# Summary of HE response and Proposal for partial scintillator replacement in LS2

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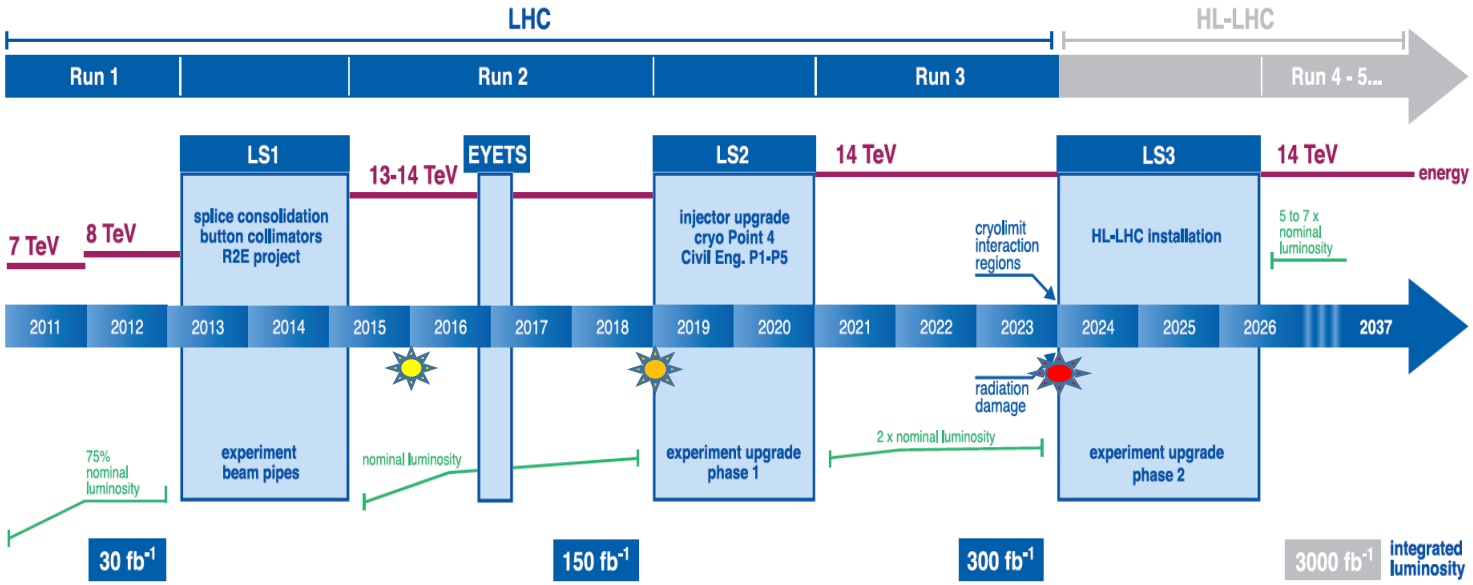
CERN Review: Response to ageing of HE scintillator
December 3, 2015

# LHC schedule (as of Dec-2015)




We are here today (end of 2015): Total integrated luminosity delivered to CMS so far : ~ 30 $fb^{-1}$.

LS2 is expected to start in early 2019 and last 2 years (24 months), Total integrated luminosity delivered to CMS by start of LS2(2019): 150 $fb^{-1}$.

LS3 is expected to start in early 2024 and last 2.5 years (30 months); Total integrated luminosity delivered to CMS by start of LS3(2024): 300 $fb^{-1}$.

**The question we are trying to answer: will HE scintillators survive* another 6 years of radiation damage (another 300-500 $fb^{-1}$) ?**

*** Survive = provide adequate physics performance**

# Outline of this talk

- What we know about radiation damage to HE
  - What we have learned from Run1 (2012) data
  - New feedback from Run2 (2015) data
- Preparing for possible partial replacement of HE scintillators in LS2
  - Justification:
    - Impact on physics performance
  - Feasibility:
    - candidate materials for scintillator/WLS fiber replacement ?
    - Plan for production and installation
- Additional information Radiation Damage and detailed discussion of justification and feasibility will be presented in later talks by M. Danilov, A. Belloni, K. Pedro and A. Kaminskiy

# Results from analysis of 2012 data

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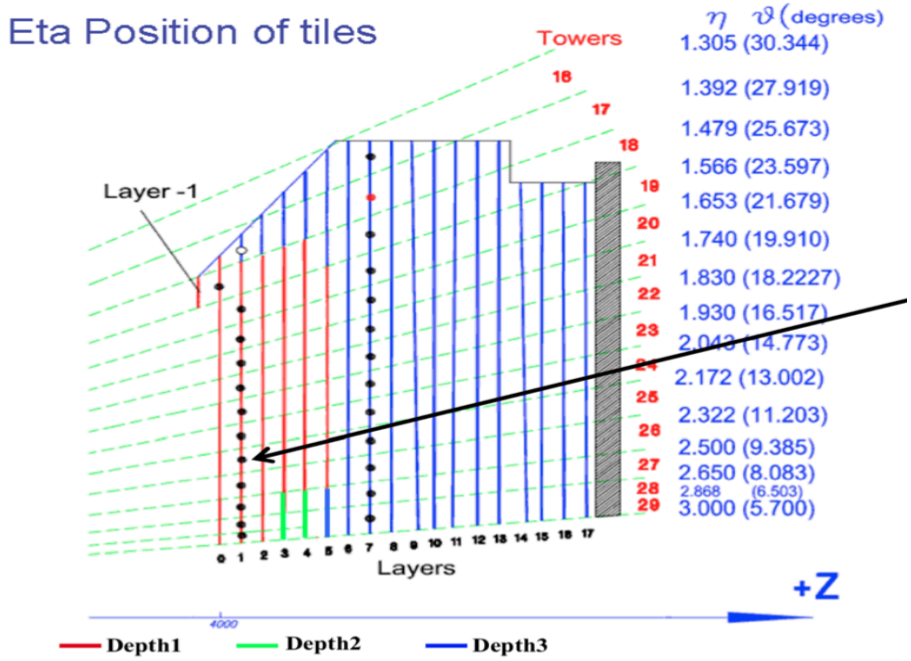
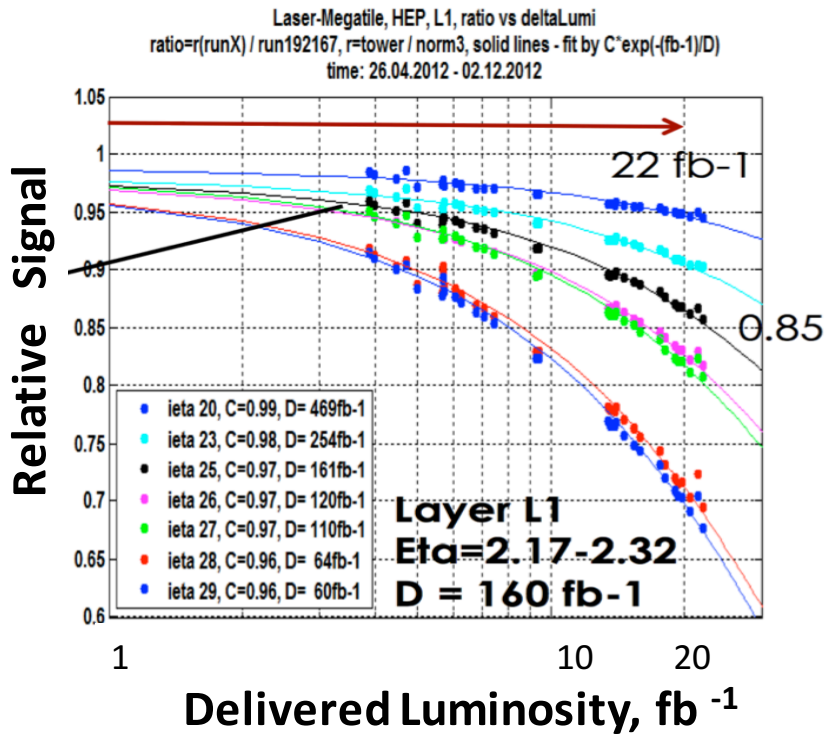
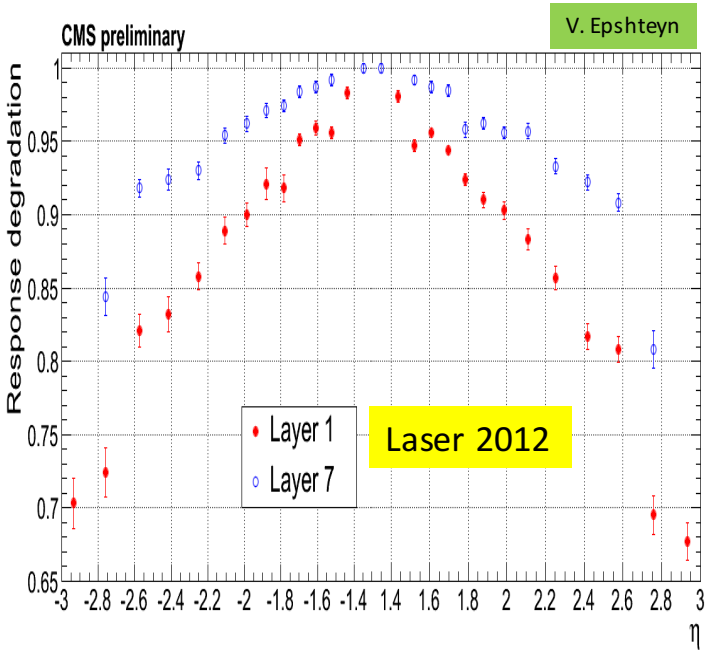
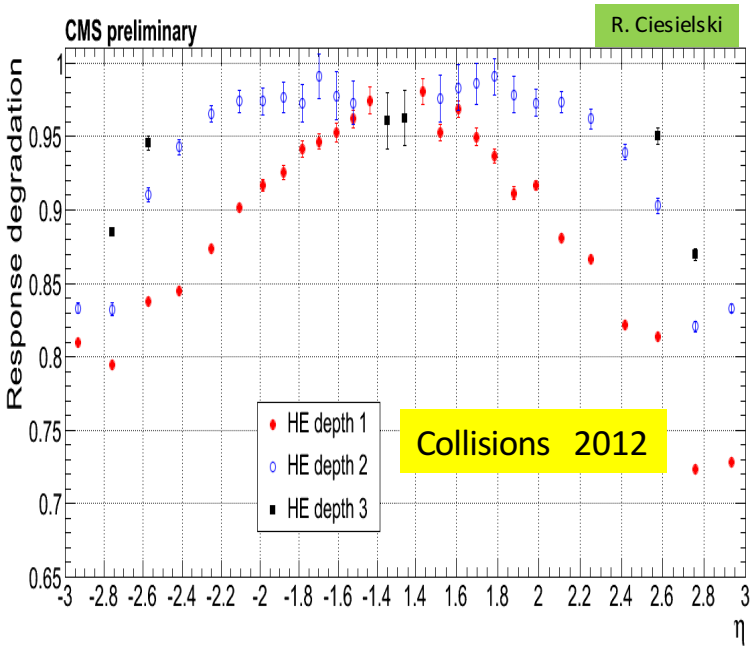
V. Epshteyn



