dual readout calorimetry for future lepton colliders

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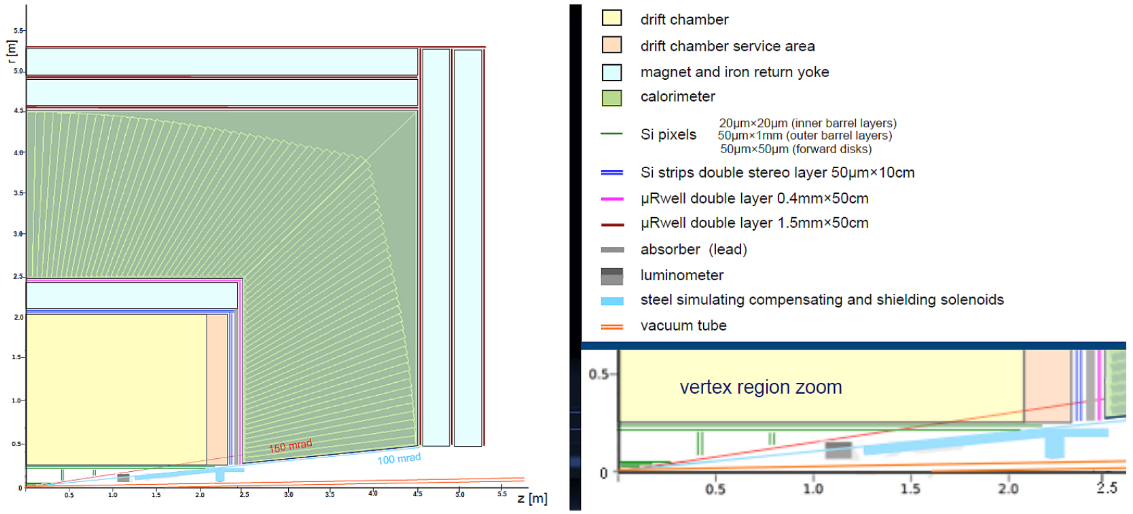
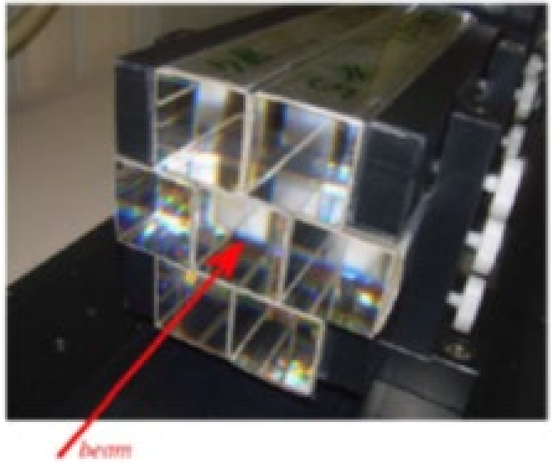
Snowmass Calorimetry session

19 July 2022

For the IDEA Calorimeter group[1] and CalVision[2] collaborators

1 CERN, Pavia, Milano, Milano-Bicocca, Roma La Sapienza, Pisa, Kyungpook, Princeton, Texas Tech, Maryland, Michigan, Seoul, Sussex, U. Va, Yonsei,
2 Argonne, Caltech, FNAL, Maryland, Michigan, MIT, Oak Ridge, Princeton, Purdue, Texas Tech, Virginia





