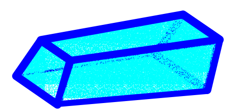
Performance of the PWO Crystals of the CMS electromagnetic calorimeter



Francesca Cavallari

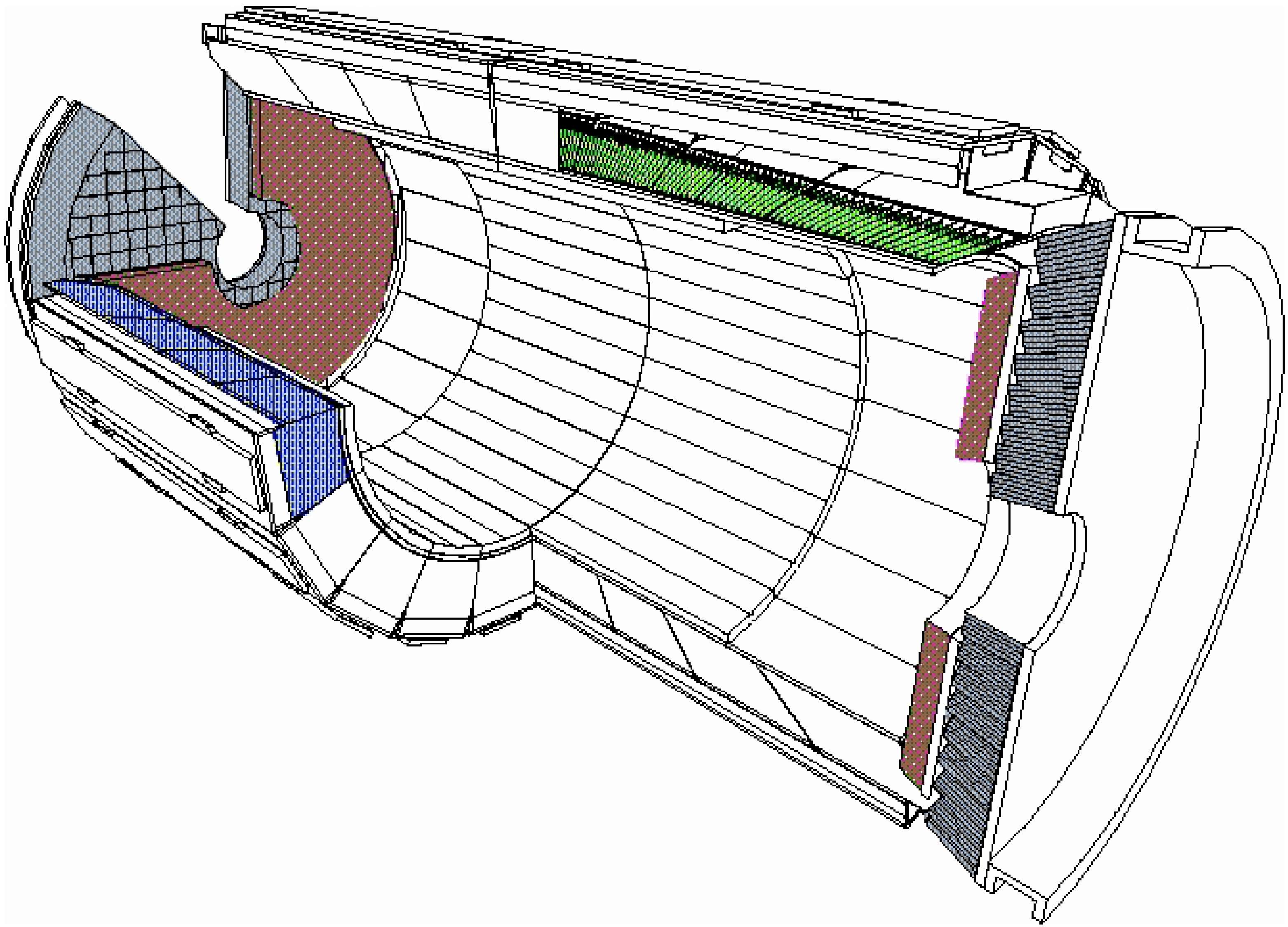
INFN Rome

(on behalf of the ECAL CMS collaboration)

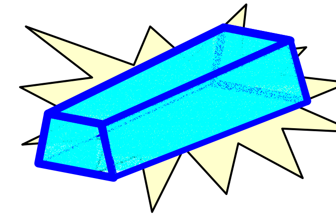
Outline

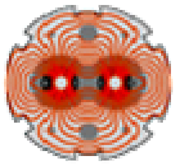
- Introduction
- The choice of the PWO
- The production
- Crystal properties
- Radiation Hardness
- Test-beam results

Introduction



The choice of the PWO





The LHC is a very demanding environment for the detectors:

Requirements:	ECAL characteristics:
•High resolution for high energy e/γ	Crystal calorimeter
•LHC bunch separation 25 ns	80% of the PWO light is collected in 25ns
•LHC Luminosity $10^{34}cm^{-2}s^{-1}$	PWO is radiation tolerant and with R&D is acceptable for LHC
•High granularity •Detector must be compact	PWO has Xo=0.89 cm RM=2.2 cm
•Magnetic field in CMS is 4T	Photon sensors: solid state devices (barrel) and VPT in Endcaps
•Cost must be limited	PWO is not so expensive (1.6 $/cm^3) and easy to produce in big quantities

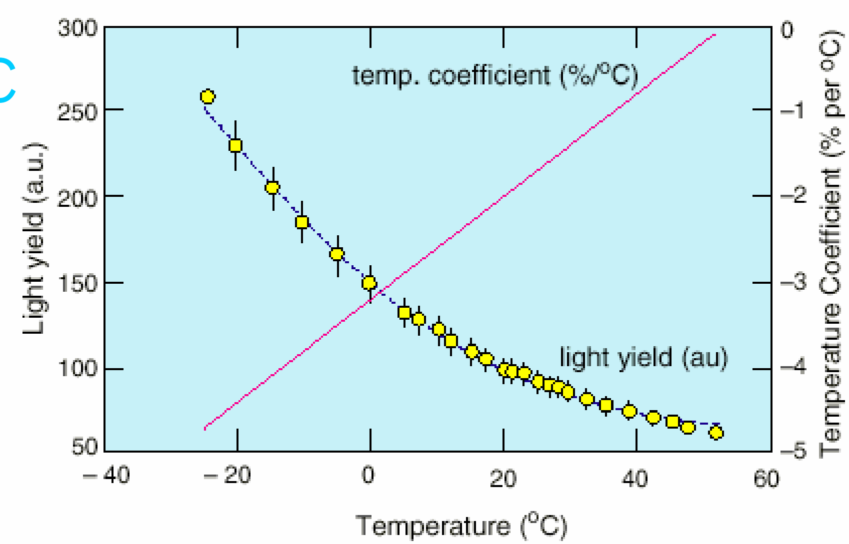
$U_{shower} = \pi R^2_M X_o = 13.5 cm^3$ => PWO cost = 21.6 $/$U_{shower}$

The choice of the PWO

PWO Disadvantages:

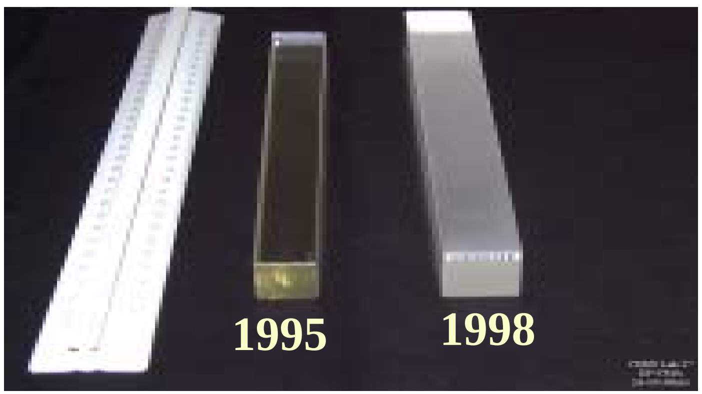
•PWO Light Yield is rather low: ~10 pe/MeV
(with PMT and tyvek wrapping at 18 C)
so photon sensors with some amplification are needed
(APD in the barrel, VPT in the Endcap)
⇒Low S/N ratio and complex electronic

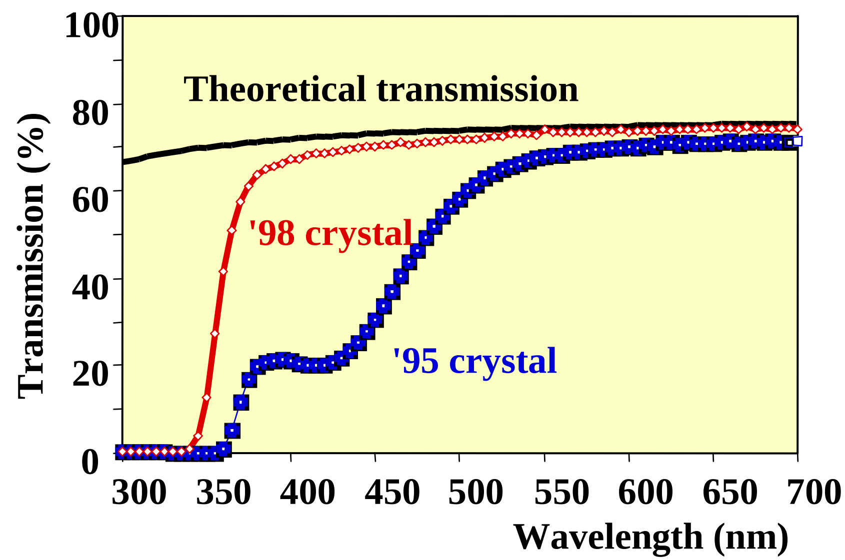
•PWO LY T coefficient is –2%/C
A good temperature stabilization is required



The choice of the PWO

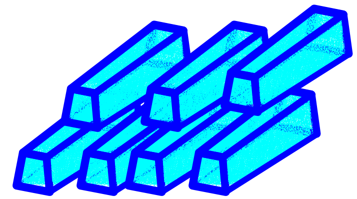
- **1992 : first expression of interest**
- **1994 : choice of PWO for CMS-ECAL**
- **1994-1998 : R&D phase**



