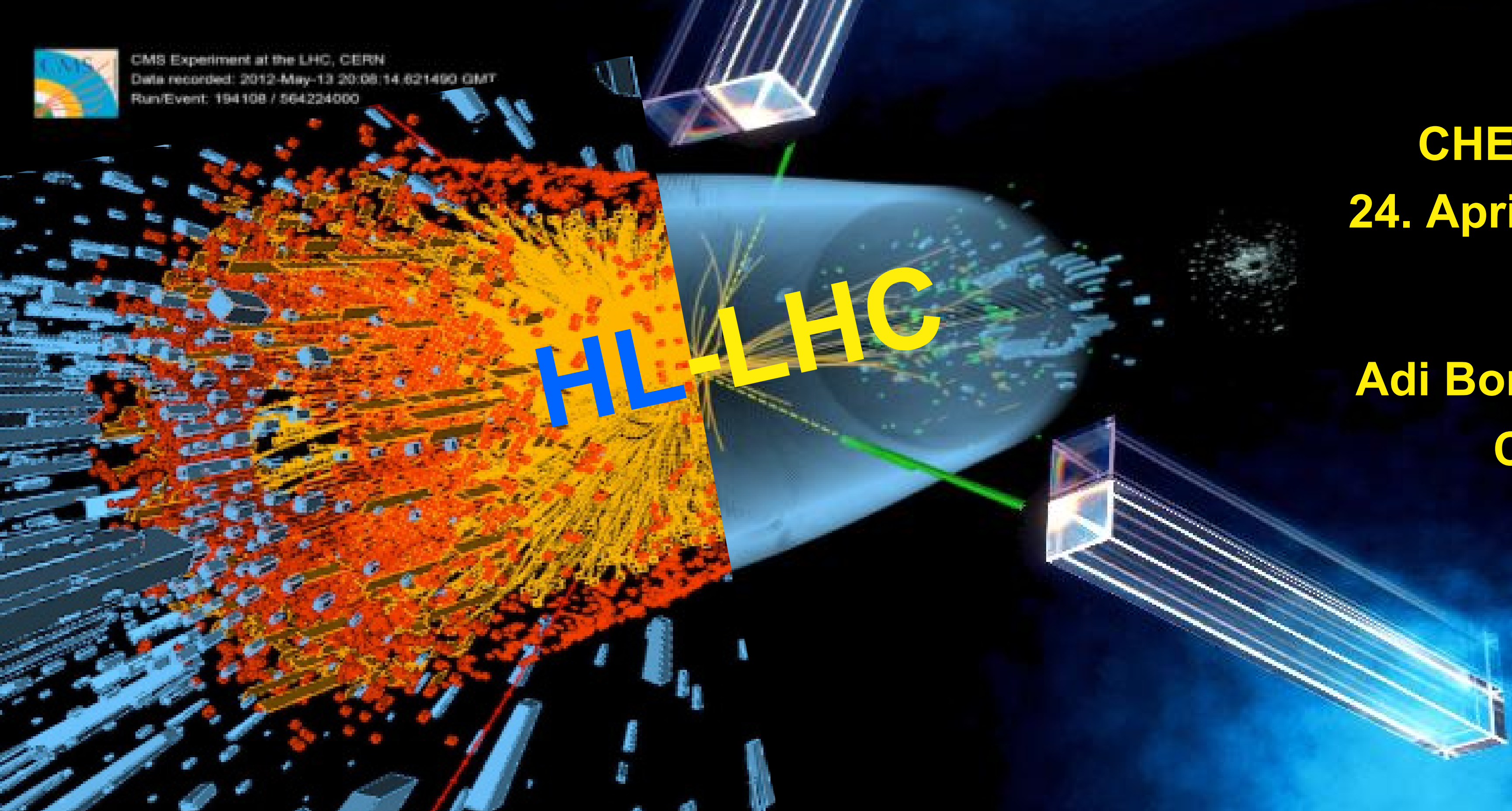
Evolution of the CMS ECAL response, R&D studies on new scintillators and possible design options for electromagnetic calorimetry at the HL-LHC



CHEF 2013

24. April, 2013

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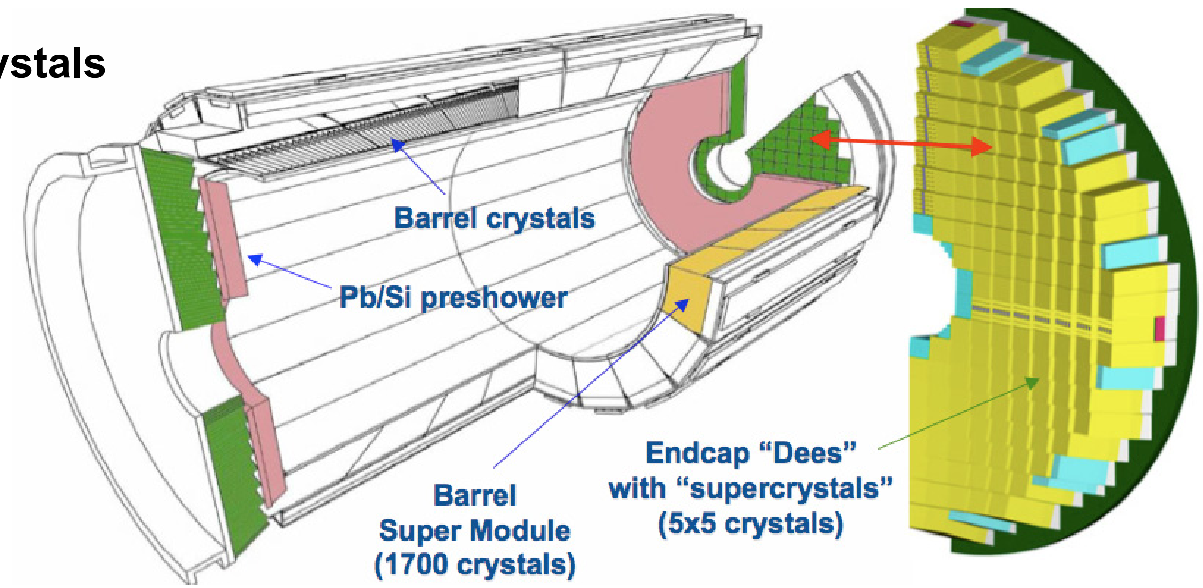
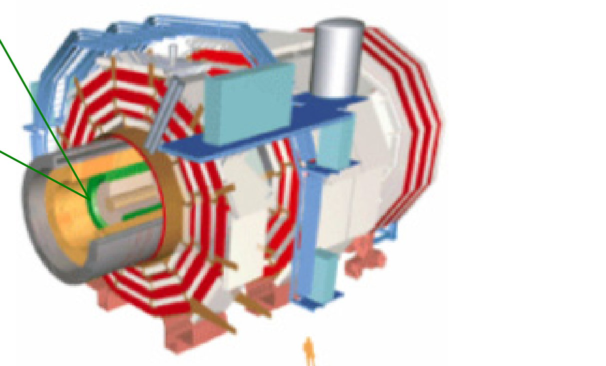
Caltech

