



# **ELECTRONICS FOR OPTICAL TOTAL ABSORPTION CALORIMETERS**

# Introduction

- Electronics are an integral part of any detector development
  - Modular instrumentation for HEP experiments ended at the turn of the century

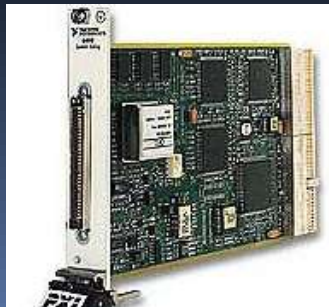
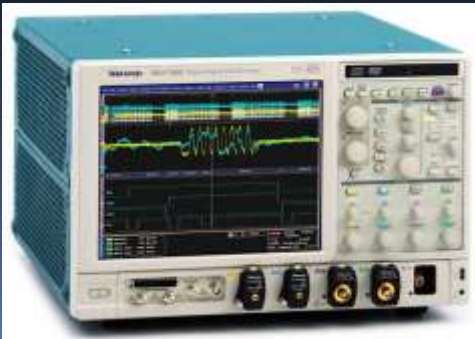
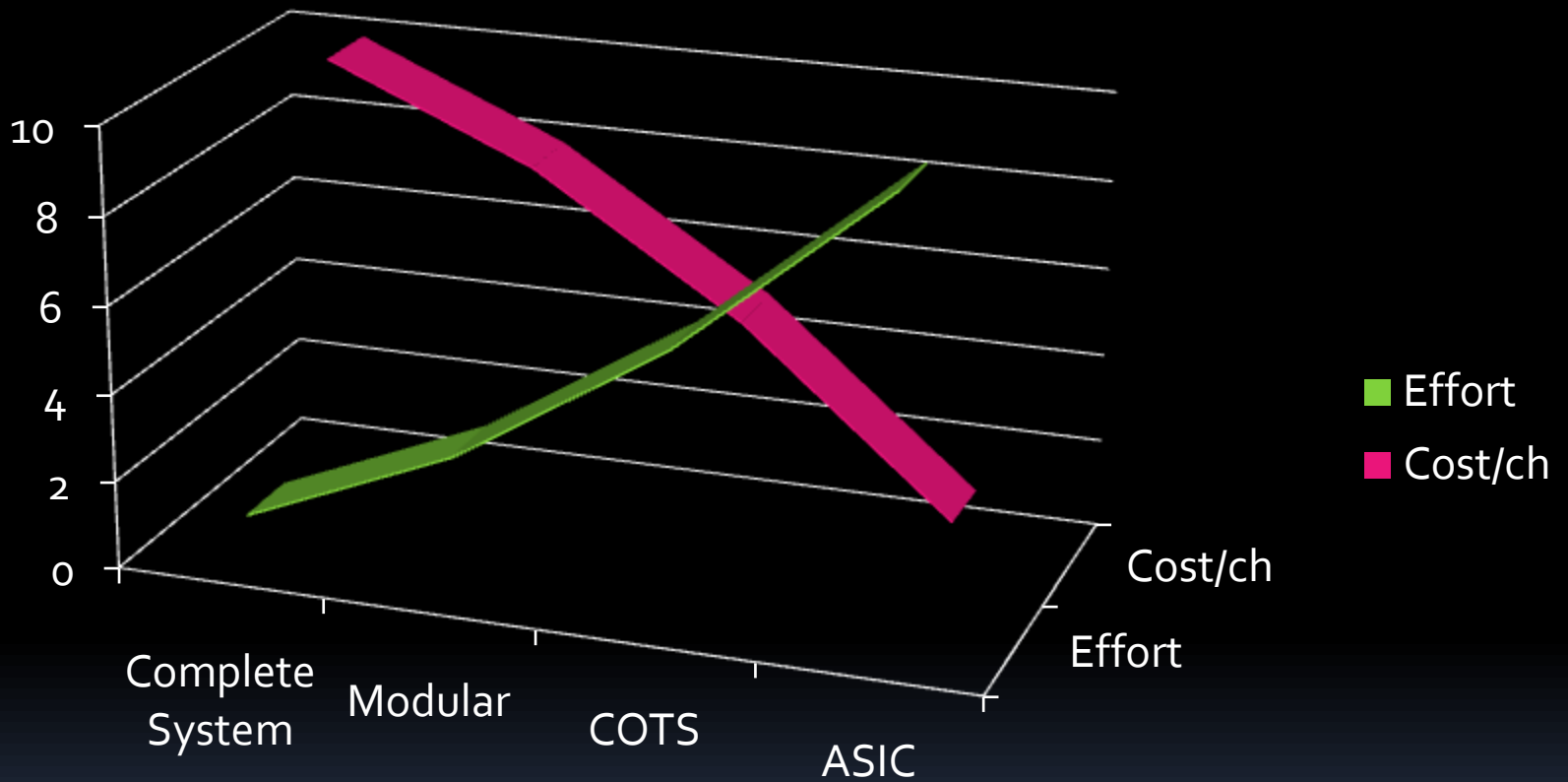
*LeCroy Corp:* January, 2001. After more than 37 years of manufacturing modular instrumentation for physics, LeCroy announced today that it will be ending production of its CAMAC, VME, NIM and FASTBUS series of modular products

- That does not mean there are no “general purpose” electronics
- It does mean you can not apply the JGSFP\* strategy



\* Just Get Something From PREP

# Thinking about electronics



# Thinking about electronics

- Electronics for SiPMs, step 1:  
***JUST BUY IT***

## 1 to 4 chan:

### Shopping list:

Amplifier, LV supply, scope, bias supply, current meter

### Design effort:

Almost none (almost because you can still screw up grounding)  
Hook them up with Labview

### Cost/ch:

a few kilo- \$ per chan

### Time to implement:

a couple of weeks (once everything in hand)

### Toughest challenge:

Getting the reqs approved

**The right choice for learning about SiPMs**

# Thinking about electronics

- Electronics for SiPMs, step 2:  
***JUST BUILD IT (like TB4)***

**5 to 50 chan:**

**Shopping list:**

PCBs, components

**Design effort:**

Analog design, digital design, layout, firmware, software

**Cost/ch:**

a few hecto-\$ per chan

**Time to implement:**

4 to 6 (wo)man-months (once everything in hand)

**Toughest challenge:**

Getting the budget code to charge the labor

**The right choice for single crystal & cosmic ray studies**

# Thinking about electronics

- Electronics for SiPMs, step 3:  
***THINK ABOUT IT – THEN BUILD IT (quarknet)***

50 to 50 000 chan:

Shopping list:

PCBs, components

Design effort:

Analog design, digital design, layout, firmware, software

Understanding the difference between what we want and what we need

Cost/ch:

a few deca-\$ per chan

Time to implement:

1 to 4 man-years (depending on #ch), including prototypes

Toughest challenge:

Getting physicists to decide what is REALLY needed

The right choice for small calorimeter with  $O(100)$  ch

# Thinking about electronics

- Electronics for SiPMs, step 4:  
***JUST DESIGN IT FROM SCRATCH***

5000+ chan:

Shopping list:

a good ASIC engineer

Design effort:

Understanding the difference between what we want and what we need

Cost/ch:

from a few \$/ch to a fraction of a cent/ch

Time to implement:

