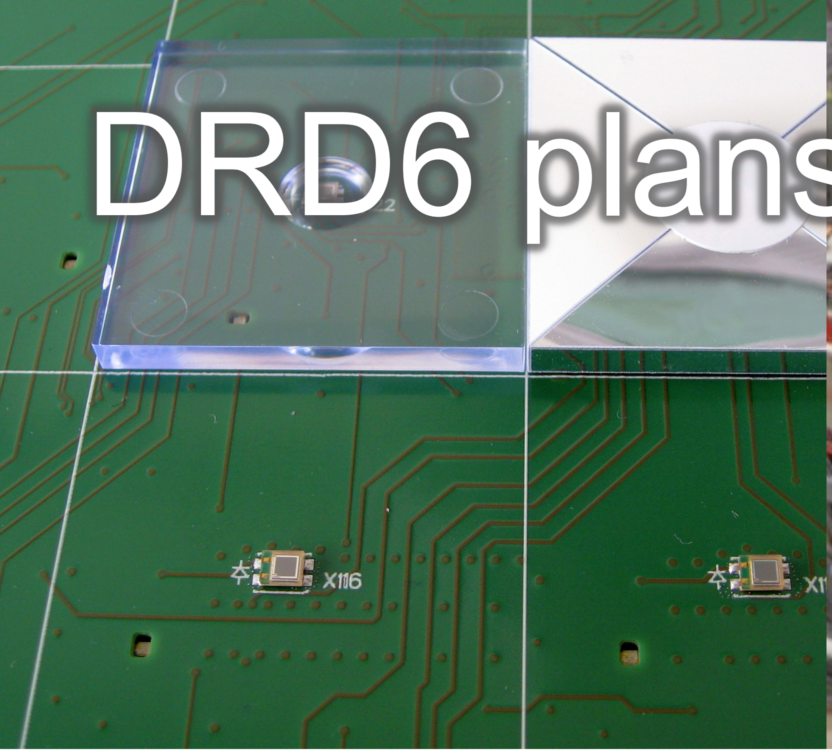
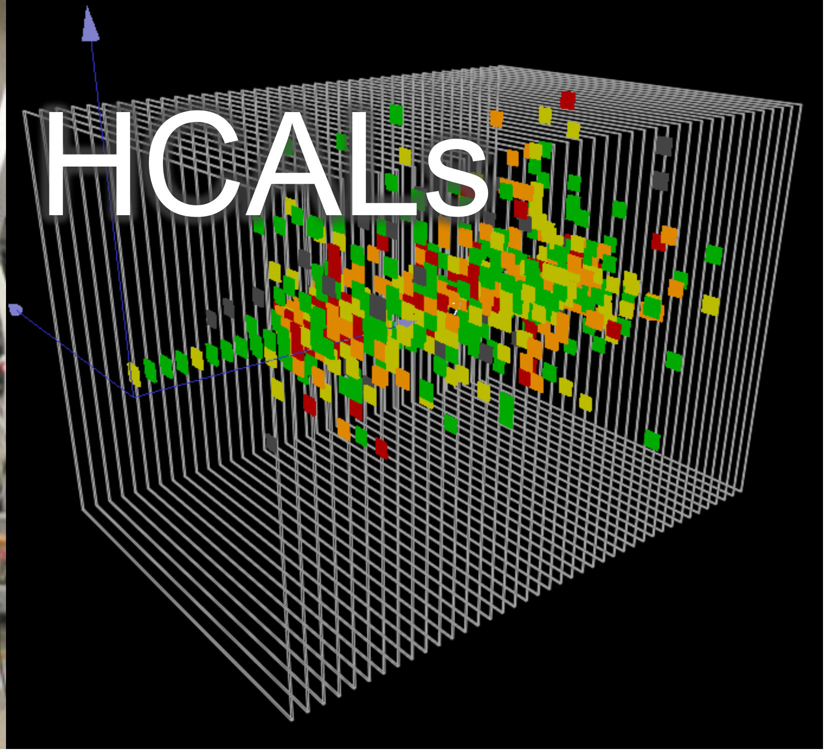
DRD6 plans for sandwich HCALs





Katja Krüger (DESY)

ECFA WG3: Topical workshop on calorimetry, PID and photodetectors
4 May 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

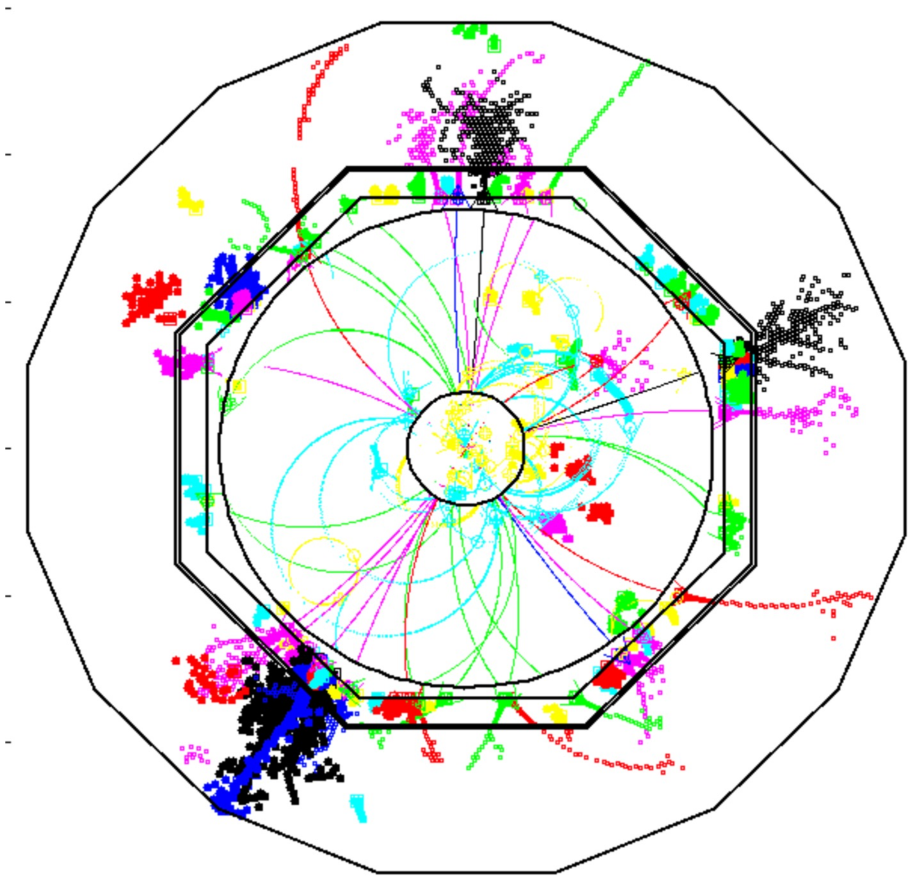
DESY.

