The CMS ECAL Laser Monitoring System

CALOR 2006

XII INTERNATIONAL CONFERENCE on CALORIMETRY in HIGH ENERGY PHYSICS

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Introduction

CMS is building a high resolution Crystal Calorimeter (ECAL) to be operated at LHC in a very harsh radiation environment.

Resolution design goal : $2.5\%/\sqrt{E} \oplus 0.55\% \oplus 0.2/E$

Calibrating and maintaining the calibration of this device will be very challenging.

Hadronic environment makes physics calibration more challenging.

⇒ Talk by G. Daskalakis at this conference.

PWO_4 Crystals change transparency under radiation.

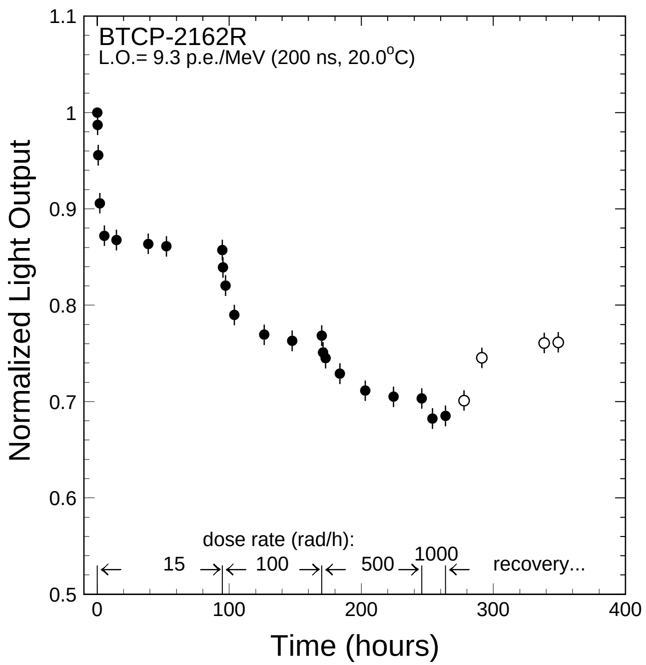
The damage is significant (few % - up to ~5 % for CMS ECAL barrel radiation levels) compared to the desired constant term (0.5 %).

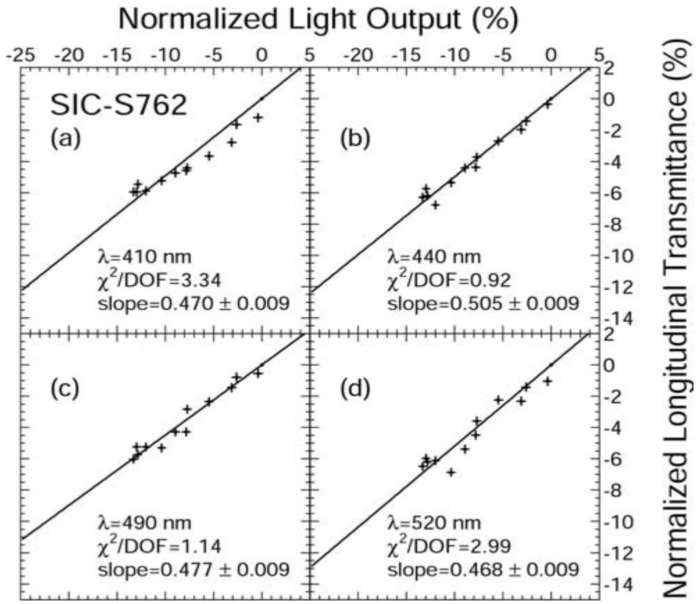
The dynamics of the transparency change is fast (few hours) compared to the time scale needed for a calibration with physics events (weeks - month).

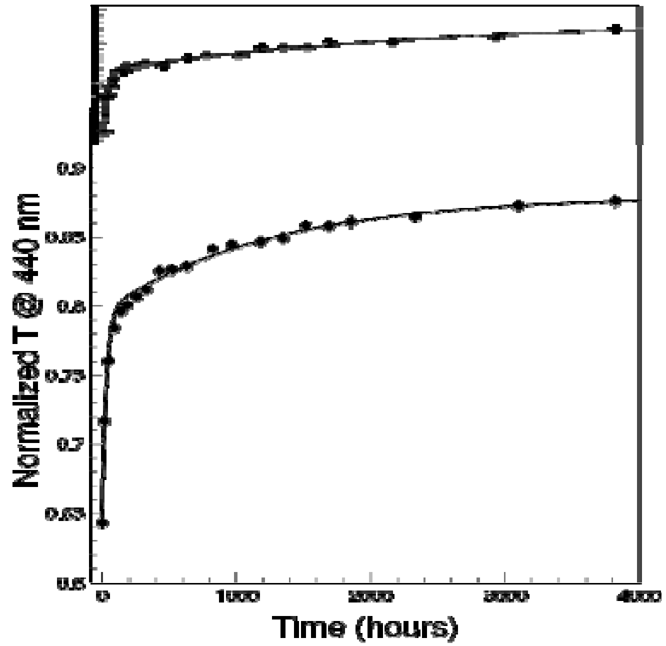
⇒ Talk on crystals by R. Paramatti at this conference.

⇒ Compensate by monitoring the change with a laser monitoring system.

