Calibration and Monitoring for Crystal Calorimetry

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SCINT03 Valencia, Spain September 11, 2003

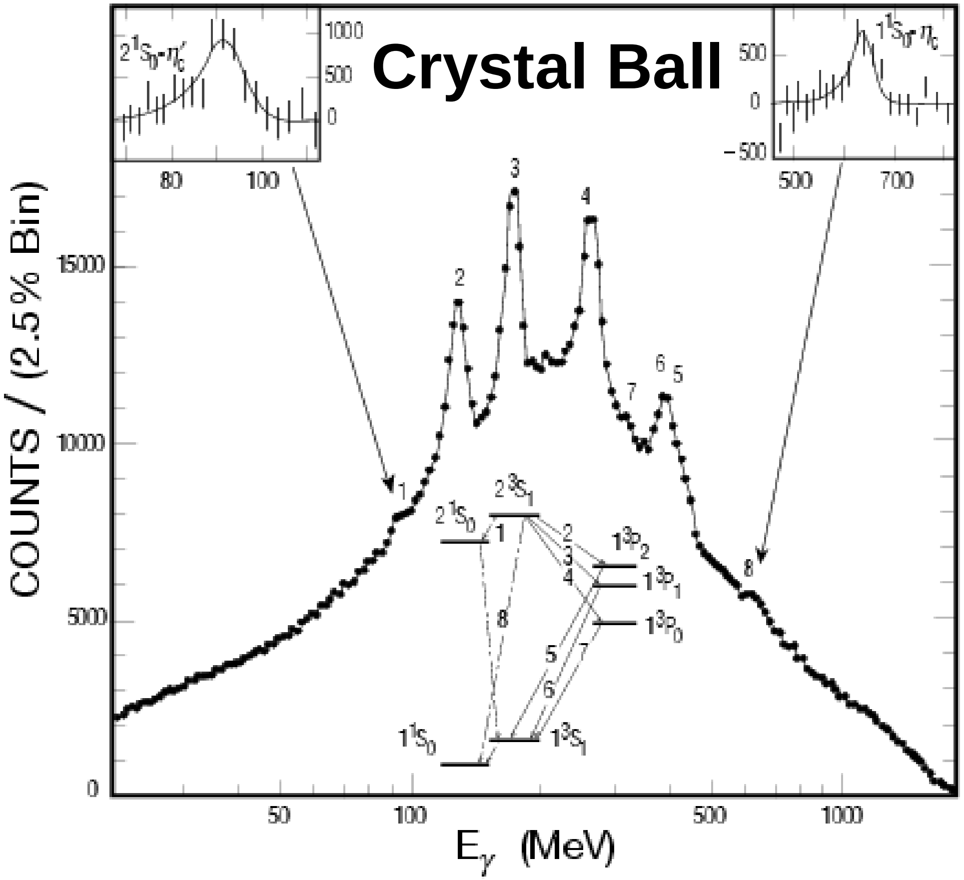
Properties of Crystal Scintillators

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 (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
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] (%/ ºC)	~0	0.3	-0.6	-2 ~0	-1.6	-1.9	?	?
Experiment	Crystal Ball	CLEO BaBar BELLE	KTeV	(L*) (GEM) TAPS	L3 BELLE	CMS ALICE BTeV…	-	-

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

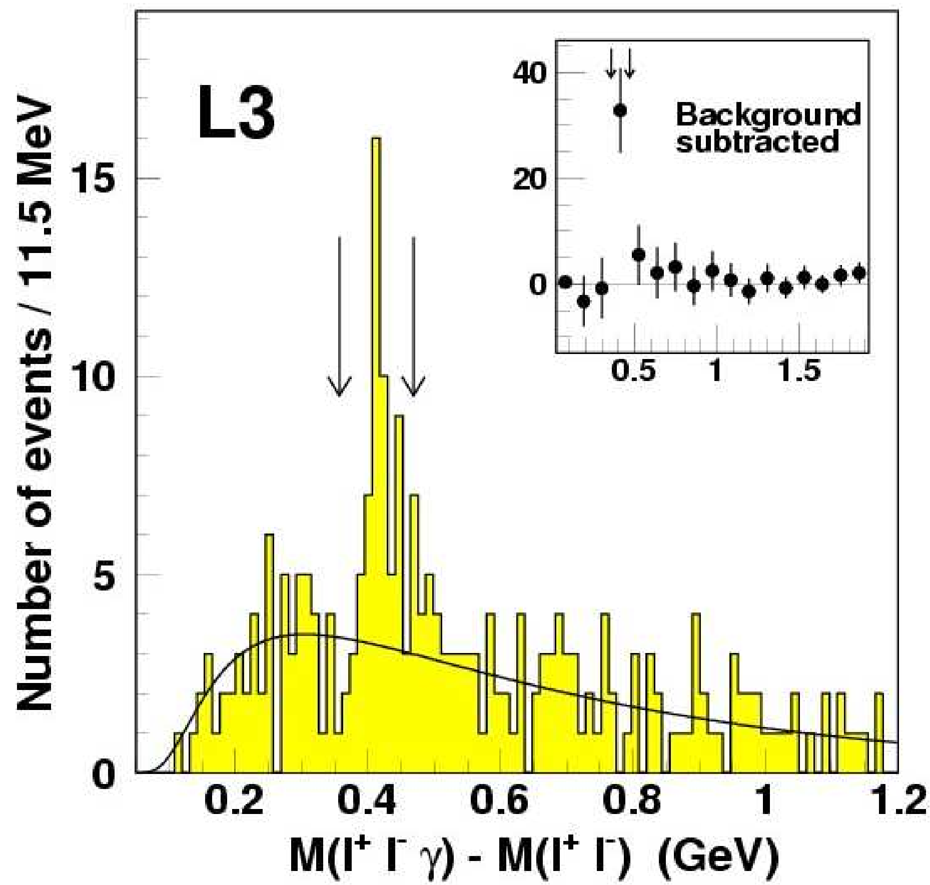
SM Physics with Crystal Calorimetry

Charmonium System Observed Through Inclusive Photons



Charmed Meson in Z Decay

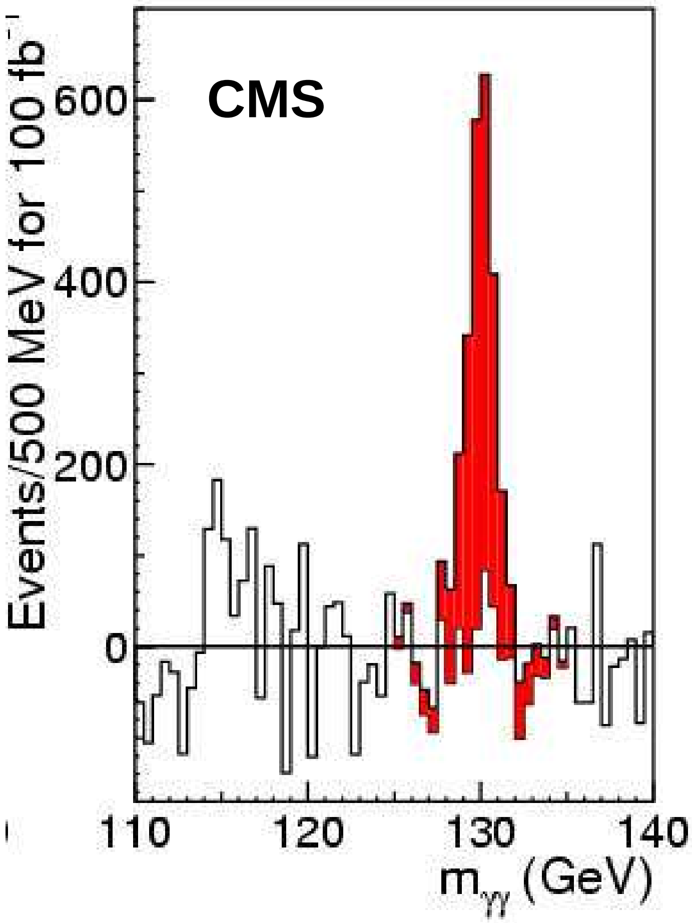
$$\chi_{c1} \rightarrow J/\psi\gamma$$



New Physics with Crystal Calorimetry

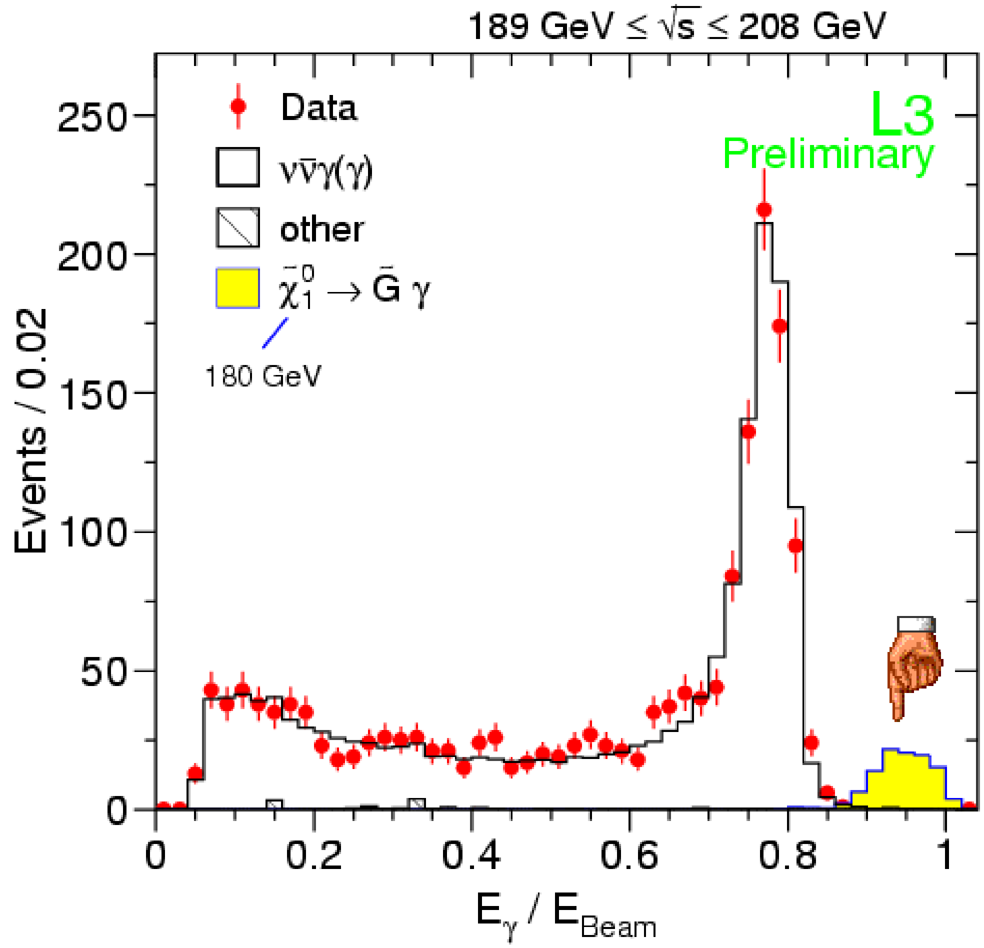
Higgs Search at LHC

$$H \to \gamma\gamma$$



SUSY Breaking with Gravitino

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



New Physics with Crystal Calorimetry (cont.)

The CDF event: 2 e + 2 γ + E_T^{miss}

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

Possible SUSY explanation

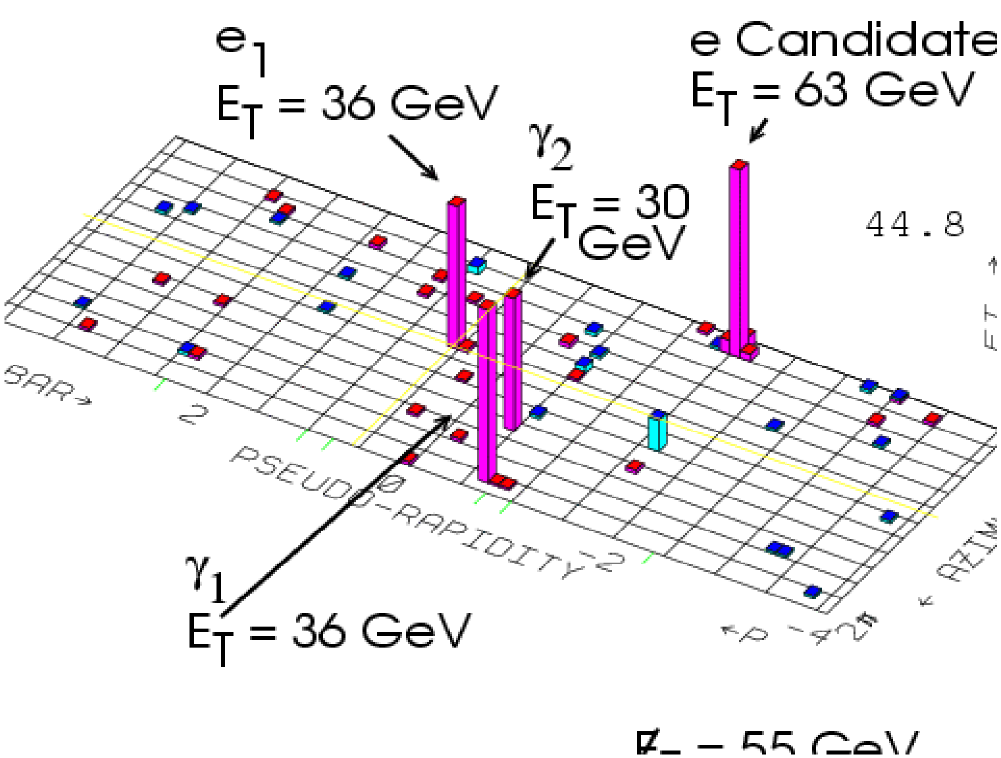
$$q\bar{q} \rightarrow \tilde{e}^+\tilde{e}^- \rightarrow ee\tilde{\chi}_1^0\tilde{\chi}_1^0 \rightarrow ee\gamma\gamma\tilde{G}\tilde{G}$$

