Date : 01/16/2016

EIC Detector R&D Progress Report

Project ID: eRD15
Project Name : R&D for a Compton Electron Detector
Period Reported: from 07/22/2016 to 01/04/2017
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Abstract

Precision polarimetry is an important component for the EIC. It aims at reaching 1% level precision. Compton Polarimetry is commonly use for electron polarimetry. It allows a non invasive measurement of the electron polarization. Accuracies up to 0.52% were achieved using the Compton Electron detection. Sub-percent precision is foreseeable for EIC though the significantly higher current and space constraints require an extensive study to reach such accuracy. This proposal is looking at the option of a semi-conductor detector in a Roman Pot chamber to detect the Compton electrons.

EIC Detector R&D Progress Report

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January 18, 2017

1 Progress Report Section

1.1 Past

1.1.1 What was planned for this period?

Here is the list of task that were approved by the committee for fiscal year 2017.

- implement simulation on the farm and run with the full detector setup to determine background in the detector from the interaction point
- complete beamline pipe in simulation to look a background contribution from the pipe
- implement beam halo in simulation
- implement polarization analysis and study the systematics
- complete the wakefield simulation to have a first estimate of the power deposit in the detector to determine if Roman Pot design is doable for the electron side
- study of synchrotron radiation effect in the detector
- reduce background and protect detector through shielding
- study of effect of shielding on measurement
- show TOTEM detector can reach less than 100 ns pulse width making it compatible with eRHIC beam structure

Also from last EIC user meeting, a parity violation experiment was presented which would benefit of better than 1% accuracy on electron polarimetry making this study all the more relevant to determine the ultimate accuracy that can be achieved for a parity violation program.

1.1.2 What was achieved ?

- implement simulation on the farm
- implement beam halo in simulation
- complete the wakefield simulation to have a first estimate of the power deposit in the detector to determine if Roman Pot design is doable for the electron side
- study of synchrotron radiation effect in the detector

1.1.3 What was not achieved ,why not and what will be done to correct ?

- run with the full detector setup to determine background in the detector from the interaction point : 75% done, simulation need to be run with high statistics and checked with physics generator
- complete beamline pipe in simulation to look a background contribution from the pipe : still need to add beampipe in magnet, pipe and chambers from IP to chicane
- implement polarization analysis and study the systematics : on-going, code was retrieved from Hall C QWeak experiment but needs to adapted to two dipole setting mostly a question of time
- reduce background and protect detector through shielding : depends on previous background analysis
- study of effect of shielding on measurement : to be redone with high statistics and need analysis for accurate assessment
- show TOTEM detector can reach less than 100 ns pulse width making it compatible with eRHIC beam structure : test stand started, analog amplifier ordered. Rest of equipment will be ordered by end of January when money is transferred. First look at analog signals shows grounding and shielding work needed to see signal.

1.2 Future

1.2.1 What is planned for the next funding cycle and beyond ? How, if at all, is this planning different from the original plan ?

For the next 6 months we will continue the efforts to complete the remaining items from the list mostly finishing, completing the beamline and adding physics event to the full simulation. From the synchrotron radiation study a large amount of power is produced and reaches the detector and beam pipe. We need to determine what those photons are doing to the detector. Synchrotron photons files will be produced to be used as input file to the GEMC simulation to determine the radiation dose deposited in the detector and evaluation the dose from synchrotron induced neutron production. From the preliminary results it seems most background are under control, though the Bremstrahlung studies assumed a fixed value for the vacuum. In real operation the quality of the vacuum can vary a lot because of the beam and how good the beam is tuned. For next fiscal, we would like to start a preliminary study of the dynamic vacuum with beam. A presentation on this topic was made at the JLEIC collaboration meeting in March 2016 [**?**] by Marcy Stutzman about codes to study the evolution of the vacuum including outgassing from the beam pipe due to synchrotron radiation using the Molflow+ and Synrad package which was used for the Advance Photon Source studies. A dedicated proposal for this topics might be proposed since it affect the general beam quality and background of the full EIC setup. Impedance and High Order Mode will be computed more accurately and the geometry will be optimized to determine the minimum power deposit in the detector.

1.2.2 What are the critical issues ?

The main critical issues to be addresses by this proposal :

- determine the signal to background expected from simulation on which depends the choice of the photon source and detector : so far from the preliminary background results the baseline laser source will be a single laser unless we find a huge source of background requiring an improvement in laser power
- have a preliminary design for the beamline for the JLEIC design based on Roman Pot for JLEIC : the Roman Pots were never used on an electron beam, there was a major concern of RF power being significantly higher but preliminary results indicates the power of the order of 2.5 kW without optimization making the roman pots a viable solution. An optimization of the thin window thickness and of the design of the beam line vacuum chambers will have to be done to minimize the effect of synchrotron radiation. Solution used in the PEPII accelerator are applicable
- obtain a detector with a timing response faster than 100 ns, to be able to separate the different sources of eRHIC in the case the ring linac design and handle high single rates for JLEIC
- have simulation and analysis to estimate the expected accuracy of polarization measurement for a given design

- determine if background from IR is an issue for the JLEIC design where the polarimeter is placed after the IR
- develop a beam test stand in the current subpercent capabable Compton Polarimeter to prove that the chosen detector reaches the needed specifications and does not introduce systematics preventing to reach 1% accuracy level. The setup could be placed at JLab or at higher current storage ring to either test the Compton accuracy or cross check RF HOM and synchrotron results from the simulations

1.3 Manpower

Reminder of planned manpower for 2017

Personnel	% FTE	location	tasks
Alexandre Camsonne	20	JLab	General organization,Wakefield studies, postdoc supervision
David Gaskell	5	JLab	Geant3, Laser system, postdoc supervision
Joshua Hoskins	50	JLab	GEMC simulation and data analysis, JLab bench testing
Michael J. Murray	5	Kansas University	detector, electronics
Christophe Royon	5	Kansas University	detector, electronics
Nicola Minafra	5	Kansas University	Wakefield and electronics

Table 1: Manpower allocation for fiscal year 2017

1.4 External funding

None

1.5 Publications

A proceeding for INPC2016 which was held in September 2016 is in the work and will be published in 2017. We plan to submit the detector bench results in fiscal year 2017.

