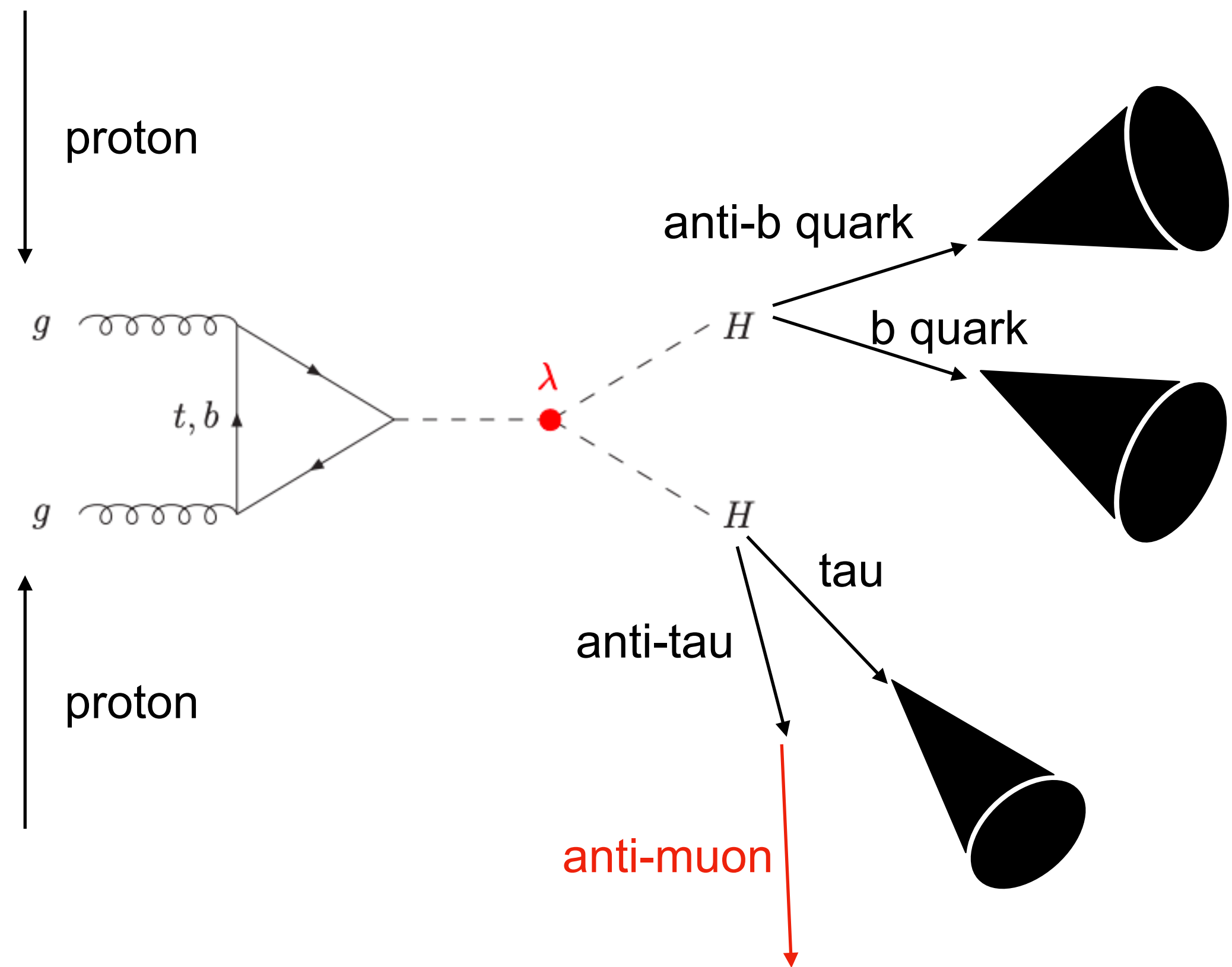
$\sim 80 \%$ of electrons are accepted



- $\tau_{had}\tau_{had}$ channel ~ 140 events $\rightarrow 6$ events
- $\tau_{lep}\tau_{had}$ channel ~ 150 events $\rightarrow 7$ events

ok...

