FLC detector R&D

DESY PRC 2020

Ete Remi
DESY, Hamburg. 5 November 2020

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

The FLC group

Activities overview

Our goals

- Prepare future experiments in particle physics, with a focus on collider experiments
- Initially focused on the ILC project
- Recently extended activities towards generic R&D for future e^+e^- colliders

Recent restructuring to a new FH group: FTX

- Grouping FLA, FLC, testbeam and LUXe
- Incorporate support for local projects
  - Axion projects, dark matter, QED (LUXe), …

The FLC activities

Software
- ILCSoft development
- Machine learning
- Future colliders software stack

HCAL
- AHCAL prototype
- CMS HGCAL

Tracking
- TPC prototyping
- Lycoris beam telescope

Physics analysis
- Detector optimization
- EW, Higgs and BSM physics

FLC *"cross-activities"*
- LUXe, DUNE, FCal, positron source

The ILD Interim Design Report

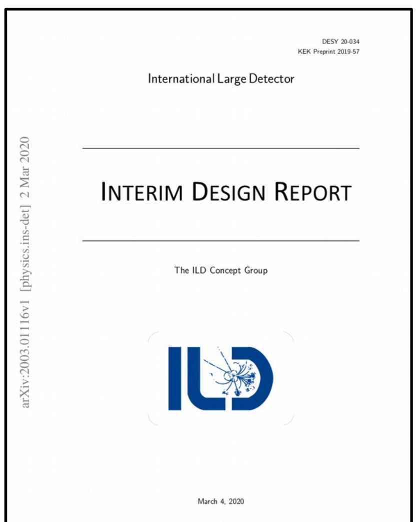
Input to the European Strategy Update

ILD Interim Design Report

- Detector technologies and integration
- Physics and detector modelling
- Detector and physics performance

Input document for EU strategy

“ILD Interim Design Report”
arXiv:2003.01116


DESY 20-034
KEK Preprint 2019-57

International Large Detector

INTERIM DESIGN REPORT

The ILD Concept Group

March 4, 2020

arXiv:2003.01116v1 [physics.ins-det] 2 Mar 2020

A major contribution from FLC

- 4 (out of 9) IDR editors from FLC
- Almost all FLC activities represented
    - TPC, Physics, Software, HCAL, FCAL
- ILD MC mass production for physics benchmarks

EPPSU outcome

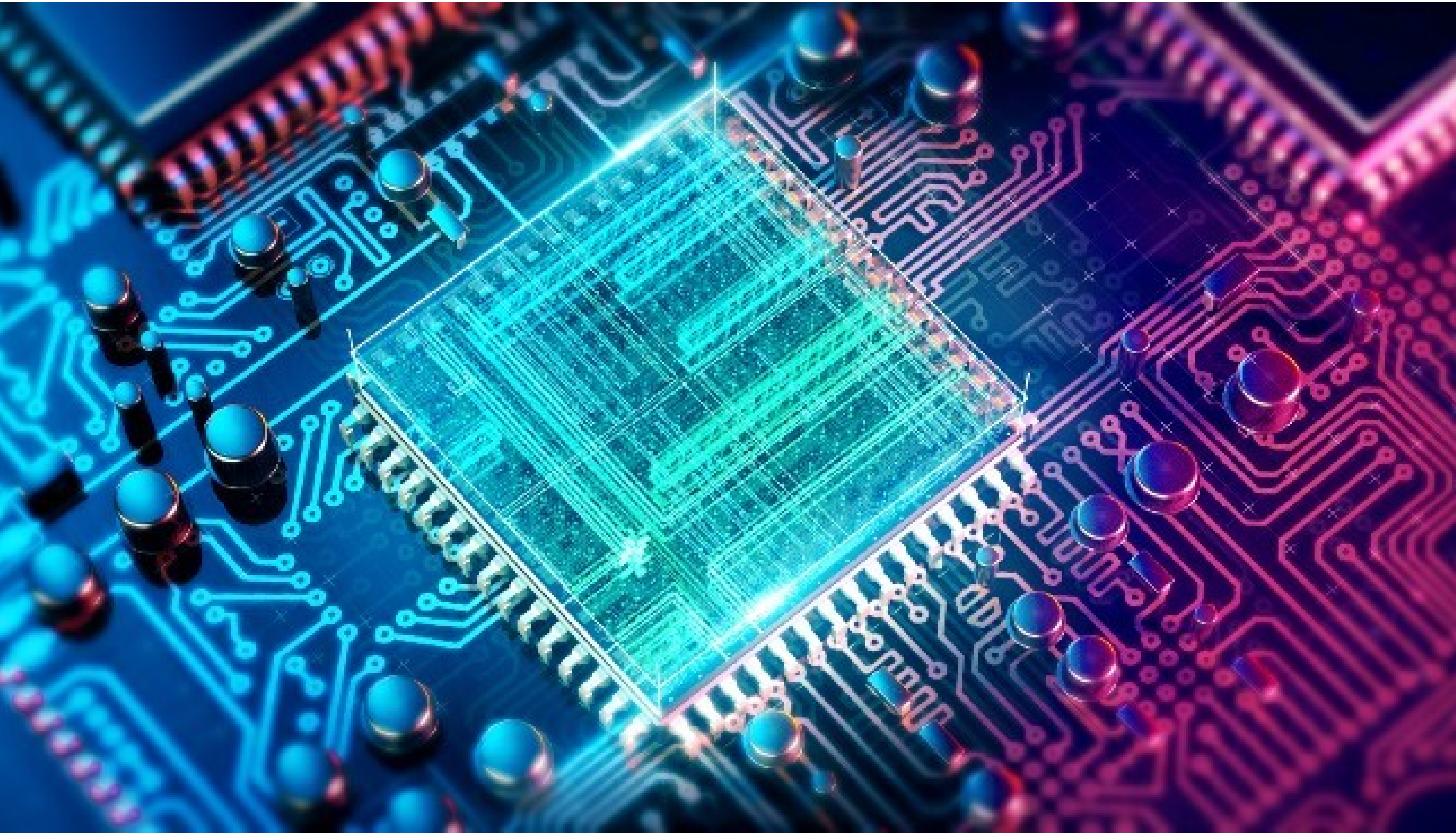
“An electron-positron Higgs factory is the highest-priority next collider.”

