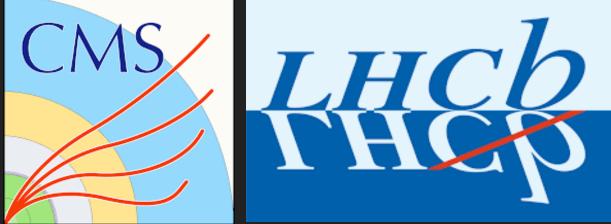
## PROSPECTS FOR PHYSICS AT THE LHC MARIE-HÉLÈNE GENEST

### ON BEHALF OF THE ATLAS, CMS AND LHCB COLLABORATIONS

PLANCK 2022

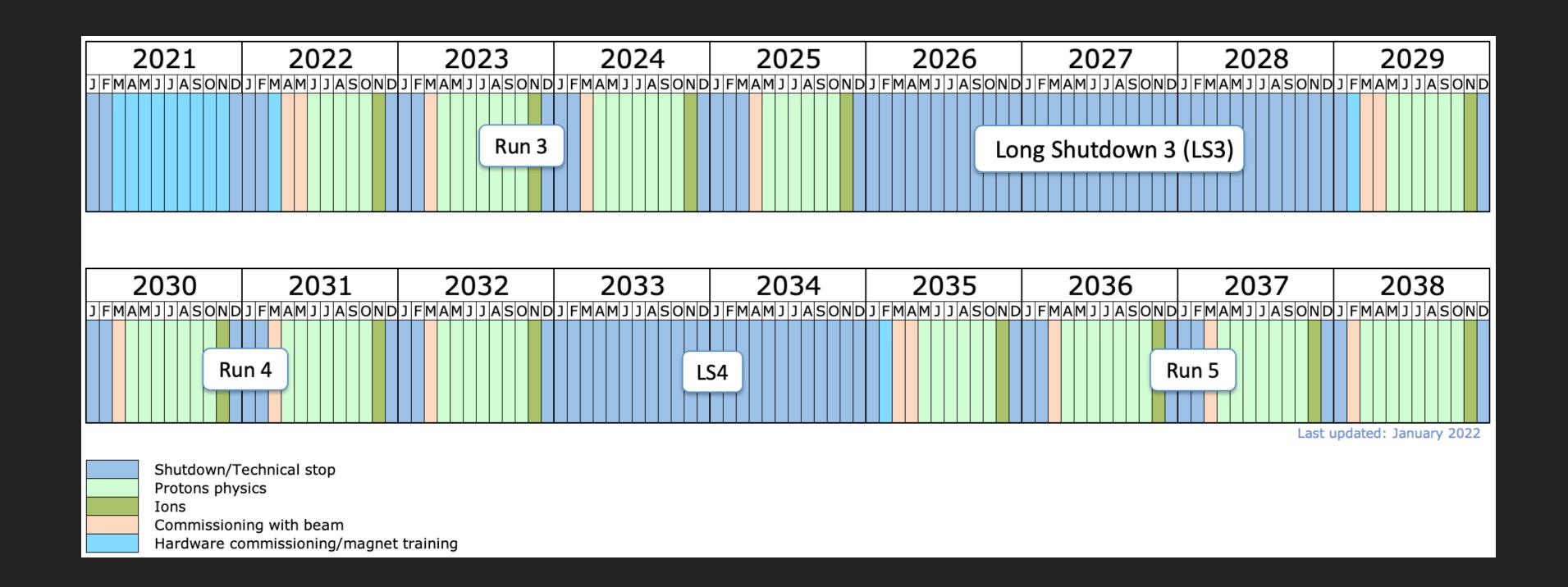






## THE FUTURE OF LHC

- In this talk, I will cover prospects comprising the entire HL-LHC program



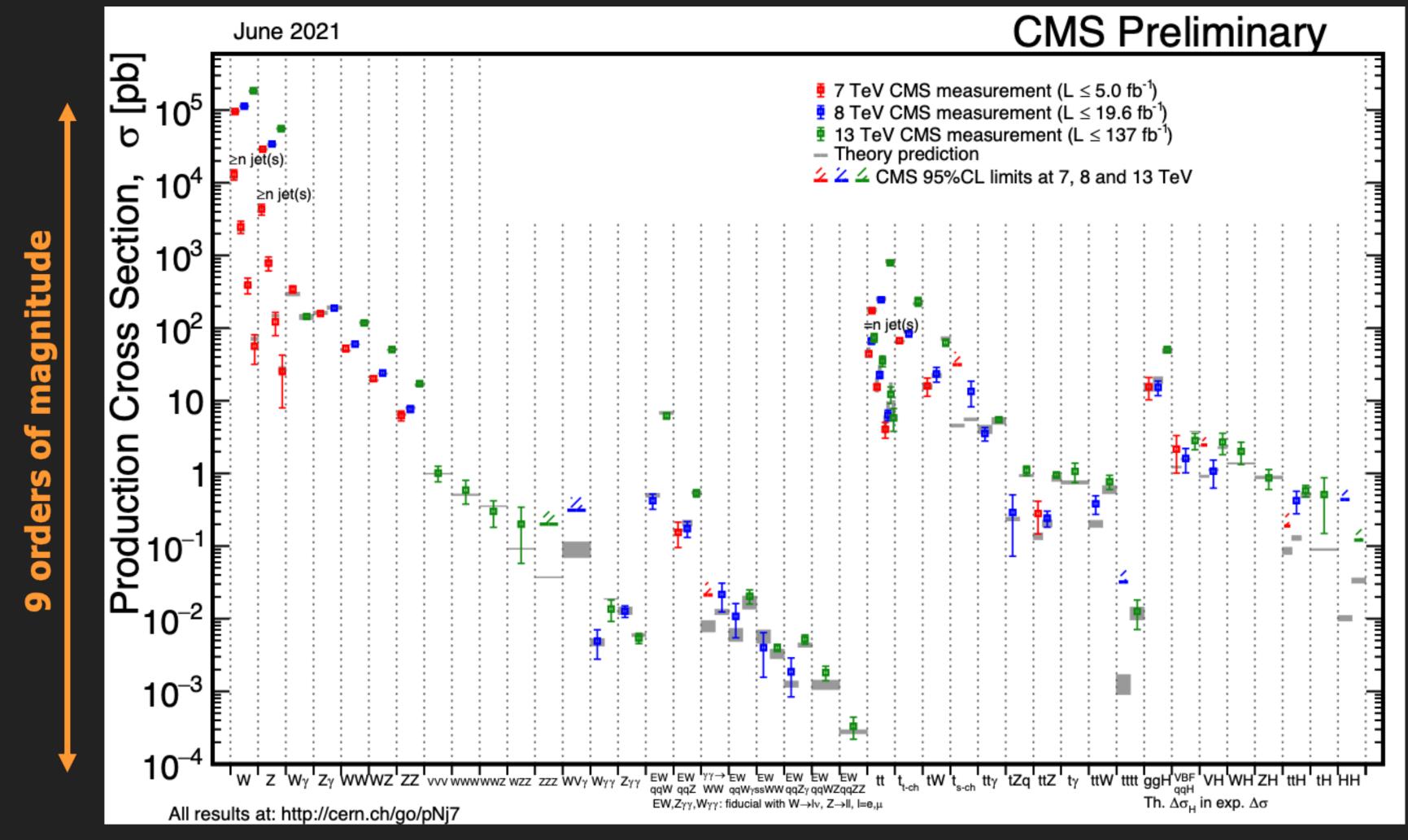
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Run-3 is about to start @ 13.6 TeV, with about 300 fb<sup>-1</sup> to be collected by each ATLAS and CMS

HL-LHC will follow, with 3-4 ab<sup>-1</sup> of data for ATLAS & CMS each (and at least 300 fb<sup>-1</sup> for LHCb)



## THE BIG PICTURE: PRECISION MEASUREMENTS



Electroweak

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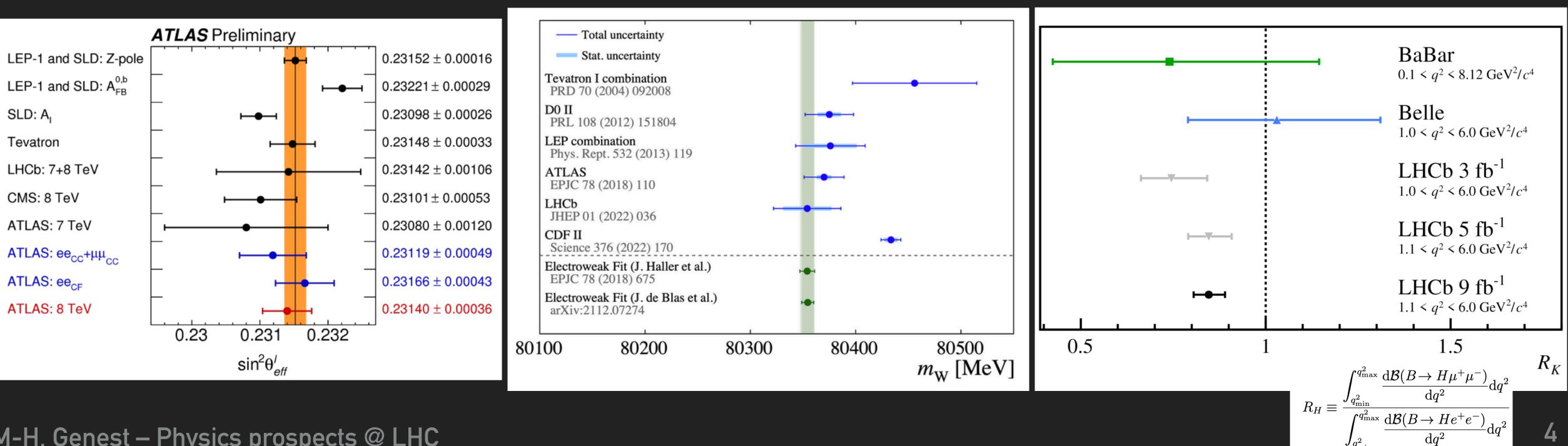


Тор



## **THE BIG PICTURE: ELECTROWEAK**

- EWK observables measured at percent precision (or better) at LEP, SLD, TeVatron, LHC,...
- Recent results on the W mass by LHCb and CDF II (intriguing tension)
- Hints of violation of the lepton flavor universality?