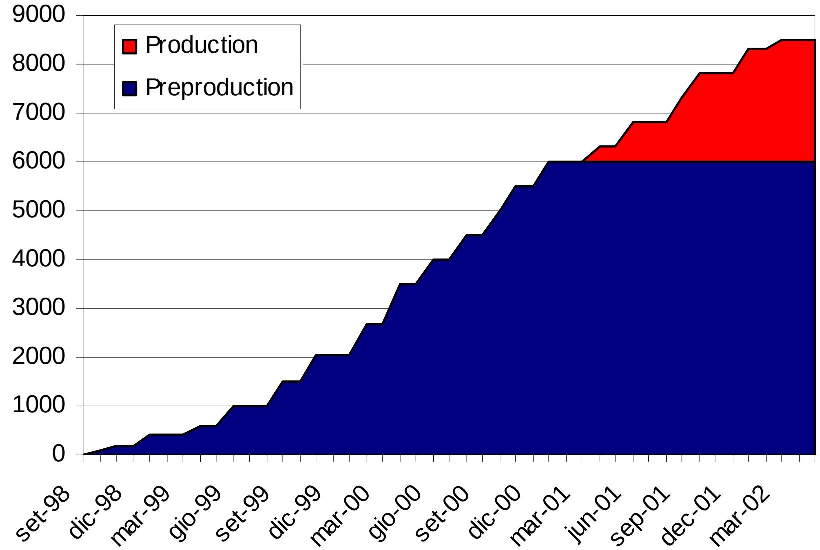


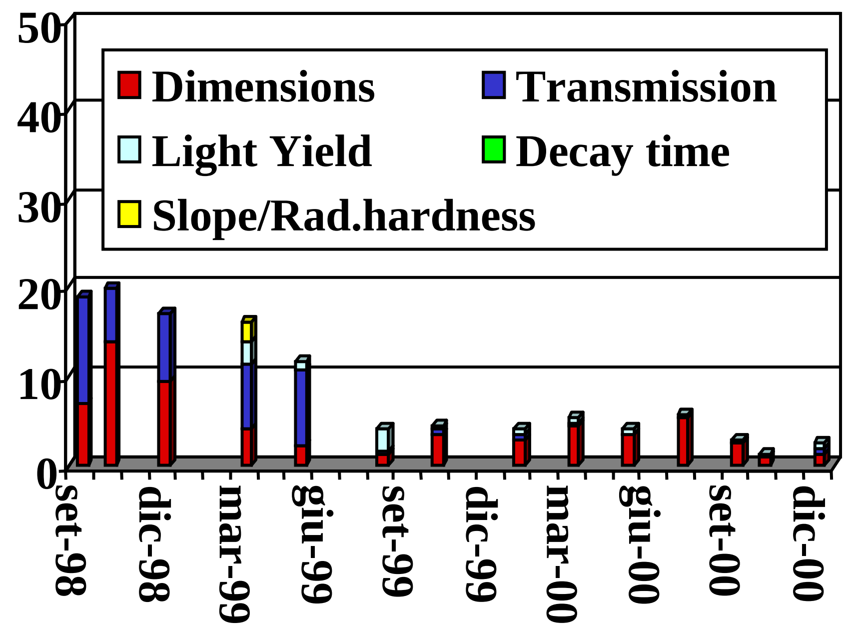
- **1998-2000 : Pre-Production of 6000 crystals**
- **2001 : Start of the Production**

The production



CMS PWO Barrel production crystals
are made by Bogoroditsk BTCP
with the Czochralski method



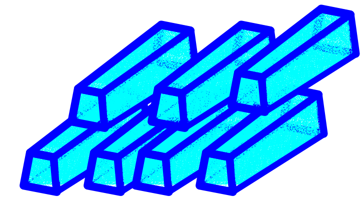


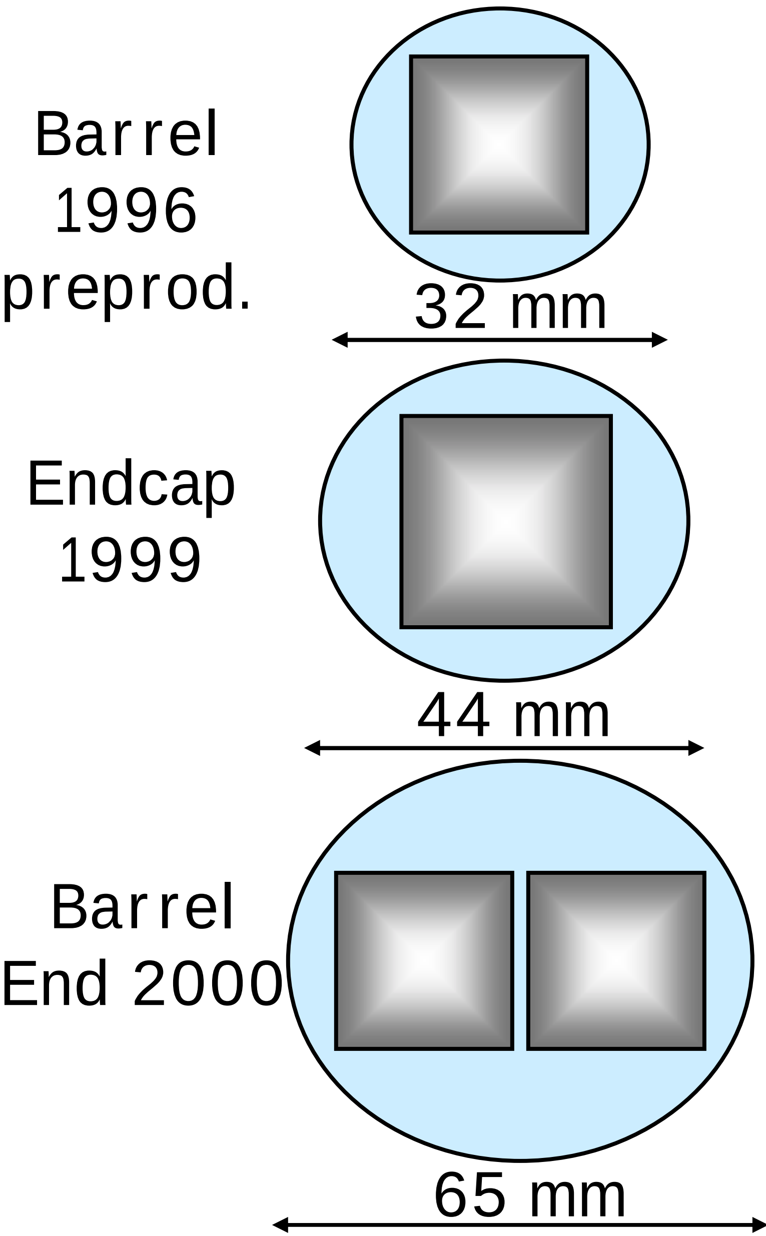
Success to:

- Increase the yield
- Increase the production rate

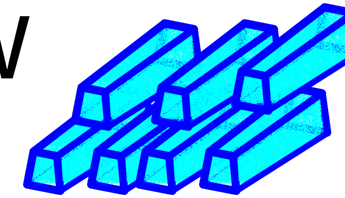
- Improve the quality
- Homogeneity of parameters

The production

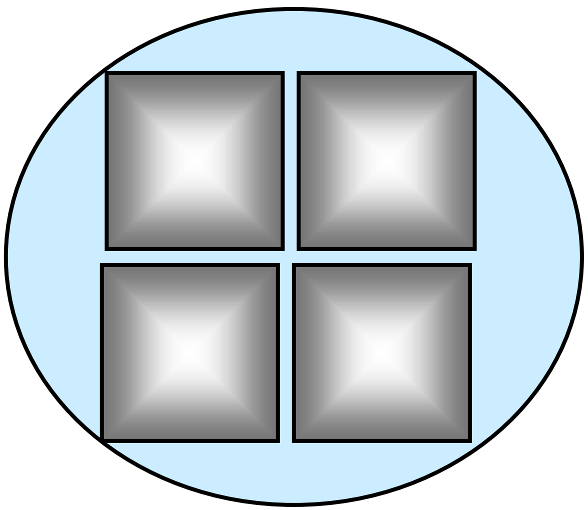




The production: new developments

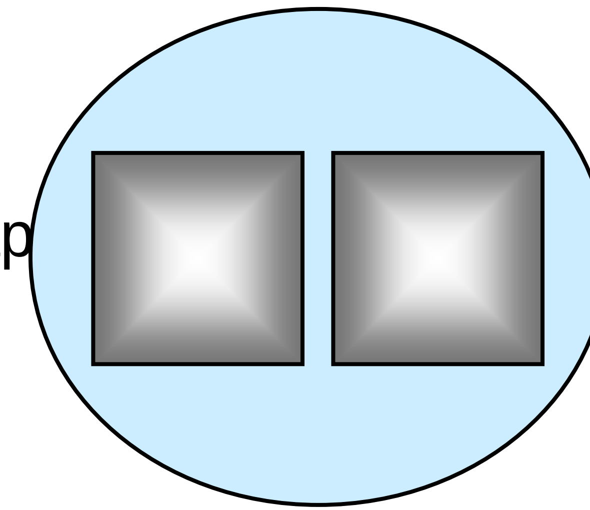


4 Barrel crystals



85 mm

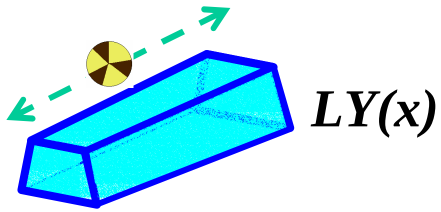
... or 2 Endcap crystals



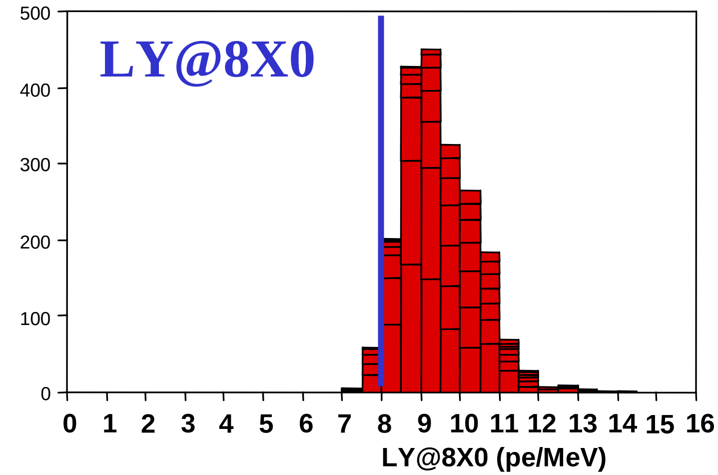
85 mm

Still R&D...

