Performance of the CLAS12 Silicon Vertex Tracker module

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Introduction

The Continuous Electron Beam Accelerator Facility's (CEBAF) Large Acceptance Spectrometer (CLAS) is being upgraded for the 12 GeV electron beam to conduct spectroscopic studies of excited baryons and of polarized and unpolarized quark distributions, investigations of the influence of nuclear matter on propagating quarks, and measurements of Generalized Parton Distributions (GPDs). Deep exclusive reactions, in which an electron scattering results in a meson-baryon final state, provide stringent requirements for the CLAS12 tracking system. The central tracker consists of a solenoid, Central Time-Of-Flight system (CTOF), and Silicon Vertex Tracker (SVT), which covers 35°–125° in θ and ~2π in ϕ. The SVT will be centered inside of the solenoid, which has 5T magnetic field.

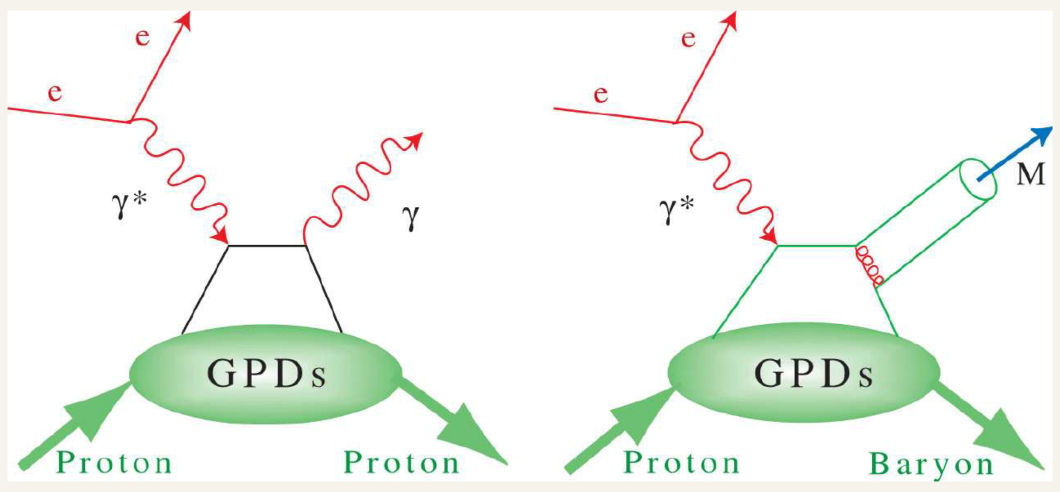


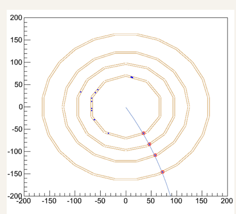
Figure 1 The "handbag" diagram for deeply virtual Compton scattering (a), and for deeply virtual meson production (b). Four GPDs describe the "soft" proton structure part. They depend not only on x, but on two more variables: the momentum imbalance of the quark before and after the interaction, and the momentum transfer to the proton.

SVT Physics requirements

Essential parts of the physics program, such as GPD's, require tracking of low momentum particles with few percent momentum and about one degree angle resolution at large angles. This is achieved by the SVT. Silicon detector technology makes an excellent match to the central tracking system in the CLAS12 configuration, small space and high luminosity operation that is needed for accurate measurements of exclusive processes at high momentum transfer.

SVT provides standalone tracking capabilities in the central detector region:

- Measure recoil baryons and large angle pions, kaons
- Polar angle (θ) coverage: 35-125°
- Azimuthal angle (ϕ) coverage: > 90% of 2π
- Momentum resolution : $\delta p_T/p_T$ < 5%
- Angle resolution: $\delta\theta$ < 10-20 mrad, $\delta\phi$ ~5 mrad
- Tracking efficiency > 90%
- Match up tracks with hits in the CTOF for β vs. p measurement (particle ID)
- Reconstruction of detached vertices, e.g. $K_s \rightarrow \pi^+\pi^-$, $\Lambda \rightarrow \pi p$, $\Xi \rightarrow \Lambda\pi$ for efficient experimental program in strangeness physics.
- Stable operation in 5 Tesla magnetic field at instantaneous luminosities $L=10^{35}$ $cm^{-2}s^{-1}$.



