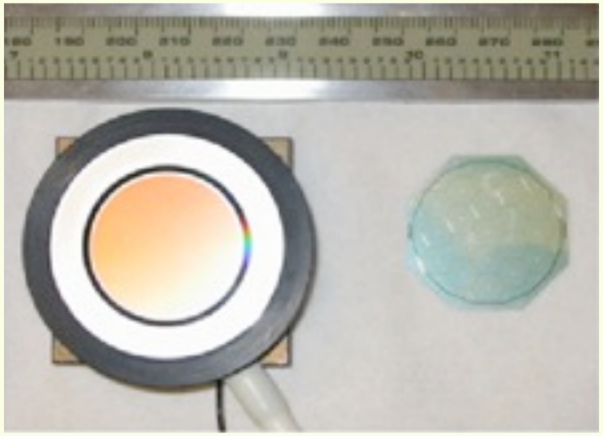
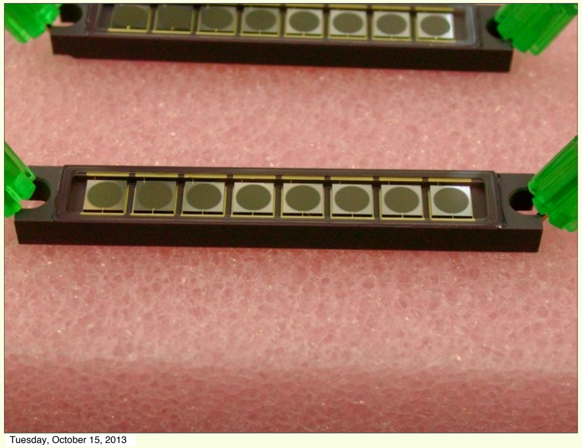
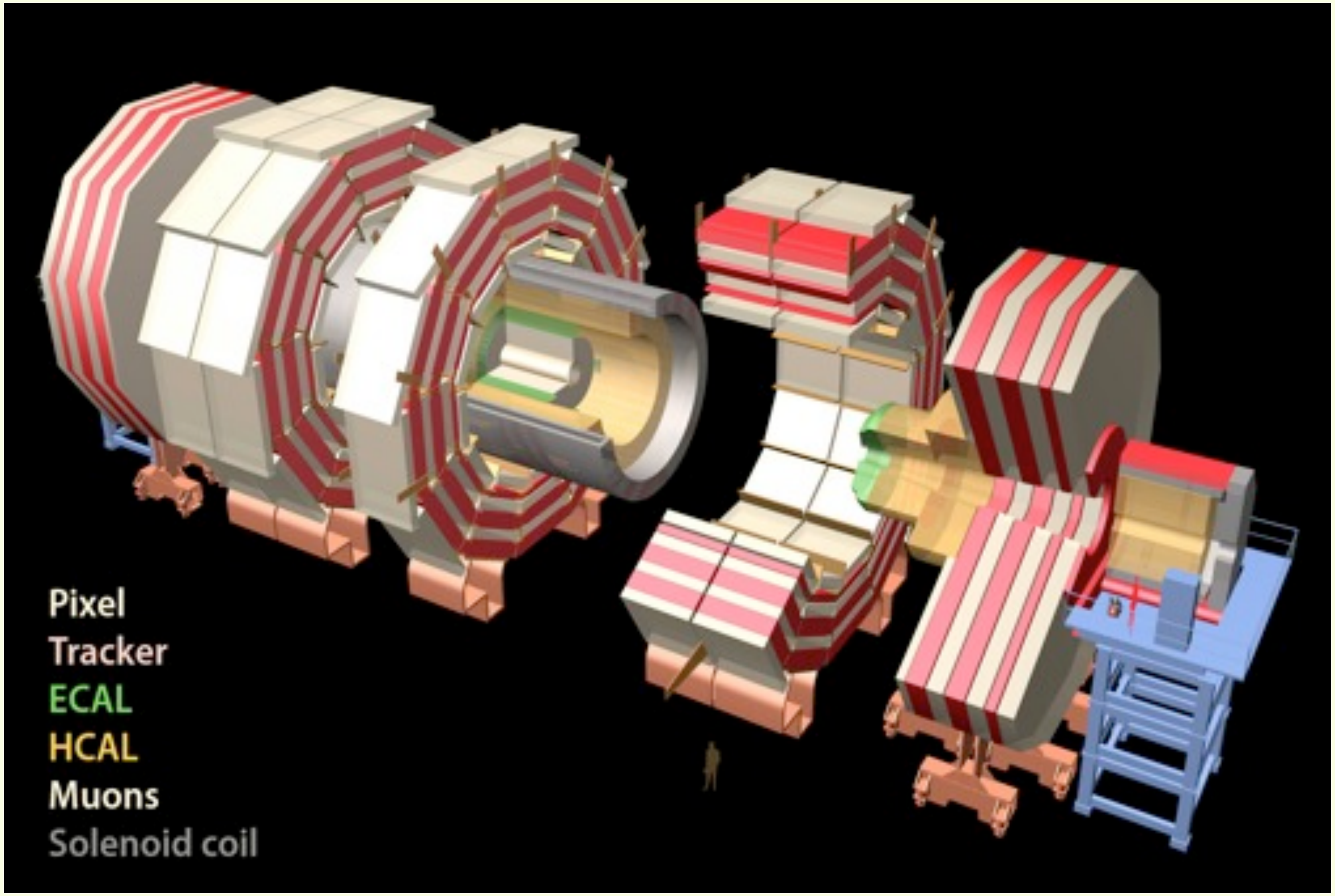
Photo Sensors Replacement for the CMS HCAL for Phase I upgrade from HPD to SiPM

