Vista2030 - ATLAS

W. Verkerke

The Big Picture – our science mission

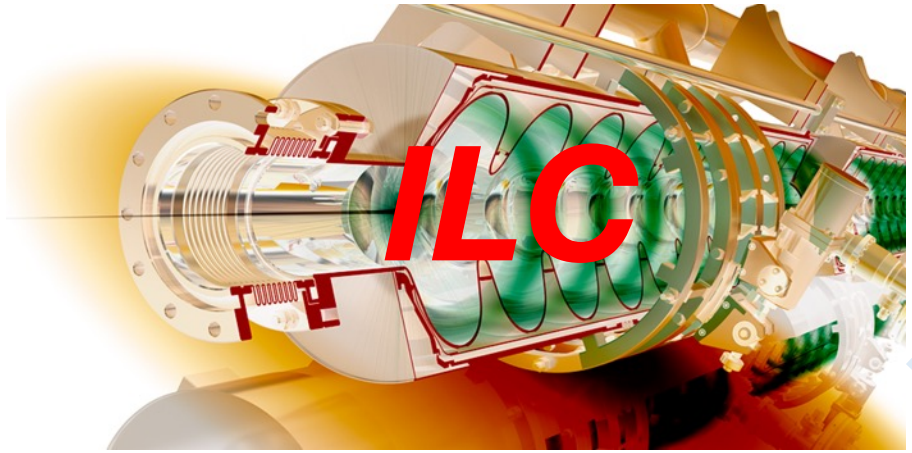
- SM describes most of what we see,
  but doesn't naturally explain all it describes

What is the origin of mass for fundamental particles?

- *Are there new symmetries, new physical laws?*
- *What explains the patterns we see in the SM?*
- *What is dark matter? How can we make it in the laboratory?*

Future colliders and the European PP strategy

European Strategy Update



Measure
properties of
known particles

Search
for new particles,

Future colliders and the European PP strategy

Measure:

European Strategy Update

ElectroWeak Symmetry breaking

h-V interaction

h-h interaction

V-V scattering

3V, 4V couplings

Vacuum Stability

m(top)

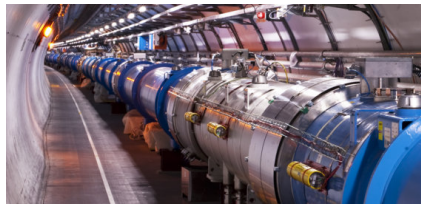
Origin of fermion masses

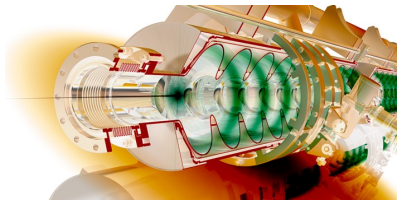
h-f interaction

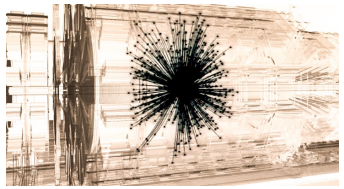
Couplings

rare and anomalous

Position of ATLAS in the science landscape







LHC Run-3 | HL-LHC | ILC/FCC-ee? | FCC-hh?

2021 2026 2040 2060

2025: 15M H, 120M tt, 30M ww/zz/wz

2032: x3.5

2040: x10

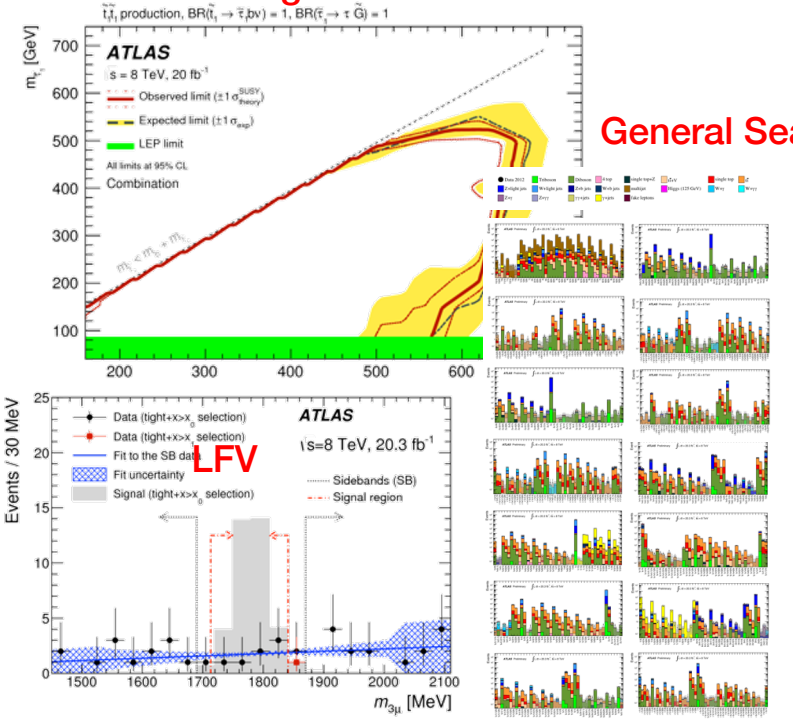
Lots and lots interesting data, and a well-functioning detector!

Doing extremely well harvesting the data

Search

for new particles,

3rd gen SUSY



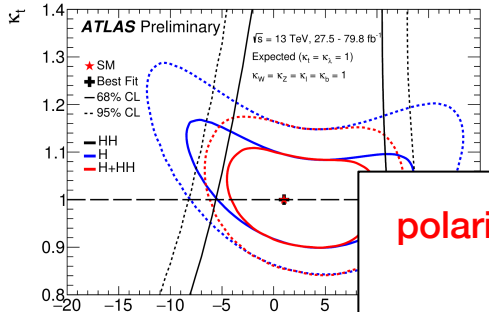
General Search

LFV

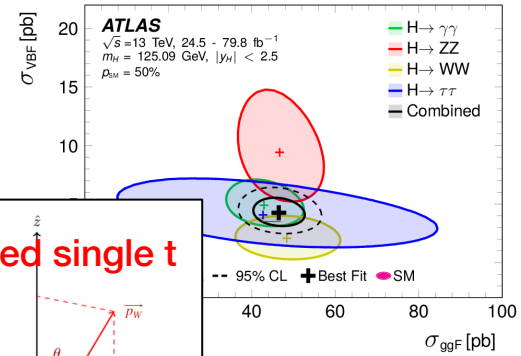
Measure

properties of known particles

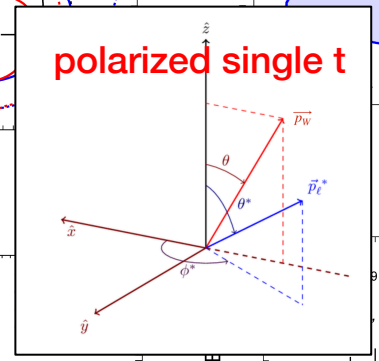
H self-coupling



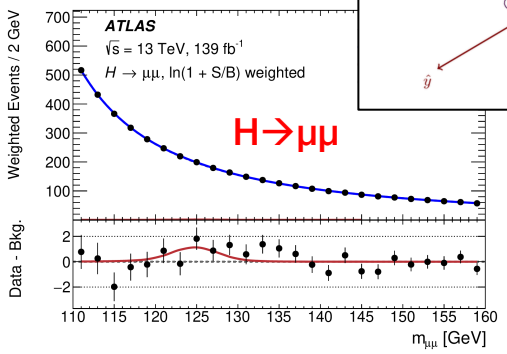
H properties



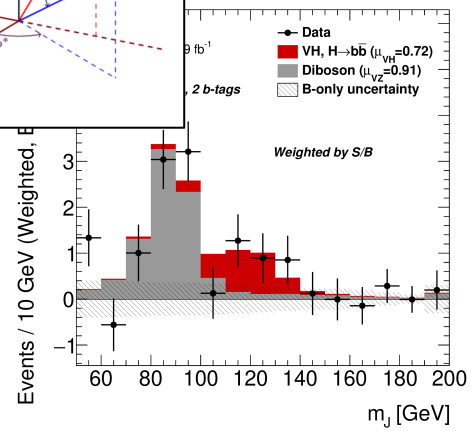
polarized single t



H→μμ



boosted VH→bb



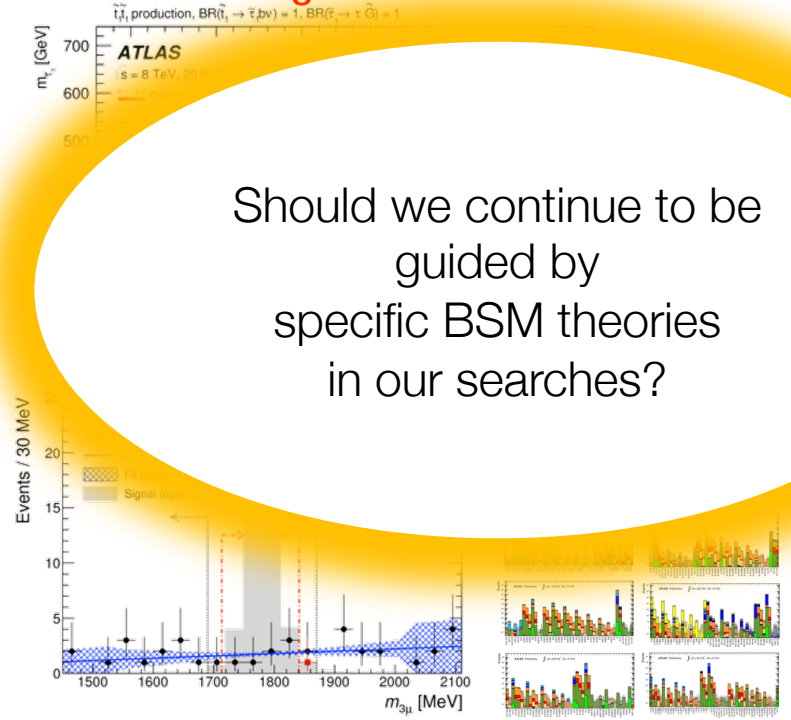
PhD Thesis on ATLAS Run 1+2
35 completed
22 in progress

