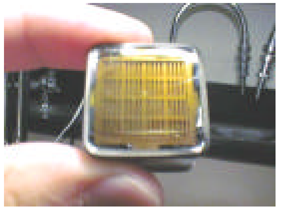
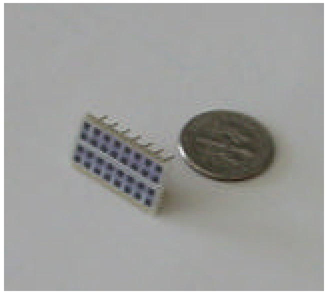
Photodetectors



Readout options for a very large scintillator detector

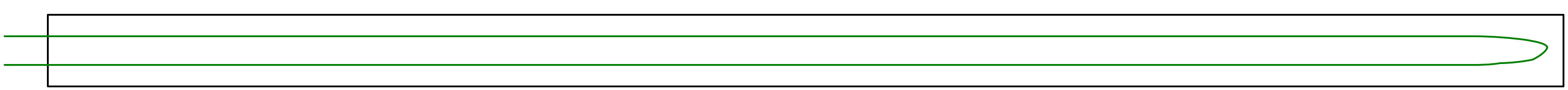
Roger Rusack



Presented by Ken Heller

Statement of the Problem

- *Readout two fibers in a single channel.*
- *Signal from a muon is 25 photons at 510 nm at 8 m in MINOS scintillator.*
- *Number of channels:*
  - 500,000 Longer scintillator strips 1/3 X_0 sampling.
  - 2,000,000 Shorter Scintillator in containers.
- *Beam-spill interval 10 microsecond.*
- *Repetition rate ~2 sec.*
- *Cost must be as low.*
- *Maintenance and operation simple (ie cheap).*

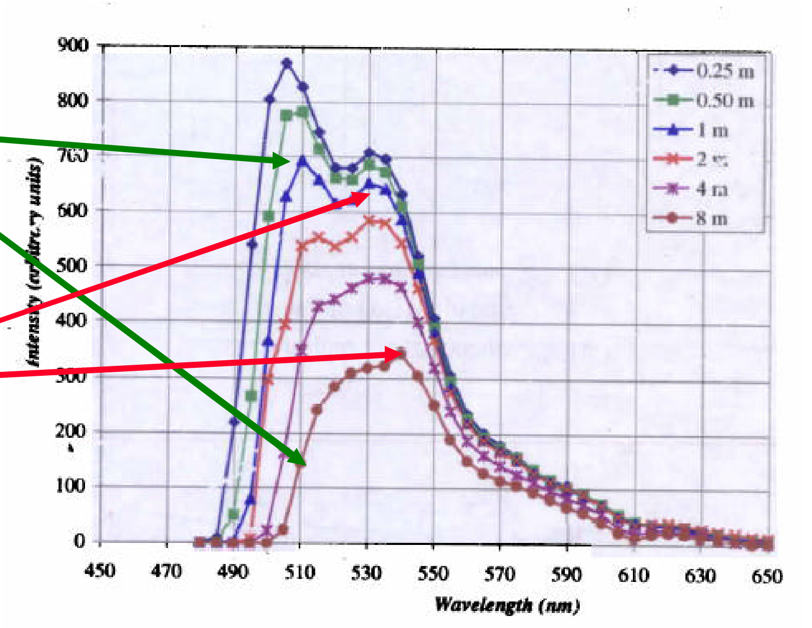


Spectrum

Attenuation 1m to 8m:

At 510 nm signal drops by 5

At 540 nm signal drops by 2



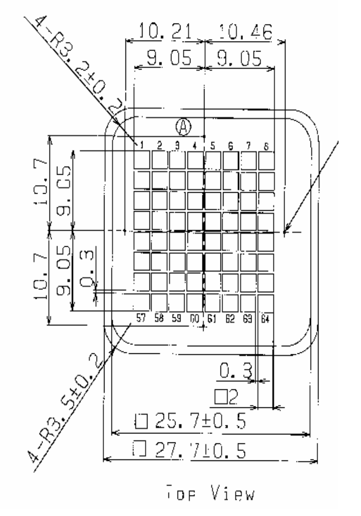
PMT's prefer it blue.