Introduction

Requirements for the Hadronic Section

Differences and common aspects with EM section

- Hadronic sections have **larger volume** than EM sections, and similar or higher number of layers
  - → Larger area to be covered
  - → Cost/area is more important
- Some **requirements are less stringent** than for EM section
  - Smaller channel density
  - Compactness not as critical
  - Hadronic energy distributed over large volume and many channels, with large fluctuations: less sensitive to single-cell precision
- Many **similar challenges**:
  - Integration
  - Industrialisation of production, QC
  - Cooling
  - Considerations in terms of power pulsing vs. continuous running
  - …



Detection Technologies for the Hadronic Section

An Overview

6 proposals for sandwich HCALs submitted to DRD6
- 2 with gaseous readout, 3 with optical readout, 1 with gaseous and optical readout
- 4 aim for Higgs factories, 1 for muon collider, 1 for REDTOP

	Gaseous Readout		Optical Readout			Optical & Gaseous RO
Technology	RPCs	MPGDs	Plastic scintillator tiles	Glass scintillator tiles	PWO and lead glass blocks	Plastic scint. tiles & heavy glass & RPCs
Name	T-SDHCAL	MPGD-based HCAL	SiPM-on-tile AHCAL	Highly Granular HCAL with Glass Scintillator Tiles	Double Readout Sandwich Calorimeter	ADRIANO3
Experimental context	Higgs Factories	Muon Collider	Higgs Factories	Higgs Factories	Higgs Factories	REDTOP

DISCLAIMERS: I'm not a member of the DRD6 Input proposal team, slides heavily relying on Frank Simon's talk

Proposals
(and their context)

Gaseous: State of the art

SDHCAL Technological Prototype

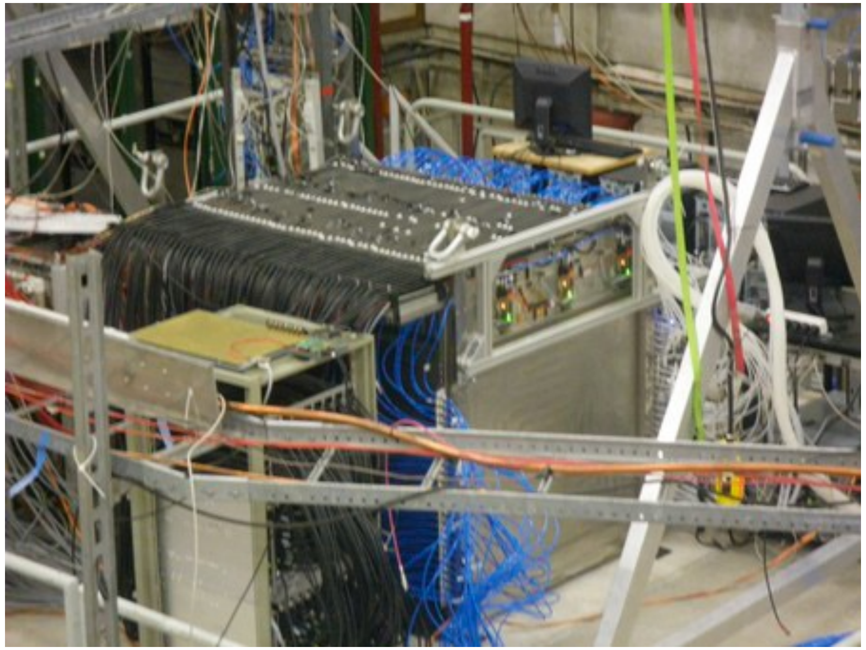
1*1*1 m^3 prototype based on RPCs with 1 cm^2 pads

- 48 layers with ~440.000 channels
- built in 2011

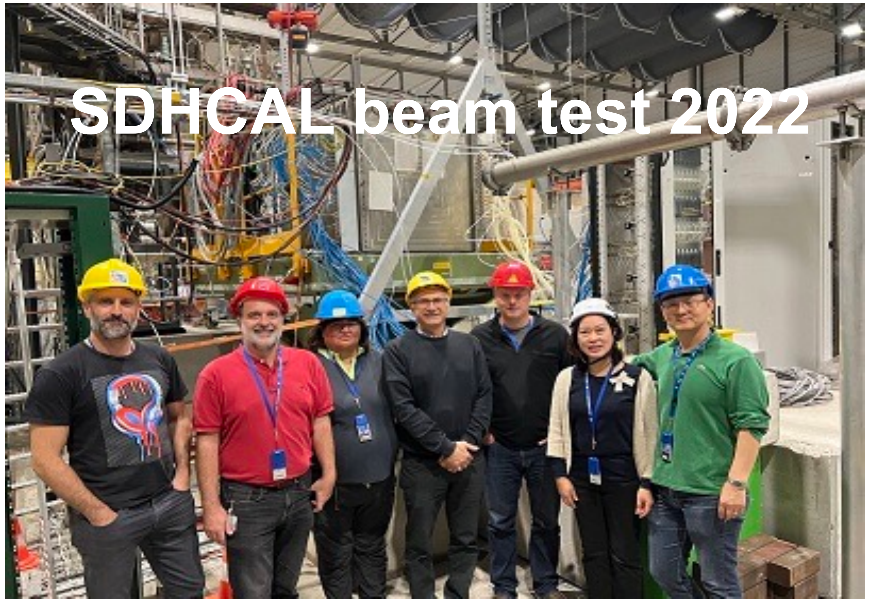
Successfully operated in many beam tests 2012 – 2022

- publications on operation, energy reconstruction, simulation

Tested also with a few μMegas layers



See also
talk by
I. Laktineh

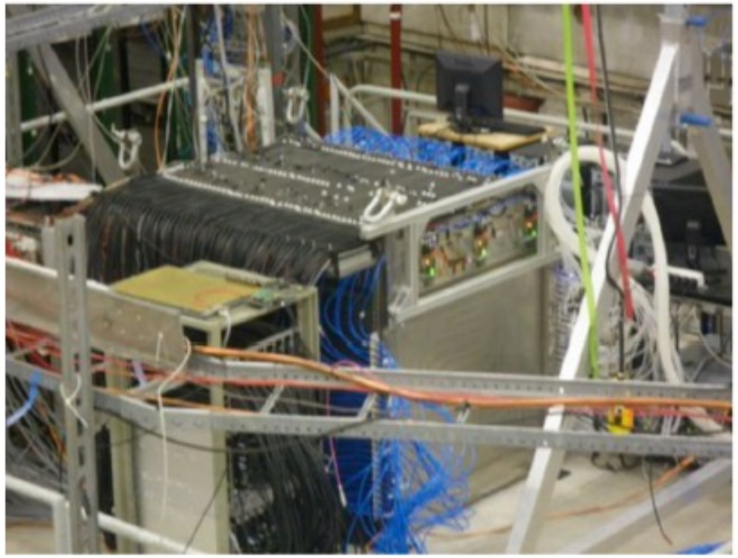


T-SDHCAL

IP2I Lyon, CIEMAT; VUB, OMEGA, U Cordoba, Yonsei Cancer Center, GWNU, SJTU, U Tunis El Manar

Karlsruher Institut für Technologie

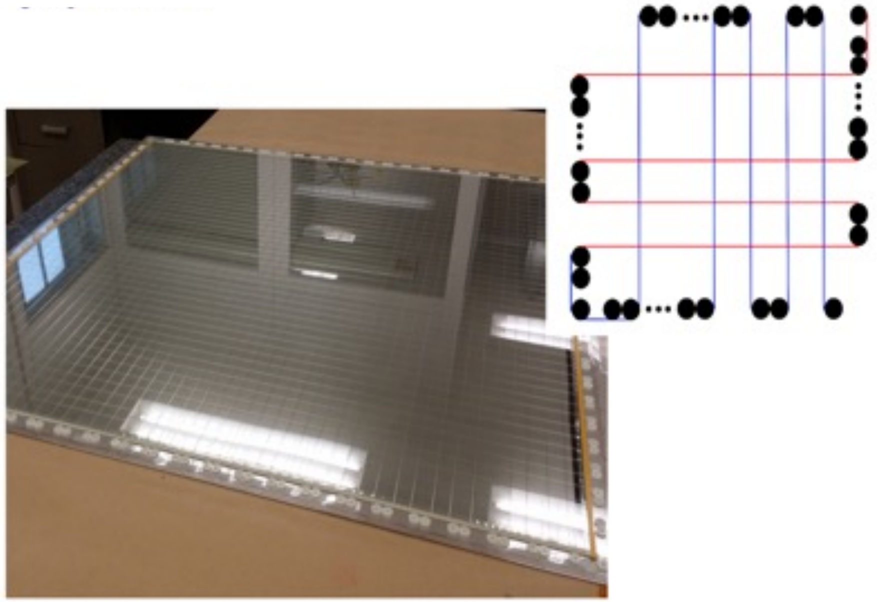
- Primary experimental context: Higgs Factories
- A RPC-based semi-digital HCAL with timing capability
  Builds on CALICE SDHCAL technological prototype
- Main R&D directions
  - Simulation studies extending to time information
  - Study and development of cooling and cassette concepts
  - Fast timing electronics
  - Development of DAQ system
  - Construction of detector units, validation in beam tests
- Until 2026: Complete initial R&D steps to propose T-SDHCAL concept for circular HF

