First results from CMS SiPM-based hadronic endcap calorimeter

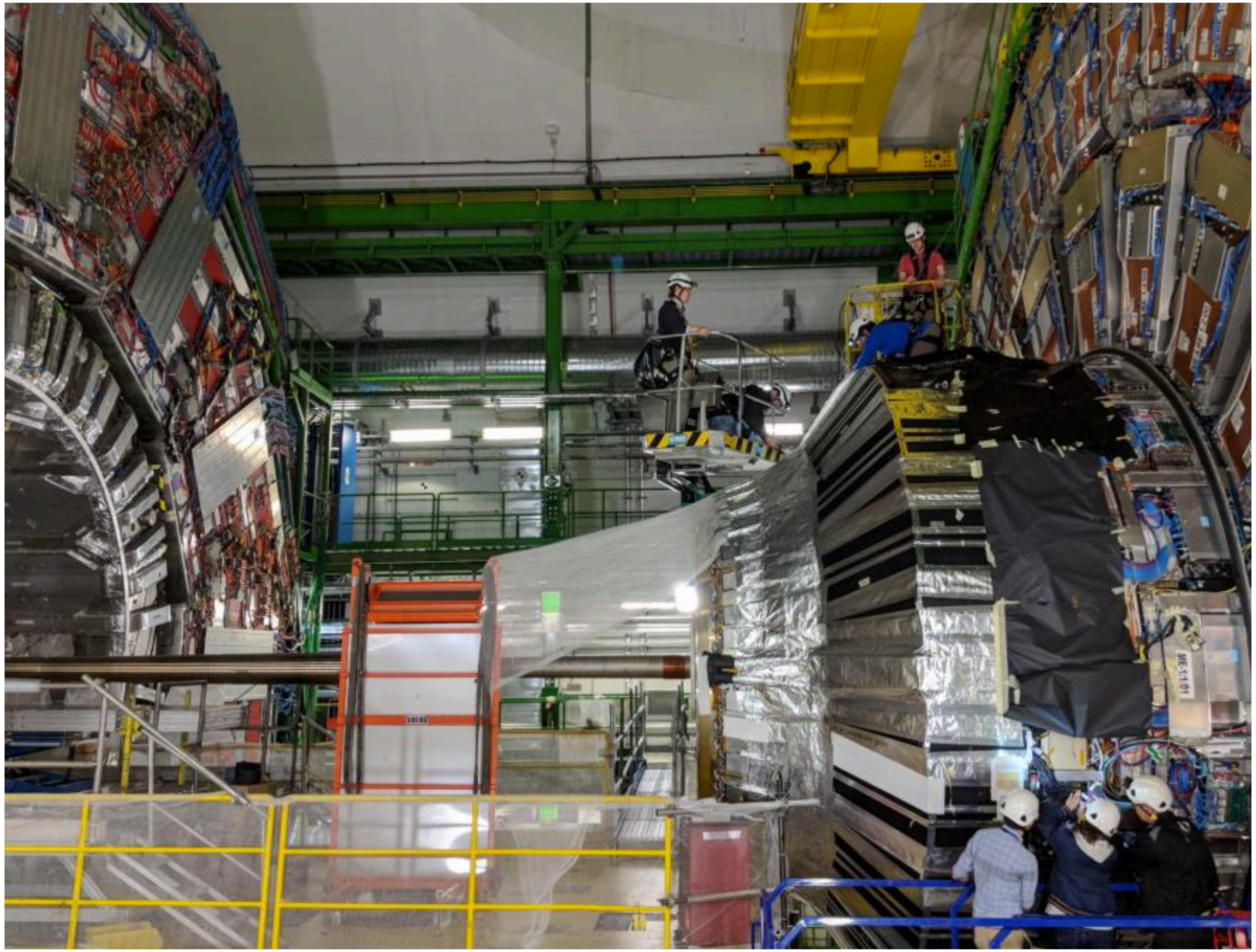
CALOR 2018

Eugene, 21-25 May 2018

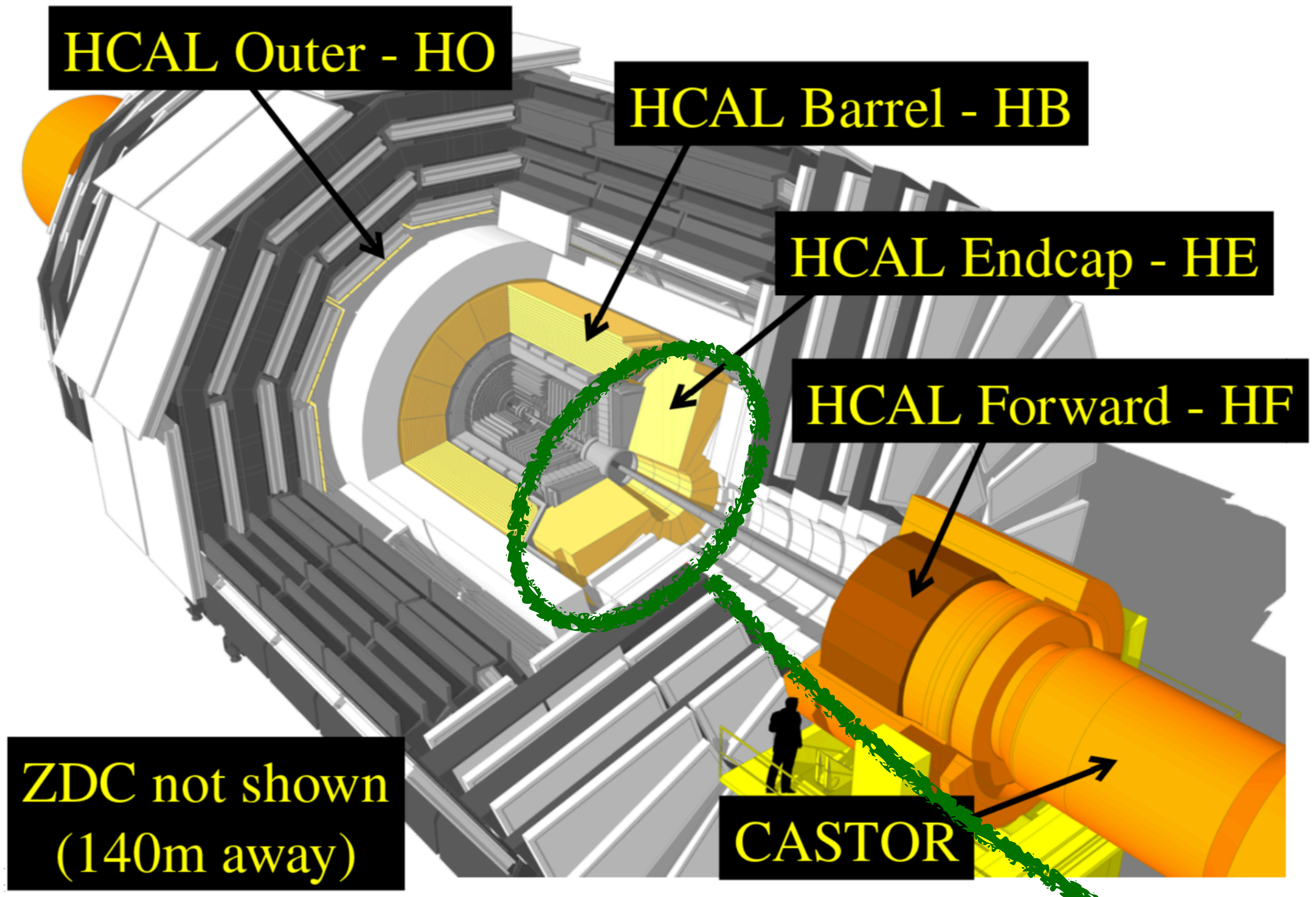
Federico De Guio - on behalf of the CMS collaboration

Outline

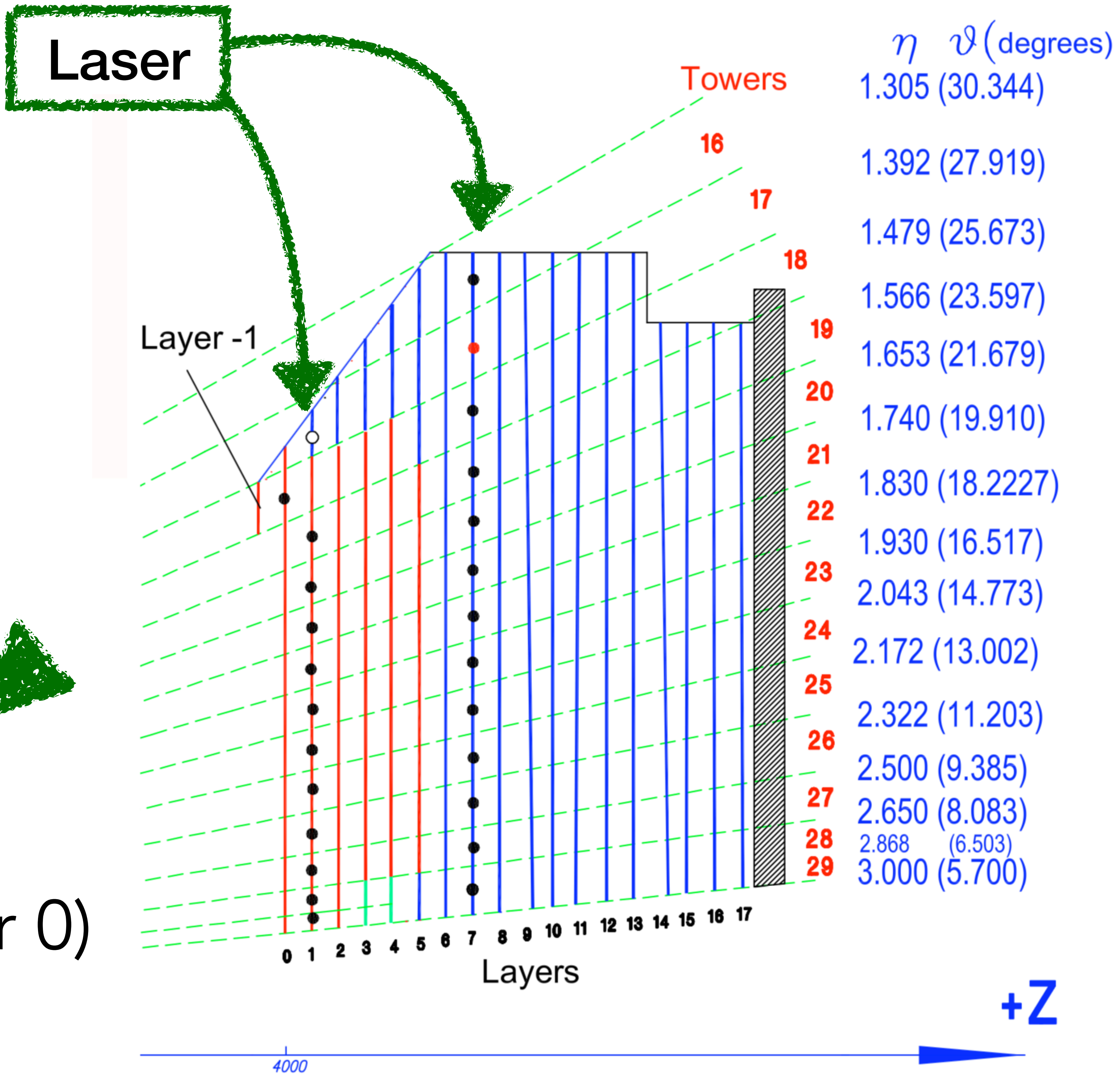
- Overview and context
- Advantages deriving from the Phase1 HE upgrade
- SiPMs operational experience
- A look forward

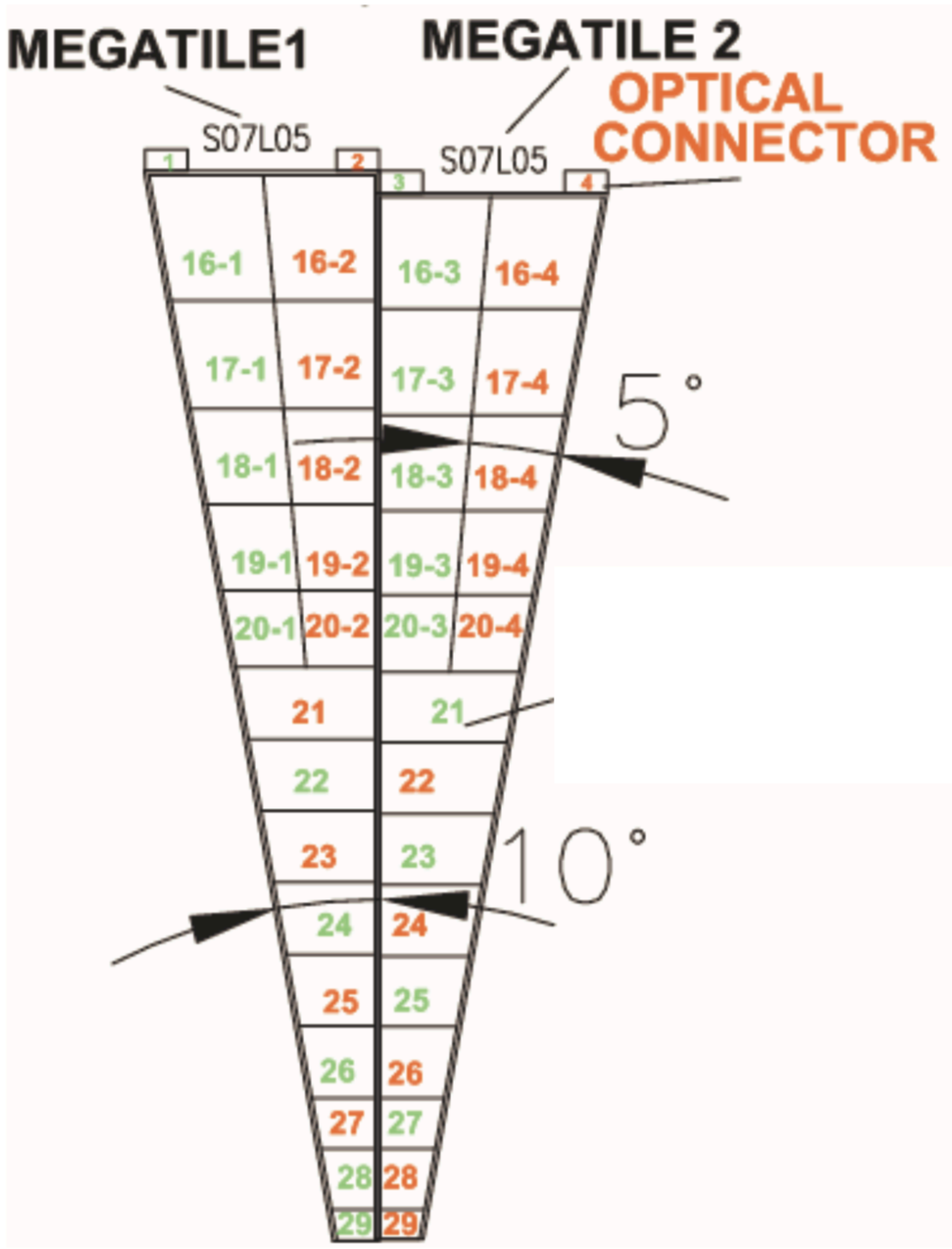


The HCAL at CMS



HCAL endcap (HE) layout





Sampling scintillating calorimeter

Endcap coverage 1.3<|η|<3

Brass absorber (~8 cm each layer)

4 mm SCSN81, 9 mm Bicron BC408 (for layer 0)

