Latest Results from ATLAS and Higgs Self-Coupling Measurements

TRIUMF Science Week

Maximilian Swiatlowski

TRIUMF

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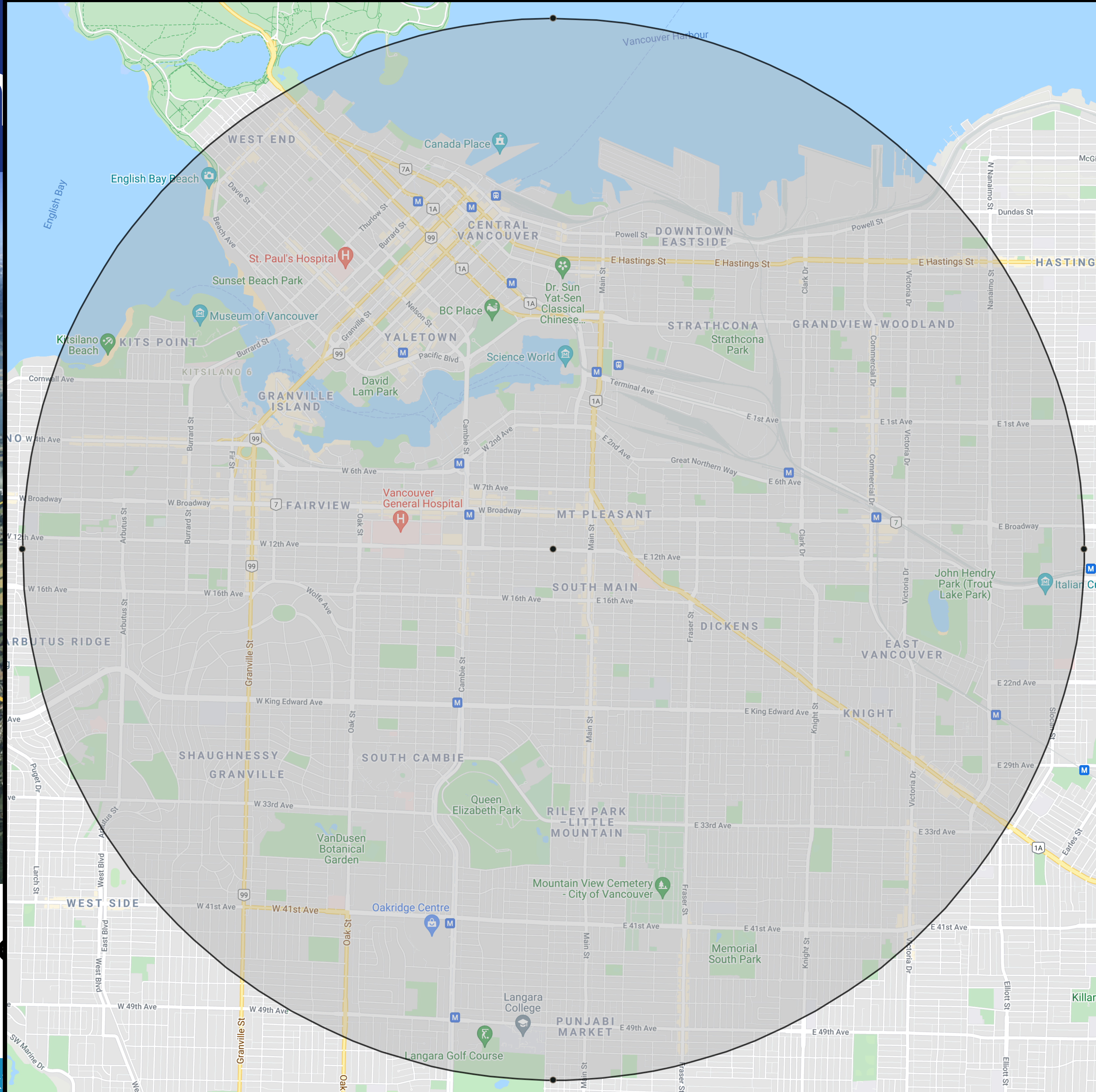

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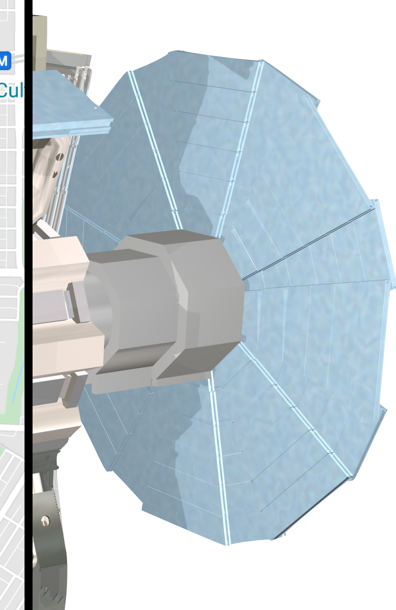

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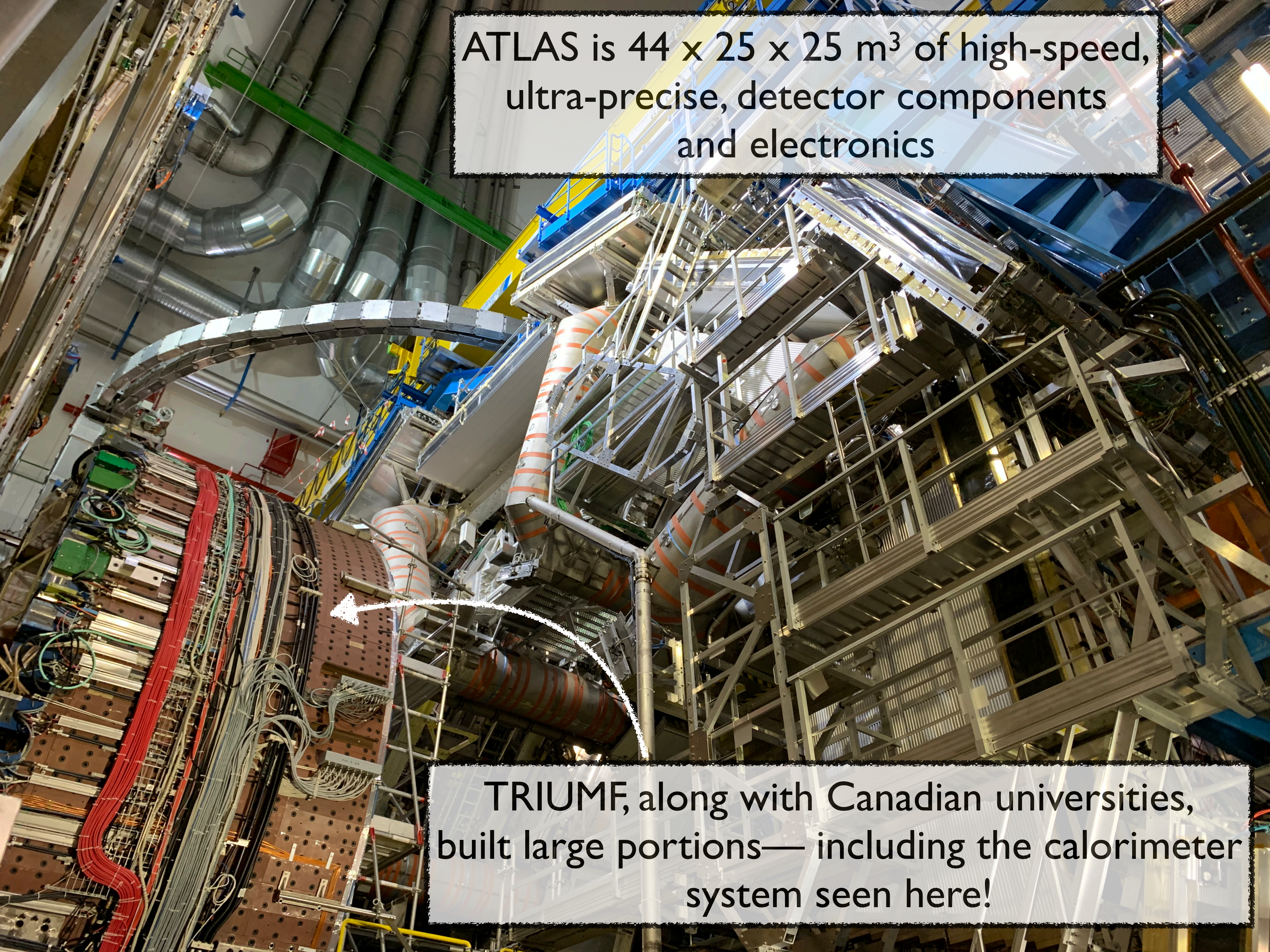
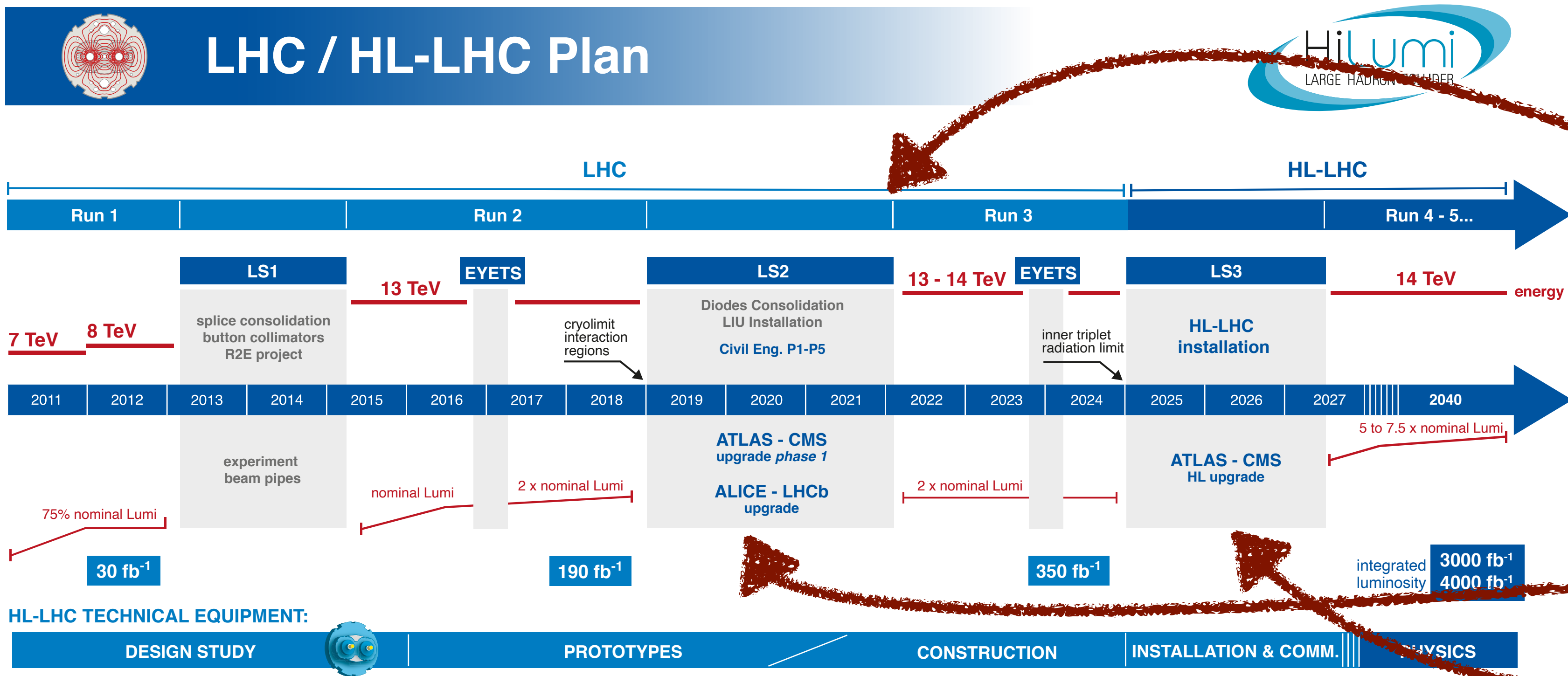


ATLAS is 44 x 25 x 25 m^3 of high-speed, ultra-precise, detector components and electronics

TRIUMF, along with Canadian universities, built large portions— including the calorimeter system seen here!

ATLAS Status

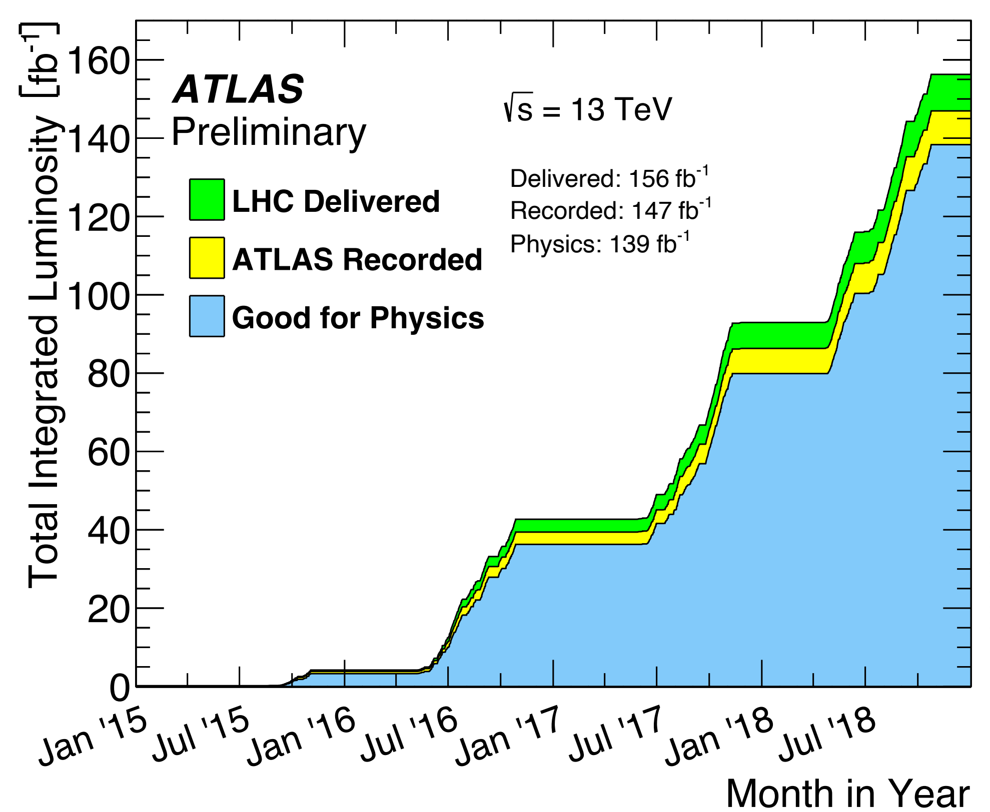


We are here:
Run3 about to start!

Huge round of upgrades installed in LS2: more preparing for LS3

Run 2 dataset is being fully mined for discovery!

