Crystal Calorimeters at Linear Collider

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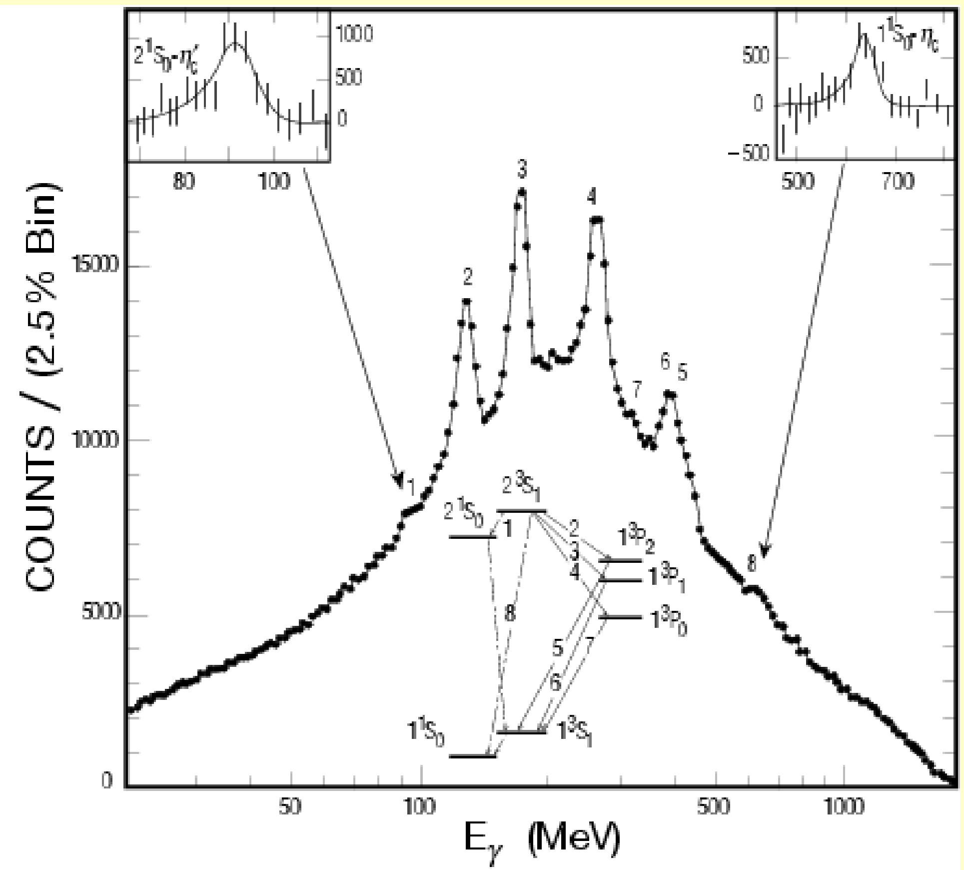
Outline

- Crystal Calorimetry for LC:
  - Why Crystal Calorimetry at LC;
  - Possible Crystal Technologies for LC.
- Recent Progress on Crystal R&D:
  - Yttrium Doped PWO Crystals for CMS;
  - PWO Crystals with High Light Yield;
  - PbF_2 Crystals;
  - LSO(Ce) and GSO(Ce).

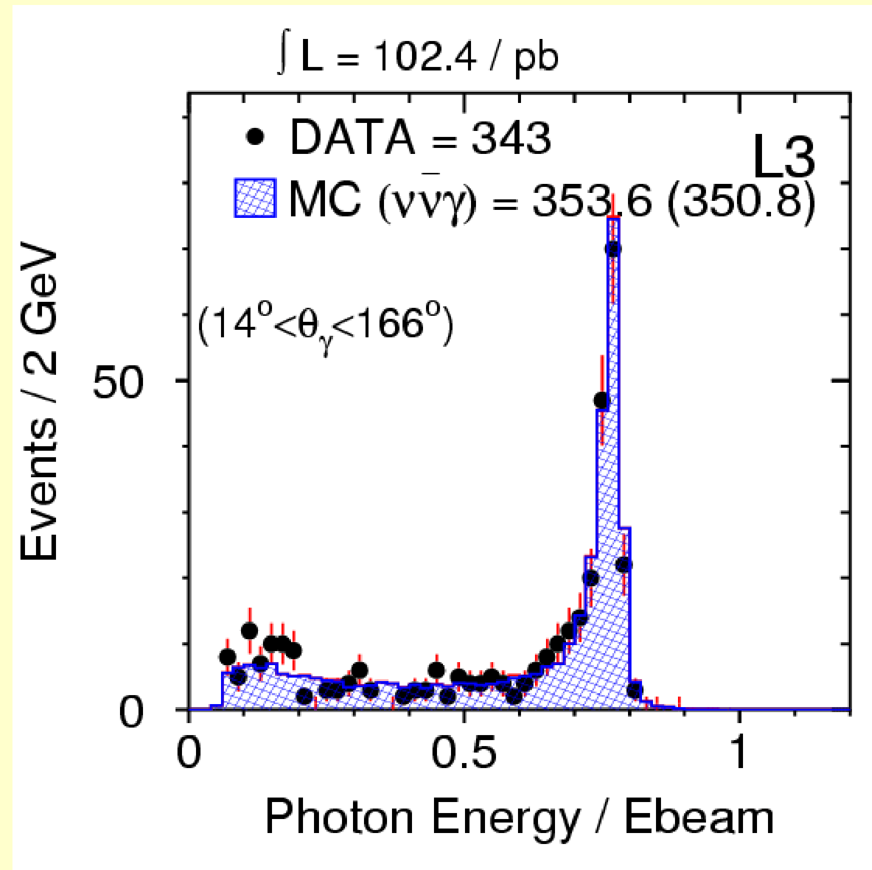
Why Crystal Calorimetry at LC (I)

Charmonium System Observed Through Inclusive Photons: CB



SUSY Breaking with Gravitino

$e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_1^0 \to \gamma\gamma\tilde{G}\tilde{G}$



Why Crystal Calorimetry at LC (II)

The CDF event: 2 e + 2 ? + E_T^{miss}

SM expectation (WW??) ~ 10^{-6} (PR D59 1999)

Possible SUSY explanation

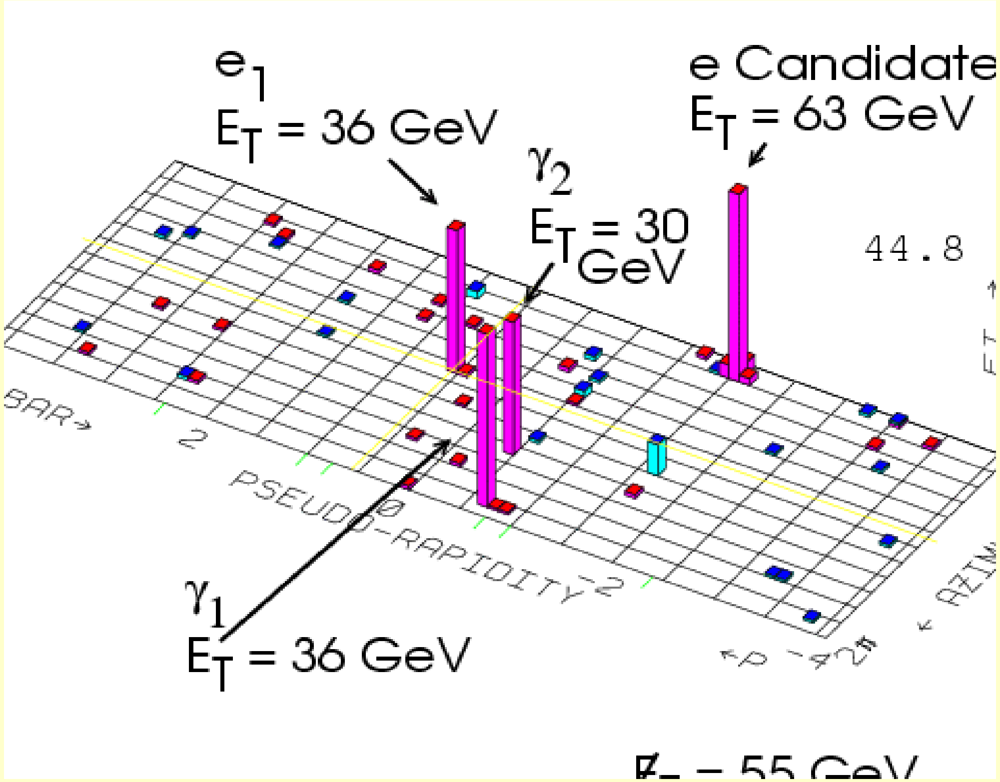
$$q\bar{q} \rightarrow \tilde{e}^+\tilde{e}^- \rightarrow ee\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow ee\gamma\gamma\tilde{G}\tilde{G}$$

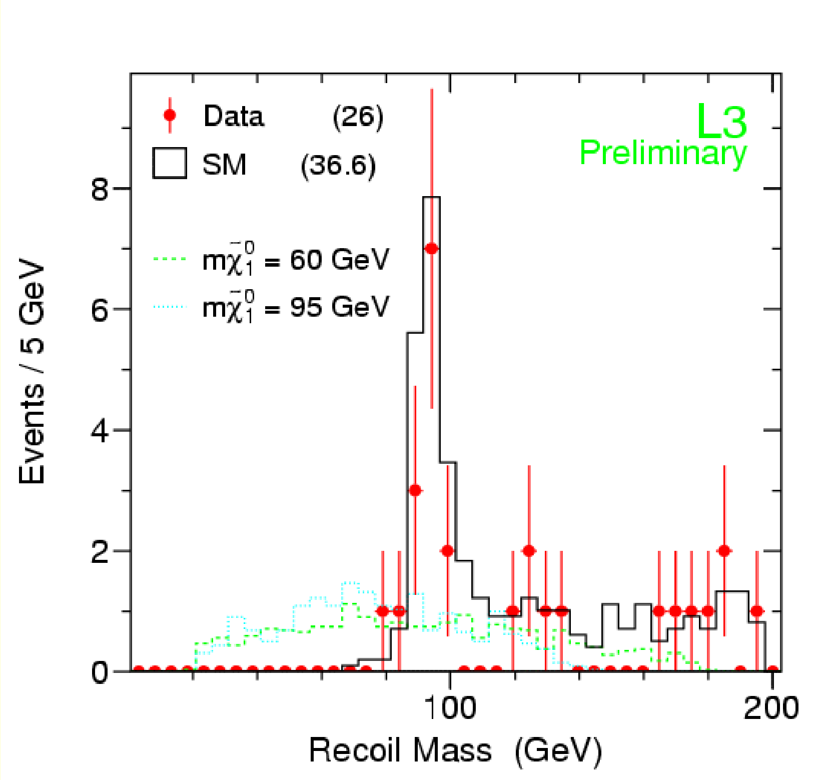
L3 should be able to observe

$$e^+e^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow \gamma\gamma\tilde{G}\tilde{G}$$