19 longitudinal layers

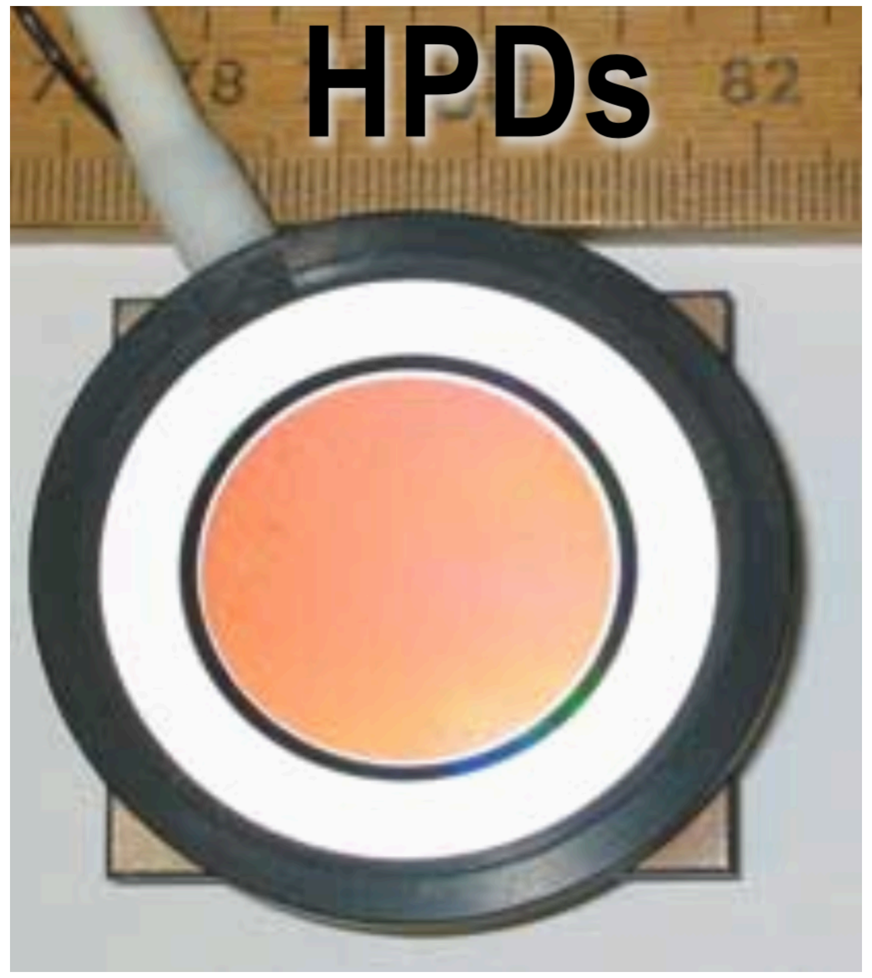
Light emission from tiles: λ=410-425 nm

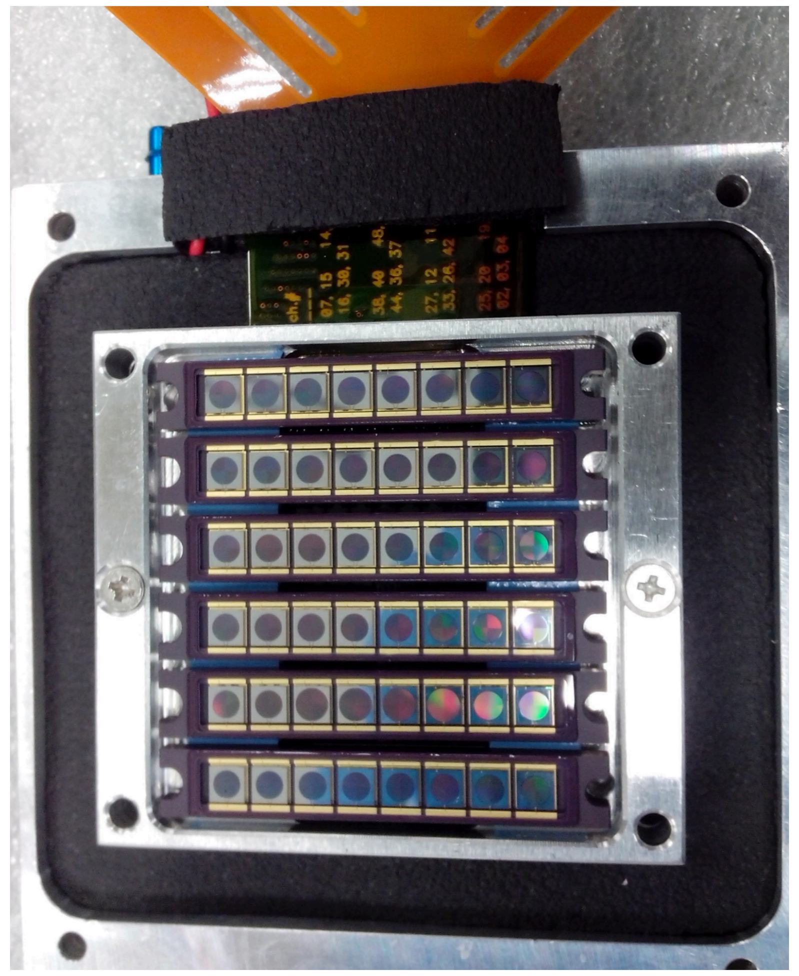
Signal collected with wavelength shifting fibers (λ=490 nm)

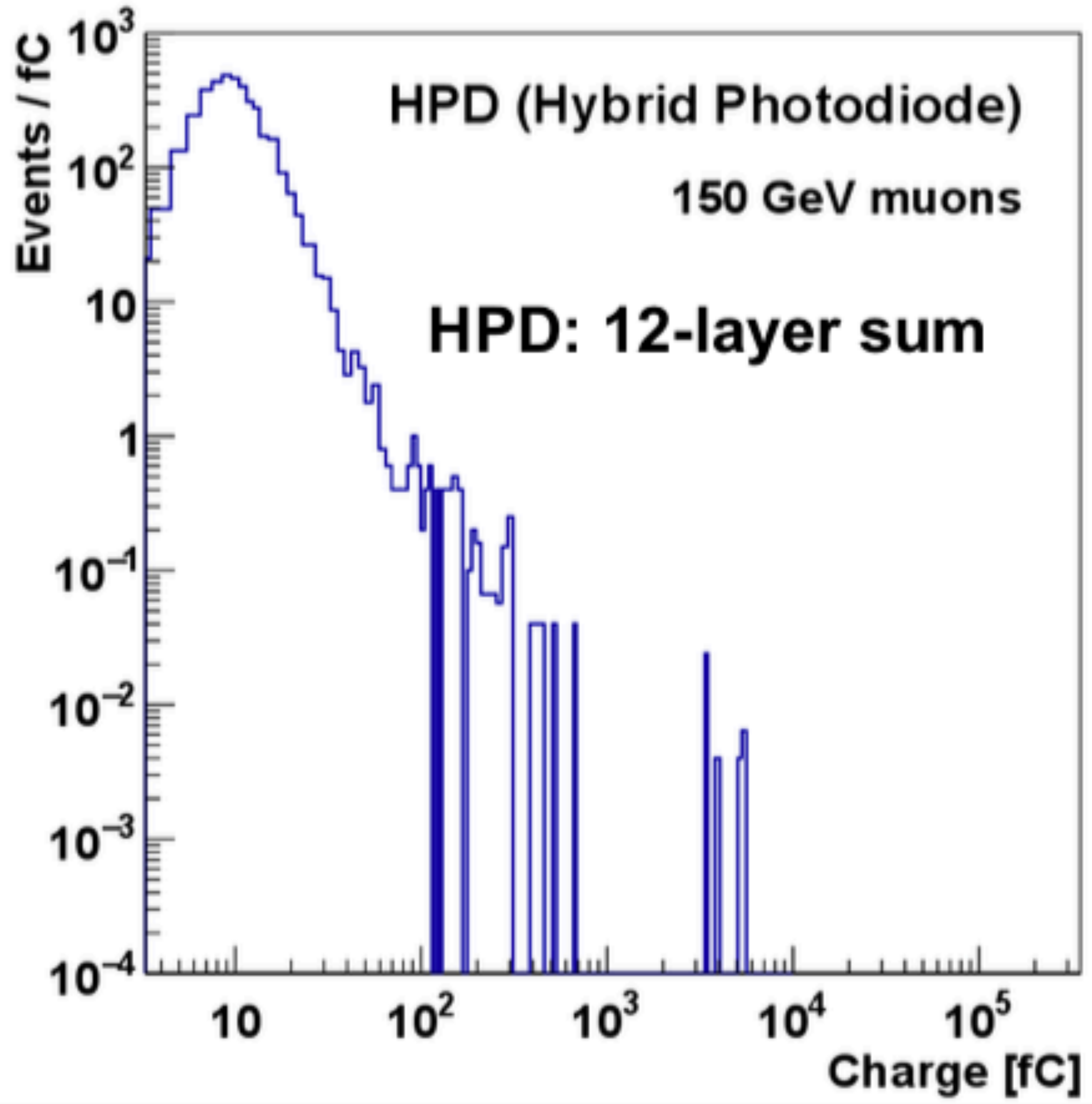
Laser system to monitor scintillator response

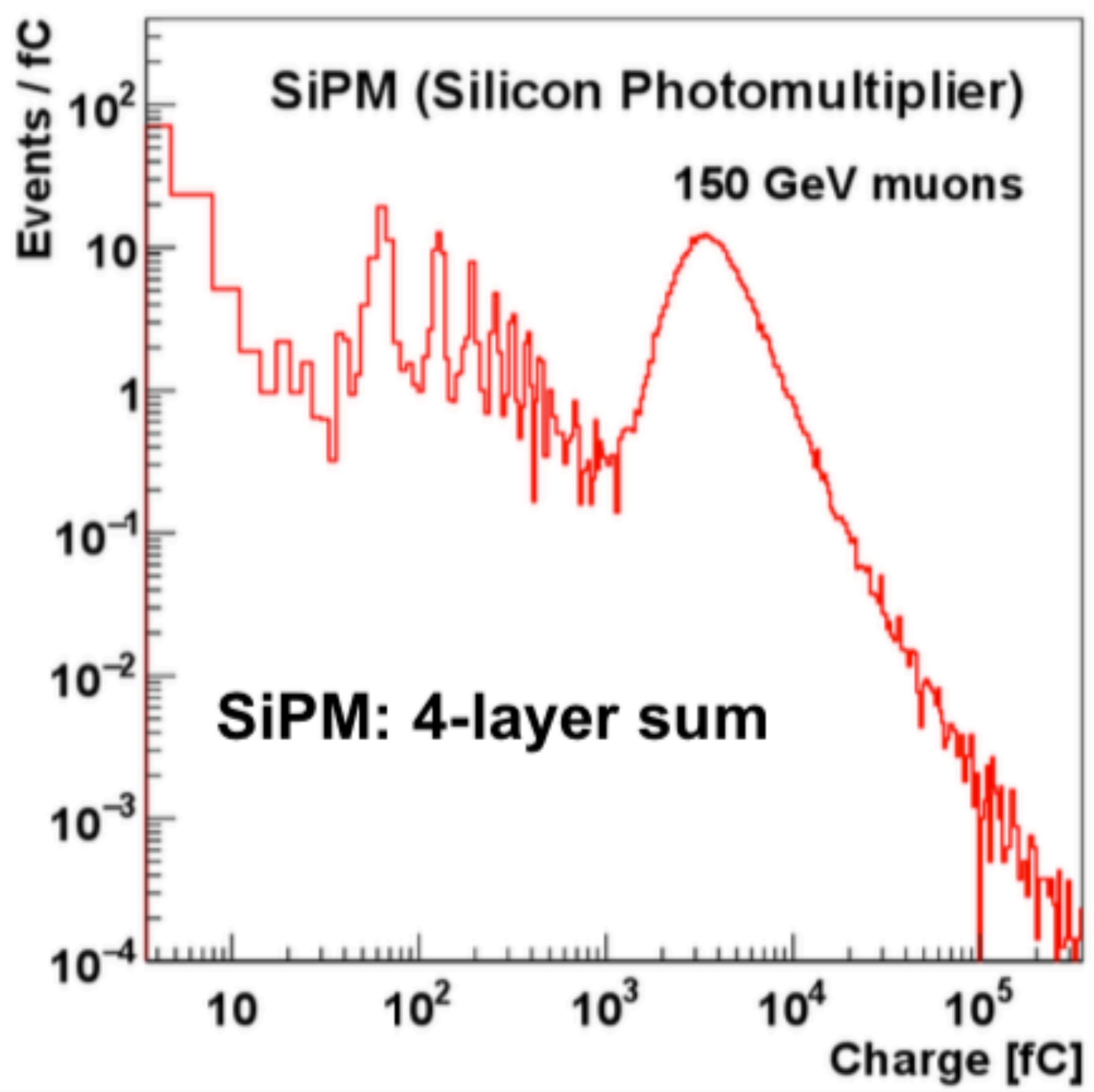
The HE Phase1 upgrade: readout

- New photo-detector: HPDs → SiPMs
  - x2.5 higher PDE
  - x400 higher response
  - Reduced noise
- New front-end electronics: QIE8 → QIE11
  - 8-bit ADC with embedded TDC
  - internal charge injection for in situ monitoring, programmable gain
- uTCA back-end
  - supports larger data volumes, new trigger primitives





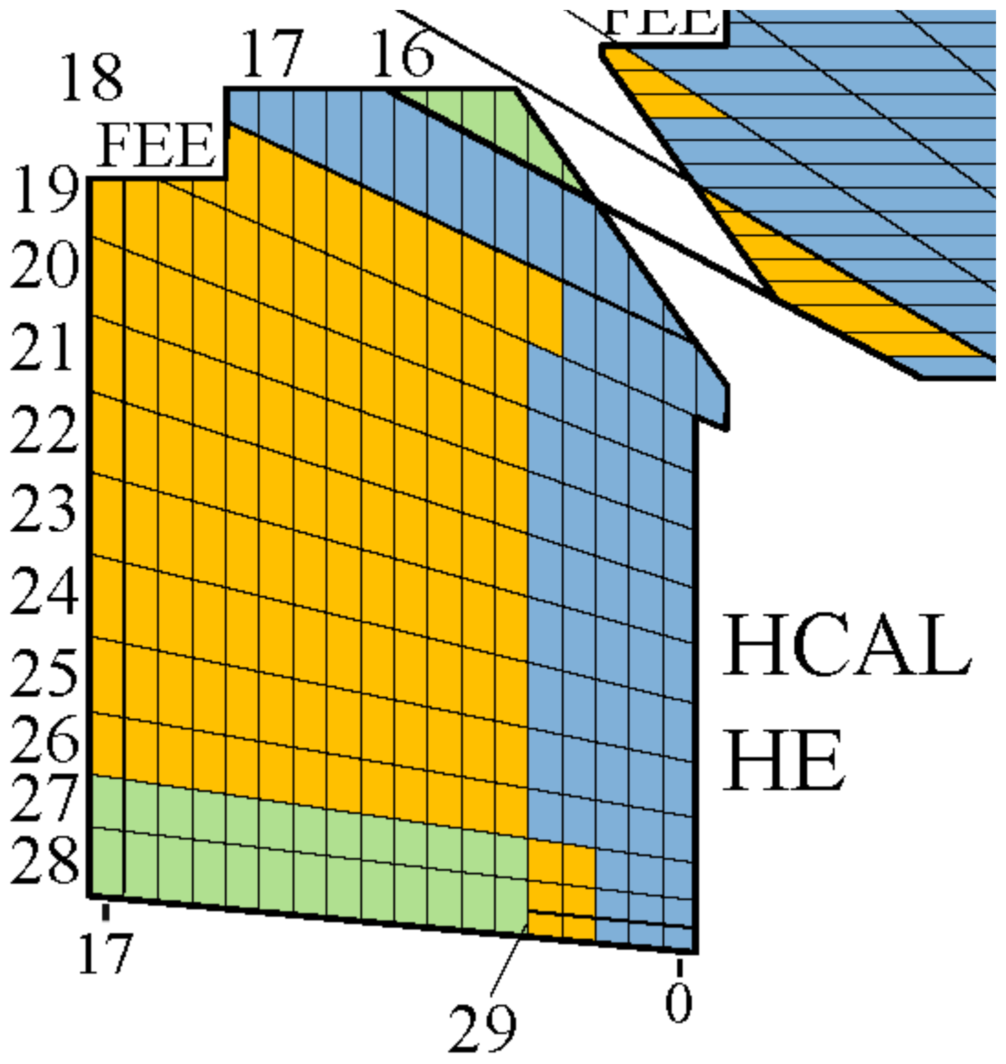




The HE Phase1 upgrade: layout

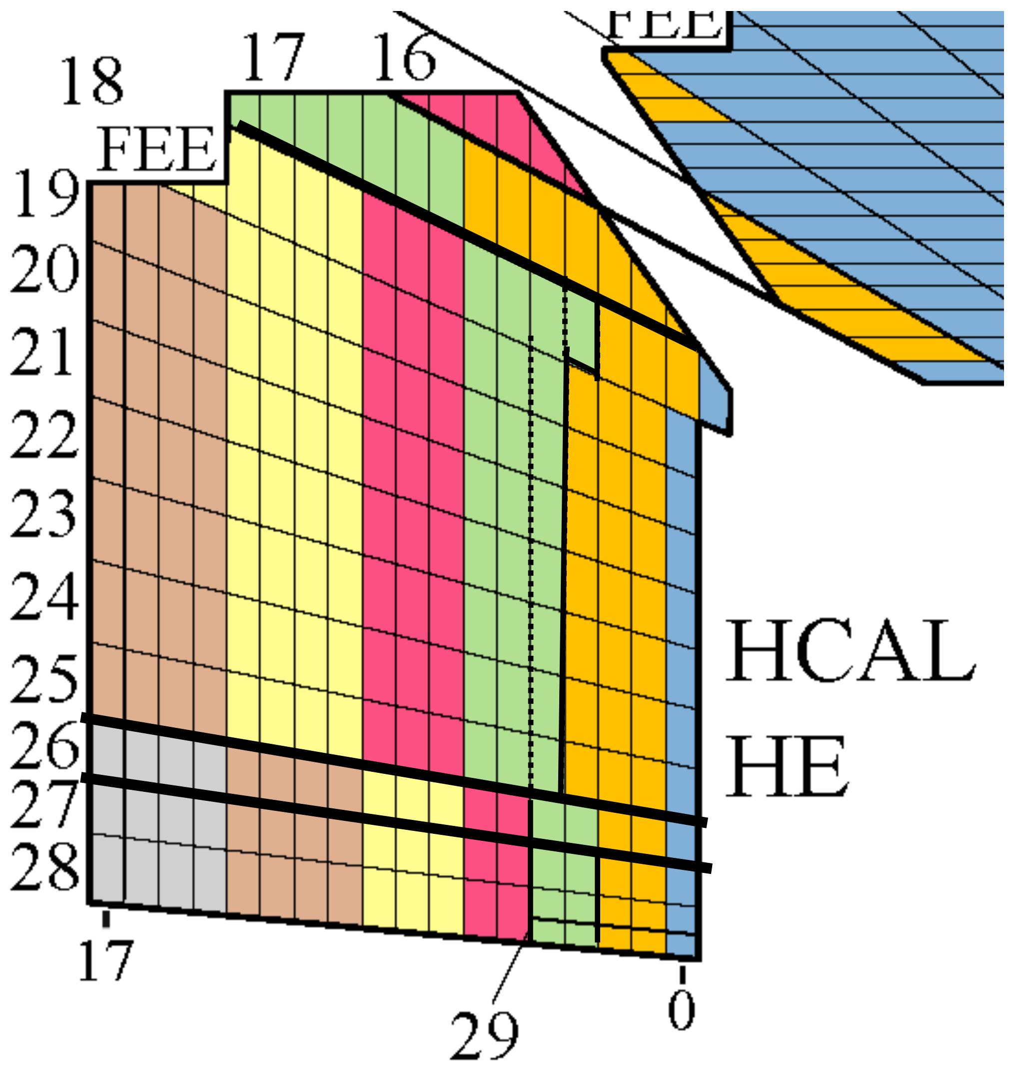
- In 2017 a **pilot system of 20°** in phi (**HEP17**) allowed deep understanding of physics performance, calibration, monitoring with no harm to data quality
- Signal from depths was summed at software level to mimic the original layout