Crystal properties: LY

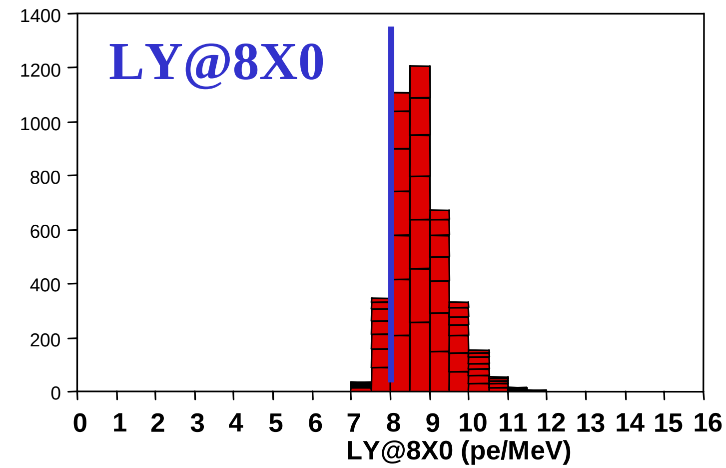


Batch 1 to 7



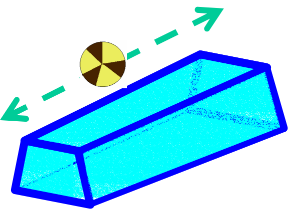
- **LY@8X_0 ≥ 8 pe/MeV at 18°C**
- **LY(100ns)/LY(1μs) > 90%**
- **-0.35 %/X_0 ≤ FNUF ≤ +0.35 %/X**

Batch 8 to 14

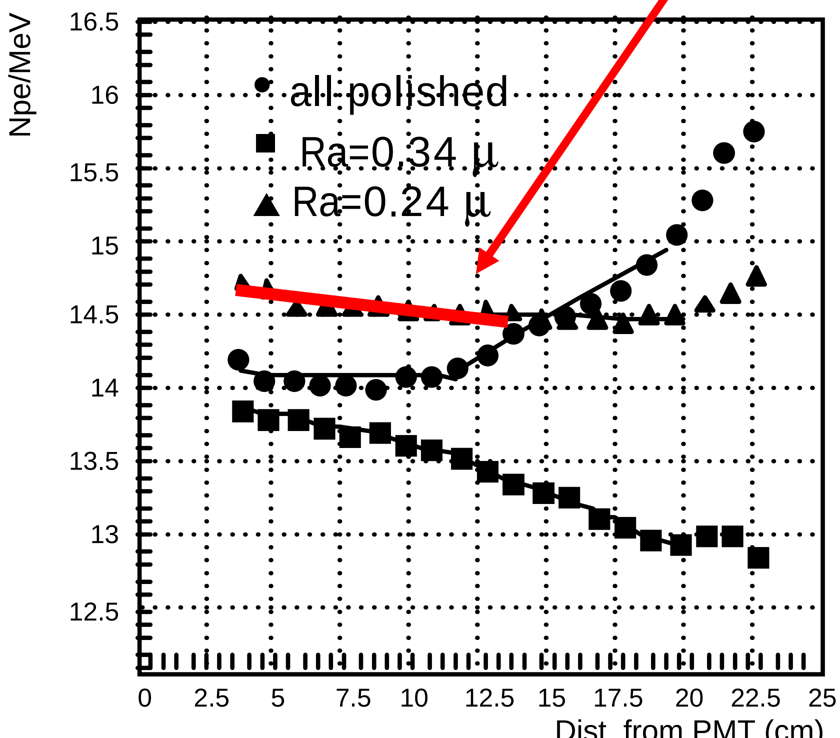


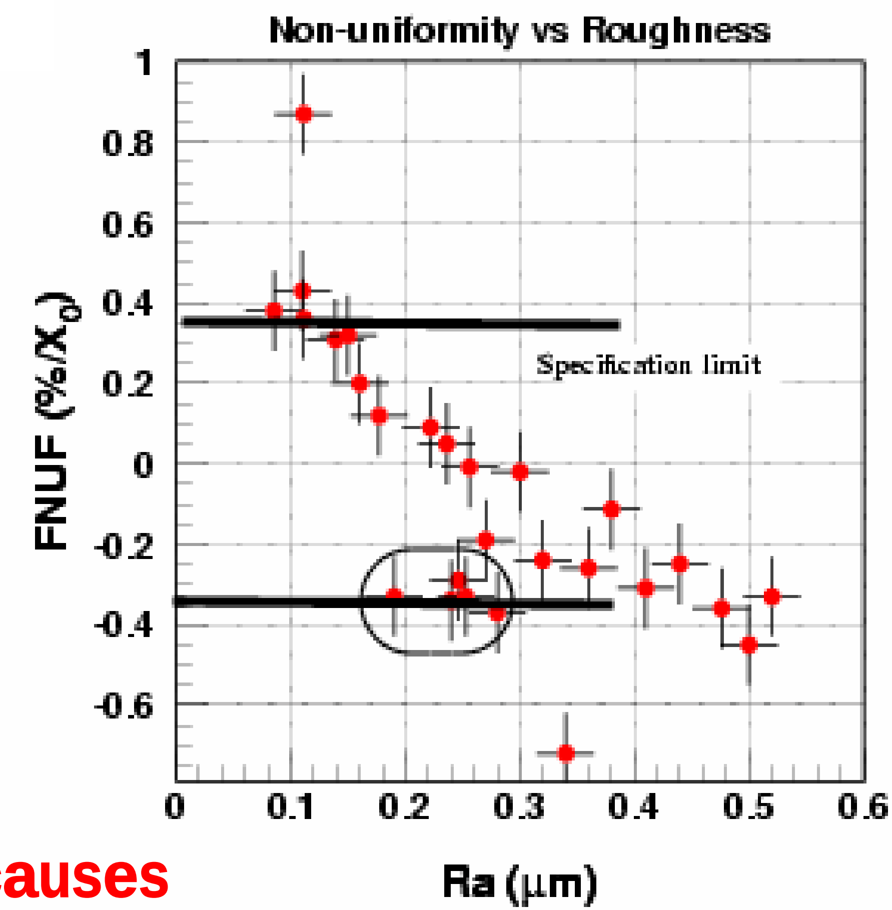
Check quality and guarantee the resolution of the calorimeter

Crystal properties: LY uniformity



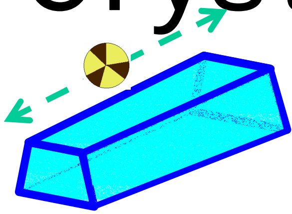
FNUF=1/LY dLY/dx
(3.5-11.5 cm)



