Crystal Developments for the Homogeneous Hadron Calorimeter Detector Concept

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March 21, 2011

Homogeneous Hadron Calorimeter

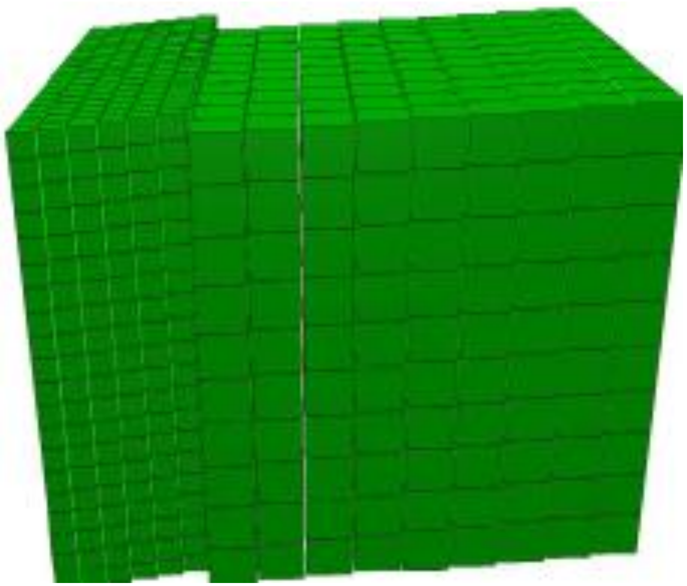
A Fermilab team (A. Para et al.) proposed a total absorption homogeneous HCAL detector concept to achieve good jet mass resolution by measuring both Cherenkov and Scintillation light. It also eliminates the dead materials between classical ECAL and HCAL. This longitudinal segmented crystal HCAL is possible because of the latest development in large area compact readout devices.

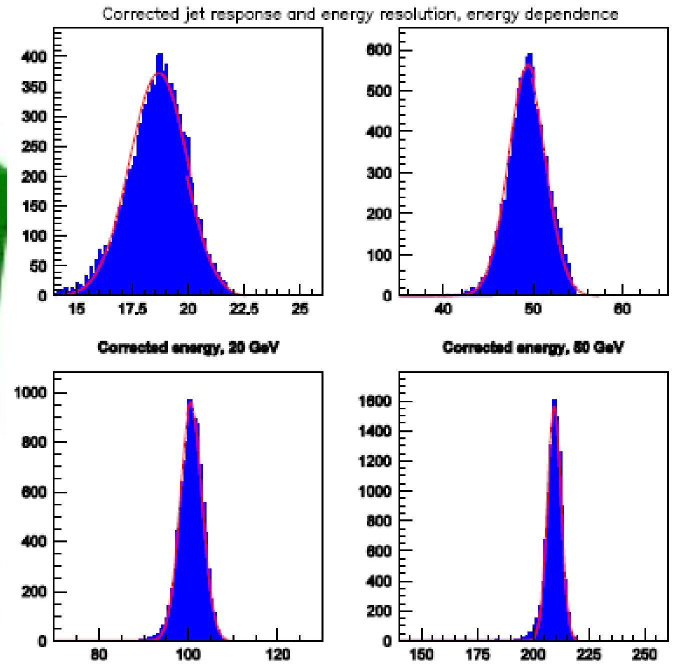
Requirements for the materials to be used for HHCAL:

- Short nuclear interaction length: ~ 20 cm.
- Good UV transmittance: UV cut-off < 350 nm.
- Some scintillation light, not necessary bright and fast.
- Cost-effective material: < \$2/cc for 100 m^3 !
- Radiation hardness is not crucial at the ILC/CLIC.

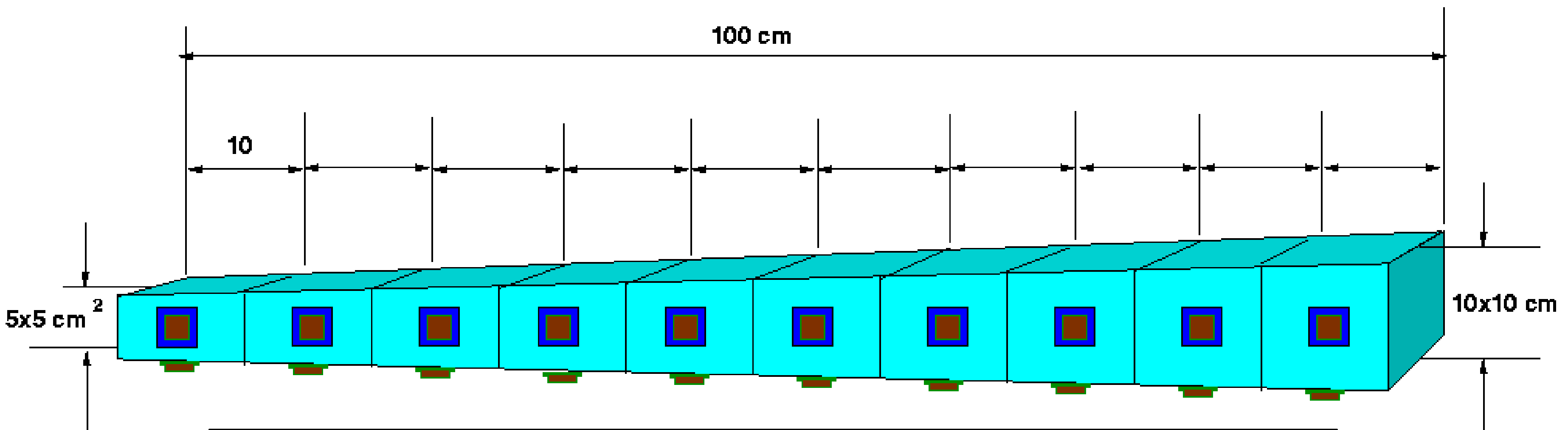
A series of workshops on material development for HHCAL:
1st 2/19/2008 at SIC, Shanghai, 2nd 5/9/2010 at IHEP, Beijing,
3rd 10/30/2010 at Knoxville, will go with SCINT, CALOR & IEEE NSS.

The HHCAL Detector Concept





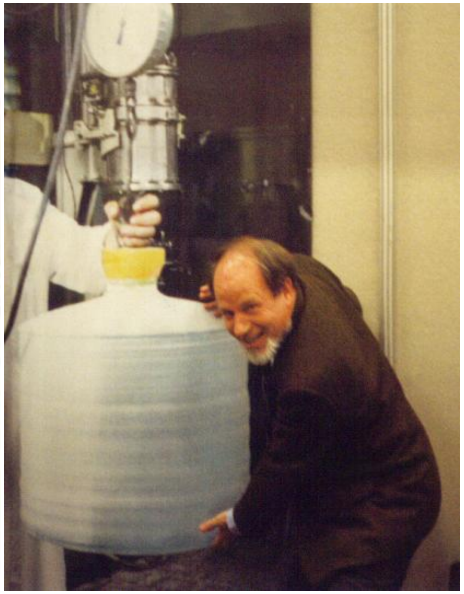
See A. Para, H. Wenzel, Callor2010: GEANT simulations show a jet energy resolution of better than 20%/√E after corrections.



R.-Y. Zhu, ILCWS-08, Chicago: a HHCAL cell with pointing geometry

Industrial Halide Growth: Kharkov

A. Gektin: Talk at the 2nd Workshop for HHCAL



Industrial Oxide Growth: SICCAS

Guohao Ren: Talk at the 2nd Workshop for HHCAL

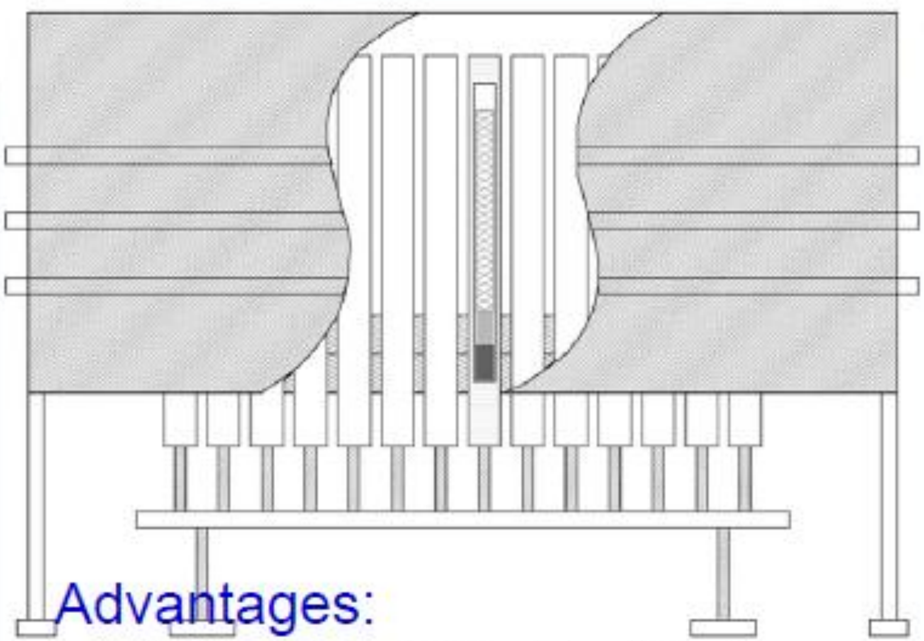
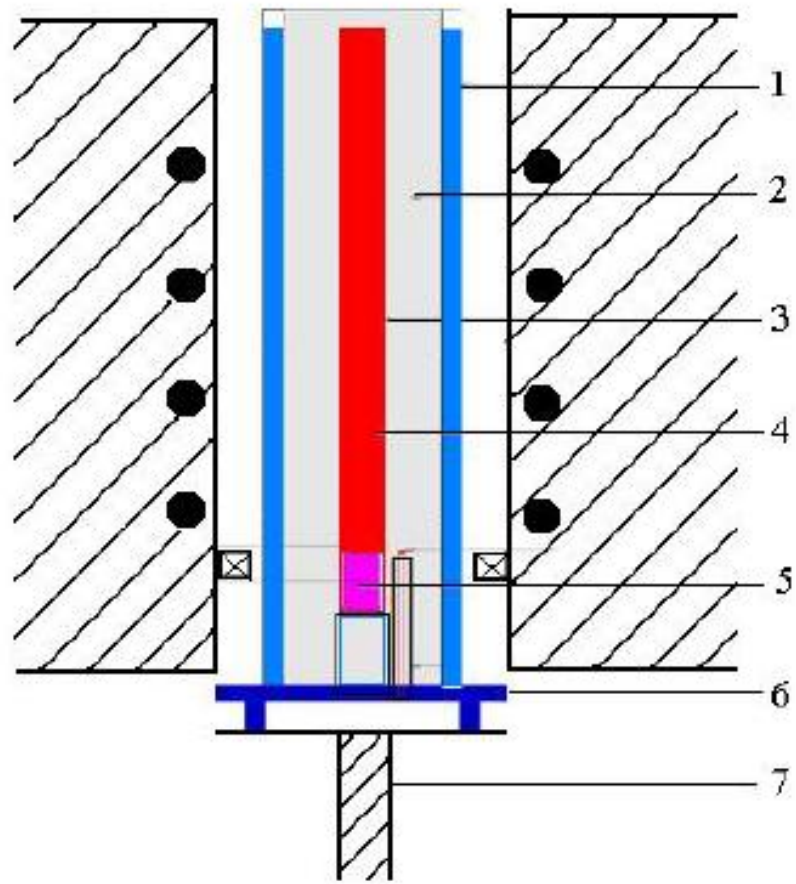


Fig. 2. A schematic of a typical Bridgman furnace with 28 crucibles.

