Polarimetry for the Q_{Weak} Experiment

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Polarimetry for the Q_{Weak} Experiment

Requirements

- Dominant systematic uncertainty for Q_{Weak}
- Polarization to absolute precision of 1%

Existing Møller Polarimeter

- Currently operation only at low currents
- Fast kicker magnet for high current operation

New Compton Polarimeter

- High precision possible with high laser power
- Independent photon and electron channels
- Systematic uncertainties different from Møller

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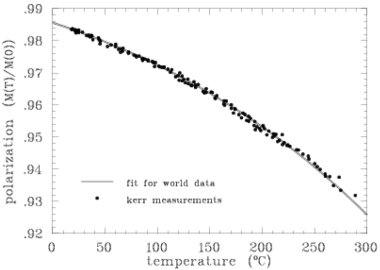
Møller Polarimeter

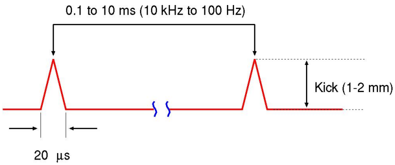
Running strategy for Q_{Weak}

- Cross-checks between Møller and Compton polarimeter

Improvements: fast kicker

- Iron foil depolarization at high currents ($\Delta P = 1\%$ at 60°C)
- Fast kicker magnet tests: short periods of beam on target



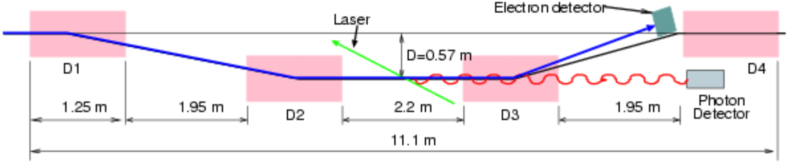


Short kick, long cool-down

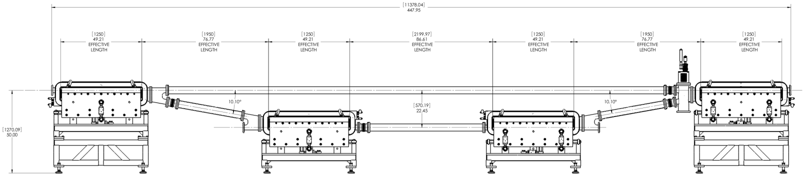
Compton Polarimeter

New Compton Polarimeter

- Chicane: dipoles (Bates), beamline (JLab CASA + MEG)
- Laser: *25 W, 499 MHz, RF-pulsed fiber laser* (JLab EGG)
- Photons: $PbWO_4$ (Yerevan, Hampton), CsI (MIT/Bates)
- Electrons: Diamond strip detector (Winnipeg, MSU)



Chicane



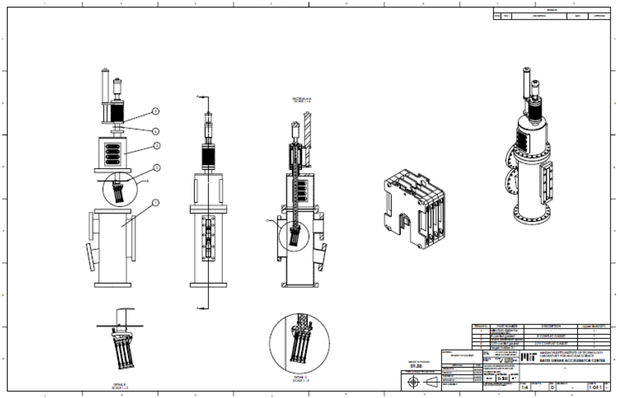
Chicane dipoles and beam layout

- Dipole magnet design complete, outside bids are back
- Power supplies: provided by MIT, or HKS-HES Danfysik PS
- Remaining parts of chicane (vacuum can) almost complete
- Interaction region design. . . depends on laser system

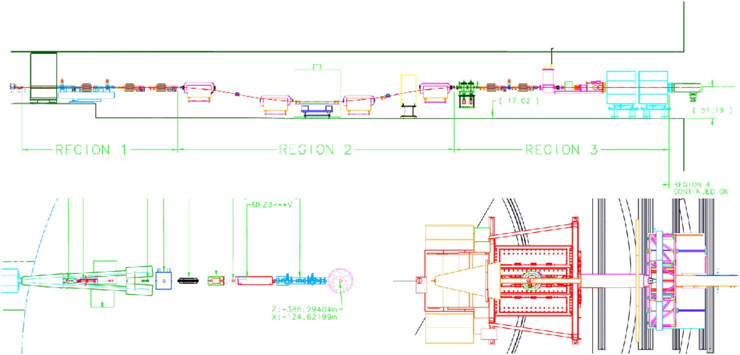
Chicane

Vacuum can and integration

- Electron detector vacuum design in progress
- Interfaces relayed to JLab MEG



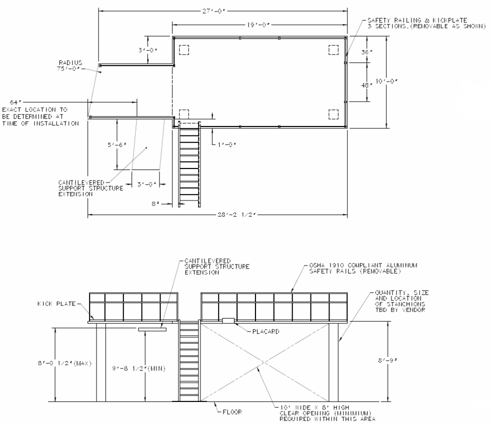
Beamline (excluding chicane)



Beamline layout almost finalized

- Some tweaks to design remain (bellows for alignment)
- Integration with chicane dipoles in progress
- On track and should be ready in time

Beamline (excluding chicane)



Support structure

- Supports items that extend into hall
- Designed and built by outside vendor
- Contract awarded to Still-Walter

Laser

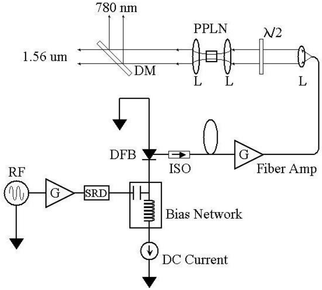
Fiber-based laser

- High duty cycle, high power

Suggested by source group

- Gain-switched IR seed (499 MHz)
- ErYb-doped fiber amp (50 W)

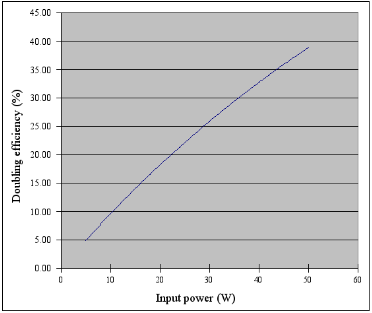
- Frequency-doubling ($\rightarrow$ 532 nm)



Laser: 5 W Amplifier Prototype

5 W fiber amplifier

- Built by Chuyu Liu (CASA)
- Achieved 150 mW of output power (after doubling)
- Doubling efficiency of 3.4%, but better for higher power
- Prototype works as expected



High-power 50 W fiber amplifier

- Experience at EGG
  - 50% (at 27 kW peak power)
  - 26% (at 2.7 kW: 50 W · 2 ns / 50 ps = 2 kW at 499 MHz)
- Amplifier not warrantied for pulsed operation
- Advised not to exceed 5 kW: lower rep rates dangerous

Laser: 50 W Amplifier Tests

First tests with 50 W amplifier (early August)

- After 50 W amplifier: pulsewidth 50 ps, linewidth 3–4 nm
- Very low doubling efficiency of 6% at various rep rates

Poor doubling efficiency

- Too much DC light? (Amplified Spontaneous Emission)
- Pulsewidth or linewidth too large for doubling?

Amplifier dumped

- Unreliable: repaired twice already, failed CW stability tests
- Outside experts suggest this amplifier will never work, wrong kind of fiber (Cornell uses large mode area fiber)

Amplifier shipped back, procurement negotiating compensation

Laser: Other Options

High duty-cycle RF-pulsed lasers

- FEL amplification technique using Nd:YVO4 slab amplifier

Low duty-cycle pulsed lasers

- 90 W, 2 kHz laser from Coherent
- 50 W, 10 kHz laser from Advanced Photonics (better M^2)

CW lasers

- High-finesse cavity (copy of Hall A system)
- Low-finesse cavity with 10 W Coherent VERDI laser

Laser: FEL Slab Amplifier

Test setup

- Gain-switched seed → 5 W fiber amplifier
- Slab amplifier from FEL system

Preliminary results

- Linewidth issues after slab amplifier
- Lower frequency-doubling efficiency
- Would need 110 W IR → many amplification stages
- Alternatively, reduce repetition rate to 100 MHz

Related developments

- Pulse-picking: higher peak power for lower rep rate
- Chirping: pulse-compression

Laser: Summary

Fiber amplifier laser

- Amplifier unreliable, not sure it would even work
- Given up this approach

Slab amplifier laser

- Test setup indicates many amplification stages needed
- Continuing to explore possibilities

Fallback option

- 10 W Coherent VERDI with low-finesse cavity
- Investigating this option in collaboration with UVa

Detectors

Mode of operation

- Independent measurements of photons and electrons
- Cross-calibration using coincident events
- Integration between zero-crossing and Compton edge

Photon detectors (2)

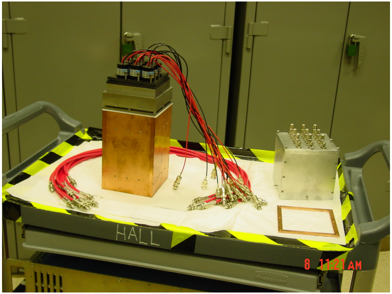
- $PbWO_4$ detector designed for 1–6 GeV beam
- CsI detector recovered from Bates polarimeter

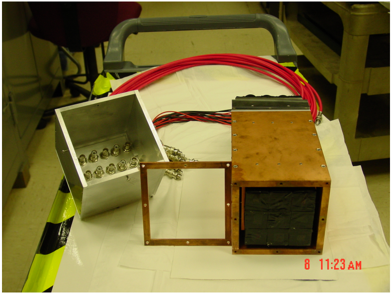
Electron detector (1)

- Diamond strip detector

$PbWO_4$ Detector

- 3×3 lead-tungstate calorimeter array
- Not optimized for Q_{Weak}, original intention was 1–6 GeV
- Concerns about light yield at 50 MeV (Compton edge)
- Prototype tested in SOS, but pion backgrounds too large
- Tested with cosmic rays, HIγS beam





$PbWO_4$ Detector

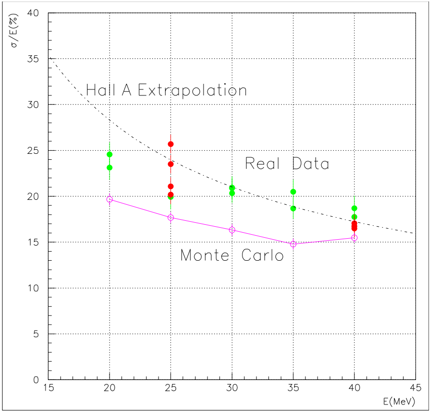
HIγS test beam

- 20–40 MeV photons
- Limited beam time
- Data taken behind CsI detector

Result (preliminary)

- Slightly worse than Monte Carlo
- Comparable to Hall A

Resolution vs. energy



- Red: direct events
- Green: behind CsI

CsI Detector

Scintillator crystal (old)

- $10 \times 10 \times 25\,\text{cm}^3$ CsI (pure), slightly tapered
- Emission maximum at 310 nm (fast), 20% at 500 nm (slow)
- Decay time: 16 ns (1000 ns), yield: 2000 γ/MeV (5% of NaI)
- Yield is temperature dependent (0.6% / °C)
- Hygroscopy: slightly (crystal affected by storage/shipping)

Photomultiplier tube (new)

- 3 inch 8-dynode Photonis XP3462/B (SOS)
- Supply voltage: 1564 V (nominal), gain: 10^6, rise time: 3 ns

Read-out (new)

- Struck SIS-3320-250 fADC (Hall A Compton)

CsI Detector

Problem

- Crystal stored without N flow
- For shipping PMT was removed (turned out to be broken anyway)
- Transmission tests performed, could be surface effect

Options

- Polishing crystals
- New crystal ($9k)

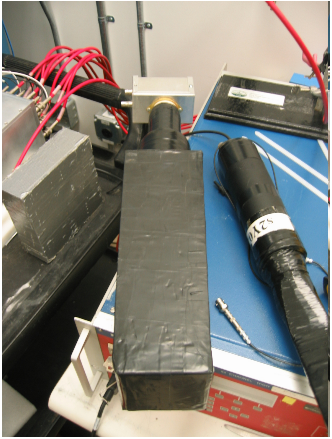


Figure: The CsI detetor with old PMT.

CsI Detector

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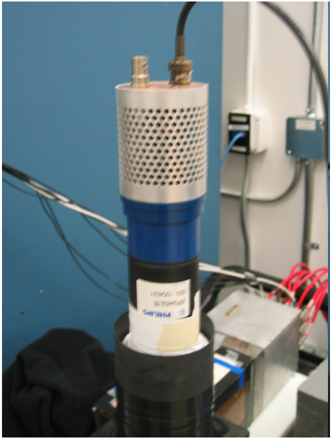
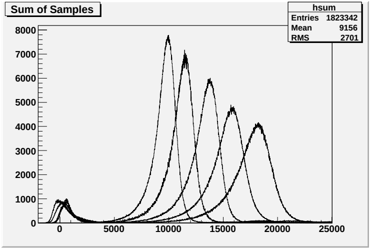


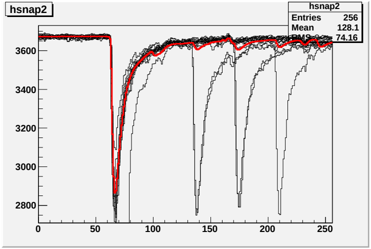
Figure: The CsI detetor with new PMT.