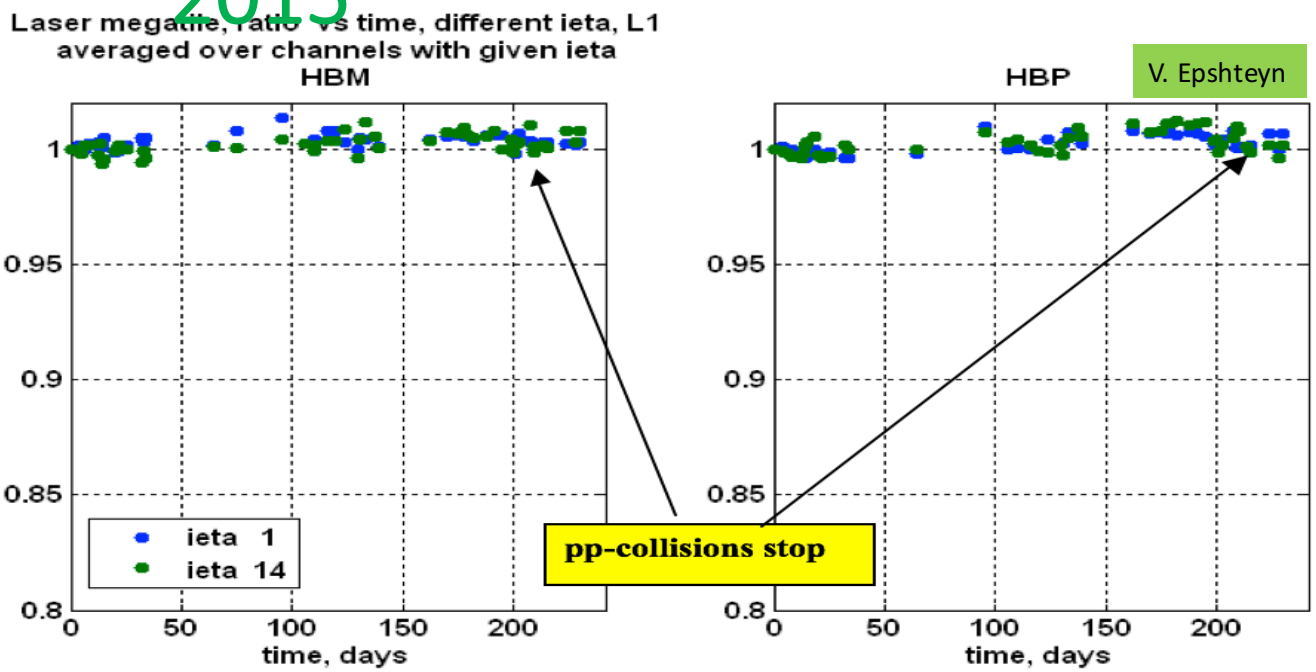
# Response degradation in HE, 2012 Laser vs collisions data (23 $fb^{-1}$)




NOTE: Laser injection going into specific Layers (L1 and L7)
HE is segmented into 2-3 depths (readout segments), depending on eta

# Relative change in HB tiles, 4 $fb^{-1}$, Apr-Nov 2015



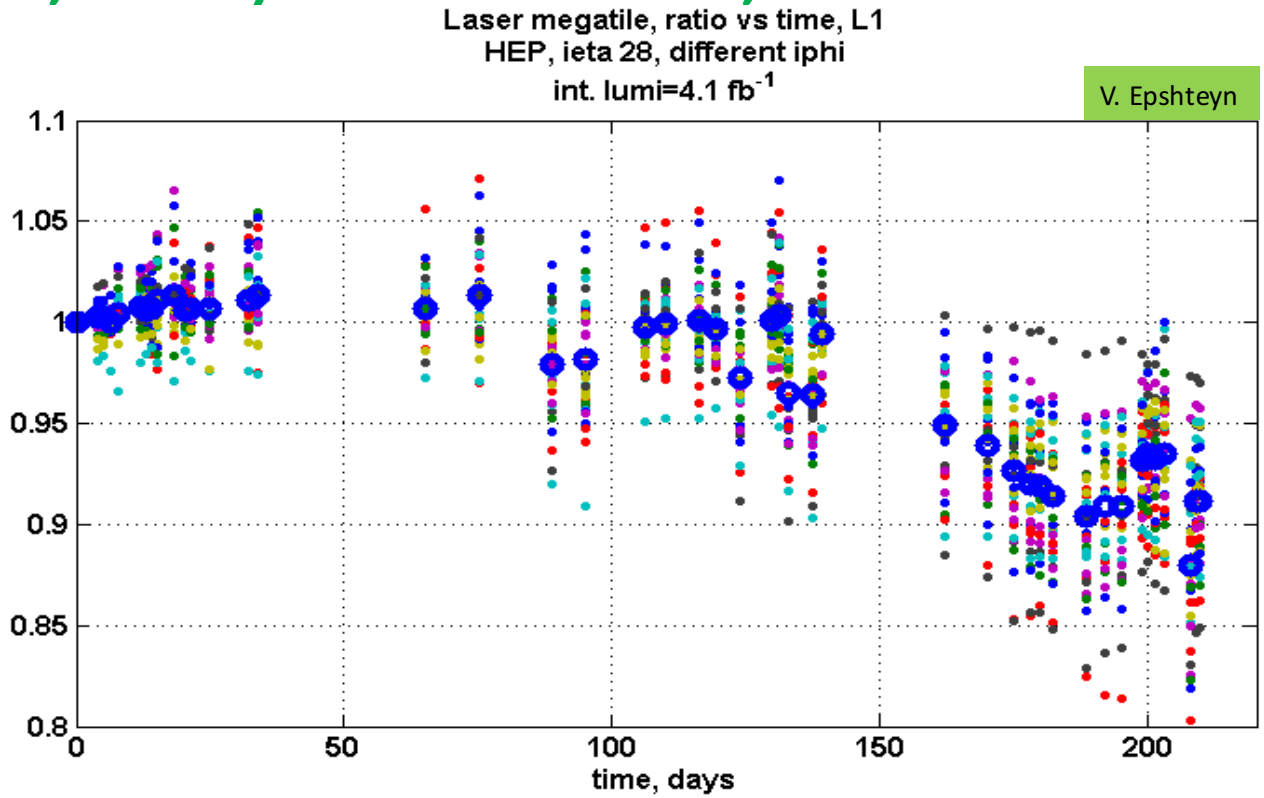

*Int. lumi=4.1 $fb^{-1}$.*
*time 09.APR.2015 - 26.NOV.2015*
*Fig.16 HB, Laser megatile, ratio vs time*

Each data point corresponds to an relative response of a single eta ring in HB (averaged over phi). Each color corresponds to different eta ring.

