DRAFT

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.

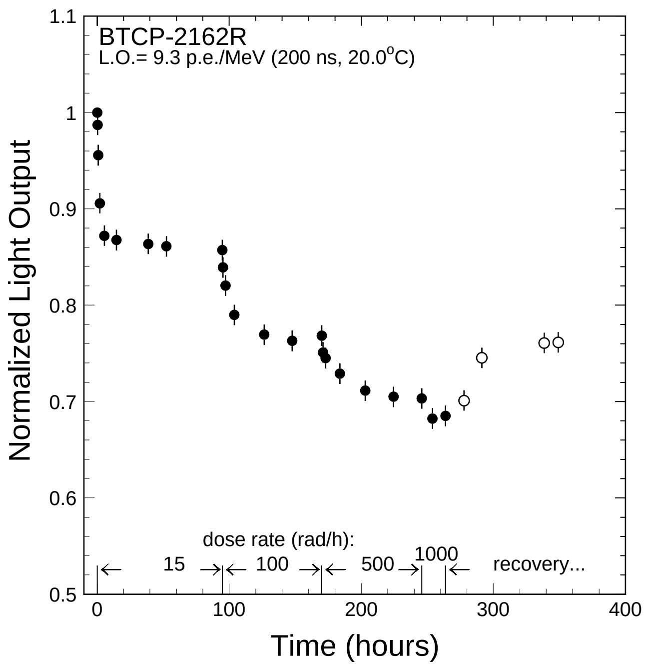
The damage is significant (few % - up to ~5 % for CMS ECAL barrel radiation levels) compared to the desired constant term (0.5 %).

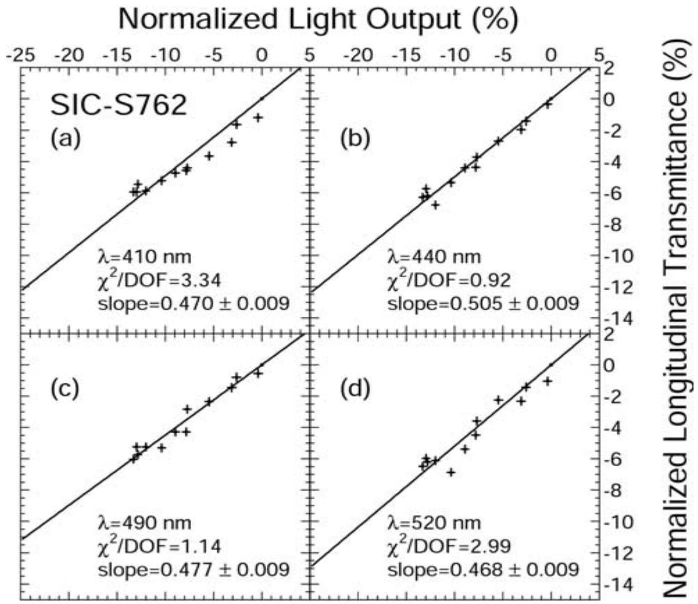
The dynamics of the transparency change is fast (few hours) compared to the time scale needed for a calibration with physics events (weeks - month).

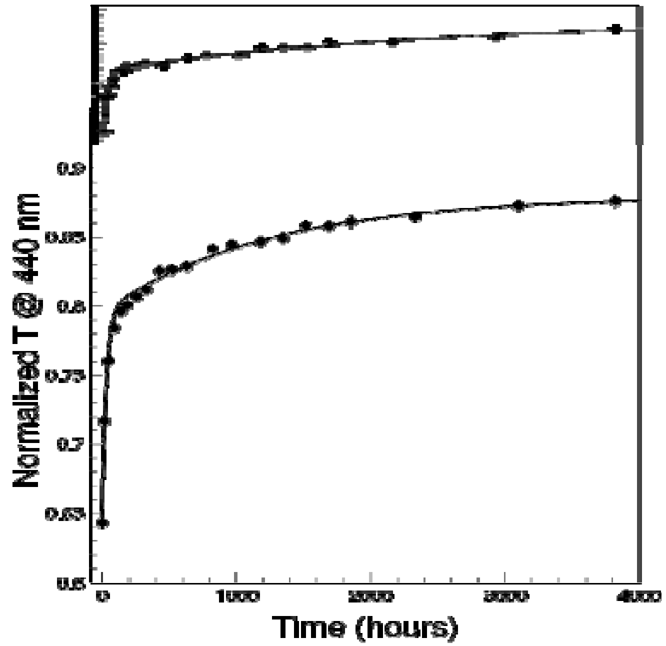
⇒ Talk on crystals by R. Paramatti at this conference.

