SWITCHYARD BPM

Brajesh Choudhary

Fermilab

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OUTLINE OF THE TALK

1. Acknowledgements
2. SY120 BPM & Beam - Brief description with pictures
3. Reasons to make these BPMs operational
4. BPMs in different sections of the SY120 beam line
5. Block Diagram of the SY Resonant BPM System
6. SY Resonant BPM – Some Deatils
7. Problems with the SY120 resonant BPM system
8. Why an upgrade ?
9. Work done by Jim Fitzgerald and John Seraphin
10. Recommended upgrade, and preliminary cost estimation
11. Summary and Conclusion

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SWITCH YARD 120 BEAM & BPM

1. At present the beam sent to SY120 goes via P1, P2, and P3 line into the old SY and then it can be taken to the MESON line or to the DUMP. In the MESON beam line the beam can be sent to MEAST (at present blocked), MCENTER (MIPP/E907) and MWEST/MTEST (BTeV/ILC/ATLAS).
2. P1, P2, and P3 lines have normal single turn as well as resonant BPMs.
3. In and beyond the old SY all the BPMs are resonant only.
4. The resonant BPM system in the SY was developed to measure beam position and intensity for 53MHz bunched resonant extracted beams of either 1.5ms fast spill of low gain with broad bandwidth, or 20s slow spill with high gain narrow bandwidth. Before 2000 the beam to the SY for fixed target runs used to be extracted from the Tevatron.
5. The SY BPM literature mentions that a beam intensity of $1X10^{12}$ protons/pulse (pps) of 53MHz bunched beam extracted over 1.5ms or 20s from Tevatron corresponds respectively to $1.25X10^{7}$ or 1000 protons/bunch (ppb) CW beam. Earlier the beam intensity for fast spill varied from $1X10^{13}$ to $fewX10^{12}$ pps. The beam intensity for slow spill varied from $severalX10^{12}$ pps out of the Tevatron to $fewX10^{10}$ pps in the PCENTER beam line. PCENTER beam line had the least beam current and it was rather challenging to measure its position and intensity.
6. At present the beam to the SY is extracted from the MI. In a mixed stacking mode with protons for the Pbar production, the SY slow spill flat top is ~0.6s.
7. Depending on the physics requirements one may need to resonantly extract slow spill beam extending from 0.5s to 4.0s spill time. In near future, with protons for pbar production and planned NuMI running, one expects to have dedicated SY running (for ~5% of the timeline) with slow spill flat top varying from 0.5-4.0s.

SWITCH YARD 120 BEAM & BPM

1. **Radiation safety requires not to have more than ~2X10^{12} ppp at 3s repetition rate in the SY120 line. Possibly with extra shielding one can hope to run ~5X10^{12} ppp at 4.2s repetition rate in the SY120 out of the MI, which translates to ~2.5X10^{4} ppb CW beam. A lower beam intensity of ~1X10^{10} protons every 0.5s in one of the split lines (because target attenuates the beam) translates to ~400 ppb CW beam, although the beam out of the MI may still be closer to 1X10^{11} pps.** ***This is an hourly rate maintained over 3s spill time. If SY is getting beam only for few seconds/minute, the number of particles/spill could be much higher.***

2. ***This requires a dynamic range of ~60+ for slow extraction.***

DO WE NEED THE FAST SPILL CAPABILITY FOR THE SY BEAM ? NO.

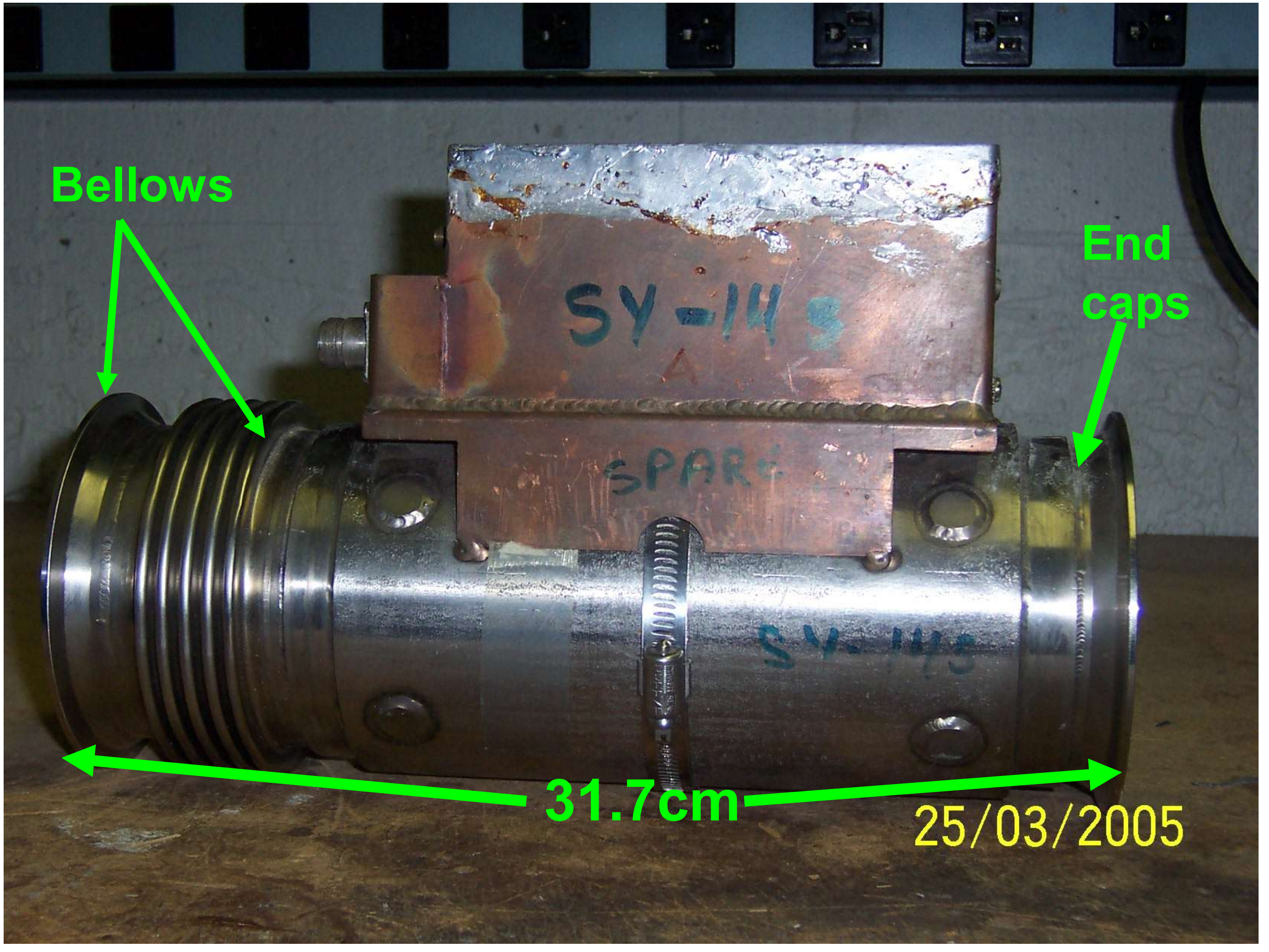
2. Historically fast spill was needed for the neutrino program and one of the test beam groups from RICE University used it for their "Cerenkov Counter" study.
3. These days the neutrino physics at FNAL is not part of the SY, so perhaps one doesn't need to have fast spill capability in the SY. **Will this hurt test beam?? NO.**
4. It will be prudent to have fast spill measurement capability for the P1, P2, & P3 line, especially to tune them for the resonant extraction.
5. P1 and P2 lines have already working single turn fast extraction BPMs.
6. P3 line has 25 installed single turn BPMs. The cables from these BPMs were used for the TeV upgrade. It will cost about $50K (rough estimate) to replace these cables and make these BPMs operational. **Shouldn't we think about it??? NO. TOO COSTLY.**

SY BPM – A BRIEF DESCRIPTION

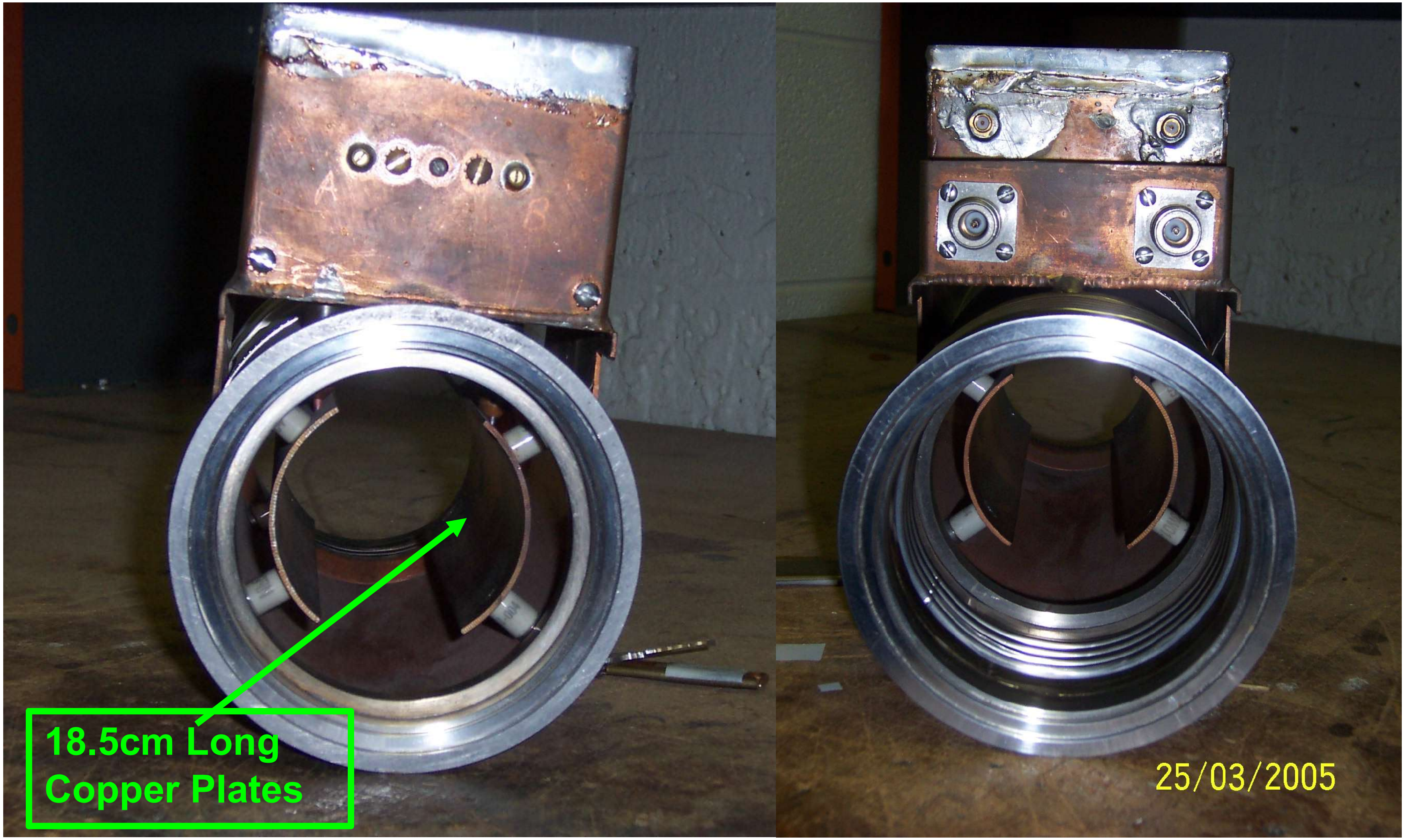
Resonant BPMs of two different size have been used in the switchyard.

