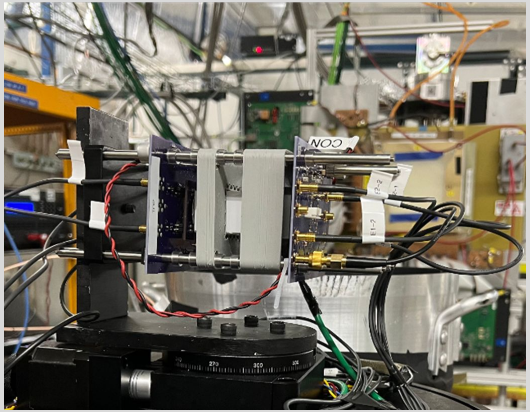
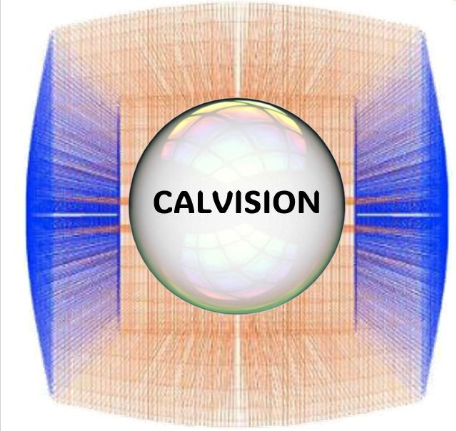
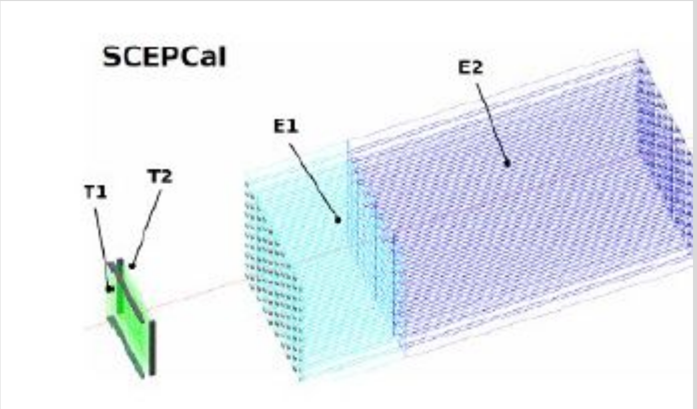
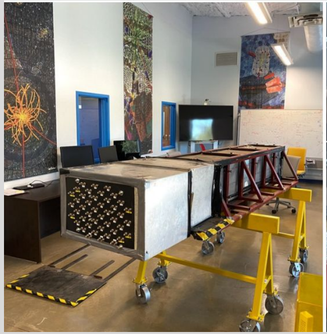


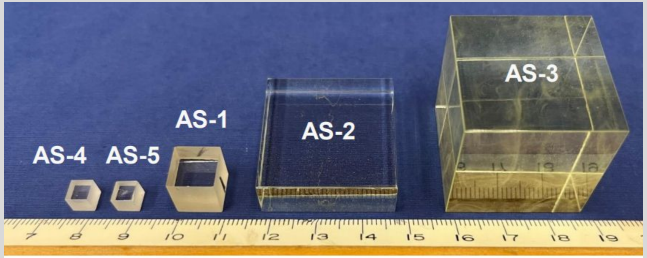




First results from CalVision



Sarah Eno
U. Maryland



Calvision

Calvision is an international collaboration was formed in 2020. Current members are: FNAL (Cummings, Freeman, Hirschauer, Merkel, Wenzel), Argonne (Sergei Chekanov), Caltech (Newman, Zhu), CERN (Hillemanns), Lyon (Gascon-Shotkin), Maryland (Belloni, Eno), MIchigan (Qian, Zhou, Zhu), Milano-Bicocca (Lucchini), MIT (Harris),Oak Ridge (Demarteau), Perugia (Cecchi), Princeton (Tully), Purdue (Jung), Texas Tech (Akchurin, Kunori), U. Virginia (Hirosky, Ledovskoy).   US members are supported by US DOE grant DE-SC0022045. Milano is supported on an Italian grant starting 2023.

Our goals are:

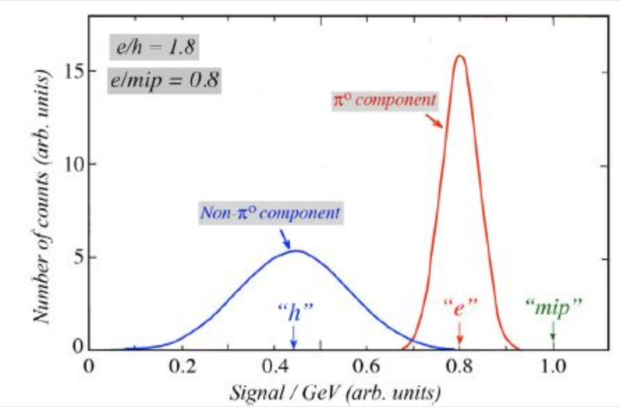
- Develop techniques to improve homogeneous calorimetry for use in hadron measurement
- In concert with the IDEA Calorimeter team, develop techniques to improve fiber-based dual readout calorimetry
- Use simulations to optimize inclusion of a homogeneous calorimeter in a future electron-positron collider
- Develop innovative “Particle Flow” algorithms appropriate for homogeneous calorimeters
- Find new less expensive suitable materials for homogeneous calorimeter
- Develop infrastructure to improve the measurements (asics, photodetectors, structural materials, etc)
- Develop physics cases that benefit from homogeneous calorimeter

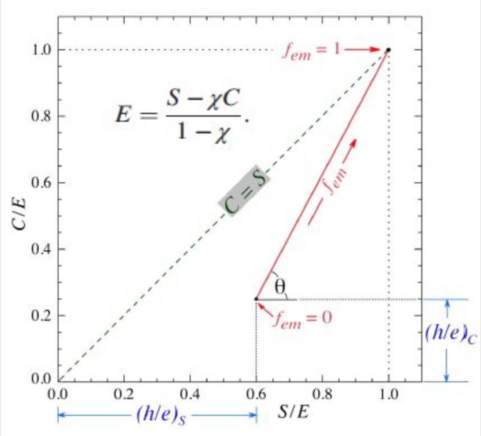
We are active members of DRD6 MAXICC, the CPAD Calorimetry RD, and the IDEA detector concept.