Another possible channel

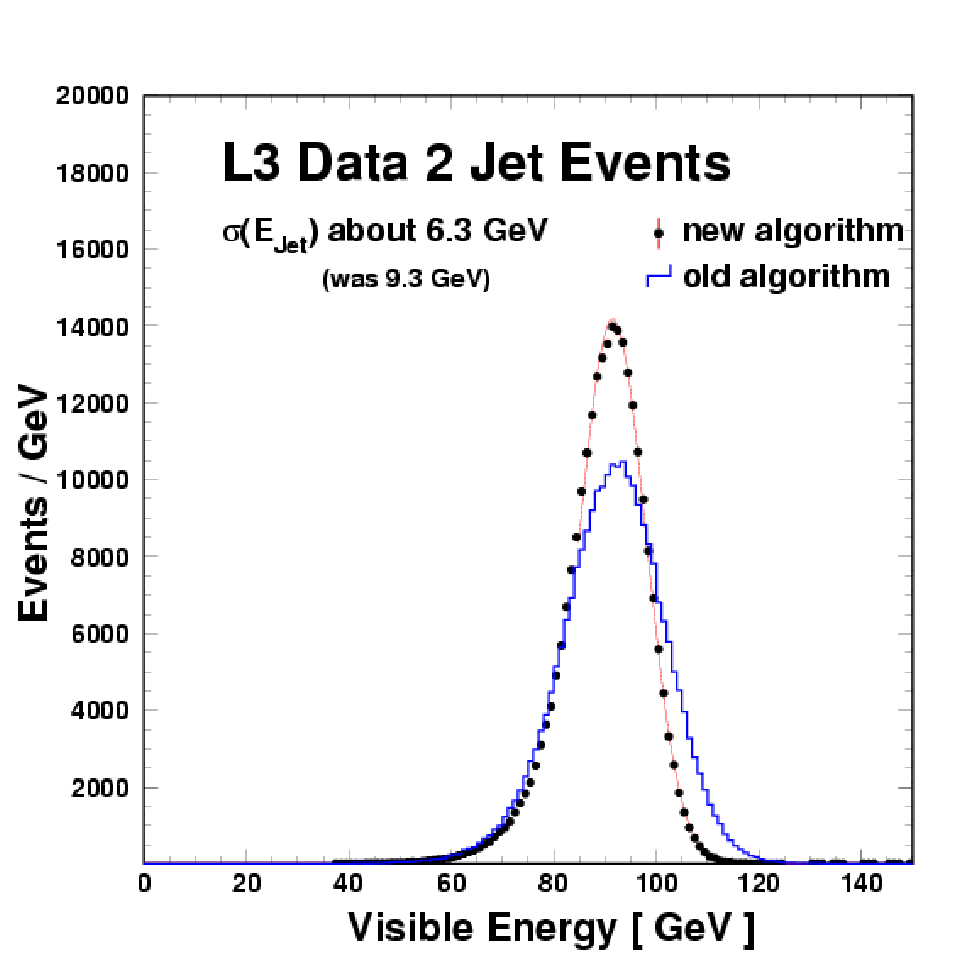
$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \gamma\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$$

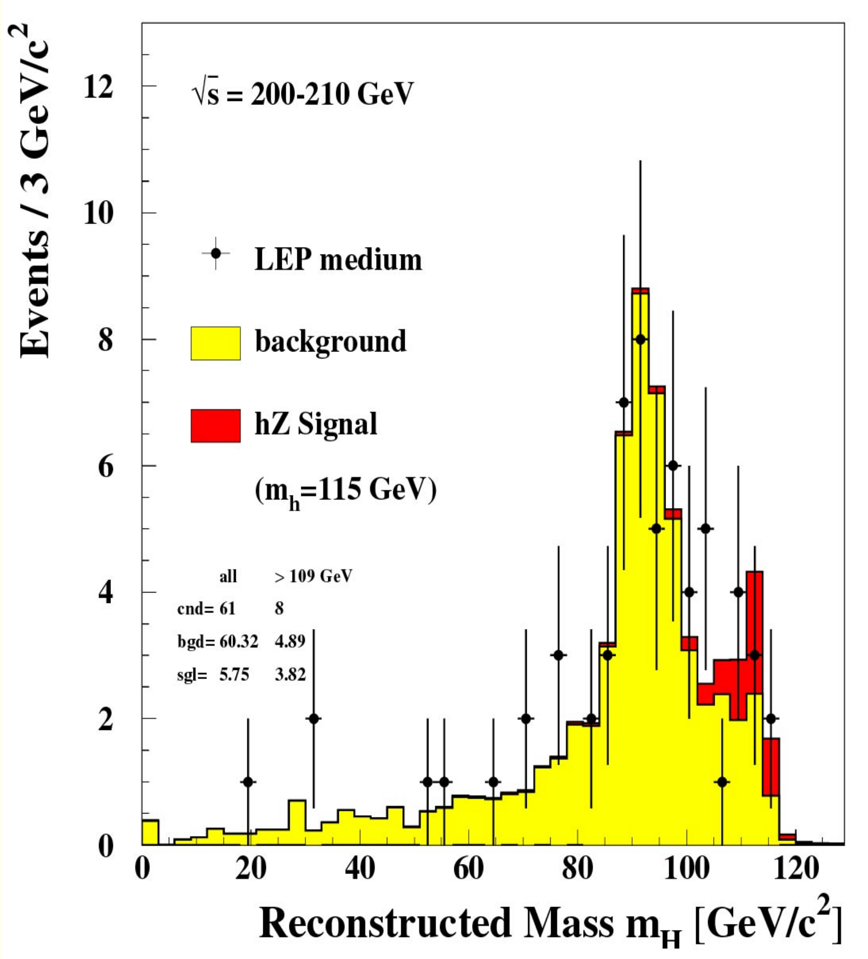




Improved by using Tracker, I.e. Energy Flow Concept: 10% to 7%

Further Improved by using Kinematic Constraints: 3%



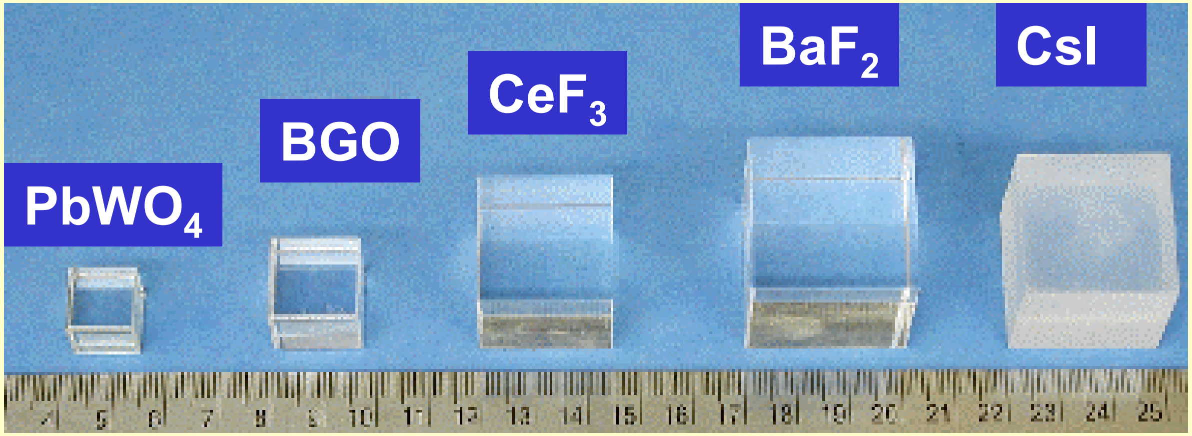


Properties of Crystal Scintillators

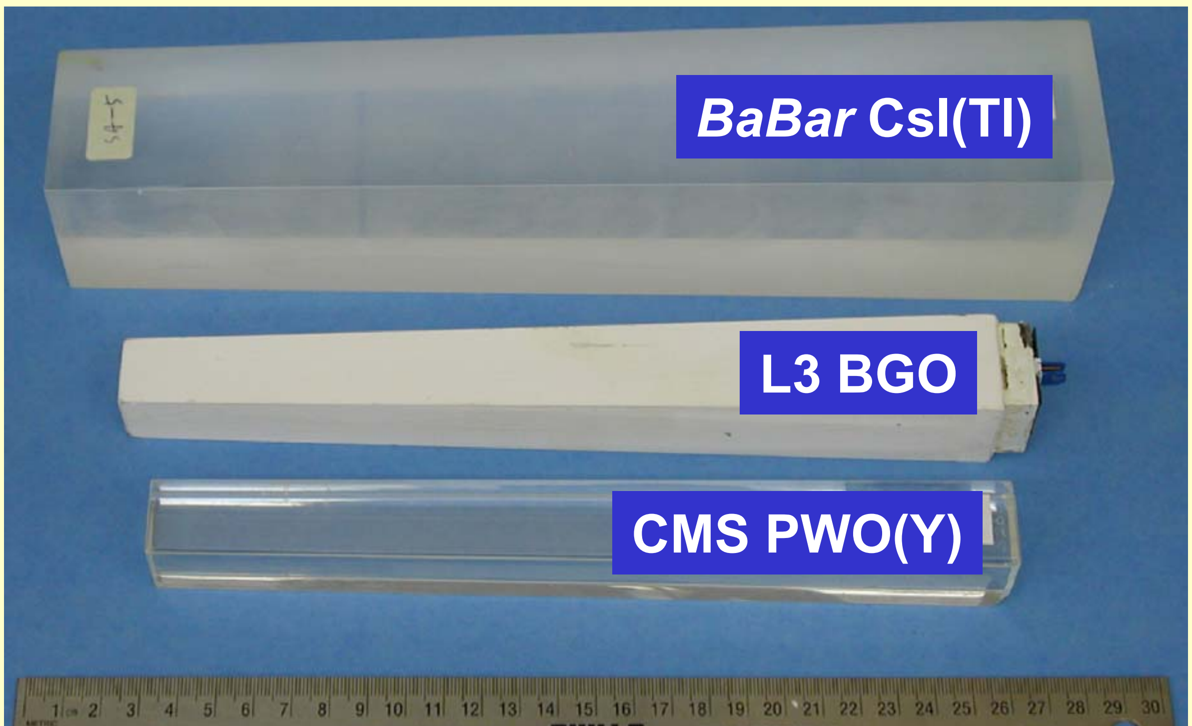
Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	$PbWO_4$	LSO(Ce)	GSO(Ce)
Density (g/cm^3)	3.67	4.51	4.51	4.89	7.13	8.3	7.40	6.71
Melting Point (?C)	651	621	621	1280	1050	1123	2050	1950
Radiation Length (cm)	2.59	1.85	1.85	2.06	1.12	0.9	1.14	1.37
Moliere Radius (cm)	4.8	3.5	3.5	3.4	2.3	2.0	2.3	2.37
Interaction Length (cm)	41.4	37.0	37.0	29.9	21.8	18	21	22
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	2.2	1.82	1.85
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	560	420 310	300 220	480	560 420	420	440
Decay Time [b] (ns)	230	1300	35 6	630 0.9	300	50 10	40	60
Light Yield [b,c] (%)	100	45	5.6 2.3	21 2.7	9	0.1 0.6	75	30
d(LY)/dT [b] (%/ ?C)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	?	?
Volume Price ($/cm³)	1 to 2	2	2.5	2.5	7	2.5	-	-

a. at peak of emission; b. up/low row: slow/fast component; c. measured by PMT of bi-alkali cathode.

