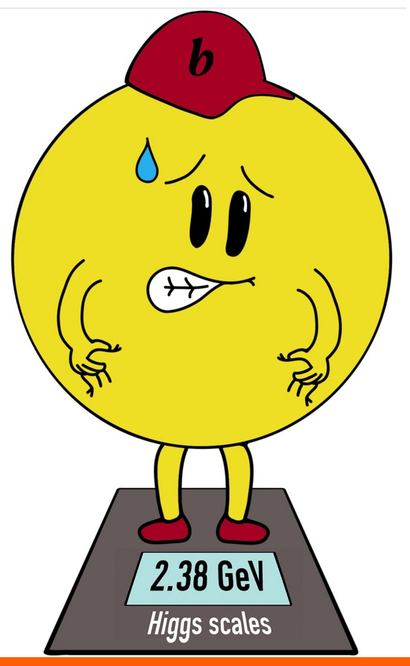

$m_b(m_H)$: the bottom quark mass at high scale

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CPAN Ingenio 2010

XVII CPAN DAYS. VALÈNCIA 2025

Motivation

- A key prediction of the Standard Model (SM) is that **quark masses** m_q "run" i.e. **evolve with the energy scale** μ: $$\frac{\partial m_q(\mu)}{\partial \log(\mu^2)} = \gamma_m[\alpha_s(\mu)]\, m_q(\mu)$$ ← Renormalization Group (**RG**) Equation
- The **bottom quark mass**, m_b, has been measured with great precision at relatively low energies (the scale of the mass itself) [1] and at the scale of the Z-boson mass m_Z (LEP/SLD) [2]: $$m_b(m_b) = 4.18^{+0.03}_{-0.02}\ \text{GeV} \qquad m_b(m_Z) = 2.82 \pm 0.28\ \text{GeV}$$
- The **LHC** provides a way of **measuring m_b** at the even higher **scale of the Higgs boson mass m_H** by using measurements of Higgs decay widths (or rates). A **first result** of this method using **results from ATLAS and CMS** experiments is given in Ref. [2]: $$m_b(m_H) = 2.60^{+0.36}_{-0.31}\ \text{GeV}$$
- **Updated results** on $m_b(m_H)$ have the potential of turning the study of m_b running into a **precise test of SM and QCD**, especially at **new collider facilities**.

Extraction of $m_b(m_H)$ from decay rates

- The $m_b(m_H)$ sensitive observables for this work are **ratios of decay rates** (normalized to their SM predictions), namely of $H \to bb$ divided by either $H \to ZZ^*$, $H \to \gamma\gamma$ or $H \to \tau\tau$: $\mu_{bb/ZZ}$, $\mu_{bb/\gamma\gamma}$ and $\mu_{bb/\tau\tau}$.
- These ratios must be **computed for each production channel** (input measurements are $\sigma_i \times B_f$) and then **combined** (cross-checked with Convino, [4]) to provide a **single value** for each ratio (considering **correlations**!):

$$x_{avg} = \frac{1}{\sum_{p=1}^{N}\sum_{q=1}^{N}\left(C^{-1}\right)_{pq}} \left\{\sum_{i=1}^{N} x_i \left[\sum_{j=1}^{N}\left(C^{-1}\right)_{ij}\right]\right\} \qquad \sigma^2_{avg,\pm} = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left\{\left[\sum_{s=1}^{N}\left(C^{-1}\right)_{si}\right]\left[\sum_{r=1}^{N}\left(C^{-1}\right)_{rj}\right]\left(C^{\pm}\right)_{ij}\right\}}{\left(\sum_{p=1}^{N}\sum_{q=1}^{N}\left(C^{-1}\right)_{pq}\right)^2}$$

