Position measurement in RPCs using timing difference at both ends of strips

Jones JP [1,2], B Satyanarayana [1], G Majumder [1], K C Ravindran [1], K Hari Prasad [2, 3], M N Saraf [1], RR Shinde [1]

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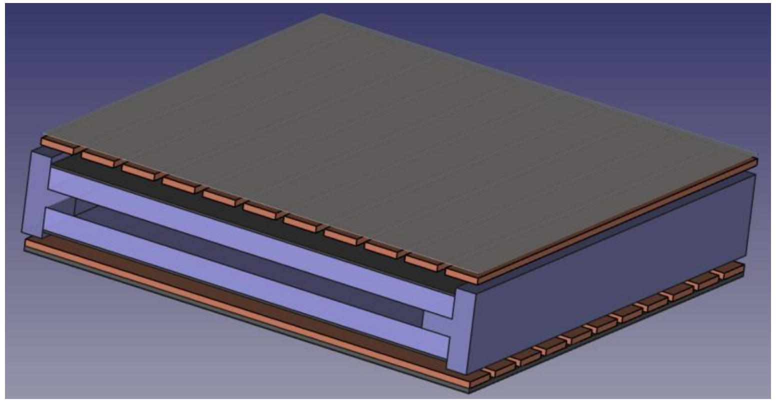
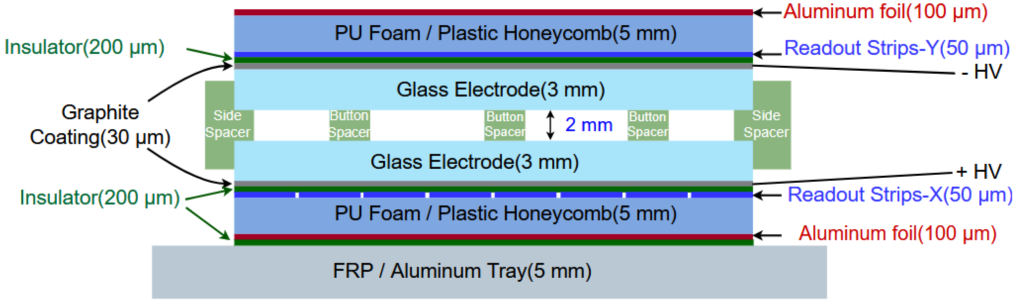
Contents

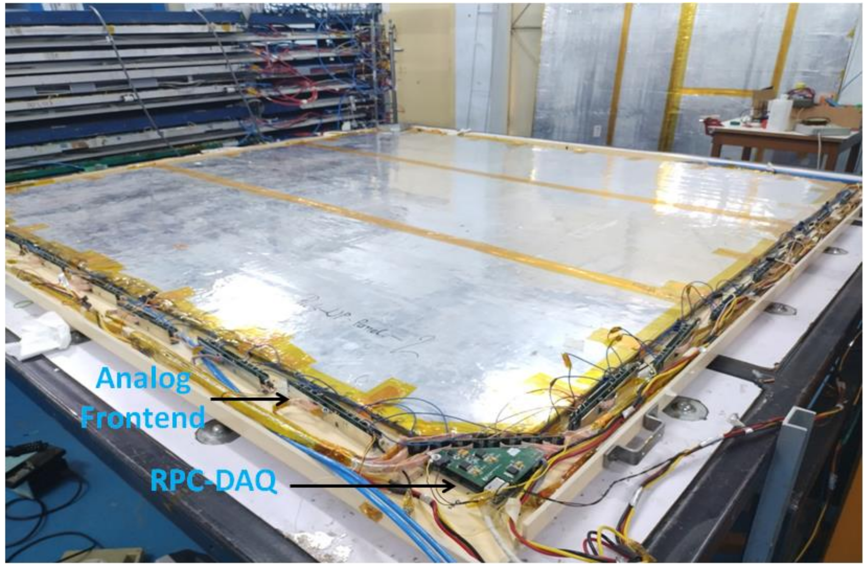
1. Resistive Plate Chamber



RPC model (not to scale)



RPC cross section

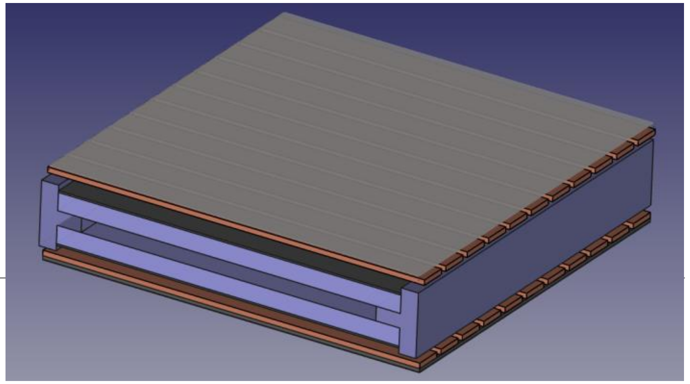


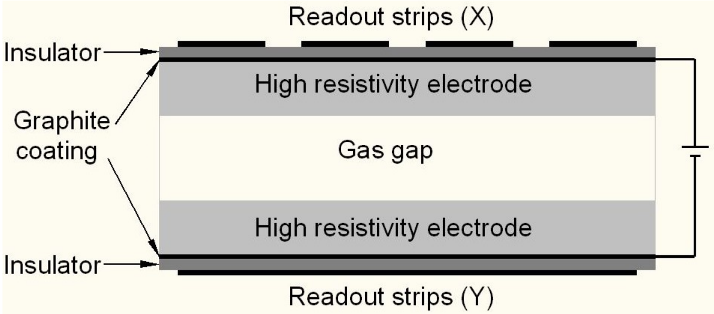
2mx2m fully assembled RPC at mini ICAL

- Gas mixture used: 95.2% R134a, 4.5% isobutane, 0.3%SF6
- Position resolution: ~6mm
- Timing resolution: ~0.6ns

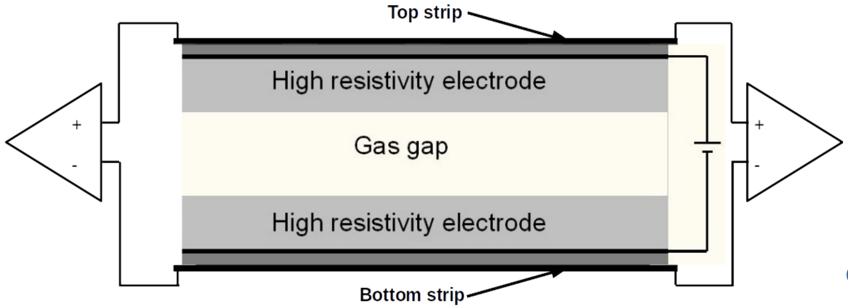
[1] arXiv:2201.09279

2.1 Alternate Readout Concept





Traditional RPC readout



NB: Top and bottom strips aligned in the same direction

Proposed alternate RPC readout

- Traditional RPC readout scheme has **two pickup panels** with conducting strips, with the pickup panels kept orthogonal so that **one gives the X-coordinate and the other gives the Y-coordinate**.
- This work proposes an alternate readout system, where we have top and bottom strips kept aligned in one direction (let's say X). Readout electronics (differential) is kept at both the ends of the strip. **From the difference in time of arrival (TOA) at both ends of the strip the position along the strip is reconstructed. The uncertainty in the development of avalanche will be cancelled out when taking the difference in TOA.**
- Advantages: lower electronic noise (both due to differential readout as well as due to return current flowing symmetrically) better timing and position resolution, similar costs, (slightly) less dead space.