Response of HB in Apr-2015, eta=2 ring is used as normalization to account for Laser

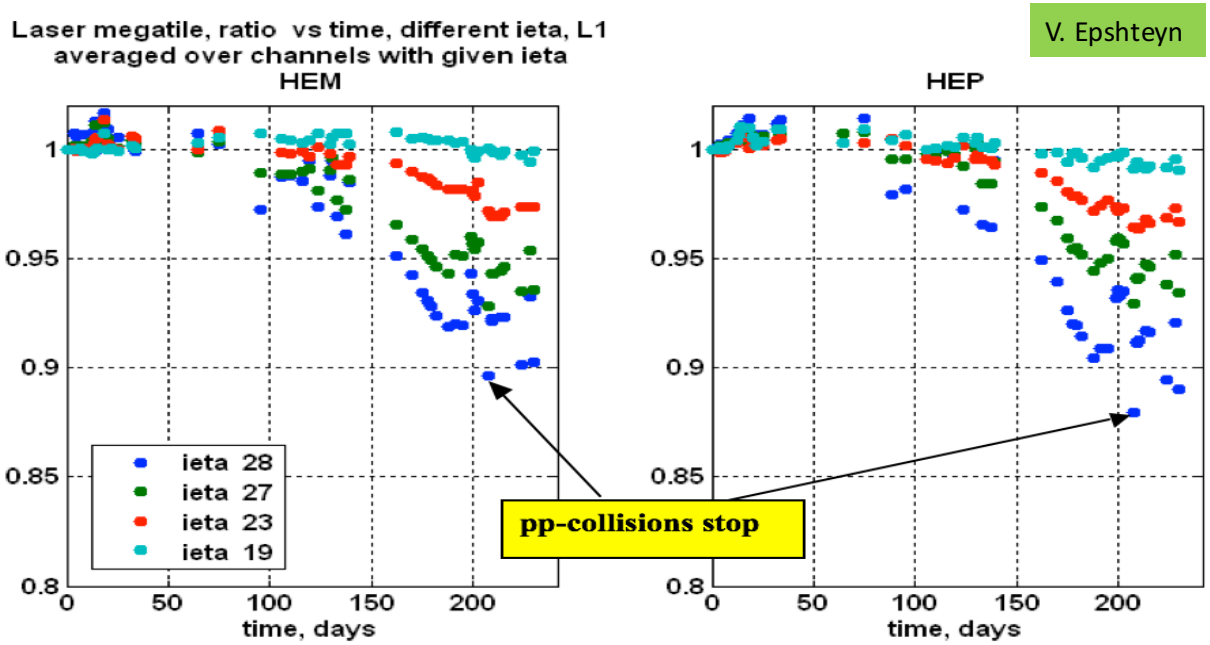
No eta-dependent signal reduction in HB tiles (Layer 9) is observed.
Stability of monitoring is at the level of 1%, both on HBM(Minus) and HBP(Plus) sides.

# Relative response of individual tiles vs time (ieta=28, HEP) after 4 fb $^{-1}$ , 2015 data



# Relative change in HE tiles,4 $fb^{-1}$, Apr-Nov 2015

V. Epshteyn

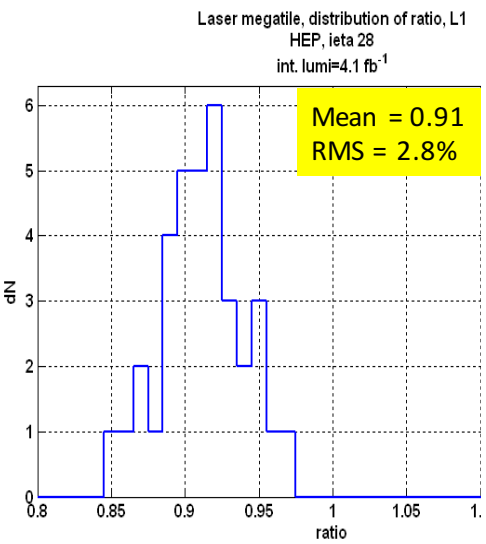


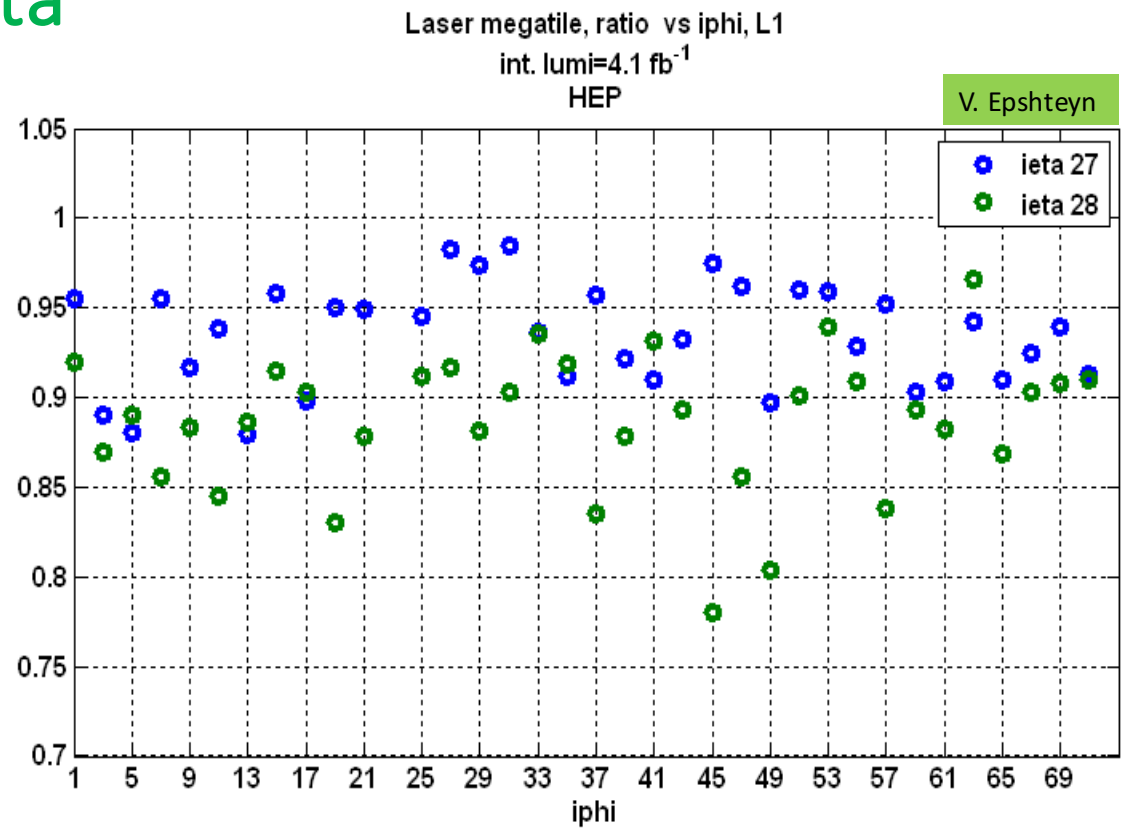

*Int. lumi=4.1 $fb^{-1}$.*
*time 09.APR.2015 - 26.NOV.2015*
*Fig.15 HE, Laser megatile, ratio vs time*

Each data point (color-> eta) corresponds to an average response of a single eta ring in HE (averaged over phi). Response of HE in Apr-2015, eta=16 ring is used as normalization.

We observe eta-dependent signal reduction in HE tiles (Layer 1). Effect is visible both in HEM (Minus) and HEP (Plus) sides.