PWO_4 Transparency Change Characteristics

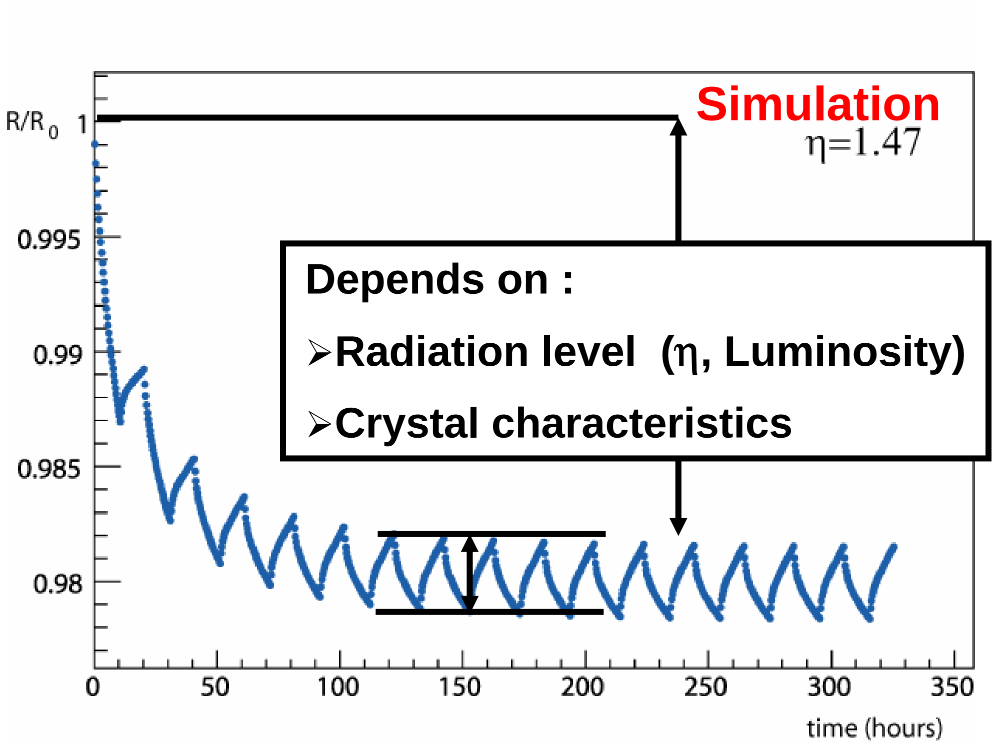


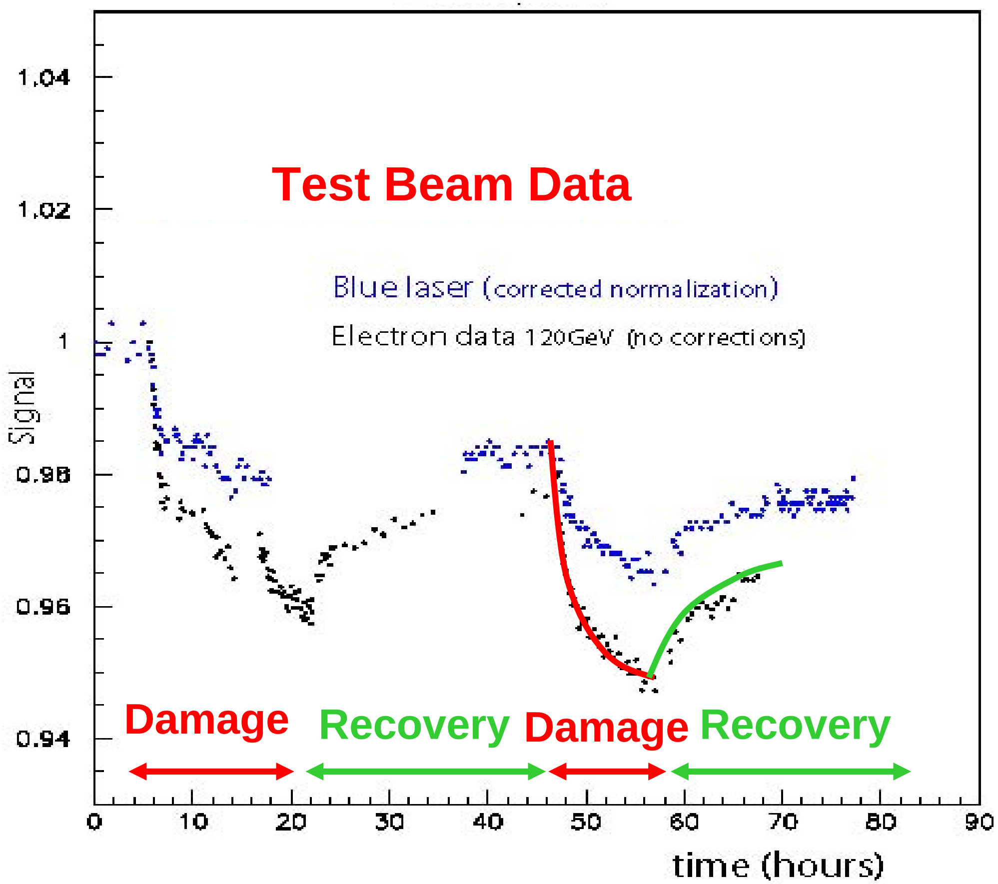




- Crystal light yield changes under irradiation. Change is dose rate dependent.
- Crystal light yield change under irradiation is linearly correlated with longitudinal transmittance (transparency).
- Magnitude of the transparency change is crystal dependent.
- Transparency change recovers at room temperature. Recovery time is crystal dependent with two time constants, one of few 10 hours and one >1000 hours.

Damage and Recovery in a 'LHC Cycle'





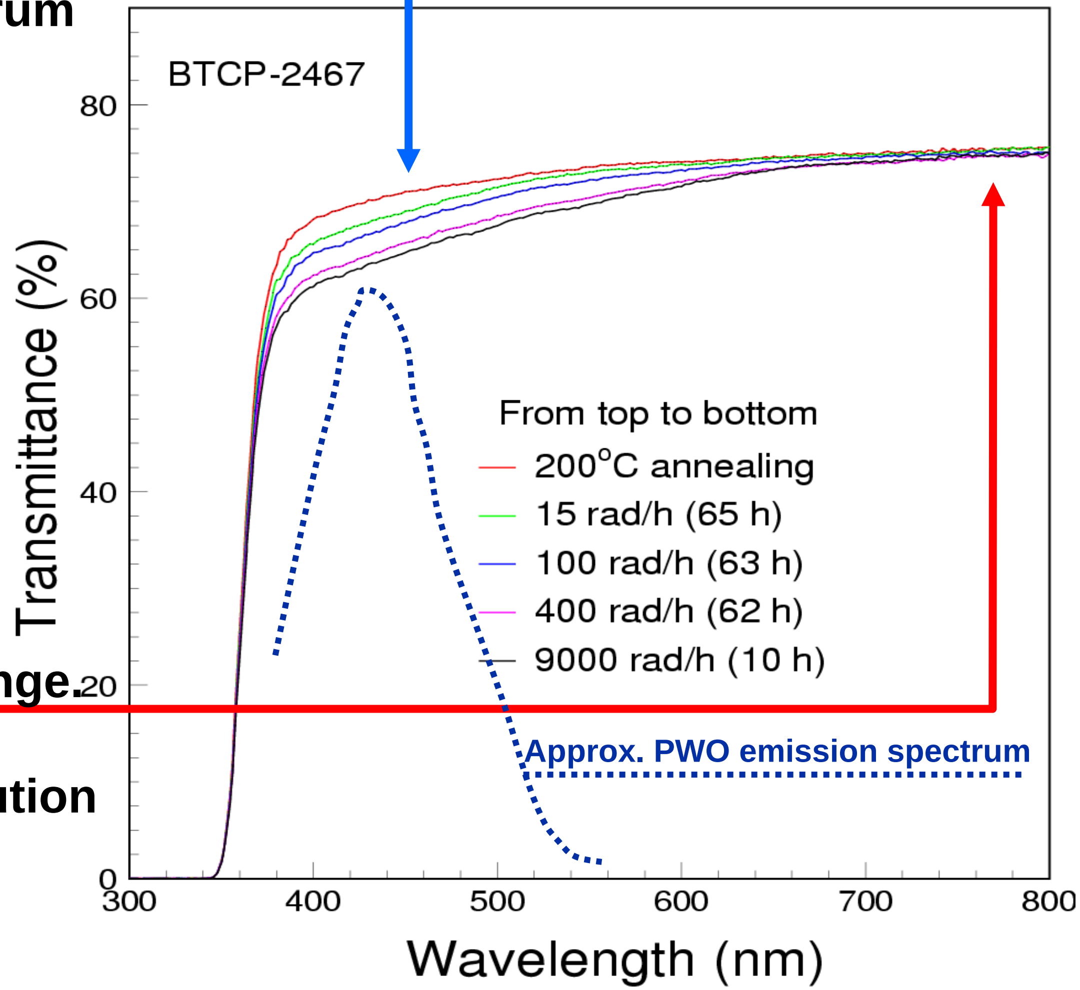
⇒ Damage-recovery cycle in sync with the ~12 hour LHC fill cycle

Radiation Effects on PWO_4 Transparency

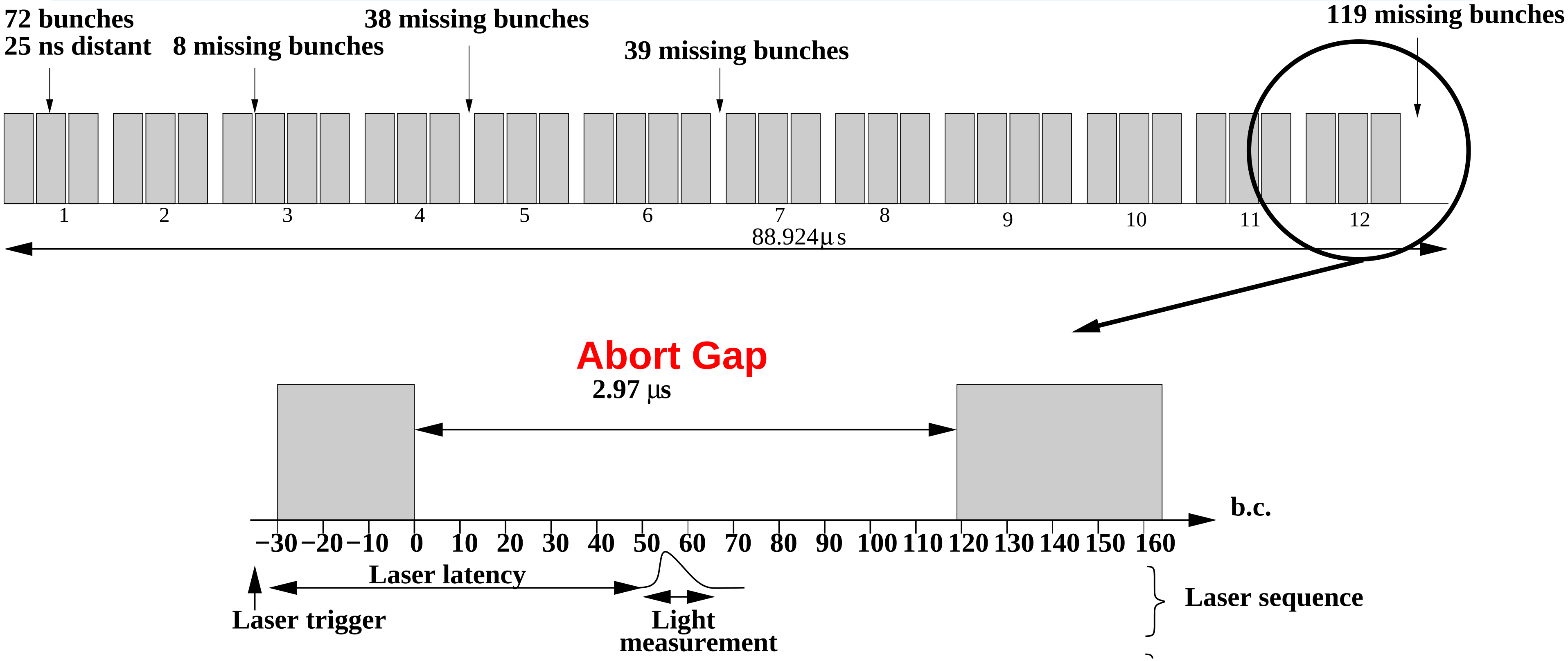
- **Radiation Reduces transmittance in the blue and green, peak of PWO_4 emission spectrum**
- **Effect is dose rate dependent.**
- **Monitoring relative loss of PWO_4 transmittance with pulsed laser light.**

For the expected dose rate at CMS barrel (15 rad/hour), transmittance loss is at a level of up to ~5%.