2 to 4 years for 2 to 4 people

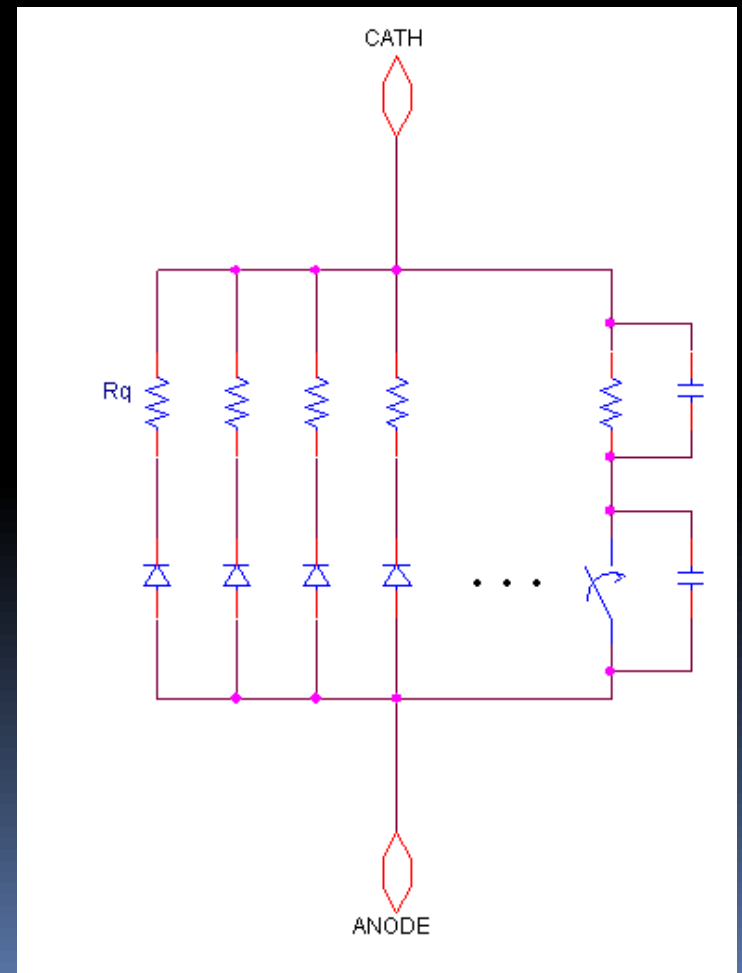
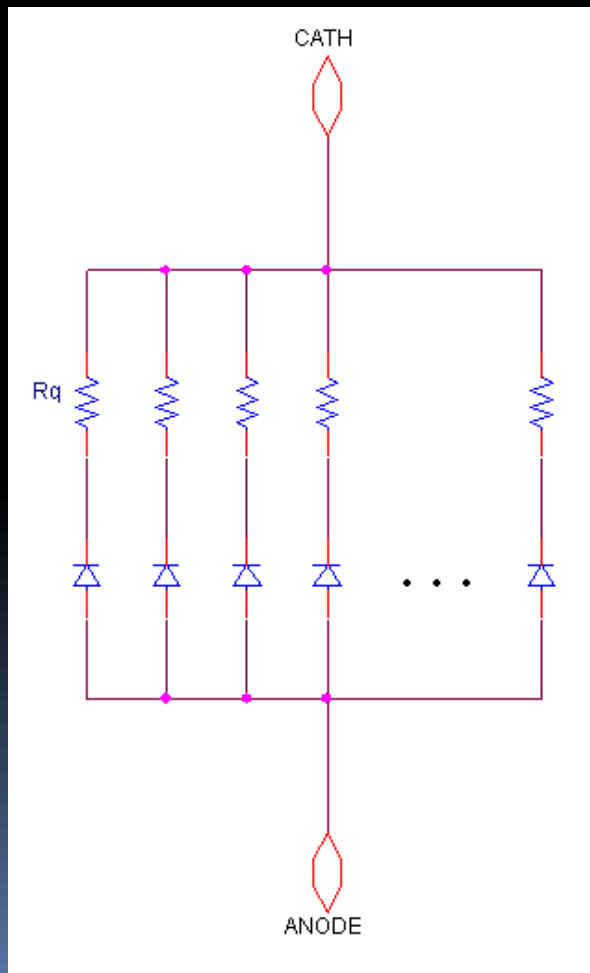
Toughest challenge:

Getting physicists to decide when its good enough

**An ASIC is the only way to achieve sufficient performance at reasonable cost**

# Thinking about SiPMs

- SiPMs are different: think about the circuit





# Thinking about SiPMs

- SiPMs are different: think about the circuit

These numbers come from p52 of Adam's RTS seminar

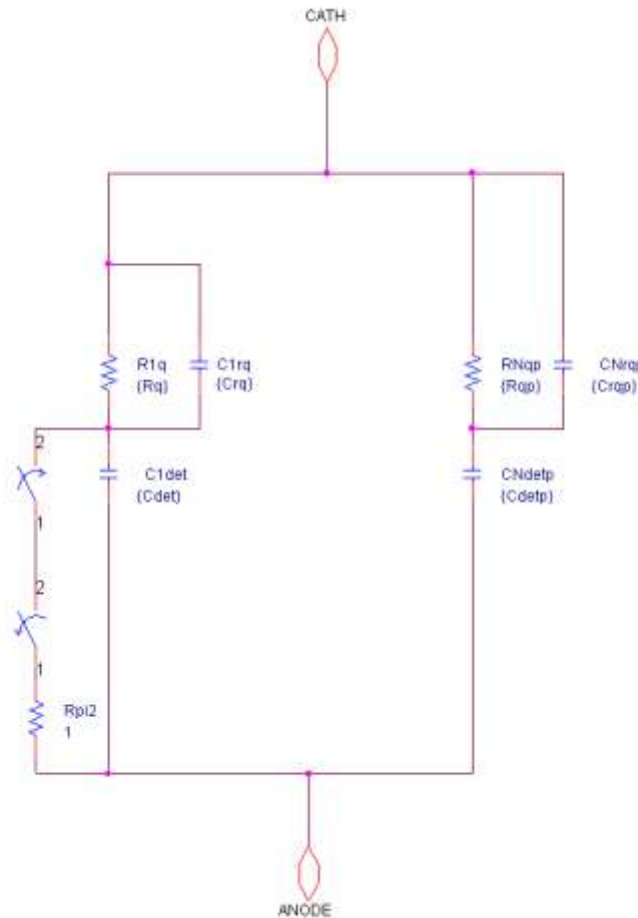
They correspond to measurements for Hamamatsu 1600 pixel device.

## PARAMETERS

$R_q = 244k$   
 $C_{rq} = 1.6e-14$   
 $C_{det} = 2.2e-14$   
 $t_s = 1001ns$   
 $t_q = 1001.2ns$   
 $C_{rap} = (C_{rq} * 1600)$   
 $R_{rap} = (R_q / 1600)$   
 $C_{delp} = (C_{det} * 1600)$

