Crystal Production and Properties in CMS - ECAL

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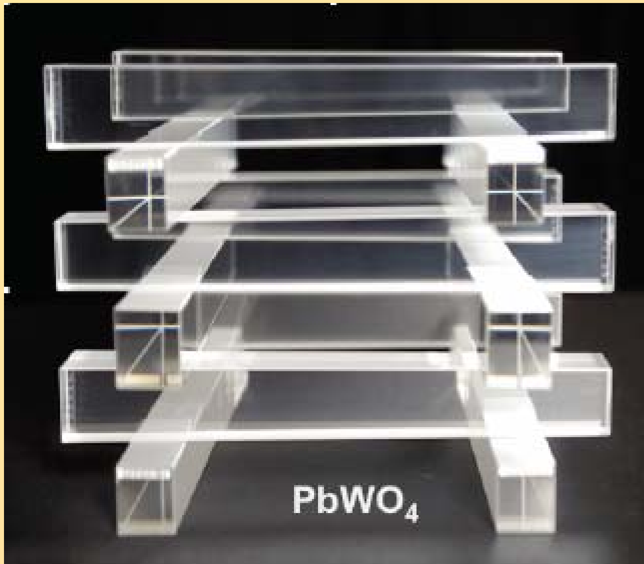
on behalf of CMS ECAL Group

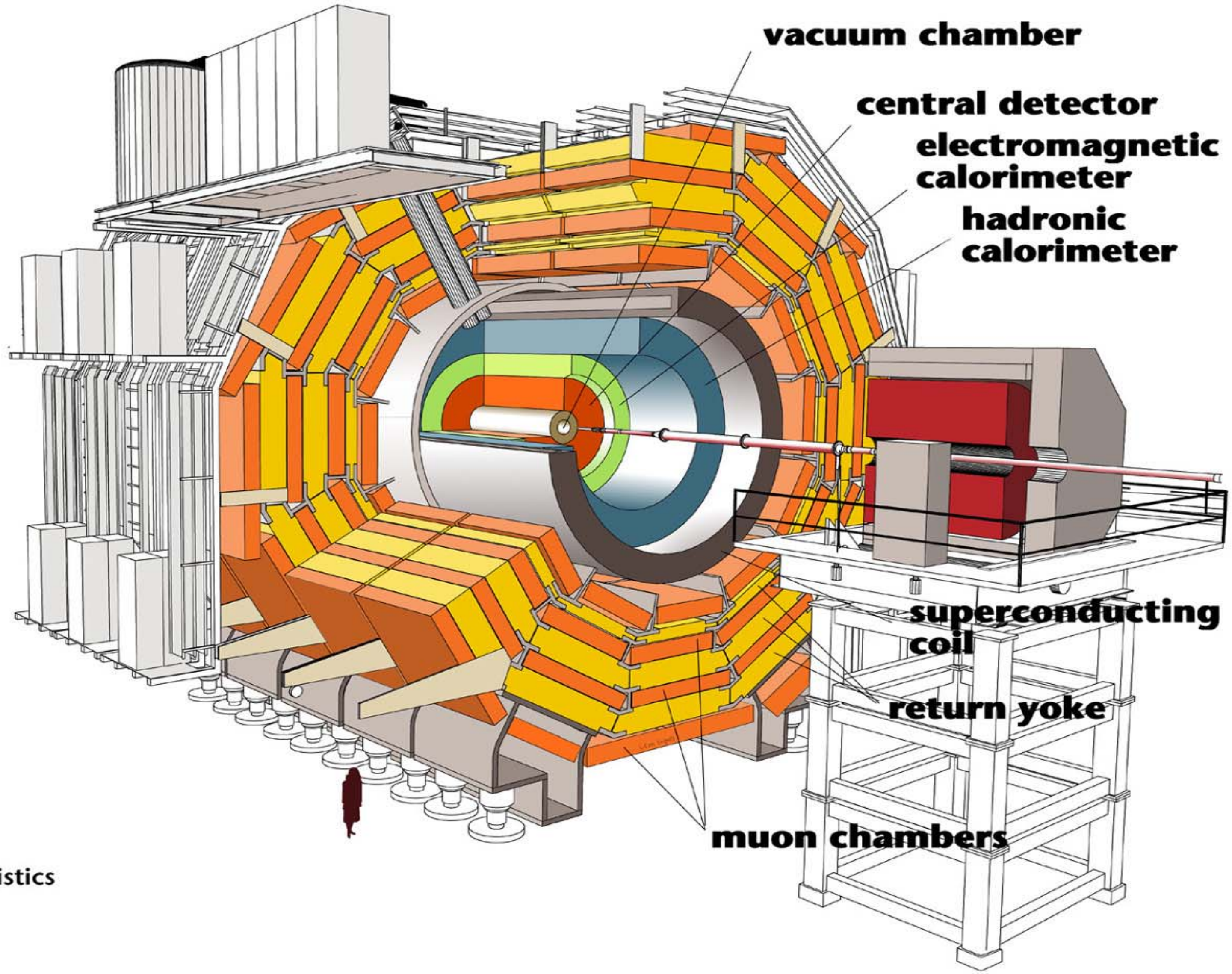
Chicago - 6 june 2006

Outline

- CMS and ECAL introduction
  - Crystal Properties
- Crystal production and construction status
- Cern and Rome Regional Center activities
  - Transmission and Light Yield measurements
- Non uniformity and precalibration of the crystals
- Conclusions



Compact Muon Solenoid

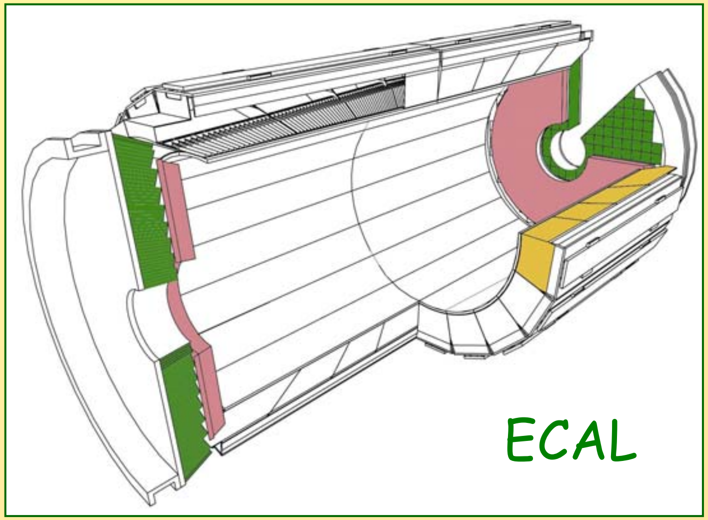


Detector characteristics

Width: 22m
Diameter: 15m
Weight: 14'500t

CMS ECAL

- Homogenous calorimeter
- Lead Tungstate Crystals $PbWO_4$
- Solenoidal Magnetic Field: 4 Tesla



Parameter	Barrel	Endcap
η coverage	$\lvert\eta\rvert < 1.48$	$1.48 < \lvert\eta\rvert < 3.0$
Granularity ($\Delta\eta\times\Delta\phi$)	0.0175×0.0175	varies in η
Crystal Dims. (cm^3)	$2.18\times2.18\times23$	$2.85\times2.85\times22$
Depth in X_0	25.8	24.7 (+3X_0)
No. of crystals	61,200	14,950
Crystal Volume (m^3)	8.14	3.04
Photodetector	APDs	VPTs
Modularity	36 supermodules	4 Dees

Crystal Producers: Bogoroditsk (Russia), Shanghai Institute of Ceramics (China)

Construction Regional Centers: CERN in Geneva and INFN/ENEA in Rome

Characteristics

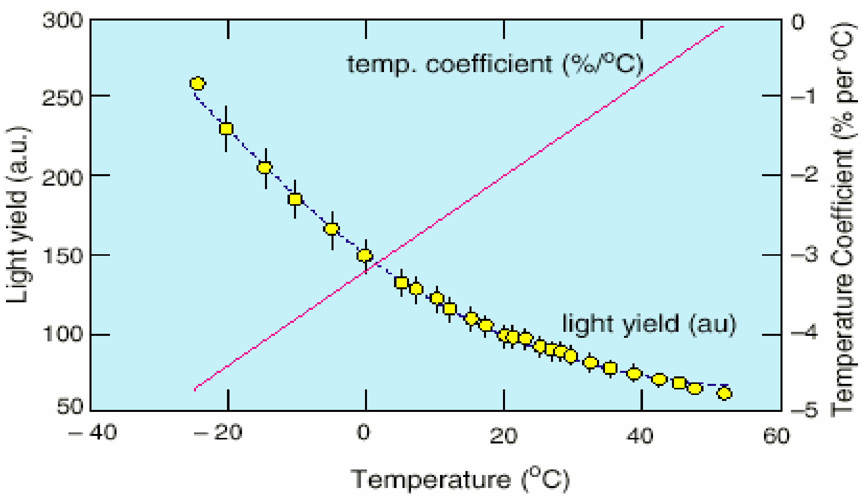
☺

- Fast scintillation
- Small X_0 and R_m
- Radiation hardness
- Relatively easy to grow

☹

- Low Light Yield
- Strong LY dependance on T

% of light in 25 ns:	~80%
Peak emission: (visible region)	~420 nm
Radiation length X_0:	0.89 cm
Molière radius R_M:	2.20 cm
Radiation resistant to very high doses	

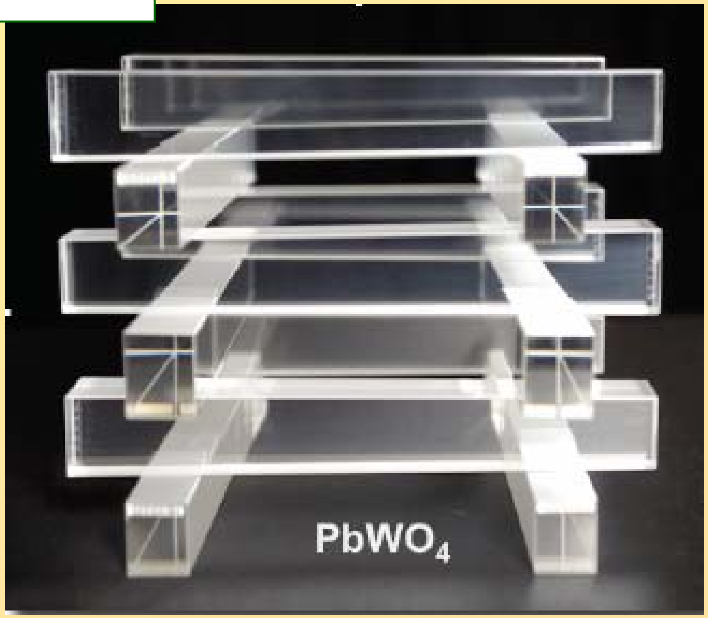


ECAL Construction

- Crystal R&D phase (1995-1998)
- 6000 crystal preproduction (1998-2000)

- Crystal production:
  2001 - feb. 2007 Barrel
  2006 - jan. 2008 Endcap

From ingots to crystals



Crystal Quality Control

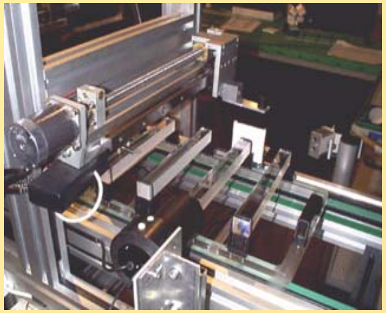
Automatic Crystals Quality Control Systems

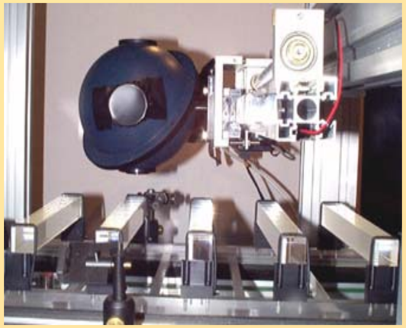
for reception tests

- Automatic processing of crystals in sets of 5 on a tray, also used for storage and capsule gluing
- Measurements of dimensions by a standard 3D machine
- Light yield on several points (unif.)
- Transmission (lateral on several points, longitudinal)
- Bar code ID of each crystal information into database, via a distributed process control system

