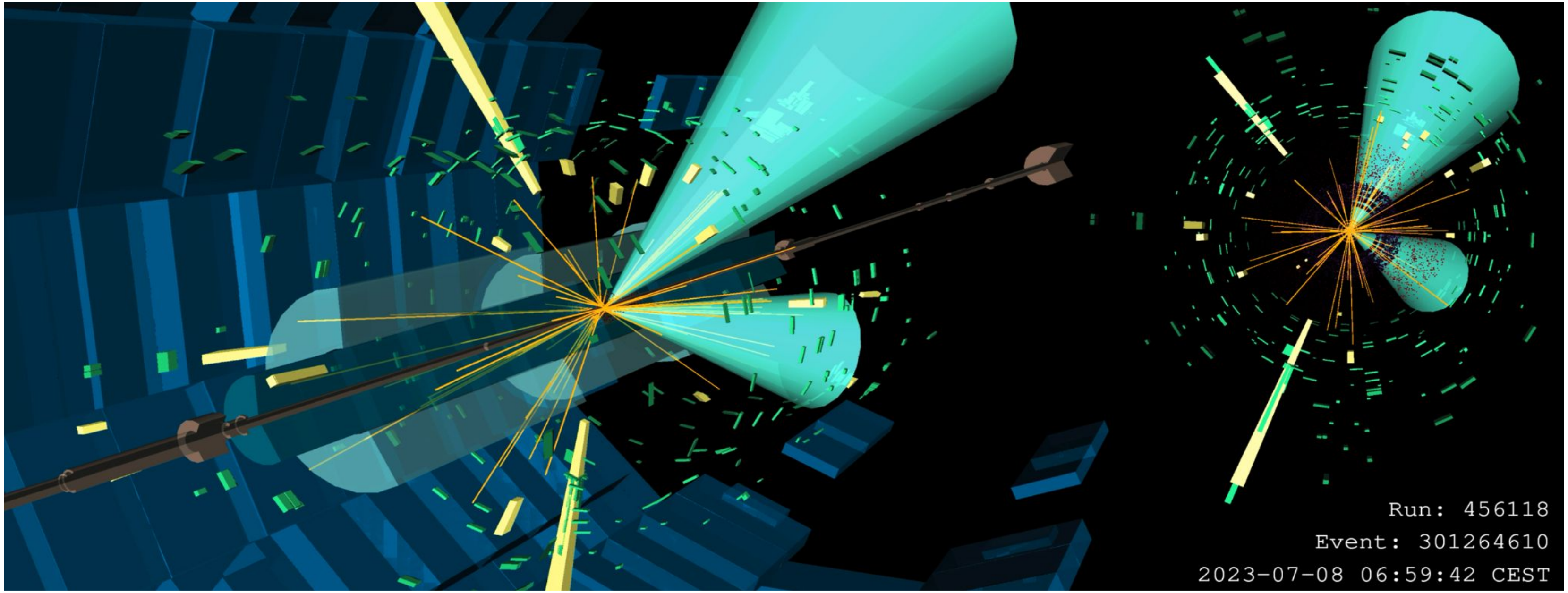
ATLAS Highlights

100th PRC meeting



Ludovica Aperio Bella on behalf of the DESY-ATLAS group

Hamburg, Nov 11th, 2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

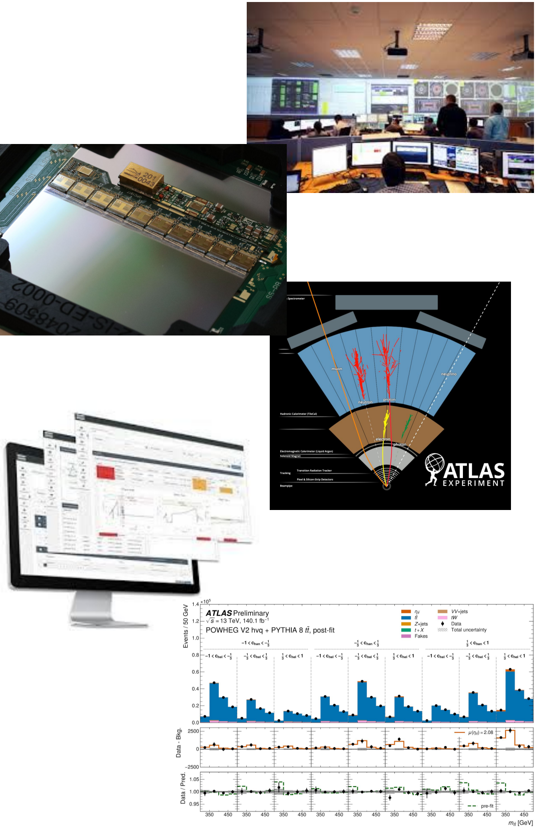
DESY.

DESY ATLAS group

Group outing (October 2025)

DESY ATLAS Group overview of the activities

Strong involvement in almost all the areas of the ATLAS collaboration



Detector operation, tools and software

Operation, monitoring and calibration of current detector (SCT)
Luminosity measurement

Detector upgrade - ITk

Design, test and assembly of future detector

Physics Object performance & reconstruction

b-tagging, electrons, photons and forward protons
Tracking for current and upgraded detector

Software and Computing

Monte Carlo software and production, data reprocessing and physics and pileup modelling.

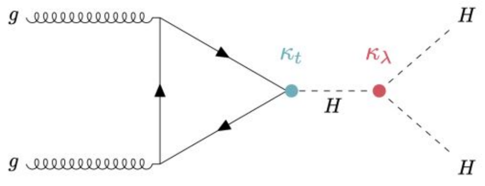
Data analysis

From SM precision measurements to searches for new phenomena

DESY group cover several **leadership roles**: Computing coordinator ; Deputy ITk Strips project leader ; Physics-Coordinator & many more

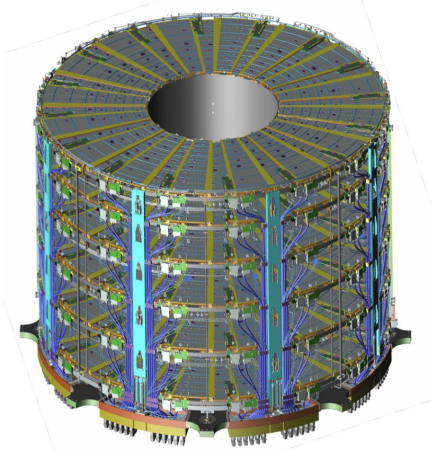
Highlights TODAY

Study of ***Higgs boson pair production*** *in the HH→ bbγγ final state with 308 fb-1 of data collected at √s = 13 TeV and 13.6 TeV by the ATLAS experiment*

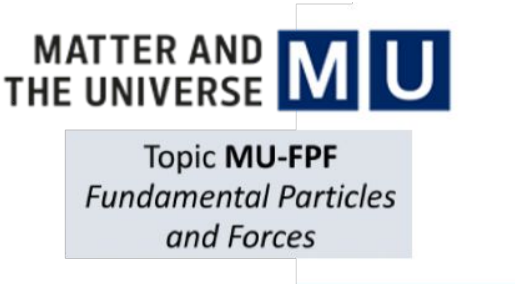


e-print arXiv:2507.03495

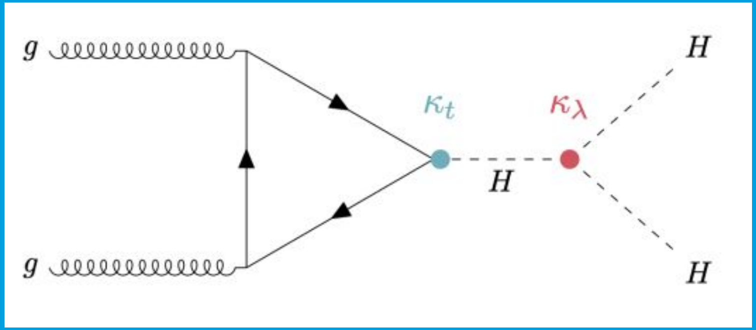
Status of the ATLAS detector ***ITk*** *end-cap upgrade*



ATLAS ***PoF-V*** *strategy proposal*



Study of Higgs boson pair production in the HH→ $b b\gamma\gamma$ final state with 308 fb^{-1} of data collected at $\sqrt{s}$ = 13 TeV and 13.6 TeV by the ATLAS experiment

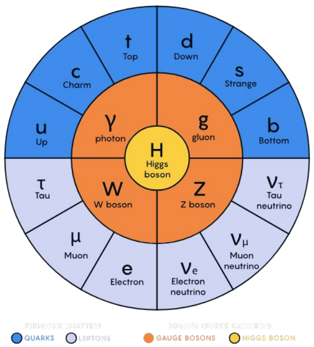


arXiv:2507.03495

Briefing

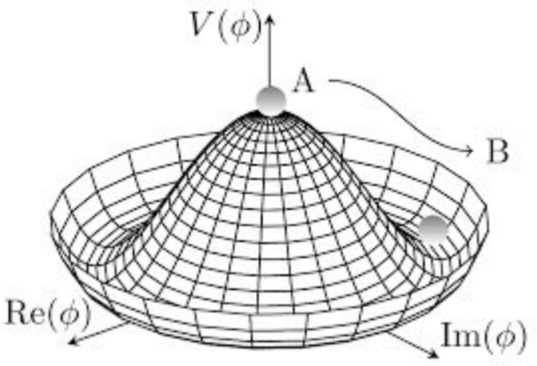
Why chasing double Higgs decay ?

