nSTORM Decay Ring Instrumentation

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Common Types of Beam Current Transformers (BCTs)

	•DESCRIPTION
Integrating Current Transformer (ICT)	•Passive current transformer depending on short (< 1 nsec), isolated (±50 nsec) beam bunch to drive impulse response of transformer •Output pulse shape is fixed by design and independent of shape of sufficiently short beam pulse •Output amplitude is directly proportional to charge of beam pulse •Useful in synchrotrons, storage rings, and transport lines provided short isolated bunch criteria are met
Direct Current Transformer (DCCT, PCT, etc.)	•A strong well-controlled magnetizing force is applied to one or more toroids enabling sampling of magnetic bias imposed by beam •Operates in zero flux mode, a feedback current equal and opposite to the beam is driven through the toroidal cores of the device •Practical DCCTs for particle beams are a combination DC section and AC transformer to prevent aliasing and extend bandwidth •Useful in synchrotrons and storage rings, not transport lines
Classical AC Transformer	•Beam current couples magnetic flux to toroidal transformer core inducing current in sense winding on same core •Output signal can provide hi fidelity representation of beam current pulse shape over wide bandwidth (10's of Hz to few MHz) •Passive device that can be supplemented with various active circuits to modify performance (e.g. Hereward and 'active-passive' configurations)

Common Types of Beam Current Transformers (BCTs)

	ADVANTAGES	DISADVANTAGES
Integrating Current Transformer (ICT)	•Simple, relatively inexpensive, stable passive calibration •Output stretched in time relative to very short beam pulse	•Bunch shape information is not available
Direct Current Transformer (DCCT, PCT, etc.)	•Measures 0 Hz (DC) component of bunched or unbunched beams •Long term stability and <1 microampere DC resolution	•Relatively expensive for applications not requiring DC response
Classical AC Transformer	•Simple and available in many configurations to suit application	•NOT DC coupled, provides NO DC output component

For nSTORM Transport Lines

- Recommend AC Transformer-based BCTs
- All signal processing would be done digitally in a VME front end instead of an analog circuit
  - Noise Filtering
  - Signal Averaging
  - Baseline correction
  - Droop correction

FNAL Transfer Line Toroid Systems

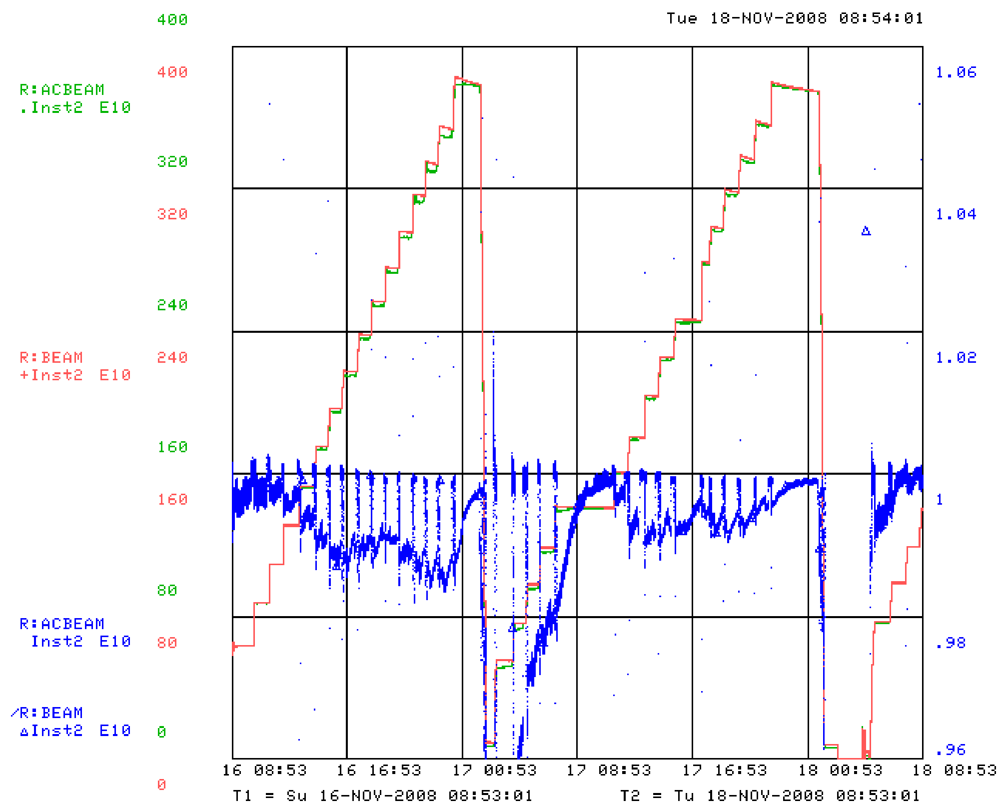
- Installed systems in the RUNII transport lines use older design with an analog integrator.
  - With this system designed for 8E12 full-scale, we have achieved ±0.1% RMS pulse-to-pulse variation and ±0.5% long-term drift [MiniBoone].
  - With this system designed for 4E13 full-scale, the ratio between upstream and downstream toroids have had observed resolutions of 1.5E-4 [NuMI].
- The entire Linac is currently being upgraded to VME-based electronics; two VME-based toroid systems will be installed for ANU. Further system noise analysis will be done at startup.
- nSTORM toroid systems in transport line would use latest VME-based design