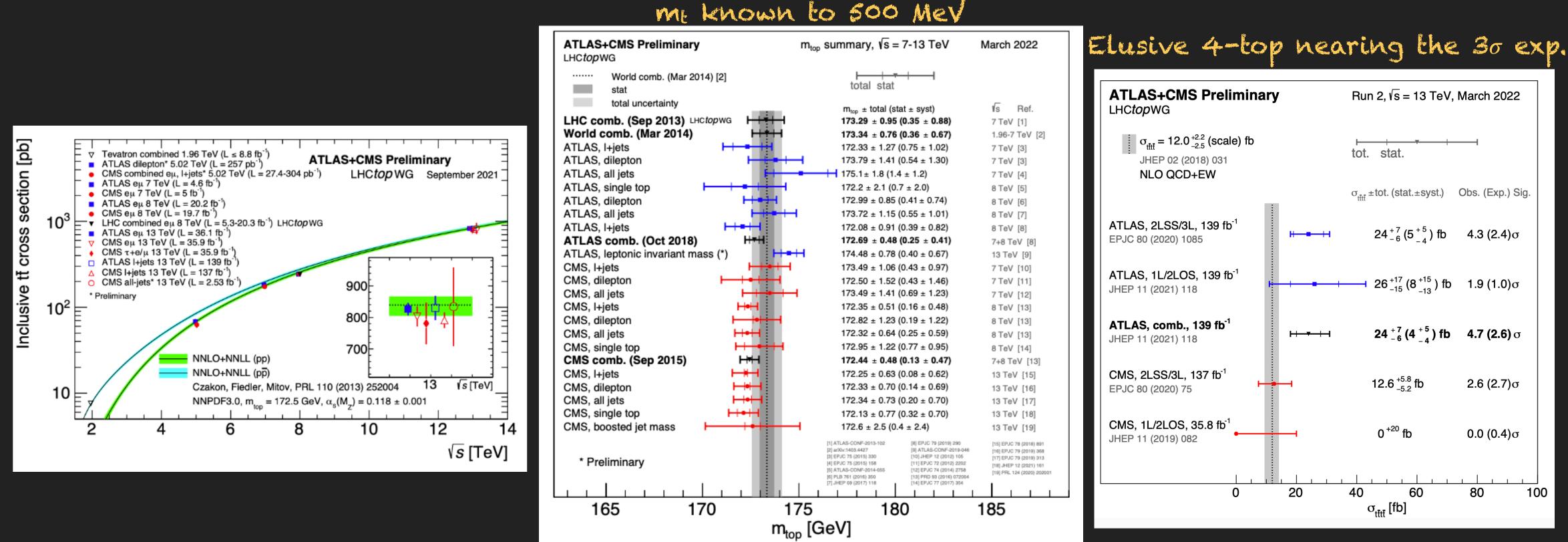


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## **THE BIG PICTURE: TOP**

Top quark: special role in EWSB?

Knowledge of processes with top: limiting factor in many analyses



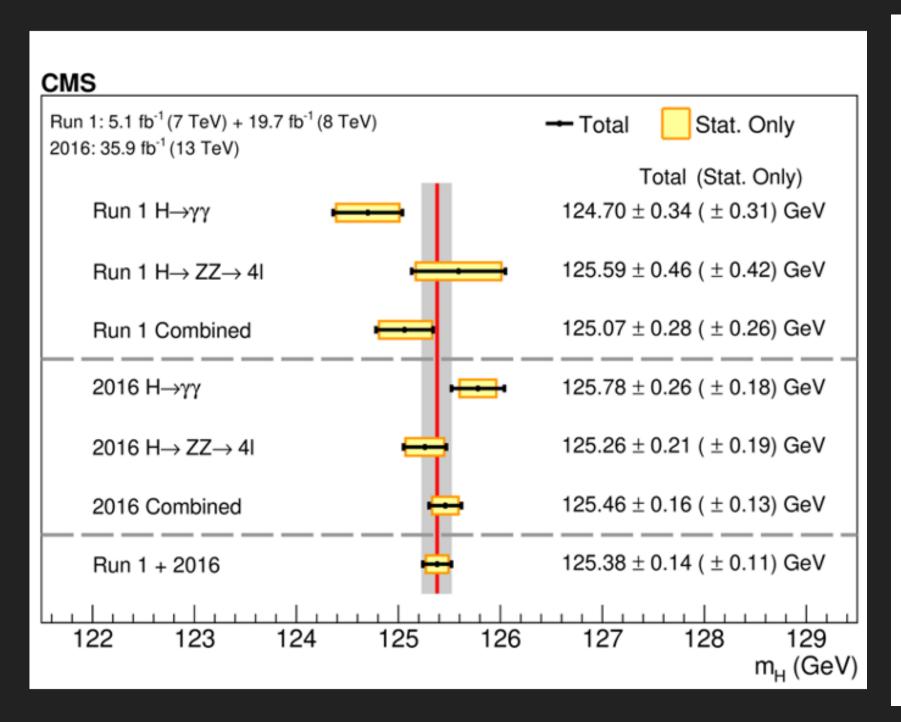
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### THE BIG PICTURE: HIGGS SECTOR

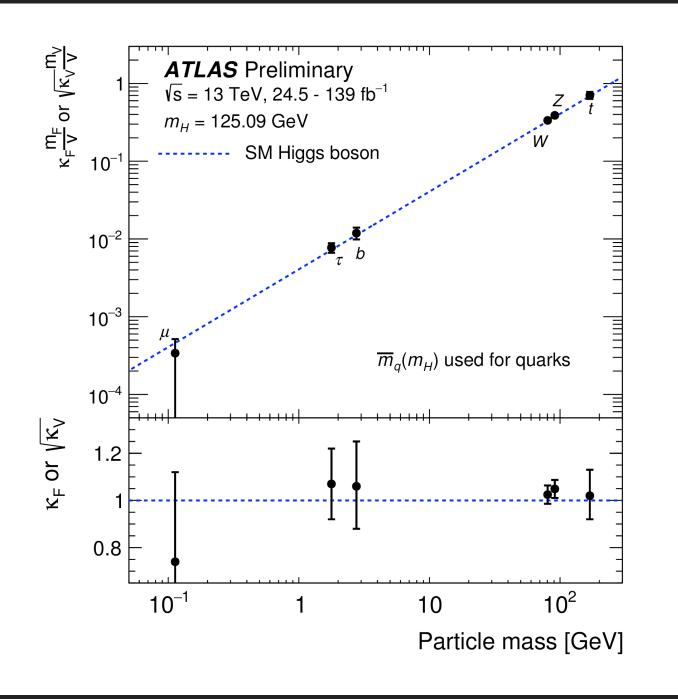
- Coupling to vector boson & 3rd generation fields known up to ~10%
- 0+ state favoured over other J<sup>PC</sup> hypothesis



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# $m_{\rm H} = 125.38$ GeV with 0.11% precision & narrow width ( $\Gamma_{\rm H} = 3.2^{+2.8}_{-2.2}$ MeV)



Direct search @ CMS (CMS-PAS-HIG-21-008)

 $1.1 < \kappa_c < 5.5$  obs. ( $\kappa_c < 3.4$  exp.)

Indirect through Higgs boson pTYY normalisation and shape @ ATLAS (arXiv:2202.00487):

 $-2.7 < \kappa_c < 2.6$  obs. (-3.2 <  $\kappa_c < 3.2$  exp.)







