



An LSO/LYSO Crystal Calorimeter for the ILC

Ren-Yuan Zhu

California Institute of Technology



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.



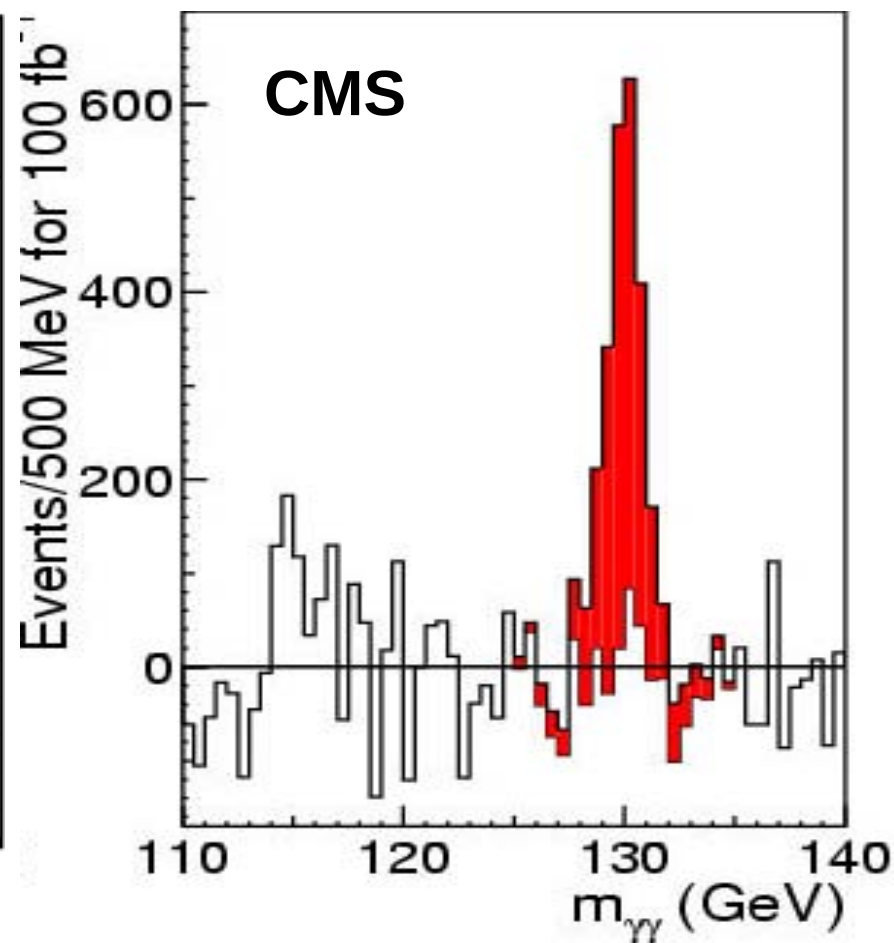
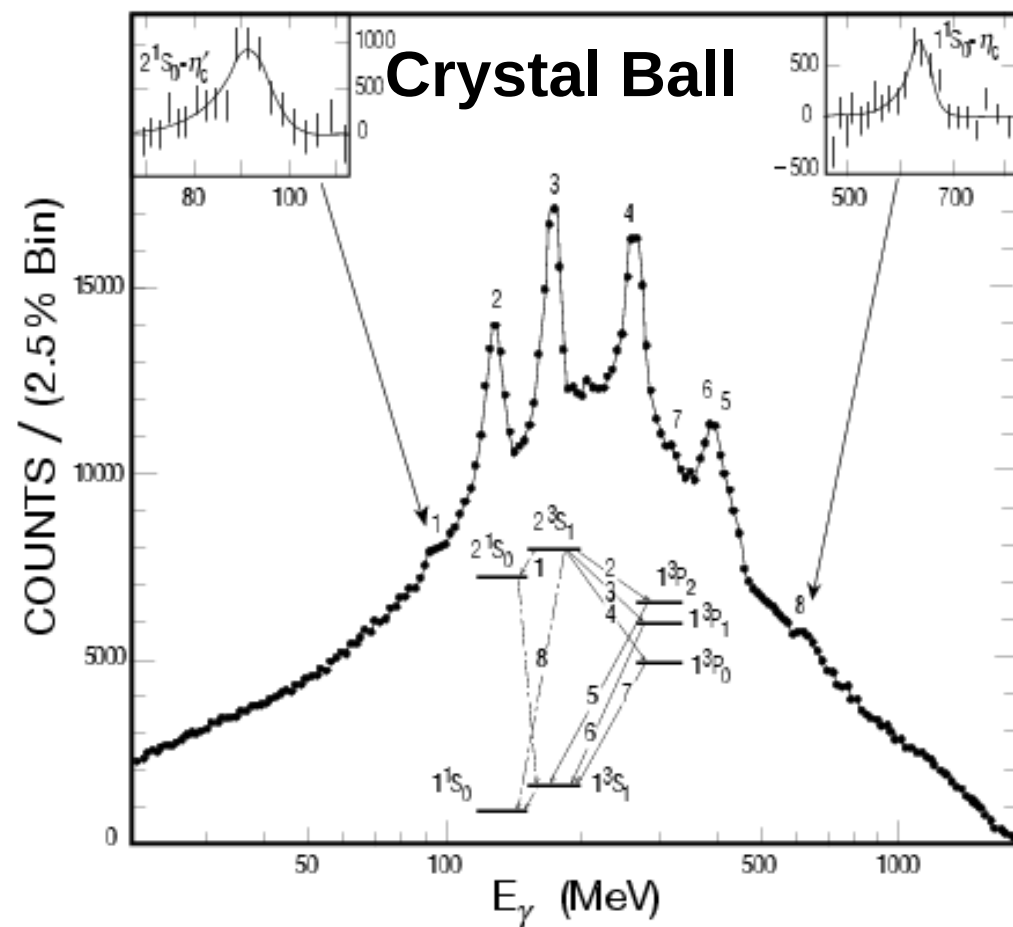
Physics in Crystal Calorimeters



Charmonium System Observed Through Inclusive Photons

Higgs Searches at LHC

$$H \rightarrow \gamma\gamma$$





Summary of Crystals for HEP



Crystal	Nal(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
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
Refractive Index							1.85	1.85
Hygroscopic							No	No
Luminescence (at peak)							40	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 (%/ °C)	~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)



Total
Con
For



SIPAT LSO

Quoted Price: 13-15 USD/cc



$\Phi 80 \times 70$



$\Phi 80 \times 120$

Large size LSO ($\text{Ce:Lu}_2\text{SiO}_5$) crystals are in production

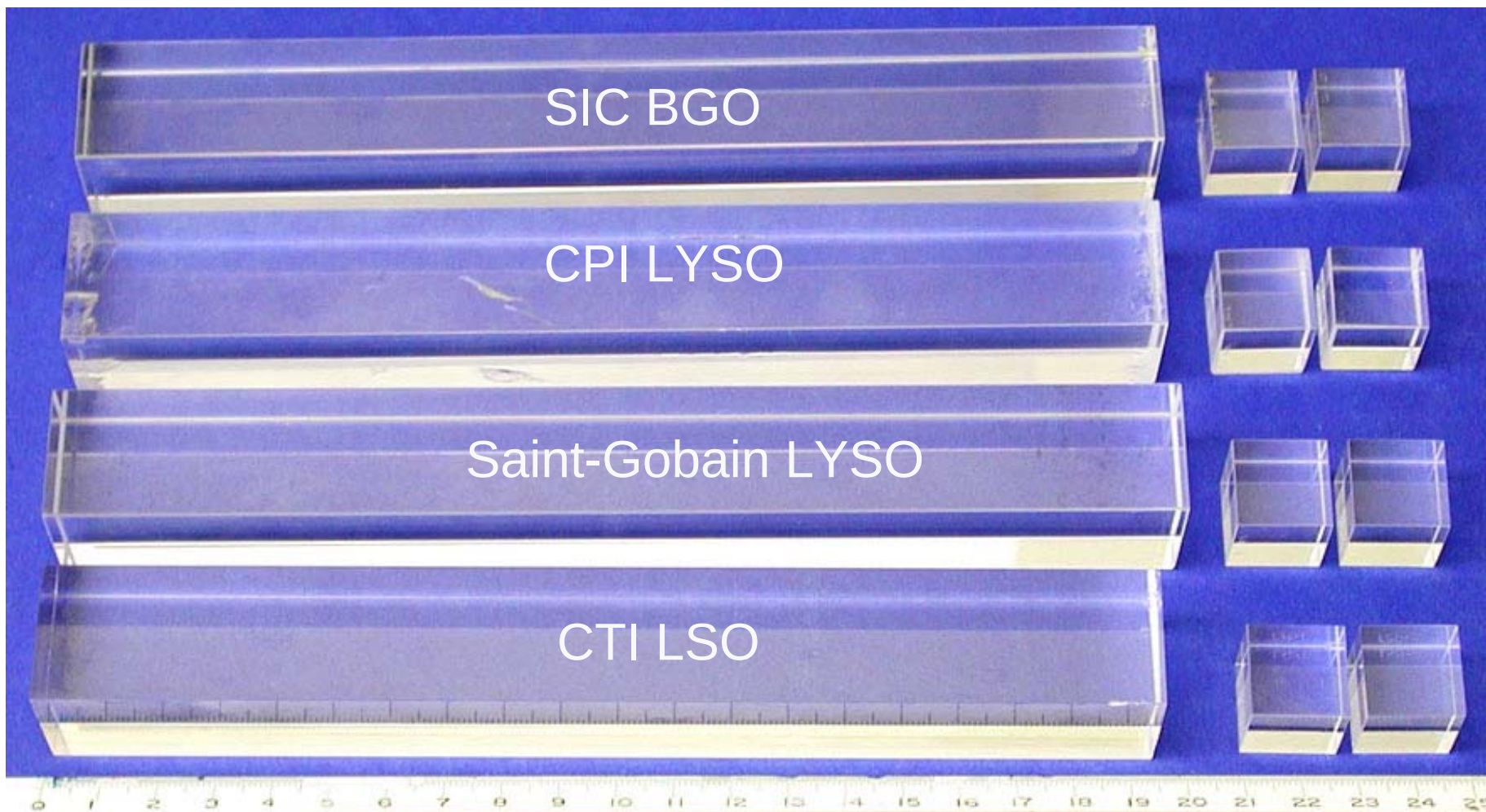


BGO, LSO & LYSO Samples



Cube: 1.7 X 1.7 x 1.7 cm (1.5 X_0)

Bar: 2.5 x 2.5 x 20 cm (18 X_0)