2 Budget

Following is the expected requested budget for next fiscal year in order or priority (highest first). It mostly consist of the parts which were requested last time for the beam test setup and not funded, the man power and travel.

Allocation	Amount (K$)	Amount with overhead (K$)	Cumulative (K$)
Postdoc	33	50.99	50.99
Travel	15	23.175	74.16
CST license	7	10.9	85
Amplifier design	20	30.9	115.9
Discriminator design	20	30.9	146.8
Vacuum chamber	7	11	157.59
Detector holder	7.5	11.6	169.175
Test flange	5	7.725	176.9
Total	114.5 K$	176.9 K$	

Table 2: 2017 Budget request. This list is prioritized, with the highest priority items at the top.

Half of a CST license was added to be allowed to run the Wakefield studies without interfering with other work going on the SRF JLEIC group. This would allow more accurate results and the possibility to optimize the geometry.

The budget requested is 146.8 k\$. This would allow us to have a multichannel amplifier and discriminator to test several channels of detectors at time for efficiencies studies on the bench.

If budget has to be cut by 25% we could continue the background simulation work, optimize the RF shield by only funding the first three items 115.9 k\$.

If budget can be increased by 25% we will design and build parts for the beamline vacuum chamber for a total of 176.9 k\$. A full polarization measurement could be carried on with JLab beam.

3 Report

3.1 Simulation

The focus of the work thus far has been determination of signal-to-noise and background contributions due to halo via simulation. This work required construction of beamline and detector models in GEANT4 as well as development of Compton electron generator and halo generator. Results from the our model are intended to be cross checked with our GEANT3 model; the GEANT4 model can then be added in to the full EIC beamline. Currently the simple beamline geometry has been implemented, including the electron detector and apertures. Subsequent beamline elements and shielding will be added as, for example, studies of the backgrounds from the upstream IP progress. All simulation software is set to be run on the batch farm so higher statics run should be possible in the future.

3.1.1 Compton Generator

A Compton event generator and accompanying analysis software have been developed. Originally we had planned on using a Compton generator developed by Richard Petti from eRD12 by editing the output format to work with our simulation software. We found a discrepancy of the results with Geant3 and theoretical asymmetry. Since we were planning to optimize the generator a new generator was written closely replicating the Compton Event Generator from the simulation package which was used for QWeak analysis. We are crosschecking to try to find the issue with how we are using the initial generator since the theoretical values given by the generator agrees with ours, we suspect a possible bug in the generation of the input file from the generator.

Using the new generator we have preformed GEANT4 simulations to characterize the electron detector rate and signal-to-noise ratio. Simulations were done for a single pass, CW laser with 10 W of power. The beam energy was taken to be 5 GeV at 1 A current and the beamline vacuum was set to be 10^{-9} torr. Signal-to-noise results for both the electron detector and photon detector using GEANT3 are shown in Figure 1 and results for the electron detector using GEANT4 are shown in Figure 2.

Results from both GEANT3 and GEANT4 are consistent in the predictions of the electron detector rates and signal-to-noise suggests, not taking into account additional backgrounds from the upstream interaction region, that a 10 W single pass laser could be a valid choice. The measured asymmetry in the detector was computed in Figure. 5 and is consistent with theoretical predictions.

An estimate of the radiation dose was computed using simulation in Figure. 6. The plot shows that the majority of the dose is due to Compton scattering with fairly low rates during laser off periods. More work is to be done in determining the time needed to make a sufficient measurement of the polarization and determine the best choice of detector, however dose rate per hour per strip the simulation give a radiation hard detector such as diamond is a top candidate.

[ht!]

Halo Generator A halo generator was developed to look at backgrounds generated due to halo interaction with mirror apertures associated with a Fabry-Perot cavity in the Compton chicane. The generator was modeled using a double Gaussian distribution as described in the PEPII report and is given by,

$$\frac{dN}{dxdy} = e^{-\frac{x^2}{2\sigma_x^2}-\frac{y^2}{2\sigma_y^2}} + Ae^{-\frac{x^2}{2(S_x\sigma_x)^2}-\frac{y^2}{2(S_y\sigma_y)^2}}. \quad (1)$$

The generator has been finished and works properly with our GEANT4 simulation software, GEMC, however due to the unexpected need for a new Compton generator and the high amount of statistics needed we have not finished a study of the halo background. The event generation will be optimized for the halo study to make it more efficient.

