Pure CsI Crystals

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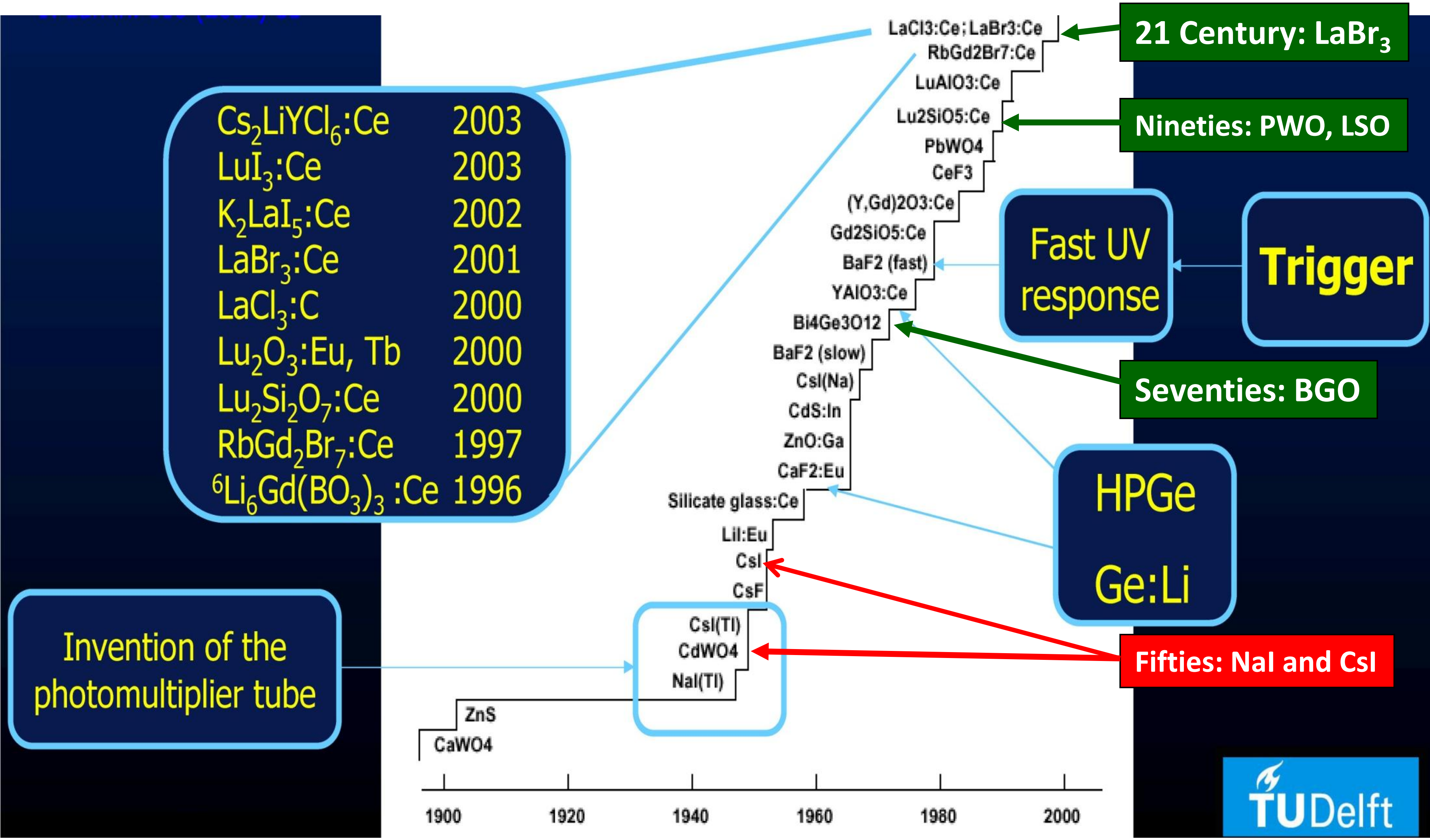
History of Scintillating Crystals

M.J. Weber, J. Lumin. 100 (2002) 35



Cs_2LiYCl_6:Ce	2003
LuI_3:Ce	2003
K_2LaI_5:Ce	2002
$LaBr_3$:Ce	2001
$LaCl_3$:C	2000
Lu_2O_3:Eu, Tb	2000
$Lu_2Si_2O_7$:Ce	2000
$RbGd_2Br_7$:Ce	1997
$^6Li_6Gd(BO_3)_3$:Ce	1996

21 Century: $LaBr_3$

Nineties: PWO, LSO

Fast UV response

Trigger

Seventies: BGO

HPGe

Ge:Li

Fifties: NaI and CsI

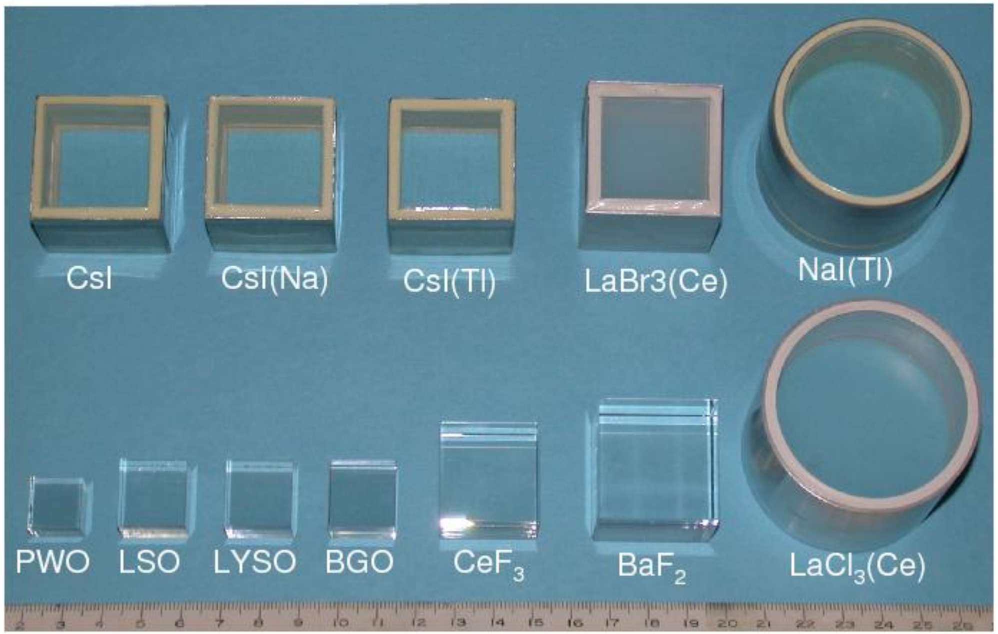
Invention of the photomultiplier tube

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 (°C)	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] (%/ °C)	-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	KLOE-2 SuperB SLHC?	CMS ALICE PANDA	HHCAL?

