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RECENT ADVANCES IN CALORIMETRY

Disclaimer:

This is a very short summary of a very large field.

Talk covers some points in that are in a CPAD summary report document based on the CPAD meeting at Brown last year.
Authors – A. Apresyan (Fermilab) R. R, and R-Z (Caltech)

Details of CPAD detector document in back up

Pardigm Shifts in Calorimetry

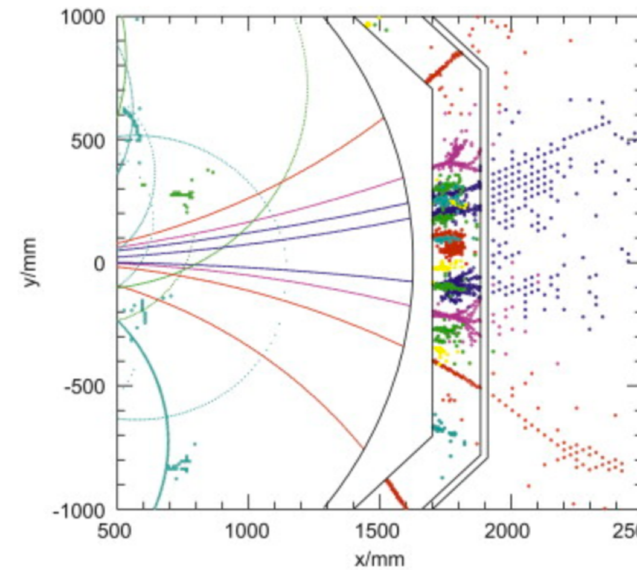
Two Paradigm Shifts in calorimetry:

1. Particle Flow -- Move away from standalone calorimetry at collider experiments to detector system design where the tracker, the calorimeter, and the muon detectors are seen as a complete systems.

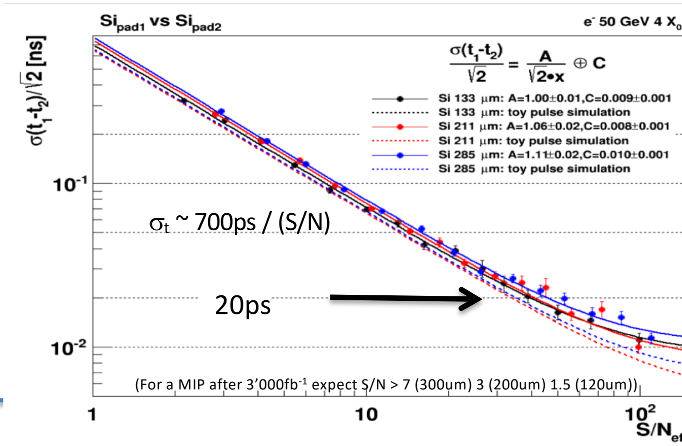
The key concept of PF that combines electrons and charged hadrons measured in the tracker and neutrals in the calorimeter. yields a better energy measurement than a simple stand alone system.

2. Precision timing - ≈50ps timing precision for energy depositions in the detector.

The old metric of energy resolution and tails in the energy distribution have given way to a more complex set of criteria

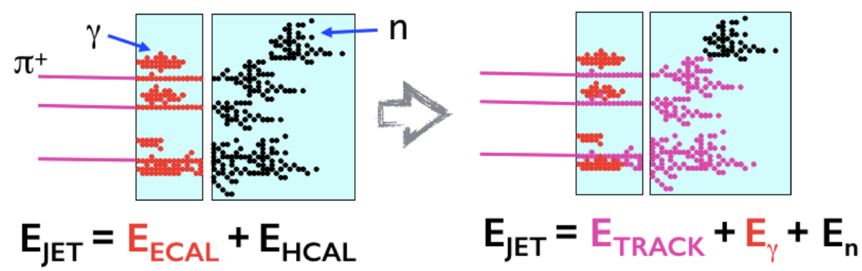


From "Particle flow calorimetry and the PandoraPFA algorithm". M. Tomson, NIM A. Volume 611, Issue 1, 2009.



Calorimeters for Particle Flow

Pioneered by the CALICE collaborations in the context of the ILC detector development.