A. Heering
For the CMS Collaboration



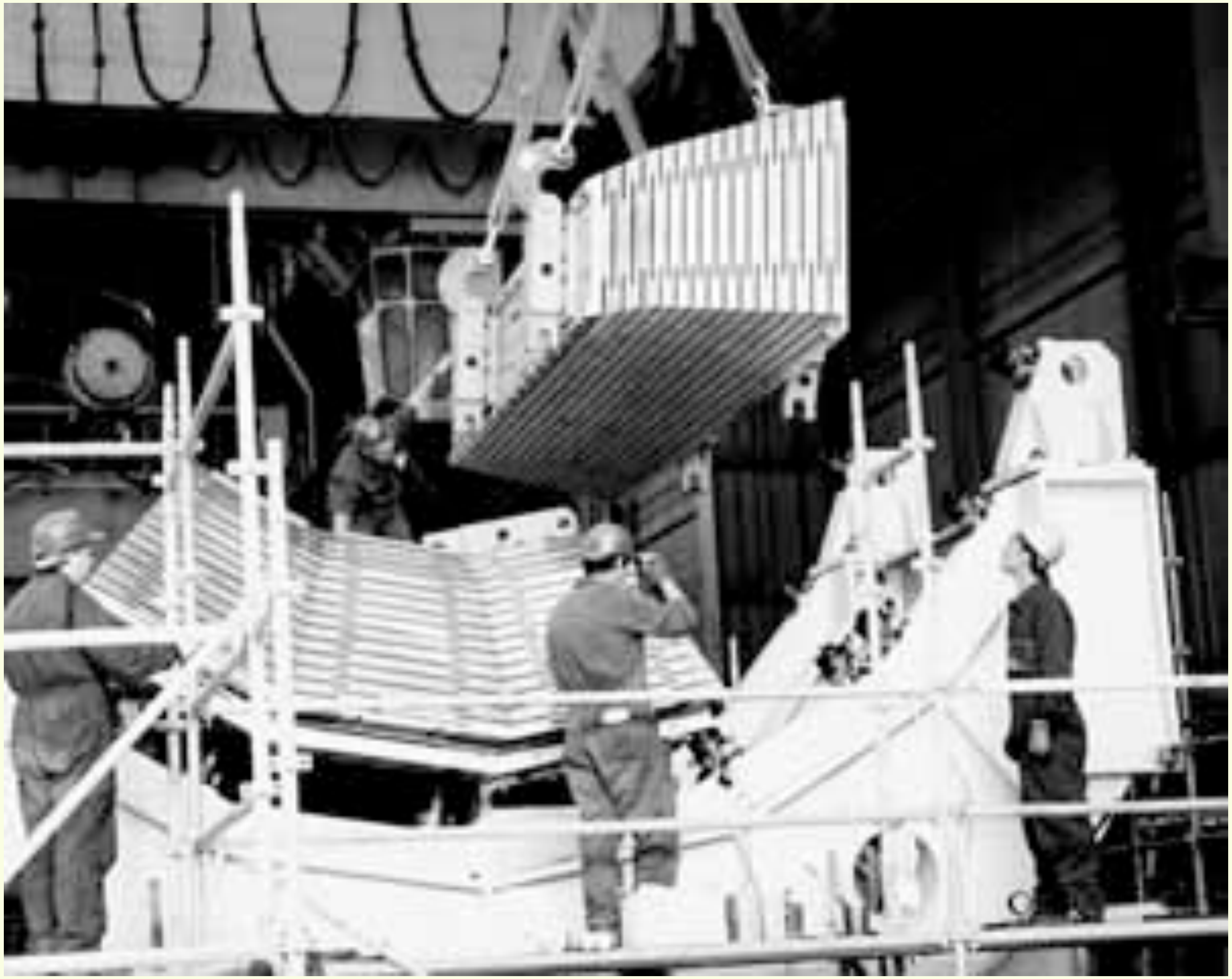


The CMS detector

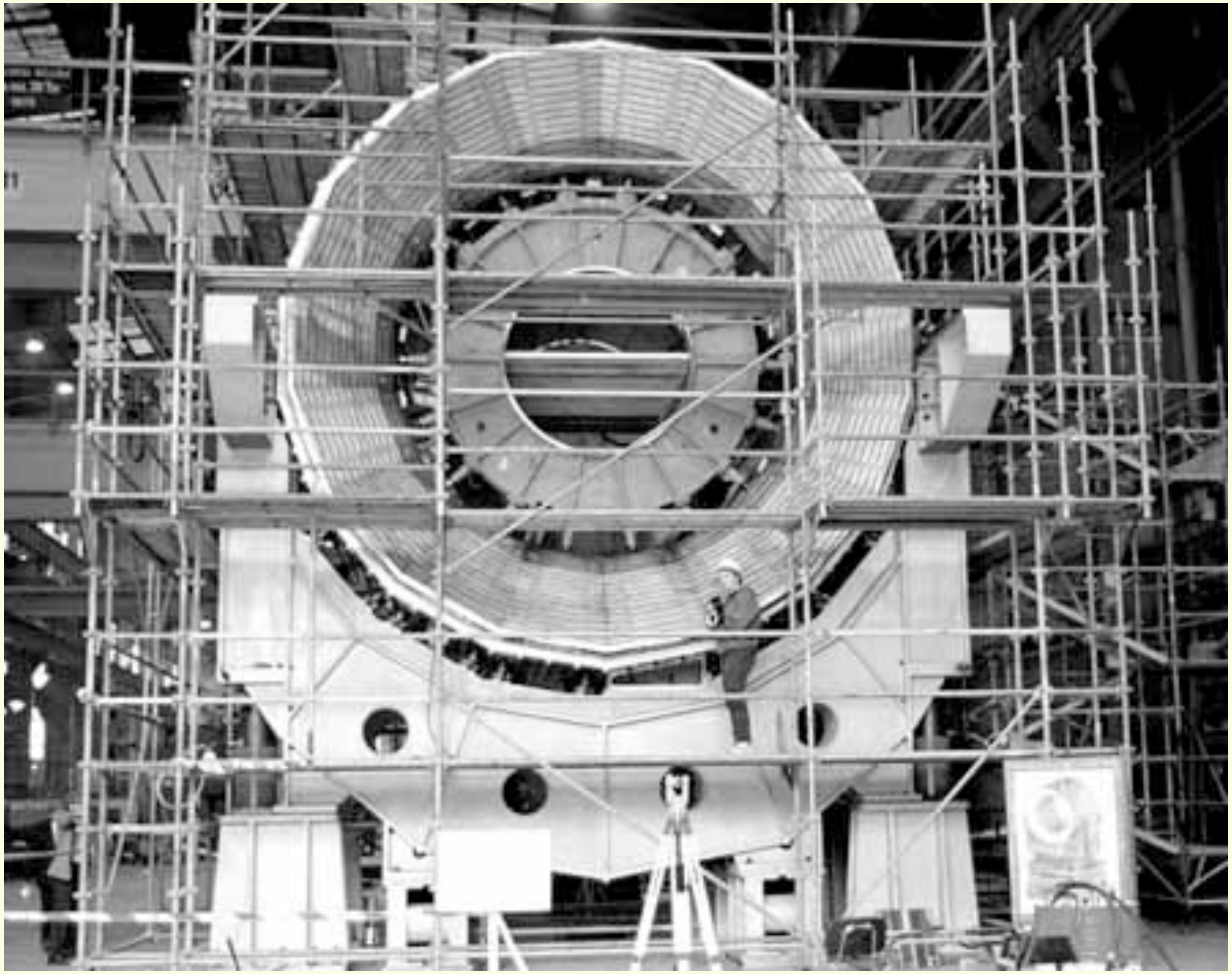


HCAL is a scintillator sampling calorimeter inside the 4 Tesla field

HB wedge loaded in to Cradle



Full HB



HCAL Longitudinal View

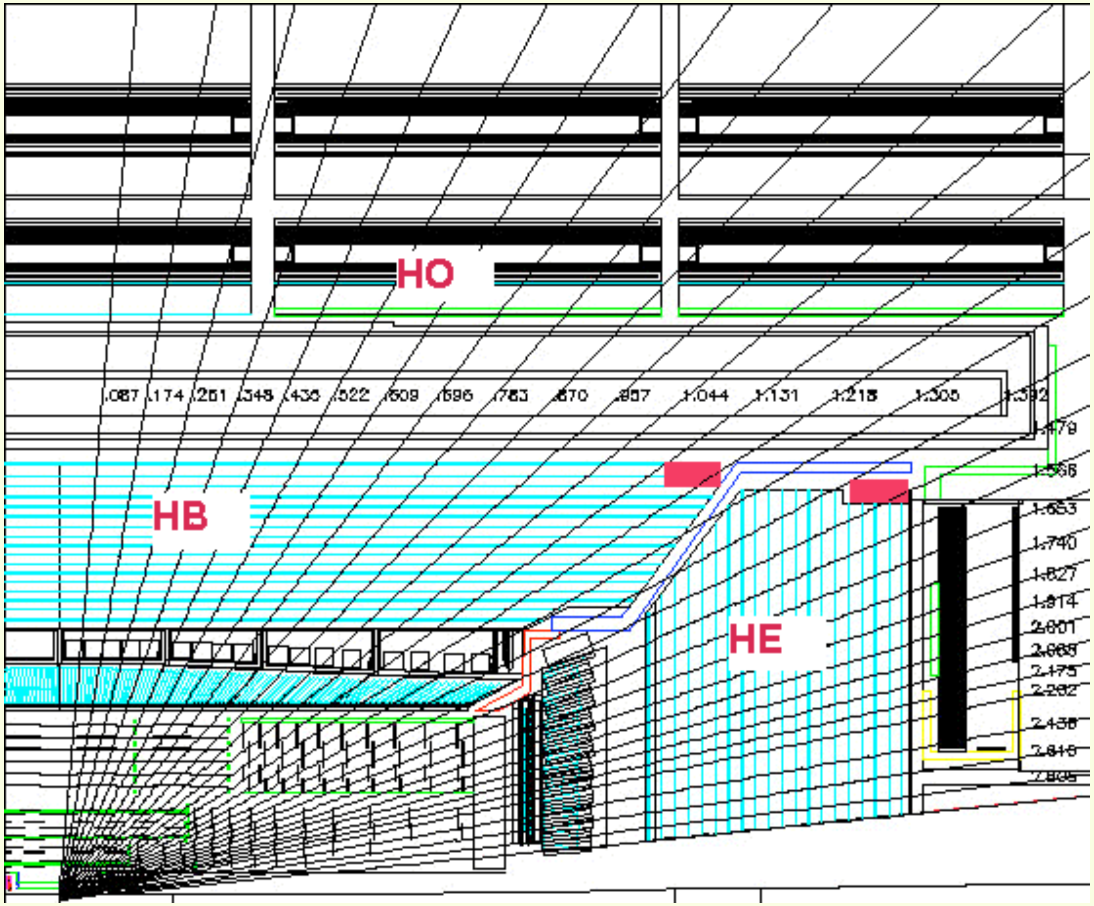


Photo detectors and readout electronics

Dose: HE = 9E10 n/cm2 , HB = 6.5E11 n/cm2

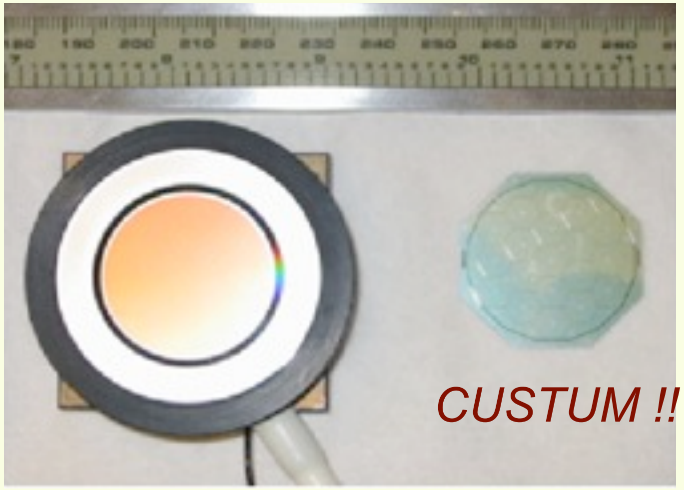
OutLine

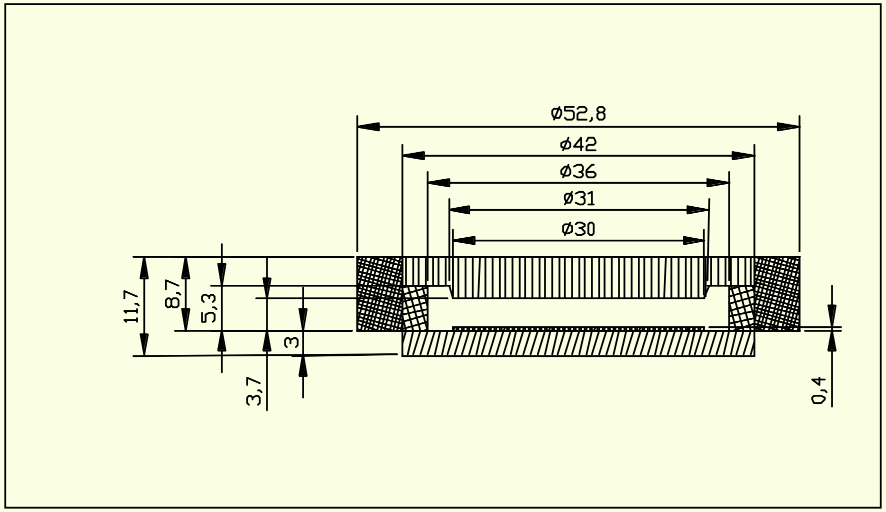
- Our experience with HPD in the CMS detector
  - Magnetic field operation
  - Long term stability data

- SiPM R&D done with 3 main vendors for replacement

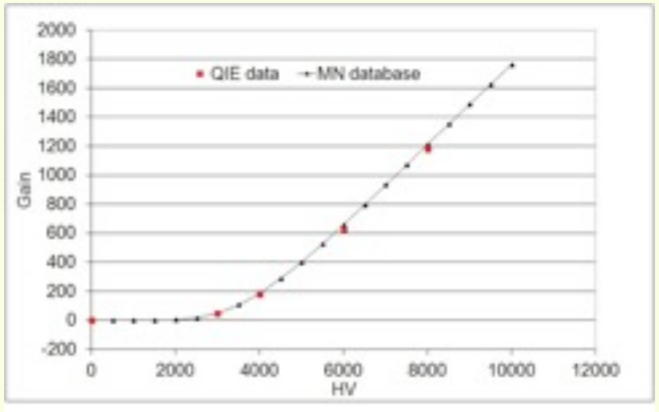
CMS HCAL baseline HPD

HPD was only "real" PD choice in 2000, we use DEP (now Photonis)

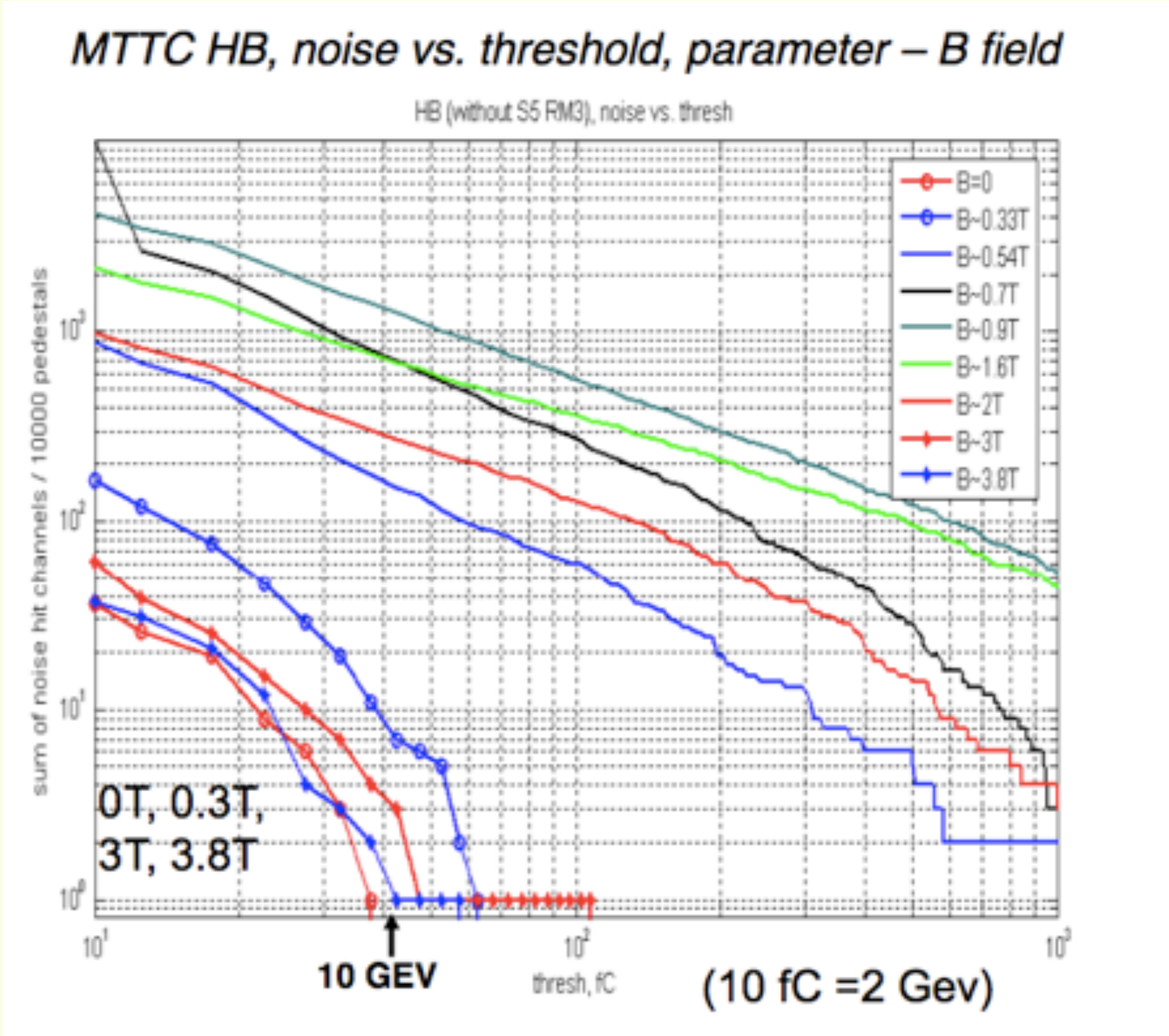




- Electrons get accelerated over 3.5 mm gap and absorbed by PIN diode
- Gain = HV-Threshold divided by 3.6 eV (electron hole pair)
- Diode is segmented into honey cone 19 pixel configuration
- Fiber optic window used instead of thick glass

