

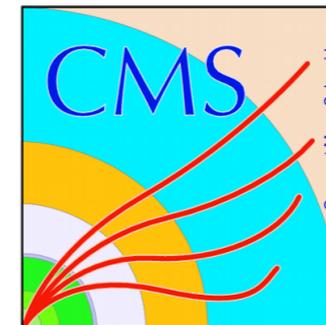


# The CMS ECAL Laser Monitoring system and its upgrade for High-Luminosity LHC

Bruno Lenzi (CEA / Université Paris-Saclay) on behalf of CMS ECAL

DPF2019

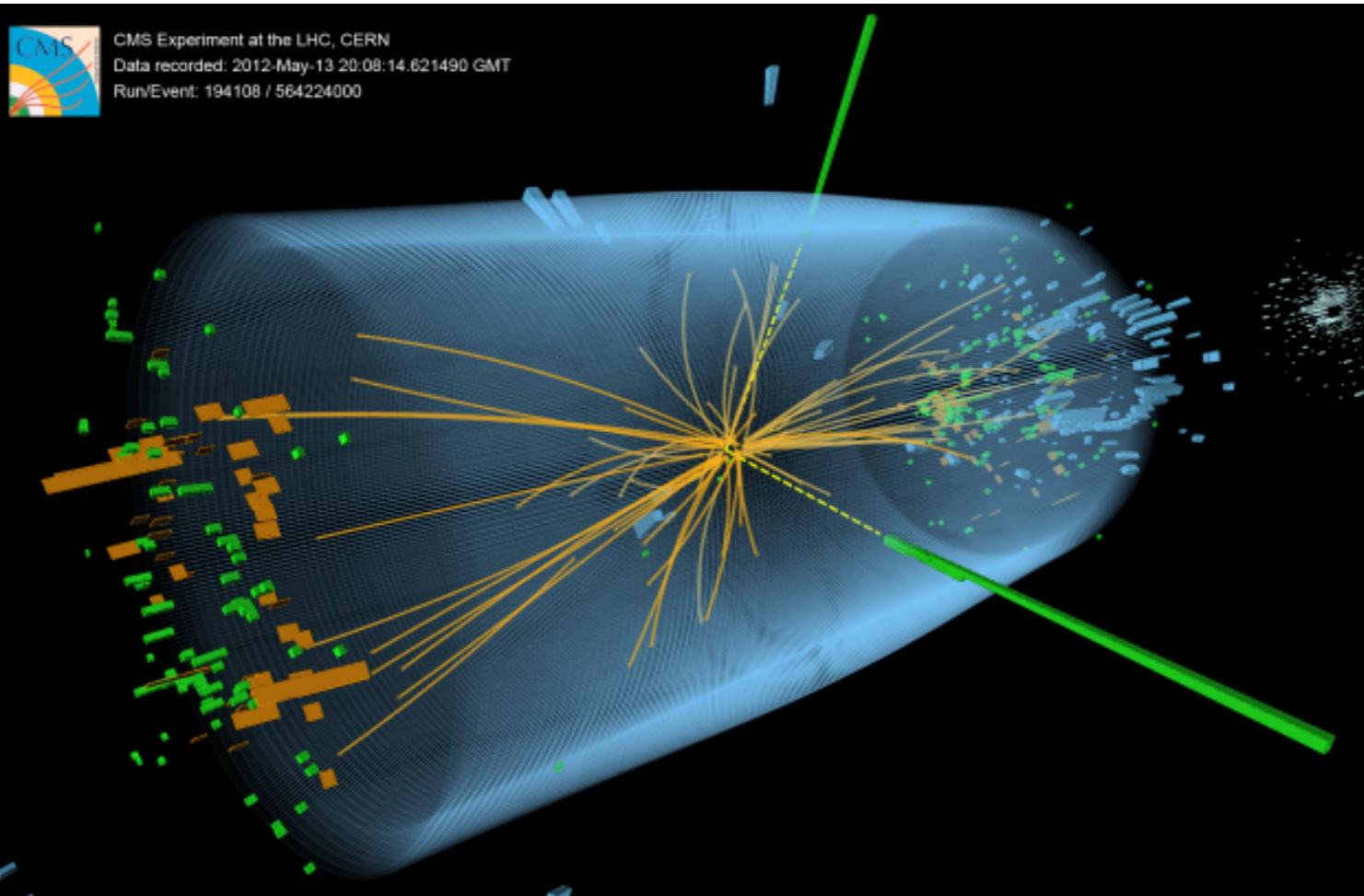
01/08/2019