2 Higgs in ATLAS



Large branching ratio



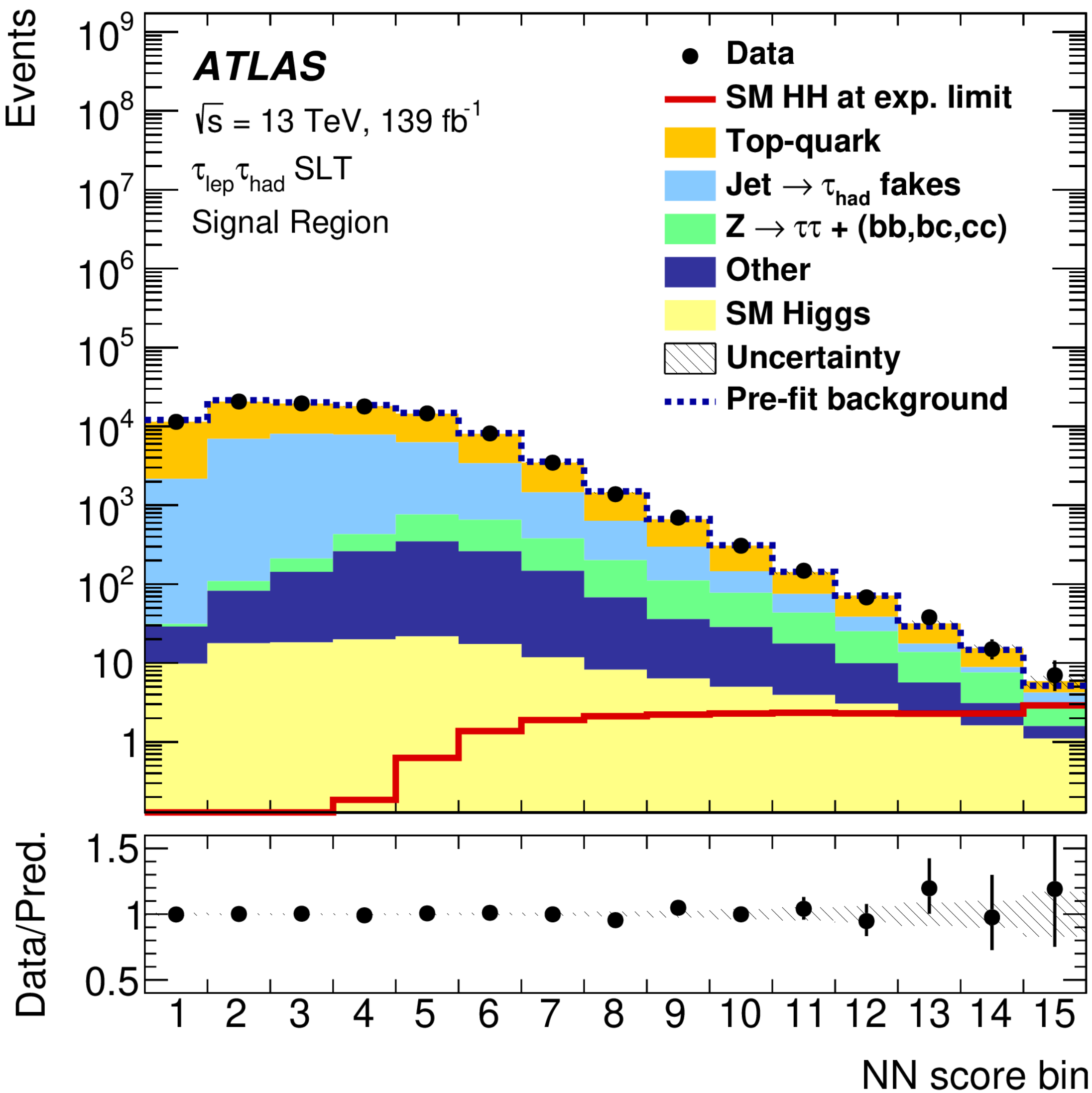
