

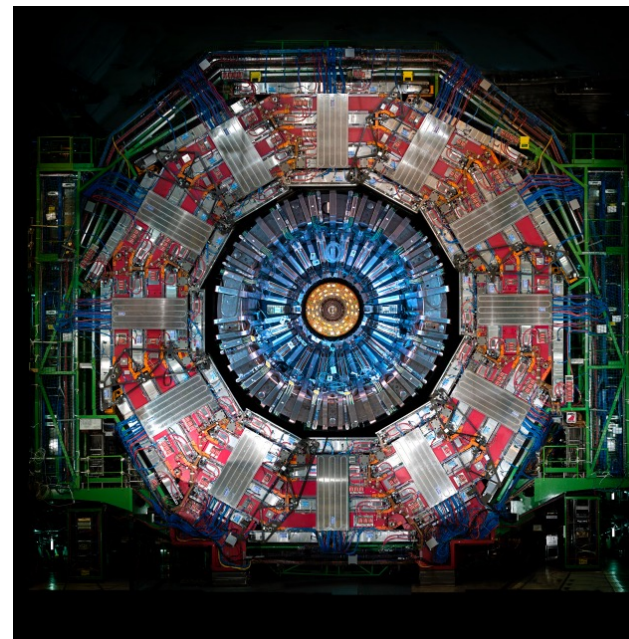
CMS AT DESY.

Highlights and Plans

Andreas Hinzmann
DESY FH CMS

11. Nov 2025

HELMHOLTZ

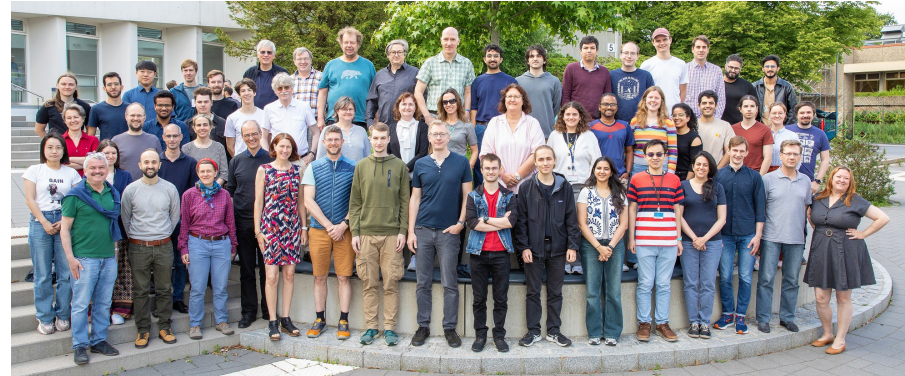


Activities

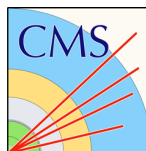


Detector operation
BRIL, DQM

Computing
Tier2, NAF

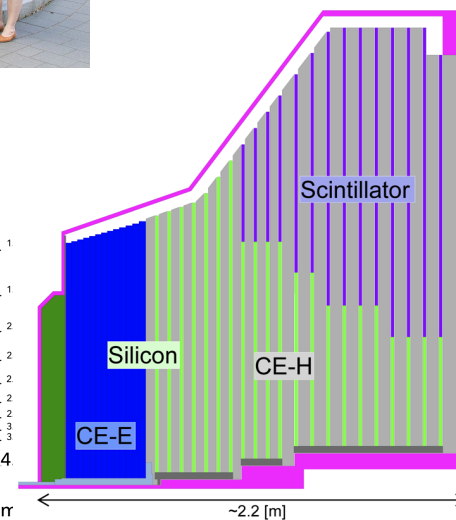
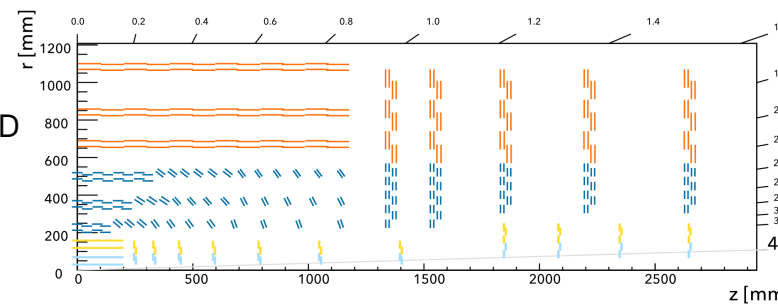


Physics analysis
Higgs, SM, Top, Searches



Reconstruction/Calibration
Alignment, Luminosity, Taus, Jets

Detector upgrade
Outer tracker, HGCAL, BCM1F, generic R&D

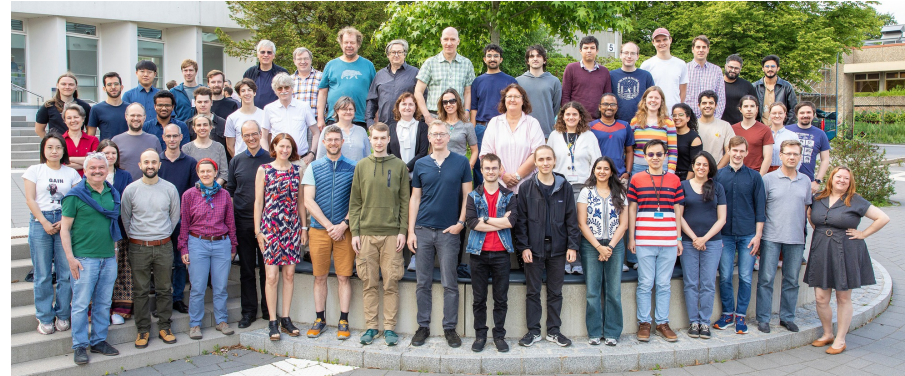


Activities and timeline

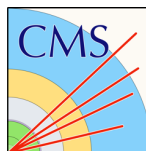


Detector operation
BRIL, DQM

Computing
Tier2, NAF

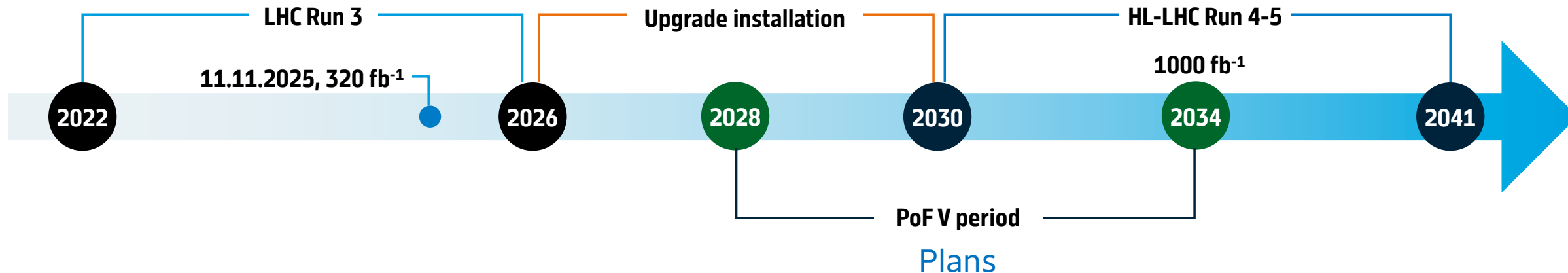
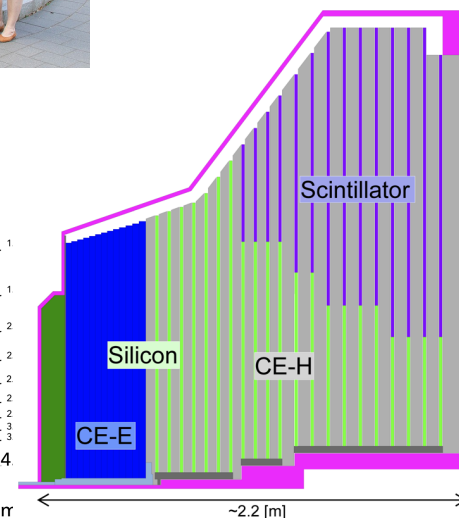
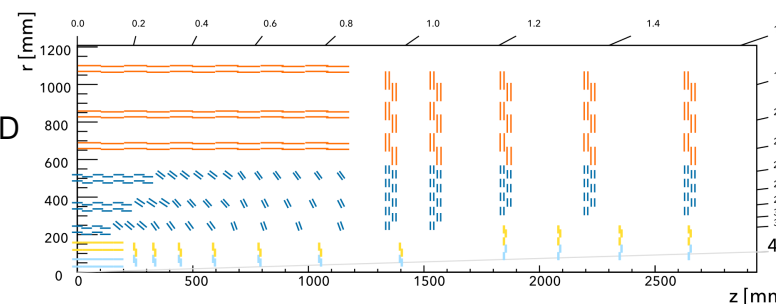


Physics analysis
Higgs, SM, Top, Searches

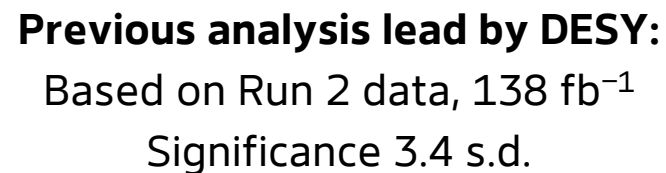


Reconstruction/Calibration
Alignment, Luminosity, Taus, Jets

Detector upgrade
Outer tracker, HGCal, BCM1F, generic R&D

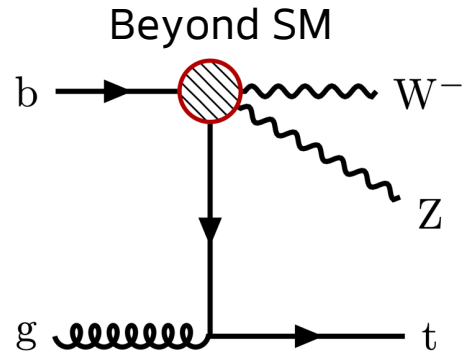
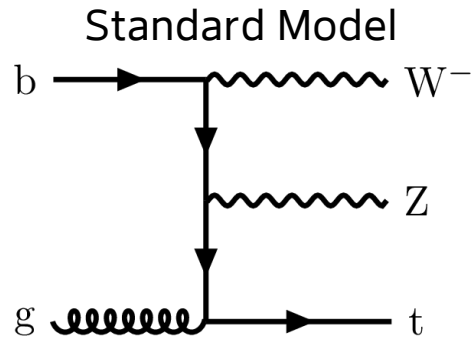


Submitted to PRL on 21.10.25, arXiv:2510.19080



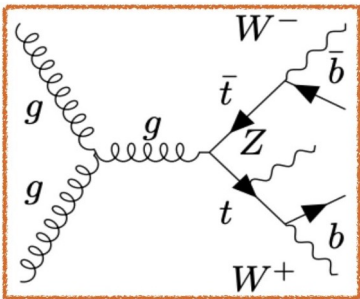
Observation of tWZ production

Submitted to PRL on 21.10.25, [arXiv:2510.19080](https://arxiv.org/abs/2510.19080)