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

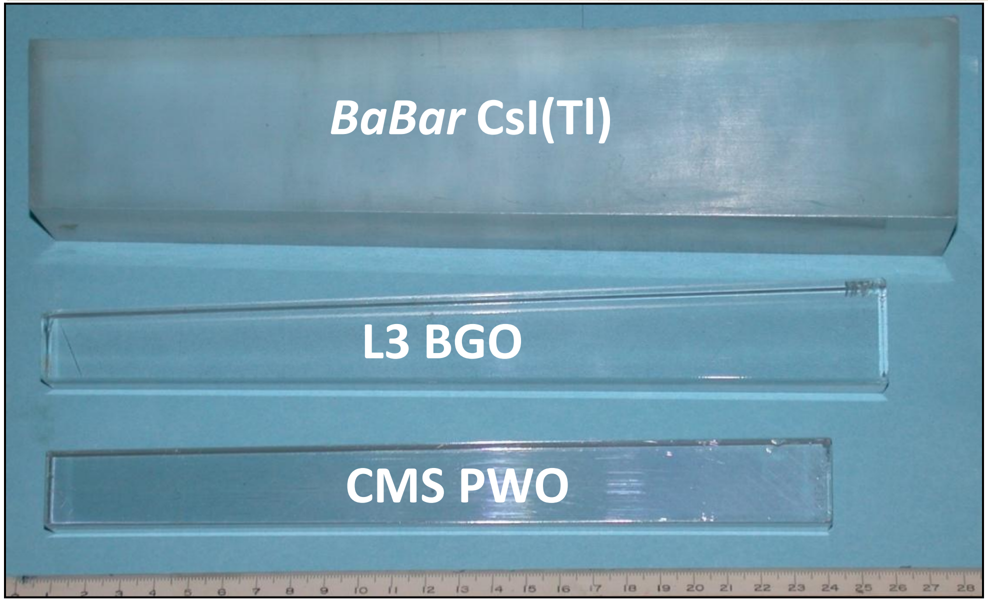
Crystal Density: Radiation Length



1.5 X_0 Cubic Samples:

Hygroscopic: Sealed

Non-hygro: Polished



Full Size Crystals:

BaBar CsI(Tl): 16 X_0

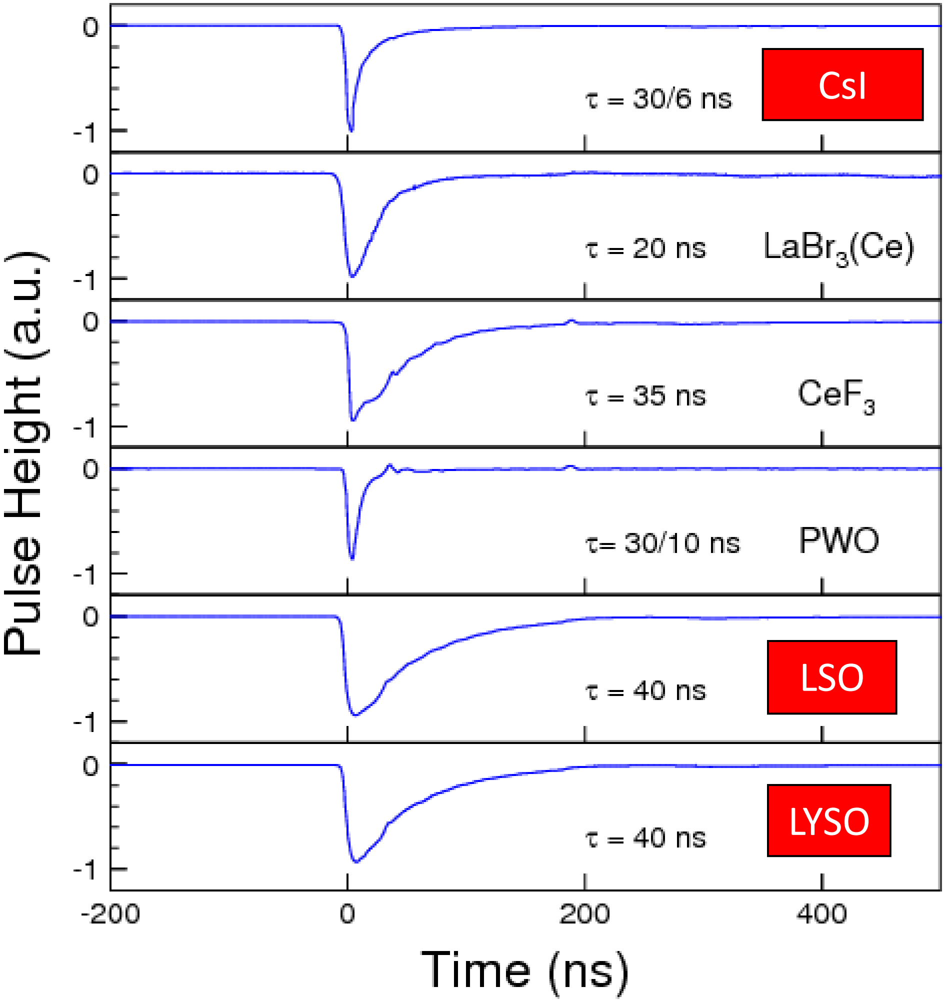
L3 BGO: 22 X_0

CMS PWO(Y): 25 X_0

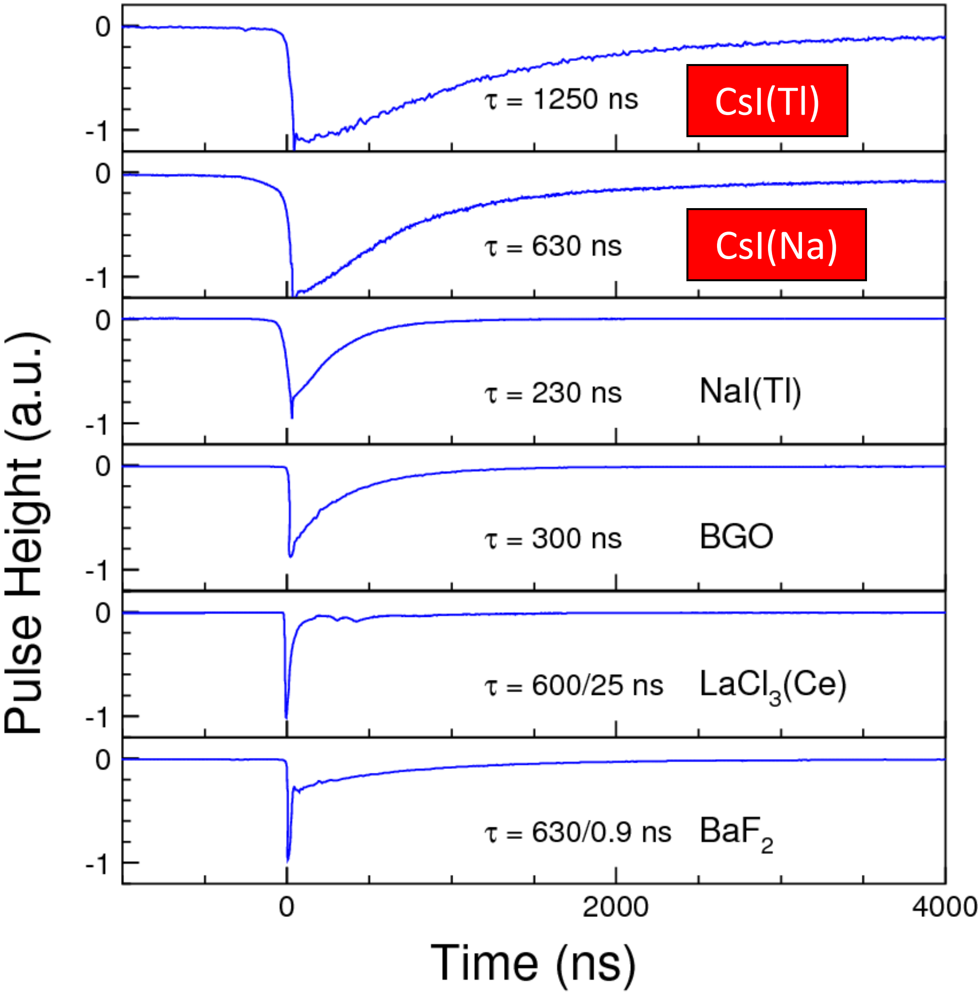
Scintillation Light Decay Time

Recorded with an Agilent 6052A digital scope

Fast Scintillators



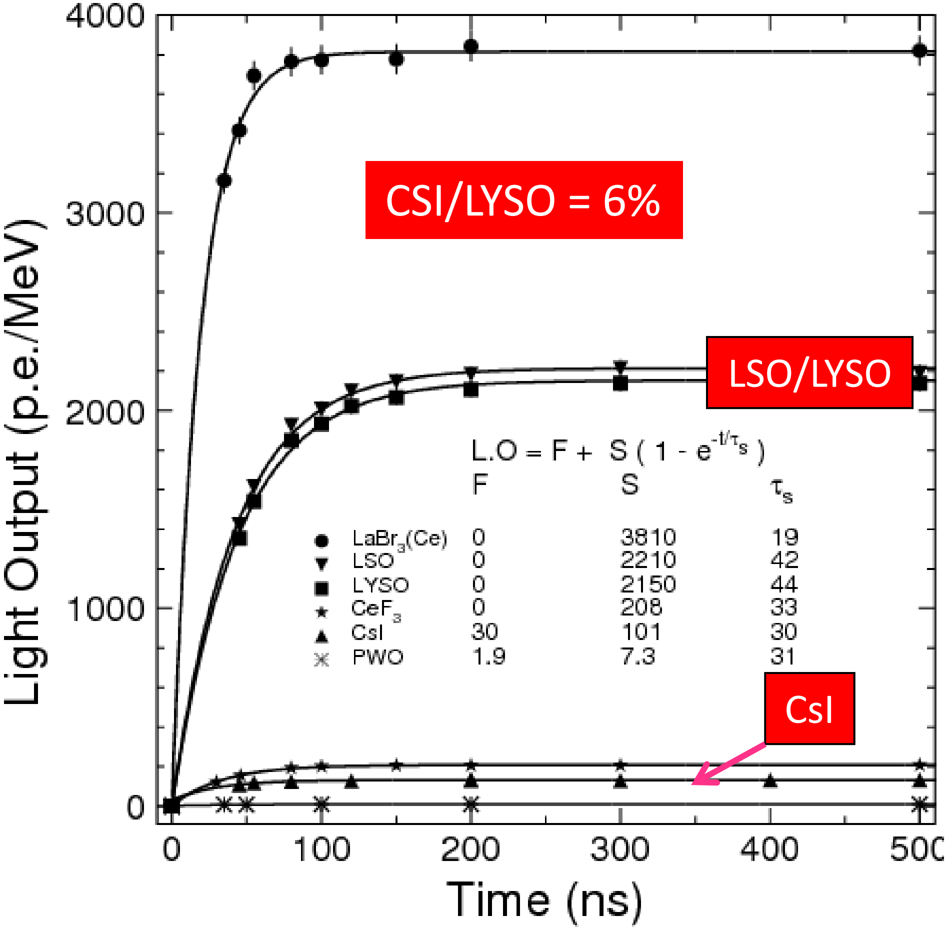
Slow Scintillators



Light Output & Decay Kinetics

Measured with Philips XP2254B PMT (multi-alkali cathode)
p.e./MeV: LSO/LYSO is 6 & 230 times of BGO & PWO respectively

Fast Crystal Scintillators



CSI/LYSO = 6%

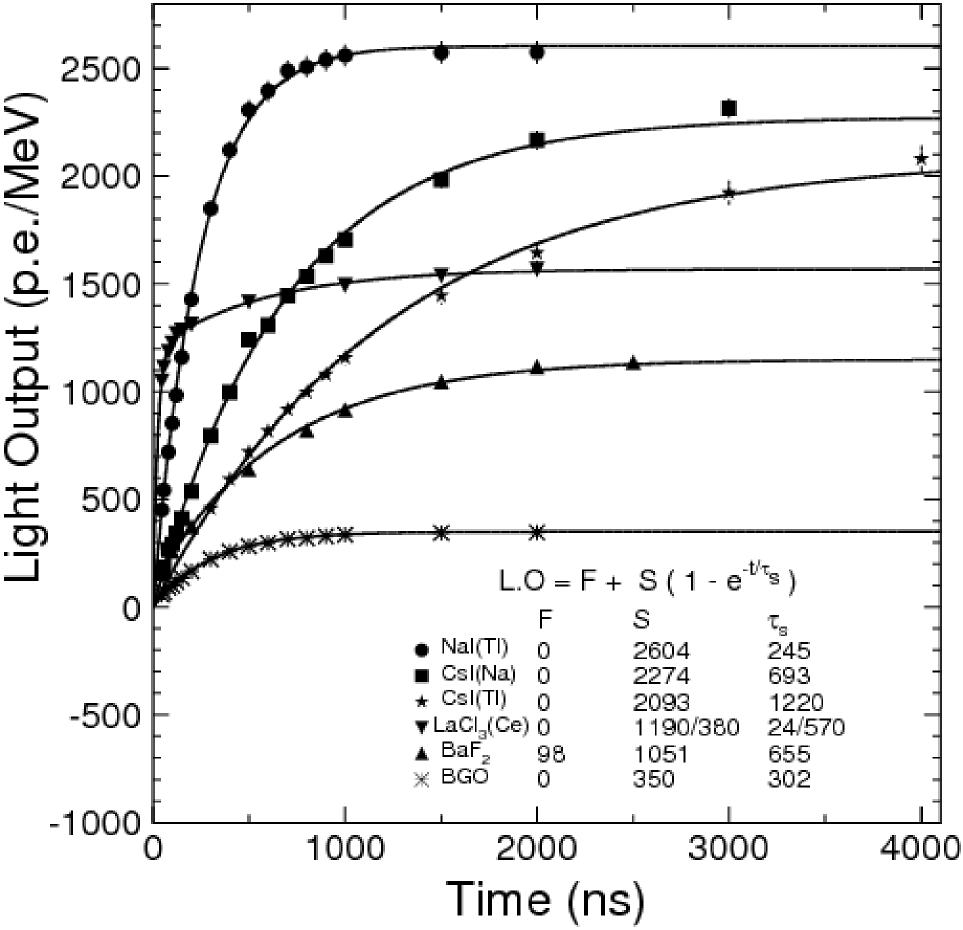
LSO/LYSO

CsI

$L.O = F + S(1 - e^{-t/\tau_s})$

		F	S	τ_s
●	$LaBr_3(Ce)$	0	3810	19
▼	LSO	0	2210	42
■	LYSO	0	2150	44
★	CeF_3	0	208	33
▲	CsI	30	101	30
✳	PWO	1.9	7.3	31