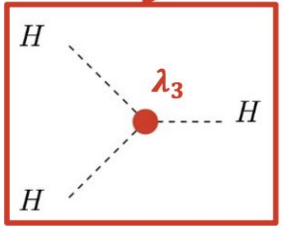
The Higgs potential and the stability of our Universe

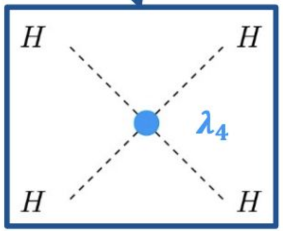


- The Standard Model has been explored and probed at unprecedented levels of precision by LHC experiments.
  - At its core lies the scalar sector of the Higgs boson, responsible for electroweak symmetry breaking and mass generation

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4 \xrightarrow[V(\phi)\to V(h+v)]{\text{EWSB}} V(h) = \underbrace{\boxed{\frac{1}{2}m_H^2h^2}}_{\text{Mass term}} + \underbrace{\boxed{\lambda v h^3}}_{\text{Trilinear coupling}} + \underbrace{\boxed{\frac{1}{4}\lambda h^4}}_{\text{Quartic coupling}}$$





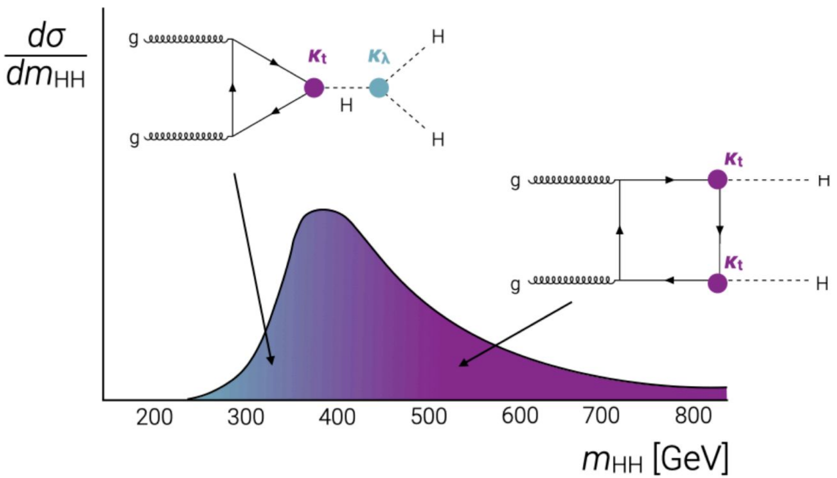


Higgs boson pair production at the LHC

HH→ bbγγ channel special feature

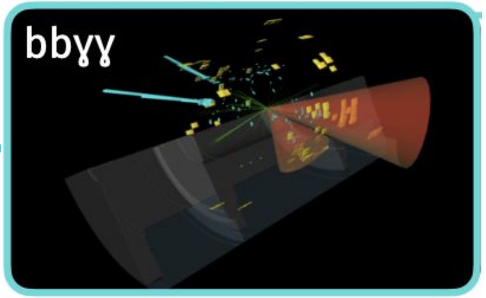
Gluon fusion (ggF)

$\sigma \approx 30.8\, fb\ @\ 13\, TeV$



H_1 →, H_2 ↓

BR	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%



- Non-resonant HH events from the self-interaction diagrams are close to threshold
    - special role of the **HH→ bbγγ** channel which allow to trigger on event with low-m_{HH}

New HH → bbγγ analysis

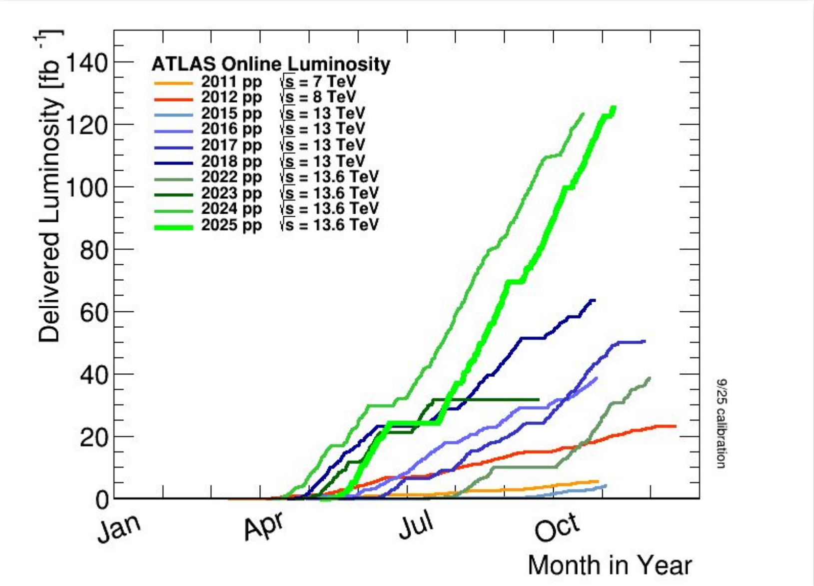
First Di-Higgs searches with Partial Run-3 dataset

1. **More data:**
   First ATLAS analysis with > 300 fb−1 of data
   (*Partial Run3 included 2002-2024*) [+50% impact on final results]

   - Higher **cross-section in Run 3**
     ~ 34 fb @ 13.6 TeV vs ~ 31 fb @ 13 TeV [+10%]

2. **Cutting edge Object performance:**
   Improved flavour tagging [+ 20% impact on final results]

   - New tagger **GN2** @ 85% b-efficiency WP
   - Previous tagger DL1r @ 77% b-efficiency
     [~ same bkg rejections]



140 fb^{-1} @13TeV Full Run-2
168 fb^{-1} @13.6TeV Run-3 ('22-'24)

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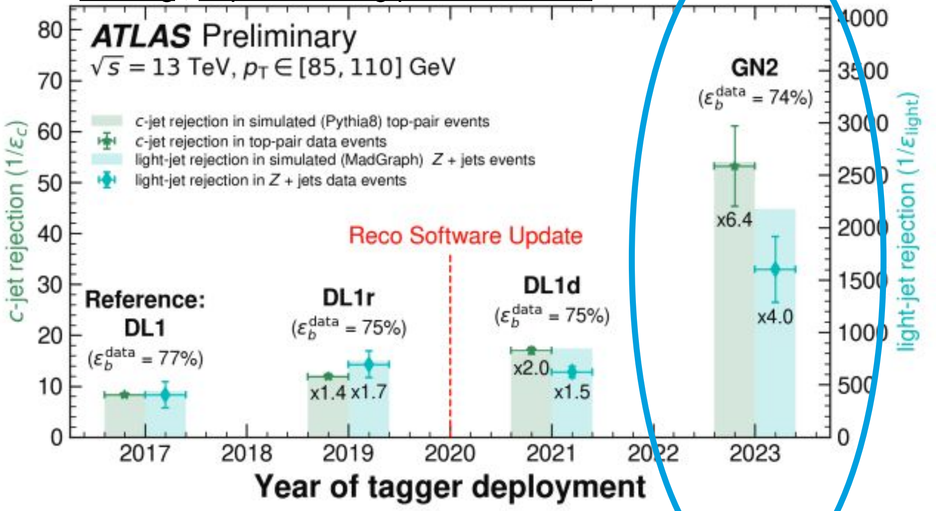
Briefing ; https://arxiv.org/pdf/2505.19689



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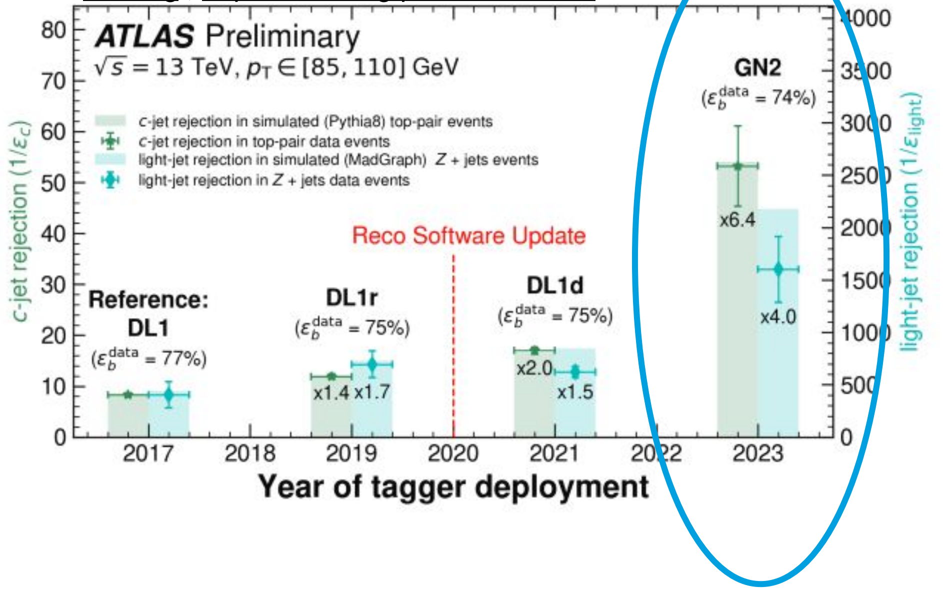
Strong DESY involvement in photon identification and b-tagging work connected with this analysis