CMS ECAL

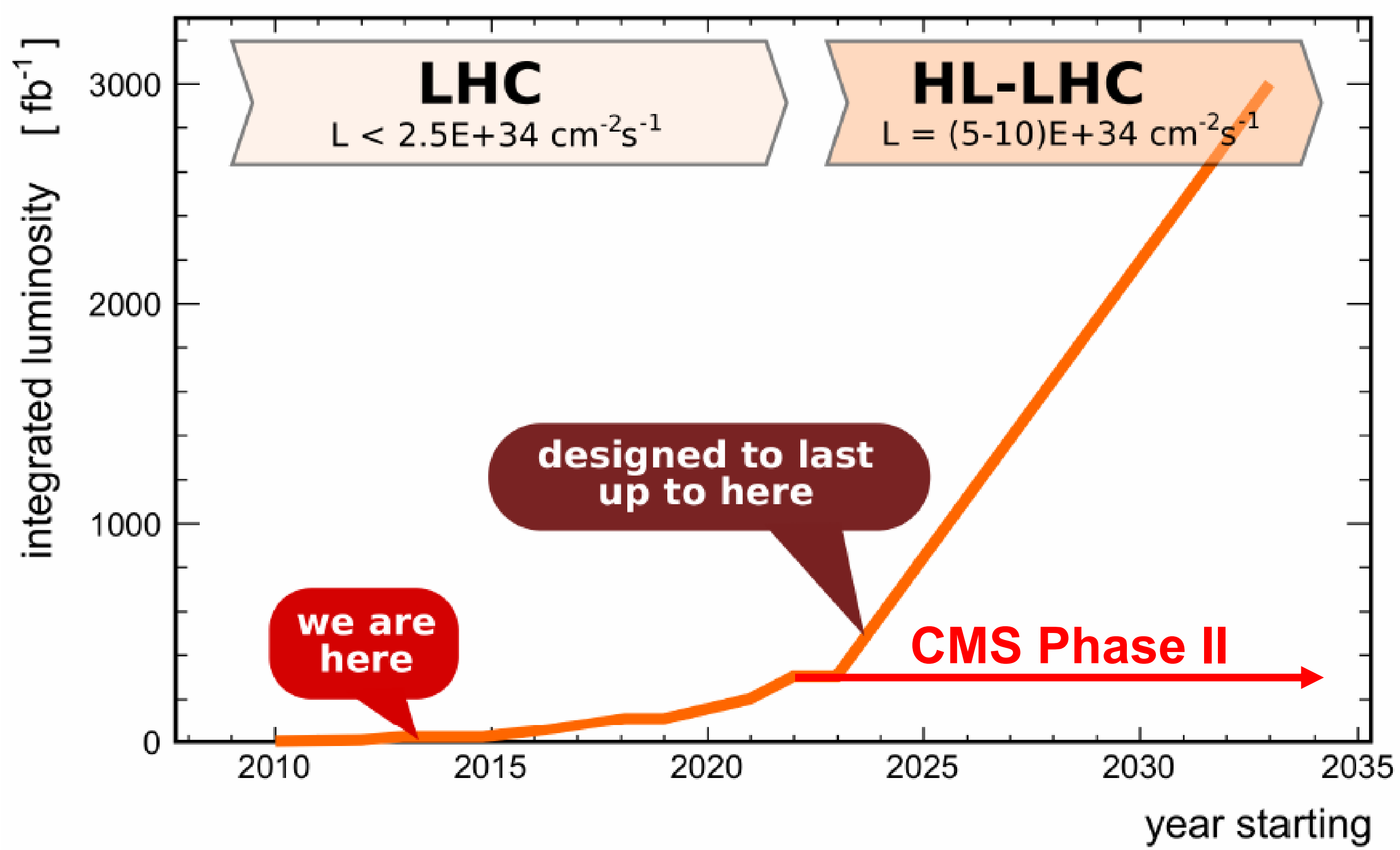
- Homogeneous, compact, hermetic, fine grain $PbWO_4$ crystal calorimeter
  - → Emphasis on energy resolution
  - → No longitudinal segmentation (except preshower)
- **Barrel (EB) :**
  - $|\eta| < 1.48$
  - 36 Super Modules: 61200 crystals
  - ($2.2\times2.2\times23$ cm^3) ~$26X_0$
- **Endcaps (EE) :**
  - $1.48 < |\eta| < 3.0$
  - 4 Dees:14648 crystals
  - ($3.0\times3.0\times22$ cm^3) ~$25X_0$
- **Preshower (ES) :**
  - $1.65 < |\eta| < 2.6$
  - $3X_0$ of Pb/Si strips
  - 1.90×61 mm^2 x-y view
- CMS Characteristics:
  - Tracker coverage: $|\eta| < 2.5$;
  - CMS Magnetic field: B = 3.8 T
  - ECAL fully contained inside the coil





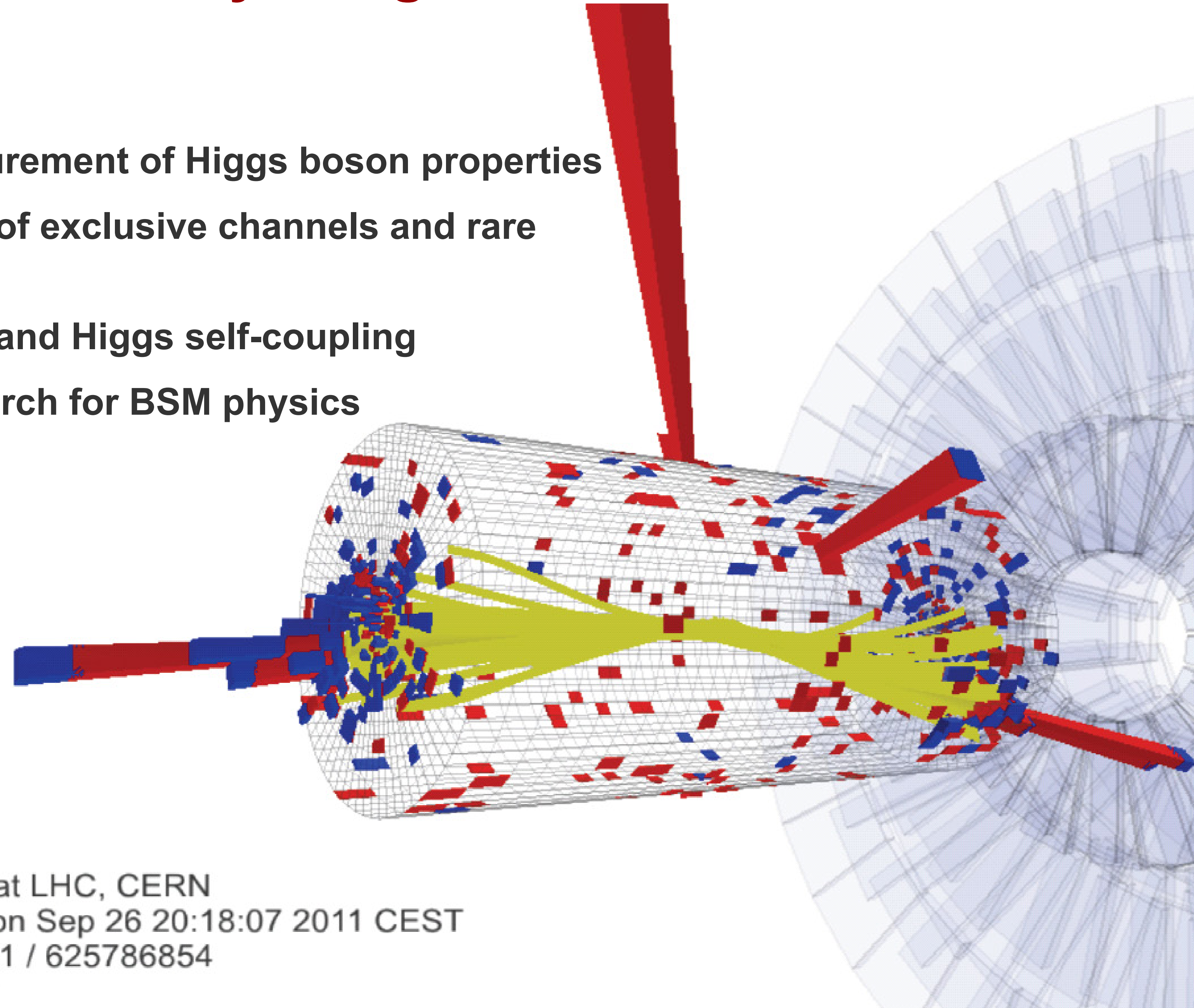
HL-LHC Upgrades – CMS Phase II

- Anticpated time frame >2022 to beyond 2032.
- Integrated luminosity : 3000 fb^{-1} (today :30 fb^{-1})
- $L_{peak} = 10^{35}$ $cm^{-2}s^{-1}$, leveled to 5×10^{34} $cm^{-2}s^{-1}$ (today : 7.7×10^{33} $cm^{-2}s^{-1}$)
- Expect >100 pile-up interactions per bunch crossing



