Scint-SiPM Muon/Tail-catcher R&D

Feb 17, 2009

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Distributions from Composite Run 6446 at (+38, -38)

11450 Total Events

S+ mean 439.2

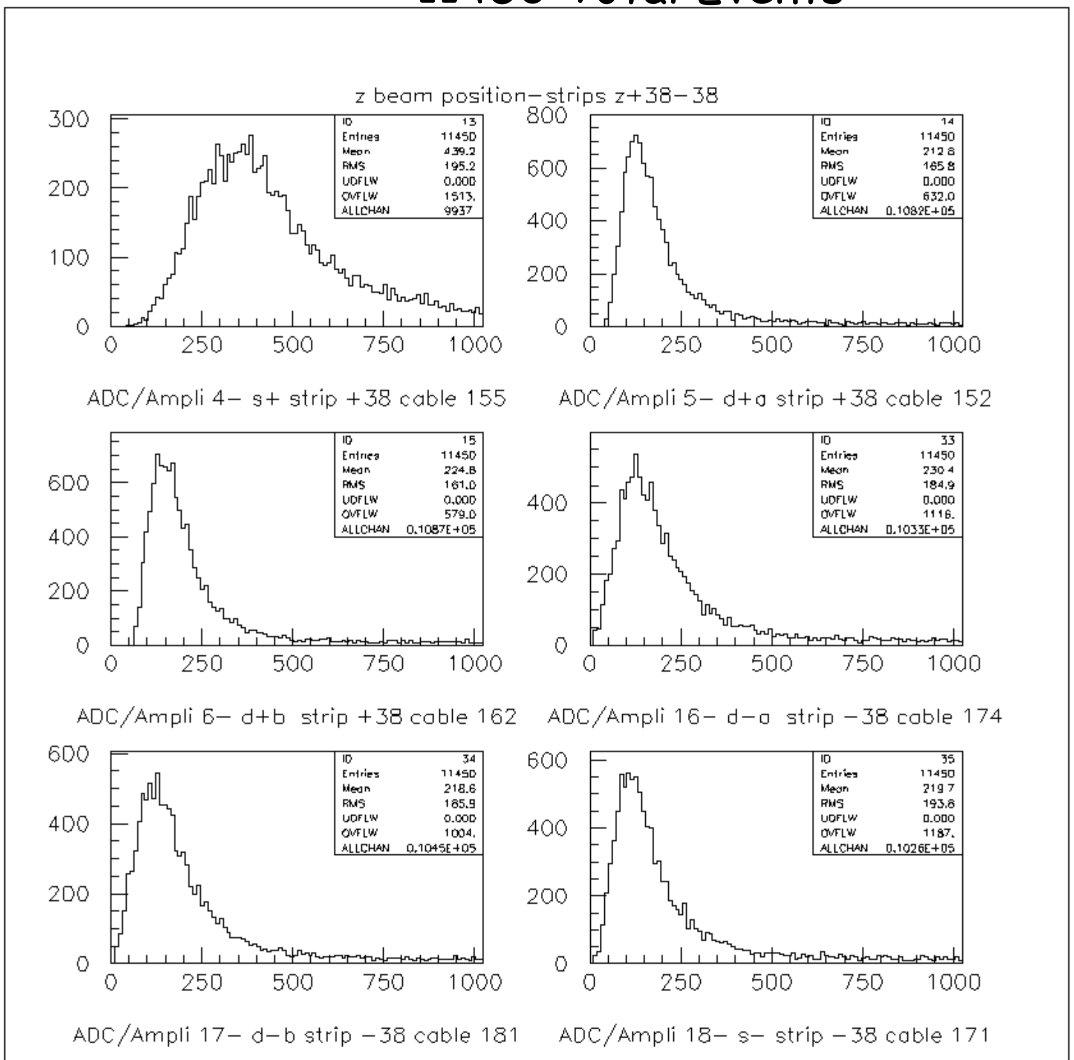
D+a mean 212.8

D+b mean 224.8

D-a mean 230.4

D-b mean 185.9

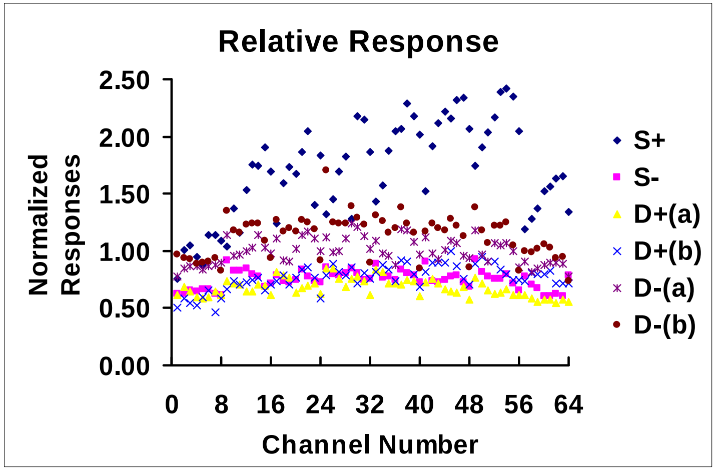
S- mean 219.7



What R&D have we done?

Hamamatsu H7546B

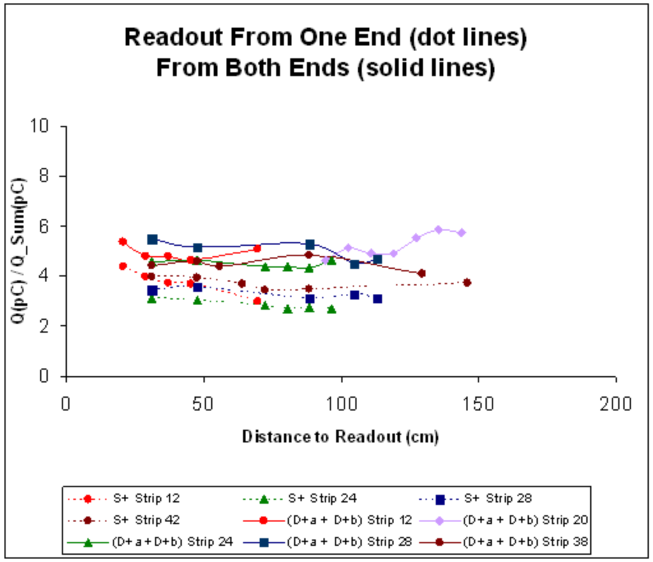
64 channel MAPMTs calibrated using a 5mCi Sr^{90} in contact w/plastic scintillator and WLS fiber to ea ch MAPMT pixel.



Measured both single ended (S) and dual (D) readout.

3 pC for (S), 5 pC for (D)
~50% more light with (D)

Nominal gain ~ $2X10^6$ @ 960 V



What R&D are we doing?

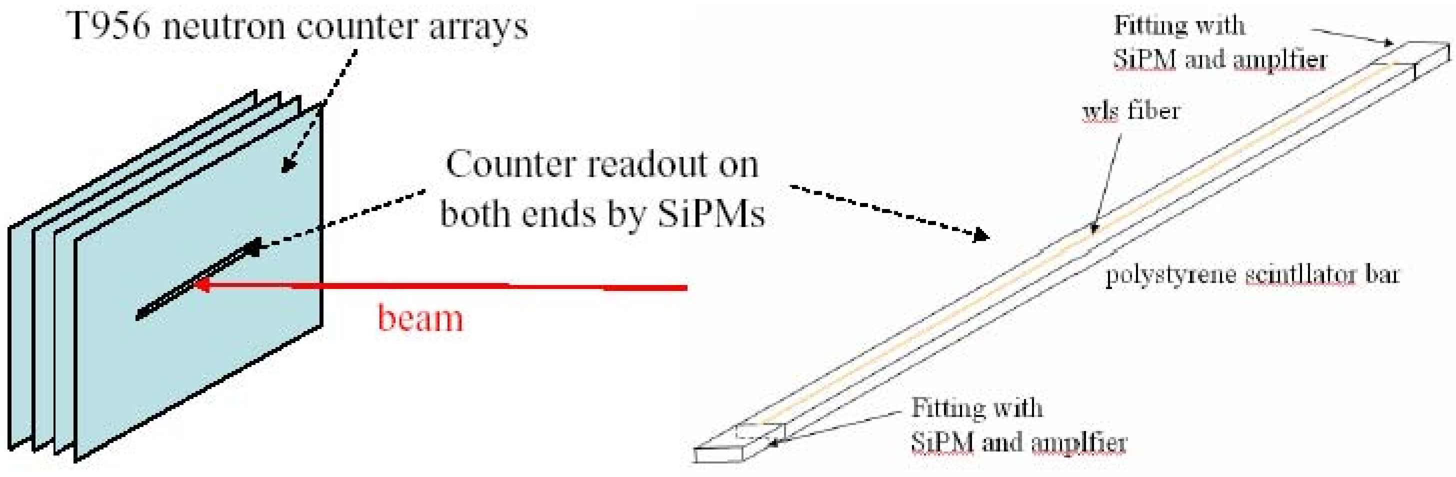
From slide (2) we see there are no zeros in any of the histograms.

