READOUT OF EXTRUDED SCINTILLATOR WITH EMBEDDED WLS FIBER & HIGH GAIN AVALANCHE PHOTODIODES

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(SLAC, CALTECH, UMass)

MOST OF THIS WORK HAS BEEN DONE ONLY SINCE LAST SUMMER AS R&D FOR AN UPGRADE TO THE MUON SYSTEM IN BABAR

GOAL:

REPLACE ~9 to 12 of 19 LAYERS OF RPC IN THE BARREL MUON SYSTEM – BALANCE IN BRASS ABS.

EXISTING GAPS ARE 2.2 cm high X 3.7m Long

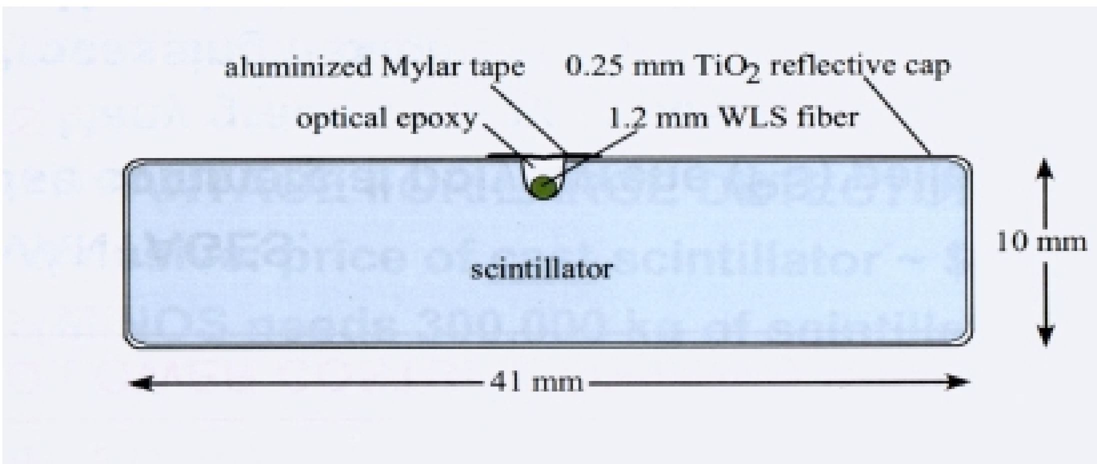
DESIRED RESOLUTION ~ 4 cm in PHI
~ 20 cm IN Z

DESIRED EFFICIENCY ~100% - GEOM LOSS / Layer
For Hits at Far (3.7m) end

BASIS OF IDEA

- BUILD SHORT (3.7m vrs 8m) VERSION OF MINOS SCINTILLATION SYS. WITH ΔT TO GET THE SECOND COORDINATE ALONG BAR

- MINOS USES ~300 Tons OF CHEAP CO-EXTRUDED SCINTILLATOR BARS (8m x 4cmx1cm) WITH A SINGLE 1.2mmØ Y11-175 multiclad (polystyr., pmma, Teflon) WLS FIBER EPOXIED IN EXTRUDED GROOVE



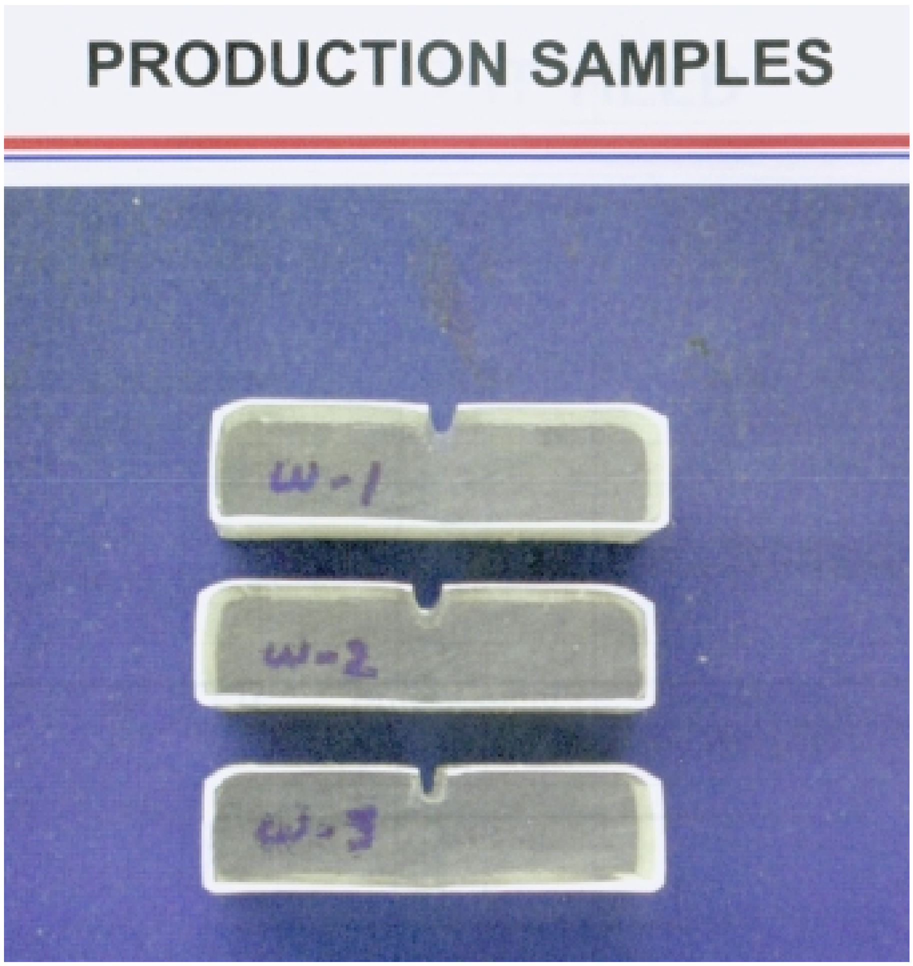
MINOS:

- WLS FIBER → LONG CLEAR FIBER → PIXELATED PMT ~3→4 pe/fiber at ~3.7 m INCL. CONNECTS & PMT QE

  PMT IS MAIN PROBLEM FOR RETROFITTING OF BABAR

- STARTED LOOKING AT WHETHER SCINTILLATOR BARS COULD BE READ OUT SIMPLY BY ATTACHING A LARGE AREA APD (25mm^2 Hamamatsu S8664-55 APD for CMS) TO EACH END
  - SIMULATION and LAB WORK SHOW WE WOULD NEED ~150mm^2 (~6 APD/end) TO GET ENOUGH SIGNAL WITH THESE DEVICES (low gain ~50X, high cap. 4pf/mm^2)

- RETURNED TO MINOS IDEA OF COLLECTING LIGHT ALONG A BAR VIA DIFFUSE SCATTERING INTO EMBEDDED WLS FIBER WHERE λ_{att} ~4 m RATHER THAN TRANSPORT IN EXTRUDED SCINTILLATOR (where λ_{att} ~ 20cm to 100cm)
- THEN COUPLING FIBER(S) TO A SMALLER AREA / HIGH GAIN APD FOR READOUT

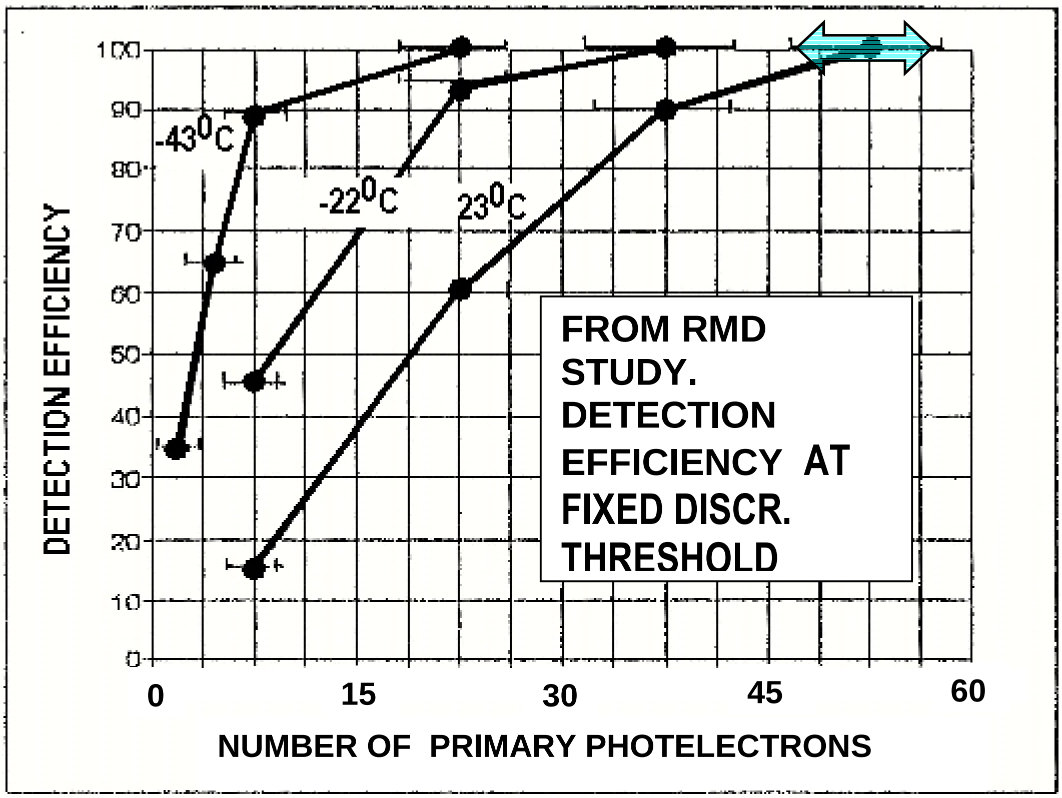


MINOS PRODUCTION BARS SHOWING
4 x 1 cm^2 CROSS SECTION WITH CO-EXTRUDED TiO_2
AND ~2mm GROOVE FOR WLS FIBER

ADVANTAGES: COMPACT, ROBUST, MECHANICALLY SIMPLE LITTLE AND VERY LITTLE DEAD SPACE

TO SET SCALE: WE FOUND AT LEAST TWO PRODUCERS OF SMALL HIGH GAIN APD's THAT MIGHT WORK (RMD and ADV. PHOTONICS).

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

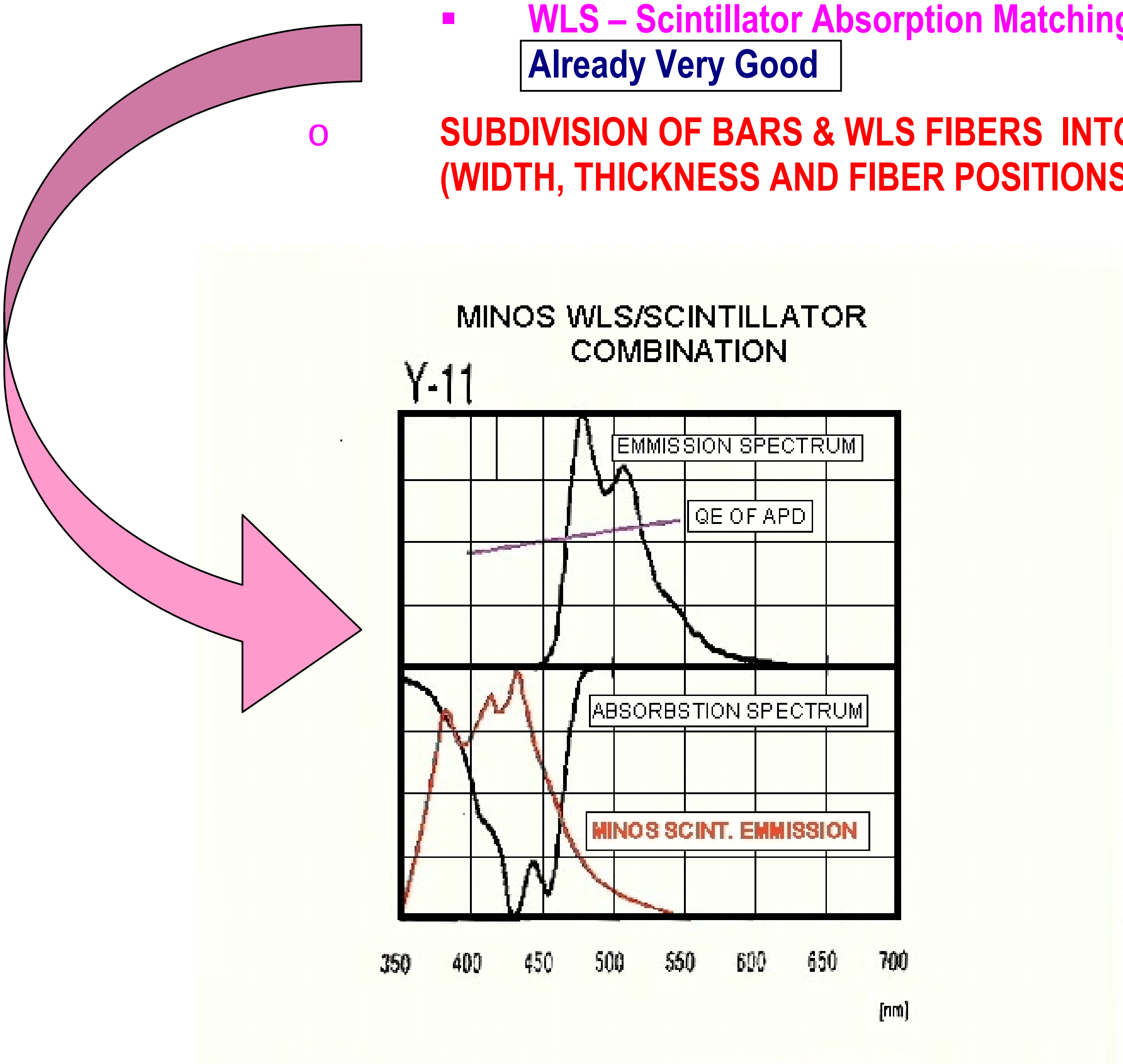


QUESTION : UNDER BABAR CONSTRAINTS ON THICKNESS & LENGTH, COULD WE GET ENOUGH LIGHT USING THE INEXPENSIVE WLS ($1/m) & SCINTILLATOR ($10/Kg vrs $50 to $100/Kg) FOR HIGH EFFICIENCY DETECTION AND SUITABLE TIME RESOLUTION FOR Z-COORDINATE

