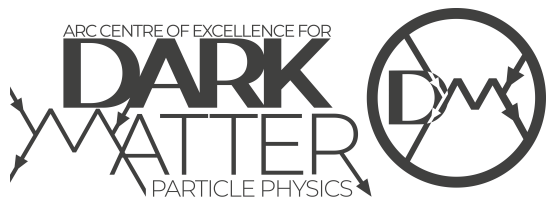
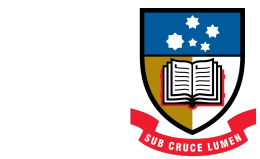
Recent Results From ATLAS Searches for Dark Matter

Harish Potti and James Webb, on behalf of the Australian ATLAS group

The ARC Centre of Excellence for Dark Matter Particle Physics &
The University of Adelaide

2022 CDM Annual Workshop





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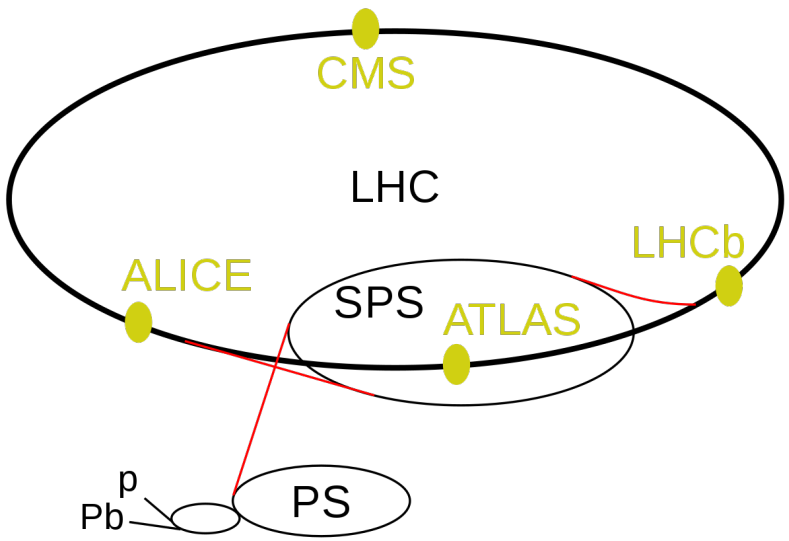
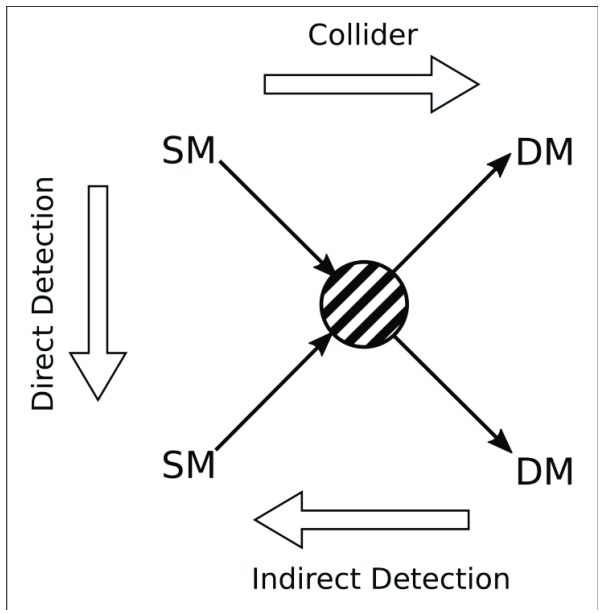
ATLAS: Introduction

- ATLAS is a general purpose detector. Designed for
  - Precision SM measurements
  - New physics like **Dark Matter**

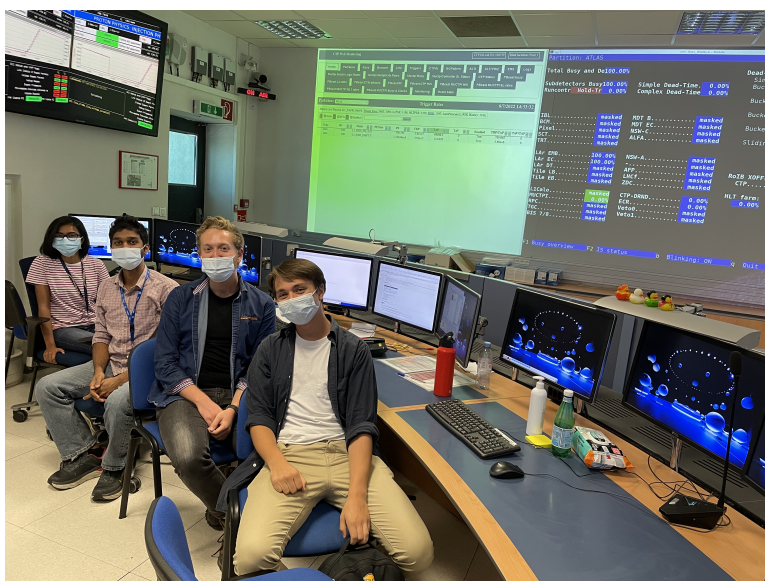


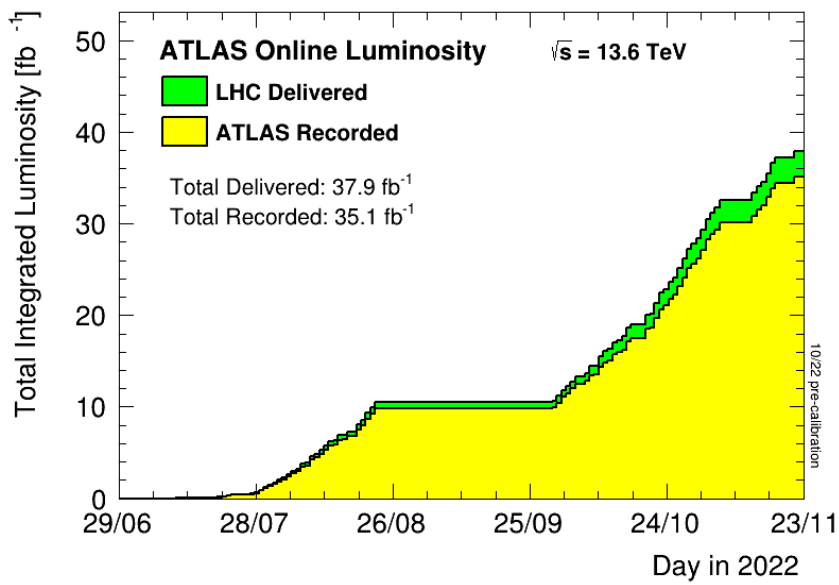


- Only $\sim 30/5000$ people are from Australia. Yet, Australian participation in all major areas
  - Detector building & Operation
  - Trigger
  - Data Preparation
  - Software & Computing
  - Physics analyses

CURRENT STATUS

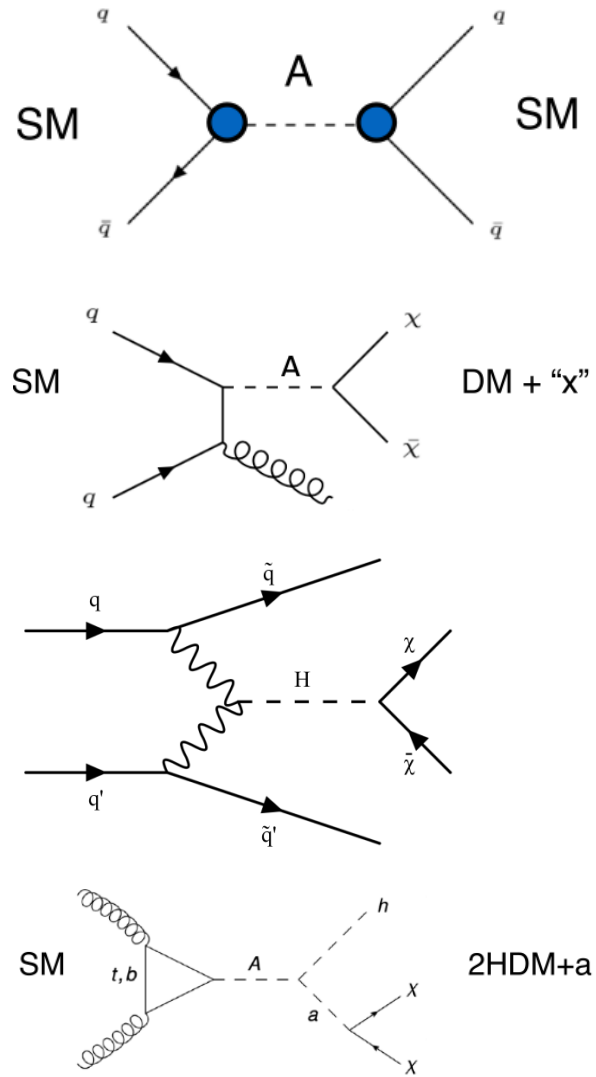
- Run-3 of the LHC has been successfully started in July this year at $\sqrt{s} = 13.6$ TeV.
- ATLAS already recorded 35 fb^{-1} data this year.
- By end of 2025, we expect to collect double the amount of data compared to Run-2
- Most of the ongoing physics analyses are still with Run-2 data





