An LSO/LYSO Crystal Calorimeter for the ILC

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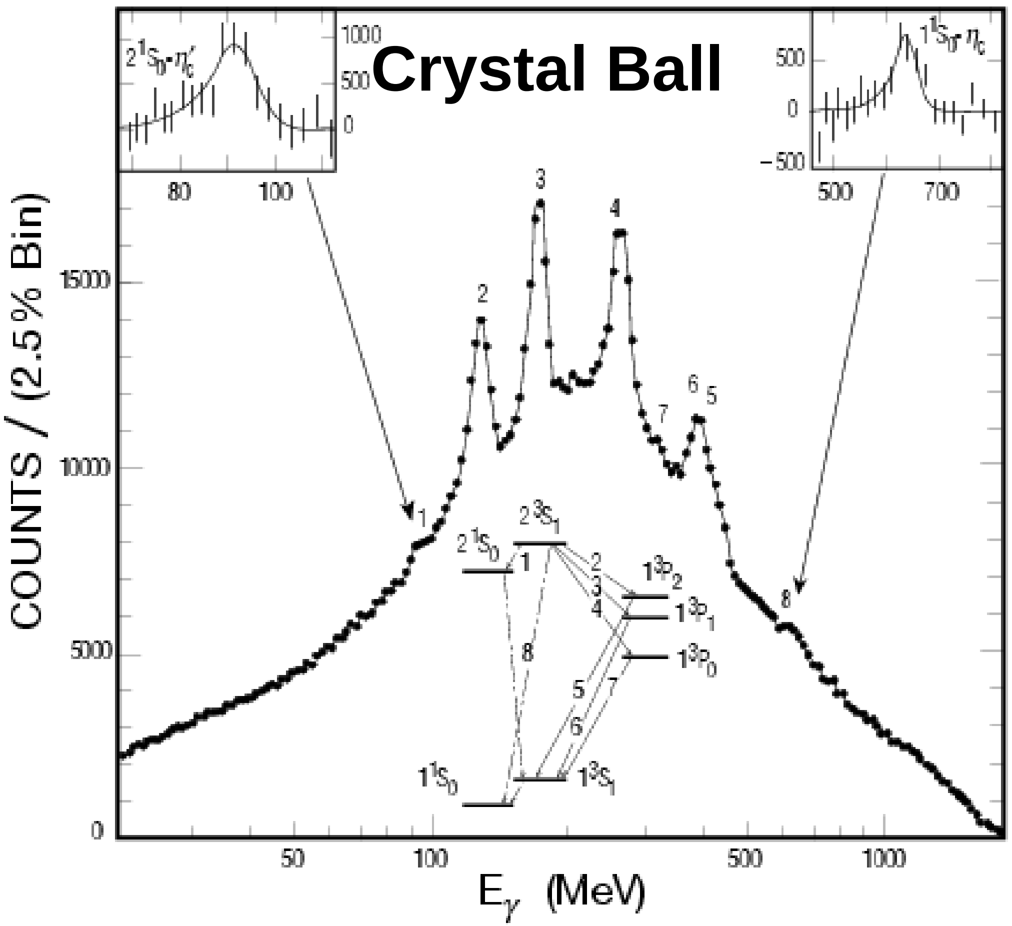
Why a Crystal Calorimeter

- Photons and electrons are fundamental particles in the SM and for new physics.
- Performance of a crystal calorimeter is well understood:
  - The best possible energy resolution, good position and photon angular resolution;
  - Good e/photon identification and reconstruction efficiency;
  - Good missing energy resolutions;
  - Good jet mass resolution.
- Physics discovery potential.

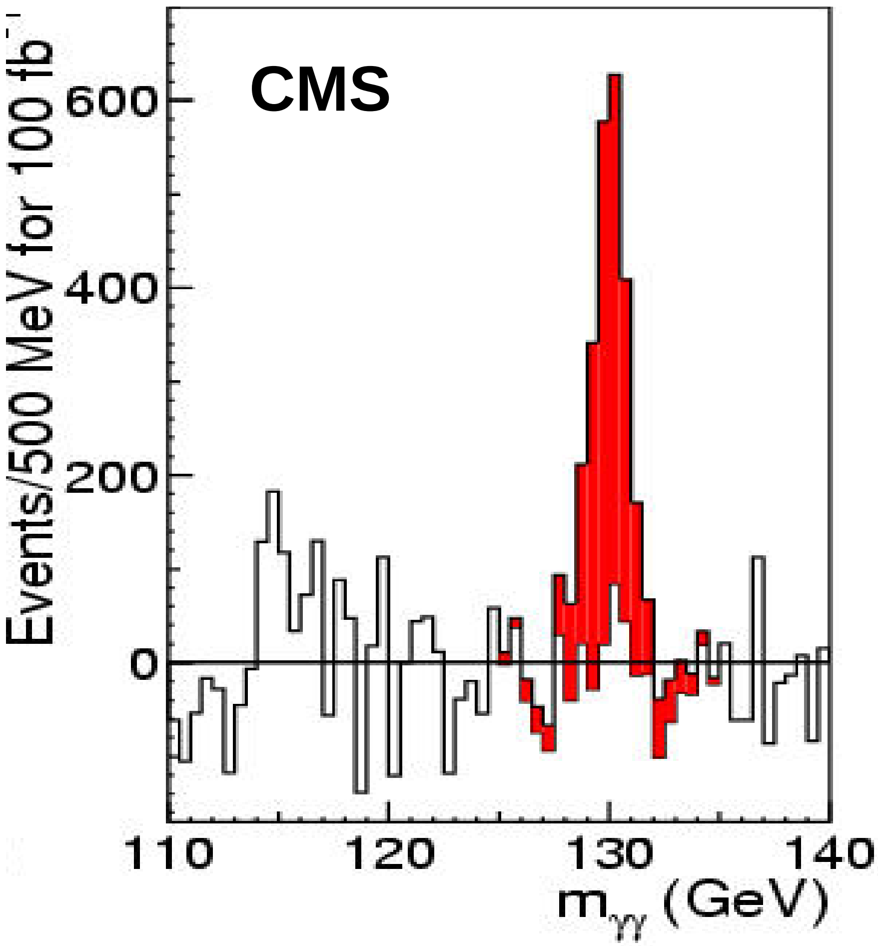
Physics in Crystal Calorimeters

Charmonium System Observed Through Inclusive Photons



Higgs Searches at LHC

$$H \to \gamma\gamma$$



Summary of Crystals for HEP

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 (ºC)	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
Molière 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
Refracti								.85
Hygros								No
Lumine (at peak								40
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	13	0.1 0.6	75	30
d(LY)/dT [b] (%/ ºC)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	-0.3	-0.1
Experiment	Crystal Ball	CLEO BaBar BELLE BES III	KTeV	TAPS (L*) (GEM)	L3 BELLE PANDA?	CMS ALICE PANDA? (BTeV)...	-	-

LSO/LYSO is a unique crystal with high light output & fast decay time

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

LSO/LYSO Mass Production

CTI: LSO

CPI: LYSO

Saint-Gobain LYSO

Additional Capability: SIPAT @ Sichuan, China

Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT)

SIPAT LSO

Quoted Price: 13-15 USD/cc

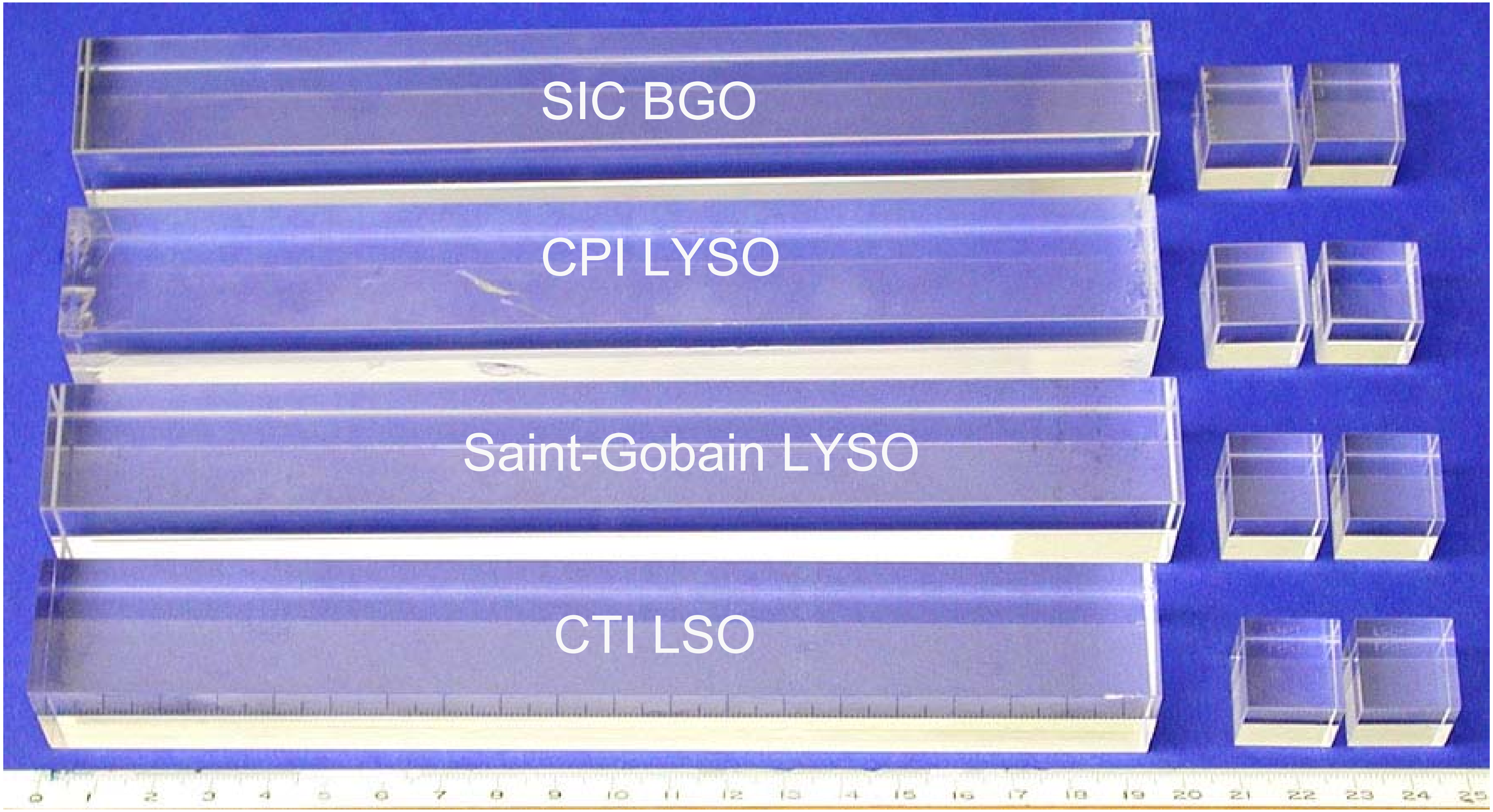
Φ80 x 70

Φ80 x 120

Large size LSO ($Ce:Lu_2SiO_5$) crystals are in production

BGO, LSO & LYSO Samples

Cube: 1.7 X1.7 x 1.7 cm (1.5 X_0)
Bar: 2.5 x 2.5 x 20 cm (18 X_0)

