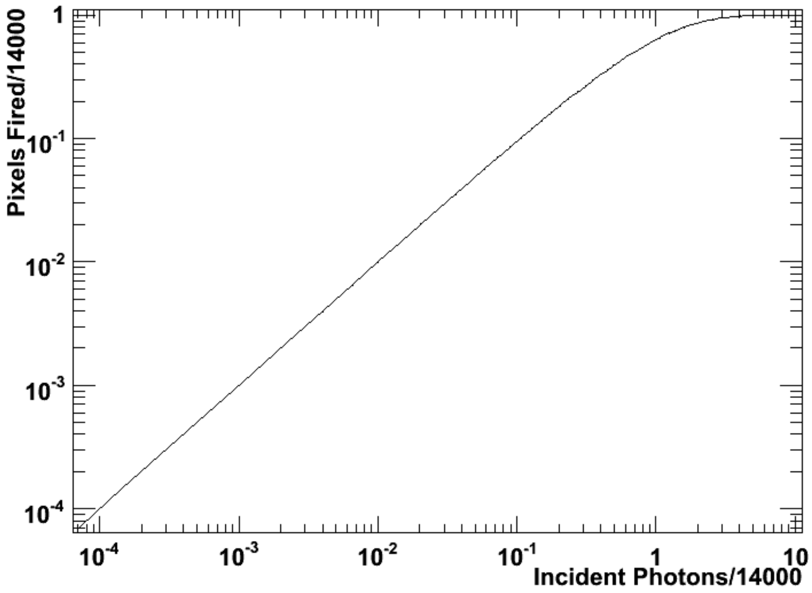
What SiPM will get the job done?

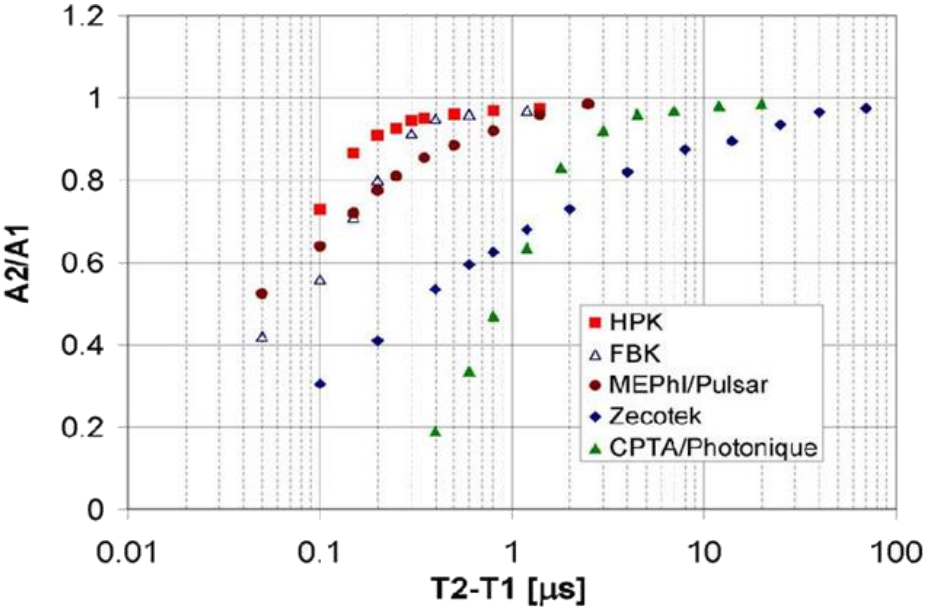
Jacob Anderson, Jim Freeman, Sergey Los, Julie Whitmore

Fermilab

SiPM characteristics

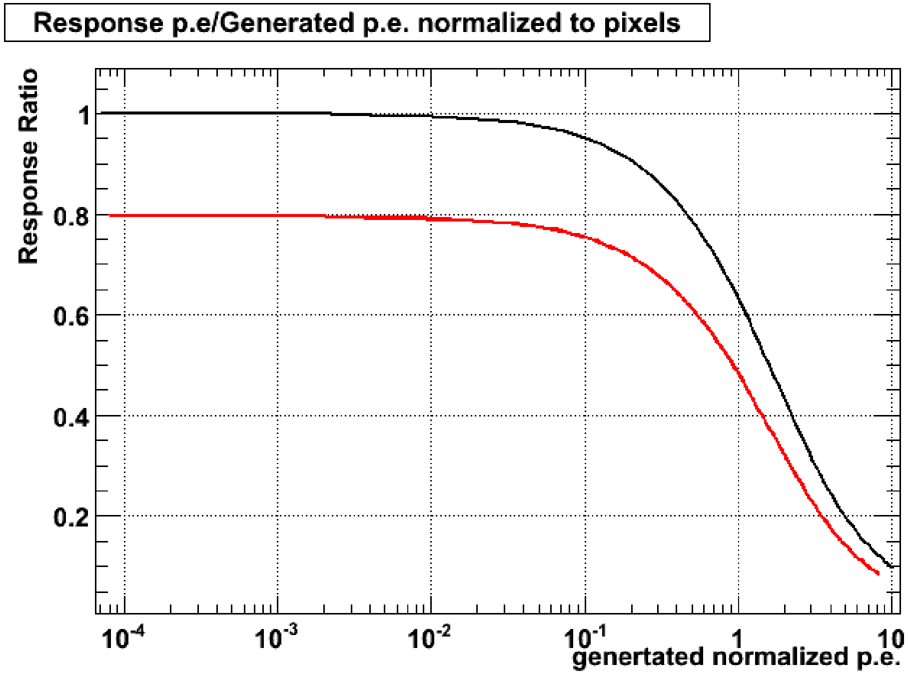
- Dynamic range is determined by the pixel count of the device.
- A pixel which has fired takes some time to charge back up.



