25th RD50 workshop (CERN)

Signal and Charge Collection Efficiency of n-in-p strip detectors after proton and neutron irradiation to HL-LHC fluences

Sven Wonsak on behalf of the ATLAS Upgrade Strip Sensor Collaboration

ATLAS Upgrade Strip Sensor Collaboration

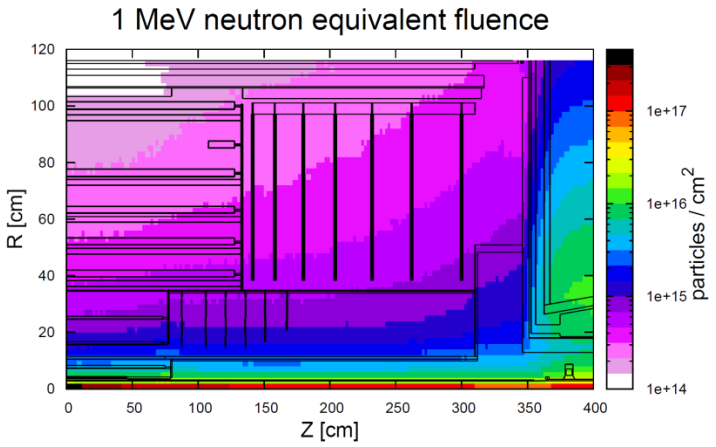
University of Birmingham, BNL, Cambridge University, DESY, University of Freiburg, University of Geneva, Glasgow university, KEK, Kyoto University of Education, Lancaster University, University of Liverpool, JSI and University of Ljubljana, University of New Mexico, NIKHEF, Osaka University, Charles University in Prague, Academy of Sciences of Czech R., Queen Mary University of London, UC Santa Cruz, University of Sheffield, Tokyo IT, University of Tsukuba, IFIC Valencia, CNM and HPK

Outlook

- Sensor properties
- Charge collection measurement method
- Measurement results after irradiation at different fluences
  - Neutrons
  - Charged particles
  - Gammas

ATLAS Phase II upgrade

- FLUKA predictions of the maximum 1MeV n_{eq} fluences normalized to 3000fb^{-1} of HL-LHC
  - Pixel innermost barrel: $1.4\times10^{16}n_{eq}/cm^2$ ($2.8\times10^{16}n_{eq}/cm^2$)
  - Strip barrel: $5.3\times10^{14}n_{eq}/cm^2$ ($1\times10^{15}n_{eq}/cm^2$)
  - Strip endcap: $8.1\times10^{14}n_{eq}/cm^2$ ($1.6\times10^{15}n_{eq}/cm^2$)
- ATLAS qualifies with 2× safety with respect to predicted radiation



Radiation background studies for the Phase II inner tracker upgrade; P. S. Miyagawa and I. Dawson; ATL-UPGRADE-PUB-2014-003

Sensors

ATLAS07

- p-type FZ(100)
- ~ 6.7kΩcm
- **Depletion voltage ≈190V**
- 310µm thick
- Full size sensor (10cm×10cm), surrounded by mini's (1cm×1cm)
- 6 Zones for mini's with different n-strip isolation
  - Individual p-stop
  - p-spray
  - p-spray + p-stop
- 74.5 µm pitch (Zone 6 100 µm)

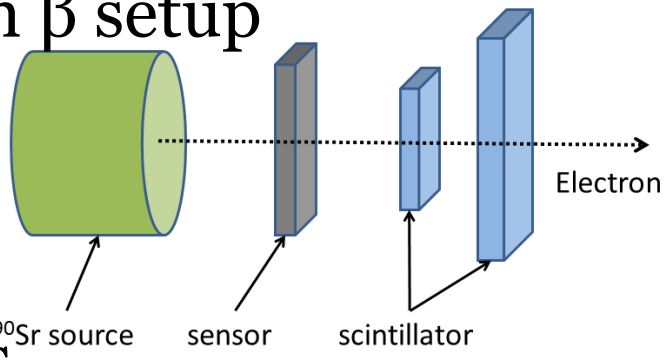
ATLAS12A (differences to 07)

- ~ 3kΩcm
- **Depletion voltage ≈350V**
- 320 µm thick
- Bond-pads modified to match new ASIC (ABC130)
- Improved PTP for main sensor
- Mini's: additional PTP gate structures and End-Cap structures

Produced by HPK

Charge Collection Measurements

- Charge collection measurements in β setup
  - ^{90}Sr source
  - Scintillator for trigger
  - Analogue Beetle chip (LHCb) for read-out with ALiBaVa system
- ALiBaVa system with kazu settings
  - Longer falling time compared to LHCb operation settings
  - 40MHz read-out clock: delay not relevant due to ready signal from chip
- Measurements in cold environment (-20°C to -25°C)
- Common clustering algorithm