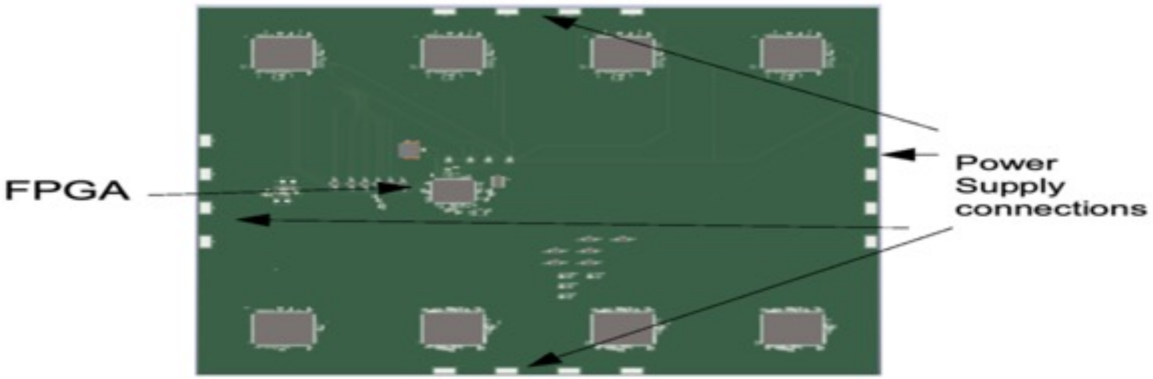


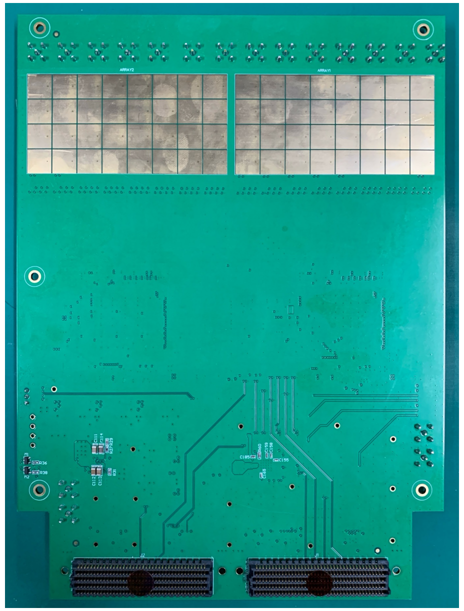
T-SDHCAL

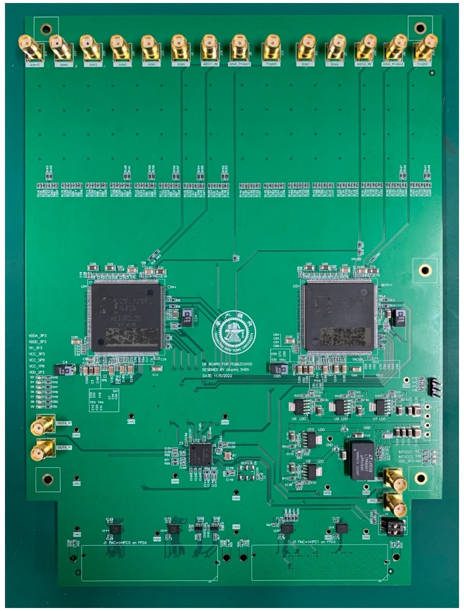
Status of developments

- Multi-gap RPCs allow time resolution better than 100 ps
  - MRPC have been produced. A new method allows the production of such detectors to be greatly simplified
- First test boards with PETIROC ASICs have been built
  - the internal TDC of PETIROC will be used to validate the concept but an external TDC will be probably needed to cope with the high rates in future Higgs factory









MPGD-based Hadronic Calorimeter

INFN & U Bari, Weizman Inst.

- Primary experimental context: Muon Collider
- Inspired by CALICE DHCAL & SDHCAL
- Using MPGDs (examples uRWELL, resistive Micromegas) for higher-rate environments
- Already ongoing activities: testing of detectors, test of a small calorimeter prototype with up to 6 GeV pions in 2023
- Main R&D topics
  - Simulation for HCAL design definition
  - Construction of a prototype with 50 x 50 cm^2 active layers, further extensions
  - Test beam campaigns
- NB: At the moment prototypes do not have integrated electronics: R/O at detector edges

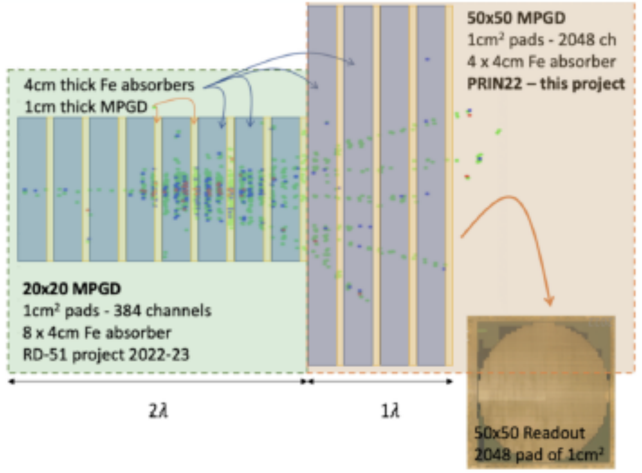
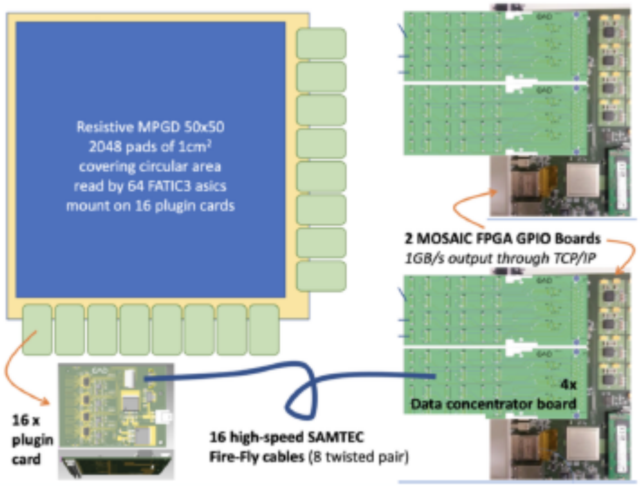


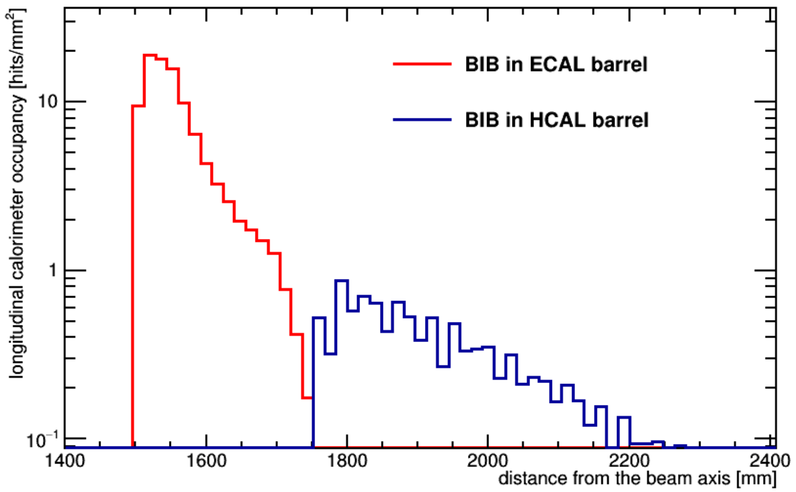
Fig. 2.4: Layout of the HCAL prototype with 3λ depth. The first 2λ is made of the 20x20cm^2 prototype developed in the RD-51 project in 2022, while the last λ necessary to contain longitudinally (95%) protons and pions of 1-6 GeV is made of 50x50cm^2 detectors developed in this project.