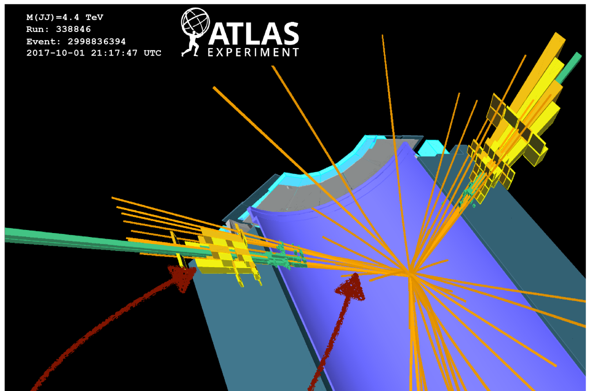
Basic premise energy sharing in a jet

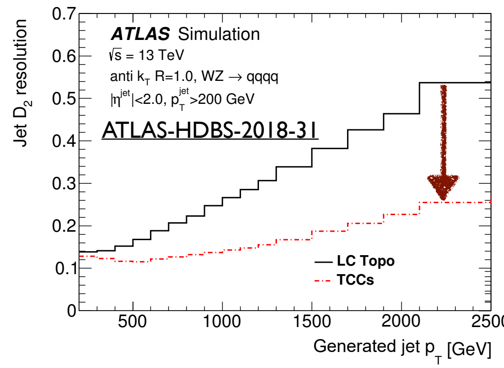
- Tracker – 60%
- ECAL – 30%
- HCAL – 10%

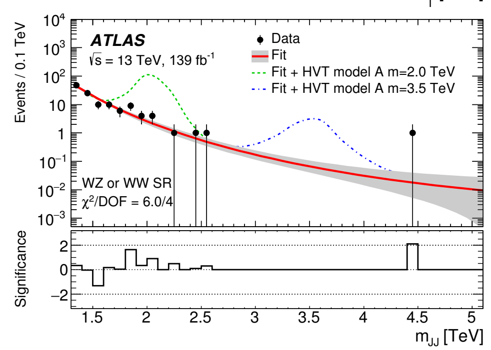
ILD and SLD pioneered this approach motivated by the requirement to measure W and Z from their hadronic decays.

Example from ATLAS

Tagging at High pT







Utilize better spatial resolution from tracker to separate energy deposits in the calorimeter!

Enables strongest sensitivity yet to boosted all-hadronic final states

M. Swiatlowski (UC) 17 July 31, 2019

From M. Swaitlowski's plenary Wednesday morning

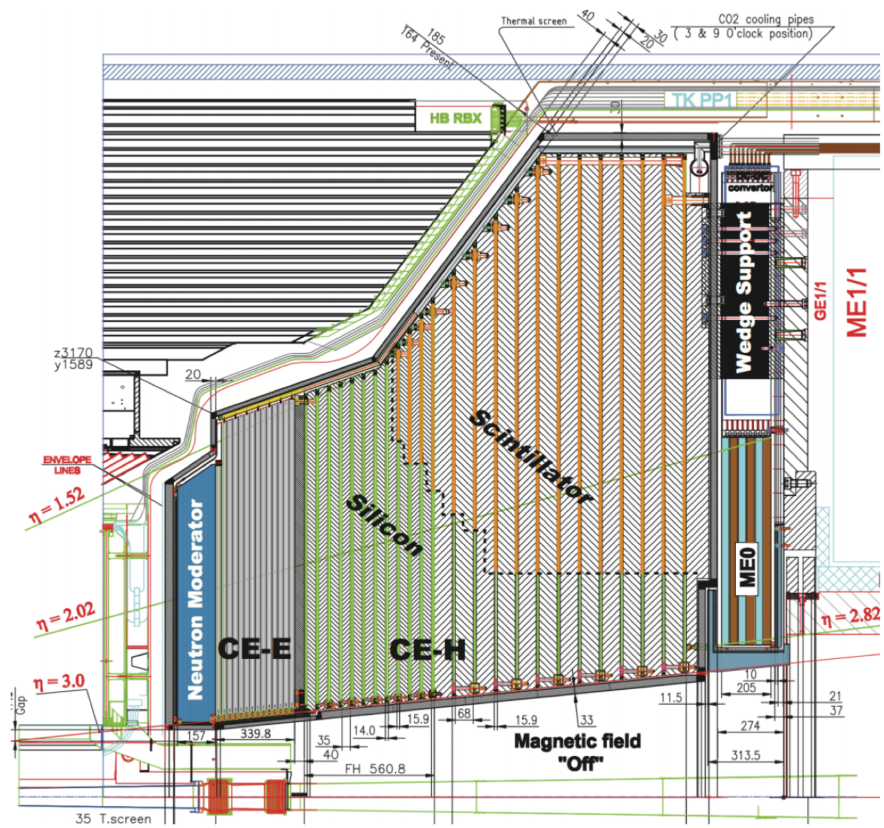
CMS HGCAL

The new CMS endcap calorimeter for the HL-LHC used many ideas from CALICE.

