



Calorimeters

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AIDA++ Open Meeting, CERN

4. September 2019

Calorimetry R&D: general trends

Radiation hardness

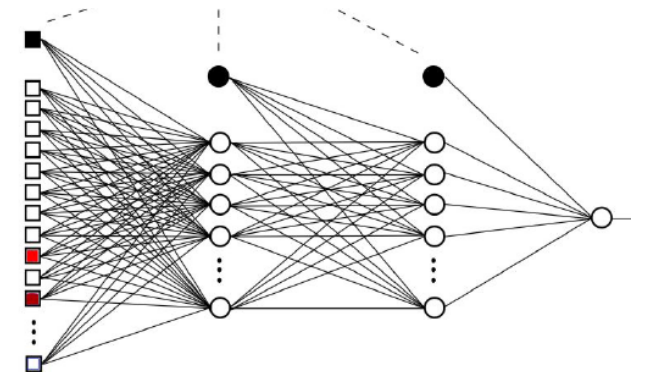
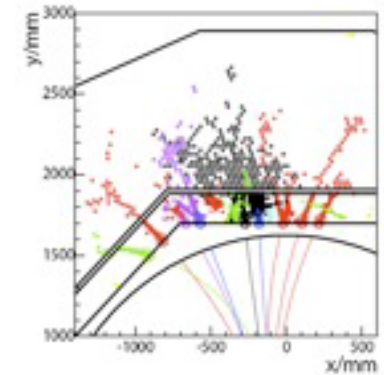
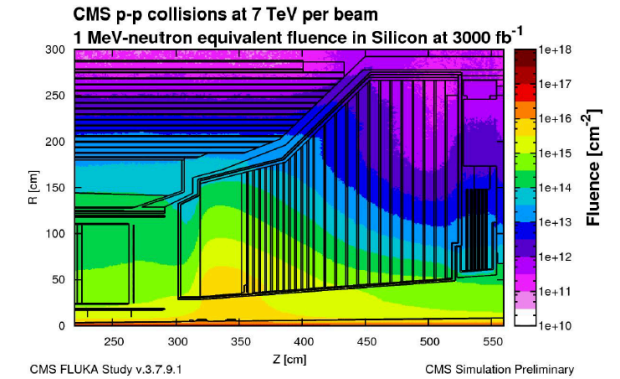
- upgrades for HL-LHC on their way, next (huge) step would be FCC-hh
- forward calorimeters: not only radiation, but also hit rates and pile-up

Granularity

- Originally developed for particle flow, but gaining importance also for pile-up rejection
- Challenge for integration, data & trigger rates, ... → readout electronics

New compared to AIDA-2020

- Fast timing: hundreds to tens of ps
- Machine learning: more and more complex analysis, also in real time (beam steering, trigger, ..)



Overview: Calorimeter Eols

Statistics

- In total 19 Eols on Calorimetry
 - Total cost ~10 MEUR, EC contribution ~3.4 MEUR
- was 9 in AIDA-2020 preparation
was ~6.3 MEUR EC in AIDA-2020

Structure of this presentation

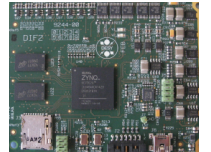
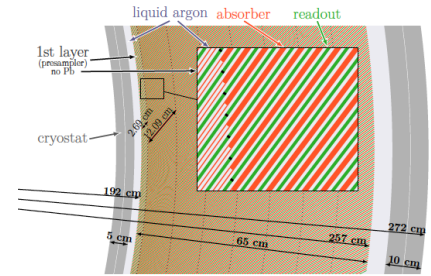
- Nowadays, nearly everybody is aiming at high(er) granularity and fast timing
- No clear next collider project
- Grouped Eols to make possible connections and synergies visible
 - Large calorimeters as part of the main detector vs. (forward) calorimeters for high-pile-up environment
 - Active material: noble liquid vs. silicon vs. scintillator vs. gaseous detectors

Calorimeters for Main Detectors

Noble Liquid

Eol 7: R&D for future high-granularity noble liquid calorimetry

- Institutes: CERN, LAL Orsay, OMEGA, Prague Charles Uni, LAPP Anney, CPPM Marseille
- Company: -
- Experiment/Machine: main calorimeter at FCC-hh, FCC-ee
- Budget: 250 kEUR (EC) + ~700 kEUR (matching)
- **Design, prototyping and characterisation of a readout electrode for a high-granularity LAr (or LKr) calorimeter, including some readout electronics**