# Electromagnetic Calorimetry at CMS

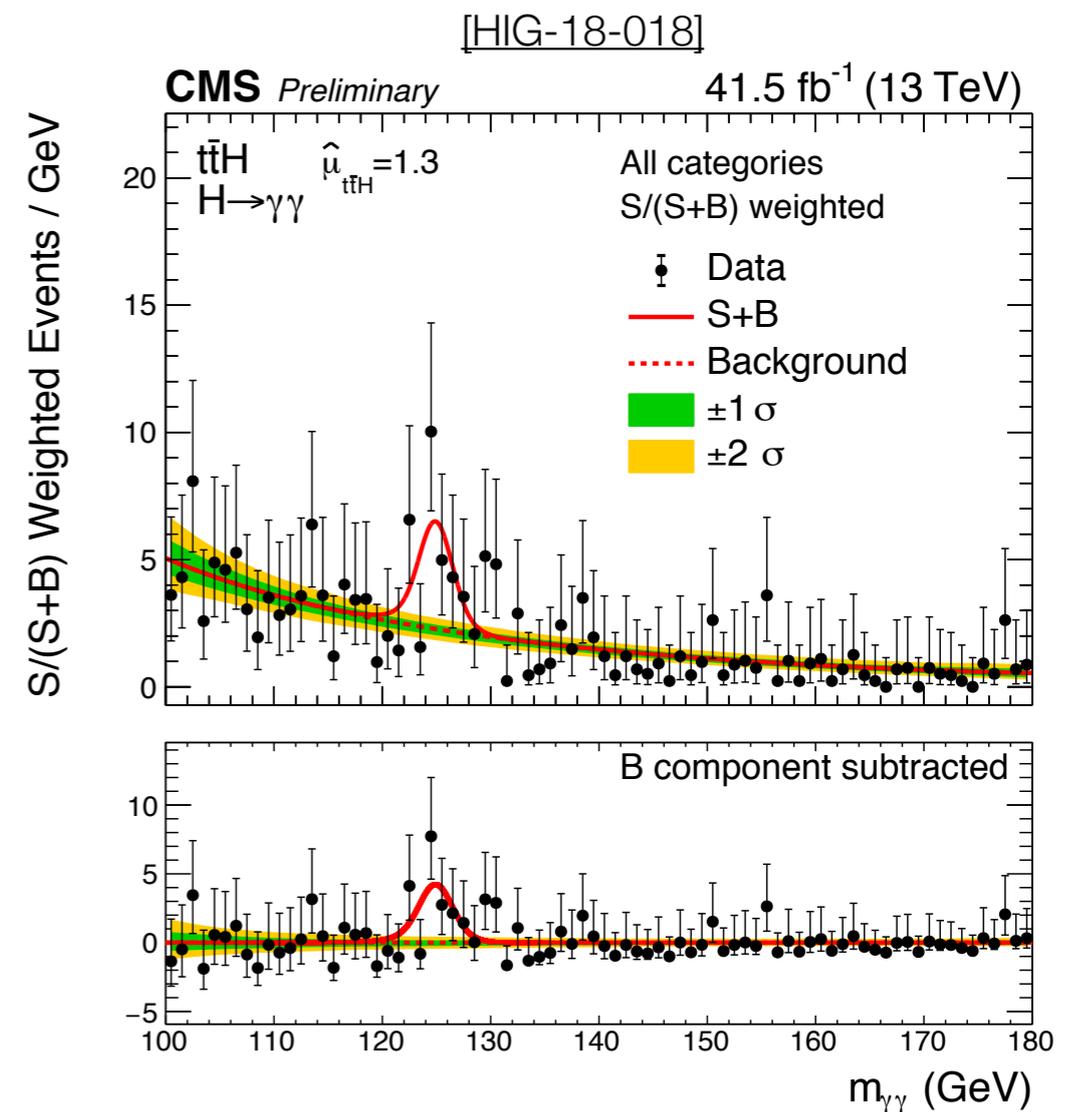
## Central role in the CMS physics program

[CMS-PHO-EVENTS-2012-005]



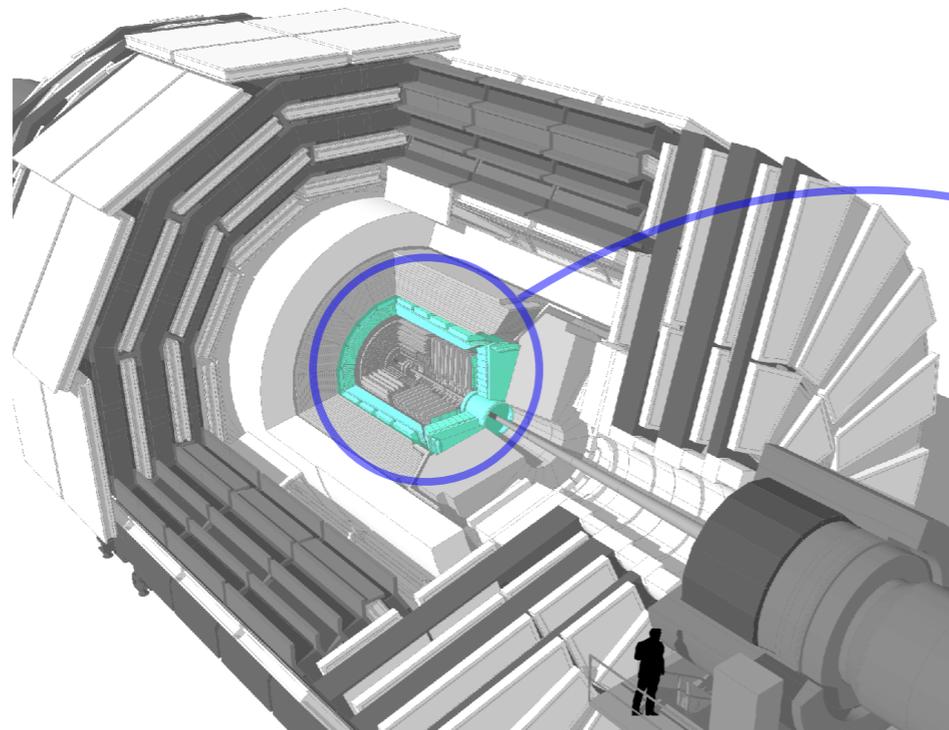
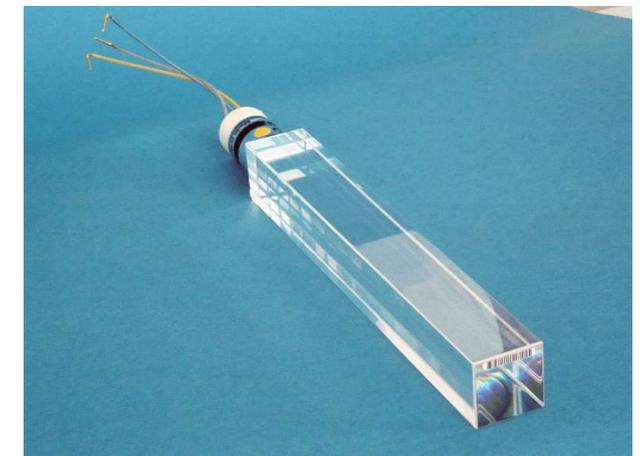
From the Higgs boson discovery...