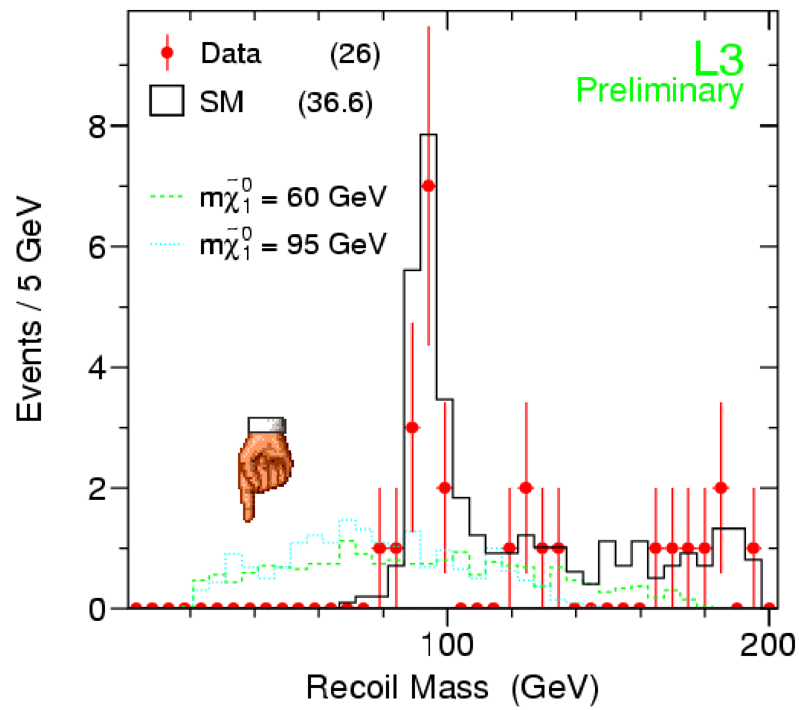
L3 should be able to observe

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

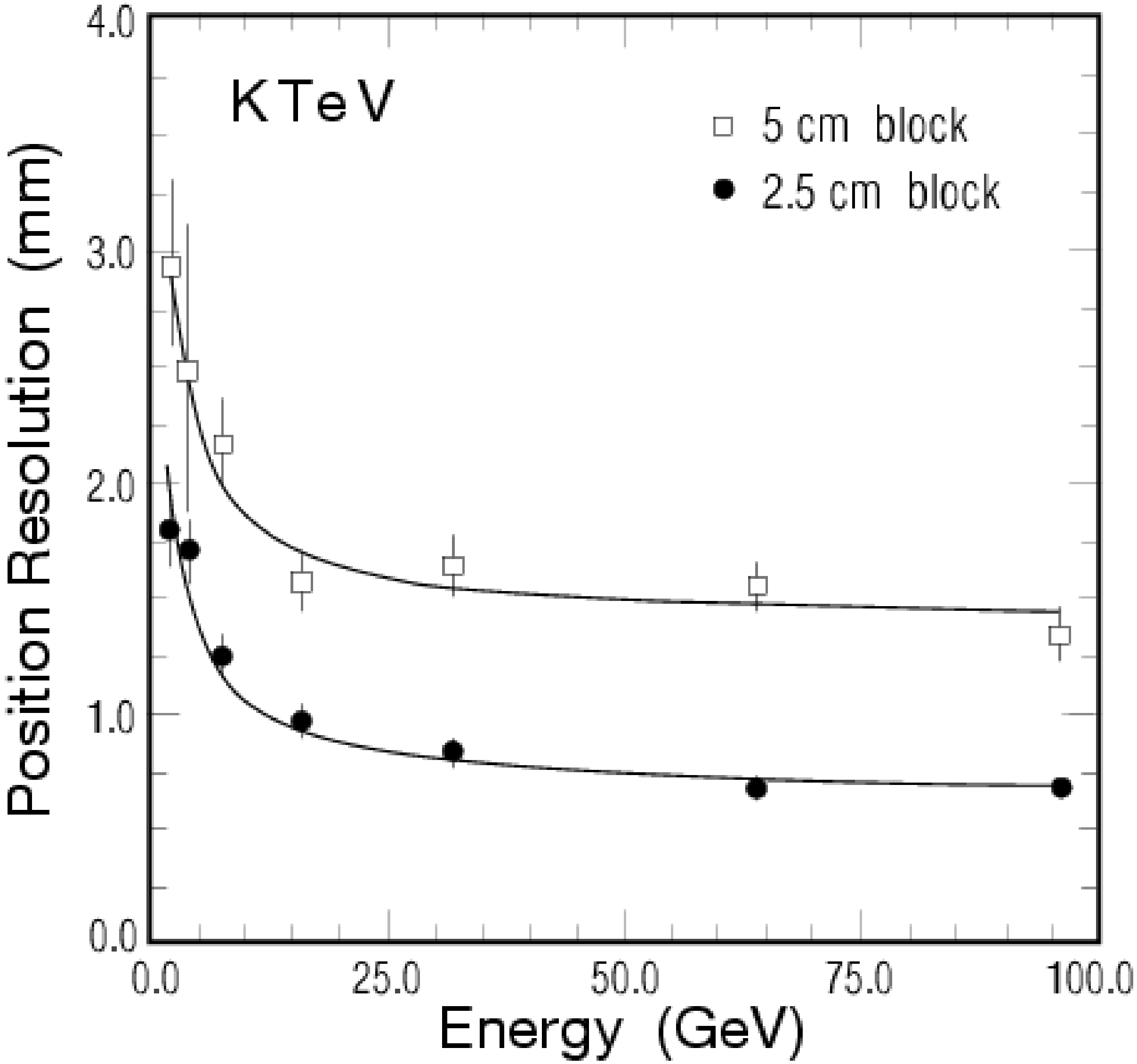
Another possible channel

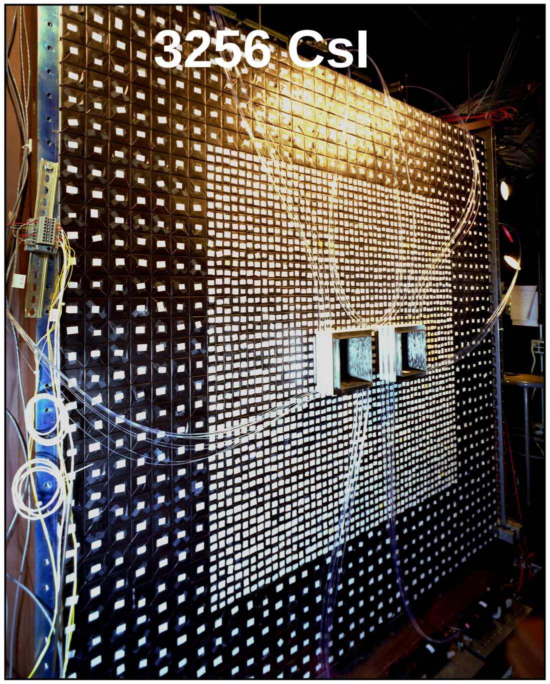
$$e^+e^- \rightarrow \tilde{\chi}_2^0\tilde{\chi}_2^0 \rightarrow \gamma\gamma\tilde{\chi}_1^0\tilde{\chi}_1^0$$





KTeV CsI Position Resolution





Sub mm position resolution is achievable.

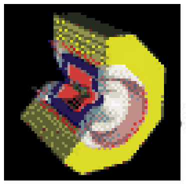
L3 BGO & CMS PWO: 0.3 mm at high energies.

CLEO & *BaBar* : CsI(Tl) Degradation

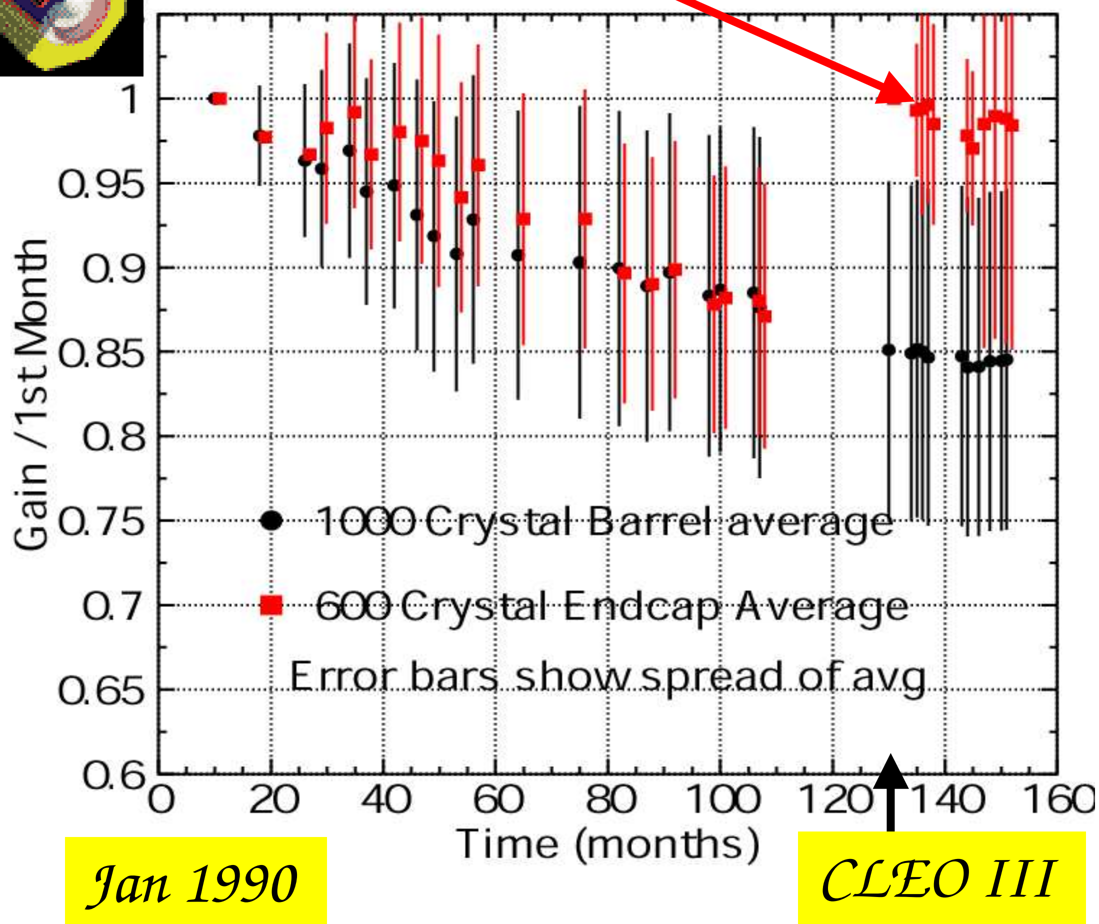
CLEO: ~15 % over 12 years

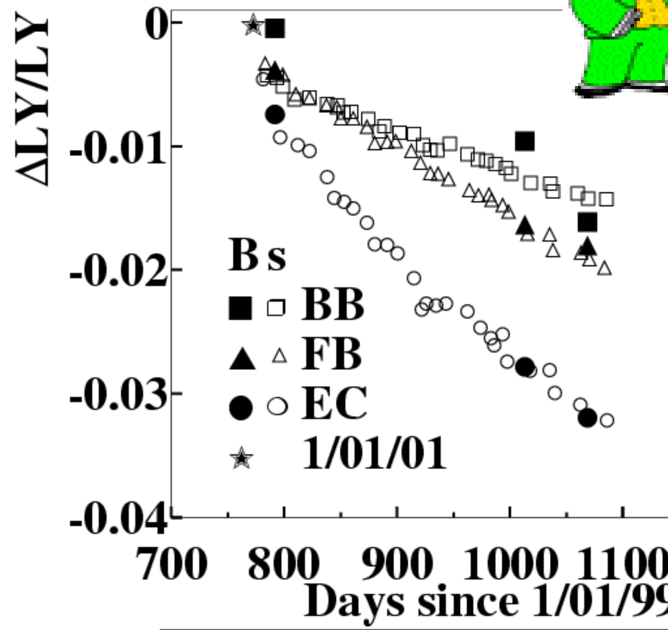
BaBar : 1 — 3 % per year

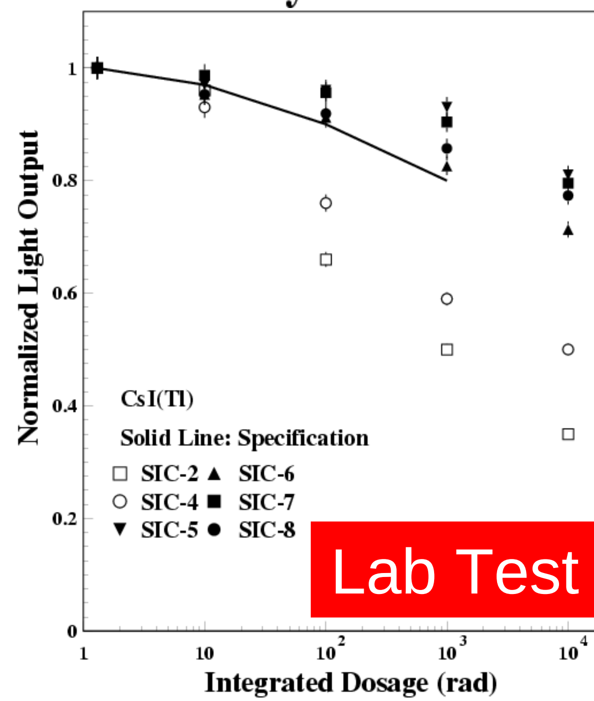
Brian Heltsley (http://www.lns.cornell.edu/~bkh)