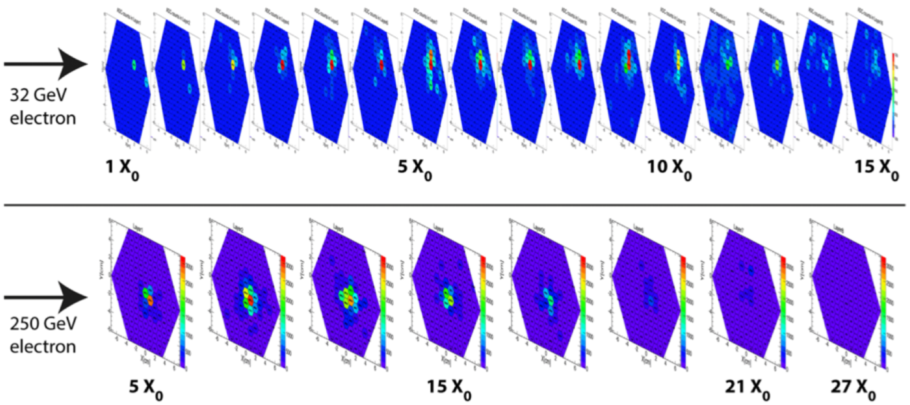
Electromagnetic: Si-W in the
Hadronic: Si-Steel or Scintillator-steel

- Wafer-scale sensor modules
- ~ 6M channels
- CO_2 Cooling

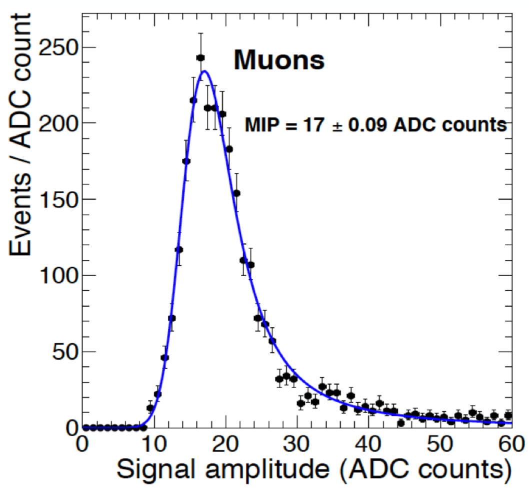
Low-power high bandwidth electronics essential.