... to the measurement of its properties and beyond

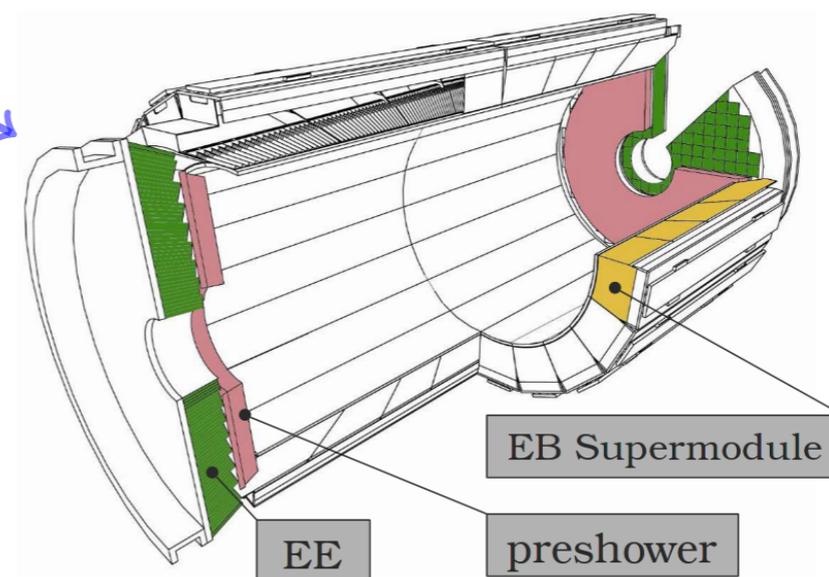


# CMS Electromagnetic Calorimeter (ECAL)

- Homogeneous, hermetic, high granularity  $\text{PbWO}_4$  crystal calorimeter
  - Compact: density 8.3 g/cm<sup>3</sup>, radiation length 0.89 cm, Molière radius 2.2 cm
  - Fast:  $\approx 80\%$  of scintillating light in  $\approx 25$  ns
- Barrel: 61200 crystals, Avalanche Photo-Diode (APD) readout
- Endcaps: 14648 crystals, Vacuum Photo-Triode (VPT) readout
- Preshower (endcaps only):  $3X_0$  of Pb/Si strips

