ATLAS Experiment

Carl Gwilliam
(obo the Liverpool ATLAS group)

22nd May 2025
HEP Annual Meeting

ATLAS EXPERIMENT

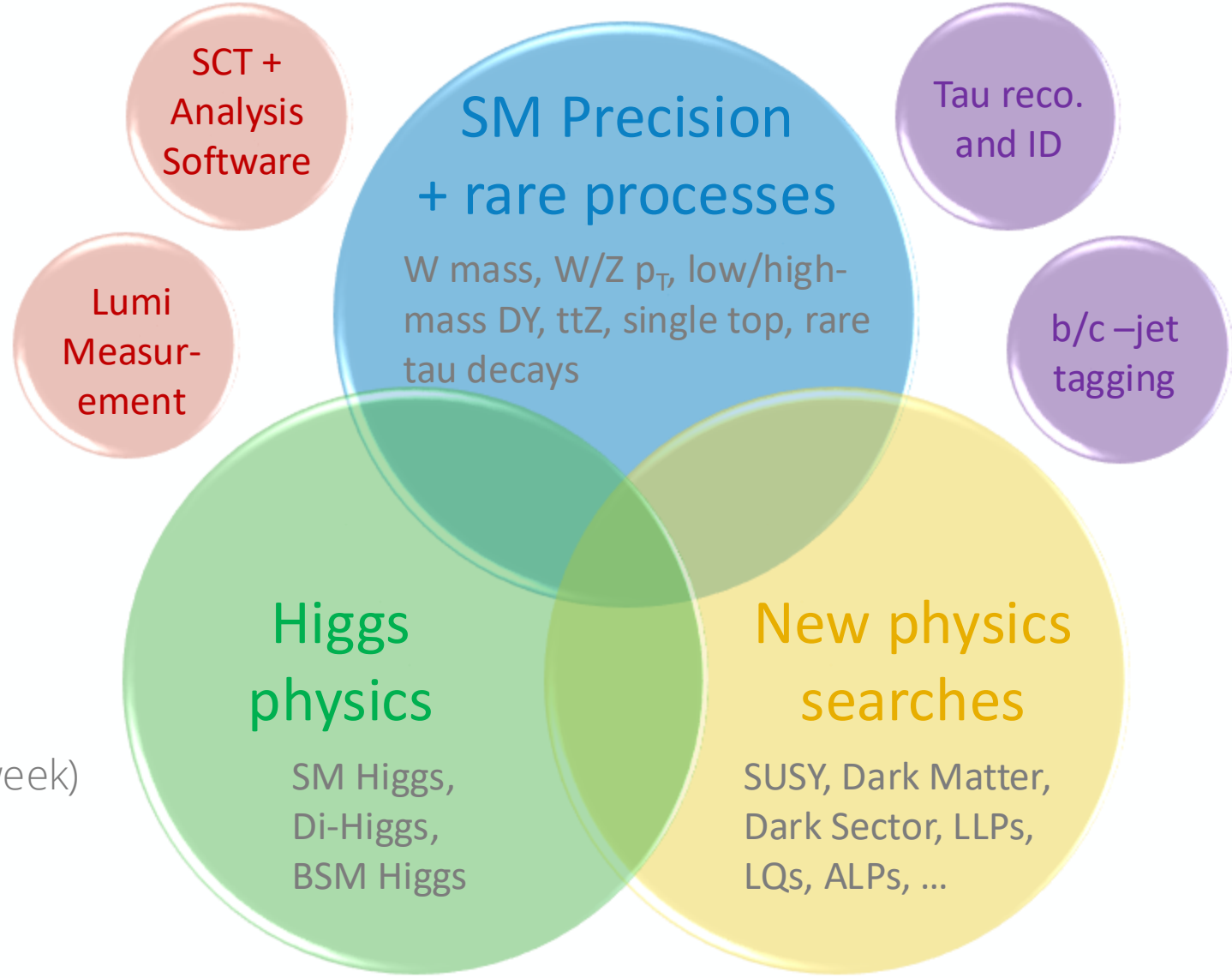
UNIVERSITY OF LIVERPOOL

Liverpool ATLAS Group

- 7 Academics
  - Andy, Carl (TL since 01/25), Jan (DTL) , Monica, Nikos, Uta, Sergey (low FTE)
- 2 Physics Analysis PDRAs
  - Jordy Degens + John Anders (who returned in October)
  - Goodbye to Cristiano (CERN fellow) and Joe (DESY PDRA)

- 9 PhD students (+2 incoming)
  - Y1: Shirsendu, Stephen
  - Y2: Mehul
  - Y3: Bhupesh, Josh, Rob
  - Y4/5: Conor, Rebecca, Samuel (viva next week)
  - Graduated: Dr. Ting
    - (PDRA at York, CA)

- Along with upgrade staff (see Helen's talk)



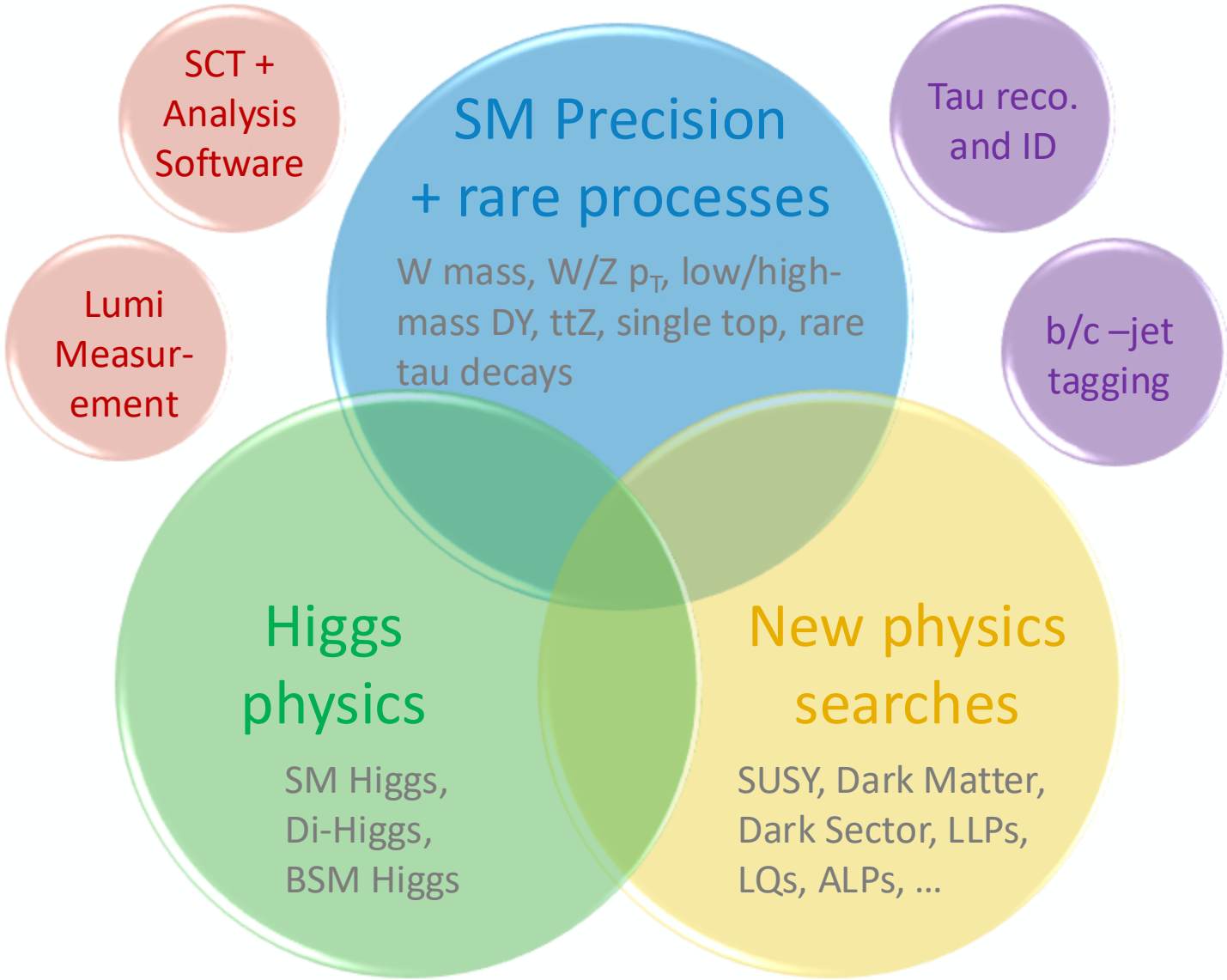
Ubiquitous use of Machine Learning across almost all areas

Liverpool ATLAS Group

- Work on wide variety of areas
  - Operations, performance, physics
  - Excellent feedback from CG
- Leadership across the board

(Deputy) Publications Coordinator	Jan
(Deputy) ATLAS UK Spokesperson	Monica
CB chair advisor group member	Monica
SCT offline coordinator	John
Analysis release coordinator	Andy
Computing Resource Mgmt Board chair	Carl
Luminosity Z-counting contact	Uta
Tau Reco + ID convener (~30)	Jordy
Strong SUSY convener (~100)	John
ATLAS LHC Higgs group coordinator for extended Higgs sector + NMSSM	Nikos

- ATLAS published 127 papers in 2024
  - Significant Liverpool input to 11 papers



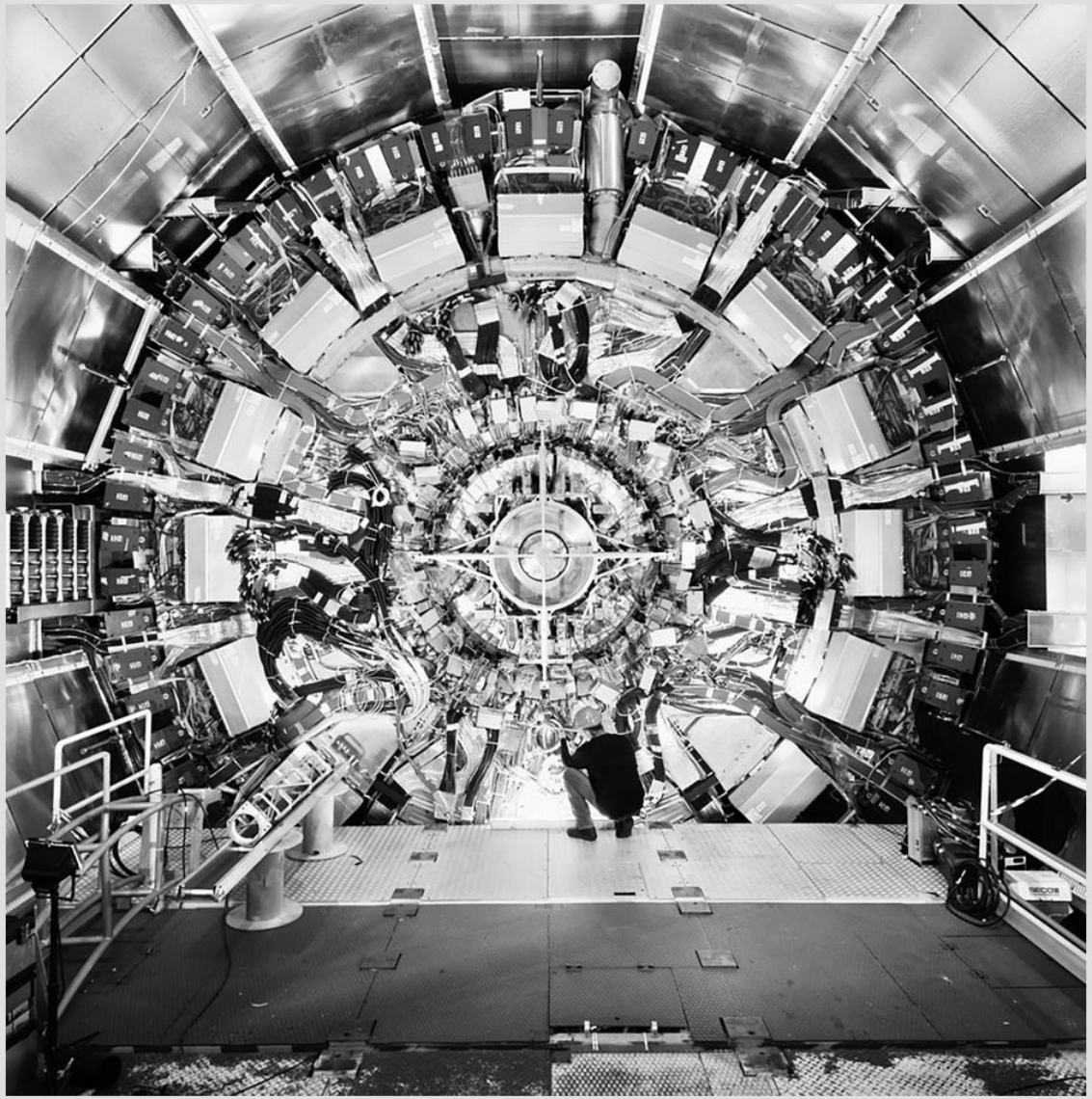
Ubiquitous use of Machine Learning across almost all areas