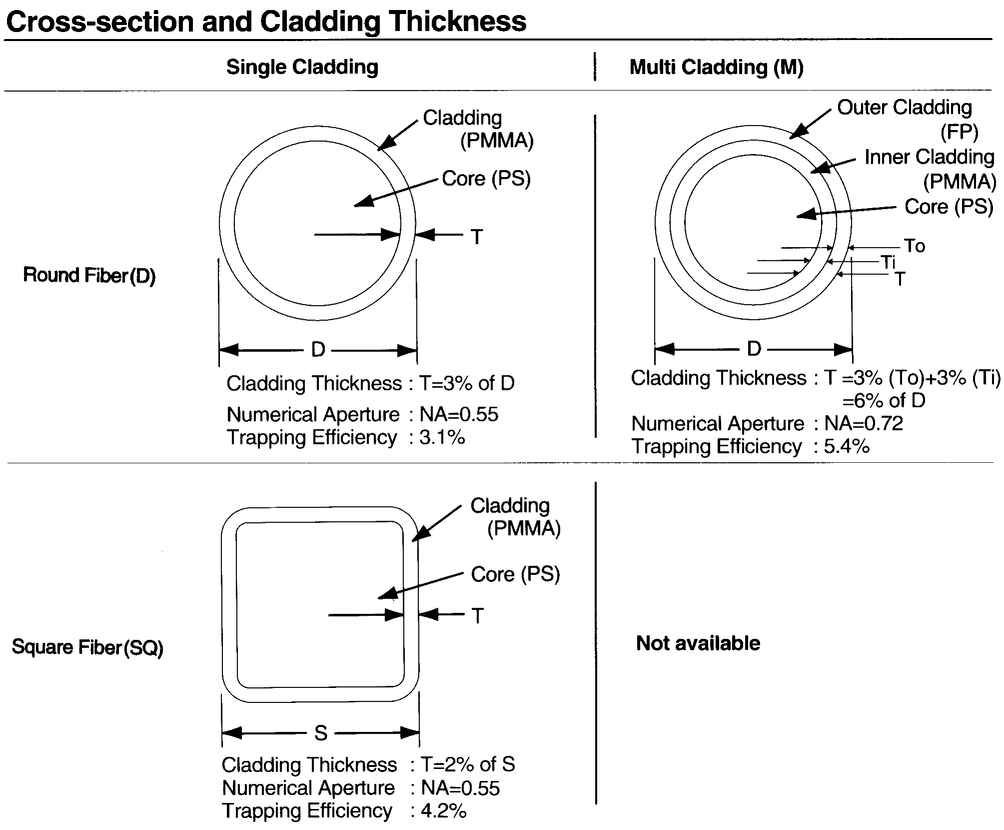
- **MANY POSSIBLE WAYS TO INCREASE LIGHT YIELD OVER MINOS**

  - o INCREASE # FIBERS PER BAR
  - o INCREASE BAR THICKNESS
  - o IMPROVE SCINTILLATOR & WLS
    - Cast vrs Extruded (cost 4→8X to Get +30%) X
    - Improve Quality of Extruded Material (λ=20→λ=100) ☻
    - Improve Coating (Reflectivity→97%) ☻
    - WLS – Scintillator Absorption Matching ☻

      Already Very Good
  - o SUBDIVISION OF BARS & WLS FIBERS INTO APD (WIDTH, THICKNESS AND FIBER POSITIONS)



◦ WLS FIBER CLADDING AND SHAPE



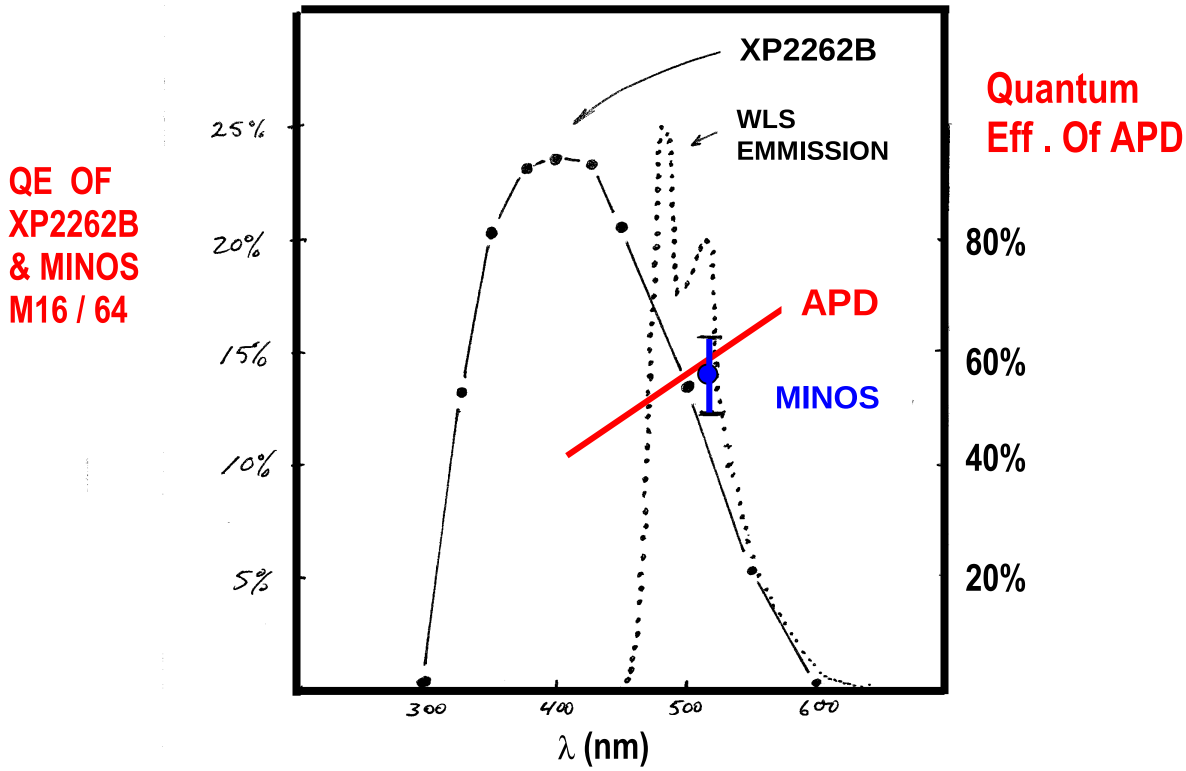
3.1% → 5.4% TRAPPING GOING SINGLE TO MULTICLAD
(already factored in from MINOS)
3.1% → 4.2% TRAPPING BY GOING FROM ROUND → SQUARE
(potentially additional gain of 25%)

- **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)**

- ## QUANTUM EFFICIENCY OF READOUT DEVICE

WE EXAMINED SEVERAL APD ON MARKET – DEVICE FROM RMD APPEARED CLOSEST TO NEEDS & COST (More Later)

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

THIS QE IS TYPICAL OF Si APD DEVICES

GIVEN THE BABAR CONSTRAINTS, WHAT WE MIGHT EXPECT BASED ON MINOS AND OUR MONTE CARLO?

- REPLACE PMT WITH APD (~4X HIGHER QE)
- INCREASE # OF FIBERS TO 4 (~2X MORE LIGHT)
- INCREASE SCINT. THICKNS TO ~2cm (~1.5 X MORE LIGHT)
- IMPROVED SCINT. & WLS (1.3 X MORE LIGHT)

IMPLIES ~ 60pe at ~3.7m FOR MIN ION INTO A 2 x 2mm^2 APD

CLOSE TO SUFFICIENT TO MEET EFFICIENCY GOAL!

FOR POSITION RESOLUTION :

- POSITION in PHI (ϕ) set BY STRIP WIDTH (4 → 7 cm)
  - σ_ϕ ~ 1.2 cm (inner layer)
  - σ_ϕ ~ 1.7 cm (outer layer)
- PROPAGATION TIME OF 17cm/ns IN WLS FIBER IMPLIES σ_z ~ 25cm FOR EACH END iF σ_t ~ 1ns
  - APD Risetime ~5ns
  - Dispersion of Signal Edge in WLS (MC <1ns)
  - Risetime of Preamp (A250F) (thry < 25ns)
- MEASUREMENTS FROM BOTH ENDS MUST BE:
  - COMBINABLE TO σ_z ~ 15 cm

  LOOKS OKAY TOO !

BABAR PROPOSAL:

- REPLACE 9 LYRS INSIDE FLUX RETURN STEEL WITH EXTRUDED SCINTILLATOR STRIPS READ OUT WITH WLS FIBER & AVALANCHE PHOTODIODES – OPER. IN 15Kg

- PHI COORDINATE FROM STRIP WIDTH, Z COORDINATE FROM TIMING

- GEOMETRY OF EACH SEXTANT

  - EACH LAYER IN EACH SEXTANT CONTAINS 3 ~ IDENTICAL MODULES SIMILAR TO MINOS IN CONSTRUCTION

  - EACH MODULE IS THE LENGTH OF THE STEEL (3.74 m) & CONTAINS 14 SCINTILLATOR STRIPS OF WIDTH 4cm to 7cm In PHI, & EXTENDS TO ~3 cm OF STEEL EDGE

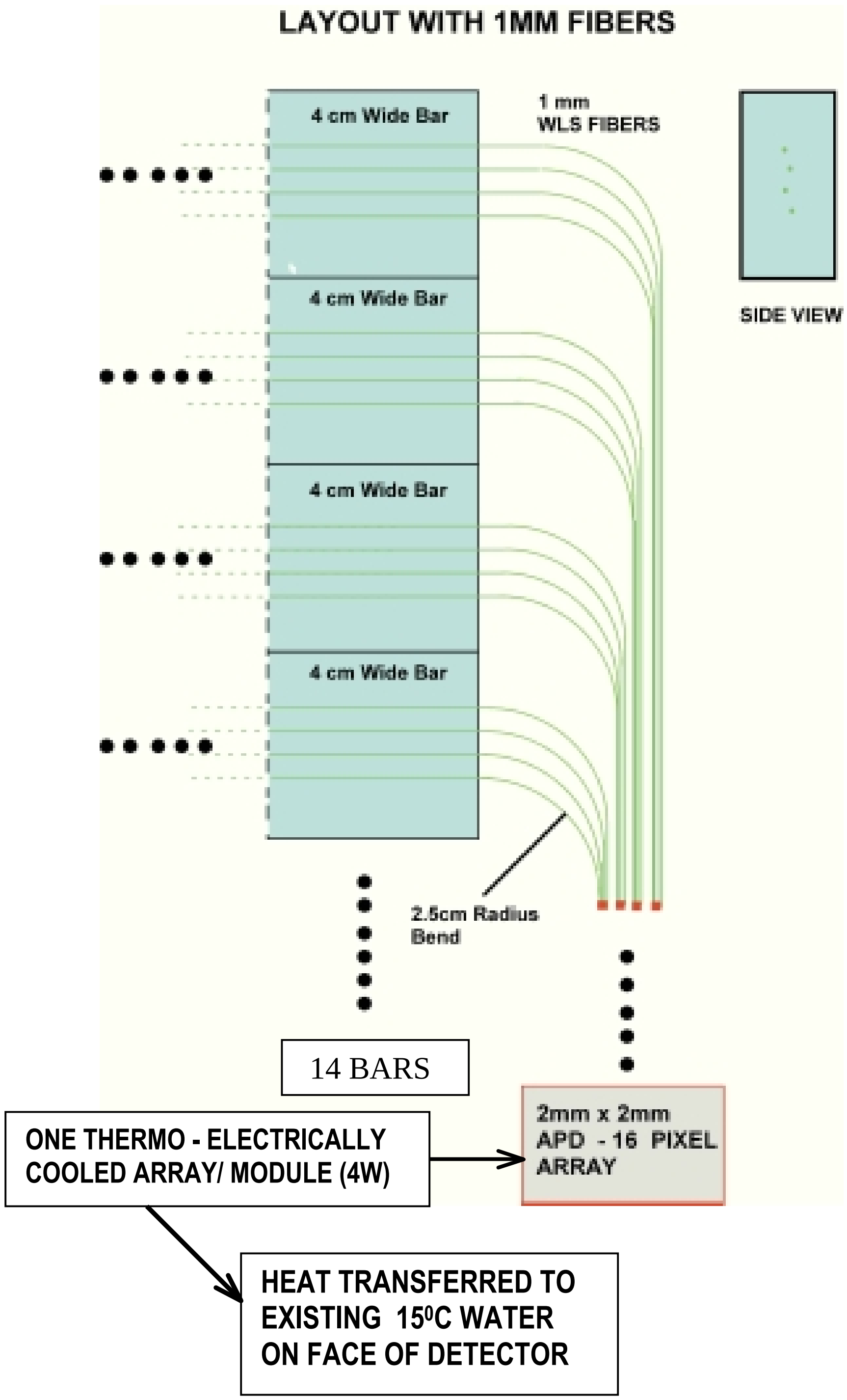
  - SCINTILLATOR IS LOW-COST CO-EXTRUDED MATERIAL OF ~2 cm(-) THKNS; EPOXIED INTO 0.5mm AL CRIMPED BOX

  - WLS FIBER IS 1.2mm KURARAY DBL–CLAD S-TYPE Y11(200)

  - EACH OF 14 STRIPS HAS 4 WLS FIBERS. EACH END GANGED INTO ONE 2x2mm^2 PIXEL OF 16 PIXEL RMD A1604 APD ARRAY, SPECIFIED TO HAVE 14 → 16 PIXELS MEETING NOISE SPEC.

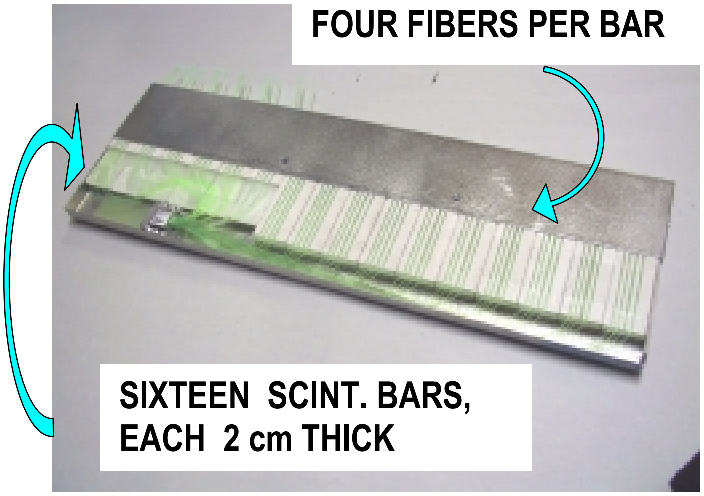
  - 1 APD ARRAY, 1 PREAMP/DISCR. CARD RESIDE ON EACH END OF MODULE.

