SVT radiation damage constraints

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Radiation damage will be the limiting factor to the lifetime of the SVT

Two different aspects:

A) Radiation damage to the sensors:

   Instantaneous

   - Creation of p-stop shorts => inefficiency

   From integrated radiation (bulk damage)

   - Increase in leakage current => shot noise

   - Change in the depletion voltage and type-inversion => electronics noise
   - Damages to the crystalline structure
   => decrease in charge collection efficiency
B) Radiation damage to the electronics:

- Increase in noise $\Rightarrow$ decrease S/N
- Decrease in gain $\Rightarrow$ decrease S/N
- Digital failures $\Rightarrow$ inefficiency

All these issues have been addressed in the past with projects aimed to quantify the impact on the SVT operation and lifetime
Instantaneous radiation damage to the sensors

Intense burst of radiation
=> discharge of detector capacitor
=> Vbias (40V) momentarily drops across the coupling capacitors
- deposited charge needed

\[ Q_R = (C_D + \frac{C_N C_P}{C_N + C_P}) V_{Bias} \approx 2.6 \, nC/\text{strip} \]

on a time scale \( \tau = R_{Bias} \times C_{det} \approx 1 \, \text{ms} \)

=> critical radiation: 1 Rad/1 ms
Damage Rate

- All the sensors have been tested for AC breakdown up to 20V during construction

- A later study on detectors with a pitch similar to the SVT inner layers has shown an expected rate of failures of about 1-2%

The effect has been observed in the real system: 65 pin-holes / 20k channels in L1,2
Trickle injection

Trickle injection => intense bursts of radiation associated to injected bunch
=> instantaneous damage?

We measured deposited charge in the detector after the injected pulse using the silicon sensors themselves:
-limit is 2600nC/1M/1ms
=> 3 orders of magnitude safety
Bulk damage: increase in Si leakage current

This effect implies an increase in the noise and a potential problem to bias the detector to very high voltages.

- Measuring the leakage current of SVT Si wafers vs. time allows to evaluate the radiation damage.
- I-V measurements performed since 1999.
- Current measured at 40V and the radiation dose estimated from the nearby PIN diode.

0.5-0.7 mA/Mrad/cm² @ T=17°C

=> 1mA hardware limit is not an issue.
Bulk damage

Non uniform irradiation induces a localized modification in the density of donors in the silicon: possible impact on

- detector resolution
- charge collection efficiency (decreased S/N)
- bias voltage

Several test beams have been organized at SLAC and at Elettra (Trieste) to study bulk damage to the SVT from electrons in the GeV range (0.9 to 3 GeV)

2000: Wafer irradiations to doses up to 5 Mrads using both a direct electron beam and an electron beam scattered by a copper target.

2001: Also tests with non-uniform irradiation to simulate the conditions of middle plane modules

2003: Tests with non-uniform irradiation to study the change in depletion voltage and charge collection efficiency
Bulk damage: depletion voltage

Irradiation with 0.9 GeV e⁻ beam at Elettra (Trieste, 2000-2001)

- $C^{-2}$ vs V curve indicates type-inversion results in ~ agreement with NIEL scaling hypothesis (not obvious): 3MRad Leakage current increase of order 2 µA/Mrad/cm² (T=23 °C) in agreement with measurement in the real SVT

After type-inversion up to 5MRad detector electrical properties still look OK

Gabriele Simi

Background Workshop, SLAC, September 2003
Bulk damage: Charge Collection Efficiency

2003 irradiation with 0.9 GeV e- beam at Elettra:

Still in progress. Two runs till now. #1: peak dose: 1.3 Mrad +
#2: peak dose: 1.2 Mrad

This project will also study the reduction in charge collection efficiency to doses up to 10 Mrads

Non uniform irradiation

σ_y = 1.44 mm

beam profile
Depletion Voltage shift

Set of LED measurements with different Vbias to repeat the study of the depletion voltage as a function of position on the module.

Integral of charge collected per pulse vs. Vbias

Vbias (V)

Vdepl ~ 30 V

Vdepl ~ 15 V

Center of the elettra beam

before irradiation (p-side)

after irradiation (p-side)
CCE studies: results after first irradiation

Ratio between CCE after and before irradiation is consistent with 1 at 2-3% level in each x strip => OK up to 1.3 MRad

Efficiency ratio

Mean=1.00
RMS=0.02

Increase in leakage current and decrease of depletion voltage consistent with estimated dose
Irradiation tests on the Atom chips

Radiation tests performed on Atom chips in 2001 using Co\textsuperscript{60} sources at SLAC and LBL.

Chips powered and running during irradiation.

\[ \text{noise} = \alpha + \beta C_{\text{load}} \]

Foreseen decrease of signal/noise down to a factor 2 (mid plane). This determines an upper limit on the ATOM chips lifetime (5 Mrads).

No digital failure observed up to 5 MRads.

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Measurements of SVT FEE Radiation Damage

SVT FEE noise and gain vs. Dose

- preliminary study, work in progress
- estimate accumulated dose from pin diodes: 1.8 MRad worst case
- gain decreases by ~5%/Mrad
- noise increases by ~15-20%/Mrad

Consistent with irradiation tests with Co\(^{60}\)

- Initially Signal/Noise ~ 20
- after 5 MRad Signal/Noise ~ 10

=> this set the lifetime of SVT
Threshold offset

Pedestal increase on channels on a few SVT chips
-not fully understood effect, not seen with Co$^{60}$ test
-observed on chips more exposed to radiation (west side only)
Threshold offset

Radiation-related effect
- Seems to turn on around 1MRad of dose
- 5/168 chips (3%) affected in layer 1
- Shifts up to 35 (in arbitrary units)
- Chips became inefficient above 63
- The effect on the physics is being investigated
  (roughly 5% inefficiency in layer 1)
- Depending on the impact on physics this could reduce the SVT radiation budget
- To study this effect in controlled conditions we are setting up the irradiation of FEE chips with electrons
Summary

**Instantaneous damage to Silicon:**
- OK (also for Trickle Inj.)

**FEE chips damage:**
- Signal/noise: OK up to 5 Mrad
- Digital funct.: OK up to 5 MRad
- Offset: (in progress)

**Bulk damage to Silicon:**
- V_depl: OK up to 10 Mrad
- I_leak: OK > 10 MRad
- CCE: (in progress)

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**Graph:**
- SVT layer-1 Signa/Noise versus dose
- Dose (Mrad) vs. Noise (ENC)
- Signal/Noise
- Total S/N
- Total Noise
- ATOM noise
- I leak noise
Conclusion

- SVT radiation constraints have been investigated in the past in many aspects
  - Effect on silicon sensors
  - Effect on FEE chips
- Dominant factor is $S/N$ decrease due to FEE damage
- Limit was set at $S/N \sim 10$ corresponding to 5 Mrad
- New effect recently observed on thresholds for middle plane chips was unexpected
- This could affect the SVT radiation budget