The FLC detector R&D

A physics driven development (examples)

Detector R&D	Detector Performance	Physics Benchmarks / Observables
HCAL Energy resolution, readout granularity	Jet energy resolution, scale: ~3-4%	W-Z separation, all jet physics
TPC dE/dx, low material budget, momentum resolution	Particle identification, Particle flow applicability, P resol ~ 2×10^{-5} GeV^{-1}, Heavy flavor tag	Kaon mass, All jet physics, $H \rightarrow c\bar{c}$, $H \rightarrow b\bar{b}$
FCAL Granularity, hermiticity	Photon ID (veto) Bhabha suppression	Dark matter search $e^+e^- \rightarrow XX\gamma$

Software activities



ILCSoft development

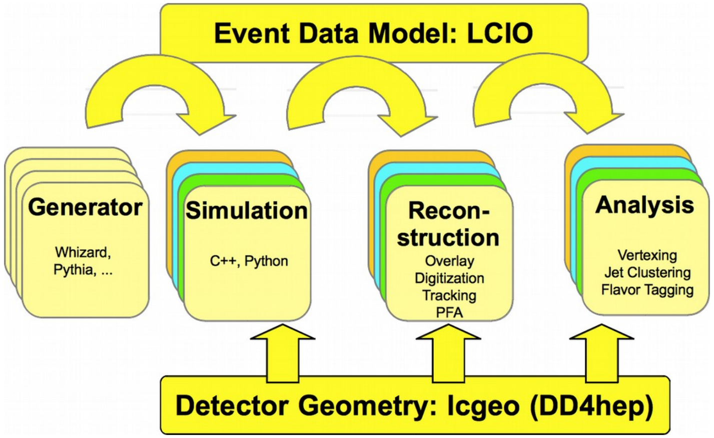
Software modernization

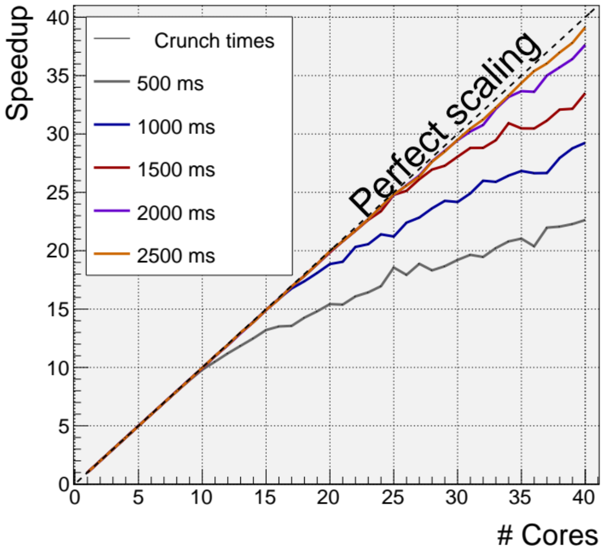
ILCSoft: a collaborative history

- Software stack of ILC (ILD & SiD) and CLIC
- 20 years of collaborative development
  - DD4hep (AIDA2020) developed by the LC community, adopted by CMS and LHCb
  - LCIO: shared with other experiments

Software stack modernization

- Full stack ported to C++17
- Evolving towards multi-core architectures
  - MarlinMT: Marlin re-implementation using multi-threading





"MarlinMT - parallelising the Marlin framework"
CHEP 2020 proceedings submitted in July

Future colliders - Software stack

The Key4HEP project

- Future detector studies (ILC, CLIC, CEPC, FCCee, FCChh) rely on well maintained software to properly study possible detector concepts and their physics reach and limitations
- Wants to avoid:
  - To "re-invent the wheel"
  - Unnecessary duplicate efforts
  - Complicate software maintenance
- Creation of a *"turnkey"* software stack: Key4HEP
  - Gather existing software packages (e.g DD4hep, Gaudi, Pythia, …)
  - Provide event generation, simulation, reconstruction, analysis tools
  - Distribute via CVMFS, Docker, …
- Identified as important project in the *CERN EP R&D initiative*

"Towards a Turnkey Software Stack for HEP Experiments"
CHEP 2020 proceedings submitted in July

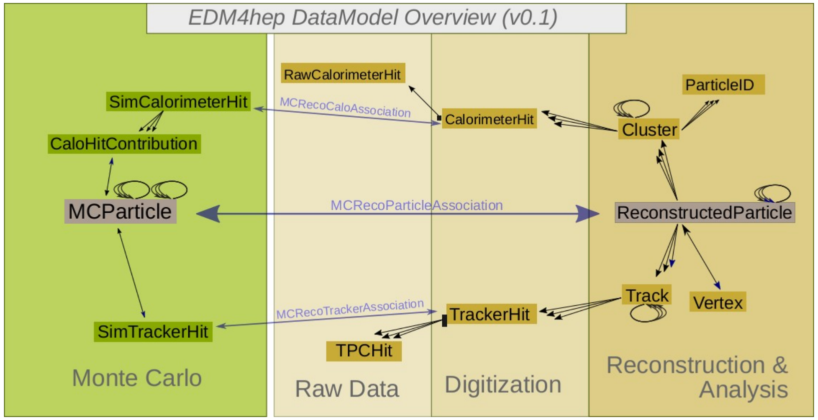
The FLC contribution

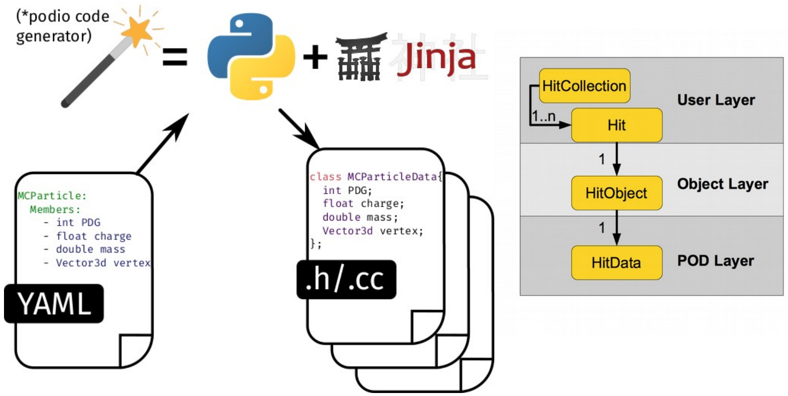
- Involvement from (before) the start of DD4hep
- Development of key components: PODIO and EDM4HEP