2016
Original configuration
2664 HPD channels
Up to 3 depths

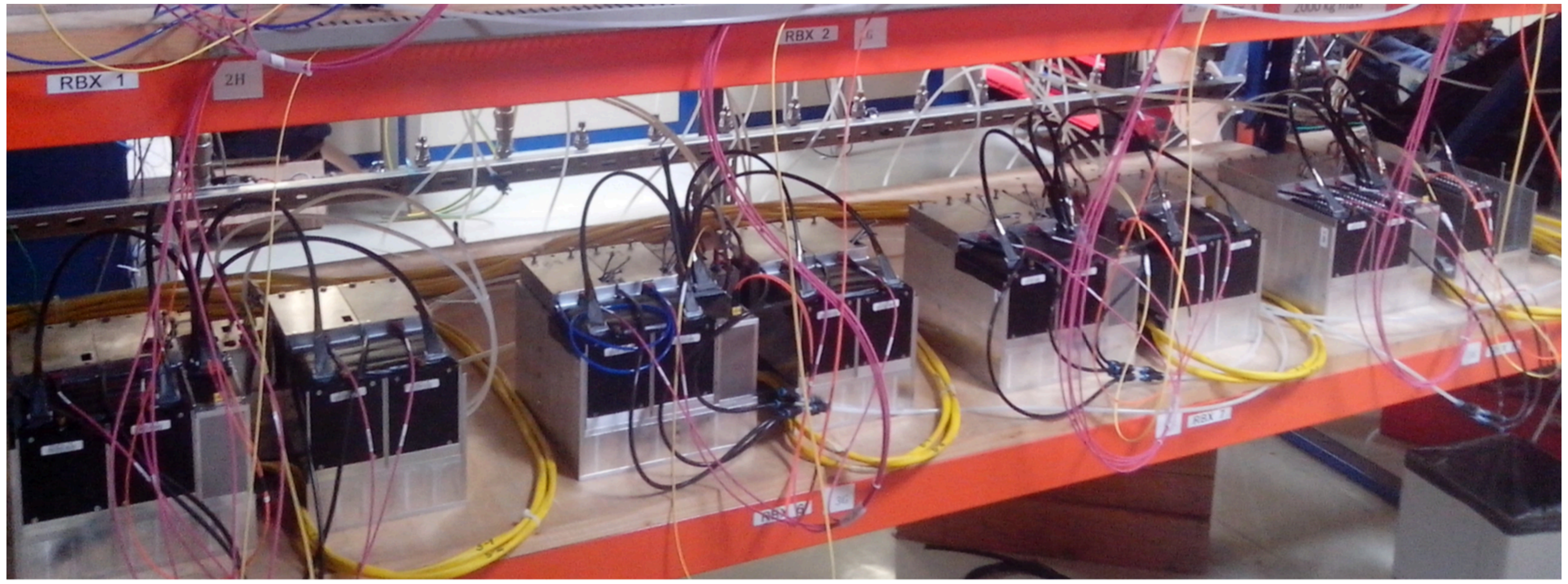


2017
1 wedge upgraded: **HEP17**
20° of endcap
184 SiPMs channels
Up to 7 depths

2018
Full HE upgraded
184*36 SiPMs channels
Up to 7 depths

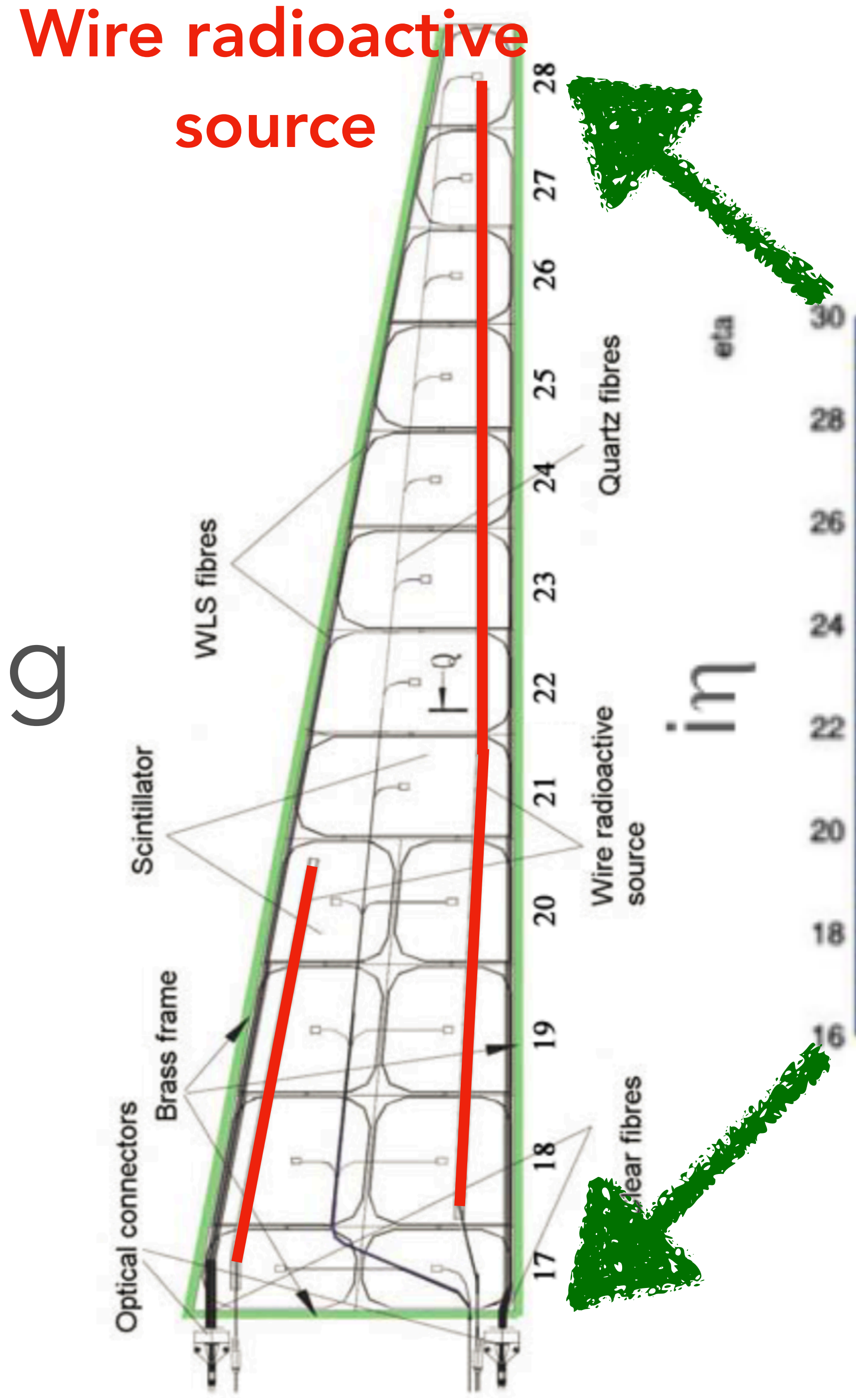


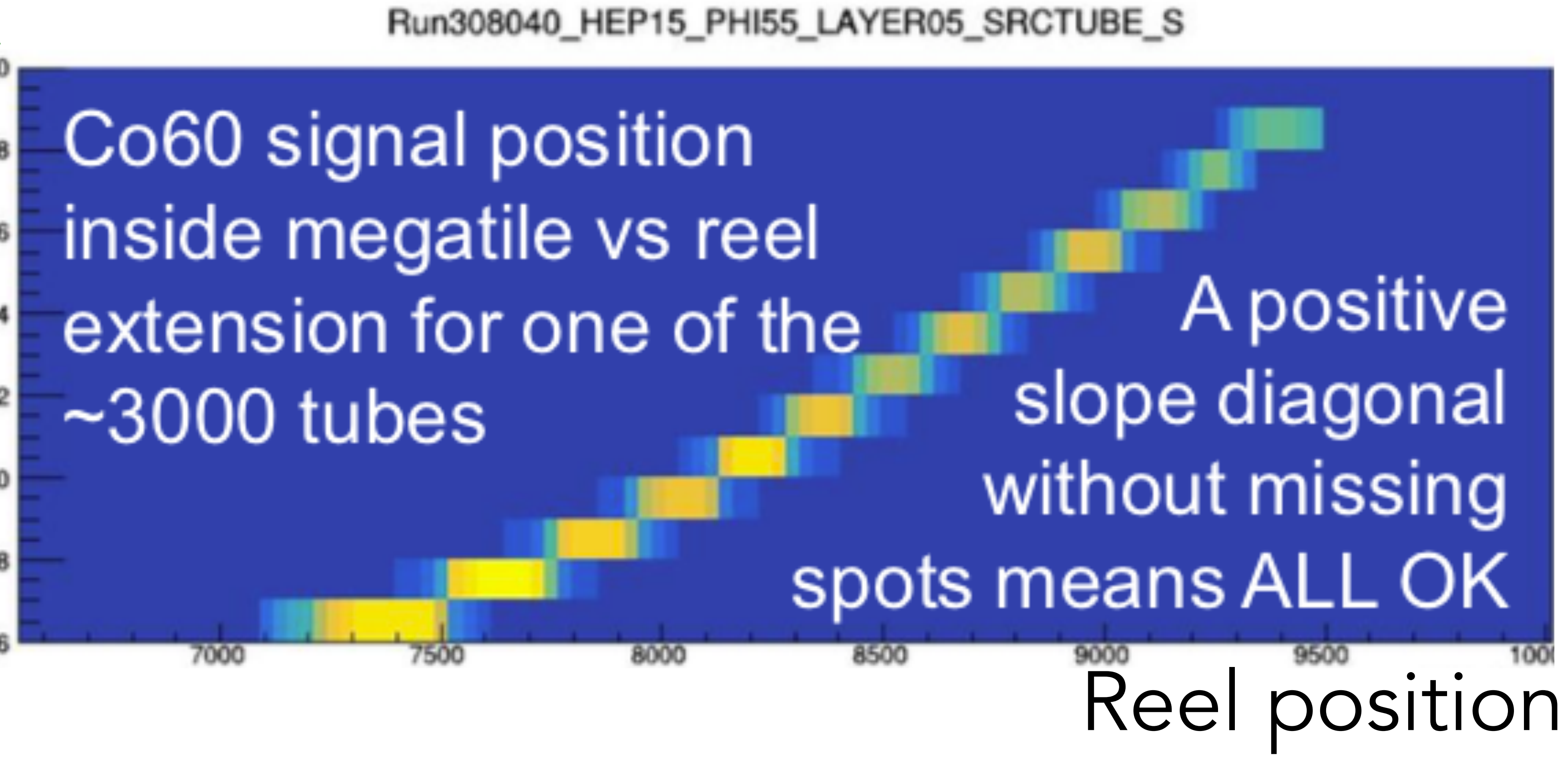
The HE Phase1 upgrade: commissioning



- 36 readout boxes upgraded
  - 6624 channels
  - System burned in for 8 detector-months in 2016-17 prior installation

- Calibration with ^{60}Co source
  - ^{60}Co wire-source inserted into tubes embedded in HE megatiles
  - Verify end-to-end detector functioning and tile-by-tile mapping
  - Provides startup calibration

