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EIC Detector R&D Proposal

Project ID: eRDX
Project Name : Study of feasibility of electronics and detectors to determine bunch by bunch beam properties for the EIC ring ring designs
Period Reported: New proposal
Project Leader : Christophe Royon
Contact Person : Christophe Royon, christophe.royon@ku.edu

Abstract

For the JLab EIC and eRHIC ring-ring design, it will be desirable or even compulsory if the study shows that the electron and ion ring have to have the same number of bunches for stability. To obtain bunch by bunch information such as polarization or luminosity. We are proposing to study the feasibility of electronics and detectors capable to separate bunches spaced by a time of the order of 1.5 ns

EIC Detector R&D Proposal

Christophe Royon[1], Michael J. Murray[1], Nicola Minafra[1], Alexandre Camsonne[2], and David Gaskell[2]

[1] Kansas University
[2] Thomas Jefferson National Accelerator Facility

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1 Motivation for the proposal

Since the future EIC is a high luminosity doubly polarized machine. Polarimetry can be a limiting factor for all the measurement of an EIC. Polarization goes directly in asymmetry measurement or in measurements ad-hoc measurement such as luminosity measurement for cross section measurement. For example the electron polarization can be a major source of error for the parity violation program mentioned in the EIC white-paper section 4.3 where accuracy at 0.5 % level.

2 State of the art technologies

In order to be able to measurement bunch by bunch polarization accurately and efficiently, one need to be able to separate different successive bunch. The JLEIC beam structure will be 476 MHz and 119 MHz and planned to be 560 MHz for eRHIC ring-ring giving a spacing between bunch . A few detector can reach pulse width of less than 2 ns, namely MCP PMTs, thin gap MRPC, for some polarization or luminosity measurement high rates are expected and aging of those detectors could be premature. We are planning to investigate solid state detectors in particularly diamond which exhibit the fastest timing response and best radiation hardness at the cost of a reduced amplitude. In order to make up for the loss in amplitude, fast amplifiers are required to ensure a good signal to noise ratio for good efficiency of the detector. For the TOTEM experiment, the roman pots detectors are being optimized for 30 ps timing resolution for time of flight, while this timing resolution is overkill for an EIC, this electronics can serve as a base for a fast electronics capable of separating nanosecond level pulses taking advantage of the available analog bandwidth.

3 Preliminary results for different detectors

The following pictures were taken while investigating the possibility of separating pulses at 9.8 MHz frequency for erD15 proposal. Typically speed of semiconductor detector is driven by the preamplifier and shaping electronics. During our meeting with Nicola Minafra in Kansas University we took the opportunity to test their fast amplifier design. Signal with diamond and silicon detectors were recorded with a beta source and with a laser for the silicon detector. As expected detector response was much faster than 100 ns. For diamond detector, the pulse is around 8.55 ns wide as shown in Fig. **??**

For silicon detector, the pulse width was a bit larger around 14 ns as seen in Fig. 3. The signal is not as clean as for diamond, this still needs to be understood (we suspect a inhomogenous field due to only one strip being powered up but it would need to be tested by powering more than one strip). The silicon used was a 500 um thick silicon detector with 250 μm strips.

Since silicon is sensitive to the laser (unlike the diamond), we were able to test the timing response of the fast amplifier with the silicon diamond using a pulsed laser up to 10 MHz repetition rate, to make sure no overlap or saturation effect occurs because of a slow shaping time.

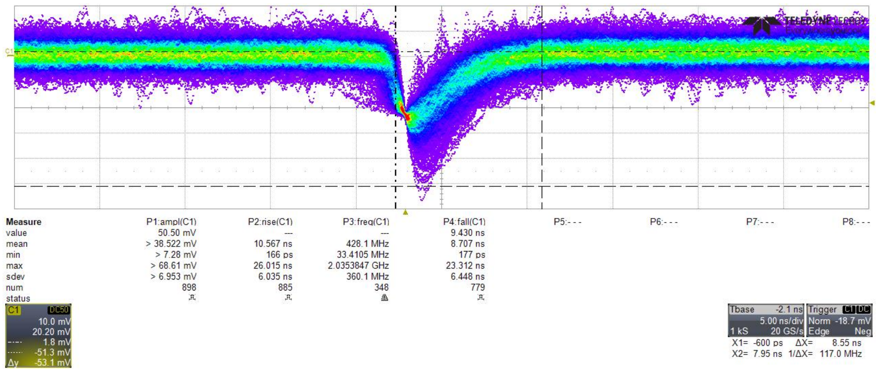


Figure 1: Diamond pulse infinite persistence with Fast KU amplifier with Sr90 source