Future colliders - Software stack

EDM4hep and podio

- The Event Data Model is the language in which different software components communicate
- EDM4HEP tries to define a common EDM
  - Based on LCIO and experiences from ILC and CLIC
- podio is used to generate an efficient implementation of EDM4HEP starting from a high level description
- Targetting different I/O backends for persistency
  - Recently added SIO (developed by R. Ete for LCIO) as alternative to ROOT (F. Gaede, T. Madlener)



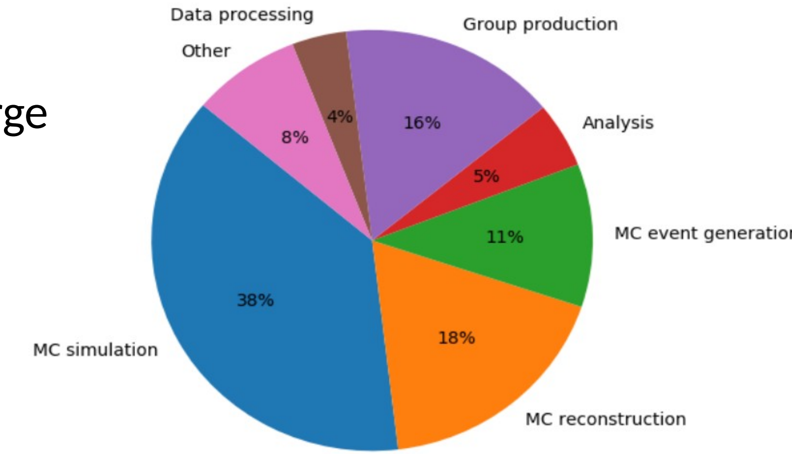


"PODIO: recent developments in the Plain Old Data EDM toolkit"
AIDA-2020-CONF-2020-018

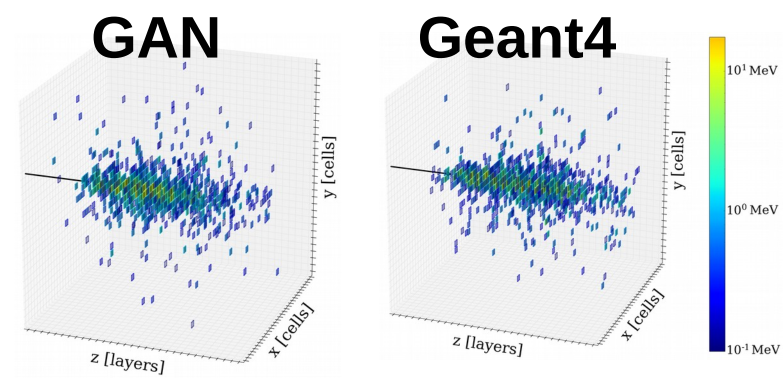
Machine learning for fast simulation

GANs to the rescue

- Full simulation is very CPU intensive, due to large number of interacting particles
- Current bottleneck in full simulation: shower simulation time
- Use GANs (Generative Adversarial Network) as fast shower generator
  - Save enormous amount of CPU
  - Architectures: GAN, WGAN, BIB-AE PP, …
- Intensive training on **GPUs** @ Maxwell HPC cluster
- **Measured from 3 up to 2800 times faster generation of EM showers !**