ATLAS Collaboration

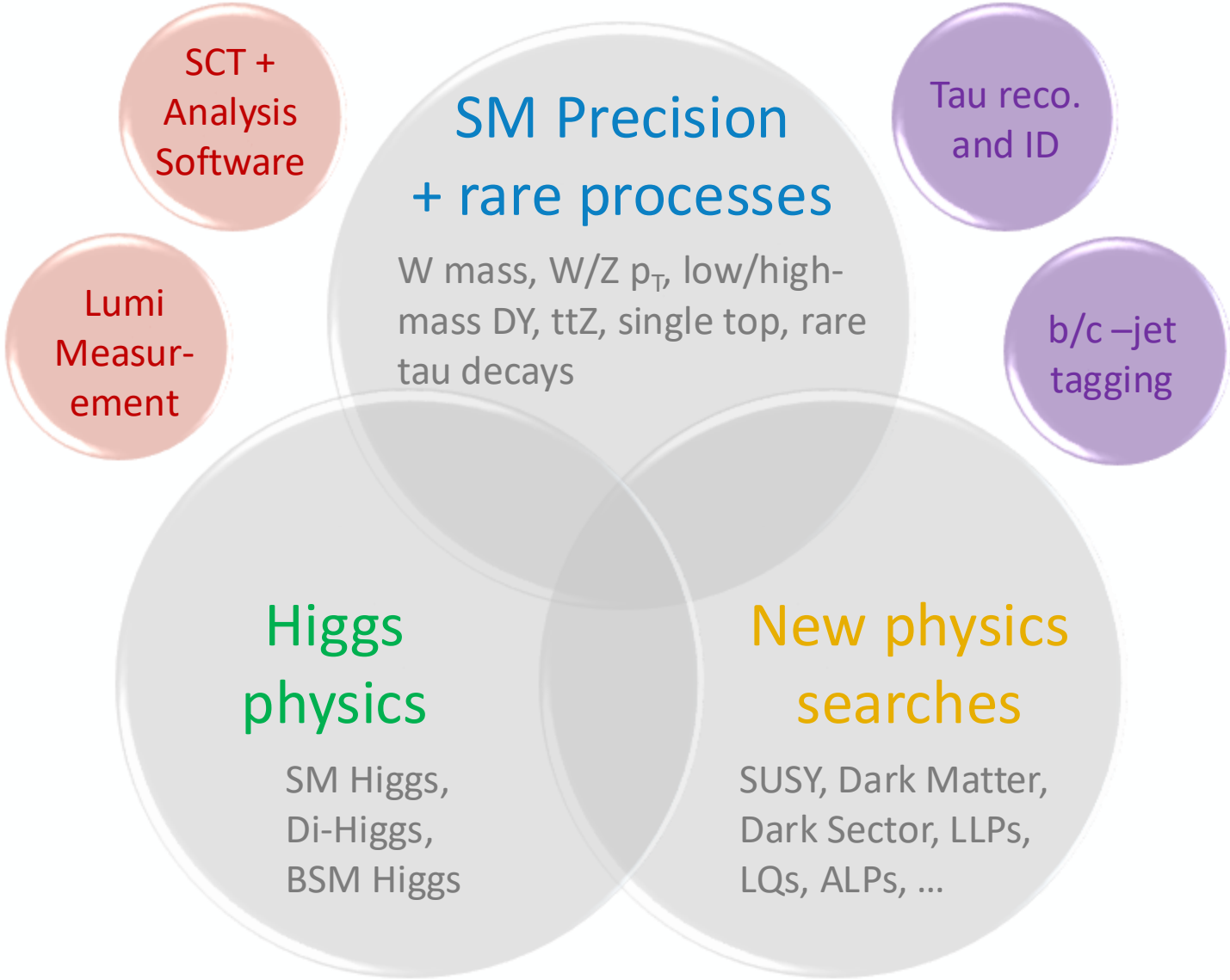
2025 Breakthrough Prize in Fundamental Physics

For detailed measurements of Higgs boson properties confirming the symmetry-breaking mechanism of mass generation, the discovery of new strongly interacting particles, the study of rare processes and matter-antimatter asymmetry, and the exploration of nature at the shortest distances and most extreme conditions at CERN's Large Hadron Collider.

Andreas Hoecker (CERN, spokesperson 2021 to 2025) accepted the prize on behalf of the collaboration. The $1 million (of the $3 million prize) allocated to ATLAS was donated to the CERN & Society Foundation for grants to doctoral students from member institutes to spend research time at CERN.

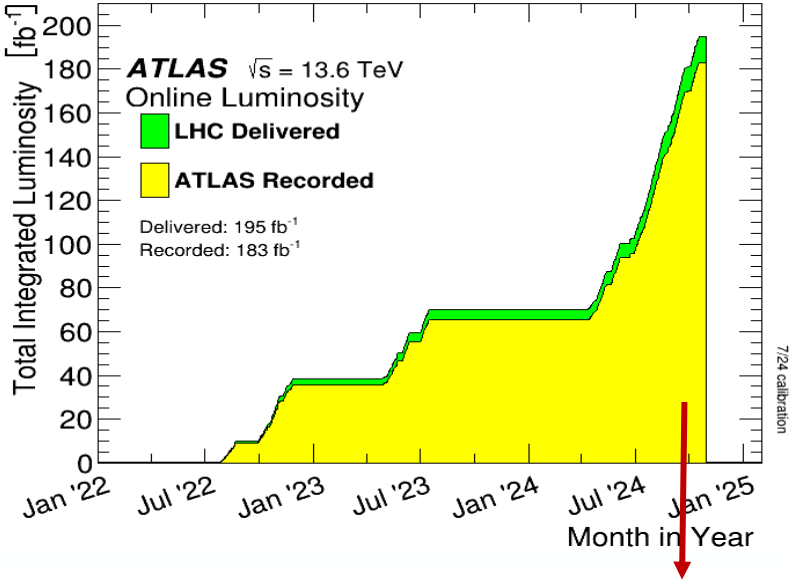


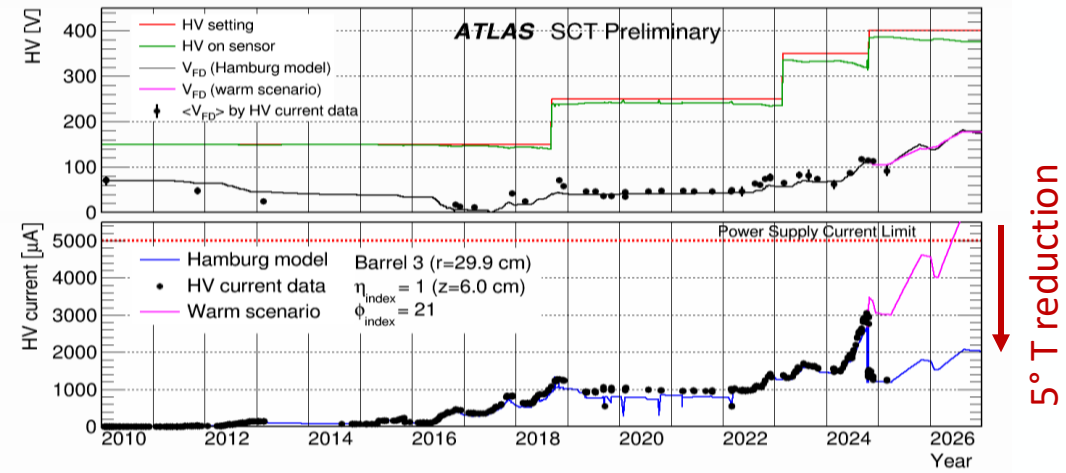
Operations and Performance



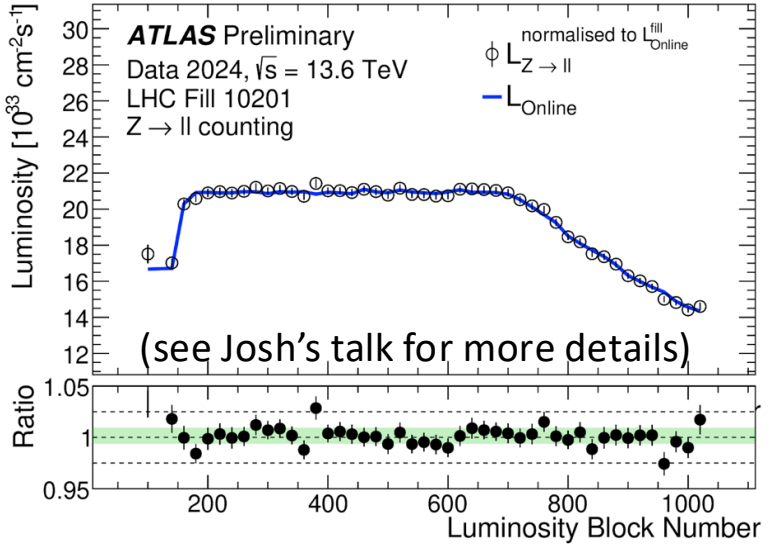
Status and Operations

- ATLAS well into successful run-3 data-taking → 183 fb^{-1}
  - Expect total run-2+run-3 yield of 460 fb^{-1} by summer 2026
  - Followed by LS3 for HL-LHC upgrade (see Helen's talk)
- Uta, Jan, Josh, Samuel contribute to precision lumi measurement
  - Using Liv-pioneered Z-counting method for rapid results
  - Public preliminary results for 2024 + run on 2025 as data arrives
- John coordinates the SCT offline activities
  - Crucial to keeping SCT operating with high efficiency
  - Leading final run-3 performance paper