More information at: https://detectors.fnal.gov/projects/calvision/

Develop techniques to improve homogeneous calorimetry for use in hadron measurement

This aspect of our work builds on the pioneering work of the RD52 collaboration*.





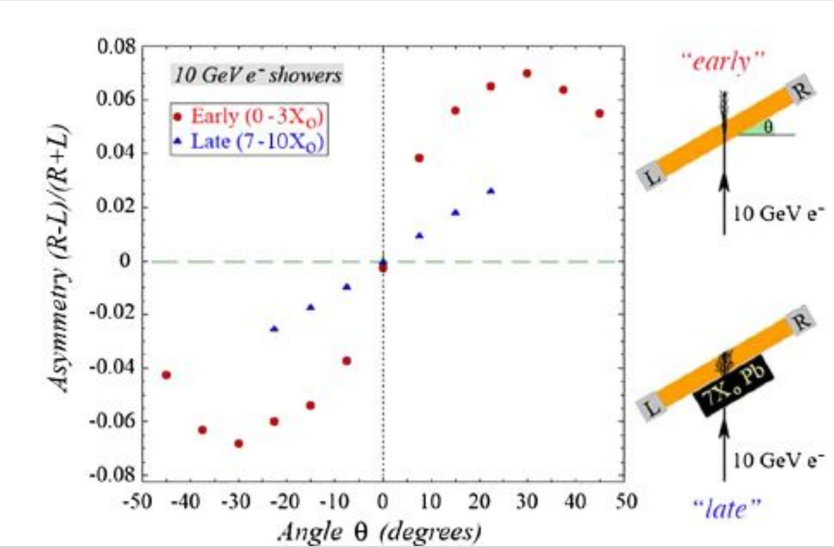
Proxies for the number of nuclear interactions can be used to improve the calorimeter resolution. Here scintillation and cerenkov lights are used. Can separate these using

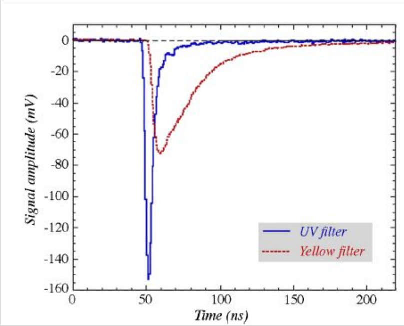
- Wavelength
- Timing
- polarization

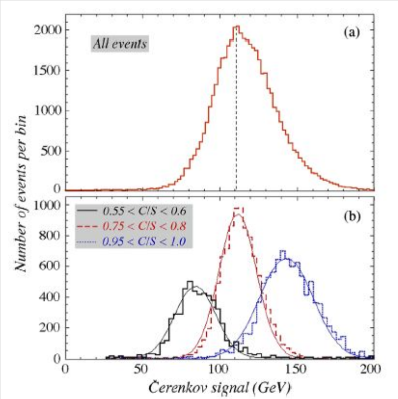
- https://journals.aps.org/rmp/abstract/10.1103/RevModPhys.90.025002

RD52

Studied many types of crystal, showed separation of light is possible, and showed its potential efficacy in a calorimeter.







Develop techniques to improve homogeneous calorimetry for use in hadron measurement

Participants are Milano, Napoli, U. Virginia, U. Michigan, FNAL, U. Maryland

Our main contribution is to revive this work. At the time of their work, they assumed that only one photodetector per crystal was possible (due to cost). In this case, Cherenkov light was distinguished by scintillation by timing. To see the Cherenkov prompt peak, the scintillation light had to be cut down so much that it degraded the EM resolution to that of a sampling calorimeter, removing the benefit of homogeneous calorimetry. The advent of SiPMs makes multiple readouts possible with high efficiency in the red.

Test beams

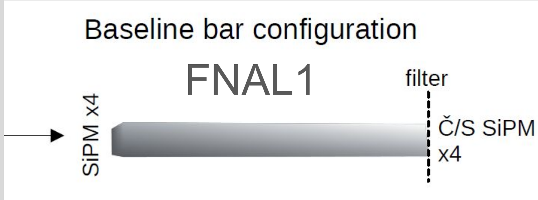
Using Hamamatsu SiPM S14160-6050HS

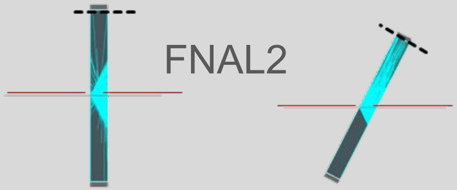
Have completed three test beams studying single crystals PbWO4, PbF2, BGO

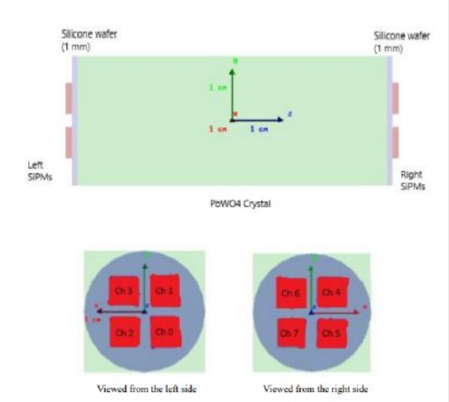
- Notre Dame radiation lab 8 MeV electrons
- FNAL1 120 GeV protons
- FNAL2 120 GeV protons

Have two upcoming planned

- DESY electrons April 2024
- CERN SPS H8 late July?