With 11,500 events and no zeros we conclude P(0) = exp{-a} is less than 1/11,450 = 8.3 E-05 => a = -ln(8.3 E-05) = 9.3

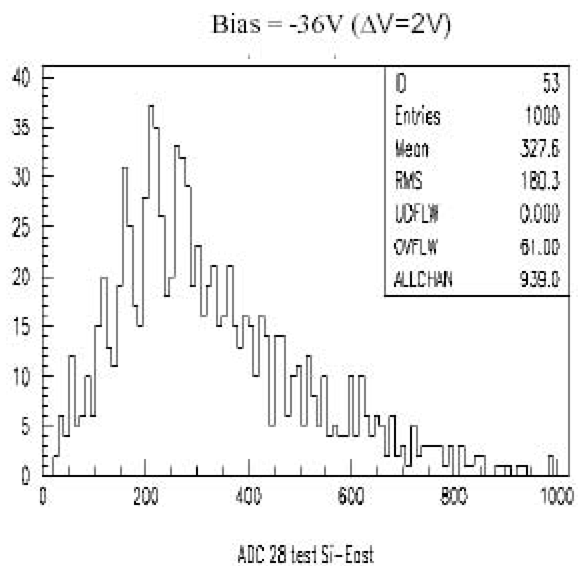
No. of photo-electrons is > 9.3 (**Sept 2006**)

Enter SiPMs from IRST (INFN Trento) via
Giovanni Pauletta INFN Udine first Mtest SiPM data
Seminar by Claudio Piemonte from IRST Oct 2006
(other devices tested by Adam Para before this)

Preliminary study   Scint. Strip viewed by IRST SiPM



w/X10
Amp



Data with 120 Gev p - beam

$$N_{p.e.} \approx 6.5\, p.e.$$

$$\varepsilon = 99\%$$

$$N_{d.c.} \approx 1.5 MHz$$

$$G \approx 1.6 \times 10^{6}$$

Giovanni Pauletta INFN Udine

Geiger-mode APD

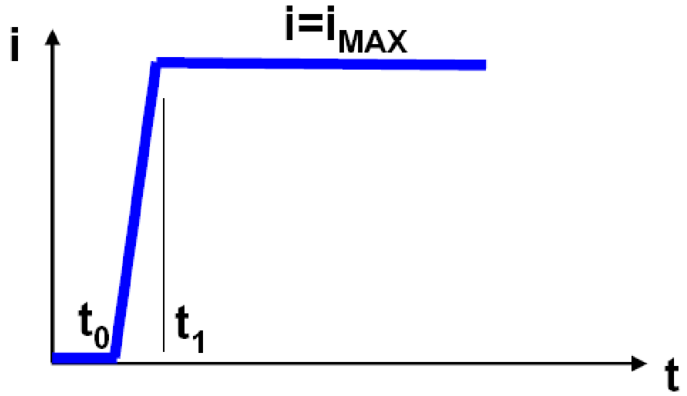
Diode biased at $V_D > V_{BD}$

$t < t_0$ ....**i=0** (if no free carriers in the depletion region)

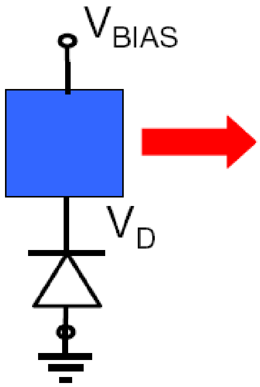
$t = t_0$ ....**carrier initiates the avalanche**

$t_0 < t < t_1$....**avalanche spreading**

$t > t_1$ ....**self-sustaining current** (limited by series resistances)

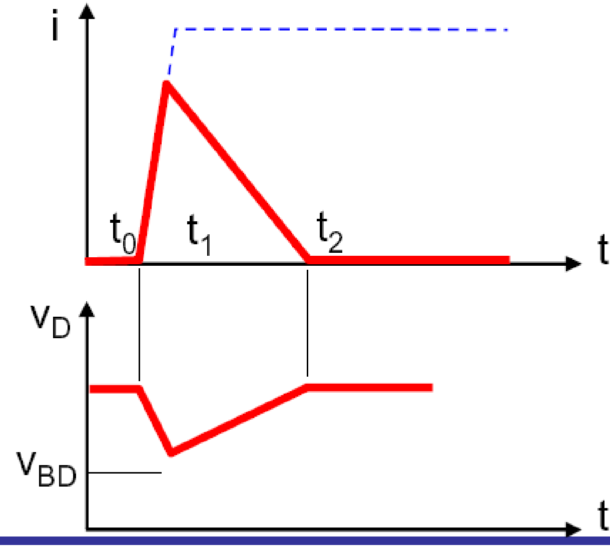


To detect another photon a quenching mechanism is needed!



Two solutions:

- **large resistance:** **passive quenching**
- **analog circuit:** **active quenching**

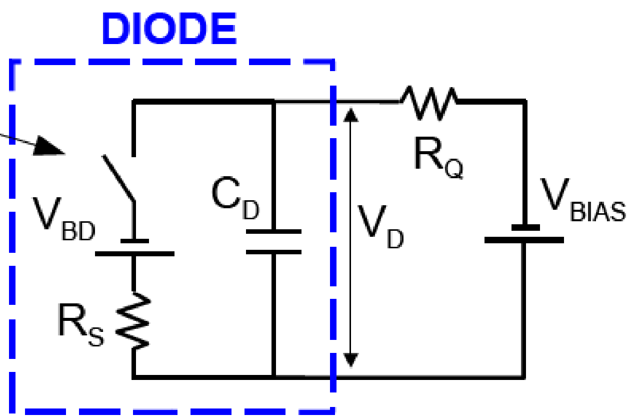


Operation principle of a GM-APD

Passive quenching studied in detail in the '60 to model micro-plasma instabilities McIntrye JAP 32 (1961), Haitz JAP 35 (1964)

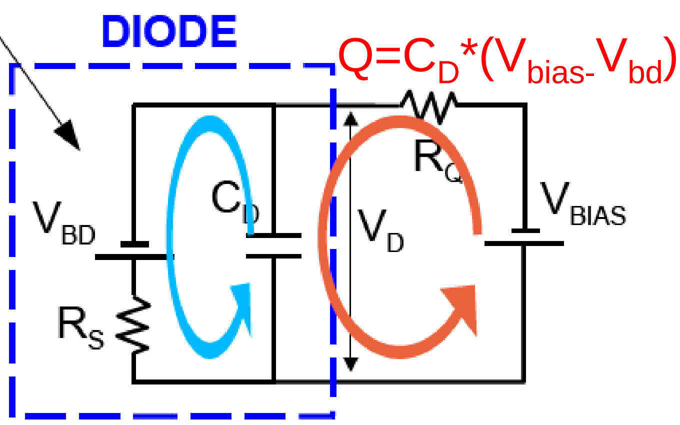
The Geiger-Mode APD can be modeled with an electrical circuit and two probabilities:

- Switch OFF = micro-plasma non-conducting
- Switch ON = micro-plasma conducting



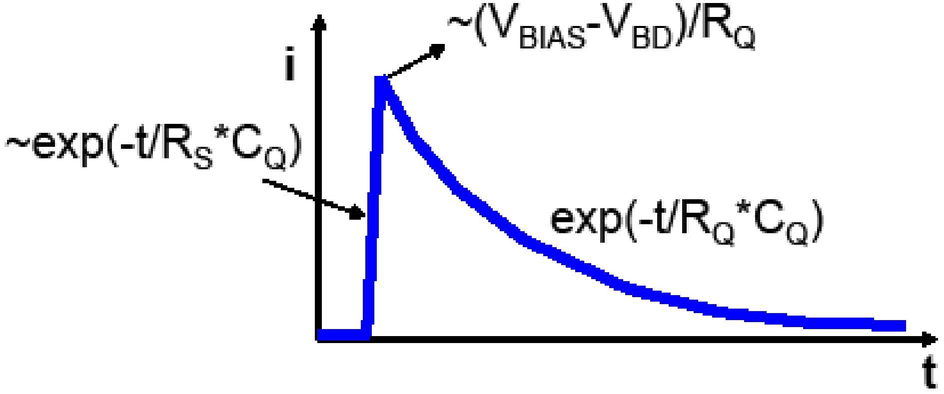
- C_d diode capacitance (some 10fF)
- R_s series resistance (~1KΩ)
- R_q quenching resistance (> 300KΩ)
- $V_{bd} < V_{bias}$ (few % relative)

- P_{01} turn-ON
  Probaility that a carrier traversing the high field region trigger an avalanche
- P_{10} turn-OFF
  Probaility that number of carriers in the high field region fluctuates to 0



Internal/external currents

GAIN in GM-APD



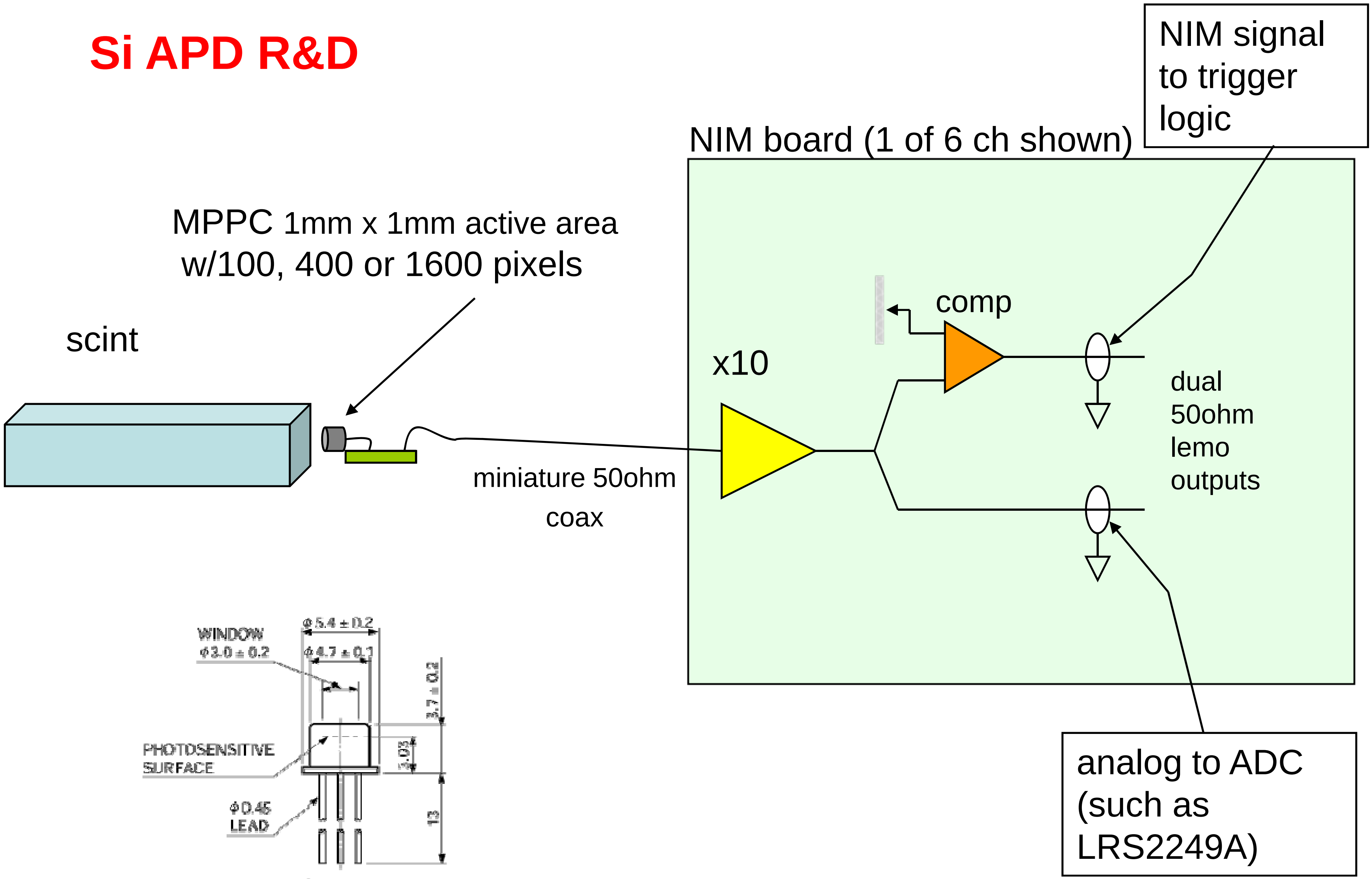
The first part of the signal is much faster than trailing edge