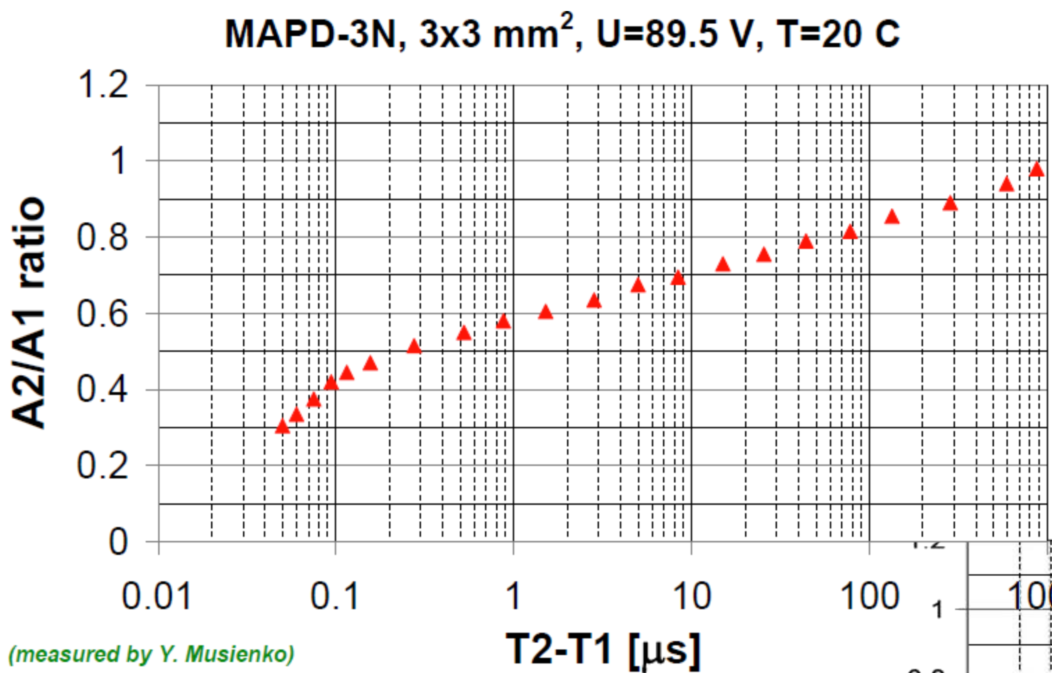


Consequences

- If you have too many photons striking a SiPM it will saturate.
- 25 ns is not long enough for a pixel to recover so history matters.
- Other things may matter too, but so far I haven't studied them.

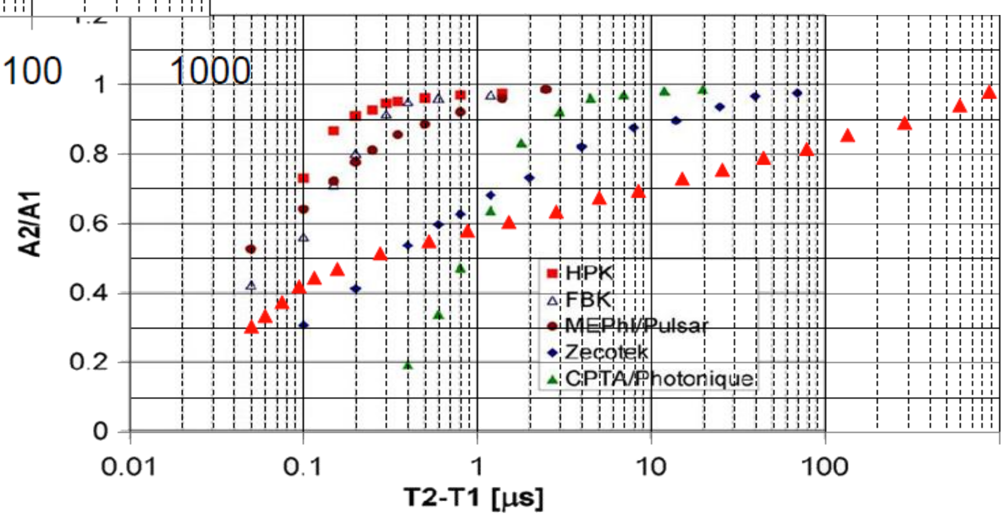


The tale of two SiPMs
Zecotek



- Zecotek has 15k or 40k pixels/mm^2. Excellent dynamic range.
- The Zecotek takes 1 ms to charge back up. That is 40k bunch crossings.

- What does it mean for the response of the device?



Tale of two SiPMs
Hamamatsu

- The Hamamatsu devices have 400, 625, or 1600 pixels/mm^2.
- Their dynamic range is significantly limited compared to the Zecotek
- They are very fast in comparison. Taking only 300 ns to charge up fully.
- Will the dynamic range be sufficient?

Going back in time

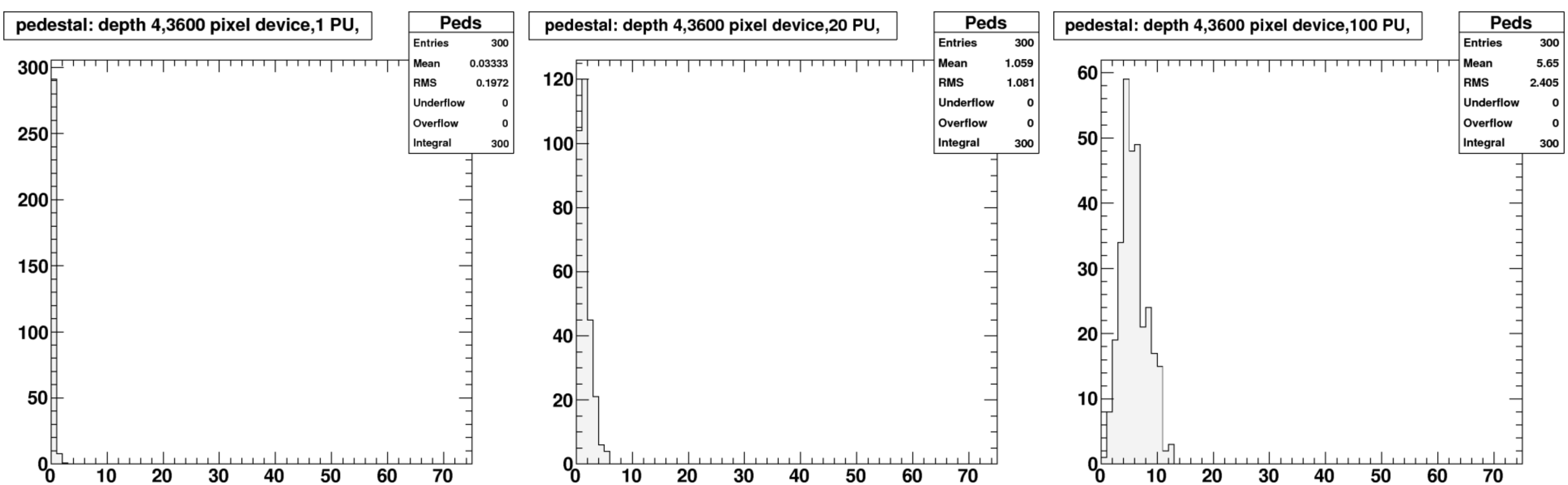
- Take minimum bias events generated in CMSSW 3.1.2 with sim hits for every scintillator layer.
- Use these hits to make p.e. spectra in 4-eta bins in HB, HE, and HO.
- Simulate the last 40–40k bunch crossings using the min. bias spectra to model the needed pile up events.
- Simulate the SiPM as an array of pixels each of which keeps track of the percentage it is charged up.
  - Use the measured recovery curved to track the charge fraction on each pixel through the history period.