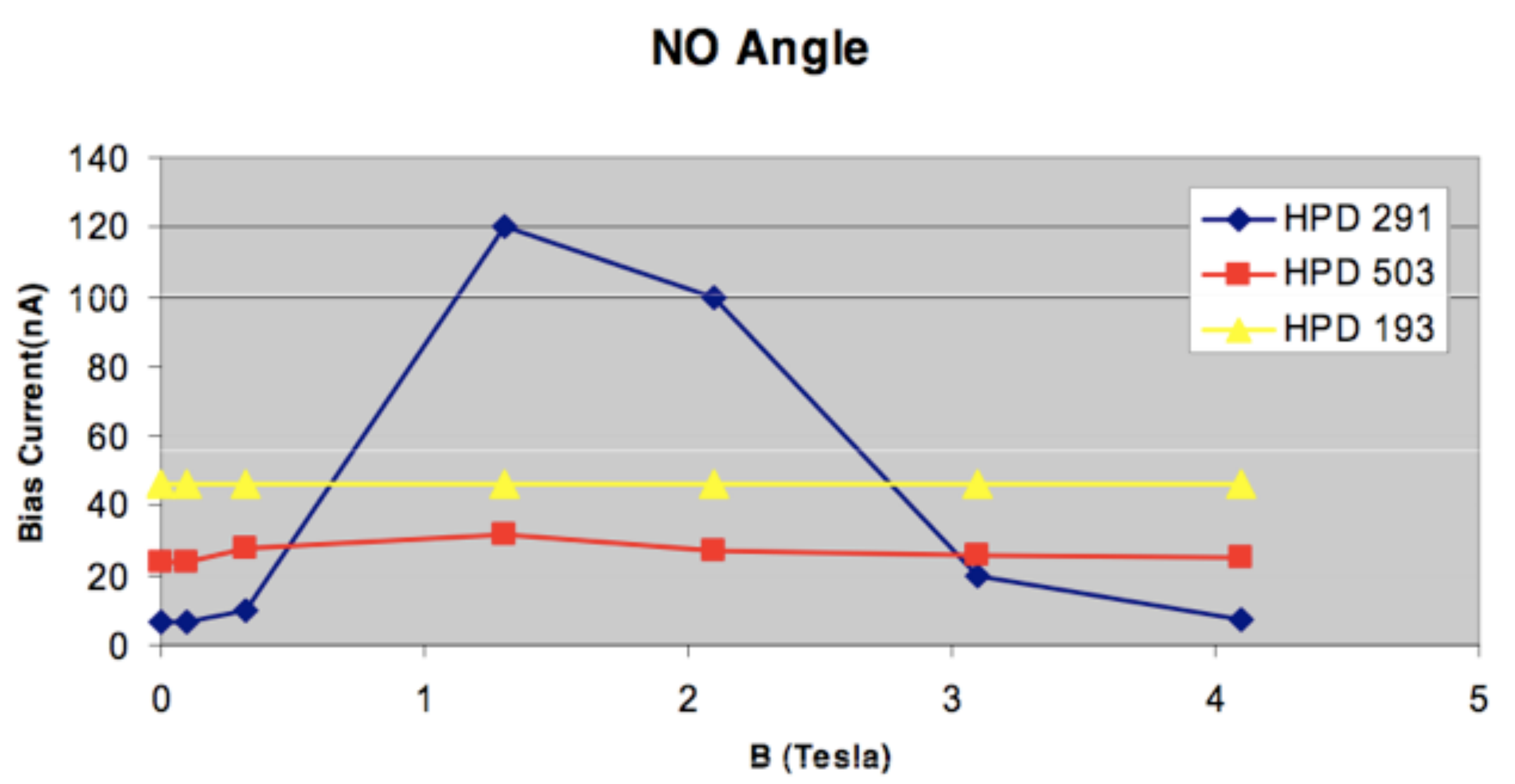


First magnetic field operation in CMS



HPD current vs Magnetic field

3 Selected HPDs tested in the Tesla lab



Investigation and Literature scan

Research in the 1980s on high voltage applications in vacuum

THE INFLUENCE OF MAGNETIC FIELDS ON DIELECTRIC SURFACE FLASHOVER

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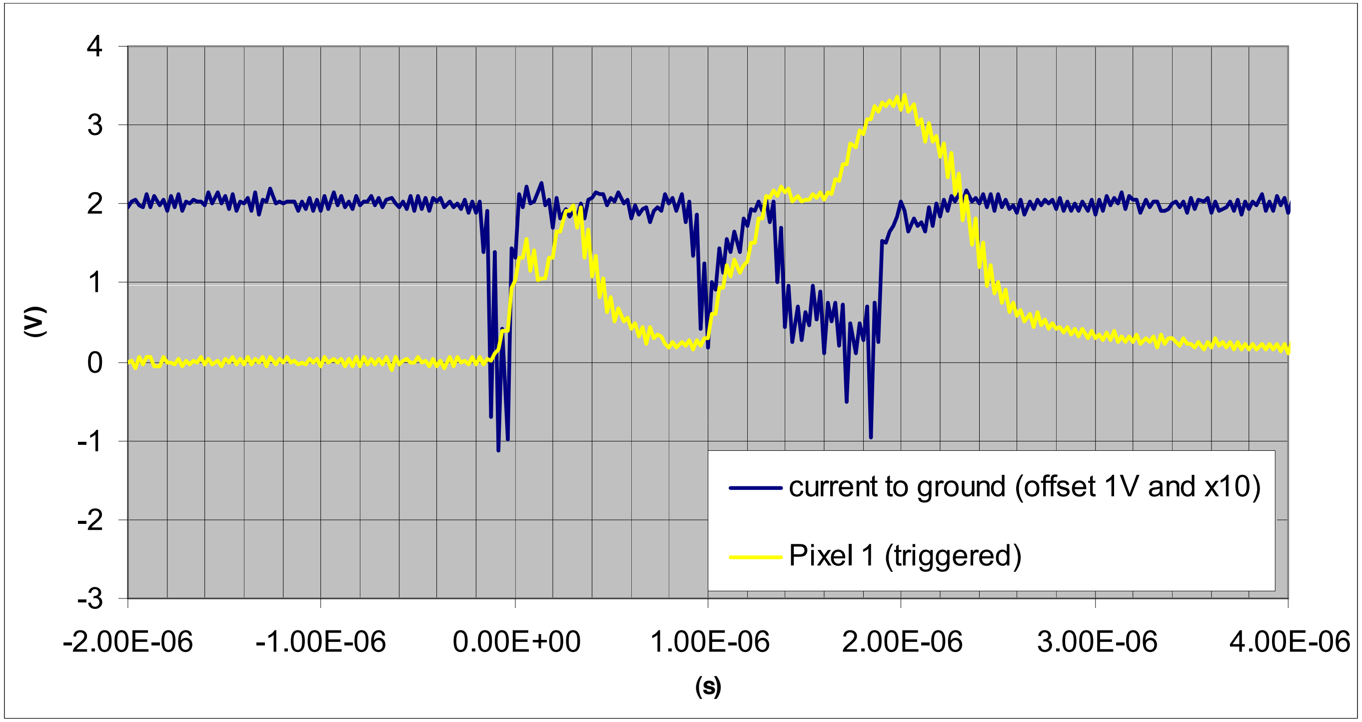
Pulsed Power Laboratory
Department of Electrical Engineering
Texas Tech University
Lubbock, TX *79409-4432*

ABSTRACT
The influence of low amplitude magnetic fields, in a variety of configurations, on pulsed dielectric surface flashover has been investigated. These variations include dc magnetic fields; pulsed magnetic fields simulating conditions for magnetic self insulation; and different environments (vacuum, ambient gas, plasma), geometries, dielectric materials, and orientations of the magnetic field. For field amplitudes of 0.3 T, typically *a doubling* of the flashover voltage is observed, if the **ExB** drift is away from the surface. For flashover in vacuum, it is sufficient to place permanent magnets in the cathode vicinity to increase the flashover voltage. The observations are consistent with the "saturated surface secondary avalanche model" and electron induced gas desorption. The pulse shape of light emission during the prebreakdown phase depends on the orientation and amplitude of the magnetic field and shows that electron trajectories above the surface are altered by magnetic fields.

Correlation of HV current and noise pulse

Correlation between discharge (measured in HV current through the side-walls) of HPD and Large noise pulses

(Pulse in the HV current is first) (negative so it is opposite from photo current)



During installation 2007-2008

HPD **Selection** was done vs magnetic field to optimize HB and HE operation

- HB and HE (at 3.8 Tesla)

288 HPDs x 18 channels installed
very small trigger increase vs ON/OFF magnetic field
During ramp up and down HPDs are turned OFF with interlock

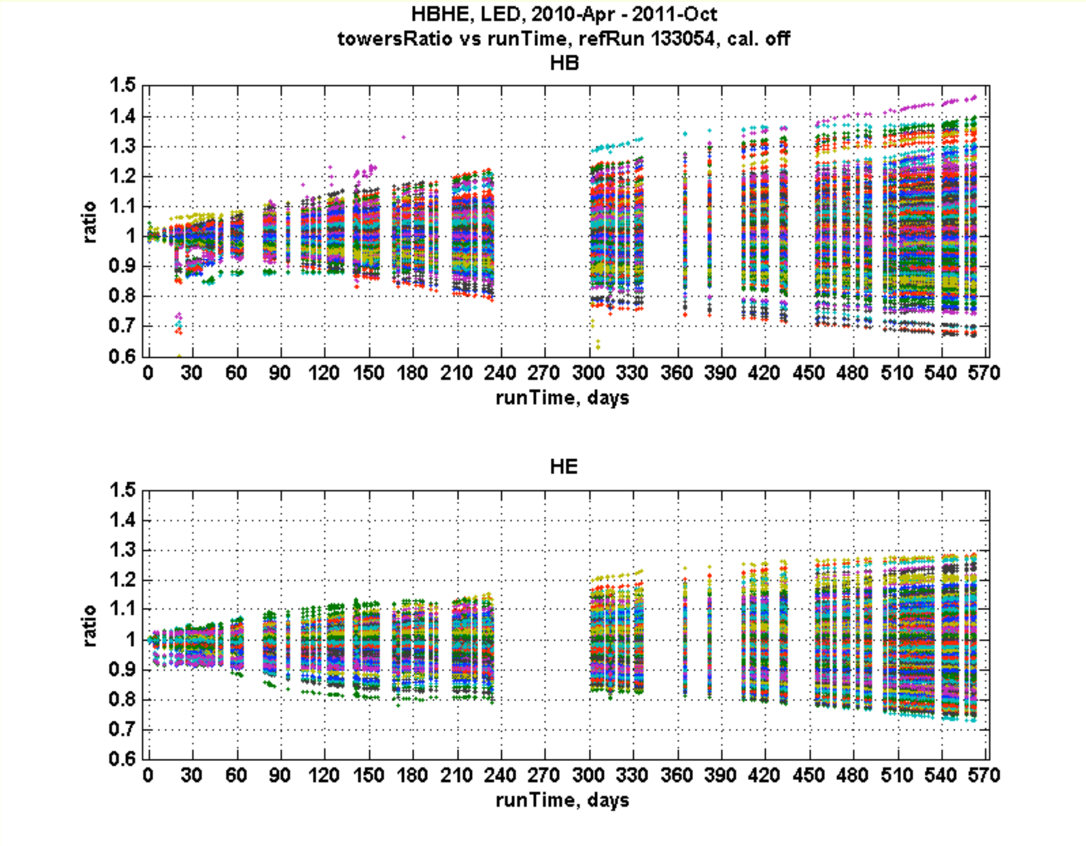
- HO (in Fringe field of ~0.3 Tesla)

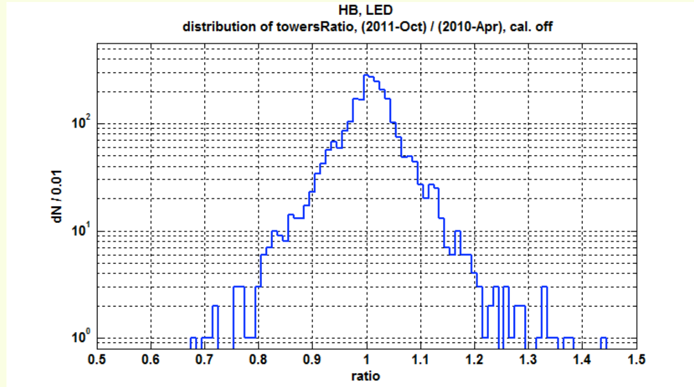
96 HPDs x 18 channels
More noise due to additional angle but HO is not in the trigger
YB2 with highest field

Long term stability data

HB & HE, towers Ratio in time

~2 year Standard LED runs with B=3.8T

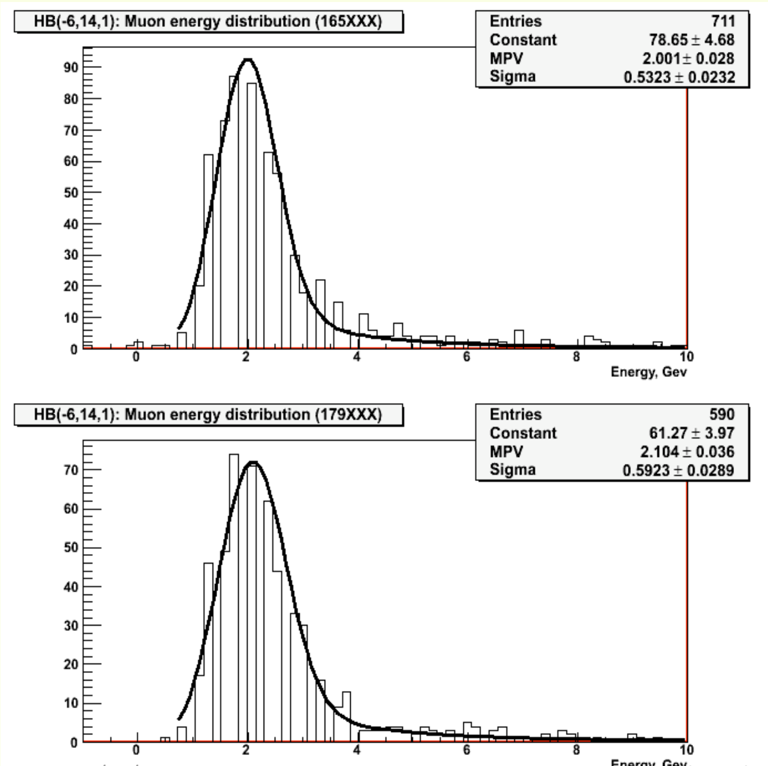


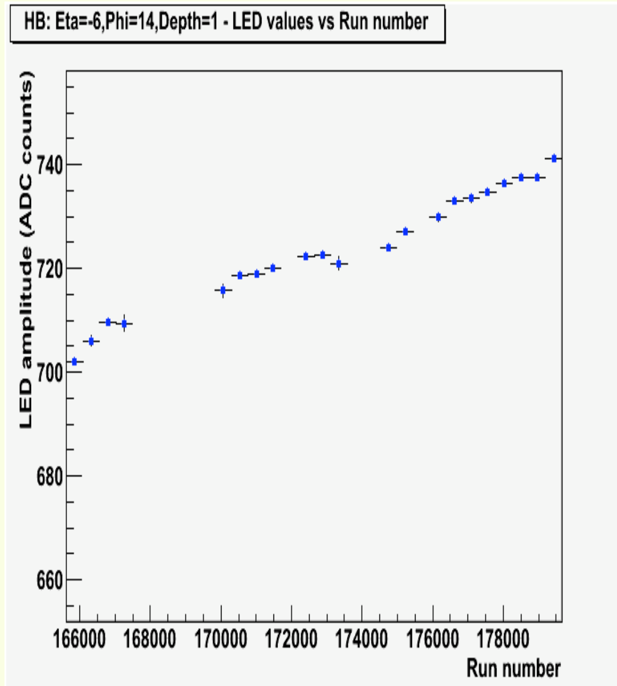


Questions:

- ***Muon correlation***
- ***RMS of LED spectra***
- ***Vacuum stability***

Example 1: HB(-6,14,1)





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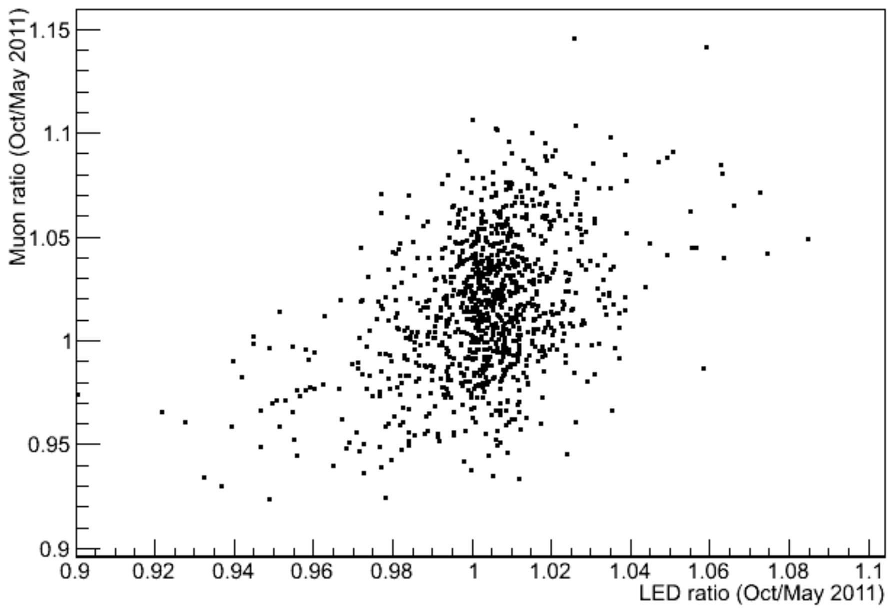
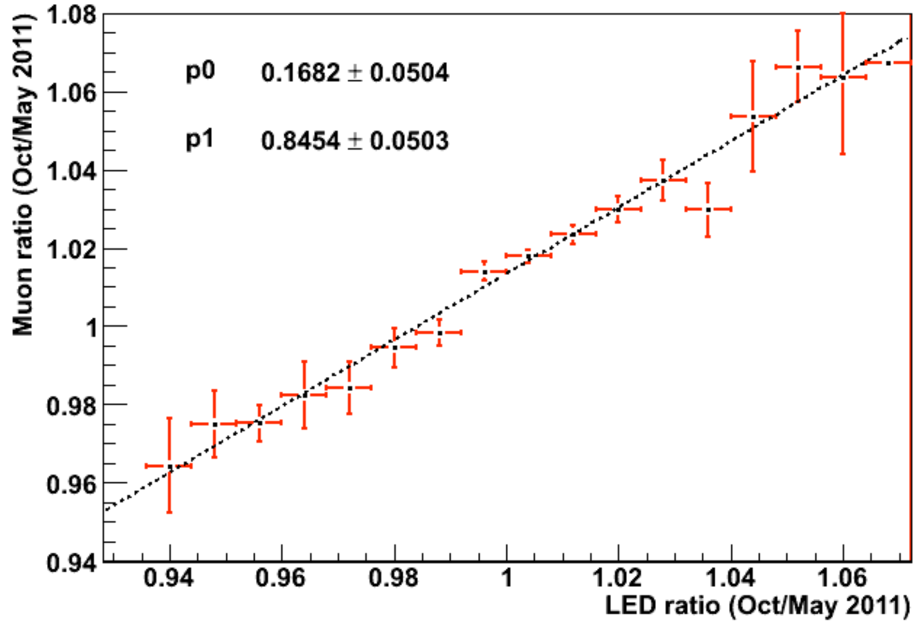
Correlation for all HB towers