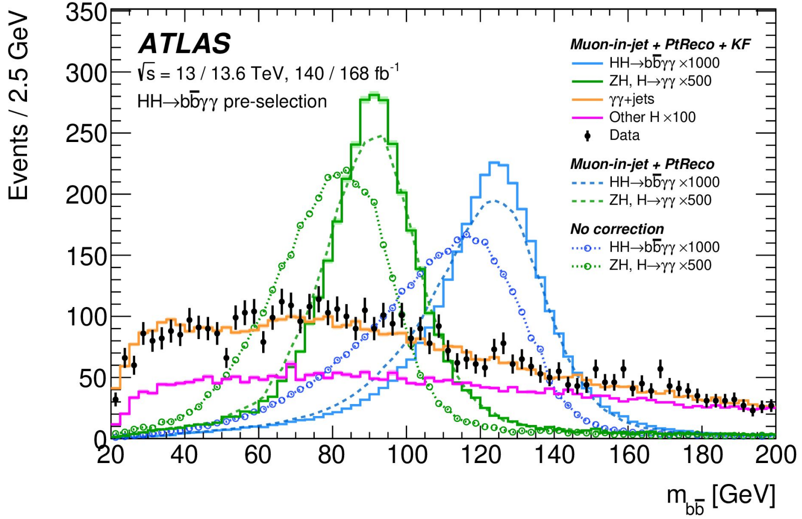
Briefing ; https://arxiv.org/pdf/2505.19689

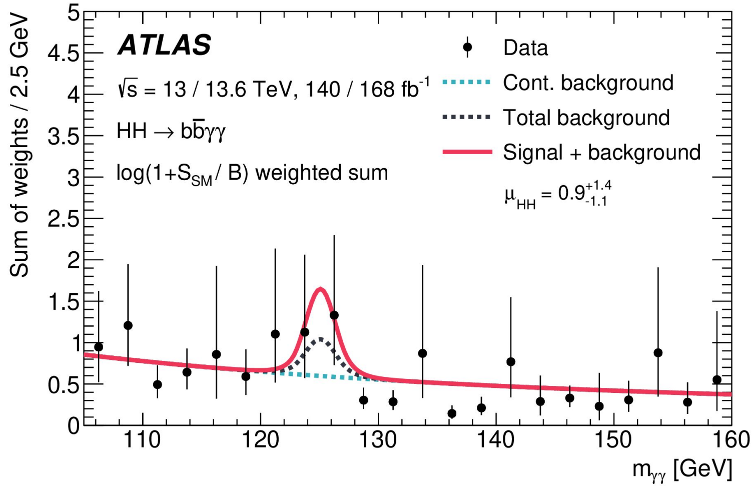


New HH → bbγγ analysis

First Di-Higgs searches with Partial Run-3 dataset

3. **More performant analysis strategy** [+15% impact on final results]
   - **Improved m_{bb} resolution** via a kinematic fit (p_T balance against the γγ-system)
   - **Training MVAs** to **optimize categories** in low-m_{HH} and high-m_{HH} regions

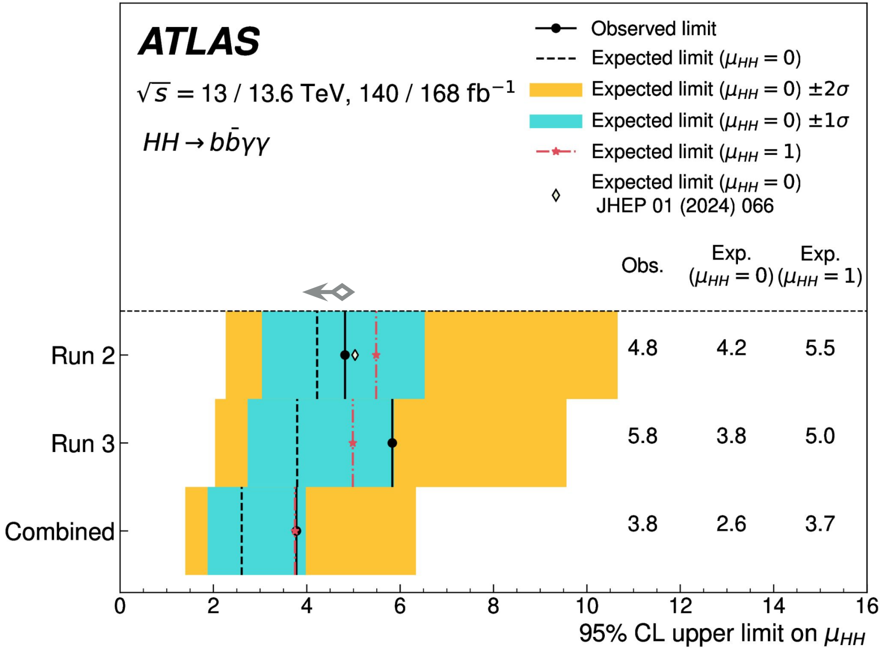




Unbinned fit to the di-photon spectrum to extract the HH signal in different m_{HH} and signal / bkg purity categories

New HH → bbγγ

Result as sensitive as Run 2 combination

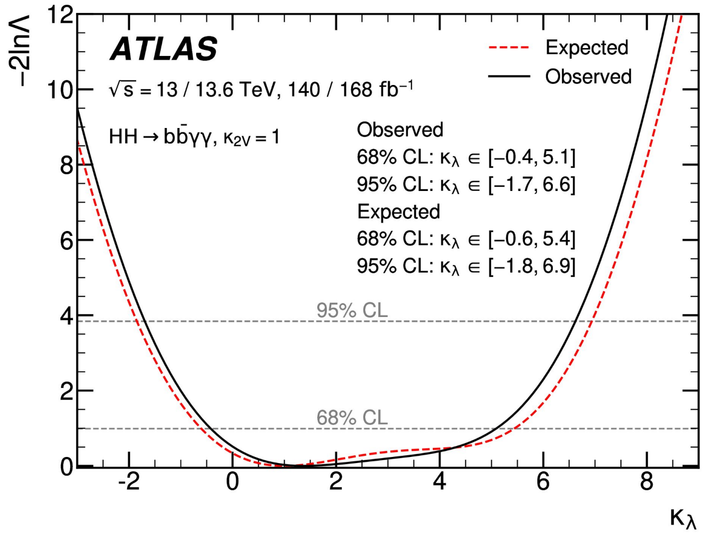


Results:

Signal strengths $\mu_{HH} = 0.9^{+1.4}_{-1.1}$ (exp. $1.^{+1.3}_{-1.0}$).

Constraints on the Higgs boson self-coupling k_λ at the same level of FullRun 2 HH-combination:

$-1.7 < k_\lambda < 6.6$ (95% C.L.)

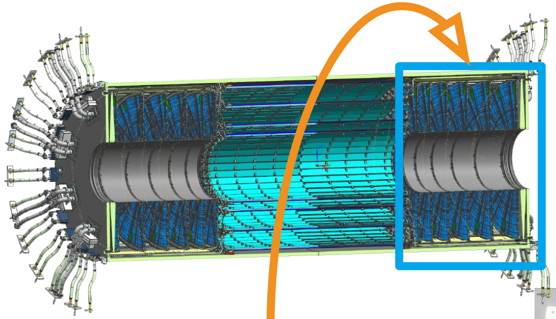


ATLAS detector upgrade Inner Tracker (ITk)

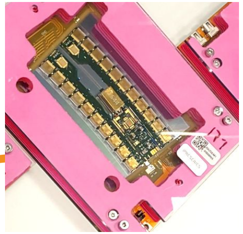
end-cap

ATLAS Detector Upgrade - Inner Tracker (ITk) for the HL-LHC

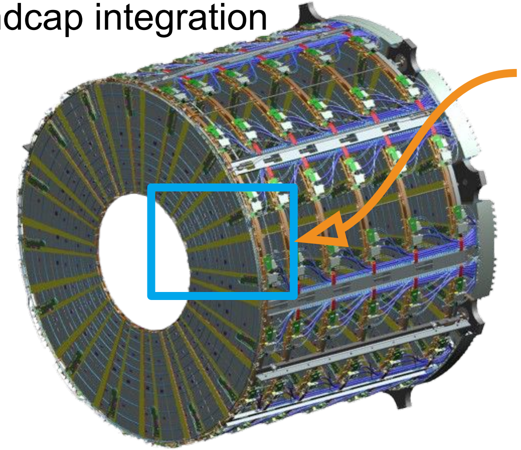
Huge DESY endeavor: responsible for building one ITk end-cap & more