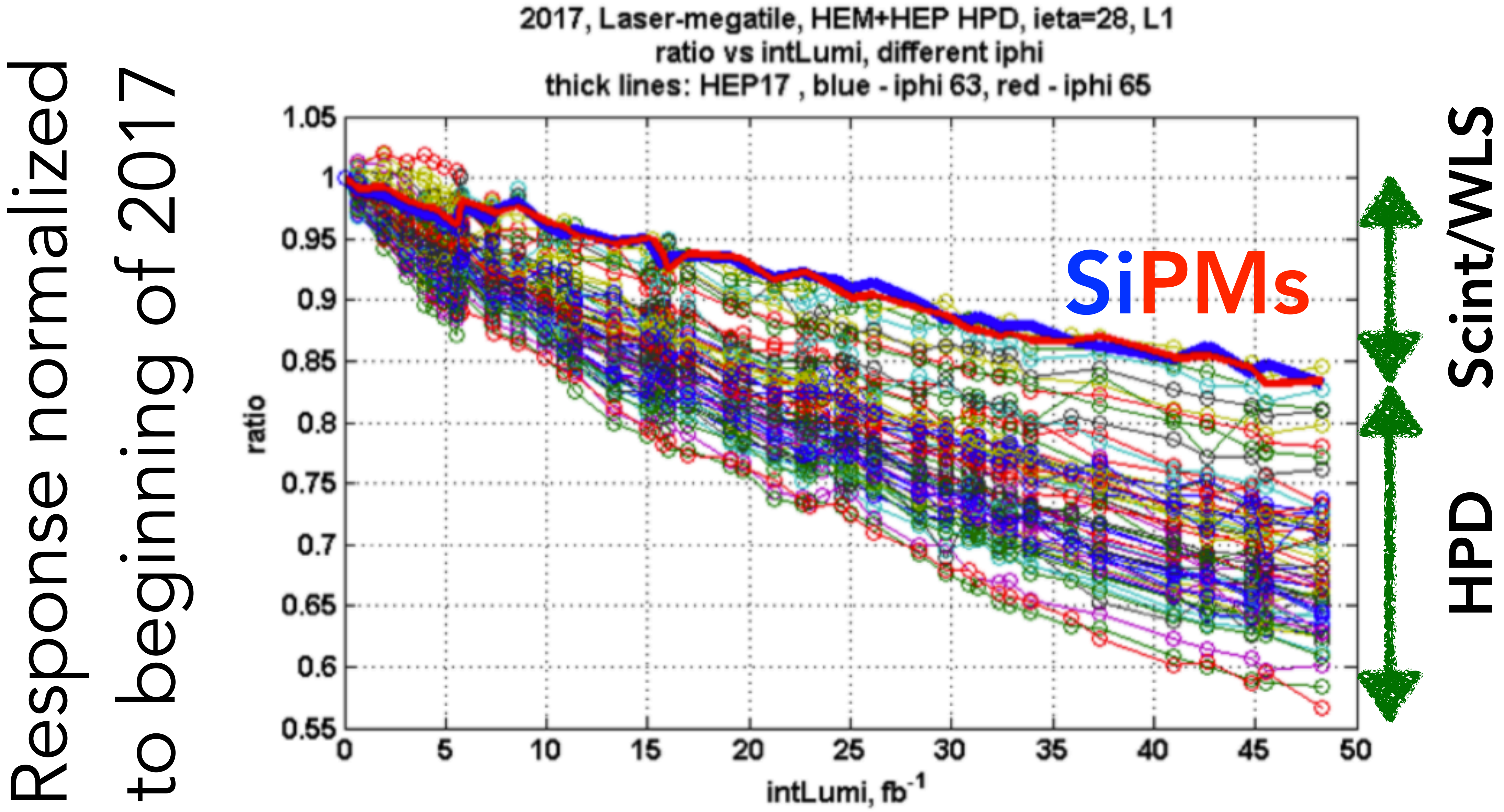




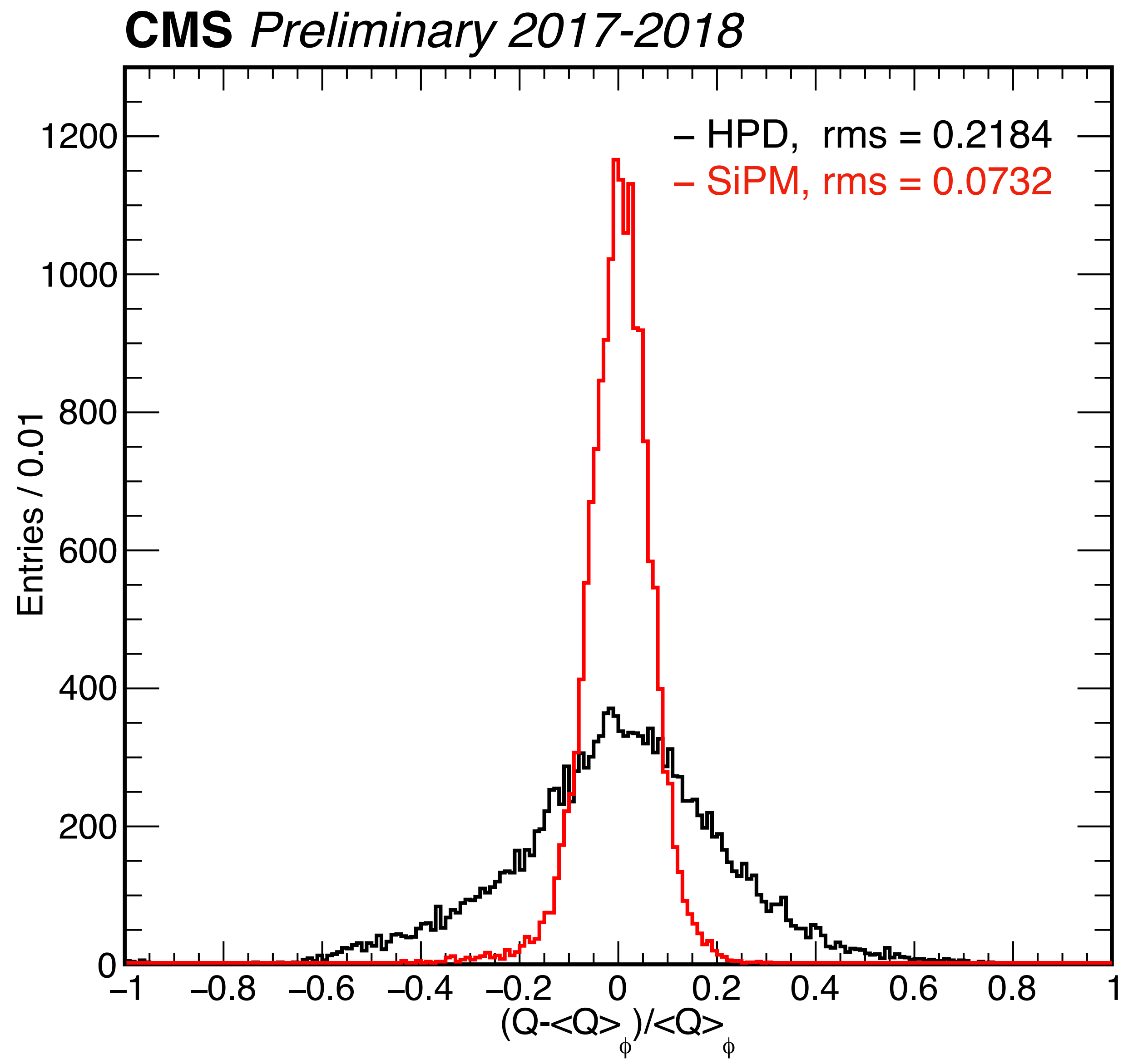
Immediate benefits deriving from the upgrade

Restore the symmetry of the response

- ... vs Time
  - Unpredictable degradation of the HPDs
  - Large spread between channels
  - High η region is the most affected
  - SiPMs are behaving as the 'best HPD'
- ... vs Phi
  - RAW detector response is much more uniform
- Moreover the **scintillator damage** due to radiation is **mitigated** via 2.5x higher photon detection efficiency



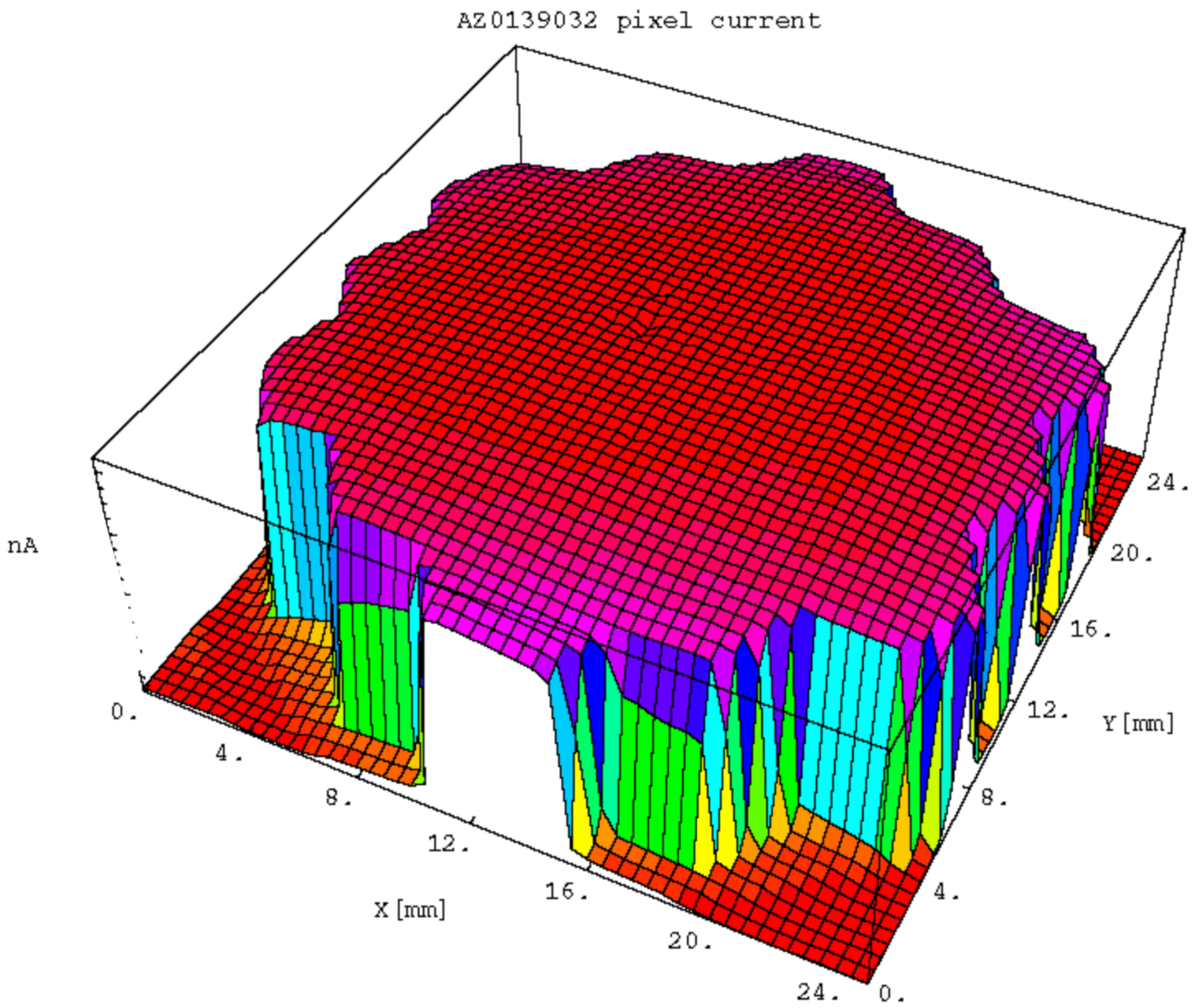
^{60}Co data:
2017/HPD
2018/SiPM



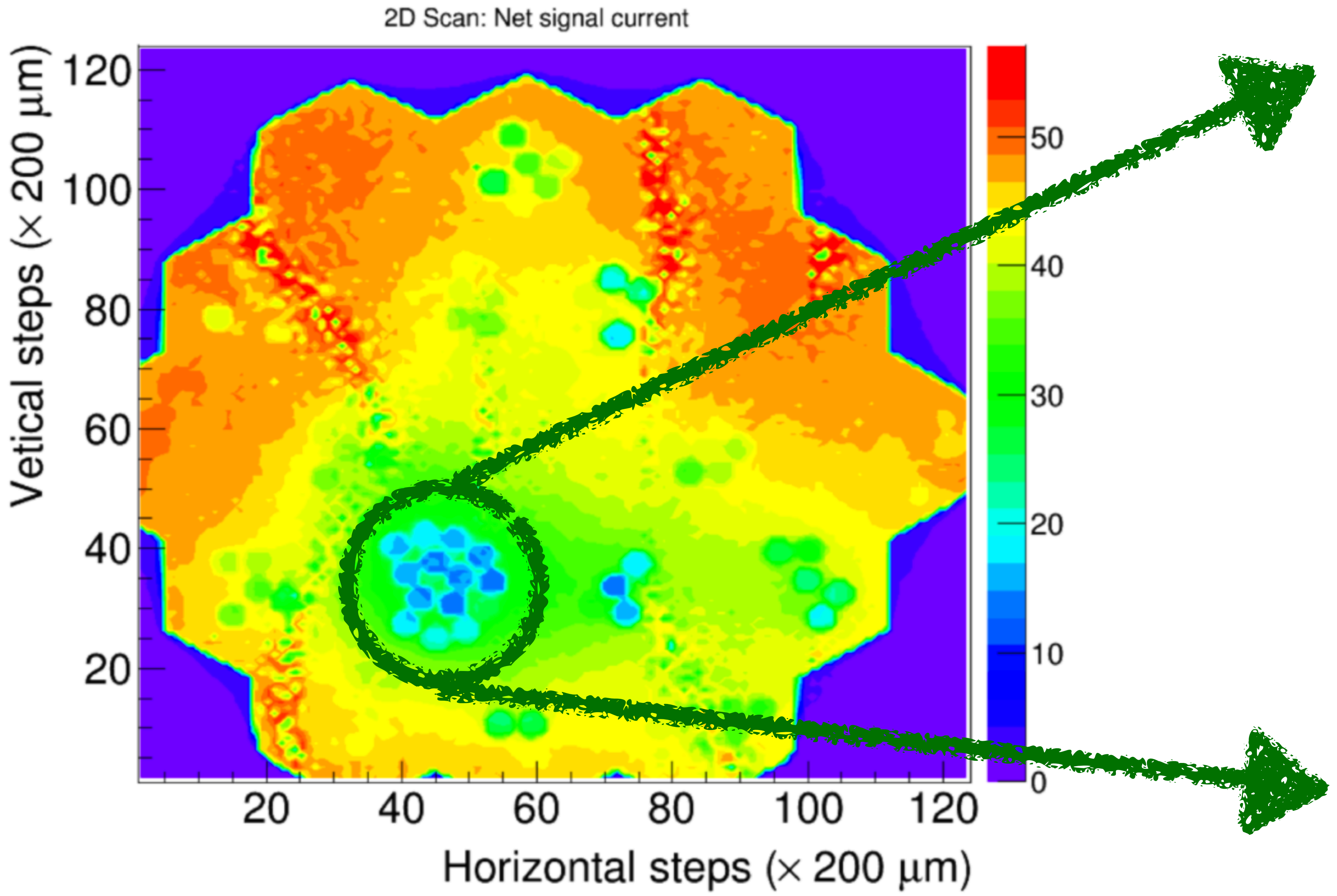
A posteriori analysis of HPDs from HEP17

- Scan of a damaged HPD photocathodes using laser light
  - the response is reduced in a highly non-uniform way
  - localized damage spots corresponding to position of fibres from tiles
- Real structural damage: hard to model and predict

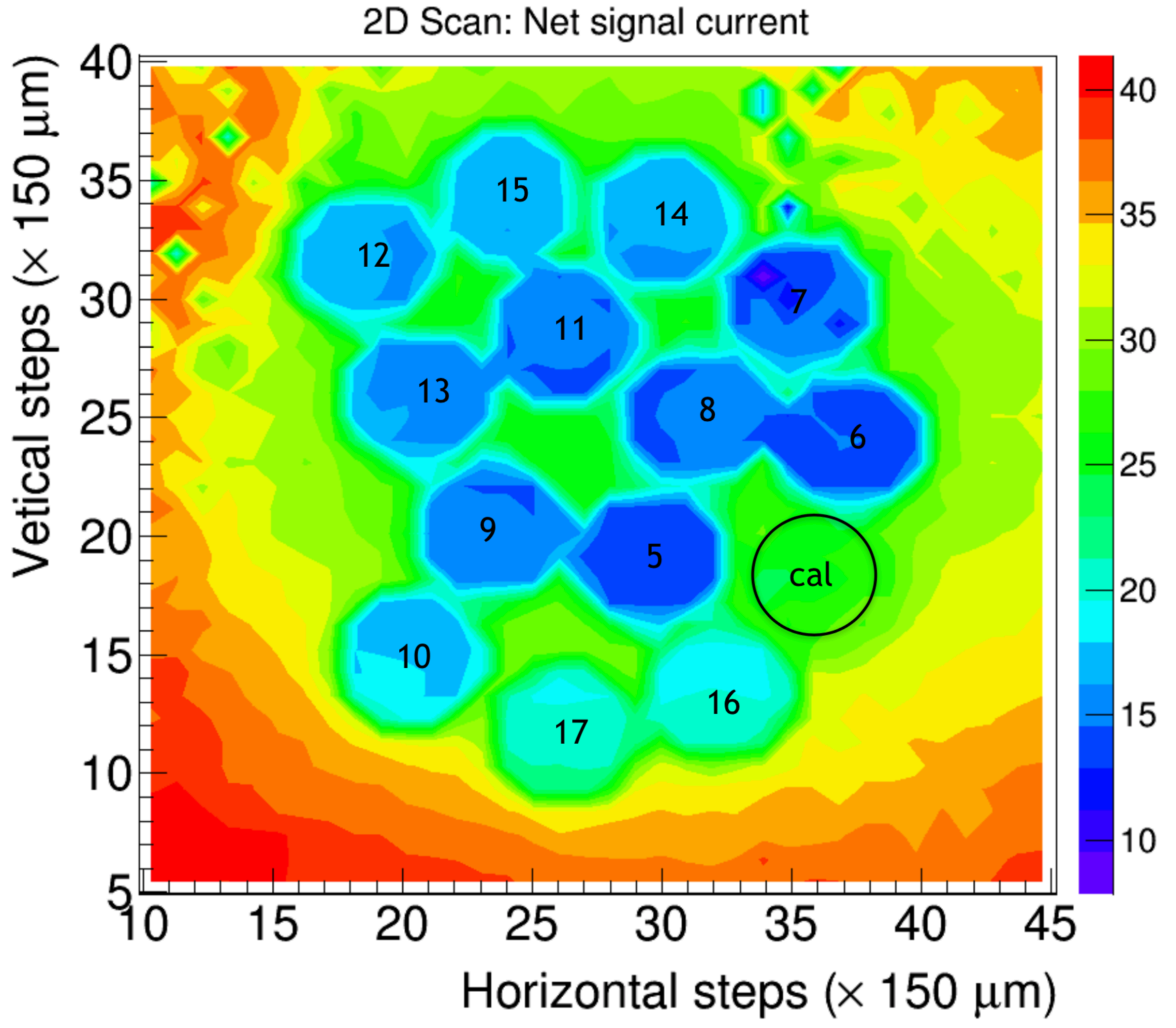
New



From HEP17



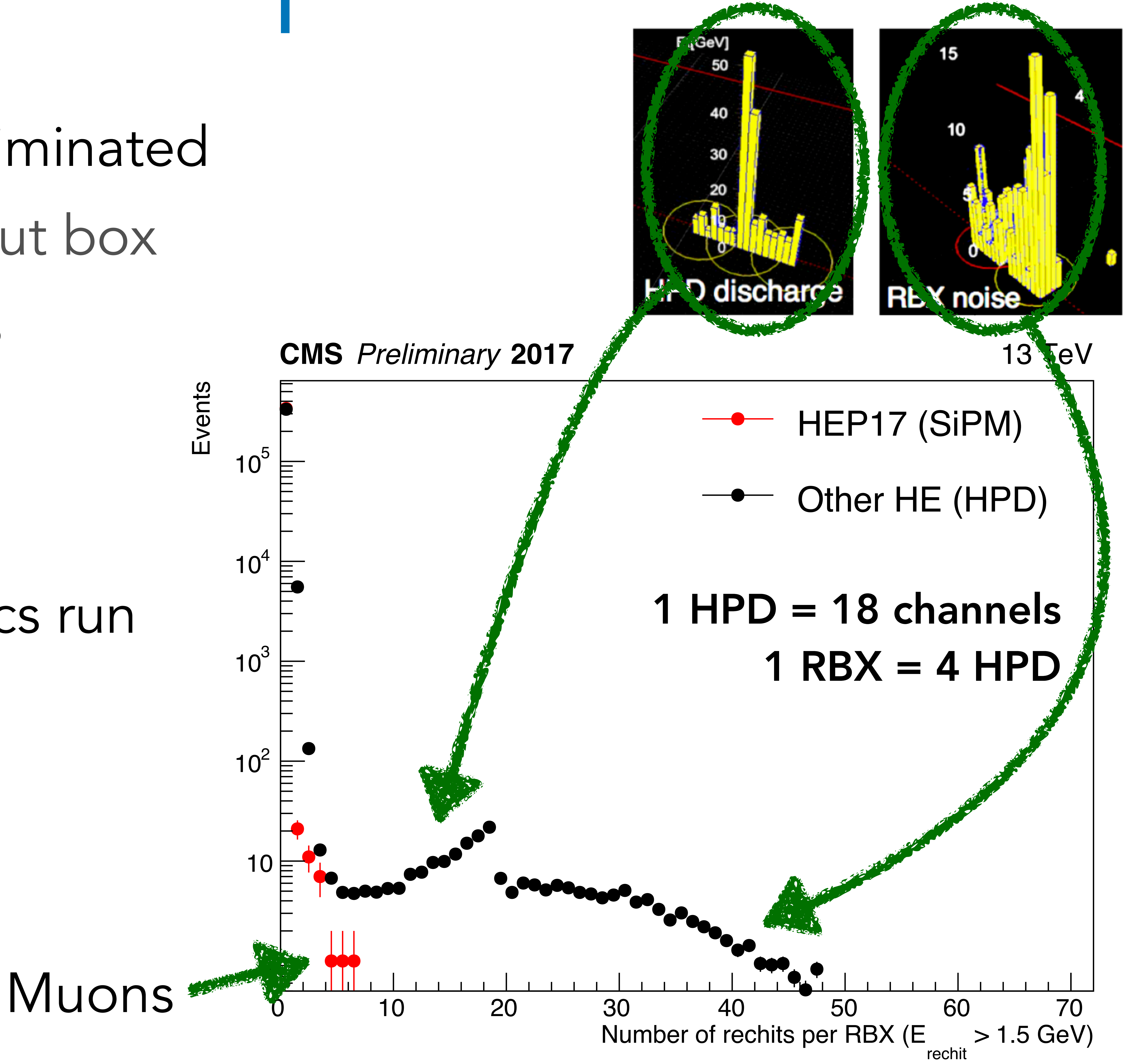
From high eta



Eliminate catastrophic noise

- Sources of catastrophic noise are eliminated
  - No noise associated to the readout box
  - No noise associated to the SiPMs

