Study of the CMS-ECAL crystal radiation damage monitoring at CERN GIF/X5 facility

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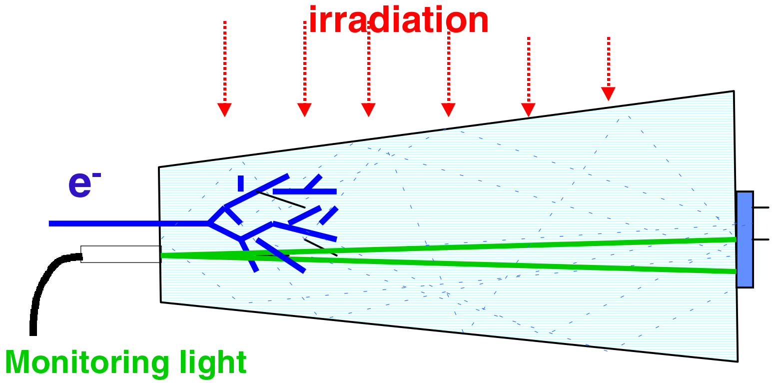
☛ **R: signal/monitoring ratio**

- **wavelength dependence**
- **optical path length dependence**
- **stability**

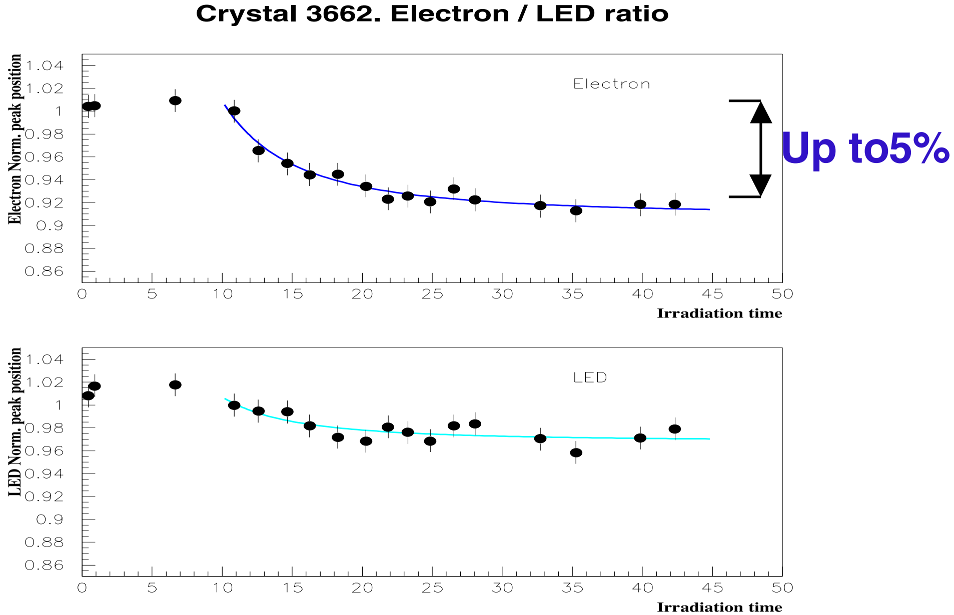
☛ **Summary**

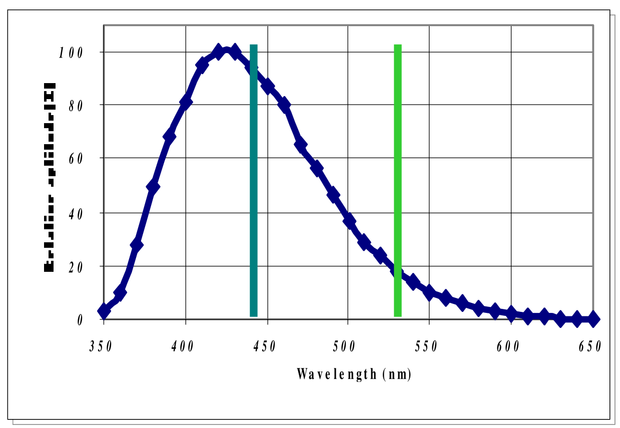
Particle/Monitoring ratio



$$R \equiv \Delta_{particle} / \Delta_{monitoring} \neq 1$$

1. Geometry:
   - **particle**: 4π light emission essentially from the shower maximum
   - **monitoring**: collimated light from 200µm quartz fiber
2. Wavelength