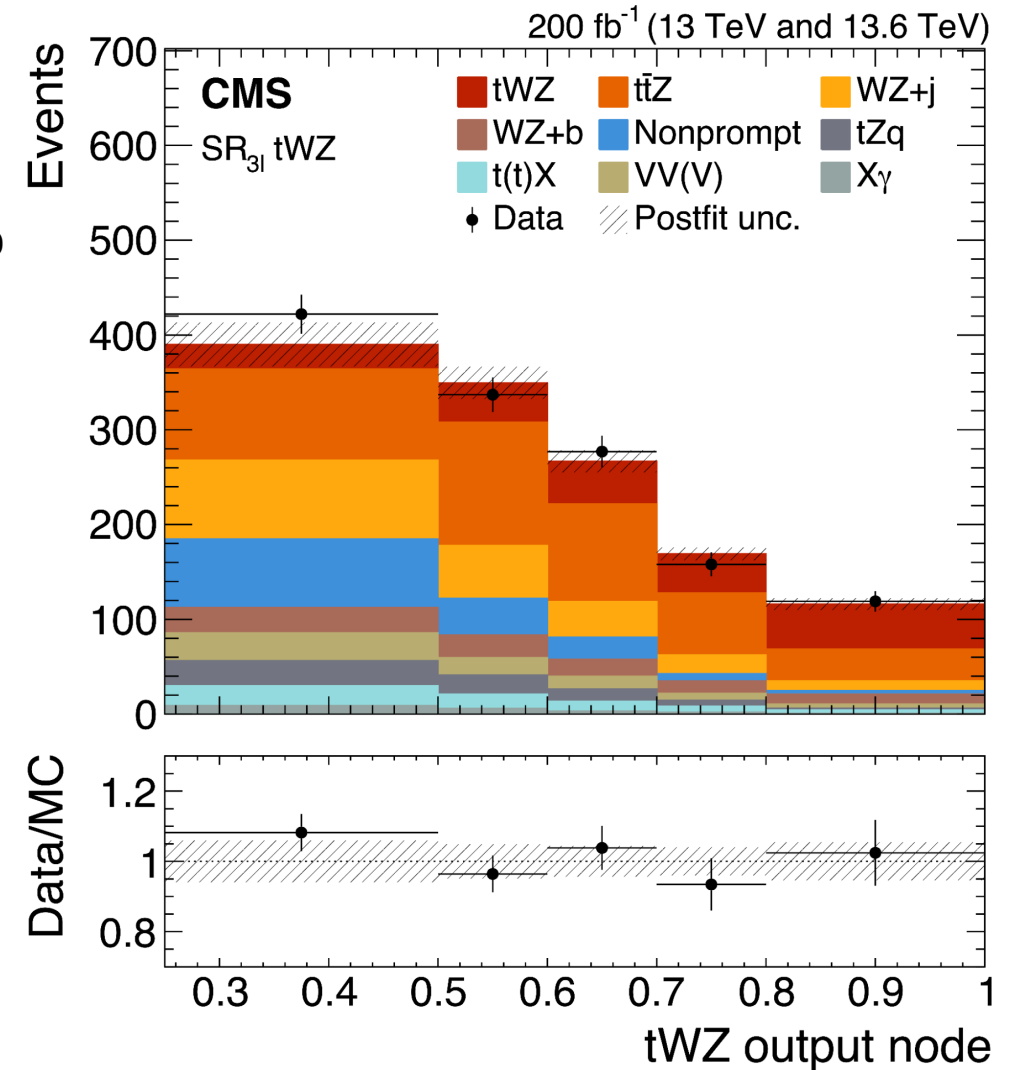


High sensitivity to
top-EW and
top-Higgs
couplings

Main background

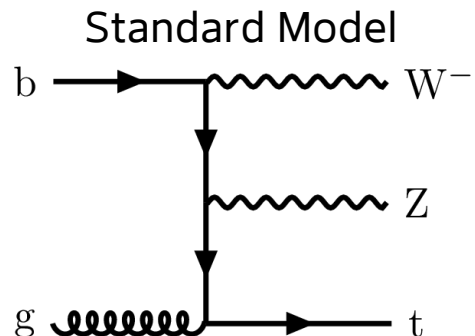


Improved machine-learning
separation: Transformer-based

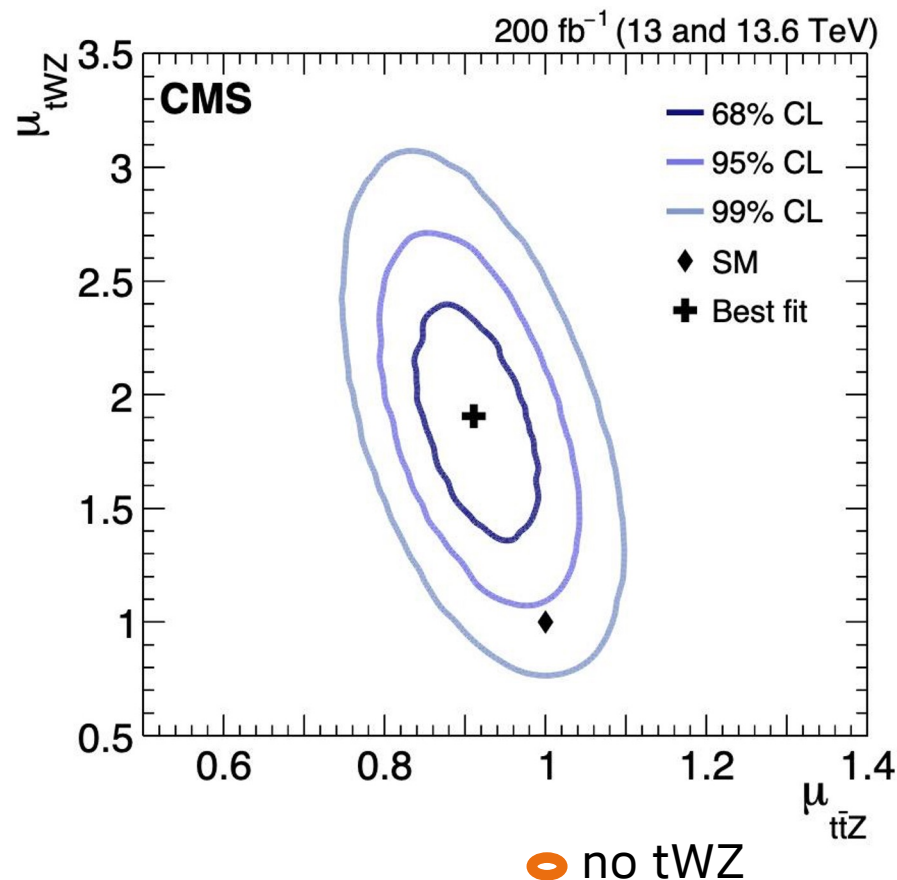
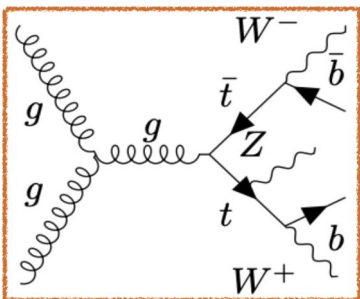


Observation of tWZ production

Submitted to PRL on 21.10.25, [arXiv:2510.19080](https://arxiv.org/abs/2510.19080)



Main background



Sensitivity improvement by factor 2 on Run 2 alone!

Larger dataset: 200 fb⁻¹ from 2016-2023

$$\sigma_{tWZ}(13 \text{ TeV}) = 248 \pm 38(\text{stat}) \pm 35(\text{syst}) \text{ fb}$$

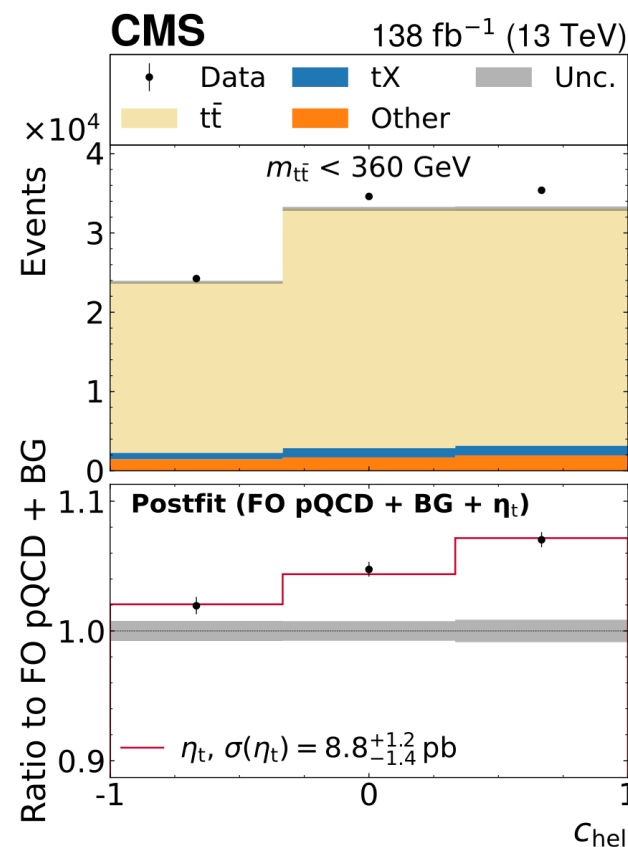
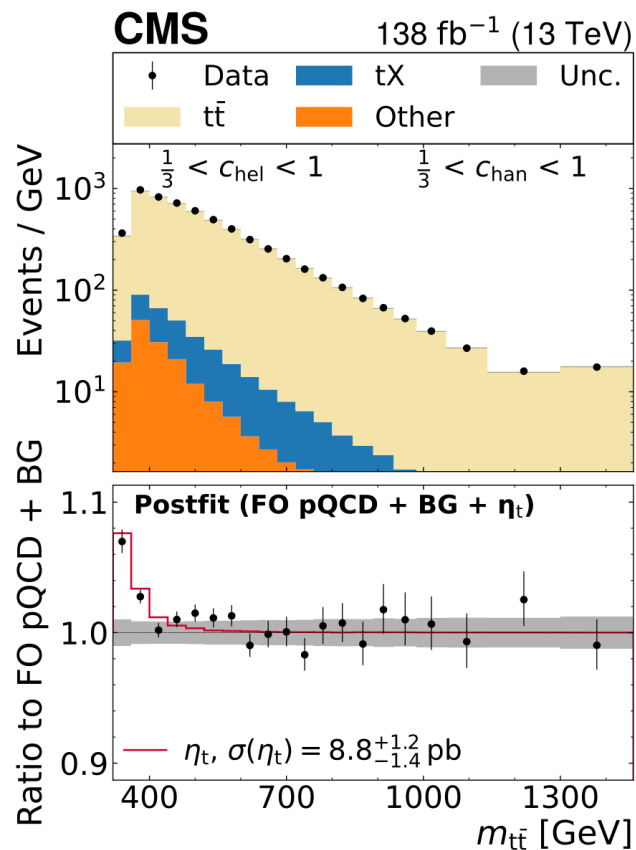
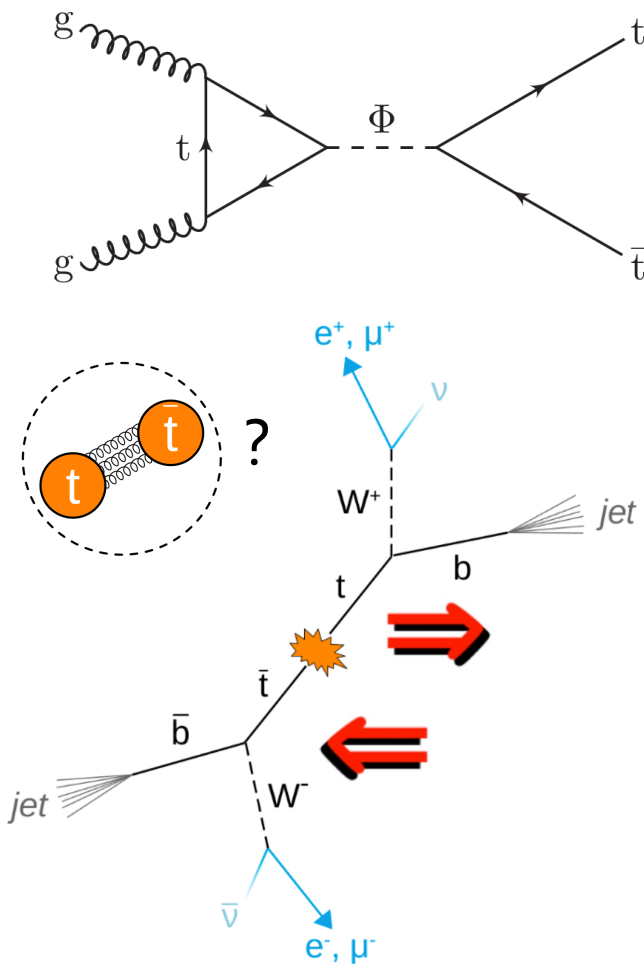
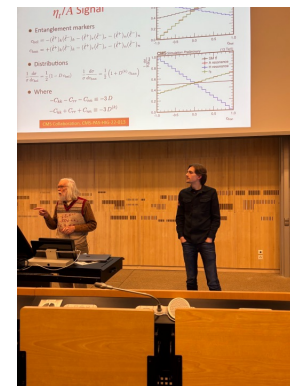
$$\sigma_{tWZ}(13.6 \text{ TeV}) = 242 \pm 62(\text{stat}) \pm 46(\text{syst}) \text{ fb}$$

tWZ observed significance: 5.8 σ
(expected significance: 3.5 σ)

Observation of an enhancement consistent with pseudoscalar toponium

Rep. Prog. Phys. 88 (2025) 087801 and arXiv:2507.05119

Laurids Jeppe (DESY)
talk at CERN
with John Ellis
9.12.2024



3D search using 2 spin observables and $m_{t\bar{t}}$

exciting excess >5 sigma

Confirmed by ATLAS!

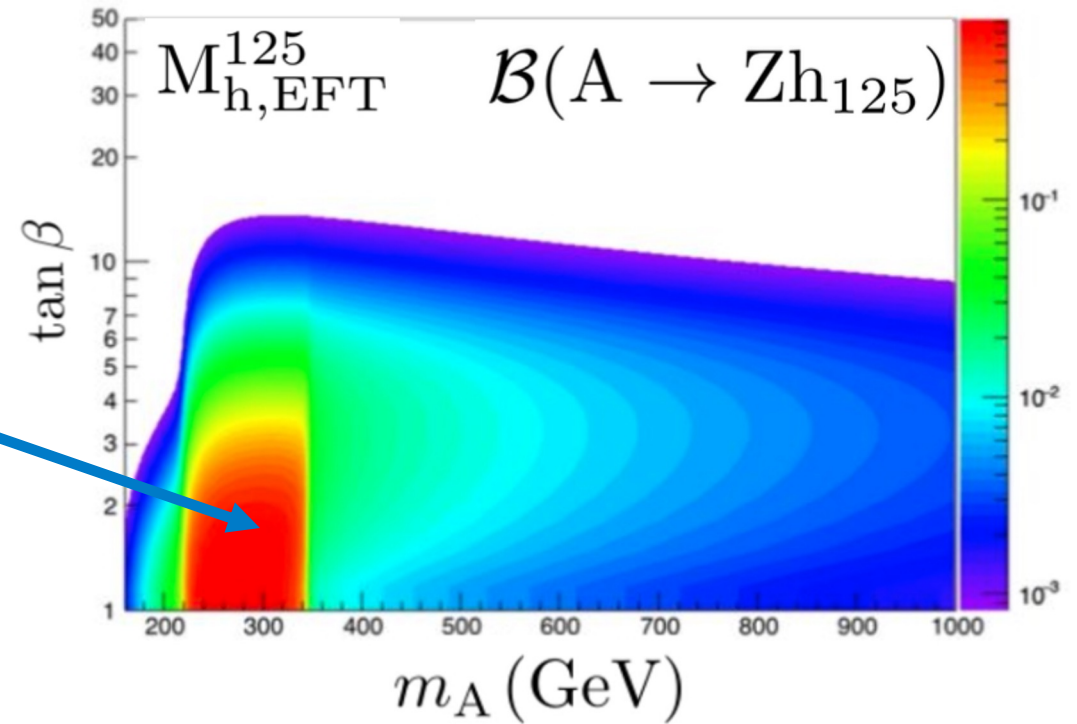
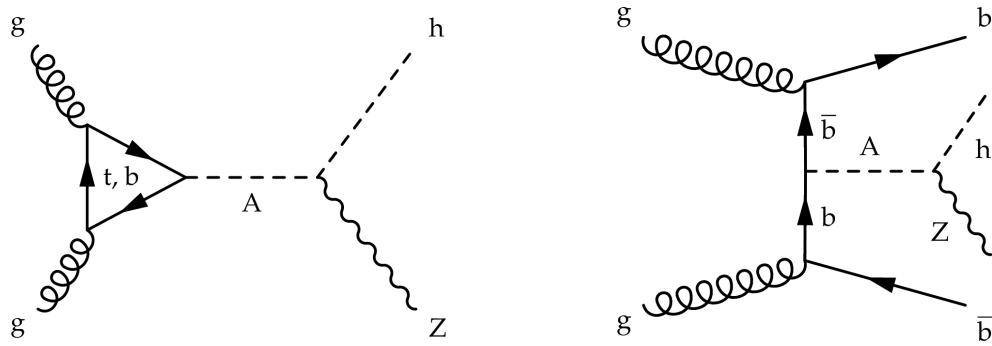
in threshold region color-singlet pseudoscalar $^1S_0^{[1]}$ bound state model based on NRQCD in addition to fixed-order pQCD fits to data well

pseudoscalar toponium seems to be a valid explanation within the SM

Search for $A \rightarrow Zh_{125} \rightarrow (ee, \mu\mu)(\tau\tau)$

[JHEP 10 \(2025\) 074](#)