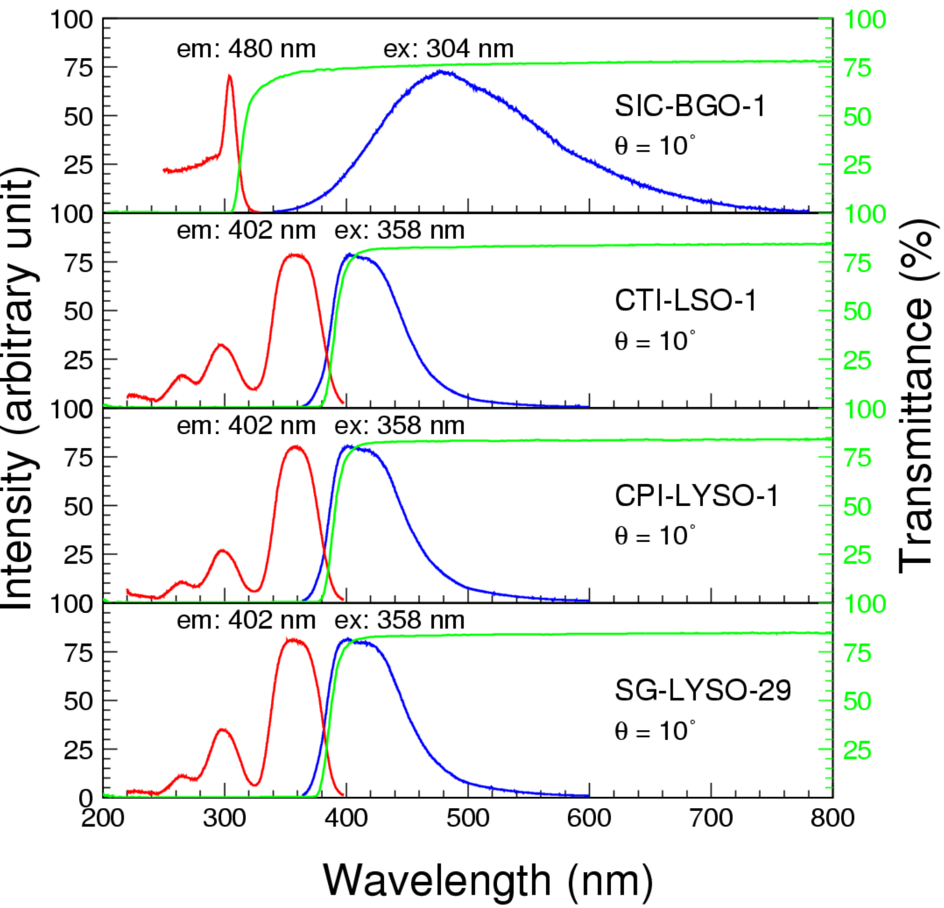


Excitation, Emission & Transmittance

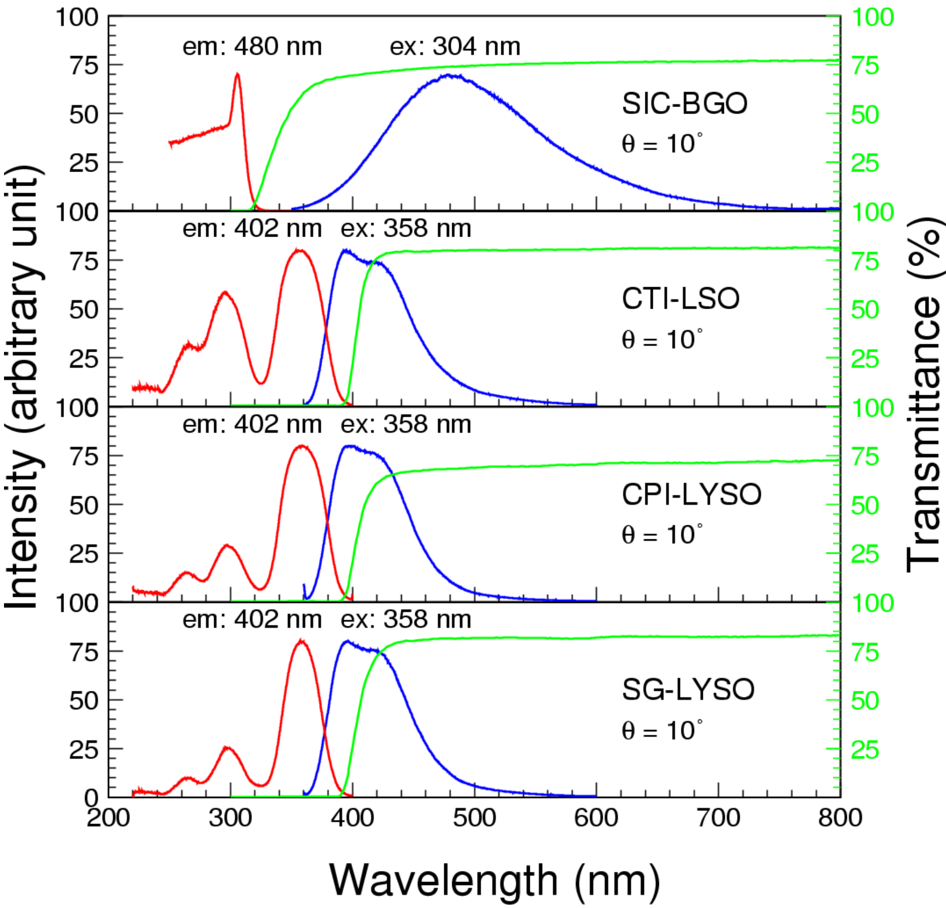
Identical transmittance, emission & excitation spectra

Part of emitted light may be self-absorbed in long samples

1.7 cm Cube



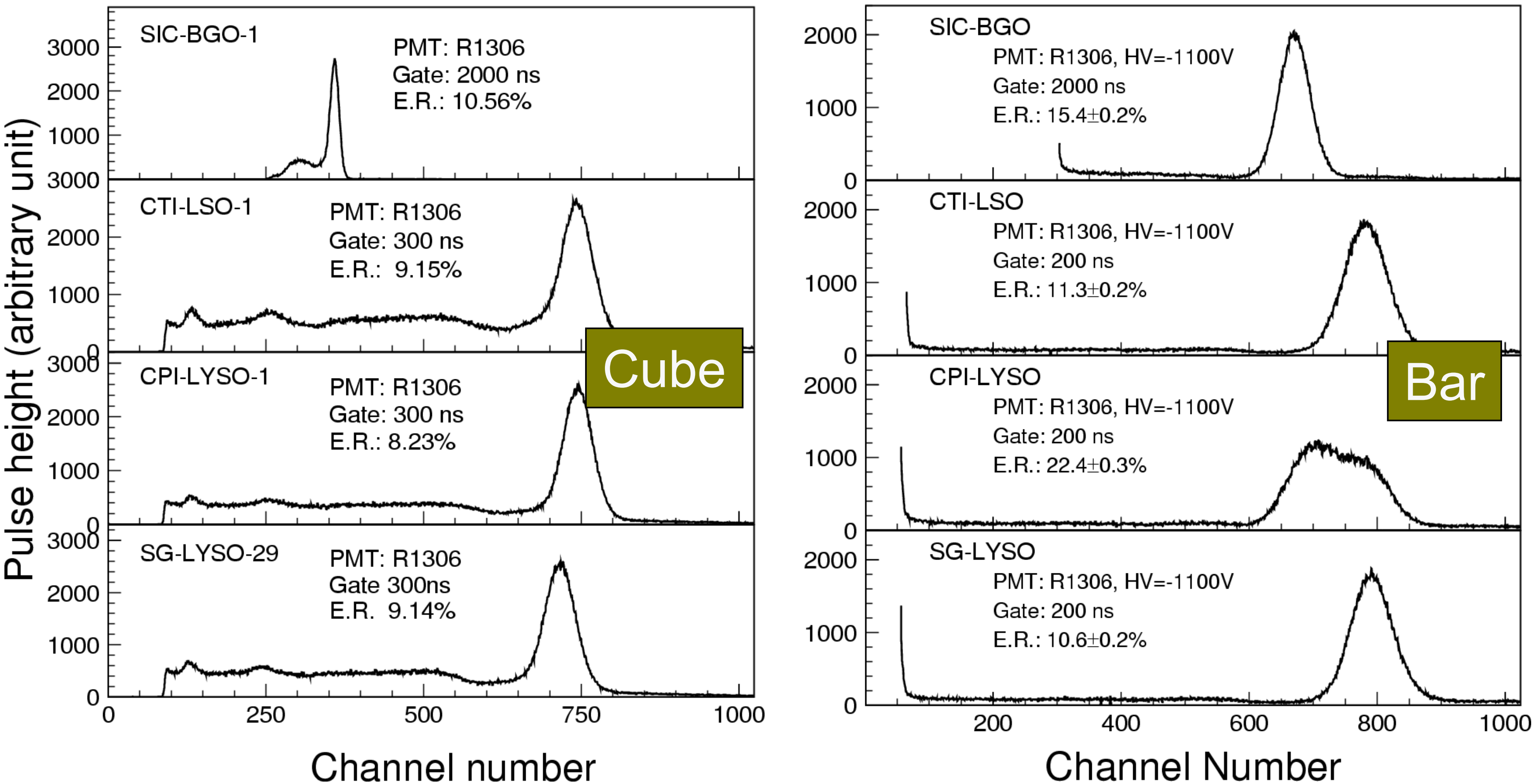
2.5 x 2.5 x 20 cm Bar



^{137}Cs & ^{22}Na Pulse Height Spectra

Cube and bar samples have 8% and 10% FWHM resolution respectively for ^{137}Cs (0.66 MeV) and ^{22}Na source (0.51 MeV)