- Analysis of the hits in HE in a cosmics run
  - Muon deposits are visible



Operational experience and calibration

HEP17 experience

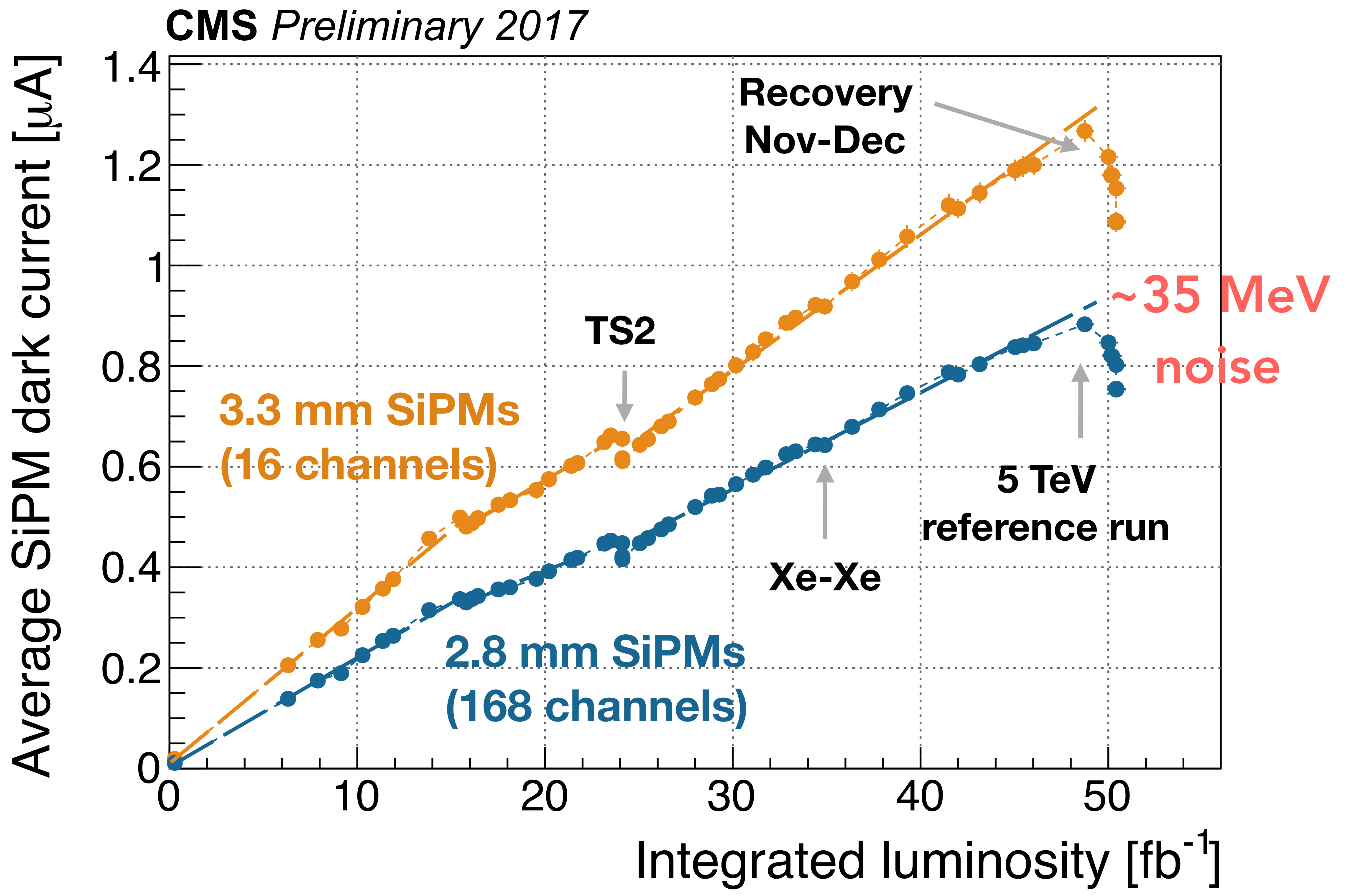
- All 184 channels corresponding to HEP17 were functional during the whole 2017 data taking
  - Smooth operations, negligible downtime related to the upgraded detector

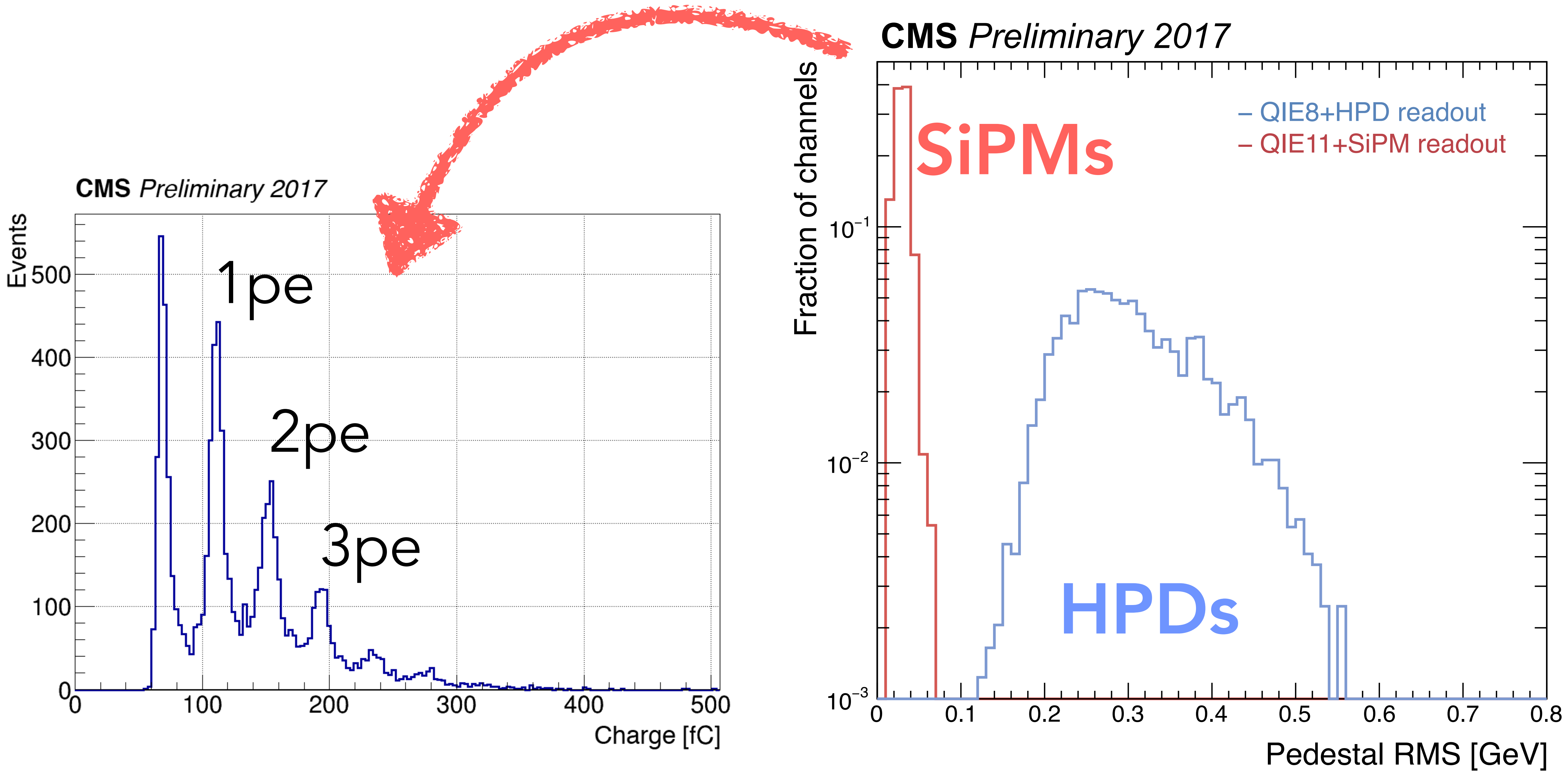
- The HEP17 pilot system allowed to:
  - Measure the pulse shape for scintillator+fibre+SiPM+QIE11 from data
  - Project the reconstruction performance to the full scale HE
  - Fine-tune the simulation of the upgraded detector
  - Perform noise measurements
  - Gain experience in commissioning the trigger

More in Jay's talk

SiPMs dark current measurement

- SiPMs dark current has been monitored during data taking
  - Slope is proportional to the SiPM area
  - Deviation from linearity are due to recovery time in absence of beam and variation in instantaneous luminosity
- 110 MeV of noise are expected at the end of Run3 (500/fb, projecting linearly)
  - To further reduce the noise one handle is to operate the SiPMs at 0°C





SiPMs gain stability

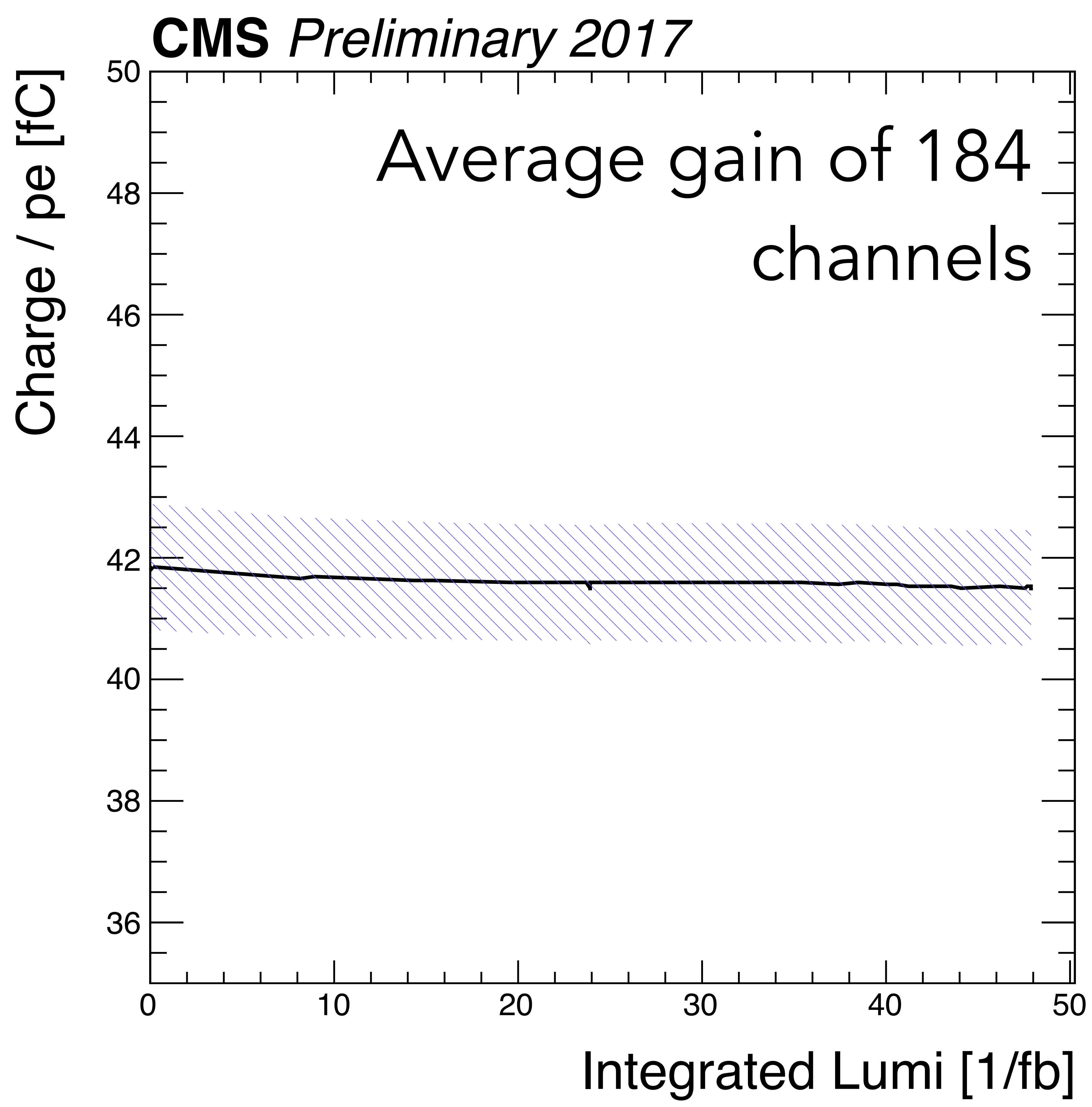
- The gain of each channel is measured individually
  - Single fit function to the multi-peak charge spectrum in pedestal and low intensity LED runs

$$f(x) = \sum_{i=0}^{N_{peaks}-1} A_i e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}$$

$$\mu_i = \mu_0 + iG$$

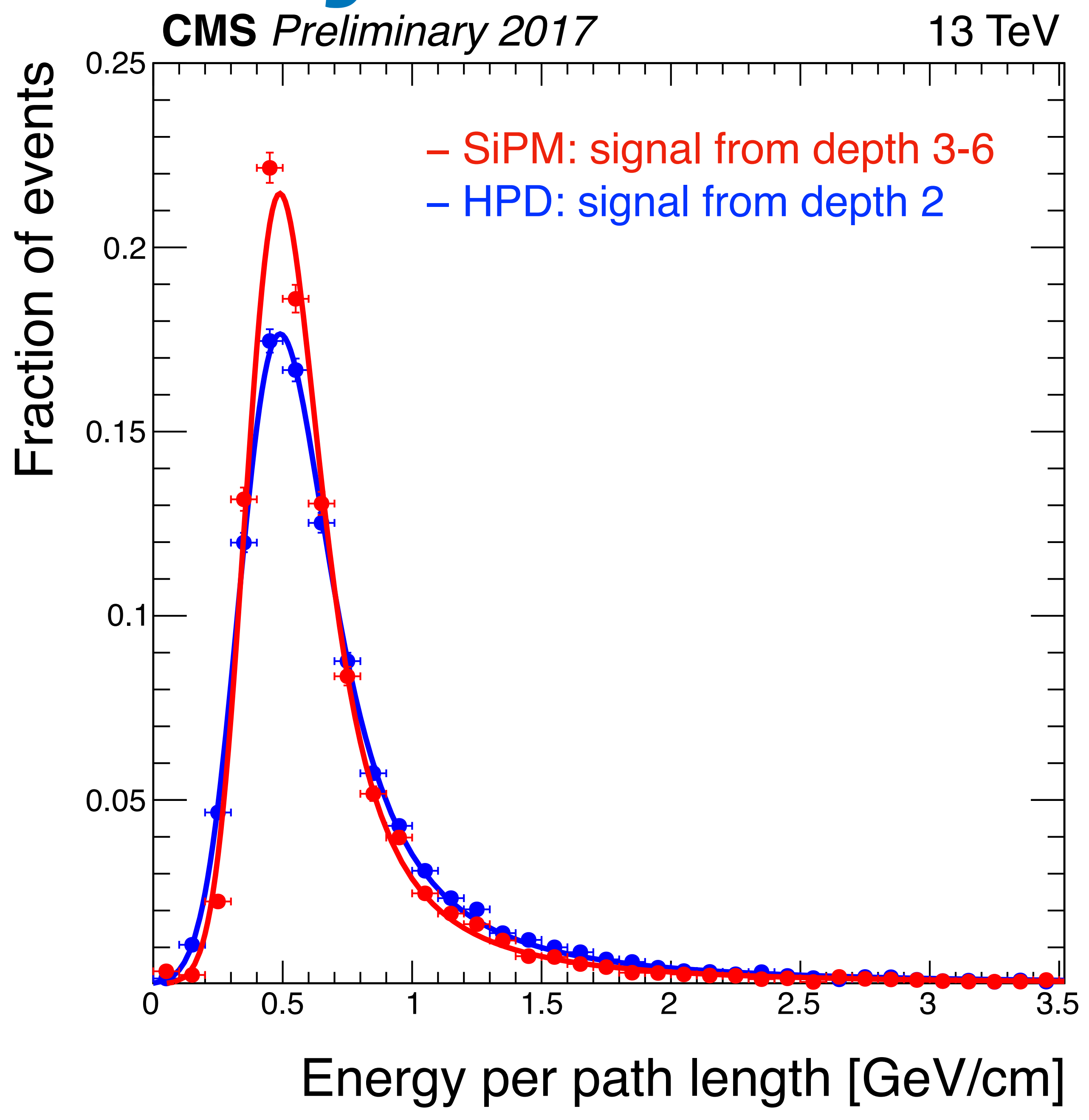
$\boldsymbol{A_i}$: amplitude of the i[th] peak
$\boldsymbol{\sigma_i}$: width of the i[th] peak
$\boldsymbol{\mu_i}$: mean of the i[th] peak
$\boldsymbol{G}$: gain

