

# Precision SM & Higgs physics

---



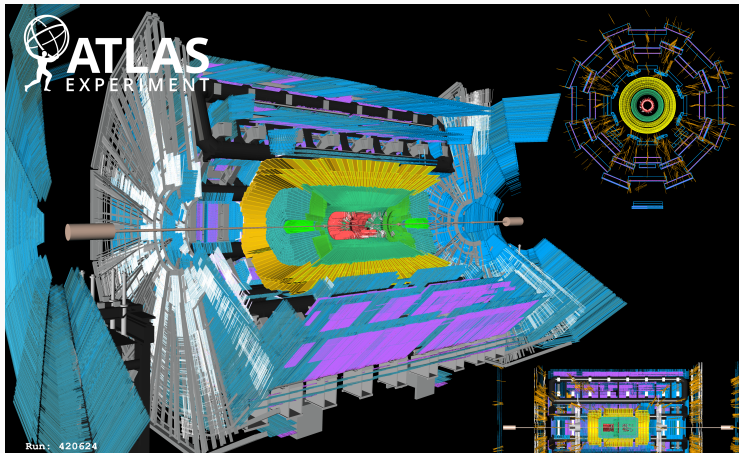
Matt Sullivan, on behalf of the ATLAS group

20<sup>th</sup> May 2022

Liverpool HEP meeting

# Exciting times for ATLAS!

- Run-3 beam splash event from 7<sup>th</sup> May! We are actively contributing to new data taking efforts (see Cristiano's talk)
- In addition, Liverpool team in full swing exploiting excellent Run-2 data



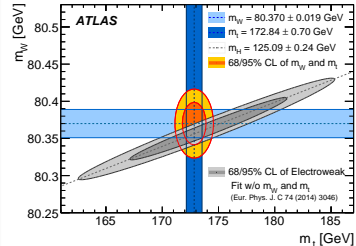
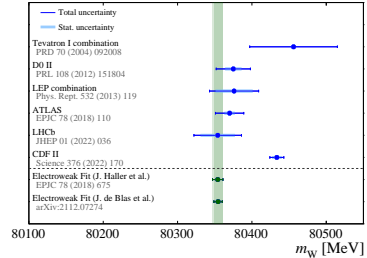
## Team and achievements in a slide

- Congratulations to **five** new doctors: Alan, Hamish, Adam, Michael, Jordan
- Welcome to Rebecca, our new PhD student
- Complemented our work with a grant on ML and explainable AI (**See Joe's talk**)
- New & continued leadership roles:
  - **Carl**: ATLAS UK Physics Coordinator
  - **Jan**: ATLAS Physics Modelling Group Convener
  - **Nikos**: ATLAS LHC Higgs group convener for extended Higgs sector & NMSSM groups
  - **Andy**: Analysis release coordinator
  - **Cristiano**: SCT software coordinator
  - **Uta**: Z-counting Luminosity group leader
  - **Monica**: PPAP member, Strategic Review panel member
  - **Max**: UK ECFA chair, rECFA and PPTAP member
- In addition, we have leading and coordinating roles in the analyses we carry out

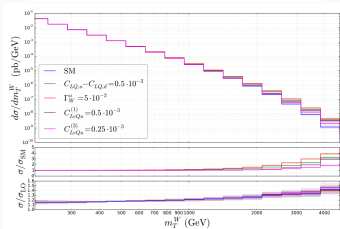
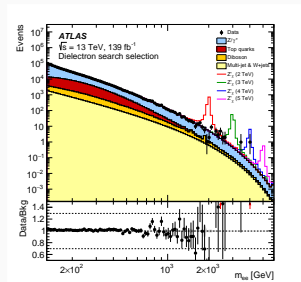
- 2021 publications & work in progress shown
- Physics analyses:
  - Precision  $W$  boson mass measurement
  - High and low mass Drell-Yan measurements
  - Precision Higgs measurements
  - Search for Higgs pair production
  - Search for lepton flavour violating  $\tau$  lepton decays
  - 4<sup>th</sup> July 2022: Higgs 10<sup>th</sup> anniversary celebration at CERN and at Liverpool (TBC)
  - Upcoming paper fest: Celebration of 1000 papers from ATLAS & CMS
- Detector performance:
  - Luminosity monitoring, jet flavour tagging,  $\tau$  lepton calibration, physics modelling
- See Cristiano's ATLAS BSM talk to complete the picture