2.2 Existing work


Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

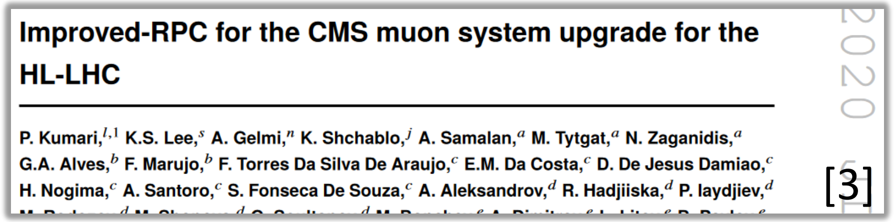
journal homepage: www.elsevier.com/locate/nima

MRPC-PET: A new technique for high precision time and position measurements

K. Doroud[a,*], D. Hatzifotiadou[b], S. Li[a], M.C.S. Williams[b], A. Zichichi[c,d], R. Zuyeuski[a]

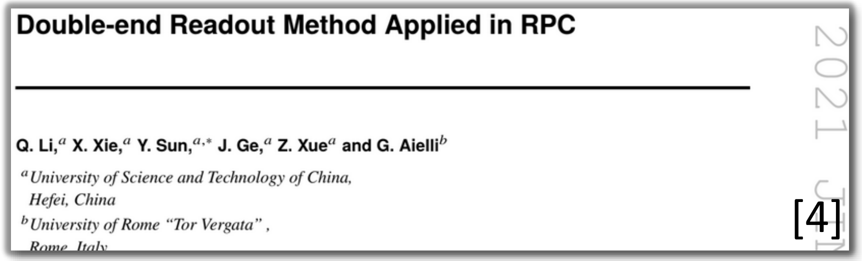
[a] World Laboratory, Geneva, Switzerland
[b] Sezione INFN, Bologna, Italy
[c] Dipartimento di Fisica dell'Università, Bologna, Italy
[d] PH Dept. CERN, Geneva, Switzerland

[2]


Improved-RPC for the CMS muon system upgrade for the HL-LHC

P. Kumari,[l,1] K.S. Lee,[s] A. Gelmi,[n] K. Shchablo,[j] A. Samalan,[a] M. Tytgat,[a] N. Zaganidis,[a] G.A. Alves,[b] F. Marujo,[b] F. Torres Da Silva De Araujo,[c] E.M. Da Costa,[c] D. De Jesus Damiao,[c] H. Nogima,[c] A. Santoro,[c] S. Fonseca De Souza,[c] A. Aleksandrov,[d] R. Hadjiiska,[d] P. Iaydjiev,[d]

[3]


Double-end Readout Method Applied in RPC

Q. Li,[a] X. Xie,[a] Y. Sun,[a,*] J. Ge,[a] Z. Xue[a] and G. Aielli[b]

[a] University of Science and Technology of China, Hefei, China
[b] University of Rome "Tor Vergata", Rome, Italy

[4]

[2] K Doroud et al, 2011. In multigap RPCs (MRPC):

Results: 104ps/cm, 18.3ps (1.7mm)

Caveat: the rise time of signals in MRPC is intrinsically smaller, this is due to the electric field set. So in RPCs we may not get as good results.

[3] In CMS iRPC , 2020:

Results: ~100ps/cm, ~160 ps (16mm)

[4] Q. Li et al, 2021:

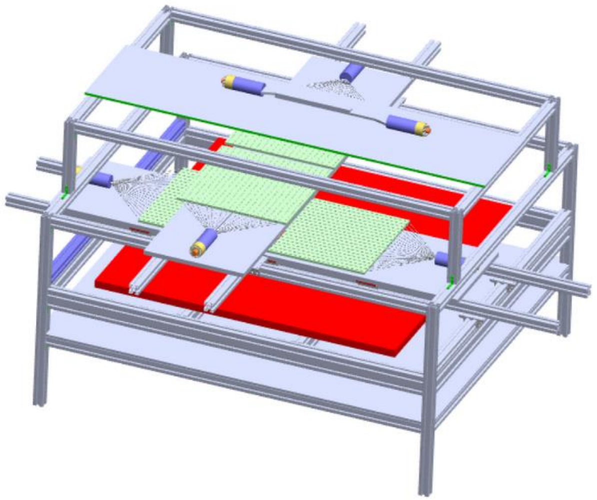
Results: ~93ps/cm, 11 mm

[5] Yuexin Ding et al, RPC 2022: Reflection readout method

Results~93ps/cm ~5mm

- This work: Combine the benefits of differential readout and fast timing measurements

3.1 Experiment Design - Source

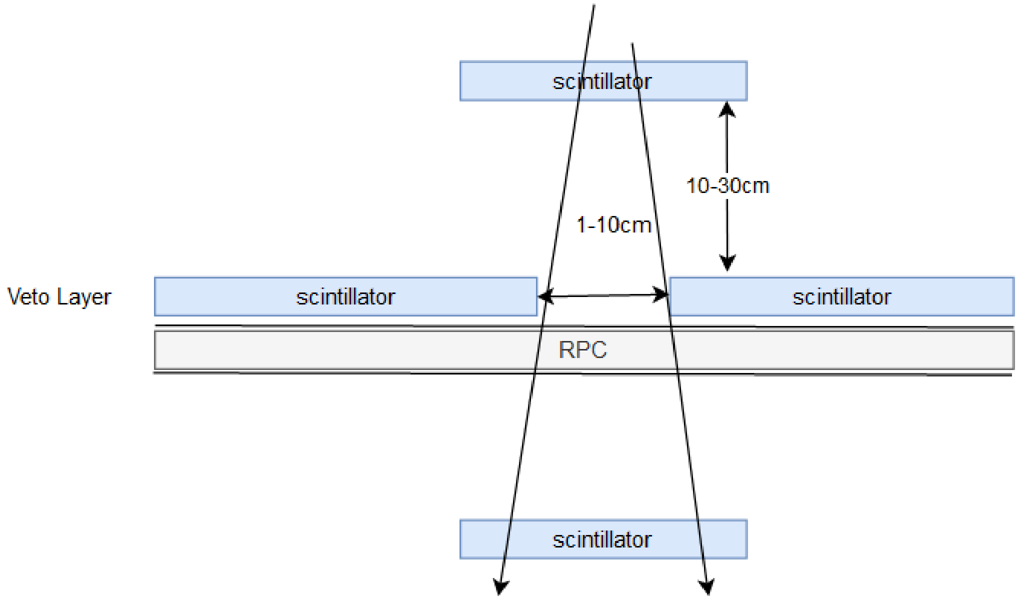


Muon Telescope

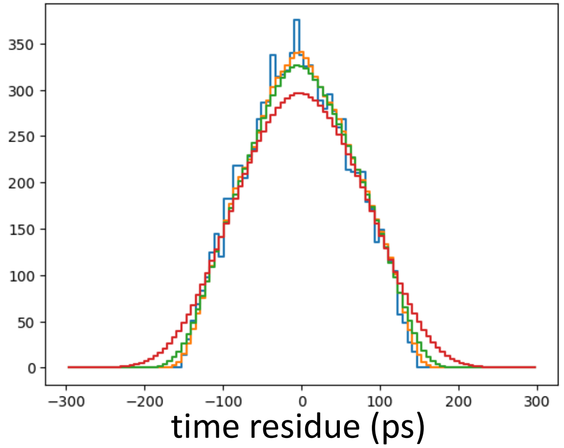
- Accurate to ~2mm

Monte Carlo Aperture Simulation

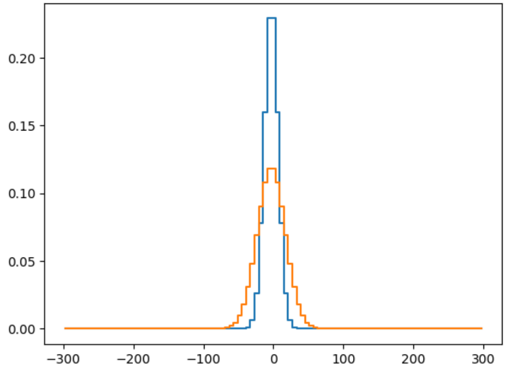
- The measured distribution will be convolution of the aperture and the time difference distribution.