Advantages:

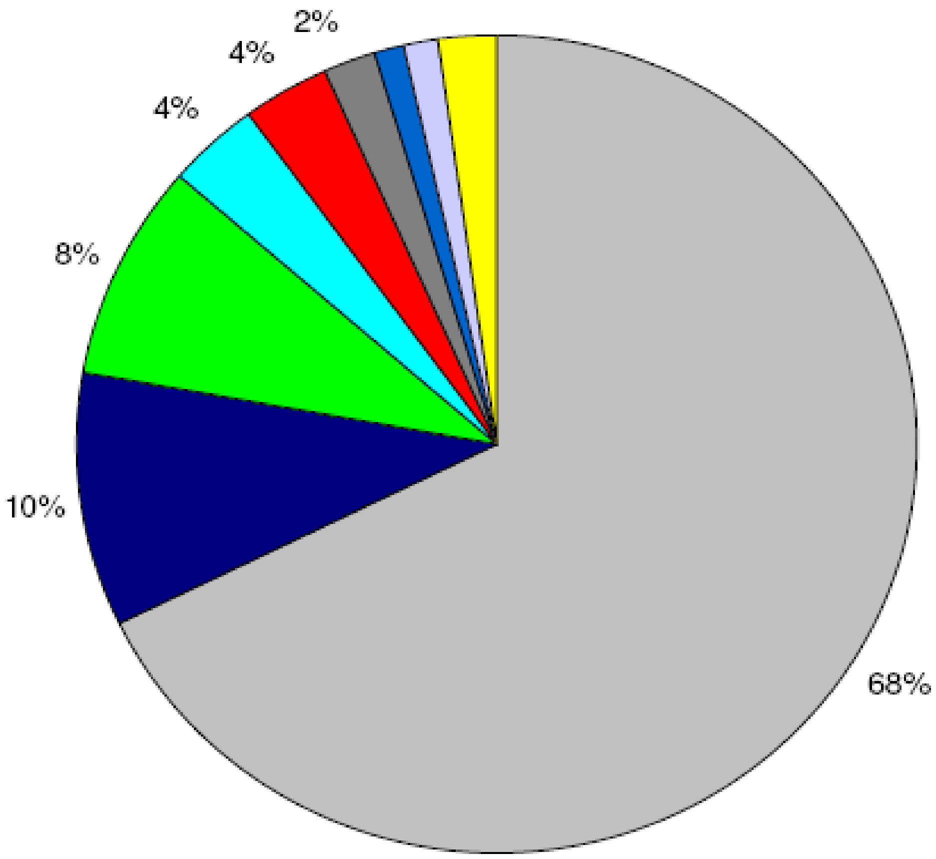
1) Low infrastructure investment
2) Simplified the techniquue
3) Suitable for mass production



Growth Assembly of Bridgman Method

Cost for Crystal Growth

A. Gektin: for mass produced Si crystals raw materials share 70% of the cost



Crystal cost structure (Si)

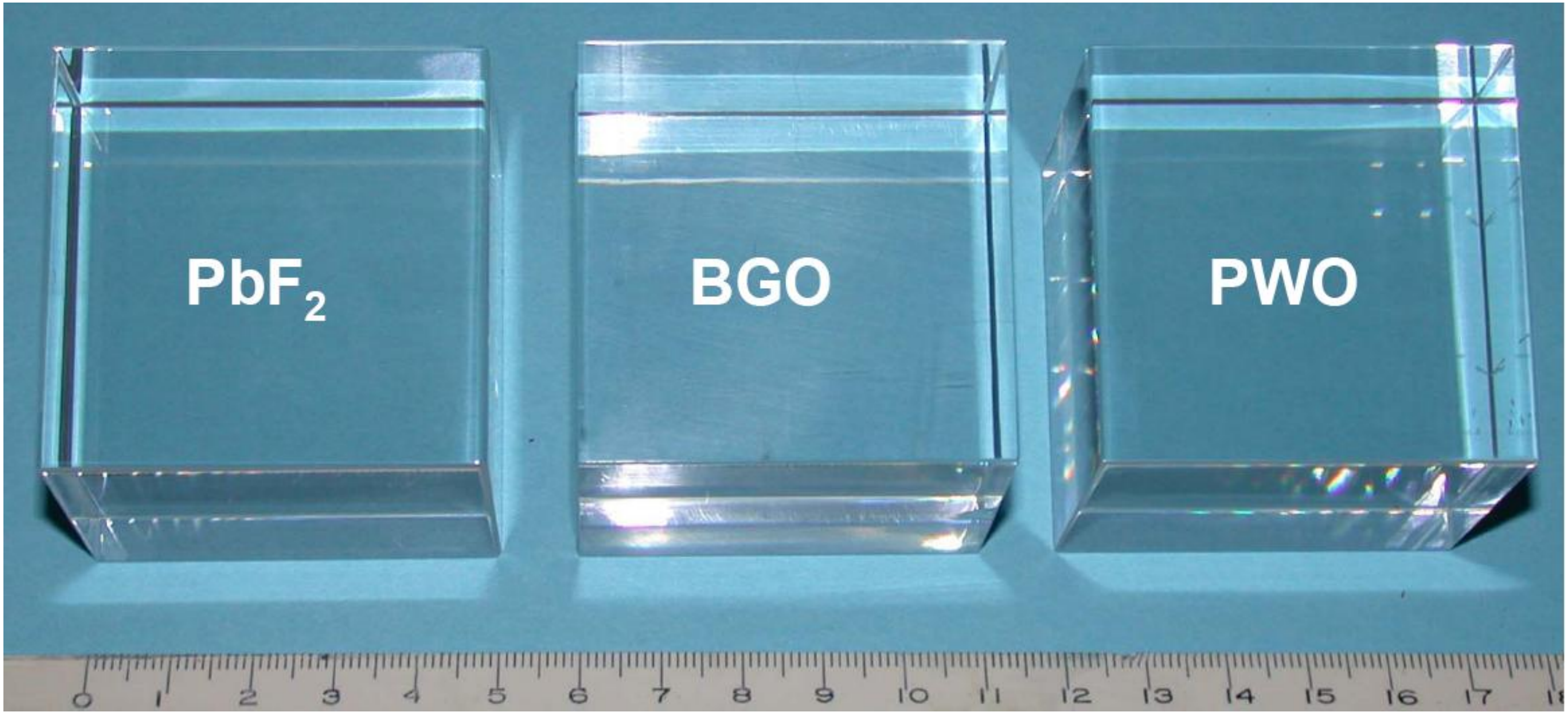
68% - raw material
10% - crucible
8% - system cost
4% - labor cost
4% - power
6% - other

Candidate Crystals for HHCAL

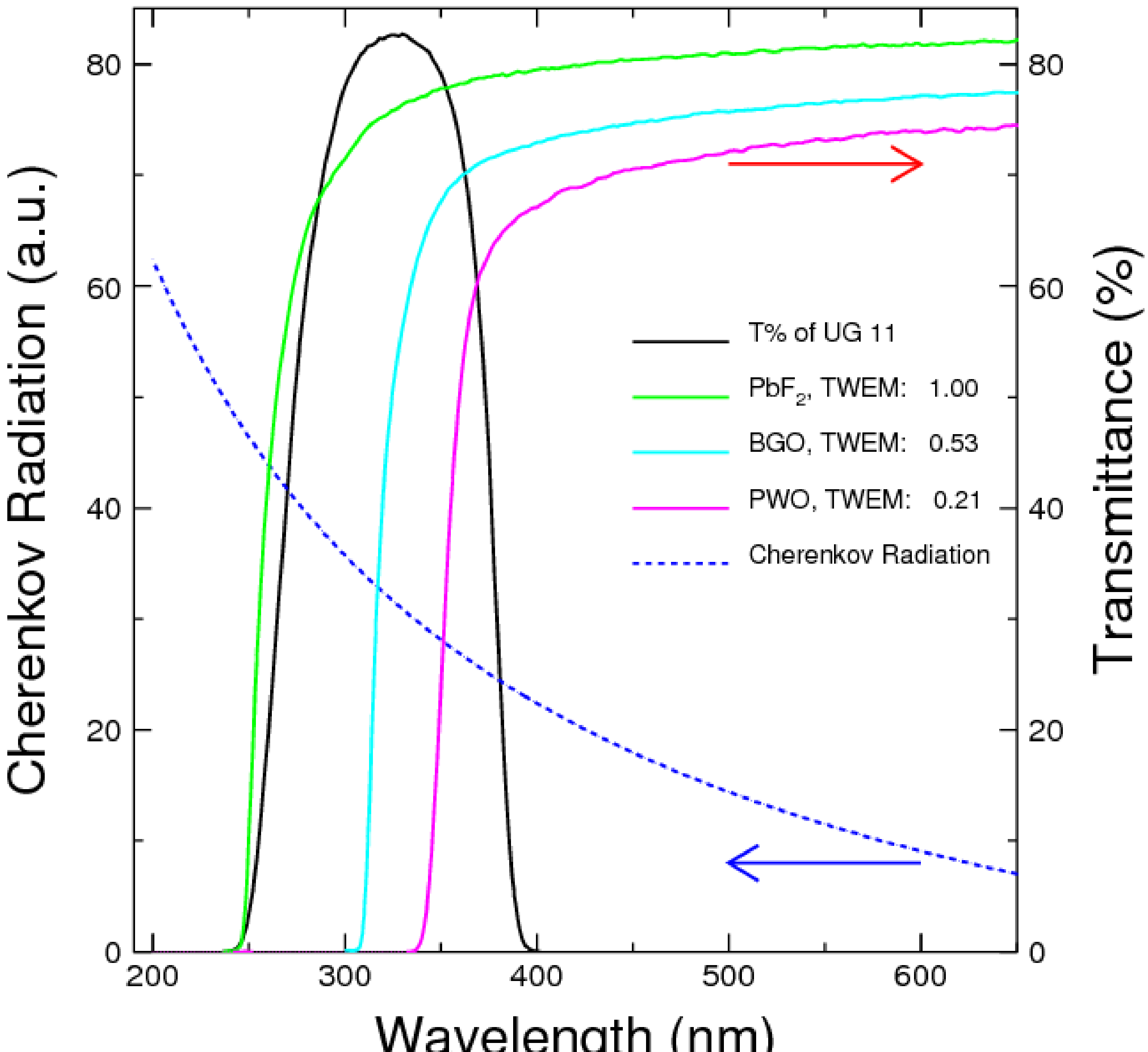
Parameters	$Bi_4Ge_3O_{12}$ (BGO)	$PbWO_4$ (PWO)	PbF_2	PbClF	$Bi_4Si_3O_{12}$ (BSO)
ρ (g/cm^3)	7.13	**8.29**	**7.77**	7.11	6.8?
λ_I (cm)	22.8	**20.7**	**21.0**	24.3	23.1
n @ λ_{max}	2.15	2.20	1.82	2.15	2.06
τ_{decay} (ns)	300	30/10	**?**	30	100
λ_{max} (nm)	480	425/420	**?**	420	470
Cut-off λ (nm)	**310**	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

Crystal for Homogeneous HCAL

Crystals of high density, good UV transmittance and some scintillation light, not necessary bright and fast, are required. The volume needed is 70 to 100 m^3: cost-effective material.
Following 2/19/08 workshop at SICCAS, 5 x 5 x 5 cm samples evaluated.