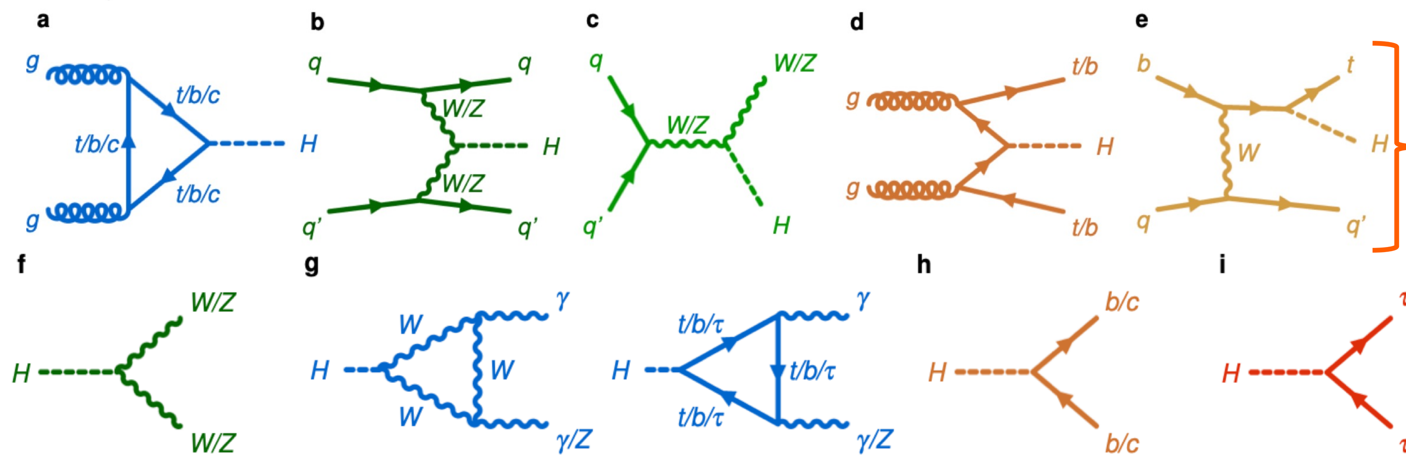
- If the two **decay rates don't share the same production channels**, a **combination of the relevant ones** is done beforehand:

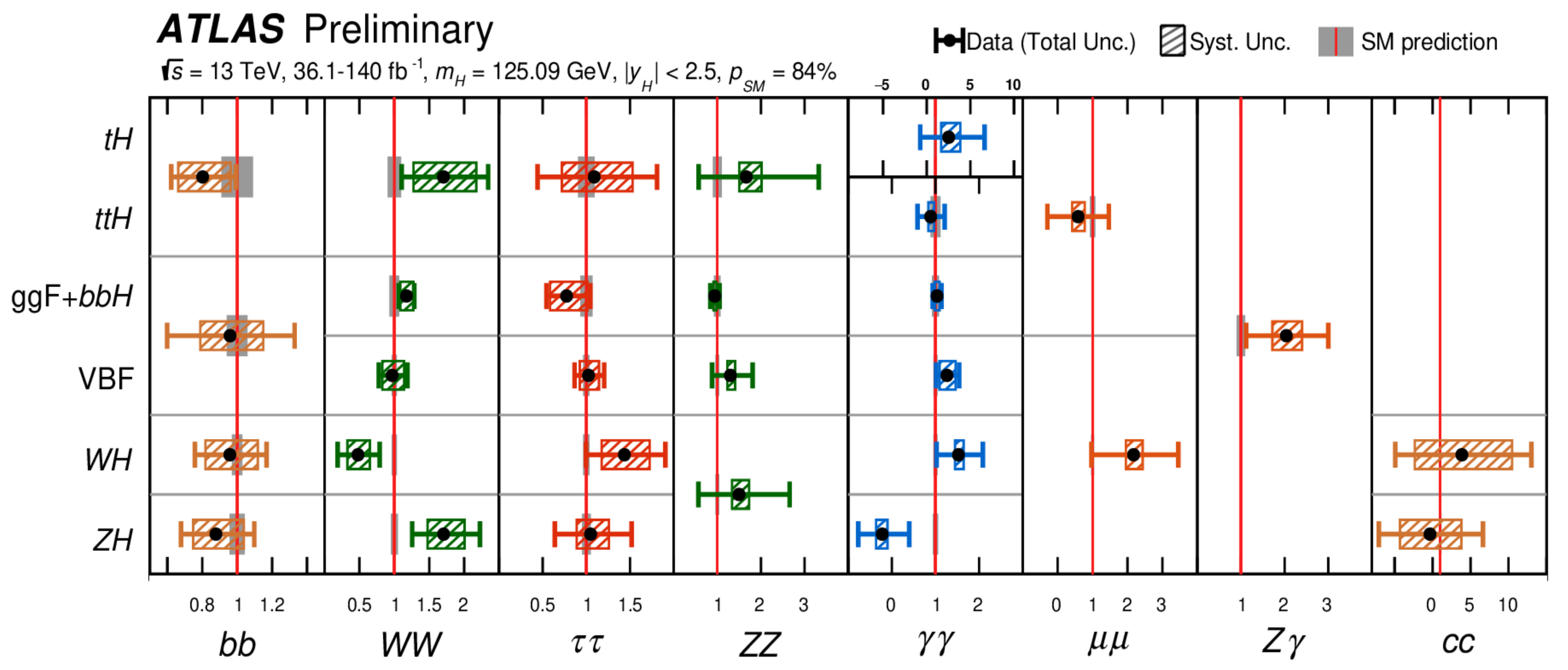
$$\mu^{\sigma_{A+B}}_{BR_X} = \frac{(\sigma^{SM}_A \times BR^{SM}_X)\,\mu^{\sigma_A}_{BR_X} + (\sigma^{SM}_B \times BR^{SM}_X)\,\mu^{\sigma_B}_{BR_X}}{\sigma^{SM}_A \times BR^{SM}_X + \sigma^{SM}_B \times BR^{SM}_X} = \frac{\sigma^{SM}_A\,\mu^{\sigma_A}_{BR_X} + \sigma^{SM}_B\,\mu^{\sigma_B}_{BR_X}}{\sigma^{SM}_A + \sigma^{SM}_B}$$