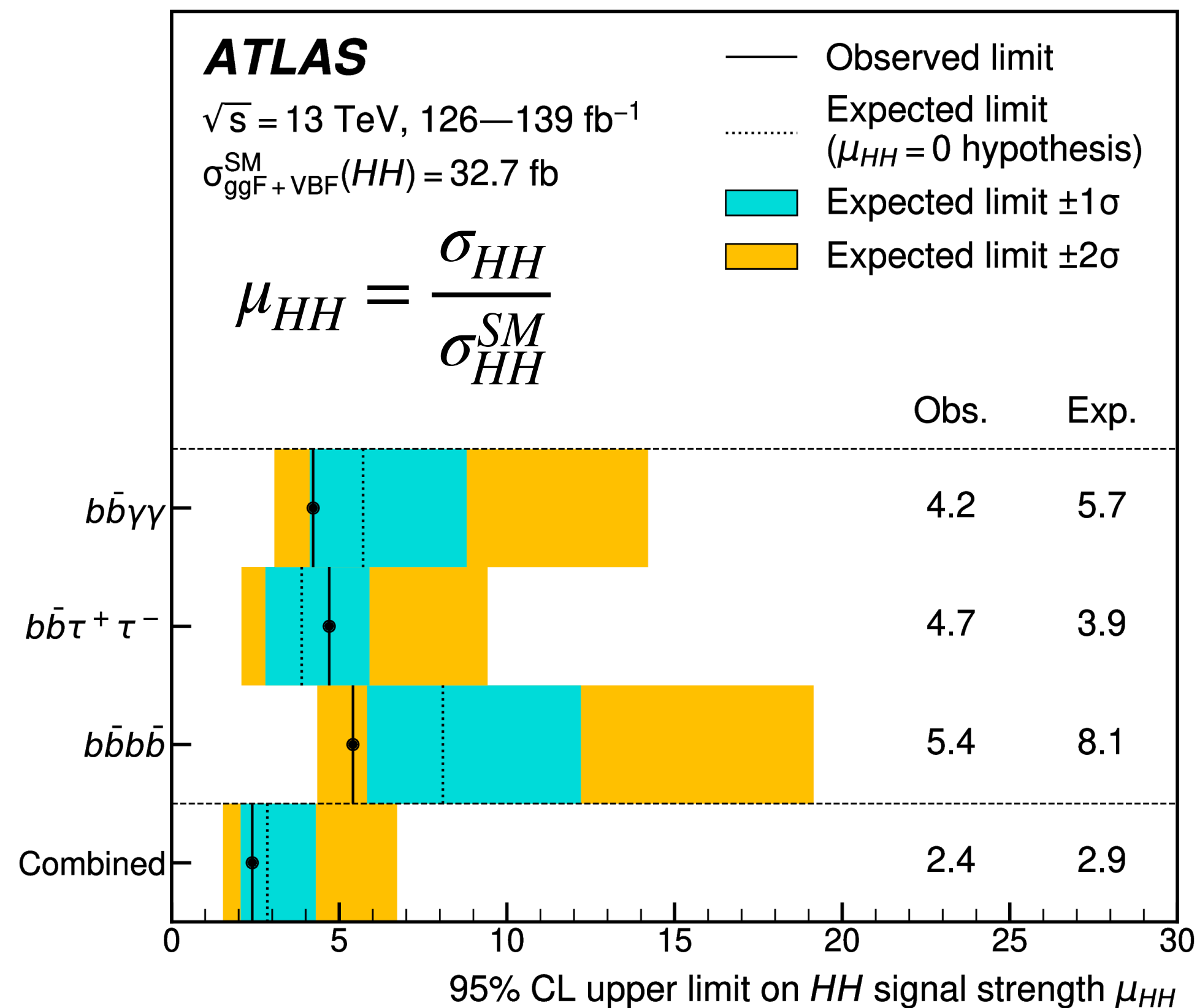
Clean final state

