Crystals for Homogeneous Hadron Calorimeter

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November 18, 2008

Why Crystal Calorimeter?

- Photons and electrons are fundamental particles. Precision e/γ measurements enhance physics discovery potential.
- Performance of crystal calorimeter in e/γ measurements is well understood:
  - The best possible energy resolution;
  - Good position resolution;
  - Good e/ γ identification and reconstruction efficiency.
- Crystals may also provide a foundation for a homogeneous hadron calorimeter with dual readout of Cherenkov and scintillation light to achieve good resolution for hadrons and jets.

Crystal Calorimeters in HEP

Date	75-85	80-00	80-00	80-00	90-10	94-10	94-10	95-20
Experiment	C. Ball	L3	CLEO II	C. Barrel	KTeV	*BaBar*	BELLE	CMS
Accelerator	SPEAR	LEP	CESR	LEAR	FNAL	SLAC	KEK	CERN
Crystal Type	NaI(Tl)	BGO	CsI(Tl)	CsI(Tl)	CsI	CsI(Tl)	CsI(Tl)	$PbWO_4$
B-Field (T)	-	0.5	1.5	1.5	-	1.5	1.0	4.0
r_{inner} (m)	0.254	0.55	1.0	0.27	-	1.0	1.25	1.29
Number of Crystals	672	11,400	7,800	1,400	3,300	6,580	8,800	76,000
Crystal Depth (X_0)	16	22	16	16	27	16 to 17.5	16.2	25
Crystal Volume (m^3)	1	1.5	7	1	2	5.9	9.5	11
Light Output (p.e./MeV)	350	1,400	5,000	2,000	40	5,000	5,000	2
Photosensor	PMT	Si PD	Si PD	WS[a]+Si PD	PMT	Si PD	Si PD	APD[a]
Gain of Photosensor	Large	1	1	1	4,000	1	1	50
σ_N/Channel (MeV)	0.05	0.8	0.5	0.2	small	0.15	0.2	40
Dynamic Range	10^4	10^5	10^4	10^4	10^4	10^4	10^4	10^5

Future crystal calorimeters in HEP:

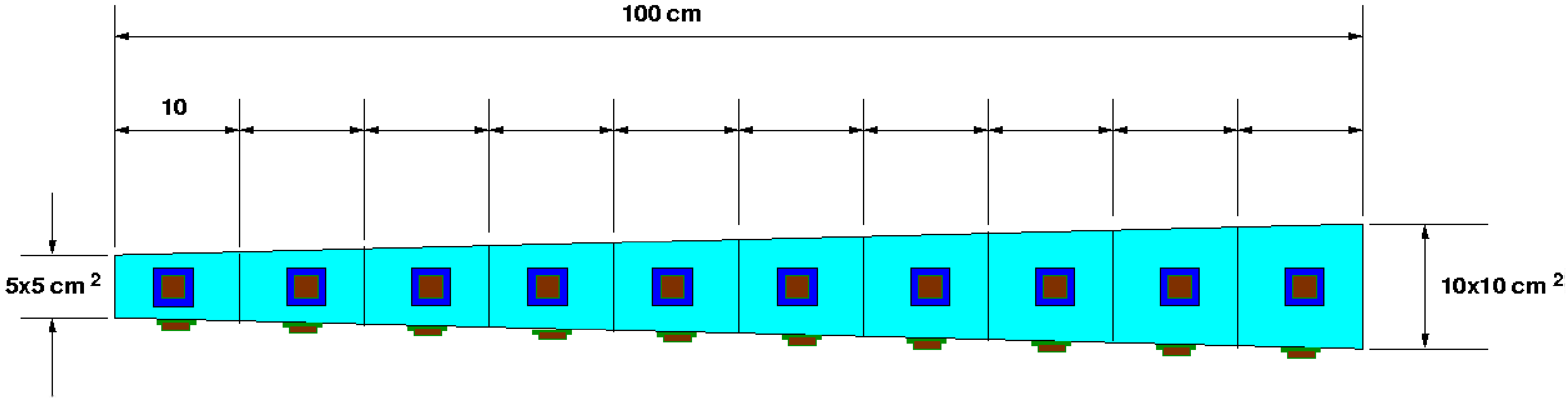
PWO for PANDA at GSI

LYSO for a Super B Factory, Mu2e and CMS Endcap Upgrade

PbF_2, BGO, PWO for HHCAL

A Basic Cell Design for HHCAL

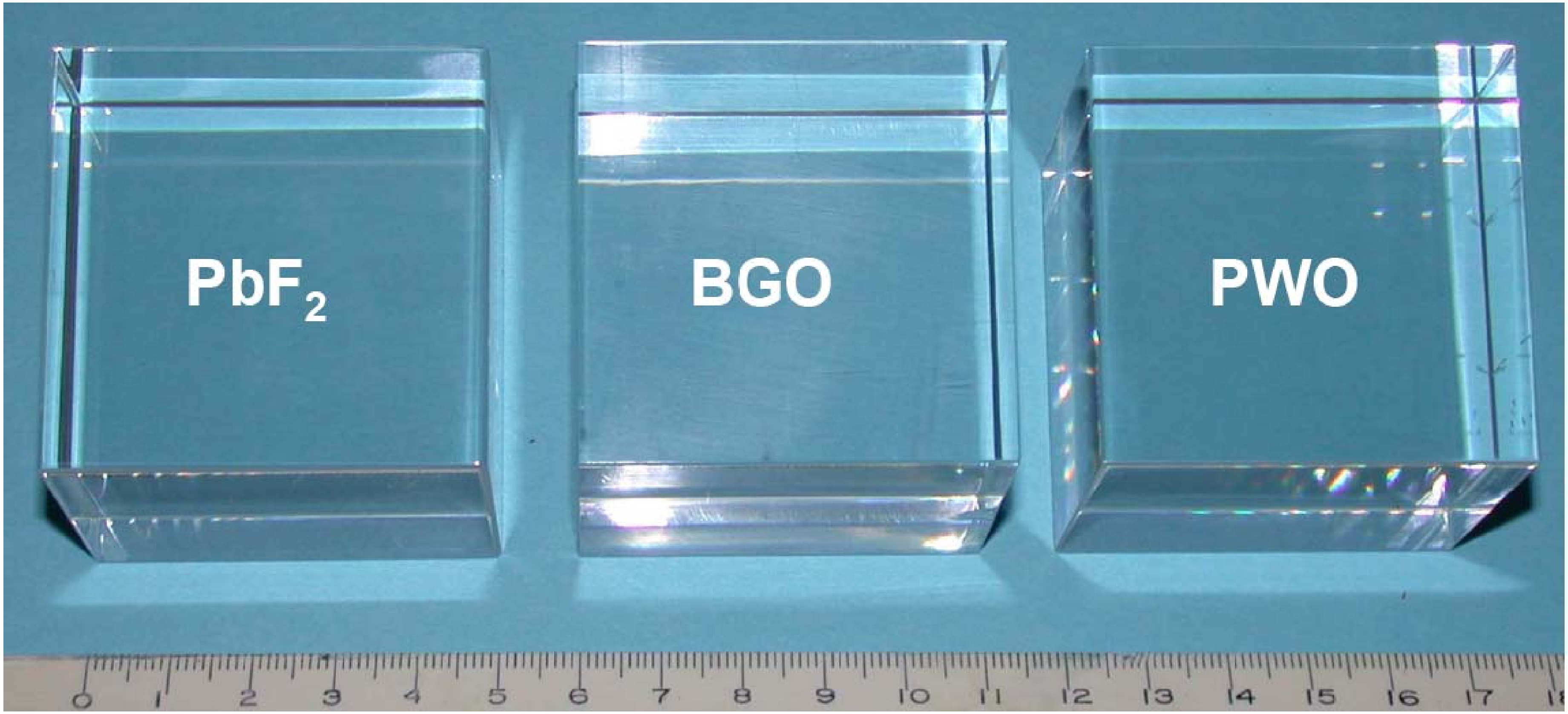
Calorimeter with dual (Cherenkov and Scintillation) readout was proposed a long time ago, and has been pursued recently by the Dream collaboration (R. Wigwams et al.) and a Fermilab team (A. Para et al.) for the ILC. The later proposed an interesting homogeneous HCAL concept eliminating the dead materials between classical ECAL and HCAL. This is possible because of the latest development in compact readout devices.