Going back in time

- After an appropriate time apply a test based on single pion simulation.
  - Take layer by layer p.e. deposits from the tower with the largest sum of sim hit energy.
  - Select a test event at random from the sample.
  - 50k - 500 GeV single pion
  - 2k - 1 TeV single pion
- What is the state of the simulated SiPM, and what size of signal comes from it?

First the HO

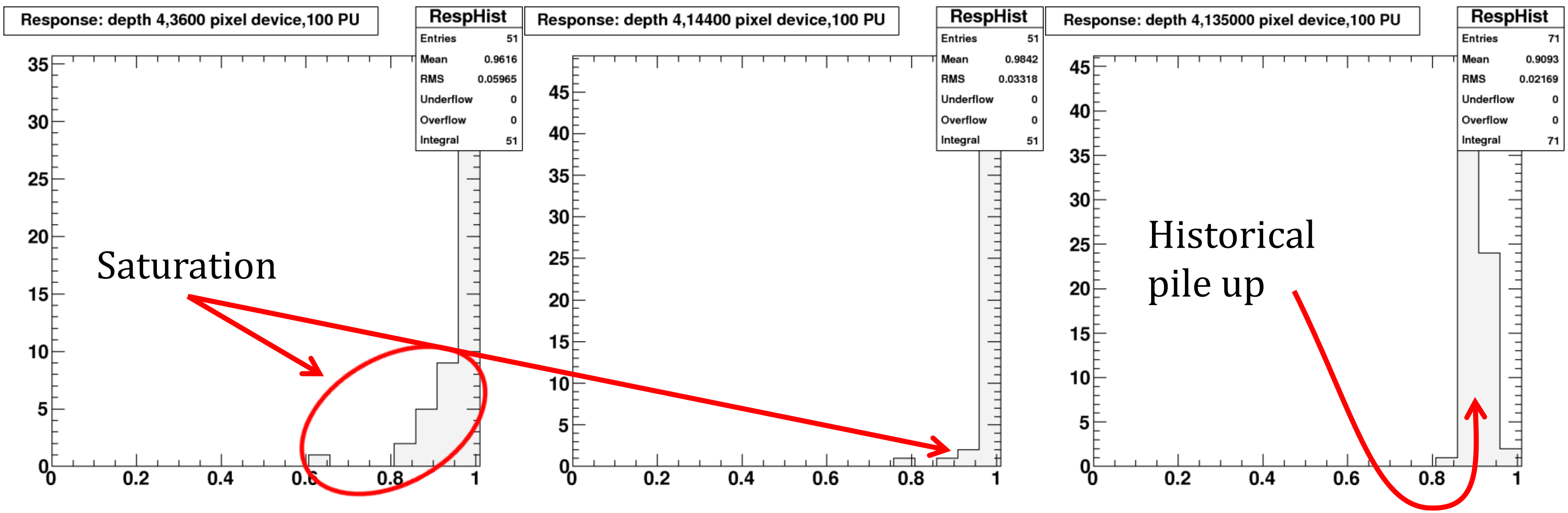
- ~2000 p.e./ms/interaction/layer assuming 18 p.e./mip from min bias interactions.
- Saturation is less of a problem.



HO Performance

- The long history of the Zecotek is visible at high luminosity even out in HO.

Hamamatsu 3x3 Zecotek 3x3



1 TeV single pion

HB/HE upgrade

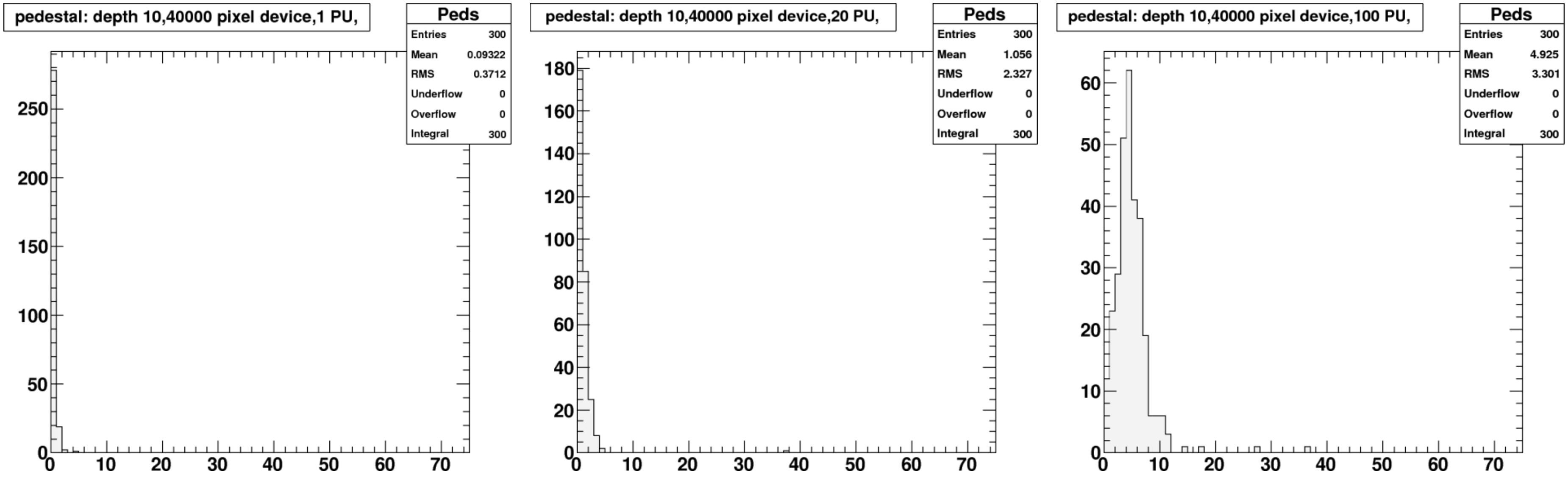
- In the future we would upgrade the current HPDs with a better photodetector.
- We would hopefully gain longitudinal depth segmentation in the barrel.
- We need to be able to operate in high luminosity conditions.
- Here I look at two options
  - With electronic signal summing
  - With optical signal summing