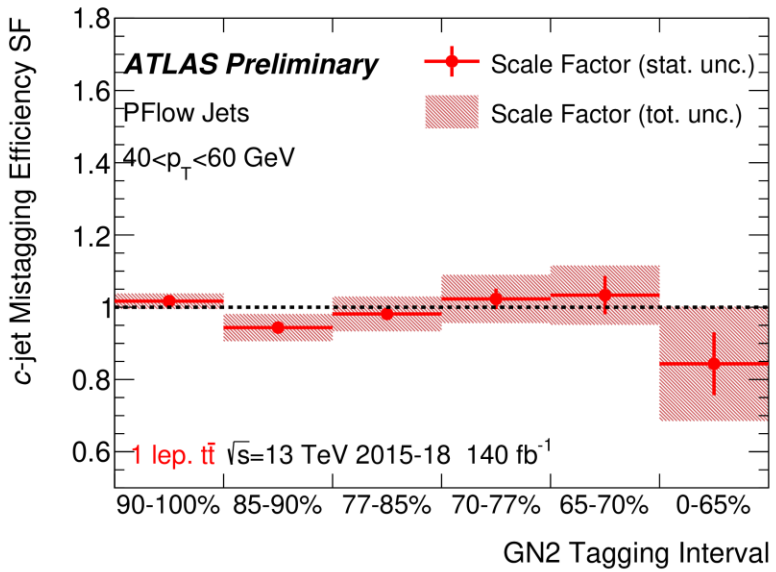
5° T reduction



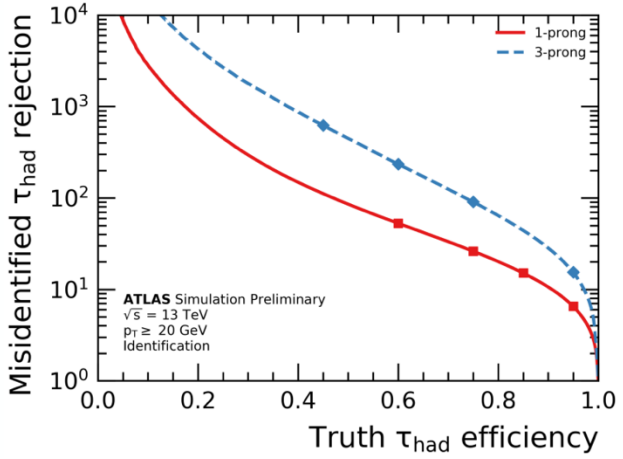
- Many people performing control room (ID, run control) and remote (DQ, analysis, computing) shifts

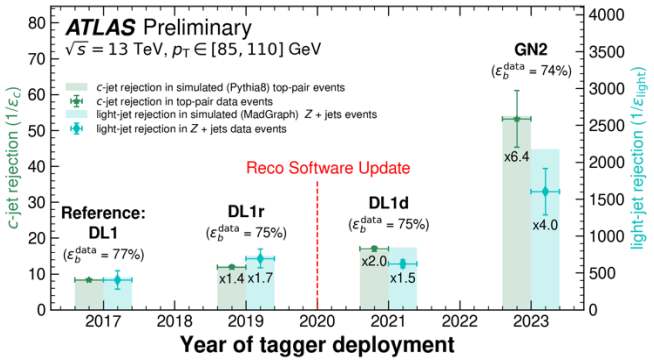
Tau and Heavy-Flavour ID

- Liverpool heavily involved third-generation taggers, key for Higgs measurements + BSM searches
- b/c-jet calibration (Andy, Nikos)
  - Simultaneous b-tagging efficiency + c-mis-ID probability from data using 1-lepton ttbar events
  - Dedicated c-tag calibration on-going

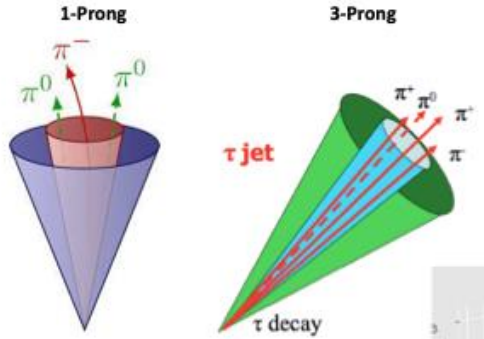


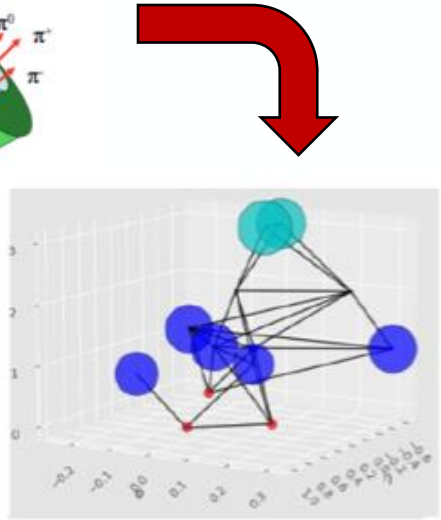
- Two publications in progress





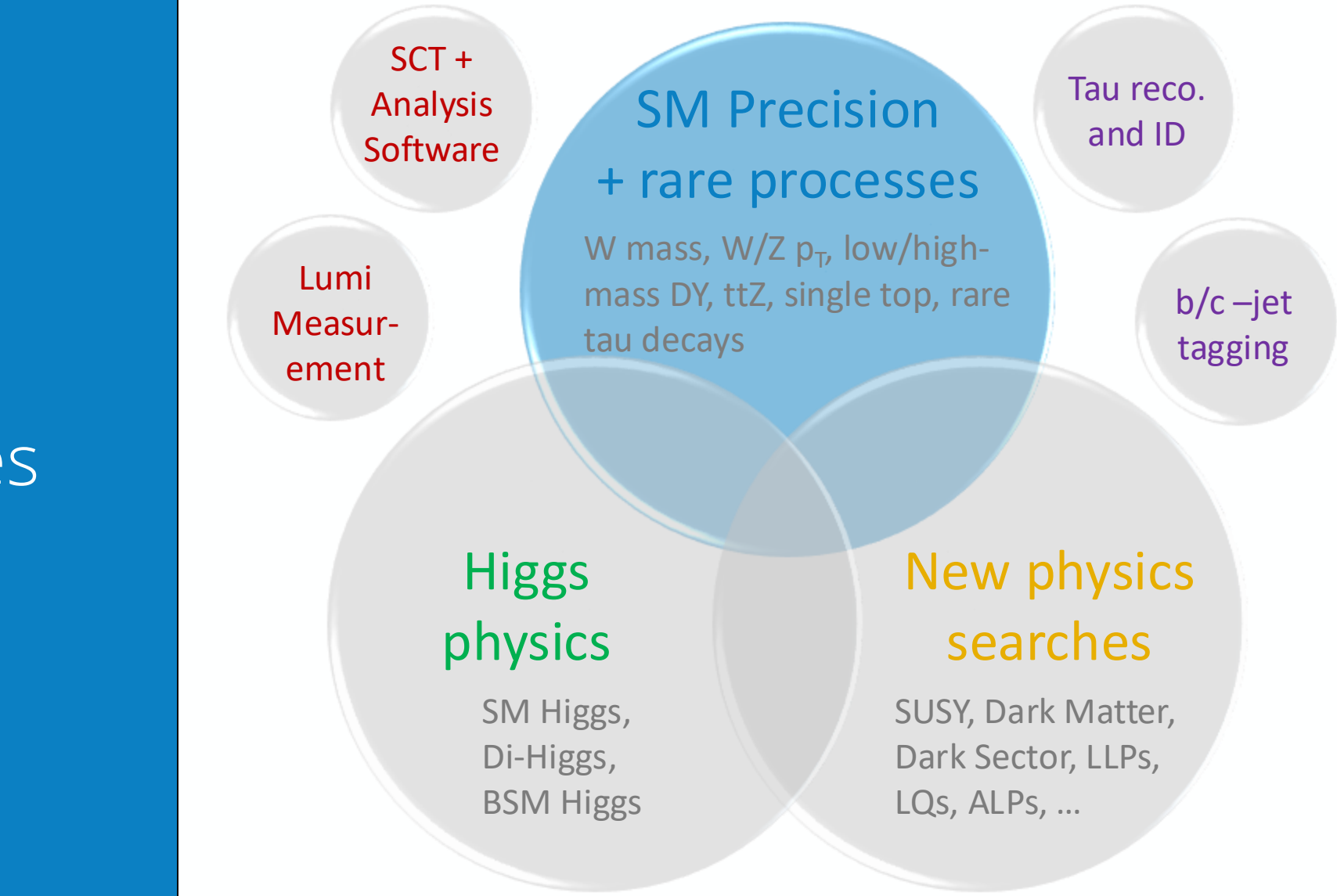
- Tau reco/ID (Jordy, Monica, Mehul, Rob, Nikos)
  - Led by Jordy as subconvener
  - Focusing on improving ID of hadronically decaying taus using graph NNs (GNNs)
    - Liverpool developed one of two GNNs and currently comparing perf to b-tag approach
    - See Mehul's talk for more details





- Public note by end of year

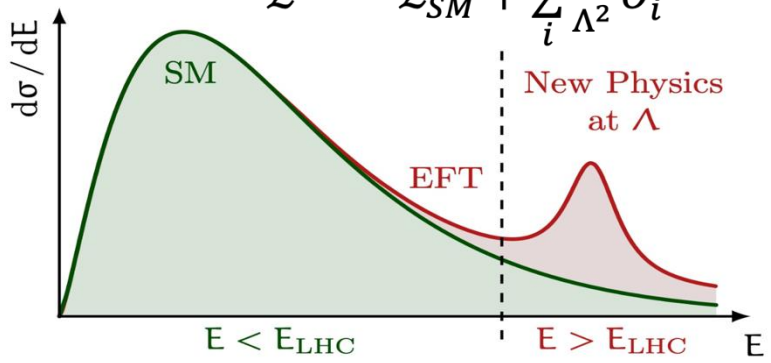
Precision SM Measurements & Rare Processes