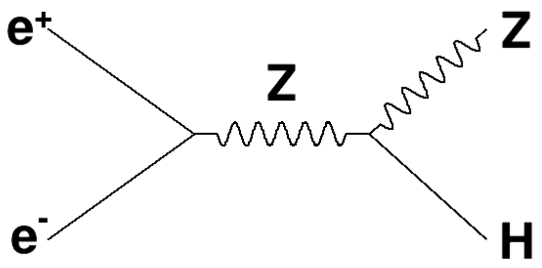
Calorimetry at future colliders

IDEA

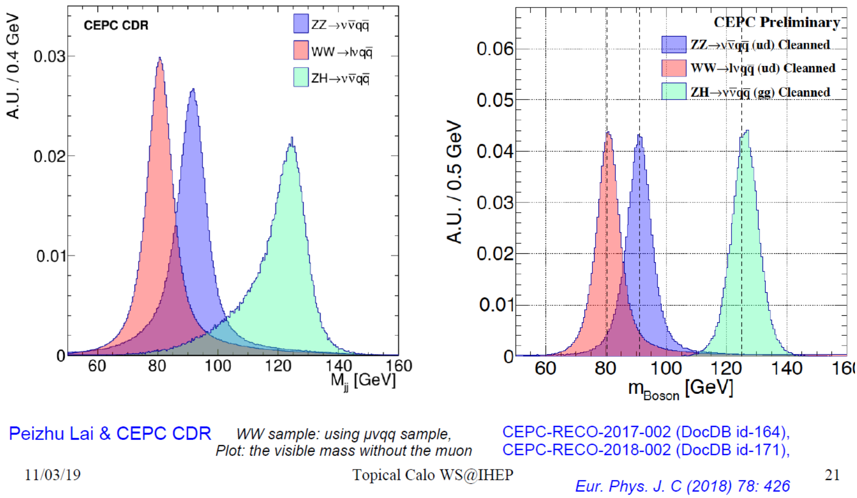
CalVision

Energy Frontier Snowmass report: after the physics of the HL-LHC:

> The e^+e^- colliders are the vehicle that will enable a program in the electroweak sector and will increase the precision of the measurements. The physics case for an e^+e^- Higgs factory is compelling and the program is possible essentially with current technology. (pg 88)



Massive Boson Separation



The Higgs measurements put a strong emphasis on jet energy resolution (3-4% at 100 GeV), allowing separation of W, Z, and H bosons. As discussed in the previous talk, high-granularity calorimetry meets these goals. This option has been well studied through the seminal work of the CALICE collaboration. HL-LHC will give our community ample experience with this type of calorimetry with the CMS HGCAL detector.

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HGC's achieve excellent jet resolution via the tracker and shower pattern recognition

