SCINTILLATOR / WLS FIBER OPTION

FOR

BABAR MUON DETECTOR UPGRADE

PETER KIM

SLAC

HAWAII SUPER B FACTORY WORKSHOP

JAN 19-22, 2004

BABAR BARELL RPC MUON SYSTEM DETERIORATING RAPIDLY

WE NEED REPLACEMENT IN 2004/2005

BARELL RPC: **Finely segmented 19 layers**
5.1 Interaction length

Without Layer 19 dies, we loose 10 cm of Fe
--> 4.5 Interaction length.

Fill 6 out of 18 Layers with 2.2 cm BRASS
-> 5.2 Interaction Length
Fill Remaining 12 Layers with ACTIVE DEVICE
Must Fit in 2.2 cm Gap between Irons…

THREE PROPOSALS WERE MADE in 2002

RPC

LST (Limited Streamer Tube)

SCINTILLATOR/WLS DETECTOR

SCINTILLATOR/WLS FIBER DETECTOR WITH AVALACHE PHOTODIODE READOUT

S. Fan, G. Dubois-Felsmann, D. Hitlin, P. Kim
M. Lometti, D. Nelson, R. Schindler, J. Stelzer,
W. Wisniewski (SLAC & Caltech)

Utilize Existing Technology of Scintillator/WLS readout

Very Fast Scintillator Signals: few ns

Avalanche Photodiode Readout:

All READOUT ELECTRONICS inside IRON
NO Problem with 1.5 T Magnetic Field

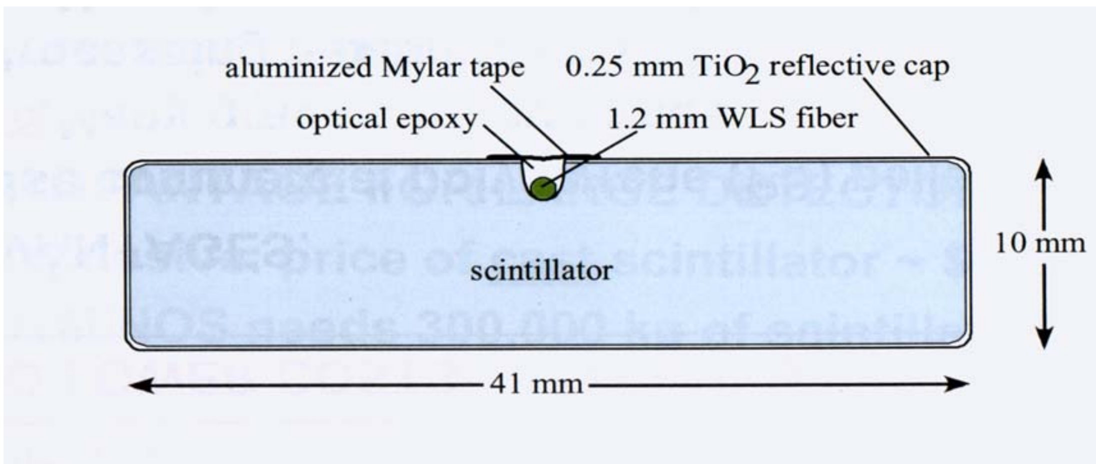
➔ Modular Design Easily Installed & Replaceable

Questions: APD Gain Much Lower than PMT
Unknown Long Term Reliability of APD
APD Cost Issue

MINOS MUON DETECTOR

- MINOS: 300 Tons OF <u>CHEAP</u> CO-EXTRUDED SCINTILLATOR BARS (8m x 4cmx1cm)

  A SINGLE 1.2mmØ Y11-175 multiclad WLS FIBER (polystyr., pmma, Teflon)



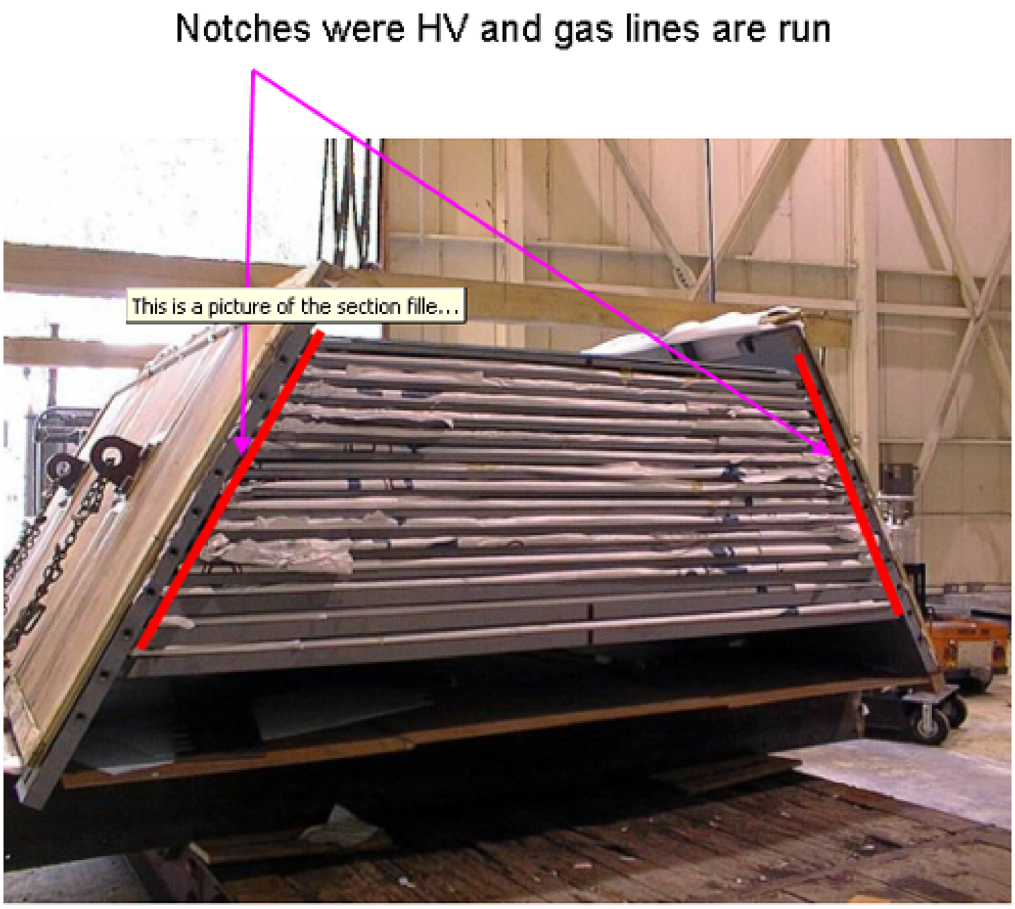
- LIGHIT COLLECTED VIA DIFFUSE SCATTERING INTO EMBEDDED WAVE LENGTH SHIFT (WLS) FIBERS WHERE λ_{att} ~ 4m RATHER THAN TRANSPORT IN SCINTILLATOR (where λ_{att} ~ 20cm to 100cm)