$T_{CLOSE} = (t_s)$   
 $R_{CLOSED} = 1$   
 $R_{OPEN} = 1e11$   
 $T_{TRAN} = 0.1ns$

$T_{OPEN} = (t_q)$   
 $R_{CLOSED} = 1$   
 $R_{OPEN} = 1e11$   
 $T_{TRAN} = 0.1ns$

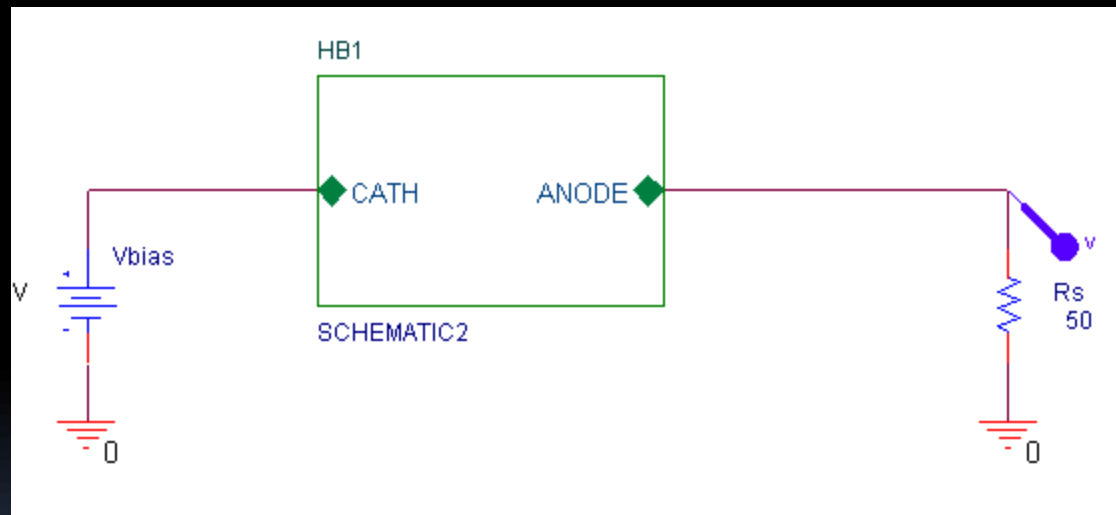


R data for Ham 25u from Jeff

-60	367072
-50	354498
-40	334476
-30	310649
-20	295361
-10	280443
0	276121
10	259728
20	244005
30	233310
40	231025
50	226669

# Thinking about SiPMs

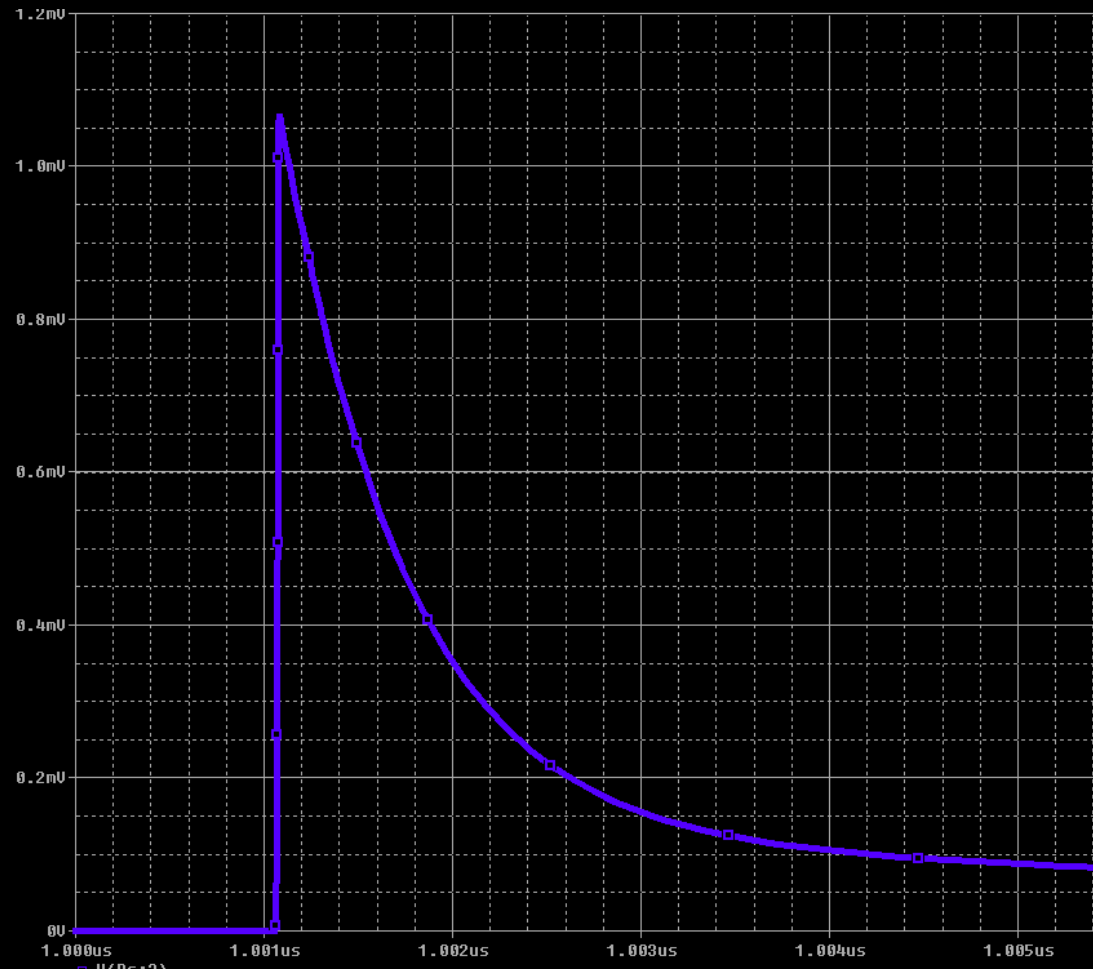
- SiPMs are different: think about the circuit



# Thinking about SiPMs

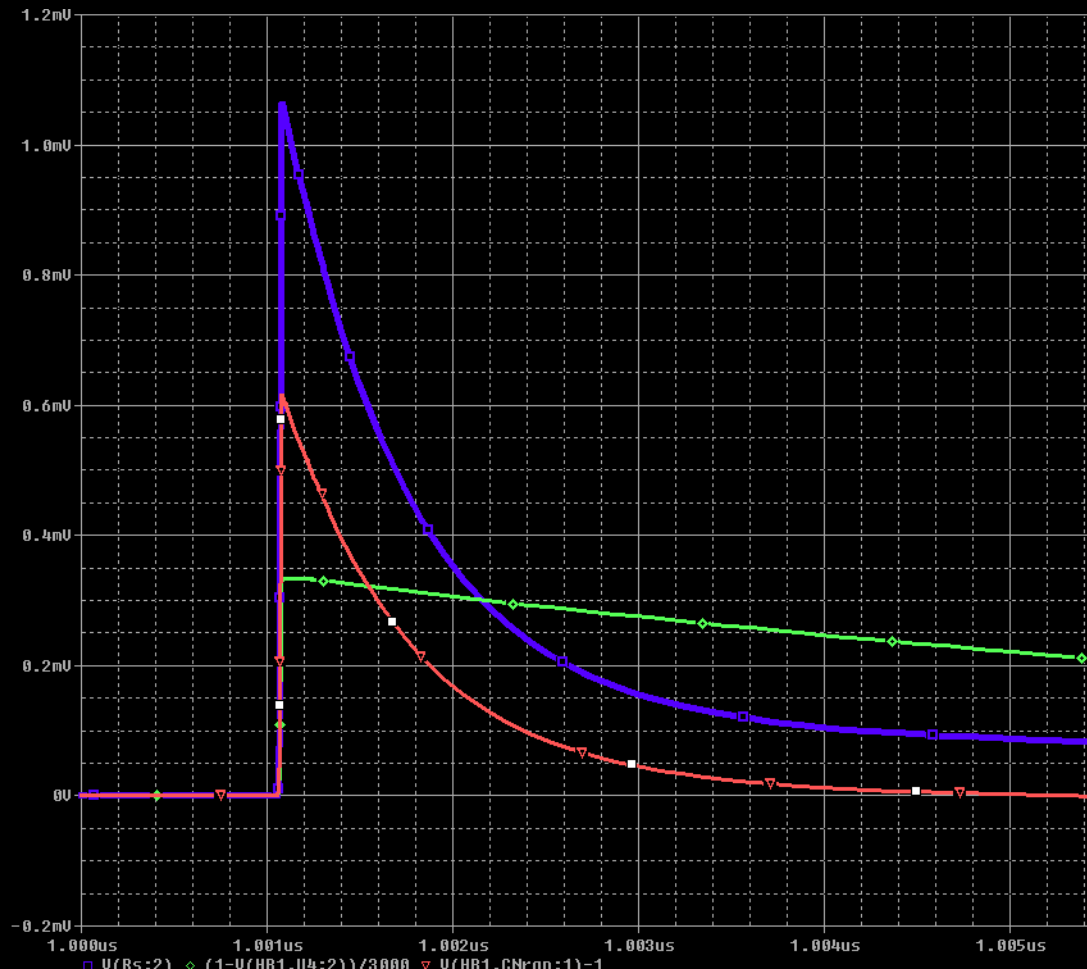
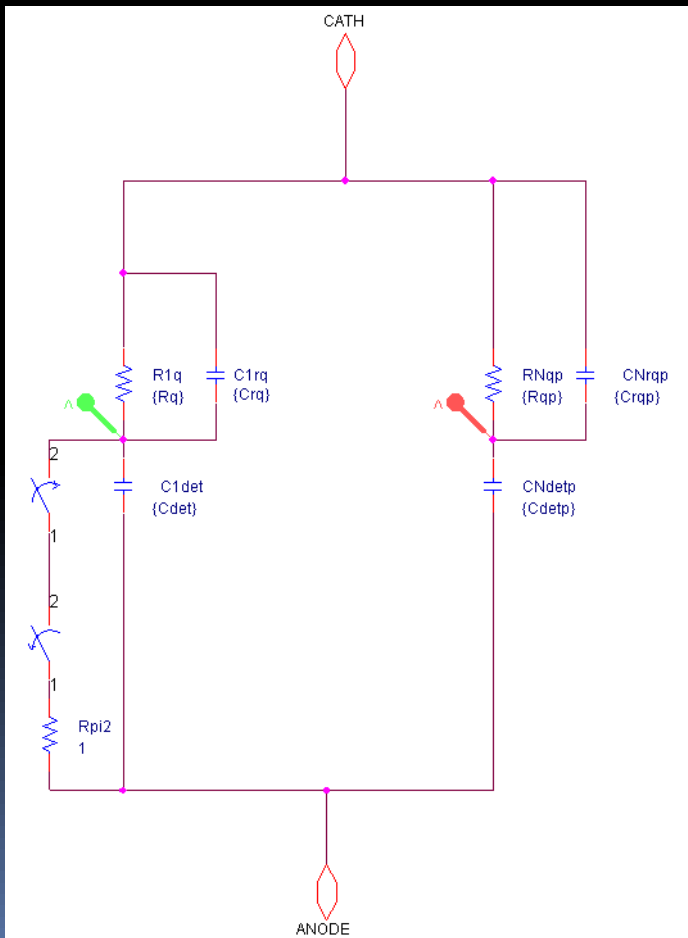
SiPMs are different: let SPICE think about it...