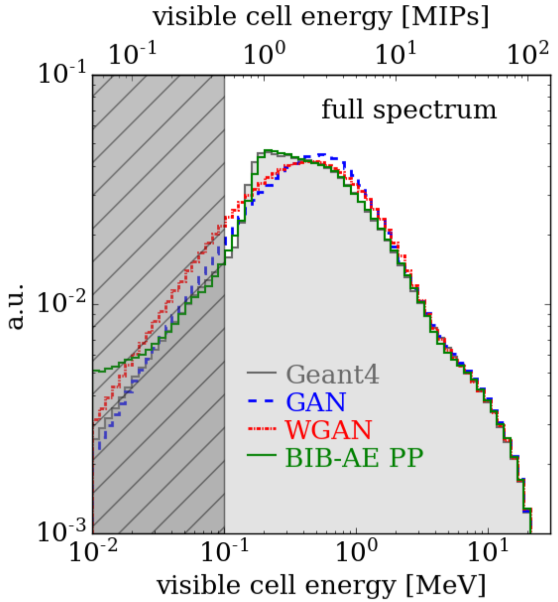
ATLAS CPU time

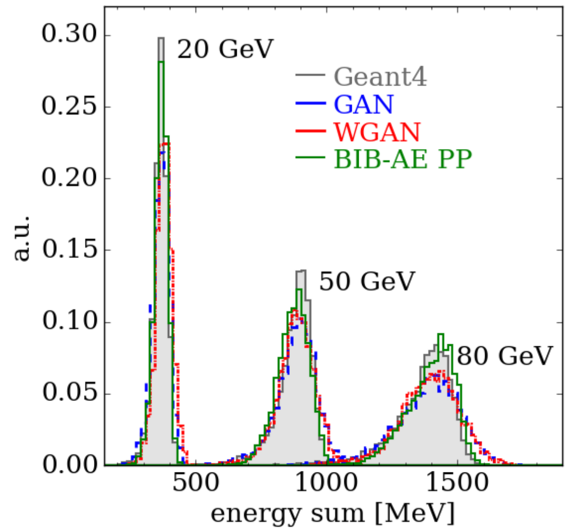


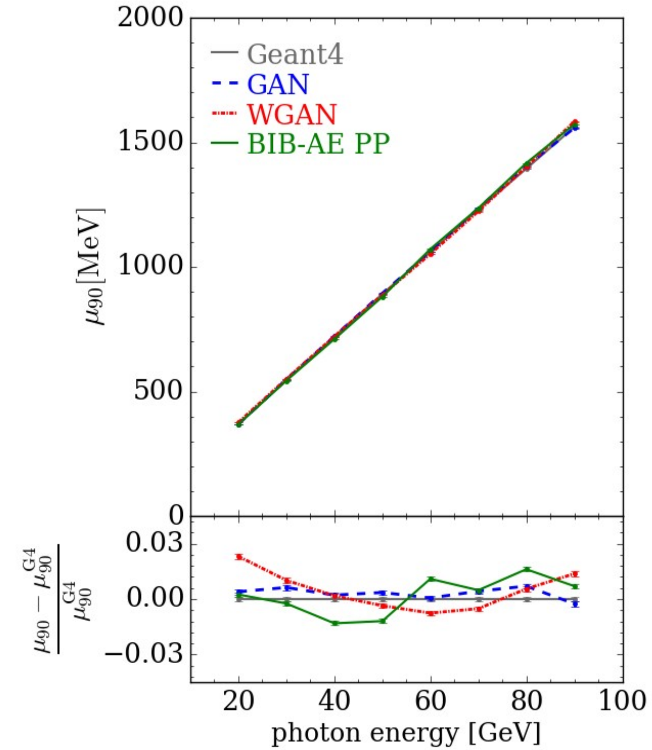
In collaboration with Hamburg UNIV and QU

Machine learning for fast simulation

Current GANs performances (EM showers)







✗ Both GAN and WGAN fail to capture MIP bump around 0.2 MeV

✔ BIB-AE model is able to produce this feature

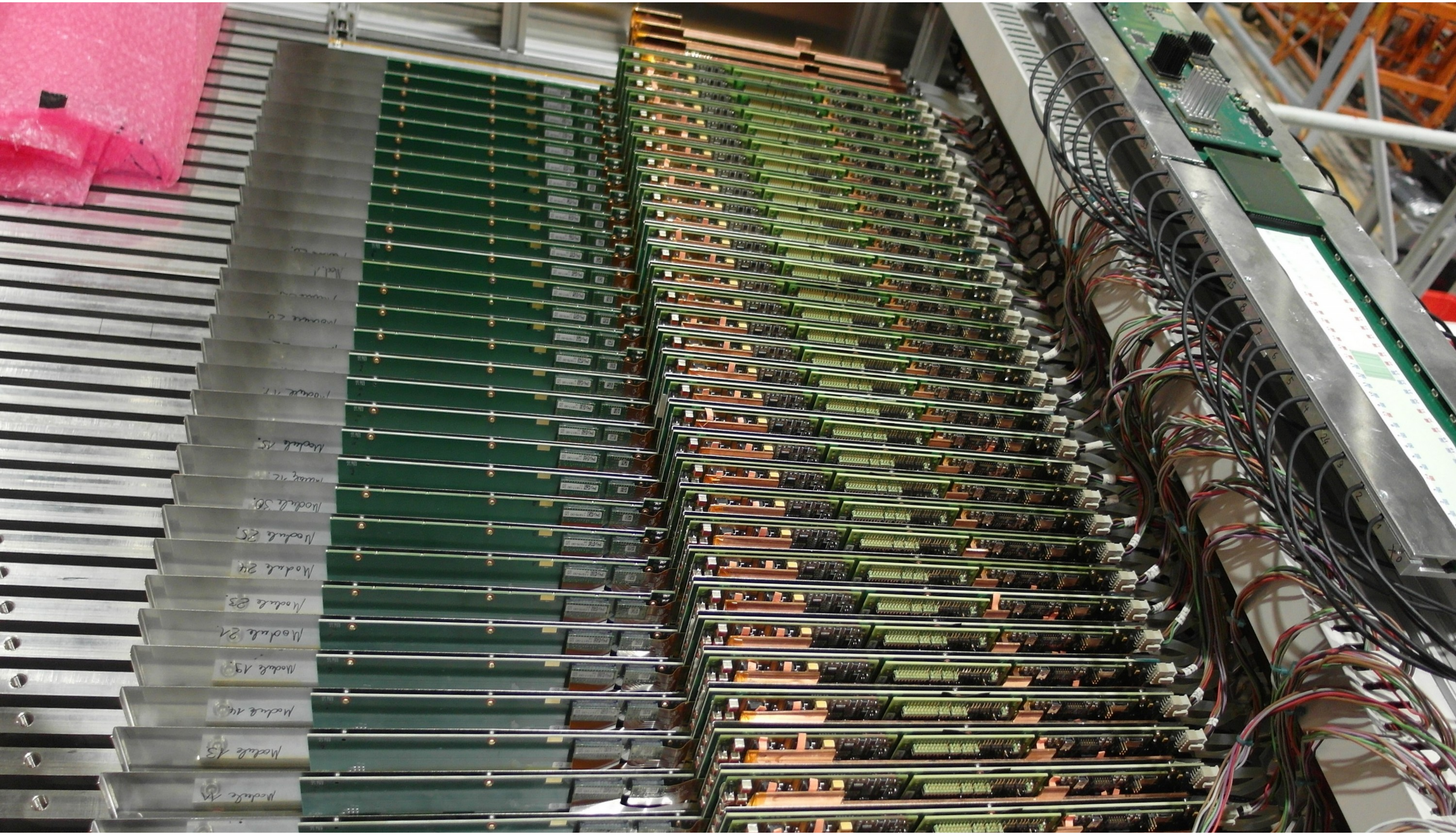
✔ The shape, center and width of the Energy sum peaks are well produced by all models!