CsI Detector: HIγS test beam

Different energies, rates

- 1 kHz and 10 kHz look very good
- 100 kHz will require more work
- Pile-up, multiple events



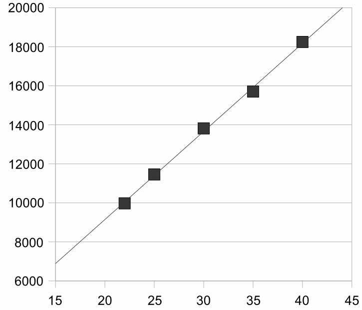


CsI Detector: HIγS test beam

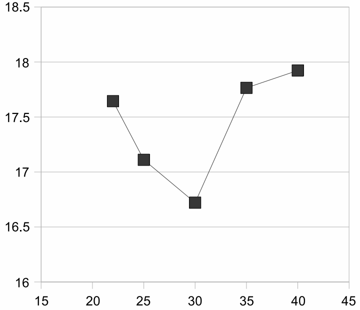
Linearity and resolution

- Preliminary results
- Energy not calibrated

Linearity (in a.u.)



Resolution (FWHM in %)

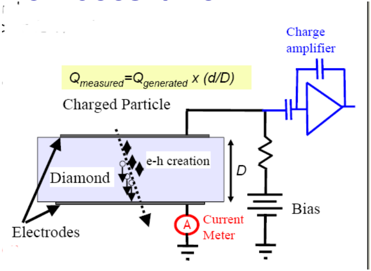


Electron Detector

Diamond strip detector

- Typical choice for electron strip detector is silicon
- Electron displacement at Compton edge: 23 mm
- Radiation hardness of diamond much better
- Advantages: lower leakage current, faster, lower noise
- Disadvantages: signal smaller

How does it work

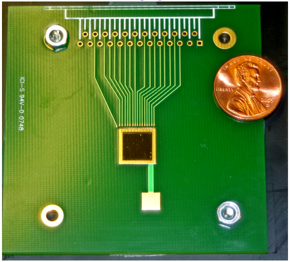


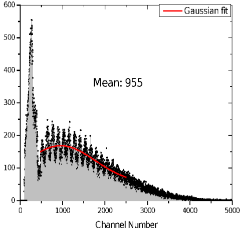
Detector characteristics

- 4 planes of 96 strips with 200 μm pitch
- Bias voltage 1000 V

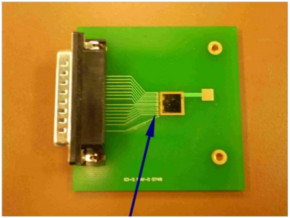
Electron Detector: Prototypes with ^{90}Sr Tests

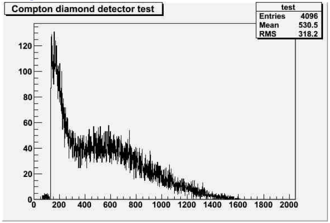
Mississippi (15 strips with 500 μm pitch)



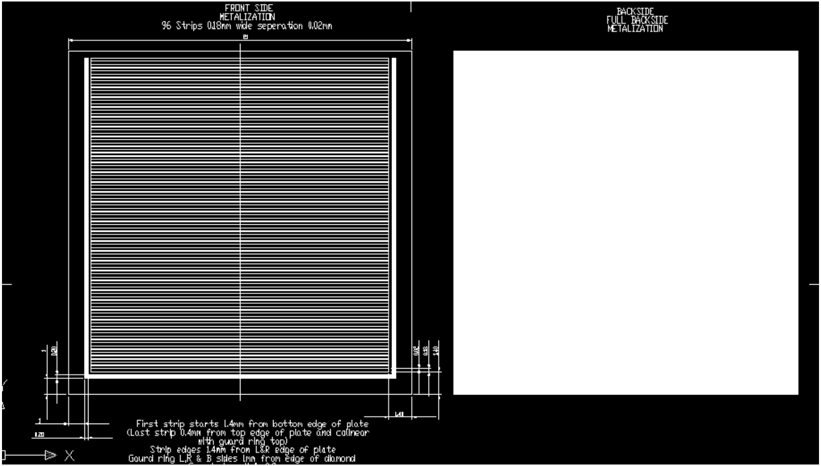


Winnipeg (37 strips with 200 μm pitch)





Electron Detector: Full-size Detectors



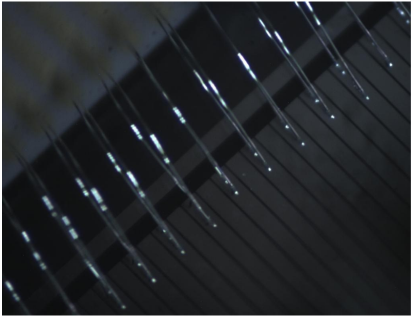
Front: 96 strips and guard ring

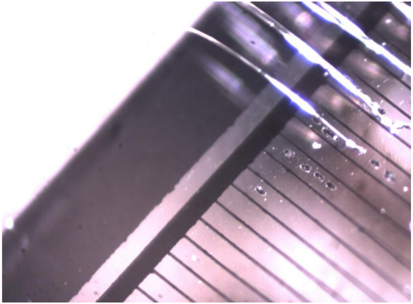
Back: full metallization

Electron Detector: Full-size Detectors

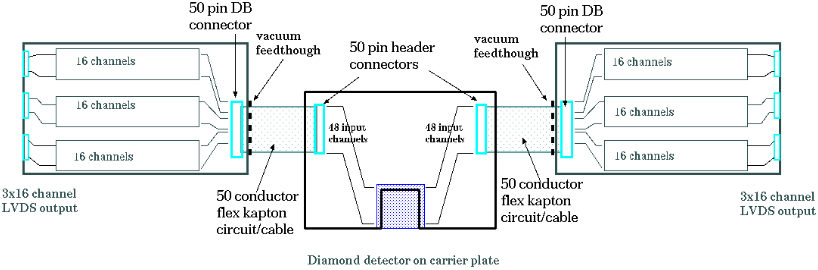
Production status

- 7 of 8 detector planes produced
- Last detector plane: wire bonding problems





Electron Detector: Read-out and DAQ



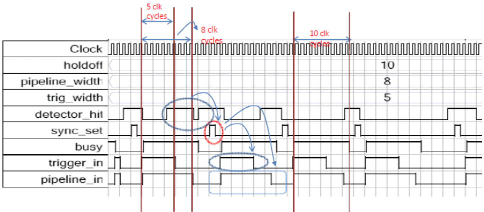
Pre-amplifier boards

- Modified AGAM board (developed at TRIUMF)
- Gain increased ($\times$ 3–4) without increasing noise
- Checked for oscillations due to changes
- Design finalized, now building prototype boards, then mass production

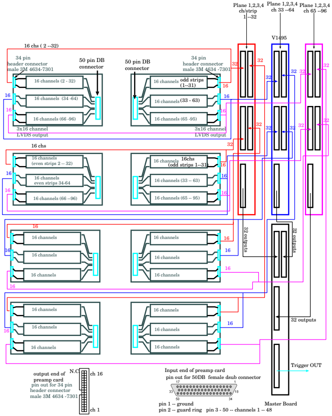
Electron Detector: Read-out and DAQ

V1495 modules

- VHDL programming started
- Timing studies in progress
- Planes processed as 3 regions
- One master board to rule them all, three modules to find them
- Testing on board and integration with CODA planned



Timing Analysis of the Signal Recondition Circuit



Summary

Møller

- Kicker magnet tests continuing
- Important: only proven polarimeter during Q_{Weak} running

Compton

- Laser
  - High duty-cycle fiber amplifier laser option abandoned
  - FEL slab amplifier laser could work, but needs testing
  - Fall-back options (10 W with low-gain cavity) important
- Chicane
  - Design of dipoles and beamline almost complete
  - Dipoles ready for production
  - Interaction region depends on laser option

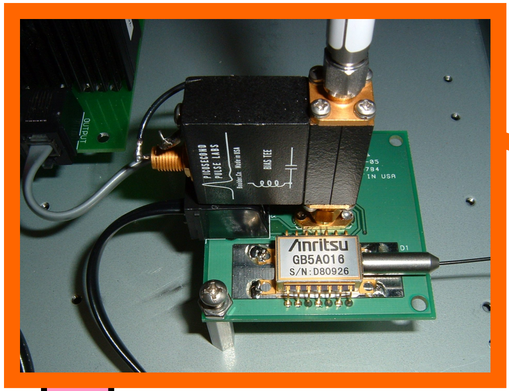
Summary

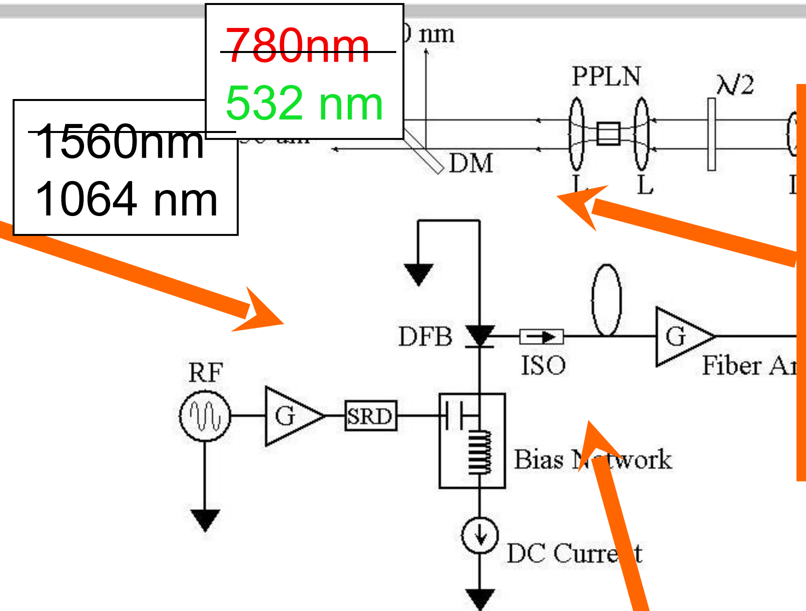
Compton (cont.)

- Photon Detector
  - CsI detector as alternative to $PbWO_4$ identified
  - Test beam measurements at HIγS successful
- Electron Detector
  - Diamond planes in production, ready soon
  - Progress on read-out and DAQ

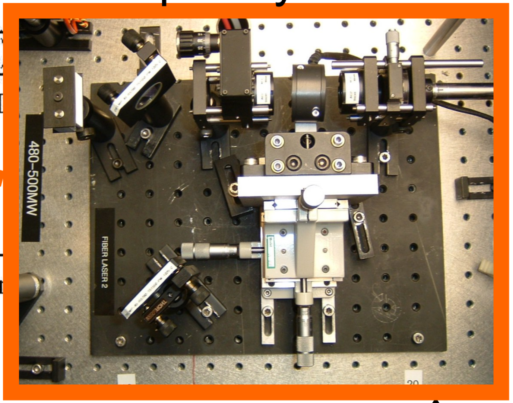
Fiber-Based Laser

Gain-switched seed





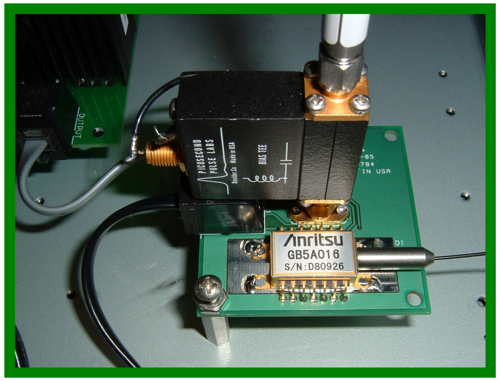
Frequency-doubler



ErYb-doped fiber amplifier

5 W Prototype

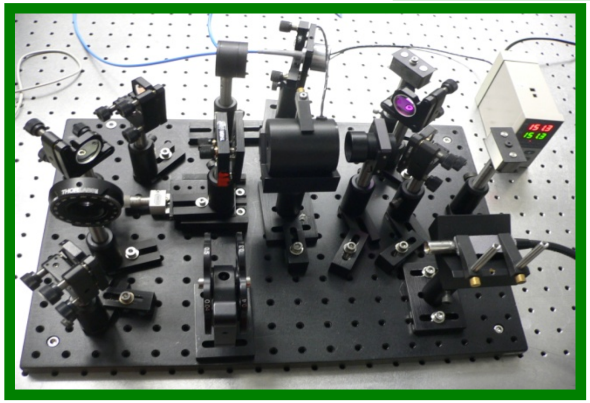
Gain-switched seed



Starting February, Chuyu Liu, CASA/Peking graduate worked on 5W prototype of laser

YAR-5K-LP-SF
5 W amplifier

Successfully achieved 150 mW of green power → 3.4% doubling efficiency



LBO frequency doubling crystal

Doubling Efficiency

Shukui Zhang has achieved 50% doubling efficiency for peak powers of 27 kW (26% for 2.7 kW)

- → Pulse width of gain switched diode ~ 50 ps (FWHM)
- → At 499 MHz, peak power = 50 W (2 ns)/(50 ps) = 2 kW
- → At 249.5 MHz peak power = 4 kW

50 W amplifier not warrantied for pulsed operation – advised by IPG not to exceed 5 kW peak power

- →249.5 MHz may be too close to damage threshold

Based on Chuyu's calculations, we can likely expect 25-30% efficiency (15 W average green power) roughly consistent with Shukui's experience