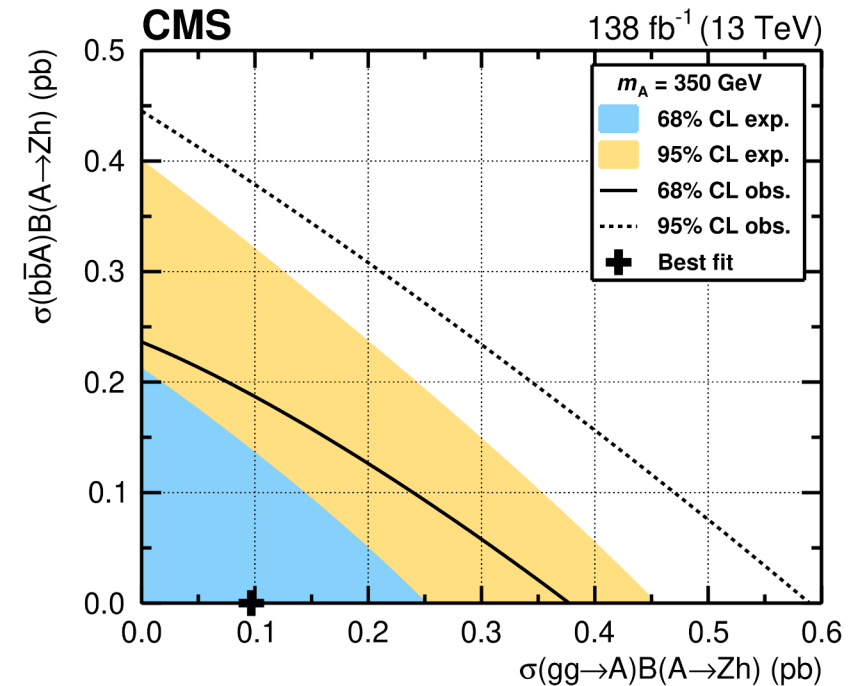
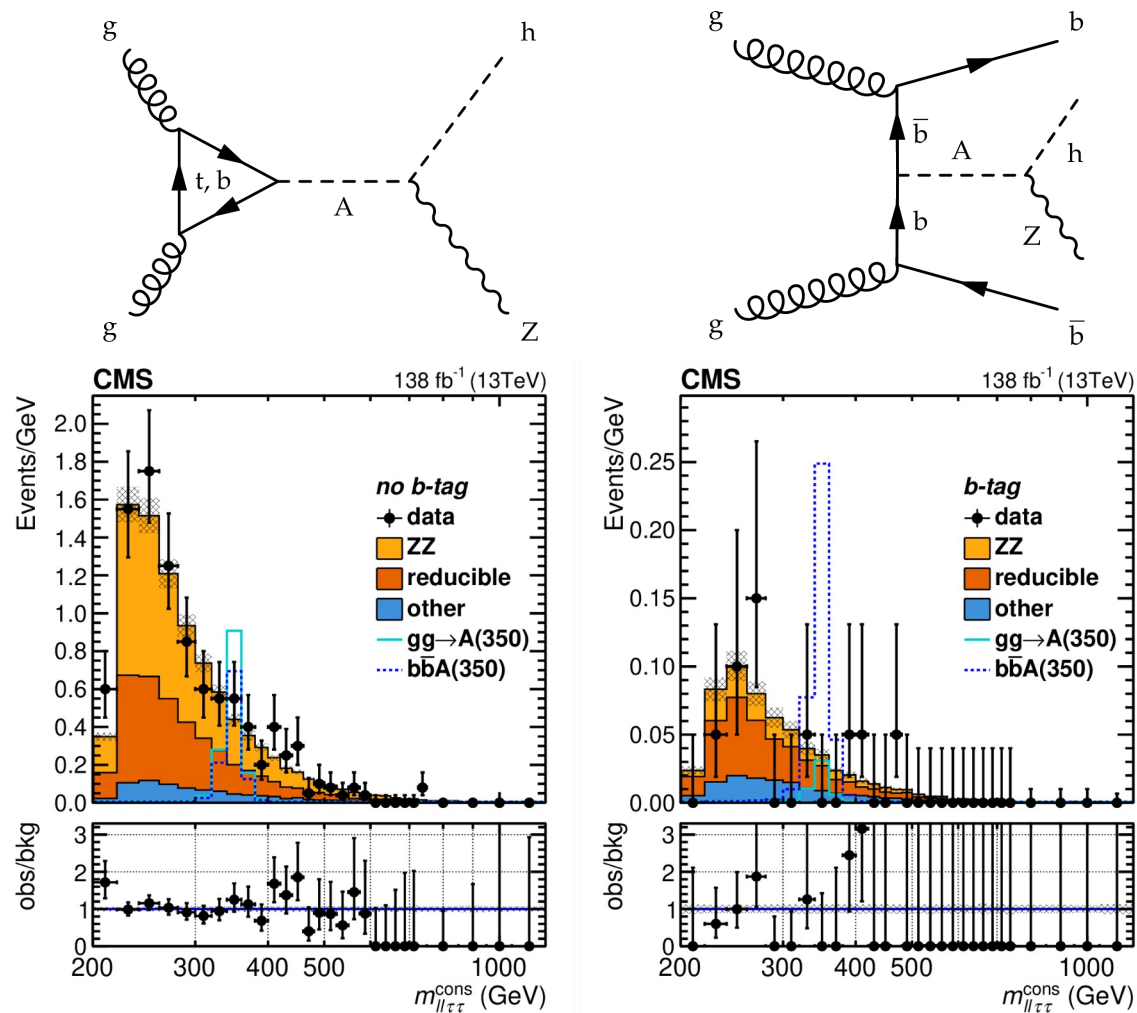
Sensitive probe of MSSM scenarios at low $\tan \beta$ and $m_A \lesssim 2m_{\text{top}}$



Search for $A \rightarrow Zh_{125} \rightarrow (ee, \mu\mu)(\tau\tau)$

JHEP 10 (2025) 074

Sensitive probe of MSSM scenarios at low $\tan \beta$ and $m_A \lesssim 2m_{\text{top}}$



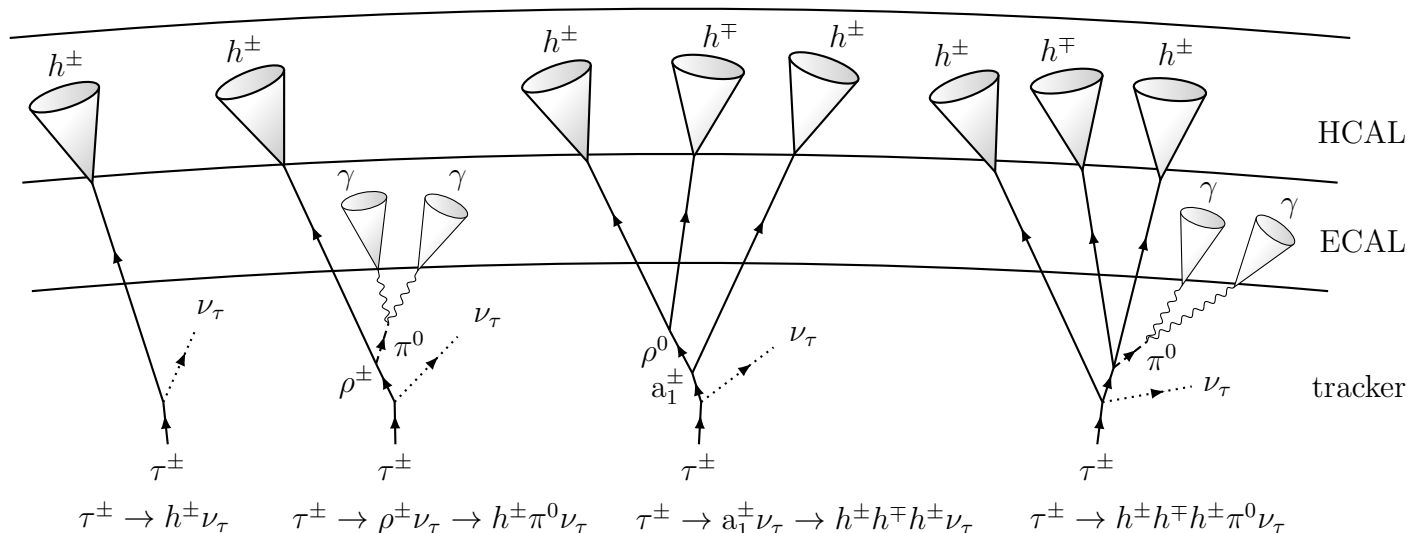
No observation of CP-odd Higgs boson A in $A \rightarrow Zh_{125}$ decay near $t\bar{t}$ threshold

Interpretation of $t\bar{t}$ excess as CP-odd Higgs boson A disfavoured in this model (though not excluded)

Commissioning of new tau tagger

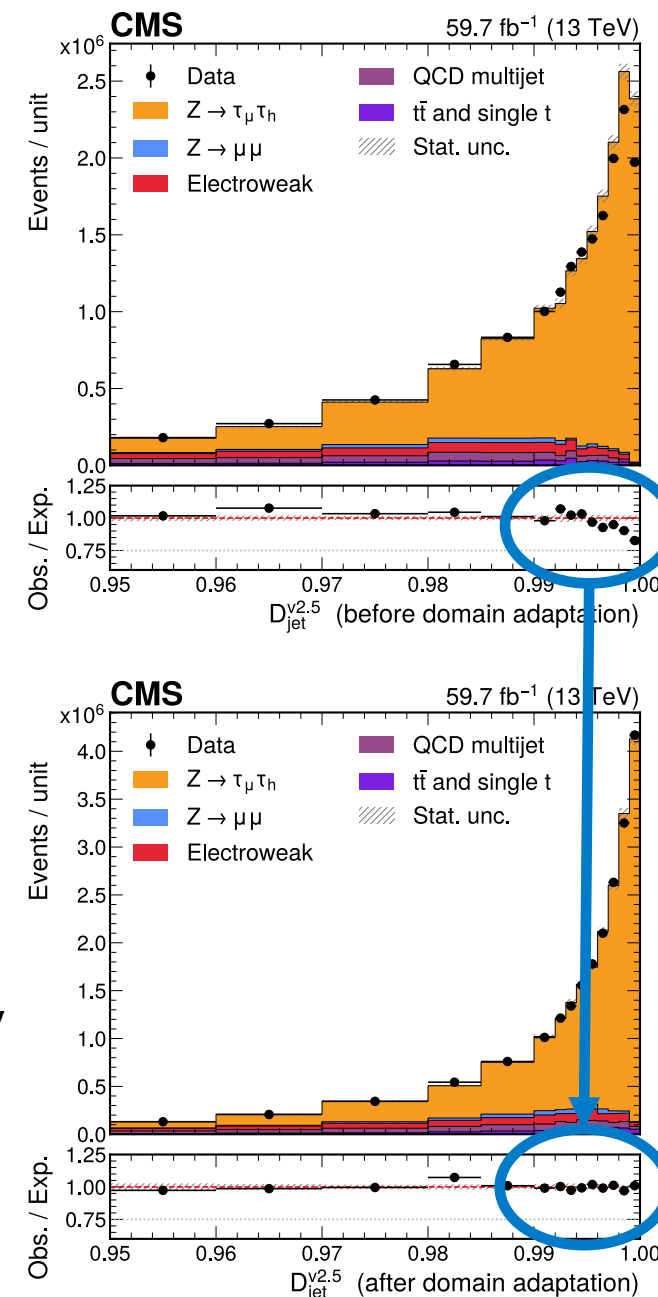
Submitted to JINST, [arXiv:2511.05468](https://arxiv.org/abs/2511.05468)

deepTau (v2p5) based on deep convolutional NNet

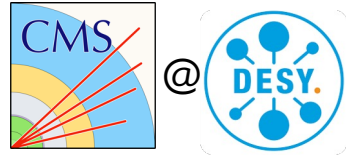


Tagger implements **domain adaptation** mechanism via adversarial sub-neural network **to mitigate discrepancies** between data and simulation
 → reduction of systematic uncertainties related to modeling of tau ID efficiency

