Introduction to FNAL

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Current interests

- Wilson Fellow at Fermilab since 2013.
- I work with two postdocs (Andrew Whitbeck and Nadja Strobbe) on:

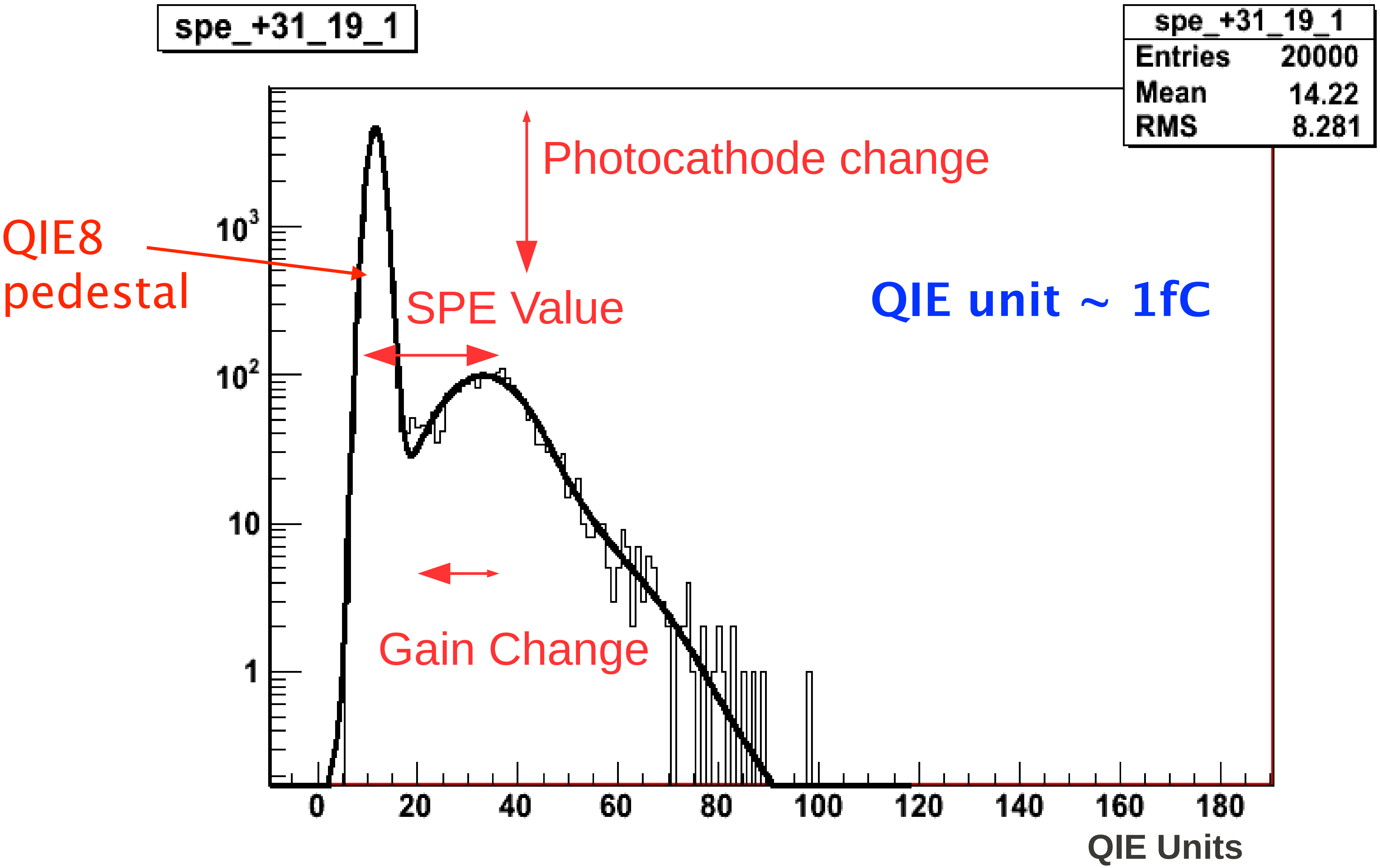
- **CMS run 2 SUSY searches**
  - inclusive/gluino jets+MET
  - stop jets+MET
  - inclusive + rare objects (disappearing tracks, Higgs, etc)
- **CMS hadron calorimeter barrel/endcap (HB/HE) phase** I upgrade:
  - brass+scintillator sampling calorimeter
  - replacing hybrid photodiodes + QIE8 with **silicon photomultipliers (SiPMs) + QIE11**
  - I lead upgrade with contributions to
    - **overall system design** (readout chain, SiPM control/monitoring, calibration system, power/cooling, etc)
    - design, production, characterization of **QIE10/11 charge integrating ASICs**

- **MilliQan**
  - trying to determine how best to fit in …

Gain monitoring in CMS forward calorimeter PMTs in 2011

- In CMS HF, we observed decrease in response to calibration LED over 2011.
- Used low intensity LED data taken in 2011 to determine R7225HA PMT gain via position of single photoelectron (SPE) peak.

