The Next Generation of Crystal Detectors

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Crystal Detectors

- Crystal detectors have been used in many HEP experiments
  - Crystal Ball NaI(Tl) ECAL
  - L3 BGO ECAL
  - BaBar CsI(Tl) ECAL
  - kTeV CsI ECAL
  - CMS PWO ECAL
  - GLAST CsI(Tl) ECAL
- Crystal detectors are also being proposed for new experiments: HL-LHC, Mu2e, ORKA, ILC, EIC, ...

- R&D Issues:
  - Excellent radiation hardness for HL-LHC
  - Crystal detectors with fast response time
  - Crystal detectors for total absorption calorimetry (jet mass reconstruction)

Radiation Hardness

- Superb radiation hardness is required for the HL-LHC environment.
- Fast timing is also required to reduce the pile-up effect.
- Cerium doped LSO/LYSO are being considered

- R&D Topics:
  - Data on neutron induced damage in scintillation crystals very limited. An R&D program to investigate radiation damage effect induced by gamma-rays, charged hadrons as well as neutrons, in various crystal detectors is needed
  - LSO/LYSO crystals are relative expensive; Development of fast and radiation hard crystals, glass and ceramics detectors is of general interest.
  - For an LSO/LYSO based Shashlik ECAL radiation hard photo-detectors as well as wavelength sifters need also be developed.

Fast Response Crystals

	LSO/LYSO	GSO	YSO	CsI	BaF_2	CeF_3	$CeBr_3$ ❶	$LaCl_3$	$LaBr_3$	Plastic scintillator (BC 404) ❷
Density (g/cm³)	7.40	6.71	4.44	4.51	4.89	6.16	5.23	3.86	5.29	1.03
Melting point (°C)	2050	1950	1980	621	1280	1460	722	858	783	70[#]
Radiation Length (cm)	1.14	1.38	3.11	1.86	2.03	1.70	1.96	2.81	1.88	42.54
Molière Radius (cm)	2.07	2.23	2.93	3.57	3.10	2.41	2.97	3.71	2.85	9.59
Interaction Length (cm)	20.9	22.2	27.9	39.3	30.7	23.2	31.5	37.6	30.4	78.8
Z value	64.8	57.9	33.3	54.0	51.6	50.8	45.6	47.3	45.6	-
dE/dX (MeV/cm)	9.55	8.88	6.56	5.56	6.52	8.42	6.65	5.27	6.90	2.02
Emission Peak[a] (nm)	420	430	420	420 310	300 220	340 300	371	335	356	408
Refractive Index[b]	1.82	1.85	1.80	1.95	1.50	1.62	1.9	1.9	1.9	1.58
Relative Light Yield[a,c]	100	45	76	4.2 1.3	42 4.8	8.6	141	15 49	153	35
Decay Time[a] (ns)	40	73	60	30 6	650 0.9	30	17	570 24	20	1.8
d(LY)/dT [a,d] (%/°C)	-0.2	-0.4	-0.1	-1.4	-1.9 0.1	~0	-0.1	0.1	0.2	~0

a. Top line: slow component, bottom line: fast component.
b. At the wavelength of the emission maximum.
c. Relative light yield normalized to the light yield of LSO
d. At room temperature (20°C)
#. Softening point

1. W. Drozdowski et al. ***IEEE TRANS. NUCL. SCI***, VOL.55, NO.3 (2008) 1391-1396
Chenliang Li et al, ***Solid State Commun***, Volume 144, Issues 5–6 (2007),220–224
http://scintillator.lbl.gov/
2. http://www.detectors.saint-gobain.com/Plastic-Scintillator.aspx
http://pdg.lbl.gov/2008/AtomicNuclearProperties/HTML_PAGES/216.html

Fast Response Crystals

- R&D issues for crystal detectors with very fast response time include three key aspects:
- The slow scintillation component in BaF_2 needs to be suppressed by selective doping and/or selective readout by using solar blind photo-detector. The radiation harness of BaF_2 crystals needs to be further improved.
- Development of novel fast crystal detectors with sub-nanosecond decay time, e.g. CuI etc., is of general interest.
- For a segmented crystal calorimeter with photon pointing resolution R&D on detector design and compact readout devices are required.

Total Absorption Calorimetry

- Enables obtaining very good hadronic energy resolution. Need to separate Cherenkov from scintillation light

Parameters	$Bi_4Ge_3O_{12}$ (BGO)	$PbWO_4$ (PWO)	PbF_2	PbClF	$Bi_4Si_3O_{12}$ (BSO)
ρ (g/cm³)	7.13	**8.29**	**7.77**	7.11	6.8
λ_I (cm)	22.8	**20.7**	**21.0**	24.3	23.1
n @ λ_{max}	2.15	2.20	1.82	2.15	2.06
τ_{decay} (ns)	300	30/10	**?**	30	100
λ_{max} (nm)	480	425/420	**?**	420	470
Cut-off λ (nm)	**310**	350	**250**	**280**	**300**
Light Output (%)	100	1.4/0.37	**?**	17	20
Melting point (°C)	**1050**	**1123**	**842**	**608**	**1030**
Raw Material Cost (%)	100	49	**29**	**29**	47

Total Absorption Calorimetry

- R&D Topics:
  - Development of cost-effective crystal detectors is crucial because of the unprecedented volume (70 to 100 m^3) foreseen for an HHCAL.
  - The material must be dense, cost-effective, UV transparent (for effective collection of the Cherenkov light) and allow for a clear discrimination between the Cherenkov and scintillation light.
  - The preferred scintillation light is at a longer wavelength, and not necessarily bright or fast.

Recent BSO crystals are very promising.

Also studying glasses

Summary

- Crystal development is at the core of many future HEP (and NP) experiments
- Promise is that they can really extend the physics reach
- Long-term development plan