Endcap crystals re-glued for CLEOIII



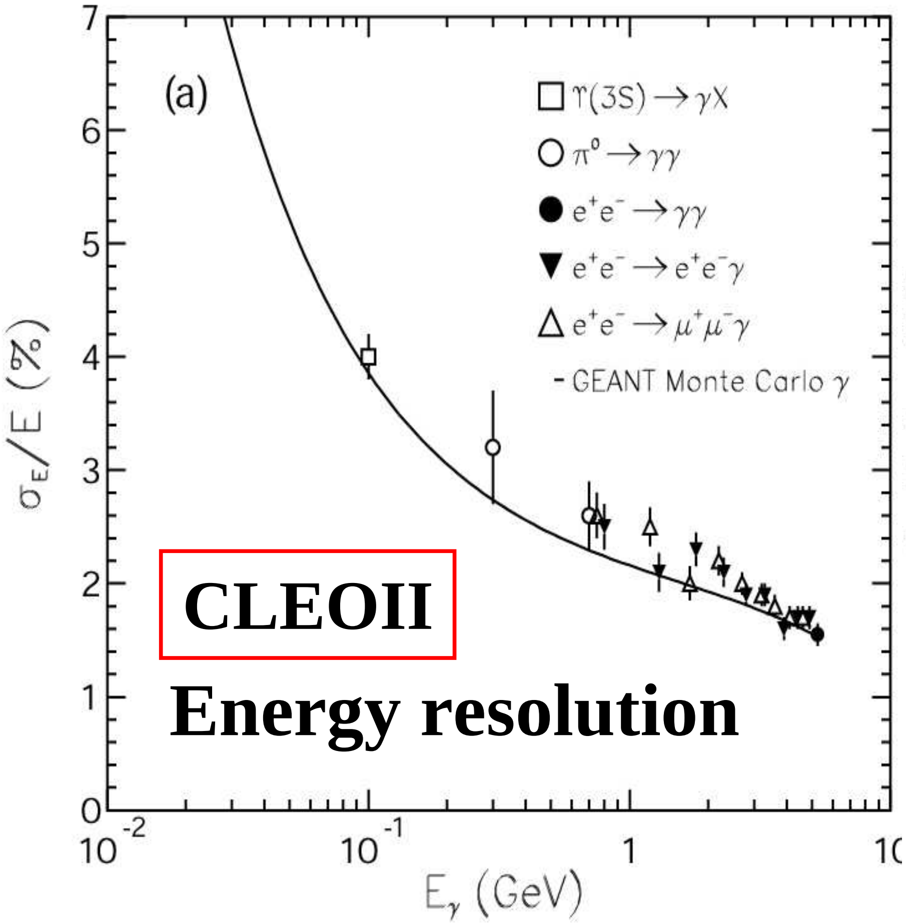


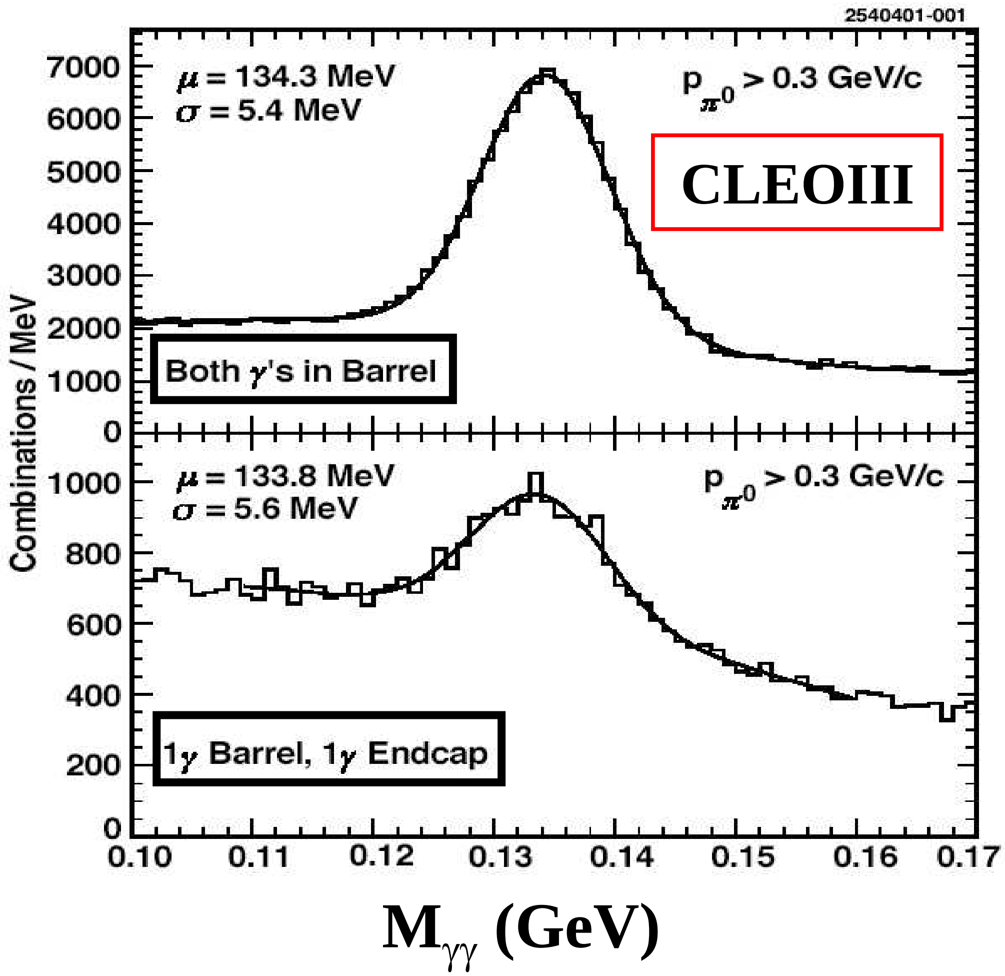


CLEO CsI(Tl) Calibration

With Bhabha Electrons & Photons from π^0's

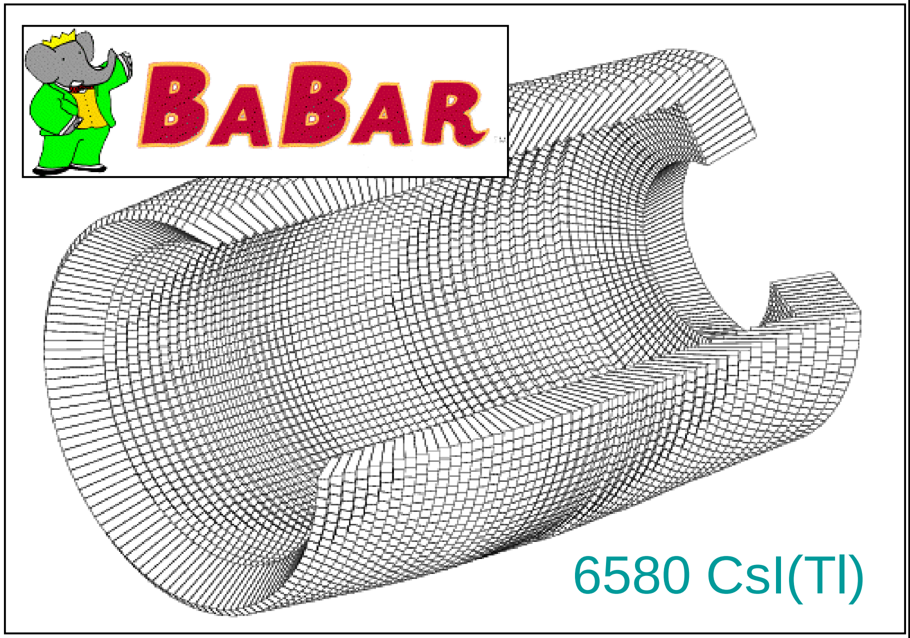
Brian Heltsley (http://www.lns.cornell.edu/~bkh)

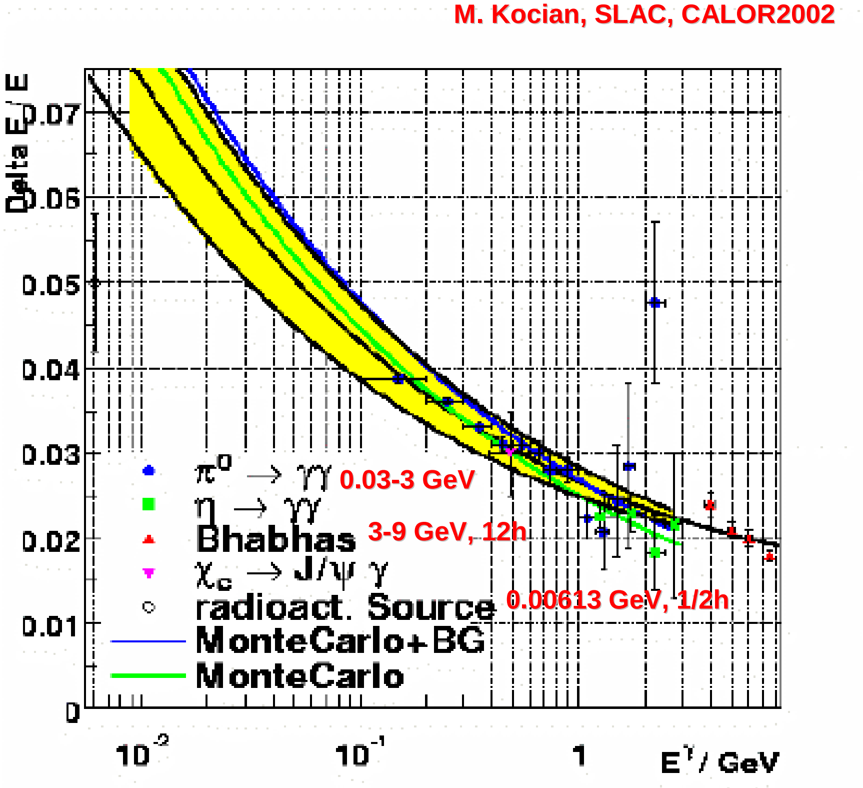




BaBar CsI(Tl) Calibration

By using a γ–ray source at 6.13 MeV, Bhabha electrons and photons from π^0's





$$\frac{\sigma_E}{E} = \frac{\sigma_1}{\sqrt[4]{E}} \oplus \sigma_2$$

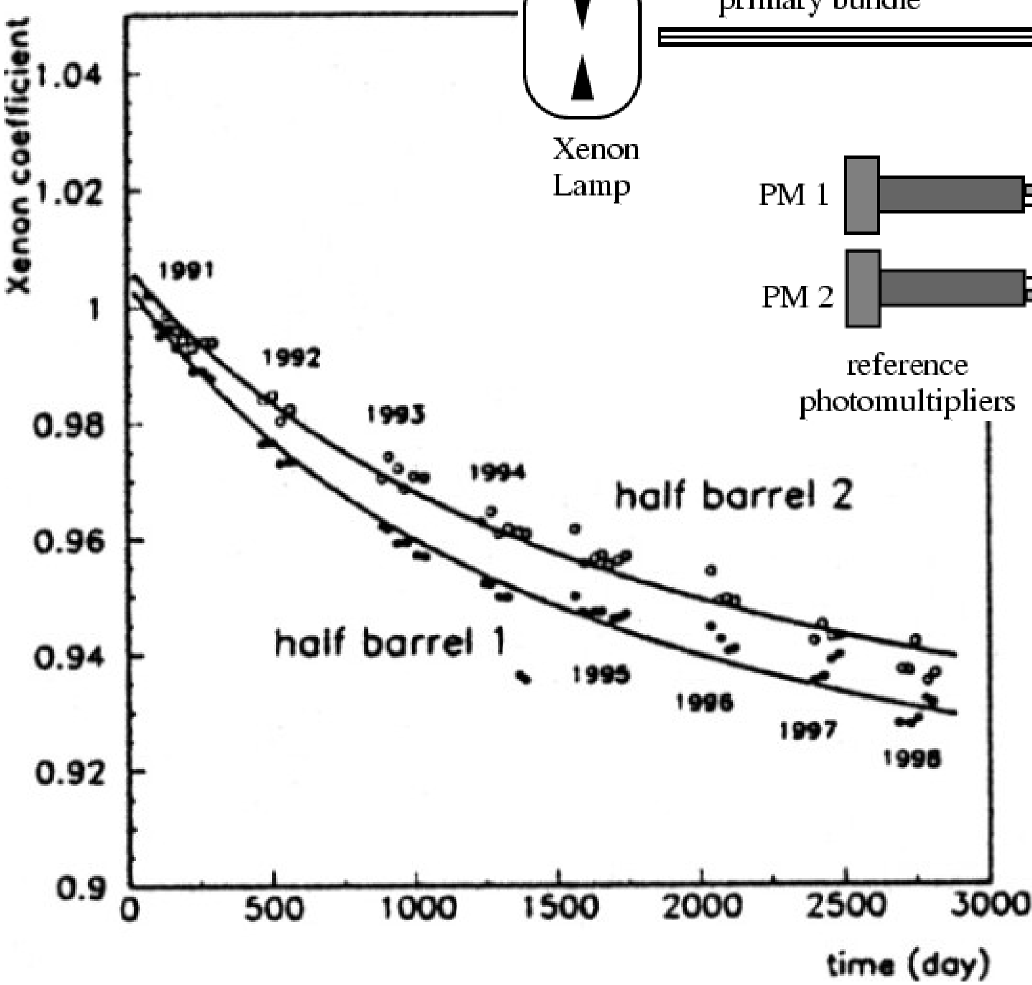
$$\sigma_1 = (2.30 \pm 0.03 \pm 0.3)\%$$