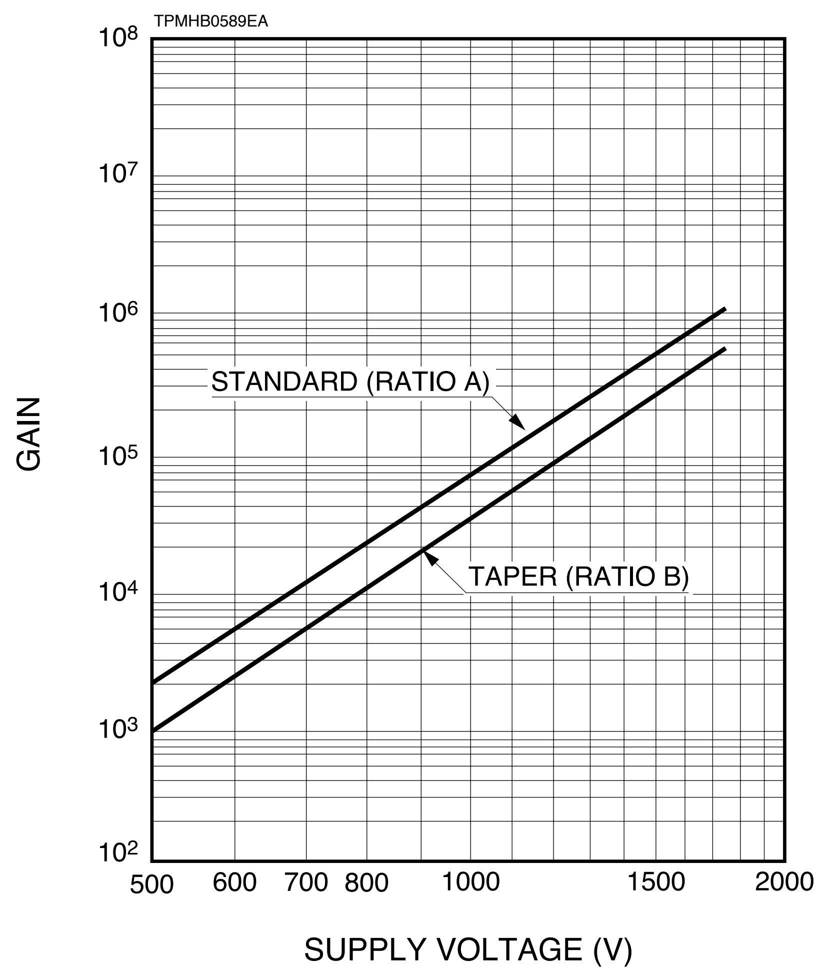
Single PE sample fit



Compare to expectation

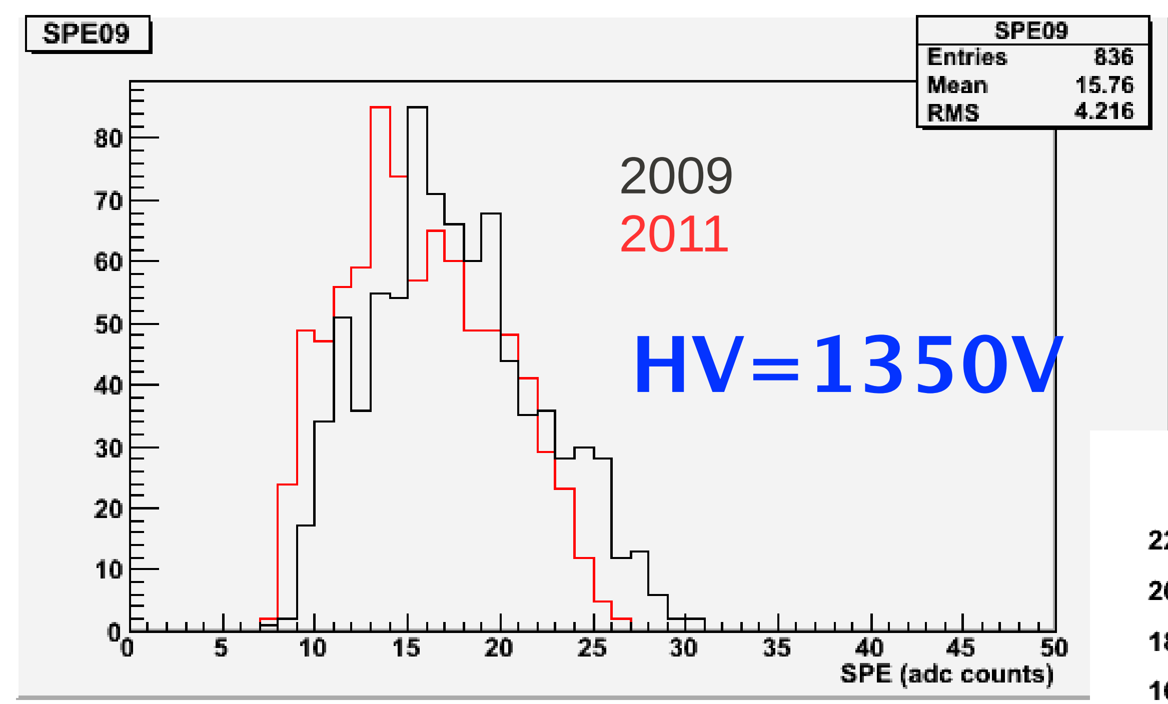
R7525HA datasheet

Figure 2: Typical Gain



gain ~ 150k
at 1350V
no aging

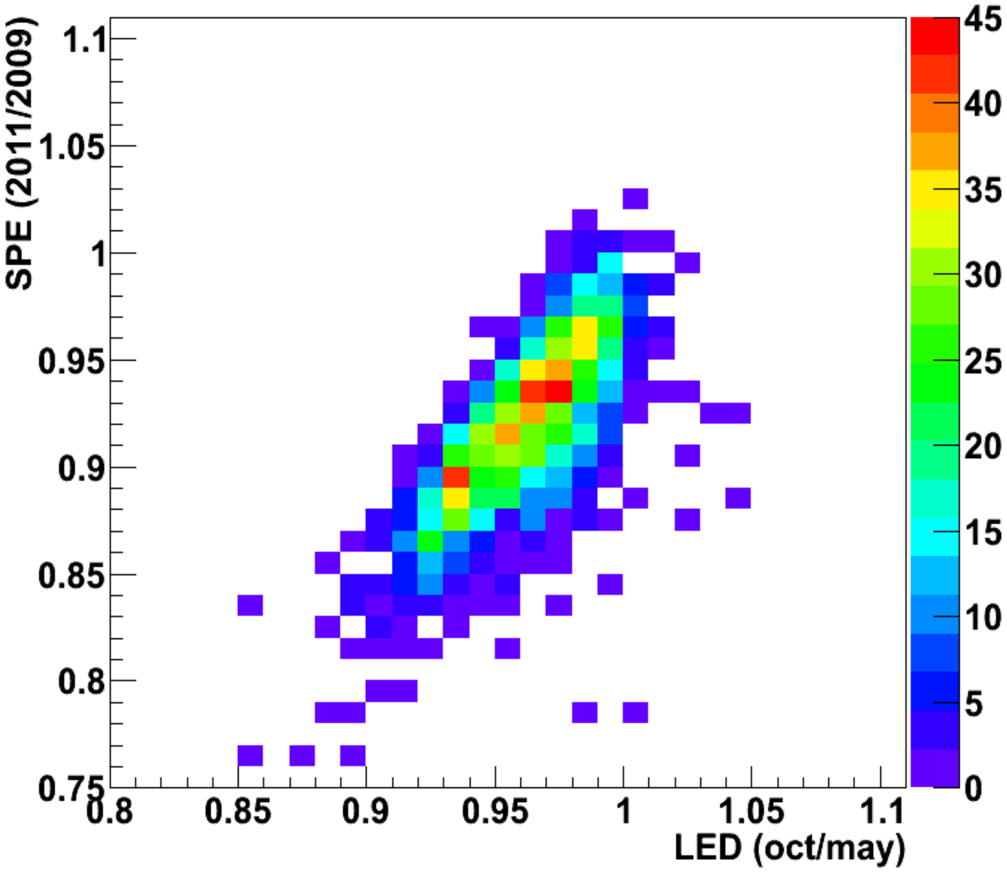
CMS SPE measurements



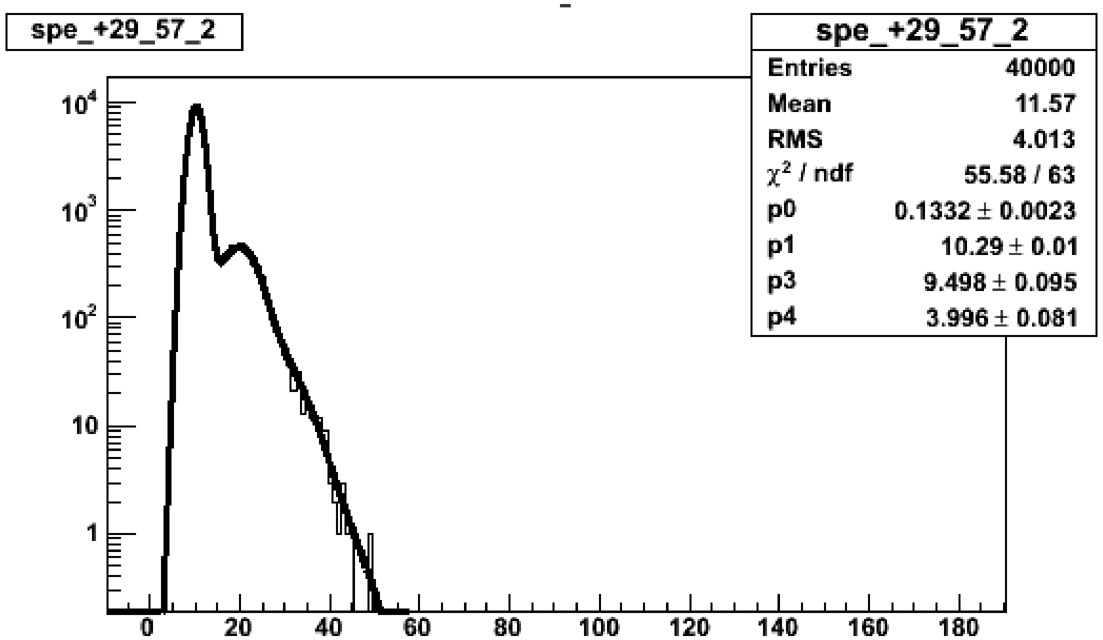
SPE~16 fC
gain~100k
aging since ~2005

Cross checks

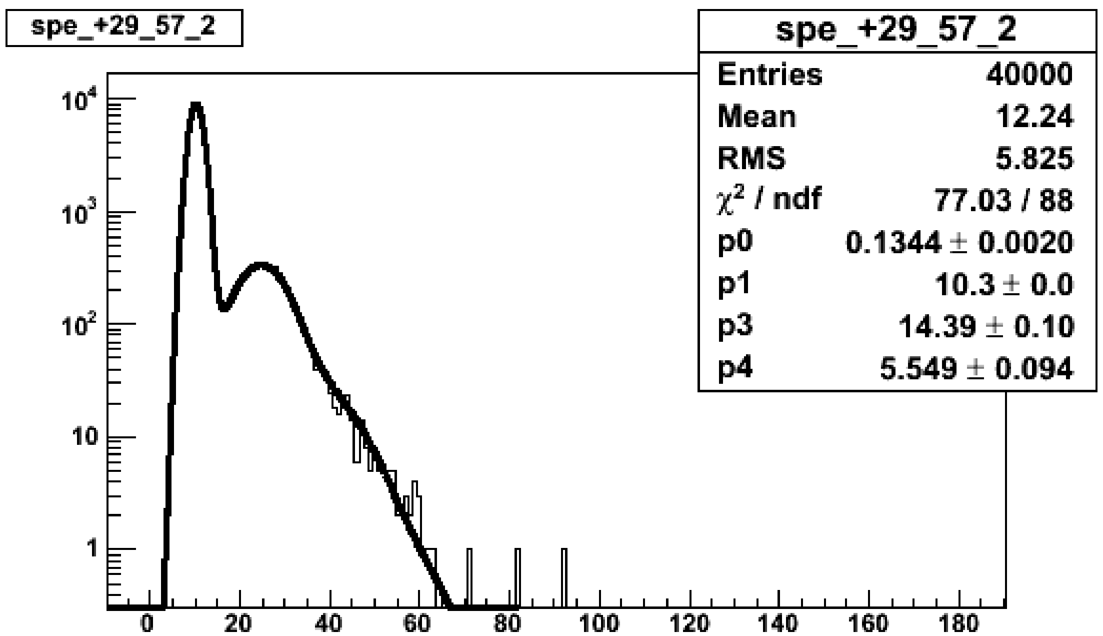
- SPE position **depends on HV**
- SPE gain change b/w 2009 and 2011 **correlates with LED response change over 2011**.