+ spot checks of radiation tolerance

ACCOCE at CERN



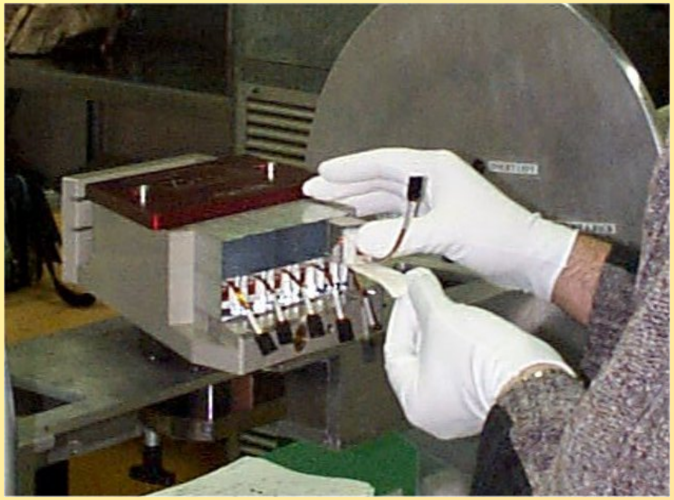


ACCOR at INFN-ENEA Rome

Barrel Construction

CERN and INFN/ENEA Regional Centers activities:

- Automatic measurements of:
  crystal dimensions, transmission, light yield and uniformity
- Gluing of APDs on the crystal and test
- Submodule assembly and test (10 crystals)
- Module assembly and test



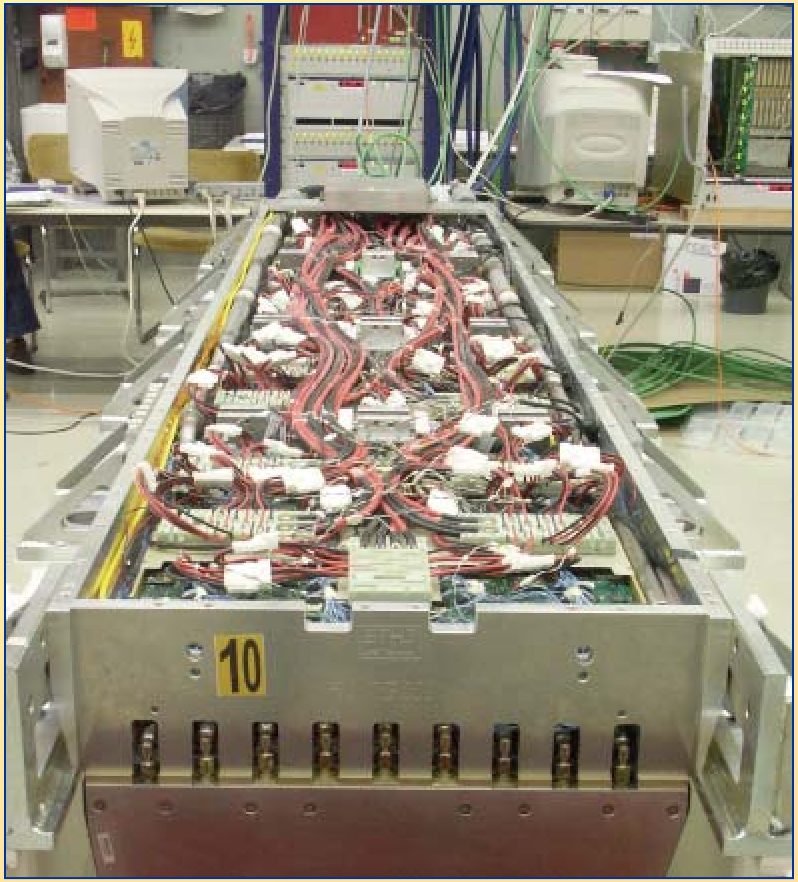
Module type 2 - Rome

Module type 4 - Cern

Barrel Construction (2)

Modules from Rome RC

1 SuperModule = 4 Modules
= 1700 xtals + 3400 APDs +
68 TriggerTowers + 34 HV channels + ...



- The SuperModules are assembled at Cern Regional Center with a rate of one SM per month.
- The cooling system, the laser, the high voltage, the electronic chain are assembled and tested at Cern.
- Final SuperModules are tested with cosmics and beam (see G. Franzoni and A. Zabi talks)

Production Status

- About 51500 crystals have been delivered up to now.
- ~ 51000 (out of 61200) barrel crystals and ~ 500 (out of 14648) endcap crystals.
- ~ 50000 from Bogoroditsk and ~ 1500 from SIC.
- 27 (out of 36) barrel SuperModules are mechanically assembled.
- 18 barrel SuperModules are ready to be installed in CMS.

In the following slides the measurements of almost 50000 russian crystals are presented.

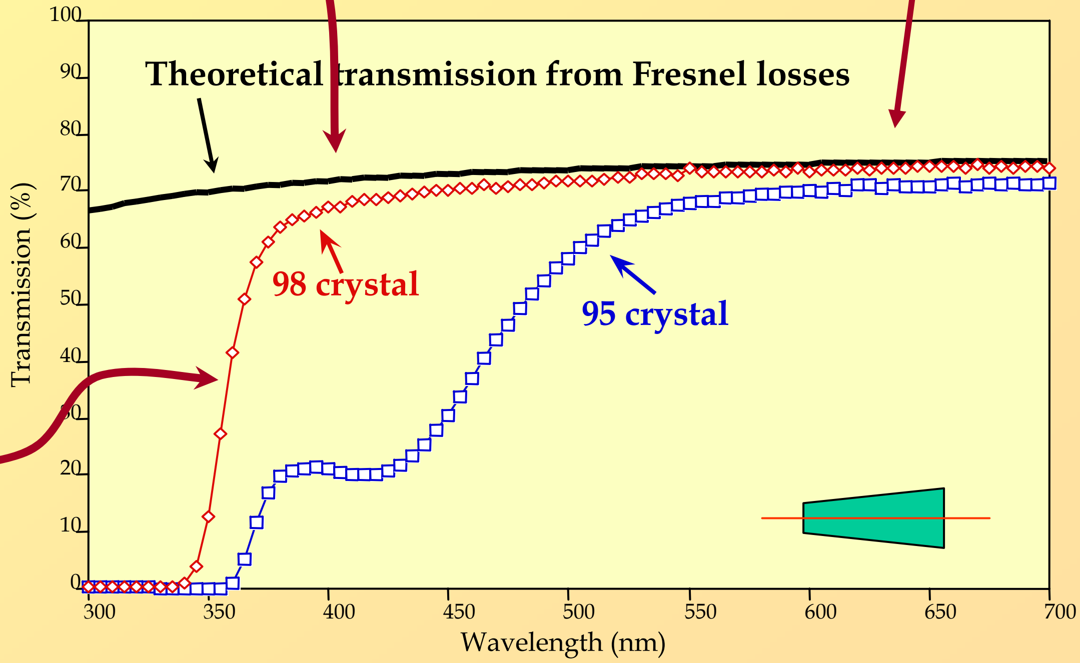
Longitudinal Transmission

The spectrum of transmission along the crystal axis has to satisfy a selection in order to accept the crystal.

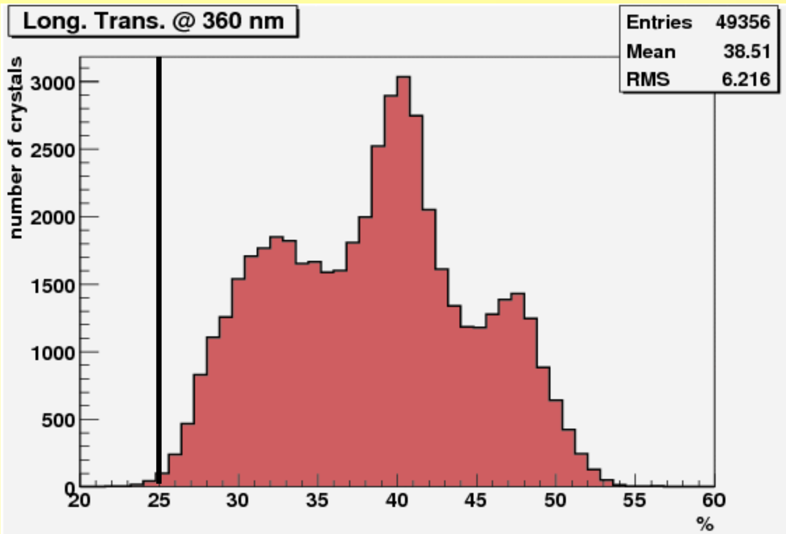
transmission @ 620 nm:
crystal core defects
acceptance cut: LT > 65%

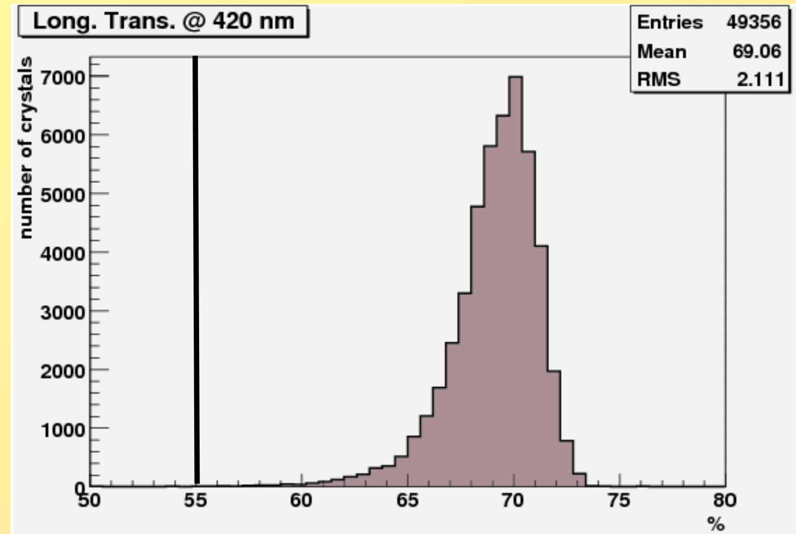
transmission @ 420 nm:
small L_{abs} at emission peak -> high LY
acceptance cut: LT > 55%

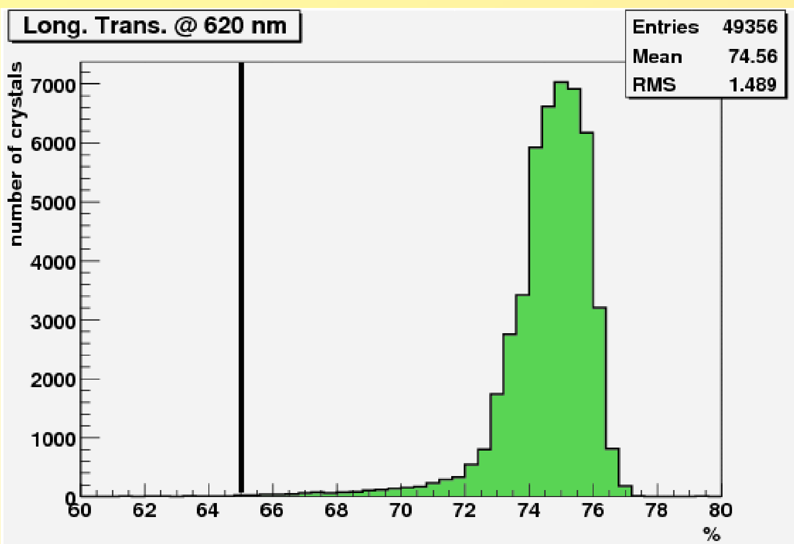
transmission @ 360 nm and band-edge slope:
radiation hardness
acceptance cut: LT > 25%



Longitudinal Transmission (2)







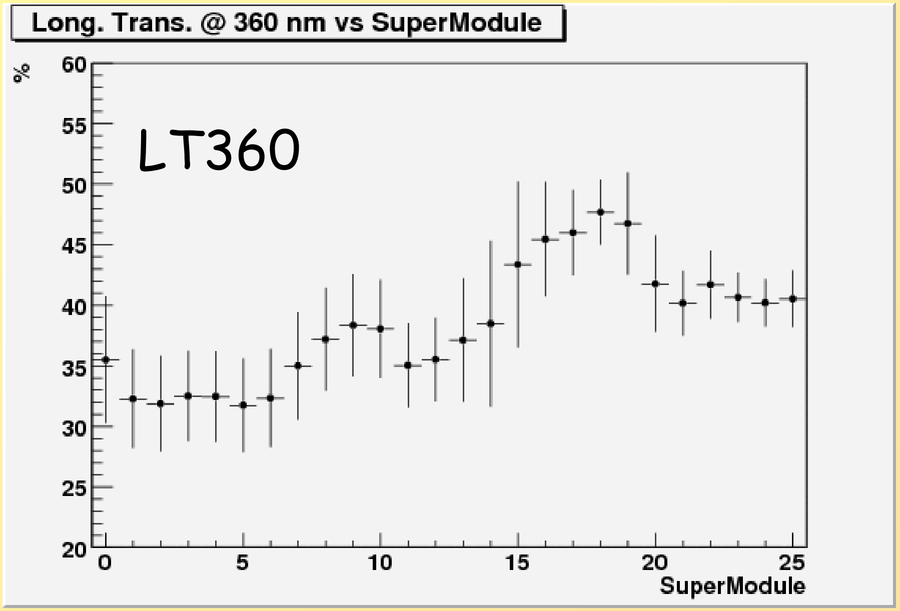
crystal to crystal transmission variation at 360 nm is related to a spread in the edge position of less than 10 nm.