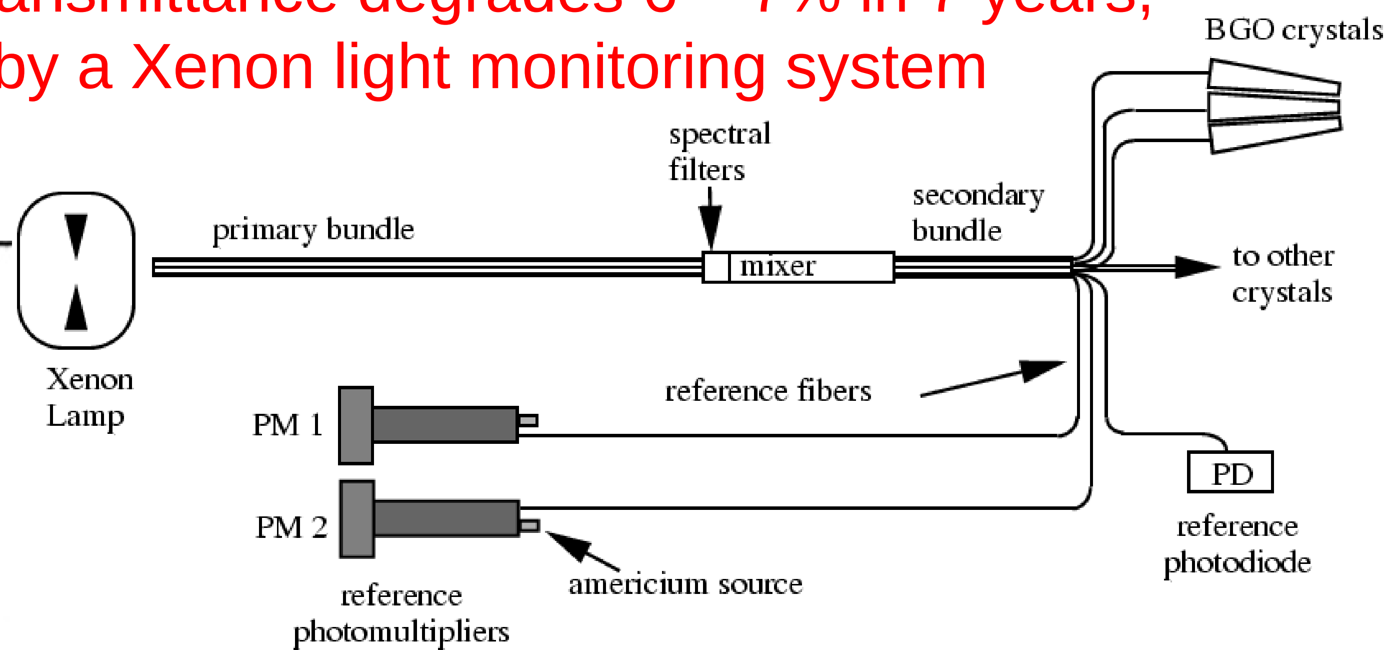
$$\sigma_2 = (1.35 \pm 0.08 \pm 0.2)\%$$

Crystal Calorimetry at Low Energies

L3: BGO Degradation

L3: BGO transmittance degrades 6 – 7% in 7 years, measured by a Xenon light monitoring system





-pulsed light from Hamamatsu L2453 Xenon lamps;

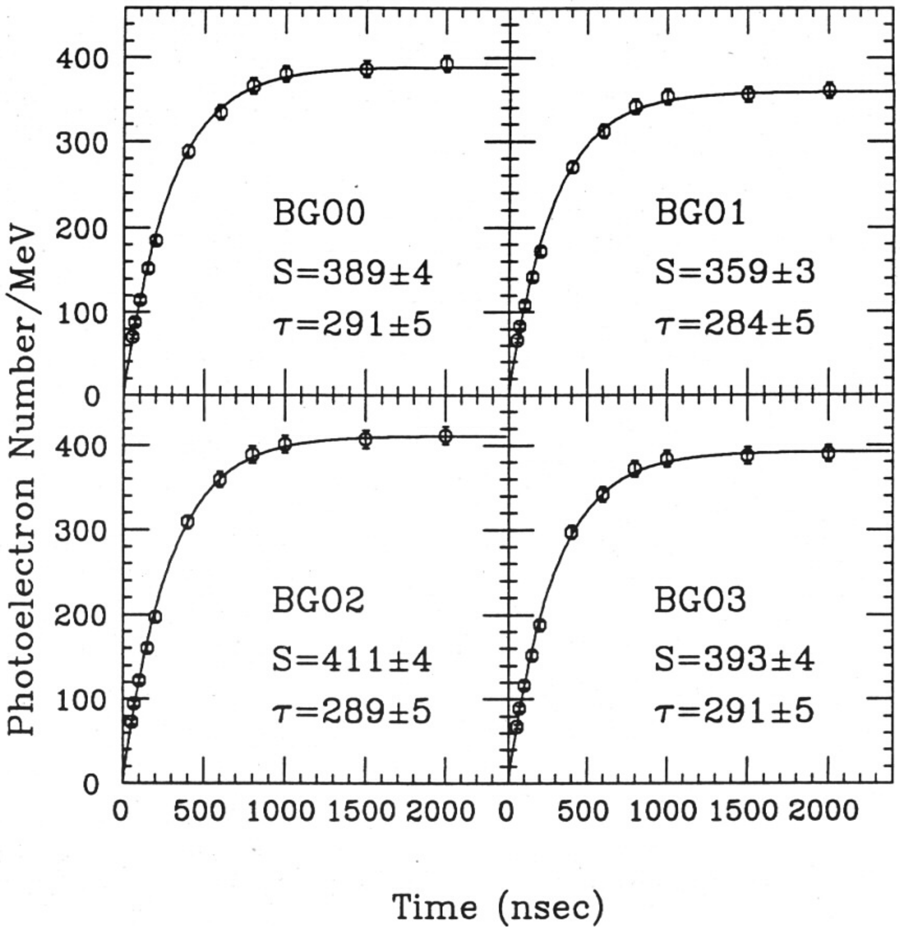
- two fibers per crystal crystal;

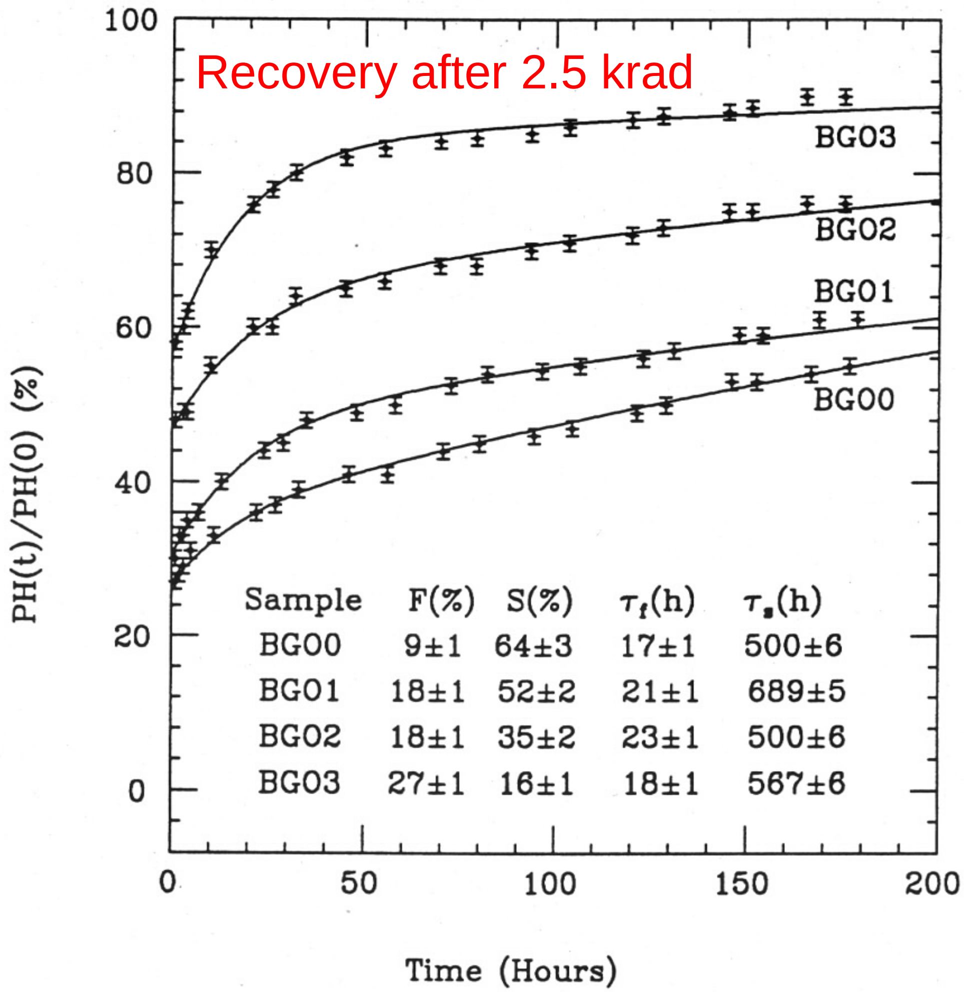
- response normalized to reference photo detectors.

BGO Quality Improvement

Z.Y. Wei *et al.*, Nucl. Instr. and Meth. A302 (1991) 69.

No change in decay time
by Eu doping: 0, 5, 30, 100 ppm

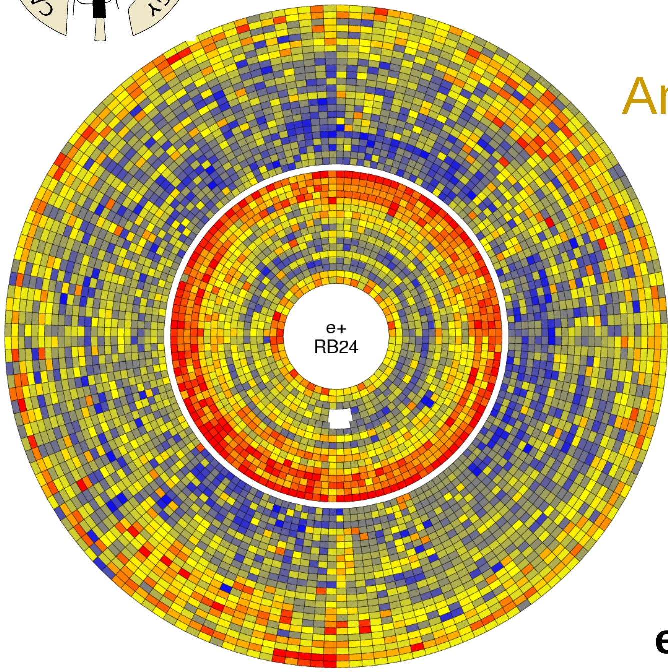


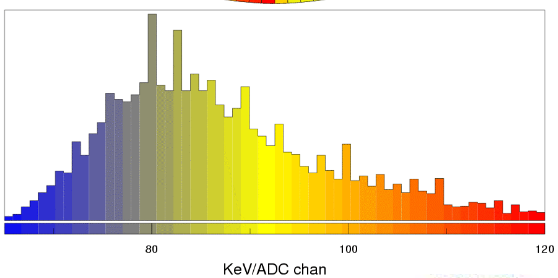


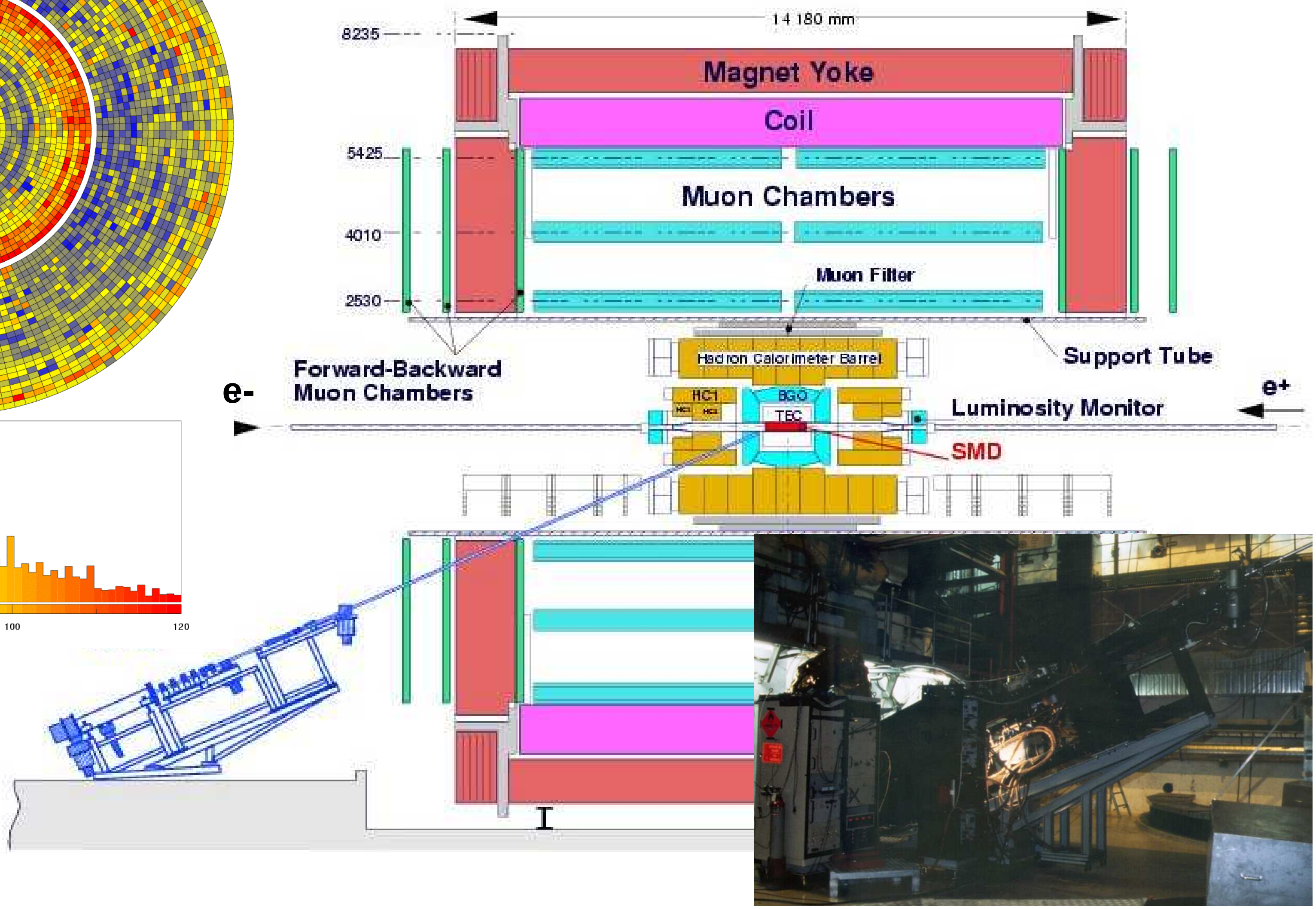
Significant Improvement in
radiation hardness by Eu doping