A typical cell of HHCAL

Crystal for Homogeneous HCAL

Crystals of high density, good UV transmittance and some scintillation light, not necessary bright and fast, are required. Because of the huge volume cost-effectiveness is crucial.
Following 2/19/08 workshop at SICCAS, 5 x 5 x 5 cm samples evaluated

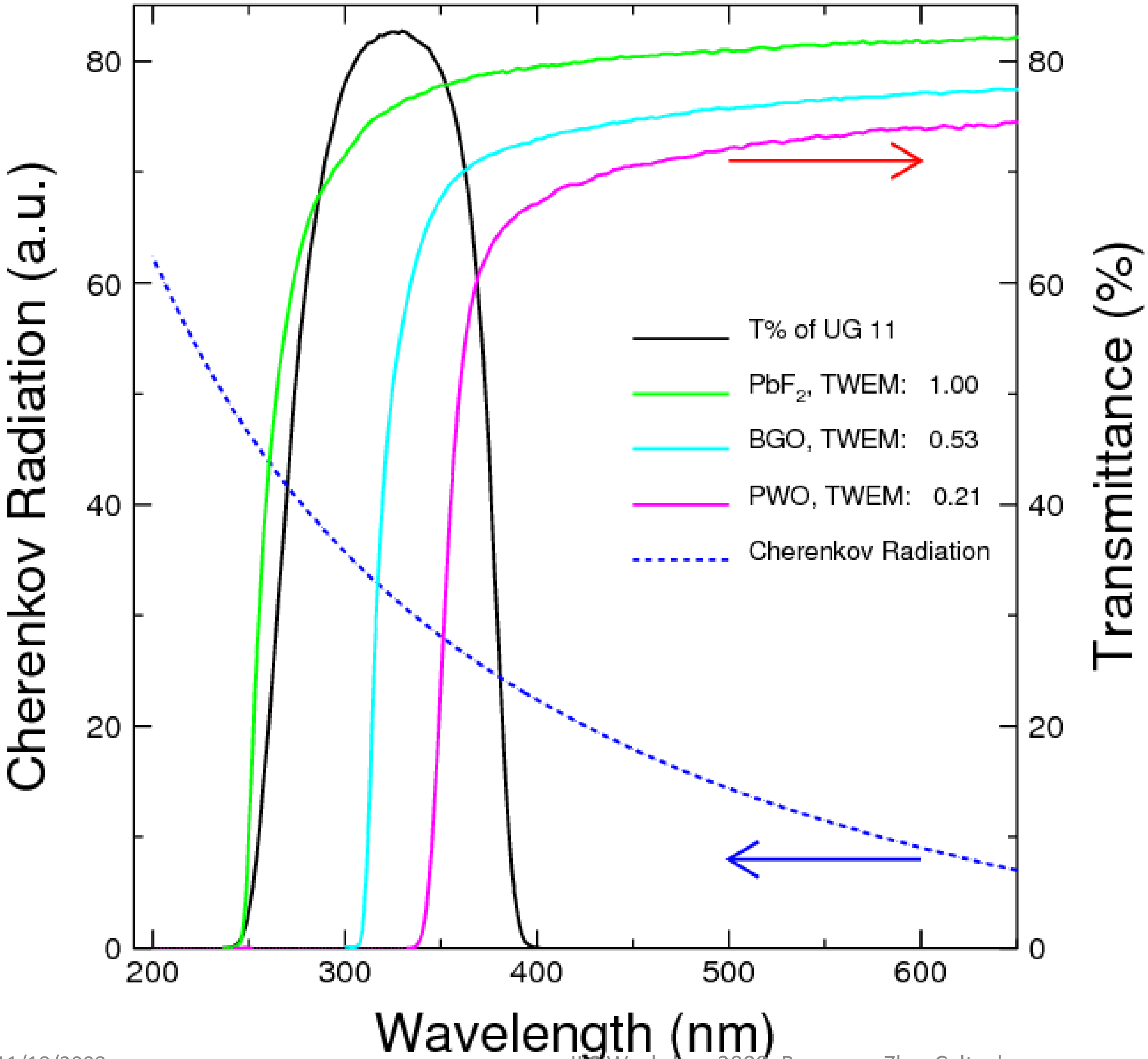


Crystals for HEP Calorimeters

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	LYSO(Ce)	PWO	PbF_2
Density (g/cm^3)	3.67	4.51	4.51	4.89	7.13	7.40	8.3	7.77
Melting Point (ºC)	651	621	621	1280	1050	2050	1123	824
Radiation Length (cm)	2.59	1.86	1.86	2.03	1.12	1.14	0.89	0.93
Molière Radius (cm)	4.13	3.57	3.57	3.10	2.23	2.07	2.00	2.21
Interaction Length (cm)	42.9	39.3	39.3	30.7	22.8	20.9	20.7	21.0
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	1.82	2.20	1.82
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420 310	300 220	480	402	425 420	?
Decay Time [b] (ns)	245	1220	30 6	650 0.9	300	40	30 10	?
Light Yield [b,c] (%)	100	165	3.6 1.1	36 4.1	21	85	0.3 0.1	?
d(LY)/dT [b] (%/ ºC)	-0.2	0.4	-1.4	-1.9 0.1	-0.9	-0.2	-2.5	?
Experiment	Crystal Ball	BaBar BELLE BES III	KTeV	(L*) (GEM) TAPS	L3 BELLE	SuperB	CMS ALICE PANDA	HHCAL?