Samples of Crystal Scintillators



1.5 X_0 Cubic



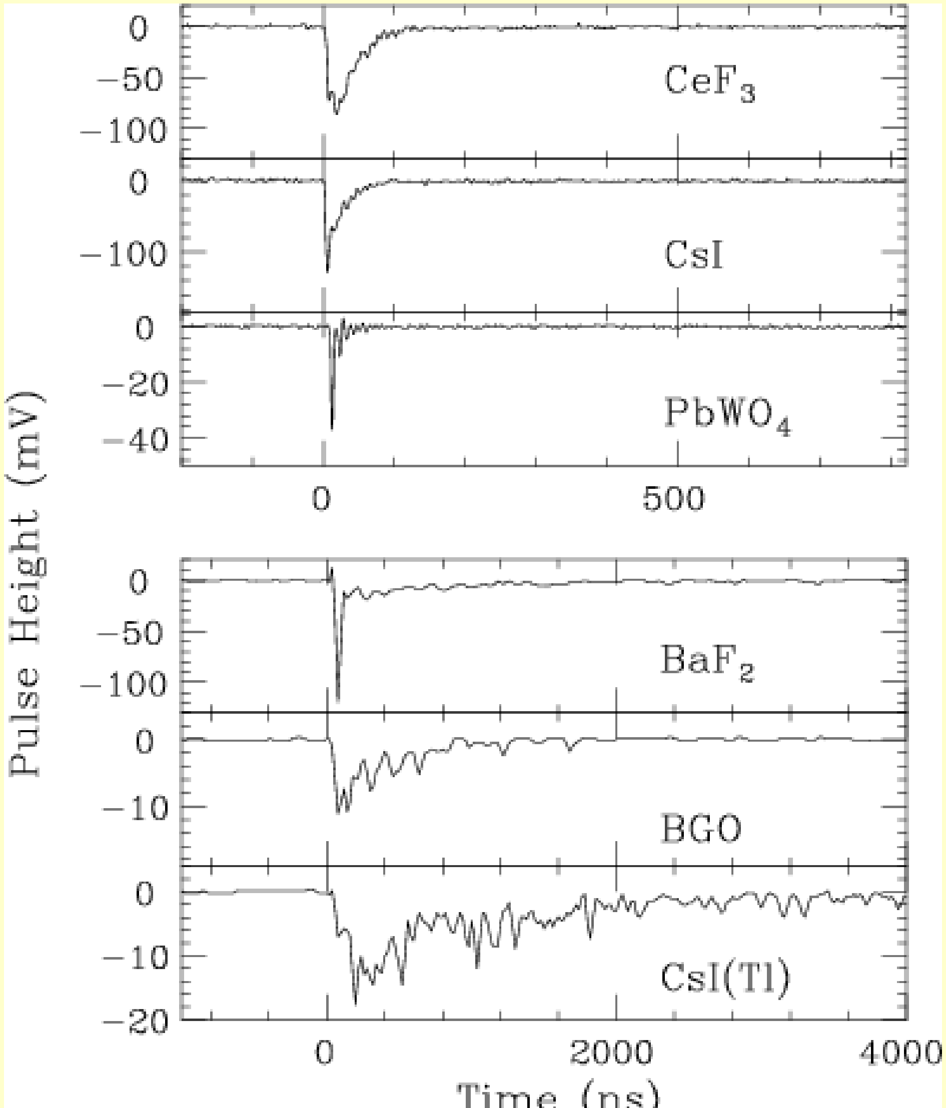
Full Size Samples

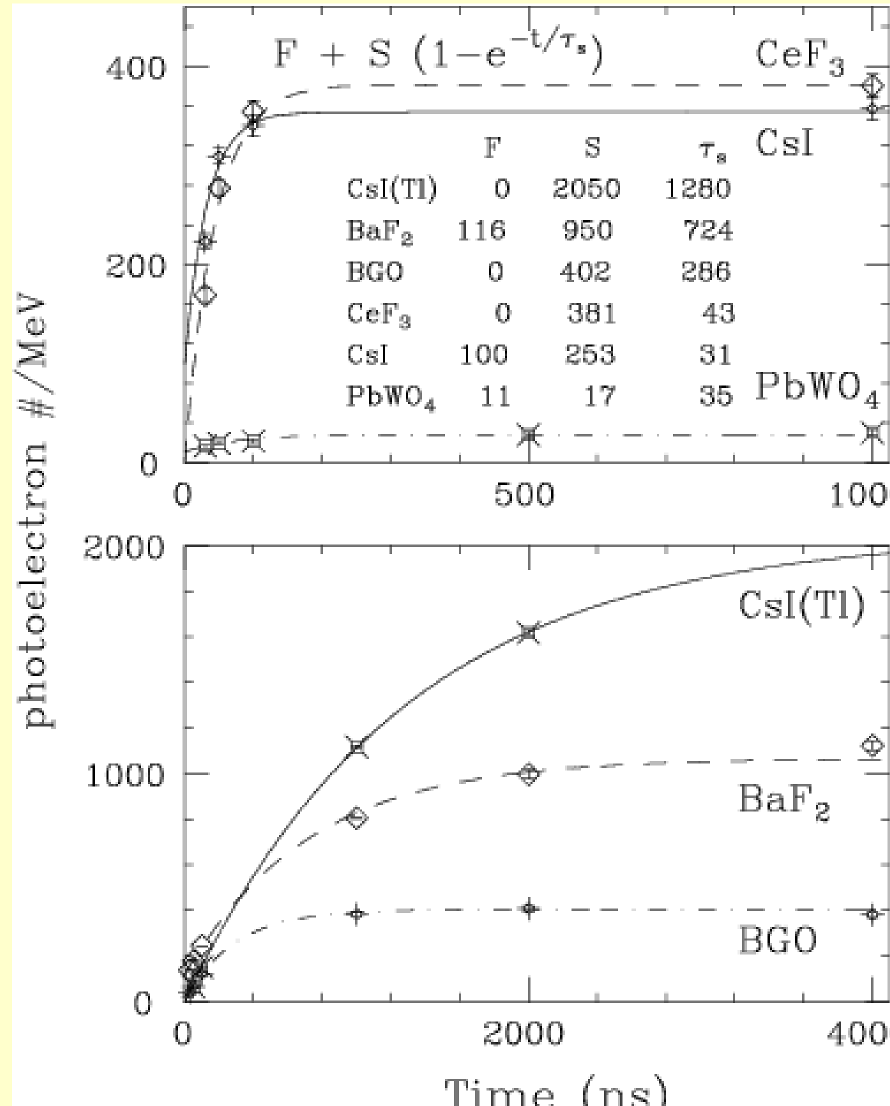
***BaBar* CsI(Tl): 16 X_0**

L3 BGO: 22 X_0

CMS PWO(Y): 25 X_0

Scintillation Light of 6 Samples



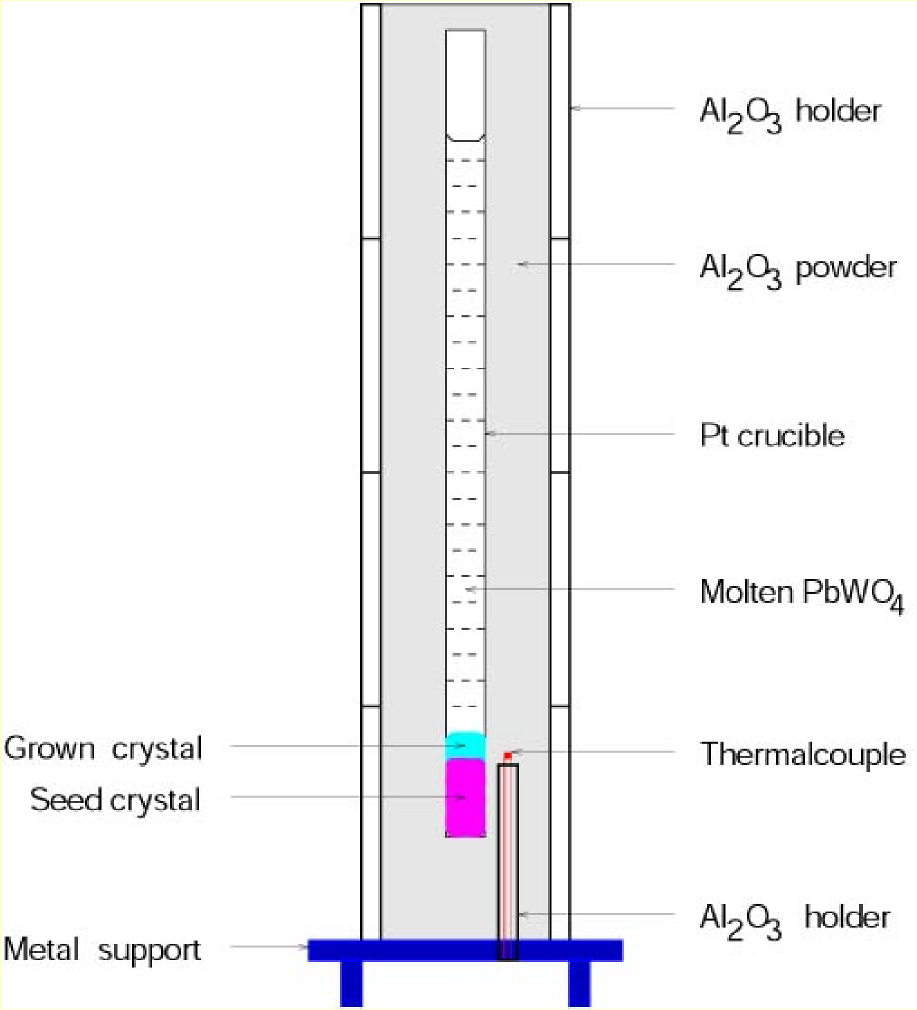


Summary: Crystal Calorimetry for LC

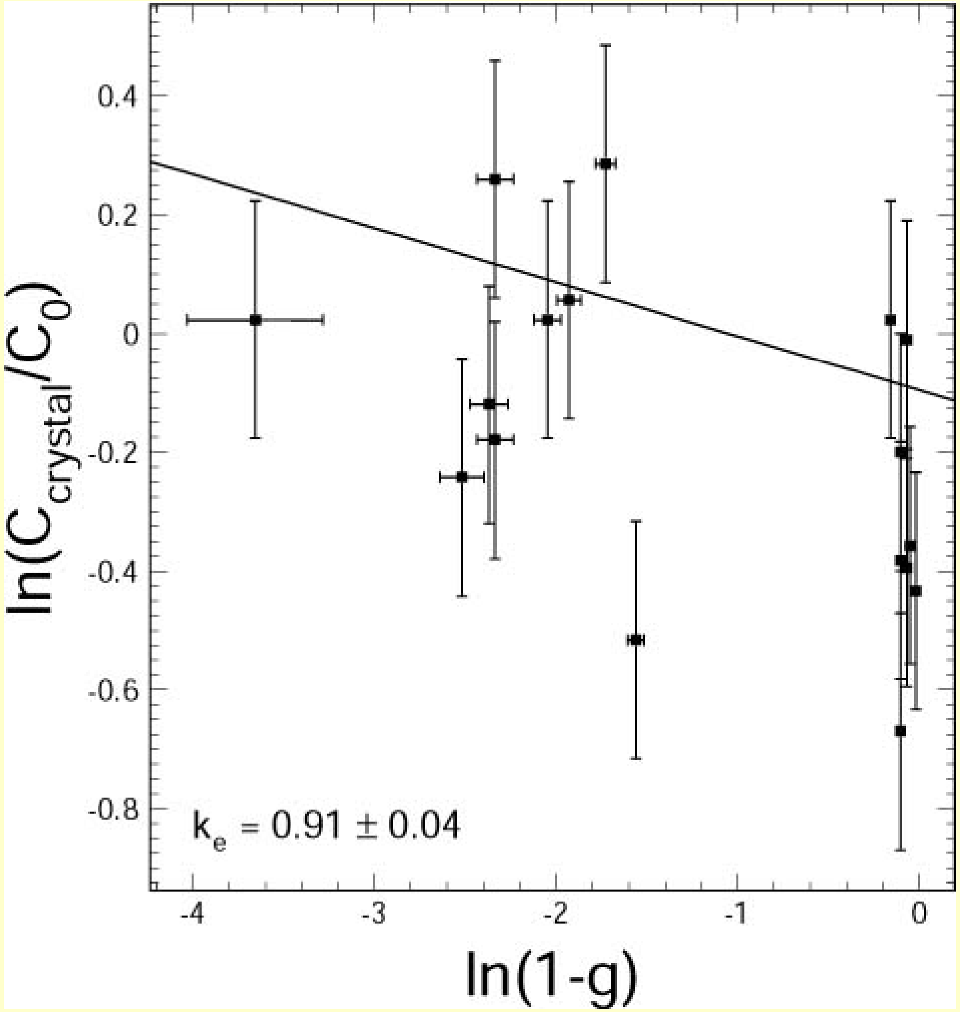
- To maximize physics reach, calorimetry for LC should have good measurement on electrons, photons and jets.
- The crystal calorimetry provides the best achievable EM resolution, good missing energy and jet resolution.
- Heavy crystal scintillators may provide a cost effective EM calorimeter solution.