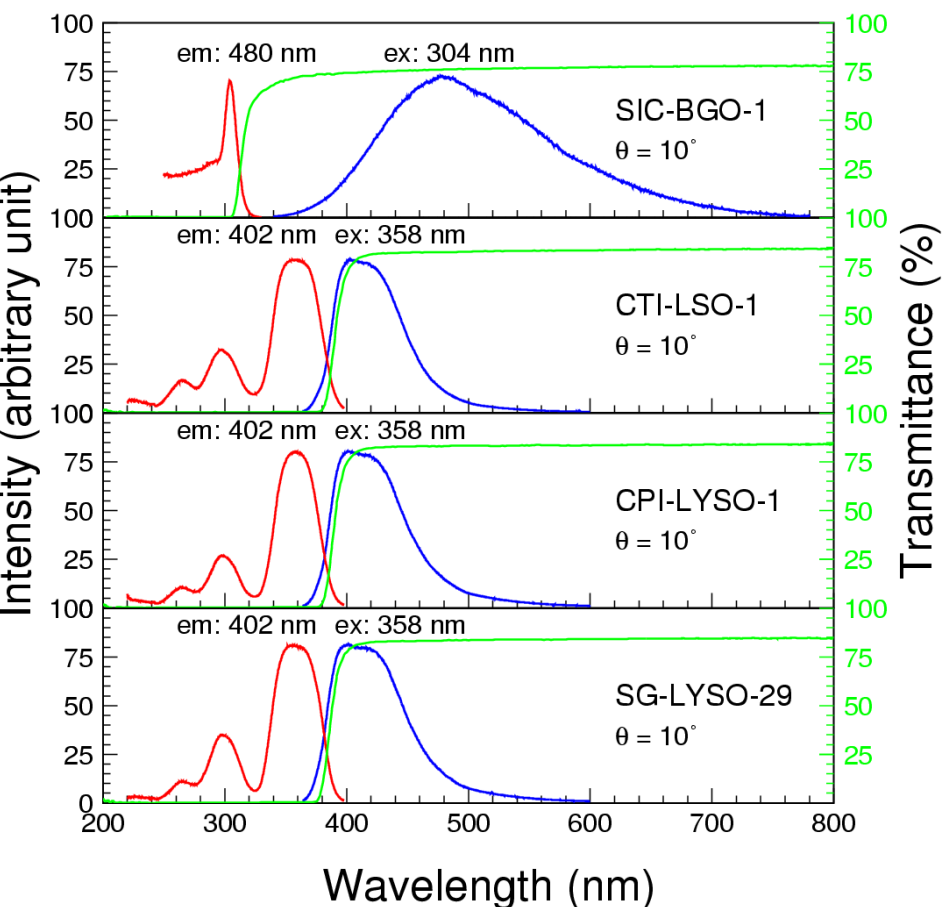
Excitation, Emission & Transmittance



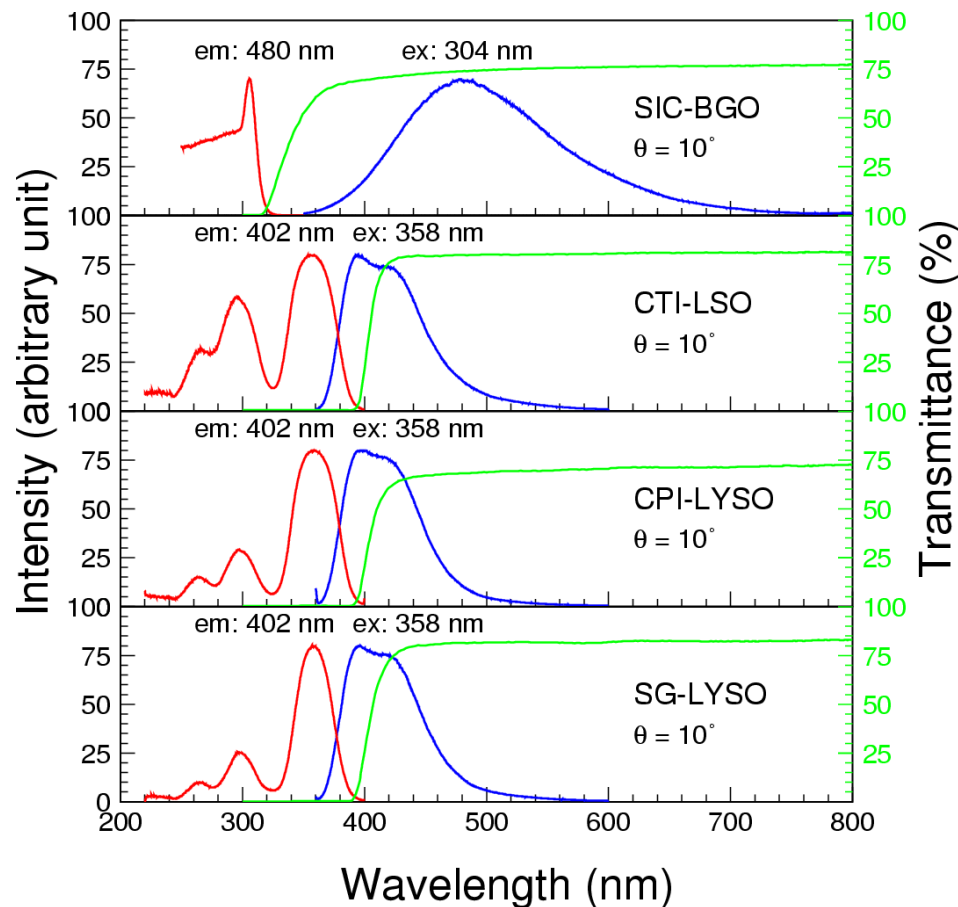
Identical transmittance, emission & excitation spectra

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

1.7 cm Cube



2.5 x 2.5 x 20 cm Bar



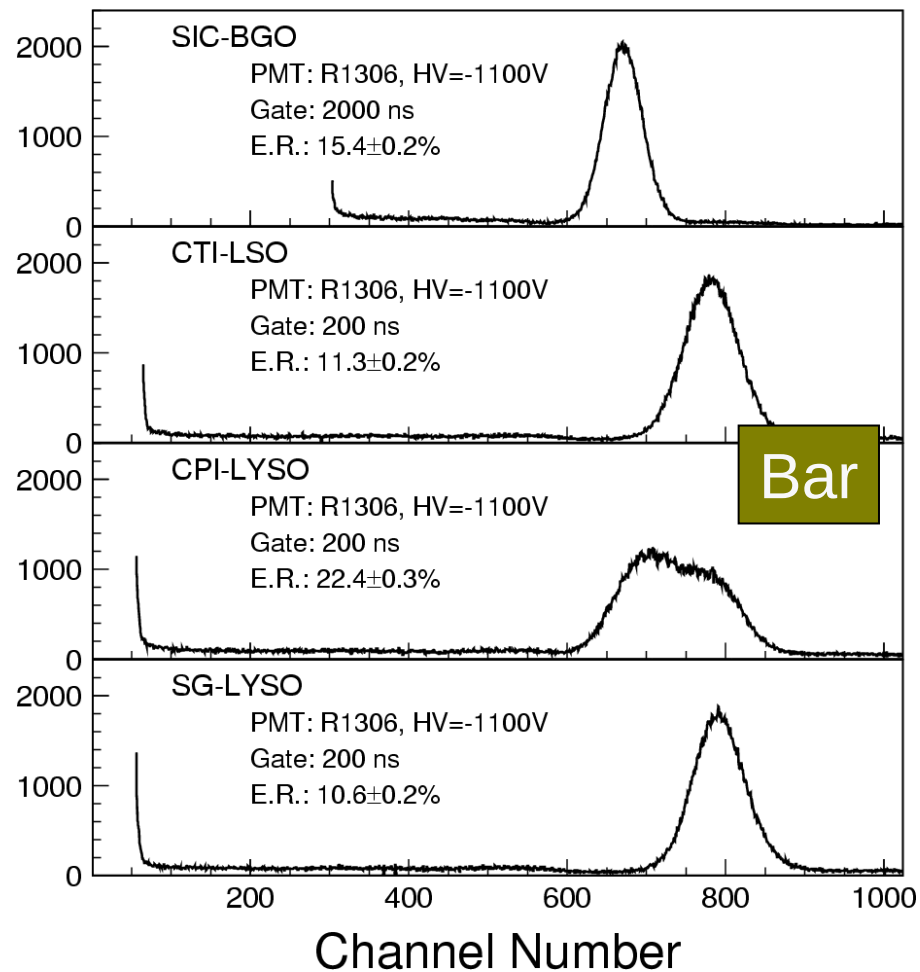
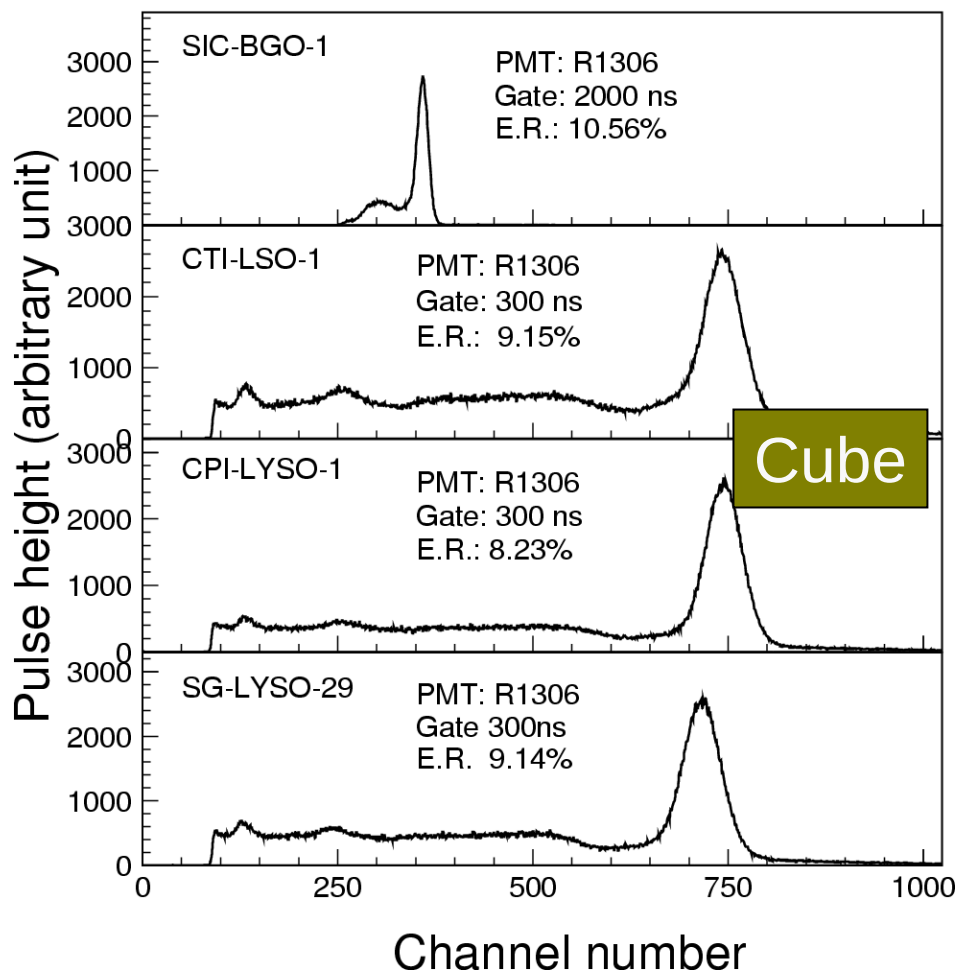


^{137}Cs & ^{22}Na Pulse Height Spectra



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





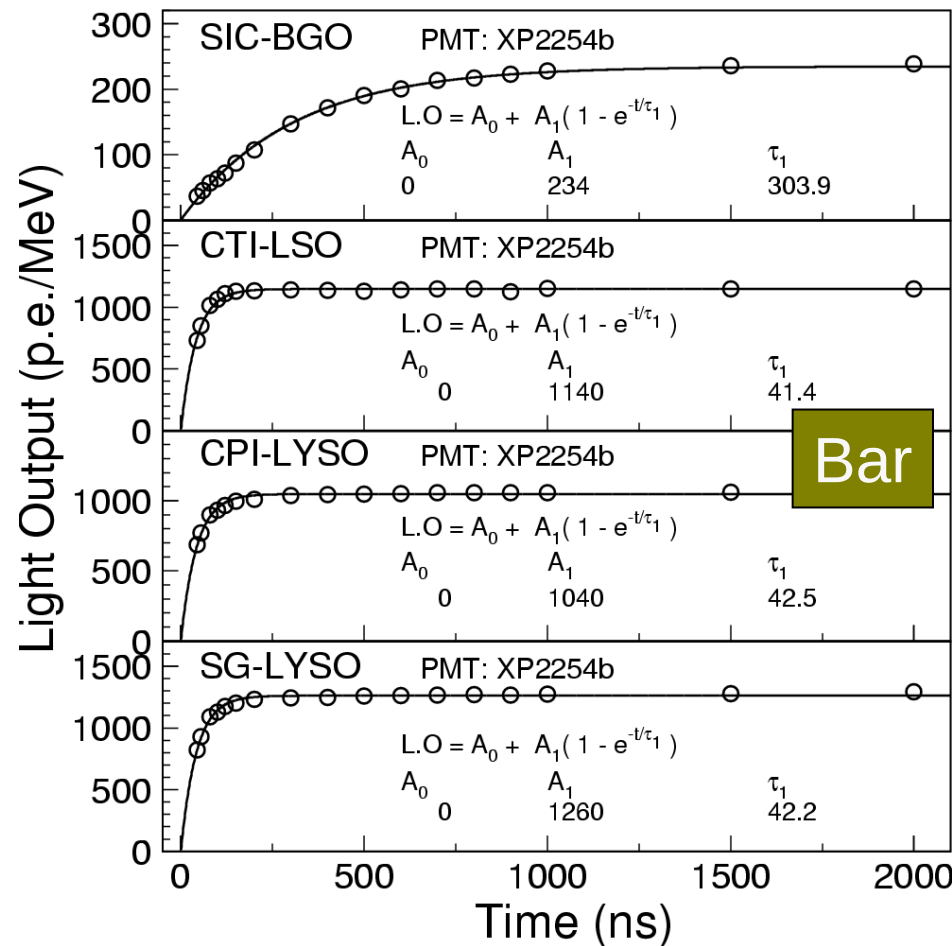
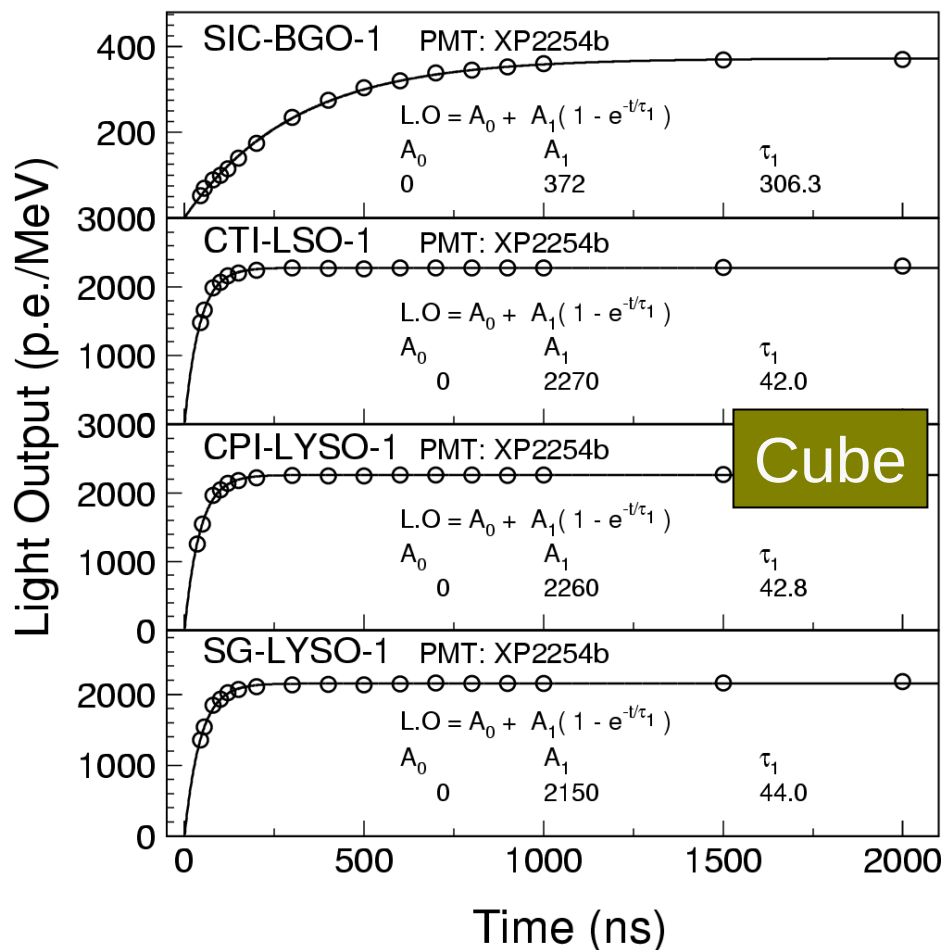
Light Output & Decay Time