Cherenkov Needs UV Transparency

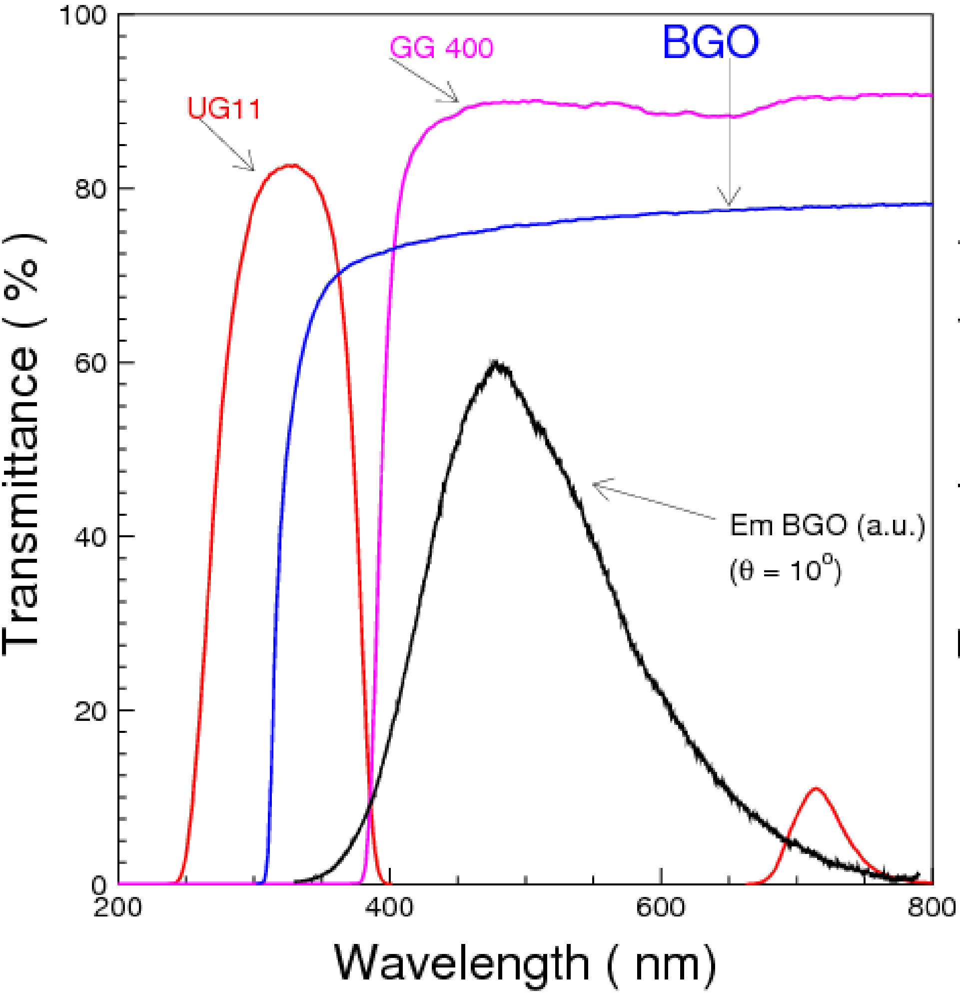


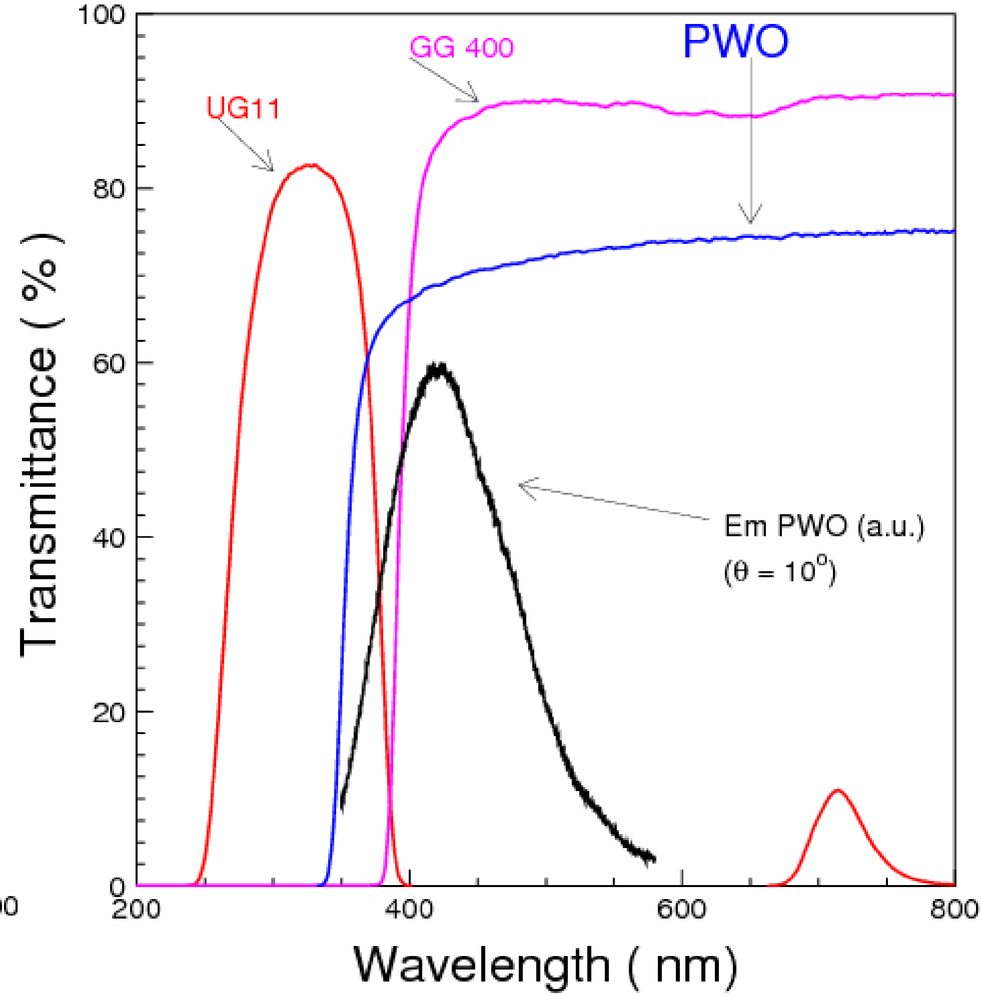
Cherenkov figure of merit

Using UG11 optical filter Cherenkov light can be effectively selected with negligible contamination from scintillation

Scintillation Selected with Filters

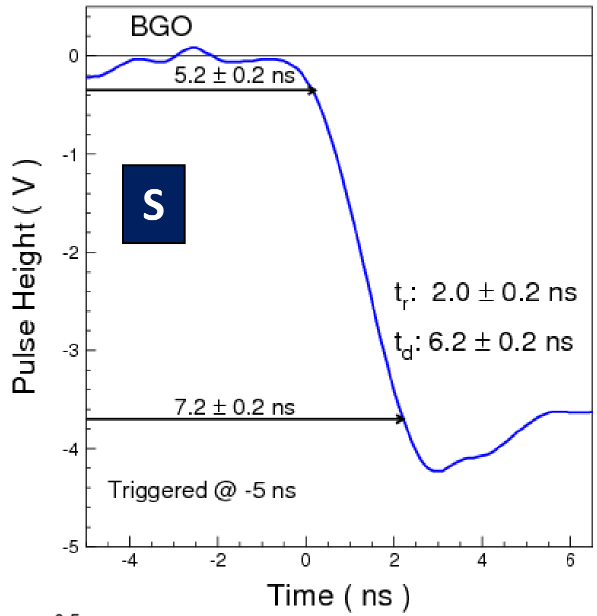
UG11/GG400 optical filter effectively selects Cherenkov/scintillation light

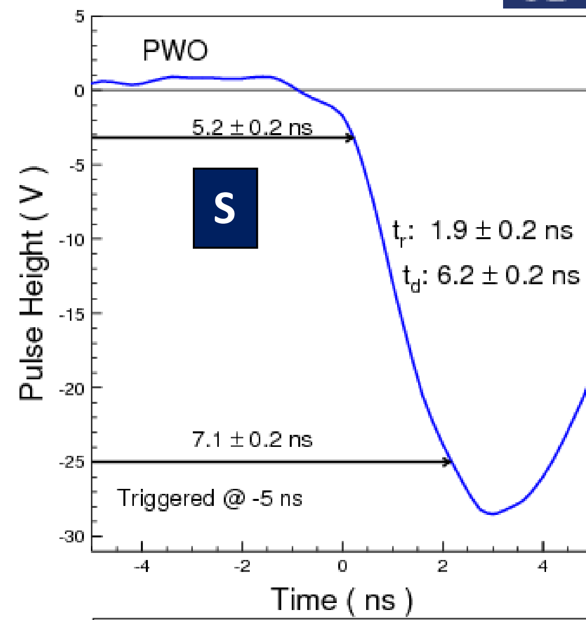


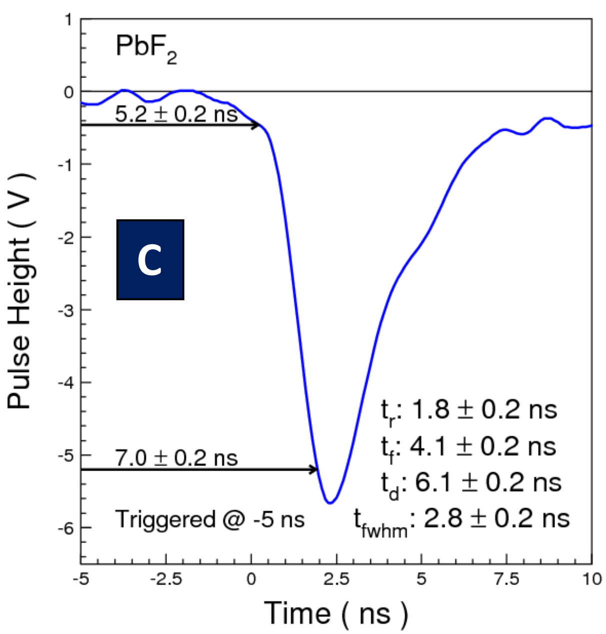


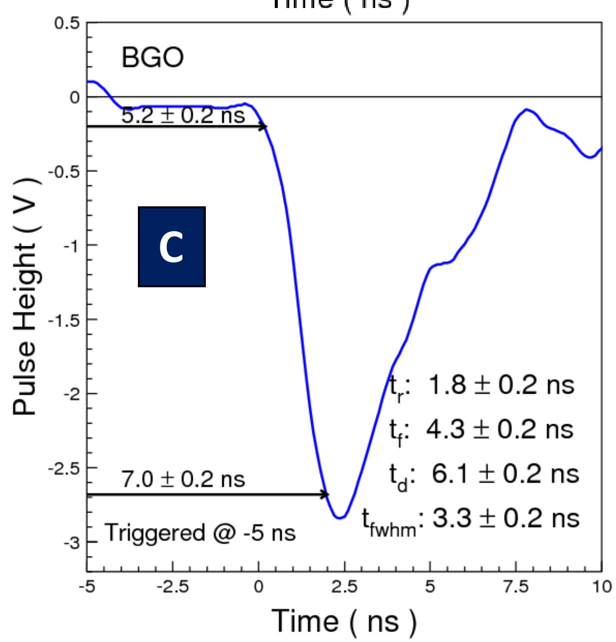
No Discrimination in Front Edge

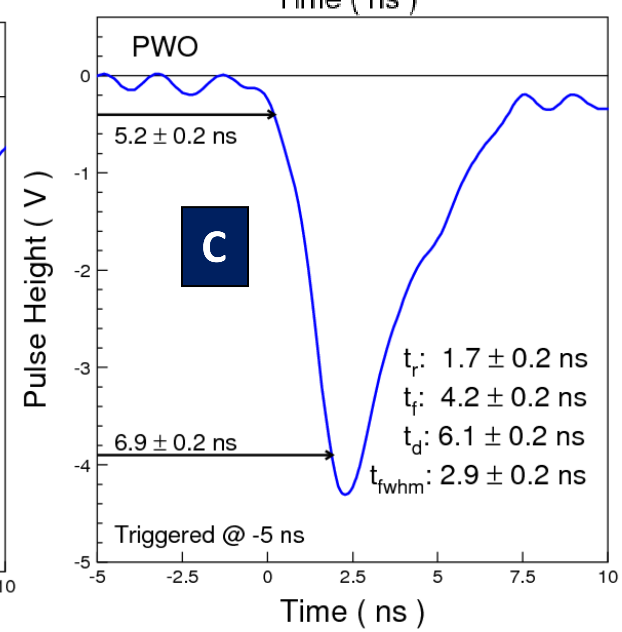
Consistent timing and rise time for all Cherenkov and scintillation light pulses observed.