- charge collected per event is the area of the exponential decay which is determined by circuital elements and bias.
- **It is possible to define a GAIN**

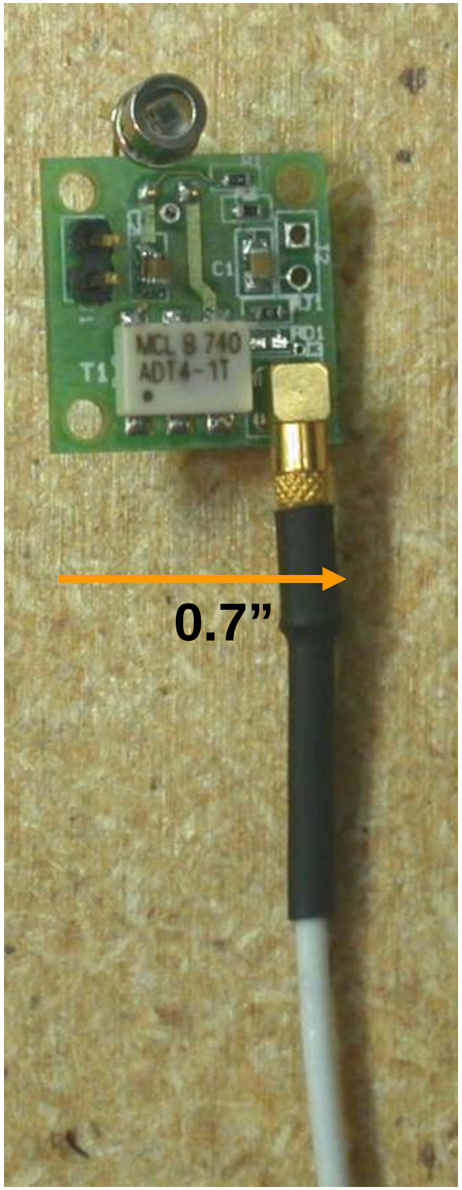
$$\text{Gain} = \frac{I_{MAX}*\tau_Q}{q} = \frac{(V_{BIAS}-V_{BD})}{R_Q}\frac{*\tau_Q}{q} = \frac{(V_{BIAS}-V_{BD})*C_D}{q}$$

This property is exploited in a Silicon photomultiplier….

Si APD R&D



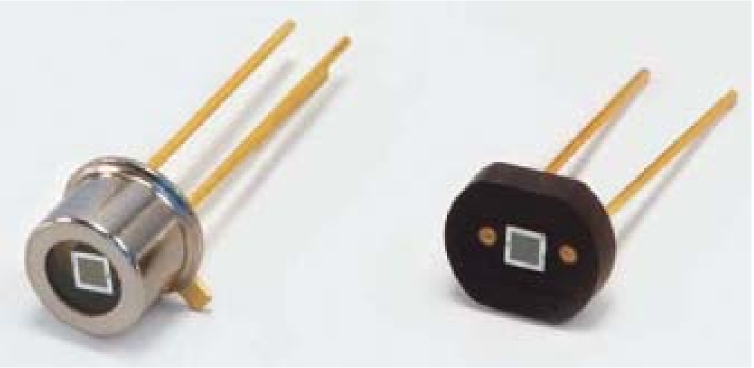
HPK MPPC

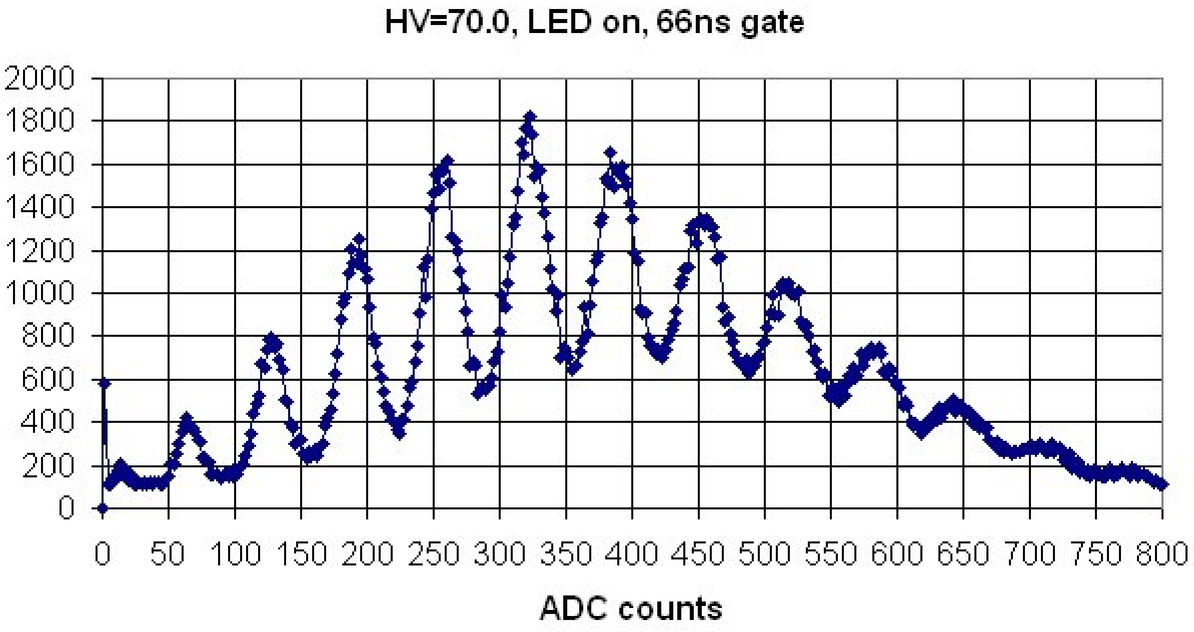


Hamamatsu MPPC
100 pixels 100μ X 100μ

Paul Rubinov

5mv/pe at nominal
bias voltage for
a 100 pixel device

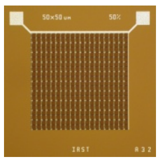
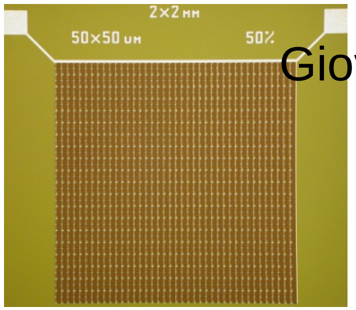


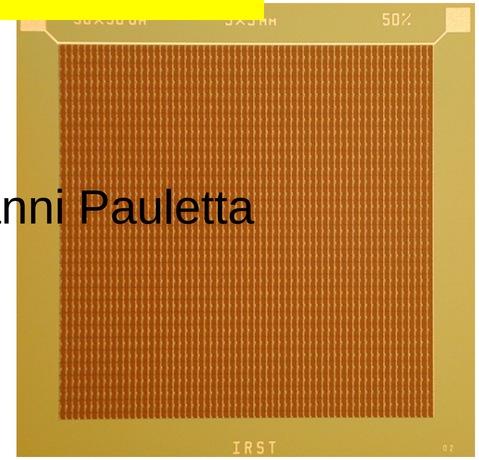


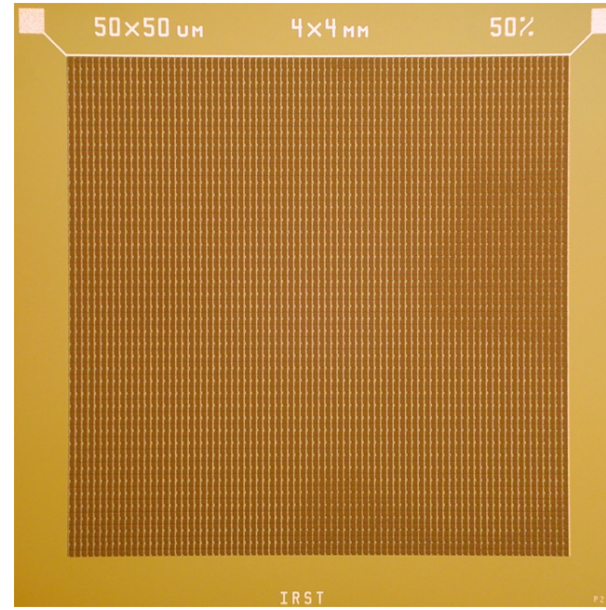
INFN/IRST C. Piemonte
G. Pauletta INFN/Udine