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

PWO_4 Transparency Change Characteristics

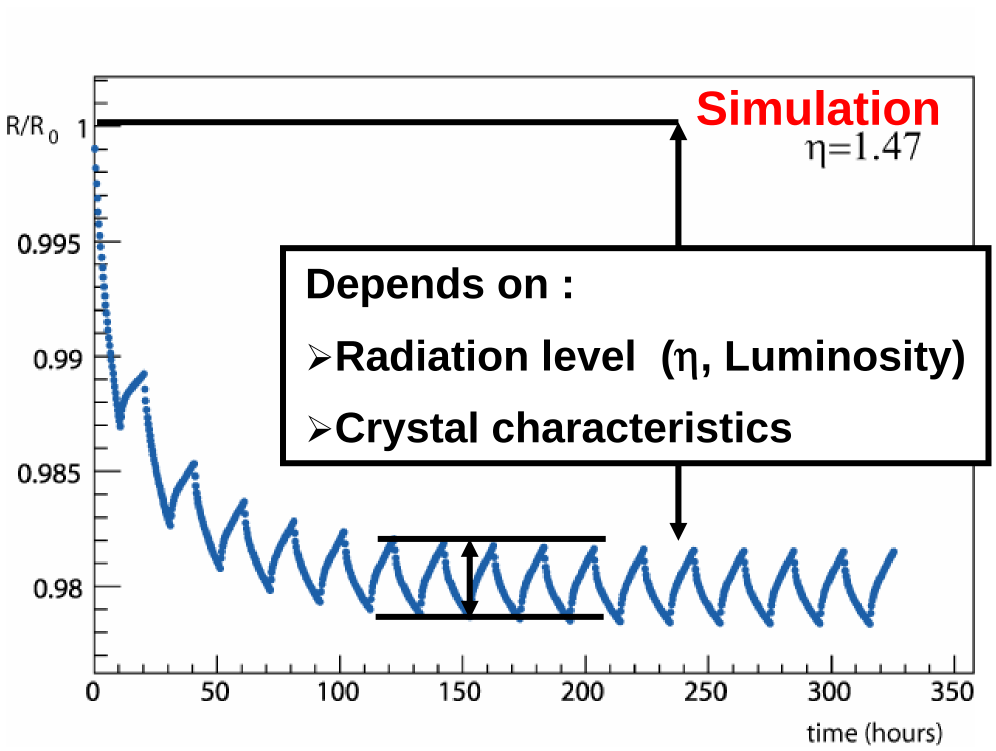


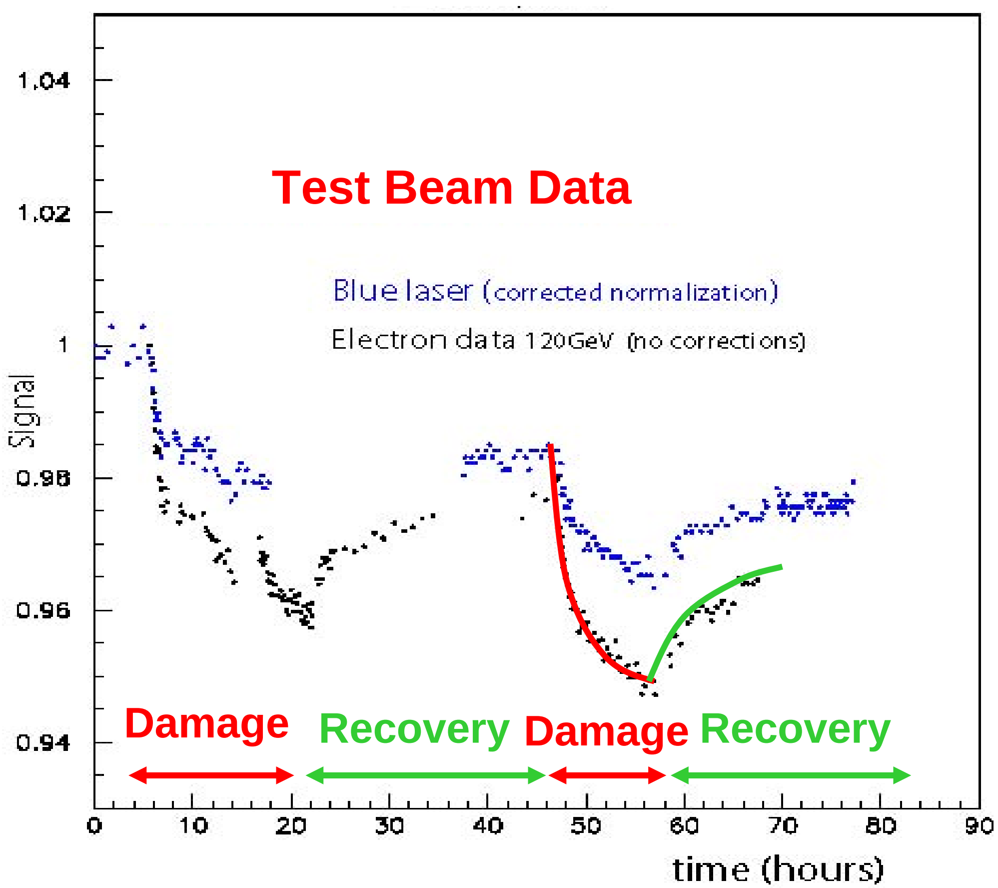




- ➢ **Crystal light yield changes under irradiation. Change is dose rate dependent.**
- ➢ **Crystal light yield change under irradiation is linearly correlated with longitudinal transmittance (transparency).**
- ➢ **Magnitude of the transparency change is crystal dependent.**
- ➢ **Transparency change 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'



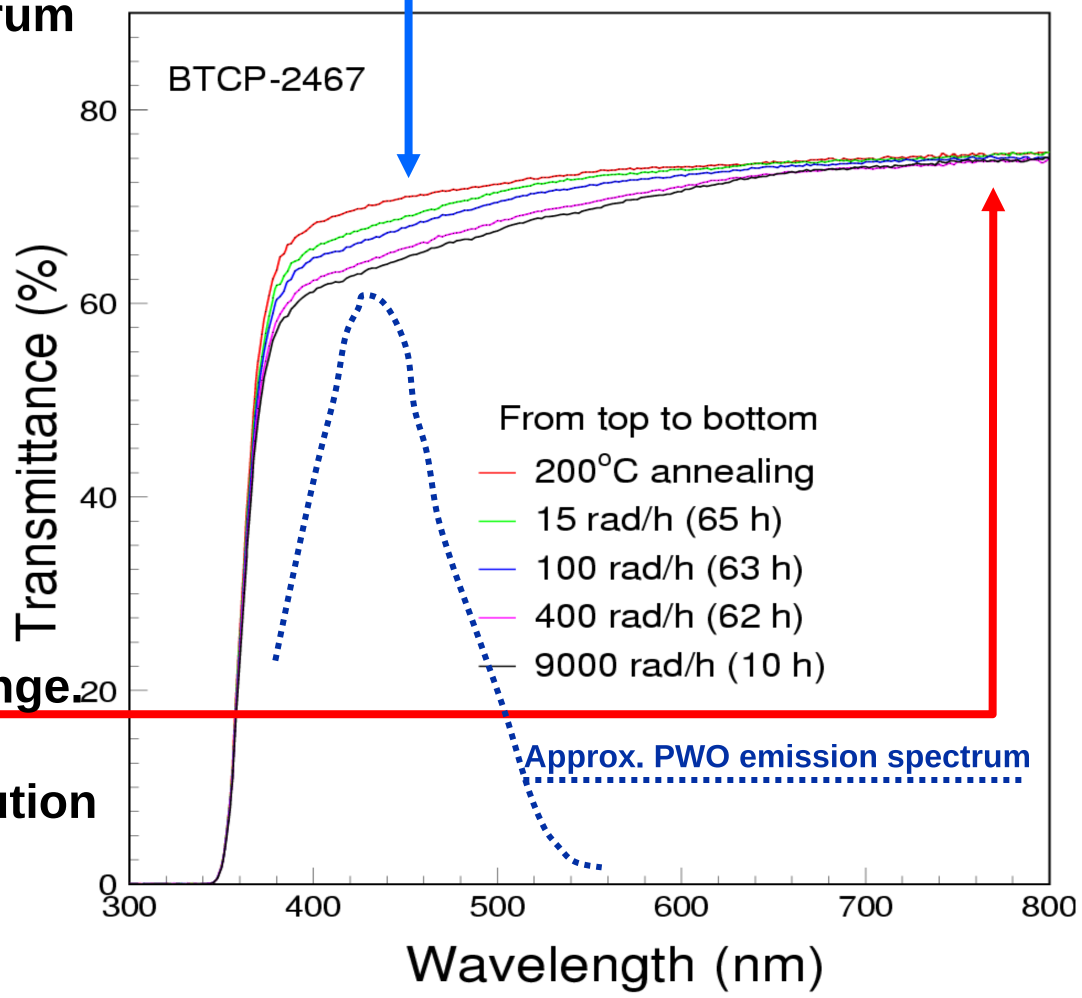


⇒ **Damage-recovery cycle in sync with the ~12 hour LHC fill cycle**

Radiation Effects on PWO_4 Transparency

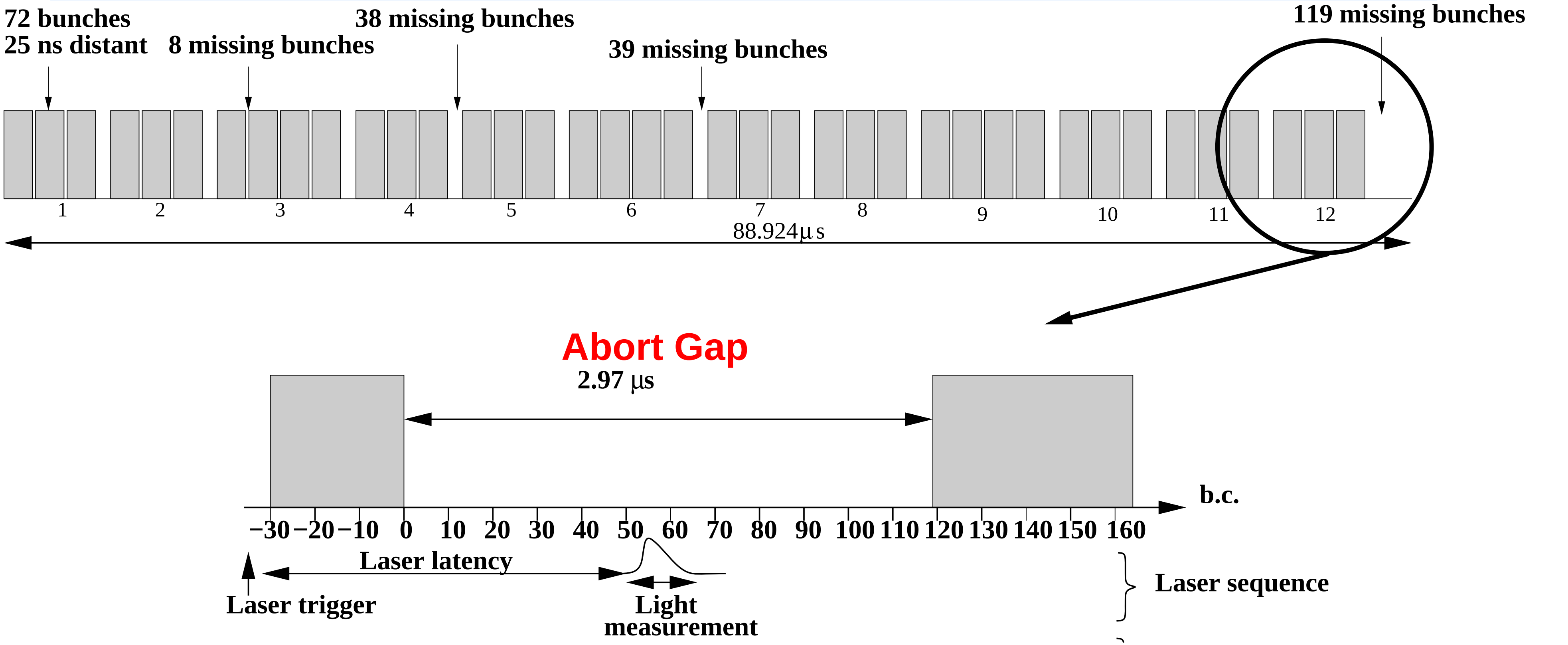
- **Radiation Reduces transmittance in the blue and green, peak of PWO_4 emission spectrum**
- **Effect is dose rate dependent.**
- **Monitoring relative loss of PWO_4 transmittance with pulsed laser light.**

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.