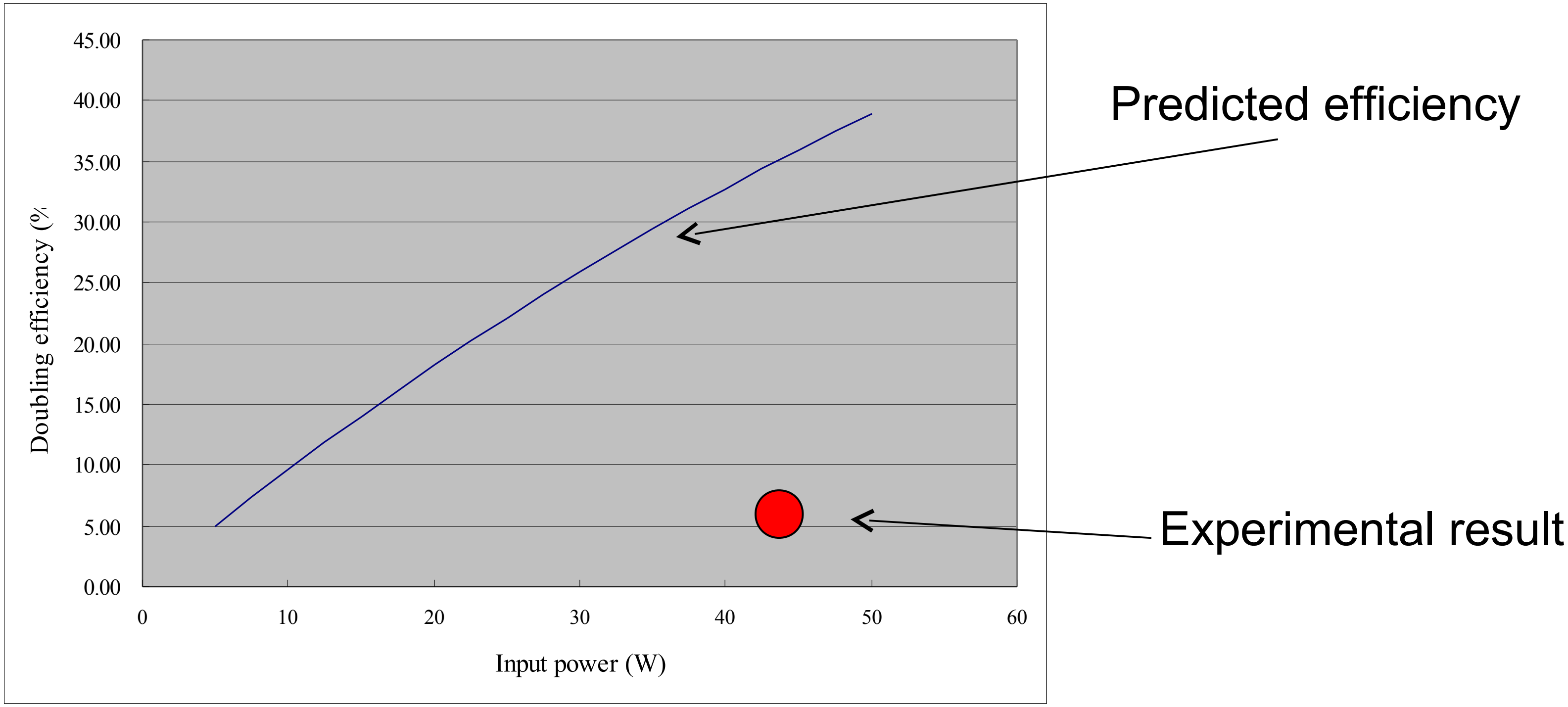
Doubling Activities Since Summer 2008

LSOP for operation of 50 W amplifier signed off after ISM review at JLab (late June)

50 W amplifier found to be defective. Shipped back to manufacturer second week of July→ returned early August

Initial results with 50 W amp:
→Pulsewidth after amp = 50 ps at 500 MHz (similar to 5 W amp)
→Linewidth = 3-4 nm
→Doubling efficiency: 6% at 499 MHz (2.7 W/44 W)
6.6% at 300 MHz
4% at 700 MHz

Doubling Performance



Why such poor doubling efficiency?

1. Amplifier puts out too much DC light (Amplified Spontaneous Emission)
2. Doubling crystal bad (LBO) → unlikely
3. Gain-switching doesn't work well for doubling: pulsewidth and/or linewidth too large?

Amplifier Failure

Before more tests could be performed, amplifier failed (August 18)
→ Shipped back to manufacturer
→ Repaired for free – last amplification stage burned out. Claimed this can be caused by back-reflection or power fluctuation

Amplifier returned early October
→ Put 50 W amp through simple stability test
→ Ran in CW mode at large fraction of max output
→ After 6 days, began failing again

2 key issues

1. IPG Amp unreliable – it has spent more time at IPG than in our lab
2. Consultation with outside experts (Dimitre Ouzounov, Cornell) suggests this kind of amp will never work well for our purposes – wrong kind of fiber → Cornell uses LMA (large mode area) fiber

We have shipped 50 W amp back to IPG and asked procurement to negotiate some kind of compensation

Laser Options

- 50 W IPG fiber amp is a lemon! What is the path forward?
- RF-pulsed options
  - Build our own fiber amplifiers (with help from Cornell)
  - **Copy FEL amplification technique → Nd:YVO4 "slab" amplifier**
- CW options
  - Copy Hall A high finesse system
  - Build low-finesse system with Coherent VERDI laser
- Low duty-cycle pulsed options
  - 90 W avg. power, 2 kHz laser from Coherent
  - 50 W (or larger), 10 kHz laser from Advanced Photonics → better M^2

Laser Development Plans

- Test our GS seed + 5 W fiber amp with Shukui's system at FEL
  - This will tell us if gain-switching is a viable "source" for this kind of system
  - If this works, our most likely avenue of attack
- Chuyu is working on "pulse picking" GS seed
  - GS only "works" down to 250 MHz
  - If we can pick-off at some lower rep rate before 5 W amp, larger peak power
- Chuyu is also making measurements to determine if pulse compression is viable ("chirp")
- Still useful tests can be done at Cornell, but making our own fiber amps is likely beyond the scope of what we can accomplish
- DG will work with KP at UVa to see if we can couple a CW VERDI laser (10 W) to a low gain cavity

Compton Milestones

Task	Responsible Institutions	Planned Completion Date
Dipole magnet design	MIT-Bates	Summer 2008
Finalize whole chicane	MIT-Bates	Fall 2008
Photon detector tests	Yerevan/HU/MIT	September 2008
Photon detector final construction	Yerevan/HU	Spring 2009?
Fiber laser low/high power prototypes	JLab	Spring-Summer 2008
Final laser choice	JLab	Fall 2008
Laser transport setup	JLab/Uva	Summer-Fall 2008
Electron detector fabrication	Winn./Man./TRIUMF/ Miss.St.	October 2008
Compton Installation	JLab	Fall 2009-Spring 2010

Diamond: A Closer look …

Silicon is a typical choice for a multi-strip position sensitive electron detector

Property	Silicon	Diamond
Band Gap (eV)	1.12	5.45
Electron/Hole mobility (cm^2/Vs)	1450/500	2200/1600
Saturation velocity (cm/s)	0.8×10^7	2×10^7
Breakdown field (V/m)	3×10^5	2.2×10^7
Dielectric Constant	11.9	5.7
Displacement energy (eV)	13-20	43
e-h creation energy (eV)	3.6	13
Av. e-h pairs per MIP per micron	89	36
Charge collection distance (micron)	full	~250

Low leakage current, short noise

Fast signal collection

Low capacitance, noise

Radiation hardness

Smaller signal

Advantages: lower leakage current, faster, lower noise and rad. hard

Disadvantages: smaller signal ~ 40% smaller

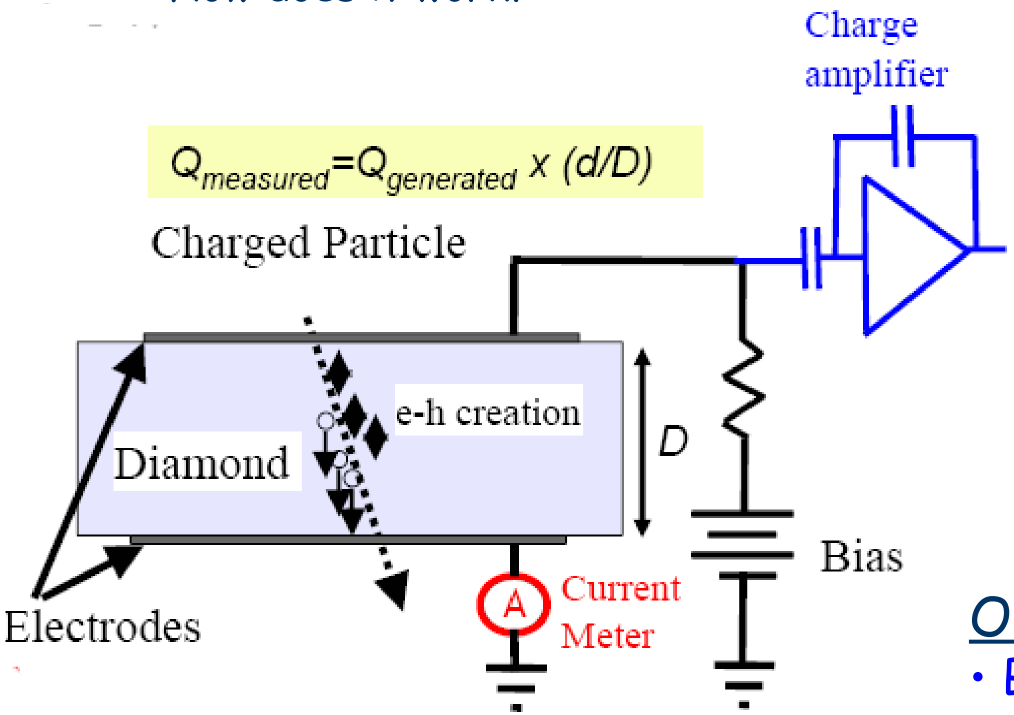
Recall that the Compton edge is 2cm from beam for recoil e^-

Thanks: Dr. R. Wallny (UCLA)

The Diamond Detector

- Diamond is known for its radiation hardness
- We chose Diamond (artificially grown by Chemical Vapor Deposition) for the detector

How does it work?



Operation of Diamond Detectors

- Bias voltage ~ 1000 V,
- Charge collection distance ~ 250μ

Prototype Diamond Detectors

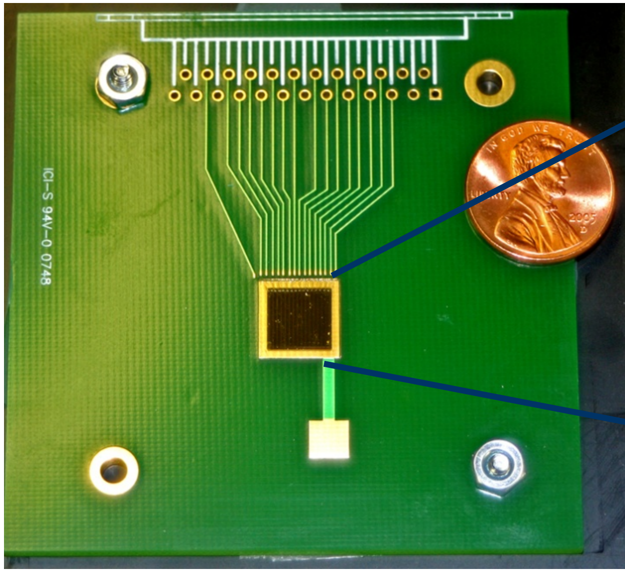
Summer 2007: 10x10x0.5 mm^3 poly-crystal CVD diamond plates were procured.Visit OSU (Prof.Harris Kagan's lab)
Learn how to clean and deposit metal on diamond.
Fabricated at OSU, 15 strip prototype for MSU

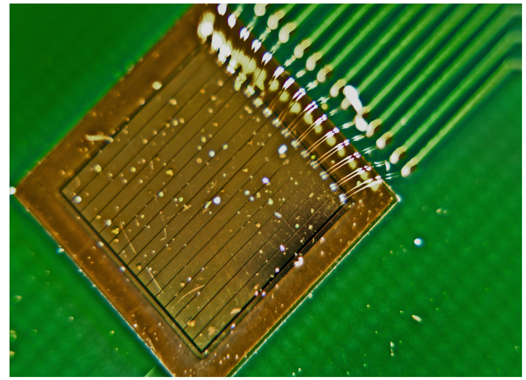
funding for the e-detector project from NSERC and DOE

Fall 2007: Winnipeg group reproduces process at the Nono Lab in U. of Manitoba (EE). Fabricates a 37 strip prototype (same pitch as full-size detectors)