- Each different $\mu_{bb/XX}$ is then fed to a **parametrisation** of its prediction as a **function of $m_b(m_H)$**, allowing an **extraction of the mass for each ratio**. The **predictions** are obtained from the program **HDecay** [5].

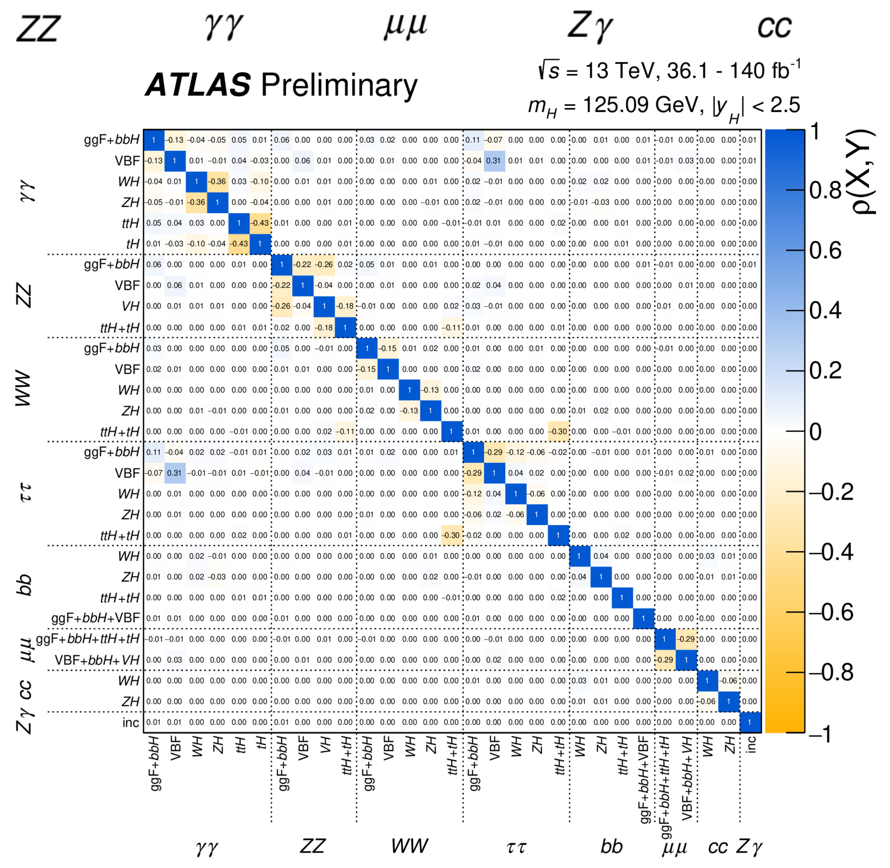
Input measurements

- Updated **ATLAS measurements** on Higgs boson at $\sqrt{s} = 13$ **TeV** and $\int \mathcal{L} = 140$ **fb^{-1}** from **2025 CONF Note** [3].