  - WLS FIBER → LONG CLEAR FIBER → PIXELATED PMT

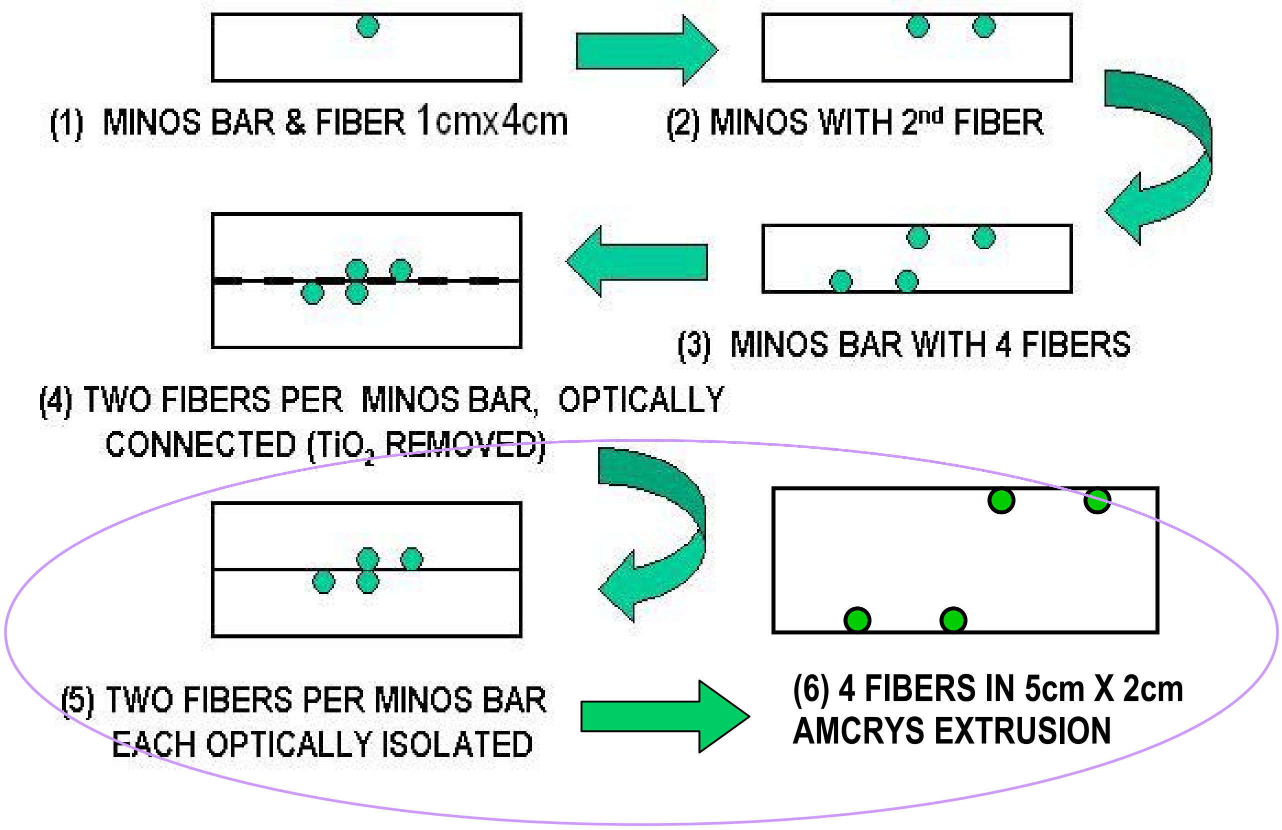
    3-4 pe/fiber at ~3.7 m INCL. FIBER CONENCTON & PMT QUANTUM EFF.

DIFFICULT TO FIND SPACE OF PMT's in BABAR

A SEXTANT FULL OF RPC
READY FOR INSTALLATION



MORE WLS FIBERS MEANS MORE LIGHT



- **FOR EACH CASE WE EVALUATED**
  - **RELATIVE LIGHT YIELD,**
  - **ATTENUATION LENGTH,**
  - **TIME (POSITION RESOLUTION)**

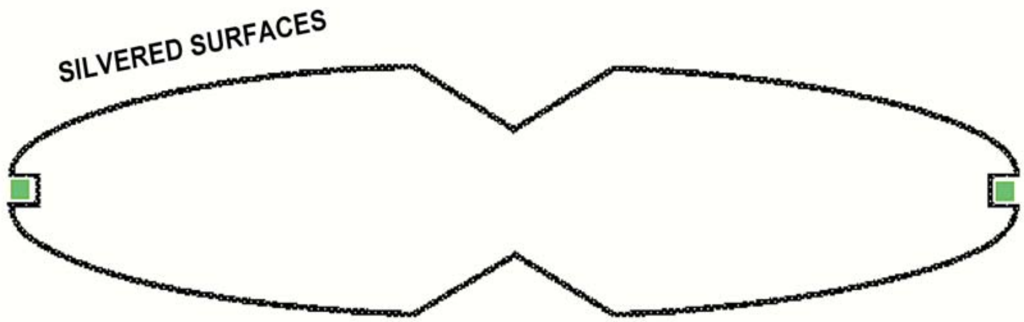
COMPARISON WITH MC PREDICTIONS
(J. Stelzer and M. Lometti)

b

ANOTHER SHAPE OPTION

PROPOSED BY D. HITLIN AND GREGORY DUBOIS:

PAIR OF OPPOSING WINSTON CONE PARABOLAS WITH SQUARE FIBERS AT THE FOCII

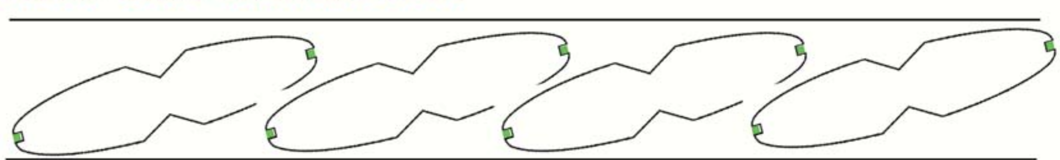


RELY ON SPECULAR REFLECTION TO SEND LIGHT EFFICIENTLY INTO THE FIBERS ...... INSTEAD OF DIFFUSE REFLECTION

THE NOTCHES AT THE MIDPOINTS REDUCE TRAPPING OF LIGHT AT THE CENTER .....

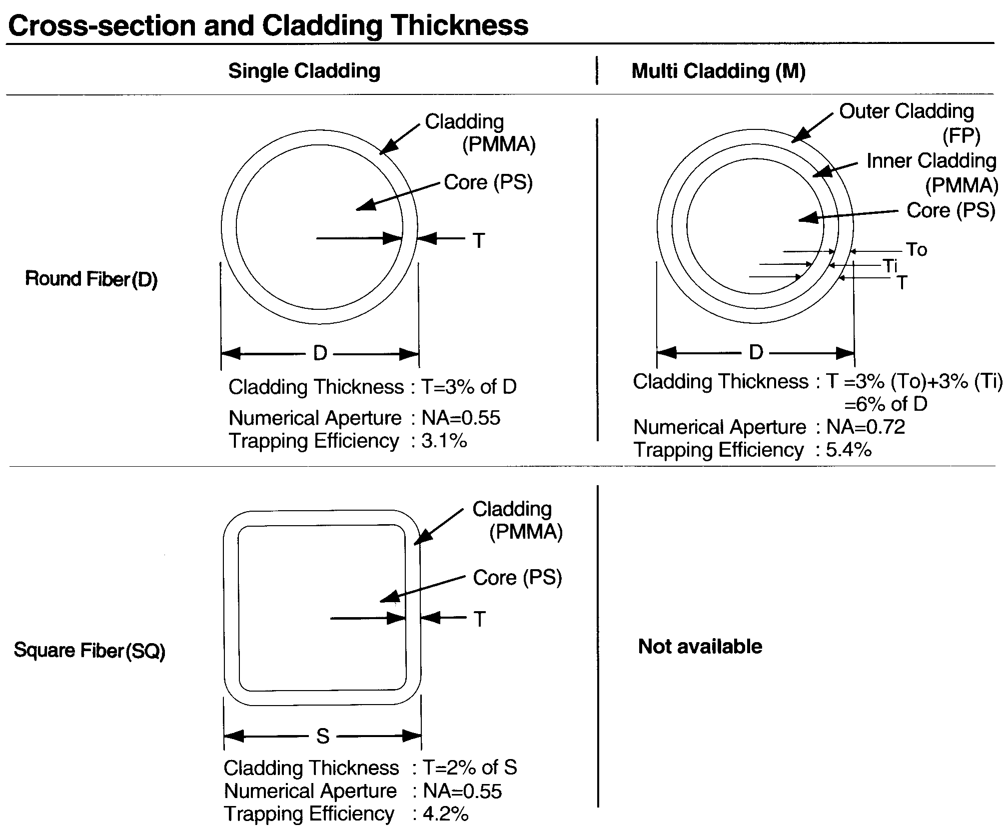
INVESTIGATING WITH ITASCA (MINOS EXTRUDER) THE ISSUES OF SILVERING THE SURFACES OF THE SCINTILLATOR

MIGHT GANG THEM LIKE THIS:



(VERY SIMPLE TO TEST IN SLAC SETUP)