For *L* large, the attenuation length of light at 500 nm is 10m – determined by the plastic in the fiber not the internal reflections.

This is measured with a PMT.

What's new and what's not new.

- ***Multi-Channel PMT's.***
  - **Hamamatsu still are manufacturing M-64's.**
    - **QE ~ 10% at 510 nm.**
    - **Gain 10^5-10^6.**
    - **Well known to MINOS collaborators.**
    - **Cost could be less than they were for MINOS if are relaxed.**



- ***Flat Panel PMT's***
  - **As advertised on the back of the CERN Courier.**
  - **Are very nice**
  - **And very expensive.**

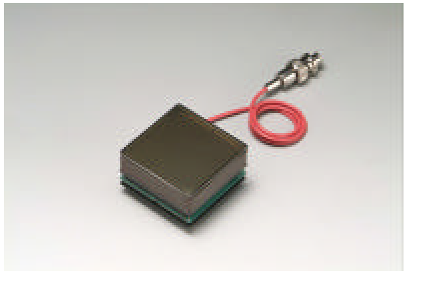
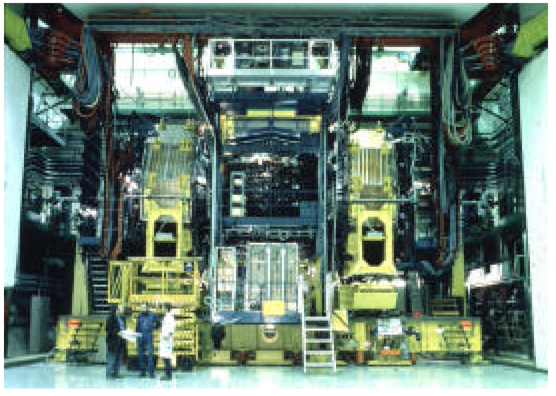
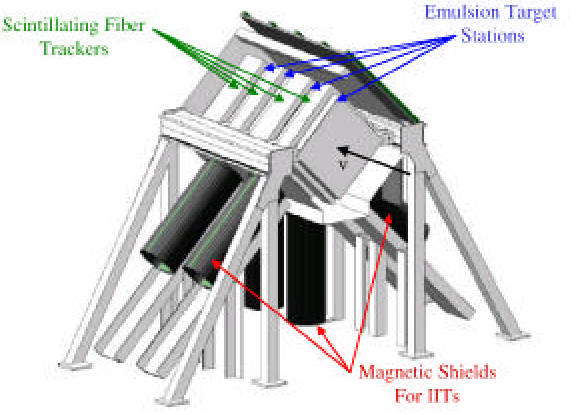


Image Intensifiers

Have been used in
UA2 to readout 80,000 1mm fibers.



DONUT (E872) to readout 500,000 fibers.



CHORUS to readout 1,000,000 fibers.

K2K to readout 275,000 fibers.

Image Intensifiers

- *Well understood technology.*
- *Individual II chains are expensive (~$10,000).*
- *Readout ~ 6,000 0.5 mm fibers per II chain.*
- *Electronics is cheap: CCD + electronics (~$2,000).*
- *Costs ~ $4.00/doubled fiber.*
- *Triggerable with 1 microsecond gate.*
- *10% QE*

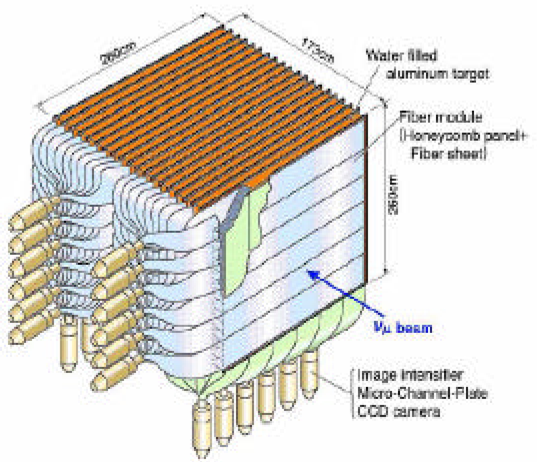


Fig. 2. A schematic view of the K2K scintillating fiber detector. The detector has the dimension of 260cm×260cm×173cm in (x, y, z). The central fiducial mass region is defined to be 220cm×220cm×150cm in (x, y, z).