**SiPMs  
ARE NOT  
little PMTs**



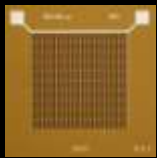
# Thinking about SiPMs

- This is not an exp, it has 2 components



# Thinking about SiPMs

- Thinks get more complicated:  
different SiPMs are different! (Rq, Cdet, etc.)



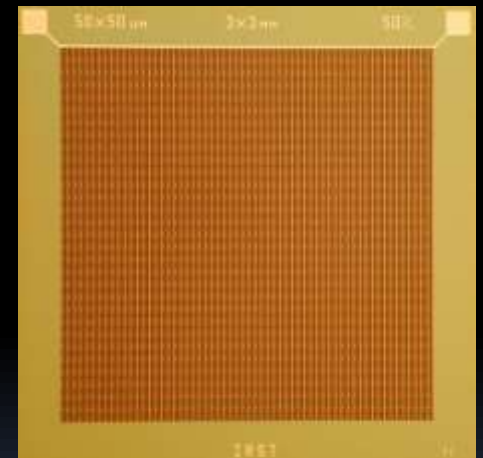
1x1mm

fill factor:

$40\mu\text{x}40\mu \Rightarrow 44\%$

$50\mu\text{x}50\mu \Rightarrow 50\%$

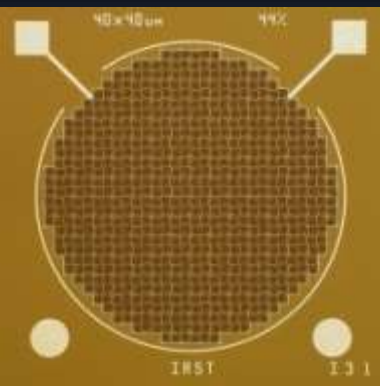
$100\mu\text{x}100\mu \Rightarrow 76\%$ ;



2x2mm

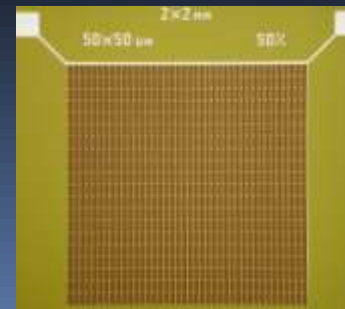


3x3mm



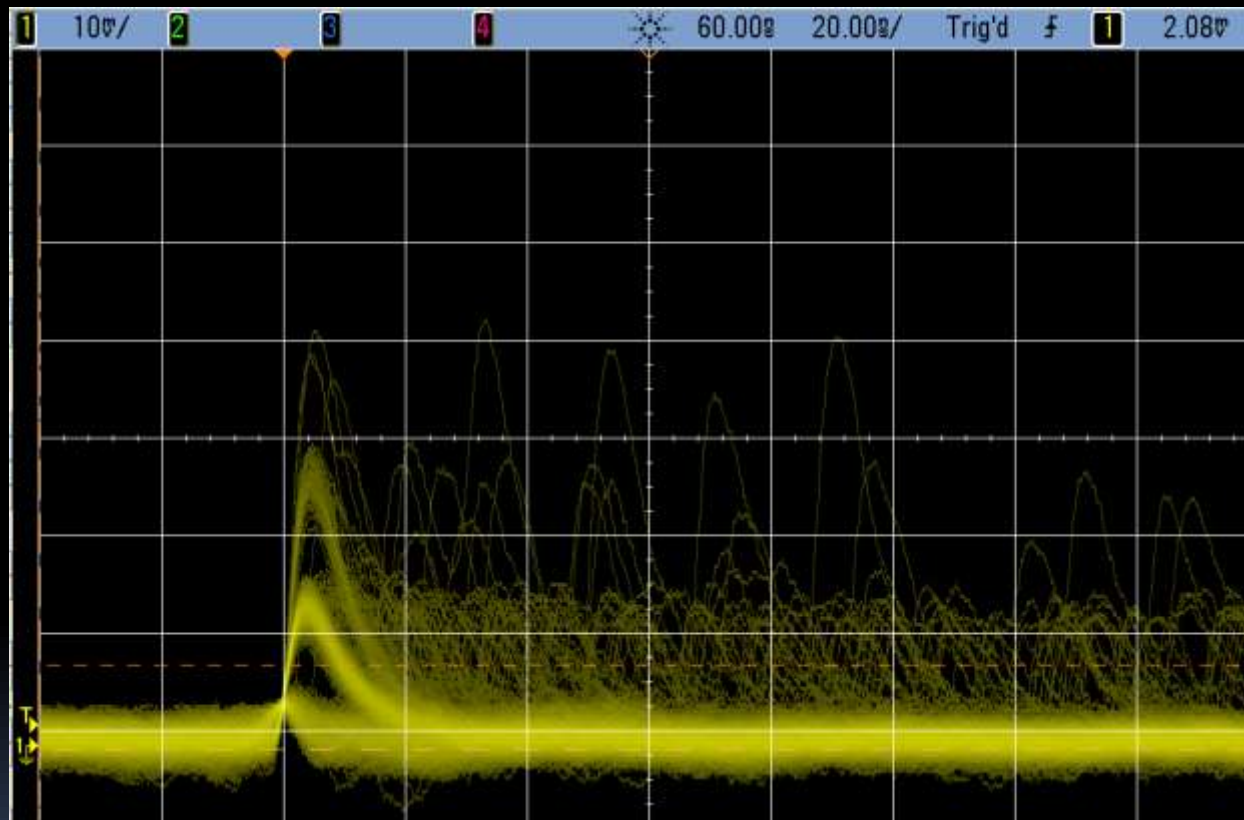
Circular Array 1.2mm dia.  
~ 650 pixels  $40 \times 40 \mu^2$