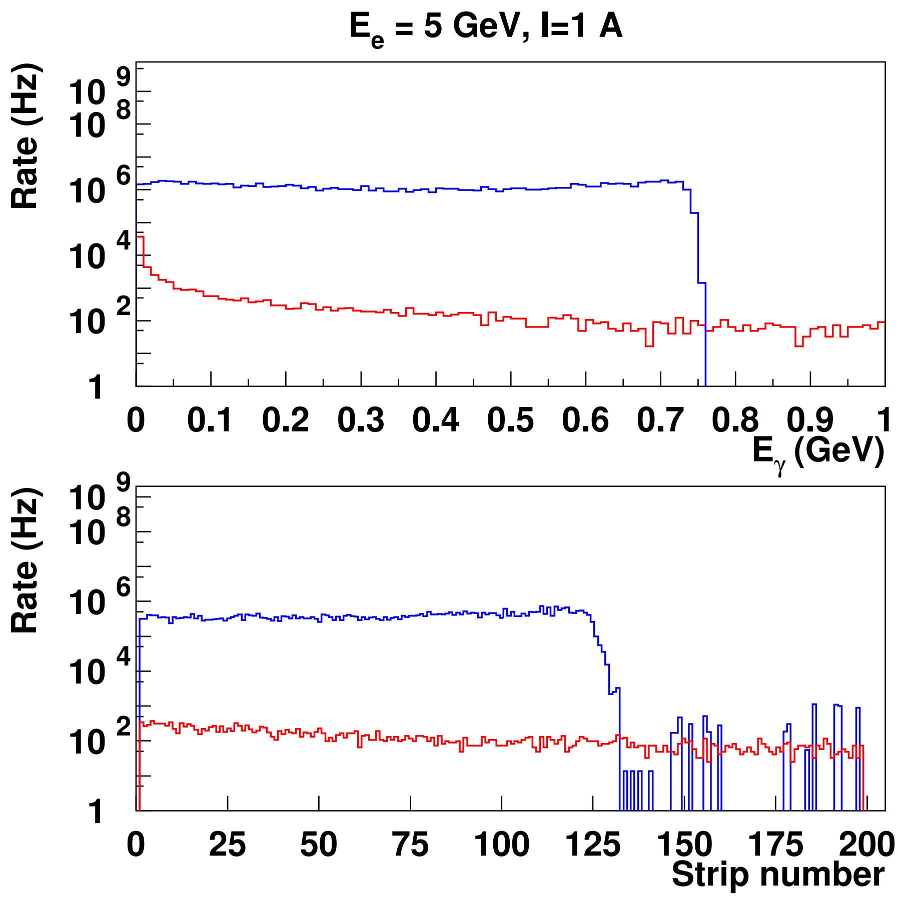

Figure 1: *Simulated rates in the photon detector (top) and electron detector (bottom) for Compton backscattering (blue curve) and Bremsstrahlung (red curve). The beamline vacuum is taken to be* 10^{-9} *with a beam energy/current of 5 GeV/1 A. The electron detector spectrum is plotted vs. strip number in this case strip 25 corresponds to the zero-crossing of the asymmetry (about 2 cm from the beam for our layout).*

3.1.2 To be done

A number of thing still need to be finished in the second half of the project, and we were significantly slowed by the need for a Compton event generator. In the coming year we plan to include the full EIC lattice into our model and look at backgrounds originating from the upstream IP. The only hold on this at the moment is the need for a generator for that region (this has been developed by other member of the JLEIC group as has been in use for some time). As mentioned we also plan to look at the background due to halo; this should be started in short order after the new year given that we have a working generator and have only been lacking time with other parts off the project to finish it. Lastly we plan to work on polarization extraction. Initially we had planned on using software previously used in the Qweak experiment to extract the polarization from the electron detector signal, but we found that the geometry on which the extraction is based is incompatible with the current EIC Compton geometry. The changes needed to fit the extraction code to our geometry is straightforward and will be a priority after the halo studies in the coming year.

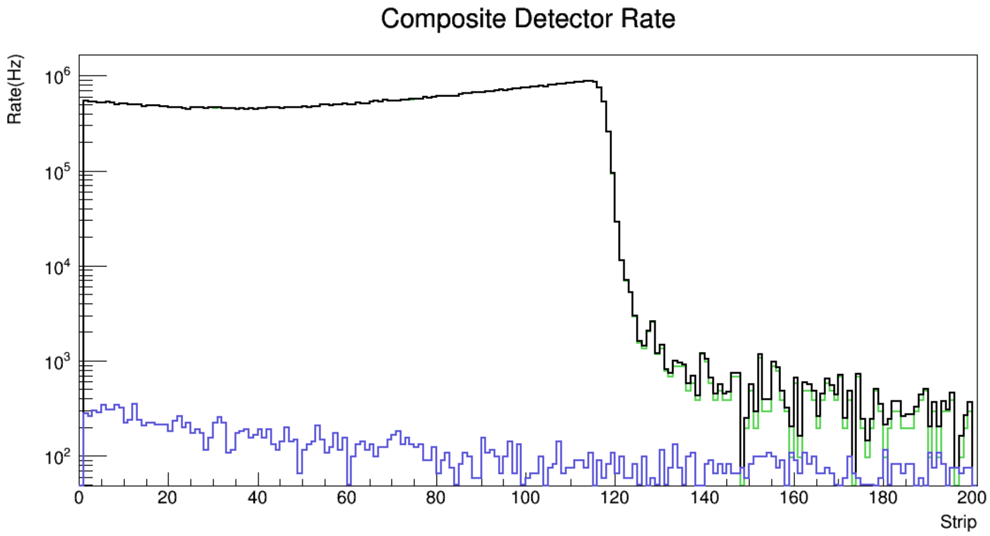

Figure 2: *Composite rate in electron detector due to both background and Compton scattering. The background alone is shown in blue, Compton in green, and composite rate in black.*

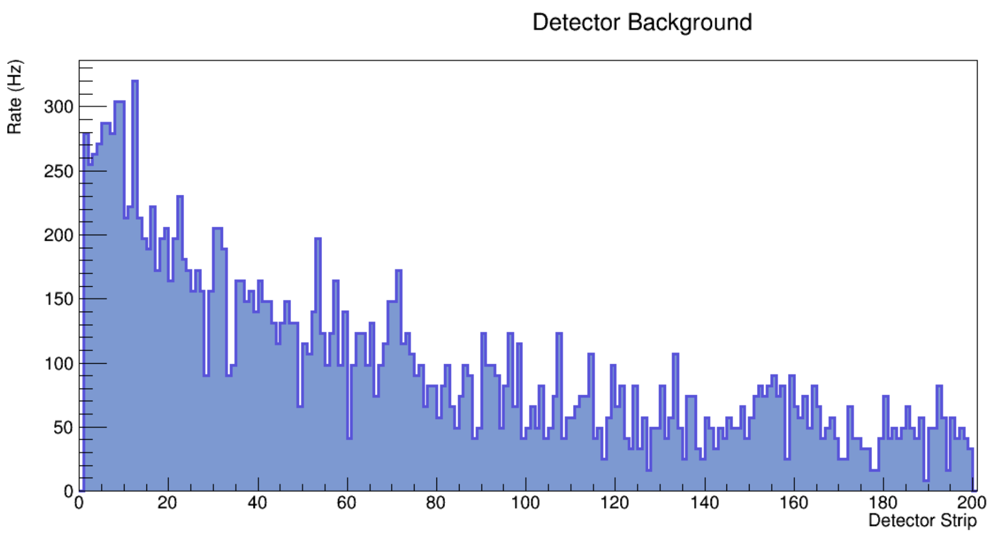

Figure 3: *Background rate seen by electron detector plotted versus position on detector(strip number).*

4 Wakefield estimate

An impedance calculation was performed using the simple geometry showed in Fig. 4 Fig. 8 and Fig. 9.

Calculation had to be interrupted after 37 hours of computation since we only own a single license of the software. Most of the modes were resolved as shown in figure 10.