Doing extremely well harvesting the data

Search

for new particles,

3rd gen SUSY

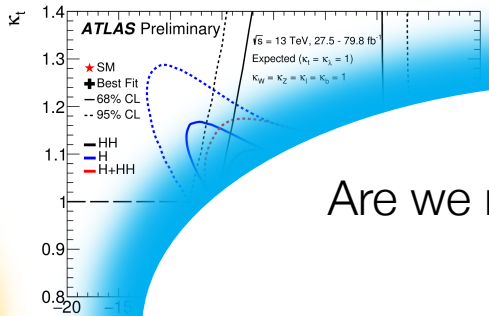


Should we continue to be guided by specific BSM theories in our searches?

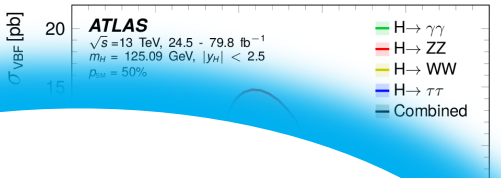
Measure

properties of known particles

H self-coupling

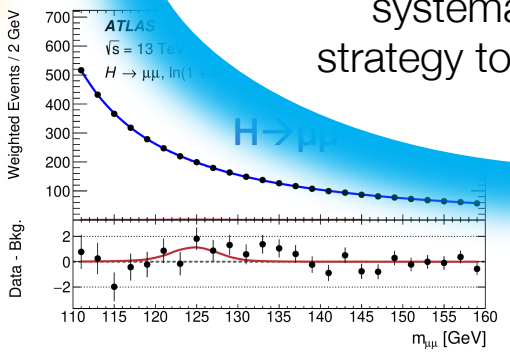


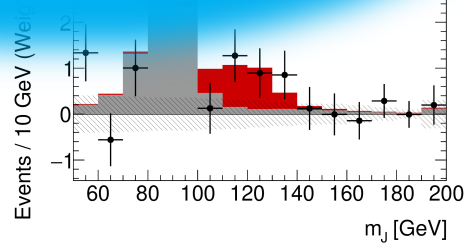
H properties



Are we measuring the right things?

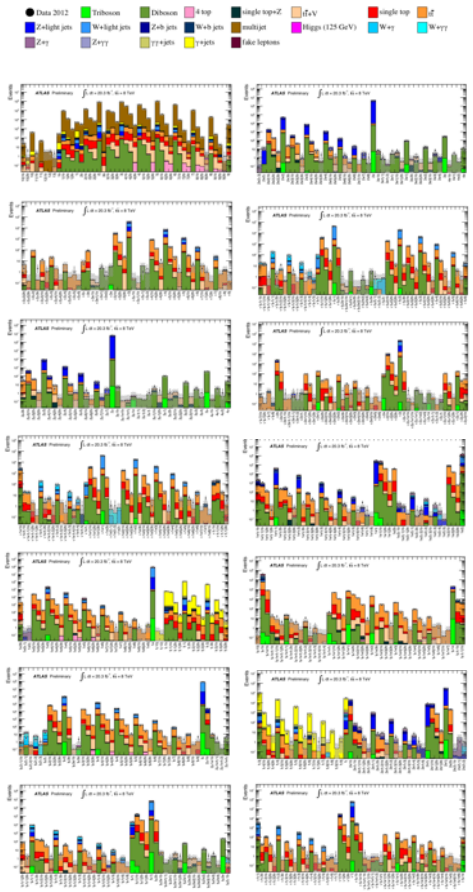
Do we have consistent, systematically improvable strategy to see effects of BSM?



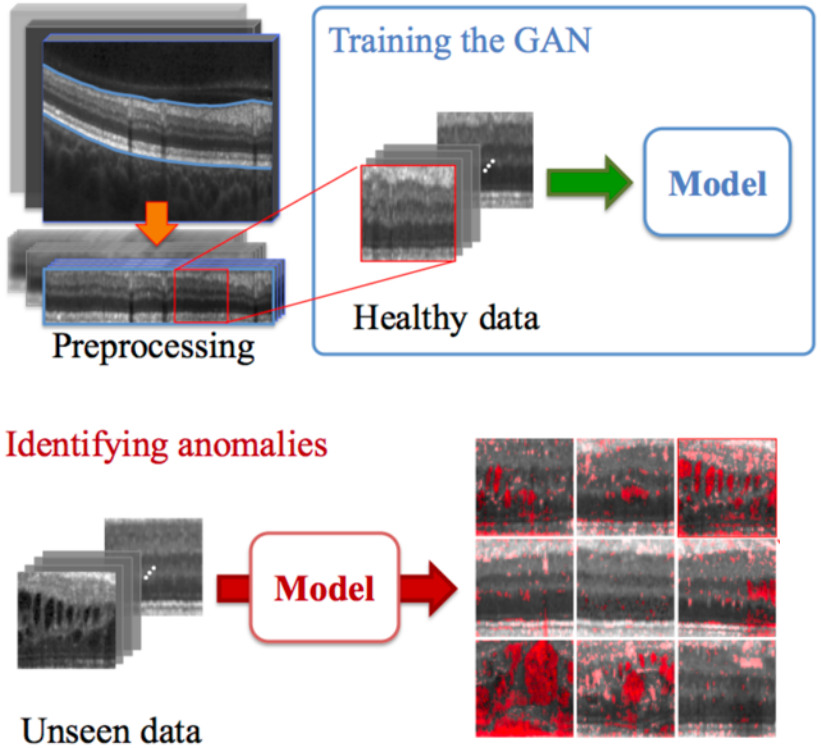


Looking forward: Searches – the methodology revolution

'*Look everywhere*'
for deviation from the SM
(General Search)

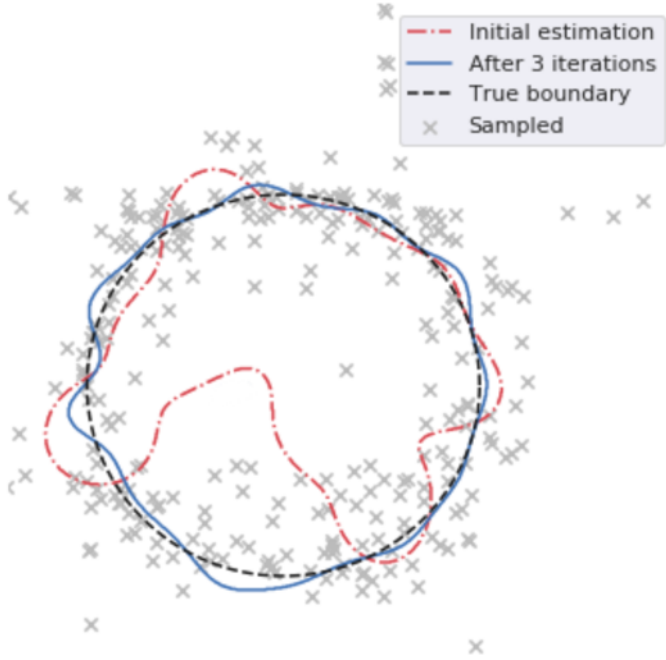


'*Unsupervised Anomaly Detection*'
Example: Generative Adversarial Networks
no model guidance needed



link with
Computer Science / Data Science

'*Active Learning*'
Self-learning approach
to highly non-trivial models
(e.g. non-simplified SUSY)



link with
Dark Matter / Astrophyics

Looking forward: Measurements – the methodology revolution

- Can the SM predict what new physics looks like at LHC?
- No, but SMEFT can!
  - If high energy NP must obey SM symmetries at LHC energies then it can only manifest itself in a finite number of ways

"SMEFT is the new SM"