a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

Cherenkov Needs UV Transparency

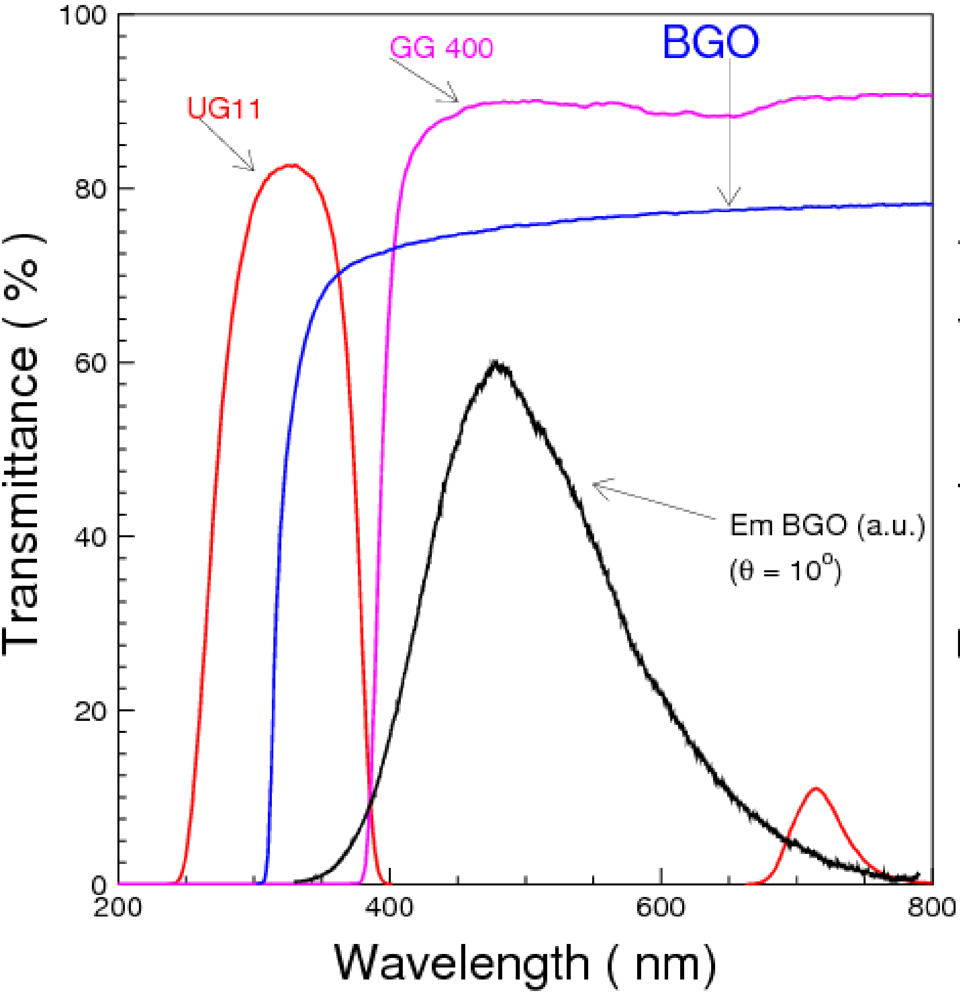


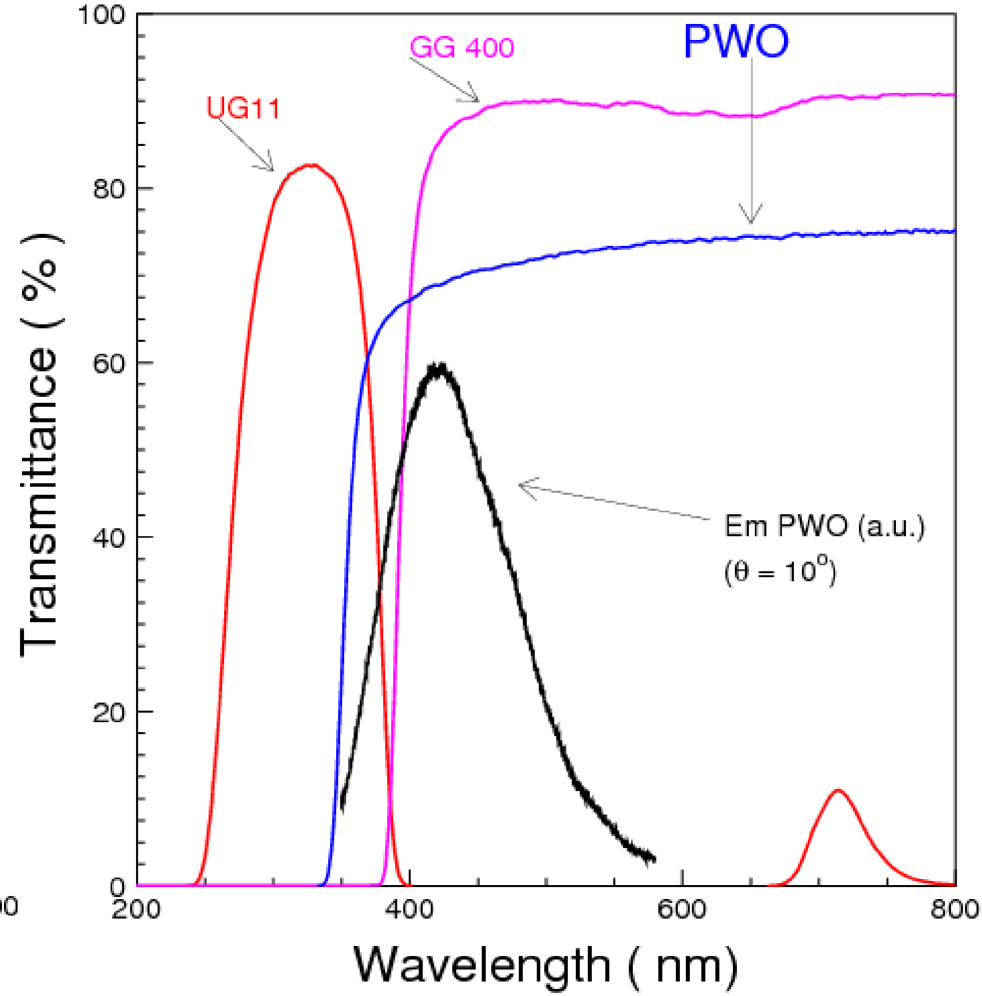
Cherenkov figure of merit

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

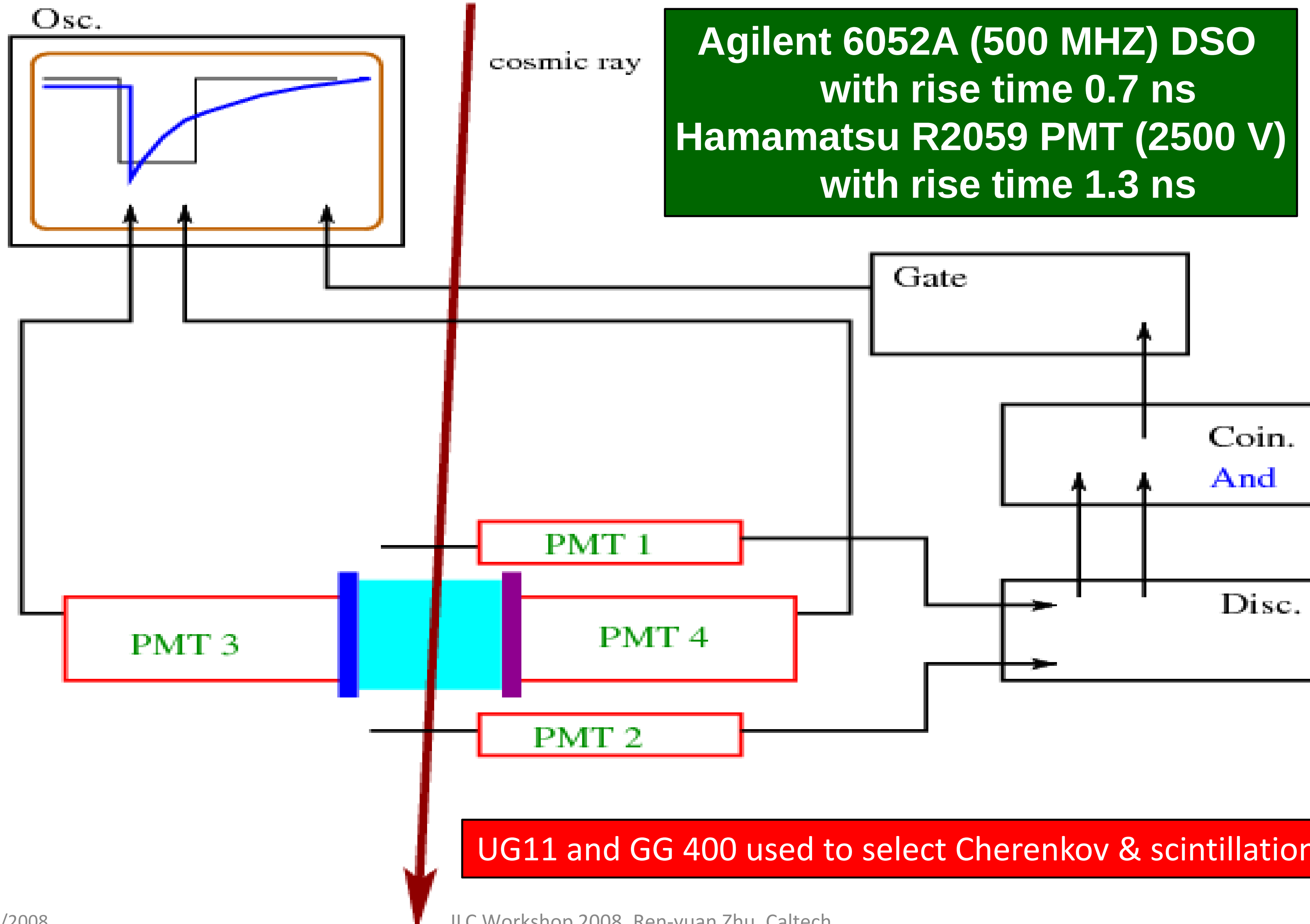
Scintillation Selected with Filter

GG400 optical filter effectively selects scintillation light with very small contamination from Cherenkov





Cosmic Setup with Dual Readout

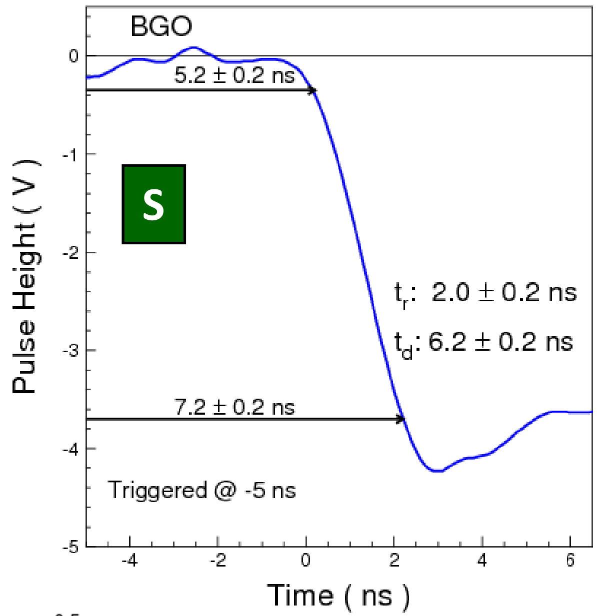


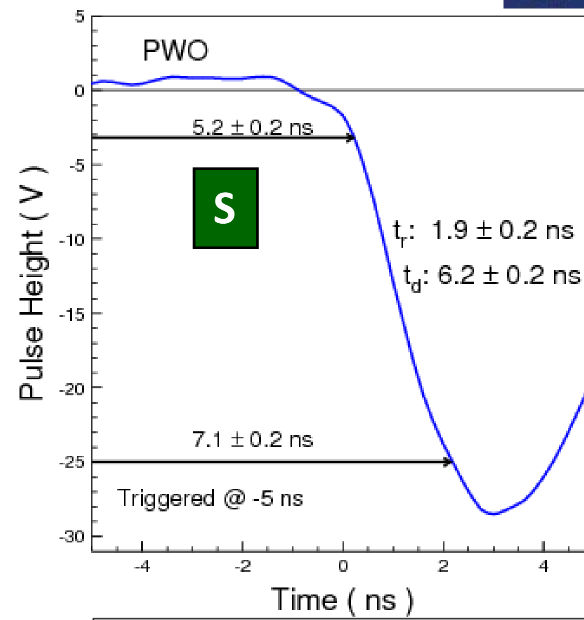
Agilent 6052A (500 MHZ) DSO with rise time 0.7 ns
Hamamatsu R2059 PMT (2500 V) with rise time 1.3 ns

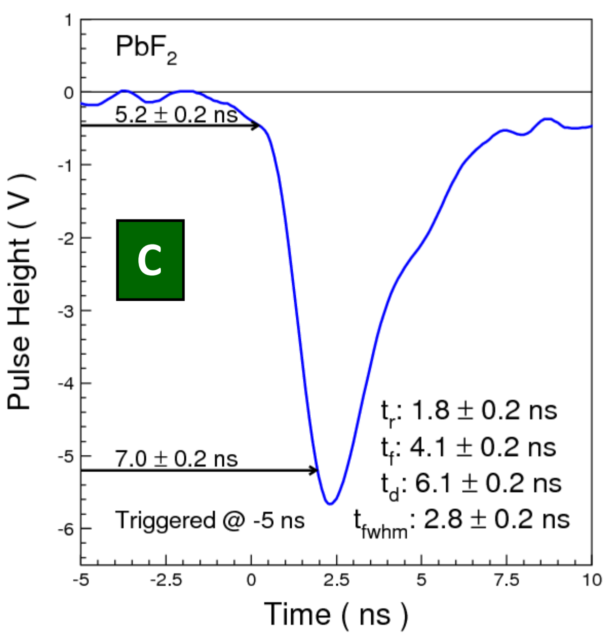
UG11 and GG 400 used to select Cherenkov & scintillation