Folding in the electron beam structure

With the impedance spectrum and the electron beam structure shown in Fig.11, a preliminary value of 340 Watts, leading to a value of around 2.5 kW at 3A. This shows that the HOM is worse as expected for JLEIC electron beam but the value is not unreasonable since the setup was not optimized and has a lot of hard edges. This kind of power could already be handled with a liquid cooling system. A more realistic model will be used for the next computation and its geometry will be optimized to reduce further the impedance and power deposit. Preliminary results show the HOM RF power does not seem to be a show stopper for the Compton electron beam polarimeter.

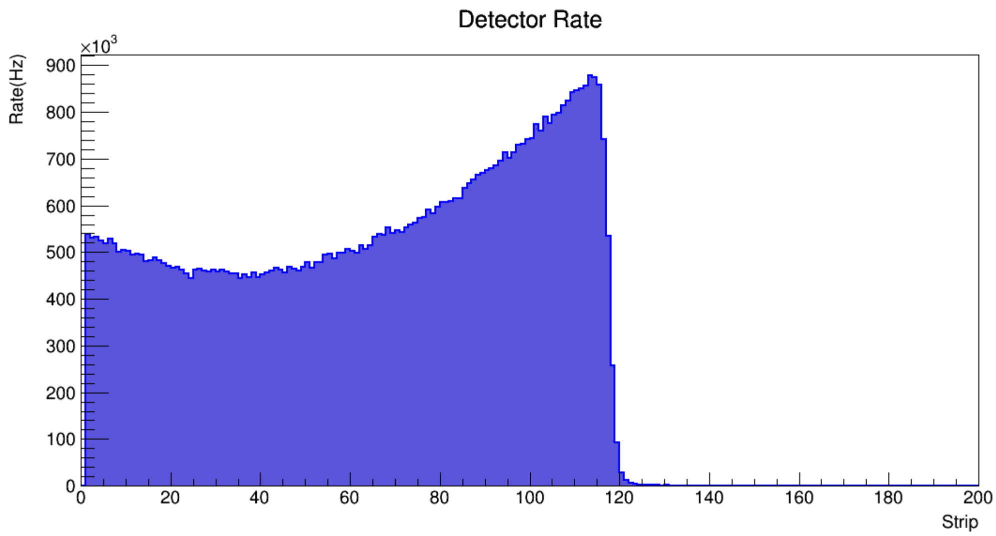

Figure 4: *Rate seen by electron detector due to Compton scattering plotted versus position on detector (strip number).*

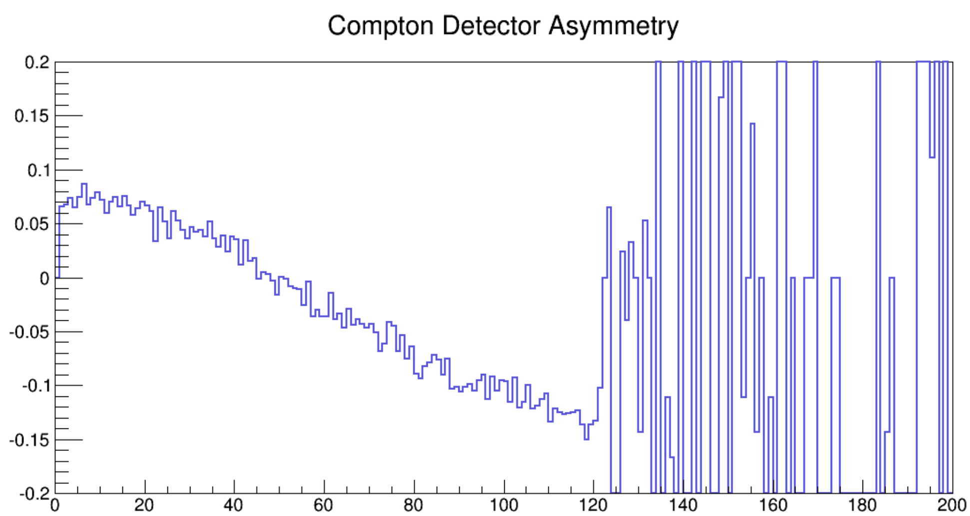

Figure 5: *Measured asymmetry on the electron detector.*

5 Synchrotron radiation studies

Further studies for synchrotron radiation were carried by Mike Sullivan.

5.1 Photon detector

After our first meeting with Mike Sullivan, he advised to switch to a double dipole setup to soften the bend and reduce the amount of synchrotron making it to the detector. The new synchrotron radiation setup is shown in figure in Fig. 13

With this magnet and exit window configuration the photon detector seems to be fine 3 : the 5 and 7 GeV cases have no background, the 10 GeV case still has a large number of photons incident on the detector and probably will need a shield in front of the detector. The linear power density on the beam pipe wall is also fine of the order of (50 W/cm).

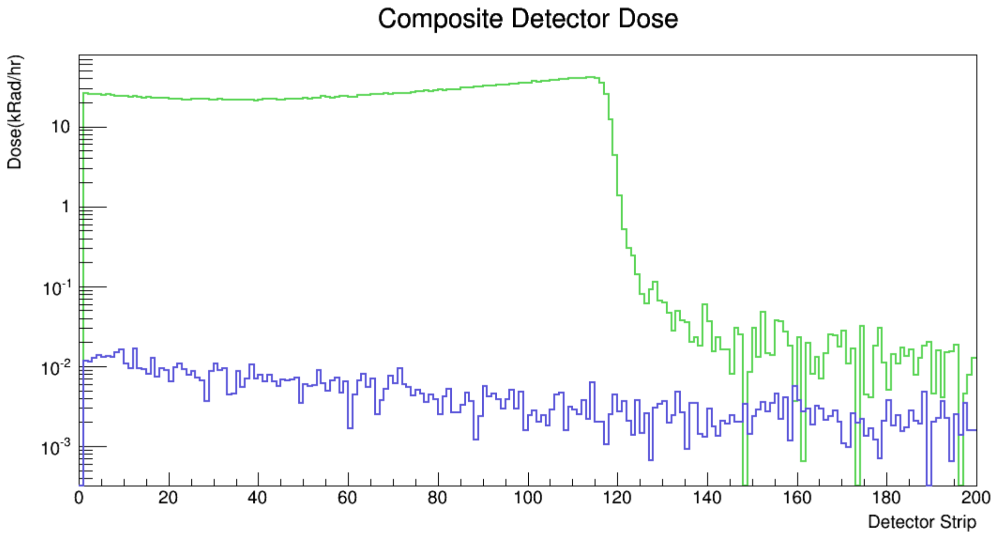

Figure 6: *Radiation dose (kRad/hr) on electron detector due to background(blue) and Compton scattering(green).*