From K2K

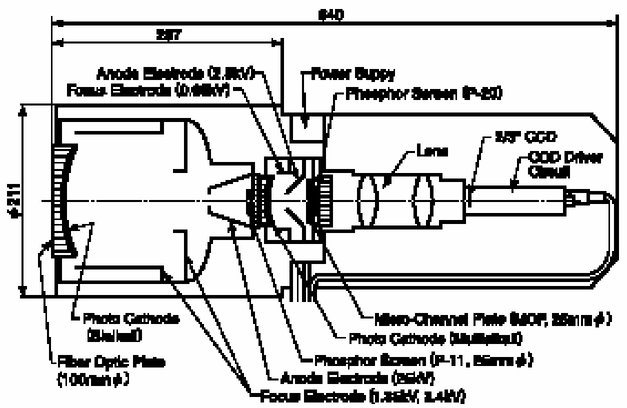


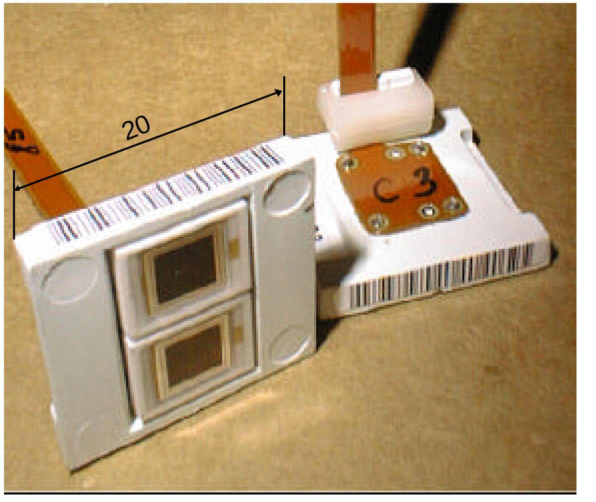
Fig. 2. IIT-CCD chain.

Avalanche Photodiodes.

- ***APD's have been around since 1968.***
- ***Different types:***
  - **Perkin-Elmer (formerly EG&G and RCA) reverse APD**
  - **API/RMD Neutron Transformation Doped (NTD) devices.**
  - **Hamamatsu epitaxial growth APD's.**
- ***Status:***
  - » **API and RMD**
    - **Small companies without major manufacturing background**
    - **They die through thermal run away in radiation environments –not popular.**
  - » **Perkin Elmer**
    - **Hard to manufacture, which makes them expensive.**
  - » **Hamamatsu**
    - **Uses standard industry techniques in manufacture.**
    - **LHC expt. CMS is using 126,000 5 mm x 5 mm APD's.**

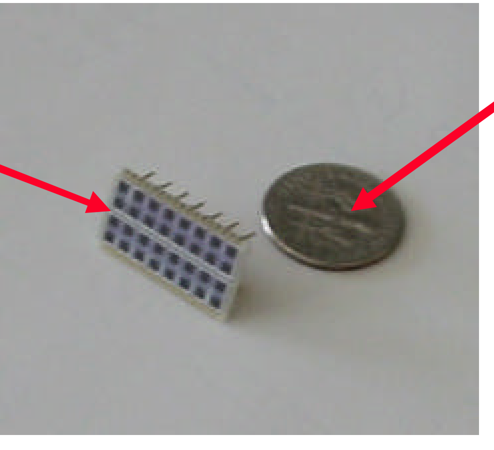
Hamamatsu APD's

- *CMS crystal readout:*
  - 5 x 5 mm².
- *86,000 delivered.*
- *Delivery rate 7000/month.*
- *Cost 42.5 CHF (~$30) each.*



Hamamatsu have developed an 1.6 x 1.6 mm² array based on the same junction structure developed for CMS.