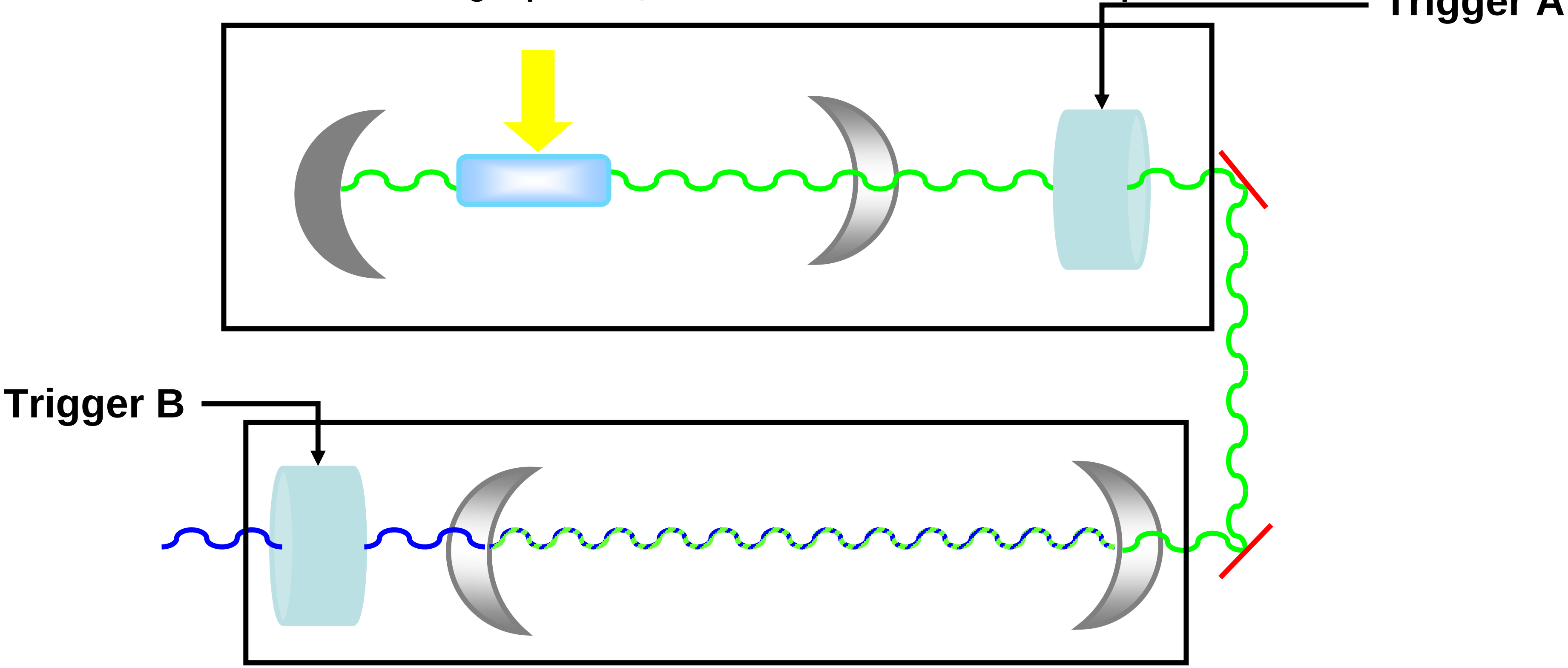
⇒ Mimic scintillation light as closely as possible.

⇒ 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.

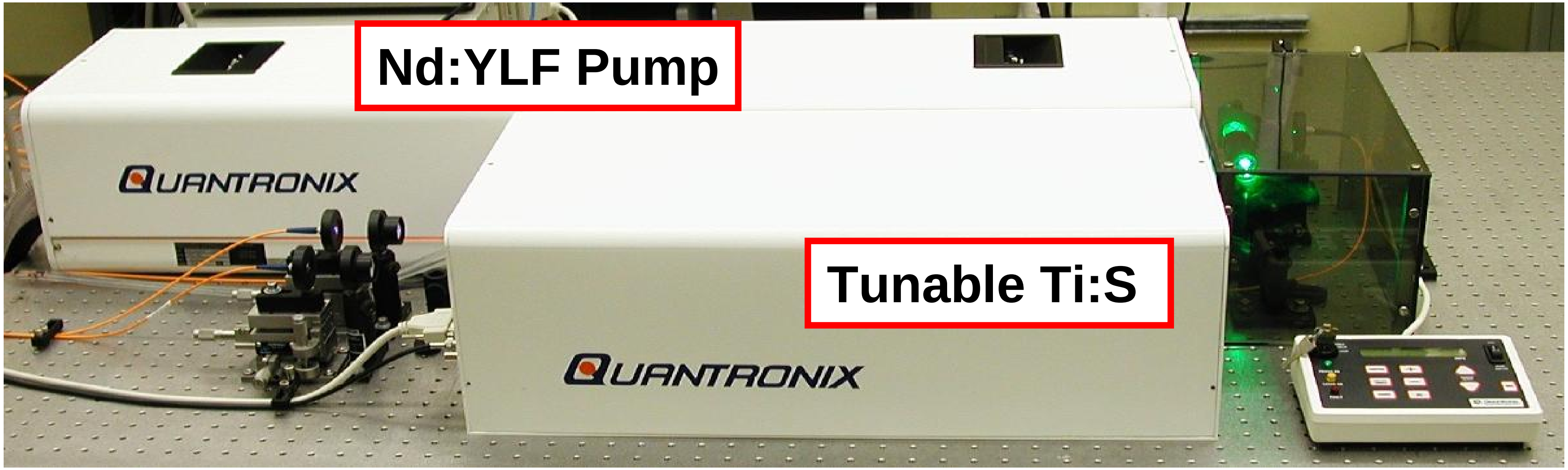


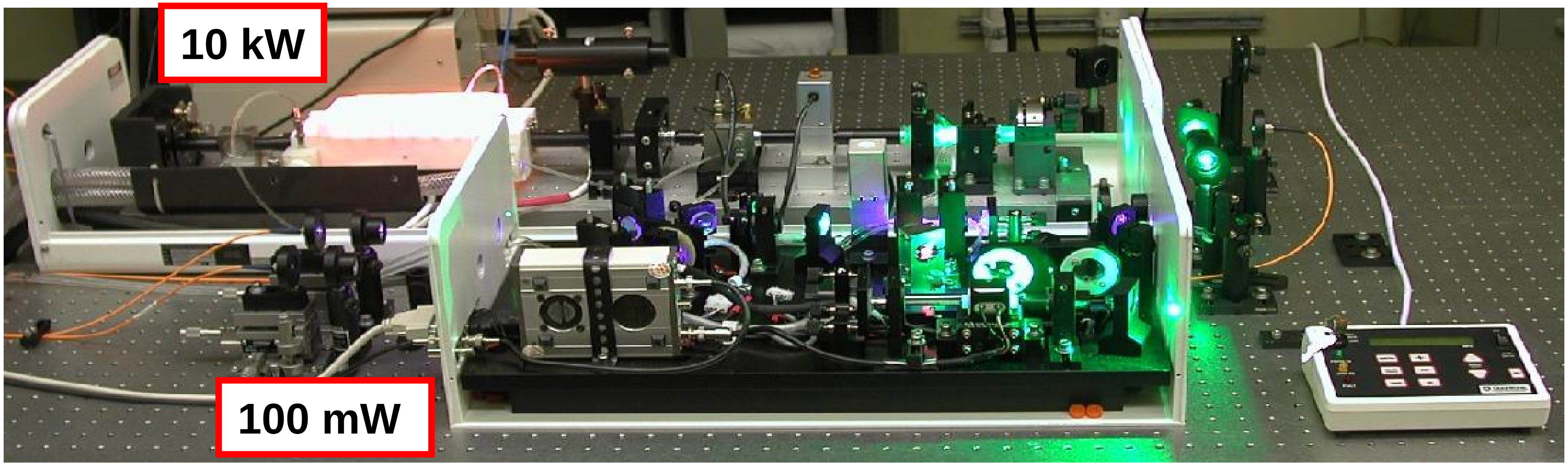
TiS :

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.