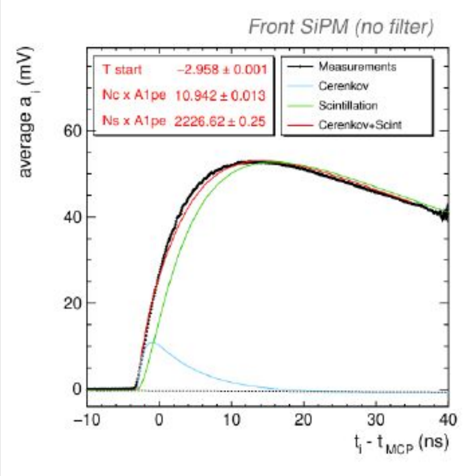




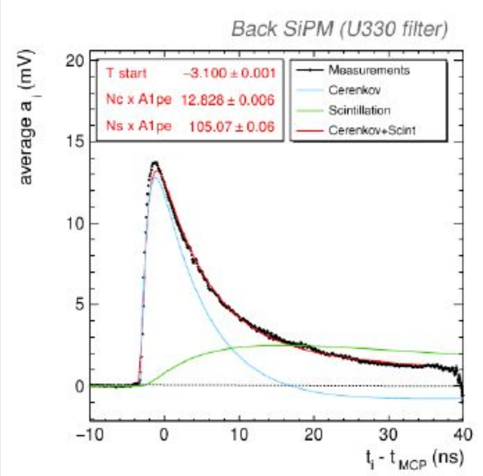


FNAL1

4 orientations
beam
PbW0$_4$
w/ scint filter
w/o filter
BGO
w/ scintfilter
w/o filter
660 nm long-pass
interference filter on PWO
Results shown here
U330 absorptive
notch- filter on BGO



Front SiPM (no filter)
T start −2.958 ± 0.001
Nc x A1pe 10.942 ± 0.013
Ns x A1pe 2226.62 ± 0.25
Measurements
Cerenkov
Scintillation
Cerenkov+Scint
average a$_i$ (mV)
t$_i$ - t$_{MCP}$ (ns)



Back SiPM (U330 filter)
T start −3.100 ± 0.001
Nc x A1pe 12.828 ± 0.006
Ns x A1pe 105.07 ± 0.06
Measurements
Cerenkov
Scintillation
Cerenkov+Scint
average a$_i$ (mV)
t$_i$ - t$_{MCP}$ (ns)

Novel cost-effective glass scintillators potentially suitable for homogeneous calorimetry

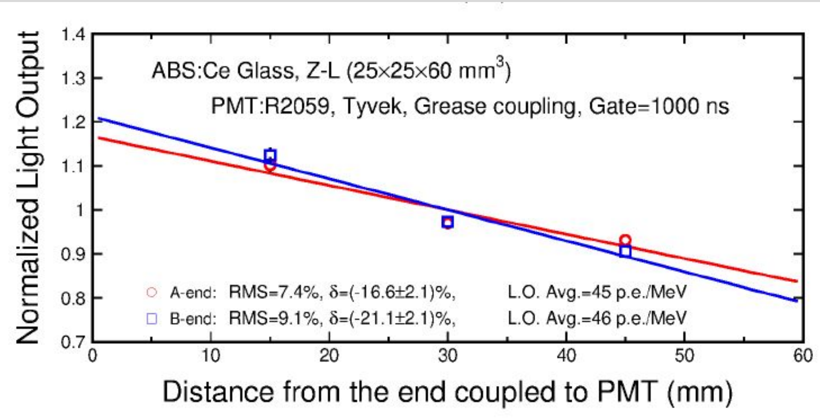
Work by Caltech

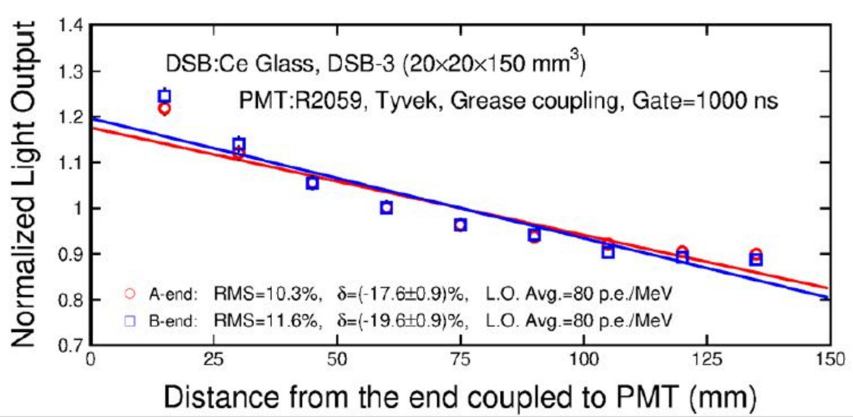
Goal: a dense (>6 g/cc^3) transparent inorganic scintillators with a cost of < 1$/cc^3.
Have tested promising glass samples obtained from IHEP and Giessen produced in BGRI* and Schott*: aluminoborosilicate (normal "ABS" and Gd-loaded "Z") and barium di-silicate (DSB), respectively.
Expect glass samples from RMD* Inc.

	BGO	BSO	PWO	Z-L	DSB-3
dimensions (mm^3)	17x17x17	17x17x17	13x13x13	25x25x60	20x20x150
density (g/cm^3)	7.1	6.8	8.3	6	4.3
radiation length (cm)	1.12	1.15	0.89	1.55	2.58
interaction length (cm)	22.7	23.4	20.7	24.7	30.9
Decay time (ns)	300	100	30/10	1200	500
emission-weighted PHOTON DETECTION EFFICIENCY S14160-3015PS SiM	31	31	28	29	32
cost ($/cc)	8	8	9	<1	2

- http://www.scitlion.com/index.php?m=content&c=index&a=lists&catid=112
  https://www.schott.com/en-us/product-selector?productselectormode=truei
  https://www.rmdinc.com/

Longitudinal uniformity of glass samples





Attenuation length on order 110 cm for ABS and 210 cm for DSB-3. Improvement expected following R&D.

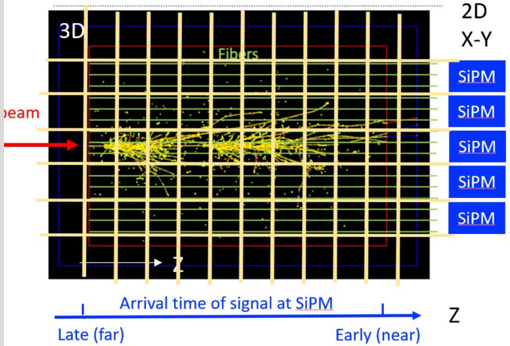
In concert with the IDEA Calorimeter team, develop techniques to improve fiber-based dual readout calorimetry

Work by Texas Tech

3D Imaging Cherenkov Fiber Calorimeter

Segmentation by
- transverse (X-Y): SiPMs in 2D grid (2x2 cm^2)
- longitudinal (Z): arrival time of signal at SiPM

Δt = 100 ps → dZ = 5 cm



Timing of signal to measure the Z-position of shower.