CalVision

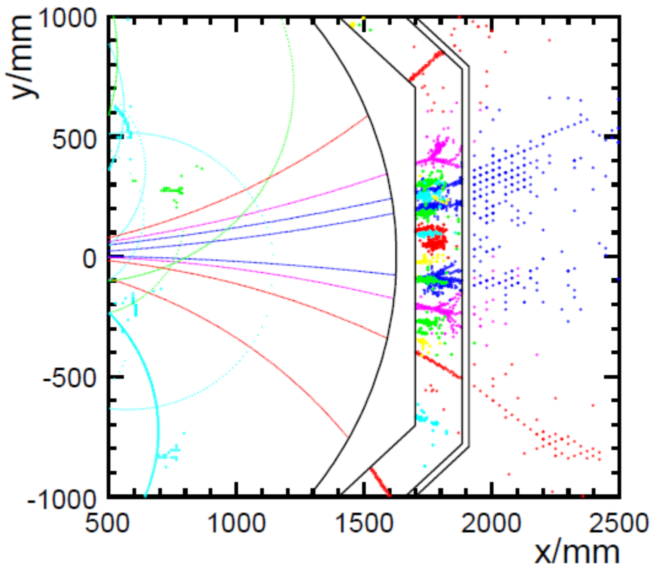
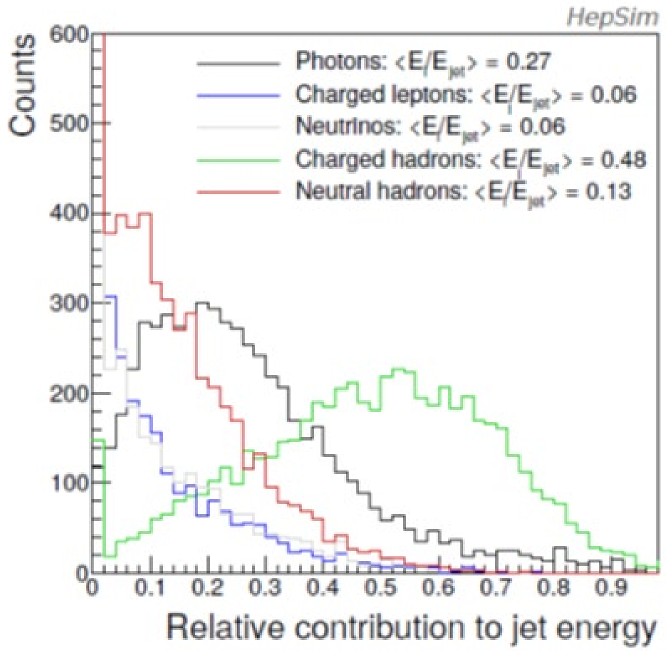
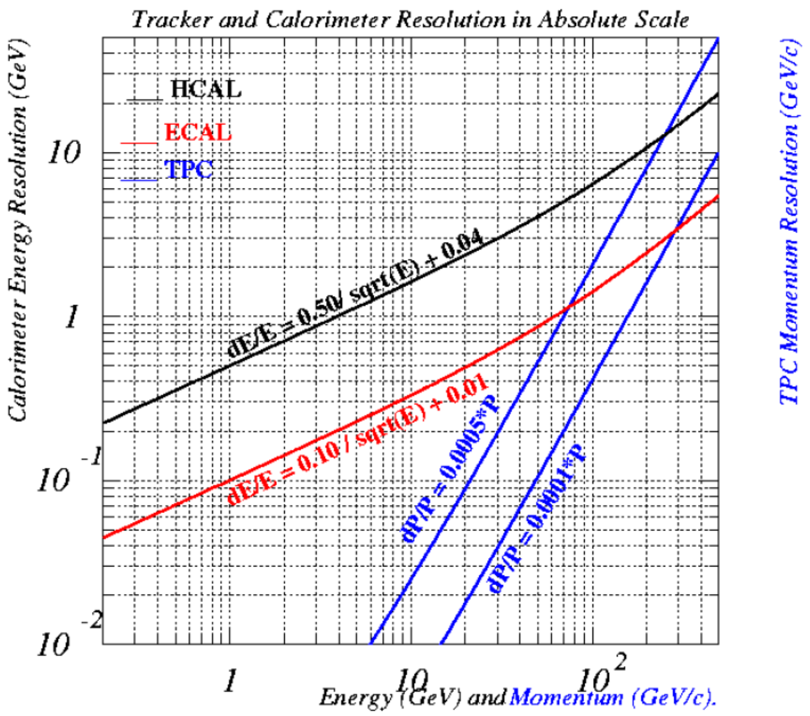


Figure 6: PandoraPFA reconstruction of a 100 GeV jet in the MOKKA simulation of the ILD detector. The different PFOs are shown by colour/grey-shade according to energy.





Calorimeter resolution requirements not that stringent: 50% HAD and 10% EM stochastic terms

Pöschl https://indico.ihep.ac.cn/event/11938/

IDEA

Dual readout calorimeters

CalVision

Circular e^+e^- Higgs factories, such as FCC-ee and CEPC, will have multiple detectors. Other paths forward, like muon colliders, will also have multiple detectors. There is another kind calorimetry that satisfies the goal: dual readout calorimetry, pioneered by the RD52/DREAM/IDEA collaborations. The goal is to improve, rather than bypass, the calorimeter measurement itself by identifying the particles produced in the shower using ancillary information like the particle velocity or interaction time.