- **Almost no effect in the red wavelength range.**
- **Monitor with red light to separate out possible variations in the light distribution system and the readout chain.**



In-Situ Monitoring & LHC Bunch Train



- Abort gaps occur at ~10 kHz - Laser pulses at ~100 Hz ⇒ Use ~1% of gaps.
- Measure transparency of all crystals from one half-module at a time - limited by data flow rate. Use 600 laser shots for one measurement.
- Laser pulse latency ~4 μs

⇒ Scan entire ECAL every 20 minutes

Laser Source Requirements

- **Pulse Energy : 1.0/0.6 mJ at 440nm/495nm**
  Enough to flash several hundred crystals via a multi level light distribution system.

- **Pulse Energy Stability: ECAL specification < 10 % RMS**
  Small enough to avoid possible non-linearities in the APD/PN ratio.

- **Pulse Width : ECAL specification < 40 ns**
  Match the 25 ns read out cycle of the ECAL electronics.

- **Pulse Width Stability : < 2 ns**
  Prevent bias in the amplitude reconstruction. ⇒ See A. Zabi talk

- **Pulse Jitter : Pulse timing, long/short term, typically <4 ns / < 2 ns**
  Ensure precise triggering in time with LHC 25 ns cycle.

- **Wave Length :**
  440 nm primary wavelength at the PWO emission peak,
  495 nm / 800 nm / 700 nm for systematic cross checks.

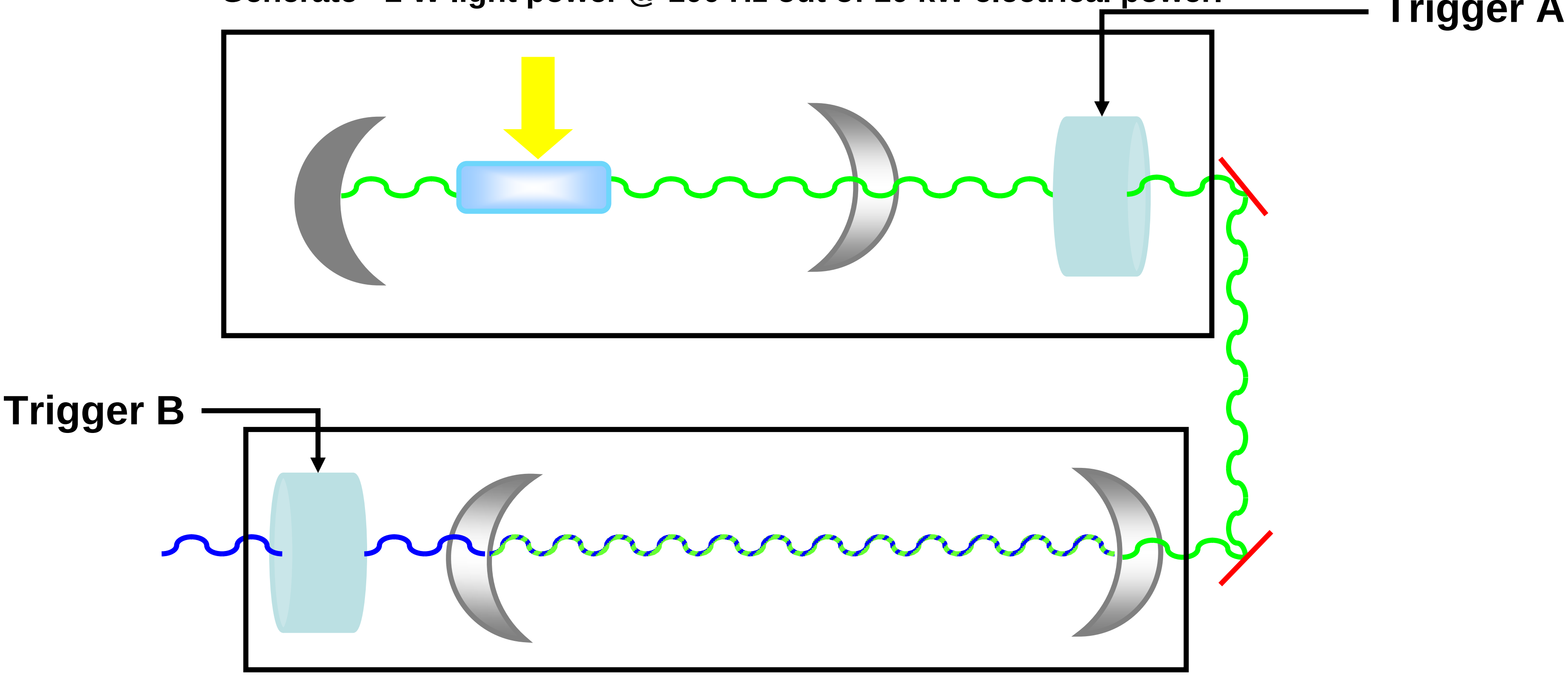
⇒ Mimic scintillation light as closely as possible.

⇒ Allow monitoring in sync with normal data taking.

Laser System Layout

YLF Pump Laser :

Generate ~2 W light power @ 100 Hz out of 10 kW electrical power.



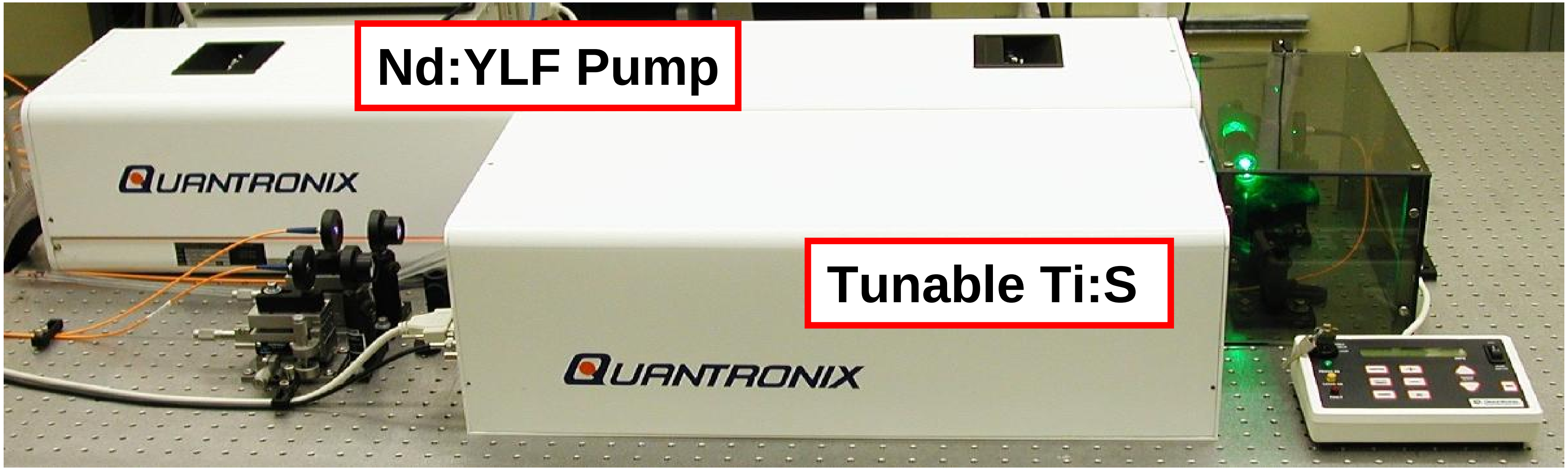
TiS :