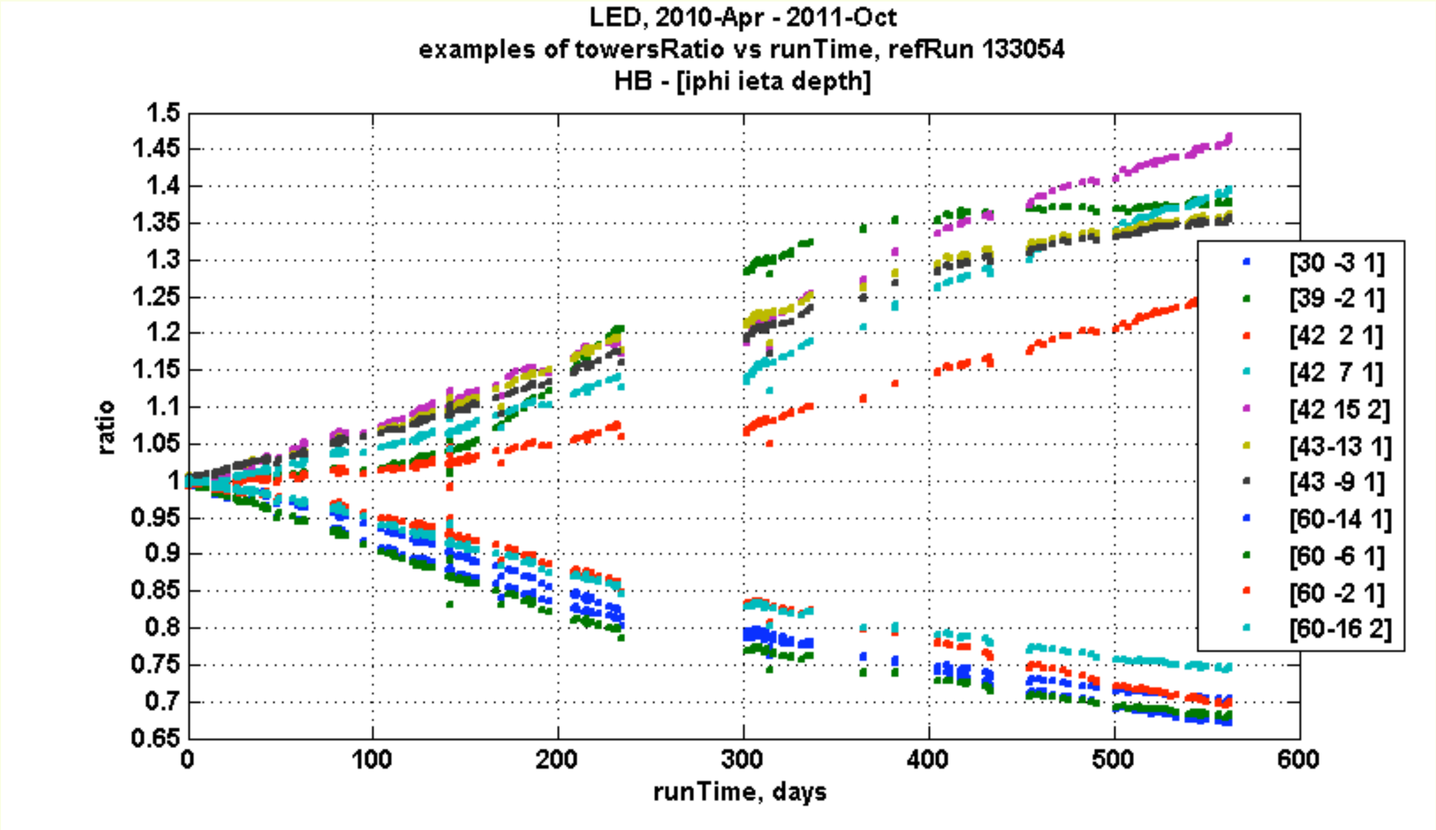
Muon data ratio vs LED ratio

correlation FIT

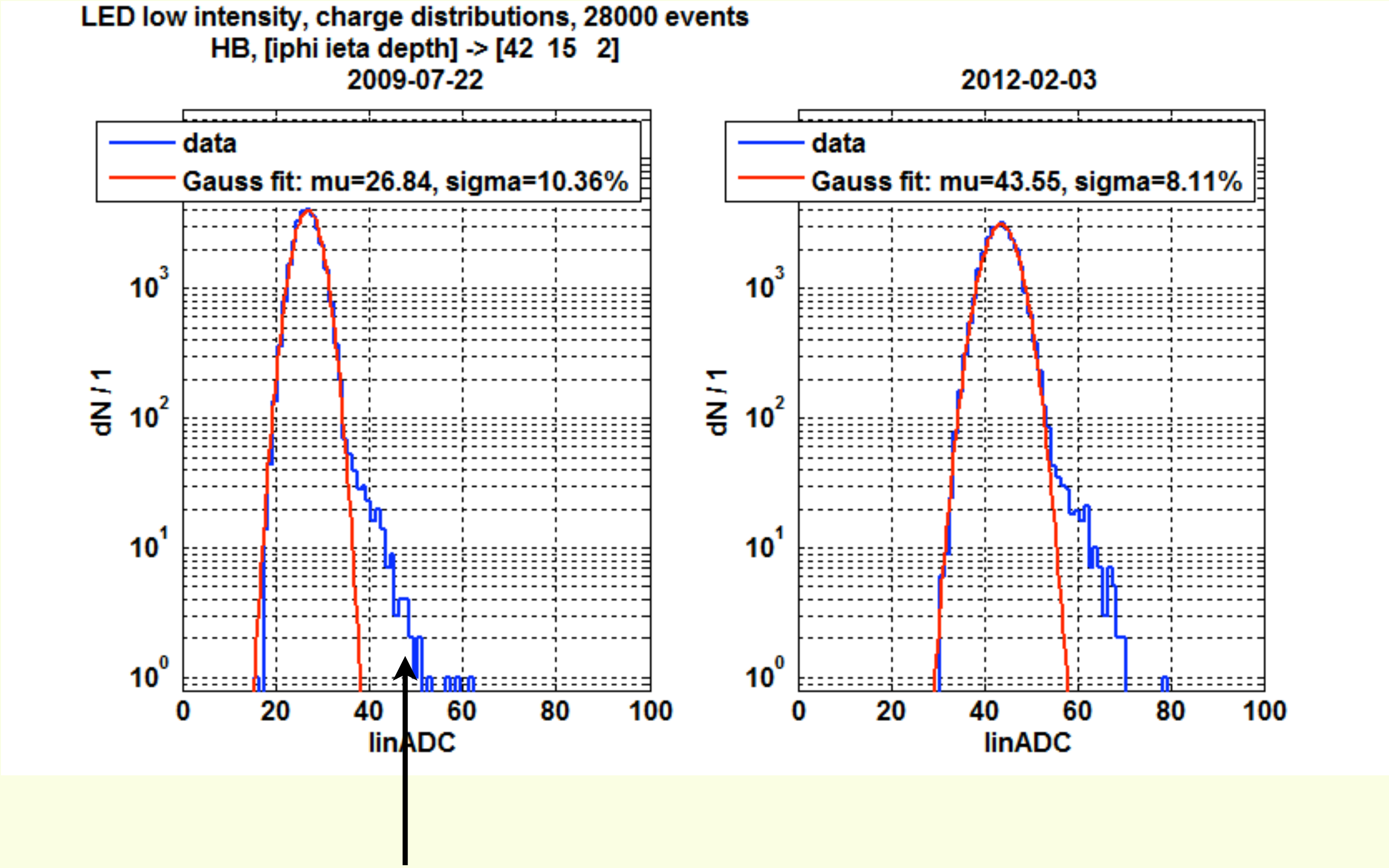




LED standard runs for selected towers



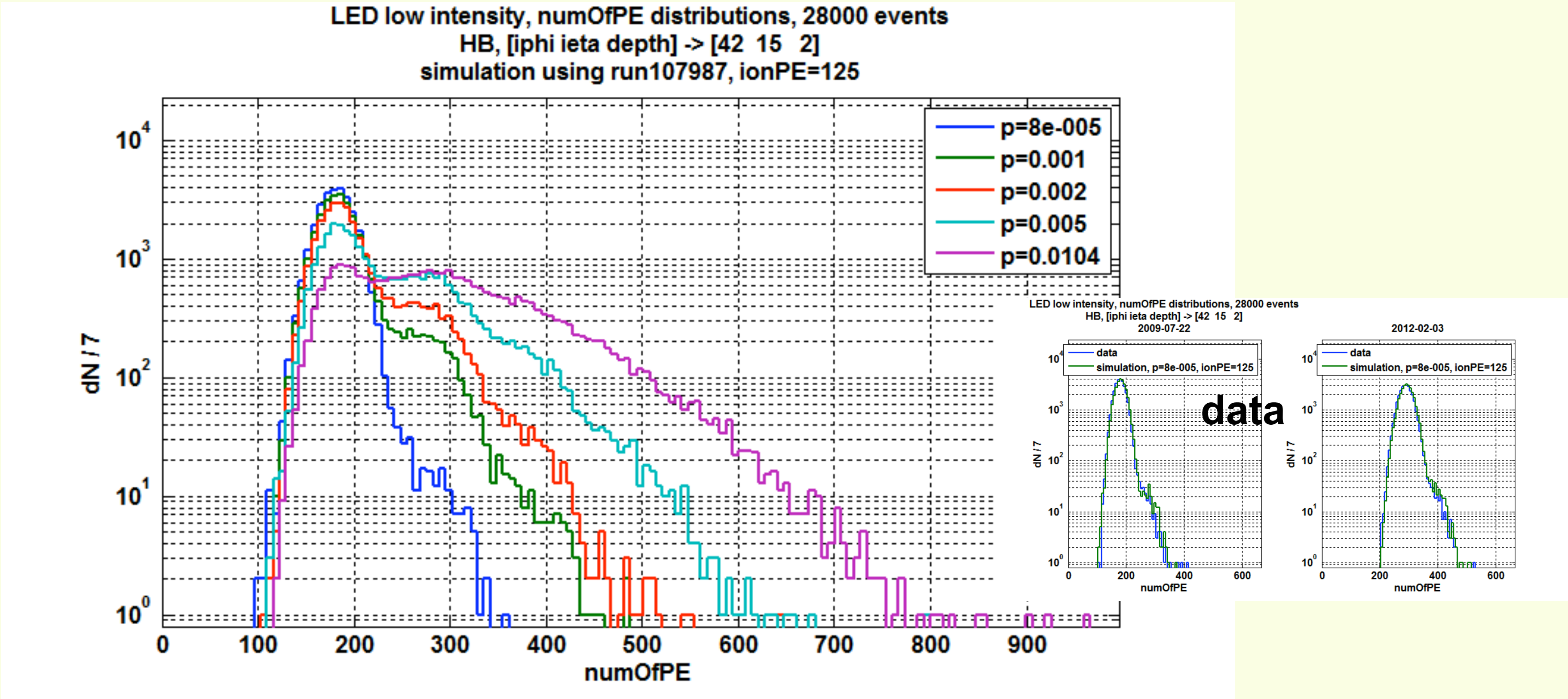
“Low” LED run results



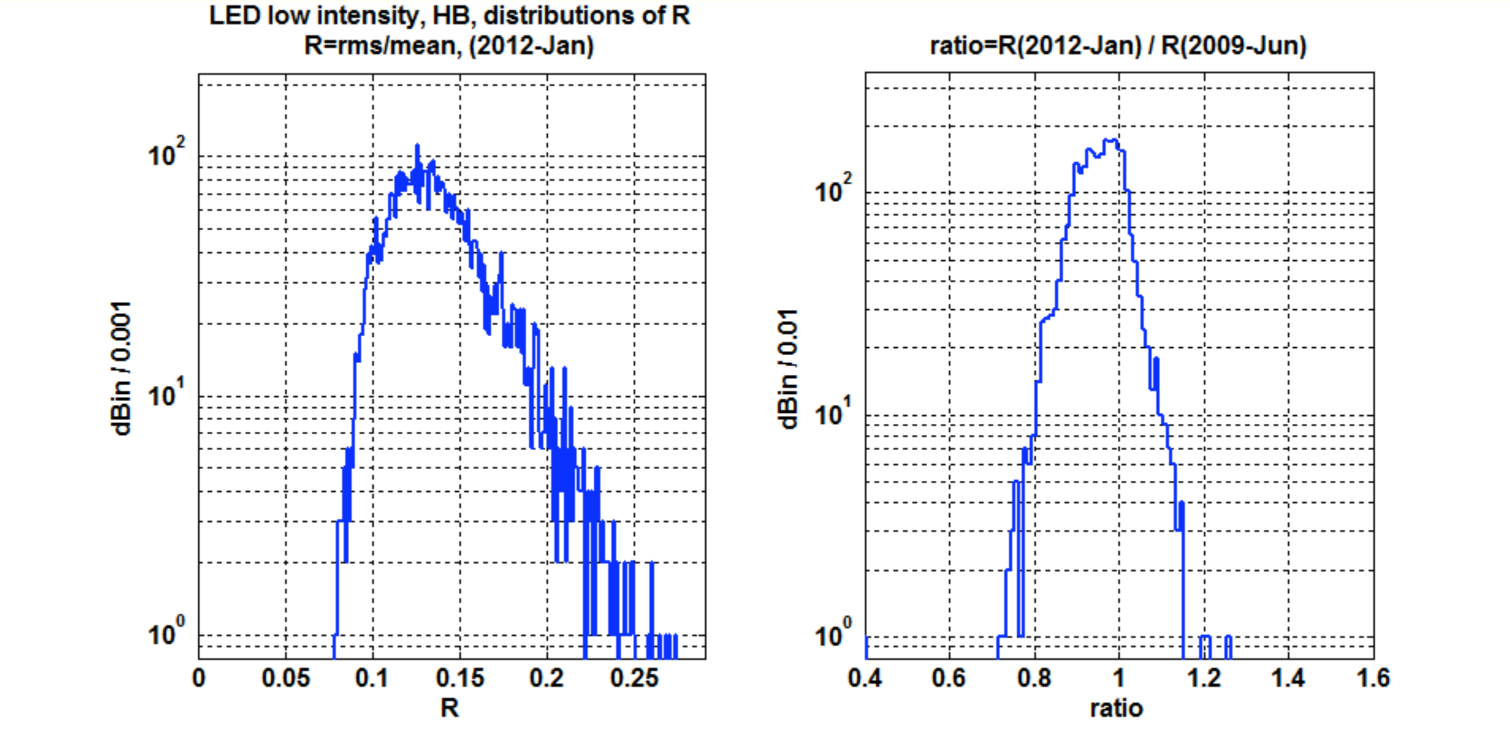
Ion feedback tail

"Low LED" Ion feedback simulation

We measured ion feed back probability tube to tube in 2006 and found spread between **10-4 to 10-3**.
Using the ionization cross section we found 10-4 correspond to ~10-6 bar



“Low” LED Mean/RMS



Conclusion:

We found no evidence that feedback is increasing in HB HPDs !