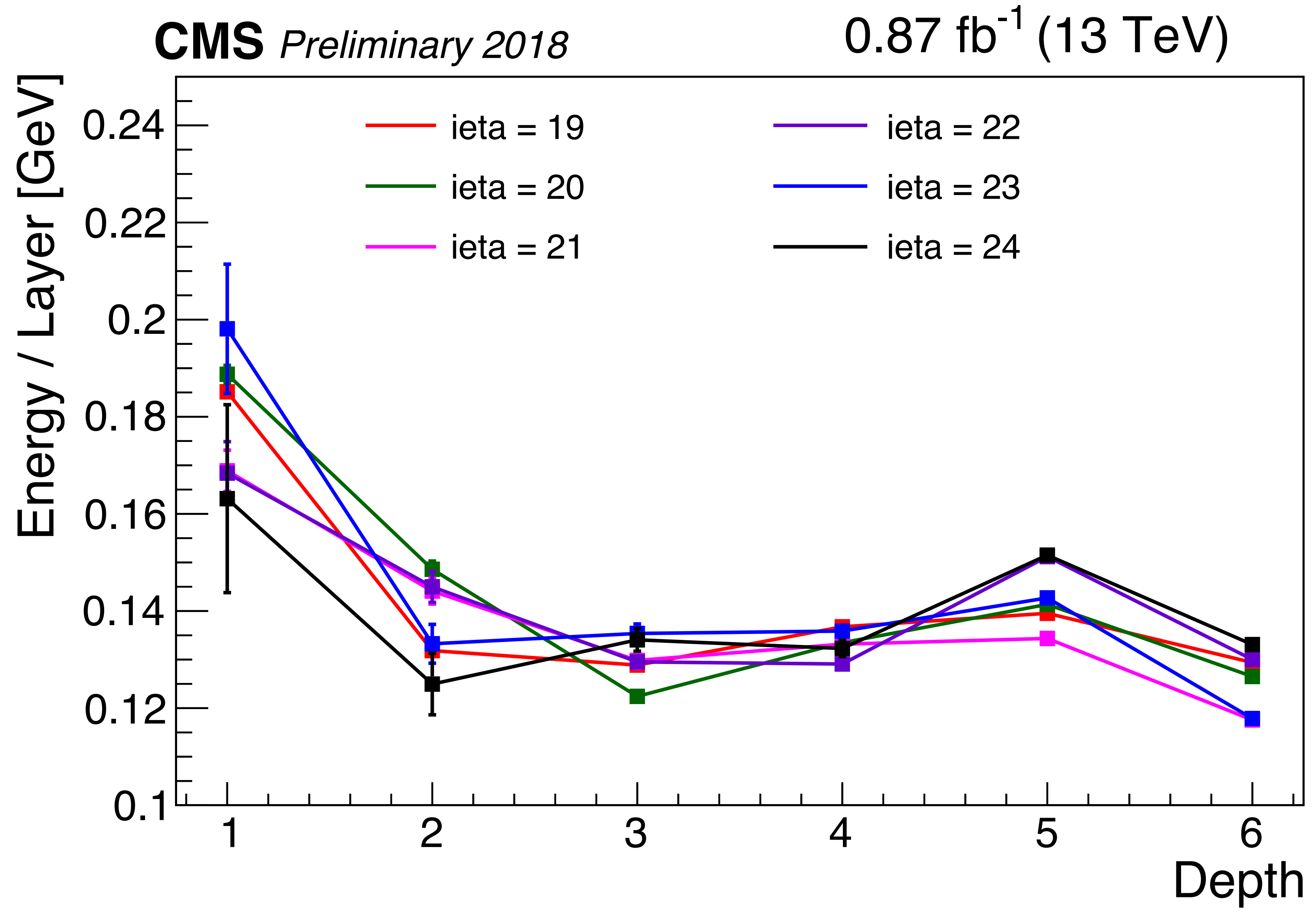
- The gain was found to be stable during the whole 2017 data taking at the 1% level



Response calibration and sensitivity to MIPs

- The HCAL calibration makes use of:
  - E/p from isolated tracks for the energy scale measurement vs pseudorapidity
  - phi-symmetry for equalizing the response along phi
- From 2018 the depth inter-calibration is also performed
  - MIP deposits from muons are used to correct for depth dependent effects like ageing
  - The improved sensitivity to MIPs (~5 pe/MIP/layer) is also exploited to extend the scale calibration beyond the tracker coverage





A look forward

HE in Run3

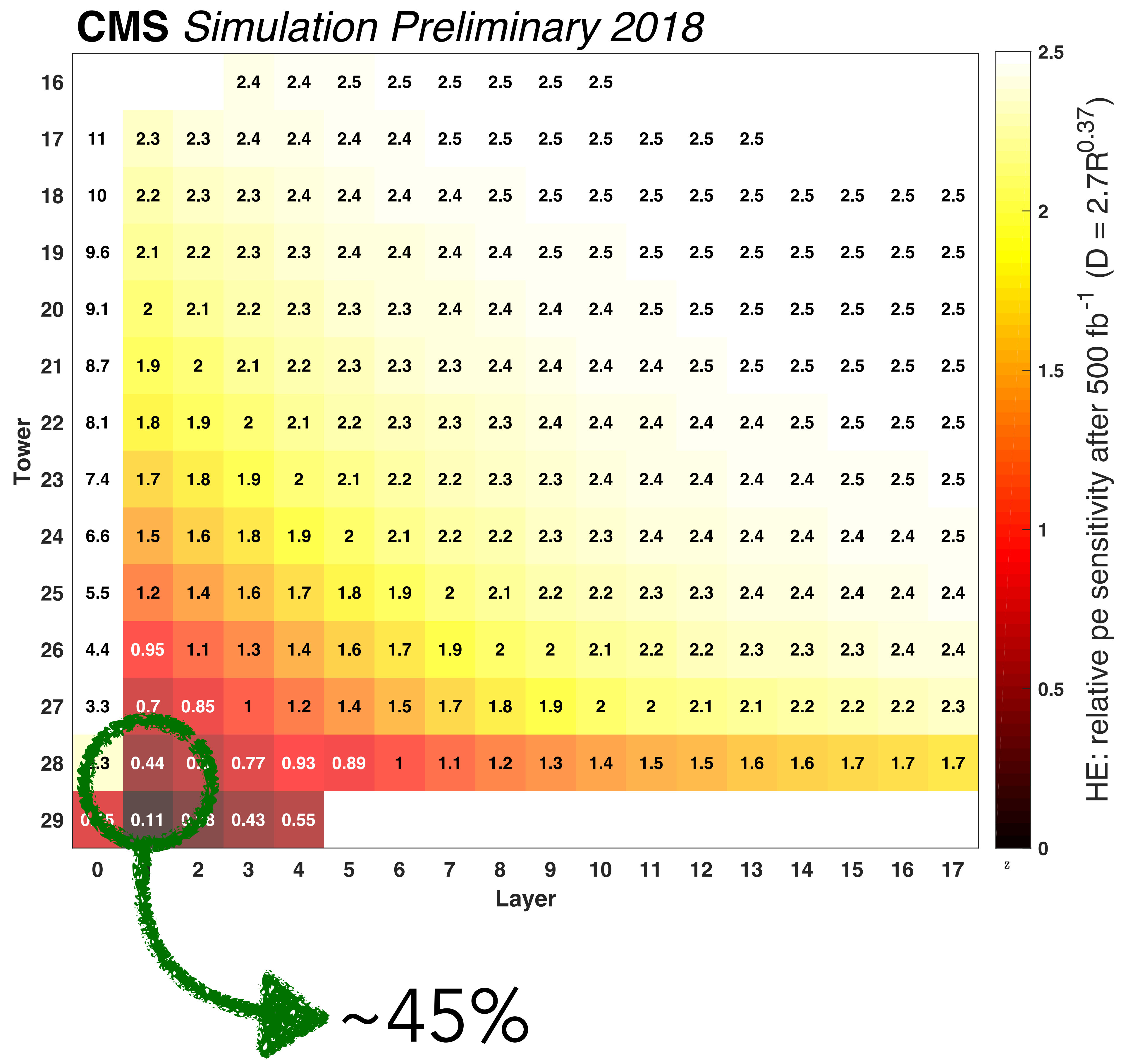
- Detector response assumed to follow an exponential loss for periods of constant dose rate:

$$L(d) = L_0\, e^{-d/D}$$

D [Mrad] = dose constant
d [Mrad] = total dose

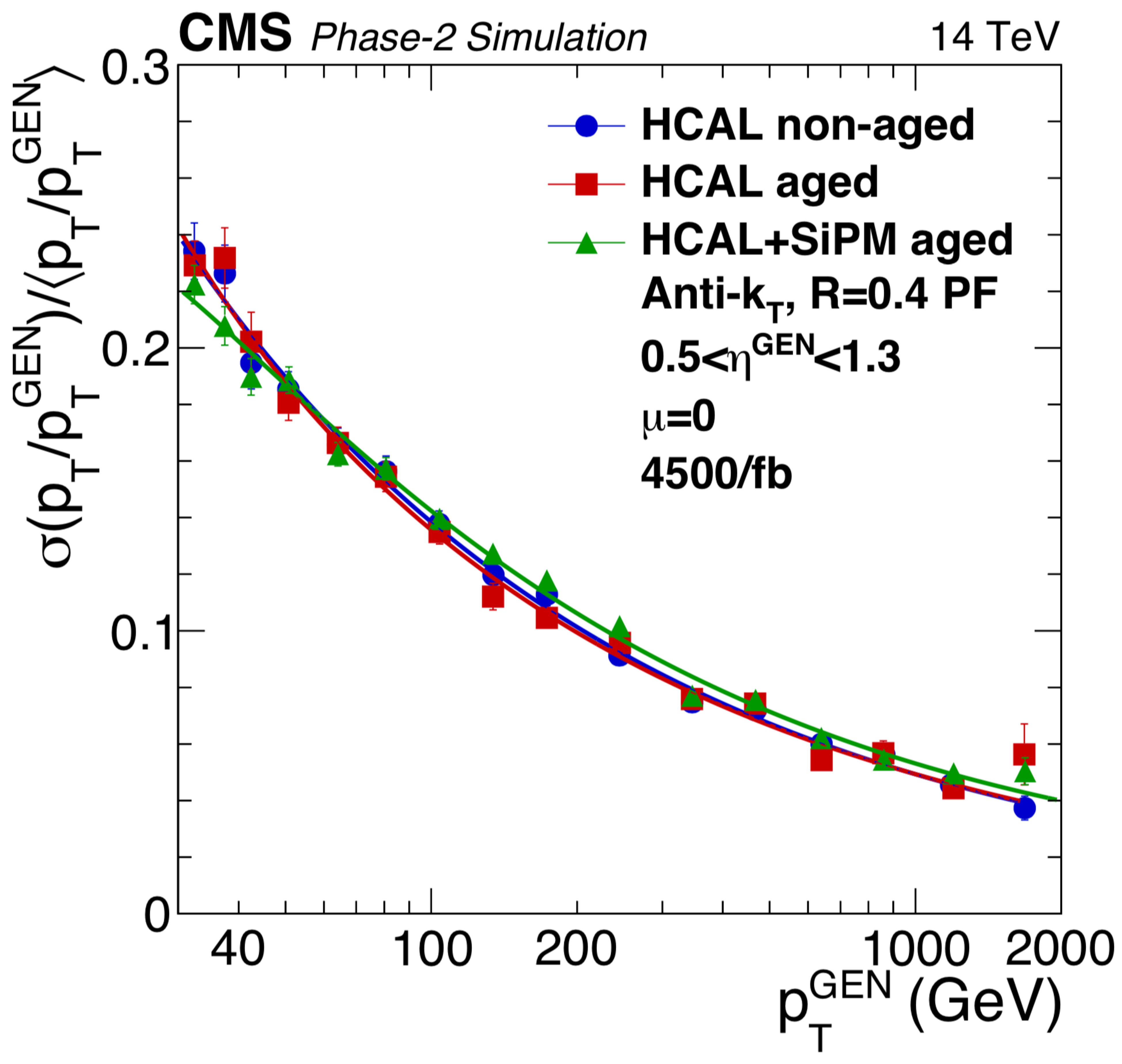
- Remaining light output in the front layers at high eta of HE after 500/fb:
    - As low as 5% (ieta 29) and 20% (ieta 28)
    - Light loss is recovered/exceeded by the higher PDE of SiPMs w.r.t. HPDs
- HE will survive to end of Run 3 with performance ~unaffected

HE light yield * PDE relative to beginning of Run1



In conclusion: will do the same to HB :)

- Extremely positive experience from the operation of the upgraded HE in 2017 and 2018
- A look forward: the response loss (50-70%) of the front layers of the HCAL Barrel after 4500 fb^{-1} will be largely recovered by the higher SiPM photodetection efficiency
  - No impact on performance



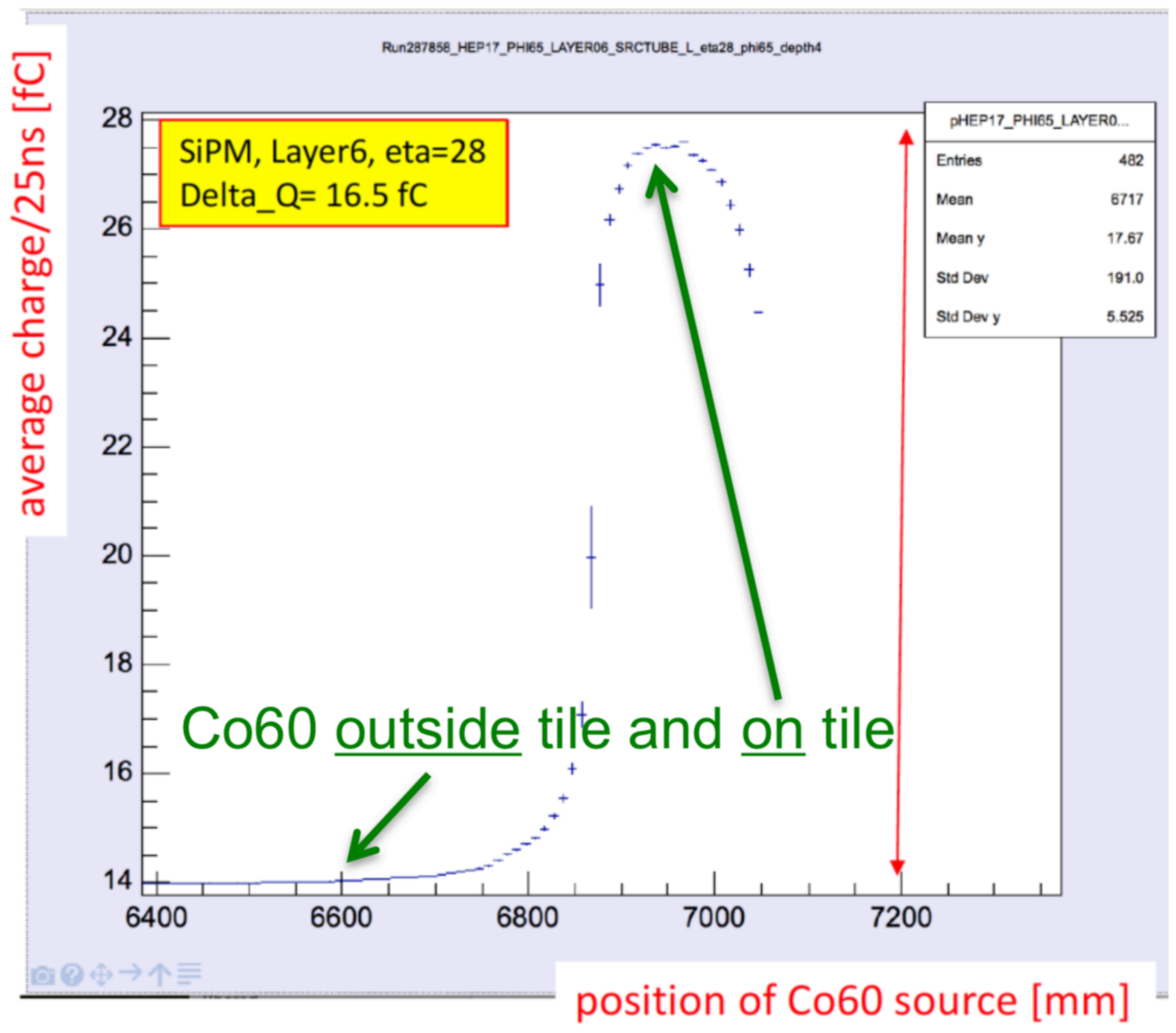
Additional slides

Being explored

- Exploit the increased longitudinal segmentation to acquire information on the shower development:
  - Improve the pile-up suppression and improve the jet resolution