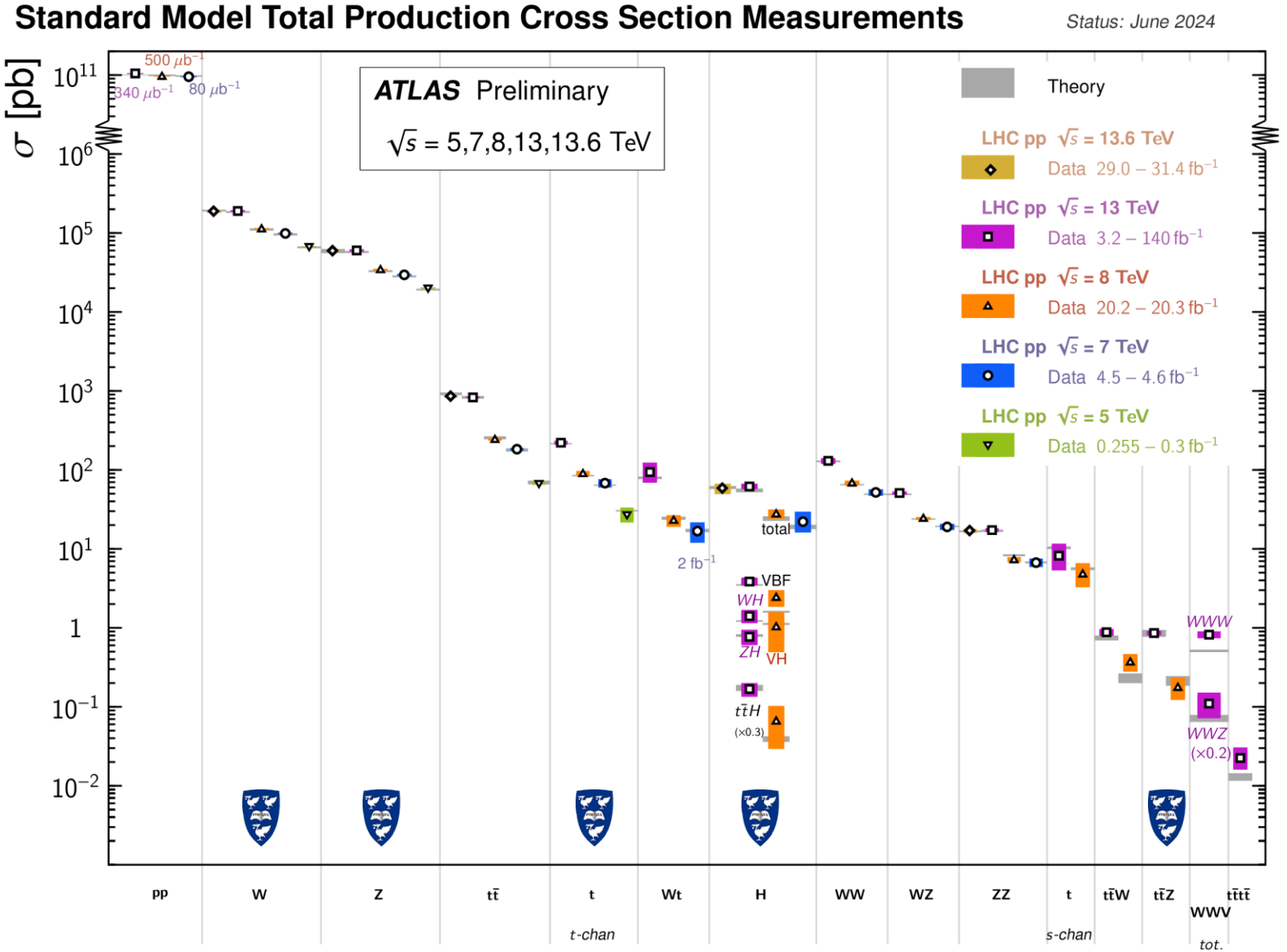


Standard Model Measurements

- The LHC can make highly precise measurements of fundamental SM particles and interactions
  - Probing cross sections over 12 orders of magnitude down to some of rarest SM processes
  - Rivalling LEP sensitivity
- Tests SM consistency in extreme phase space + searches for new physics effects beyond E_{LHC}
  - Model independent constraints in Effective Field Theories (EFTs)

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{c_i}{\Lambda^2} O_i^6$$

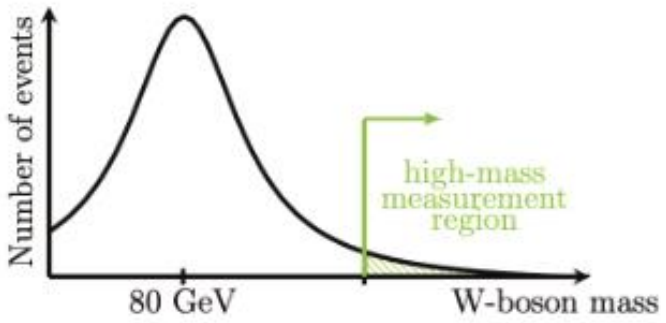


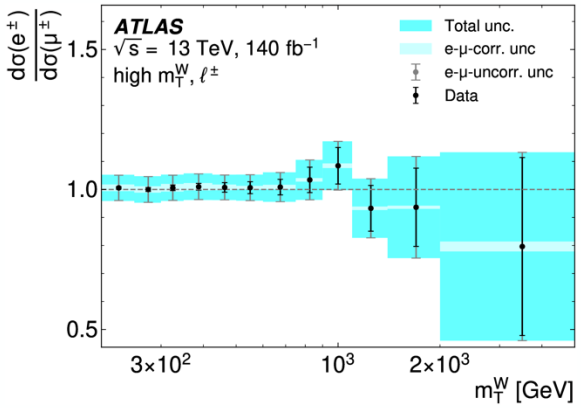


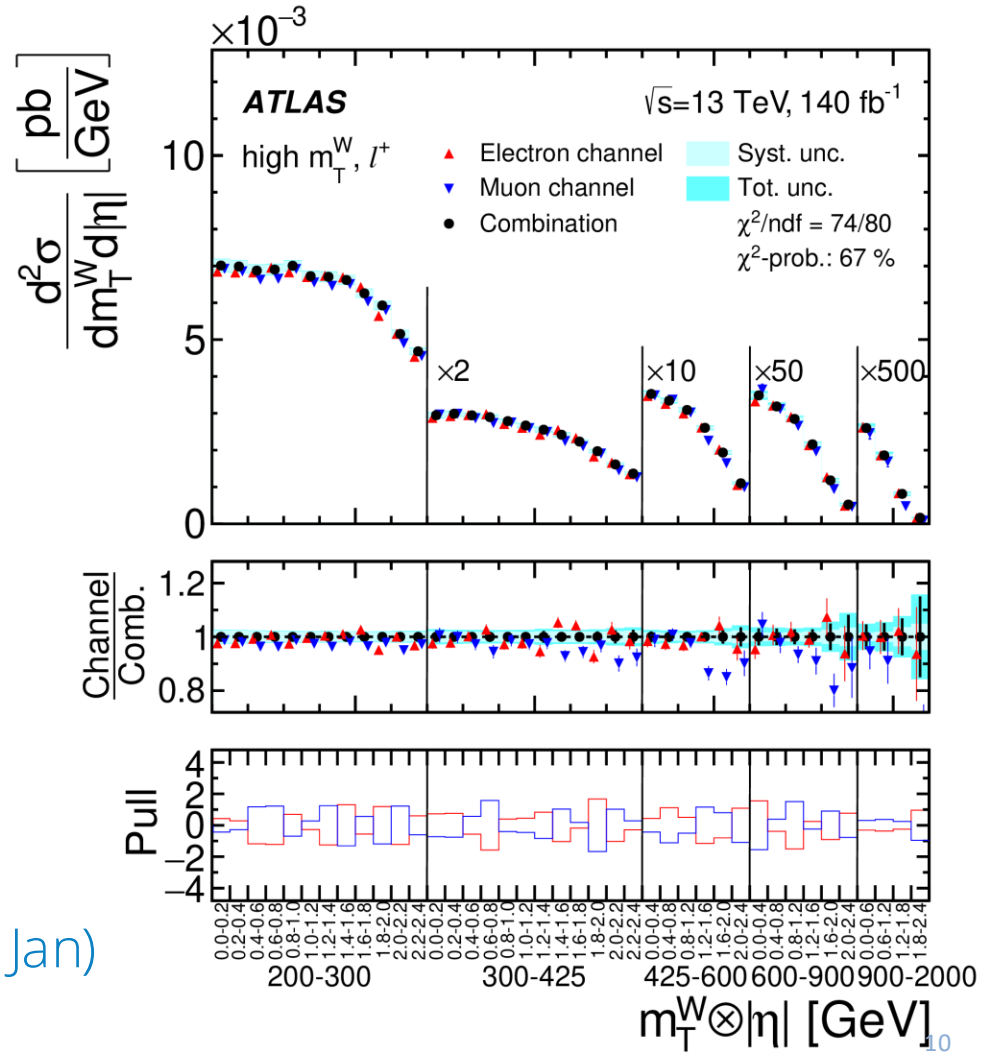
Low/High mass Drell Yan

arXiv:2502.21088

- NC and CC Drell-Yan (DY) measurements away from W/Z peak are a powerful tool to study the proton structure (PDFs), test precision pQCD predictions and probe the EW sector of the SM
  - As well as LFU test and search for new physics effects
- Recent full run-2 CC DY paper is first ever measurement of W cross-section at high m_T (Uta, Sam)
  - Double differential cross-section in m_T & η for e/μ up to 5 TeV
  - Ratio of e/μ shows no significant evidence of LFU
  - Place limits on lepton-quark operator in SM EFT
  - Subject of Samuel's PhD thesis





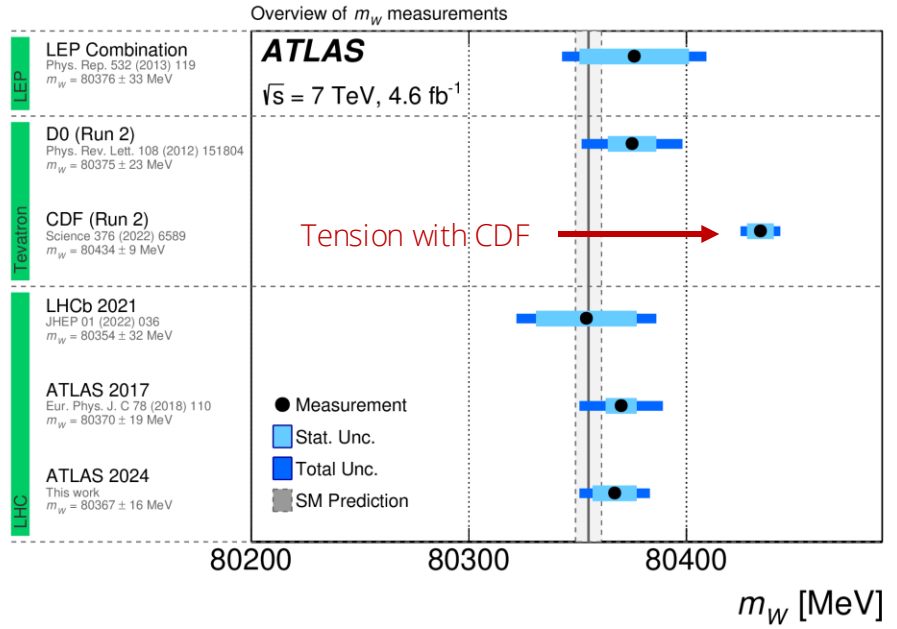


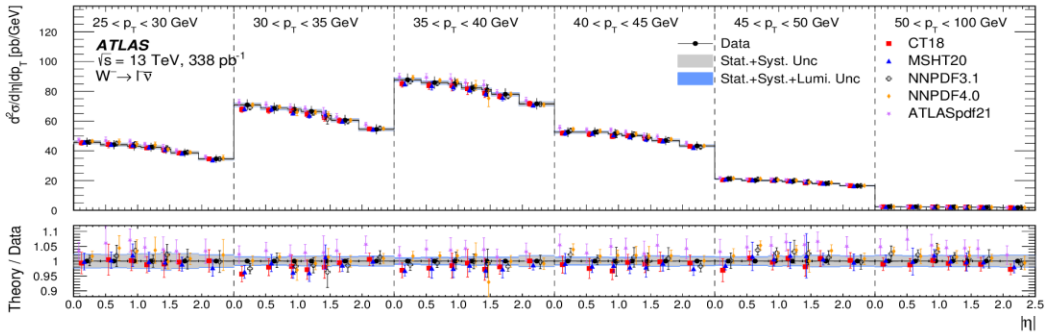
- Measurement of low and high-mass NC DY in progress (Uta, Jan)
  - Liverpool particularly involved in HO theory predictions