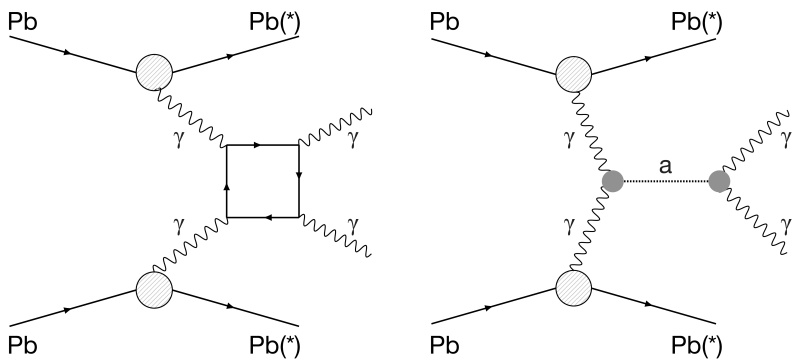
ATLAS Searches for Dark Matter

- Searches for Mediator Dark Matter
  - Dijet resonances
  - Dilepton resonances
- Searches for Recoiling Dark Matter (X + MET)
  - Jet + MET
  - γ + MET
- Higgs Portal Models
  - Higgs boson is the mediator and decays to invisible particles
- Other models:
  - 2HDM
  - Light by Light scattering
  - SUSY, etc



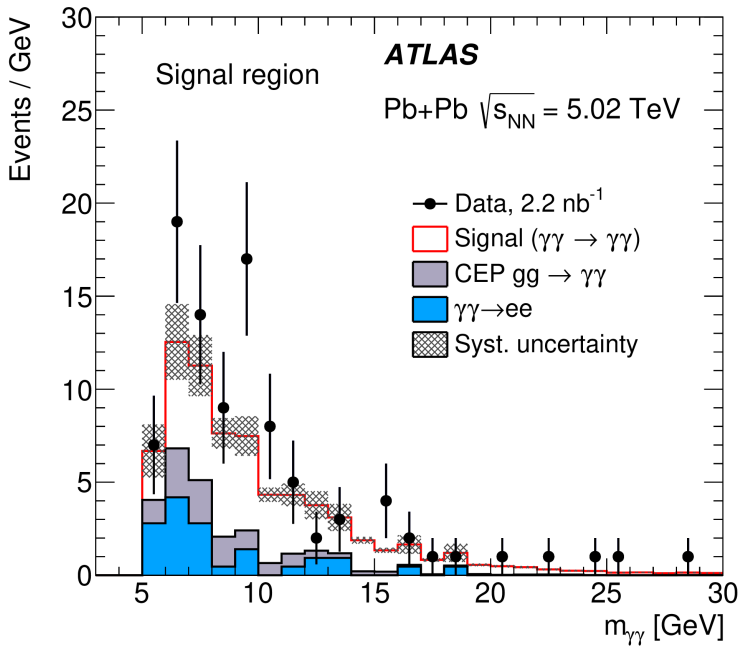
Axion-like particles in light-by-light scattering

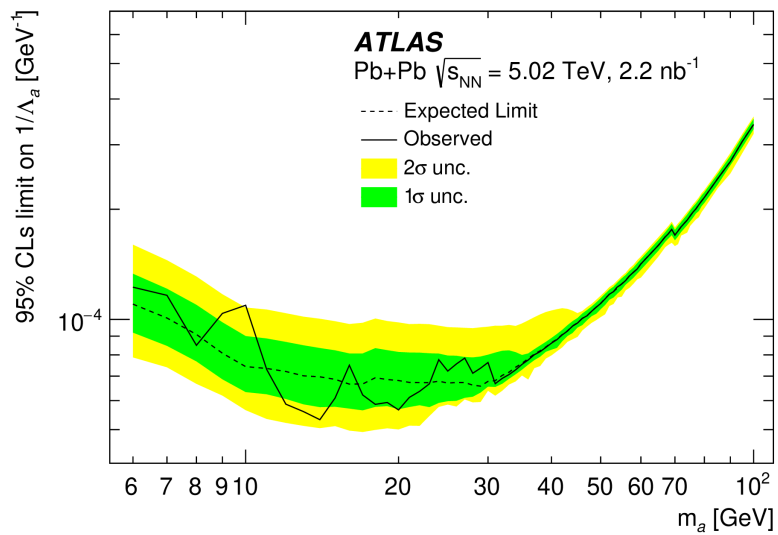
- Light by light (LbyL) scattering is a very rare phenomenon.
- First observed by the ATLAS experiment in 2019.
- Sensitive to axion-like particles (ALP) which can enhance the LbyL cross-section through $\gamma\gamma \to a \to \gamma\gamma$ diagrams
- JHEP03(2021)243



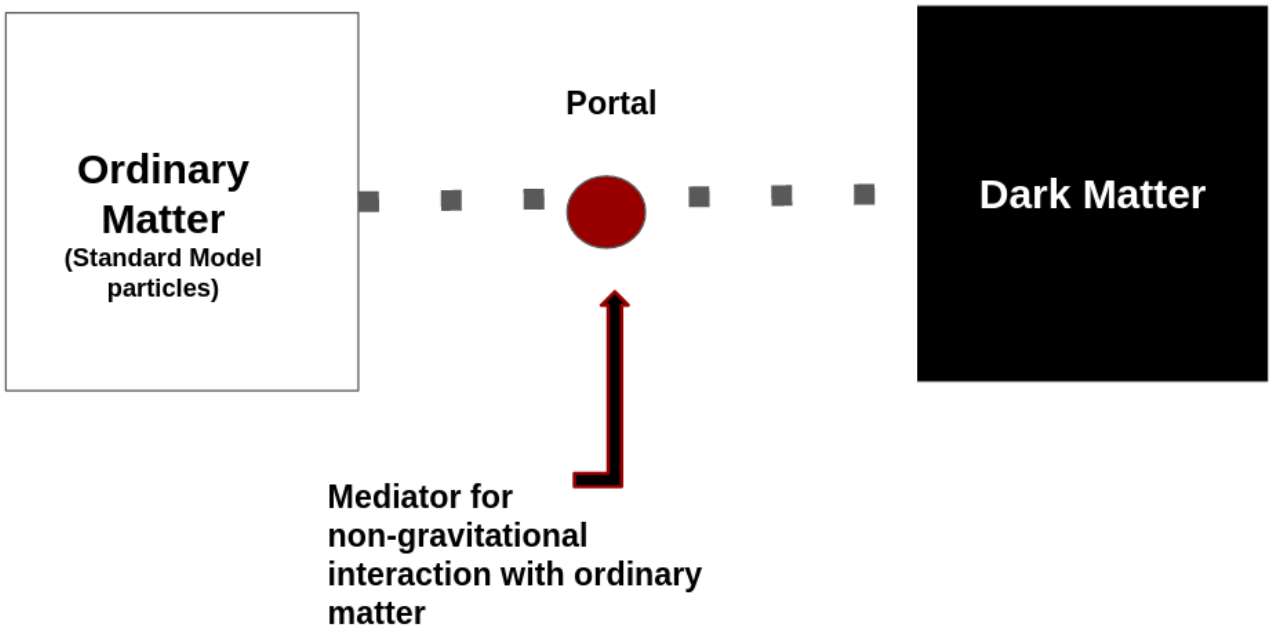
LIGHT BY LIGHT SCATTERING

- Measured fiducial crosssection $\sigma_{fid} = 120 \pm 17$ (stat) ± 13 (sys) ± 4 (lumi) nb. Predicted $\sigma_{fid} = 80 \pm 8$ nb
- Best exclusion limits so far over the mass range of 6 $< m_a <$ 100 GeV