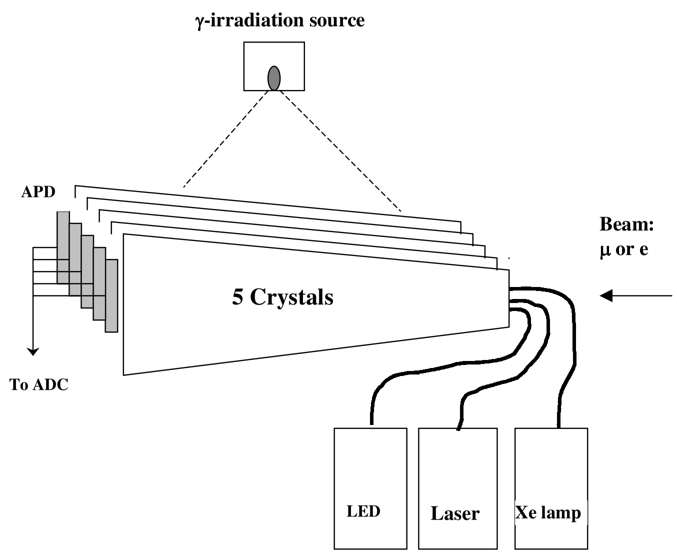


R: crystal-to-crystal variation

- $PbW0_4$ scintillation spectrum is the superposition of the several emission lines, relative intensity of which depend on the production technology
- radiation damage effect is the superposition of the several absorption lines, which depend on the raw material purity, doping profile … finally on the production technology
- the particle signal degradation due to the radiation damage depend on the convolution of the emission and induced absorption spectra, while the effect on the monitoring signal depend on the induced absorption at the particular wavelength

Once the crystal production technology is not infinitely stable, one can expect a certain crystal-to-crystal variation of the damage effect on the particle signal, not correlated with the monitoring signal variation $\equiv$ R crystal-to-crystal variation