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

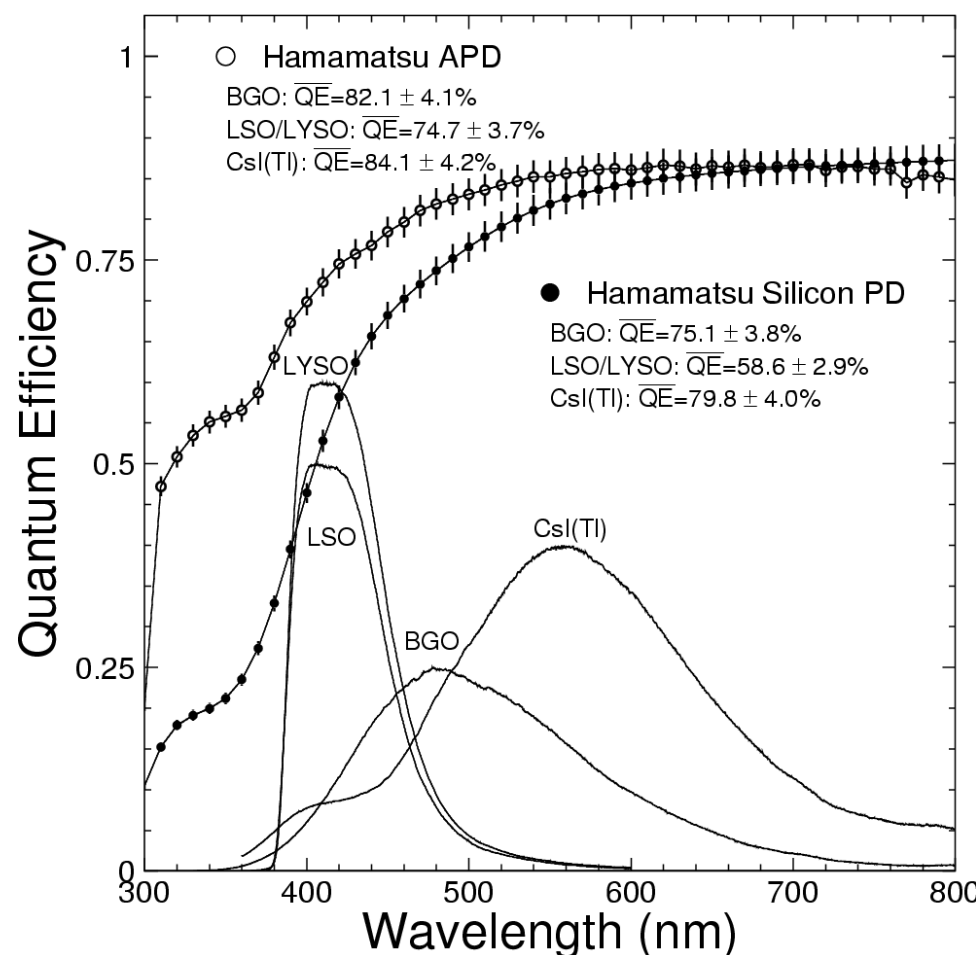
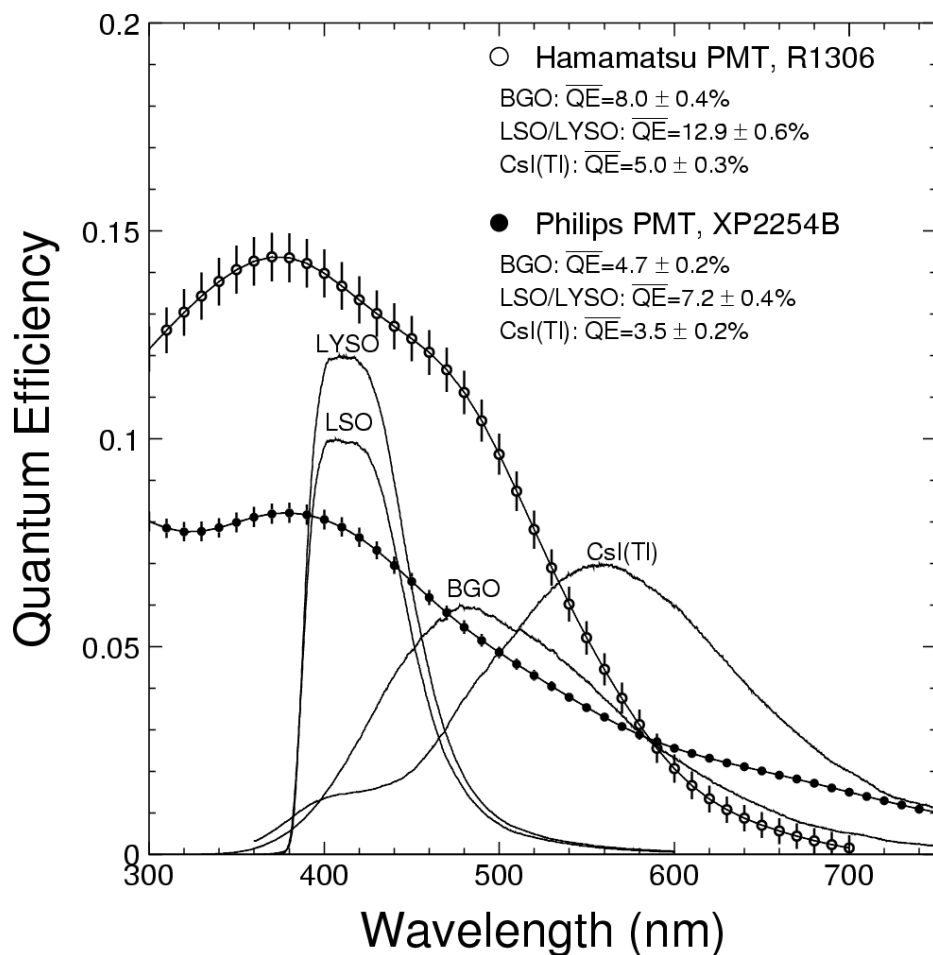




Emission Weighted Q.E.

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

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

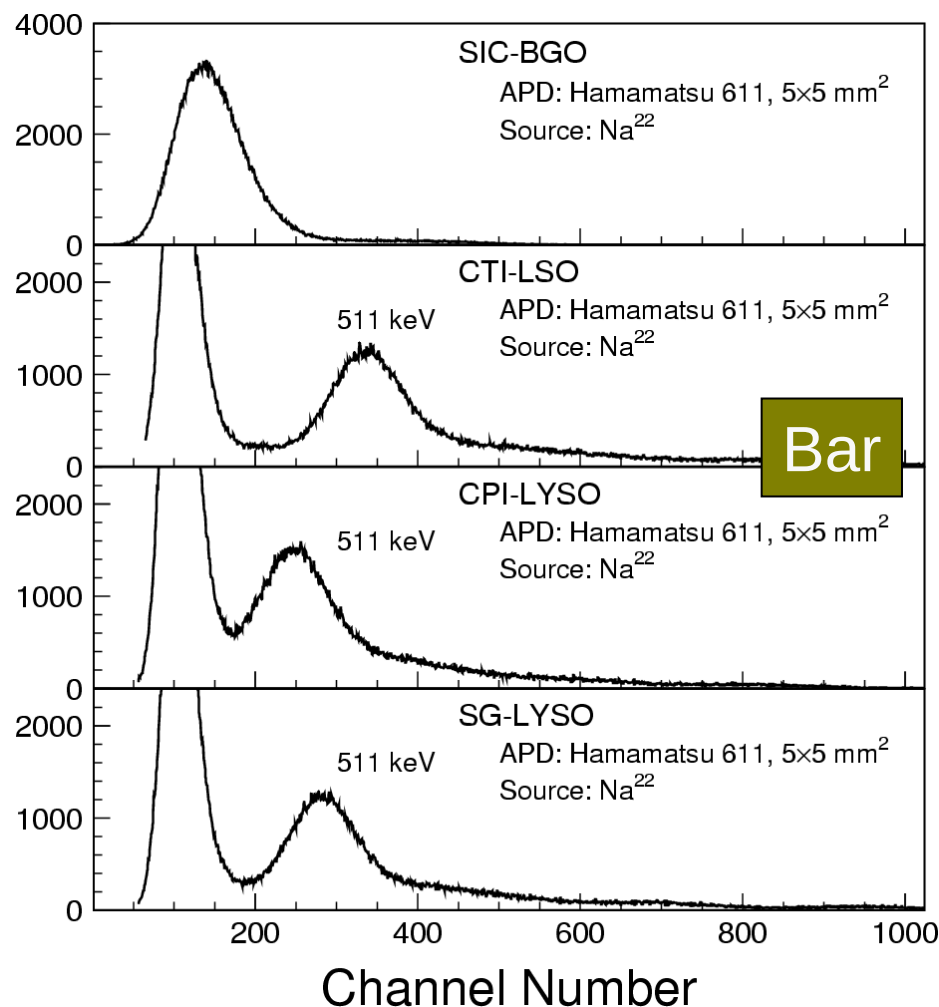
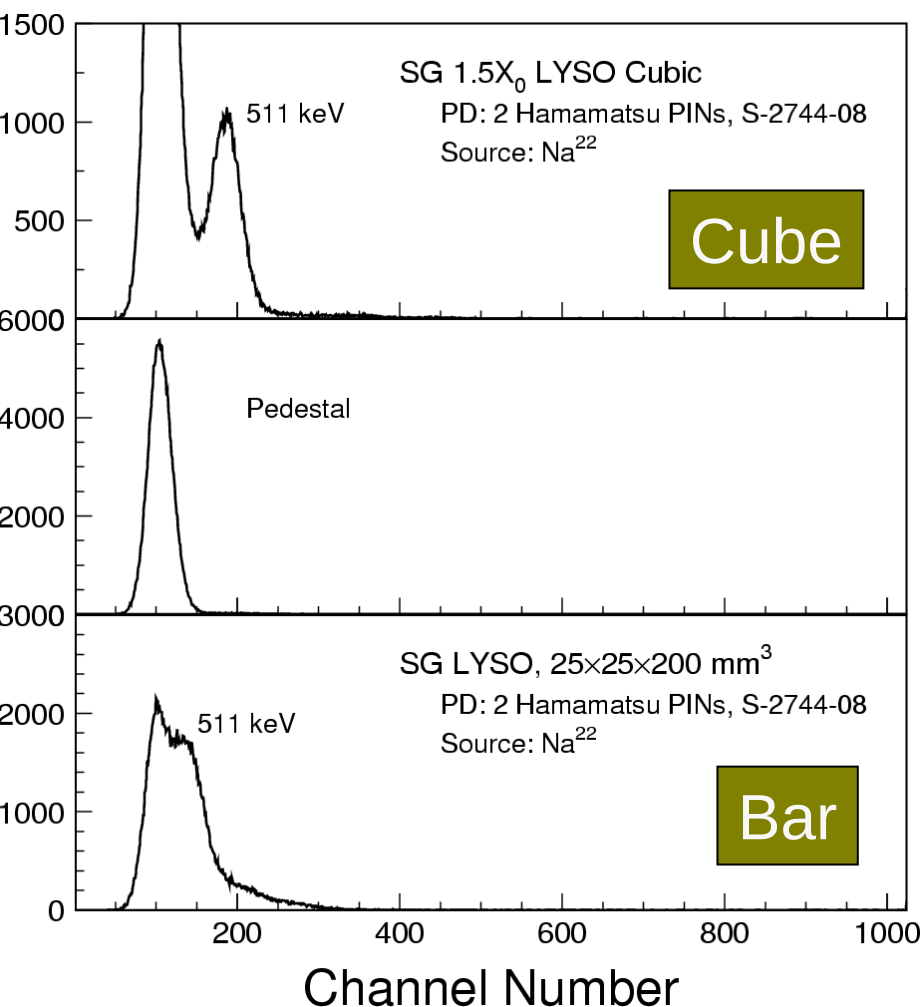