CPI LYSO bar has double peak because of poor annealing

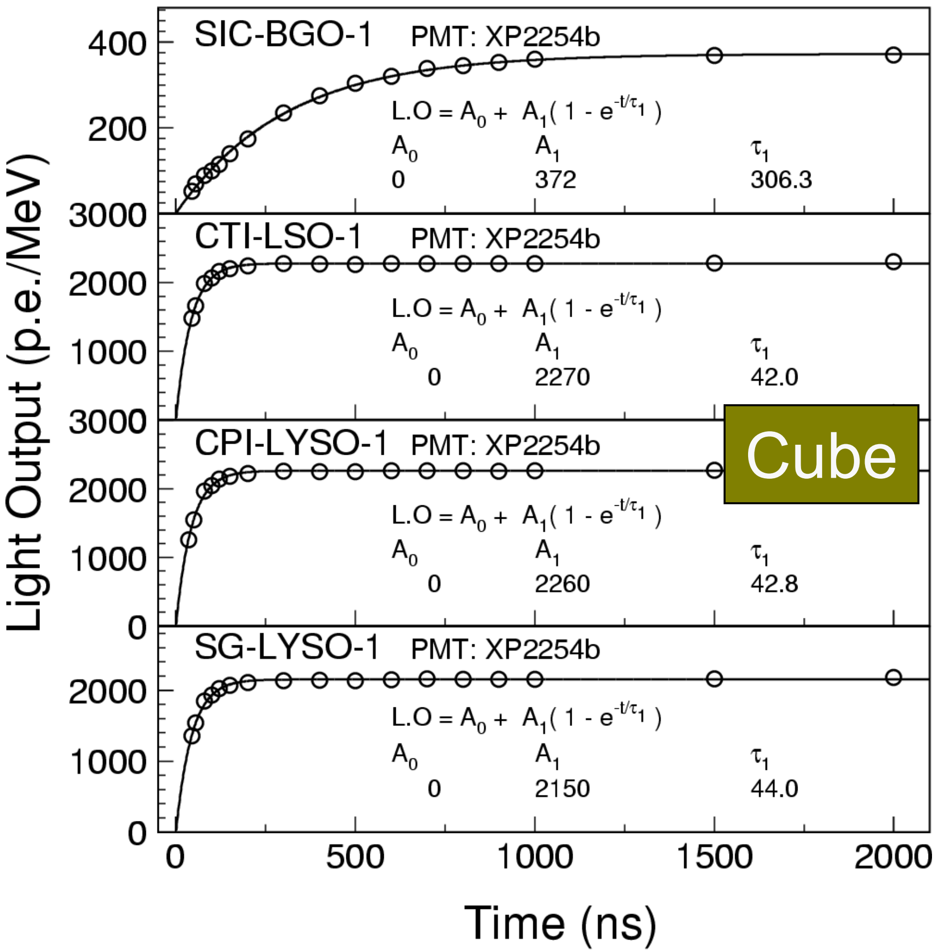


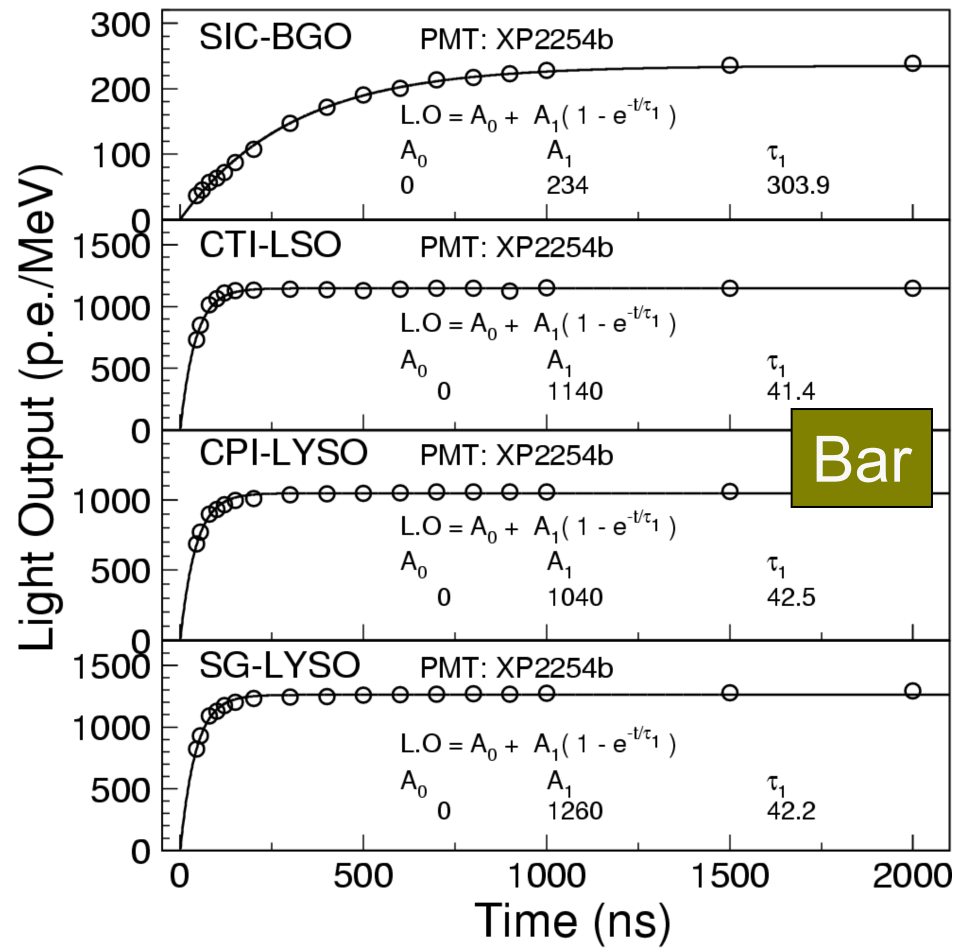
Light Output & Decay Time

LSO/LYSO Light yield: a factor of 6/100 of BGO/PWO

Bar sample has ~50% light of the cube sample

LSO/LYSO decay time: 42 ns compared to 300 ns of BGO

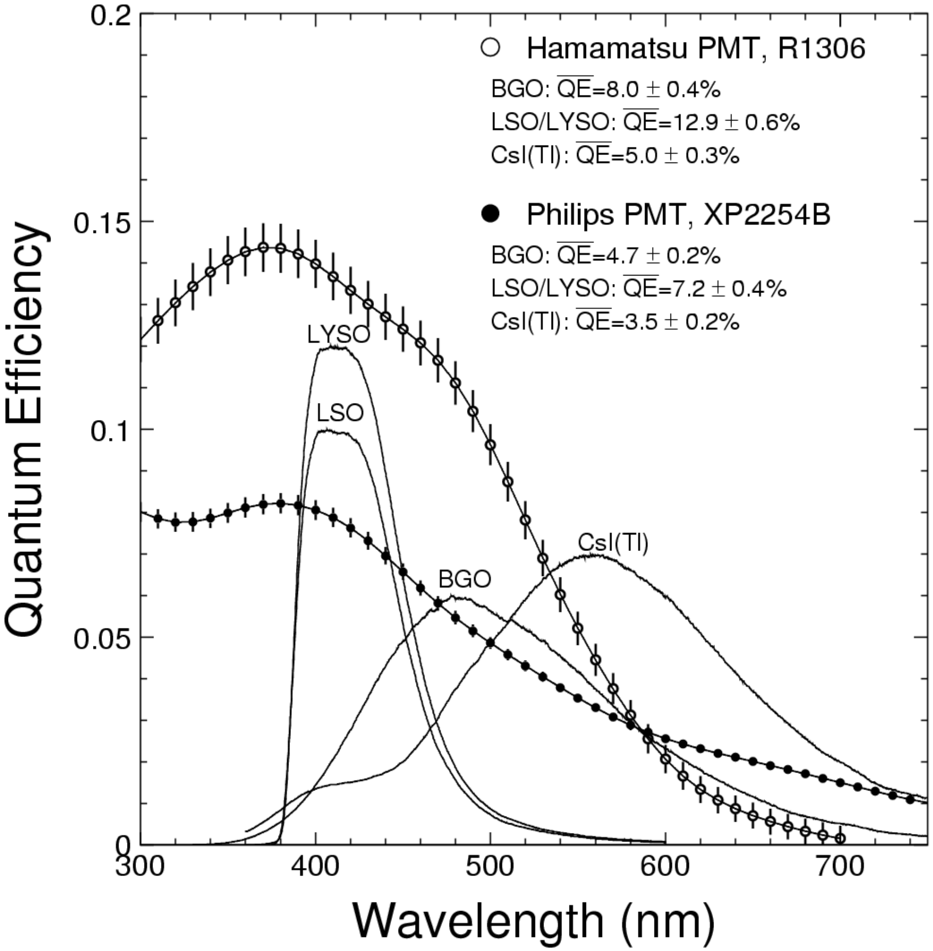


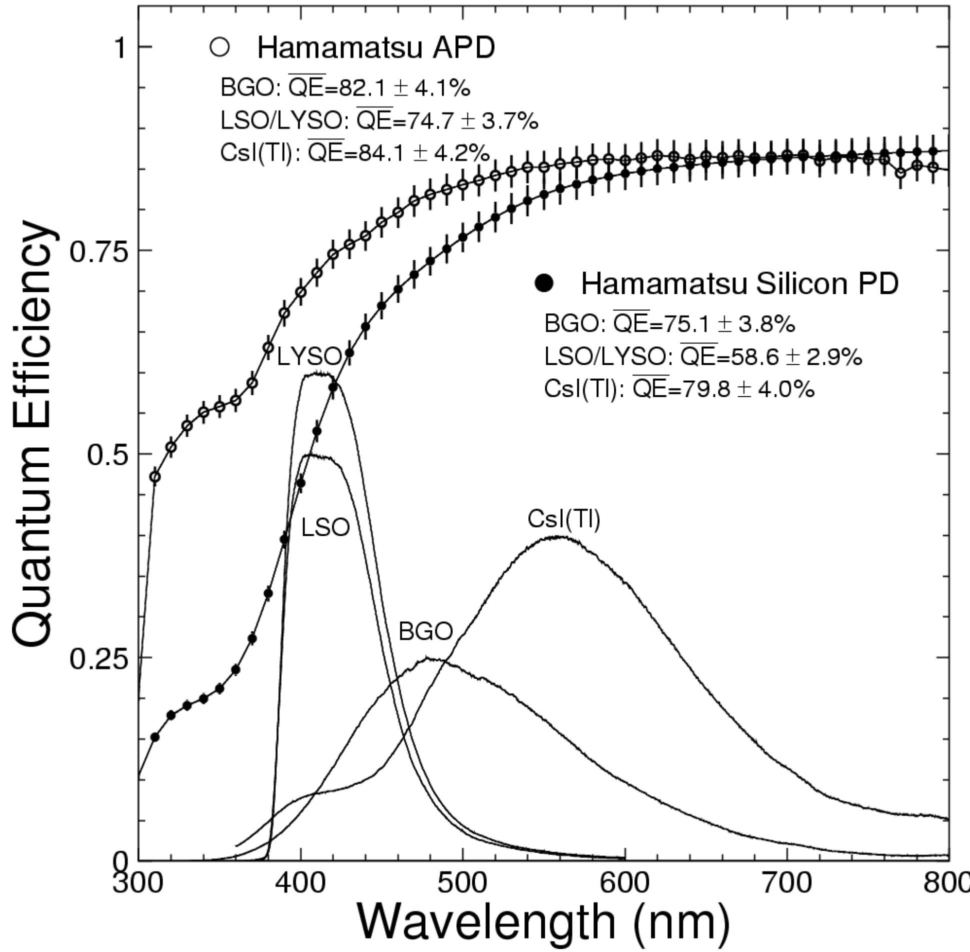


Emission Weighted Q.E.

Taking out PMT QE, LO of LSO/LYSO is 4 times BGO

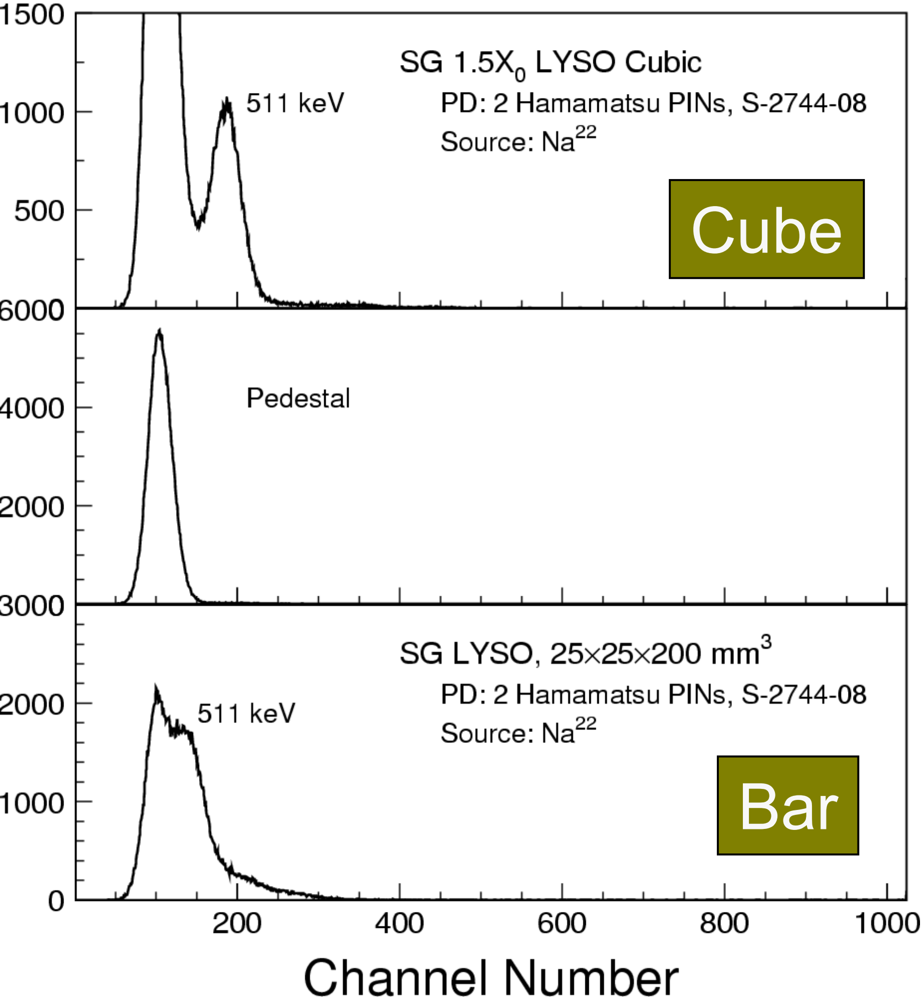
For Si PD and APD, QE is 59% and 75% respectively