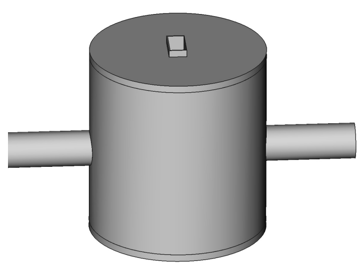

Figure 7: Simple CAD model of Roman Pot

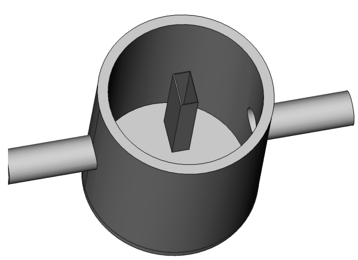

Figure 8: Simple CAD model of Roman Pot inside view

5.2 Electron detector

The electron detector is placed in a favorable position out from the primary fan of synchrotron radiation from the dipoles.

The only contribution of synchrotron radiation can come from multiple bounces in the beam pipe which is typically of the order of 3 per cent.

Total incoming power from synchrotron radiation are summarized in Table 4.

To evaluate the synchrotron radiation power reaching the detector because of bounces, the pipe was

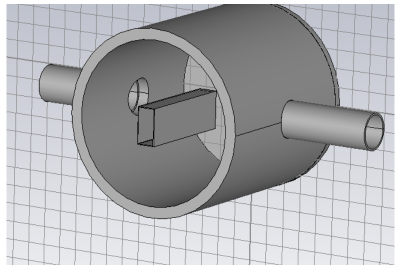

Figure 9: Simple CAD model of Roman Pot imported in CST particle studio

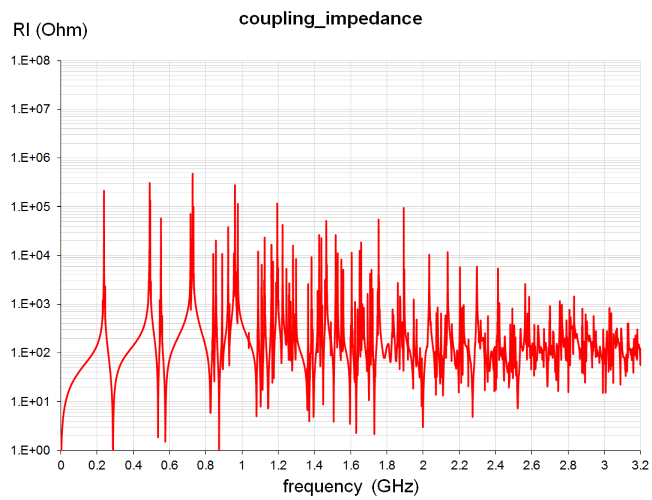

Figure 10: Impedance of the simple RP setup

Energy (GeV)	Energy deposit in detector (keV)
5	0
7	25.4
10	46.6

Table 3: Energy deposit in the photon detector

Energy (GeV)	Current (A)	Energy deposit in detector (MeV)	Photons	Power deposition kW
7	3	175	1.60×10^{11}	35.7
10	0.7	969	5.4×10^{10}	35.2

Table 4: Synchrotron power deposit on the electron detector beam pipe at 7 GeV and 10 GeV beam energies

divided into 6 regions as shown in Fig. 14 and the values can be found in Table 5.

Applying a 3 per cent reflection coefficient the synchrotron radiation reaching the detector from a bounce (Fig. 15)of the main synchrotron fan on the beam pipe is significant of the order of 4 GeV for both energies.

The case of 1 mm thick aluminum window was studied giving a value of 175 MeV per bunch at 7 GeV and 969 MeV per bunch.

In order to reduce the direct reflections to the detector, tips were integrated to the beam pipe as

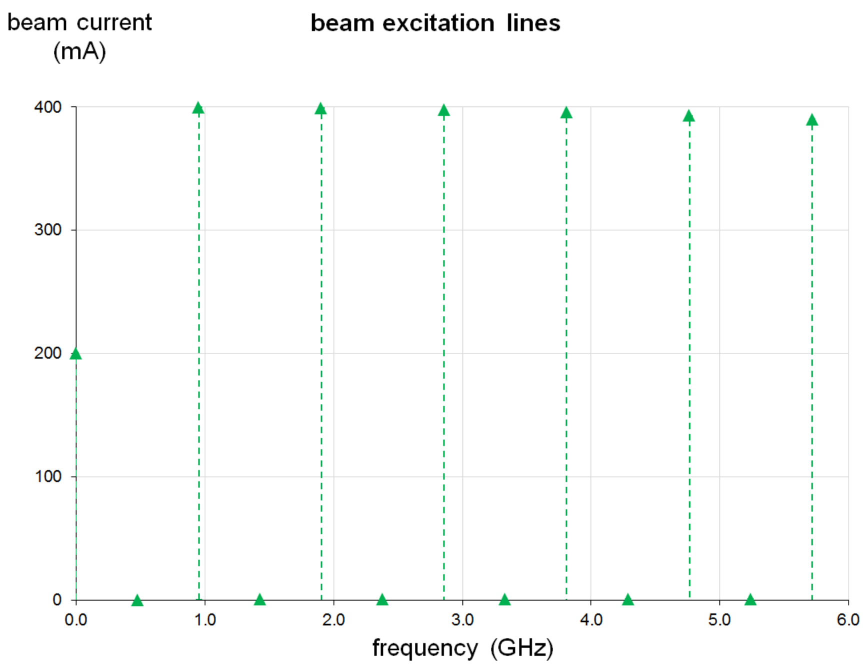

Figure 11: Electron beam structure for 0.4A of beam

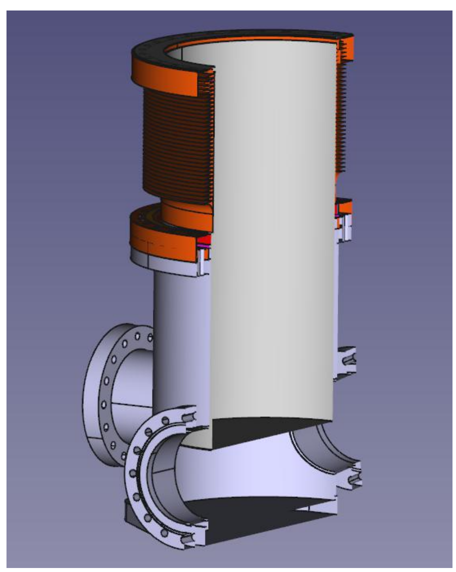

Figure 12: Realistic model (in terms of RF) using real design parts

shown in Fig. 16.