Slow Crystal Scintillators

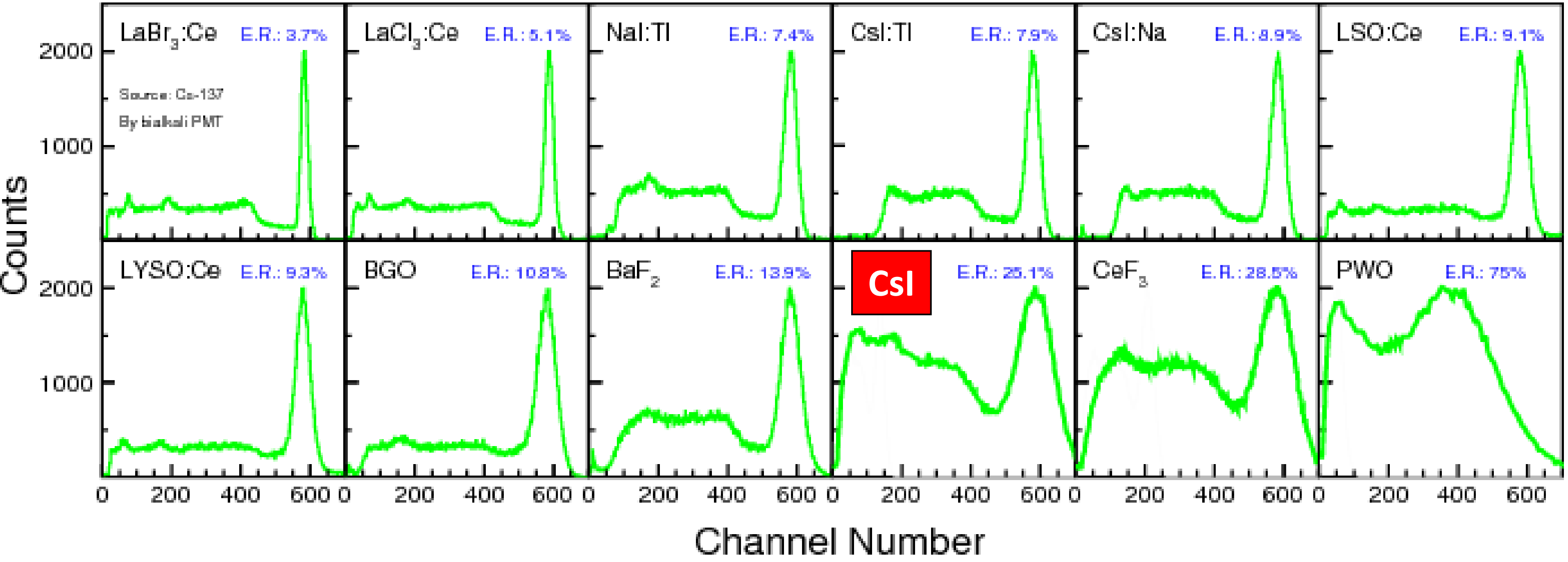


$L.O = F + S(1 - e^{-t/\tau_s})$

		F	S	τ_s
●	NaI(Tl)	0	2604	245
■	CsI(Na)	0	2274	693
★	CsI(Tl)	0	2093	1220
▼	$LaCl_3(Ce)$	0	1190/380	24/570
▲	BaF_2	98	1051	655
✳	BGO	0	350	302

^{137}Cs FWHM Energy Resolution

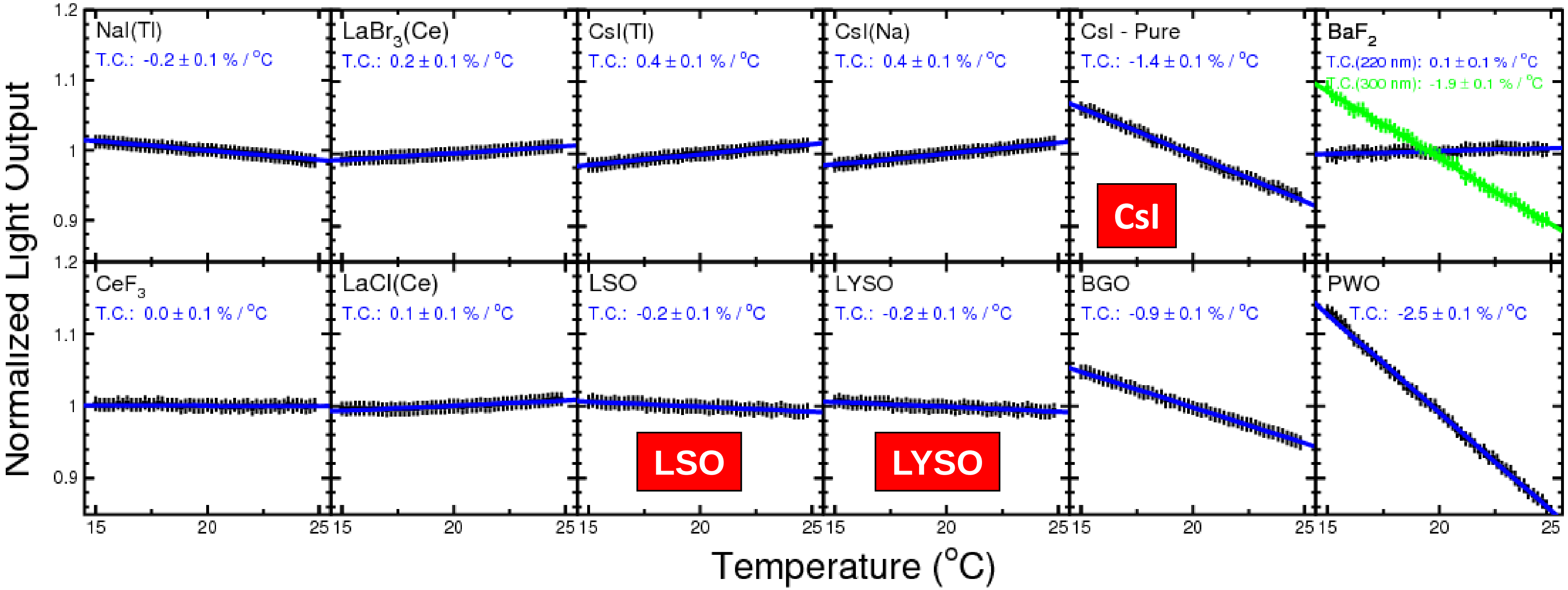
25% measured with Hamamatsu R1306 PMT with bi-alkali cathode, 2.5 times of BGO/LYSO