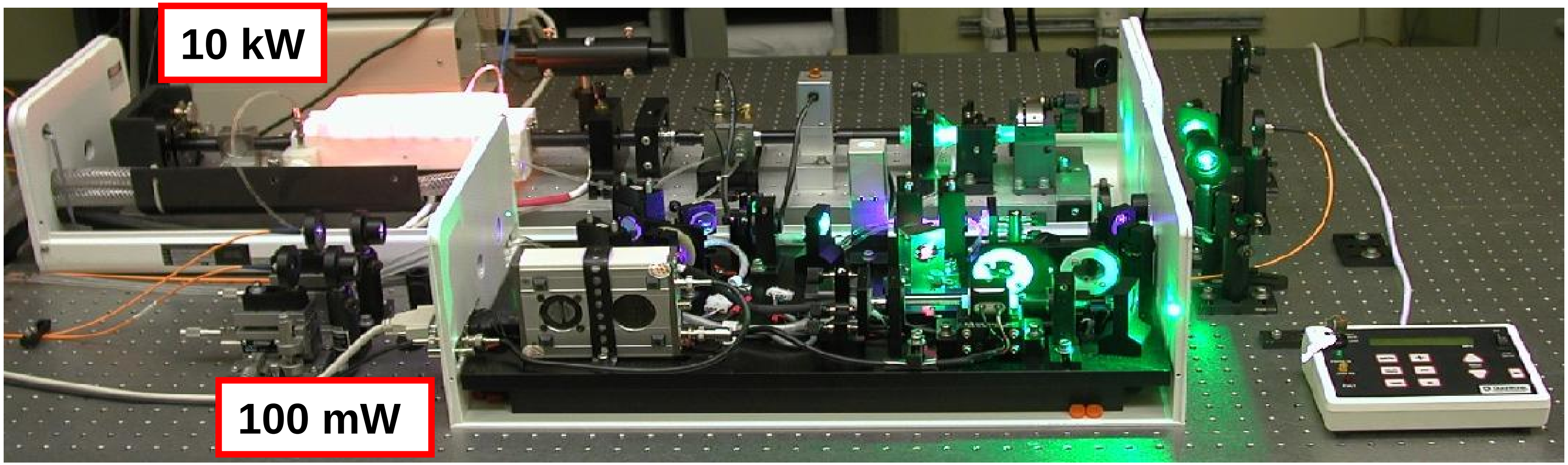
Wavelength shifting, Pulse compression
Release 100 mW @ 100 Hz light power to ECAL

There is a 3 μs delay between trigger A & B to allow pulse buildup.

The pulse timing of the TiS output has an additional delay of a few 100 ns with a few ns jitter.

