# The CMS ECAL Laser Monitoring System

**Kejun Zhu**

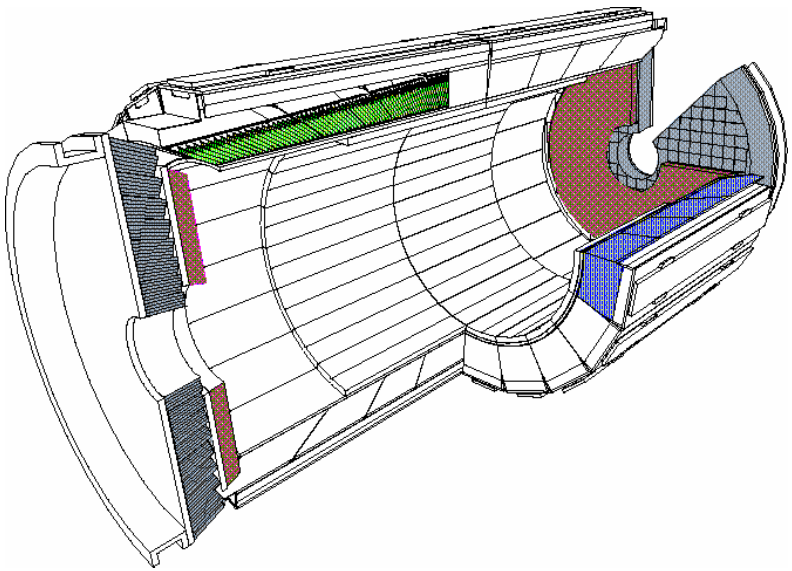
**California Institute of Technology**

**On Behalf of the CMS ECAL Group**

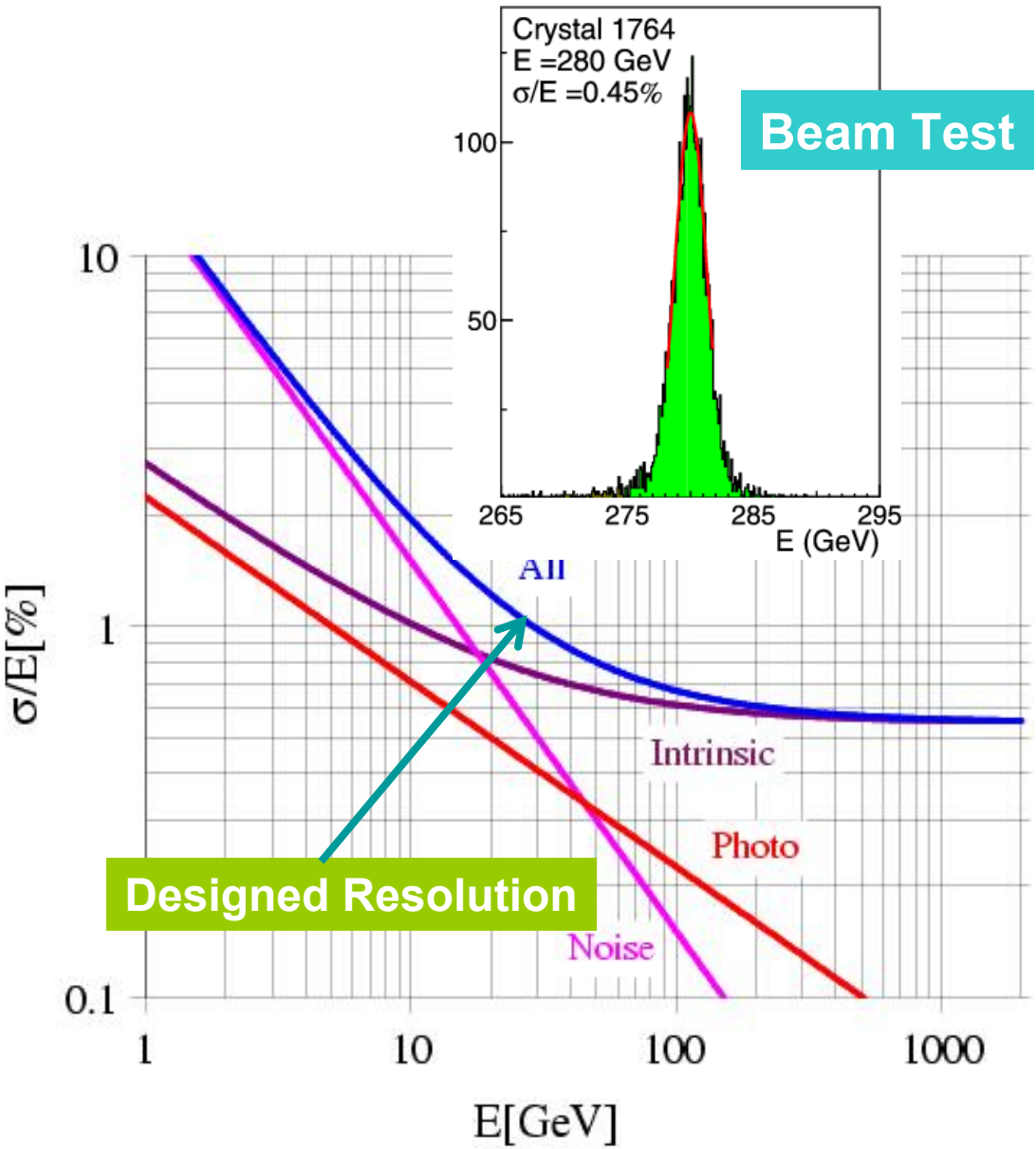
# Introduction

- At the LHC design luminosity, the CMS ECAL is exposed in a harsh radiation environment (dose rates of 15 rad/hour for the barrel and 500 rad/h for the endcaps at $10^{34}$ $cm^{-2}s^{-1}$). The lead tungstate ($PbWO_4$) crystals suffer from a dose-rate dependent radiation damage.
- Radiation causes a degradation in crystal transparency because of color center formation. The crystals recover in absence of radiation with two time constants ranging from days and weeks. Changes in crystal transparency, and therefore calorimeter response, must be corrected for to maintain the ECAL resolution.
- A laser based light monitoring system is designed to measure the transparency variations of each crystal continuously during LHC running with 0.2% precision.