GIF/X5 setup

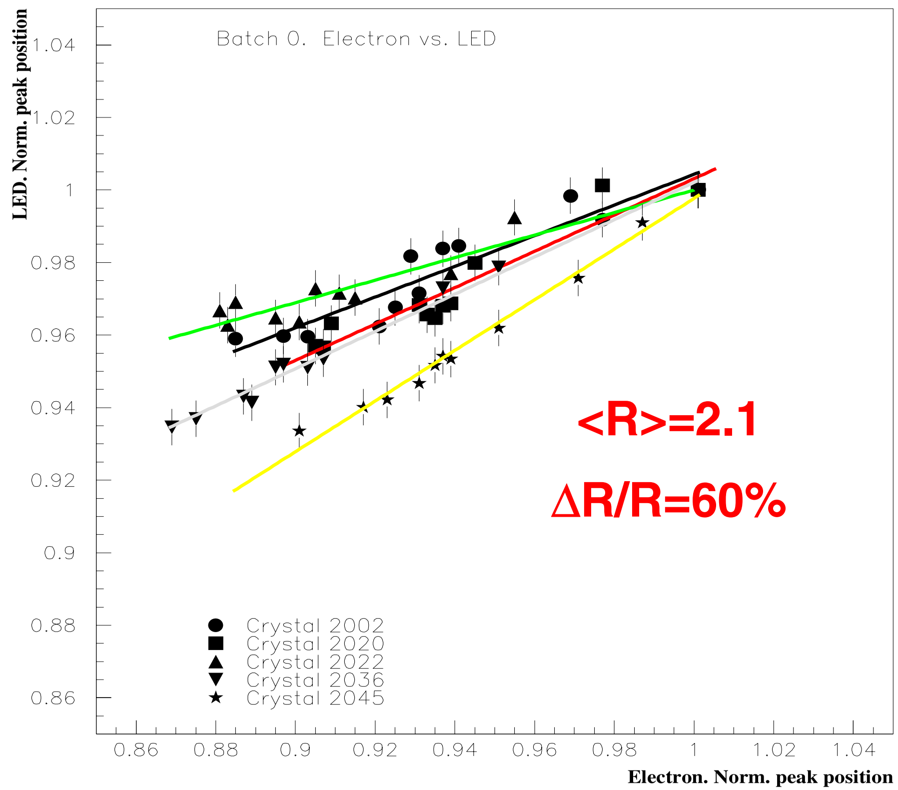


GIF/X5 setup:

- realistic CMS-ECAL light readout
- 3 light monitoring systems in parallel
- 10-100 GeV electrons, pions and muons from SPS X5 beam

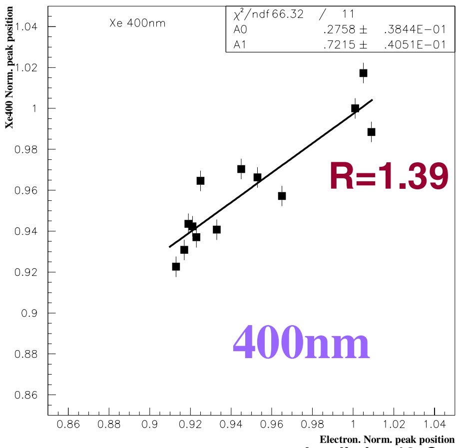
First results on R obtained with the BTCP R&D crystals

Irrad 18. 50 GeV electrons. APD readout



R≠1: wavelength dependence

Irradiation 18. Crystal 3662, Cs irradiation, APD readout.



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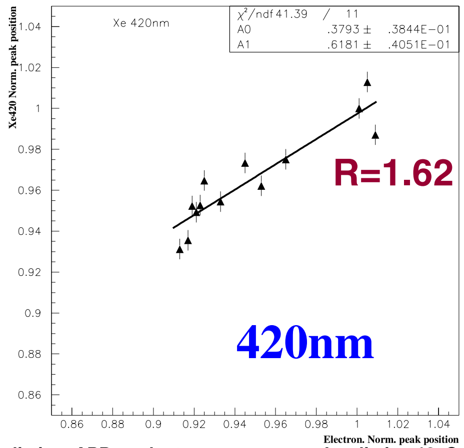

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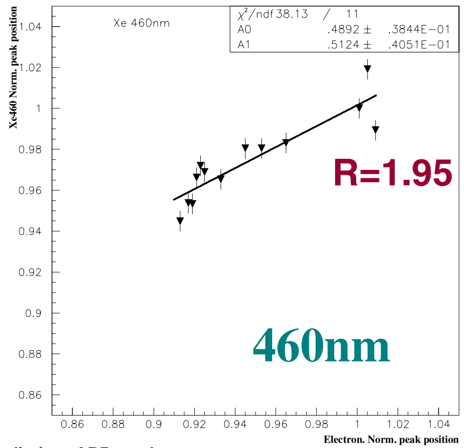

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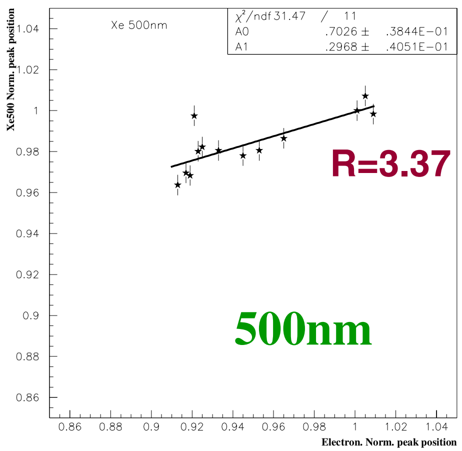