Ti:Sapphire Laser with Two Wavelengths

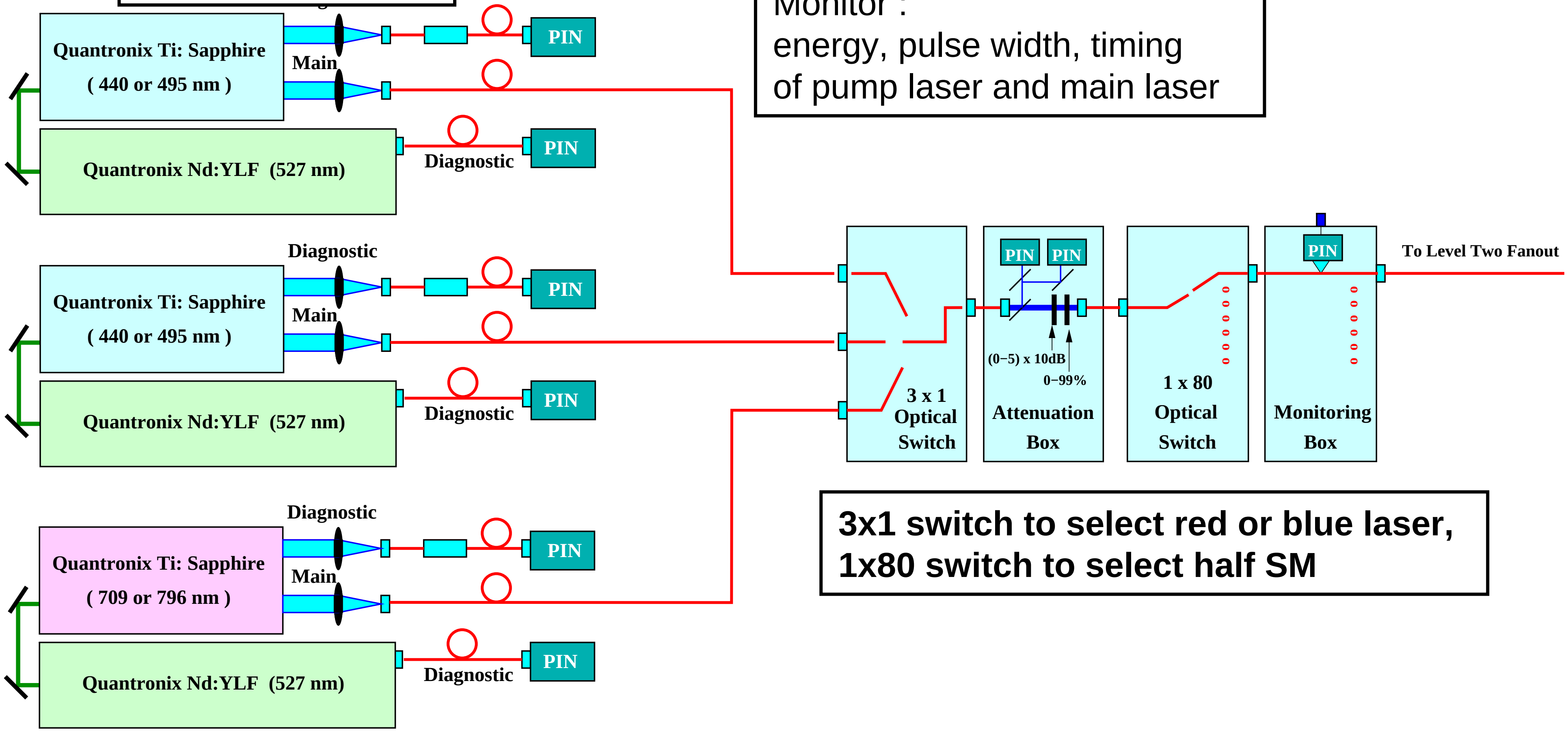




Laser Source Layout for CMS ECAL

BLUE Laser (x2) :
Provides 440 nm
and 495 nm

Monitor :
energy, pulse width, timing
of pump laser and main laser

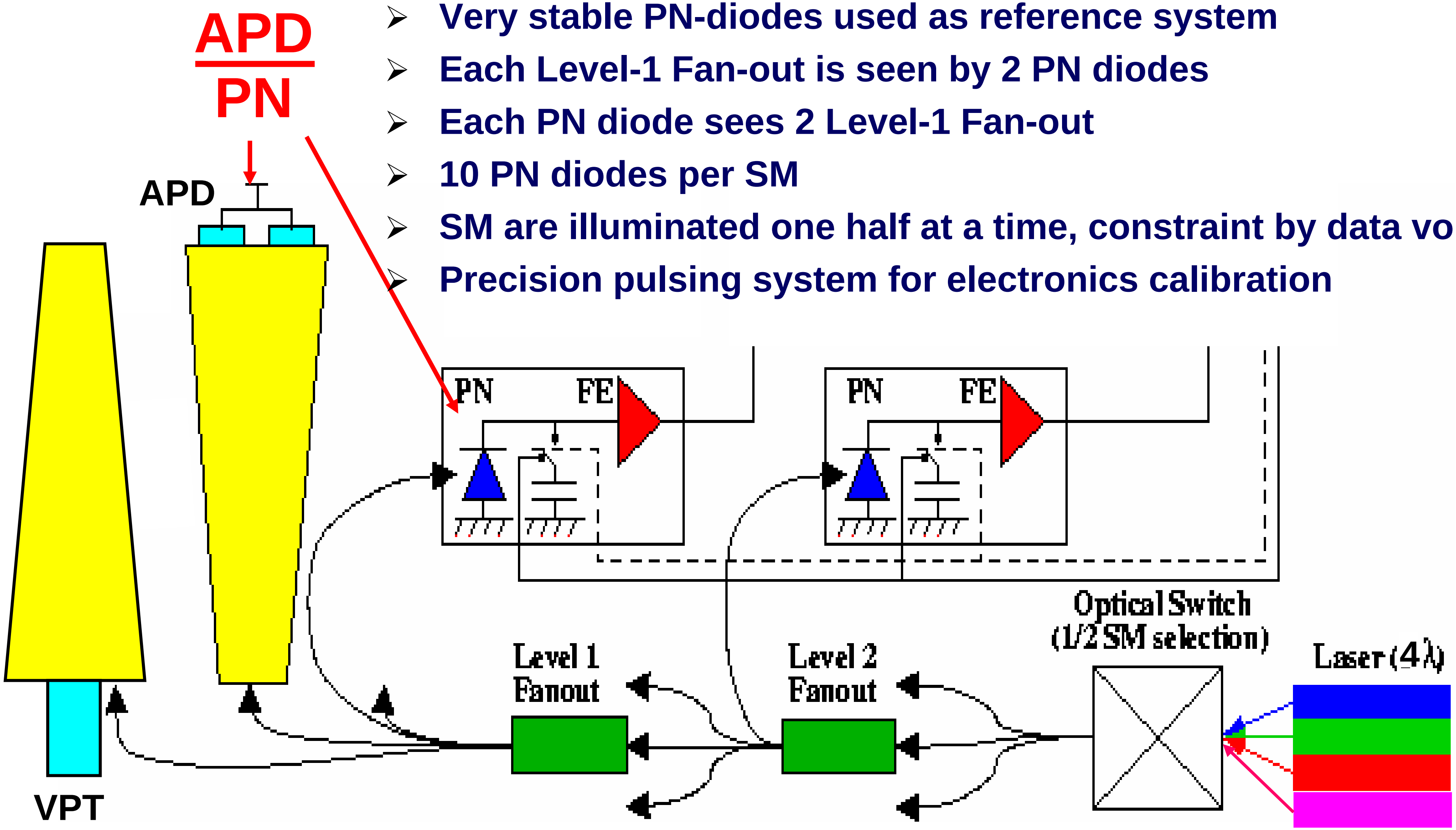


3x1 switch to select red or blue laser,
1x80 switch to select half SM

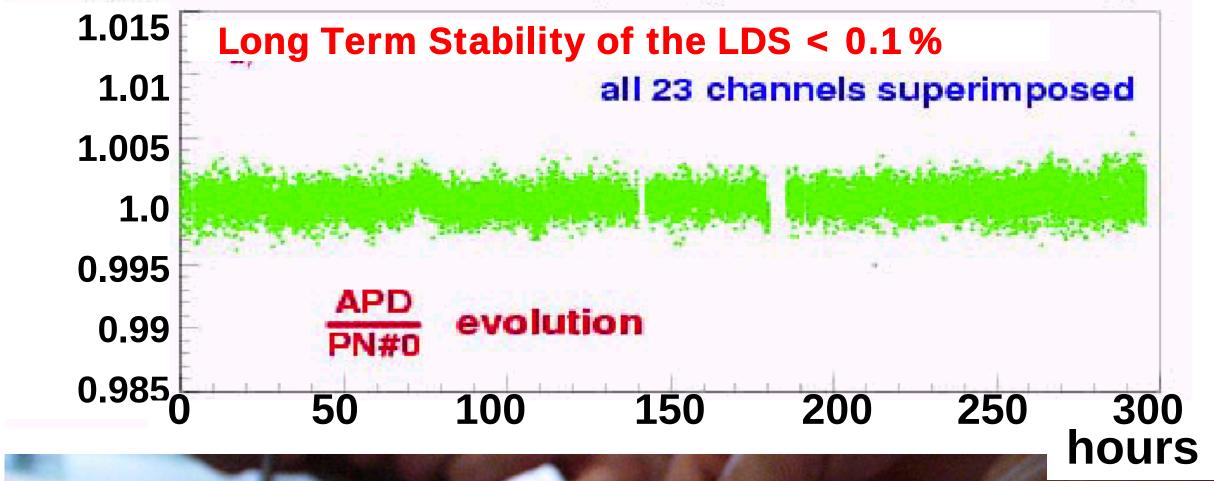
RED Laser:
Provides 800 nm
and 700 nm

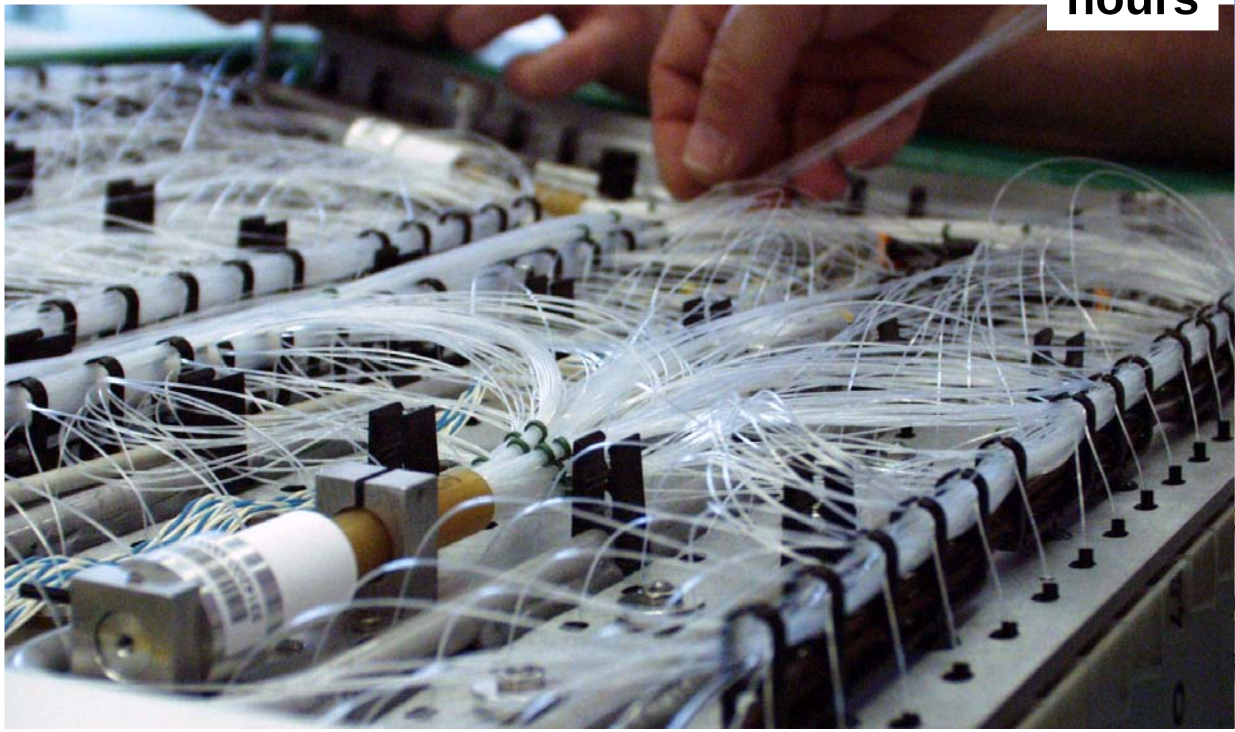
On-Detector Monitoring System

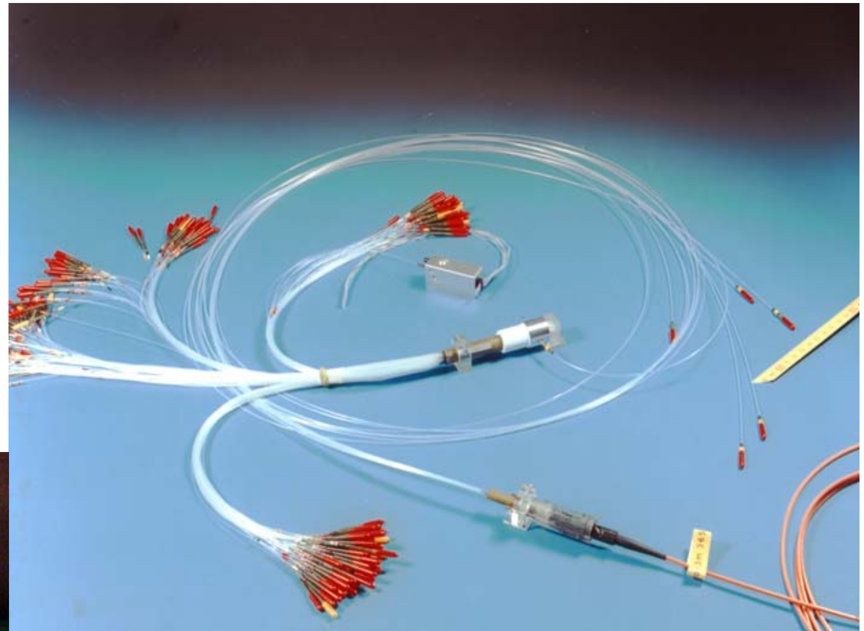
- Very stable PN-diodes used as reference system
- Each Level-1 Fan-out is seen by 2 PN diodes
- Each PN diode sees 2 Level-1 Fan-out
- 10 PN diodes per SM
- SM are illuminated one half at a time, constraint by data volume
- Precision pulsing system for electronics calibration