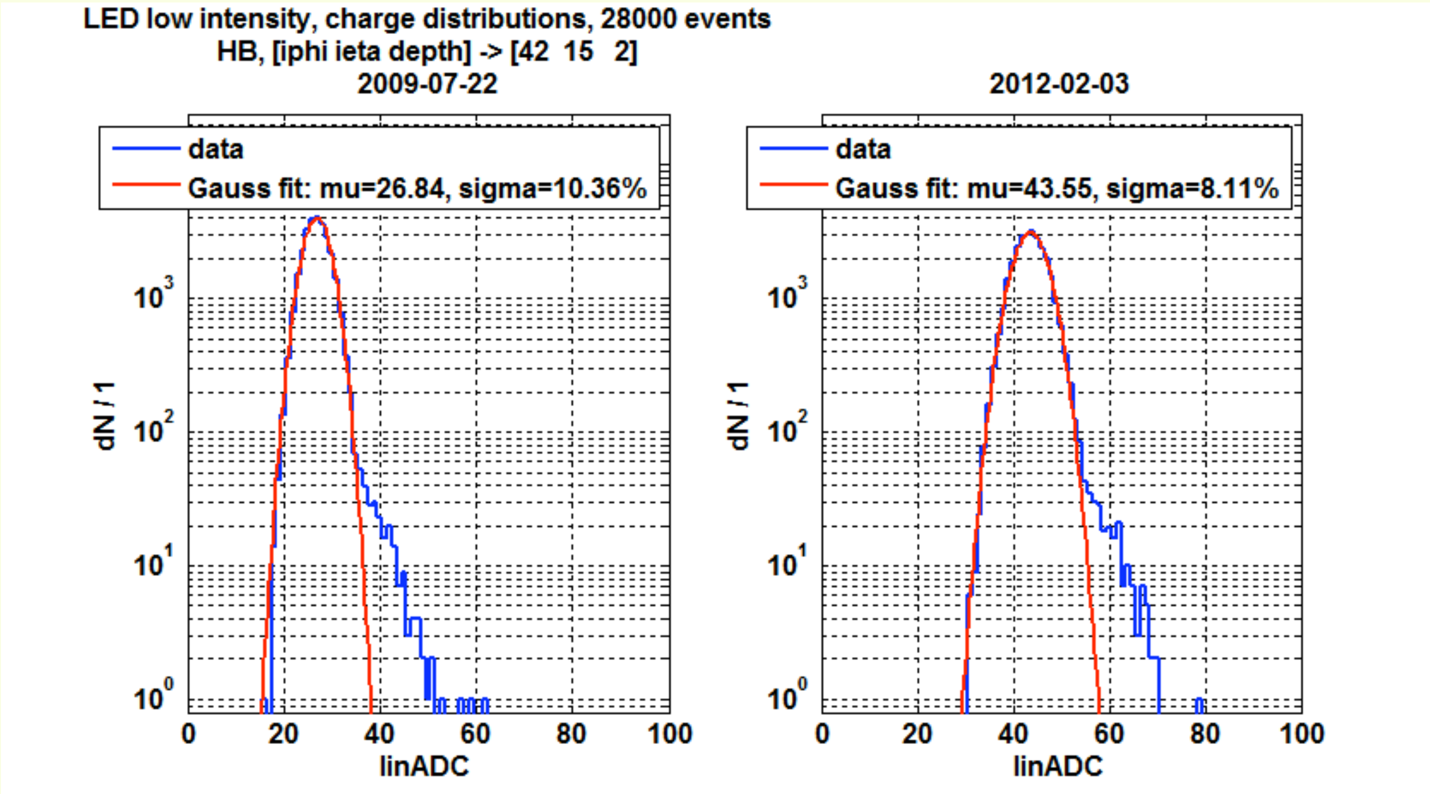
Gauss fit on "low" LED spectra

$\#PE = (1/sigma)^2 = 93$

gain = Mu / PE = 0.29 fC/p.e

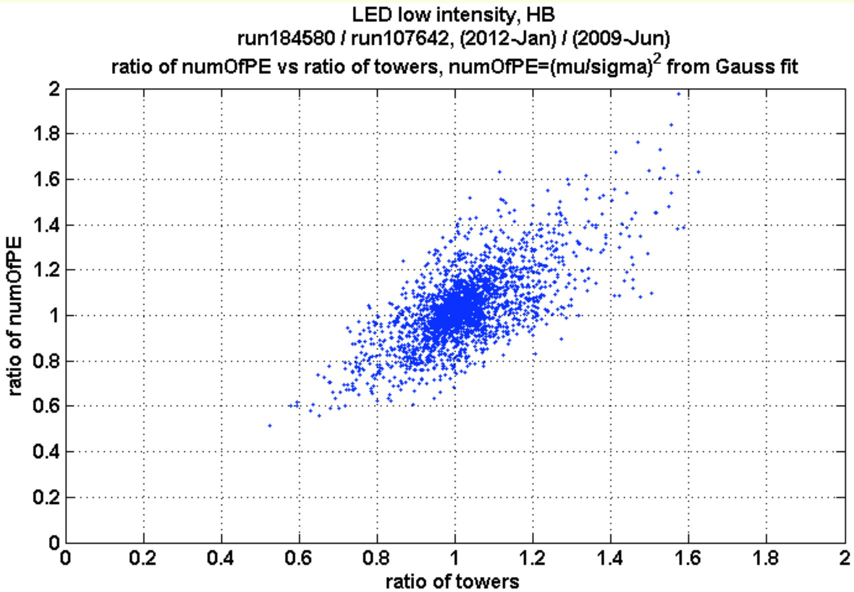
$\#PE = (1/sigma)^2 = 152$

gain = Mu / PE = 0.29 fC/p.e

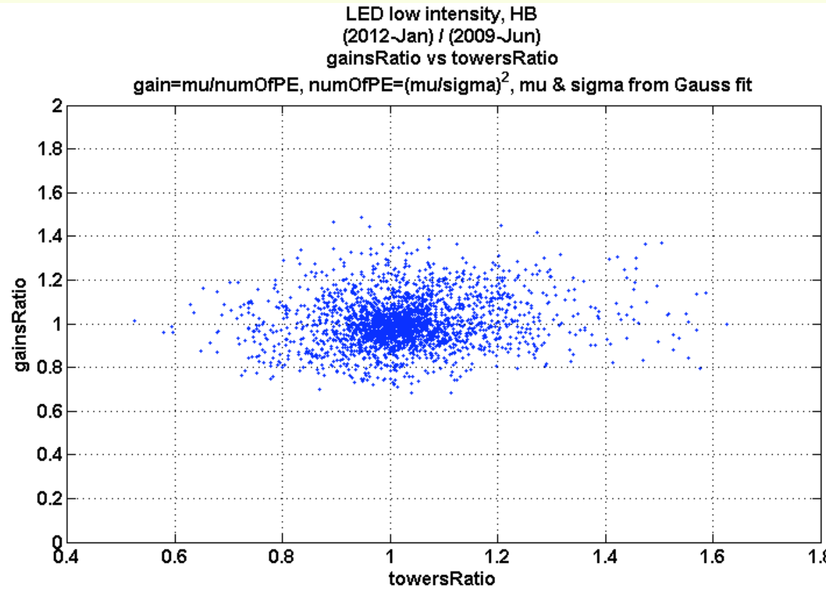


HB low LED gauss fits

Increase in #PE



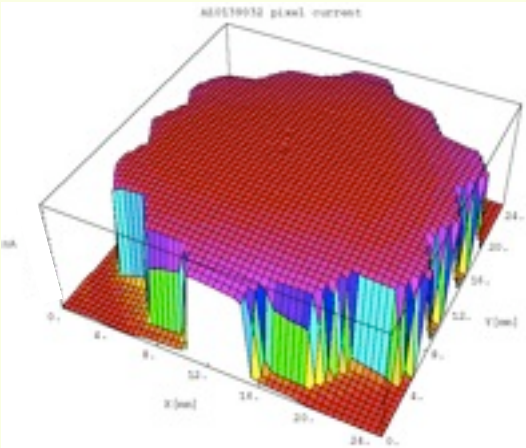
No change in GAIN



Good Correlation was found
with real increase in PE from Photocathode

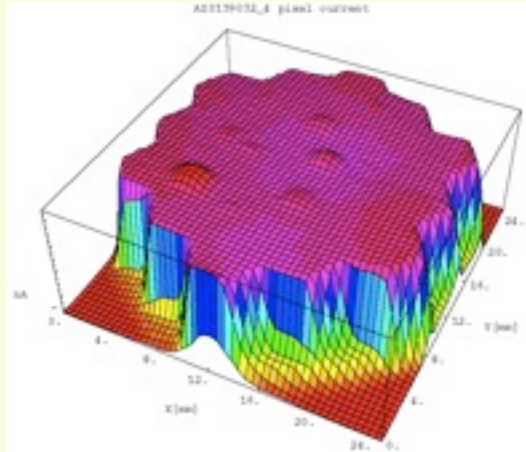
Speculations.........

Do we have Photo-Cathode deformation due to strong electric field inside HPD ??   E= 7kV/3.5mm



~2 weeks of 13 kV

(7-8 KV = normal operation)



We have seen strange effect running HPD at
Very HV for periods of time. Increase of QE in spots of HPD...

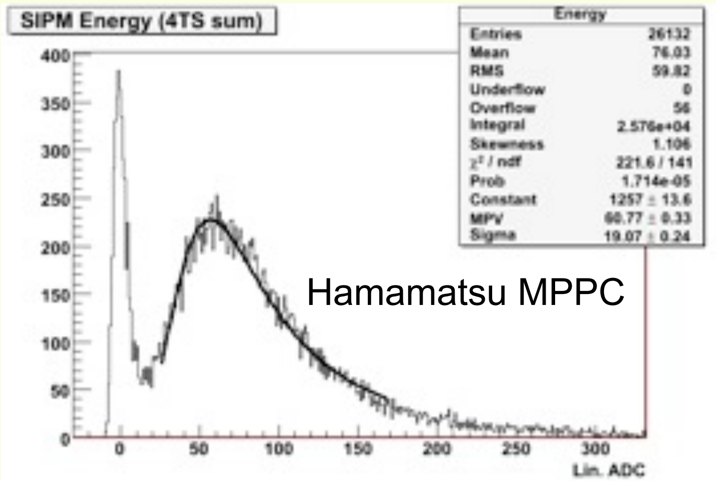
We know that QE is a function of Electric field specially for high red sensitive Photocathodes.

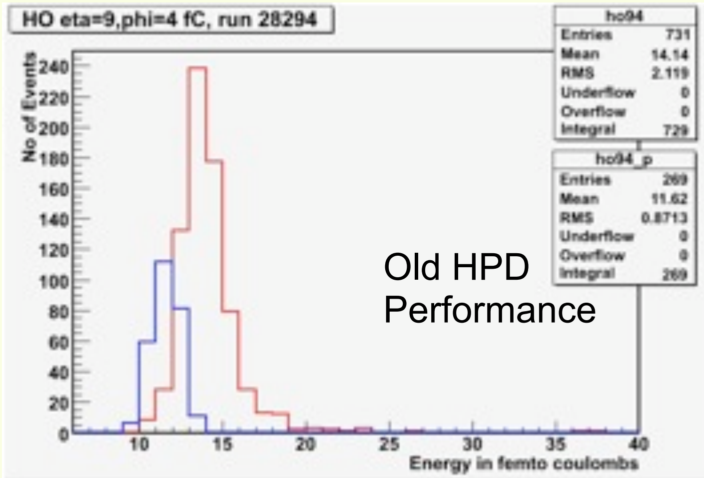
HPD change to SIPM

HO SIPMs were bought in 2010 and installed this year 2160 (channels)

50 micron 3x3 mm HPK SiPM SMD package

SiPM vs HPD MIP performance





After cosmic run of all 2160 channels HO is now considered in muon trigger

HPD to SiPM cont.

HCAL Barrel and Endcap need large Linear range (MIP to TeV Jets)

- R&D between 2010-2014 on small cell devices with different companies
We worked mainly with Zecotek, FBK, KETEK and HPK

- **There is significant scintillator damage measure in HE measure scintillators during the first 22 fb-1 of operation**

So the main goal is Better S/N and depth segmentation

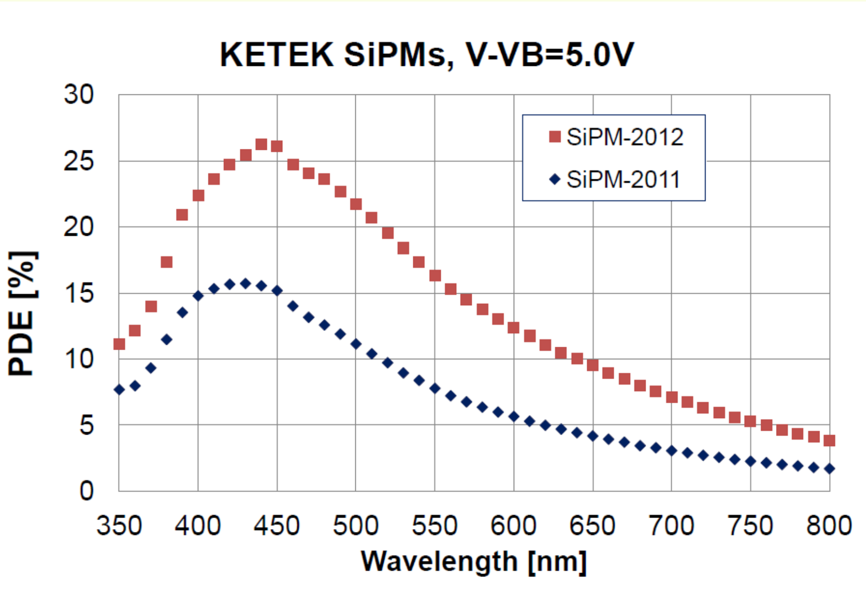
SiPM installation in HE is next we push for 2016-2017

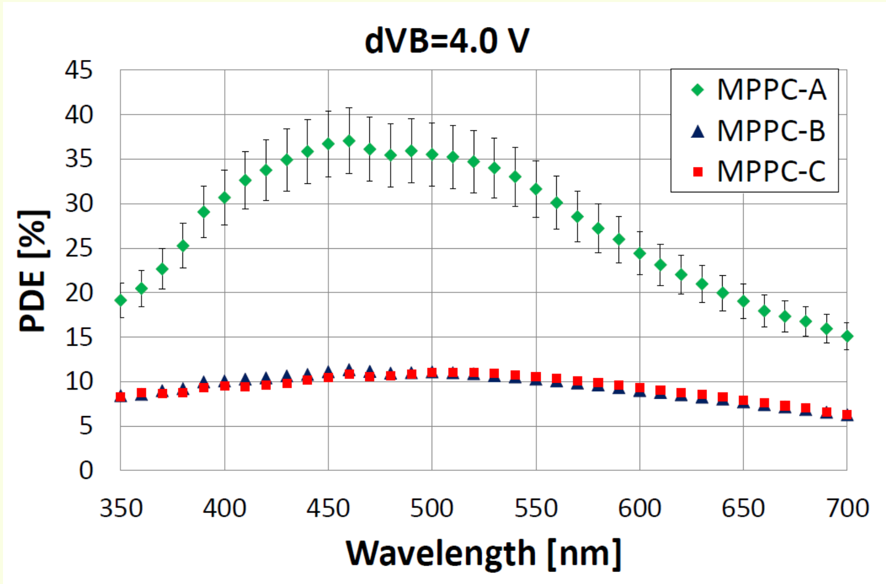
HCAL Barrel is schedule for 2018

Additional advances in PDE in 2012 R&D

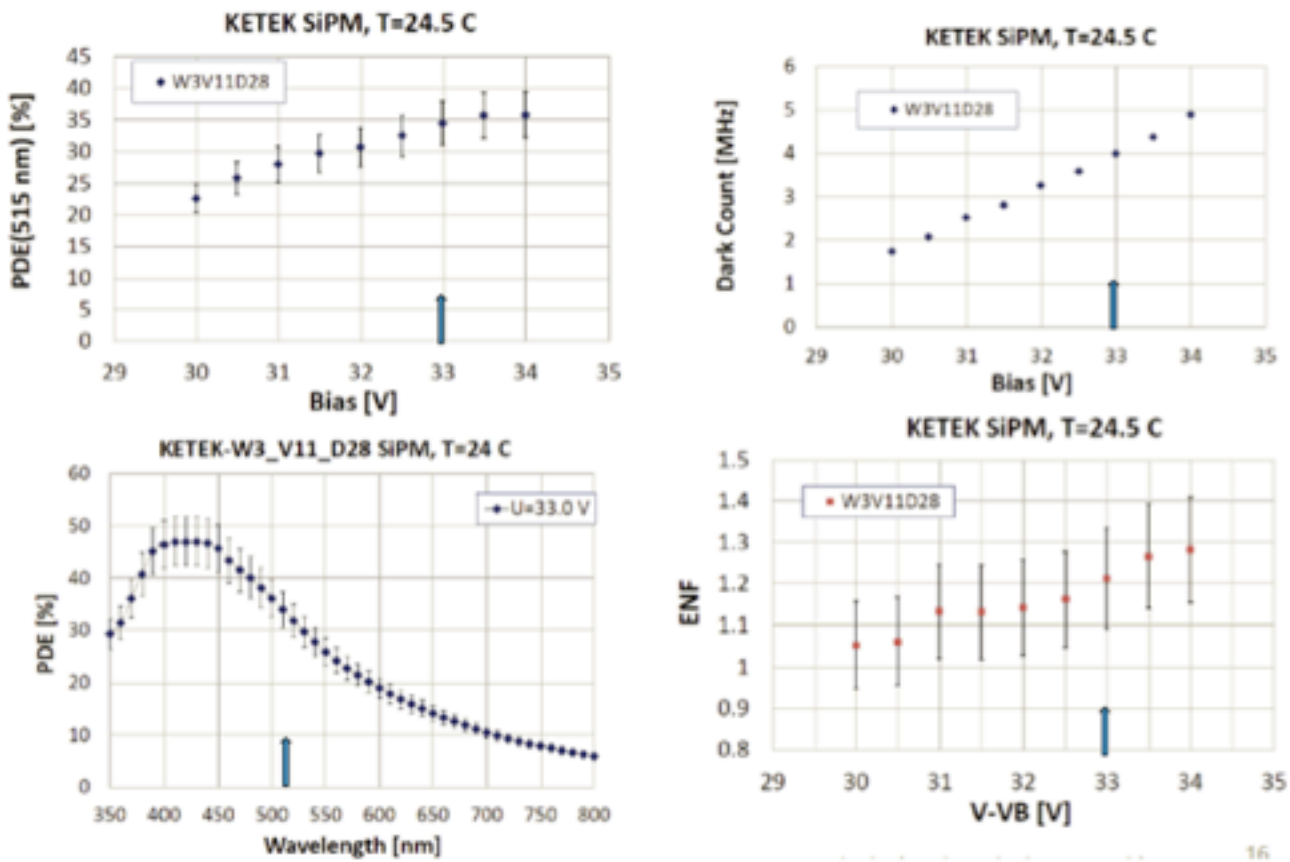
2011 **2012** **New 2014**

Huge improvement with HPK new R&D SiPM with transparent Metal Film Quenching Resistor to create maximum Geometric factor