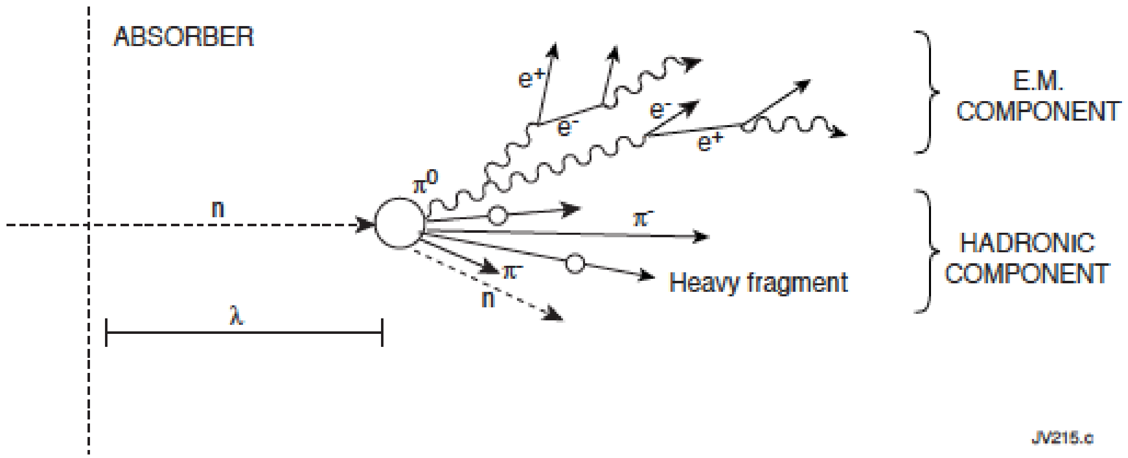
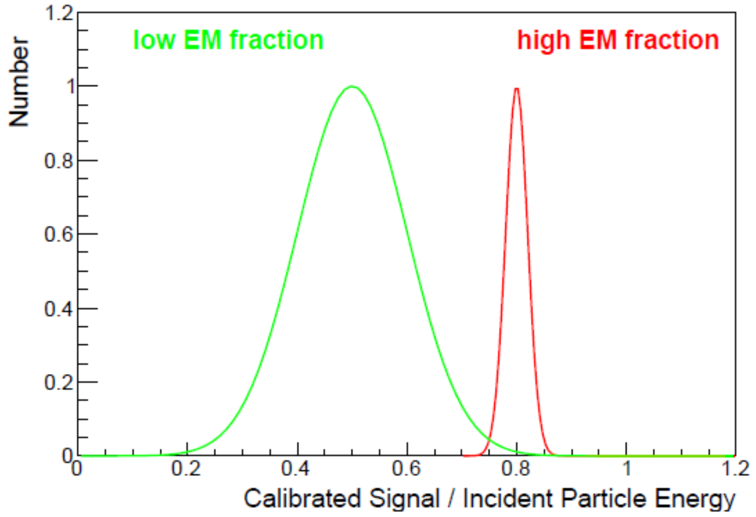


Fig. 9: Schematic of development of hadronic showers.