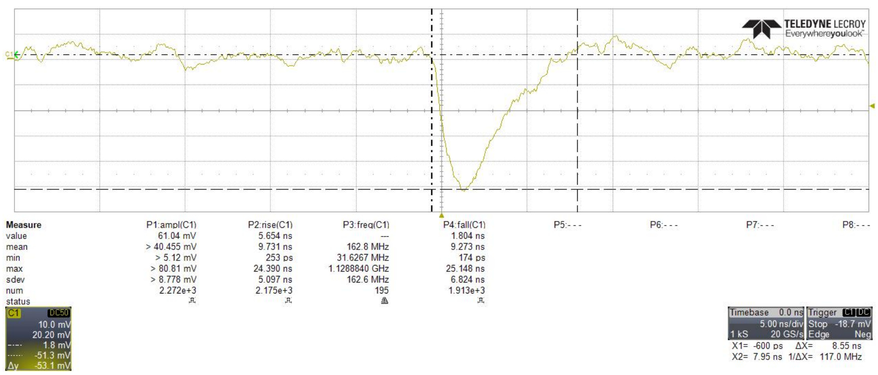


Figure 2: Width measurement of diamond pulse with Fast KU amplifier

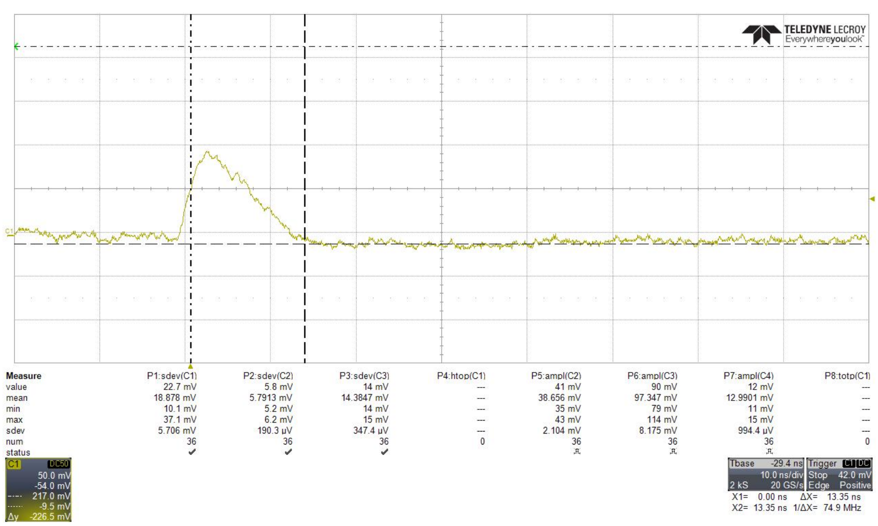


Figure 3: Single silicon detector pulse with beta source at 200V bias voltage

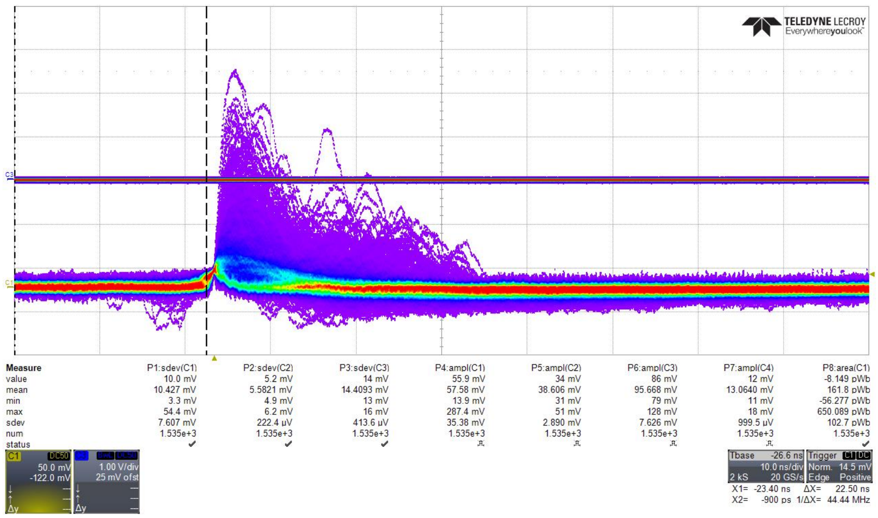


Figure 4: Persistence silicon detector pulse with beta source at 200V bias voltage