## THE BIG PICTURE: BEYOND THE SM

### No new particle discovered so far...

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits ATLAS Preliminary									
Sta	atus: March 2022	l ar latat	E <sup>miss</sup> ∫£		1 : :4	$\int \mathcal{L} dt =$	(3.6 – 139) fb <sup>-1</sup>	$\sqrt{s} = 8, 13 \text{ TeV}$	
Extra dimensions	ModelADD $G_{KK} + g/q$ ADD non-resonant $\gamma\gamma$ ADD QBHADD BH multijetRS1 $G_{KK} \rightarrow \gamma\gamma$ Bulk RS $G_{KK} \rightarrow WW/ZZ$ Bulk RS $G_{KK} \rightarrow WV \rightarrow \ell \nu qq$ Bulk RS $g_{KK} \rightarrow tt$ 2UED / RPP	$\begin{array}{c c} \ell, \gamma & \text{Jets} \\ \hline 0 \ e, \mu, \tau, \gamma & 1-4 \ j \\ 2\gamma & - \\ - & 2 \ j \\ - & 23 \ j \\ 2\gamma & - \\ \hline multi-channel \\ 1 \ e, \mu & 2 \ j / 1 \ J \\ 1 \ e, \mu & \ge 1 \ b, \ge 1 \ J \\ 1 \ e, \mu & \ge 2 \ b, \ge 3 \end{array}$	Yes 1 - 30 - 3 - 3 - 1 30 Yes 1 /2j Yes 30	MD           39         MD           5.7         MS           6.0         Mth           8.6         Mth           8.7         GKK mass           8.7         GKK mass           8.9         GKK mass           8.9         GKK mass           8.1         GKK mass           8.1         GKK mass	Limit	11.2 8.6 TeV 8.9 TeV 9.55 TeV 2.3 TeV 2.0 TeV 3.8 TeV 1.8 TeV	FeV $n = 2$ n = 3 HLZ NLO n = 6 $n = 6, M_D = 3$ TeV, rot BH $k/\overline{M}_{Pl} = 0.1$ $k/\overline{M}_{Pl} = 1.0$ $k/\overline{M}_{Pl} = 1.0$ $\Gamma/m = 15\%$ Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	2102.10874           1707.04147           1703.09127           1512.02586           2102.13405           1808.02380           2004.14636           1804.10823           1803.09678	
Gauge bosons	$\begin{array}{l} \operatorname{SSM} Z' \to \ell\ell \\ \operatorname{SSM} Z' \to \tau\tau \\ \operatorname{Leptophobic} Z' \to bb \\ \operatorname{Leptophobic} Z' \to tt \\ \operatorname{SSM} W' \to \ell\nu \\ \operatorname{SSM} W' \to \tau\nu \\ \operatorname{SSM} W' \to \taub \\ \operatorname{HVT} W' \to WZ \to \ell\nu qq \text{ model} \\ \operatorname{HVT} W' \to WZ \to \ell\nu \ell'\ell' \text{ mod} \\ \operatorname{HVT} W' \to WH \text{ model B} \\ \operatorname{LRSM} W_R \to \mu N_R \end{array}$		- 30 - 30 J Yes 1 Yes 1 J - 1 Yes 1 J - 1 Yes 1 J 2 1		340 GeV	5.1 TeV 2.42 TeV 2.1 TeV 4.1 TeV 6.0 TeV 5.0 TeV 4.4 TeV 4.3 TeV 3.2 TeV 5.0 TeV	$\Gamma/m = 1.2\%$ $g_V = 3$ $g_V c_H = 1, g_f = 0$ $g_V = 3$ $m(N_R) = 0.5 \text{ TeV}, g_L = g_R$	1903.06248 1709.07242 1805.09299 2005.05138 1906.05609 ATLAS-CONF-2021-025 ATLAS-CONF-2021-043 2004.14636 ATLAS-CONF-2022-005 2007.05293 1904.12679	
CI	Cl qqqq Cl ℓℓqq Cl eebs Cl μμbs Cl tttt	$\begin{array}{cccc} - & 2  j \\ 2  e, \mu & - \\ 2  e & 1  b \\ 2  \mu & 1  b \\ \geq 1  e, \mu & \geq 1  b, \geq 1 \end{array}$	- 1 - 1 - 1	Λ       39     Λ       39     Λ       39     Λ       39     Λ       31     Λ		1.8 TeV 2.0 TeV 2.57 TeV	$\begin{array}{c c} \textbf{21.8 TeV} & \eta_{LL}^- \\ \hline \textbf{35.8 TeV} \\ \textbf{g}_* = 1 \\ \textbf{g}_* = 1 \\  C_{4t}  = 4\pi \end{array} \qquad $	1703.09127 2006.12946 2105.13847 2105.13847 1811.02305	
DM	Axial-vector med. (Dirac DM) Pseudo-scalar med. (Dirac DM) Vector med. Z'-2HDM (Dirac D Pseudo-scalar med. 2HDM+a	M) $0 e, \mu$ 2 b	Yes 1 Yes 1	39 <mark>m<sub>med</sub> 39 39 30 30 30 30 30 30 30 30 30 30 30 30 30 </mark>	376 GeV 560 GeV	2.1 TeV 3.1 TeV	$\begin{array}{l} g_q = 0.25,  g_{\chi} = 1,  m(\chi) = 1   {\rm GeV} \\ g_q = 1,  g_{\chi} = 1,  m(\chi) = 1   {\rm GeV} \\ {\rm tan} \beta = 1,  g_Z = 0.8,  m(\chi) = 100   {\rm GeV} \\ {\rm tan} \beta = 1,  g_{\chi} = 1,  m(\chi) = 10   {\rm GeV} \end{array}$	2102.10874 2102.10874 2108.13391 ATLAS-CONF-2021-036	
δŢ	Scalar LQ 1 <sup>st</sup> gen Scalar LQ 2 <sup>nd</sup> gen Scalar LQ 3 <sup>rd</sup> gen Scalar LQ 3 <sup>rd</sup> gen Scalar LQ 3 <sup>rd</sup> gen Scalar LQ 3 <sup>rd</sup> gen Vector LQ 3 <sup>rd</sup> gen	$\begin{array}{cccc} 2 \ e & \geq 2 \ j \\ 2 \ \mu & \geq 2 \ j \\ 1 \ \tau & 2 \ b \\ 0 \ e, \mu & \geq 2 \ j, \geq 2 \\ \geq 2 \ e, \mu, \geq 1 \ \tau \geq 1 \ j, \geq 1 \\ 0 \ e, \mu, \geq 1 \ \tau & 0 - 2 \ j, 2 \\ 1 \ \tau & 2 \ b \end{array}$	Yes 1 Yes 1 b Yes 1 b – 1 b Yes 1	39         LQ mass           39         LQ mass           39         LQ" mass	1	1.8 TeV 1.7 TeV 1.2 TeV .24 TeV 1.43 TeV 1.26 TeV 1.77 TeV	$\begin{split} \beta &= 1\\ \beta &= 1\\ \mathcal{B}(\mathrm{LQ}_3^u \to b\tau) &= 1\\ \mathcal{B}(\mathrm{LQ}_3^u \to t\nu) &= 1\\ \mathcal{B}(\mathrm{LQ}_3^d \to t\tau) &= 1\\ \mathcal{B}(\mathrm{LQ}_3^d \to b\nu) &= 1\\ \mathcal{B}(\mathrm{LQ}_3^v \to b\tau) &= 0.5, \text{ Y-M coupl.} \end{split}$	2006.05872 2006.05872 2108.07665 2004.14060 2101.11582 2101.12527 2108.07665	
Heavy quarks	$\begin{array}{c} VLQ\ TT \to Zt + X\\ VLQ\ BB \to Wt/Zb + X\\ VLQ\ T_{5/3}T_{5/3} T_{5/3} \to Wt + X\\ VLQ\ T \to Ht/Zt\\ VLQ\ Y \to Wb\\ VLQ\ B \to Hb \end{array}$	$\begin{array}{c c} 2e/2\mu/\geq 3e, \mu \geq 1 \ b, \geq 1 \\ multi-channel \\ 2(SS)/\geq 3 \ e, \mu \geq 1 \ b, \geq 1 \\ 1 \ e, \mu  \geq 1 \ b, \geq 3 \\ 1 \ e, \mu  \geq 1 \ b, \geq 1 \\ 0 \ e, \mu  \geq 2b, \geq 1j, \end{array}$	30 j Yes 30 j Yes 1 j Yes 30	5.1 T <sub>5/3</sub> mass 39 T mass		1.4 TeV 1.34 TeV 1.64 TeV 1.8 TeV 1.85 TeV 2.0 TeV	SU(2) doublet SU(2) doublet $\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3}Wt) = 1$ SU(2) singlet, $\kappa_T = 0.5$ $\mathcal{B}(Y \rightarrow Wb) = 1, c_R(Wb) = 1$ SU(2) doublet, $\kappa_B = 0.3$	ATLAS-CONF-2021-024 1808.02343 1807.11883 ATLAS-CONF-2021-040 1812.07343 ATLAS-CONF-2021-018	
<b>Excited</b> fermions	Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited lepton $\ell^*$ Excited lepton $\nu^*$	$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	- 30 - 30 - 20	39     q* mass       3.7     q* mass       5.1     b* mass       9.3     l* mass       9.3     v* mass		6.7 TeV 5.3 TeV 2.6 TeV 3.0 TeV 1.6 TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ $\Lambda = 3.0 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1910.08447 1709.10440 1805.09299 1411.2921 1411.2921	
Other	Type III Seesaw LRSM Majorana $v$ Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$ Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$ Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$ Multi-charged particles Magnetic monopoles	$\begin{array}{ccc} 2,3,4 \ e, \mu & \geq 2 \ j \\ 2 \ \mu & 2 \ j \\ 2,3,4 \ e, \mu \ (SS) & various \\ 2,3,4 \ e, \mu \ (SS) & - \\ 3 \ e, \mu, \tau & - \\ - & - & - \\ $	- 30 Yes 1 - 1 - 20 - 30	39         H <sup>±±</sup> mass           39         H <sup>±±</sup> mass           0.3         H <sup>±±</sup> mass	400 GeV particle mass 1.	3.2 TeV 3 TeV .22 TeV 2.37 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$ DY production DY production DY production, $\mathcal{B}(H_L^{\pm\pm} \rightarrow \ell\tau) = 1$ DY production, $ q  = 5e$ DY production, $ g  = 1g_D$ , spin 1/2	2202.02039 1809.11105 2101.11961 ATLAS-CONF-2022-010 1411.2921 1812.03673 1905.10130	
	$v_{2} = o_{1} = v_{2}$		data	10	-1	1	<sup>10</sup> Mass scale [TeV]		

\*Only a selection of the available mass limits on new states or phenomena is shown. *†Small-radius (large-radius) jets are denoted by the letter j (J)* 

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### PROSPECTS ON SM PHYSICS

- The increased dataset will allow to i measurements
- The systematically limited measurements will benefit too!
  - More data = better understanding of experimental systematic uncertainties
  - Theoretical uncertainties may become dominant in some measurements
- Also benefit from detector upgrades, e.g. the inner detector improved forward coverage in ATLAS and CMS

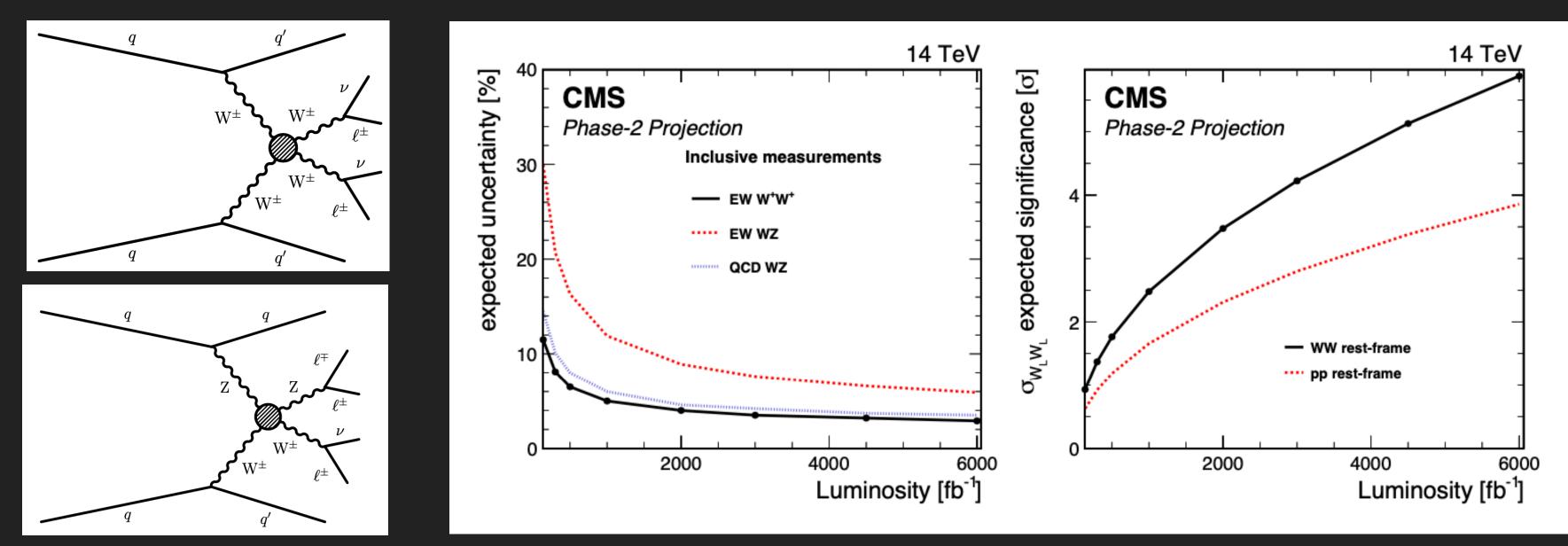
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The increased dataset will allow to improve sensitivity in statistically limited



## SM: MULTIBOSON PRODUCTION (STATISTICALLY LIMITED)

- gauge interactions
- Very low cross section only possible to investigate at the HL-LHC
- of the vector boson scattering amplitude production through Higgs boson