Shower details

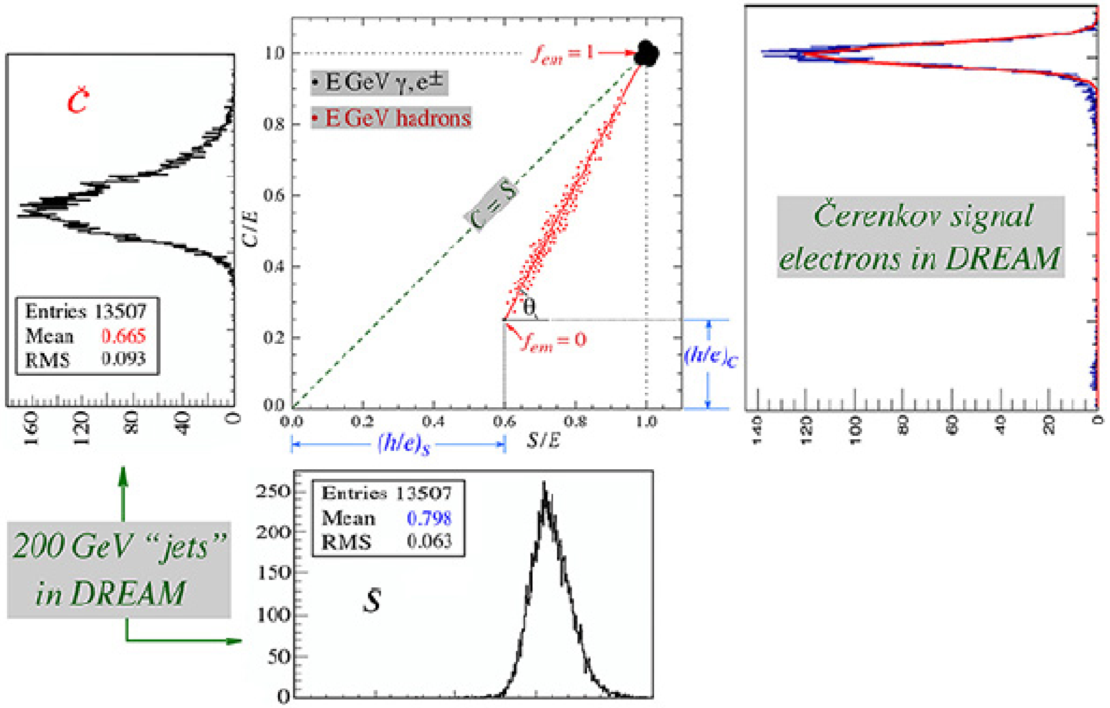
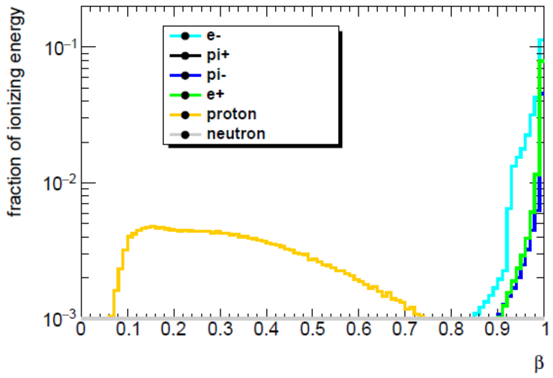
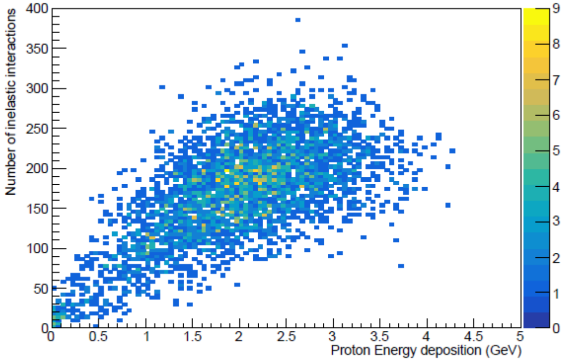


FIG. 8: The $S-C$ diagram of the signals from a (generic) dual-readout calorimeter [29]. The hadron events are clustered around the straight (red) line, the electron events around the point (1,1). Experimental signal distributions measured in the scintillation and Čerenkov channels for 200 GeV "jets" with the DREAM fiber calorimeter [30] are shown as well. Also shown is a typical (Čerenkov) response function measured for electrons in DREAM.



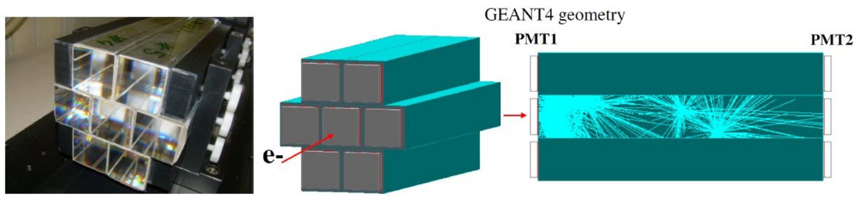


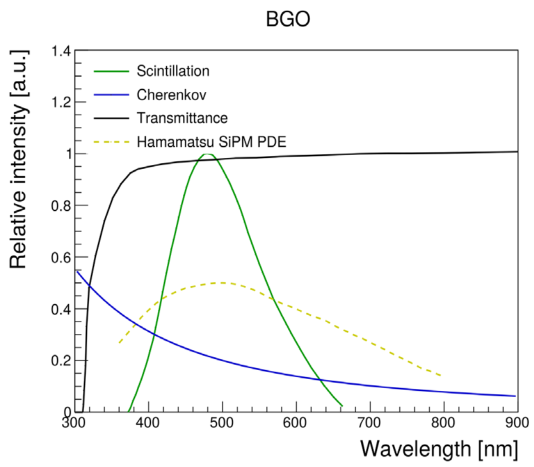
Typically done with relativistic/non-relativistic particles via Cherenkov photon measurement, but can also be done using late energy deposits by neutrons