Physics goals for HL-LHC

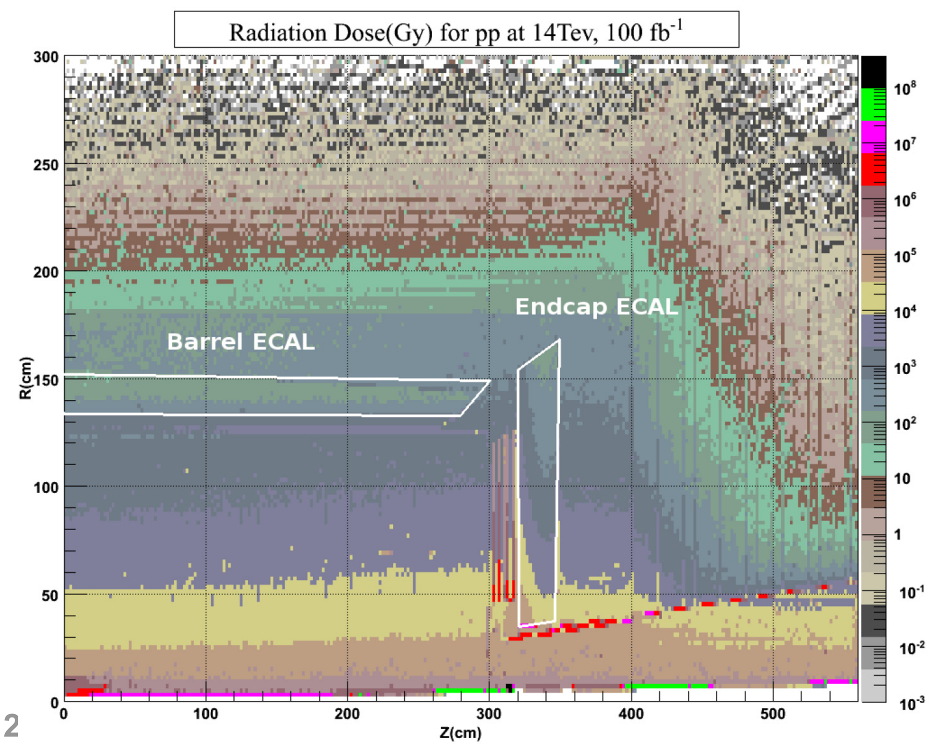
- Precise measurement of Higgs boson properties
- Measurement of exclusive channels and rare decays
- VV-scattering and Higgs self-coupling
- Continued search for BSM physics

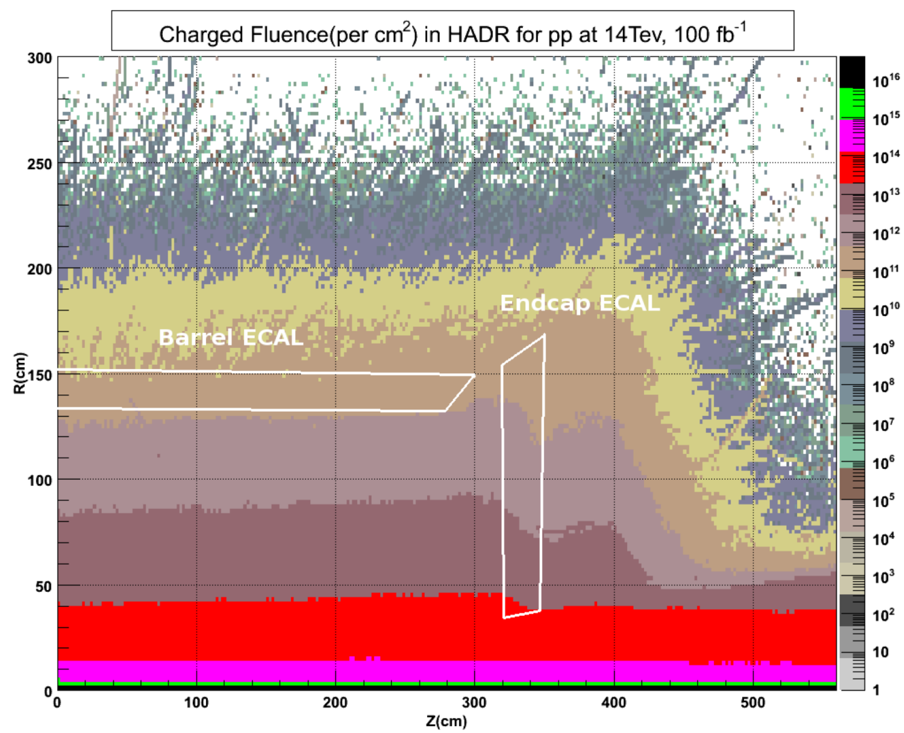


Radiation levels in CMS

- Radiation levels uniform in EB, strong dependence on η in EE
  - Radiation dose at the EM shower max for $L = 10^{34}\ cm^{-2}s^{-1}$:
    - 0.3 Gy/h in EB
    - 6.5 Gy/h at η=2.6
  - Charged fluence per cm^2 for L_{Int} = 500 fb^{-1}
    - 4×10^{11} in EB
    - 3×10^{13} in EE at η=2.6

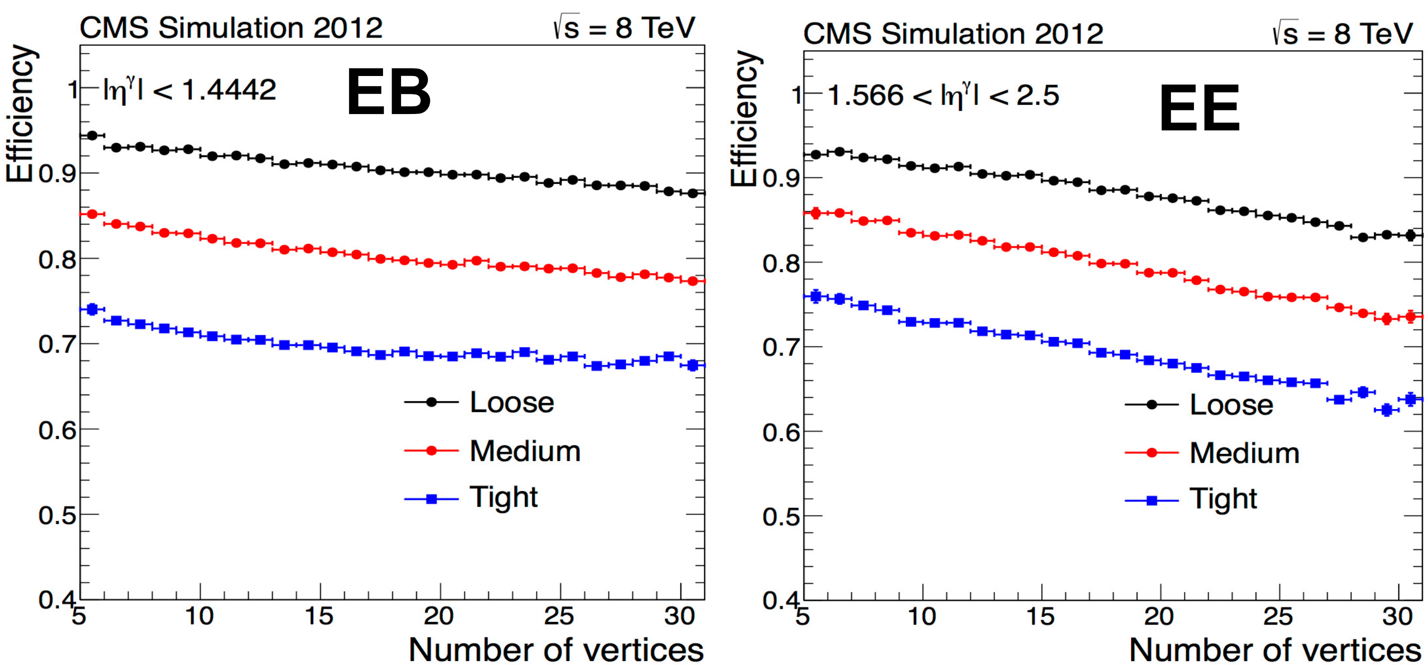
MARS calculations,
P.C. Bhat et al., CERN-CMS-NOTE-2013-001