Giovanni Pauletta




# Electronics for SiPMs

- Step 1: Scope



- MPPC-11-050C#37 at 71.1deg F operating at 69.81 (recommended V is 70.02 at 25C)
- Current reading is 0.044uA
- 1pe is about 13.25mV

# Electronics for SiPMs

- Step 2 : build our own, but generic 
- Enable applications that would not otherwise be possible
- Aim to support test beam
- Provide support
- Appropriate for studies with single crystals
- They also work for PMTs

But... more on that later

# Electronics for SiPMs: Step2

- Best available commercial components without heroic efforts and reasonable \$  
(~1ns resolution, ~400 pe range)
- Integrated with SiPM specific features  
(bias generator, current readback, temp sensor)
- Optimized for 4-48 ch count (dozen(s) SiPMs)
- Flexible: using 50 ohm input, generic daughter board connection to support faster readout/more memory
- Large FPGA to allow DSP features



# A bit more about TB4



50ohm inputs

12bit ADC, so large dynamic range, 212MSPS, up to 4k samples/ch  
~100MHz bandwidth, noise ~30uV RMS

Up to 16ch per MB

Bipolar, so ped is around 8100 (half scale)

Setup over USB, readout over 100mbit Ethernet

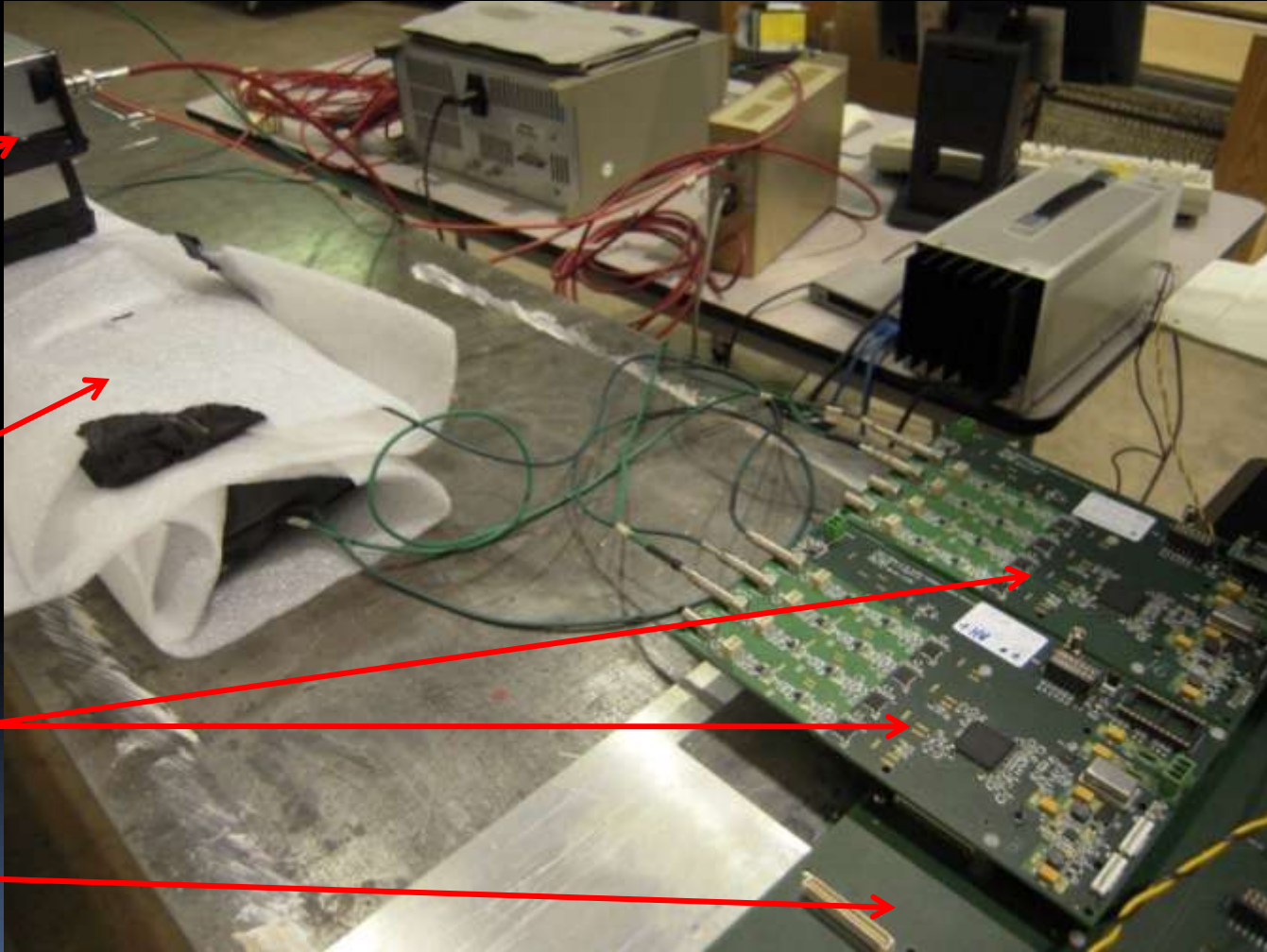
# Test Beam 4 channel electronics: TB4

Cosmic Ray  
Trigger  
Counters

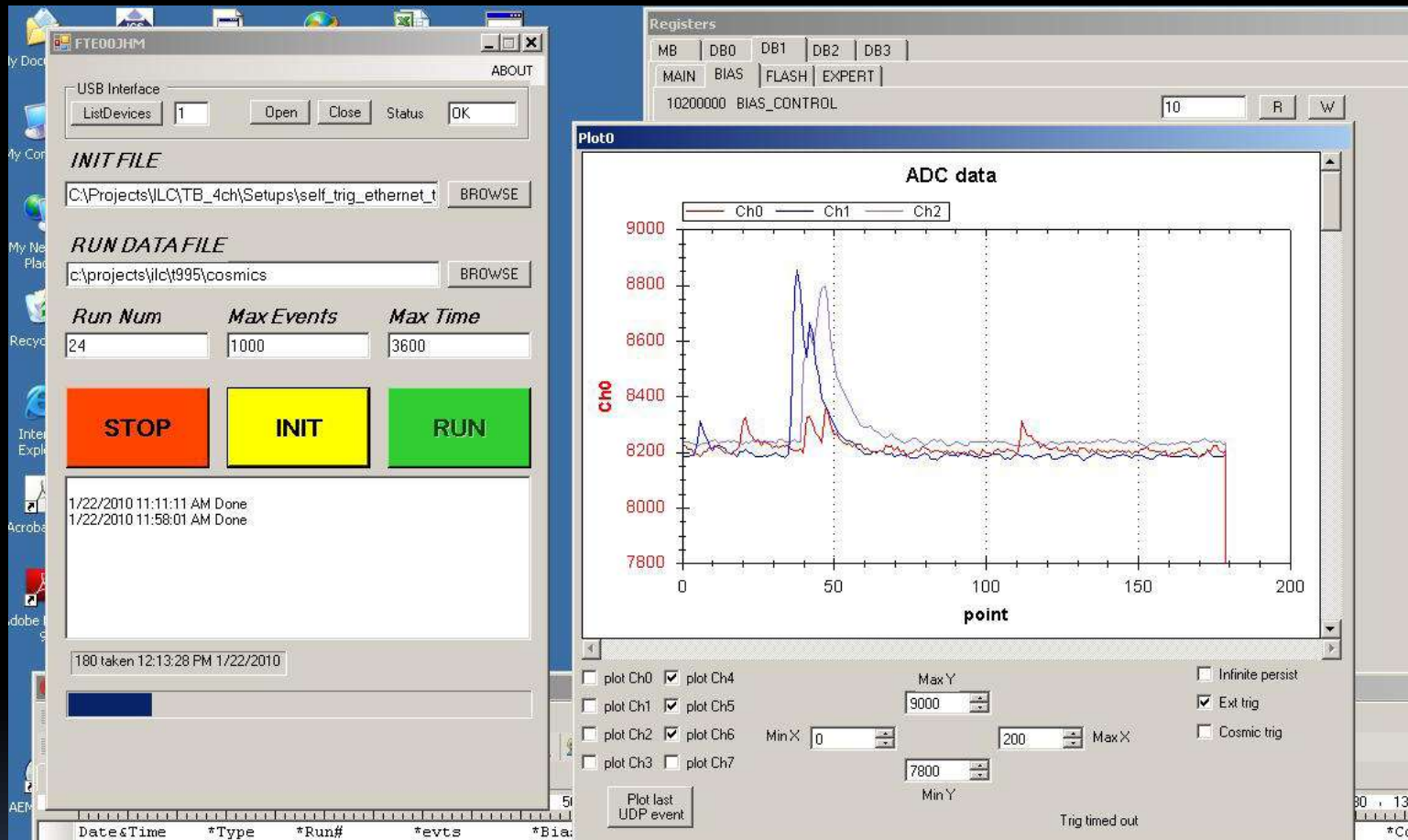
Strip  
Scintillators

TB4 Daughter  
Boards

TB4 Mother  
Board

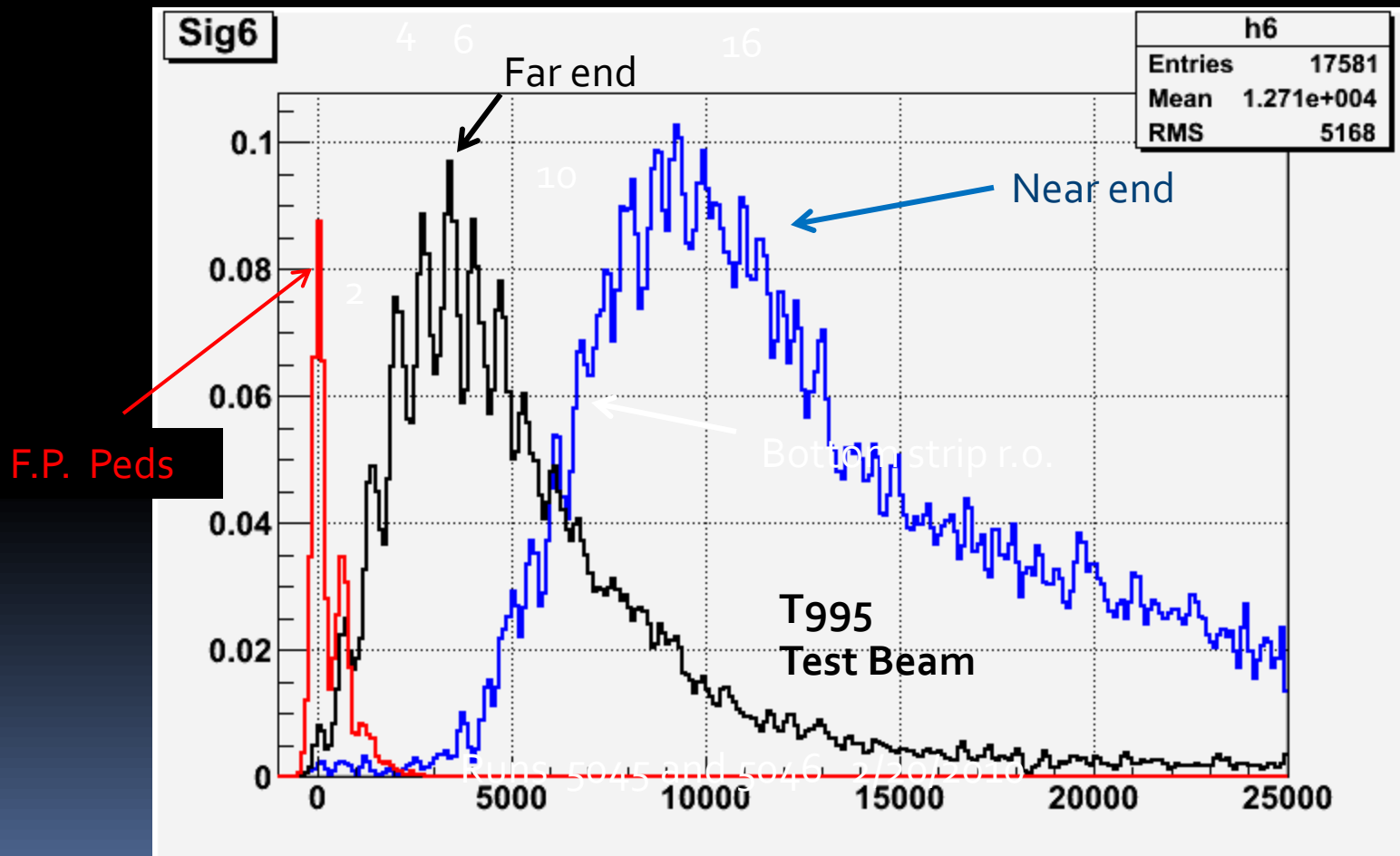


# TB4 Set-up at D0: Cosmic Rays



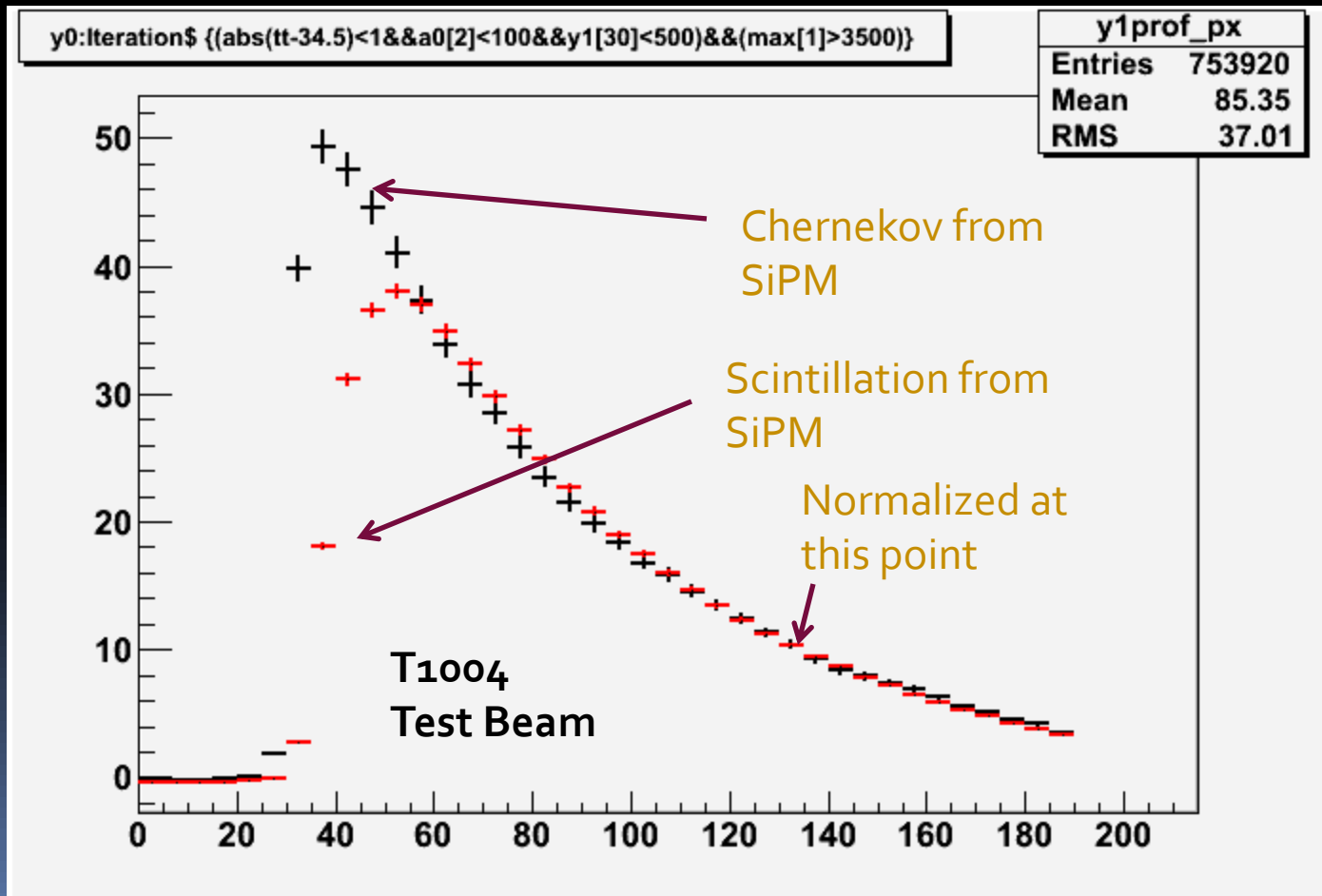
180 digitizations \* 4.708ns = 847ns . Small pulses and Large pulses!

# Muon detector (7m MINOS extrusion) read both ends with 1.2mm SiPM and TB4 electronics



# Electronics for SiPM

- TB<sub>4</sub> also works for dual readout calorimetry (single 5x5c, crystal in 4GeV beam)



# Electronics for Bigger Calorimeter

- Step 3 ? : detector specific electronics
  - Precision calorimetry is a challenge
    1. Dynamic Range
    2. Linearity
    3. Calibration
- Next step is still COTS (no ASICs) but much more application specific