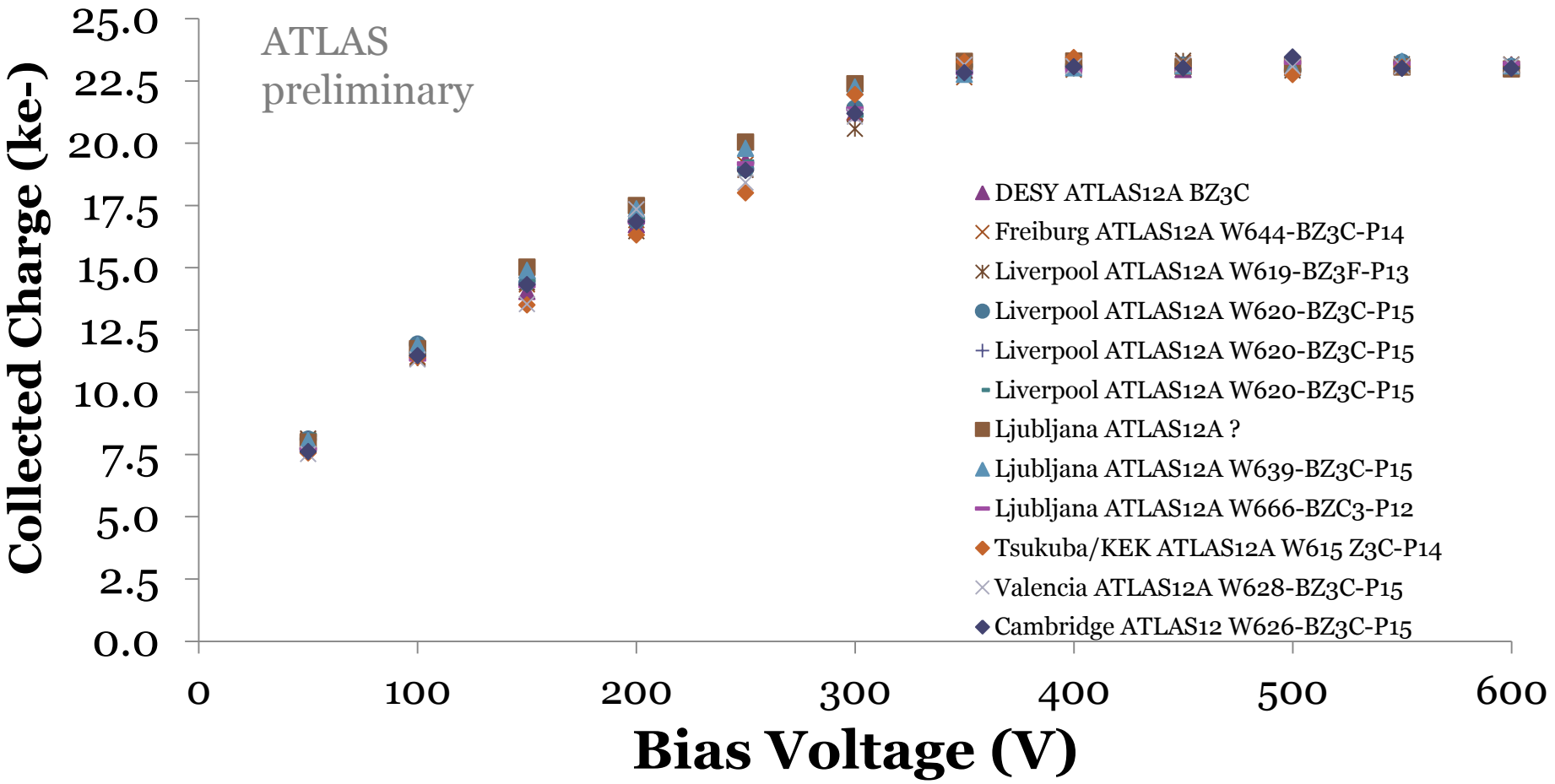
Normalization

- Using charge collection measurements of un-irradiated ATLAS12A for calibration
  - Use mean of all measurements when sensor is fully depleted
  - Charge Q depends on sensor thickness:

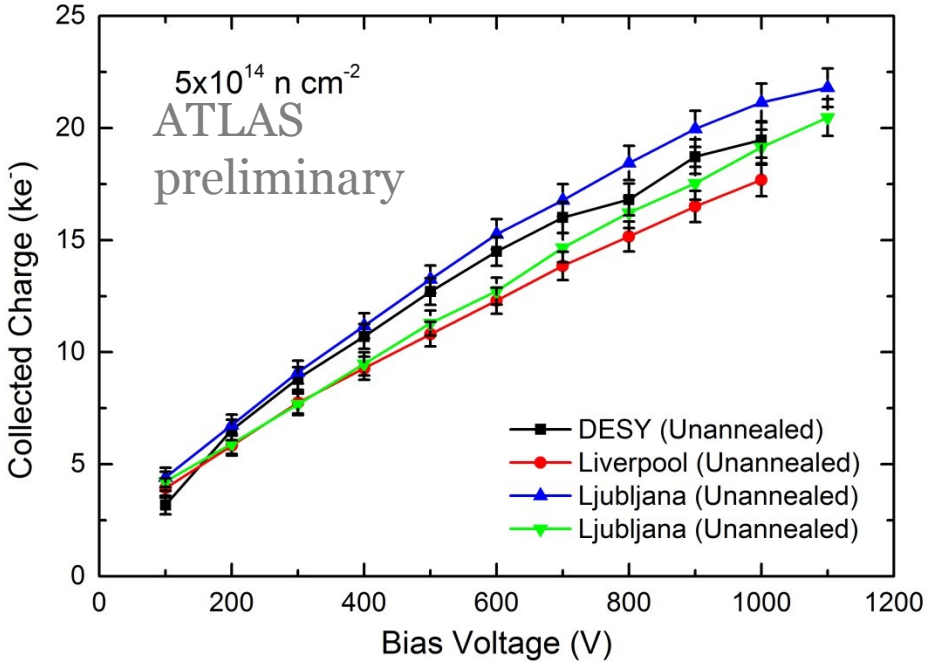
    $Q = \frac{d}{3.68} * (190 + 16.3 * \ln(d))$