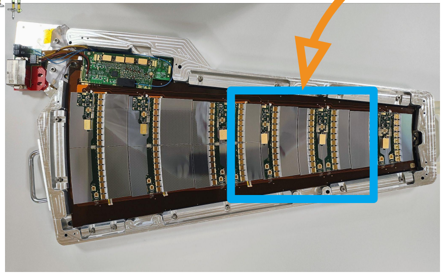


Module building



Endcap integration





Petal Loading

Latest highlights :

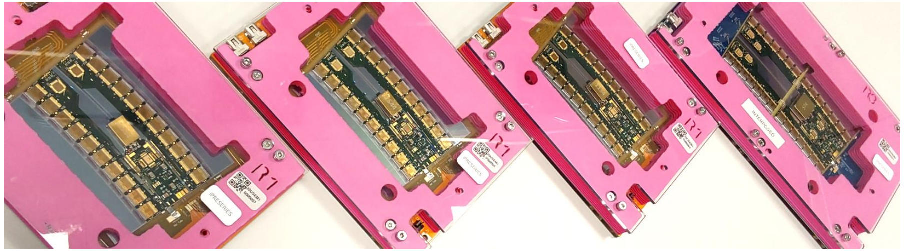
- Started module production both sites meeting nominal 50% production rate
- Established as main hybrid array interposing site
- Produced two petals (module loading)
- Core production on track (40% reached)
- End of substructure (EoS) board production re-initiated (after solving issue with the readout electronics)
- DAF and end-cap ready for integration

Module building and Hybrid Array Interposing

Module Pre Series production has started (both in Zeuthen and Hamburg site)

- More than 40 modules built of all types
- DESY-driven effort that will benefit the entire collaboration:
  - Quality control of Modules via temperature cycling
  - Powerboard wire bonding

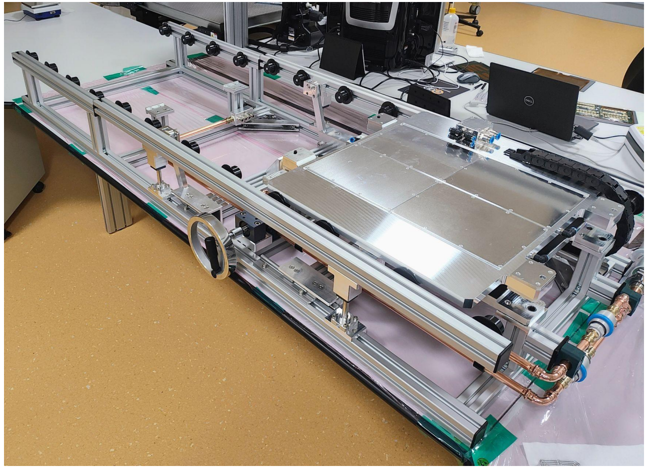
bPol-custom radiation-hard voltage converter used on <u>all ITk Strips modules</u>.
- Potential issue under specific conditions (gamma-irradiated and cold).
- Main current concern — closely monitored for all LHC upgrades.



Hybrid array interposing

- Required step for solving cracking-issue
- Fully operational now at DESY (~40–50 arrays/month)
- Interposing process is recently transfer to industry partner underway

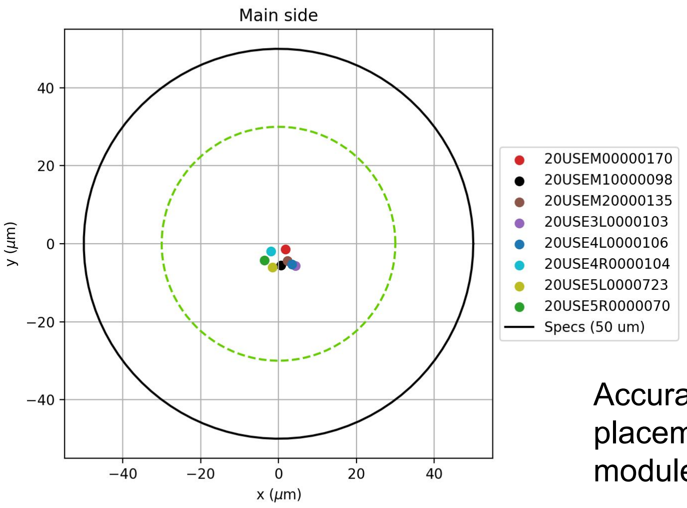
Interposing tool developed by DESY



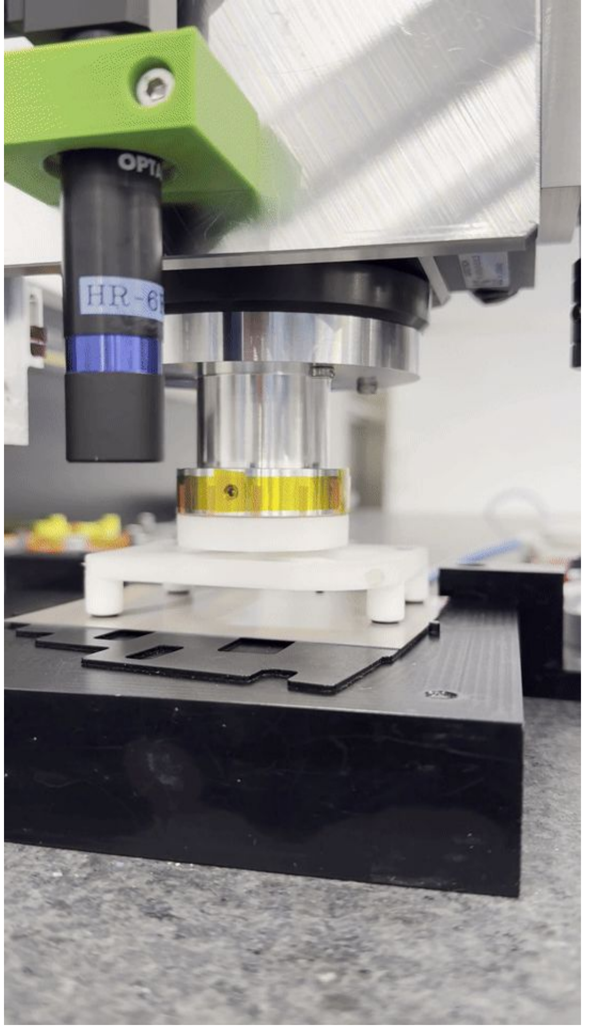
Module loading

Production has started!

- Final preparations for production completed (including Gluing routine and Testing)
- Loading of the first two pre-series petals at DESY
  - Excellent accuracy of module placement (< 10 µm)
- First thermal cycle (to -35°C) of first pre-series petal
  - Overall, very good electrical results!



Accuracy of the placement of the modules < 10 µm



Integration of the Full End-cap

Preparation for the petal insertion and cold tests

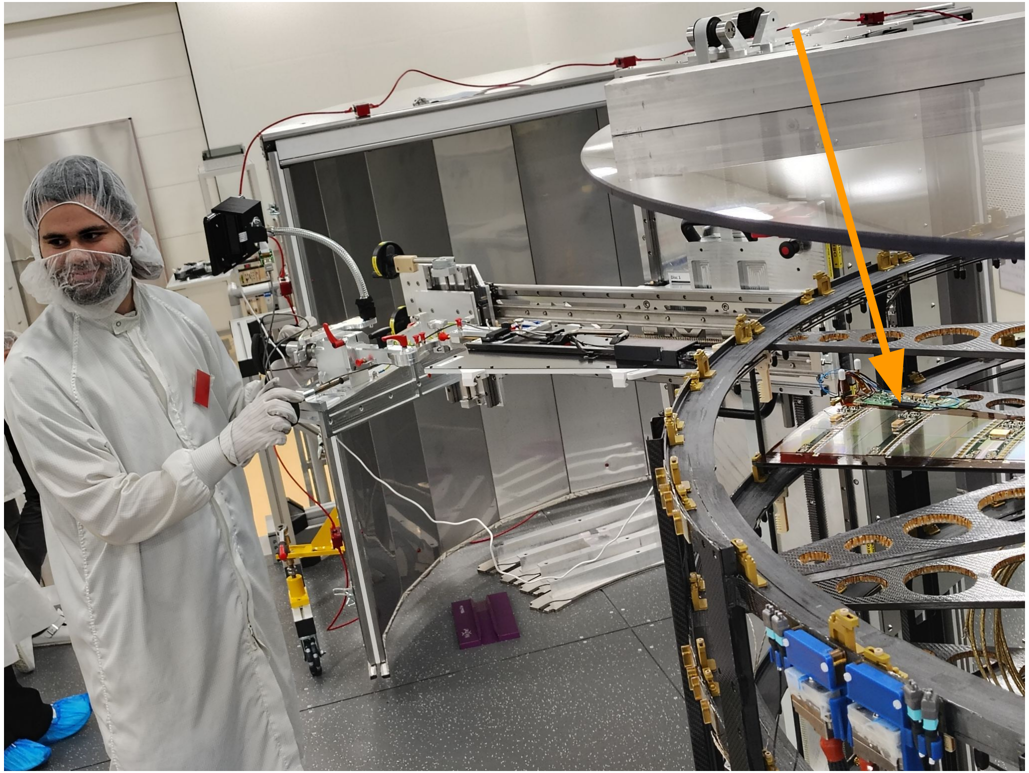
Large mechanics

- Global structure being prepared for petal insertion and cold testing
- Large mechanics in place (access/insertion platforms, thermal enclosure insertion, tower)

Tooling

- Finalisation of tools for petal insertion, welding, pipe bending
- Installation of the first Service Module successful
- First real petal inserted → ***huge milestone***

First real petal inserted!