- 1250 V



- 1350 V



Thoughts on applicability of CMS phase I HCAL readout for MilliQan

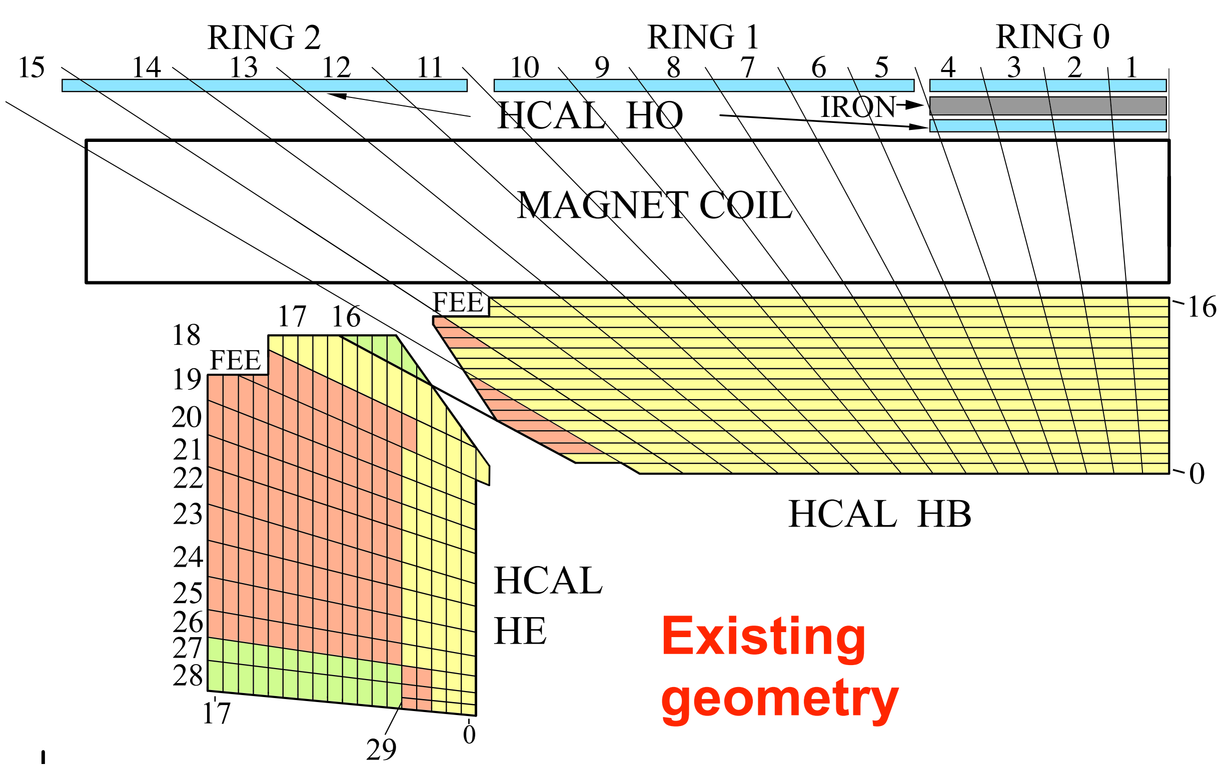
- Not attempting to convince anyone that SiPM or QIE readout is preferred — I'm not convinced, myself!
- At least potentially useful for answering review questions on alternatives

HCAL barrel/endcap: SiPM+QIE

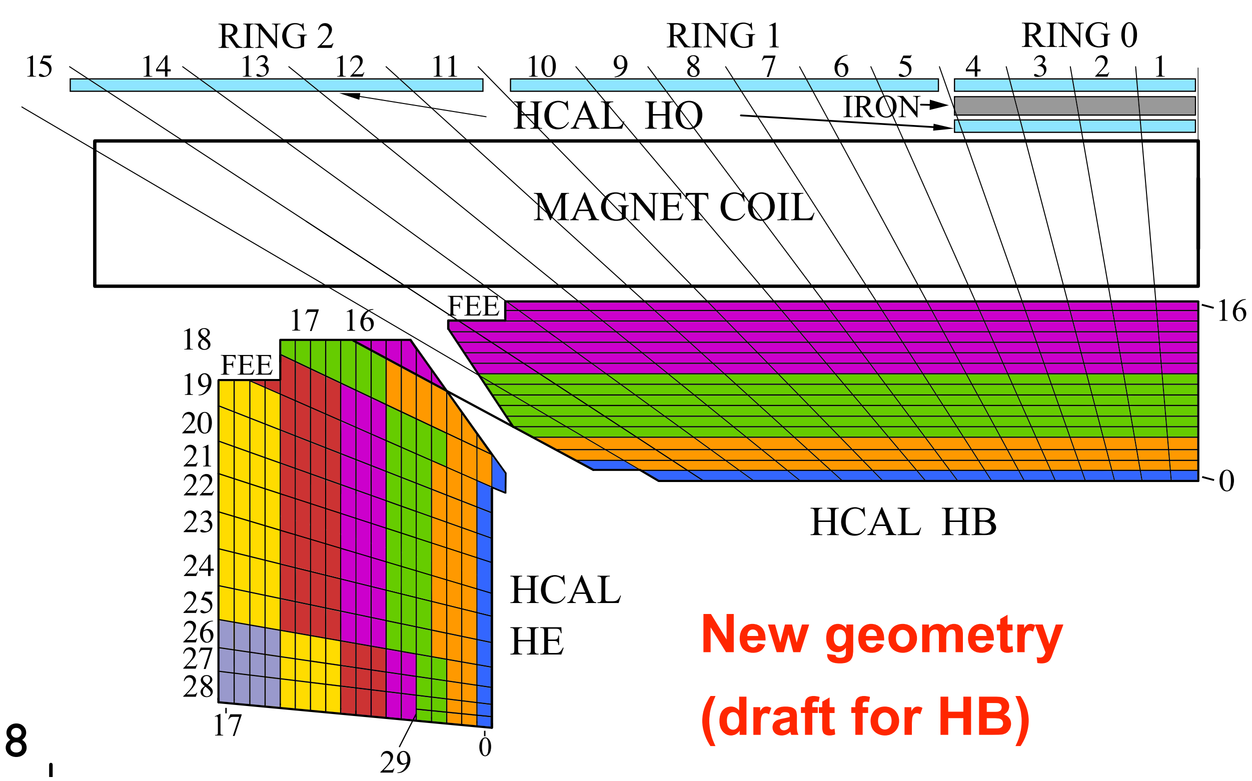
- SiPMs allow mitigation of **radiation damage** to HCAL scintillator
  - **High photo-detection efficiency (PDE) and gain** of SiPM for low light levels.
  - Small size allows more channels ➔ **longitudinal segmentation** for calibration of depth-dependent effects.

- Readout with QIE11 on QIE card.