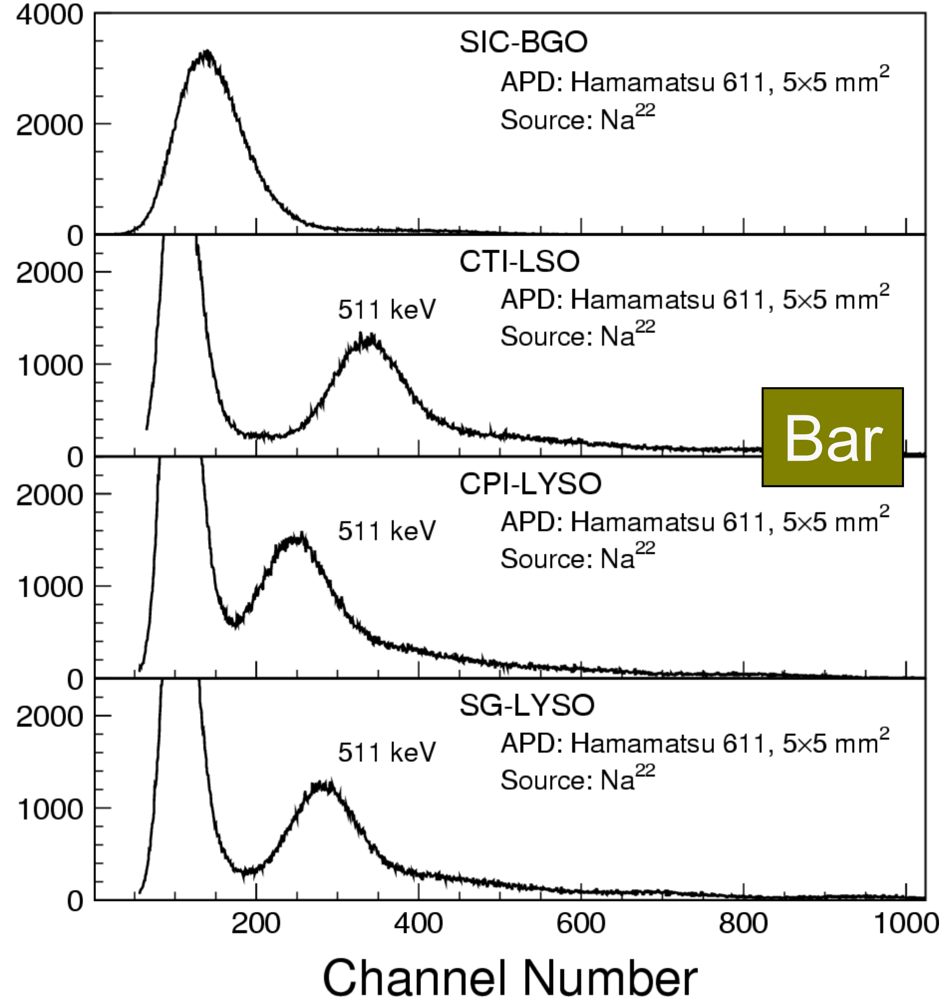




LSO/LYSO with Si Readout

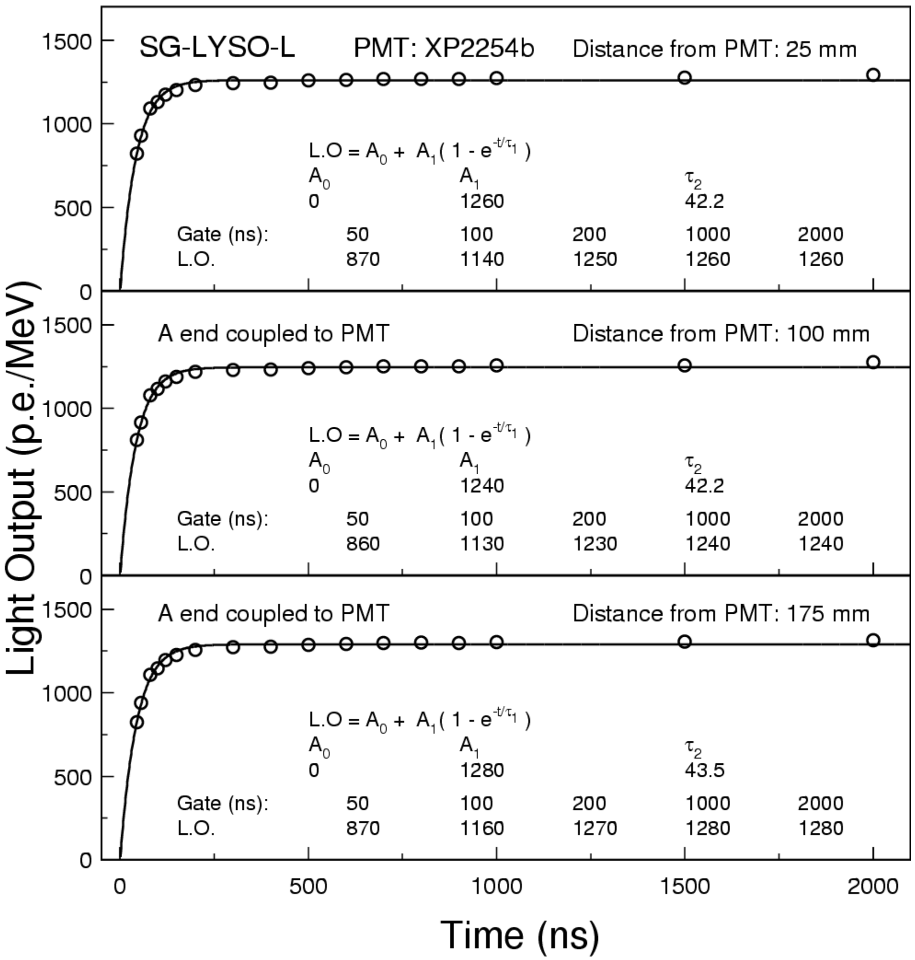
LSO/LYSO (not BGO) bars can be read in lab by using a single APD of 25 mm^2 (not Si PD) and 0.51 MeV ^{22}Na source

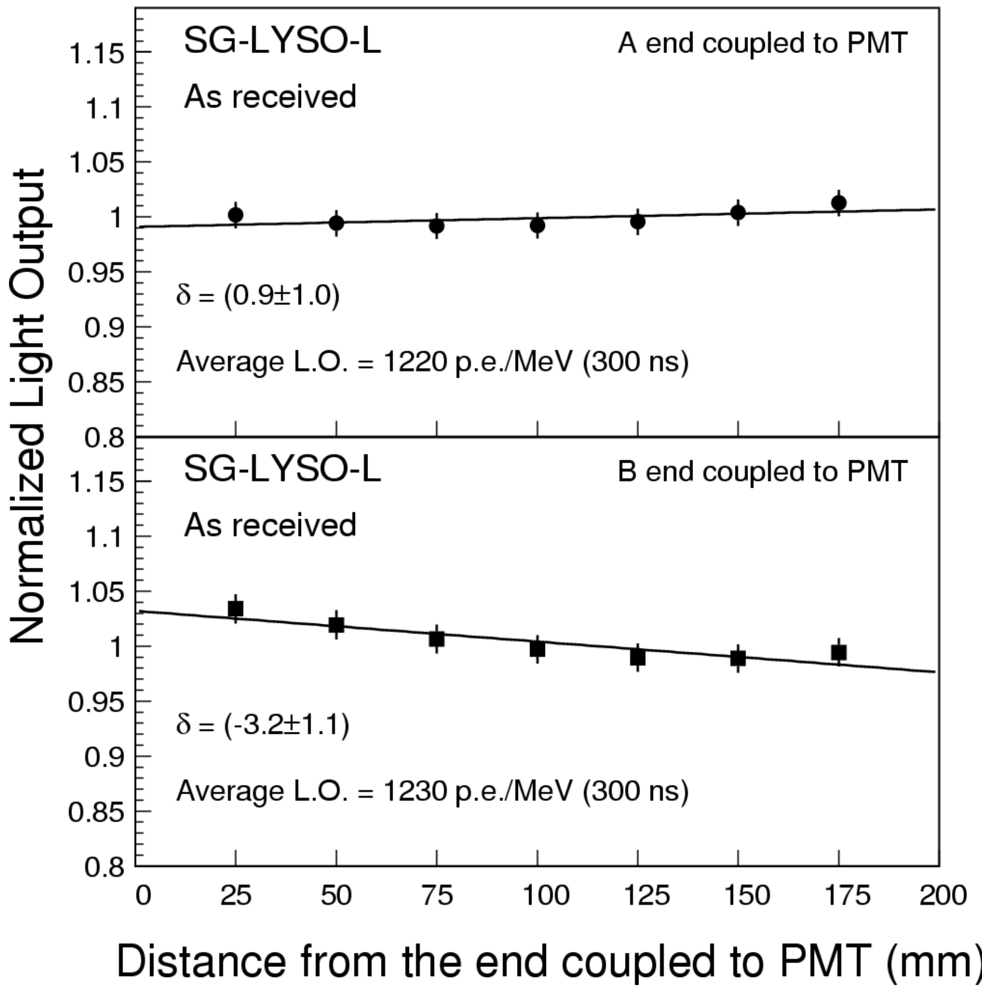




LYSO Light Response Uniformity

Uniformity depends on which end coupled to the PMT, indicating a not uniform light yield along crystal

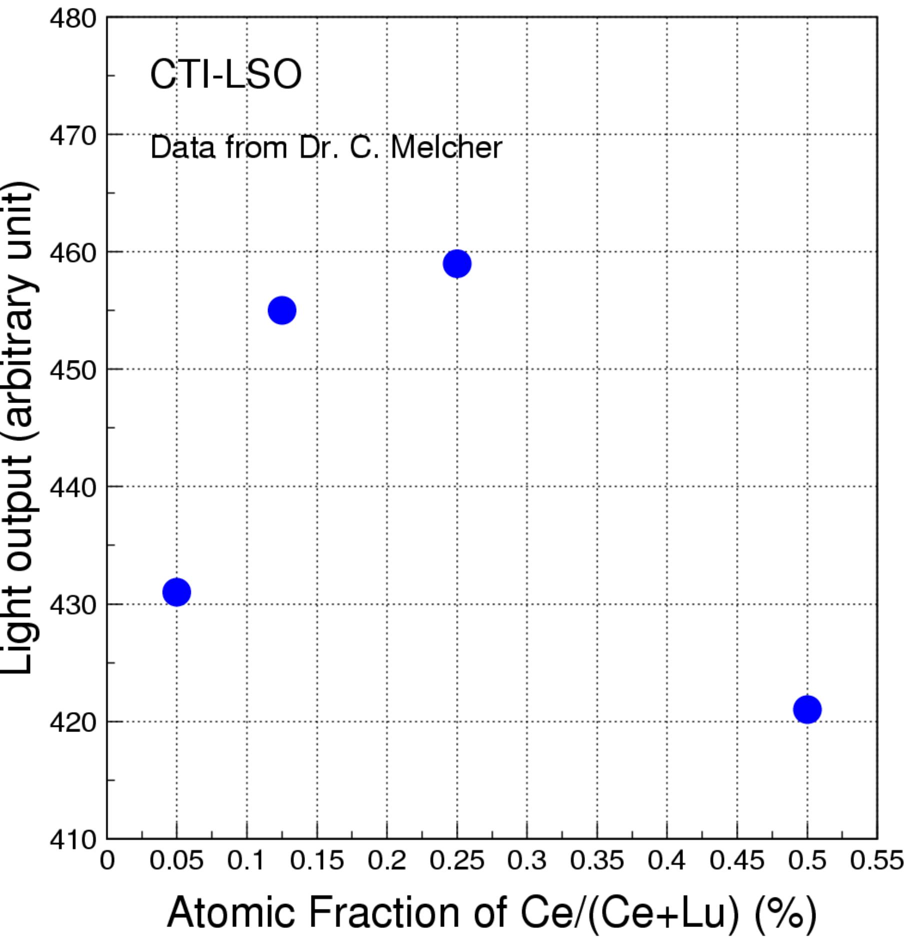


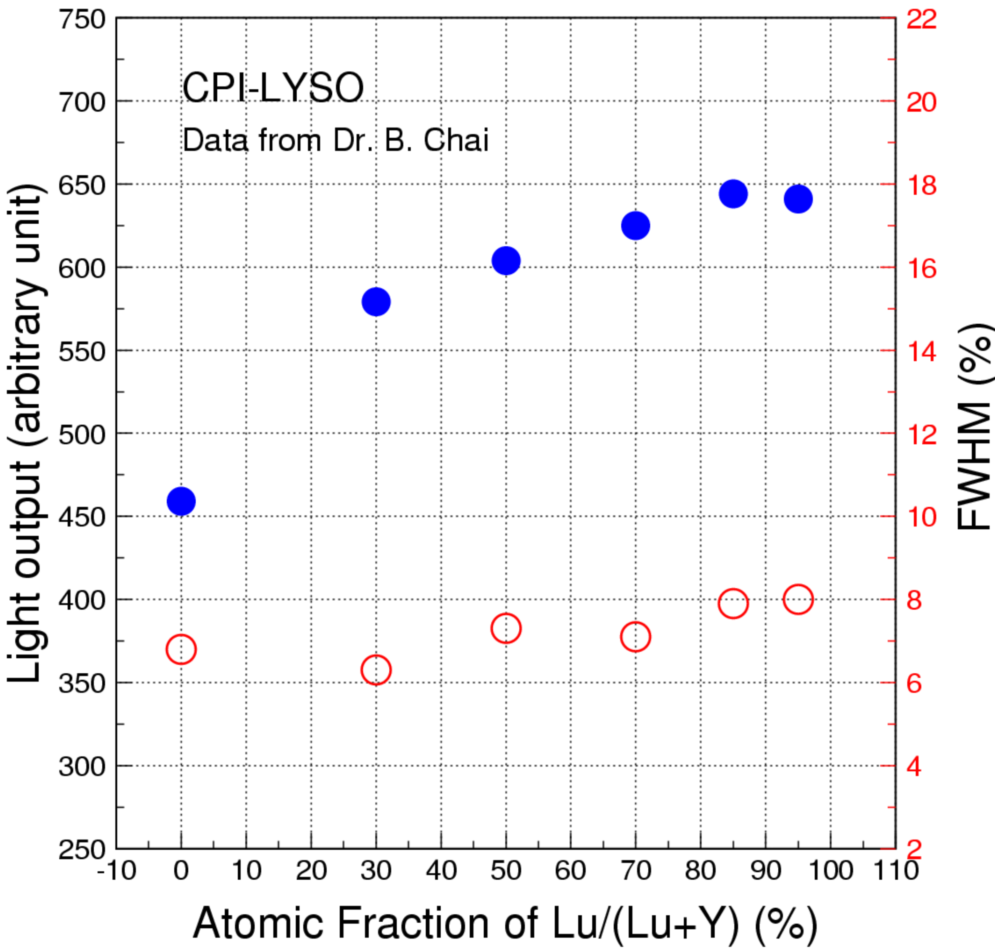


Possible Origin of Non Uniformity

C. Melcher: LO in LSO is a function of Ce concentration

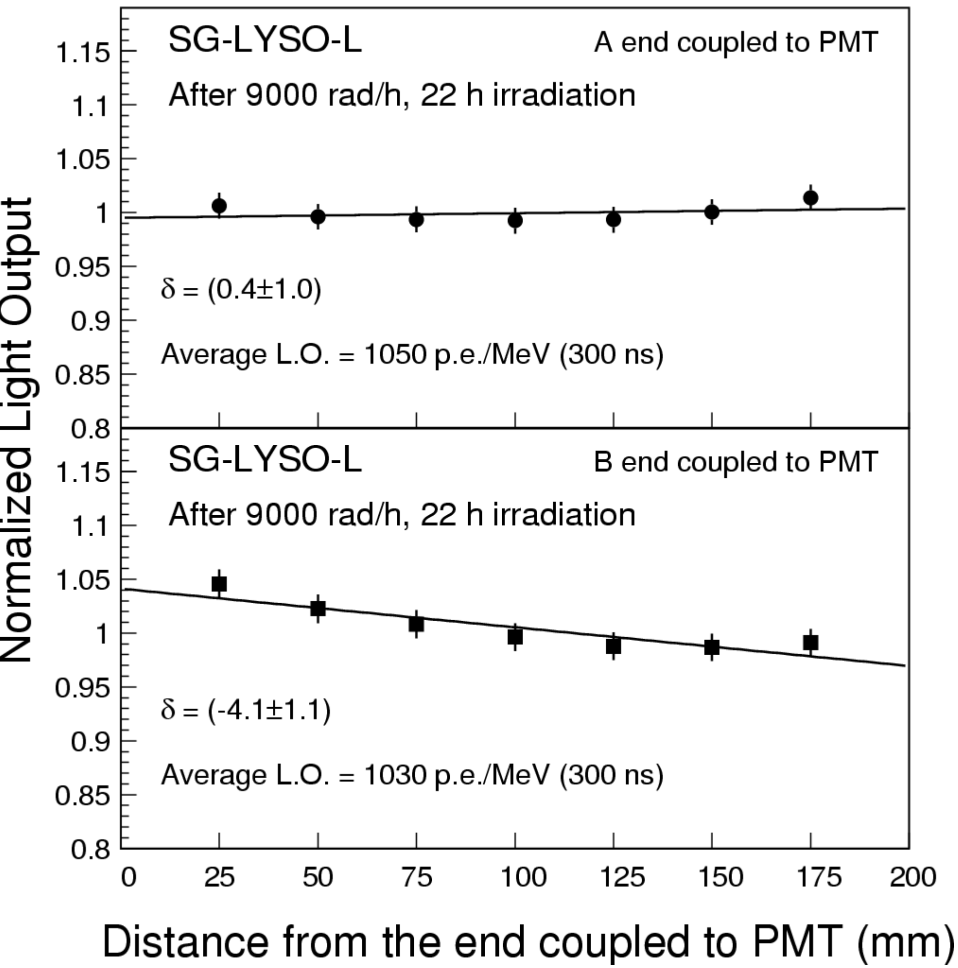
B. Chai: LO in LYSO is a function of atomic fraction of Yttrium