# CMS $PbWO_4$ ECAL Resolution

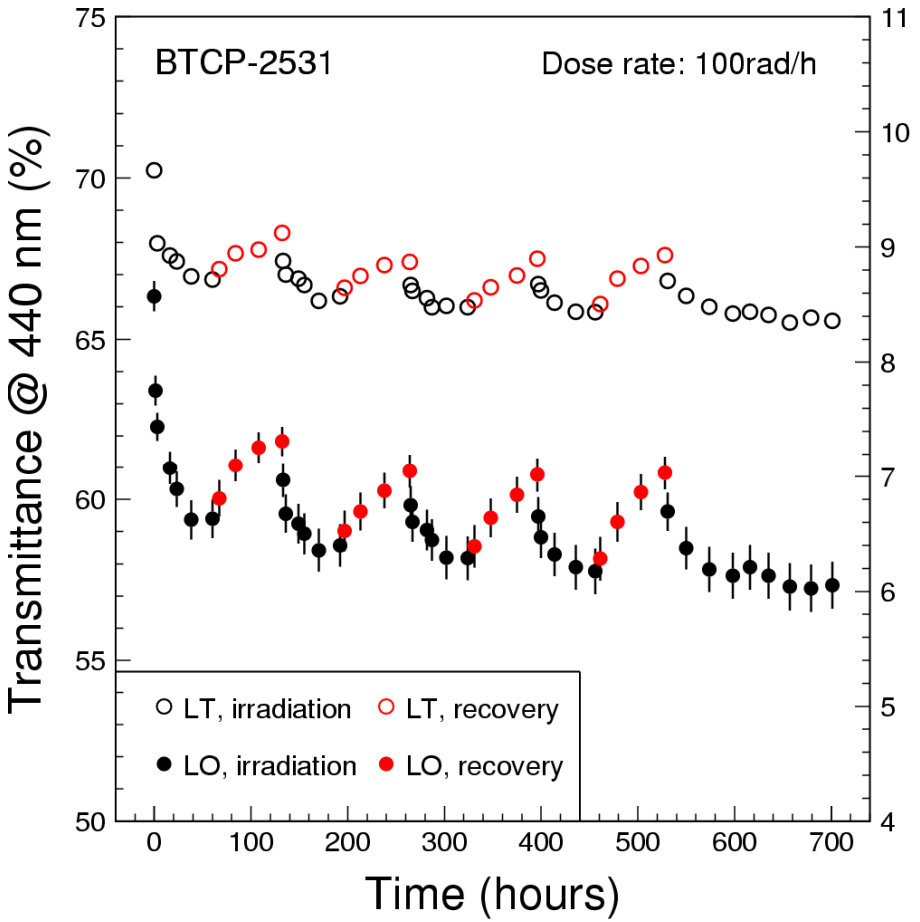


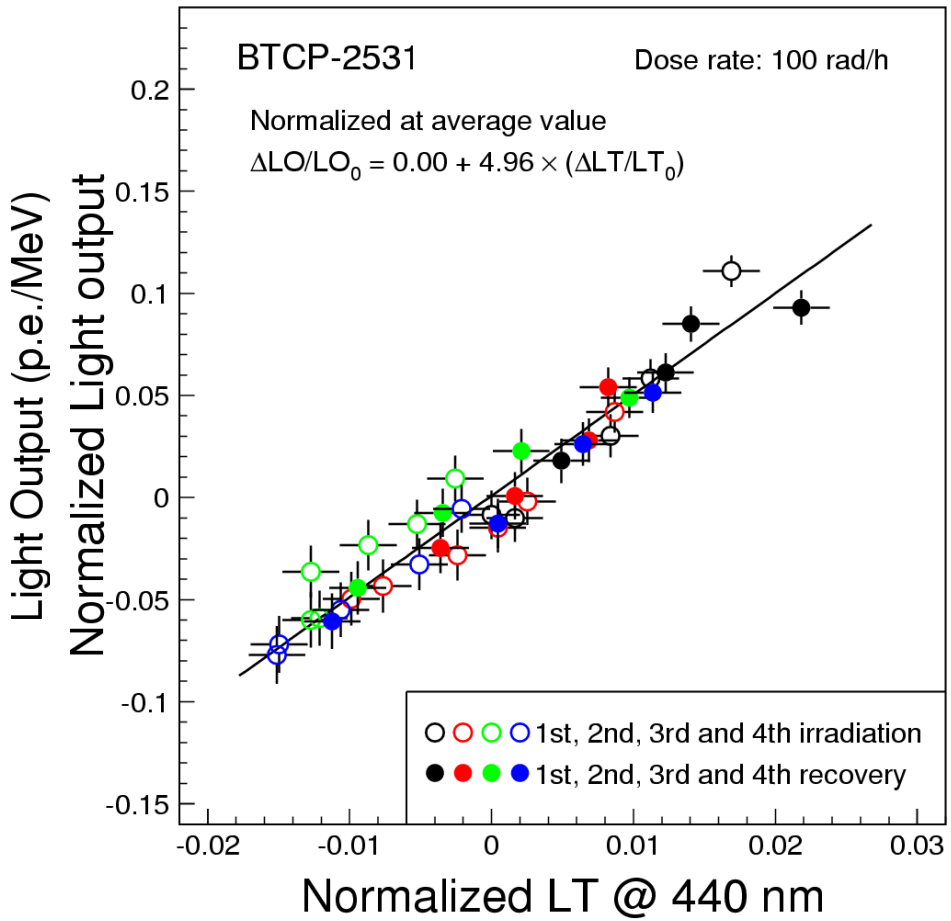
- 75,848 $PbWO_4$ crystals
- To maintain 0.5% constant term in energy resolution, the monitoring precision is required to be 0.2%.



# δLO/LO versus δLT/LT @ 100 rad/h

Strong correlation observed between variations of the light output and the longitudinal transmittance for full size $PbWO_4$ crystals in multi cycles of irradiation and recovery



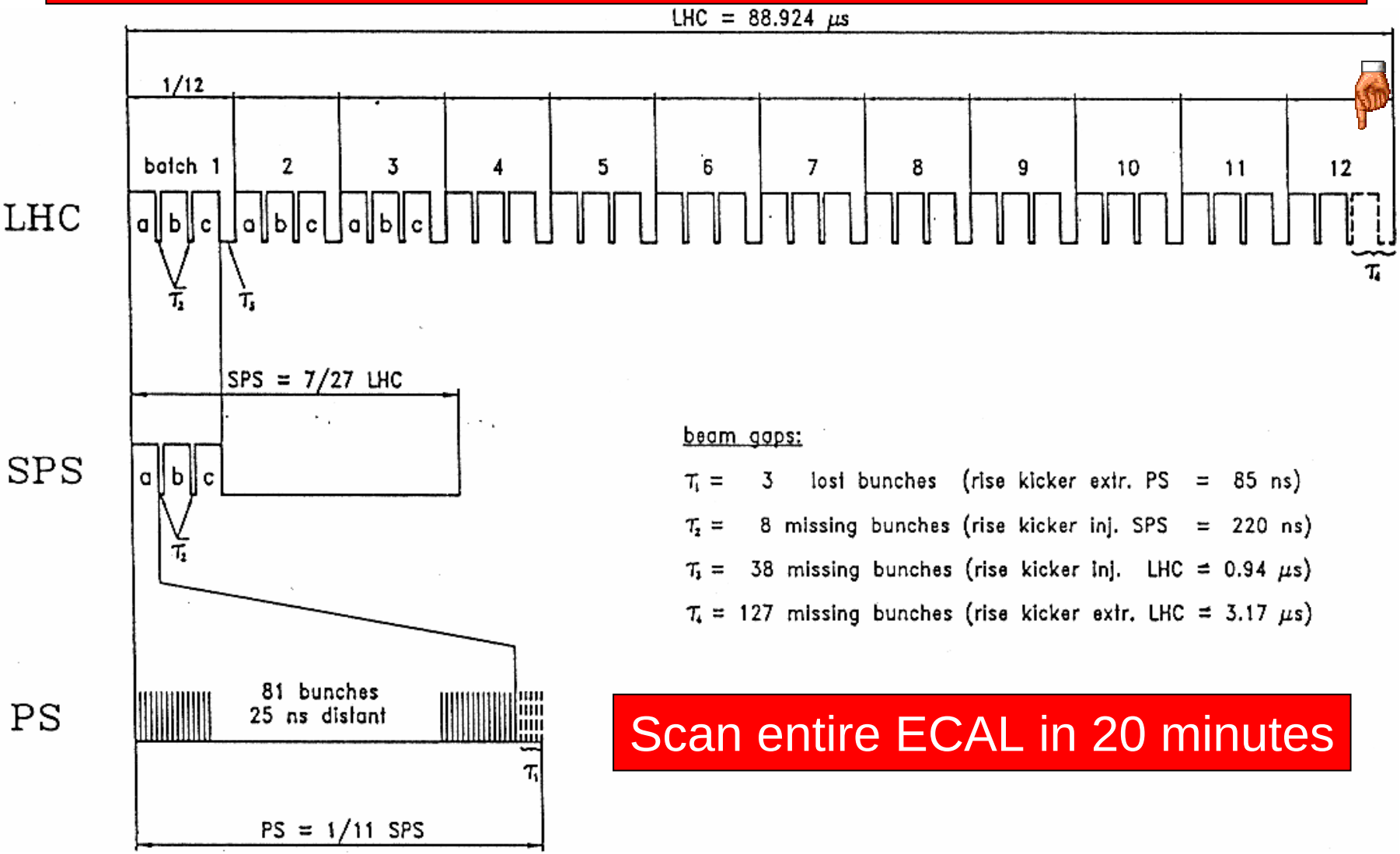



# Laser Source Specifications

- → 2 wavelengths per laser
- → Pulse FWHM: < 40 ns to match ECAL readout
- → Pulse jitter: < 3 ns for synchronization with LHC
- → Pulse rate: ~100 Hz, scan of full ECAL in 20min
- → Pulse intensity instability: < 10%
- → Pulse energy: 1 mJ/pulse at 440 nm, equivalent to 1.3 TeV in dynamic range

