Oxford Particle Physics Strategy: Energy Frontier

Update of 2020 strategy covering:

Physics priorities
- Higgs
- Searches
- SM

Future facilities

Future challenges and strategic hiring plan

Academics at the Energy Frontier

c. 2020

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The Higgs boson

The Higgs field is the only fundamental scalar in the Standard Model. However, there may be more than one fundamental scalar field, as predicted by many BSM theories. Interactions with the existing Higgs field (or any new field) could be the only non-gravitational interaction of the universe's dark sector. New interactions could also contribute to charge-parity violation, helping explain the observed baryon asymmetry in the universe. The detailed exploration of this new and fundamental sector of physics will continue to be a major scientific objective throughout the 21st century.

Our priorities in the Higgs sector are to:

(i) perform precise measurements of the Higgs-boson mass and couplings to SM particles;

(ii) measure the self-coupling of the Higgs field;

(iii) search for a Higgs portal to the dark sector through measurements of the Higgs boson's width, its branching ratio to invisible particles, and its production in association with invisible particles;

(iv) search for new CP-violating interactions involving the Higgs field; and

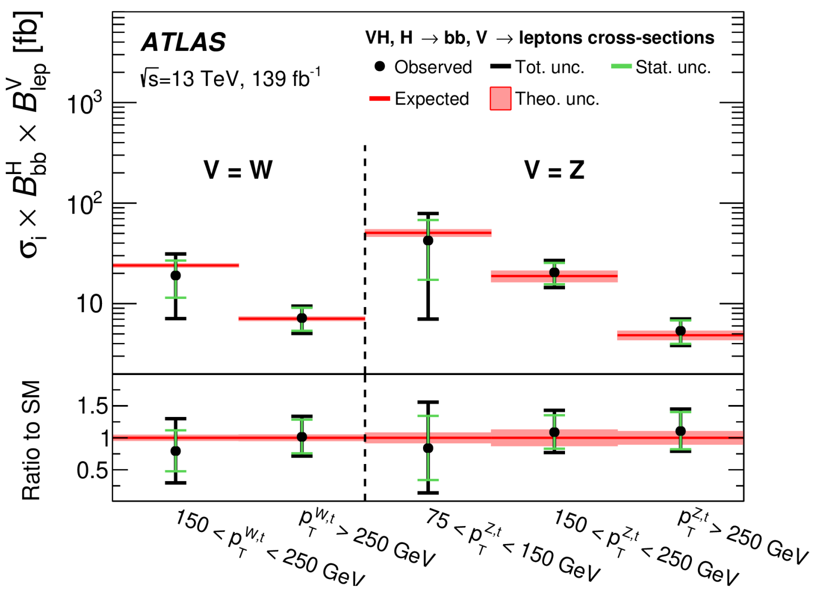
(v) use the Higgs boson as a tool to test fundamental principles of quantum mechanics.

These studies rely on calculations performed within the theory subdepartment, and complement direct dark matter searches performed within the particle physics subdepartment.

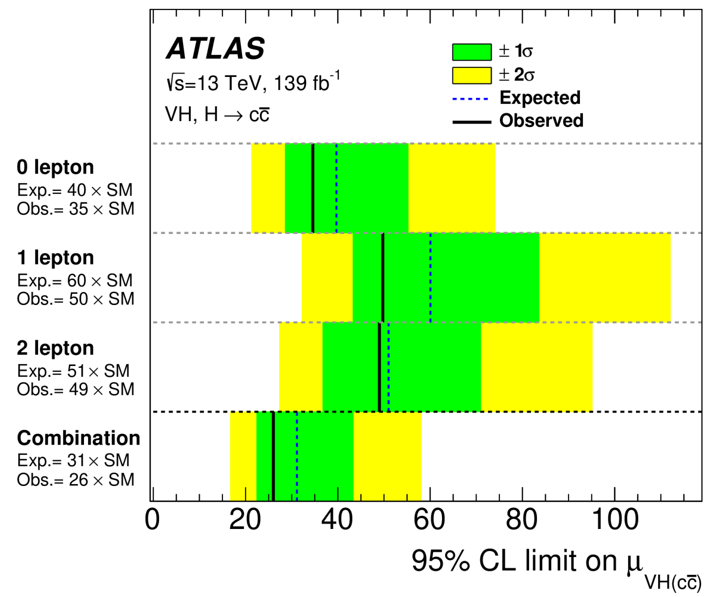
The Higgs boson @ LHC Run 3

Run 3 programme in the CG:

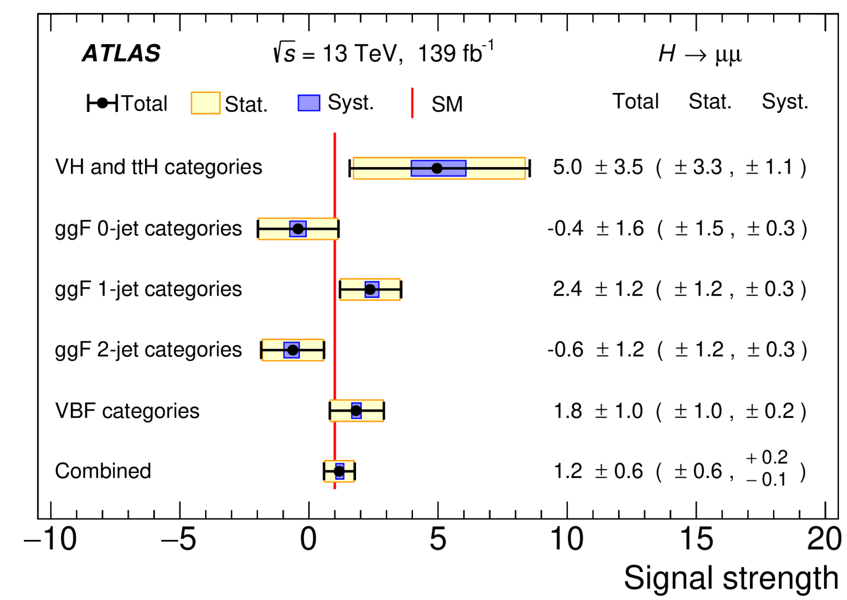
(i) perform precise measurements of the Higgs-boson mass and couplings to SM particles;