"Getting High: High Fidelity Simulation of High Granularity Calorimeters with High Speed"

ArXiv:2005.05334

Submitted to "Computing and Software for Big Science

HCAL activities

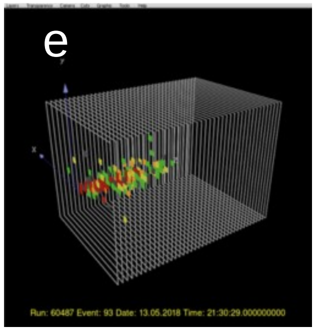


Highly granular SiPM-on-tile calorimeter

Large HCAL prototype

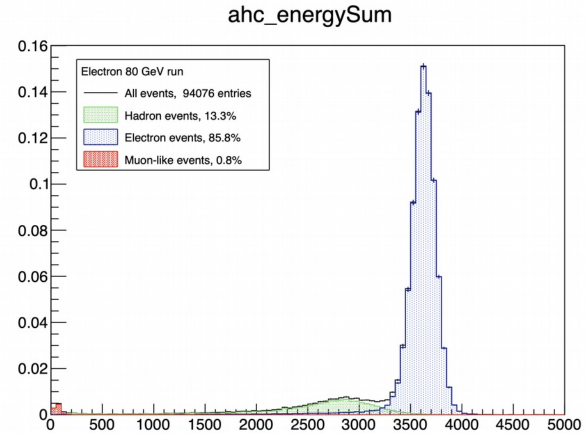
SiPM-on-tile HCAL for a linear e+e− collider

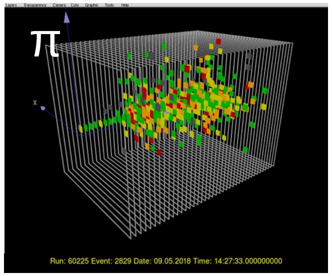
- AHCAL developed within the CALICE Collaboration
- Have built a large technological prototype with 22000 channels in steel absorber structure
  - Tested with various particle types in 2018 at CERN SPS
  - Built using scalable production and QC procedures
- Studies of alternative tile technology and readout ASIC



Analysis of 2018 data

- All calibrations determined
- Large simulation samples produced
- High level analysis tools developed
  - Particle ID based on Boosted Decision Trees
  - Application of Particle Flow Algorithm



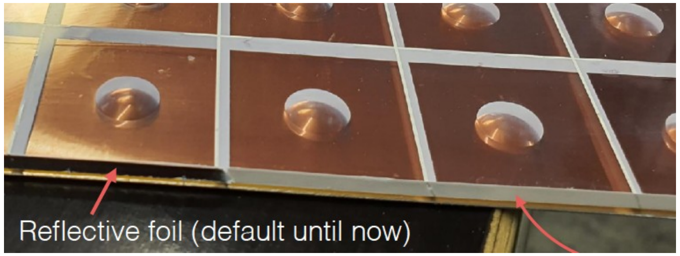


Highly granular SiPM-on-tile calorimeter

Further AHCAL development

Alternative scintillator technology (Megatiles)

- Developed by Uni Mainz
- Would allow larger units for mechanical assembly
- DESY: read-out boards and support for beam tests



Alternative Readout ASIC (KLauS)

- Developed by Uni Heidelberg
- New analog input stage: low noise
- Wide range of applications, e.g continuous readout
- DESY: read-out boards and support for beam tests

"Operation and Calibration of a Highly Granular Hadron Calorimeter with SiPM-on-Tile Read-out"
[*arXiv:2004.00370*](arXiv:2004.00370)

Further AHCAL plans

- Continue beam tests at DESY with small setups
- More testbeam with the technological prototype at CERN SPS:
  - ➔ sub-ns timing resolution, tungsten absorber, ECAL+AHCAL

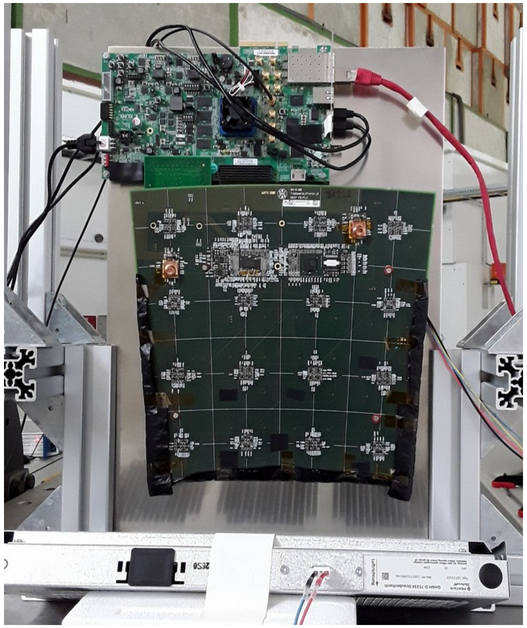
Highly granular SiPM-on-tile calorimeter

CMS Endcap Calorimeter Upgrade: HGCAL

New challenges: radiation levels, data rates, operation at -30 °C

DESY responsibilities in HGCAL:

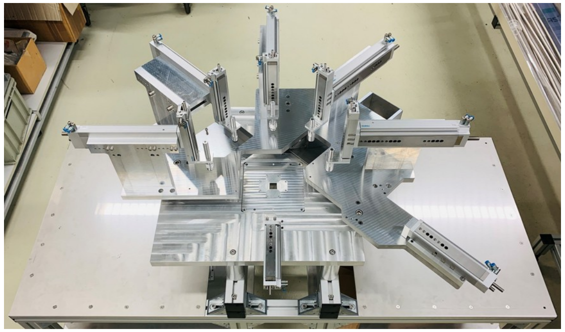
- Board level design for SiPM-on-tile readout boards ("Tileboards")
- Development of assembly and test procedures
- Production of Tilemodules in cooperation with Russian groups
- Coordination