For nSTORM Storage Ring

- If anticipated operation similar to antiproton (pbar) transfer into recycler (RR) during RUNII...
  - Recommend AC Transformer-based BCTs, which would act similarly to R:ACBEAM
  - Requires a “no beam” region in storage ring
    - For example, accumulated pbars are added to an existing RR ‘stash’. About 10 to 20e10 pbars enter the RR in four 2.5MHz bunches. These bunches are adiabatically transformed into a 1.6uSec barrier bucket and merged with the larger barrier bucket holding the ‘stash’
- If anticipate no “notch”...
  - Recommend DCCT application to detect DC response
  - ÿ nSTORM DCCT system would follow updated design expected for use in RR during NoVA

R:ACBEAM

- AC-coupled signal from core is digitized and integrated.
- Algorithm is used to find “no beam” region to determine baseline level needed to correct the integrated value.
- The blue trace is R:ACBEAM divided by R:BEAM. Should be close to 1. The variation is caused by the changing of the structure of the barrier buckets.
- When beam is bunched, similar rms noise levels observed on R:ACBEAM compared to RR DCCT (<0.02E10rms).



FNAL Storage Ring DCCT Systems

Machine	System Type	Full-Scale Current	Full-Scale Intensity	Measured RMS Noise
Recycler (NPCT)	Bergoz NPCT	200 mA	13.9×10^{12} particles	2.34×10^{8} particles
Main Injector	FNAL Design	600 mA	41.6×10^{12} particles	1.36×10^{7} particles
Tevatron	FNAL Design	400 mA	52.3×10^{12} particles	3.79×10^{9} particles
Debuncher	FNAL Design	400 mA	4×10^{12} particles	1.08×10^{7} particles
Accumulator	FNAL Design	400 mA	4×10^{12} particles	3.97×10^{7} particles
* RR DCCT will be upgraded to a new design after Spring 2013.				