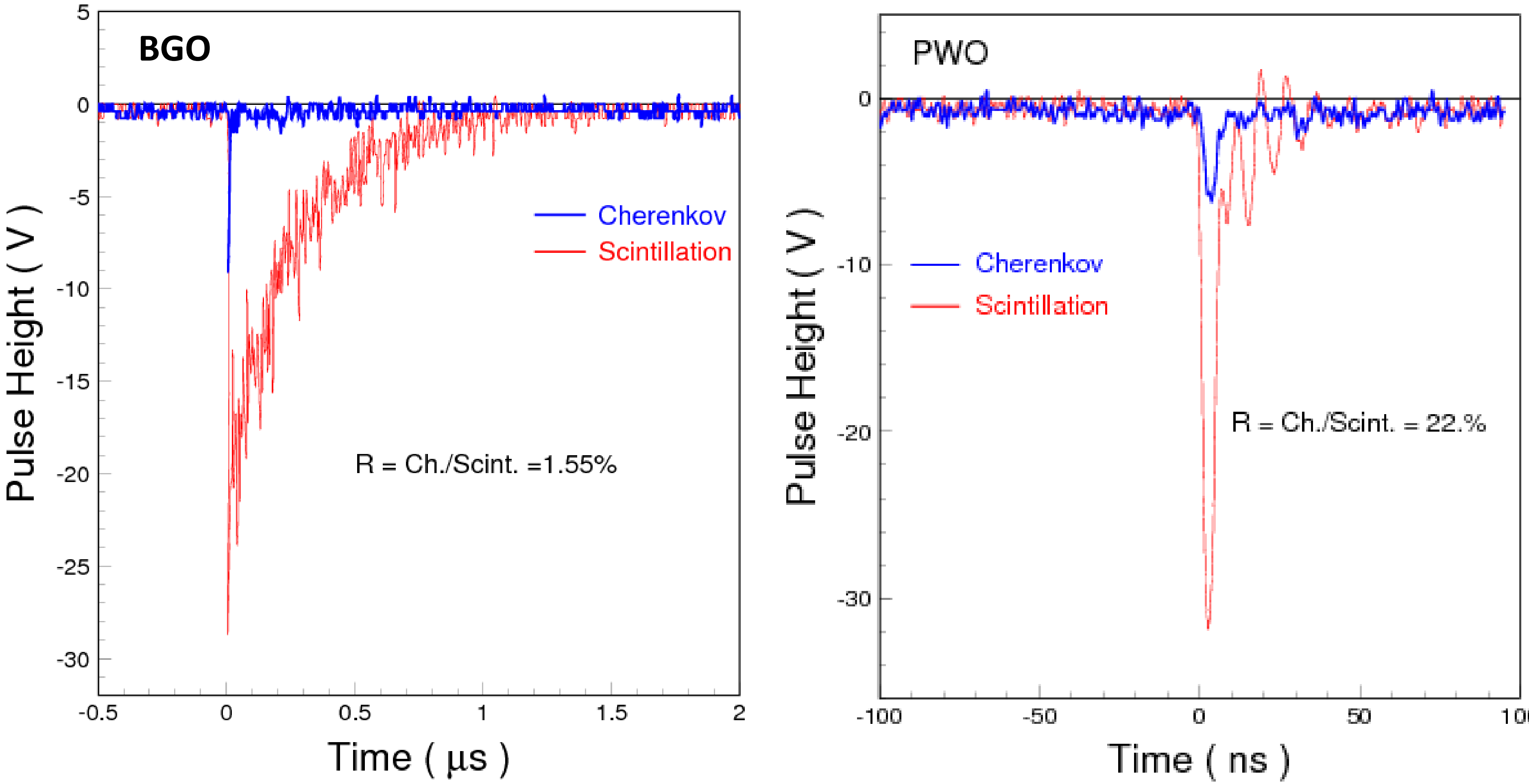






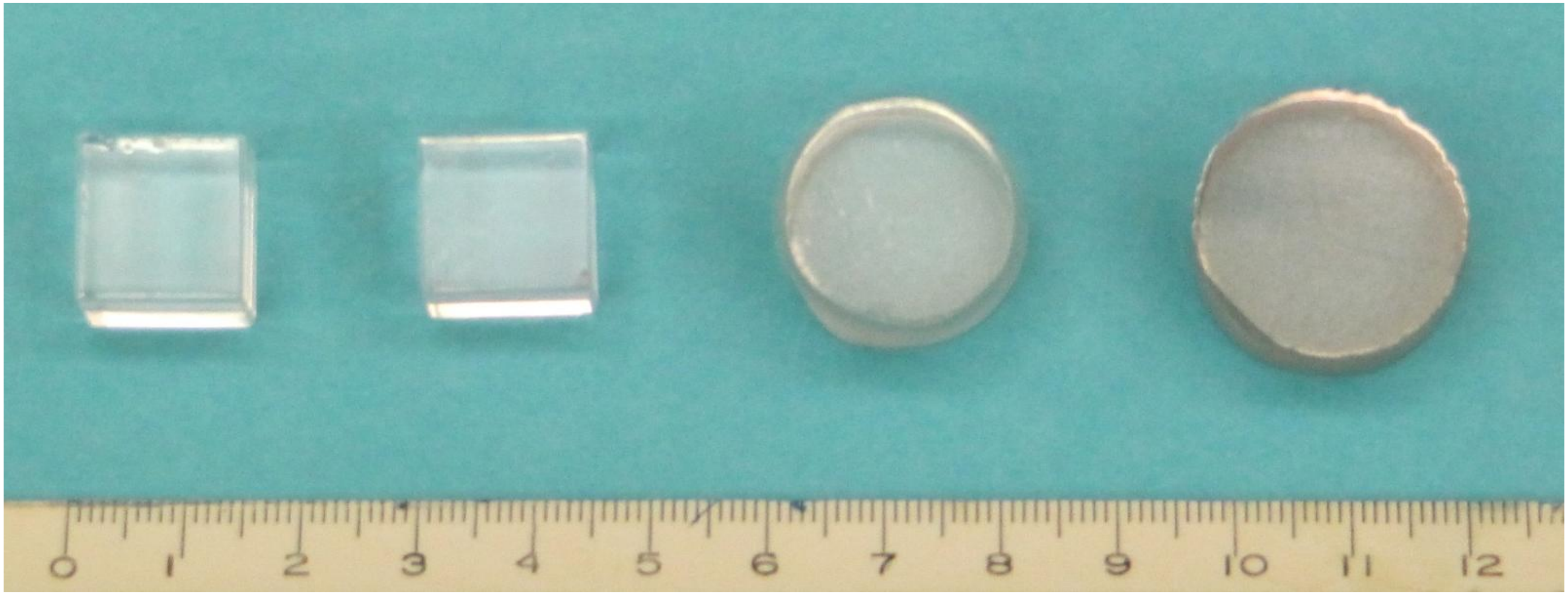
Ratio of Cherenkov/Scintillation

1.6% for BGO and 22% for PWO with UG11/GG400 filter and R2059 PMT, which is configuration dependent.



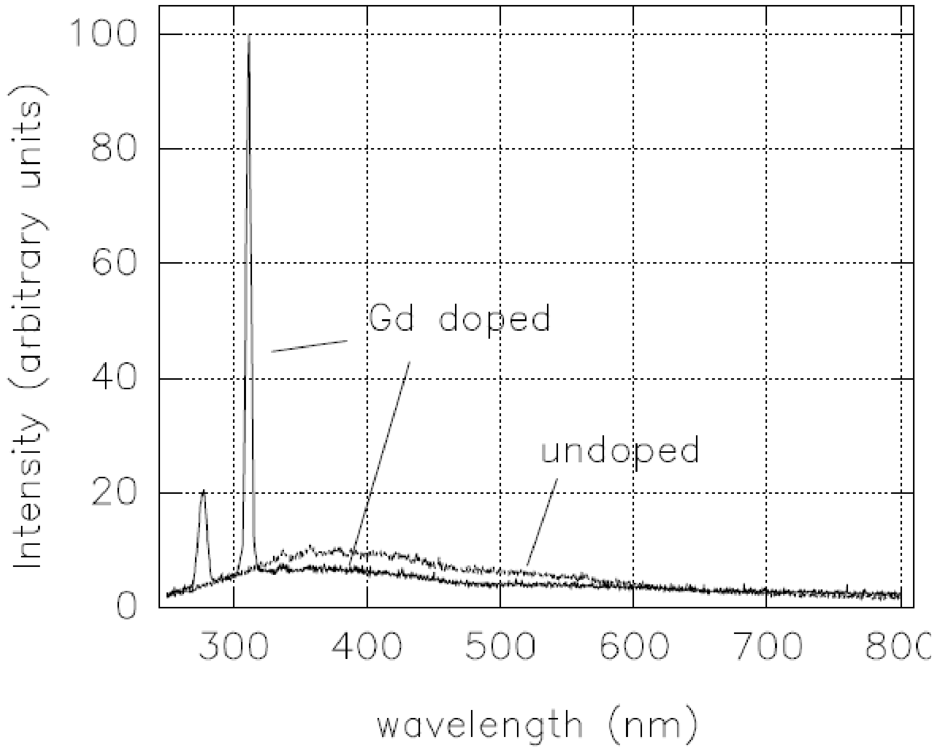
PbF_2 Crystal Samples

- A total of 116 samples with various rare earth doping were grown by vertical Bridgman method at SIC and Scintibow.
- SIC samples: grown in **platinum** crucible, 1.5 X_0 (14 mm) cube.
- Scintibow samples: grown in **graphite** crucible, Φ 22 x 15 mm.

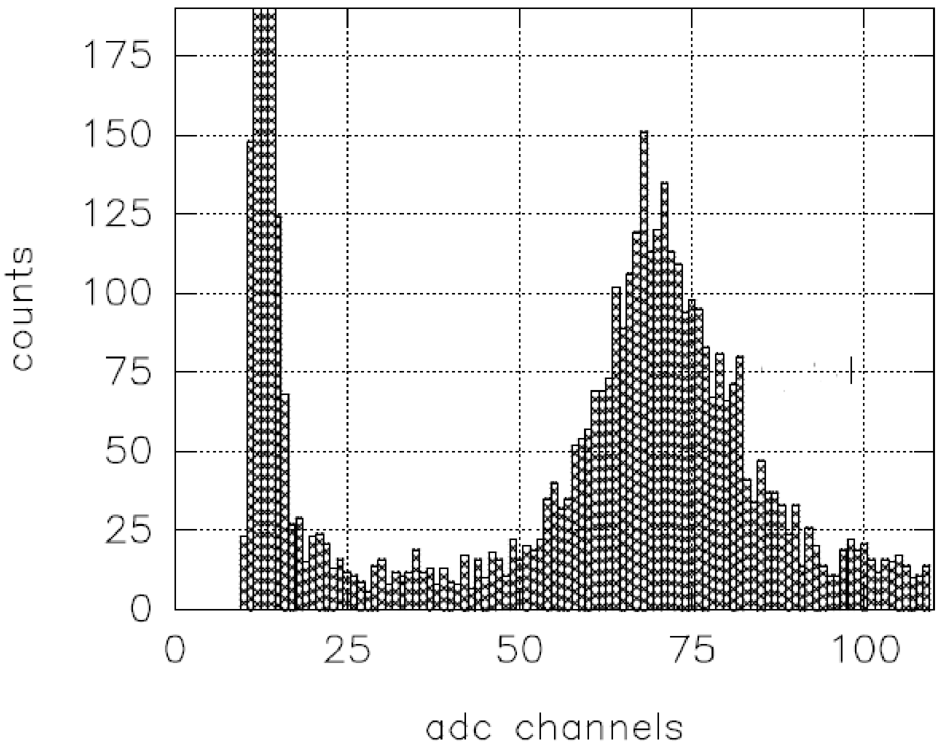


Scintillation was Observed in PbF_2:Gd

Scintillation of PbF_2(Gd)