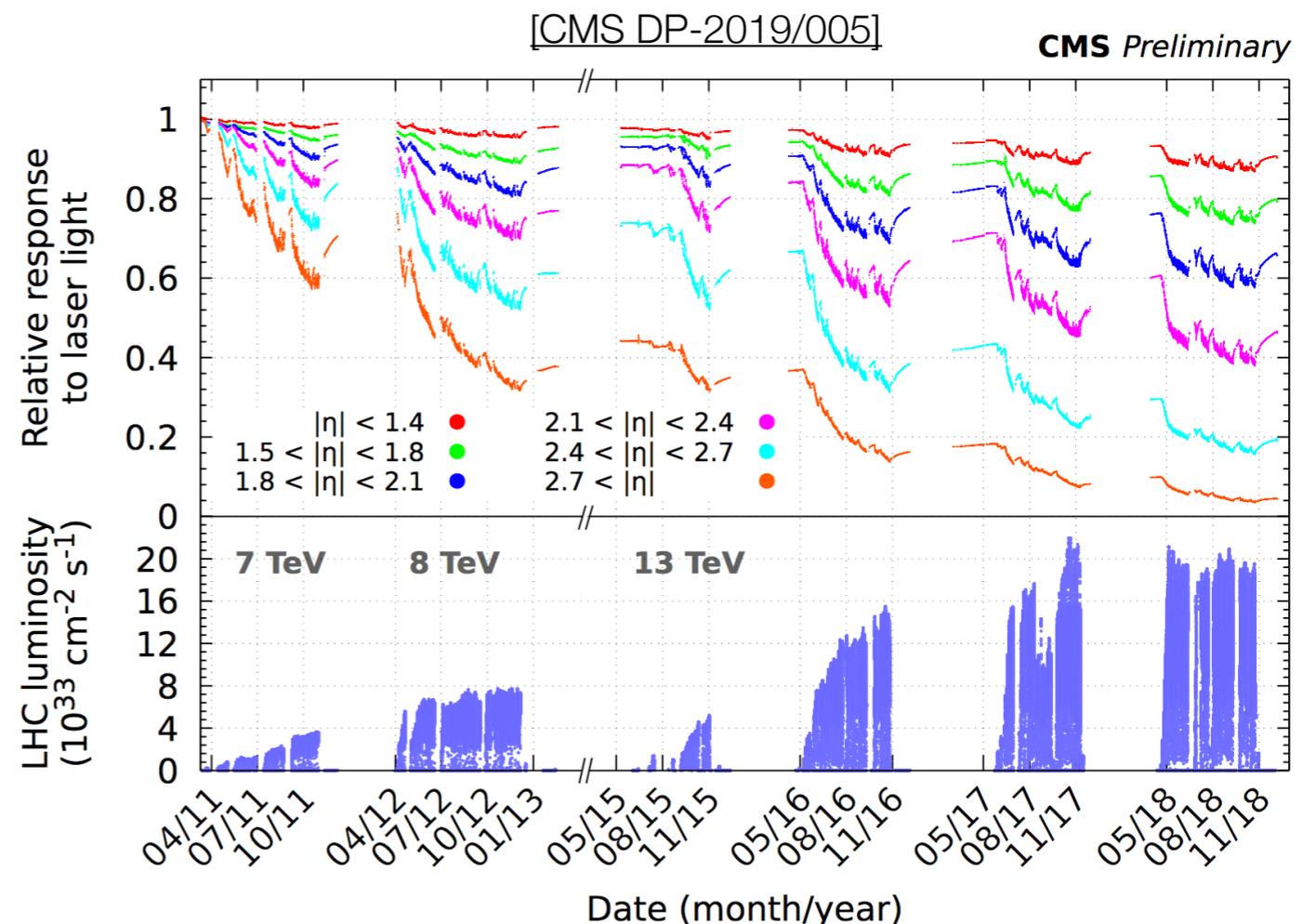


- Solenoidal magnetic field: 3.8 T  
ECAL fully contained in the coil
- CMS tracker coverage:  $|\eta| < 2.5$



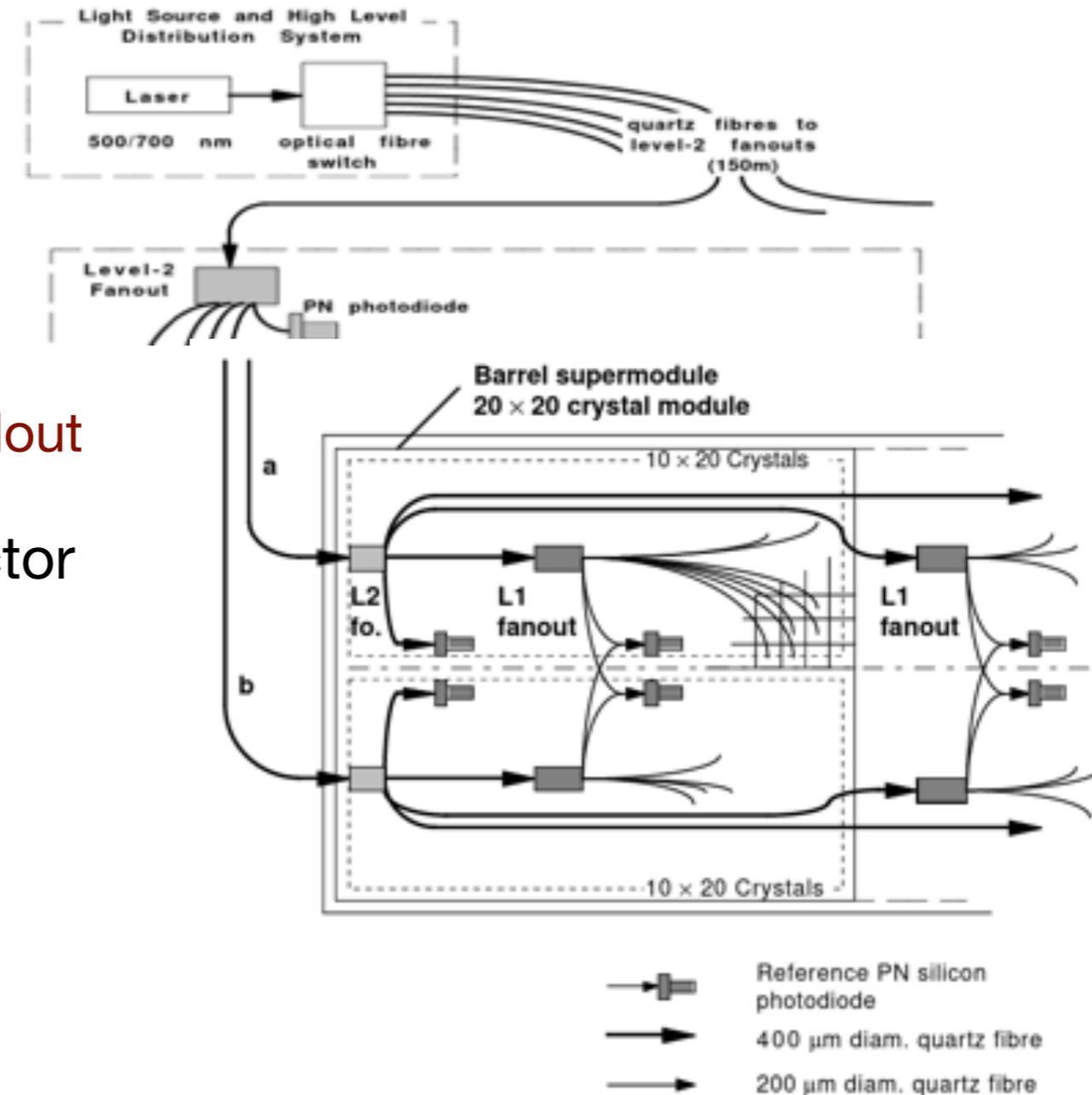
# Monitoring the ECAL crystal response

- Scintillation mechanism radiation hard but crystal transparency affected
  - Recoverable (EM) or not (Had)
- Laser light injected into every crystal during LHC abort gap @ 100 Hz
  - Blue (447 nm - close to scintillation peak) and green lasers (527 nm)
- Continuous measurements, 1 point / crystal every 40 min
- Corrections obtained and applied promptly (~48h)
- Expected precision: 0.2%