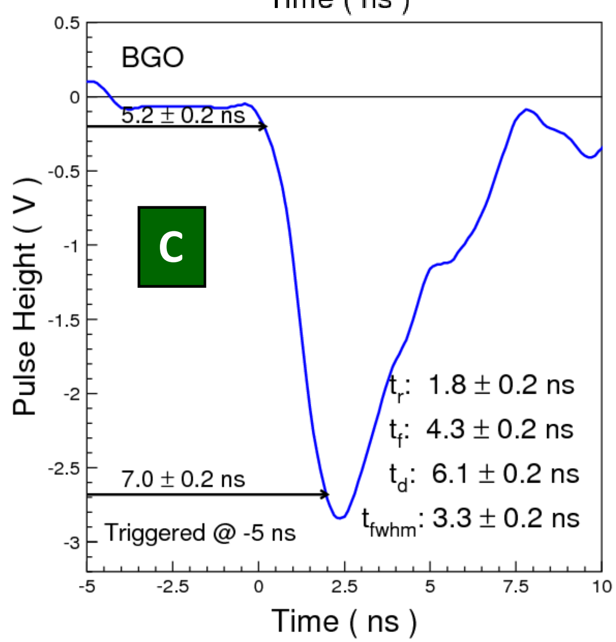
No Discrimination in Front Edge

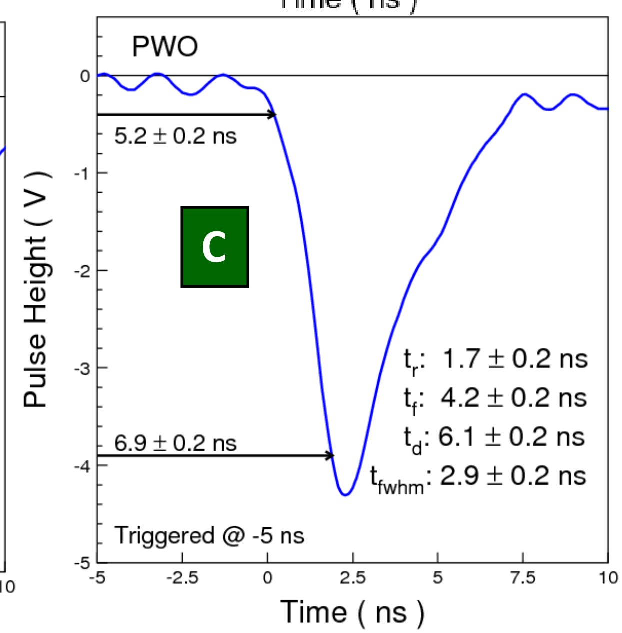
Consistent timing and rise time for all Cherenkov and scintillation light pulses observed.