ATLAS PoF-V strategy proposal:

Matter and the Universe (MU)

Helmholtz *Matter*

MATTER AND THE UNIVERSE MU

Topic **MU-FPF**
Fundamental Particles and Forces

Fundamental Interactions
Pushing the limits of our under-standing of fundamental interactions

- EW precision and Higgs physics (HH, H potential)
- SF QED
- QCD (incl. lattice and QC)
- Probing SM extensions

The Origin of Mass
Covering the puzzle of the origin of mass and of flavour, and the imbalance between matter and ant-matter in the universe

- EWSB
- Higgs portal
- Top, beauty, tau physics
- CPV
- LFU

The Early Universe
Exploring the evolution of the early universe and the nature of the dark sector

- Cosmology (inflation, ...)
- DM searches (WIMPs, axions, ALPs, ...)
- GW
- EW phase transitions

POF-V : next founding period from 2027-2034

Expected Luminosity for ATLAS physics program
Full Run-3 ($\mathcal{L}$ ~ 500 fb^{-1})
+ early HL-LHC ($\mathcal{L}$ ~ 1 ab^{-1})

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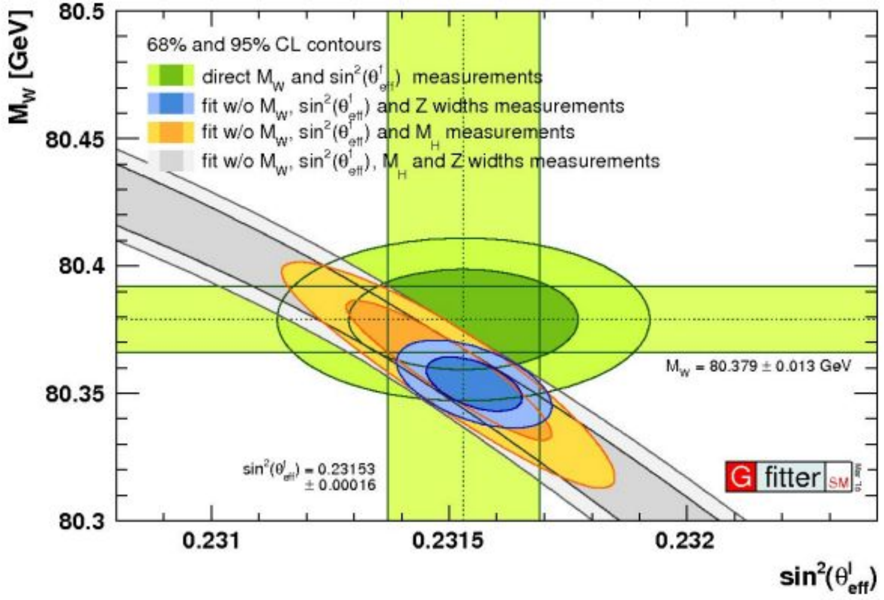
- Standard Model and forward physics
- Di-/tri-Higgs measurements and searches
- Anomaly detection
- Low-mass resonances

Highlight: SM precision

Over past decade, LHC has proven to be a powerful precision measurement machine

Test internal consistency of the Standard Model looking at the **Custodial symmetry** (protects SM fundamental parameters from large radiative corrections):

- W mass linked to top quark and Higgs masses
  - Sensitive to new particles in the loop
- Mixing angle determines relative strength of weak and electromagnetic forces



Key measurement targets:

- W boson mass in high and low pile-up conditions
- Running of electroweak mixing angle using $Z/\gamma^* \to ll$, especially in forward region

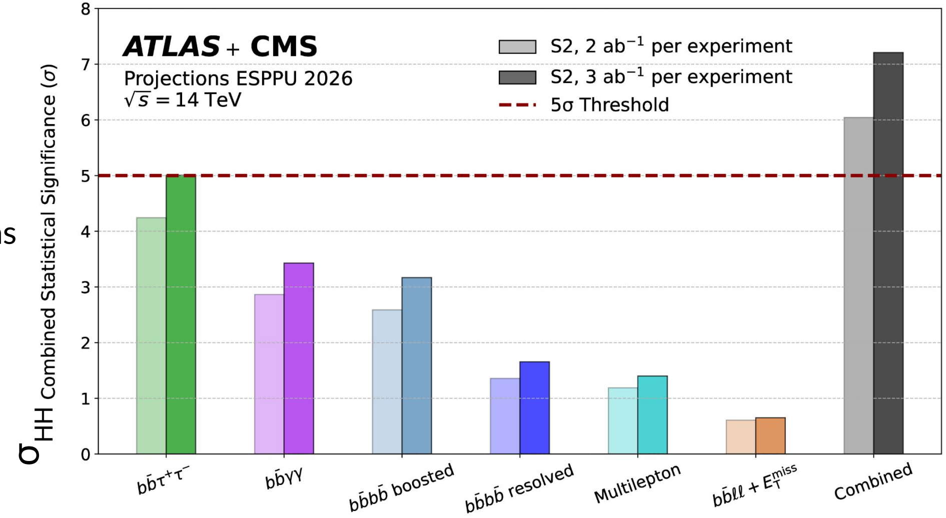
Highlight: Di-Higgs searches

Constraining the Higgs self-coupling is one of the primary physics goals of HL-LHC

Best way to get access to the **Higgs potential**

- Perform measurements in channels with expertise on object performance using the new data set
- Pursue channels that optimally span the full m_{HH} range
  - **bbbb**
    - Expertise on flavour and boosted Xbb tagging
    - Connections with tracking activities
  - **bbγγ**
    - Profit from e/γ experience
    - Connections with work on H->γγ
  - **Combinations**
    - ATLAS and ATLAS+CMS legacy combinations

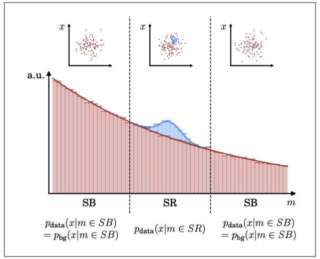
ATL-PHYS-PUB-2025-018



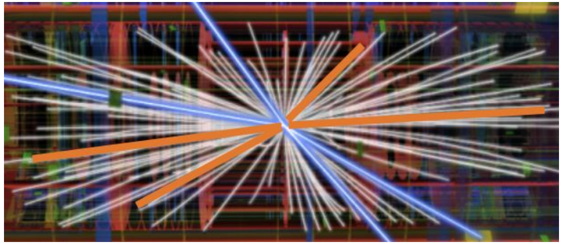
Highlight: Anomaly detection

Novel tools enabled by AI/ML, as well as the unique opportunities offered by the upgraded ATLAS detectors will be used to search for new particles

- Very large dataset will be exploited to perform *anomaly (= outliers)* detection tests aimed at identifying “unknown unknowns”
- Little-to-no guidance from new physics models.



CATHODE, UHH et al



ANOMALY DETECTION IN DATA (Resonance+X, Tracking-related signatures …)

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- Single-Higgs couplings (including CPV)
- Exotic Higgs boson decays
- Measurements with (multi-)top and rare top processes

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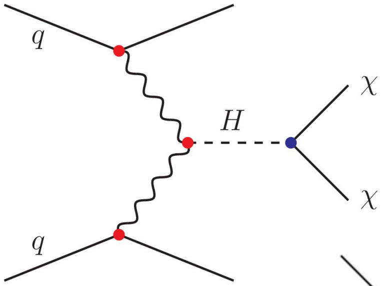
- EW phase transitions

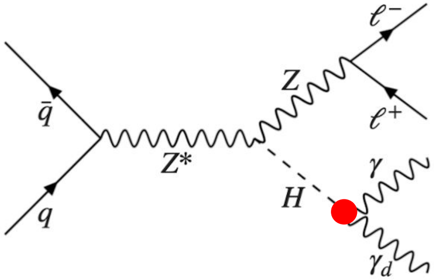
Highlight: Higgs decays to new particles

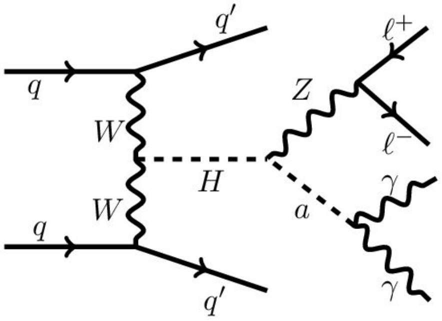
Exploiting the mass-depending coupling strength

- Higgs boson: only scalar particle in the SM with **mass-dependent couplings** strength.
  - Possible "**portal**" to new or dark-sector particles.