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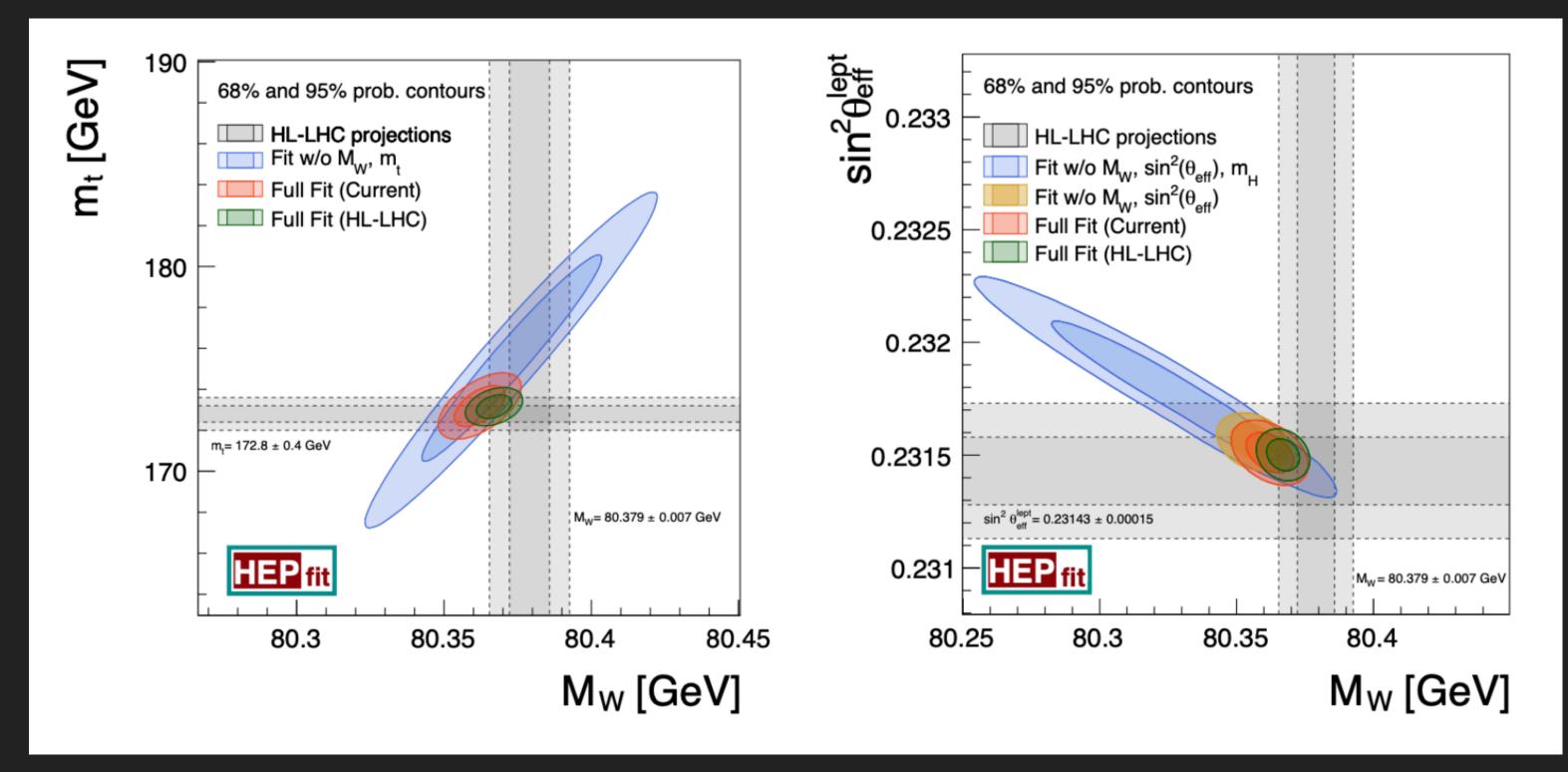
Purely electroweak diboson production VVjj - sensitive to the nature of mass generation as well as quartic-

The final state in which the two bosons are longitudinally polarized directly probes the unitarization mechanism

=> should be available at HL-LHC through combination of CMS and ATLAS



## SM: GLOBAL EW FIT (ACCEPTANCE / SYSTEMATIC IMPROVEMENTS)



Same input SM central values + reduced exp. uncert. + more precise EW measurements : could significantly increase the tension between the indirect and direct determinations of m<sub>z</sub>, m<sub>t</sub>, and m<sub>H</sub>

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Global fit to EW precision observables with HEPFit for current and expected HL-LHC results:

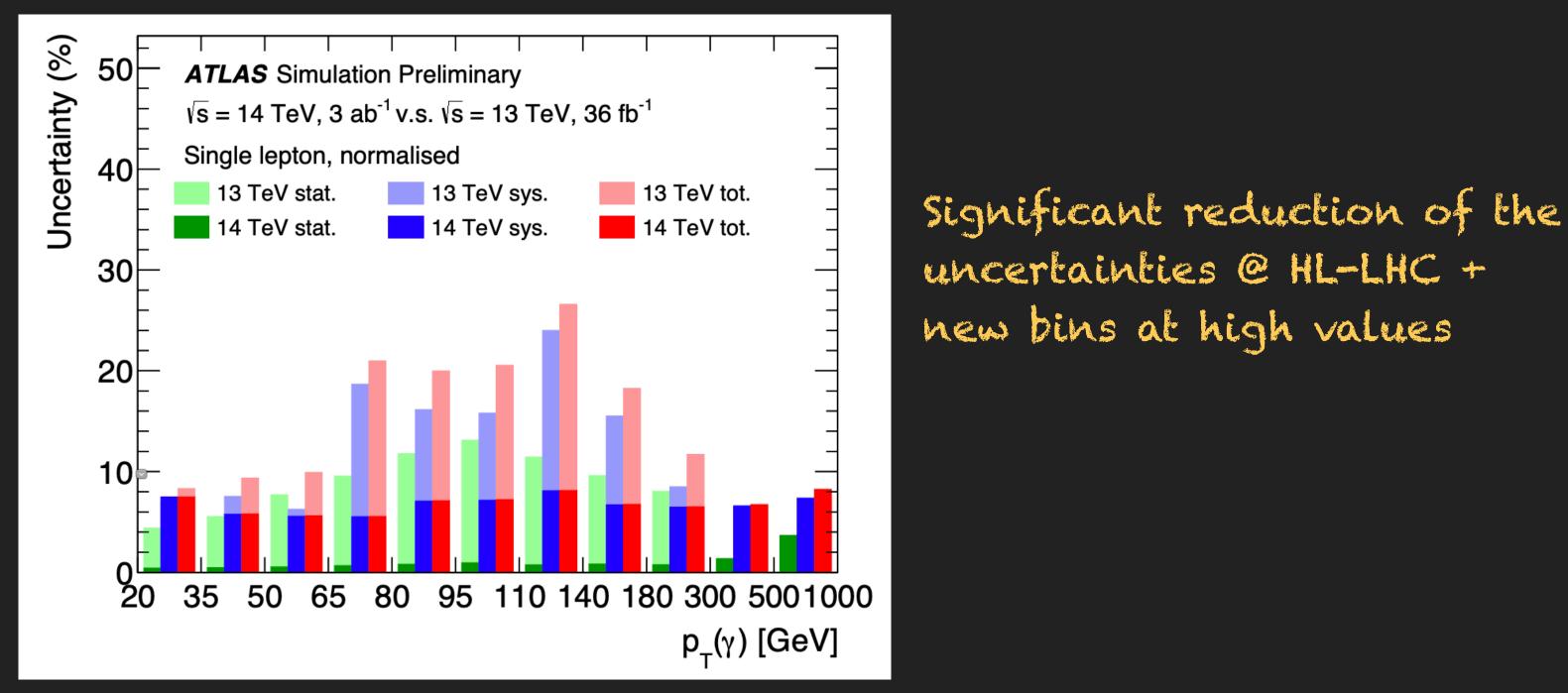
Improvement on W mass: special low-lumi runs + larger acceptance from upgrade (Lower PDF uncert.)

The larger acceptance will also help the weak angle measurement through dileptonic AFB



## FFRFNIIAI MFA<u>s</u>

- higher momentum
  - Look for deviations from BSM, improve on the PDF uncertainties,...
- dipole moments of the top quark



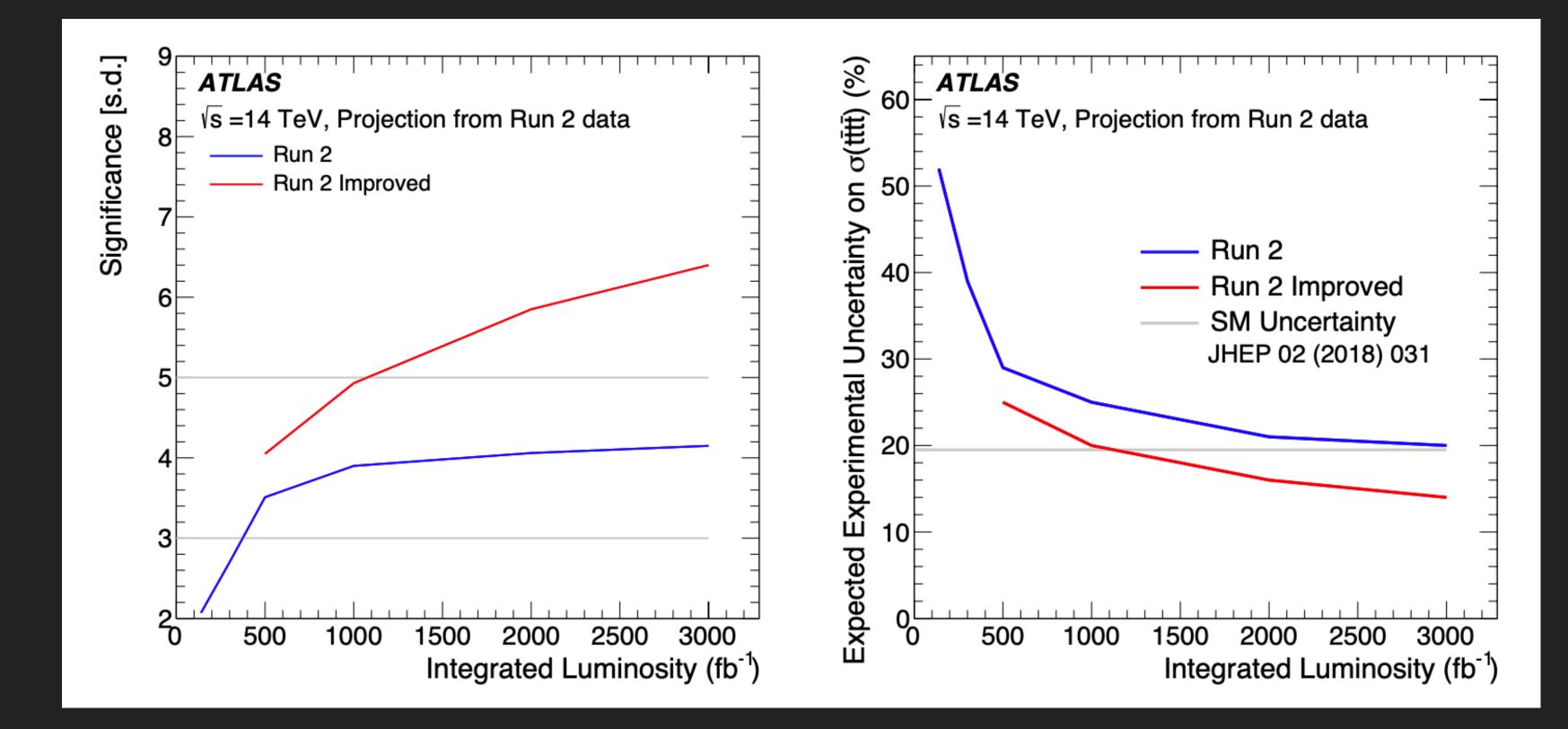
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Significant improvement expected: increased precision, reduced bin size, new phase space at

As an example: the tty production - the photon  $p_T$  distribution can probe for anomalous

### **SM: 4T0P**

- Extrapolation of the full Run-2 analysis to the HL-LHC



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### ATL-PHYS-PUB-2022-004

≥ 2 leptons (2 of same charge or ≥3), ≥ 6 jets of which ≥2 are b-tagged, high  $H_T > 500$  GeV

Run 2 Improved scenario driven by smaller uncertainties assumed for the 4 top and ttv+jets modeling

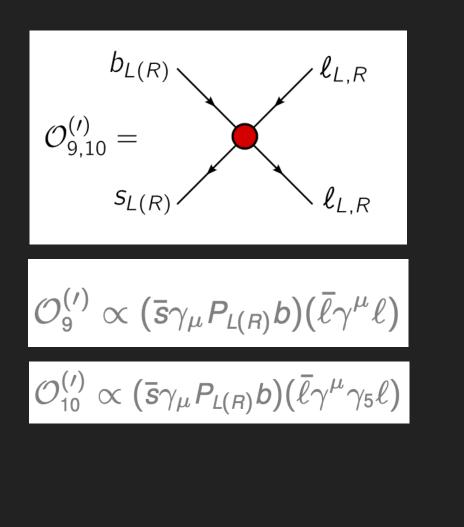
14% uncertainty on the measured cross section at the end of the HL-LHC