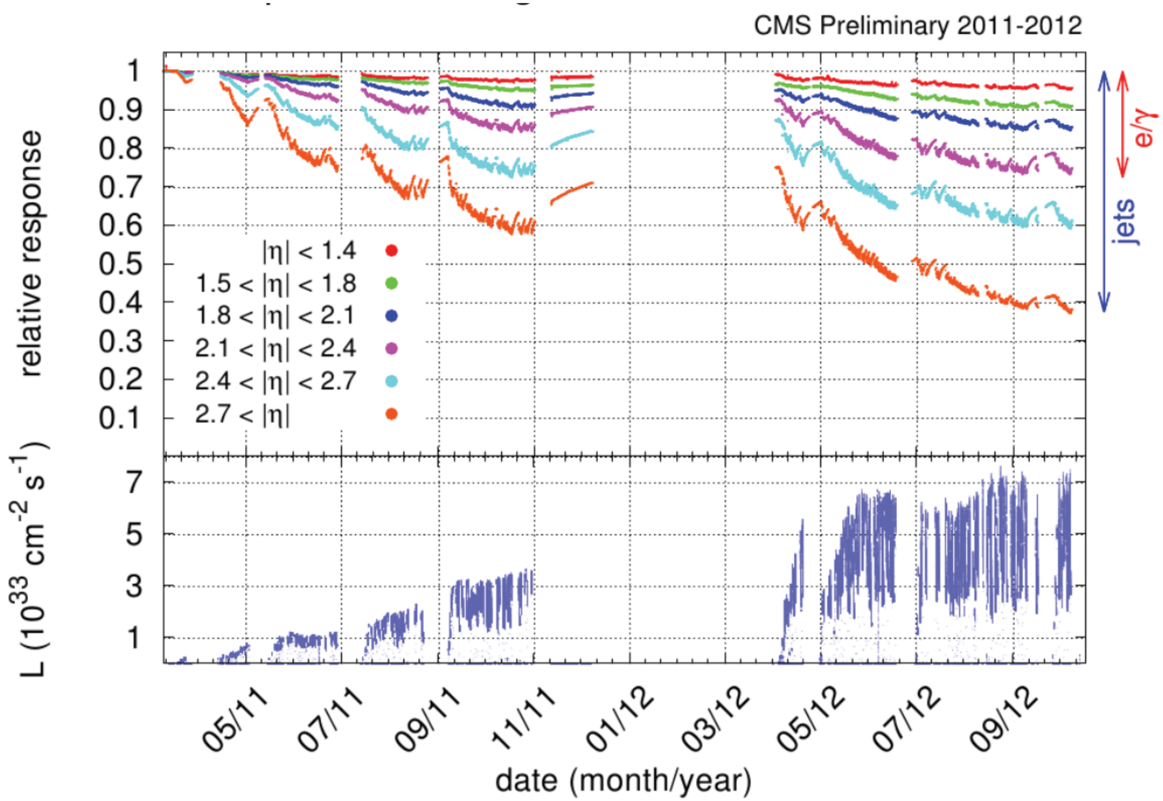
Additional Challenges for HL-LHC

- To achieve luminosity target, LHC will need to operate with more than 100 pile-up interactions.
- In-time and out-of-time pile-up activity will have a significant impact on physics object performance.
- Present ECAL may not have sufficient granularity to maintain performance.
- Example : Cut-based photon identification efficiency vs pile-up.



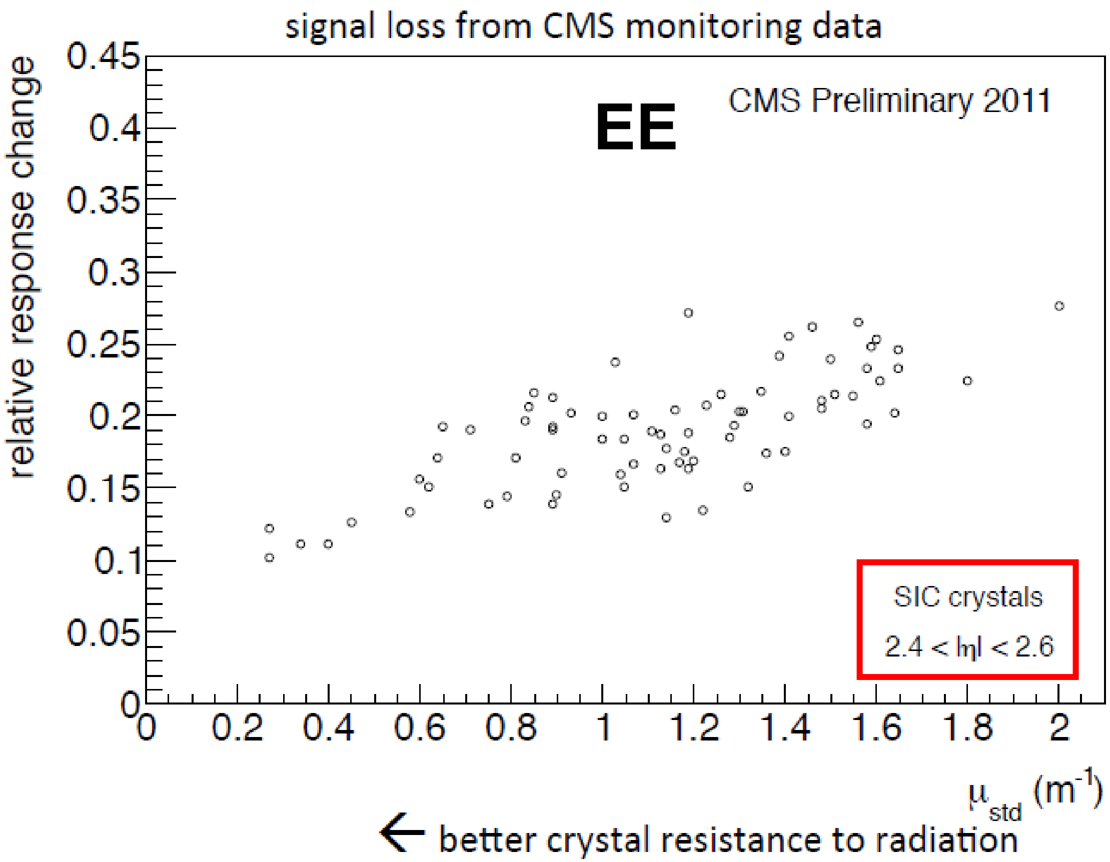
Evolution of the CMS ECAL response

- Short term ECAL response variations measured with light monitoring system.
- Additional long term corrections with physics calibration.
- Response change currently dominated by transient, dose rate dependent ionisation effects (`EM damage`).
- See presentations by M. Dejardin and M. Obertino (Monday).