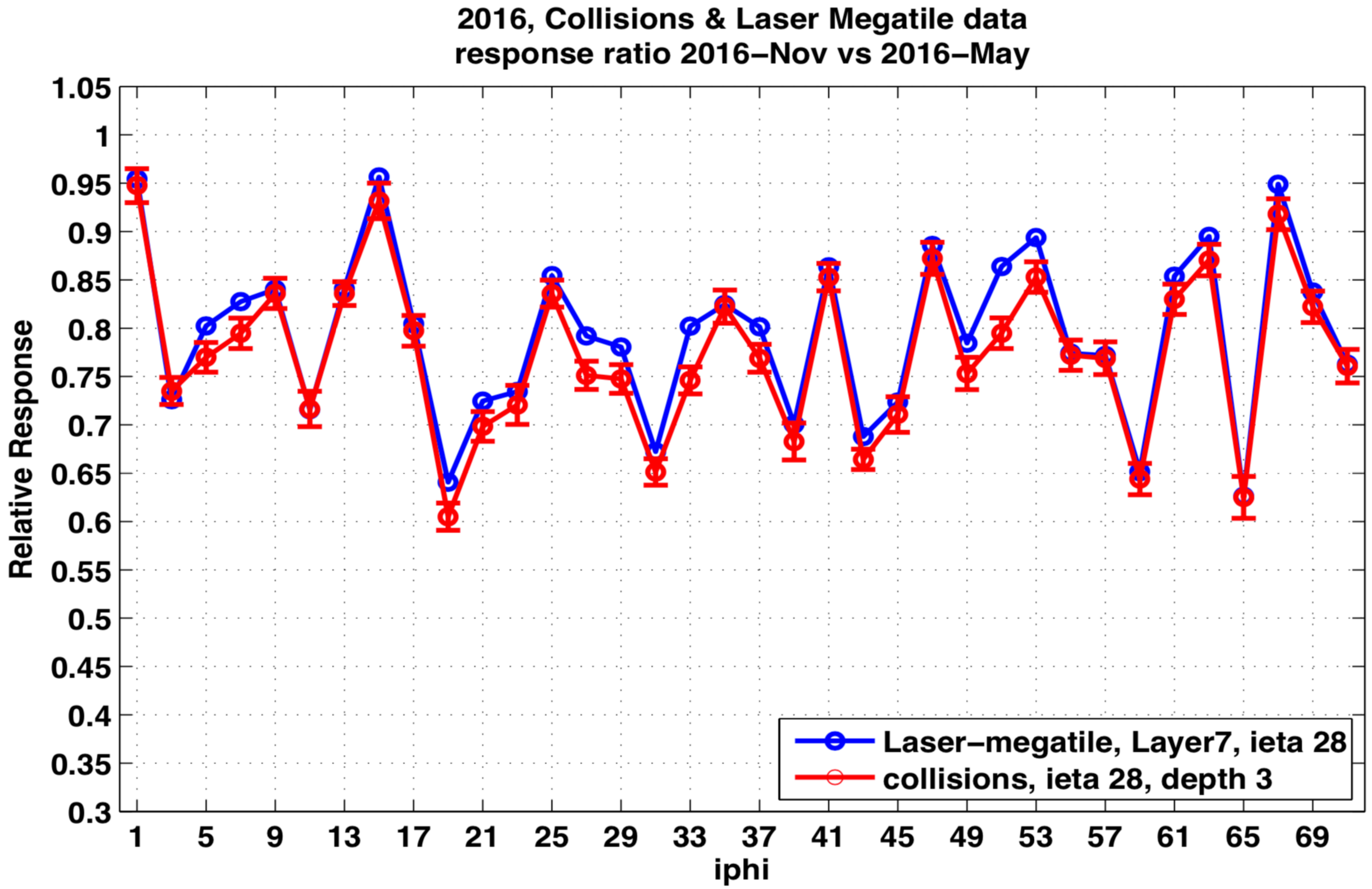
- Exploit the improved sensitivity to MIPs to develop a MIP/muon trigger beyond tracking acceptance

HE ^{60}Co source calibration



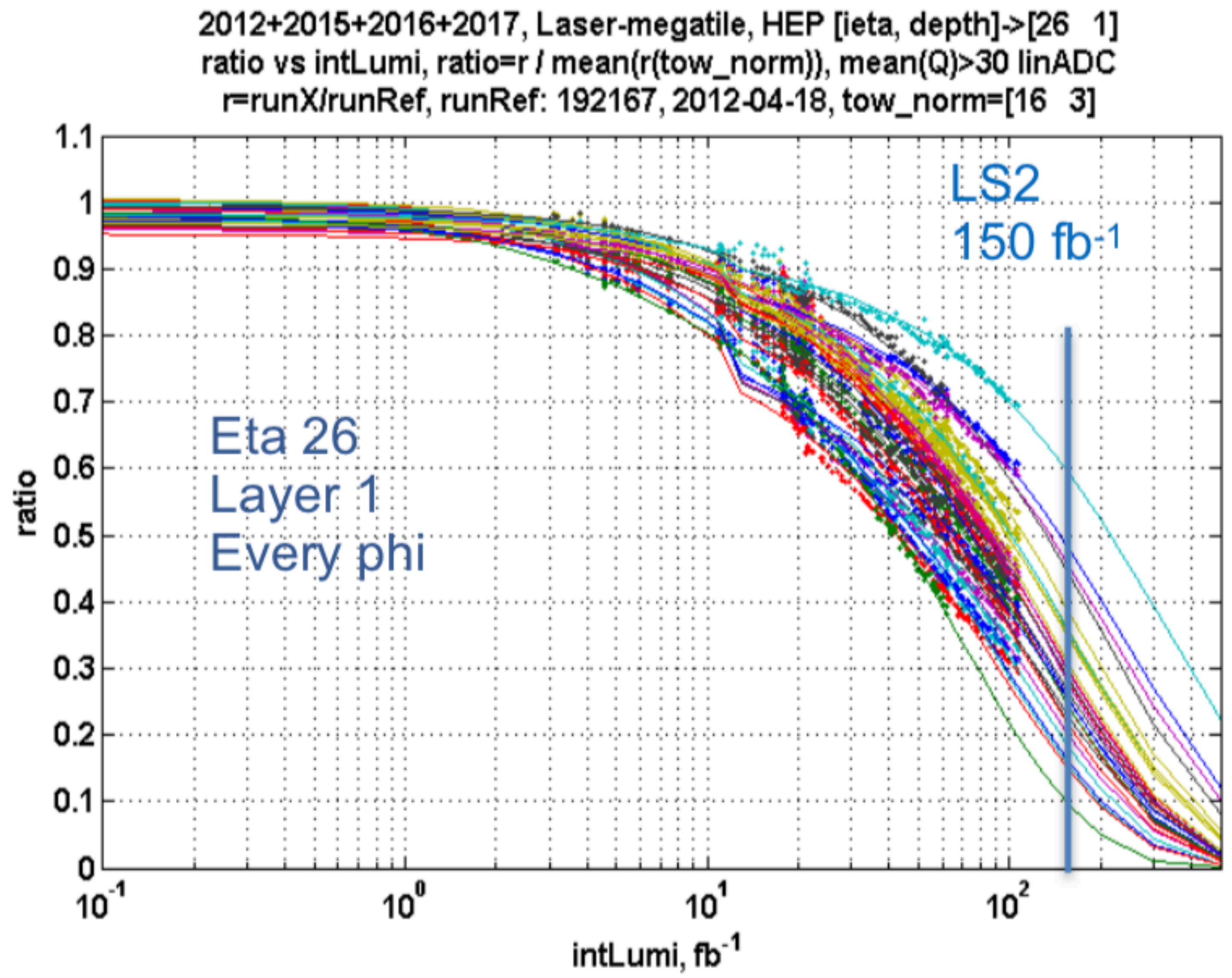
Response vs phi from HPDs in 2016

- Response for towers at ieta=28 at the end of the 2016 data taking, relative to the response at the beginning of the year from in-situ calibration. The response measured with collision events is compared to the one extracted from laser data. The response is plotted as a function of the azimuthal variable iphi.

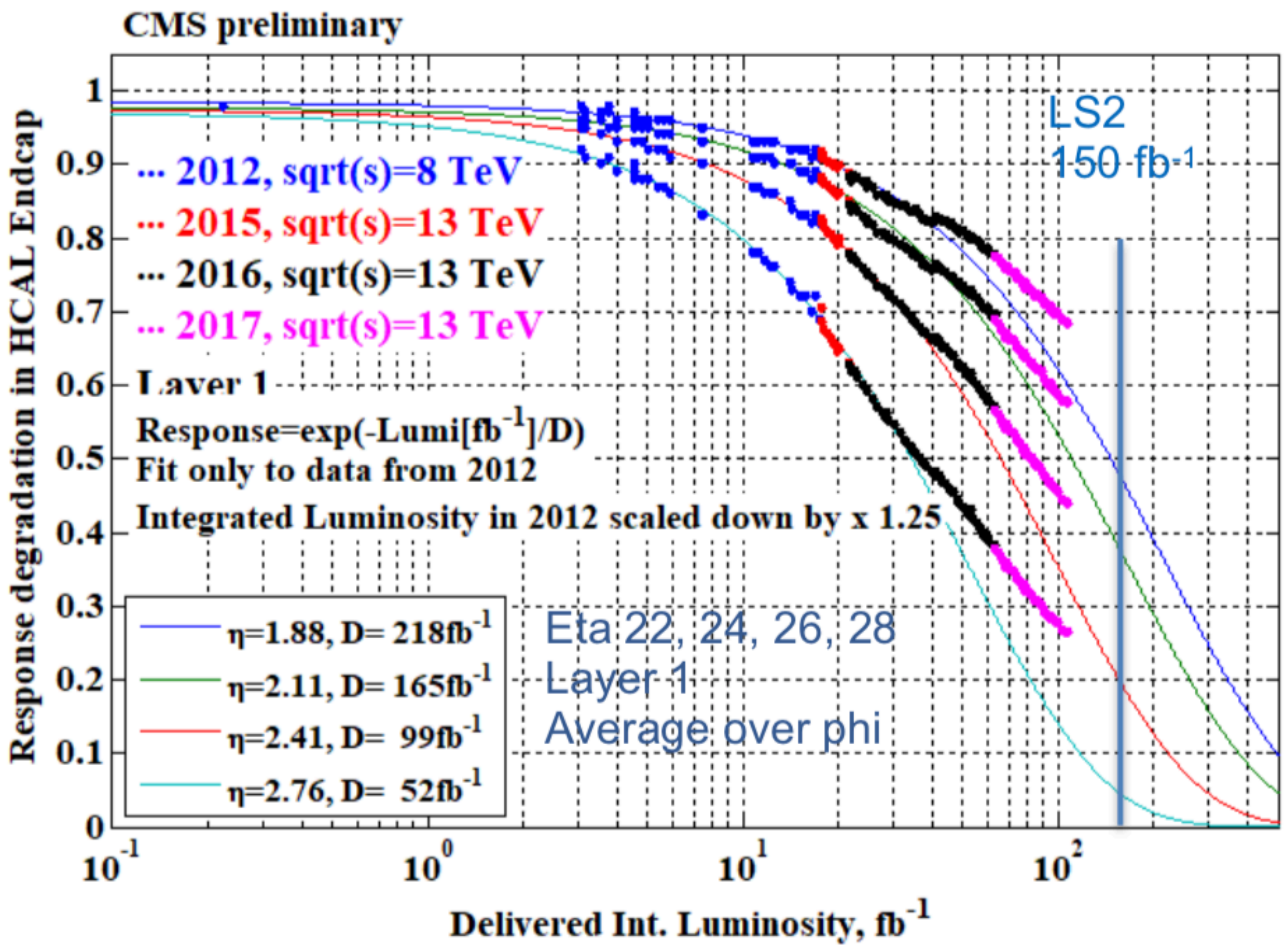


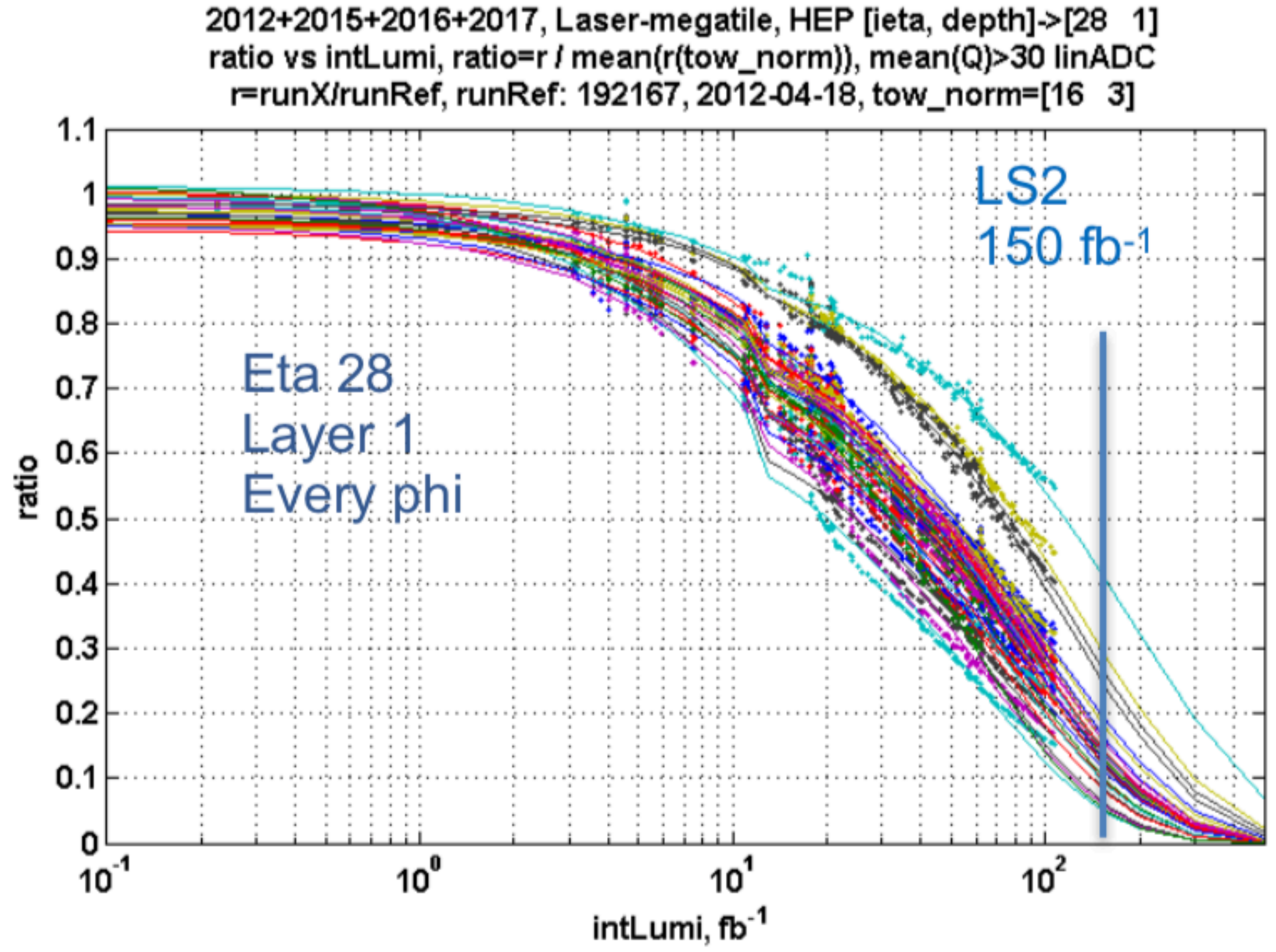
What if we didn't upgrade HE?