June 13th, 2007, Perugia

Giovanni Pauletta

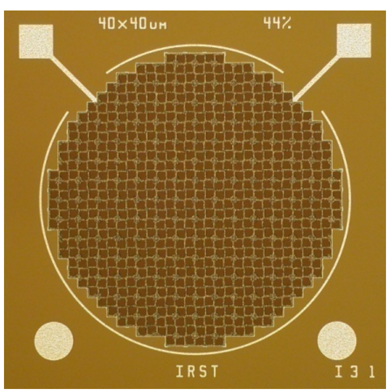




1x1mm 2x2mm 3x3mm (3600 cells) 4x4mm (6400 cells)

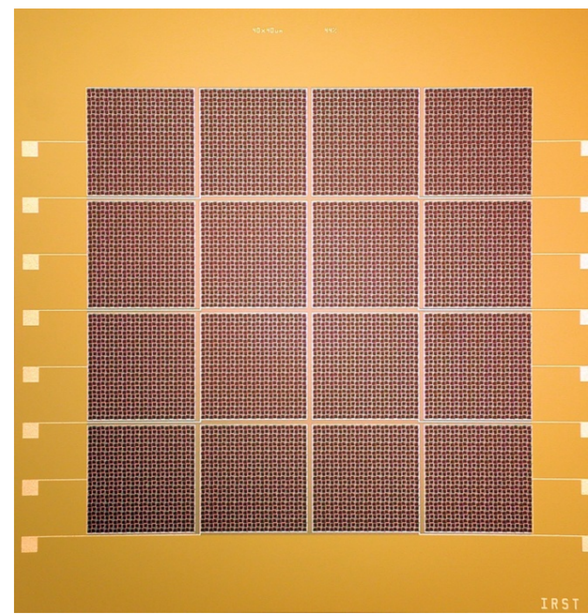
increased fill factor:

40μx40μ => 44%
50μx50μ => 50%
100μx100μ => 76%;

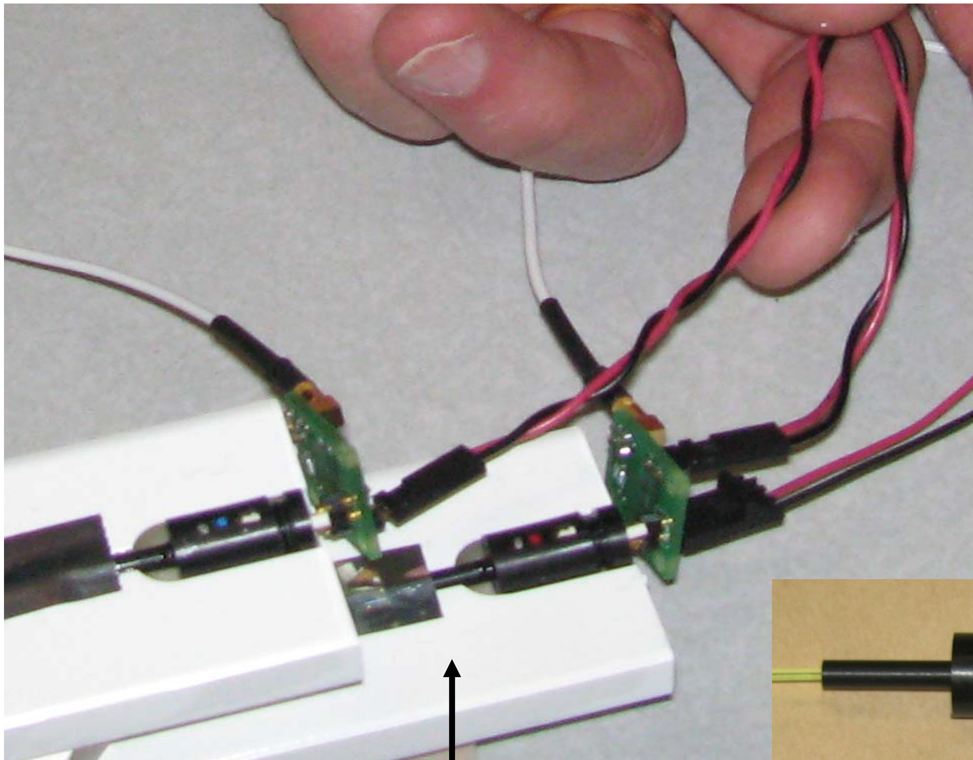


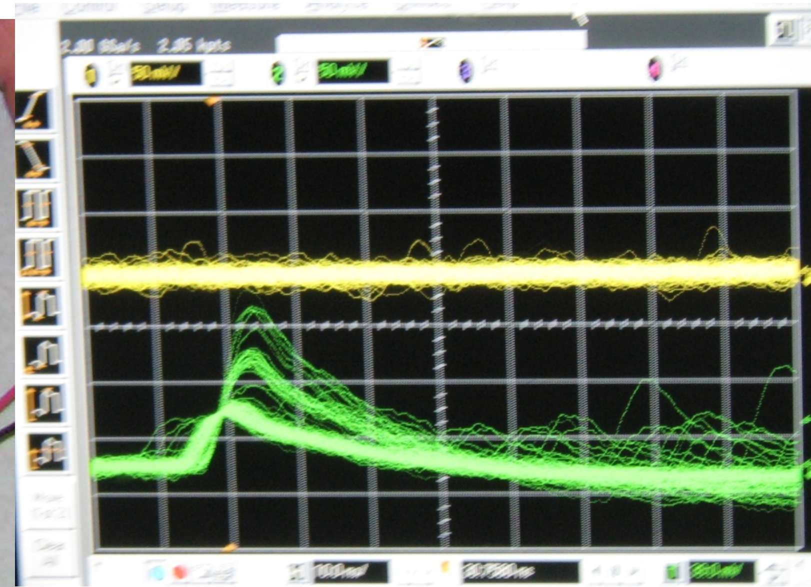
Circular (1.2 mm – diameter)

Array

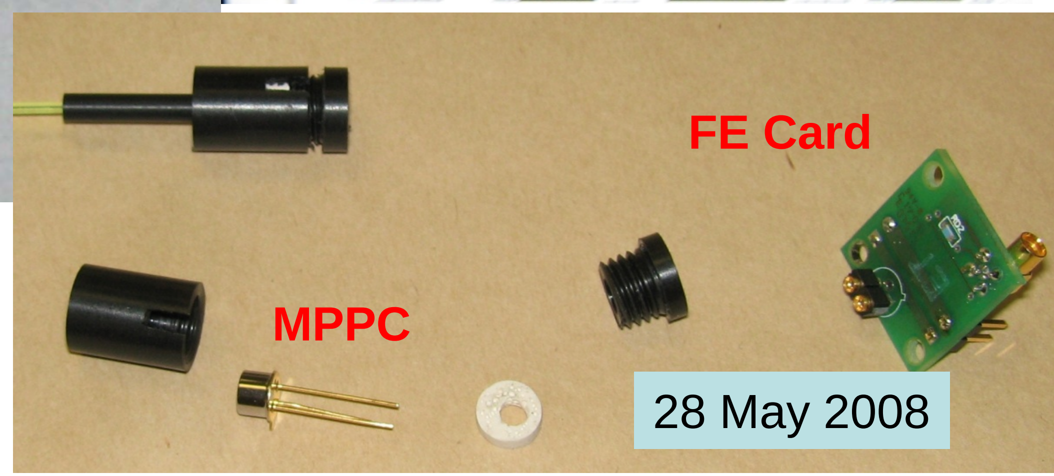


Strip-scint/Si-APD Tests at Notre Dame





Two strips w/ WLS fiber, HPK MPPC, plastic holder assembly + front-end card &connectors



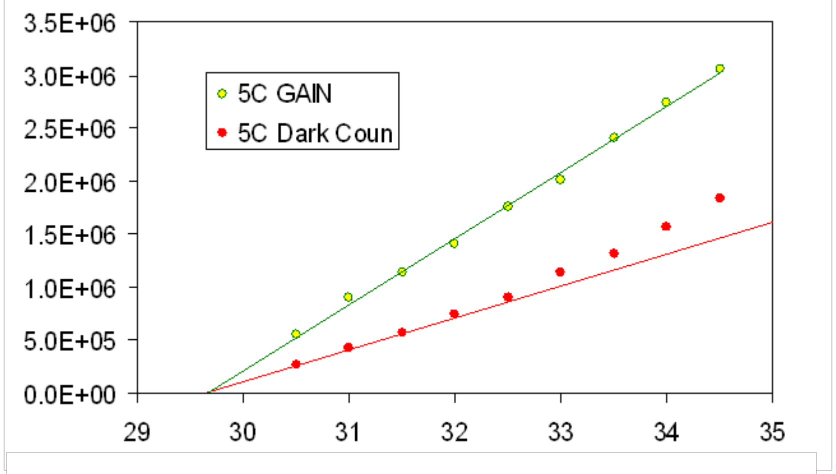
First signal and noise characteristics of the last devices