Energy reconstruction with Neural Networks
- Significant improvement over traditional methods (e.g. simple sum)
- Compatible with advanced methods (e.g. dual-readout of S and C fibers)

GNN with timing (*)

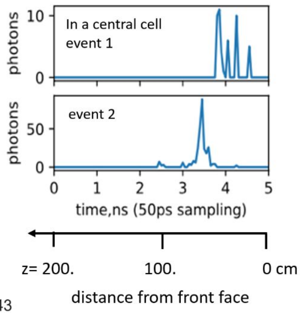
Timing Resolution	σ/E @ 100 GeV
0 ps	3.6 %
100 ps	3.9 %
200 ps	4.2 %
Simple sum	13 %.
Dual readout	4.0 %

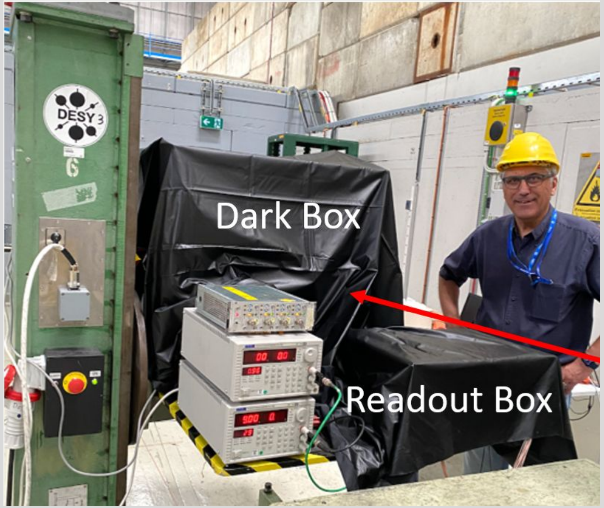
(*). CALOR 2022, 20-May-2022, *Instruments* **2022**, *6*(4), 43

Quartz fiber calorimeter
- Radiation hard
- Very fast

dSiPM
- Multi-hits, Δt 100 ps
- R&D required

Time Structure of signal

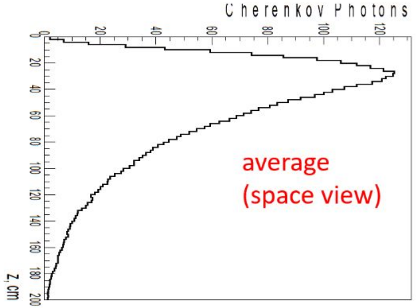


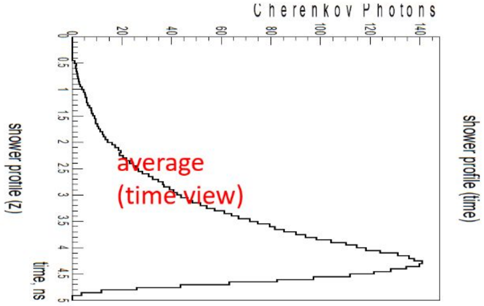


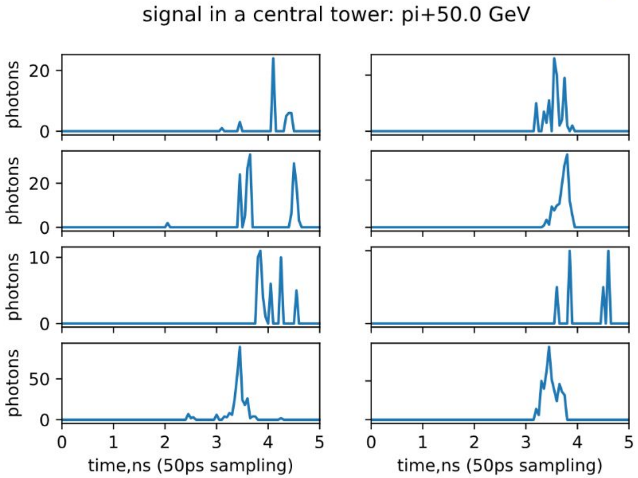
Fiber timing

Simulation: Longitudinal Hadron Shower Profile

The average hadron shower profiles in space and time (top row), and individual showers (bottom row) in simulated DREAM prototype module



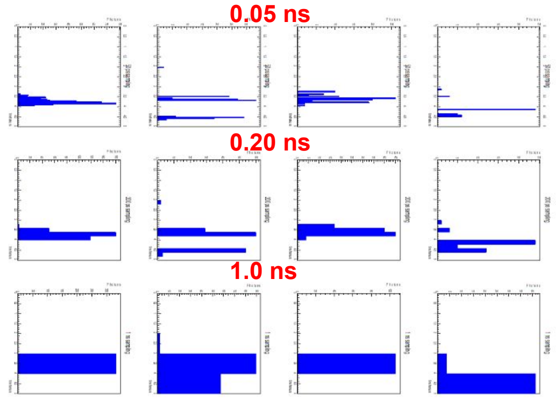




Showers in a central tower (1.2 x 1.2 cm^2) for individual events

Left: 50 ps sampling,
Right: 3 different sampling cases

The shower structure is not recognizable with 1 ns sampling



Develop infrastructure to improve the measurements (asics, structural materials, etc)

Work by Purdue

PURDUE UNIVERSITY

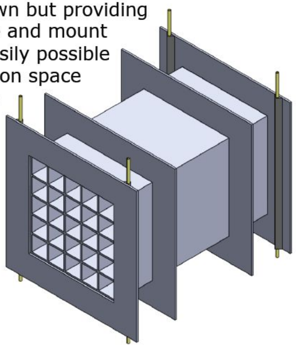
Very first / rough sketches

CMSC Composites Manufacturing & Simulation Center

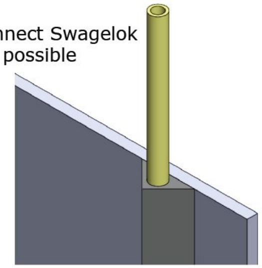
Learning phase of what is needed for CalVision beam test & beyond