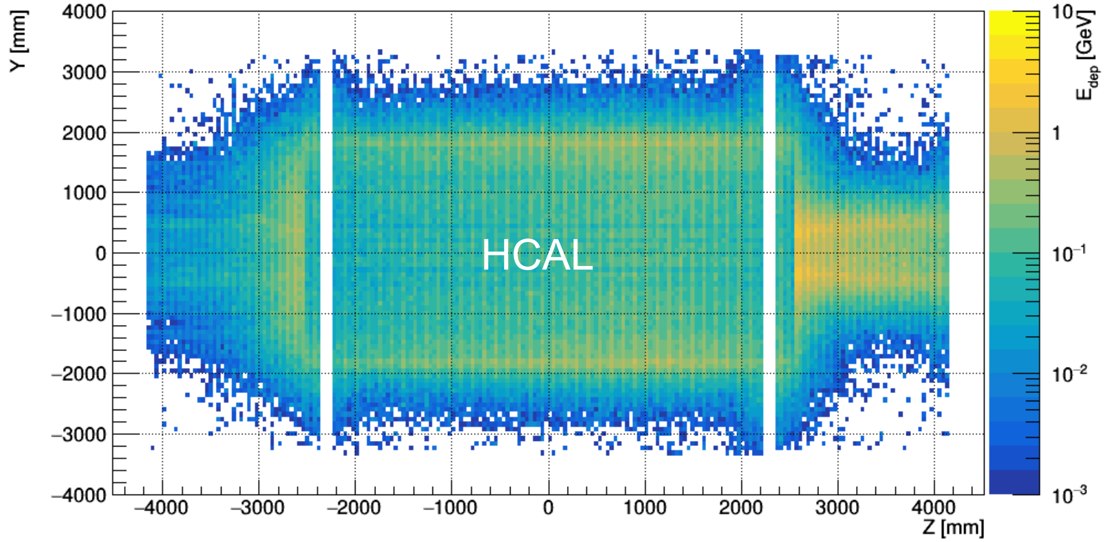


Muon Collider Environment

Differences to Higgs Factories

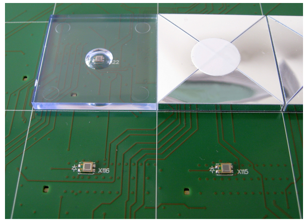
- Many detector considerations for Higgs Factories apply to Muon Collider detectors as well, but
  - Beam background conditions are different and much more challenging
  - Beam-induced background (BIB) leads to large occupancy and significant energy depositions in the calorimeters
- Detector design considerations driven by physics requirements and BIB considerations
- HCAL concept for Muon Collider very likely also suitable for Higgs Factory
  - Would probably require layout optimisation





Optical: State of the art

AHCAL technological prototypes



AHCAL prototype for ILC

- 0.72*0.72*1 m^3 prototype based 3*3*0.3 cm^3 scintillator tiles
- 38 layers with ~22.000 channels
- built 2017-2018

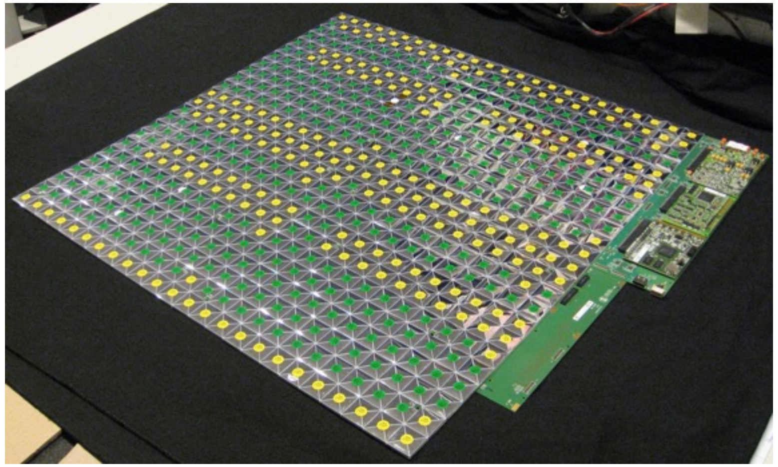
Several successful beam tests 2018 – 2022

- First publication on construction & operation

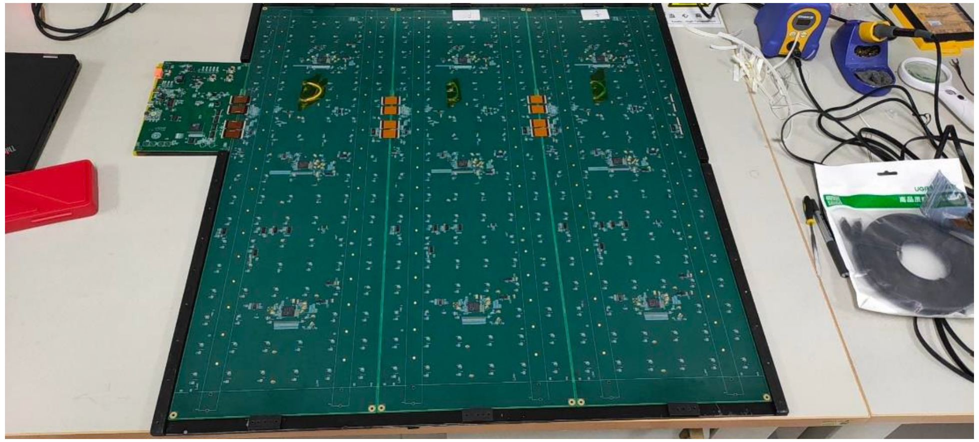
AHCAL prototype for CEPC

- 0.72*0.72*1 m^3 prototype based 4*4*0.3 cm^3 scintillator tiles
- 43 layers with ~14.000 channels
- built 2021-2022

Successful first beam test in 2022



Both prototypes use electronics developed for ILC (power pulsing)

