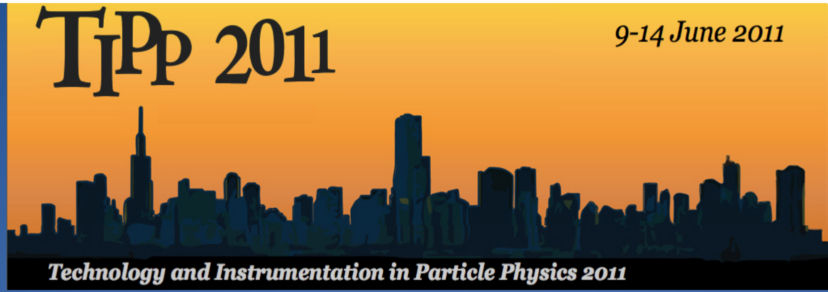


Scintillator-based muon detector/tail catcher with SiPM readout

Gene Fisk, Giovanni Pauletta and Paul Rubinov

for the
T995 collaboration

Collaborators

FNAL: H.E. Fisk, A. Para, E. Ramberg, P.M.Rubinov, A. Soha, T. Fitzpatrick

Notre Dame: M. Wayne, M. McKenna

Udine: D. Cauz, A. Driutti, G. Pauletta, L. Santi

Trieste: W. Bonvicini, L. Bosisio, I. Rashhevskaya

NIU: S. Cole, I.Viti, D. Hedin, R. Shea, Sasha Dychkant

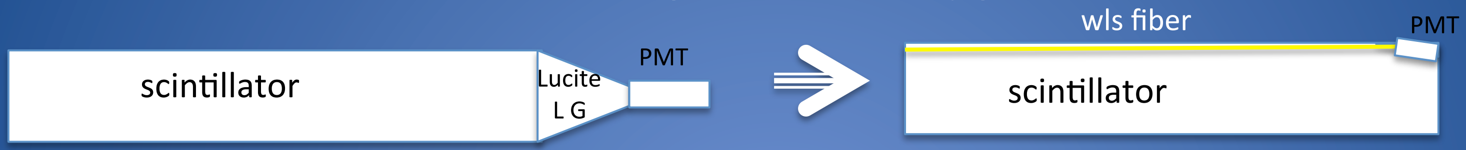
Wayne State: P. Karchin, A Gutierrez

Recent evolution of large area scintillator – based detectors

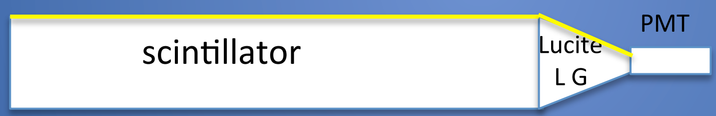
1990

development of double-cladded wls fiber → more flexible/compact alternative to classical light guides

(e.g. CDF muon upgrade)



moreover, light collection by wls fiber *is much less susceptible to deterioration in scintillator transmission* (e.g. recovery of aging CDF muon counters)



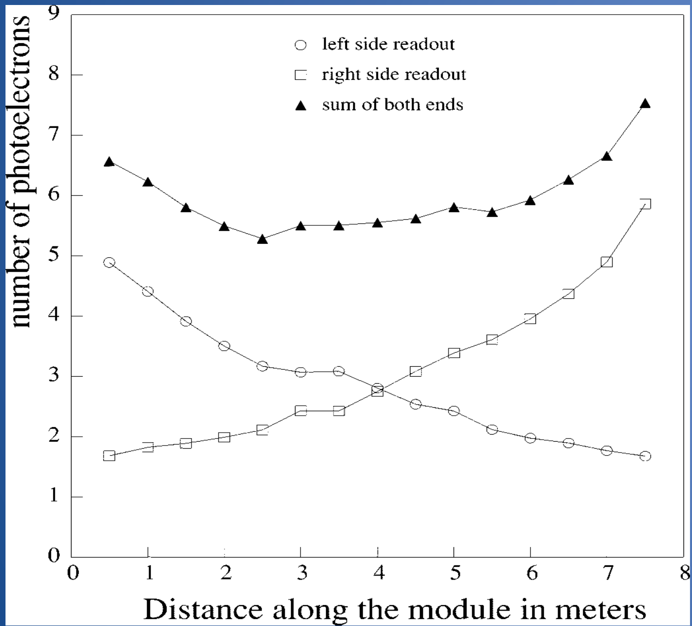
Use of wls fiber for light collection & transmission can compensate for lower scintillator quality

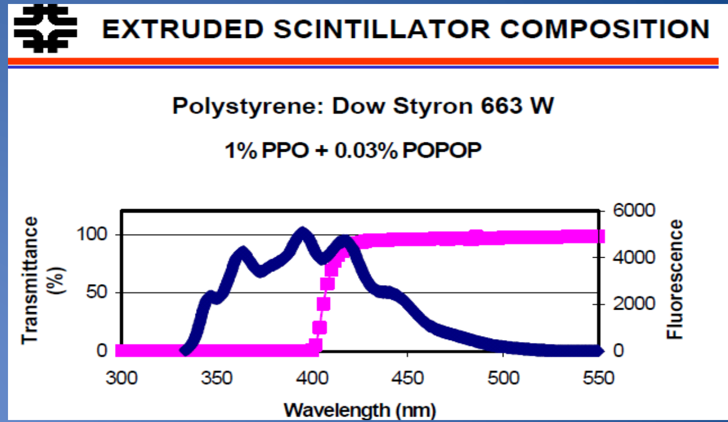
⇓

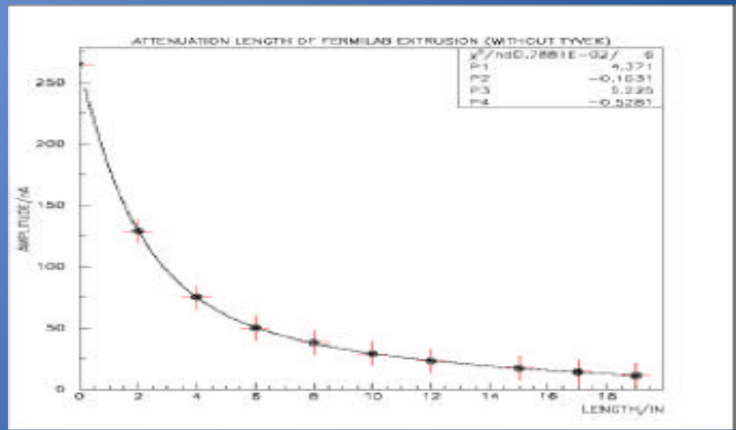
Development of cost effective extrusion techniques of commercial-grade polystyrene- based scintillator (FNAL/NICADD)

2000

MINOS type extrusions with *single fiber readout* have the potential to satisfy large-scale (e.g collider) muon detector/tail-catcher requirements







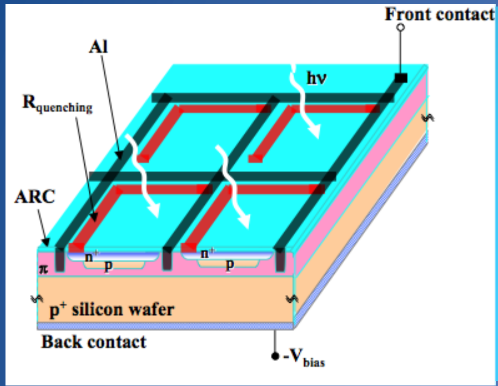
MAPMTs (or APDs) first used for single – fiber readout

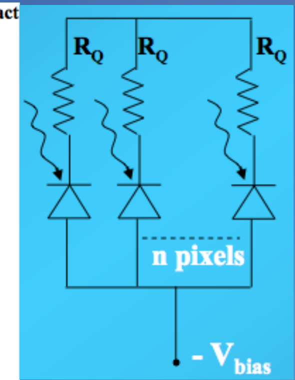
Silicon Photomultipliers (SiPMs) are developed around the same time

1990

- Matrix of N micro-cells ("pixels") in parallel, connected to a common output node
- Each micro-cell: GM-APD + $R_{quenching}$
- V.M. Golovin and A. Sadygov (Russian patents 1996-2002)

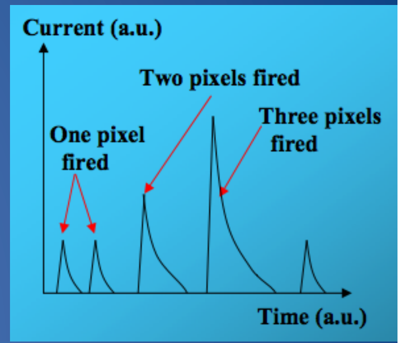
|





Each element is independent and gives the same signal when fired by a photon
output signal is proportional to the number of triggered cells =number of photons for PDE=1

$Q = Q_1 + Q_2 = 2*Q_1$



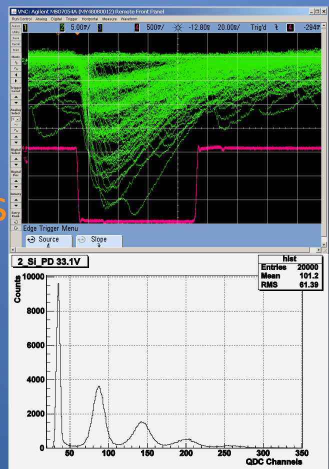
|

Dimensionally well-matched to wls fiber

and:

- self-calibrating
- low bias (20-70 V)
- insensitive to magnetic fields
- potentially cheap
- fast (ps)
- Rugged
-

|



but:

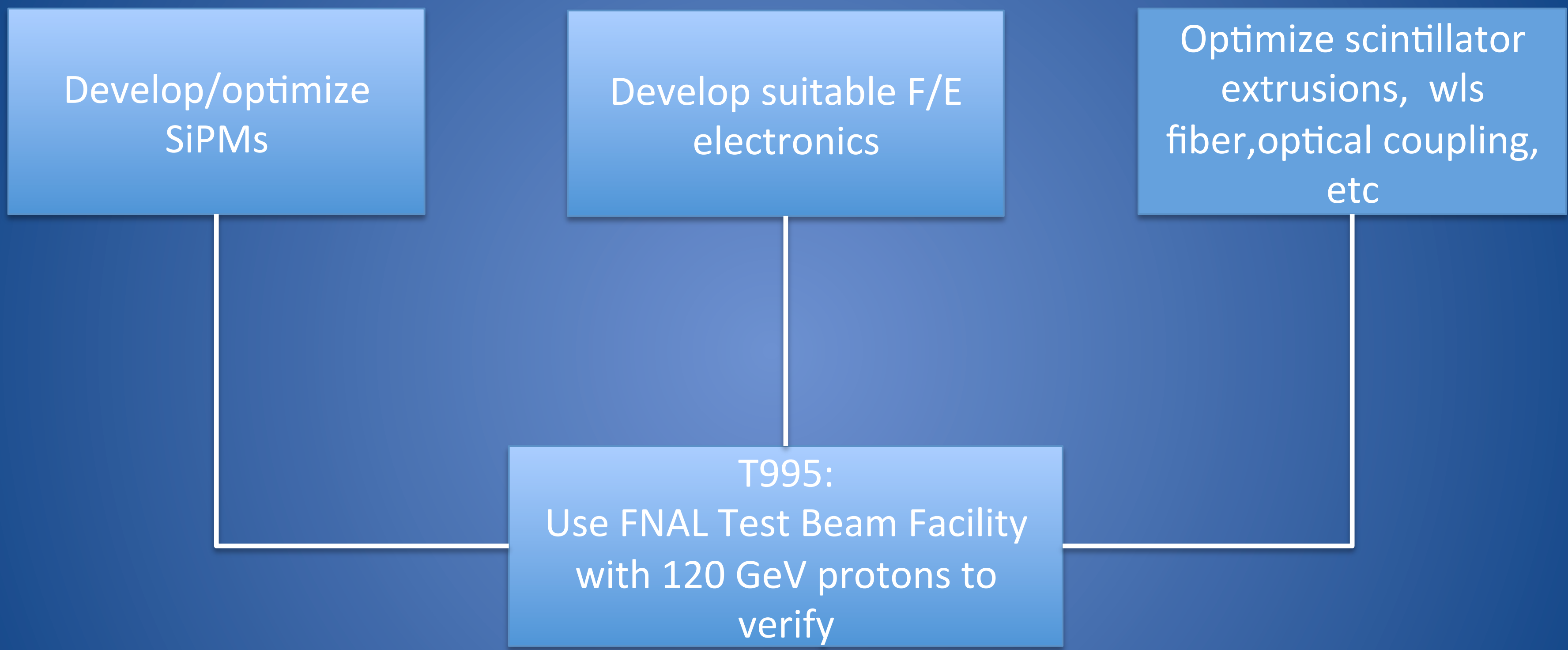
- High (~1 MHz) 1 p.e. dark current
- After – pulsing
- Dynamic range
-

|

2000

|

R&D program: continue development of Scintillator-based muon detector/tail catcher with SiPM readout



Develop/optimize SiPMs

INFN – supported projects:

FACTOR (2007 – 2010): Trieste, Udine, Roma1 & Messina

TWICE (2011–): Trieste, Udine, Roma1, Messina, Como, Lecce

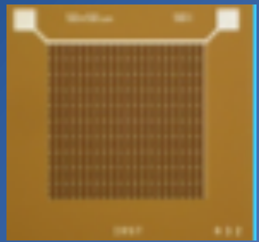
In collaboration with: FBK (Bruno Kestler Foundation) – IRST (Yrento Italy)

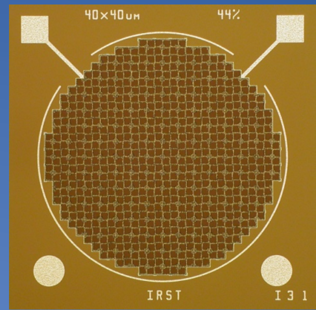
Objectives: develop/optimize SiPM and FE electronics for HEP applications
- Current emphasis on calorimetry and large area scintillation counters

- Optimize parameter space (SiPM pixel size, fill factor, Q.E., etc.) for specific application
- test (static and dynamic measurements in climatically – controlled conditions)
- Irradiation tests (X- Rays and neutrons)
- Development of FE electronics