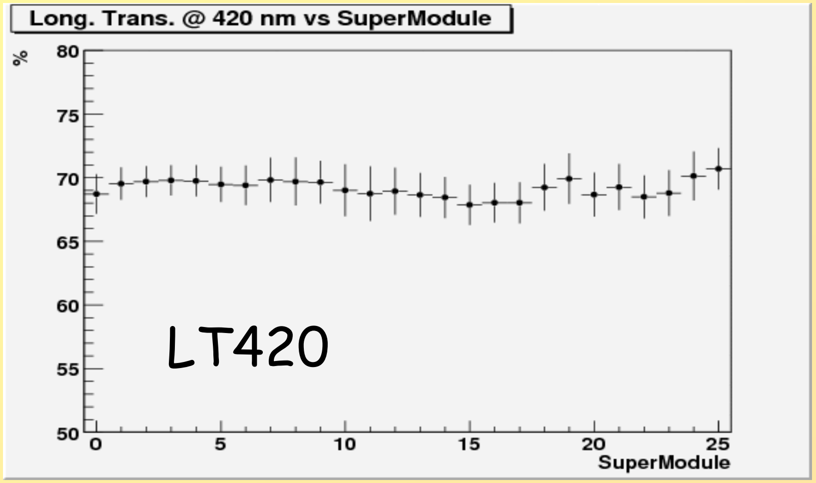
transmission wavelength	Mean	RMS
360 nm	38.5 %	6.2 %
420 nm	69.1 %	2.1 %
620 nm	74.6 %	1.5 %

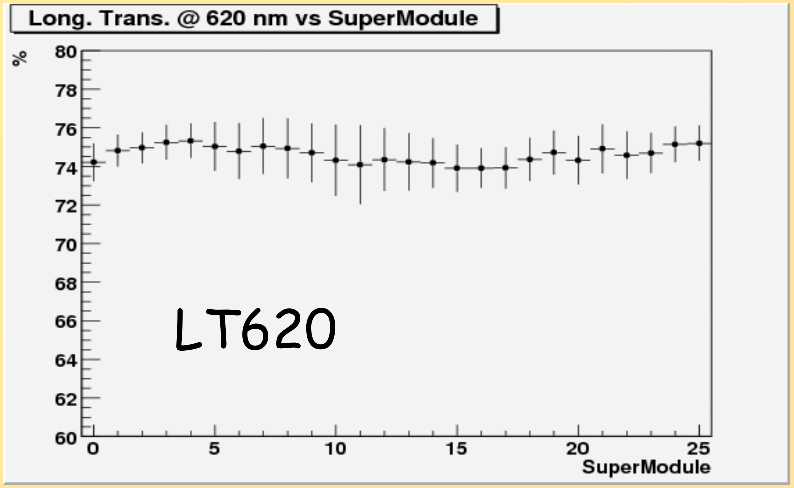
Longitudinal Transmission (3)

Transmission measurements as a function of SuperModule index (i.e. as a function of time).

Crystal production is made up of several batches; variation at band-edge (360 nm) is due to the extreme sensitivity of this region to production conditions.

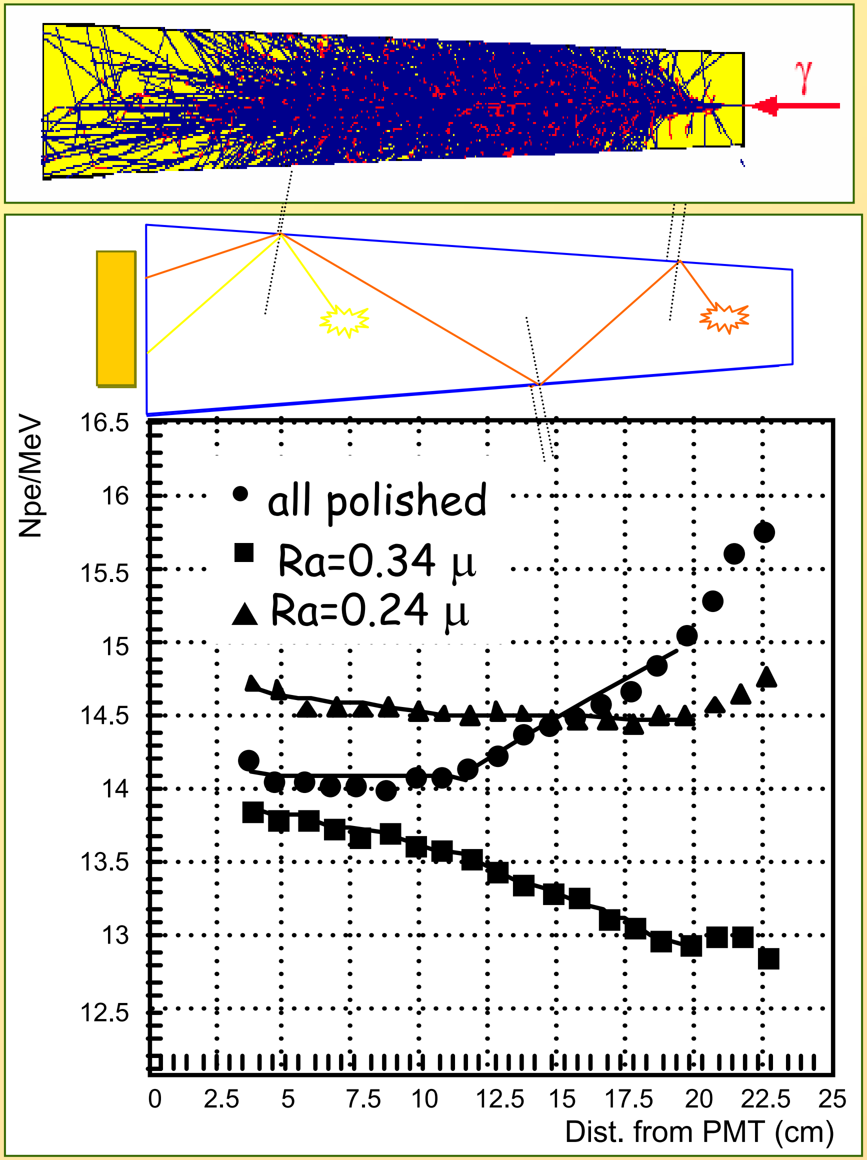






Non uniformity of light collection

• Smearing of the response at fixed energy due to shower fluctuations (can not be corrected)
• Focusing effect due to tapered shape of crystals: non linearity of the response (can be corrected).
• Uniformity can be controlled by depolishing one lateral face with a given roughness (paying a loss in LY)
• Uniformity treatment is performed in the Prod. Centers.

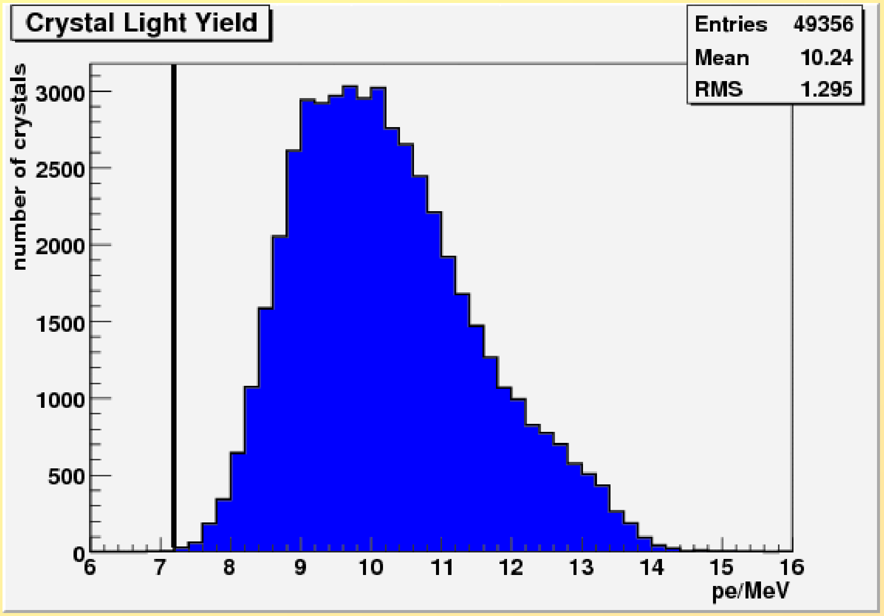


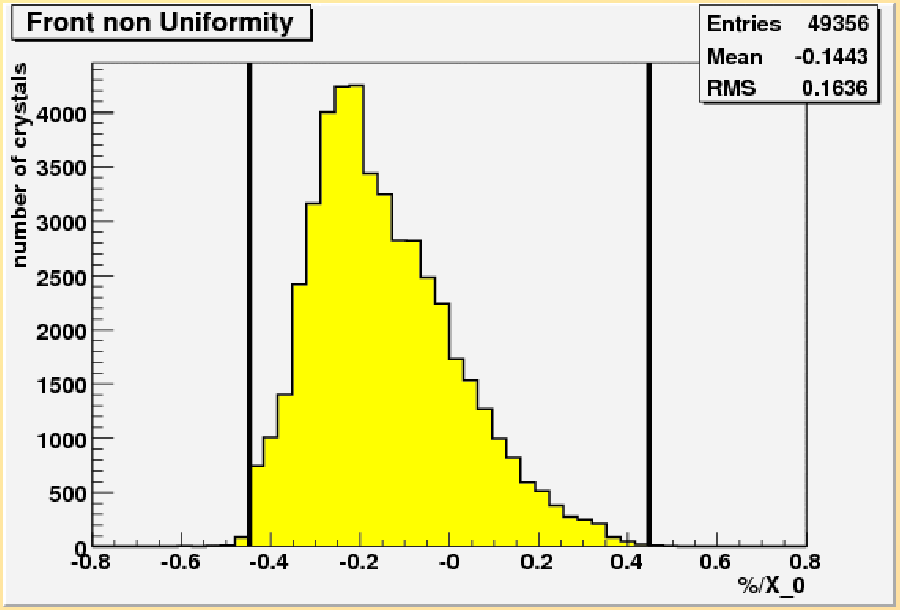
The contribution to the constant term due to crystal non uniformity should not exceed 0.3% (the global constant term is 0.5%)

Light Yield and FNUF

A measurement per cm with a source of Co60, crystal in tyvek and PMT.
LY@8X_0 and FrontNonUniFormity are the results of linear fit between 3.5 cm and 11.5 cm.

LY@8X_0 must be greater than 7.2 pe/MeV in order to have an acceptable stochastic term in the energy resolution.
The acceptance cut -0.45 %/X_0 < FNUF < 0.45 %/X_0 is due to the contribution of non uniformity in the constant term.