Expected integrated luminosity per year 500 fb^{-1}. Radiation dose for forward sensors (carbon target) 2.5 Mrads.

Detector design

Barrel Silicon Tracker (BST) has 33792 channels of silicon strip sensors in eight layers (four regions). There are three sensors per layer. Each layer has 256 strips with linearly varying angles of 0°–3°. The readout strips have a constant φ pitch of 1/85°. To measure, with a precision better than 5%, tracks with p_T up to 1 GeV, a resolution of 50 μm in the bending plane is needed. Silicon Vertex Tracker uses single sided microstrip sensors fabricated by Hamamatsu. The sensors have graded angle design to minimize dead areas and a readout pitch of 156 μm, with intermediate strip.

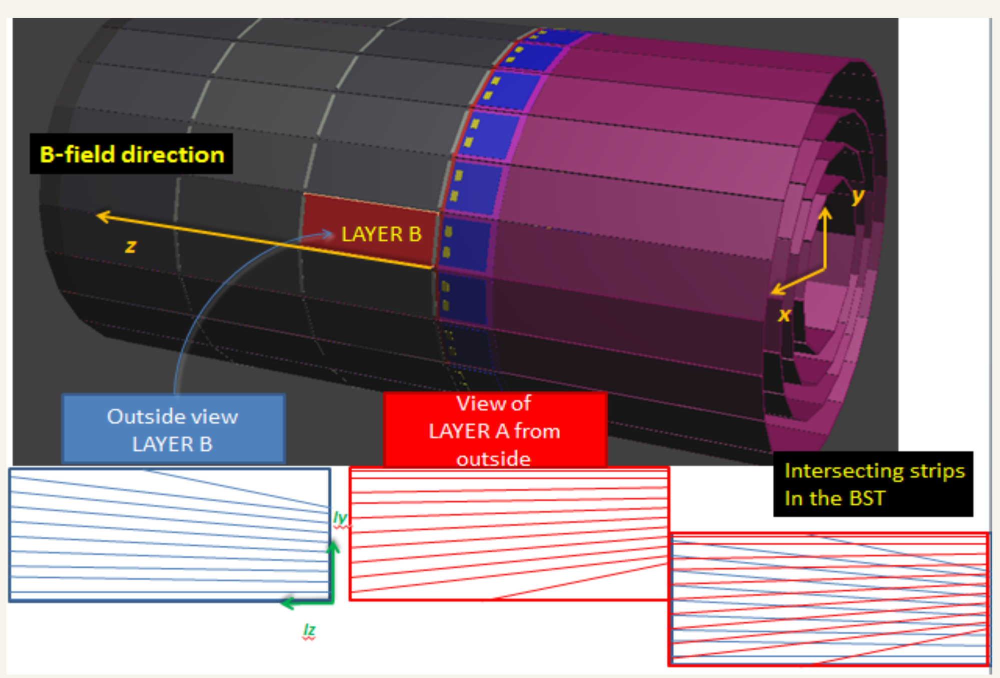