L3 RFQ Calibration System

An accelerator & a Li target provide 17.6 MeV γ–rays





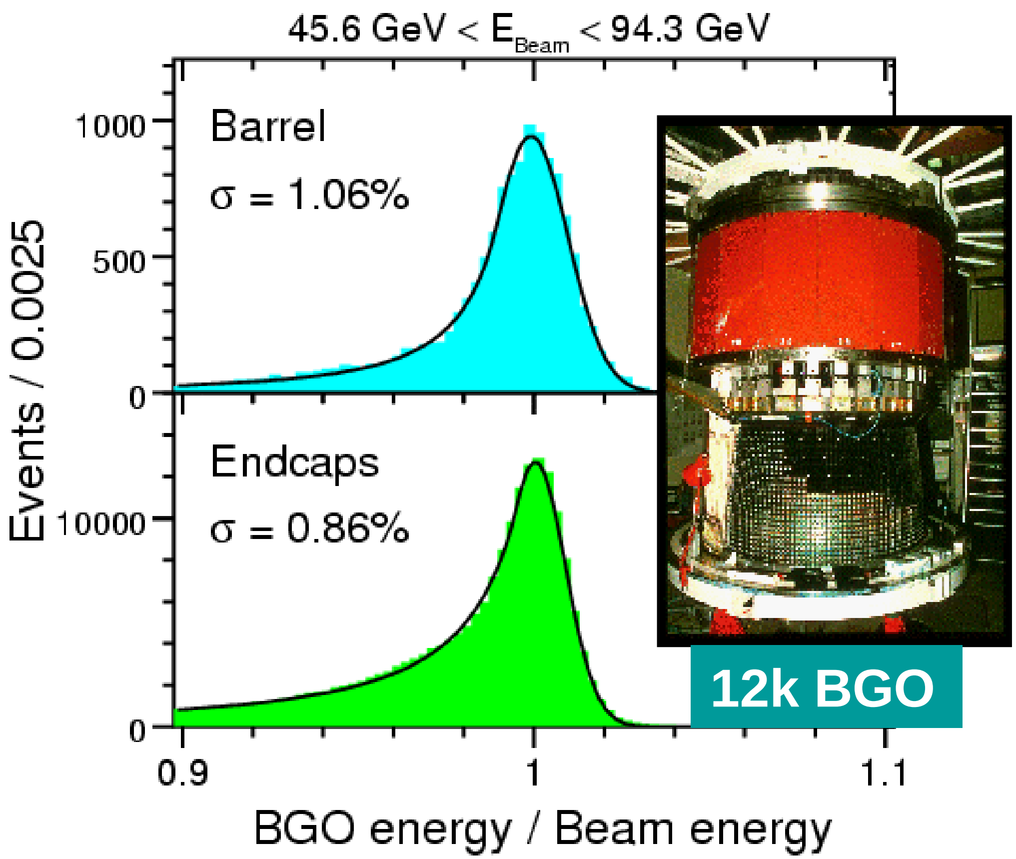


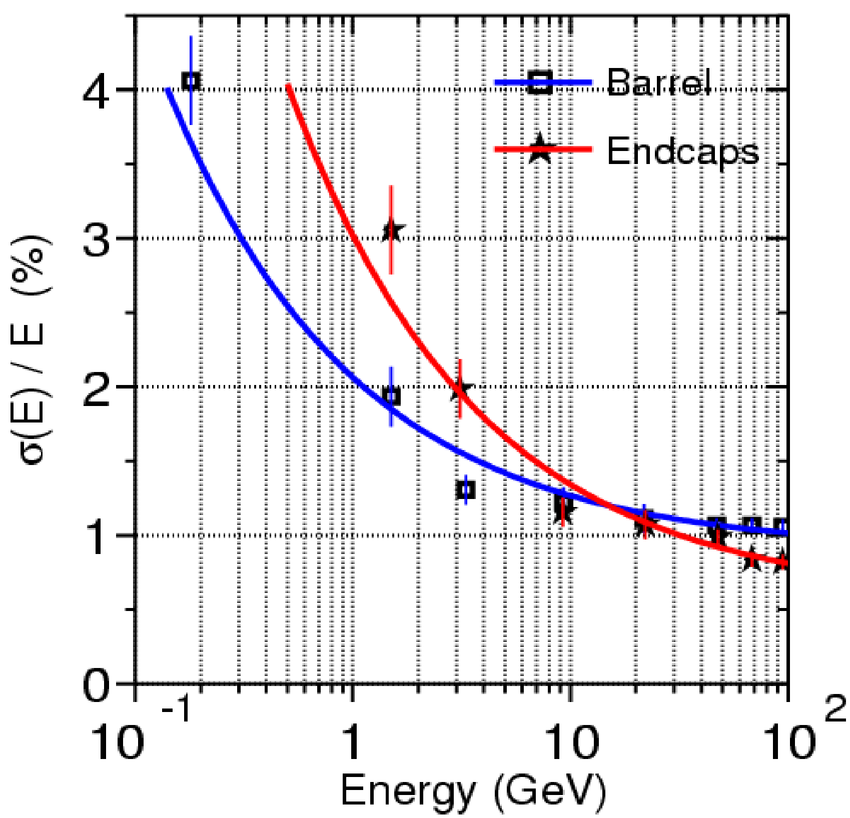
H- Ion Source
RFQ, HEBT
Neutralizer
Beam Pipe
Li Target

L3 BGO Calibration

With 17.6 MeV γ–ray from RFQ and Bhabha Electrons

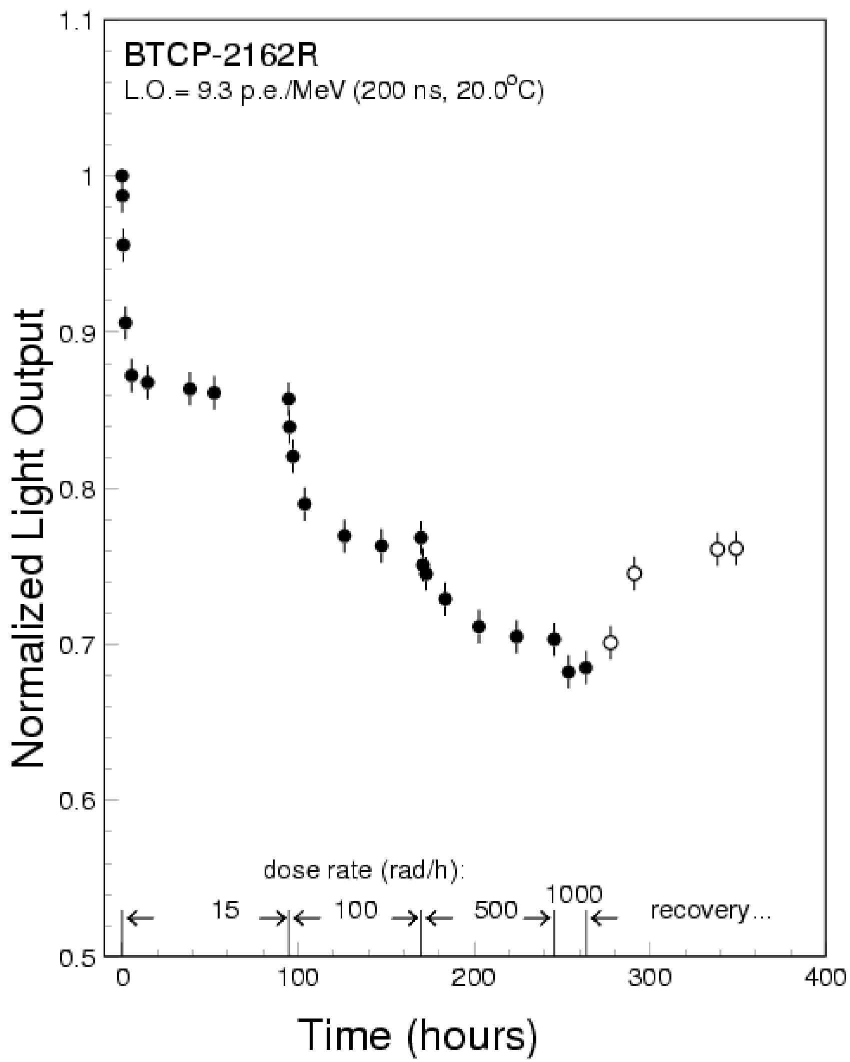
Contribution	"Radiative"+Intrinsic	Temperature	Calibration	Overall
Barrel	0.8%	0.5%	0.5%	1.07%
Endcaps	0.6%	0.5%	0.4%	0.88%