SiPM developmentor T995

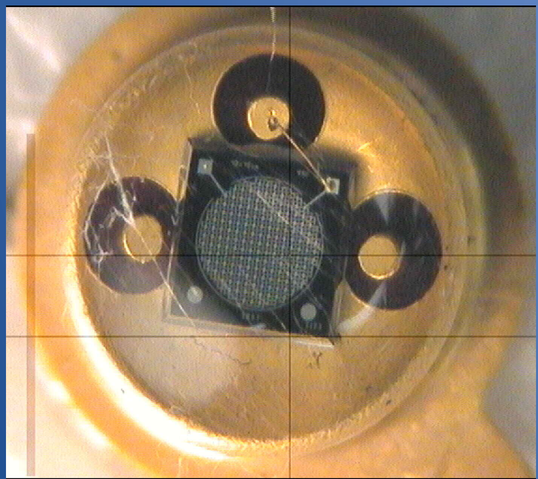
$1\ mm^2$
~ 20%
fill - factor

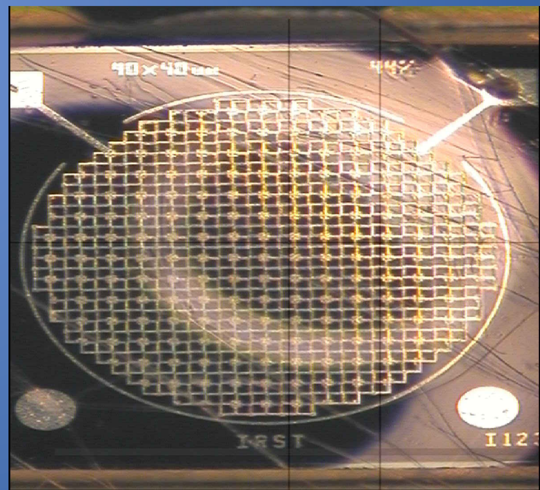




Geometry: circular
diameter: 1.2 mm
Microcell: 40 x 40 μm
Improved fill-factor (44%)
Breakdown voltage ~30.5V

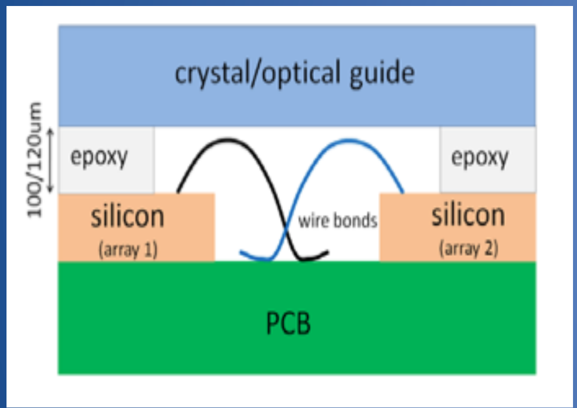
Epoxy protective coating (for direct contact with fiber) implemented on TO18 package

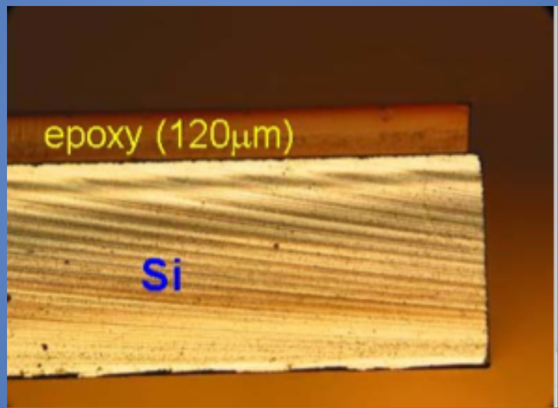


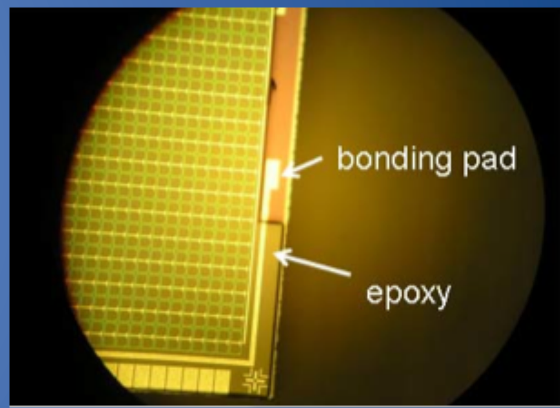


Further improvements

- no need for large dynamic range → increase microcell size (100 μm→improved fill – factor →improved light collection efficiency
- Implement latest SiPM assemblies to develop coupling/cabling schemes appropriate for assembles of many extrusions/channels







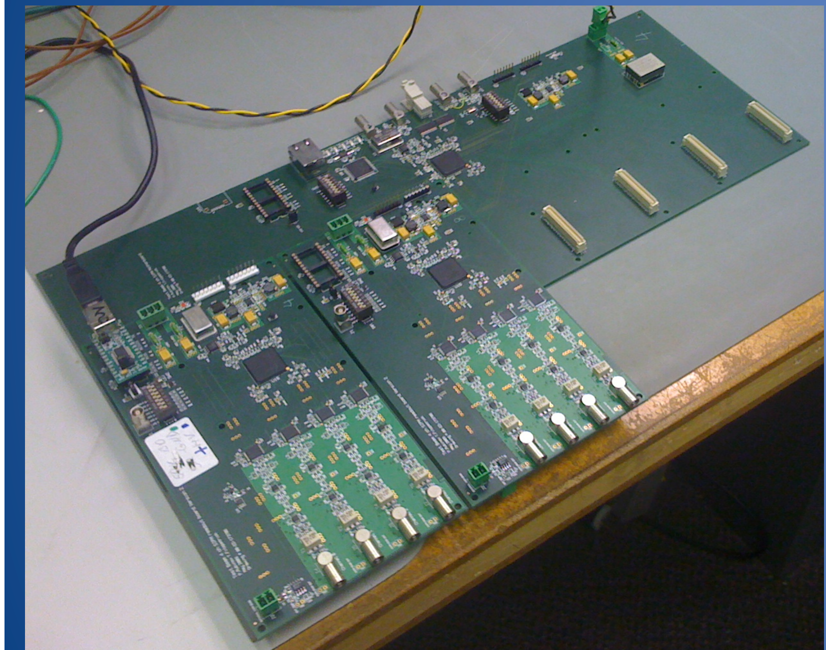
Pc – mounted SiPms with epoxy layer are well – suited for distribution along "ribbons" incorporating transmission lines and some FE electronics.

FE electronics

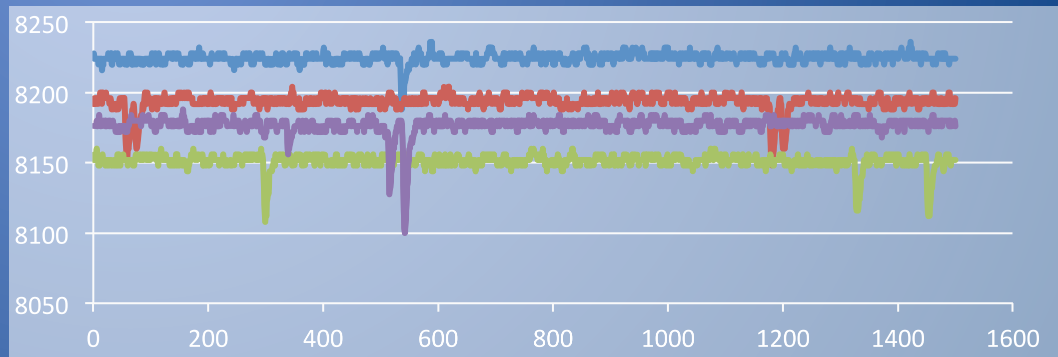
For T995: FE electronics have been developed in-house at FNAL

Strategy: development of a board SiPM studies that strikes a good balance of performance and cost, simple to use with relatively few channels and easy to adapt to new needs/ideas

TB4 F/E electronics

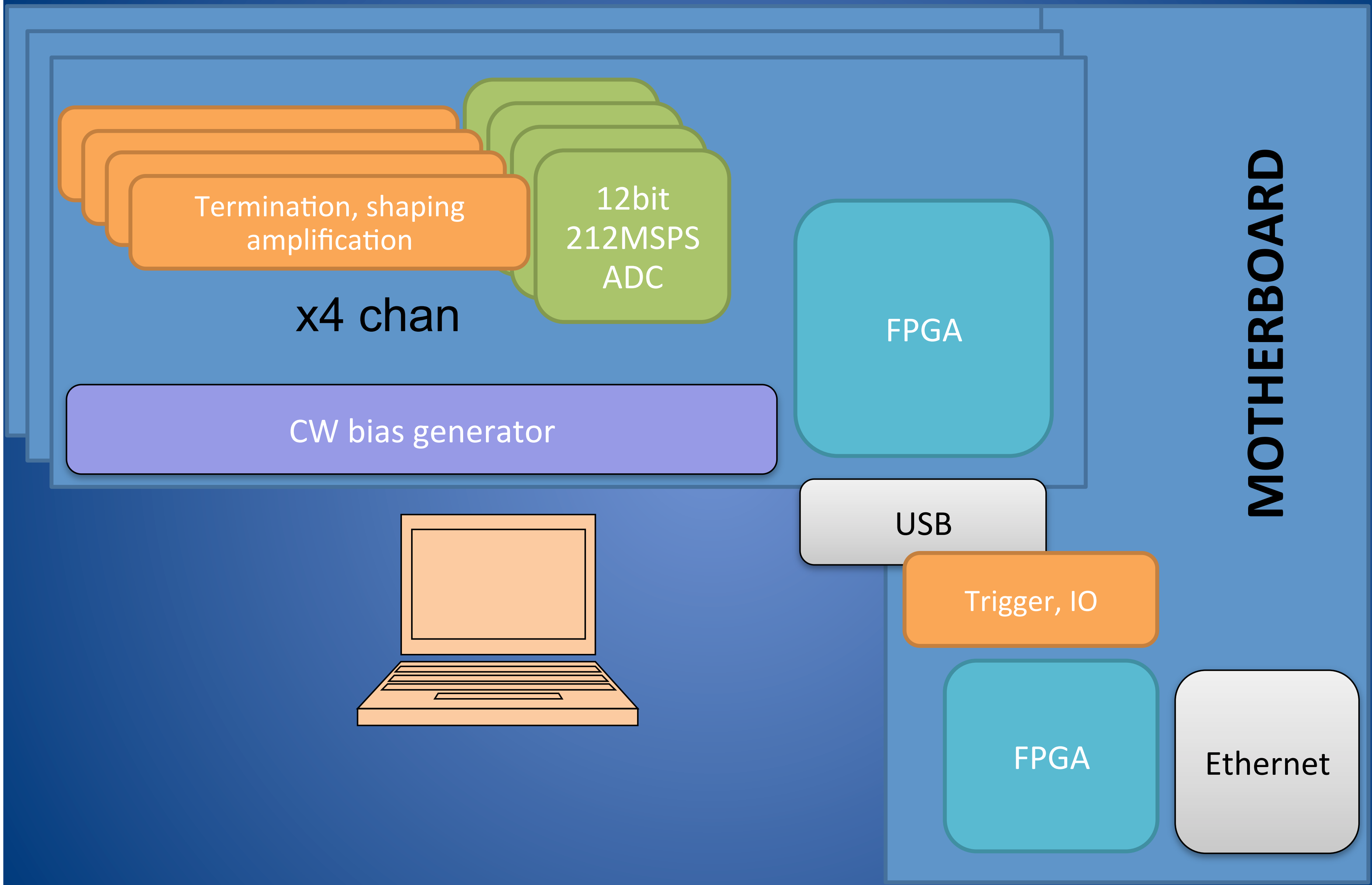


- On-board bias – shares signal connection
- 50 ohm input, ~ x 100 amplification
- ~100 MHz bandwidth, noise ~ 30μV RMS
- 12 bit ADC →large dynamic range, 212 MSps, <4k samples/ch, 4,7 ns/ch
- Bipolar : pedestal is around half scale (8100)
- Set up over USB, read out over 100 mbit/s ethernet



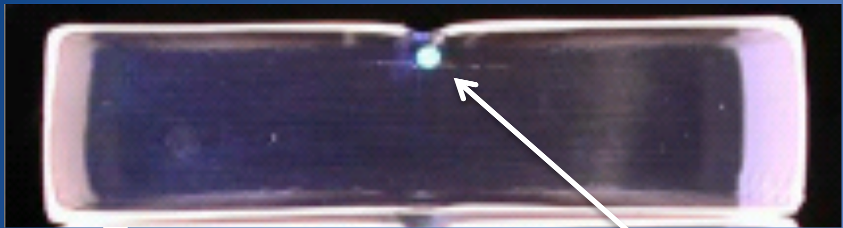
(1)Alternative FE electronics incorporating fast amplifiers developed at Trieste (pp and conventional independent digitization schemes have been used for calorimeter tests at CERN