Silicon

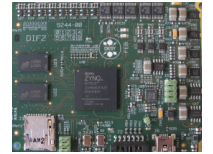


Eol 46: High-granularity silicon-based calorimetry for future experiments

- Institutes: CERN
- Company: -
- Experiment/Machine: main EM calorimeter in future collider experiment (CLIC, FCC-ee, FCC-hh, ILC, CEPC)
- Budget: 400 kEUR (EC) + 800 kEUR (matching)
- **Engineering design, construction and test of modules, industry collaboration, exploration of opp. outside HEP**

Eol 139: Development of Ultra-flat and active modular detector systems

- Institutes: LAL, LLR, OMEGA, LPNHE
- Company: -
- Experiment/Machine: main EM calorimeter at future electron-positron collider
- Budget: 215 kEUR (EC) + 447 kEUR (matching)
- **Fabrication of ultra-flat silicon-based detector layer, innovative readout cards, prototype of advanced power distribution system**



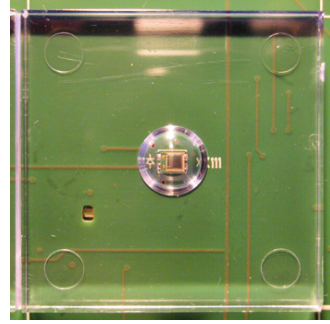
Eol 148: Versatile Assembly, Qualification and Measurement Framework for Complex Detectors

- Institutes: LLR, OMEGA, Uni Kyushu (Japan)
- Company: -
- Experiment/Machine: main EM calorimeter at future electron-positron collider
- Budget: 120 kEUR (EC) + 270 kEUR (matching)
- **Development of a Qualification and Measurement bench: requirements, software and database infrastructure, prototype bench**

Scintillator tiles + SiPM

Eol 84: Sensitive elements for highly granular calorimeters with optical readout

- Institutes: MPI Munich, Uni Mainz, Uni Göttingen
- Company: -
- Experiment/Machine: main calorimeter at future collider experiment, EM calo for DUNE Near Detector
- Budget: 200 kEUR (EC) + 400 kEUR (matching)
- **Test systems for fast scintillator elements, performance studies of for fast scintillator elements and photon sensors, report on options for neutrino Near Detector**

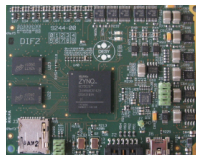


Eol 86: Performance Studies of Scintillator Tiles with Readout with New SiPMs with respect to Optimal Energy, Position and Timing resolution

- Institutes: Uni Bergen (Norway), Uni Göttingen, Institute of Physics CAS Prague
- **Company: FOTON s.r.o**
- Experiment/Machine: main calorimeter at future collider experiment
- Budget: 94+15 kEUR (EC) + 188+15 kEUR (matching)
- **Prototype of adaptive power supply for SiPMs, tests of SiPM properties, gain stabilisation studies (-40 to +50 C), timing studies of scintillator tiles+SiPMs**

Eol 144: Compact readout electronics for a highly granular SiPM-on-tile calorimeter

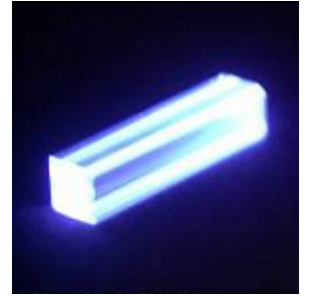
- Institutes: DESY, Uni Heidelberg, Institute of Physics CAS Prague, Uni Mainz, Uni Wuppertal
- Company: -
- Experiment/Machine: main calorimeter at future collider experiment, DUNE Near Detector
- Budget: 200 kEUR (EC) + 400 kEUR (matching)
- **Development of a readout ASIC and readout cards for SiPM readout, very compact and homogenous interconnection and integration scheme**



Silicon and Scintillator

Eol 91: Compact Timing Calorimeter

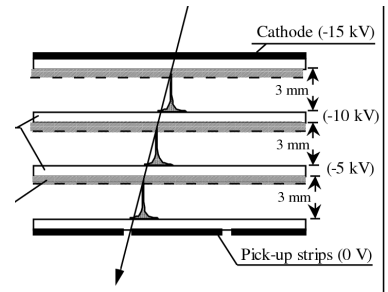
- Institutes: INFN Torino, INFN Padova, INFN Bologna, LAL
- Company: -
- Experiment/Machine: future muon collider, LHCb Phase-2 upgrade
- Budget: 200 kEUR (EC) + 400 kEUR (matching)
- **Highly granular sampling calorimeter with silicon layer for fast timing: design and beam test, prototype test as part of LHCb slice test**