# Continuous Monitoring *in situ*

Using 1% beam gaps (100 Hz) in the LHC beam structure




beam gaps:

$\tau_1$ = 3 lost bunches (rise kicker extr. PS = 85 ns)

$\tau_2$ = 8 missing bunches (rise kicker inj. SPS = 220 ns)

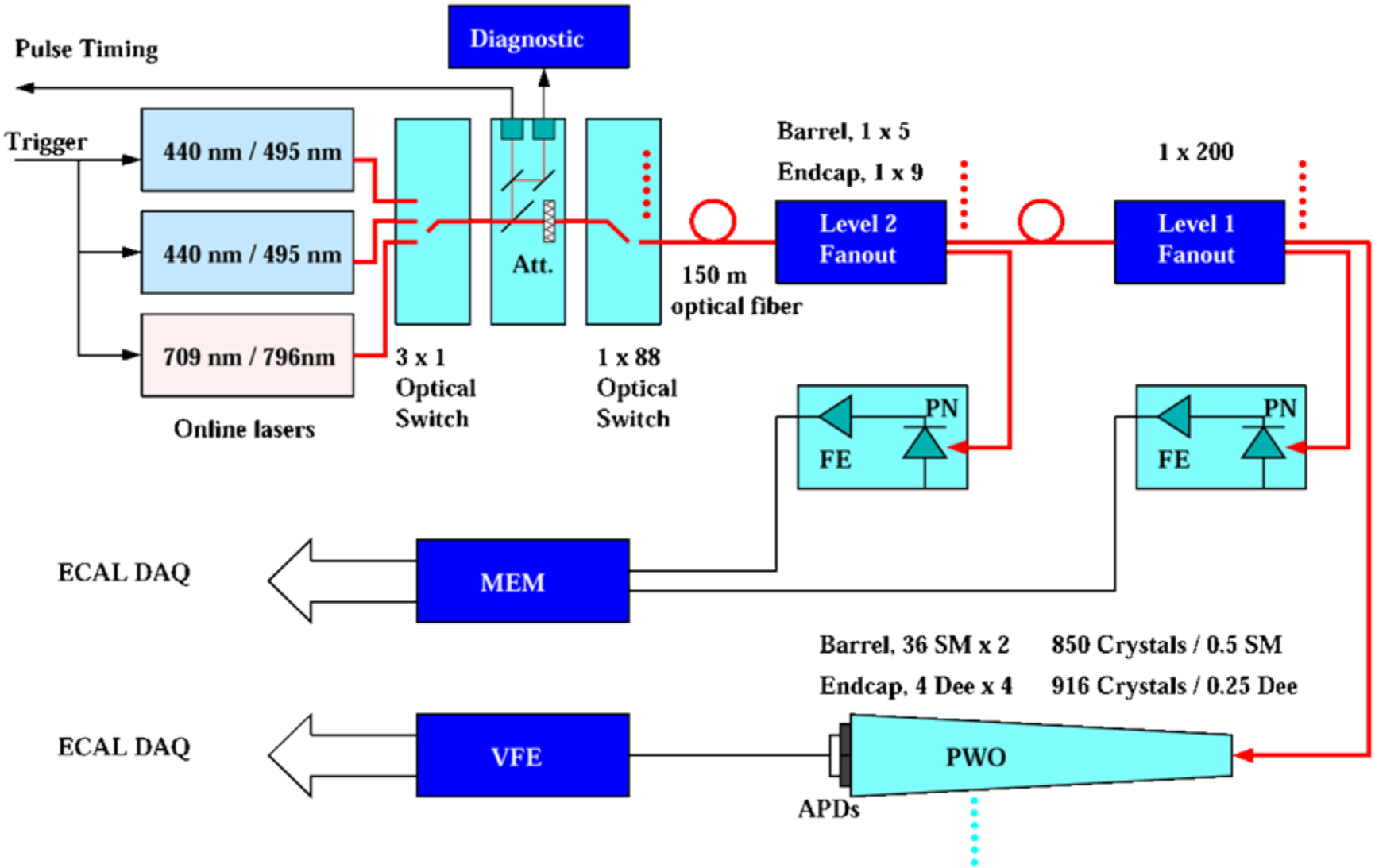
$\tau_3$ = 38 missing bunches (rise kicker inj. LHC = 0.94 μs)

$\tau_4$ = 127 missing bunches (rise kicker extr. LHC = 3.17 μs)