Tileboard unit

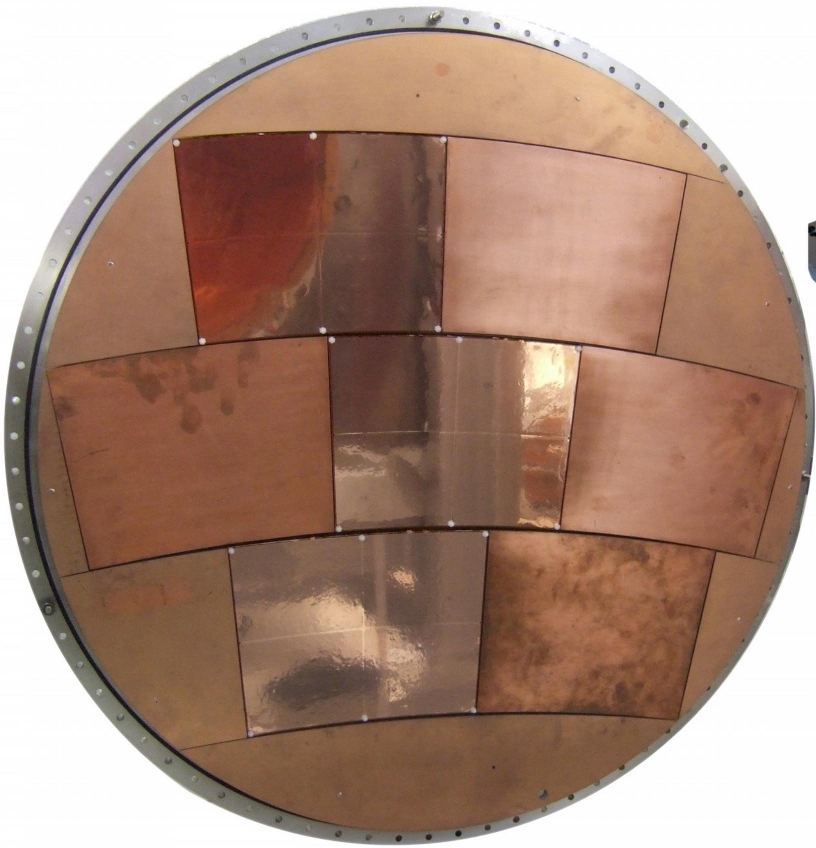
Recent activities:

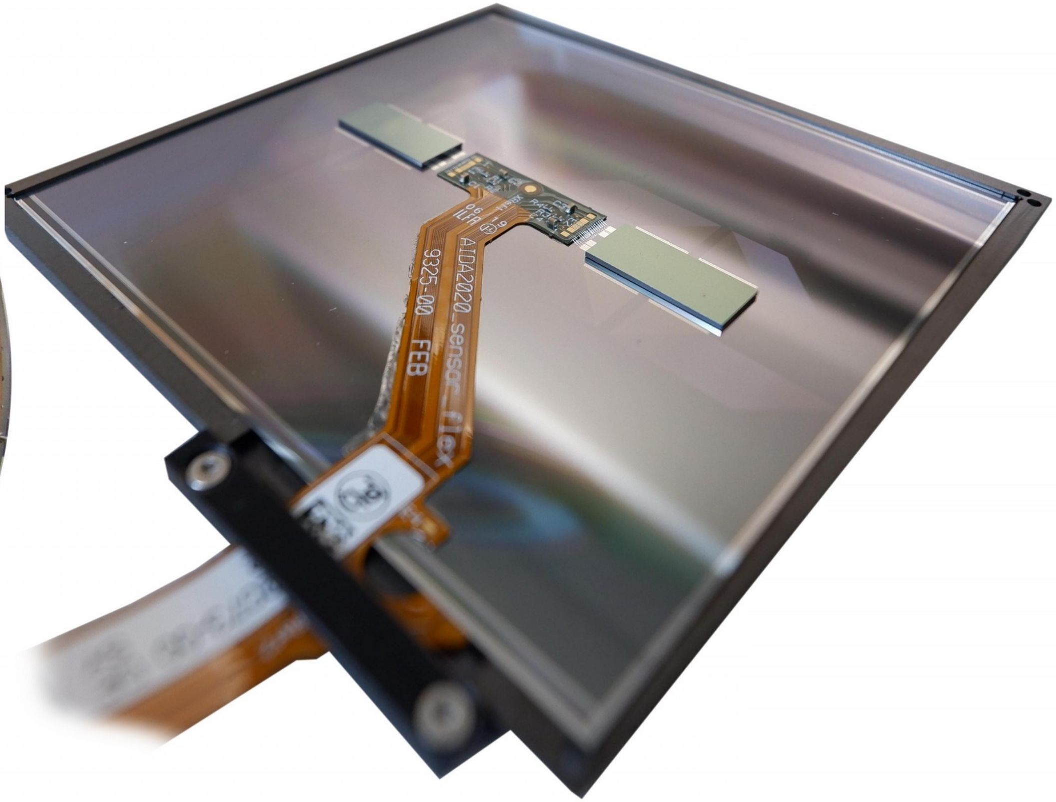
- Test of a Tilemodule in the DESY testbeam
  - ➔ More details in CMS talk
- Development of production procedures: benefits from AHCAL tools and techniques
- Preparation for Tilemodule assembly at DESY DAF ongoing