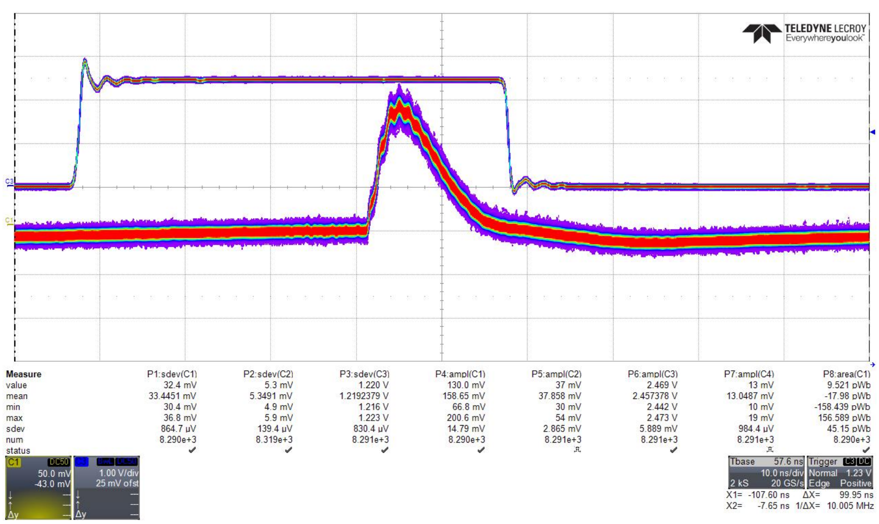


Figure 5: Pulse silicon at 10 MHz, large time scale

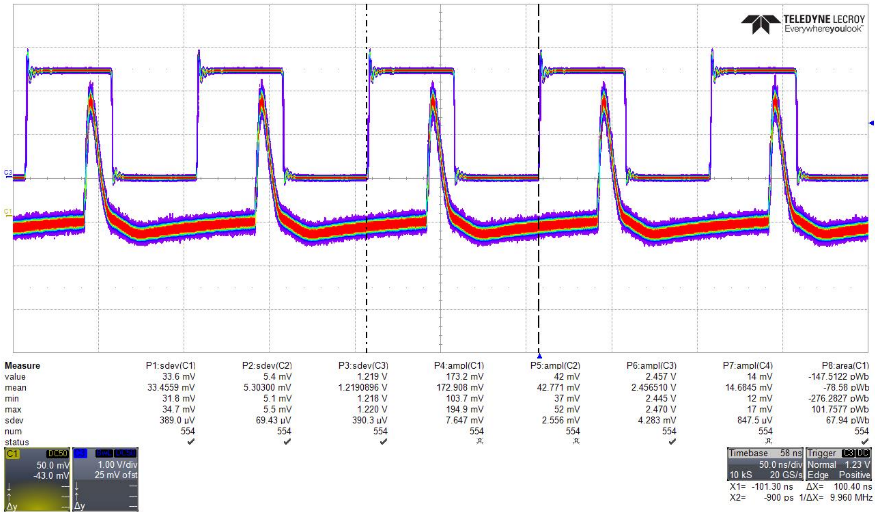


Figure 6: Pulses silicon laser pulsed at 10 MHz, large time scale

The pulses are seen to be cleanly separated at 10 MHz Fig. 6. Those results are encouraging to look at the feasibility of reaching nanosecond level pulses.