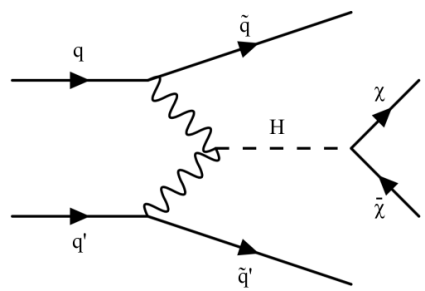
Higgs Portal to Dark Sector



- Many BSM theories with various mediators
- Higgs boson could be a mediator between ordinary matter and dark matter
- Higgs decays into a pair of WIMPs like $\chi\chi$ in these models.

INVISIBLE HIGGS DECAYS

- In the SM, $B_{inv}(H \rightarrow \text{invisibles}) \sim 0.1\%$ due to $H \rightarrow ZZ^* \rightarrow 4\nu$
- In many BSM theories, B_{inv} is enhanced due to Higgs decays to stable dark matter particles
- E.g. SUSY (LSP), large extra dimensions (Graviscalar)
- Events are tagged using the associated production of W/Z or a recoiling jet

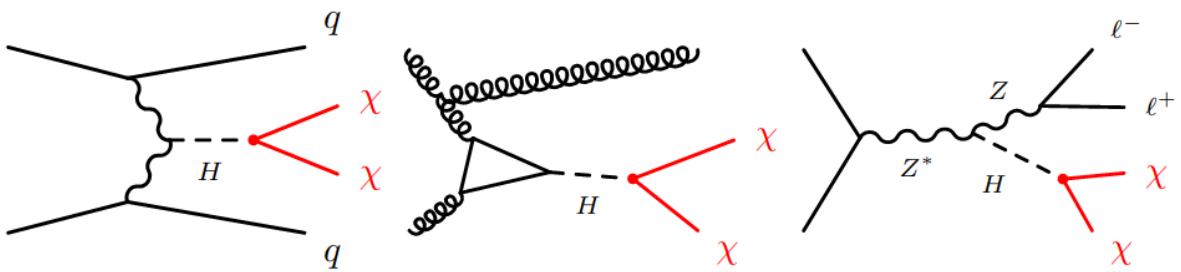


- Higgs boson will be invisible and will be manifested as the *"imbalance in momentum in transverse direction"* (MET)

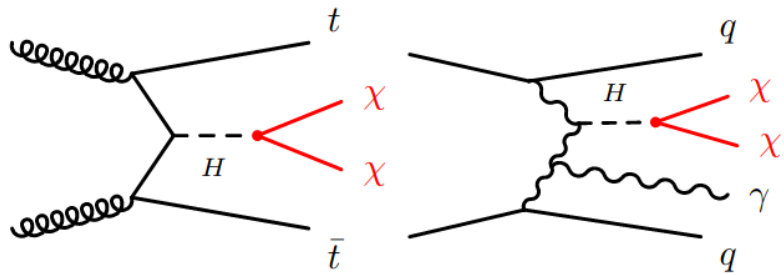
ATLAS $H \rightarrow$ INVISIBLES SEARCHES

- ATLAS collaboration has performed six independent searches for invisible Higgs decays with full Run-2 data

Analysis	Results
VBF+MET	JHEP 08 (2022) 104
MET+$Z(\ell\ell)$	Phys. Lett. B 829 (2022) 137066
$t\bar{t}$ + MET	ATLAS-CONF-2022-007
VBF + MET + γ	Eur. Phys. J. C 82, 105 (2022)
Monojet	Phys. Rev. D 103, 112006
Run-1 combination	JHEP11(2015)206
Combination	Ongoing



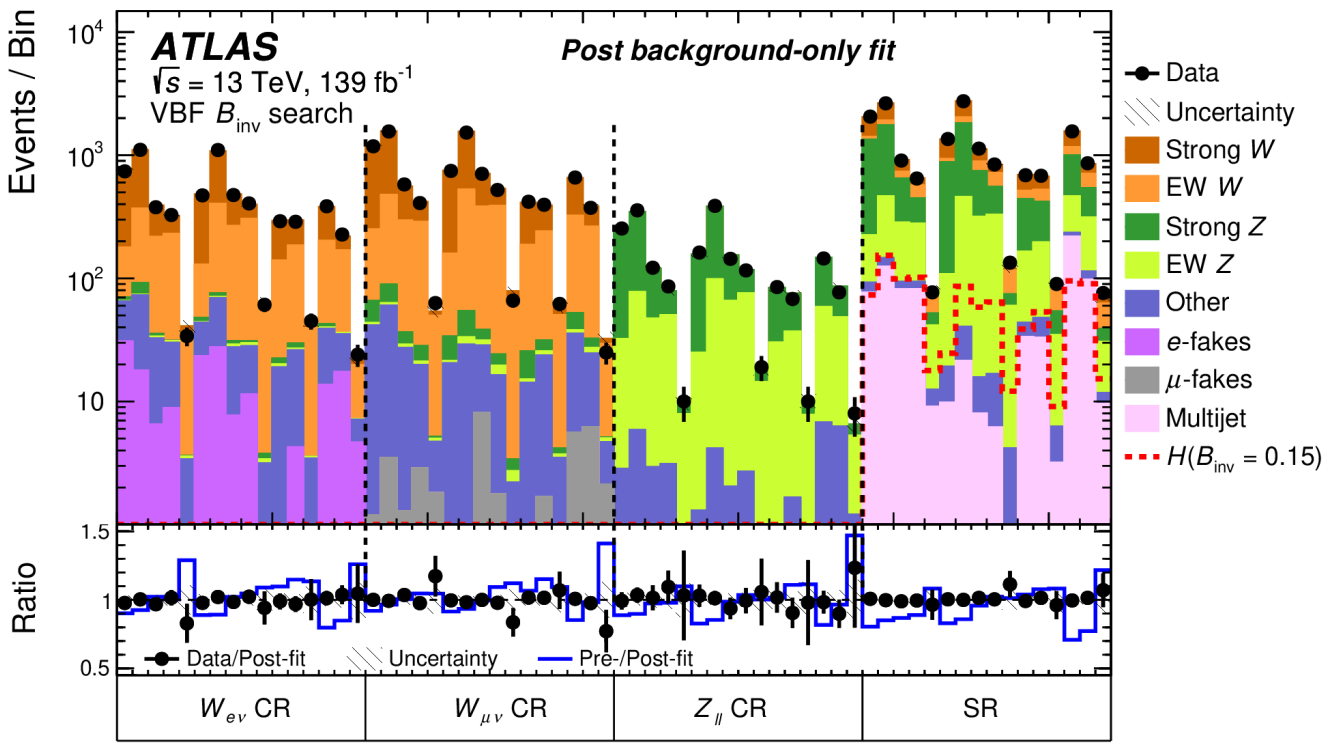
(a) VBF + $E_{\mathrm{T}}^{\mathrm{miss}}$ (b) Jet + $E_{\mathrm{T}}^{\mathrm{miss}}$ (c) $(Z \rightarrow)\ell\ell + E_{\mathrm{T}}^{\mathrm{miss}}$



(d) $t\bar{t} + E_{\mathrm{T}}^{\mathrm{miss}}$ (e) VBF + $E_{\mathrm{T}}^{\mathrm{miss}} + \gamma$