Two 16-channel arrays

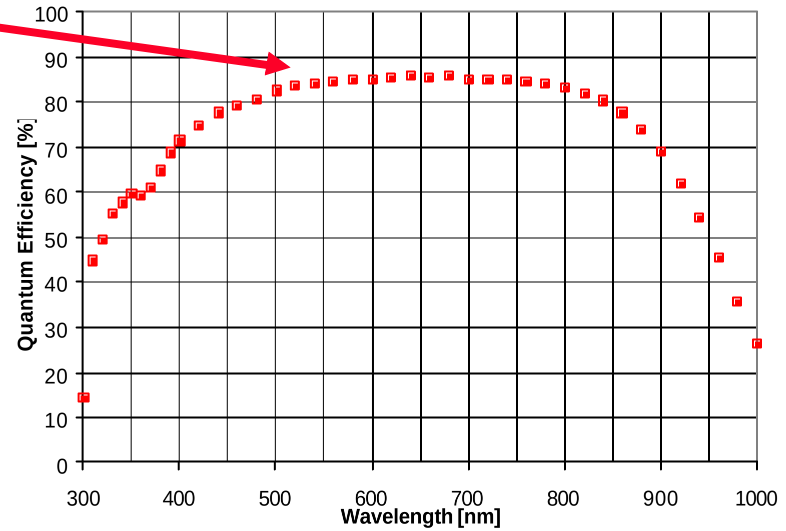


A dime (10¢)

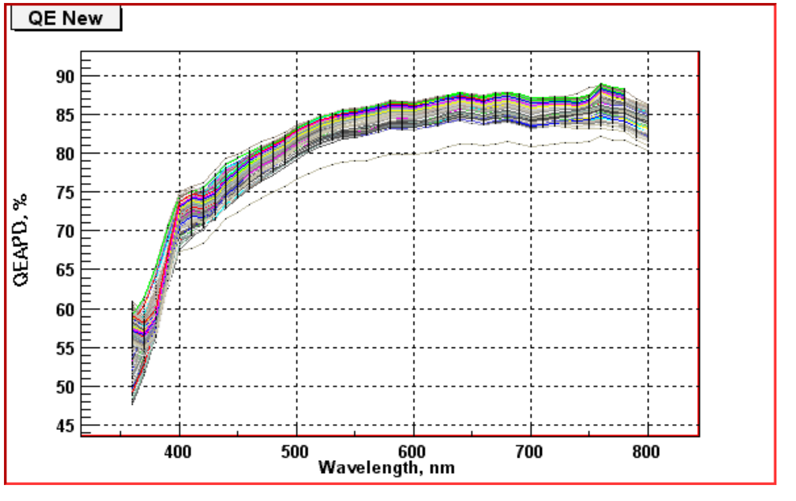
Operating characteristics are the same as the CMS APD.

Characteristics.

- *QE sits is around 85%.*
  at spectral peak:



and is repeatable.