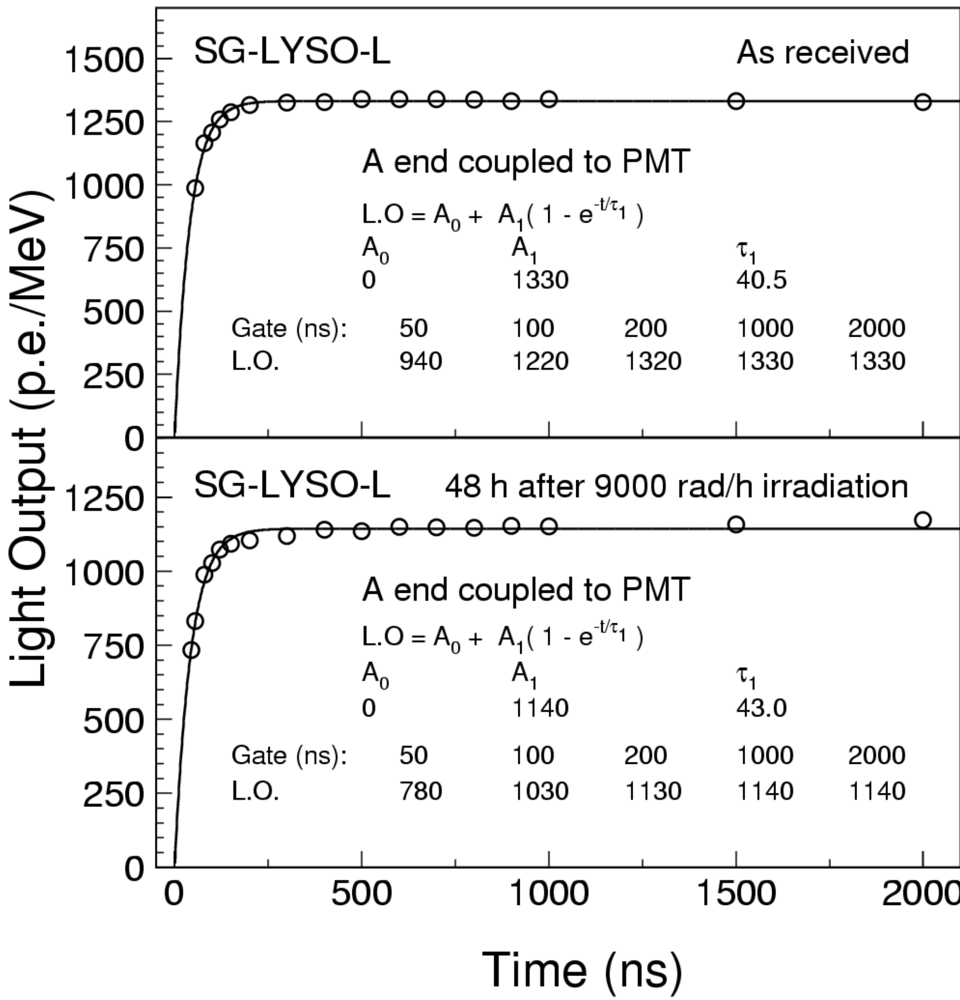




Radiation Damage in LYSO

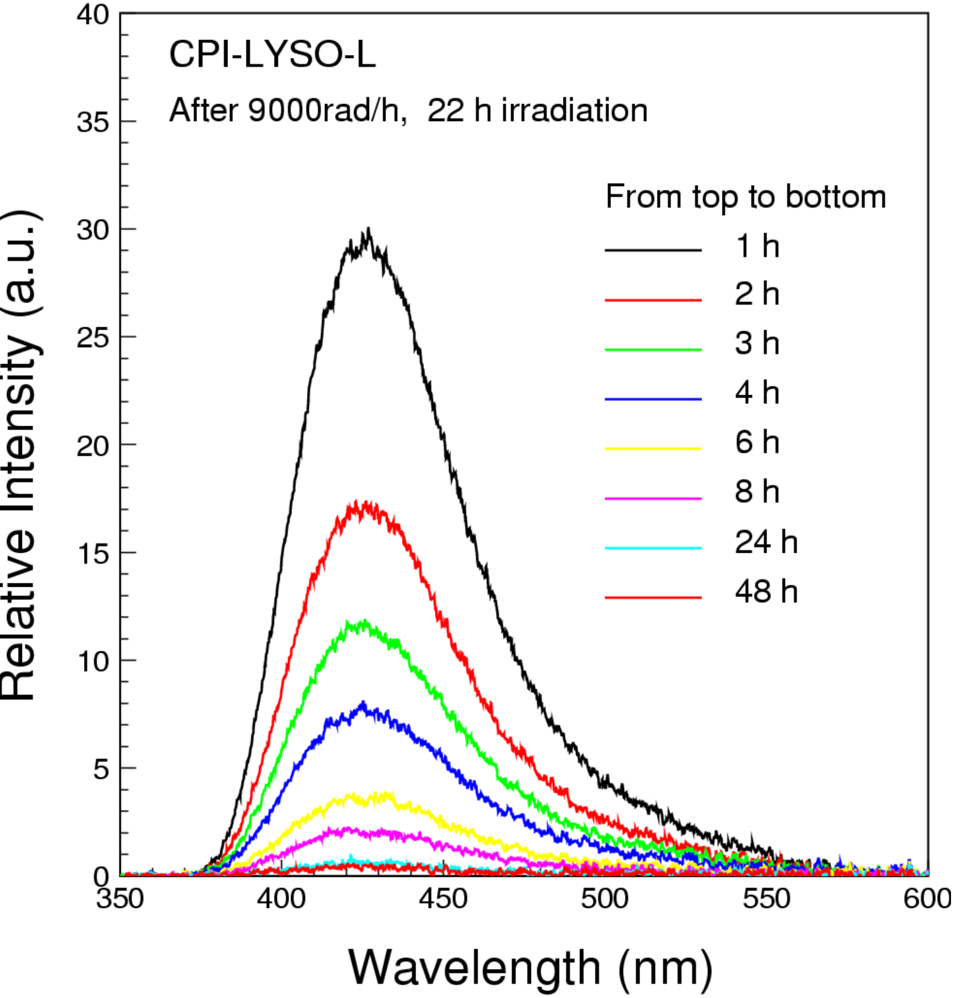
Damage effect in LRU and LO is small after 22 h γ–ray irradiations at 9,000 rad/h: better than PWO

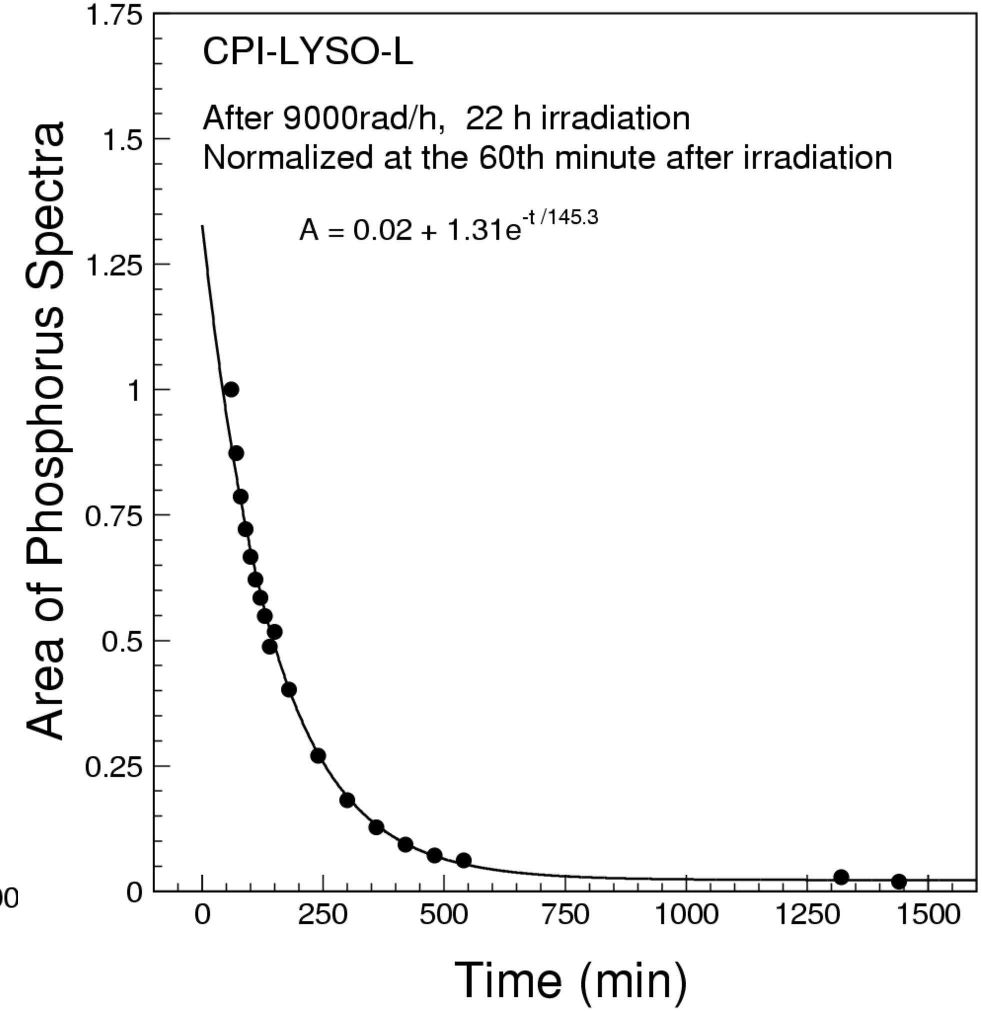




Radiation Induced Phosphorescence

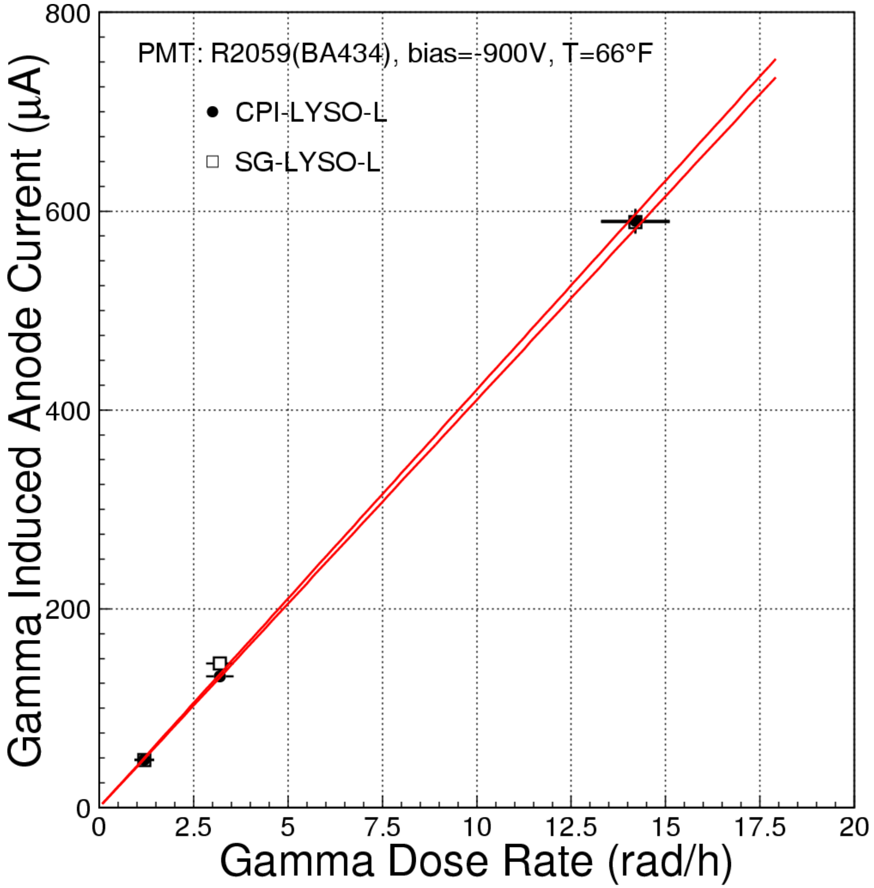
Phosphorescence peaked at 430 nm with decay time constant of 2.5 h observed