PbF_2(Gd) Response to MIP of 1 GeV/c

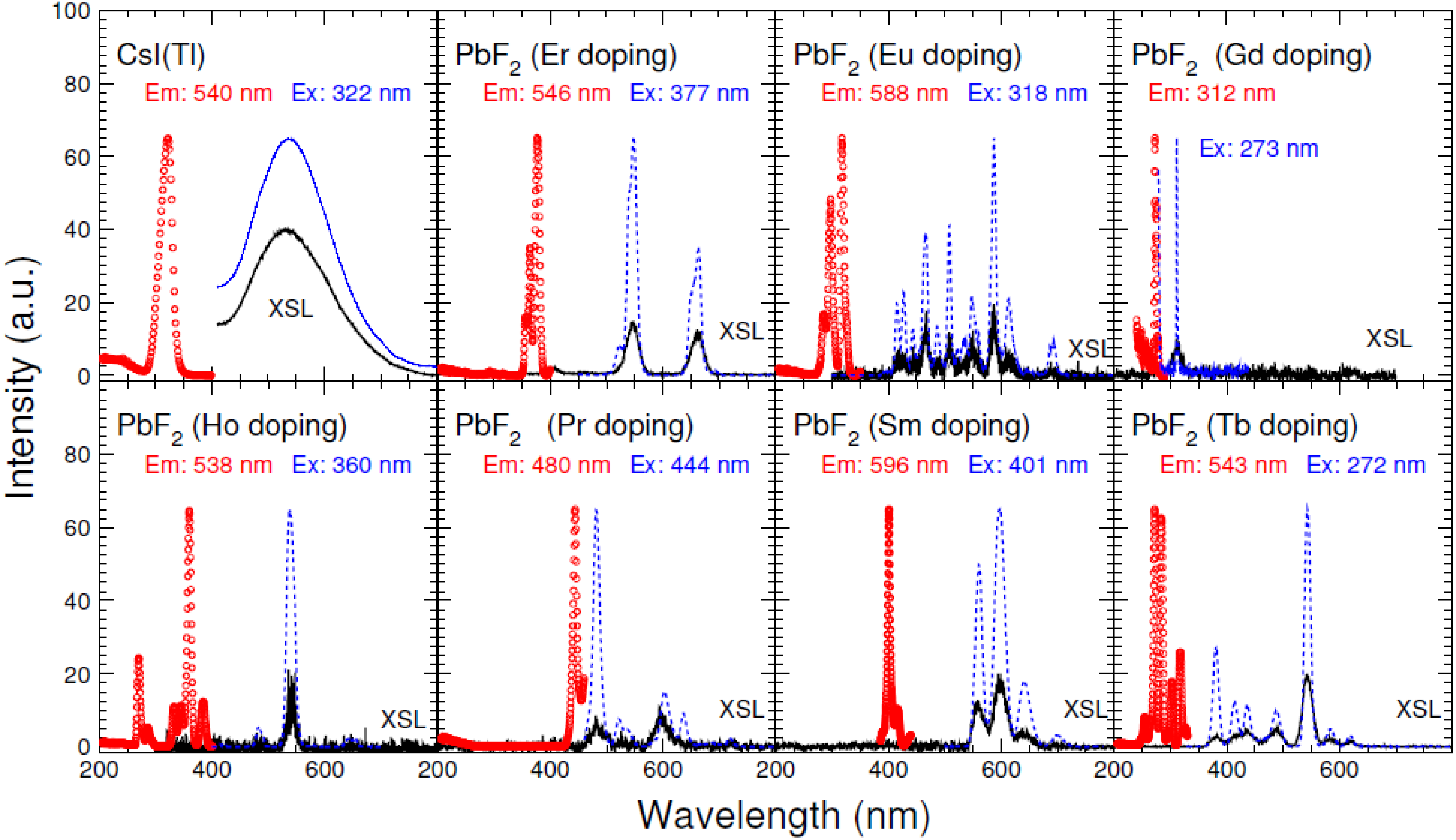


Fast Scintillation of 6.5 p.e./MeV with decay time of less than 10 ns

C. Woody *et al., IEEE Trans. Nucl. Sci.* ***43*** *(1996) 1303*

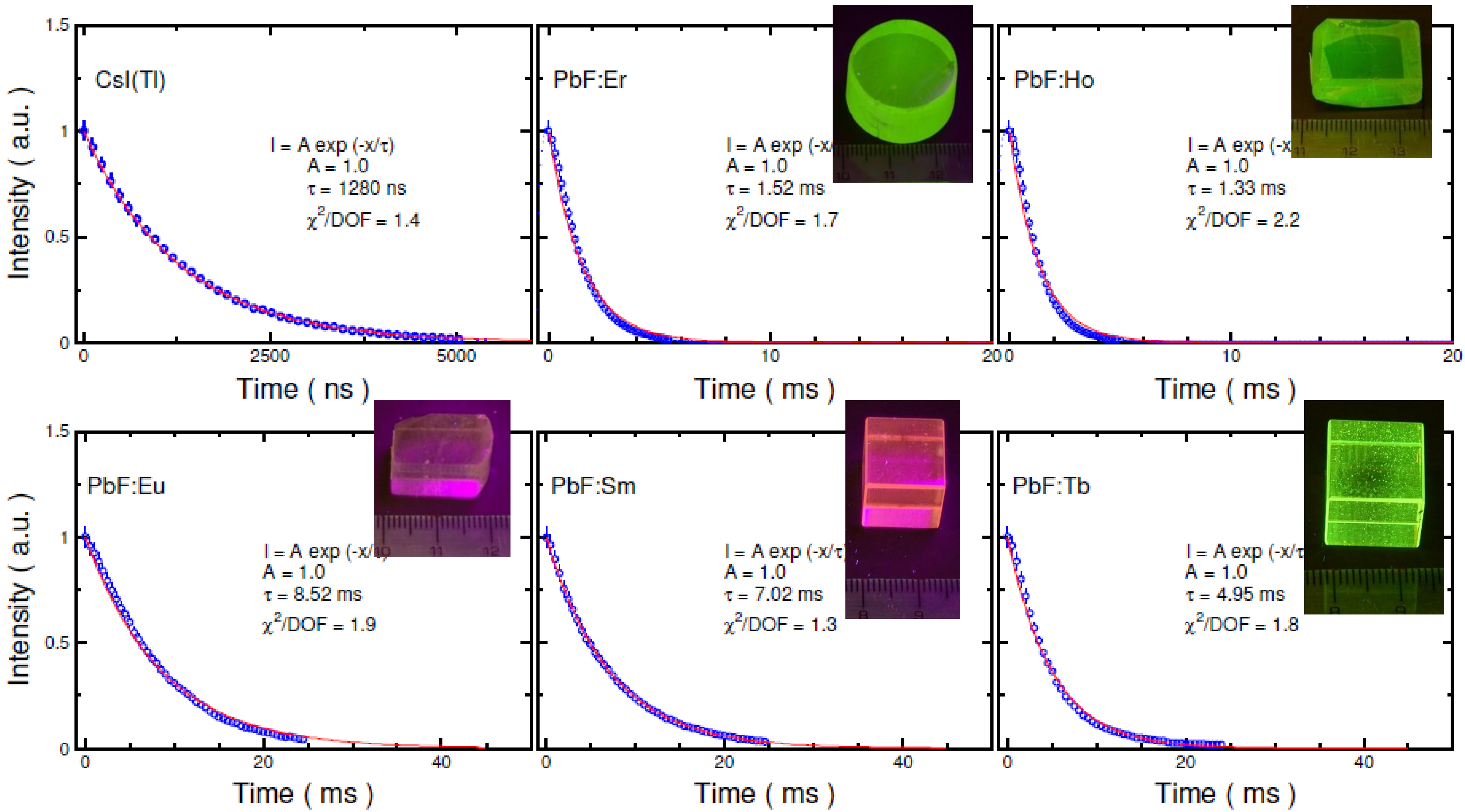
Luminescence Observed in PbF_2

Consistent Photo- and X-luminescence observed in doped PbF_2 samples grown by Prof. Dingzhong Shen of SIC/Scintibow.



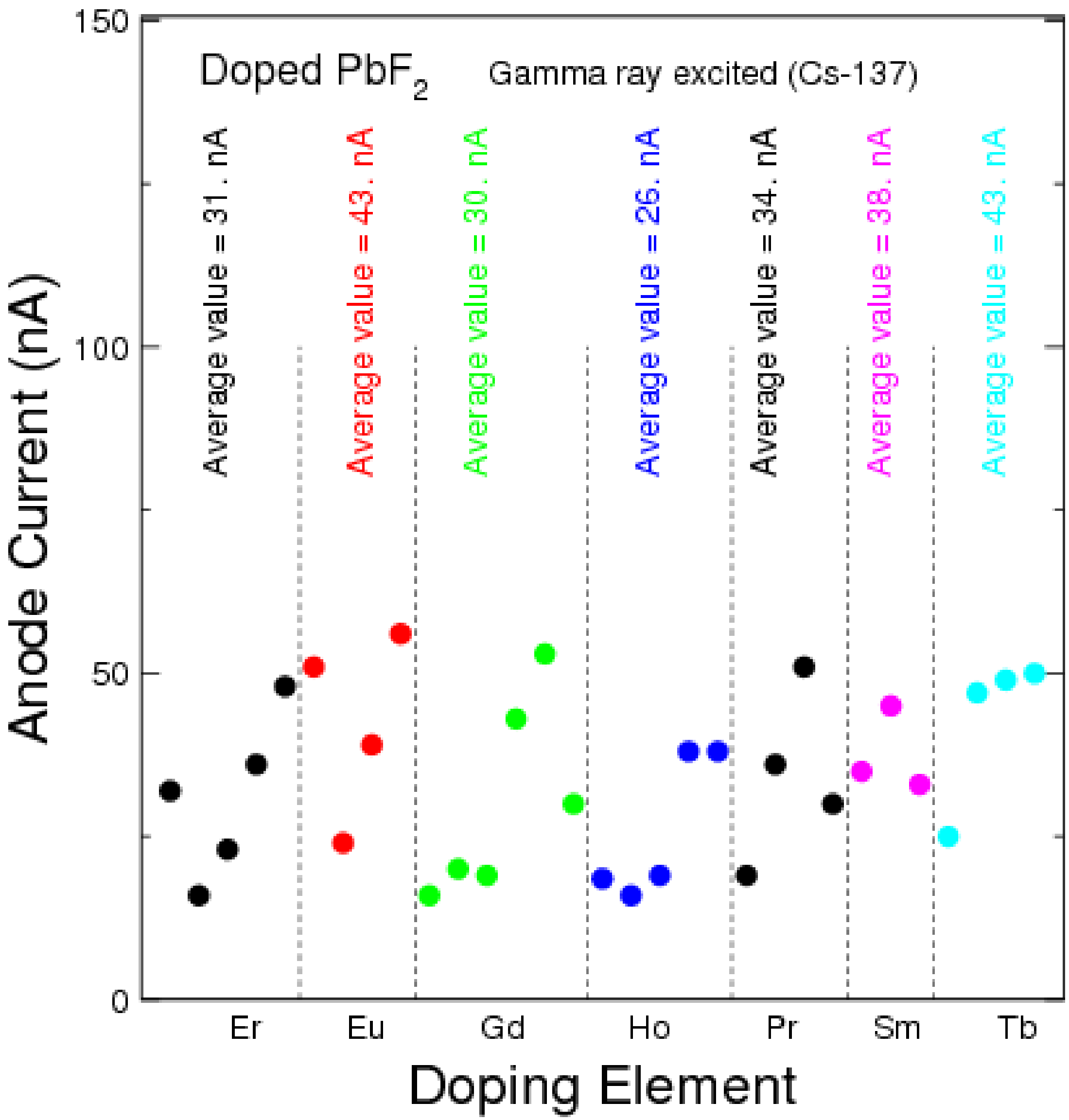
Rare Earth Doped PbF_2

Multi-ms decay time observed, indicating f-f transitions of these rare earth elements which is too slow to be useful.



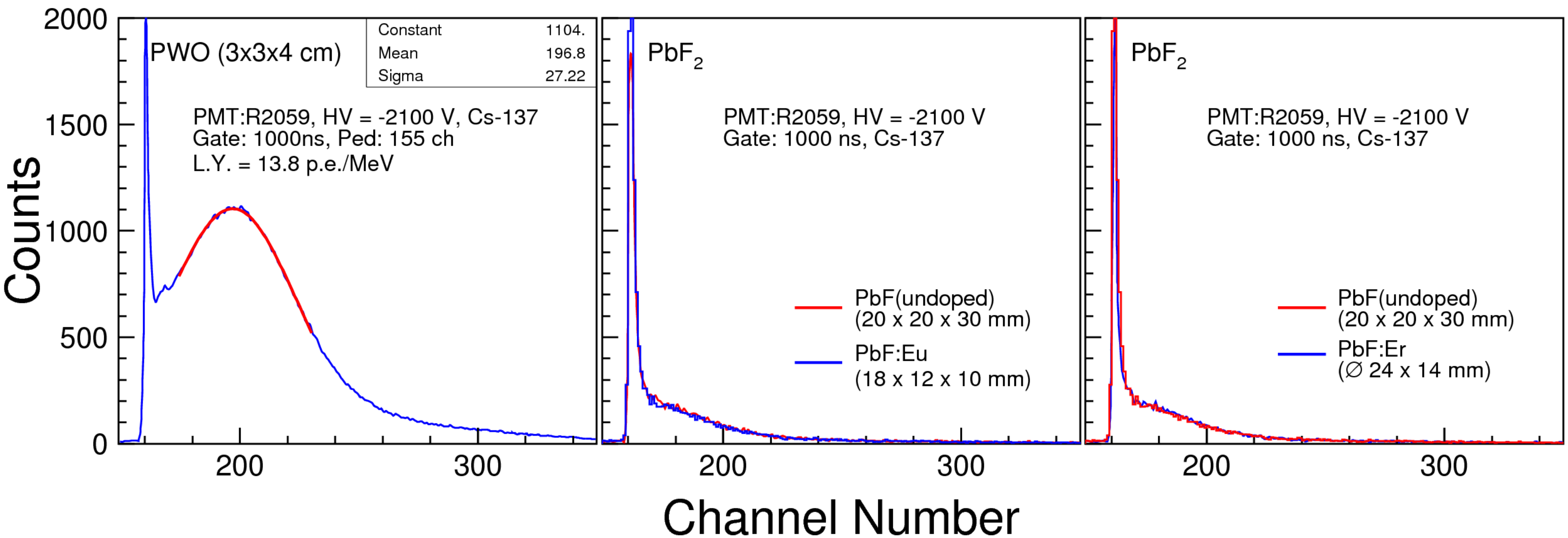
Anode Current

Anode current measured for doped PbF2 samples is at the same level as undoped crystals, indicating weak light.



