Experience of a former Gentner Student

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CERN
Experimental Physics Department
Detector Technology Group

25th Wolfgang Gentner Day - CERN
24 April 2024

Main steps and activities in High-Energy Physics

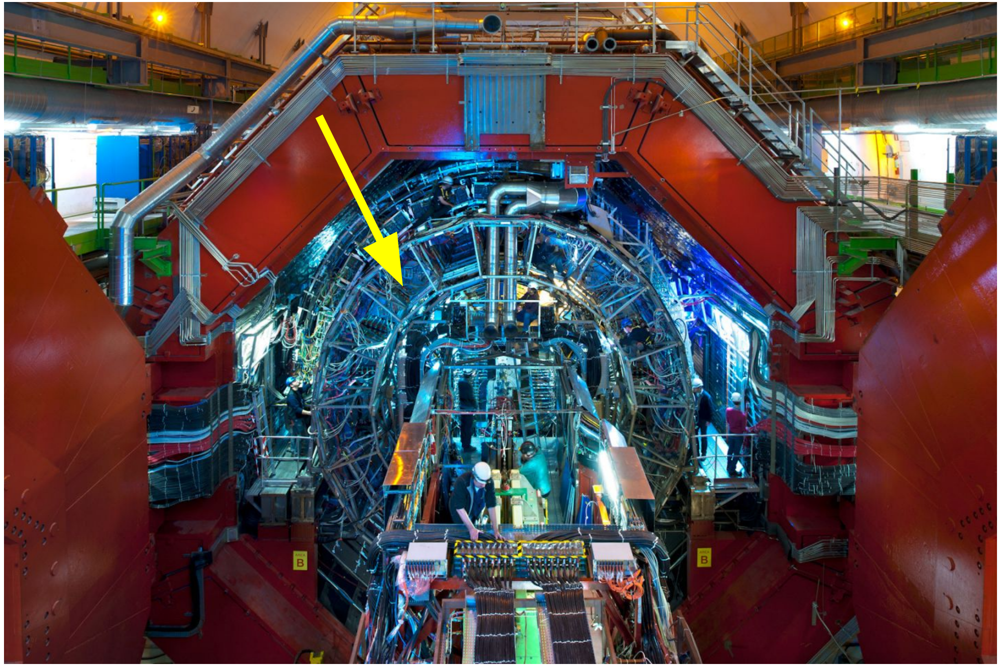
Institutes: Universität Münster | Universität Münster, CERN | CERN, lapp, Uni Freiburg | | CERN

	Years	2007--------2009	2009---------------------2012	2012---------------------------2015	2016	2016---today
	Experiment	ALICE	ALICE	CLICdp	ATLAS	CMS & CLICdp
	Status	MSc student	PhD student	Fellow & Postdoc	Postdoc	Staff
HEP activity	Physics analysis		■	■		
	Simulation		■	■		
	Detector hardware	■		■	■	■
Detector techno-logy	Gas detector	■	■			
	Scintillator tile detector			■		
	Silicon detector			■	■	■
Detector type	PID: Transition Radiation	■				
	Tracker	■	■	■	■	
	Imaging Calorimeter			■		■
Supervision	Formal supervision		1x summer student	2x summer students 1x technical student		3x technical students, 1x trainee (MSc) 5x doctoral students 5x fellows
	Thesis supervision			1x MSc		2x PhD, 1x MSc 3x PhD, 1x MSc ongoing
	Team size					Increasing from 3 to ~10

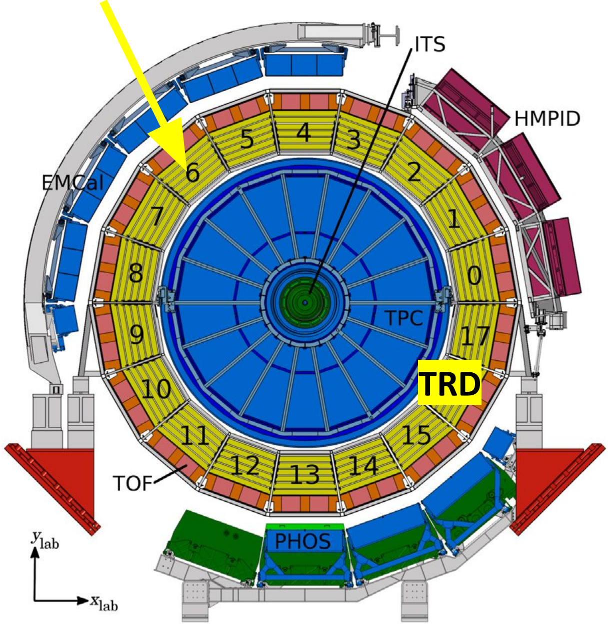
Indefinite CERN contract since end of 2022

Master student

Physik Diplom (~MSc): ALICE experiment

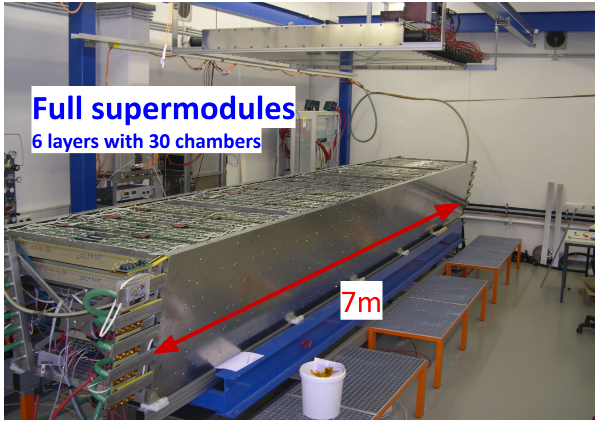


TRD: Barrel detector with 18 sectors called “supermodules”



- Thesis work in time with planned start up of the LHC (2008)
- Joined Münster university group working on ALICE Transition Radiation Detector (TRD)
  - Charged particle **tracking** and **e/π separation** via Transition Radiation emitted by light electrons

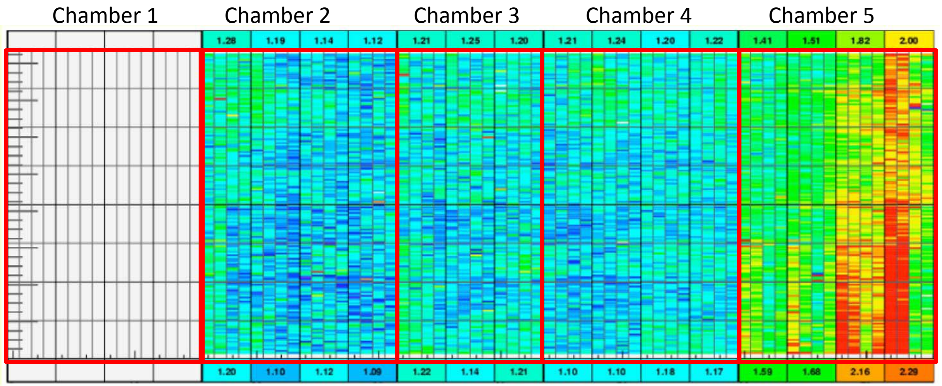
Assembly of ALICE TRD supermodules in Münster



- Assembly work with fellow students and postdocs
  - Mechanical structure
  - Installation of readout units ("chambers")
  - Connecting low and high voltage, gas supply (Xe-CO_2), water cooling, Ethernet, glass fibres (trigger, readout)
- First visit of CERN
  - Supermodule repair and re-assembly before installation