- Recent CDF  $m_W$  measurement with 9 MeV accuracy  $\rightarrow$  BSM discovery?
  - CDF measurement has  $7\sigma$  tension with SM expectation and EW fit
  - ATLAS team driving effort in LHC Electroweak working group to combine TeVatron & LHC results and understand physics modelling
- Multiprong effort to obtain an ATLAS  $m_W$  with uncertainty improved from 19  $\rightarrow$  10 MeV:
  - Direct measurements of  $p_T(W)$  with low pileup data
  - Improved QCD predictions
  - New & updated  $m_W$  measurements with 5, 7 and 13 TeV data



- High mass DY versatile measurement:
  - Sensitivity to PDFs at high  $x$  & photon-induced  $\gamma\gamma \rightarrow \ell\ell$
  - Lepton flavour universality tests & constraints on BSM physics
- Neutral current  $pp \rightarrow \ell\ell$ :
  - Example of  $m_{ee}$  distribution from  $Z'$  search
  - Cross section unfolded to Born level for EFT interpretations (see Cristiano's talk & Ricardo's poster)
- Charged current  $pp \rightarrow \ell\nu_\ell$ :
  - Precision  $m_T(W)$  measurement (see Samuel's talk)
  - $m_T(W)$  can provide strong EFT constraints



- Higgs decay modes (e.g.  $H \rightarrow \mu\mu$ ) published in the last two years (Jan, Andy, Hanna)

- To be reconsidered in Run-3

- Measure Higgs production in association with a Z boson

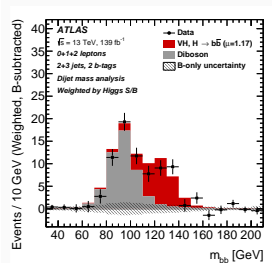
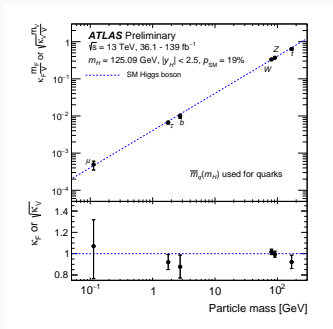
- $Z \rightarrow \ell\ell$ ,  $H \rightarrow b\bar{b}$

- Unique result probing high energy Higgs physics

- Room to improve with future data

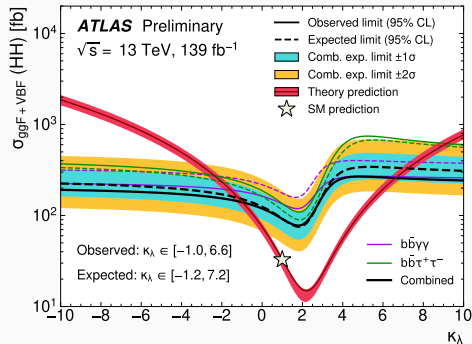
- Improved analysis underway with  $VH \rightarrow b\bar{b}$ ,  $VH \rightarrow c\bar{c}$  combination expected in 2023 (See Ting's talk)

Eur. Phys. J. C 81 (2021) 178



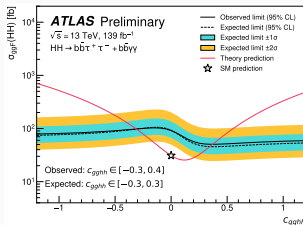
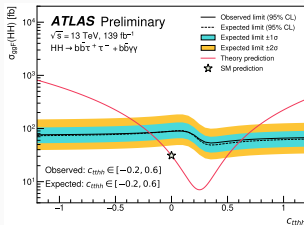
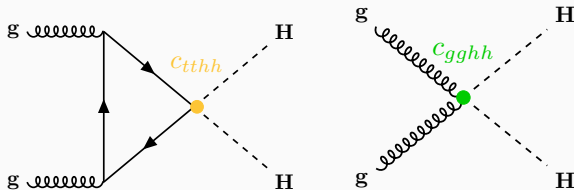
- Higgs pair production ( $HH$ ) gives experimental handle on Higgs self-coupling ( $\lambda_{HHH}$ ).
  - Observing  $HH$  is one of the principle goals of HL-LHC
- $HH \rightarrow b\bar{b}\tau\tau$  search published July 2021:
  - Best cross section limit in this channel to date:  $4.7 \times \text{SM}$
- Reinterpret result to constrain  $\kappa_\lambda = \lambda_{HHH}/\lambda_{\text{SM}}$ .
  - Combine  $HH \rightarrow b\bar{b}\tau\tau$  and  $HH \rightarrow b\bar{b}\gamma\gamma$
- Higgs self-coupling modifier constrained to within  $-1.0 \leq \kappa_\lambda \leq 6.6$ .
  - Best limit yet! [ATLAS physics briefing](#), [CERN Courier article](#)
  - Input to  $H + HH$  combination being published for Higgs 10<sup>th</sup> anniversary