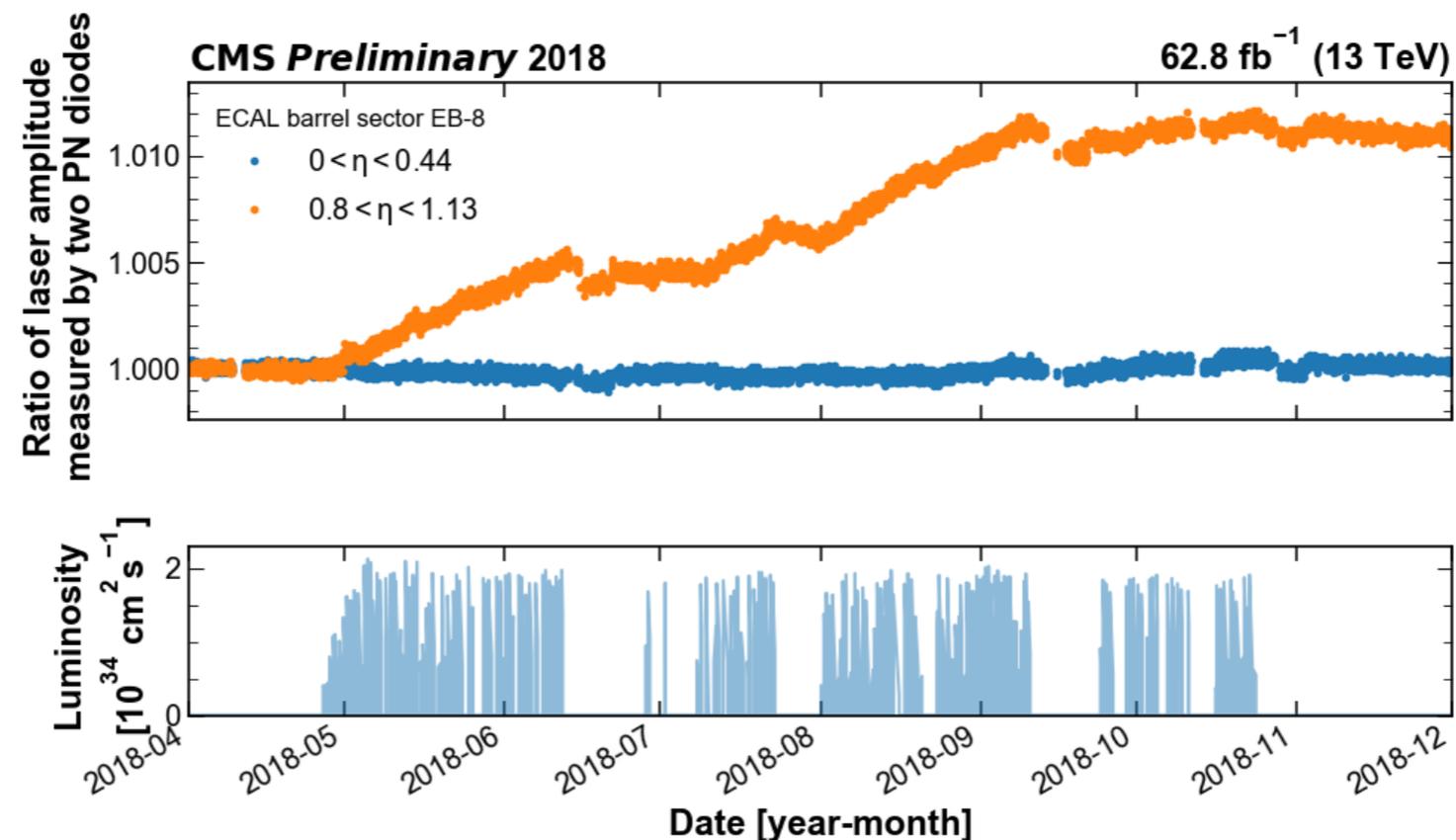
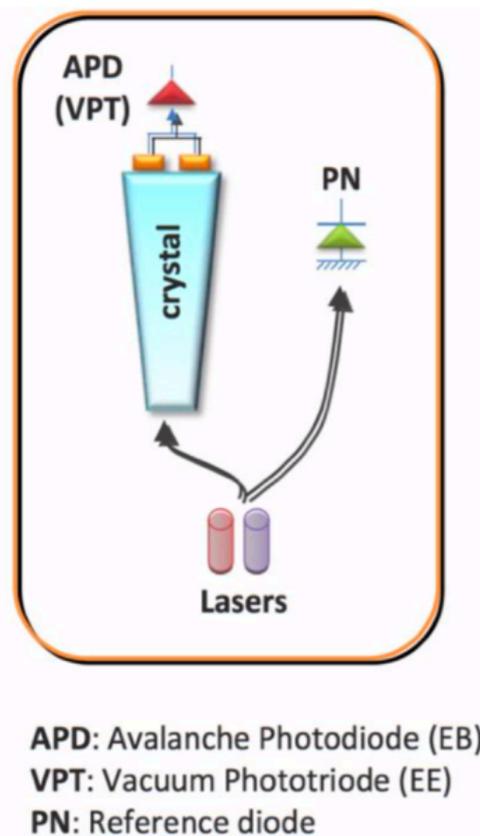
# The ECAL laser monitoring (LM) system