First measurements with TRD supermodules

Noise measurements with one layer

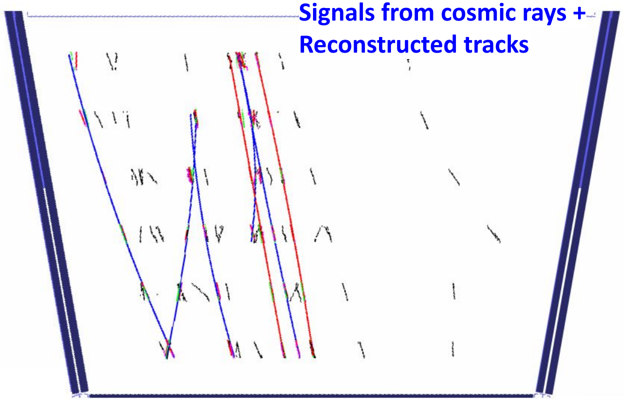


No data: Chamber not connected

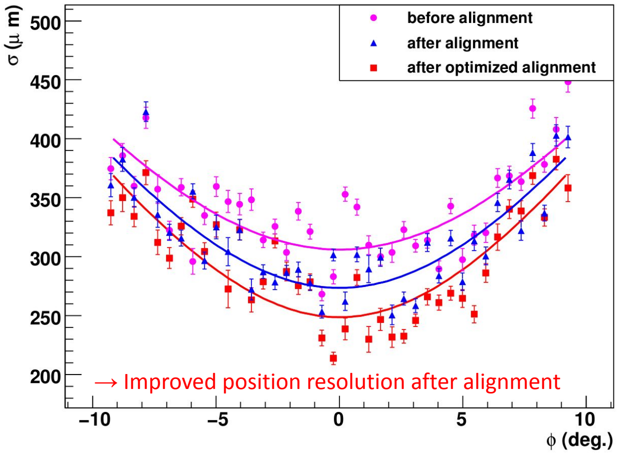
High noise: Verify grounding

- Noise measurements
  - Verify connectivity and grounding
- Record cosmics ray data
  - First tests of reconstruction software
  - Alignment of sub-components ⟶ Diplomarbeit

Signals from cosmic rays + Reconstructed tracks



TRD position resolution vs. track angle



Gentner Doctoral student

PhD studies in ALICE (University of Münster / CERN)

My main work topics in
ALICE Offline group

1. **Data quality monitoring** of first collision data with focus on ALICE's barrel tracking detectors ITS and TPC

2. **Geant4** (and Fluka) detector simulations of ALICE, as alternative to Geant3

3. **Physics analysis** of first proton-proton collision data, to better understand soft particle production

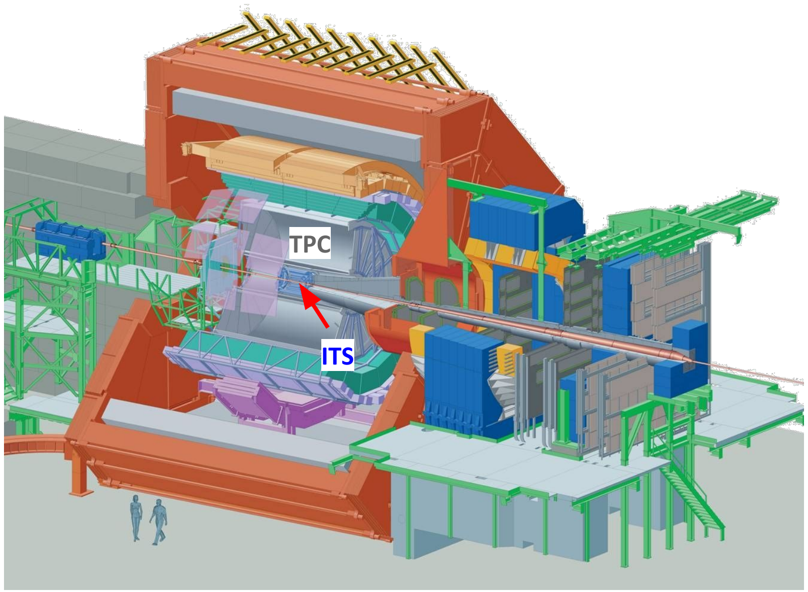
Major external events

- 2009: Talk Geant4 workshop
- 2010: Talk CHEP (co-author)
- 2010: Talk ALICE overview, MPI@LHCC
- 2010: European School of High-Energy Physics
- 2011: Poster Annecy Quark Matter
- 2011: CERN-Fermilab Hadron Collider Physics School
- 2012: Talk Rencontres de Blois
- 2012: Talk Geant4 technical forum
- 2012: Talk Collider cross talk (theory/experiment)
- 2012: Talk MPI@LHC
- 2013: Talk LHC seminar

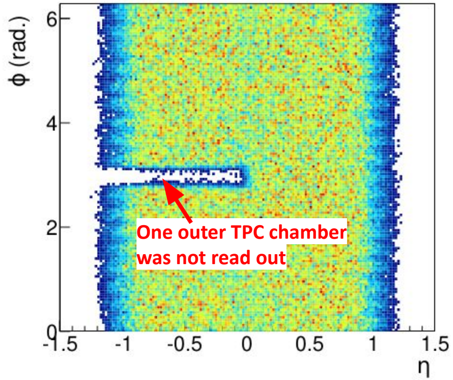
Thesis timeline

- 04.2009: First working day
- 10.2011: Starting write-up
- 08.2012: Thesis submission
- 09.2012: Defense

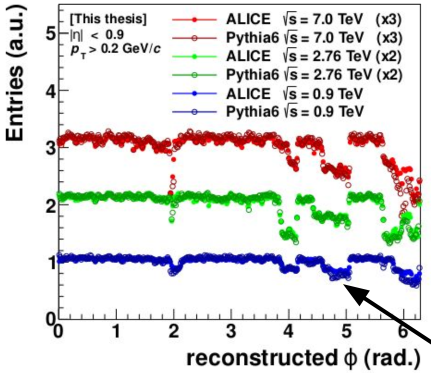
ALICE data quality monitoring



Tracks reconstructed with the TPC

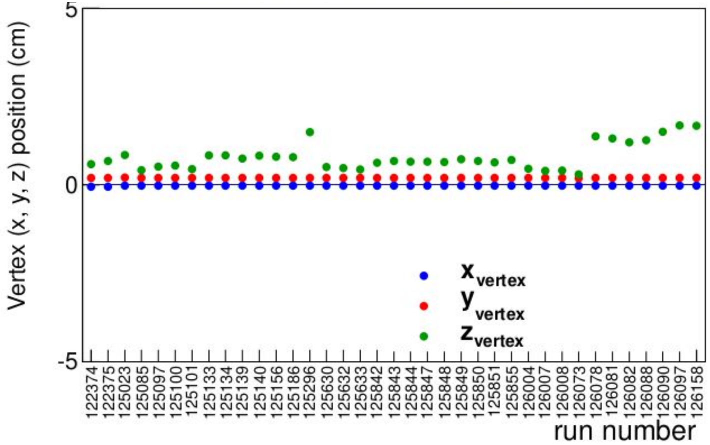


ITS+TPC reconstruction vs. azimuthal angle



Inefficiencies due to dead areas in innermost pixel detector of ITS

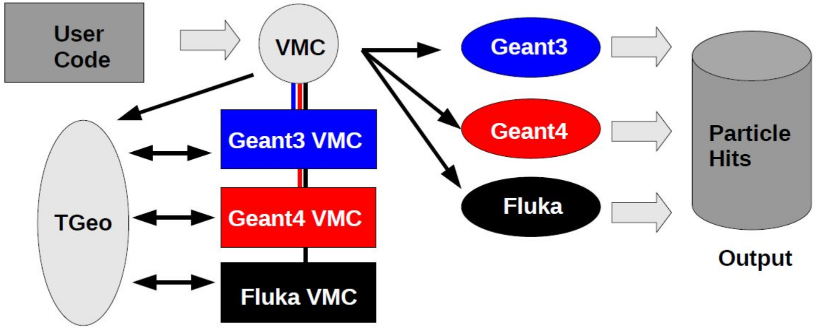
Mean vertex position vs. run number



- Data taking started in November 2009
- Analysed reconstructed pp and Pb-Pb collision data for tracking detectors ITS and TPC
  - Search for non-active or miscalibrated detector areas
  - Verify that detector status from data is mirrored in simulations
  - Study stability of reconstruction results over time (runs)

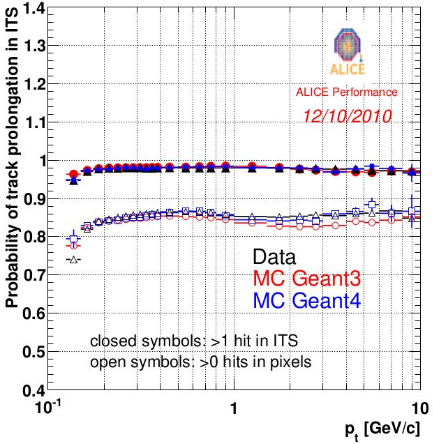
ALICE detector simulations

ALICE simulations using the Virtual Monte Carlo (VMC)