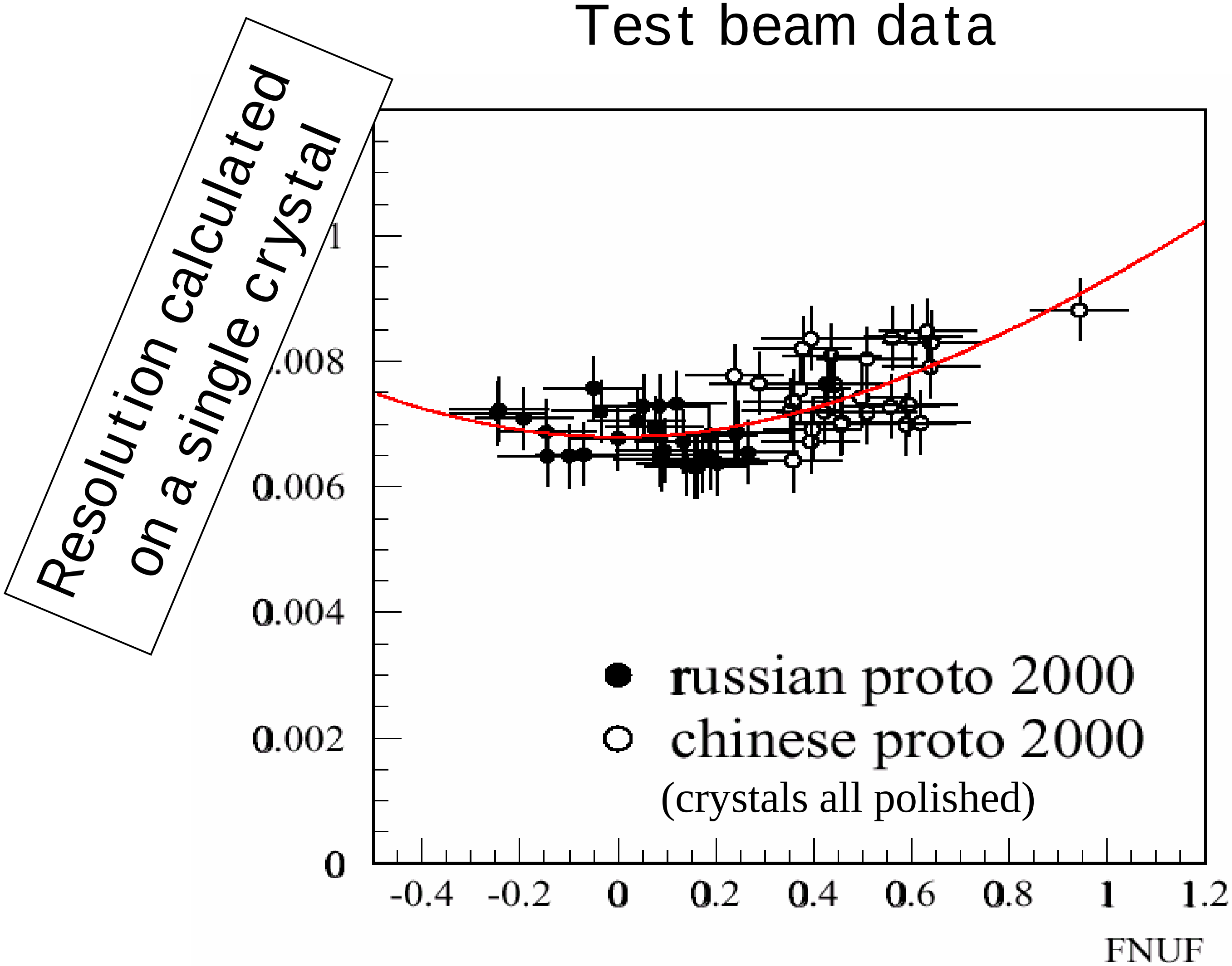


Depolishing 1 lateral face causes LY loss but gives required LY uniformity

Crystal properties: LY uniformity



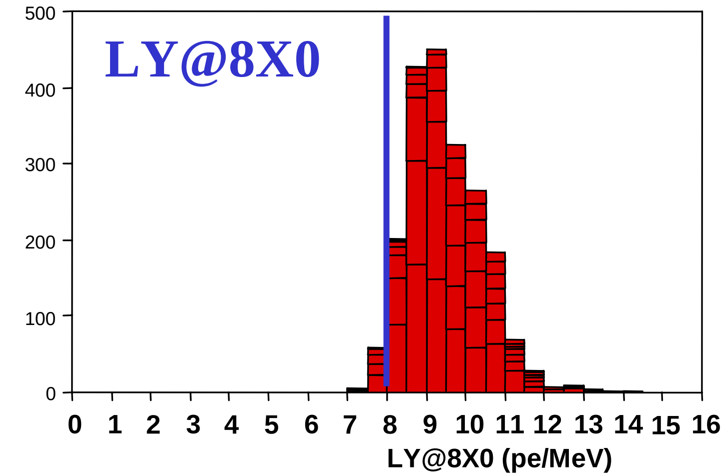
Test beam data

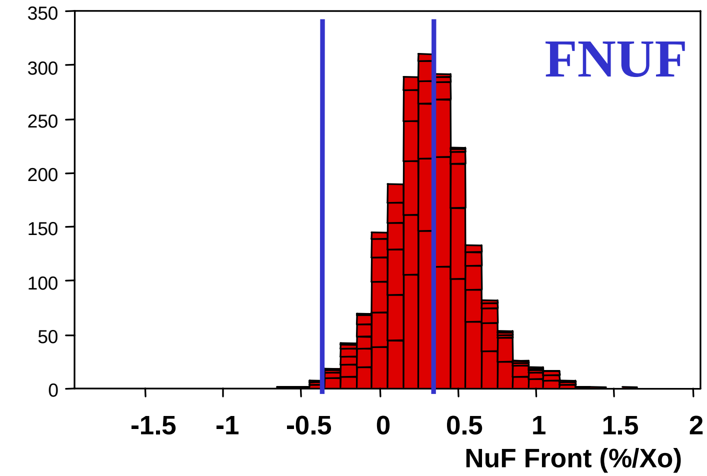


Lab measurement

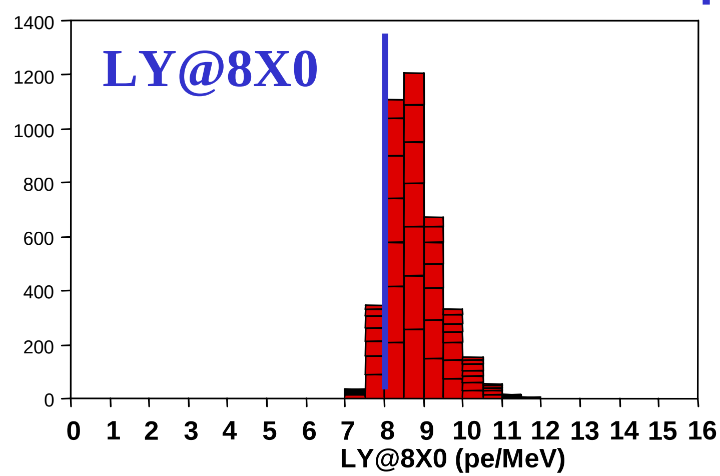
Crystal properties: LY uniformity

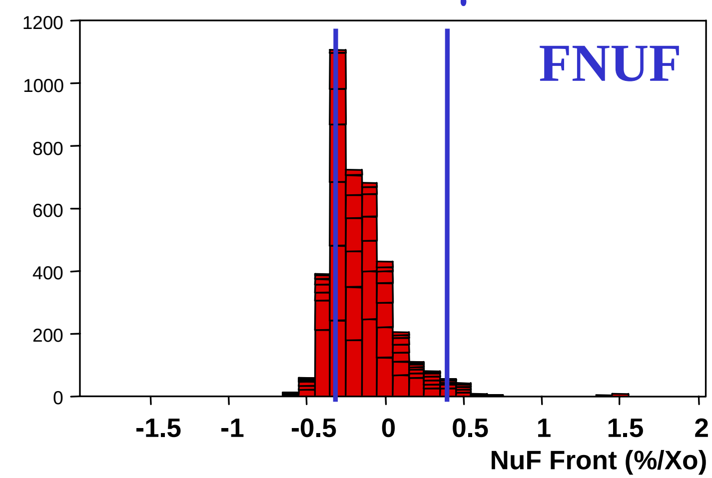
Batch 1 to 7 <Ra> depolished face +0.2μ



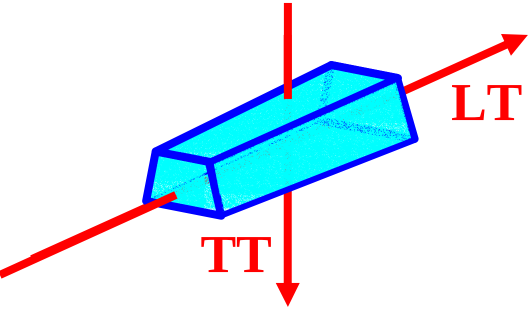


Batch 8 to 14 <Ra> depolished face +0.39μ

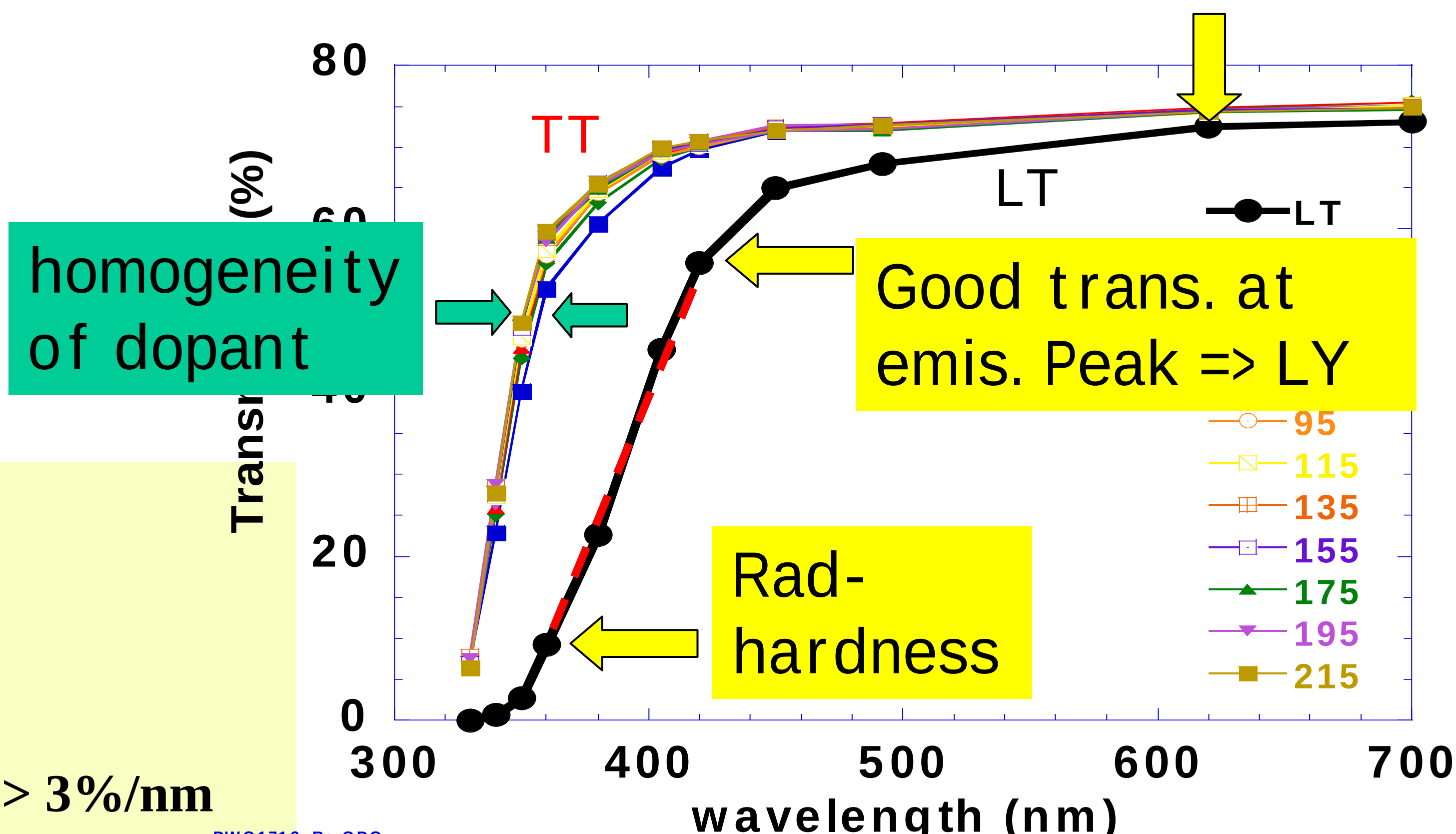




Crystal properties: Transmission

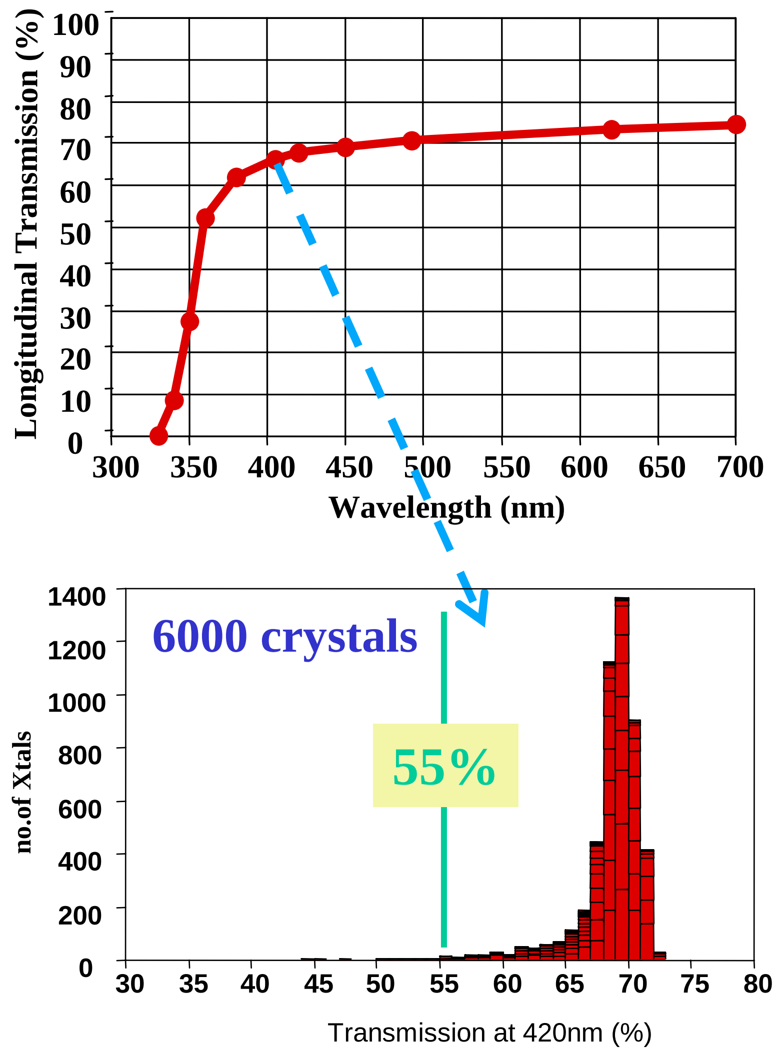


$$T = p_2 \cdot \exp(-(p_3)/w - \exp((p_0 - w)\cdot p_1))$$

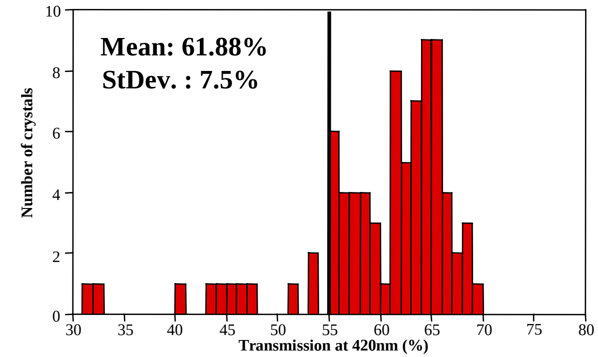


- $LT_{360nm} \geq 25\%$
- $LT_{420nm} \geq 55\%$
- $LT_{620nm} \geq 65\%$
- $LTslope_{inflection} > 3\%/nm$
- $\delta\lambda_{TT=50\%} \leq 3nm$