LSO/LYSO with Si Readout



LSO/LYSO (not BGO) bars can be read in lab by using a single APD of 25 mm² (not Si PD) and 0.51 MeV ²²Na source

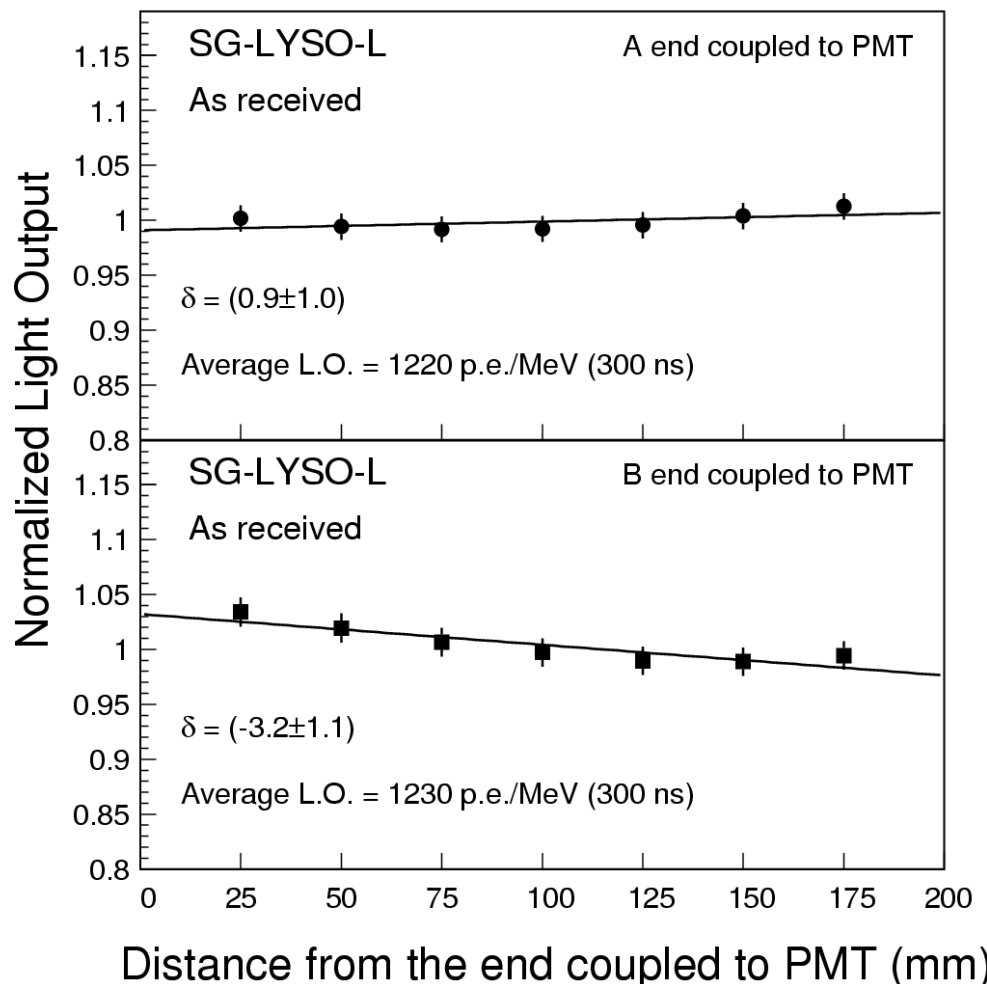
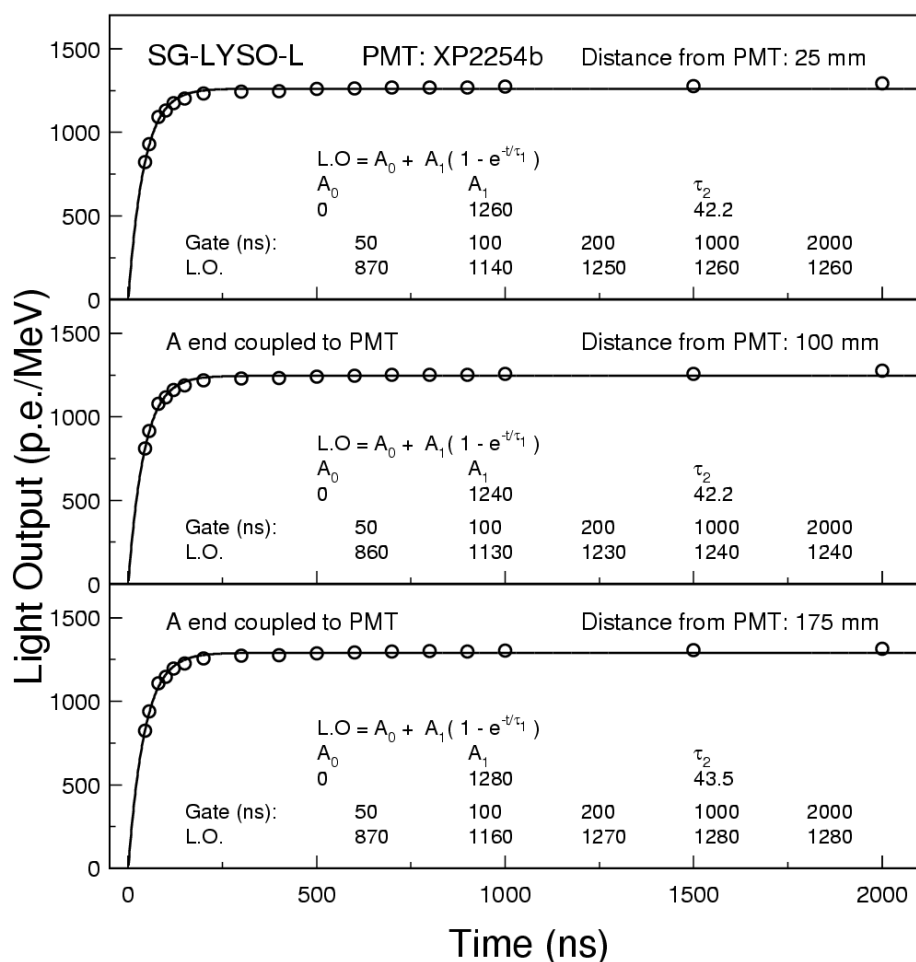




LYSO Light Response Uniformity



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

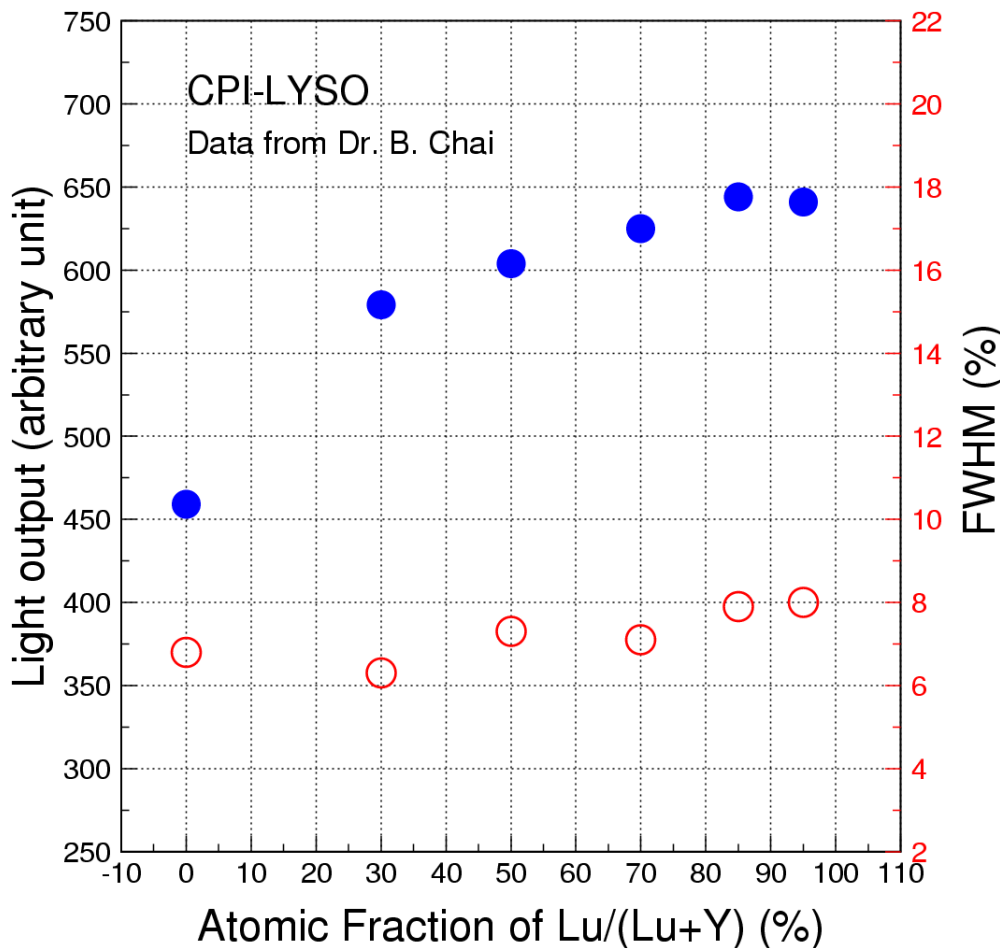
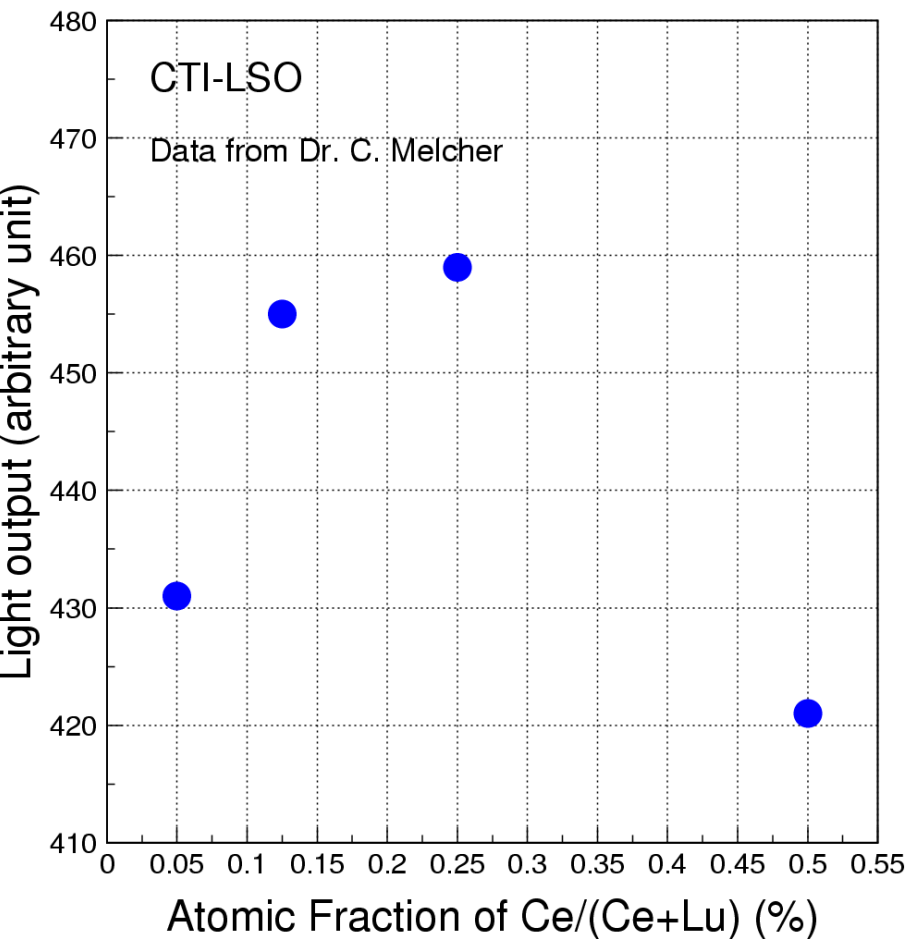