Yttrium Doped PWO for CMS

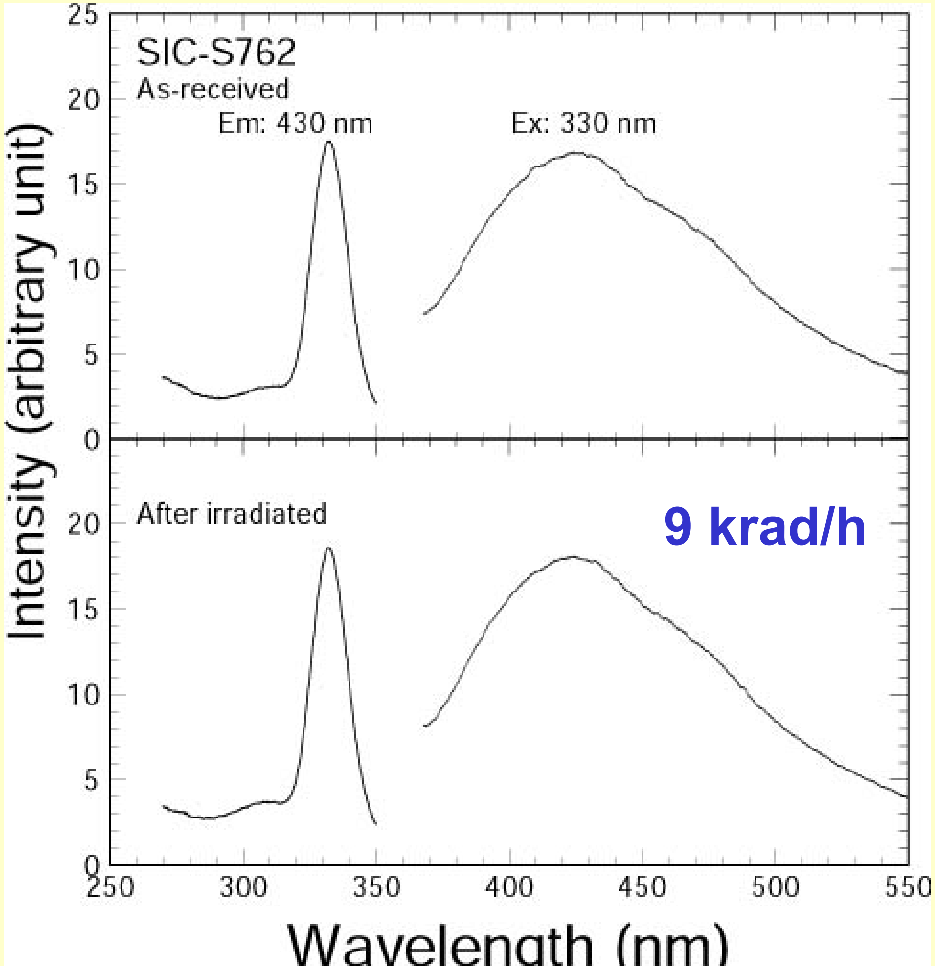
Bridgman Growth

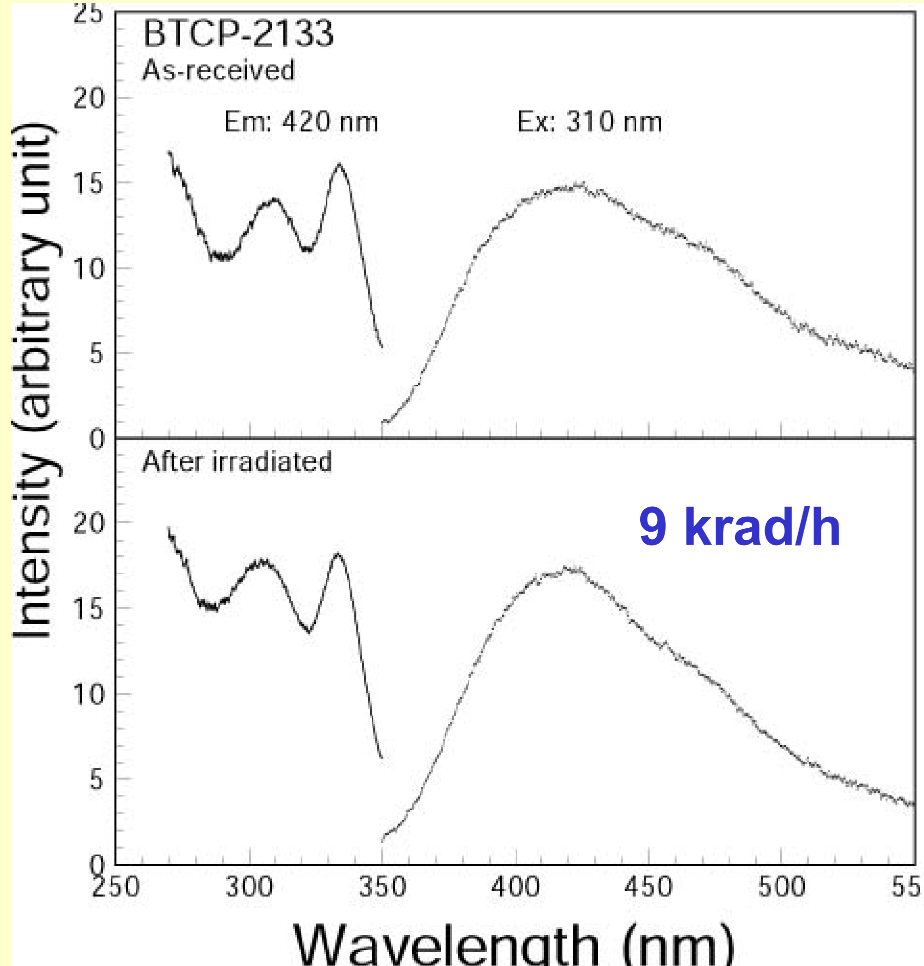


Segregation = 0.91 ± 0.04



CMS PWO(Y) Emission

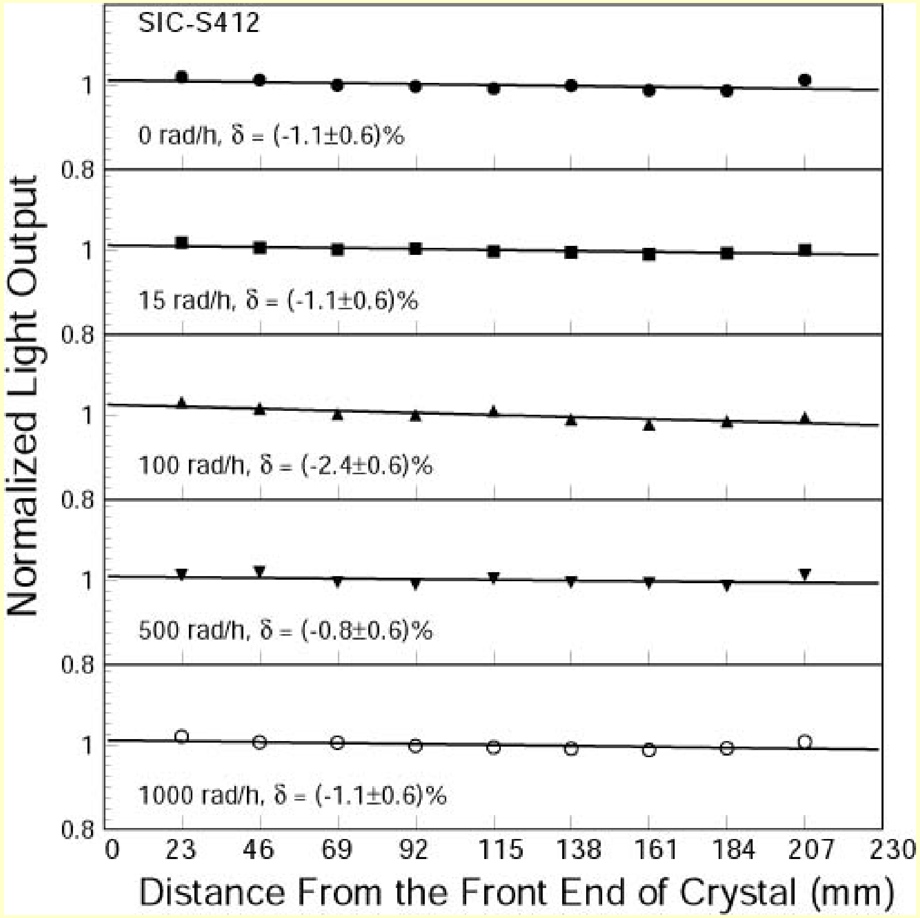


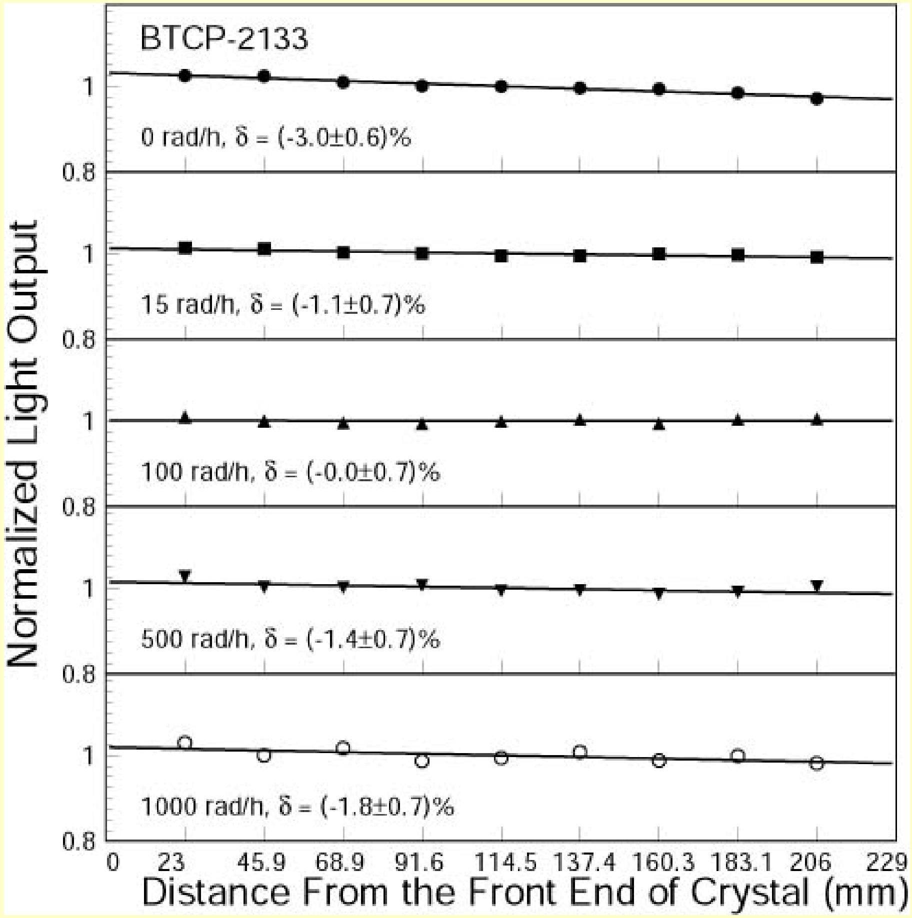