HB/HE with an EDU

- One potential upgrade would use 1x1 mm SiPMs to read out each layer individually.
- The SiPM signal would be electrically summed to form a readout cell allowing longitudinal segmentation of the HB.
- How is the signal from each layer affected by the dynamic range and recovery time of the SiPM device used?

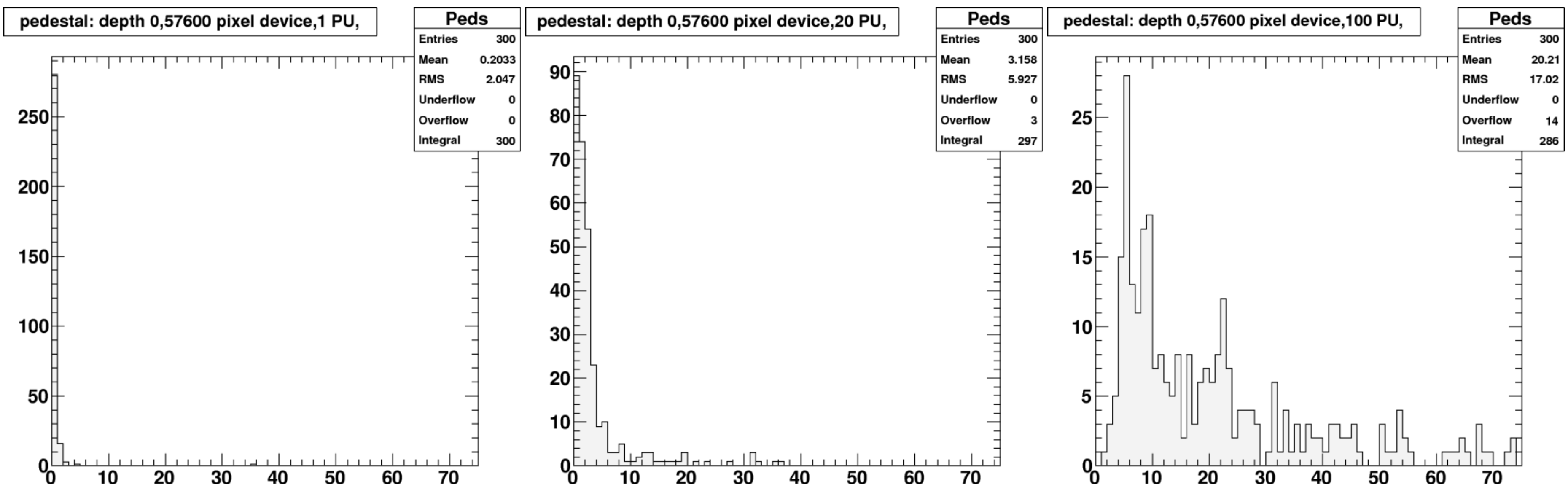
Occupancy

- The HB and HE see between 2k and 10k p.e./ms/interaction/layer depending layer and location assuming 30 p.e./GeV.



Occupancy challenging layers

- Inner layers are more problematic.
- Higher rates and more energy. Start to see more ragged average pedestal.