One option to reduce the bounce is to add tips inside of the beam pipe to prevent reflections to the detectors.

This solution reduces the Synchrotron radiation energy deposit to 29 MeV. Though the addition of tips increase the power density beyond what can be sustained by the pipe.

Another solution used in PEPII was tested using an additional chamber, as shown in Fig. 17

Using an antechamber design with a thin vacuum chamber fitting inside of the dipole, synchrotron radiation coming from the first bounces can be mitigated and using a sloped edge linear power density

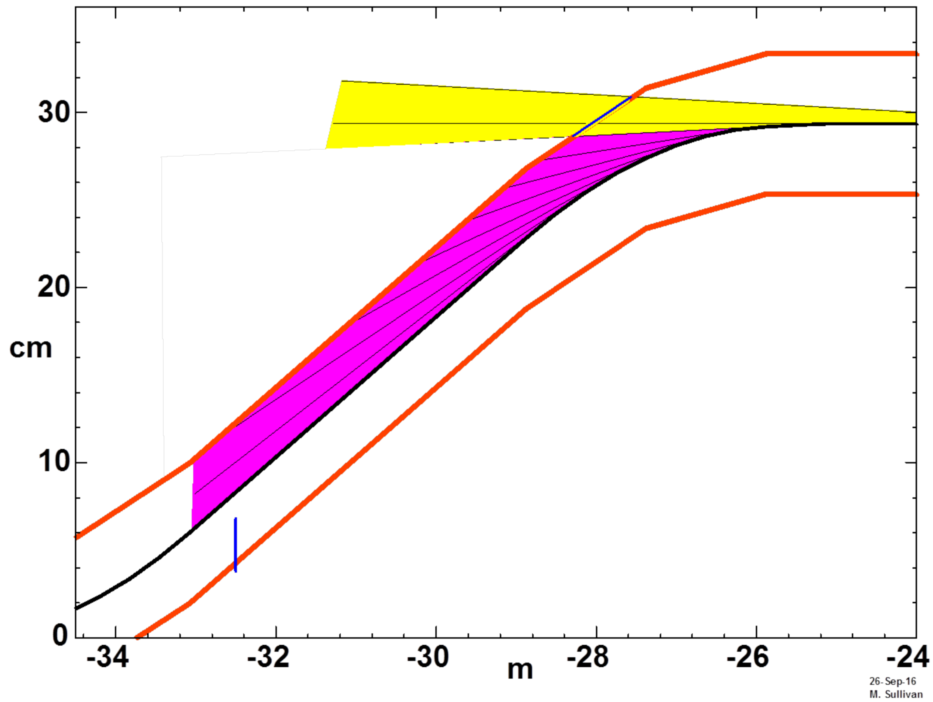

Figure 13: Synchrotron radiation in the double dipole setup

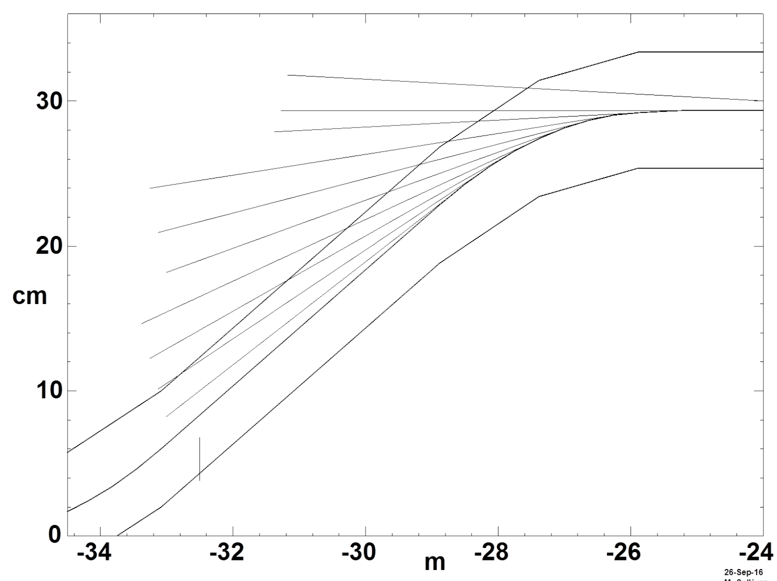

Figure 14: Synchrotron radiation power deposition on the beam pipe

can get as low as 63 kW/cm. A bit of design work is needed to determine interferences, cost and vacuum pumping needs but this kind of design has already been done for Hall A Compton 12 GeV upgrade.

Segment	7 GeV W/cm	7 GeV N γ	10 GeV W/cm	10 GeV N γ
1	131	9707	129	3350
2	135	12594	133	4358
3	128	16385	127	5540
4	94	23018	92	7883
5	66	40693	65	13759
6	37	2.98×10^5	36	1.01×10^5
Total		4.00×10^5		1.35×10^5

Table 5: Incoming linear density power and numbers of incoming photons from synchrotron radiation on each segment