$H \to bb$: Daniela



$H \to cc$: Daniela

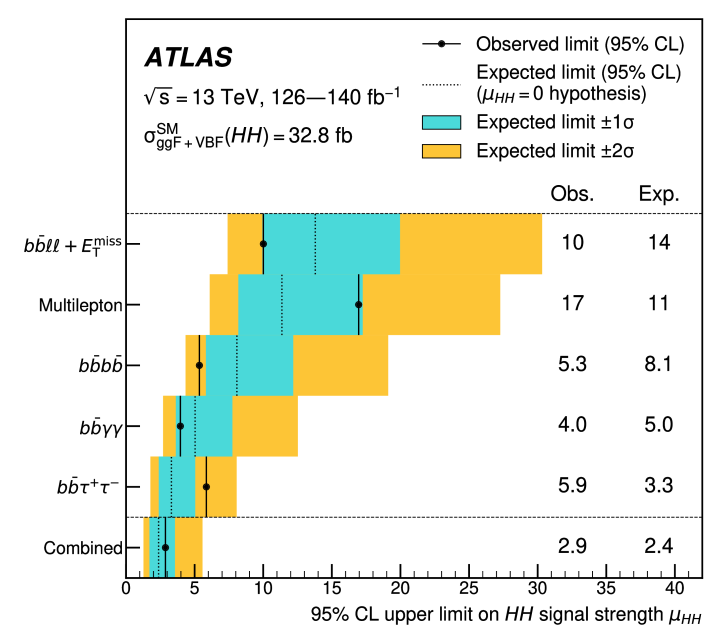


$H \to \mu\mu$: Ian

Higgs mass ($H \to ZZ^* \to 4\ell$): Daniela and Ian

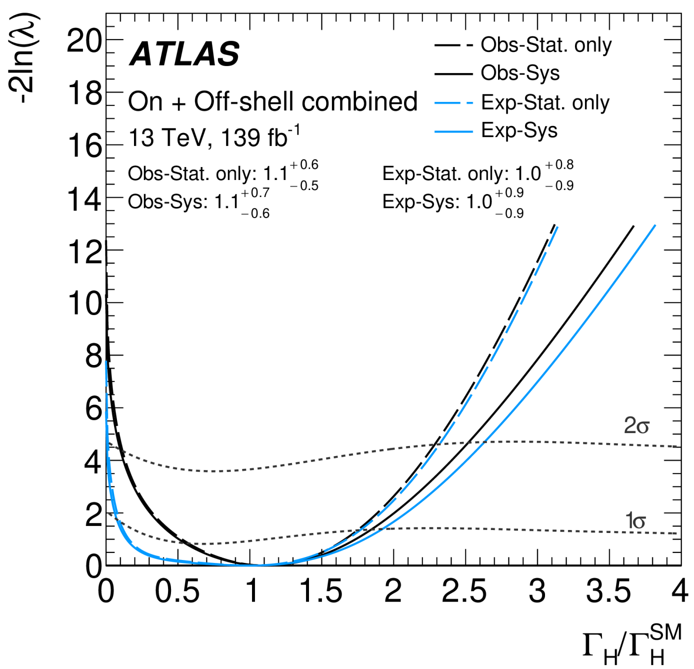
(ii) measure the self-coupling of the Higgs field;

$HH \to bb\tau\tau$: Daniela, Todd, Chris

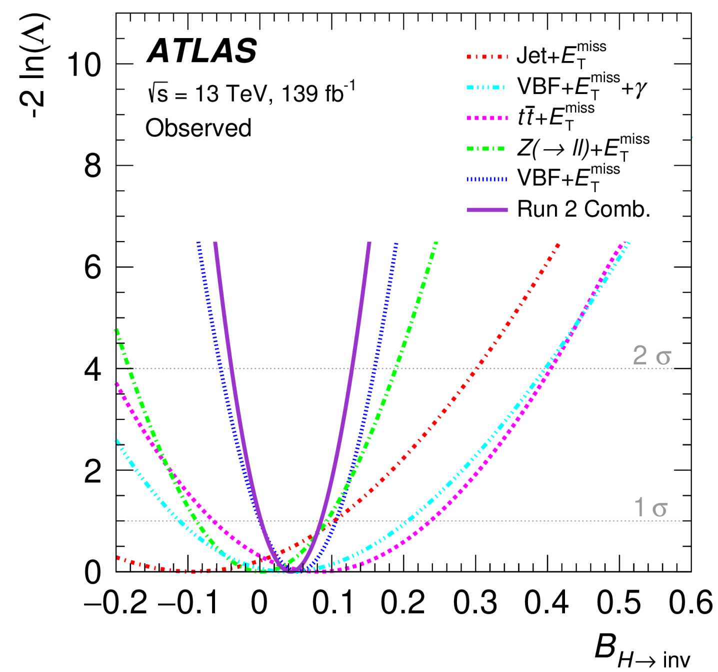


The Higgs boson @ LHC Run 3

(iii) search for a Higgs portal to the dark sector through measurements of the Higgs boson's width, its branching ratio to invisible particles, and its production in association with invisible particles;



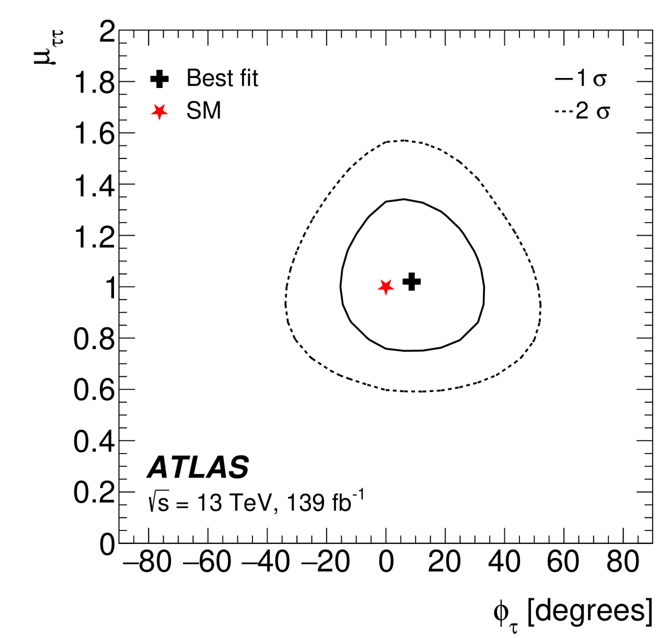
Γ_H: Daniela and Ian



$H \to inv$: Alan and Daniela

$H + inv$: Uncovered

(iv) search for new CP-violating interactions involving the Higgs field; and



$H \to \tau\tau$: Uncovered

(v) use the Higgs boson as a tool to test fundamental principles of quantum mecnanics.