2. Short Beam Detector – with 18.5 cm long copper plate electrodes. The overall length of the detector, including end caps and bellows is 31.7 cm.
3. Long Beam Detector – with 100 cm long copper plate electrodes. The overall length of the detector, including the end caps and bellows is ~114 cm.
4. The detector body is a stainless steel beam pipe of 10.3 cm (4.056”) internal diameter.
5. Each electrode is bent to a 3.5cm radius of curvature, and subtends 110^0 of arc for a centered beam. The available aperture is about 7cm, the same as the accelerator beam pipe. The arc length and the spacing from the wall of the stainless steel pipe were selected to provide a uniform position response including lack of sensitivity to motion in the orthogonal plane.
6. The curve detector plates made of copper are supported of the pipe bore by 0.5cm diameter G-10 spacers.
7. According to John Seraphin after the detectors are tuned by peaking each plate for maximum signal output and setting the crosstalk to a minimum value, the measured "Q" value for the short detector is ~ 160, and for the long detector is ~180.
8. With same input signal the long detector has 10dB more signal output compared to the short one. This implies that the long detectors are a factor of ~3 better in sensitivity than the short ones.

SHORT BPM – SIDE VIEW

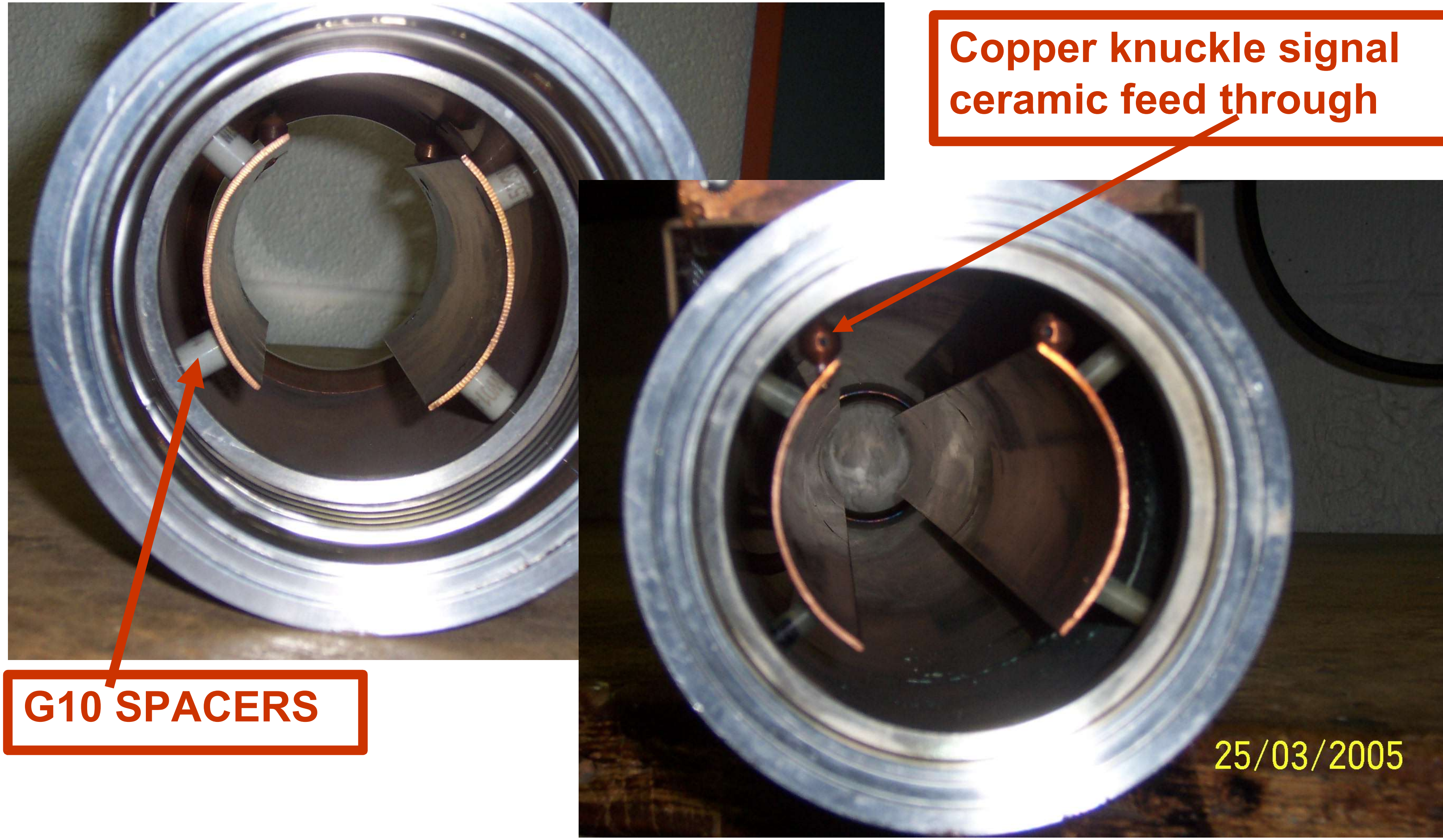


SHORT BPM – FRONT VIEW



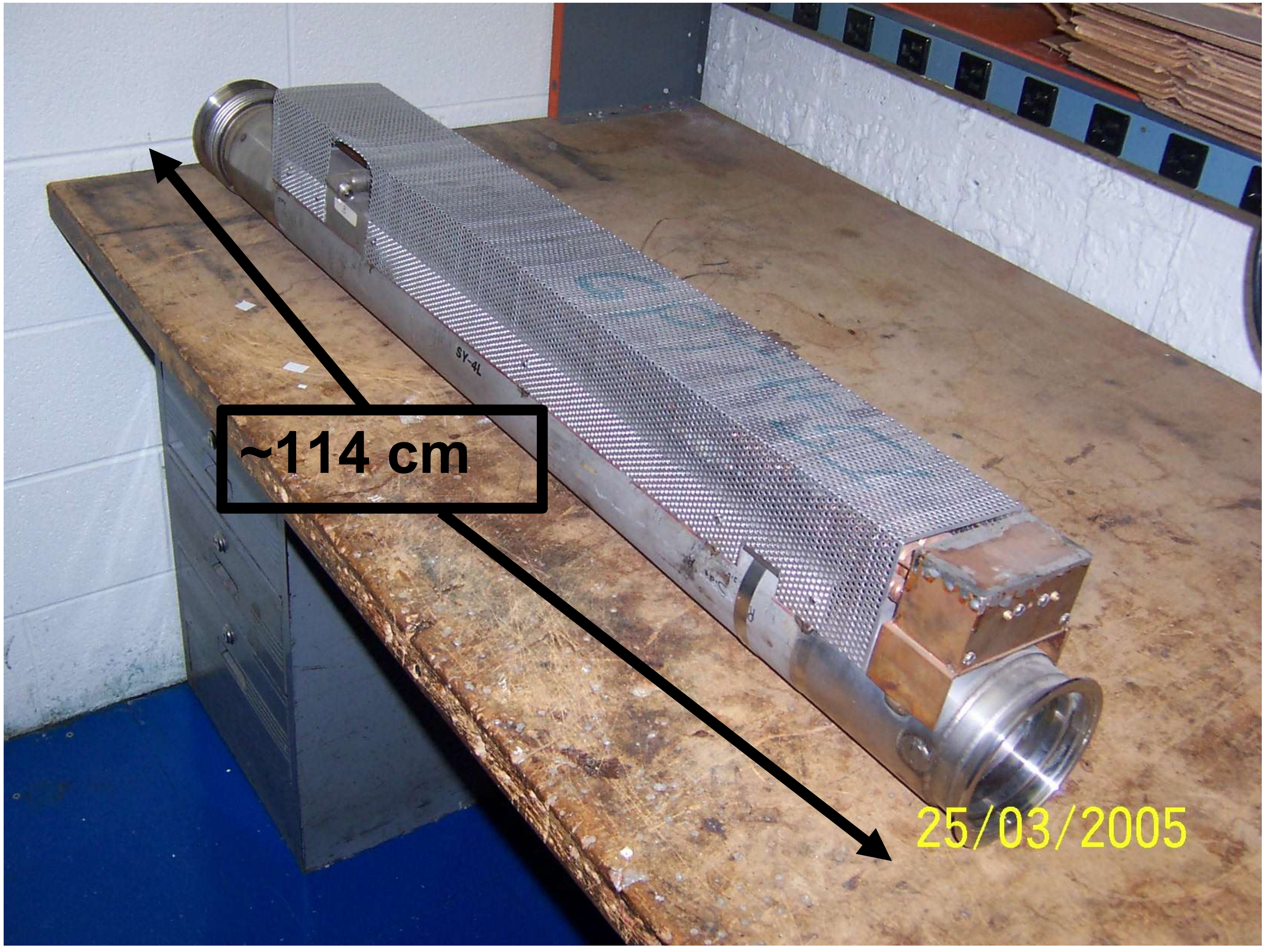
SHORT BPM – FRONT VIEW

Copper knuckle signal ceramic feed through

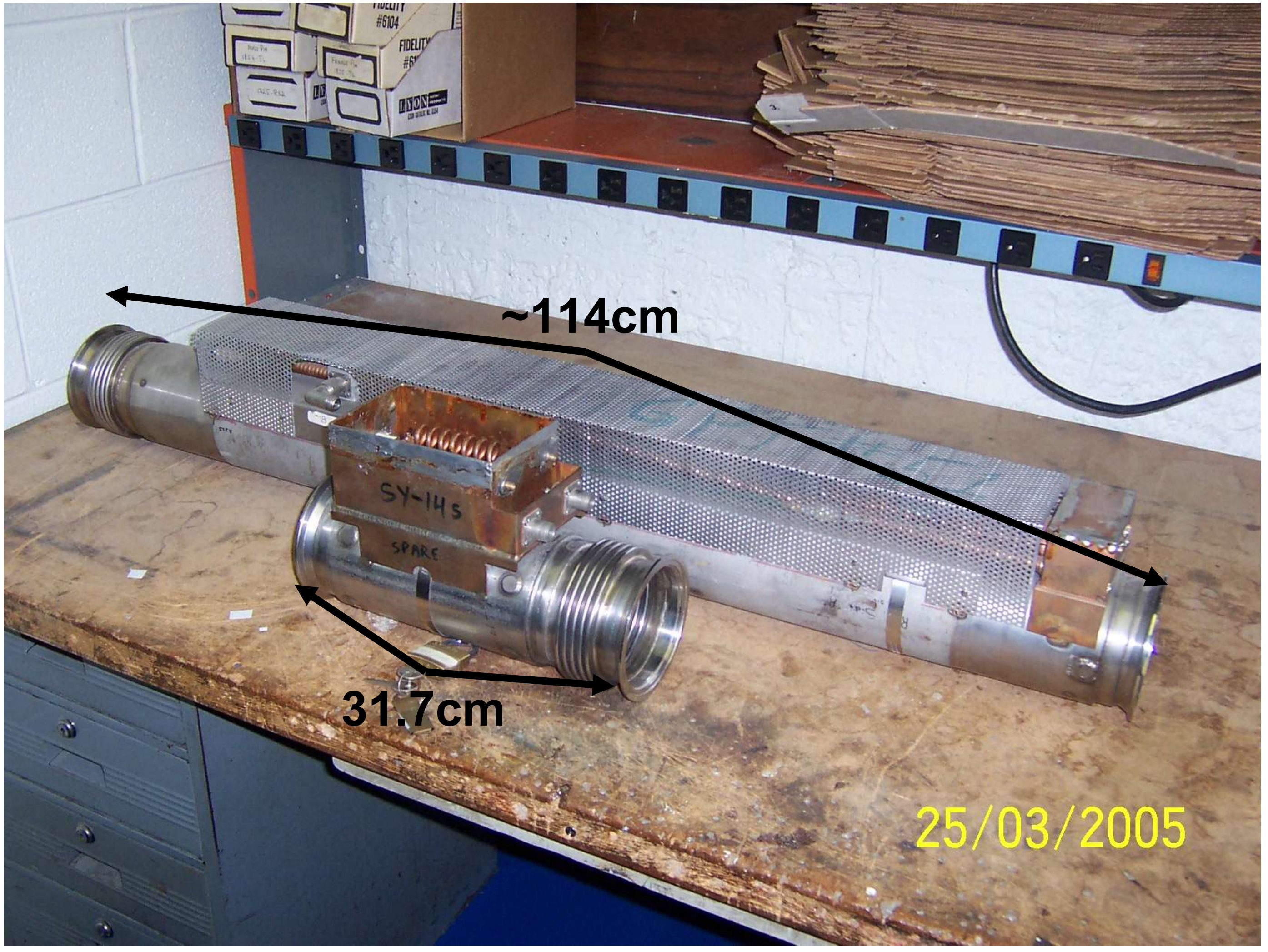


G10 SPACERS

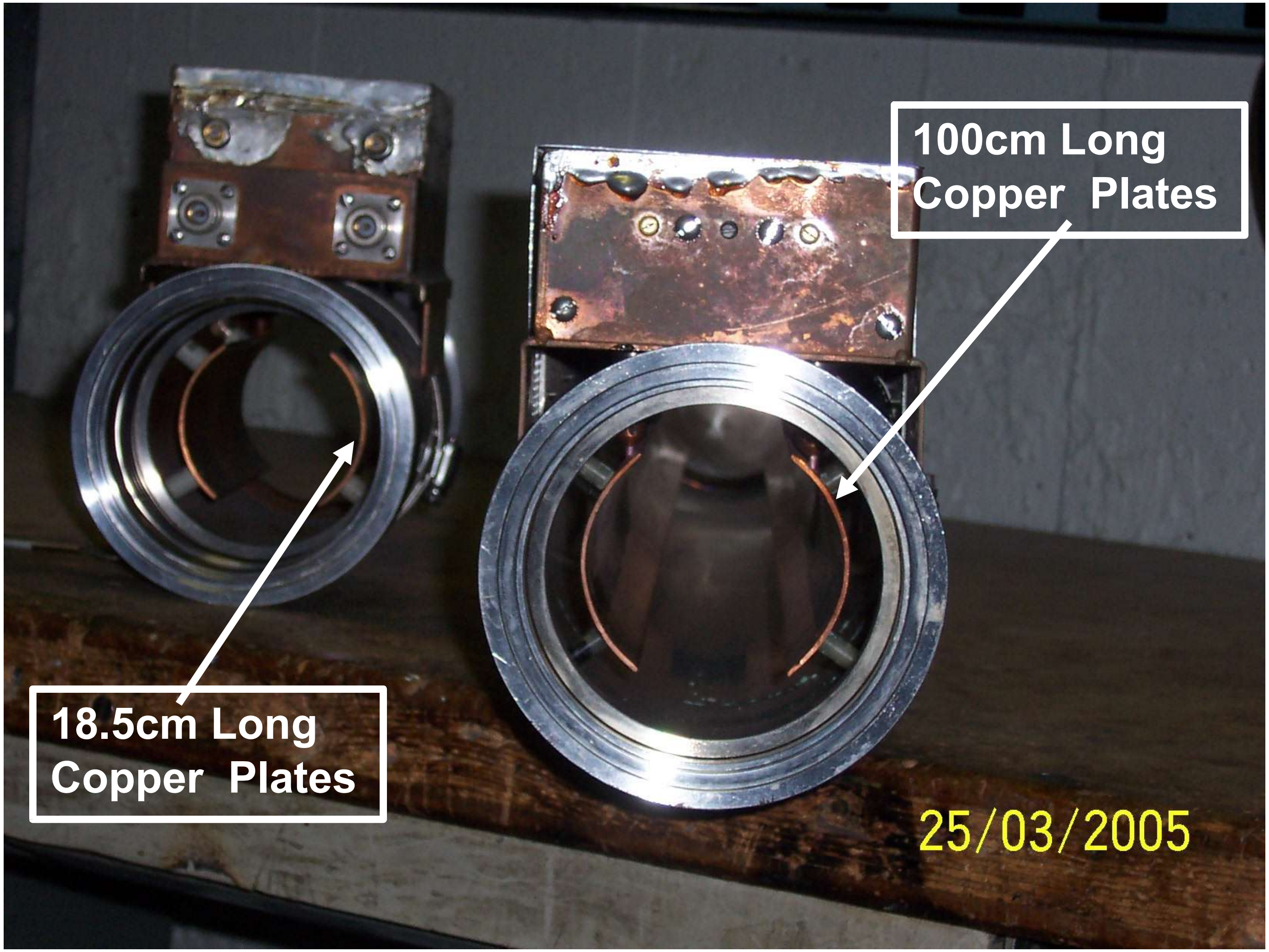
LONG BPM – SIDE VIEW



LONG & SHORT BPM – SIDE VIEW TOGETHER



LONG & SHORT BPM – FRONT VIEW TOGETHER



SHORT BPM – TOP VIEW

REASONS TO MAKE SY BPM OPERATIONAL