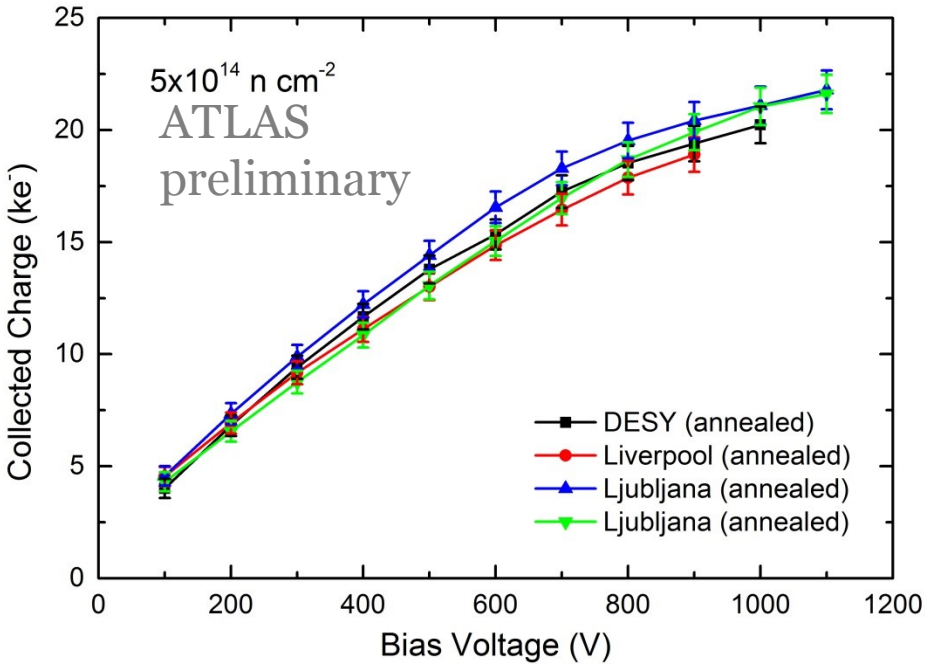
    d: sensor thickness
  - Active thickness of ATLAS07/ATLAS12 sensors, derived from CV of large area sensors and by eTCT
    - ATLAS07: 293µm => 22.5ke$^-$
    - ATLAS12A: 302 µm => 23.2ke$^-$