Commissioned with Run2 and early Run3 data



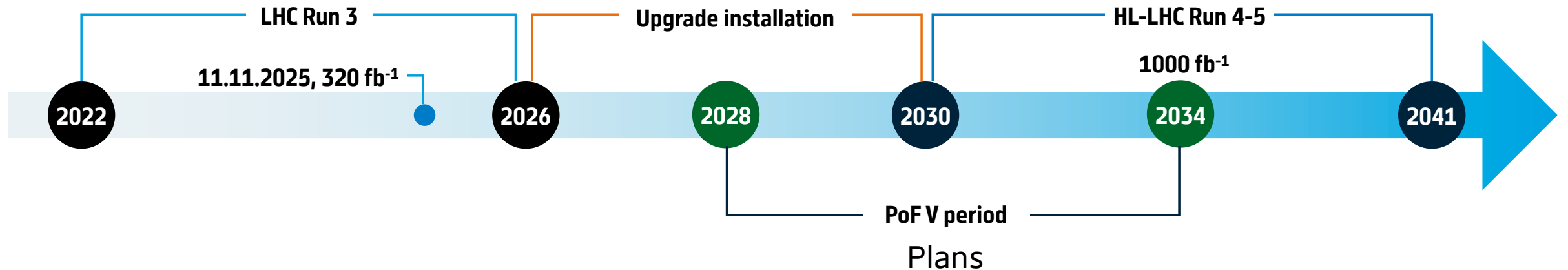
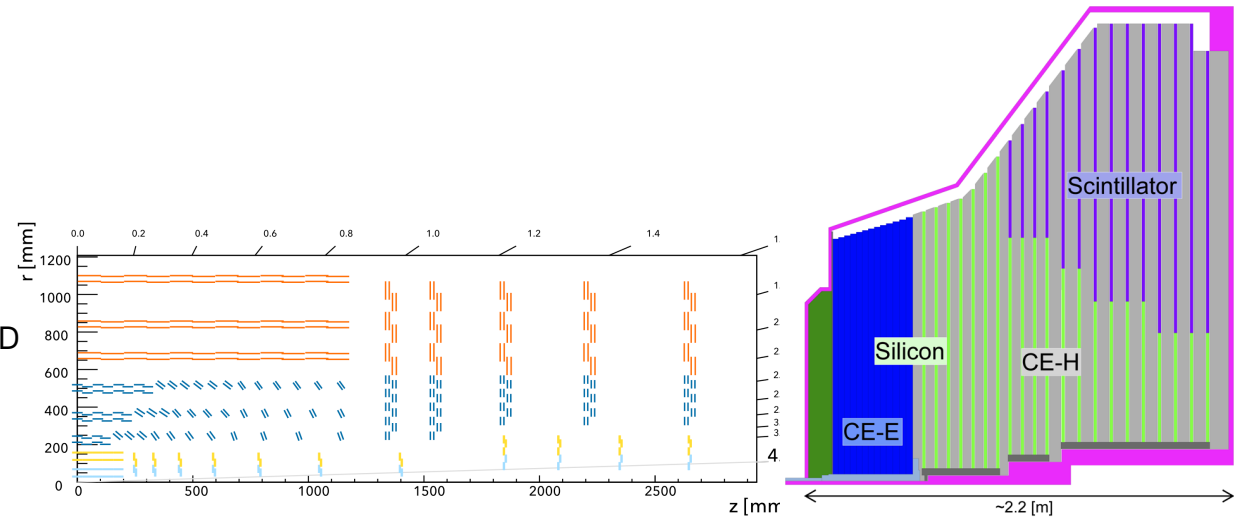
Activities and timeline



Detector upgrade

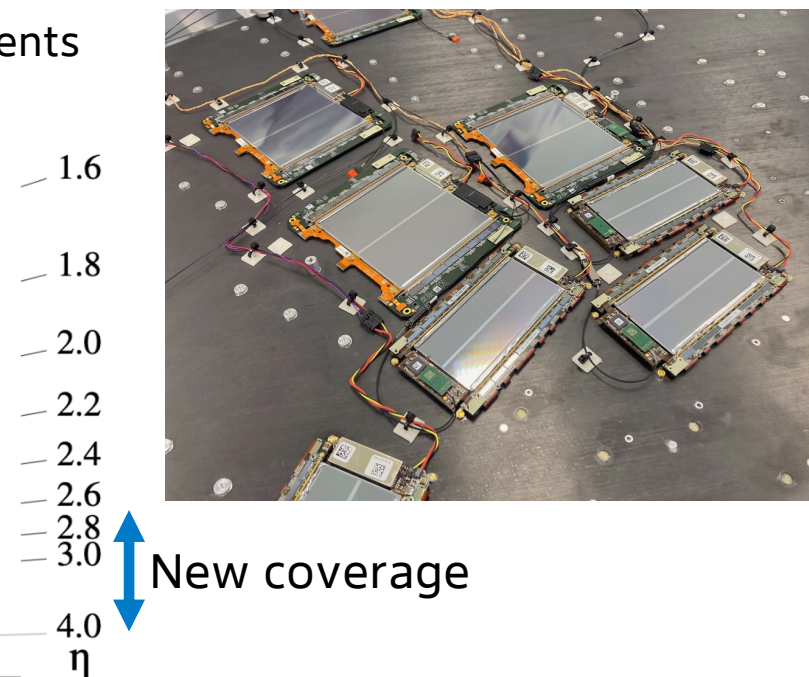
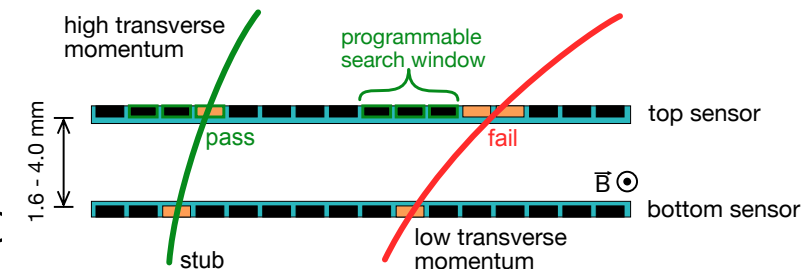
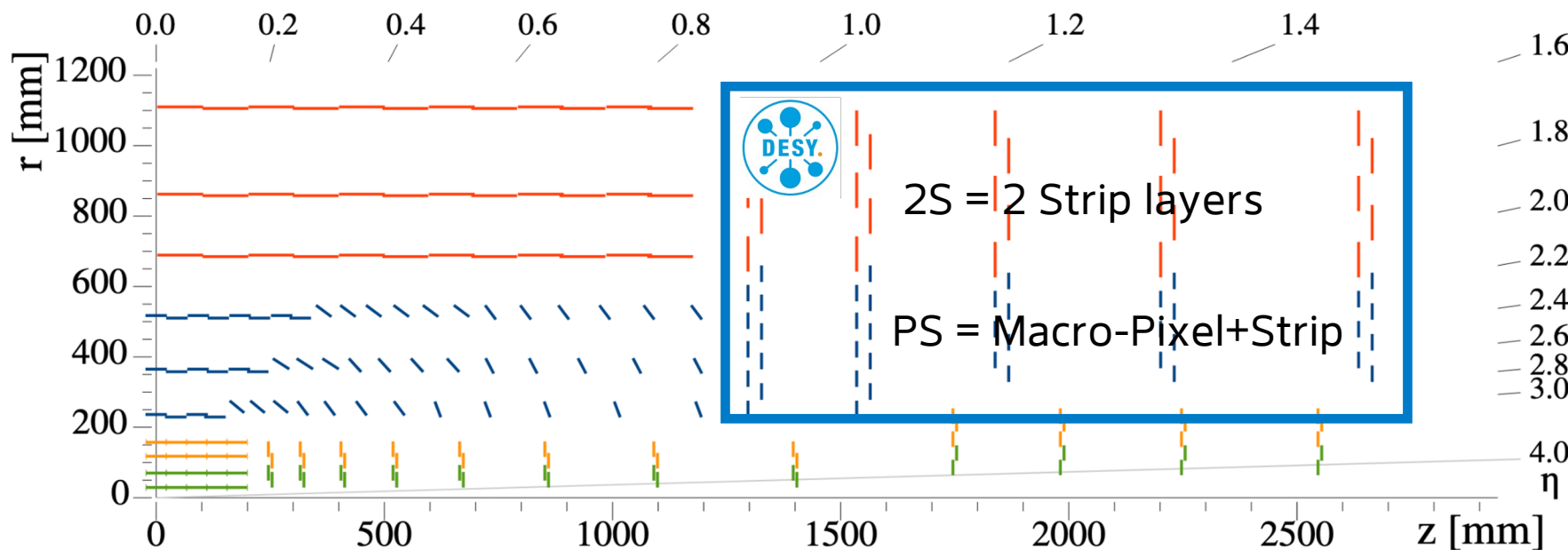
Outer tracker, HGCal, BCM1F, generic R&D

112 fb⁻¹ in 2025!



Upgrade project: Outer tracker endcap

- Complete rebuild with **innovative design** and new technology
- Increased **granularity** → cope with the dense environment at HL-LHC
- Increased **radiation tolerance** → cope with the harsh environment at HL-LHC
- **Track trigger** → data reduction at trigger readout by factor 10-20
- Extended tracking to the **forward region** → better access to VBF measurements



Tracker: DESY Deliverables

modules

- 1120 4.0 mm PS modules
- Burn-in test of modules
 - 1120 DESY PS and 800 RWTH Aachen 2S modules

local supports

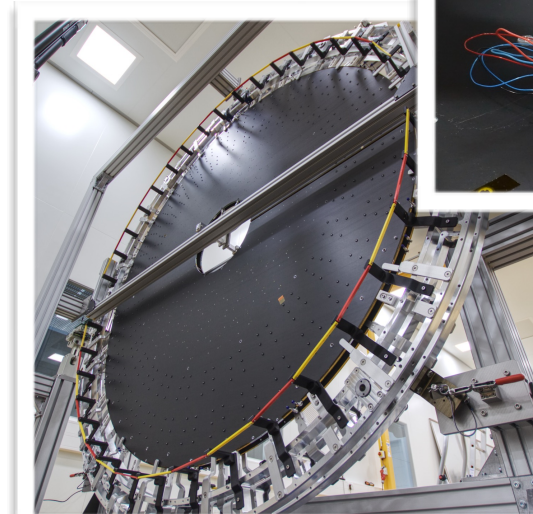
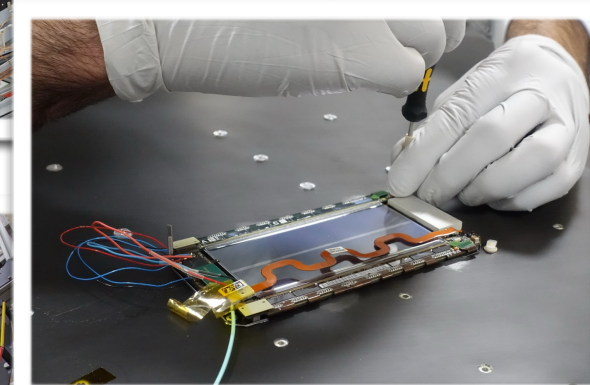
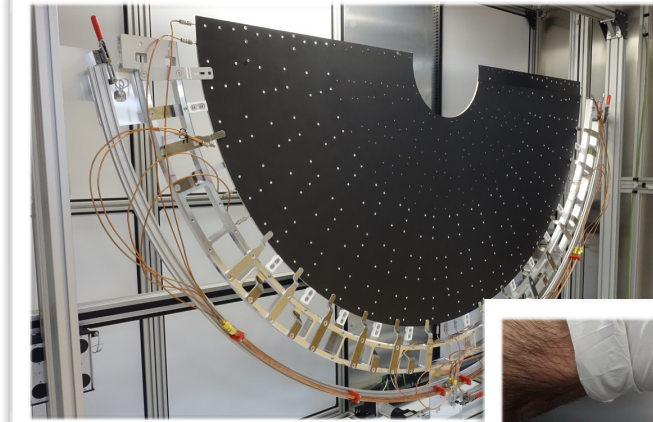
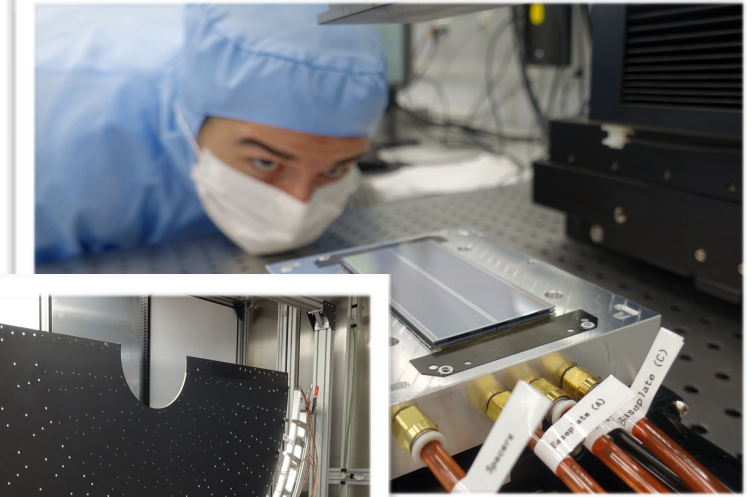
- 16 TEDD1 Dees
 - production in industry supervised by DESY

integrated local supports

- 16 integrated Dees
 - in collaboration with KIT and RWTH Aachen
 - 4/5 of one end-cap

end-cap

- 5 integrated Double-Disks
- 1 integrated TEDD
 - assembly and services done at CERN in close collaboration with UC Louvain and IP2I Lyon