1. SY120 is a long term facility provided by the FNAL AD for ILC/ATLAS and other future experiment detector testing, future fixed target physics program and possibly other R&D efforts at the laboratory.
2. The facility is expected to be operational at least till 2010, if not beyond.
3. Position and intensity measurement of the beam sent to the experimental area is crucial for beam tuning as well as for understanding many of the beam related systematic errors and further physics parameters.
4. SWIC's don't measure intensity. BPM's do provide very precise position and intensity measurement. For example, the RR BPM provides position precision of ~±10μm rms (intensity dependent) and intensity precision of ~±3-5%.
5. It has been claimed that in past SY resonant BPMs have provided intensity precision of ~2-3% or better. Since resonant BPMs average over the slow spill timing they are less sensitive to bunch beam variation compared to non resonant BPMs and thus provide better intensity precision than non-resonant BPMs. Theoretically this is true.
6. When built the present SY BPM system provided precise instantaneous and integrated luminosity (few %) over the spill. But with present spill structure it is not possible.
7. At present the slow spill is sampled at a rate of 10Hz for position and intensity measurement. The intensity measured within the spill varies widely depending upon the spill structure, the bunch length variation and the time of the sampling. Sampling done at two different time within the same spill can give wildly varying numbers.
8. With present spill structure the BPM system is also unable to provide integrated intensity over the spill (integrated number of protons/spill) because of the limited sampling rate and varying measurement precision. It can be done with an upgraded system.