Pre-irradiation ATLAS12



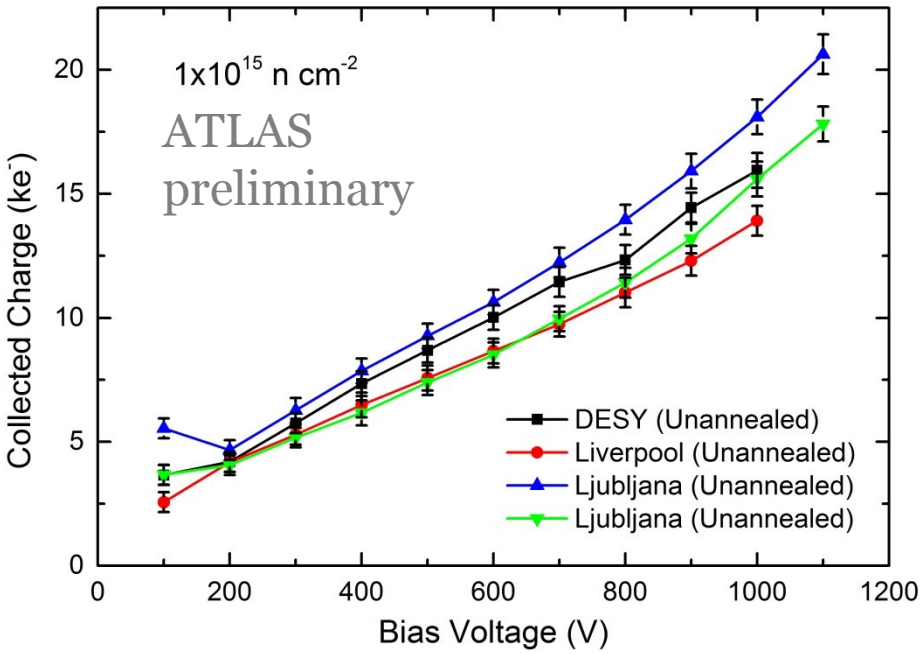
ATLAS12 Neutrons 5×10^{14} n_{eq}/cm^2

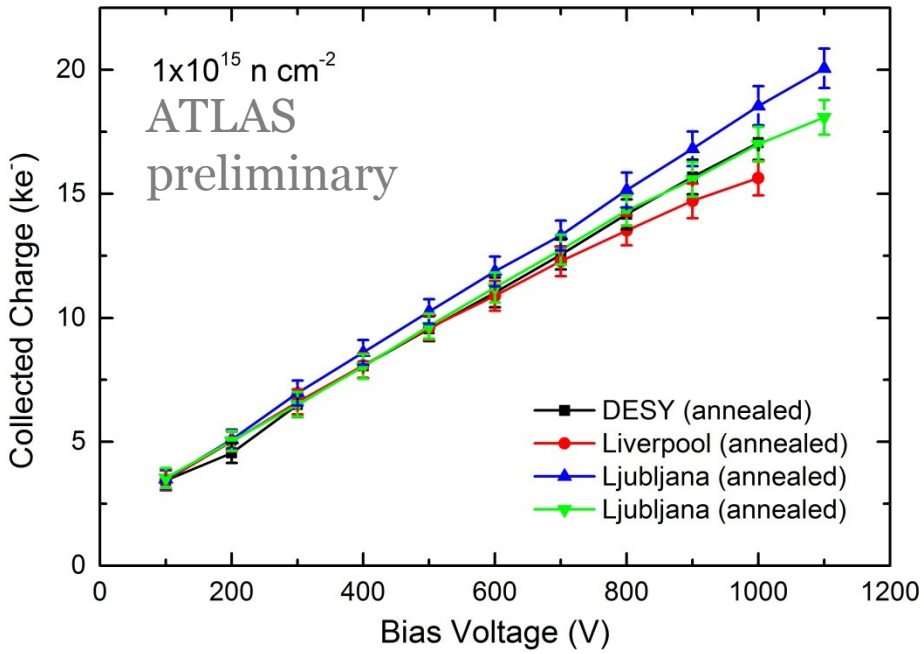




- Accelerated annealing: 80min at 60°C (10days at 20°C)
- Uniformity after annealing much better
  - Different annealing times (order hours) after irradiation due to shipment and handling
  - Largest difference of charge at beginning of annealing cycle
    - After 80min at 60°C less sensitive to small differences in time and temperature