4 Proposal

4.1 What are the critical issues ?

The main critical issues to be addresses by this proposal :

- can a detector separate pulses spaced by only 1.5 nanosecond ?
- can standard CMOS technology amplifier be fast enough to cleanly separate 1.5 nanosecond separated bunches ?
- are there any major issues for scaling the current amplifier design to a large channel count amplifier ?

5 Proposal

5.1 Proposal deliverables

- simulate the detector and electronics response to determine if 1.5 ns pulses can be separated with a reasonable signal to noise
- modify the current amplifier one channel prototype optimized for short pulse width rather than timing resolution
- test the electronics performance using a laser on the bench with existing silicon detector, use a splitter to generate two pulses with time difference adjustable from 1 to 2 ns by varying pathlength on an optical table
- procure a detector with thickness optimized and test timing response with radioactive source
- test the detector performance in beam to determine efficiency and effectively separate beam bunches

6 Simulation and modeling

Nicola Minafra has all the codes to simulate the detector and electronic response as explained in his thesis [1] chapter 3 and 4. This allows to quickly simulate the signal to noise ratio of the detector and electronics to optimize the detector thickness and electronics. A quick example can be seen in Fig. 7.

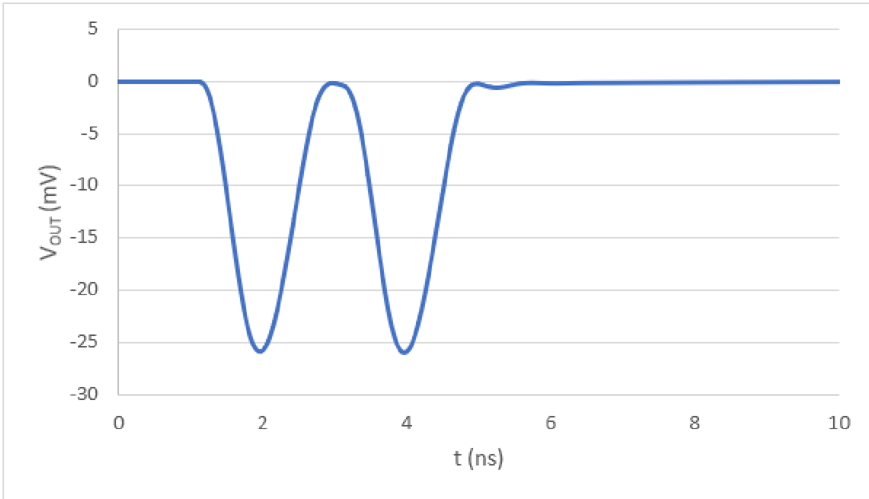
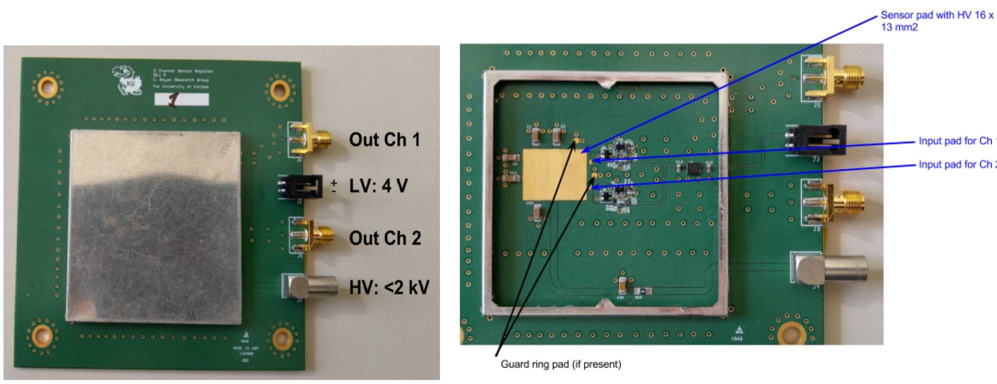


Figure 7: Simulation of two pulses 2 ns apart detected by a 5 pf detector fed to an amplifier setup for short pulses



(a) Shield plate.

(b) No shield plate.

Figure 8: The 2-channel version of the fast amplifier is shown with and without the shielding plate. The shielding plate is plugged onto the board and can be removed by lifting it with a screw driver. Inputs and outputs are shown along with biases voltages for the detector(high voltage) and electronics(low voltage).