Gaseous calorimeters

Eol 58: Timing for SDHCAL

- Institutes: Lyon, Clermont-Ferrand, Gangneung-Wonju (South Korea), OMEGA, SJT (China), CIEMAT
- Company: -
- Experiment/Machine: main HAD calorimeter at future electron-positron collider
- Budget: 220 kEUR (EC) + 440 kEUR (matching EU) + 275 kEUR (matching non-EU)
- **Building and test of 1*1 m² multi-gap RPC detector layers with precise timing electronics**



Eol 85: R&D towards MPGD based SDHCAL for high radiation environment

- Institutes: Weizmann (Israel), Technion (Israel)
- Company: -
- Experiment/Machine: main HAD calorimeter at future circular electron-positron collider (FCC-ee, CEPC)
- Budget: 100 kEUR (EC) + 200 kEUR (matching)
- **Building and test of a 1*1 m² RPWELL (and possibly other MPGD based) layer, capable of operating at rates of 10⁵ Hz/cm²**

Eol 135: GRPC Digitizer for Hadronic Calorimeter

- Institutes: IP2I Lyon, LPC
- Company: -
- Experiment/Machine: main HAD calorimeter at future electron-positron collider
- Budget: 80 kEUR (EC) + 160 kEUR (matching)
- **Improved digitiser for simulation of GRPCs, simulation of environmental-friendly gases**

Detectors for high pile-up environments

Silicon

Eol 35: Precision Compact Electromagnetic Calorimeter

- Institutes: AGH-UST Krakow, DESY, ISS, TAU (Israel)
- **Company: Intel (?), Tower Jazz (?)**
- Experiment/Machine: lumi measurement at future electron-positron collider
- Budget: 200 kEUR (EC) + 400 kEUR (matching)
- **Prototype infrastructure of a miniaturised EM calorimeter with ultra-low power consumption**



Scintillating crystals + SiPM

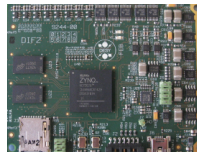


Eol 36: Development of ultra-fast, high performance calorimeters for next-generation experiments

- Institutes: INFN Frascati, INFN Roma, INFN Ferrara, INFN Napoli, INFN Torino
- Company: -
- Experiment/Machine: small angle calorimeter for KLEVER@CERN SPS and PADME@Frascati BTF
- Budget: 175 kEUR (EC) + 350 kEUR (matching)
- **Validation of components (crystals and SiPMs), irradiation tests, beam tests of a prototype, tests with oriented crystals to enhance conversion by coherent interactions**

Eol 37: Development of a fast digitizing readout system for high performance calorimeters

- Institutes: INFN Roma, INFN Pisa, INFN Torino, INFN Frascati
- Company: -
- Experiment/Machine: small angle calorimeter for KLEVER@CERN SPS and PADME@Frascati BTF
- Budget: 180 kEUR (EC) + 360 kEUR (matching)
- **High rate readout for >1 MHz: test of CAEN digitisers in PADME and NA62, readout system specification for PADME upgrade and KLEVER, building and test of prototype readout boards**



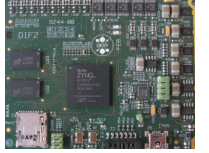
Eol 74: Fast crystal calorimeters for high background environments

- Institutes: Uni+INFN Perugia, Uni+INFN Napoli, BINP (Russia)
- Company: -
- Experiment/Machine: future Belle II upgrade
- Budget: 126 kEUR (EC) + 252 kEUR (matching)
- **Study of fast, radiation hard scintillating crystals and photosensors, radiation tests, beam tests**

Beam diagnostics

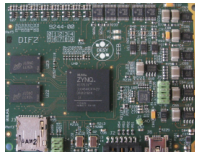
Eol 117: Beam diagnostics in high radiation environments

- Institutes: CEA, Uni Birmingham, Uni Thessaloniki
- Company: -
- Experiment/Machine: beam loss monitor based on neutron detection with MPGD or strips for LINACs
- Budget: 192 kEUR (EC) + 384 kEUR (matching)
- **Evaluation of correlation between beam losses and count rate, use in real time beam correction based on machine learning; radiation hard electronics for beam instrumentation**



Eol 158: Compact multi-layer calorimeter as luminometer in extremely intense environments