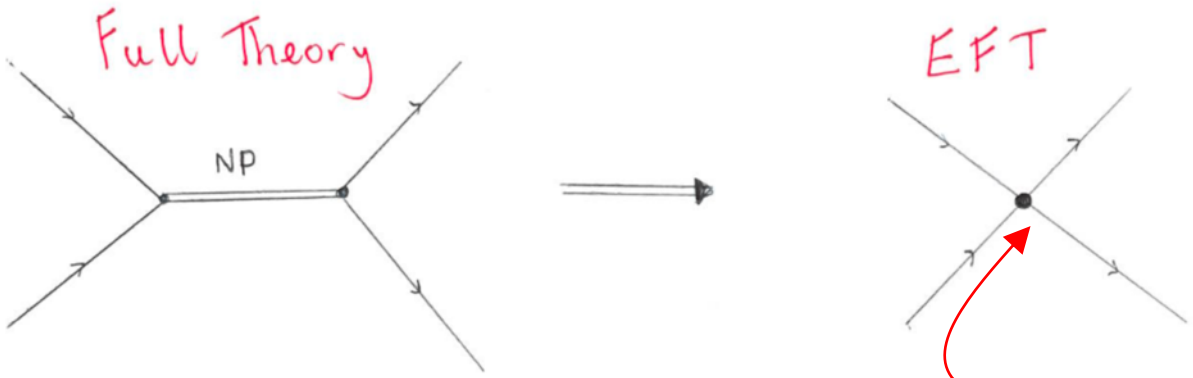
link with Nikhef Theory

Higgs

+

top

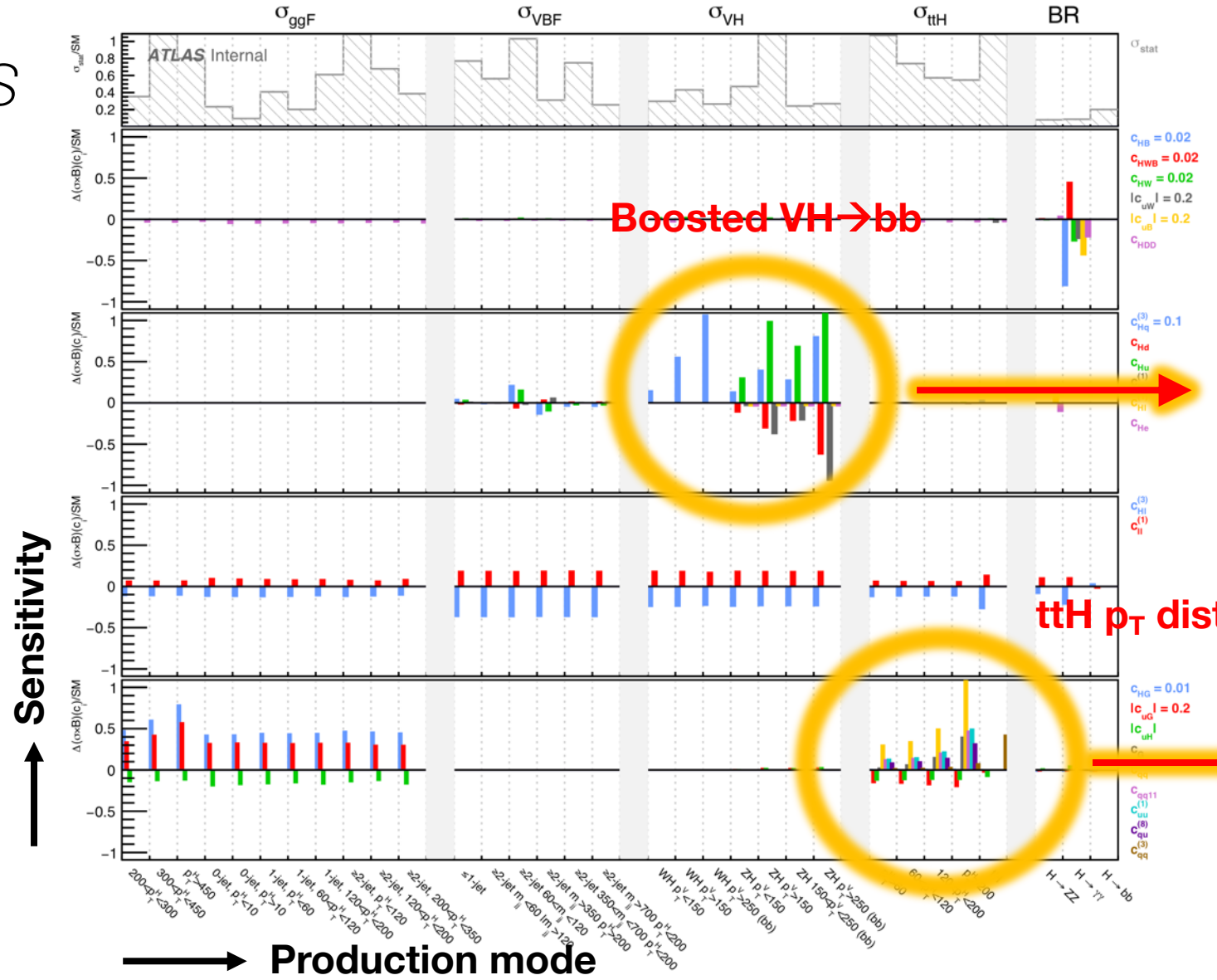
+



$$\mathcal{L} = L_{SM} + \sum \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \sum \frac{c_i}{\Lambda^4} \mathcal{O}_i^{d=8} + \ldots$$

Looking forward: Measurements – the methodology revolution

SMEFT is telling us where to look

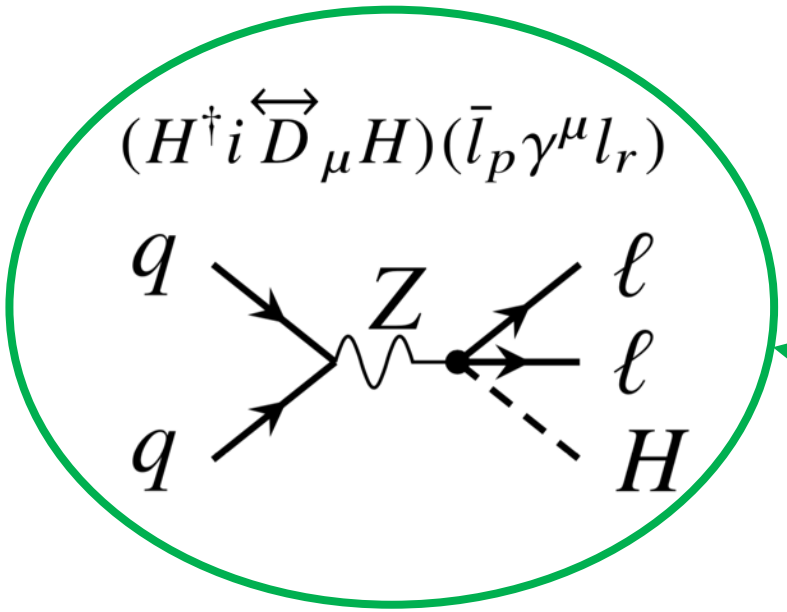


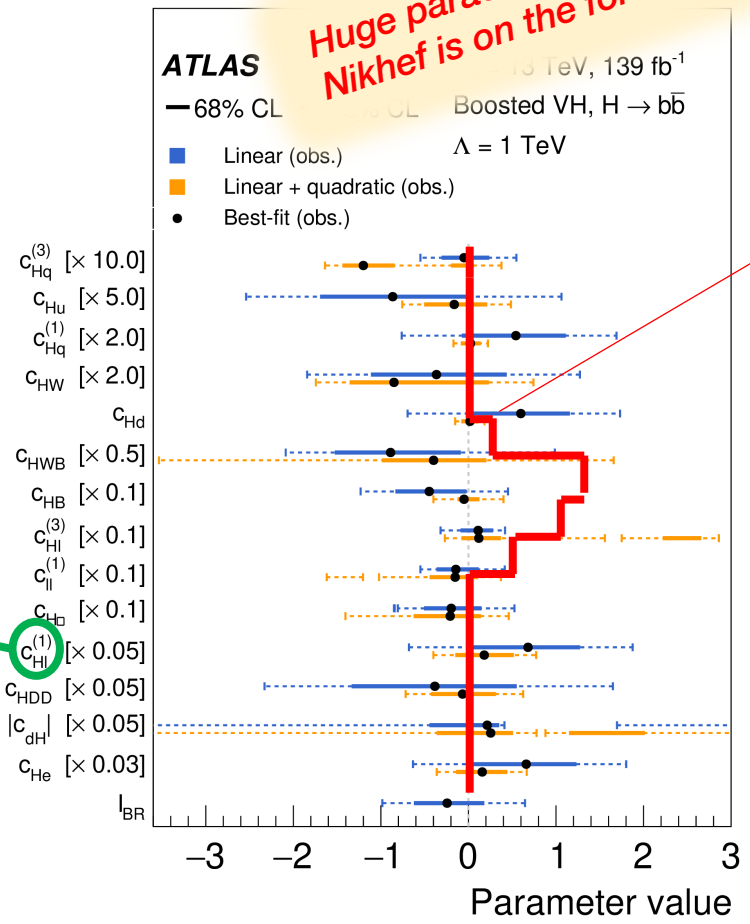
And we are looking!