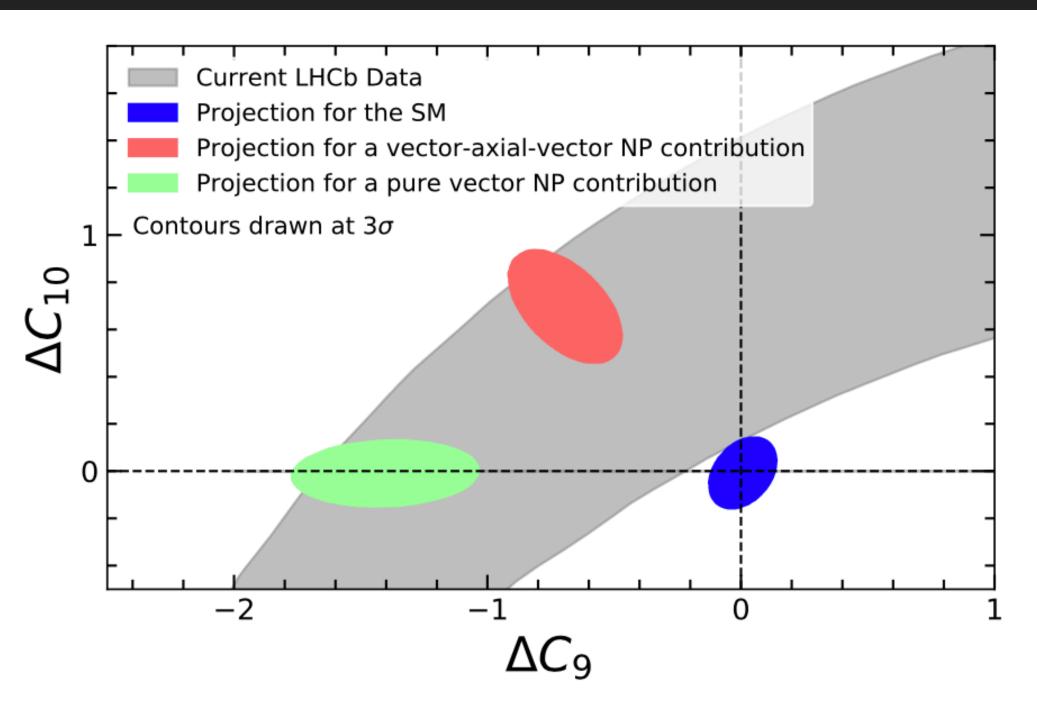




## **SM: LEPTON FLAVOUR UNIVERSALITY TESTS**

- excellent probe for some BSM theories
  - vector nature of a potential BSM particle





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LHCB-TDR-023

Exact LFU in the SM gauge couplings & corrections due to mass effects are calculable to good precision:

▶ With 300 fb<sup>-1</sup> @ LHCb will also allow to compare angular distributions for  $b \rightarrow s\mu^+\mu^-$  and  $b \rightarrow se^+e^-$ : axial or

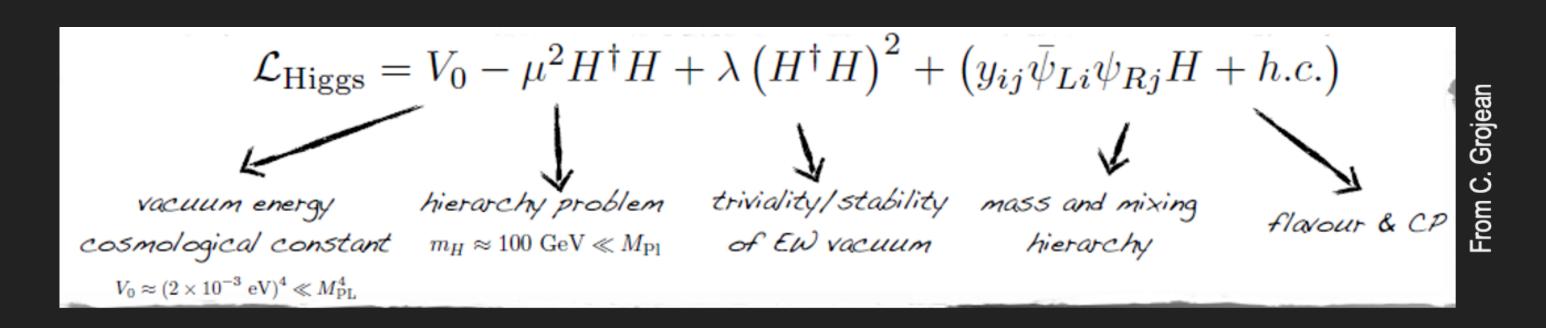
> Will not only allow a potential BSM contribution to be established with an overwhelming significance, but also provide a characterisation of the BSM that will be essential to distinguish between theoretical models

> Grey region: current 3-sigma uncertainty



## PROSPECTS ON HIGGS PHYSICS

- The Higgs boson is a fundamental scalar particle and its theory is unlike anything else we have seen in nature
- It is linked to several deep problems in High Energy Physics:



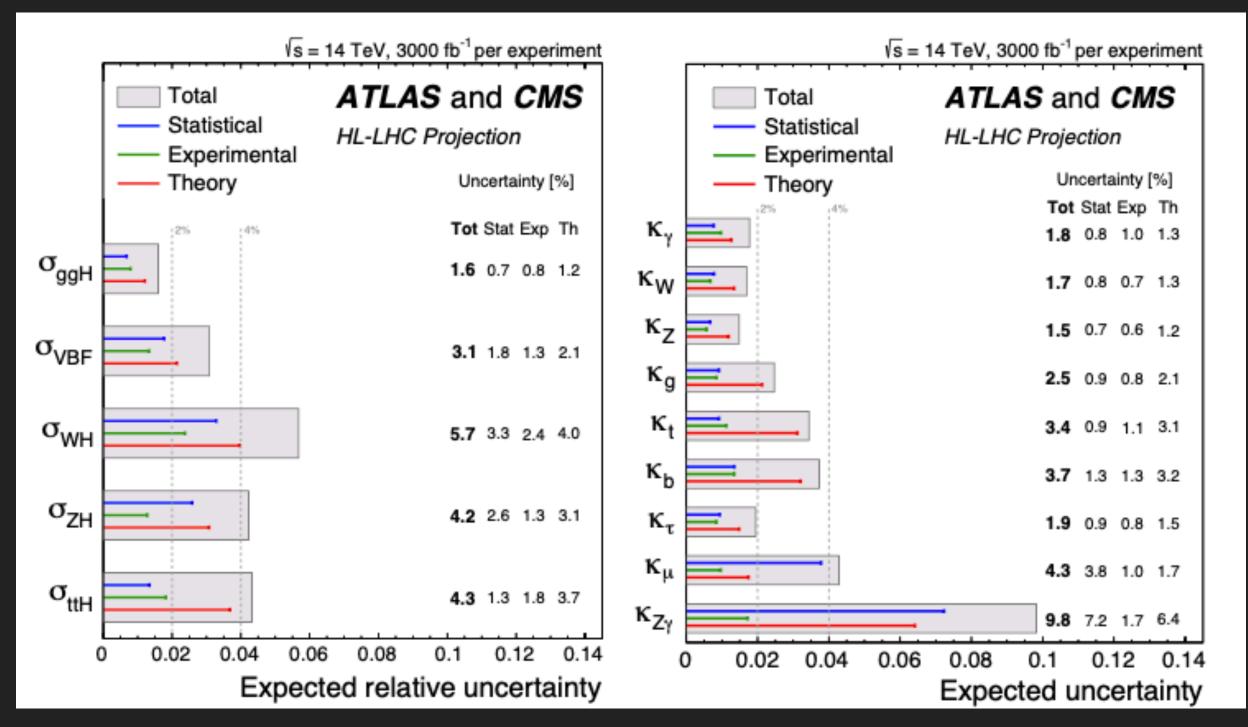
precision is not enough to significantly challenge many BSM models

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While the results obtained so far are in agreement with the SM, the current



## HIGGS: CROSS SECTION, COUPLINGS, MASS & WIDTH



- Constraining the width  $\Gamma/\Gamma_{SM}$ :
  - From a fit to the couplings (assume  $|\kappa_V| \le 1$ ): 4% uncertainty at HL-LHC from CMS projection

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CERN-2019-007 ATL-PHYS-PUB-2022-018 CMS PAS FTR-22-001

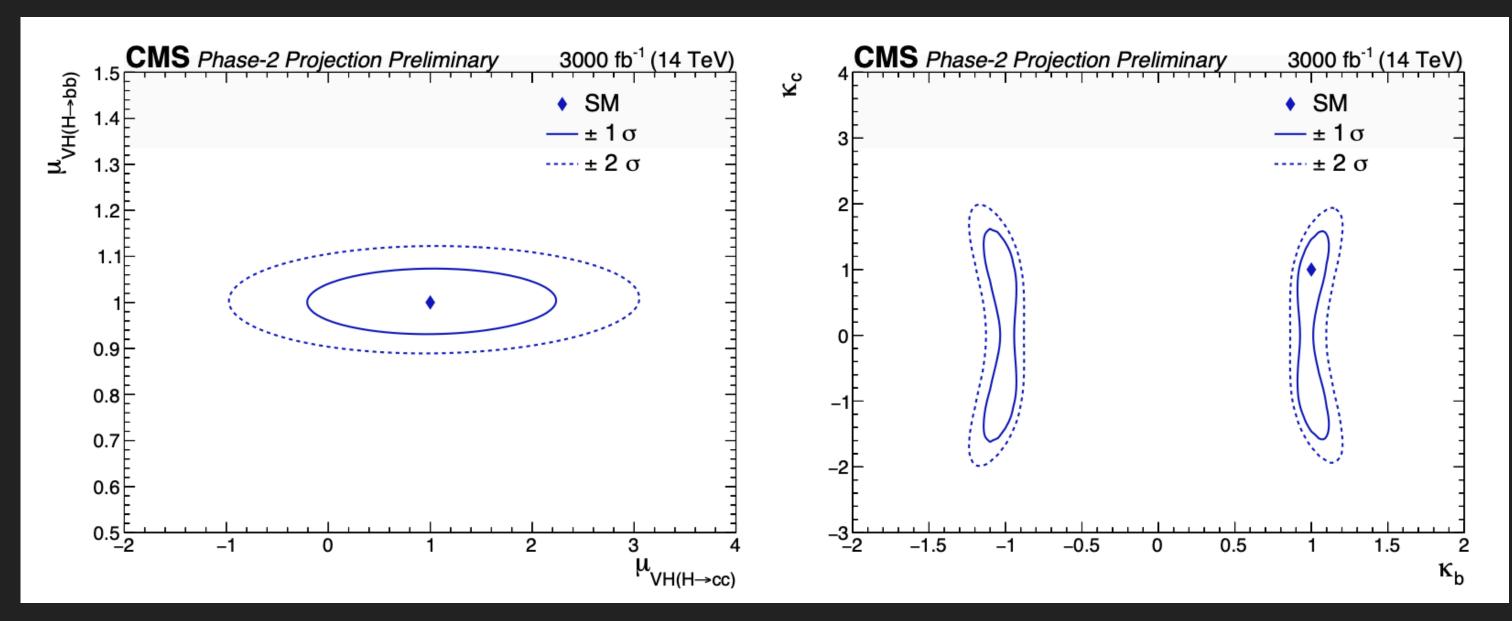
In the diphoton channel, CMS predicts an expected mass measurement of  $m_{\mu}$  = 125.38 ± 0.02 (stat) ± 0.07 (syst) GeV