Possible Origin of Non Uniformity

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

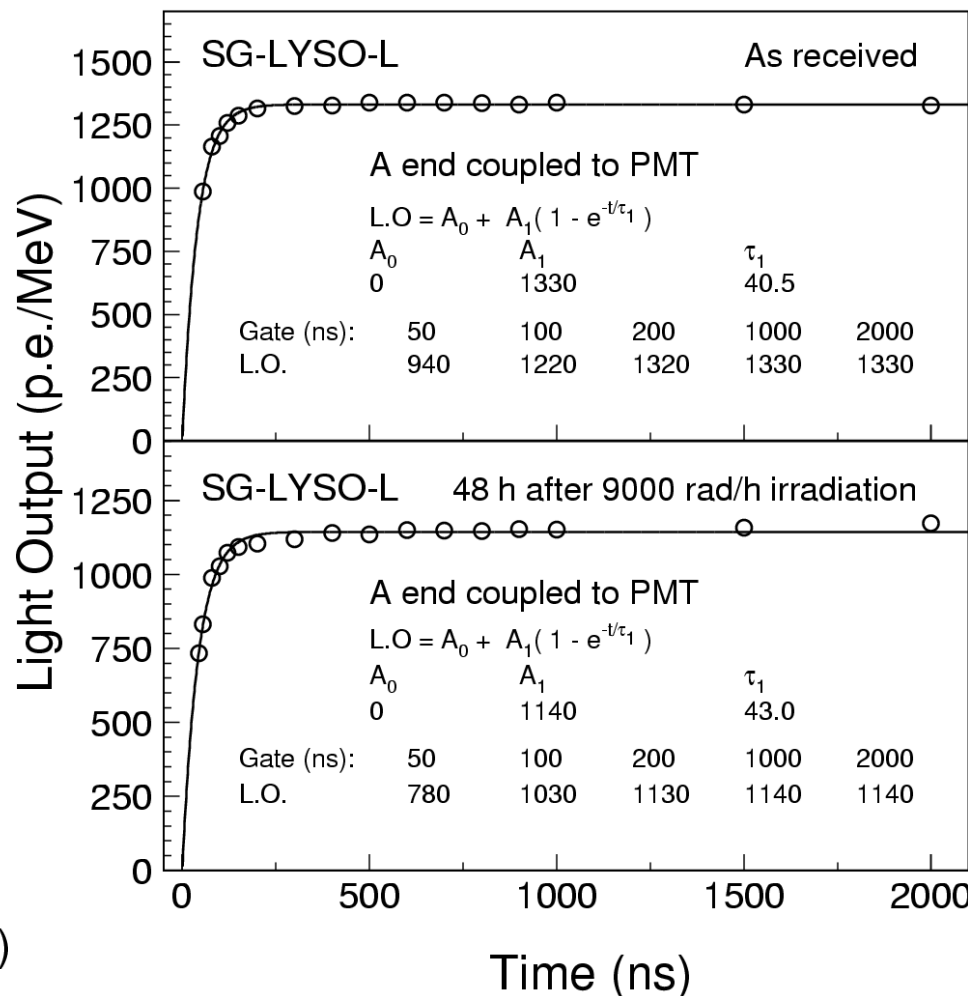
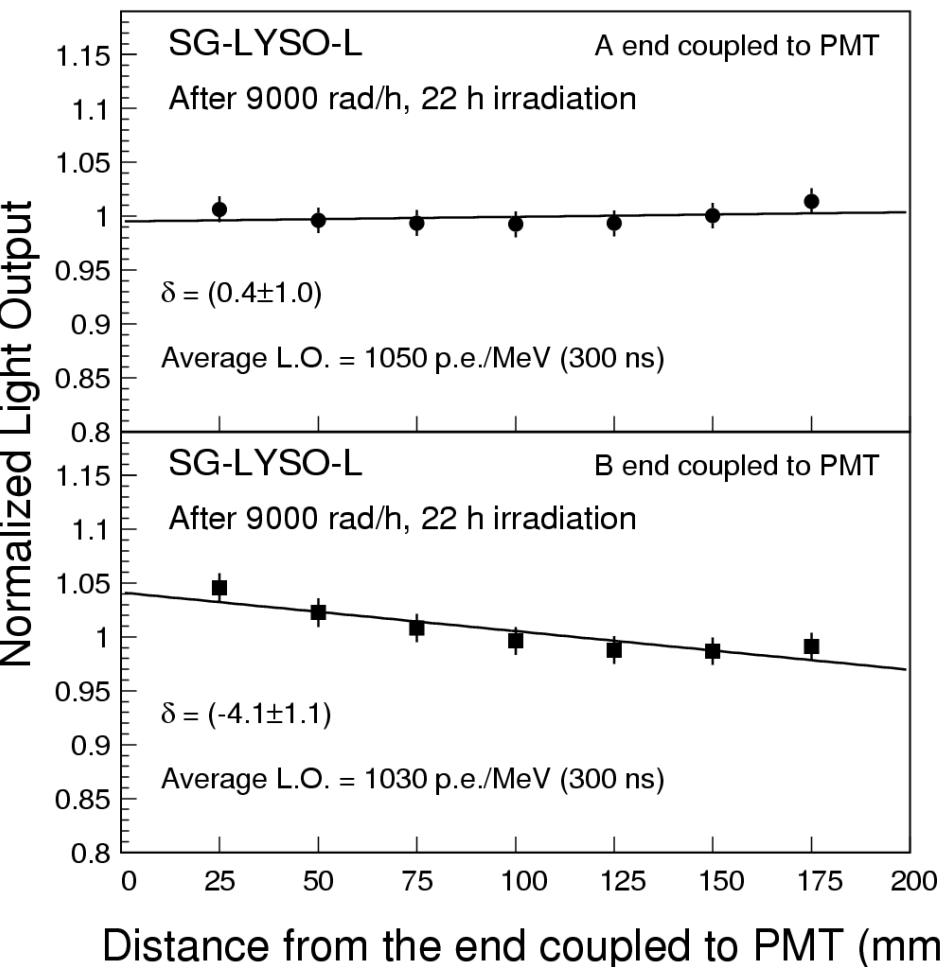
B. Chai: LO in LYSO is a function of atomic fraction of Yttrium





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

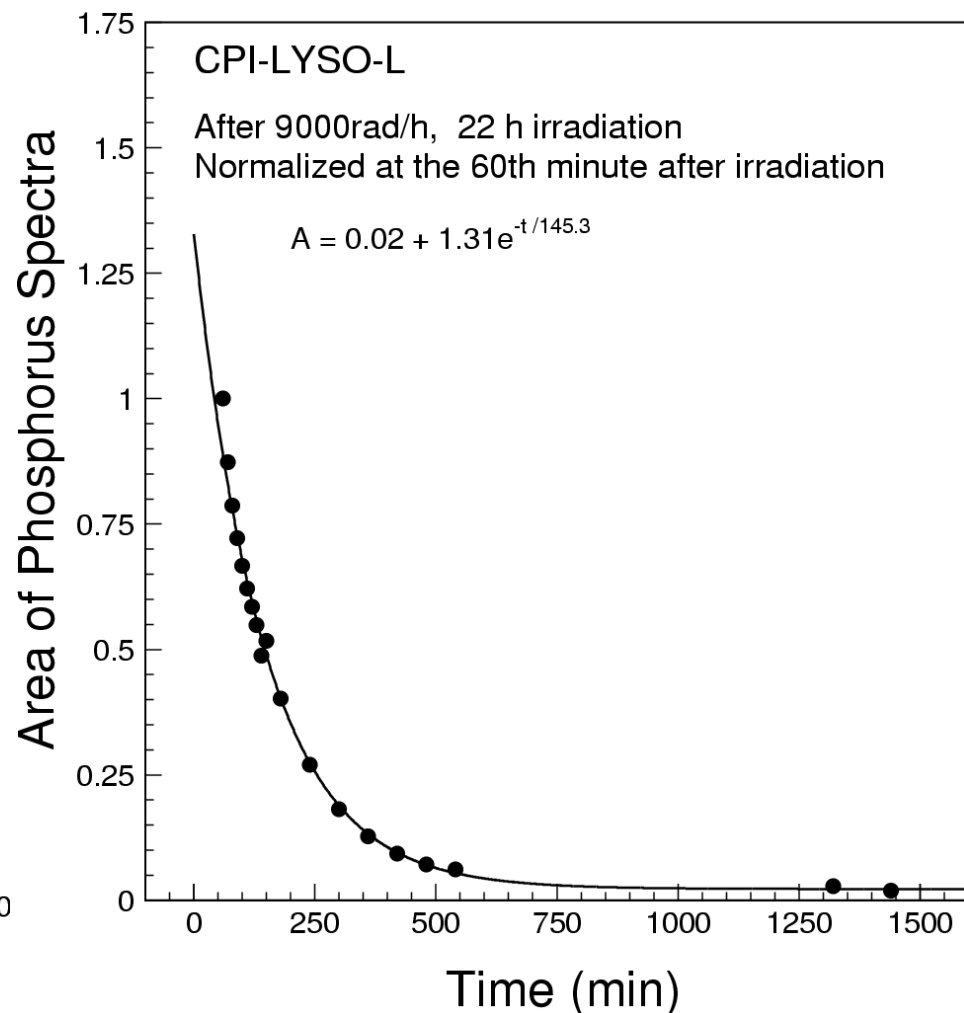
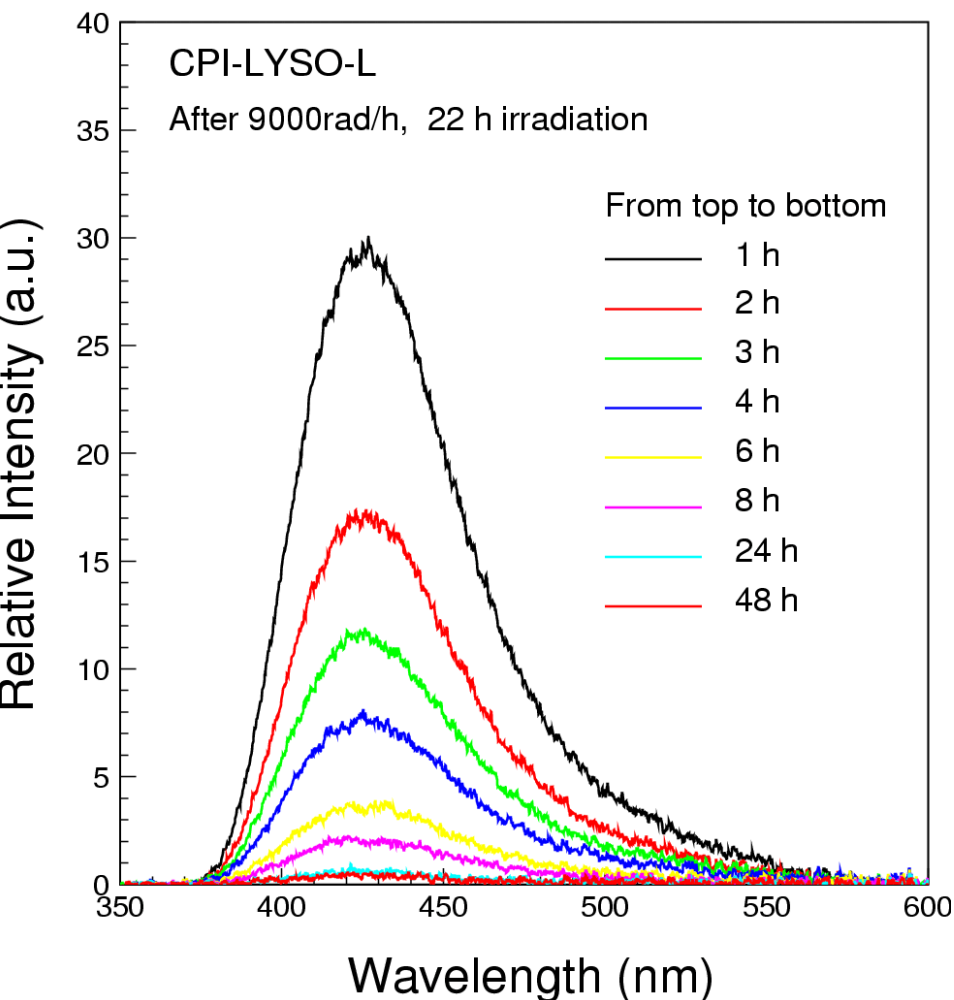