Noise and charge resolution

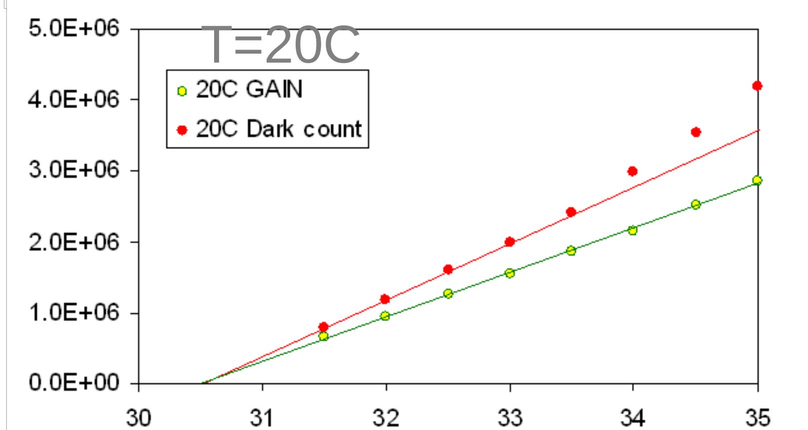
1x1mm^2 SiPM with 40x40μm^2 cells

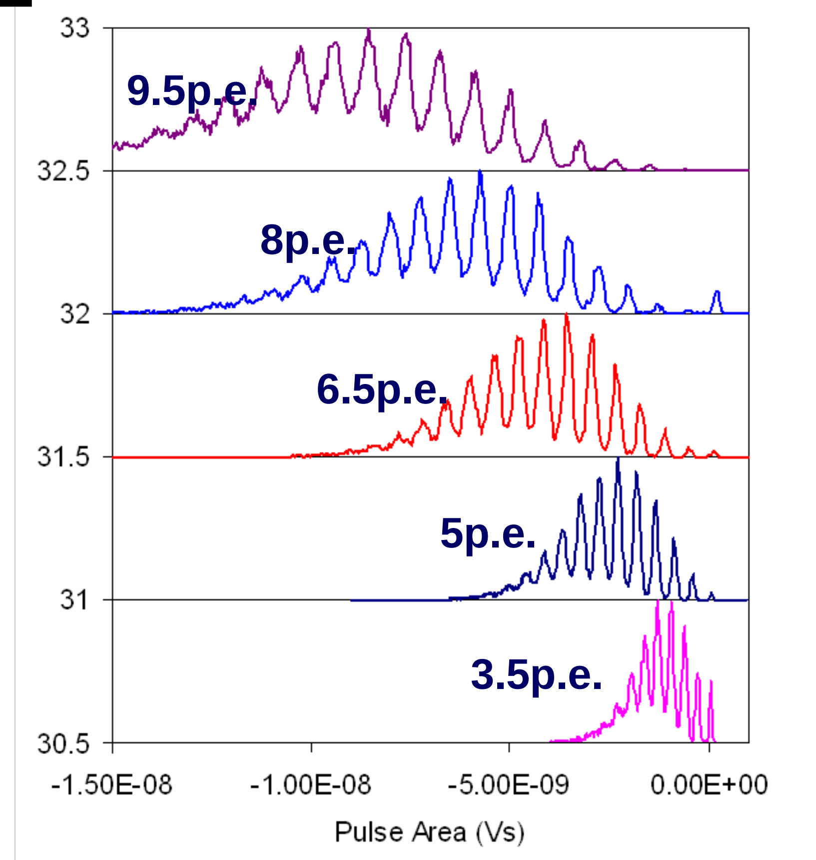
Charge spectra at different Voltages with the same light Intensity (pulsed)

T=5C



T=20C





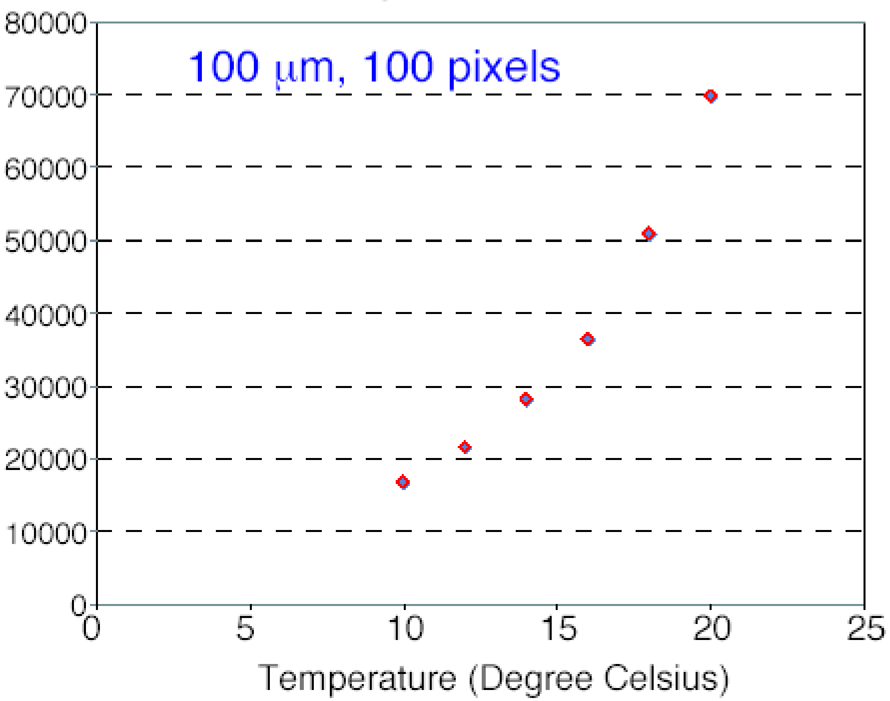
resolution limited by electronic noise

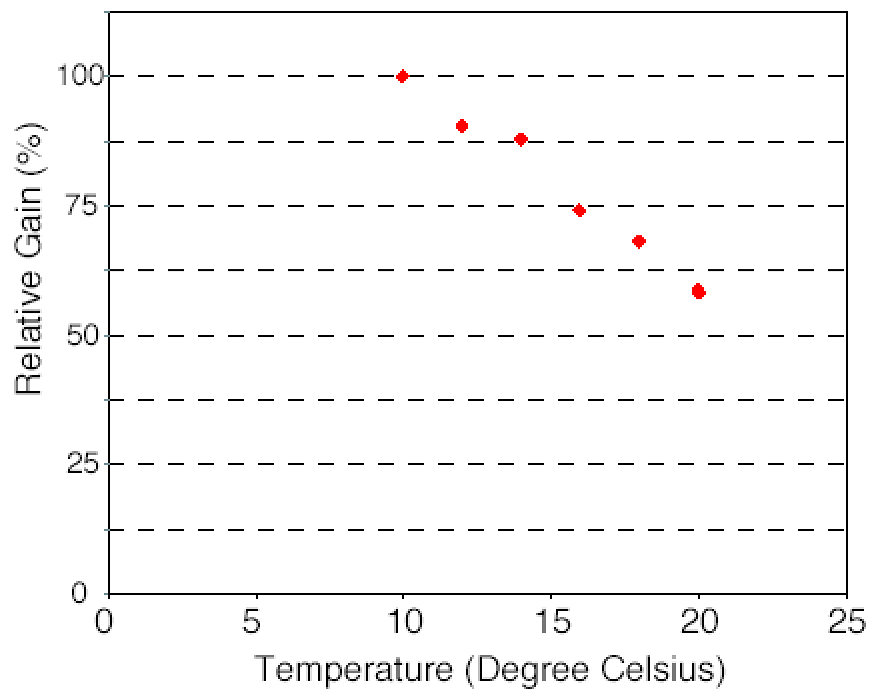
Temperature Behavior of Hamamatsu MPPC's

- Average gain of three 100 μm, 100 pixel devices @ 20 deg. C is found to be 2.52×10^6
- Variation of various properties with temperature:

R. Van Kooten & P. Smith Ind. U

Ham100U 19 - Background Rate with Temperature





- Cooling not necessary for dark rate; but stable temp. needed (and bias voltage stability to ~0.05 – 0.10 V)

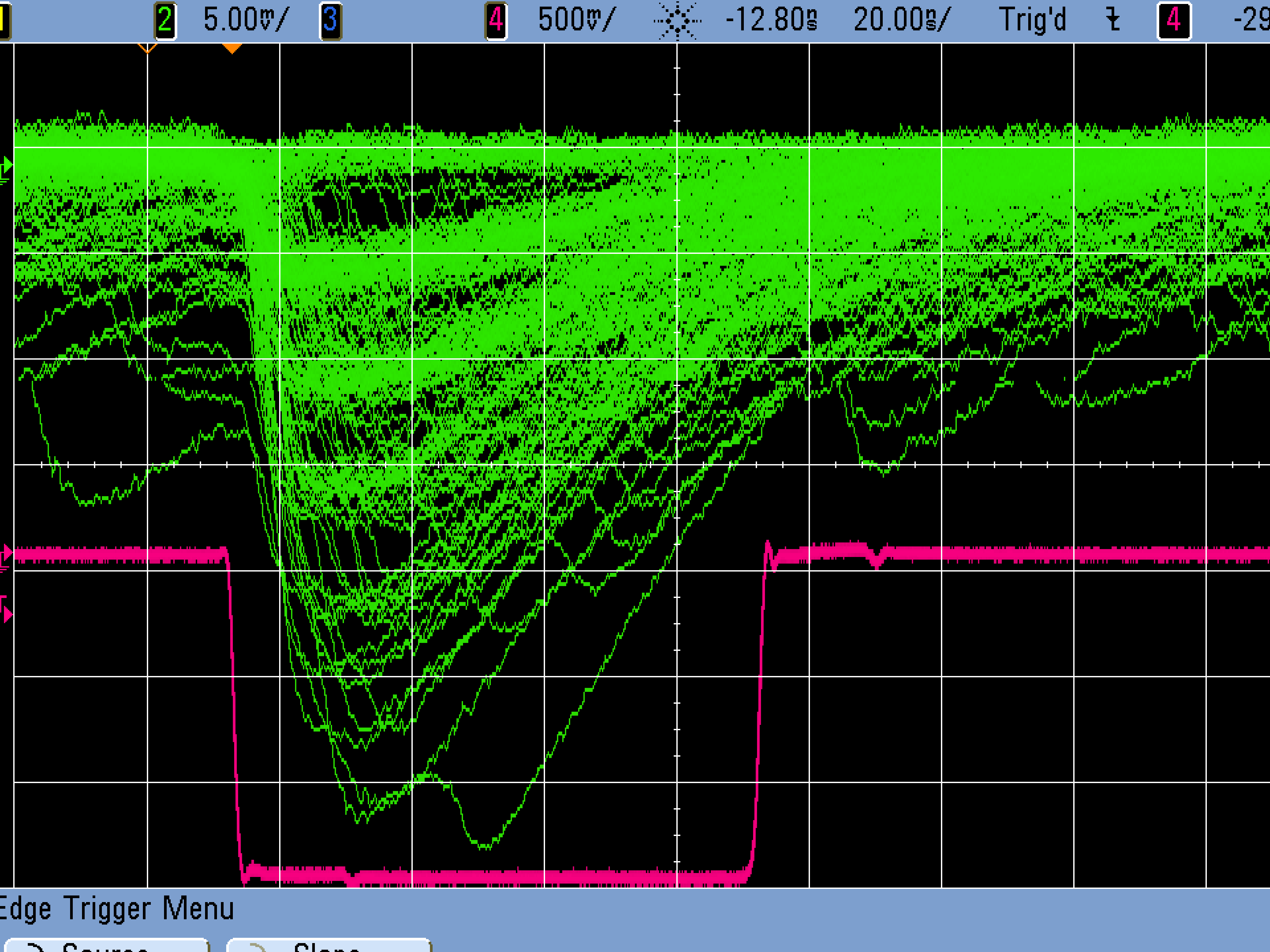
MTest 2008

Beam from Nov10 to 16

- Minerva test of TOF counters
- Added one bar with SiPM for testing (Ham, IRST)