WLS FIBER CLADDING AND SHAPE



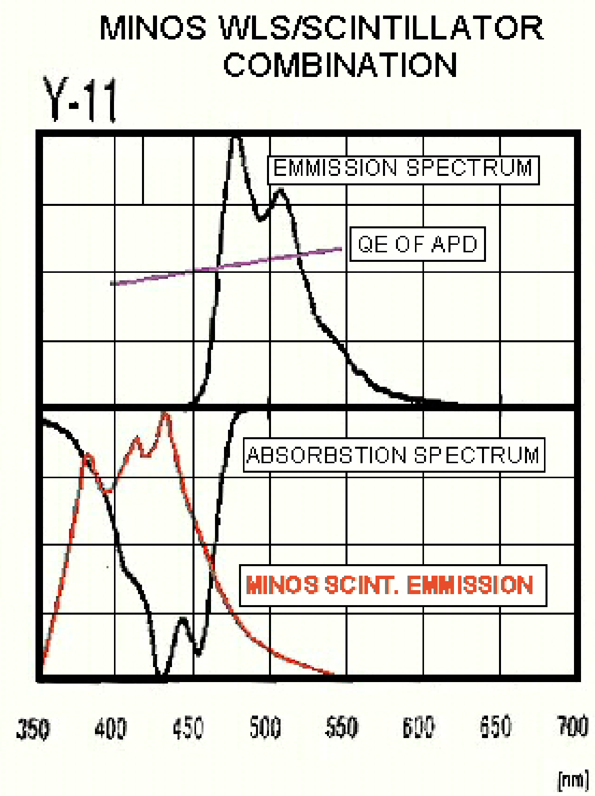
3.1% → 5.4% TRAPPING GOING SINGLE TO MULTICLAD

3.1% → 4.2% TRAPPING BY GOING FROM ROUND → SQUARE
(potentially additional gain of 25%)

- **SQUARE FIBERS IMPROVE GEOMETRICAL MATCH TO A SQUARE APD**

- **UNFORTUNATELY ONLY BICRON PROVIDES MULTICLAD SQR FIBER AND THE MATCHING OF ABSORBTION TO SCINT WAS FOUND TO BE POOR (NEEDS DEVELOPMENT)**

WLS FIBER & SCINTILLATOR ABSORPTION MATCHING

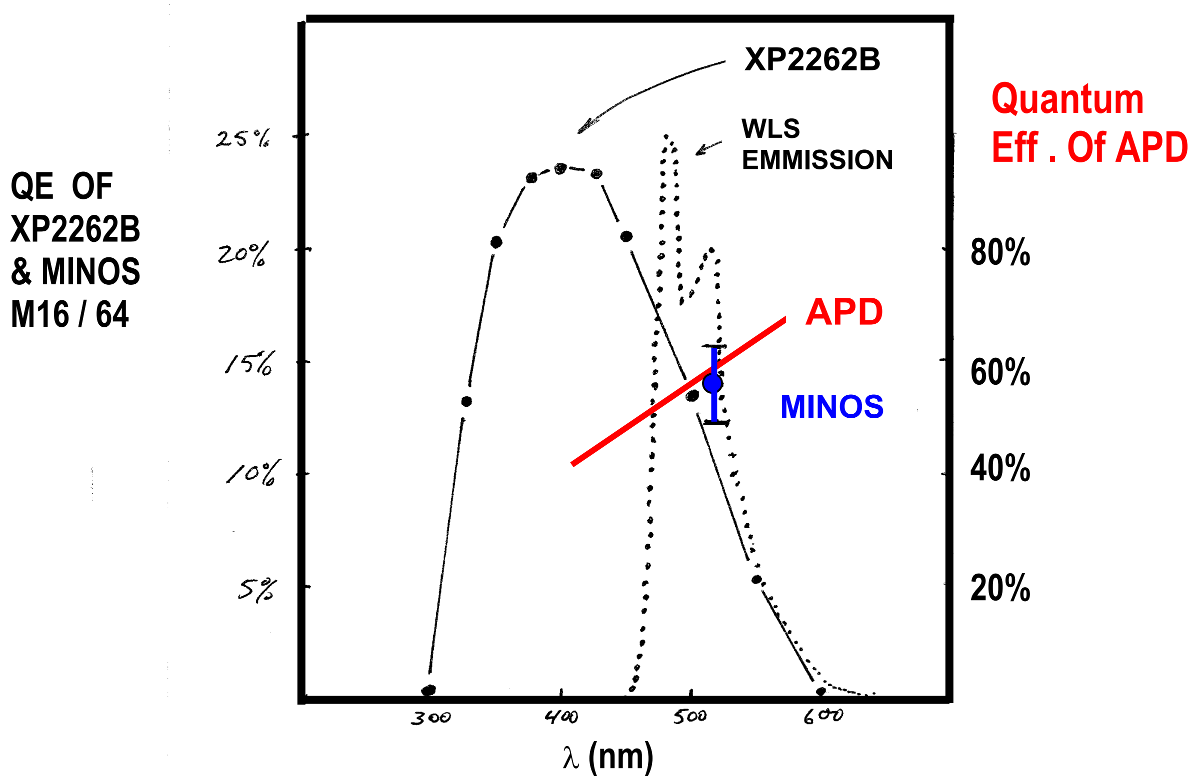


Y11 Kuraray WLS FIBER

1.2 mm Round Fiber
Double Cladding
Excellent Attenuation Lengths > 3 m

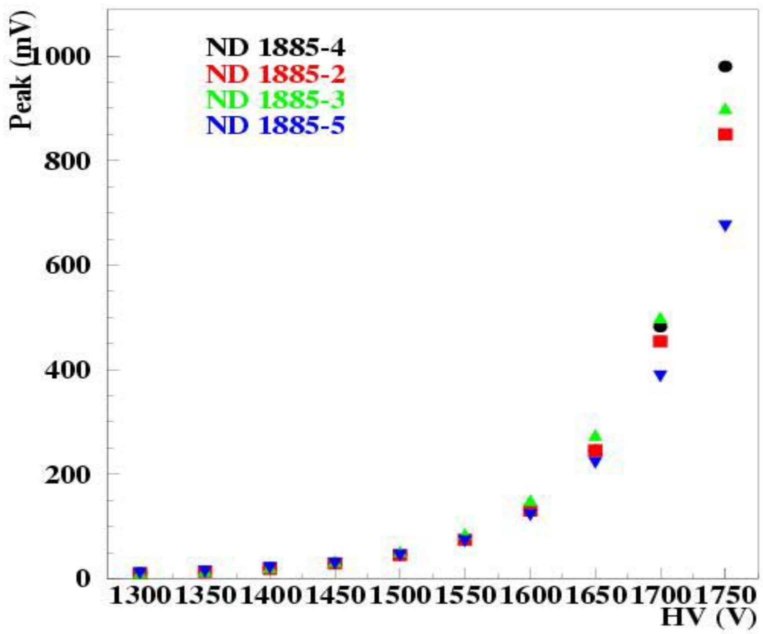
QUANTUM EFFICIENCY OF READOUT DEVICE

QE OF PMT & 2mm x 2mm RMD APD COMPARED WITH WLS EMMISSION SPECTRUM BELOW:



ABOUT A FACTOR OF 4X IN QUANTUM EFFICIENCY FOR APD OVER PMT AT ~520 nm

APD GAIN MEASUREMENT

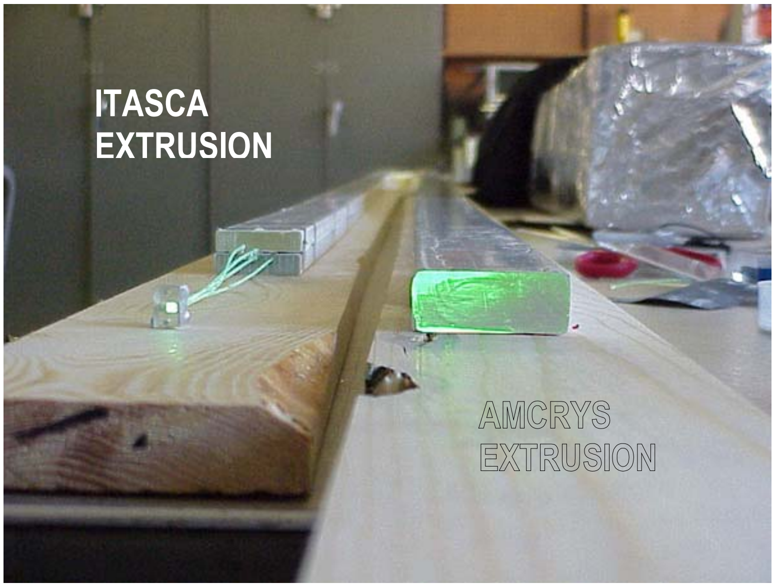


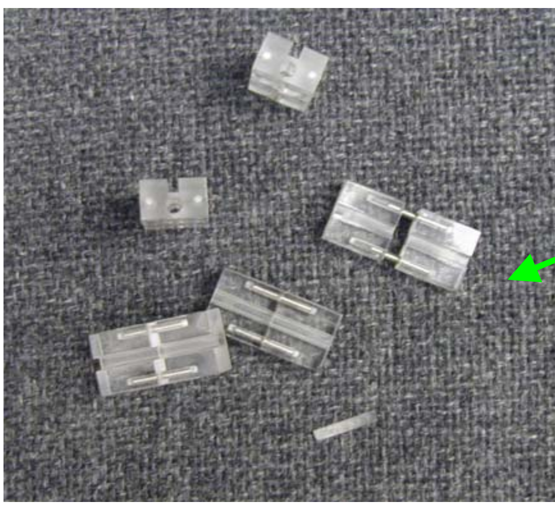
- RMD's PLANAR APD #S0223 ($2x2mm^2$, $0.7pf/mm^2$)
- QE > 65% at >530 nm,
- ~5 NS RISETIME AT 500nm
- Gain >1000X, (0^0C), AT ~1750v