139 fb^{-1} of data: huge dataset for measurement and discovery



Latest
ATLAS Highlights

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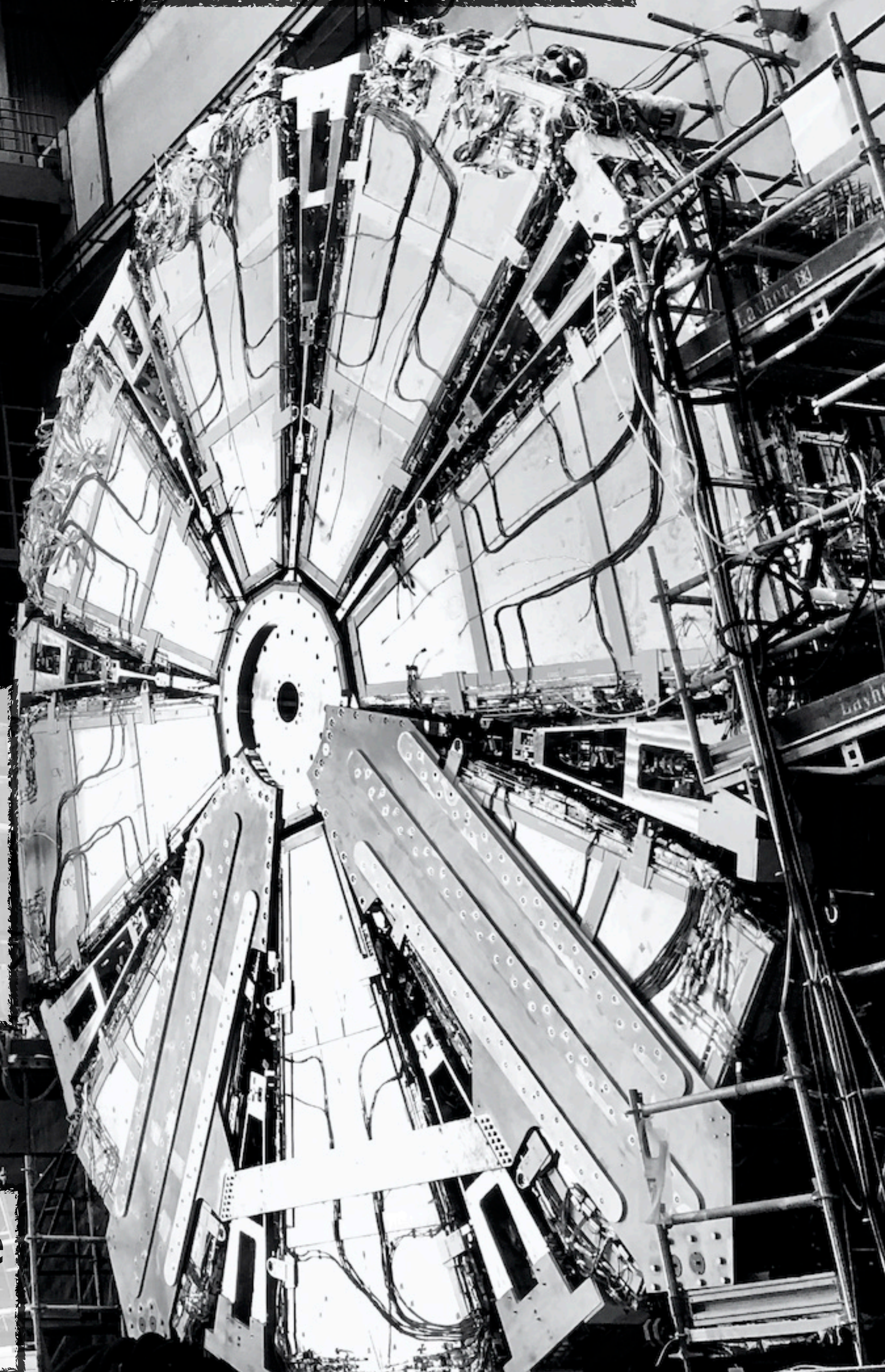
The New Small Wheels are the highlight of ATLAS's LS2 upgrades:
Two enormous new muon detectors being inserted in the detector now
(Huge TRIUMF contributions!)

~10 m in diameter!



New and improved reconstruction and trigger algorithms, especially with Machine Learning

Tremendous progress on hardware upgrades: new inner tracker system, calorimeter read-out, and more in preparation for 2025

Dozens of new results this summer: some highlights today!

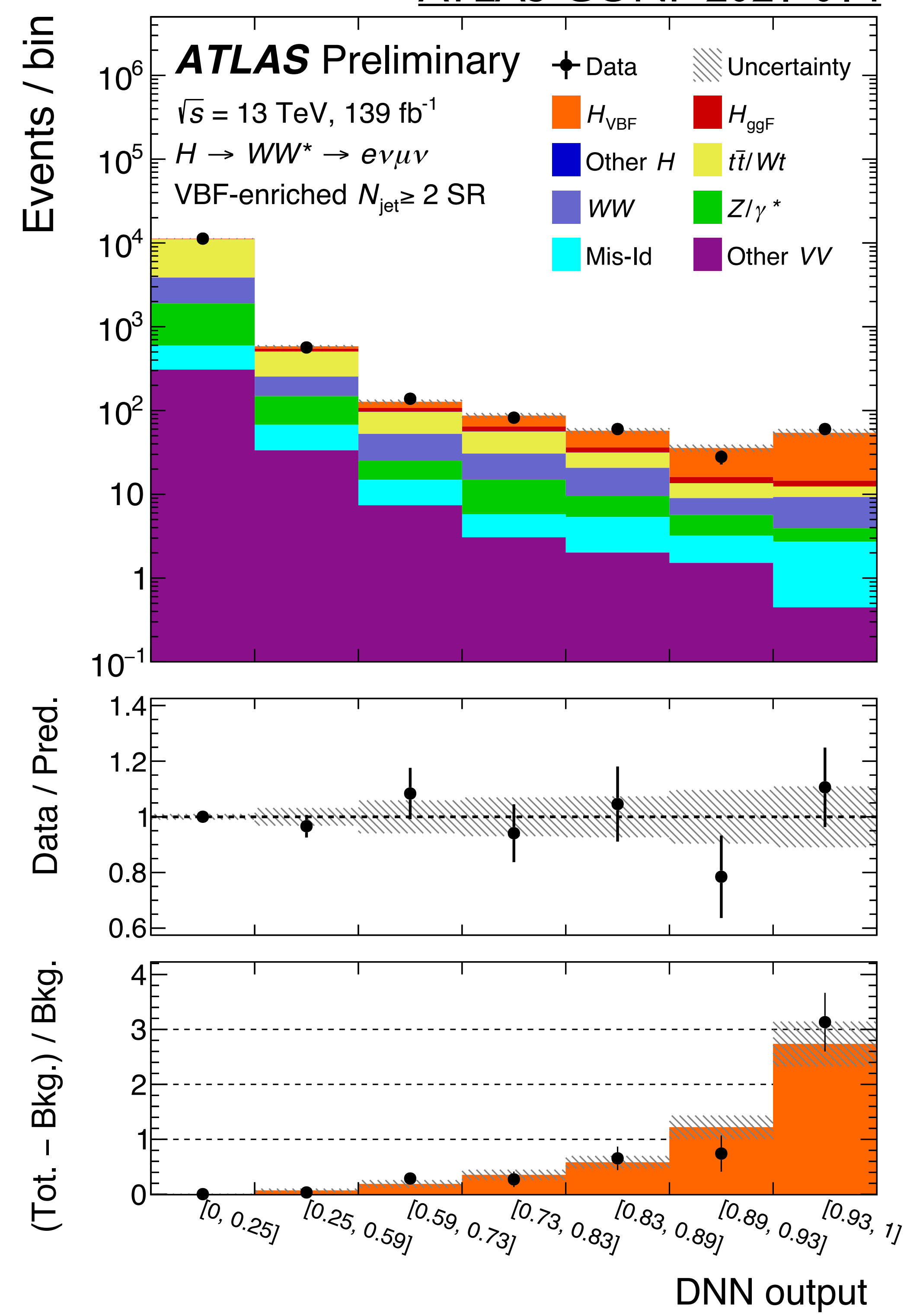
Higgs Boson Measurements

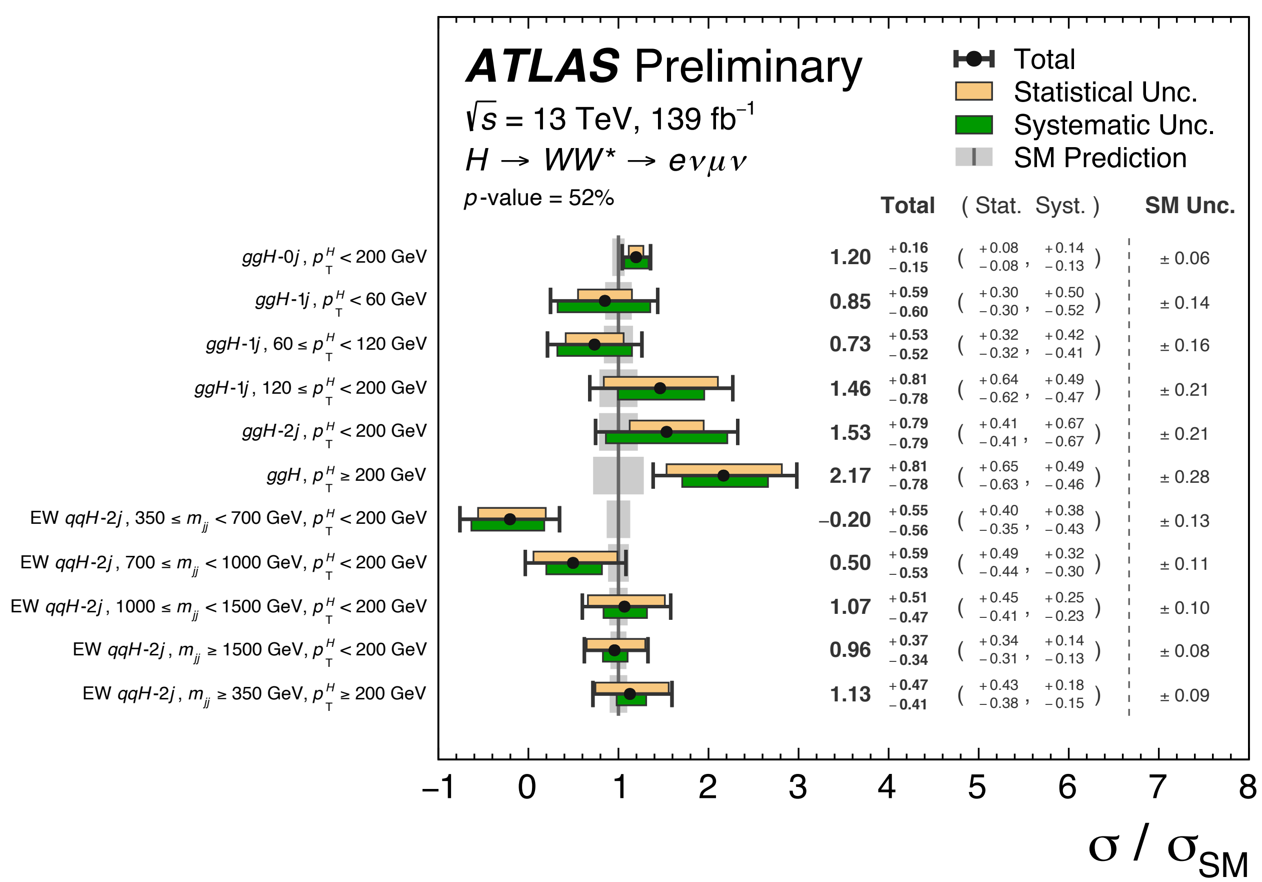
We only discovered the Higgs a few years ago, but we are moving into the precision measurement era

Neural networks are increasing our sensitivity to levels never before seen!

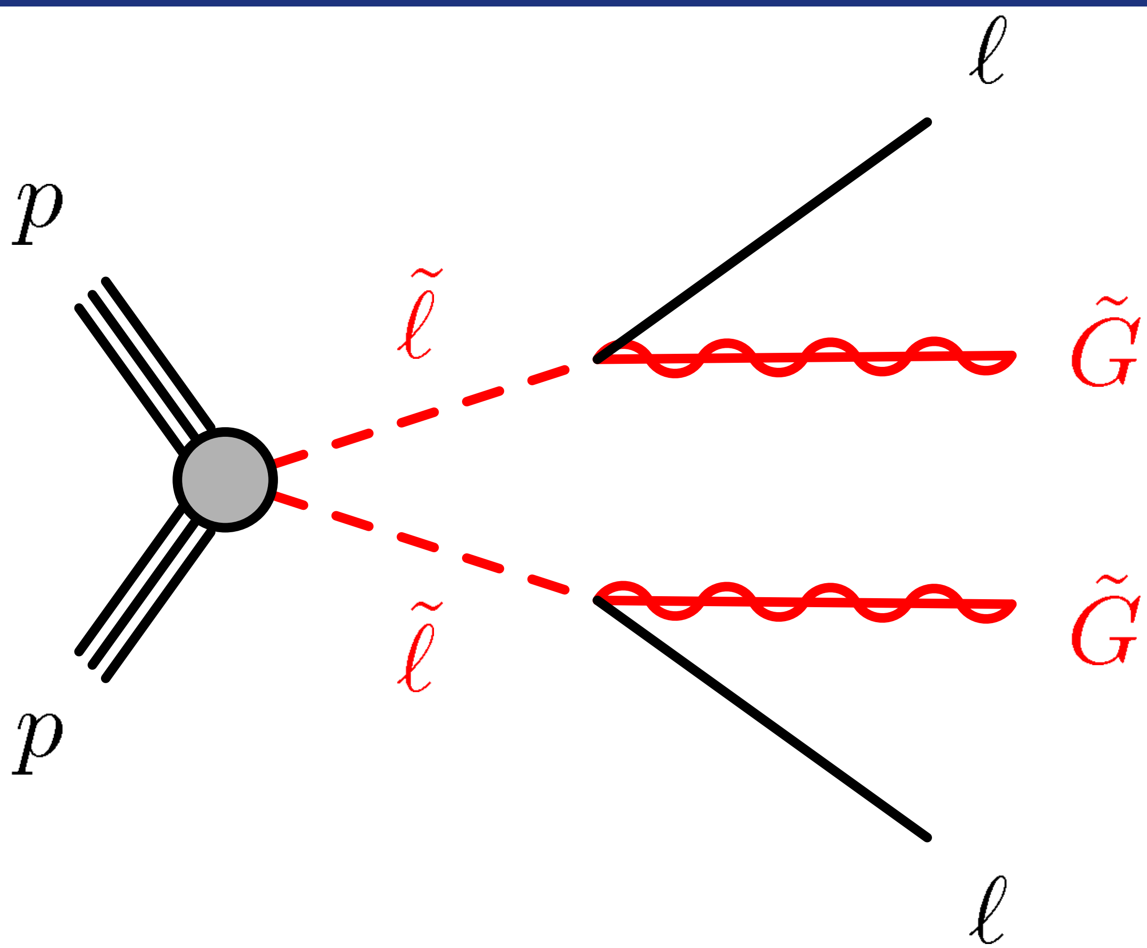
Huge datasets enable hugely differential measurements