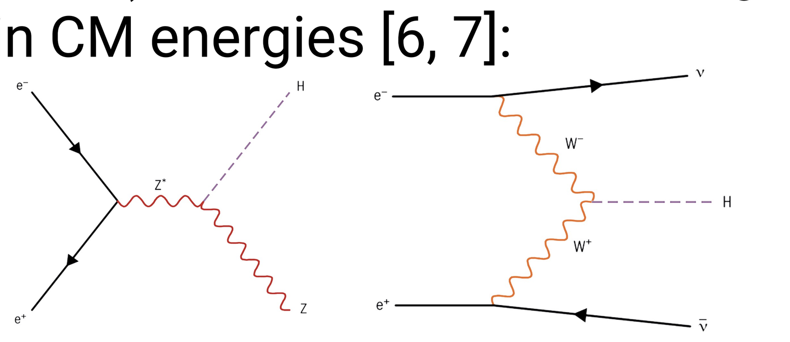
Decay mode	Prod. mode	Ratio to SM
$H \to bb$	ggF + bbH + VBF	1.0 ± 0.4
	WH	$0.96^{+0.21}_{-0.20}$
	ZH	$0.88^{+0.22}_{-0.20}$
	$ttH + tH$	$0.80^{+0.19}_{-0.18}$
$H \to \tau\tau$	ggF + bbH	$0.77^{+0.27}_{-0.23}$
	VBF	$1.03^{+0.18}_{-0.16}$
	WH	$1.4^{+0.5}_{-0.4}$
	ZH	$1.1^{+0.5}_{-0.4}$
	$ttH + tH$	$1.1^{+0.7}_{-0.6}$
$H \to ZZ^*$	ggF + bbH	$0.94^{+0.11}_{-0.10}$
	VBF	$1.3^{+0.5}_{-0.4}$
	VH	$1.5^{+1.2}_{-0.9}$
	$ttH + tH$	$1.7^{+1.7}_{-1.1}$
$H \to \gamma\gamma$	ggF + bbH	1.04 ± 0.10
	VBF	$1.26^{+0.28}_{-0.25}$
	WH	$1.5^{+0.6}_{-0.5}$
	ZH	-0.2 ± 0.6
	ttH	$0.89^{+0.32}_{-0.30}$
	tH	$2.5^{+4.0}_{-3.3}$



Prospects for Future Colliders

- **High-Lumi LHC (HL-LHC)**: immediate upgrade of LHC, operating at $\sqrt{s} = 14$ TeV and $\int \mathcal{L} = 3\ \text{ab}^{-1}$.
- Future implementation of an e^+e^- **Higgs factory** at CERN: **Linear Collider Facility** (LCF) or **Future Circular Collider** (FCC-ee). Both facilities envisage operation at two main CM energies [6, 7]:

Collider	$\sqrt{s}$ [GeV]	$\int \mathcal{L}$ [ab^{-1}]
FCC-ee	240	5
	365	1.5
LCF	250	3
	550	8



- LCF & FCC-ee will allow to measure **Higgs boson couplings** with **unprecedented precision**. The **bb/WW^* ratio** is expected to be measured with **sub-% precision** on both facilities (**estimates** on **LCF only** but expected to be **similar for FCC-ee**):

Operation	Relative precision on $BR(H \to bb)/BR(H \to WW^*)$
LCF250	0.65 %
LCF550	0.38 %
LCF250+550	0.33 %

Preliminary estimates on LCF provided by Junping Tian (Tokyo U., ICEPP).

References

[1] P. Zyla *et al.* (Particle Data Group), PTEP 2020, 083C01 (2020)
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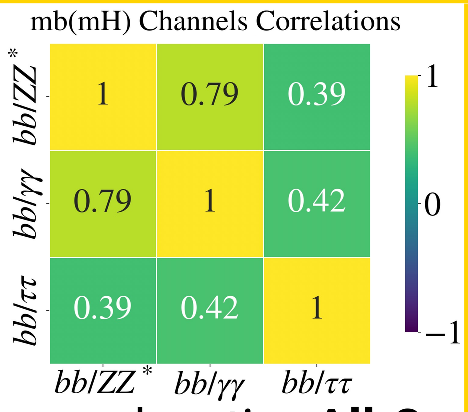
Results at LHC and Future Higgs Factories