Design considerations – need some feedback here:

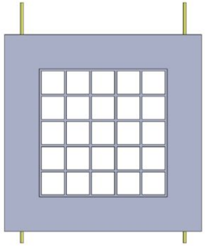
- Provide cooling for R/O boards and SiPM (need also temp stability)
- Swagelok and piping allows cooling and connecting "substrates"
- Integrate "box" or casing to allow tilting is simple
- Construction of such a box is fairly fast since no "tolerances" or envelopes in the way
- Want a fairly "rigid" box to travel to test beam and not damage it easily…
- Work towards a realistic concept to support FCC-ee sized structure



1. Not shown but providing a substrate and mount board is easily possible depending on space constraints



2. Connect Swagelok easily possible



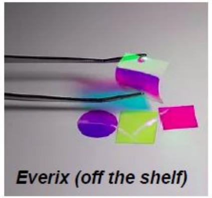
3. Segmentation can be made highly TC to allow temp stability for crystals

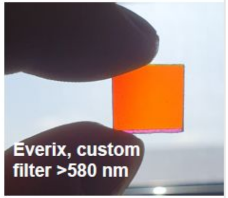
filters

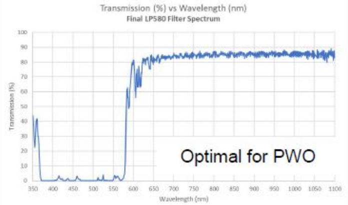
Work by Milano

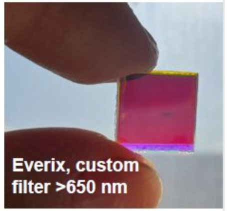
R&D on optical filters

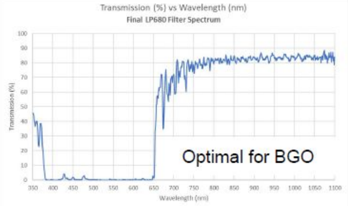
- Exploring both absorption and interference optical filters
- Interference filters
  - Custom development ongoing with *Everix*
  - Possibly very thin O(200) um → possibility to embed into SiPM protective window
  - Transition edge shifts with incidence angle (impact with scintillation light to be assessed)
- Absorption filters
  - Off-the-shelf product
  - Typically thicker O(2) mm
  - Insensitive to incidence angle

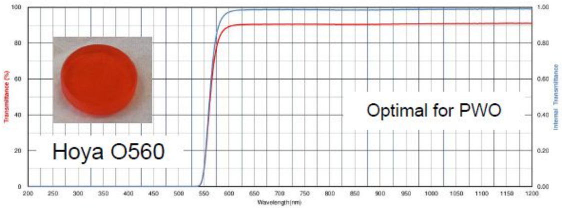


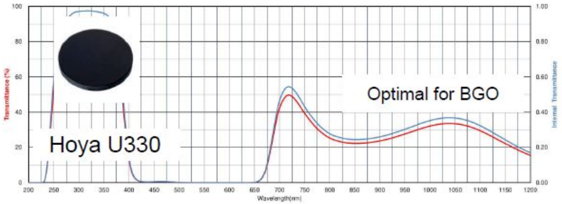












Use simulations to optimize inclusion of a homogeneous calorimeter in a future electron-positron collider

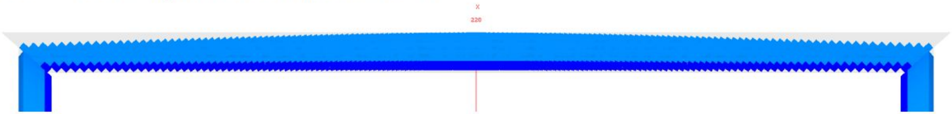
Work by the Milano and Princeton groups, with the DD4hep team.

Status of Segmented Crystal ECAL Simulation – Jan 2024

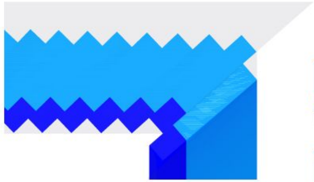
Flavia Cetorelli[2,3], Wonyong Chung[4] , Marco Lucchini[1,2], Chris Tully[4]

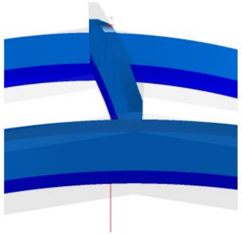
1. Università degli Studi di Milano – Bicocca
2. INFN Milano-Bicocca
3. CERN
4. Princeton University

- Detector geometry optimizations complete after feedback from dd4hep developers
  - Created intermediate volumes (barrel –> slices, endcap -> conic sections) to limit to ~ <1000 daughter volumes per mother volume



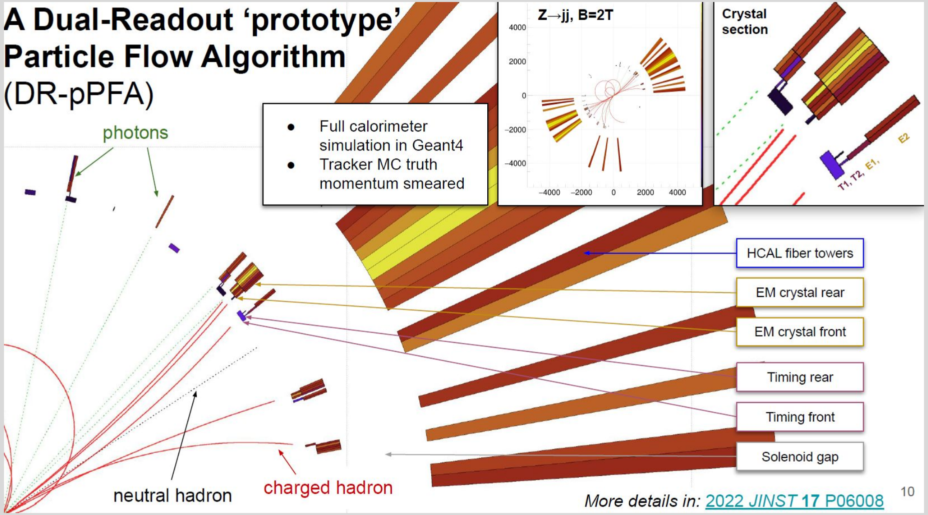
- Able to run at full granularity (10x10 mm crystal faces)
- Able to run with latest key4hep environment on lxplus7
  - Local install runs on AlmaLinux 9 with spack package manager and provided key4hep-spack environment
- Migration to ddsim WIP
- Ongoing discussion of merging with tracker, IDEA into a full sim with shared data types ("Sensitive Detectors")
- Flavia to present at Annecy FCC workshop next week

