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EPM (External Beam Profile Monitor)

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Steve Bellavia, I-Hung Chiang, David Kipp, Charlie Pearson, Al Ravenhall

Report by I-Hung Chiang

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I. Introduction:

The residual ionization beam profile monitor has been used in the Accelerator for a long time. It makes use of multiple traversal of the beam through the high vacuum residual gas to produce enough ionization for observation. The device is normally called IPM (internal Beam Profile Monitor). It was realized that the AGS external beam area is another application of this principle. In the Switch Yard, the vacuum is at micron range, before 1995 AGS high intensity upgrade. The beam intensity was less than 10 TP in the individual line. The combination of intensity and vacuum uniquely provide the opportunity of a new device, call EPM (External beam Profile Monitor). The idea is the same as IPM, collected the residual ionization with an out-of-beam collector. After the AGS high intensity, the Vacuum in the Switch Yard deteriorated to many tens of Micron. This spoils the capability of EPM. The device can no longer function as beam profile device. RSVP requires a very high intensity beam, 100 TP. It becomes desirable to revive this device, since it not intrusive and with no material in the beam line. The Study is aiming at the possibility to extend the range of Vacuum for EPM operation

II. Operation Principle:

The charge particle path through material causes the atom/molecule to be ionized. Collectingg this ionization gives us the intensity distribution of the charge beam. We have applied this principle in wire gas ionization chamber (SWIC), used extensively in the heavy ion beam line, also some secondary charge beam line. In normal air, the ionization of a minimuion ionized particle creates about 60 ion pairs in one centimeter. In the vacuum, around one micron, the secondary ionization is no longer exists/dominate. The primary ionization is about 12/cm of STP of air. For 10**12 proton travel 10 cm air produced.

1E12 x 12 x 10 x 1.6E-19= 19.2 micro coulomb.

For 1 micron, which is about 10E-6 of STP. We then get

19.2 pico coulomb.

This is at the low end of our normal integrator. at the time of the original conception. On the other hand, the intensity could be higher and the vacuum is not exactly at 1 micron.

III. EPM design

The initial criteria of the design was to create a simple and flexible construction. Pearson came up with end plate mounted system, using 12" beam pipe as housing. Fig. 1 shows the detail.

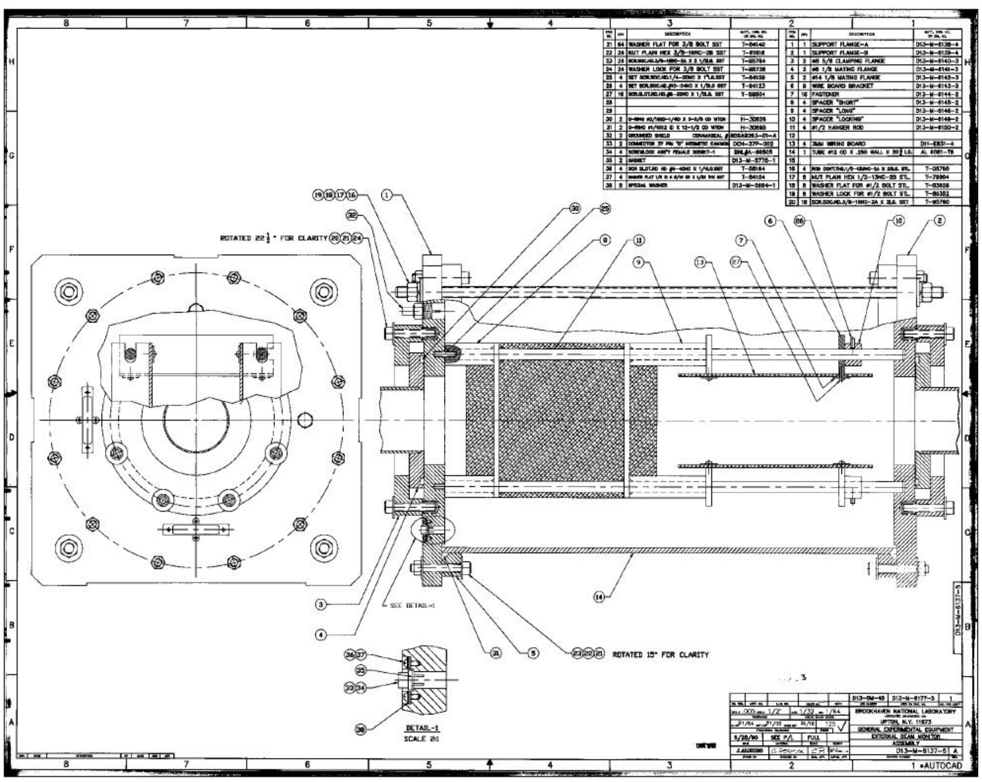


Fig 1. EPM Drawing

The collecting and bias plates are mounted on the Rods, which are mounted on the Supporting end plate. There are two sets of plates, one for Horizontal and the other for the Vertical. The “signal plane” is a printed circuit board with strips 2 mm apart. (Fig. 2).