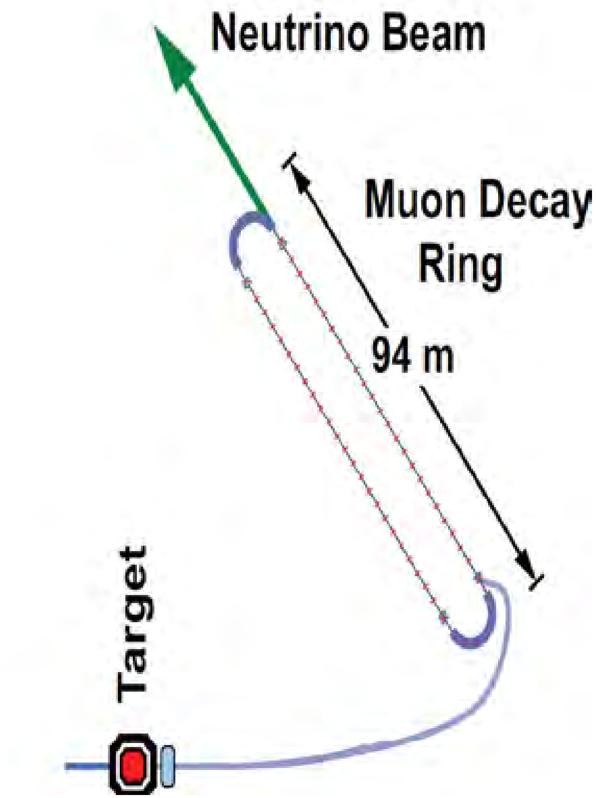
Conclusion

- For all options, the biggest obstacle is the physical feasibility. Cost and delivery times will be a significant factor for any customized item.
- Beam pipe size, in combination with the expected beam pulse widths, heavily affect tape-wound transformer and ceramic break selection.
- For DCCT application, power requirements needed to excite the cores also increase significantly for larger sizes.

Profile Monitors

- **Beam parameters:**

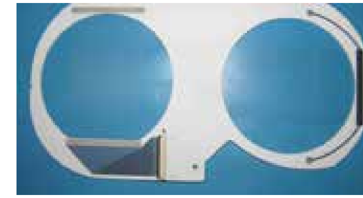
- $10e^{12}$ protons on target
- $10e^{11}$ π after the horn and through the collection beamline (20 cm diameter)
- $10e^{10\text{-}11}$ μ in the ring (30 cm).
- Beam Profile Detectors:
  - Secondary Emission
  - Ionization
  - Scintillation



Primary Beamline

- SEMs
- Material: Ceramic frame.
- X, y planes are made using a 0.0075” to 0.003” Ti or BeCu wire soldered or Epoxied on pads on both sides of the ceramic board.
- Wire: AuW 2% Re wire made by California Fine Wire.
- Wire pitch: choice of 0.5, 1 and 2 mm.
- Wire tension 20-80 g depending on wire diameter.
- No bias foils are used (NuMI tests show no change in signal).
- Kapton tapes take the signals from the wire plane to the feedthroughs
- Pbar SEM have Ti strips between bias foils.
- **Signal estimate:** Charge due to secondary emission: $Q = \varepsilon N e$ where ε is the secondary emission efficiency, typically around 3%. N is the number of particles through the wire and e is the electron charge 1.602 x 10^{-19} Coul. For a 10^{10} ppp beam the charge on a full foil is 48 pCoul. The charge on individual strips is a percentage of this value depending on beam intensity, beam size and strip surface area. This is about 10 time about noise level.