Excitation & Emission not affected by radiation.

CMS PWO(Y) Uniformity

$$\frac{y}{y_{mid}} = 1 + \delta(x / x_{mid} - 1)$$

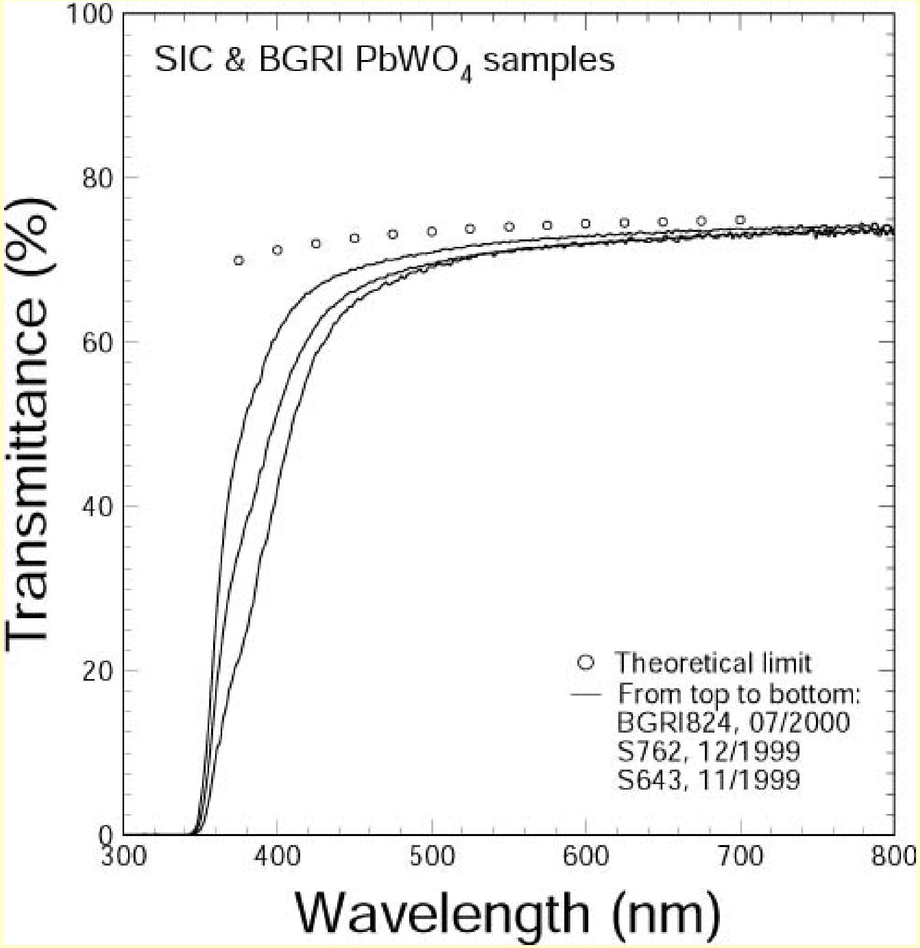




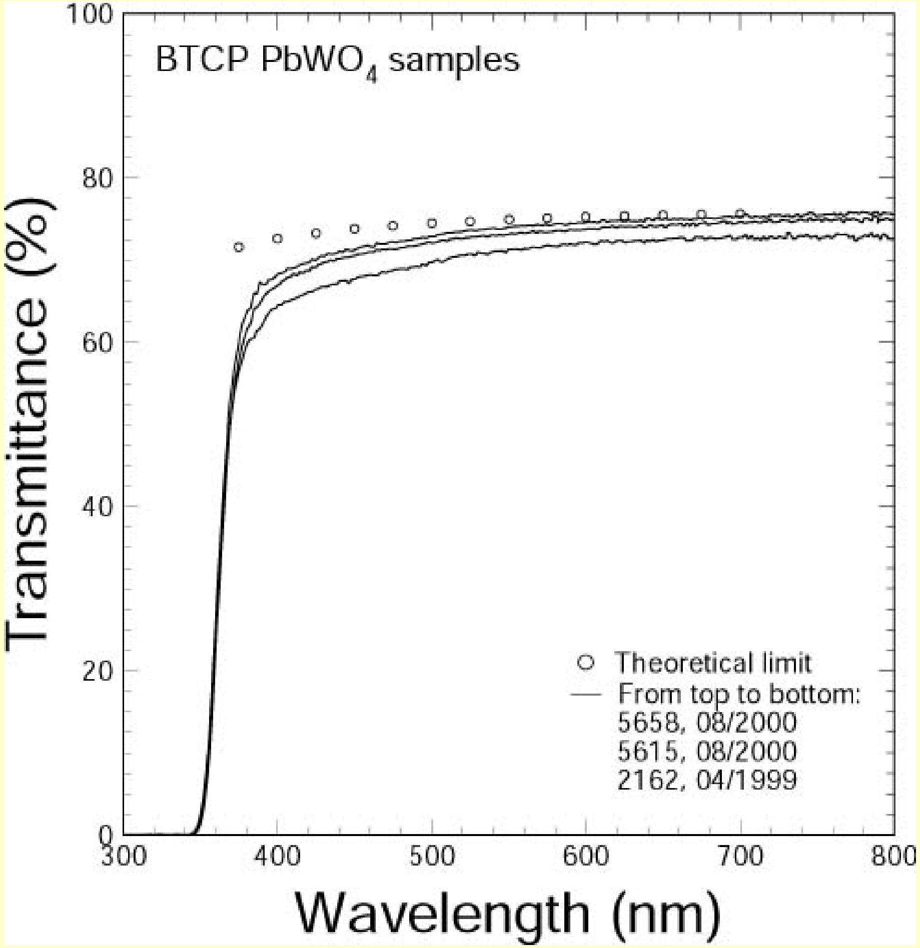
Light response Uniformity is not affected by radiation