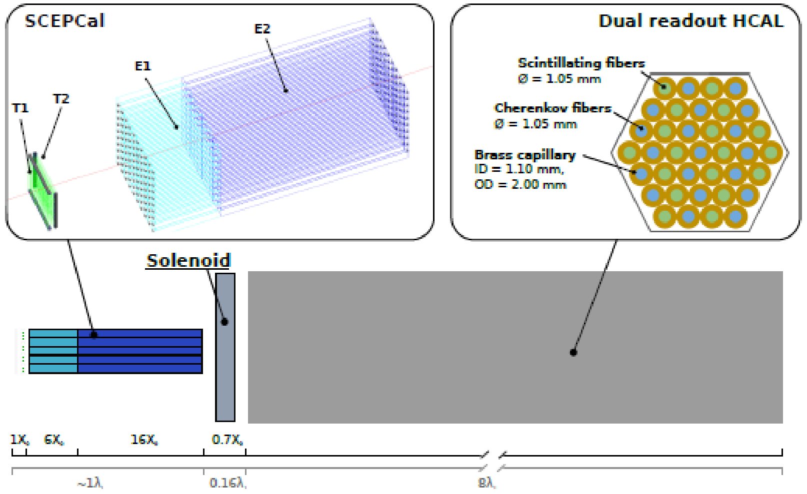
Precision EM possible

While past attempts by RD52/DREAM to use crystals for dual readout failed due to the photodetector technology at that time, modern wavelength extended SiPMs may change this.

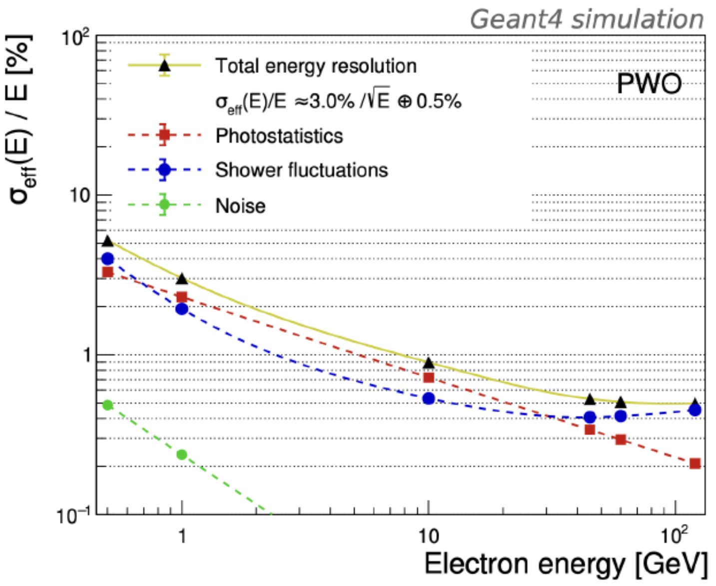
A plethora of flavour physics could be enabled by this precision EM calorimetry (e.g. https://arxiv.org/abs/2107.12832)