TB4 F/E electronics



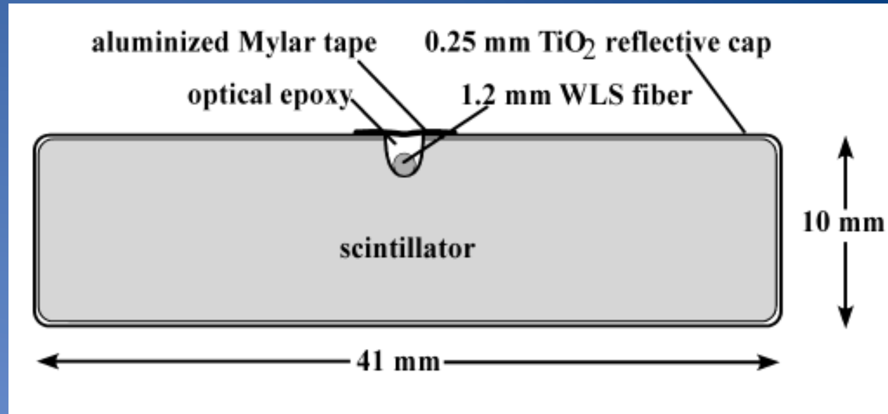
T995: Test beam measurements

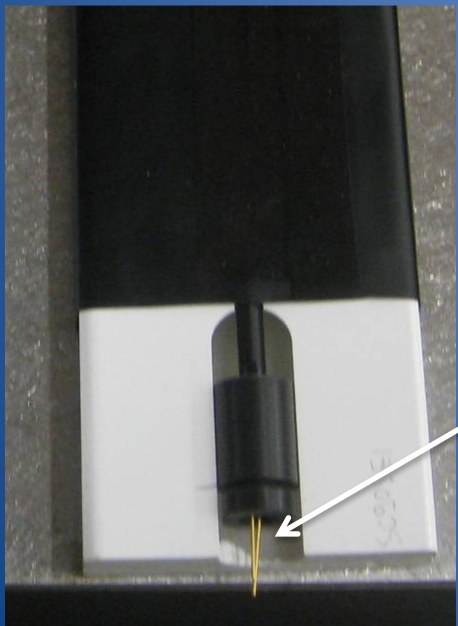
MINOS die extruded scint.
142" X 4.1cm X 1 cm



co-extruded reflective coating

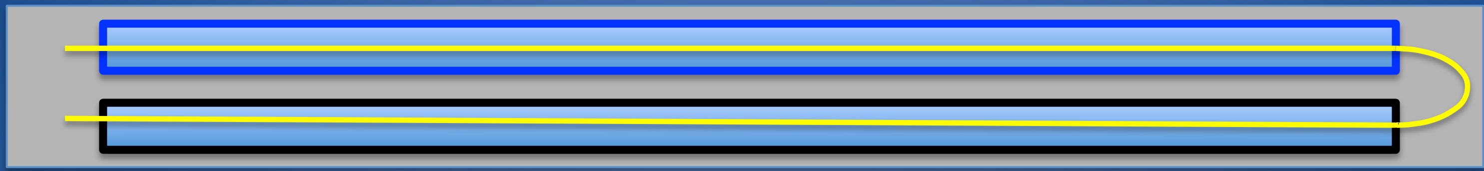
Kuraray Y11 wls

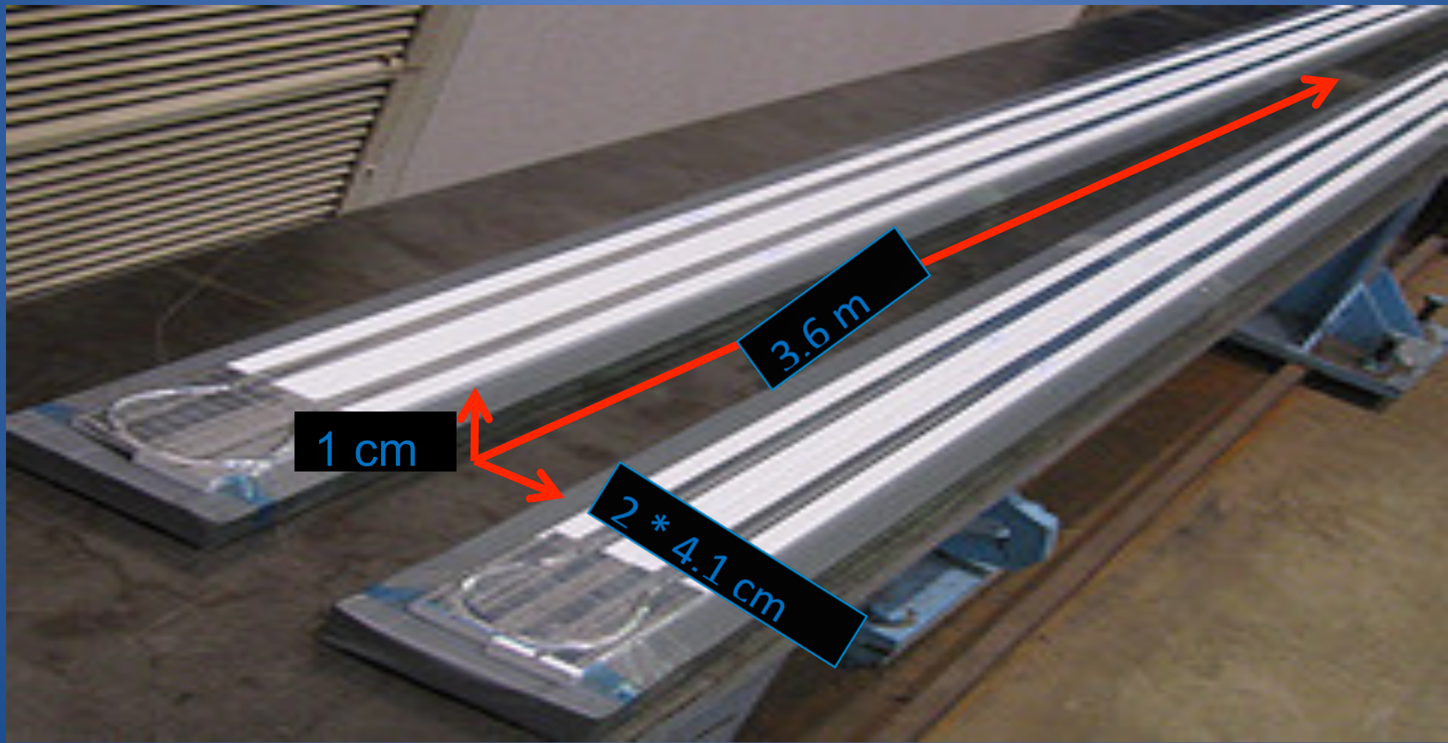




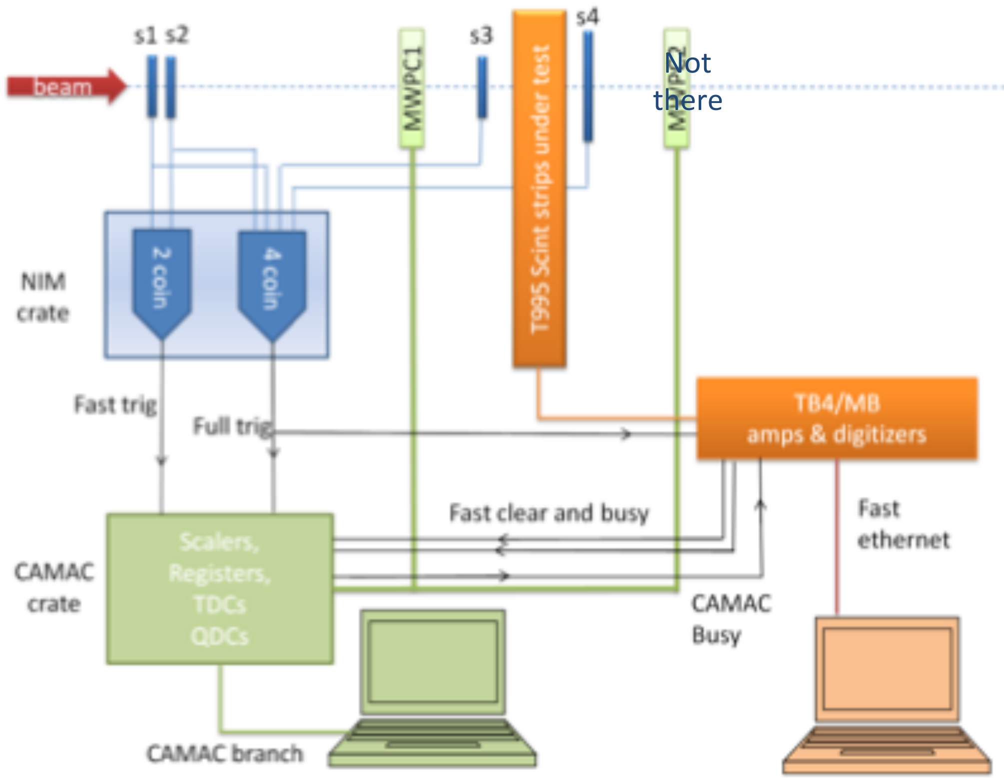
FBK-IRST
1,2 mm diam
SiPM

Two 3.6 m extrusions read out by single wls fiber → 7.2 m



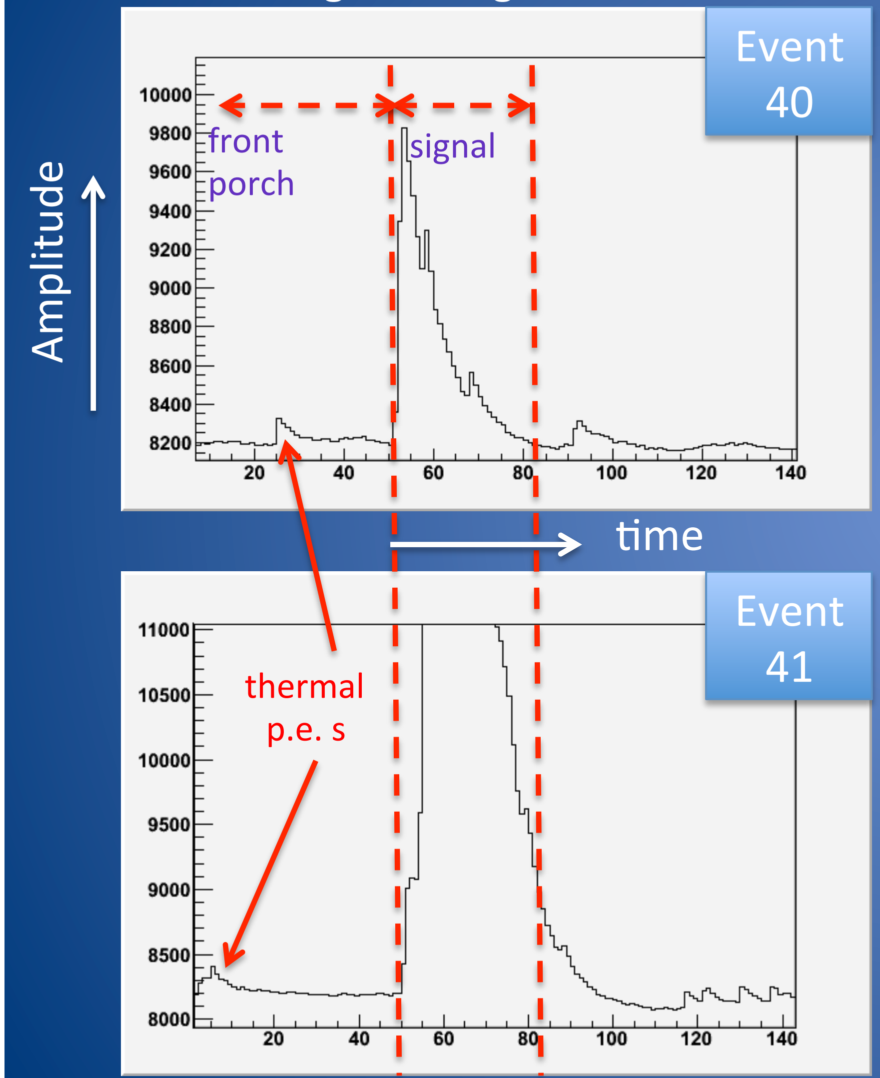


T995 at Fermilab Test beam Facility

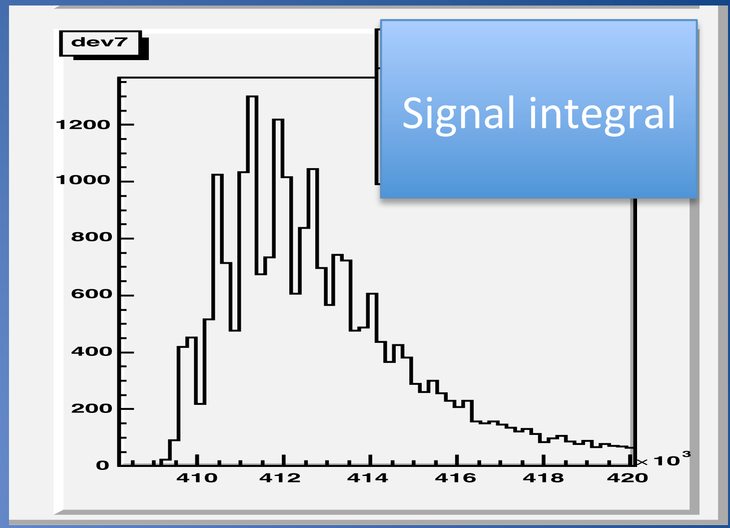


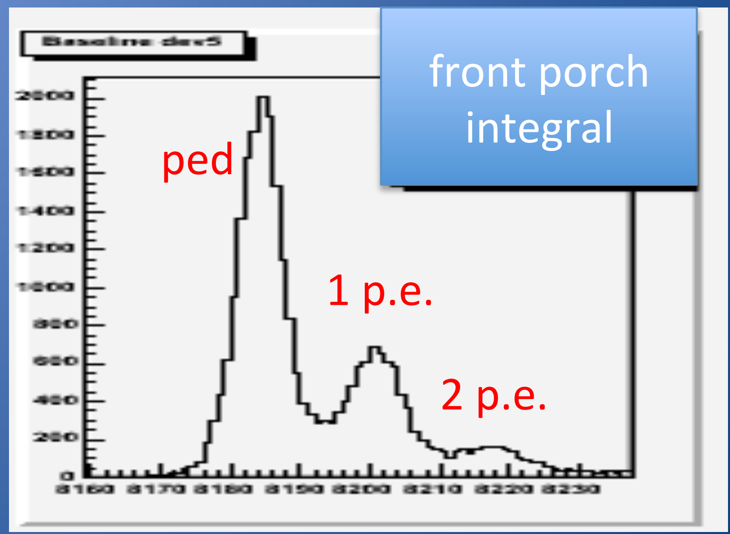
Data taking with simultaneous autocalibration