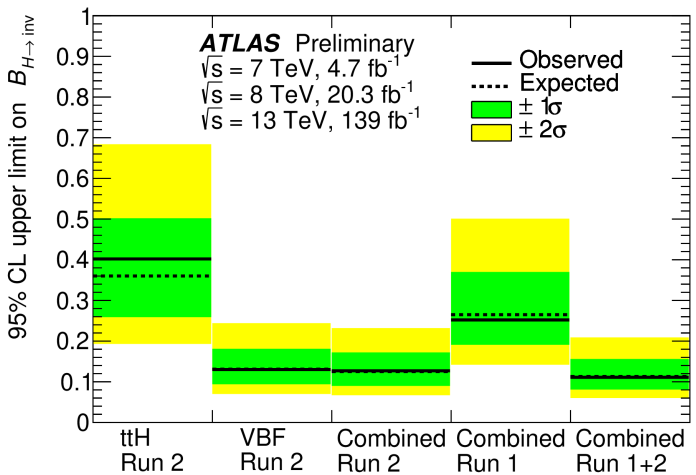
VBF + MET ANALYSIS

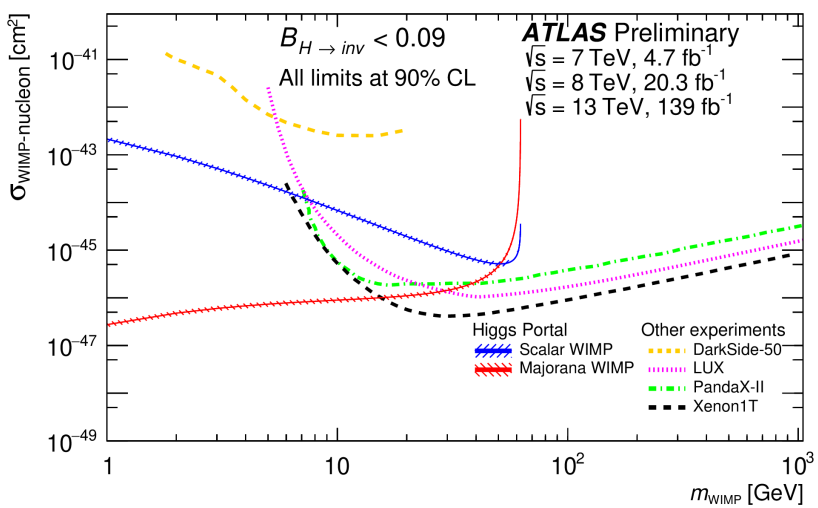
- Most powerful analysis
- Distinct characteristic is a pair of energetic jets with wide pseudo-rapidity gap ($|\eta_{jj}|$) and a large invariant mass (m_{jj})
- Major backgrounds: single vector production + two jets due to QCD radiation
- $E_T^{\text{miss}} > 160$ GeV , $p_T^{\text{all-jet}} > 140$ GeV



Results from the $H \to$ Invisibles Combination

- Observed (expected) upper limits on the B_{inv}: 0.11 (0.11)
- ATLAS-CONF-2020-052





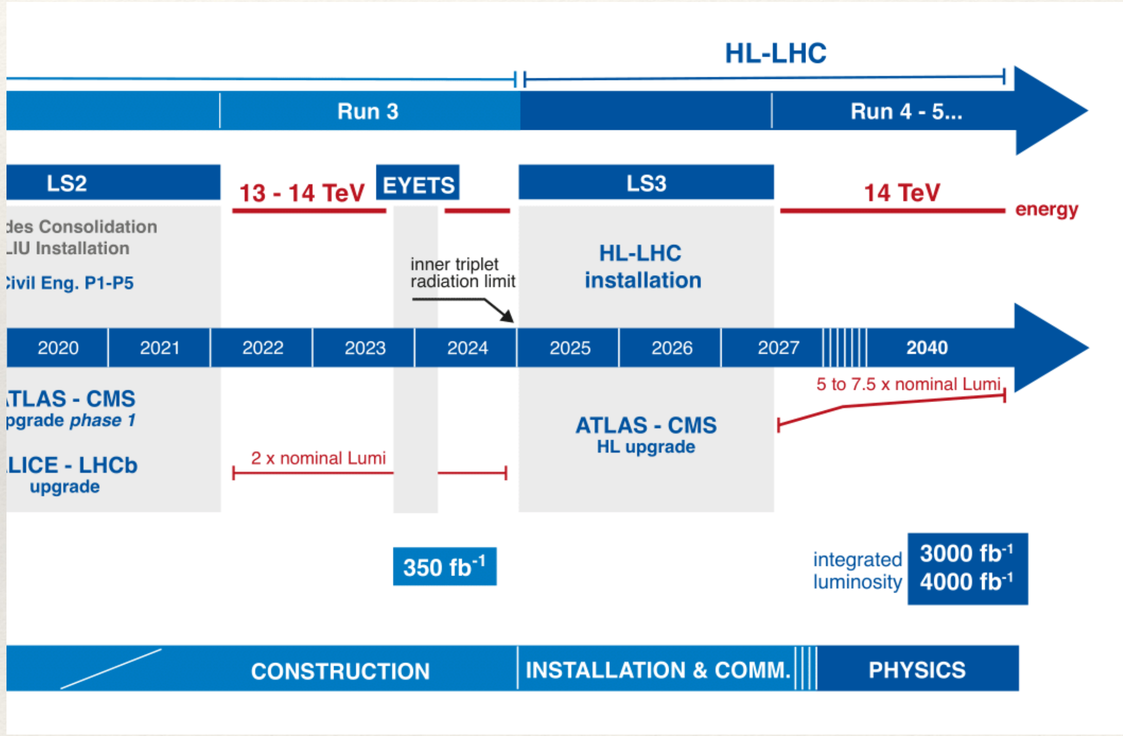
OUTLOOK

- Many interesting ATLAS results from dark matter searches performed with full run-2 dataset
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- Run-3 has already produced a lot of data at $\sqrt{s} = 13.6$ TeV
- Detector upgrades for the HL-LHC are ongoing