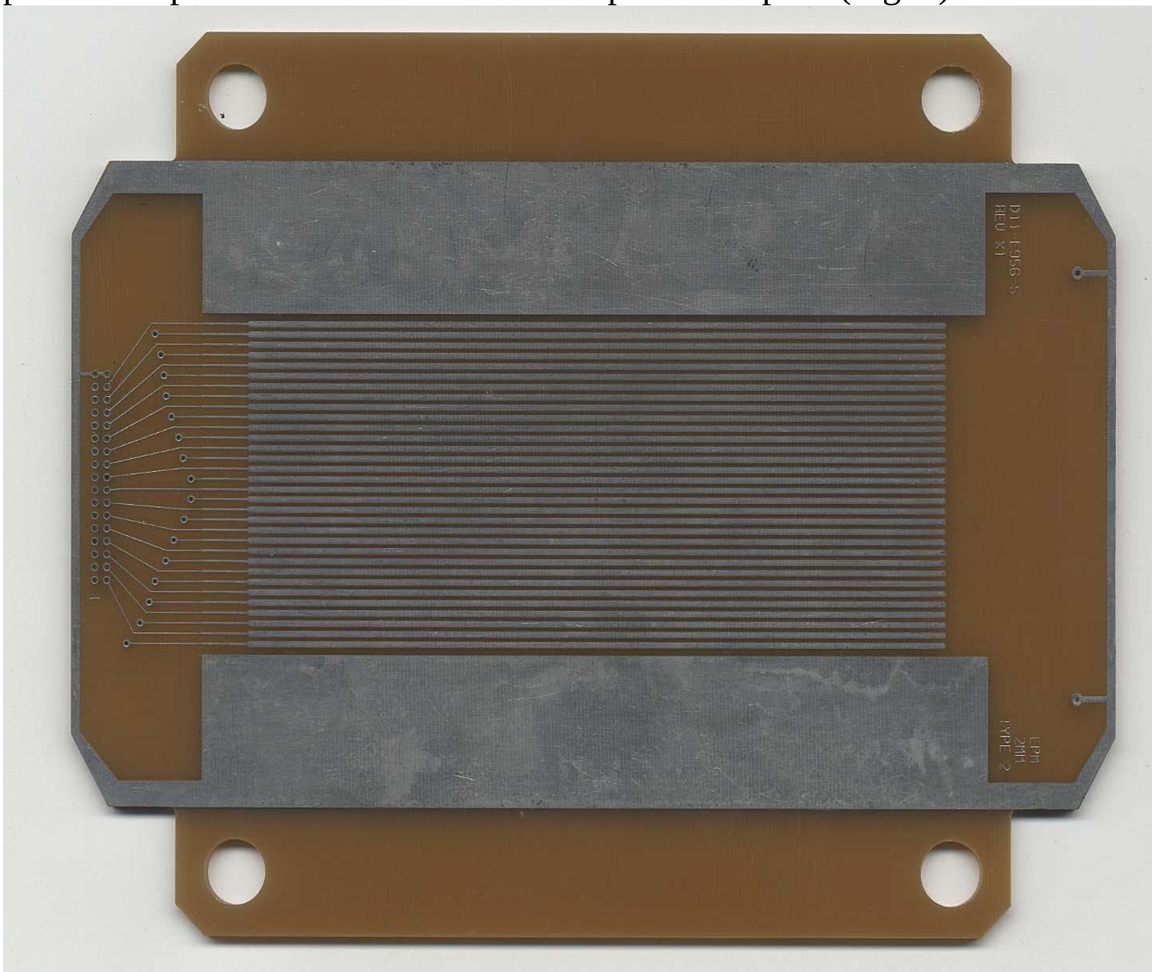


Fig. 2. Signal board.

On top of the signal plane, there is a guard plate to shape the electrical field. (Fig. 3). The active area of the collecting region is 14.7 cm along the beam direction. The maximum beam active width is 2 mm x 32=6.4 cm. The distance between signal and bias plane is 10 cm. This limited the beam size to be less than 10 cm to avoid the obstruction to beam. Fig. 4 shows the detectors mounted on the rods and Fig 5 shows the actual device mounted on the D line.

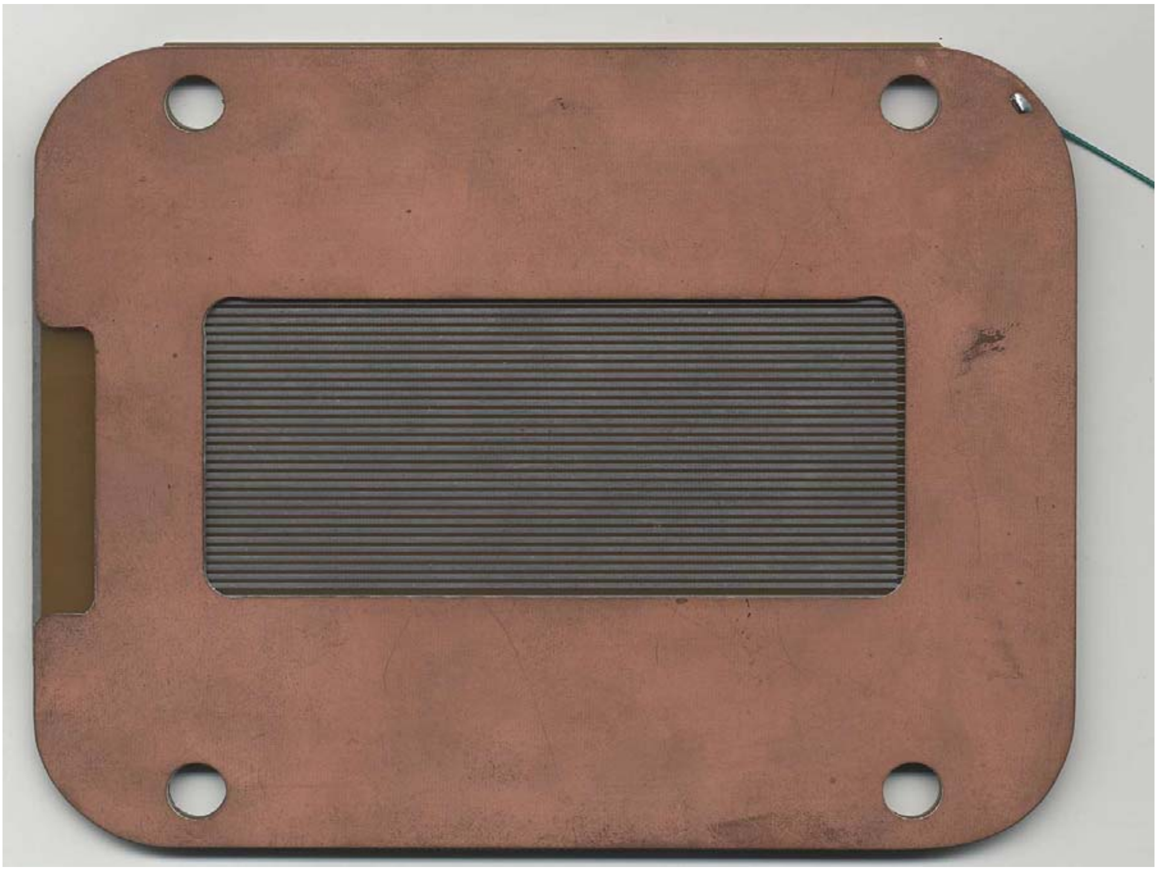


Fig. 3, signal board guard plane.

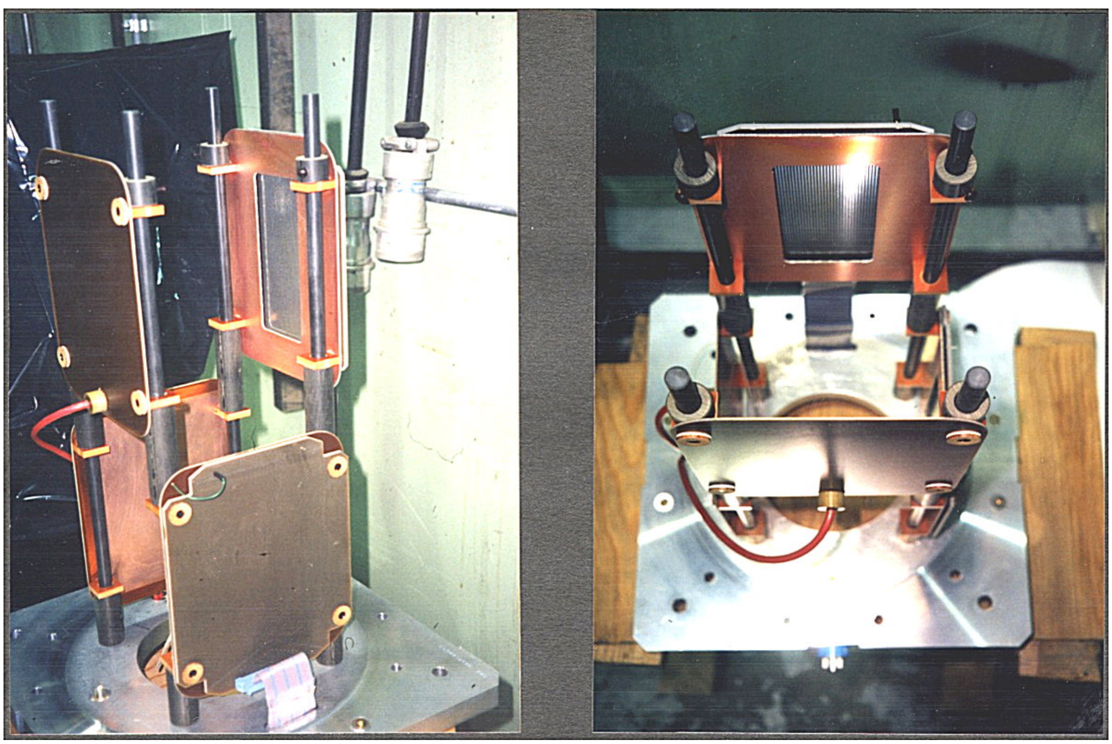


Fig. 4. Photo of the detectors mounted on the end plate.

