Heavy Scitillating 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 compesation and optimum resolution
- Combine the EM and Hadron Colormeter

Consider two options

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

Basic Requriements

- Total thickness: ~7 λ
- 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 radition length

- short Molière radius

- short interaction length

Requirements for Scintillation Only Readout Mode

- Sufficient light yield
- Decay time suitable for an ILC experiment (≤ ~ 1 μs)
- 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_2O_3-BaO Glass
Doping	La/Y	Pr, Zn, Mo...	?	Ce_2O_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 (?)

$PbWO_4$ crystal for scintillation only readout

High density and short interaction length

7 λ → 126 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 ~ 1 μs

  (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 m^3

\$3.5/cm^3 (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

PbF_2 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% - SiO_2 42%, Ce_2O_3 doping

Density 3.5 g/cm^3, 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

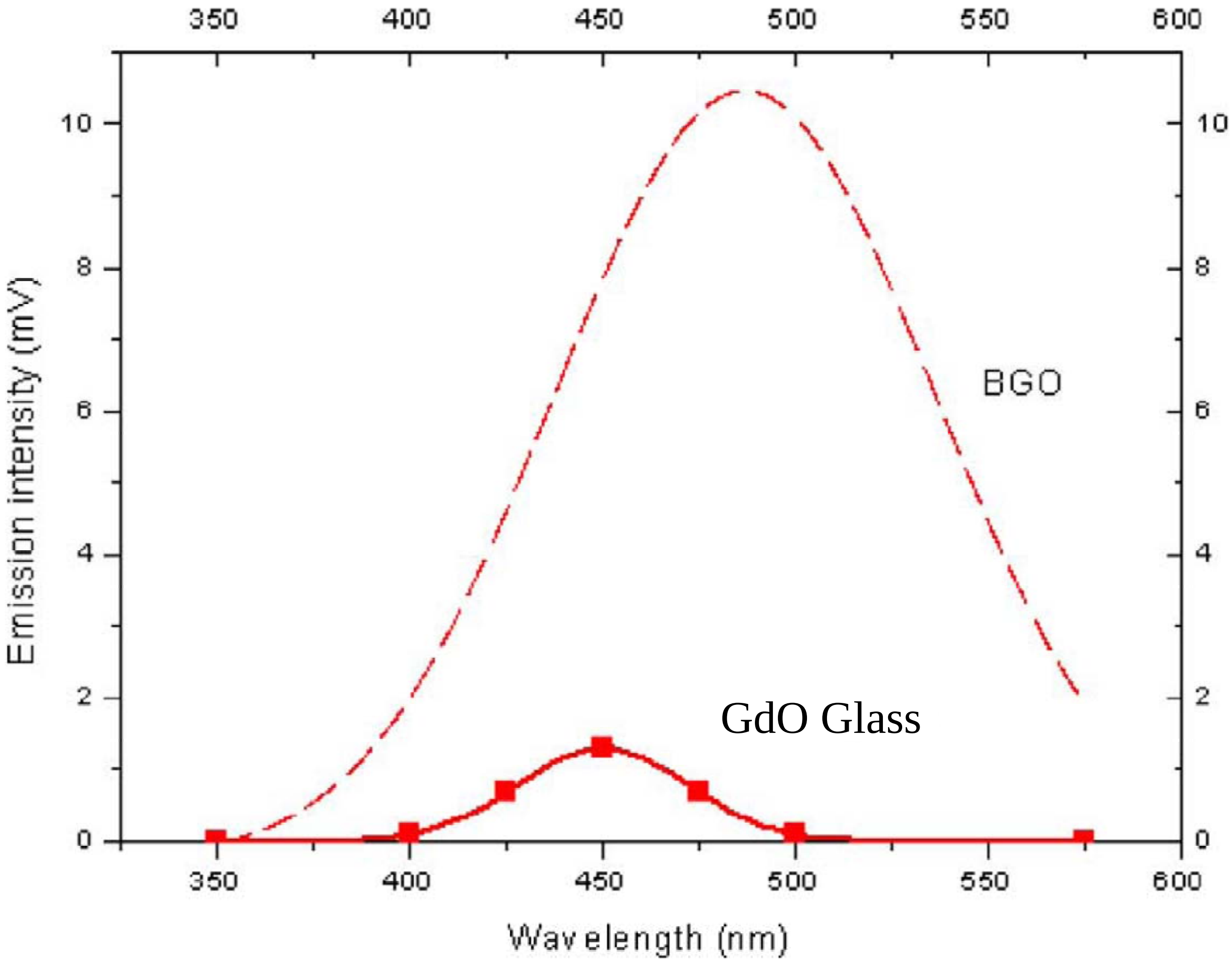
- Thermal neutrons react to ^{157}Gd and resulted ionization signals can be used to compensate the invisible energy in hadron showers

Problems

- Glass is difficult to form once Gd_2O_3 exceeds ~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


350
400
450
500
550
600
10
8
6
4
2
0
Emission intensity (mV)
BGO
GdO Glass
Wavelength (nm)

Special Requirements for Dual Readout Materials

- Transparent to short wavelength light
- Separating scintillation and cherenkov light requires:
  - Scintillation light spectrum peak > ~500 nm
  - and/or
  - Scintillation light decay time > ~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_2O_3-BaO Glass
Doping	Pr, Zn, Mo …	Pr, Zn, Mo …	Pr, Zn, Mo …
Density (g/cm3)	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

$PbWO_4$ 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 !

PbF_2 crystal for dual readout Calorimeter

Need to identify a dopant that can generate scintillation light at proper level while maintaining the transparency of the PbF_2 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

Gd_2O_3/BaO Glass for dual readout Calorimeter

Traditionally in order to obtain fast scintillation light, Ce_2O_3 is used as dopant in scinitllating 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 exit, but can be developed
- The two Chinese groups involved are eager to collaborate with us. But R&D funding must be identified