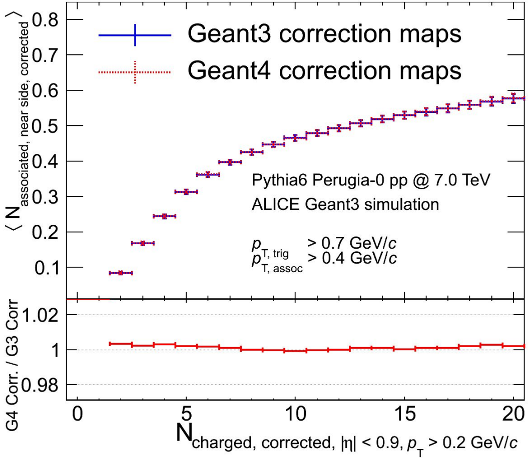


- Optimised and validated existing implementation of Geant4 simulation in the ALICE simulation framework
- Performed first large-scale ALICE Geant4 simulations on the ALICE computing grid
- Established Geant4 as the second official transport Monte Carlo besides Geant3

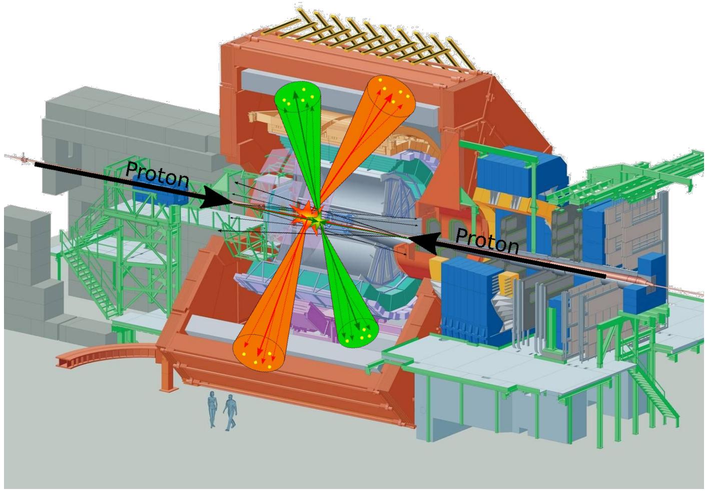
Comparison of TPC-ITS matching efficiency



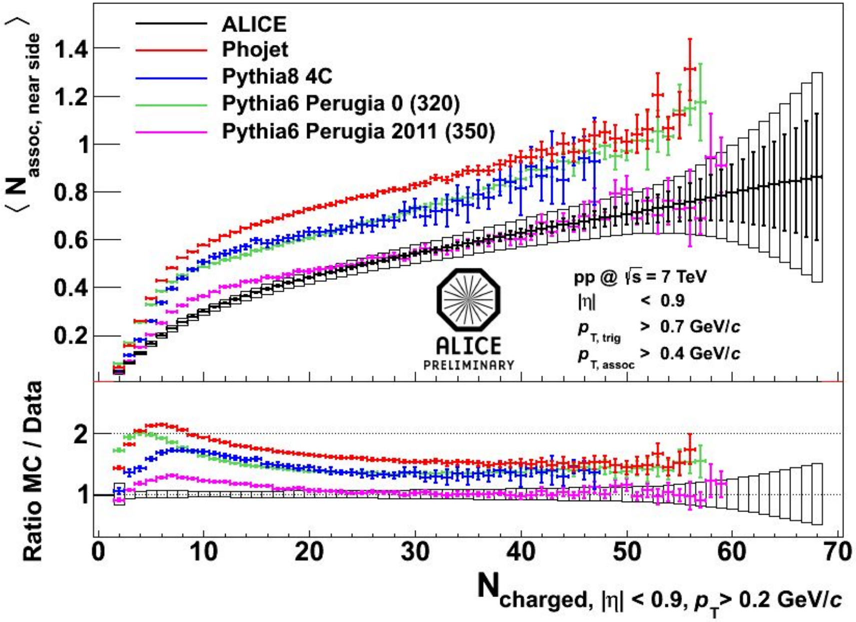
First use of Geant4 in systematic uncertainties



Study origin of particle production in pp collisions



Particles in near side jet cone:
Comparison of data to event generators



High-energy pp collision

- Potentially more than one parton-parton interaction
- Each parton-parton interaction can produce di-jets

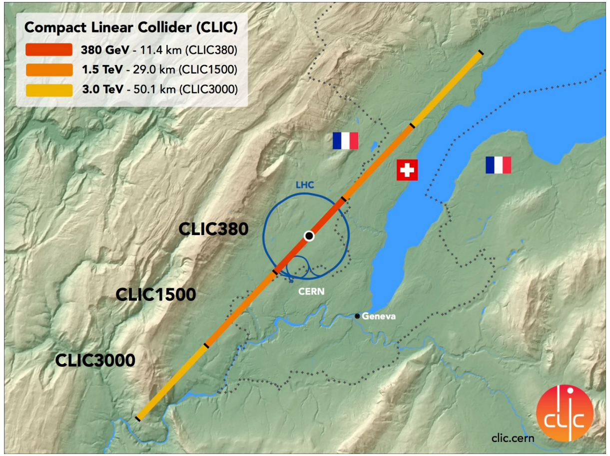
Study jet properties via two-particle angular correlations

- Information about jet fragmentation
- New method to probe multi-parton interaction and their contribution to particle production
- Improve event generators

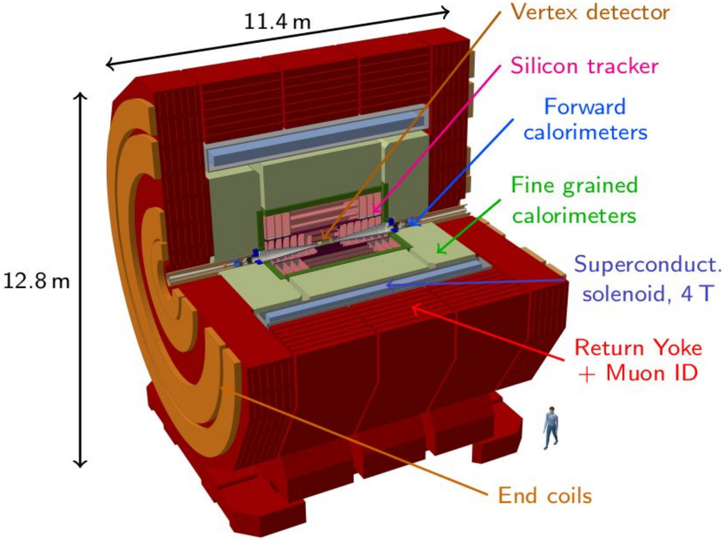
Fellow and Staff:
CLIC Detector and Physics

Detector and physics at CLIC

- Compact Linear Collider: CLIC
    - Future e^+e^- collider option for time after HL-LHC



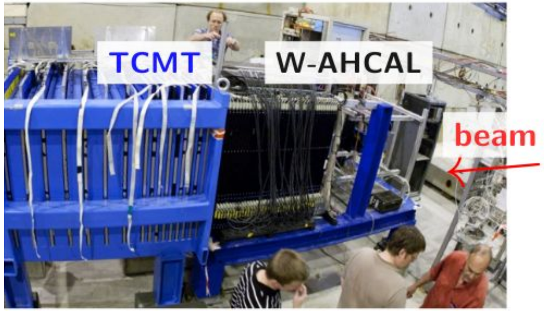
- CLIC detector and physics (CLICdp)
    - Detector development for CLIC
        - My focus: highly granular calorimeters, Calorimetry R&D collaboration: CALICE
    - Physics potential of CLIC
        - My focus: Higgs physics



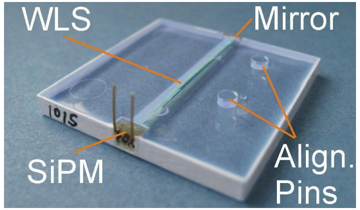
Calorimetry R&D for future collider experiments (2012–2015)

Test beam analysis:

Tungsten Analogue HCAL: Scintillator tiles + SiPMs



Scint. Tile: 3 x 3 x 0.5 cm^3

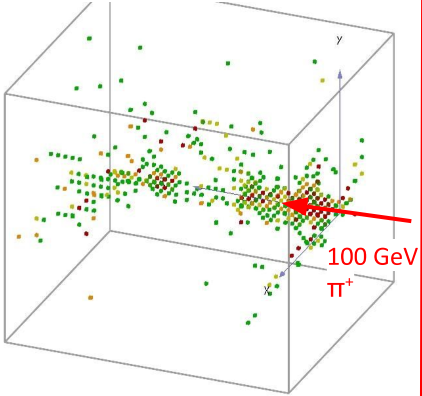


Beam test at CERN SPS:

- Data analysis, detector simulation and publication
- Studied detector response, shower shapes for different particle types
- Detailed study of systematic uncertainties

→ Two summer student projects on data analysis and simulation: Note

Example event:
~8000 readout cells in ~1m^3



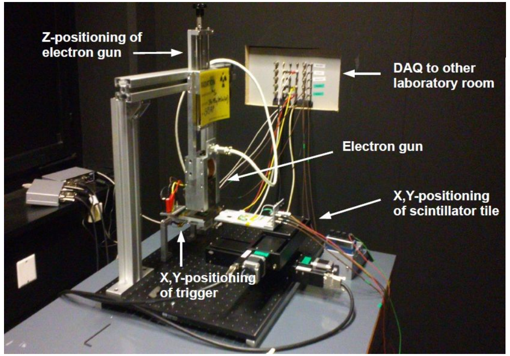
Hardware:

W-AHCAL results limited by understanding of

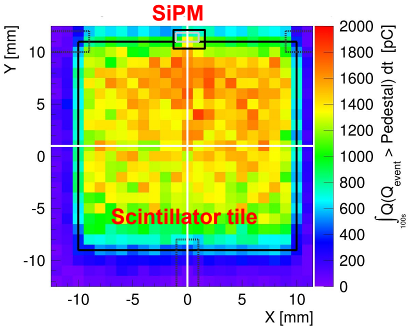
- SiPM temperature dependence
- Uniformity of tile response
- Inter-tile cross-talk

→ Technical student project on SiPM and scintillator lab measurements to improve understanding (MSc thesis)

SiPM and scint. characterisation setup based on electron gun



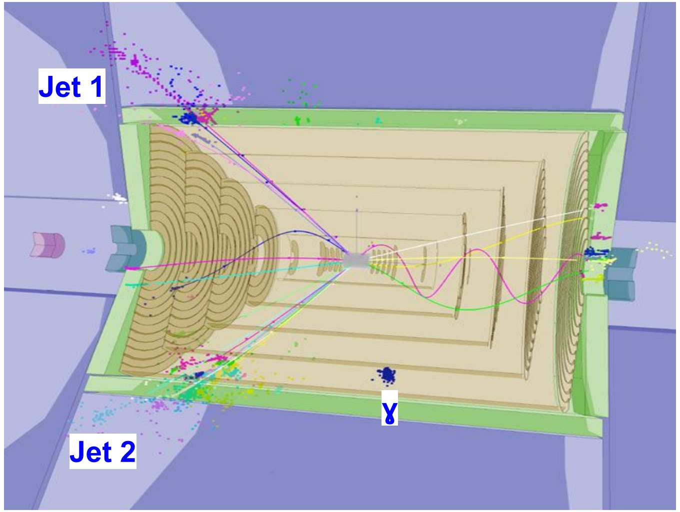
Calibrated Scint.+SiPM response

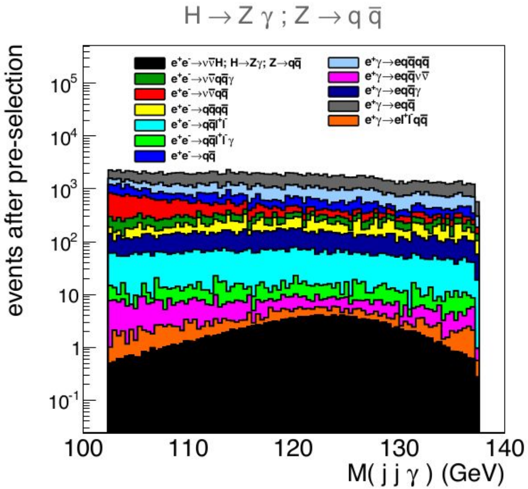


Physics potential of CLIC (2012–2017)

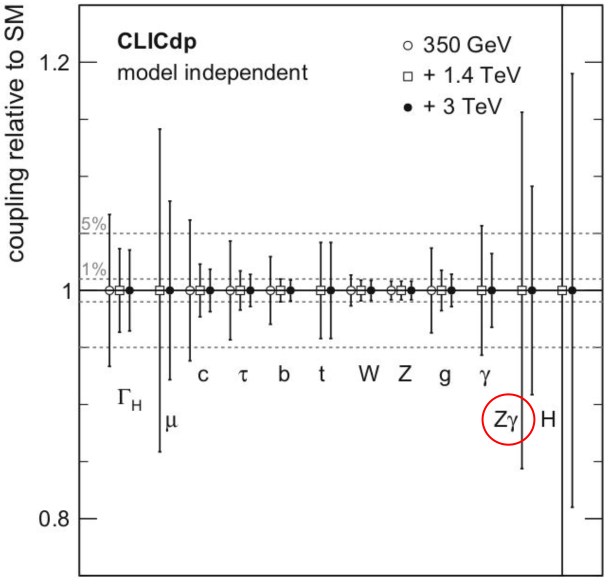
- Physics benchmark process $e^+e^- \longrightarrow H\nu\nu$; H ⟶ Zγ
- Event simulation, detector simulation, analysis and publication
- Contribution to the overview publication on Higgs physics at CLIC

Event display of H->Zɣ event at CLIC





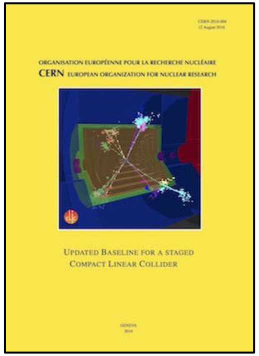
Precision of Higgs couplings in model independent fit

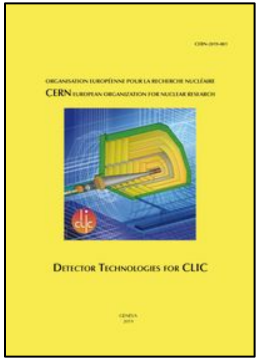


CLIC communication and outreach

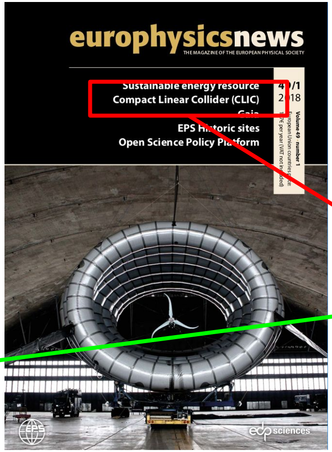
- Co-editor and author of 3 CERN Yellow Reports on CLIC
  as input to European Particle Physics Strategy Update 2019/2020
  1. Updated staging baseline of CLIC (2016) →link
  2. CLIC physics, accelerator & detector summary (2018) →link
  3. Detector Technologies for CLIC (2019) →link

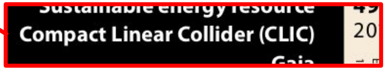
3 CERN Yellow Reports on CLIC

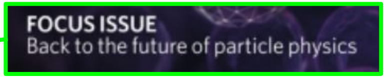




- Corresponding author of **"Nature Physics"** article on CLIC for focus issue on European Strategy Update (2020) →link
- Co-author for outreach article on CLIC in "Europhysics News" (2018) →link