Figure 2 Side view of the SVT detector

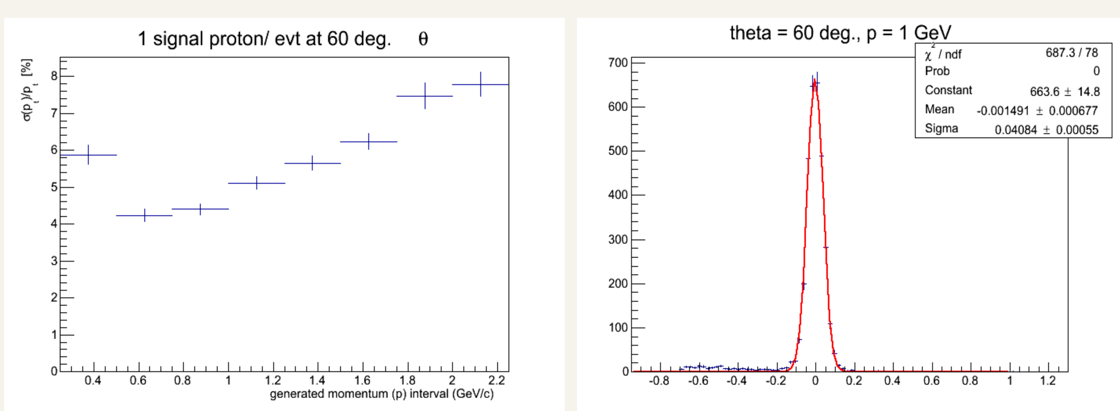


Figure 3 Results of Monte Carlo Simulation for the SVT momentum resolution

SVT Module

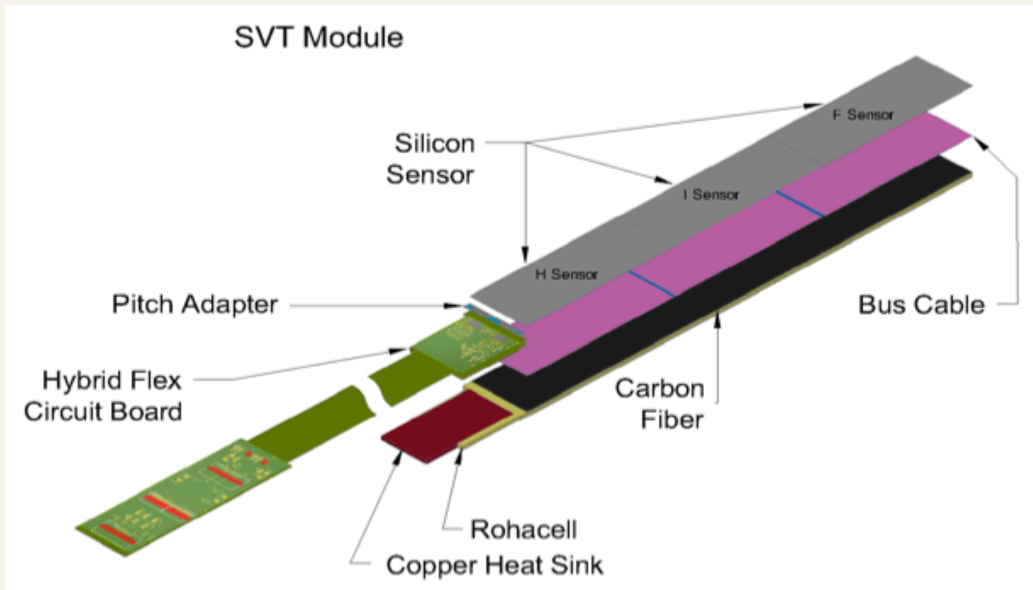


Figure 4 Layout of the SVT module

Sensor
- All modules have 3 types of sensors
  - Hybrid, Intermediate, and Far
- Sensors are cut from 6 inch wafers
  - 2 sensors per wafer
- All sensors have the same size
  - 111.625 mm × 42 mm

FSSR2 ASIC
- Developed for BTeV

Readout cable
- Hybrid Flex Circuit Board (HFCB)

Backing structure
- Composite structure
  - Rohacell and Carbon Fiber

Pitch Adapter
- 156 μm to 50 μm
  - Metal on glass technology

All SVT modules are identical

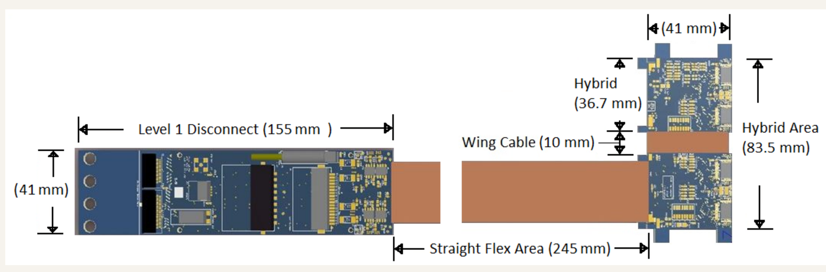


Figure 5 Hybrid Flex Circuit Board (HFCB)