A HiLumi future

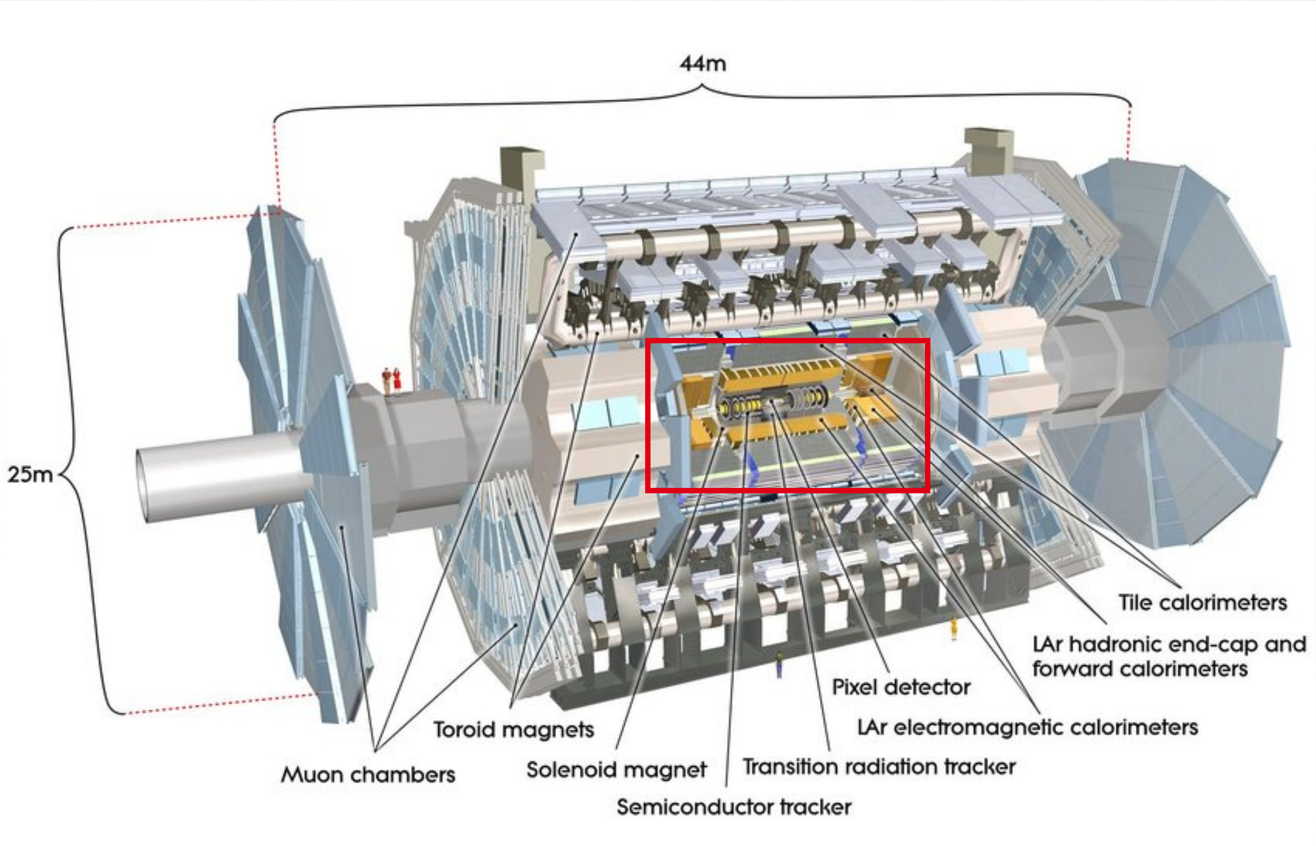
HL-LHC

- Intense data collection phase
- Aim to increase $\mathscr{L}_{peak} = 7 \times 10^{34}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$, 3000 - 4000 fb^{-1} data-set over ~10 year operation
- Increase from 50 to 200 p-p collisions per beam crossing



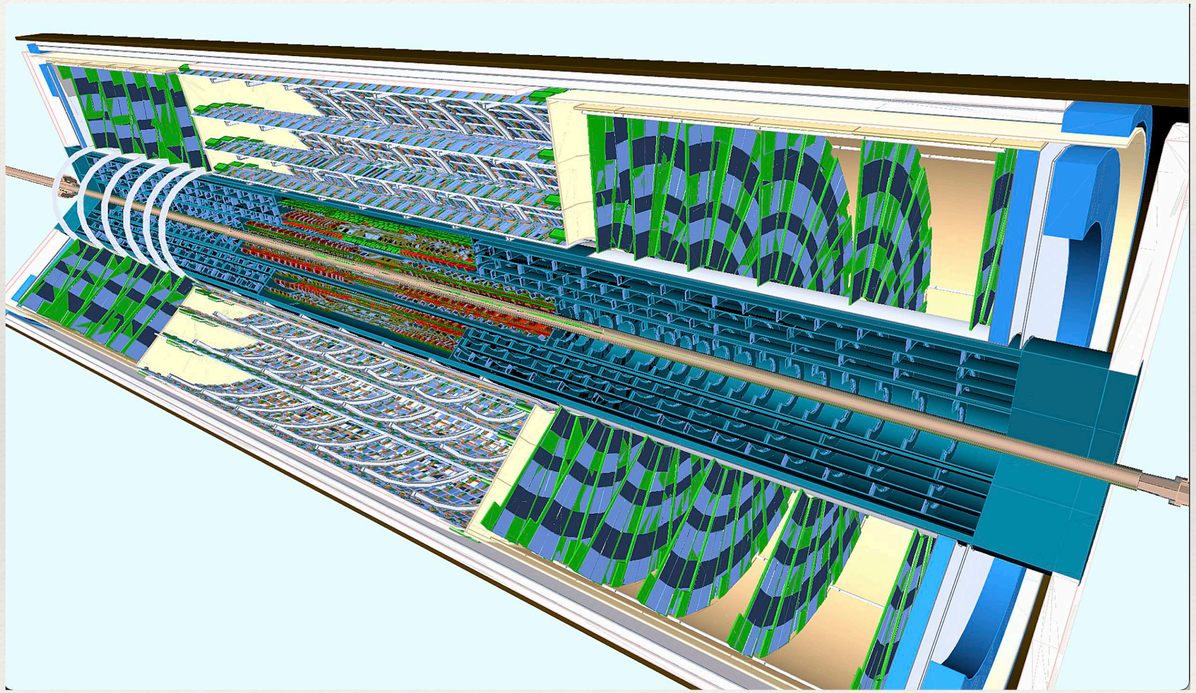
Towards a full silicon tracker

- Current inner-tracker (Pix, SCT, TRT) limited by readout rate and radiation damage, unsuitable for HL-LHC
- Moving to a fully silicon based tracker



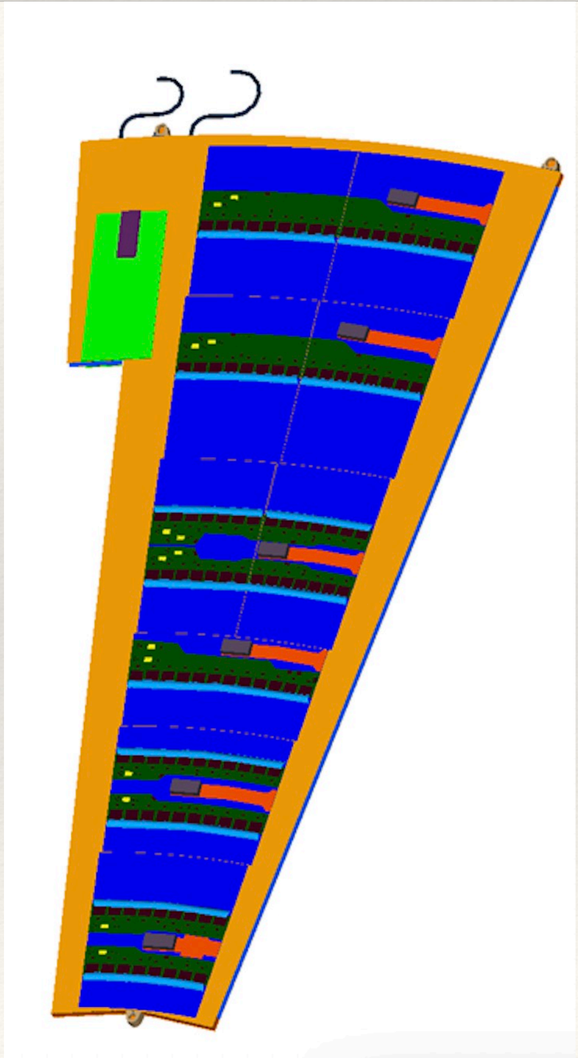
ITk strips

- Strip detector is comprised of two sections: barrel and the end-caps
- Redesign of inner tracker, extending geometry, sensitivity to larger $\Delta\eta$
- New readout chips (ABCstar) and increased strip granularity