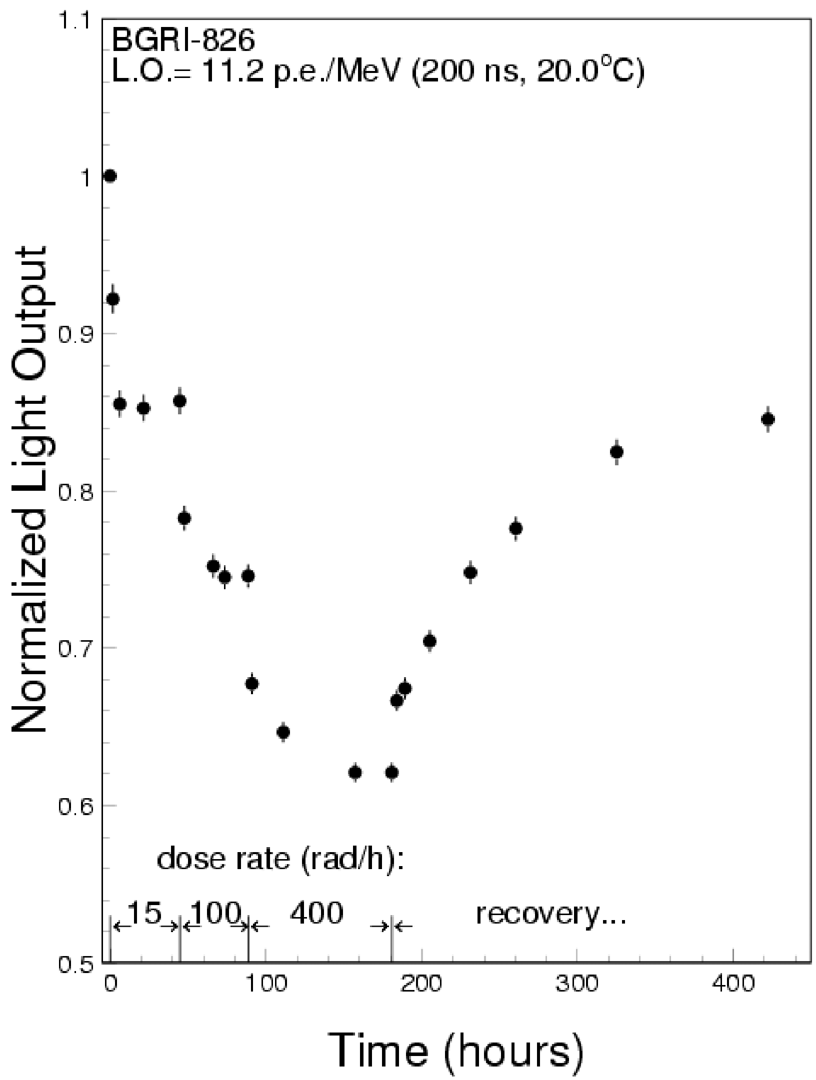




PWO Light Output Variation

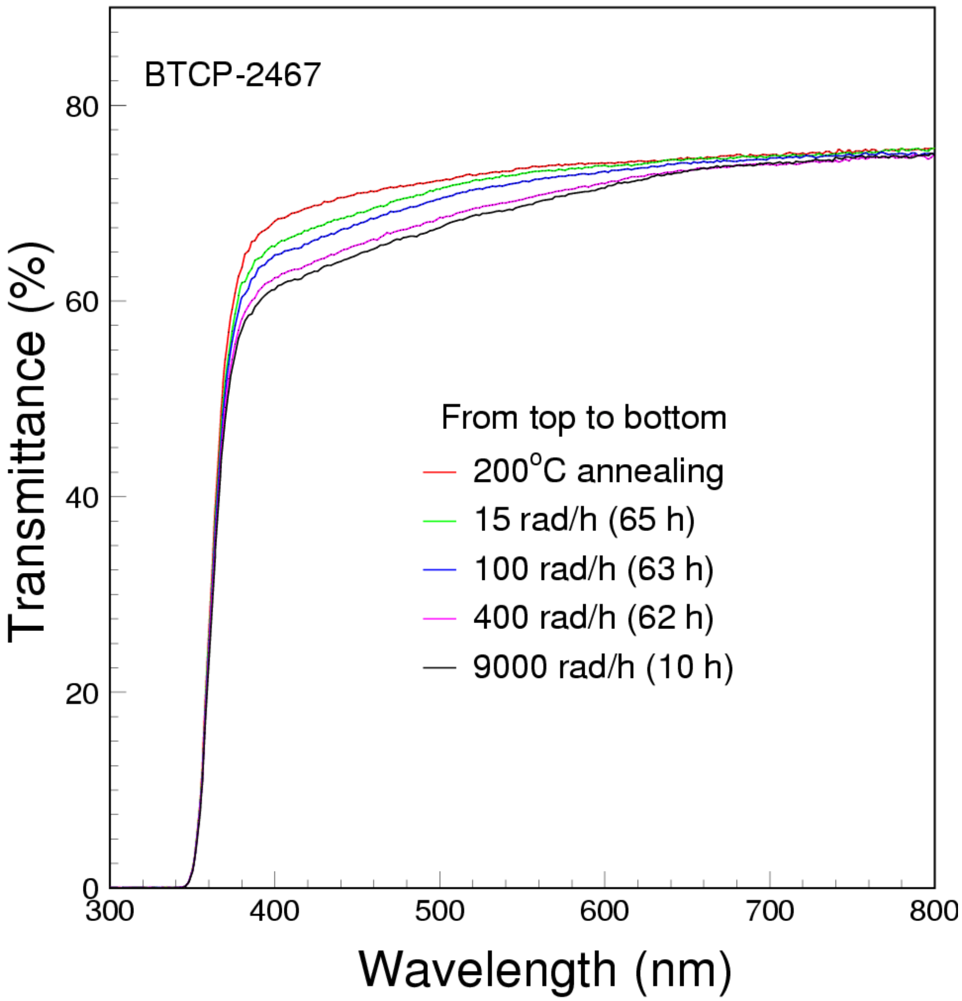
Damage and Recovery Causes Complication

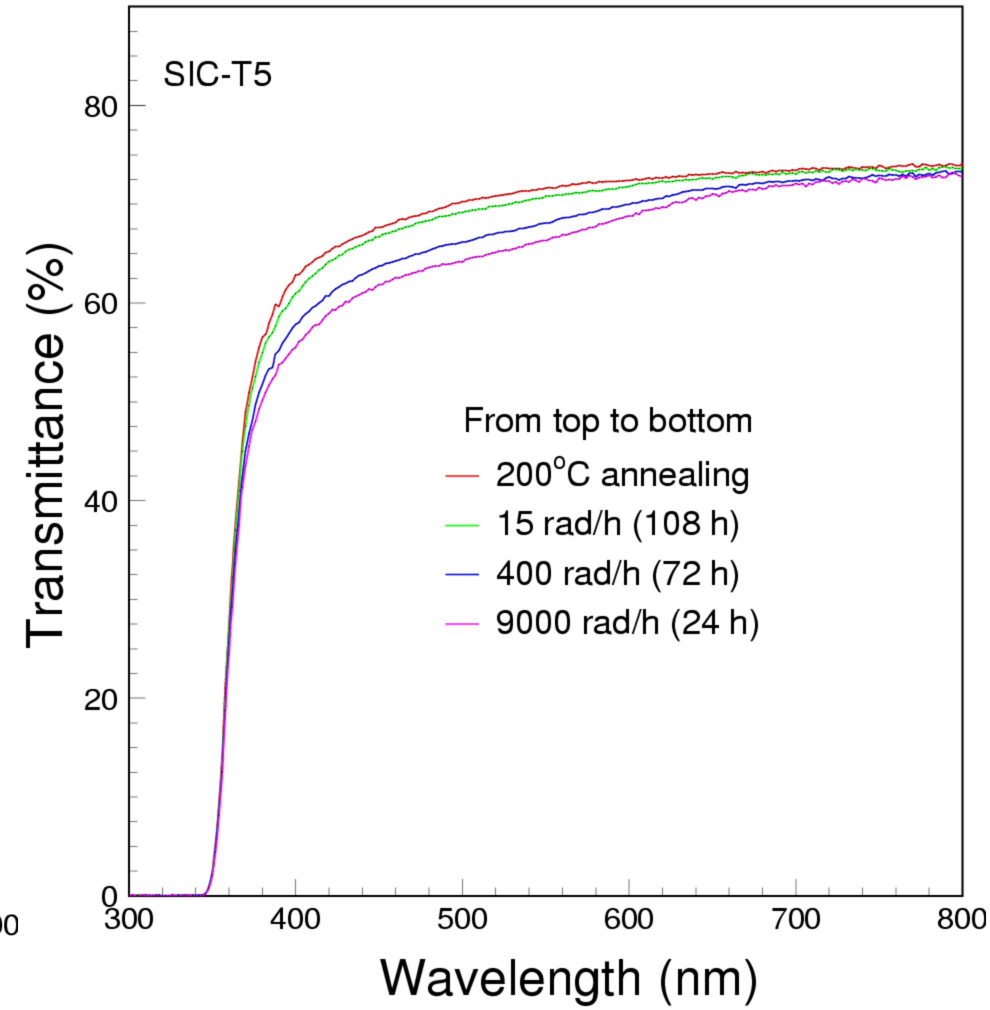




PWO Radiation Damage

Radiation induced absorption caused by color center formation, but no damage in scintillation mechanism



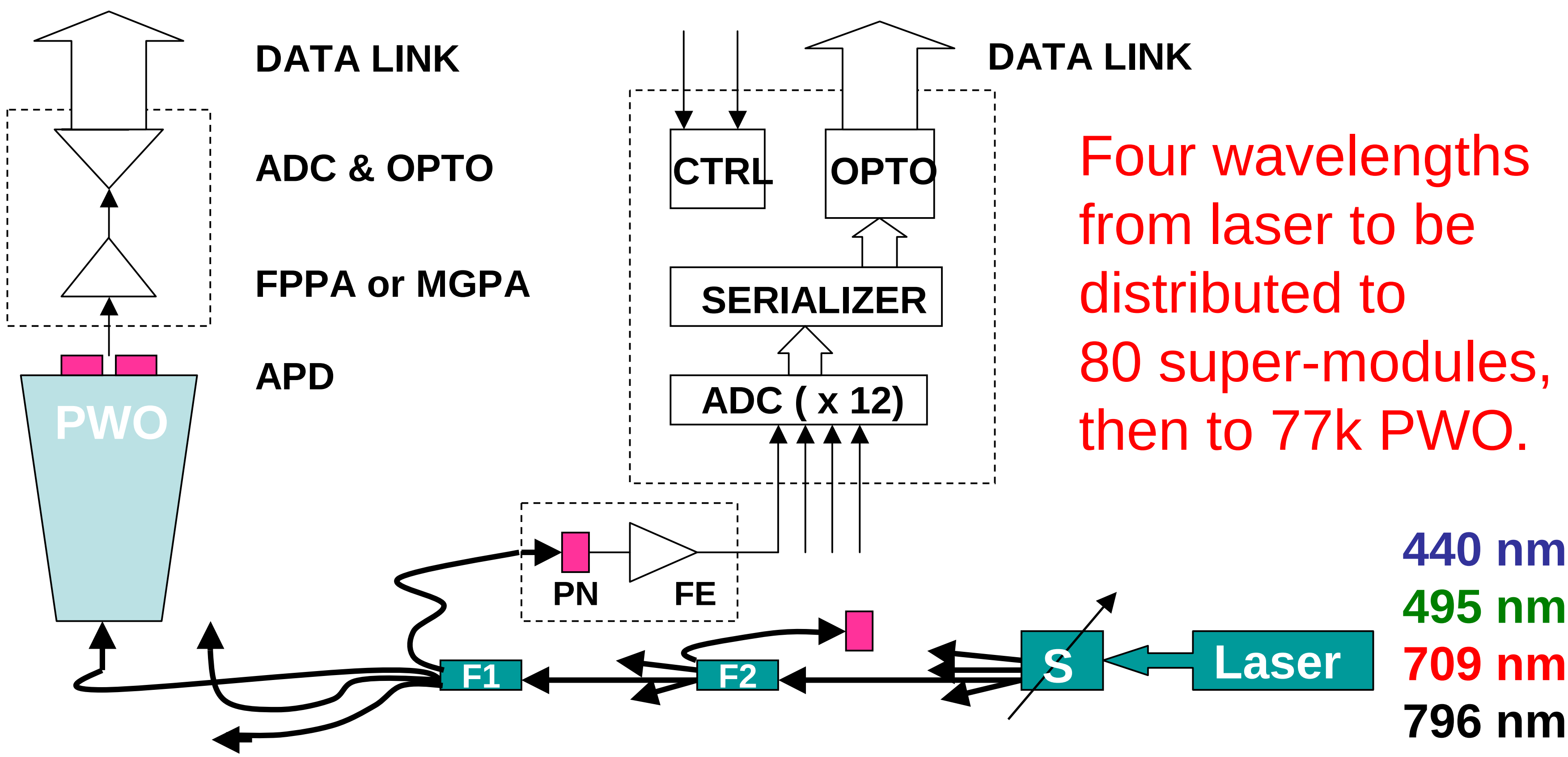


CMS ECAL Monitoring System

Initial calibration on test beam (as much crystals as possible)

In situ calibration with physics ($W \rightarrow e^+n$, $Z \rightarrow e^+e^-$): using E/p allows an inter-calibration of 0.5% in 35 days at low luminosity.

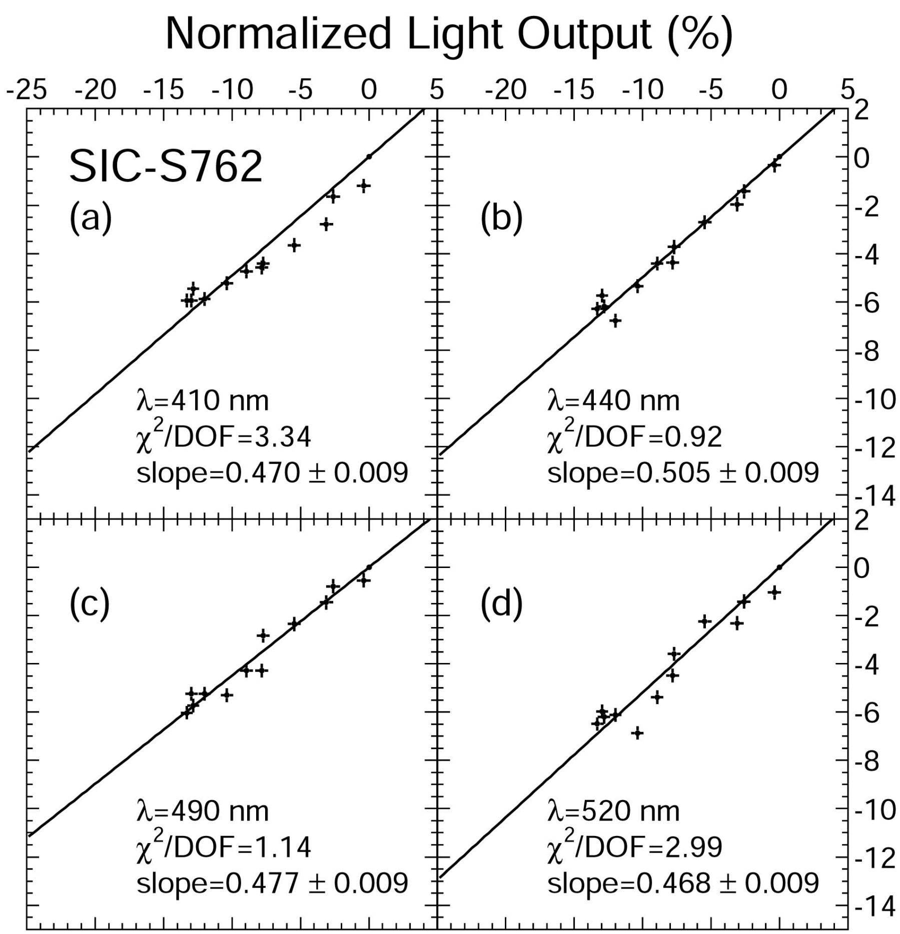
Monitoring evolution of crystal response by light injection system



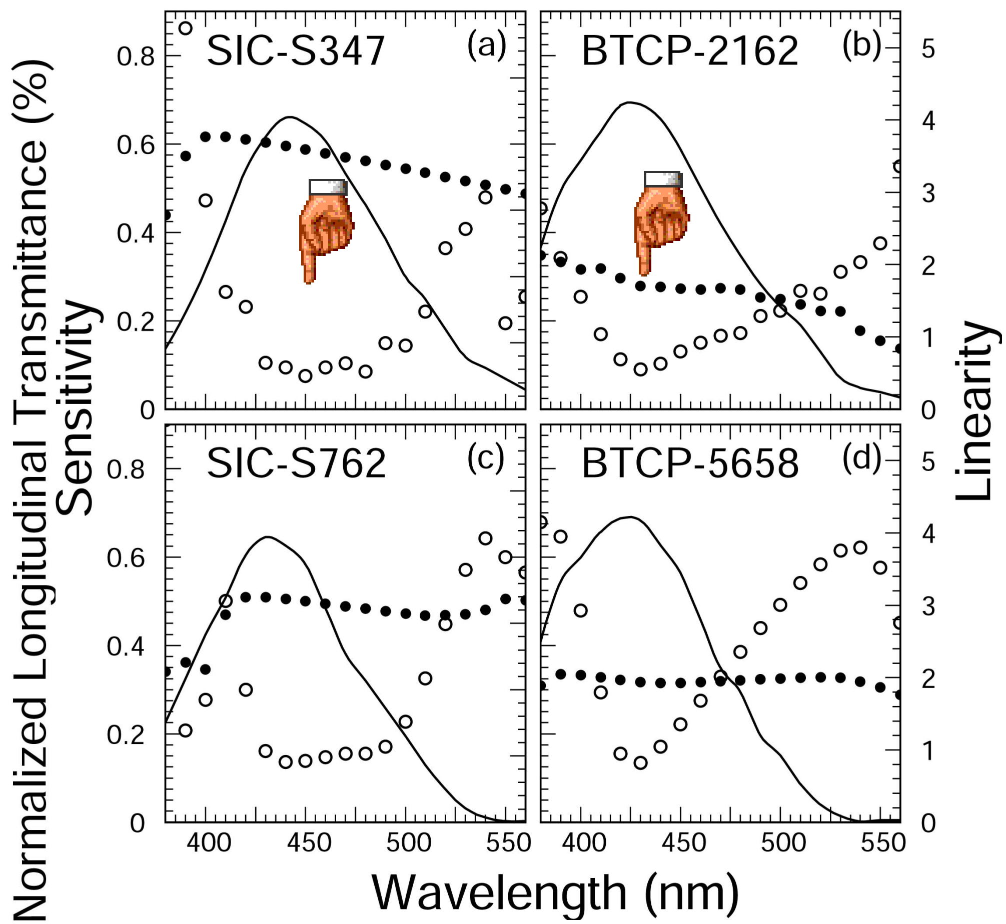
Four wavelengths from laser to be distributed to 80 super-modules, then to 77k PWO.