Aperture and convolved distribution



Deconvolved time difference distribution



3.2 Experiment Design – Readout Electronics

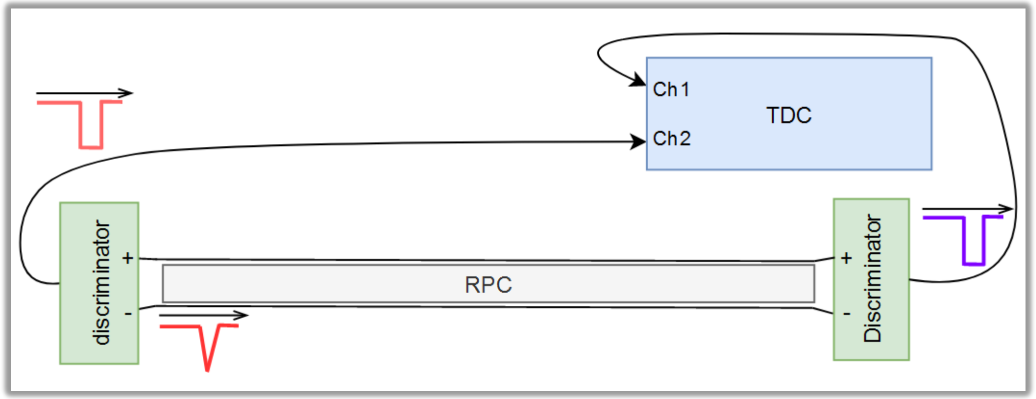
Testing two different setups:

1. preamp-discriminator+TDC
2. Preamp+Oscilloscope/Digitizer

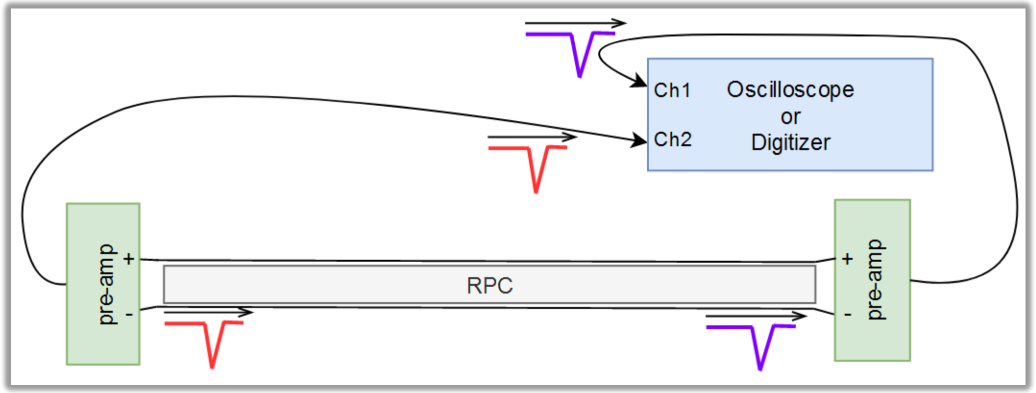
Expected sensitivity (i.e. 2/propagation_speed) is ~100ps/cm.

Expected performance:

1. Preamp-discriminator (NINO: 15s jitter) + PICOTDC (7ps) / FPGA TDC (15ps) / HPTDC (35ps): 2.2mm-5mm
2. Preamp (<10ps)+ oscilloscope(5-50ps depending on SNR): 1.5mm to 6mm.



Setup 1: preamp-discriminator + TDC



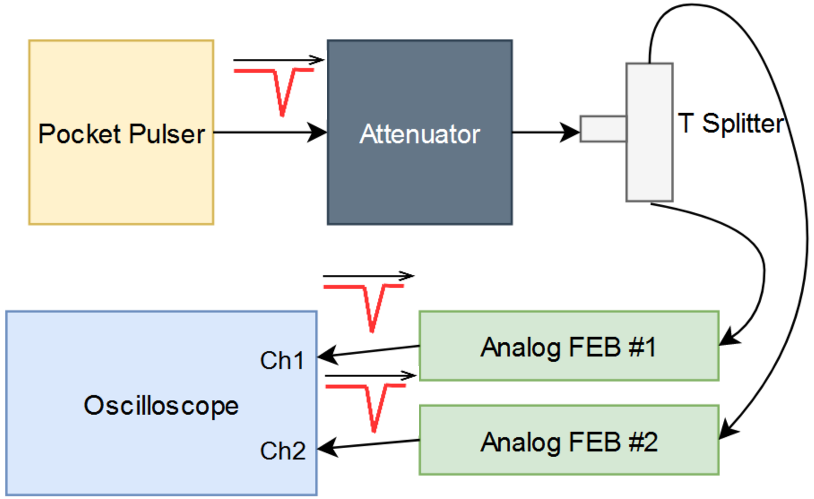
Setup 2: preamp + oscilloscope/digitizer

4. Time Measurement with Oscilloscope

Q – How precisely can we measure time differences with an oscilloscope?

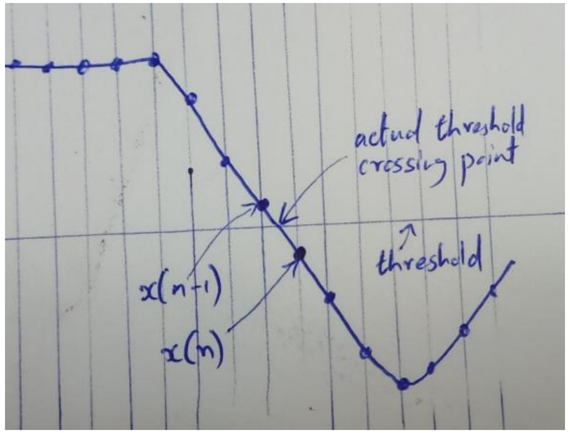
We used Lecroy WavePro 725Zi oscilloscope:

- bandwidth of 2.5 GHz
- Maximum sampling rate of 40GSa/s (i.e. samples spaced 25ps apart)