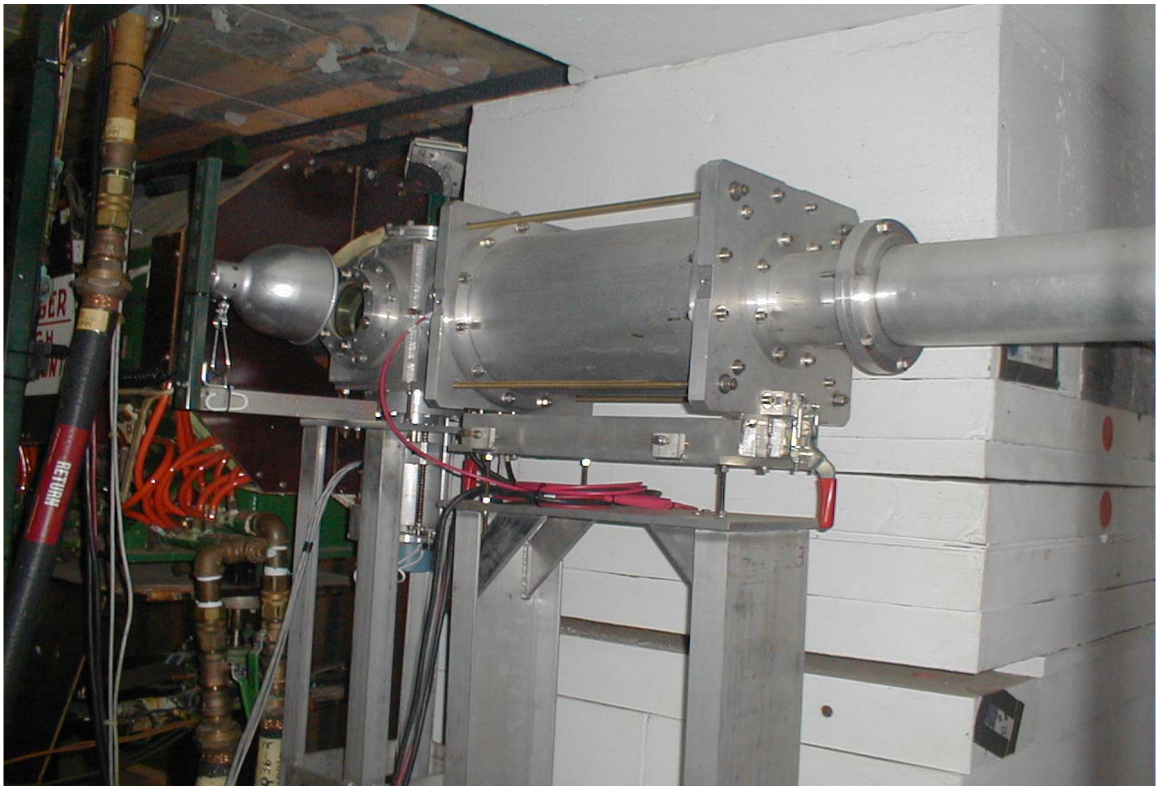


Fig. 5. Finished EPM mounted on the D line.

IV. Vacuum limitation:

The ion drift in the vacuum will collide with the residual gas. The average length of travel is about 5 cm. The “estimated” collision length is about $1.0x10^{-5}$ cm in the STP. At 1-micron vacuum, the collision length becomes 10 cm. This put the normal operation vacuum of the EPM to be in 1-micron range. Fig. 6 shows the maximum Positive voltages we could apply on the bias plane vs. the vacuum. The pump used in the test setup limits the lowest vacuum. For good operation, the vacuum needed to be 10 micron or less. (for more than 2 kv apply across 10 cm gap).

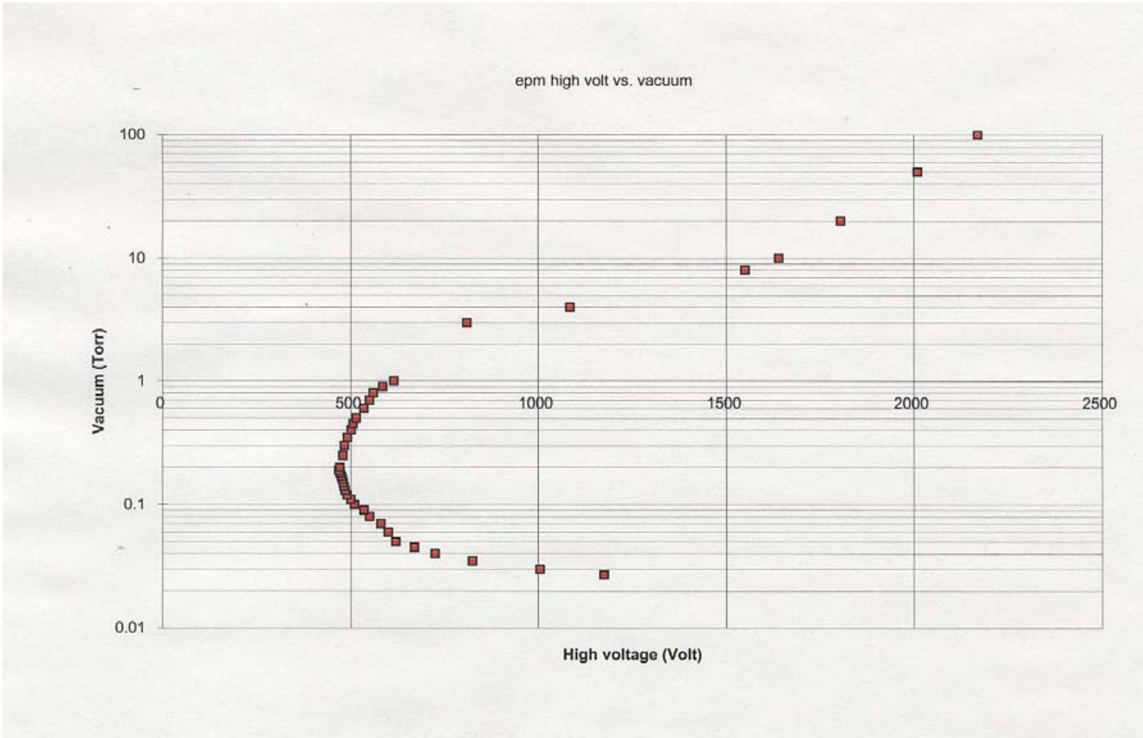


Fig. 6. Maximum voltage of EPM vs. Vacuum in the EPM.