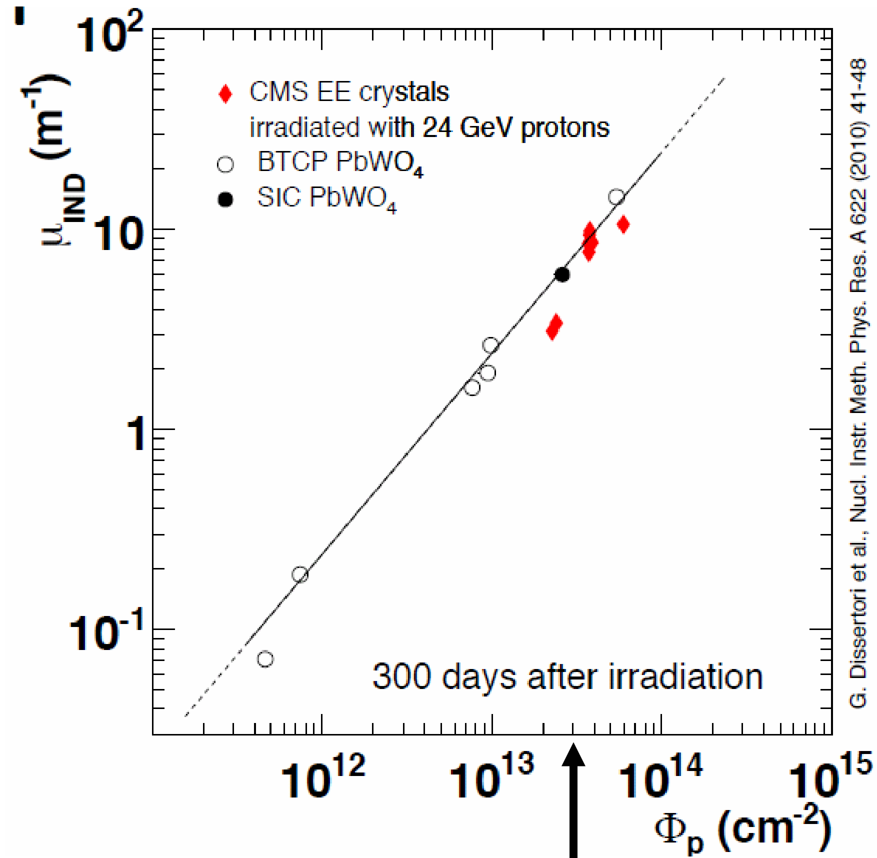
Response evolution ECAL EE

- **Response change correlates with crystal raditation hardness (μ_{ind}) measured as quality control with standardized γ irradiation.**
- **Non-zero intercept suggests additional effects uncorrelated with crystal properties (eg. conditioning of photo detectors).**



Proton Induced Crystal Damage

- Hadron fluence causes damage to the crystals by a different mechanism.
- Does not recover at room temperatue, cumulative with luminosity.
- Results in transparency loss as for EM induced damage, however damage depth profile different.
- Performance of crystals from different producers (BTCP, Russia and SIC, China) identical.

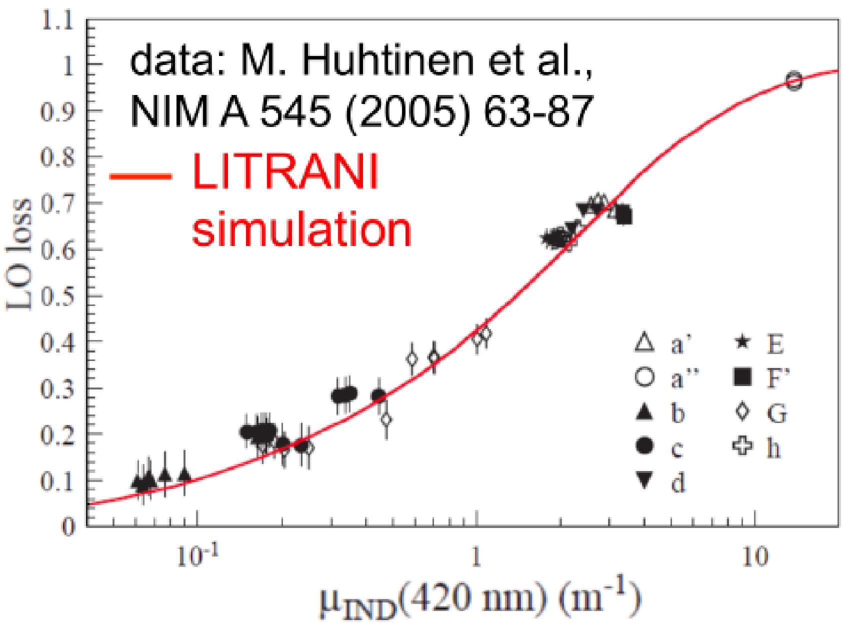


EE at η=2.6, 500 fb^{-1}

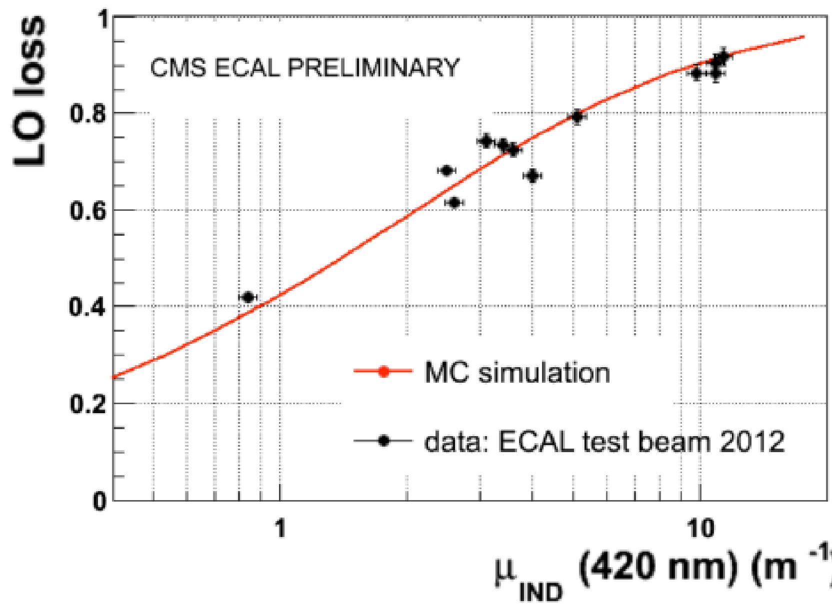
Validation of MC simulations (I)
Crystals with proton damage

- Compare light output from traversing or absorbed particles with light transmission.
- Ray tracing MC (LITRANI) accurately describes relation.