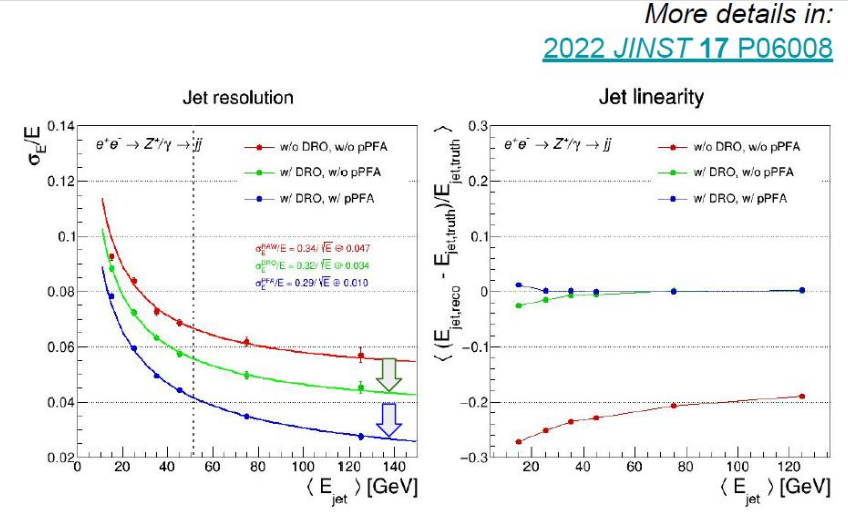




Develop innovative “Particle Flow” algorithms appropriate for homogeneous calorimeters

Work by Milano, Princeton

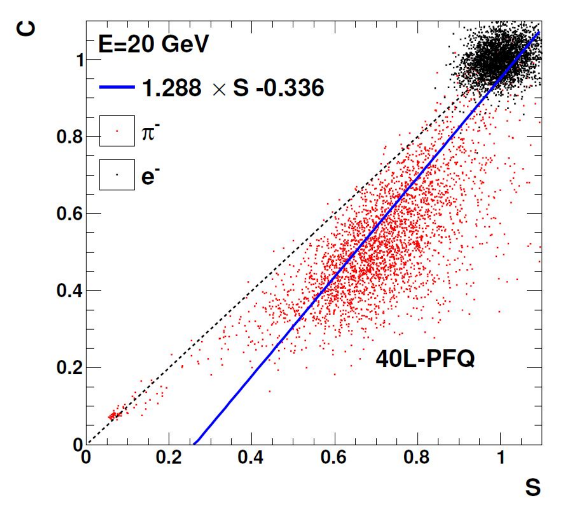




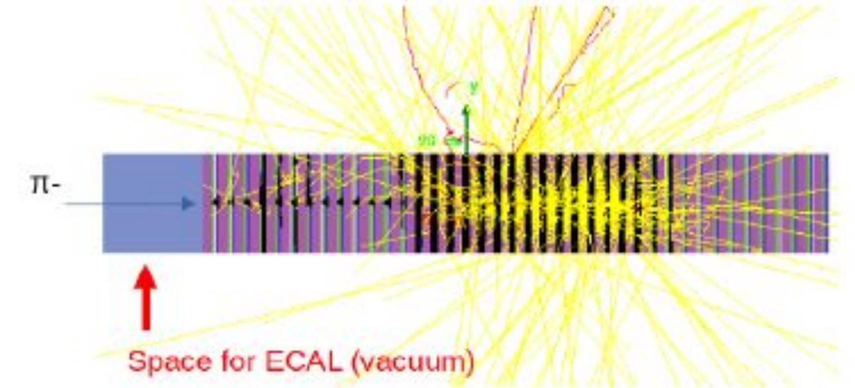
simulations

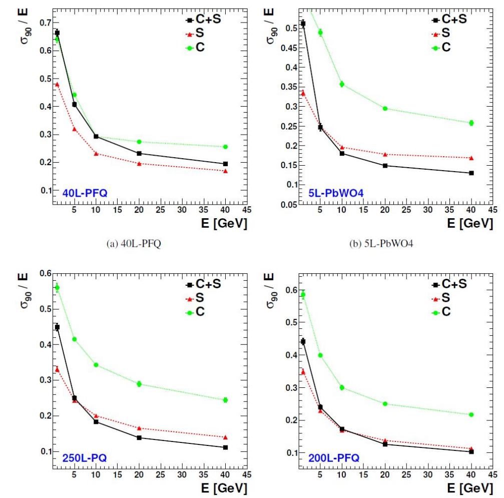
Work by Argonne, Maryland

Also exploring efficacy of dual-readout for a traditional longitudinally segmented HCAL.



Correlation between scintillation (S) and Cherenkov (C) for a 40-layer steal/PS/quartz calorimeter