γ–ray Induced Readout Noise

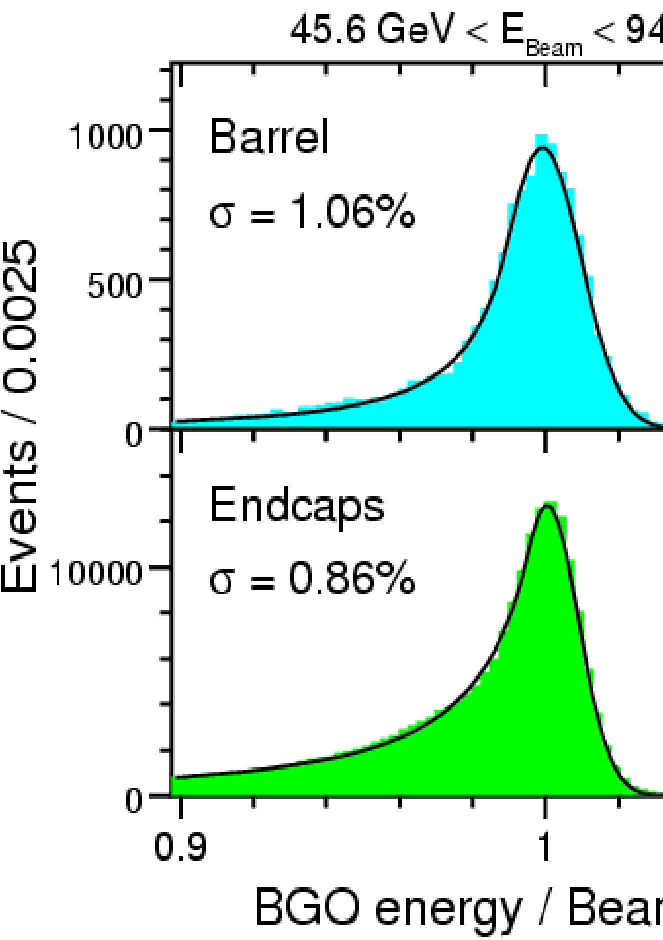
Sample ID	L.Y. p.e./MeV	F μ A/rad/h	$Q_{15\ rad/h}$ p.e.	$Q_{500\ rad/h}$ p.e.	$\sigma_{15\ rad/h}$ MeV	$\sigma_{500\ rad/h}$ MeV
CPI	1,480	41	6.98×10^4	2.33×10^6	0.18	1.03
SG	1,580	42	7.15×10^4	2.38×10^6	0.17	0.97

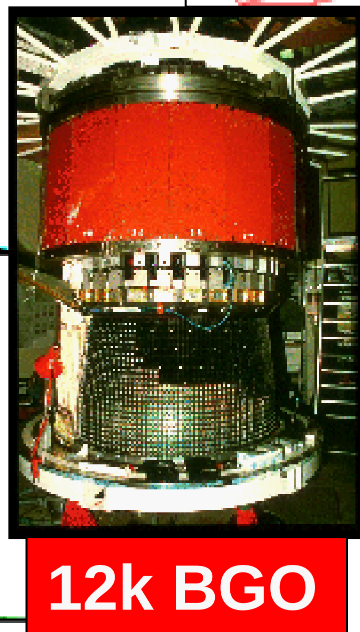


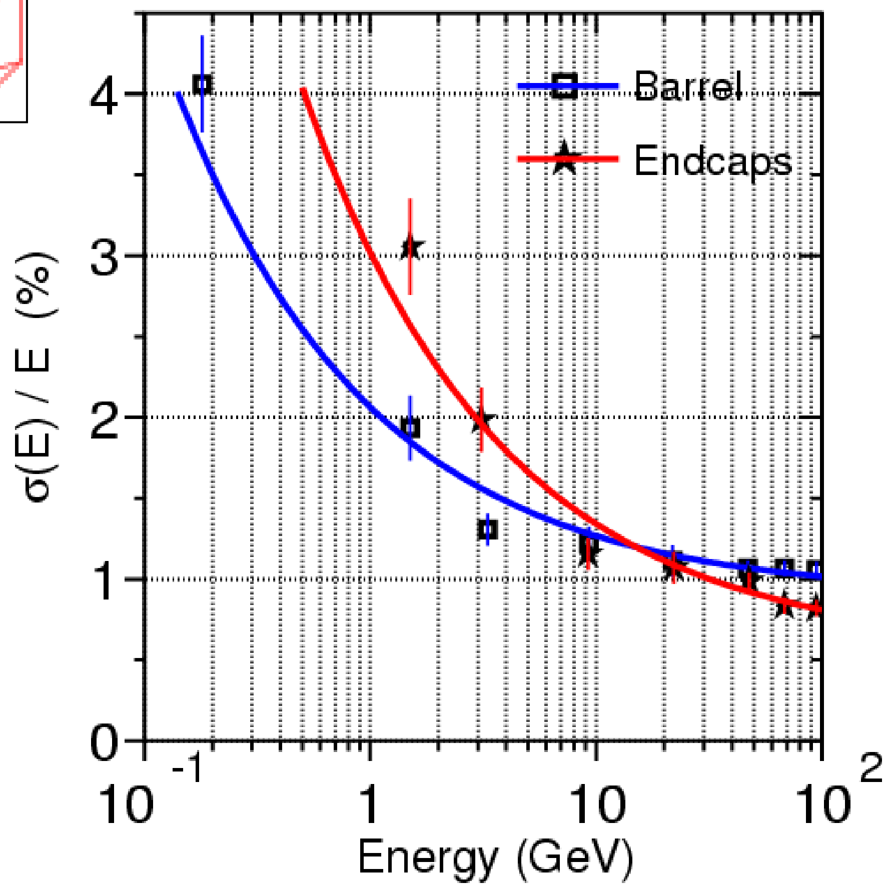
γ–ray induced PMT anode current can be converted to the photoelectron numbers (Q) integrated in 100 ns gate. Its statistical fluctuation contributes to the readout noise (σ).

L3 BGO Resolution

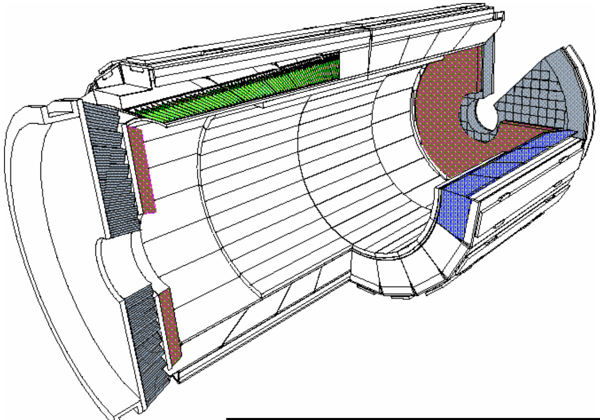
Contribution	"Radiative"+Intrinsic	Temperature	Calibration	Overall
Barrel	0.8%	0.5%	0.5%	1.07%
Endcaps	0.6%	0.5%	0.4%	0.88%



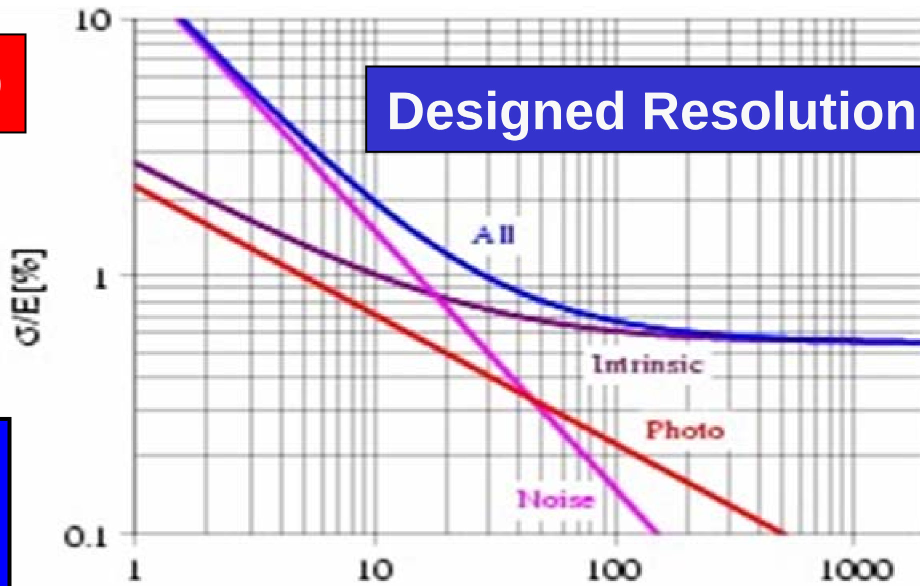




CMS PWO Resolution



77k PWO

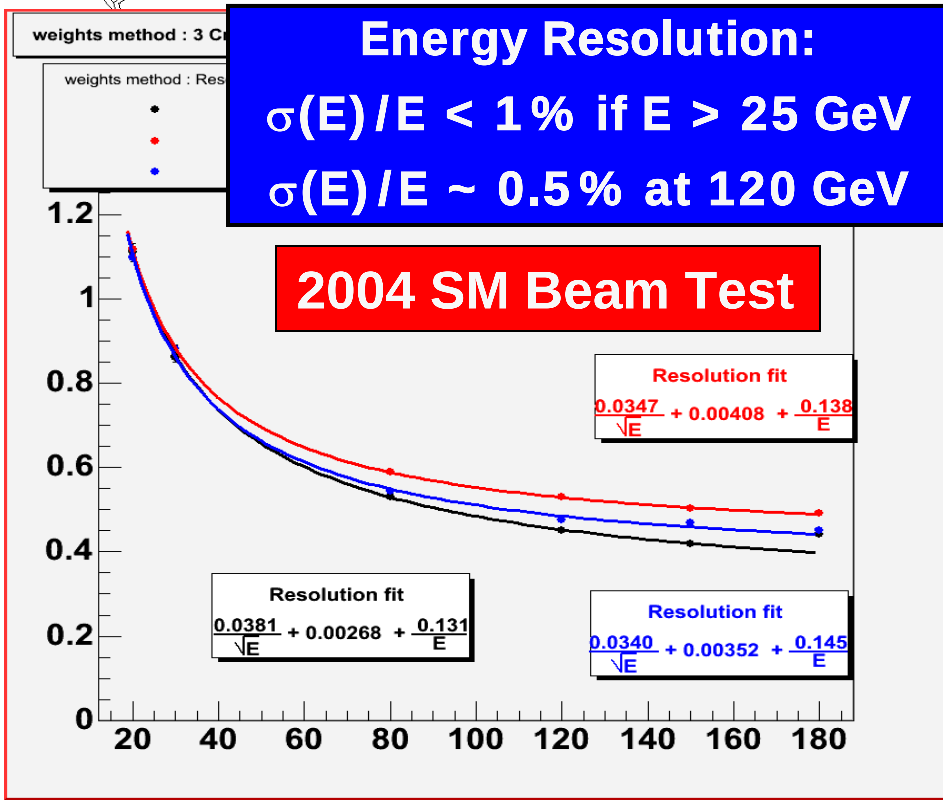


Energy Resolution:

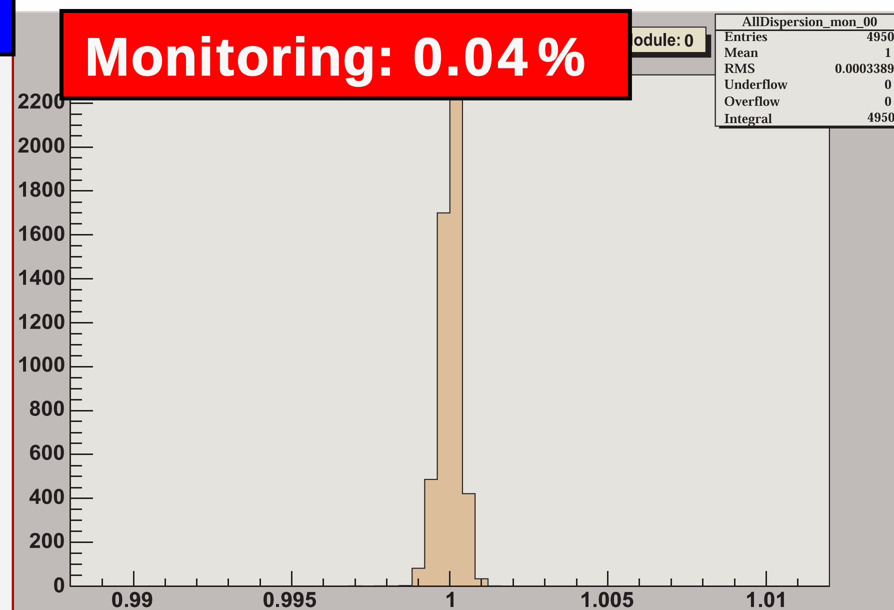
$\sigma(E)/E < 1\%$ if $E > 25$ GeV

$\sigma(E)/E \sim 0.5\%$ at 120 GeV

2004 SM Beam Test



Monitoring: 0.04%



LSO/LYSO ECAL Performance

- A better energy resolution, σ(E)/E, at low energies than L3 BGO and CMS PWO because of its high light output and low readout noise:

$$2.0\%/\sqrt{E} \oplus 0.5\% \oplus .002/E$$

- Less demanding to the environment because of small temperature coefficient.
- Radiation damage is less an issue as compared to the CMS PWO ECAL.
- No degradation if ILC energy increases.