cosmic muons



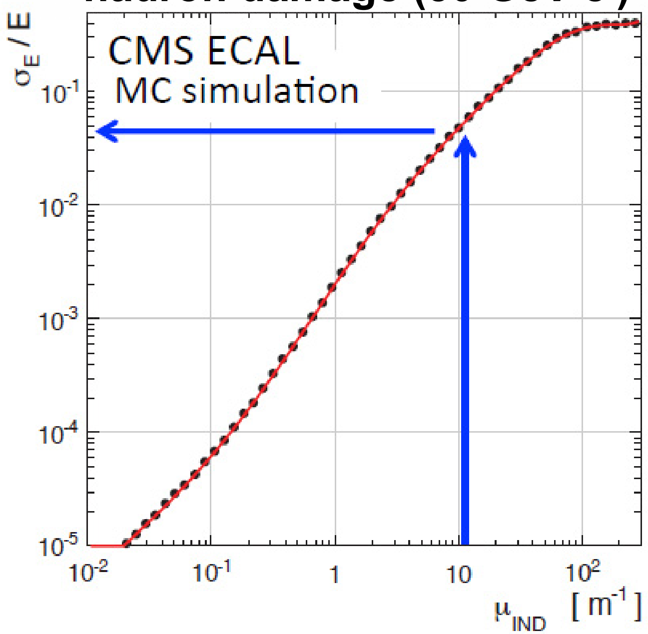
electrons 50 GeV

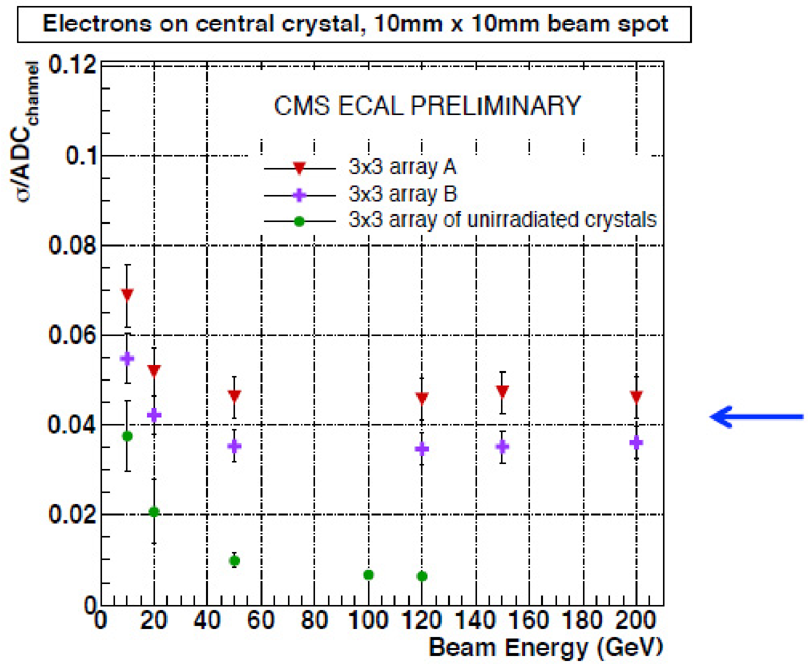


Proton Damaged Induced Resolution Degradation

- Proton irradiated crystals (24 GeV proton beam, fluence 6×10^{13} p/cm^2, μ_{Ind}=11 m^{-1}) exposed to electron test beam.
- Measured energy resolution in agreement with simulation.

Constant term contribution from hadron damage (50 GeV e^-)

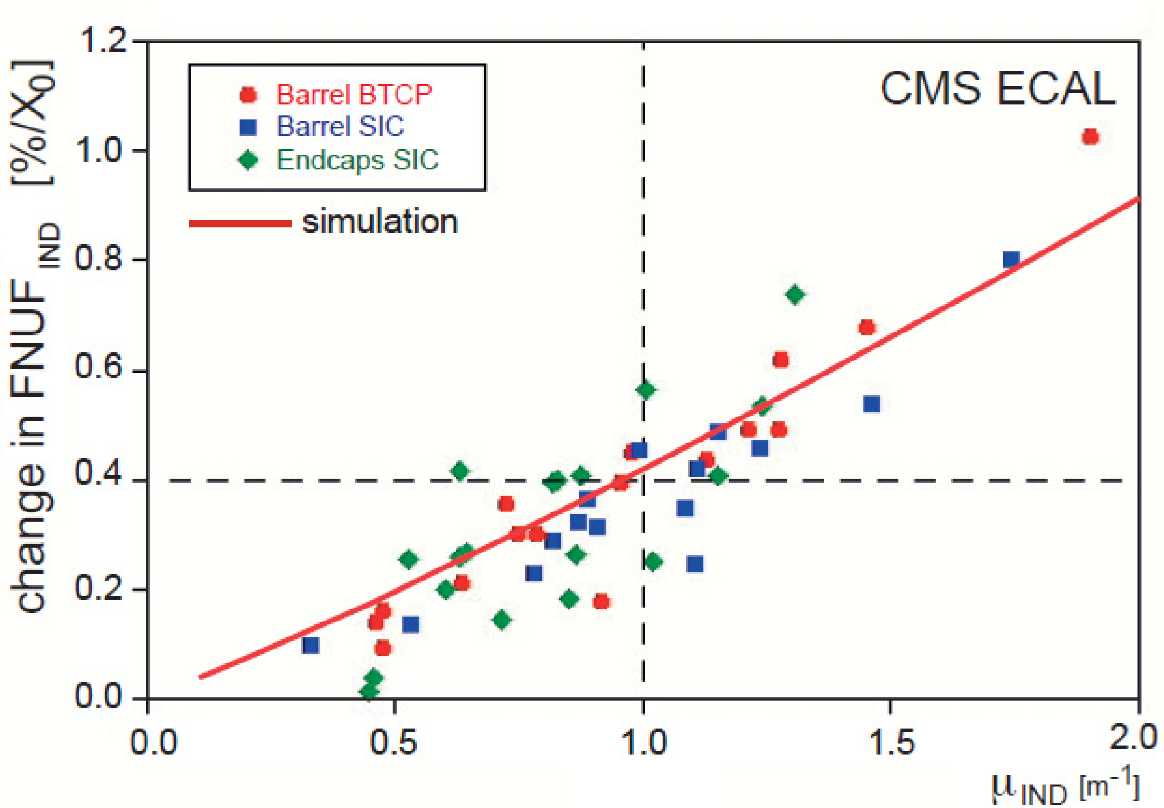




Validation of MC simulations (II) Response Uniformity under Irradiation

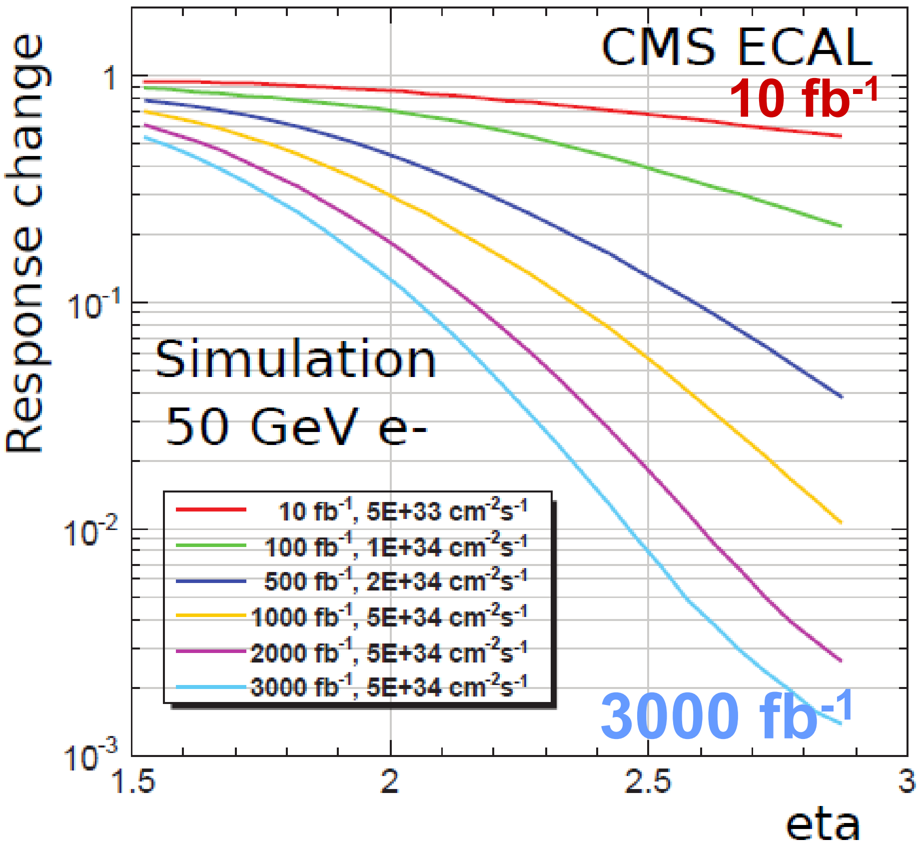
- **Correlation between μ_{int} and variation of light output between 4 X_0 and 13 X_0 (FNUF).**

- **Important benchmark, affecting the constant term of the energy resolution.**



Resolution Degradation at Large Transparency Loss

- With large transparency losses, energy resolution will degrade :
  - Photo statistics reduced.
  - Relative noise increased
  - Crystal non-uniformity.
- Impact on physics analysis is being investigated.