  ΔGain/ΔV (G=1000,0^0C) = +5%(-2%)
  EMCO CA20P HV Power Supply (Ripple < 0.001%)

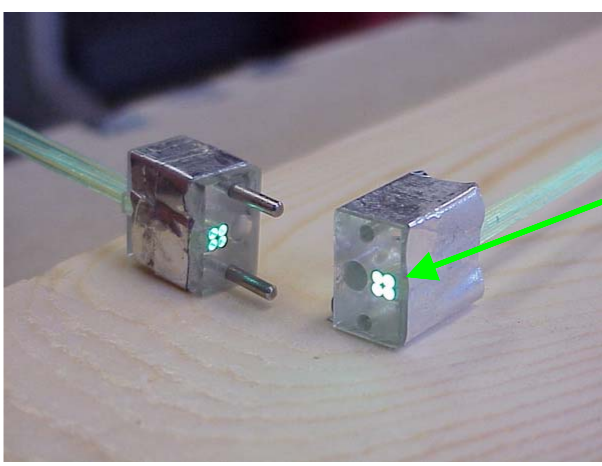
Scintillator/WLS Prototype

- TWO 3.7m LONG FULL LENGTH STRIP PROTOTYPES (ITASCA, AMCRYS SCINTILLATOR) & CHARACTERIZE THEM USING PMT, THEN WITH APD
  - TESTS ITASCA vrs AMCRYS EXTRUSIONS
    - LIGHT YIELD
    - POSITION RESOLUTION By TIMING
    - POSITION RESOLUTION By PULSE HEIGHT
- DEVELOP PELTIER COOLING & OPTICAL CONNECTIONS TO APD
  - TEST THERMAL, CONFORMAL, & OPTICAL EPOXY
  - ASSEMBLE TE COOLER MODULE & TEST
  - DETERMINES NOISE, GAIN vrs TEMPERATURE
- CHARACTERIZE FULL LENGTH PROTOTYPE WITH A COOLED APD READOUT





MINI-CONNECTORS WITH DOWEL REGISTRATION LIKE MINOS

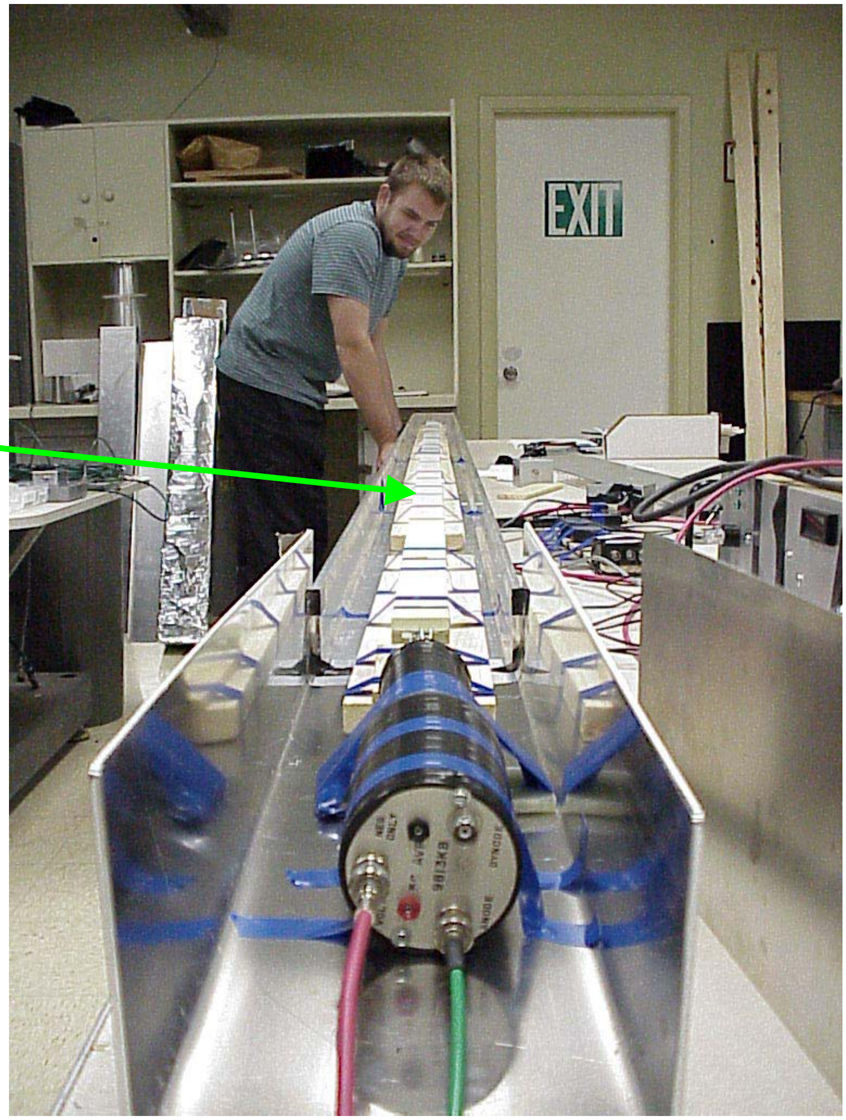


WITH 4 WLS FIBERS

3.7 METER LONG
2cm THICK BAR

BOTH SCINT.
HAVE A MID-PT
EPOXY JOINT –

MAY LOCALLY
EFFECT TIMING
RESOLUTION

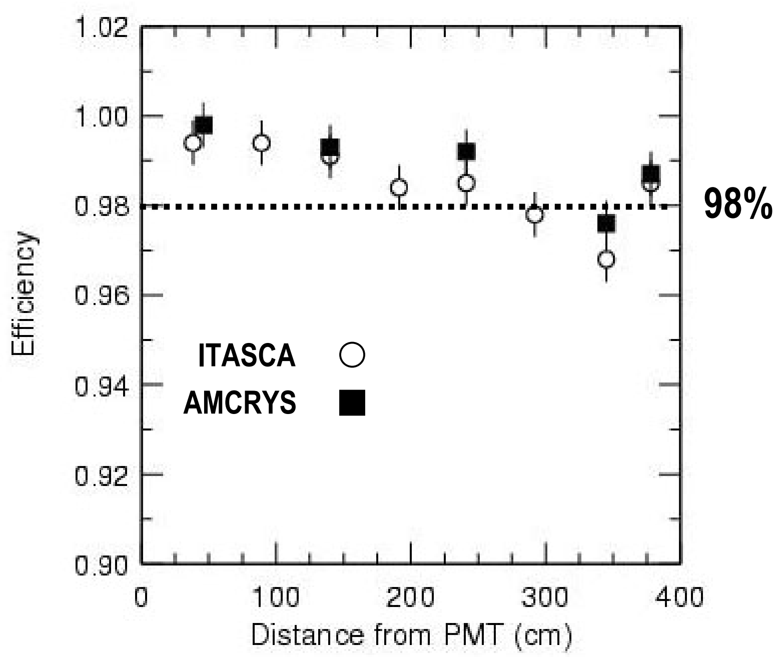


RESULTS FROM TWO FULL LENGTH PROTOTYPE

TESTS WITH PMT READOUT (BOTH ENDS):