2% resolution and proportionality are important for γ–ray spectroscopy between 10 keV to 2 MeV

L.O. Temperature Coefficient

-1.4%/ºC measured between 15 - 25ºC
Temperature stabilization is required



Large temperature coefficient: CsI, BGO, BaF$_2$ and PWO

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

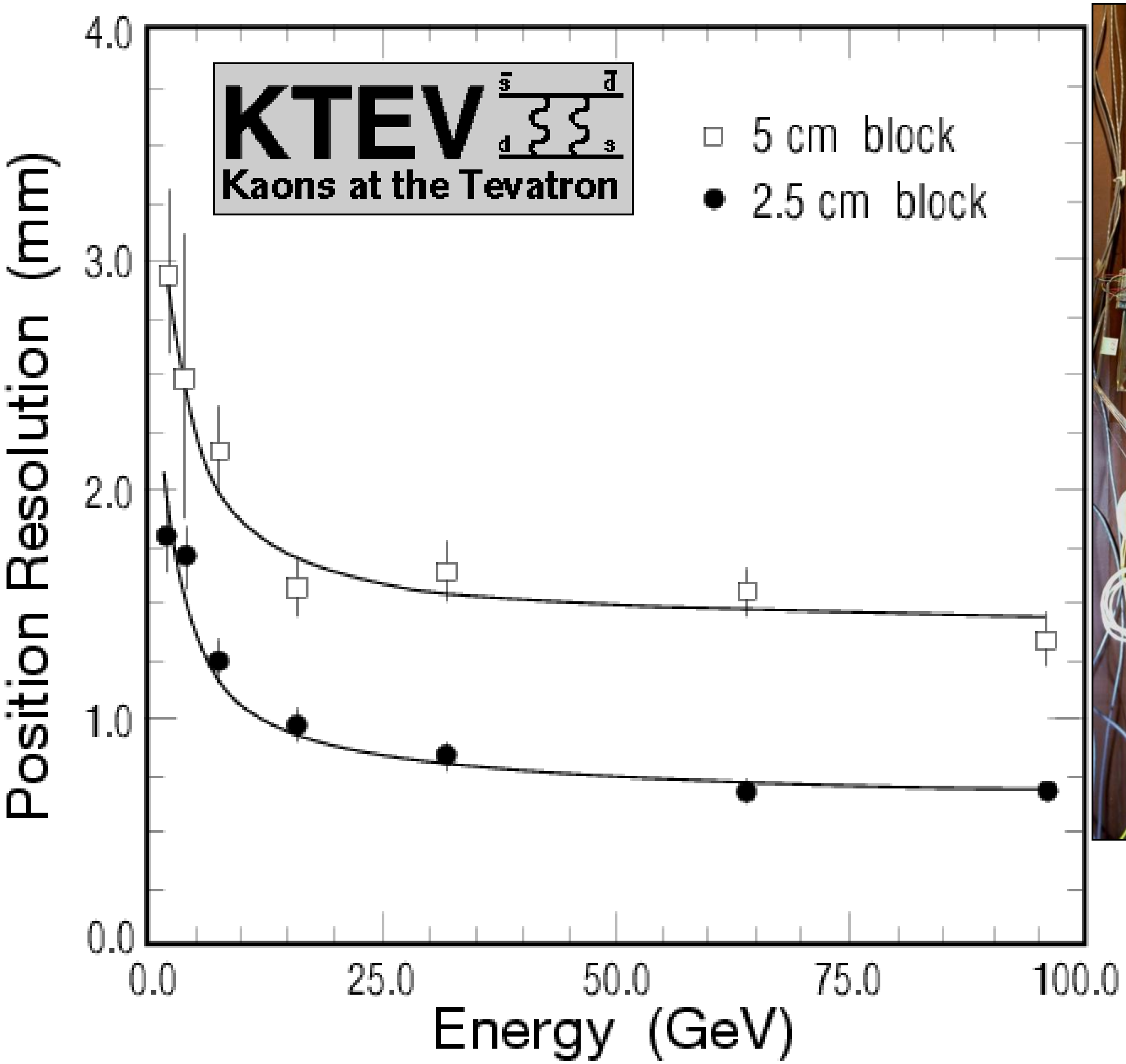
Future crystal calorimeters in HEP:

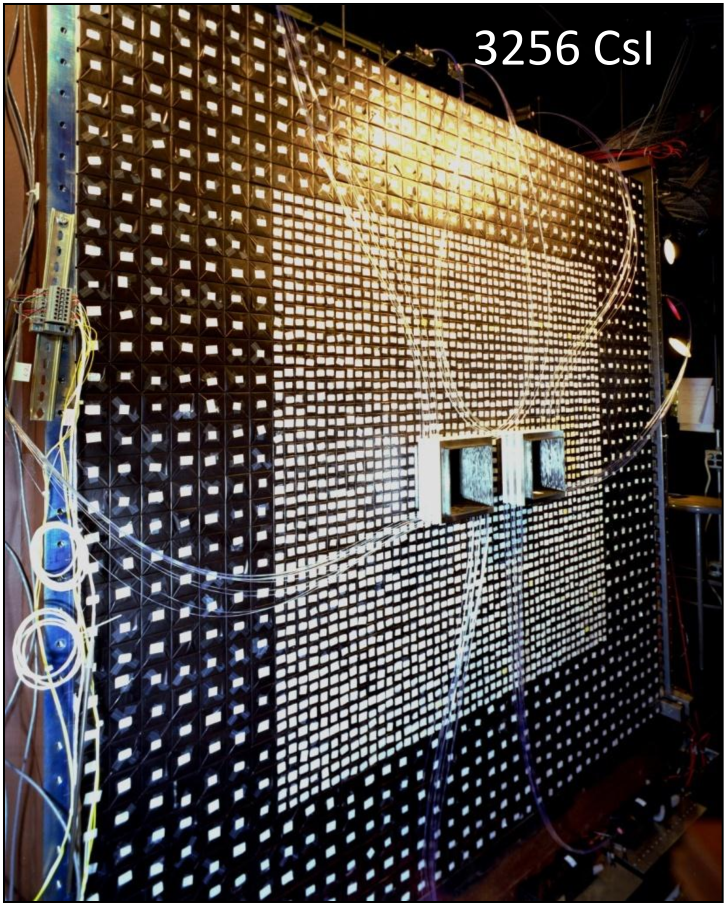
PWO for PANDA at GSI

LYSO for Mu2e, Super B and HL-LHC

PbF_2, PbFCl, BSO for Homogeneous HCAL

KTeV CsI Position Resolution





Sub mm position resolution.
L3 BGO & CMS PWO: 0.3 mm.