Radiation Induced Phosphorescence



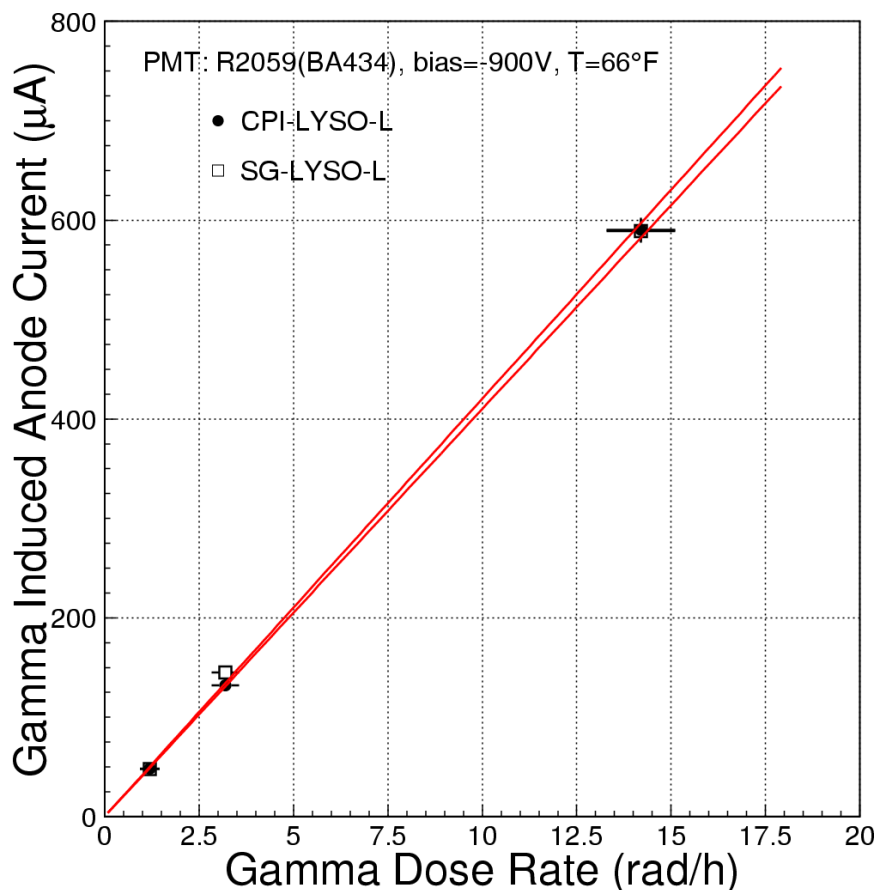
Phosphorescence peaked at 430 nm
with decay time constant of 2.5 h observed





γ -ray Induced Readout Noise

Sample ID	L.Y. p.e./MeV	F μ A/rad/h	$Q_{15 \text{ rad/h}}$ p.e.	$Q_{500 \text{ rad/h}}$ p.e.	$\sigma_{15 \text{ rad/h}}$ MeV	$\sigma_{500 \text{ rad/h}}$ 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

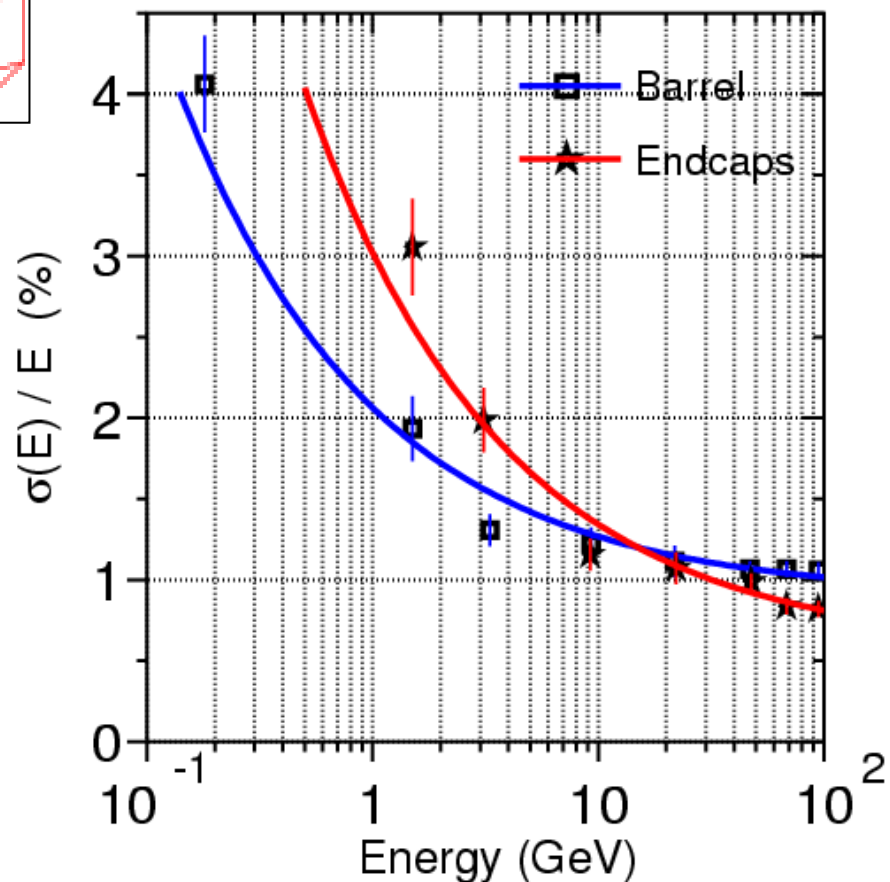
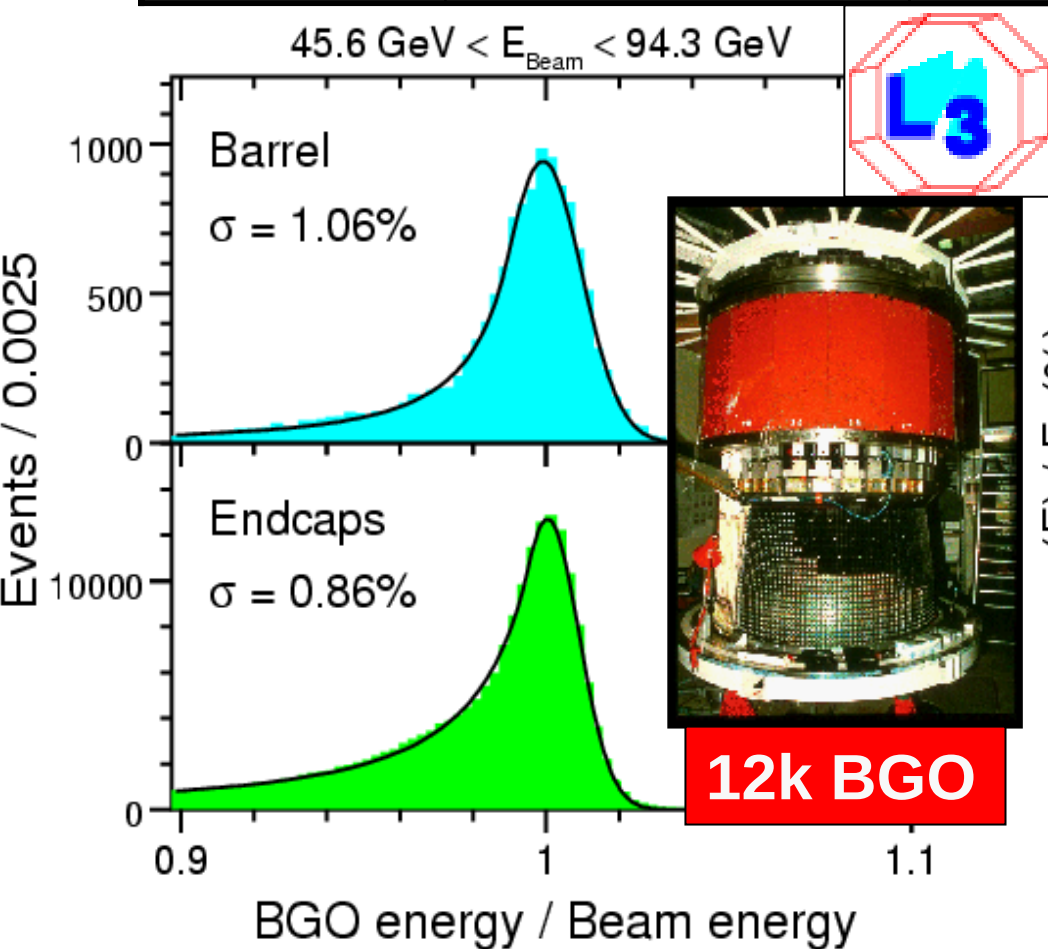


γ -ray induced PMT anode current can be converted to the photoelectron numbers (Q) integrated in 100 ns gate. Its statistical fluctuation contributes to the readout noise (σ).



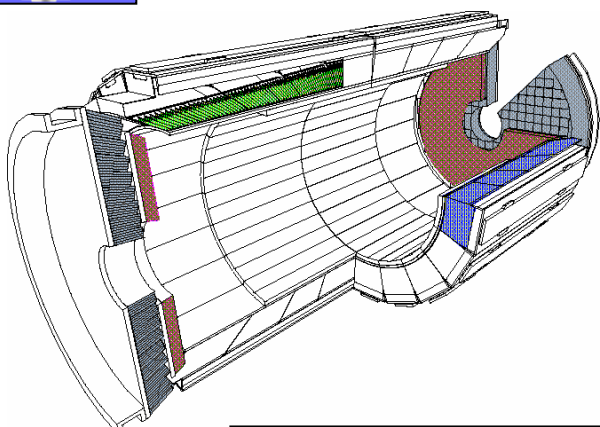
L3 BGO Resolution

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

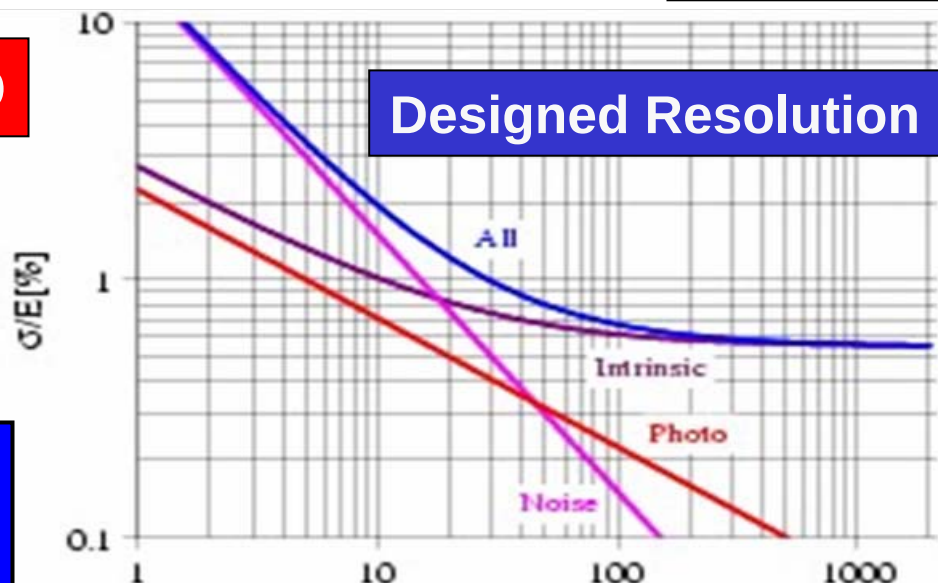




CMS PWO Resolution



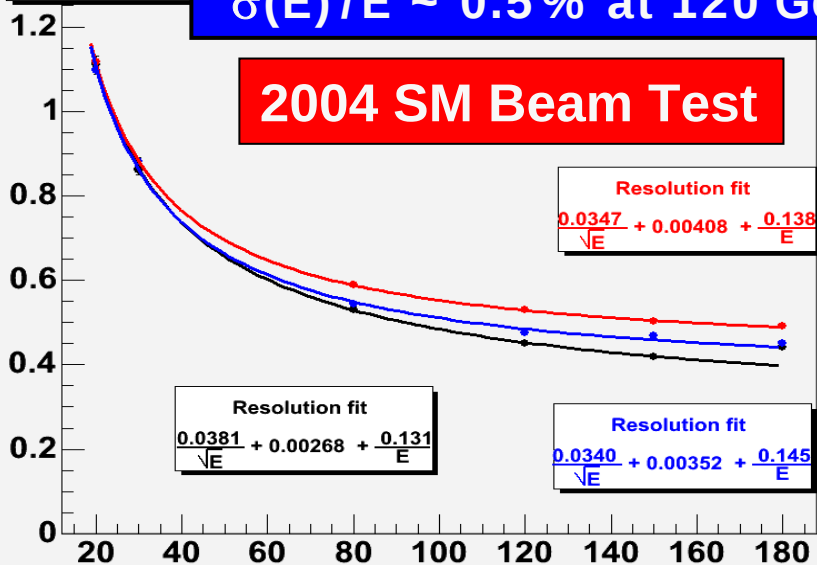
77k PWO



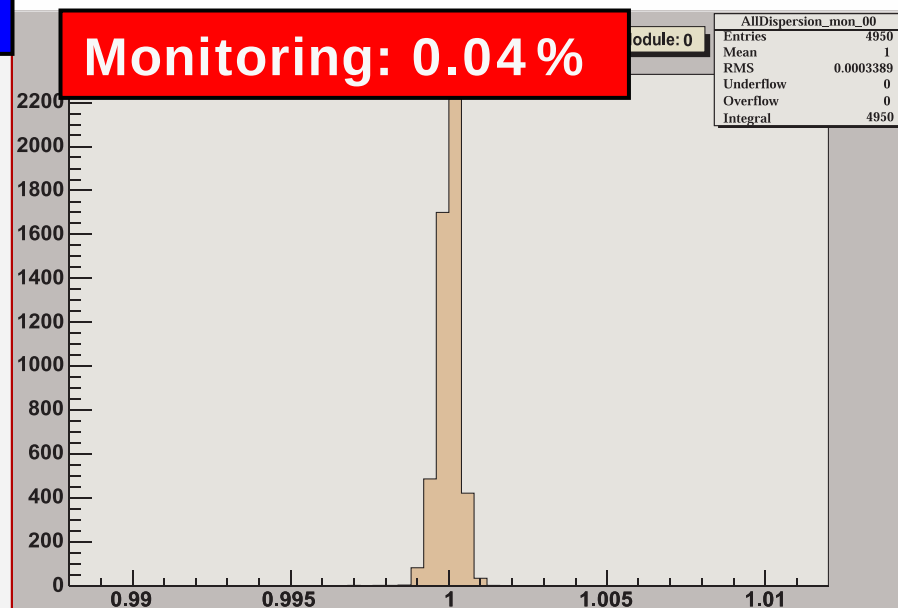
Energy Resolution:

$\sigma(E)/E < 1\%$ 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, $\sigma(E)/E$, 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 $\sim 73\%$

Purity $\sim 99\%$:

Precision: 0.5% (RFQ calibration)

Best sensitivity at LEP

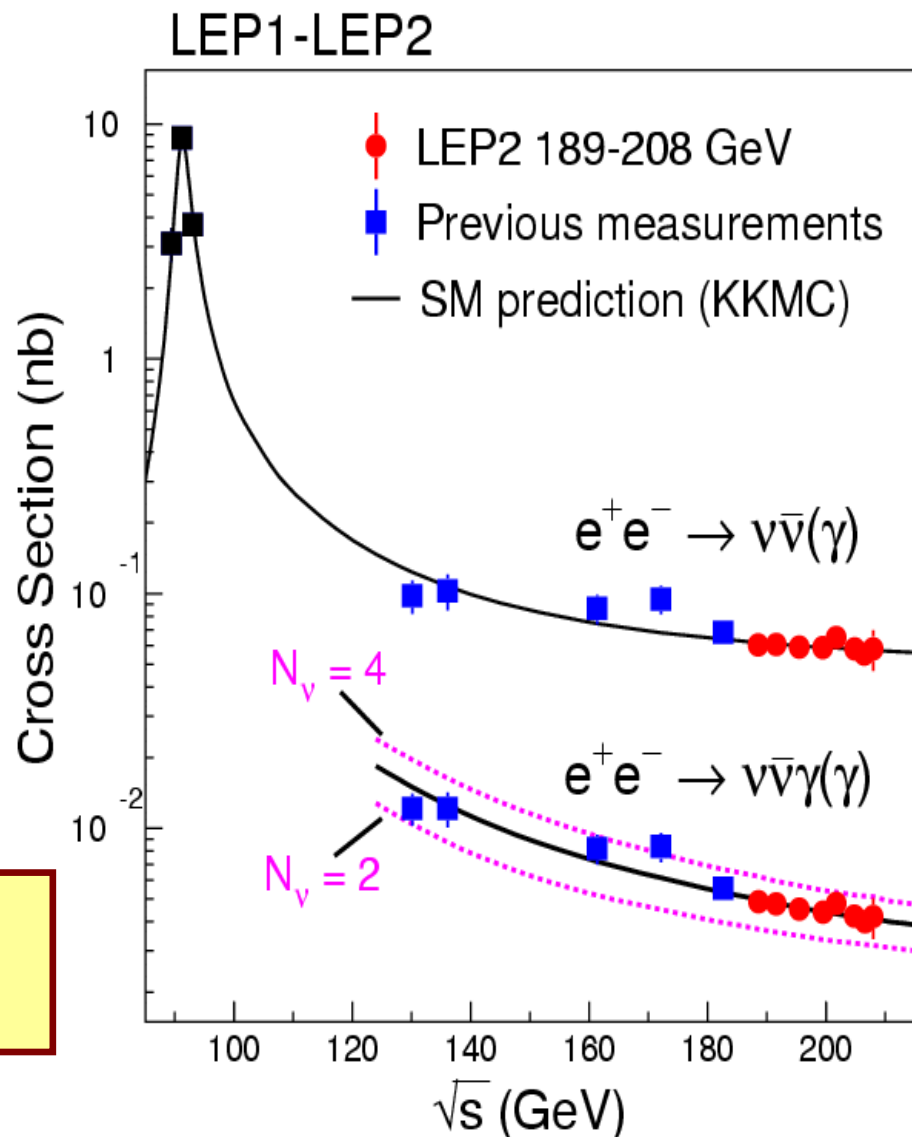
Physics Topics Include:

- 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

$$N_v = 2.98 \pm 0.06$$

More precise than PDG'04

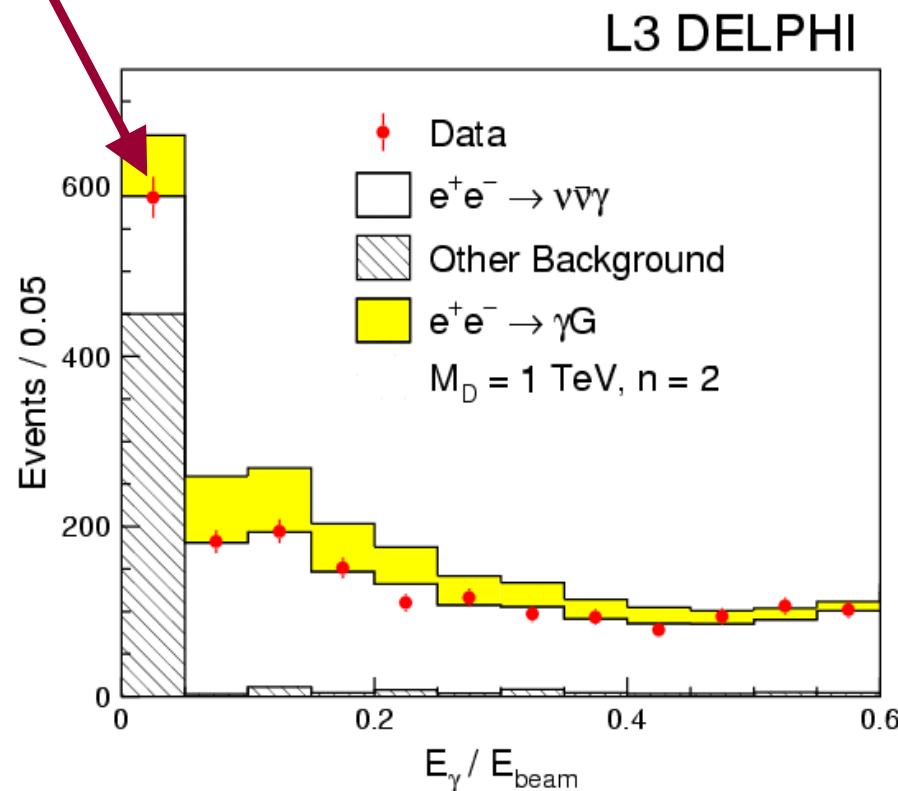
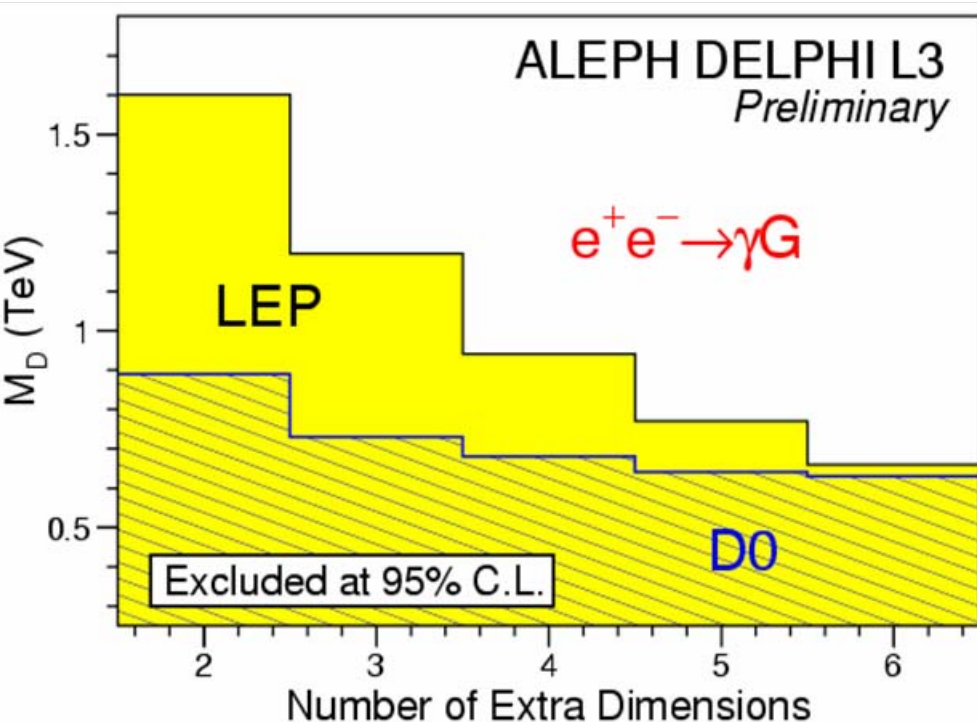
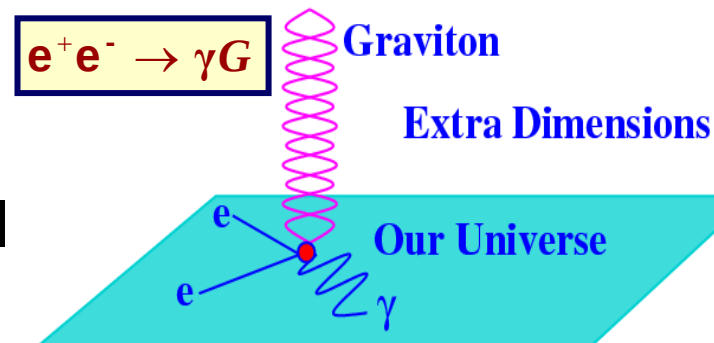