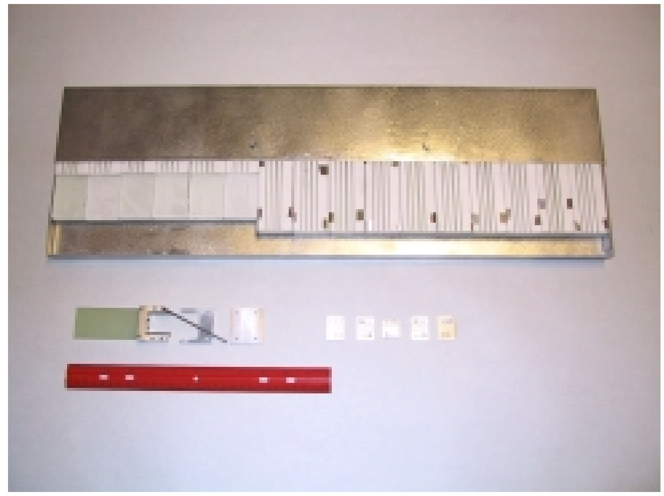
  - APD COOLING ACCOMPLISHED BY 4 Watt PELTIER DEVICE WITH HEAT TRANSFER VIA MODULE COVER. TWO TE COOLERS WILL BE PRESENT FOR REDUNDANCY. 1 cfh DRY AIR OR N2 REQ. PER MODULE

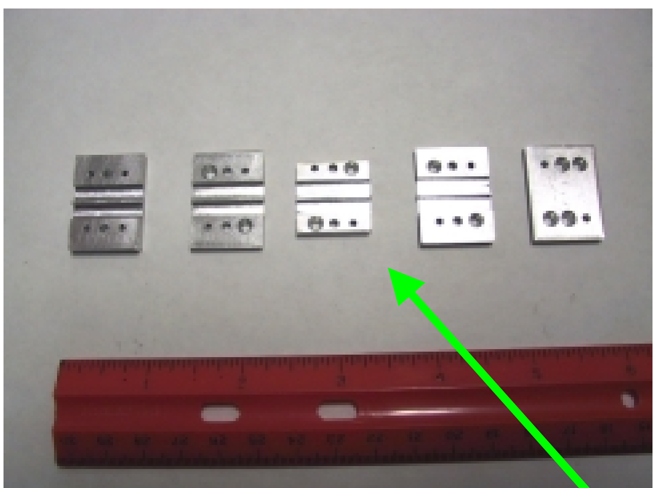


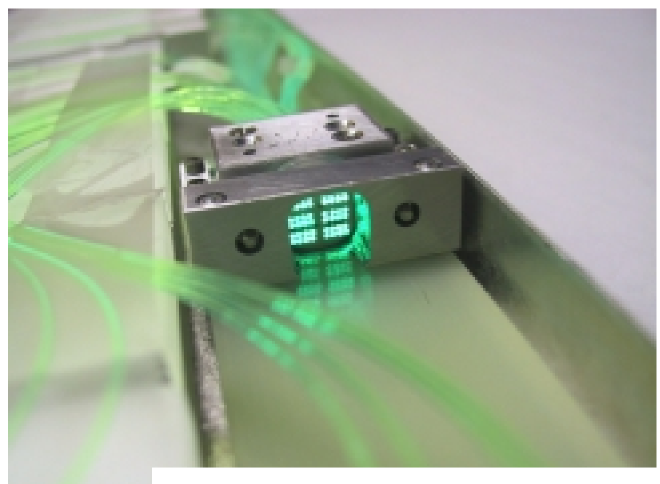
LAYOUT WITH 1MM FIBERS
4 cm Wide Bar
1 mm
WLS FIBERS
SIDE VIEW
4 cm Wide Bar
4 cm Wide Bar
4 cm Wide Bar
2.5cm Radius
Bend
14 BARS
2mm x 2mm
APD - 16 PIXEL
ARRAY
ONE THERMO - ELECTRICALLY
COOLED ARRAY/ MODULE (4W)
HEAT TRANSFERRED TO
EXISTING 15⁰C WATER
ON FACE OF DETECTOR

START OF STUDY OF FIBER & MODULE LAYOUT

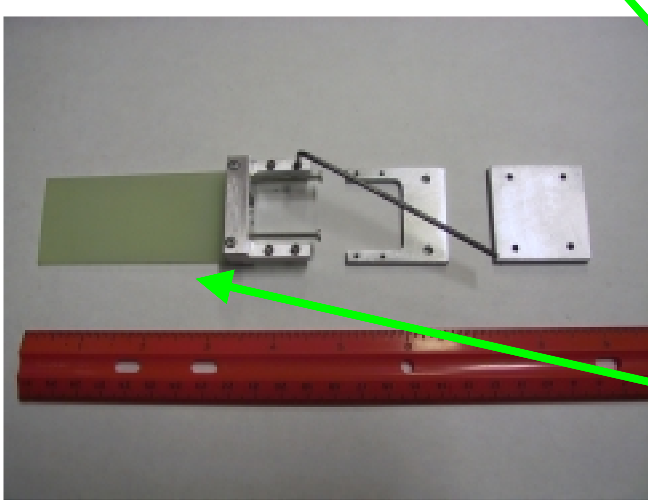








CONNECTOR TO 4x4 APD ARRAY
& THERMO ELECTRIC COOLER,
PREAMP& DISCR CARD



PIECES BUILT UP TO MAKE
FIBER OPTIC CONNECTOR

PREAMPLIFIER CARD

PROPOSAL (CONTINUED)

- **DAQ MIMICS DIRC TDC SYSTEM**
  - DISCRIMINATOR OUTPUT OF EACH END PIXEL GOES TO DIRC STYLE DFB (8 TDC/CARD) WITH σ ~1ns LOCATED ON END OF BABAR IN REUSED IFB CRATES FROM IFR
  - TDC DATA GOES TO RE-USED IFR TPC - ROM

- **CALIBRATION**
  - THRESHOLD DIGITALLY SET IN PREAMP / DISCRIMINATOR
  - LED IN EACH APD BLOCK FOR STAT CHK & ROUGH T_0
  - GAIN ADJUSTED VIA SNGL HIGH VOLTAGE / MODULE END
  - PRECISE ΔT CALIBRATED VIA DIMUONS / PUNCHTHRU

- **SERVICES**
  - DRY N_2 TO EACH MODULE ~1cu ft/h (RE-USE IFR SYS)
  - CHILLED H_2O (15^0 C) TO @ MODULE TO REMOVE 4W+Preamp
  - FILTERED HV (0.1%) TO @ MODULE (~1850 v).
    (Re-Use IFR as Caan Regulation better than 0.5 v)
  - EXTERNAL LINEAR PROP. CTRL FOR TE MODULES POWER SUPPLIES (TEMP MEASURED VIA THERMOCOUPLES)

STATISTICS OF A 9 LAYER REPLACEMENT

STATISTICS: LAMBDA=	6.29	FULL BARREL		PER SEXTANTS
NUMBER OF REPLACED LAYERS:		9	Layers	9
NUMBER OF REPLACED SEXTANTS:		6	Sextants	1
NUMBER OF MODULES/SEXTANT LAYER		3	Modules/Sext Layer	
NUMBER OF STRIPS/SEXTANT/LAYER		42	Strips/Module	
NUMBER OF COMPOUND STRIPS (TOTAL):		2268	Compound strips	378
NUMBER OF MODULES (TOTAL)		162	Modules	27
KG OF SCINTILLATOR:		11615	Kg	1936
KILOMETERS OF WLS FIBER		41	Km	7
READOUT CHANNELS:		4536	Channels	756

FIRST GOAL OF R&D WAS TO ESTABLISH GEOMETRY WITH SUITABLE LIGHT YIELD

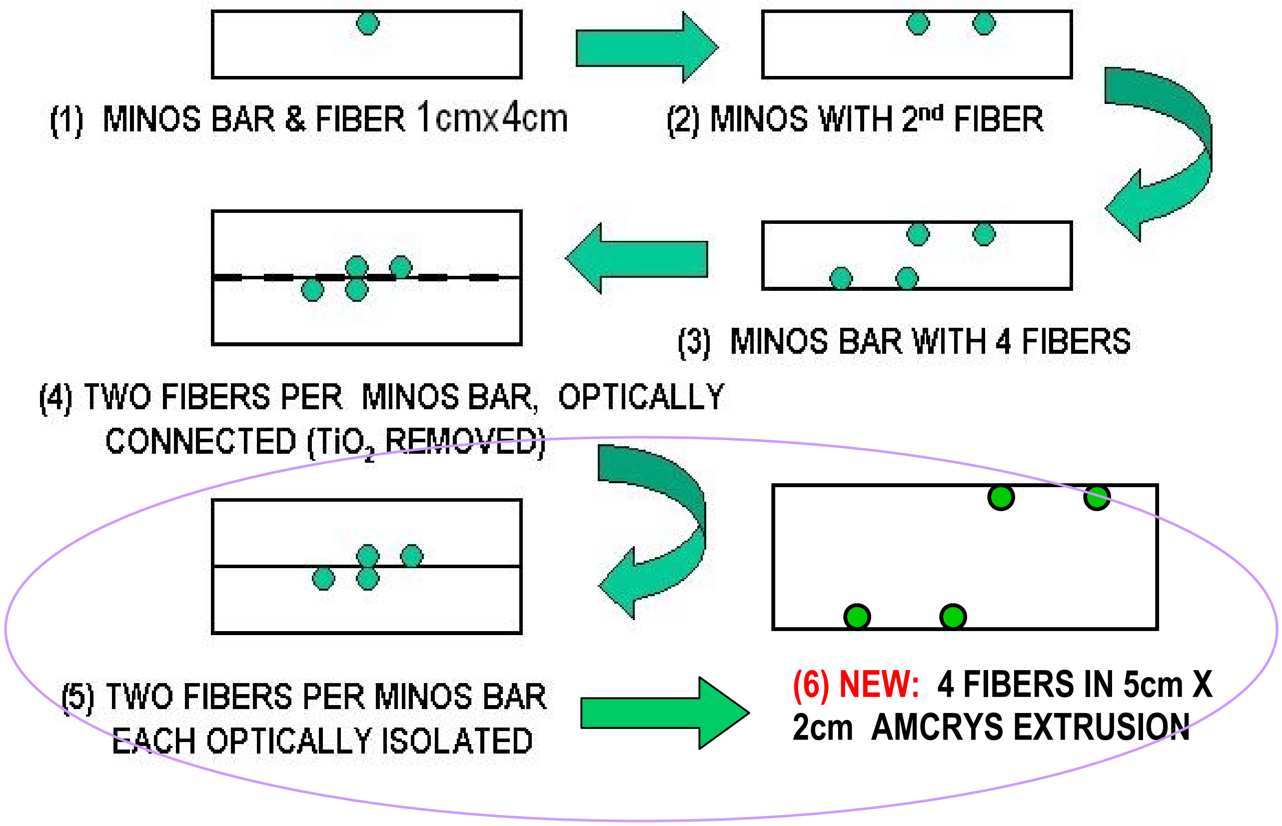
- PERFORMED MANY BASIC MEASUREMENTS TO STUDY GEOMETRY & PROPERTIES OF MINOS SCINTILLATOR + ROUND WLS + READOUT & COMPARE WITH MONTE CARLO

BASIC SETUP:

- ~2m LONG BARS & PMT/APD IN 4m LONG BOX
- 4 WLS (1.2mm) FIBERS BROUGHT OUT INTO SHORT ACRYLIC BLOCK FROM EACH END & POLISHED
- XP2262B PMT TO READOUT FIBERS – OPTICAL GREASE CONNECTION ON ONE END
- OTHER END OF FIBERS POLISHED AND TERMINATED INTO APD WITH AN OPTICAL GREASE JOINT
- TWO 4cm x 4cm x 1cm DEFINING COUNTERS (1cm Pb) (TO GENERATES TRIGGER & GATES)
- PMT SIGNAL SPLIT
    - → ADC (Lecroy 2249W) (50ns gate)
    - → AMPLITUDE - RISETIME CORRECTED DISCRIMINATOR (Philips 730)
    - → TDC (Lecroy 2228A)

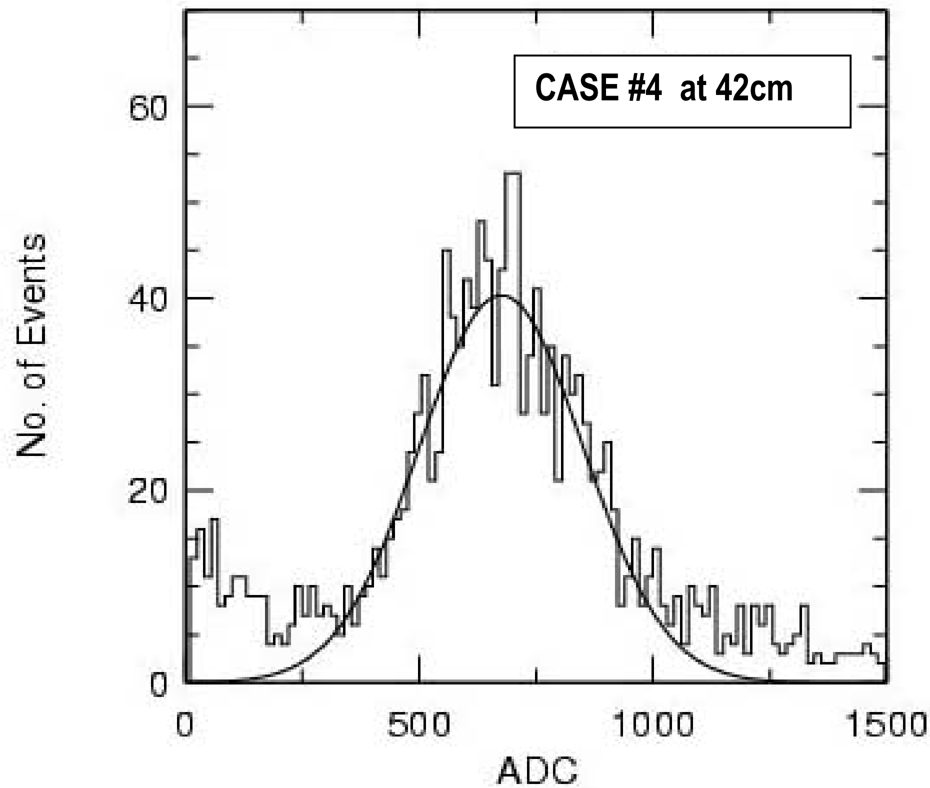
- DEVELOPED TRANSPORT MC SIMULATION TO STUDY GEOMETRY, TIMING EFFECTS & COMPARE WITH DATA

SIX GEOMETRICAL CASES



- **FOR EACH CASE WE EVALUATED**
  - **RELATIVE LIGHT YIELD,**
  - **ATTENUATION LENGTH,**
  - **TIME (POSITION RESOLUTION)**
- **CASE #4 IS STUDIED IN THE MOST DETAIL INITIALLY**
- **CASE #5 & #6 USED FOR FULL LENGTH (3.7m) PROTOTYPE**
- **PHOTOELECTRON CALIBRATION OF ADC**
- **COMPARISON WITH MC PREDICTIONS**