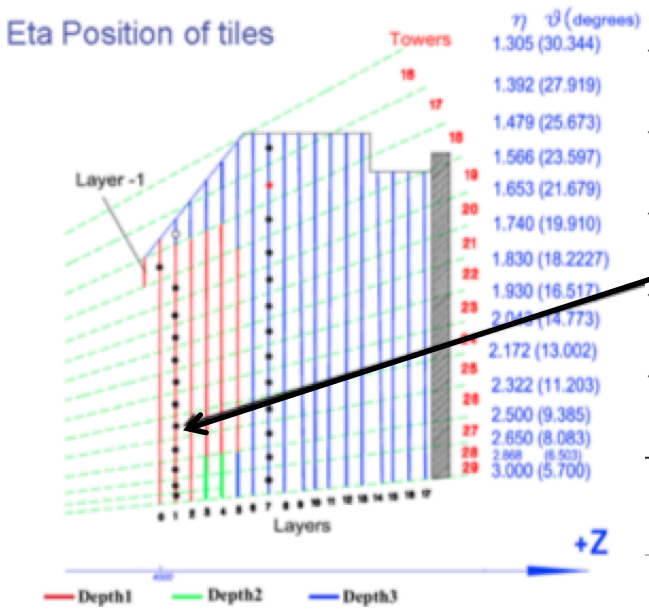
# Spread in signal loss in HEP (ieta=27, 28) vs Int. Lumi: 4.1 $fb^{-1}$, 2015 data

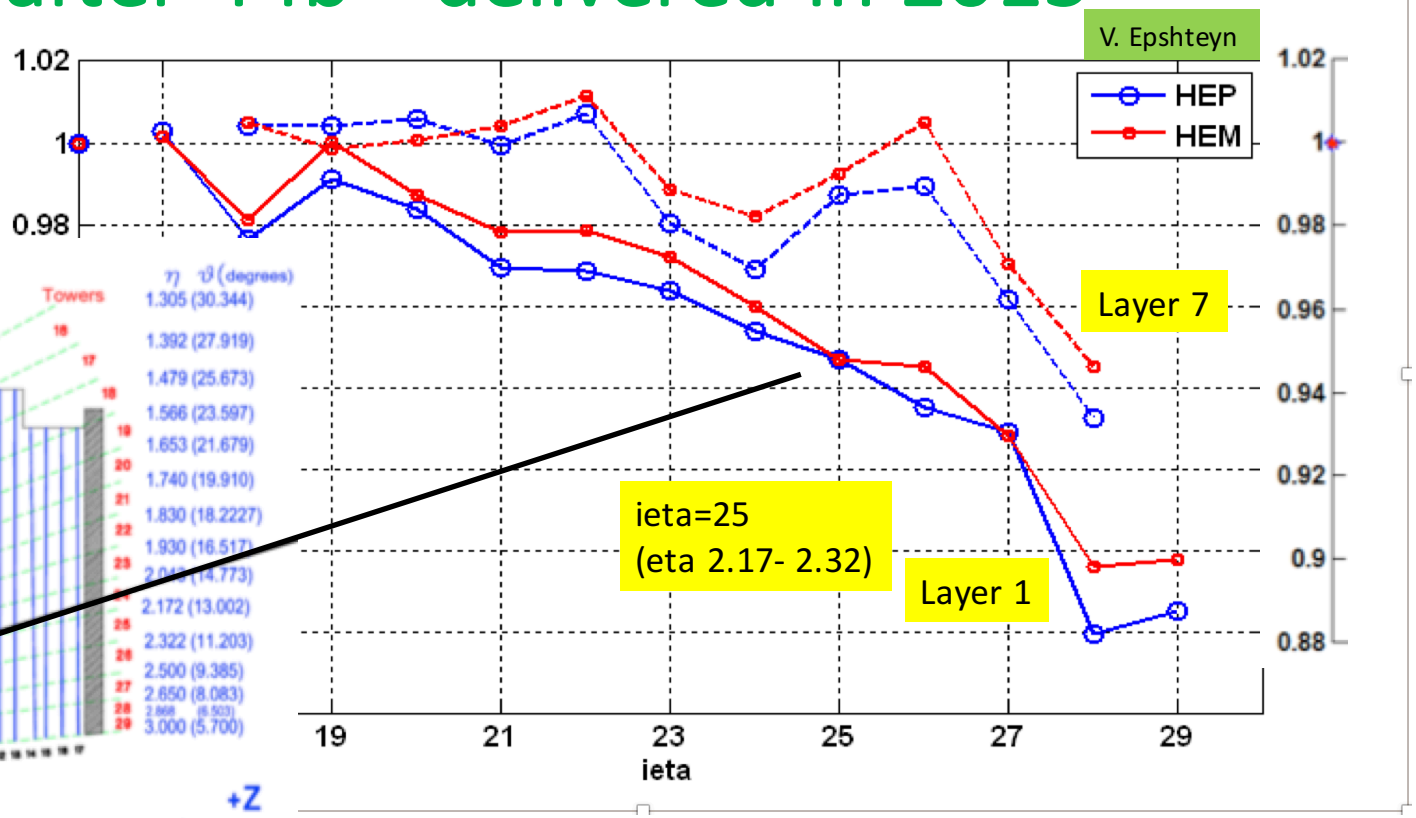



RMS of tile-to-tile spread is 2.8%, mean signal loss of 11% (ieta=28, 4.1 $fb^{-1}$)

# Average signal loss vs ieta in HE after 4 $fb^{-1}$ delivered in 2015



# Annealing ?

Based on Laser-> Megatile data collected in 2012 and 2015, we do not see any evidence of annealing no recovery of HE scintillator response):

- No short term recovery:
  - Response of scintillator remains flat since end of pp run in early Nov-2015, ~ 1 month)
- No long term recovery:
  - Ratio of response of HE scintillators is flat vs eta (Jul-2015 vs Dec-2015, ~ 2.5 years)

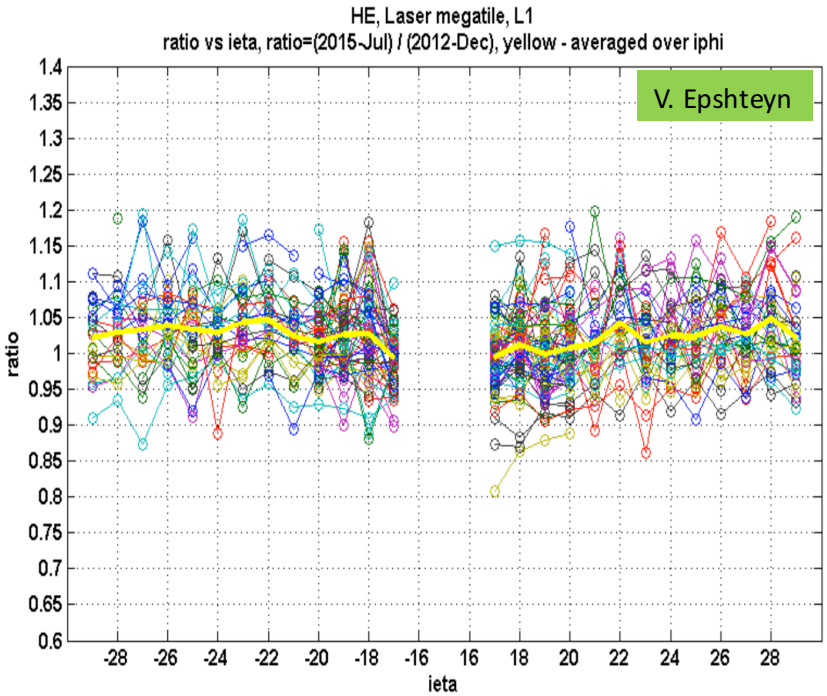
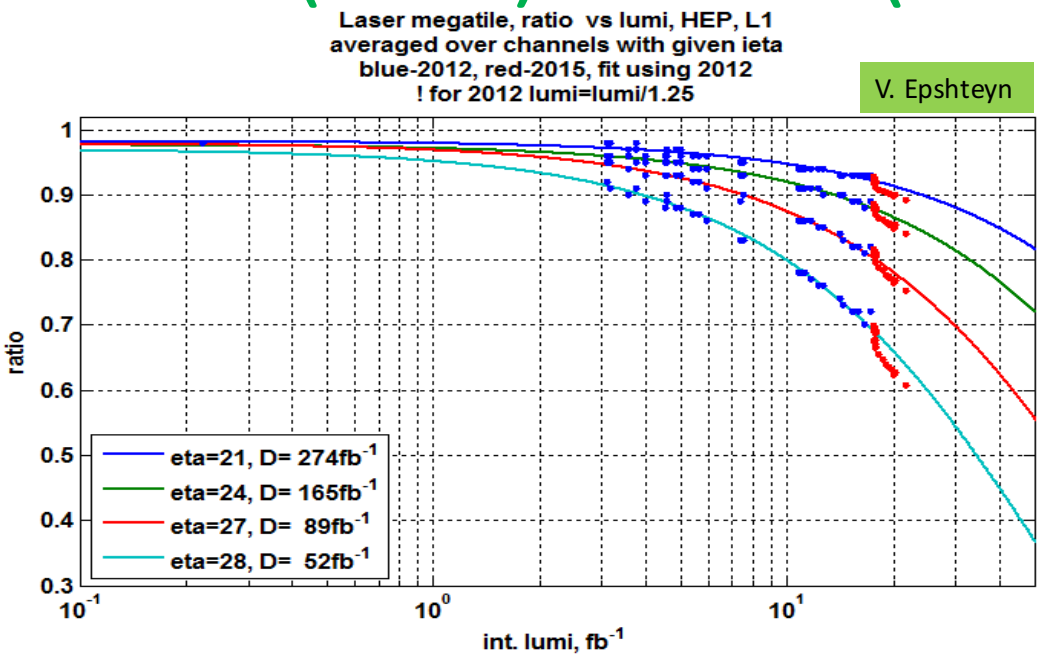
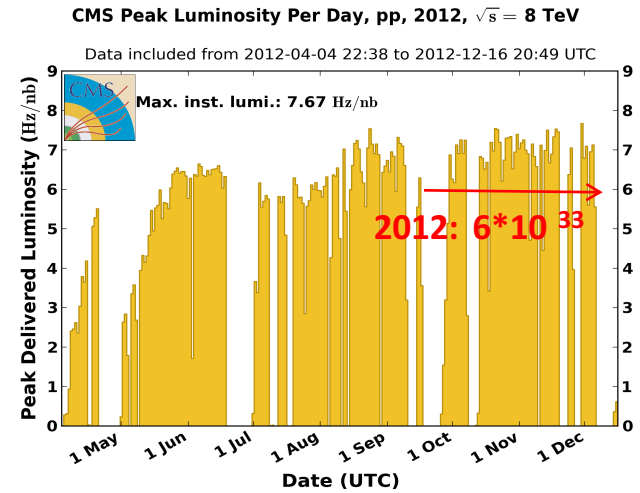
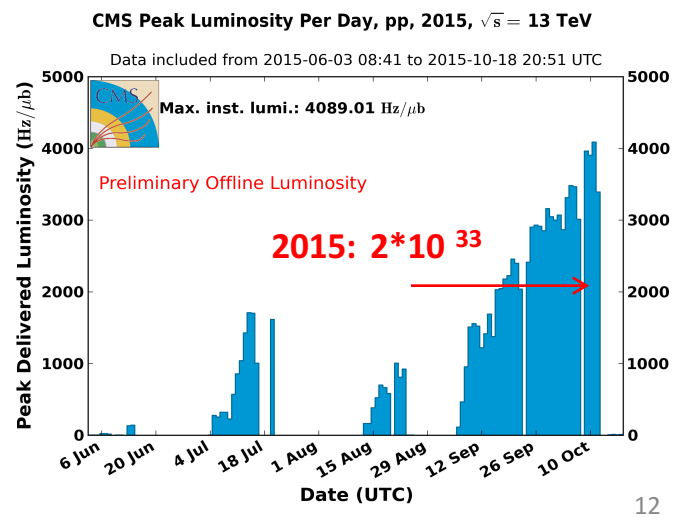