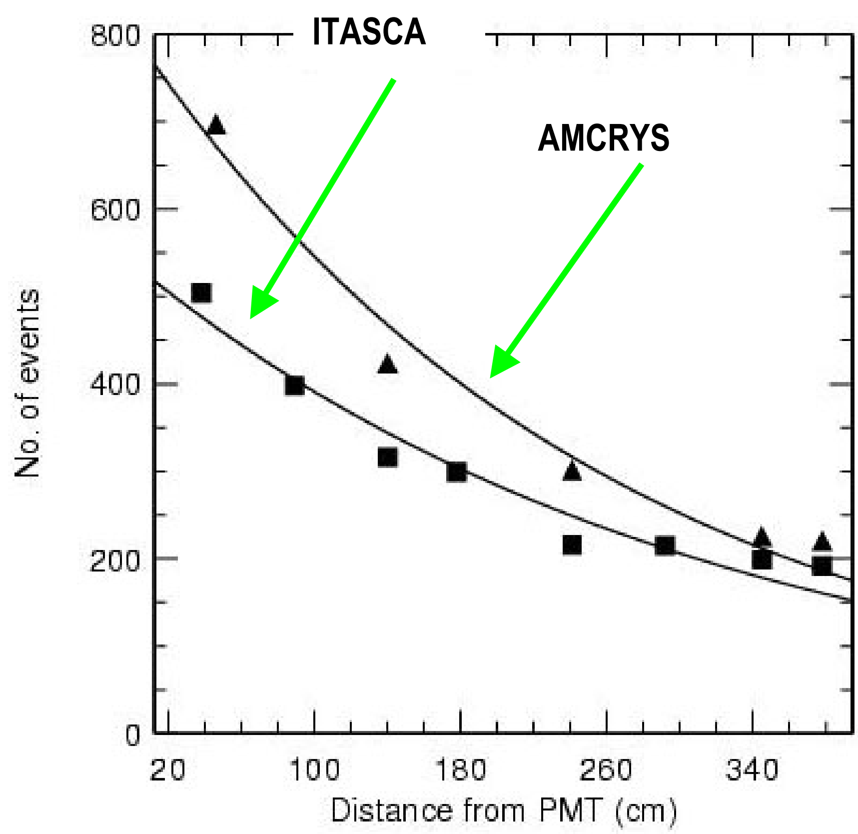
- **EFFICIENCY:**
    - REQ. EXT. TRIG. HODOSCP ~ 4cm RGN ALONG BAR
    - REQ. PMT2 TO SEE >10 adc cts (~1 γ) > PEDISTAL
    - >1500 SAMPLES / POSITION

SINGLE SIDED EFFICIENCY OF FULL LENGTH BAR



- LIGHT YIELD AND ATTENUATION LENGTH:

REQ. EXTERNAL TRIGGER HODOSCOPE TO DEFINE ~ 4cm REGION ALONG BAR (COSMIC MUONS)



- <ATTENUATION LENGTH >(ITASCA) = 312 cm
- <ATTENUATION LENGTH >(UKRAINIAN) = 259 cm

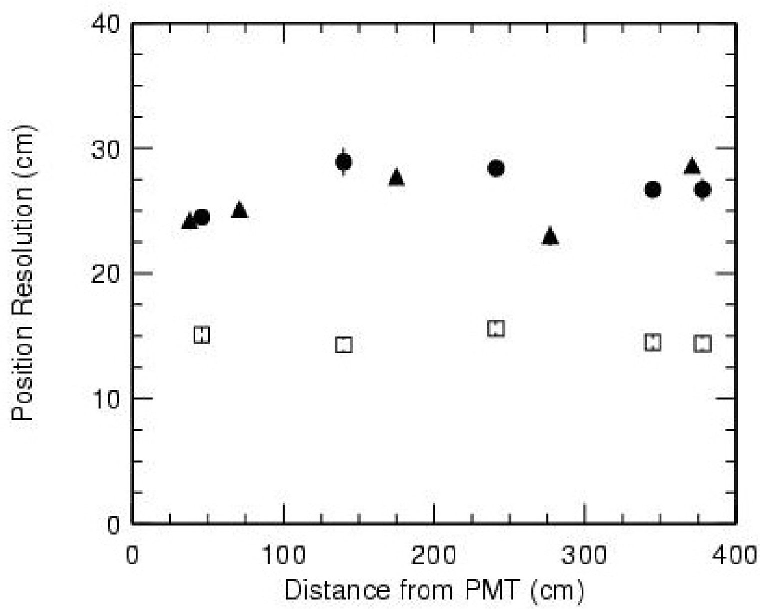
FITS SHOW NON-EXPONENTIAL BEHAVIOR BECAUSE OF WAVELENGTH DEPENDENCE

- AVERAGE LIGHT YIELD UKRAINIAN ~31% > ITASCA

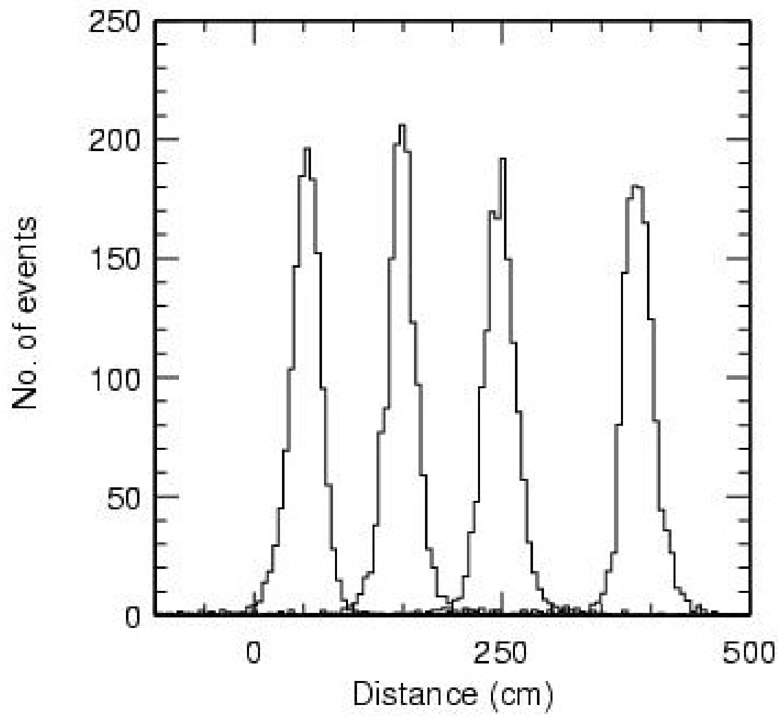
- **TIMING MEASUREMENTS (PMT) OF FULL LENGTH BARS (AVERAGED OF BOTH ENDS)**

(Total Length + (Pos(PMT1) – Pos(PMT2)) * 0.5
Could improve with Weighted Average
OBSERVE ~17cm/ns Propagation Velocity

DIST.	Pos. Resolution ITASCA	DIST.	Pos. Resolution AMCRYS
(cm)	(cm)	(cm)	(cm)
38	17.8 +/- 0.3	46	15.1 +/- 0.2
89	16.2 +/- 0.5		
140	17.8 +/- 0.4	140	14.3 +/- 0.4
178	16.6 +/- 0.8		
241	17.9 +/- 1.3	241	15.6 +/- 0.3
292	17.1 +/- 0.6		
345	17.1 +/- 0.8	345	14.5 +/- 0.3
378	16.8 +/- 0.8	388	14.4 +/- 0.4



AMCRYS SCINTILLATOR



XP2262B PMT and Photo Electron Calibration

700 ADC cts/MIN ION at 42cm
PMT QE~14% at 520 nm IMPLIES ~500 PRIMARY PHOTONS FROM THE 4 FIBERS REACH PMT

With APD QE of 60%, we expect 240 pe at 42 cm.