Single & Multi-Photons Physics

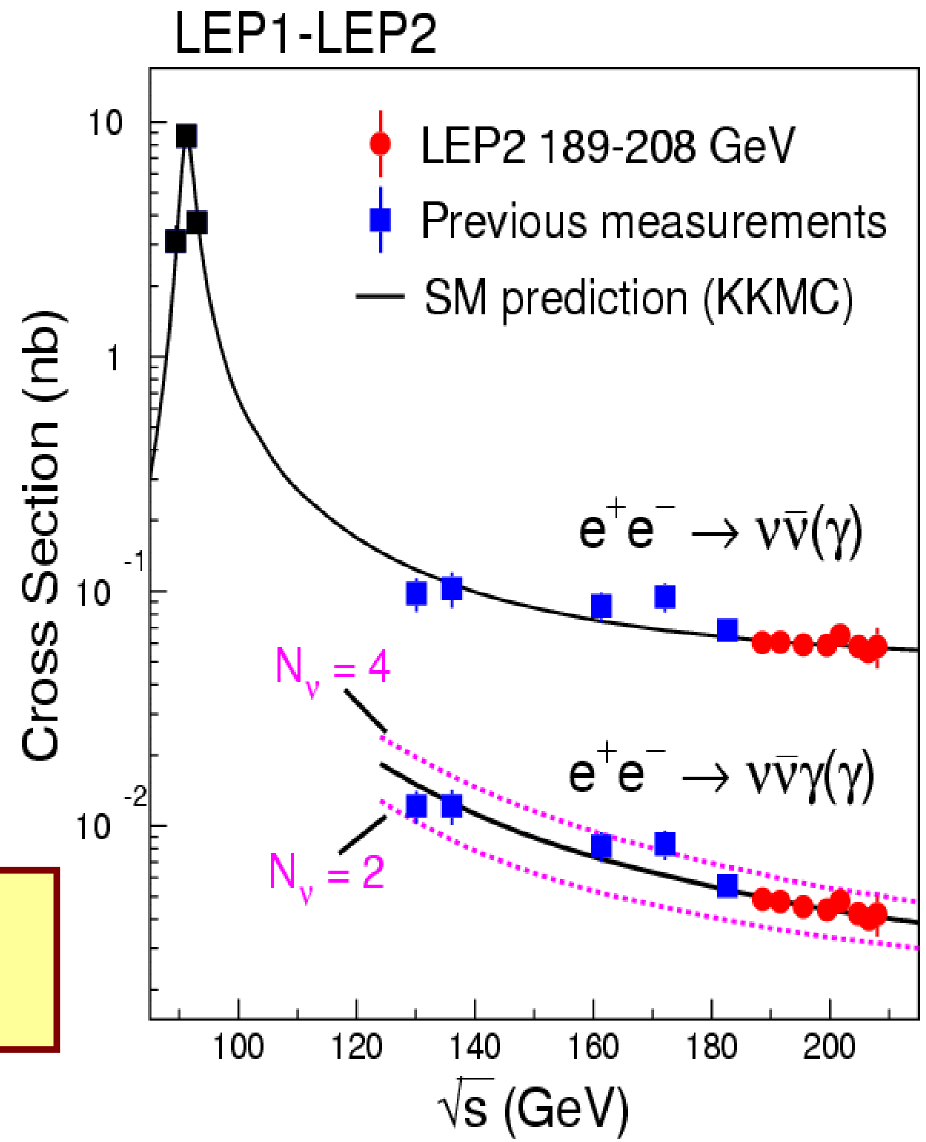
L3 BGO was the best ECAL at LEP
Efficiency ~ 73%
Purity ~ 99%:
Precision: 0.5% (RFQ calibration)
Best sensitivity at LEP

Physics Topics Include:

- Neutrino Production (SM)
- Extra Dimensions and SUSY
- Additional light neutrino flavors
- Anomalous gauge couplings through γ-W and γ-Z vertices

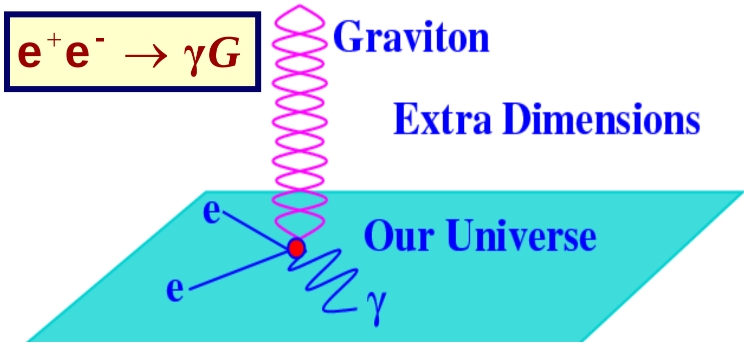
Number of neutrino species
$N_\nu = 2.98 \pm 0.06$

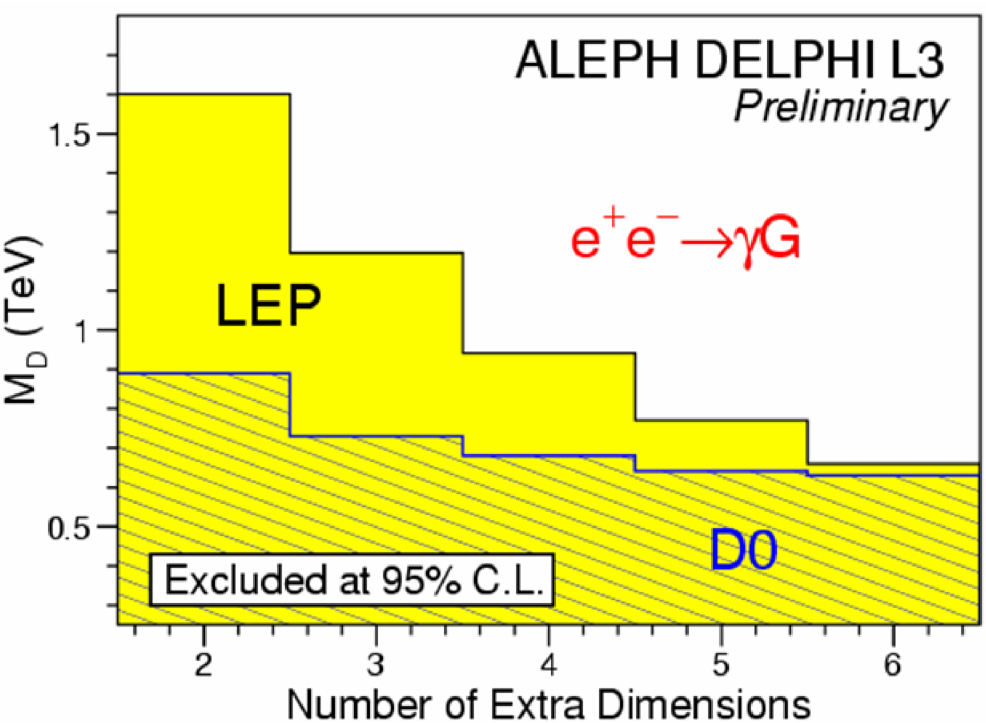
More precise than PDG'04

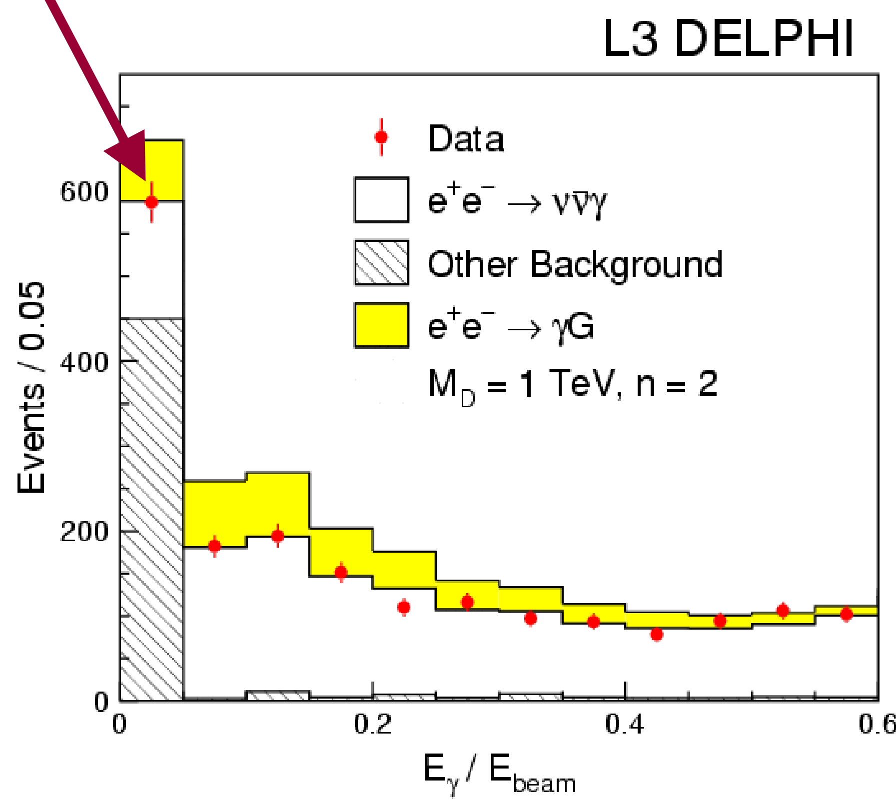


Extra Dimensions at LEP

- SM particles live on a 3D wall, gravity propagates in extra dimensions
- *Single photon* is the discovery channel
- Low P_t selection increases sensitivity