*Fig.11 HE, ratio vs ieta, ratio=(2015-Jul) / (2012-Dec)*

# Run2 (2015) vs Run1 (2012)




Preliminary studies of radiation damage of HE active material (scintillator/WLS files) in 2015 data indicated an additional 10% signal loss for 4 fb$^{-1}$ delivered to CMS in Run2 by early November 2015.

- The observed degradation of signal in 2015 is faster (vs fb$^{-1}$) than in 2012.
- The effect is consistent with lower dose rate (krad/hr) in Run2 (2015 data) with respect to dose rates observed in Run1 (2012 data)
  - lower inst. luminosities (factor of 2-3 decrease 2015 vs 2012)
  - 25% flux increase for 13 TeV vs 8 TeV collisions.

# Dose rate effect ?

We can characterize damage effect using exponential function:

Relative signal = exp (-x/D [Mrad])

CMS Laser-> Megatile data confirms hypothesis of 'dose rate effect':
-> damage to scintillator happens 'FASTER' (== is LARGER for given value of DOSE, parameter D[Mrad] is SMALLER) for SMALLER Dose rates (in krad/hr)

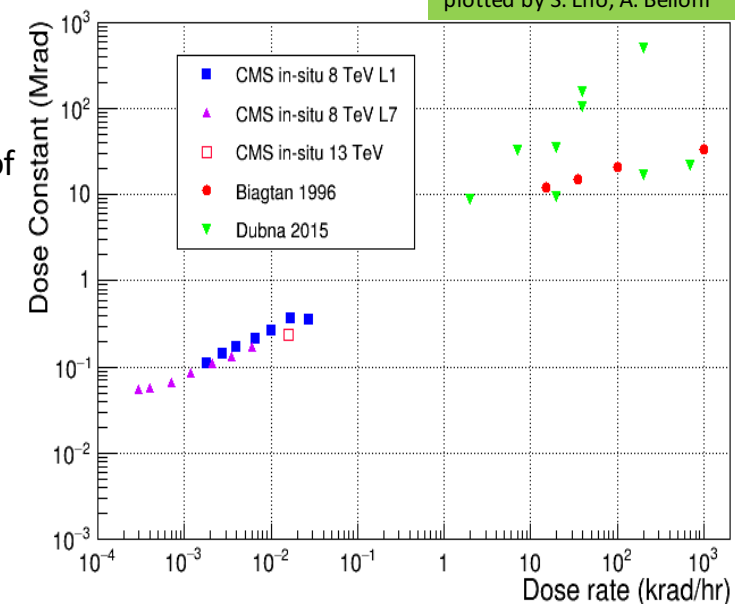
Note that we expect that in 2016, LHC will operate at higher instantaneous luminosities (-> higher dose rates) wrt 2015:

-> 2012: typical max inst. Lumi ~ 0.6 * $10^{34}$
-> 2015: max inst.Lumi ~ 0.1- 0.4 * $10^{34}$
-> 2016: goal max inst. Lumi ~ 1.2 * $10^{34}$
-> 2021-23: goal max inst. Lumi > 2 * $10^{34}$

We can therefore expect somewhat SLOWER damage in 2016 and beyond.

Note: In the following slides, we use parameterizations of 2012 data, corrected for 13TeV/8TeV flux increase (conservative PoV) to predict future behavior of HE.

Data points collected and plotted by S. Eno, A. Belloni




Comment: Dose rate for CMS data calculated with assumption 1y = 8,000 hr
(maybe more realistic assumption would be: 1wk =100hr, 30wk/y -> 1y = 3000hr

# Extrapolation to 500 fb$^{-1}$ (based on Run1 data)

In ~23 fb$^{-1}$ delivered in 2012, in the high |η| region (2.65 < |η| < 3), Layer 1 (L1) lost 30% of its original signal, and Layer 7 (L7) lost 15 % of its original signal.

Even at |η| = 2.4 (ieta = 26), the loss was non-negligible: L1 lost ~15% of its original signal, and L7 lost 5% of its original signal.

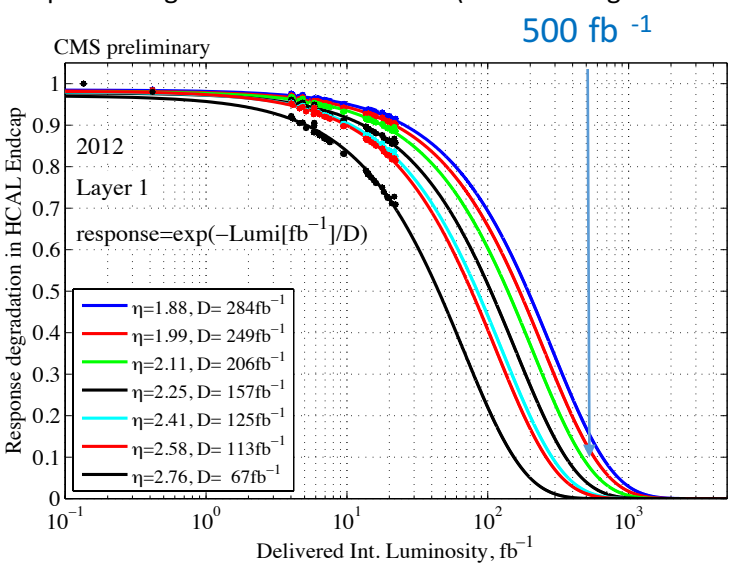
Extrapolation of the exponential fits (2012 data) to 500 fb$^{-1}$ gives following predictions:

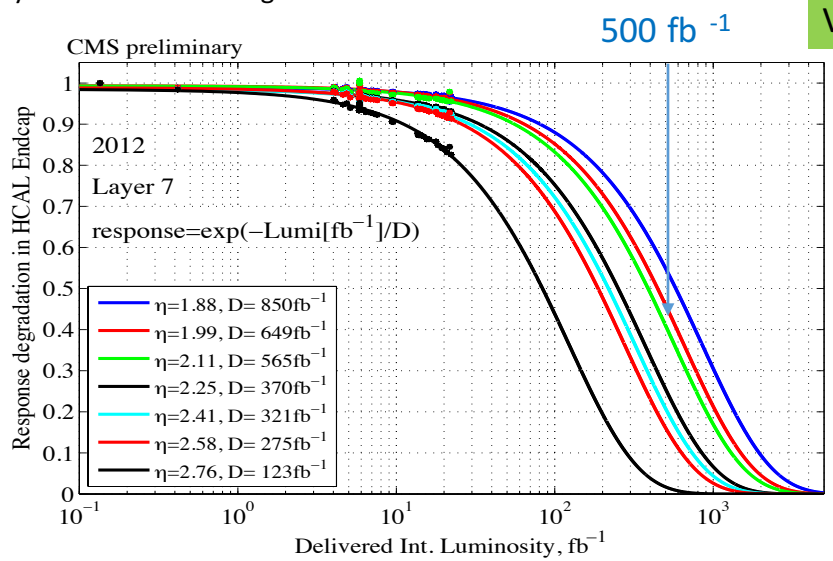
* Only 10% of original signal left (x10 reduction) at Layer1/ eta = 2
* Only 40% of original signal left (x2.5 reduction) at Layer7/ eta = 2

Note that this extrapolation DOES NOT account for dose rate effect:

Expected higher dose rates in 2016 (and even higher in 2021-23) likely to lead to lower degradation.