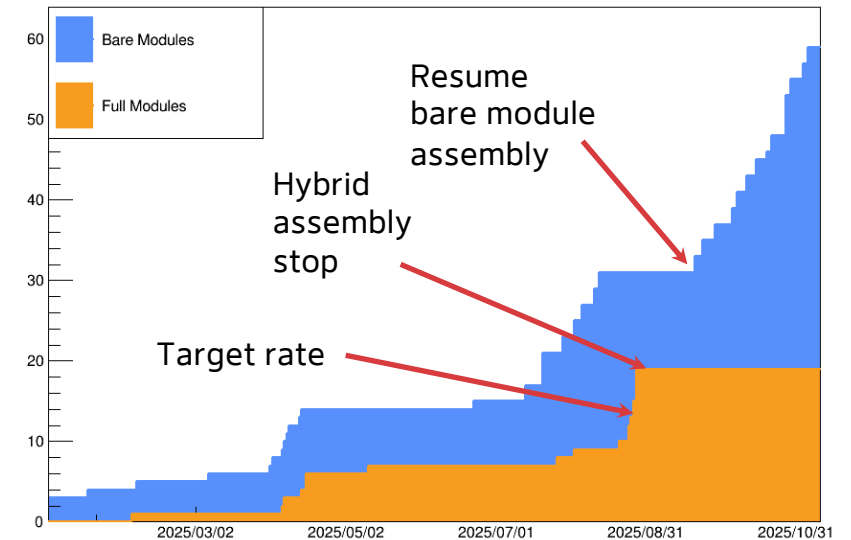


Tracker: PS module assembly pipeline exercise

- **Assembly pipeline exercise successfully completed**
 - Started 1 module per day until assembly pipeline was filled → 8 modules in total
 - Gained important insights and input to further optimize assembly procedures & workflows
- Successfully exercised assembly of four bare modules in a single day
- **Reach target rate when available**
 - Limited by availability of hybrids from industry
 - bPOL12V issue



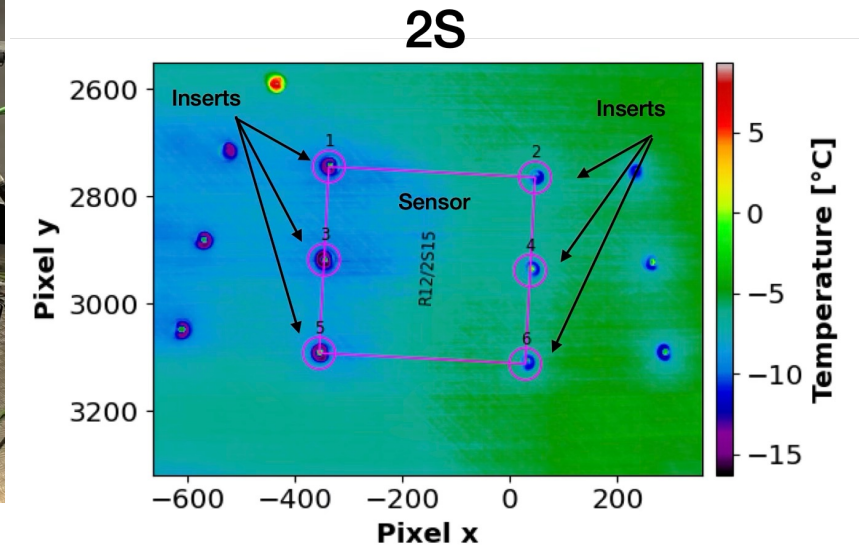
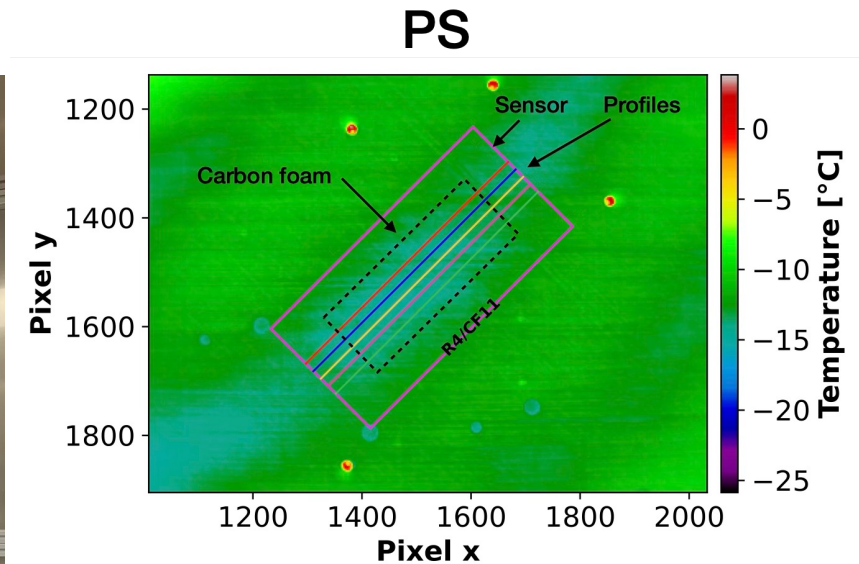
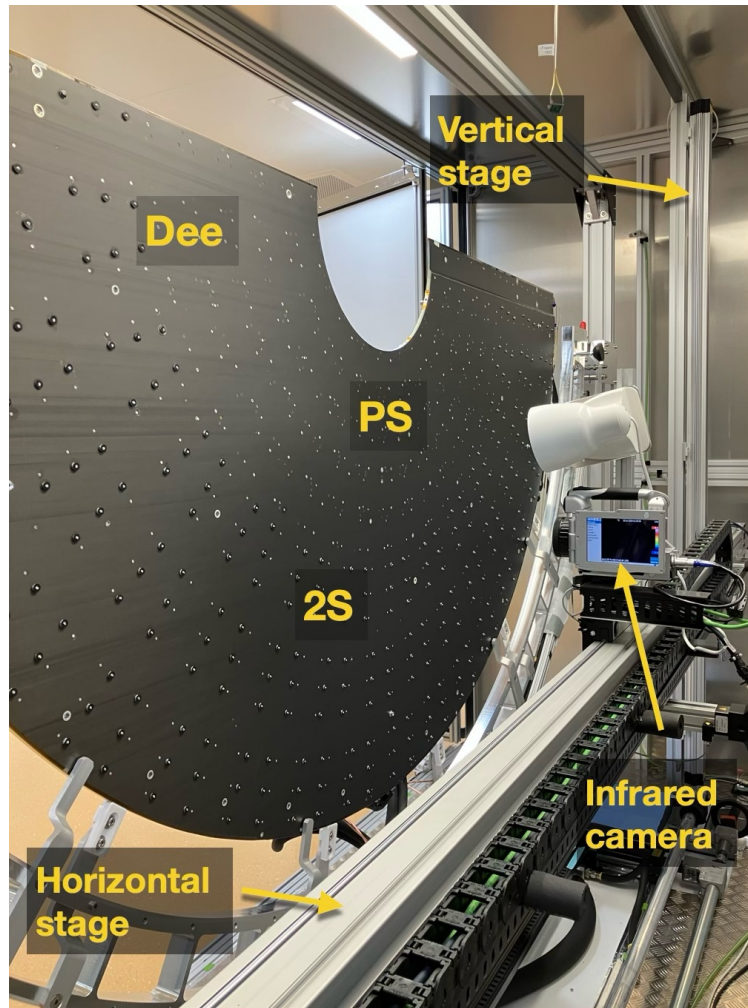
Four PS modules assembled on a single day



Production progress at DESY

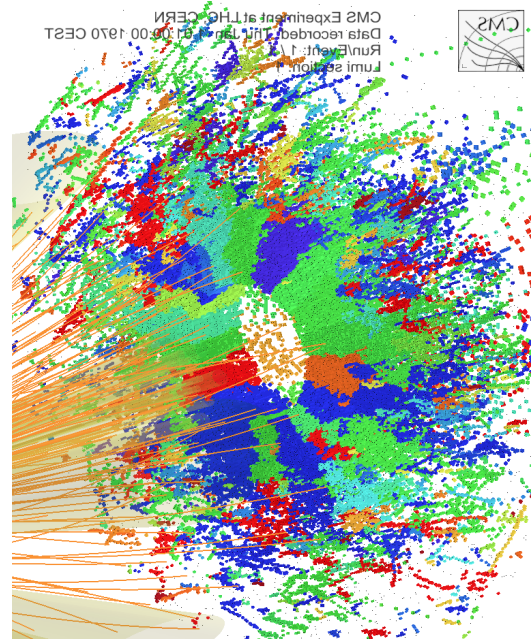
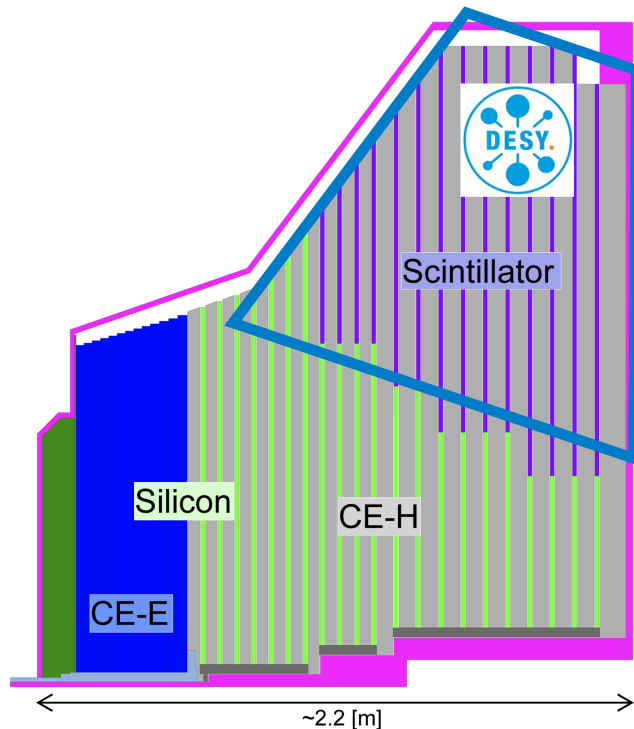
Tracker: Dee production progress

- **Dee production well on track**
 - Deliveries according to schedule
 - Only observed minor issues with components and during production that could be solved without compromising the Dee quality
- 4 pre-production and 6 production Dees measured in the infrared setup as part of the reception test
 - Thermal performance of the Dees are comparable with each other



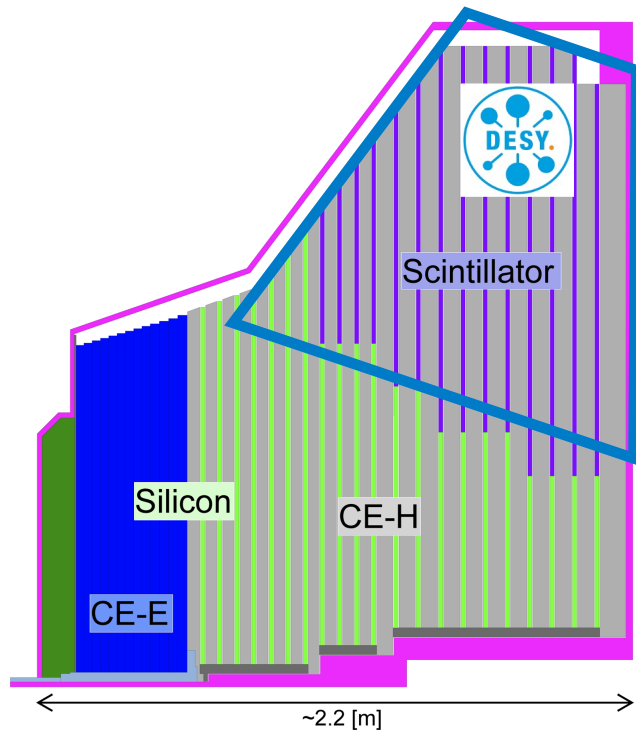
Upgrade project: High Granularity Calorimeter (HGCAL)

Silicon-photo-multipliers on scintillator tiles („SiPM-on-tiles“) part at DESY

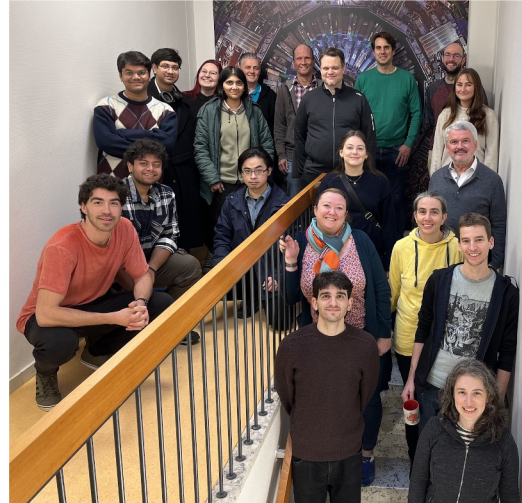


- First **particle flow calorimeter** at a hadron collider, first precise **5-D** calorimeter with the timing information
- First machine-learning calorimeter!
- HGCAL is key to **improving high profile physics topics** at HL-LHC that we are interested in:
 - HH, H signatures, VBF, tau signatures, vector-boson scattering
 - Pileup improvement
 - Forward flavour-tagging
 - Enabling more exotic signatures and specific searches with HGCAL

HGCAL scintillator part: DESY contribution



CMS + FTX team



2x 14 mixed layers
1008 Motherboards & Wingboards
3744 Tilemodules in 32 variants
280'000 tiles & SiPMs

Tilemodule = Tileboard + tiles

DESY contribution

- Development of active elements and automated production
- **Production of 2000 modules (50%)**
- System tests / test beam
- Low-level software (mapping and calibration)

Now in (pre-)production at DESY

- Tiles: >6% of tiles wrapped and QCed
- Tileboard PCBs: 65% produced
- Tileboard electrical assembly: 15% done
- **Tilemodule tile glueing: 4% modules done**
- Quality so far: excellent