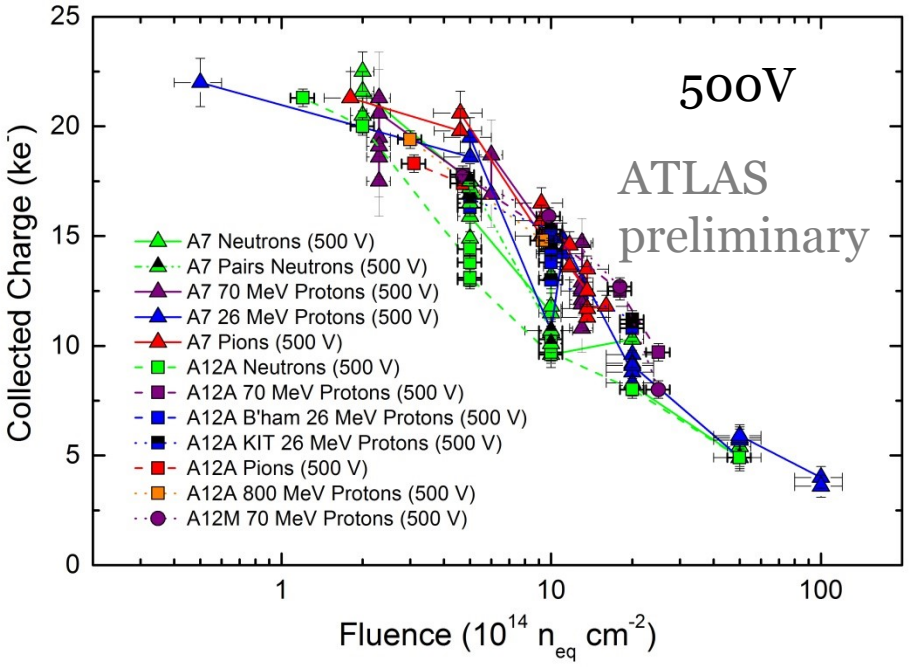
ATLAS12 Neutrons 1×10^{15} n_{eq}/cm^2

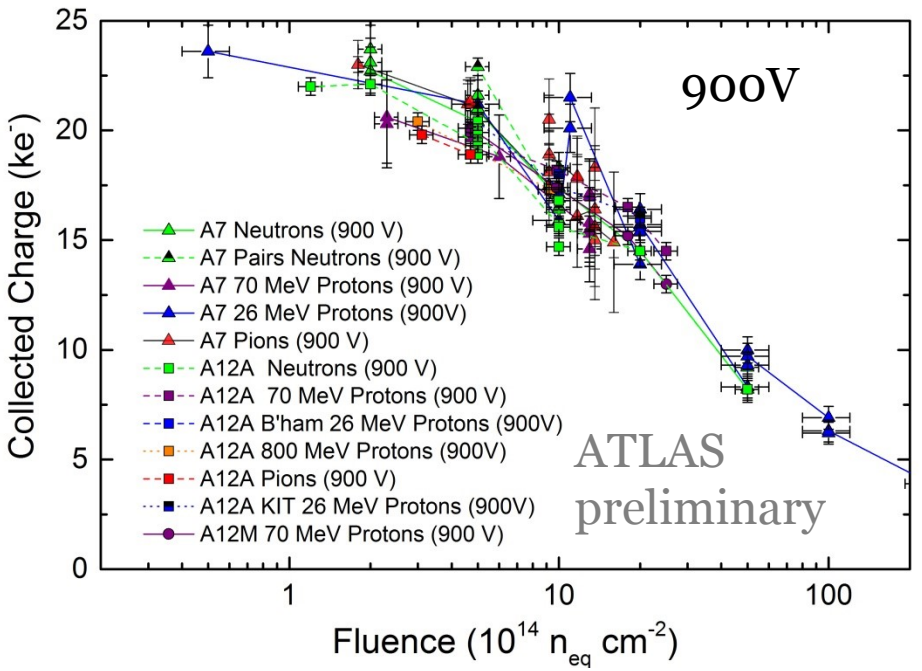




- Accelerated annealing: 80min at 60°C (10days at 20°C)
- Uniformity after annealing much better

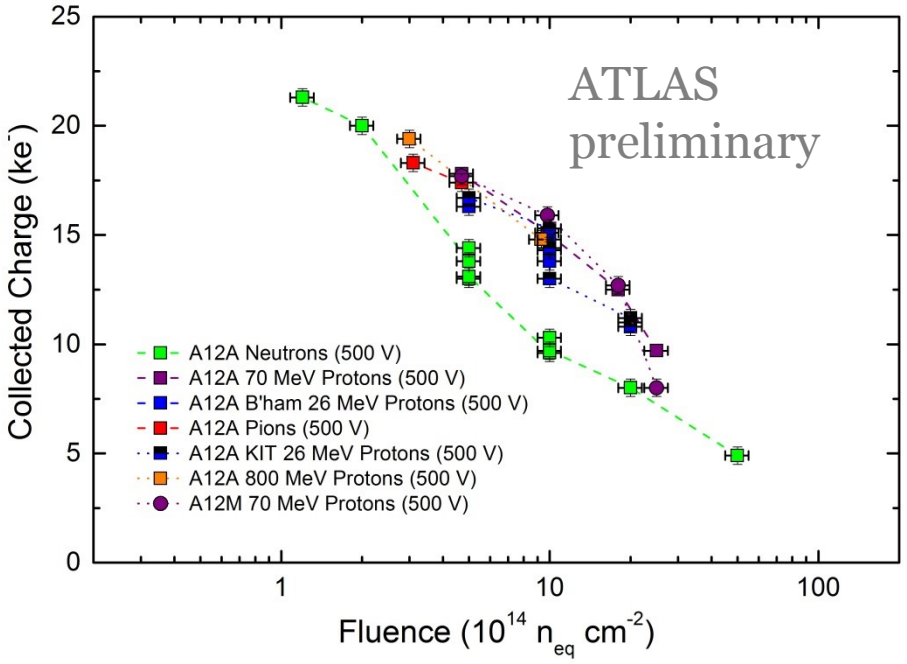
All ATLAS07/ATLAS12 measurements





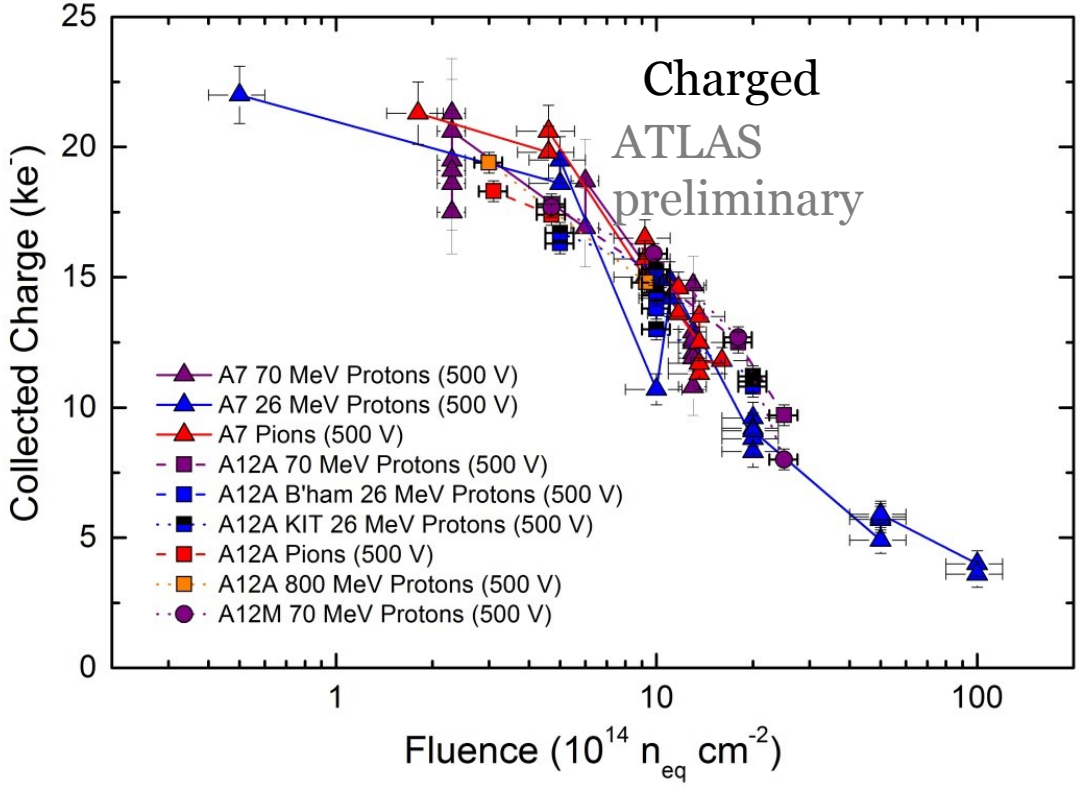
- Larger spread at 500V for medium fluence -> sensors not fully depleted
- All measurements after annealing
- Look into details in the next slides