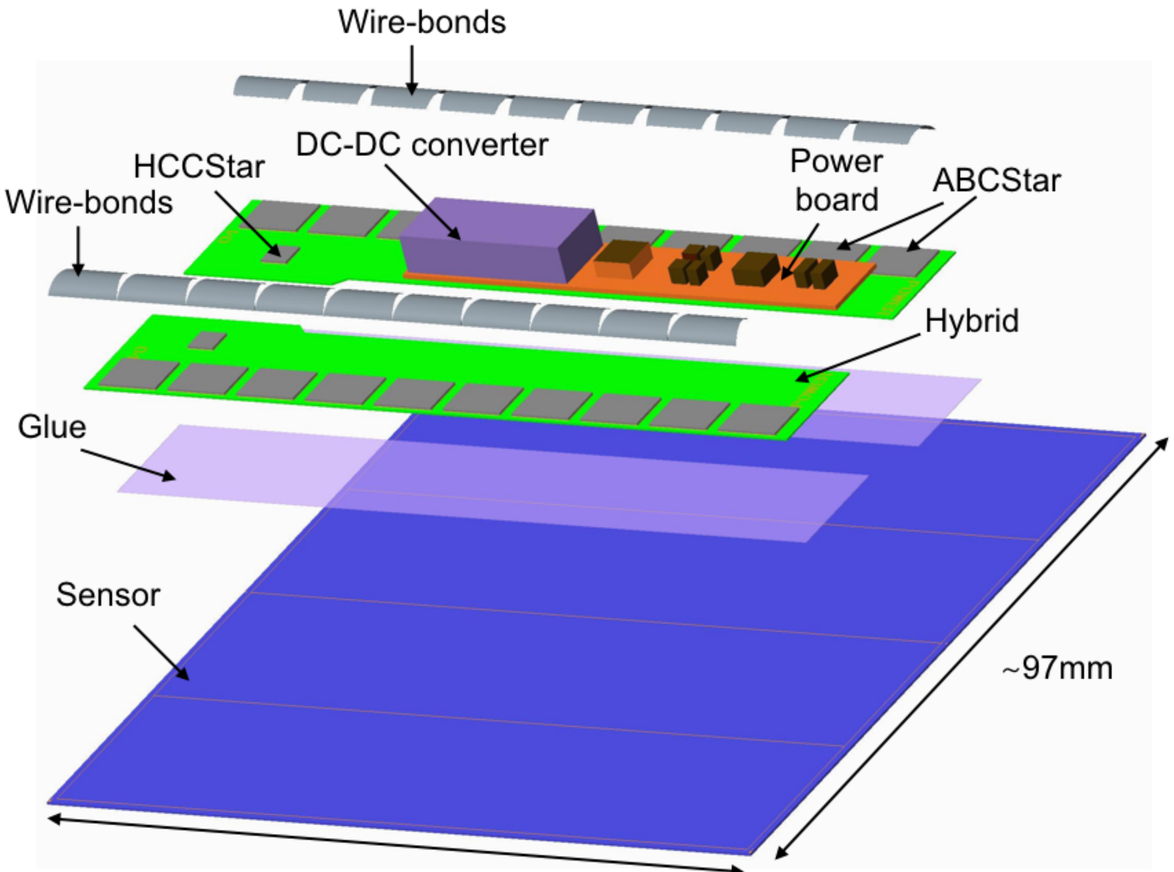
Endcap petals

- End-caps comprised of ‘petals’
- Each petal consists of six modules denoted R0 - R5
- Melbourne to build R1 and R4 modules, early prototyping done with R0
- 32 petals comprise a single end-cap disk



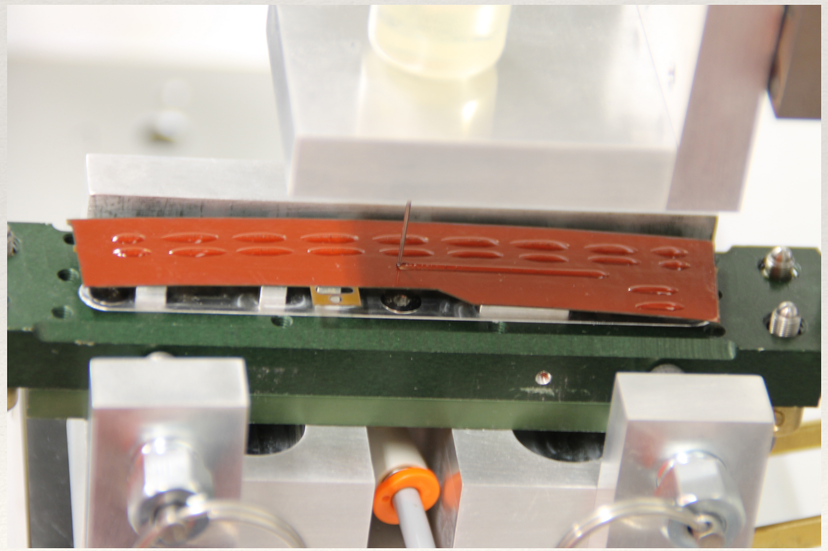
Module assembly

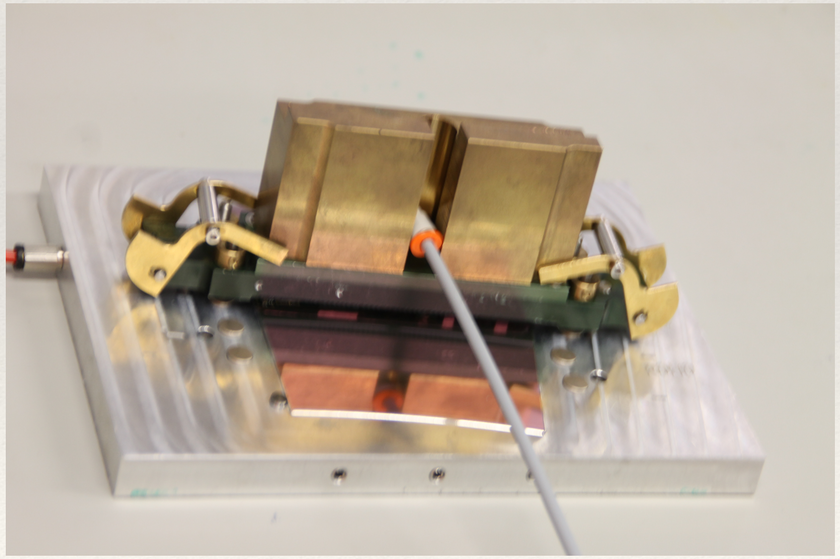
- Relatively simple design, full assembly requires only a few jigs.
- Hybrids/powerboards to arrive pre-populated with ASICs.

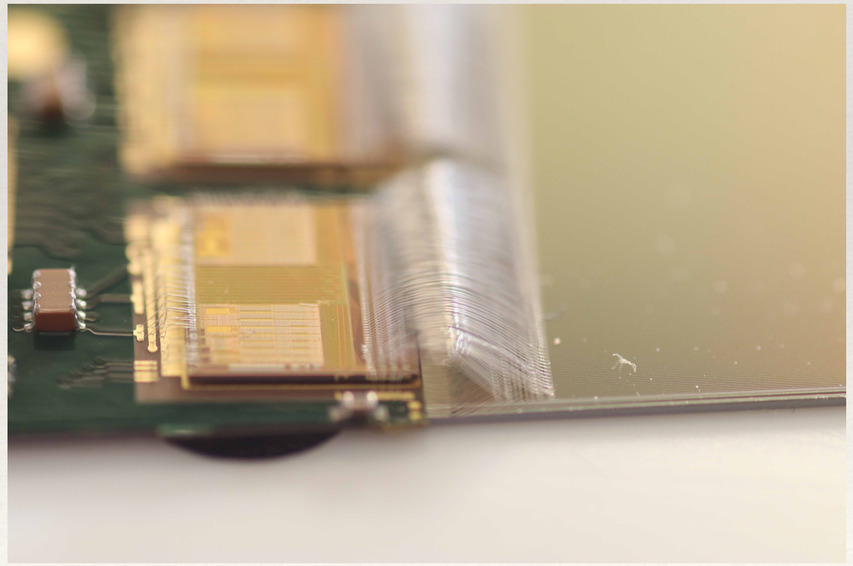


Module assembly II

- Glue dispensing robot resolved uncontrolled glue spread observed in early prototyping.
- 256 wire-bonds connect each chips read out channels to the sensor.

