Radiation damage status of the ATLAS silicon strip detectors (SCT)

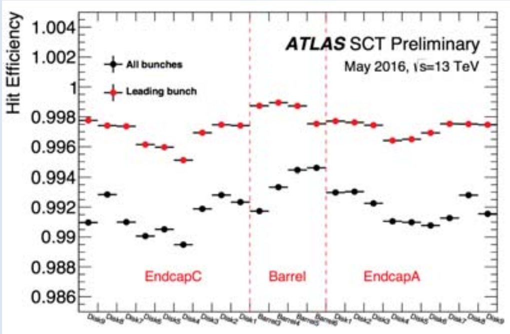
Poster at the11th International "Hiroshima" Symposium on the Development and Application of Semiconductor Tracking Detectors (HSTD11), Okinawa, Japan. 10-15 December 2017

Summary

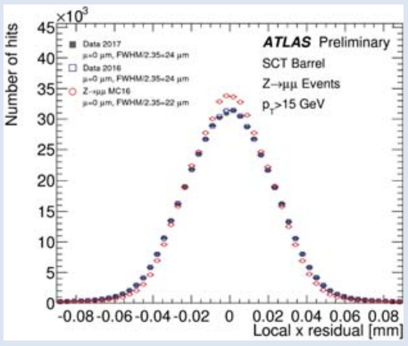
- ATLAS SCT (~60m^2) has been working well over 7 years at LHC.
- Radiation received is now up to 3x10^{13} cm^{-2} in 1MeV n-eq fluence.
- Steady increase and annealing of leakage current have been observed in good agreements with two models.
- Part of sensors pass the type inversion point. Detailed studies continue.

Operational status

- 98.7% of the SCT elements are active as of Nov. 2017.

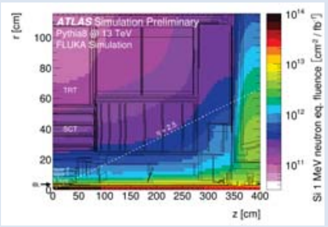


Strip hit efficiency May 2016)

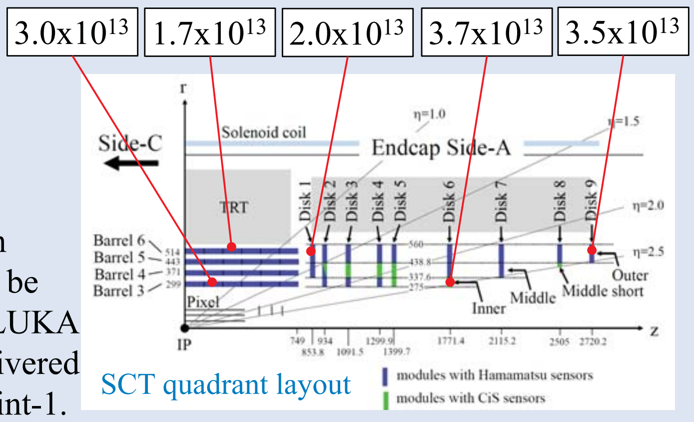


Position resolution (Barrel, 2017)

Radiation in 1MeV n-eq Fluence [cm^{-2}]



- Accumulated radiation levels at 2017 end can be estimated using the FLUKA simulation [1] and delivered luminosity at LHC Point-1.

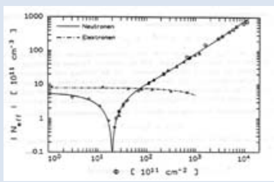


SCT quadrant layout

Full Depletion Voltage

- Full depletion voltage V_{FD} depends on the effective doping concentration N_{eff}

$$V_{FD} = \frac{e}{2\varepsilon_0 \varepsilon_{Si}} \cdot |N_{eff}| \cdot d^2$$

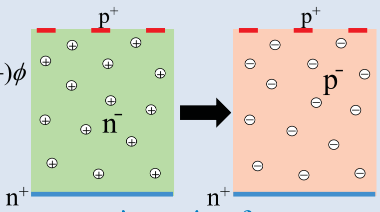


R. Wunstorf 's Thesis [2]

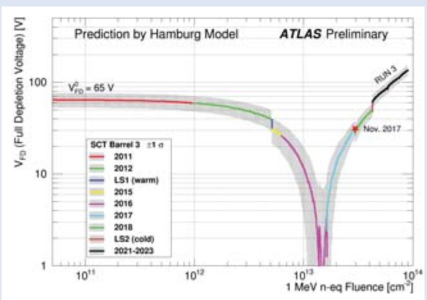
- Radiation ϕ creates acceptors and removes donors and N_{eff} changes as [3]