To minimize multiple scattering a unique module design with extra long 33 cm strips has been developed which allows to reduce material budget to 1% of radiation length per region. The SVT modules are cantilevered off a water-chilled cold plate, designed to remove the heat generated by the electronics, located only at one end of the module. Double sided SVT module hosts three single sided daisy-chained microstrip sensors fabricated by Hamamatsu on each side. The sensors have graded angle design to minimize dead areas and a readout pitch of 156 μm, with intermediate strip. There are 512 channels per module read out by Fermilab Silicon Strip Readout (FSSR2) chips featuring data driven architecture, mounted on a rigid-flex hybrid.

A readout system which instruments both sides of a module with a single rigid-flex Hybrid Flex Circuit Board (HFCB), has been developed and is located on the upstream end of the module. The HFCB uses four FSSR2 ASICs, two on the top and two on the bottom side. Each of the four FSSR2 ASICs reads out 128 channels of analog signals, digitizes and transmits them to a VXS-Segment-Collector-Module (VSCM) card. The hybrid areas are connected by a 10 mm-long wing cable.

Fermilab Silicon Readout Chip (FSSR2)

- 128 channels / chip, 50 μm input pitch
- Data-driven architecture - self-triggered, time-stamped
- 1 MHz input rate with < 2% missed
- Beam Cross Over (BCO) clock: from 128 ns
- DAQ synchronized with timestamp clock
- Zero-suppressed data readout
- 1-6 programmable serial outputs (for hit data output)
- Double Data Rate (DDR) output
- Maximal data output rate 840 Mbits/s
- Anticipated data rate ~ 200 Mbits/s
- Data readout clock: 70 MHz
- 24 bit data format for 'hit' channel
  - 12 bit Address
  - 8 bit BCO clock counter
  - 3 bit ADC
  - 1 Sync
- Power consumption < 4 mW / channel
- Designed to handle 5 Mrad

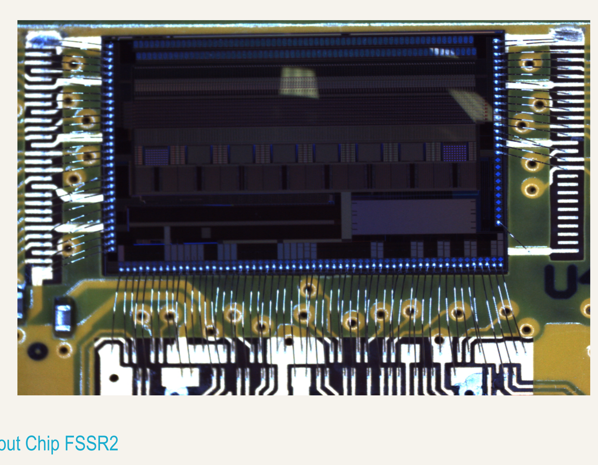


Figure 6 Fermilab Silicon Readout Chip FSSR2

Sensors QA summary

SVT Sensor Test Results

Specification Item	Specification Value	Hamamatsu Measured Average Values: Hybrid	Intermediate	Far	Comments
Full Depletion Voltage	40<V<100 (25°C@<45%RH)	77 Volts	78 Volts	72 Volts	Meets Specification
Total Leakage Current	≤10 nA/cm² (At full depletion voltage)	2.66 nA/cm²	2.61 nA/cm²	2.80 nA/cm²	Exceeds Specification
Interstrip Capacitance	<1.2 pf/cm	0.52 pF/cm	0.52 pF/cm	0.52 pF/cm	Exceeds Specification
Strip to backside Capacitance	<0.4 pf/cm (Hybrid); <0.45 pf/cm (Intermediate); <0.5 pf/cm (Far)	0.30 pF/cm	0.32 pF/cm	0.44 pF/cm	Exceeds Specification
Resistance of Al electrode on strips	< 20 Ω/cm	7.06 Ω/cm	6.96 Ω/cm	6.96 Ω/cm	Exceeds Specification
Value of poly-silicon bias resistor	1.5 MΩ ±0.5 MΩ	1.21 MΩ	1.19 MΩ	1.27 MΩ	Meets Specification
Strip Yield	Bad channel rate (avg. over every 100 sensors) ≤1% Max # of channels per sensor ≤ 2%	0.003% Bad Channel Rate; 0.39% Max # of Chan per sensor	0.001% Bad Channel Rate; 0.20% Max # of Chan per sensor	0.011% Bad Channel Rate; 0.51% Max # of Chan per sensor	Exceeds Specification