	bb	WW	$\tau\tau$	ZZ	$\gamma\gamma$
bb	34 %				
WW	25 %	4.6 %			
$\tau\tau$	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 %

Di-Higgs in ATLAS

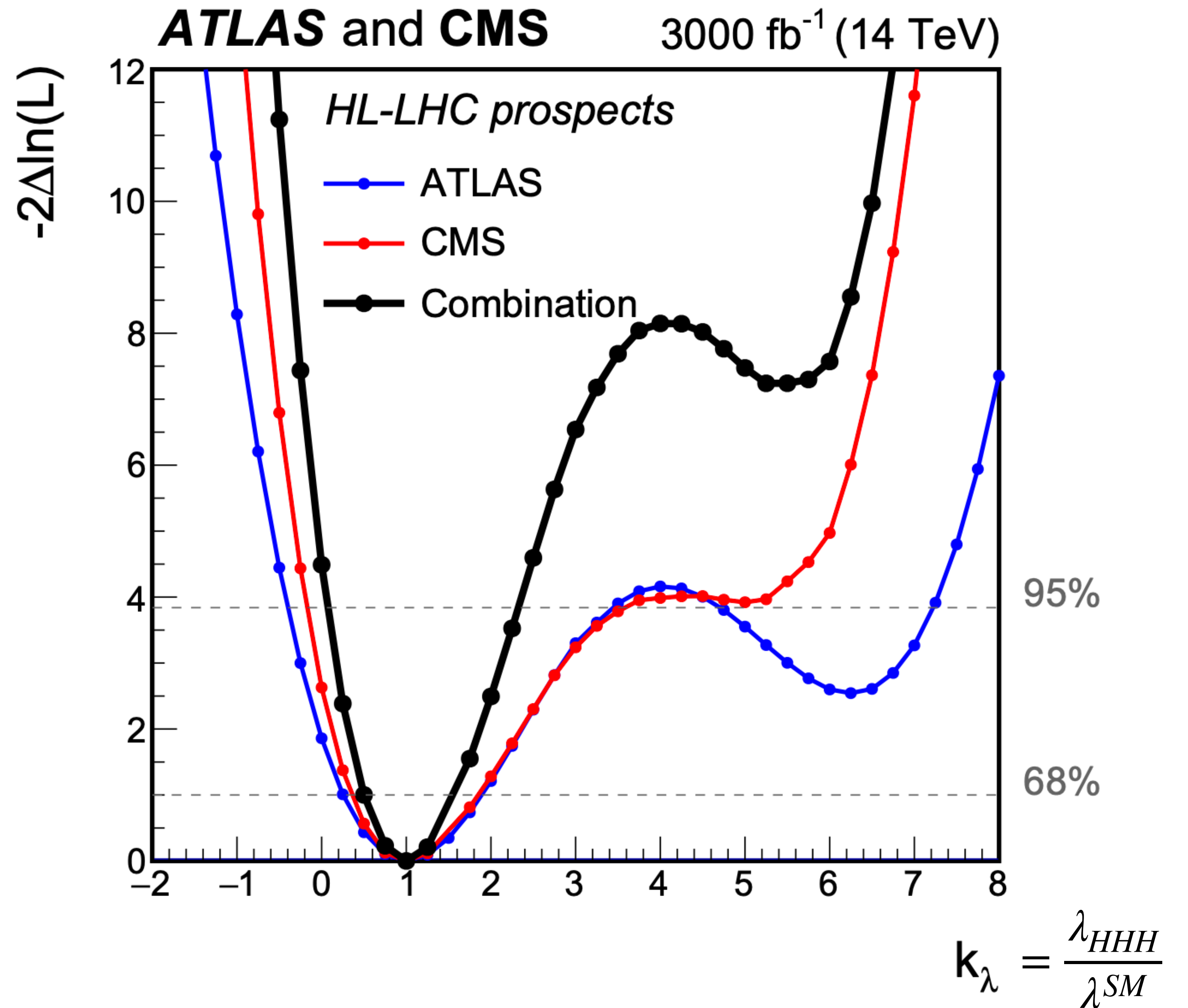
How we treat events: (examples)

- 1. Trigger: high-energy muon -> save the data!
- 2. Event selection: 2 b-jets of combined mass < 150 GeV
- 3. Use machine learning to separate signal from background
- 4. Statistical fit signal strength to data



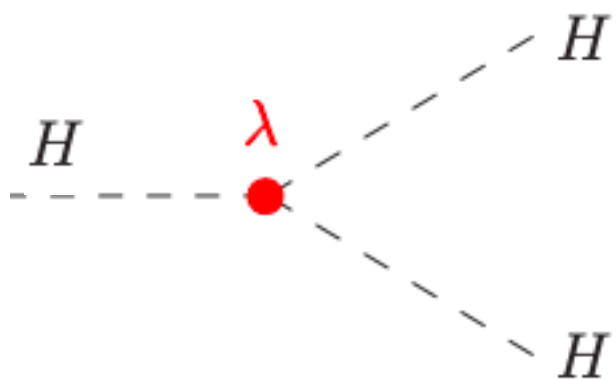
Di-Higgs in ATLAS

High Luminosity LHC coming!
X10 more data!
Launch round 2030



Di-Higgs with High Lumi LHC (~2030) (10 x data)

Shape of Higgs?



$$0.5 < \kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{SM}} < 1.5$$

New Physics?!