LIGHT YIELD MEASURMENTS OF 5 GEOMETRIES



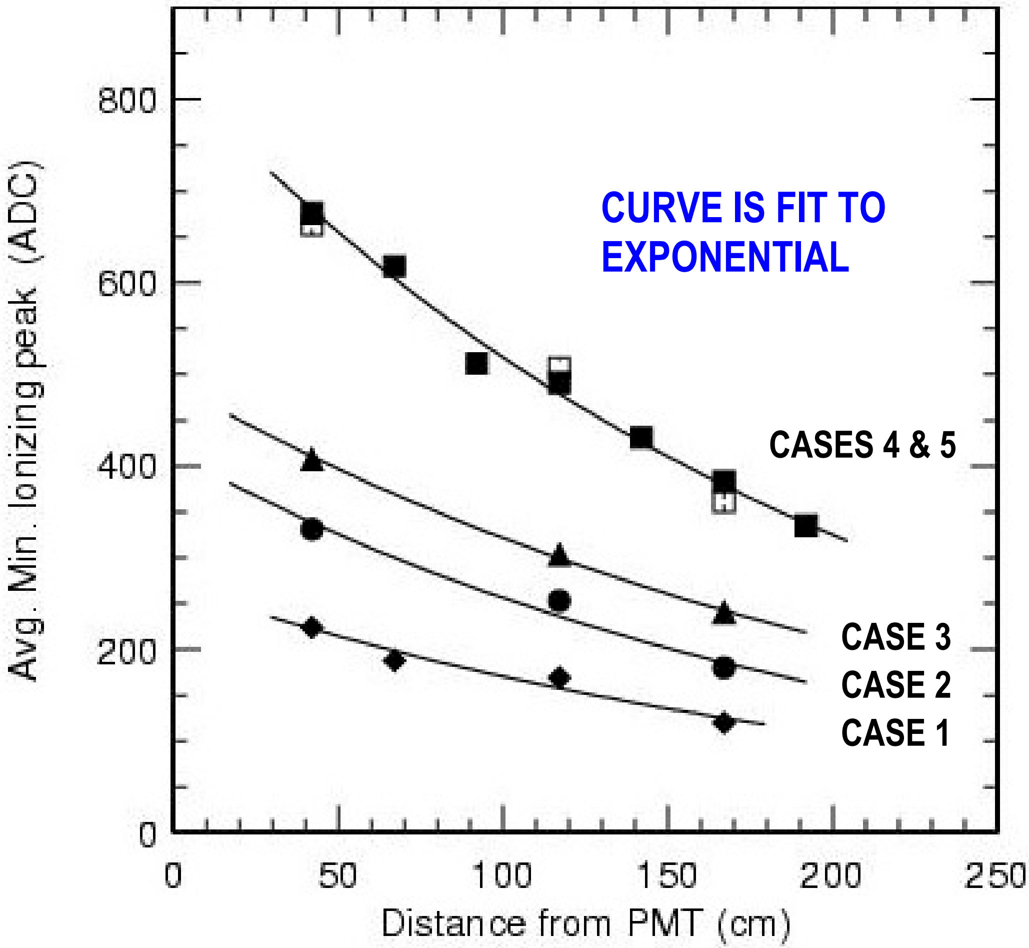
TYPICAL COSMIC RAY SPECTRUM FOR CASE #4 AT 42cm FROM PMT

RESULTS FROM LIGHT YIELD MEASURMENTS (FIT TO PEAK)

GEOMETRY	LY (42cm)	MC (LY)
1	1.00	1.00
2	1.47	1.53
3	1.81	2.00
4	3.02	3.13
5	2.96	3.06

← 3X MINOS

ATTENUATION LENGTH MEASUREMENTS FOR 5 CASES



RESULTS FROM ATTENUATION LENGTH MEASURMENTS

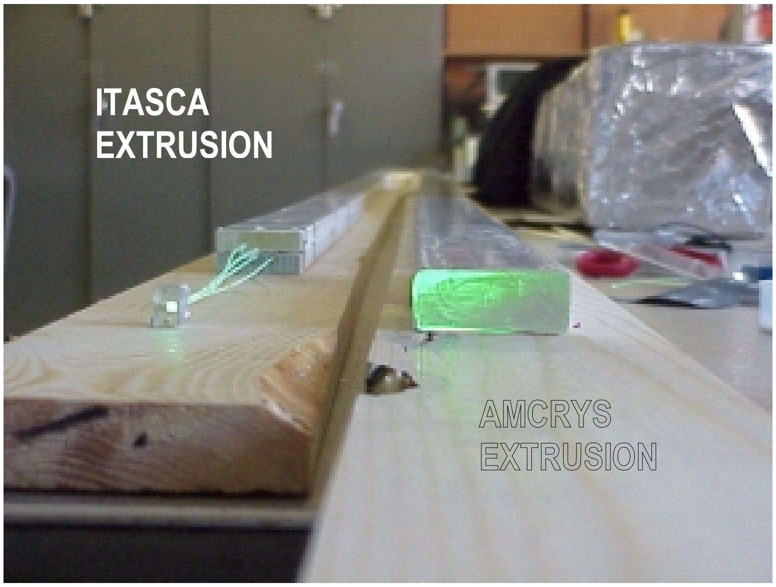
GEOMETRY	LY (42cm)	λ (cm)
1	1.00	217
2	1.47	208
3	1.81	238
4	3.02	213
5	2.96	208

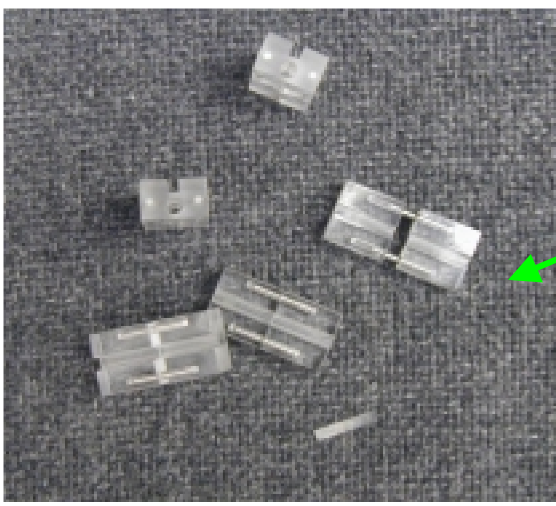
λ ~210 cm

LOSE ~5X IN LIGHT FROM 42cm To 3.7 m ← WORSE THAN MINOS (~3.5X) SEE LATER DISCUSSION

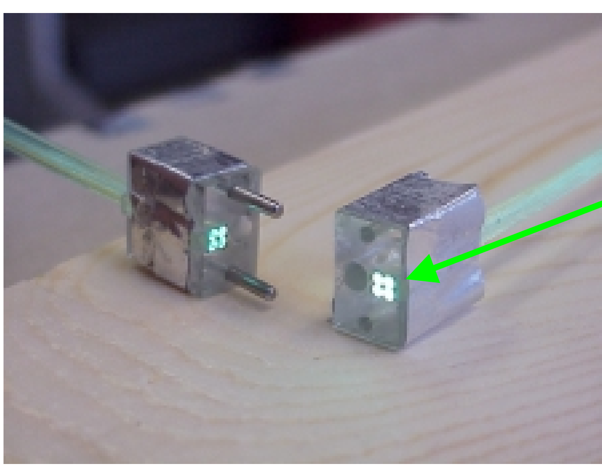
BULK ATTENUATION LENGTH DEPENDS ON LENGTH OF TEST SAMPLES
(λ DEPENDENT ABSORBTION)

TWO FULL LENGTH (3.7m) PROTOTYPE PROOF OF PRINCIPLE:





MINI-CONNECTORS WITH DOWEL REGISTRATION LIKE MINOS

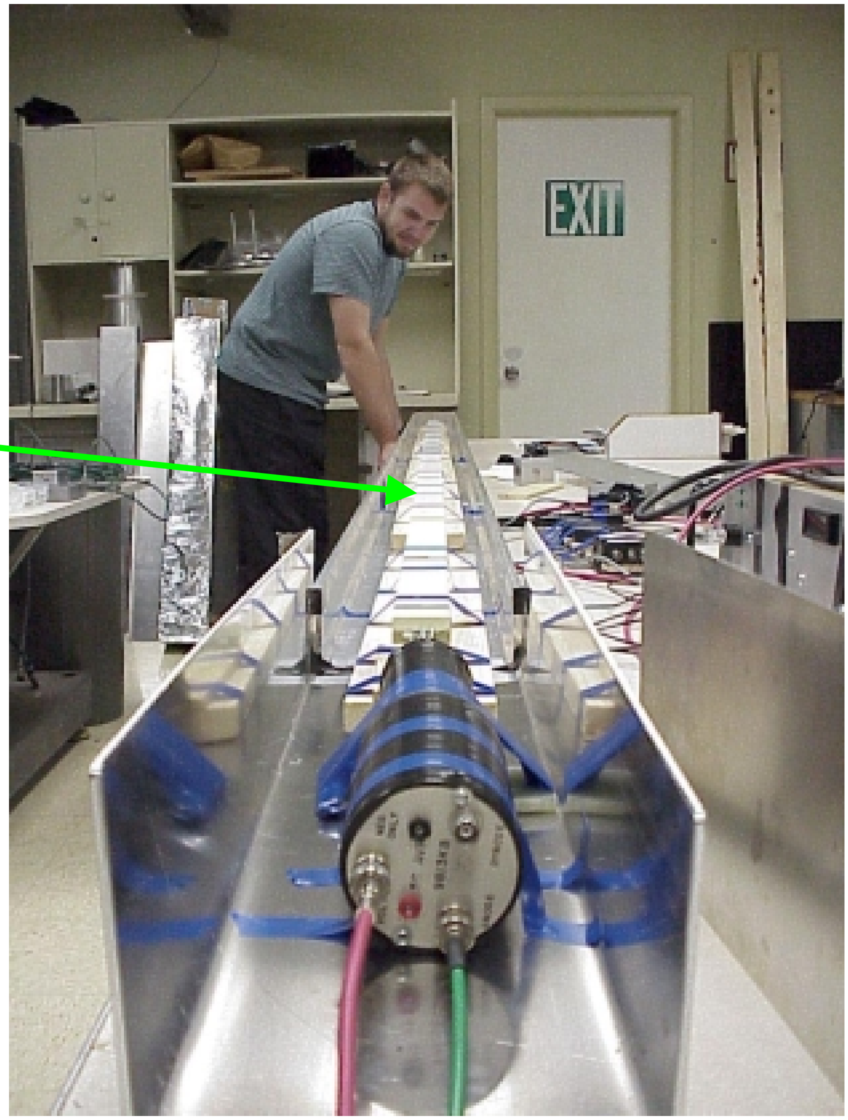


WITH 4 WLS FIBERS

3.7 METER LONG
2cm THICK BAR

BOTH SCINT.
HAVE A MID-PT
EPOXY JOINT –

MAY LOCALLY
EFFECT TIMING
RESOLUTION



- **LIGHT YIELD & ATTEN. LENG. 3.7M LONG GEOM. 5 & 6:**

  - REQ. EXTERNAL TRIGGER HODOSCOPE TO DEFINE ~ 4cm REGION ALONG BAR

DIST. TO PMT1 (cm)	Light Yield ITASCA (4cm)	DIST. TO PMT1 (cm)	Light Yield Ukrainian (5cm)
38	504+/-10	46	697+/10
89	398		
140	316	140	423
178	299		
241	216	241	301
292	215		
345	199	345	225
378	192	378	220

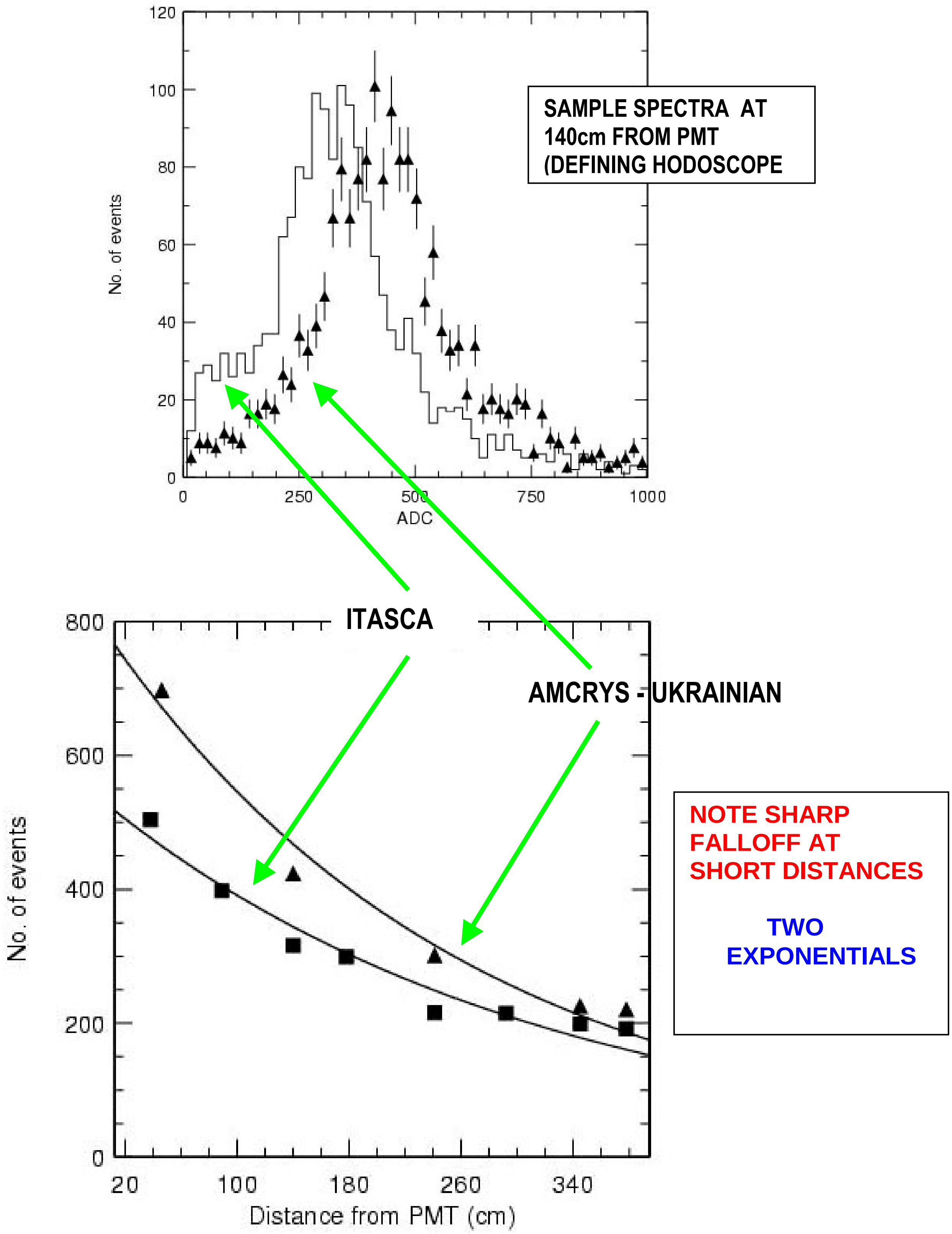
- <ATTENUATION LENGTH >(ITASCA) = 312 cm
- <ATTENUATION LENGTH >(UKRAINIAN) = 259cm

FITS SHOW NON-EXPONENTIAL BEHAVIOR BECAUSE OF WAVELENGTH DEPENDENCE

NOTE VERY SHARP INITIAL LOSS (PREVIOUS 2m BAR RESULTS GAVE λ ~210 cm)

