

Heavy Scintillating Crystals and Glasses for a Combined EM and HCal at ILC

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Motivation

To identify a dense and affordable calorimeter media for an ILC experiment with the following characteristics:

- Total absorption for compensation and optimum resolution
- Combine the EM and Hadron Calorimeter

Consider two options

- Scintillation only readout mode
- Dual readout mode: scintillation/Cherenkov in same media

Basic Requirements

- Total thickness: $\sim 7 \lambda$
- Calorimeter volume : 50 m^3 to 100 m^3
(for SiD depend on material used)
- Cost comparable to the EM/HCal options currently considered by the SiD group

High density

- short radiation length
- short Molière radius
- short interaction length

Requirements for Scintillation Only Readout Mode

- Sufficient light yield
- Decay time suitable for an ILC experiment ($\leq \sim 1 \mu\text{s}$)
- Wavelength suitable for the chosen readout method
 - APD, WLS fiber + APD
 - SiPM, WLS fiber + SiPM

Properties of Suitable Scintillation Materials

	PbWO ₄ Crystal	PbWO ₄ Crystal	PbF ₂ Crystal	Gd ₂ O ₃ -BaO Glass
Doping	La/Y	Pr, Zn, Mo...	?	Ce ₂ O ₃ 5%
Density (g/cm ³)	8.3	8.3	7.8	5.4
Light yield (γ's/MeV)	200	~1000	?	~1000 (?)
Decay time	few ns	~ 1 μs	?	60 - 80 ns
Spectrum peak	440 nm	> 500 nm	?	460 nm
Radiation length (cm)	0.89	0.89	0.93	1.8
Molière Radius (cm)	2	2	2.2	?
Interaction length (cm)	18	18	20 (?)	25 (?)

PbWO₄ crystal for scintillation only readout

High density and short interaction length

$$7 \lambda \rightarrow 126 \text{ cm}$$

- Use different doping materials can improve light yield of CMS PWO crystals by a factor of up to eight
- Decay time of these new PWO are typically $\sim 1 \mu\text{s}$
(still suitable for an ILC experiment)
- “Enhanced” PWO typically has emission peaked at 500 nm. Readout by WLS fiber will be difficult

PWO Cost Issues

CMS has ~100,000 crystals with total volume ~10 m³
\$3.5/cm³ (Shanghai Institute of Ceramic to CMS)

Note: the cost of SiD EM+HCal may exceed \$200M

Shanghai Institute of Ceramic is willing to provide samples of PWO and enhanced PWO if we want to test them

PbF₂ crystal for scintillation only readout

- Potentially a cheaper alternative to PWO
- Traditionally used as cherenkov radiator
- Should scintillate if doped properly
- Only Shanghai Institute of Ceramic can grow high quality crystals
- Raw material is inexpensive
- Melting temperature is only 850 °C, significantly lower than PWO
- But F ions are reactive to crucible

Need R&D !

Scintillating Glasses (1)

Conventional scintillating glass: SCGI-C (Ohara, Japan)

BaO 44% - SiO₂ 42%, Ce₂O₃ doping

Density 3.5 g/cm³, too low for our application

- Efforts to develop dense scintillating glasses for SSC and LHC experiments were not successful
- Density of heavy metal fluoride glasses can be quite high. But they are very expensive and cannot be made large enough
- Dense lead glass cannot be made scintillating because Pb ions in glass absorb short wavelength light

Scintillating Glasses (2)

B_2O_3 - SiO_2 - Gd_2O_3 - BaO 30:25:30:15 glass with 5% Ce_2O_3

(developed by Prof. Jiang Chun at Shanghai Jiaotong University has promising characteristics)

Density: 5.4 g/cm^3 , sufficient for an ILC calorimeter

Light yield is quite high

Cost should be much lower than single crystals

Scintillating Glasses (3)