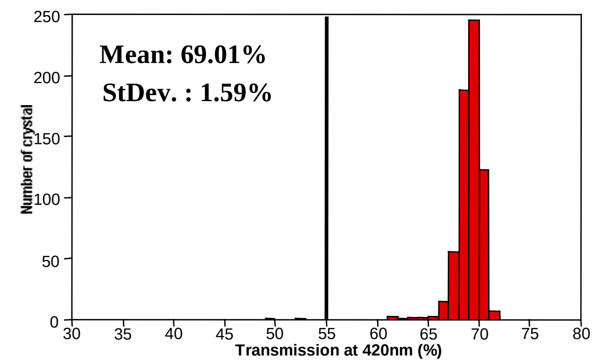
Crystal properties: Transmission



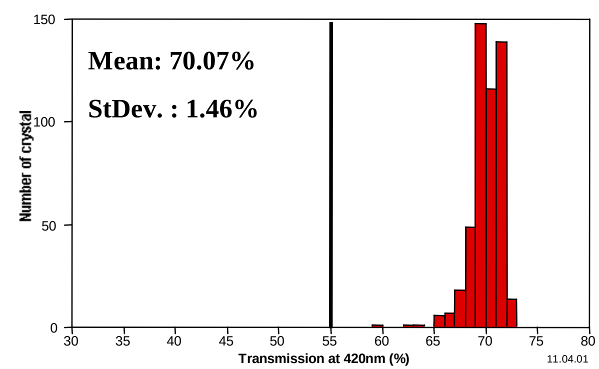
batch 1



batch 8

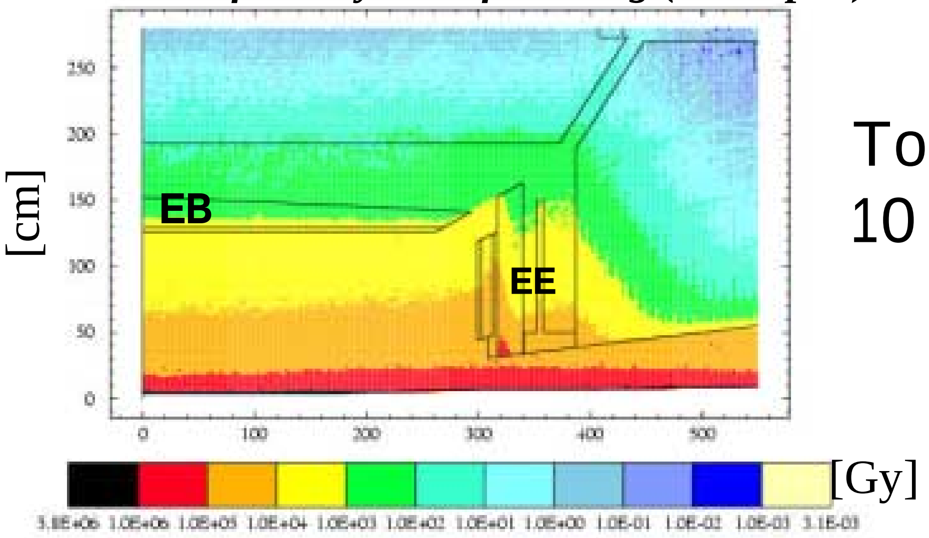


batch 14

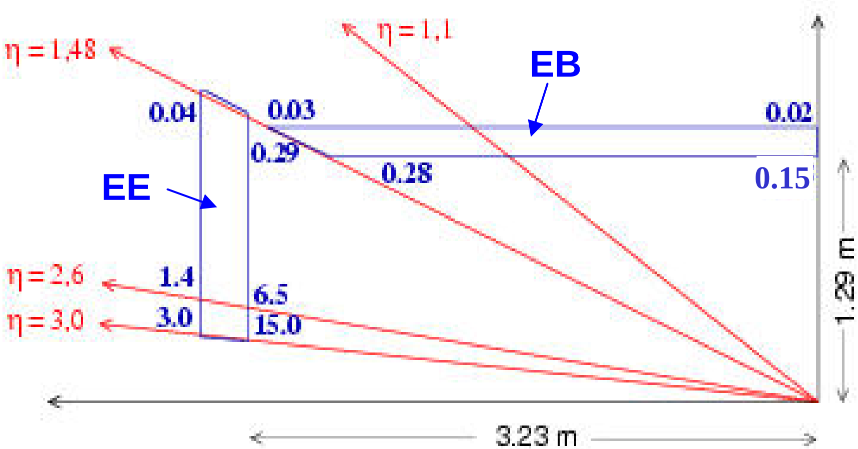


Radiation environment in CMS

Total dose after 10 years of running ($5x10^5$ pb^{-1})

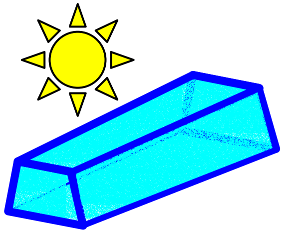


Total dose in the barrel after 10 years at the LHC is ~$2*10^3$Gy



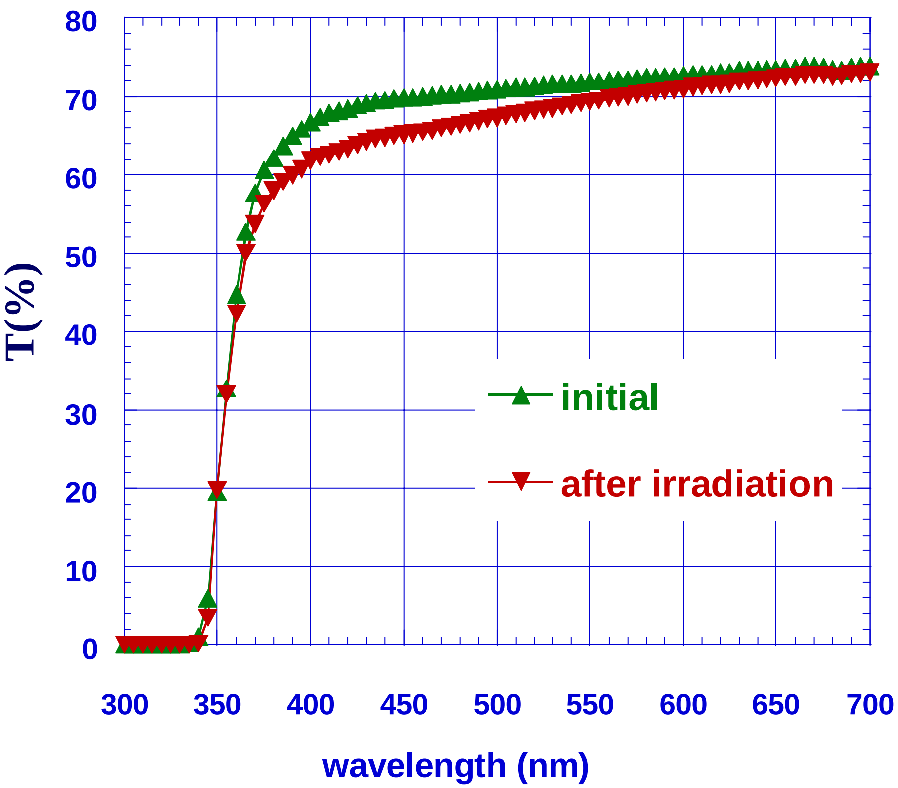
Dose rates [Gy/h] in ECAL at luminosity $L=10^{34}cm^{-2}s^{-1}$

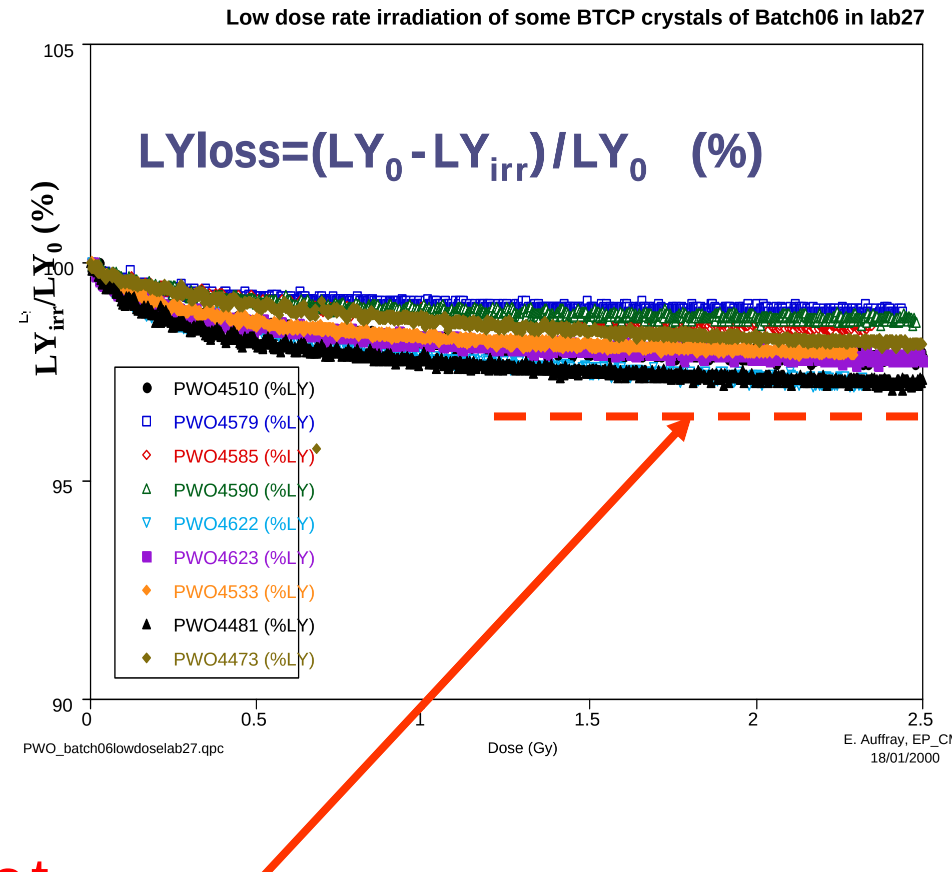
Dose rate at high L in the Barrel is 0.15 – 0.3 Gy/h in the Endcaps 0.3-15 Gy/h



Crystal Radiation Hardness

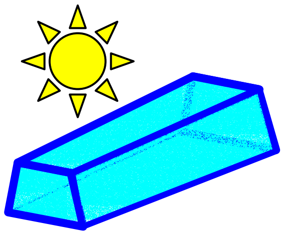
Front irrad., 1.5Gy, 0.15Gy/h





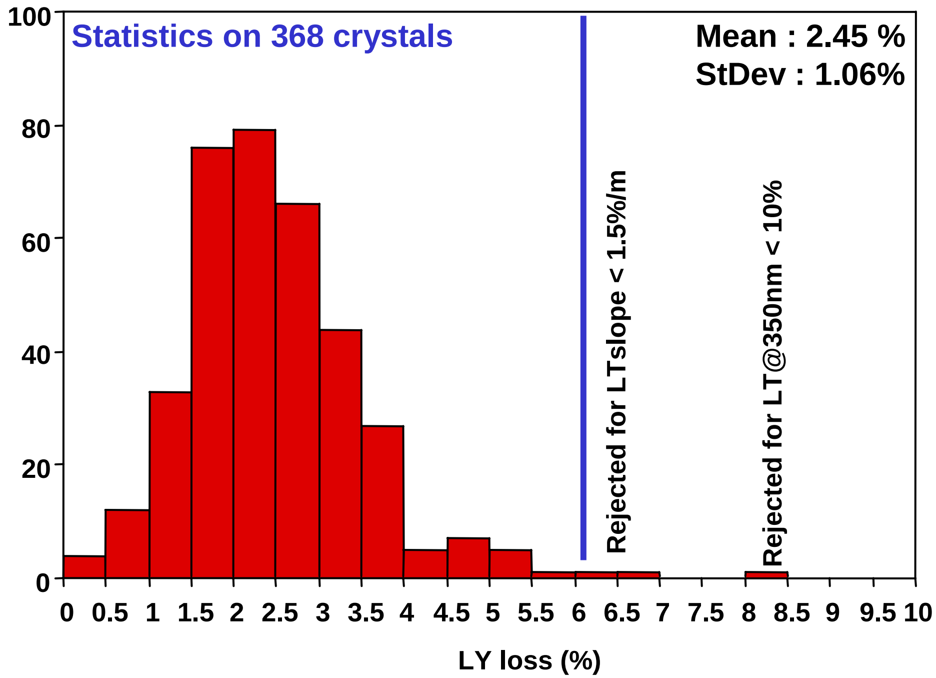
1) Scintillation mechanism not affected but Transparency loss