ATLAS12 measurements (500V)



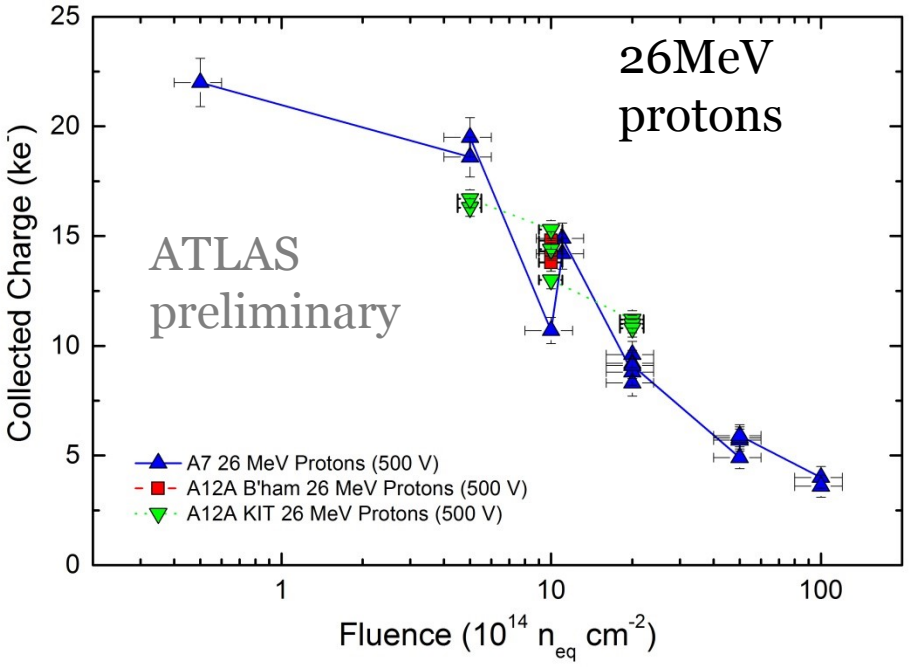
- Measurements after Neutron irradiation clearly lower collected charge than for Protons/Pions
  - Different damage types
  - Difference in charge caused by oxygenation

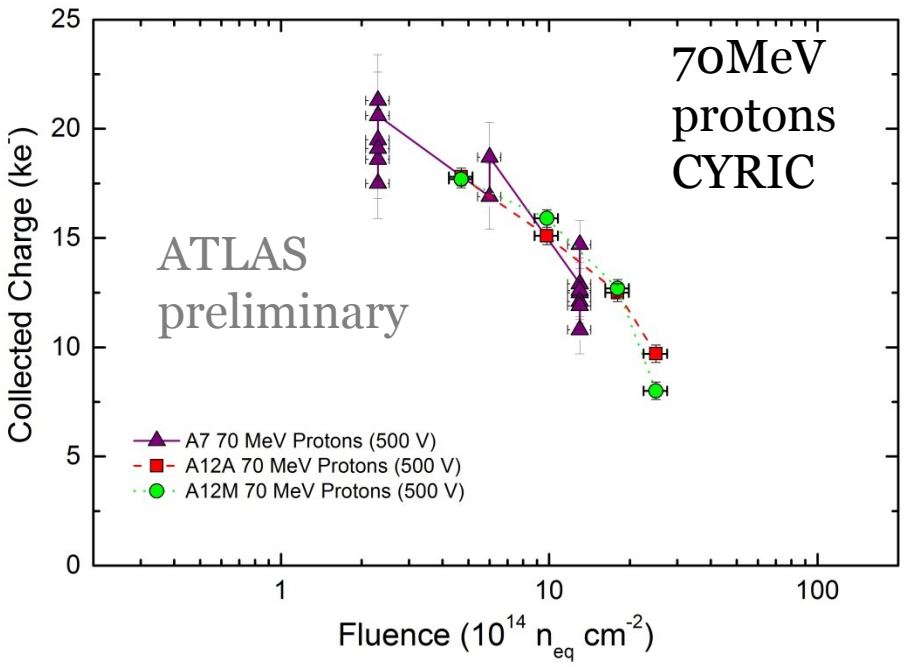
ATLAS07/ATLAS12 charged (500V)