CMS PWO(Y): Transmittance

Grown along *c* axis

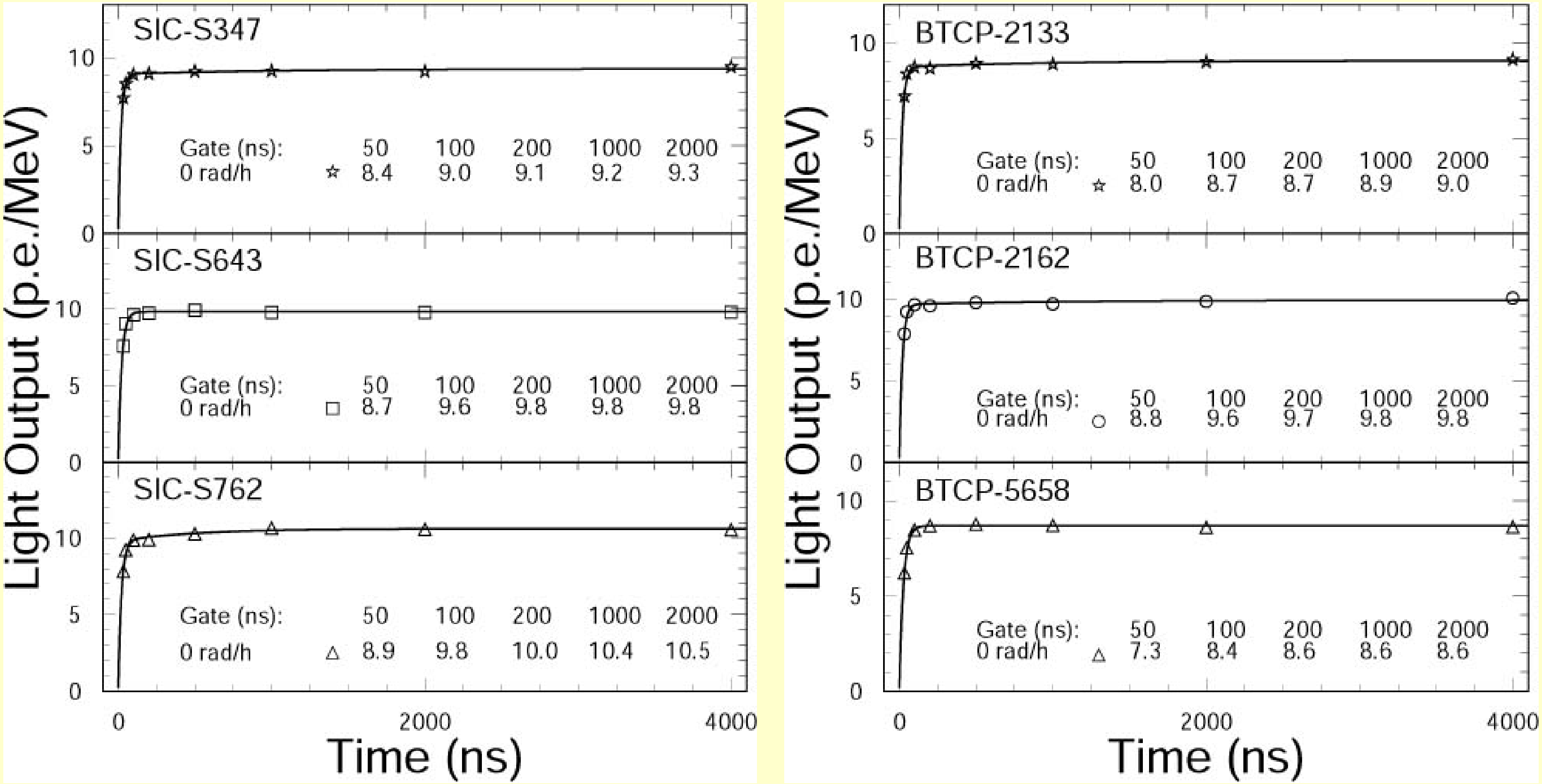


Grown along *a* axis



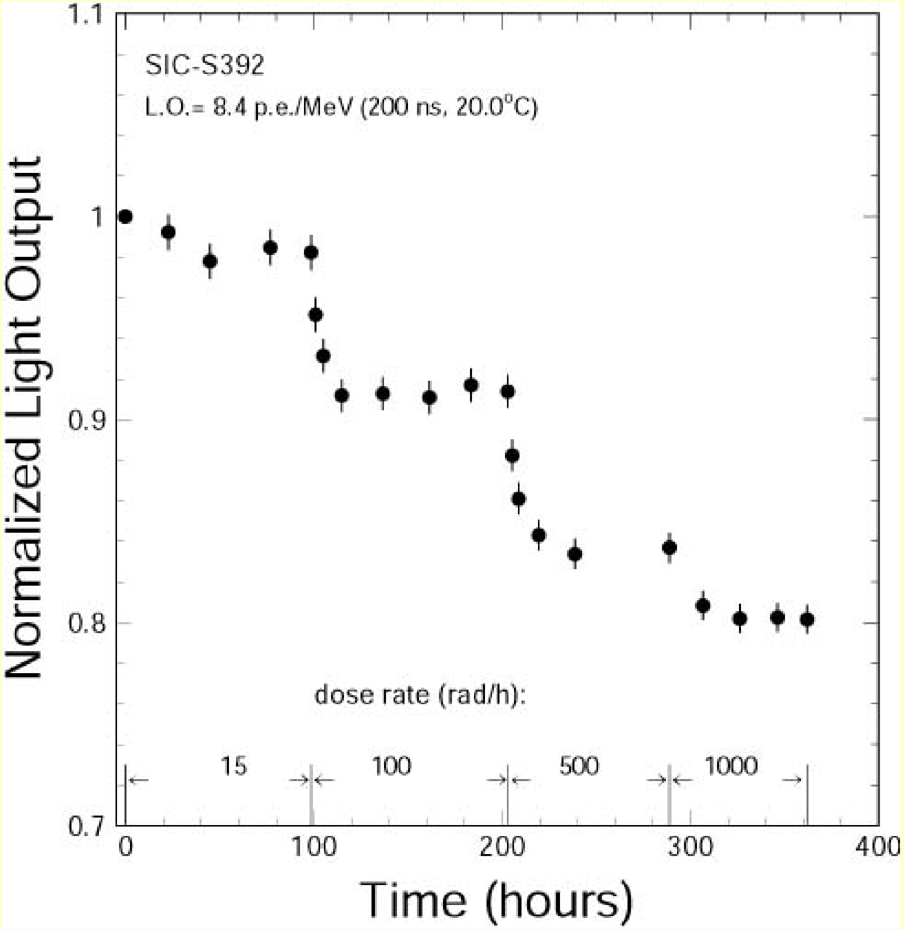
Progress observed during crystal development

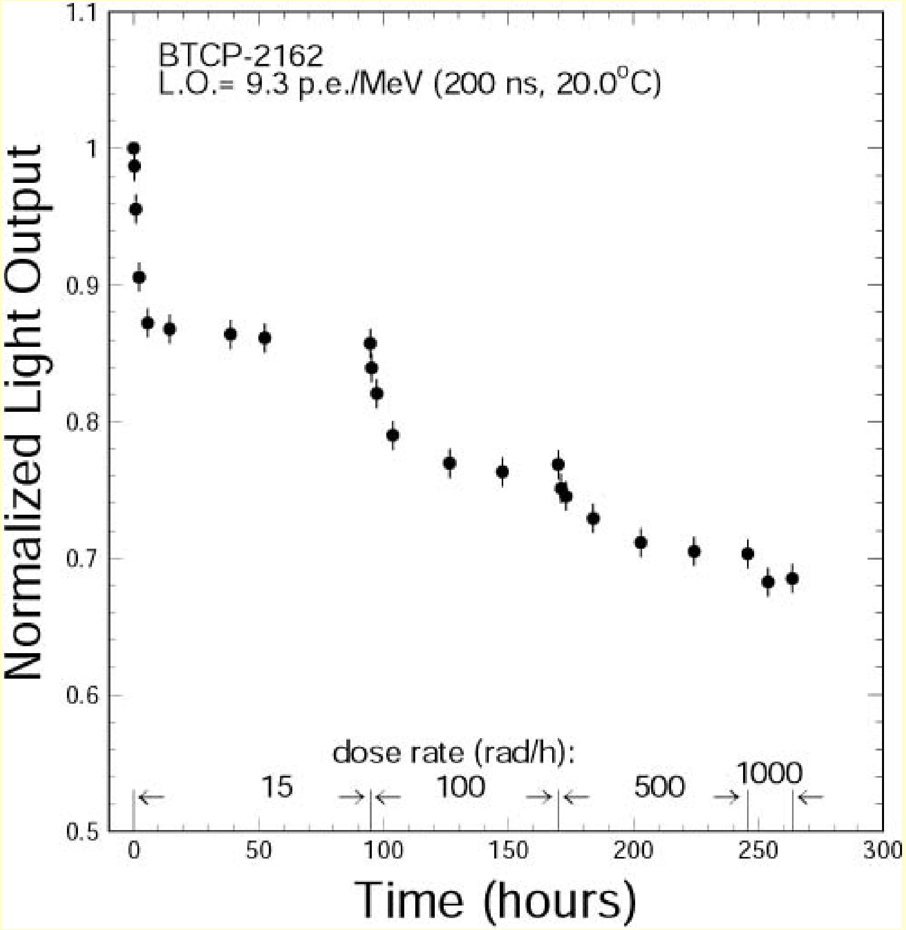
CMS PWO(Y): Decay Kinetics



90 and 95% of light output in 50 and 100 ns respectively

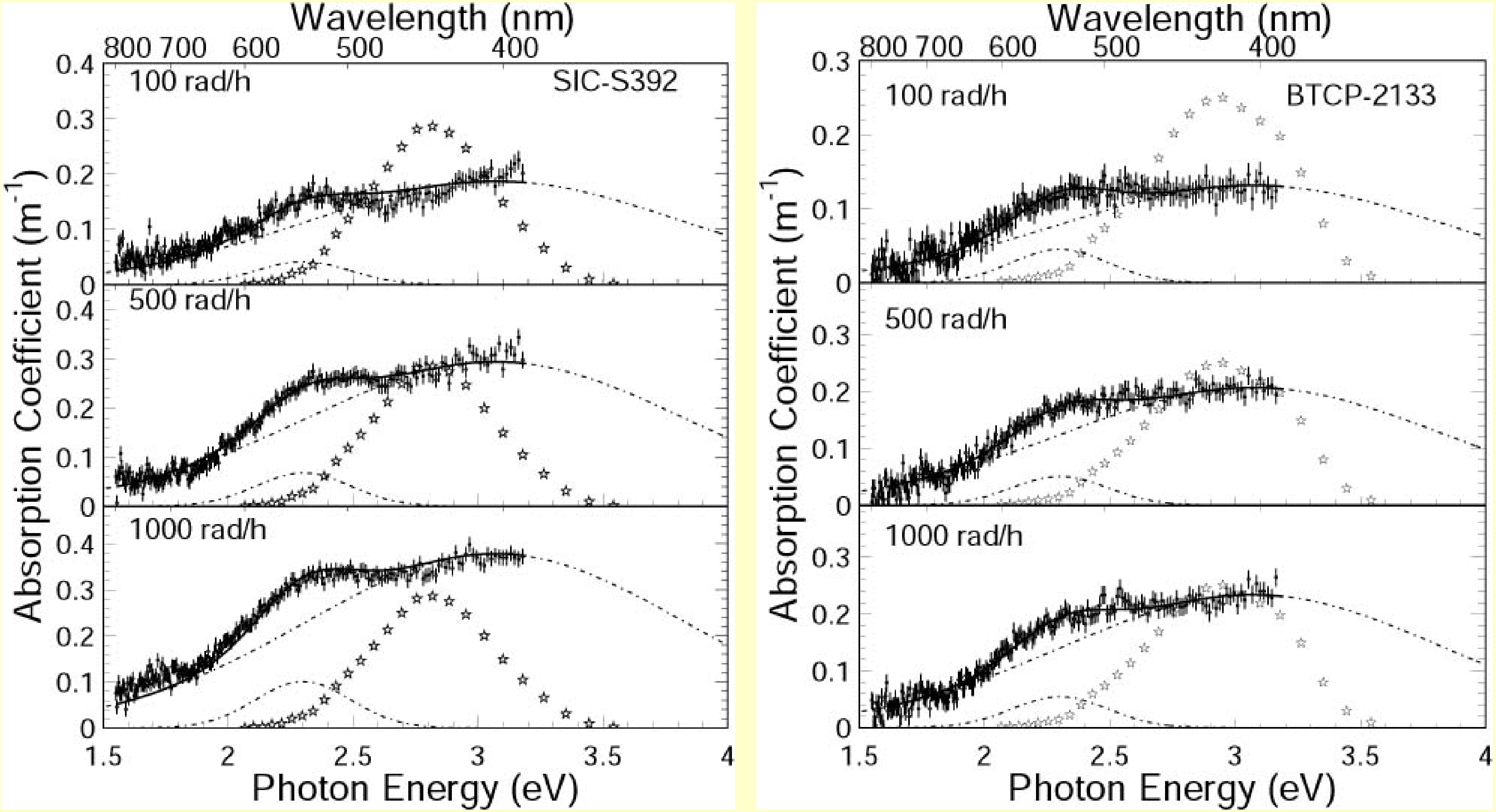
CMS PWO(Y): Radiation Damage





5 to 15% loss of light output at 15 brad/h (the maximum in barrel)