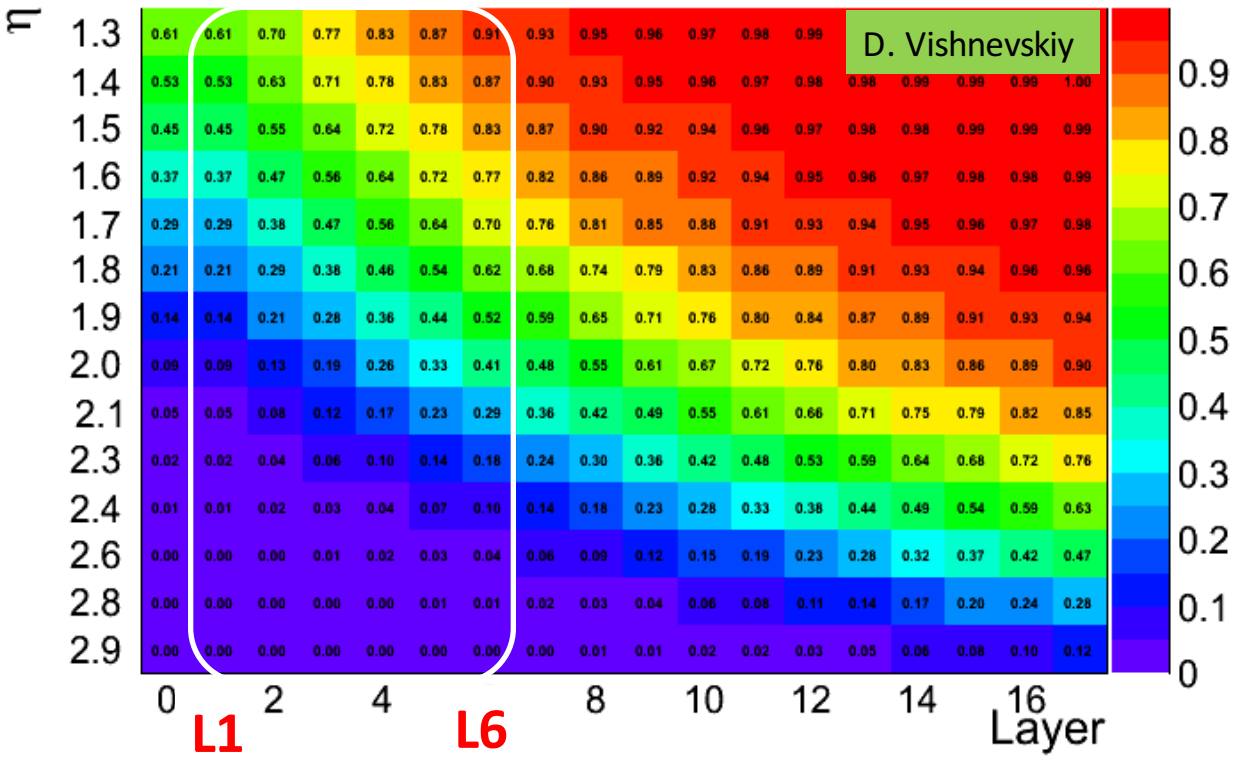
V. Epshteyn



# Response Degradation in HE, 500 $fb^{-1}$ :

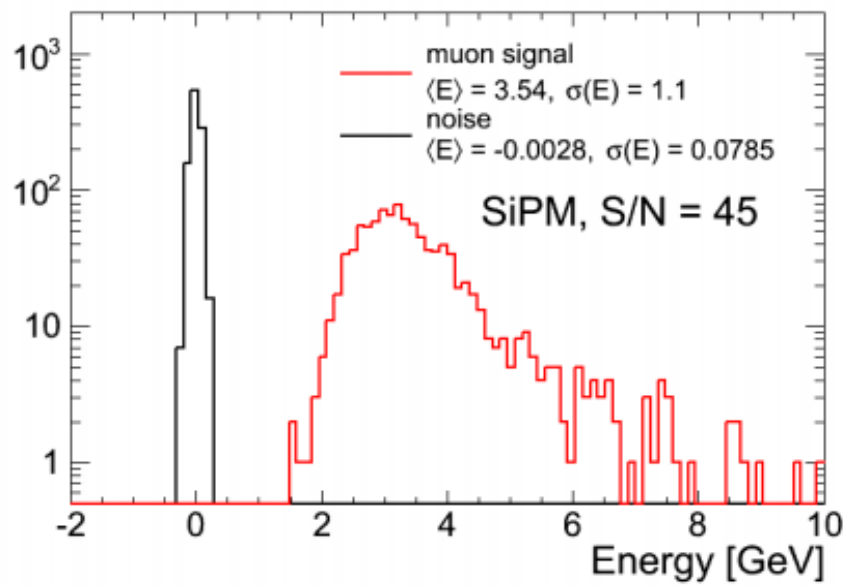
model based on 2012 data, corrected for 13TeV/8 TeV flux ratio




The reduction in the signal is based on an exponential fit to the data collected during the 2012 LHC run (23 $fb^{-1}$). Dose-rate effects are not included (conservative approach).

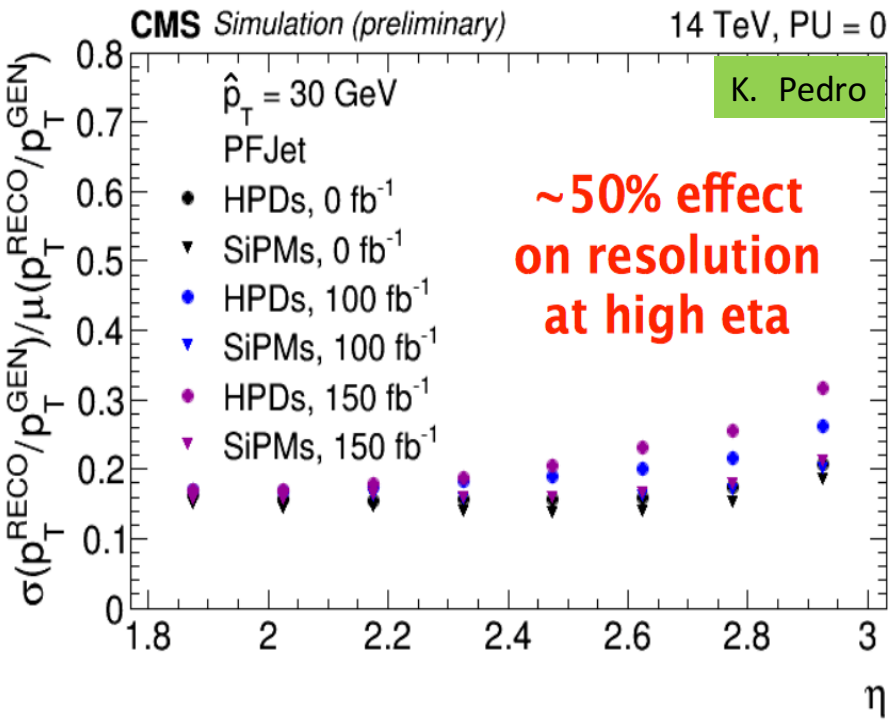
# Mitigation strategy: HPD-> SiPM replacement in EYETS 2016/17

- Silicon photodetectors (SiPMs) offer superior performance wrt present photo-detectors on HE (HPDs) and thus would provide partial mitigation of RadDam effect:
  - X3 higher Photon Detection efficiency
  - Much higher gain
  - Smaller surface allowing to accommodate finer longitudinal segmentation
- Since CMS Upgrade Meeting in Hamburg (May-2013) significant effort has been made by HCAL to accelerate installation date of HE Front-End Phase1 upgrade (new photo-detectors + new FE electronics) from nominal LS2 to EYETS 2016/17
- Schedule is tight, but **HE FE is on track for installation** in **EYETS 16-17**.