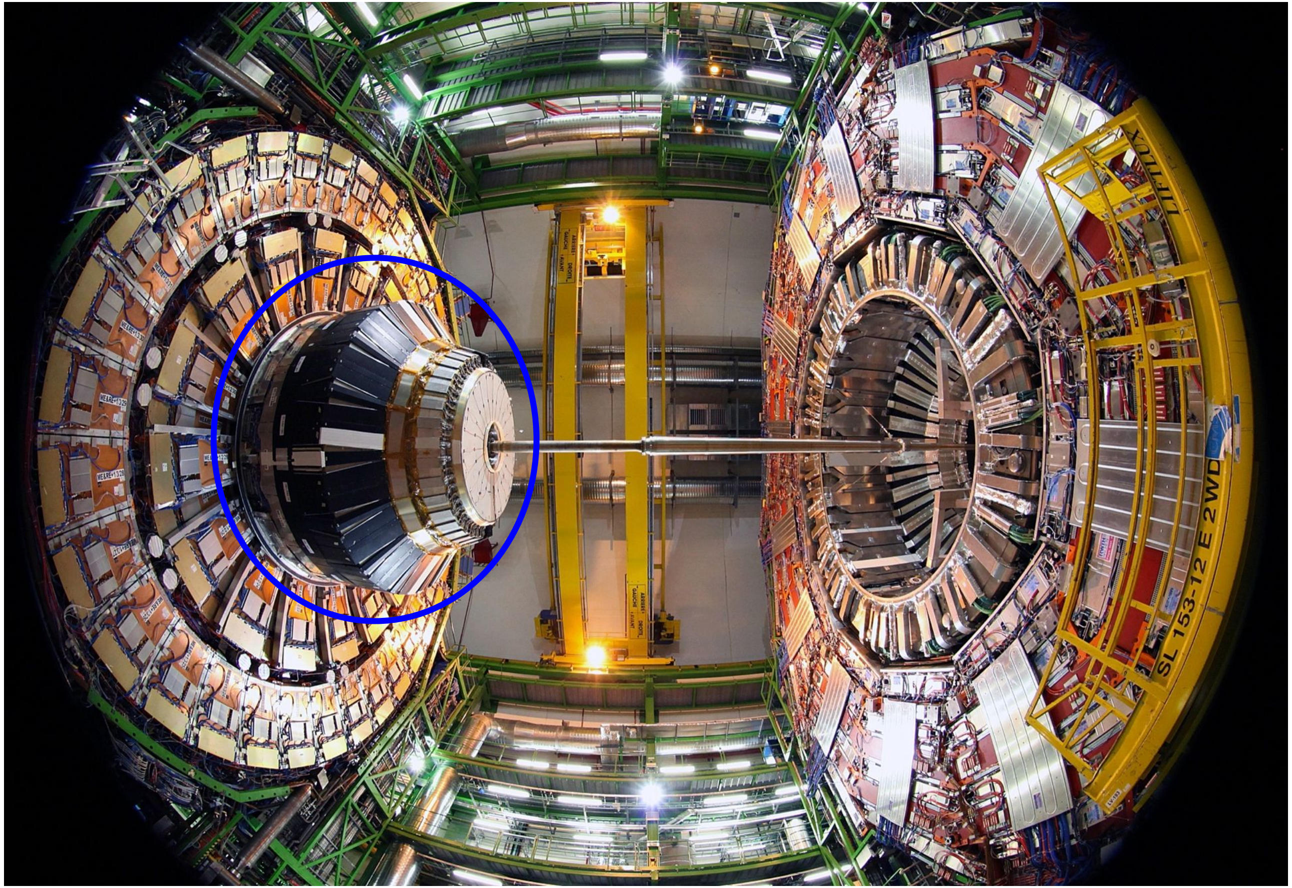


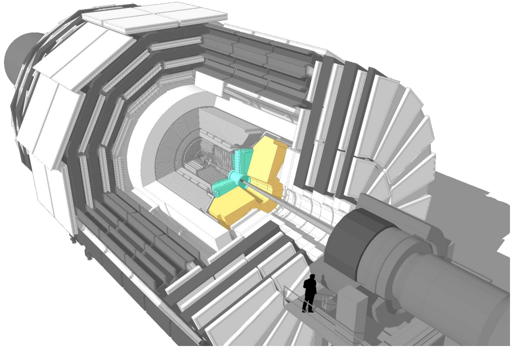




Staff:
CMS Calorimeter Endcap Upgrade

Current CMS Calorimeter Endcap



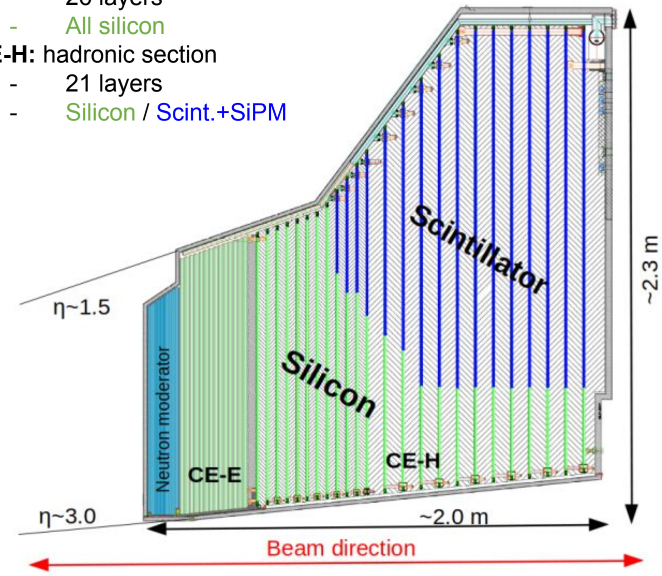


- At the end of the LHC life time, CMS calorimeter endcaps will have suffered severe radiation damage
- Requires replacement for operation of HL-LHC
- Requirements
  - Needs to be able to cope with harsh radiation environment and pileup

CE → in **H**ighly **G**ranular **CAL**orimeter concept

CE as highly granular sampling calorimeter

- **CE-E**: electromagnetic section
  - 26 layers
  - All silicon
- **CE-H:** hadronic section
  - 21 layers
  - Silicon / Scint.+SiPM



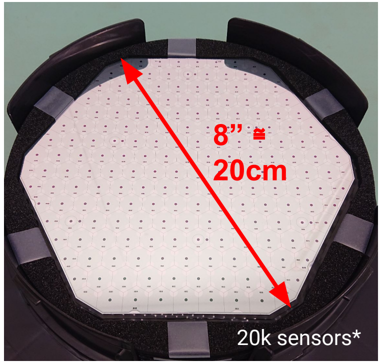
- Joined HGCAL with background from Linear Collider calorimeter R&D
- Started with beam tests
- Then took on silicon sensors & radiation hardness

Project scale and challenges:

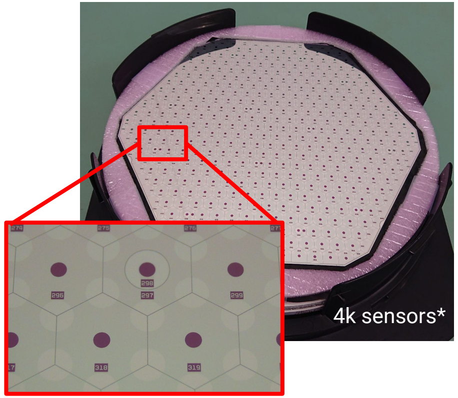
- By far largest project based on silicon sensor in HEP
  - → **~620m^2** of silicon: 3x area of ATLAS/CMS trackers
- First full-size imaging calorimeter
  - → Pave the way for all future collider detectors (e.g. CLIC, FCC)
- First application of 8” sensors in a detector at CERN (cost reduction)
  - → Very large and fragile objects
  - → Develop novel production process together with industrial suppliers
  - → Radiation hardness qualification
  - → Needed novel irradiation facilities

Main silicon sensor types

“Low-density” sensor with 199 cells



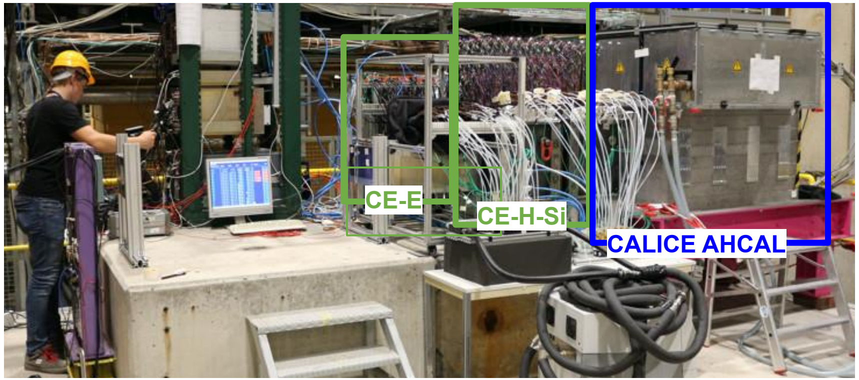
“High-density” sensor with 445 cells



* needed in the final detector

HGCAL beam tests (2016–2018)

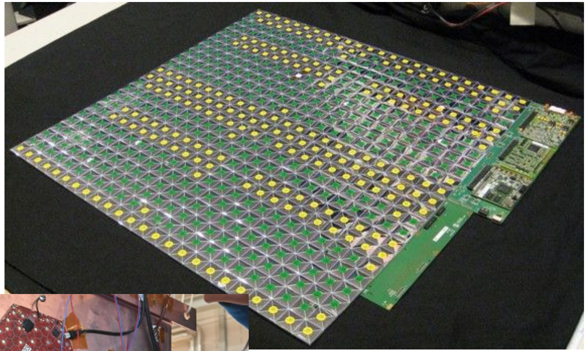
HGCAL 6-inch prototype: ~12'000 silicon channels