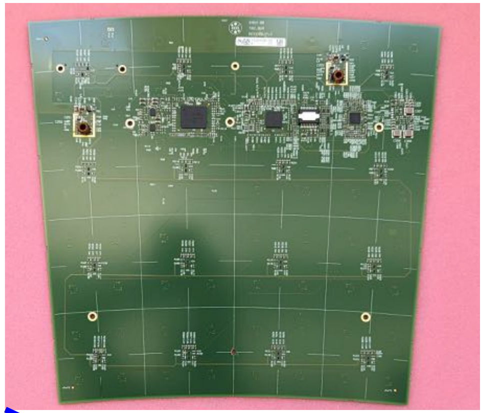


Optical: (soon) state of the art

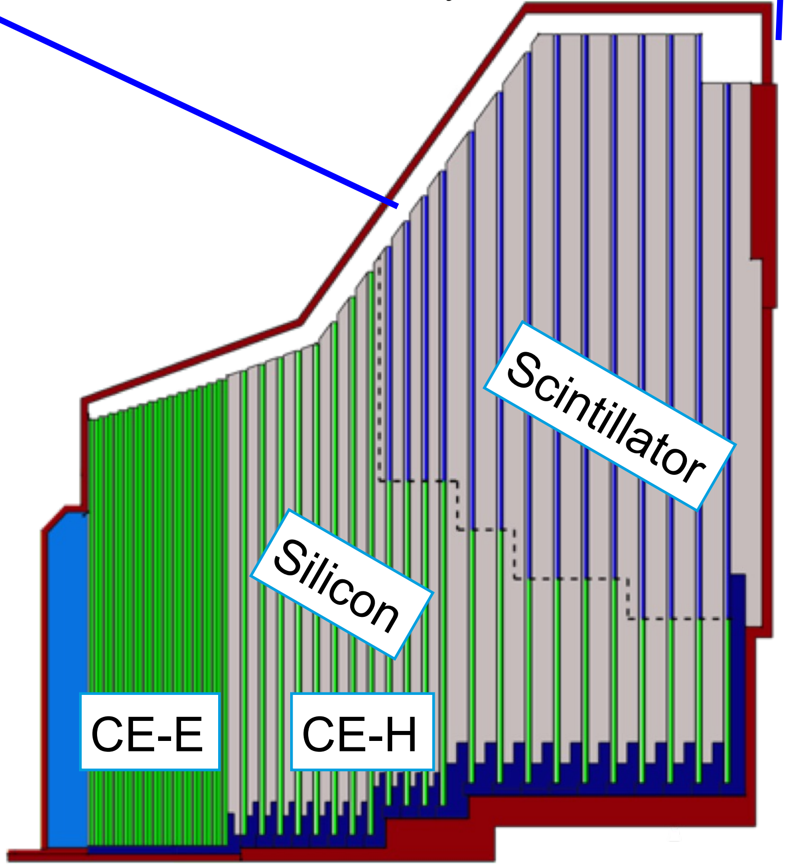
High granularity for HL-LHC

- CMS calorimeter endcap will be replaced for HL-LHC by **H**igh-**G**ranularity **cal**orimeter
  - High granularity for pile-up rejection & particle flow
- Synergy with high granularity calorimeter concepts developed for electron-positron colliders
  - silicon in the front and close to the beam pipe
  - scintillator tiles wherever radiation levels allow
    - ~400 m^2 in ~4000 boards
    - ~240k scintillator channels, 4-30 cm^2 cell size
- New challenges compared to e+e-
  - Radiation levels
  - Operation at -35º C → CO_2 cooling
  - Data rates, continuous running
- Needs to be ready for installation in LS3
  - Transition from R&D phase to production ongoing

Valuable experience for the construction of a highly granular calorimeter as part of any future collider detector



Dummy scintillator module



SiPM-on-Tile AHCAL

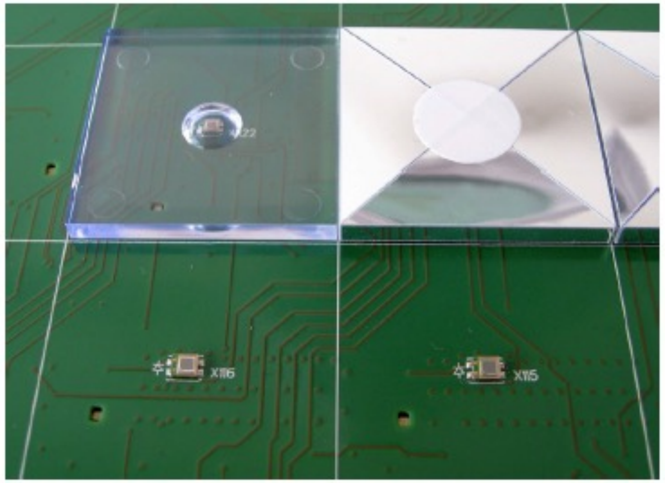
DESY, U Göttingen, U Hamburg, U Heidelberg, KIT, U Mainz, FZU Prague, OMEGA

Karlsruher Institut für Technologie

- Main experimental context: Higgs Factories
- SiPM-on-tile / steel HCAL
  Builds on CALICE AHCAL Technological Prototype

- Main R&D topics:
  - Extension of current detector concept to circular colliders with continuous readout
    - evaluate consequences of higher data rate
    - re-evaluate need for cooling
    - re-optimisation of detector to ensure optimal performance while respecting new constraints
- Corresponding hardware development: ASICs (KLAuS, OMEGA), HBU and interfaces, mechanical and thermal design; scintillator geometry

- First layers for new system design in 2026, EM stack with ~15 layers ~ 2029



***Track 1 Overview** - DRD6 2nd Workshop, April 2023*

Frank Simon (frank.simon@kit.edu)

Institute for Data Processing and Electronics

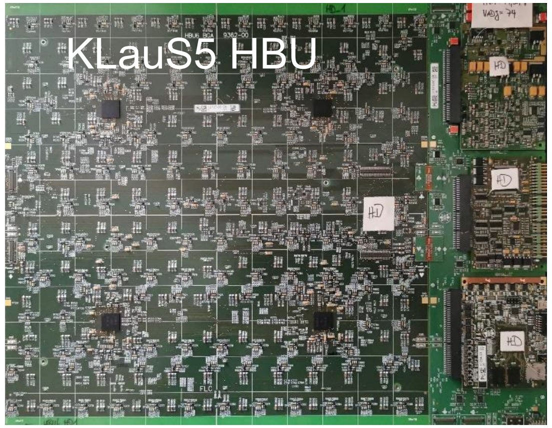
9

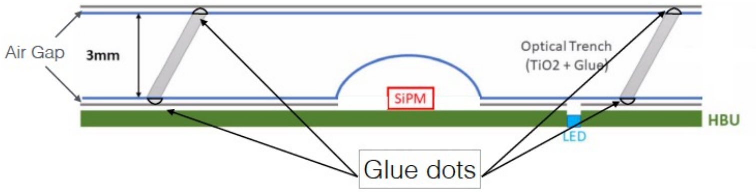
AHCAL

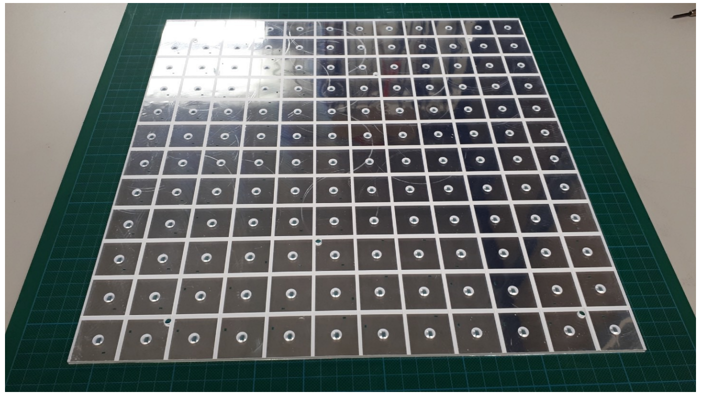
Status of developments

First steps of hardware developments

- Readout electronics supporting continuous readout
  - First board with KLauS5 produced and tested
  - Will need updates for the most recent ASIC
- Optimised scintillator geometry
  - Megatiles would allow larger units for mechanical assembly
  - Last Megatile shows reasonable uniformity and light yield, working on optimization of edge cells