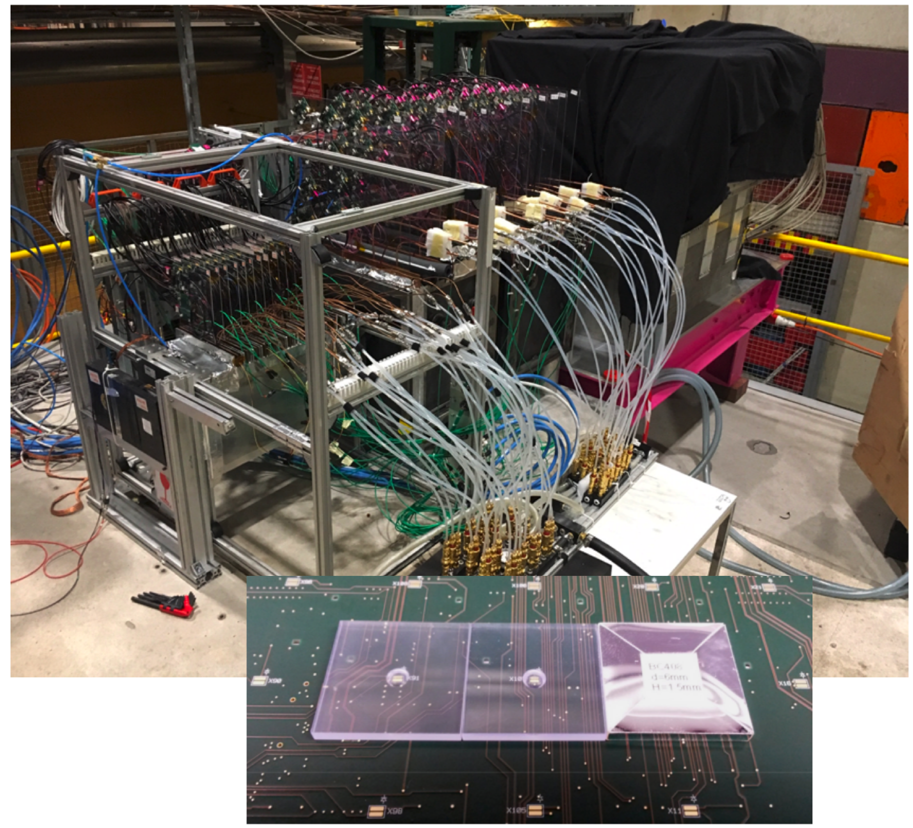
CMS HGCAL



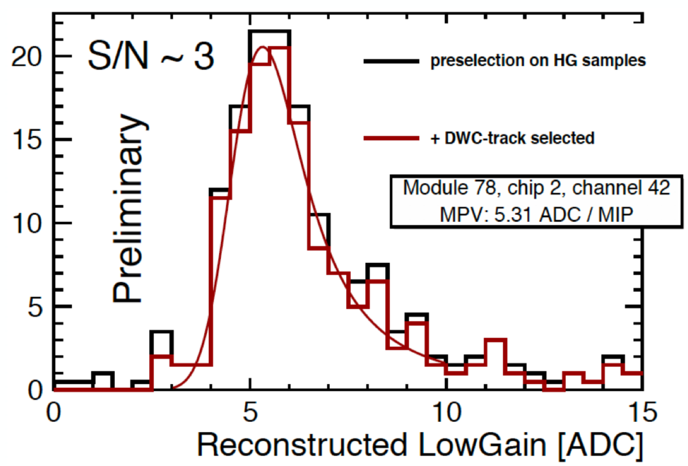
2016 tests

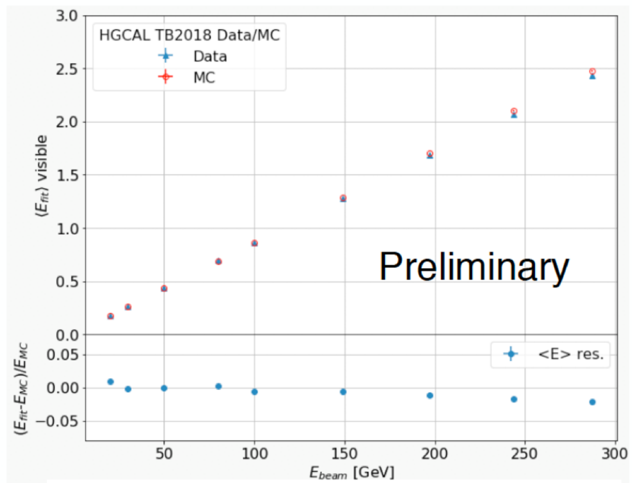


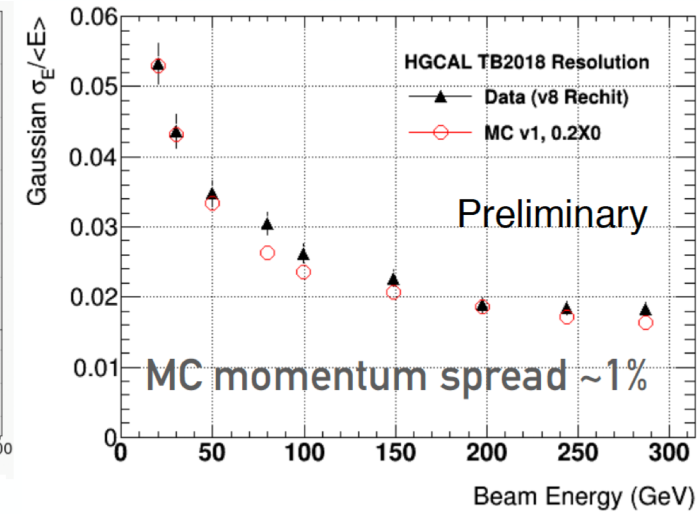
2018 Test setup in CERN H2



CMS HGCAL

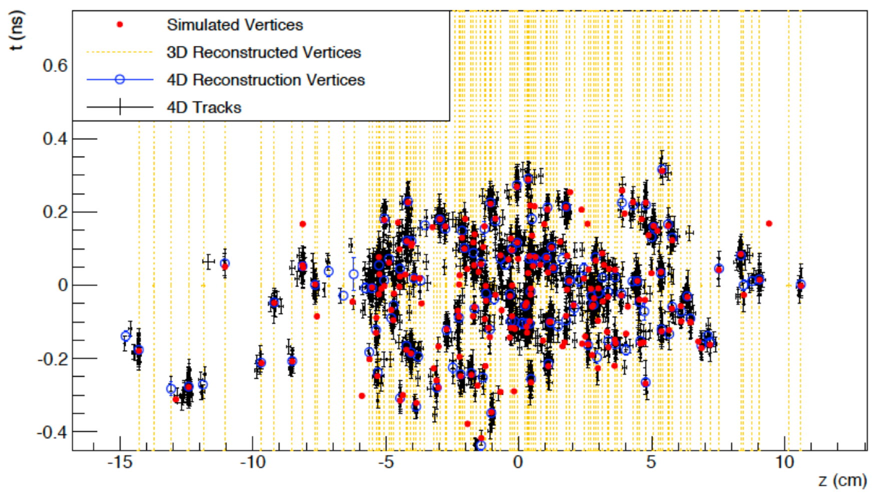