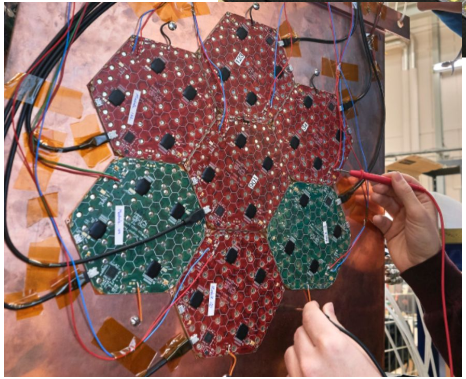
Event display: 250 GeV π^-

➔ PhD theses [1,2]
➔ CMS thesis award / Springer thesis by Gentner student
(annually for 3 CMS theses out of ~100 CMS theses)

CALICE AHCAL layer:
576 scintillator tiles + SiPMs



CE-H-Si layer:
Seven 6" modules



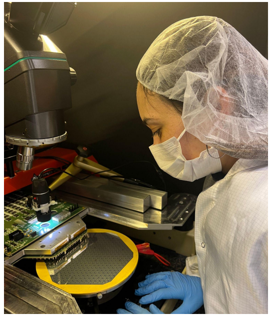
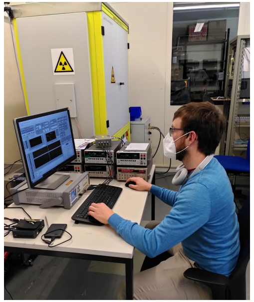
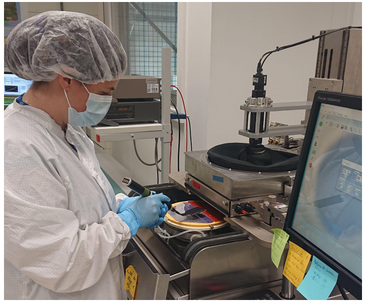
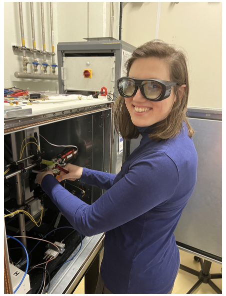
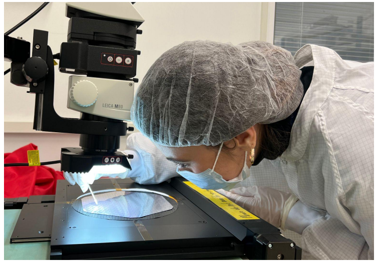
- Test beams with electrons and hadrons
- Close collaboration between CALICE and CMS
- Journal publications [1,2,3,4,5]

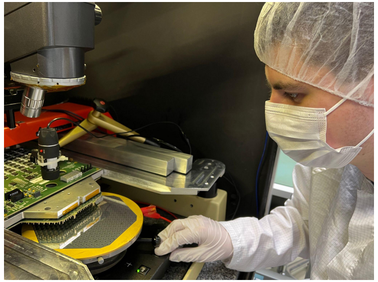
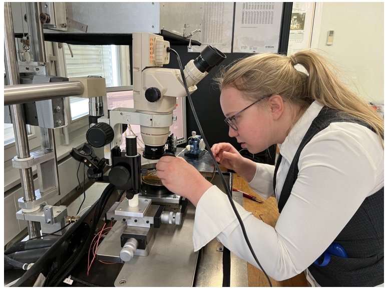
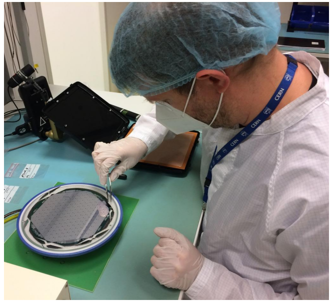
CERN HGCAL silicon sensor activity (since 2016)

Built up CERN HGCAL silicon team

- 10+ persons at a time with 25-100% working time
  - From student to senior staff
  - Often first hardware experience
  - Regularly rotating team composition
- Broad scope of activities
  - Setup development
  - Sensor irradiation
  - Sensor characterisation
  - Full sensors and small test structures from same wafer

➔ 1 MSc thesis, 2 PhD theses [1,2]
➔ 3 PhD, 1 MSc theses ongoing
➔ Strongly benefit from existing infrastructure and know-how in EP-DT/SSD, -CMX and -ESE

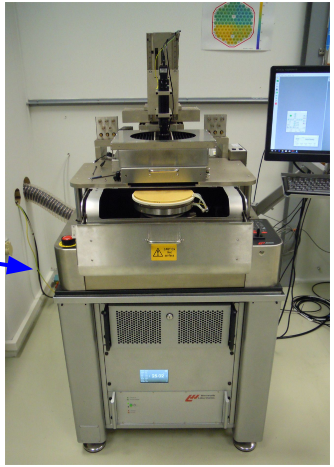





New LCD-HGCAL cleanroom (since 2017)

Before

After renovation

- New 60m^2 ISO 7 cleanroom
- Renovated from ground up to host CERN HGCAL silicon qualification center
- New temperature-controlled semi-automatic probe station

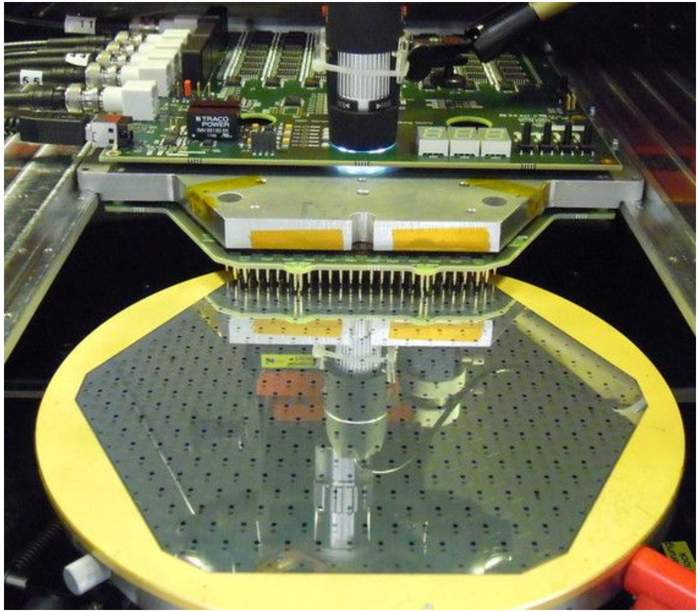


Novel system for silicon sensor testing

System for large-area multi-pad silicon sensor characterisation

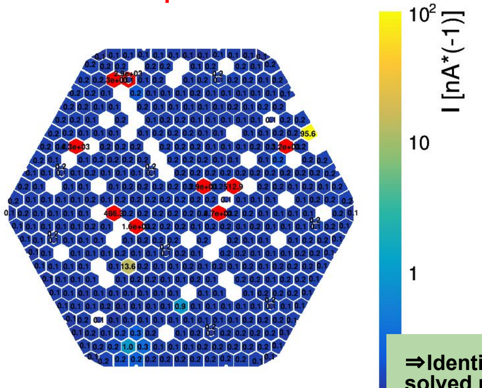
- Modular probe- and switch-card design, adaptable to different sensor layouts
- Essential tool for identification of problems in design, production process, sensor handling, as well as for production sensor testing

ARRAY system in probe station



NIM A 2019 06 007, open hardware publication

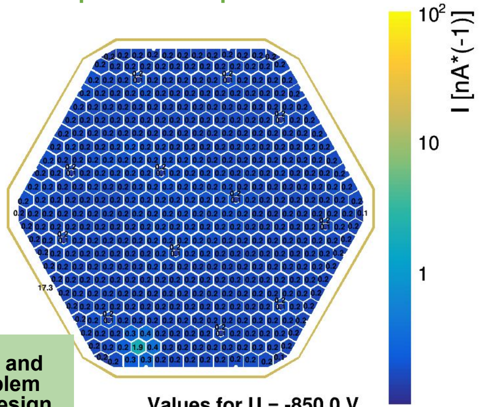
Early prototypes
fails acceptance test



Values for U = -35.0 V

⇒Identified and solved problem in sensor design

Production sensors
passes acceptance test



Values for U = -850.0 V

- HGCAL silicon sensor production ongoing: 2023–2025
  - Sample test ~2’000 sensors of 30’000 sensors needed for HGCAL
  - Tests system in operation at 5 institutes