  - Probably different electronics for PMTs and SiPMs
- More specific = lower cost/ch but more effort
  - Optimize for  $O(100)$  ch

# Electronics for Calorimeter

- Step 4 : designed for a specific calorimeter
  - For a “real” calorimeter:  $O(5000)$  chan
  - System aspects: power, cooling, control, readout
  - ASICs required
    - ASICs take a long time to develop (critical to have experience!)
    - Need to start prototypes so they can participate in small calorimeter ( $O(100)$  = MOSIS MPW)
    - System design: calorimeter AND electronics

# SPARC

- ASIC in progress!
  - Basic idea is QIE on steroids
    - 16bit+ dynamic range, 1ns timing, 0.2pe noise

## Preliminary Specifications for a Silicon Photo-diode Amplifier and Readout Chip (SPARC)

V1.0 PDR 5/24/2010

### 1. Introduction

Recent developments in photodetectors have continued to rapidly evolve the state of the art in SiPMs. New devices are appearing and new companies are joining the development effort. ST Micro devices has shown new SiPMs samples and Zecotek has produced devices that have on the order of 14000 micro pixels per mm<sup>2</sup>. Currently at Fermilab we have devices from HEP, PHOTONIX, SensL, Zecotek. These manufacturers and others are working to optimize SiPMs for use in astrophysics, medical imaging, calorimetry. We believe that the development at Fermilab should focus on supporting core competencies already present at the lab. One such core competence is scintillator extraction. Fermilab has world leading competence in designing and manufacturing extruded scintillators, including Misas, Miserva, TOS and other experiments. Such scintillators use WLS fibers to collect the light from the scintillator and carry it to the photodetector. Because the typical diameter of the WLS fiber is on the order of 1mm, this is a very good match for SiPMs.