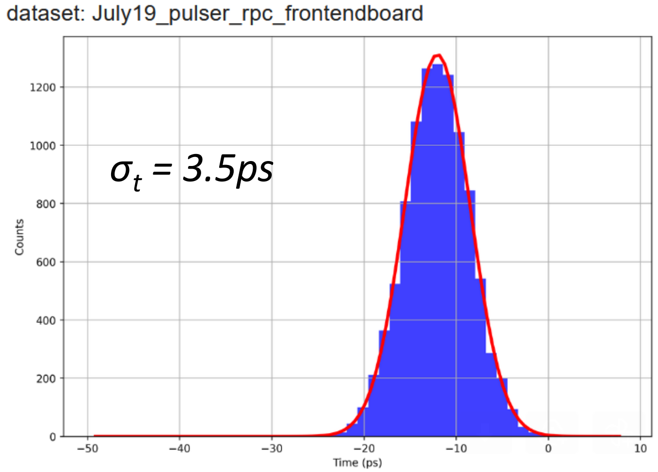


Measurement setup: Timing resolution of oscilloscope

	Measured σ_t
No attenuation	3.5ps
1/10	~60ps
1/100	~100ps



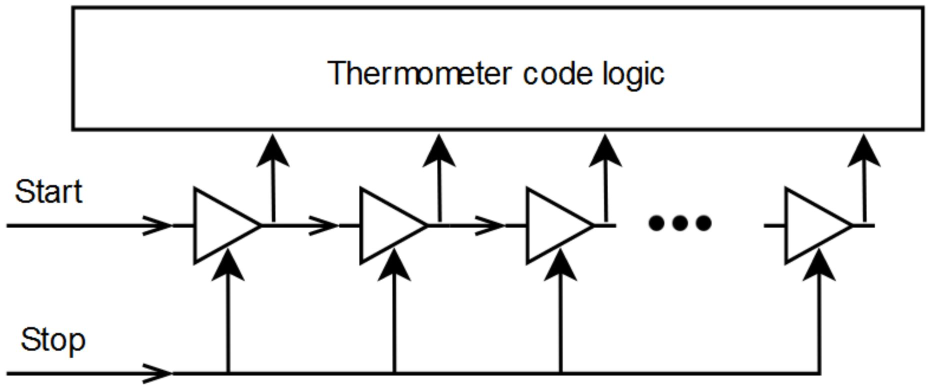
Interpolation – CFD



Time difference distribution (without attenuator)

5. FPGA TDC

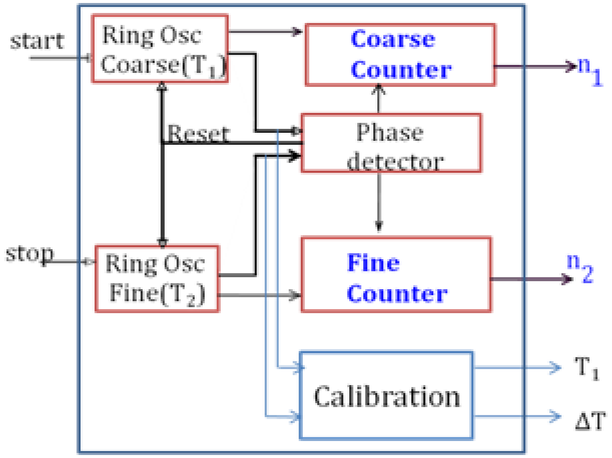
- FPGA TDCs have become a viable alternative to TDC ASICs
  - Cost, integrable into the FPGA DAQ
- Basic idea behind an FPGA TDC is to use inherent propagation delay of an electronic gate as the scale or clock period.
  - Present day FPGAs have fast gates (~10ps) built in for computing carry logic.
- A simple architecture called “delay line TDC” conveys this idea.



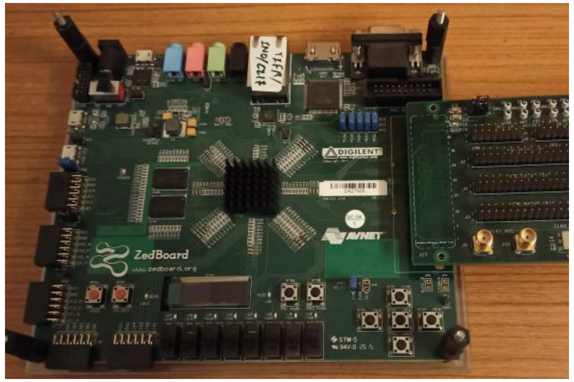
Delay line TDC – Basic concept

5.1 Vernier FPGA TDC

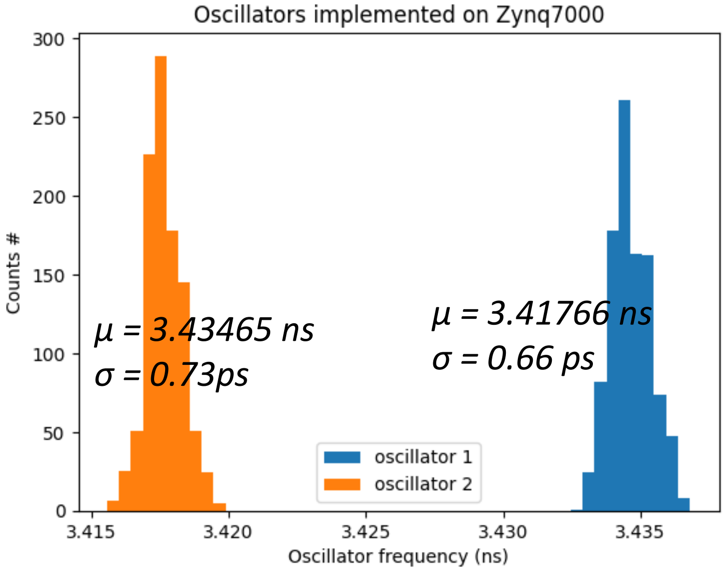
- Vernier FPGA TDC is another architecture, which uses two oscillators running with slightly different time period. The concept of vernier scale is used here, and the resolution is equal to the difference in the time periods.

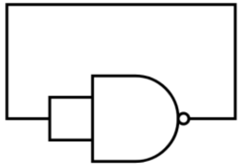


Vernier TDC – block diagram



Zedboard housing ZYNQ7000





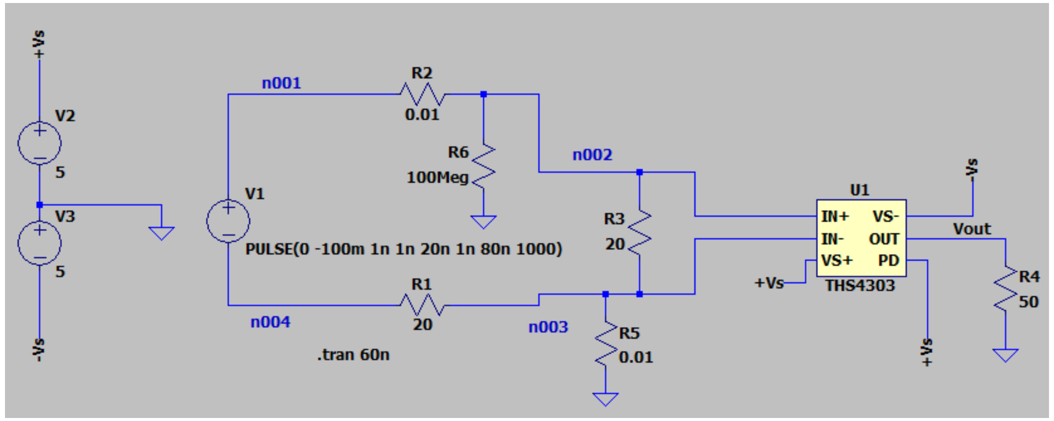
Basic ring oscillator

- We have implemented oscillators at different locations in ZYNQ7000, with two oscillators having time period difference of 17ps.