	PDE	gain	V_{op}	B-field performance	size
HPD	12%	2k	8 kV	good	(18 channels)/5°
SiPM	35%	350k	70 V	excellent	(64 channels)/5°



Existing geometry

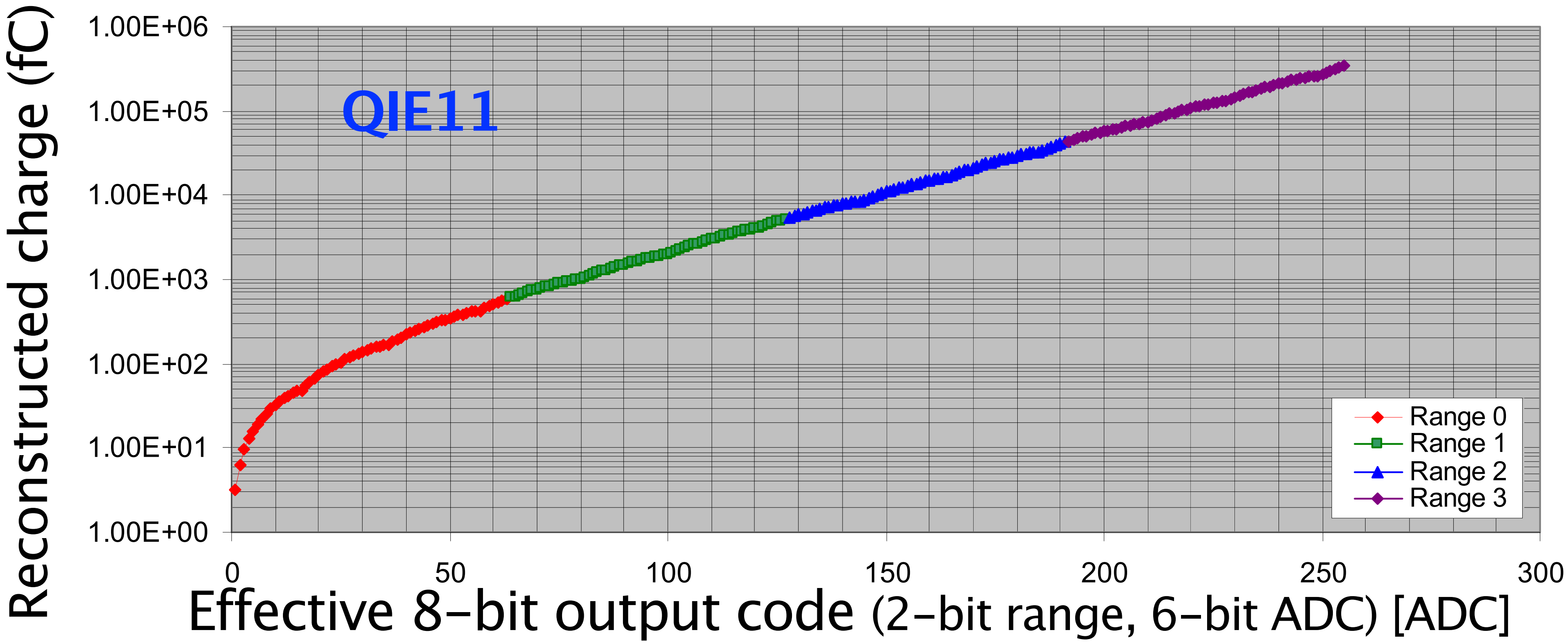


New geometry (draft for HB)

QIE10/11 overview

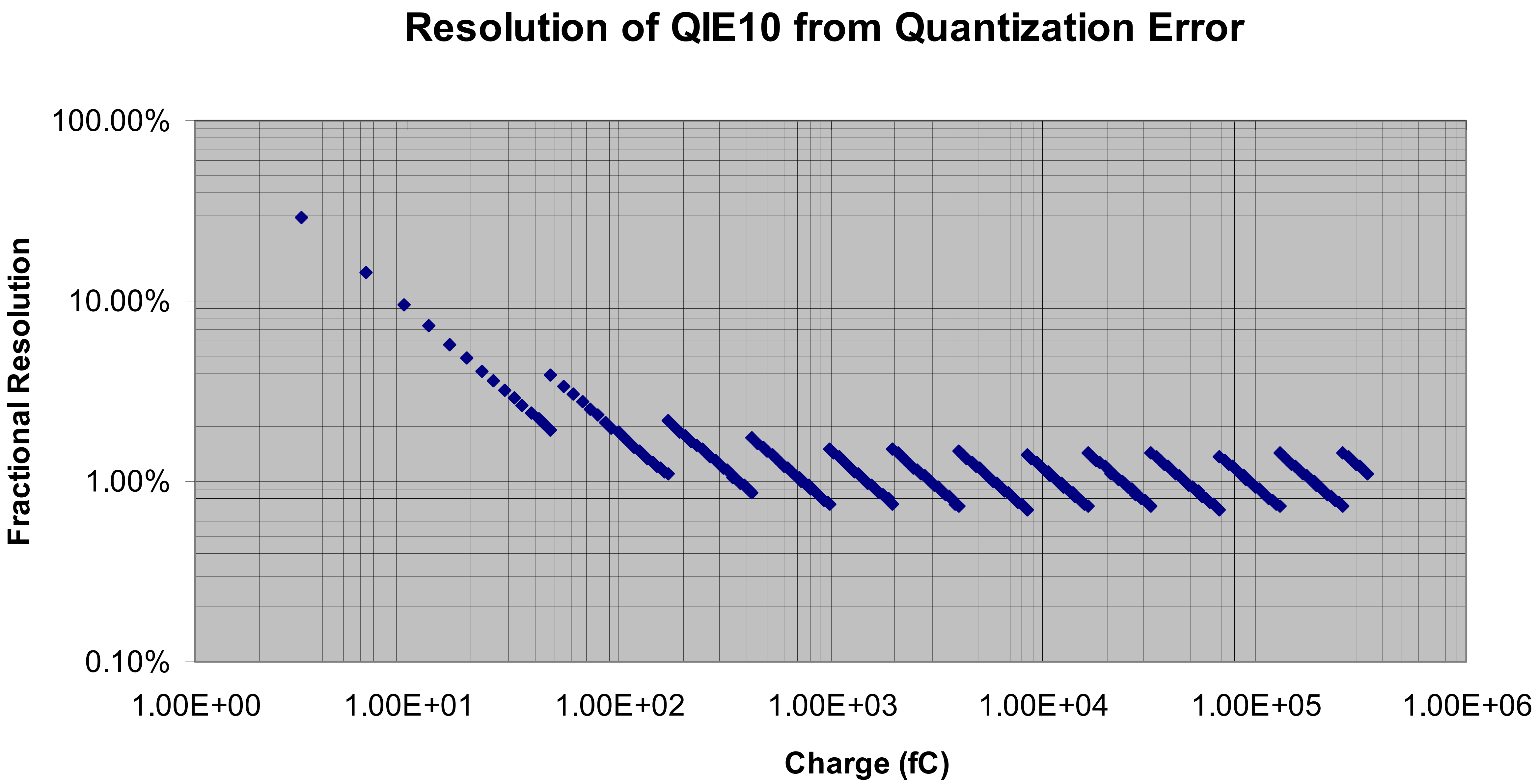
- **Deadtimeless** gated charge integration at **40 MHz** (25ns integration period)
- 8-bit pseudo-logarithmic ADC with **3fC LSB and 17-bit dynamic range**.
  - 4-range, logarithmically weighted current splitter
  - piecewise-linear, exponential 6-bit ADC
- **6-bit TDC** with 500 ps binning
- QIE10 appropriate for PMT use, QIE11 for SiPM use.

Compare 3fC LSB and ~1.5fC noise to ~1pC expected SPE charge.