$H \to WW^*$: Alan

Beyond the Standard Model

While the discovery of the Higgs boson was a major scientific achievement, the existence of a scalar field creates a profound dilemma. The mass of any fundamental scalar ought to be substantially changed by quantum corrections. In the case of the Higgs boson, these should increase its mass by orders of magnitude compared to that observed. Protecting the Higgs boson's mass generally requires new particles and symmetries at or near the TeV energy scale. Such particles have not yet been observed, but their existence could explain anomalous measurements in precision experiments. In addition, astrophysical observations indicate the presence of dark matter, the source of which naturally has a mass at the electroweak scale. New particles are further motivated by the three generations of fermions and the non-zero neutrino masses.

Our priorities in the direct search for new particles and interactions are to:

(i) seek evidence of new particles that might be responsible for dark matter;

(ii) probe for new flavour-dependent interactions;

(iii) investigate mechanisms for neutrino mass generation at the TeV scale; and

(iv) perform wide-ranging tests of well-motivated extensions to the Standard Model.

These searches utilize models developed within the theory subdepartment and complement neutrino experiments, flavour experiments, and direct dark matter searches within the particle physics subdepartment.

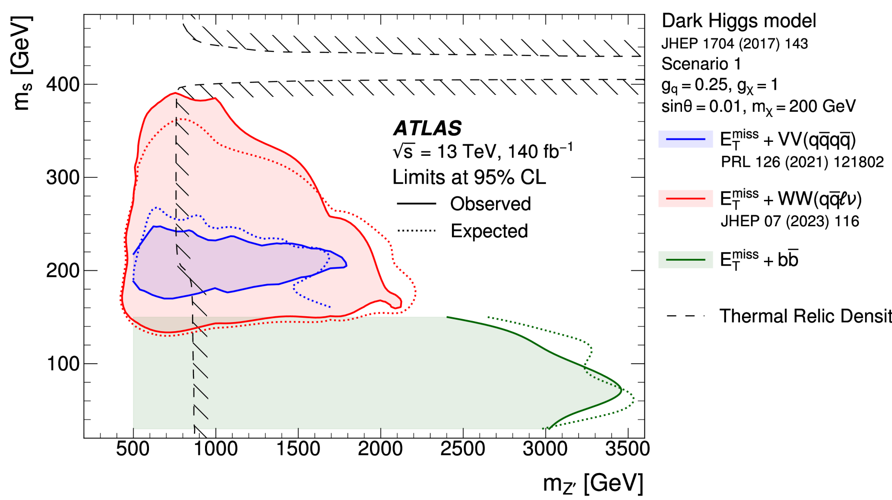
Beyond the Standard Model @ LHC Run 3

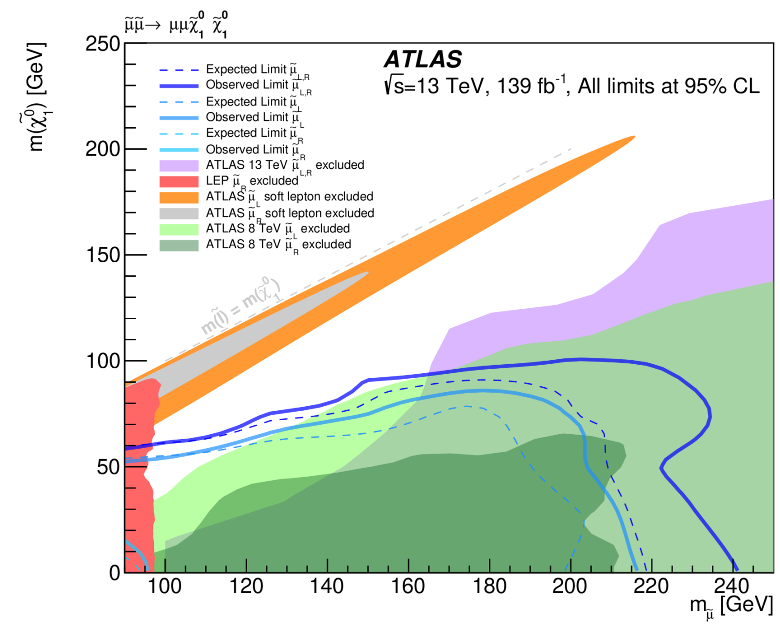
Run 3 programme in the CG:

(i) seek evidence of new particles that might be responsible for dark matter;

DM + VV or BSM Higgs:

Todd

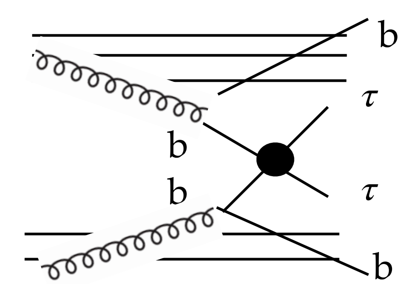




LSP: Alan

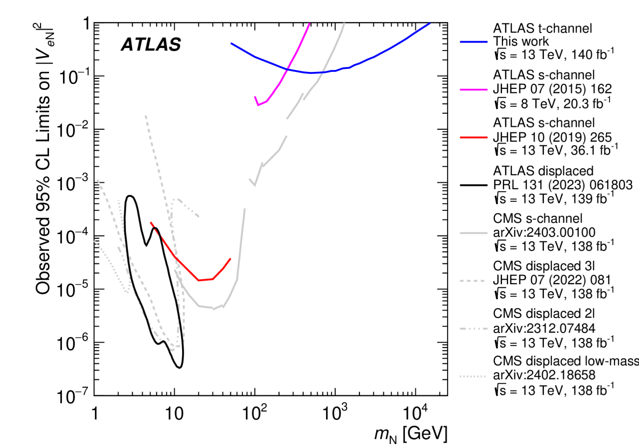
(ii) probe for new flavour-dependent interactions;

Non-resonant $\tau\tau bb$ production: Chris



(iii) investigate mechanisms for neutrino mass generation at the TeV scale;

Right-handed neutrino production: Uncovered



(iv) perform wide-ranging tests of well-motivated extensions to the Standard Model.

SUSY: Alan

The Standard Model

Progress in the Higgs and search sectors is facilitated by the understanding of SM processes and the interpretation of SM measurements. Sensitivity to BSM effects is frequently limited by perturbative QCD calculations and by empirical models of non-perturbative QCD processes. Precise measurements of SM processes provide indirect sensitivity to new particles at the TeV scale and beyond, and the interpretation of measurements in this context can be performed using an effective field theory.

Our priorities in the measurement of SM processes are to:

(i) perform measurements that test perturbative-QCD calculations;

(ii) develop and improve models of non-perturbative QCD;

(iii) precisely measure electroweak processes; and

(iv) perform broad EFT interpretations of SM measurements.

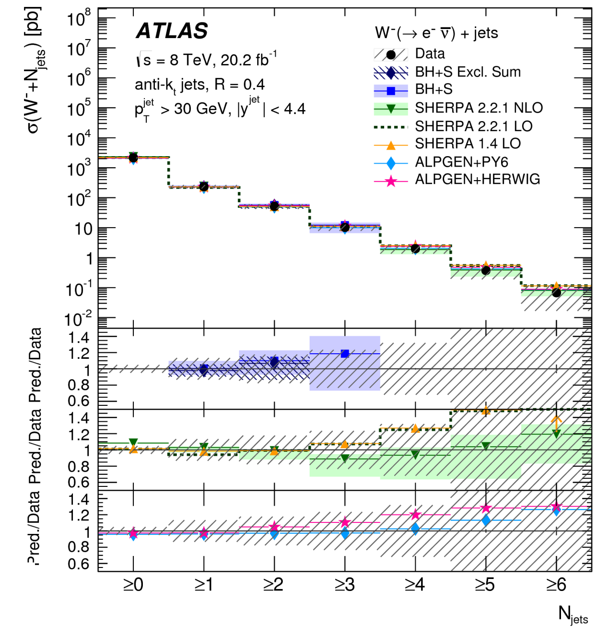
Each priority utilizes calculations or models developed within the theory subdepartment.