6. Frontend Electronics (Analog Preamp)

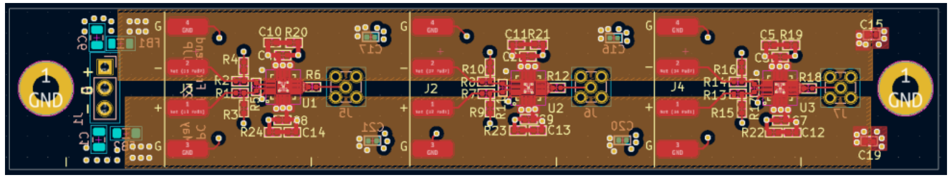
Requirements

- Differential input impedance:
- Bandwidth: 350MHz assuming 1ns rise time signals
- SNR?

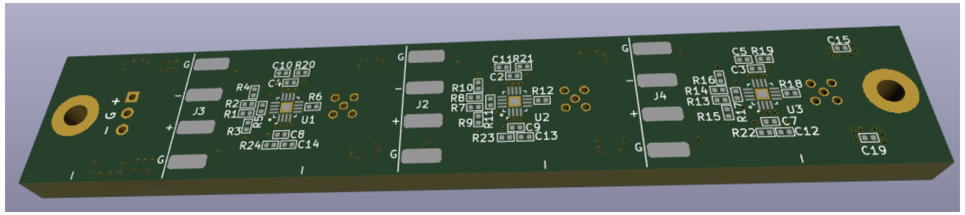


Circuit diagram (in LTSpice for simulation)

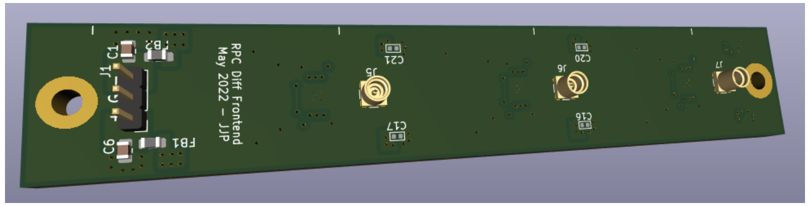
- The input impedance is 40ohm, set by R1+R3
- Gain is 2.5, set by internal resistances in THS4303.



Board layout – 4 layer impedance controlled, power planes

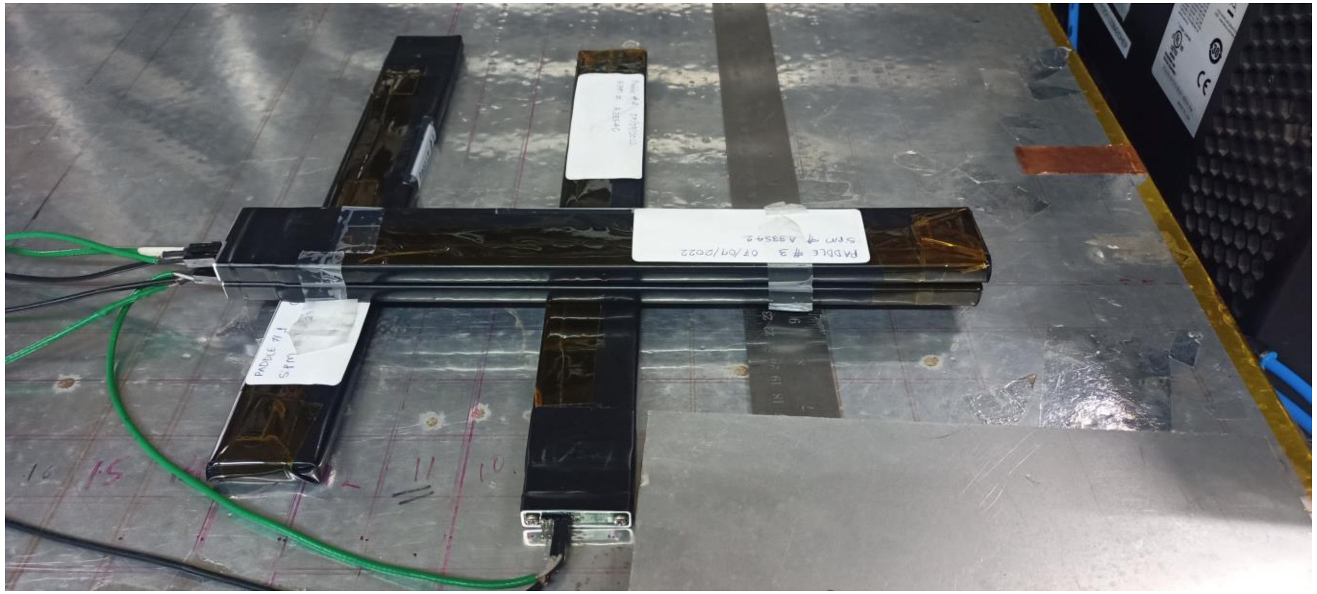


3D view – front side (to be soldered to strips)



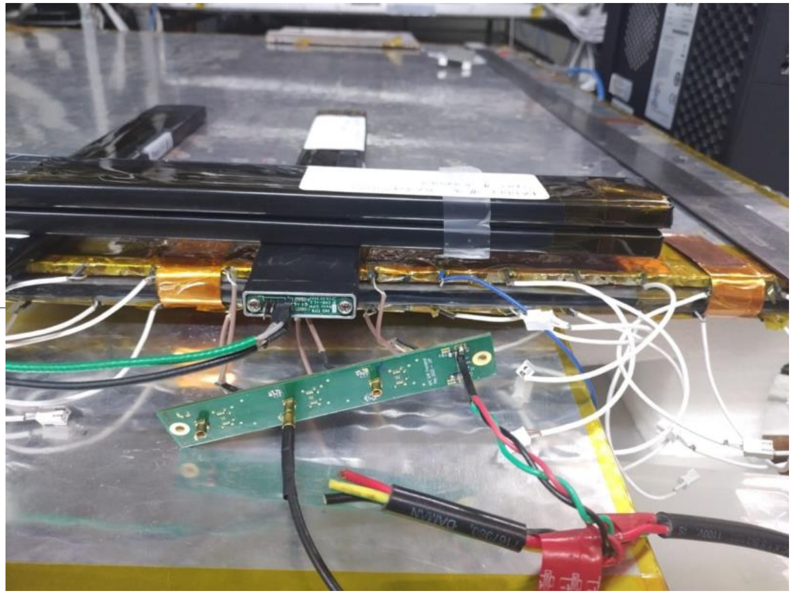
3D view – back side (supply and output connectors)

7. Setup and Results

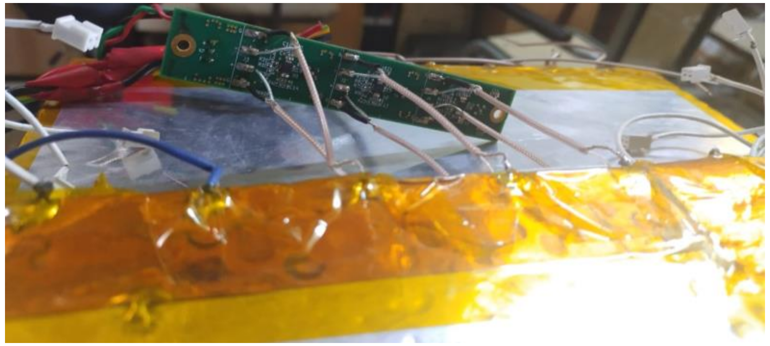


At the position 25cm from one end of strips

The black paddles are scintillators which are connected to SiPMs.
(The vertical paddle on the left is kept only for support)