2) Saturation level

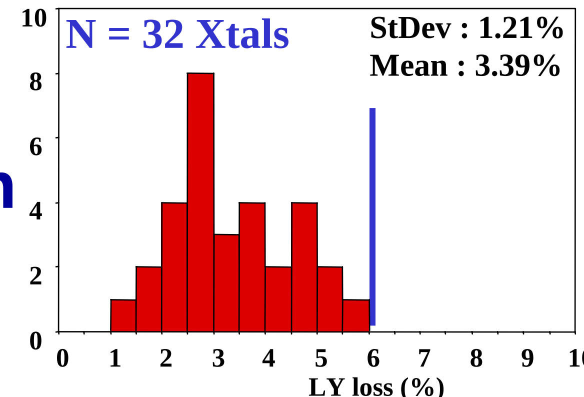


Irradiation tests

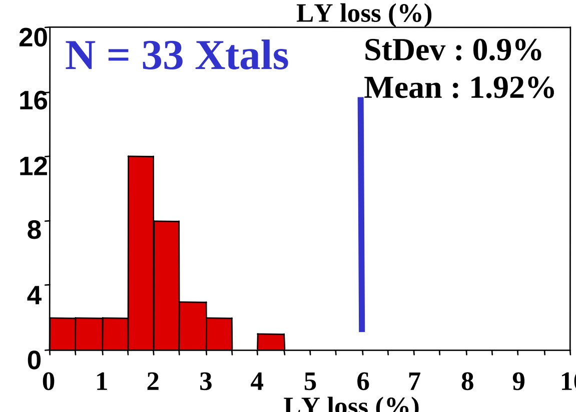
Front irrad., 1.5Gy, 0.15Gy/h



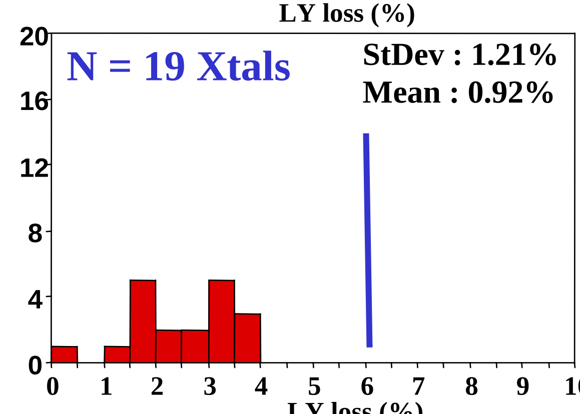
$$LYloss=(LY_0-LY_{irr})/LY_0 \quad (\%)$$



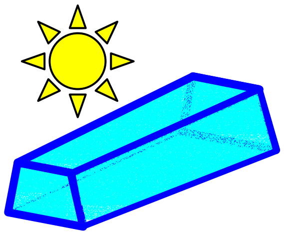
batch 1



batch 8

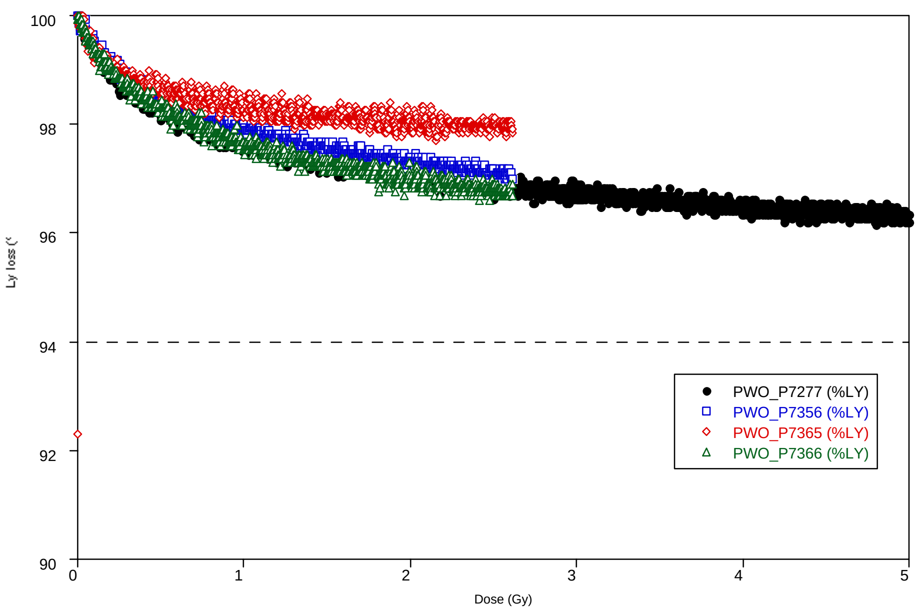


batch 14

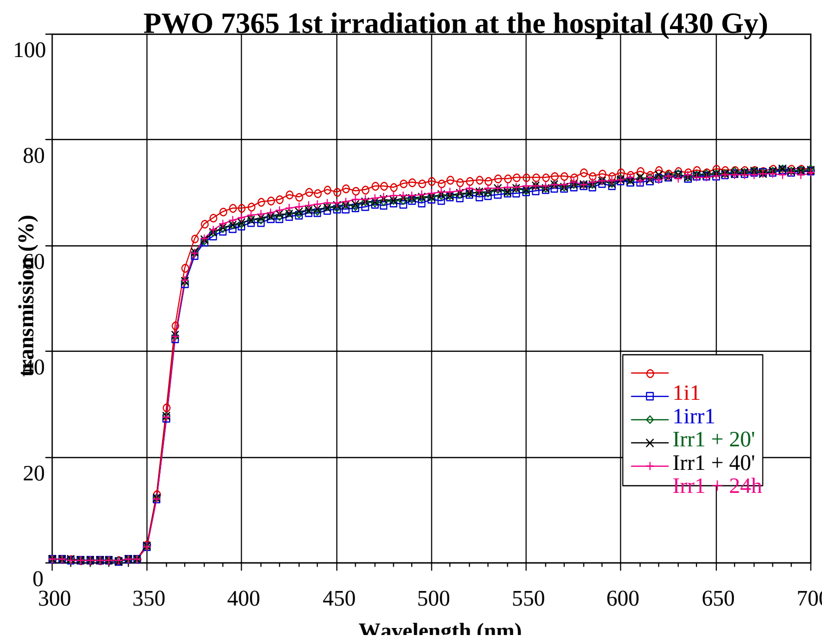


Irradiation tests

Low dose rate 0.15Gy/h front irradiation

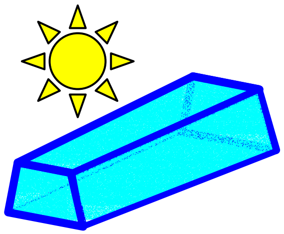


High dose rate 250Gy/h lateral irradiation



$LYloss=(LY_0 - LY_{irr})/LY_0 \quad (\%)$

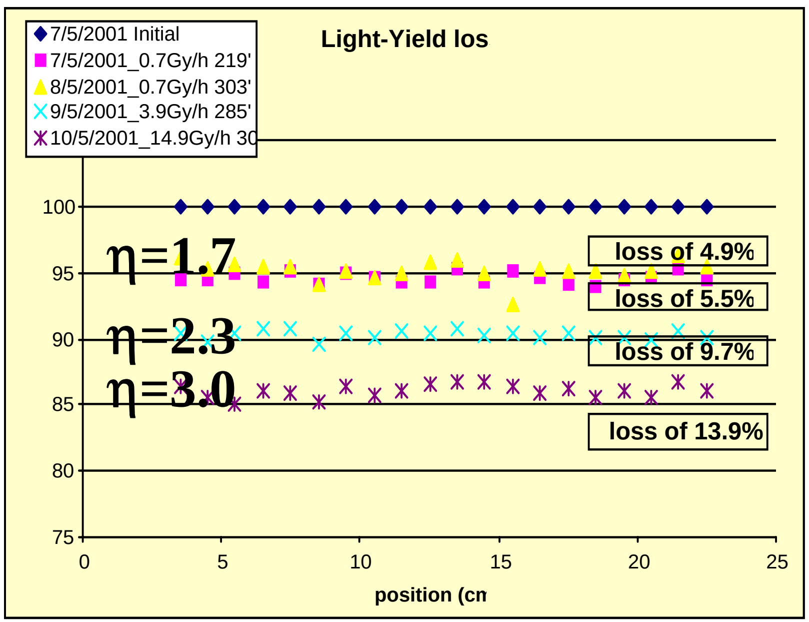
New technology crystals (2 in 1 ingot)