^{137}Cs Pulse Height Spectra

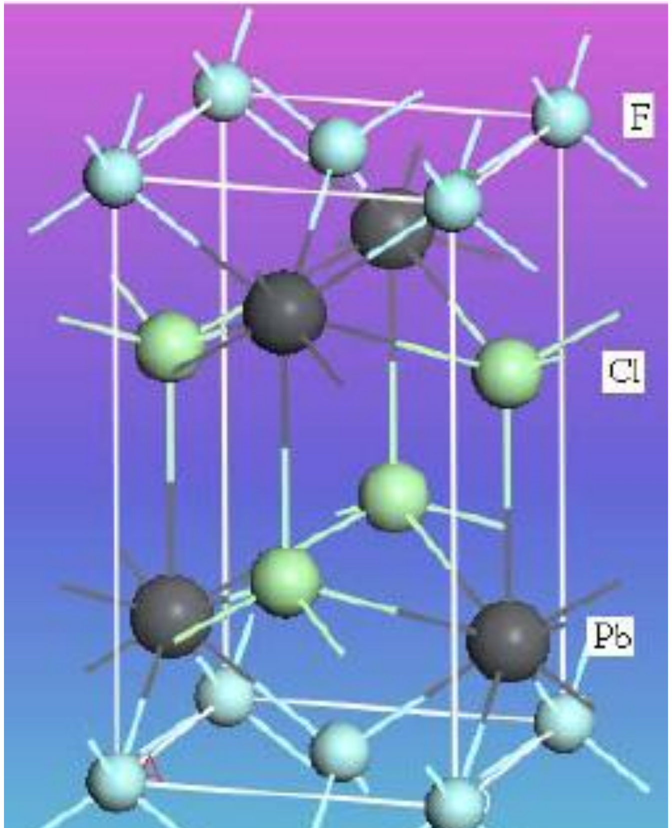
So far, no detectable scintillation was found



R.H. Mao et al., IEEE TNS Vol 57 No 6 (2010) 3841-3845

PbClF Crystals

Guohao Ren of SIC: Talk at the 2nd Workshop for HHCAL



Crystal structure of PbClF

D= 7.11g/cm³

Melting point =608°C

Space group=P/4nmm

a=4.10Å;c= 7.22Å

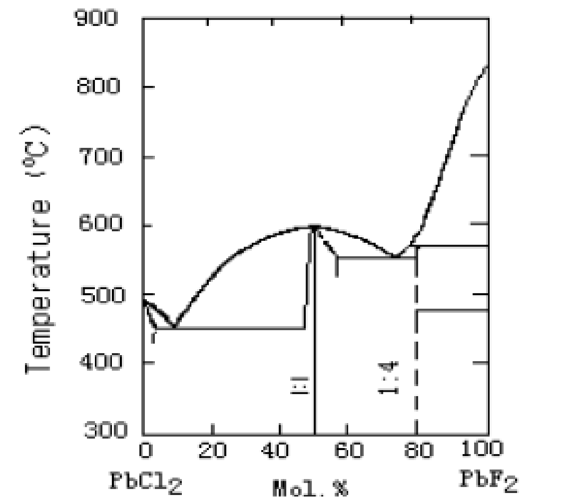
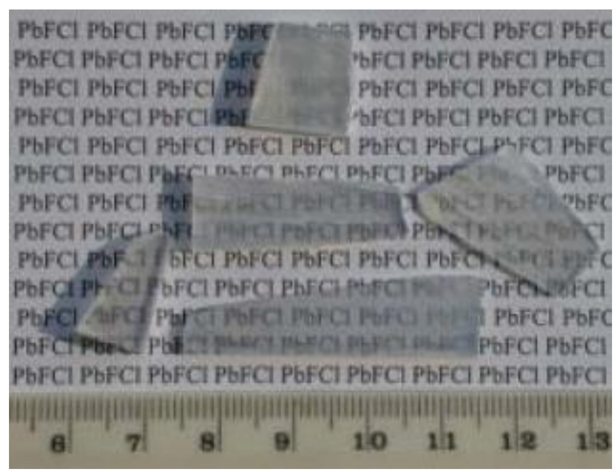
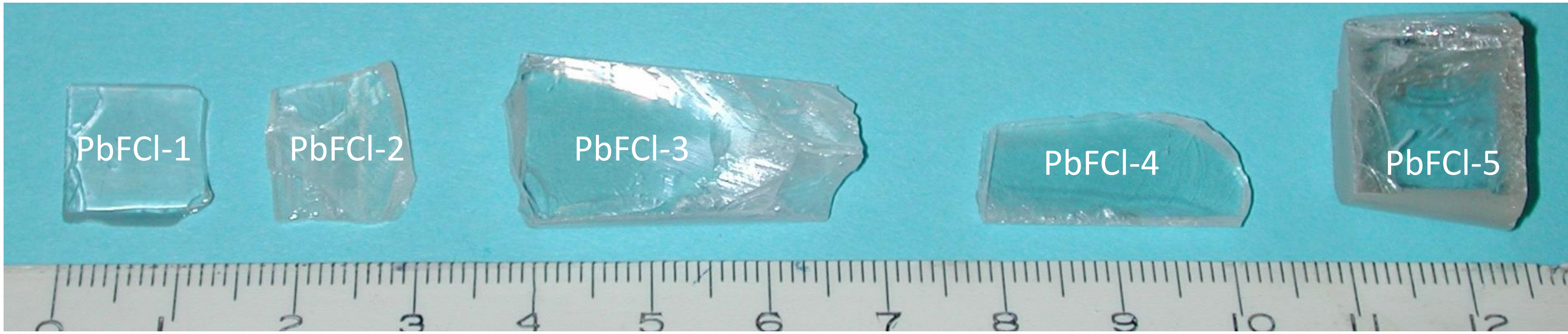


Figure 2.1 Phase relations in $PbCl_2$-PbF_2 system



PbClF Crystal samples grown at SICCAS

PbFCl Samples

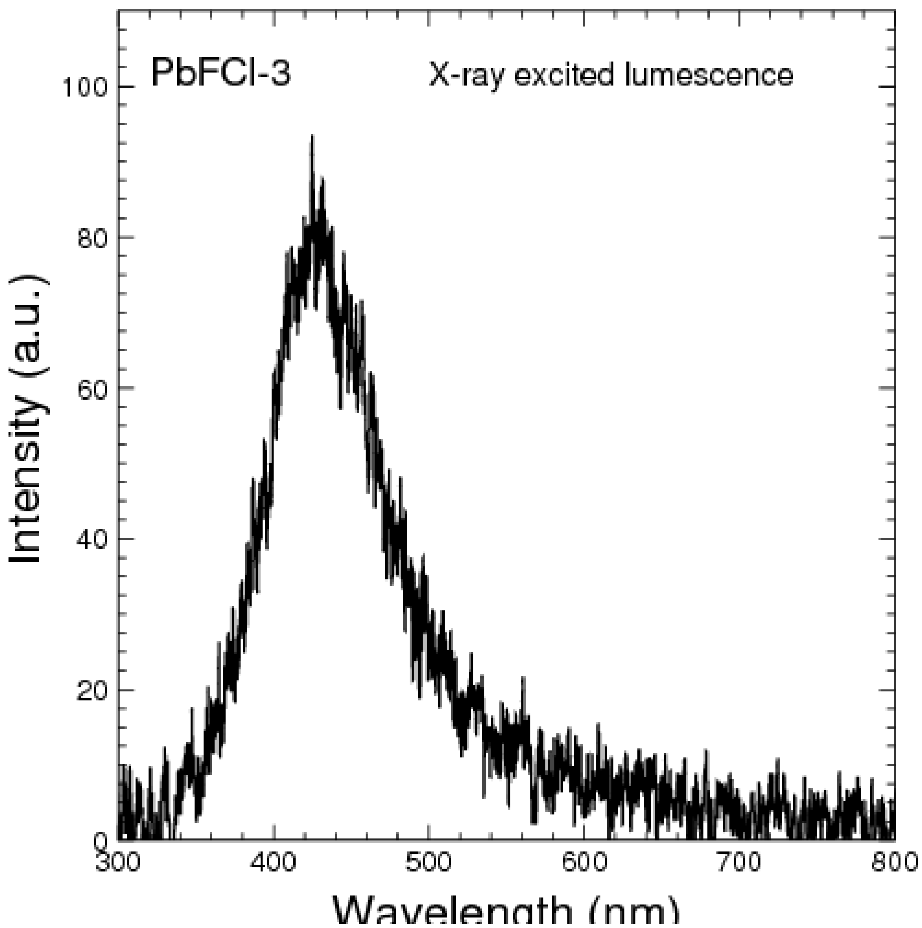


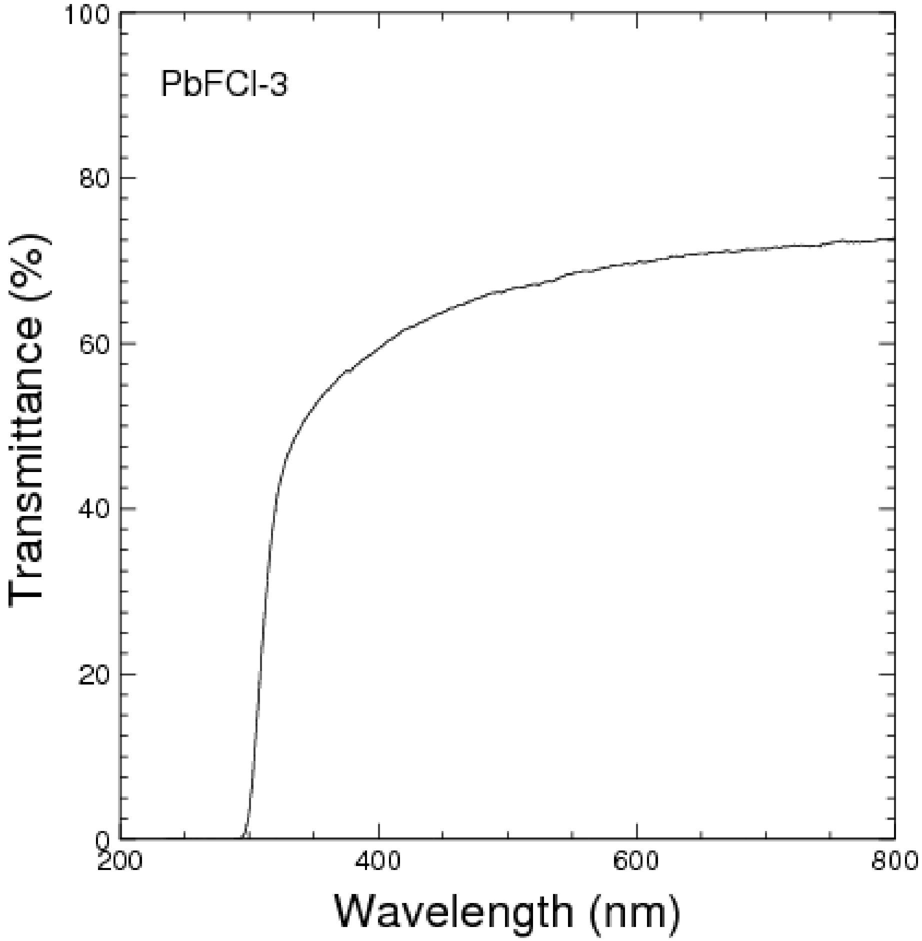
ID	PbFCl-1	PbFCl-2	PbFCl-3	PbFCl-4	PbFCl-5
Doping	--	Na 0.5at%	--	--	
Dimension (mm)	10x10x2	10x10x2	30x10x5	20x10x3	~10x10x9

ID	PWO	PbFCl-1	PbFCl-2	PbFCl-3	PbFCl-4	PbFCl-5
X-luminescence		Peaked @ 420 nm				
L.O. (% PWO)	100	14	64	33	35	31
L.O. (% BGO)	1.8	0.25	1.1	0.59	0.63	0.56

X-Luminescence & Transmittance

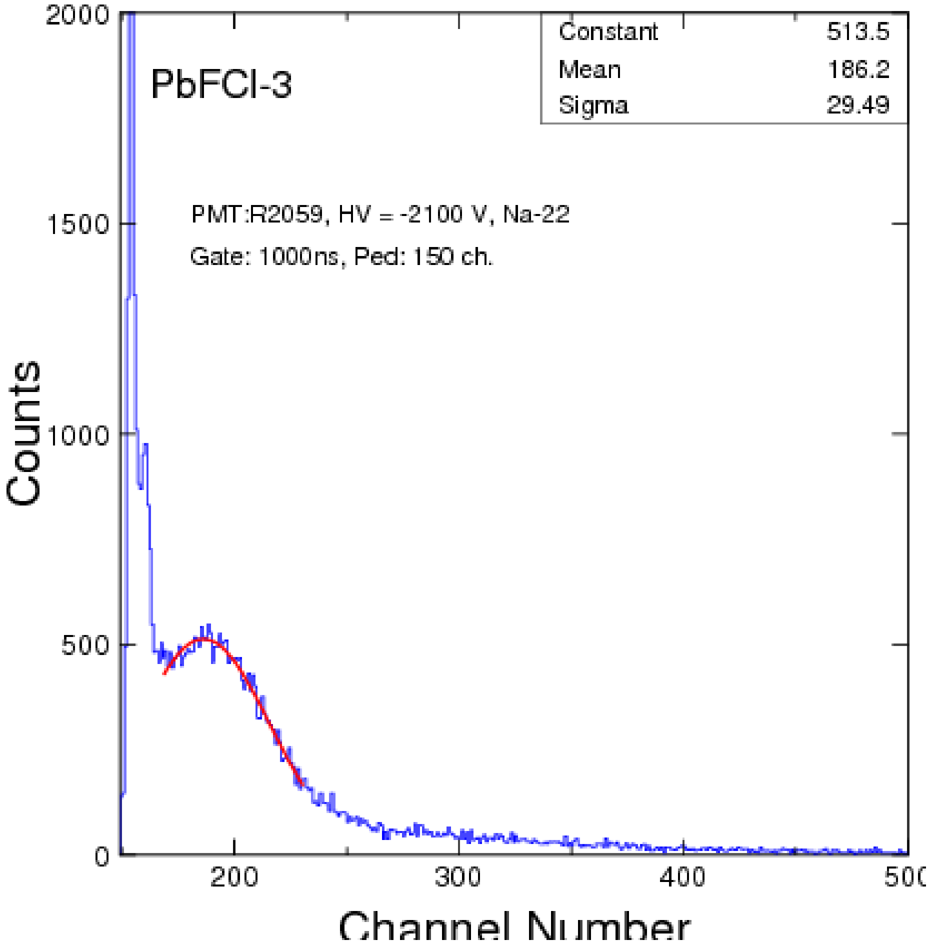
Consistent X-luminescence peaked at 420 nm observed in all PbFCl samples. Transmittance cut-off at 300 nm.