REASONS TO MAKE SY BPM OPERATIONAL

1. BPM system presents no material in the beam while SWICs or MWPCs do. This may lead to degradation of certain kind of beams. Beam transmission measurement with more than few SWICs degrades beam optics. It may also lead to radiation problems in case of high intensity beam, although it may be small compared to current losses. **Not an issue at present.**

2. While running a beam line, it takes time to put the SWICs in the beamline, so in practice it is not used very often by the operators. A BPM display page will be much more user friendly and likely to be used at all times. **Practical reality.**

3. BPM systems are usually automated. The beam information can be fed in the auto-tune program to tune the beamline. The beam position can be seen on the fast time plot. SWICs are automated too, but more BPMs in the beam line means better position measurement and better tuning or handling of the beam. **Another practical reality for the smooth functioning of the beam line.**

BPM's IN DIFFERENT SECTIONS OF SY120 BEAMLINE

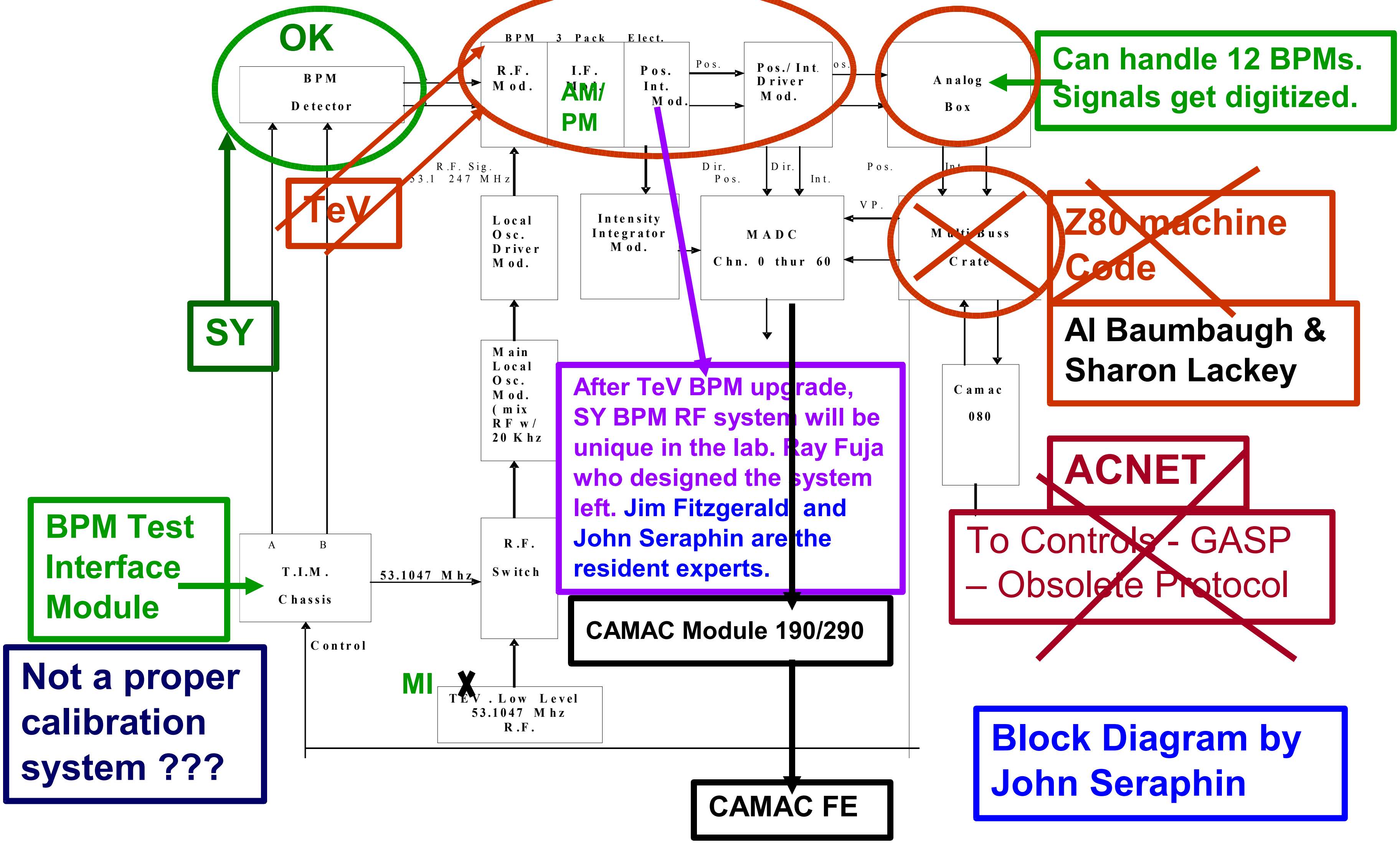
Beam Line	# of Resonant BPM	SPILL (SLOW[c]/FAST) CAPABILITY	# of single turn Horizontal BPM	# of single turn Vertical BPM
P1[a]	4(Short)	S/F	8	7
P2[a]	4(Short)	S/F	4	5
P3[b]	6(Short)	S/F	12	13
Old SY	12(10L + 2S)	S/F		
MESON	12(Long)	Slow only		
DUMP	4(Long)	S/F		
TOTAL	42(26L+16S)	31(S/F) + 11 Slow Only		

a. P1 and P2 line single turn BPM's are operational.

b. P3 line which formed part of the original MR, there was a total of 25 single turn BPMs. The cables from these BPM's were used for TeV upgrade. It will cost about $50K (rough estimate) to have these cables restored and the single turn BPMs operational.

c. Slow spill BPMs, must use Heliax signal cables.

BLOCK DIAGRAM OF THE SY120 RESONANT BPM SYSTEM



SY RESONANT BPM – SOME DETAILS

1. The Switchyard resonant BPM system was designed in 1985 and installed in 1986.
2. The new hardware design for SY BPM included resonant pickups and analog RF processing electronics, also called 3-pack electronics. Other hardware components were same as the Tevatron BPM system.
3. The Tevatron BPM hardware designed earlier (~1981 to 1983) was used for the data acquisition of the position and intensity outputs of the RF modules, controls systems interface and the test signals.
4. The analog box (analog front end of the multi-bus system basically a MADC), the multi-bus crate and cards, test interface module and the C080 CAMAC card were same as those used in the Tevatron.
5. The RF processing unit was designed by Raymond Fuja. At present he is working at SNS at ORNL, Oak Ridge, TN. His contacts are rfuja@ornl.gov or 865-241-6133(O). I did talk to him.
6. The RF module or 3-pack consisted of three NIM modules; the RF module, the IF module, and the I/P (intensity/position) module. A set of these modules can monitor two pickups if only slow spill is monitored or one pickup if slow and fast spill from the same detector is monitored.
    a) The RF module amplifies (53MHZ amplifier for slow spill only), filters (53MHz band pass filter for slow spill only) and mixes the BPM signals with the local oscillator frequency which produces 20KHz output signals.
    b) The IF module does the amplitude to phase (AM to PM) conversion, more filtering using a 1KHz bandwidth filter and outputs to I/P module.
    c) The I/P module converts the rms into a DC intensity signal and a phase detector to recover the position signal. The I/P module also has a switch selectable low pass filter of 1000, 100, or 10 Hz for slow spill, and 10KHz, 5KHz, and 3KHz for fast spill.

SY RESONANT BPM – SOME DETAILS

1. The position and intensity information goes to position/intensity driver module which is just a buffer that can drive a 50Ω termination.
2. It has multiple channels, so it can handle several (actually 12 BPMs) 3-pack BPM electronics.
3. The position and intensity information from the driver module goes to an analog box where the information is digitized, then passed on to multi-bus crate. The multi-bus crate controls the analog box and also sends the beam position and intensity information to the CAMAC system to be further read out.
4. Multi-bus crate also sends the information to the test interface module.
5. Two selected channel from the multi-bus crate also goes to the separate MADC where fast time plot can be made for those channels.
6. For some of these BPMs either only position, or position and intensity information from the position/intensity driver module goes to the MADC and read out. The MADC is connected to CAMAC 190/290 and CAMAC front end.
7. The BPM precision as per the literature was:
    a. Position Precision = 85mV/mm. Still applies.
    b. Intensity Precision = 0.5V/1E12 protons (for Tevatron slow spill). May not be applicable in present setup.

HOW THE BPM WAS MADE OPERATIONAL?

- **In the Tevatron, the beam was distributed around the ring with a gap to accommodate the extraction kicker rise time. This gap provided a trigger to the electronics each time it passed the pickup. If the intensity was greater than a threshold voltage which could be externally set, a trigger was generated and the hardware digitized the RF module output signals. Since the slow spill beam was continuous for 20-40s with no gaps, this scheme would not have worked for the SY BPM.**
- **Sharon Lackey modified the assembler language programs that Al Baumbaugh wrote for Tevatron to fool the electronics that it has seen a gap. The interrupt service routine to switch the threshold voltage between two levels was modified. The lower level needed to be set such that it was higher than the pedestal (intensity signal when there was no beam) and the higher threshold needed to be above the highest intensity signal when beam was present. Thus when the threshold moved through the beam intensity the electronics thought that the beam intensity was moving through the threshold and a trigger was created.**
- **In hardware this was achieved by changing the resistor network on the operational amplifier on the mother board of analog box to increase the slew rate. [Modified TeV Analog Box].**
- **Even after modification the system had an inherent problem at very low intensity. At intensity below $1X10^{12}$ particles over 20s spill or below 1000 protons per bunch CW beam, the resolution and triggering reproducibility degraded considerably. It was possible that out of the 12 BPMs sampled through one analog box, some of them did not trigger properly. A minimum intensity threshold to trigger was required. Since the minimum threshold set was same for all the BPMs sampled through one analog box, it was possible that some BPMs with higher noise did not trigger at all. Also, if a set of BPM for different beam lines were routed through same analog box it could lead to problem because of varying intensity in different lines.**
- ***At present this problem may not be as severe as earlier times when we had several beam lines with different beam currents, but it may be there even now, especially at very low intensity.***

HOW THE BPM WAS MADE OPERATIONAL?