TB4 output :
digitized signals

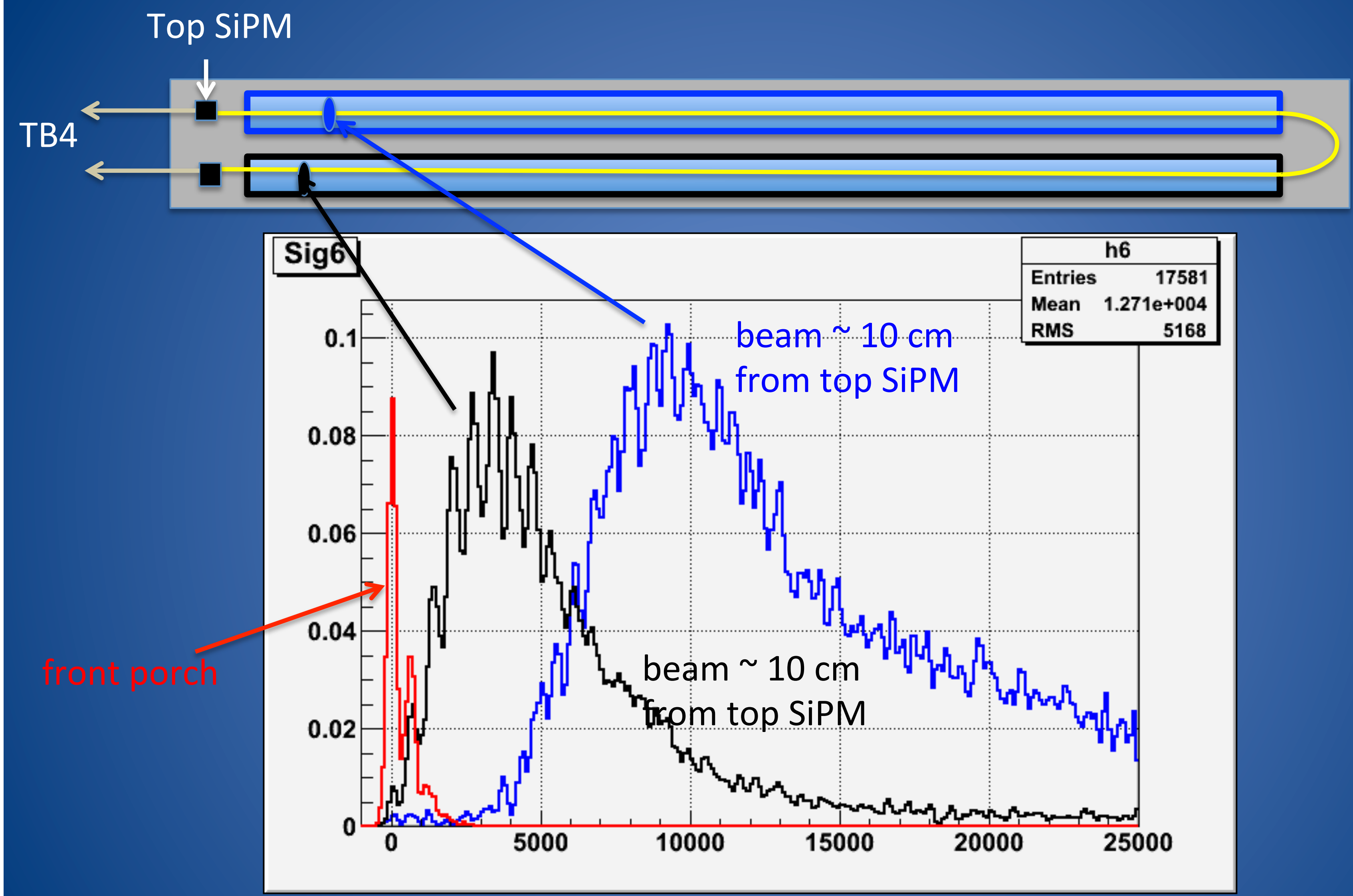


Distributions of integrals

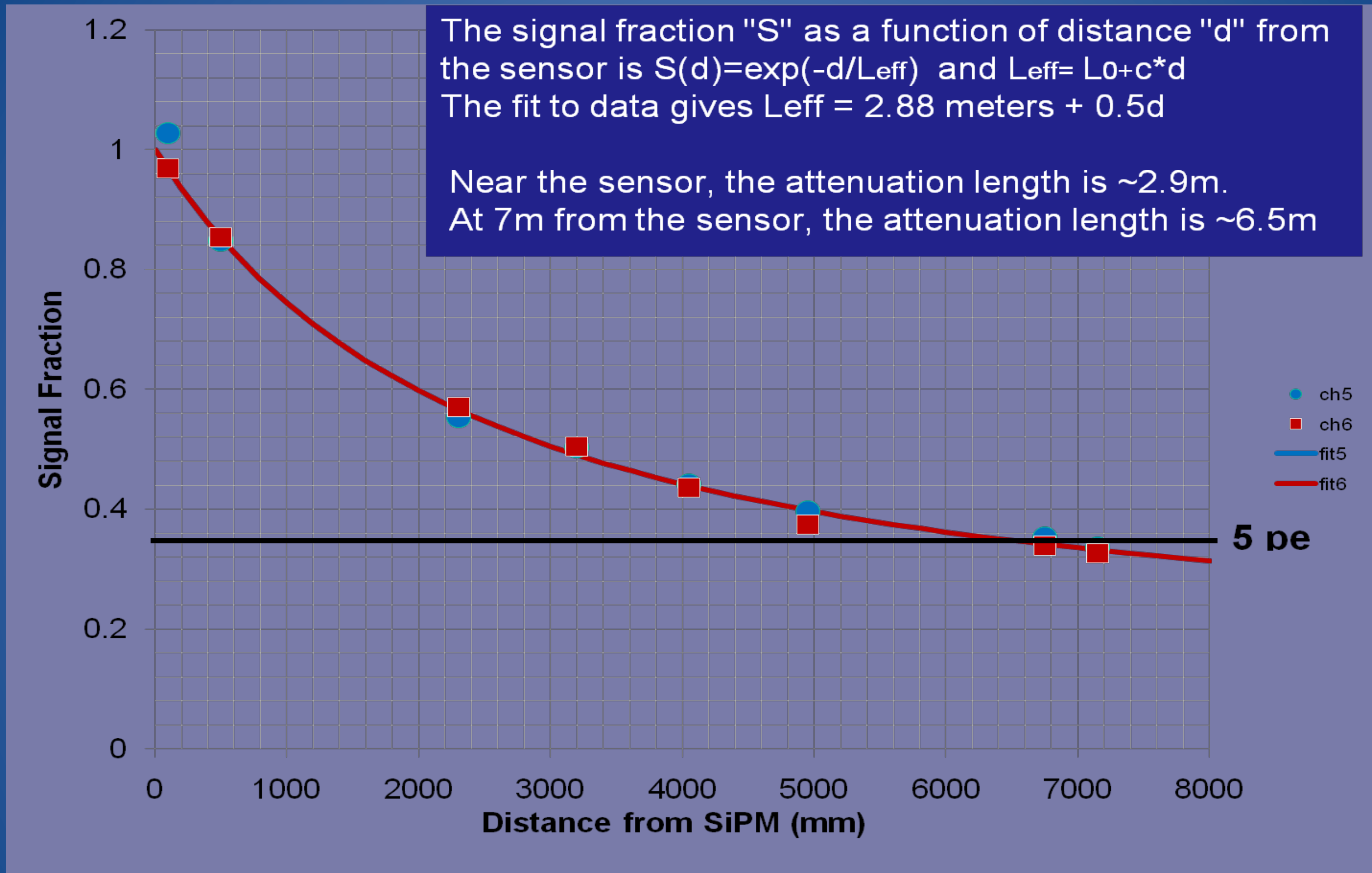




Signal distributions from top SiPM



Attenuation length



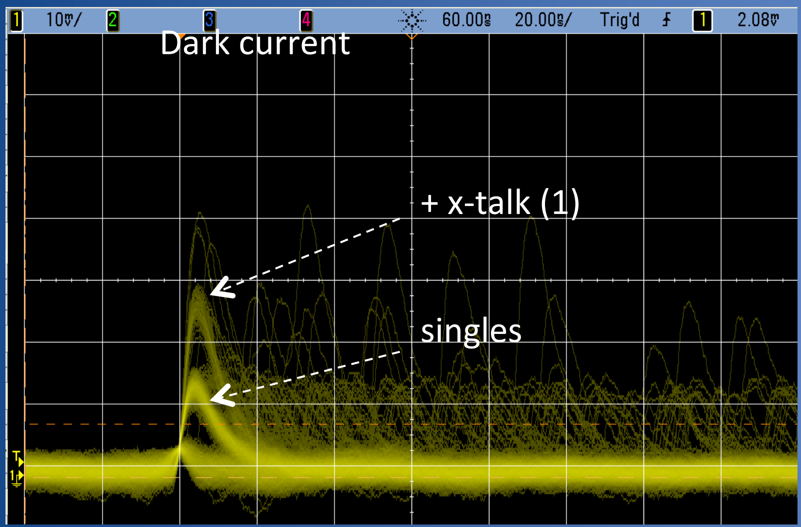
N.B. The fiber is read out from both ends.
This attenuation length is calculated using only one of the two readouts.

Efficiencies and backgrounds

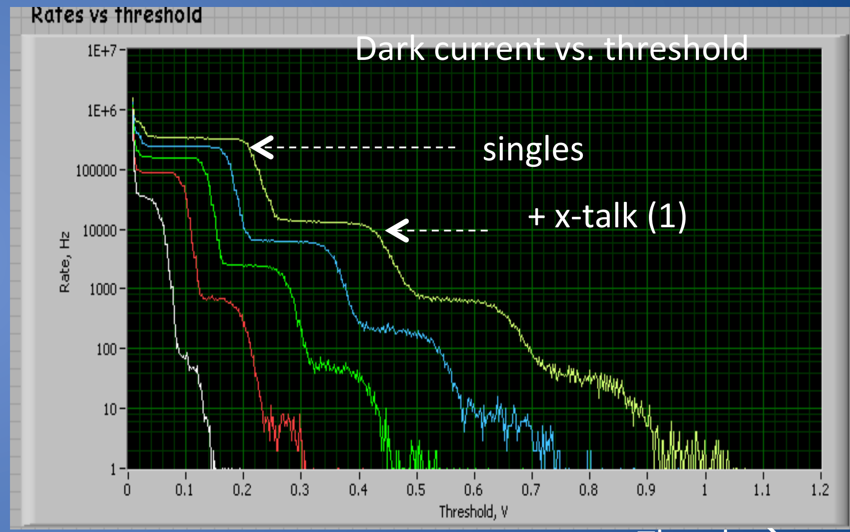
$$p(n) = \left(\frac{\mu}{n!} e^{-\mu}\right)$$

With a mean number of p.e.s $n = 5$ (at 7 m), assuming poisson statistics and a threshold $n < 1$, we might achieve inefficiencies of 99,3 %

however a dark current of ~ 1 MHz, combined with cross-talk, might impose (depending on background tolerance), a threshold > 1 p.e.



D.C.