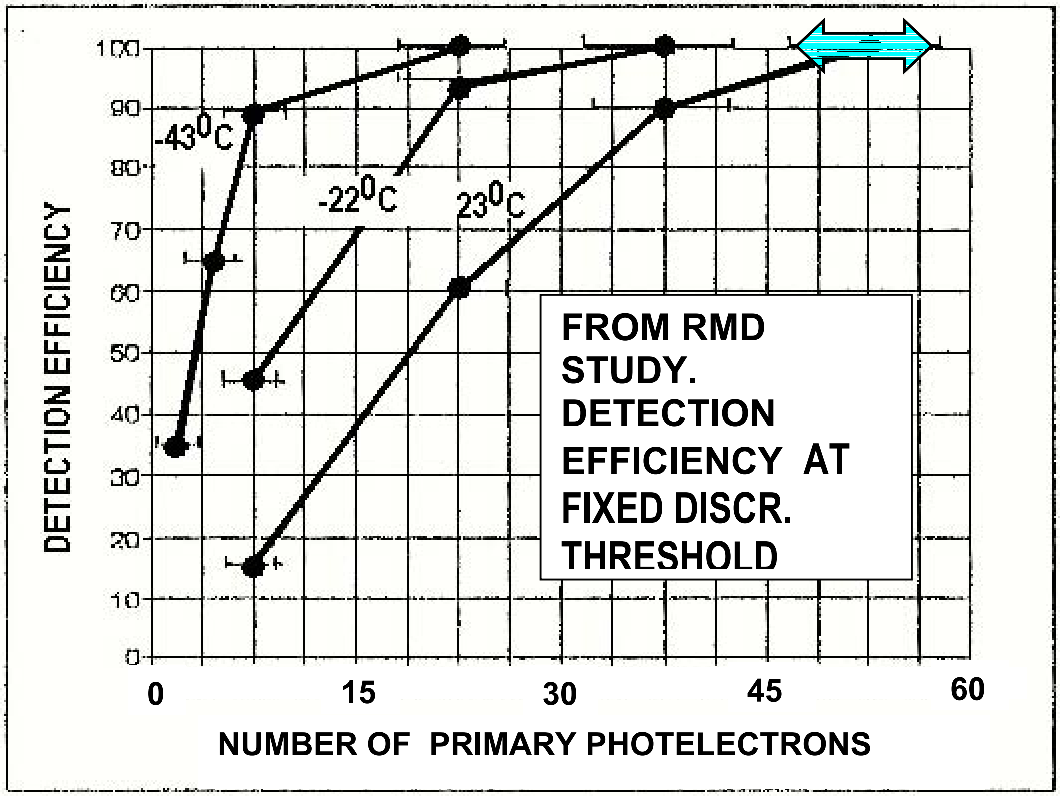
➔ > 60 pe at 370 cm

NOISE IN APDS & COOLING

- 4 PRIMARY SOURCES OF NOISE & PEAK BROADENING IN PLANAR (NON-BEVELED EDGE) APDS:
  - USUAL ELECTRONICS NOISE FROM C & R AT INPUT OF FET (measure at ~50v when fully depleted)
  - FLUXUATIONS IN AMPLIFICATION OF DARK CURRENT (BULK) IN APD DEPEND ON STATISTICAL NATURE OF THE IMPACT IONIZATION PROCESS
  - FLUXUATIONS IN EDGE CURRENT (NOT AMPLIFIED)
  - FLUCTUATIONS IN SIGNAL AMPLIFICATION WHICH DEPEND ON STATISTICAL NATURE OF THE IMPACT IONIZATION PROCESS
- COOLING THE APD HAS THREE EFFECTS:
  - REDUCES BULK LEAKAGE CURRENT (halves @ -10^{0}C)

    →REDUCES AMPLIFIED NOISE CONTRIBUTION
  - INCREASES IMPACT IONIZATION PROBABILITY OF CARRIERS (both α and β increase as T decreases)

    →GAIN INCREASES AT FIXED VOLTAGE
  - REDUCES EXCESS NOISE FACTOR (F) ($\Delta\alpha > \Delta\beta$ for a decrease in T)



DATA FROM RMD SUGGESTED THAT BY COOLING APD TO ~0⁰C, THE DETECTION EFFICIENCY FOR MIN ION WILL BE ~100% EVERYWHERE.

SIGNAL TO NOISE TARGET

50 –60 pe /APD (Worst Case of 3.7 m Distance)
APD Gain of 1000x ➔ 60,000 electrons

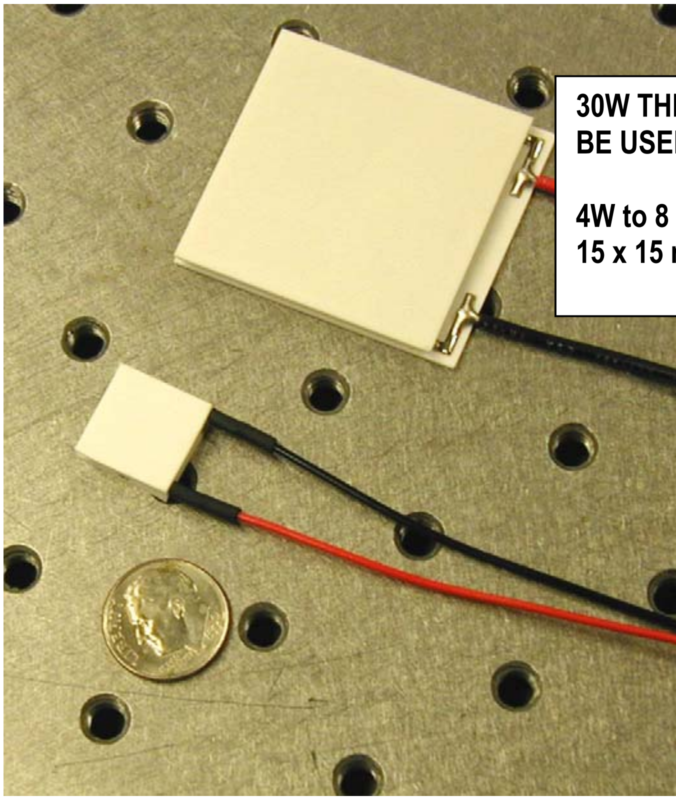
A250F Charge Sensitive Amplifier

Integration Time ~ 100 ns
Gain : 4 mV / fc
Amplifier Noise: ~220 e
(APD + Stray capacitance = 10 pf)

Worst Case Signal: ~40 mV

Masured Noise ~ 1-2 mV RMS at 1.85 kV

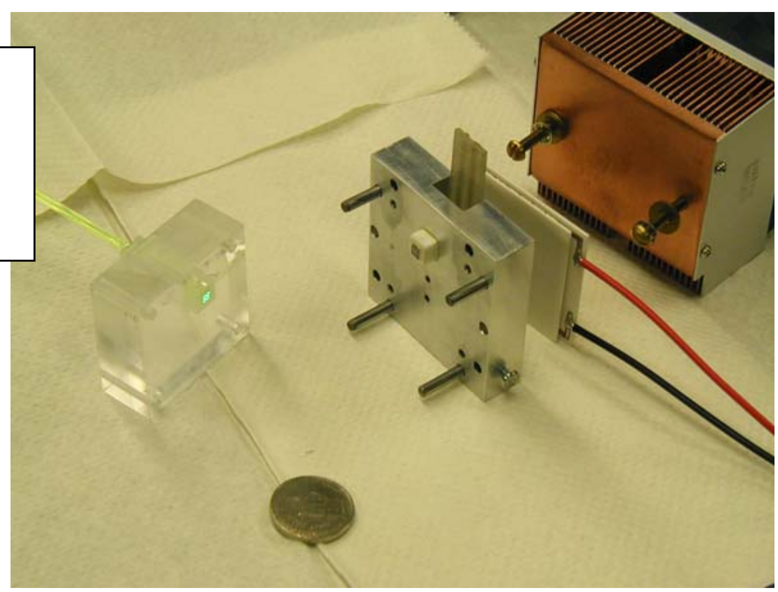
PELTIER COOLING & OPTICAL CONNECTS TO APD



30W THERMO-ELECTRIC COOLER TO BE USED INITIALLY

4W to 8 W SMALLER ONES
15 x 15 mm FOR ACTUAL USE IN IFR

APD COOLER, MACOR APD HOLDER, HEAT SINK & FIBER OPTIC CONNECTOR BEFORE EPOXYING (FRONT VIEW)