- Lasers in underground service cavern send light to crystals via multi-level optical fiber system
- Optical switch  $\rightarrow$  1/88 regions
  - Defined by laser power and ECAL readout
- Two-level distribution system on detector



# The ECAL laser monitoring system

- Laser pulse amplitude and shape measured at injection by PiN diodes
  - **Stability: few %**
- Reference PN diodes (radiation-hard) inside ECAL modules (100-200 crystals)
  - **Transparency obtained by APD / PN (VPT / PN), event-by-event**
  - **Redundancy allows to detect faulty PNs (at least one working in each module)**



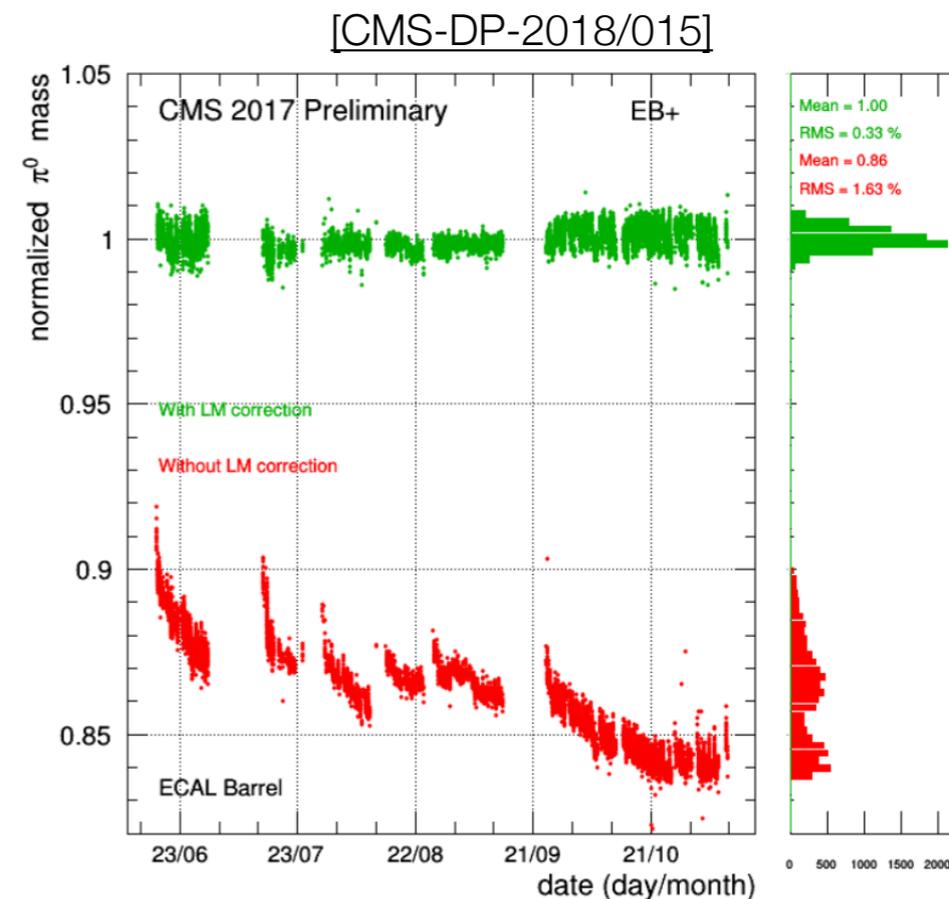
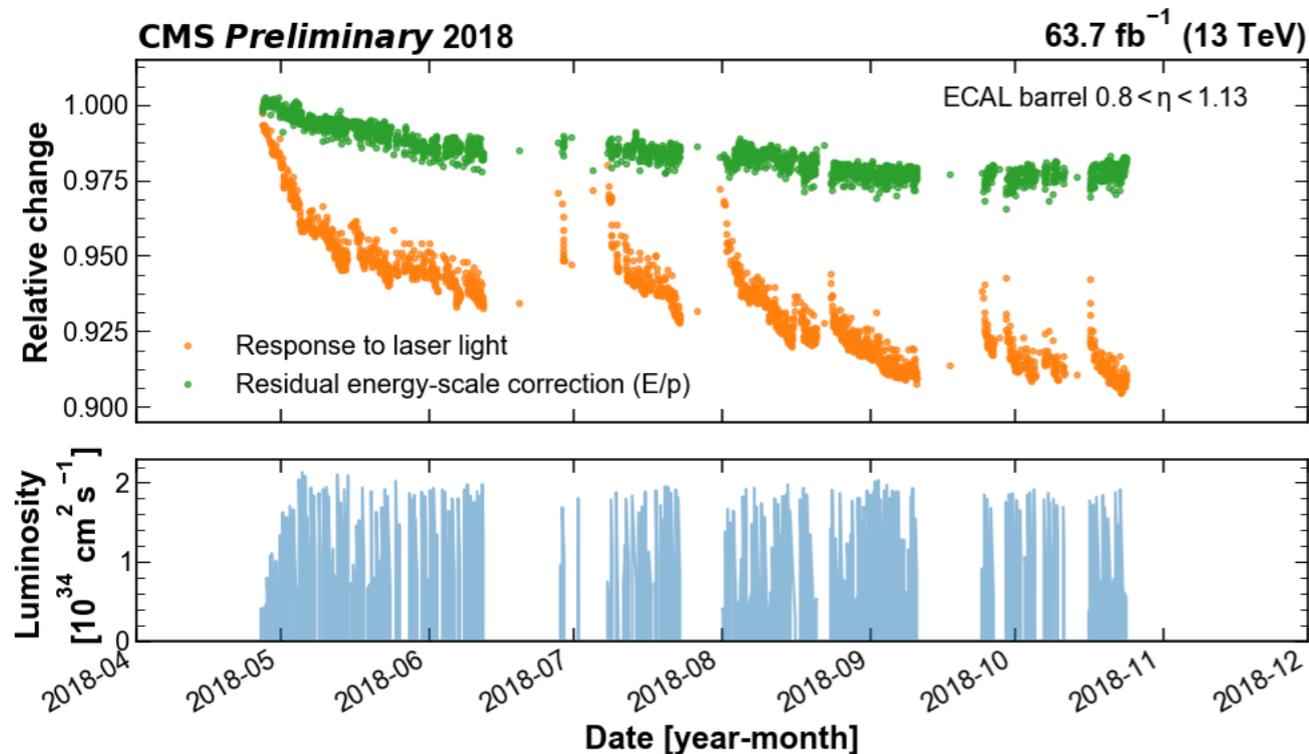
One bad PN  
 Both PNs good