The rest of the story……

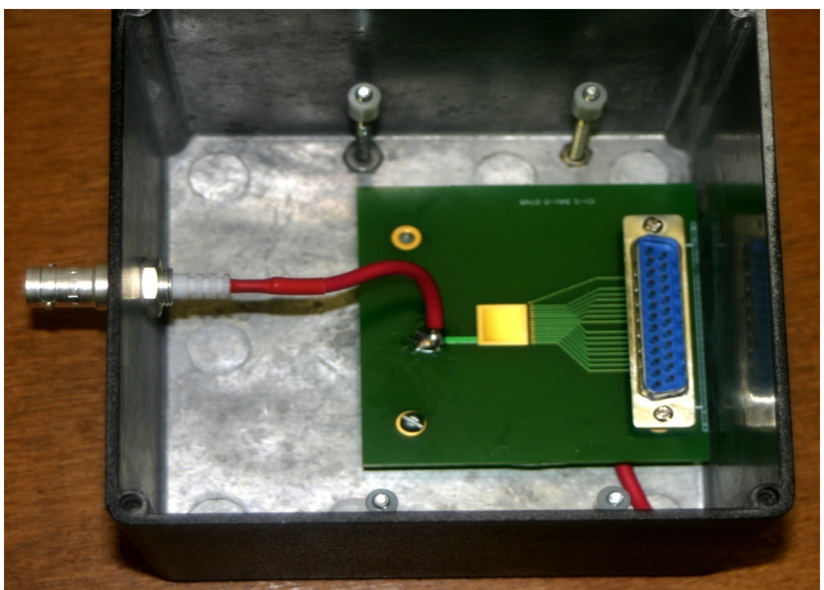
The MSU Prototype

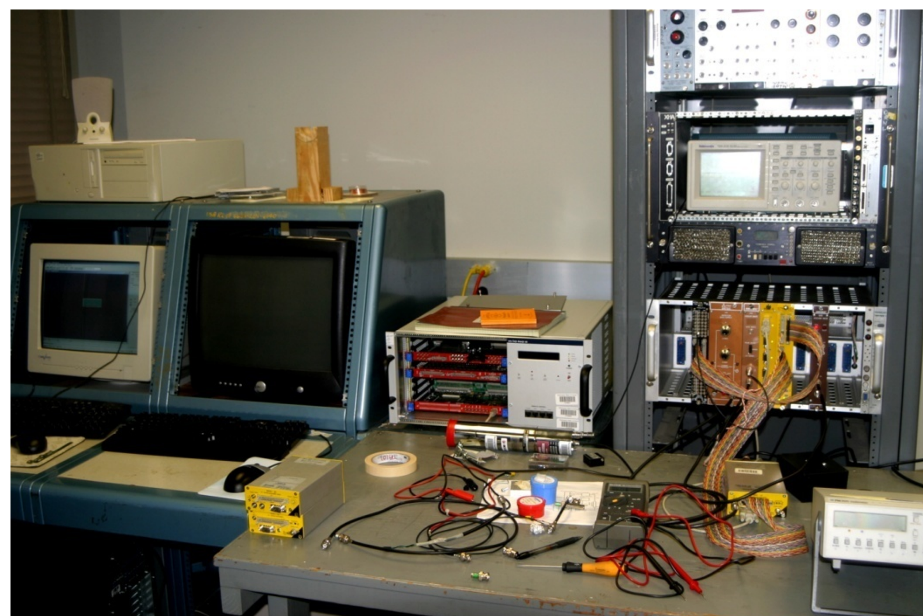




- 10x10 mm^2
- 500 μm thick
- 15 strips ~450 μm wide

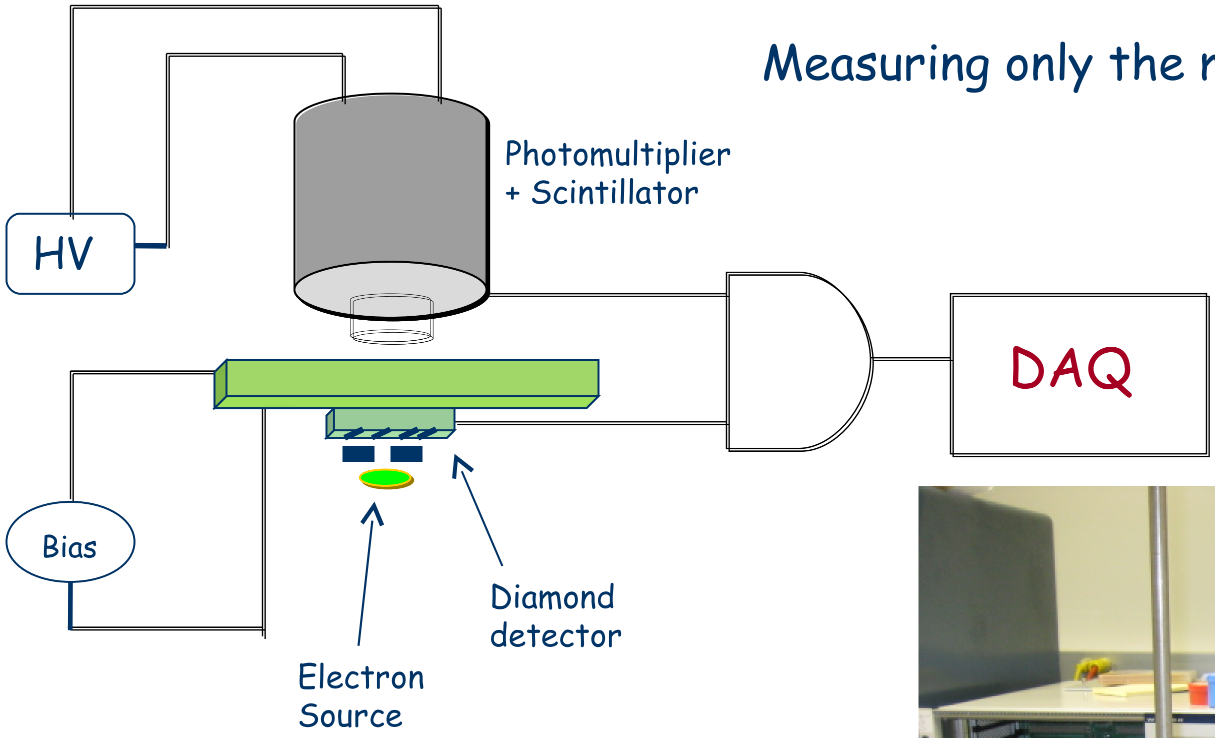
Metallization, Lithography & wire bonding done in High Energy Physics Lab at Ohio State University. Thanks Prof. Harris Kagan and his group at OSU.



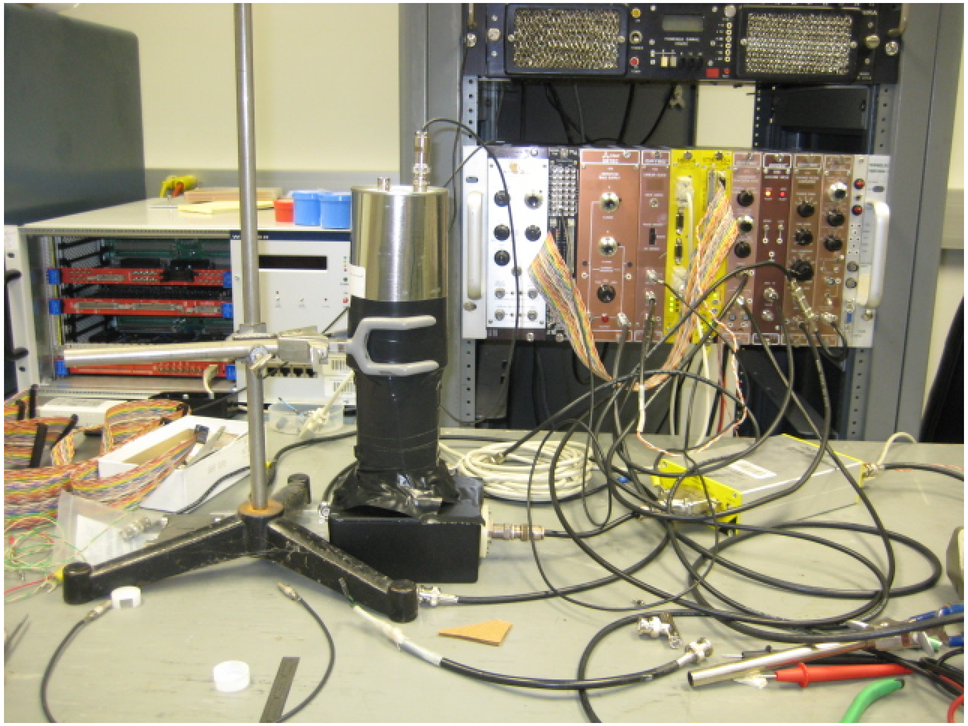


The MSU Prototype

Measuring only the minimum ionizing particles.

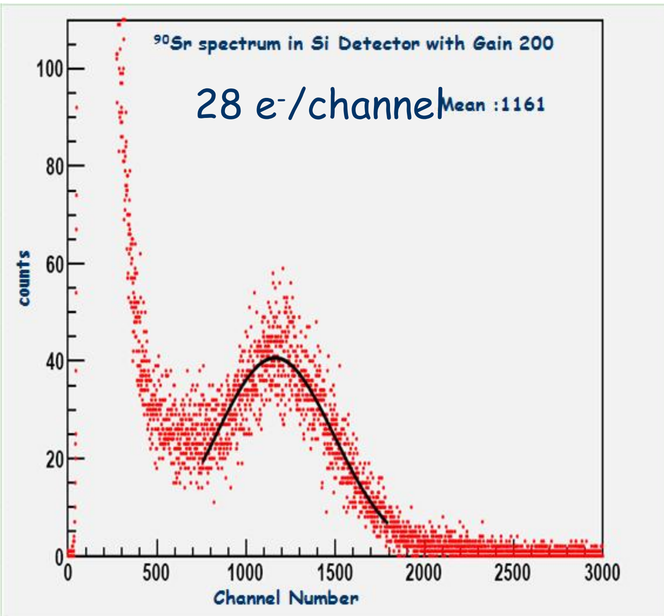


Only those beta particles would be detected which pass the detector and reach the Scintillator.

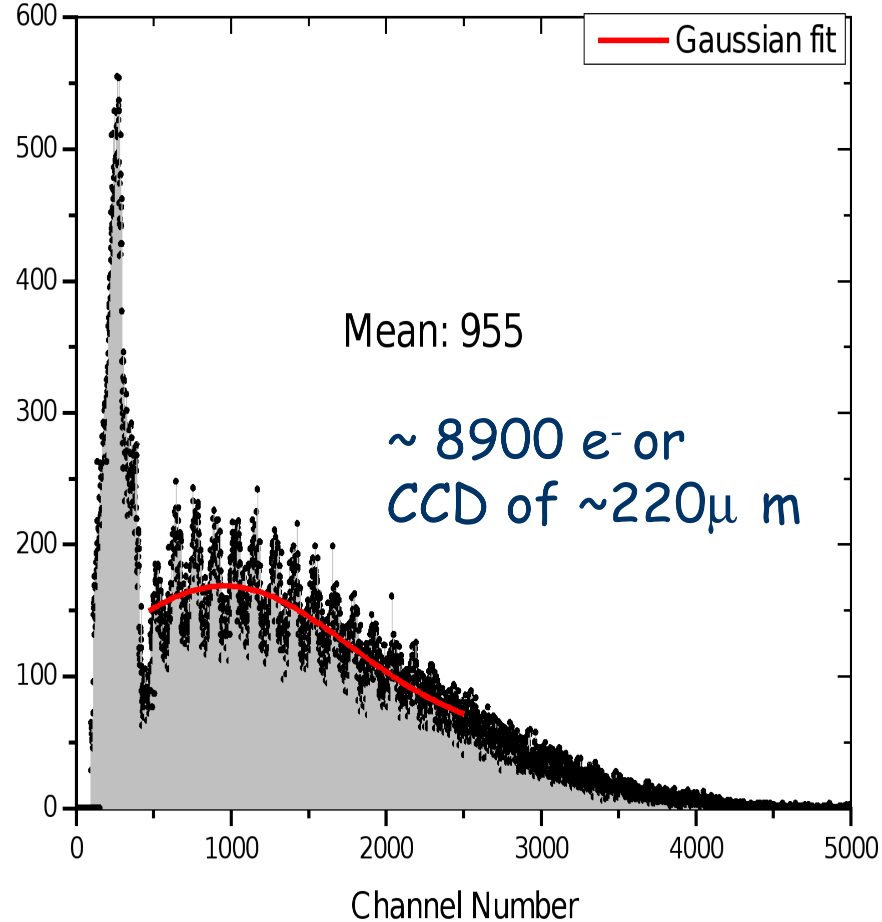


The MSU Prototype

^{90}Sr spectrum in Si (300μ m) Detector @ gain 200



^{90}Sr spectrum in Diamond @ gain 600

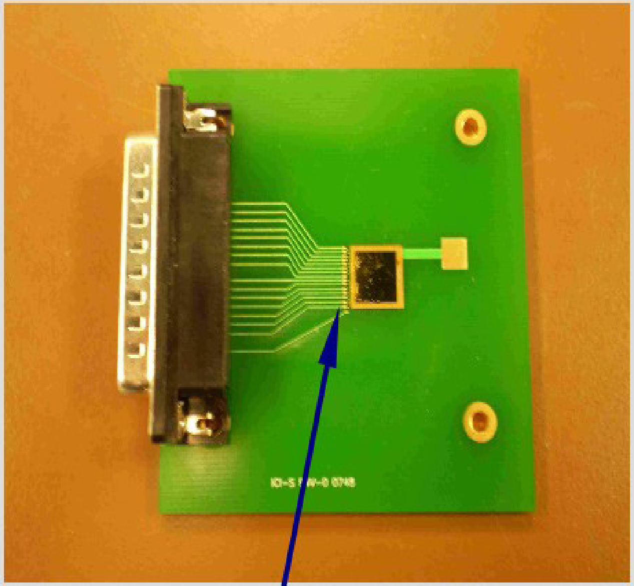


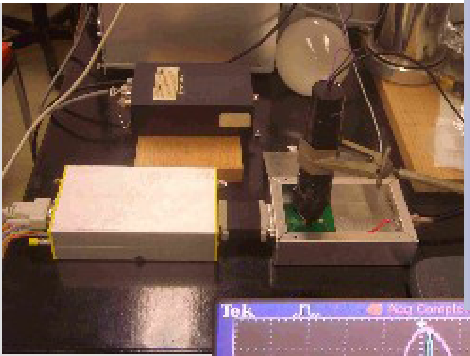
Single strip spectra

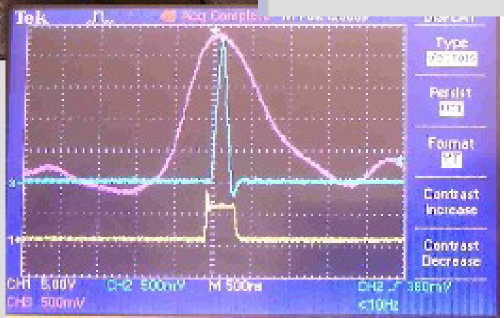
Consistent with CCD measurement at OSU with a metal dot deposited on the diamond.