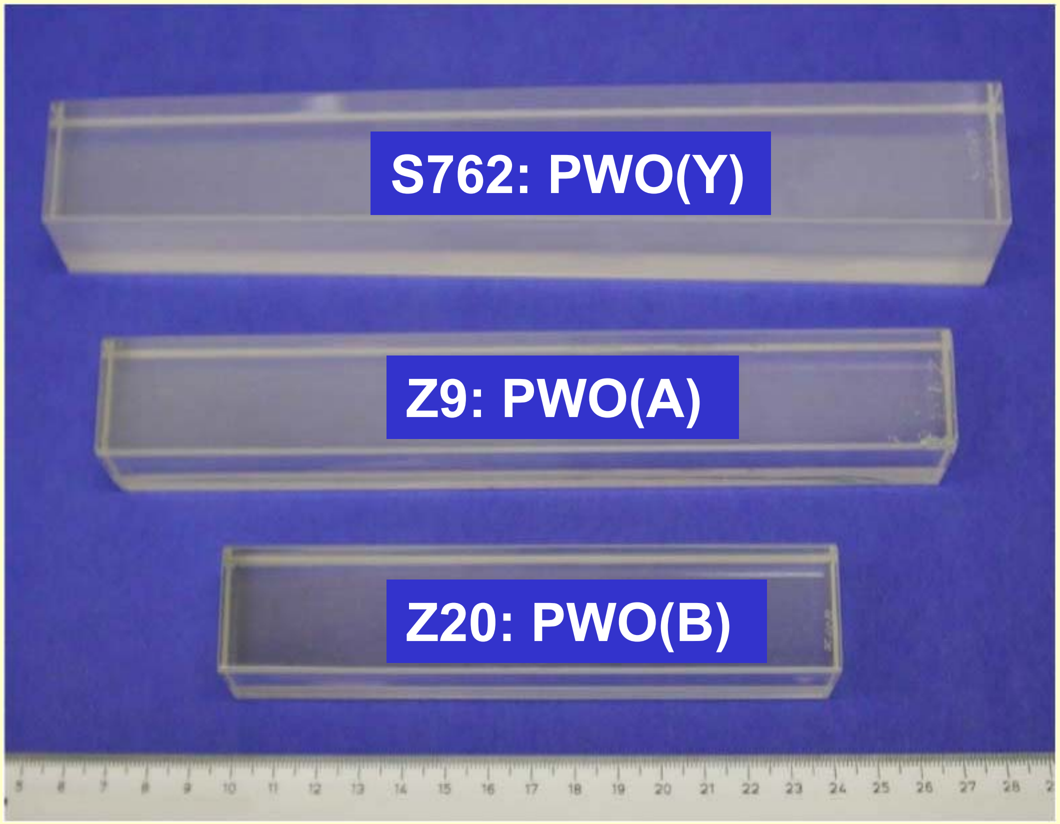
CMS PWO(Y): Color Centers



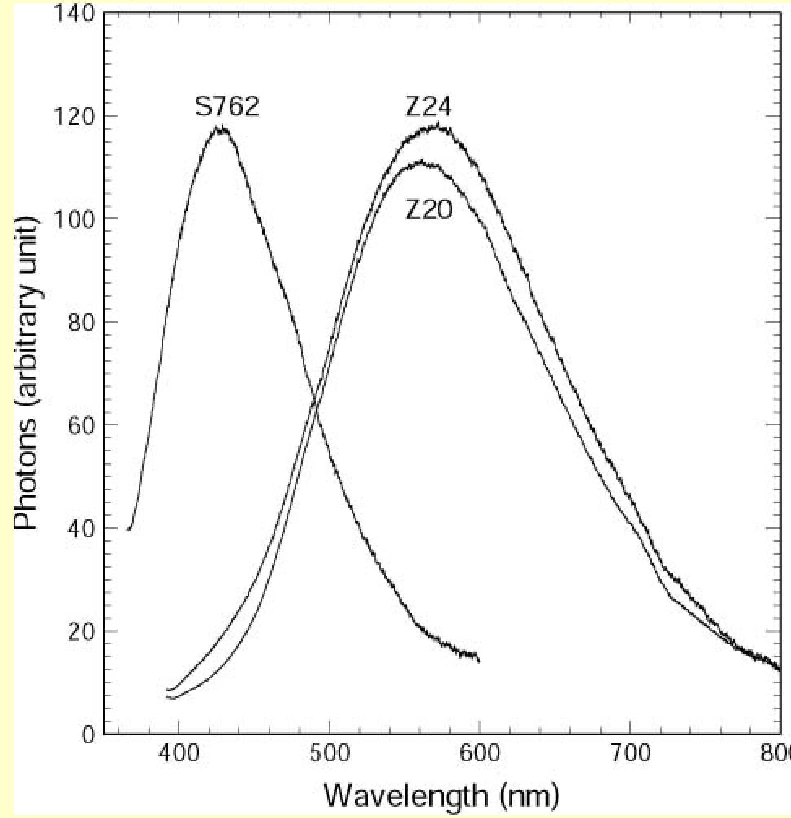
C_1: 3.07 eV (400 nm) / 0.76 eV, C_2: 2.30 eV (540 nm) / 0.19 eV