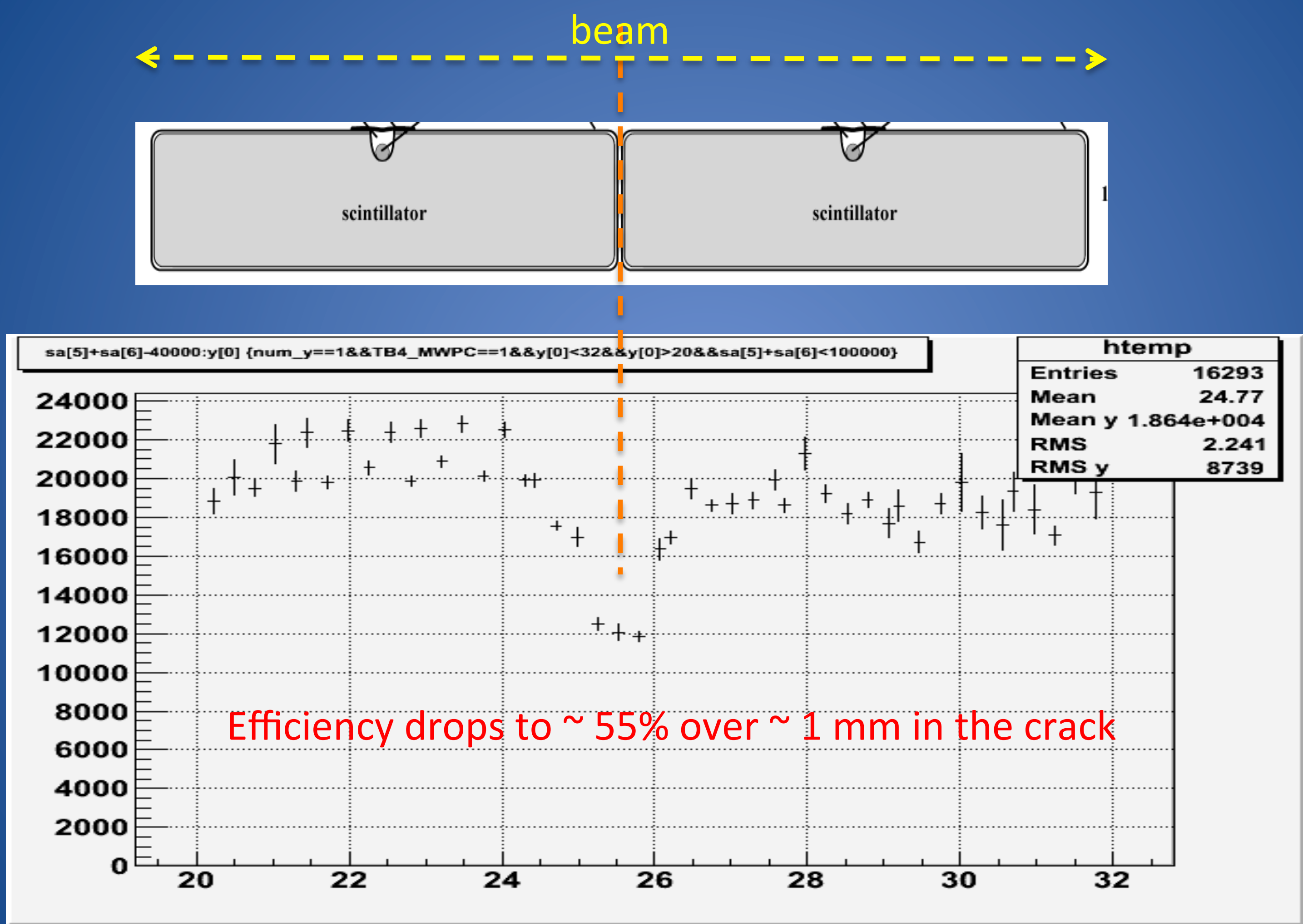


Thresh-→

…. with a consequent growth in inefficiency

Thresh (pe)	ε (%)
< 1	99, 3
< 2	96,7
< 3	91,6

Inter-strip crack inefficiency



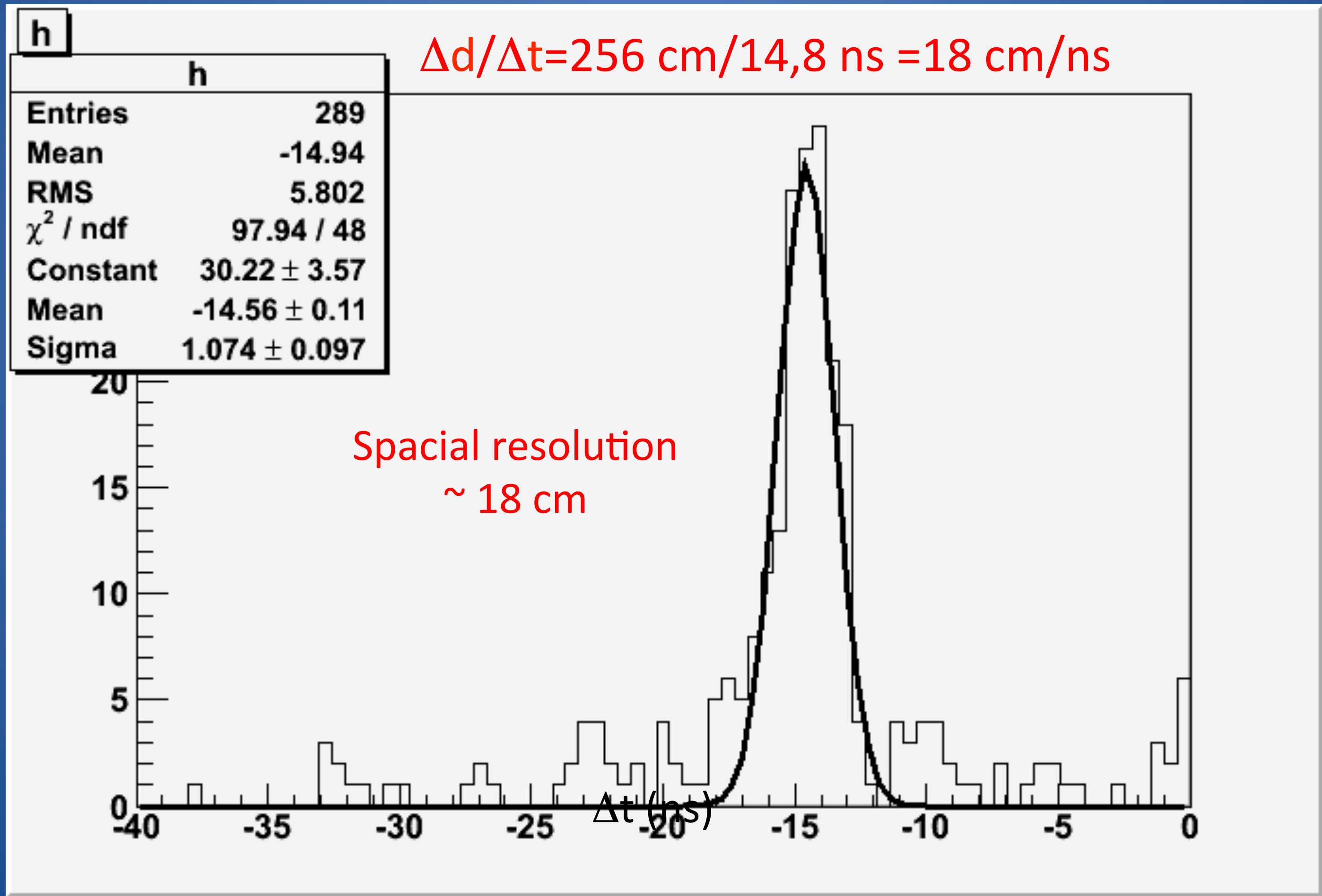
Efficiency drops to ~ 55% over ~ 1 mm in the crack

Spacial resolution along strip

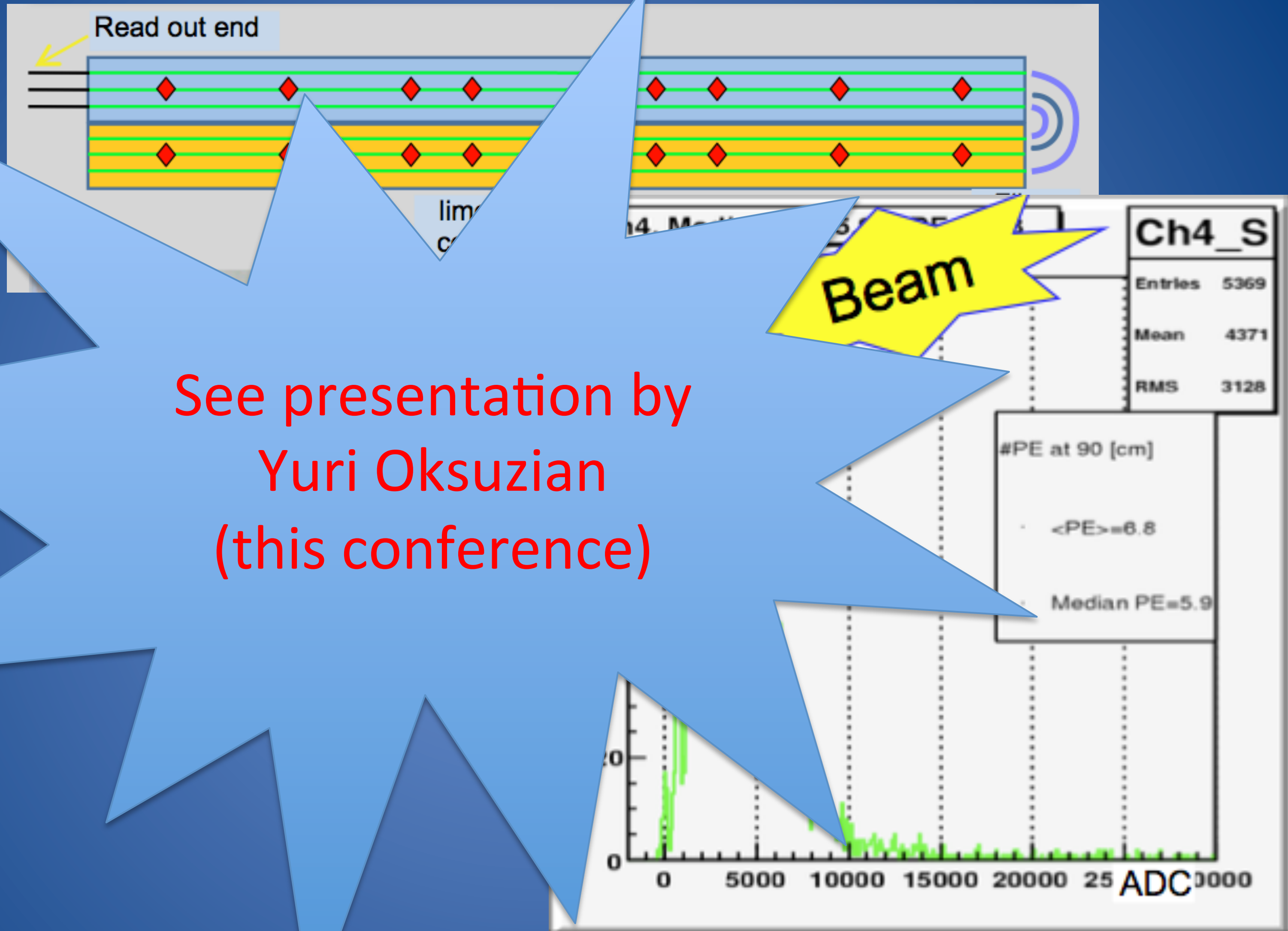
$\Delta t = \Delta$(time of arrival) of signal at two ends of the fiber

--- corresponds to ----

$\Delta d=\Delta$(distance of beam) from two ends of fiber



Also tested mu2e extrusions



See presentation by
Yuri Oksuzian
(this conference)

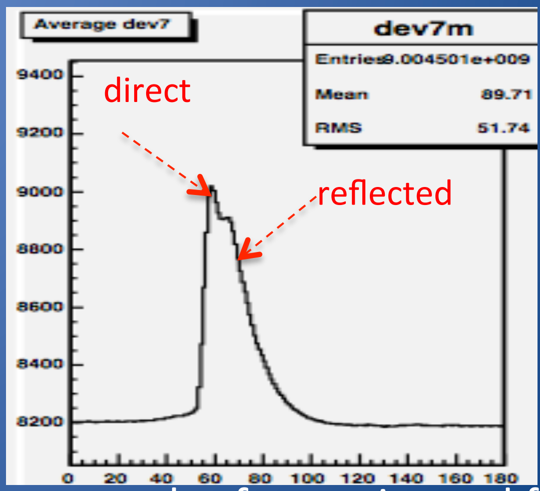
Still to be done

* The results reported here are for data read out from one end of the wls fiber (which was also read out from the other end)

* Performance of extrusions with single-ended readout and mirrored opposite ends yet to be established (data analysis to be complete, maybe more data needed).

* However, can only improve on results for efficiency reported here for readout from one end (without mirroring)

* One would timing information from other end → location of hit along extrusion. However, with good timing resolution and an appropriate algorithm, on might be able to seperate direct from reflected pulses to recover some of that information.



Average pulse from mirrored fiber

Summary/Conclusions

- Signal corresponding to ~ 5 p.e. s have been measured at ~ 7 m for basic MINOS – style extrusions (without mirroring) read out with 1.2 mm Kuraray Y11 wls fiber and FBK SiPMs

- TB4 electronics, developed at Fermilab, allows for efficient and versatile DAQ with simultaneous self – calibration

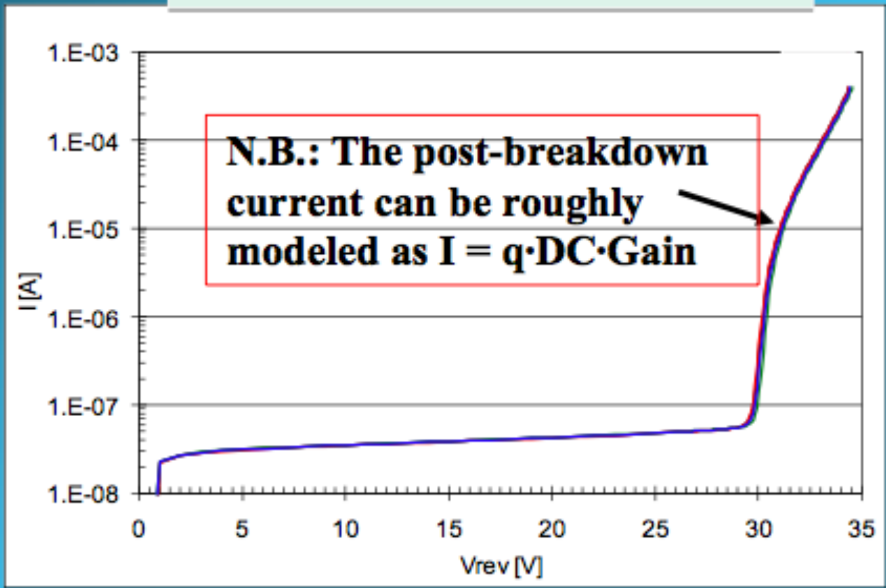
- There is room for further improvement:
  - ➢ Mirroring of wls fiber
  - ➢ SiPMs with larger microcells and improved fill-factors
  - ➢ Development of improved extrusions/optical couplings

- Attention shoild now focus on problems related to integration:
  - ❖ Assembly of strips in to planes
  - ❖ Distributed optical couplings and cabling
  - ❖ ASICS

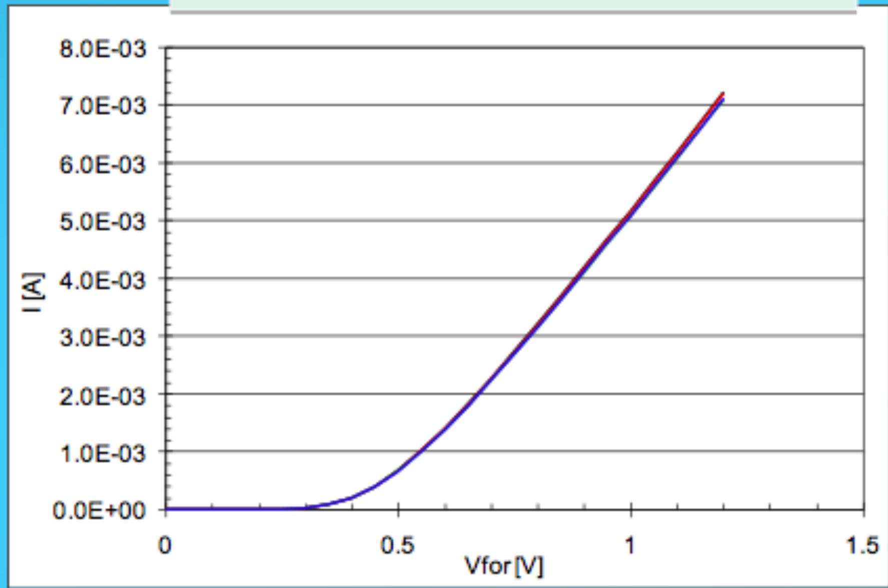
Backup

Static measurements on SiPMs

Reverse I-V



Forward I-V



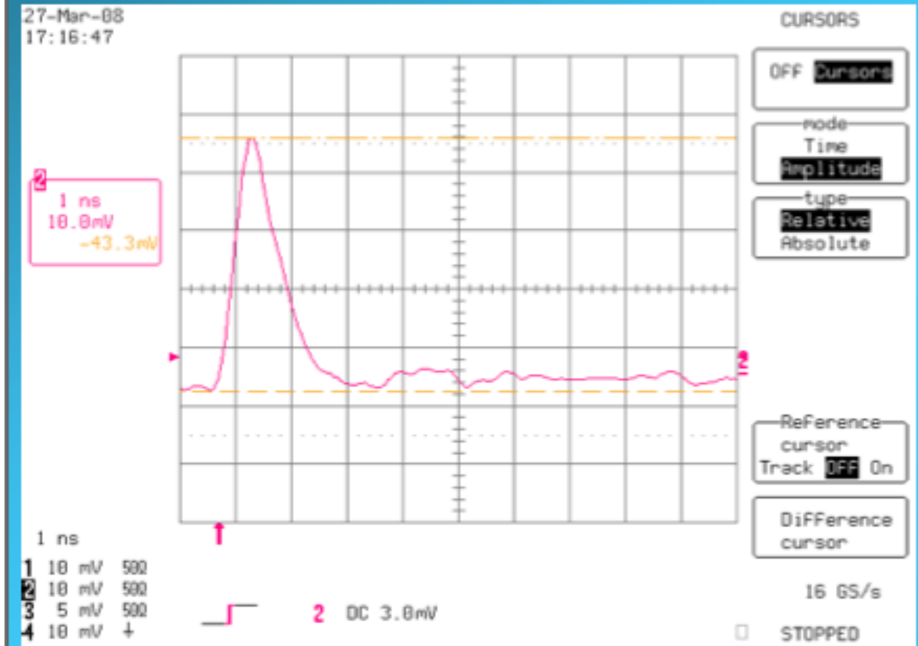
- Functionality of the device
- Breakdown voltage V_{BD}
- Dark count estimate