V. Performance:

With D line Vacuum of order of one micron. The beam intensity of 7 TP. The three EPM's, D224, D355 and D380 profiles are shown in Fig. 7. The integrator is at high gain (1.0 nano farad) and display gain at time 2. The display is at .5 volts per cm. The profile remains fairly constant when bias voltage is more than 2 KV. We normally operated at 4 KV positive bias Voltage. Estimate of the charge collected is about 1,600 pico coulomb. (The integrated area is 18 Volts. The gain is factor of 2 and capacitor is 182 pico Farad) It gives about 230 pico coulomb per TP. It is more than factor of 10 than the estimate ionization of 1-micron pressure. Part of answer could be that the pressure is really more than 1 micron and other could be that the residual gas is more ionization. It is welcome gain for the EPM application.

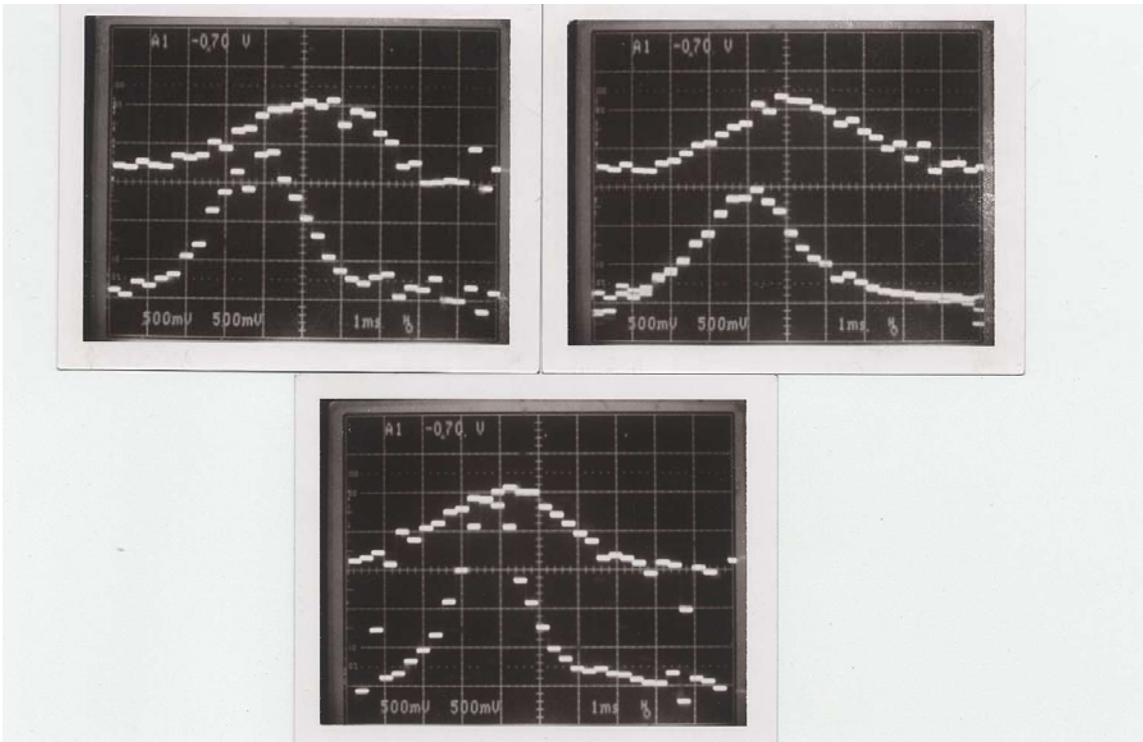


Fig. 7. Scope trace for the Horizontal and Vertical profile of 3 EPM.

VI. KOPIO Instrumentation Need:

The new RSVP experiment will demand 100 TP beam being extracted and delivered to the target station. Two problems rose.

a. The beam intensity monitor is needed. The old SEC (Secondary Emission Chamber) is know to deteriorated, the secondary emission coefficient reduced by almost 40 % after one years of 40 TP running.
b. Need for less intrusive detector for beam profile monitor: The Swic and Flag will create beam loss in the beam transport system. This will reduce the effectiveness of the instrumentation.

In this context, the EPM idea was revitalized. We could use EPM to monitor the beam both in profile and intensity. For the intensity, we need to monitor the vacuum pressure and also the component of the residual gas. The first step of the development is to check on the Vacuum requirement of EPM. We know it works with l micron Vacuum, but how much we could relax the Vacuum requirement.

VII. Modification of EPM:

We know from experience that EPM profile and amplitude grow to unmanageable level when the vacuum spoils to more than 30 micron. That is why we stop using the device when the vacuum in the Switch Yard was spoiled. The idea of confining the electron with magnetic field was used in the accelerator. Adding the magnetic field in the drift direction should confine the spread of signal. It is not clear how the collision will disperse the signal width. Since electron should have 4 time longer collision length (assuming the size of electron is zero compare with atom), the collision effect should be smaller. On the other hand, the electron will have more intrinsic velocity, thermo motion and recoil momentum in the ionization process. The magnetic field will minimized these effect on the profile.

VIII. Magnetic Field:

The simplest way to add Magnetic field is using permanent magnet. Figures 8 and 9 shows the modification.