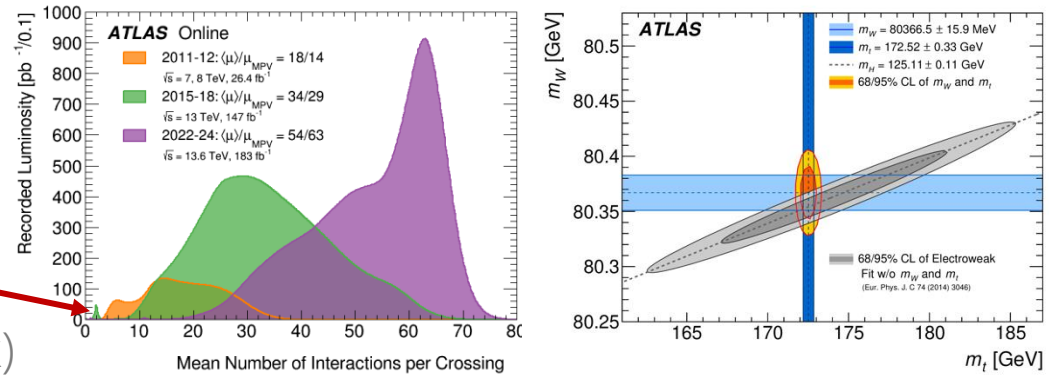
W mass

arXiv:2502.09403
arXiv:2403.15085

- W mass is one of most precisely calculated quantities in the SM and LHC measurements are able to probe deviations at the level of 1 part in 10000.
  - Unique test of SM consistency + probe for new particles/forces
- Long standing Liverpool leadership (Jan et al)
  - Precise run-1 measurement of mass (16 MeV)
  - First LHC measurement of width (Γ = 2202 ± 47 MeV)
- Recently measured W x-sect differentially in lepton p_T & η
  - Dominant uncertainty on previous m_W + probe of pQCD/PDFs







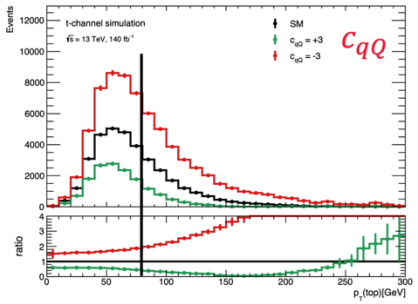
- Currently lead effort with 5 & 13 TeV low-pileup data
  - Josh working on in-situ electron E calibration + FSR (see talk)
- Expected run-2 precision of 15 MeV, allowing to reach 10 MeV when combined with run-1 data

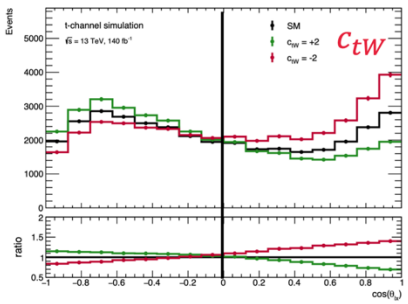
Top-quark Measurements

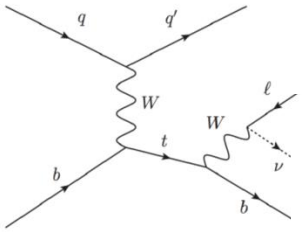
Jordy's Thesis

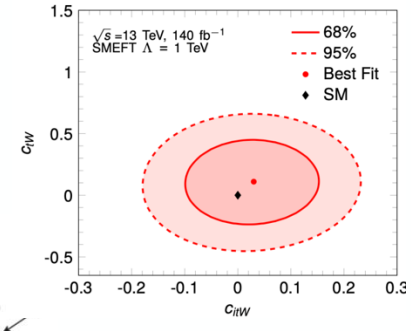
- Heaviest SM particle provides unique access to bare quark and can only be produced at the LHC

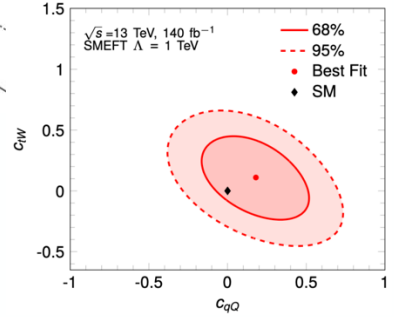
- t-channel single top analysis (Jordy's thesis)
  - First simultaneous EFT determination in t-chan.
  - Measure x-section, p_T spectrum + angular vars to extract 3 Wilson coefficients: $O^3_{\varphi q}$, O^3_{qQ} & O_{tW}
    - Latter split into Re+Im → World best limits on Im





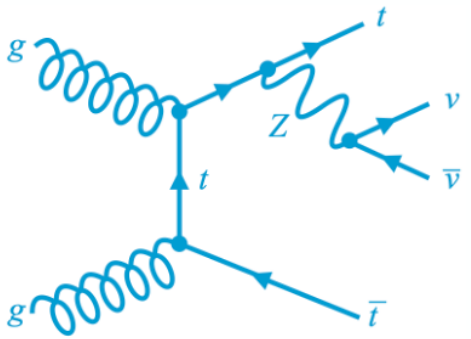


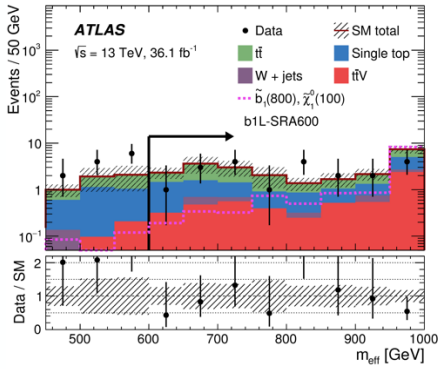




  - On track for publication this summer

- ttZ cross-section in Z→νν channel (John)
  - Major background to many SUSY searches but has not yet been measured directly
  - Convert BSM search into x-section analysis benefiting from large Z → νν BR c.f. Z → ee, μμ



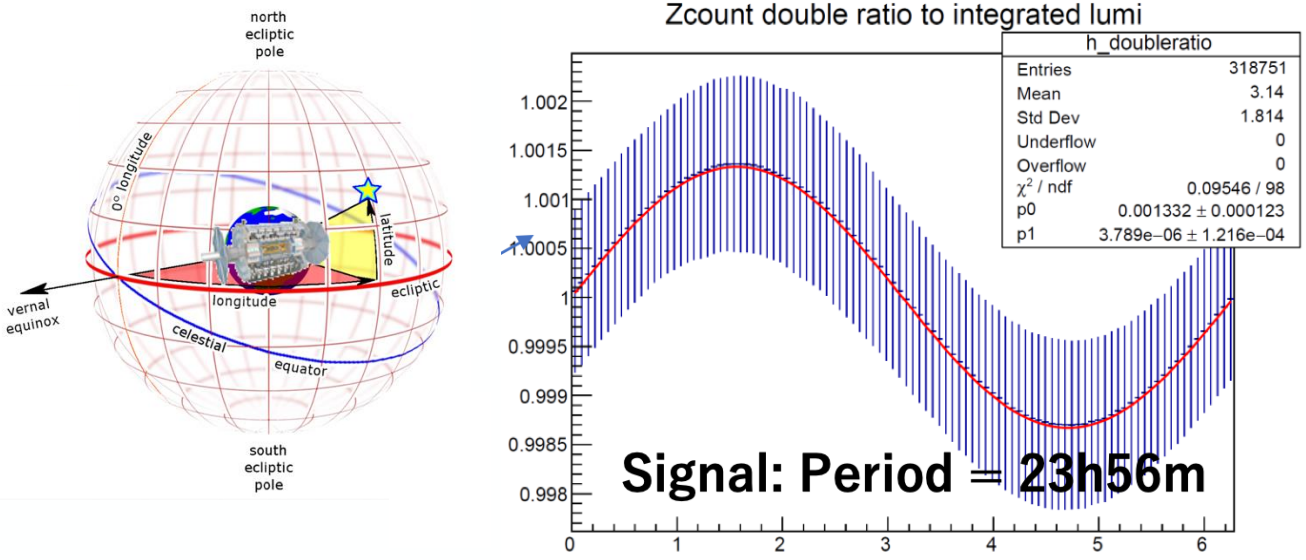


  - EFT interpretation sensitive to left-handed lepton and top-boson Wilson coefficients
  - Aiming for publication by the end of the year

Measurements as Model-Independent BSM probes

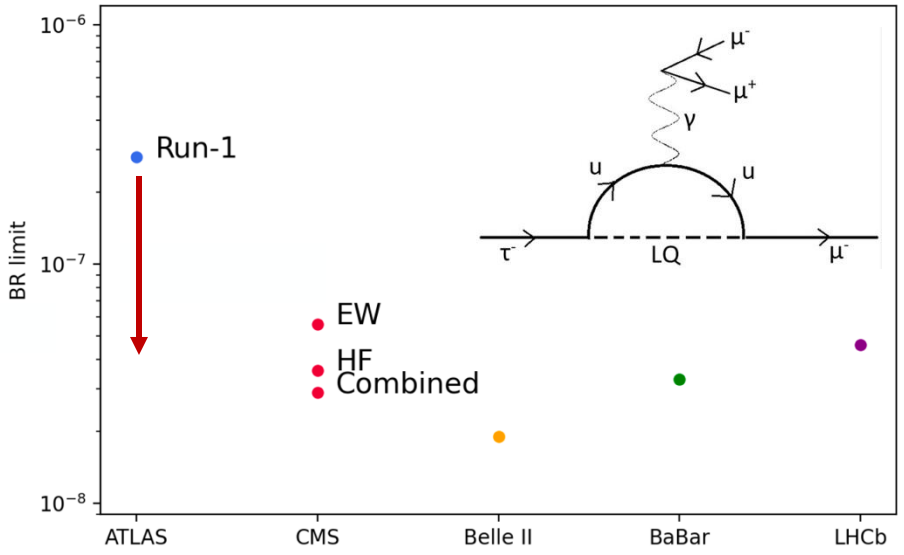
- Precision measurements and rare processes are powerful model-independent new physics probes

- Searches for Lorentz + CPT invariance violation
  - Non-isotropic background field leads to time-dependent periodic modulations
  - Uta initiated novel time-dep. Z→ll measurement
    - Build on SM expertise and Z-counting lumi