NOW GIVE CLOSE TO MINOS RESULT ~3X to ~3.5X LOSS OVER WHOLE BAR LENGTH

- AVERAGE LIGHT YIELD UKRAINIAN ~31% > ITASCA

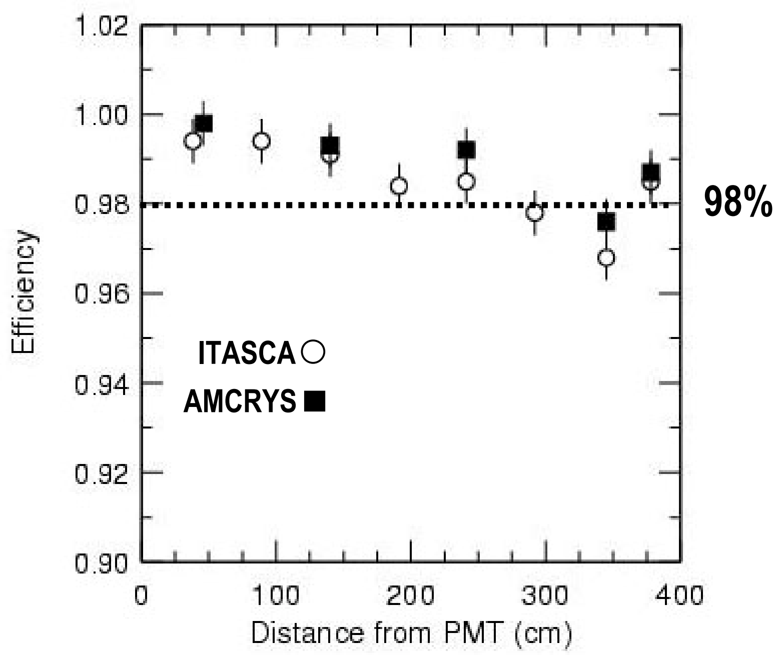


SAMPLE SPECTRA AT
140cm FROM PMT
(DEFINING HODOSCOPE
No. of events
ADC
0
20
40
60
80
100
120
250
500
750
1000
ITASCA
AMCRYS - UKRAINIAN
No. of events
Distance from PMT (cm)
200
400
600
800
100
180
260
340
NOTE SHARP
FALLOFF AT
SHORT DISTANCES
TWO
EXPONENTIALS

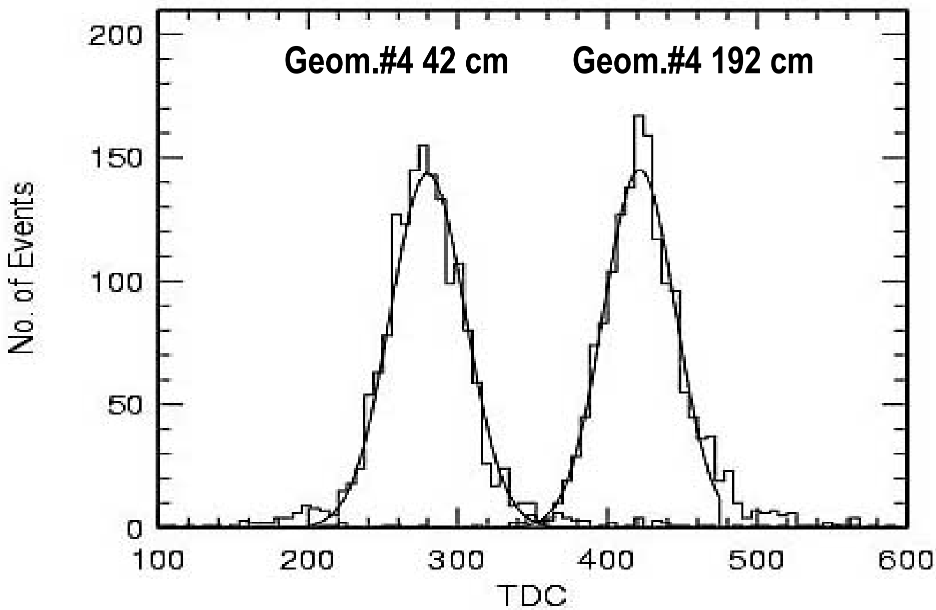
- **SINGLE SIDE EFFICIENCY:**
  - **REQ. EXT. TRIG. HODOSCP ~ 4cm RGN ALONG BAR**
  - **REQ. PMT2 TO SEE >10 adc cts (>1 pe) > PEDSTL**
  - **>1500 SAMPLES / POSITION**

DIST. TO PMT1 (cm)	Efficiency ITASCA (4cm)	DIST. TO PMT1 (cm)	Efficiency Ukrainian (5cm)
38	0.994	46	0.998
89	0.994		
140	0.991	140	0.993
178	0.984		
241	0.985	241	0.992
292	0.978		
345	0.968	345	0.976
378	0.985	378	0.987

SINGLE SIDED EFFICIENCY OF FULL LENGTH BAR



TIME/POSITION RESOLUTION MEASUREMENTS FOR 5 CASES



$V_{prop.}$ ~ 17cm / ns (n=1.5 + fiber path in 26^0 cone)

APD RISETIME ~ 5 NS

RESULTS ON SNGL SIDED POSITION RESOLUTION MEASURMENTS (PMT)

GEOMETRY	LY (42cm)	λ (cm)	σ_L (cm)	σ_L (cm)
			Near to PMT (42 cm)	Away From PMT (167cm)
1	1.00	217	33	38
2	1.47	208	27	32
3	1.81	238	26	32
4	3.02	213	26	24
5	2.96	208	27	29

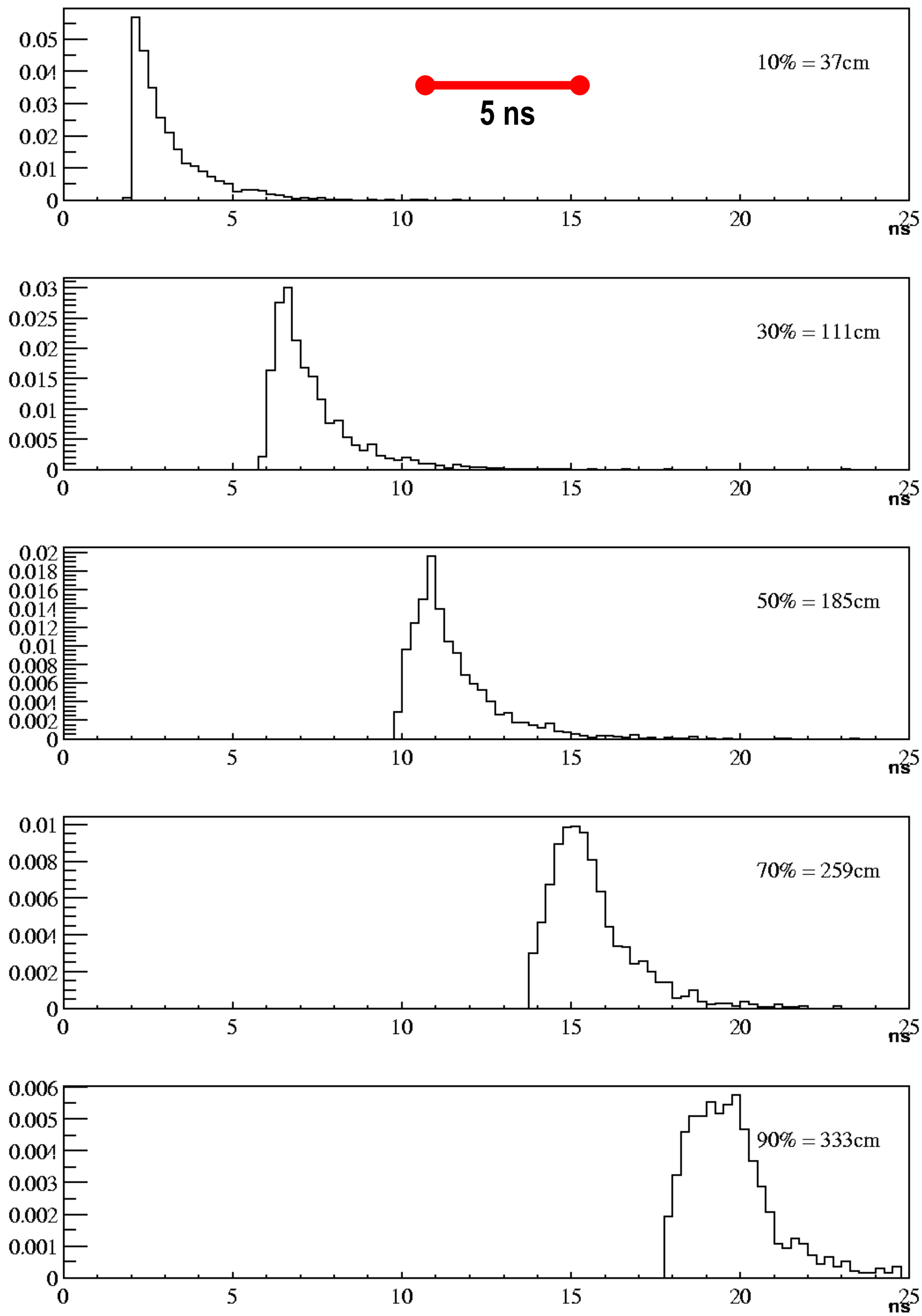
σ_{SS} ~ 25→30cm

USES ONE END & NO PULSE HEIGHT INFO; ←SHOULD IMPROVE WHEN BOTH ENDS USED

MC PREDICTS CONTRIBUTION OF RISETIME FROM GEOMETRICAL & LIGHT PROPOGATION EFFECTS TO GO FROM 0.2 TO 1.5 ns ←SMALL

APD RISETIME ~ 5 NS; ← RISETIME SHOULD THEREFORE BE DOMINATED BY PREAMPLIFIER

MC SIMULATION



ARRIVAL TIMES OF PHOTONS FROM MIN ION AT ONE END OF A 3.7m BAR (CASE #4)

TIMING MEASUREMENTS (PMT) OF 2 FULL LENGTH BARS (GM# 5 & 6)

- DONE AS BEFORE WITH DUAL LEVEL DISC+ TDC
- OBSERVE ~17cm/ns PROP. VEL. IN BOTH SCINT.

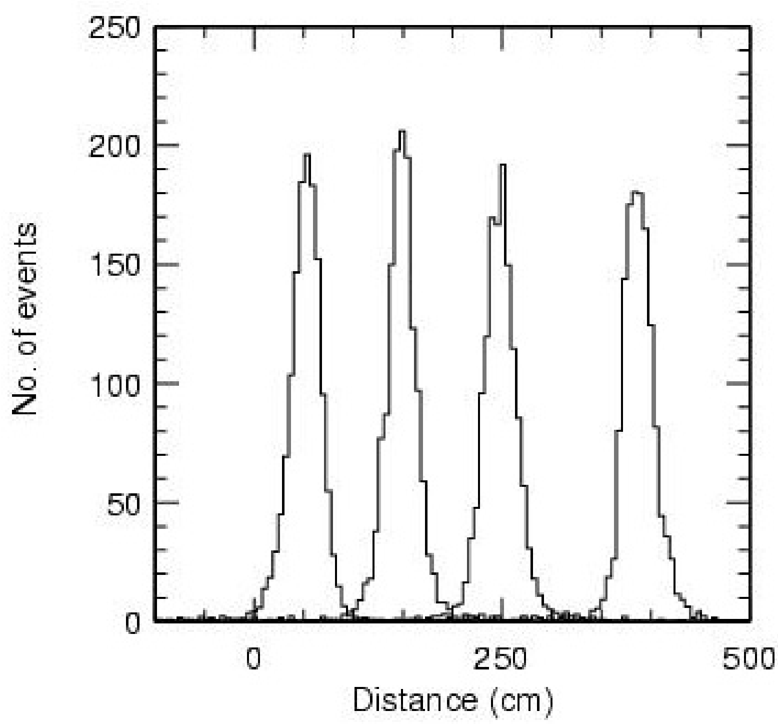
RISE MAY BE ASSOCIATED WITH EPOXY JOINT (rows 178–292)

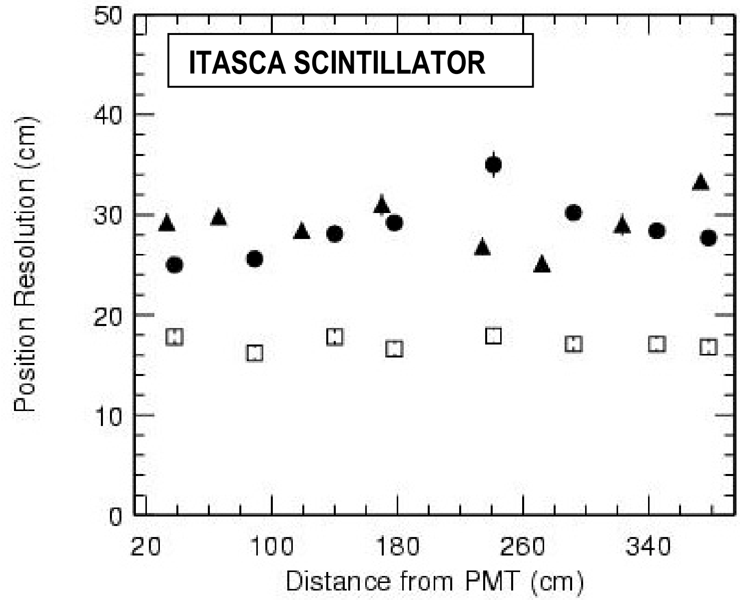
DIST.	Pos. Resolution ITASCA PMT 1	DIST.	Pos. Resolution ITASCA PMT 2
(cm)	(cm)	(cm)	(cm)
38	25.0+/-0.4	373	33.3+/-0.5
89	25.6+/-0.8	323	29.0+/-1.1
140	28.1+/-0.8	272	25.1+/-0.6
178	29.2+/-0.8	234	26.8+/-0.9
241	35.0+/-1.3	170	31.0+/-1.1
292	30.2+/-0.6	119	28.4+/-0.5
345	28.4+/-0.8	66	29.8+/-0.8
378	27.7+/-0.8	33	29.2+/-0.9

DIST.	Pos. Resolution AMCRYS PMT 1	DIST.	Pos. Resolution AMCRYS PMT 2
(cm)	(cm)	(cm)	(cm)
46	24.5+/-0.4	371	28.6+/-0.5
140	28.9+/-1.1	277	23.0+/-0.8
241	28.4+/-0.4	175	27.7+/-0.5
345	26.7+/-0.7	71	25.1+/-0.6
378	26.7+/-0.9	38	24.2+/-0.7

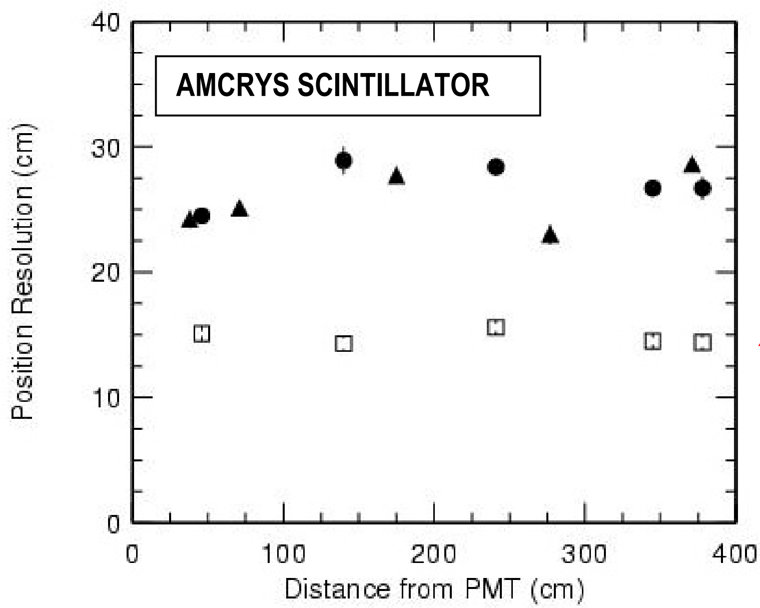
- **AVERAGED TIMING RESOLUTION OF BOTH ENDS**
  - (Pos(PMT1) + Total Length – Pos(PMT2)) * 0.5
  - Could improve with Weighted Average