Looking forward: Measurements – the methodology revolution

- *Many LHC measurements (SM,top,Higgs) will speak the same language*
- *Ultimate combination power*

Huge paradigm change on the way
Nikhef is on the forefront of this!

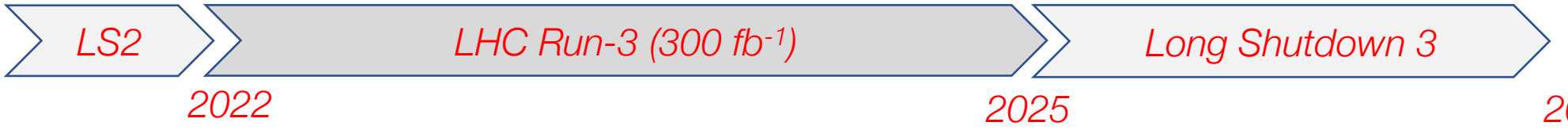




Fingerprint of NP theories, current or future "10-D Fleischer Theory"

link with Theory, LHCb, eDM

Physics program 2022-2027



h

- *Higgs and **2nd generation** fermions (μμ,cc)*
- *Precision Higgs physics (WW/ZZ/bb/ttH) – **SMEFT** **global fits***
- *Higgs **self-couplings** (diHiggs and single Higgs)*

Supported by

ENW-Groot
”At the heart of the Higgs”

ENW-Klein-II
“Fingerprinting the Higgs”

V

- ***Dibosons** (WW scattering, anomalous triple/quartic couplings) **SMEFT***

t

- *Anomalous **couplings in top** quark production and decay, **NLO** **SMEFT***

X

- *Data-driven and ML-driven **searches for anomalies** in data*

Physics program 2028-2035

LHC Run-3 (2022) → *Long Shutdown 3* (2025) → *LHC Run-4,5 (3000 fb^{-1})* (2027)

*Higgs and **2nd generation** fermions (μμ,cc)*

***SMEFT fits** of 2nd generation (μμ,cc)*

*Precision Higgs (WW/ZZ/bb/ttH) – **SM** **fits***

*focus on **high-p_T tails & ttH***

*Higgs **self-coupling** ...ggs)*

*focus on **di-Higgs***

Exploration potential
mostly limited by available data
for the foreseeable future!

Dib *(vWW scattering, TGC/QGC)*

***Dibosons** (WW scattering, Quartic couplings*

*Anomalous **couplings in top** quark*

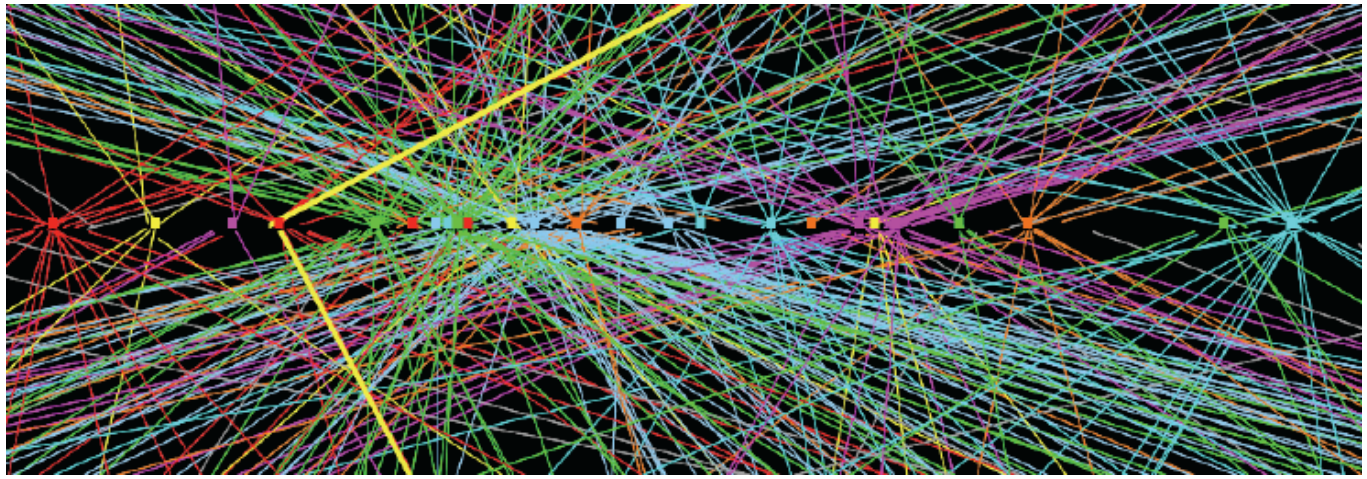
*Anomalous **couplings in top** quark*

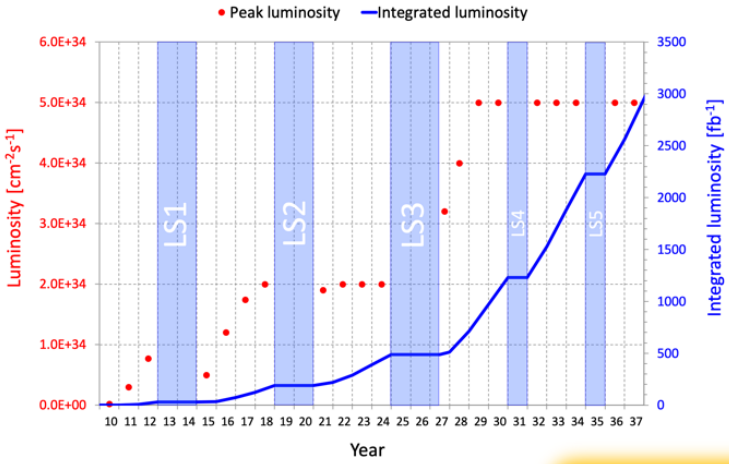
***searches for anomalies** in data*

*ML-driven **searches for anomalies** in data*

Future detectors for future science

- Taking (much) data requires strong increase in luminosity
- The LHC is a harsh environment that will only get harsher
  - Now: Every bunch crossing has ~40 collisions → ~200 in HL-LHC





- Need new **detectors** that can
  - Handle the large occupancy caused by O(1000) tracks
  - Withstand radiation damage
  - Handle the increased data rates
- Need **reconstruction** that works in dense environments

Nikhef Expertise

parallelization

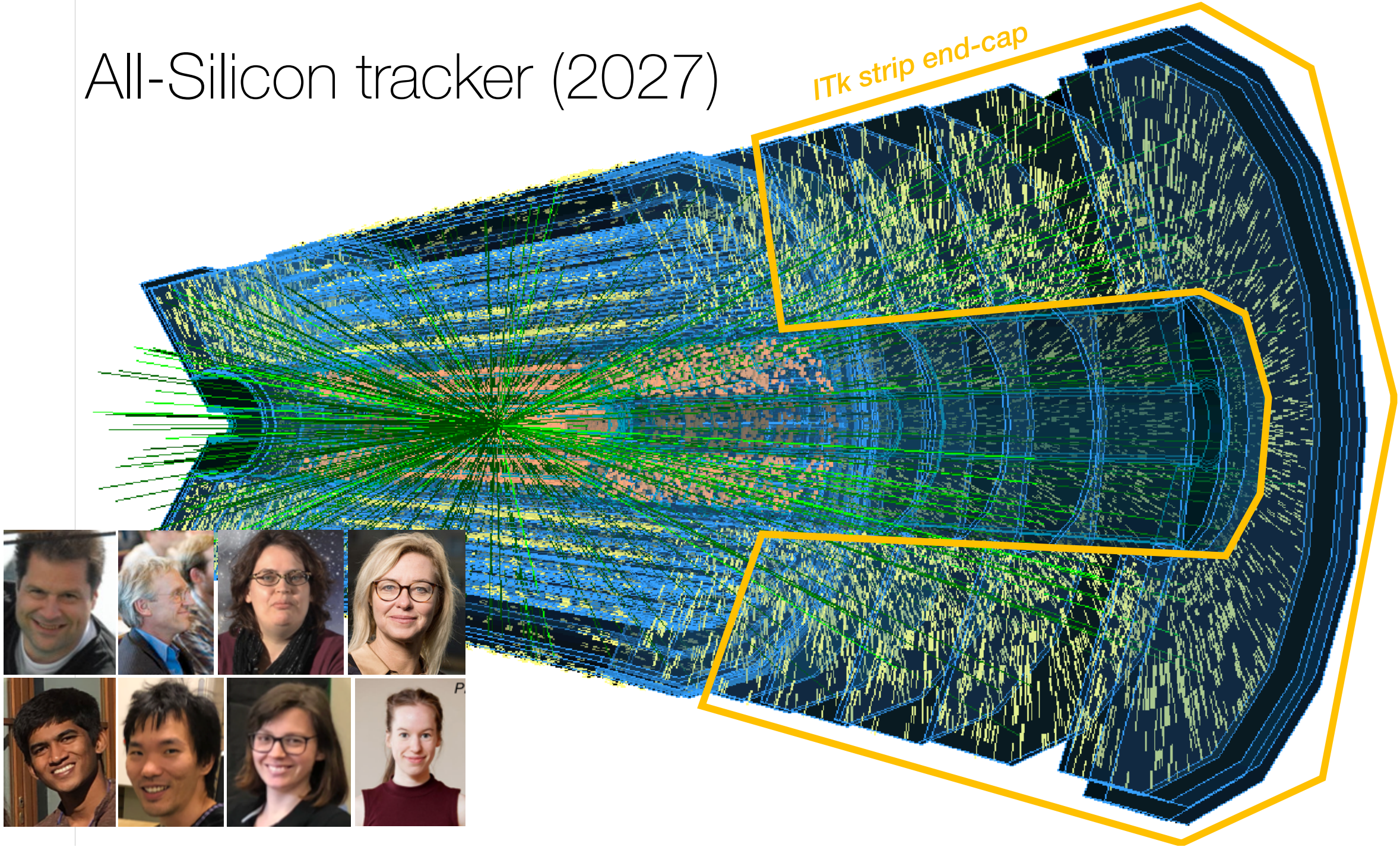
+Ana (lvl) (via Roel)