$$N_{eff} = N_{eff}^0 - N_C^0 (1 - e^{-c\phi}) - g_C \phi - g_a e^{-t/\tau_a} \phi - g_Y \left(1 - \frac{1}{1 + t/\tau_Y}\right)\phi$$

- Type inversion n → p occurs and V_{FD} gets higher due to the anti-annealing effect.



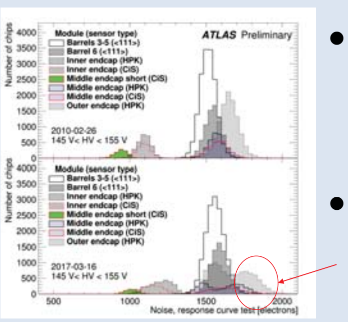
type inversion from n to p



Full depletion voltage of Barrel 3

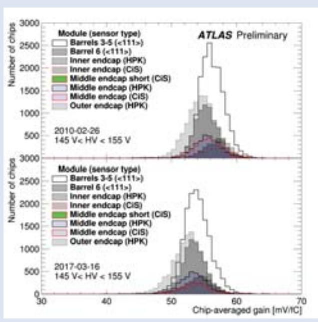
- V_{FD} has been studied using I_{leak}, cluster-size and noise, but no reliable methods are found yet.
- According to Hamburg model, Barrel 3 is type inverted by now and V_{FD} will reach 150V at the 2023 end.

Noise and Gain



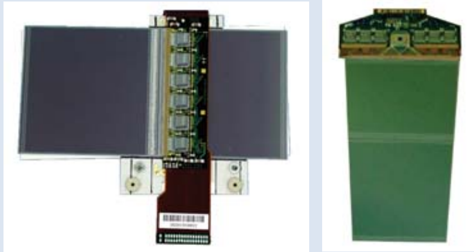
ENC at the input [e]

- Noise and gain are stable from 2010(top) to 2017(bottom).
- Anomalous noise increases observed in endcap strips facing to the N_2 gap spaces.



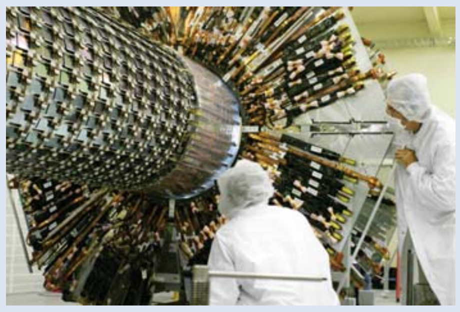
Front-end gain [mV/fC]

The ATLAS SemiConductor Tracker (SCT)



2112 Barrel + 1976 Endcap modules

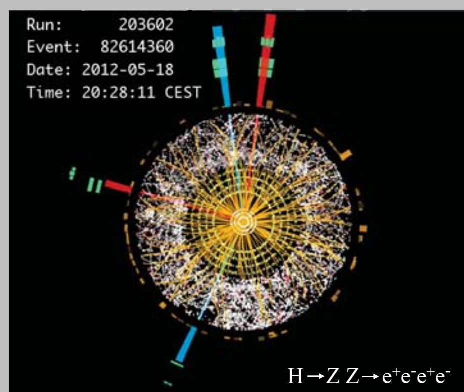
- p-on-n 285μm thick Si sensors with 80μm pitch strips, 12cm long
- Total Silicon sensor area ~60m^2
- Hamamatsu (88%) and CiS(12%)
- ~ 6M channels of digital readout with 1 fC threshold at every 25ns
- Cooled at -5^{o}C to 6^{o}C by 2-phase C_3F_8