QIE10/11 precision

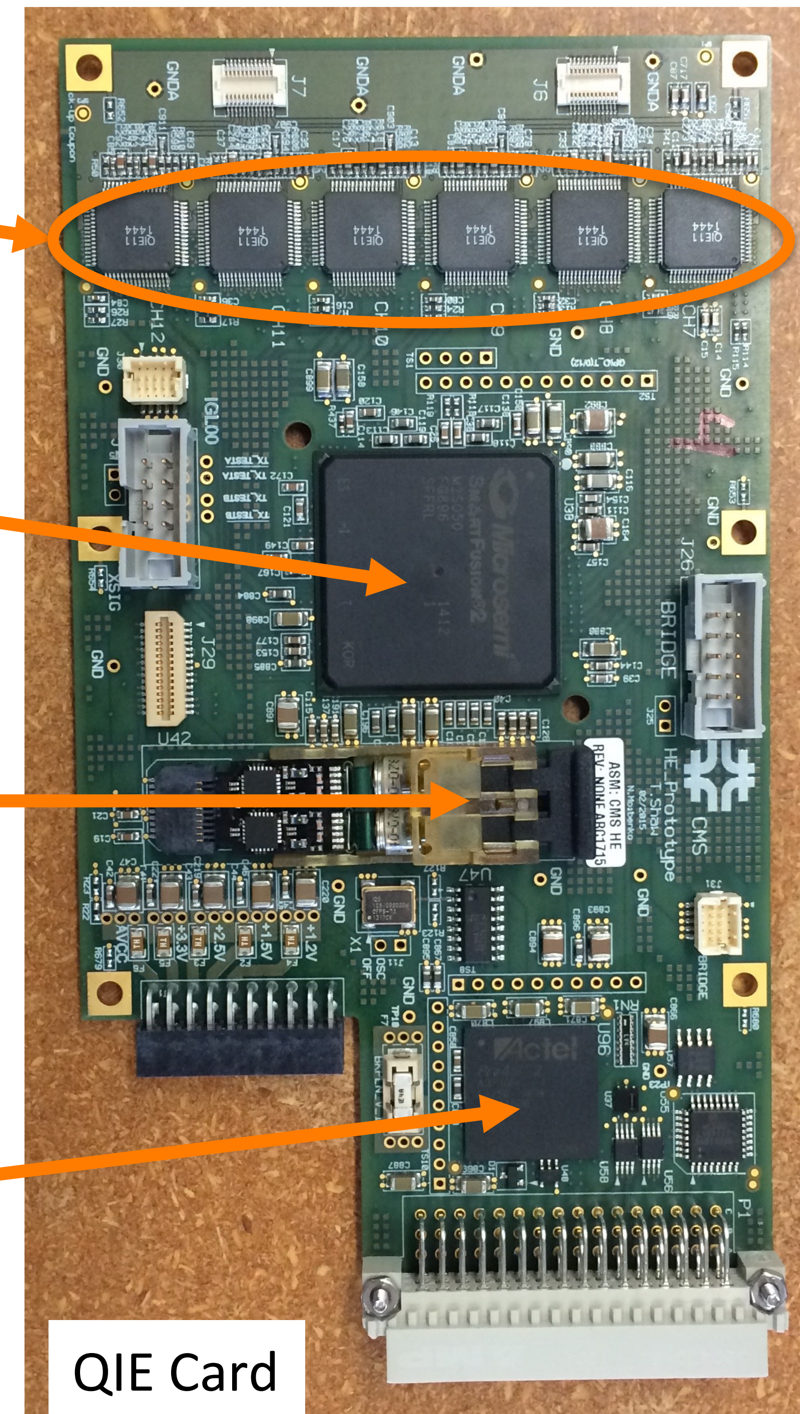
- **Better than 2% digitization precision** at high charge.
- QIE10/11 have same response.



QIE11 readout concept

- 16-channel board is ~$1000.
- In HCAL design, SiPMs sit close to QIE electronics, which complicates for MilliQan

- 12 QIE11 ASICs (6 on each side)
- Igloo2 FPGA serializes and formats the data and sends it to the Versatile Twin-Transmitter module (VTTx)
- VTTx transmits optical data to backend electronics
- ProASIC3 FPGA provides access for fast and slow controls from readout box (RBX) backplane



QIE Card

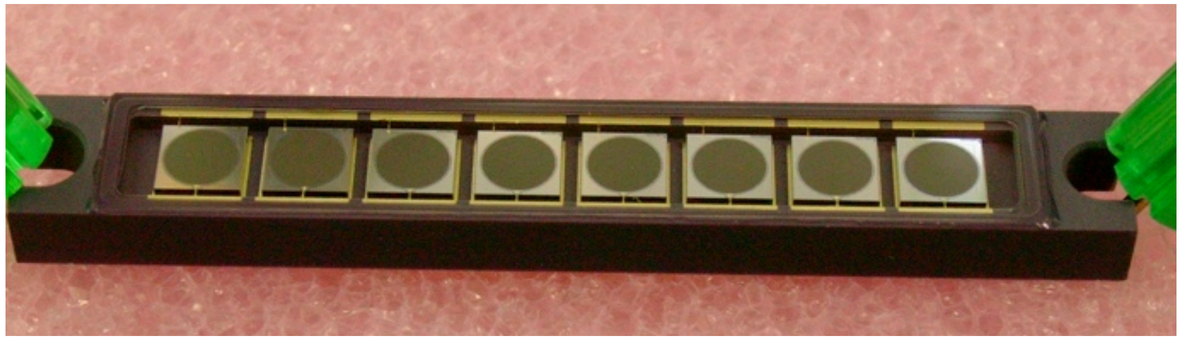
SiPMs

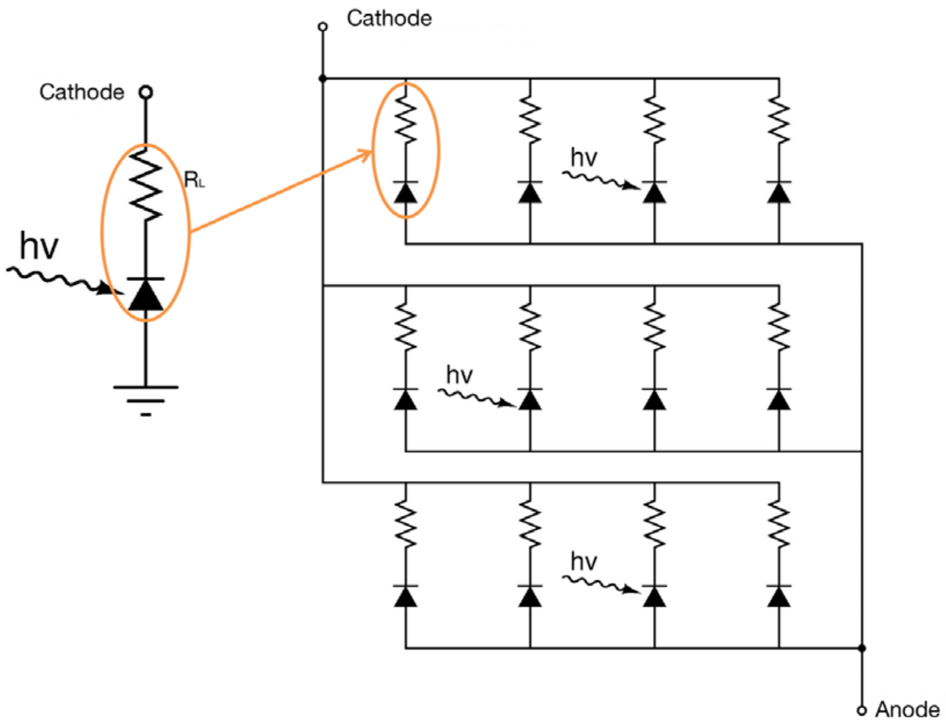
- array of avalanche photodiodes operating in geiger mode (15 um pixels)
  - each pixel is binary, but array of 30k has proportional response

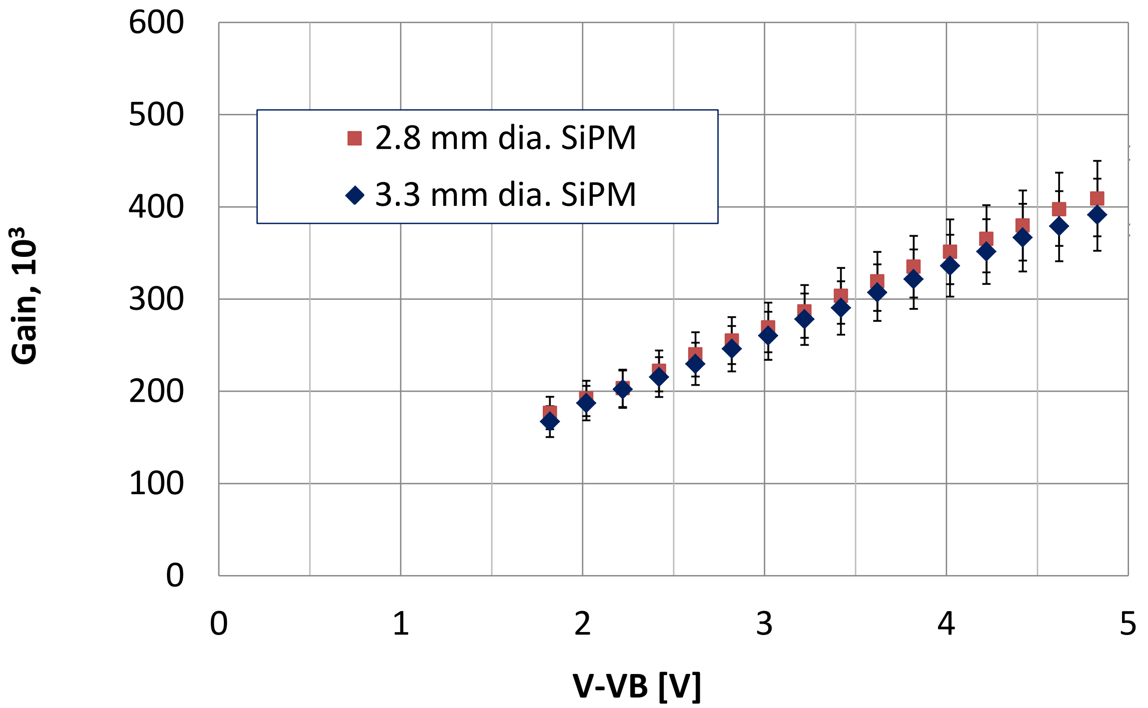
- ~5k pixels / mm^2 for 15 um APDs

- Fast response and recharge time (~5ns) increases effective pixel count by factor ~3.