ATLAS-CONF-2021-052



- Can describe  $HH$  production in Higgs Effective Field Theory (HEFT) framework
  - Two SM, three BSM couplings:  $c_{hhh}$ ,  $c_{tth}$ ,  $c_{ggh}$ ,  $c_{tthh}$ ,  $c_{gghh}$
- Seven HEFT benchmark models defined:
  - Each benchmark model represents choice of coupling
- Set limits on anomalous  $HH$  couplings and HEFT benchmarks.

ATL-PHYS-PUB-2022-019



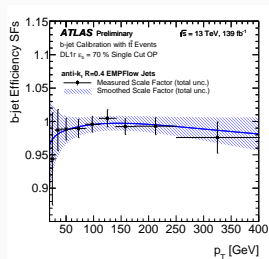
- 
- A Feynman diagram for muon decay. A muon ( $\mu^-$ ) enters from the top left and emits a  $W^-$  boson, becoming a muon neutrino ( $\nu_\mu$ ). The  $W^-$  boson then decays into an electron ( $e^-$ ) and an electron antineutrino ( $\bar{\nu}_e$ ).



# Detector & software work

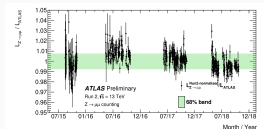
b- and c-jet calibration:

- Carl, Jordan, Andy, Nikos



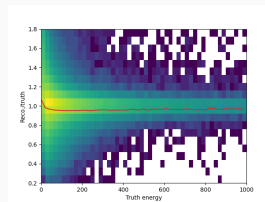
Luminosity measurement through Z counting:

- Samuel, Ricardo, Uta, Jan, Harry, Michael



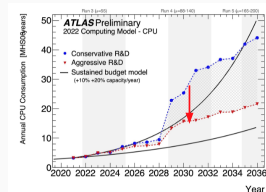
Deep learning for  $\tau$  calibration

- Matt



Physics modelling & computing

- Jan (PMG), Andy (software)



- In addition, work on pile-up simulation (Carl) and triggers for Run-3 (Cristiano)

# Summary

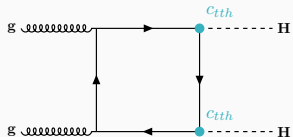
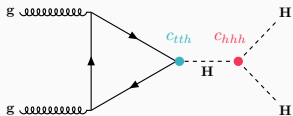
- Despite challenges, ATLAS team has had a very successful year!
- Liverpool has strong presence across ATLAS analyses and detector-related leadership roles
- Broad physics programme producing world-leading results
- Run-2 data continues to provide many insights into precision measurements
- Run-3 very promising to further our understanding of the SM and beyond
- Save the date: Higgs 10<sup>th</sup> anniversary celebration on 4<sup>th</sup> July 2022



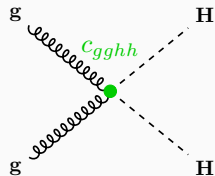
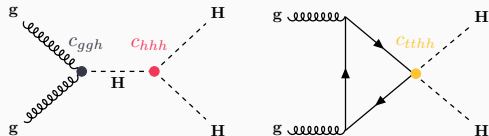
Additional content

# Higgs pair production: HEFT diagrams

## SM leading-order diagrams

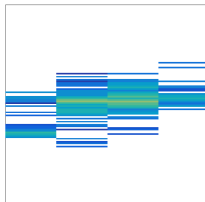


## BSM diagrams



- Deep learning studies for  $\tau$  decay mode classification and energy calibration
- Generate pixelated images from calorimeter cell content
- Use CNN to identify tau decay mode ( $N_{\text{prong}}$ ,  $N_{\text{neutrals}}$ )
- Predict true  $\tau$  energy given reconstructed energy and decay mode using DNN
- Move to graph NNs for combined ID & energy prediction network

EM barrel calo. layer 1



EM barrel calo. layer 2