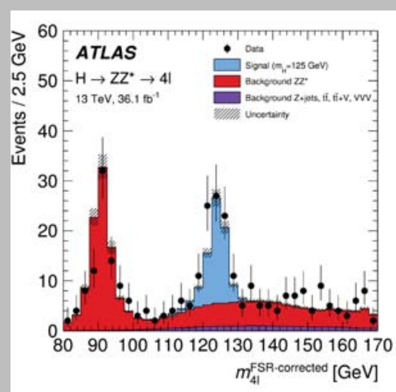


Barrel cylinder assembly (2005)

Barrel modules and cooling pipes

- SCT is the central tracking device for the Higgs discovery (2012).





Leakage Current

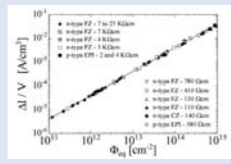
- Leakage current is proportional to the fluence ϕ ,

$$I_{leak} = \alpha(T,t) \cdot V \cdot \phi$$

with temperature-sensitive annealing like

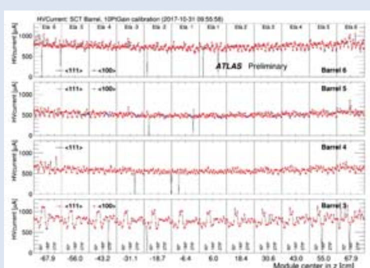
$$\alpha(t) = \alpha_I \cdot \exp(-t/\tau_I) + \alpha_0^* - \beta \cdot \ln(t/t_0) \quad \text{Hamburg model [3]}$$

$$\alpha(t) = a_1 e^{-t/\tau_1} + a_2 e^{-t/\tau_2} + a_3 e^{-t/\tau_3} + a_4 e^{-t/\tau_4} + a_5 e^{-t/\tau_5} \quad \text{Sheffield - Harper model [4]}$$

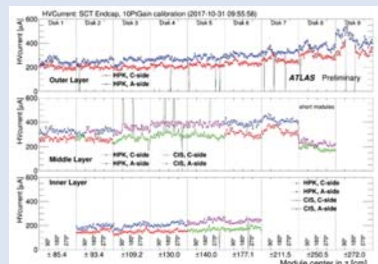


M. Moll's thesis [3]

- All modules draw rather uniform HV current as of Oct. 2017

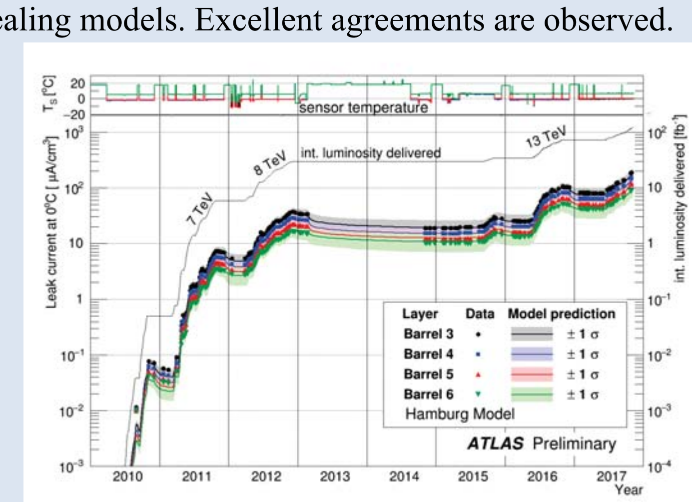


Barrels (Periodic bumps in Barrel 3 due to higher temperature setting in one cooling loop.)



Endcaps (Side-A is higher due to higher temperature. High-eta modules draw higher current as predicted by FLUKA simulation.)

- Using histories of sensor temperatures and delivered luminosities since 2010, the leakage current data are compared with predictions by two annealing models. Excellent agreements are observed.



Evolution of leakage current of 4 barrel layers and model prediction

Taka Kondo (KEK) on behalf of the ATLAS Collaboration

Ref: [1] ATL-GEN-2005-001, [2] R. Wunstorf, Thesis NIM A466(2001)308, [3] M. Moll, Thesis DESY(1999), [4] R. Harper, Thesis U of Sheffield(2001)