- gain = C_{GAPD} x (V_{op}–V_{bd})
  = ~100 fF (~1V) = 10^6

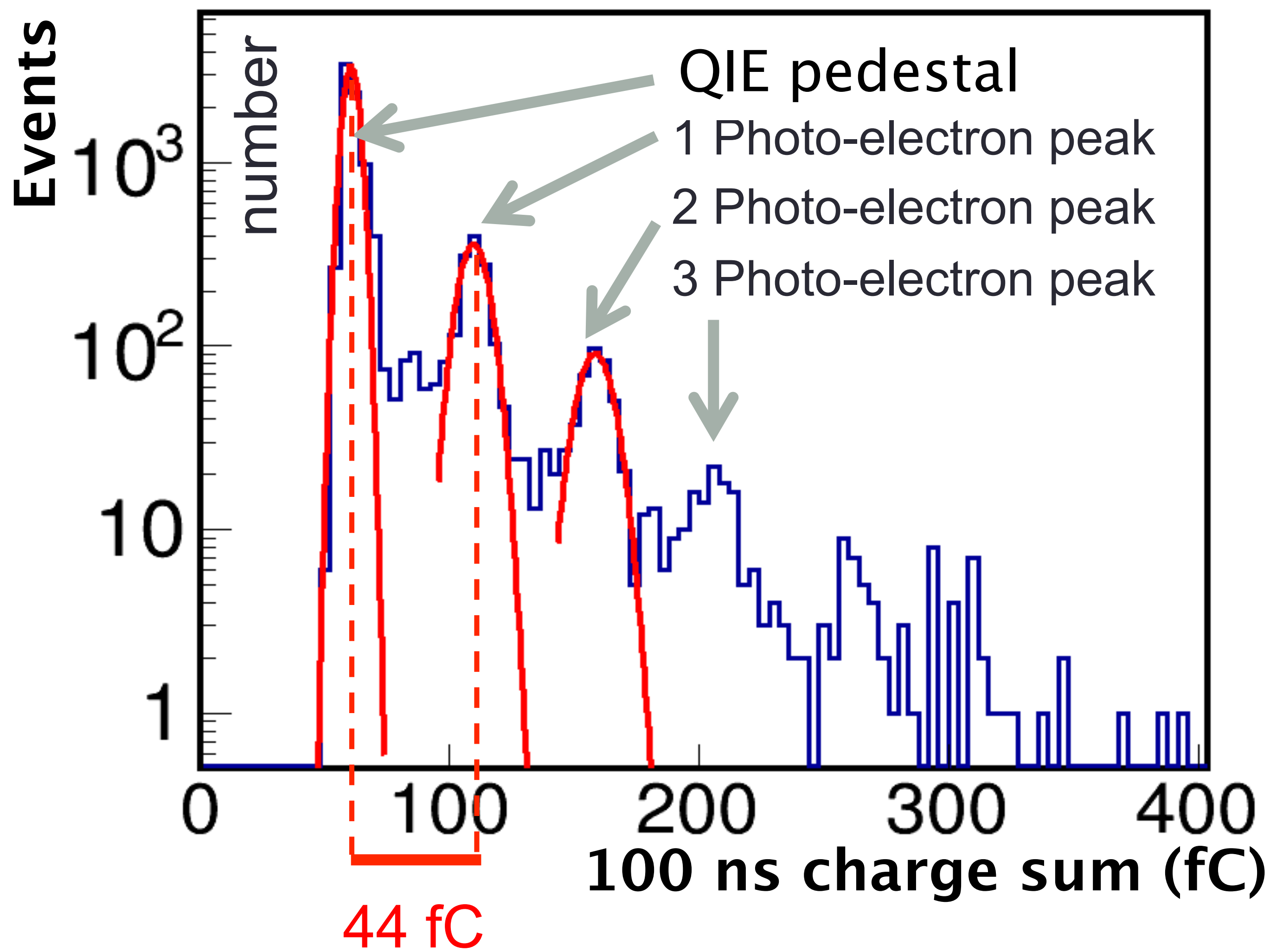




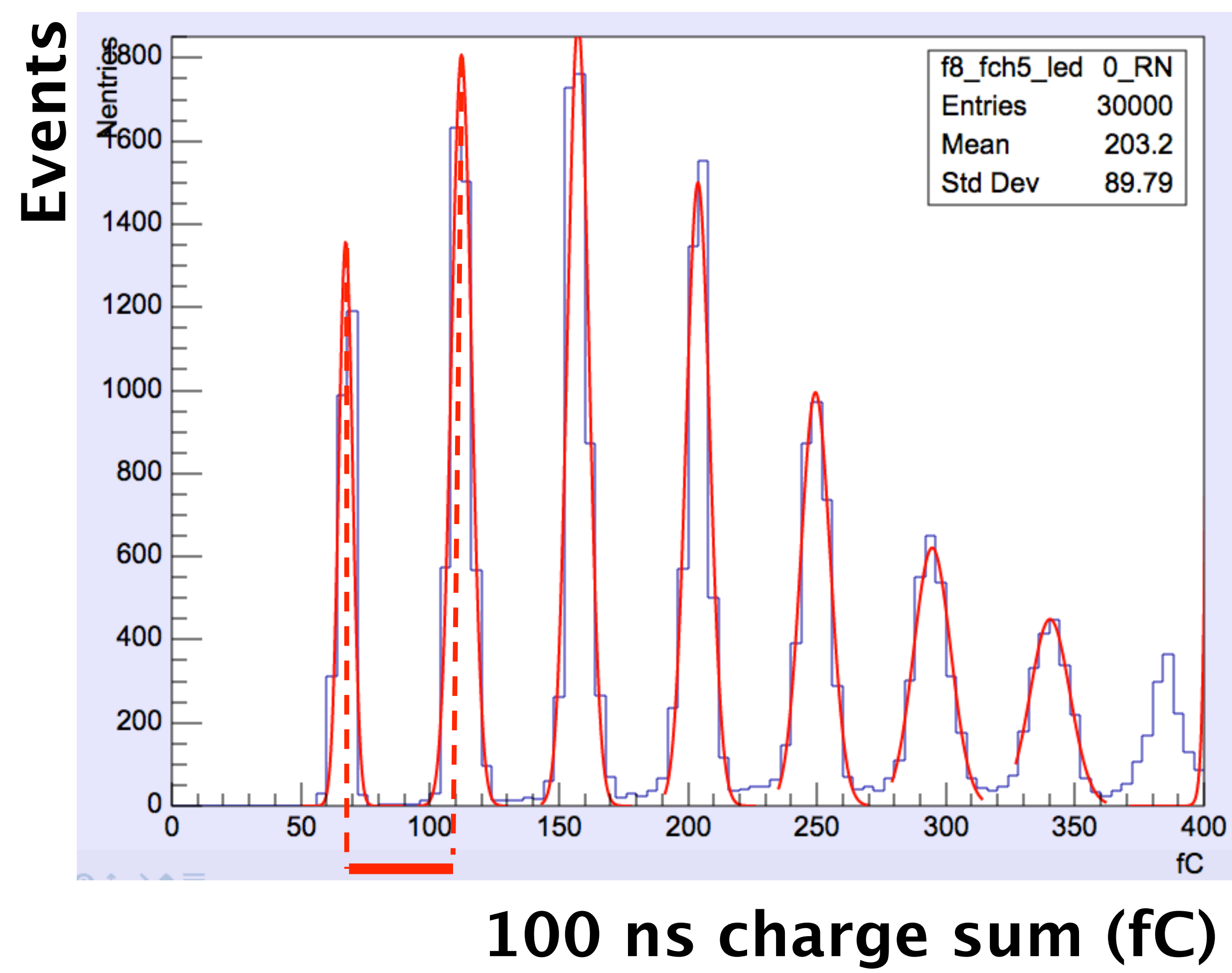


Photon counting with SiPM+QIE

Dark noise : random trigger



Low intensity LED