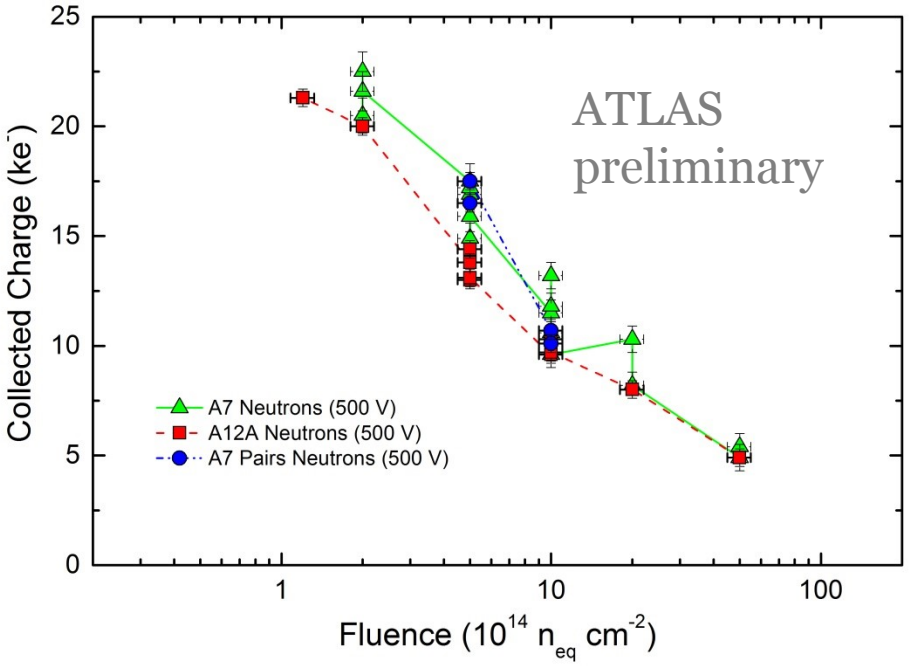
- Irradiation with charged particles
  - Protons with different energies
  - Pions
- Uniformity between ATLAS07 and ATLAS12 better
  - No difference in depletion voltage for this irradiation type after fast donor removal
- Details in next slide

ATLAS07 / ATLAS12 (500V)



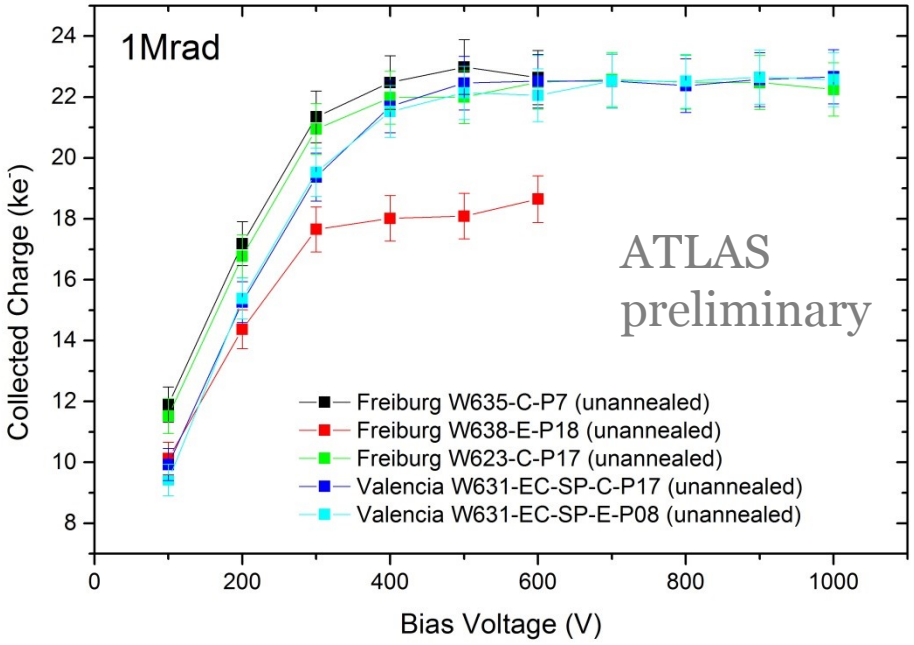


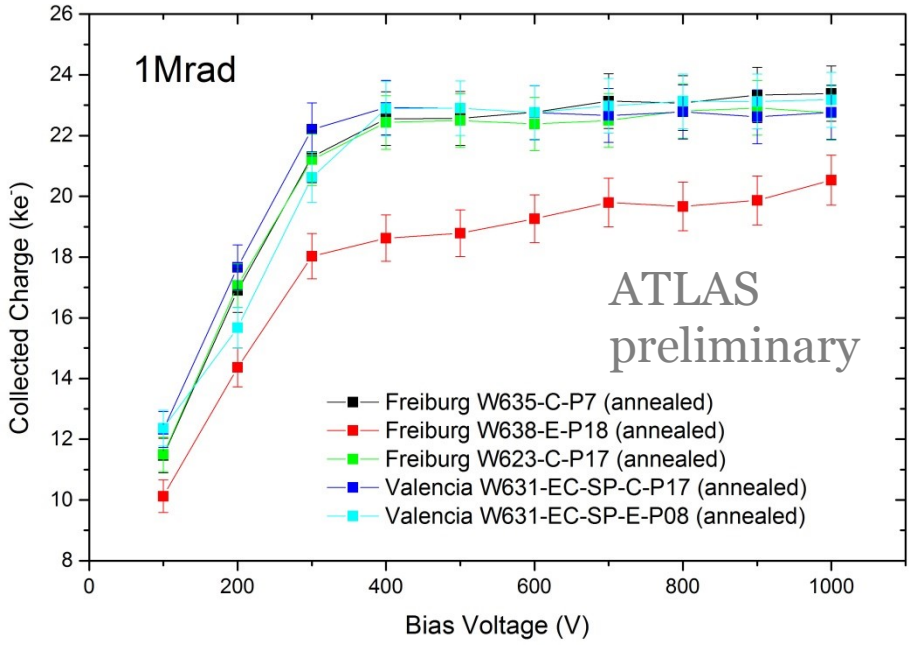
ATLAS07/ATLAS12 neutrons (500V)