- **Snapshots (averaged over several readings) were taken with the slow spill data.**
- **No FLASH feature was available for the slow spill data.**
- **Slow spill (over several 10's of seconds) BPM data were used fairly effectively. Slow spill extraction was used to set the beam trajectory in the switchyard.**
- **Fast spill (millisecond timing) was never used to tune the beam.**
- **For PINGS (millisecond timing), FLASH data taking mechanism of Tevatron was modified to work for the SY. The other major software changes involved changing the Tclock events that were decoded and used to prepare for beam, take PING and return to SNAPSHOT.**
- **The fast reading (PING) was harder because of the timing issues. Tclock was used to trigger the PING and it was difficult to time them just right to catch the beam.**
- ***Feature such as single turn extraction (μs timing) was never even attempted.* *Do we need it ?? NO.***
- **Test Interface Module (TIM) was modified to send the test RF signal to the pickups rather into the back of the analog RF modules as done for the TeV. This was done to check the resonant detector circuits. The output of the TIM was an RF signal that was split to be distributed to the 12 RF modules in a system. To save cabling, the final splitting was removed from the TIMs and splitter was installed in the tunnel. These test signals were used mostly to diagnose the problems with the system.**
- **The TIM was not used to calibrate the system but just to make sure that the system in working. Anyhow the calibration would have been limited by the resolution. Also, the signal size sent to the plates needed to be small, the level of isolation required was not possible, and hence effective calibration was not possible. *Thus the SY BPM system has no proper calibration mechanism.***

PROBLEMS WITH SY120 BPM SYSTEM

➢The actual physical hardware - the BPM detector are fine, *although at places 3σ beam envelope can take up most of the space between the BPM plates and their may be beam sprays on the plate.* – **HOPEFULLY IT WILL POSE NO PROBLEMS.** – ***Please see plots on next two pages & discuss.***

➢Signal from the actual hardware goes to a 3-Pack system. The 3-Pack system consisting of RF module, IF module, and the I/P module are unique for the SY BPM system. They were designed by Ray Fuja who is at ORNL. No one is expert on the system. Of the two engineers who worked on the resonant system with Ray Fuja, Hingzi Ma (hengjie@ornl.gov) also went to ORNL. Jim Fitzgerald did work on the resonant system. John Seraphin was the technician with Ray Fuja. Now John Fitzgerald and John Seraphin are working on the system. – **SO WE HAVE PEOPLE WHO ARE SOMEWHAT FAMILIAR WITH THE SYSTEM BUT ARE NOT ACKNOWLEDGED EXPERTS.**

➢***Disscussion on 3-Pack electronic system will follow.*** **PROBLEMS HERE TOO.**

➢Position and intensity information goes to position/intensity driver module which is just a buffer. From here the position/intensity information goes either to the MADC or to the analog front end of the multi-bus system which digitizes the information and passes it to multi-bus crate.

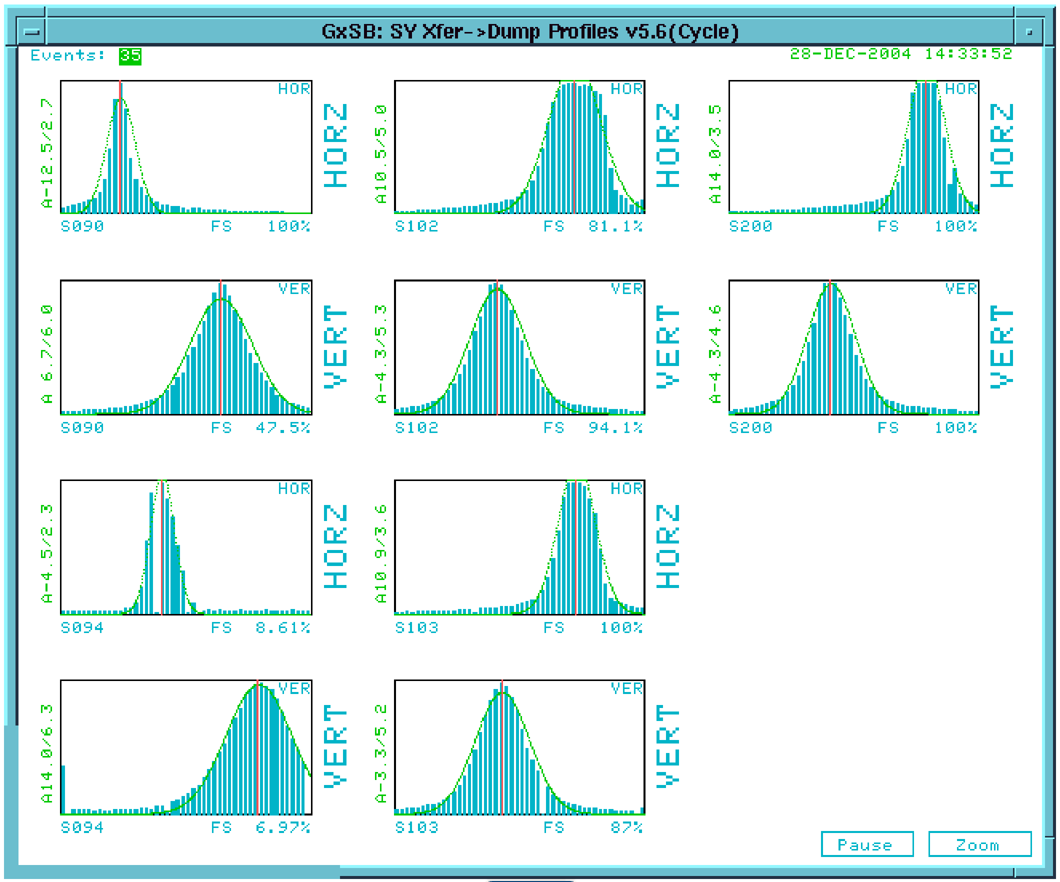
➢ **MADC HAS LIMITED FEATURES** ***- It can only read one pair of BPM at a time. NO S/H.***

➢ **MULTI-BSS PROCESSOR HAS RELIABILITY PROBLEM.**

➢ **CONTROL SYSTEM PROTOCOL HAS BEEN DEPRECATED BY THE CONTROLS DEPT.**

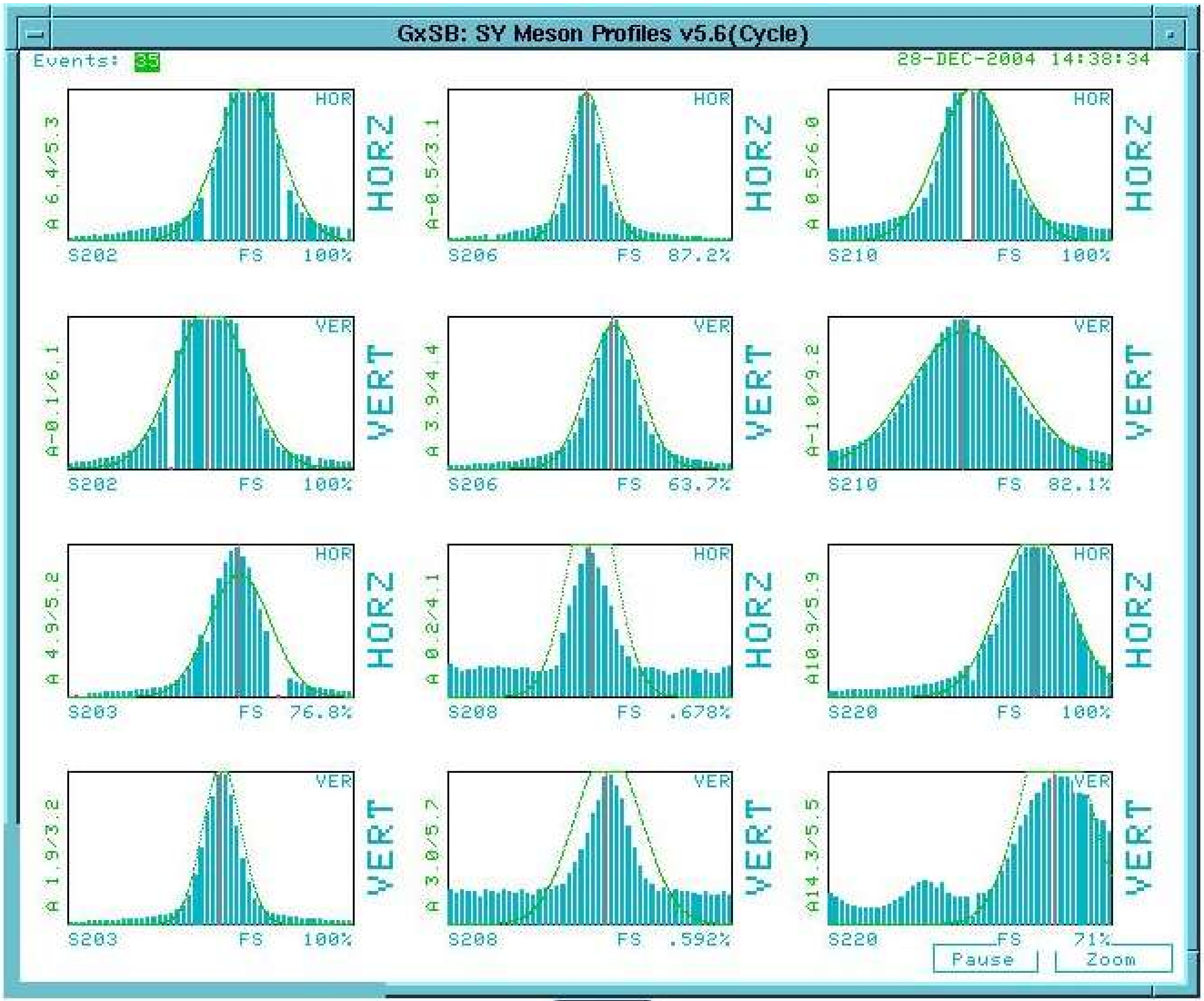
NOMINAL BEAM SIZE IN SWITCHYARD -12.28.2004 – Chuck Brown & Rick Coleman

For a beam through the center of the pipe the copper plates are separated by ± 35mm.