Monitoring Wavelength Determination

Δ(T) versus Δ(LY)



Sensitivity and Linearity



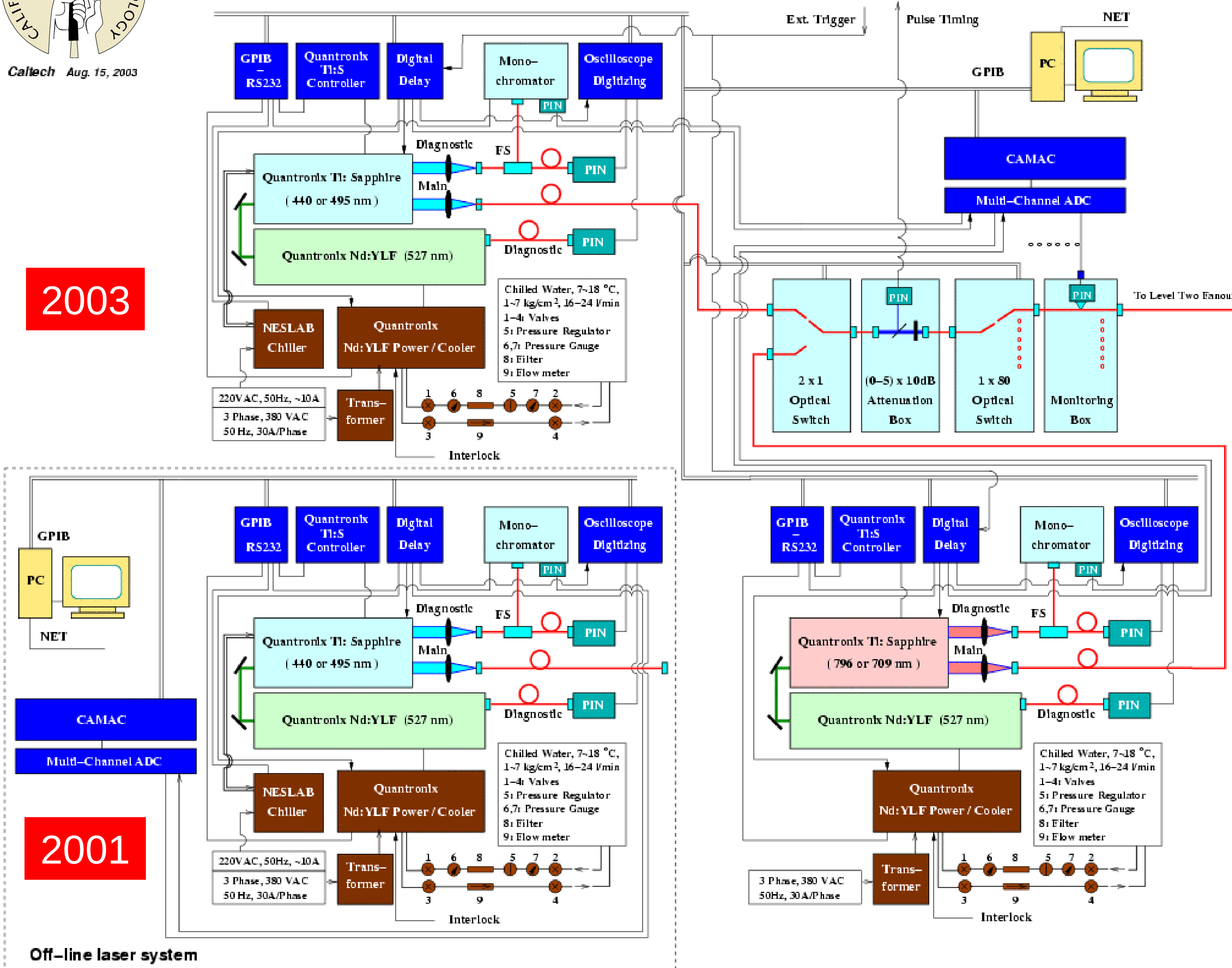
→ 440 nm is chosen for the best linearity

Lasers at CERN for PWO Monitor

Caltech Aug. 15, 2003

2003

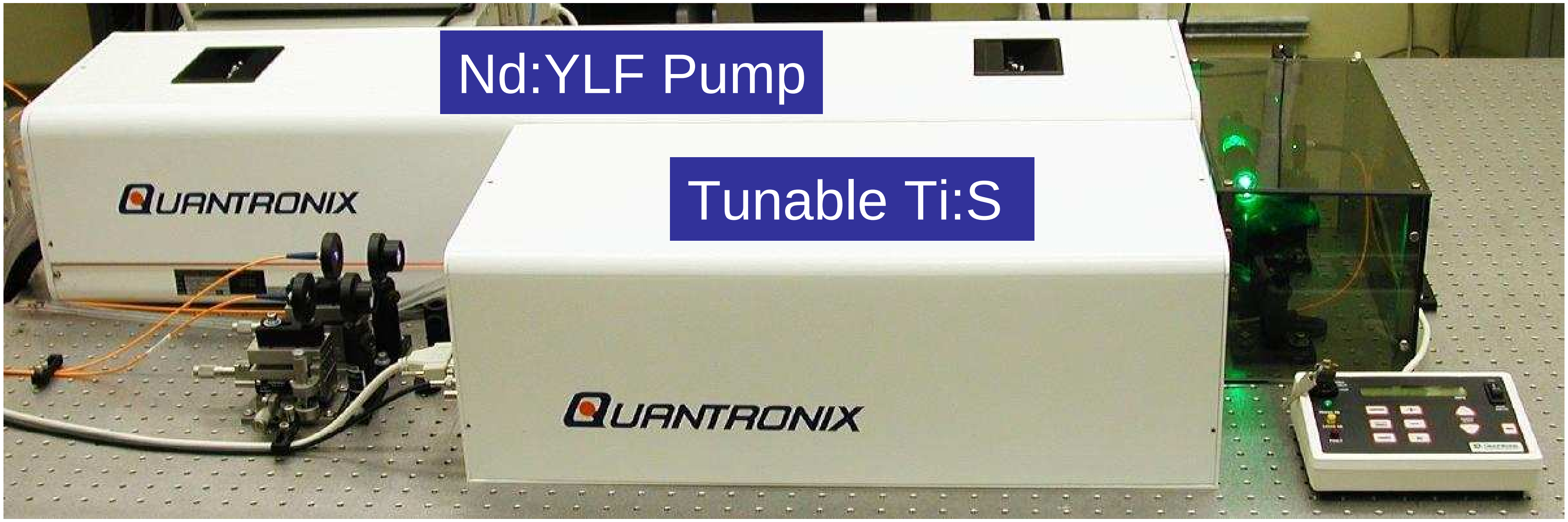
2001

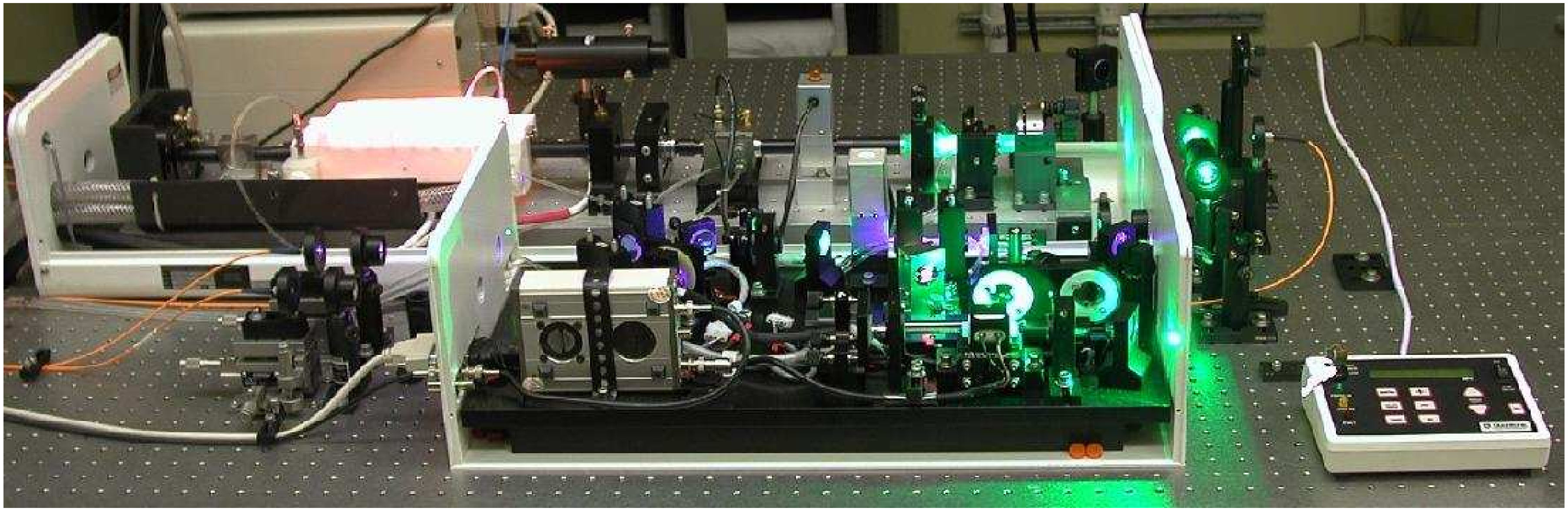


The 1st laser system was Installed in 2001, and used in 2002 beam test.

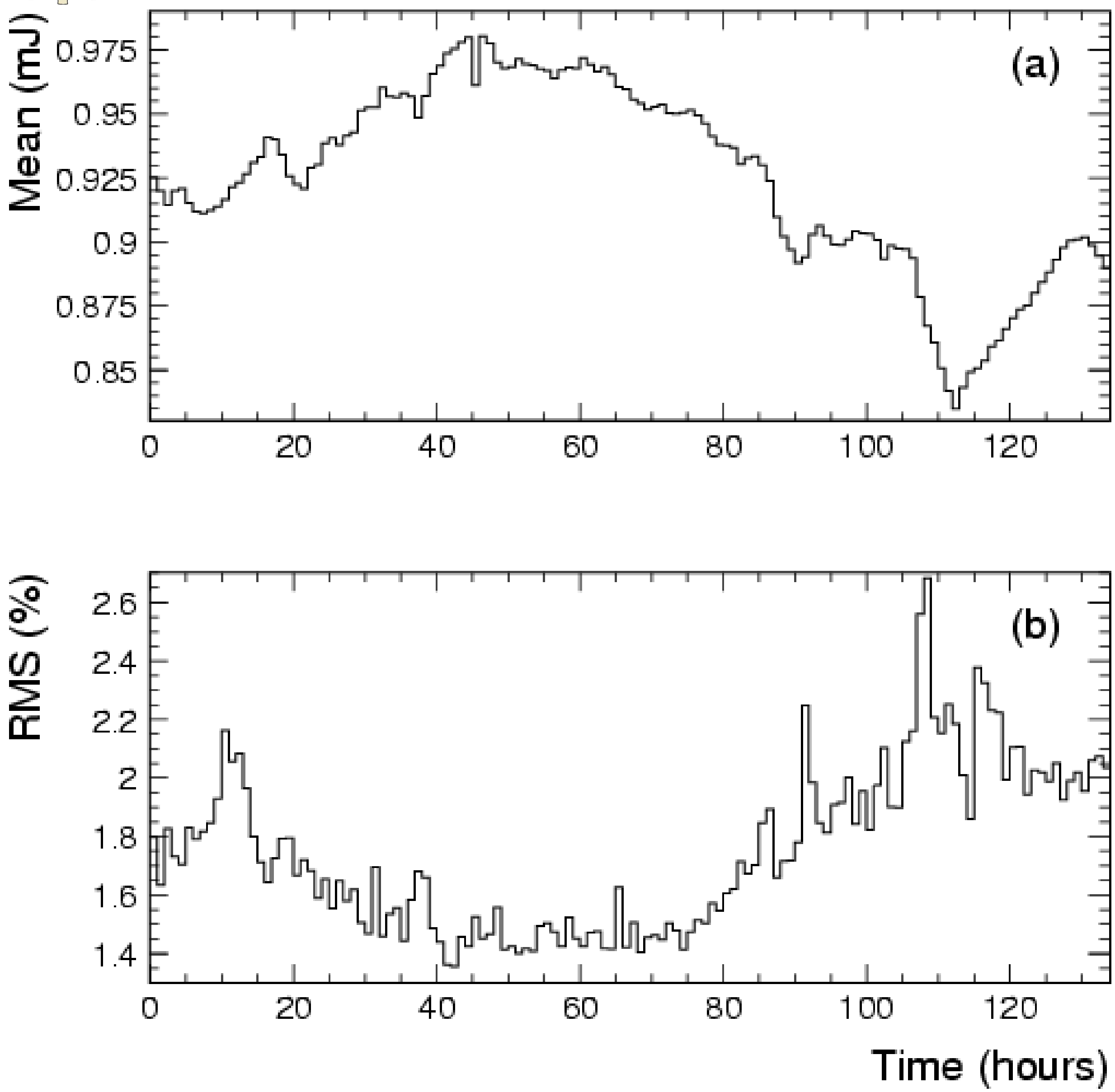
The 2nd and 3rd laser systems installed at CERN in August, 2003.