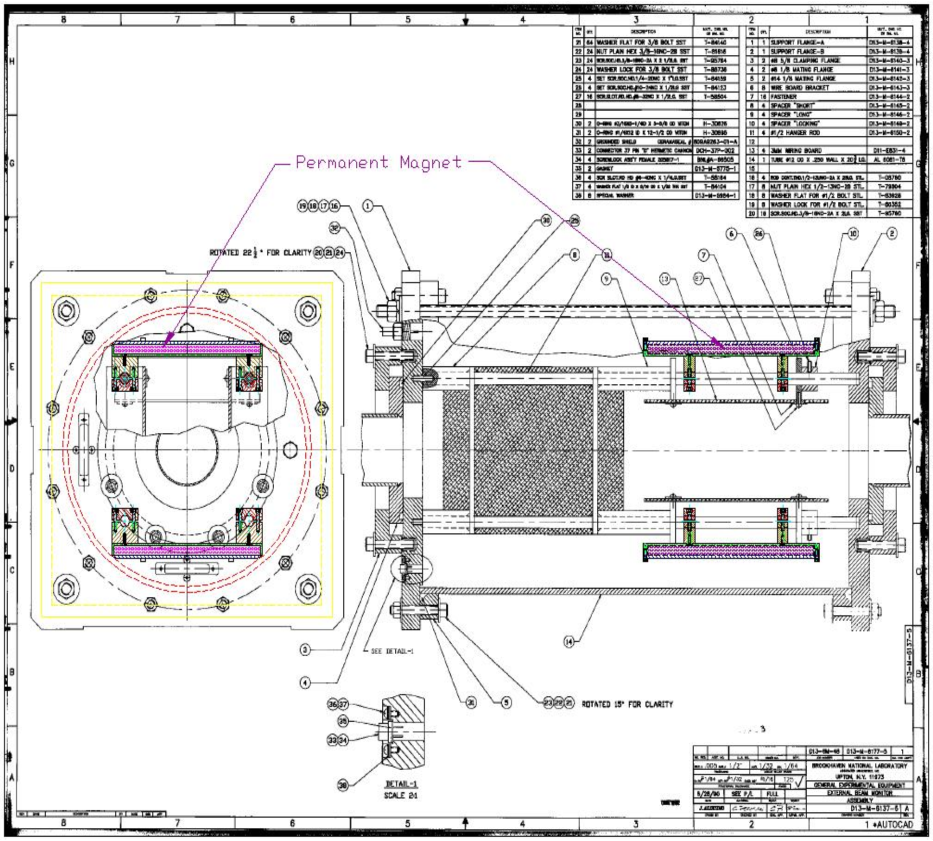
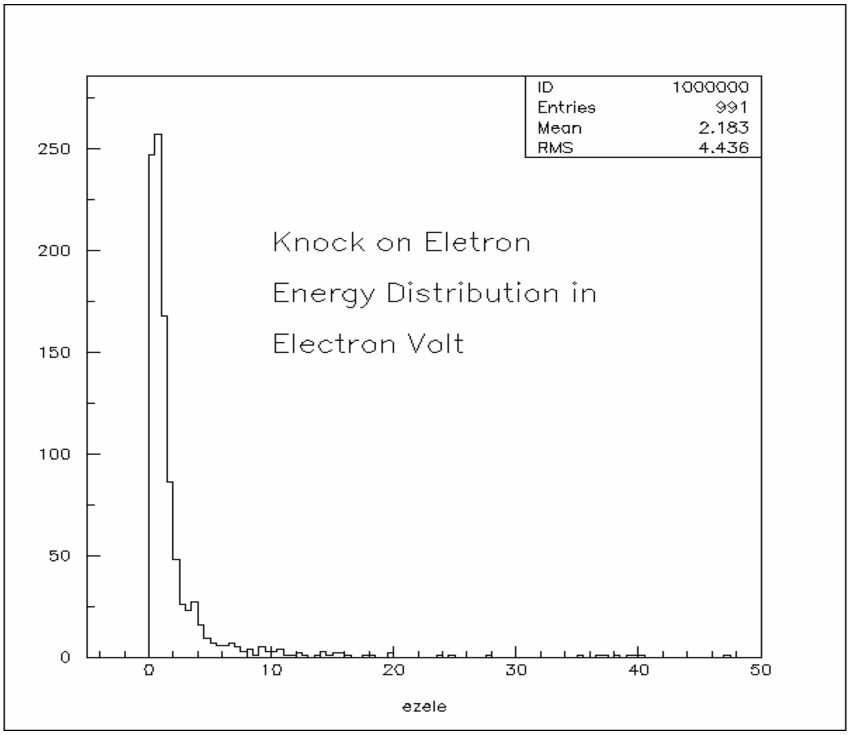


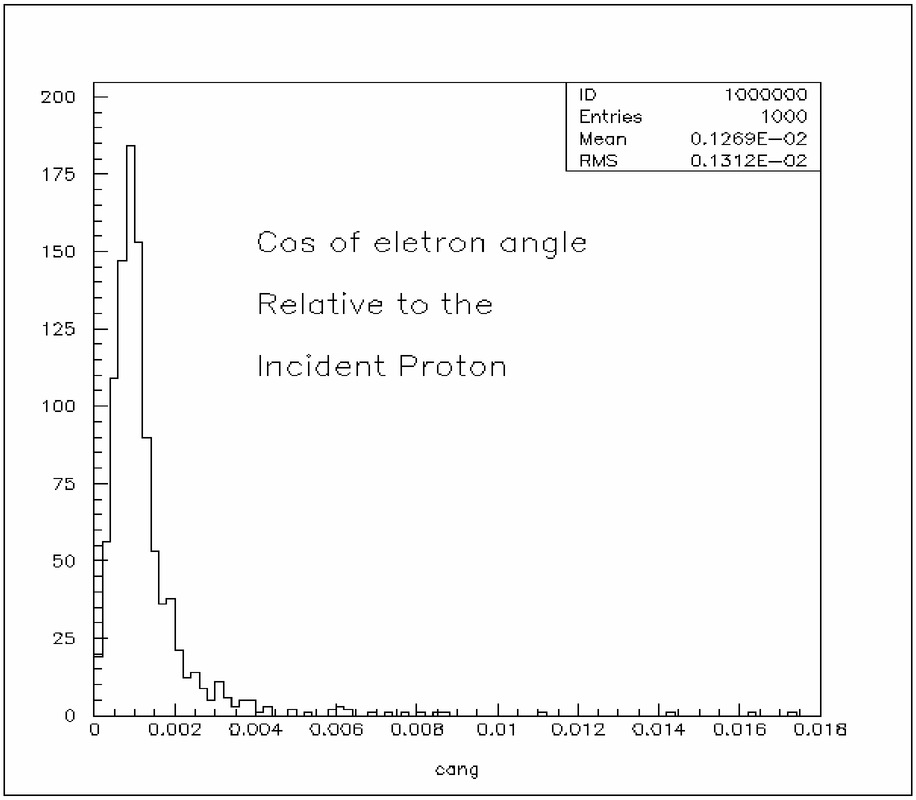
Figure 8: Drawing of modified EPM

Figure 9: Photos of final assembly of EPM with permanent magnets

The reasonable selection of 100 Gauss is selected. This will not perturb the beam that much. For 10 cm long plate, it will only deflect 24 Gev Proton by 0.0123 mili-radian. On the other hand, a 10 ev electron will have radius of 1 mm in this field. Montecarlo shows the energy distribution of electron is:



The direction of the electron is almost perpendicular to the incident proton.



This means the effective velocity seen by the perpendicular magnetic field is reduced by square root of 2.