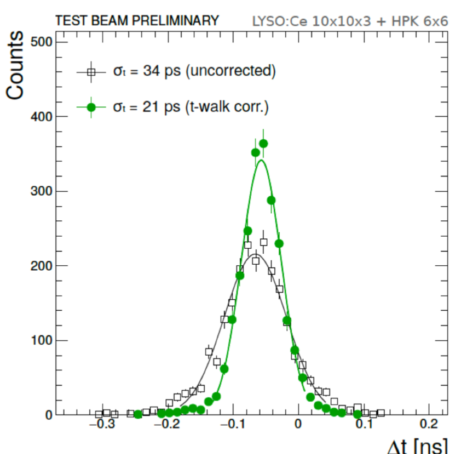


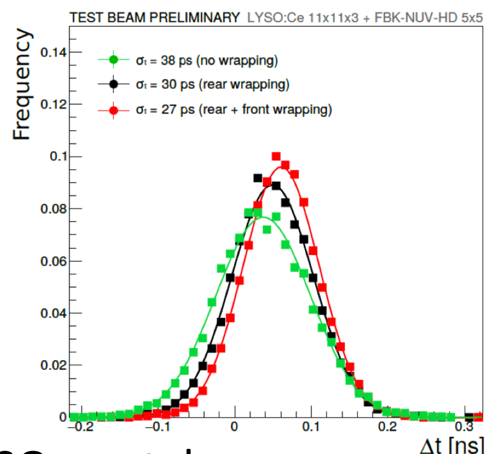
More details in the talk by Maral Alyari later today

Timing and Calorimeters



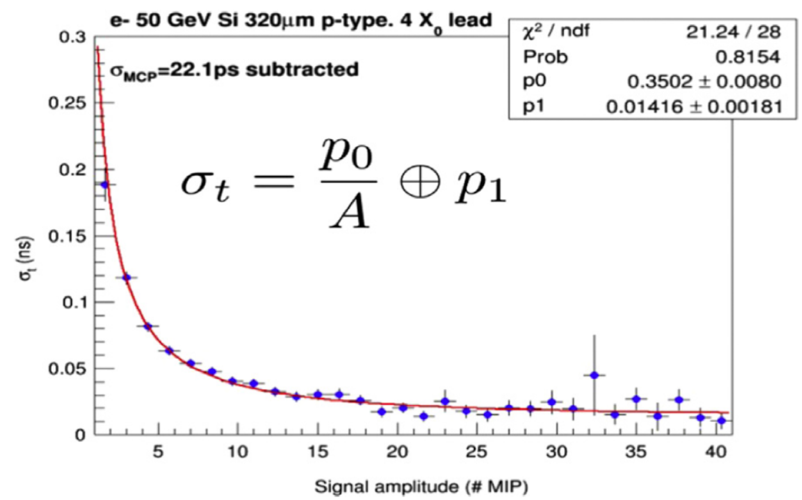
CERN-LHCC-2017-027/LHCC-P-009





MIP timing with LYSO crystals

Precision timing with silicon.