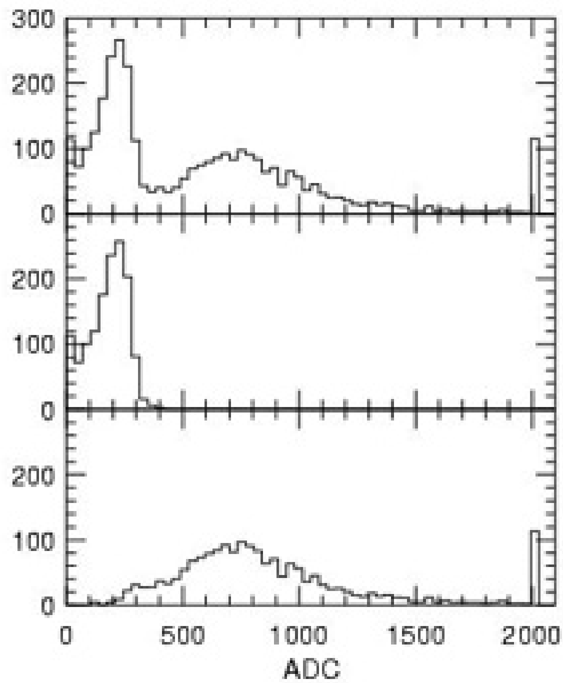


DATA USING COOLED APD ON FULL LENGTH BAR:

APD Cooled to 0-Deg C. HV = 1765 V
Defining Counters positioned at 380 cm from APD

Preamp Output Amplified x20 (To fit ADC range)

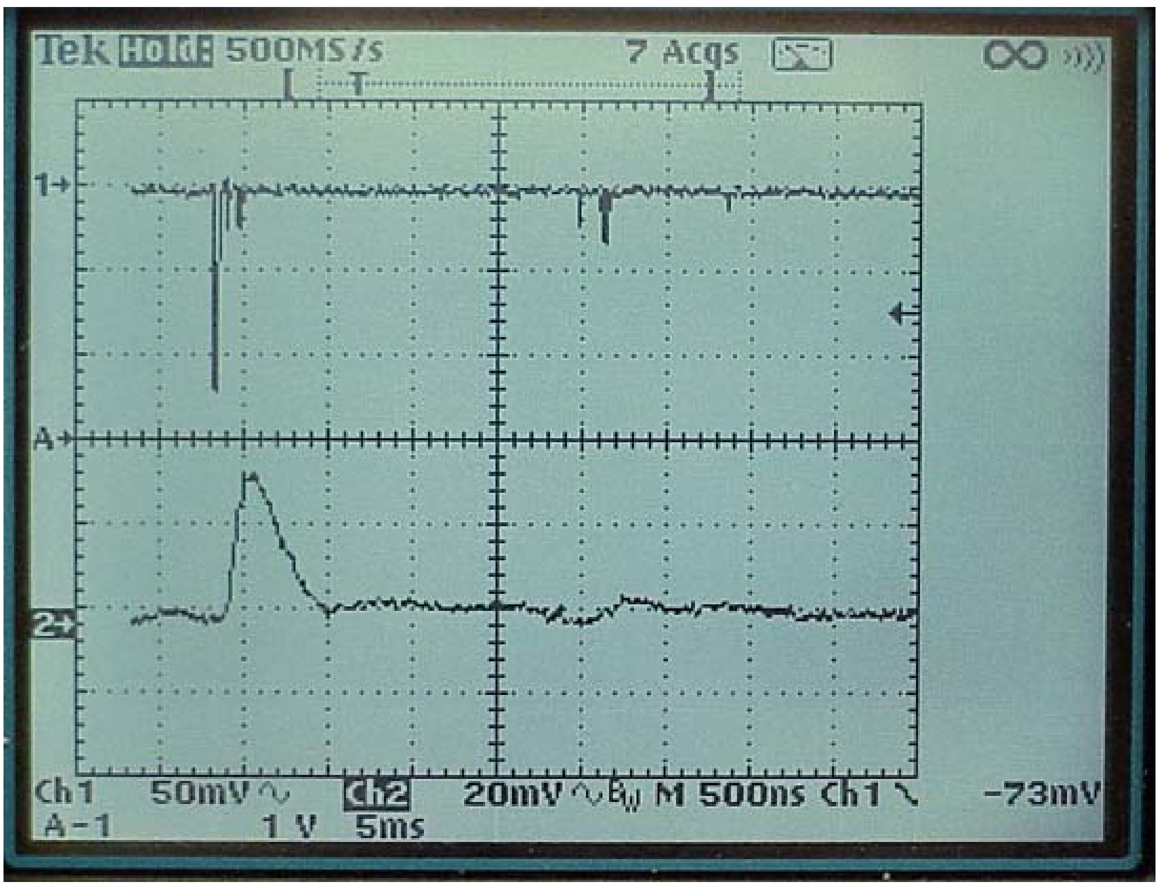
Top: All Signals with No Threshold Cut
Middle: < 60 mV Threshold Cut
Bottom: > 60 mV Threshold Cut MIN I Signal!



Signal Efficiency: > 98% with 60 mV Threshold
Background Rate: < 1%

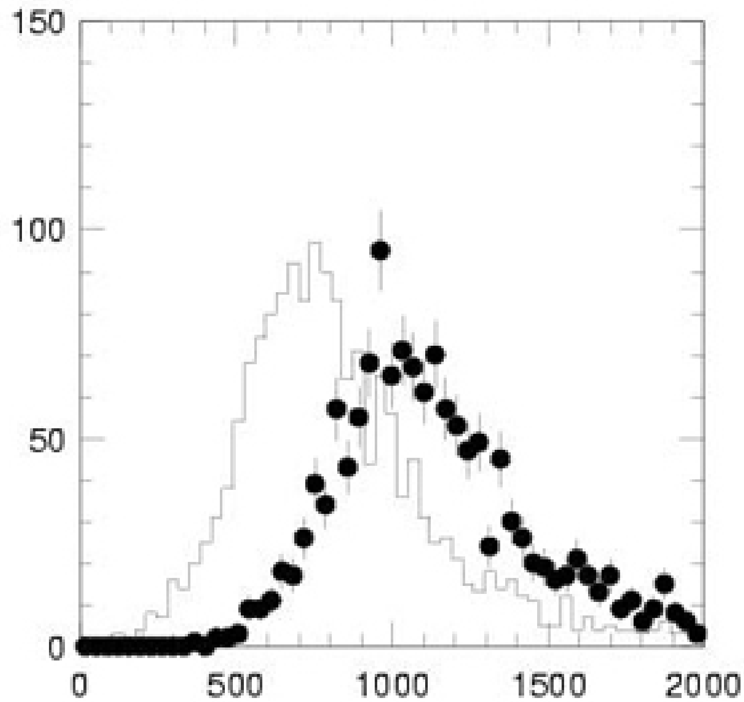
Example Scope Shot of PMT and APD Signals

Top: PMT Signal
Bottom: APD Signal



ADC COUNTS AT DIFFERENT DISTANCES

Histogram: 380 cm Away from APD
Dots: 75 cm Away from APD



TIMING RESOLUTION IS POOR

Sigma (Position) = 75 cm

Due to SLOW RISE time of Preamp
~100 ns

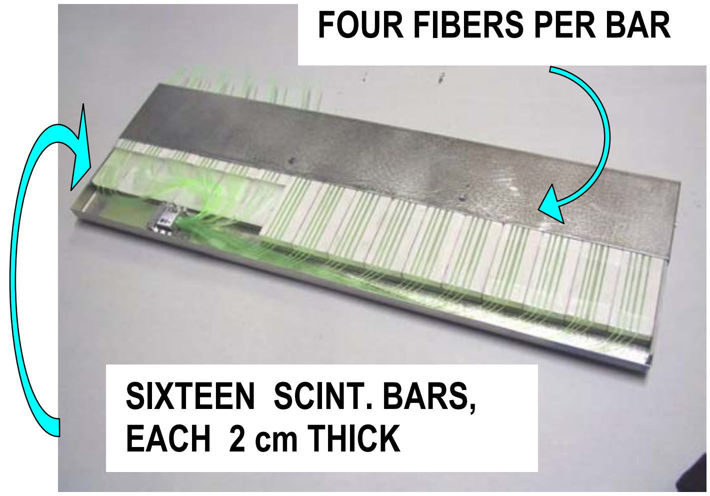
Work in Progress to modify Feedback Capacitor for AMPTEK 250F Preamp without loosing Sig/N ratio.