New Type PWO Crystal Samples

PWO Samples from SIC



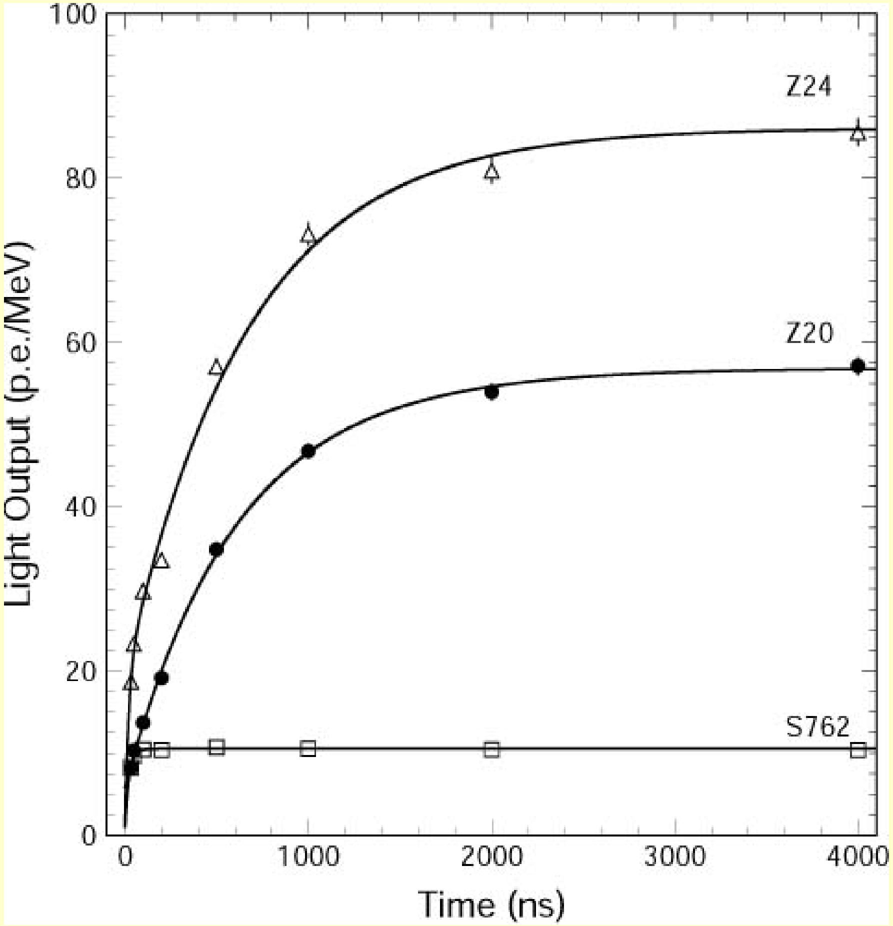
Emission Spectra



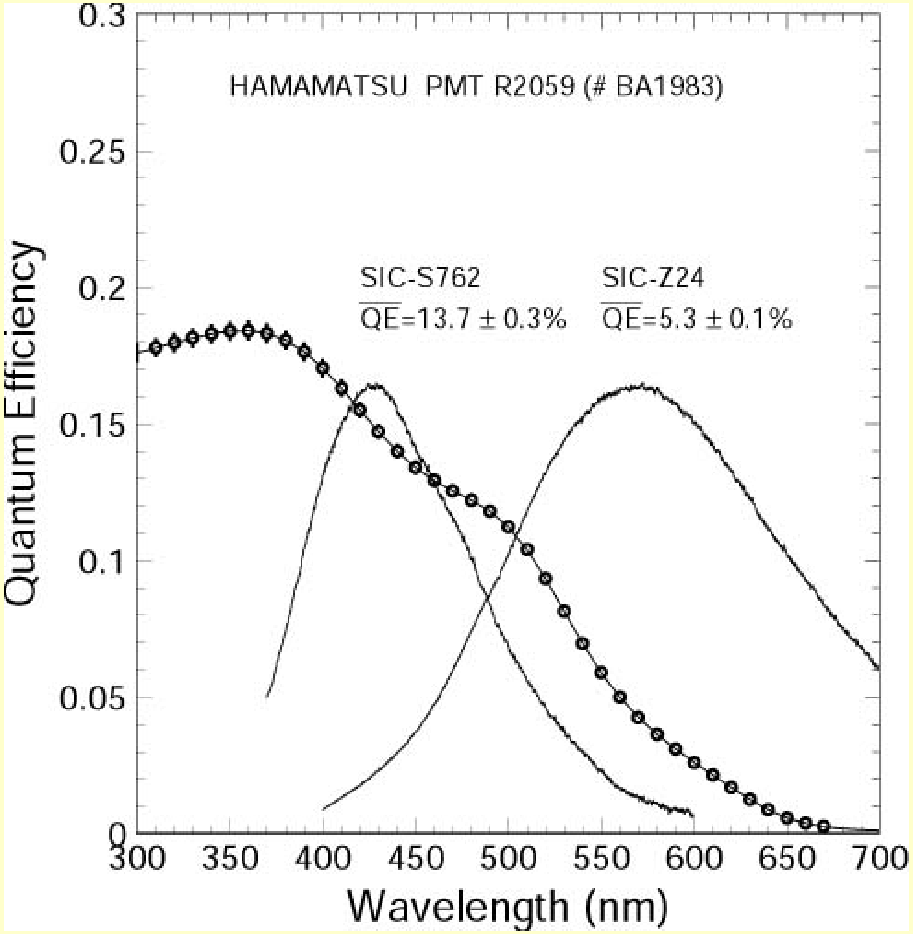
New PWO has emission peaked at 560 nm

PWO Crystal with High Light Yield

Decay Kinetics



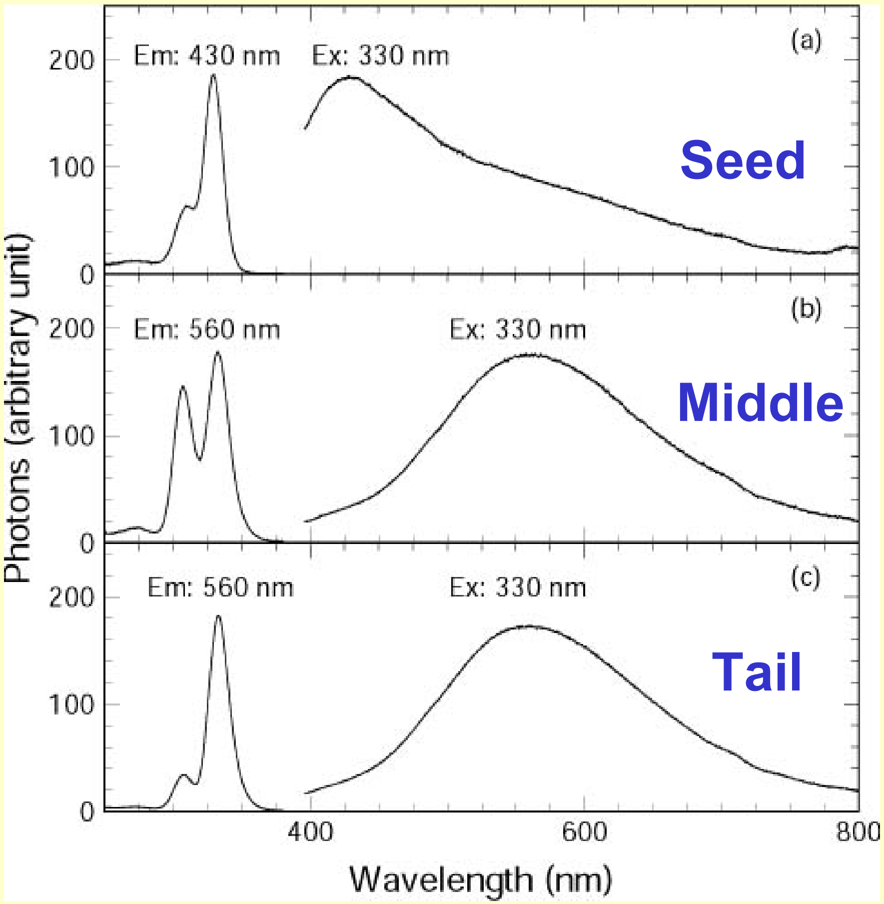
QE of PMT and Emission



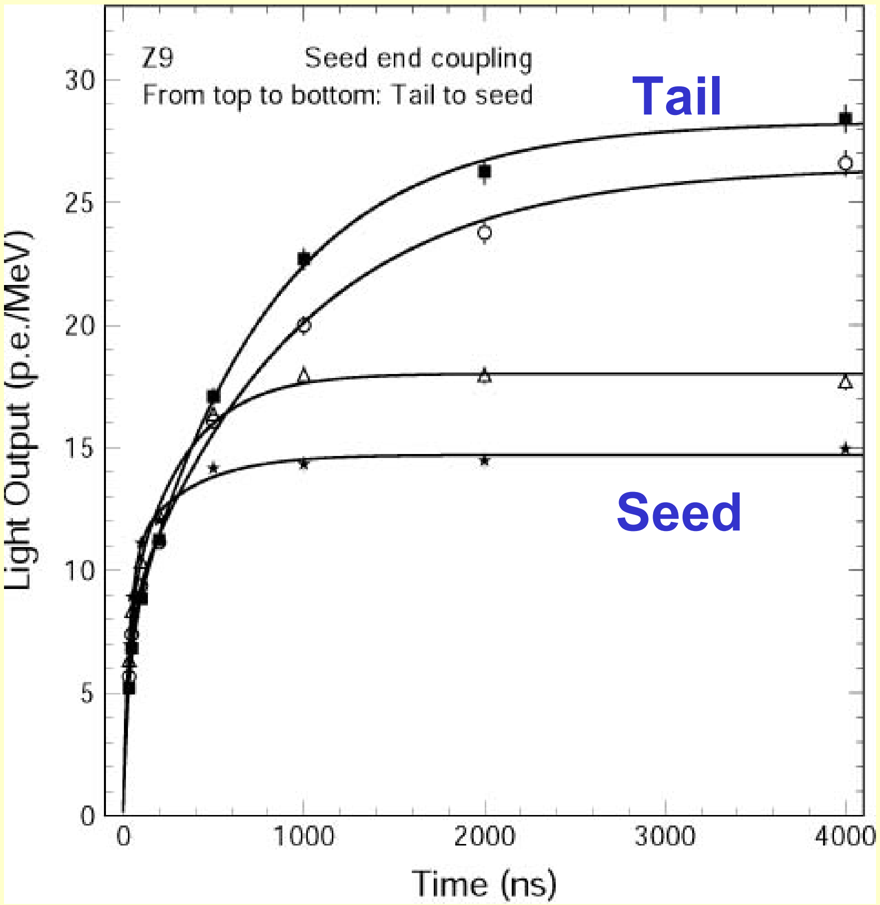
Taking into account of PMT QE, new PWO has 10 X LY

Poor Longitudinal Uniformity

Z9 Emission: Seed, Middle, Tail



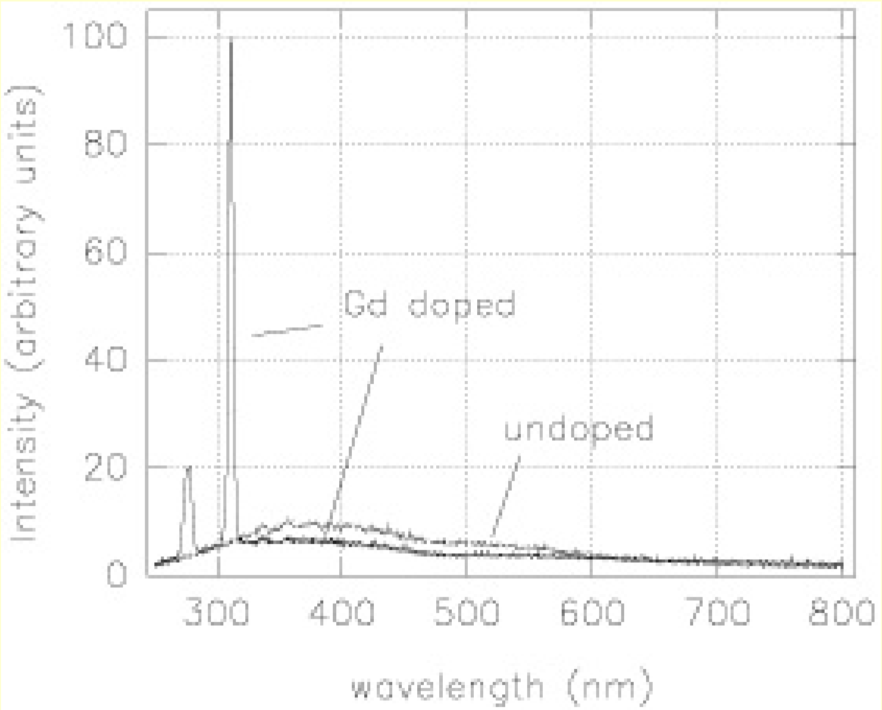
Z9 Decay: Tail, Middle, Seed



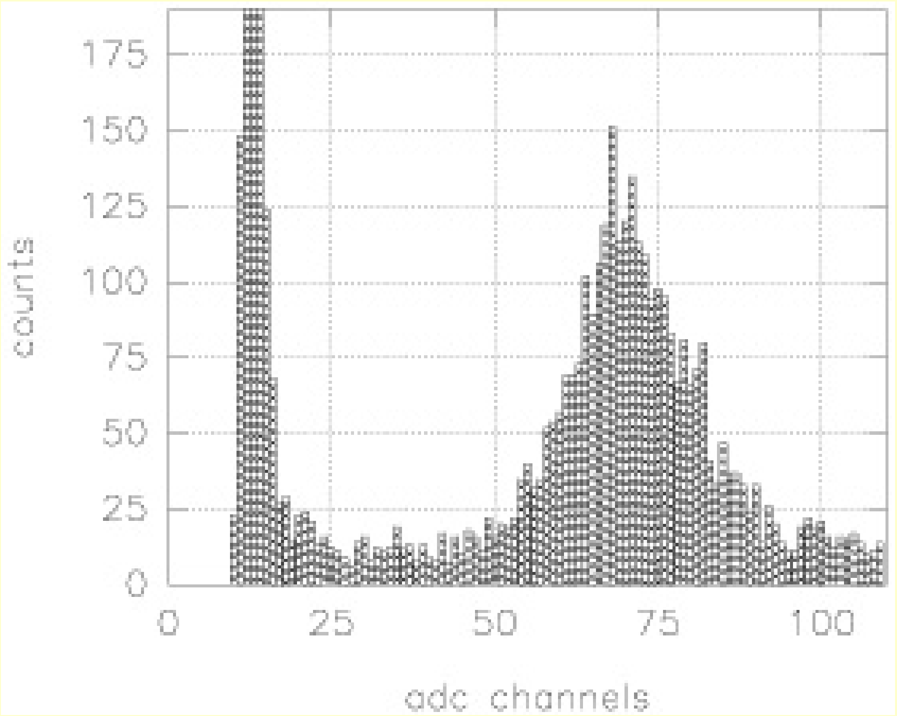
Doping is not uniform: Segregation < 1

Status of Lead Fluoride

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., in Proceedings of SCINT95, Delft, The Netherlands

Summary: Crystal R&D

- Two dopants increase PWO light output by ten folds as compared to PWO(Y). Both have poor longitudinal uniformity due to different segregation coefficients. **Approach: double doping.**
- Scintillating PbF_2 has light yield of 6 p.e./MeV after trying dopants of Sm, Tb, Na, K, Eu, La, Pr, Ce, Nd, Pm, Dy, Er and Gd at SIC.
- Ce doped lutetium oxyorthosilicate, LSO(Ce), and gadolinium orthosilicate, GSO(Ce), have light yield of 75% and 30% of NaI(Tl) and 40 and 60 ns decay time, respectively, but high price (60$/cc during R&D stage) caused by high melting point (~2,000^{o}C) and expensive raw material and poor uniformity.

  Approach: try mass production at SIC.