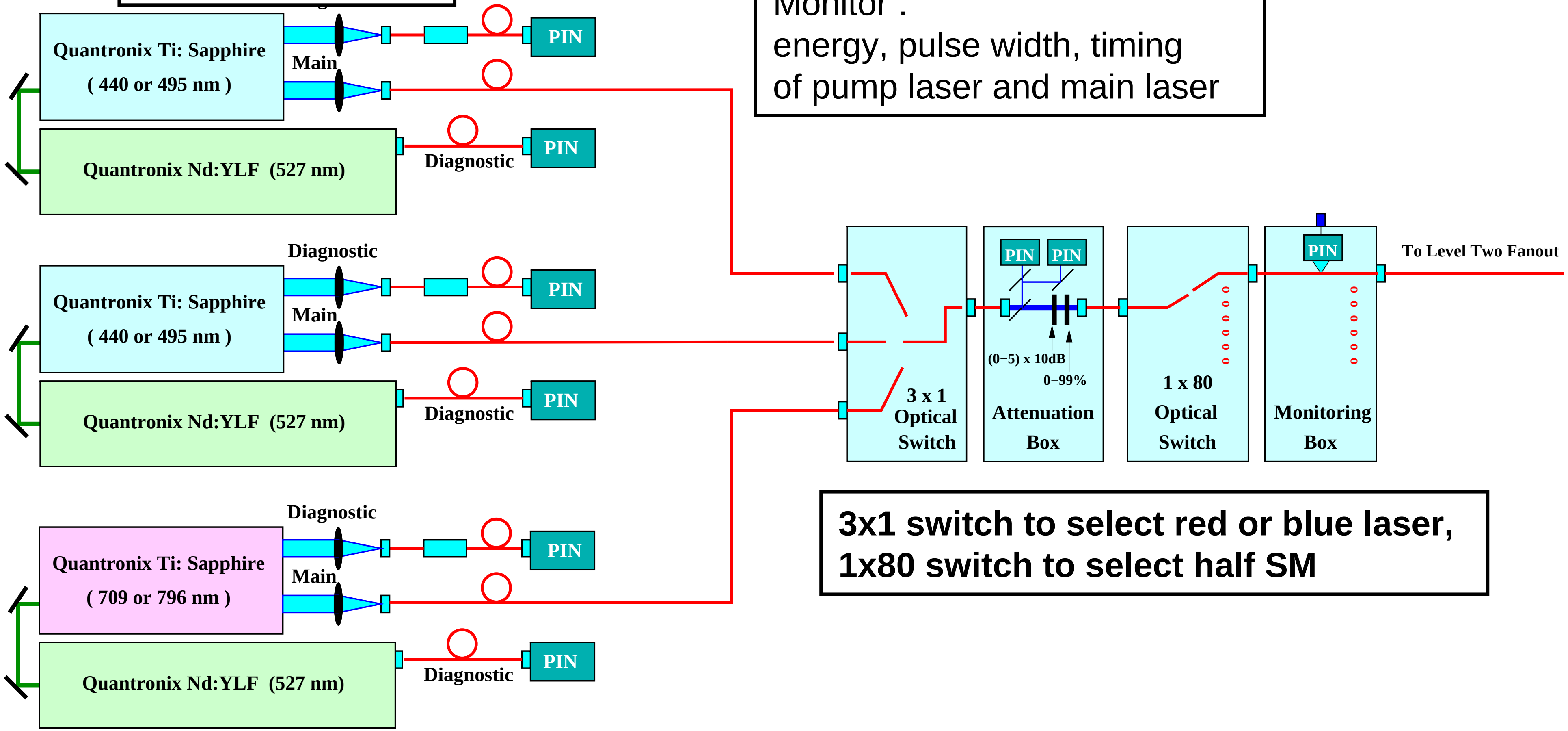

Nd:YLF Pump
QUANTRONIX
Tunable Ti:S
QUANTRONIX


10 kW
100 mW

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

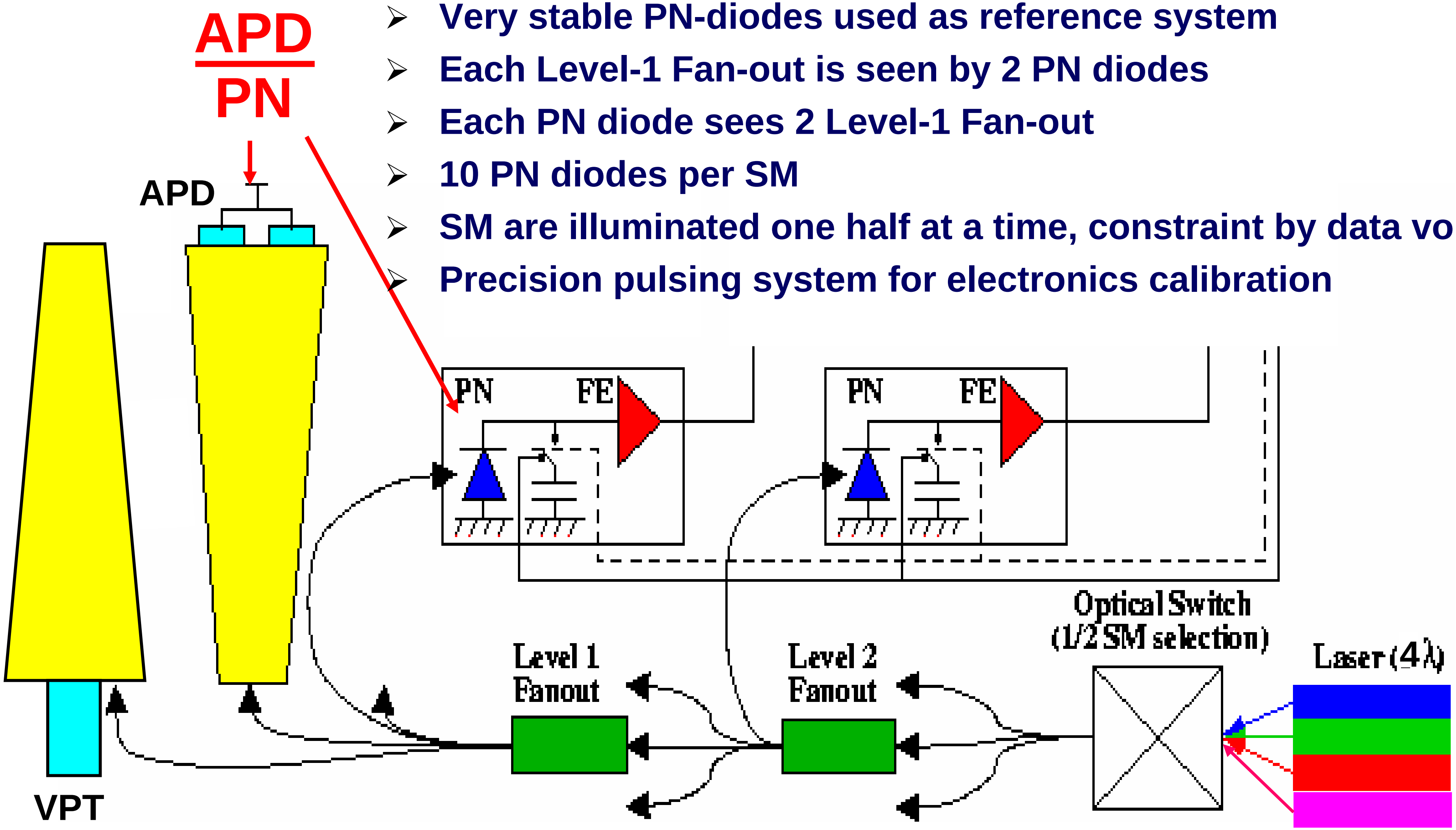


3x1 switch to select red or blue laser,
1x80 switch to select half SM

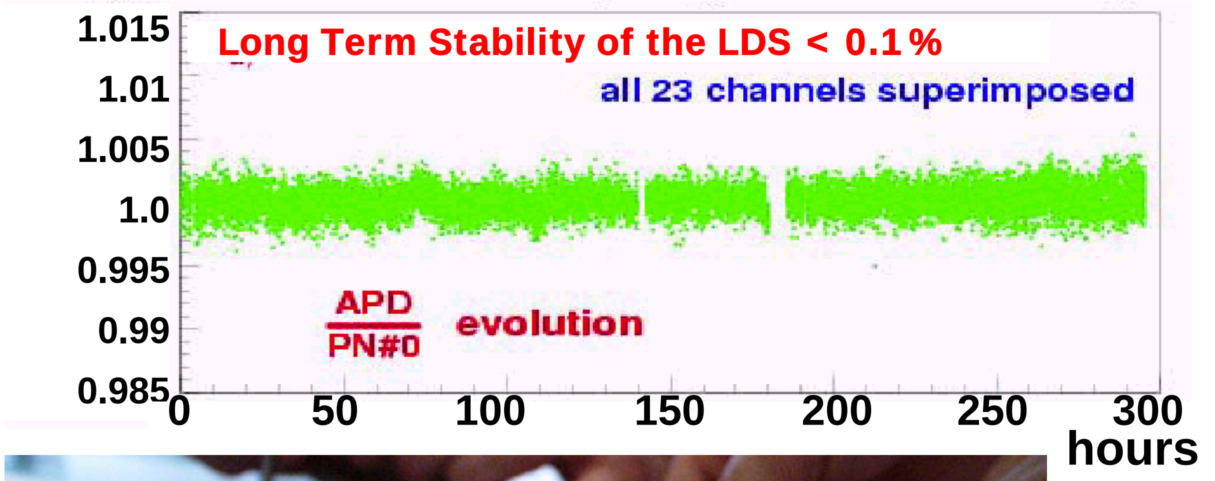
RED Laser:
Provides 800 nm
and 700 nm