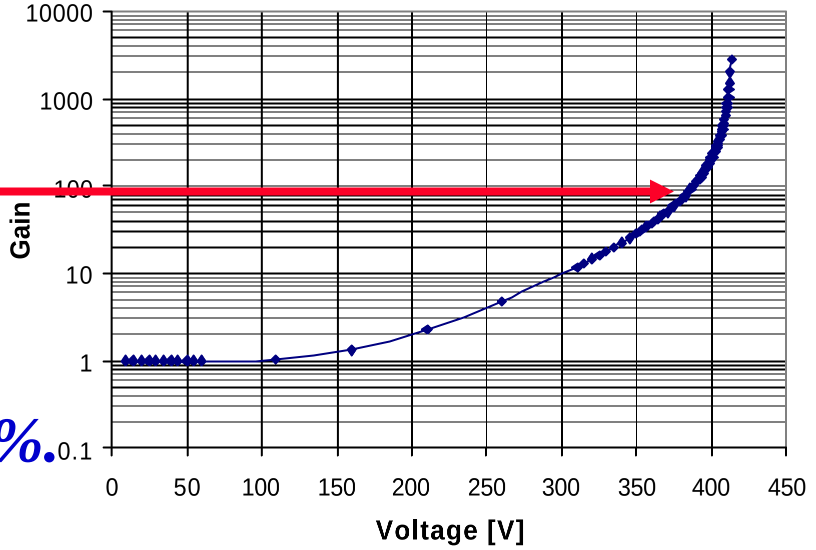


Gain

- ***Can run at gains up to 200 with reasonable headroom (10V).***

$V_{operating} - V_{breakdown} \sim 30$ V

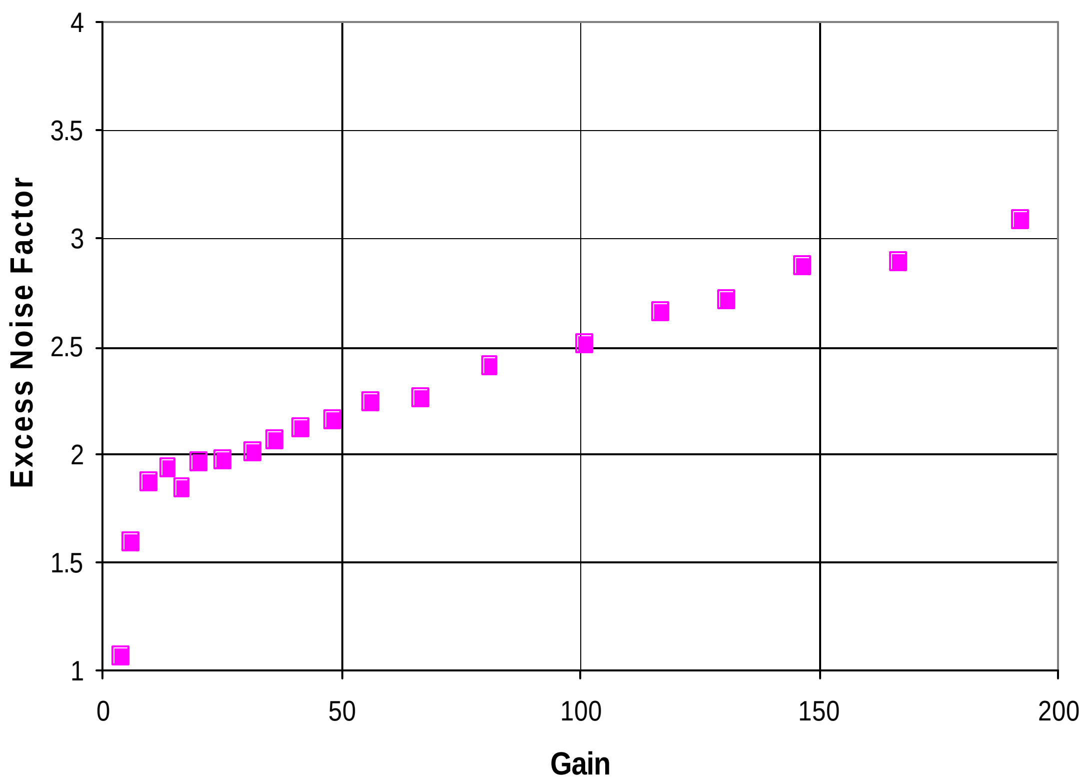
- ***We assume a gain of 100.***



- ***Pixel-to-pixel uniformity is ± 3%.***

Excess Noise Factor

- ***Excess noise Factor increases with gain.***



This means that device gets noisy at high gain.

Costs

- ***Pixel size is 1.6 x 1.6 mm^2.***
- ***Use bare die (Protected with Si_3N_4 coating – not epoxy) just like the silicon trackers.***
- ***Price in quantities of 500,000 channels - $2.65 - $2.75 ea.***
- ***Price in quantities of 1,500,000 channels - $2.00 - $2.10 ea.***

Variations in price is determined by value of the yen and what specs we require.