Scan entire ECAL in 20 minutes

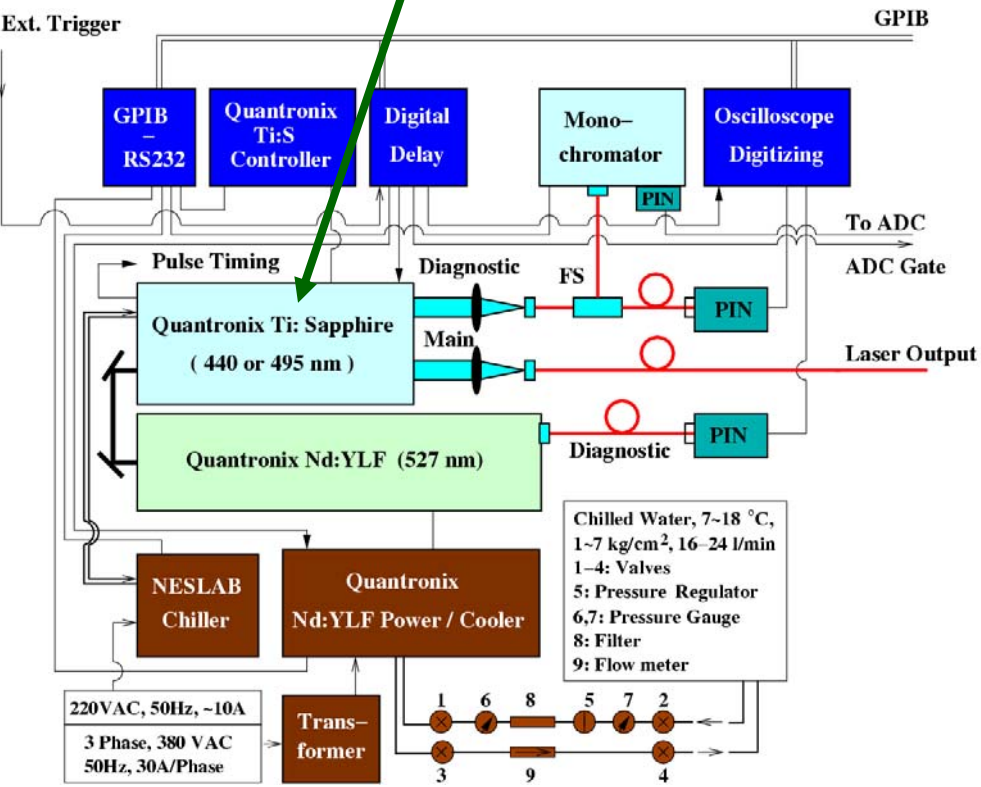
# Laser Light Monitoring System

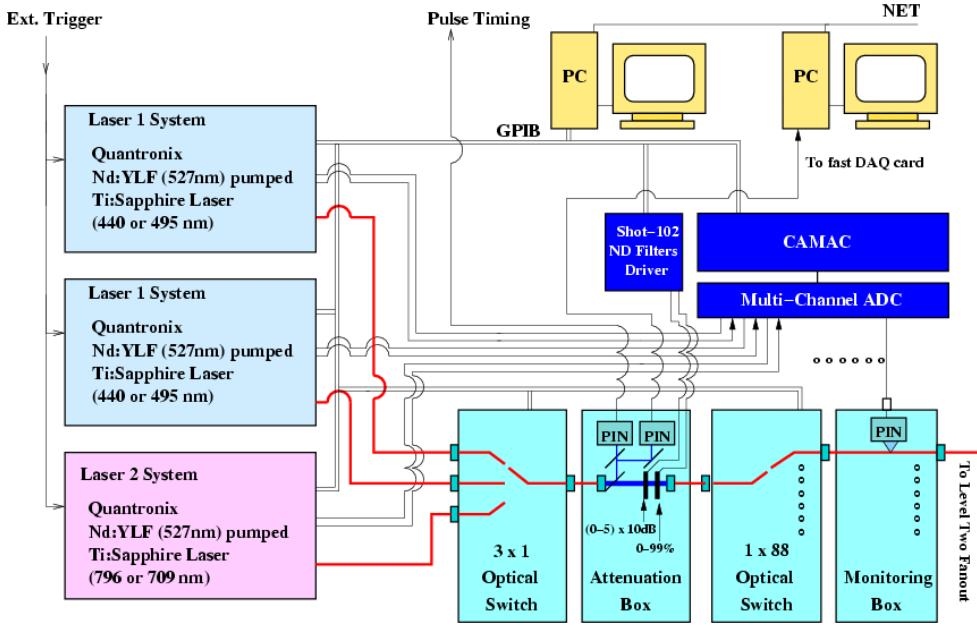
Two lasers to guarantee 100% availability of 440 nm



# Laser System Commission at CERN

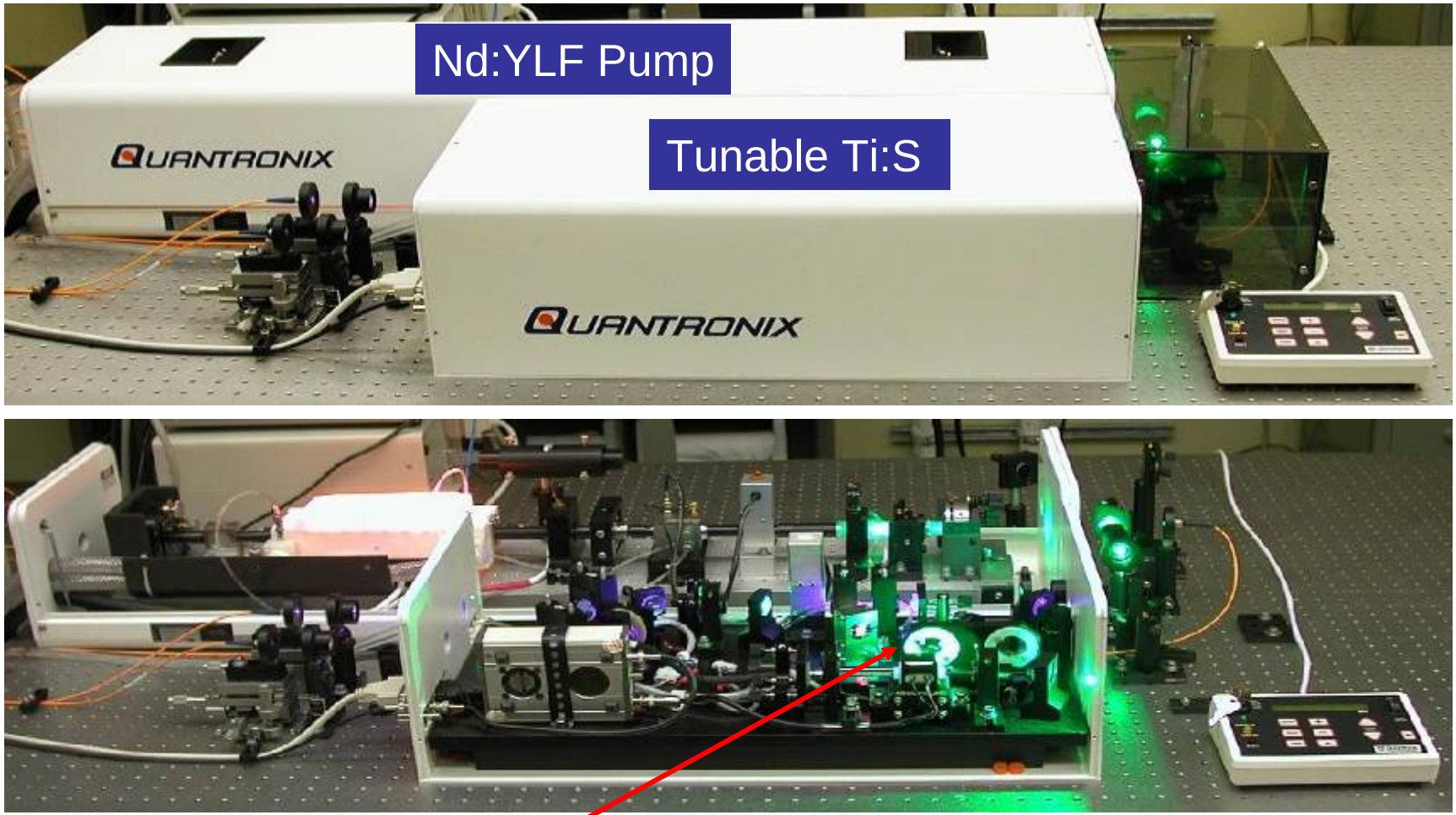
Each laser system contains an Nd:YLF pump laser and a tunable Ti:Sapphire laser with dual wavelengths