ATLAS-CONF-2021-014





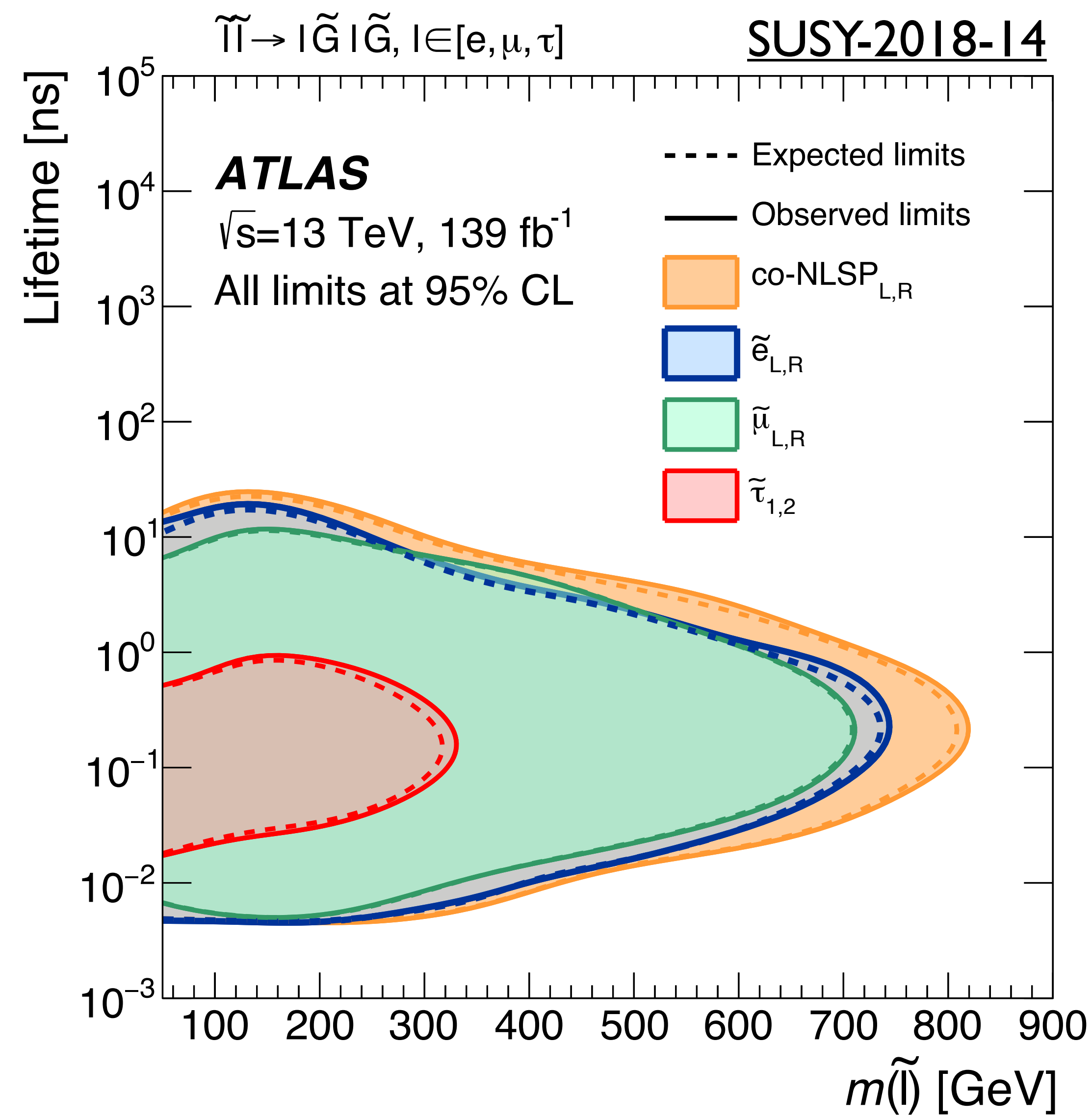
Searches for BSM



Set limits based on slepton flavor, lifetime, mass

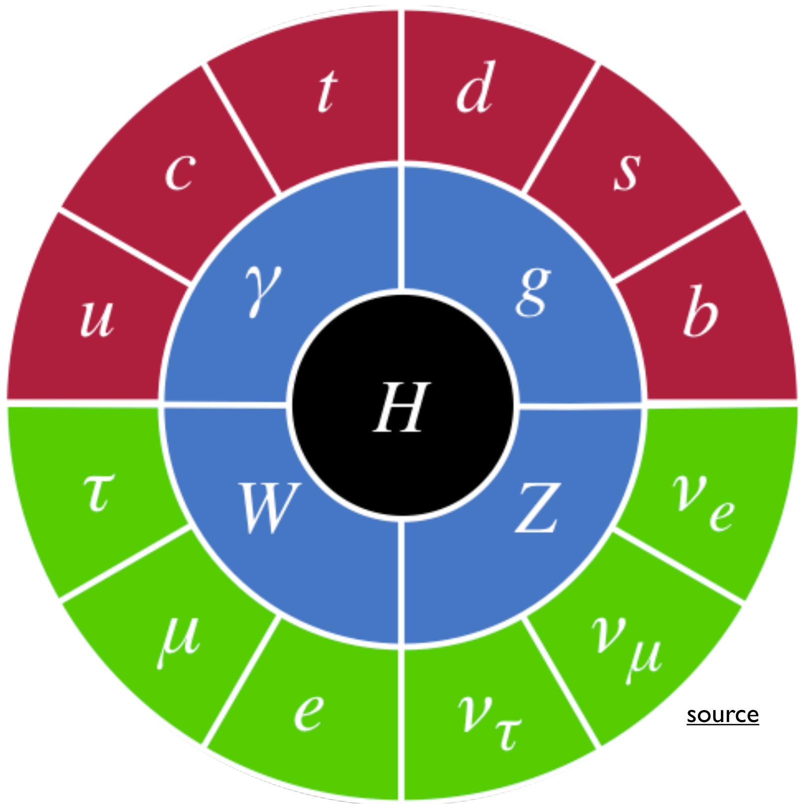
First limits since LEP on these models!

New searches for ***long-lived*** BSM particles



The Higgs Self-Coupling

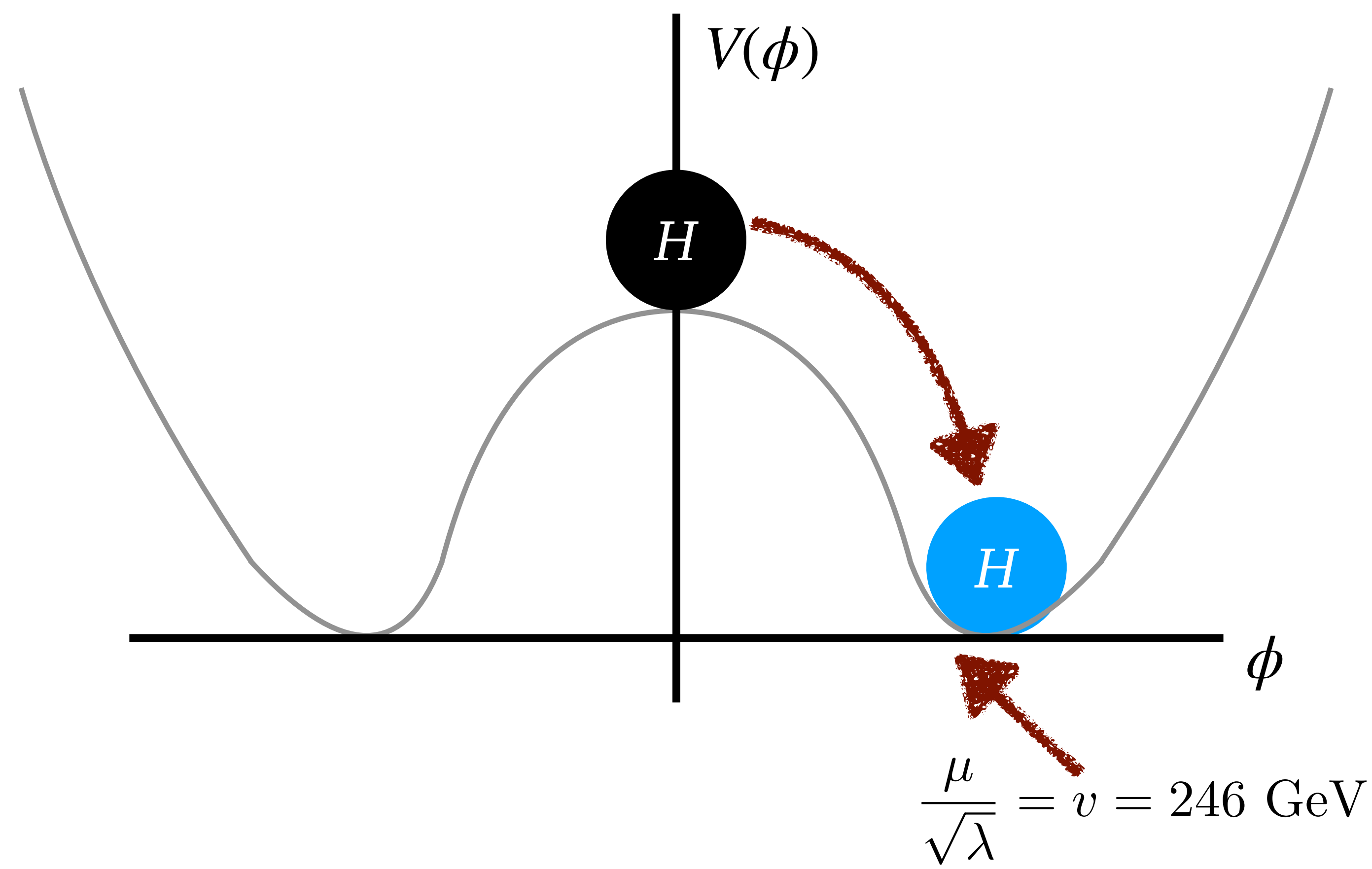
The Higgs Potential



The Higgs is the center of the Standard Model!

The Higgs is unique:
Originates from "Electroweak Symmetry Breaking" of the **Higgs potential**

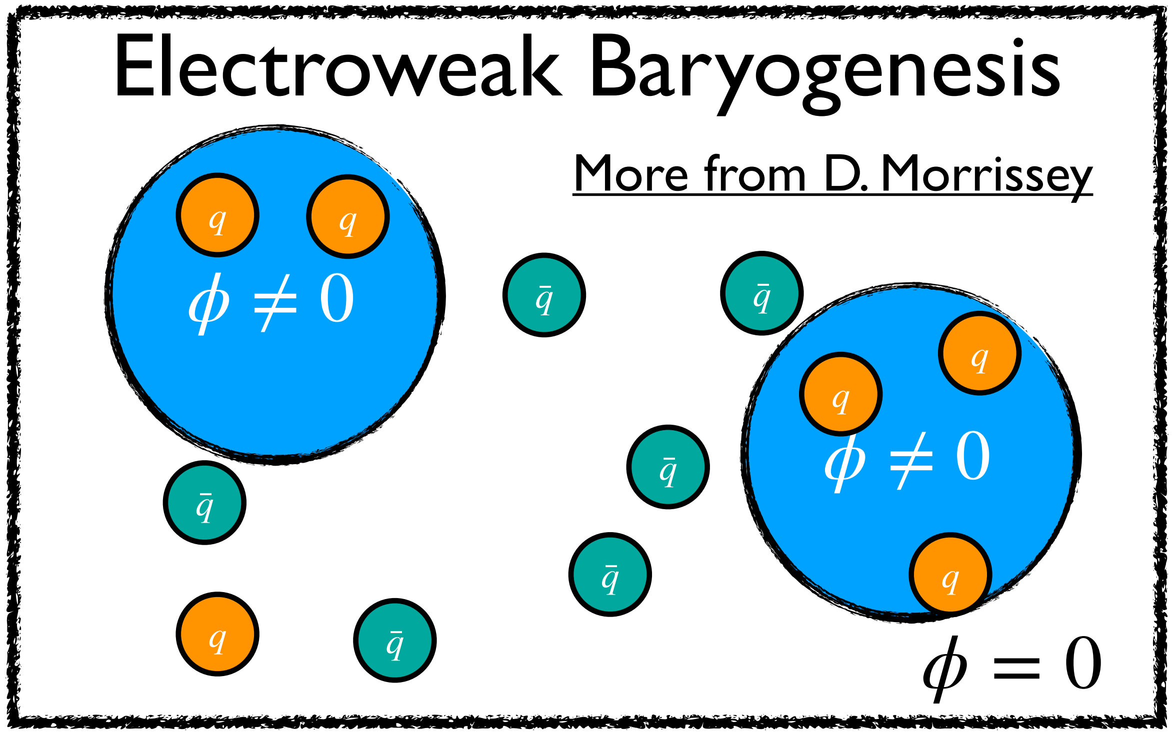
$$V(\phi) = -\frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$



Why Measure the Potential?

The potential isn't static: it had a different shape in the early universe

If the potential had the *right shape* as it cools after the Big Bang, this phase transition might explain the universe's matter/anti-matter asymmetry!