- Detailed studies focus on:
  - Invisible decays
  - Exotic decays
  - Modified couplings to SM particles







Highlight: top quarks to search and measure

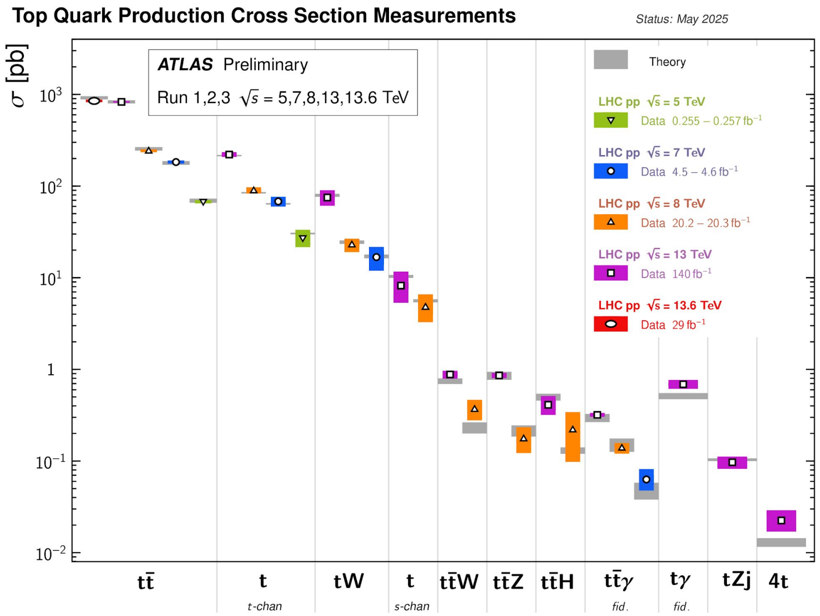
Leverage synergies between searches and measurements

Precision measurements of $t\bar{t}$ final state probing:

- Quantum effects (close to $t\bar{t}$ threshold and in boosted top quarks)
- Non-relativistic QCD (quasi-bound states - toponium)

Interference searches

- Unique sensitivity to BSM Higgs at high masses or ALPs at the GeV scale



Leverage synergies between searches and measurements from $t\bar{t}$ to rare (multi-)top processes

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- EW phase transitions

- ALPs / Supersymmetry searches
- Minimal dark matter searches

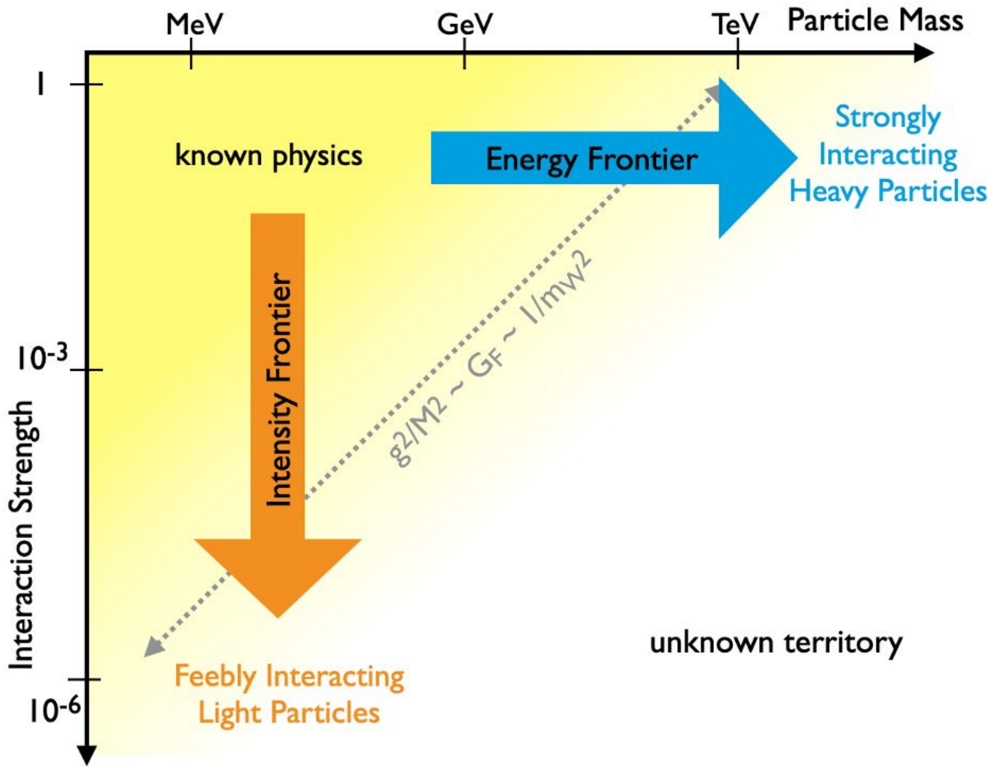
Highlight: several probes for dark matter

Hints for dark matter particles in the LHC data will be sought in prompt and long-lived scenarios

Broad search programme spanning across mass and lifetime in model-driven phase space

- ALP searches (coupled to tops, Z …)

- High-mass WIMPs exploiting also unconventional signatures (disappearing tracks, delayed showers, …)



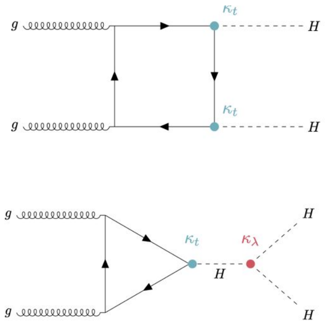
Summary

DESY ATLAS Highlights

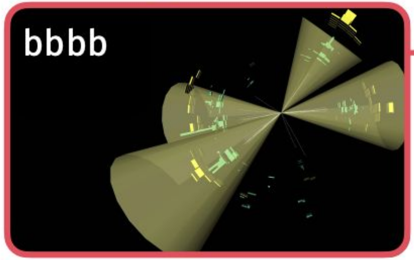
- Strong contributions to **detector operations, performance, and software/tool development**
- **Leading role** in several high-impact **data analyses**, resulting in exciting new **results and publications**
- **Full commitment to the ATLAS upgrade**: delivery of a complete **ITk end-cap**
- **Group plans fully aligned** with the objectives of the **PoF-V proposal**

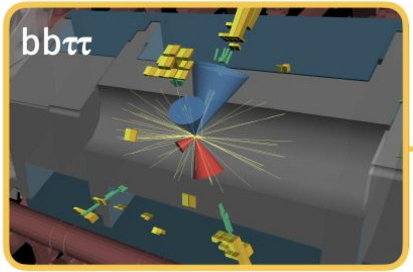
Higgs boson pair production at the LHC

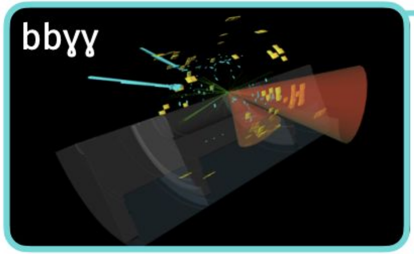
Very rich ATLAS HH program



Gluon fusion (ggF)
$\sigma \approx 30.8\, fb\ @\ 13\, TeV$



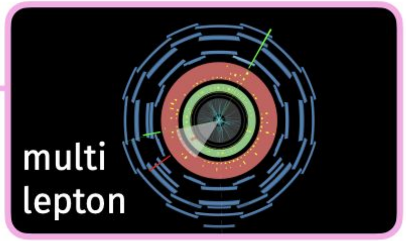


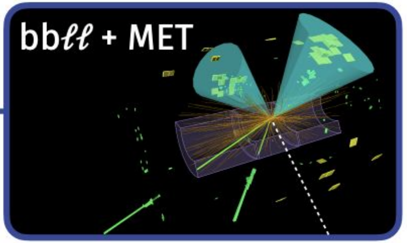


H_2 →, H_1 ↓

BRs	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%

HH branching ratios



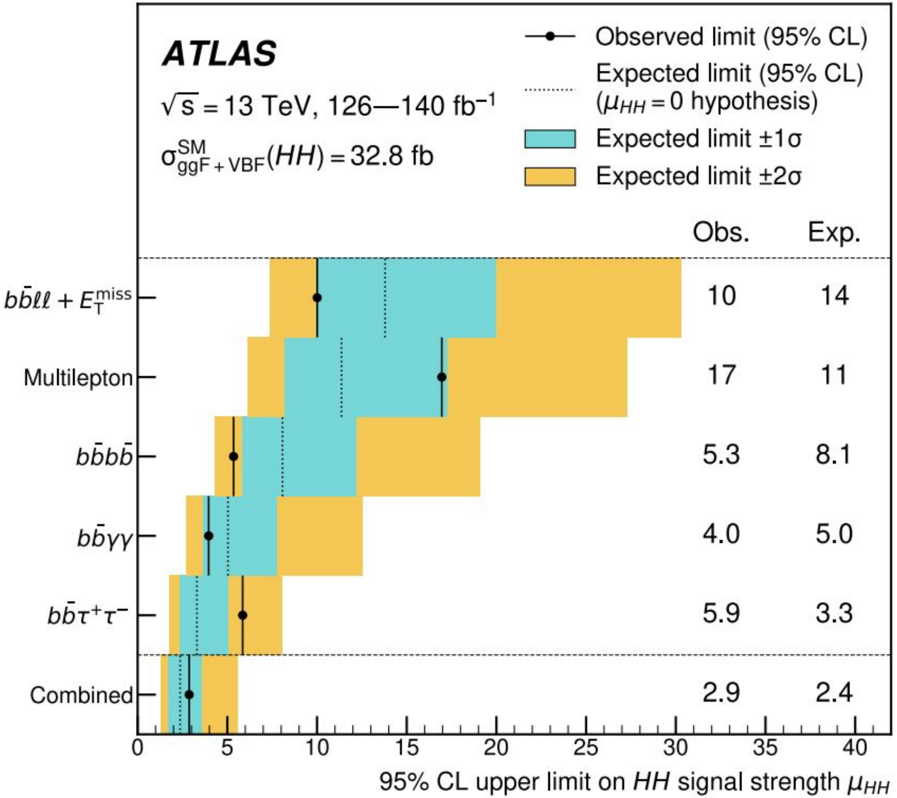


other searches

- bbℓνqq
  [JHEP 04 (2019) 092]
- VHH production
  [EPJC 83(2023)519]