IX. The Beam Test:

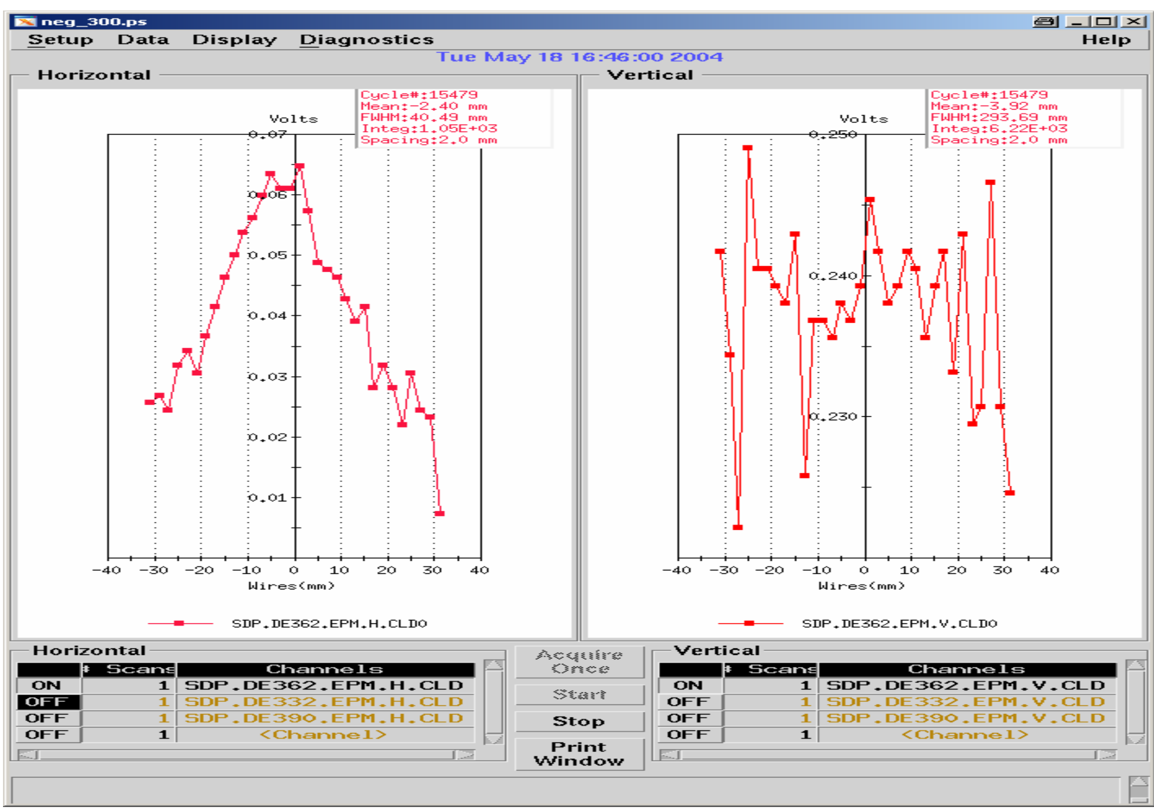
The Vacuum achieved in the D line is limited to 10 Micron. That is a good point to get started. We know, the EPM worked at 1 micron, the intensity of the beam is very low, few 10**11 proton / pulse. At 10 micron we should be able to see the effect of higher pressure. Since there is no reliable intensity monitor at this range. The machine was kept at as stable as possible.

The first test is with negative high voltage, collecting the electron. The left display is the horizontal plan, which has magnetic field. The voltage was rise from –300 volts to –1400 volts. There seems a big jump in gain at around –1300 volts. It is not known whether it is due to intensity/beam transmission or gain in the device. At 10 micron, the collision length is about 1 cm.

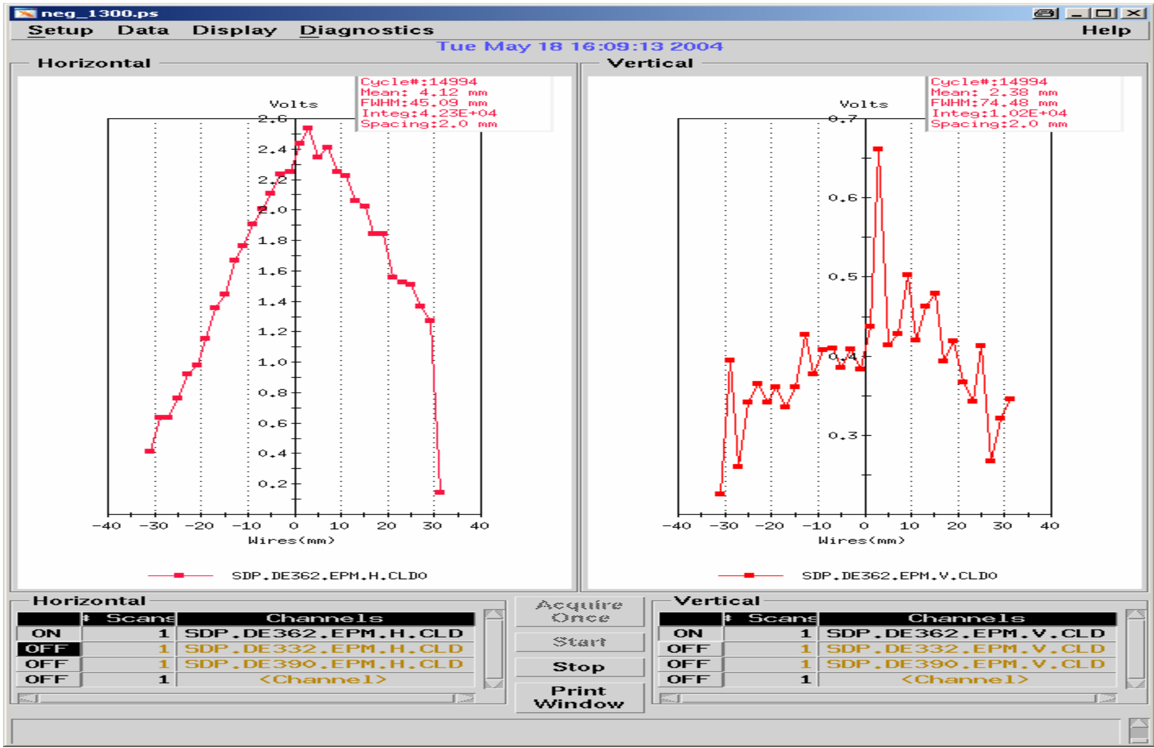
A). Negative bias with 10 micron pressure

The following two plots show the –300 volts and – 1400 volts display. The left side is the horizontal profile with 100 gauss magnetic field while the right one is the vertical profile without magnetic field. In a sense, this is the primary result of the test. The magnetic field works as conceived. The working range of EPM extended to at least 10 micron (as measured in the beam line). The –1400 volts shows there is a gain of up to factor of 40. This could be partly due to machine fluctuation in addition to the gain. Normally, there is no gas gain in the Gas ionization chamber, with voltage less than 100 KV / cm. At –1400 volts, the E field is only 140 volts/cm. The low pressure increases the collision length. This allows the electron to accelerate to high enough energy to ionize the gas in the next collision. It is then not unreasonable to see gain. The expected collision length is about 1 cm and the electron energy before collision is 140 eV, which is consistent with peak of ionization energy of the electron.

The vertical does not show profile in either setting. Further shows the effect of the magnetic field.