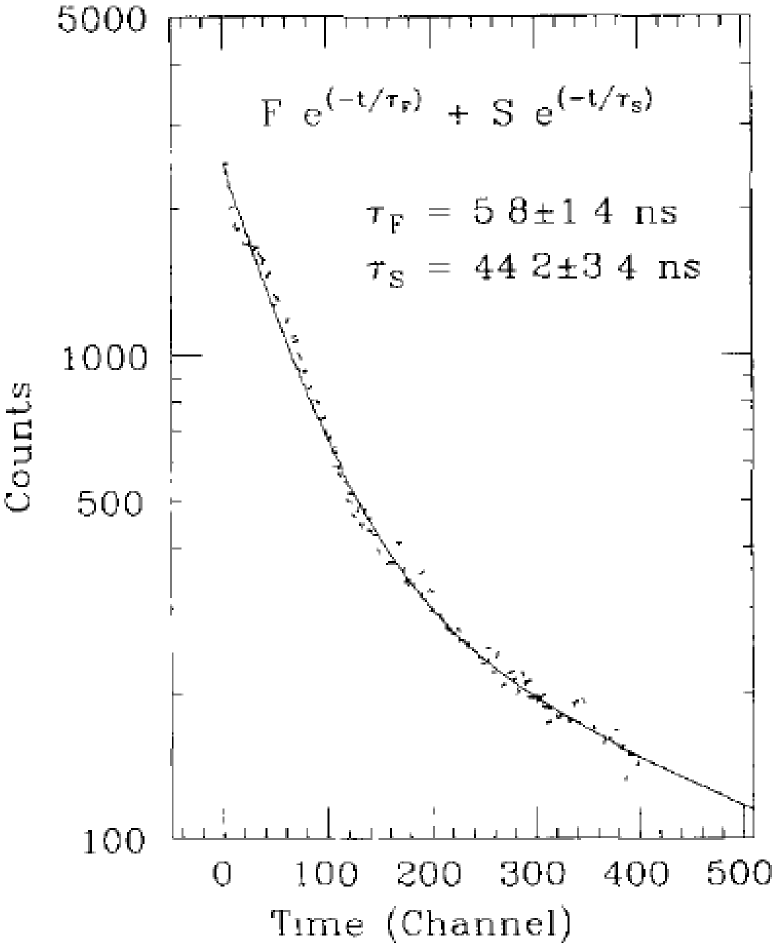
Light Output and Decay Time

Z. Wei and R.-Y. Zhu, NIM A326 (1993) 508-513

Sample	Dimension [cm]	Wrapping
CsI-1	∅2×2	Teflon
CsI-2	∅2×2	Teflon
CsI-3	4×4×20	aluminum
CsI-4	5×5×19	aluminum

Sample	*F* [%]	τ_F [ns]	*S* [%]	τ_S [ns]
CsI-1	33	6.1 ± 1.2	67	30 ± 8
CsI-2	29	6.6 ± 1.7	71	27 ± 5
CsI-3	22	7.1 ± 1.0	78	41 ± 6
CsI-4	27	6.8 ± 1.1	73	43 ± 6

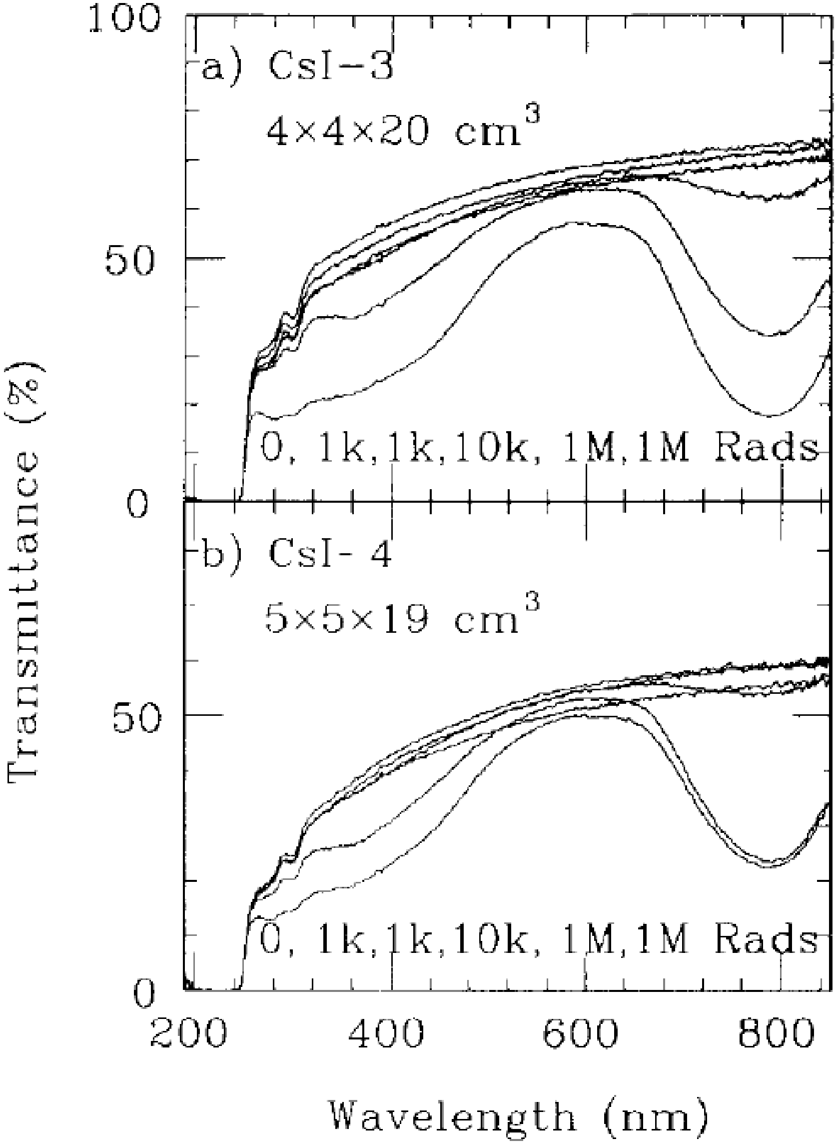
Sample	S.G. [ns]	L.Y. [p.e./MeV]	L.G. [ns]	L.Y. [p.e./MeV]
CsI-3	30	55	4000	96
CsI-4	30	55	4000	94