From ATLAS '25 RESULTS

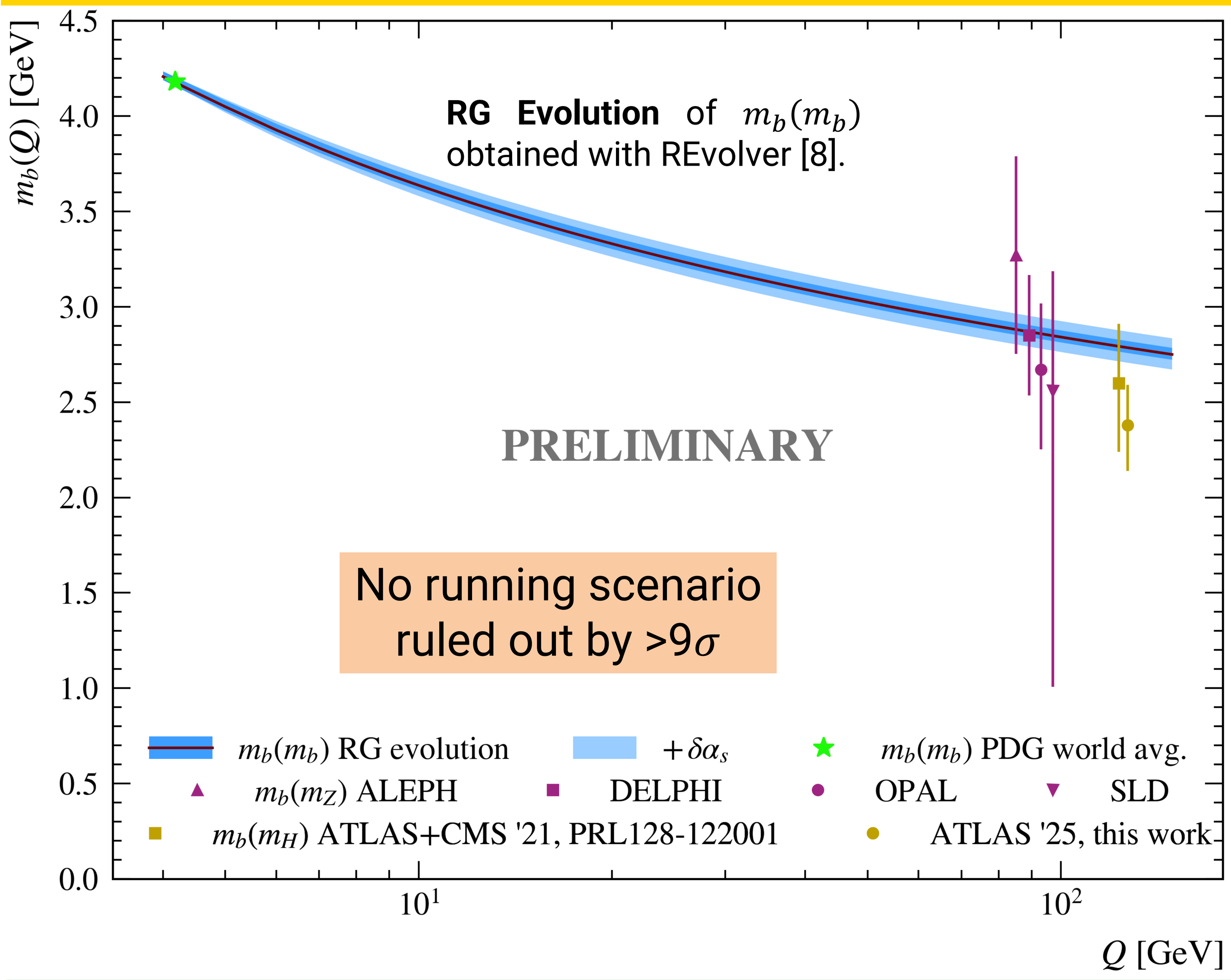
Ratio	μ_{bb}/μ_{XX}	$m_b(m_H)$ [GeV]
bb/ZZ^*	$0.69^{+0.25}_{-0.20}$	$2.31^{+0.41}_{-0.32}$
$bb/\gamma\gamma$	$0.71^{+0.18}_{-0.16}$	$2.34^{+0.30}_{-0.26}$
$bb/\tau\tau$	$0.78^{+0.20}_{-0.17}$	$2.45^{+0.31}_{-0.26}$