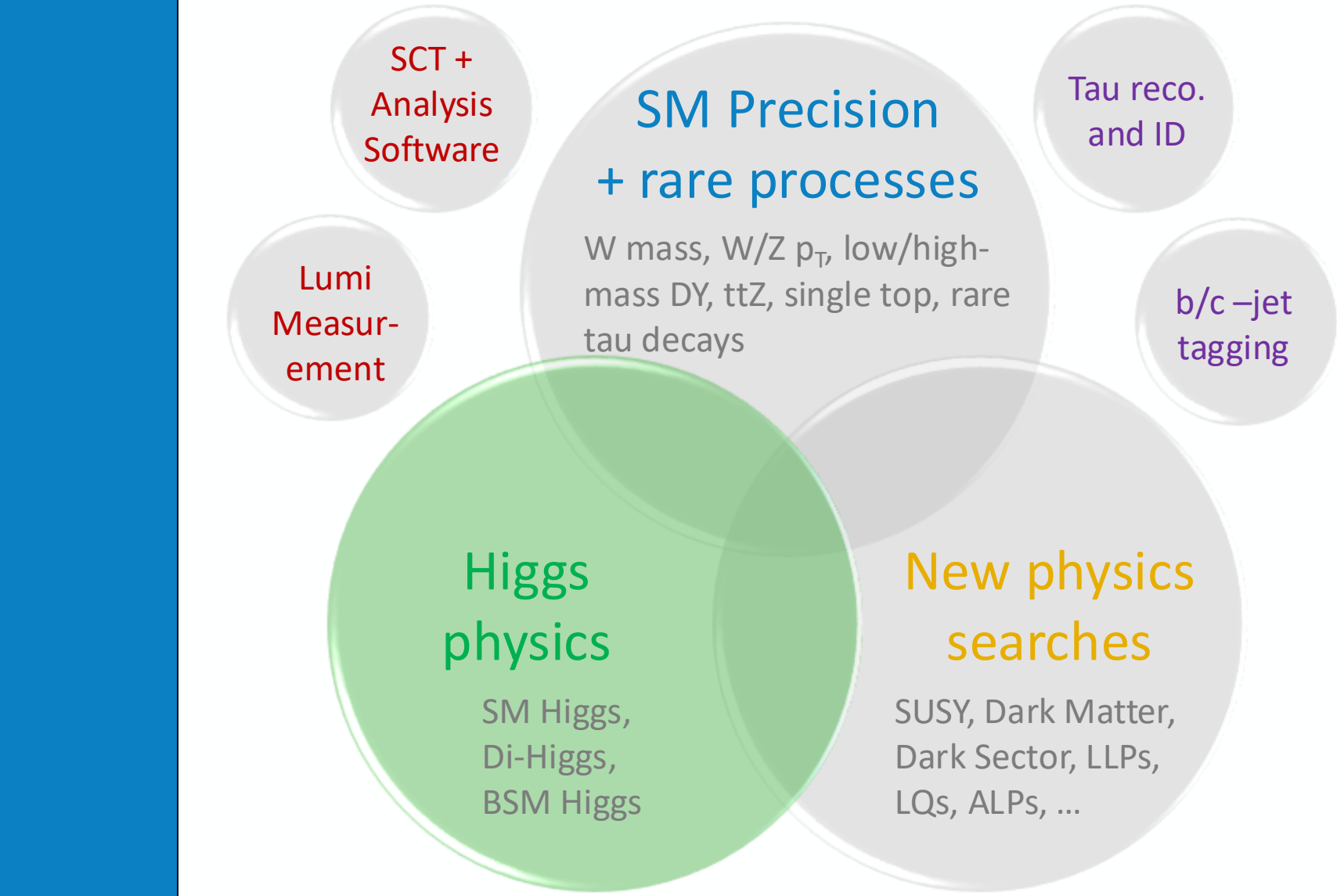
- Suffering a bit from lack of person power

- Search for cLFV τ → 3μ (Carl, Conor, Jan)
  - Flavour not a fundamental symmetry of SM
  - cLFV searches provide model-indep. NP probe
    - Tau limits 10^4 less stringent than muon
    - SM rate tiny (~10^{55}), but many BSM enchantments



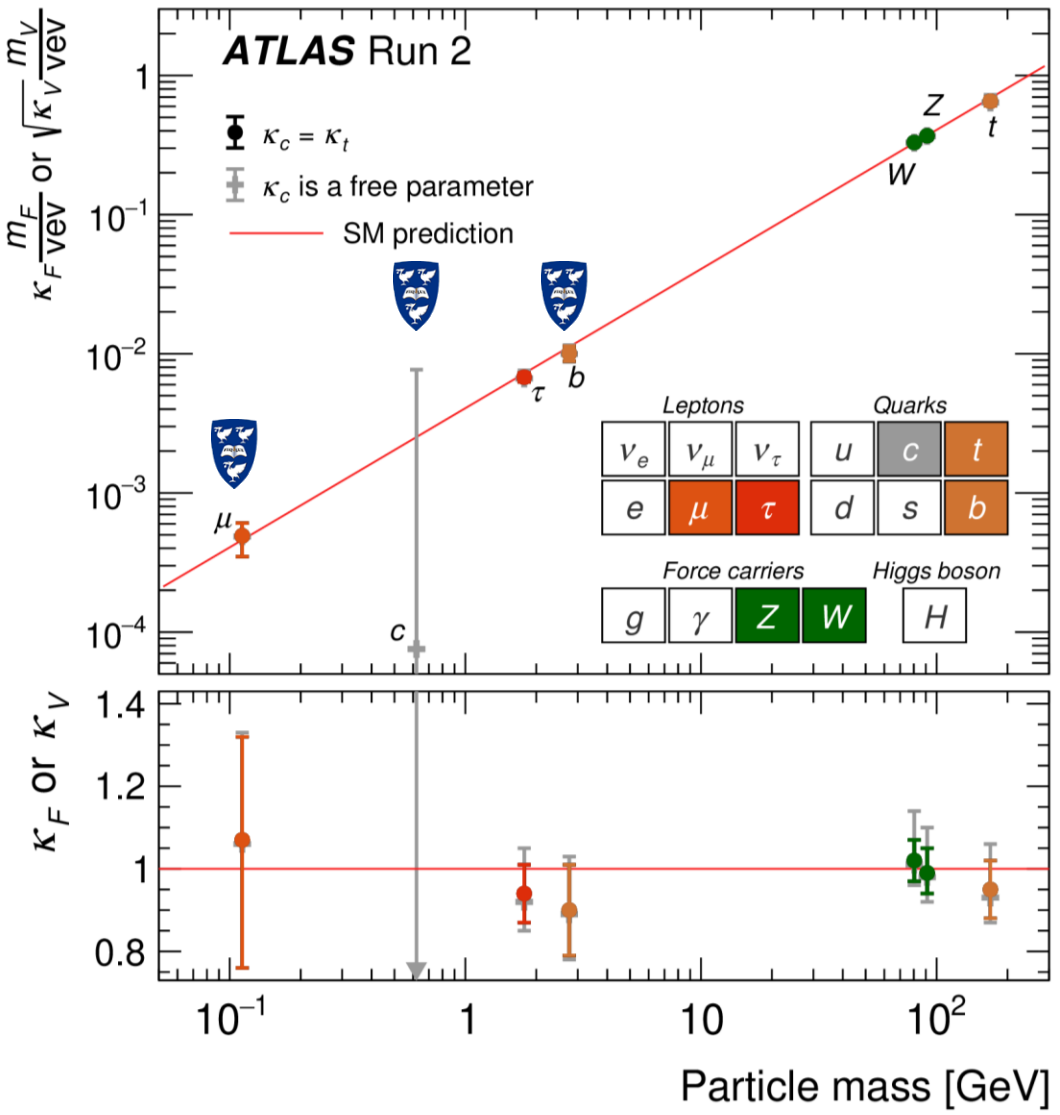
- Conor's PhD thesis is first run-2 ATLAS analysis
  - Submission by end of Sept, followed by paper

Higgs Physics



Higgs

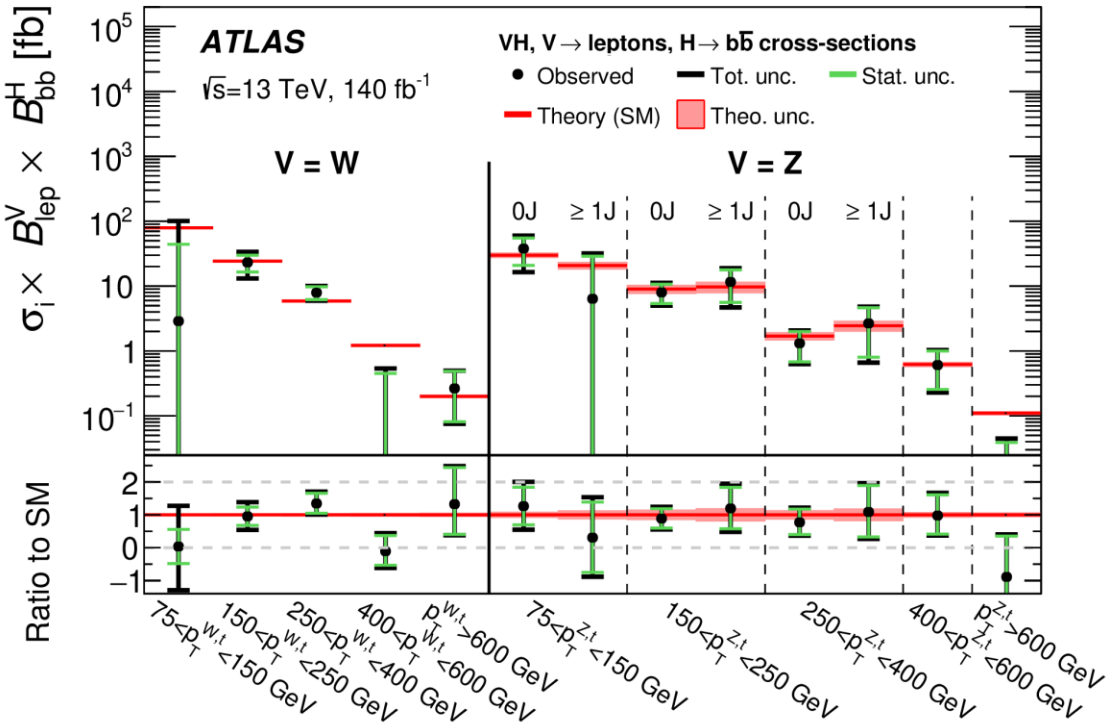
- The Higgs boson is central to the standard model
  - Key to understanding EWSB and evolution of Universe
  - Constrains any new physics getting mass from Higgs
    - See John's talk for direct BSM Higgs searches
- Have made huge progress since discovery
  - Measured mass to < 0.1%
    - 125.11± 0.11 GeV
  - First measurement of width
    - 4.5 +3.3 –2.5 MeV (SM: 4.1 MeV)
  - Couplings to vector bosons all measured
    - Including differentially as a function of p_T^H & N_{jet}
  - Couplings to 3rd gen fermions all measured
    - Including differentially as a function of p_T^H & N_{jet}
  - Couplings to second generation fermions within reach