Advantages

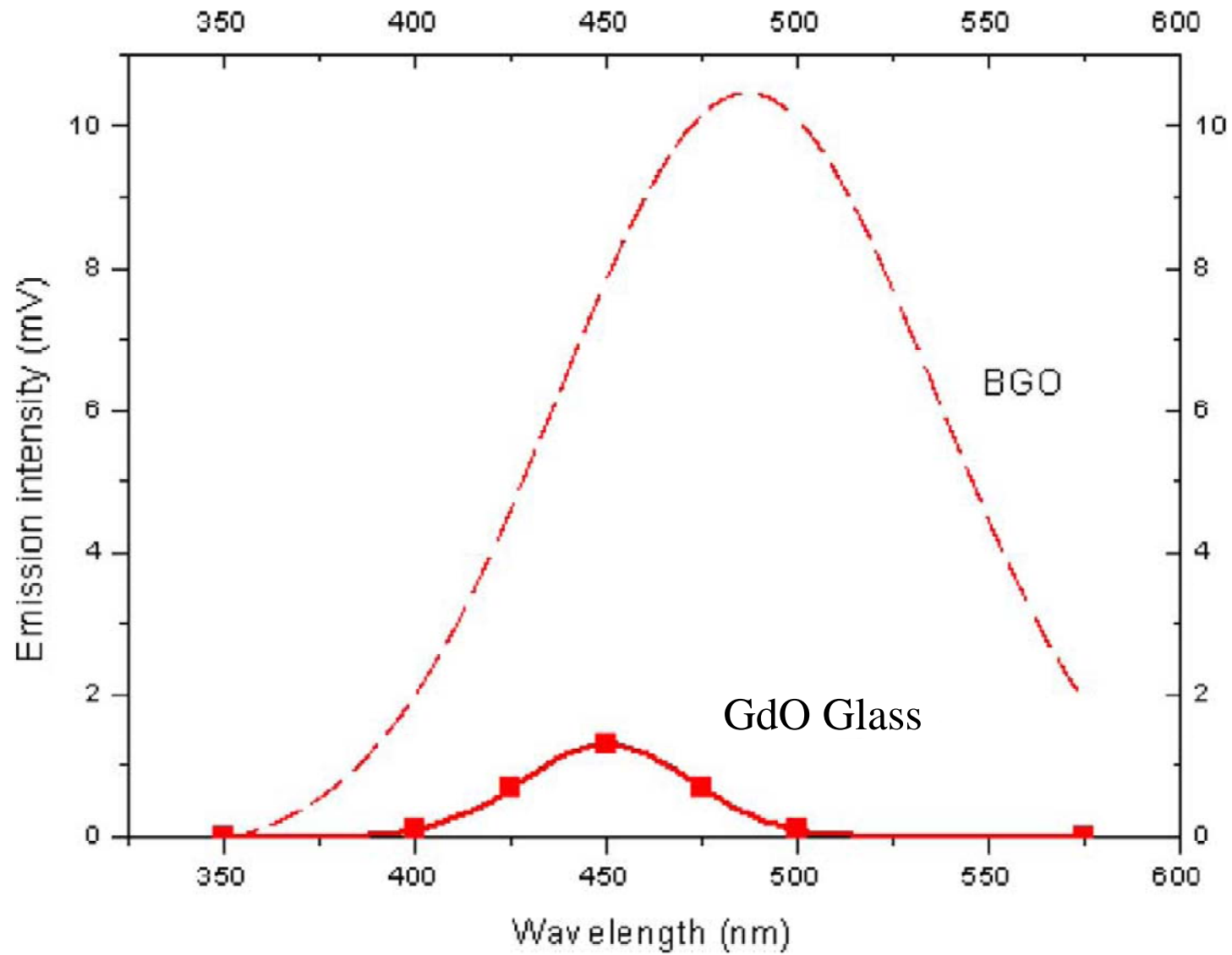
- Thermal neutrons react to ^{157}Gd and resulted ionization signals can be used to compensate the invisible energy in hadron showers

Problems

- Glass is difficult to form once Gd_2O_3 exceeds $\sim 30\%$
- Only small samples are made and tested
- The inventor claim that glass plates of several centimeter thick are possible to make

Need R&D !

Light Yield



Special Requirements for Dual Readout Materials

- Transparent to short wavelength light
- Separating scintillation and cherenkov light requires:
 - Scintillation light spectrum peak $> \sim 500$ nm
 - and/or
 - Scintillation light decay time $> \sim 100$ ns
- Scintillation light yield should not be too much higher than the Cherenkov light yield
(50 -100) γ 's/MeV is about right

Dual Readout Materials

- I have not found any material that satisfies conditions discussed above
- I am proposing three material that potentially can be developed into suitable materials.

Properties of Suitable Dual Readout Materials

	PbWO ₄ Crystal	PbF ₂ Crystal	Gd ₂ O ₃ -BaO Glass
Doping	Pr, Zn, Mo ...	Pr, Zn, Mo ...	Pr, Zn, Mo ...
Density (g/cm ³)	8.3	7.8	5.4
Light yield (γ's/MeV)	Up to ~1000	?	?
Decay time	~ 1 μs	~ 1 μs	~ 1 μs
Spectrum peak	> 500 nm	> 500 nm	> 500 nm
UV cut-off (nm)	Depends on doping level	Depends on doping level	Depends on doping level

PbWO₄ crystal for dual readout Calorimeter

W⁺ ions in PWO lattice generate fast scintillation light with short wavelength. The light yield is on the order of 100 γ 's/MeV.

A proper dopant with correct concentration must be identified in order to suppress the W⁺ scintillation and generate scintillation light that can be separated from Cherenkov light

Need R&D !

PbF₂ crystal for dual readout Calorimeter

Need to identify a dopant that can generate scintillation light at proper level while maintaining the transparency of the PbF₂ crystal to short wavelength light

R&D is not expected to be difficult since the scintillation light yield must be low, long wavelength light and decay time can be tolerated

Gd₂O₃/BaO Glass for dual readout Calorimeter

Traditionally in order to obtain fast scintillation light, Ce₂O₃ is used as dopant in scintillating glasses. Here, we need to identify a dopant that can generate scintillation light at proper level while maintaining the transparency of the glass to short wavelength light

R&D is not expected to be difficult since the scintillation light yield must be low, long wavelength light and decay time can be tolerated

Conclusions

- Several attractive options exist for a compact total absorption calorimeter using scintillation light only
- Materials for a homogeneous total absorption calorimeter do not yet exist, but can be developed
- The two Chinese groups involved are eager to collaborate with us. But R&D funding must be identified