The Winnipeg Prototype

- Sample detector:
  10 mm x 10 mm x 0.5 mm
  polycrystalline Chemical Vapor Deposition (pCVD) diamond
- Total 37 strips,
  16 strips were wired out
  on a G-10 fiberglass carrier board
- Strip pitch 200 μm
  strip width 175 μm, gap 25 μm
- Smaller detector, but have all features of the final large 20 mm x 20 mm x 0.5 mm detectors

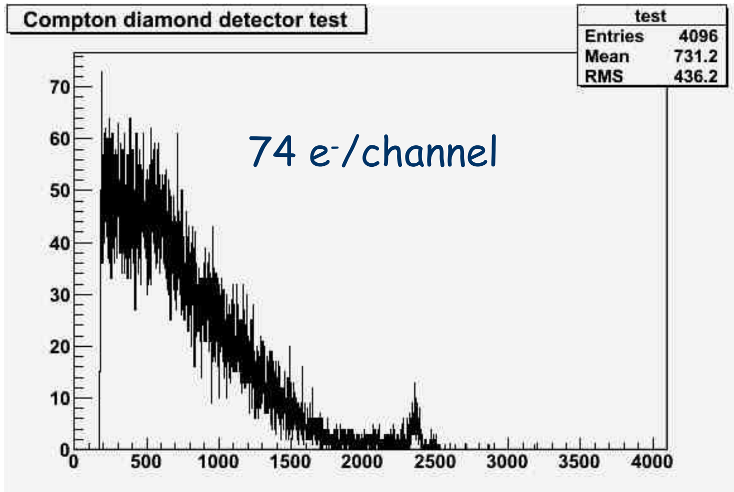




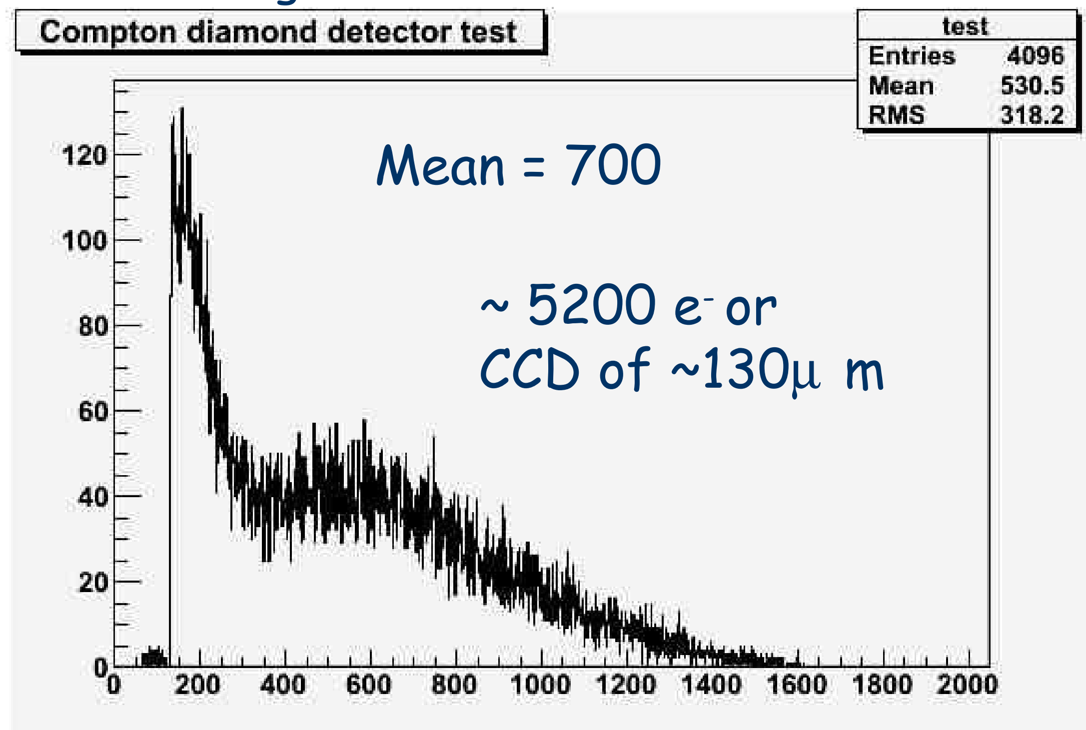


The Winnipeg Prototype

^{137}Cs spectrum on Si
@ gain 1



^{90}Sr spectrum in Diamond
@ gain 10



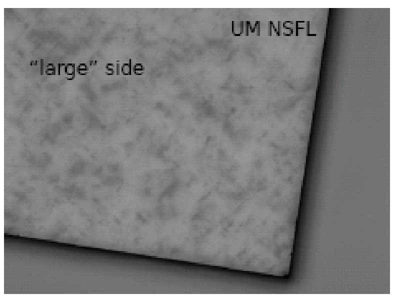
Single strip spectra

Finer strip pitch, more difficult to collimate beam

The Full Size Detector

"CERN" grade diamond was purchased from:

elementsix ADVANCING DIAMOND

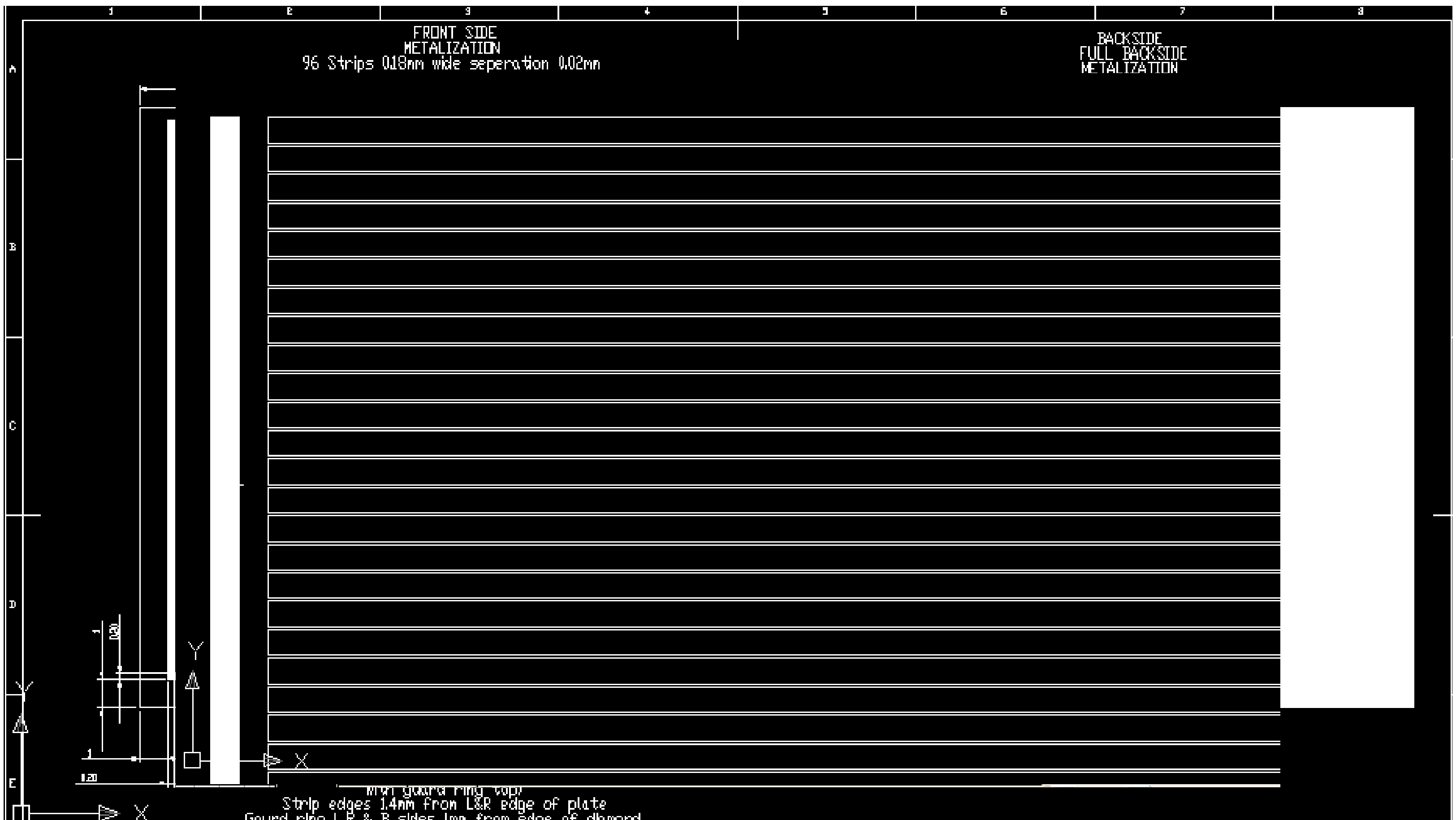


8 plates of 21x21x0.5 mm^3 poly-crystal CVD diamond (4 spare plates).

Decision was made to contract the diamond metallization, carrier plate, wire-bonding and assembly to DDL a subsidiary of Element-6

Full Size Detector

DDL a subsidiary of E6 is metalizing the diamond plates

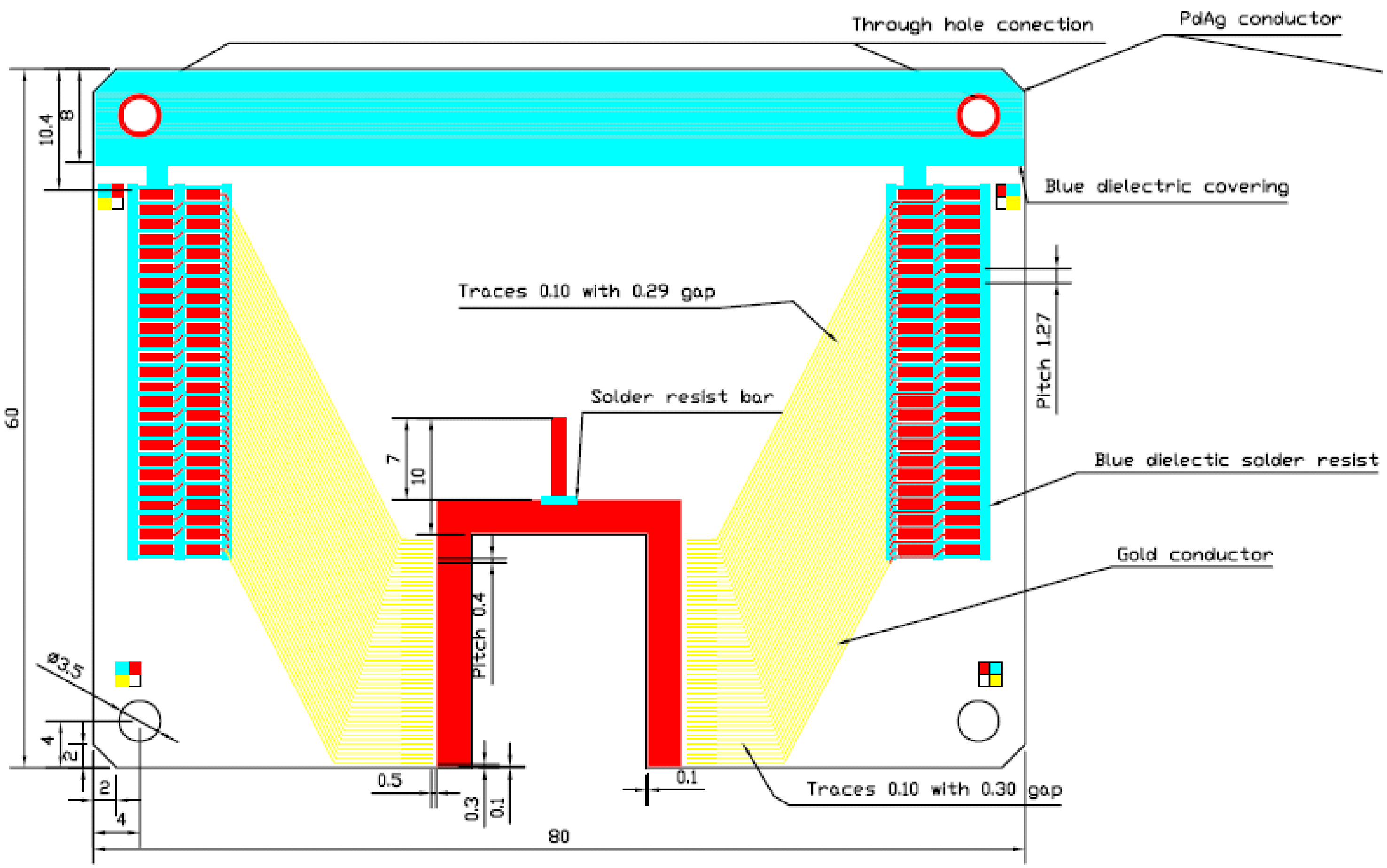


Mask was approved 07/15

Metal = TiPtAu

Carrier Board

Diamond plates to be epoxied (a silver epoxy) to Alumina carrier plates and wire-bonded, by DDL