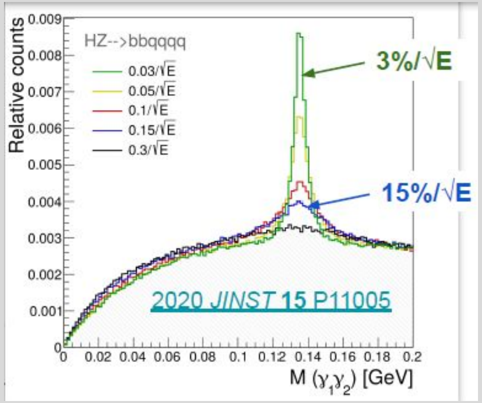


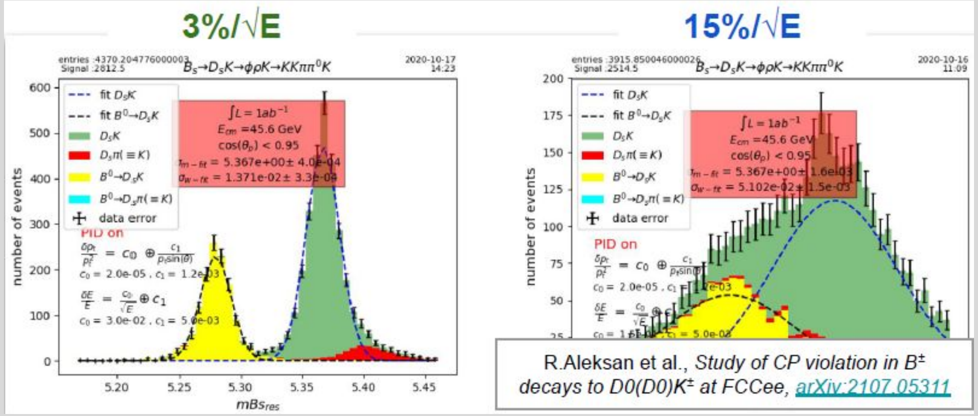


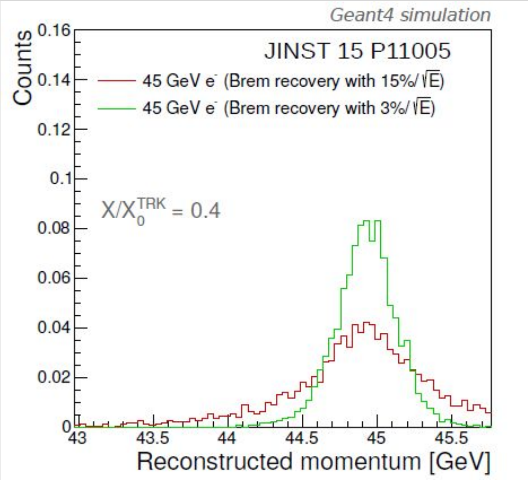
https://arxiv.org/abs/2311.03539

Develop physics cases that benefit from homogeneous calorimeter

Milano, Princeton plus beyond CalVision







Summary

- Homogeneous calorimetry can be useful for future detectors due to excellent resolution
- A strong team is working on its development to provide the best possible use for future experiments
- Good process is happening.

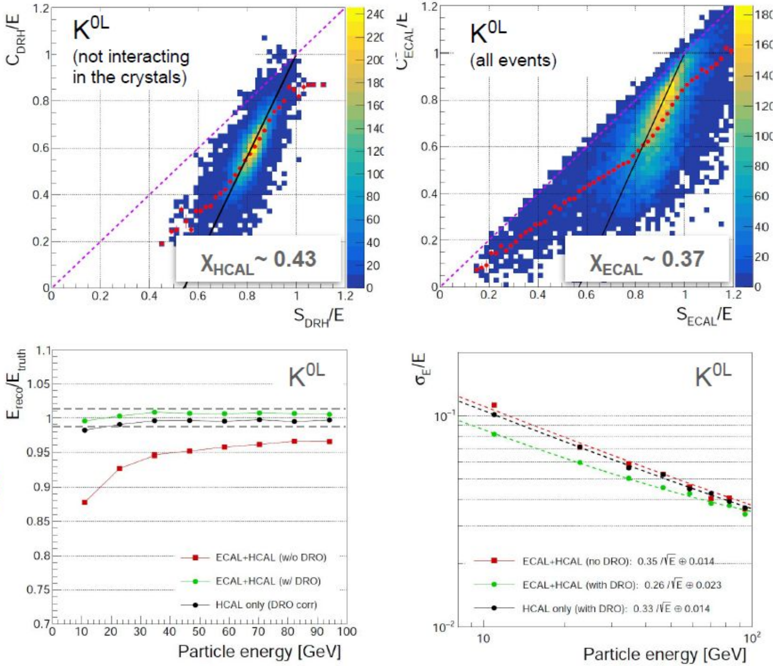
backup

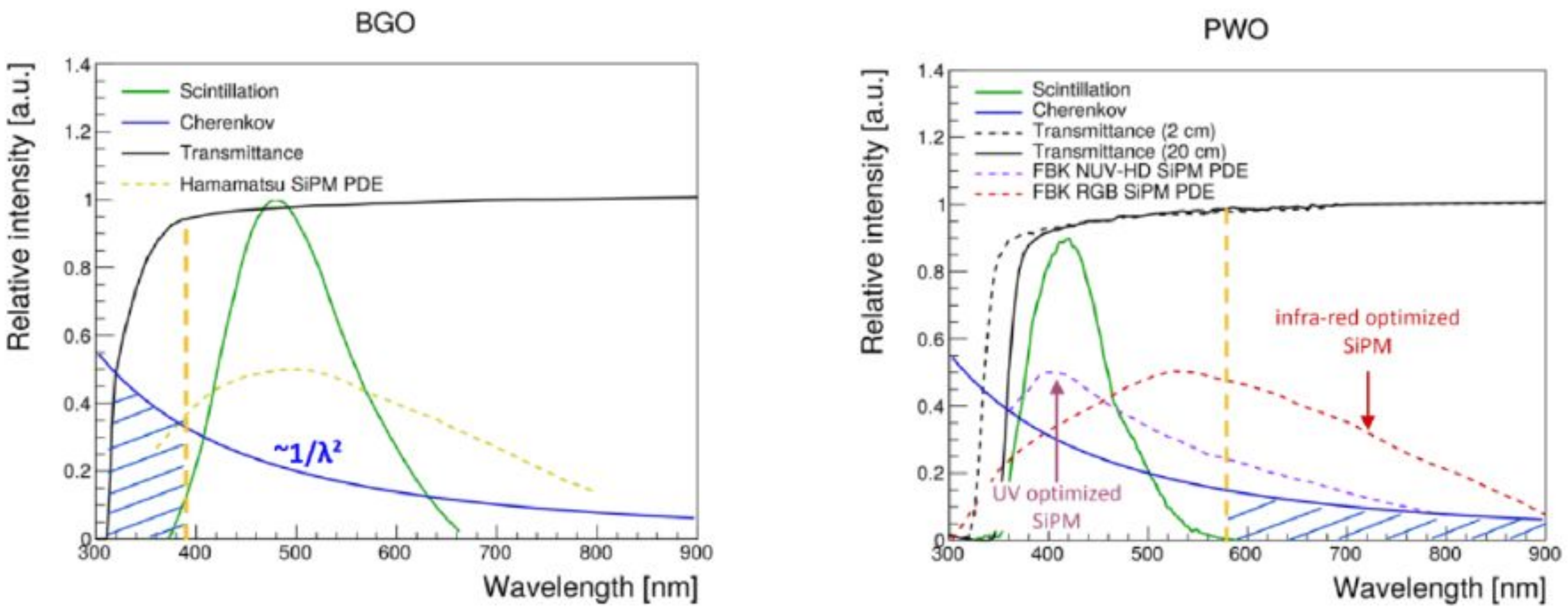
The **dual-readout method** in a hybrid calorimeter