BPM	Mean (mm)	RMS Value (mm)	±3σ value (± mm)
HP90	-12.5	2.7	8.1
VP90	6.7	6.0	18.0
VP94	14.0	6.3	18.9
VP102	-4.3	5.3	15.9
HP103	10.9	3.6	10.8
VP103	-3.3	5.2	15.6
VP200	-4.3	4.6	13.8
HP202	6.4	5.3	15.9
VP202	-0.1	6.1	18.3
HP206	-0.5	3.1	9.3
VP206	3.9	4.4	13.2
HP210	0.5	6.0	18.0
VP210	-1.0	9.2	27.6

NOMINAL BEAM SIZE IN SWITCHYARD -12.28.2004 – Chuck Brown & Rick Coleman



PROBLEMS WITH SY120 BPM SYSTEM

1. Resonant BPM's in P1, P2, P3 lines have only raw MADC channels connected. They can measure both position and intensity. The analog signal out of electronics is plugged into MADC channel and the data is logged. ***They have no MULTIBUS computer. Thus one will be unable to distinguish between "beam" and "no beam" situation. One will have to monitor the intensity to make sure the presence of beam and then measure the position. They also have limited data sampling capability.***
2. In old SY and beyond (SY, MWEST and DUMP) resonant BPM's have MULTIBUS computers.
3. Some of the OLD SY(2-intensity only, 1-position & intensity), MESON(2- position only, 2-intensity only) and DUMP(1-intensity only, 1-intensity and position) BPM's also have MADC channels connected. Some of these read intensity only, and some of them read position as well as intensity.
4. **Thus P1, P2, and P3 line BPM's are not compatible with BPMs in the Old SY, MESON line & DUMP. MADC is not sufficient and MULTIBUS is very old and unsupported.** ***The readout should be similar for both the sections.***
5. **Readout can be replaced by VME based system – a la RECYCLER.**

WHY AN UPGRADE?

- The feeling about the SY BPM system varies to these two extreme ends:
    - The system worked very well when built. It was a generation level improvement in instrumentation over what existed. This is a true statement.
    - But today it is an outdated system. This statement is also true because the system is unable to meet present day needs.
- The last fixed target run with beam extracted from the Tevatron was during 99-00.
- The slow spill length from Tevatron was around 20sec. The extracted beam current from Tevatron for slow spill varied from ~$1X10^{13}$ pps (~10K protons per bunch CW beam) at higher end to about ~$1X10^{12}$ pps on lower end (~1000 protons/bunch CW beam).
- The spill length from MI may/will vary from 4.2s to 0.5s and the beam current will be of the order of $5X10^{12}$ pps (spill length=4.2s) extracted from the MI to $1X10^{10}$ pps (spill length=0.5s) for one of the split lines, or between 25000 to 400 protons/bunch CW beam.
- The beam current for slow extraction will have a dynamic range of 60+.
- The present dynamic range may not be sufficient. An engineer should answer this question.
- The present electronics may not be sufficient for 400 protons/bunch CW beam. It will have a position resolution σ ~ 275μm or worse at a 10Hz sampling rate.
- The system is self (beam intensity threshold) triggered. It does not have a general purpose beam-synch clock based trigger.
- Resonant BPM's in P1, P2, P3 lines are not compatible with the old SY and beyond resonant BPMs. They should have the similar readout.

WHY AN UPGRADE? HISTORICAL MULTI-BUS

- In old SY and beyond, the computer interface is a multi-bus based system with 8 bit ADC readout. *This is one of the most fundamental limitations of the system.*
- The multi-bus system was designed in 1981. It is a 25 years old system. It is past its life span. Carl Wegner from the Research Division designed it. Alan Baumbaugh worked on the firmware.
- The person who inherited it from Carl Wegner was transferred. The person who inherited next left the laboratory. Bob Marquardt inherited it next. He retired. The person in charge these days is Mark Averett/Paul Kasley.
- According to Mark Averett they work on the system because they have no choice. They are perhaps not the best expert on the system and hope that nothing seriously breaks down. Will definitely like the system replaced with a modern one.
- The system is not very robust. One of the in-house build cards in the system fails frequently. Some spares are left, and the system can be made to work while spares last. There may be programmable parts in the system which are not available anymore. Not many experts left at the laboratory. Alan Baumbaugh has been called to consult on the system for MI and TeV but cannot spent 100% of his time supporting the system. People are not very familiar with the system and errors it gives. With TeV BPM upgrade, spare parts may not be a big factor.

WHY AN UPGRADE? REDUNDANT FIRMWARE

- The firmware is written in Z80 machine code, which is now arcane. The dual Z80 system used in these BPMs have in-house built as well as custom made cards with shared memory. Only one person at the laboratory, Alan Baumbaugh is familiar with the code. It takes longer to figure out the problem than to fix the problem. Nearly 20 years ago Sharon lackey modified Alan's Tevatron code to work for the SY. If really needed she can be called to help. ***But both of them are of the opinion that the readout should be changed.***

- Z80 is a strictly assembler language code. It has 16 bit addressing, ***8 bit data output, which does not give enough resolution.***

- The new BLM system for TeV, MI, and Booster has firmware written in EZ80, which is also an assembler language code compatible with Z80 but has C compiler. It has 24 bit addressing and 8-bit data output, which is sufficient for the BLM system. Initially the code will be written in programmable language but if needed it can also be done in C. ***No such latitude is available for the Z80 language.***

- ***In summary, the firmware must be changed with modern version.***

WHY AN UPGRADE?

- The control system is in GASP, an obsolete protocol that is being phased out by the controls department. ***No one at the lab knows GASP. Everyone who knew GASP has retired.*** It is like a black box which works but one can't add new features to it. ***This was one of the important reasons for replacing the Tevatron BPM electronics.***

- ***Bob Joshel who wrote the application software has left the laboratory. M.J. Yang and Rich Coleman are somewhat familiar with the software.***

- ***More standard software will be desirable.***

- ***It is a ~25 year old system. The system is approaching its end-of-life and one can expect increasing failure rates. Some spare parts are not commercially available.***

- ***The system at best may last another few years. The system is so old that it is better to replace it. Even if hardware works, there may be no one left to work on the firmware.***

BPM's PRECISION REQUIREMENT

1. The copper electrodes in the BPM body are bent to a 3.5cm radius of curvature. For a beam going through the center of the pipe the copper plates are separated from each other by 7cm. ***The 8-bit ADC readout of the multi-bus system translates to 275µm position resolution. Sam Childress recalls from his memory that he got a <0.1mm sigma when read out with 12 bit ADC.***

2. ***A 3σ requirement, or 99.73% of the measurement will lead to variation as large as 1mm or more.***

3. With the 8-bit ADC, typical auto-tune tuning tolerance was 200µm with 10Hz position measurement. The tuning was initiated when any BPM position was off by a value greater than 400µm and tune till the value was within 200µm.

4. **Position Precision – 0.1mm sigma for beam intensities for as small as $4X10^2$ protons per RF bucket to $2.5X10^4$ protons per RF bucket.**

5. **A readout system with 10/12/14-bit ADC readout will give 70/20/5µm resolution.** ***[Engineers should decide how to meet this condition].***

6. **Intensity Precision – Instantaneous and integrated intensity measurement with a precision of ±5% or better over the whole dynamic range.**

WORK DONE OR TO BE DONE BY JIM FITZGERALD & JOHN SERAPHIN

1. They plan to instrument the P lines resonant BPM's with S/H. It will be hard to sample beam with varying time structure. It may be necessary to use low frequency output filters or integrators to measure the position and the intensity.
2. Reprogrammed the clock decoder chips in the multibus system for the SY and pre-target area to recognize MI clock events. Earlier it was based on the TeV clock events because beam to SY used to be extracted from the TeV.
3. The P1, P2 and P3 lines does not have multibus ADC system. Timing for S/H or integrators will be from the standard CAMAC cards.
4. The MI LLRF has been patched through replacing the TeV LLRF for P1, P2, P3, old SY lines and beyond. In some cases the LLRF is derived from controls group beam synch clock and in some cases it is actual LLRF signal. This is needed for down conversion as well as for test interface modules.
5. They have looked at bench test for the functioning of the BPM electronics, summarized in Beams-doc-1750-V1.
6. They have also looked at signals out of the BPM with oscilloscope with beam from the MI for an intensity range of 0.2E12pps to 1E12pps, with a nominal intensity of 0.5E12pps (for spill length of ~0.5s). The beam was thought to be 30 bunches, but may have varied from 15 bunches to 60 bunches.