Tile wrapping machine

Tracking activities





Time Projection Chamber R&D

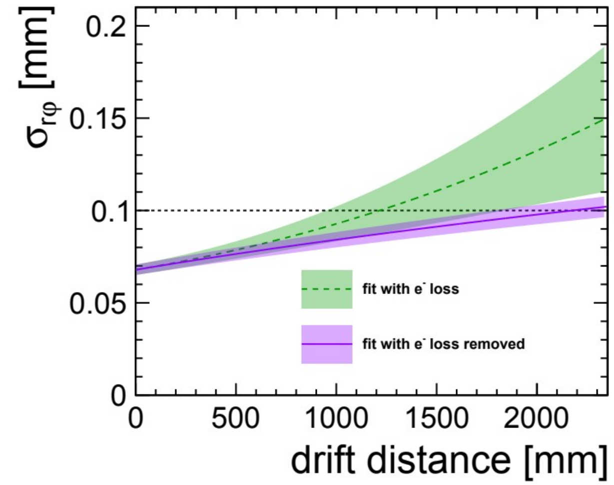
Motivation and status

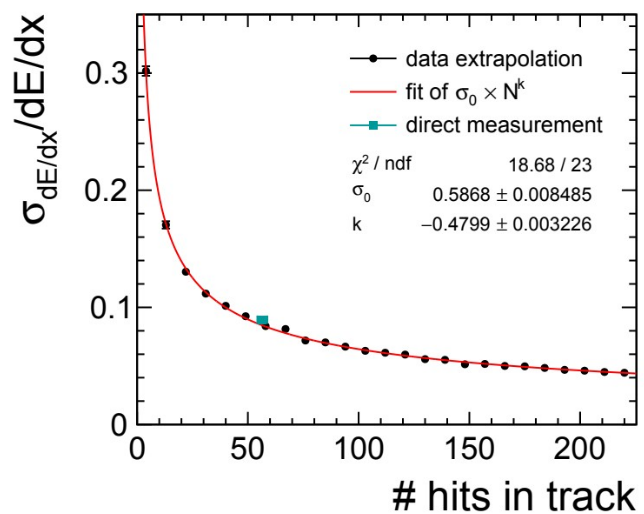
Light weight, high precision TPC for ILD @ ILC

- Developed a prototype readout module with triple GEM amplification, showing applicability for ILD TPC:
  - Stable operation
  - Point resolution: rφ ≤ 100 µm (also in z: ≤ 1.4 mm)
  - Double hit/track separation: ~ 2 mm
  - dE/dx resolution ~ 5 %

Next step

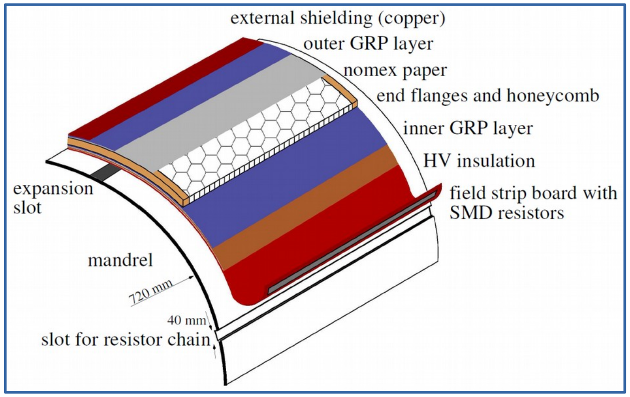
- Momentum resolution using new field cage and Lycoris telescope





Time Projection Chamber R&D

TPC field cage – Composite materials & more



Scaling up expertise

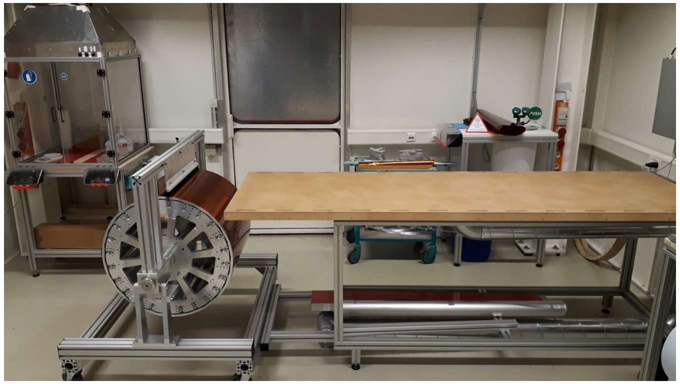
- Field cage requirement: Integrated (gas vessel + field shaping + HV shielding)
  - High mechanical precision: order of 100 µm
  - High HV stability ≥ 25 kV
  - Low material ~ 1 % X_0 per wall

"Recent Performance Studies of the GEM-based TPC Readout (DESY Module)"

arXiv:2006.08562

Last step

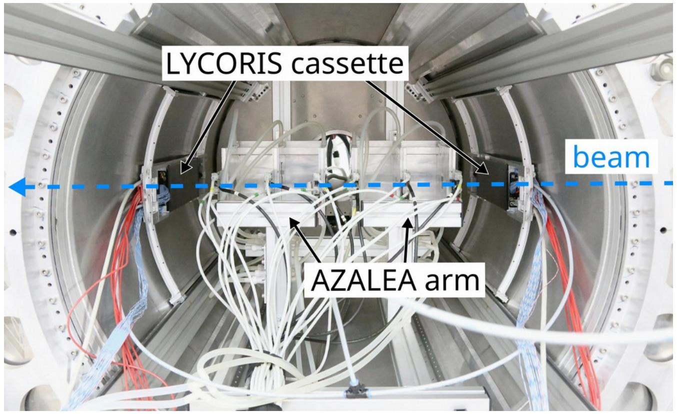
- First iteration field cage build external
  - mechanically not precise enough -> field homogeneity insufficient
- Now: techniques developed for in-house production
  - Based on experience with small prototypes and first iteration
  - Material, tooling and procedures ready
  - Actual construction foreseen to be finished till end of this year



Lycoris Beam Telescope

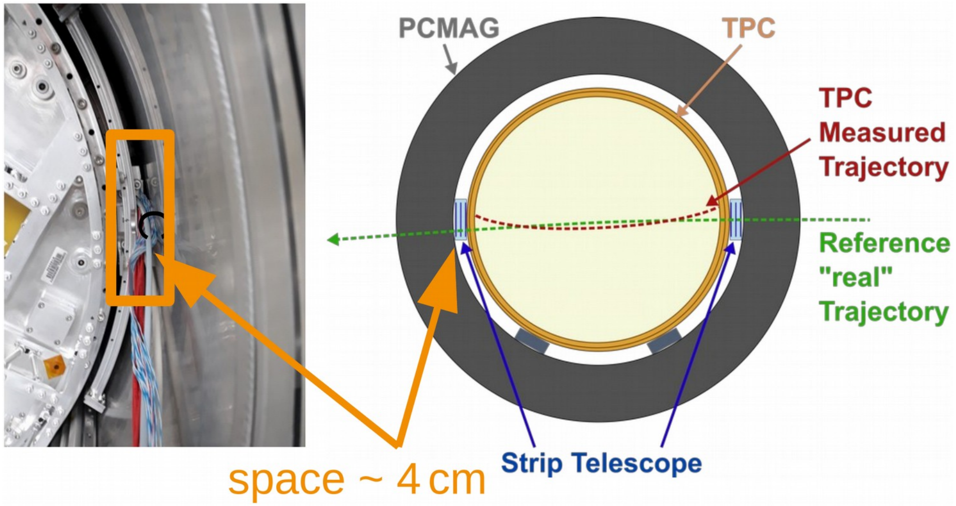
Reference and Momentum Measurements

"First performance results of the Lycoris large area strip beam telescope"
[10.1109/NSS/MIC42101.2019.9059775](10.1109/NSS/MIC42101.2019.9059775)