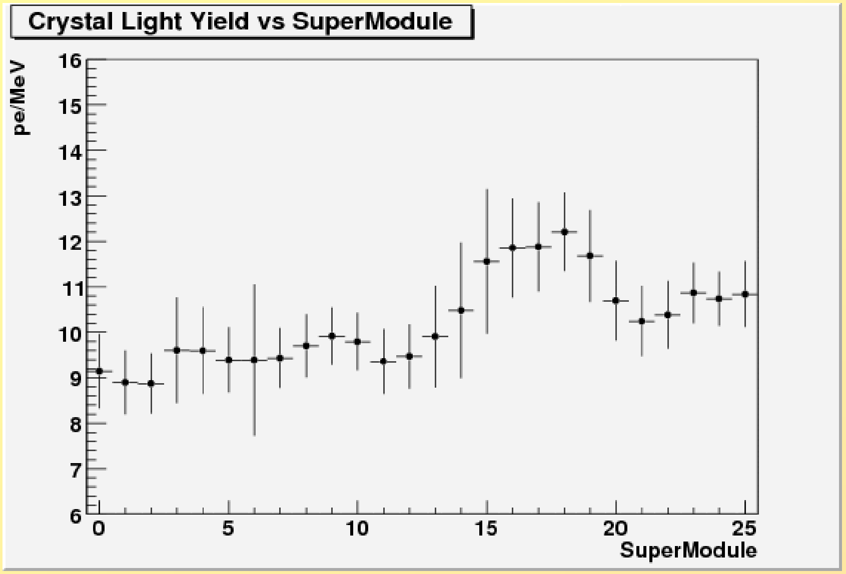


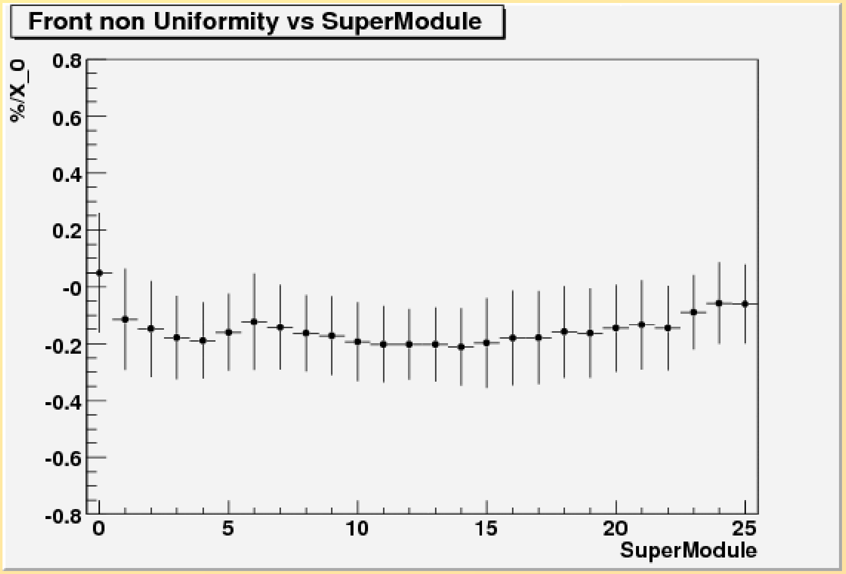


Light Yield and FNUF (2)

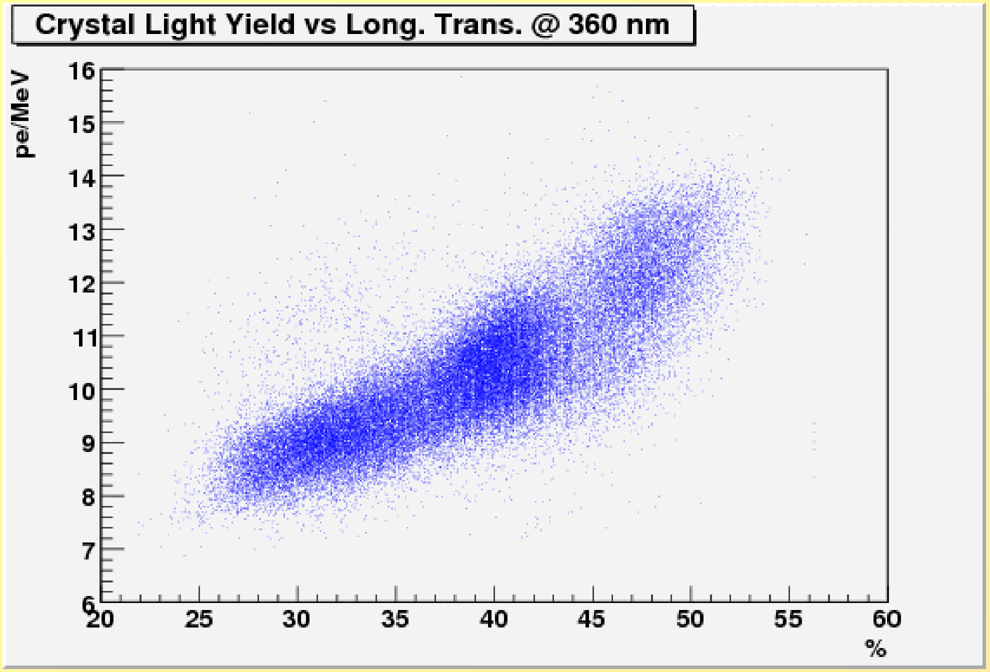
LY and FNUF measurements as a function of SuperModule index (i.e. as a function of time).

- FNUF is stable during the production (few crystals are depolished again at Cern).
- LY shows a pattern very similar to the LT360 one.
- In fact a strong correlation between LY and LT360 has been found.





LY - Transm. Correlation



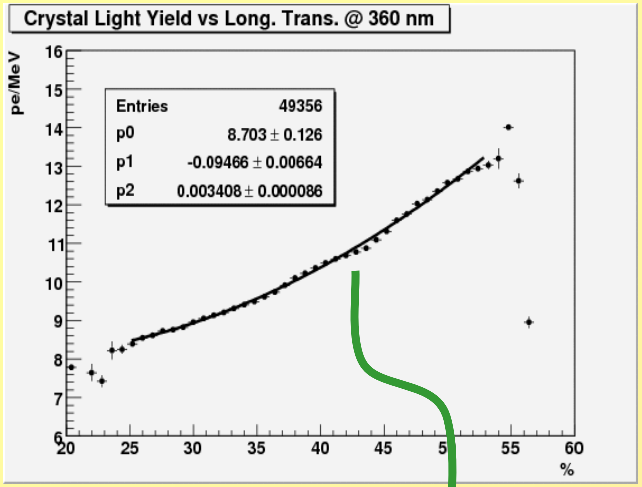
<u>Crystal LY is correlated with the position of the absorption edge.</u>

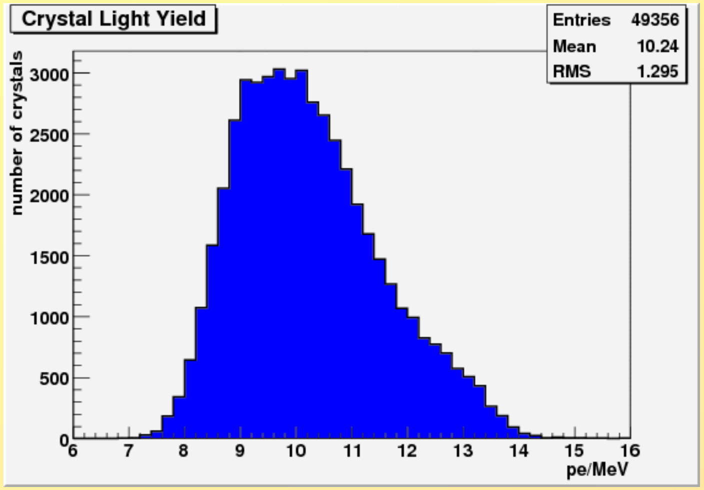
- This correlation is not only self absorption i.e. cannot be entirely attributed to variations of the optical transmission. There is a more general correlation between the amount of light produced and transmission curve edge.

There is no correlation at different wavelength (even in the scintillation peak)

Light Yield vs	Correlation
LT @ 360 nm	77,3%
LT @ 420 nm	1,5%
LT @ 620 nm	1,1%

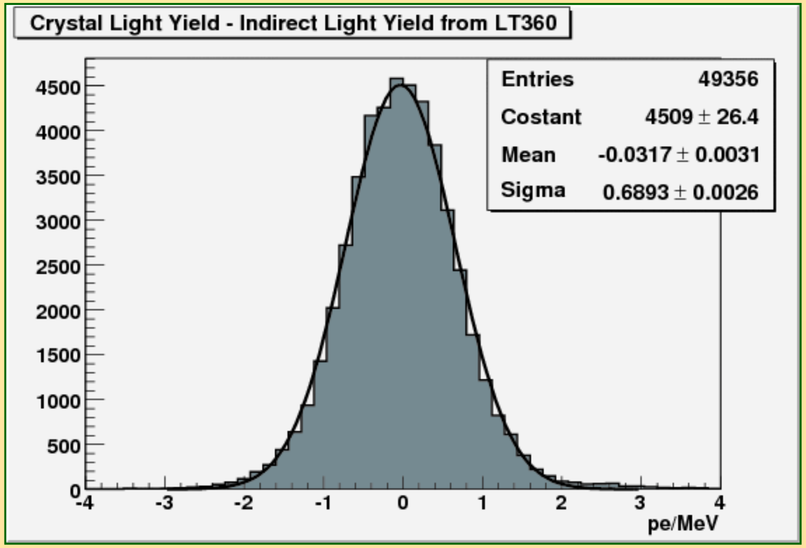
LY - Transm. Correlation





RMS ($LY_{meas.}$) = 1.30 pe/MeV

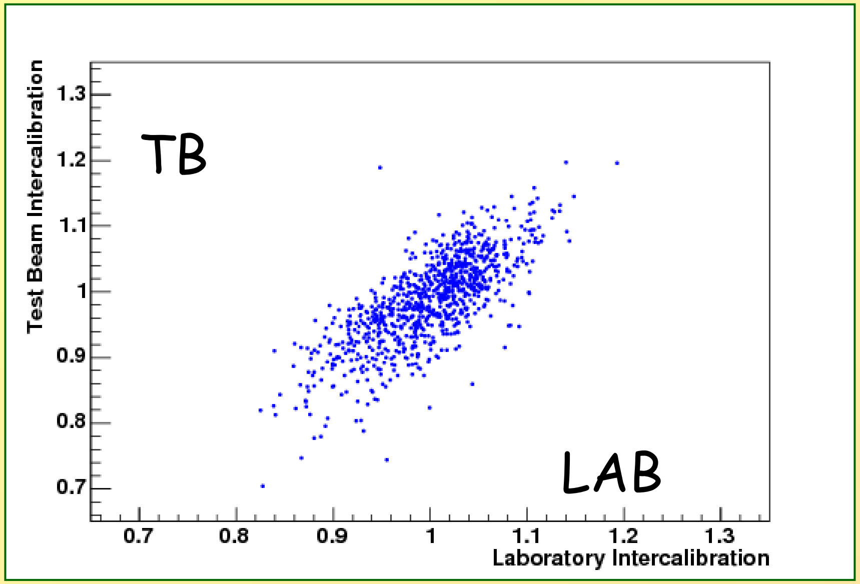
$$LY_{indirect} = P_0 + P_1 \cdot T_{360} + P_2 \cdot T_{360}^2$$

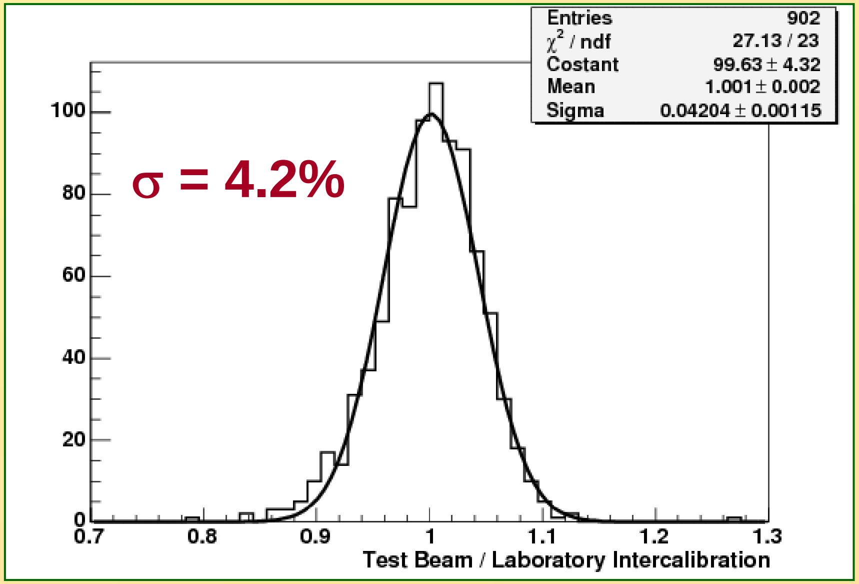


σ ($LY_{meas.}$ - $LY_{indir.}$) = 0,69 pe/MeV

Test Beam vs LAB. calibration

- LY best estimation is the average between direct LY and LY from LT360. This has been verified with calibration from test beam.
- Agreement between laboratory measurements and test beam is at level of 4%; excellent result considering five order of magnitude in energy (1.2 MeV of Co60 source in lab. vs 120 GeV of electron beam)
- Calibration results in test beam will be shown tomorrow by G. Daskalakis





Summary

• The construction of CMS ECAL Barrel is in the final phase; the construction of the Endcaps is starting now.