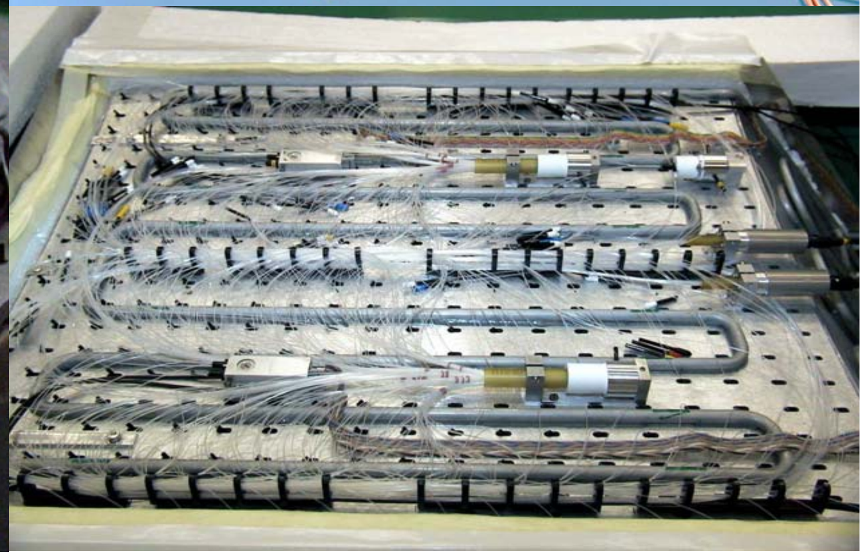


Light Distribution System



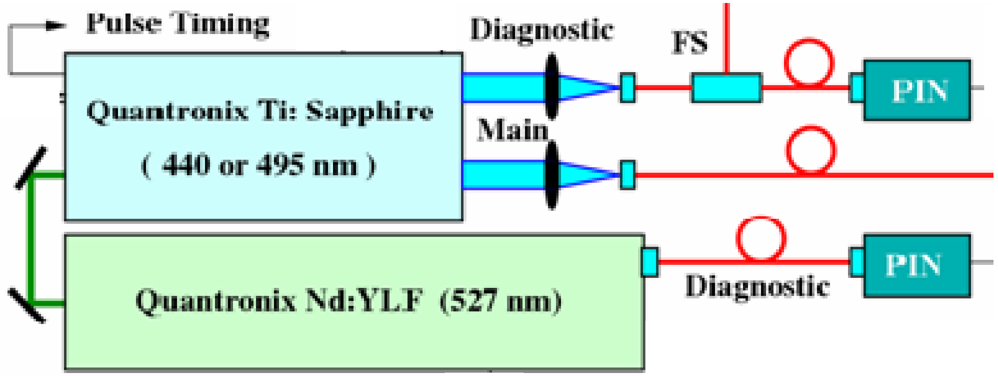


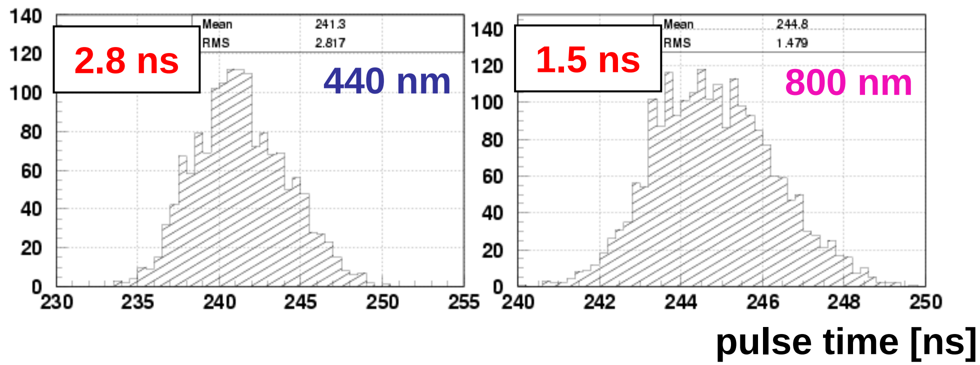


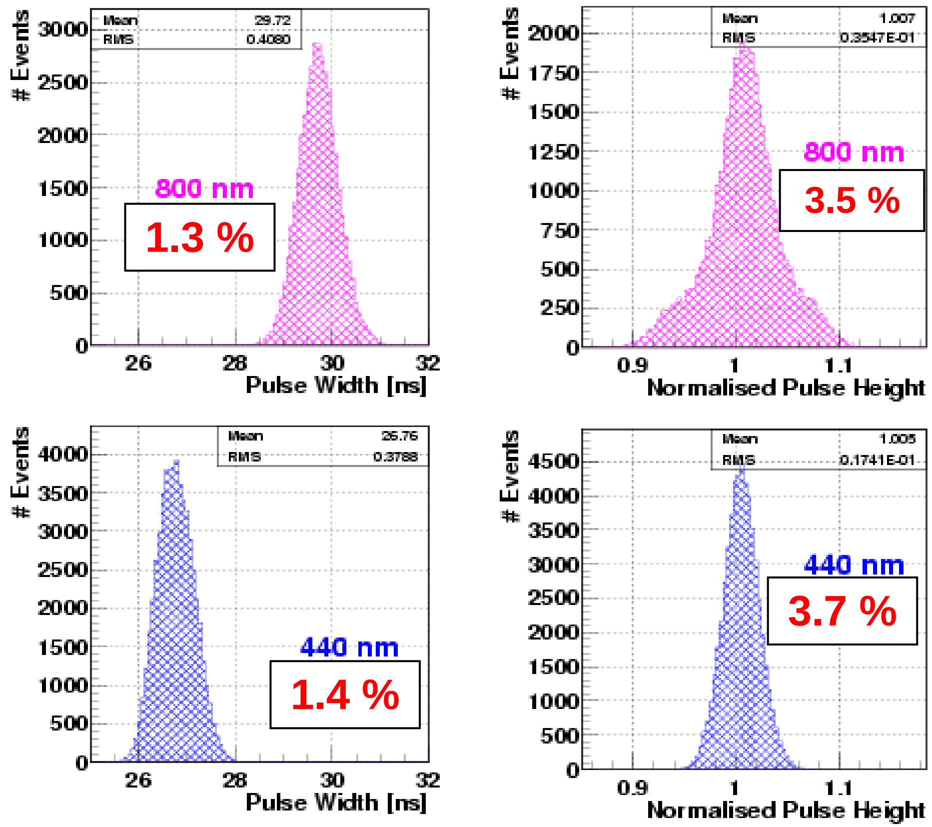


Laser Source Monitoring

Each laser has a monitor output which allows to adjust and monitor its performance of pulse energy, pulse width and pulse timing.



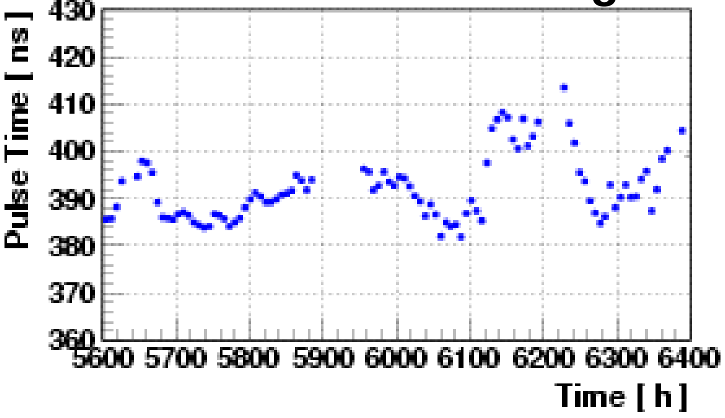


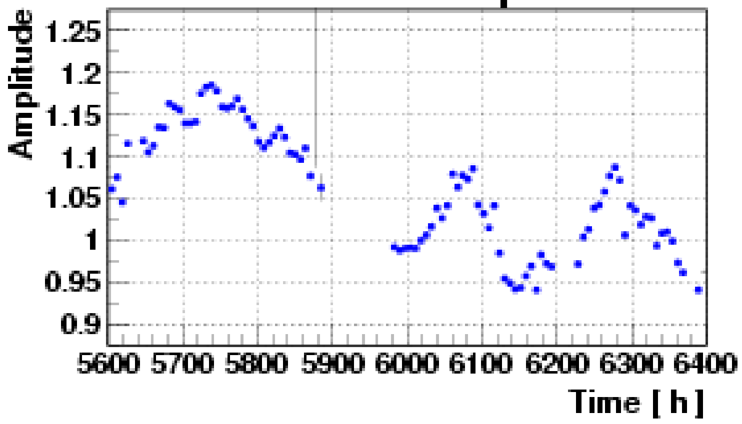


⇒ Short term stability typically a few percent / few ns (RMS) over several hours.