SY120 BPM ELECTRONICS MEASUREMENT
BY JIM FITZGERALD AND JOHN SERAPHIN

1. **The bench study was performed for the case of present SY slow extraction with spill length ~0.6s to understand the performance and sensitivity of the BPM electronics to the number of extracted bunches from the MI to the SY.**
2. **A 53MHz signal gated at the MI revolution rate of 11µs, with a RF burst duty factor ranging from 5% to 100% for a constant output intensity was used to simulate the extracted beam. A constant output intensity means that when input power was low i.e, less proton per bunch simulation then the number of bunches was increased to have same output every time. The simulation was done for 30 bunches to 588 bunches from the MI, which corresponds to a factor of 20 (or 5% to 100%). The 100% duty factor corresponds to ~1X10^{12} pps.**

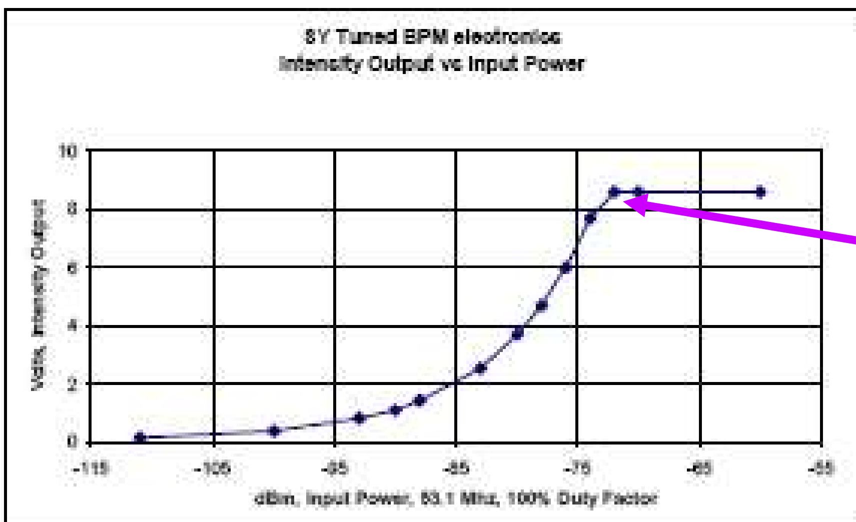


Fig. 1

The picture on the left shows intensity output in volts vs. input power at 100% duty factor for a 53MHz signal before an internal component reaches saturation.

The figure shows that saturation happens at an input power level of -71dB and output level of ~8V.

FROM Beams-Doc-1750-V1

SY120 BPM ELECTRONICS MEASUREMENT
BY JIM FITZGERALD AND JOHN SERAPHIN

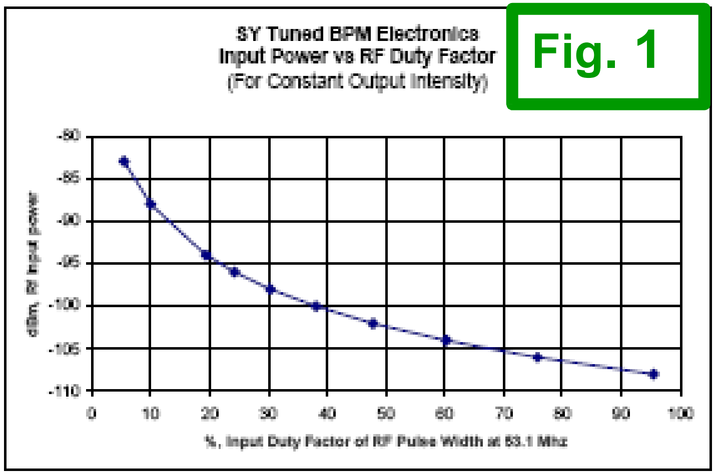


Fig. 2

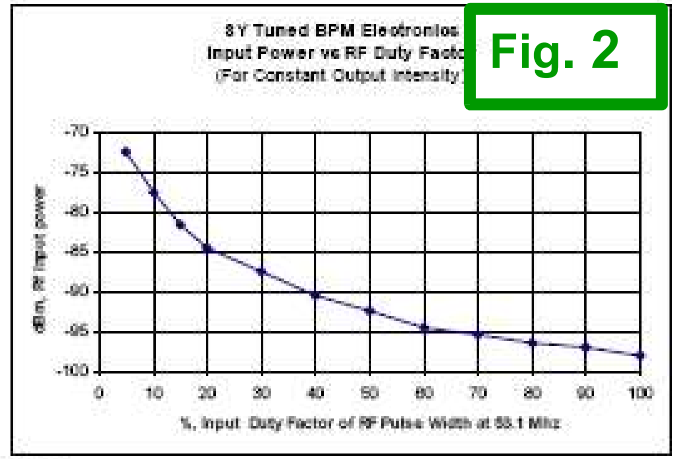


Fig. 3

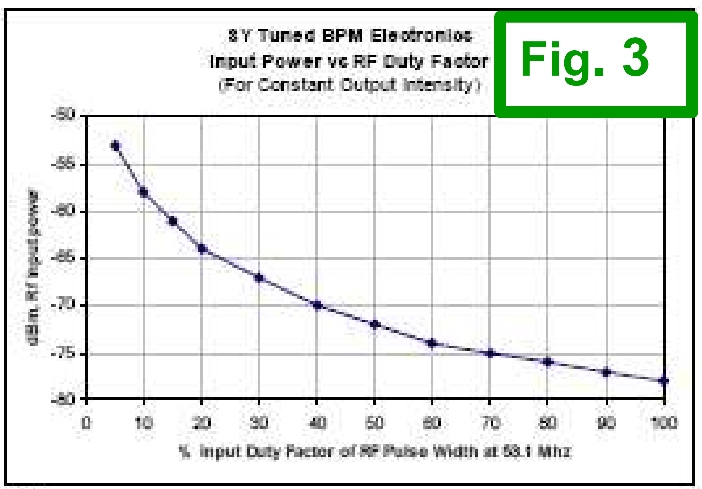


Fig. 4

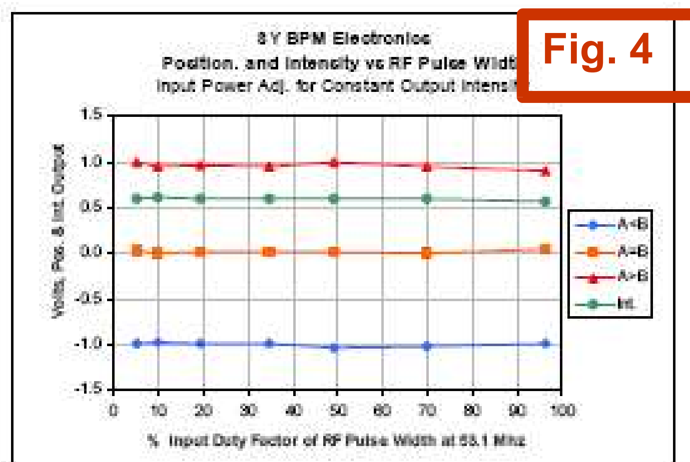
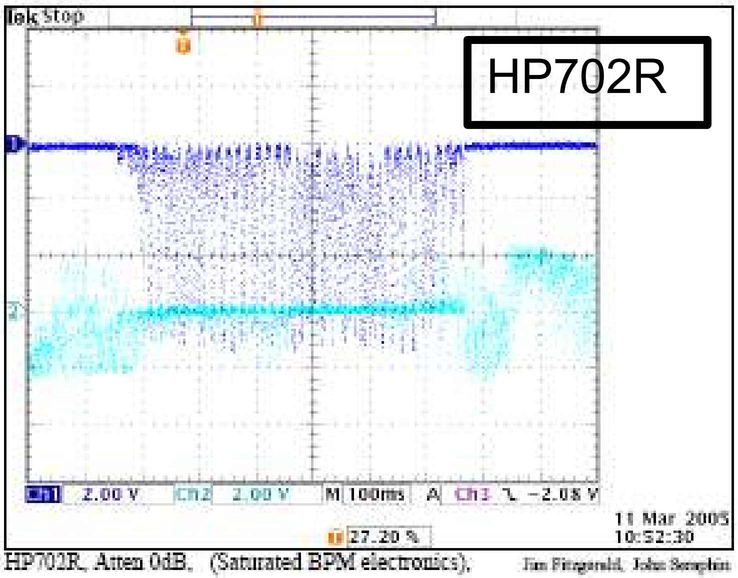


Fig. 5

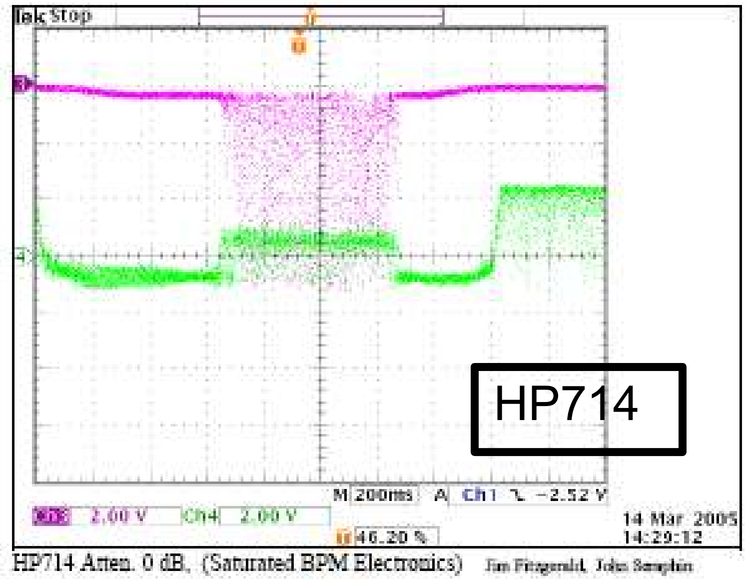
FROM Beams-Doc-1750-V1

SY120 BPM ELECTRONICS MEASUREMENT BY JIM FITZGERALD AND JOHN SERAPHIN

1. On last page, figures 1, 2, and 3 shows the RF input power adjusted to maintain a constant intensity output equal to 100% duty factor power level vs. RF duty factor varying from 5% to 100%, a factor of 20.
2. At 5%, it simulates 30 buckets of the MI and for 100% it simulates 588 buckets from the MI. This was done for three intensity output in the non saturated region of the figure shown two pages earlier.
3. The curves are exponential and non-linear.
4. It shows that the gain will have to be varied by 25dB to measure the range described above.
5. Figure 4, shows the intensity and position outputs in volts vs. input RF duty factor or pulse width for a constant output intensity equivalent to 100% duty factor. The input power was set at ~85dB to ensure non-saturation at 100% duty factor. It shows that the electronics is capable of measuring position and intensity accurately as long as the measurement is made within the dynamic range of the electronics and non-saturated region.
6. When BPM output for live beam was measured with an oscilloscope it was found that for beam current >0.5E12p/spill (30 bunches in MI) the gain of the RF module is too high and saturates the electronics (figures on next page). To avoid it one will need to either:
   - **Modify the RF module and reduce gain which requires low gain amplifier. It will be time consuming as all the RF modules will need to be modified and will require money, or**
   - **One can attenuate the signal coming out of the pickups by reducing the gain there by ~25dB. This may be easier but can lead to noise.**