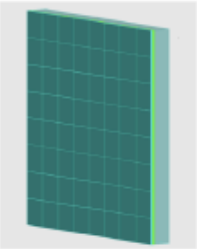


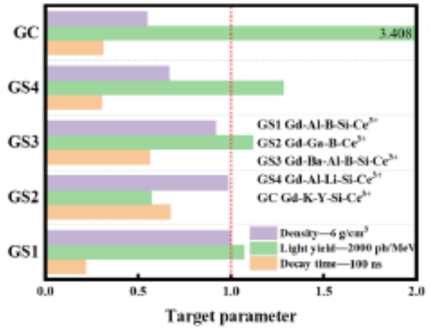
Highly Granular HCAL with Glass Scintillator Tiles

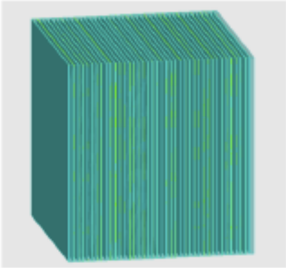
IHEP, Glass Scintillator Collaboration (CN institutes, universities)

- Primary experimental context: Higgs Factories
- A variation of the CALICE AHCAL concept: Using glass scintillator tiles instead of plastic
  - Increased sampling fraction - with the potential for improved energy resolution

- Main R&D directions:
  - R&D of scintillator material - main targets: high density, high light yield, low cost
  - Simulation studies of hadronic performance: single particles, jets
  - Development of modules:
    - setup for characterization,
    - EM prototype ~2025
    - HCAL prototype ~ 2027



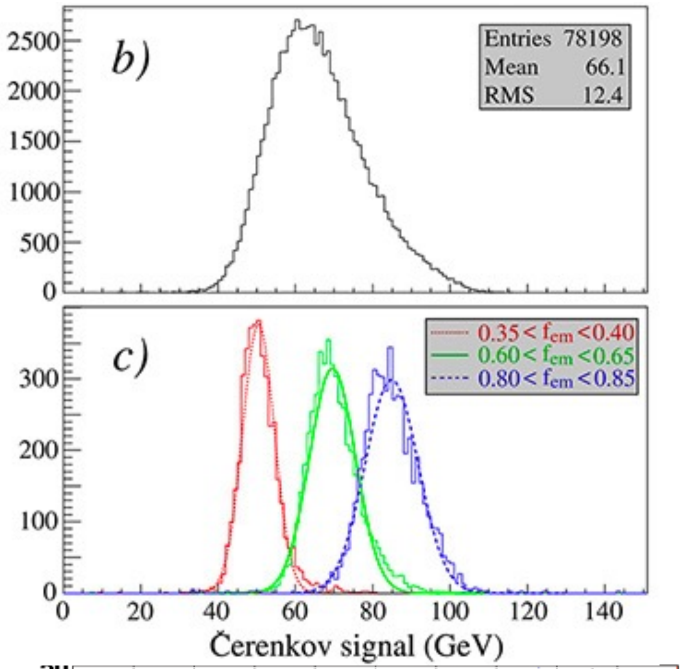


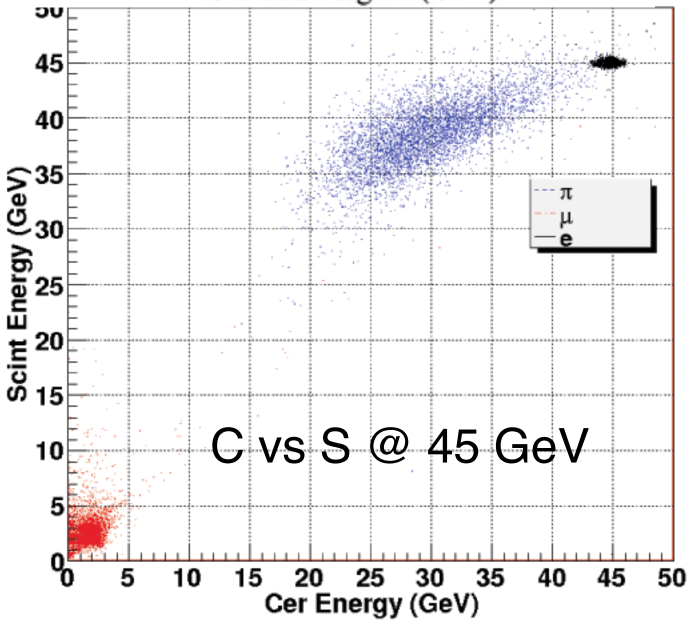


Principle of dual (triple) readout

Combining readout technologies

- Fluctuations are dominating the energy resolution for single hadron energy
  - Fluctuations of the energy sharing between hadronic and electromagnetic component
  - Fluctuations of the neutron component (in the hadronic component)
- Dual Readout: disentangle hadronic and electromagnetic component
  - Simultaneous measurement of scintillation and Cerenkov signal
- Triple readout: add also sensitivity to neutron component
  - Use three active media
    - Cerenkov: EM component
    - Plastic scintillator: HAD component including neutrons
    - RPCs: non-neutron HAD component
  - Interesting also for particle ID



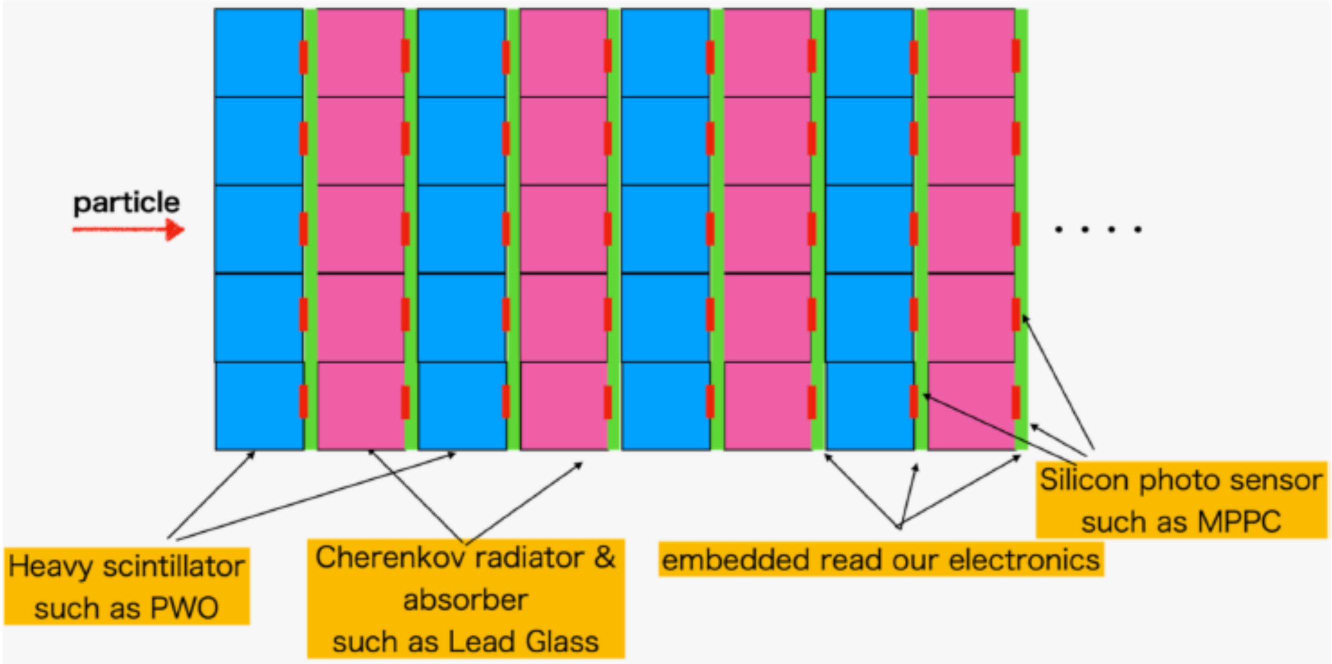


See also talk by I. Vivarelli

Double Readout Sandwich Calorimeter

Shinshu U

- Primary experimental context: Higgs Factories
- A concept for an (almost) fully active hadron calorimeter
  - Alternating layers of heavy scintillator (PWO) and Cherenkov medium (lead glass)
    Each read out by embedded SiPMs
- Currently studied in simulations only on the system level, studies of individual prototype cells in progress
- Goal: construction of up to 5 layers in 2024, a 20 layer prototype in 2026



Initial focus on optical materials and RPCs:
Track 3 as home?

