Snowmass2021 - Letter of Interest

[High Precision Timing and High Rate Detectors]

Instrumentation Frontier Topical Groups: (check all that apply □/■)

□ (IF1) Quantum Sensors

• (IF2) Photon Detectors

• (IF3) Solid State Detectors and Tracking

□ (IF4) Trigger and DAQ

□ (IF5) Micro Pattern Gas Detectors (MPGDs)

• (IF6) Calorimetry

□ (IF7) Electronics/ASICs

□ (IF8) Noble Elements

• (IF9) Cross Cutting and Systems Integration

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Abstract: Future circular and linear colliders as well as the Large Hadron Collider in the High-Luminosity era have been imposing unprecedented challenges on the radiation hardness of particle detectors that will be used for specific purposes e.g. forward calorimeters, beam and luminosity monitors. We perform research on the radiation-hard active media for such detectors, particularly calorimeters, in two distinct categories: Quartz plates coated with thin, radiation-hard organic or inorganic compounds, and intrinsically radiation-hard scintillators. In parallel to the effort on identifying radiation-hard scintillator materials, we also perform R&D on radiation-hard wavelength shifting fibers in order to facilitate a complete active medium for detectors under harsh radiation conditions.

High Precision Timing and High Rate Detectors

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Abstract: High precision timing is becoming an important issue in particle physics especially in Energy and Intensity Frontiers. Signals with FW10%-10% Max < 25ns and segmentation to handle >200 pileup (PU) are advantageous in many future colliders and upgrades. Similarly tagged neutrino beams (from pions or muon factories) and tagged kaon beams would benefit from MIP rates exceeding 100's of MHz. The high track density and pile-up in high luminosity particle colliders are challenges for event reconstruction and analysis. MIP (minimum ionizing particle) pileup is a few percent in ~1x1 cm^2, 1200 cm radially along h=0. The case for adding a timing 4^{th} dimension to calorimetry and tracking is becoming compelling. Timing detectors must withstand 50 MRad and neutrons >$3x10^{15}$ n/cm2. Timing has been shown by CMS and ATLAS to improve ET miss resolution, and tag secondary vertices to ±few mm. Precise timing of calorimeter deposits and vertexes enable rejection of spurious data inconsistent with the primary vertex time. We discuss detectors for MIPs capable of timing precision to ±10's ps, and rate capabilities exceeding 100's of MHz.

We discuss detectors for MIPs capable of timing precision to ±10's ps, and rate capabilities exceeding 100's of MHz. Issues for defining a Figure of Merit for timing scales as τdecay/√Nelectrons, and the rate capability scales inversely as τdecay. For optical transducers (SiPM, PMT, MCP-PMT), the timing precision is dominated by Trise and inversely by S/N. Noise in the experiments from low energy photons/x-rays scales inversely with Xo. SiPM and MCP- based detectors have rise times shrinking to ~100-20ps.

Optical signals include scintillators with decay constants less than 2ns, Cherenkov radiators, and secondary emission detectors. Scintillators with high FOM include ZnO:Ga(GZO) (0.7ns decay), CdS:In (0.2 ns decay) and organic solid and liquid (with rad resistance) scintillators with decays less than 1 ns. We discuss scintillators, Cherenkov radiators (aerogels, quartz, Teflon AF, water, oils) and direct secondary emission MIP detectors as precision timing and high rate detectors.

	ZnO:Ga (GZO)	CdS:In	EJ-232Q	Liq Scint A	*$CeBr_3$*	*LYSO*
Light: γ/MeV	10,000-15,000	~3000-4,000	2900	1800	*60,000*	*40,000*
Decay (ns)	0.5-0.7	0.2	0.7	0.2	*17*	*41-44*
γ/MeV/ns	6,000	2,500	1,200	1500	*1,700*	*740*
T_{melt} (°C)	1,980	1,750	80	-10	*722*	*2,050*
dE/dx: MeV/cm	8.4	8.7	2	2.1	*6.7*	*9.55*
Xo (cm)	2.51	1.3	33	32	*1.9*	*1.14*
Peak λ(nm)	390-375	520	405	~400	*371*	*420*
Index n	1.85	2.53	1.6	1.55	*1.91*	*1.82*
Density (g/cc)	5.6	4.86	1	0.9	*5.33*	*7.4*