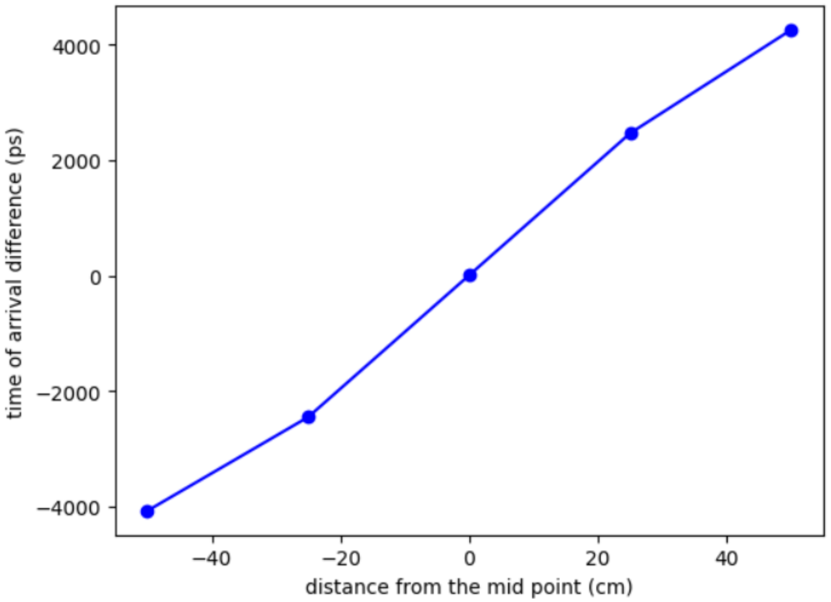


At the one of strips

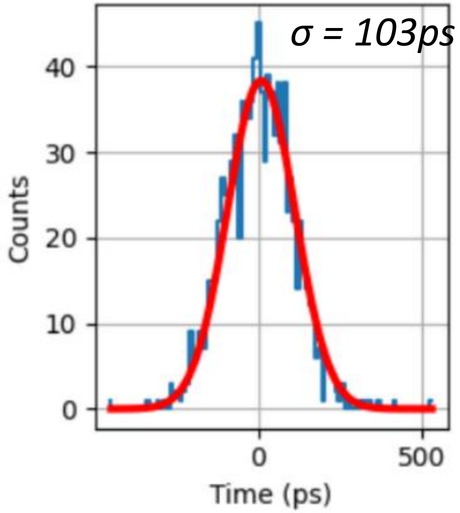


Connections soldered from strips to the frontend board.

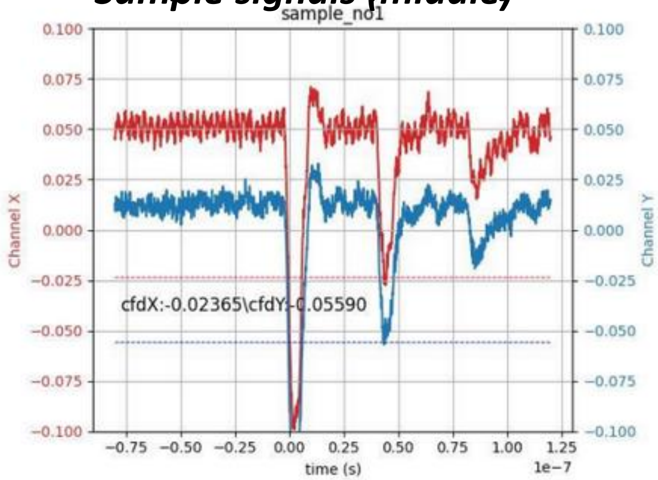
7.1 Propagation speed measurement with RPC off



Time distribution (middle)

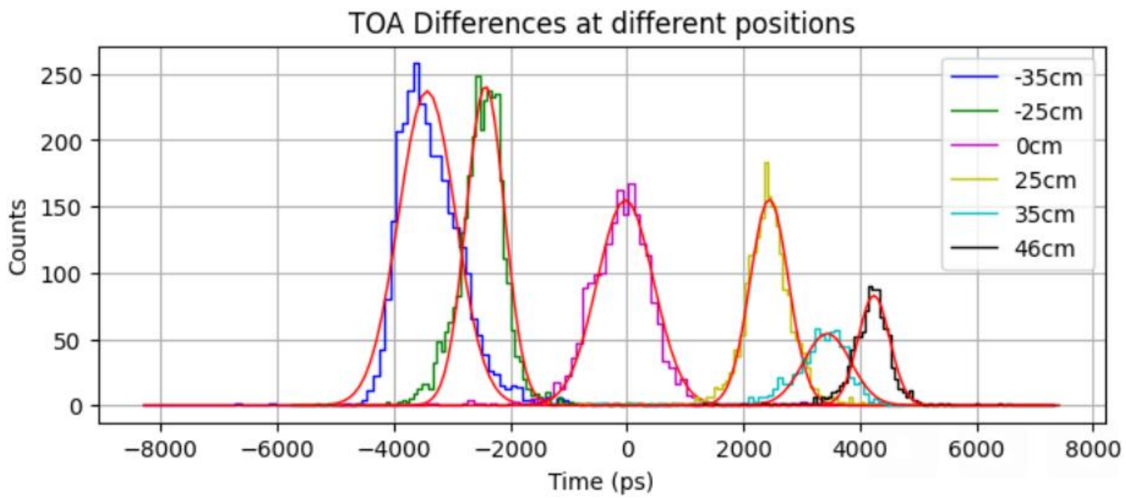


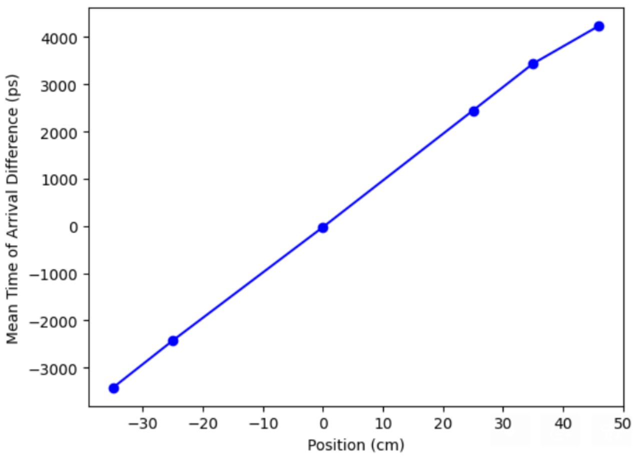
Sample signals (middle)
Sample signals (middle)

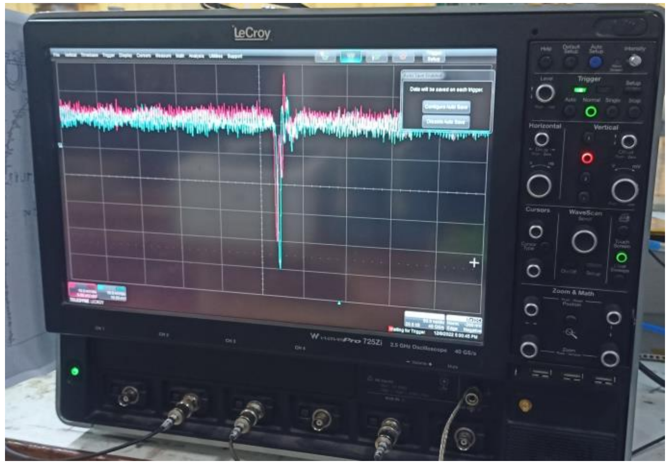


- Before turning the RPC high voltage on, signals were conductively coupled into second strip from the edge of the RPC at different locations along the strip. Sensitivity: 98ps/cm excluding the points at the edges.
- The signal is clearly riding on top of noise. The reflected signals are also seen, indicating that the termination on the frontend board (44ohms) is not matching the pickup panel transmission line.