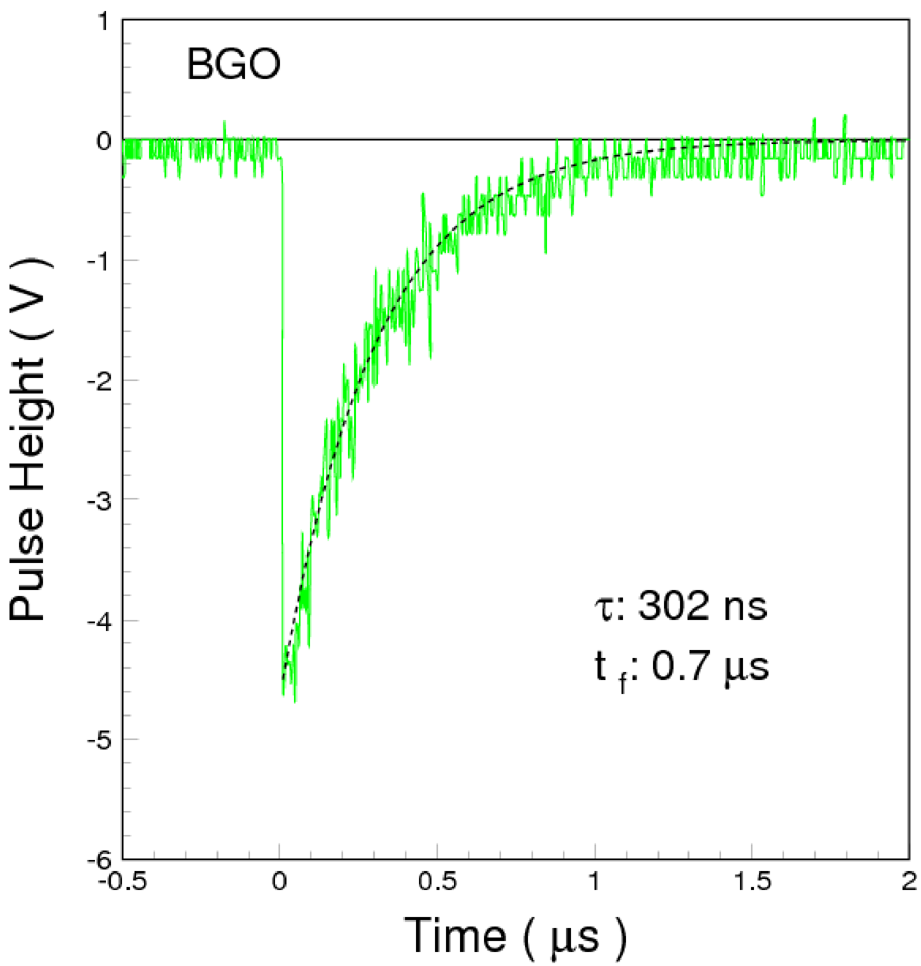


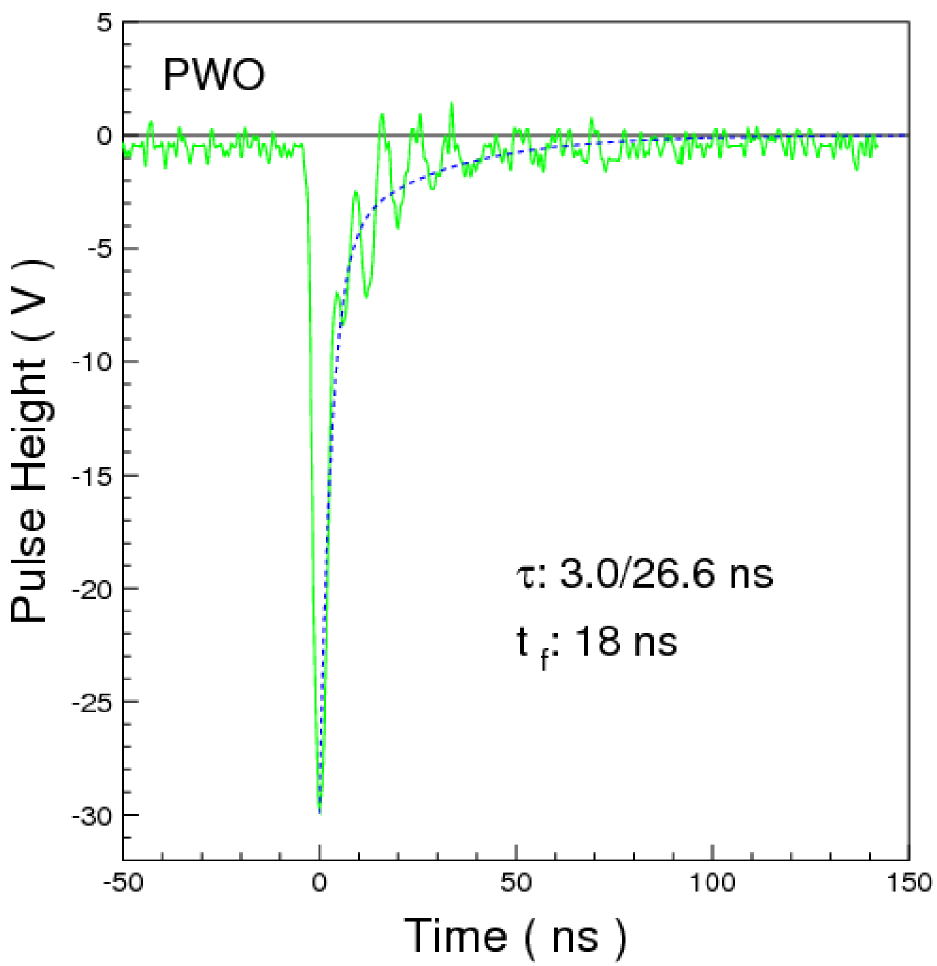




Slow Scintillation Decay May be Used

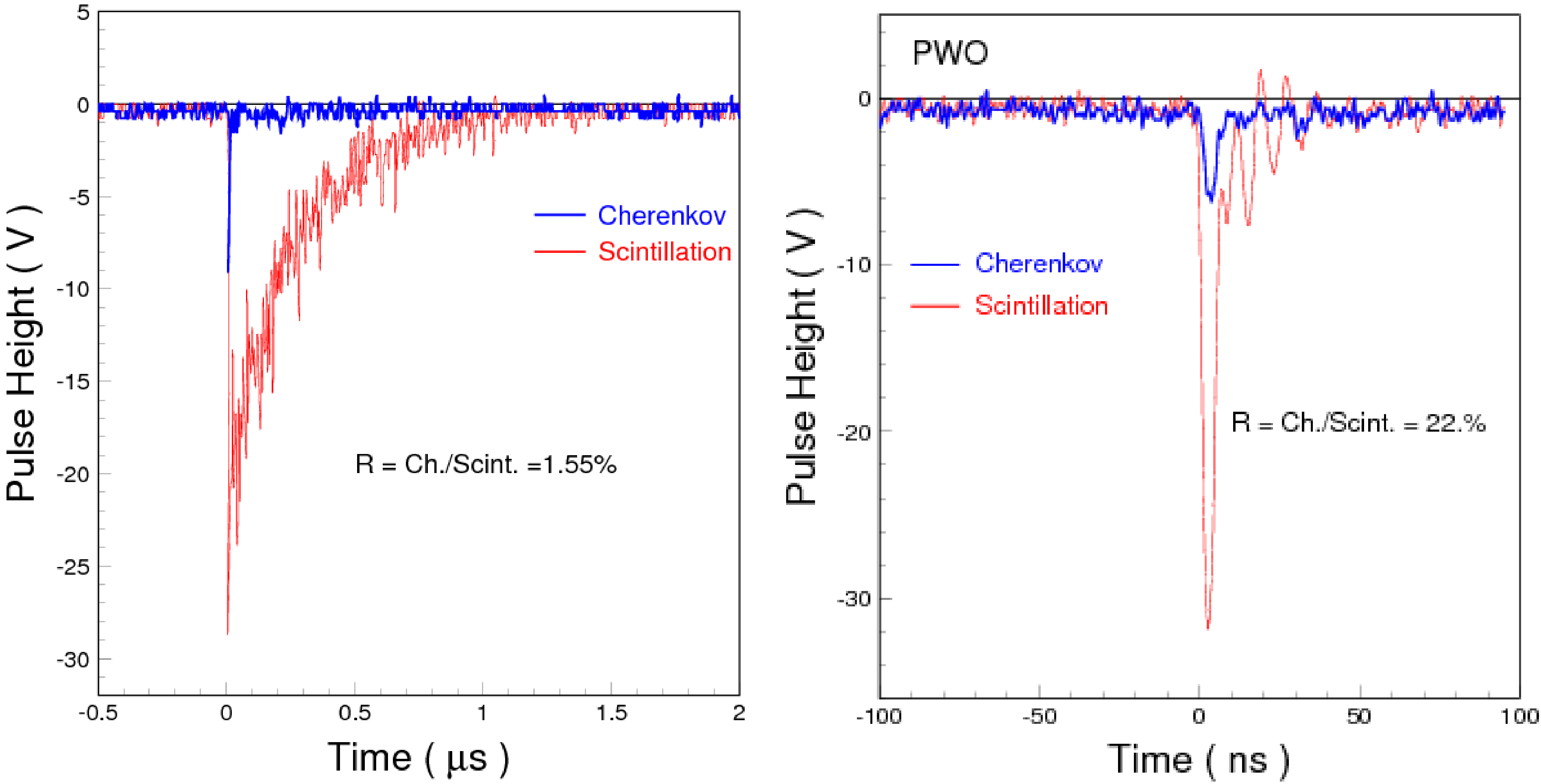
After 15 ns no Cherenkov contamination



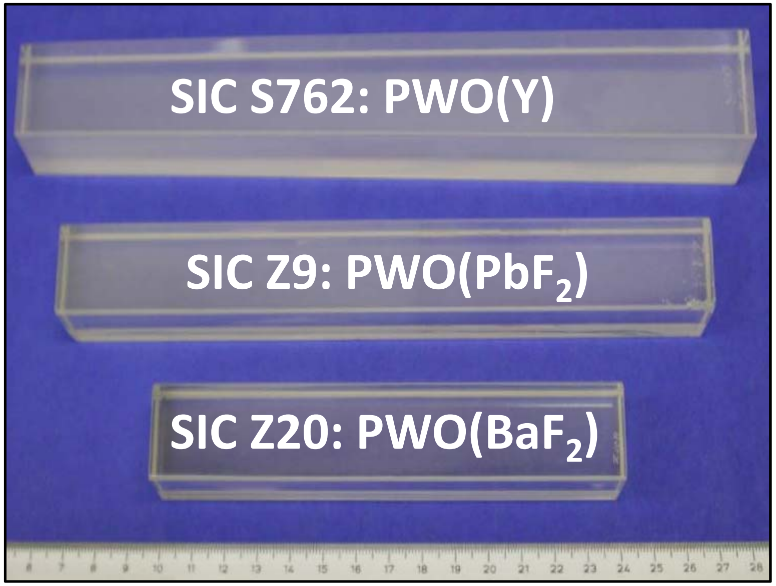


Ratio of Cherenkov/Scintillation

1.6% for BGO and 22% for PWO with UG11/GG400 filter and R2059 PMT

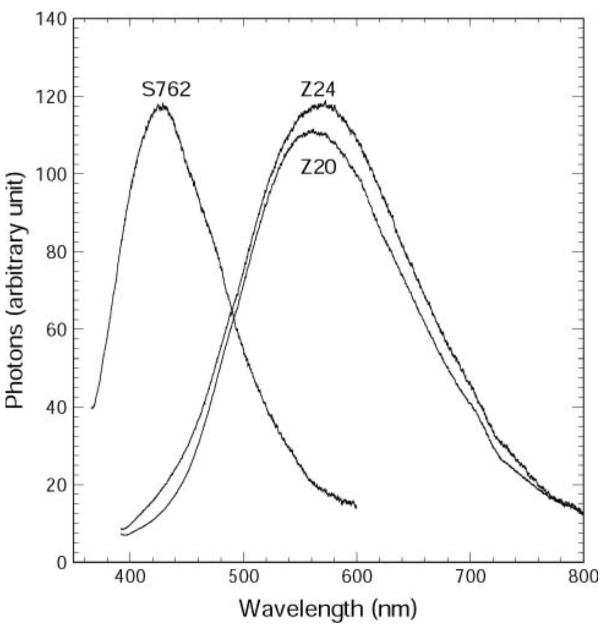


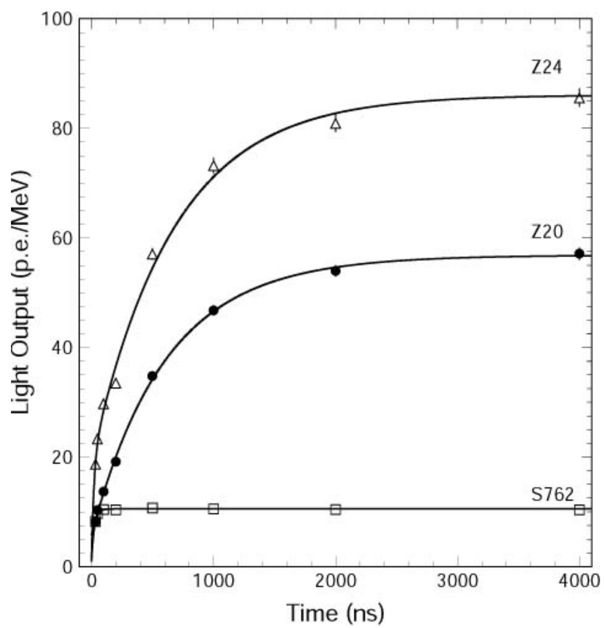
Green Slow Scintillation in PWO

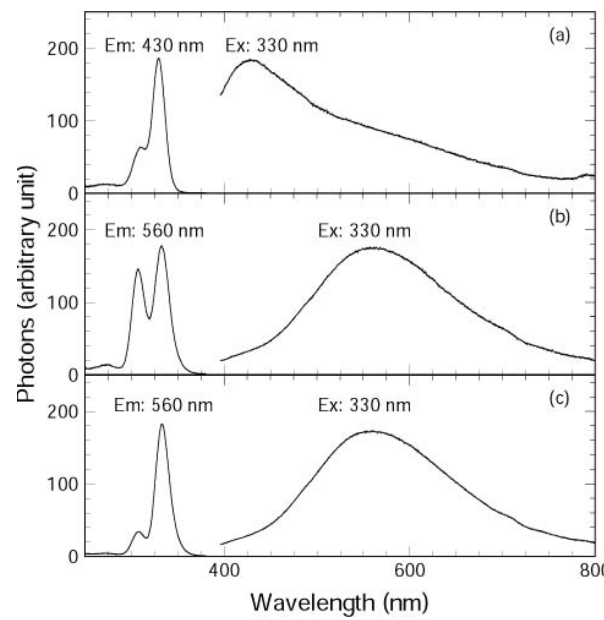


A factor of ten intensity of slow (μs) green scintillation light (560 nm) was observed in PbF_2/BaF_2 doped PWO.