• Production and delivery of crystals drive the calorimeter construction schedule.

• Crystal properties are continuously monitored in the ECAL Regional Centers.

• Crystals are very uniform thanks to the precise depolishing of one lateral face; this allows to reach the foreseen energy resolution.

• A very interesting correlation between LY and Longitudinal Transmission is observed. This additional and independent measurement of the crystal LY leads to an improvement of the LY resolution.

Backup slides

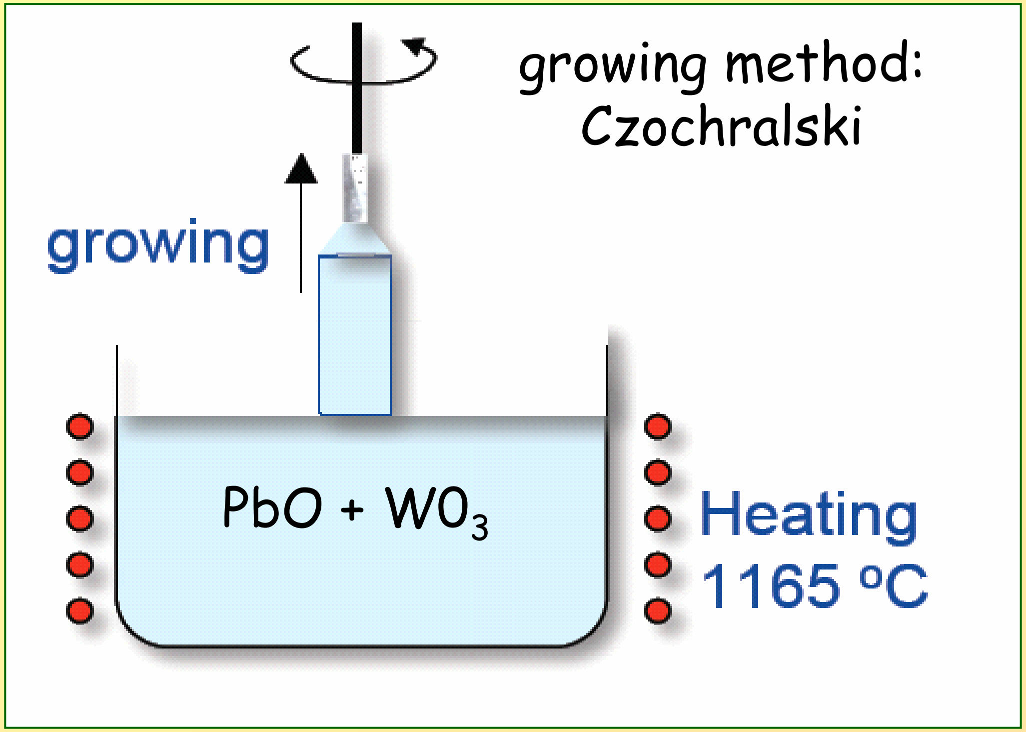
Crystal choice

	NaI(Tl)	BaF_2	CsI(Tl)	CsI	CeF_3	BGO	PWO	
ρ	3.67	4.88	4.53	4.53	6.16	7.13	8.26	g/cm^3
X0	2.59	2.05	1.85	1.85	1.68	1.12	0.89	cm
RM	4.5	3.4	3.8	3.8	2.6	2.4	2.2	cm
τ	250	0.8/620	1000	20	30	300	15	ns
λp	410	220/310	565	310	310/340	480	420	nm
n (λp)	1.85	1.56	1.80	1.80	1.68	2.15	2.29	
LY	100%	15%	85%	7%	5%	10%	0.2%	%NaI

Typical light yield of NaI ~ 40000 γ/MeV

Construction (1)

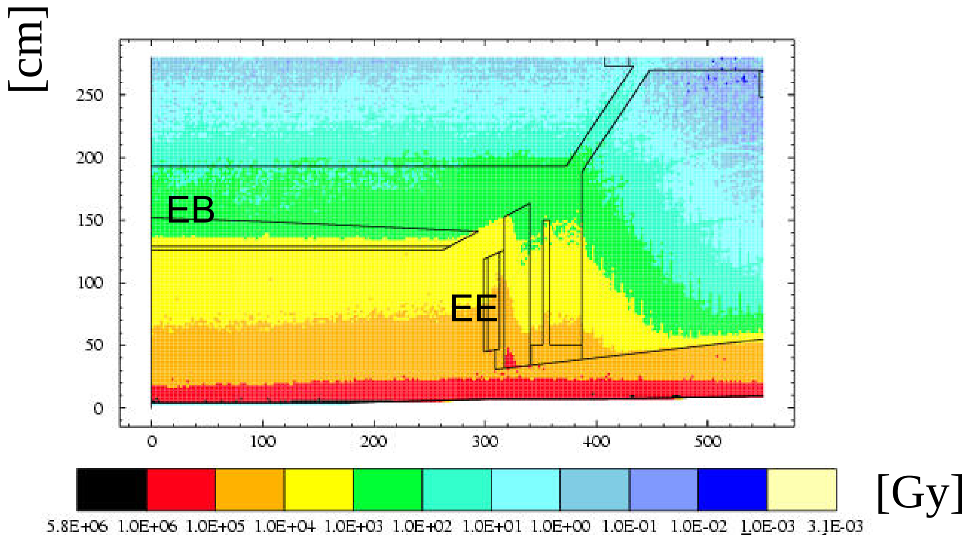
- Crystal R&D phase (1995-1998)
- 6000 crystal preproduction (1998-2000)
- Crystal production:
  - 2001 - feb. 2007 Barrel
  - 2006 - jan. 2008 Endcap



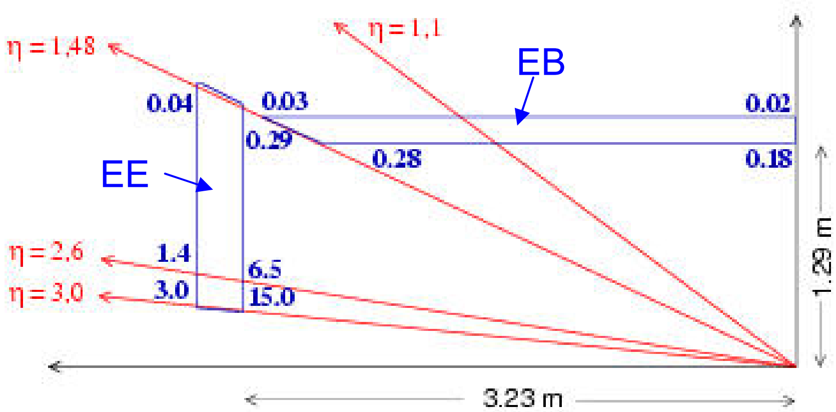
BARREL ingot

SIC: Bridgman-Stockbarger method

Crystal's radiation damage



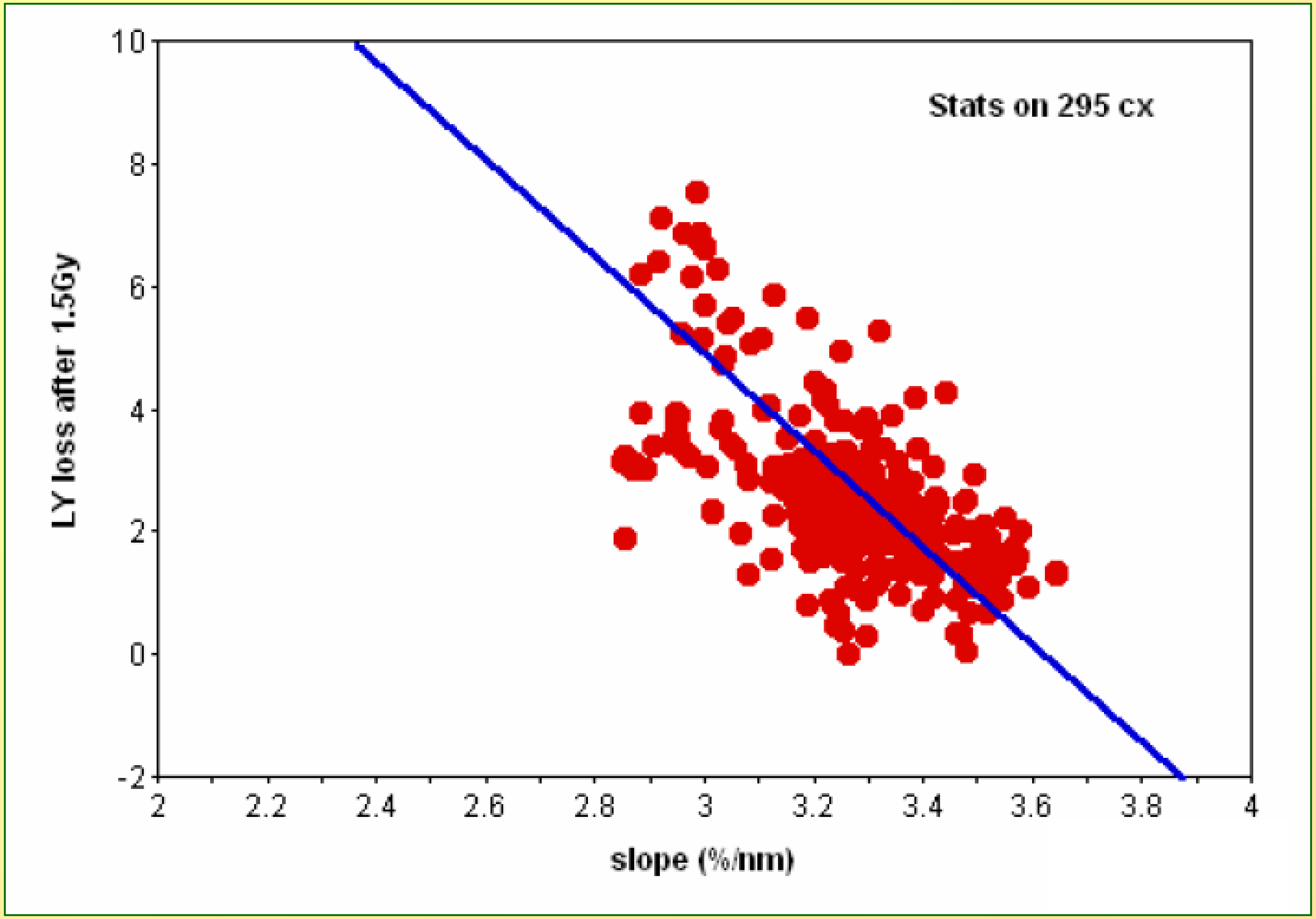
Total dose after 10 years of running ($5x10^5$ pb^{-1})