100ms



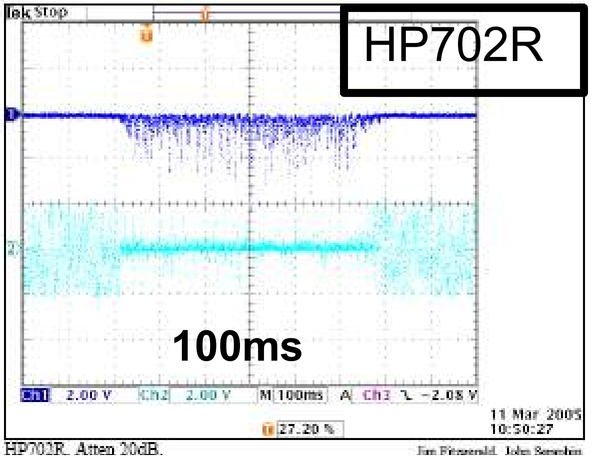
200ms

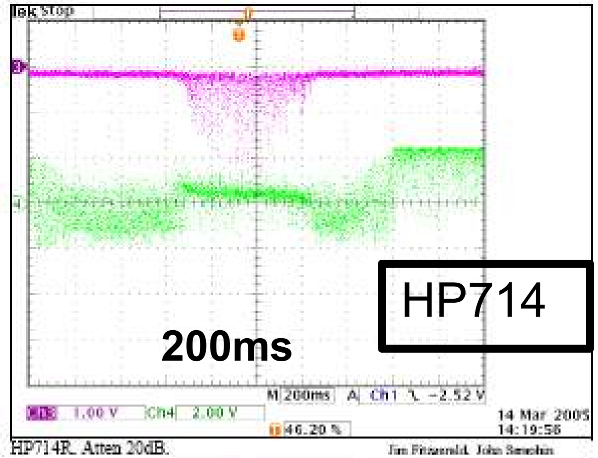
No attenuation on signals.

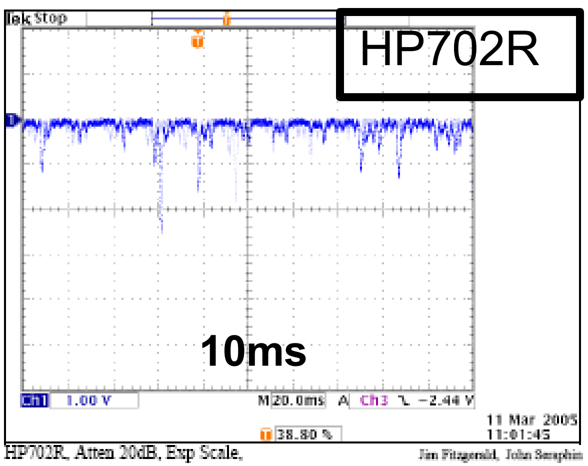
Beam intensity ~0.25-0.75E12protons/spill. (30 bunches, MI flat top=0.6sec.)

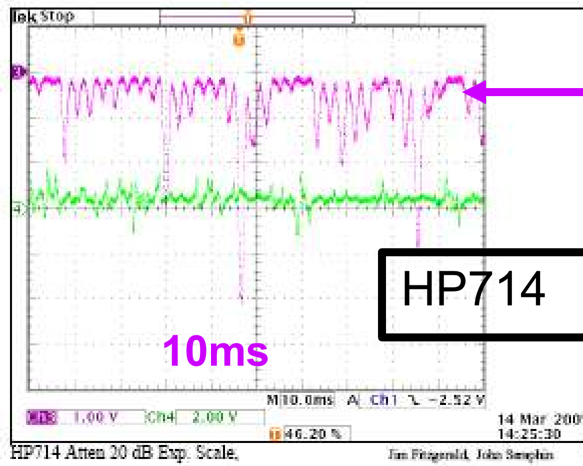
The BPM electronics saturates around 7-8V.

SY120 BPM SIGNAL ON SCOPE BY JIM FITZGERALD AND JOHN SERAPHIN









Typical spill structure in the SY120 line.

1. After an attenuation of 20dB, the measured output value is 3-4V.
2. With 30dB attenuation the signals gets overly attenuated.
3. On smaller time scale one sees the structure in the beam – signal modulation.

ON SIGNAL MODULATION - R. WEBBER

1. The pink trace on the last page shows the typical spill structure in the SY.
2. On a scale of few milliseconds one does not know when the signal will be present.
3. When the signal is not present, or due to large variation in the signal size within the spill or from spill to spill, the measured position of beam in case of no signal or very small signal, varies dramatically and gives completely erratic measurement of the position.
4. To avoid this either one has to measure the position when the signal is present or one has to integrate over a long enough time to make sure that sufficient signal will be present within the time window.
5. Simple timing of sample signal when it is present is not a solution since the structure changes within a spill and from spill to spill. Basically a S/H circuit will not work with the present spill structure.
6. Accepting inputs only when the signal is above certain threshold while ignoring the signal any other time may provide a solution, but that feature is not built into the present hardware, nor is a feature in any of the now existing Echotek implementation. This feature can be implemented in either the present system or in the Echotek, but will be something completely new.
7. Integrating the input over sufficiently long time to guarantee steady signal requires an integration window of the order of 100ms. The present hardware in fact offers a long integration, but it is performed at the final output stage of the position circuit. That is a completely inappropriate place in that signal processing scenario and it produces wrong answer.
8. The Echotek board as currently used in any implementations at the laboratory does not accommodate possibility of such long integration times. But there are software and possibly even hardware solutions.
9. What ever route we go there will be new work but it is possible to process the signal properly.

SOLUTION FOR THE SWITCHYARD BPMs

It is my understanding that the RF processing electronics, also called BPM 3-pack electronics used in the SY may be functionally OK. The position and intensity signal coming out of it may be usable but more tests are required. The front-end data acquisition (analog box, multi-bus crate/MADC, as well as the controls) does not meet the need of the time and is not well supported. So, the recommended solution is to:

- Replace everything after the RF module with EchoTek digital processor unit. The board has an A/D section followed by digital down-conversion and digital filtering and finally by an output.
- EchoTek digital processor technology has been used for the Recycler and the Tevatron BPM upgrade, and has been recommended and approved for the MI BPM upgrade.
- RF module may be needed for gain amplification, filtering and mixing of the BPM signals with the local oscillator frequency. **So it may be kept.** **More investigation on this may follow.**
- It is likely that one may not need to use the local oscillator with the EchoTek board. The local oscillator has to be synchronized with the beam. The EchoTek board does not care about the phase but the amplitude only. So, one can use an EchoTek clock generator card. Thus one may be able to use a fixed frequency crystal oscillator.
- Get rid MADC as well as Multi-bus system with 8-bit ADC, Z80 machine code, and GASP protocol.
- Having processing electronics, front-end and application software similar to other machines will be best for the optimum use of the system and the manpower.
- A digital processing unit with an 80MHz sampling unit (ex: EchoTek board) will allow for large dynamic range, large sampling frequency, and precision position and intensity measurement.

ECHOTEK CARD NEEDED – TOTAL 13

One EchoTek card can handle eight pickup plates or 4 BPMs.

# of BPMs	Device name	Type	Tunnel Location	Echotek Card
4	HPR702,VPR702,HPR714,VPR714	Short	MI60-110	1
2	HPRF11,VPRF11	Short	F0-108	1
2	HPRF17,VPRF17	Short	F1-17	1
3	VPRF33,HPRF34,VPRF42	Short	F3-17	1
3	HPRF42,VPRF49,HPRF49	Short	F4-16	1
10	VP90,HP90,VP94,HP94,VP100 HP100VP102,HP102 HP103,VP103	Long	TG9-ZRR-91 TG9-ZRR-91 TG9-ZRR-92	3
12	VP200,HP200,VP105,HP105,VP106 HP106,VP201,HP201 VP202,HP202,VP206,HP206	Long	SSB2-ZRR-13 SSB2-ZRR-13 SSB2-ZRR-14	3
6	VP208,HP208,VP210,HP210 VP220,HP220	Long	G2SB-ZRR-5	2

PRELIMINARY COST ESTIMATE

The BPM electronics is located at 8 service buildings as shown on last page. Since one would not like to pull new cables, electronics need to be replaced in those service buildings. Based on above logic the preliminary cost estimate is:

- 13 EchoTek digital processors needed. 13 units at ~$13K/unit. COST ~ $169K.
- One VME crate with power supply/location. 8 units at ~$4K/unit. COST ~$32K.
- One VME processor/location. 8 units at ~$3K/unit. COST ~ $24K.
- Calibration System Hardware – 8 units at ~$10K/unit. COST ~ $80K.
  - **Do we need a fancy calibration system or can we reduce the cost by $80K.**
- Engineers and Technicians time for R&D, installation and testing. Cost it.
- Front End Software – Similar to Recycler. Manpower needed. Cost it.
- Application Software – Manpower from lab needed. Cost it.

Total COST ~ $300K+, plus

Engineers + Technicians + Software and other experts time.

SUMMARY & CONCLUSIONS

1. Switchyard is an integral part of the Fermilab physics program.
2. Physics will be done with the SY beam lines for at least next five years if not longer.
3. Having a precision BPM system for position and intensity measurement is a necessity, not a luxury.
4. The present BPM system is incapable of precision measurements.
5. Many parts of the system is old and are reaching end of their life span.
6. Even if the RF electronics could be salvaged, the front-end readout and control system are almost unusable.
7. Most of the experts involved with the present system are no more at the laboratory.
8. Recycler and Tevatron BPM electronics have been replaced with digital processing technology. MI BPM electronics will also be replaced with the same technology.
9. ***So we must replace SY BPM electronics with same/similar technology for better performance and availability of expertise.*** ***Doesn't cost much.***