Design was approved 08/20

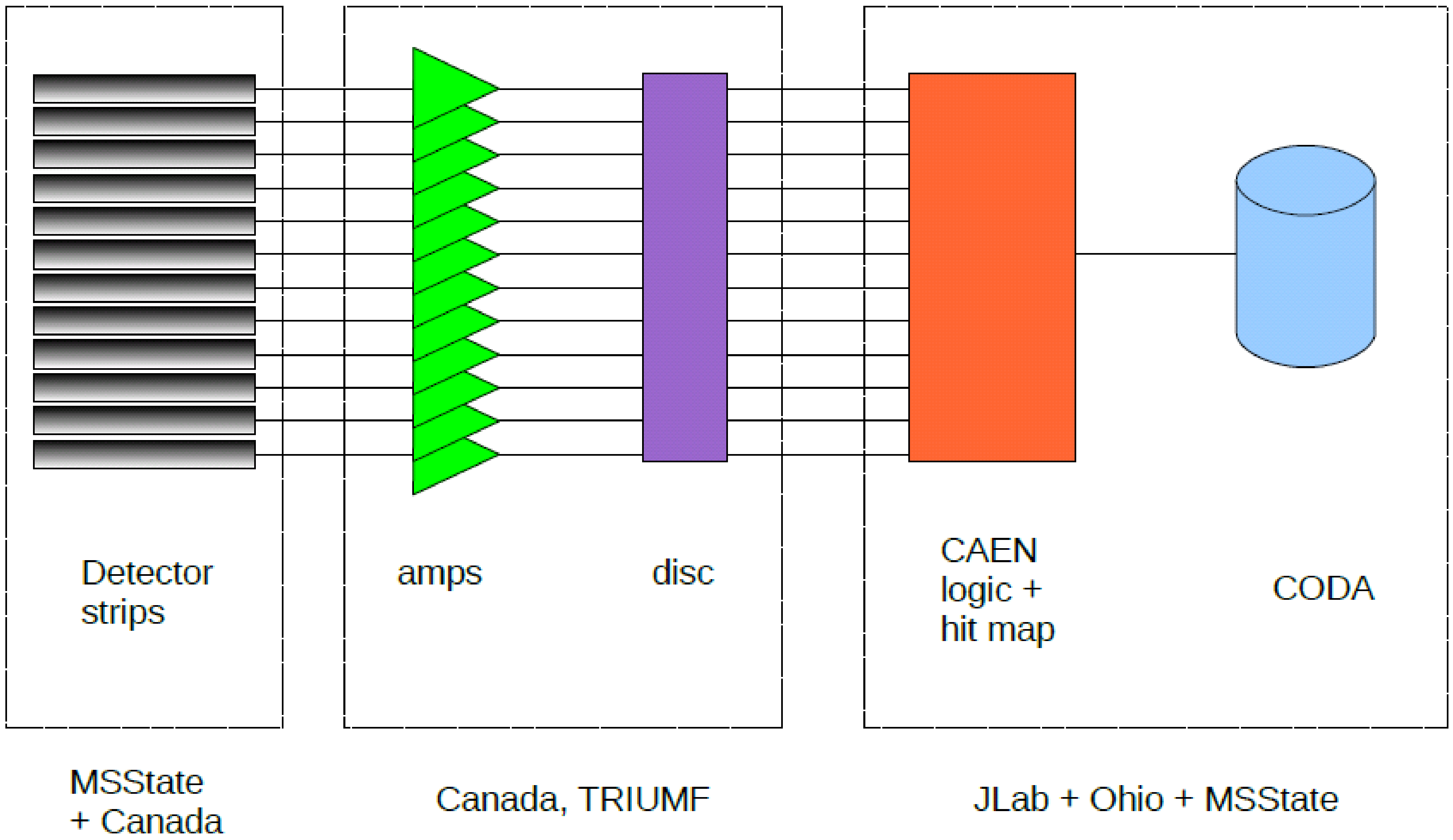
Update on Full Size Detector

Metallization completed on 4 planes, another 4 in progress

All 8 carrier boards are also being metallized as we speak.

Detector are expected to be ready in shipment in mid-Dec.

Readout and DAQ

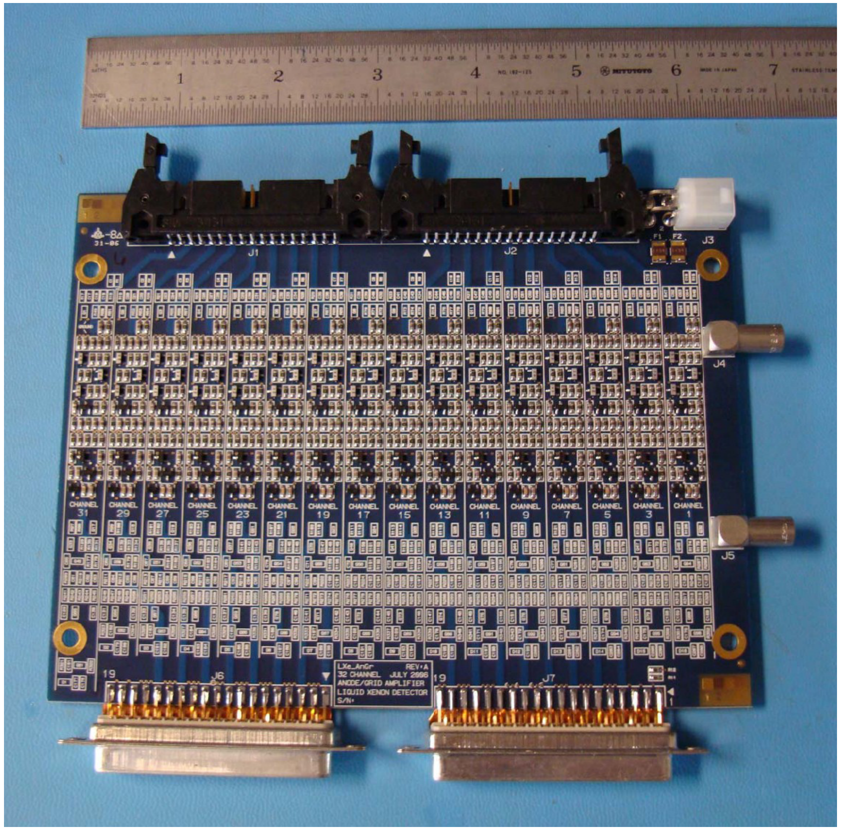


Readout Electronics

Summer 2008: decided to test A pre-amp+shaper board from the LiXe experiment called the AGAM board.

Designed by L. Kurchaninov at TRIUMF

Gain ~ 15mv/fC, ENC ~ 700 e^-
gain decreases, noise increases with input capacitance.

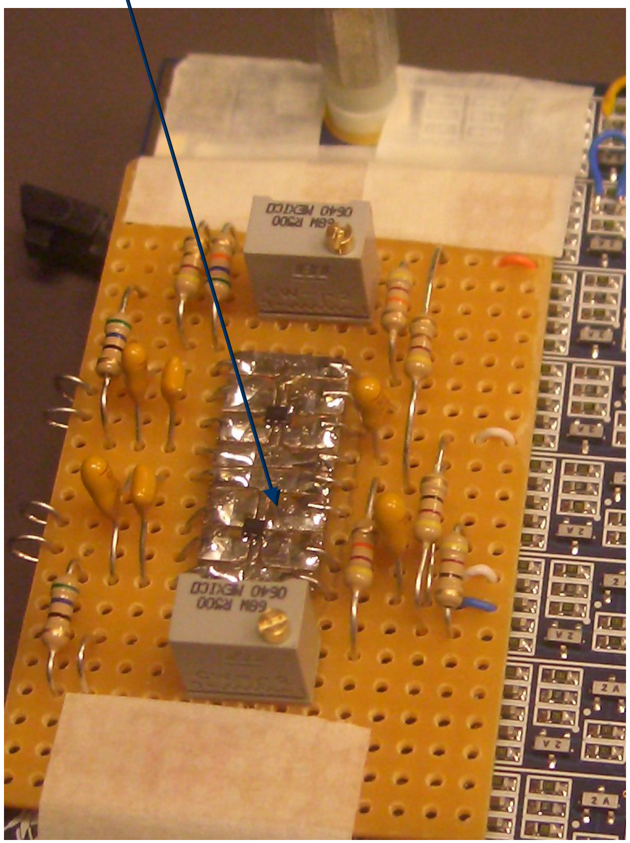


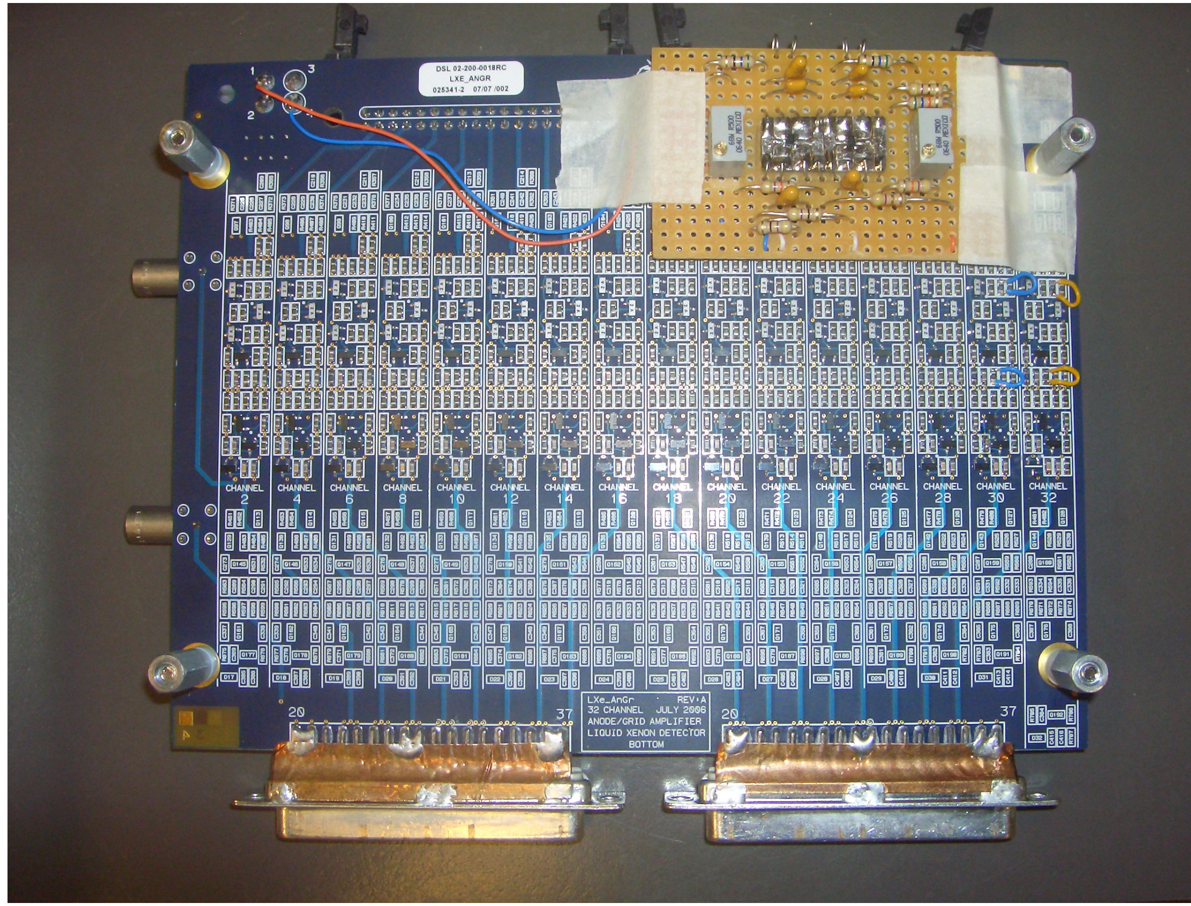
Needeed to increase gain (x3-4)
and add discriminators without increasing noise
and check for oscillation.

Readout Electronics

Peiqing Wang made these modifications @ Winnipeg

ADC MP604 Comparator

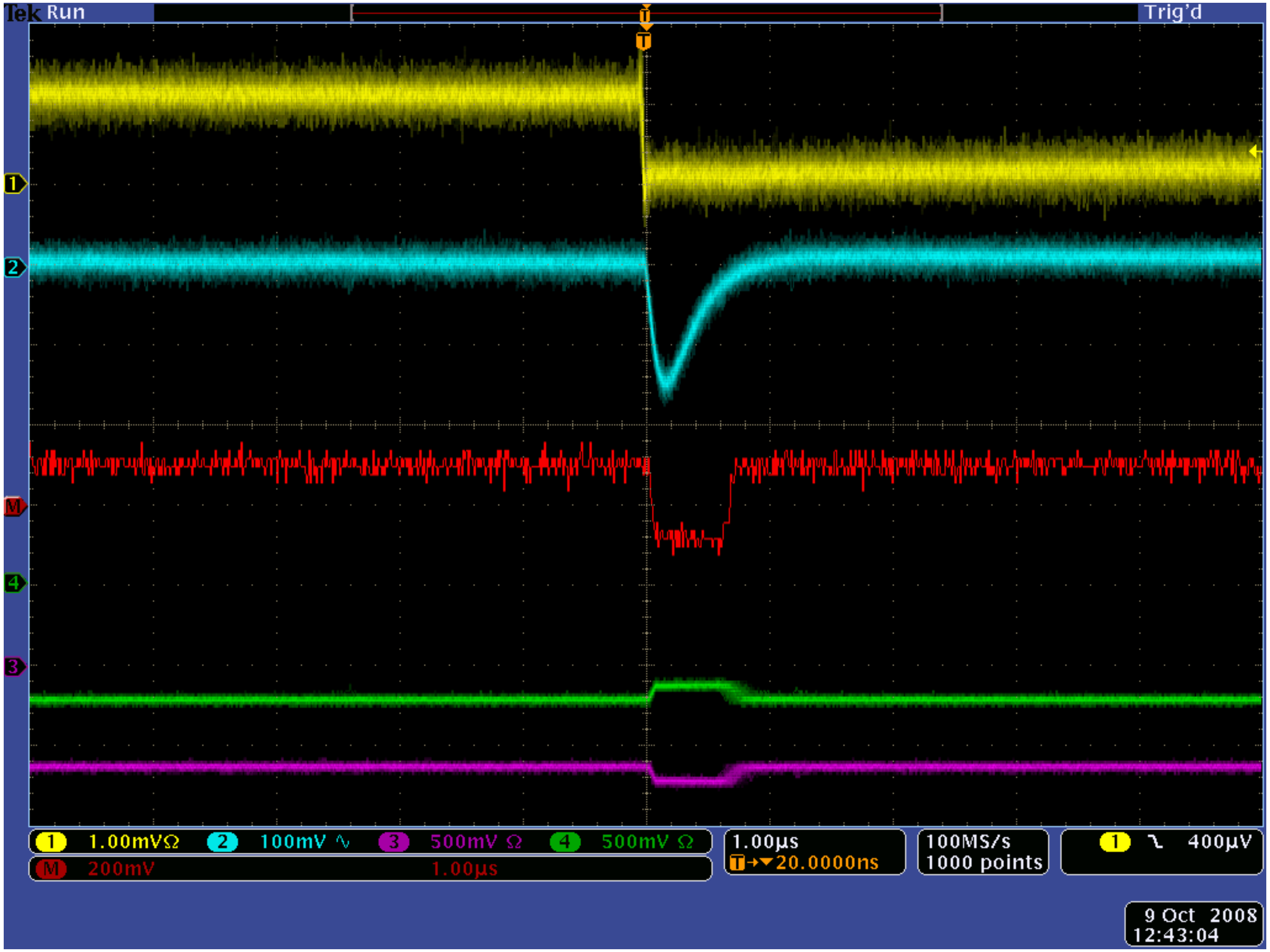




Increased gain on 2 channels and
add discriminators

Readout Electronics

Results from Peiqing Wang



Gain increased to 100mV/fC
Width ~ 0.6µ s

LVDS output from the discriminator

No oscillations
No increase in input capacitance

Need to retest with increased input capacitance to account for ~3ft of cable between detector and card.