- Apply the DR correction on the energy deposits in the crystal and fiber segments first and then sum up the corrected energy from both segments

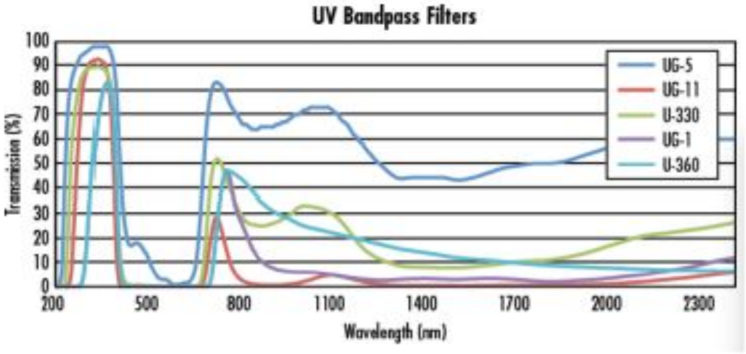
$$E_{HCAL} = \frac{S_{HCAL} - \chi_{HCAL} C_{HCAL}}{1 - \chi_{HCAL}}$$
$$E_{ECAL} = \frac{S_{ECAL} - \chi_{ECAL} C_{ECAL}}{1 - \chi_{ECAL}}$$
$$E_{total} = E_{HCAL} + E_{ECAL}$$

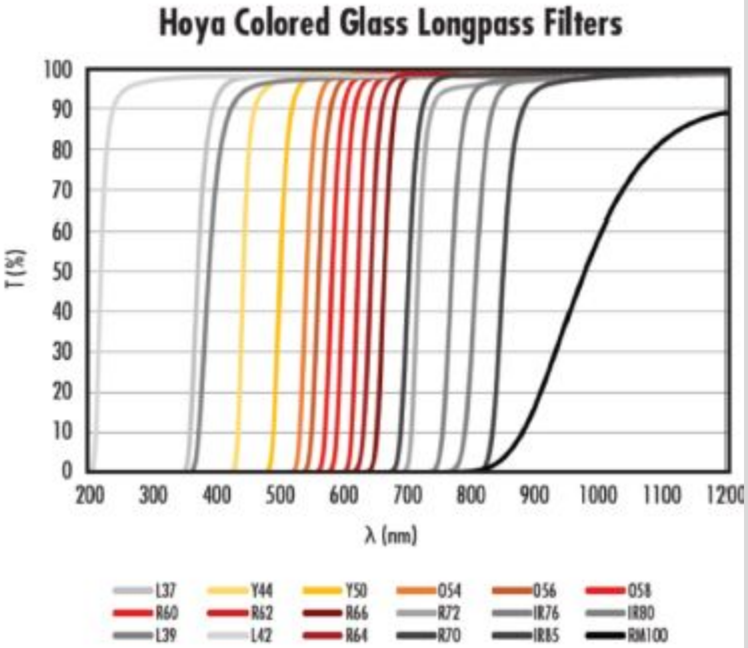
- **Dual-readout method confirms its applicability in a hybrid calorimeter**
  - Response linearity to hadrons restored within ±1%
  - Hadron energy resolution comparable to that of the fiber-only IDEA calorimeter

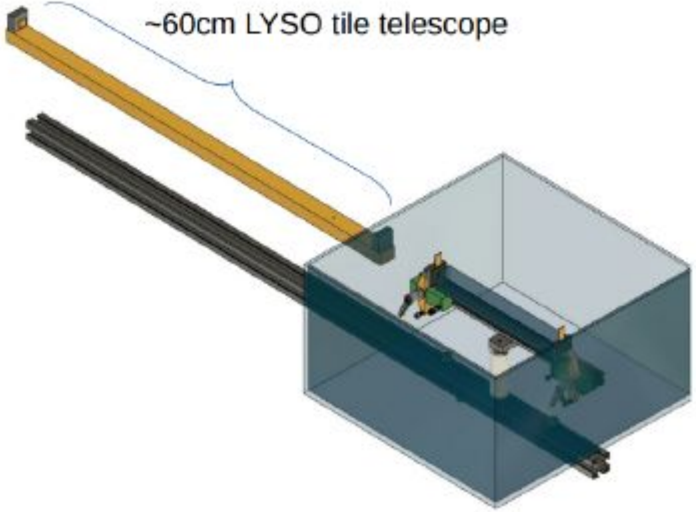




BGO
Scintillation
Cherenkov
Transmittance
Hamamatsu SiPM PDE
~1/λ²
Relative intensity [a.u.]
Wavelength [nm]
PWO
Scintillation
Cherenkov
Transmittance (2 cm)
Transmittance (20 cm)
FBK NUV-HD SiPM PDE
FBK RGB SiPM PDE
infra-red optimized
SiPM
UV optimized
SiPM
Relative intensity [a.u.]
Wavelength [nm]


UV Bandpass Filters
Transmission (%)
Wavelength (nm)
UG-5
UG-11
U-330
UG-1
U-360
100
90
80
70
60
50
40
30
20
10
0
200
500
800
1100
1400
1700
2000
2300


Hoya Colored Glass Longpass Filters
T (%)
λ (nm)
100
90
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
800
900
1000
1100
1200
L37
Y44
Y50
O54
O56
O58
R60
R62
R66
R72
IR76
IR80
L39
L42
R64
R70
IR85
RM100


~60cm LYSO tile telescope