 $\blacktriangleright$  from a comparison of the on-shell and off-shell  $H \rightarrow ZZ$  production (assume that the gluon and Z couplings) evolve off-shell as in the SM): ATLAS+CMS projection at 4.1<sup>+0.7</sup>-0.8 MeV (dominated by theory uncertainties)



## **HIGGS: COUPLING TO CHARM**

- Probing the coupling to the charm quark directly through  $H \rightarrow cc^{-}$  searches
  - future development in charm tagging techniques could result in a significant increase of the sensitivity
- Projection to HL-LHC using the boosted Higgs category analysis of the recent Run 2 CMS result
  - > HL-LHC systematics used except for the b and c-tagging efficiencies which will be constrained using  $VZ(Z \rightarrow bb)$  and  $VZ(Z \rightarrow cc)$



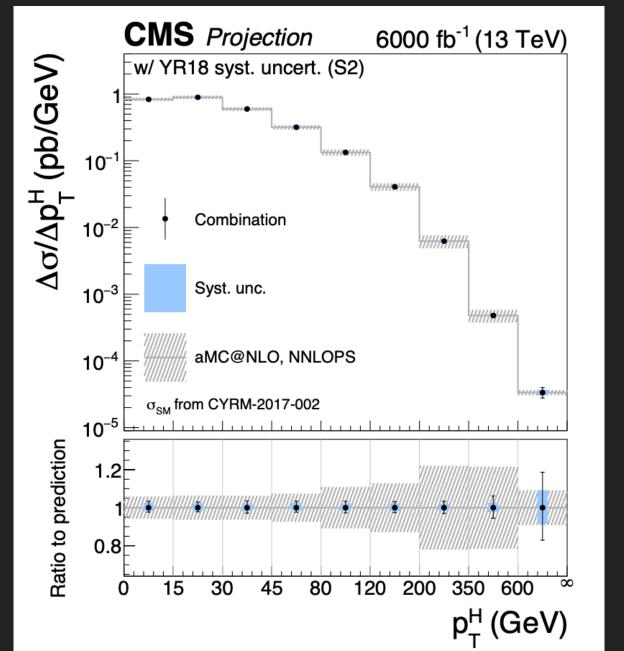
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### $\triangleright$ Combined fit of bb- and cc-enriched categories to simultaneously measure VH(H $\rightarrow$ bb) and VH(H $\rightarrow$ cc)



## **HIGGS: DIFFERENTIAL MEASUREMENTS**

- - measure the  $p_T^H$  distribution
- Can improve the constraint on the top Yukawa coupling by looking at top channels where the Higgs momentum can be reconstructed (e.g.  $tt^{-}H$  with  $H \rightarrow \gamma\gamma$  or  $H \rightarrow bb$ )
- Used of improved jet substructure tools to reconstruct boosted Higgs can significantly enhance the sensitivity of these analyses



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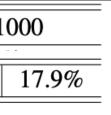


Potential BSM physics may reside in the tails of distributions, which cannot be measured in inclusive measurements

Combination of  $H \rightarrow \gamma \gamma$  (ATLAS+CMS)  $H \rightarrow ZZ (ATLAS+CM)$  $H \rightarrow bb$  (CMS)

Precision per bin:

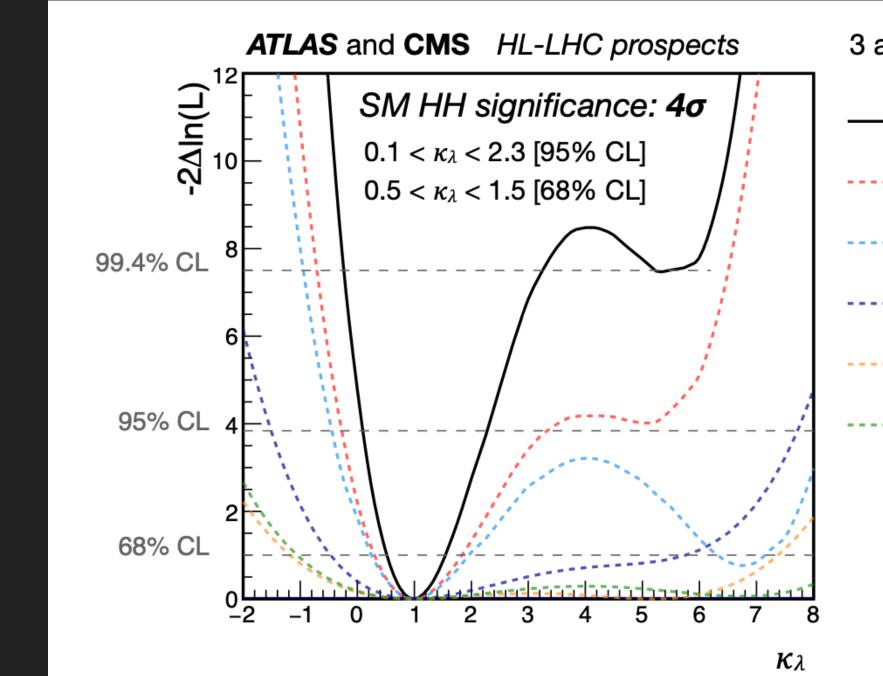
$p_{\mathrm{T}}^{\mathrm{H}}$ [GeV ]	0-10	10-15	15-20	20-30	30-45	45-60	60-80	80-120	120-200	200-350	350-1	0
Combination	2.9%		2.6%		3.2%	2.9%		3.0%	2.9%	3.2%	5.8%	



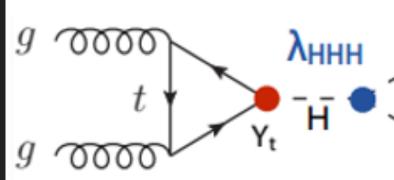


## HIGGS: TRILINEAR SELF-INTERA

- Directly measuring the coupling ( $\lambda_{HHH} = m_H^2 / 2v^2$ ) with HH production\* will constrain the shape of the Higgs potential and verify the EWSB mechanism
- Mainly  $HH \rightarrow bbbb$  (33.9%),  $HH \rightarrow bb\tau\tau$  (7.3%) and  $HH \rightarrow bb\gamma\gamma$  (0.26%)



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3 ab<sup>-1</sup> (14 TeV)

- ---- Combination
- $---- b\overline{b}\gamma\gamma$ 
  - bbττ
  - bbbb
  - bbZZ\*(4I)
  - bbVV(lvlv)

+ snowmass updated projections leading to even higher significances:

For ex.: ATLAS extrapolation from full Run 2 analyses, benefiting from updated reconstruction algorithms and analysis methods

```
-bb\tau\tau : 2.1\sigma \rightarrow 2.8\sigma
-bb\gamma\gamma: 2.0\sigma \rightarrow 2.2\sigma
```

\*1000x smaller than single H production!



### **PROSPECTS FOR BSM PHYSICS**

- No clear deviation seen so far, but only 5% of the expected data analysed
  - the first years of new runs!)
  - performance studies, reducing systematics as well
- Probe for BSM:
  - At higher masses (resonances in spectrum, kinematic tail deviations,...)
  - methods to reduce BG / trigger on these events!
  - Explore new channels
  - Upgraded detectors and innovative analysis approaches (eg ML)

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The sensitivity should improve at sqrt(L) or as L for searches with no BG (interesting avenue in

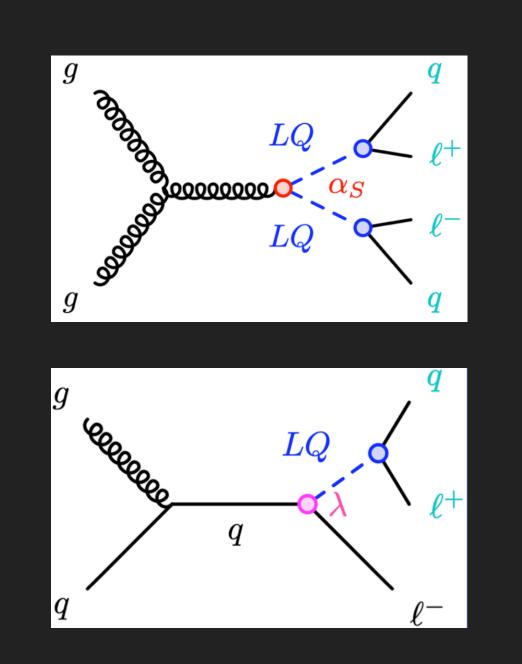
Not only improving by stats only as already noted before: bigger samples should benefit

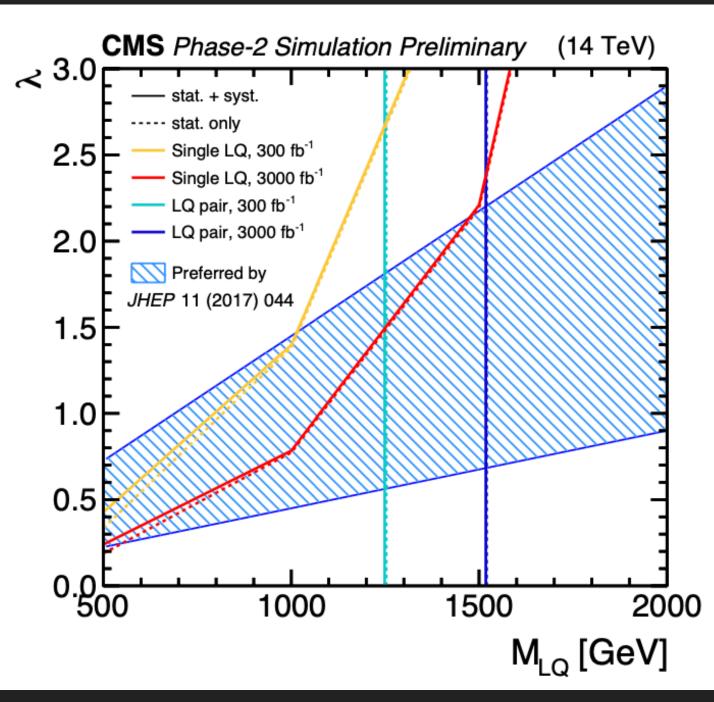
At low masses (could have escaped detection due to low couplings!) - need innovative



### **BSM: PROBING HIGHER MASSES**

- - 6.4 TeV
  - Right-handed W' (ATLAS): up to 4.3 TeV in the tb channel
- Renewed interest in direct searches for leptoquarks from hints of flavour anomalies