R&D studies on new scintillators

- **R&D on new crystal materials ongoing. See eg.**

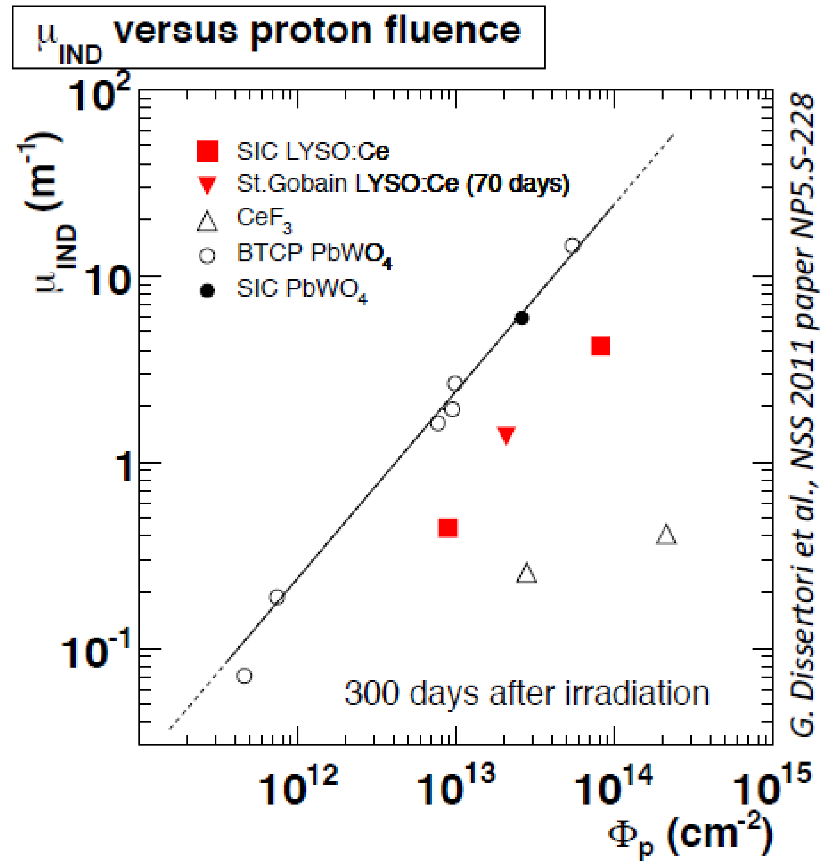
R. Mao et al., Journal of Physics: Conference Series 293 (2011) 012004

G. Dissertori et al., NSS 2011 paper NP5.S-228

G. Dissertori et al., Nucl. Instr. Meth. A 622 (2010) 41-48

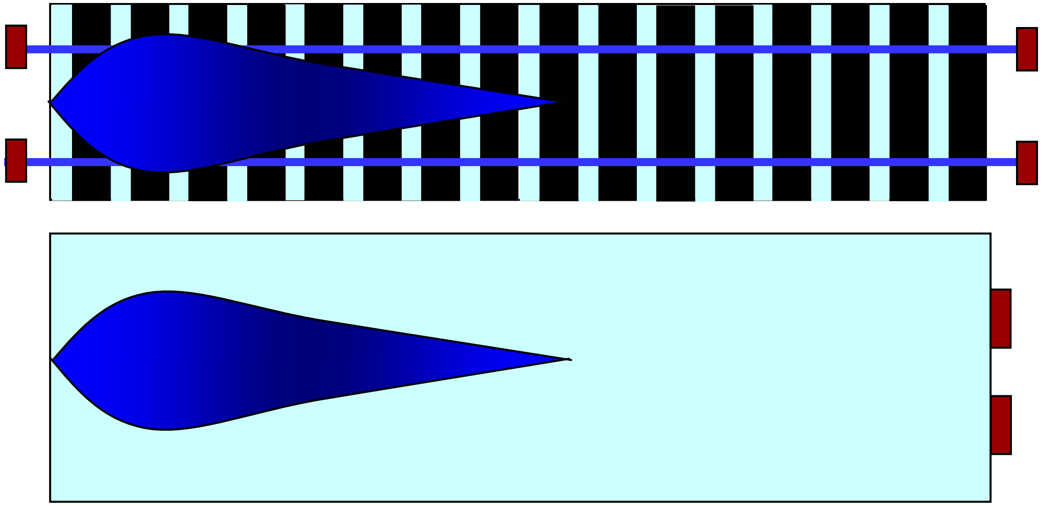
K. Pauwels, paper N41-6, E. Auffray, IEEE NSS/MIC 2010 paper NM3-1

- **Investigations on LYSO, YSO, LuAG, CeF_3.**
- **Key objective : Increase radiation hardness, in particular against hadron damage**



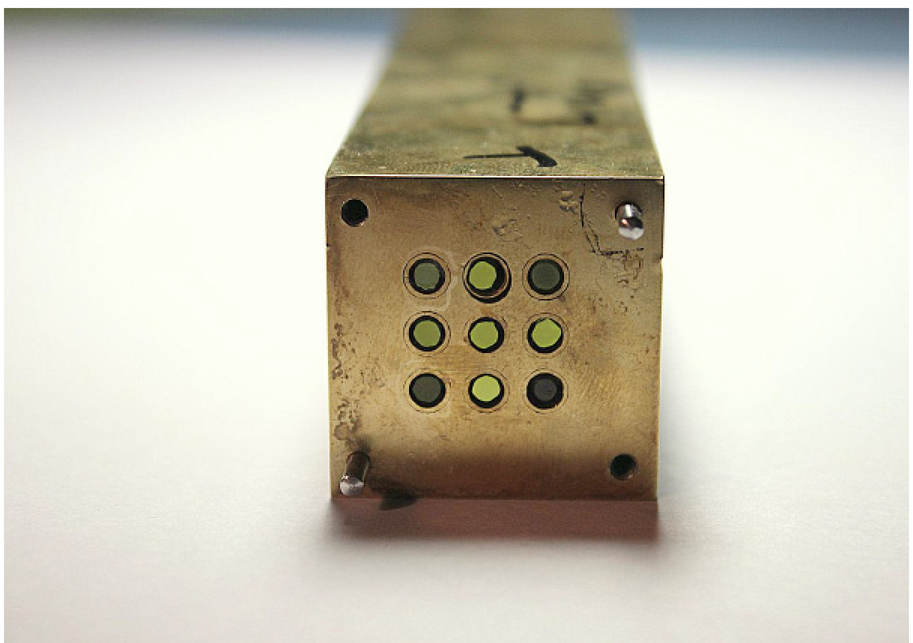
Possible design options for electromagnetic Calorimetry at HL-LHC

- Some scintillator materials under consideration can be machined easily into thin plates with holes.
  - Shashlik design with fiber readout can be considered
  - Depth segmentation and dual readout is an option.
- Sampling option has several desirable features :
  - Reduce light path length from >20 cm (length of current EE crystals) to <1cm (transverse size of active material).
  - Reduced amount of active material needed to achieve full shower containment.
  - Very dense absorber allows smaller cell size $\Rightarrow$ optimize segmentation.
- A prototype using LYSO and lead or tungsten is being built to go into test beams in late 2013 / early 2014.