1st laser: 8/2001
2nd & 3rd lasers: 8/2003
Two lasers at P5: 3/2007

# Nd:YLF pumped Ti:Sapphire Laser



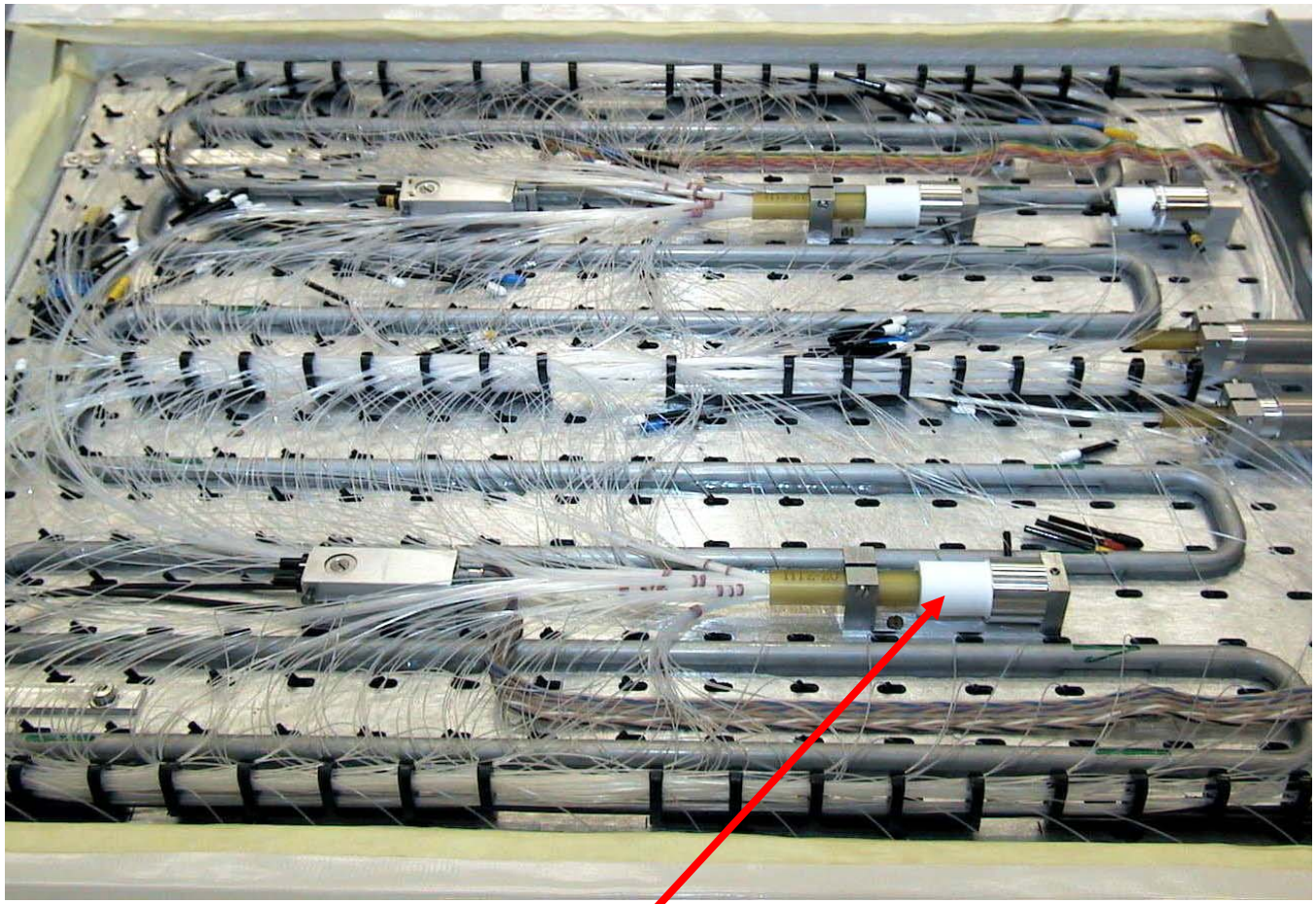

Lasers operate at two wavelengths by using interference filters in path

Blue/green: 440/495 nm

IR/Red: 796/709 nm

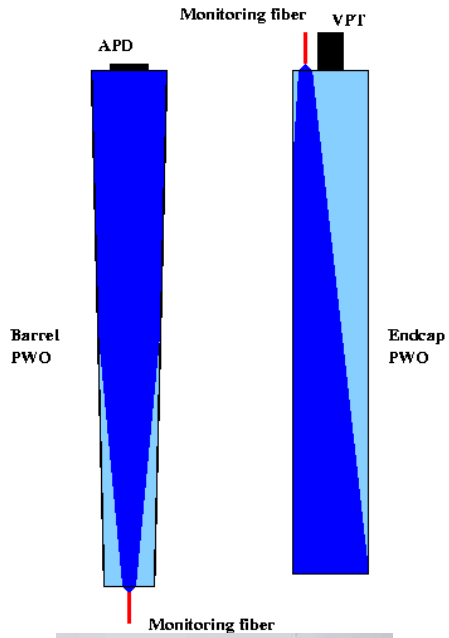
# Laser Light Distribution System

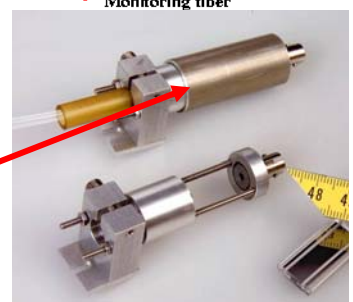
An optical fiber based two-level light distribution system designed and constructed by the Saclay group



Fibers at front for barrel crystal

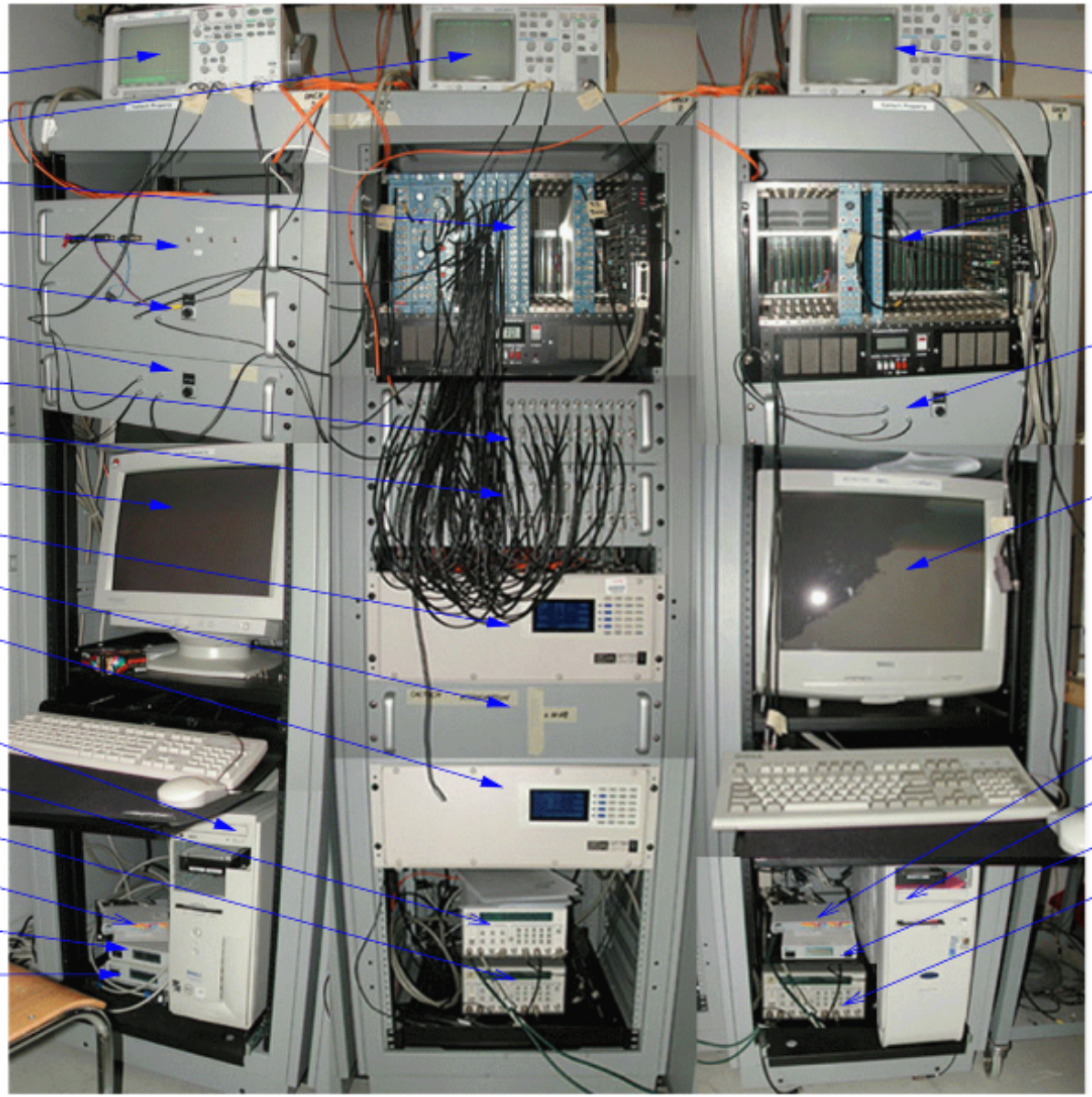
Fibers at back for endcap crystal



Integrating sphere based level-1 distribution for good uniformity

# Laser DAQ and Distribution System

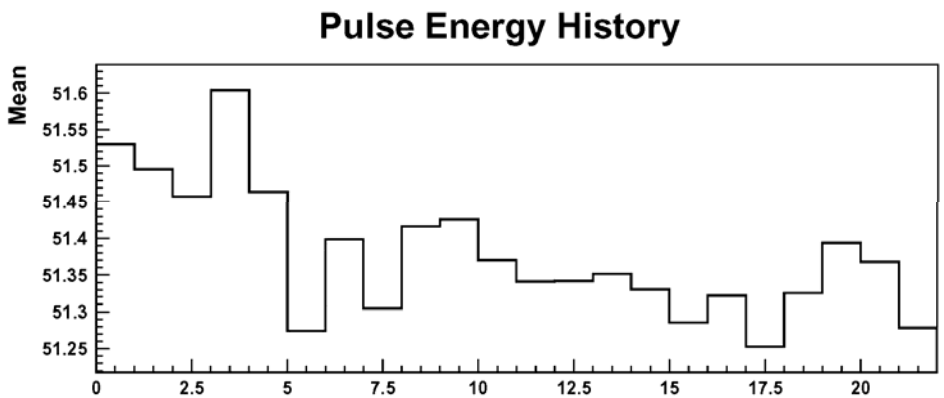


# Lasers Performance Monitoring


An Acqiris DP210 card of 2 GS/s was installed in 2004 to provide pulse energy, FWHM and timing information for each laser pulse.