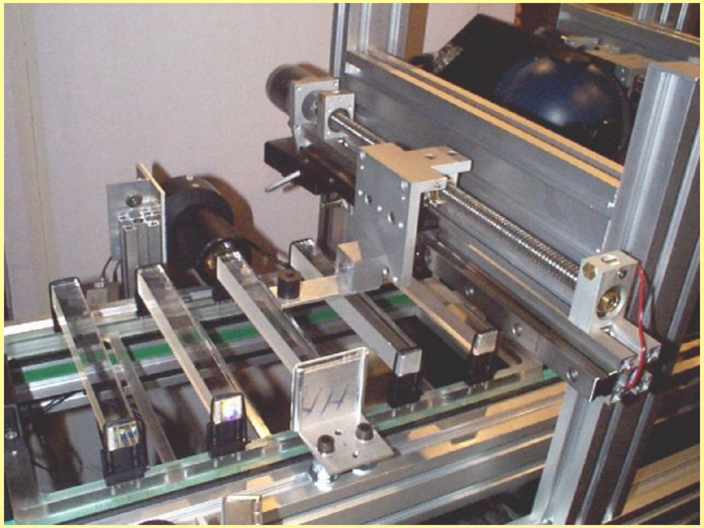
Dose rates [Gy/h] in the ECAL luminosity $L=10^{34}cm^{-2}$ s^{-1}

- → No damage by neutrons
- → An effect observed with γ
- → No damage to scintillation mechanism
- → Only transmission properties affected through formation of color centers due to defects. Changes can be tracked through light injection monitoring system
- → Equilibrium ("saturation") observed
- → Recovery observed
- → Loss in extracted light of few % tolerable

LY loss vs Slope at band-edge

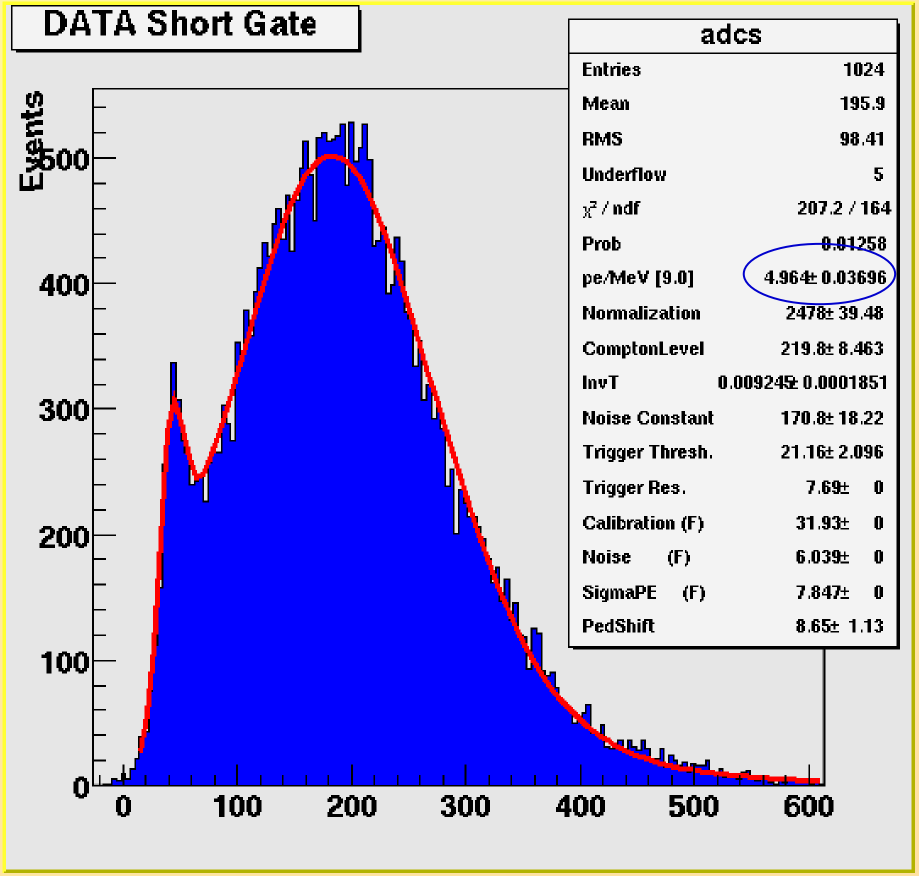


Light Yield measurement



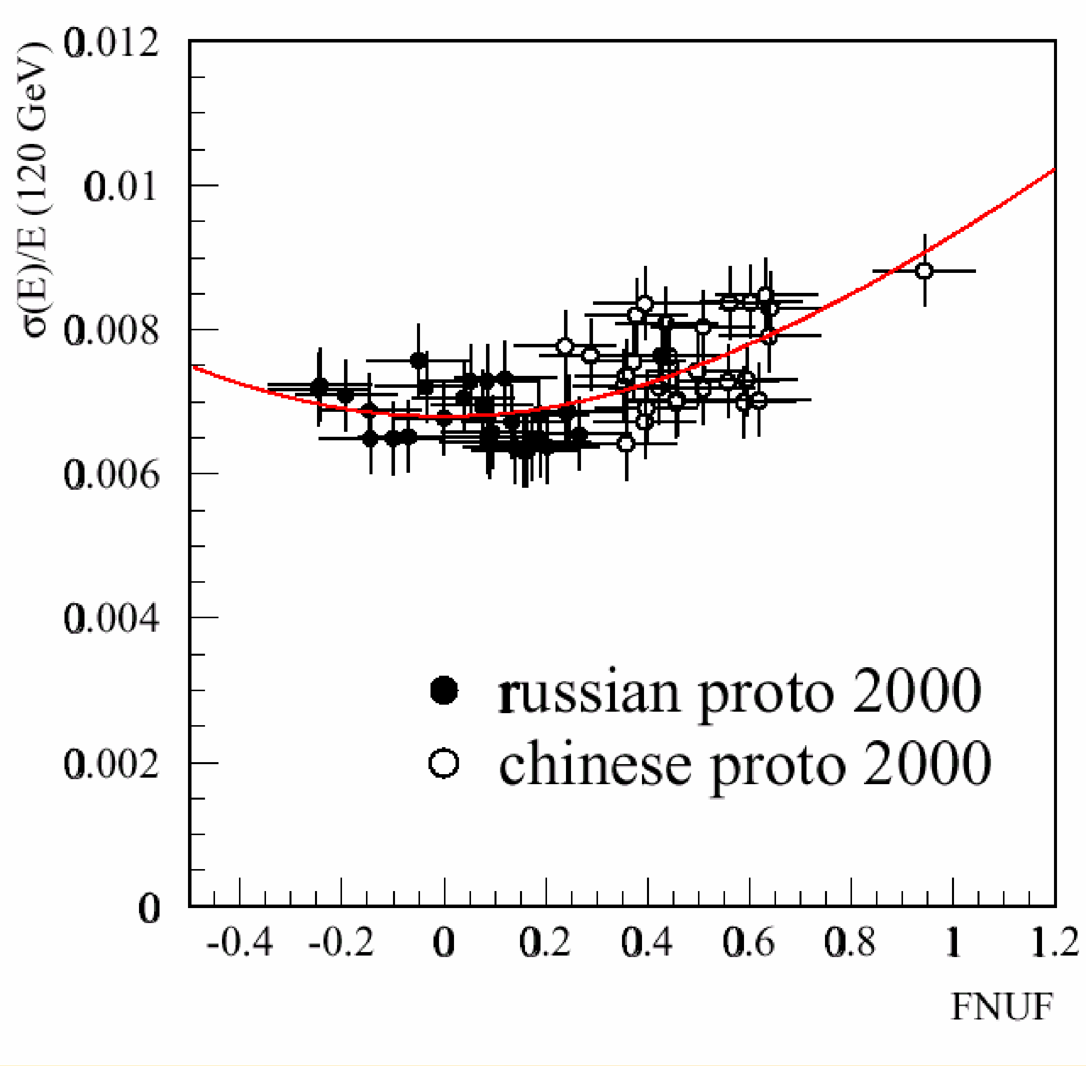
- Tray of 5 crystals
- One measurement per cm along the crystal axis
- Source of Cobalt 60
- Not in optical contact with the PMT (Hamamatsu R1847)

The typical light yield is around 4-5 pe/MeV.



Light Collection Uniformity

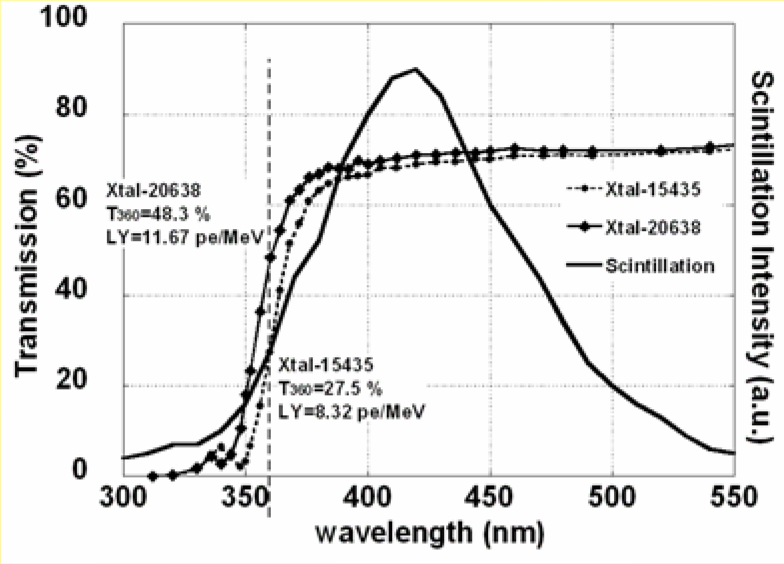
- Resolution @ 120 GeV (constant term) measured on test beam as a function of FNUF determined in LAB measurements
- Chinese crystals were not uniformized



LY – Transm. Correlation

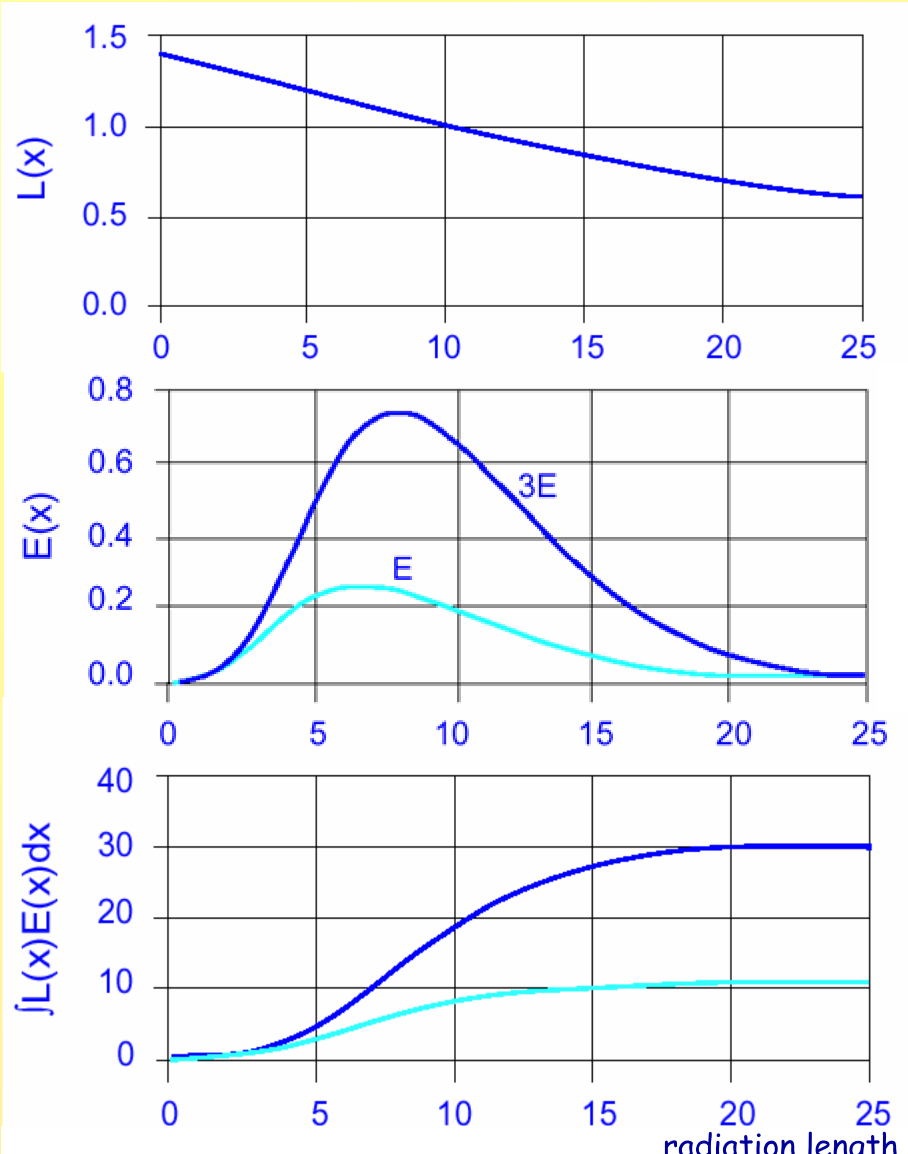
- Correlation found between LY@8X0 and LTO near the fundamental absorption edge is not a light transport effect i.e. cannot be attributed (only) to variations of the optical transmission.
- We observed a LY variation greater than 50% while the maximum LY variation expected is below 10% assuming the same scintillation spectrum S(λ) for all the crystals.