HGCAL: Production quality control (QC) tests

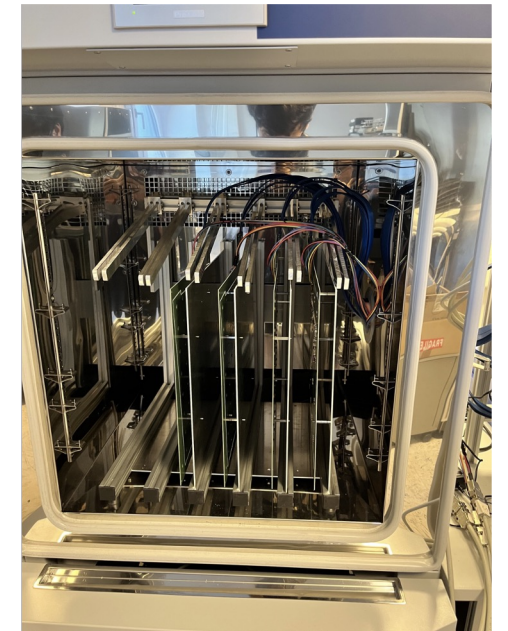
Tiles, Tileboards and Tilemodules

- Now **all QC test stands complete** and fully operational
 - Tiles: size and Light Yield
 - Tileboards warm and cold QC, determination of operational parameters
 - Tilemodules: mechanical cold test, cosmic test stand
- All test stands **reach expected throughput** (150 modules/month) or are close
 - Tiles: few minutes/tile
 - Tileboard warm QC: 35 minutes/board, 2 test stands
 - Tileboard cold QC: ~2.5 hours/3 boards
 - Tilemodule cosmic test stand: 2-3 days/18 modules

Tileboard warm QC



Tileboard cold QC



cosmic test stand



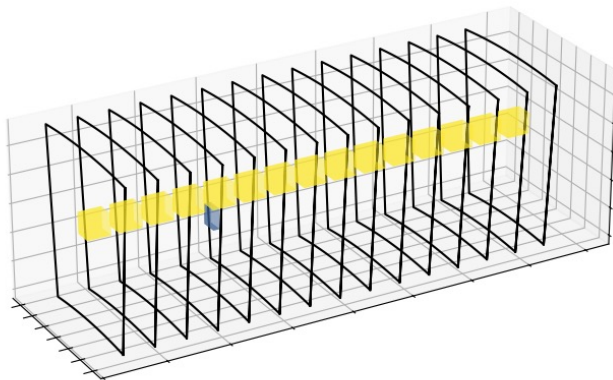
HGICAL: Small EM stack with pre-series tilemodules

Beam test at CERN SPS in Sep. 25

- 15 layers of 1.7 cm steel absorber
- **15 layers of pre-series tilemodules: 8 DESY modules, 7 US modules**
- Readout system developed by KIT, defined by availability of hardware
- Tested with 8 modules in DESY beam test in March 2025
- Testing ground for DESY-developed low-level software

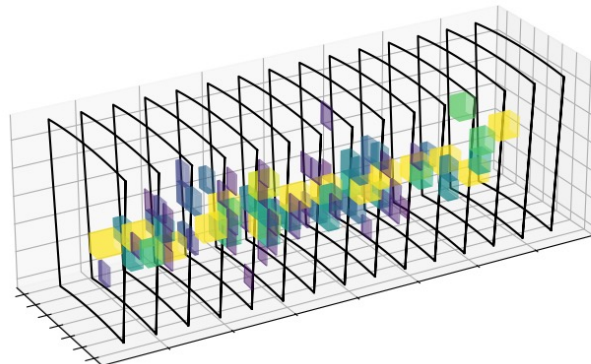
Run '2025-09-26_15-33-12_muons_200GeV_S1S4_pos6'
Event 16217827895258

Position scan with **muons**



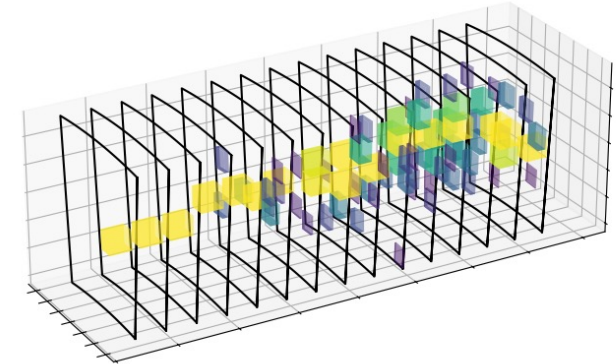
Run '2025-09-26_20-50-22_electrons_20GeV'
Event 16217856697036

Energy scan with **electrons**



Run '2025-09-29_17-19-15_piminu'
Event 16217856697036

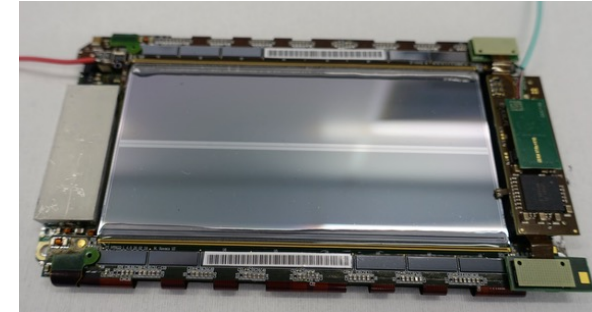
Pions for comparison



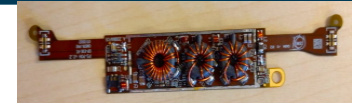
bPOL12V DCDC converter issue

Affects large fraction of the HL-LHC experimental upgrades

- bPOL12V DCDC converter chip show **vulnerability when power-cycled at cold after irradiation (30Mrad)**
 - First observed by ATLAS iTK by chance and reproduced by CMS Tracker
 - Full extent of problem yet to be understood
- Outer Tracker: bPOL12V chip used on PS power hybrid and 2S service hybrid, on every module
 - Module production essentially stopped
 - **Continue producing bare modules without hybrids**
- HGCal: bPOL12V chip integrated on all tileboards
 - **Assembly of tileboards and tilemodules on hold**
- **We are on the way of finding solutions for Tracker and HGCal at DESY to mitigate the impact of the problem on the production**
- Experts/designers at CERN and elsewhere investigating, CMS has setup a task-force
- At the moment impossible to quantify the impact on the schedule



bPOL12s on PS hybrid

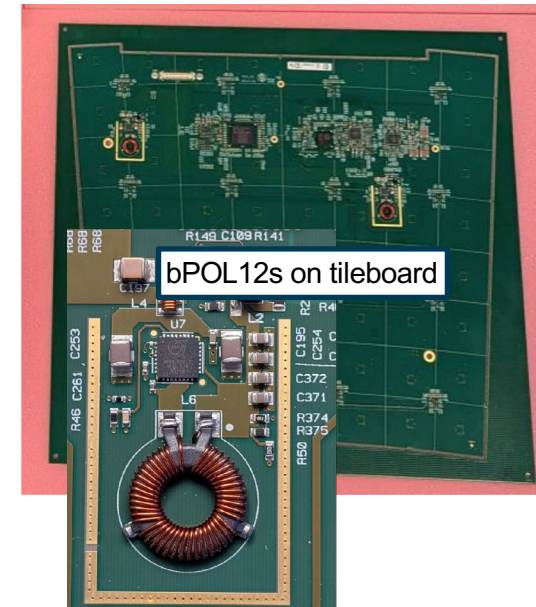


Outer Tracker 2S

- 7.6k
- -35C
- up to 12 MRad

PS

- 6k
- -35C
- up to 80 MRad



bPOL12s on tileboard

HGCal

Silicon

- 54k
- -35C
- up to 25 MRad

Tiles

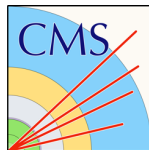
- 8.5k
- -35C
- up to 250 kRad

Activities during PoF V

Detector operation
BRIL, DQM

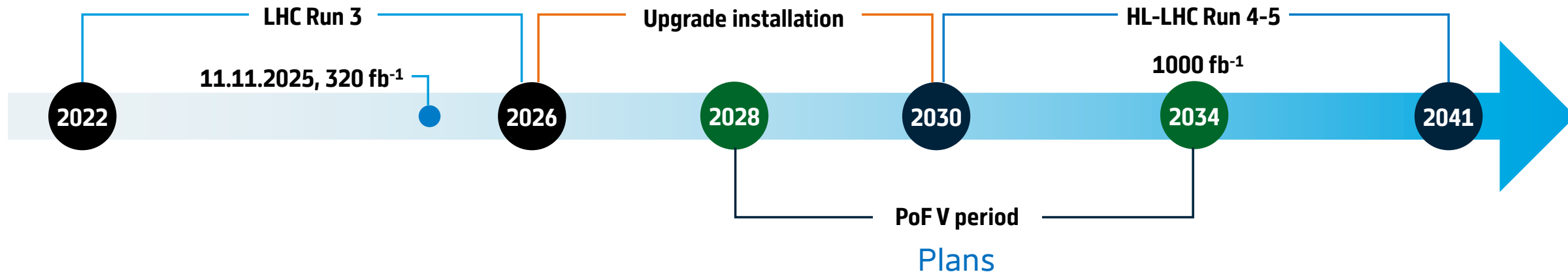
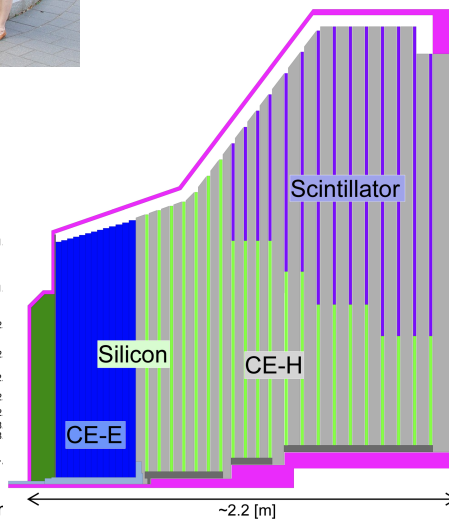
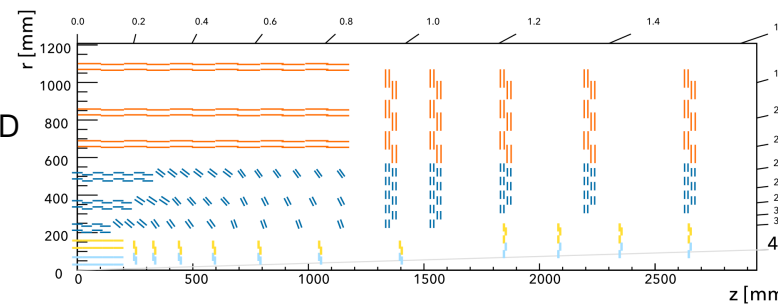
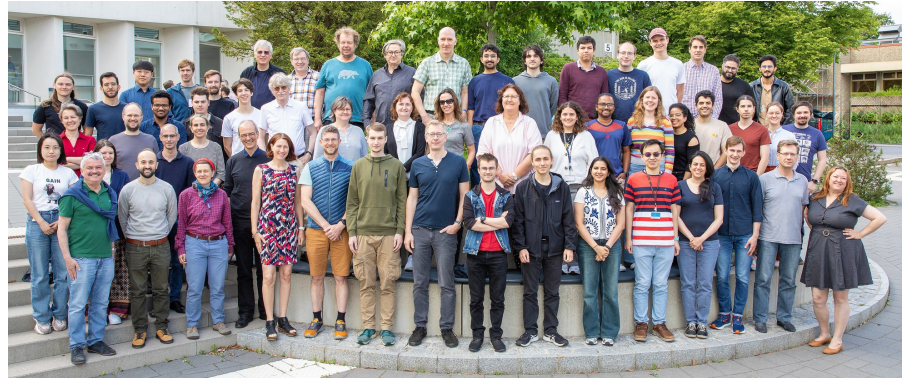
Computing
Tier2, NAF

Physics analysis
Higgs, SM, Top, Searches



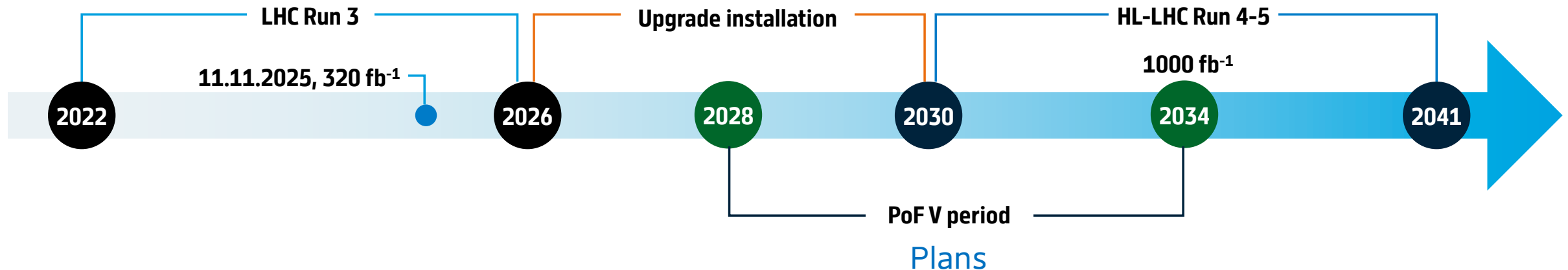
Reconstruction/Calibration
Alignment, Luminosity, Taus, Jets

Detector upgrade
Outer tracker, HGCal, BCM1F, generic R&D



Exploit group expertise in PoF V

- **Capitalize on expertise with the upgrades at DESY**
→ **Take leading role in:**
 - Commissioning (2027-2029)
 - Early data taking (2029-2030)
 - Initial alignment and calibration (2029-2030): profit from existing know-how and test beam experience
 - Initial performance papers (2030-2032) profit from production experience
- **Perfect opportunity for young people to "touch the detector" and become real experimentalists**
- **Profit of the machine learning and reconstruction/calibration papers being written in our groups**
 - Reconstruction and low-level expertise at DESY (alignment, particle flow, ...)
 - Be the first/leading to put this in HL-LHC physics analyses
 - Let's show that it works in real life!



