Material Selection for Calorimetry

Minfang Yeh

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BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Active Materials for Calorimetry

- Sampling Calorimetry
  - Absorber and Active Materials: Absorption of part of incident beam energy
  - Serves for both electromagnetic and hadronic interactions
- Homogenous Calorimetry
  - A homogenous calorimeter contains only an active material with no absorber; absorption of the most of incident energy relying on *depth* and *radiation length* of material
  - are used for only electromagnetic interactions due to their long interaction length.
- Preferable materials with high density, better optical property, high light-yield and fast/short light pulse (and *low cost*)
  - *high density* $\rightarrow$ *increased stopping power*
  - *high light-yield* $\rightarrow$ *energy and spatial resolution* $\rightarrow$ *improved reconstruction*
  - *high optical transmission* $\rightarrow$ *enhanced signal efficacy*

Scintillator Materials for Calorimetry (*example*)

Performances of different scintillator materials (*preliminary in progress)**

Materials	Decay Time		Emission	Density	Rad. Length	Light-Yield	References[+]/Comments
	F (ns)	S (ns)	nm	g/cm³	cm	photon/MeV	
Ce-doped HfG (Hafnium Fluoride Glass)	8	25	300-400	5.95	1.6	150	Better optical
Ce-doped DSB (DiSilicate Barium Glass)	30	180	400-460	3.8	3.3	1900	Better optical with improved light yield
PWO ($PbWO_4$)	6	30	400-460	8.28	0.92	380	Rad. Hard. (>1000 Krad)
Ce1%:$Gd_2Y_1Ga_{2.7}Al_{2.3}O_{12}$	93.5	615	490-590	6.3	1.8	65,000	Superior light-yield; but long pulse
Pure Liquid Scintillator (i.e. Linear Alkylbenzene)	2	15	360-460	0.86	70	11,000	Better optical & light-yield; low cost (**$3k per ton**); little degradation over 50 Mrad; **A hybrid detector design**? Mature development by neutrino and DBB experiments
Metal-doped (high-Z & -%) (water-based) liquid scintillator (i.e.15%Pb)	2	15	360-460	1	32	2,500	
Metal-doped (high-Z & -%) acrylic-based or plastics scintillator	similar time structure and emission range as LS with higher density of 1.18 for PMMA-based plastics (development in progress; 1%Gd-doped assessible at BNL), plastics scintillator development ongoing at FNAL and LLNL, 3D-print plastics scintillators						Better mechanical property for packing with less light-yield compared with LS; PMMA-based is cost effective

**selected examples at E_γ ~ 1GeV; noble gas not yet included; ionization-based materials (i.e. Si) will be encompassed…*

[+]nima: 380, pp. 524–536, 1996; J. of Phys.: Conf. Series, 587, 012062, 2015; nima: v787, pp. 144–147, 2015; nima: v820, pp. 8-13, 2016; *JINST* **11** pp 11018, 2016.

Calorimetric Materials for Physics Experiments

- Silicon, Scintillation Crystals and Glasses are most popular active materials for hadronic and electromagnetic calorimetry for collider physics
  - LHC, CMS, ATLAS, sPHENIX, EIC,…
- Scintillation Liquid developed from
  - Double-beta Decay:
    - Metal-doped Liquid Scintillator based: SNO+
    - Calorimeter: CUORE, SuperNEMO
    - Noble Gas: nEXO
  - Neutrinos:
    - Metal-doped (Water-based) Liquid Scintillator based: PROSPECT, Daya Bay, AIT/NEO, JSNS^2
    - Pure Liquid Scintillator based: Borexino, KamLAND, NoVA, MINOS
  - Dark Matter (WIMP):
    - Metal-doped Liquid Scintillator based: LZ
- New material R&Ds to include, *but not limited to*:
  - *Silicon, scintillation crystals & glasses, noble gas technology, hybrid (metal-loaded & water-based) liquid scintillator, large scintillation acrylic panel/sheet, 3D-print scintillation Bars (acrylic-based and other plastics-based), Snowball Chamber,…*
- *Identify promising active materials across different scientific fields*