SEM



Transfer lines

Standard Wire SEM

NuMI wire plane

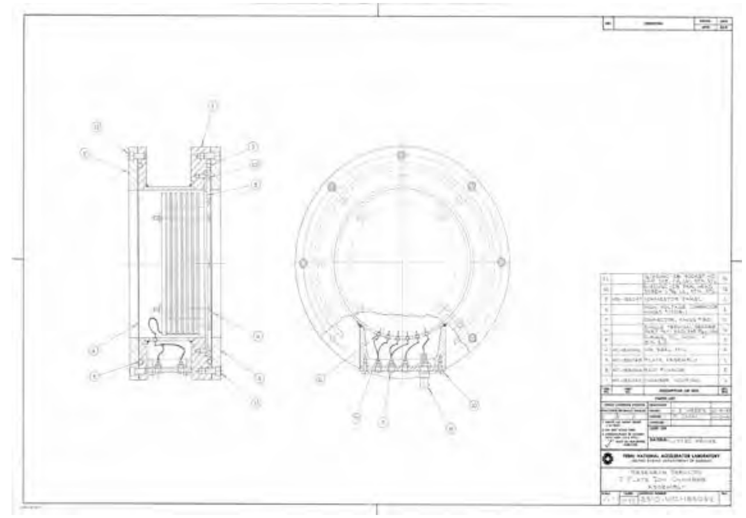
Pbar Strip SEM

Ion Chambers

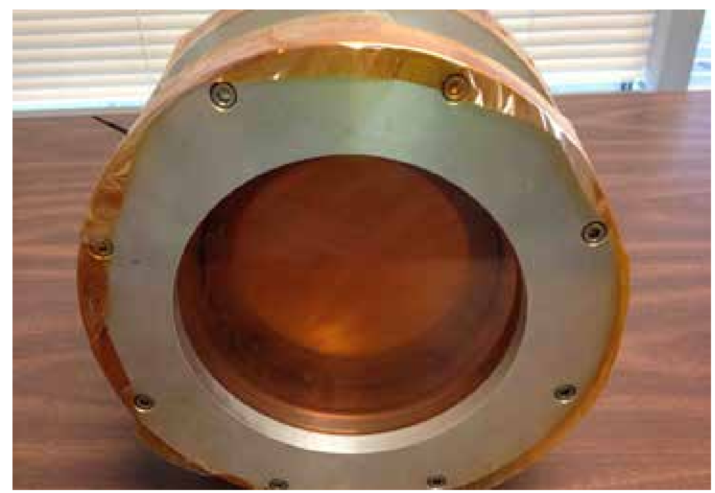
- **AD Ion Chambers:**

- Have 3 signal foils between 4 bias foils:
- D=1/4" between each foil
- **Signal Estimate:**

  - **Physics principles:** proton passing through $ArCO_2$ gas generates 96 e/ion pair or about 1.6×10^{-17} charges/cm which equals about 1.6 pCoul for 10^5 particles
  - **Calibration using foil irradiation method:** Indirect method requiring > 10^{11} ppp beam to irradiate a Cu foil placed in front of the I/C. After irradiation the foil is taken to the counting lab where the activity of the foil is measured. This in turn translates in the total number of protons. Then, by applying a scale factor the ion chamber can be calibrated. Signal depends on gas flow.



7 Foil Ion Chamber



AD Ion Chamber

Ion Chambers cont'd

- Signal analysis: Dan Schoo designed and built a current digitizer for SEMs and Ion Chambers.

IC Conversion Constants SEM/IC Current Digitizer

This chart describes typical values. Individual detectors will vary based on gas flow, wear, age and application.

Calibration Test Input	Proton Flux	IC Charge Out	Electrometer Out	Integrator Out	Output Frequency
10.0 mV	8.27E+06/S	100 pC	100.0 μV	100.0 μV	1.10Hz
15.0 mV	1.24E+07/S	150 pC	150.0 μV	150.0 μV	1.65Hz
30.0 mV	2.48E+07/S	300 pC	300.0 μV	300.0 μV	3.30Hz
100 mV	8.27E+07/S	1.00 nC	1.00 mV	1.00 mV	11.1Hz
150 mV	1.24E+08/S	1.50 nC	1.50 mV	1.50 mV	16.5Hz
300 mV	2.48E+08/S	3.00 nC	3.00 mV	3.00 mV	33.0Hz
1.00 V	8.27E+08/S	10.0 nC	10.00 mV	10.00 mV	110.0Hz
1.50 V	1.24E+09/S	15.0 nC	15.00 mV	15.00 mV	165.0Hz
3.00 V	2.48E+09/S	30.0 nC	30.0 mV	30.0 mV	330.0Hz
10.0 V	8.27E+09/S	100 nC	100 mV	100 mV	1.100KHz
15.0 V	1.24E+10/S	150 nC	150 mV	150 mV	1.650Hz
30.0 V	2.48E+10/S	300 nC	300 mV	300 mV	3.330KHz
100 V	8.27E+10/S	1.00 μC	1.00 V	1.00 V	11.00KHz
150 V	1.24E+11/S	1.50 μC	1.50 V	1.50 V	16.50KHz
300 V	2.48E+11/S	3.00 μC	3.00 V	3.00 V	16.50KHz
1000 V	8.27E+11/S	10.0 μC	10.0 V	10.0 V	110.0 KHz

NOTES:

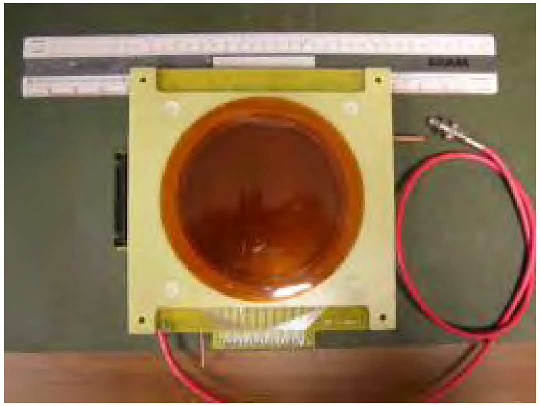
-Calibration Test Input voltages are applied to the SIGNAL INPUT with a 100 Meg resistor in series to simulate the signal from an ion chamber.