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



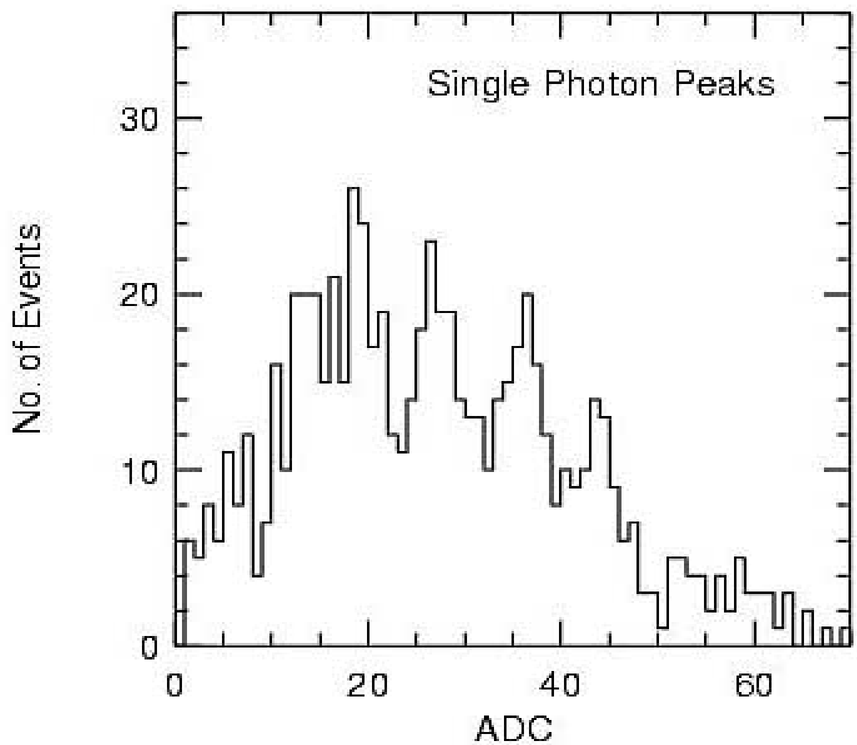


σ ~ 17 cm
TWO SIDED TIME



σ ~ 14cm
TWO SIDED TIME

PHOTO ELECTRON CALIBRATION



MOVE XP2262B PMT + SPECIAL BASE BACK FROM FIBERS & FILTER DOWN THE LIGHT STRIKING TUBE.

RESULTS: ~ 10 ADC CTS per PHOTOELECTRON WITH PMT

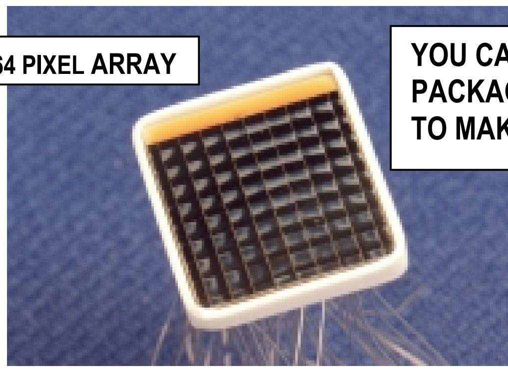
IMPLICATION: GEOM. #6 GIVES ~ 700 ADC cts/MIN ION at ~46cm.

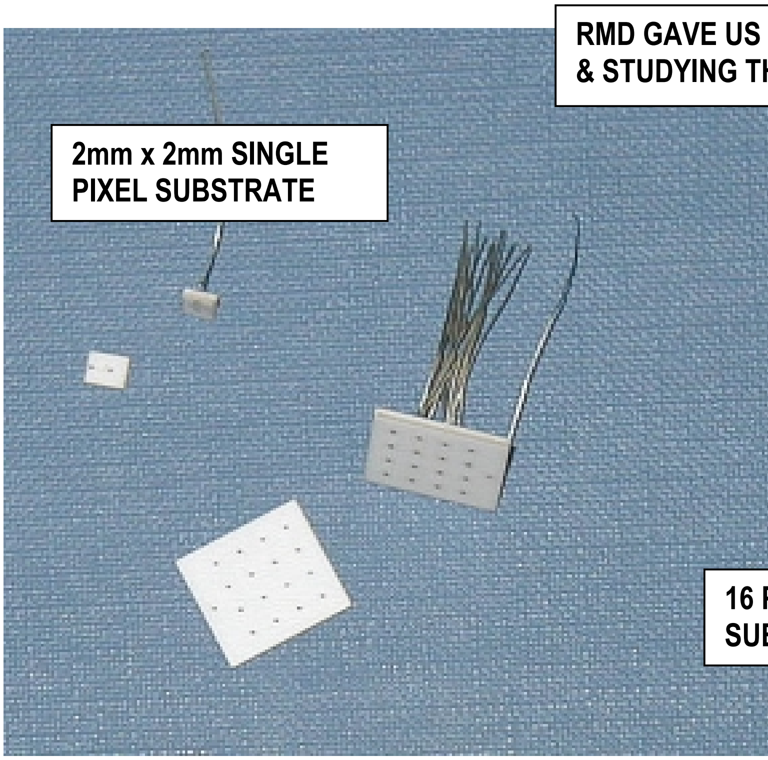
PMT QE~14% at 520 nm IMPLIES ~500 PRIMARY PHOTONS FROM THE 4 FIBERS REACH PMT

USING QE (APD) ~60% X 0.7 GEOM IMPLIES ~210 pe at 46cm. λ_{att} IMPLIES ~65 pe FOR an APD at 3.7m

APD STATUS & ISSUES

- RMD's PLANAR (NON-BEVELED EDGE) APD #S0223 ($2x2mm^2$, $0.7pf/mm^2$) IS BEST CANDIDATE ON MARKET (50µm DEEP DIFFUSED PN JUNCTION)
- USE THE 4 X 4 PIXEL ARRAY WHICH GIVES BEST COST / PIXEL
    - ASSUME YLD OF 14 of 16 MEET NOISE PERF
    - $85/working PIXEL IN LARGE (5K) QUANTITES
- QE > 60% at >530 nm, G ~1000X, (0^0C), AT ~1750v
- ~5 NS RISETIME AT 500nm
- RADIATION TESTED AT PSI – OK TO ABOUT 1 X 10^{12} n/cm*





- **MEASUREMENTS OF SAMPLE APD'S FROM RMD:**

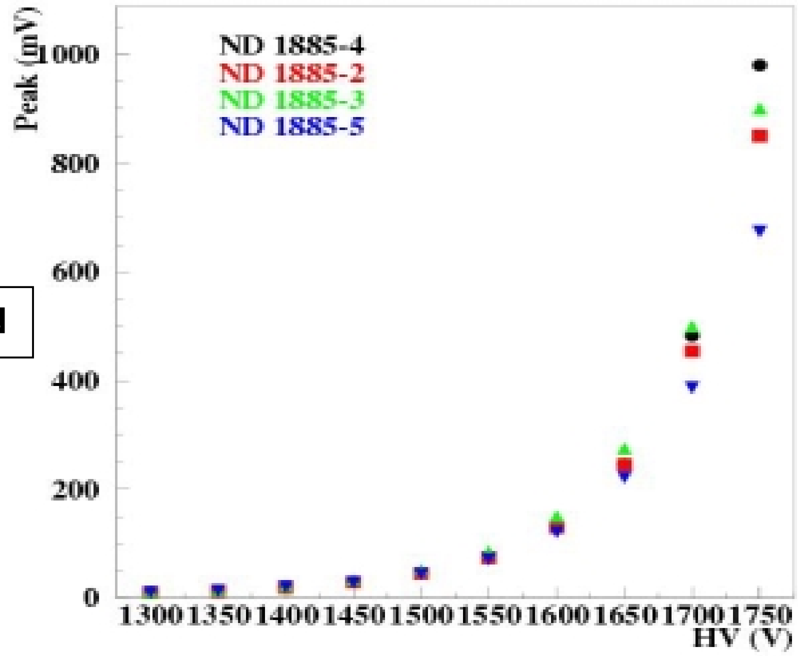
  - **VARIATIONS FOLLOW THE WAFERS**
  - **SMALL VARIATION IN BREAKDOWN VOLTAGE ACROSS PIXELS IN SINGLE ARRAY (~1v LEVEL) AS EACH ARRAY COMES FROM SINGLE 5cm WAFER**
  - **GAIN VARIATIONS BETWEEN PIXELS LESS THAN 5% WITHIN ARRAY DUE TO DIFFERENCES IN LEAKAGE CURRENT & SERIES Ω**
  - **EXAMPLES FROM SEVEN 2mm x 2mm PIXELS WE PURCHASED IN TWO BATCHES:**

RMD Serial#	BREAKDOWN VOLTAGE (21^{0}C)
ND-1873-1	1857 v
ND-1873-2	1855 v
ND-1885-1	1840 v
ND-1885-2	1840 v
ND-1885-3	1840 v
ND-1885-4	1840 v
ND-1885-5	1842 v

OUR MEASUREMENTS OF GAIN FROM THE LAST BATCHES OF 2mm DIODES SHOW SMALL VARIATIONS

(Note: ND-1885-5 WAS MEASURED EARLIER & SCALED FOR THIS PLOT, TEMP UNKN.)

GAIN



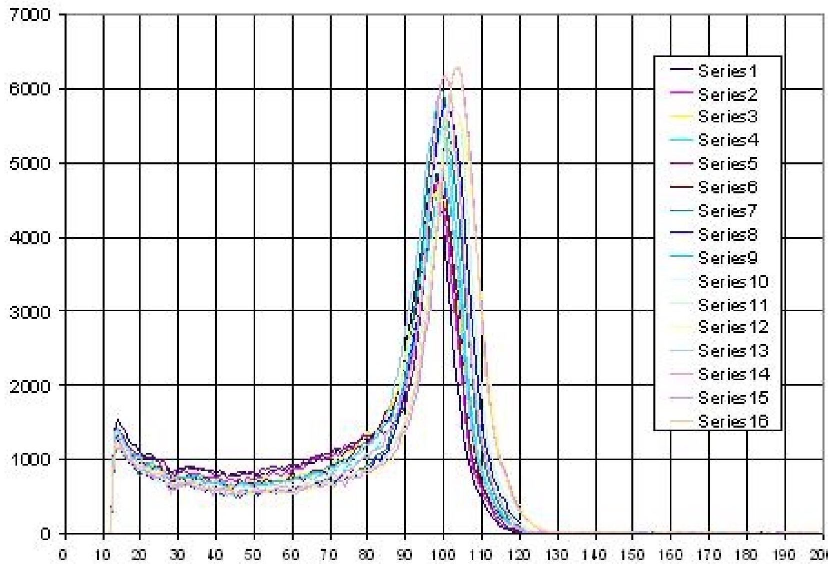
VOLTAGE

IN PRACTICE, ONE HV CONTROL ON EACH 16 ELEMENT ARRAY SHOULD SUFFICE TO GIVE ADEQUATE GAIN CONTRO PER PIXEL

ROUGHLY: ΔGain/ΔV (G=1000,0^0C) = +5%(-2%)

RMD MEASUREMENTS OF VARIATIONS OF Leakage Charge (LC) & GAIN IN PIXELS OF 16 ELEMENT ARRAYS

	Fe55 spectra		Temp: 20 deg													
HV	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700	-1700
S.T.	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec	0.25usec
C.T.	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec	10sec
L.C.	33.6	40.6	36.8	36.2	38	53.5	42	40	38.8	41.8	41	62	36.2	40.8	42.2	37.8
Pixel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Peak	97	99	98	100	99	99	99	100	99	101	102	104	99	100	104	104