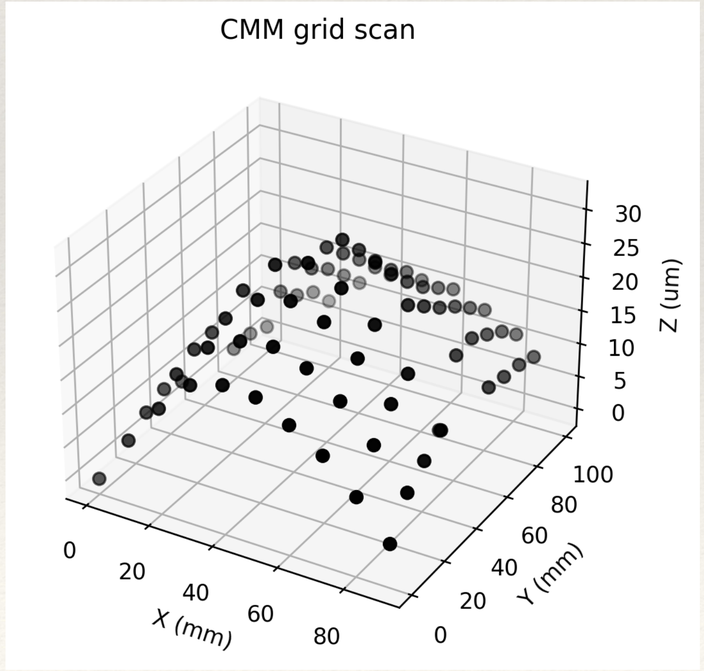


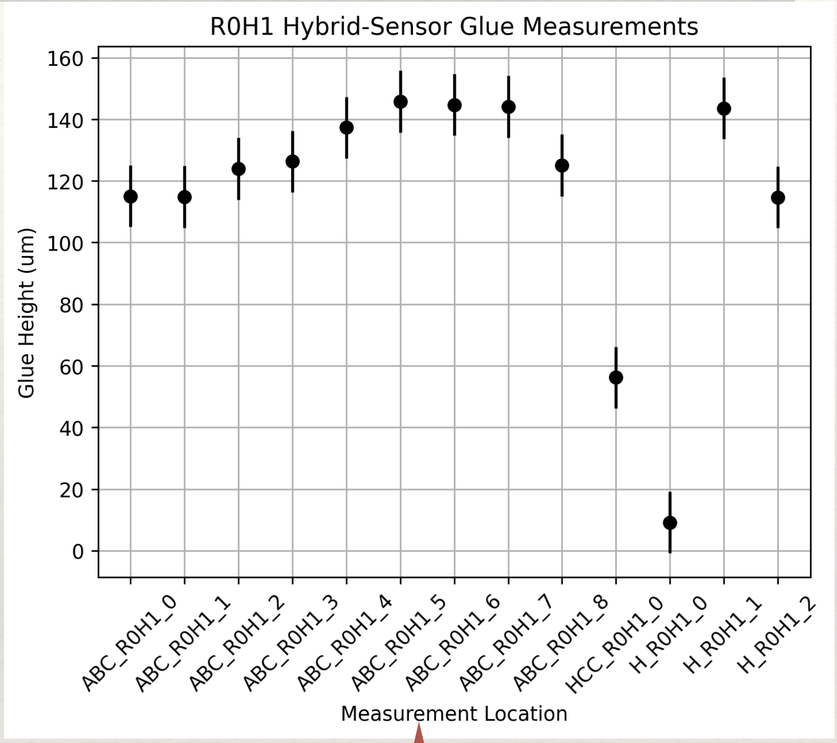


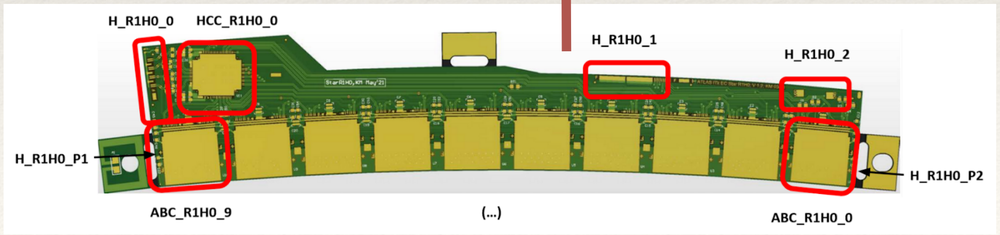


Module quality control

- Thorough module metrology to evaluate quality of assembly.
- Position, heights of PCBs, bowing