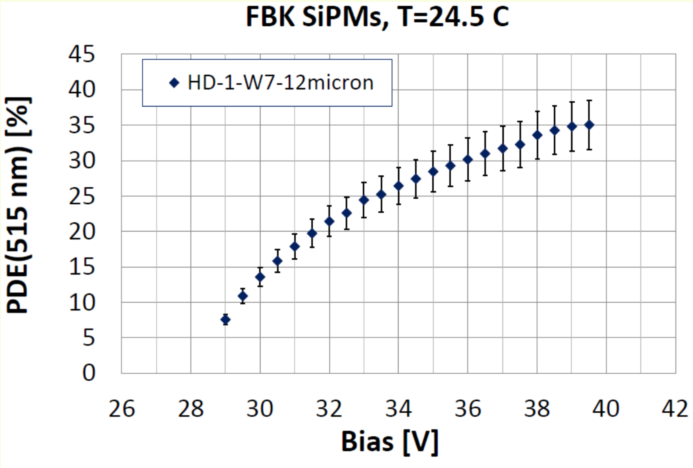
2013 KETEK 15 micron high PDE

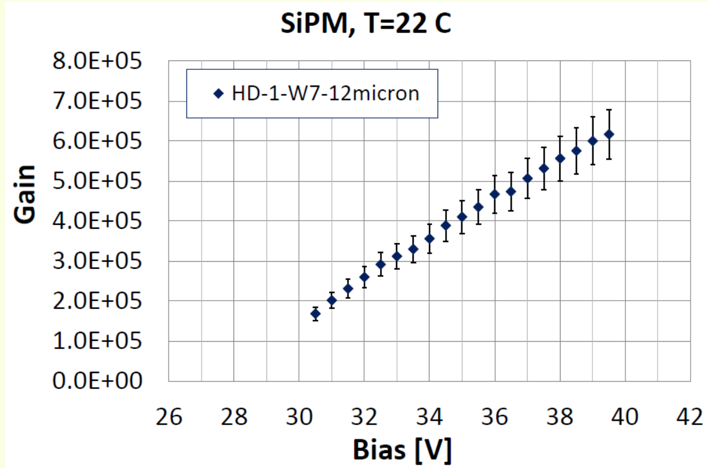


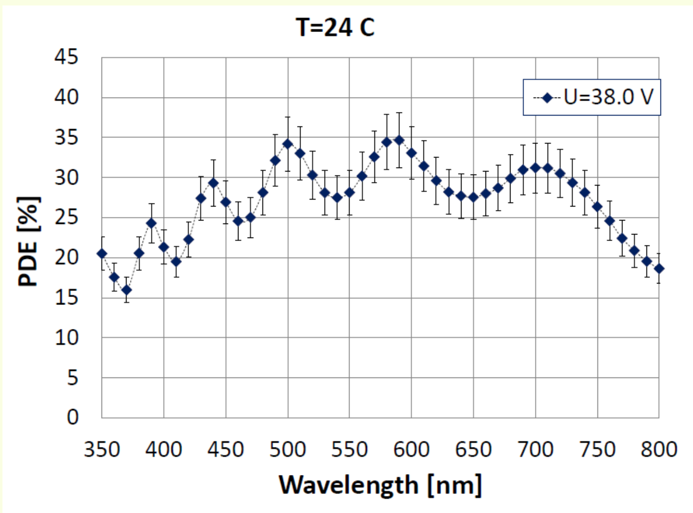
New KETEK V11 design: at V-VB = 3 volts, now PDE ~30%. Note that there is still room to optimize for wavelengths around 500 nm

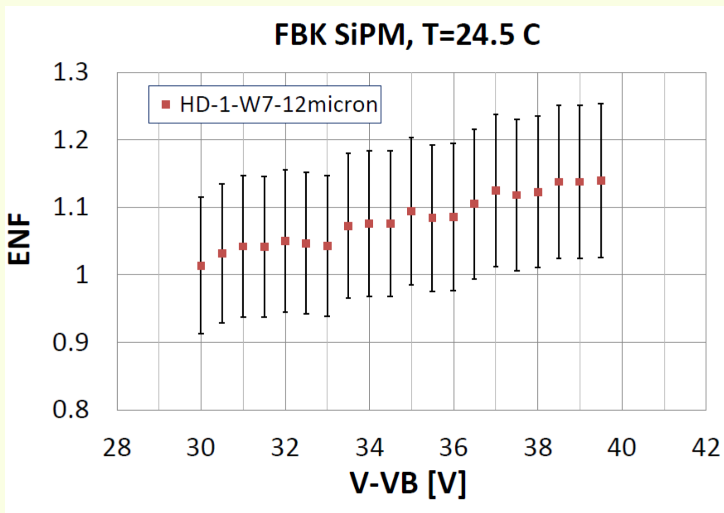
Candidate SiPM R&D results for replacement of HPDs

FBK **12 micron** pitch large dynamic range SiPMs with large PDE and small ENC for the CMS HCAL Upgrade





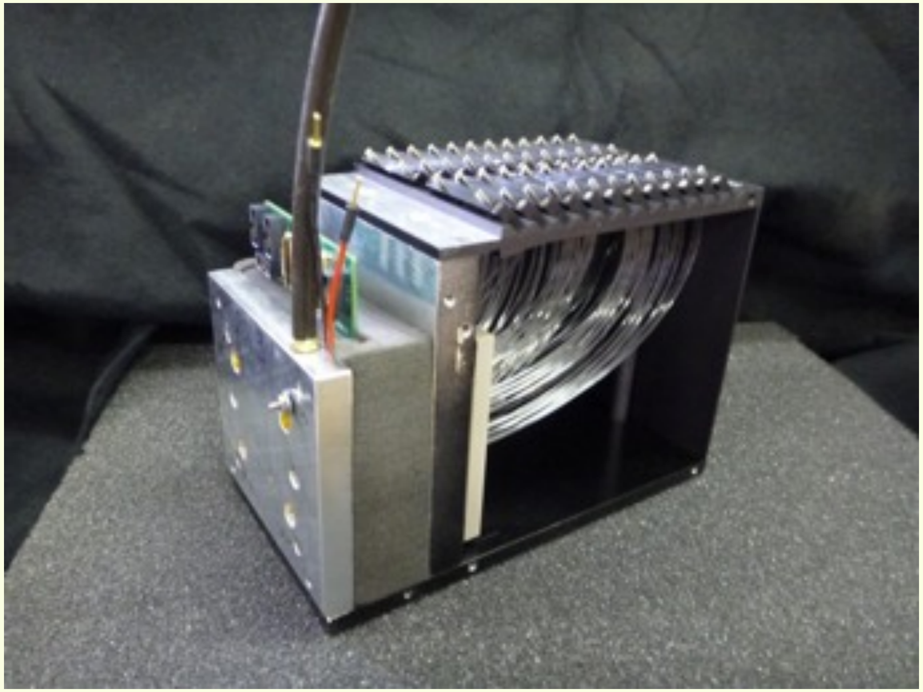


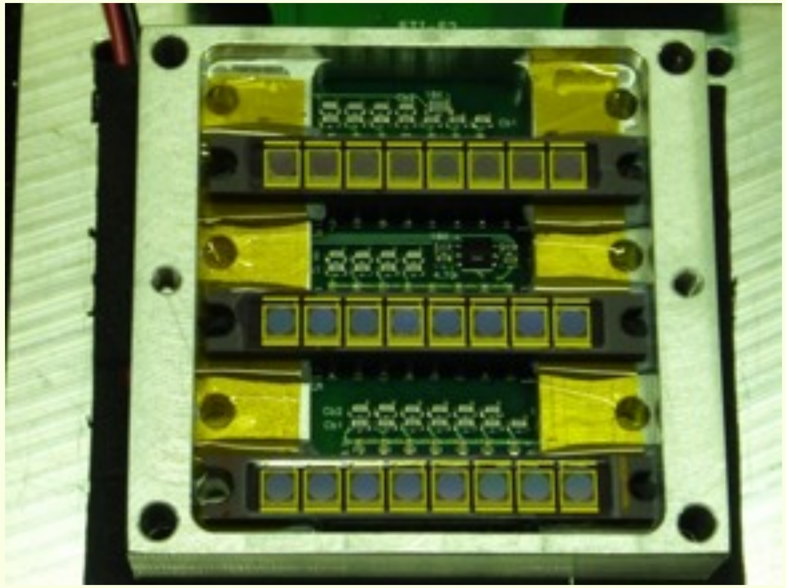


A.H Heering, University of Notre Dame

HE SiPM depth segmented readout

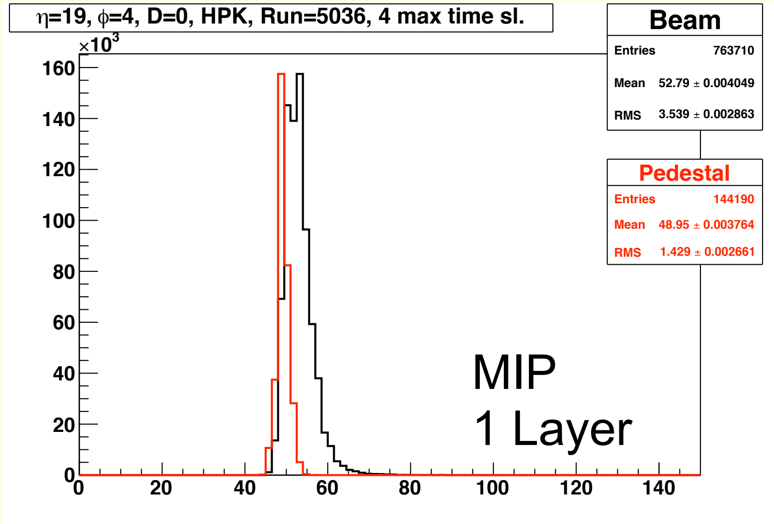
We Took data in our TEST BEAM area (FULL WEDGDE) with
5 Depth segmentations of L0, L(1+2), L(3,4,5),L(6,7,8),L(9-16)