Another key strength at Fermilab is expertise in calorimetry for High Energy Physics. The next generation of HEP detectors will need to implement significant improvements in calorimetry, especially for jets, and Fermilab has strong involvement in the two most promising approaches to achieving this goal- particle flow and dual readout. It should be noted though that the CALICE collaboration is leading this effort for particle flow approach. Another important motivating force behind SiPM development for calorimetry is potential upgrades for SLHC, the CMS HCAL, specifically. This is also a natural fit for Fermilab as the current electronics for CMS HCAL was developed here at Fermilab. A word about terminology: the Particle Data Book recommends PPD as the generic term for "pixelated photon detectors". For reasons that should be obvious to the reader we will reject this advice and will stick with the somewhat inaccurate SiPM, which is usually pronounced sip-em.

### 2. Statement of Goals

We propose the development of a new application specific integrated circuit (ASIC) designed to support the development and near term applications of SiPMs in scintillator coupled applications. These applications fall into two broad categories: minimum ionizing particle detectors and calorimetry applications. Typically minimum ionizing particle detectors would be plastic scintillator based, with wavelength shifting fiber readout. These applications would include such things as muon detectors, calorimeter tail catcher, cosmic ray veto and tomography detectors, neutron detectors. These detectors do involve some aspects of calorimetry, but in general the dynamic range required is modest. The other major area of application of SiPMs is calorimetry. In this case, the SiPM is likely to be directly coupled to a scintillating element, such as a crystal. For

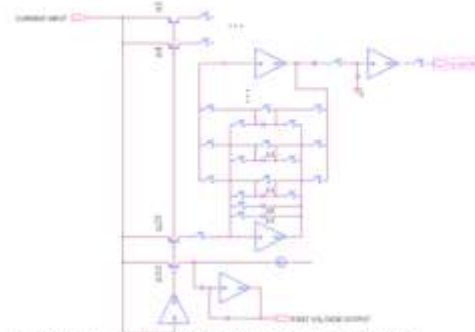


Figure 7: A more complete schematic of the SPARC, showing 4 current splitter paths and one integration path for each of these.

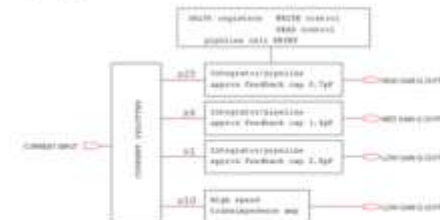


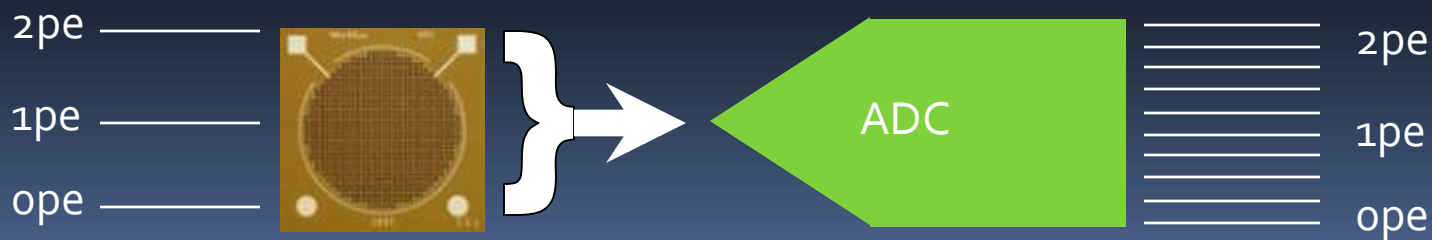
Figure 8: Functional blocks of the SPARC.