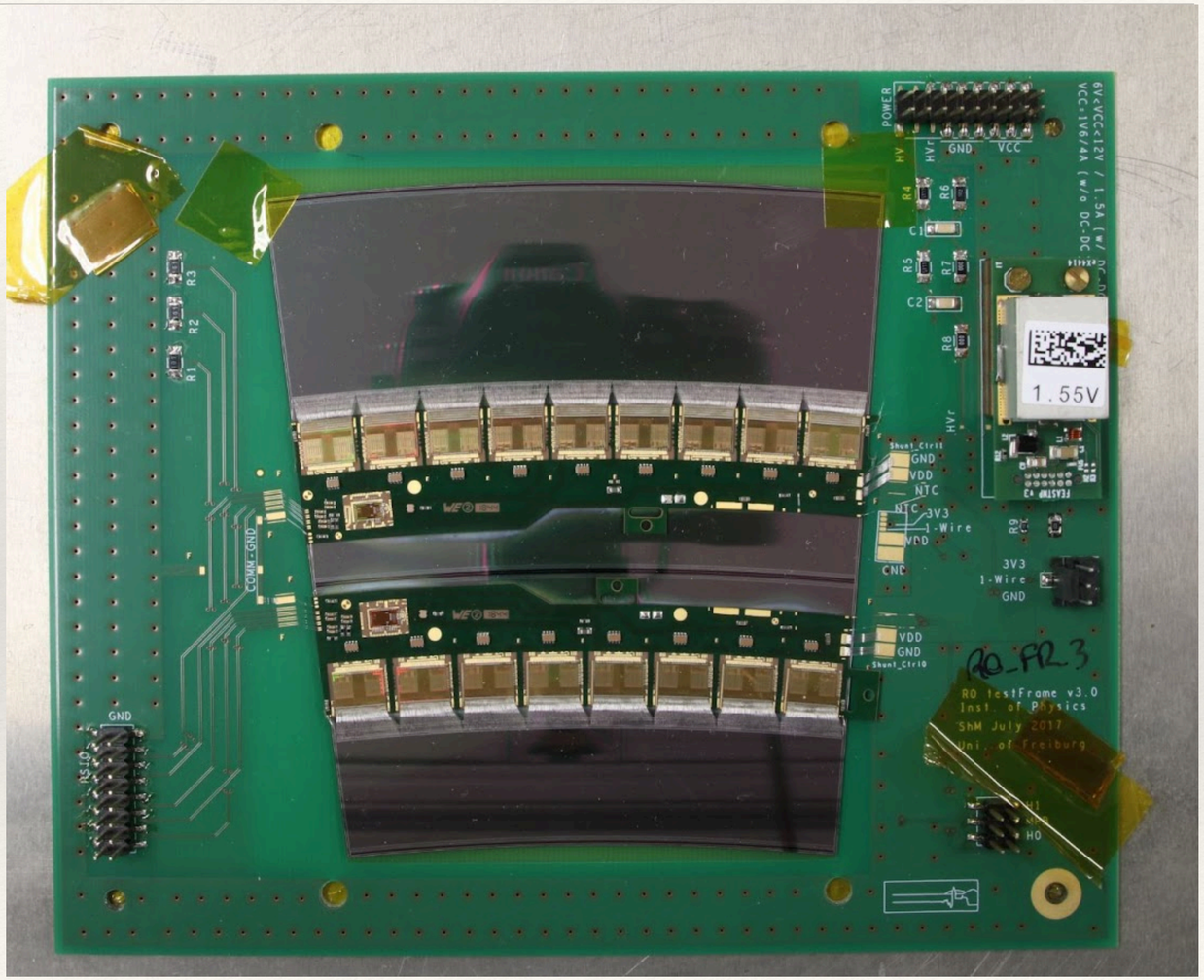






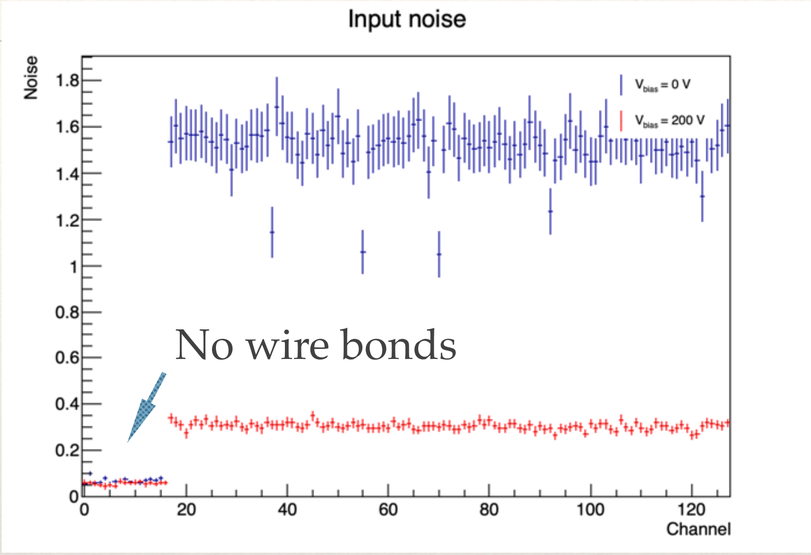
Module assembly III

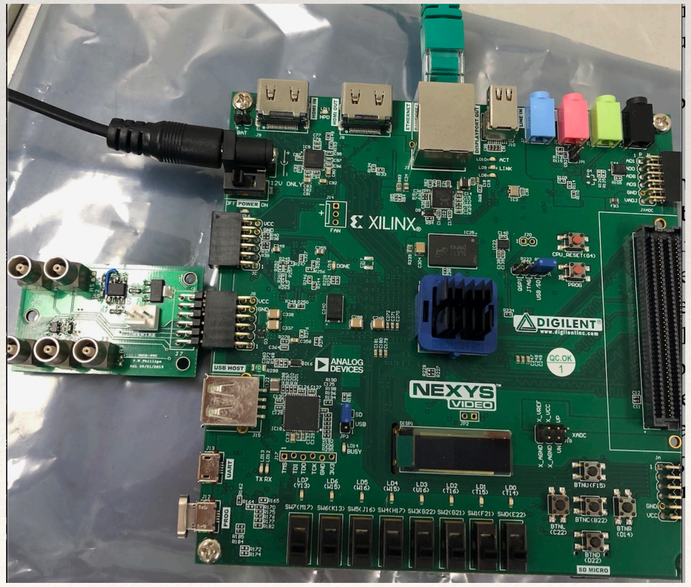
- Several prototype modules successfully assembled: good I-Vs, metrology within spec.
- Electrical issues (large dark currents/early breakdown) eliminated by controlling spread of glue.



Module electrical characterisation

- All electrical testing performed with generic FPGA boards.
- Fixed charge injection via internal capacitor
- Basis of defect classification



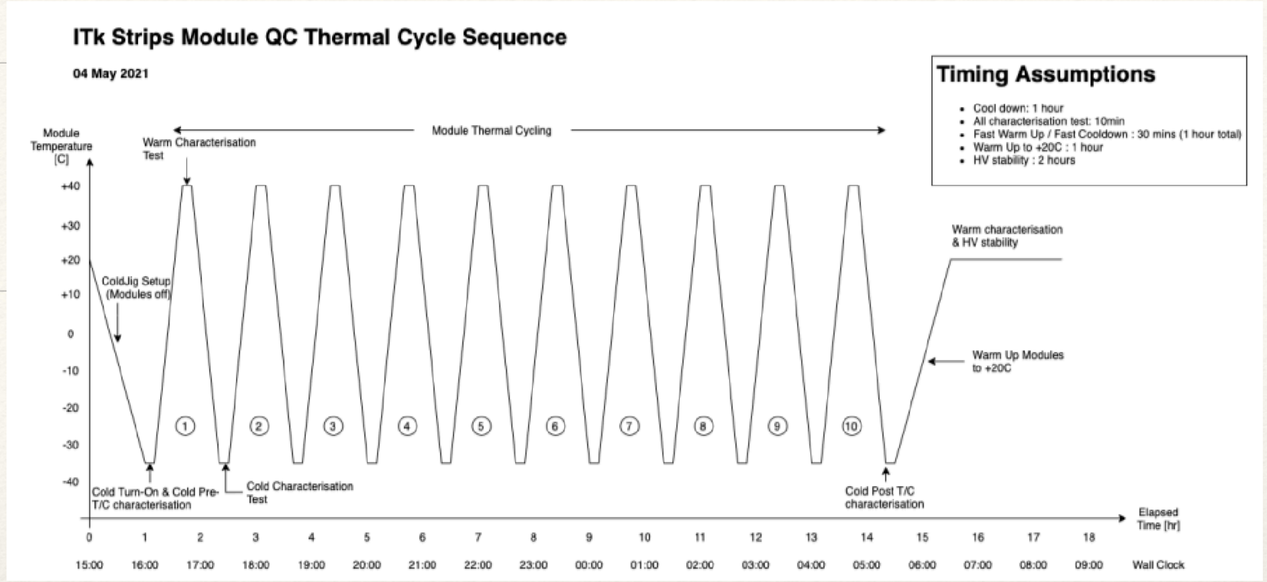


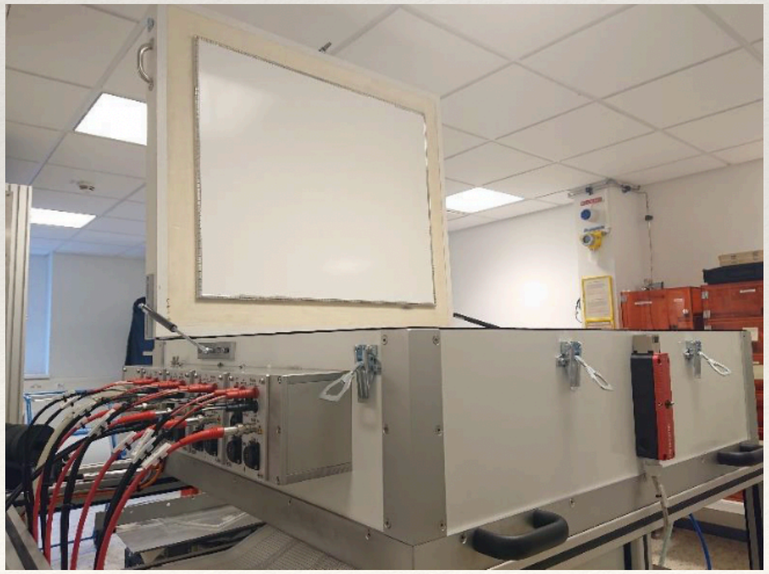
Melbourne

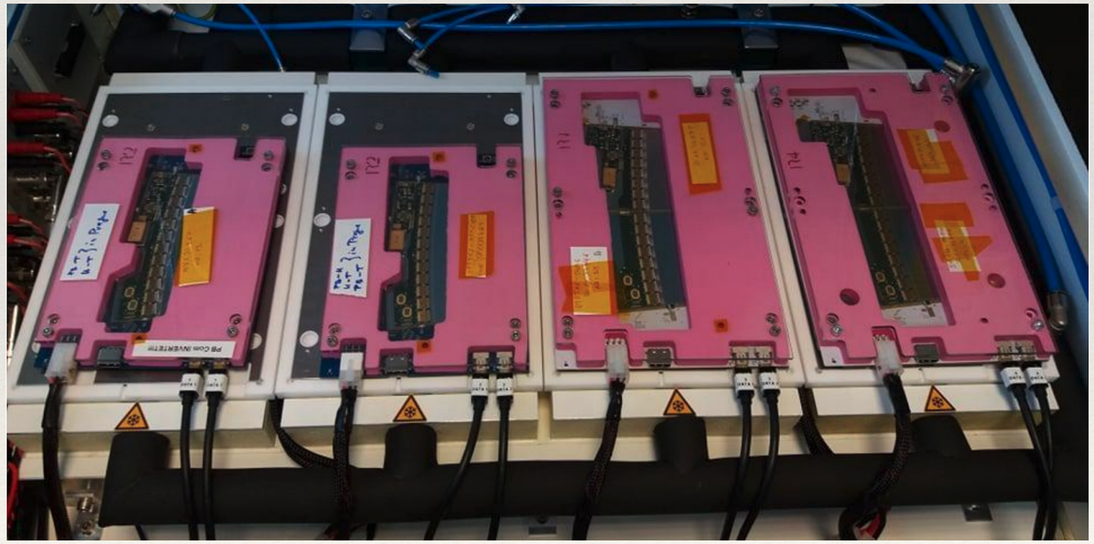
Adelaide

Module QC

- Every module stress tested prior to installation.
- Modules thermally cycled from $-35°C$ to $40°C$
- I-V and readout tests performed at key stages during cycle.







Future outlook

- Prototyping stage to conclude in the coming weeks — lab “qualified” for module assembly.
- To begin pre-production (detector ready modules) early next year in time for test petal loading at U. Freiburg.
- Australia to produce 40 R1/R4 modules per year (2-3 year production run).