Extra Dimensions at LEP



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



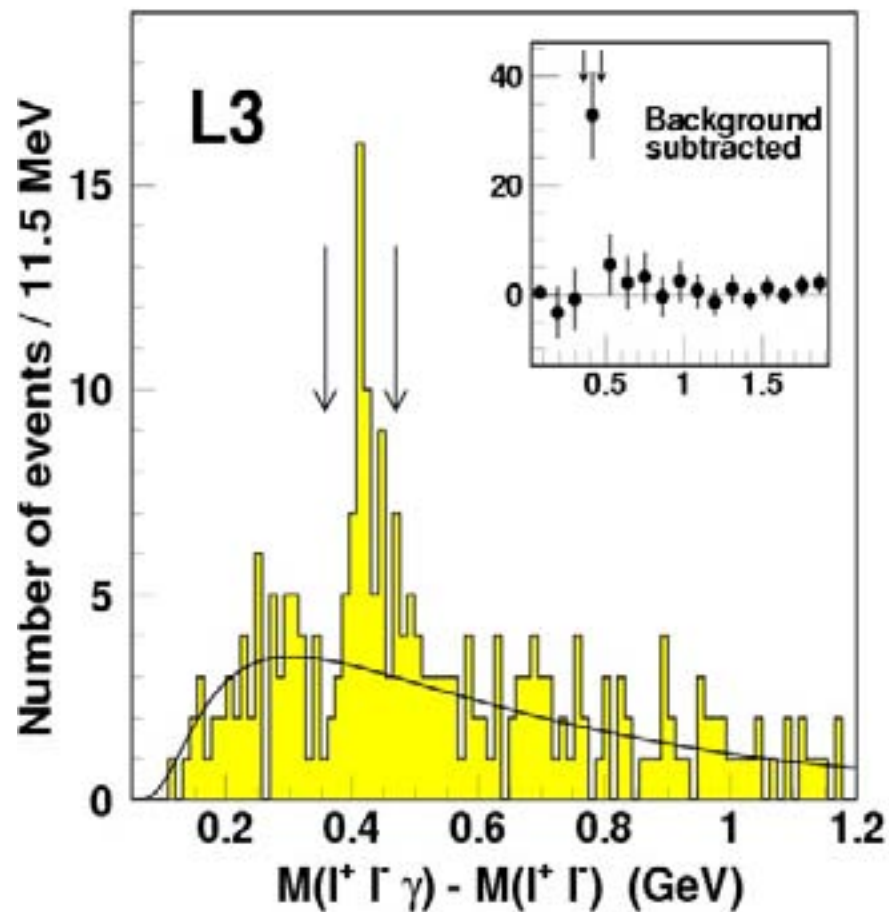


Physics in Crystal Calorimeter



Charmed Meson in Z Decay

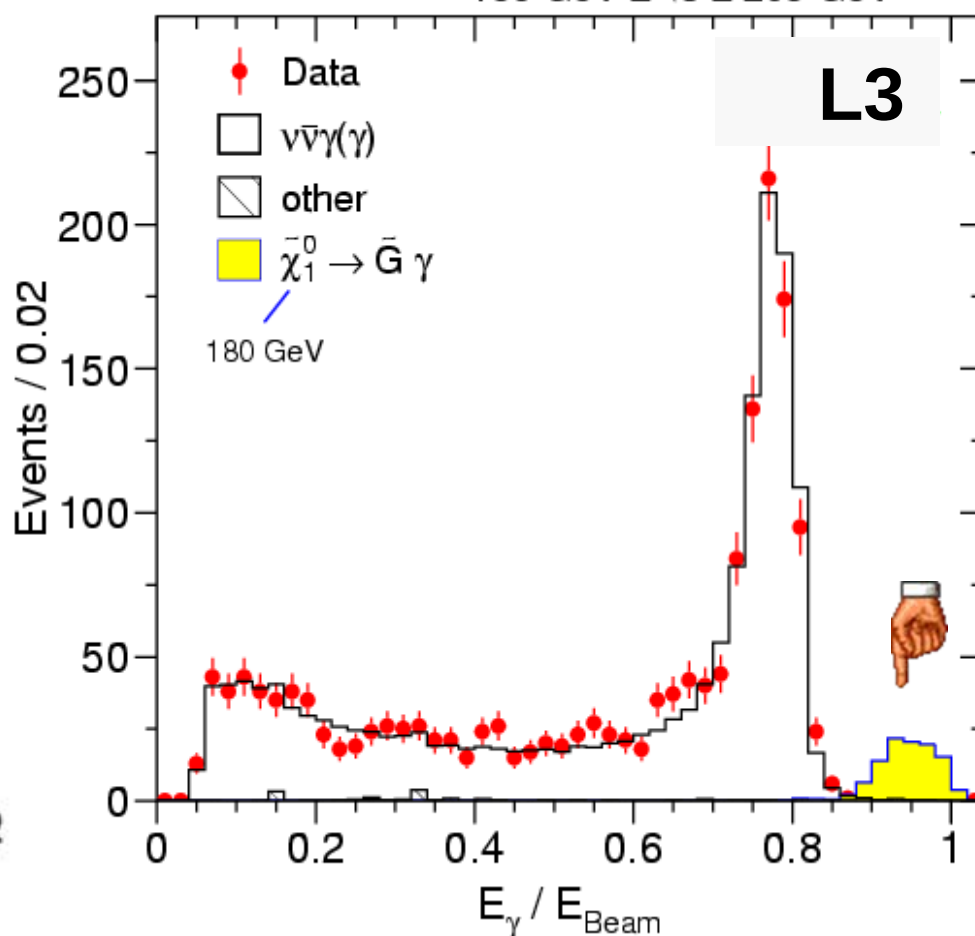
$$\chi_{c1} \rightarrow J/\psi \gamma$$



SUSY Breaking with Gravitino

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

$$189 \text{ GeV} \leq \sqrt{s} \leq 208 \text{ GeV}$$

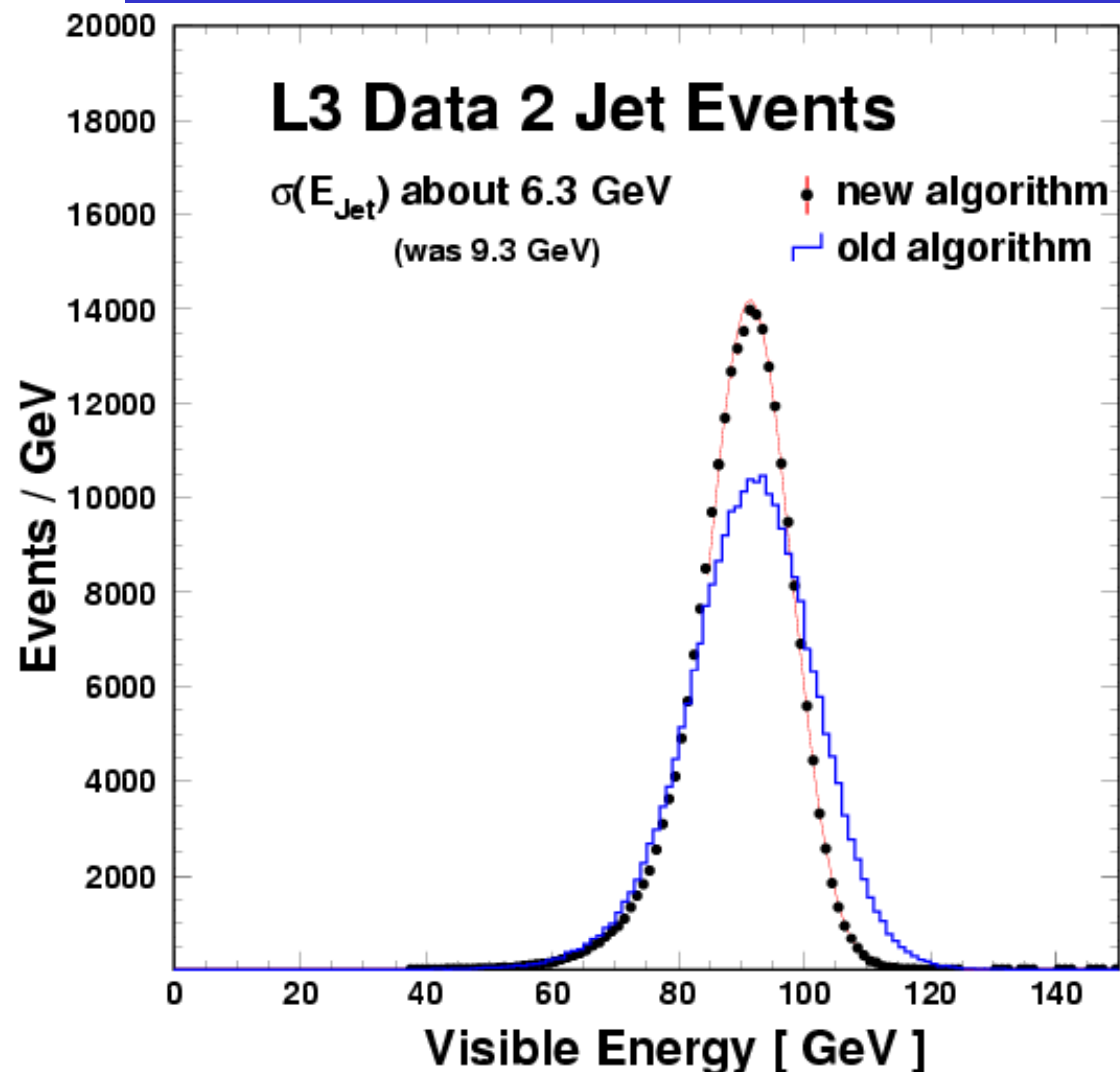




L3 Jet Mass Resolution: $Z \rightarrow qq$



Proceedings, Sitges ILC Workshop (1999)



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



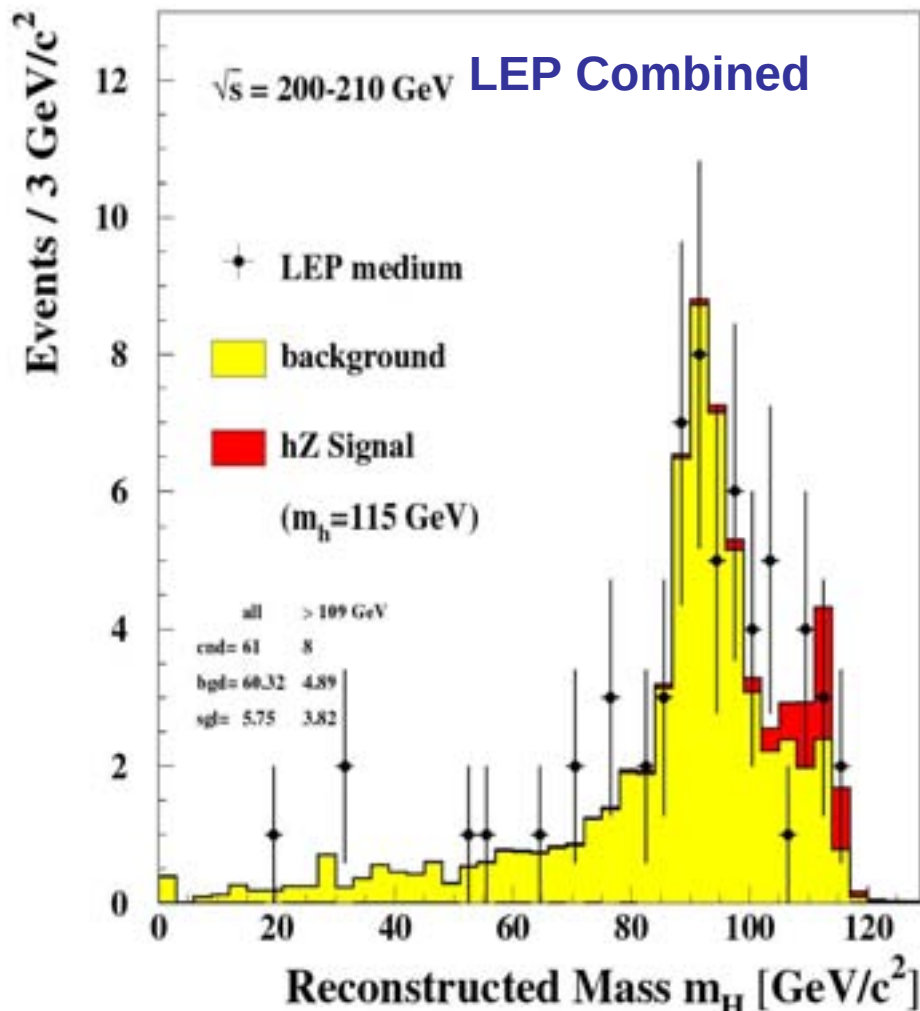
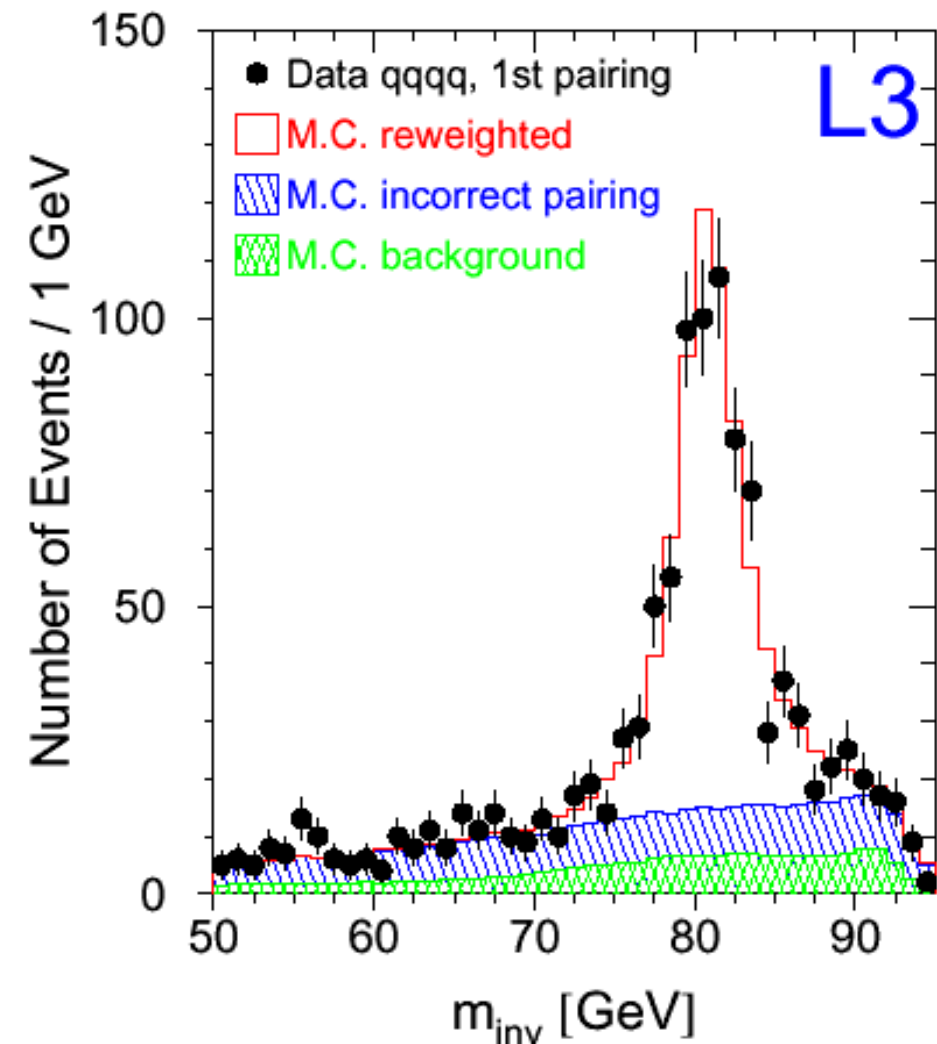
Best Jet Mass Resolution at LEP



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 mm².
- 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.