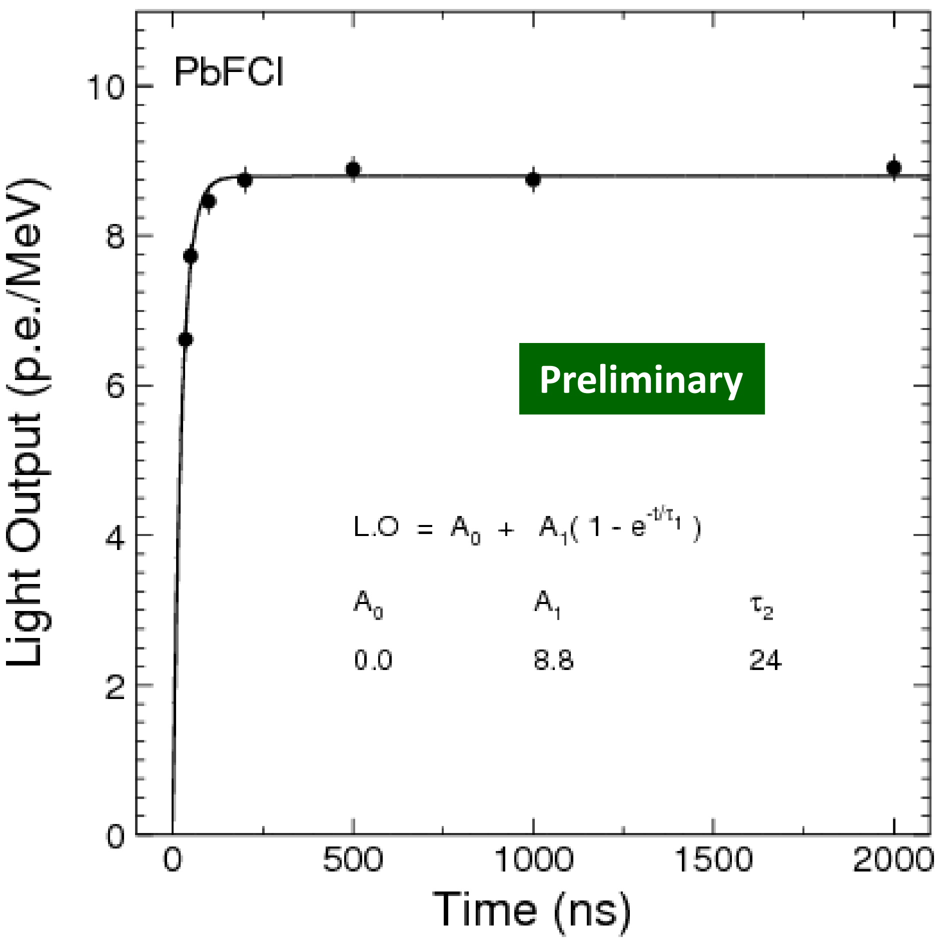




^{137}Cs Spectrum & Decay Kinetics

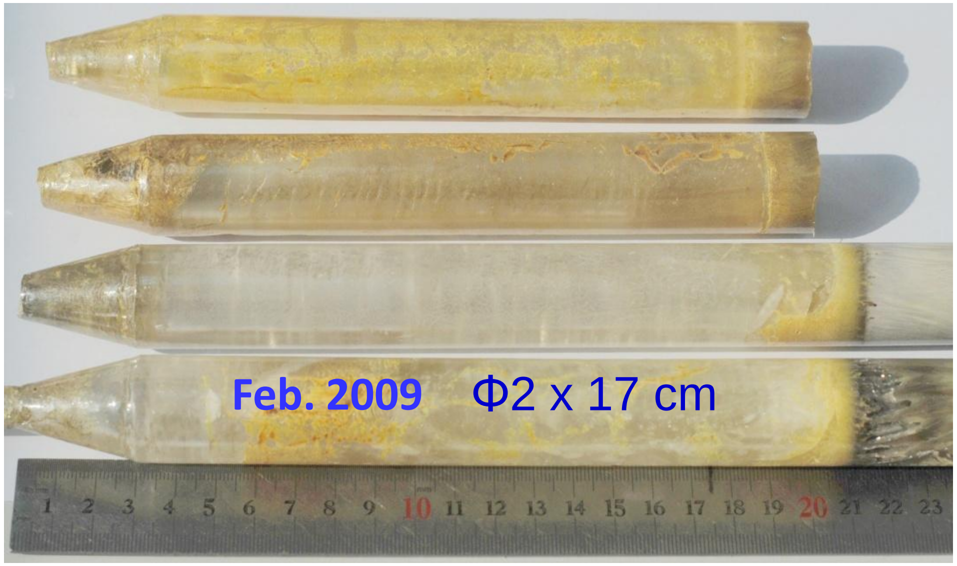
Weak scintillation light with decay time of 24 ns observed in all PbFCl samples.