- Using NIM based 6ch amp built at Fermilab for this work
- Using optical coupling designed at Notre Dame
- Using 120 GeV proton beam (1in x 1in spot)

Very preliminary results below



2
5.00mV/
3
4
500mV/
-12.80ns
20.00ns/
Trig'd
4
-29
Edge Trigger Menu
Source
Slope

Very preliminary results

- Here are typical plots

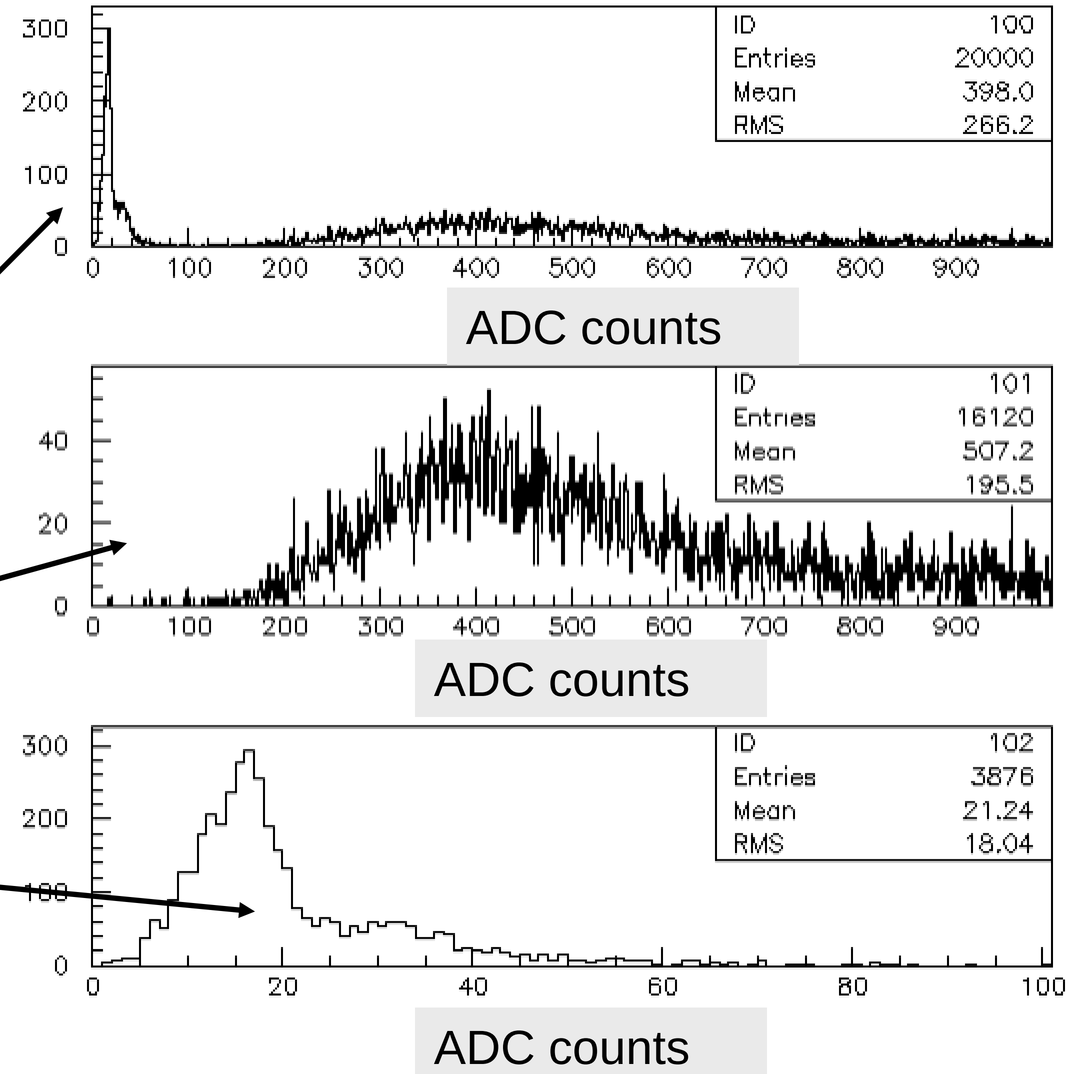
Our strategy is:

Take data with loose trigger to enable us to see pedestal.

Use other counters to select MIPs.

Extract 1pe peak from pedestal.

Peak at 400 counts is ~ 25 photo-electrons.

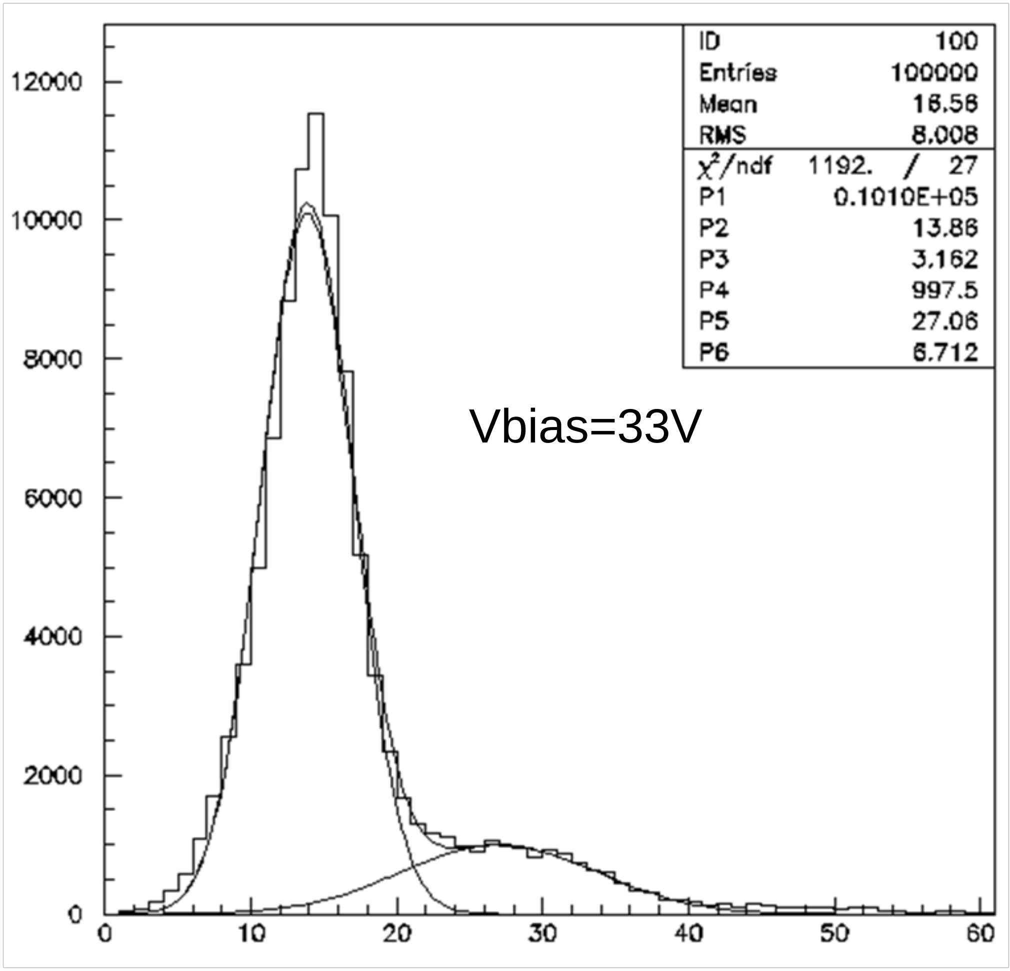


Very preliminary results

- It seems at least plausible that we can pull out the 1pe peak from the pedestal