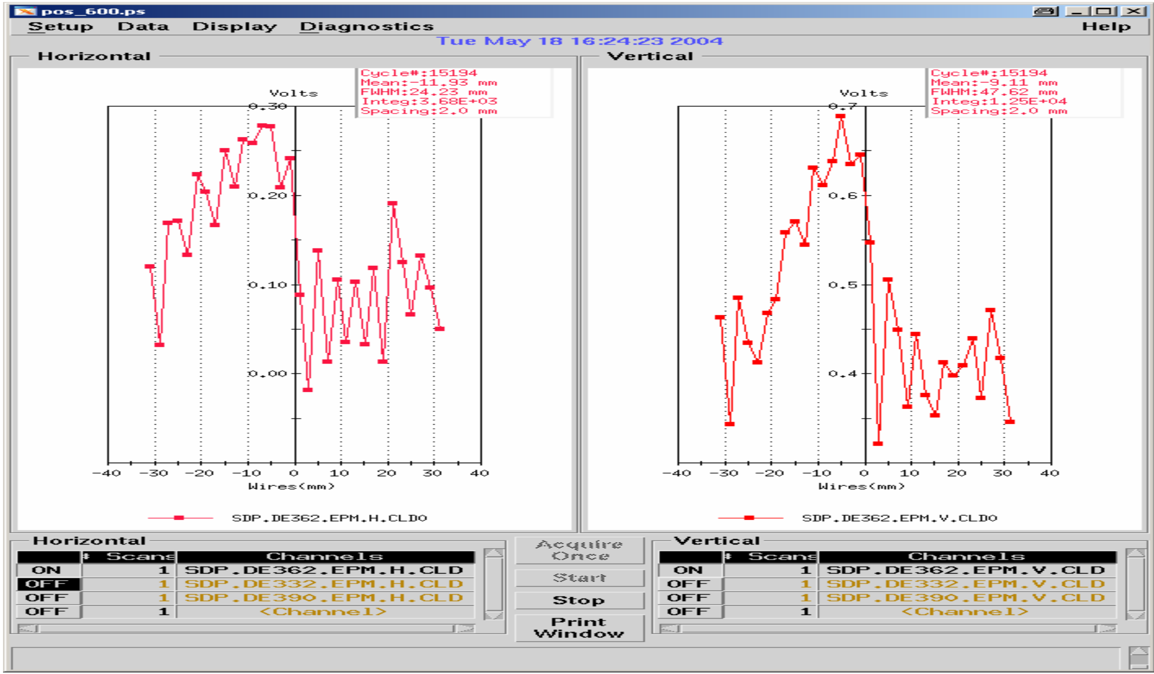
Negative – 300 Volts.



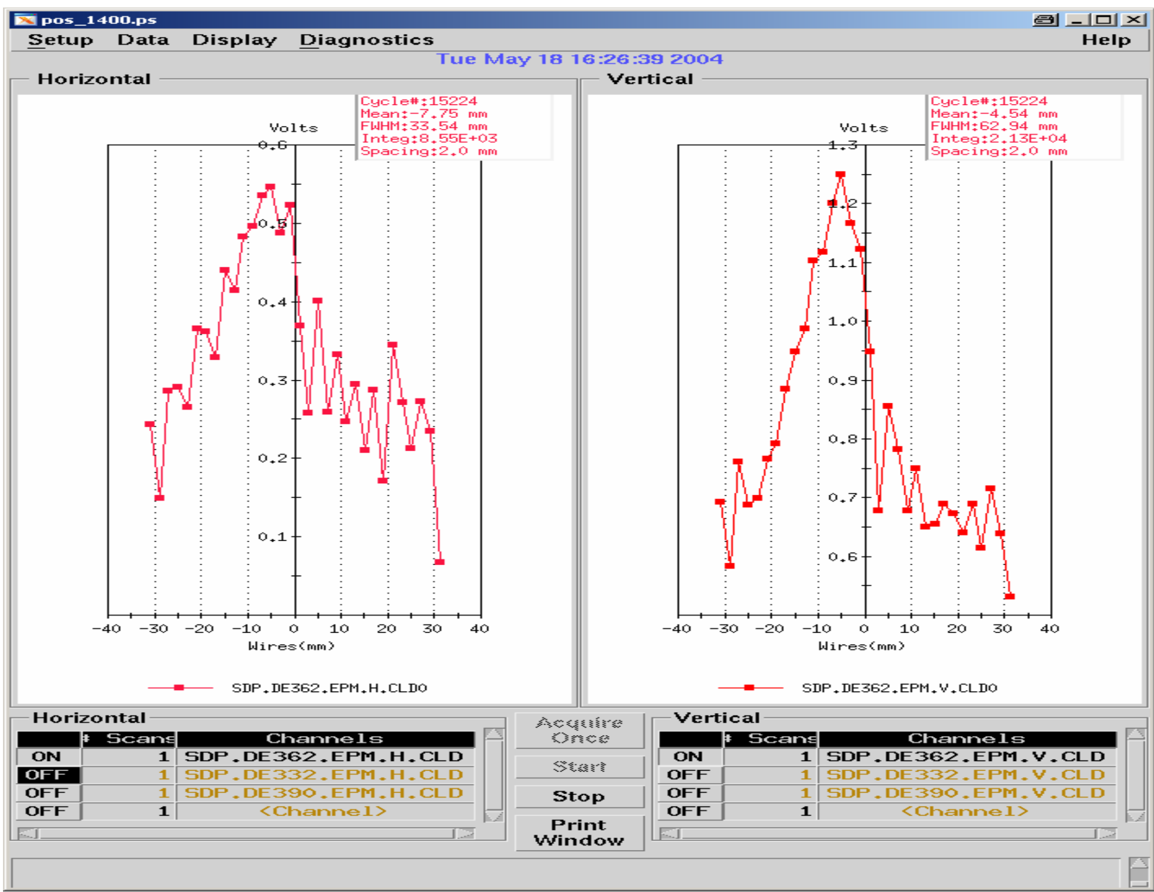
Negative –1400 Volts.

B). Positive bias with 10 micron pressure:

When the bias was reversed to positive, the signal becomes lot weaker. The shape and signal difference between Horizontal (with magnetic field) and vertical become more similar. At + 600 volts, the shapes is wider than that of the 1400 volts. At 1400 volts, the shape becomes narrower. That is understandable; the E field pulls the ion more toward the collecting plate, less diffusion. The “normal” thinking is that the collision is 4 times shorter.