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### Standard benchmark: heavy vector boson as a resonance over a smoothly falling BG

### SSM bosons: ee + $\mu\mu$ channels discovery reach (CMS): Z' up to 6.8 TeV or W'( $\tau\nu$ ) up to

Scalar LQ to bt could be probed up to 1.5 Tev (500 Gev improvement)



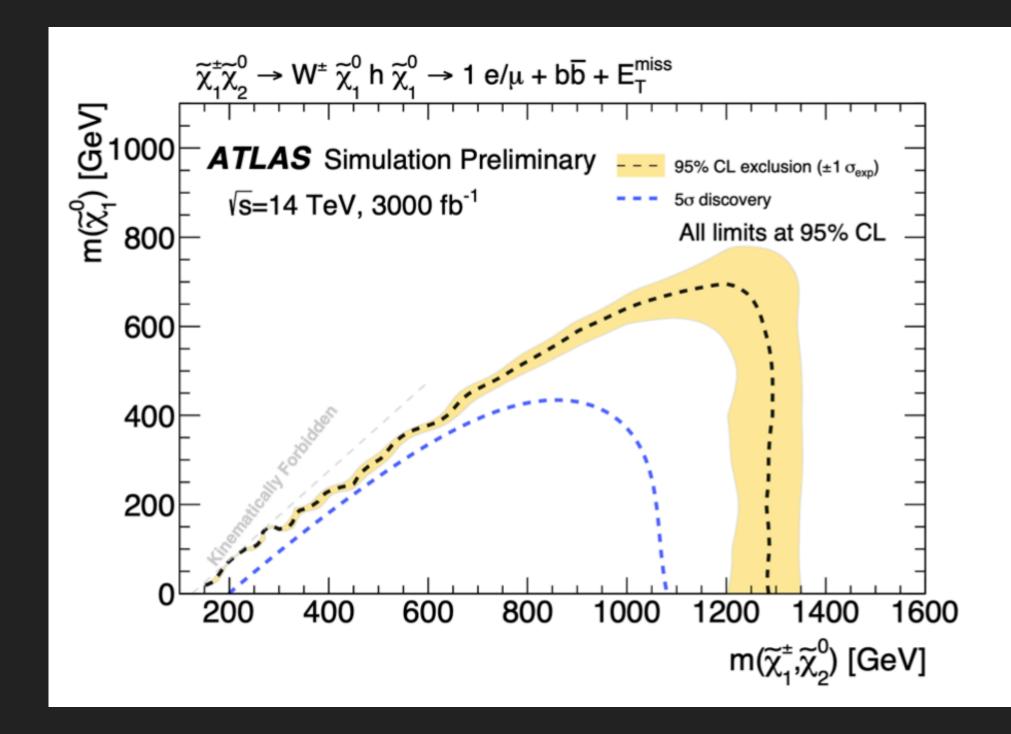
## **BSM: PROBING LOWER MASSES & COUPLINGS**

- Could have evaded detection so far due to small couplings and/or small production cross section and overwhelming backgrounds
- In the previous LHC runs: development of trigger-level (scouting) analyses
  - increase bandwidth by writing out very few information about specific objects, instead of full events for some triggers (dijet, dimuon resonance searches)
  - ATLAS/CMS: upgraded trigger systems will allow this program to continue, likely including additional final states.
  - LHCb:"triggerless" approach for the HL-LHC upgrade => complementary similar analyses in the forward rapidity region



### **RSM- FEFEIRIWFAK SIIPFRS**

- at HL-LHC
- leptonically



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### If gluinos/squarks at > 3-4 TeV, charginos and neutralinos may dominate the SUSY production

Example: final state of  $E_T^{miss}$  + 2 b-tagged jets with Higgs-like  $m_{bb}$  boson + W decaying

3 BDTs trained against top BG for different mass compression scenarios

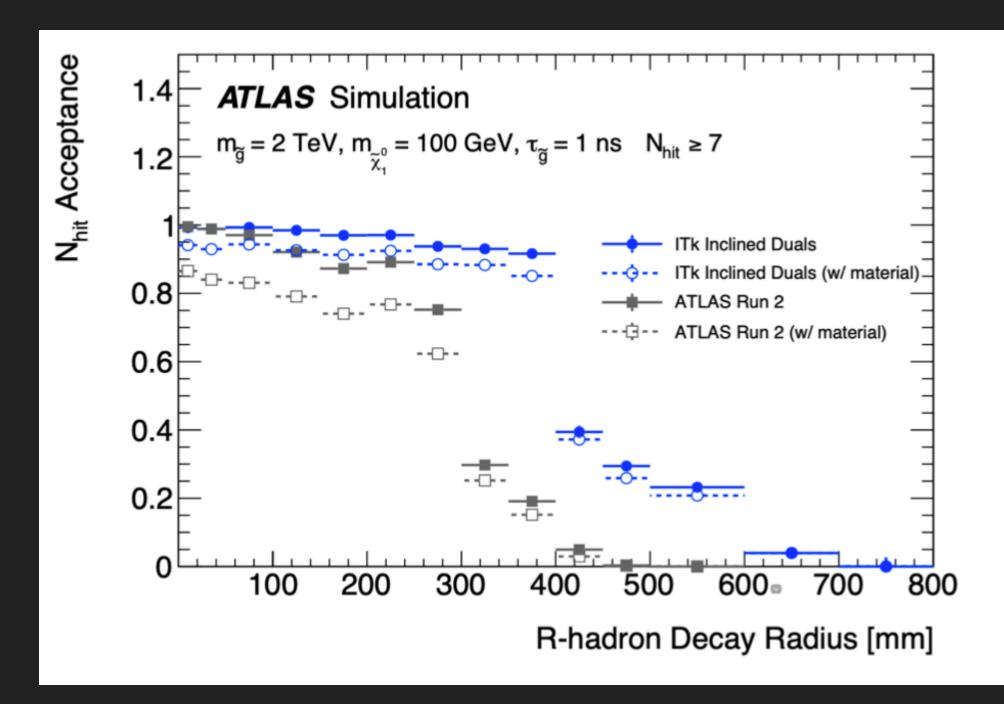
Conservative reach as fully-hadronic channel Later found in Run 2 to be more sensitive (fast evolution)

Masses at the TeV scale will be within reach even in scenarios of electroweak production!

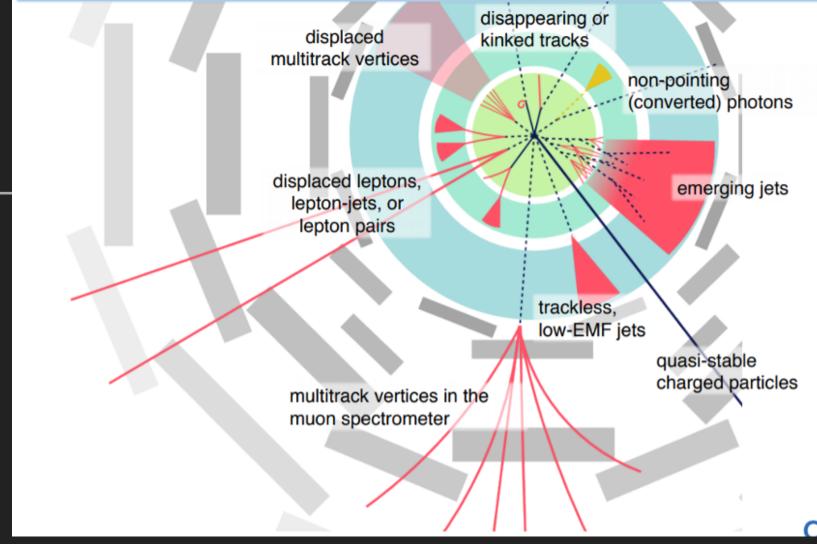


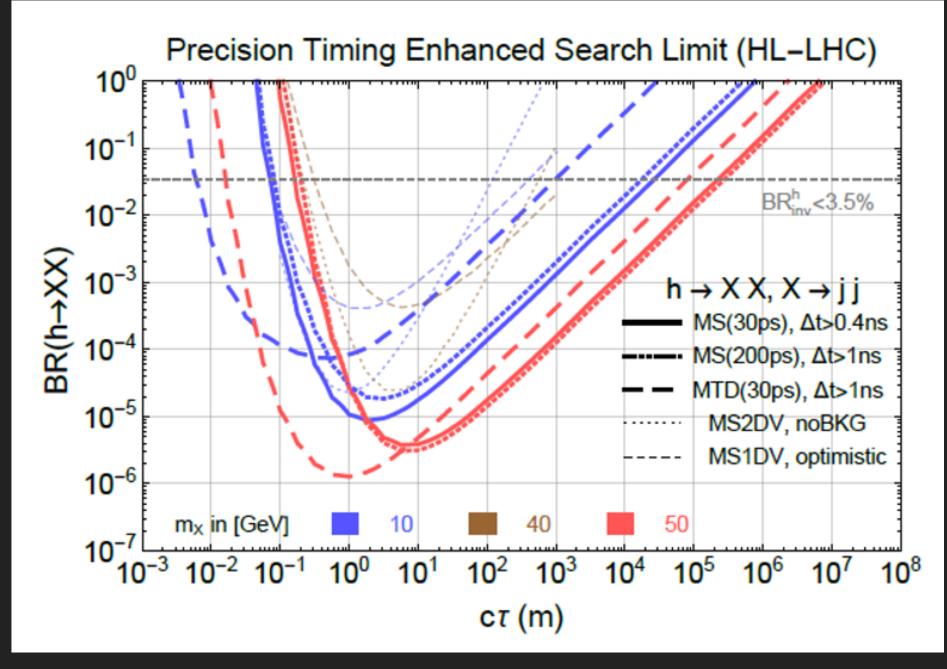
## **BSM: LONG-LIVED PARTICLES**

- LLPs occur in many BSM theories (heavy mediators, small couplings, compressed mass spectra) => decays away from the interaction point (eg displaced vertices)
  - Growing interest but need dedicated and complex reconstruction algorithms
  - Will benefit from upgraded detectors (ITk in ATLAS, MTD in CMS...)
    - And from new dedicated detectors (eg FASER)!



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Phys Rev Lett 122 131801



## NEW ANALYSIS TECHNIQUES

- Machine learning techniques used in HE frequency and breadth
- Some ML can target theories better than simple "cut-and-count" analyses, but the results obtained can highly depend on the model under study
- Exciting recent avenue: search for anomalies in the data themselves
  - Search for anomalies in objects with respect to a data-based training sample no need for a prior knowledge of the signal characteristics
    - See eg ATLAS search for dijet resonances with weak supervision (Phys. Rev. Lett. 125, 131801 (2020))
  - Gaining momentum, likely have become one of the standard search tools by HL-LHC

Machine learning techniques used in HEP for a long time, but recent increase in



### CONCLUSIONS

Just summarized a handful of projections, showing very nice prospects!

- Many others exist and some areas (eg low-mass BSM or LLP) do not have many projections made yet
- achieved by the LHC analyses
- within the Standard Model and beyond, with unprecendented sensitivities

The assumptions made are typically conservative given the rapid progress continuously

Some recent full Run-2 results are already competing with older HL-LHC projections!