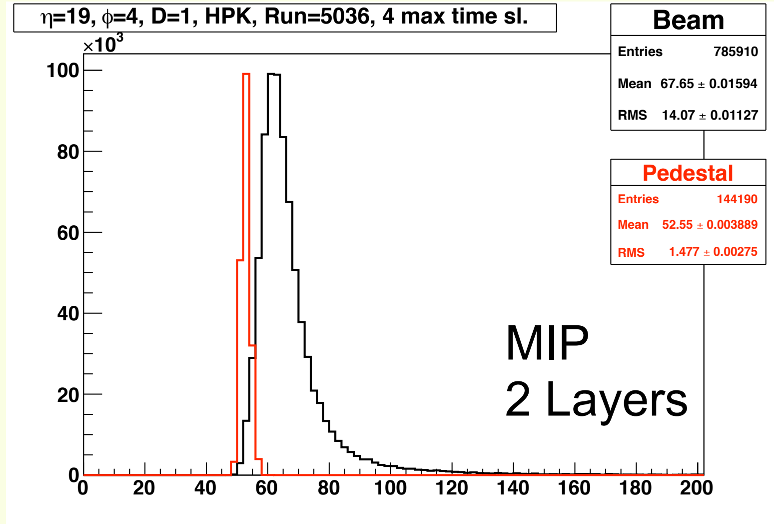


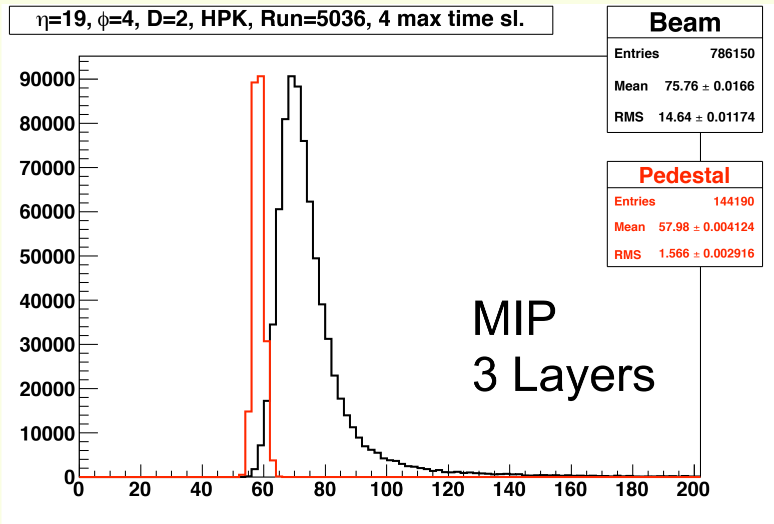


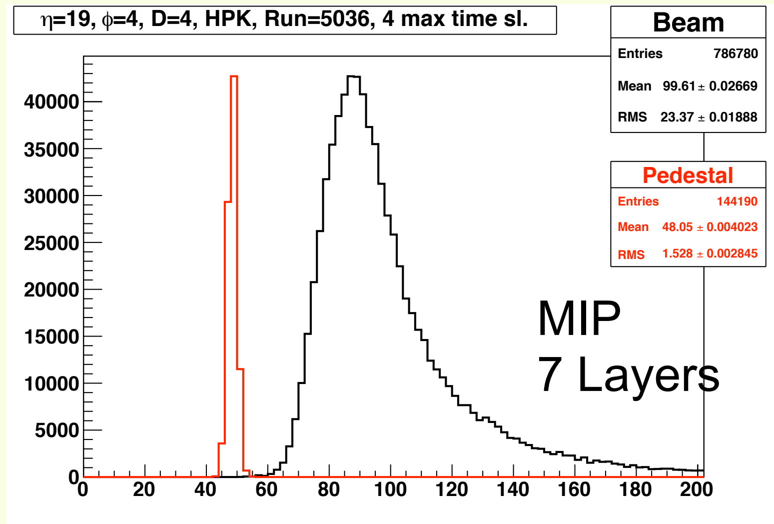
Package is developed with ***Kyocera***

TB2012 HE HPK 150 GeV muon

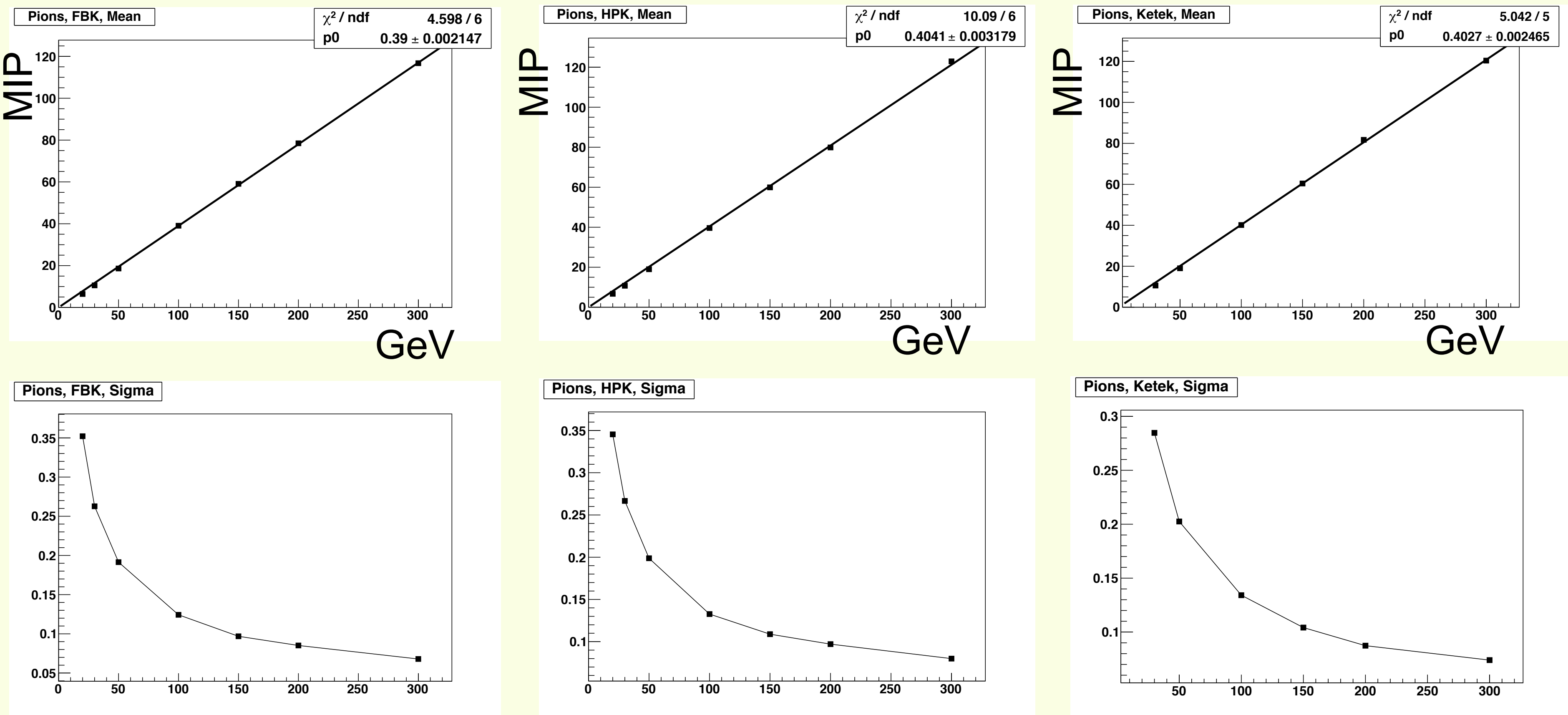








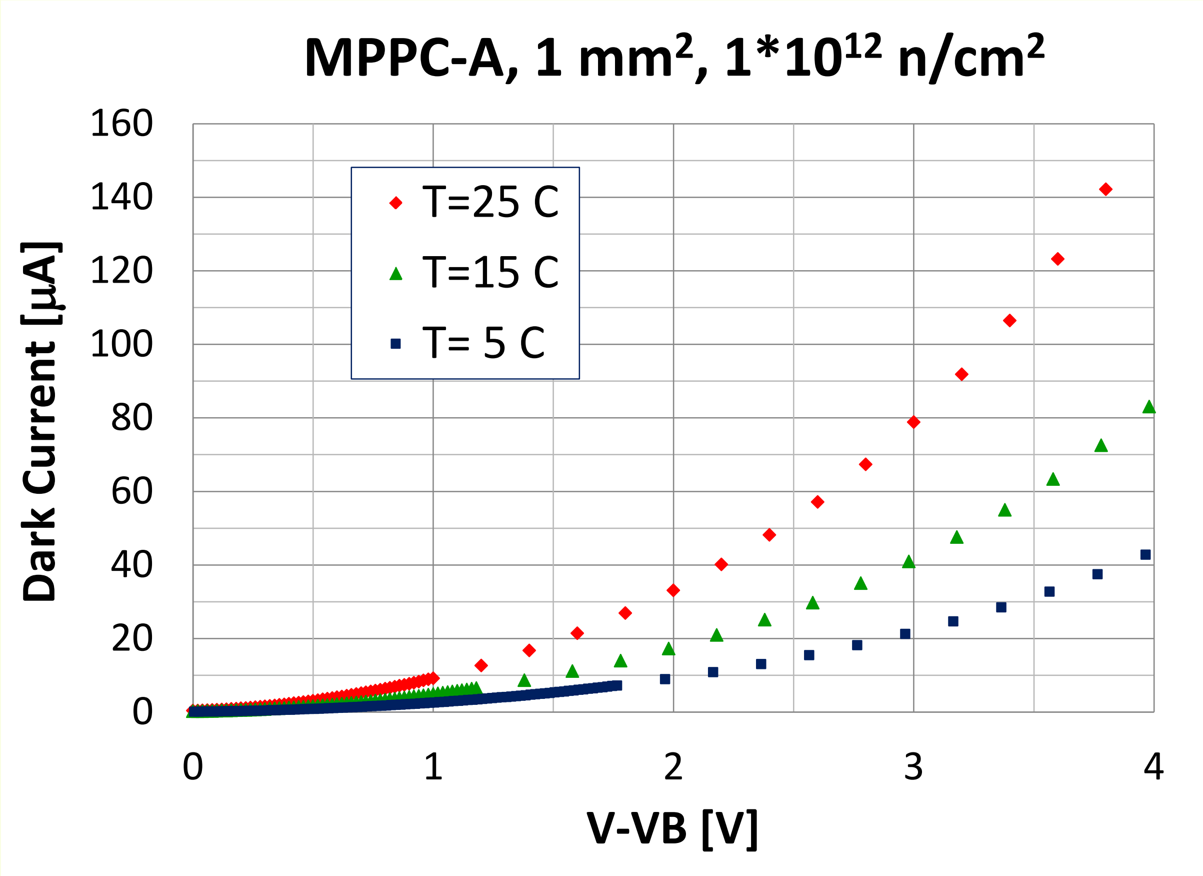
Energy scan 3 manufactures (15 mc cells)



- Pions in a 3x3x5 shows Good linear behavior
- Energy resolution is NOT dominated by SiPM or HPD

SiPM dark current vs Cooling

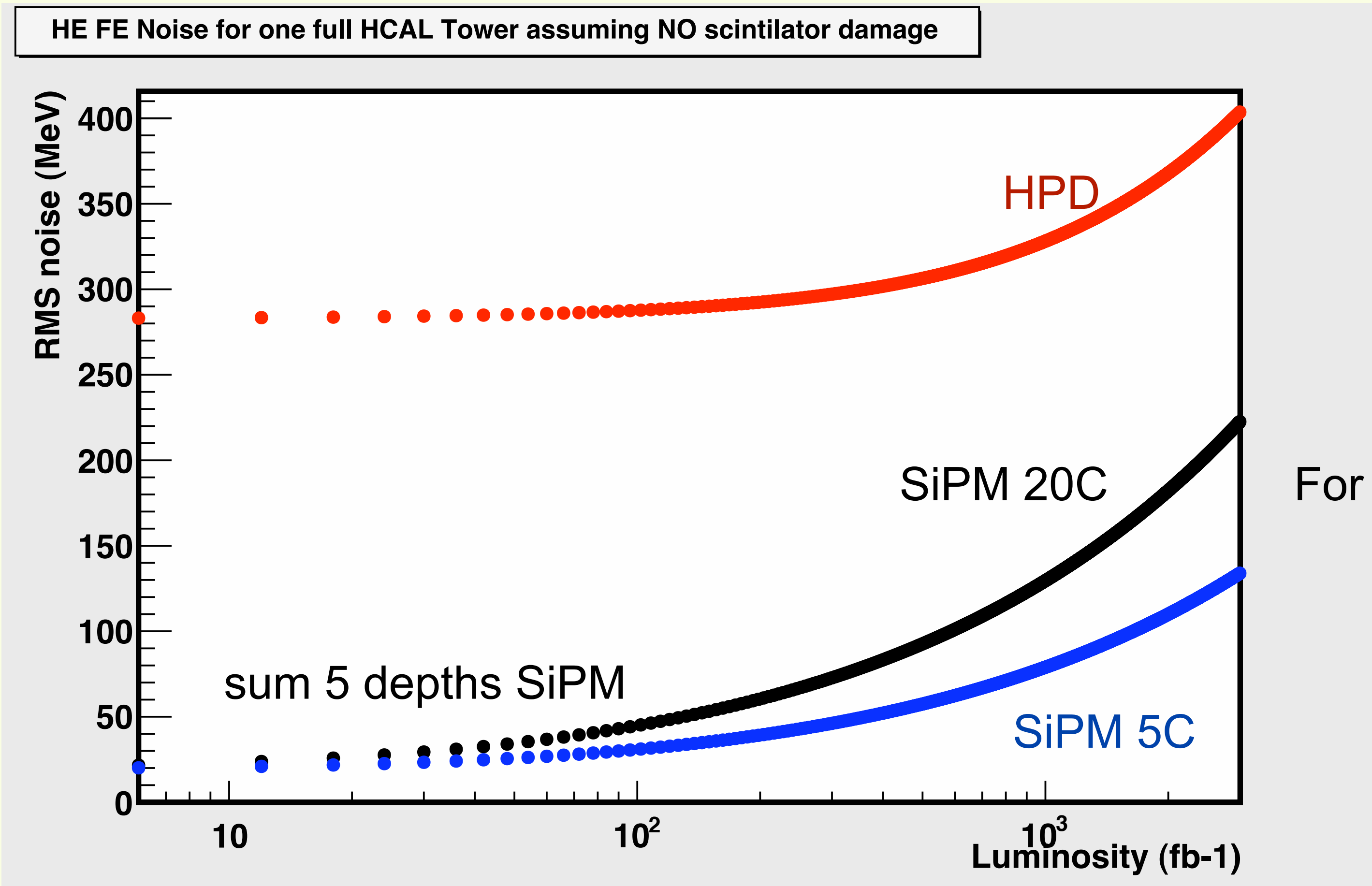
SiPM noise after **radiation damage**
- ONLY factor 2 per 10 deg C



Noise of SiPM +QIE11 vs HPD +QIE 8

Data from Test Beam and radiation test combined

Photo detector noise INCREASE with radiation



For 17% PDE

Conclusion

Even after some initial trouble with NO dead channels we reported
In HPD readout

CMS HCAL has taken good data in the first 4 years (Phase 0)
of LHC

First part of HCAL has exchanged HPDs for SIPMs (CMS- HO)
successfully. We are hopping to get the real physics first data for this next year

Getting ready for SLHC (Phase 1) we will exchange first ENDCAP to compensate as much as possible for scintillator damage

We still have many years for SiPM improvement for Phase 2 replacements

Solid State Photodetectors are a great advancement in HEP
R&D should continue !!