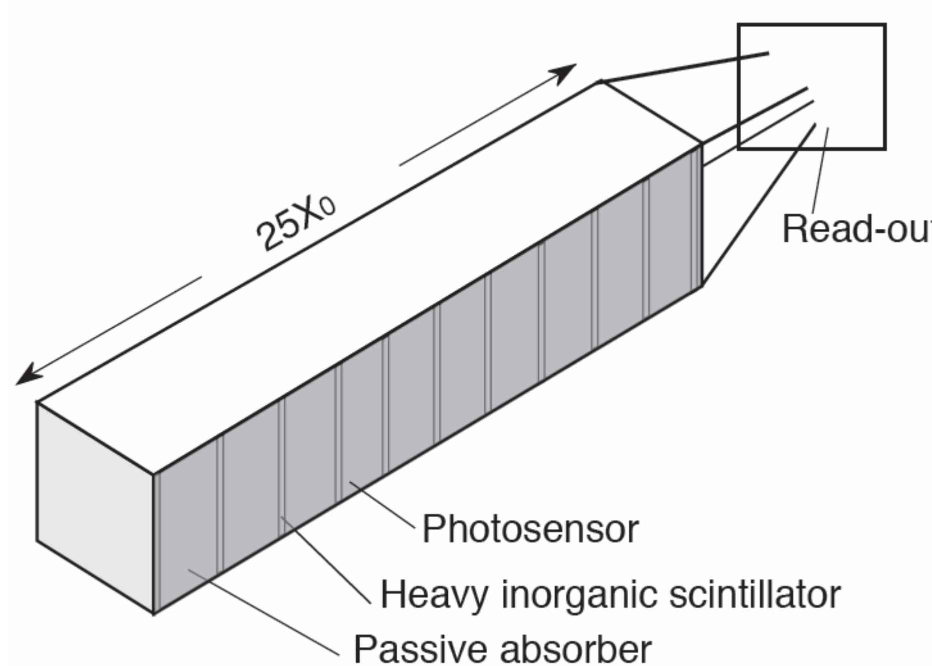


Possible design options for electromagnetic Calorimetry at HL-LHC

- Dual Read Calorimeter of single-crystalline LuAG Fibers.
- Prototype was tested in CERN beams in November 2012.

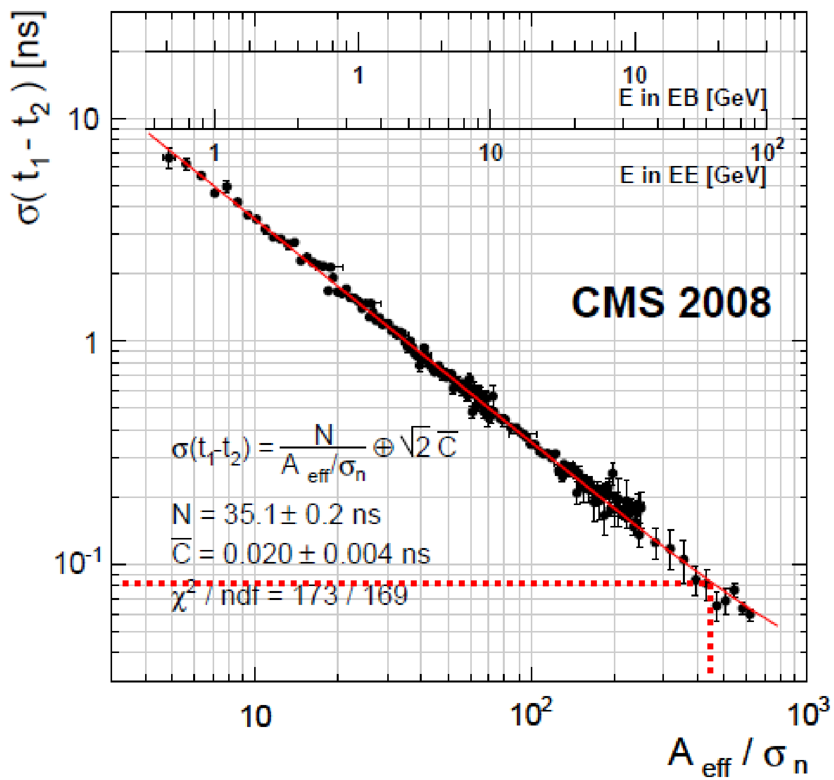


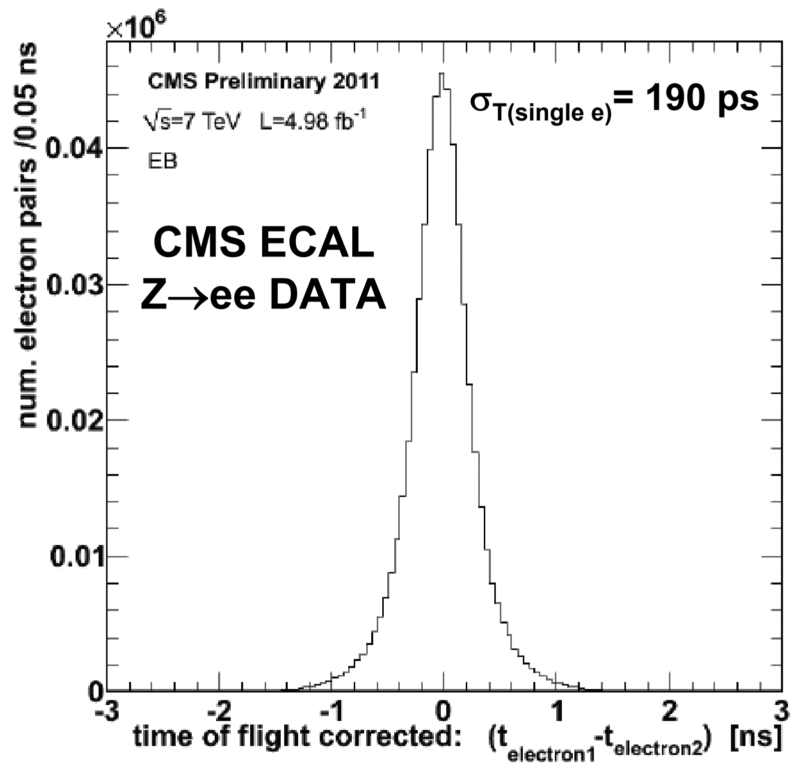
- CeF3 or YSO based sampling calorimeter.
- Less sensitive to hadron damage then LYSO.
- Detailed detector confiuration being studied.



Pico-second Timing

- Current ECAL has excellent time resolution of <100 ps in test beam.
- Better than 200 ps in-situ, even though not optimised for precision timing.
- Studies on precision timing for the upgrade ongoing. One target application is pile-up mitigation, desired resolution is order 10 ps.





Summary

- CMS ECAL performance under LHC radiation conditions is being studied in detail.
- Very good understanding of response variation achieved.
- Dedicated studies on performance and requirement for HL-LHC are ongoing.
- Options for precision calorimetry under consideration for luminosities of 10^{35} $cm^{-2}s^{-1}$ and cumulative data sets of $3ab^{-1}$.
- First prototypes are being built and exposed to test beams.