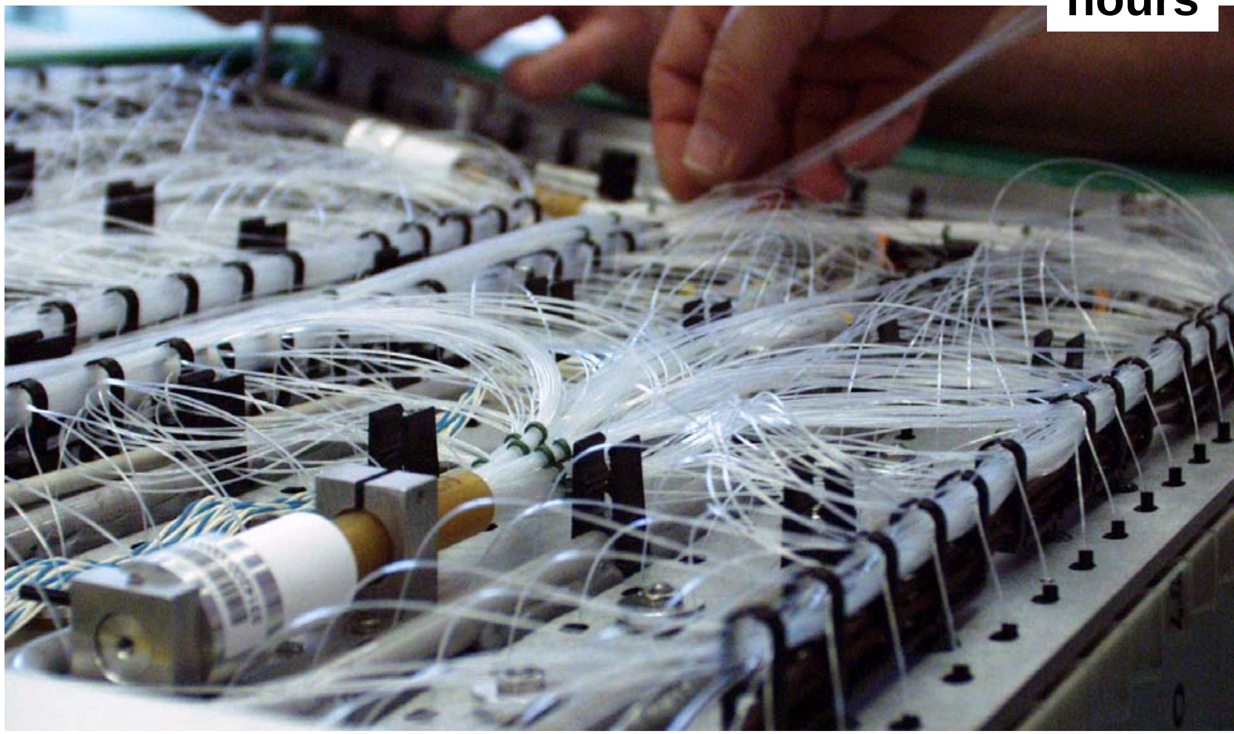
On-Detector Monitoring System

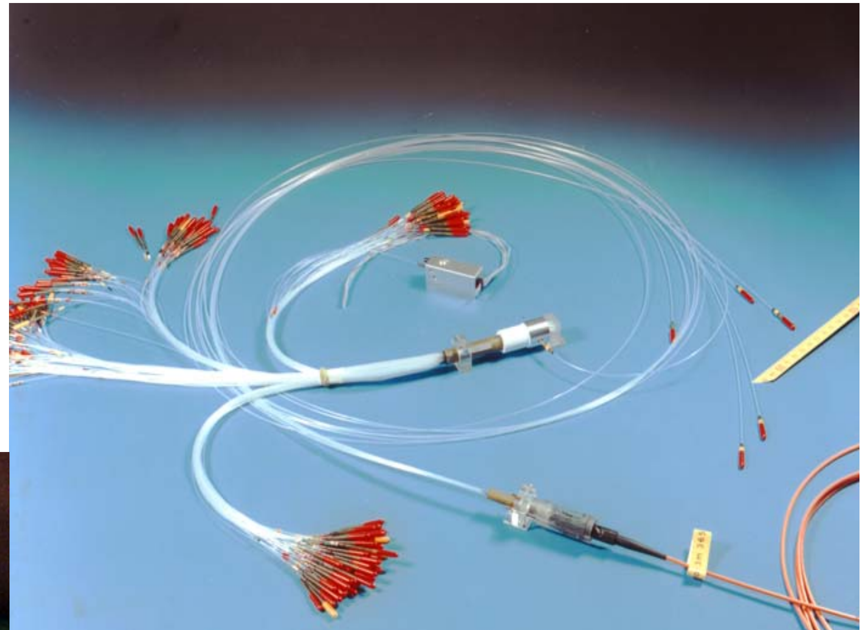
- Very stable PN-diodes used as reference system
- Each Level-1 Fan-out is seen by 2 PN diodes
- Each PN diode sees 2 Level-1 Fan-out
- 10 PN diodes per SM
- SM are illuminated one half at a time, constraint by data volume
- Precision pulsing system for electronics calibration