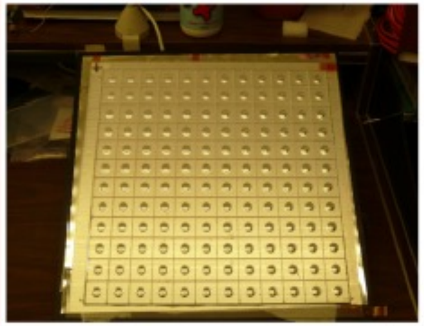
ADRIANO3 - Triple Readout Calorimeter

Beykent, U Iowa, NIU, INFN; ANL, Fairfield U, U Tokyo, Fermilab, Shinshu U, U Kansas

- Primary experimental context: REDTOP
- Extension of ADRIANO2 (fully active granular dual readout calorimeter) to three readout modes to achieve 5D shower measurement, disentangling the neutron component of the shower. Technologies:
  - High-density glass as Cherenkov Medium (and absorber)
  - Plastic scintillator tiles
  - RPCs with cm^2 pad readout
- Key R&D goals
  - optimization of the construction technique in terms of:
  - light yield, RPC efficiency, timing resolution, and cost
  - Test layers in 2024, small-scale prototype 2025
  - Larger-scale prototype 2026-2027
- Plans to use ultrafast ASICs for RPC readout
  Source (DRD7) may need discussion

Initial focus on optical materials and RPCs:
Track 3 as home?



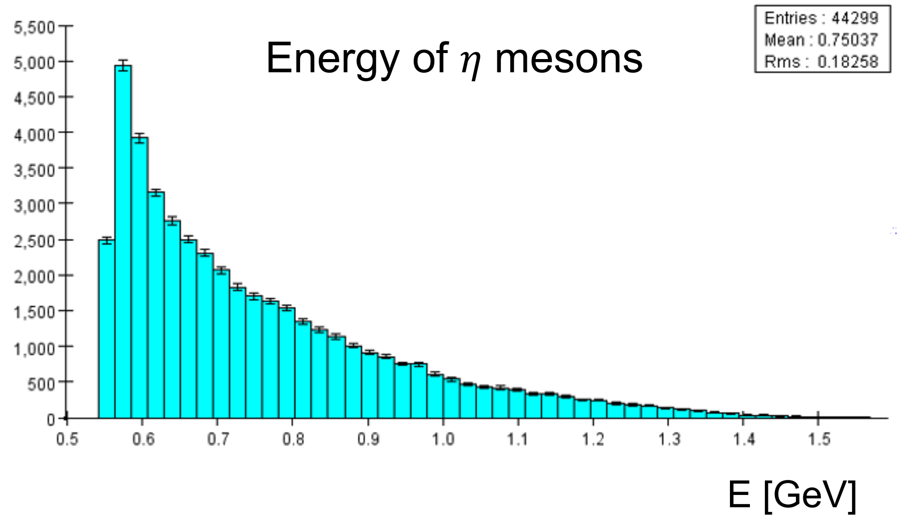


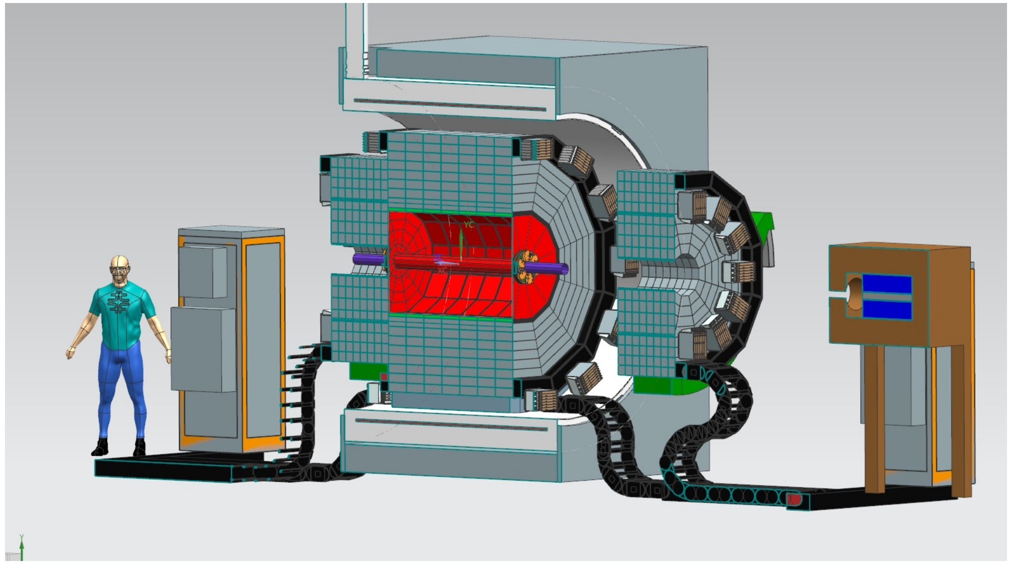
Track 1 Overview - DRD6 2nd Workshop, April 2023   Frank Simon (frank.simon@kit.edu)   11

ADRIANO3 for REDTOP

REDTOP: Rare η/η' Decays To Probe New Physics

- REDTOP plans to produce a data sample of order 10^14 η (10^12 η') for studying very rare decays
- η (η') will be produced via the formation and decay of intranuclear baryonic resonances in hadro-production
  - η is almost at rest in the lab frame
  - Energy of the decay products is small
  - Huge QCD background
- ADRIANO3 as ECAL&HCAL for REDTOP
  - Needs to be sensitive to low energy particles (>= 100 MeV)
  - Needs good energy resolution for low-energy photons from π^0 decays
  - Needs excellent particle ID
- ADRIANO3 concept would also be interesting for a Higgs factory
  - Would require layout optimisation





Common themes

Common aspects for all sandwich HCALs

- System integration
  - Electronics
  - Mechanics
  - For circular Higgs factories: need for cooling?

- System optimisation
  - Granularity
  - Compactness
  - Optimal use of timing

Main R&D Directions

Defining Track 1

Karlsruher Institut für Technologie

DRD6 Track 1

System aspects

Electronic, mechanical, thermal integration

Larger prototypes demonstrating system-level aspects of the technology - incl. fully embedded electronics

Sensor aspects

Development of calorimeter-specific sensors and materials

Test and performance studies of individual elements / cells

links to Track 3, other DRDs

Front-end & TDAQ

FE Electronics (incl. ASICs), data flow, control, trigger and general back-end solutions

links to transversal track 3, possibly DRD7

Overall system optimization

Simulation studies to establish main performance criteria with system relevance, including timing, granularity, compactness and TDAQ concepts

***Track 1 Overview** - DRD6 2nd Workshop, April 2023*

Frank Simon (frank.simon@kit.edu)

Institute for Data Processing and Electronics

15

(Instead of a) Summary

- Several proposals for highly granular hadronic sandwich calorimeters in DRD6
- They share common challenges
- A picture of DRD6 track1 starts to form

very **positive and constructive discussions** so far.

Thank you!