Total sensor count 594. 100% sensors without defective strips

Calibration of the readout chain

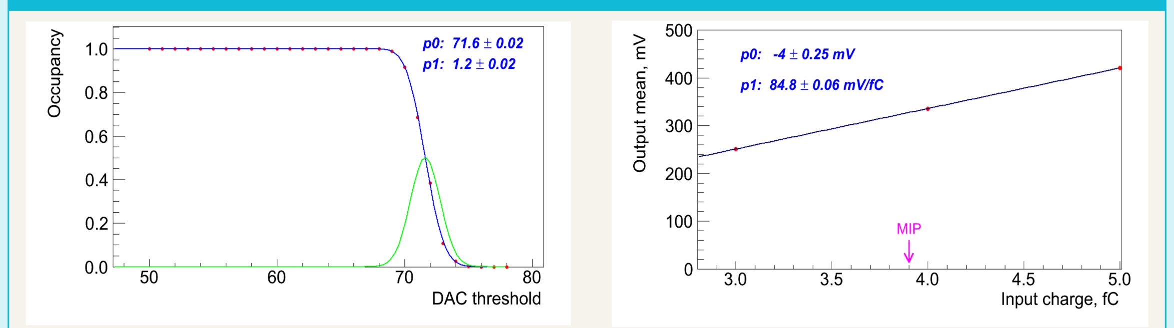


Figure 7 Threshold scan on one of the HFCB channels (left) and response curve (right)

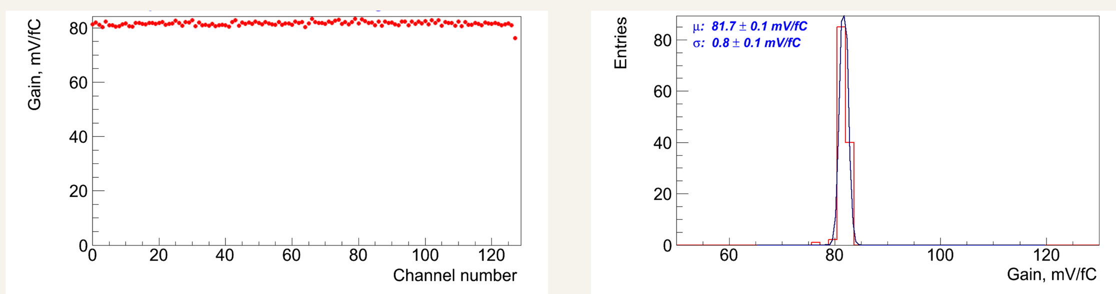


Figure 8 Gain uniformity across the chip (left) and gain dispersion (right) on one of the hybrid's readout chips

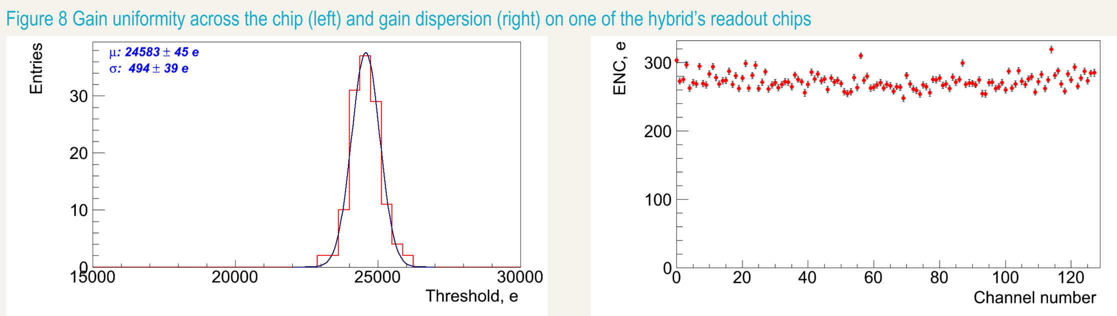


Figure 9 Threshold dispersion (left) and Equivalent Noise Charge (ENC) measurement on the HFCB (right)