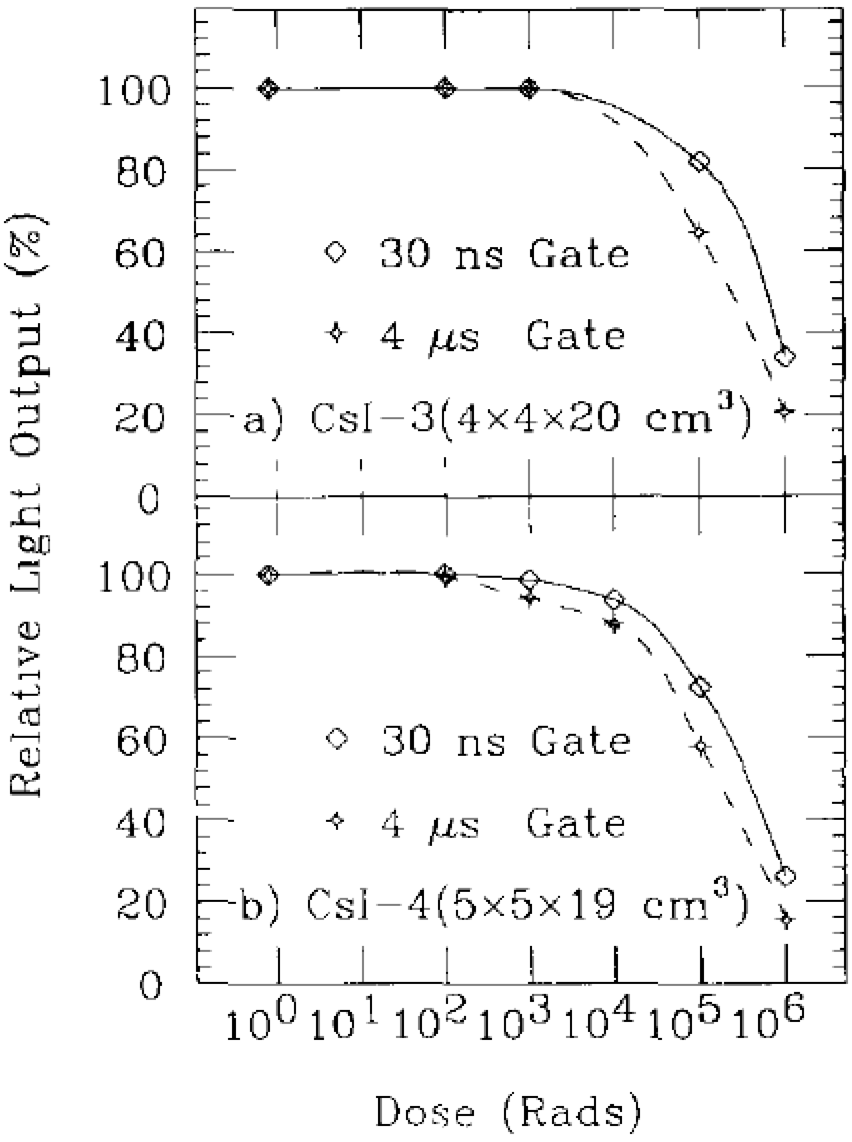


Fast/Slow: Amplitude: 1/3; Decay time: <10 ns/30-40 ns

Significant Damage: > 10 krad

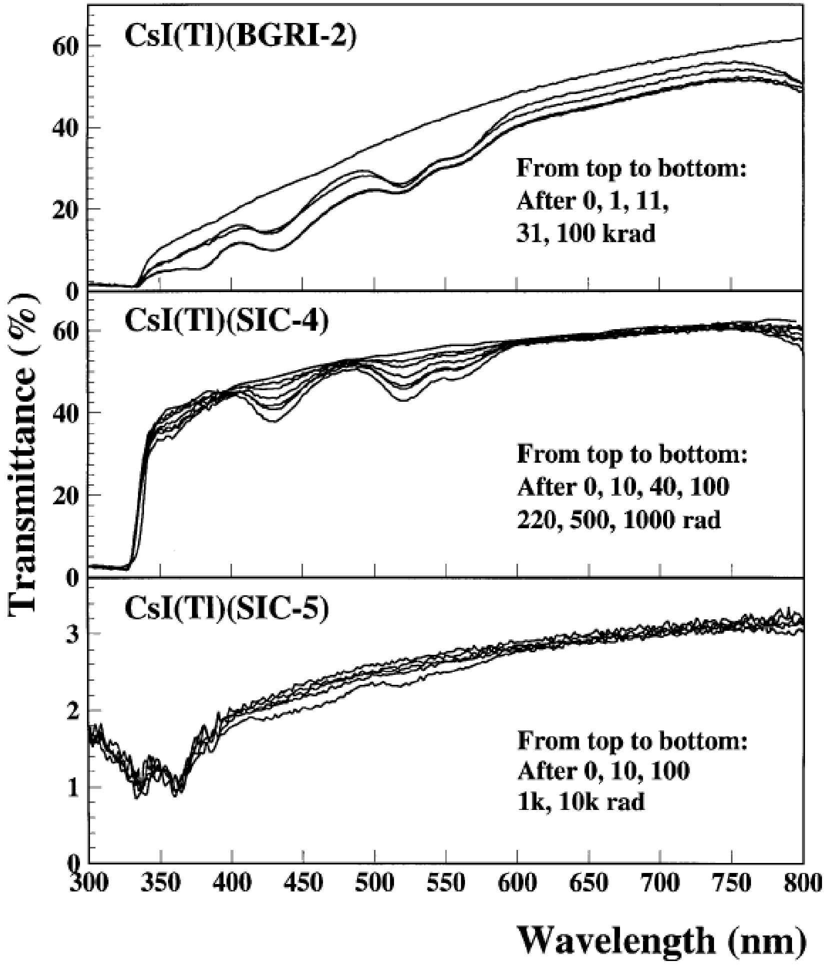
Z. Wei and R.-Y. Zhu, NIM A326 (1993) 508-513

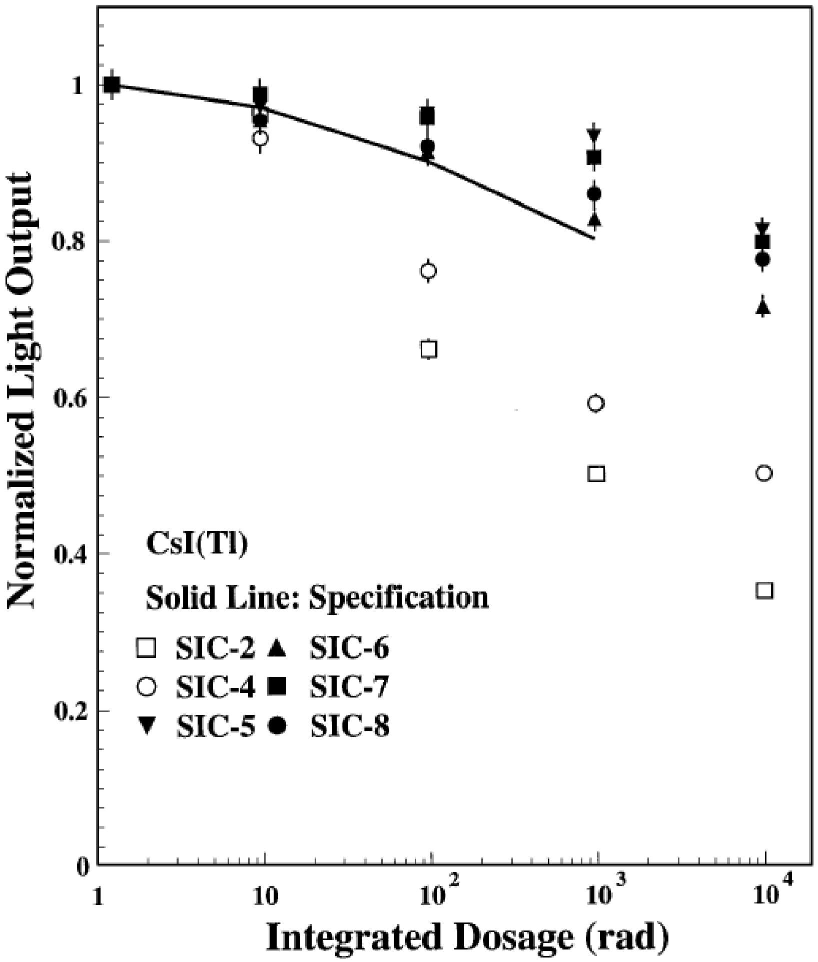




Comparison with CsI(Tl)