- HE response loss will continue to progress
  - With largest contribution from HPD damage
  - Several channels at high eta will go below 10-20% of the new detector response



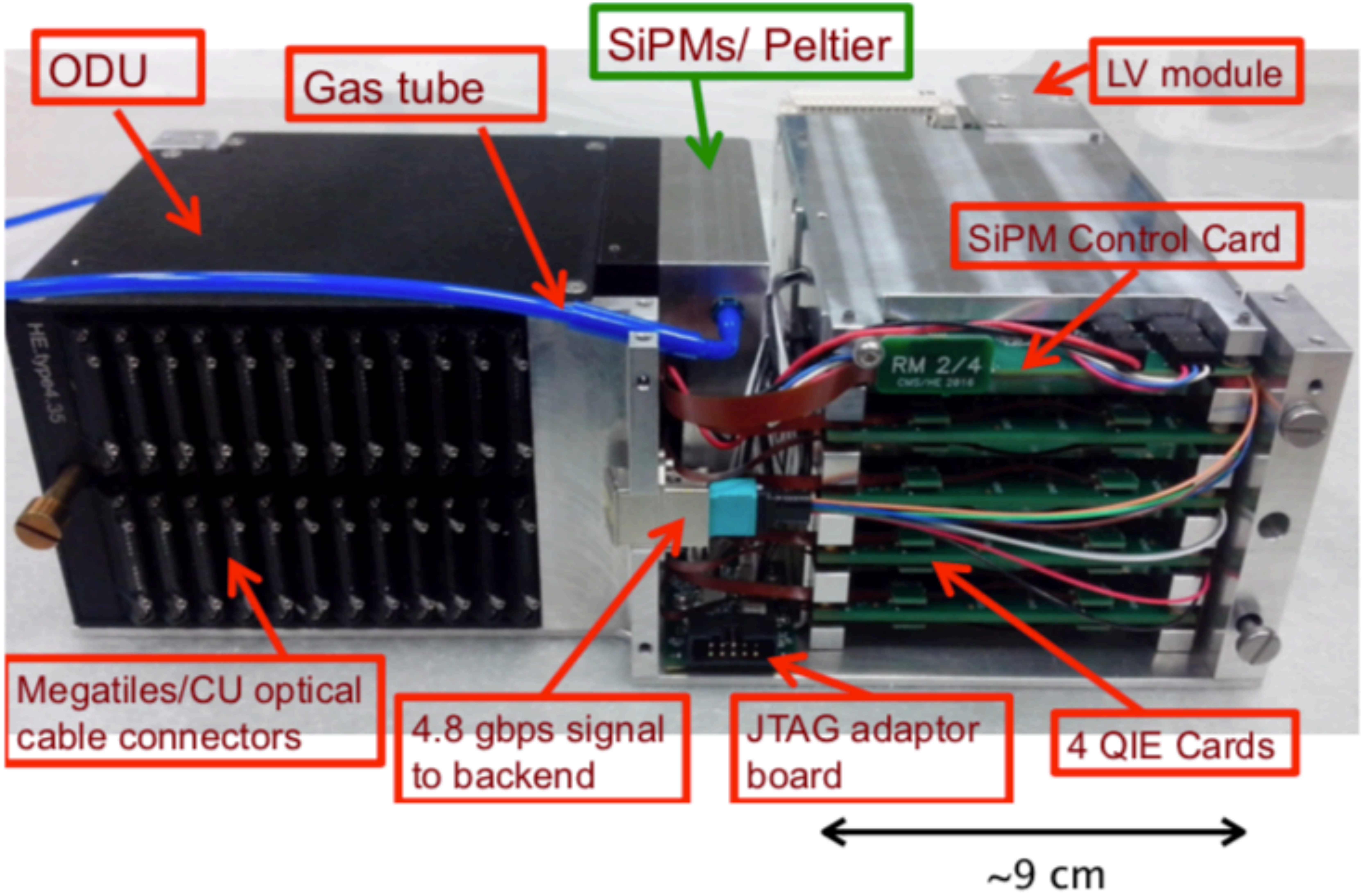
average signal loss in HE since 2012 (including 45 fb^{-1} of 2017 data)





HE readout module

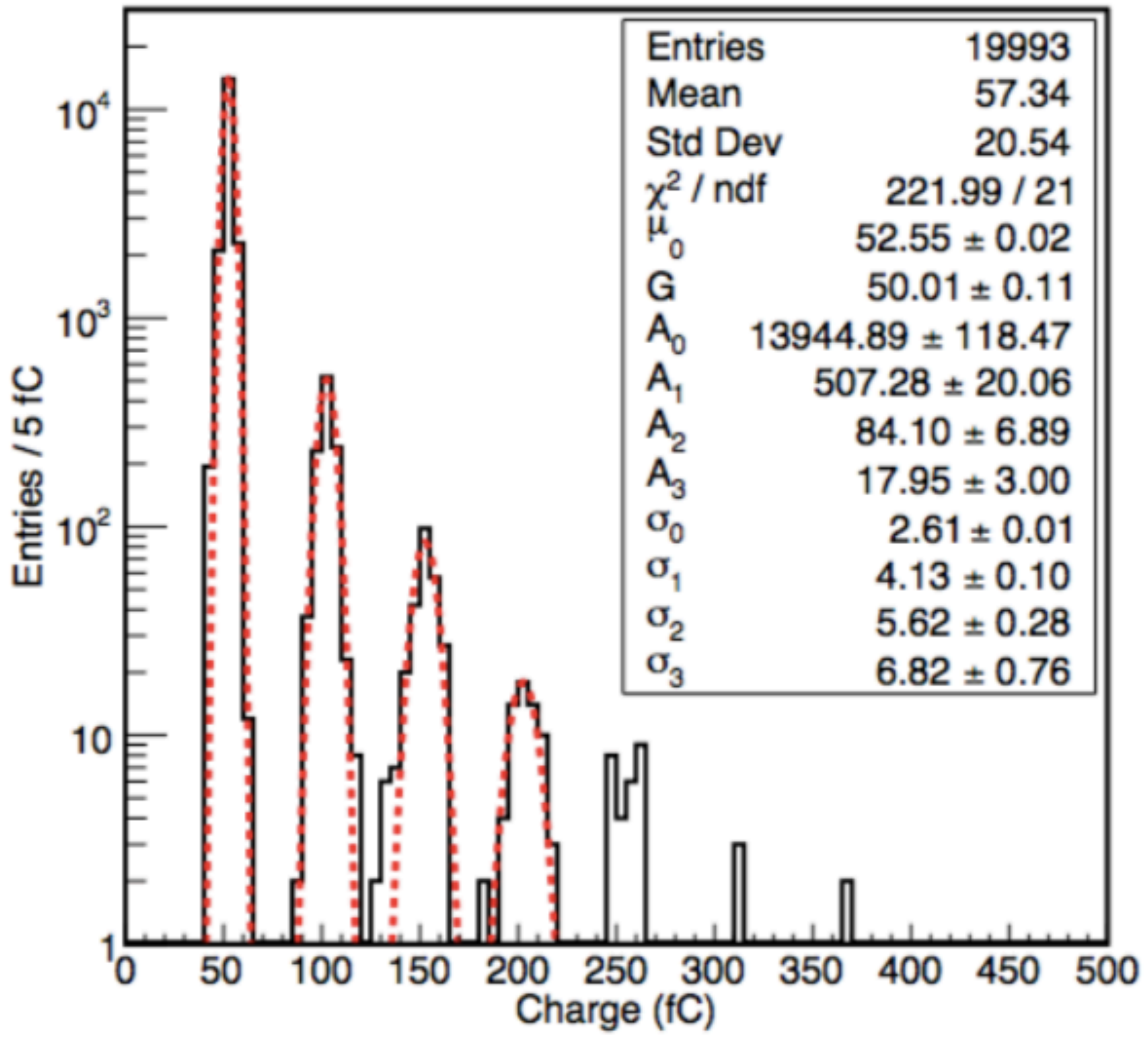
- 1 readout module = 48 channels = 5° slice in φ



SiPMs Parameters

Parameter	HE @ dVb=3V	HE @ dVb =1.7V
(MIP S/N) / (MIP S/N HE dVb=3V)	1	~1
Non-linearity @ 300 GeV	21%	13%
Lost S/N for I_{dark}→ ~I_{dark}/4	~0%	
Dark current [5C, 3.8/ab]	400µA	120µA
PDE	25%	17%
Power [mW, 5C, 3.8/ab]	27	8

Calibration of the SiPMs



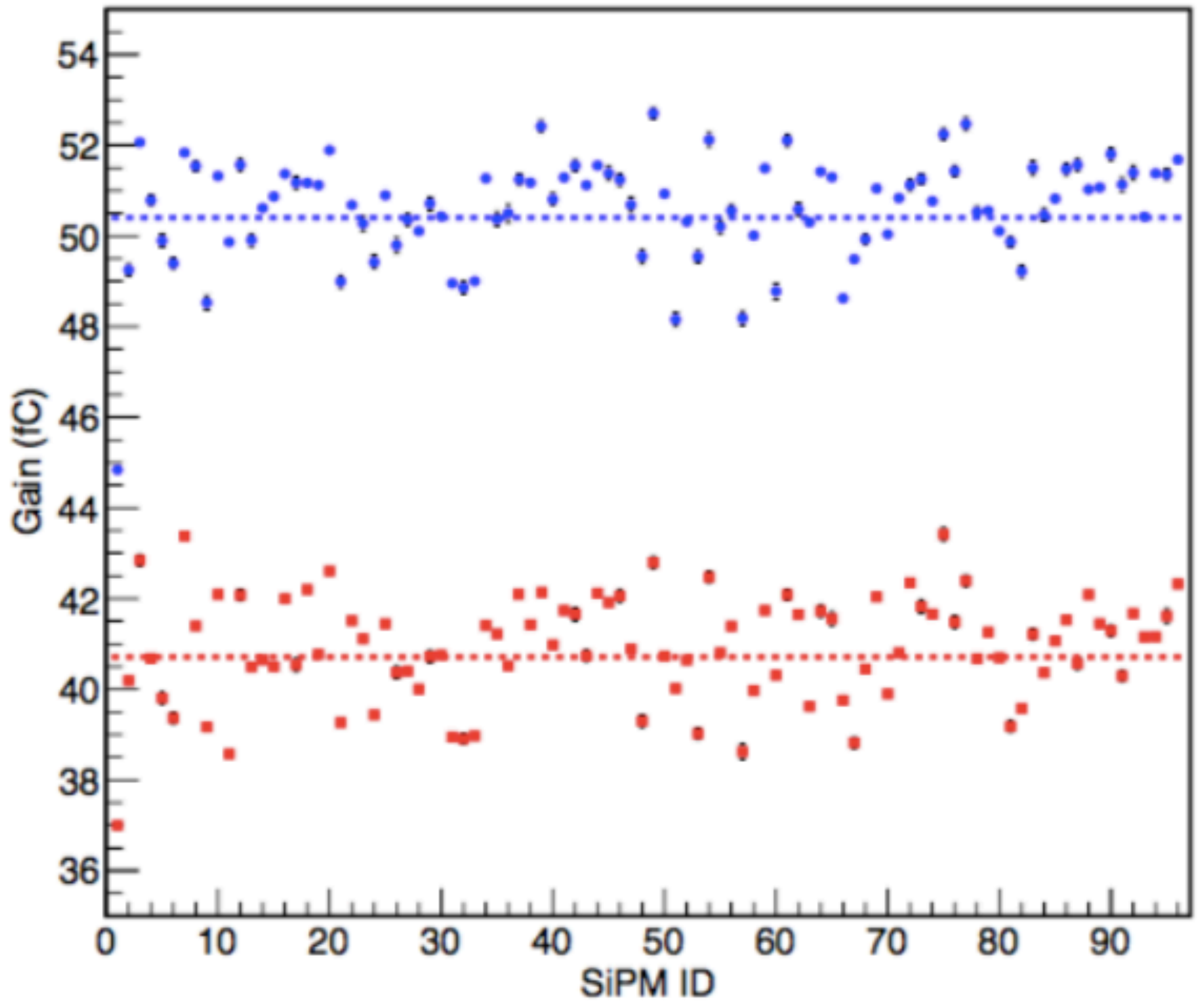
Single fit function for the entire spectrum down to three orders of magnitude drop of the peak.

$$f(x) = \sum_{i=0}^{N_{peaks}-1} A_i e^{-\frac{1}{2}\left(\frac{x-\mu_i}{\sigma_i}\right)^2}$$

$$\mu_i = \mu_0 + iG$$

$\boldsymbol{A_i}$: amplitude of the i^th peak
$\boldsymbol{\sigma_i}$: width of the i^th peak
$\boldsymbol{\mu_i}$: mean of the i^th peak
$\boldsymbol{G}$: gain

SiPM gain is a direct parameter of the fit.



◀ Measured SiPM gain when bias voltage for all SiPMs were set for:

- a nominal gain of 50 fC
- a nominal gain of 40 fC

Note: Gains have not been leveled in this plot

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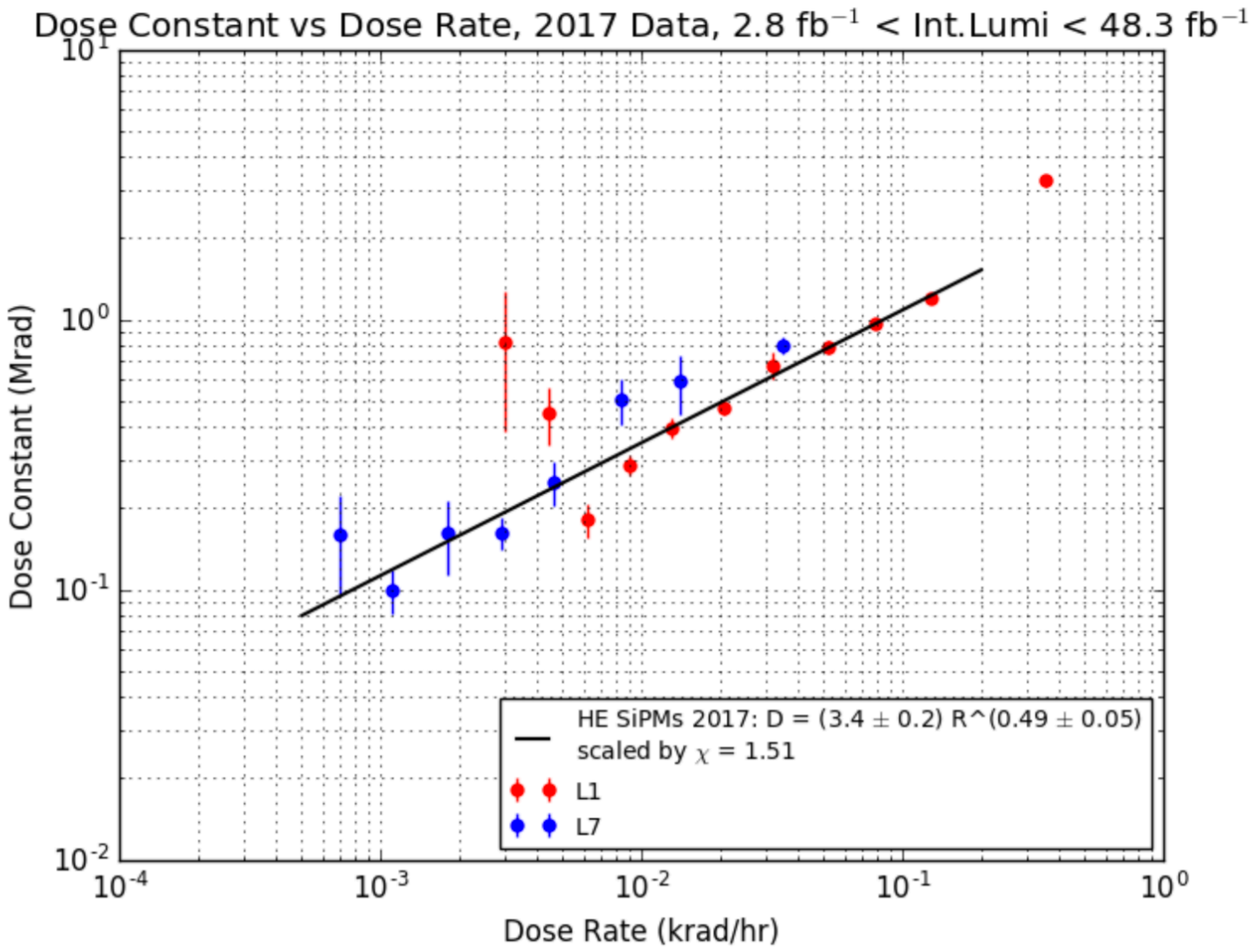
Dose-Rate plots from HEP17

- Dose constant (Mrad) vs. dose rate (krad/hr). The data points show the values of dose constants derived from the scintillator signal loss in the HE sector read out by SiPMs using 48.3 fb−1 delivered to CMS in 2017. Red points correspond to layer 1 (L1) scintillators, and blue points correspond to layer 7 (L7) scintillators. The black line represents the best fit of the 2017 data using a parametrization D = a × Rb, where D is the dose donstant (Mrad) and R is the dose rate (krad/hr).



Fractional jet p^T resolution vs eta