Application

- *Low Gain:*
- *Mean muon signal after amplification is 35 * 0.85 * 100 = 3000 electrons.*
- *Use double correlation technique to detect signal used in one Fermilab chip (MASDA) which has a level of 300 electrons with 250 nsec integration.*
- *Most significant source of noise is the Schott noise from thermally generated electrons upstream of the junction*

Schott Noise

- ***Thermal current generated <u>before the junction</u> is multiplied and is indistinguishable from the signal.***
- ***It obeys Arrenhuis relation and decreases exponentially with T – at room temp a factor 2 every 7 C.***
- ***At 28^{o}C current corresponds to 60 electrons generated in 100 nsec. This reduces to four at –7C.***
- ***Design for an operating temperature of –10^{o}C (18^{o}F).***

Readout

- *Joint Fermilab-Minnesota effort to test this idea.*
  - **Use an existing 128 channel chip MASDA,**
  - **Pre- and post- sampling integrator designed for amorphous silicon imaging.**
  - **Johnson noise levels 300 electrons in 250 nsec with 10 pF – this decreases as integration time increases.**

Cost Estimate.

- ***Assumptions:***
  - 64-channel fibers-APD modules.
  - Cooling with a single stage Thermal Electric cooler. (Peltier).
  - Cool only APD (0.2 mW) to – 10C. *Not electronics*.
  - HV (400 V) supplied by a single Cockroft-Walton supply (being designed at Fermilab). 1/module.
- ***Readout concept.***
  - 64-channel ASIC Charge in/Bits out.
  - Continuous charge integration.
  - Divide spill into 100 nsec intervals.
  - Store integrator output values on capacitors
    - » One capacitor for each interval. (Like SVX4).
    - » Convert charge on caps with one on-chip 10-bit ADC.
  - Control Logic (FPGA)
    - » Generates trigger bit.
    - » Sends all data after trigger accept to event concentrator (1024 -channels).
    - » Resets ASIC.
  - Send data to DAQ on commercial fiber optic link 1/1024 channels.

Cost Estimate

System costs were estimated by Ray Yarema all costs are fully burdened and include engineering, prototyping, fabrication and testing for 1,000,000 yielded channels.

- ***Cockroft-Walton***
  - **Chip cost $8.70**
    - **Chip area 12 mm^2, 10 wafers + masks -- $50k ($55k for masks).**
    - **Testing -- $136,000.**
  - **Other on board components. $7.00**
  - **Cost per 64 channels $15.70 ($0.25/channel.).**
- ***APD readout chip.***
  - **Chip cost $33.79.**
    - **48 mm^2 size – total area 750,000 mm^2, 40 wafers ($200k).**
    - **Testing - 50¢/die.**
  - **Cost per 64 channels $33.79 ($0.53/channel.).**

Cost Estimate

- ***Board costs:***
  - Circuit board cost = \$3.00 (15,000 4-layer 2” x 4” boards)
  - TE cooler = \$5.00 (Just the junction - Catalog)
  - Thermocouples = \$2.00
  - Small FPGA (400 NAND gates) = \$5.00
  - Four 16 channel APDs = 64 x \$2.50 = \$160
  - C-W chip and support parts = \$15.70
  - APD readout chip = \$33.79
  - Other parts = \$2.00
  - Board Assembly = \$5.00
  - Production board tester = \$2.00 (?)
  - Board test and repair = \$5.00 (?)
- ***Total estimated readout cost \$3.73 /channel including APD.***
- ***Add 25% contingency.***

Cost per channel including the APD and 25% contingency= \$4.65.

Comparison

IIT

- Advantage
  - Cost: $4/ Channel
  - Experience (DONUT, Chorus, K2K)
- Disadvantage
  - Hundreds of modules/ IIT
    - Complexity Cost
    - Fiber Cost
  - 12% QE

M64

- Advantage
  - Experience (MINOS)
  - Match to module size
- Disadvantage
  - Cost: $14/ Channel
  - 12% QE

APD

- Advantage
  - Experience (CMS)
  - Cost: $4/ Channel
  - Match to module size
  - 85% QE
- Disadvantage
  - Unfamiliar to many

Continuing Work

- **Investigate signal-to-noise with long fibers readout with a Hamamatsu APD array in a parameter space of**
  - **Temperature.**
  - **Integration time.**
  - **APD gain.**