-The ion chamber Charge Out is the average output from a typical ion chamber operating at a bias potential of -800 Volts.

-The electrometer voltage out is given assuming a 1 Meg feedback resistor.

SWIC & Proportional Ion Chambers

- **Differences between SWICs and PWCs.**
- Both detectors exploit the ionization phenomenon.
- **Segmented Wire Ion Chambers (SWICs)** have 1 HV wire plane (25 micron AuW wire) between 2 signal planes. The HV applied is positive. The gas multiplication due to the electrons occurs around the HV wires but the signal is due to the ion-flow back to the horizontal and vertical signal wires. SWICs can be placed into a vacuum can – box or bayonet or fixed in a beamline vacuum break.
- **Proportional Wire Chambers (PWCs)** have each signal plane between 2 bias foils where a negative voltage is applied. Here the gas multiplication occurs around the signal wires (positively charged with respect to the foils) giving a faster and stronger signal. With background subtraction PWCs can display beams around 10^3 ppp. SWICs about 10 times higher. PWCs are modular, allowing for replacement of wire planes if needed. SWICs's signal planes are epoxied to the HV center plane making the whole assembly much more robust.
- In the process of redesigning the PWC making it smaller so that it could be placed in a vacuum can. We are now in the process of determining how best to reference the chamber before making a testing a prototype.



Swic chamber

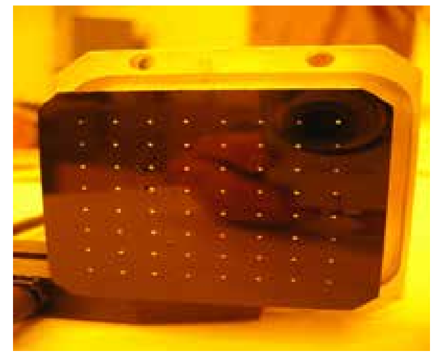
Vacuum can

PWC

Scintillation Fiber Profile Monitor

- Started as R&D project to reduce beam losses of SWICs and PWCs.
- **Detector Specifications:**
- Fiber type – St. Gobain type BCF-12MC.
- Fibers are mated to 64 channel microchannel plate PMT for electron multiplication:
- Burle Planacom # 85011-501
- HV = -2300 (Gain = 800,000)
- Light output – 5 photo-electrons/MIP/fiber.
- **Detector Assembly:**
- Set of 32 fibers/plane having Diameter 0.75 mm are epoxied to
- both sides of a ceramic board at a pitch of 2 mm.
- Fibers are bundled and epoxied into a vacuum feed-through that
- match the optical inputs of the Planacon PMT.
- Vacuum to 10^{-7} Torr – limited by the epoxy.
- Tests showed noise overcame signal around 2000 particles with background subtraction.
- We are now in the process of making a new prototype using scintillation fibers only in the active area of the beam. The fibers are then spliced to clear fibers from Saint Gobain #698MC-00151 to reduce/eliminate the noise contribution of the beam-halo. If the improvement is successful we expect to display beam down to a few 100’s particles.