The Standard Model @ LHC Run 3

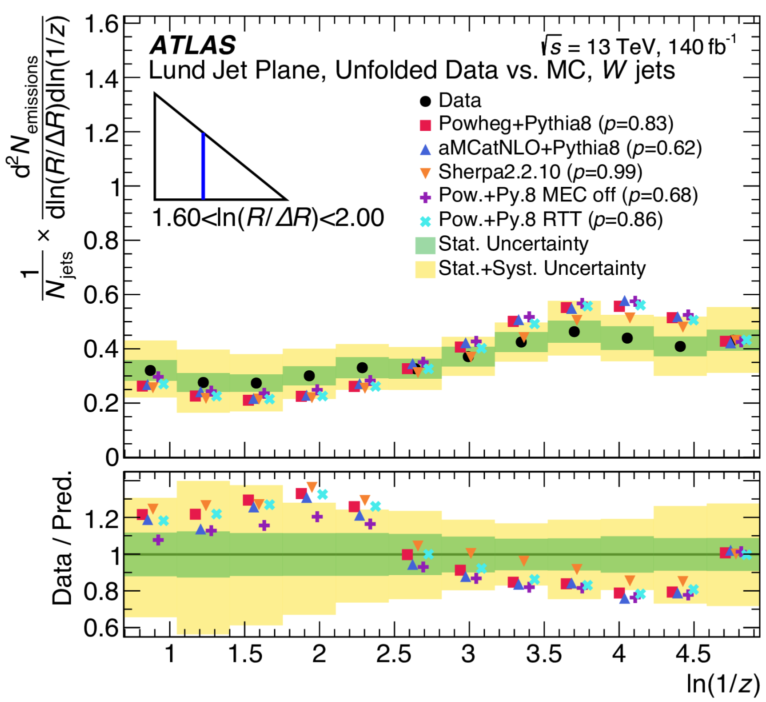
Run 3 programme in the CG:

(i) perform measurements that test perturbative-QCD calculations;

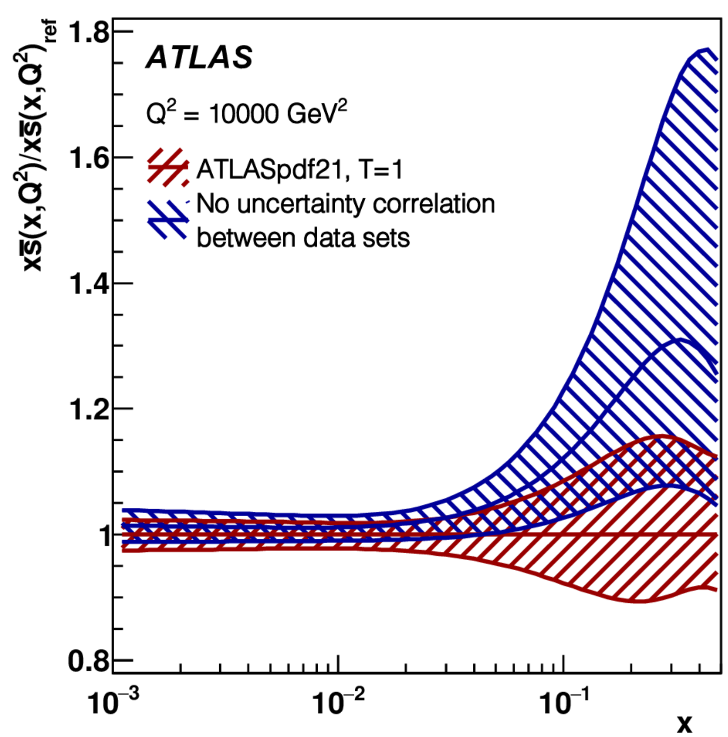
W+jets: Claire



(ii) develop and improve models of non-perturbative QCD;