(muon) tracking

flavor tagging

trigger

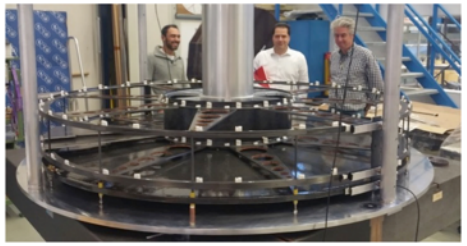
All-Silicon tracker (2027)



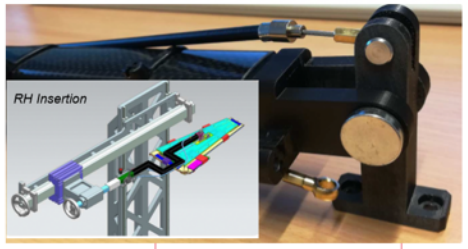
An ambitious program of work until ~2027

Valencia services mockup

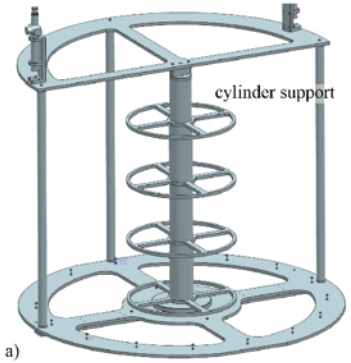
Nikhef 2-wheel EC mockup

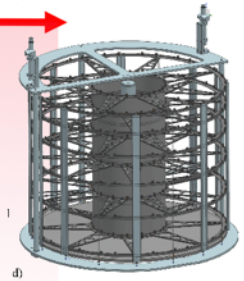


DESY: petal insertion prototype



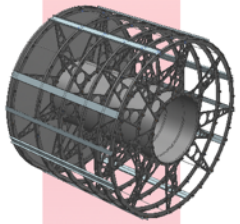
Preparing wheels, services, assembly + petal insertion frame, Cooling machines, Electrical setup lab space