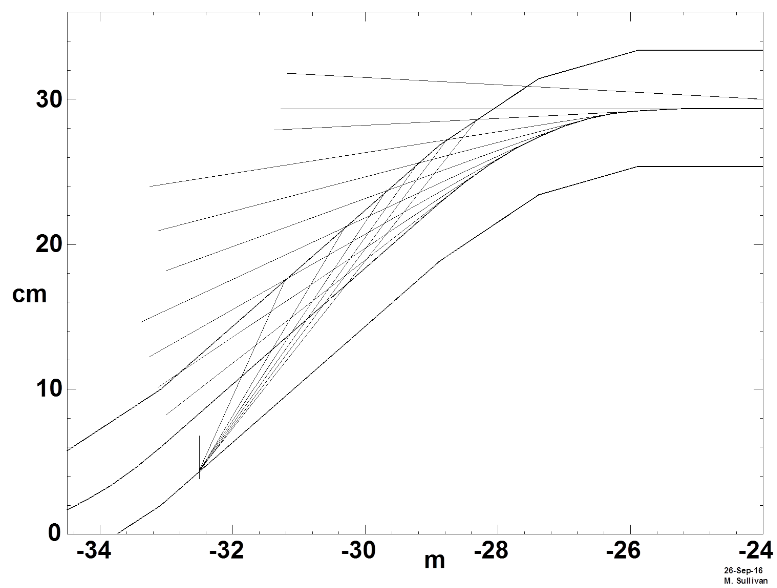

Figure 15: Synchrotron radiation bouncing of smooth beam pipe

6 Test stand

Joshua Hoskins started to gather the parts for the detector test stand and started preliminary testing using the current silicon detector and current Hall A and Hall C front end electronics Fig 18. A VME DAQ system Fig.19 and Fig.20 was setup with a TDC to readout the amplifier discriminators. This will be useful for multiple channels to study detector efficiencies.

The CIVIDEC amplifier was delivered and testing just started. We expect to be able to obtain pulse width shorter than 20 ns for one single channel. The SAMPIC system for recording of fast signal will be ordered when the money for 2017 will be transferred. Once the system is fully operational we will be able to study the timing response of the amplifier with our different detectors.

7 Conclusion

The GEMC based simulation with the new event generator matches the Geant3 simulation warranting the study of the full background using GEMC and the full JLEIC setup. So far on a preliminary incomplete setup, beam related background from Bremstrahlung and halo seem under control allowing the use of a single shot laser. Wakefield HOM RF power were evaluated on a simple design giving a value of the order of 2.5 kW which in the high range but still leaves the Roman Pot option as viable. Iterations of

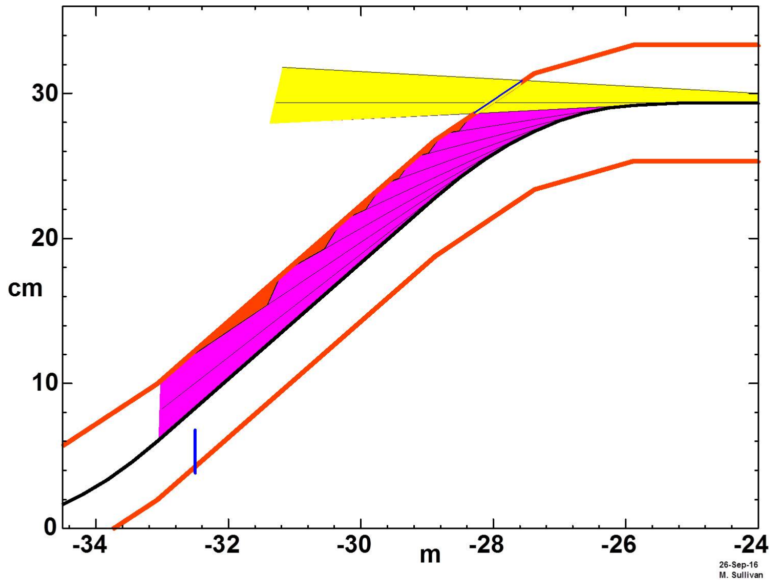

Figure 16: Beam pipe with tips to eliminate direct bounce to the detector

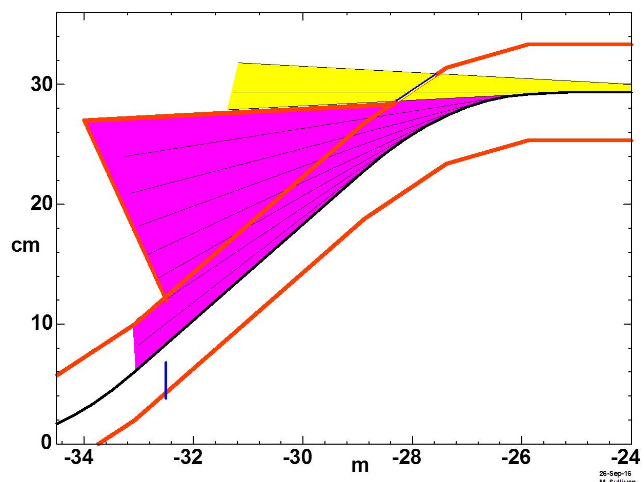

Figure 17: Antechamber design to mitigate synchrotron radiation bouncing

the geometry will be done to further reduce this power. Synchrotron energy deposit were evaluated to be high also in the detector and a solution using an antechamber was designed solving this issue. Remaining sources of background from physics from IR, halo will be studies in the next half of this fiscal year along with the effect of shielding on the polarization measurement. Additional study on sources of background from outgassing and gas of proton trapped around the electron beam will start to be evaluated in next fiscal year.