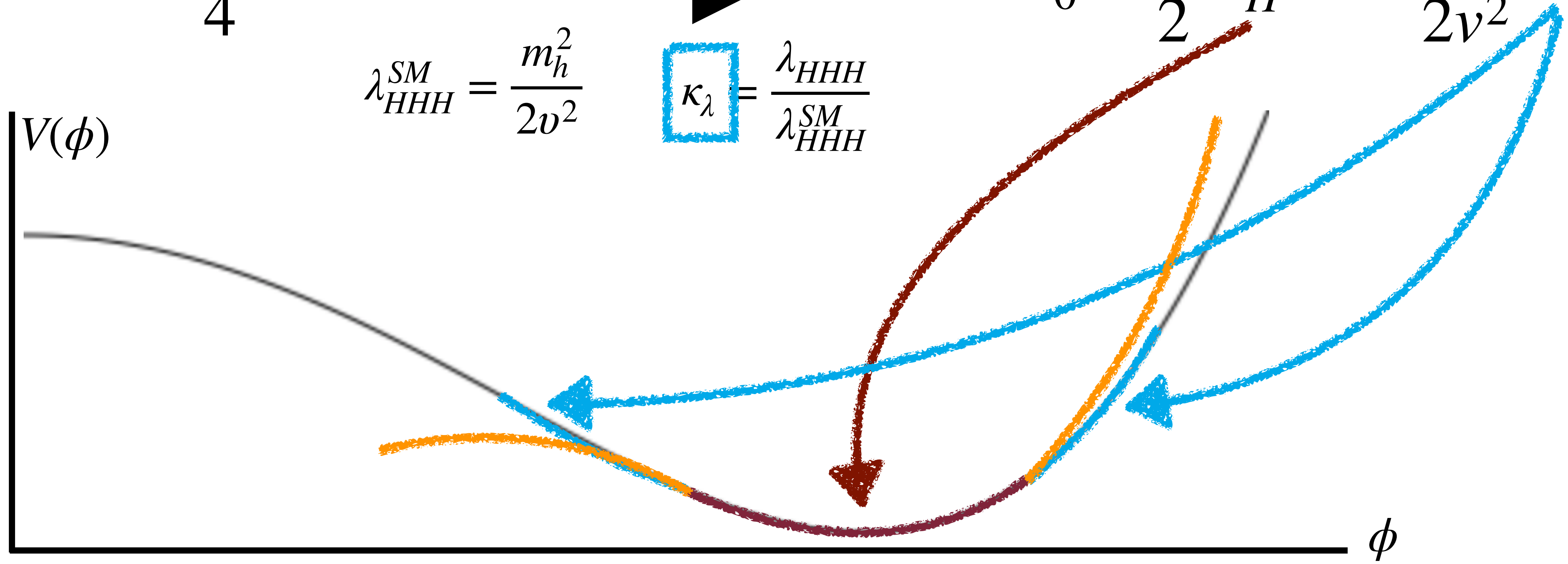
Measuring the Potential

$$V(\phi) = -\frac{1}{2}\mu^2\phi^2 + \frac{1}{4}\lambda\phi^4$$

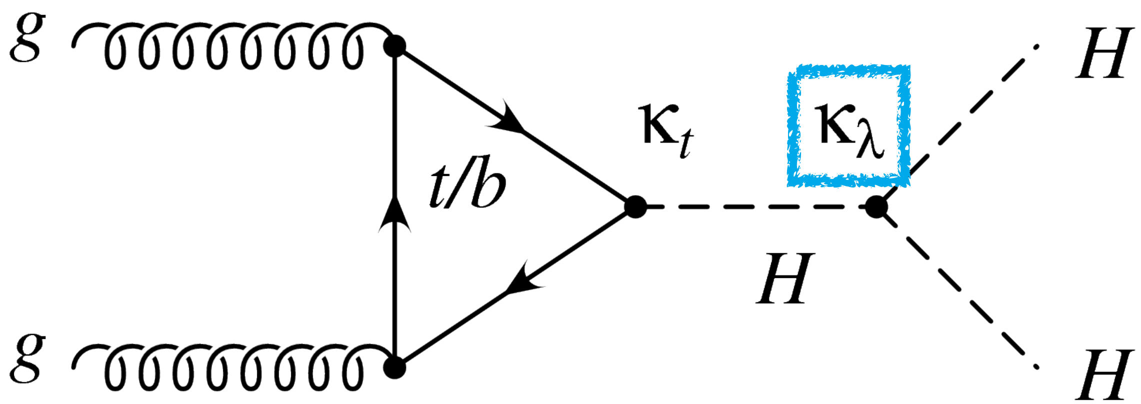
Taylor expand →

$$V \approx V_0 + \frac{1}{2}m_H^2 h^2 + \frac{m_H^2}{2v^2} v h^3 + \ldots$$

$$\lambda_{HHH}^{SM} = \frac{m_h^2}{2v^2} \qquad \kappa_\lambda = \frac{\lambda_{HHH}}{\lambda_{HHH}^{SM}}$$



We can measure these di-Higgs events at the LHC!



How often these di-Higgs happen lets us measure the Higgs potential by measuring κ_λ

If we see something completely different from the SM prediction, we know $\kappa_\lambda \neq 1$!

Searching for Higgs Pairs

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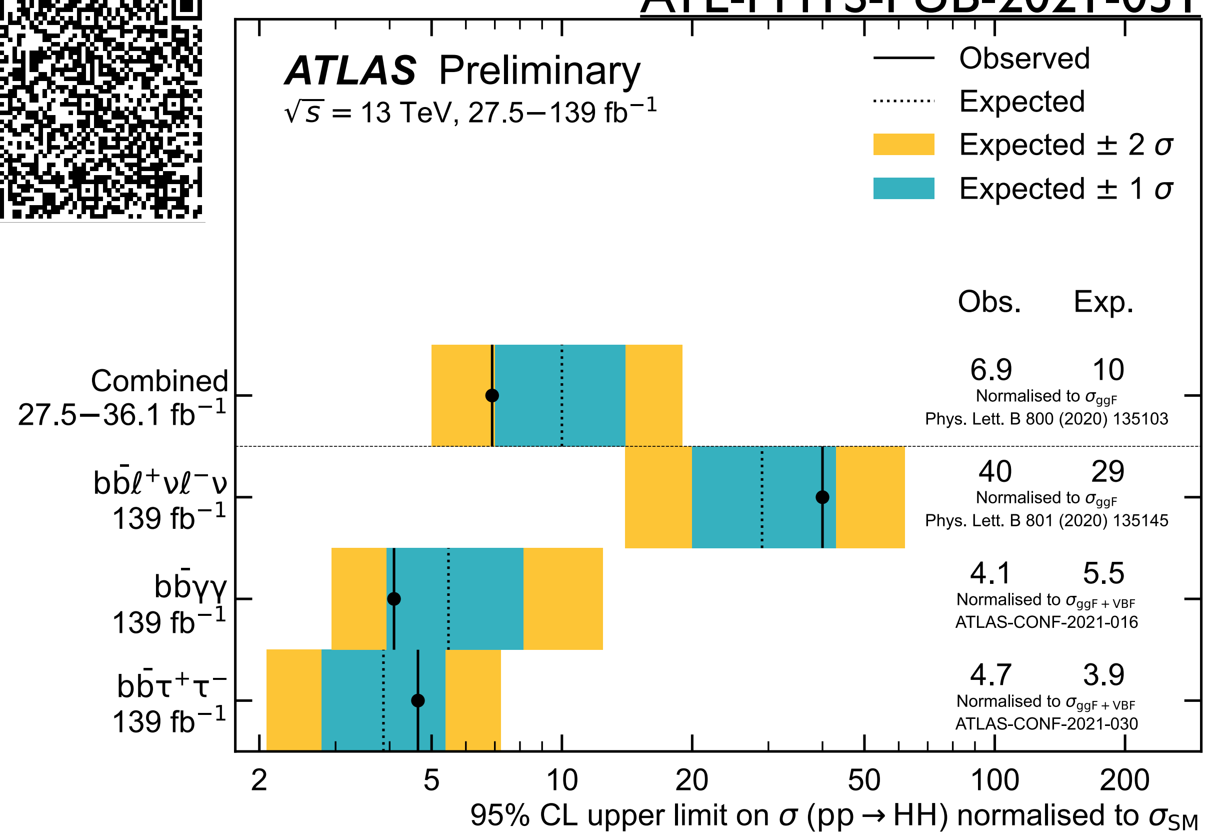

Here, show what factor of the SM x-sec we can exclude

Two Higgs bosons means two decays: $bb\gamma\gamma$ and $bb\tau\tau$ channels each exclude around 4x the SM

More channels and more data mean the SM x-sec is in sight!

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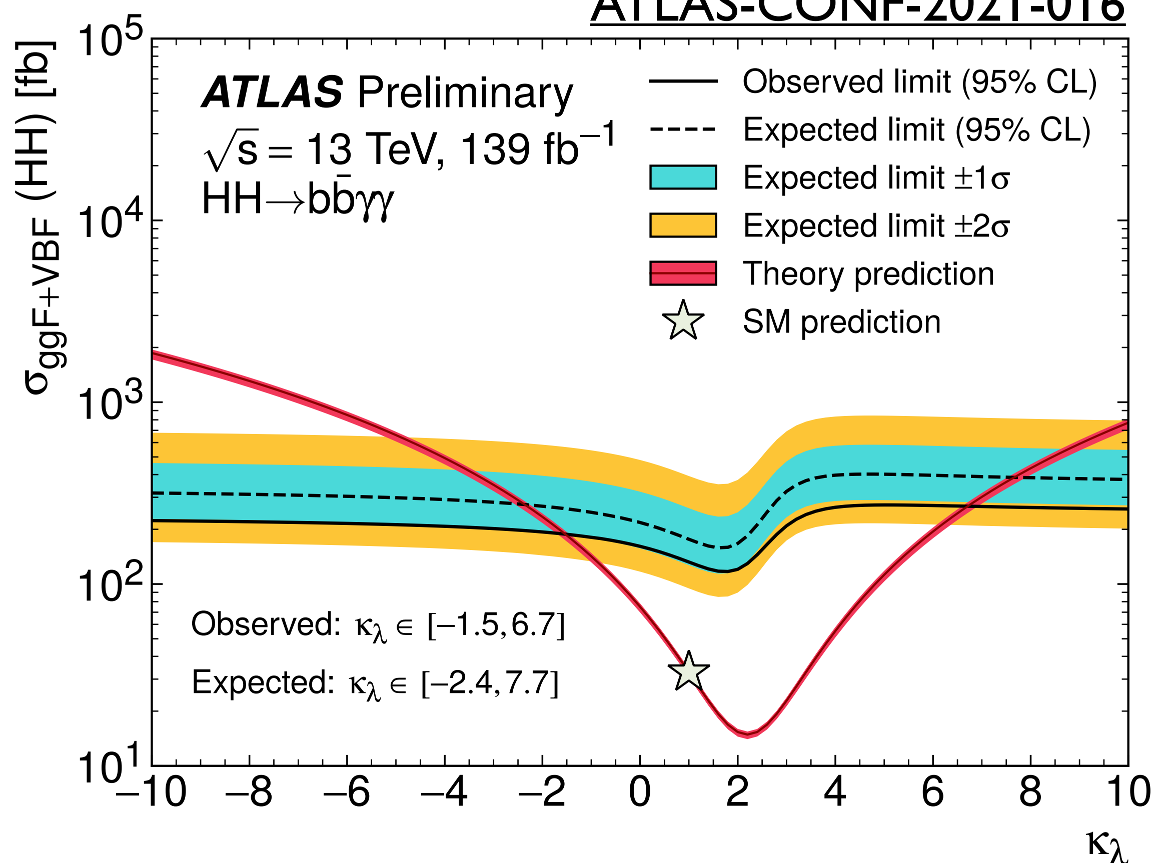

Here, show sensitivity to κ_λ: the actual deviation in the Higgs self-coupling

Values below -1.5 and above 6.7 excluded: even full HL-LHC dataset will critical to tighten this!

Searching for Higgs Pairs

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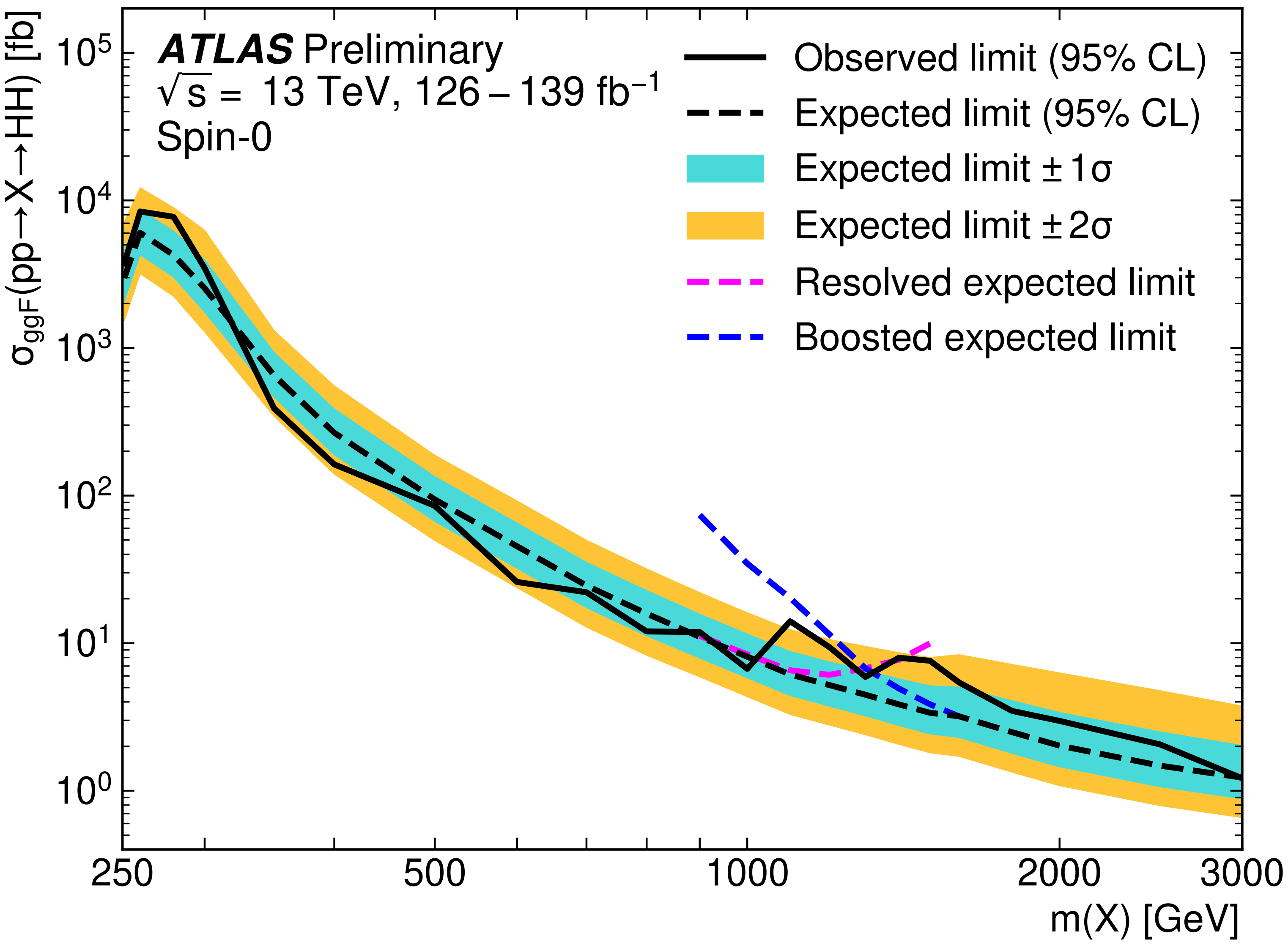
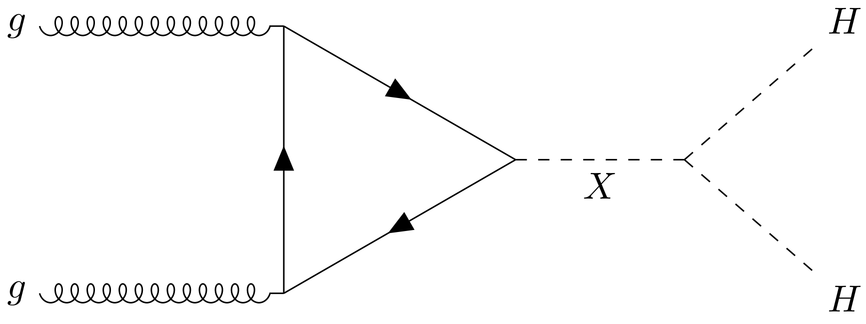




Also important to search for resonances, which actually *cause* the change in the potential