Light Distribution System

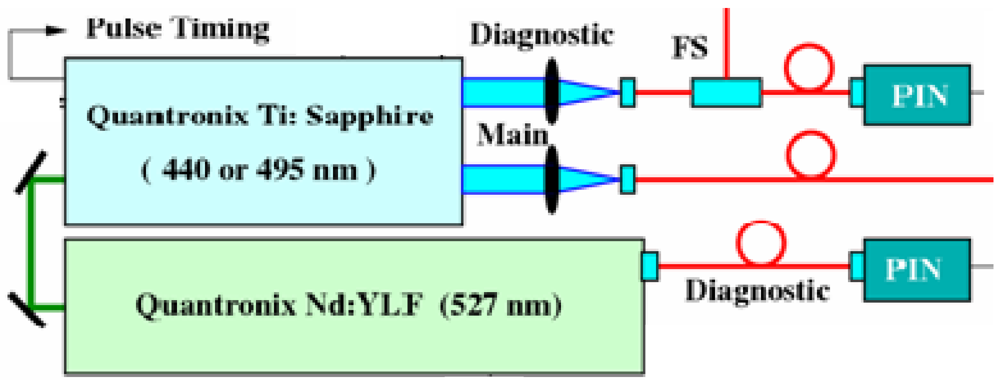


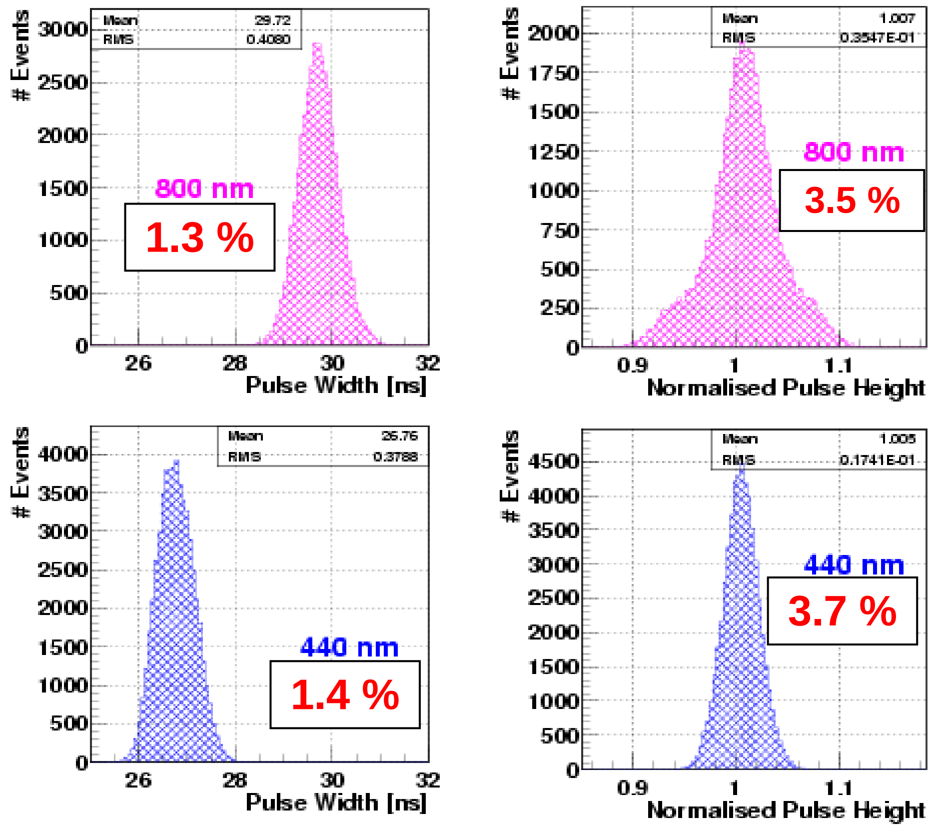


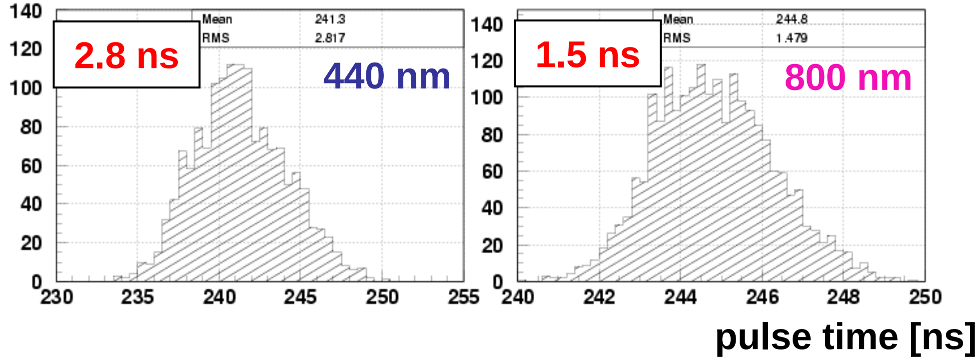


Laser Source Monitoring

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



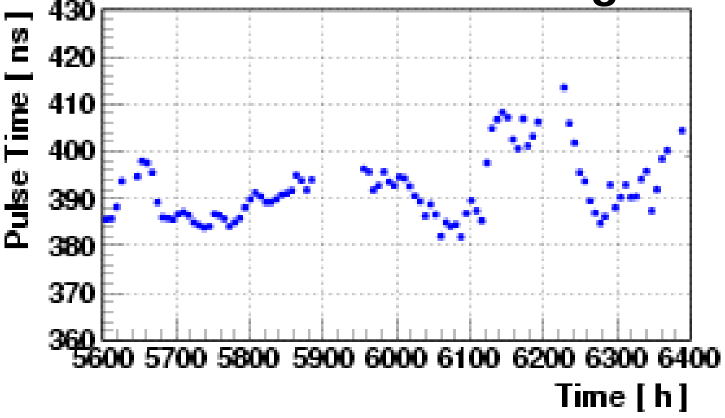




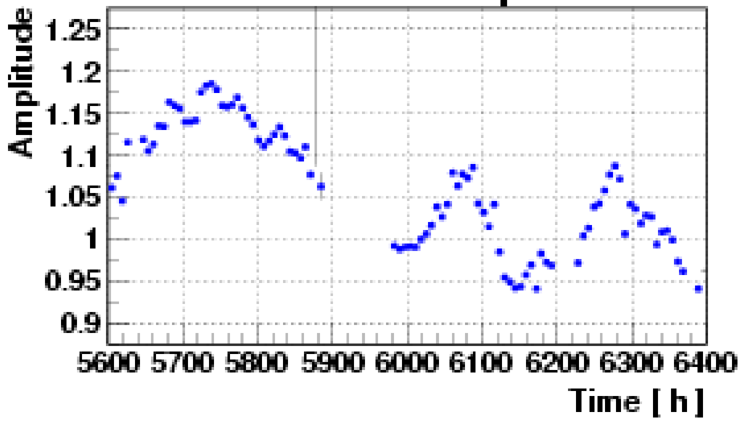
⇒ Short term stability typically a few percent / few ns (RMS) over several hours.