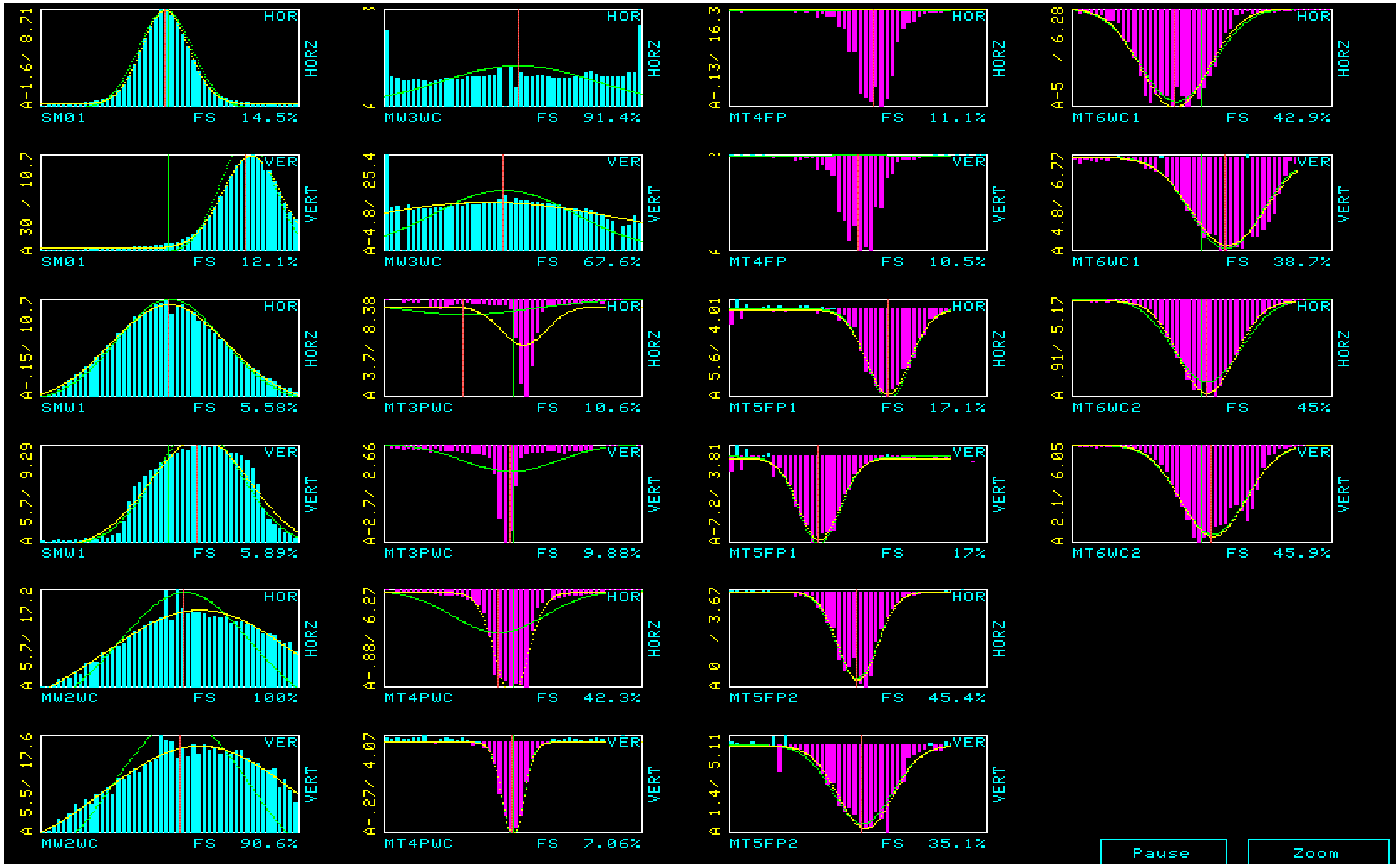

Detector during assembly


Polished epoxy block


During installation

SWIC/PWC/Fiber display

SWICs' displays are blue, PWCs' and Fibers' are magenta – i.e., MT4PWC and MT4FP. Primary beam was 10^{11} ppp and secondary beam was 10^{10} ppp.



Conclusion

- **Beam intensity monitoring:**
  - SEMs will operate above 10^{10} ppp.
  - Ion chambers saturate above 10^{10} p/cm^2-sec.

- **Beam Profile Monitoring**
  - **Wire SEMs** • Below 10^{10} particles the signal becomes marginal to be displayed with only the scanner.
    - Investigating the possibility of using preamps for smaller signals.
    - The preamps will have to reside in the tunnel. Radiation damage.
  - **SWCs, new PWCs, and SFPM** Used to display low intensity profile.
    - Because of the large dimensions of the beam in collection beamline and in the decay ring new detectors will have to be built whether they are going to be installed in vacuum cans or in a beamline vacuum break.