Fundamental Interactions

Pushing the limits of our understanding of fundamental interactions

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

- SRF systems
- Hadron & electron acc.
- Beam control, diagnostics, dynamics
- Plasma accelerators

Accelerator R&D (ARD)

Accelerator Science and Technology for highest performance and sustainability

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

- EW symmetry breaking
- Higgs portal
- Top, beauty, tau physics
- CP violation
- Lepton flavor universality

- Sensing and detecting
- Quantum technologies
- Systems and systems technologies
- Detection methods

Detector Technologies and Systems (DTS)

Advancing discovery through world-leading detector innovation

The Early Universe

Exploring the evolution of the early universe and the nature of the dark sector

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

- Frontier methods in computational and data science
- Sustainable solutions
- Innovation for research infrastructures

Data Management and Analysis (DMA)

Enabling and accelerating MATTER science with frontier digital solutions

Physics topics during PoF V



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

Fundamental Interactions

Pushing the limits of our understanding of fundamental interactions

The Origin of Mass

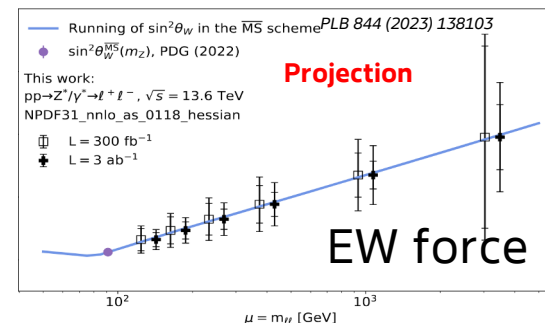
Covering the puzzle of the origin of mass and of flavour, and the imbalance between matter and ant-matter in the universe

The Early Universe

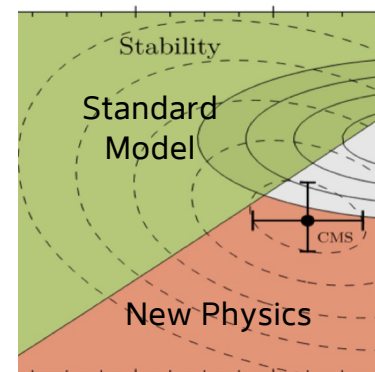
Exploring the evolution of the early universe and the nature of the dark sector

- **EW precision and Higgs physics (HH, H potential)**
 - Strong-field QED
 - **QCD (incl. lattice and QC)**
 - **Probing SM extensions**
- **EW symmetry breaking**
 - **Higgs portal**
 - **Top**, beauty, tau physics
 - CP violation
 - Lepton flavor universality
- Cosmology (inflation, ...)
 - **DM searches (WIMPs, axions, ALPs, ...)**
 - Gravitational waves
 - EW phase transitions

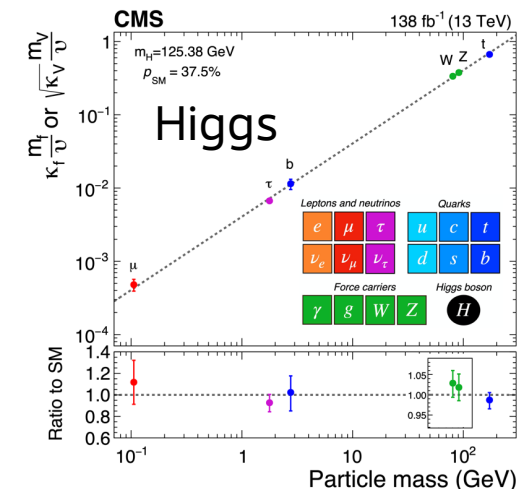
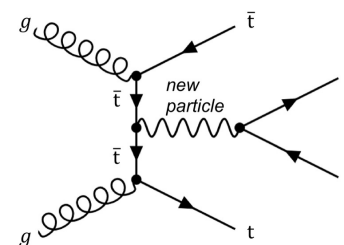
EW mixing angle



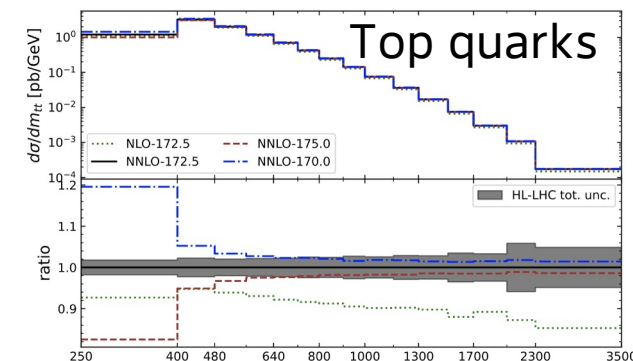
Strong coupling



Top mass

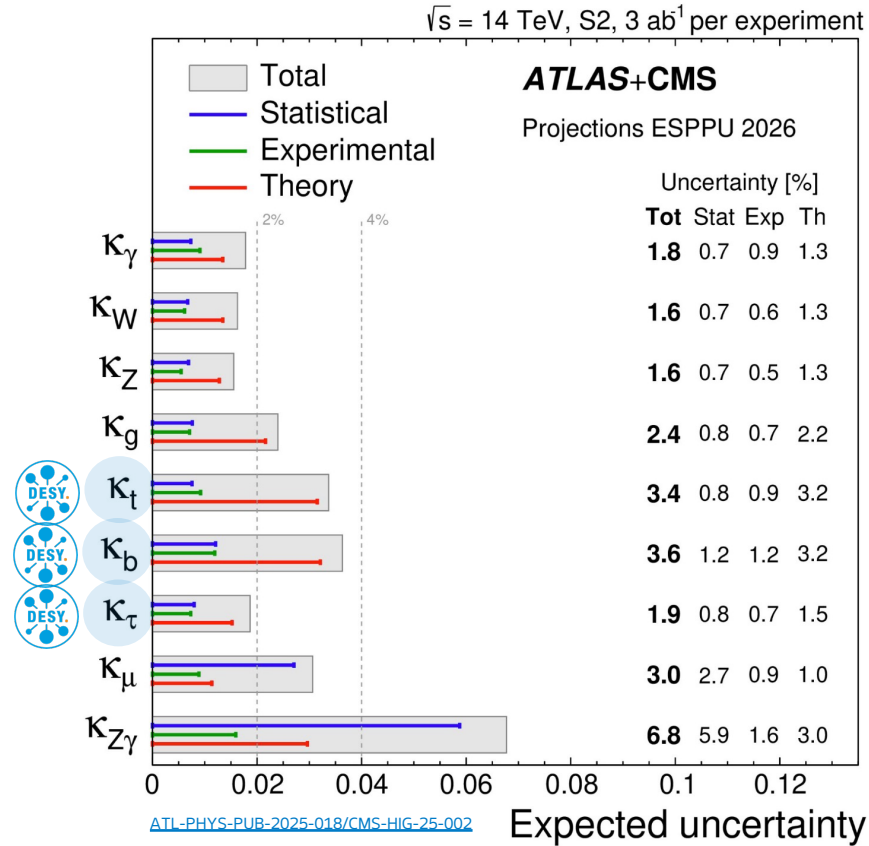
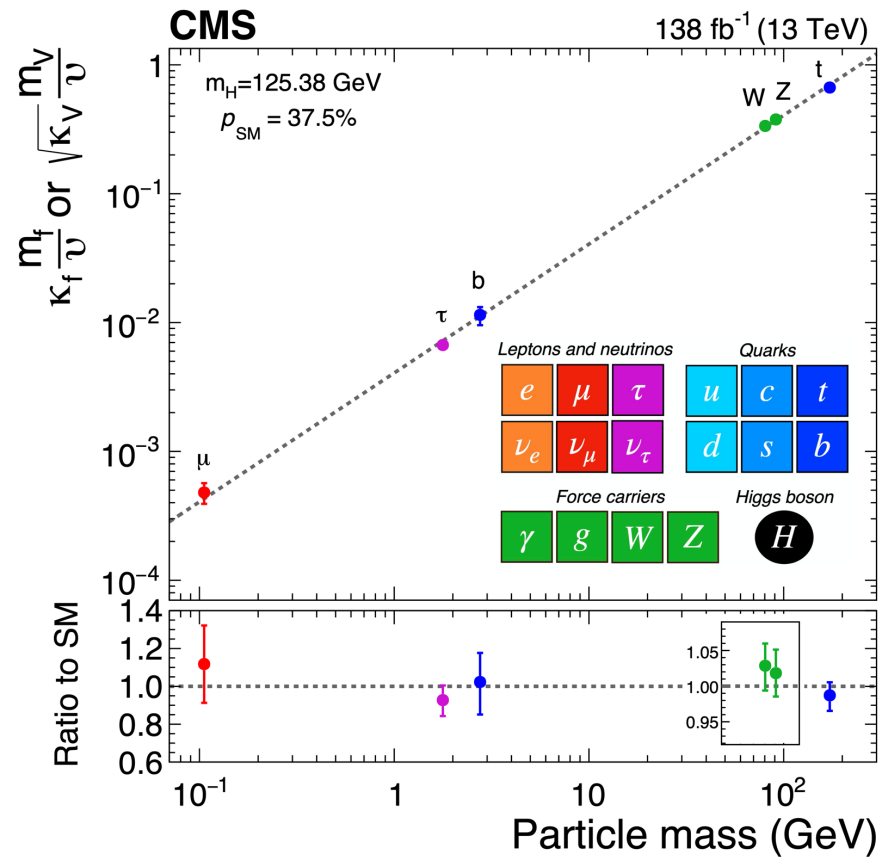


Strong force



Dark matter Axions

Investigating the detected Higgs boson

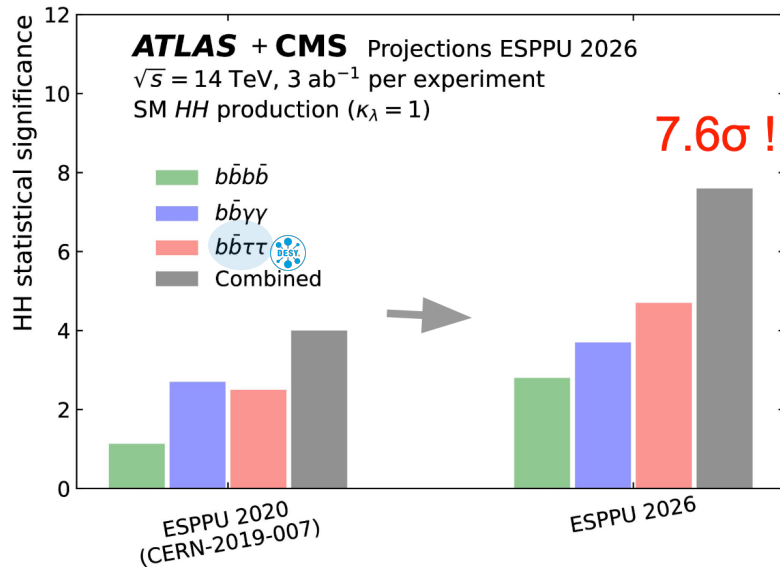
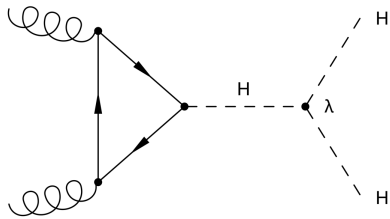
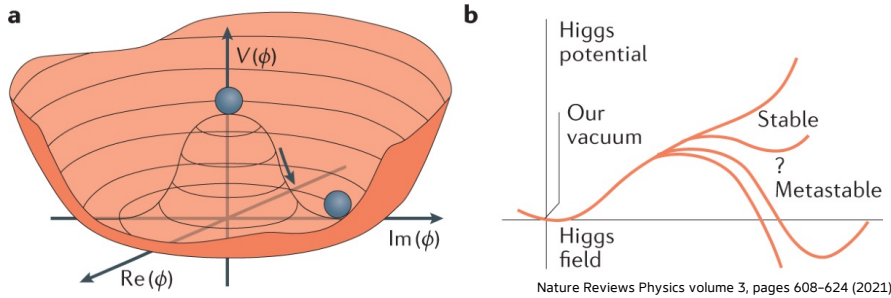


- Investigating the detected **Higgs** boson
 - CP coupling
 - BSM contributions?