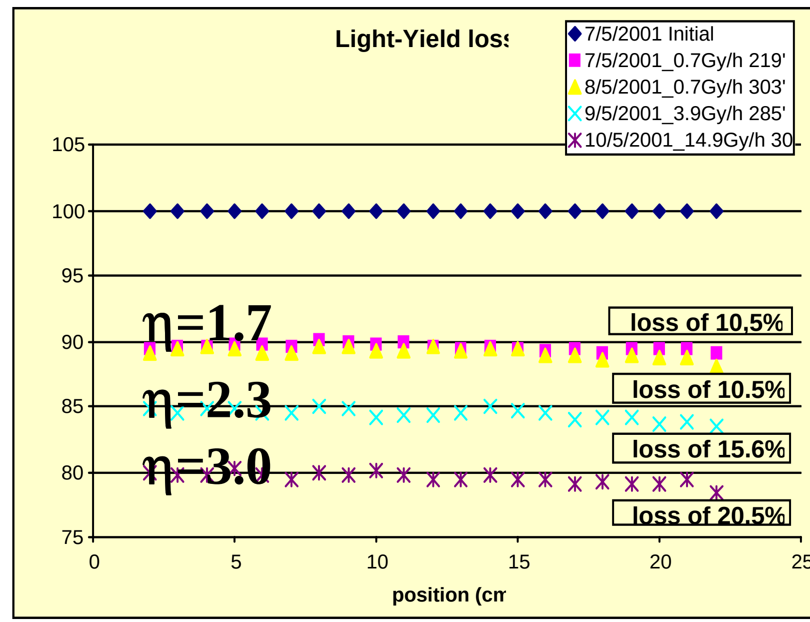
Irradiation tests

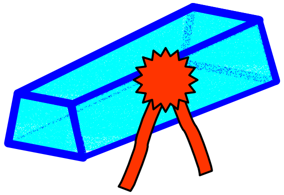
Saturation levels

Barrel crystal



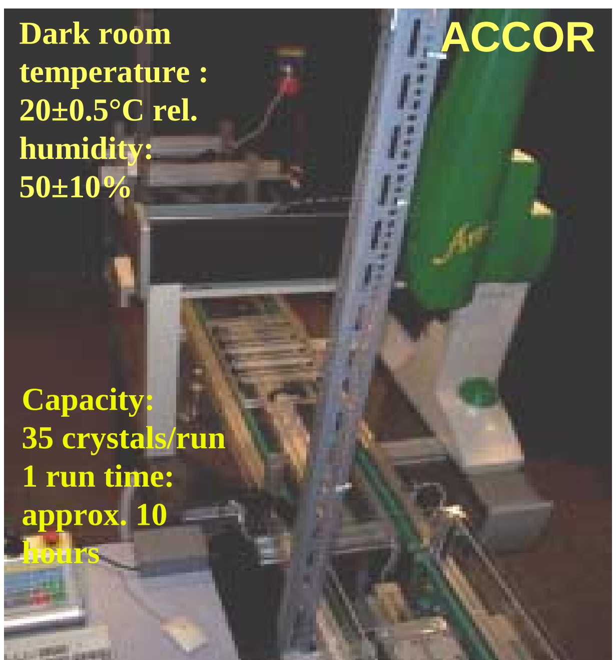
Endcap crystal





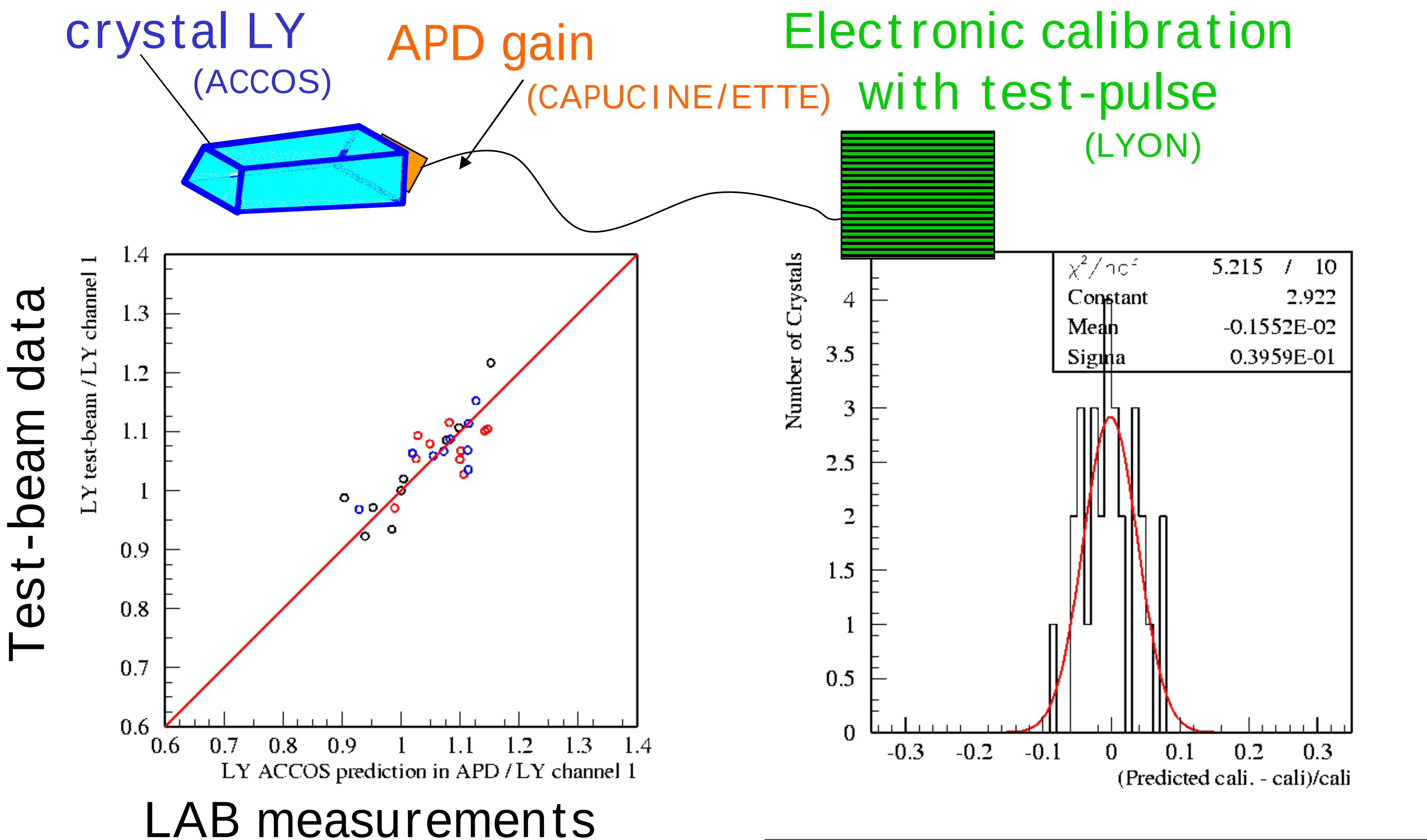
Crystal Quality Control

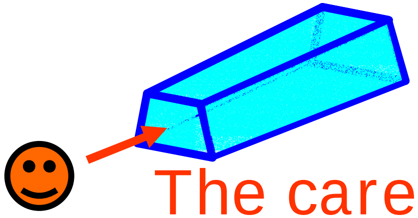
All the relevant Crystal characteristics are controlled by two automatic machines (ACCOCE and ACCOR) before assembly.



Detector Calibration with Lab measurements

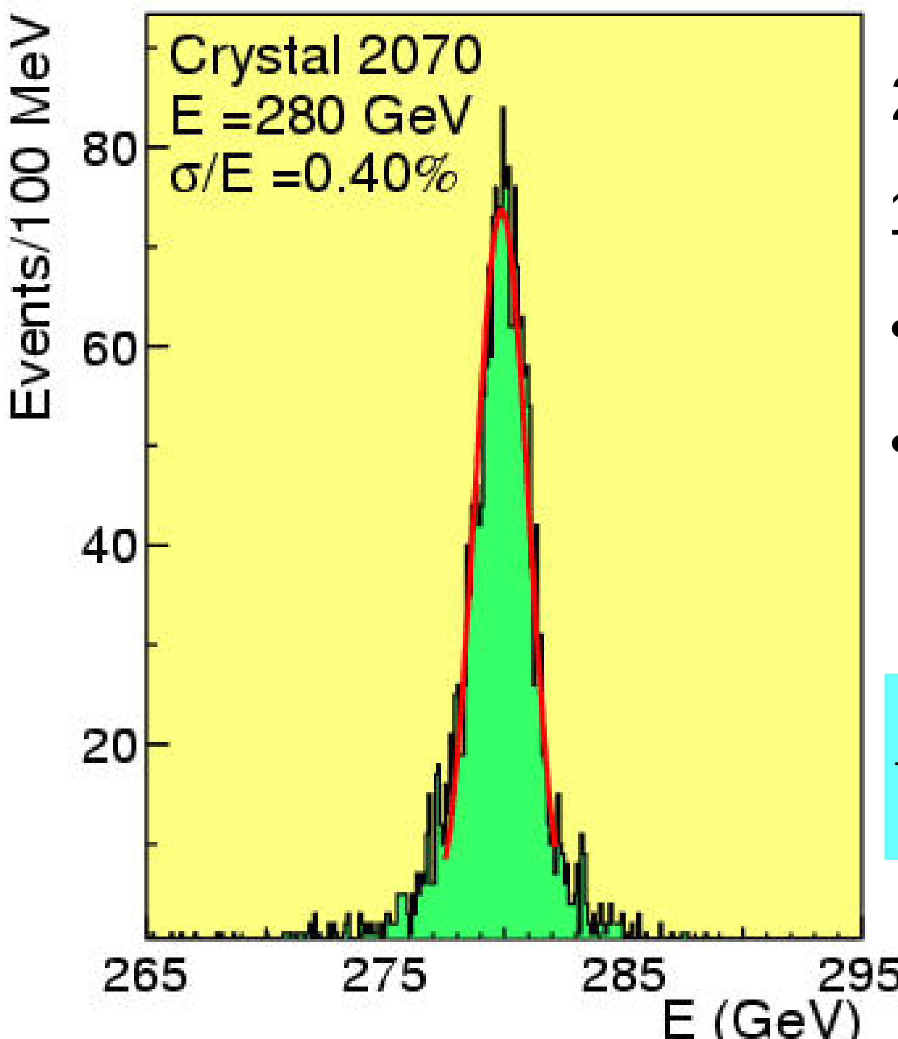
The quality of the lab measurements is so high that we can predict the crystal intercalibration in CMS at ~ 5%





Test-beam performance

The careful control of crystal properties shows that a very good resolution can be obtained