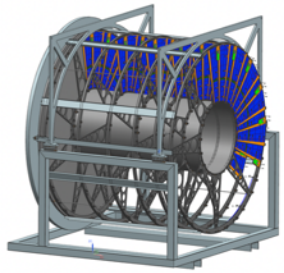




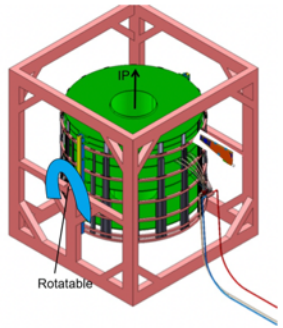
Assembly 2x

Attach Bulkhead & Services,
and Horizontal test
2x: DESY and Nikhef





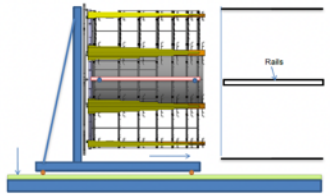
Transport CERN



Petal Insertion

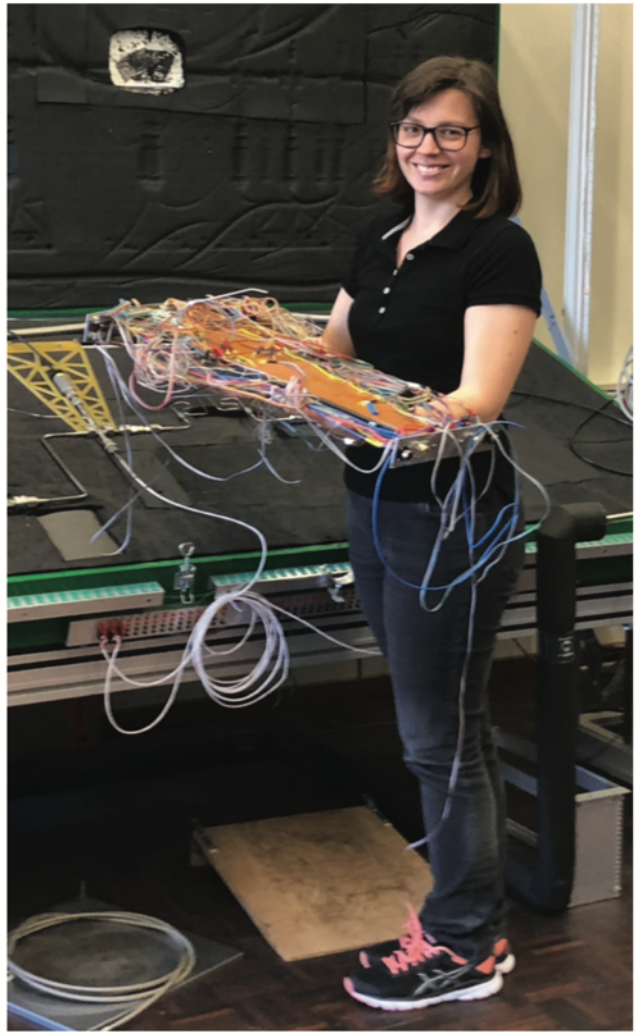
Petal Reception

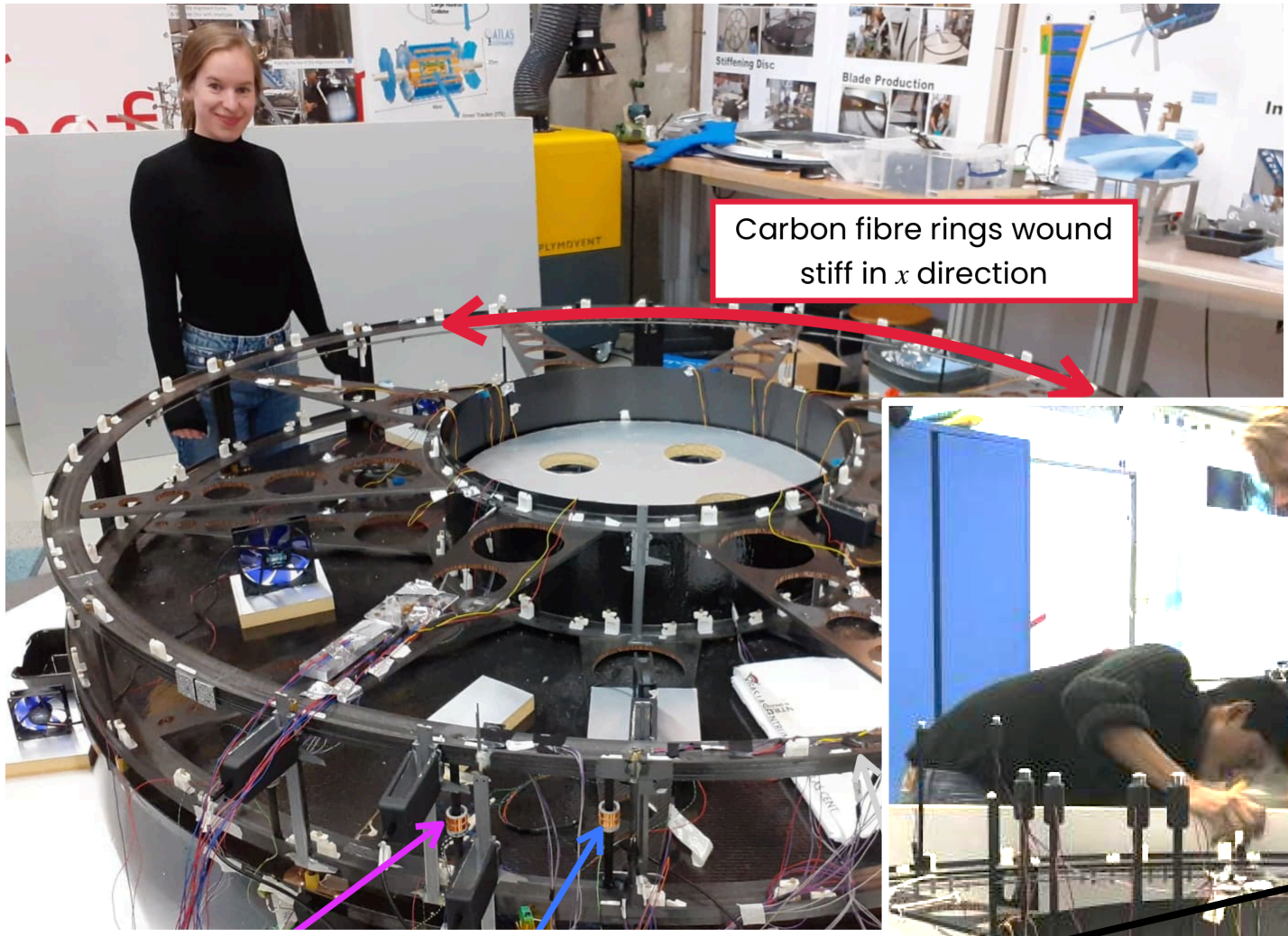
CERN test and installation



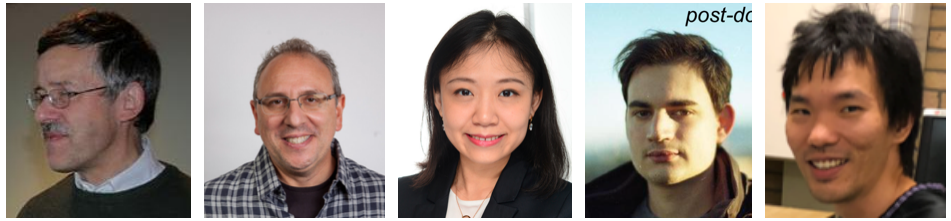
2018 2019 2020 2021 2022 2023 2024 2025

A few snapshots

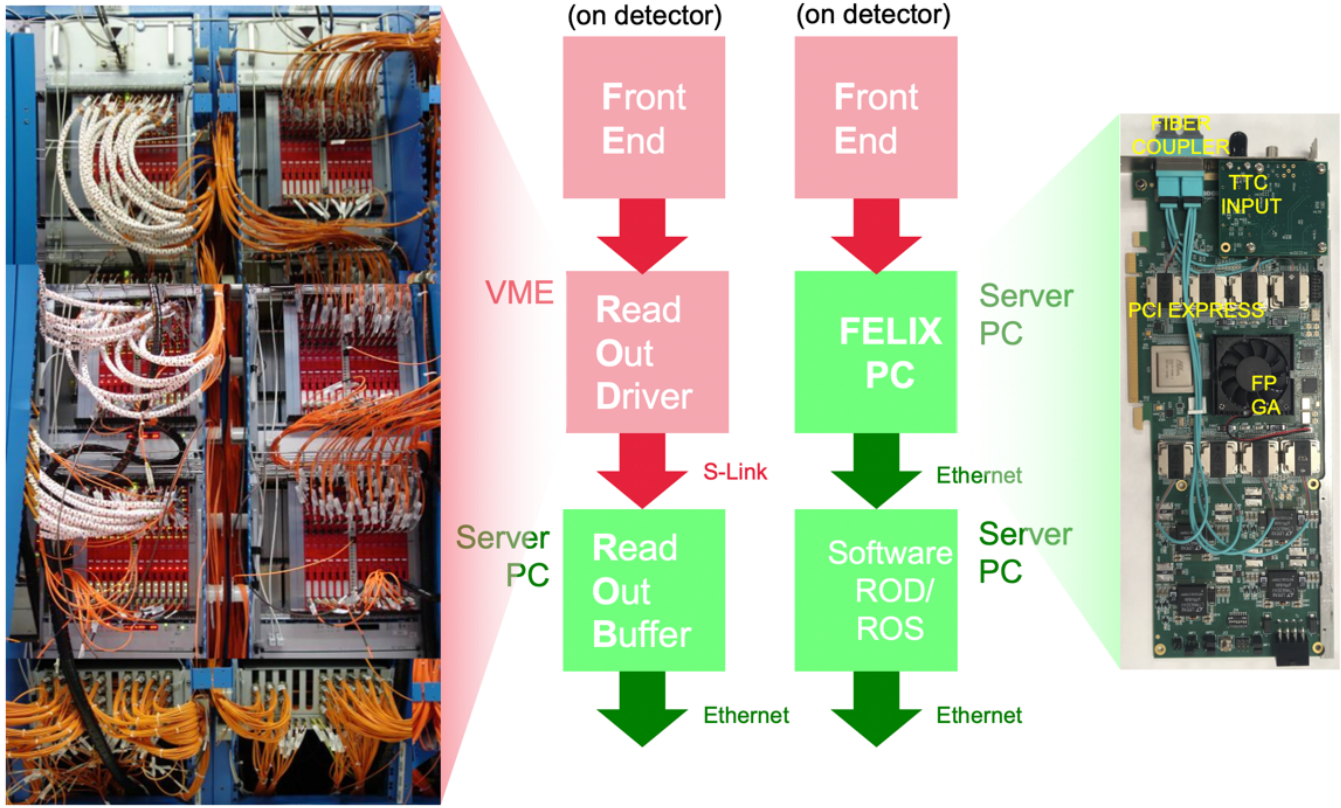




A completely new TDAQ system

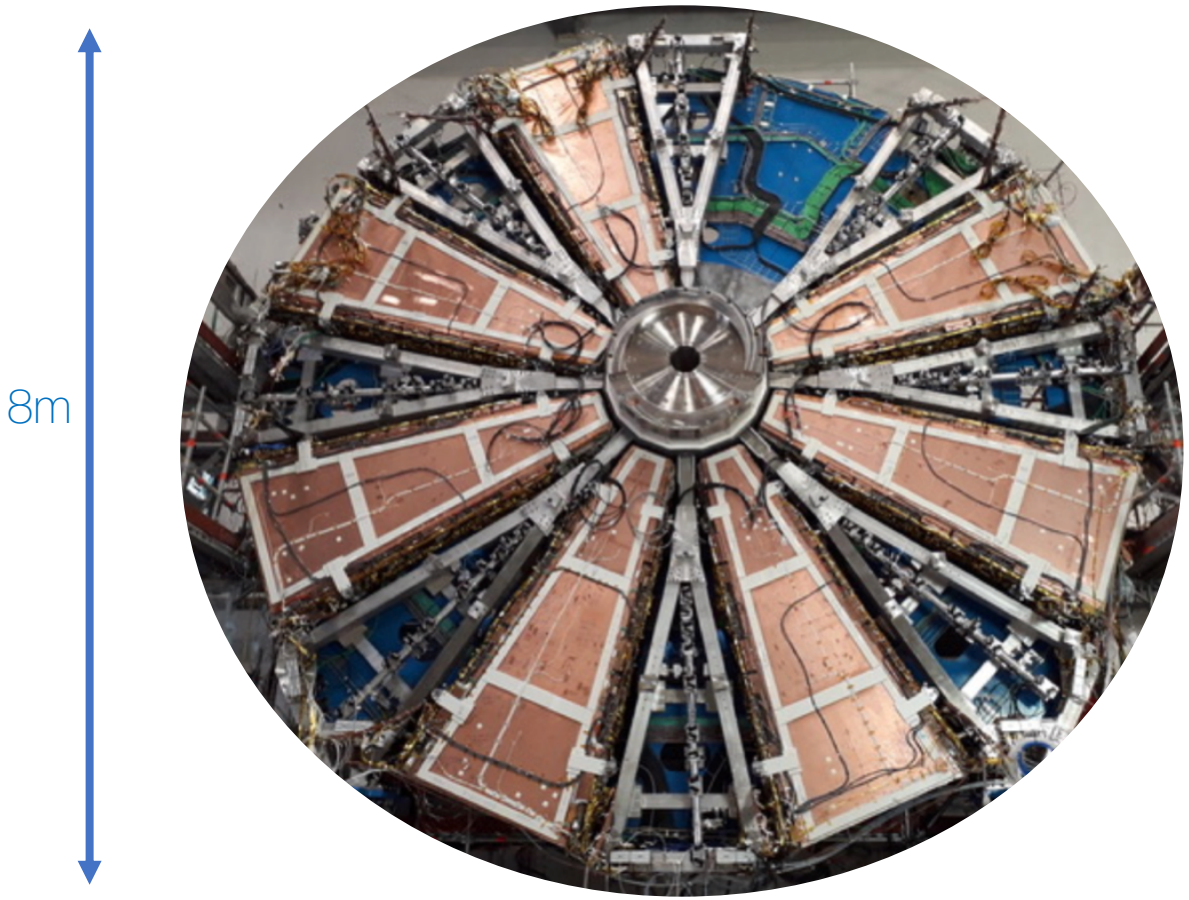


- Flexible, modular, universal DAQ system for event data, timing and trigger control (FELIX)
- Nikhef one main developers
- First deployment next year
  - On schedule
- *All of ATLAS in 2025*
  - *Specs for HL-HLC higher*
  - *Substantial R&D still needed*