- ATLAS12A lower collected charge than ATLAS07
  - Initial depletion voltage different (ATLAS12 higher than ATLAS07)
  - Difference less important at higher fluences

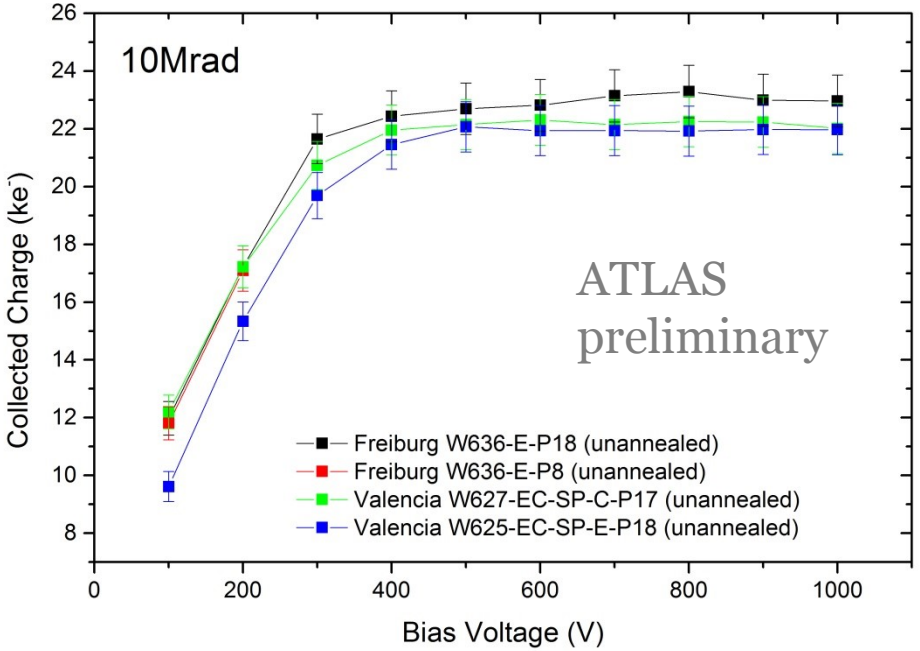
ATLAS12 Gamma 1Mrad

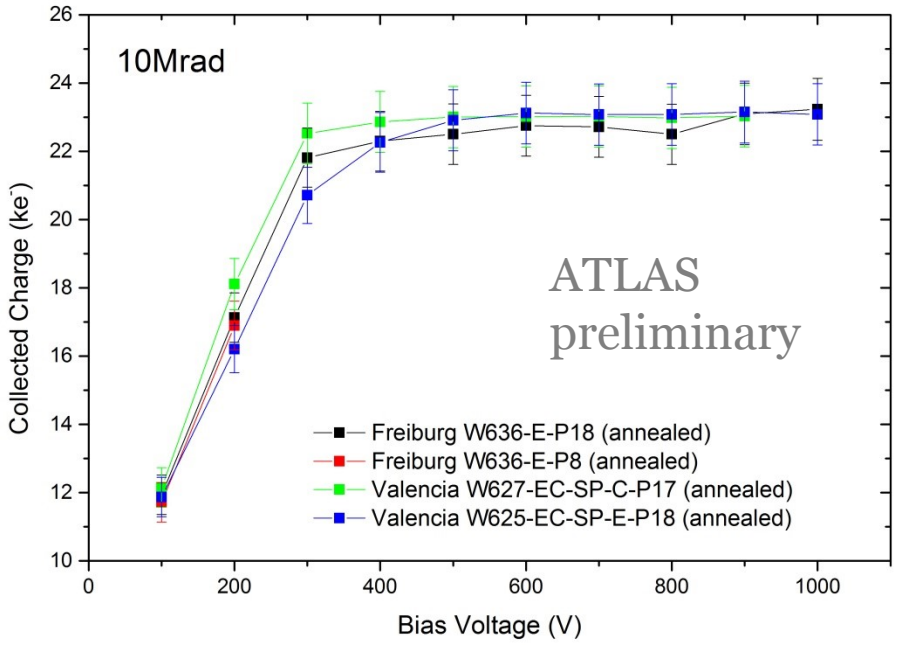




- Irradiation with 1Mrad Gamma's has no clear effect on collected charge for most sensors

ATLAS12 Gamma 10Mrad





- Also 10Mrad Gamma irradiation show no clear degradation on the collected charge

Summary

- Pre-irradiation measurements of different institutes show very good agreement
- Annealing of irradiated sensors (80min at 60°C) reduces spread of measurements
- Sensors irradiated with Neutrons show less collected charge than Proton/Pion irradiated sensors
- No clear difference before and after irradiation with gammas
- Further program is finishing detailed comparison between ATLAS07 and ATLAS12
  - Set specifications for depletion voltage for production