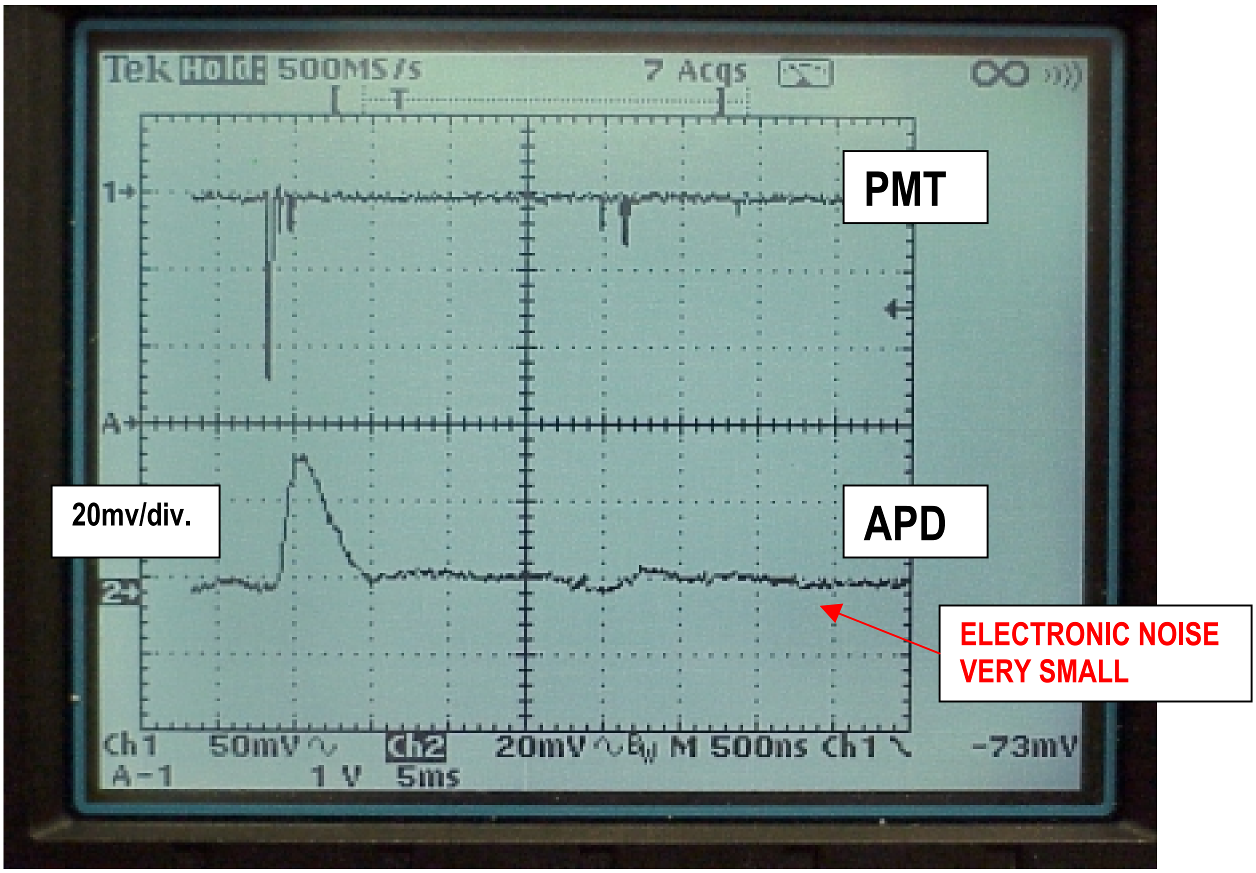


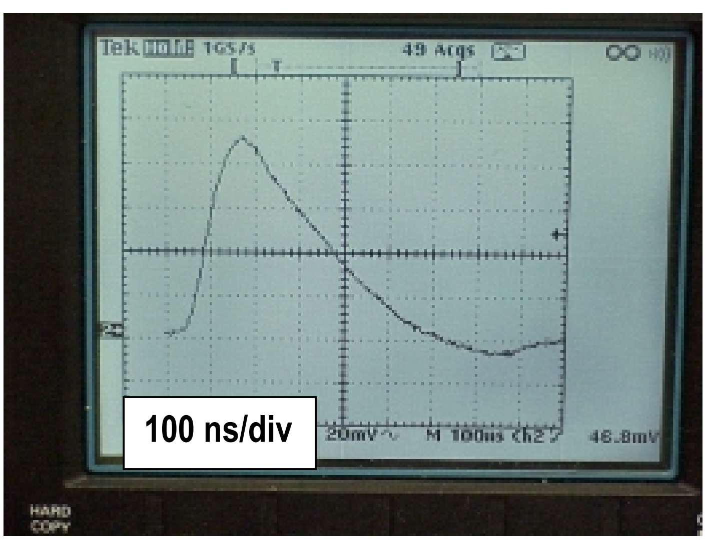
- **EACH PIXEL IRRADIATED WITH FE55 (5.9 KEV X RAYS)**
- **EACH PIXEL WAS BIASED AT -1700 V**
- **LEAKAGE CURRENT & PEAK CHANNEL NOTED**
- **YOU CAN SEE IN THE SPECTRA AND THE DATA LISTED THAT THE PEAK CHAN VARIATION DUE TO GAIN DIFFERENCES IS LESS THAN +/- 5% : MOST OF THIS DIFFERENCE IS PROBABLY DUE TO DIFFERENCE IN LEAKAGE CURRENT FROM PIXEL TO PIXEL. SOME OF THE VARIATION COULD ALSO BE DUE TO ANY SLIGHT VARIATION IN TEMP. WHILE THE MEAUREMENTS WERE BEING MADE; ALL THE SPECTRA WERE ACQUIRED OVER ~ 10-20 MINUTES**

FIRST COSMIC RAY SIGNALS WITH 4mm^2 APD (23^{0}C)

TOP SCOPE TRACE IS PMT LOOKING AT FAR END OF BAR

BOTTOM TRACE IS APD OUTPUT FROM PREAMP AFTER DIFFERENTIATION & LOW FREQUENCY FILTER





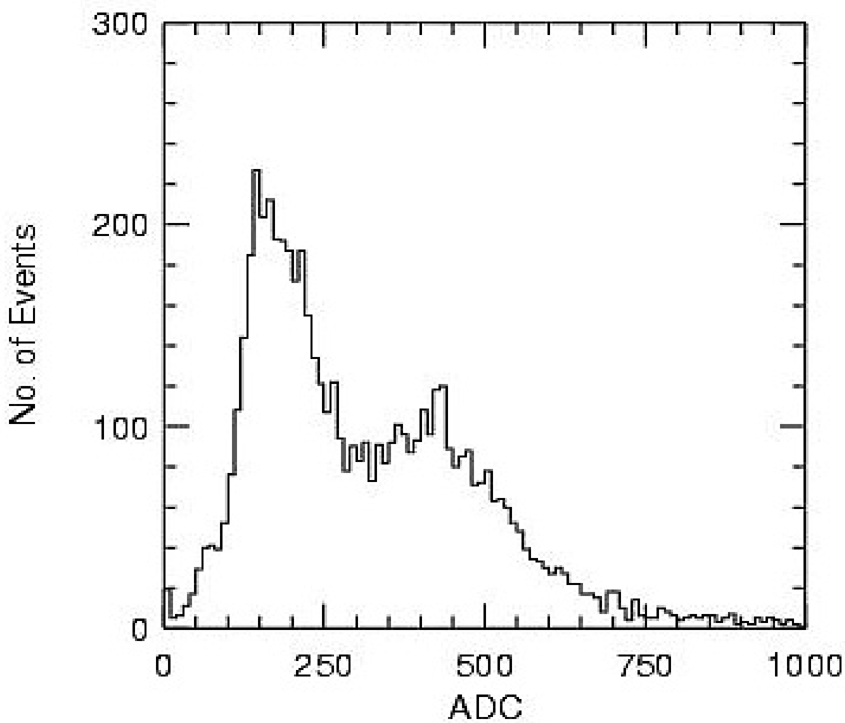
BLOWUP OF TYPICAL PULSE SHOWING A250F PREAMP

τ_R ~100 ns (C$_f$=0.25pf)

WILL INCREASE C$_f$→~1pf TO REDUCE τ_R → 25 ns

FIRST COSMIC RAY SPECTRUM

APD READOUT ON ONE END OF 2m BAR IN GEOMETRY #4



SPECTRUM TAKEN AT ROOM TEMP (VARIATIONS +/-2^{0}C).

OBSERVED CHARCATERISTICS OF SPECTRUM & SCOPE:

- SMALL ELECTRONICS NOISE ON SCOPE ~4 mv

  APD PROVIDES GAIN ~1000

- BROAD PEDISTAL & BROAD SIGNAL PEAK

  ASSOCIATE WITH "EXCESS NOISE" OF APD
  (fluxuations in amplification of signal and
  dark currents)

NOISE IN APDS & WHY WE MUST COOL THEM:

- **4 PRIMARY SOURCES OF NOISE & PEAK BROADENING IN PLANAR APDS:**

SMALL AS GAIN HIGH
  - USUAL ELECTRONICS NOISE FROM C & R AT INPUT OF FET (measure at ~50v when fully depleted)

PEDISTAL OR BASELINE WIDTH
  - FLUXUATIONS IN AMPLIFICATION OF DARK CURRENT (BULK) IN APD DEPEND ON STATISTICAL NATURE OF IMPACT IONIZATION PROCESS (I_{bulk} ~4pa/mm^2 at Hi-Gn)
  - FLUXUATIONS IN EDGE CURRENT (NOT AMPLIFIED) (I_e~5na/mm^2 ~largest non-amplified "leakage" current)

BROADENS PEAK FURTHER
  - FLUCTUATIONS IN SIGNAL AMPLIFICATION WHICH DEPEND ON STATISTICAL NATURE OF IMPACT IONIZATION PROCESS (at G=1000X, N_{pe}~50→50000e)

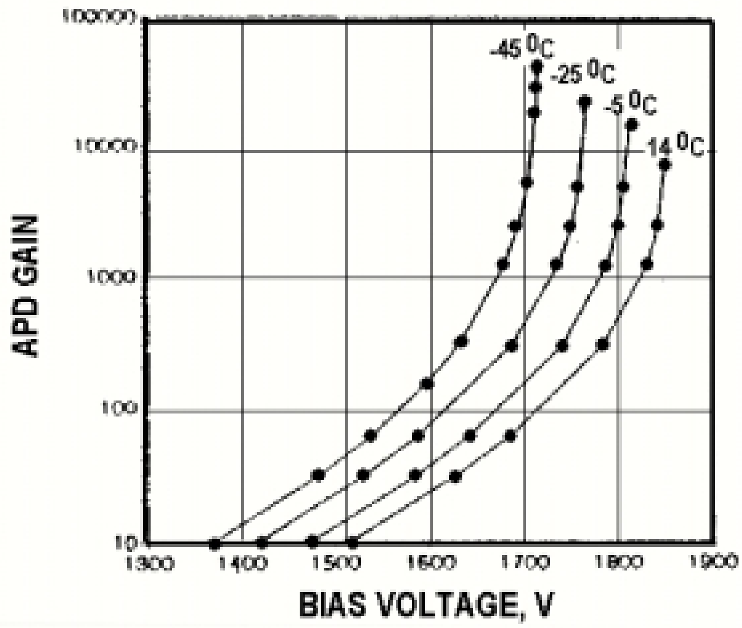
- **COOLING THE APD HAS THREE EFFECTS:**
  - REDUCES BULK LEAKAGE CURRENT (halves @ -10^{0}C)

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

    →GAIN INCREASES AT FIXED VOLTAGE
  - REDUCES EXCESS NOISE FACTOR (F ~ VARIANCE OF AMPLIFICATION) ($\Delta\alpha_e > \Delta\beta_h$ for a decrease in T)

    →REDUCES PED. & PEAK BROADENING

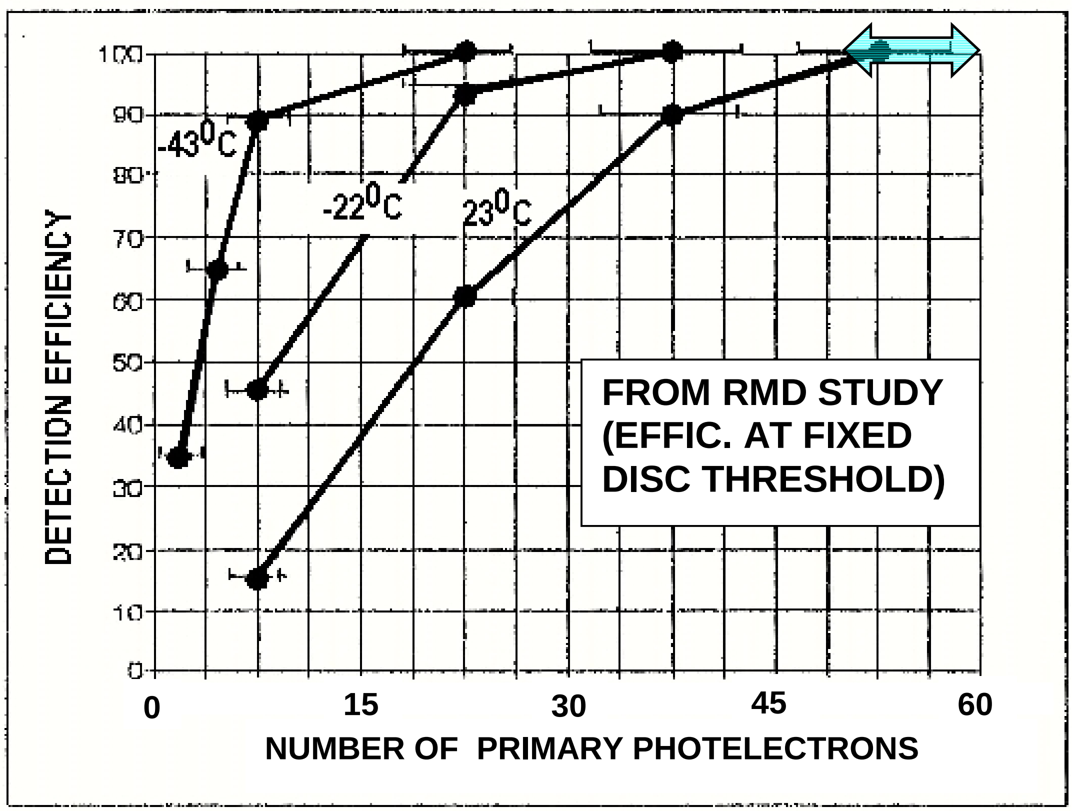
NET EFFECT OF COOLING IS INCREASE IN S/N BY REDUCING PEAK & PED WIDTH, AND INCREASING SIGNAL EFFICIENCY



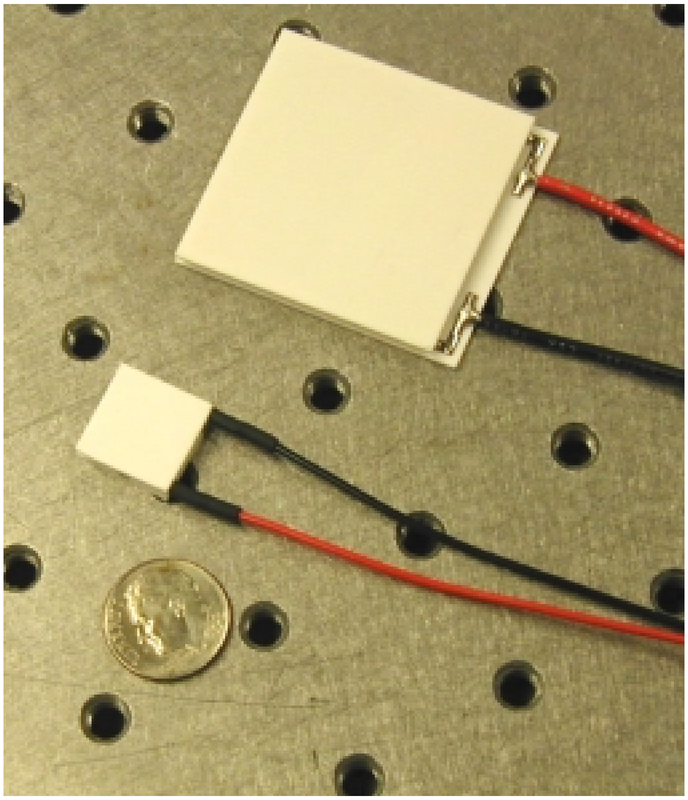
COOLING APD INCREASES GAIN AT FIXED VOLTAGE

~ 50V DECREASE WITH ΔT=-20⁰C) FOR FIXED GAIN ~ 1000X

COOLING APD INCREASES GAIN & REDUCES PED & SIGNAL WIDTH → INCREASED EFFICIENCY AT FIXED DISC. THRESHOLD



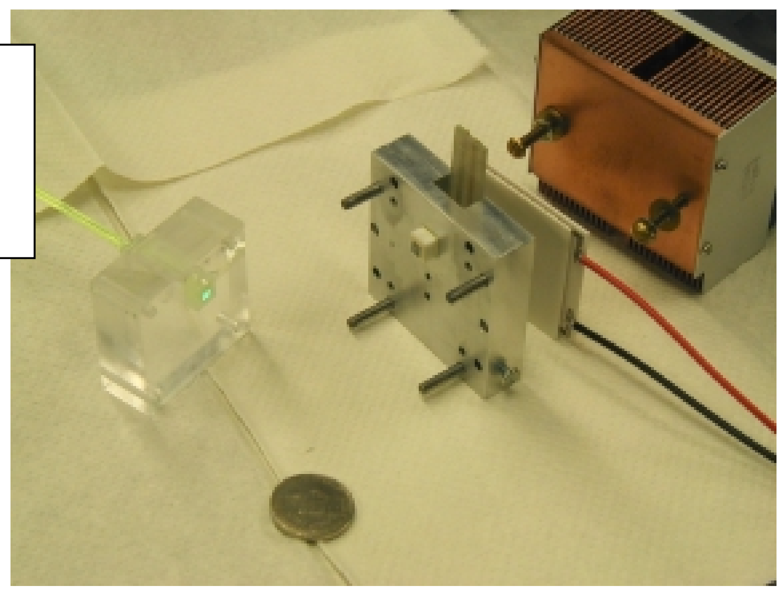
PELTIER COOLING & OPTICAL CONNECTS TO APD :