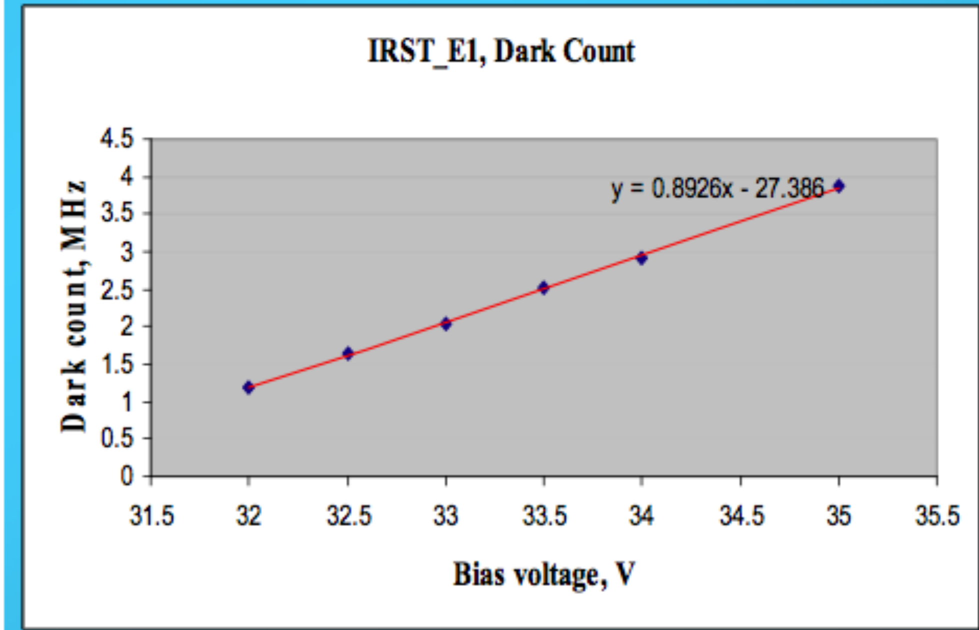
- Functionality of the device
- Quenching resistor value estimate

Trieste, 5 luglio 2010 Giornata Seminariale di Sezione Valter Bonvicini 10

Dynamic measurements in dark

- Signal shape, amplitude and timing characteristics
- Dark-count and gain





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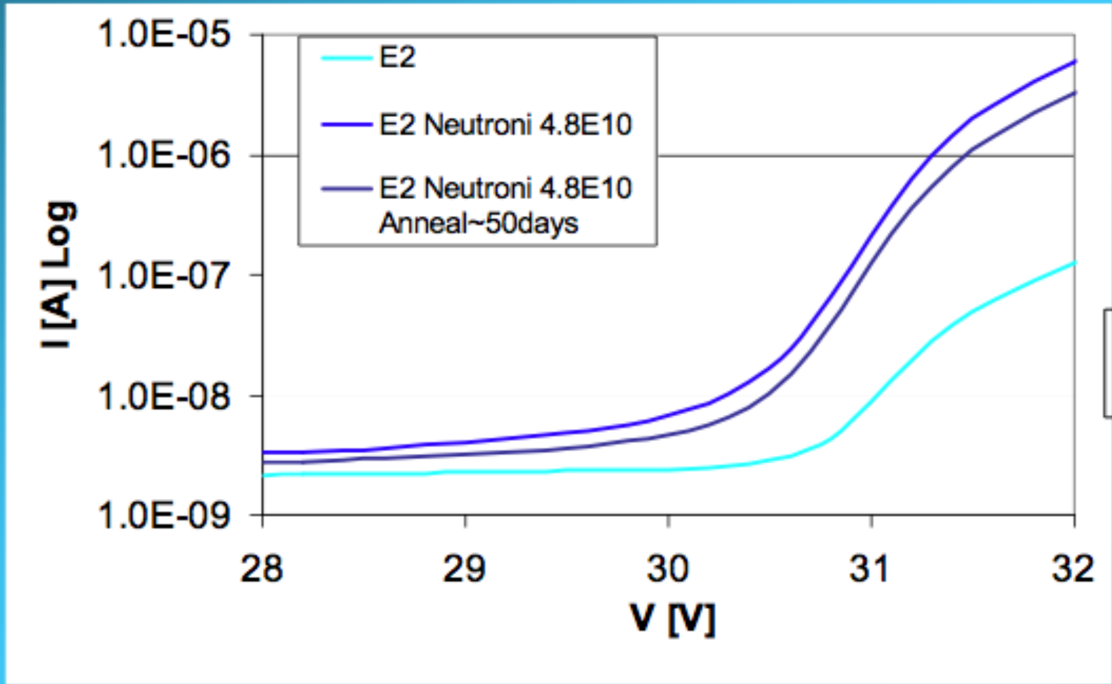
Irradiation tests of SiPMs - 2



FBK-irs circular SiPM
1.2 mm diam, 688 pixels

24 devices from FBK-irst, Photonique (CPTA) and Hamamatsu irradiated so far

- **X-rays: 50, 100, 150, 300 and 500 krad**
- **neutrons: $4.8\cdot10^{10}$ and 10^{11} n cm^{-2}**

Data analysis and study of the annealing effects are currently going on

Further irradiations are foreseen in the next months on single microcells

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Fast amplifier (Ampli-1) for SiPMs - 1

- Completely designed and realized at the "Lab. El. e Riv." of INFN-Trieste
- Realized on a special high-frequency printed circuit board
- Mounted inside a shielding/supporting metal box with SMA connectors
- AC-coupled ultra-high frequency amplifier, $f_{L\text{-}3dB}$ = 650 MHz, $f_{H\text{-}3db}$ = 3.5 GHz
- Flat gain response (21. 5 dB) over full bandwith
- Used for laboratory characterization, dark count, gain and timing measurements

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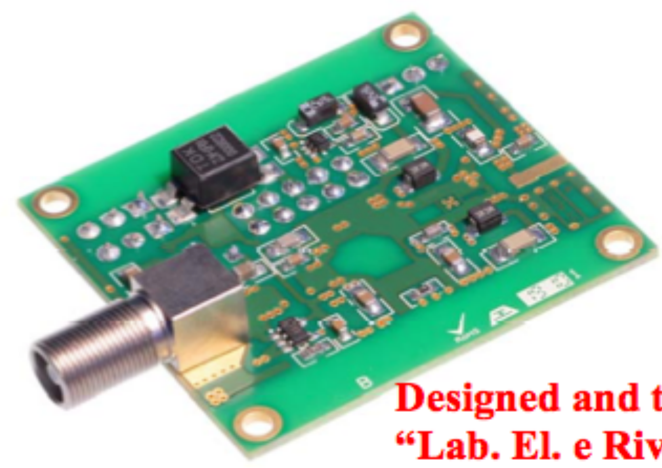
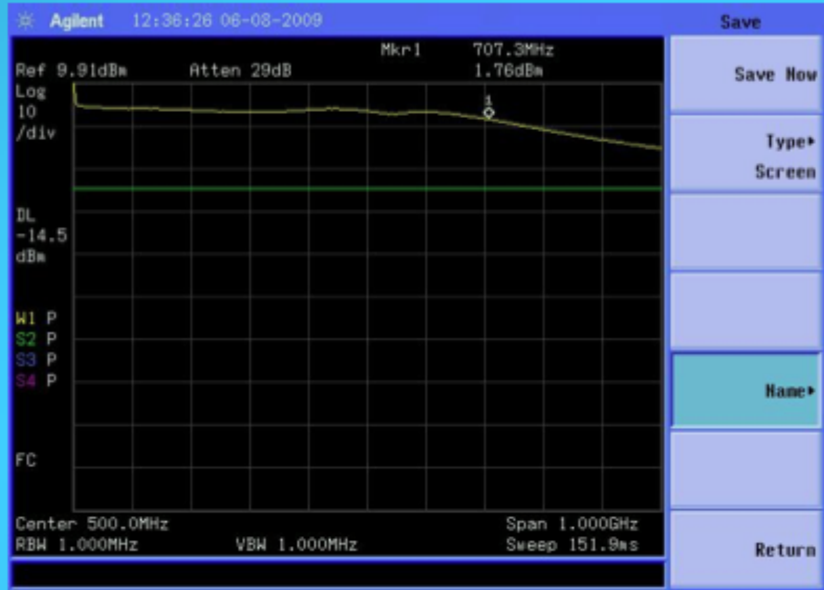
Compact front-end amplifier (Ampli-2) for the read-out of the Shashlik e.m.Calorimeter

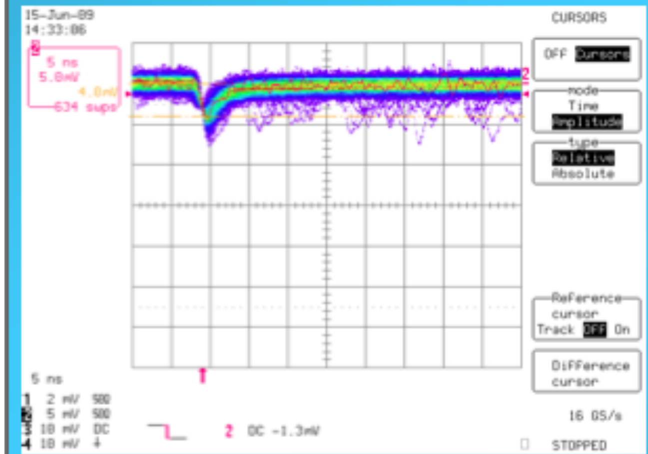


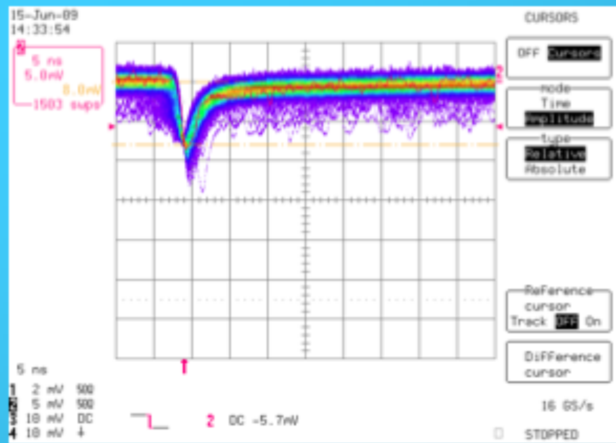
Designed and tested at "Lab. El. e Riv." INFN Trieste