R.H. Mao at al., in Calor2000 proceedings

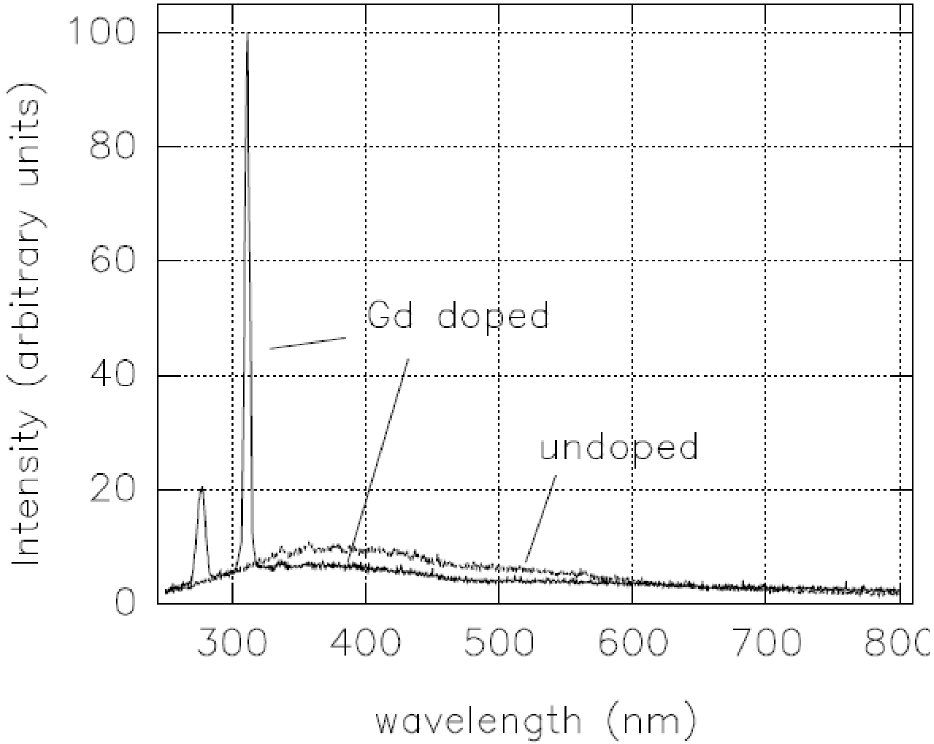




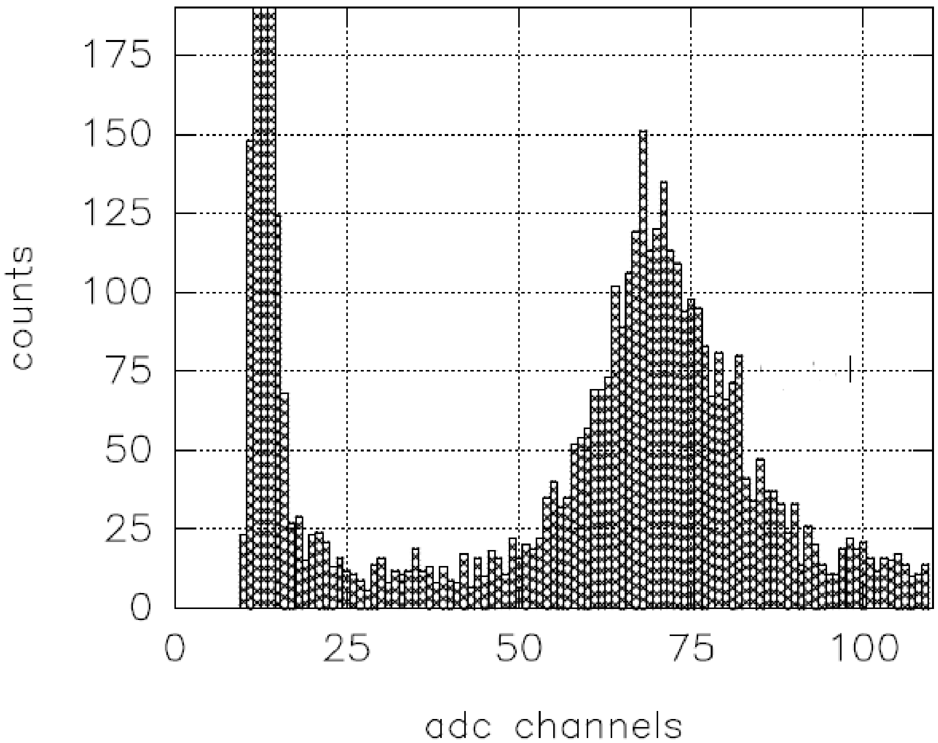


Scintillation was Observed in PbF_2(Gd)

Scintillation of PbF_2(Gd)



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

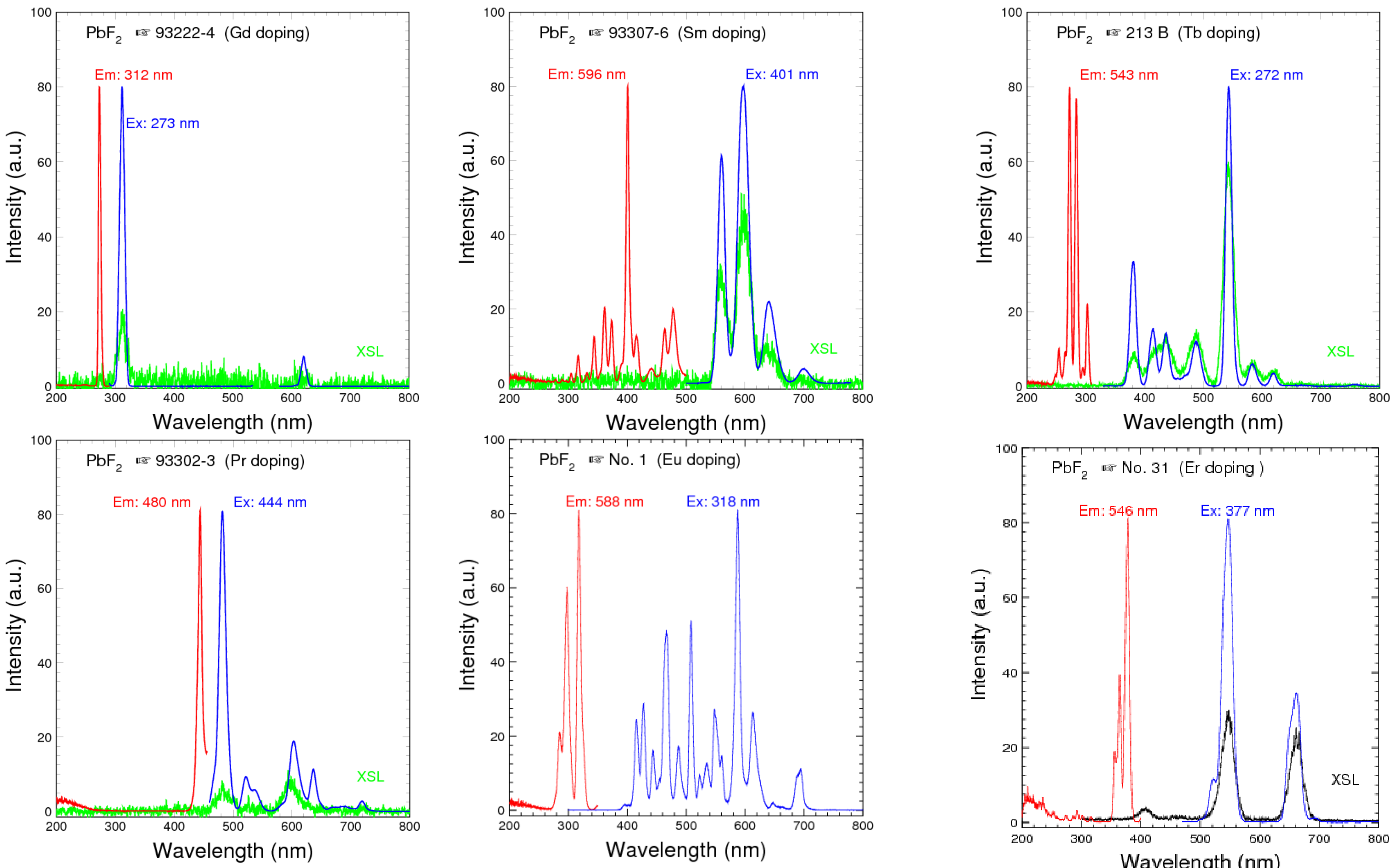


Fast Scintillation of 6.5 p.e./MeV with decay time of less than 10 ns

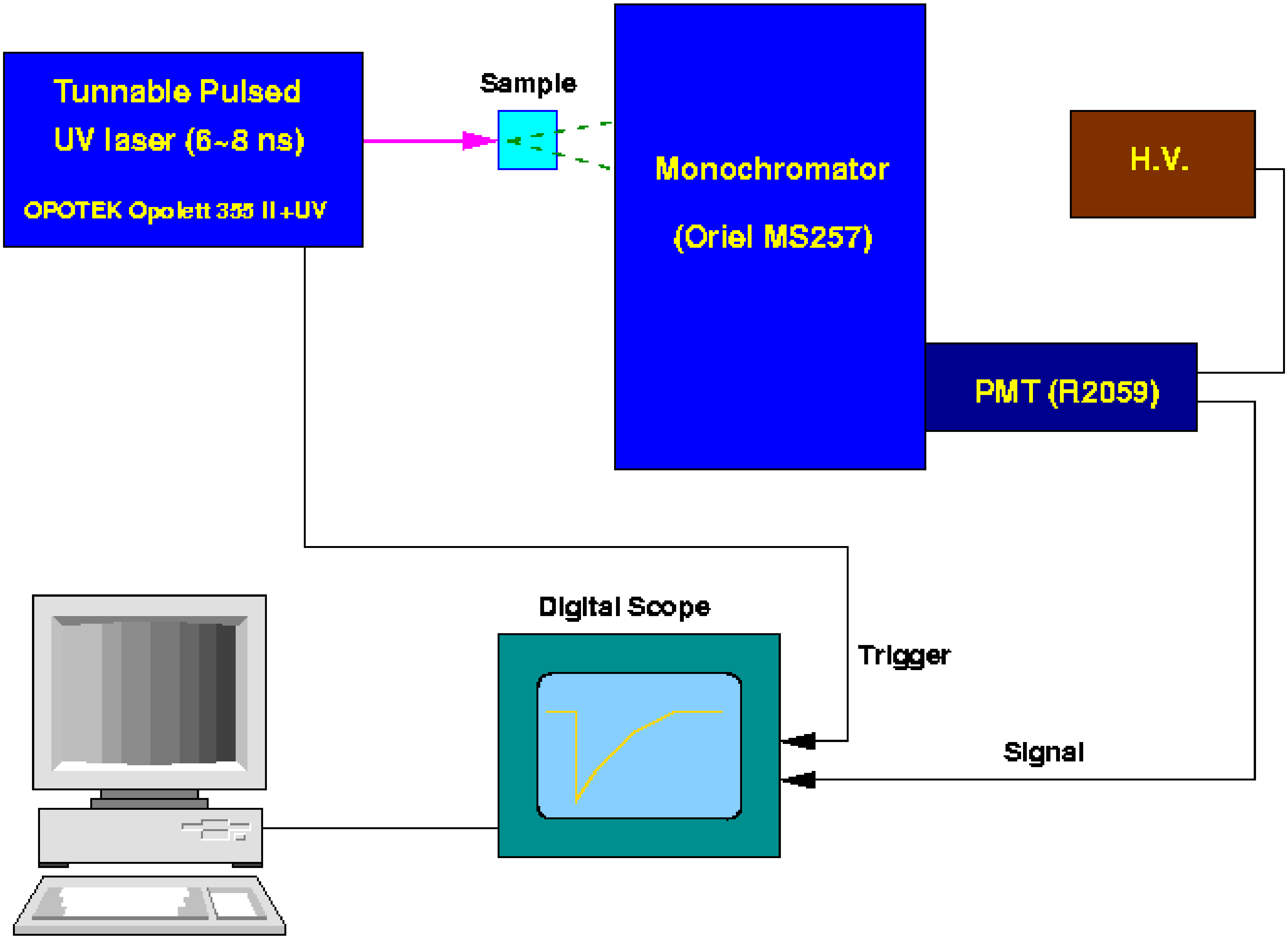
D. Shen *at al., Jour. Inor. Mater* **Vol. 101** 11 (1995).
C. Woody *et al., Proceedings of SCINT95* (1996).