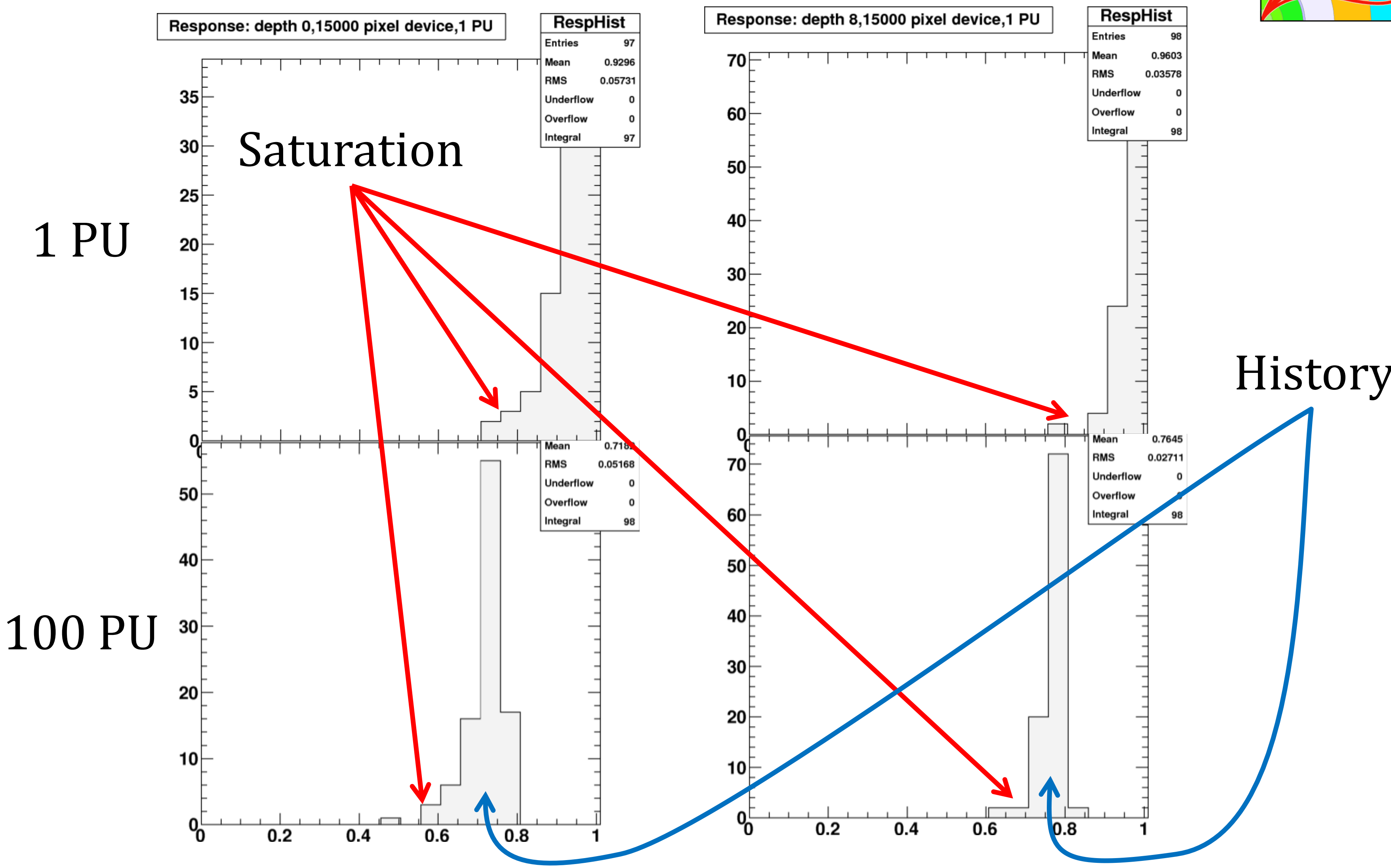
Zecotek 15k

Average fractional response to 1 TeV single pions for 1 PU, 20 PU and 100 PU
Barrel towers 9-12

L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16
0.93	0.95	0.94	0.95	0.95	0.95	0.96	0.96	0.96	0.96	0.97	0.97	0.97	0.97	0.98	0.98	0.97
0.80	0.83	0.82	0.83	0.84	0.84	0.84	0.85	0.85	0.86	0.86	0.86	0.87	0.87	0.87	0.87	0.86
0.72	0.74	0.74	0.74	0.75	0.75	0.75	0.76	0.76	0.77	0.77	0.77	0.77	0.78	0.78	0.78	0.77

- The average response degrades as a function of luminosity.
  - The primary cause of the loss is the history of dead pixels accumulated over the past ms.
  - For the inner layers saturation is also a significant problem

Zecotek 15k - Response



Zecotek 40k

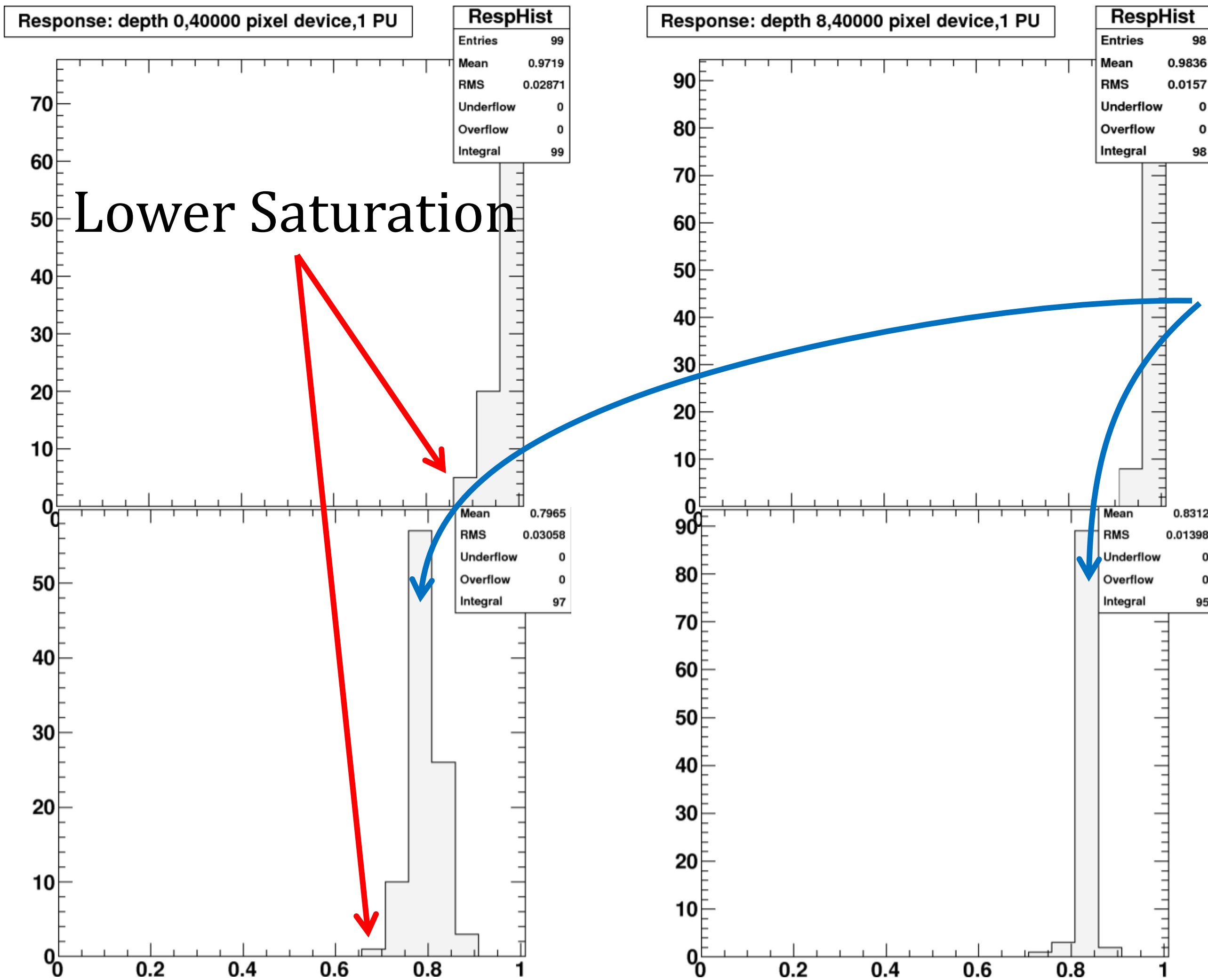
Average fractional response to 1 TeV single pions for 1 PU, 20 PU and 100 PU
Barrel towers 9-12

L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16
0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
0.90	0.91	0.91	0.91	0.92	0.92	0.92	0.92	0.92	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
0.80	0.82	0.82	0.82	0.82	0.83	0.83	0.83	0.83	0.83	0.83	0.84	0.84	0.83	0.84	0.84	0.83

- Zecotek 40k seems to have the needed dynamic range.
- The historical pileup is still a significant problem.