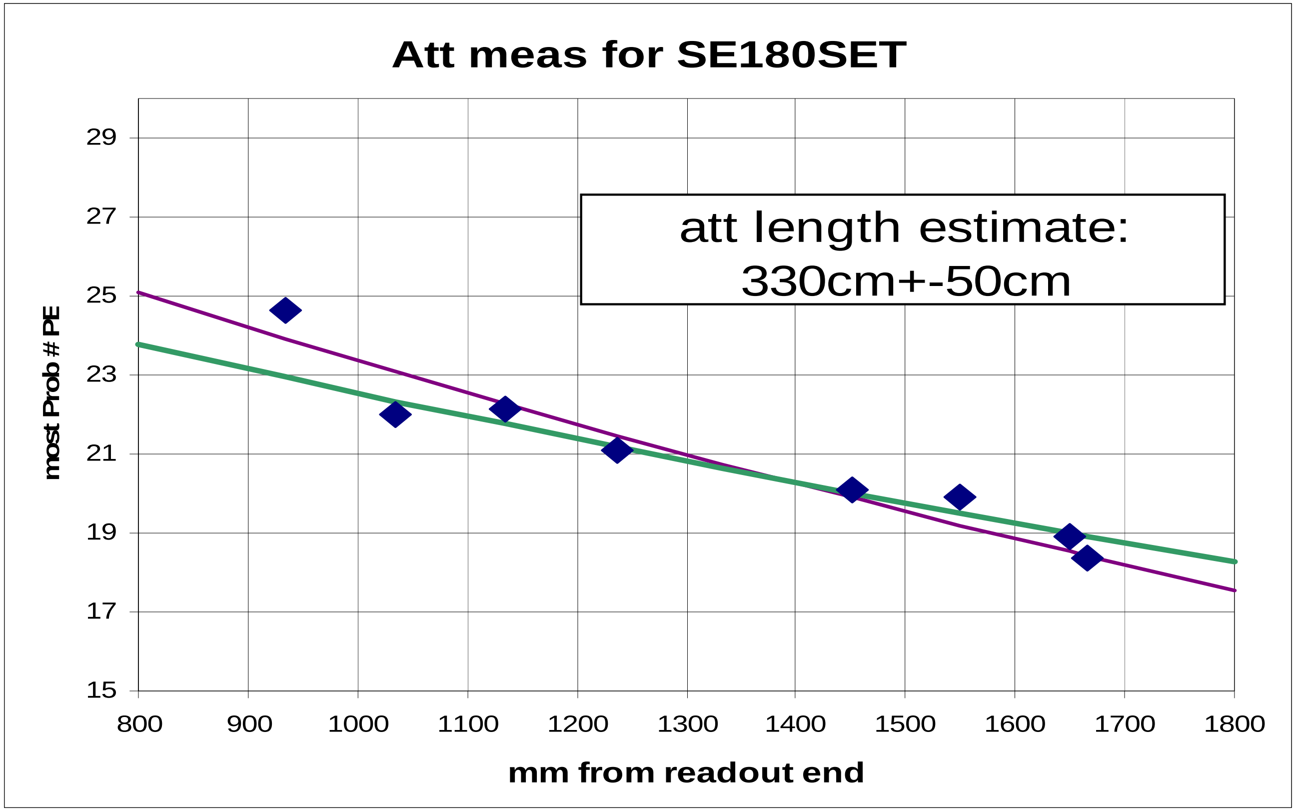
(due to dark counts)

- This makes the detector self calibrating



Very preliminary results

- A scan of the 1.8m bar across the beam gives an estimate of the attenuation length



Why should this R&D be supported?

- SiPMs deployment could save significant money. Why?
- SiPMs work in B fields greater than 5 Tesla, so we don't need clear fiber to get optical signals out of the B field.
- If the photo-electron yield is ~25 for our strips then longer strips can be used and single ended readout may be possible thereby reducing the channel count.
- If our idea of using the noise pulses for calibration works then we don't need a light pulser system and all the attendant instrumentation, which would be an additional cost saving.
- We expect the cable for handling the raw electronics signals and then digital signals would take up less space than the fiber needed to get out of the detector; another cost and space saving.
- SiPMs are a new technology that physicists here and elsewhere are interested in developing. This is not simply ILC!

Current Status

- Fermilab – Cost estimate; Fast digitizers w/firmware; MTest measurements with Rubinov digitizers.
- Indiana U.- Will measure more SiPMs to understand $\Delta G/\Delta Temp$. They will pursue on-circuit temperature monitoring and $\Delta G/\Delta V$ corrections offline and online; with Wayne State. Both will probably want Rubinov fast digitizers.
- Notre Dame – Additional strips up to 6m for measuring attenuation of light pulses at distances greater than 3m. Testing more SiPMs. UND has an HPK PS/amplifier for such testing.
- NIU – Continuing analysis and tests with CALICE at MTest; Jet energy resolution improvements with tail-catching.
- Wayne State – FE electronics; SiPM characterics; $\Delta G/\Delta Temp$
- INFN/Udine – IRST SiPM MTest beam measurements; Noise measurements, single photo-electron peak studies; signal analysis with Rubinov fast digitizer.
- Universities have submitted an LCRD proposal for the funding of further SiPM studies.

Plans for Next Five Years

- Order additional SiPMs and characterize them. Noise characteristics. Achieve gain independence from Temp.
- Test with fast digitizer boards to understand calibration with photo-peaks. Can noise pulses be used to calibrate?
- Test long strips with MTest beam. # of p.e.s vs. longitudinal position of the beam.
- Understand signal pulse shaping and develop optimal pulse shape network.
- With help from SiPM vendors determine future costs of SiPMs.
- Develop plan for determining full muon electronics chain.
- Refine cost estimate and assumptions.

Personnel and Funding Needs

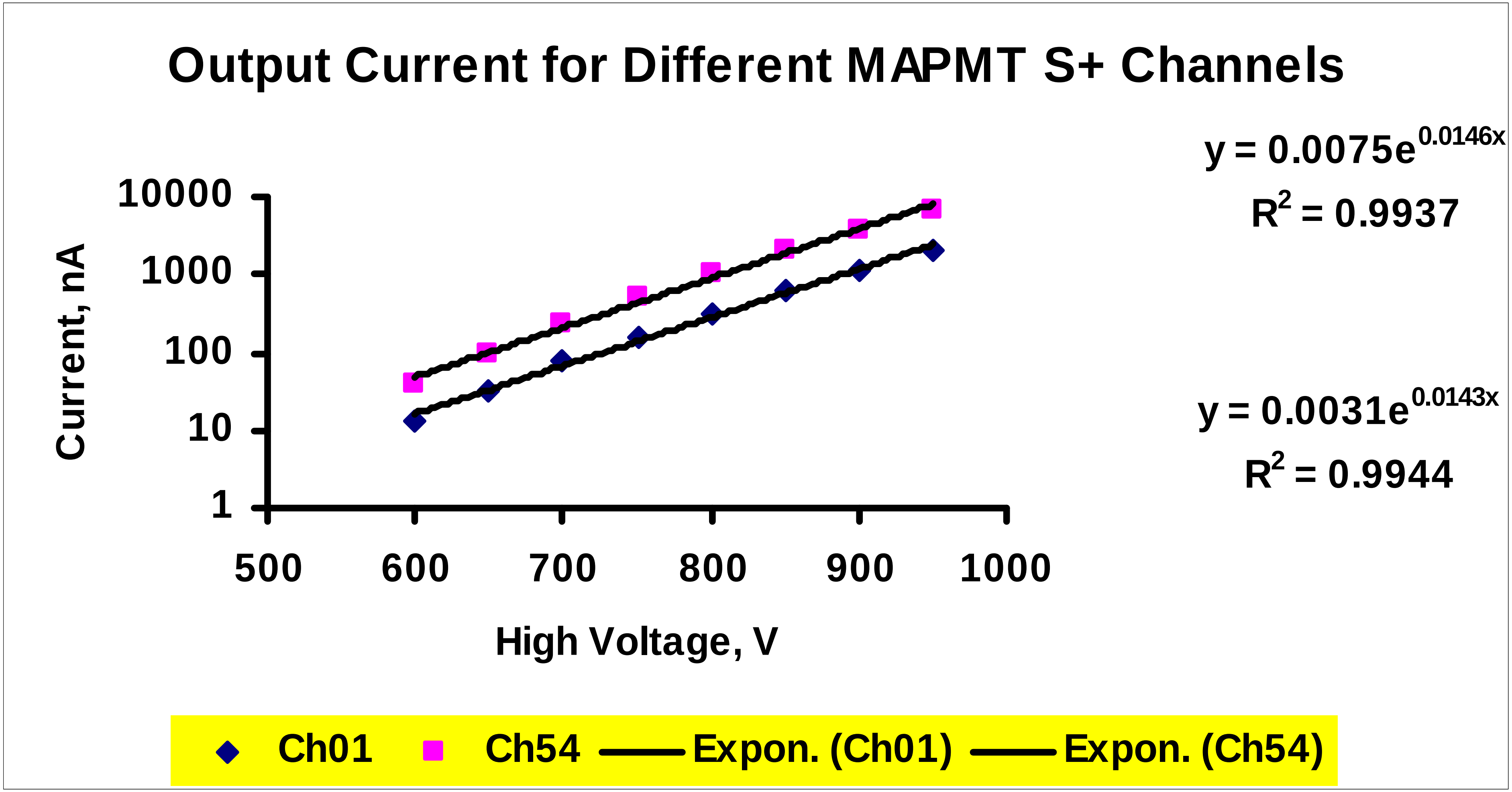
1. Read Ferminews everyday.
2. "For us, passage of the American Recovery and Reinvestment Act was the big news of the week, the year and--barring discovery of the Higgs--the decade. It makes a large investment in science and technology… Our first priority now is to do our part to support economic recovery by spending these funds wisely, productively and rapidly, as contemplated by the legislation. " Pier Oddone Ferminews 2/17/2009

- We need Rubinov and Fitzpatrick's Fast Digitizer and help from the Universities.
- We will need MTest beam.
- Before that we will need an MOU.