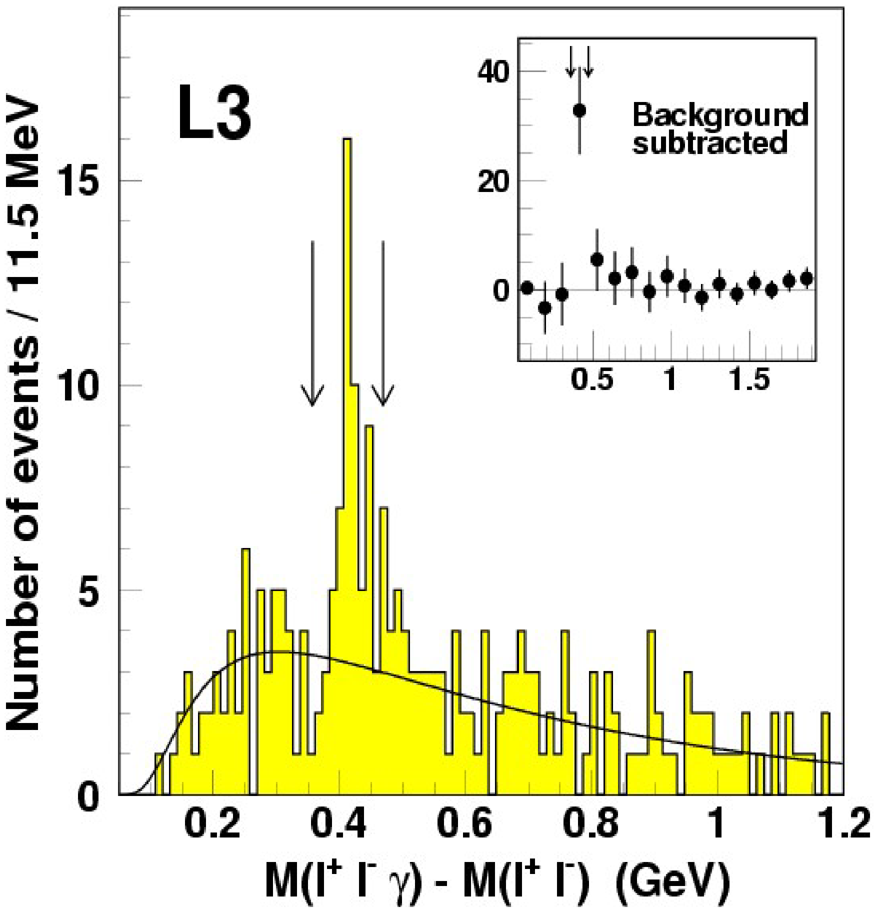




Physics in Crystal Calorimeter

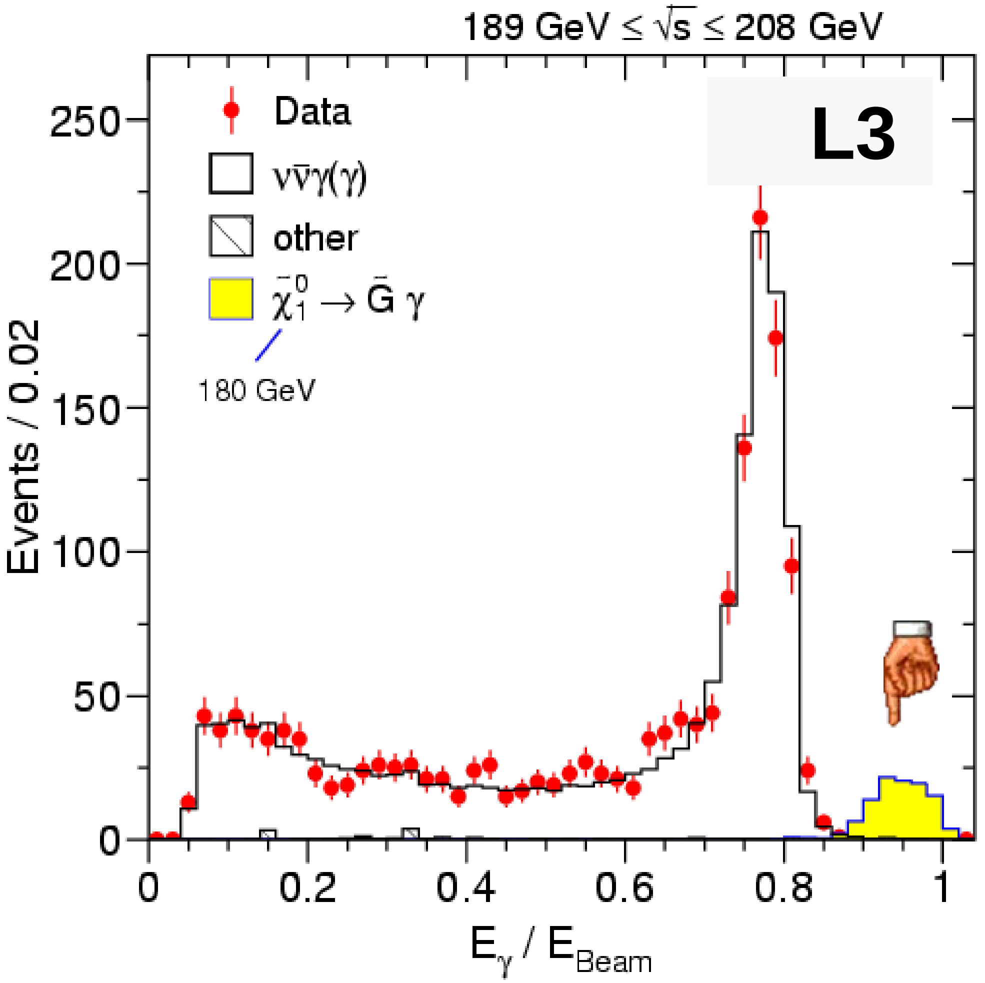
Charmed Meson in Z Decay

$$\chi_{c1} \rightarrow J/\psi\gamma$$



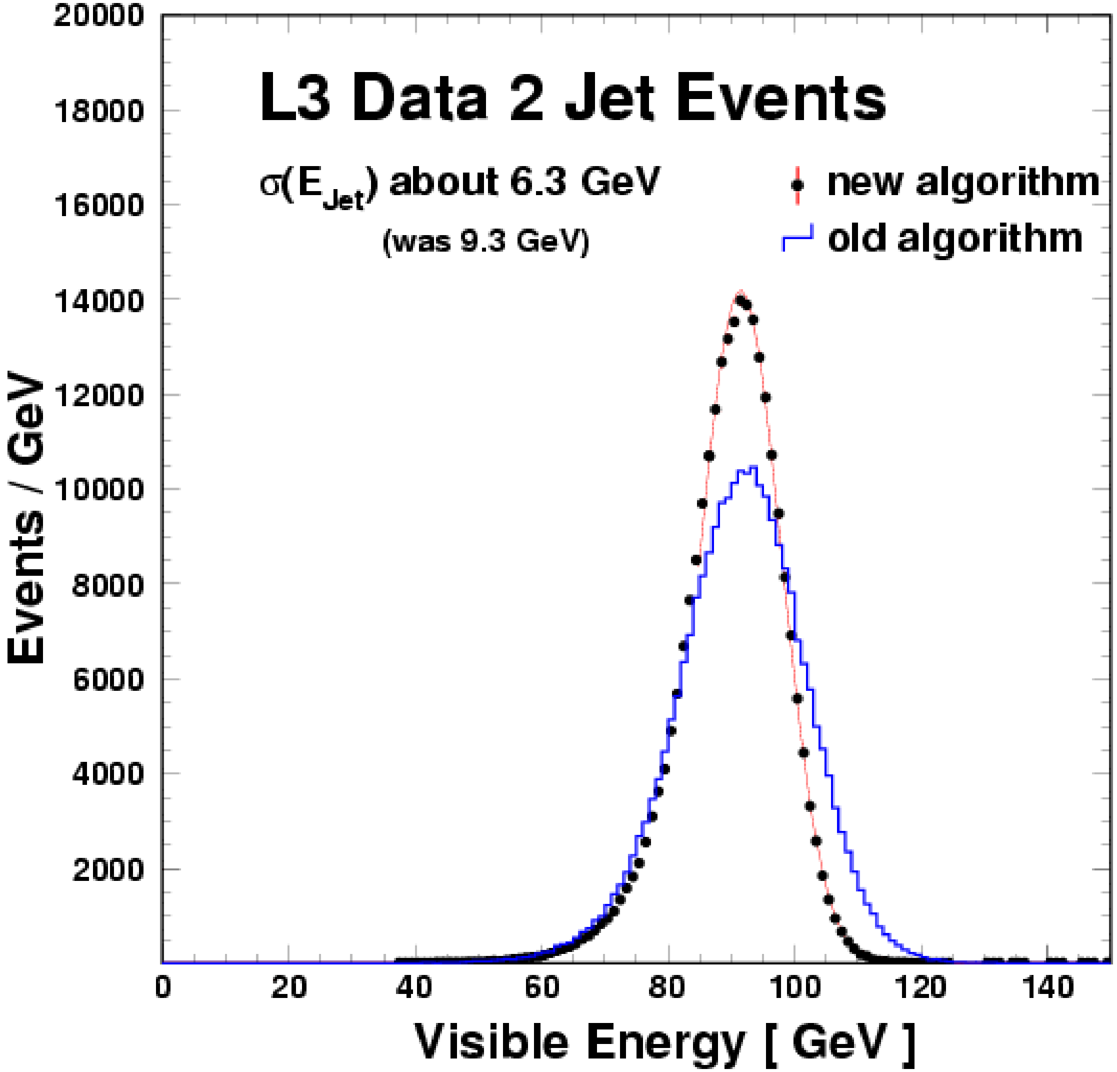
SUSY Breaking with Gravitino

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



L3 Jet Mass Resolution: Z->qq

Proceedings, Sitges ILC Workshop (1999)

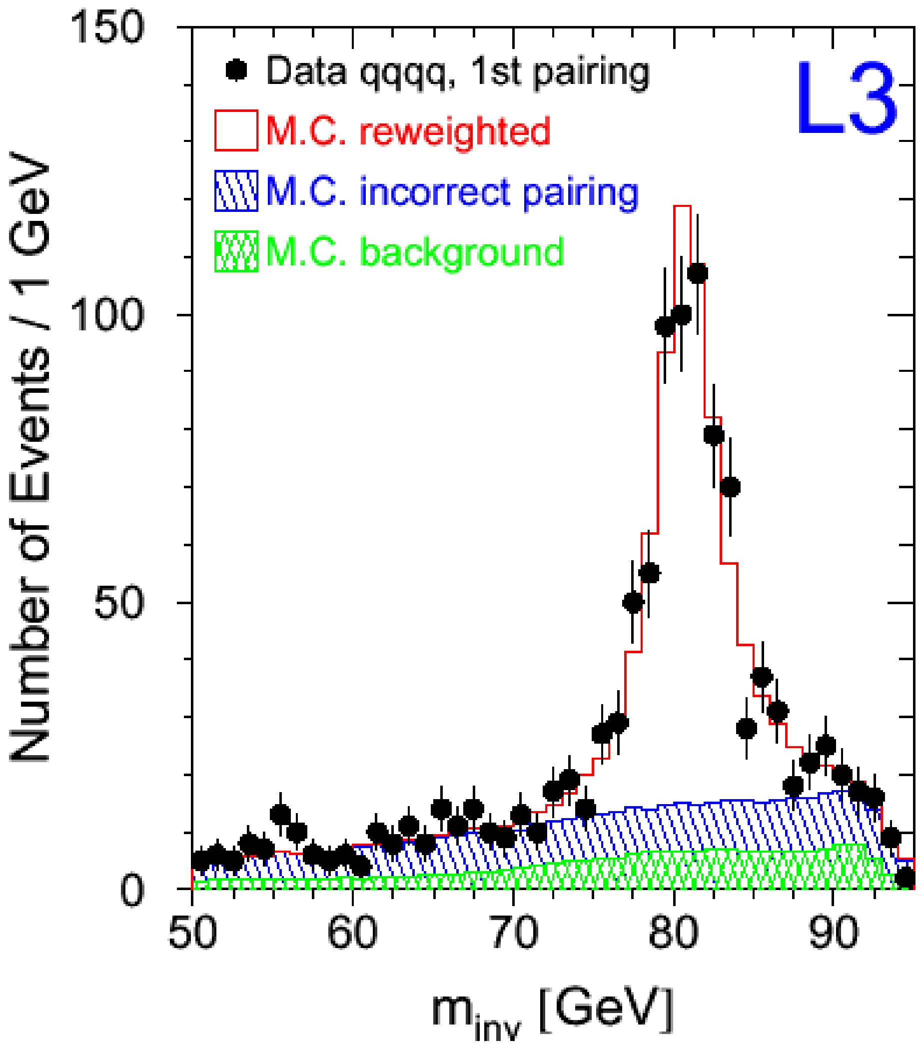


- Measured jet mass resolution: 97%/ √ E
- Using tracker momentum for charged particles: 67%/ √ E
- 30% improvement caused by the subtraction of MC calculated energy.

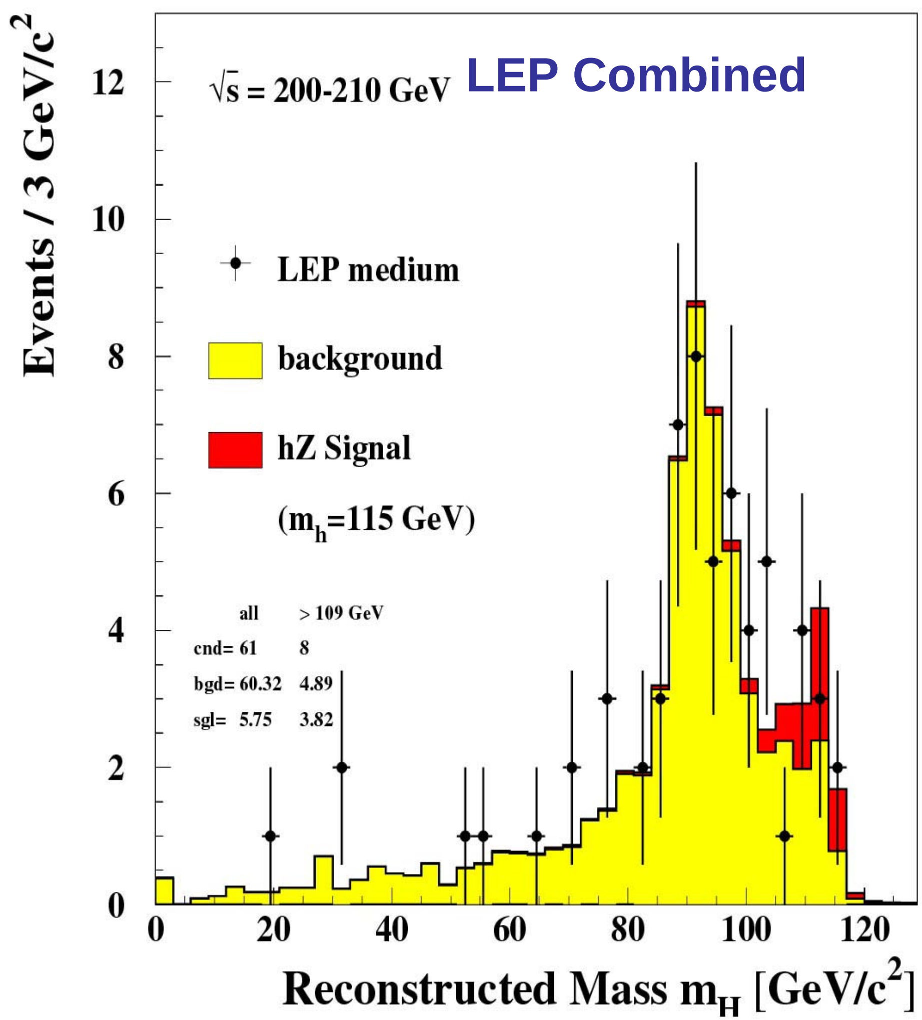
Best Jet Mass Resolution at LEP

Proceedings, Jeju ILC Workshop (2002)

W Mass with 2 jets by L3: 3%



Higgs with 2 jets at LEP: 3%



Summary

- Ce doped LSO & LYSO crystals have fast (42 ns) and high (4 X BGO) light output. The light output of 2.5 x 2.5 x 20 cm LSO and LYSO samples, excited by 0.51 MeV γ–ray, can be readout by single APD of 25 mm^2.
- LSO/LYSO has good radiation hardness. The radiation induced phosphorescence in 2.5 x 2.5 x 20 cm LYSO causes ~1 MeV noise @ 500 rad/h.
- An LSO/LYSO crystal calorimeter will provide excellent energy resolution even the beam energy increases, and will produce rich physics with precision electrons and photons at the ILC.