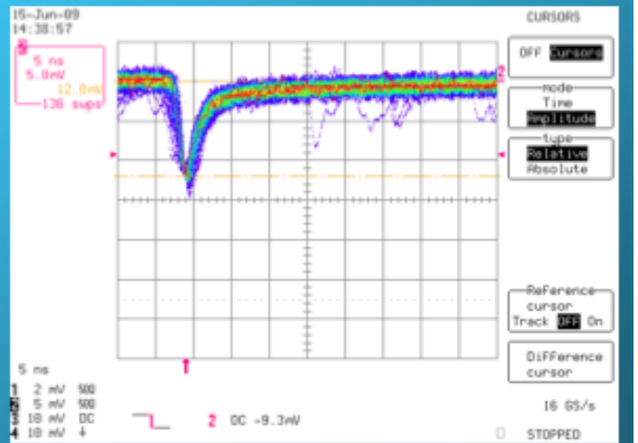


PCB dimensions 4 cm x 3 cm

Bandwidth from DC to 700 MHz, gain 16.3 dB



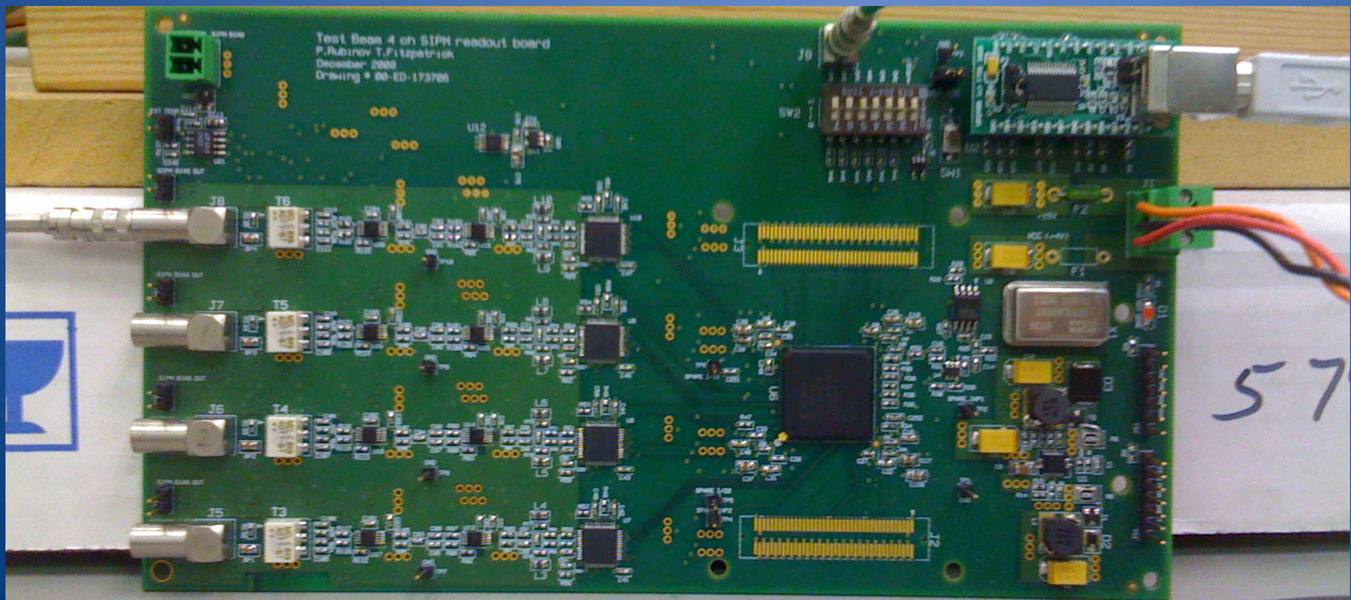




Signals corresponding to 1, 2 and 3 photoelectrons

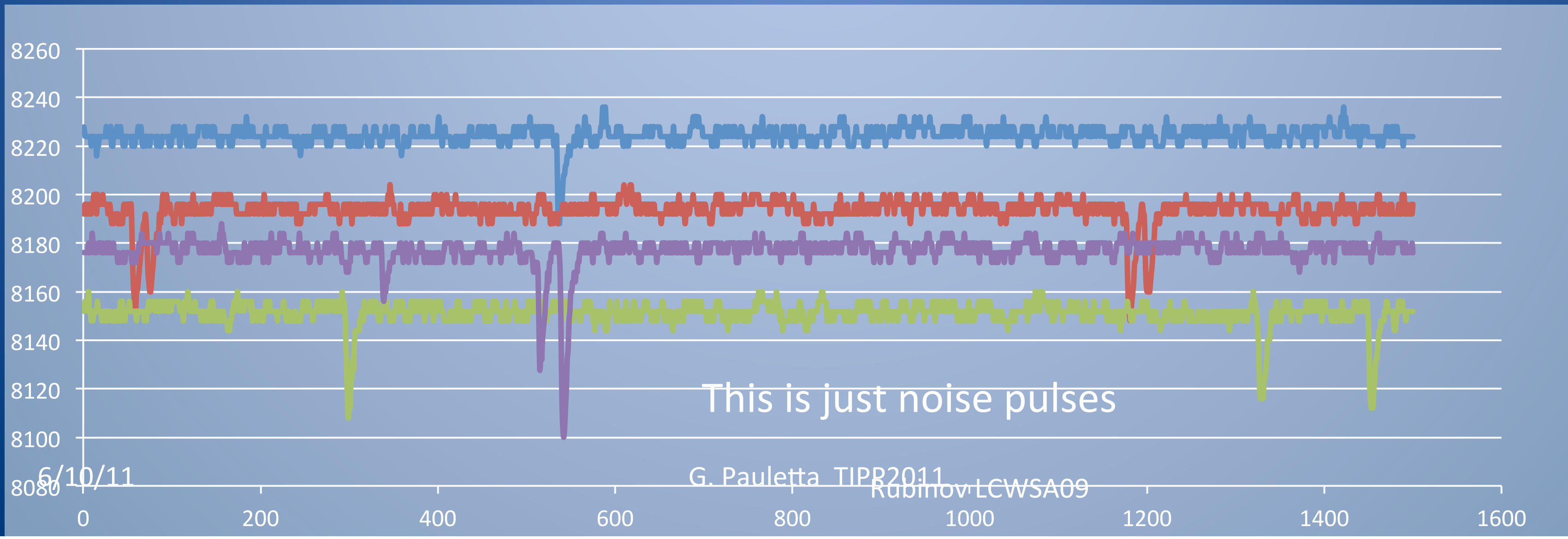
Emphasis on simple

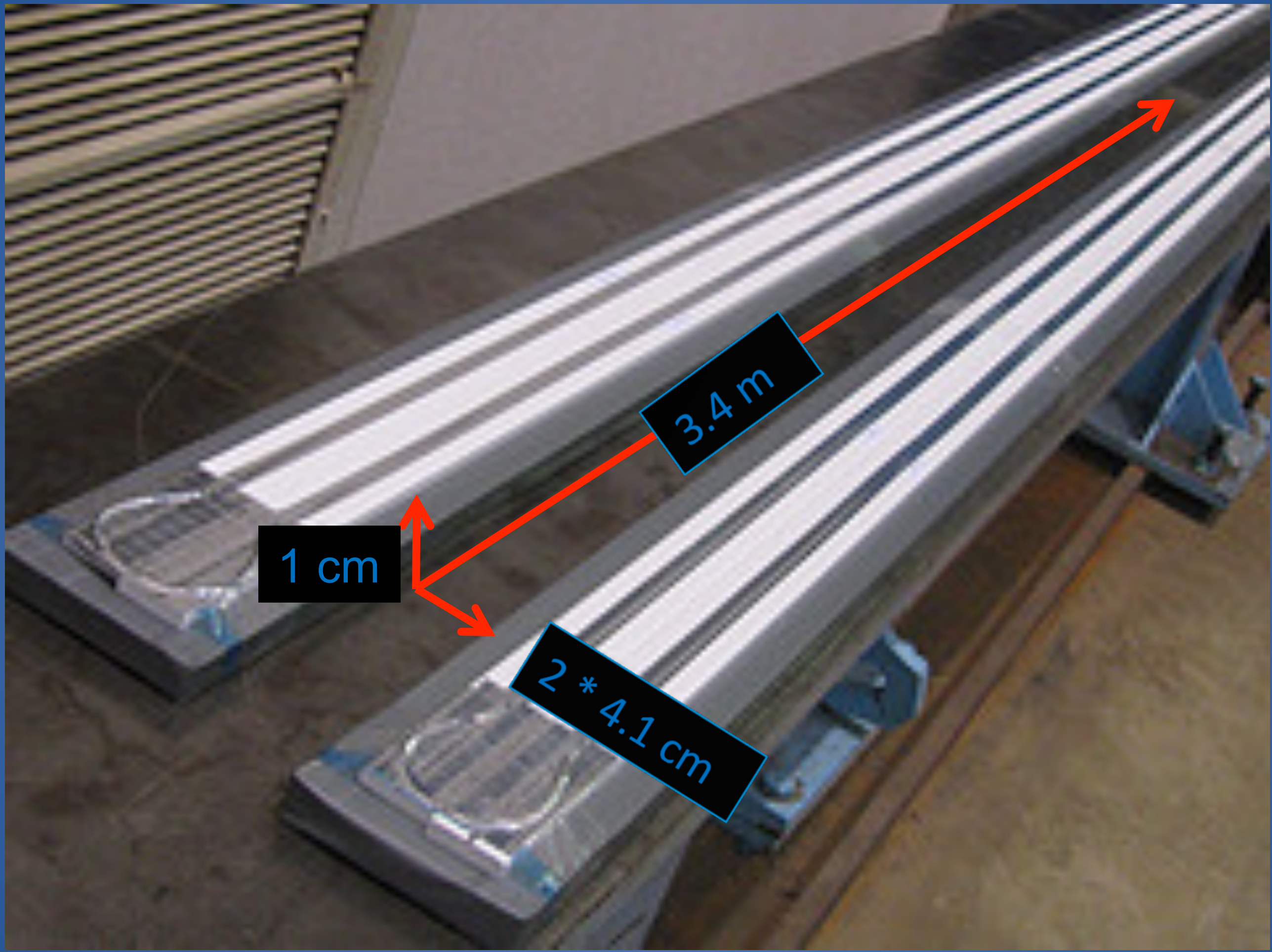
- Plug in 5V power
- Plug in SiPM into an end of a 50 ohm cable
- Plug the other end of the cable into the TB4 board
- Plug in the USB connector into your computer
- Start the software, and press the RUN button



TB4 key features

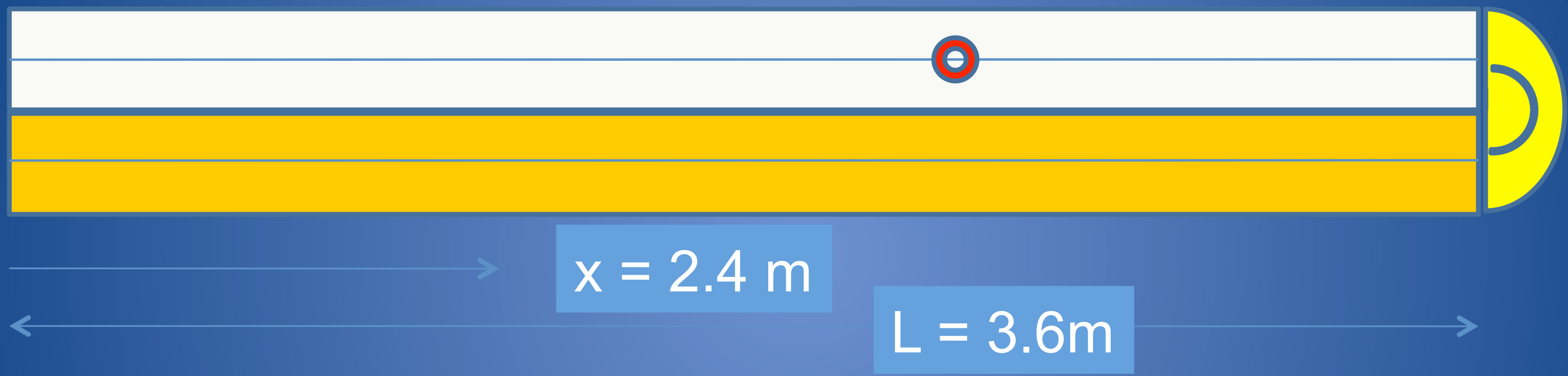
- 4ch of HS ADC (10 or 12 bit, 210 or 250 MSPS)
- Largish FPGA (with 4kpts memory/ch)
- USB interface, High Speed io
- On board bias generation for SiPMs (and current meas)




3.4 m
1 cm
2 * 4.1 cm

Dual Strip Readout

Beam in the top strip



For beam in the top strip the top distance is 2.4 m. For beam in the top strip, the bottom readout distance is 3.6m + 0.25m + 1.2m = 5.05m.

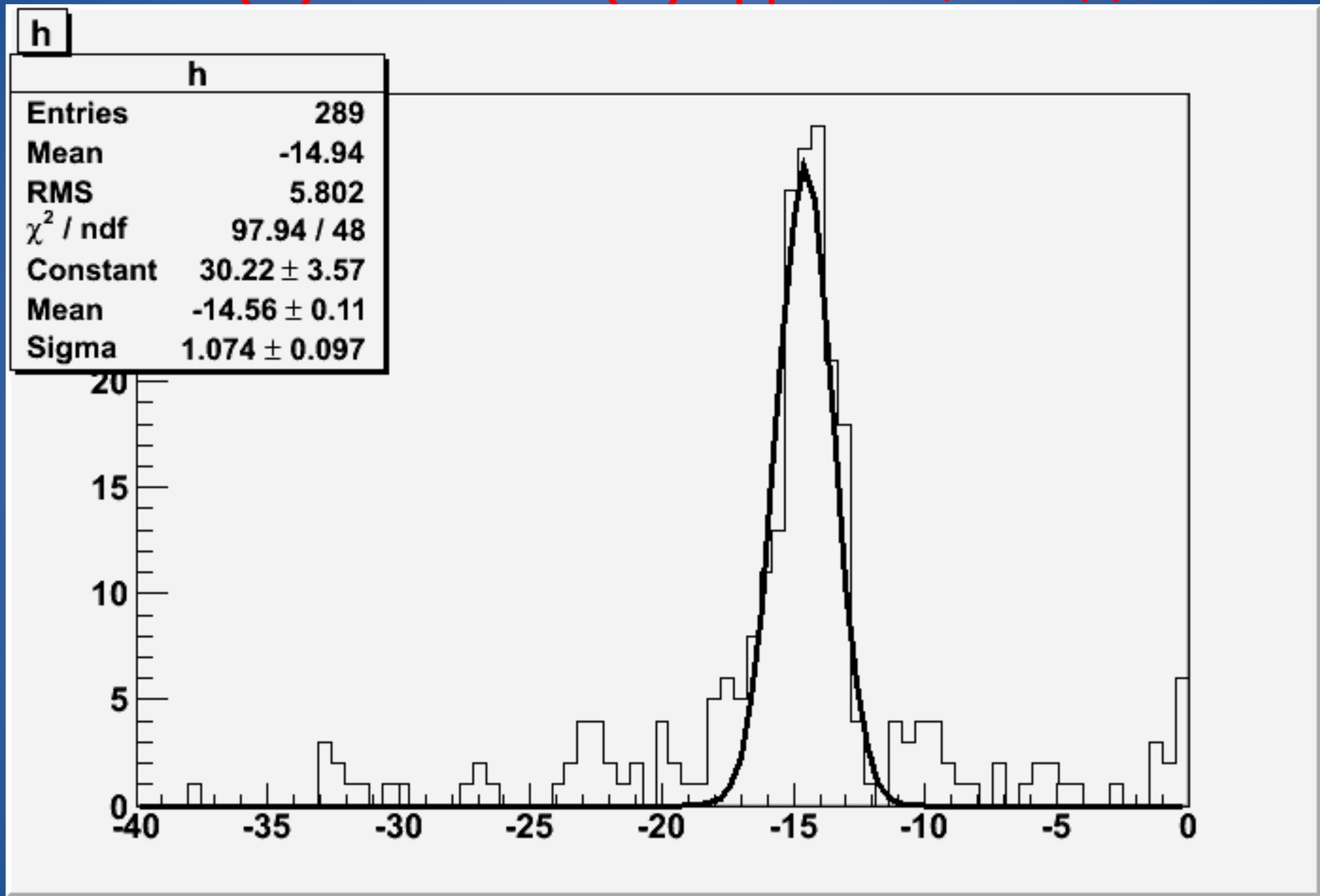
The distance difference is: 5.05 – 2.4 = 2.65 m.