Short (30 min)/long (25 h) term stabilities: < 2%/3%

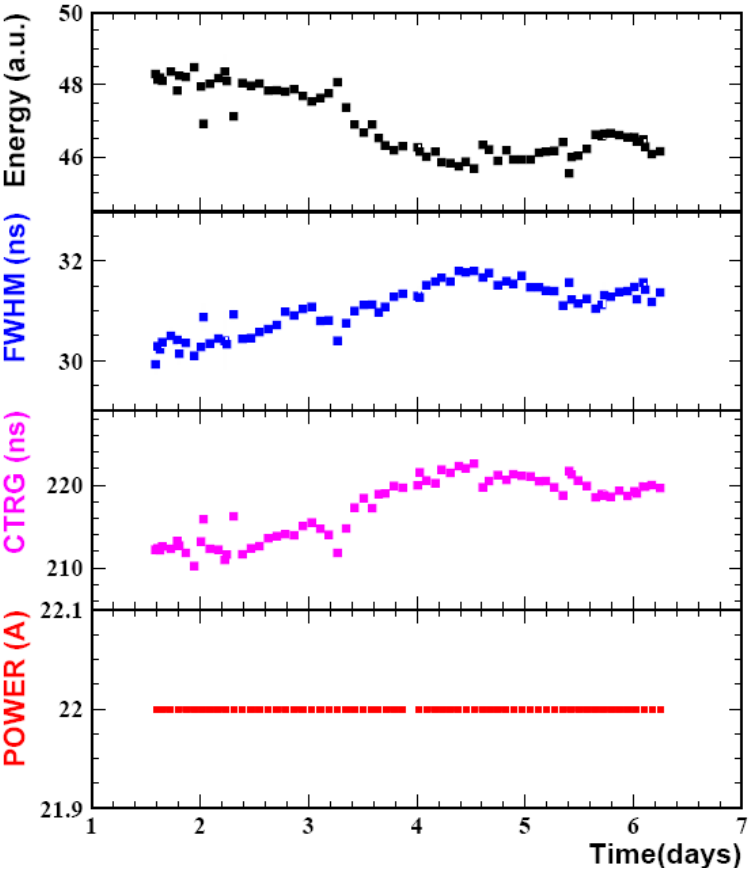
Lamp aging: 0.5% daily, leading to long term degradation.

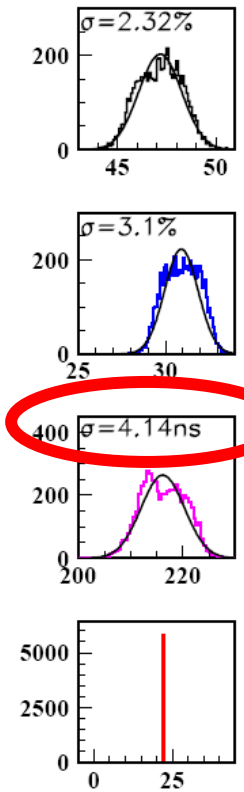


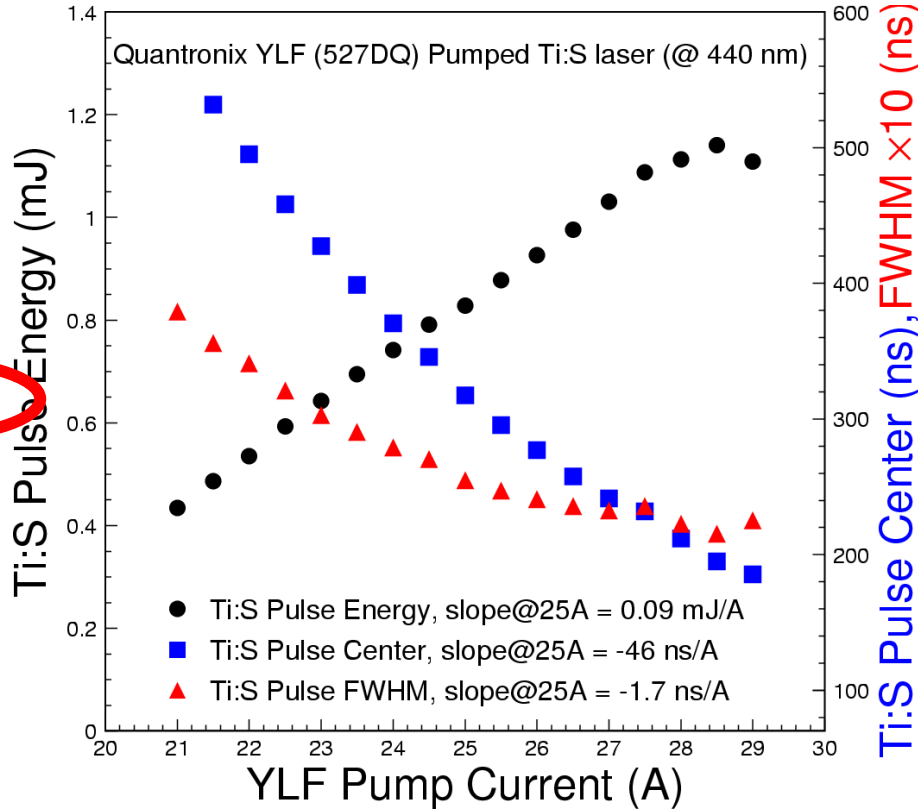
# Software Feedback to Reduce Jitters

Performance published in IEEE Trans. Nucl. Sci. vol. 52 pp. 1123-1130 (2005): 25 h stability of pulse energy & width: 3% and a long term degradation of laser pulse timing.

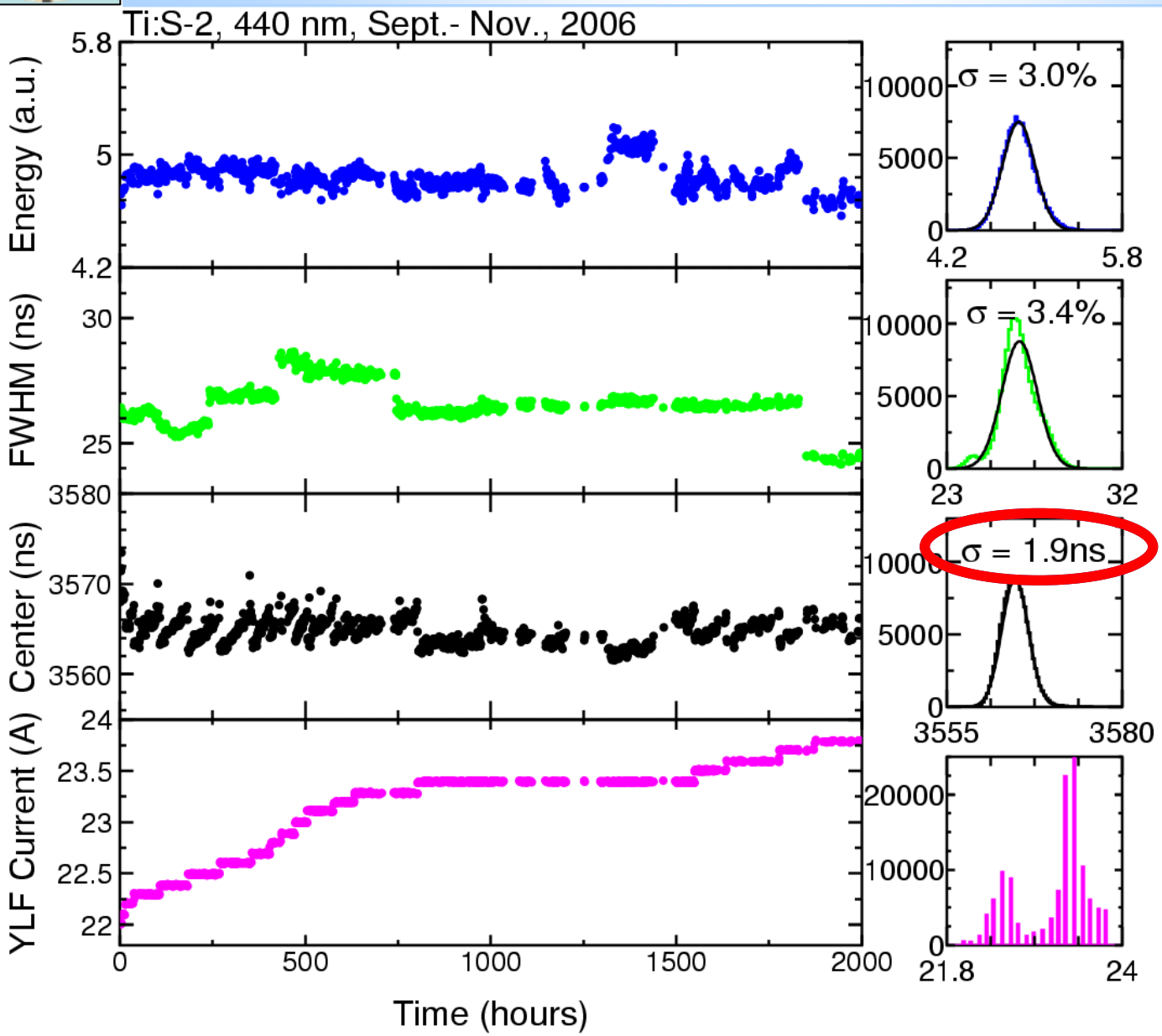
- Laser pulse intensity, width and timing are correlated to the YLF pumping current.
- Better pulse stability could be achieved by trimming the YLF laser pumping current.