Ti:Sapphire Laser with Two Wavelengths





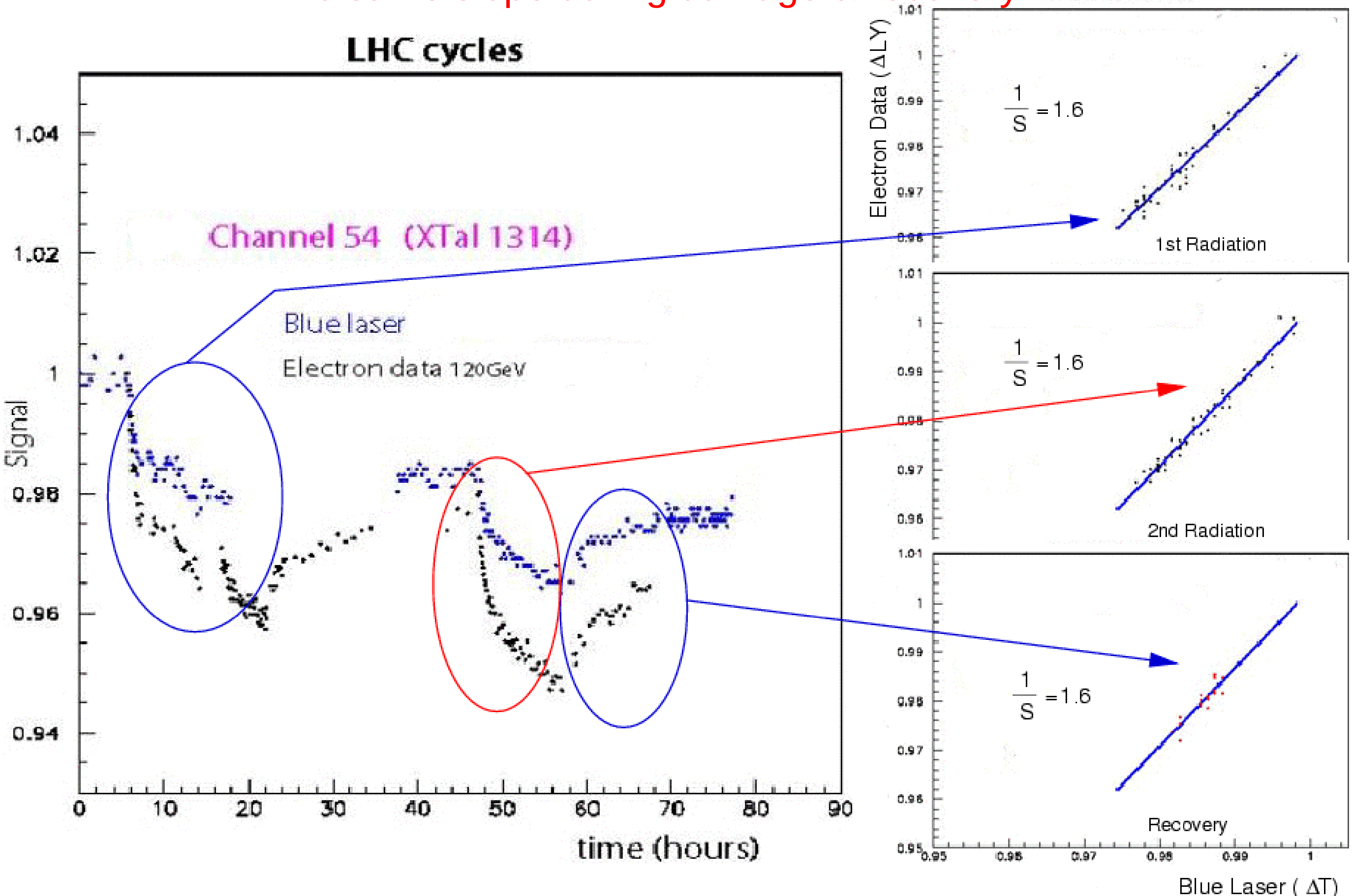
History: Laser Pulse Energy & r.m.s.



- Short term r.m.s 1.7%, or 15 uJ.
- Peak to peak variation 15%, corresponding to overall r.m.s. 3.7%.
- Specification: r.m.s. <10%.
- Drifting caused by power supply, temperature: air condition needed.

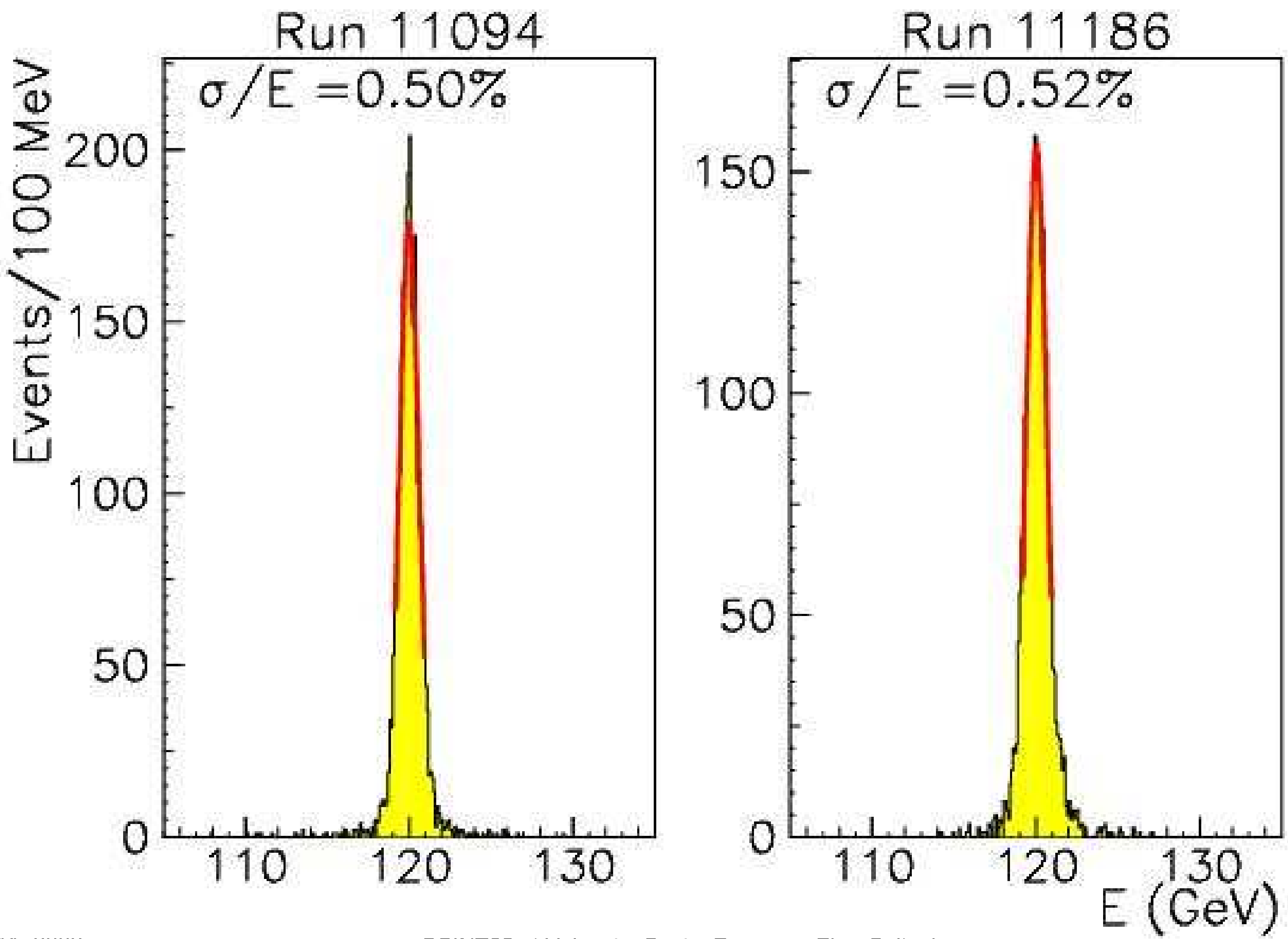
Experiences in 2002 Beam Test

The same slope during damage & recovery

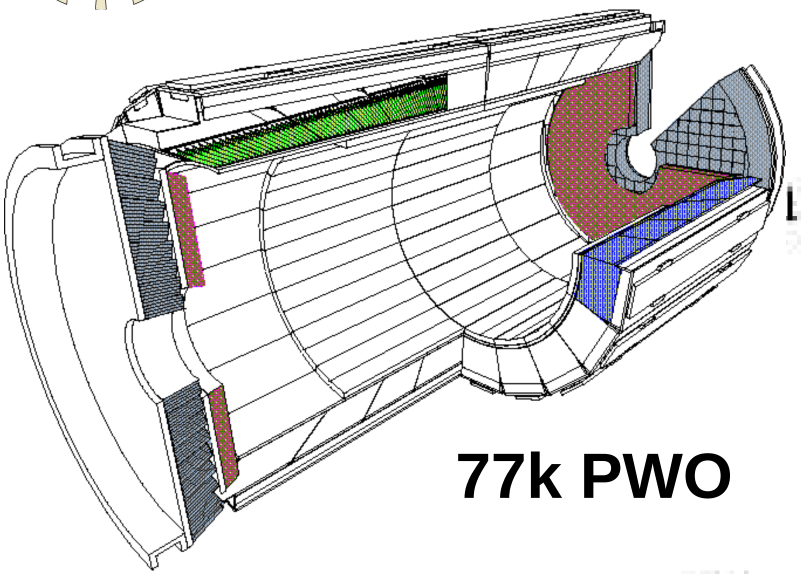


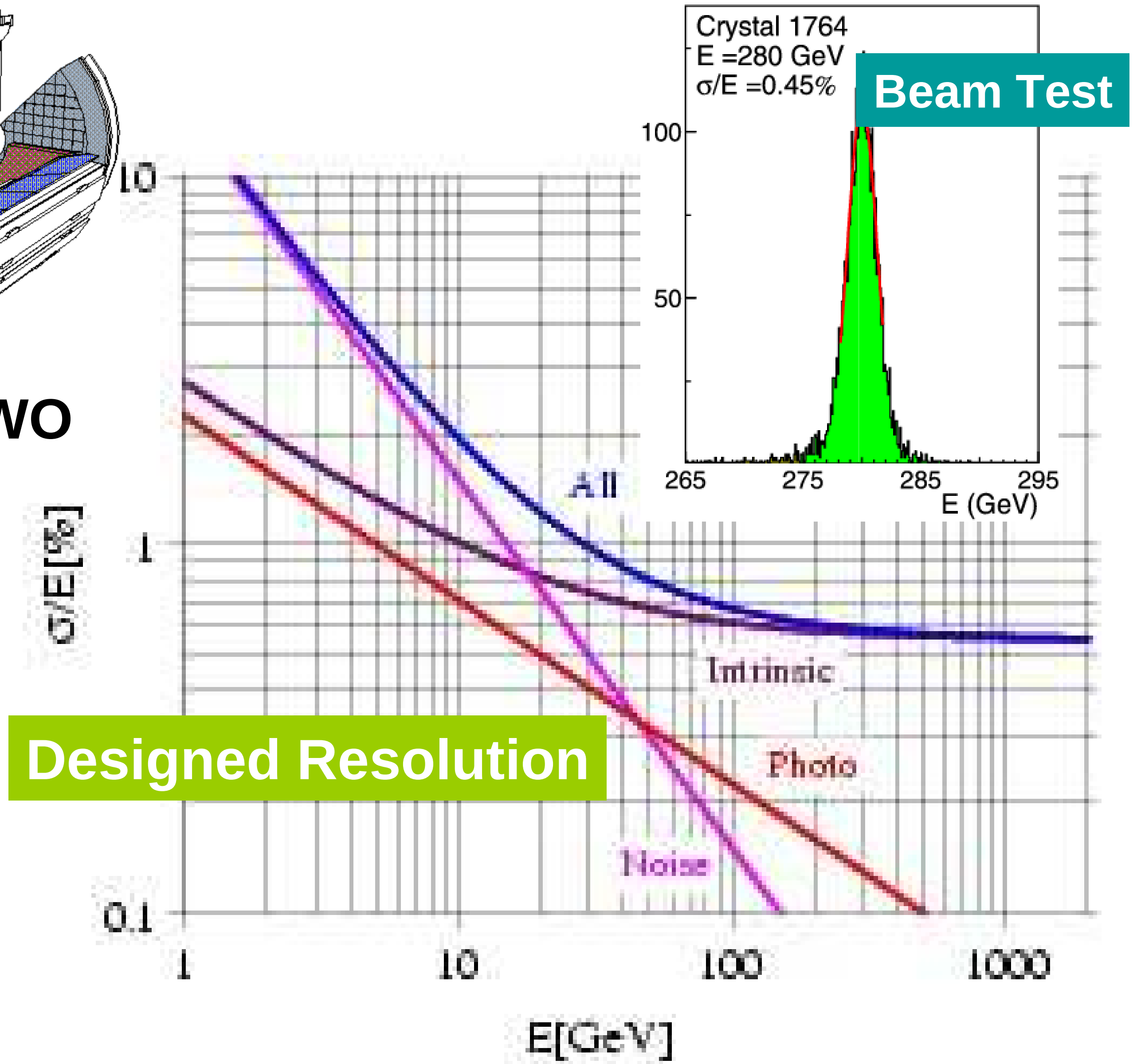
PWO Resolution With Light Monitoring

Before/after beam irradiation: 10% variation in light output



Expected CMS PWO Resolution





Crystal Calorimetry at High Energies

Summary

- Because of the total absorption, crystal calorimetry provides good resolution for electron and photon measurement, and thus excellent physics potential.
- To reach its physics potential, good radiation resistance of crystal scintillators is crucial for crystal calorimetry.
- Mass produced crystals, however, may suffer from radiation damage, which may have to be taken care of by a light monitoring system and precision calibration *in situ* with physics.