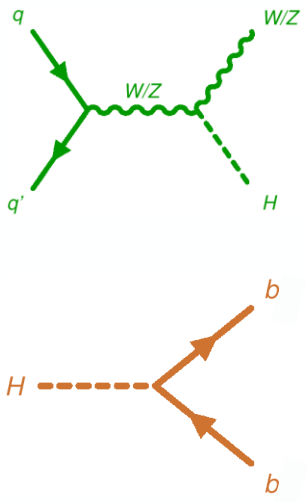


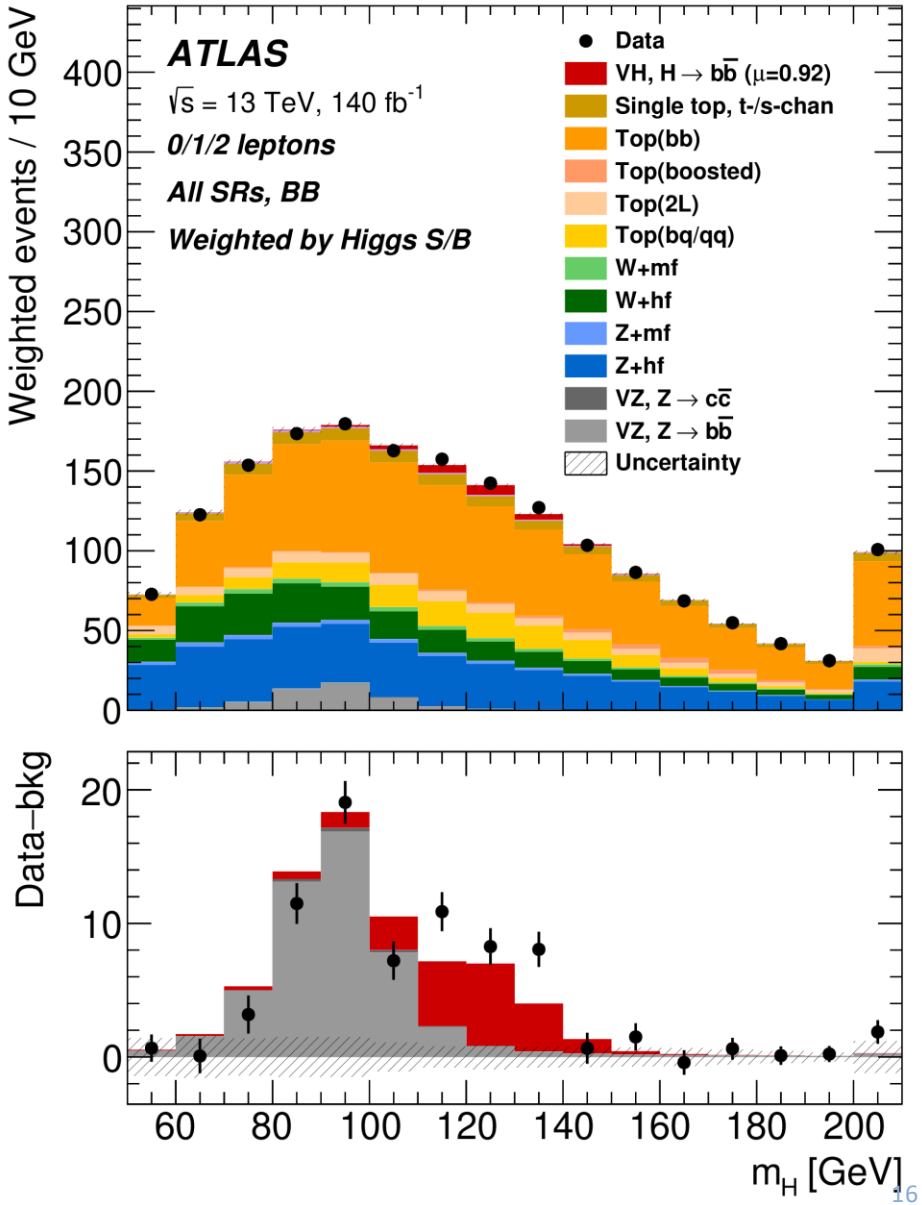
H → bb

arXiv:2410.19611

- Long standing Liverpool involvement in H→bb (Andy et al)
- Legacy run-2 paper (edited by Andy) published this year
  - Combined fit to H → bb and H → cc (next slide)
- Subject of Ting's PhD thesis
  - Event selection, MVA, theory corrections, statistical analysis
- Differential cross-sections probing $p_T^H > 600$ GeV





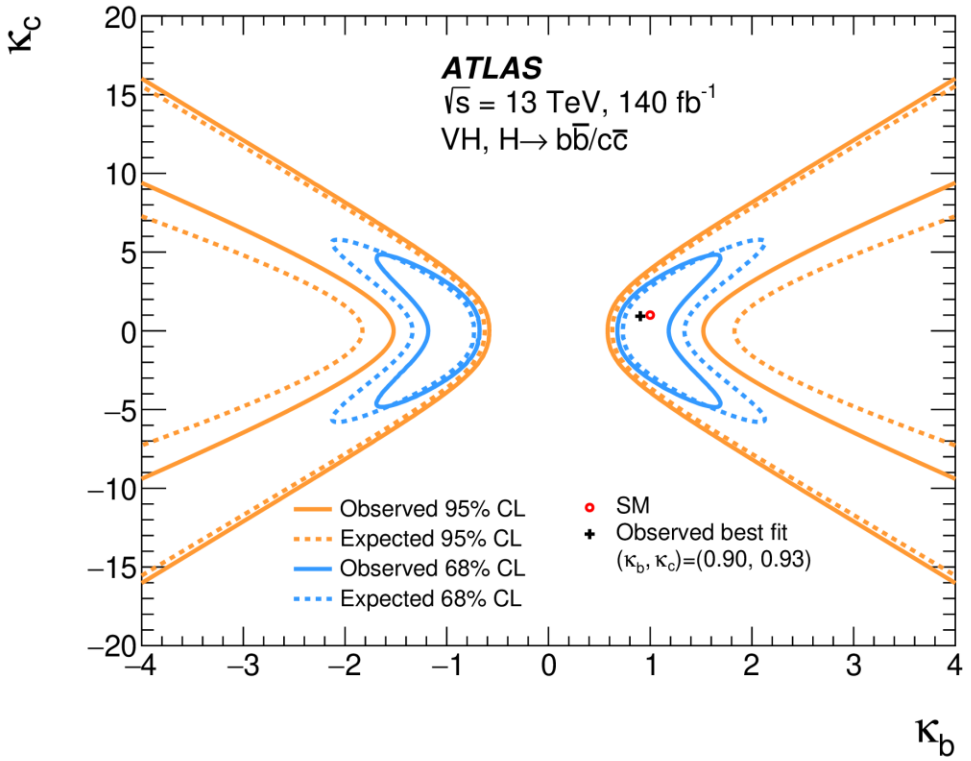


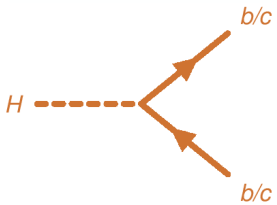
H → cc and H → μμ

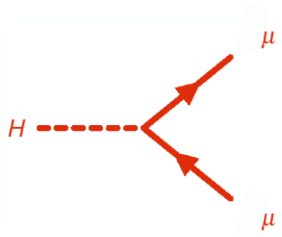
arXiv:2410.19611

arXiv:2007.07830

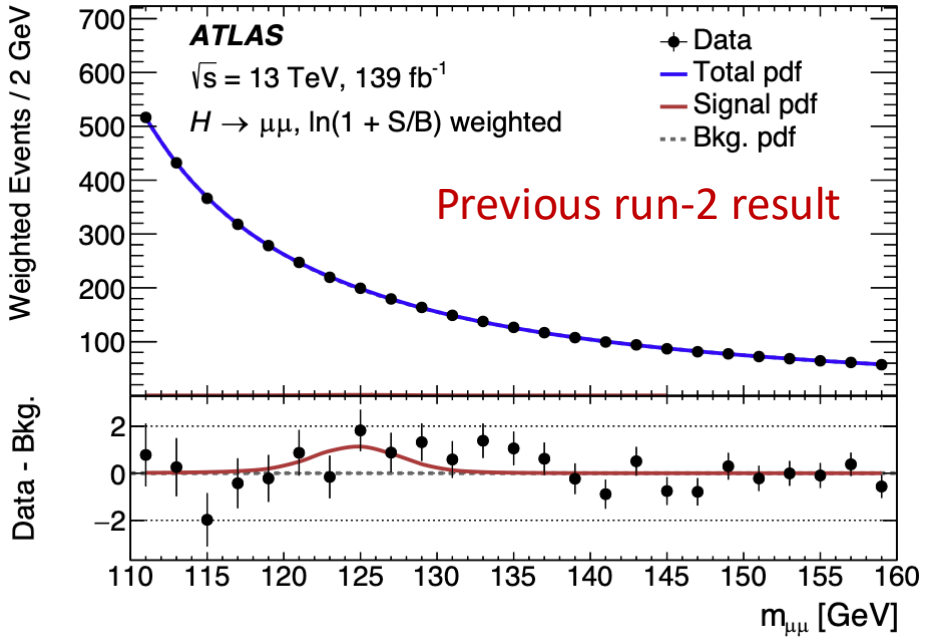
- H → cc (Andy, Ting)
  - Upper limit of 11.5 (10.6) x SM obs (exp)
  - Combined constraints on relative b- and c-coupling
  - Will continue HH → bb/cc with full run-3







- H → μμ (Jan)
  - 2σ evidence with run-2 data



  - Ongoing run-3 analysis aiming for 3σ evidence with run-2 + 2022-24 in summer
  - Followed by 5σ observation with full run-3 data from combined ATLAS+CMS

- Plan to reprise rare H→ee (first generation) and H → eμ (LFV) searches with full run-3 data
  - Giving a factor of 2-3 improvement in sensitivity

Higgs

- The Higgs boson is central to the standard model
  - Key to understanding EWSB and evolution of Universe
  - Constrains any new physics getting mass from Higgs
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- Have made huge progress since discovery
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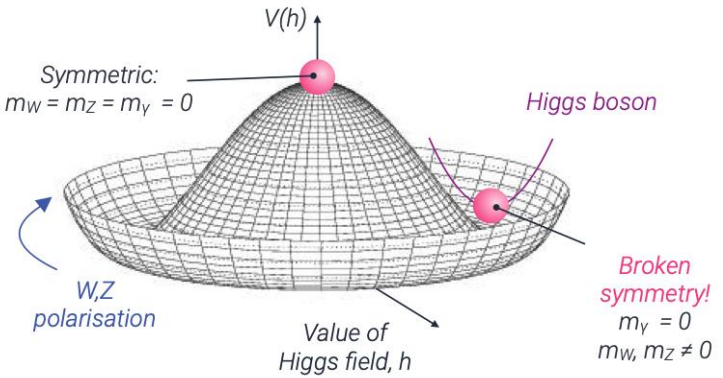
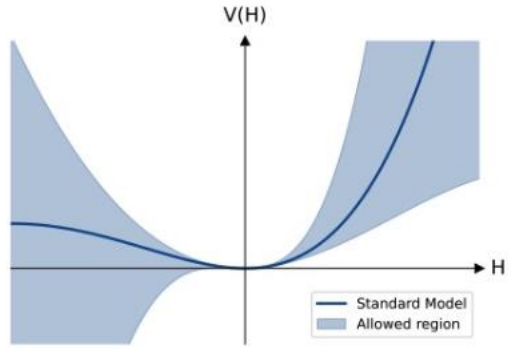
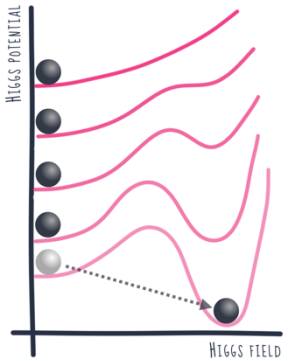
- But shape of Higgs potential still unknown
  - Many BSM models alter this with huge consequences
  - Uniquely probed via Di- and Tri-Higgs production

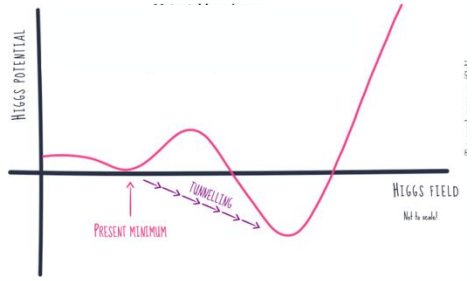




1st order phase transition?



Metastable universe?