Zecotek 40k - Response

1 PU



History induced response is still problematic

100 PU

Hypothetical SiPMs
Zecotek 40k, 10x faster

Average fractional response to 1 TeV single pions for 1 PU, 20 PU and 100 PU
Barrel towers 9-12

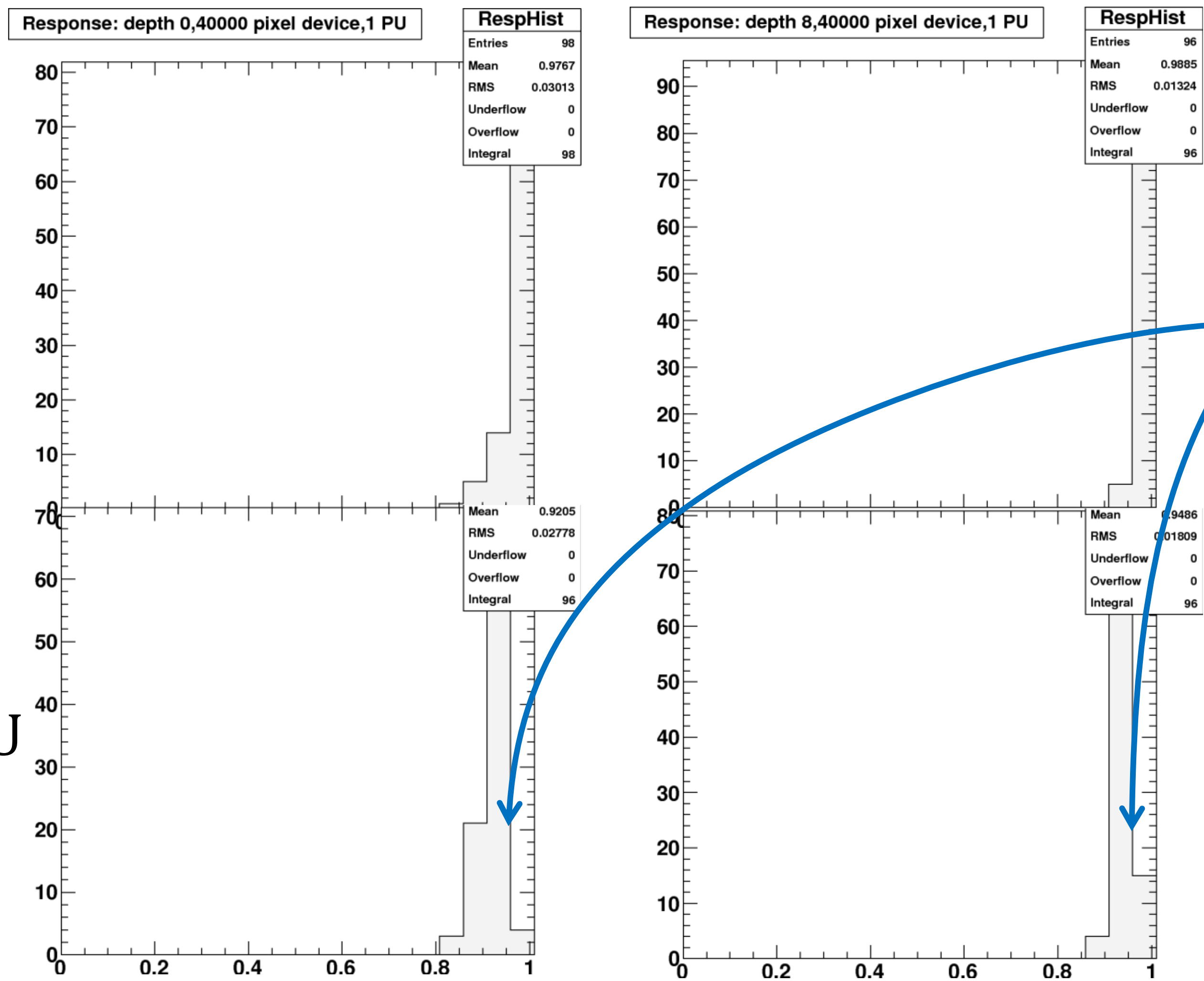
L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13	L14	L15	L16
0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00	0.99
0.97	0.97	0.97	0.97	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98	0.99	0.99	0.99	0.99	0.98
0.92	0.94	0.94	0.94	0.94	0.94	0.95	0.94	0.95	0.95	0.95	0.95	0.95	0.95	0.96	0.96	0.95

- The historical pileup is not such a problem.
- It looks like this one would be doable.

Zecotek 40k, 10x - Response

1 PU

100 PU



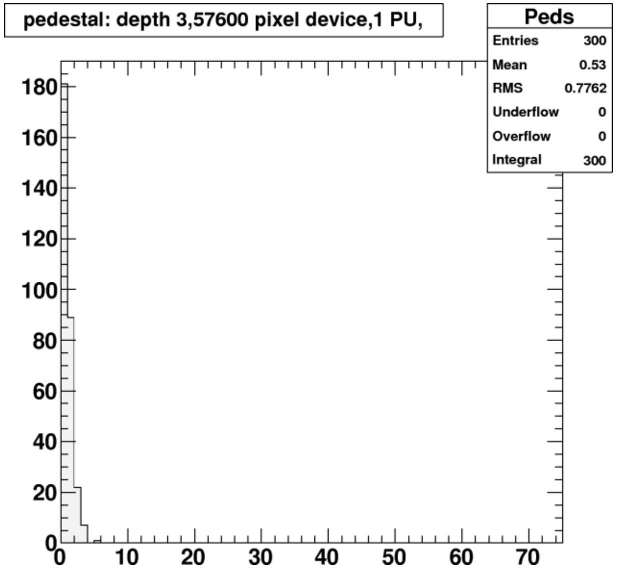
Almost fast enough to not see the effects.