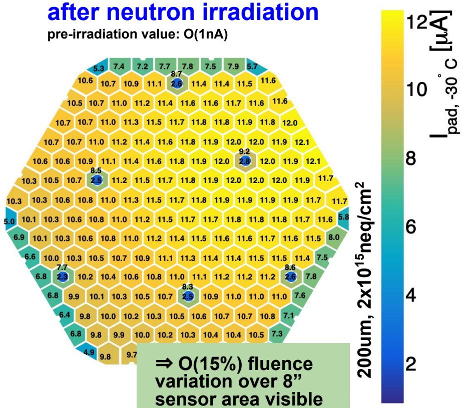
Silicon radiation hardness qualification

- HGCAL silicon sensors produced in new 8” process
- Requires validation of radiation hardness of bulk and oxide layer

- Neutron irradiation in new 8” neutron-irradiation facility: Rhode Island Nuclear Science Centre (RINSC)

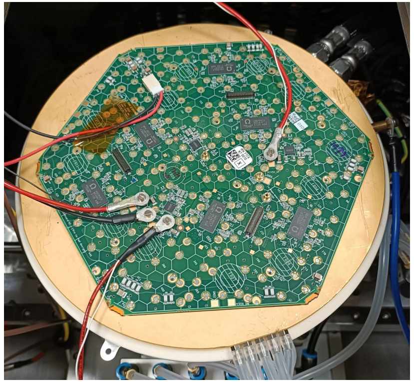
Per-cell leakage current after neutron irradiation

pre-irradiation value: O(1nA)



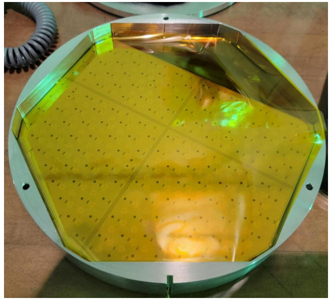
⇒ O(15%) fluence variation over 8” sensor area visible in IV and CV data

First tests with irradiated sensors assembled into detector modules

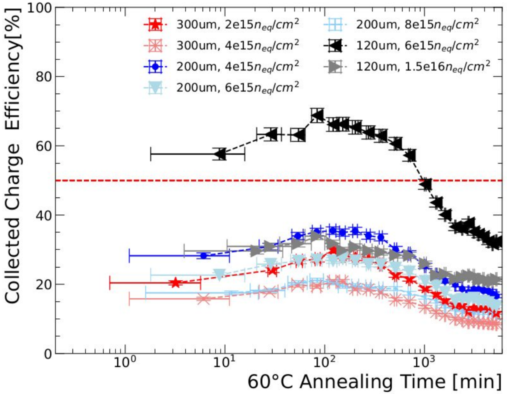


RINSC reactor beam port

Aluminum container hosting 8” partial sensors



Charge collection after warming up silicon



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Training and outreach

- Co-chair of CERN summer student lecture programme (since 2023)
- 2023 EURIZON detector school
  - Member of organisation committee and lecturer

- Lectures on detector requirements at future colliders (@TIPP17, BTTB20, TREDI20)
- CERN Academic training lecture “CLIC detector”
- German teachers programme: Lectures on particle detectors
- Supervision of student exercises

- CERN tour guide (e.g. ALICE, CLIC)

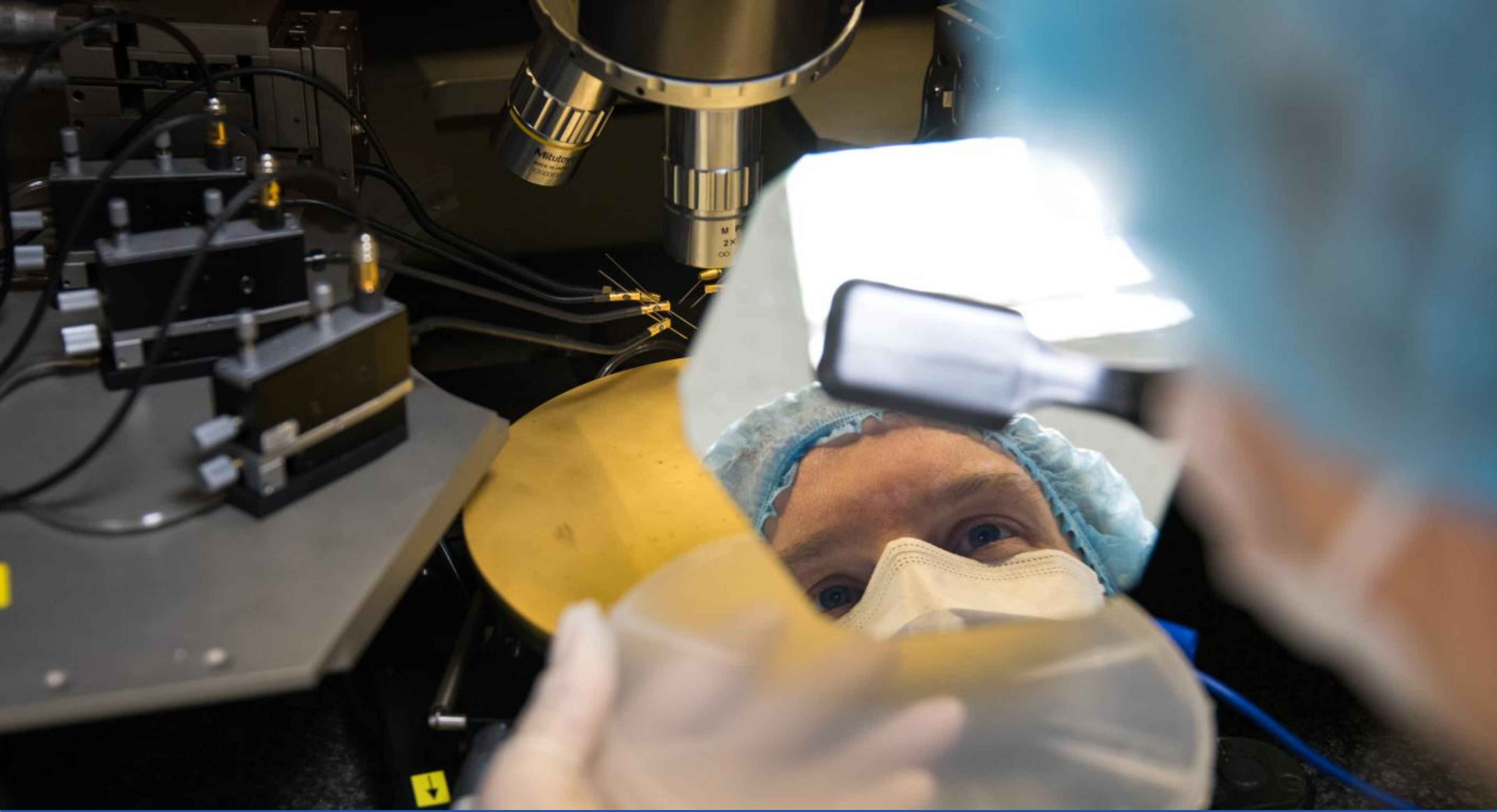
Some thoughts on

- Range of work topics

- CERN fellow application
- CERN staff applications
- Application for indefinite contract at CERN

- Postdoc time outside CERN

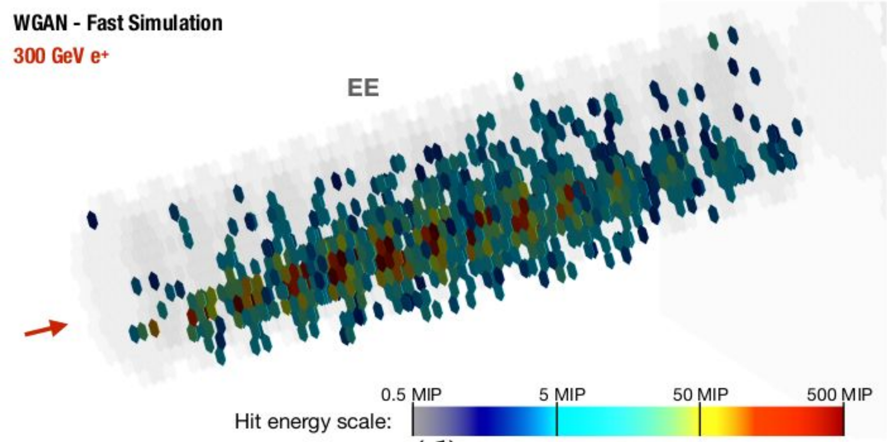
- Maternity, part time work
- Important role of supervisor