# Performance with Software Feedback

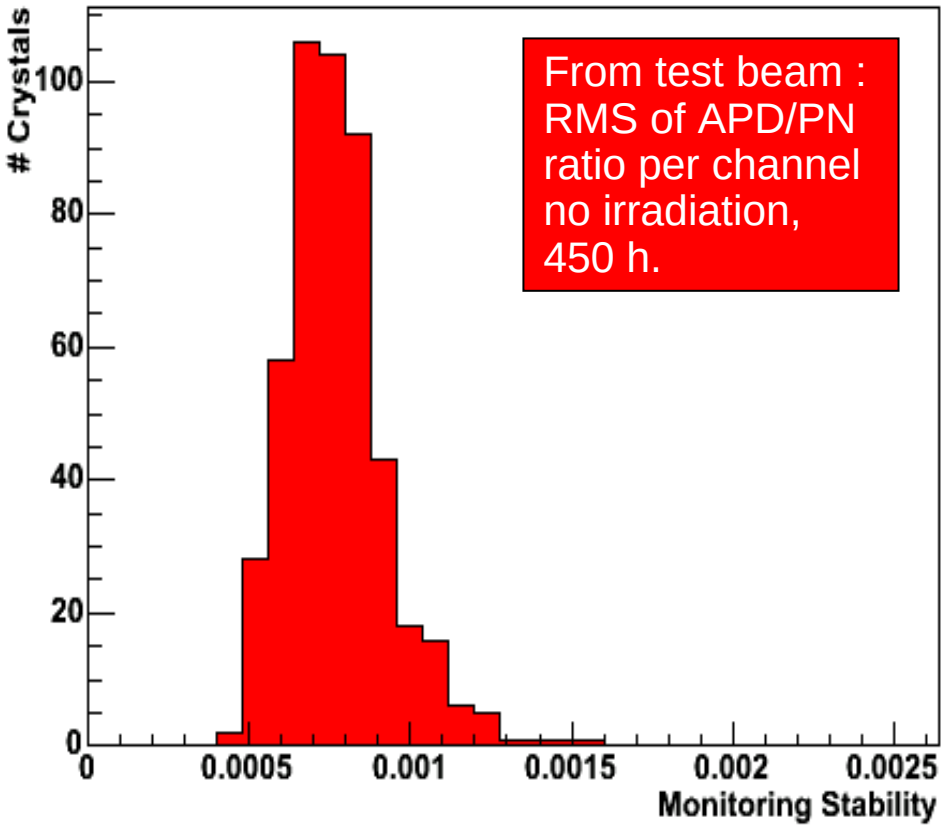


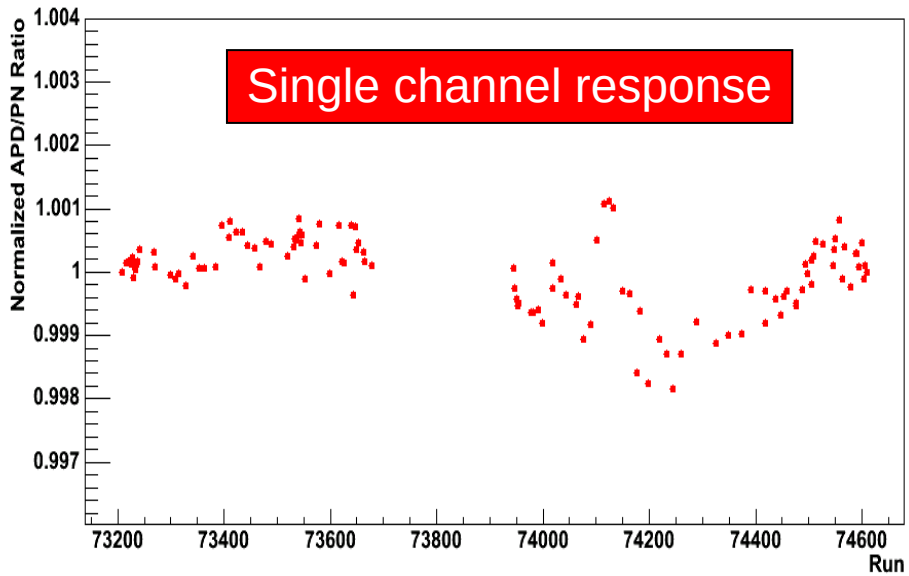

A factor of two better stability in laser pulse energy and width and a jitter of less than 2 ns were observed in laser runs lasting for about three months, when YLF current increased automatically at 0.1 nA steps.