Taus at L1 trigger
using HGCALE + ML
→ lower thresholds

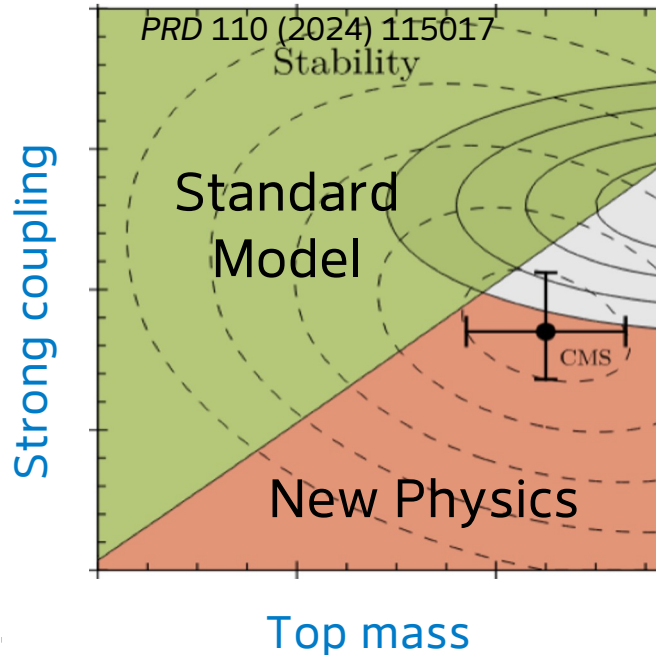
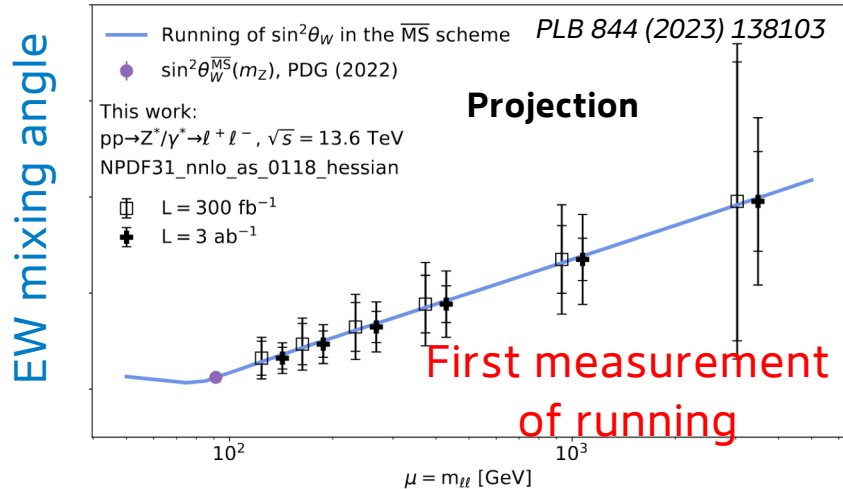
Tracker + ML
→ improved b- and
tau-tagging

Tackling the di-Higgs production



- **Probing the Higgs potential and the mechanism of electroweak symmetry breaking!**
- **Does the Higgs boson couple to itself as we expect?**
 - We can **measure this for the first time!**
 - Room for surprises:
 - new heavy resonances** could enhance cross section!
 - Most sensitive channels are exactly those where we profit from expertise on object performance
 - DESY with both ATLAS and CMS groups is in an excellent position to work on **combinations**
- **Discovery during PoF V in Run 3 and/or Run 4 expected**

Precision tests of the fundamental forces



Is our Universe stable?

Improve by factor of 2!

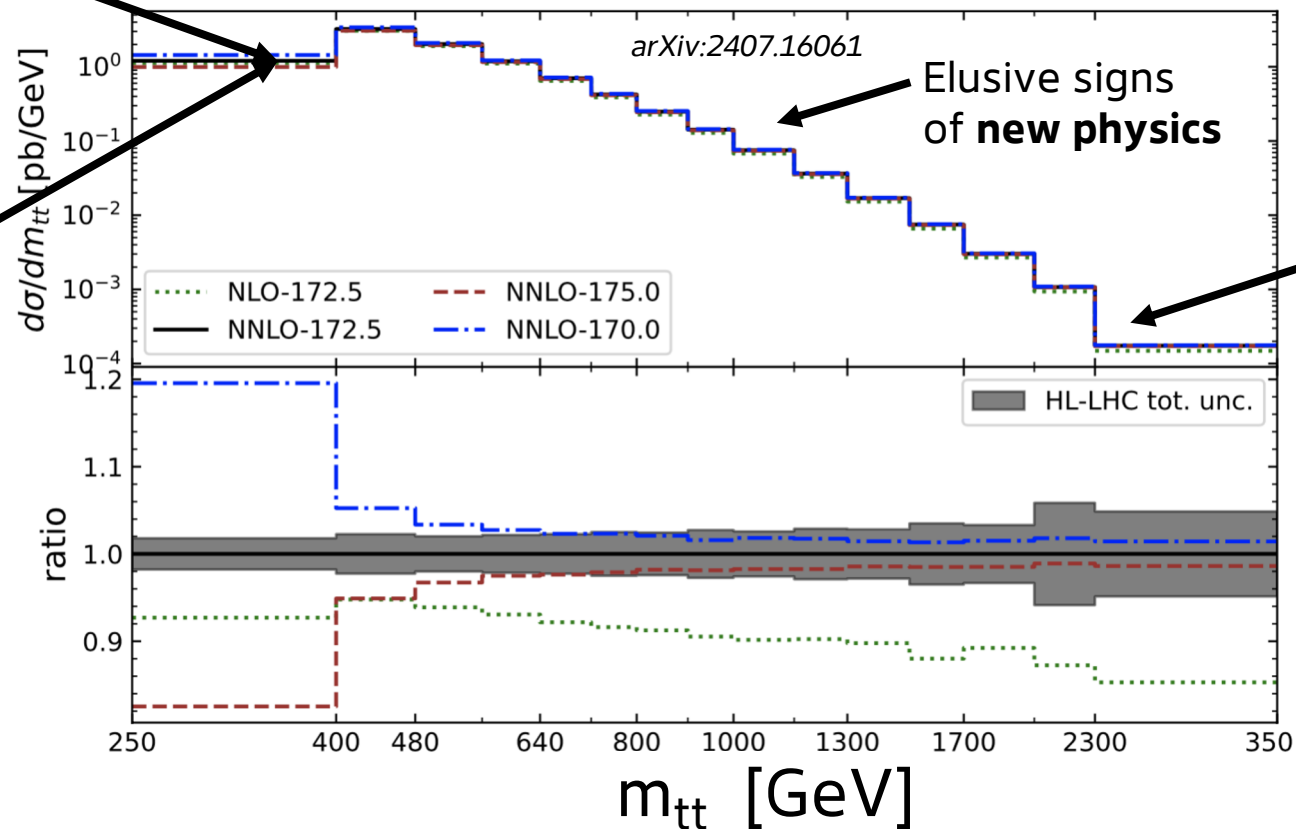
- **ElectroWeak (EW) force:**
 - Measurements of the fundamental parameters , e.g. EW mixing angle (exploiting new forward tracking)
- **QuantumChromoDynamics (QCD):**
 - Precision tests, e.g. measurement of the strong coupling parameter α_s at the LHC
 - Lattice calculations
- **Understanding of the content of matter**
 - Measurement of parton distributions
 - Common effort of theory and experiment: treat correlations of SM parameters and PDFs in global SMEFT interpretation

Understanding the top quark as a quantum state

From non-relativistic to highly-boosted regime – ultimate stress test of SM and window to BSM

Probe **tt bound-state** structures (toponium?)

Sensitive to **top mass**



Elusive signs of **new physics**

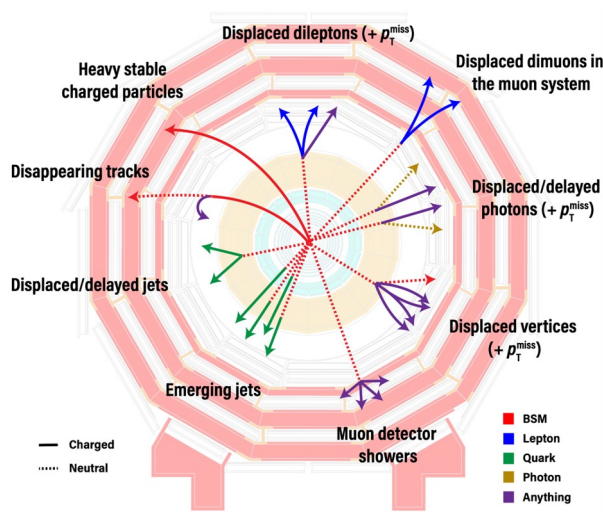
Sensitive to m_{top} from **boosted top jets**

Bring light into open questions

What is dark matter? Why is the Higgs boson so light?

Search for extensions of the SM, but also for the unknown

**New physics with long-lived particles
(incl τ leptons, jets, leptons)**

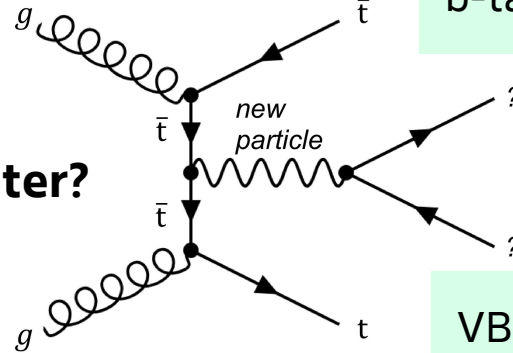


New L1 triggers (HGCAL)

τ -reco (Tracker)

New physics in (multi)top final states
(full range: single top+X through tttt(+X?) signatures)

Dark Matter?



b-tagging (Tracker)

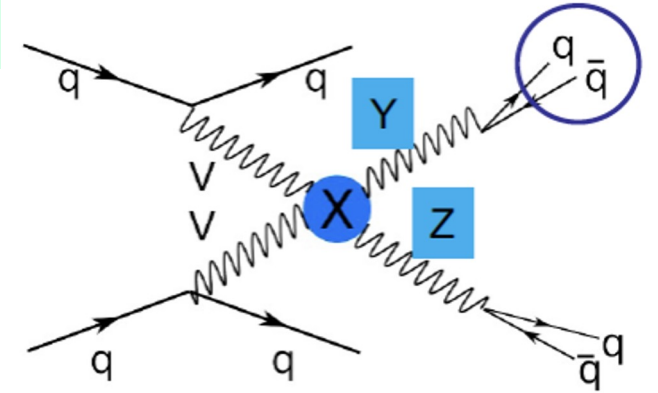
Axions?

VBF/forward jets
(HGCAL/Tracker)

Machine learning for

- Object identification
- Background prediction
- Event classification

VBF-produced new physics



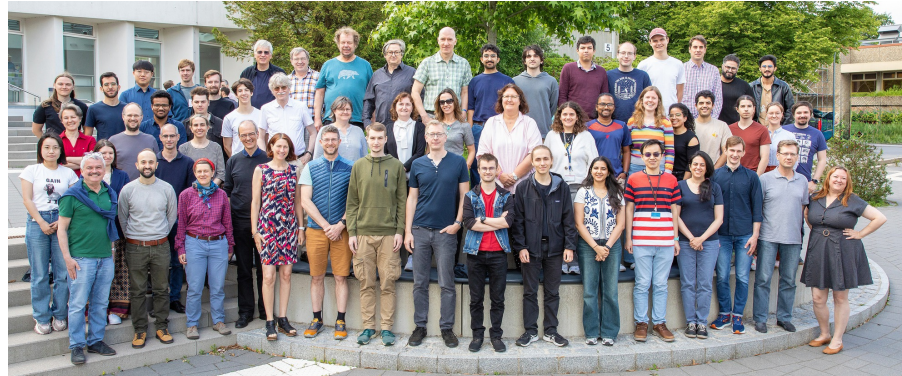
Jet-substructure (Tracker)

**This broad strategy is sensitive to many
BSM scenarios and ready for (positive)
surprises in PoF V**

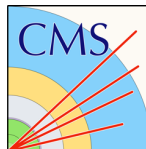
CMS AT DESY

Detector operation
BRIL, DQM

Computing
Tier2, NAF

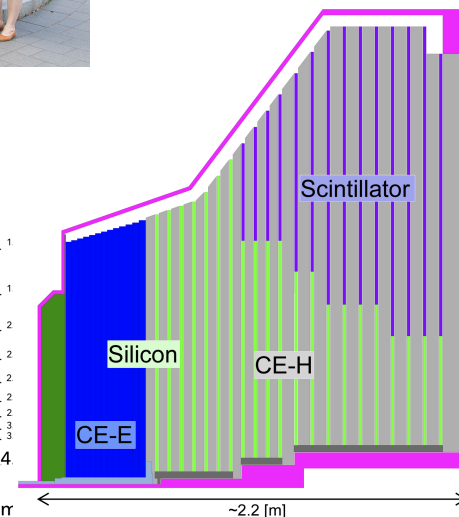
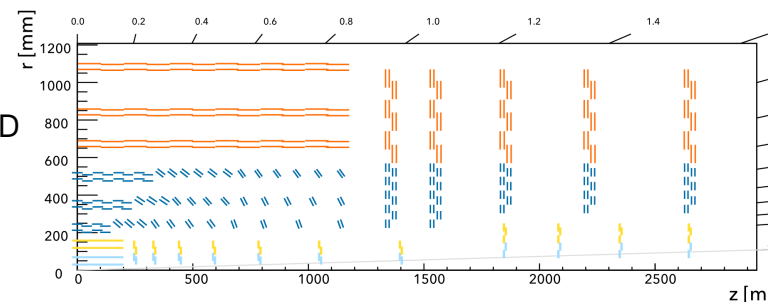


Physics analysis
Higgs, SM, Top, Searches

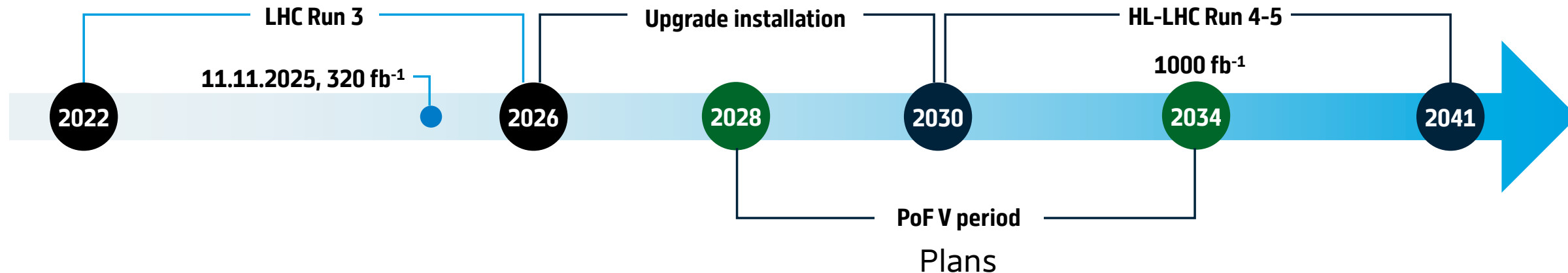


Reconstruction/Calibration
Alignment, Luminosity, Taus, Jets

Detector upgrade
Outer tracker, HGCal, BCM1F, generic R&D



112 fb⁻¹ in 2025!



Backup material



Observation of tWZ production