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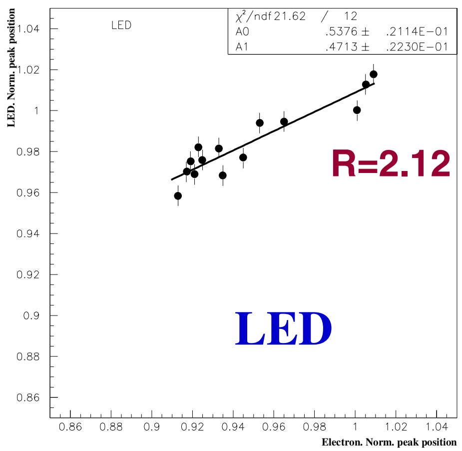
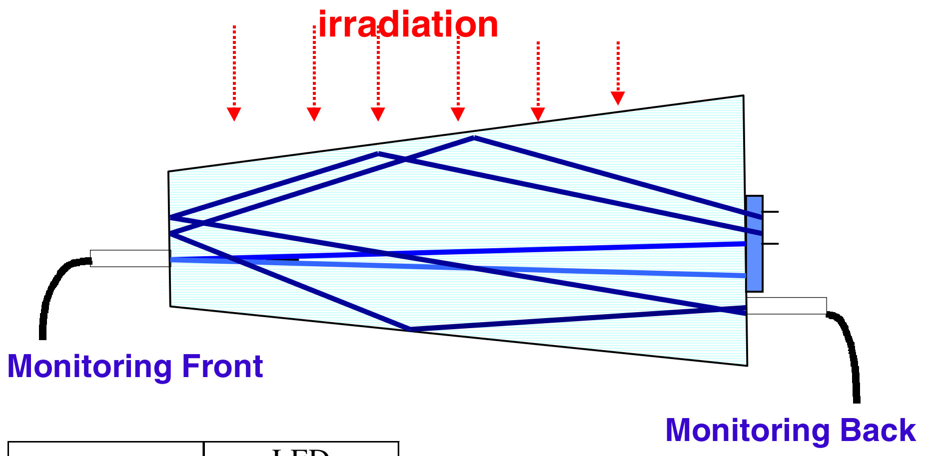
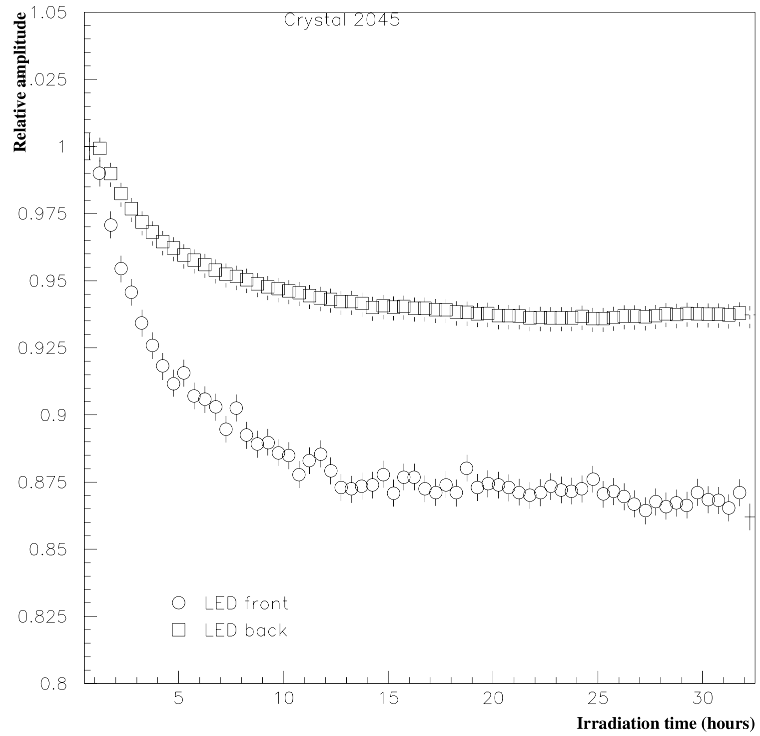