Readout Electronics

Front end electronics have been validated (ready to be layed out)

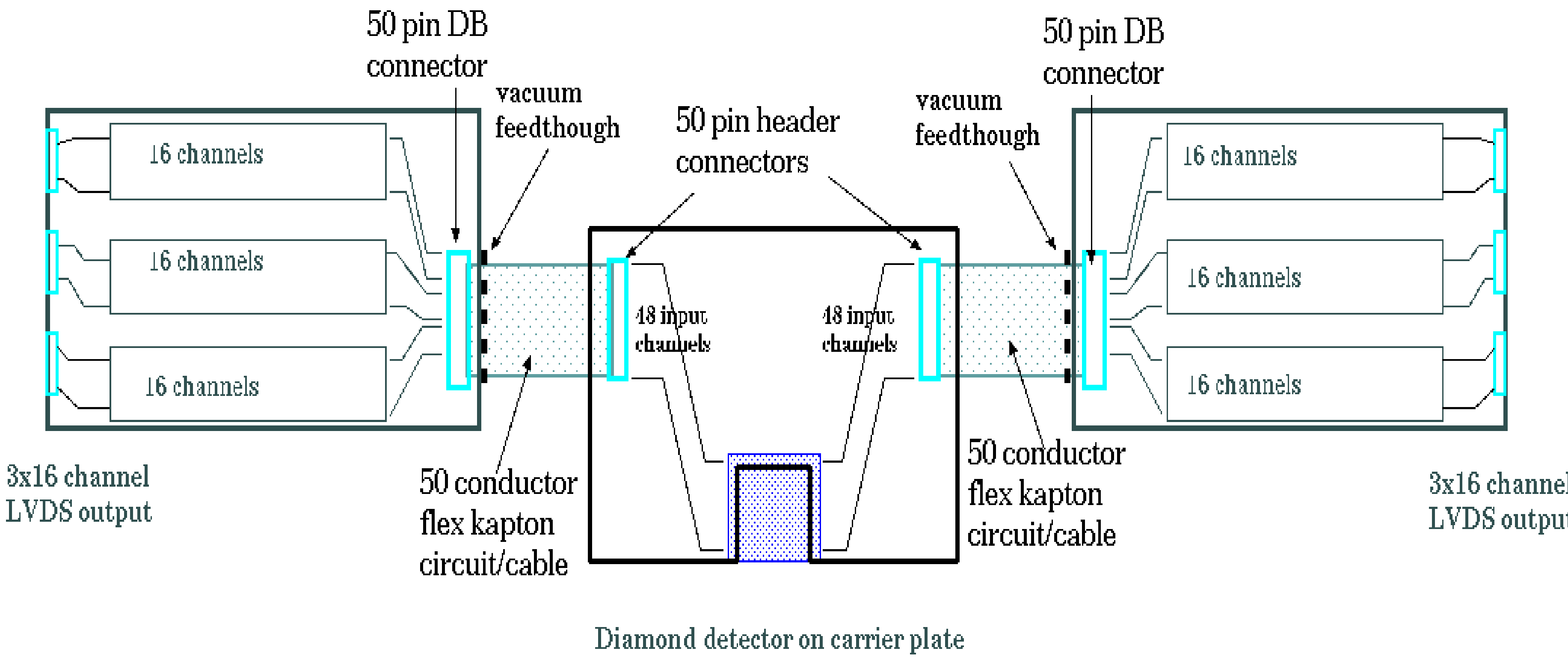
48 channels per board, 50 pin DB connectors at input end,
3x16 pin header connectors at output end

Awaits a detailed channel map.

Money has been transferred to TRIUMF

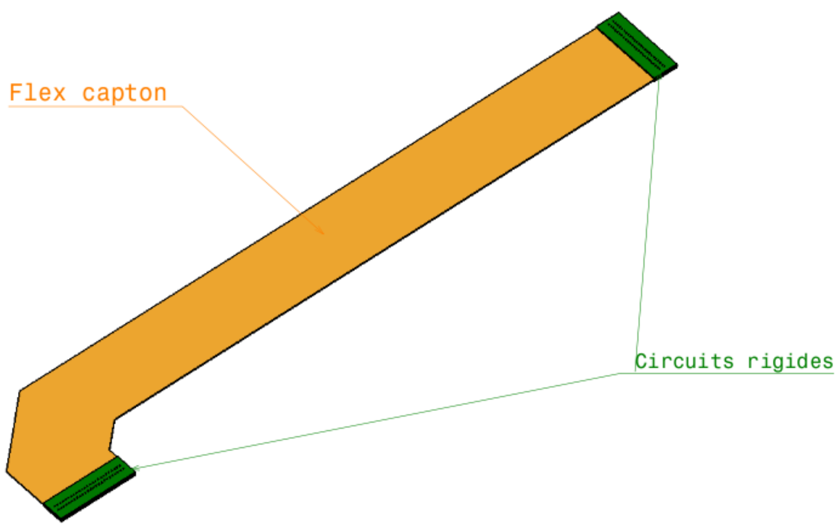
Readout Electronics

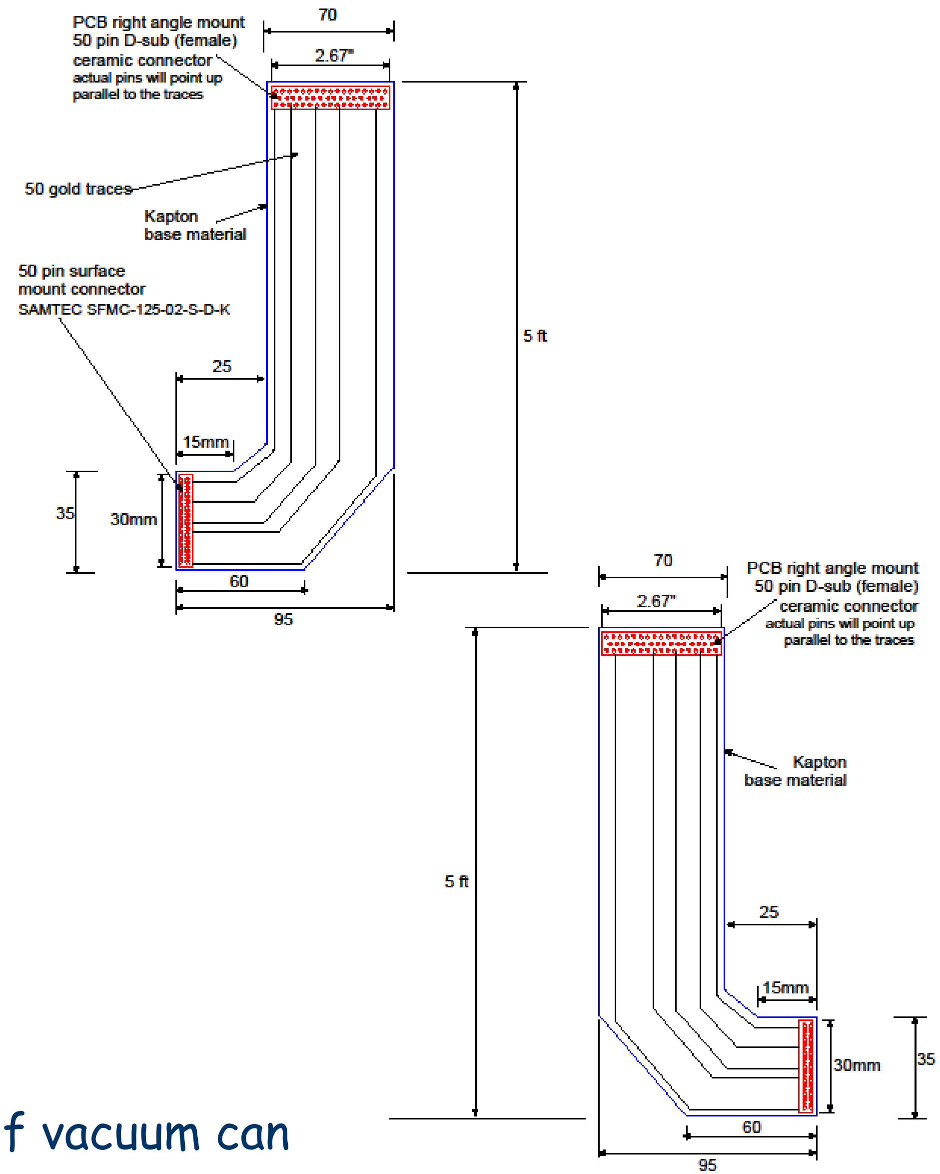
Front End Schematic



Readout Electronics

Kapton flex-circuits to be used in vacuum.

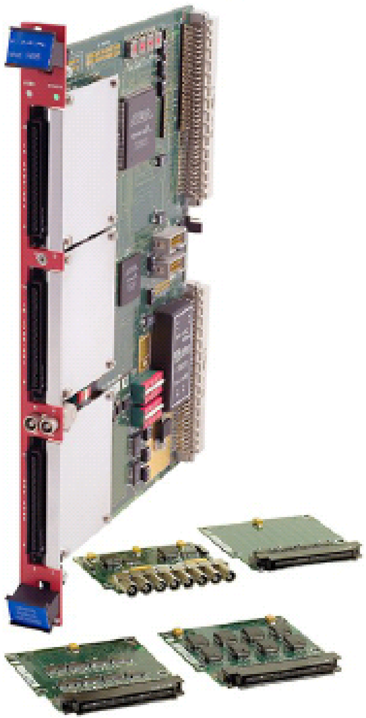




cable dimensions awaits final design of vacuum can

Logic and I/O

CAEN Module V1495



- Commercially available
- General purpose VME board
- Can be directly customized by the user
- Field Programmable Gate Arrays (FPGA)

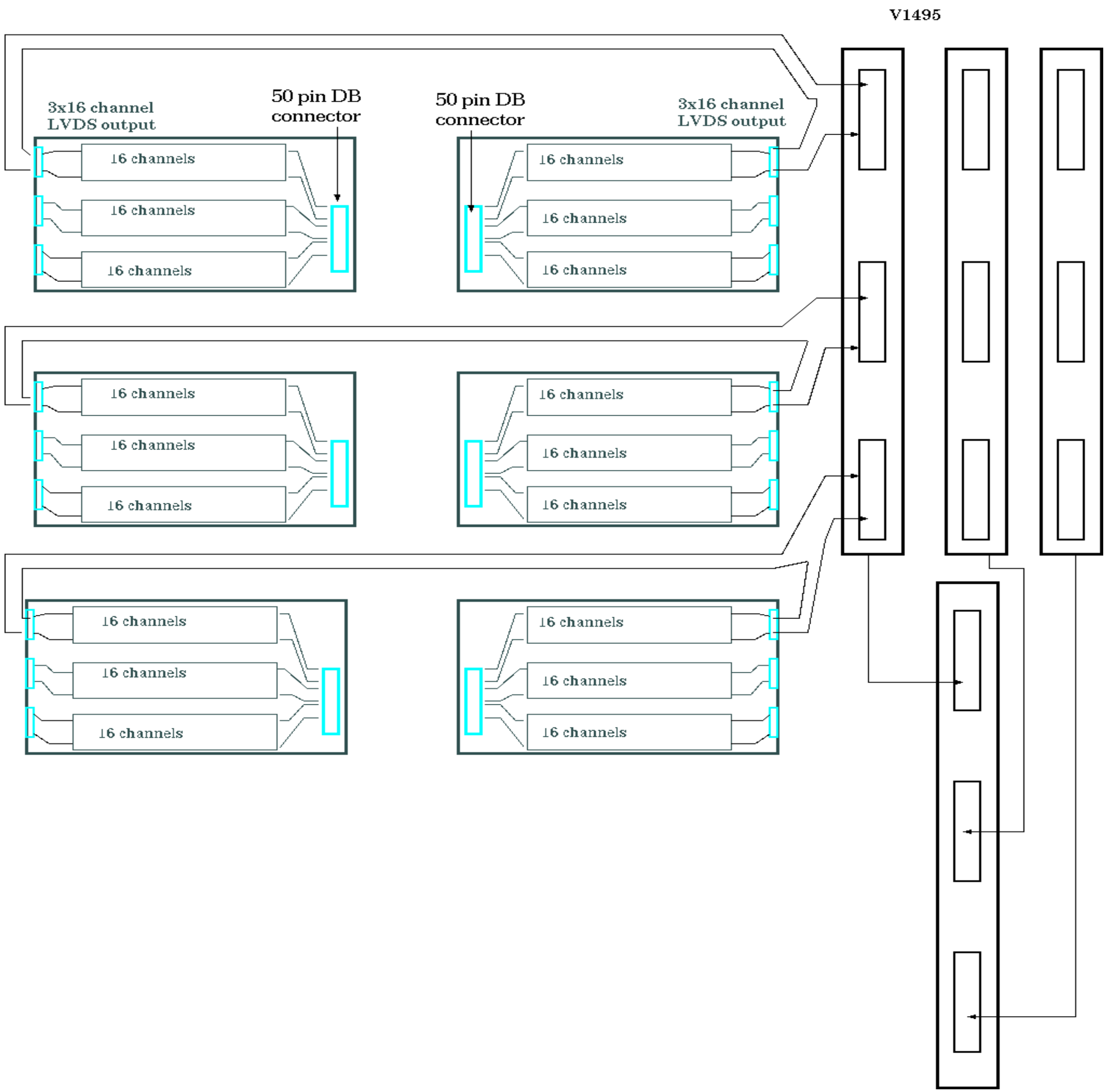
• 96 inputs with 32 outputs

Demonstrated by Tanja Horn:
Transaction time: 0.43 μs
Readout rate: 4.7 Mb/s

Conclusion: sufficient for our design rate of 100 kHz – might need two of them

Experience and help available from the JLab DAQ group

Logic and I/O



V1495
3x16 channel LVDS output
50 pin DB connector
50 pin DB connector
3x16 channel LVDS output
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels
16 channels