Backup

Relevant objectives

- DRDT 6.2 - Develop high-granular calorimeters with multi-dimensional read-out for optimised use of particle flow methods.
- DRDT 6.3 - Develop calorimeters for extreme radiation, rate and pile-up environments.

Calorimeters based on Gaseous Readout

R&D Need	Main direction	Target facilities	Related DRDT
Scalability of technology	Large area PCBs with robust interconnection, large scale precise absorber structures	ILC, FCC-ee, CLIC, FCC-hh	6.2, 6.3
Rate capability	Semi-conductive Glass RPC	FCC-hh	6.3
Control of pad multiplicity	Avoid/reduce double counting on cell edges	ILC, FCC-ee, CLIC, FCC-hh	6.2, 6.3

Table 6.3: Overview of main R&D needs and corresponding directions of development for calorimeters based on gaseous readout connected to facilities and DRDTs.

Calorimeters based on Optical Readout

R&D Need	Main Directions	Target facilities	Related DRDT
Optimisation of Photon detectors	Novel SiPMs with large spectral sensitivity and high-band semi-conductors for higher radiation tolerance, Digital SiPMs	ILC, FCC-ee, CLIC, FCC-hh, Muon Collider	6.2, 6.3
Novel crystal technologies	Co-doped garnet crystal fibres	HL-LHC, ILC, FCC-ee, CLIC, FCC-hh, Muon Collider	6.1, 6.2, 6.3
Longitudinal information	Longitudinal segmen-tation of crystals, z-position from timing	HL-LHC, ILC, FCC-ee, CLIC, FCC-hh, Muon Collider	6.1, 6.2, 6.3
Novel plastic scintillators	Radiation hardness, implementation of dual readout	ILC, FCC-ee, CLIC, FCC-hh, Muon Collider	6.2, 6.3

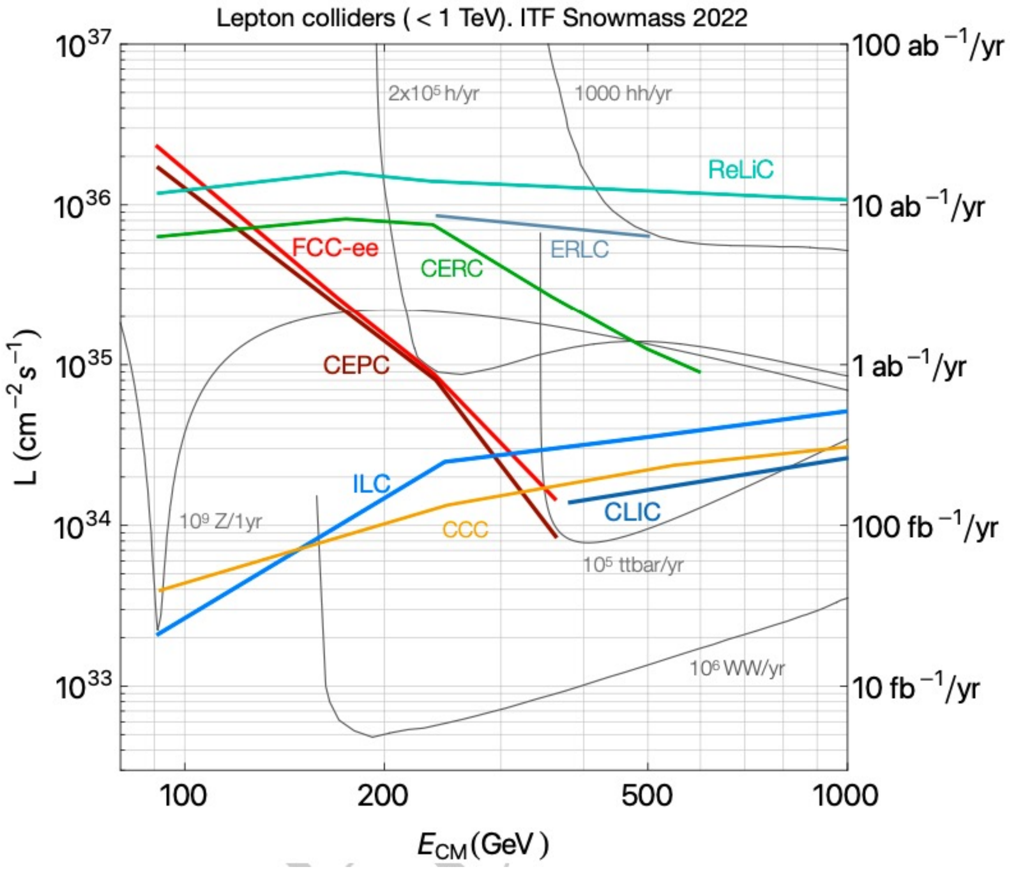
Table 6.4: Overview of main R&D needs and corresponding directions of development for calorimeters based on Optical Readout connected to facilities and DRDTs.

- For more details see also afternoon session
- **Synergies with TF4** (Particle Identification and Photon Detectors)

Differences

Linear and Circular Higgs/EW/top factories

- Higgs/EW/top factory options differ in various aspects
- Highest centre-of-mass energy
  - Impacts highest expected particle and jet energies
    → calorimeter thickness, absorber material, granularity
- Beam structure
  - Linear colliders have bunch trains, circular colliders not
    → readout electronics (power pulsing or continuous running), cooling
- High statistics Z pole running at FCC-ee and CEPC
  - Very high rates
    → trigger system, rate capability of the detector technology
  - More interest in detector capabilities for flavour physics
    → b/c tagging, particle ID



Common R&D topics for Gaseous and Optical Readout

Integration & Readout Electronics

- Large number of channels of highly granular hadron calorimeter sections make electronics embedded in the active layer essential
- The details of the integration and readout concept depend on the environment
  - Linear e+e-: Low rate, low radiation, power pulsing
  - Circular e+e-: High rate, low radiation, continuous power
  - Hadron collider: very high rate, high radiation, continuous power
- Dedicated embedded very-frontend readout ASICs
  - **Synergies with TF7 (Electronics and Data Processing)**
  - Can profit a lot from synergies between calorimeter concepts
  - Linear e+e-: HARDROC (RPC), SPIROC (SiPMs), SKIROC (Si), …
  - Circular e+e-: KLauS (SiPM), PETIROC as starting block (RPC)
  - Hadron collider: HGCROC (Si and SiPM)
- Depending on data rates, several stages of data concentration and selection might be needed
  - For existing concepts: work on miniaturization ongoing
    - AHCAL plans to exploit synergies with SiW ECAL developments of interface boards
  - For other future applications: will likely need dedicated studies
    - FCCee: Need **simulation** to estimate impact of high rate Z pole running on data rates and readout needs
  - Interesting field for new concepts like DNNs on ASICs (implemented for HGCAL)

Common R&D topics: Gaseous and Optical Readout

Timing

- Precise hit time measurement can be beneficial in several areas
- In high rate environments, interesting for pile-up rejection
- Could use “time” as additional information in particle flow algorithms to improve 2-particle separation
  - **Simulation studies needed** to determine what resolution is really needed
    - Might depend on detector and on algorithm
  - Status: first studies for SDHCAL and April PFA
- Particle ID with time-of-flight:
  - needs very good resolution O(10-30 ps)
- Current calorimeter prototypes reach O(1 ns) for MIP hits
- The technologies have a lot of potential for better time resolution
  - RPC: multi-gap RPCs have demonstrated ~60ps for MIP hits
    - Plan: build a timing layer for SDHCAL, more effort needed on electronics developments
  - Scintillator: tiles/strips with high light yield reach ~30 ps resolution for MIP hits
    - Requires small tiles, crystal scintillator
- Also readout electronics contributes to time resolution → synergies with TF7