# Performance of LM system

- Energy-scale corrections and checks using physics (E/p for W,Z;  $\pi^0$  mass)
- Below:  $\sim 1$  measurement / h for full  $\eta$  slice (or 15-20 min for half-barrel)
- Residual corrections after laser  $\sim$  few % for a whole year,  $\sim$  no dependence on instantaneous luminosity

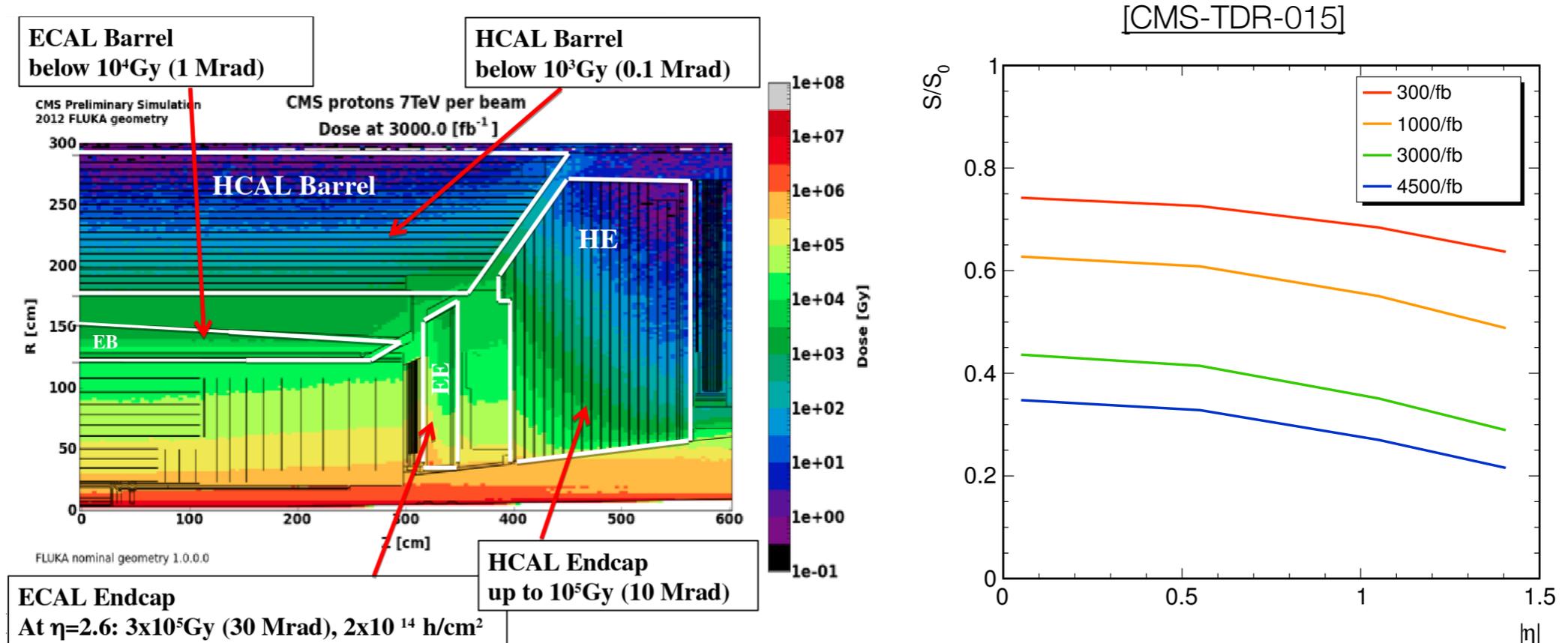
## $\pi^0$ mass after E/p corrections (2017)