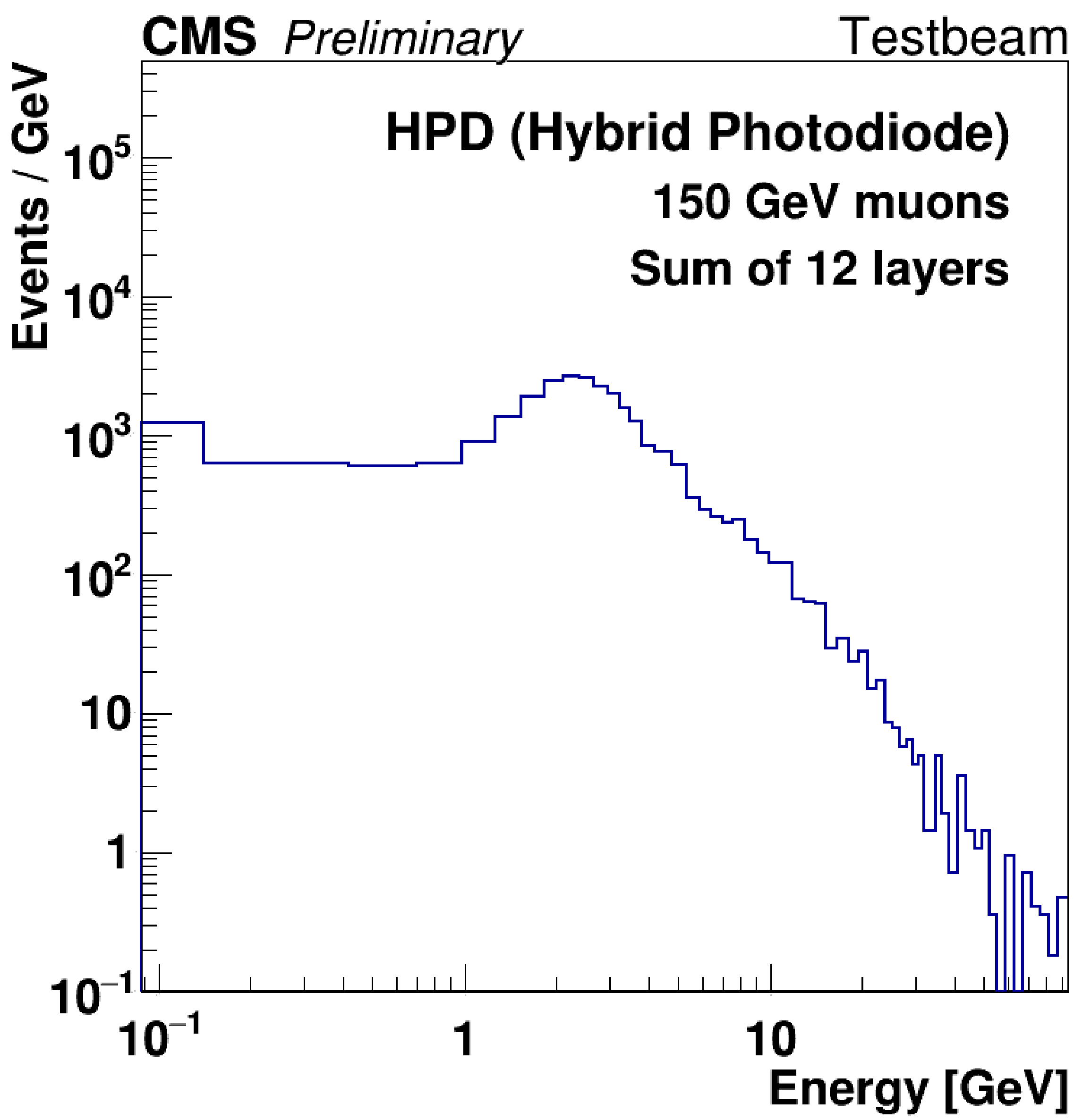


- ~275k gain gives 44 fC/PE
- QIE noise is ~3 fC per 25ns as seen in width of pedestal

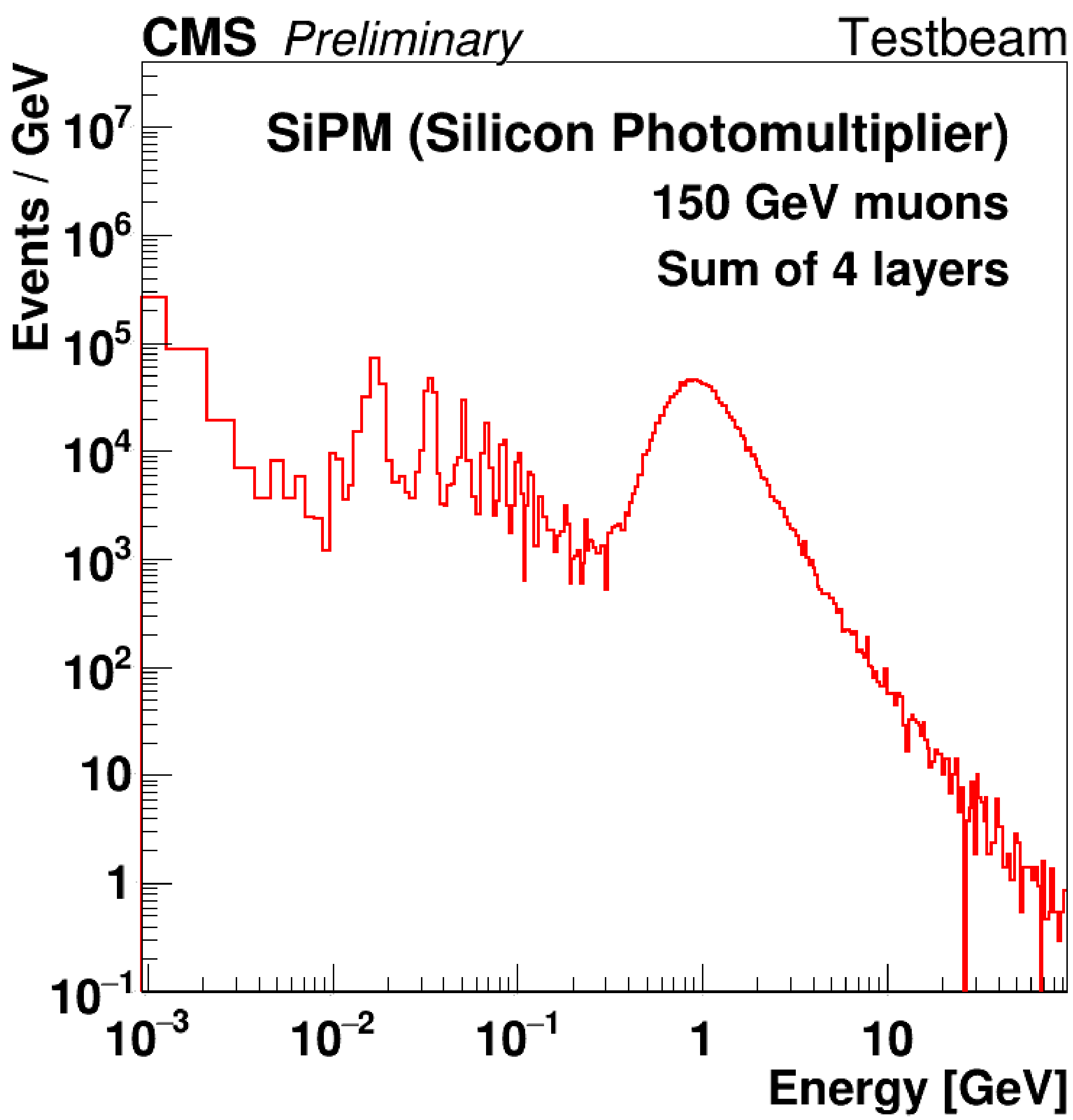
- Triggering on LED sharpens peaks because full charge is captured in time window.