Here, search in the $bbbb$ channel: most common decay mode

Conclusions

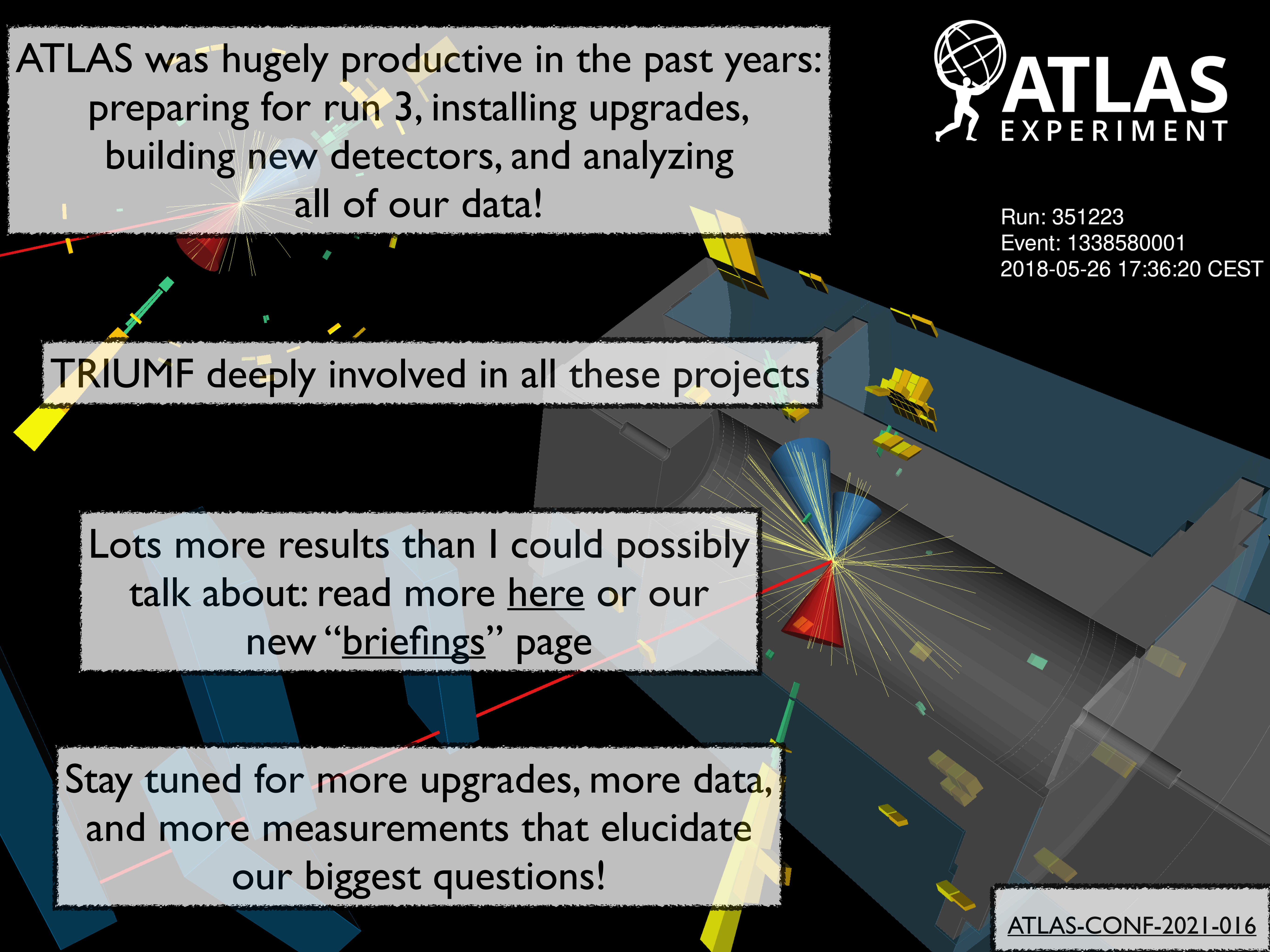
ATLAS was hugely productive in the past years: preparing for run 3, installing upgrades, building new detectors, and analyzing all of our data!

TRIUMF deeply involved in all these projects

Lots more results than I could possibly talk about: read more here or our new “briefings” page

Stay tuned for more upgrades, more data, and more measurements that elucidate our biggest questions!

ATLAS EXPERIMENT



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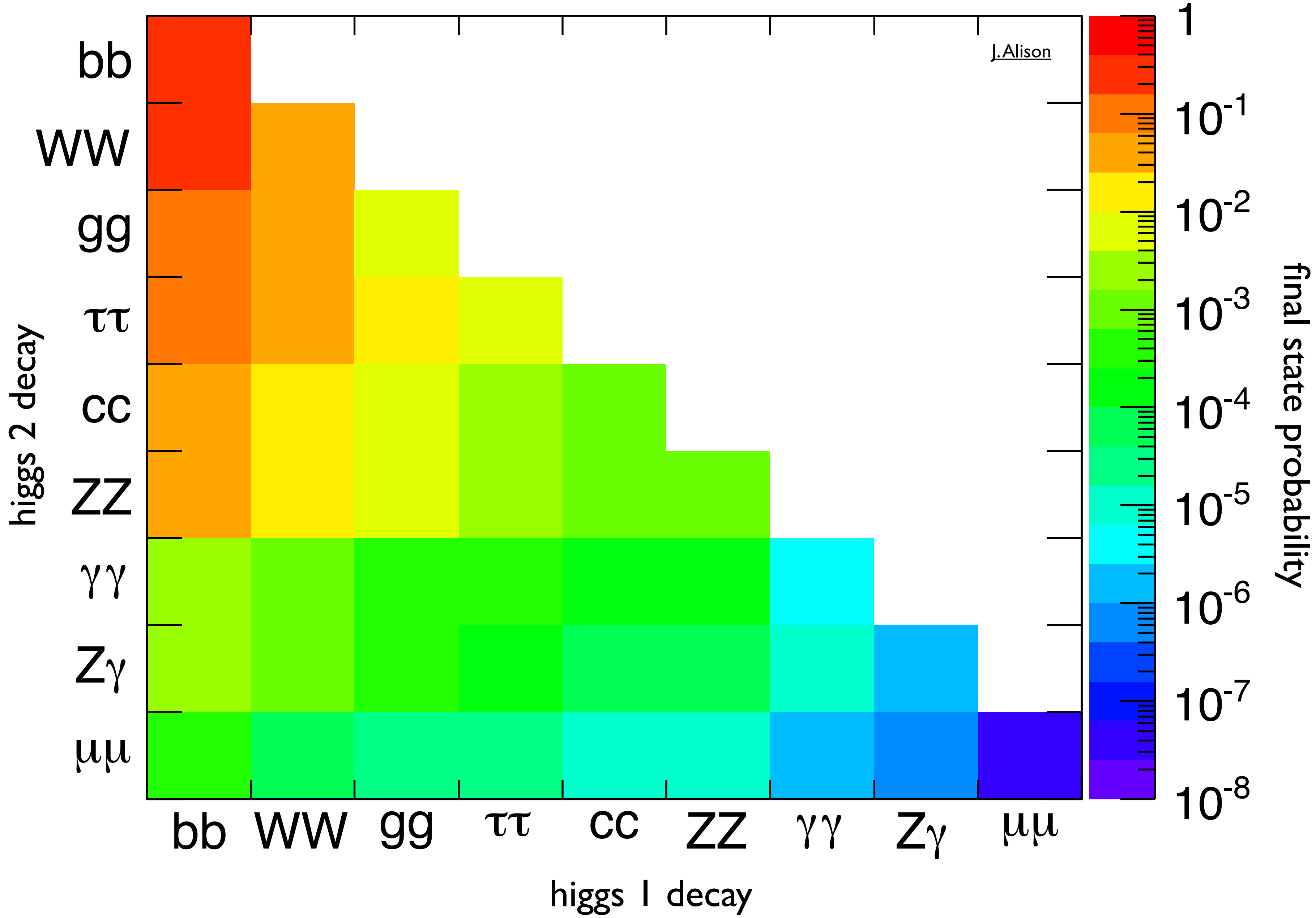
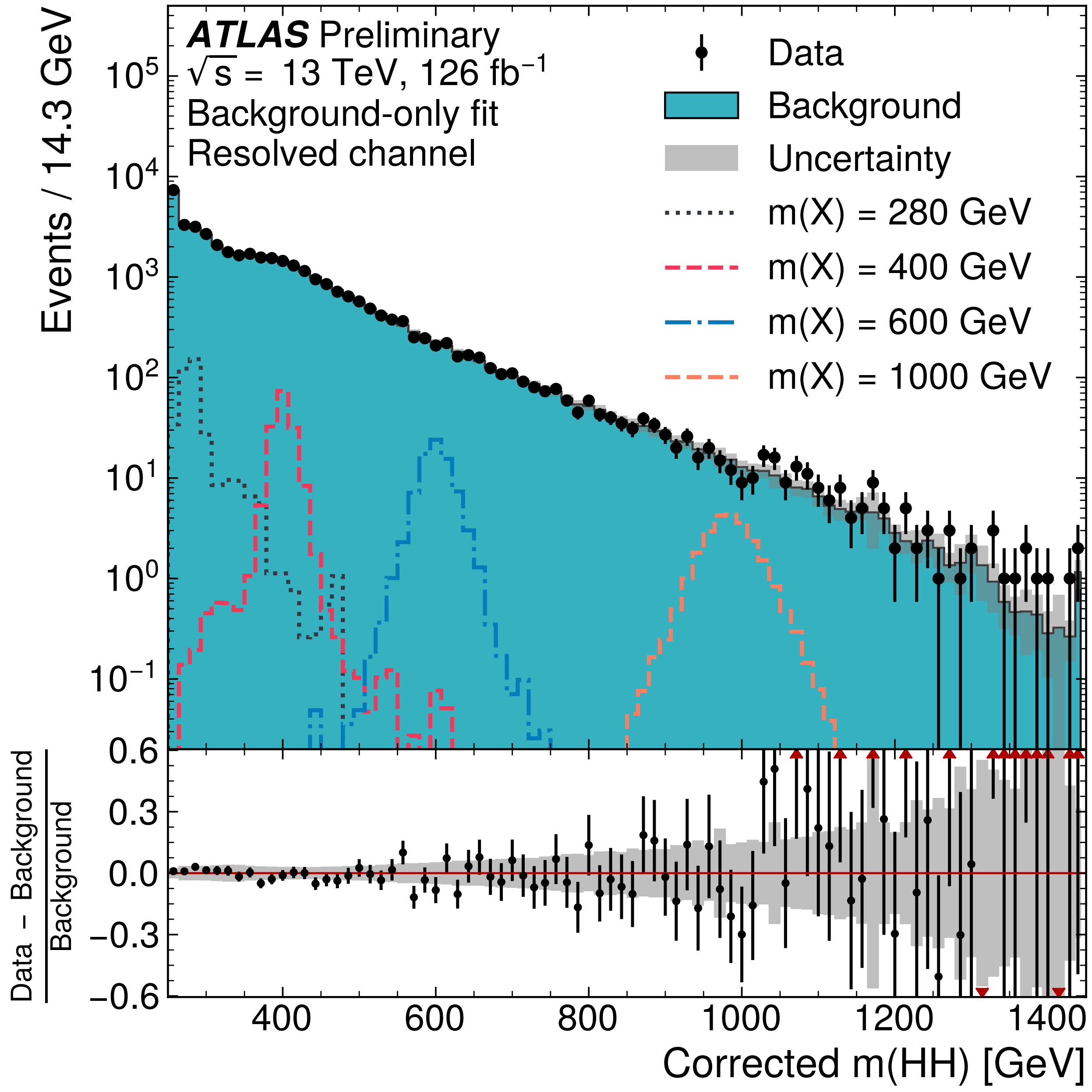
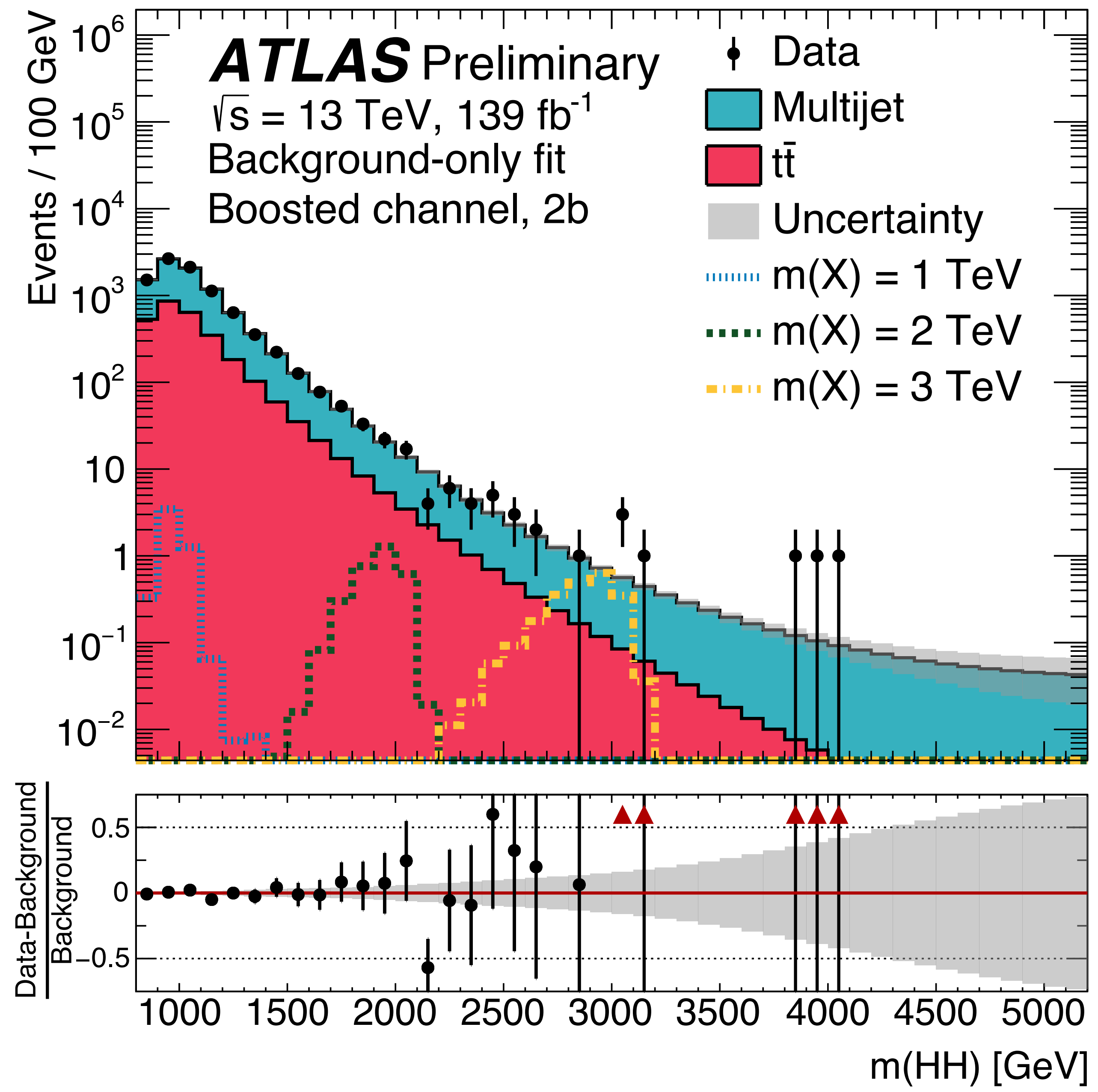
Backup