References

[1] Vacuum Consideration for the Beamline and IR, Marcy Stutzman

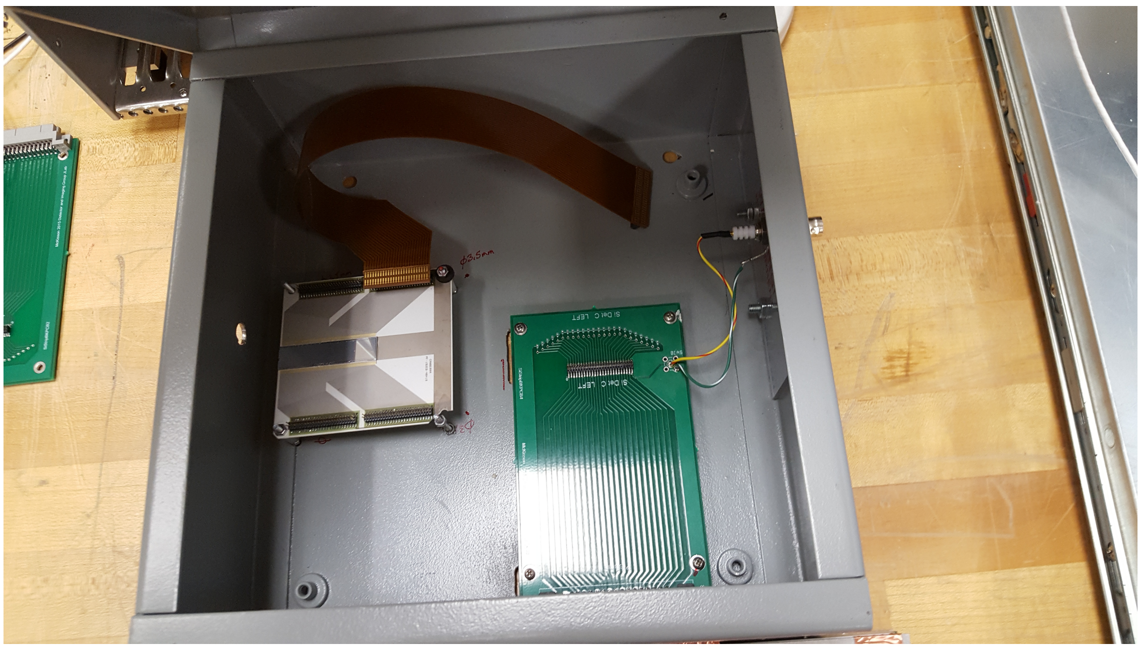

Figure 18: Silicon detector in the test box

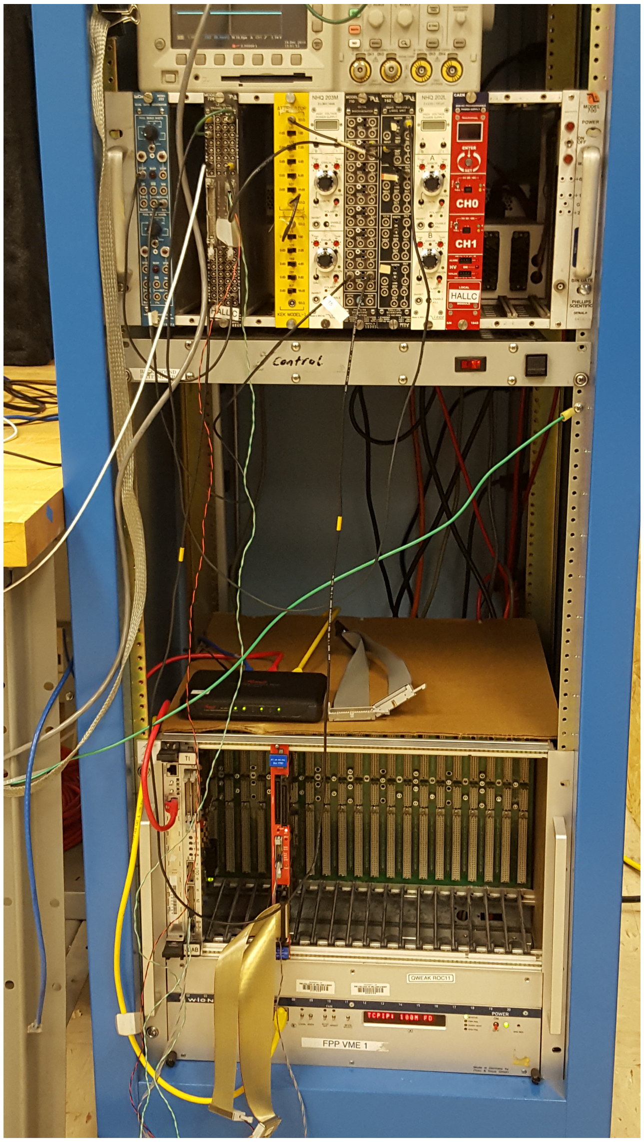

Figure 19: VME and NIM crates

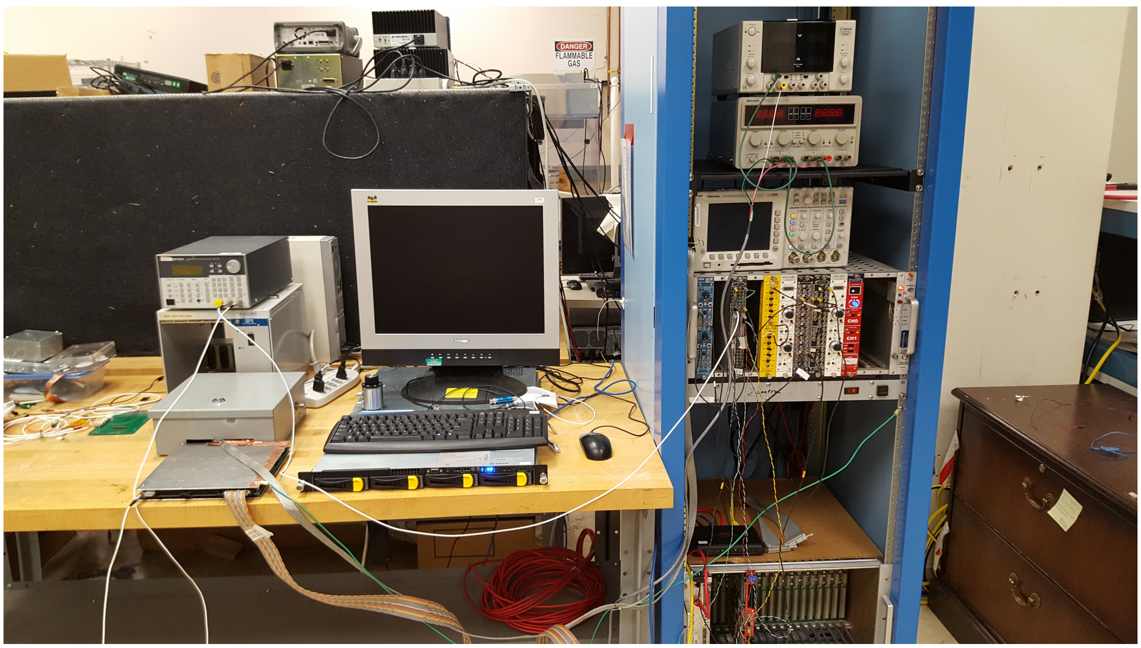

Figure 20: Full DAQ setup