7.2 Early Results…







- The aperture varies at different location – this effect is clearly seen in the symmetric distribution (484ps) at the centre and asymmetric distribution (with σ = 272ps) at -35cm for example.
- The correction for the aperture has not been done yet, so no constraint yet set for the position resolution. The sensitivity (2/propagation speed) except at the ends is 97ps/cm.

8. Future works

- Software noise removal.
- Faraday caging.
- Impedance matching.
- Front end preamp redesign: higher gain, lower noise, better connectors to the strips.
- Front end discriminator (NINO) redesign, experiment setup with discriminator + TDC.
- Calibration: The propagation speed may vary slightly along the strip. The propagation speed and resolution is expected to be dependent on the temperature also.

References

[1] J.M. John et al, 2022. *Improving Time and Position Resolution of RPC detectors using Time Over Threshold Information. JINST* **17** P04020

[2] K. Doroud et al, 2011. *MRPC-PET: A new technique for high precision time and position measurements.* Nuclear Instruments and Methods in Physics Research A, Volume 660, Issue 1, p. 73-76.

[3] P. Kumari et al, 2020 *Improved-RPC for the CMS muon system upgrade for the HL-LHC,* 2020 *JINST* **15** C11012

[4] Q. Li et al, *Double-end Readout Method in RPC*, JINST 16 P10036

[5] Y. Ding et al, *Reflection readout method*, RPC 2022

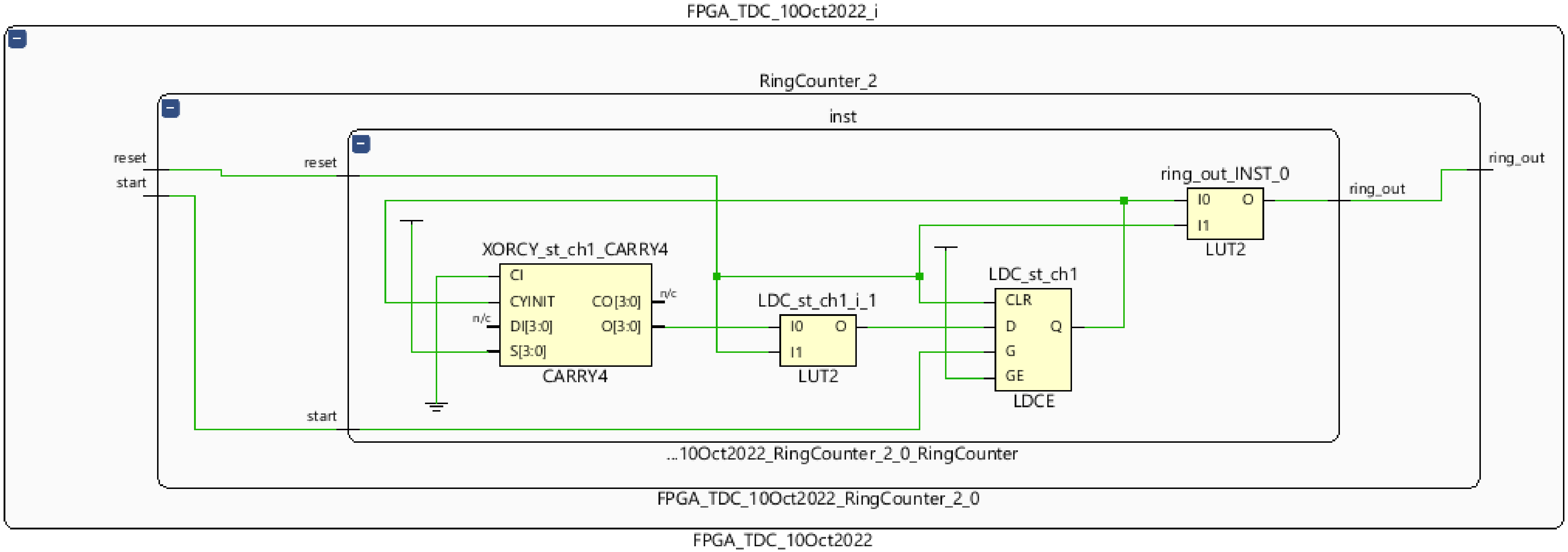
Acknowledgements

All INO Collaboration members.

DHEP, TIFR

Dr. V.B. Chandratre and BARC Micro electronics section, electronics division, BARC