7 Electronics

The KU amplifier board Fig. 8 is optimized for best timing resolution. By changing the resistor on the existing design the pulse width can be optimized instead of the leading edge.

We are planning to modify an existing board for the values of resistors from the simulation optimized for the shortest pulses.

For the second semester, a beam test at Fermi Lab or SLAC will be booked to determine the efficiency of the detector. If a beam test can be funded this year, a multichannel amplifier will be developed to be able to take data efficiently. Eventually we will try an integrated design as monolithic design or using an ASIC.

8 Detectors

In a first step we will use existing detectors to test the electronics performances. The JLab Hall A detector has 4 planes of 192 strips of 500 μm of silicon detector, we have 4 spares that can be used for testing on the bench to evaluate the timing properties of standard silicon. The JLab Hall C detector has 4 planes of 96 strips of 500 μm of diamond detector. Typical silicon detectors have a shaping time of the order of a few hundreds of nanoseconds which is not sufficient for the eRHIC beam structure in the case of several electron sources. The TOTEM experiment is using diamond detector 500 μm thick and thin silicon with thicknesses up to 50 μm thick to improve the timing resolution of the detector. Finally when all the electronics is tested with existing detector we will procure a diamond detector with the optimal size determined from the simulation. Timing response will be check with a radioactive source and efficiency will be tested using high energy beam.

9 Timeline

Task	Time estimate
Simulation, optimization, test	2 month
Amplifier modification	1 month
Development multichannel amplifier and production	2 month
Beam test preparation	1 month

Table 1: Timeline

9.1 Manpower

Planned manpower for 2017/2018

Personnel	% FTE	location	tasks
Nicola Minafra	50	Kansas University	detector and electronics simulation, amplifier design
Michael J. Murray	5	Kansas University	detector, electronics
Christophe Royon	5	Kansas University	detector, electronics
Alexandre Camsonne	5	JLAB	detector, electronics

Table 2: Foreseen manpower for 2017/2018

10 Budget

- We request to fund Nicola Minafra Kansas University postdoctoral research associate for 3 months, to carry out the simulation and design of the electronics optimized for separating particles 1.5 to 2 ns apart.
- the current amplifier design will be modified to reduce pulse width and will be testing using the laser test bench
- for beam test it will be desirable to have more than a channel of detector available, a multiple channel amplifier will be produced and a optimized detector will be procured. This would require 3 additional months of Minafra's time to prepare for a beam test.

Allocation	Amount (K$)	Amount with overhead (K$)	Cumulative (K$)
Simulation postdoc 3 months	18	27.81	27.81
Amplifier modification	5	7.725	35.535
Amplifier design postdoc 3 months	18	27.81	63.345
Diamond detector	2.5	3.86	67.20
Multichannel Amplifier prototype	20	30.9	98.1
Total	63.5	98.1	98.1

Table 3: 2017 Budget request

Budget	Amount (K$)	
Full	98.1	All deliverables, optimized detector and electronics and multichannel amplifier
-20%	82.8	beam test only single channel - multichannel amplifier designed
-40%	62.1	Simulation and bench test - no multichannel amplifier design

Table 4: 2017 Budget scenario

	Simulation and test	Single channel amplifier test	Multichannel amplifier design	Multichannel amplifier prototype	Sum
Kansas University	27.81	11.58	27.81	30.9	98.1
Sum	27.81	11.58	27.81	30.9	98.1

Table 5: 2017 Budget Matrix

All costs have to include the standard overhead of 54.5%, to summarize the minimum budget requested is 35.53 K$ which would give 3 months of simulation of electronics and detector and a one channel amplifier optimized for fast pulses. To plan for a beam test with an optimized detector this would add an additional 62.6 K$ to produce a multichannel version of the amplifier to have more than one channel for beam test to study efficiency.

References

[1] Minafra, Nicola, Development of a timing detector for the TOTEM experiment at the, LHC CERN-THESIS-2016-016, http://cds.cern.ch/record/2139815?ln=en

[2] Amrendra Narayan, Determination of electron beam polarization using electron detector in Compton polarimeter with less than 1% statistical and systematic uncertainty
https://misportal.jlab.org/ul/publications/downloadFile.cfm?pub_id=13934