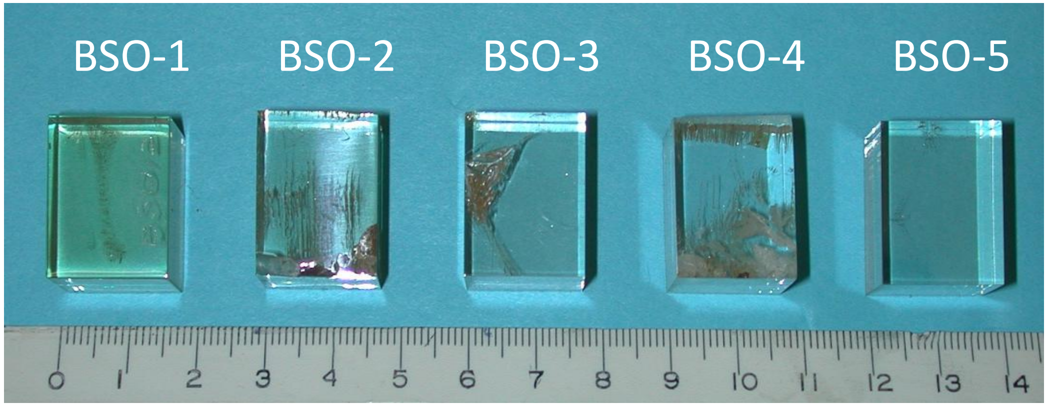


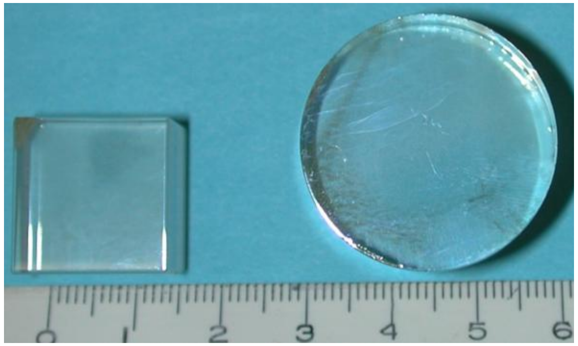
BSO Crystals

Hu Yuan of SIC: Talk at the 2nd Workshop for HHCAL

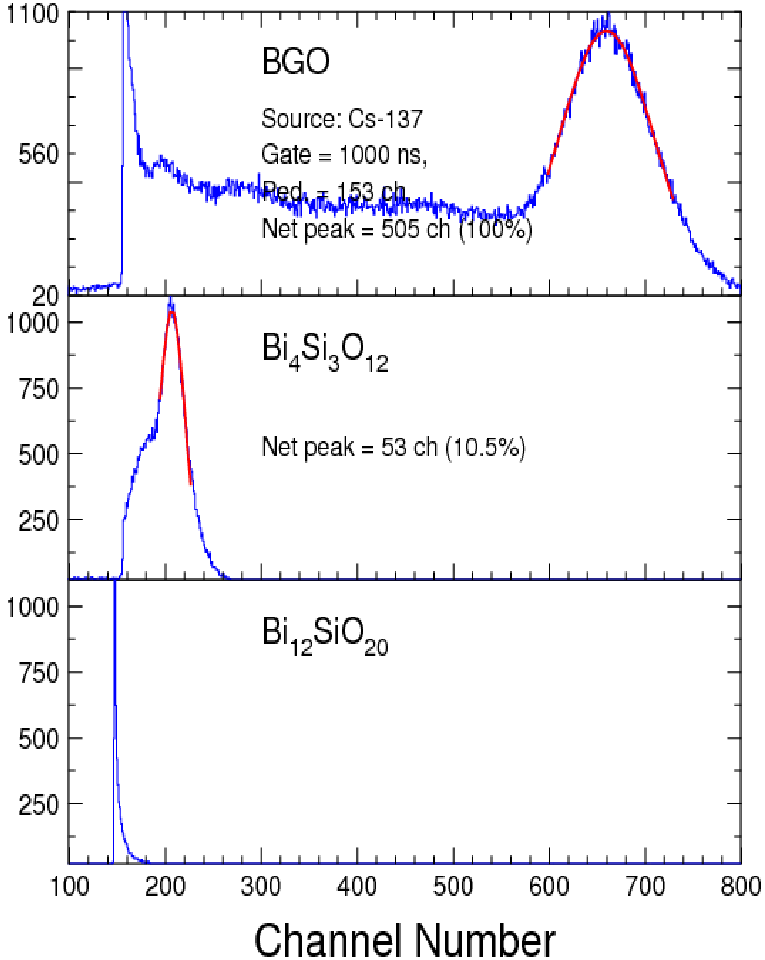


BSO Samples



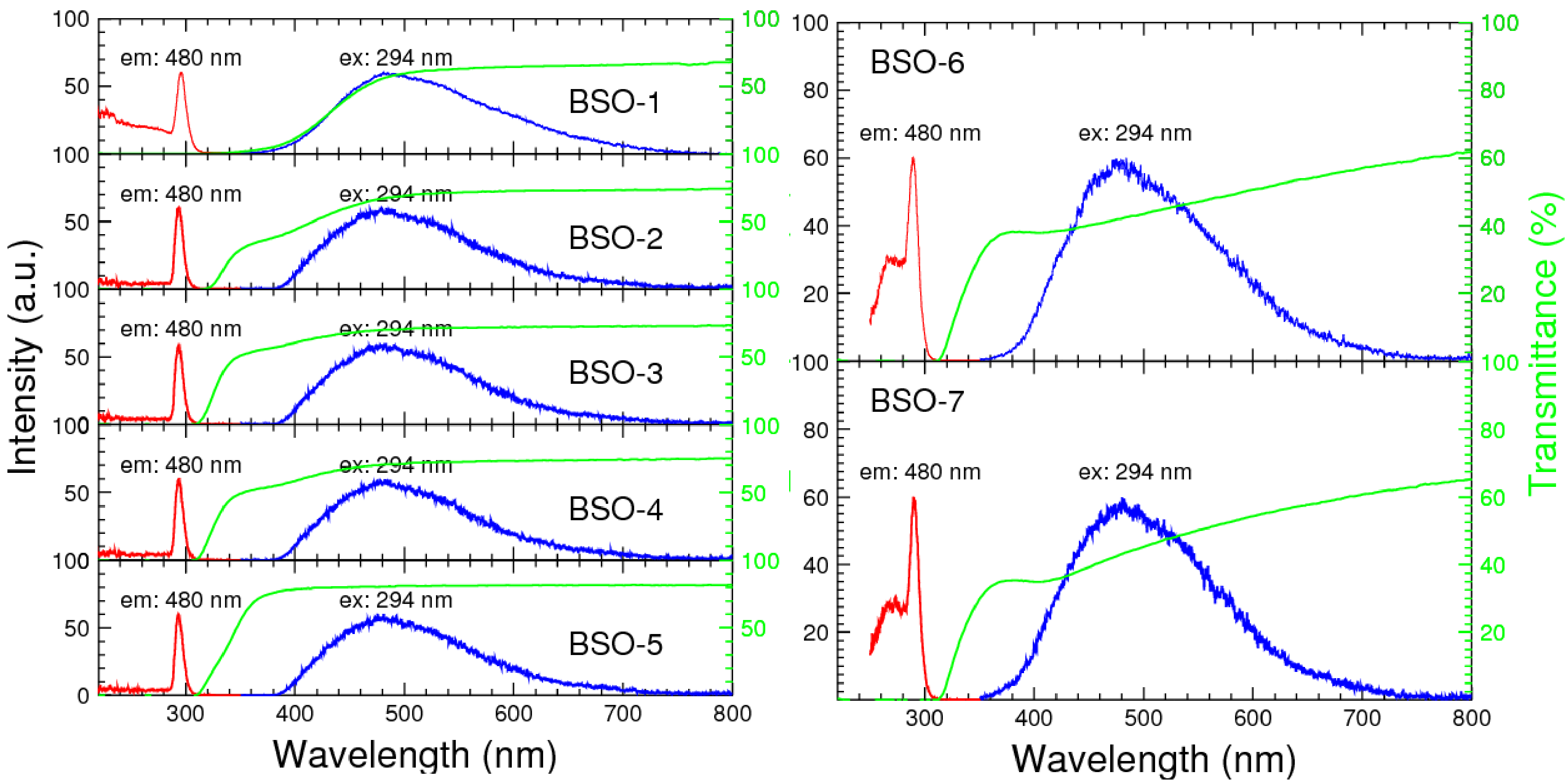


BSO has two phases



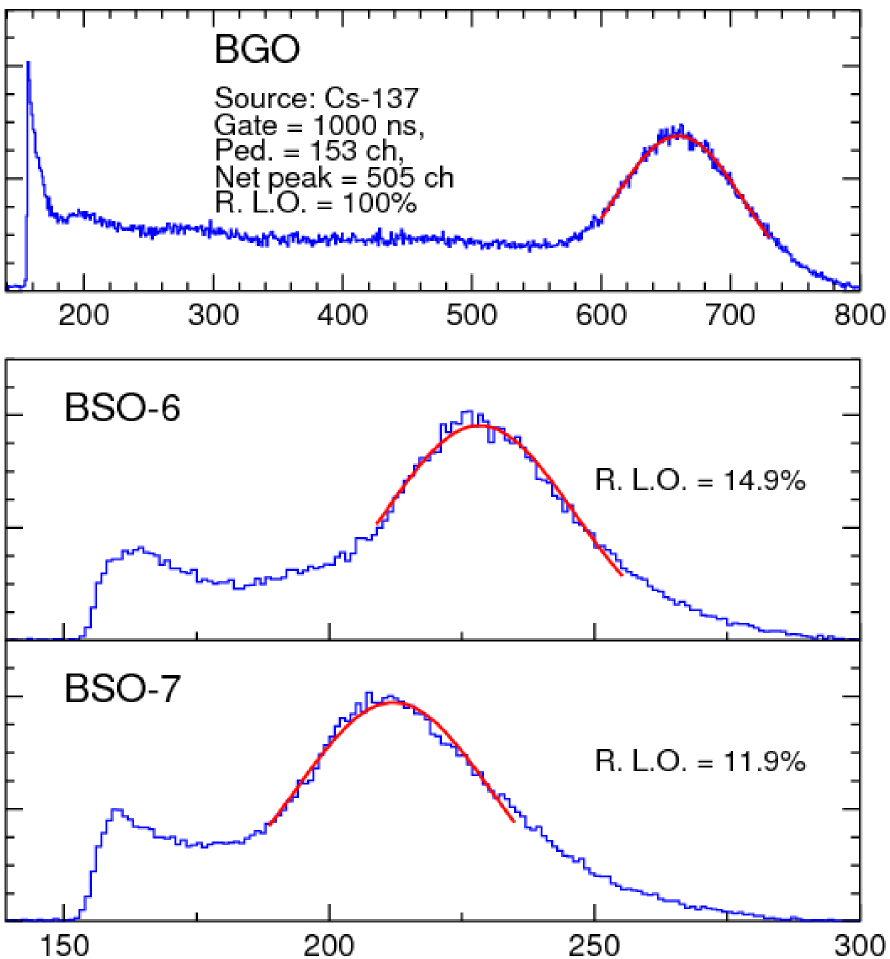
Excitation, Emission & Transmittance

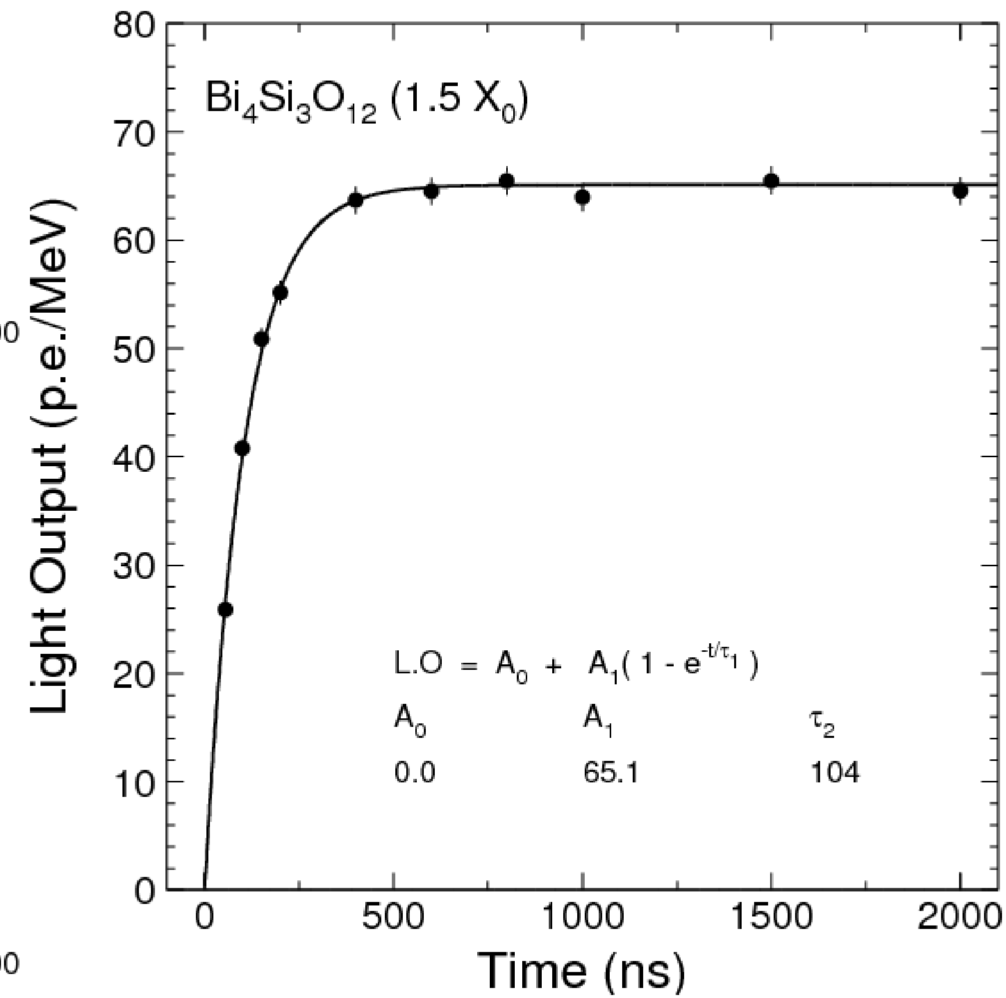
Improvement of UV absorption observed. The cut-off of transmission spectra moved toward 300 nm. Absorption visible between 350 and 600 nm.



^{137}Cs Spectrum & Decay Kinetics

Light output is about 15% of BGO, should be improved to 20% after the visible absorption removed. Decay time constant is ~100 ns.





Summary

- The HHCAL is an interesting detector concept providing a unprecedented combination of e/ɣ and jet mass resolutions. The crucial issue is to develop high quality materials of low cost: < $2/cc.
- Among all crystals, PbF_2, PbClF and BSO seem the best candidates to meet the cost goal.
- While consistent photo and x- luminescence was found in Er, Eu, Gd, Ho, Pr, Sm and Tb doped PbF_2 samples, their decay time is at ms scale as expected from the f-f transition of the rare earth elements.
- The scope of this R&D is now expanded to a broad range other of materials, including scintillating glasses and ceramics etc. See presentations at the 2nd and 3rd HHCAL Workshops.

2nd Workshop for the HHCAL

May 9, 2010, Beijing: http://indico.ihep.ac.cn/conferenceTimeTable.py?confId=1470

1) HHCAL and General Requirement:

Gene Fisk, FNAL: "Fermilab's History in the Development of Crystals, Glasses and Si Detector Readout for Calorimetry"
Adam Para, FNAL: "Scintillating Materials for Homogeneous Hadron Calorimetry"
Steve Derenzo, LBL: "Search for Scintillating Glasses and Crystals for Hadron Calorimetry"
Paul Lecoq, CERN: "A CERN Contribution to the Dual Readout Calorimeter Concept"

2) Materials for HHCAL (I) :

Alex Gektin, SCI: "Crystal Development for HHCAL: Physics and Technological Limits"
Liyuan Zhang, Caltech: "Search for Scintillation in Doped Lead Fluoride for the HHCAL Detector Concept"
Guohao Ren, SIC: "Development of Halide Scintillation Crystals for the HHCAL Detector Concept "
Hui Yuan, SIC: "BSO Crystals Development with the Modified Multi-crucible Bridgman Method for the HHCAL Detector Concept"

3) Materials for the HHCAL (II) followed by discussions

Mingrong Zhang, BGRI: "R&D on Scintillation Crystals and Special Glasses at BGRI"
Tiachi Zhao, U Washington/IHEP and Ningbo University: " Study of Dense Scintillating Glass Samples"
Jing Tai Zhao, SIC: "Status of Scintillating Ceramics and Glasses at SIC and Their Potential Applications for the HHCAL Detector Concept"
Richard, Wigmans, Texas Tech University: "Some thoughts about homogeneous dual-readout calorimeters"

3rd Workshop for the HHCAL

October 31, 2010, Knoxville: http://www.nss-mic.org/2010/program/ListProgram.asp?session=HC1,2,3,4

1. **A. Para,** Prospects for High Resolution Hadron Calorimetry
2. **G. Mavromanolakis ,** Studies on Dual Readout Calorimetry with Meta-Crystals
3. **D. Groom,** Degradation of resolution in a homogeneous dual readout hadronic calorimeter
4. **S. Derenzo,** High-Throughput Synthesis and Measurement of Candidate Detector Materials for Homogeneous Hadronic Calorimeters
5. **M. Poulain,** Fluoride Glasses: State of Art and Prospects
6. **I. Dafinei,** High Density Fluoride Glasses, Possible Candidates for Homogeneous Hadron Calorimetry
7. **P. Hobson,** Prospects for Dense Glass Scintillators for Homogeneous Calorimeters
8. **G. Dosovitski,** Potential of Crystalline, Glass and Ceramic Scintillation Materials for Future Hadron Calorimetry
9. **Tianchi Zhao,** Study on Dense Scintillating Glasses
10. **Jin-tai Zhao,** BSO-Based Crystal and Glass Scintillators for Homogeneous Hadronic Calorimeter
11. **Guohao Ren,** Development of RE-Doped Cubic PbF_2 and PbClF Crystals for HHCAL
12. **12, N. Cherepy,** Transparent Ceramic Scintillators for Hadron Calorimetry
13. **J. Dong,** Experimental Study of Large Area GEM
14. **H. Frisch,** The Development of Large-Area Flat-Panel Photodetectors with Correlated Space and Time Resolution