c(effective) = 265cm / 14.8 ns = 18 cm/ns

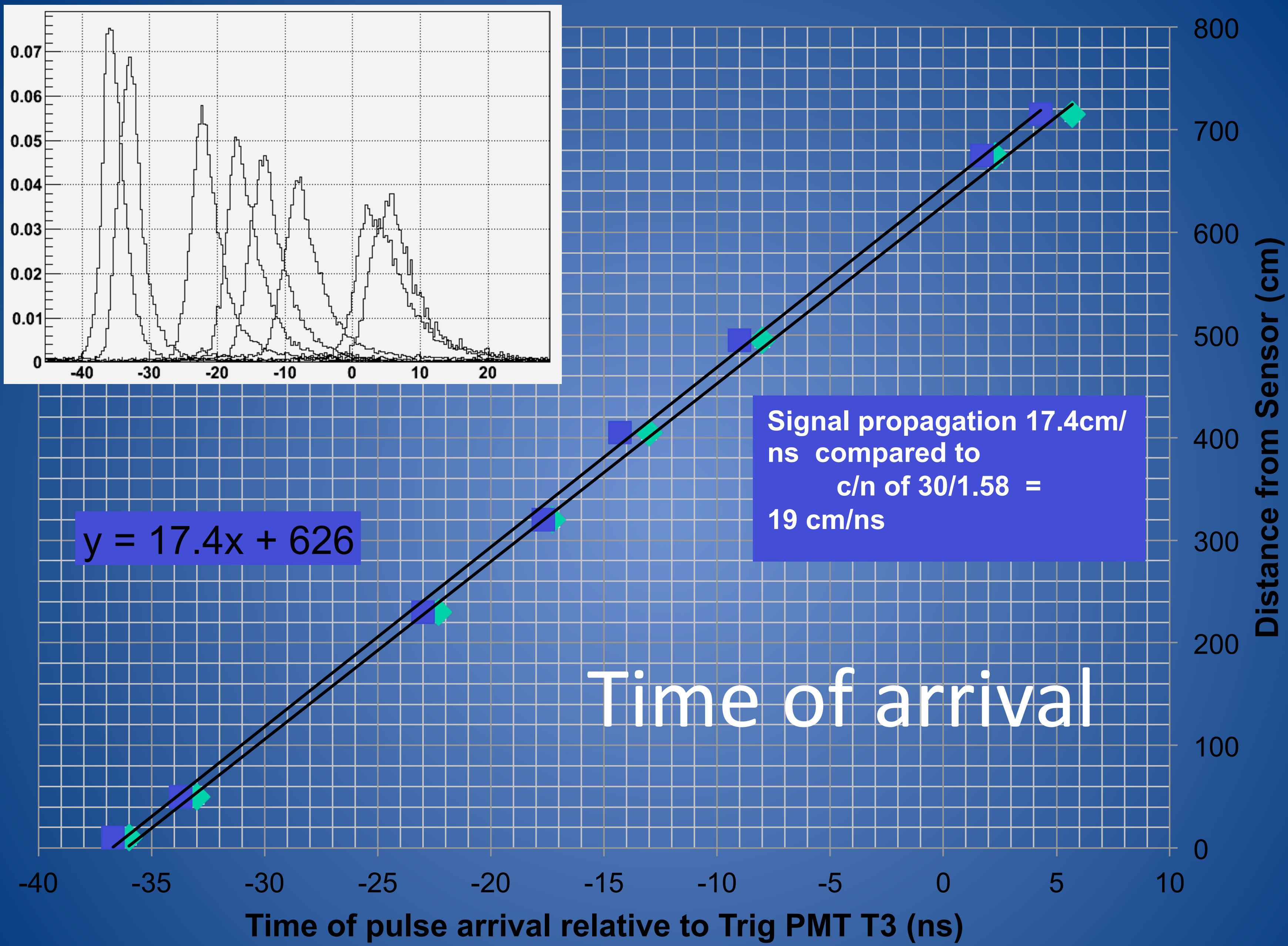
For D0's fiber tracker: c(eff.) ~ 17 cm/ns

What is the Δ(time of arrival)?

Ch(5)lower - Ch(6) upper time diff.



Time of arrival

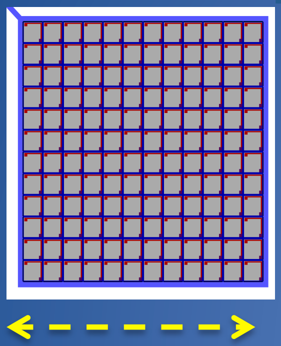


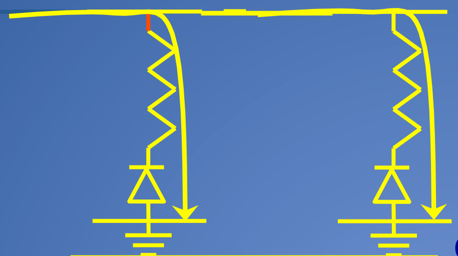
Silicon Photomultipliers (SiPMs) are developed around the same time

(first proposed by Golovin and Sadygov in the mid ’90s)

1990

Array of GM-APDs connected in parallel, each with quenching resistance





$Q = Q_1 + Q_2 = 2*Q_1$

Each element is independent and gives the same signal when fired by a photon

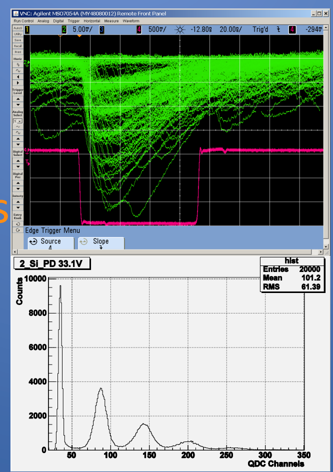
↓

output signal is proportional to the number of triggered cells =number of photons for PDE=1

Dimensionally well-matched to wls fiber

and:

- self-calibrating
- low bias (20-70 V)
- insensitive to magnetic fields
- potentially cheap
- fast (ps)
- Rugged
-

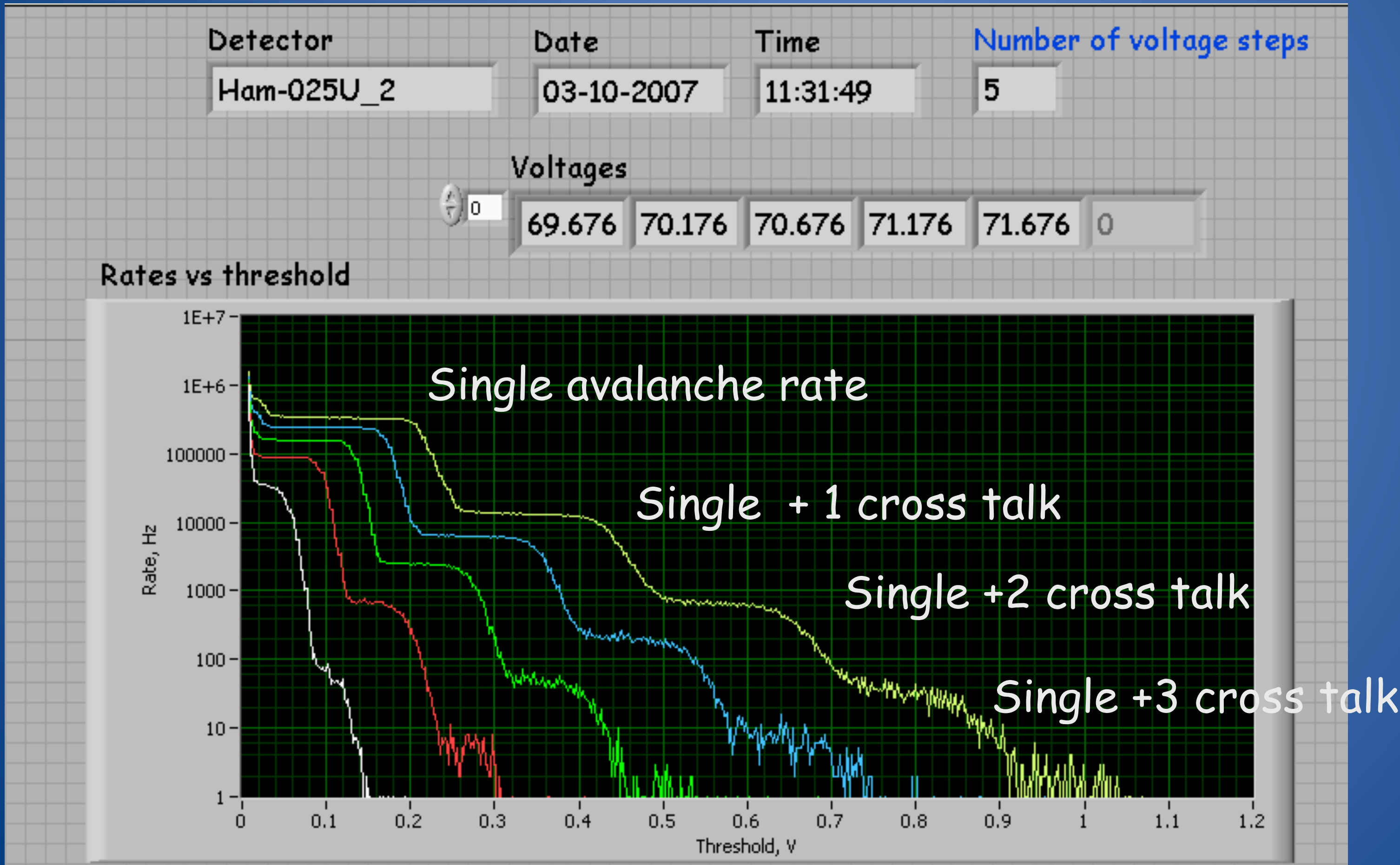


but:

- High (~1 MHz) 1 p.e. dark current
- After – pulsing
- Dynamic range
-

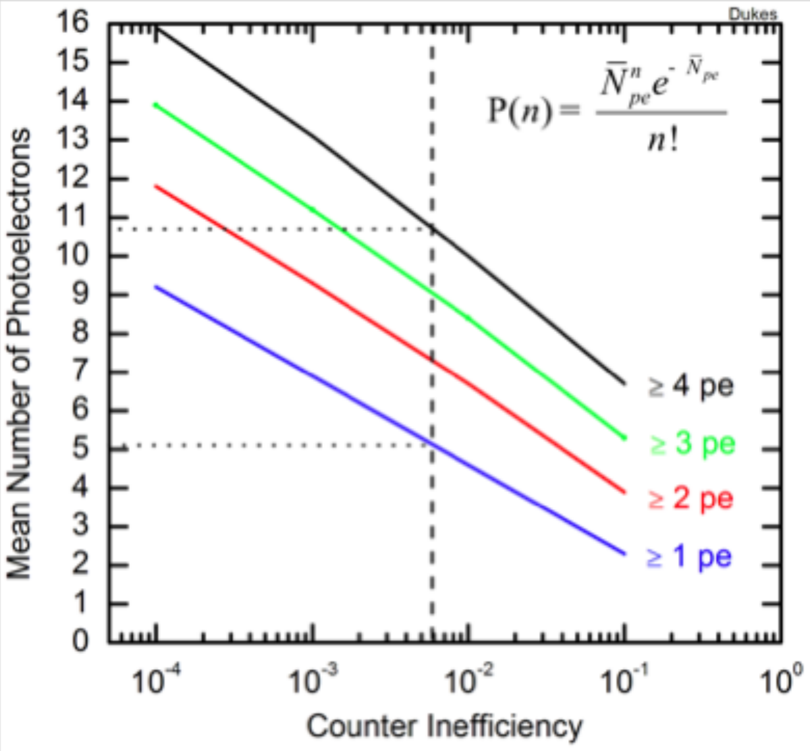
2000

Cross Talk Measurement



Ratios of rates give relative probabilities of 1,2,3 extra pixels firing due to cross-talk

Required photo-statistics

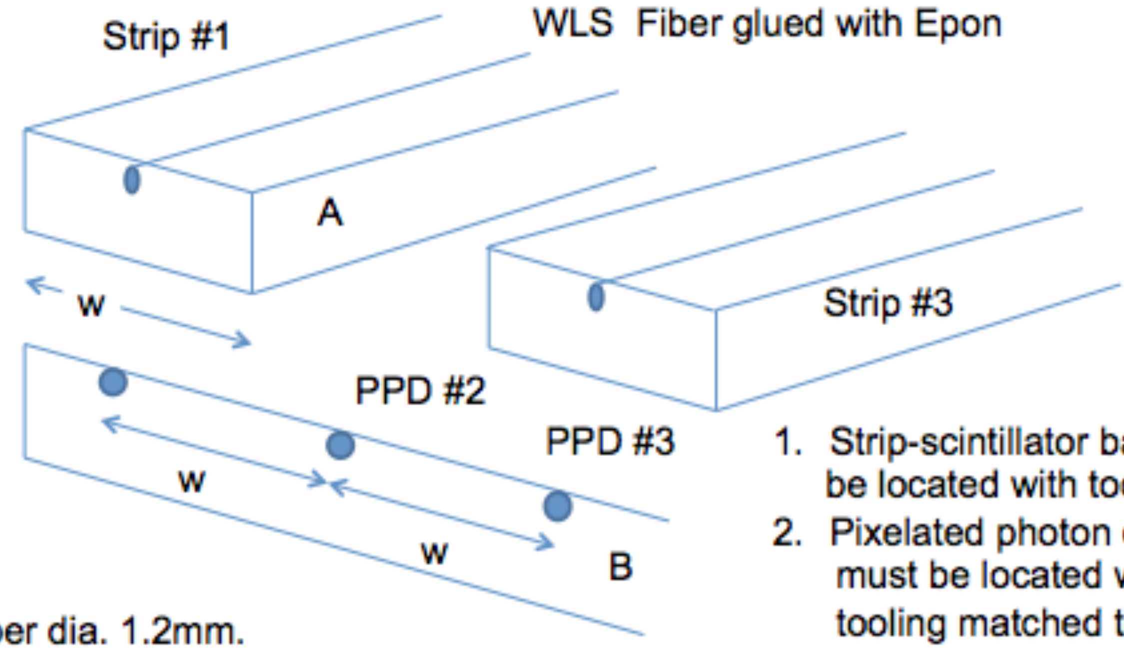


- To achieve desired inefficiency we will require 2 out 3 coincidence in CRV module
- Assuming each layer is independent, it will result in single layer efficiency of 99.4%

$$\varepsilon(2\text{of}3) = \varepsilon_{SL}^{3} + 3\varepsilon_{SL}^{2}(1-\varepsilon_{SL})$$

ε(layer)	ε(2of3)	1-ε(2of3)
99.4%	99.99%	0.0001
99.0%	99.97%	0.0003
98.0%	99.88%	0.0012
97.0%	99.74%	0.0026

"Design Idea" for Coupling WLS to PPD



Fiber dia. 1.2mm.
PPD pixels inscribed in 1.2mm dia circle.
Bar B has to be used to locate PPDs about ~1mil from polished end of WLS fiber.

1. Strip-scintillator bars must be located with tooling.
2. Pixelated photon detectors must be located with tooling matched to 1.
3. WLS polished end located with tooling matched to B.