### E/p (2018)



# High-luminosity LHC

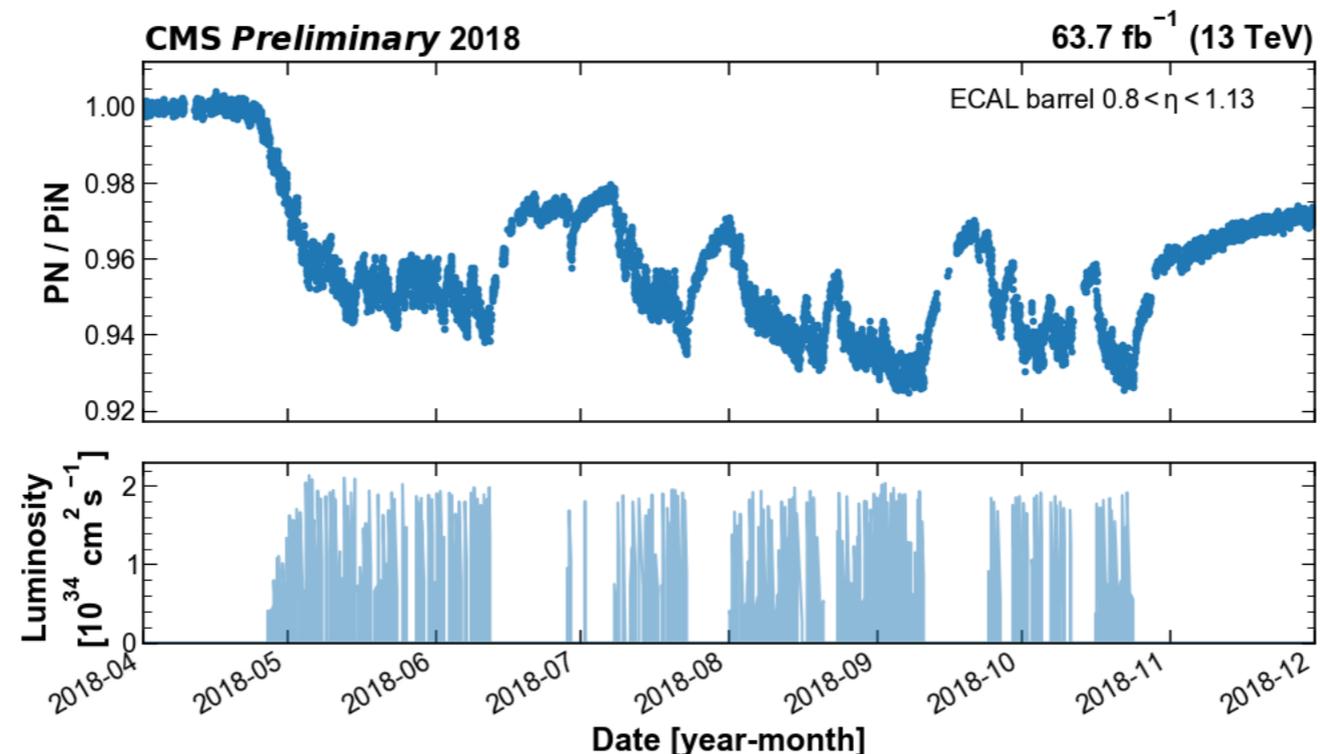
- Goal: 10x larger dataset for physics (3000-4000 fb<sup>-1</sup> in 2026-2038)
- Challenge: luminosity and radiation well beyond detector design
  - ECAL barrel crystals expected to loose < 50% of transparency (ok)
  - Upgrade of electronics for trigger and precise timing for e/γ
  - Endcap calorimeters replaced by HGCal (mostly Si)



# Limitations of the current ECAL LM system

- PN diodes tested at  $5 \times 10^{13}$  n/cm<sup>2</sup>, 2kGy ( $\sim 500$  fb<sup>-1</sup>)
  - Only 0.7% Q.E. loss but few already show strange behaviour
- Fibers darkening with radiation
  - Essential to keep the injected light measurement inside the detector (PN diodes)
- Electronics not compatible with readout scheme for HL-LHC

## Laser amplitude inside detector / at injection, normalised

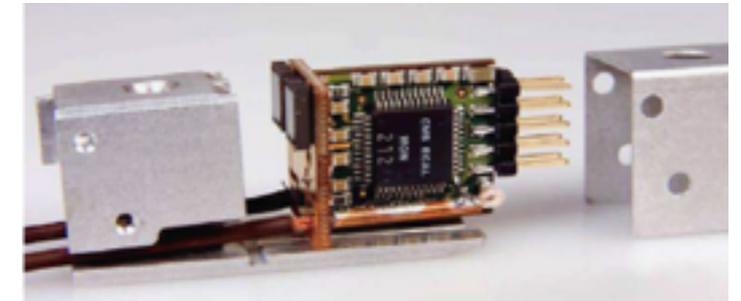


# Planned upgrade of ECAL LM system

- Use part of existing mechanics and upgraded ECAL electronics
- Upgraded electronics to be compatible with HL-LHC design and more radiation-hard
- Increase redundancy of PN diodes (x2)
  - Better identify problematic ones and minimize chances of having dead zones
- Keep the current fibers
  - Irradiation tests planned to qualify them for HL-LHC conditions

# Planned upgrade of ECAL LM system

- New front-end ASIC to read PN diodes, being designed
  - Dual gain (x1 and x10) stand-alone chip, 130 nm technology
  - Test-pulse with external reference
  - Differential output signal
- Concentrator board compatible with HL-LHC electronics
  - 24 channels per board (was 10)
  - Same ADC as upgraded ECAL, 80 MSa/s for each gain
  - Default DC-DC converters, existing mechanics
  - Distribute test-pulse and power lines to front-end
- Data from PN diodes sent to CMS DAQ, to be embedded in ECAL data
- New laser control board: interface to CMS trigger and DAQ systems
  - Digitized laser pulse measured at injection also included



# Conclusions



- Laser monitoring system essential for ECAL (and CMS) performance
  - Quasi real-time measurement of crystal transparency
  - Performed extremely well during LHC runs 1 and 2
    - From tens of % to few ‰, combined with physics data
- Planned upgrade for high-luminosity LHC to ensure good performance for another 10-15 years
  - Readout electronics compatible with new CMS / ECAL
  - Increase redundancy and improve radiation hardness in challenging environment