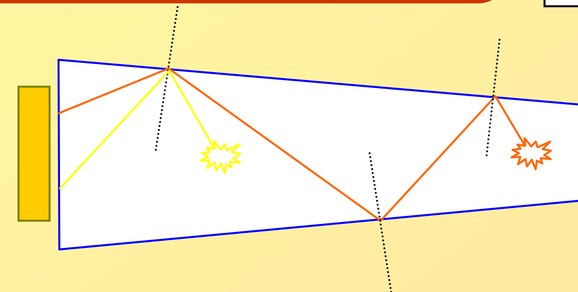
$$LY = \int S(\lambda) \cdot T(\lambda)^n \cdot \varepsilon_{PM}(\lambda) d\lambda$$



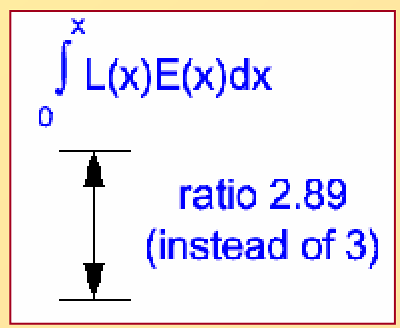
See:
I. Dafinei: "Optical and scintillation properties of Lead Tungstate crystals: a statistical approach" – Scint2005
A. A. Annenkov, M.V. Korzhik, P. Lecoq: "Lead tungstate scintillation material" – NIM A 490 (2002) 30-50

Non uniformity of light collection





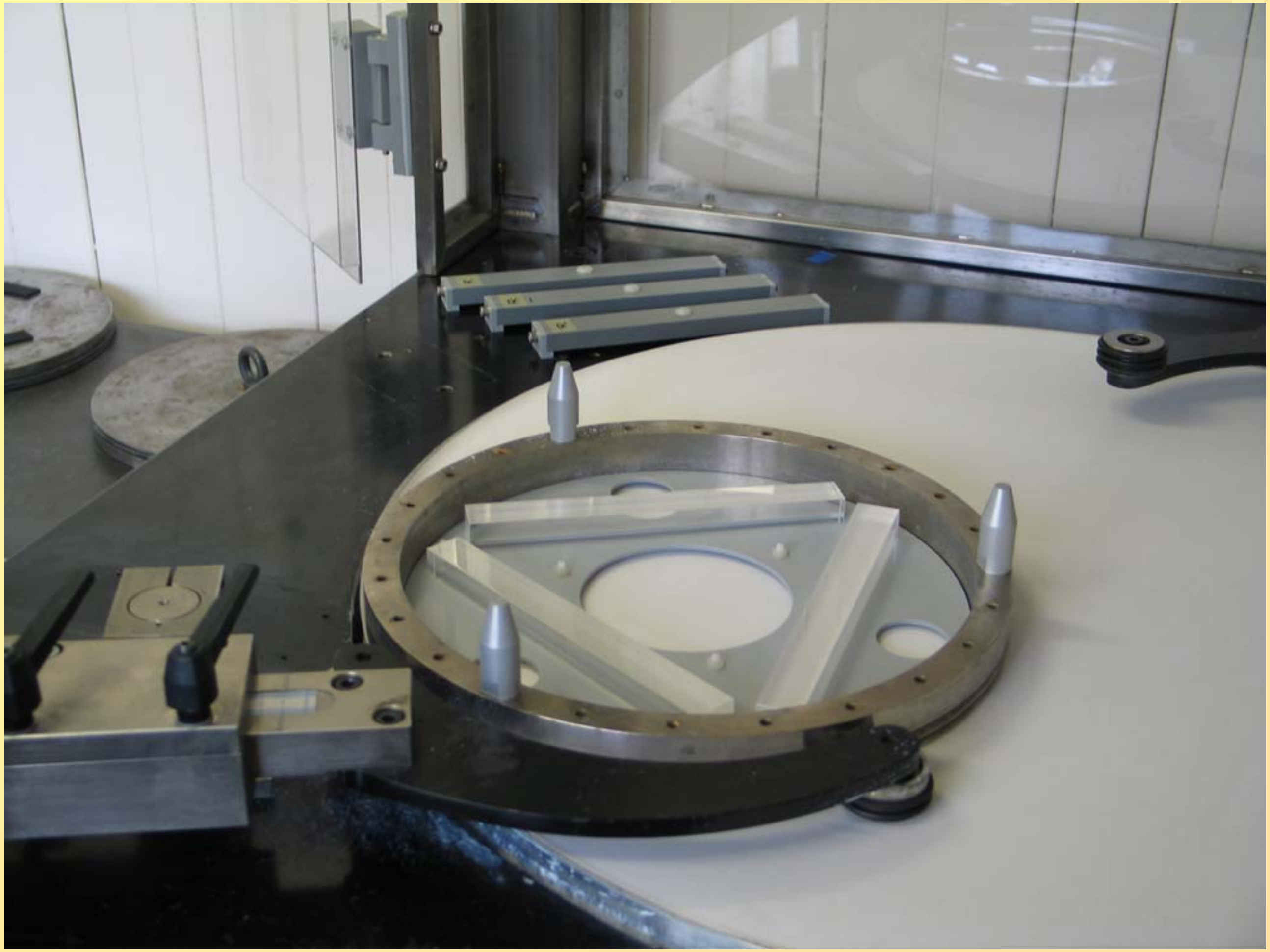
- Non linearity of the response (can be corrected)
- Smearing of the response at fixed energy due to shower fluctuations (can not be corrected)



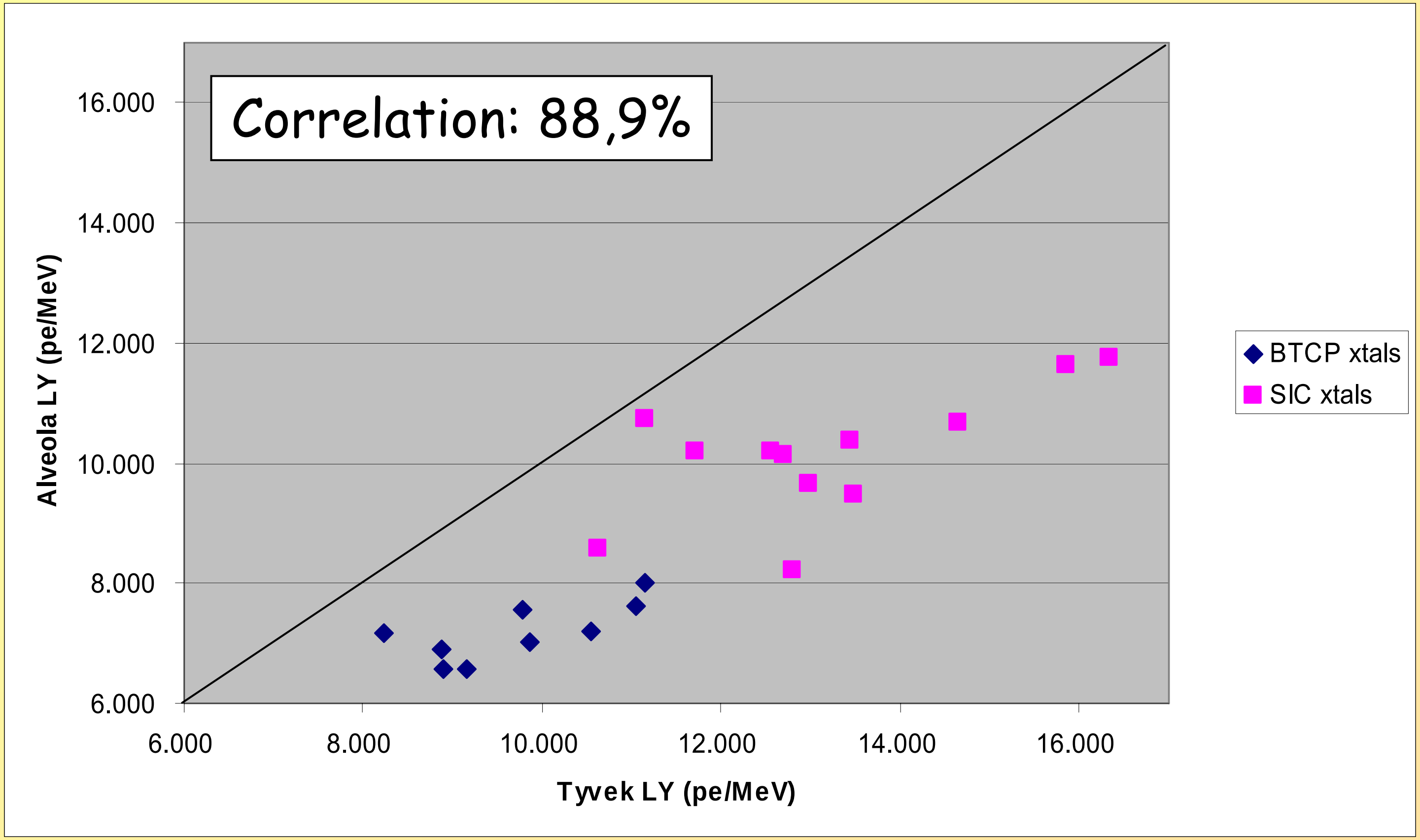
The contribution to the constant term due to crystal non uniformity should not exceed 0.3% (the global constant term is 0.5%)