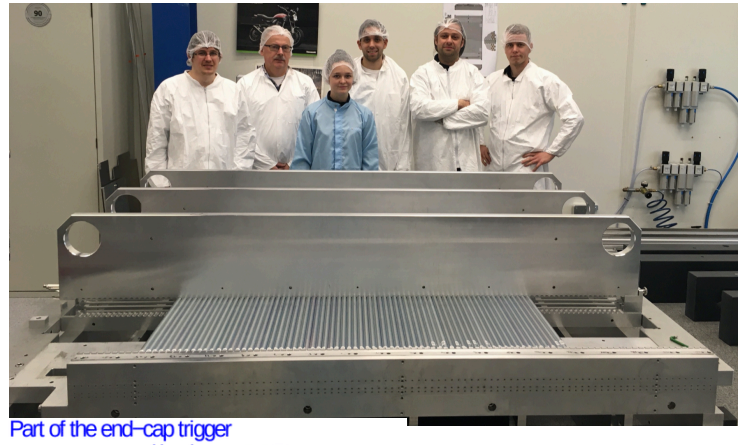


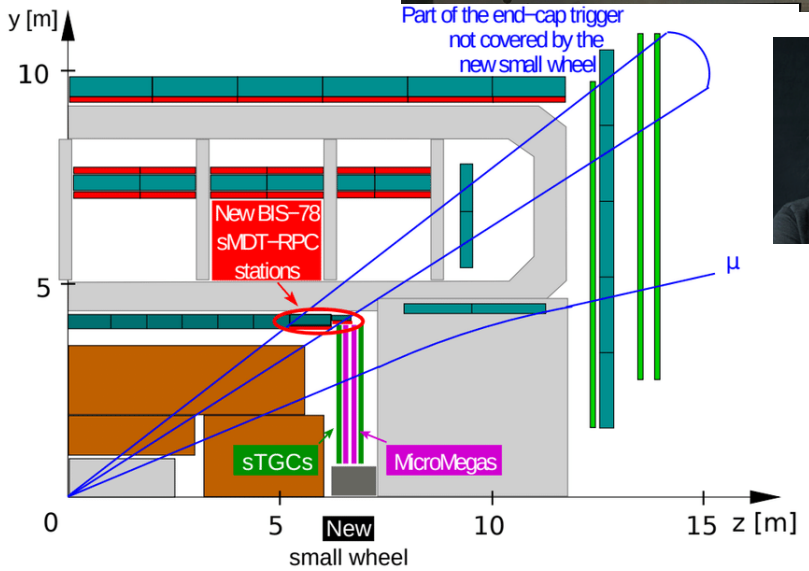
Felix in Muon NSW & MDT alignment Run-4

- Preparing for deployment in the Muon New Small Wheels (2021)