Di-Higgs Decay Modes

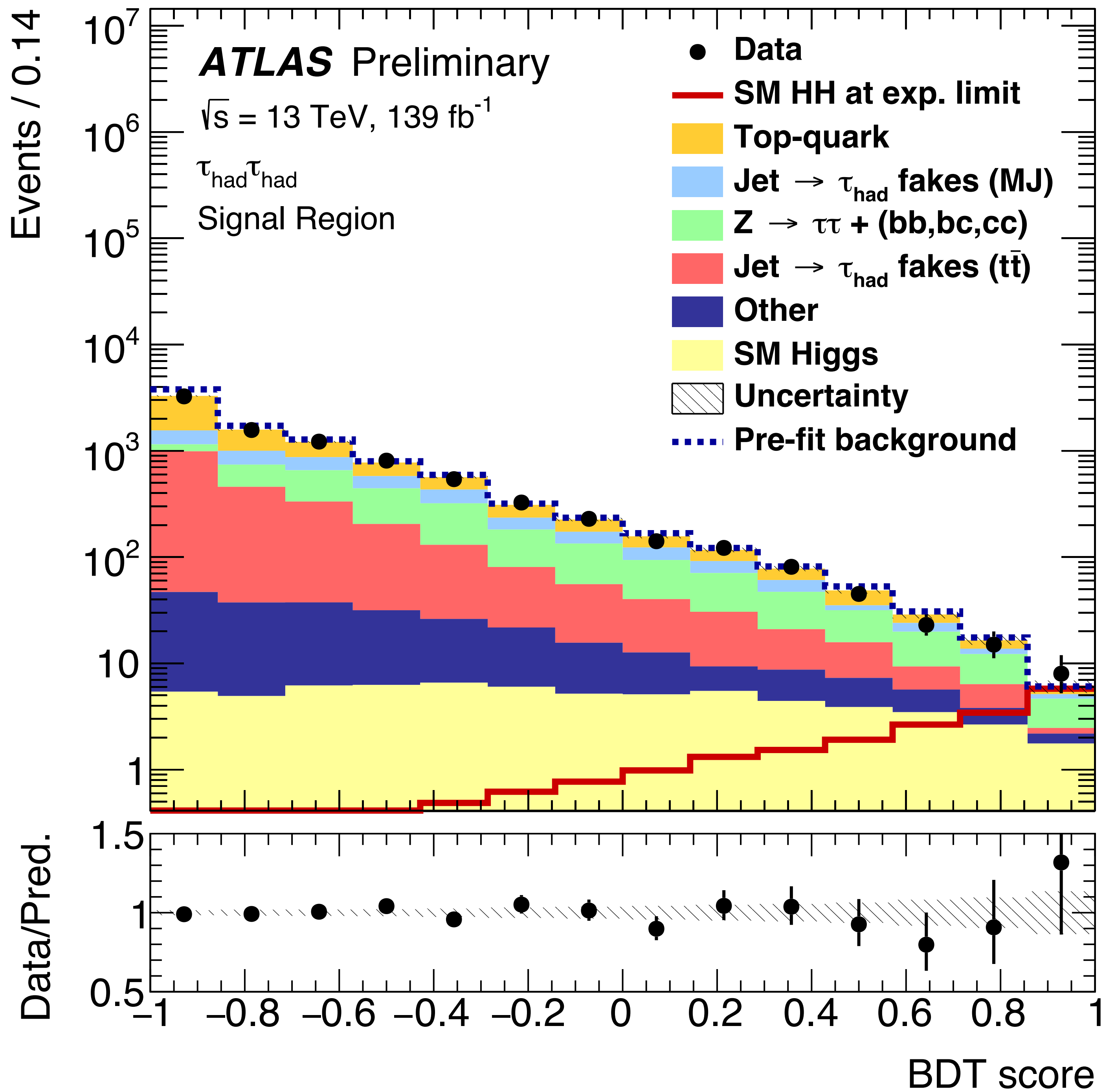


HH4b Results

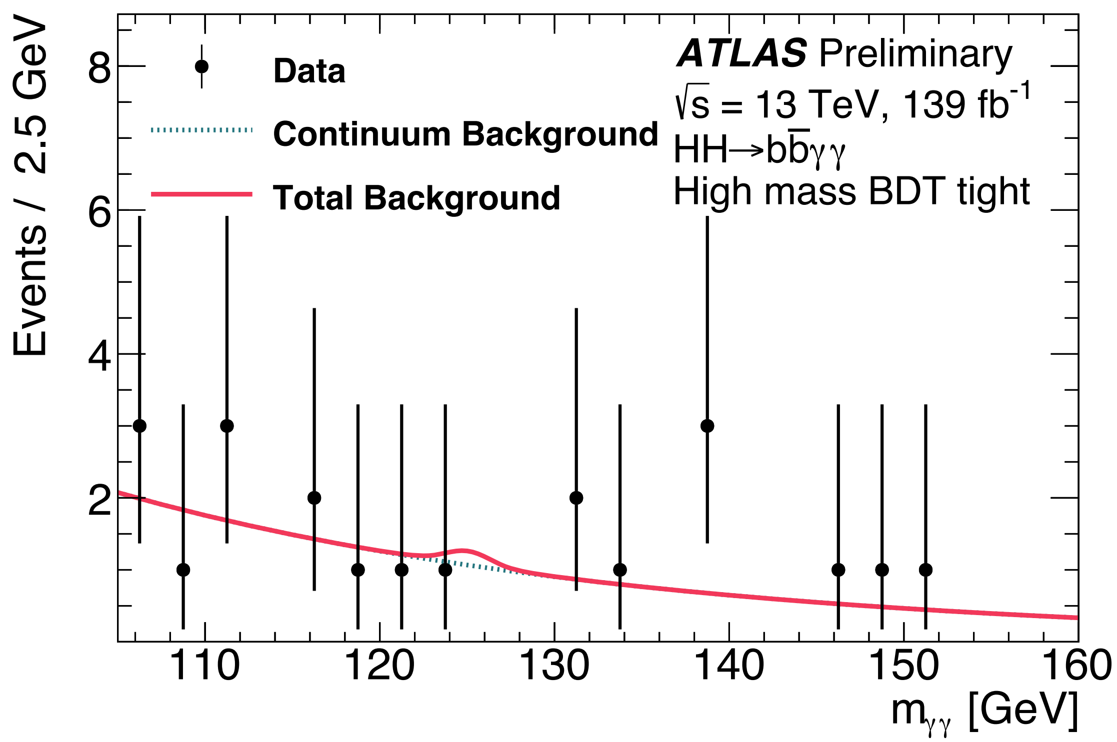


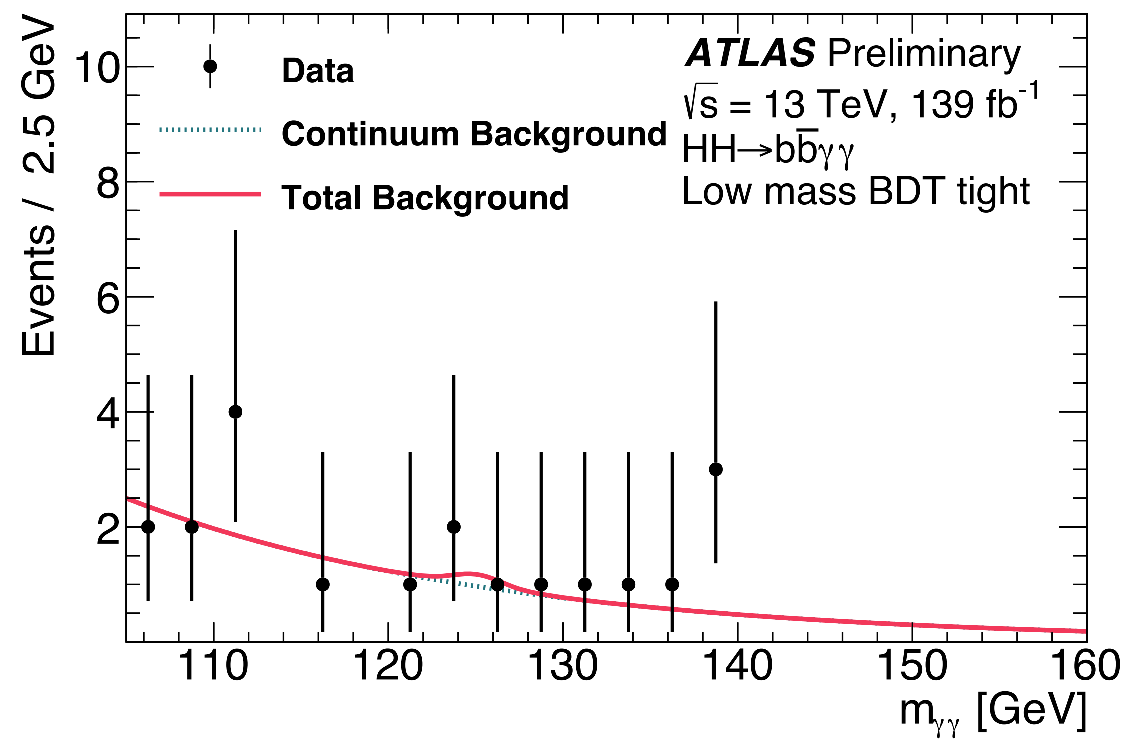


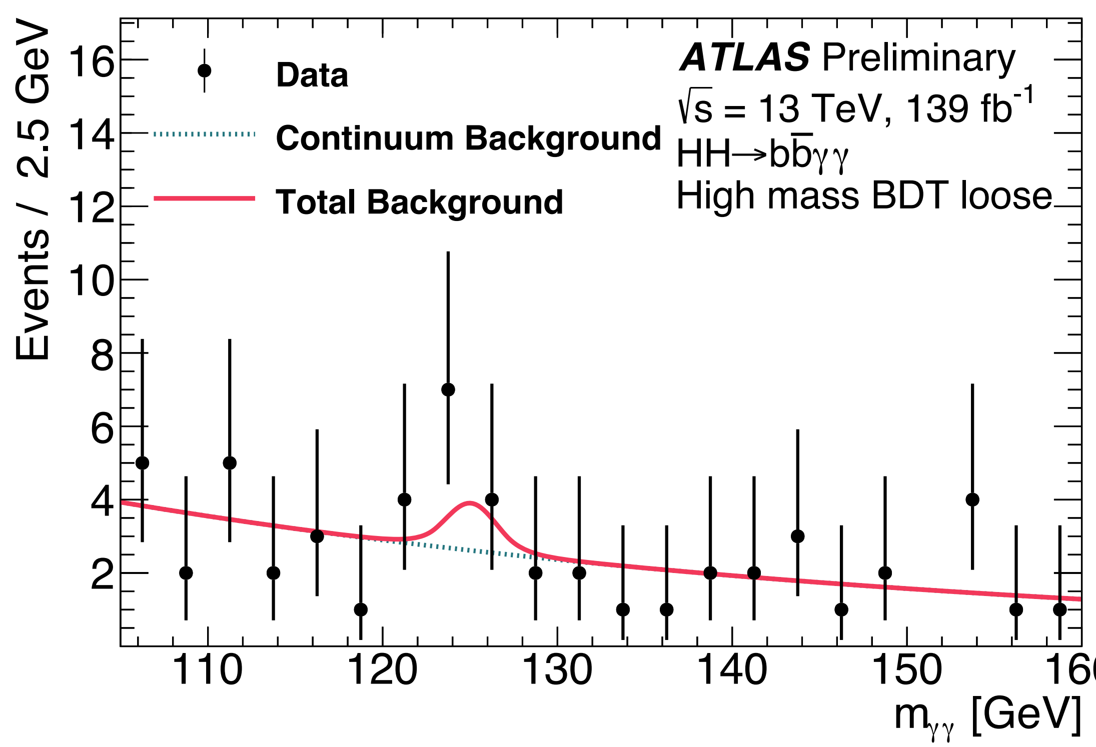
HHbbττ Results

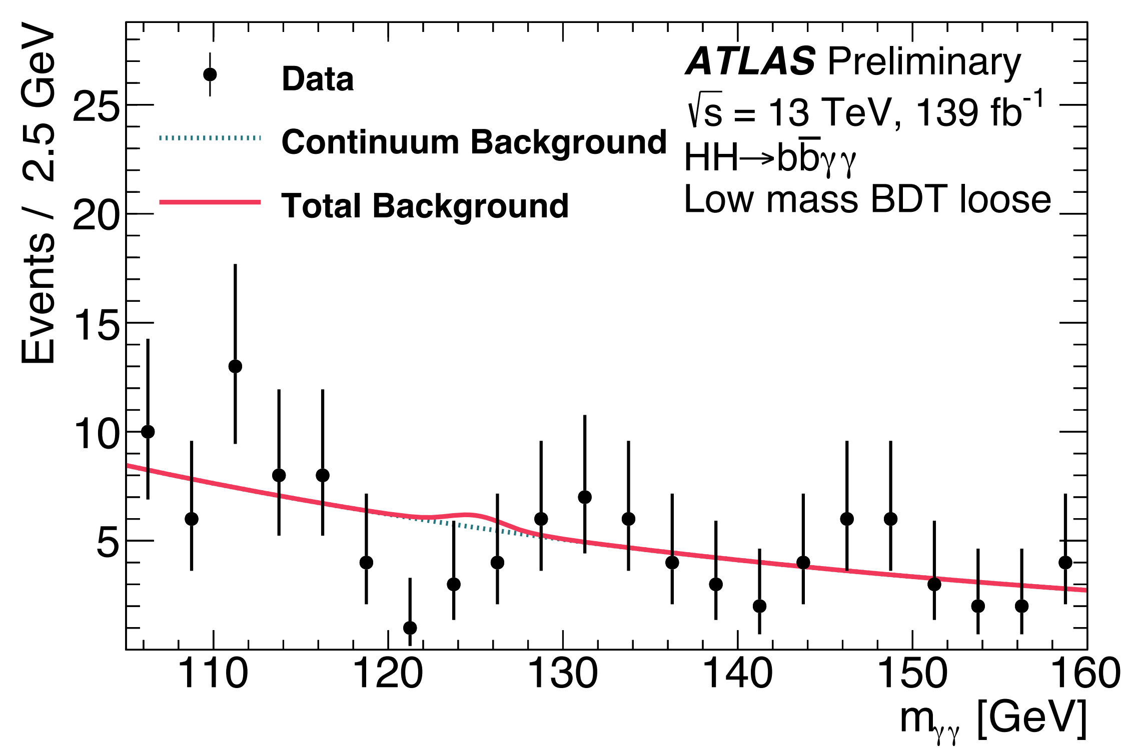


HHbbγγ Results