E. Currás et al Nuclear NIM A845(2017) 60–63

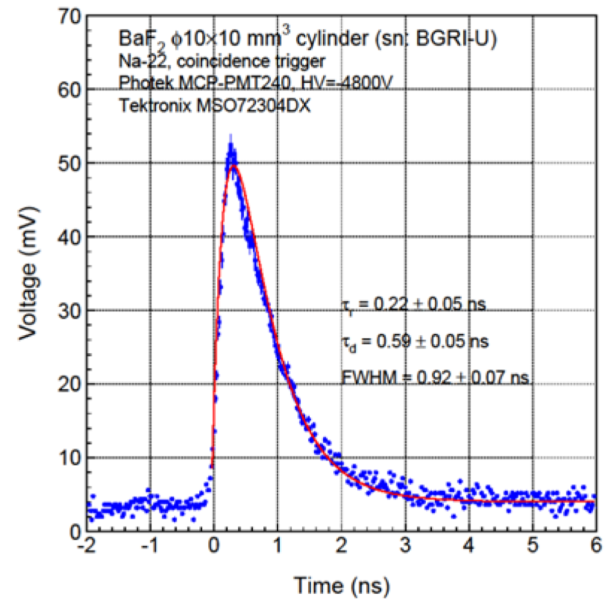
Electronics of HGCAL will give timing precision of individual cell at 50ps for large signals.

Fast Crystals

Using timing with crystals – measure time of arrival of early photon. Decay time is critical.

Barium Fluoride has a fast (cross-luminescence) UV (220 nm) scintillation component and a slower signal in at 300.

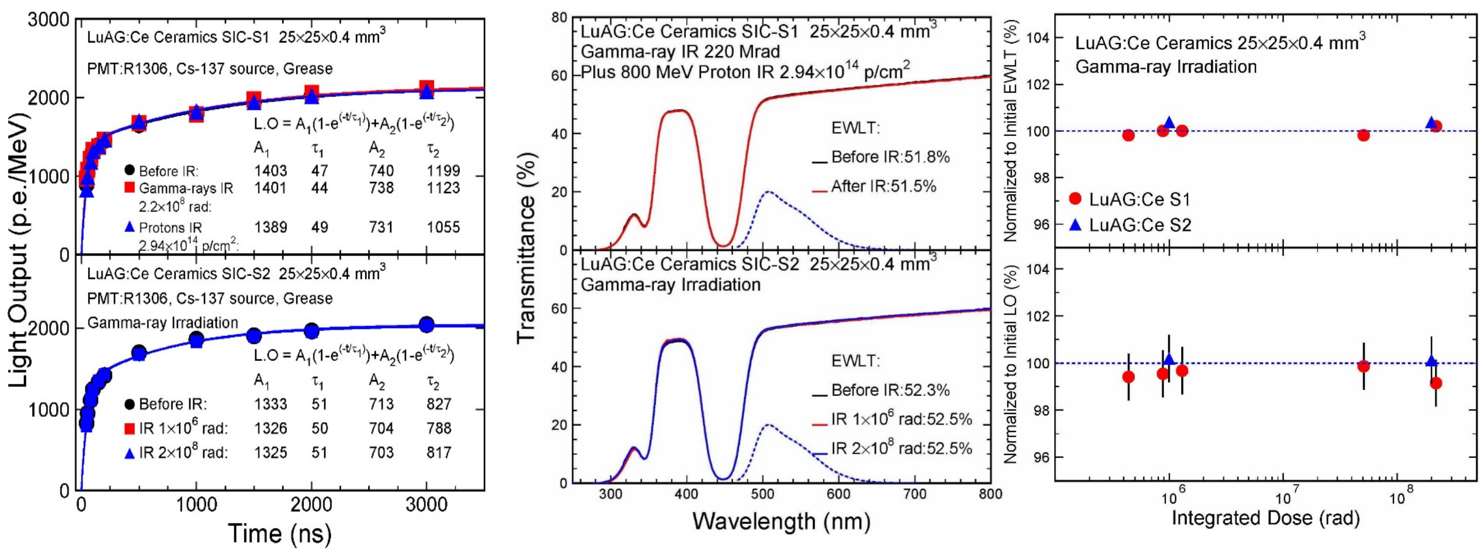
Recently been shown that yttrium doping suppresses the slow component.