Figure 1. Fast Scintillators for Precision Timing and High Rates

ZnO:Ga (GZO): ZnO:Ga is a very promising scintillator due to:

1. Rise and Fall Time: By contrast to LYSO, ZnO:Ga (1%-5%) has a rise-time 30-40 ps vs 72 ps LYSO, and a decay-time 0.5-0.7 ns. 4√Trise x √Tfall product ≤ 167ps, 10 times less than LYSO.

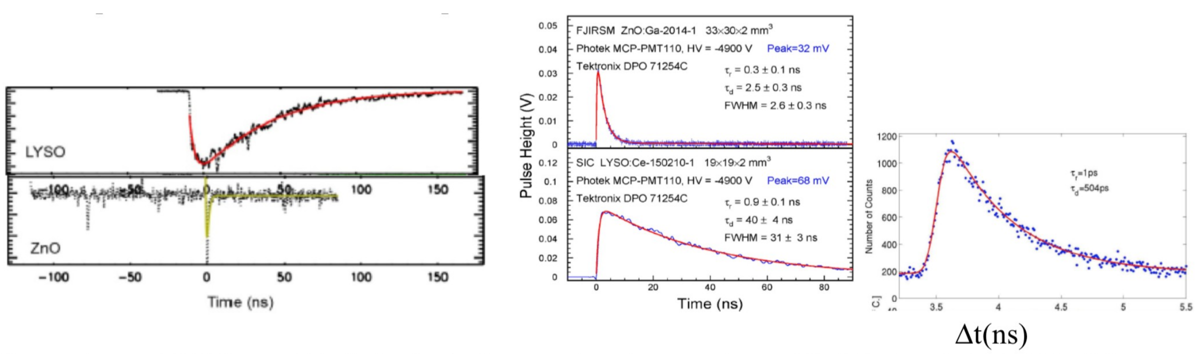
2. Large photon yield per ns per MeV: the highest of any known scintillator - ZnO:Ga produces more visible photons per ns than any other scintillator, 7,000-9,000 photons per MeV/ns, at 375-395nm, with total photons less than LYSO, but the peak photon pulse can be larger. There is no long glow.

3. Pileup is largely absent for ZnO:Ga compared to LYSO. A 90% integration time is <3ns (possibly lowering SiPM noise and reducing cooling requirements) with rate capabilities exceeding 100 MHz.

4. The radiation length of GZO is 2.2 times larger than LYSO. For MIP-detecting tiles, this means that fewer low energy gamma and x-rays will convert in the tiles, lowering background and noise rates.

5. Energy loss per mm and an index n are comparable to LYSO. A 1 mm thick layer of ZnO:Ga produces >1200 photons over 500-700ps.

6. Doped-ZnO is very rad-hard (as are most metal oxides) – it was used as a fast phosphor in e-beam gadgets. As a CRT phosphor it has >1GRad resistance (25 KeV electrons) (LYSI~10 MRad).



(L)Comparison of LYSO and ZnO:Ga flash-X-ray pulse shapes using a 20 GHz bandwidth 100 GHz sampling oscilloscope (y-axis arbitrary scale) using a fast MCP-PMT[10]. *M:* x-ray stimulated ZnO:Ga emission compared using an MCP-PMT and oscilloscope through 10 m cables.[11] R: pulse shape from a ~1 mm thick polystyrene disc loaded with 10% ZnO:Ga nanopowder with a 504 ps fitted decay.[12] Note: small variations in timing and peak signals are due to different photodetectors, DAQ, and ZnO:Ga doping levels. MIP data is essentially the same, the decay times varying between 0.5-0.7 ns for different samples.