- Institutes: HZDR, INFN
- Company: -
- Experiment/Machine: background and lumi measurement at future colliders
- Budget: 150 kEUR (EC) + 300 kEUR (matching)
- **Design and construction of prototype based on scintillators read by SiPMs/APDs using advanced unfolding, readout electronics, test with intense gamma and neutron beams**

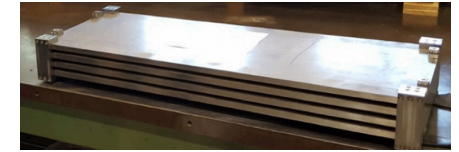


Engineering

Absorber Structure & Engineering Methods

Eol 63: Mechanical structures for high granularity calorimeters, Electron beam and Laser welding

- Institutes: CIEMAT
- **Company: ARKU Maschinenbau**
- Experiment/Machine: main HAD calorimeter (at future electron-positron collider)
- Budget: 60 kEUR (EC) + 120 kEUR (matching)
- **Two absorber structure demonstrators assembled with electron beam welding and laser welding**



Eol 77: Development of engineering methods for the construction of fibre-sampling dual-readout calorimeter matrices

- Institutes: INFN (Bologna, Milano, Pavia, Pisa), Ruder Boskovic, Uni Sussex, Yonsei Uni (South Korea), Kyungpook Uni (South Korea), Iowa Uni (US), Korea Uni (South Korea)
- Company: -
- Experiment/Machine: main calorimeter at future electron-positron collider
- Budget: 200 kEUR (EC) + 400 kEUR (matching)
- **Construction of several $0.1 \times 0.1 \times 2$ m³ dual-readout prototypes, technical documentation, engineering for the IDEA detector**