DAQ Design

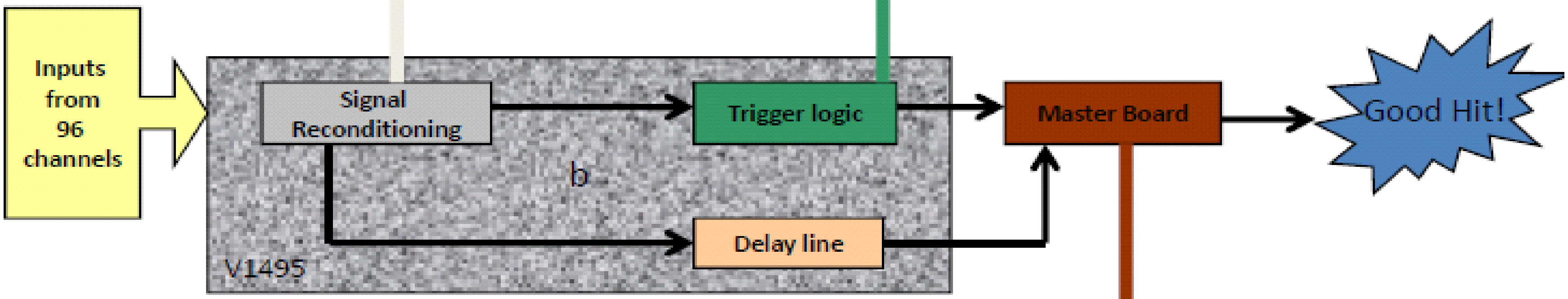
Overview of the Designs

OHIO UNIVERSITY
Buddhini Waidyawansa

Reconditions signals coming from the channels in the following way:

- ✓ A copy of the input signals with modified widths are sent to trigger logic.
- ✓ Another copy with modified pulse widths are sent to delay line.
- ✓ A variable dead time is used to adjust the total dead time.
- ✓ A busy output channel will indicate which channels are busy reconditioning.
- ✓ The pulse widths and the dead time are modified using values set via the VME bus.

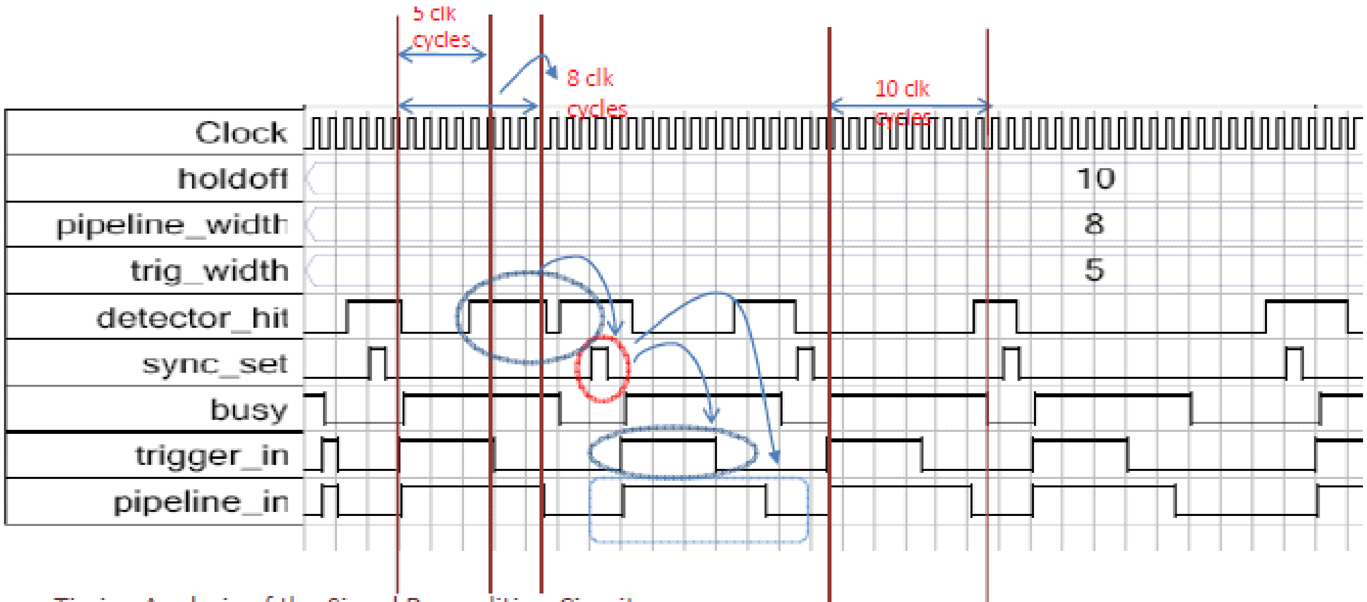
Gets 32 channels from each of the 4 planes and output data to indicate an OR of 3 consecutive channels on each plane.



Reads data from three V1495 modules that are connected to 32 strip/channels wide section of the 4 planes giving the output for a good hit when we have a hit on 3 out of 4 planes, which is latched and buffered for readout .

DAQ Design

Simulation and timing analysis of each element in progress using Software from the FPGA chip manufacturer.



Timing Analysis of the Signal Recondition Circuit

From Amrendra Narayan

According to the timing analysis, the maximum processing time for a signal on the trigger logic circuit was 16.9 ns. For the reconditioning circuit this was **22.8 ns.** These times are of the order of 0.02 micro-seconds, and if we assume the time between the events to be around 1micro-seconds, their values indicate that we have a reasonable performance in our designed circuits.

From Buddhini Waidyawansa

DAQ To Do List

Complete design and timing analysis on simulation

Test design on actual V1495 board
(on loan from JLab DAQ group)

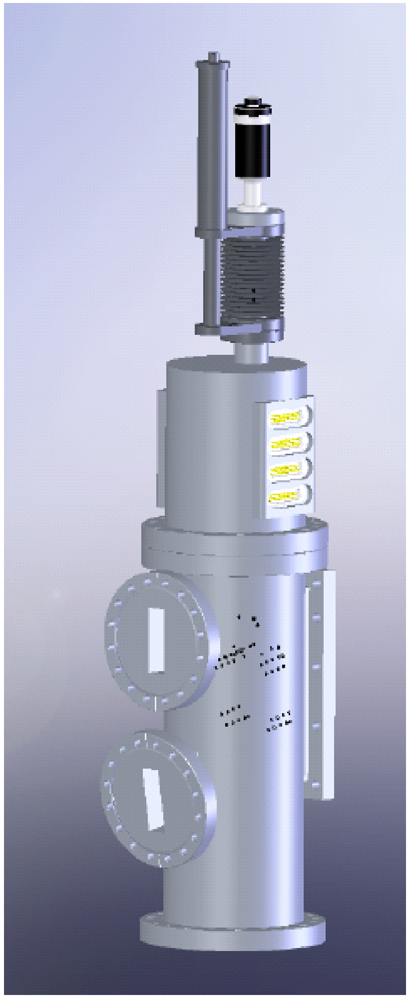
Interface with CODA

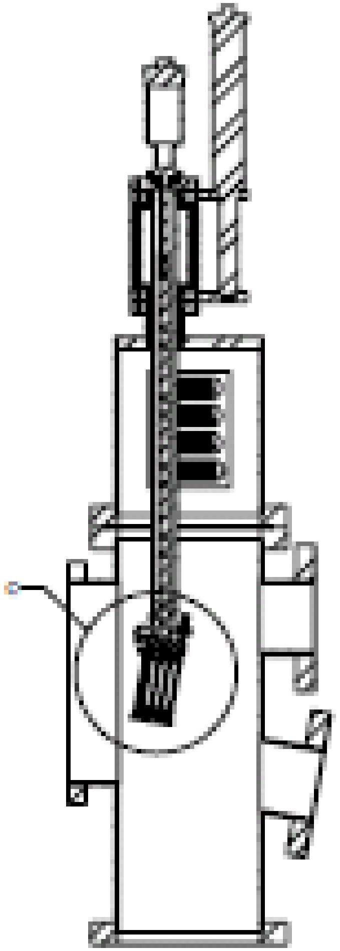
Amrendra Narayan (MSU)
+
Buddhini Waidyawansa (OU)

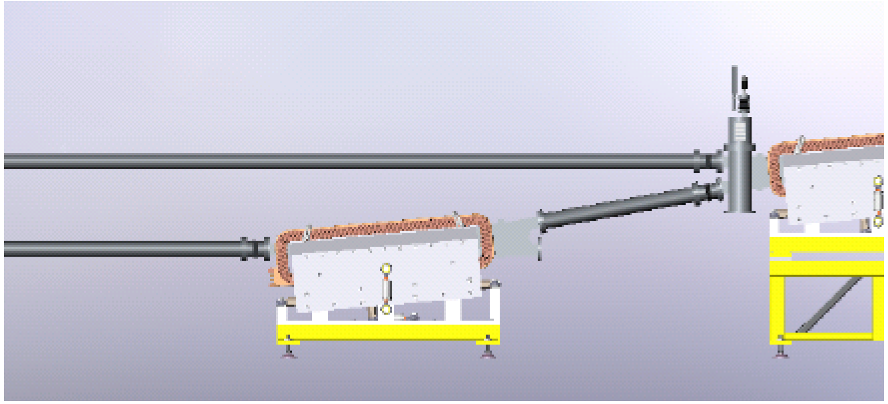
Tanja Horn

Paul King

Vacuum Can Design



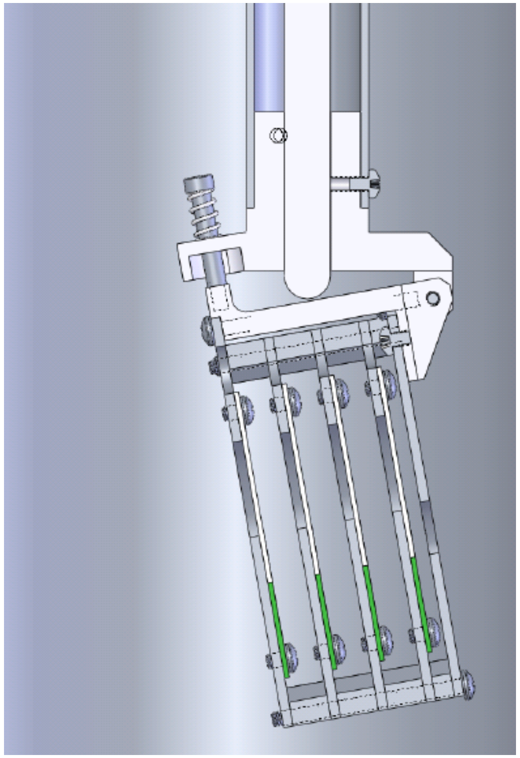


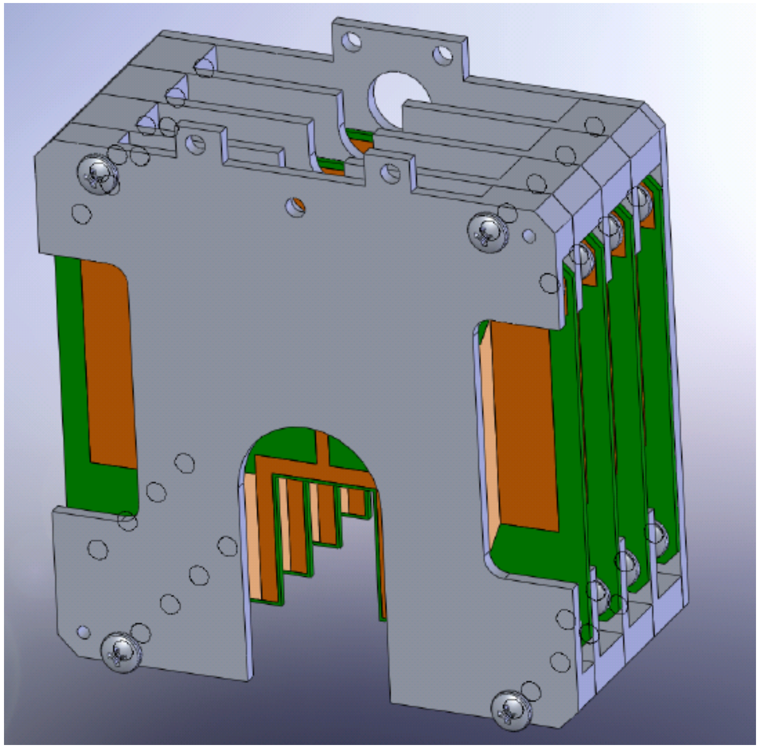


Ernie Ihloff and Chris Vidal (MIT-Bates) are designing the chamber

Vacuum Can Design

Detector Holders





Once finalized Winnipeg will buy them