Summary of Strip Scintillator/SiPM Studies

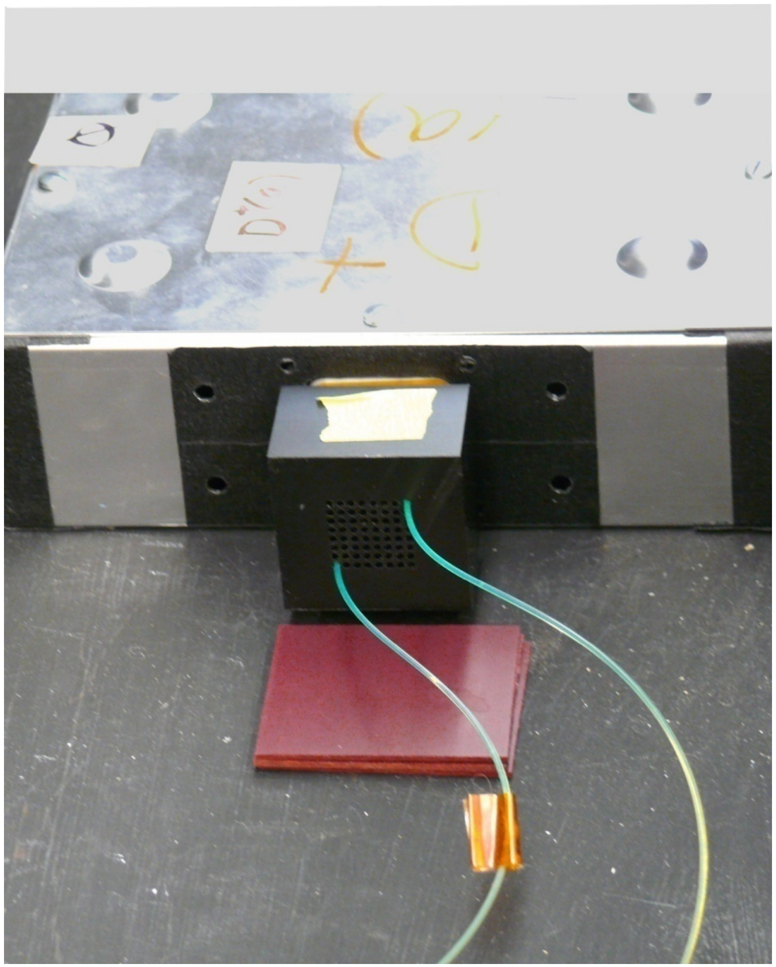
- Minimum ionizing particles seem to provide adequate numbers of photo-electrons, but this must be furter verified
- We are learning how to test and calibrate SiPMs with and without beam, but instrumentation development is necessary for further proof of methods.
- There are many issues: pixel size for muons and hadronic shower measurements; pulse shaping, ampIification, digitization; temp dependence, after pulsing, signal collection and readout, ...
- SiPMs look very promising, but a long way to go.

Thanks for your help!!

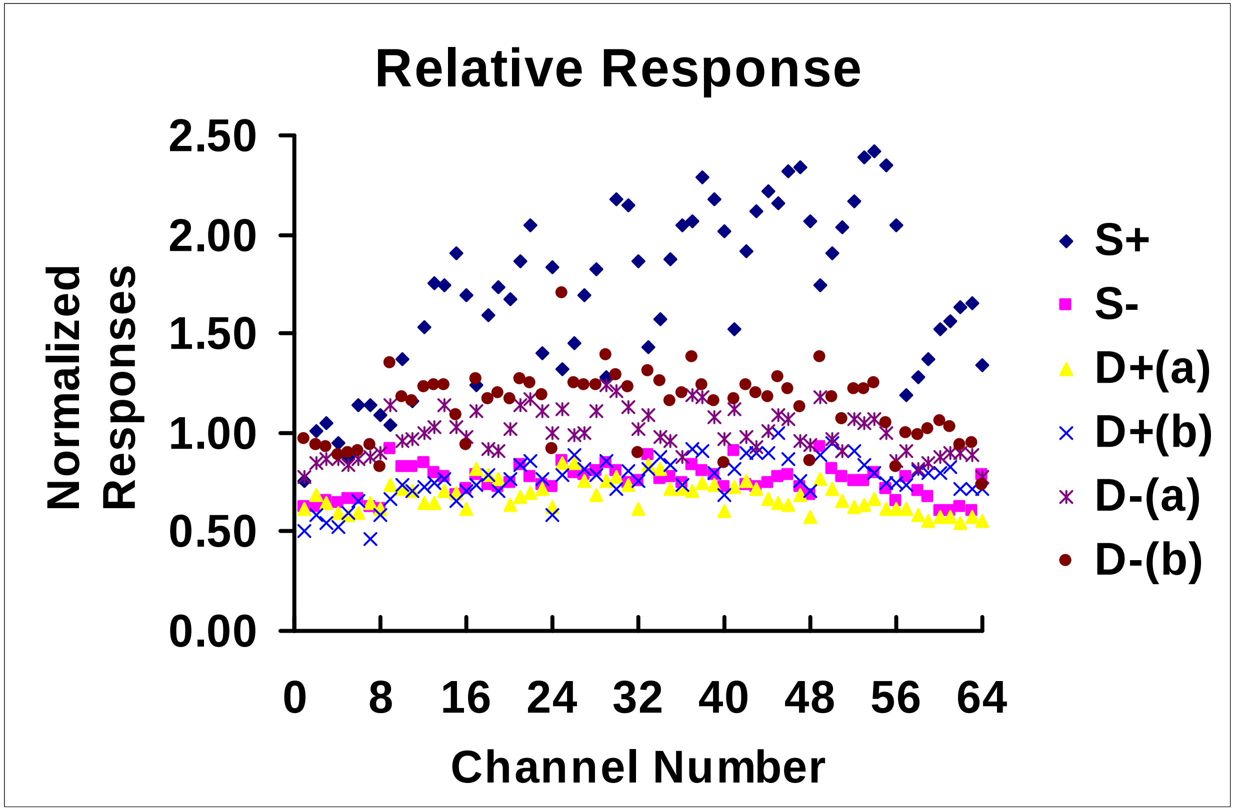


Output Current for Different MAPMT S+ Channels
y = 0.0075e^0.0146x
R^2 = 0.9937
y = 0.0031e^0.0143x
R^2 = 0.9944
10000
1000
100
10
1
Current, nA
500
600
700
800
900
1000
High Voltage, V
Ch01
Ch54
Expon. (Ch01)
Expon. (Ch54)

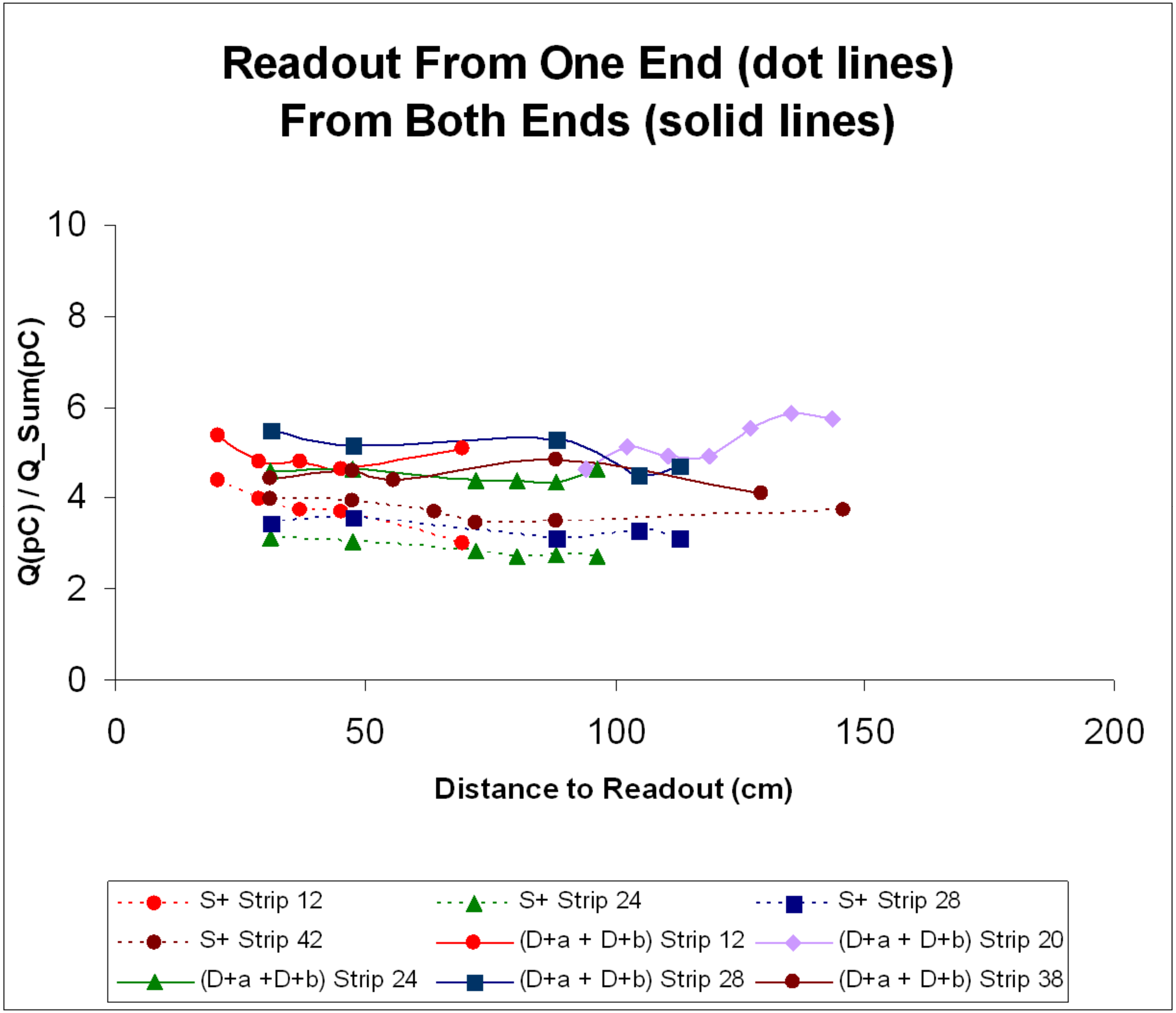
Boxed MAPMT with Interface and WLS Fibers Connected



Labeled WLS fiber is a reference always positioned At channel number 57 in each MAPMT.
Control measurements were performed using the second fiber by repeating the measurement in channel number 64.



Relative Response
Normalized Responses
2.50
2.00
1.50
1.00
0.50
0.00
0
8
16
24
32
40
48
56
64
Channel Number
S+
S-
D+(a)
D+(b)
D-(a)
D-(b)



Readout From One End (dot lines)
From Both Ends (solid lines)
Q(pC) / Q_Sum(pC)
10
8
6
4
2
0
0
50
100
150
200
Distance to Readout (cm)
S+ Strip 12
S+ Strip 24
S+ Strip 28
S+ Strip 42
(D+a + D+b) Strip 12
(D+a + D+b) Strip 20
(D+a +D+b) Strip 24
(D+a + D+b) Strip 28
(D+a + D+b) Strip 38