Scintillation Observed in PbF_2

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

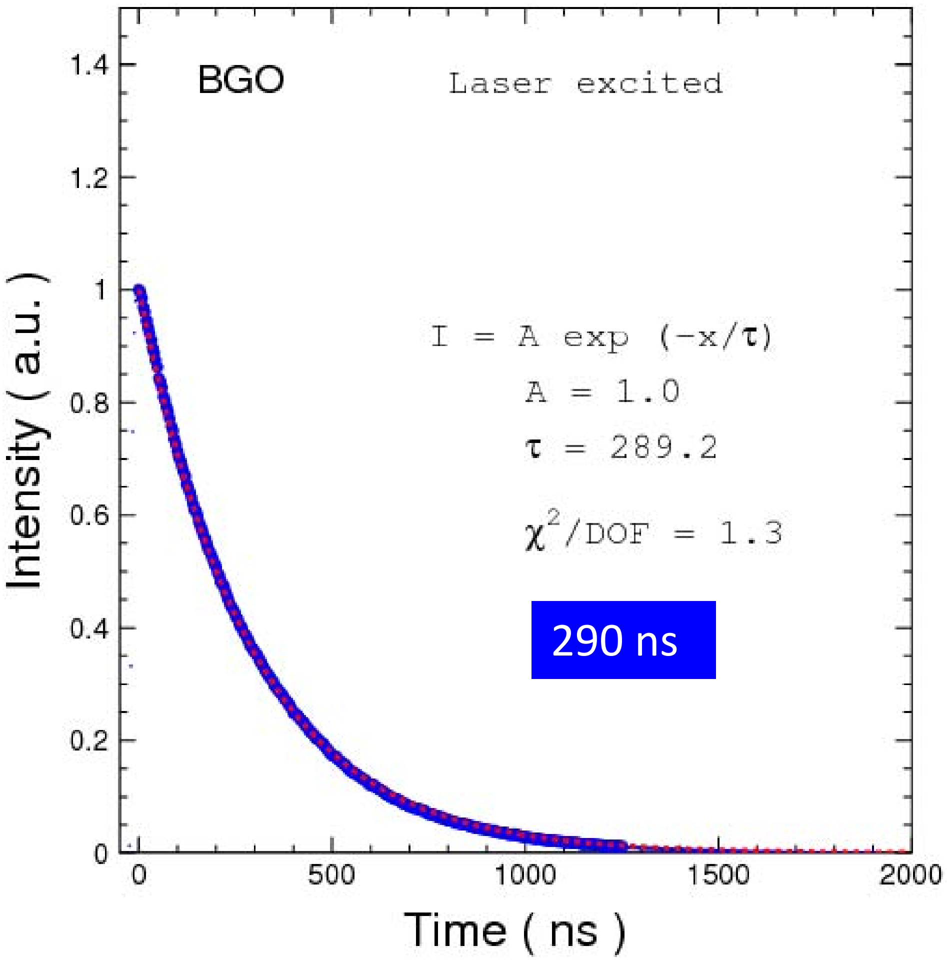


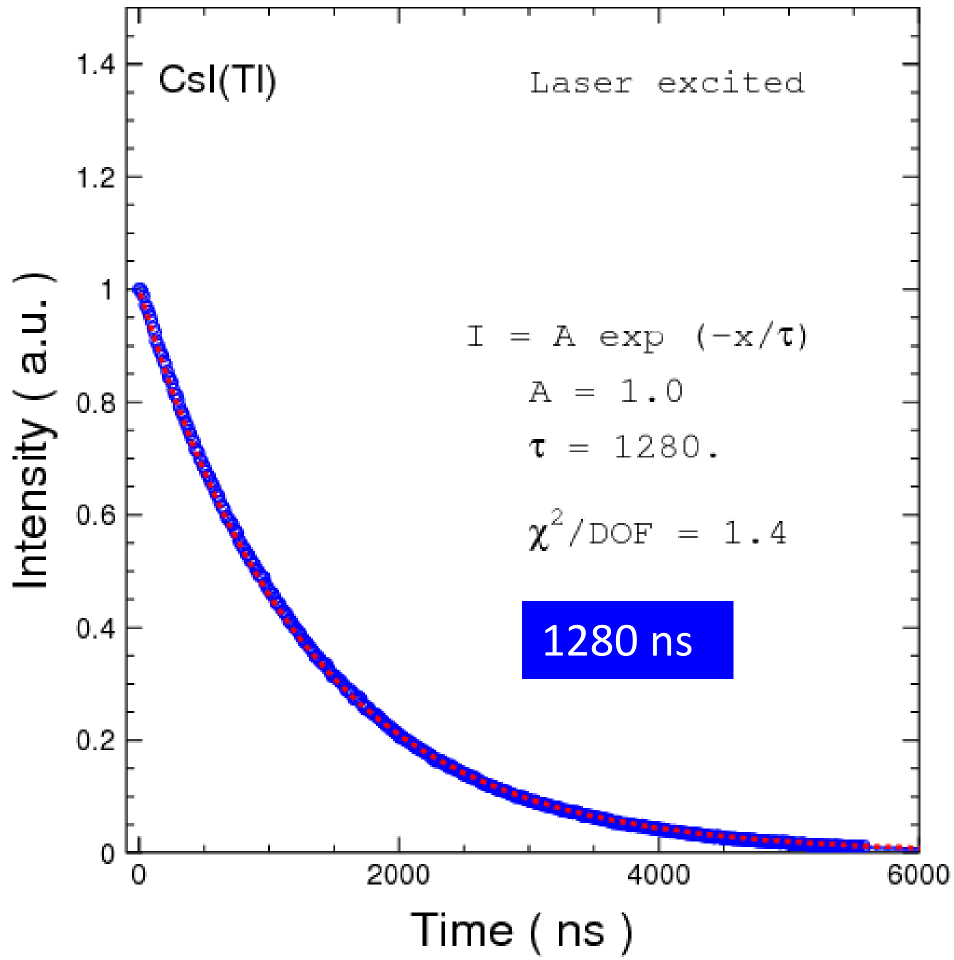
Decay Time Measurement



Set-up Verified with BGO & CsI(Tl)

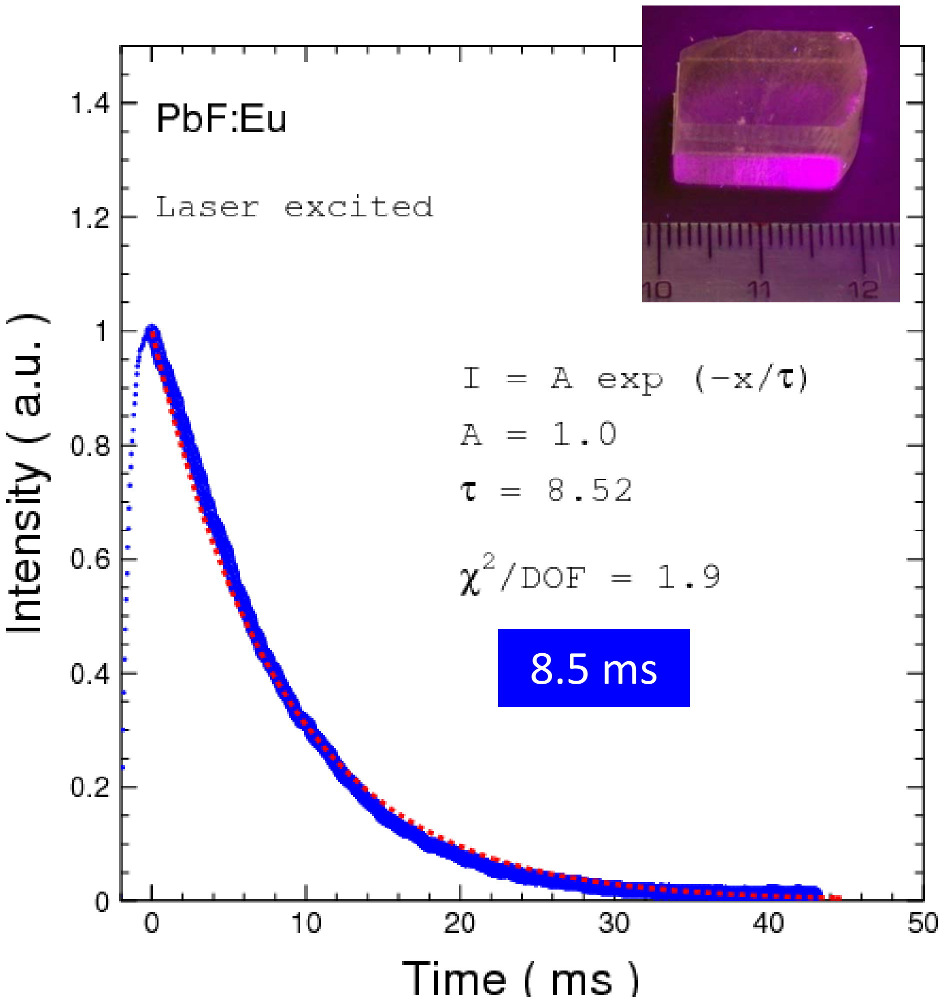
Decay time consists with well known values