# Monitoring System Stability

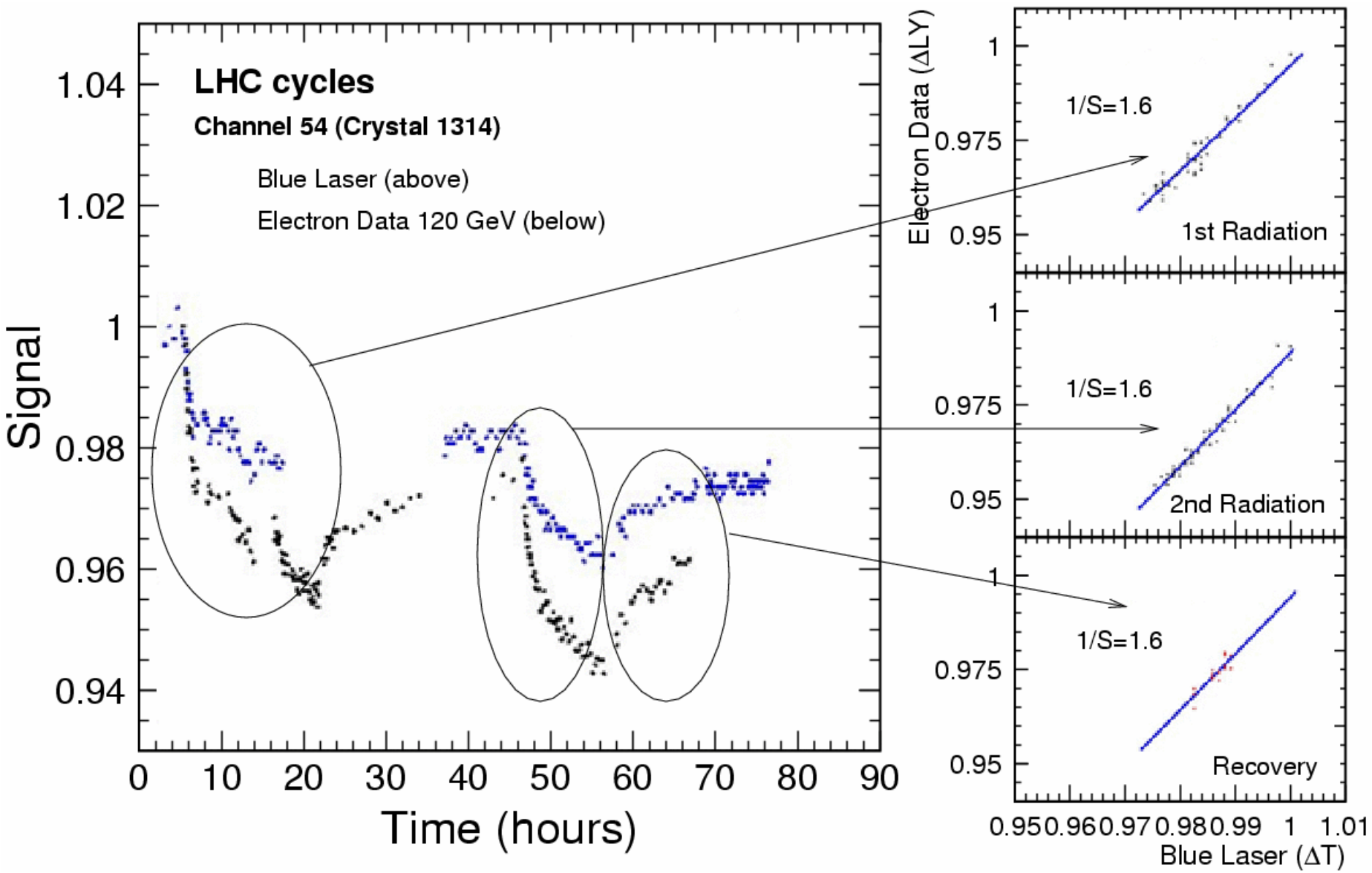
Typically ~0.1 % long term stability in real beam test environment, including the stability of the entire readout chain - temperature, HV, etc.

Transparency variation can be measured to 0.1%



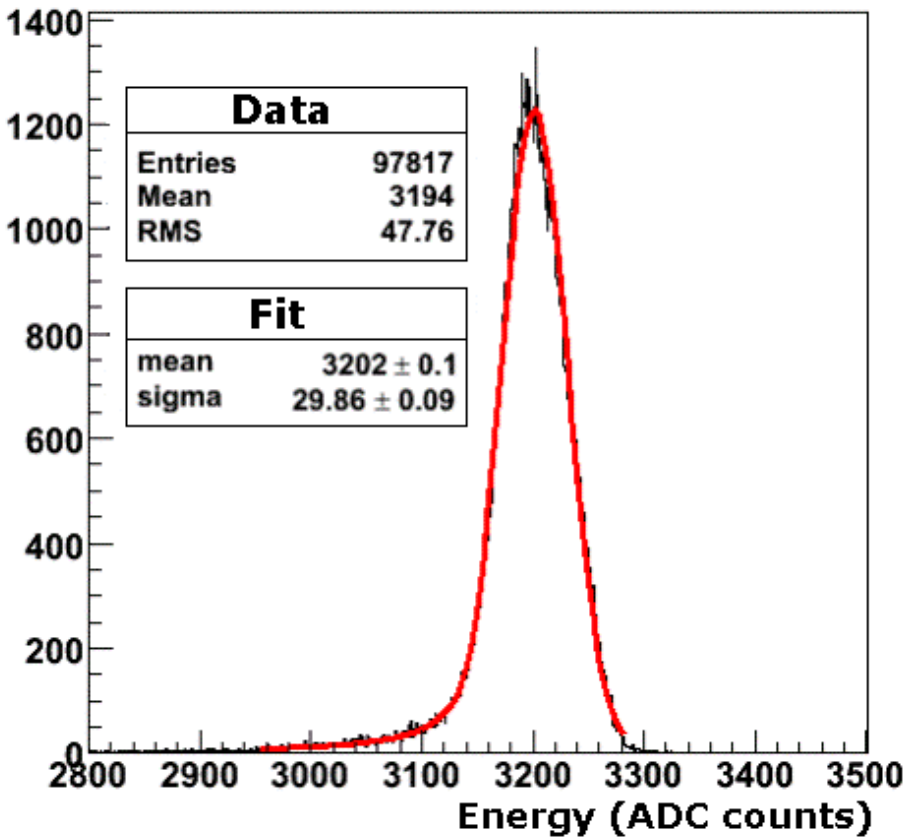



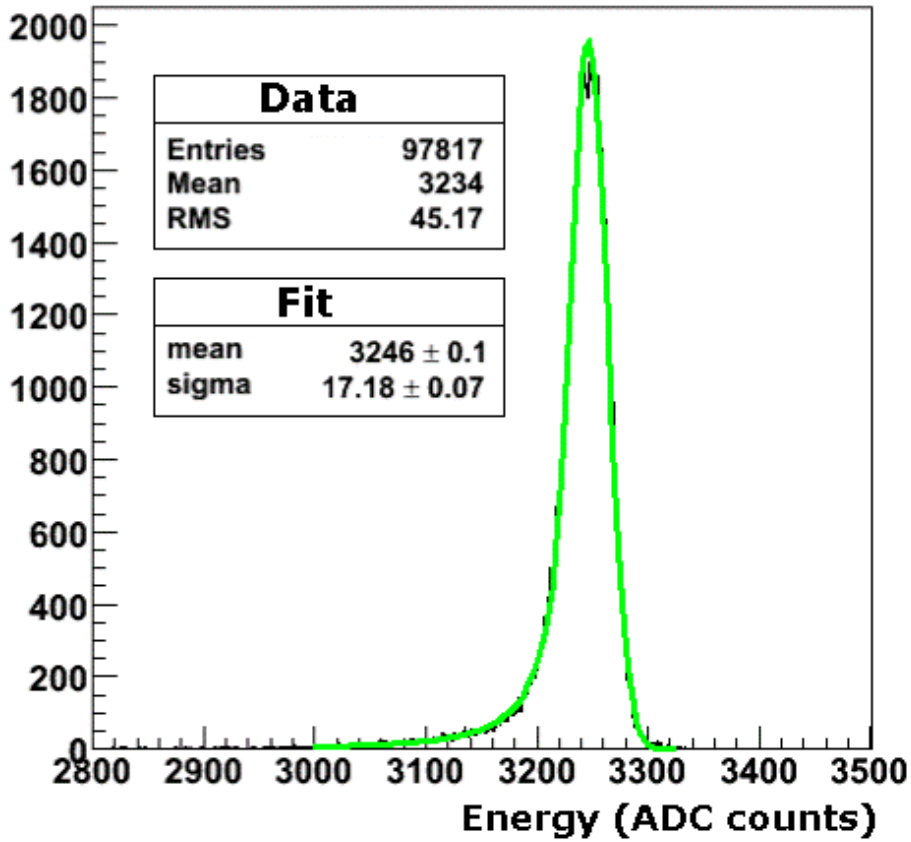
# Beam Irradiation Tests



# Laser Monitoring is Effective

120 GeV electrons reconstructed by 3x3 crystal matrix in irradiation test




| SM | Crystal | Res before | Res after |
|---|---|---|---|
| 22 | 168 | 0.93% | 0.53% |

# Summary

- A laser monitoring light source was designed and constructed at Caltech for the CMS ECAL, and was installed and commissioned at CERN since 2001.
- The 25 h laser performance satisfies the original specifications. With a software feedback, the long term (3 months) performance of the laser system also exceeds the design specifications.
- The laser monitoring system has been used in the CMS ECAL beam tests since 2001.
- Irradiation test beam data demonstrated that the laser monitoring is effective in maintaining the intrinsic crystal calorimeter resolution.