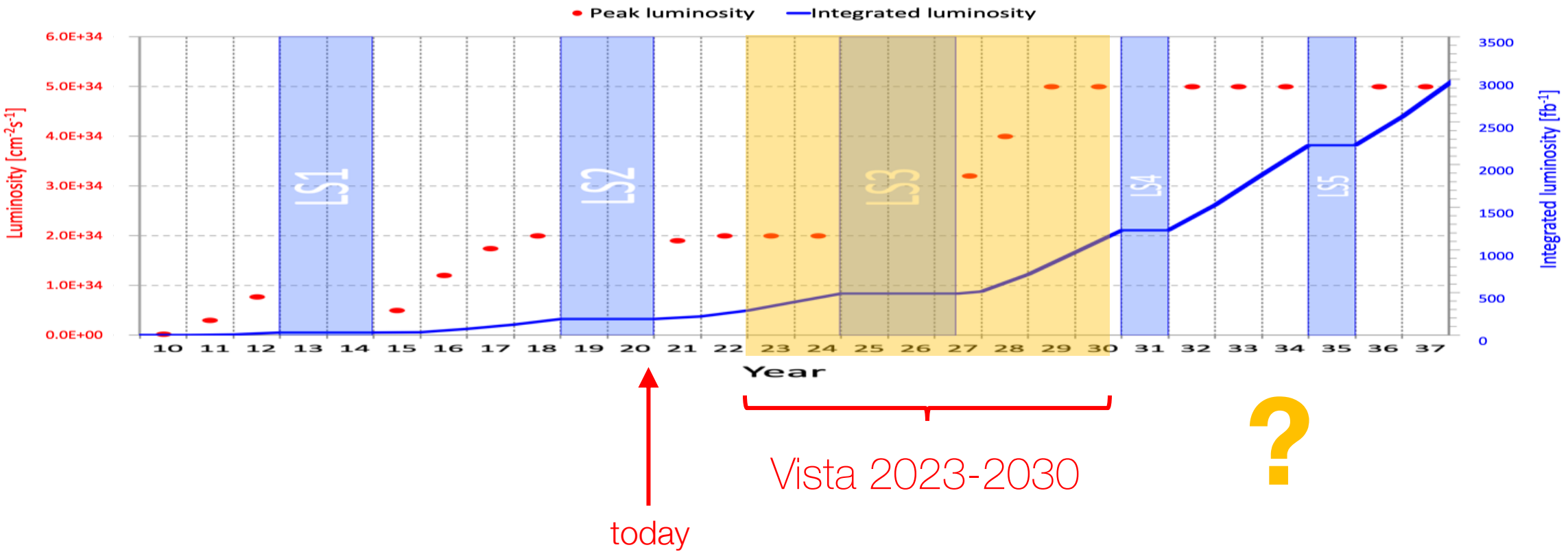
In-plane alignment new BIS chambers



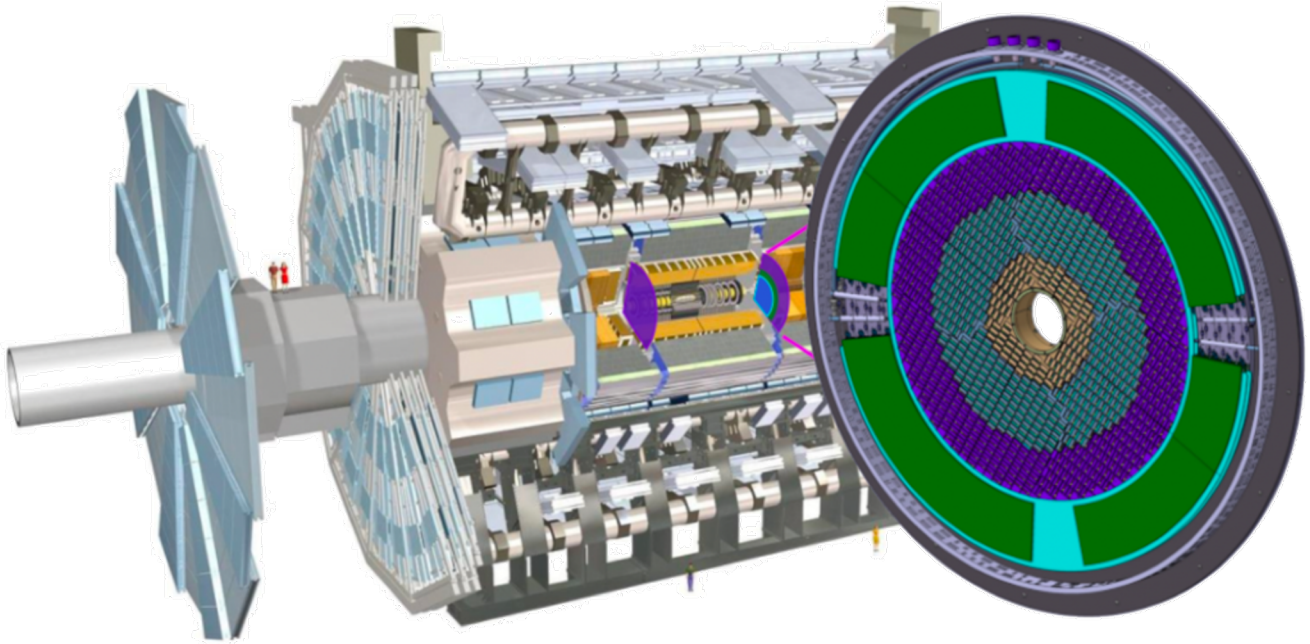


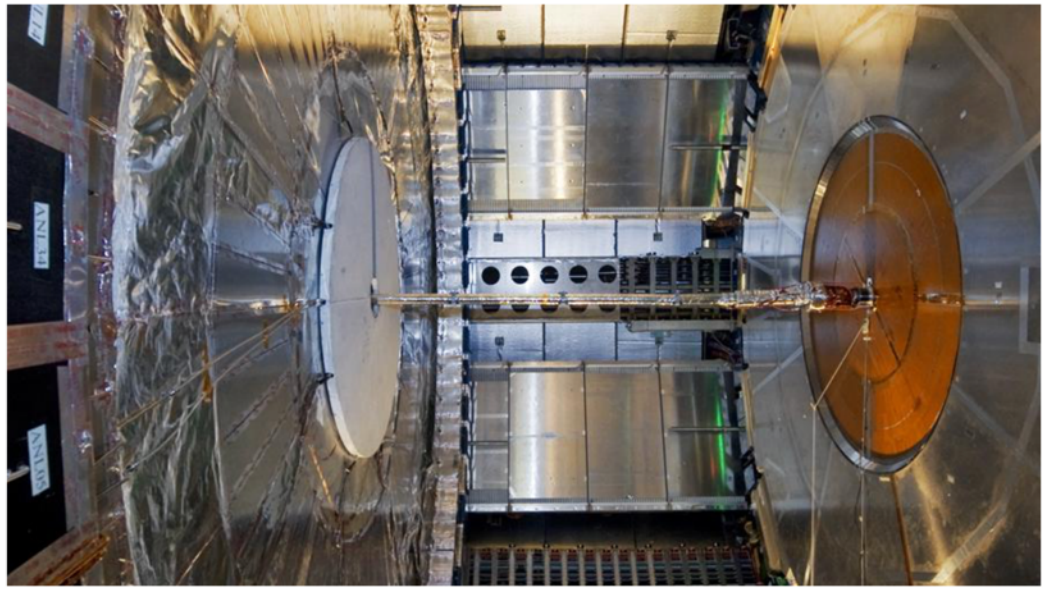
Beyond 2030….

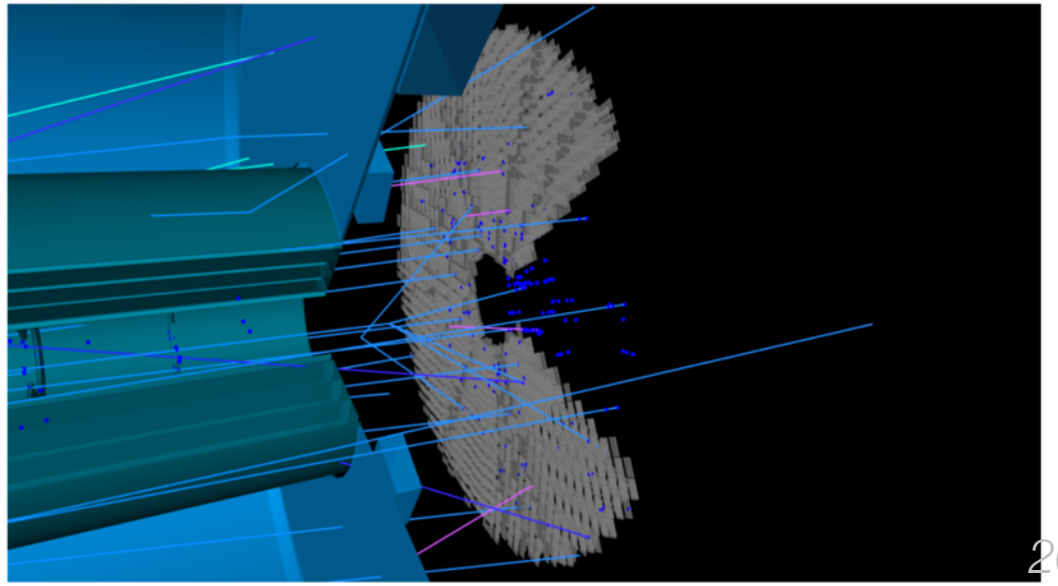
- Large program of work until 2027 (at least) with ITk / FELIX / Muon



Ideas beyond 2030 – Fast Timing Detectors







HGTD: ***Disk of LGAD detectors*** *to be placed in forward regions*
Helps reject pileup tracks with timing information

First version to be installed in 2027, lifetime 1ab^{-1}

Opportunities to get involved in next generation ***(LS4 - 2031****)*
(TDAQ, Sensors)

link with
Fast Timing (LHCb+Alice+R&D)

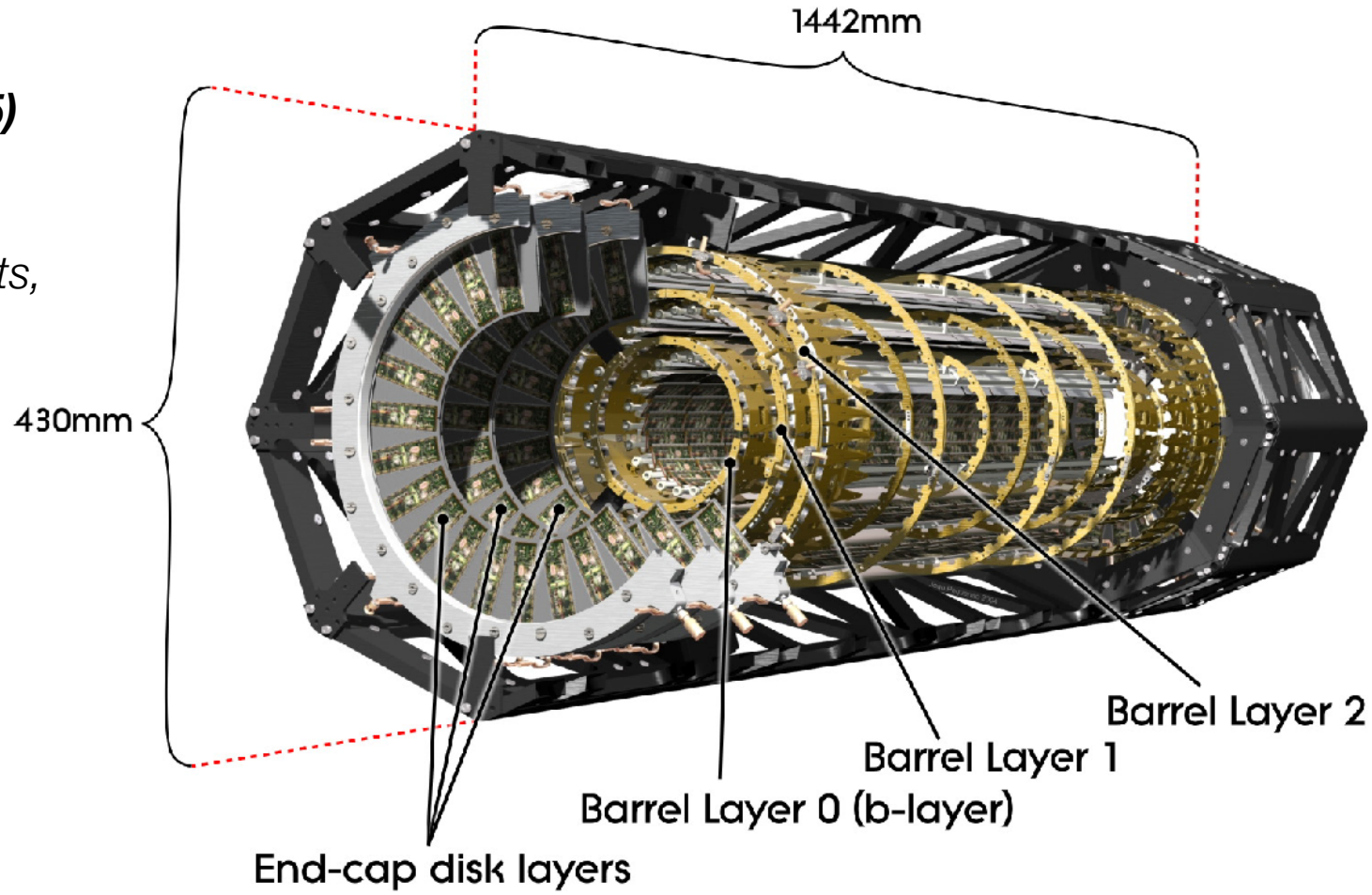
Ideas beyond 2030 – ITk inner pixel layer

Inner layer of ITk pixel detector is designed to be replaceable in ***LS5 (2035)***

Inner layer crucial for impact parameter measurement of (b)-jets,

Premium on ultra-thin material, rad-hardness (timing info bonus)

→ Opportunity for monolithic detectors (MAPS)?



link with
Fast Timing (LHCb+Alice+R&D)

Summary

- 2010-2020 (5% of data)
  - Very active and **succesful physics program** (H,t,searches)
  - Gained enormous **expertise** in reconstruction & advanced analysis techniques

- 2023-2030 (25% of data)
  - Run-3: '**Analysis revolution**' driven by ML & SMEFT
  - Nikhef often in forefront or **driving seat** (powered by ENW-Groot for next 5y)
  - **Ambitious upgrade program** in parallel (ITk end-cap, TDAQ, muon)

- beyond 2030 (all data)
  - High-lumi LHC physics program: Higgs self-couplings, rare processes, high-p_T tails
  - Multiple **opportunities for further upgrades** (HGTD 2031, Pixel 2035) under study

- *Precision EW/Higgs results will tell LHC & future colliders where to focus next*
- *95% of the LHC data is still ahead of us → interesting times ahead!*