280 GeV electrons

1999 prototype

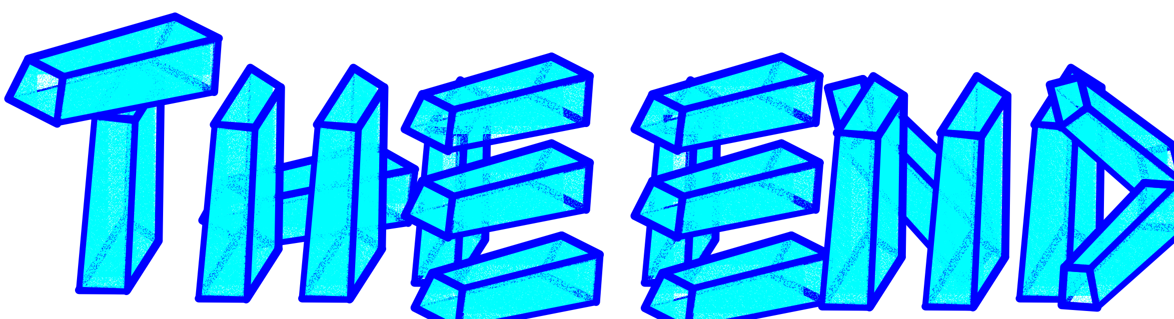
- 30 preprod. crystals
- Charge ADC

Resolution as a function of energy

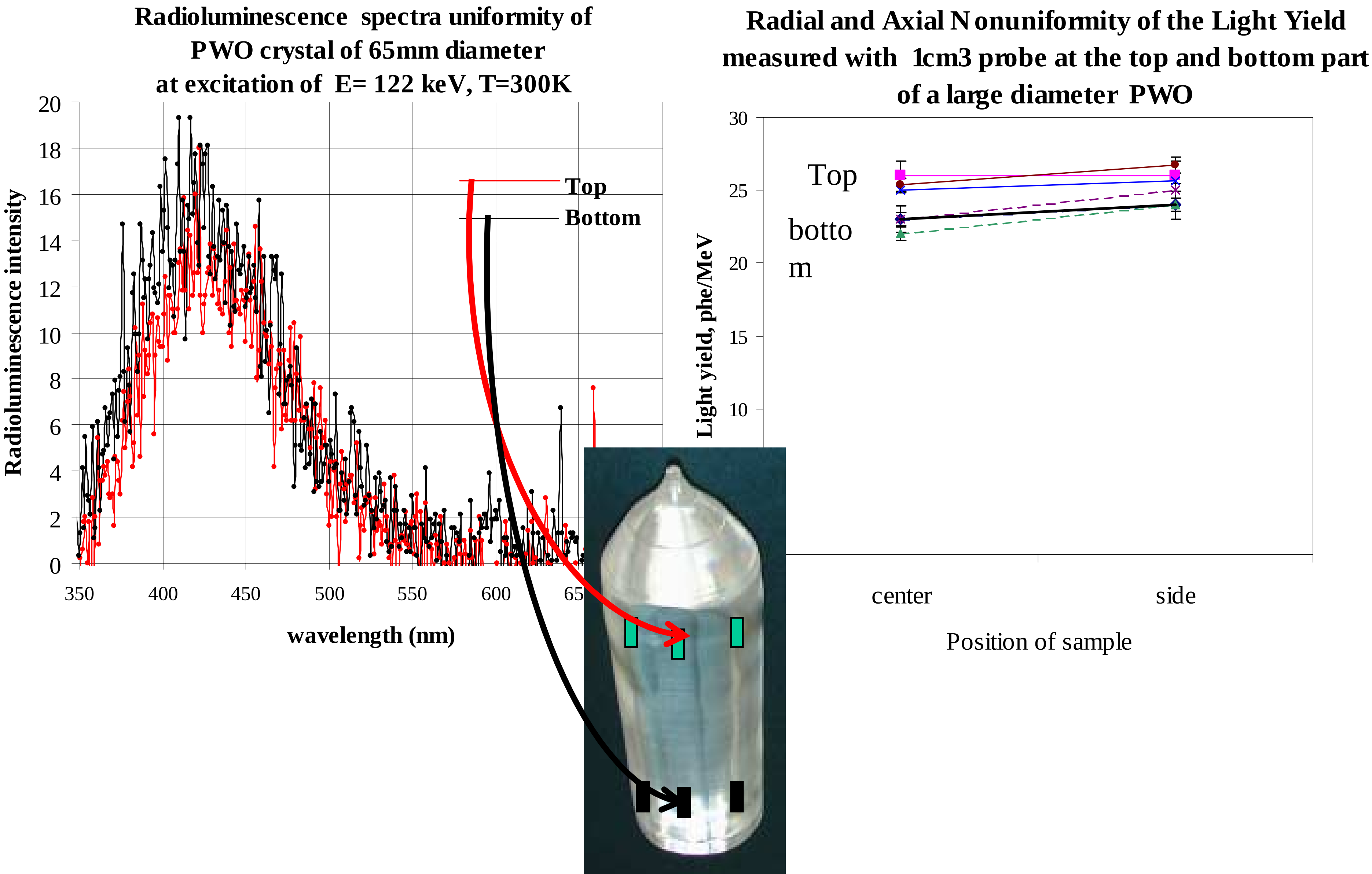
$$\frac{\sigma}{E} = \frac{2.74\%}{\sqrt{E}} \oplus 0.40\% \oplus \frac{142\,\mathrm{MeV}}{E}$$

Conclusions

- The CMS PWO prod. crystals are now well suited for CMS
- Several years of R&D have led to satisfactory and homogeneous properties of the crystals
- All relevant info about radiation hardness and calorimeter resolution can be measured in the lab. Before assembly
- BCTP has successfully produced new crystals from large ingots
- New development under way to increase further the rate



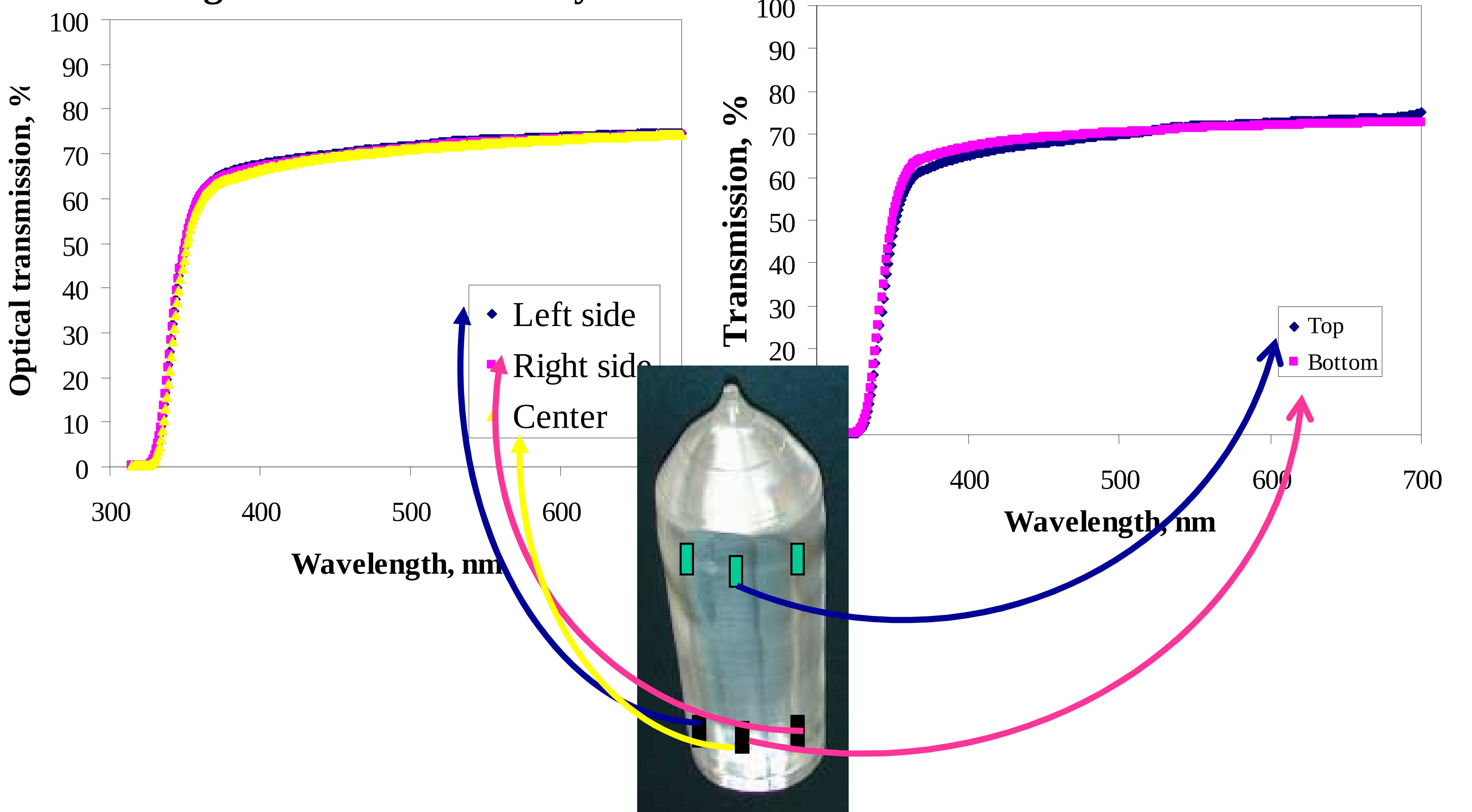
Large ingot crystals: Light Yield



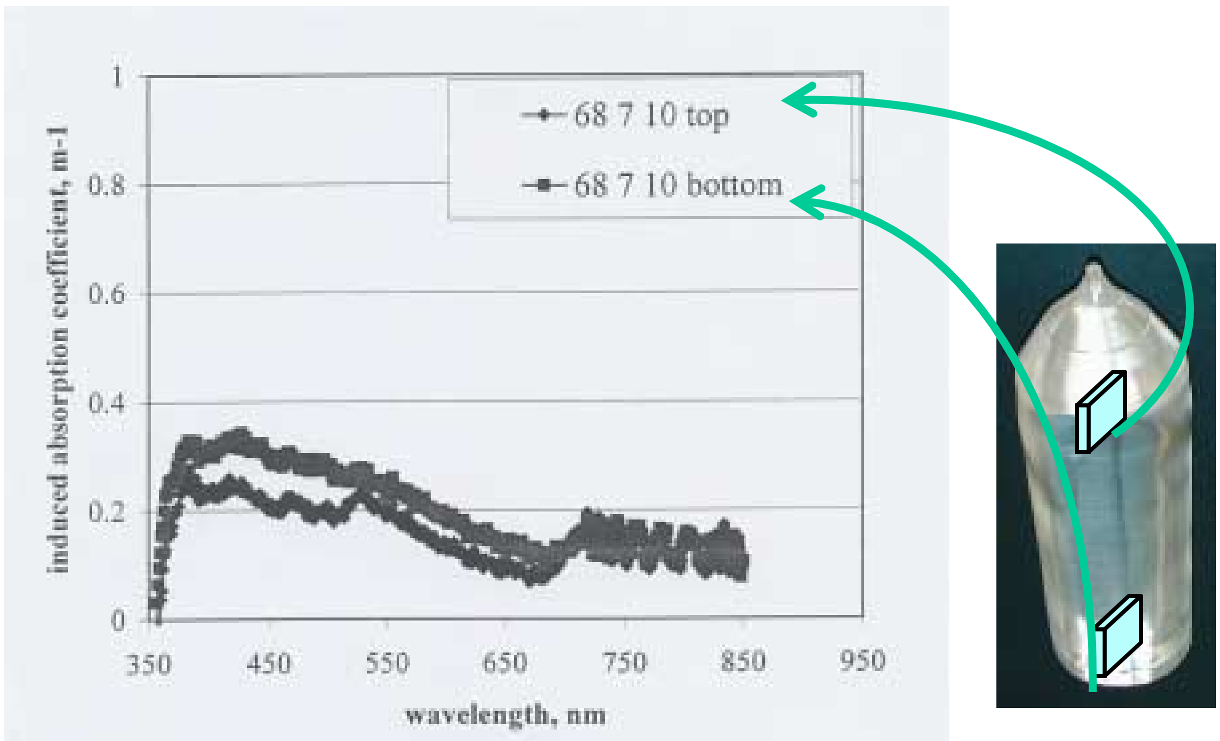
Large ingot crystals:Transmission

Radial optical transmission nonuniformity of large diameter PWO crystal

Axial optical transmission nonuniformity of a large diameter PWO crystals



Large ingot crystals: Radiation hardness



A. N. Anenkov et all, Scint2001 Conference

$$\mu(\lambda) = \frac{1}{L_{xtl}} \ln\left[\frac{T_0(\lambda)}{T_{rad}(\lambda)}\right] m^{-1}$$

Large ingot crystals: Radiation hardness

A. N. Anenkov et all, Scint2001 Conference