Laser Source Feedback – 2006 Testbeam

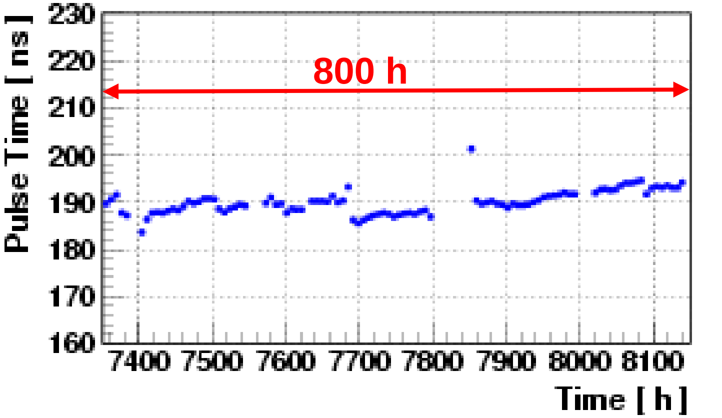
Laser Pulse Timing

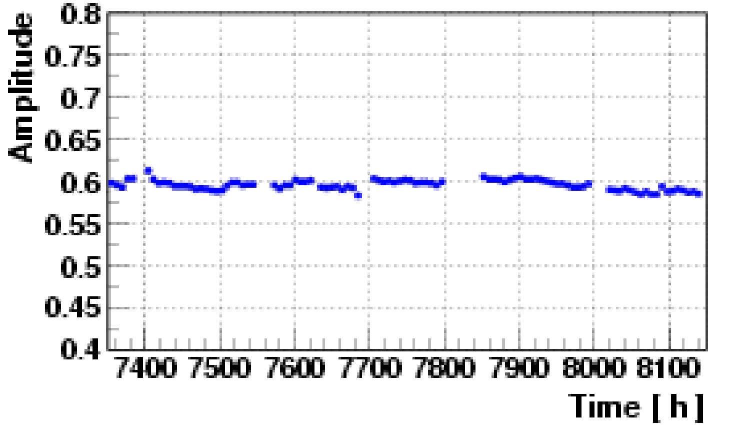


Laser Pulse Amplitude



No Feedback

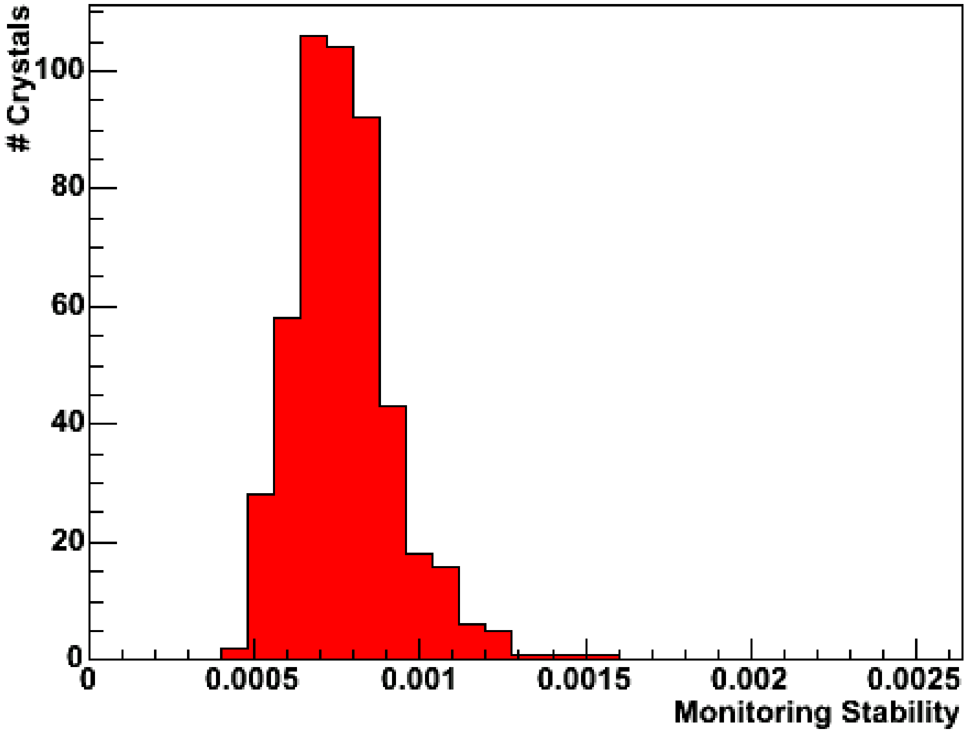




With Pulse Timing Feedback

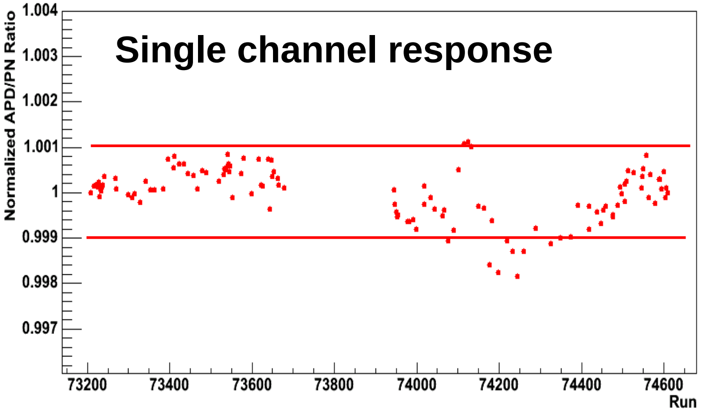
Laser source internal feedback ensures precise timing over several 100 hours.

Also improves pulse width and pulse amplitude stability.



From 2004 test beam :

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

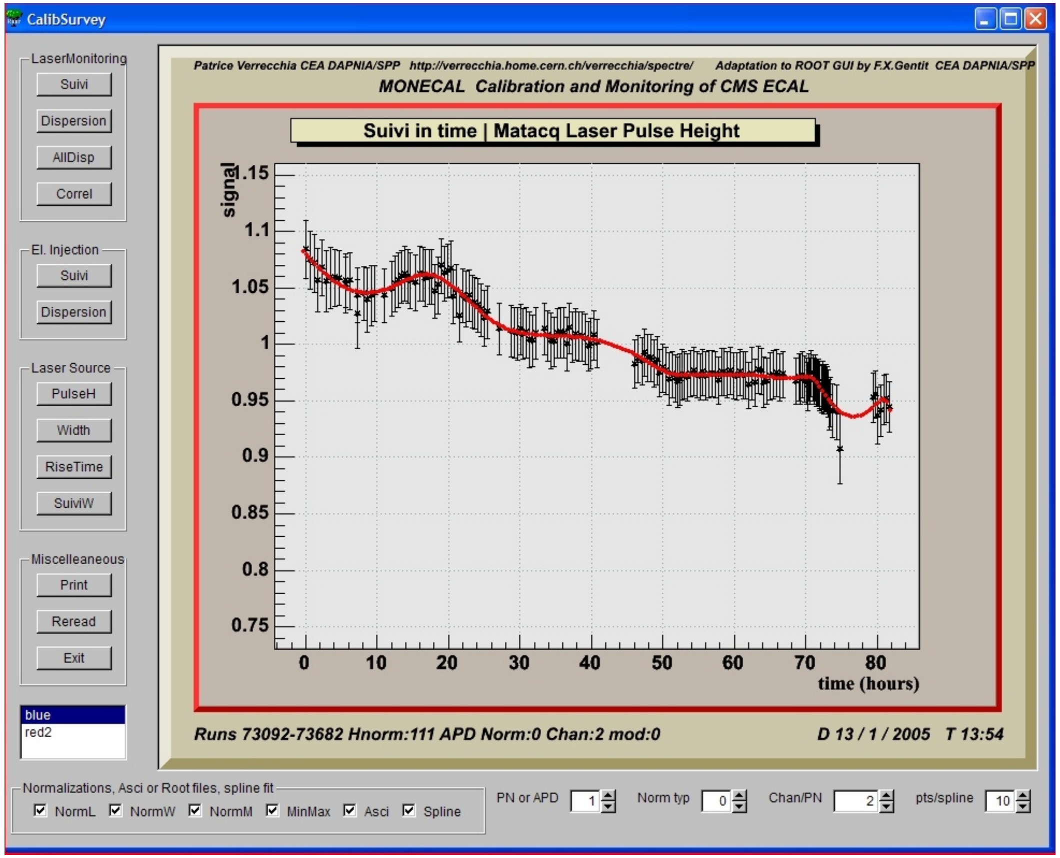


Typically ~0.1 % long term stability in real environment. This includes the stability of the entire readout chain - temperature, HV, etc.