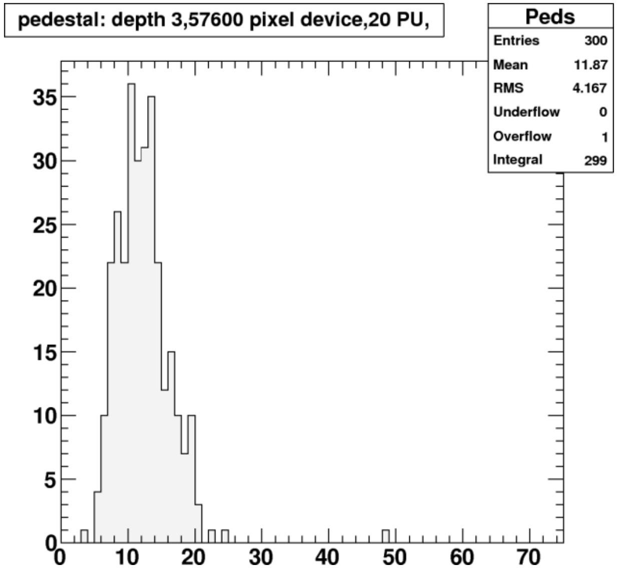
HB/HE with an ODU

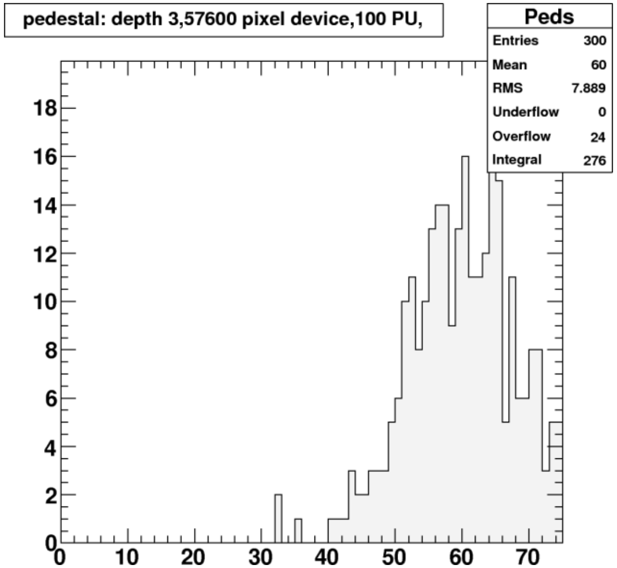
- Fibers from layers would be optically mixed before the photodetector.
- The mixed light would then shine on a 3x3 mm SiPM for each predefined longitudinal depth.
  - For this study:
    - Depth 0: first layer
    - Depth 1: 3 layers
    - Depth 2: 3 layers
    - Depth 3: rest of layers
    - Depth 4: HO (where applicable)
- The dynamic range really comes into play.

Depth Occupancy

- Depth 3 has 20 to 25 p.e./µs/interaction.
  - Others are smaller. Depth 0 is the same as the EDU option.







Hamamatsu 1600 /mm^2

Average fractional response to 1 TeV single pions for 1 PU, 20 PU and 100 PU
Barrel towers 9-12

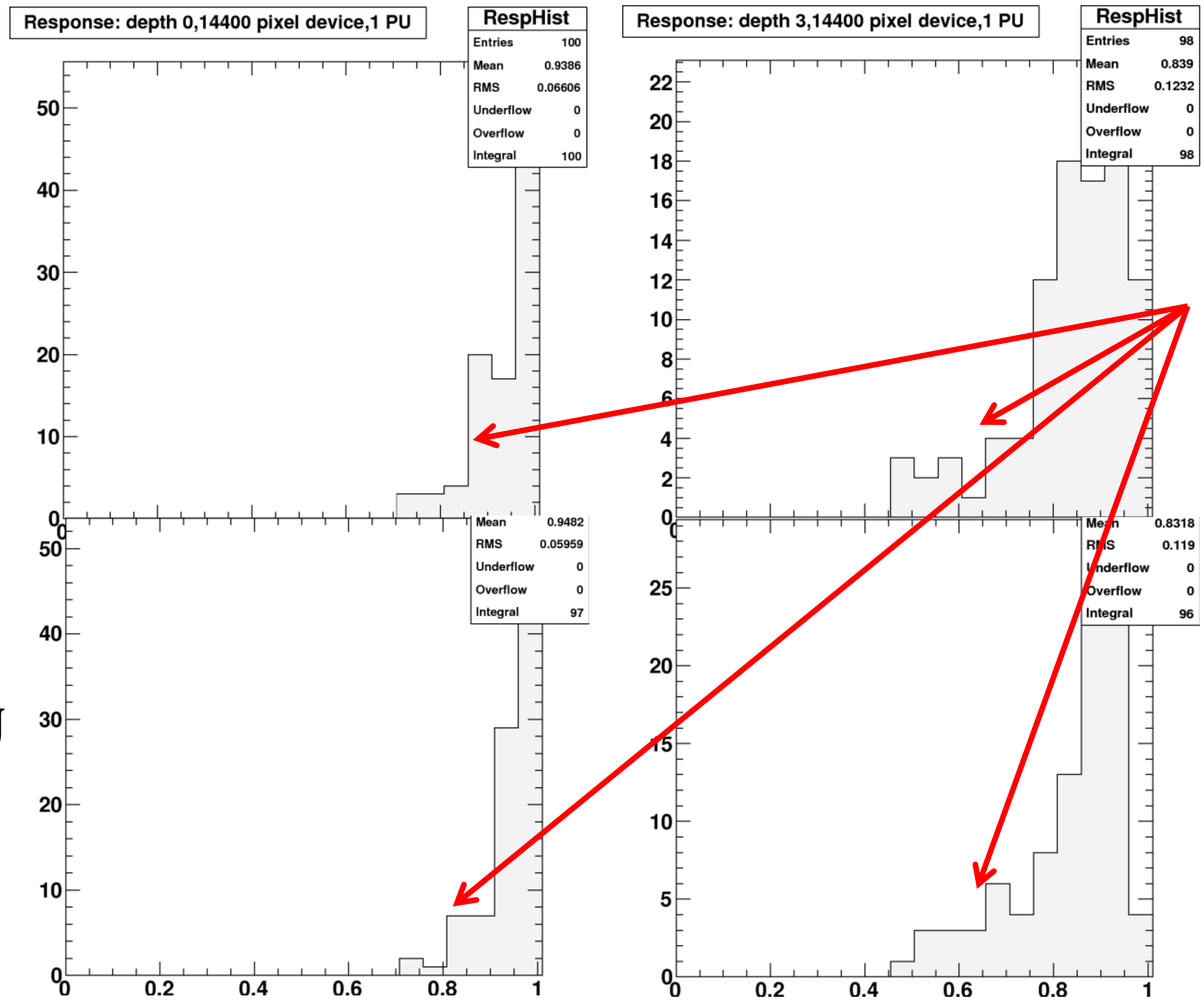
Depth 0	Depth 1	Depth 2	Depth 3
0.94	0.85	0.89	0.84
0.94	0.86	0.88	0.82
0.95	0.85	0.88	0.83