SiPM+QIE11 in HCAL beam test

HPDs (sum of 12 layers)



SiPM (sum of 4 layers)



SiPMs a factor 10^3 better signal/pedestal separation vs. HPDs!!!

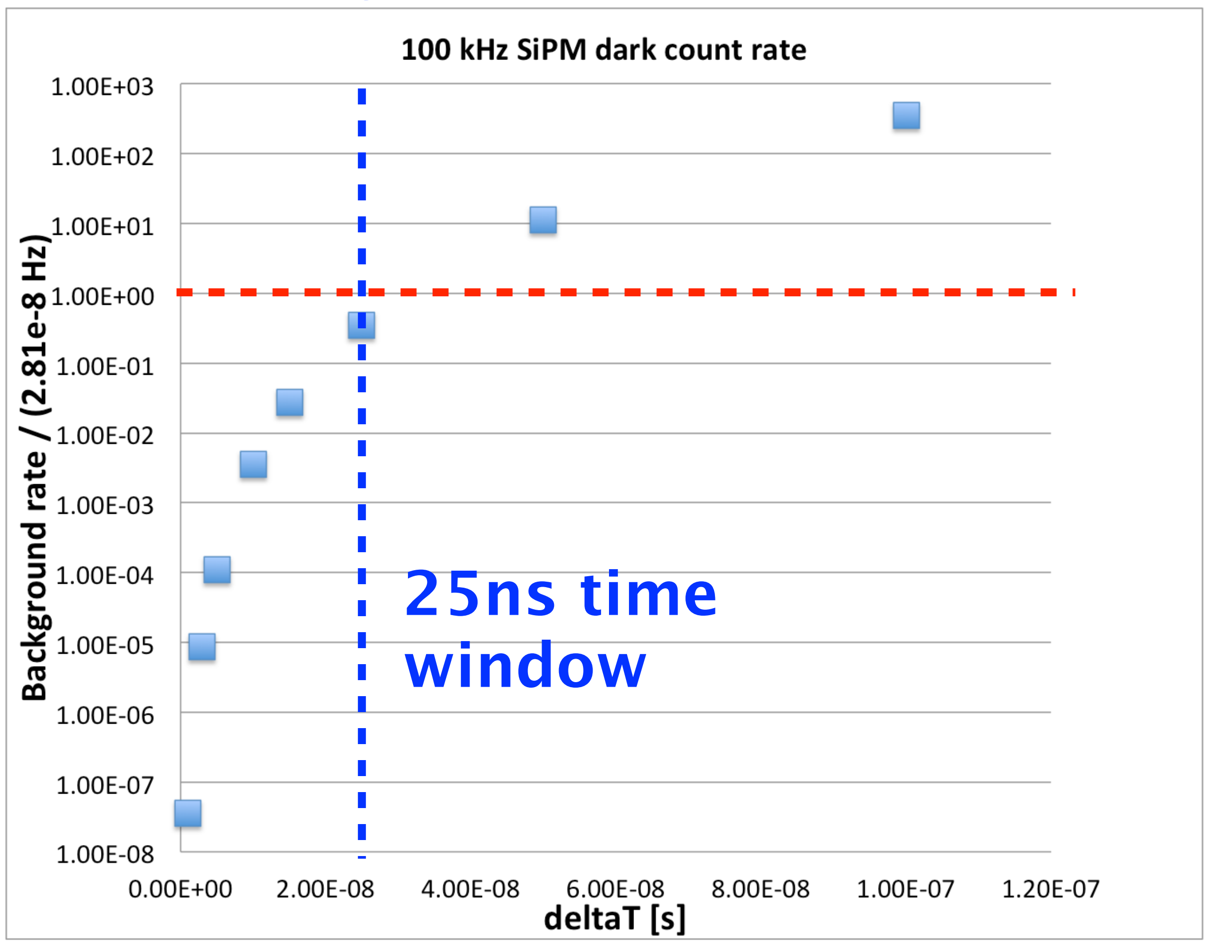
Potential SiPM use in milliQan

- **Small size** : critical for milliQan
- **Excellent photon counting performance** : critical for milliQan
- **Reasonable cost** : need to consider for ~6m^2 milliQan area (assuming double sided readout)
- high gain : 1e6,high photon detection efficiency (PDE) : 35%
- No magnetic field sensitivity : NOT important for milliQan
- **high dark count rate** : >100 kHz (kill with coincidence)
- **What about high dark rate?**

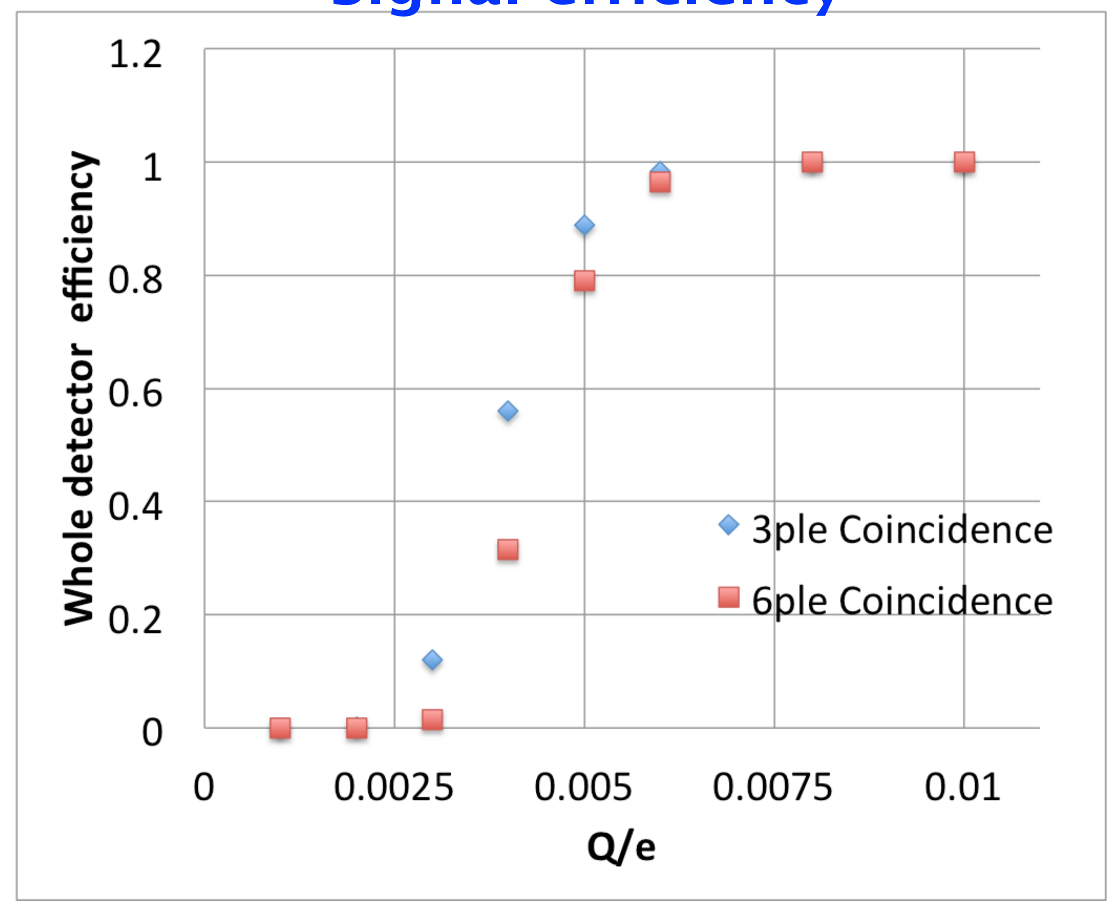
SiPM dark rate and coincidence

- Require 6tple coincidence : naively requires 2x readout electronics.
- Electrically sum SiPMs on both sides of scinitillator? Cross talk complicates this.

Background rate



Signal efficiency



- Whole detector eff = $P^{N\text{-coincidence}}$

$$P = (1 - \exp[-N_{PE}])^3,$$

$$N_{PE} = \left(\frac{Q}{\xi}\right)^2 \qquad \xi \approx 0.0024.$$

- Assumes 10% PDE
- Efficiency drops off fast below 2ξ for any number of coincidences.

- 2.8e−8 Hz is rate from LOI for 500 Hz rate, triple coincidence, and 15ns time window
- 6ple coincidence 100 kHz dark with 25ns window < 2.8e−8 Hz

Additional material