From Ren-Yuan Zhu @ Caltech

Radiation Hard LuAG:Ce Ceramics

No damage observed in both transmittance and light output after 220 Mrad ionization dose and 3×10^{14} p/cm^2 of 800 MeV Very promising for optical-based radiation hard calorimeter



Key issue: slow scintillation component

From Ren-Yuan Zhu @ Caltech

Other Crystals

	LYSO:Ce,Ca	ZnO:Ga	BaF_2:Y	YAP:Yb	LuAG:Ce	$LaBr_3$:Ce
Density (g/cm^3)	7.4	5.67	4.89	5.35	6.76	5.29
Melting Points (°C)	2050	1975	1280	1870	2060	783
X_0 (cm)	1.14	2.51	2.03	2.77	1.45	1.88
R_M (cm)	2.07	2.28	3.1	2.4	2.15	2.85
λ_I (cm)	20.9	22.2	30.7	22.4	20.6	30.4
Z_{eff}	64.8	27.7	51.6	31.9	60.3	45.6
dE/dX (MeV/cm)	9.55	8.42	6.52	8.05	9.22	6.9
λ_{peak} [a] (nm)	420	380	300 220	350	520	360
Refractive Index[b]	1.82	2.1	1.5	1.96	1.84	1.9
Normalized Light Yield[a,c]	100	6.6[e]	1.7 4.8	0.19[e]	35[f] 48[f]	153
Total Light Yield (ph/MeV)	30,000	2,000[e]	2,000	57[e]	25,000[f]	46,000
Decay Time[a] (ns)	40	<1	600 0.6	1.5	820 50	20
Light Yield in 1[st] ns (photons/MeV)	740	610[e]	1200	28[e]	240	2,200
40 keV Att. Length (1/e, mm)	0.185	0.407	0.106	0.314	0.251	0.131

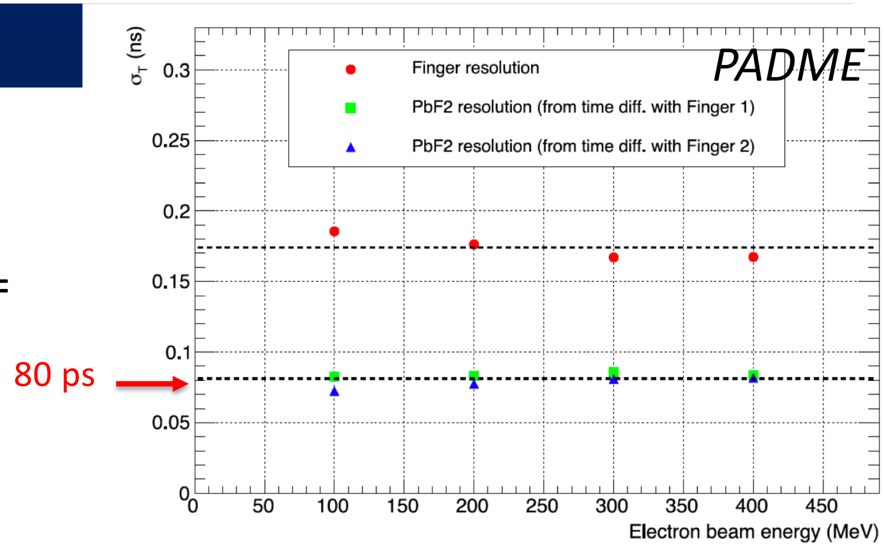
From Ren-Yuan Zhu @ Caltech

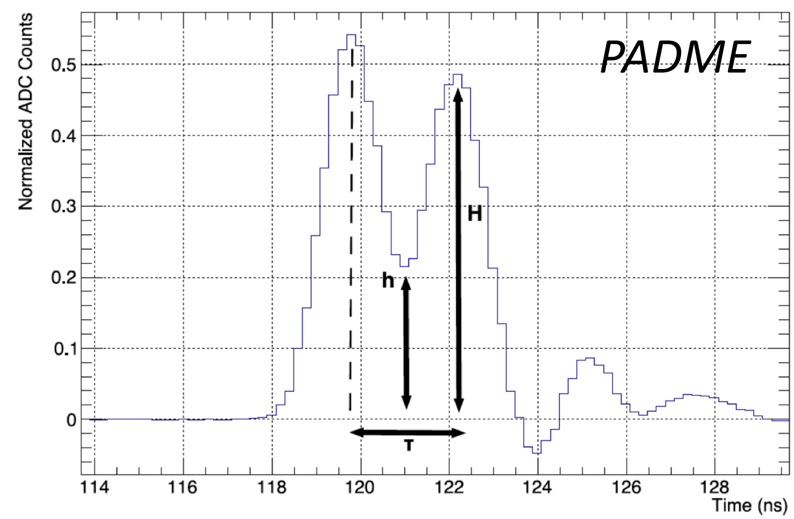
Lead Fluoride

Cherenkov radiator with X_0= 0.93 cm, density = 7.77 g/cm^3, n = 1.77

Interesting because of its fast timing signal.