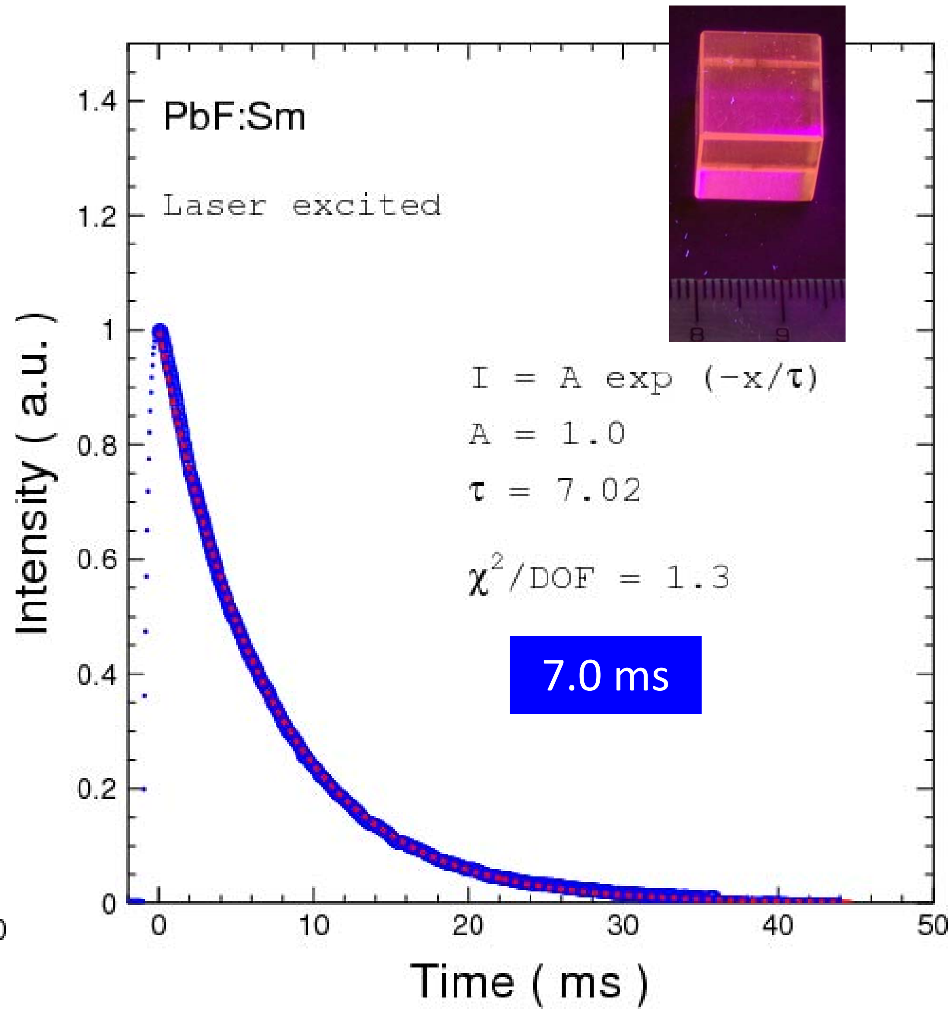




Eu and Sm Doped PbF_2

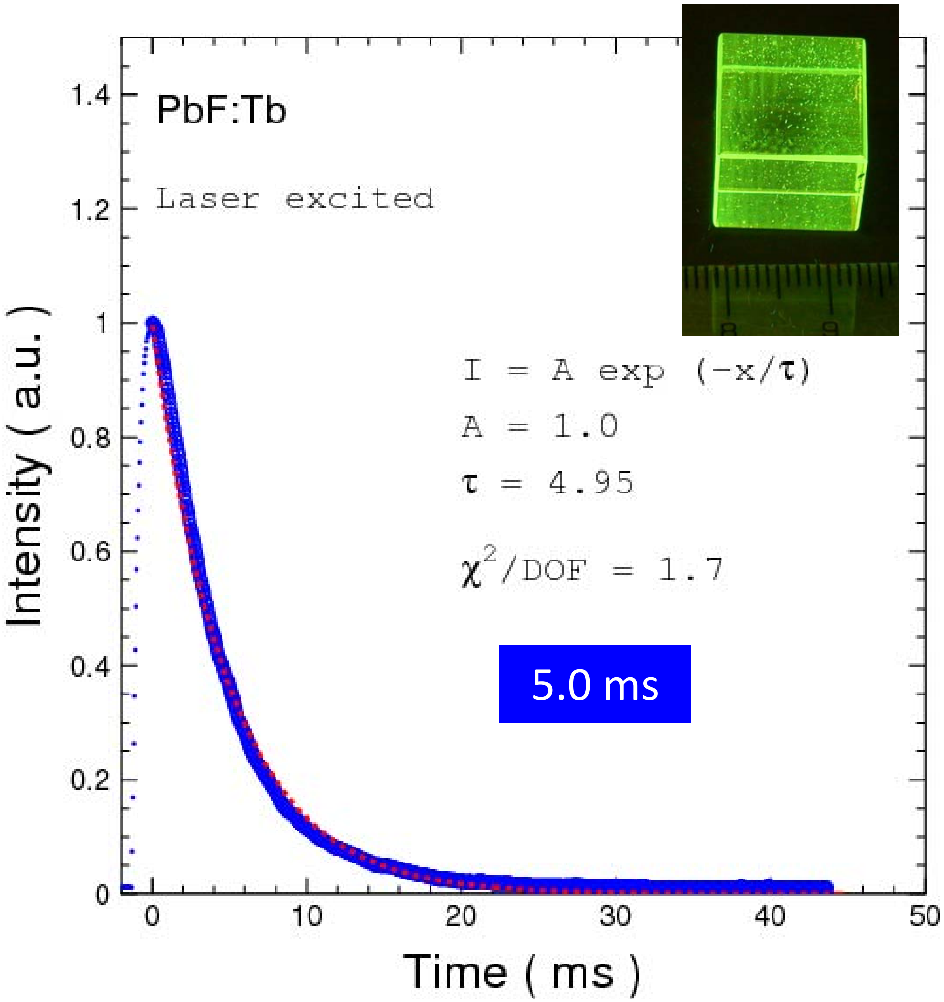
Red emission with multi-ms decay time observed

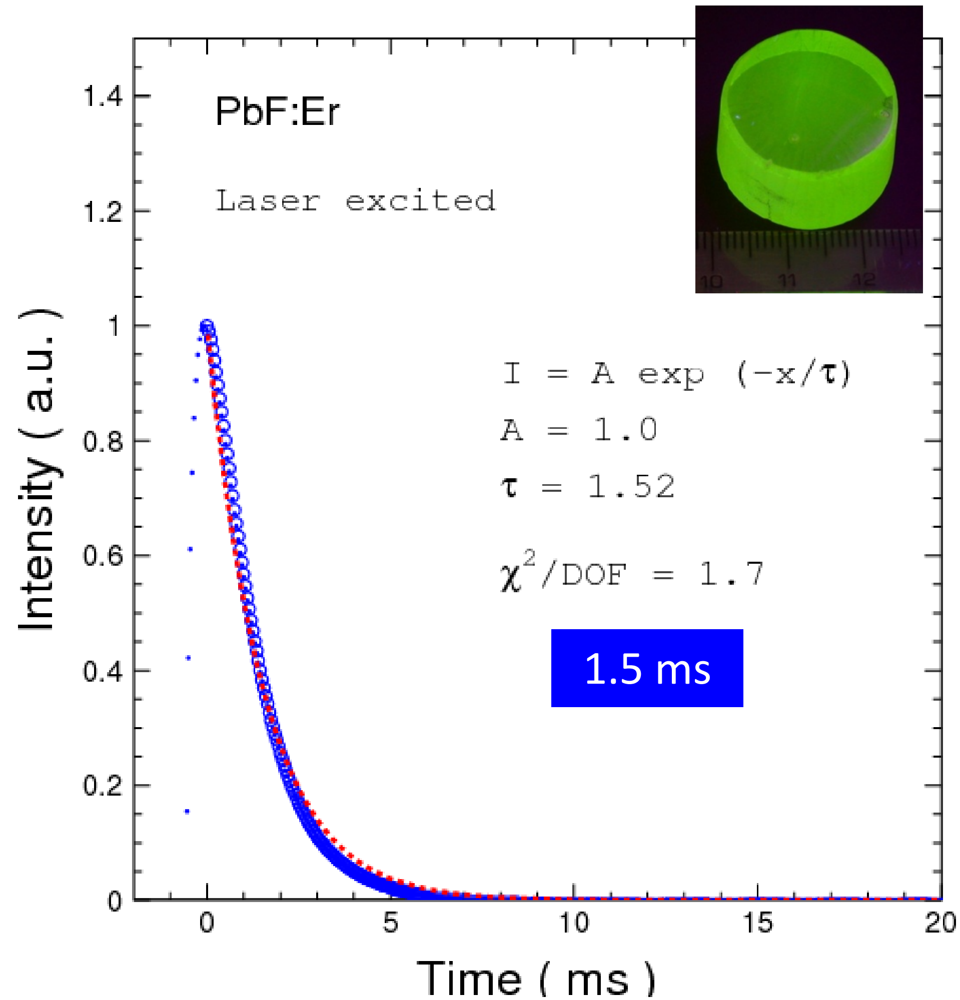




Tb and Er Doped PbF_2

Green emission with ms decay time observed





Summary

- Historically homogeneous electromagnetic calorimeter provides excellent resolution for electron and photon measurements.
- The proposed homogeneous hadronic calorimeter would provide good resolution for hadron and jet measurements.
- Because of the huge volume needed to construct a homogeneous HCAL development of cost-effective UV transparent material is crucial. Our initial investigation indicates that scintillating PbF_2 seems the best choice for this detector concept.