Setup in testbeam area

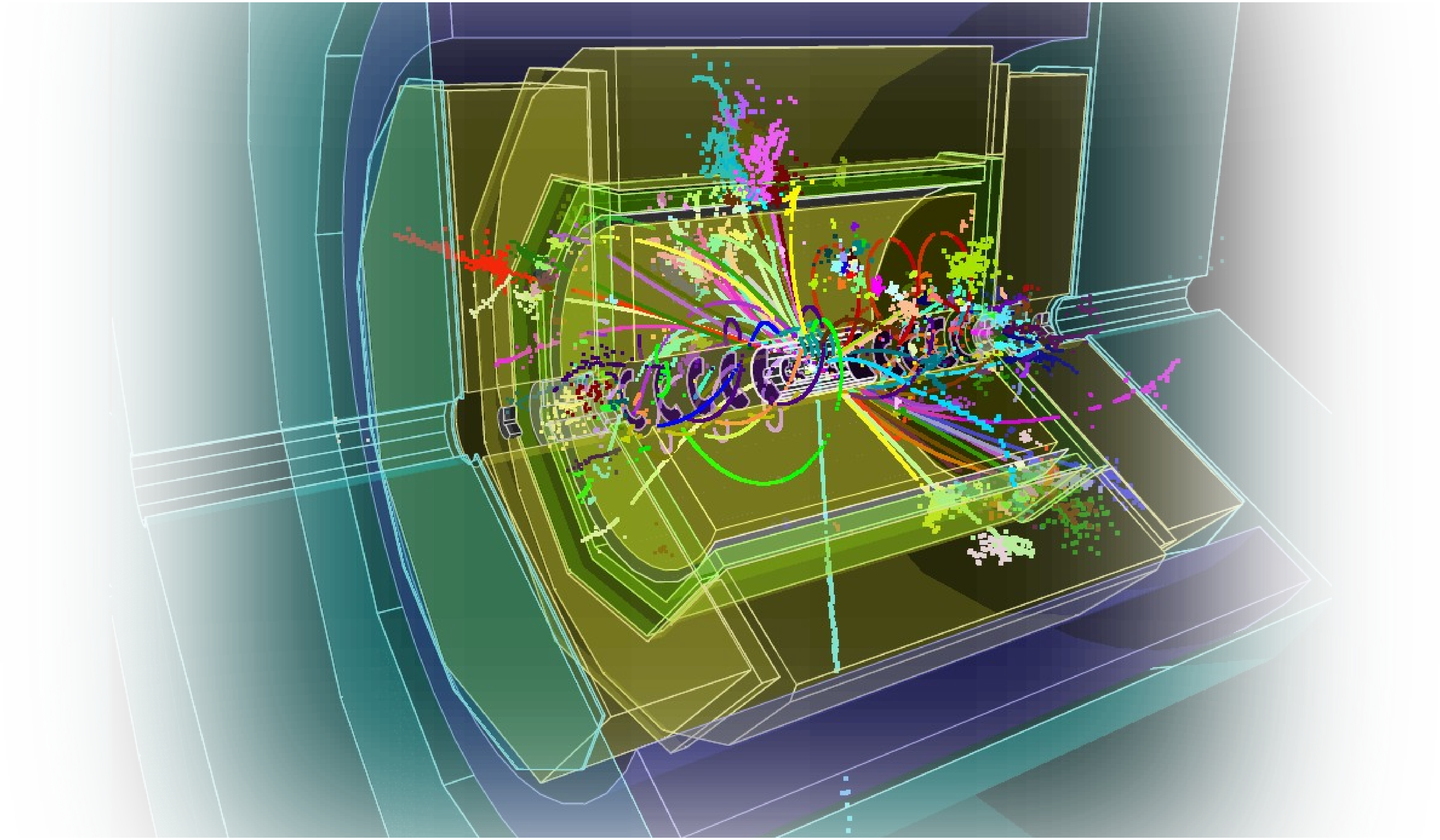
- 6 Layer strip telescope as reference tracker (supported by AIDA 2020 & SLAC)
- Requirements:
  - $\sigma_{r\varphi}$= ~10 µm, σ_z= ~1 mm
- SiD strip sensors:
  - 10x10 cm^2 area
  - Strip pitch: 25 µm,
  - 320 µm thick (0.3% X0)



Extensive beam tests in recent years

- Successful tracking demonstrated
- Point resolution 7 µm
- System has reached operational status
- System available to testbeam users

Summary and Conclusion



Summary and Conclusion

The FLC group develops detectors and software for a **future Higgs factory**

- In line with the updated **European Strategy for Particle Physics**
- With applications and benefits for ongoing research

The FLC group …

- Develops and maintains **iLCSoft** and make it evolving (multi-threading)
- Actively takes part in new development (**Key4HEP**) and technologies (**machine learning**)
- Has successfully built and tested a **technological prototype of hadronic calorimeter**
- Is taking part in the high-granularity upgrade or the **CMS endcap** calorimeter
- Has successfully developed and operated a **TPC prototype** for e+e- experiments
- Built a new silicon strip telescope (**Lycoris**) for for the **DESY testbeam facility**

Very good synergy and coherence within the FLC group activities

Strong collaboration with other groups inside and outside of DESY

Thank you

Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

ETE Remi
FH – FTX (FLC)
remi.ete@desy.de
rete.github.io