# Effect on physics performance

- At 200 $fb^{-1}$: SiPM readout and increased depth segmentation offer significant improvements in jet resolution performance with respect to the current HE (HPD readout with minimal depth segmentation), especially in the high η regions.
- At 500 $fb^{-1}$: The radiation damage is severe enough that the performance is severely degraded in the $2.7 < |\eta| < 3.0$ region, and to a lesser extent in the $2.4 < |\eta| < 2.7$ region, even with SiPM readout with increased depth segmentation.
- ACTION ITEM: we are conducting an news/independent simulation of the effect of the radiation damage on the energy resolution of HCAL in order to cross check the results described in CMS AN 2013/268. The simulation will also provide feedback on which layers to replace.




See more in presentation by K. Pedro

# Possibility of Replacement of HE scintillators was considered in HCAL TDR (1997)

The central HCAL calorimeters (HB and HE) were designed to withstand radiation damage up to 500 $fb^{-1}$. However, it was also envisioned in the 1997 HCAL Technical Design Report (TDR) that, in the unlikely event of catastrophic radiation damage to the scintillator, the trays could be removed and refurbished without removal of the absorber structure.

Fragment of original text of HCAL TRD (1997):

The advantage of this scheme is that the scintillator trays can be built and tested remotely from the installation area. Before the calorimeter absorber is lowered into the CMS pit and installed into the solenoid, the trays are rapidly inserted. Another advantage of the tray scheme is that in the unlikely event of catastrophic radiation damage to the scintillator, the trays can be removed and refurbished without removal of the absorber structure. Once in the experimental hall, optical fibers are connected between trays and the photodetectors.

Based on what we know today, the radiation damage of the HE scintillators observed during Run1 (2012) and at the start of Run2 (2015) is indeed much larger than expected in the 1997 TDR.

However, based on what we also know today, access to HE megatiles is not trivial at all.

# What is the 'HE Plan B':

* The HCAL Project has started to develop the details of a plan for an exchange of the HE scintillators during LS2, if such intervention were required to maintain physics performance of the endcap calorimeter between the LS2 and the LS3 shutdowns. This is considered as a 'Plan B' and would be carried out as a maintenance and operation task (M&O), and not as an upgrade task. This 'Plan B' is NOT meant to replace the Phase 2 upgrade of the endcap calorimeter.

* The requirement for 'Plan B' is to maintain sufficient performance of HE up to LS3 (up to 500 $fb^{-1}$ with sufficient margin). Radiation tolerance up to the end of HL-LHC (3000 $fb^{-1}$) is NOT the design criteria (requirement) for 'Plan B'.

* The suggested date for deciding how to proceed for this 'Plan B' (the 'GO/NO-GO' decision) is proposed to be in late 2016. The time period of 2.5 years between late 2016 and early 2019 is judged as sufficient to procure/produce and test the components for the replacement of the HE scintillators.

# Additional feedback expected by late 2016

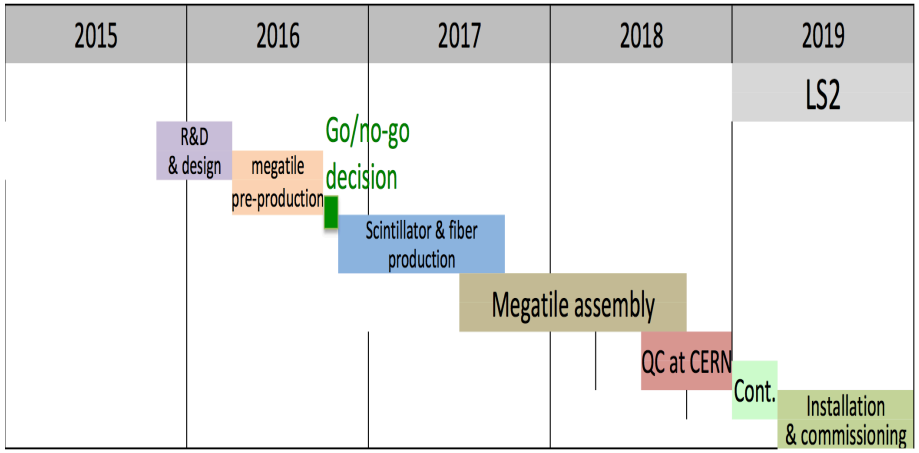
1) Observe the performance of the LHC beyond the start-up of Run2 in 2015: is ~500 $fb^{-1}$ by end of 2023 a possible (likely) scenario ?
2) Continue to monitor radiation damage of HE scintillators/WLS fibers in 2016: will the radiation damage observed in 2016 (additional 20-30 $fb^{-1}$) be consistent with the 2012 predictions, or will it 'slow down' due to dose rate effect ?
   - **R&D setup at p5**: set-up of scintillator tiles/WLS fibers + Laser distribution system on CMS Castor table, connected via HE FE prototype -> uHTR -> DAQ system, data collected in-situ during local HCAL runs. See more in presentation by A. Belloni
3) Obtain a better understanding of calorimeter performance degradation using the updated RadDam model: what is the consequence of the radiation damage on physics capability of CMS ?, include better simulation of SiPM noise, include updated(base on 2016 data) RadDam model
4) obtain feedback from monitoring the radiation damage of various samples of scintillator/WLS tiles to be installed in the forward region of CMS and exposed to the real LHC radiation environment during 2016 operations: what is the best candidate for replacement material ?

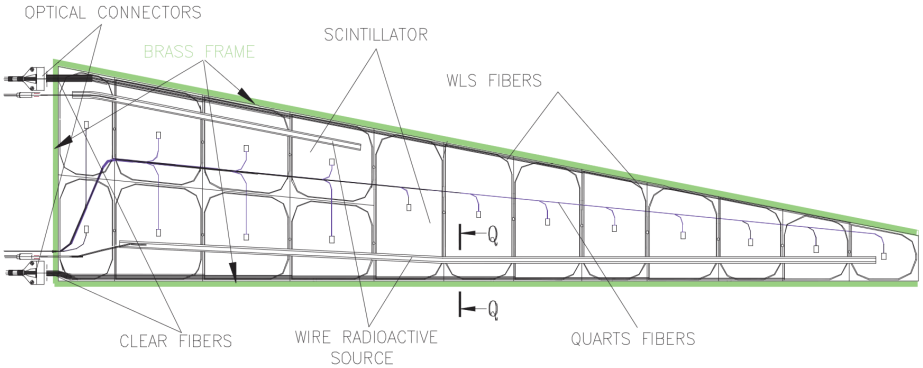
# Milestones: Dec-2015 to Oct-2016

1) **In early 2016, ahead of Run2 re-start,** set up in-situ test in the forward region of the CMS detector of the samples of scintillators and WLS fiber prototypes to confirm the radiation tolerance of the active material and validate the choice of scintillator/WLS fibers for the replacement, so that can withstand 500 $fb^{-1}$ (with sufficient margin).
2) **d**evelop an engineering design and construct few prototypes of megatiles, **be ready to test them in H2 in fall 2016.**
3) **By July 2016**, provide cost estimates for procurement of material (scintillator, WLS+clear fibers and other misc. items), for assembly and QC of replacement megatiles and their installation into the detector.
4) **By October 2016,** develop an installation plan, in particular disconnection/reconnection of endcap services, including EE and ES cooling system. This work needs to be done in close collaboration with the CMS ECAL project and the Technical Coordination team.

# What would have to be produced ?

- **We assume we will build replacement for 6 HE layers (L1 – L6)**
  - First sampling layer of HE, Layer0 (9mm BC-408) can not be removed w/o prior removal of ES.
  - We consider replacement of megatiles only: megatile cables (cables (connecting megatiles to Readout Modules), Readout Modules (ODU, SiPMs, QIE boards) would not be replaced
- **Pre-production by Summer/Fall 2016**:
  - We plan to build prototype: 2-4 megatiles (10 degree in phi),
  - to be tested at H2@CERN
- **Full Production/Assembly to be completed by Sep-2018:**
  - construct 72*6 10-degree megatiles (432 + spares = 500 in total)
  - Prepare some spare megatile cables (connecting megatiles to Readout Modules)