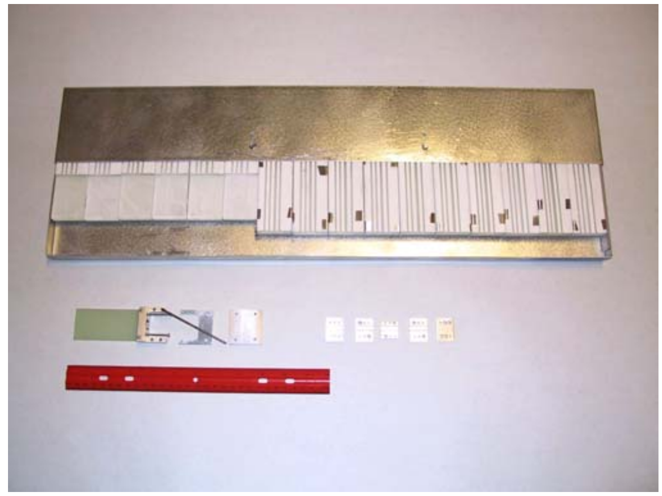
Z Position Measurement can also be obtained with the Scintillator Bars at STEREO ANGLES
(MINOS DETECTOR)

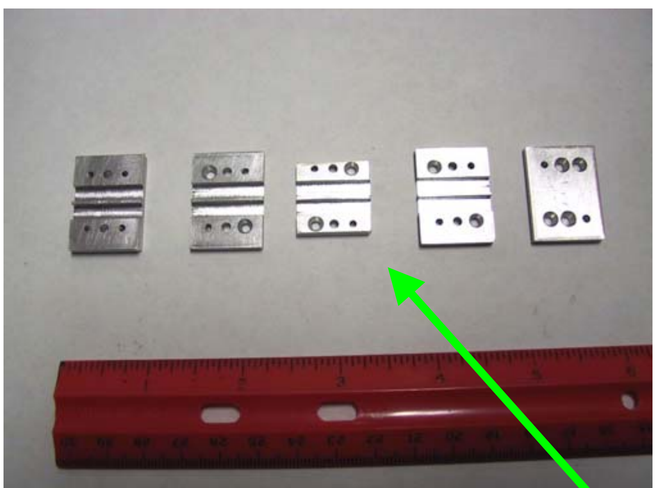
OR

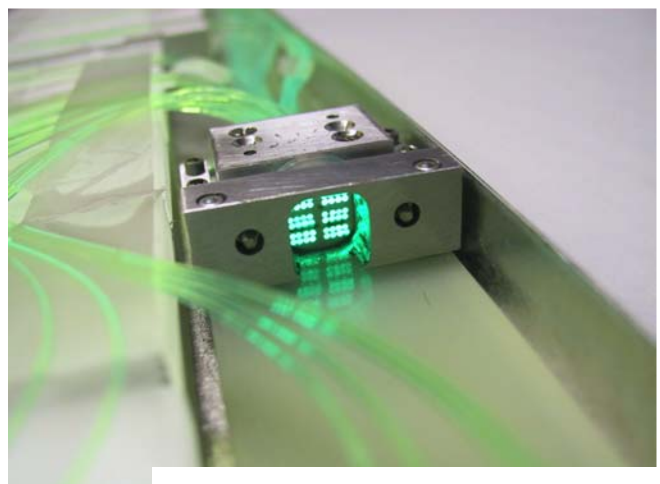
SCINTILLATOR TILES WITH WLS FIBER READOUT

STUDY OF FIBER & MODULE LAYOUT

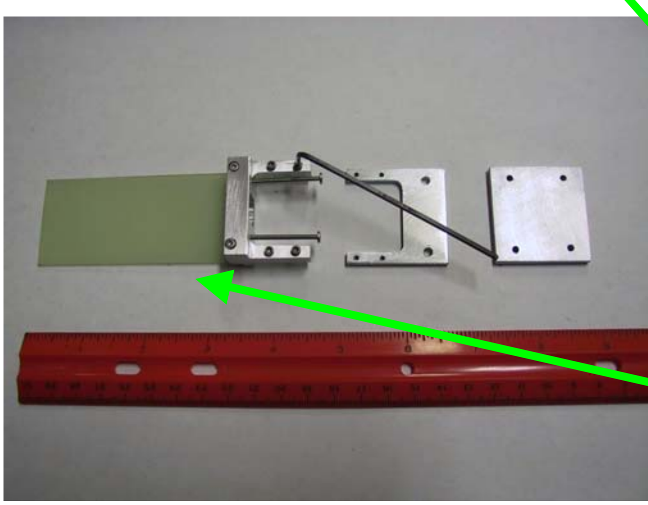








CONNECTOR TO 4x4 APD ARRAY
& THERMO ELECTRIC COOLER,
PREAMP& DISCR CARD



PIECES BUILT UP TO MAKE
FIBER OPTIC CONNECTOR

PREAMPLIFIER CARD

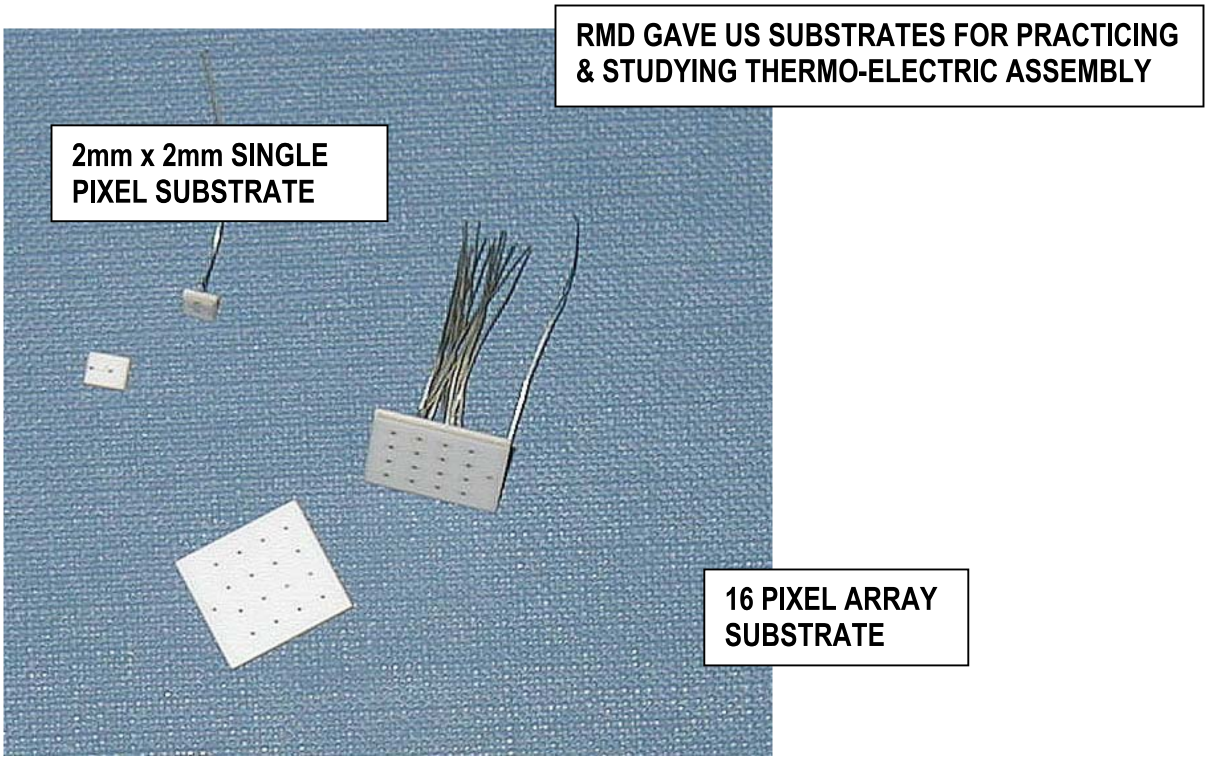
BABAR HAS CHOSEN

LIMITED STREAMER TUBES (LST)

FOR MUON UPGRADE …

R&D CONTINUES…

STUDY OF 4 x 4 (16-pixel) APD ARRAYS



LONG TERM BURNIN TEST OF APD AT HIGH TEMP

15 4x4 ARRAYS OBATINED FROM RMD

POSSIBILITY OF REPLACING ENDCAP RPC IN HIGH BACKGROUND RADIATION REGION IN 2006

SUMMARY

SCINTILLATOR/WLS DETECTOR WELL SUITED FOR MUON DETECTION AT HIGH RATES (SIGNAL & BACKGROUND)

NO PROBLEM WITH HIGH MAGNETIC FIELD (5 T in LC Detectors)

GOOD SIGNAL/NOISE RATIO CAN BE OBTAINED WITH OPTIMIZATION OF BIAS VOLTAGE AND COOLING

64 PIXEL ARRAY