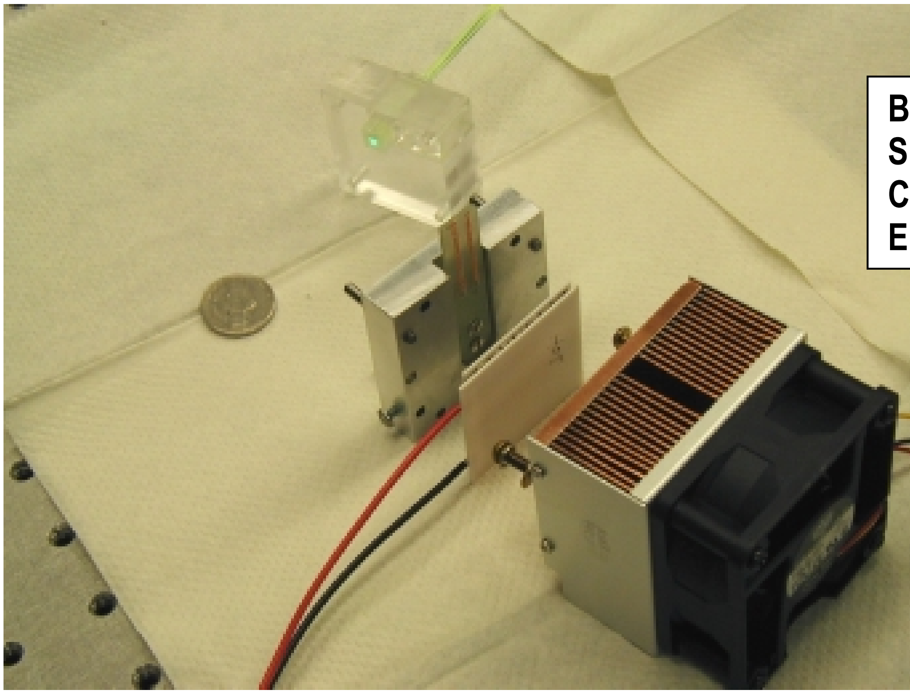


30W THERMO-ELECTRIC COOLER TO USED INITIALLY

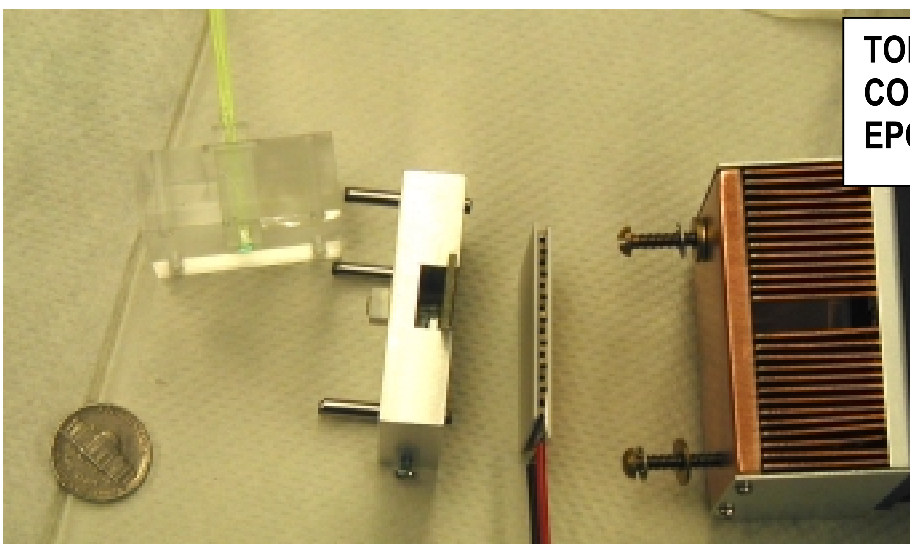
4W to 8 W SMALLER ONES
15 x 15 mm FOR ACTUAL USE IN IFR

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





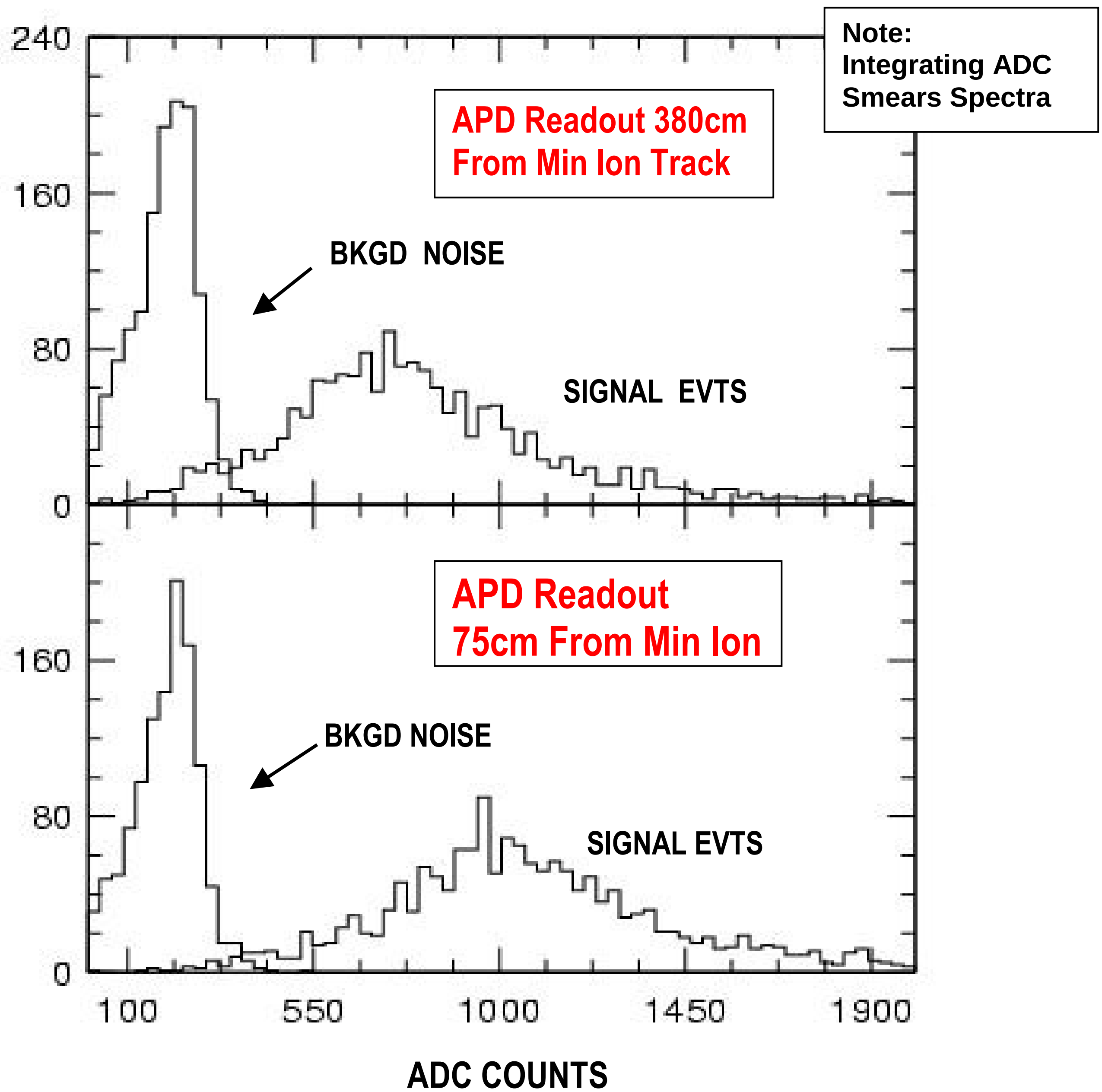
BACK VIEW SHOWING TE COOLER BEFORE EPOXYING



TOP VIEW SHOWING TE COOLER BEFORE EPOXYING

FIRST DATA WITH APD AT 0^0C : 3.7m LONG BAR

APD Cooled to ~0-Deg C.   HV = 1765 V,   PMT on One End
Defining Counters positioned at 380 cm from APD
Preamp Output Amplified x20 & Split (To Disc & Integ. ADC)

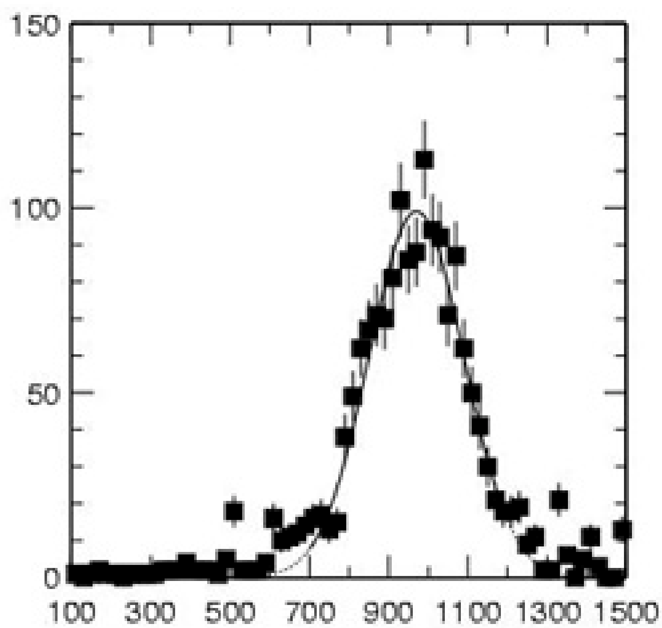


Using 60 mV Discr. Threshold + Scalars at 3.8m pt:
Signal Efficiency > 98%   Background Rate < 1%

TIMING RESOLUTION IN PRESENT SETUP - POOR

Due to slow risetime of Preamp/amp
τ_r ~100 ns

Single Side: Sigma (position) = 110 cm
At 380 cm From APD



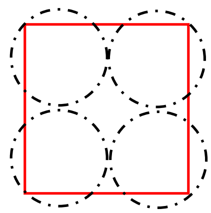
TDC COUNTS

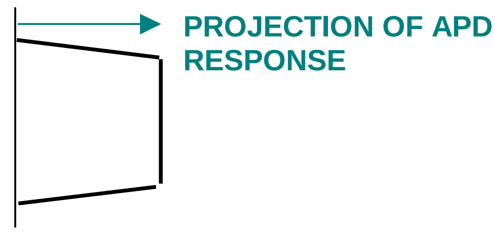
Have modified AMPTEK 250F Preamp + Postamp and will be re-measuring the time resolution.

NEXT STEPS:

- **BETTER OPTICAL MATING TO APD**

CURRENT SETUP HAS FOUR 1.2mm FIBERS ALIGNED ONTO 2mm x 2mm APD.

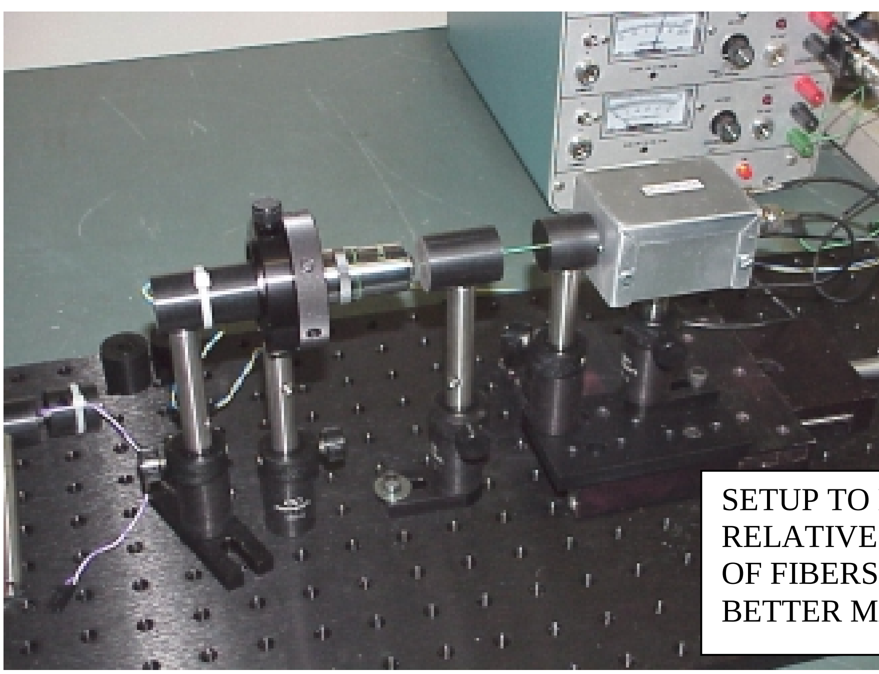




THE APD HAS A RESPONSE WHICH IS FLAT OVER THE CENTRAL PORTION, AND DROPS OFF BY THE EDGES

IN THE CURRENT SETUP, THIS MISMATCH RESULTS IN A LOSS OF LIGHT RELATIVE TO THE PMT MEASUREMENTS (~ 0.7)

THE OPTICAL CONNECTION WILL BE IMPROVED TO RECOVER A LARGE FRACTION (~85%) OF THE PRESENT GEOMETRIC LOSS



SETUP TO MEASURE RELATIVE TRANSMISSION OF FIBERS MODIFIED TO BETTER MATCH PIXEL

- INSTALL PELTIER COOLER PROPORTIONAL CONTROLLERS ALLOWING LONG & STABLE DATA TAKING RUNS WITH APDs ON BOTH ENDS. CAN THEN OPTIMIZE S:N

- AMPLIFIER IMPROVEMENTS & PEAK SENSING ADC TO DO COMPLETE TIMING & EFFICIENCY STUDY

BABAR'S MAJOR CONCERN WAS APD ROBUSTNESS

LITTLE INTEGRATED EXPERIENCE WITH RMD DEVICE & ESPECIALLY THE ARRAYS

- AS IN ANY SILICON (OR GAS) DEVICE PROVING OF ACCEPTABLE RELIABILITY OF A TECHNOLOGY IS A TWO STEP PROCESS

1) DEVELOP INFANT MORTALITY TEST PROCEDURE TO UNDERSTAND HOW TO WEED OUT EARLY FAILURES

ALREADY DONE BY RMD USING A 24hr BURN IN TEST

2) TEST LARGER SAMPLE TO ESTABLISH ACCEPTABLE MTBF

HAVE ORDERED 3 ARRAYS OF 16 pixels/array
AND SETTING UP ACCELERATED TEST AT SLAC

RMD IS LOANING 3 ADDITIONAL ARRAYS IN RETURN FOR DATA

- TEST of ~96 PIXELS-