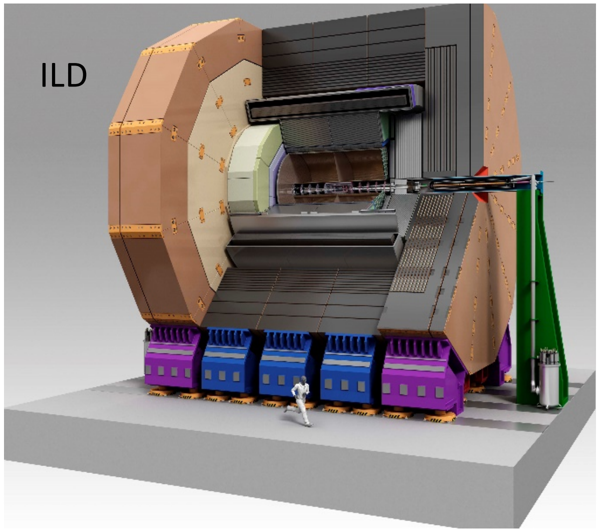
Used for precision timing in
- Fermilab g-2 experiment
- Dark photon experiment PADME.

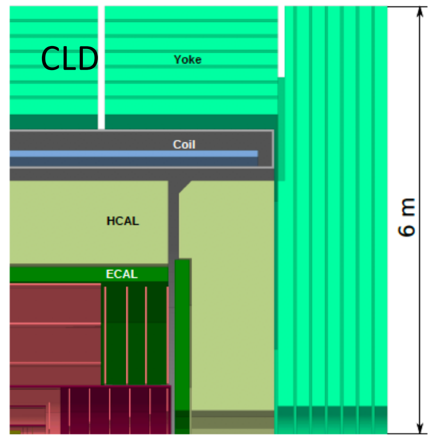




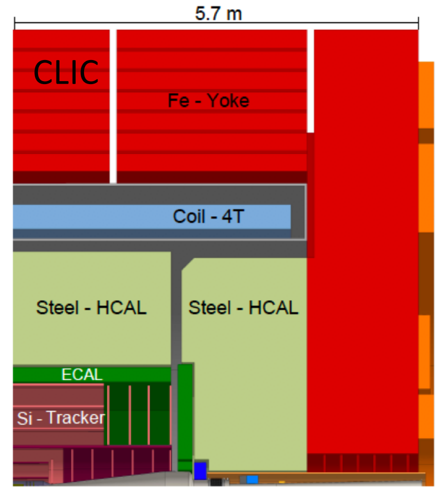
A. Frankenthal et al. NIM A 919 (2019) 89–97

Future Calorimeters at Colliders





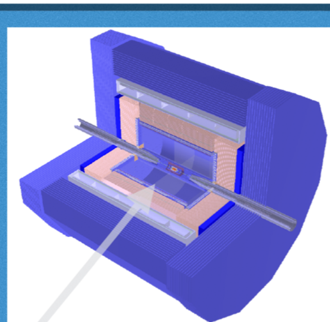
FCC-ee



CLIC

CEPC

Baseline detector ILD-like (3 Tesla)



All the major collider experiments have as their baseline design PF calorimeters.

Summary

There have been many changes in calorimetry in the past ten years lead by the CALICE collaboration in the context of calorimetery for the ILC.

- Particle Flow calorimetry
- Precision timing or 5D calorimeters

Moving away from the old paradigm of standalone devices with the best possible energy resolution to an optimization that includes timing, resolution and shower tracking.

New crystals with new stoichiometry continue to be developed for medical imaging that find their applications in HEP.

Backup

Background

The DPF committee Coordinating Panel for Advanced Detectors (CPAD) – chaired by Marcel Demarteau (ANL) and Ian Shipsey (Oxford) - was asked by the DOE to prepare a report as input to the Basic Research Needs (BRN) workshop on Instrumentation in HEP.

Editors of Calorimetry section are Arthur Apresyan (Fermilab), RR (Minnesota) and Ren Yuan Zhu (Caltech).

This report will be input to the BRN study called by the DOE to identify key technology areas that would benefit the HEP science drivers identified in the P5 report.