R≠1: path length dependence



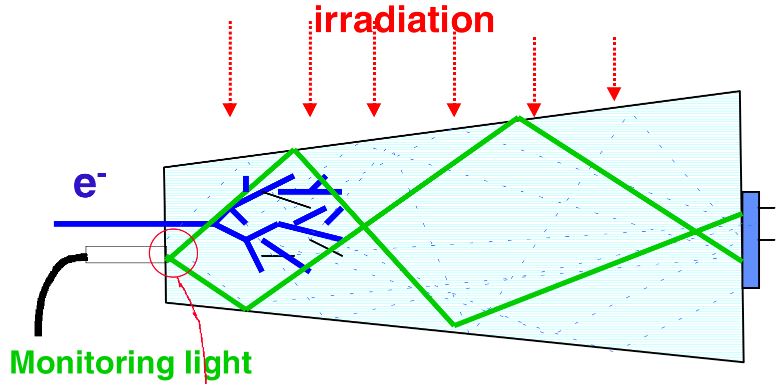
Crystal	LED back/frond loss ratio
2002	2.15±0.1
2020	2.55±0.1
2022	2.35±0.1
2036	1.95±0.1
2045	2.10±0.1

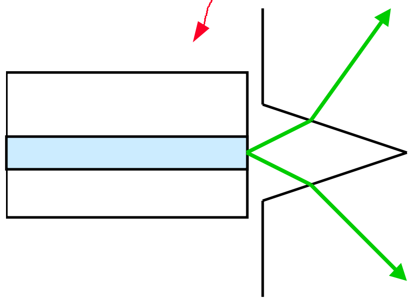
Irrad 22. APD readout. Front-back LED

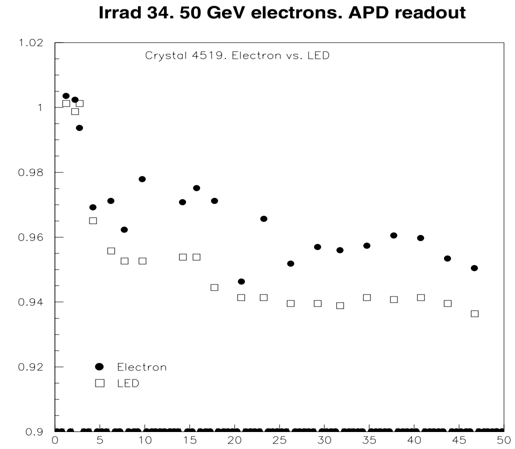


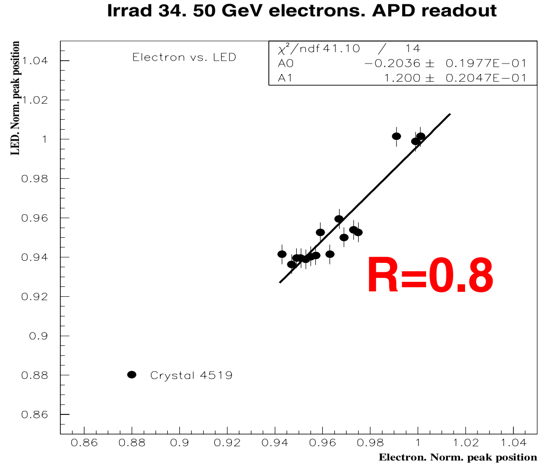
Light injection through the back of the crystal makes monitoring 2.2 times more sensitive to the crystal transmission loss

R≠1: path length dependence









Light injection through the conic hole in the front crystal surface make monitoring >2 times more sensitive to the transmission loss