A comparison of the noise for 33 cm strips with the threshold spread demonstrates that the threshold spread is negligible compared to noise and will not affect neither the efficiency nor the noise occupancy.

Results of the Full Chain Test

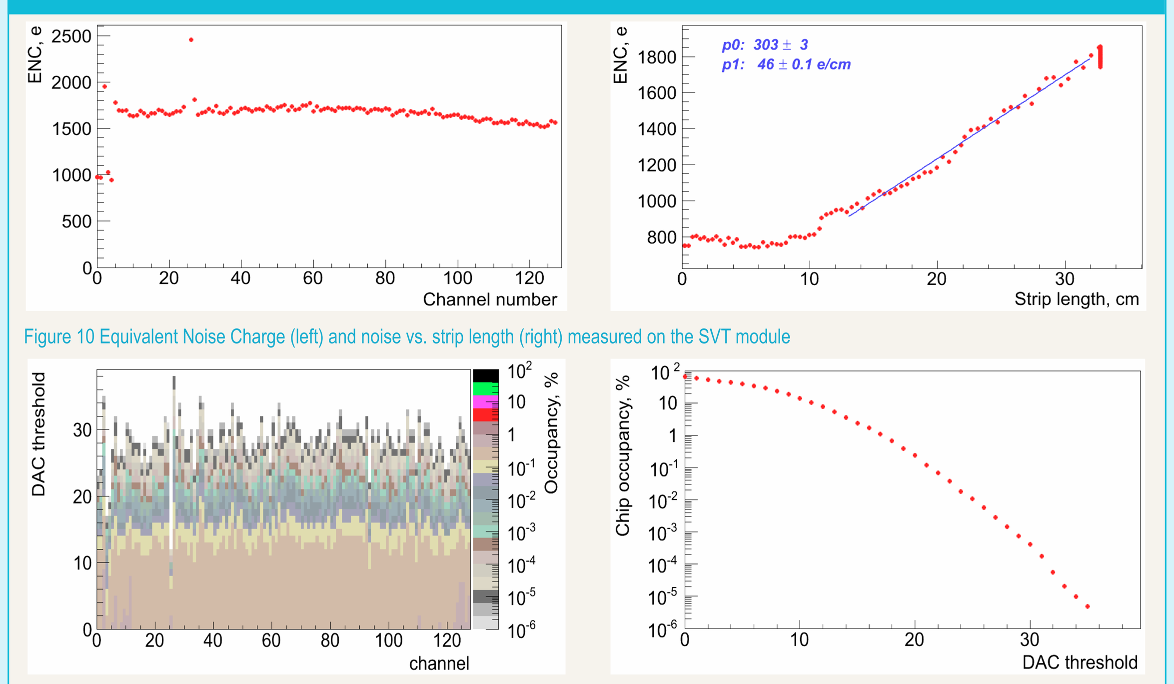


Figure 10 Equivalent Noise Charge (left) and noise vs. strip length (right) measured on the SVT module

Figure 11 Noise occupancy vs. DAC threshold and channel (left) and chip noise occupancy (right) measured on the SVT module

No significant correlated noise has been observed between the channels of the same chip, between the chips of the same module or between the closely placed modules.

Measured ENC is comparable with noise estimations based on contributions of different noise sources.

Summary

- Results of the electrical measurements demonstrate adequate noise performance of the SVT
- Sensor fabrication and testing completed, sensor parameters meet or exceed the specs
- Module production is scheduled for summer 2013
- SVT installation in CLAS12 in 2015

SVT Team