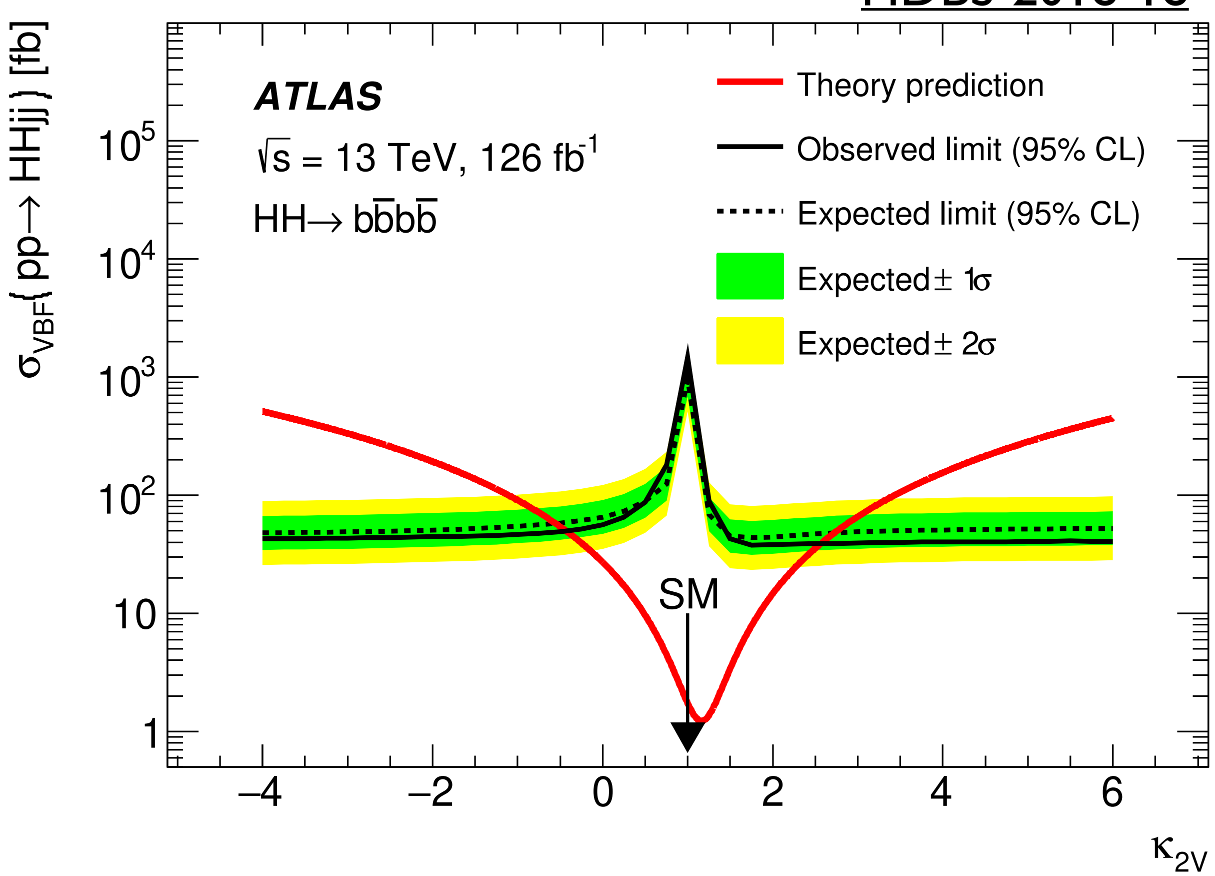


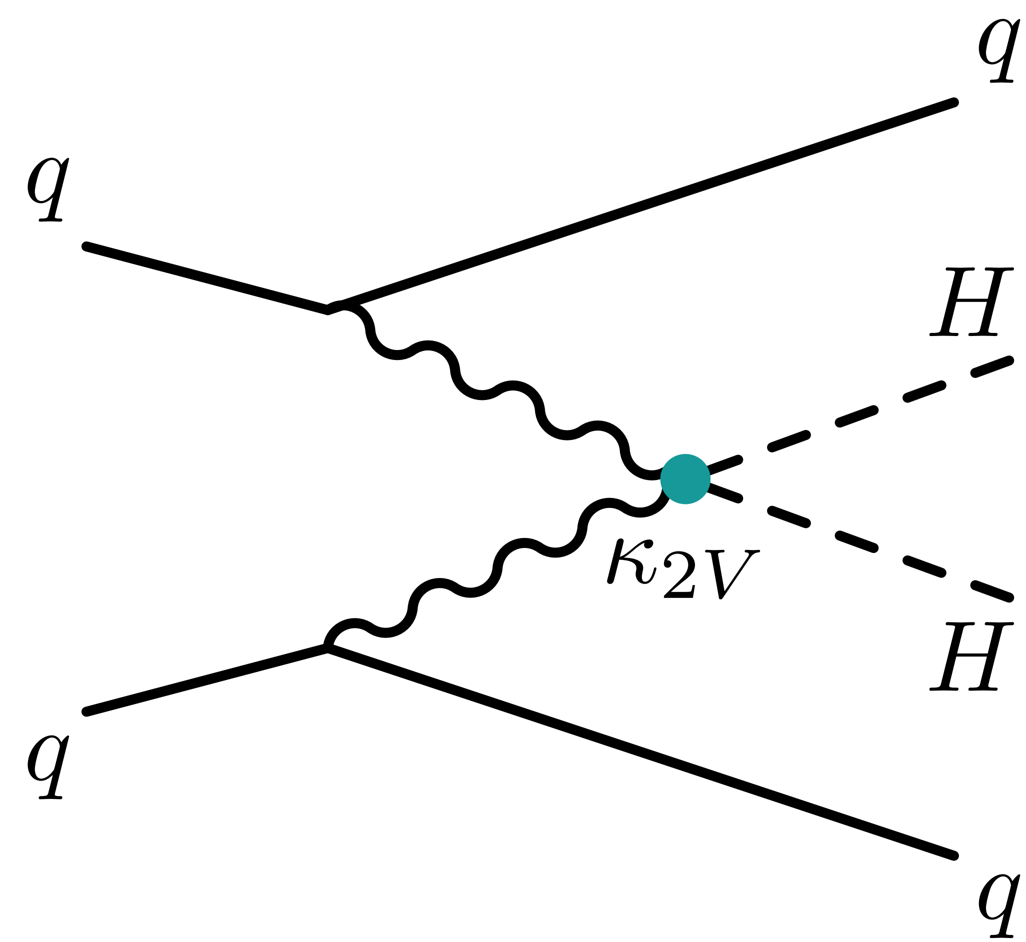




HH4b VBF

HDBS-2018-18





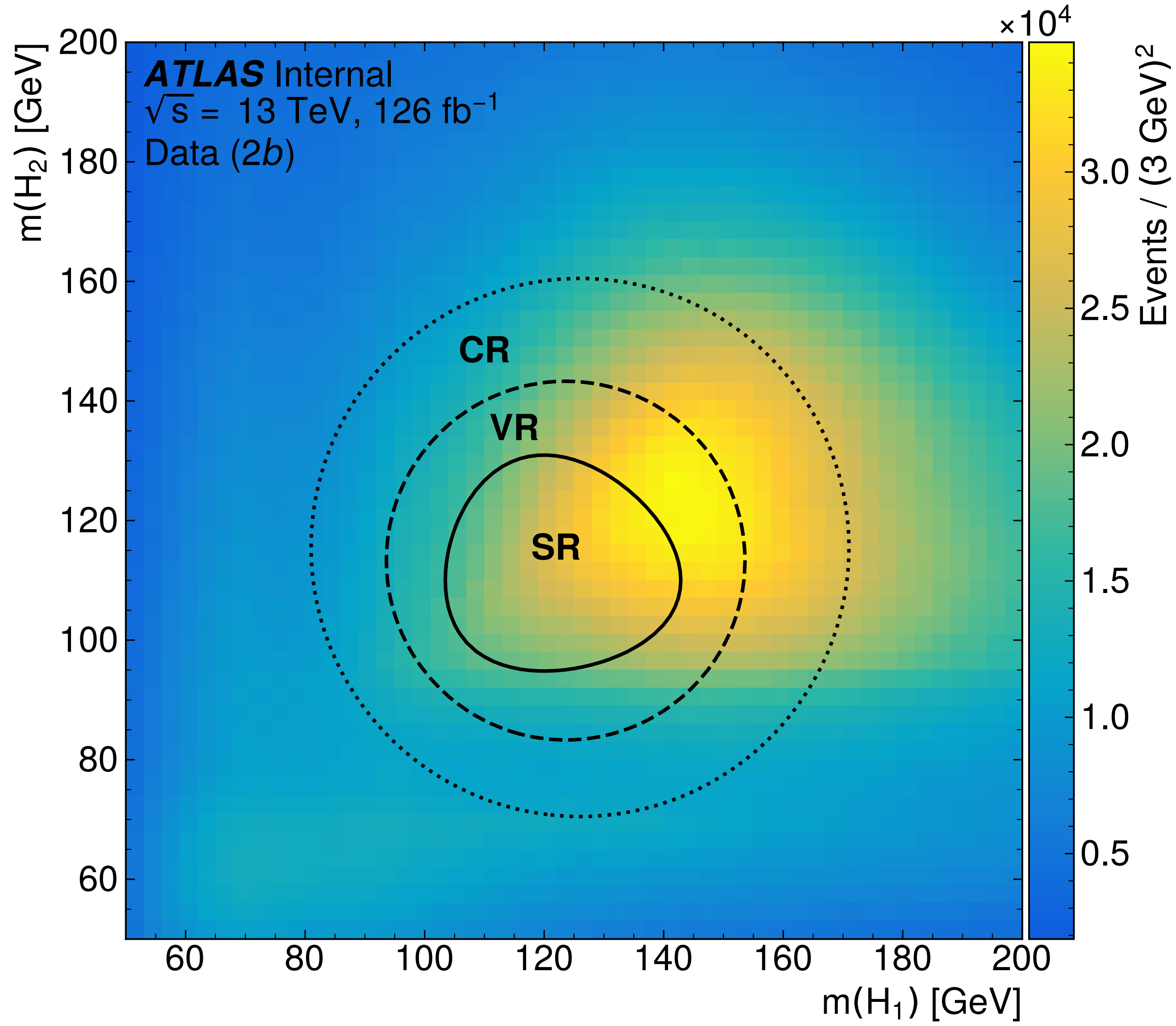
Can also measure other effects!

Here, search for 4-point VVhh coupling

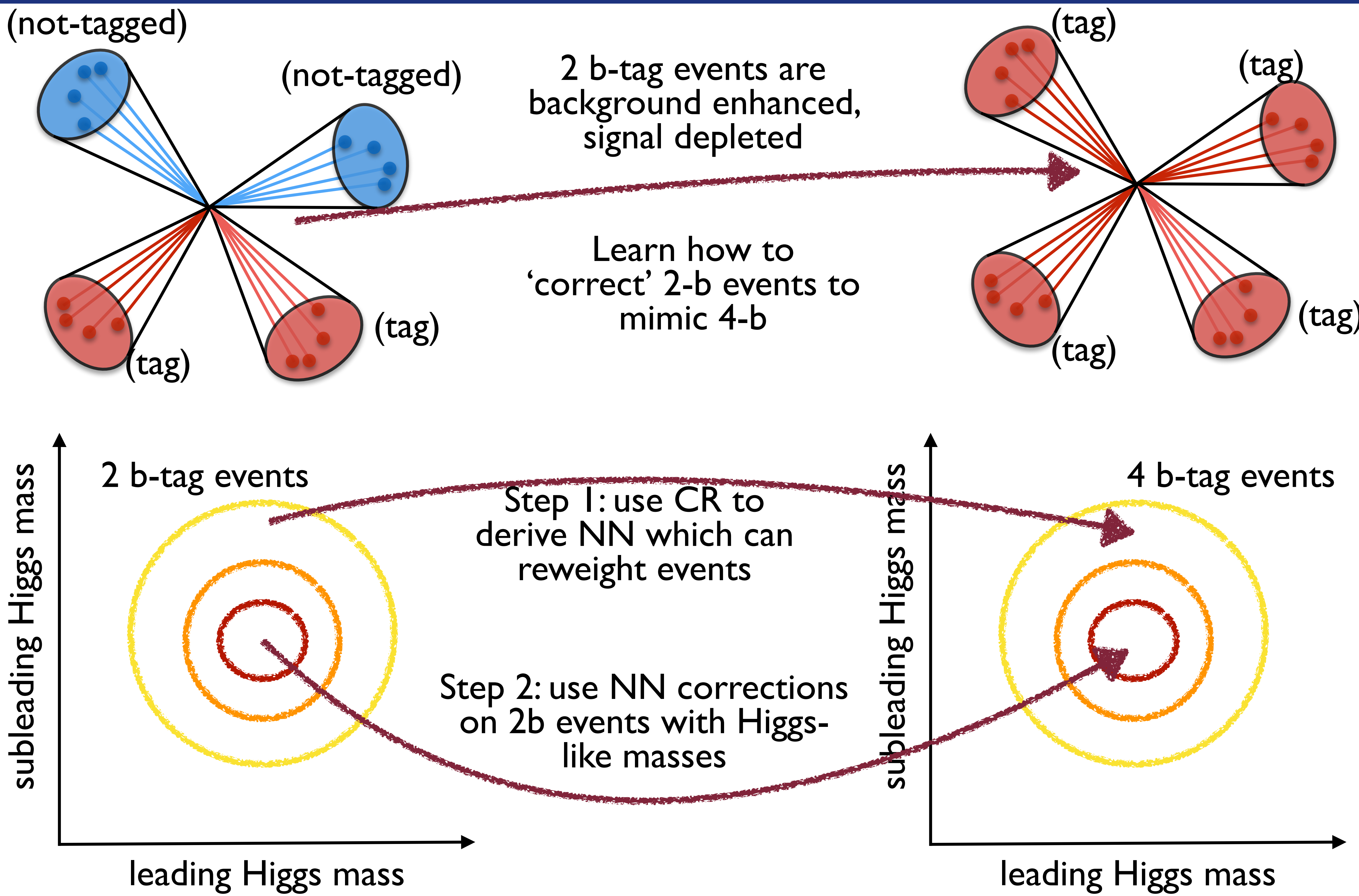
First world limits!