R: required stability

1. **$E_i = c_i(t) \times A_i$;** E-energy, A - amplitude from ADC, c(t) calibration coefficient
2. **$c_i(t) = c_i(t_0) \times (1 + R_i \Delta M_i / M_i)$;** M - light monitoring signal
3. **$\delta E_i = c_i(t_0) \times A_i \times (\delta M_i / M_i) \times \delta R$;** energy variation due to R
4. **Since $c_i(t_0) \times A_i \approx E_i$, $\delta E/E = (\Delta M/M) \times \delta R$, or**

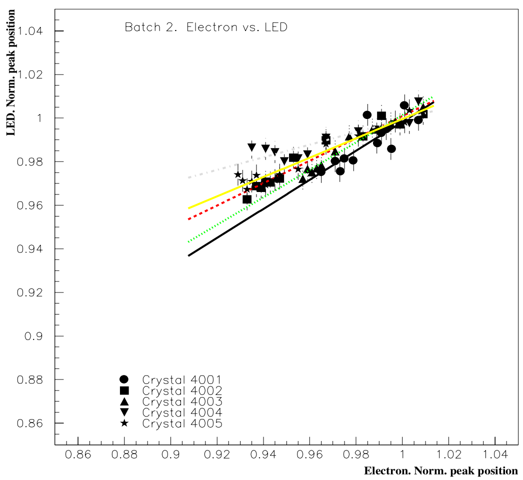
   $\delta E/E = [\, R \times (\Delta M/M)] \times \delta R/R$

- **Constant term 0.5% $\Rightarrow$ $\delta E/E = 0.2\%$**
- **Optical transmission damage <5% : $\Delta M/M = 5\%$ (ECAL TDR)**
- **if $\langle R \rangle = 1.5 \Rightarrow \delta R/R = 3\%$**

To allow a **GLOBAL R** constant for the light monitoring correction, **R crystal-to-crystal variation should be less than 5%**

R: BTCP pre-production crystals

Irrad 24. 50 GeV electrons. APD readout



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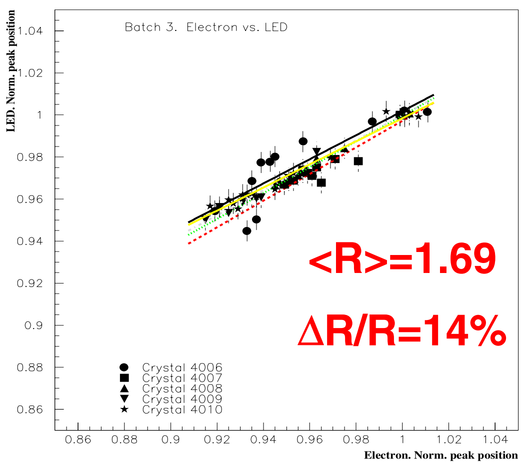

☞ $\langle R \rangle_{4001\text{-}4010} = 1.84 \pm 0.07 \pm 0.15$

☞ $\sigma_R/R = (16 \pm 9)\ \%$

Two samples with slightly different doping procedure

Sample A: $\langle R \rangle = 2.02 \pm 0.07 \pm 0.15$

$\sigma_R/R = (18 \pm 9)\ \%$

Sample B: $\langle R \rangle = 1.66 \pm 0.05 \pm 0.15$

$\sigma_R/R = (6 \pm 10)\ \%$

Sample B ➠ mass production

Summary

- The ratio R, defined as the fractional decrease in the beam signal divided by the fractional decrease in the light monitoring signal is an essential parameter for the $PbWO_4$- based calorimeter
- R dependence of the
    - monitoring wavelength
    - optical path length

  was measured
- R crystal-to-crystal variation was measured for the number of R&D and pre-production BTCP crystals
- the current measurement error is dominated by a systematics and and is too high
- the σ_R/R, measured for the pre-production crystals is too high, but the projection to the production ones is optimistic