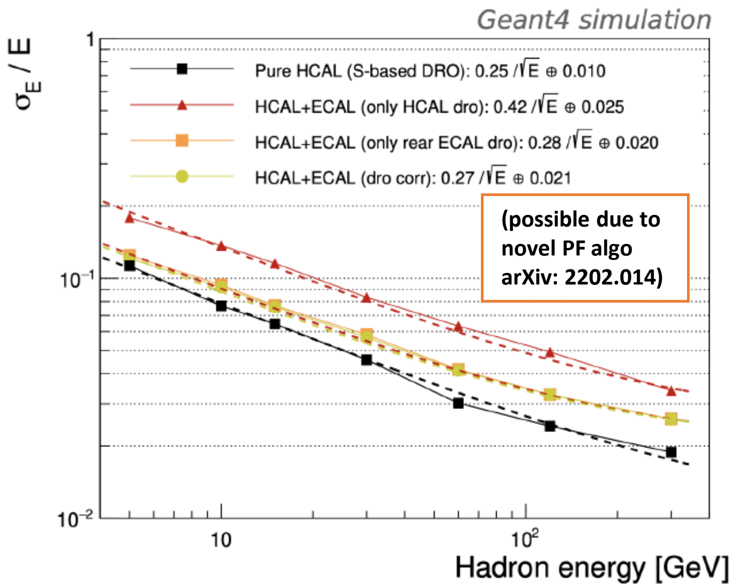






https://arxiv.org/abs/2008.00338

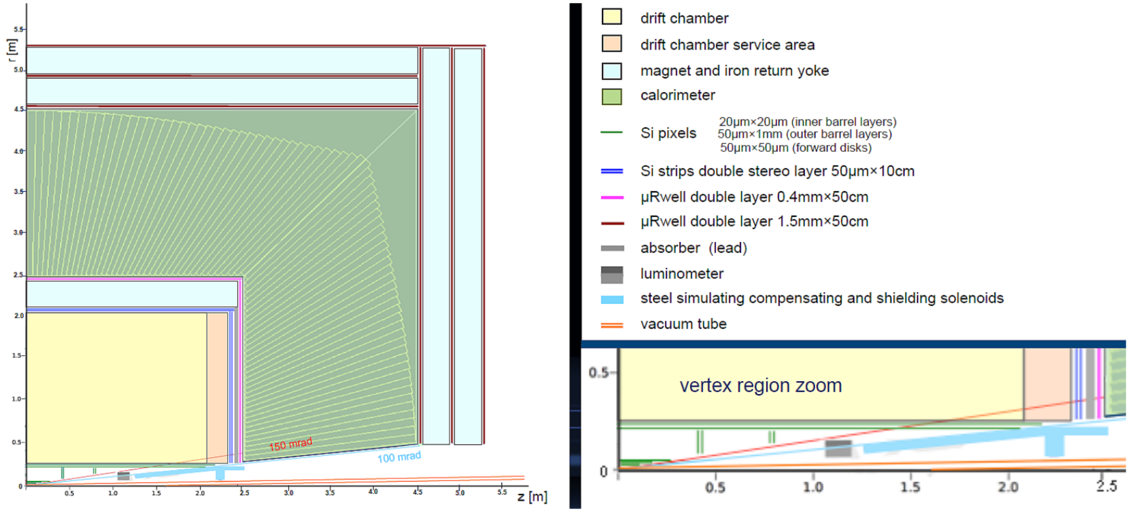


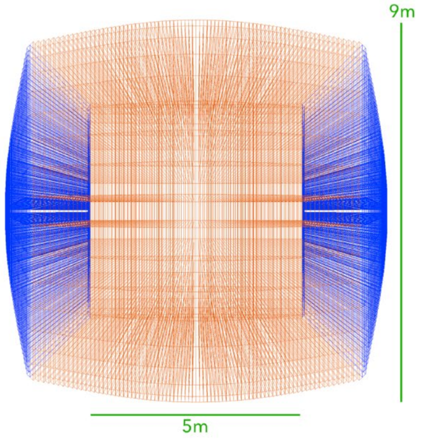


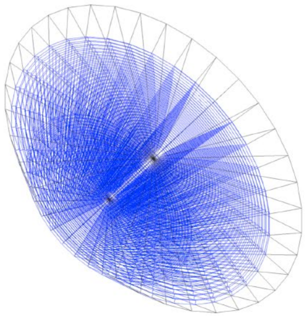
IDEA collaboration

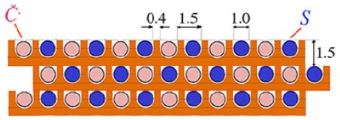
Dual readout calorimetry is the thrust for one of the proto-collaborations for future circular colliders: IDEA

The IDEA collaboration is a detector proposal for FCC-ee and/or CEPC and/or muon collider using a dual-readout calorimeter. Calorimeters with or without precision EM ECAL are considered