Jet substructure: Claire

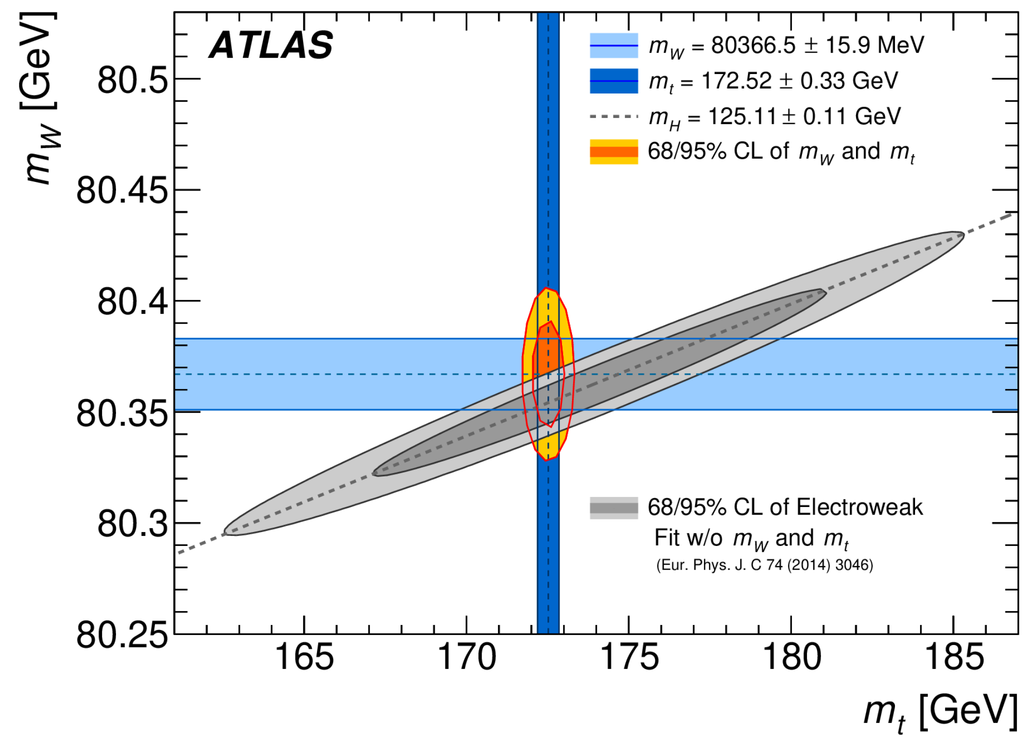


PDFs: Claire

The Standard Model @ LHC Run 3

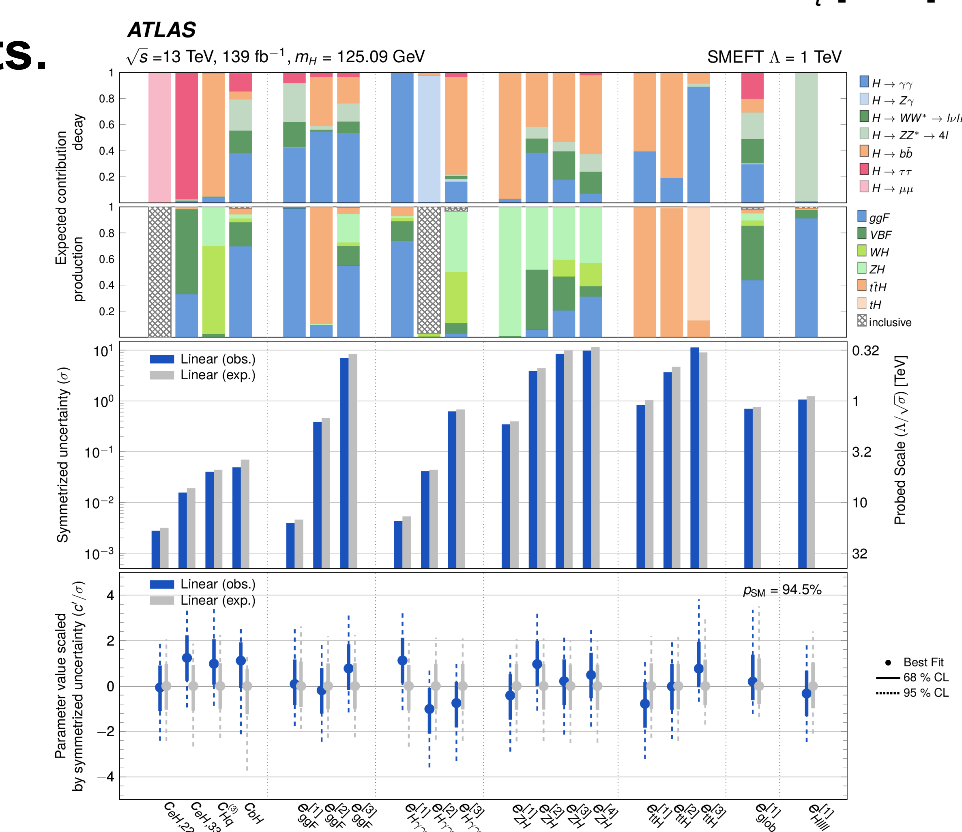
(iii) precisely measure electroweak processes;