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

Online Laser Data Analysis Farm

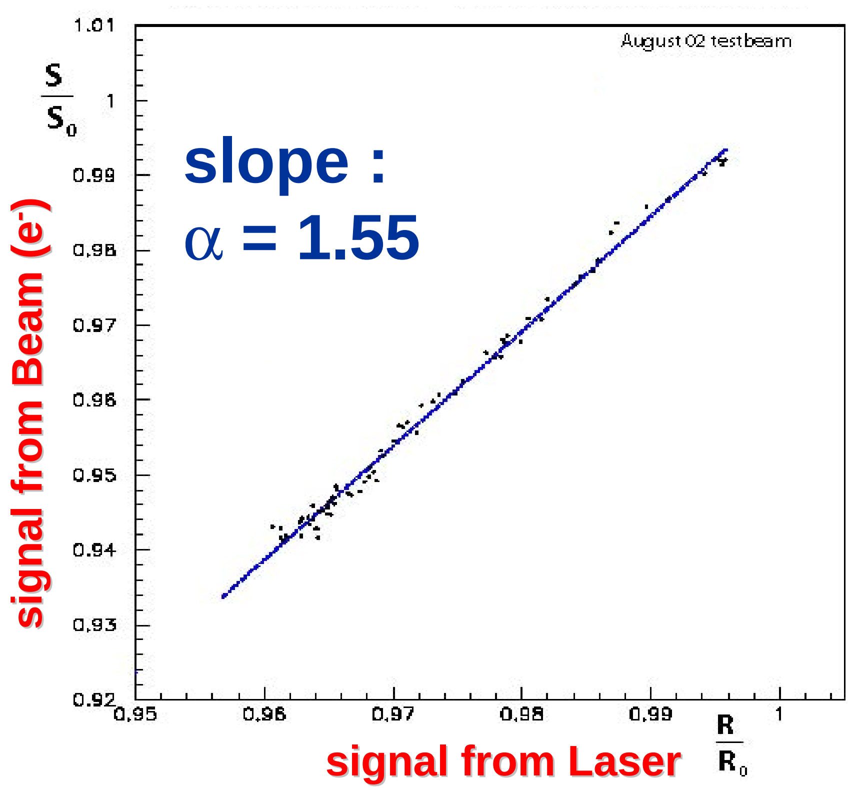
Fast online laser farm output, Crystal irradiation during test beam 2004



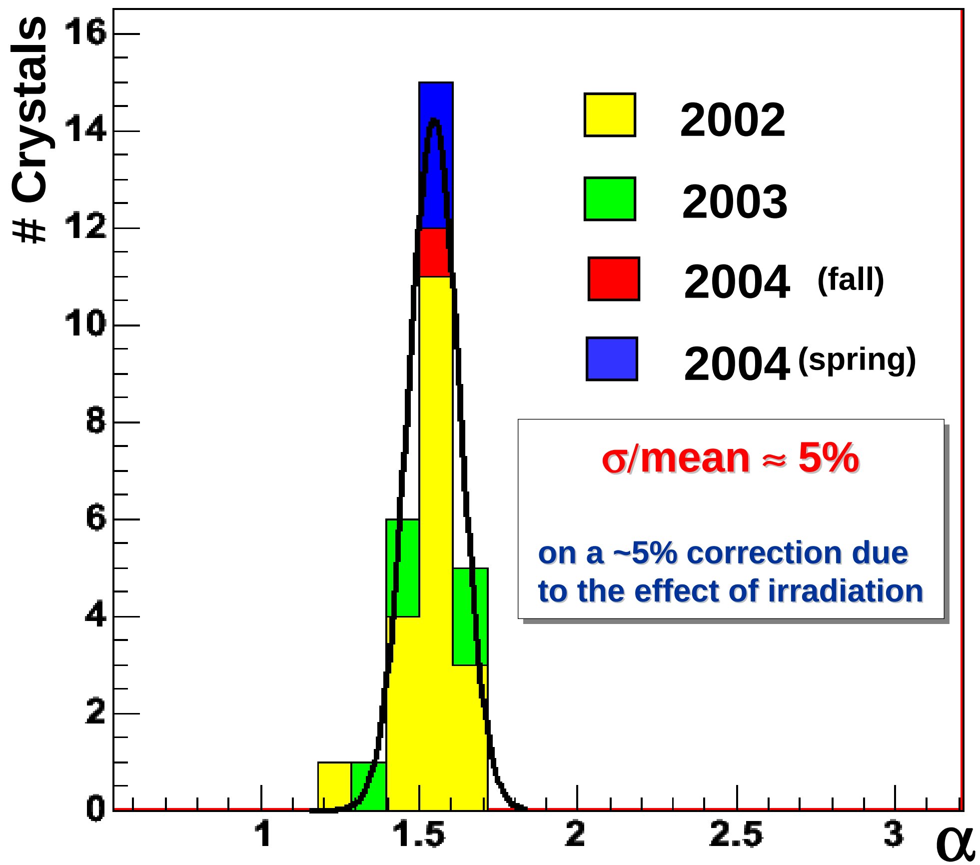
- **Fast Online Analysis in dedicated 'Laser Farm' (12 PCs) parallel to online filter farm.**
- **Extract transparency for each crystal from one laser run.**
- **Perform plausibility checks by comparing neighboring crystals, groups of crystals for single runs and groups of runs. Interpolating between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

Laser Light Loss – Electron Signal Loss



Dispersion of α for 28 BTCP crystals

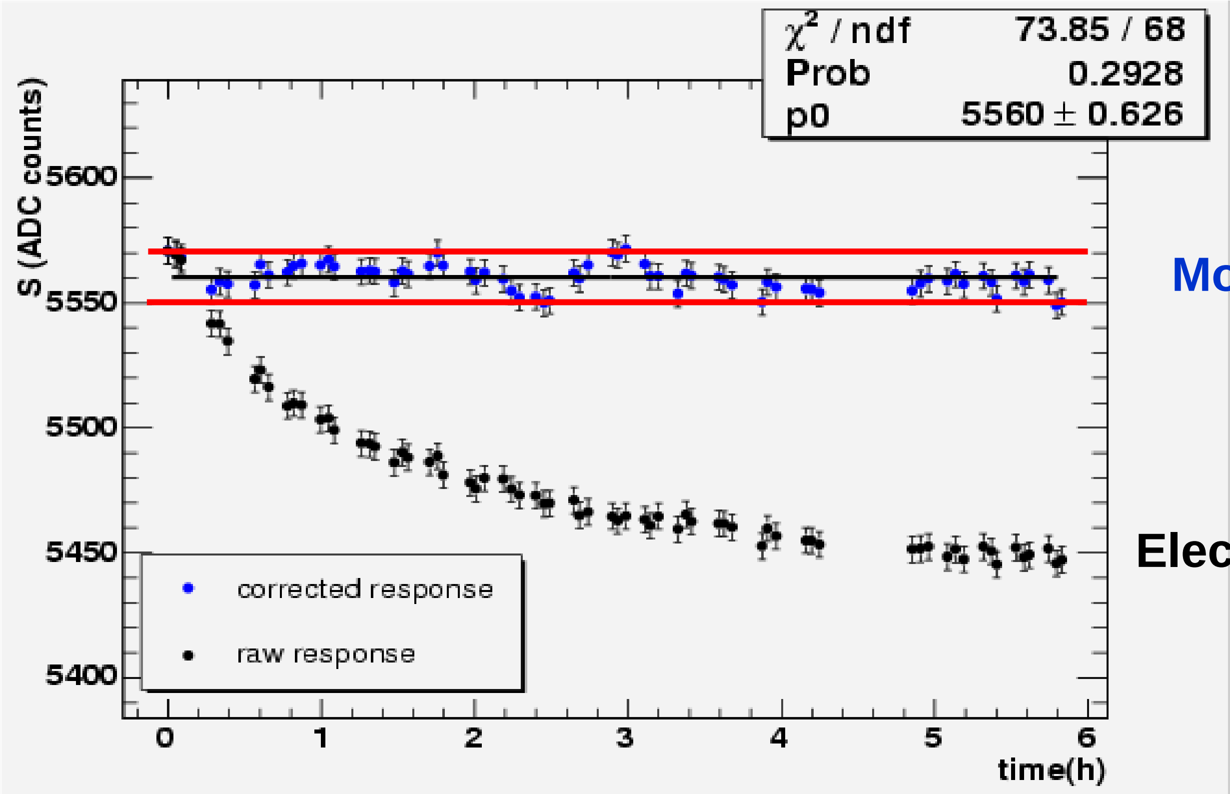


⇒ Coefficient for crystals have relatively small dispersion.

⇒ 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.