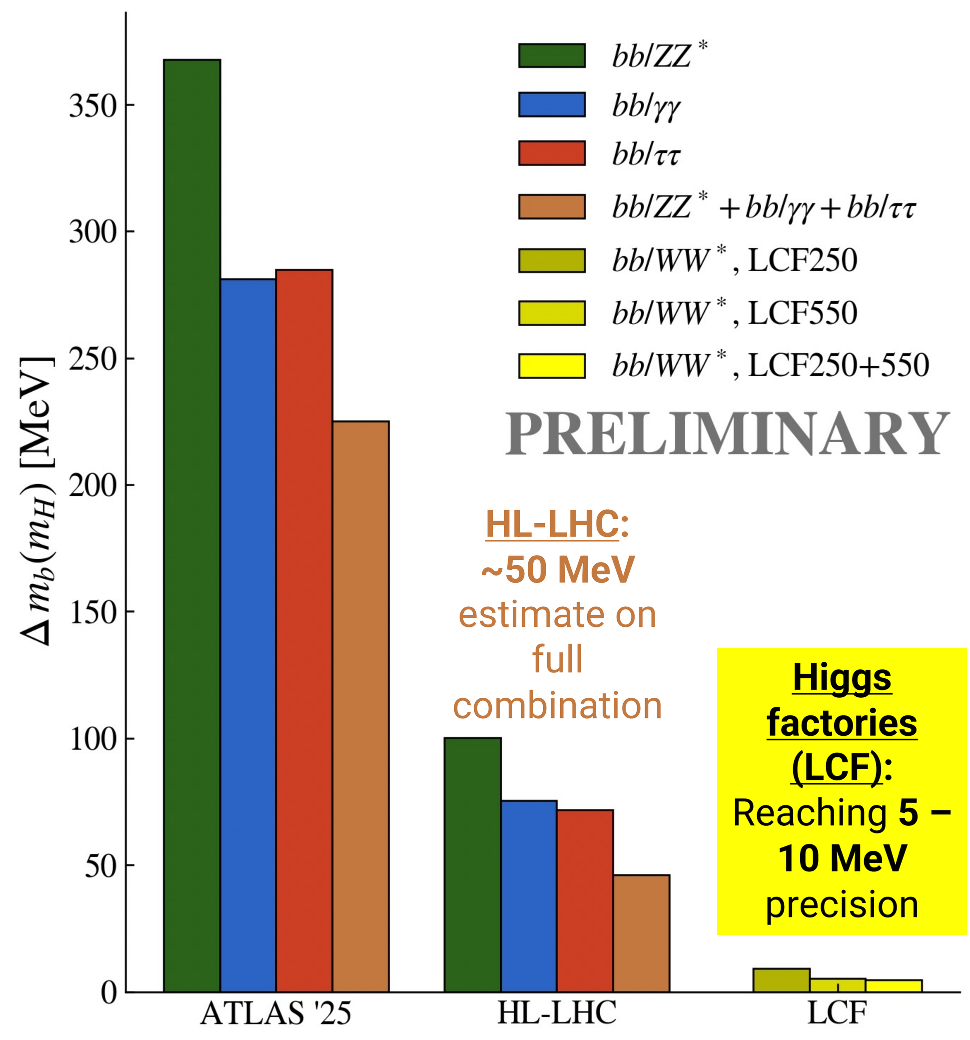
mb(mH) Channels Correlations



Independent extraction of $m_b(m_H)$ for each ratio. **All 3 are compatible**, so **combination is doable**.

- **Combined value** of **$m_b(m_H) = 2.38^{+0.24}_{-0.21}$ GeV** from latest **ATLAS results.**
- **Relative precision ~10%**, could **improve** with **CMS combination**.
- **Uncertainty reduced by 33%** w.r.t. PRL result!





- HL-LHC uncertainties scaled with $\int \mathcal{L}$ as $1/\sqrt{\int \mathcal{L}}$ (No theo. uncs. or cutoff considered).
- **$m_b(m_H)$ in Higgs factories** could **compete with $m_b(m_b)$** as the **most precise measurement of m_b**!!

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