- The response is problematic because of saturation.

Hamamatsu 1600 - Response

1 PU

100 PU



Considerable Saturation

Hypothetical SiPM Hamamatsu 6400 /mm^2

Average fractional response to 1 TeV single pions for 1 PU, 20 PU and 100 PU
Barrel towers 9-12

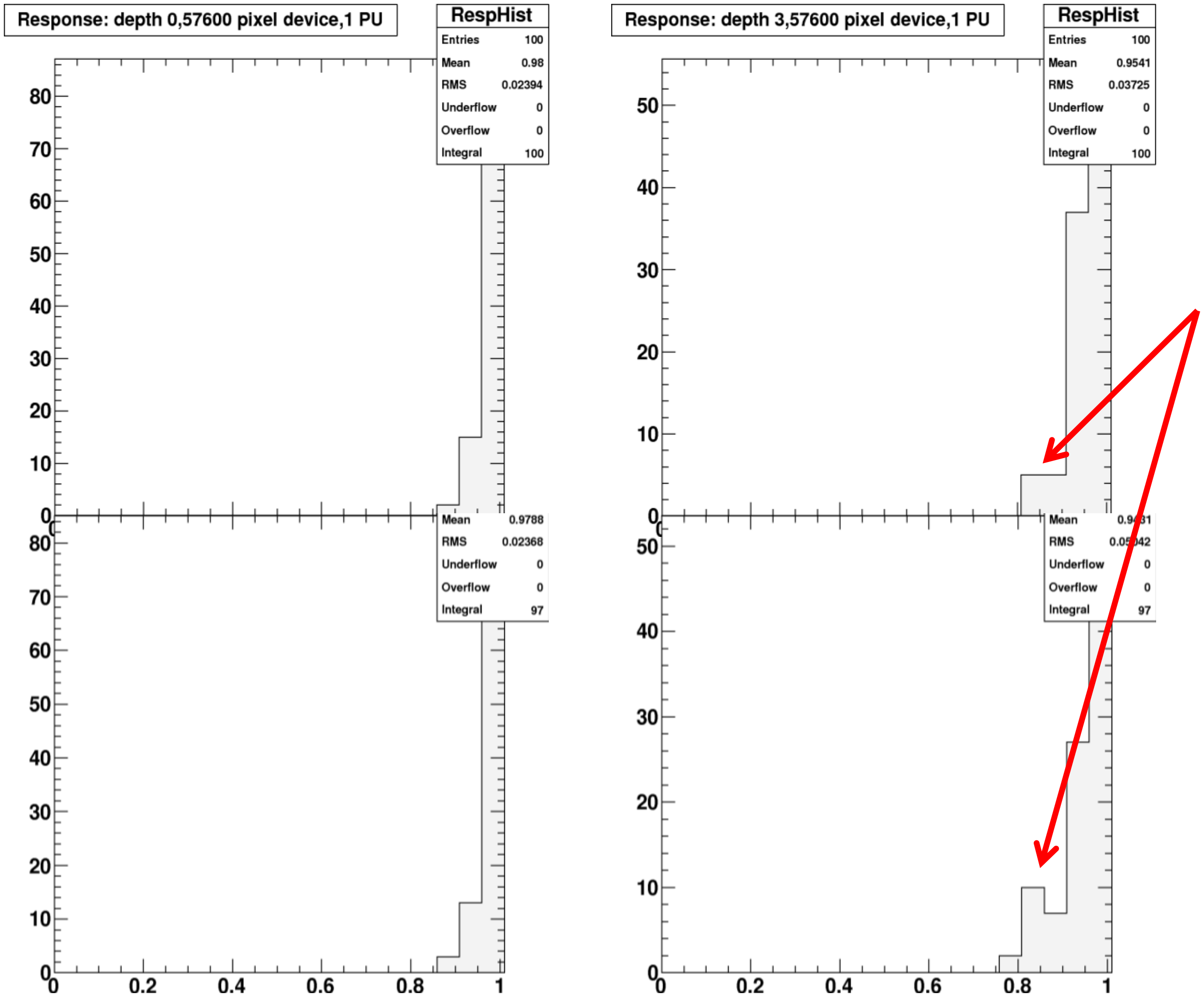
Depth 0	Depth 1	Depth 2	Depth 3
0.98	0.96	0.96	0.95
0.98	0.96	0.97	0.95
0.98	0.96	0.97	0.94

- Here the pixel count is quadrupled so the saturation is reduced.

Hamamatsu 6400 - Response

1 PU

100 PU



Slight Saturation

Summary

- The Zecotek devices have the dynamic range that is needed to meet the requirements of the Hcal.
- The current Zecotek devices are too slow to be used in high specific luminosity conditions.
- The Hamamatsu devices are fast enough to use in high luminosity conditions.
- The Hamamatsu SiPM lack the dynamic range needed for an HB/HE upgrade.

In the future

- Because HO requirements are not as extreme
  - The current generation of Hamamatsu devices with 1600 pixels/mm^2 would be sufficient.
  - The Zecotek devices have the dynamic range, but even in the HO suffer with their history at the highest luminosity.
- With the improvements, either device could be worked into an HCAL upgrade.
  - For Hamamatsu devices, we need to work with them to improve the density to achieve greater dynamic range.
  - For Zecotek devices, we would need to work with them to improve the recovery time of their pixels.