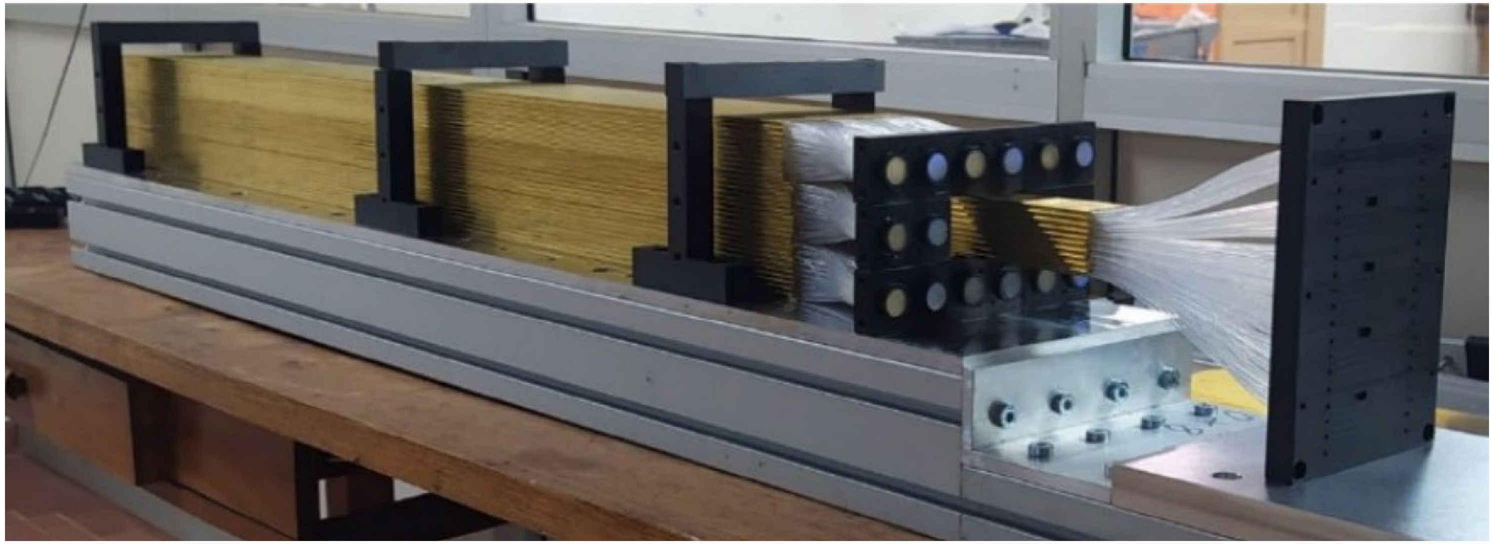








Copper + scintillating and Cherenkov fibers



IDEA

US and Dual readout: CalVision

CalVision

Physicists in the US (Argonne, Caltech, FNAL, Maryland, Michigan, MIT, Oak Ridge, Princeton, Purdue, Texas Tech, Virginia) received in 2022 funding for an initial 3-year program in dual-readout calorimetry. Our goals are:

- Advanced simulations of crystal-based measurements with maximum flexibility of materials etc. Support for Simulation like Geant4 is especially critical and requires support further development of models and continuous physics validation. There is also the need to identify small experiments that can help to further constrain and tune current model and the parameters thereof.
- Understanding how to make maximal use of possible measurements for improvement of calorimeter performance (e.g. see arXiv:2107.10207), including early and/or late timing, light polarization, light angle
- Further development of novel particle flow algorithms for this type of calorimetry, including interplay with other detector elements
- Verify the Cherenkov/scintillation yields and separation from https://arxiv.org/abs/2008.00338 on bench and via test beams
- Measure z coordinate of energy deposit in fiber via precision timing
- Find new materials with lower cost (current emphasis is glasses) (see next talk in this session)
- Follow new photodetector developments that allow further improvements (SPADs, dSiPMs)
- Design new electronics to allow on-detector measurements via new generations SoC ASICs and FPAAs with data processing (analog or digital) in the front end of timing, time over threshold, C/S ratios with 2-layer NNs (with CAEN and NALU)
- Low-mass mechanic support for the precision EM calorimeter

Our web site and indigo are https://detectors.fnal.gov/projects/calvision/ and https://indico.fnal.gov/category/1426/
We have monthly meetings. We also have a mattermost channel.
New collaborators are welcome to join! (e.g. many opportunities for short-term student simulation work)