Positive 600 Volts

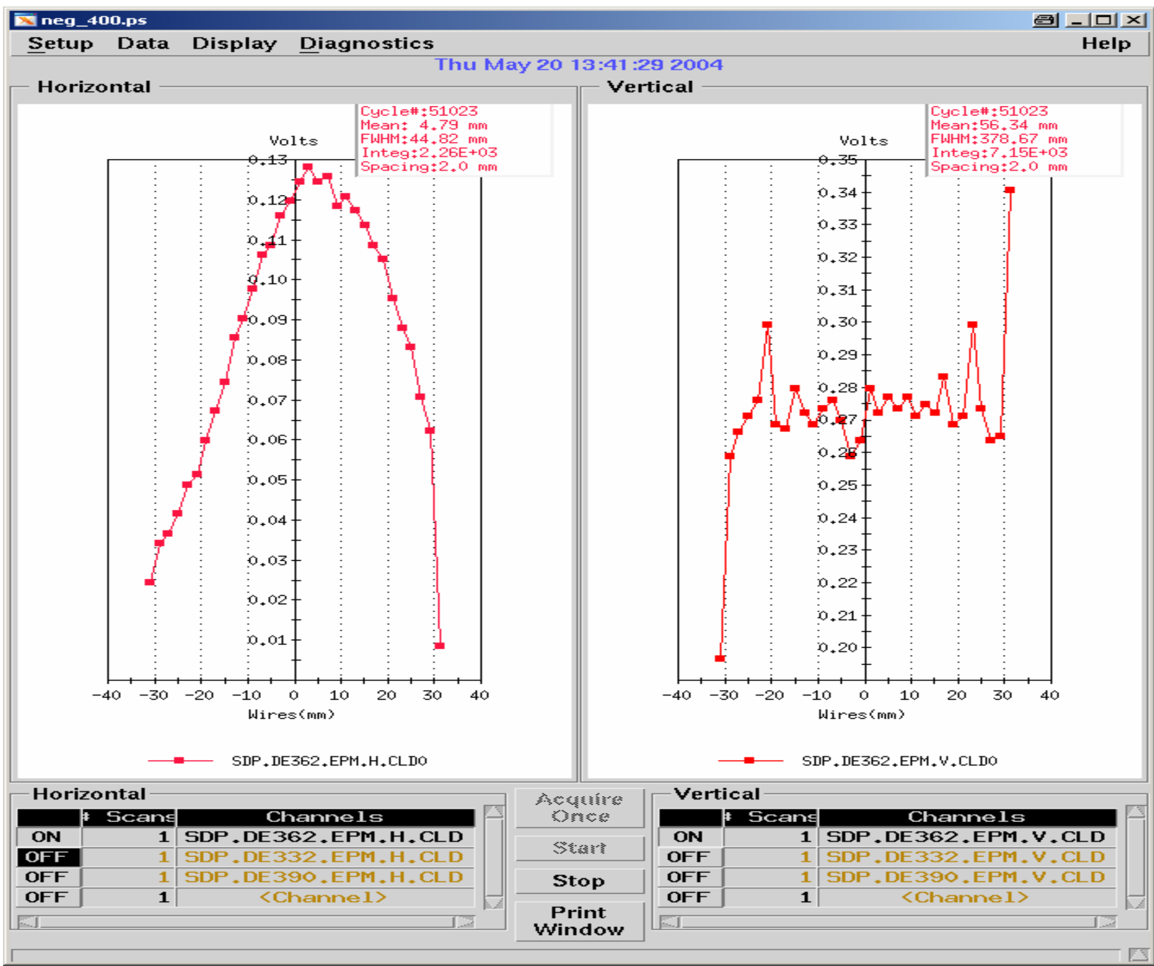


Positive 1400 volts.

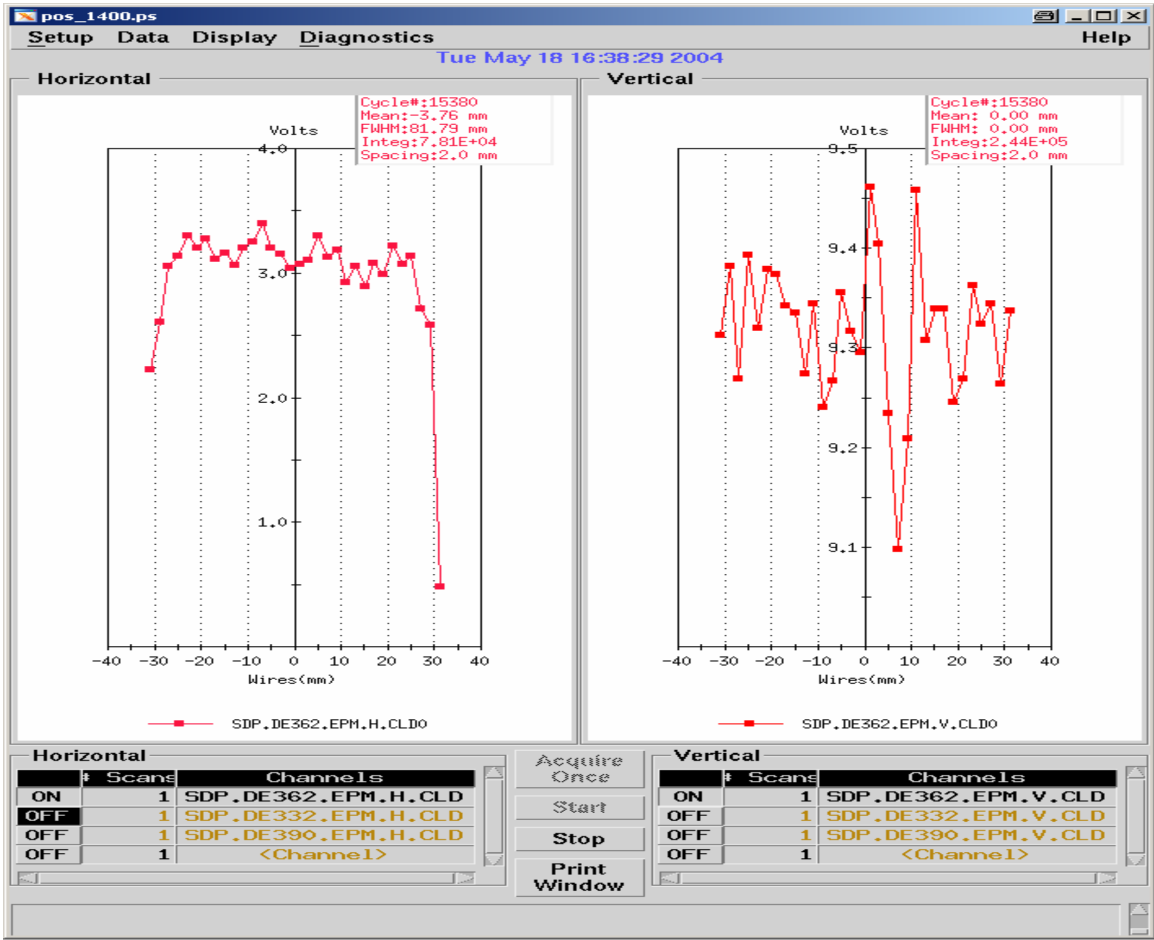
C). 20 Micron Pressure:

The bias voltage is limited to –400 volts, while the positive could reach +1400 volts. The – 400 did show beam shape is reasonable with magnetic field, but the positive bias did not see any hint of beam shape even at +1400 volts. It could simply mean there are too many collisions between ions so the original beam shape is completely washed out.

The pictures show the –400 volts bias and +1400 volts bias.



- 400 volts at 20 micron



+ 1400 Volts at 20 micron

X. Conclusion:

This test shows the 100 gauss magnetic field extends the operation pressure of the EPM to more than 10 micron with negative bias. While the Positive bias is not been helped. With this, we are assuring the EPM will work with reasonable vacuum excursions. The desirable range is still in the micron range. This will make both positive and negative bias work (with 100 gauss magnetic field).

XI. Further application

A). Intensity Monitor: We could use the sum of the signal to monitor the intensity of the primary beam. But we need to monitor the vacuum to the extent of few percent. In principle we could do that but in really, we have not demonstrated it yet, control the pressure to few % level. It will require some R&D time to achieve this goal.

The simpler approach is to try to use this device in a relative monitor. The Vacuum will not change rapidly, so as long as it is stable it is adequate. To normalized that we need another device. For now, a current transformer or plunging SEC will serve this purpose. The reason of plunging SEC is to avoid the deterioration of SEC due to long-term beam exposure. Current Transformer is not a proven device for slowly extracted beam, even it is bunched. An R&D is needed for this approach.

B) Beam Position Monitor:

If we replaced the “wire” plan by a split plat, i.e. plate split diagonally. This device will become a position monitor. The position is a function of ratio of left and right signal. With our modern control system, the position could be easily computed pulse by pulse.

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