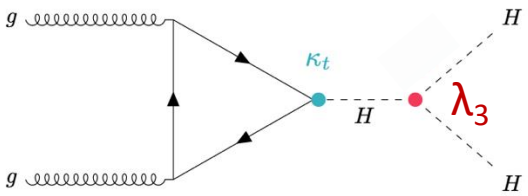
Credit: K.Leney

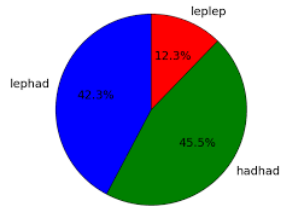
Di- and Tri-Higgs

arXiv:2404.12660

- Di-Higgs production probes H self-coupling but $\sigma_{HH} \approx 1/1000$ of σ_H

$$V(h) \simeq \frac{1}{2}m_H^2 h^2 + \lambda v h^3 + \frac{1}{4}\lambda h^4 + \ldots$$

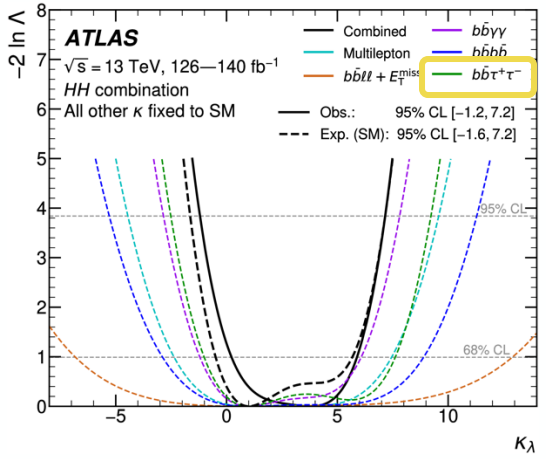


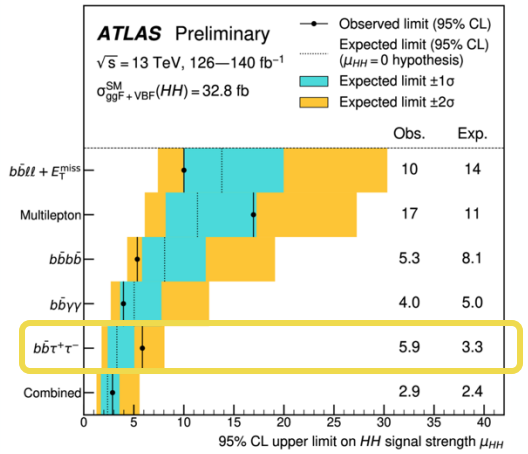


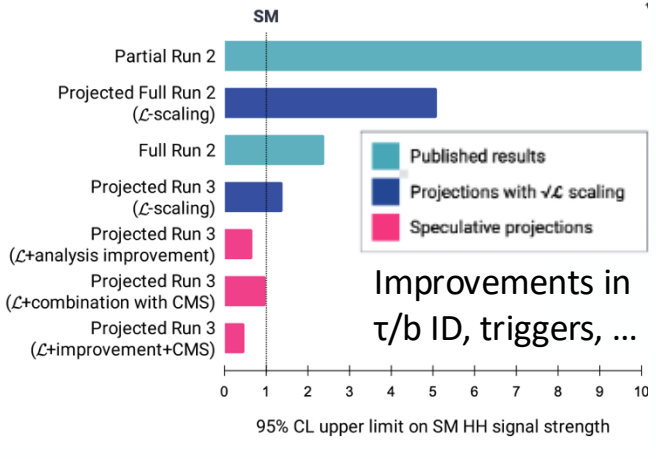
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

bbττ is sweet spot of BR & bkg

- Liverpool has been a driving force in HH→bbττ since start of run-2
  - Lead full run-2 lephad channel, giving most sensitive expected σ limit







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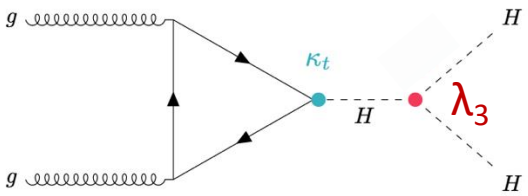

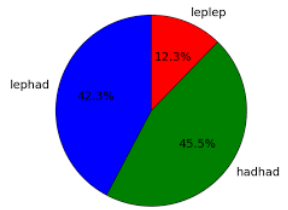

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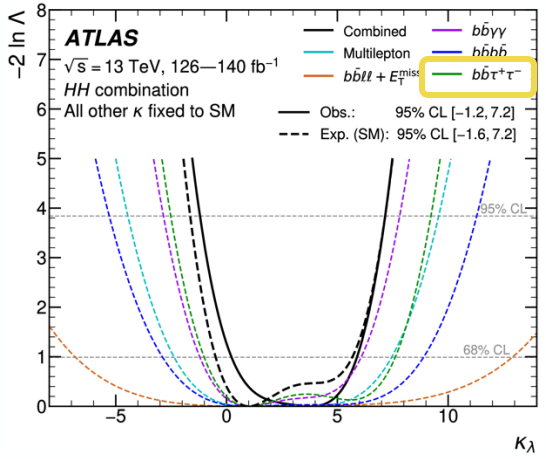
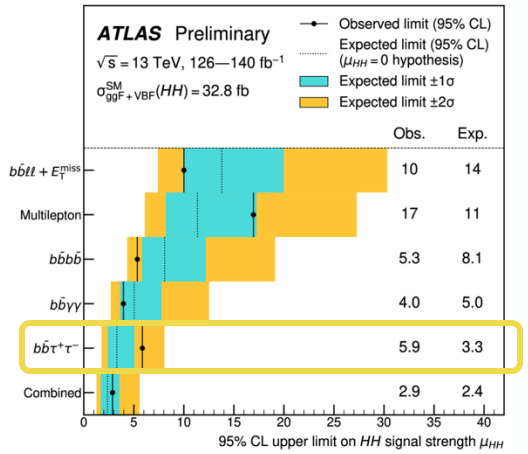
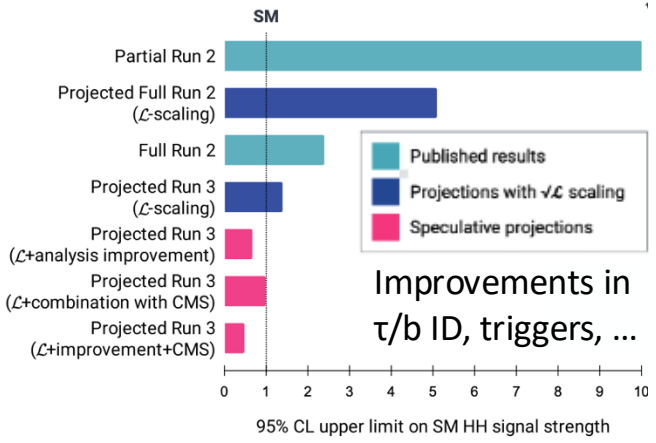
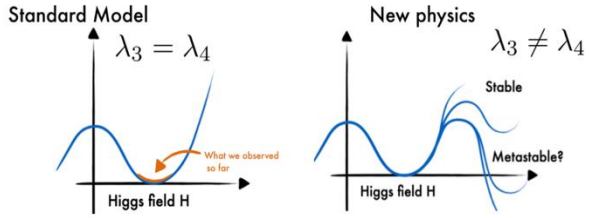






- SM predicts $\lambda_3 = \lambda_4$
  - But BSM physics can make them different



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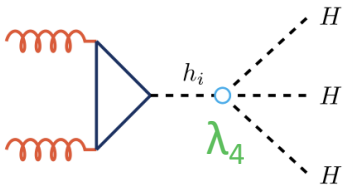
  - Measure via Tri-Higgs in HHH → bbbbττ



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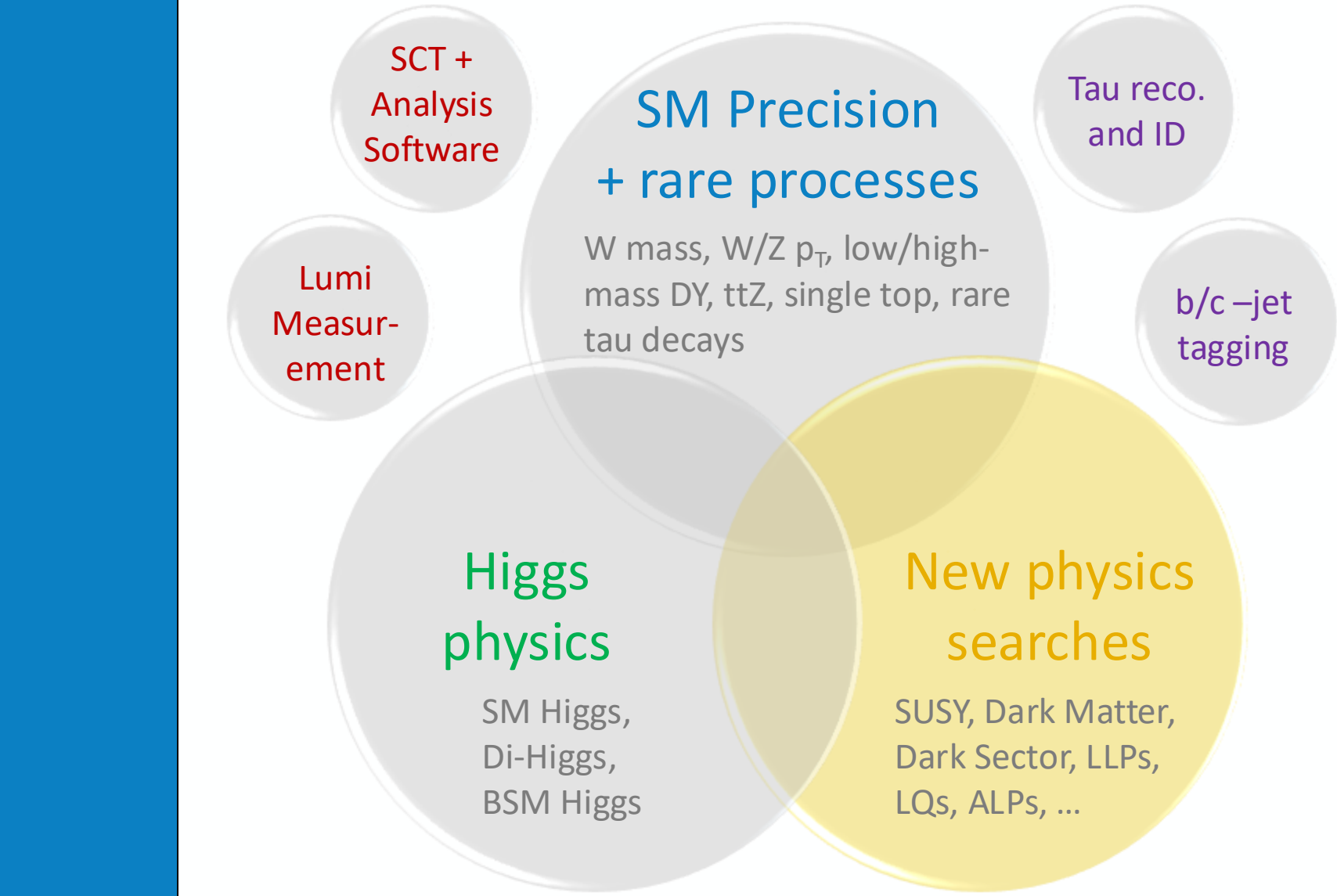
New Physics Searches

See John's talk



Conclusion

- ATLAS continues to perform vibrant and dynamic research covering a huge spectrum
  - From precise measurements to searches for new physics in unexplored phase space (John)
- Detector performing efficiently despite challenging pile-up conditions
  - Coupled with significant ML-enabled improvements in simulation and reconstruction
- Analysis of run-3 data, with factor >3 increase in luminosity expected, in full swing
  - Will provide a wealth of new results that form the long-term legacy of the LHC
- Liverpool continuing to play a central role across ATLAS, recognised by several leadership roles
  - From detector operations, via simulation and reconstruction software, to physics analysis
  - Proposing novel analyses and exploiting state-of-the-art ML techniques (e.g. MUCCA)
  - Expect ≈10 further publications by end of 2025
- With the HL-LHC just round the corner, we have only just scratched the surface of physics results
  - Liverpool playing a key role in ensuring ATLAS is ready to make the most of this (Helen)

None of this would be possible without …

- Max, who laid the groundwork for the LIV ATLAS group, and is sorely missed

- Monica, who did an amazing job of leading the group the last 7+ years