# The Future



- I have seen the future of SiPM readout
  - Readout electronics **will be integrated into the SiPM!** because
    - SiPM is an inherently digital device
    - We ALWAYS convert the signal from the SiPM to digital
    - So why do we have an analog step in between?!?



# The future

- I never said I was the ONLY one...
- SiPM is not a tiny PMT but it is a very simple ASIC

Next step for SiPMs is ROC+Sensor unit

Oct 8, 2009 Philips announces breakthrough in fully digital light detection technology  
Eindhoven, the Netherlands - Royal Philips Electronics today announced that its scientists have developed a highly innovative digital silicon photomultiplier technology that will allow faster and more accurate photon (the basic quantum unit of light) counting in a wide range of applications where ultra-low light levels need to be measured.



# There is more future yet..

Grzegorz Deptuch

on behalf of the FERMILAB ASIC design group

Raymond Yarema, Grzegorz Deptuch, Jim Hoff, Farah Khalid, Marcel Trimpl, Alpana Shenai, Tom Zimmerman

Hey! I know these people!

3D-IC technology for future detectors, FNAL, 02/17/2009



## Why 3D-IC?

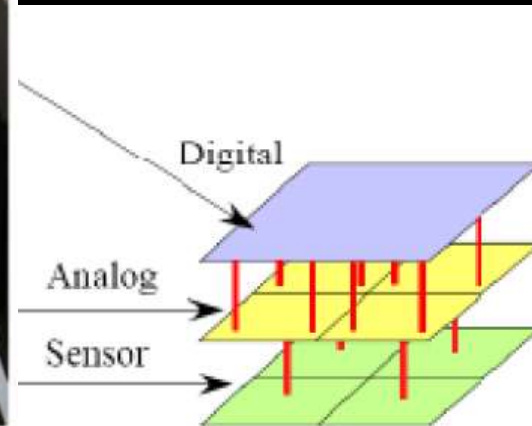
### Real estate analogy

How much time, effort and energy (gas) is needed to communicate with your neighbors in 2D assembly?

2D



3D



## Fermilab position in 3D-IC

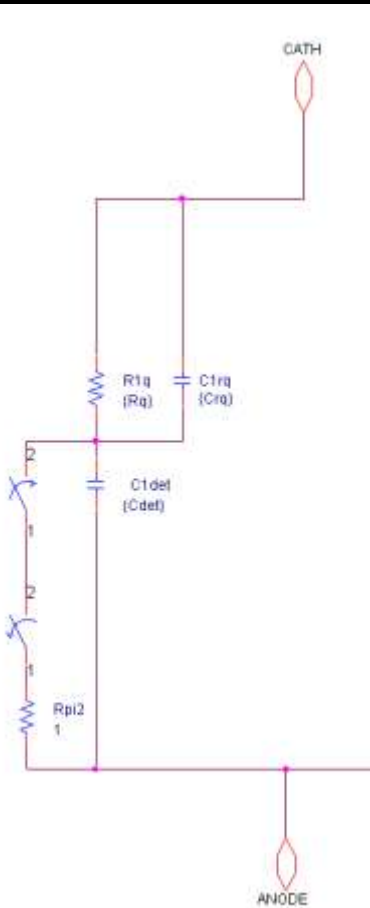
Fermilab began exploring the technologies for 3D circuits in 2006.

Fermilab is leading an Int'l Consortium (15 members) on 3D-IC for scientific applications, mainly HEP

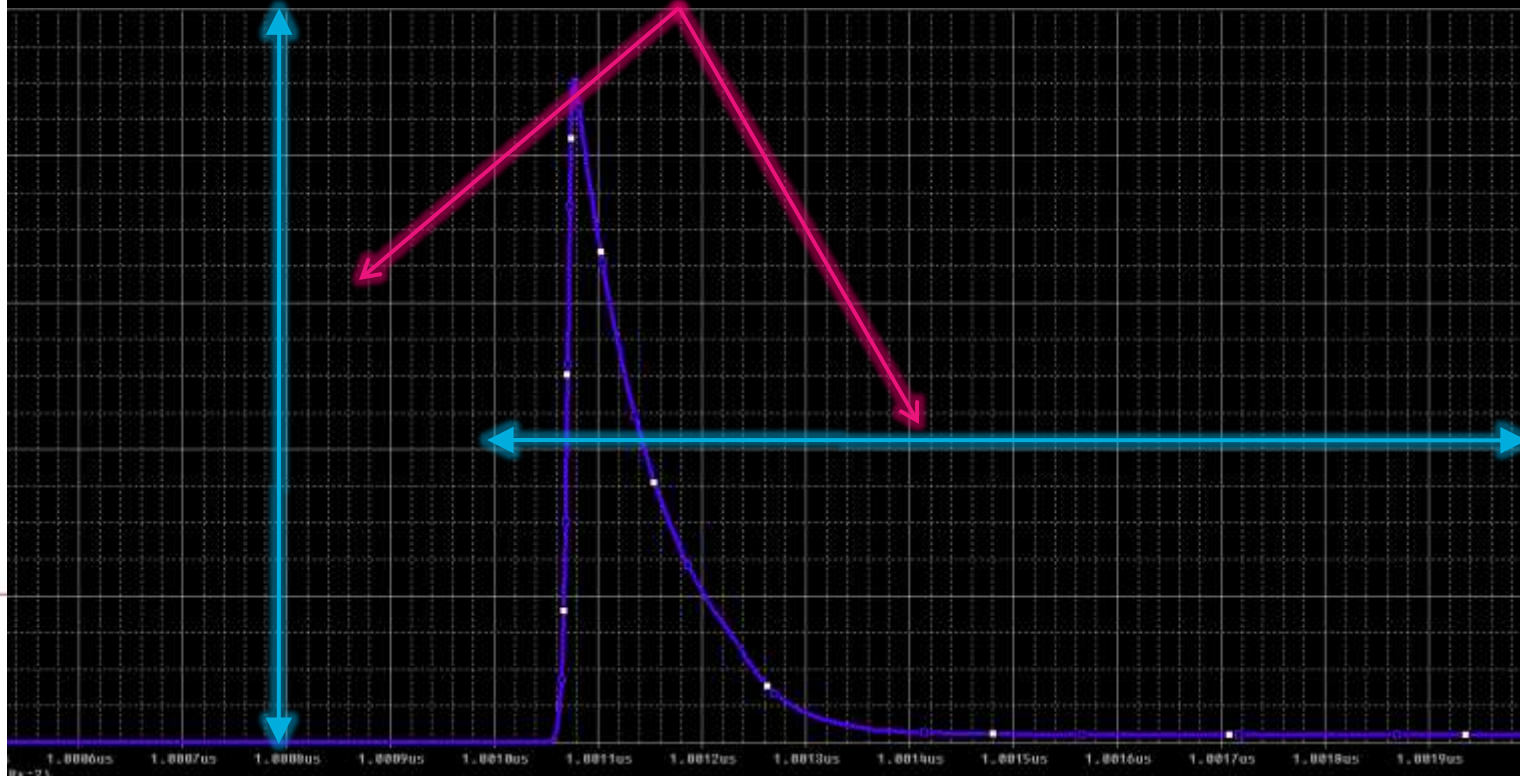
# 3-d for SiPMs?

- Oh yes. You don't need an amplifier.

Lets see what happens if we just have 1 pixel



1000 x bigger amplitude  
10 x faster pulse



# Conclusion

- We have a clear road map for electronics to support dual readout calorimetry
- Our efforts can scale to match the scale of R&D

BUT

We are in a unique position to move on 3-d SiPMs

- Modern detectors can not afford to put off thinking about electronics. Must be supported at a proportionate level