HH4b Background

- Background estimate uses 2b events to model 4b events
  - Learn correction factors from 2b to 4b using CR, and derive systematics in the VR



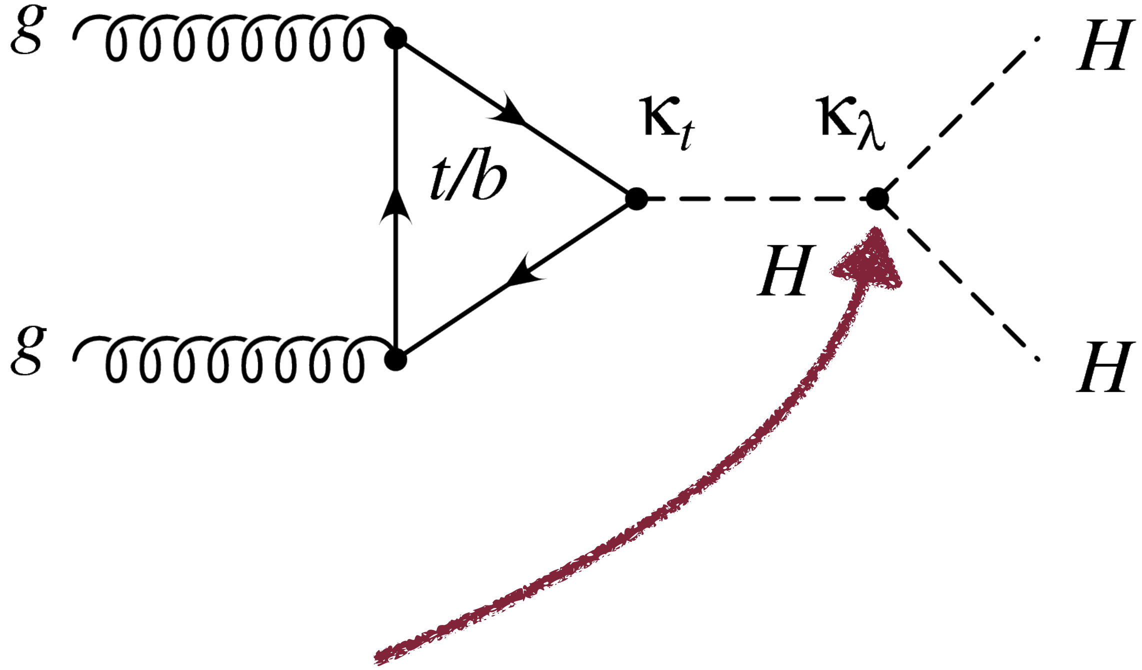
Estimating Backgrounds

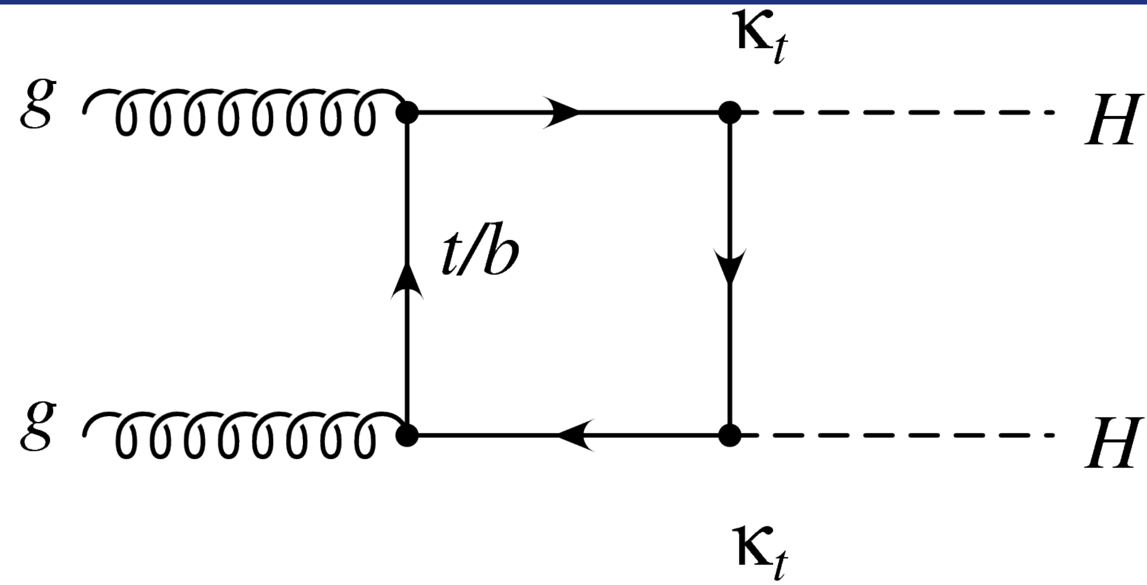


HH4b NN

1. $\log(p_{\mathrm{T}})$ of the selected jet with the 2^{nd}-highest p_{T},
2. $\log(p_{\mathrm{T}})$ of the selected jet with the 4^{th}-highest p_{T},
3. $\log(\Delta R)$ between the two selected jets with the smallest ΔR,
4. $\log(\Delta R)$ between the other two selected jets,
5. the average $|\eta|$ of selected jets,
6. $\log(p_{\mathrm{T}})$ of the HH system,
7. ΔR between the two H candidates,
8. $\Delta\phi$ between the jets making up H_1,
9. $\Delta\phi$ between the jets making up H_2,
10. $\log(\min(X_{Wt}))$, and
11. the number of jets in the event with $p_{\mathrm{T}} > 40\,\mathrm{GeV}$ and $|\eta| < 2.5$, including jets that are not selected.

Interference





This coupling is what we want to measure

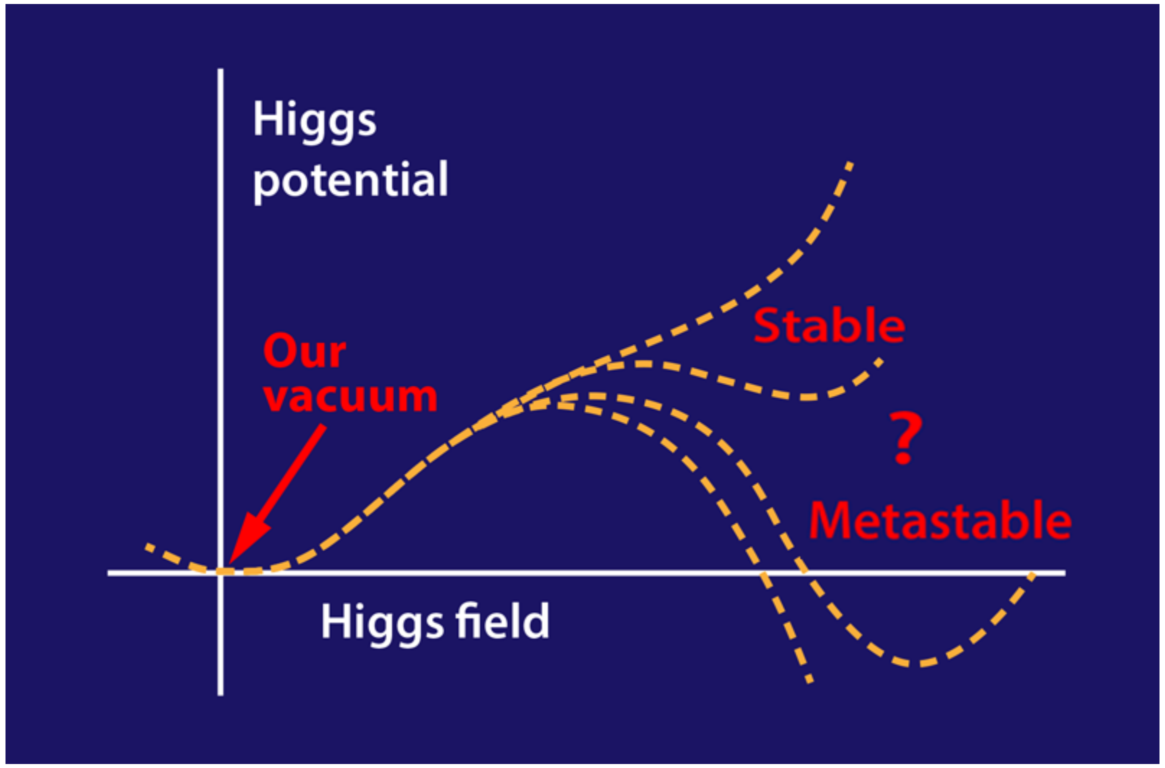
This tells us about the shape of the Higgs potential

This process has the same final state, but κ_λ doesn't appear: no information about the Higgs potential

These two processes destructively interfere in the SM, leading to **very low cross section:** 500x rarer than single Higgs

Di-Higgs production is a **rare process**

Higgs Stability



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More simply: we do not know if the Higgs potential, and our vacuum, is stable!

Measuring the potential can tell us about the fate of the universe

Dark Matter via Higgs

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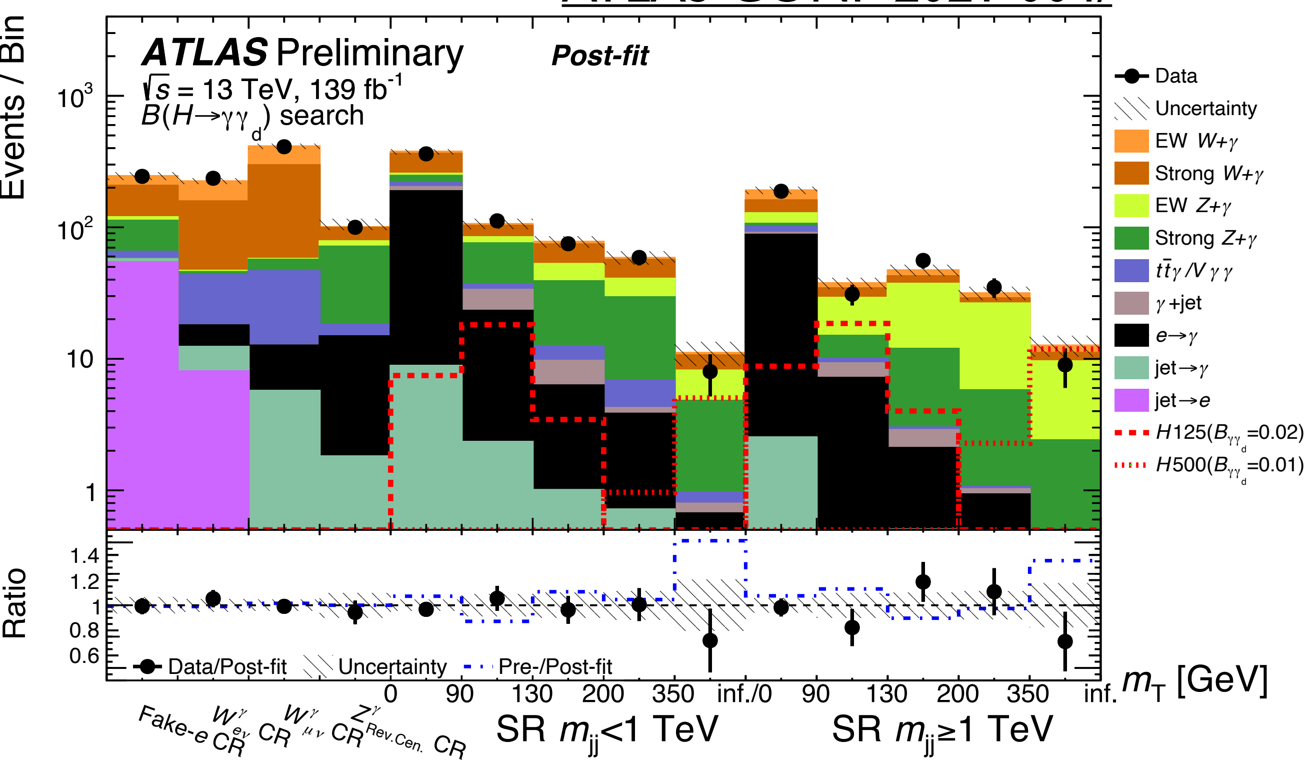
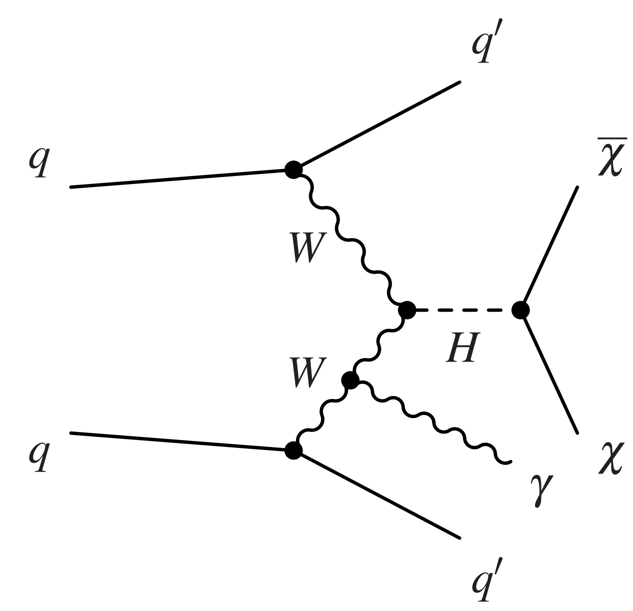


New searches for Higgs decaying to Dark Matter

New methods push sensitivity to strongest levels yet!



DNN for HWW

	Variable	VBF	V(had)H	ttH vs $t\bar{t}$	ttH vs $Z \to \tau\tau$
Jet properties	Invariant mass of 2 leading jets	•	•		
	$p_{\mathrm{T}}(jj)$	•	•		
	Product of η of 2 leading jets	•			
	Sub-leading jet p_{T}	•			
	Leading jet η				•
	Sub-leading jet η				•
	Scalar sum of all jets p_{T}			•	•
	Scalar sum of all b-tagged jets p_{T}				•
	Best W-candidate dijet invariant mass			•	•
	Best t-quark-candidate three-jet invariant mass			•	•
Angular distances	$\Delta\phi$(jet 0, jet 1)	•			
	$\|\Delta\eta$(jet 0, jet 1)$\|$	•	•		
	ΔR(jet 0, jet 1)		•		
	$\Delta R(\tau\tau, jj)$		•		
	$\Delta R(\tau, \tau)$		•	•	
	Smallest ΔR (any 2 jets)			•	
	$\|\Delta\eta(\tau, \tau)\|$			•	•
τ prop.	$p_{\mathrm{T}}(\tau\tau)$			•	
	Sub-leading τ p_{T}				•
	Sub-leading τ η				•
H cand.	$p_{\mathrm{T}}(Hjj)$	•	•		
	$p_{\mathrm{T}}(H)/p_{\mathrm{T}}(jj)$		•		
$\vec{E}_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse energy $E_{\mathrm{T}}^{\mathrm{miss}}$		•	•	•
	Smallest $\Delta\phi$ $(\tau, \vec{E}_{\mathrm{T}}^{\mathrm{miss}})$				•

HHbbττ BDT

Variable	$\tau_{\text{had}}\tau_{\text{had}}$	$\tau_{\text{lep}}\tau_{\text{had}}$ SLT	$\tau_{\text{lep}}\tau_{\text{had}}$ LTT
m_{HH}	✓	✓	✓
$m_{\tau\tau}^{\text{MMC}}$	✓	✓	✓
m_{bb}	✓	✓	✓
$\Delta R(\tau,\tau)$	✓	✓	✓
$\Delta R(b,b)$	✓	✓	
$\Delta p_{\text{T}}(\ell,\tau)$		✓	✓
Sub-leading b-tagged jet p_{T}		✓	
m_{T}^{W}		✓	
$E_{\text{T}}^{\text{miss}}$		✓	
$\mathbf{p}_{\text{T}}^{\text{miss}}$ ϕ centrality		✓	
$\Delta\phi(\tau\tau, bb)$		✓	
$\Delta\phi(\ell, \mathbf{p}_{\text{T}}^{\text{miss}})$			✓
$\Delta\phi(\ell\tau, \mathbf{p}_{\text{T}}^{\text{miss}})$			✓
S_{T}			✓

HHbbγγ BDT

Variable	Definition
Photon-related kinematic variables	
$p_{\mathrm{T}}/m_{\gamma\gamma}$	Transverse momentum of the two photons scaled by their invariant mass $m_{\gamma\gamma}$
η and ϕ	Pseudo-rapidity and azimuthal angle of the leading and sub-leading photon
Jet-related kinematic variables	
b-tag status	Highest fixed b-tag working point that the jet passes
p_{T}, η and ϕ	Transverse momentum, pseudo-rapidity and azimuthal angle of the two jets with the highest b-tagging score
$p_{\mathrm{T}}^{b\bar{b}}$, $\eta_{b\bar{b}}$ and $\phi_{b\bar{b}}$	Transverse momentum, pseudo-rapidity and azimuthal angle of b-tagged jets system
$m_{b\bar{b}}$	Invariant mass built with the two jets with the highest b-tagging score
H_{T}	Scalar sum of the p_{T} of the jets in the event
Single topness	For the definition, see Eq. (1)
Missing transverse momentum-related variables	
$E_{\mathrm{T}}^{\mathrm{miss}}$ and ϕ^{miss}	Missing transverse momentum and its azimuthal angle

Large Radius Tracking