Higgs boson pair production at the LHC

The ATLAS Run 2 Legacy HH Combination (arXiv:2406.09971)



bbττ has the best expected limit on μ_{HH}
→ observed limit worse due to an upwards fluctuation of data in the τ_{lep}-τ_{had} channel

bbγγ has the best observed limit on μ_{HH}

Smaller contribution from bbℓℓ+MET and multilepton channels

<u>Combined limit</u>:

μ_{HH} < 2.9 x SM @ the 95% confidence level

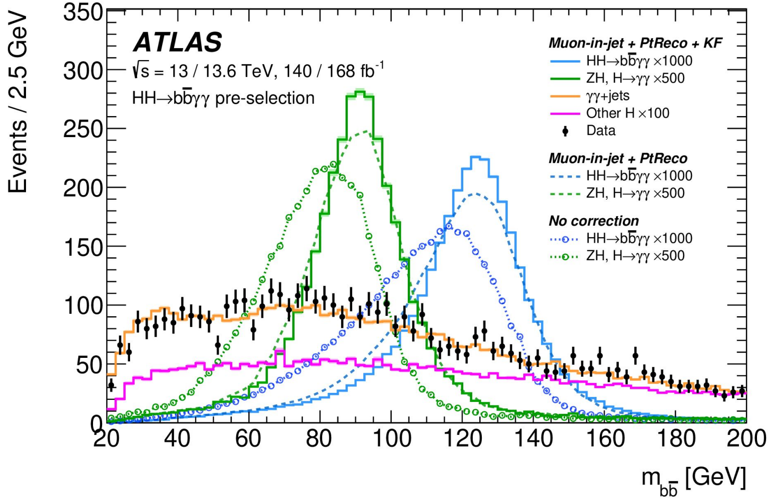
New HH → bbγγ analysis

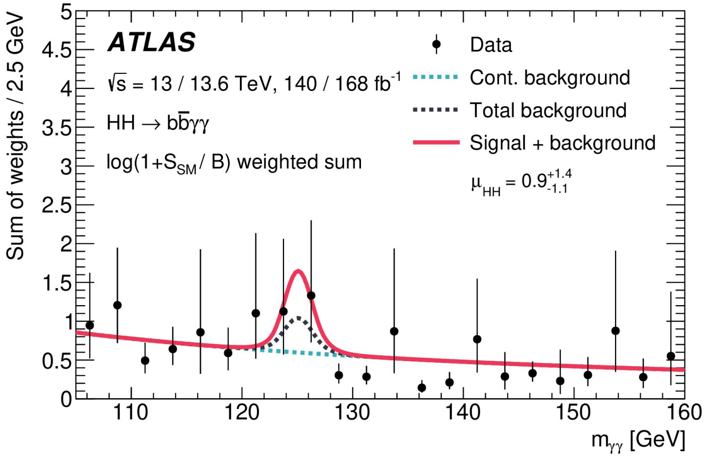
First Di-Higgs searches with Partial Run-3 dataset

1. **More data:** First ATLAS analysis with > 300 fb^{-1} dataset.
   Higher cross-section in Run 3
   ~ 34 fb @ 13.6 TeV vs ~ 31 fb @ 13 TeV [+10%]

2. **Bleeding edge Object performance:** *Improved flavour tagging*
   - New tagger @ 85% b-efficiency WP
   - Previous tagger @ 77% b-efficiency [~ same bkg rejections]

3. **Analysis improvements:**
   - **Improved m_{bb} resolution** via a kinematic fit, making use of the momentum balance against the γγ-system in the transverse plane
   - **Training MVAs** and **optimizing categories** simultaneously on Run 2 + Run 3



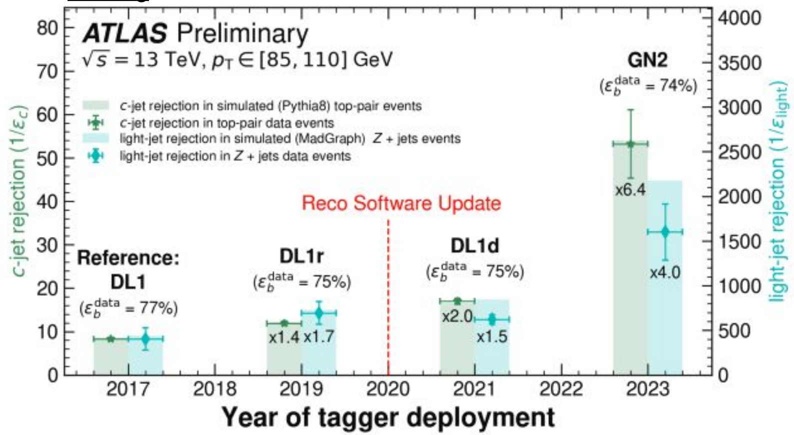


Role of the performance work

https://arxiv.org/pdf/2505.19689

b-tagging performance

Briefing



New flavor tag algorithm GN2 brings 20% improvement in the sensitivity on the HH → bbγγ analysis

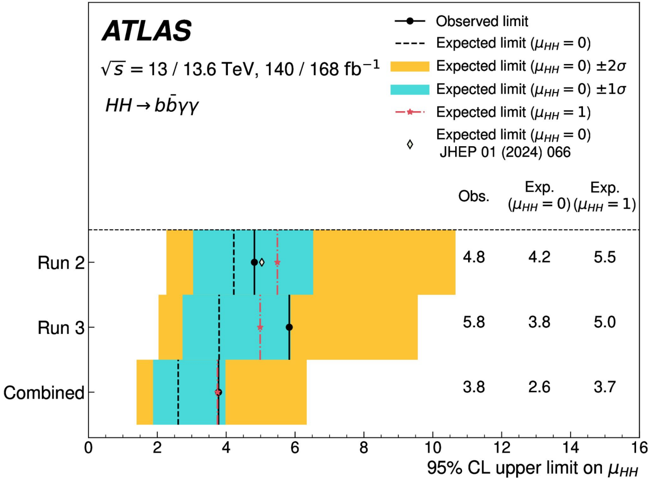
- Traditional approach (DL1r):
  - Uses low-level quantities derived from tracks
  - Followed by a high-level multivariate classifier for jet flavour identification.
- New approach (**GN2**):
  - Directly processes track and jet information using graph-based networks.
  - Incorporates auxiliary training objectives in addition to the main jet flavour separation task.These objectives aim to reconstruct the internal jet structure by grouping tracks from a common vertex.

New HH → bbγγ

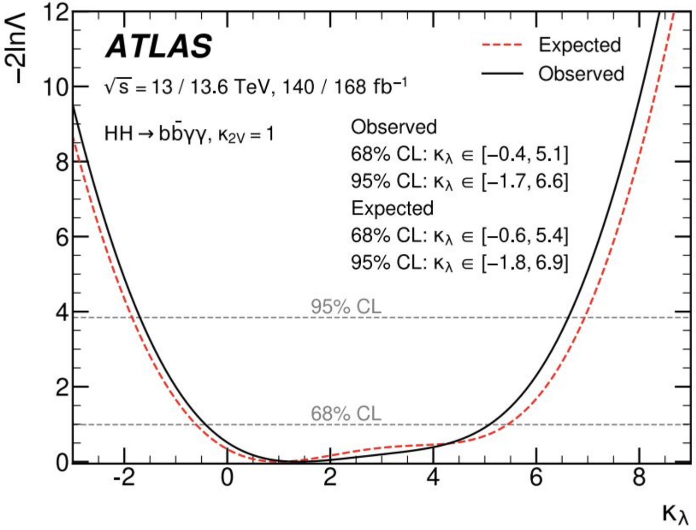
Result as sensitive as Run 2 combination

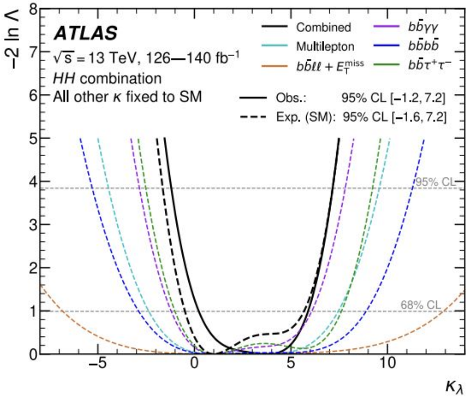
Unbinned fit to the di-photon spectrum to extract the HH signal in all 7 x 2 SRs [Run 2 + partial Run 3]

- Double-Sided-Crystal-Ball for Signal + single Higgs, exponential functions for γγ+jets background



$\kappa_\lambda \in$ [-1.7, 6.6] @ the 95% confidence level





As performant as the entire Run 2 Legacy HH combination

Results:
μ_{HH} = $0.9^{+1.4}_{-1.1}$ (exp. $1.^{+1.3}_{-1.0}$).
$-1.7 < k_\lambda < 6.6$ (95% C.L.)