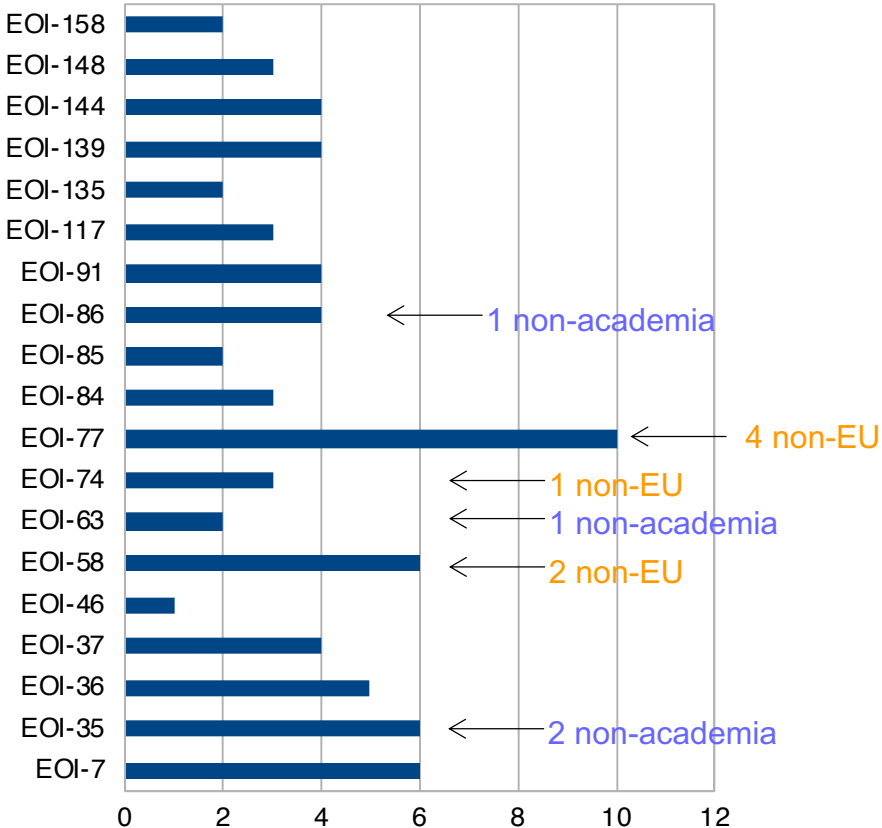
Summary

The complete picture

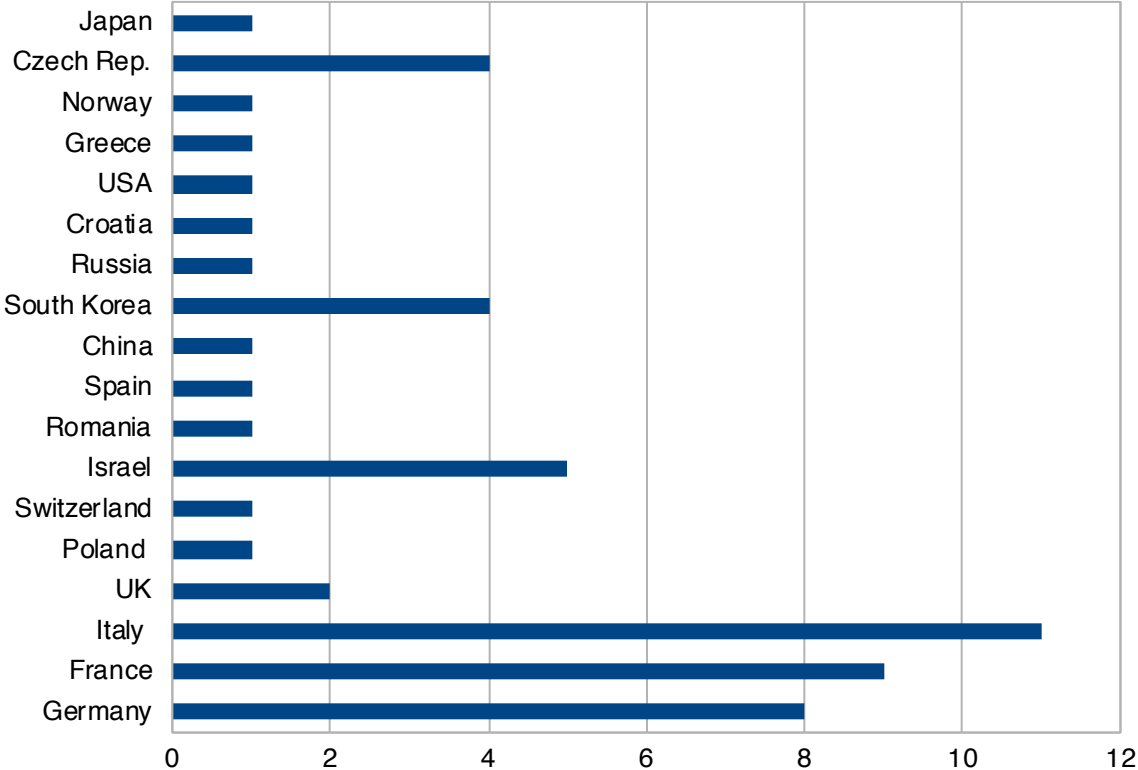
Eol no.	Title	technology				connections				Full costs	EC contribution
		silicon	Scint.	gas	other	electronics	software	beam diag.	engin.		
7	noble liquid				yes	yes				950.000	250.000
46	Future High-granularity silicon	yes								1.200.000	400.000
139	Ultra-flat modular silicon	yes				yes				669.000	215.000
148	Assembly & Q&A for complex detectors	yes								390.000	120.000
84	Scintillator for highly granular calos		yes							600.000	200.000
86	Performance Studies of Scintillator Tiles		yes							312.000	109.000
144	readout electronics for SiPM-on-tile		yes			yes				600.000	200.000
91	Compact Timing Calorimeter	yes	yes							600.000	200.000
58	Timing for SDHCAL			yes						935.000	220.000
85	MPGD based SDHCAL for high radiation env.			yes						300.000	100.000
135	GRPC Digitizer for Hadronic Calorimeter			yes			yes			240.000	80.000
35	Precision Compact ECAL	yes								600.000	200.000
36	ultra-fast, high performance calo (crystal+SiPM)		yes							525.000	175.000
37	Fast digitizing readout system for crystal+SiPM		yes			yes				540.000	180.000
74	Fast crystal calorimeters for high background env.		yes							378.000	126.000
117	Beam diagnostics in high radiation env.			yes		yes	yes	yes		576.000	192.000
158	Compact calorimeter as luminometer		yes			yes	yes	yes		450.000	150.000
63	Mechanical structures: e beam and Laser welding								yes	180.000	60.000
77	engineering methods for dual-readout								yes	600.000	200.000
										10.645.000	
		1.135.000	1.340.000	592.000	250.000						3.377.000

Some Statistics

#Members/Eoi



#Members/country



Conclusion

Interest in Calorimetry from a broad community

- Many interesting future projects
- A challenge, but also an opportunity

Synergies between Eols within Calorimetry, but also beyond

Budget heavily over-subscribed → need to identify infrastructure priorities

Room for improvement in industry participation

Looking forward to an interesting and intense discussion phase!