W boson mass: Chris



(iv) perform broad EFT interpretations of SM measurements.

Global EFT fit: Chris



Future Facilities

The effective operation of the approved high-luminosity LHC upgrade (installation 2026-2029, operation 2029-circa 2039) **remains the highest priority of the field through the next decade**. The HL-LHC will provide an order of magnitude increase in integrated luminosity, providing opportunities for Higgs self-coupling measurements, high-precision Higgs and electroweak measurements, and searches for new particles in a new coupling regime. A successful HL-LHC programme will sharpen the physics landscape at the electroweak scale.

Beyond the HL-LHC, plans are underway to fund and construct the next generation of particle accelerators. CERN is preparing a technical design report for the Future Circular Collider, which will initially collide electrons with positrons, but can then be developed into an electron-proton or proton-proton machine. China has also made a large electron-positron circular collider, the CEPC, a top priority. In Japan interest has been expressed in an electron-positron linear collider (the ILC), and although it is not currently a high priority, it cannot be excluded. Research and development of a high-energy linear collider (CLIC) continues at CERN, offering the possibility of TeV-scale collisions. Finally, the US is developing new linear-collider technologies and is prioritising the development of a muon collider.

Scenarios and priorities for future energy-frontier machines are currently under discussion in the European Strategy process. Oxford is engaged in these studies, and is well positioned to play a leading role in accelerator and detector design and construction, as well as in simulation and exploitation. If new colliders are constructed at multiple sites, their timescales and physics reach will inevitably differ. **As a world-leading institution, Oxford plans to make significant contributions to any energy-frontier collider.**

Future Challenges and Strategic Hiring Plan

While the HL-LHC offers a wealth of frontier physics opportunities, it also presents significant challenges. The trigger rates will grow faster than the order of magnitude increase in luminosity, and new strategies will be required to efficiently collect data for the physics programme. ATLAS will have an entirely new inner tracker that will require commissioning, monitoring, and maintenance throughout the run. A targeted detector upgrade during the extended running period can be expected, as it is a common practice for general purpose detectors to address identified deficiencies after extreme collider conditions commence.

The successful running of the HL-LHC will thus require significant investment in the operation and exploitation of the ATLAS detector. Oxford is developing the upgraded Inner Tracker and plans to commission it in ATLAS. Furthermore Oxford expects to continue its leadership in trigger and object reconstruction, which are essential to the success of the ATLAS physics programme.

In order for Oxford to retain these capabilities, it needs to renew its investment in key areas. Prior to HL-LHC running, a leader in detector construction and commissioning (vice-Weidberg) will ensure the successful installation of the new tracker and will lead the study of future technologies for any potential upgrade. On a similar timescale, an expert in trigger and reconstruction (vice-Huffman) will lead novel methods for efficiently collecting the data. In order to fully exploit the ATLAS data and achieve the Oxford physics goals, a third hire (vice-Bortoletto) will be required during the HL-LHC run.

Oxford has historically been a leader in the direction of the field. With the retirement of Brian Foster, former leader of the ILC, Oxford no longer has a chair-level appointee developing a vision for the future. It is imperative that Oxford restore its leadership at the Energy Frontier by filling the position of the Donald H Perkins chair.

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