Integration

Preparation for the petal insertion and cold tests

Large mechanics

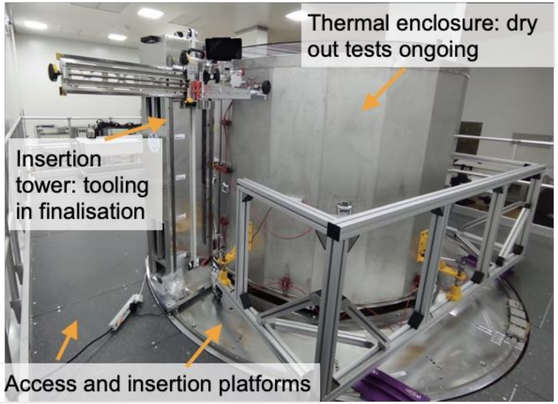
- Global structure being prepared
- Large mechanics in place (access/insertion platforms, thermal enclosure, insertion tower)
- LUCASZ CO_2 cooling in commissioning

Tooling

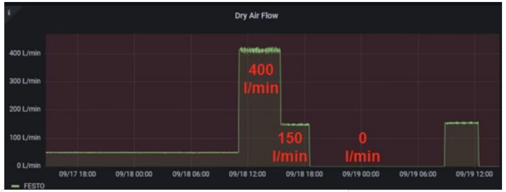
- Finalisation of tools for petal insertion, welding, pipe bending
- Welding tools developed at Nikhef
- Installation test of the first Service Module successful

Testing

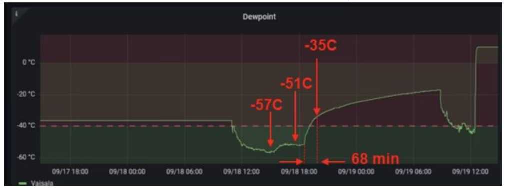
- Cold boxes for petal reception in preparation
- Dry out tests with the Thermal Enclosure ongoing
- EC integration workshop last week (3-5 November)




Installation test of the first Service Module



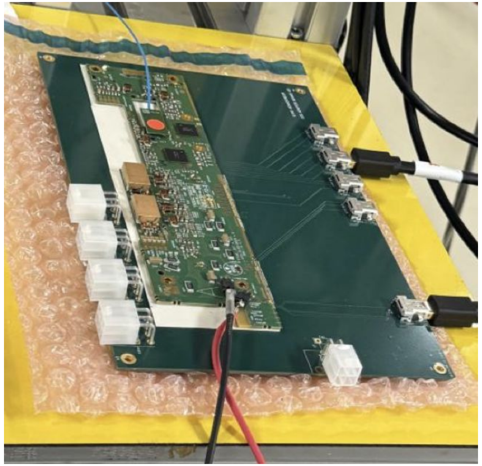
First dry out test



Testbeam

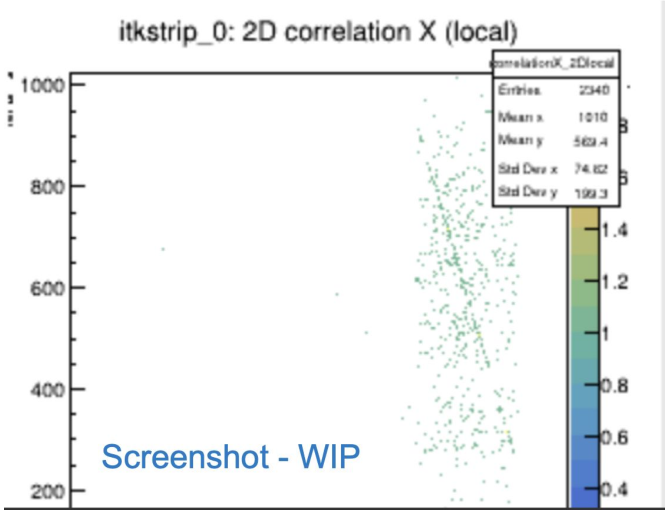
Towards running larger object test beams using official ATLAS DAQ

Successful test on the EoS adapter board



Transition to FELIX-based readout with a single module setup; ~12.5kHz trigger rate achieved with beam and beam profile visible.

Correlation with telescope data achieved;
But loose synchronisation early on due to the scrambled trigger ID;
Overall a good start!

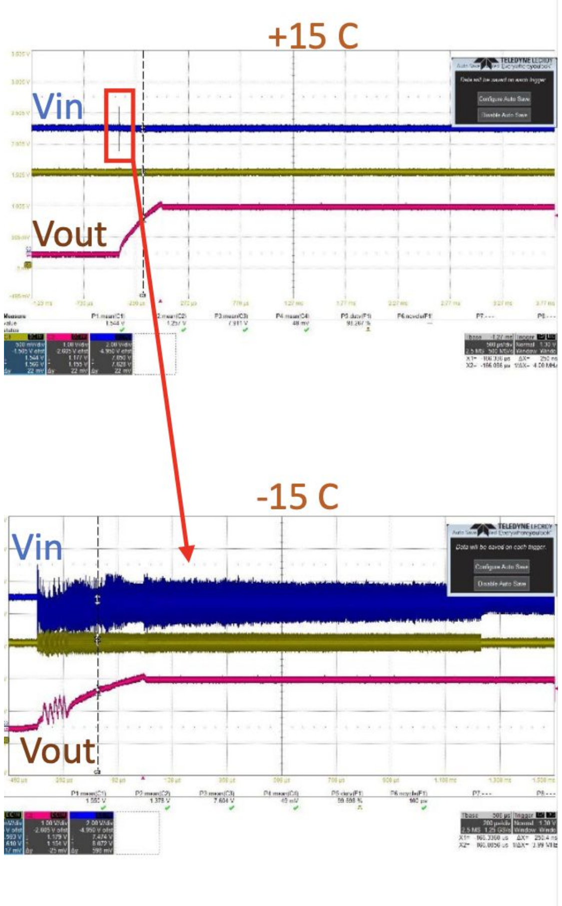


The bPol Issue

bPol-custom radiation-hard voltage converter used on every ITk Strips module.

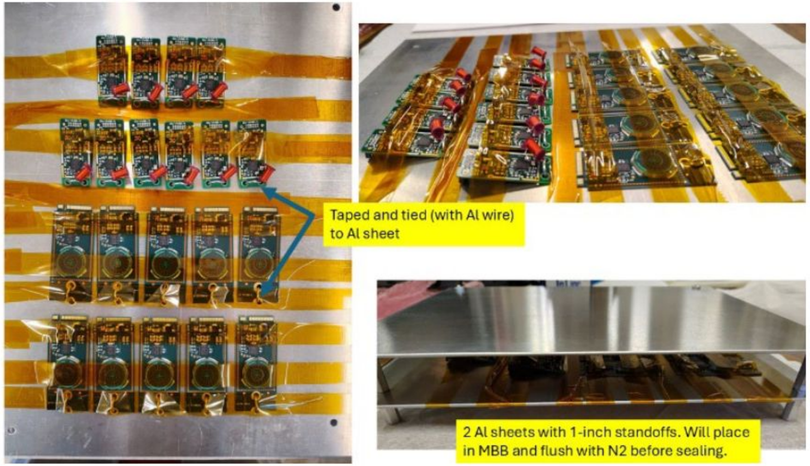
- Potential issue appears in full petal tests with repeated power-up under specific conditions (gamma-irradiated and cold).
  - Studies ongoing to assess risk vs. irradiation (dose, rate, etc.).
  - Exploring quick circuit-level fixes using current bPol design.
- Full chip redesign would cause major delays.
  - **Chip used across all HL-LHC experiments upgrades (~220k units).**
- High-priority issue; joint working group established.

Biggest issue right now - have to watch carefully to understand full implications at DESY



The bPol Issue

- Current efforts on ATLAS side:
- Study the details of the issue:
  - Re-testing previously irradiated modules
  - Checking (in parallel) the effect of circuit modifications
- Irradiation effects
  - Gamma-irradiating CERN circuits
  - Checking low-doses of 5 and 10 Mrad
  - Checking if can irradiate more board with protons



- Planning a more realistic radiation exposure: lower dose, cold, powered

Change in the schedule :

- This phenomenon could impact our plans.
- The current approach is to proceed with production of modules and staves/petals at measured pace while gaining new information quickly
- The powerboard production is essentially paused wrt bPOL loading
- Will continuously evaluate the risk balance in the near future

Biggest issue right now - have to watch carefully to understand full implications at DESY