Uniformity treatment

Tuned at Cern

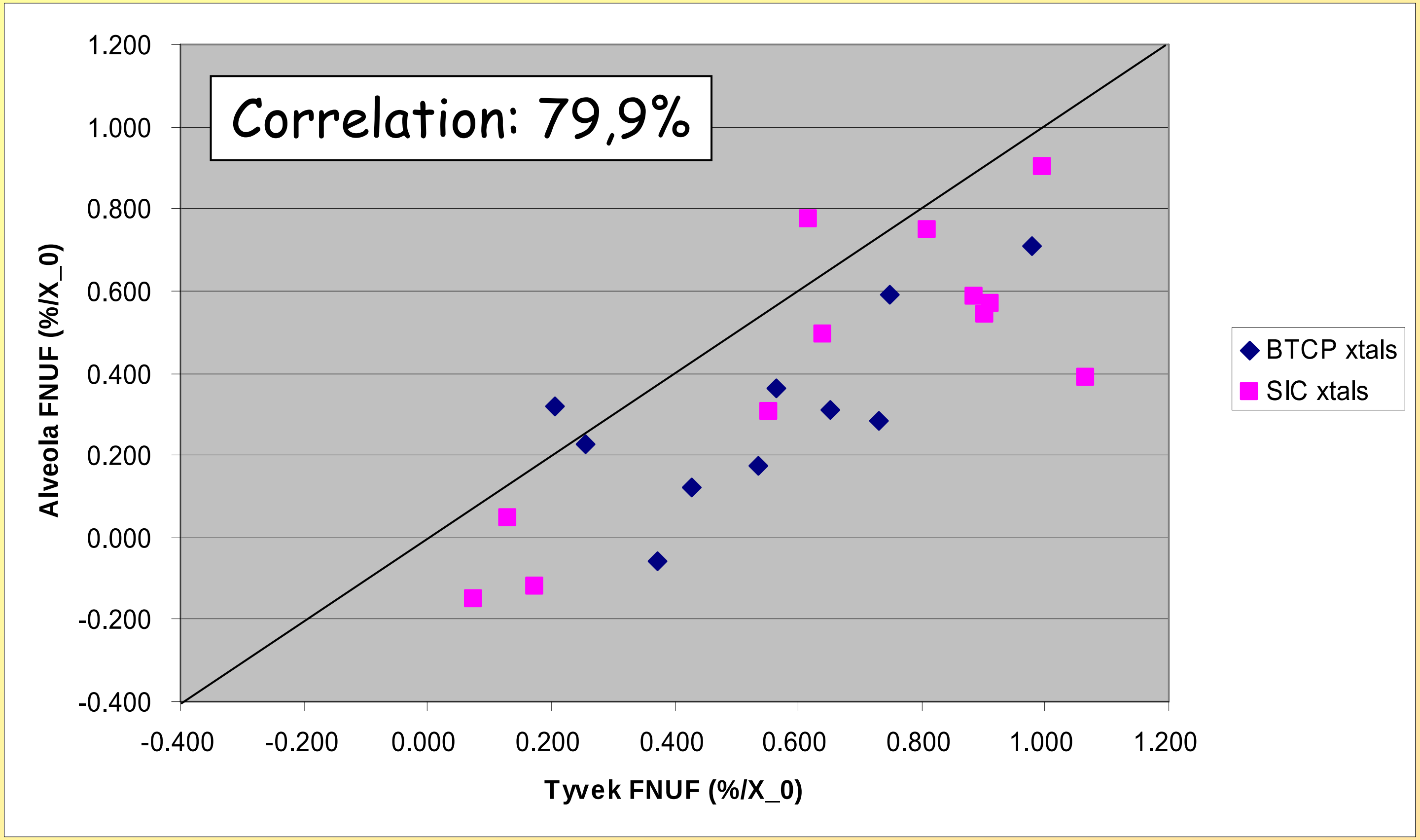


LY: Tyvek vs Alveola



BTCP xtals	Alveola LY / Tyvek LY: (73.4 ± 1.9) %
SIC xtals	Alveola LY / Tyvek LY: (77.5 ± 2.4) %
full sample	Alveola LY / Tyvek LY: (75.6 ± 1.6) %

FNUF: Tyvek vs Alveola



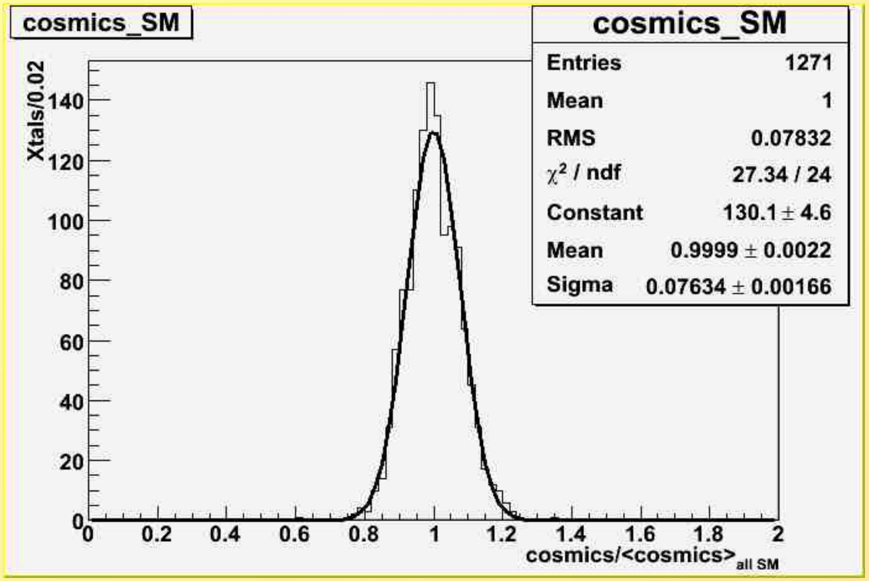
BTCP xtals Tyvek FNUF – Alveola FNUF: (0.243 ± 0.057) %/X_0

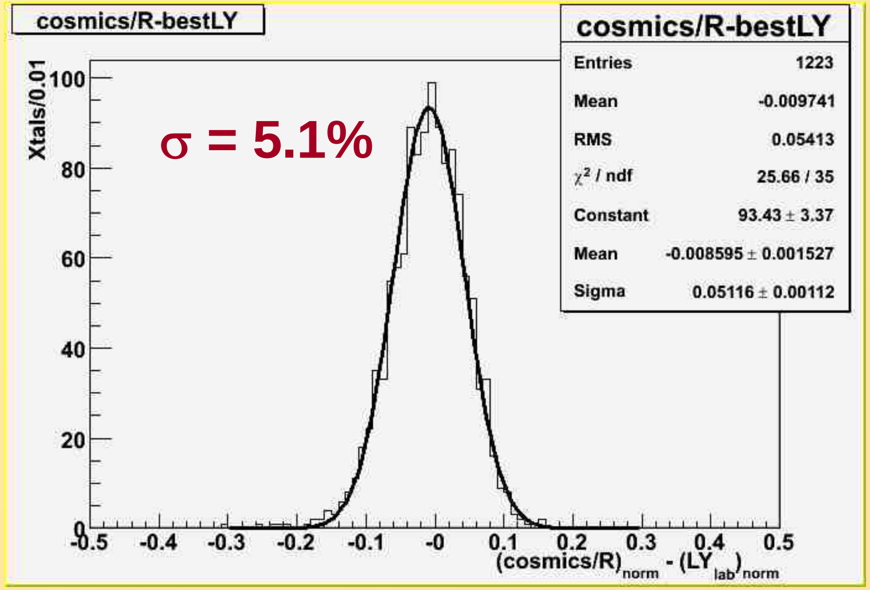
SIC xtals Tyvek FNUF – Alveola FNUF: (0.222 ± 0.059) %/X_0

full sample Tyvek FNUF – Alveola FNUF: (0.231 ± 0.040) %/X_0

Cosmics vs LAB. calibration

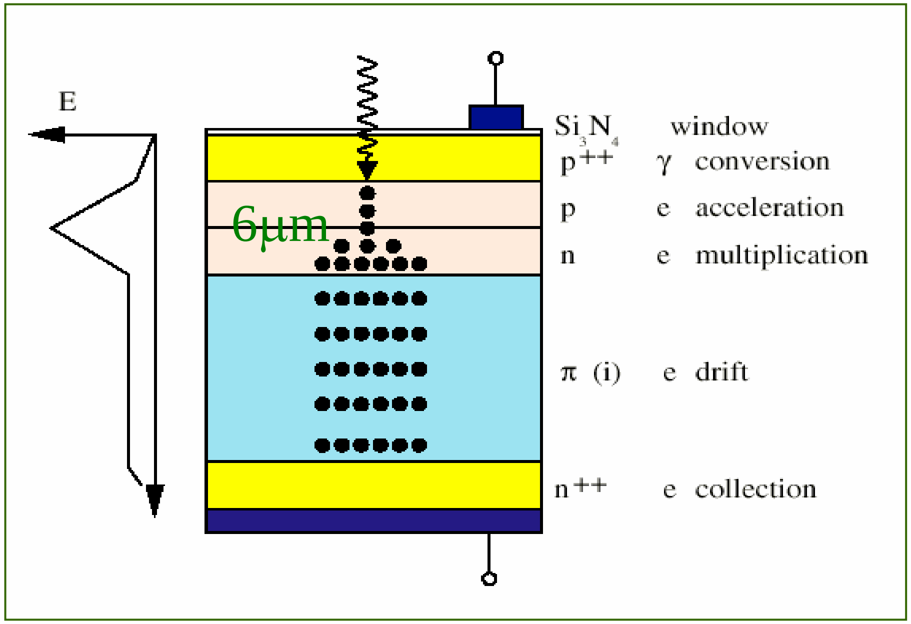
- SuperModules are under calibration with cosmics rays.
- Agreement between laboratory measurements and cosmics calibration is at level of 5% (precision of cosmics is not negligible)
- Similar results on other SuperModules
- Cosmics calibration results will be shown tomorrow by G. Franzoni

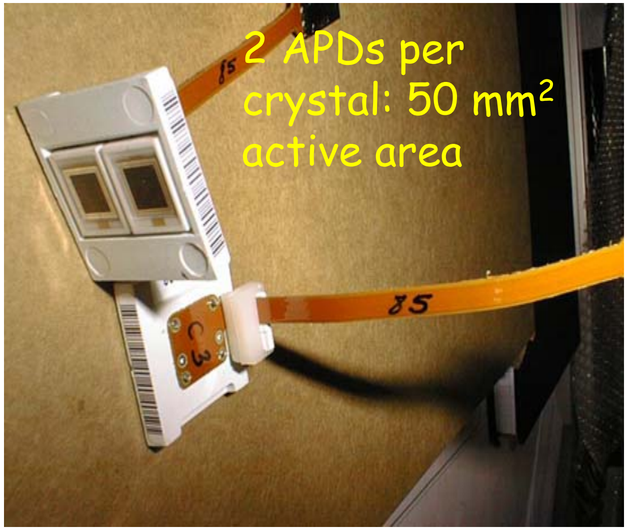




Avalanche Photo Diodes

Due to low light yield, need photodetector with intrinsic gain.
Radiation hard and insensitive to magnetic field (4T)

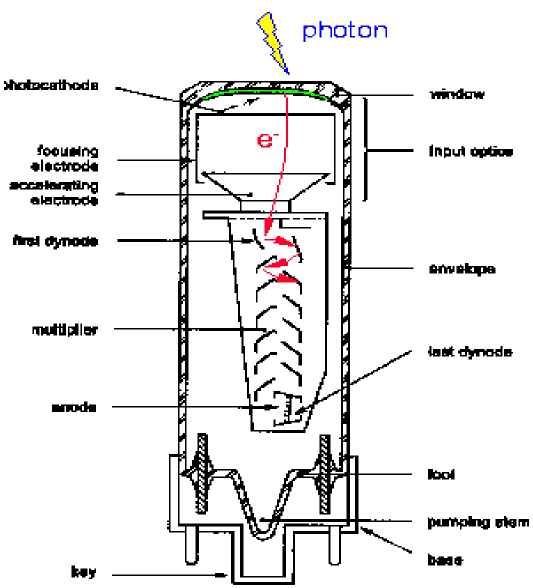




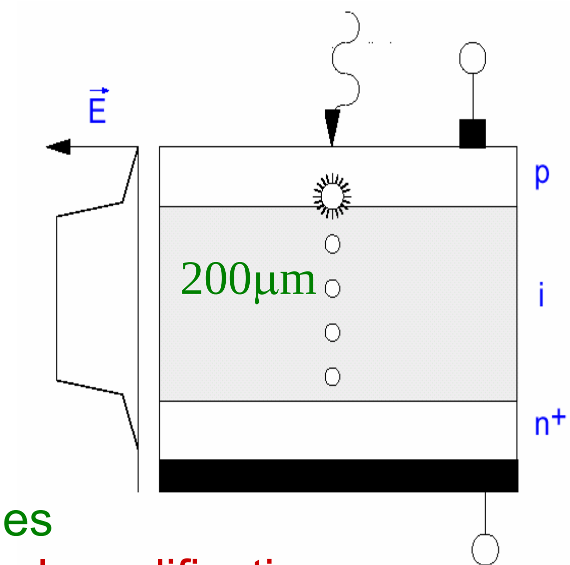
- Internal gain: M=50 @ HV ≈ 380 V
- Good match to PWO scintillation spectrum (Q.E. ≈ 75% @ 430 nm)
- Strong sensitivity of gain to Voltage and Temperature variations: good stability needed

Photon detectors for PWO

- Not sensitive to 4T magnetic field
- High quantum efficiency for λ 400 – 500 nm
- Internal amplification (low PWO LY)
- Fast and good for high rate (40MHz)
- Radiation hard
- Not (too much) sensitive to charged particles



Photomultipliers
- affected by magnetic field
- large volume



PIN photodiodes
- no internal amplification
- too sensitive to charged particles (Nuclear Counter Effect)