R.-Y. Zhu, NIM A413 (1998) 297-311

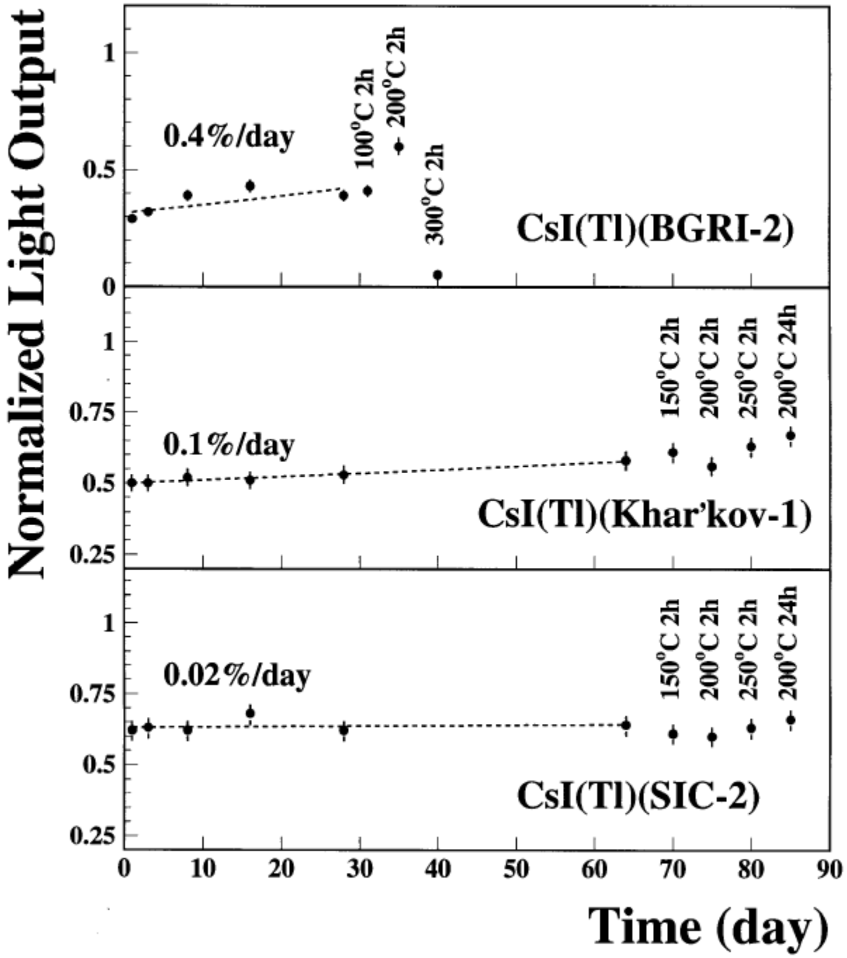


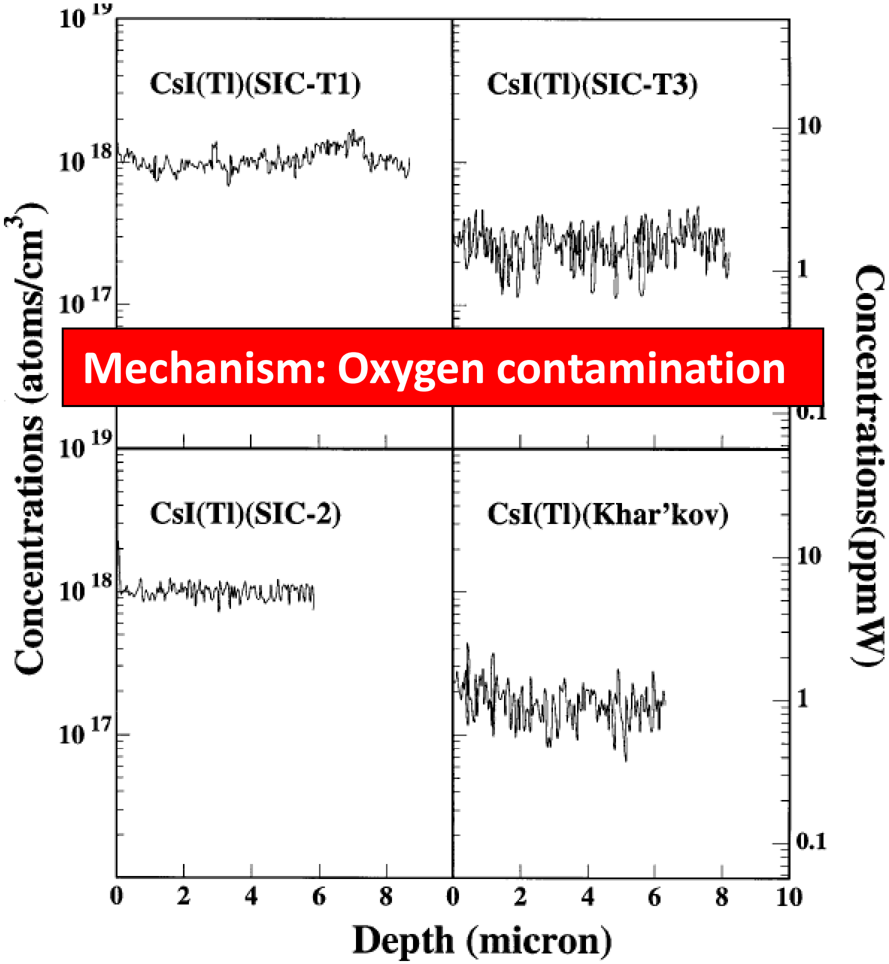


CsI is more than ten times radiation harder than CsI(Tl)

Damage Recovery & Mechanism

R.-Y. Zhu, NIM A413 (1998) 297-311





Mechanism: Oxygen contamination

Damage recovers very slow, so monitoring is less important
No thermal annealing, so crystal is wasted after radiation damage

Summary

- Pure CsI is a fast crystal with decay time less than 30 ns, and light output of 5.5%/22% of LYSO/BGO.
- It has reasonable radiation harness: more than ten times worse than LYSO, but more than ten times better than CsI(Tl).
- Its radiation damage does not recover under room temperature, indication a calorimeter more stable than BGO or PWO.
- Thermal annealing does not work for CsI(Tl).
- Radiation damage mechanism of CsI(Tl) is understood to be due to oxygen contamination. Crystals grown in vacuum would help to improve its radiation hardness.
- Commercially produced CsI is not radiation hard. For SuperB applications an R&D program should include the last three points with an aim to improve quality of CsI crystals to meet SuperB requirements. Since crystals can not be reused, this will be an expensive exercise as compared to other crystals.
- Vendors: Saint-Gobain, Kharkov and SIC. Mass production cost at $5/cc seems achievable assuming a successful R&D program leading to <5% rejection caused by the radiation hardness requirement. The cost will be increased correspondingly if this rejection rate is higher than 5%.