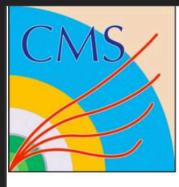
Expected to be further refined by the start of the HL-LHC data-taking, following developments in the object reconstruction performance and analysis methods

The program of the (HL-)LHC will continue to span a very wide range of physics topics,

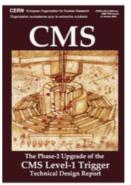


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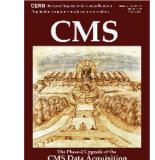
## The CMS Phase-2 Upgrade



### **Level-1** Trigger

https://cds.cern.ch/record/2714892

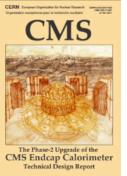
- Tracks in L1 Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



### **DAQ & High-Level Trigger** https://cds.cern.ch/record/2759072

- Full optical readout

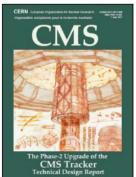
- 7.5 kHz HLT output



### **High-Granularity Calorimeter** Endcap

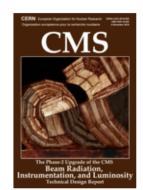
### https://cds.cern.ch/record/2293646

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/Cu-W/SS



### Tracker <a href="https://cds.cern.ch/record/2272264">https://cds.cern.ch/record/2272264</a>

- Si-Strip and Pixels increased granularity
- Extended coverage to η ≈ 4
- Design for tracking in L1 Trigger

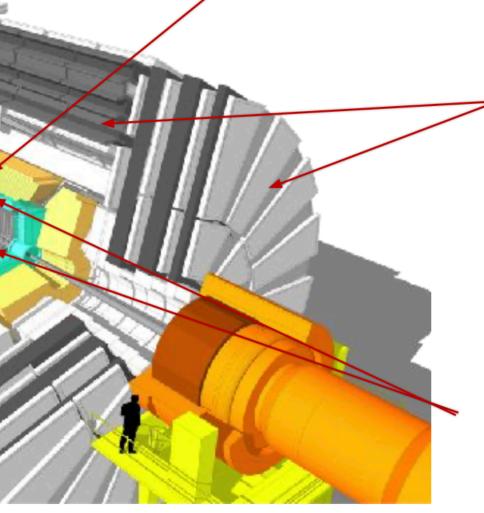


### **Beam Radiation Instrumentation and Luminosity** http://cds.cern.ch/record/2759074

- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

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• Heterogenous architecture • 60 TB/s event network



### **Barrel Calorimeters**

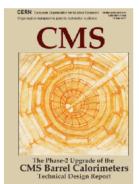
### https://cds.cern.ch/record/2283187

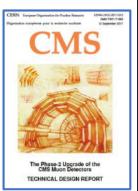
- ECAL single crystal granularity readout at 40 MHz with precise 30 ps timing for  $e/\gamma$  at 30 GeV
- Spike rejection
- ECAL and HCAL new Back-End boards



https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC BE electronics
- New GEM/RPC 1.6 < η < 2.4
- Extended coverage to η = 3





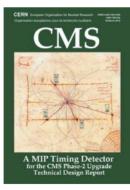
### **MIP Timing Detector**

### https://cds.cern.ch/record/2667167

Precision timing with:

- Full coverage to  $\eta \approx 3$
- 30-50 ps time resolution for MIPs
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

### Gabriella Pásztor





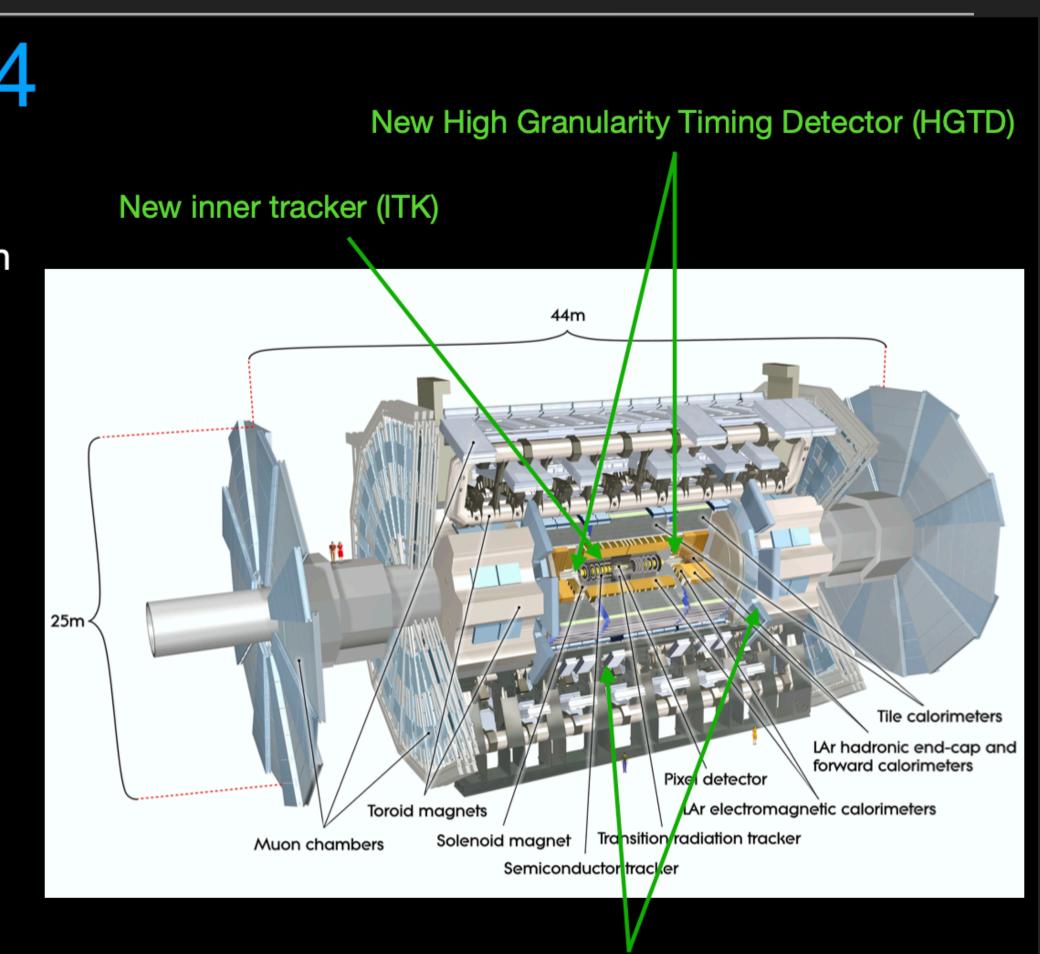
## ATLAS upgrades for Run4

- New systems in the cavern:
  - ITk: silicon inner tracker (pixels + strip detector) with eta coverage up to 4
  - RPC and sMDT muon detector in the barrel inner region, sTGC in the end-cap inner region
  - High Granularity Timing Detector in the forward region
  - Calorimeters and muon detectors (TGC/RPC/MDT) front-end readout at 40 MHz
  - Upgrades of luminosity and forward detectors
- New TDAQ off-detector electronics:
  - Level-0 hardware trigger: calorimeter, topological, muon, global, CTP (FPGA-based boards)
  - Readout: FELIX for all ATLAS detectors
  - Event Filter processor farm and hardware tracking

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Riccardo Vari - INFN Roma
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**ATLAS Upgrades** 

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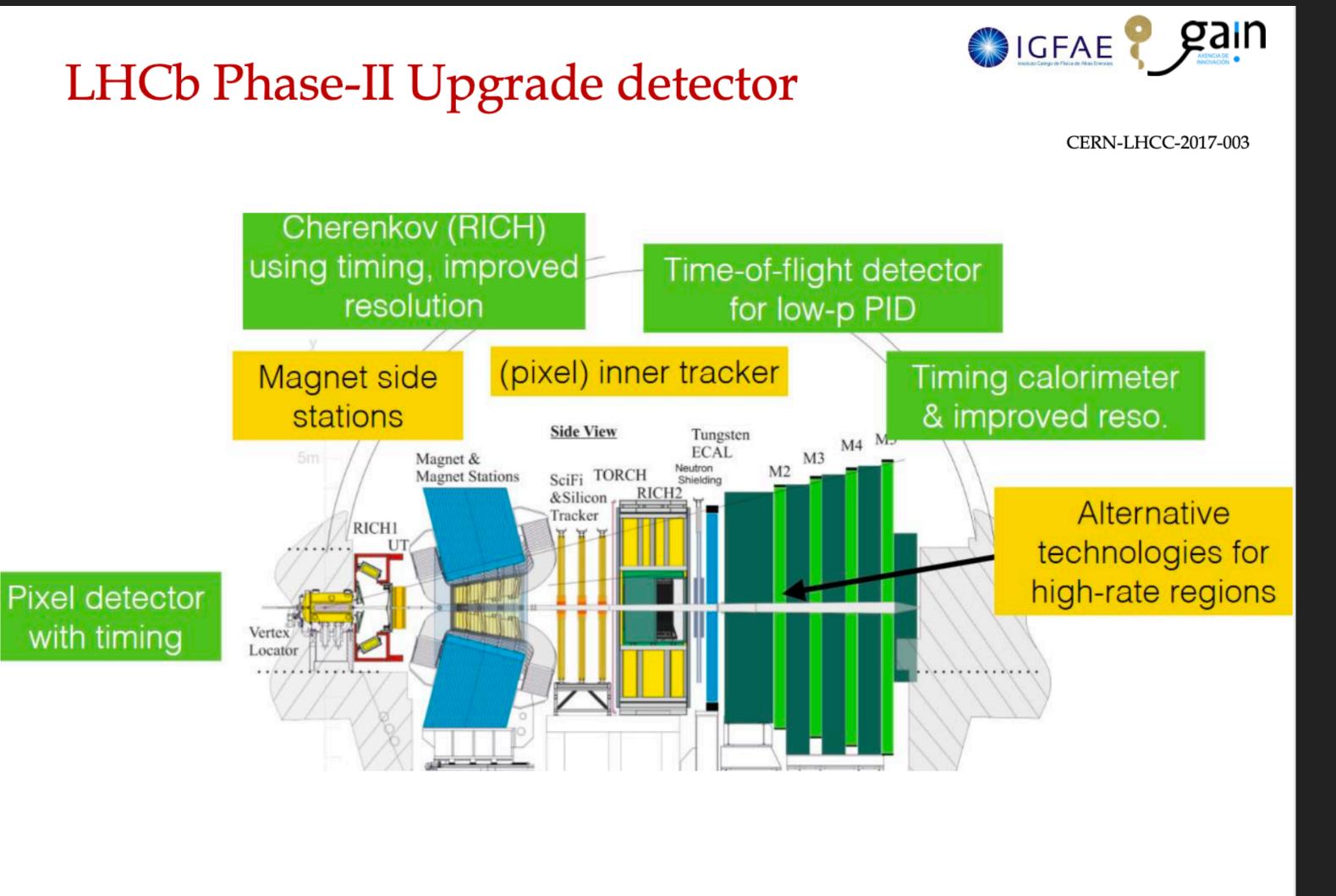


### New muon detectors (RPC + sMDT + TGC)

### Front-end replaced for calorimeters and muon detectors

LHCP2022 - 20 May 2022





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