Mitutoyo

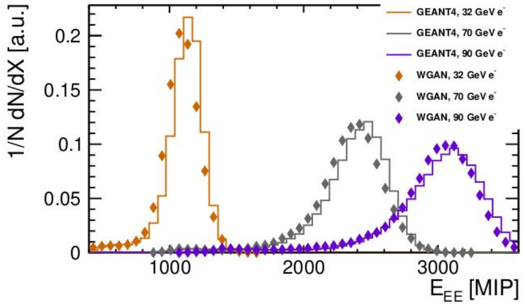
Backup

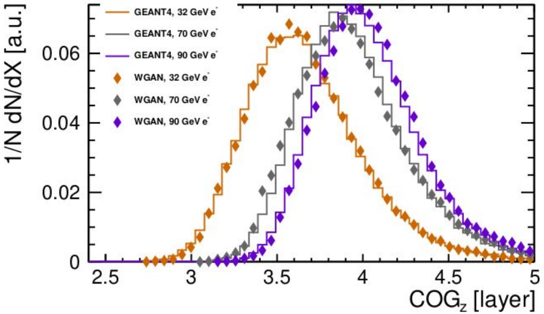
HGCAL: ML-based detector simulation

Usage of machine-learning (ML) techniques within HGCAL:
- Full Geant4 detector simulations are very time intensive
- Investigate if ML tools can be used to simulate electromagnetic showers
- Used Wasserstein Generative Adversarial Neural Network (WGAN)
- Simulation speed-up by up to factor 20’000 while reproducing detailed shower properties



(d)





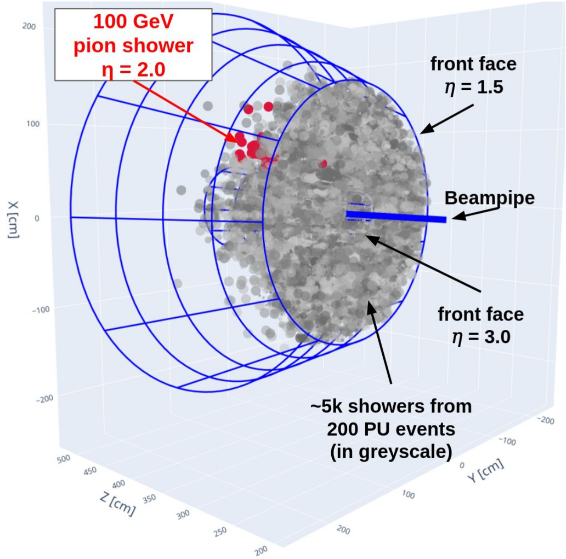
	GEANT4 std. (2017) CPU	**WGAN** Intel© Xeon© CPU E5-1620	**WGAN** NVIDIA© GTX™ 1080 GPU
20 GeV e^+	550 ms [x1]	10 ms **[x55]**	0.4 ms **[x1375]**
80 GeV e^+	2200 ms [x1]	10 ms **[x220]**	0.4 ms **[x5500]**
150 GeV e^+	4000 ms [x1]	10 ms **[x400]**	0.4 ms **[x10000]**
300 GeV e^+	8000 ms [x1]	10 ms **[x800]**	0.4 ms **[x20000]**

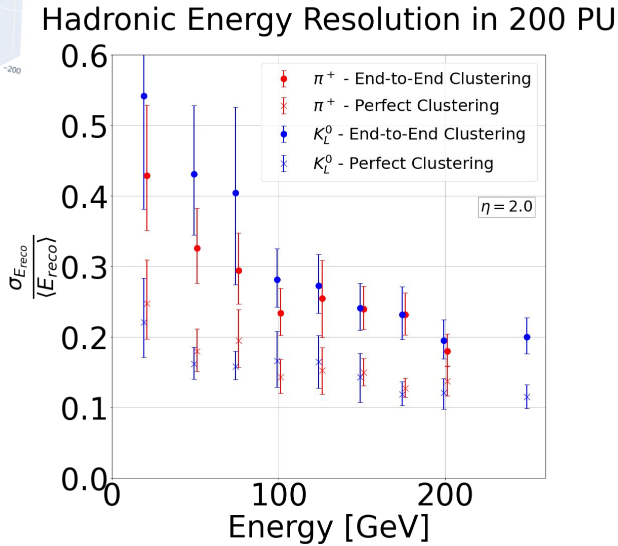
CERN-THESIS-2020-209
Comput.Softw.Big Sci. 3 (2019)

HGCAL-inspired: ML-based shower reconstruction

ML4Reco: End-to-end reconstruction approach to reconstruction software

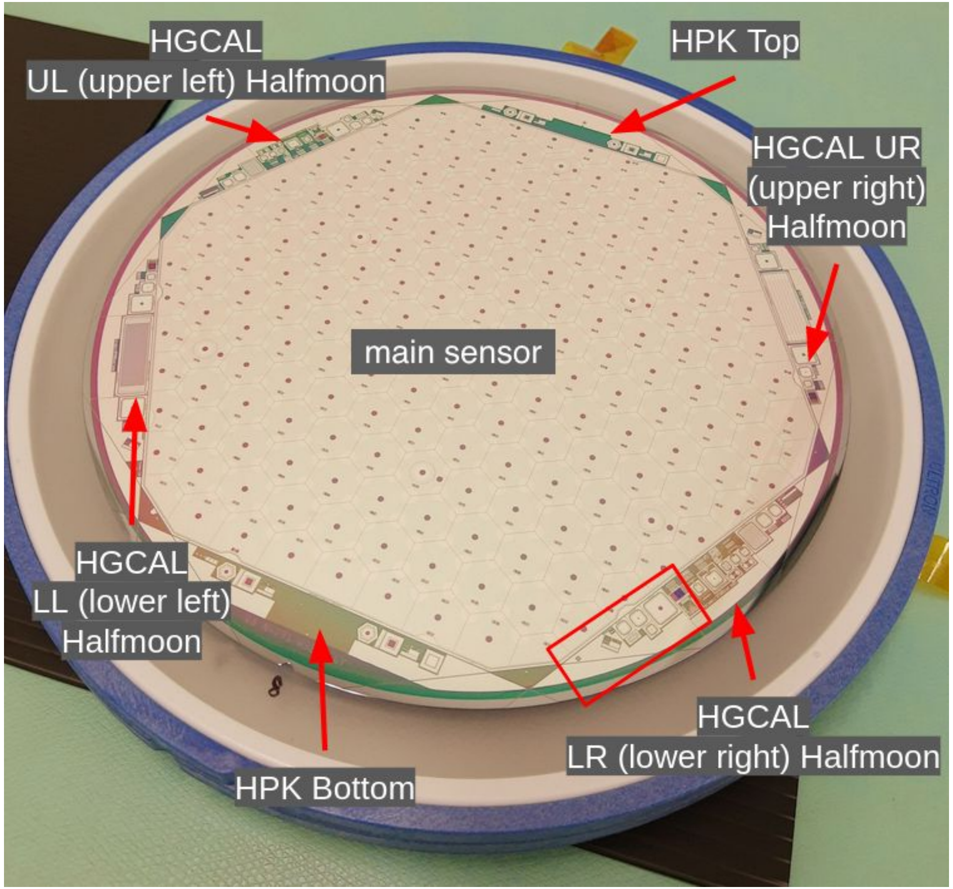
- Algorithm uses distance-weighted **Graph Neural Network**, trained with **Object Condensation**, a graph segmentation technique
- Promising reconstruction performance (efficiency, resolutions) of particles and jets in up to 200 pile-up (PU) events
- Less than 10s execution time for 200 PU events scaling linearly with number of detector hits (on NVIDIA 2080 Ti GPU)
- Adding tracks as additional network input to achieve end-to-end particle flow algorithm





[ML4Reco status]

Test structures from HGCAL-sensor wafers



- Hexagonal sensor from circular wafer
- Remaining space used for small sized test structures, e.g. diodes
- 8-inch wafers (~20 cm), diodes with $0.5 \times 0.5\ \text{cm}^2$ active area