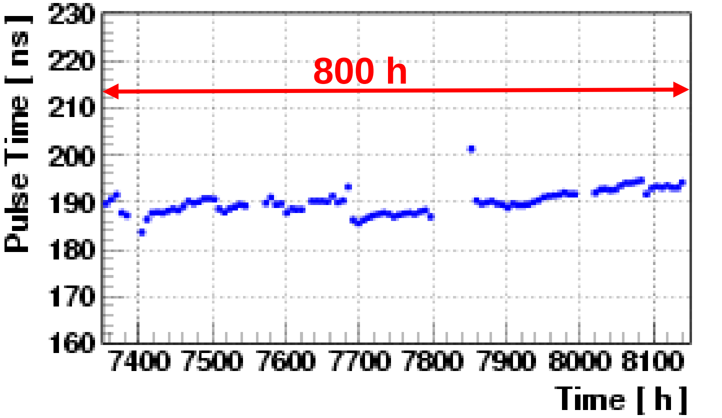
Laser Source Feedback – 2006 Testbeam

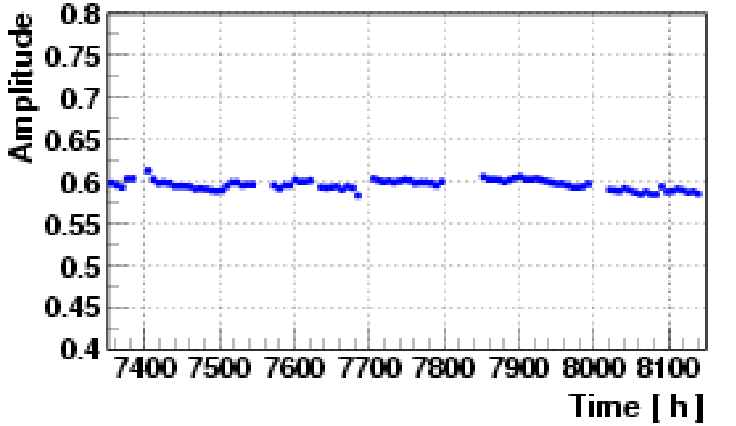
Laser Pulse Timing | **Laser Pulse Amplitude**





No Feedback



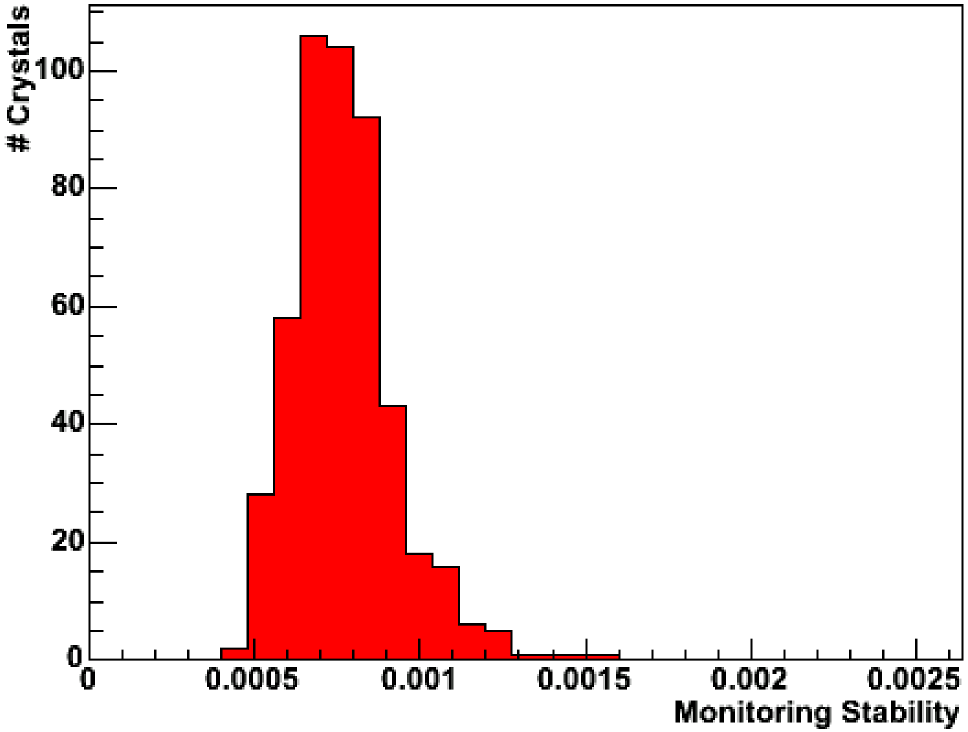


With Pulse Timing Feedback

Laser source internal feedback ensures precise timing over several 100 hours.

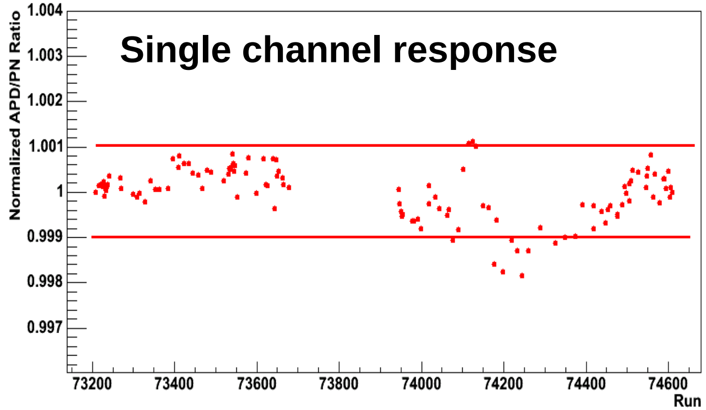
Also improves pulse width and pulse amplitude stability.

Monitoring System Performance - Stability



From 2004 test beam :

RMS APD/PN ratio per channel, no irradiation, 450 hours, 500 channels.

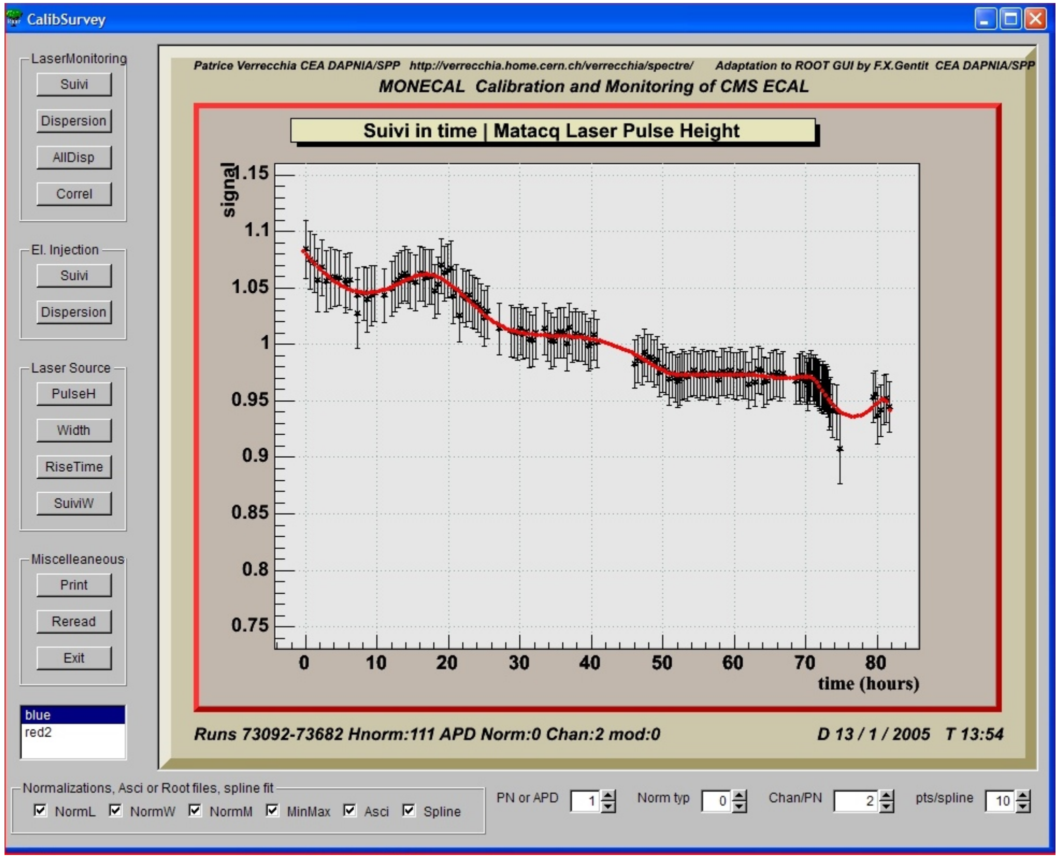


Typically ~0.1 % long term stability in real environment. This includes the stability of the entire readout chain - temperature, HV, etc.

⇒ We can measure the crystal transparency with better than 0.1 %.