Thank you ☺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O
I1
LUT2
ring_out
ring_out
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CYINIT
CO[3:0]
n/c
n/c
DI[3:0]
O[3:0]
S[3:0]
CARRY4
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I0
O
I1
LUT2
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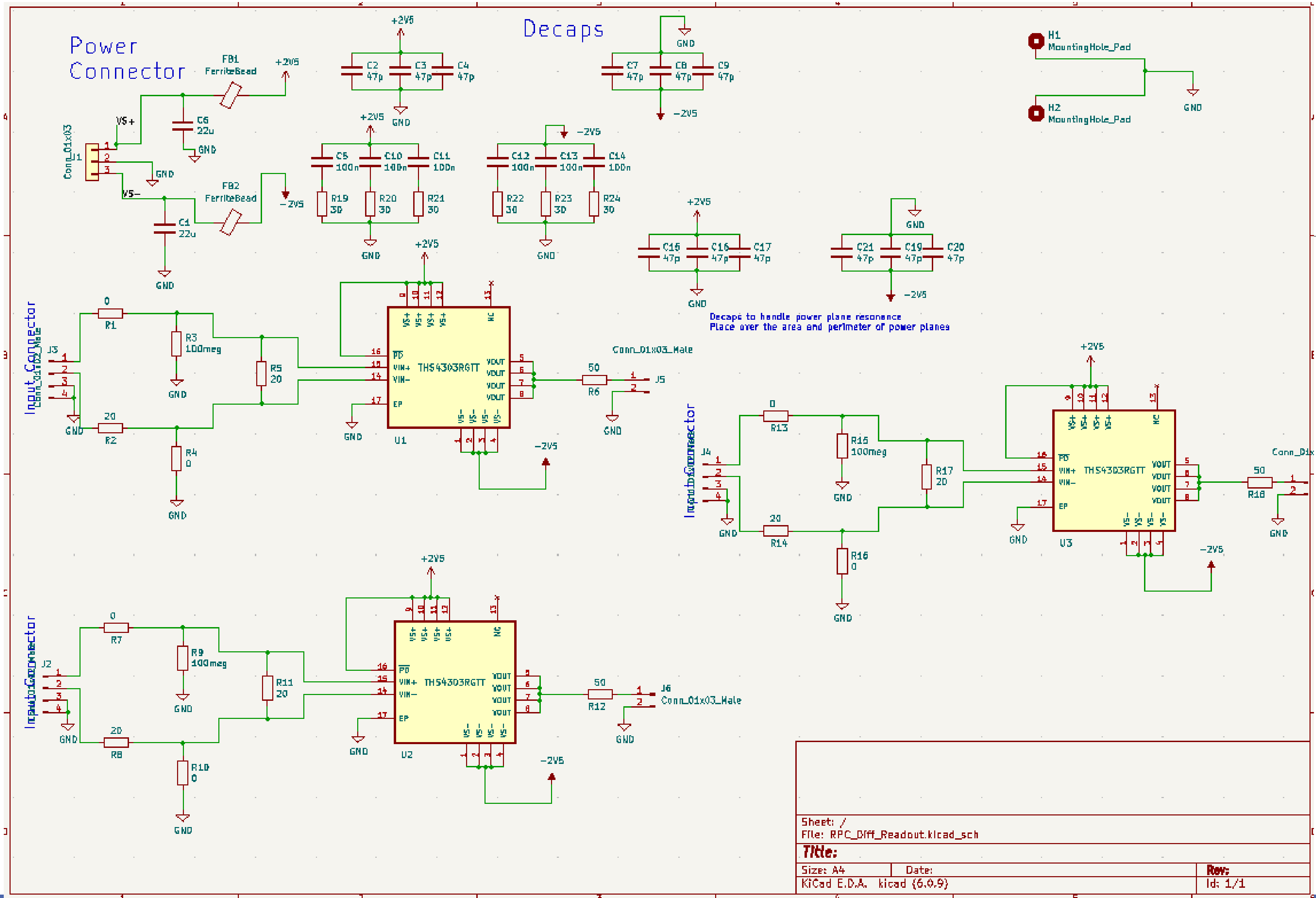
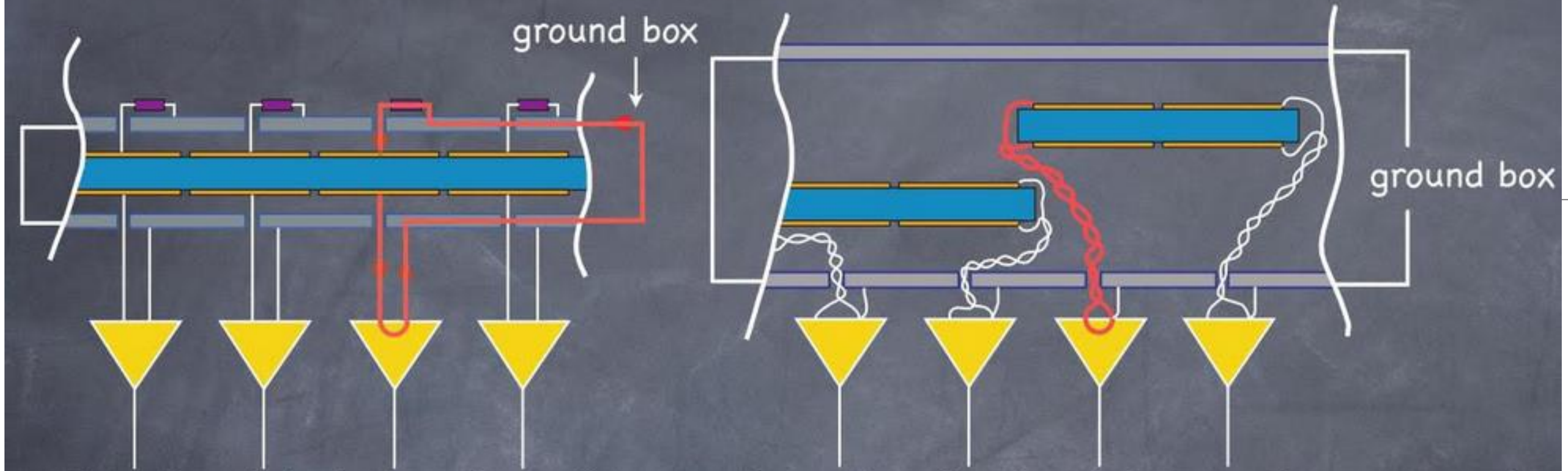


Add on slides – Schematic Entry of the Frontend Board

Add on slides – Setup full view

Big reduction in noise if care is taken with the signal return



The signal is induced on the anode and cathode pickup pads - current flows from anode pad through amplifier and returns to cathode pad. The strip design allows the use of a transmission line (twisted pair cable) to connect this 'signal generator' to the amplifier - otherwise return path is via the outside grounding box (therefore sensitive to all the noise in the ground). In reality this is a key ingredient to substantially reducing the noise and improving the time resolution

If you want to get better than 50 ps time resolution - must use differential readout - must have access to anode and cathode readout pads

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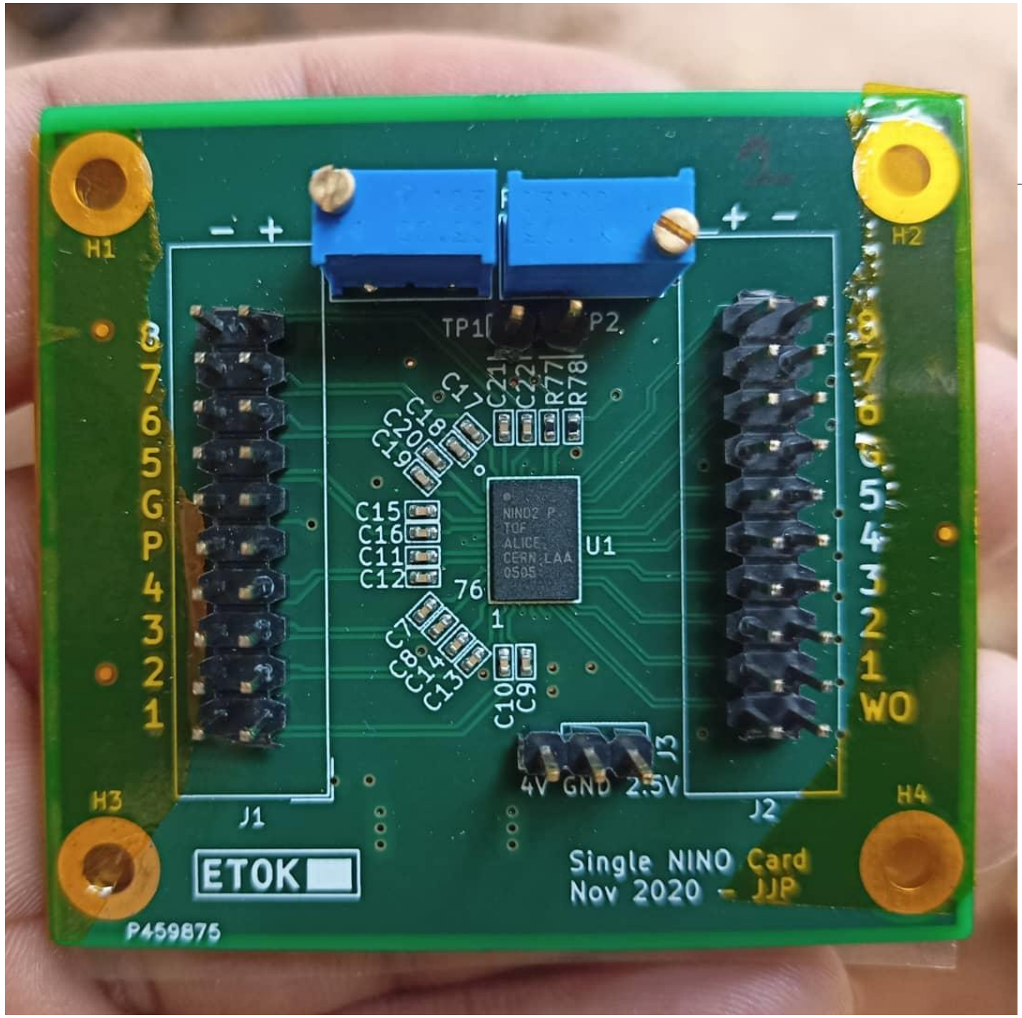
Add on slides – slide copied from Crispin Williams "the mrpc, a detector for excellent timing resolution", 2010



Add on slides – NINO Board rev0