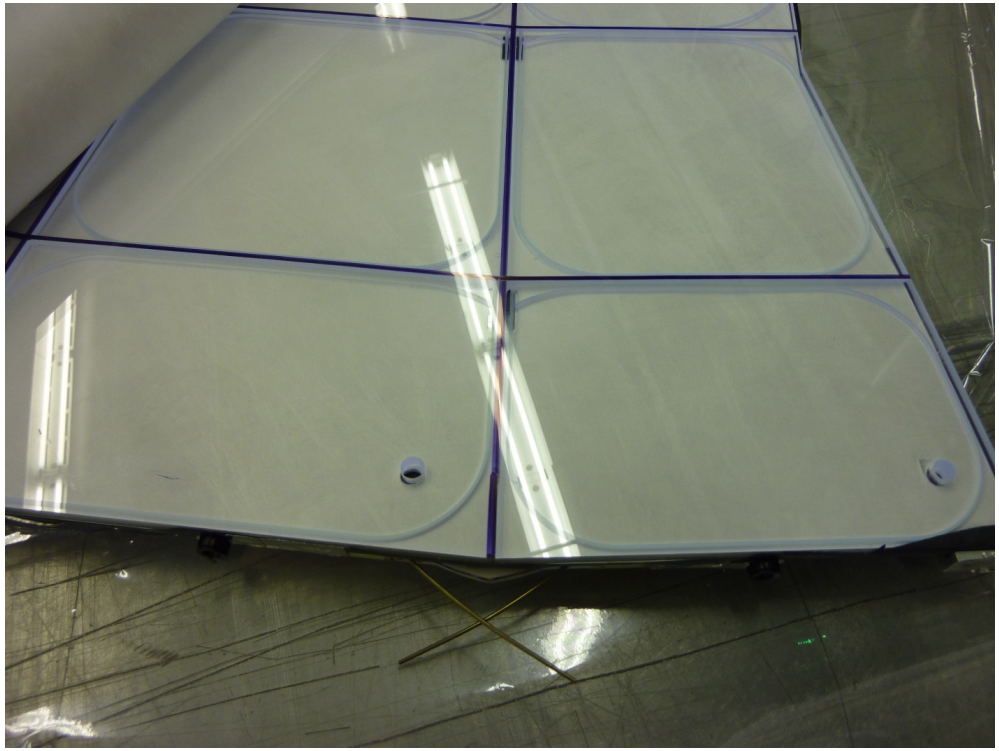



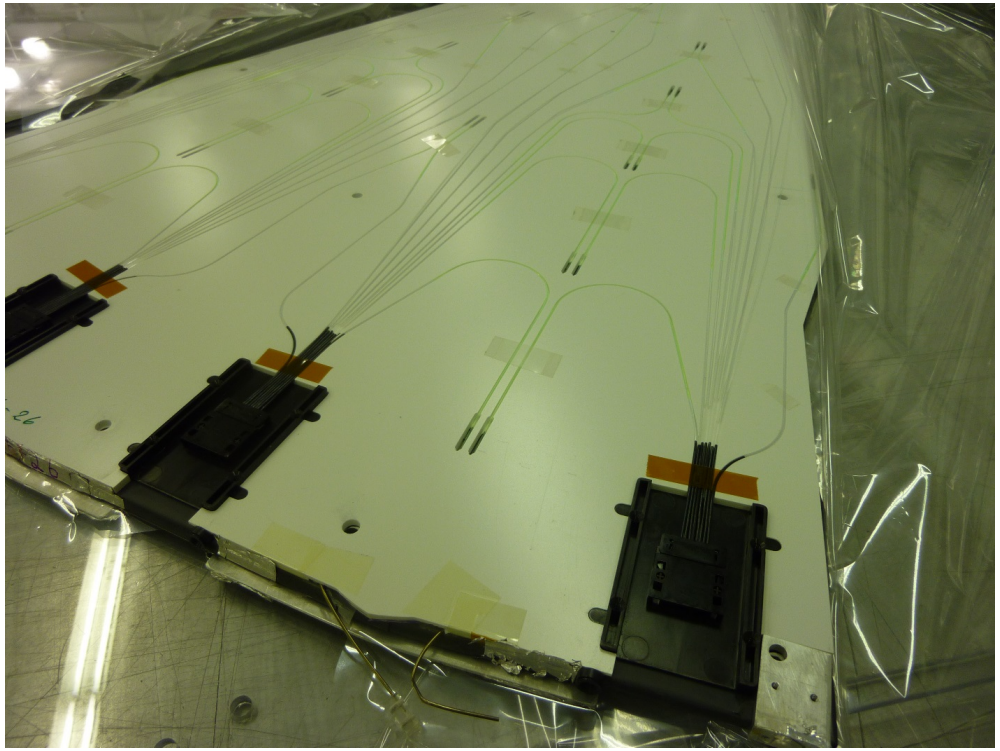
# summary

- **We continue to observe loss of signal in HE with strong eta dependence.**
- **The observation is based on Laser-> megatile data and confirmed by collisions data.**
  - For 23 $fb^{-1}$ delivered to CMS in 2012, reduction for highest eta towers in Layer1 was on average 30 %.
  - For 4 $fb^{-1}$ delivered to CMS in Run2, by early Nov-2015, we saw additional reduction of 10% for highest eta towers in Layer1.
- **We are in process of developing specific plans for possible partial replacement of HE megatiles during LS2**
  - Preparing for go-nogo decision to be made in late 2016
  - Actively working on following issues:
    - Better, more precise understanding of the physics consequences of the radiation damage of HE;
    - improving Castor table setup to complete R&D for scintillator/WLS fiber material choice;
    - Developing specific plan be ready to design, build and test prototypes, and production on time-scale consistent with start of LS2 (early 2019).
    - Starting up discussion with Technical Coordination and ECAL teams on how to carry out work at p5
- **A task force that would include members of HCAL and ECAL projects, Technical Coordination and Physics Coordination teams would be most welcome to properly prepare ourselves for GO/NOGO decision by Oct-2016.**

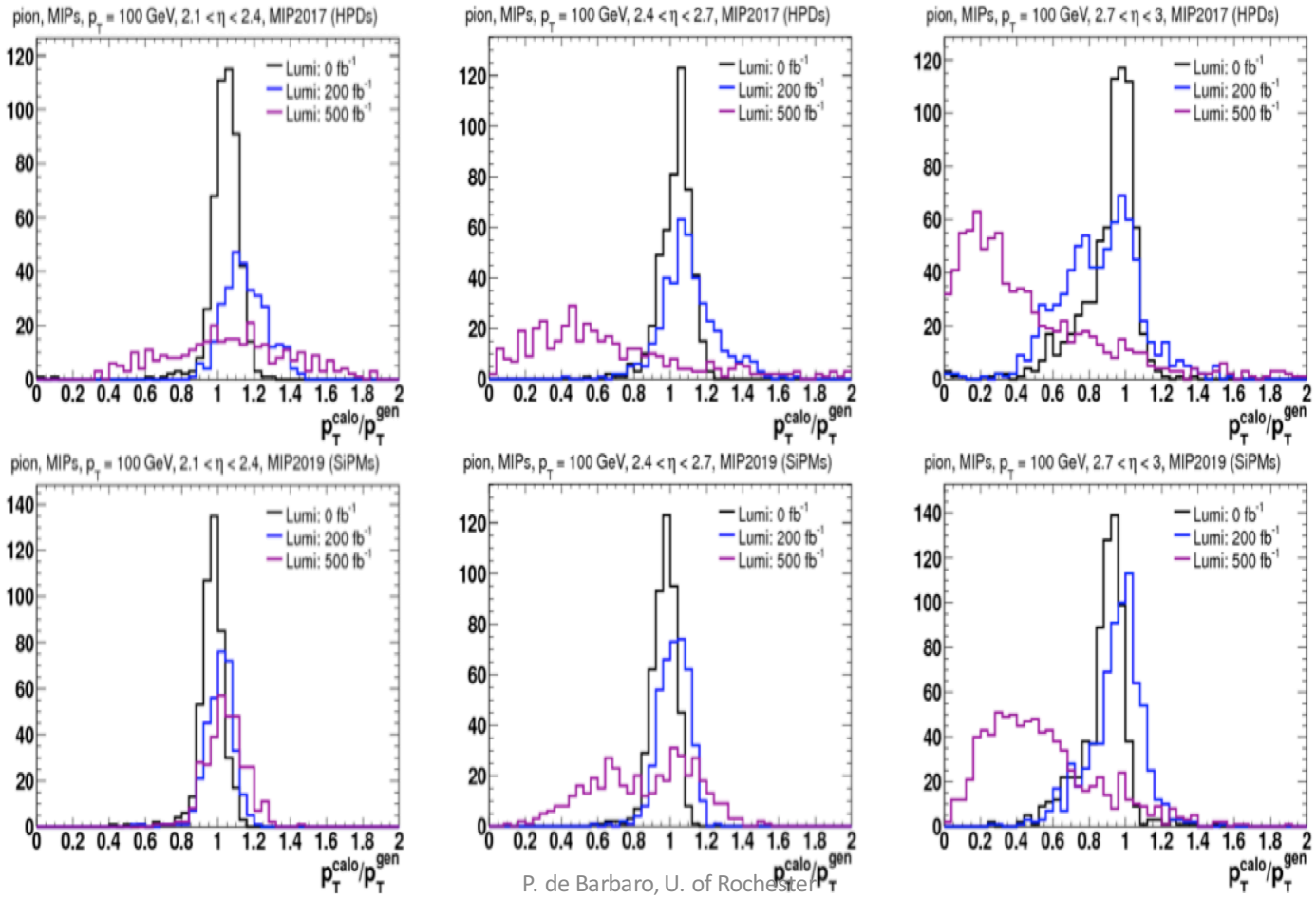
# Back-up

# HE Megatile (CDF), produced in late 1990s





Photos taken on Nov-19-2015

# Performance Degradation

K. Pedro