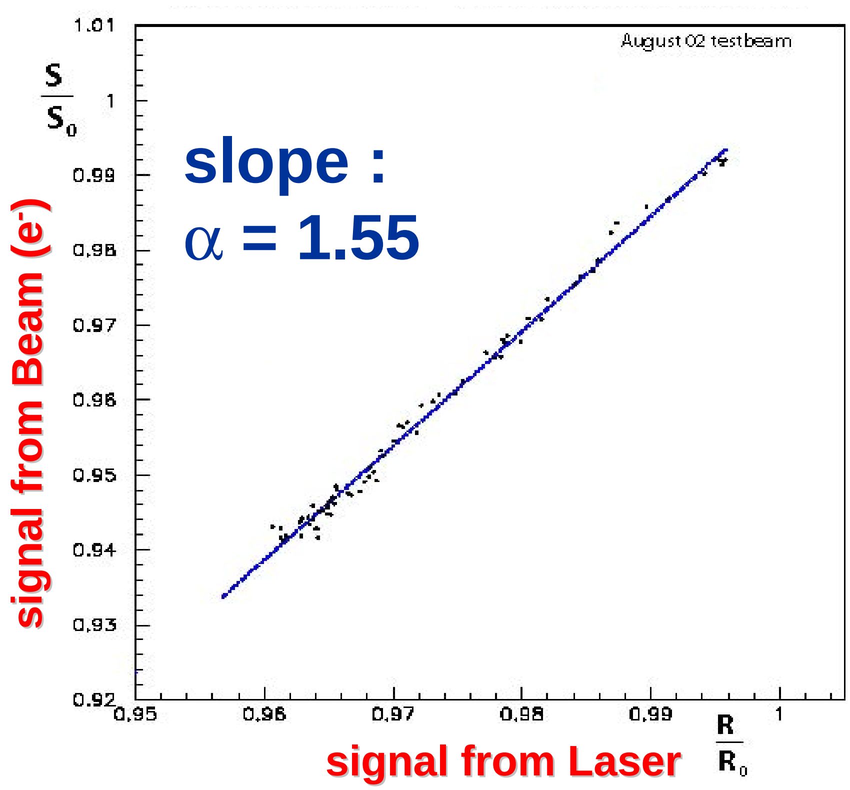
Online Laser Data Analysis Farm

Fast online laser farm output, Crystal irradiation during test beam 2004

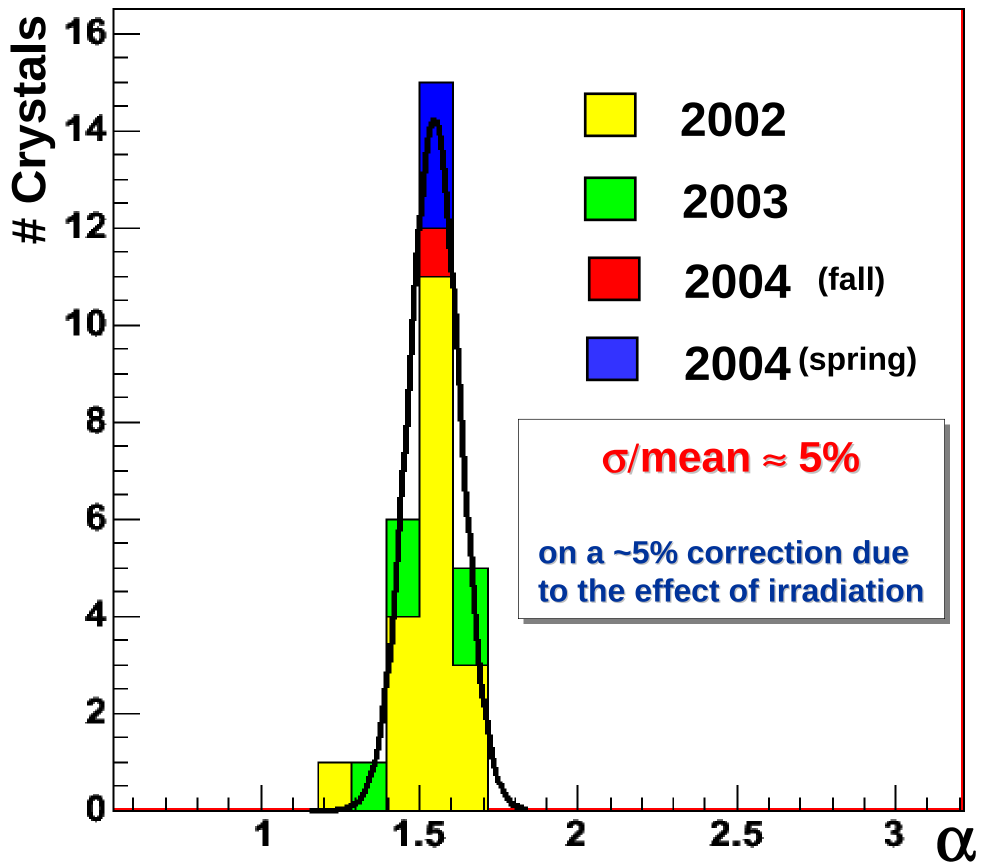


- Fast Online Analysis in dedicated 'Laser Farm' (12 PCs) parallel to online filter farm.
- Extract transparency for each crystal from one laser run.
- Perform plausibility checks by comparing neighboring crystals, groups of crystals for single runs and groups of runs. Interpolating between laser runs and smoothing of the measured transparency change.
- Transfer results to database (online and offline).

⇒ All ECAL laser data will be analysed in quasi real-time to allow fast feedback.



Dispersion of α for 28 BTCP crystals

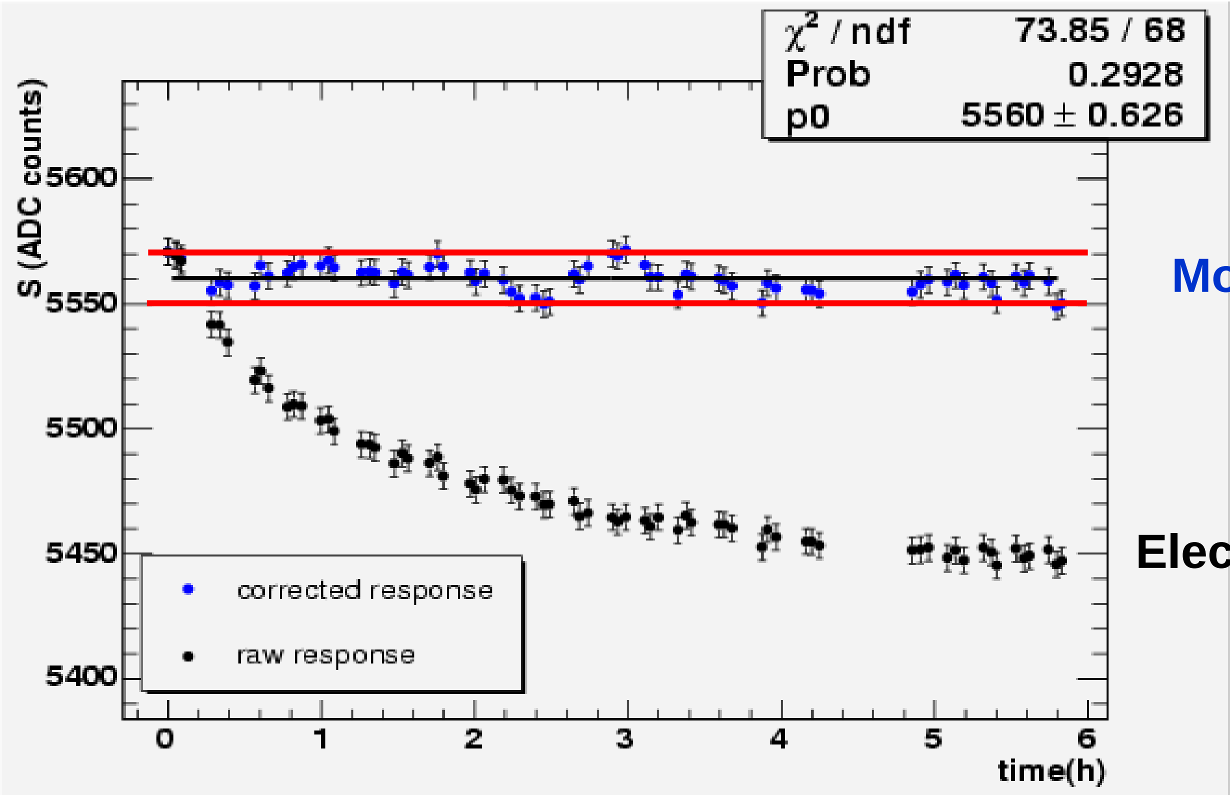


⇒ Coefficient for crystals have relatively small dispersion.

⇒ At startup use same parameters for all crystals from one producer.

An in-situ determination of α is under consideration.

Correcting Transparency Change



Monitoring corrected response

Electron response under irradiation

⇒ Transparency change can be corrected to better than 0.15 % **(RMS over 4 crystal irradiations)**

Summary

- Final Laser Monitoring System has been installed and tested over several thousand hours at the test beam.
- All performance criterions have been achieved.
- Next step is commissioning the system on the final detector in the cavern.
- Then, operating the system and follow the crystal transparency on the level of 0.1% over 10 years.