Digital Design and Dependability group,
Czech Technical University in Prague
and
Nuclear Physics Institute of the Czech Academy of Sciences

A System for Radiation Testing and Physical Fault Injection into the FPGAs and Other Electronics

Tomáš Vaňát, Jan Pospíšil, Filip Křížek,
Jozef Ferencei and Hana Kubátová

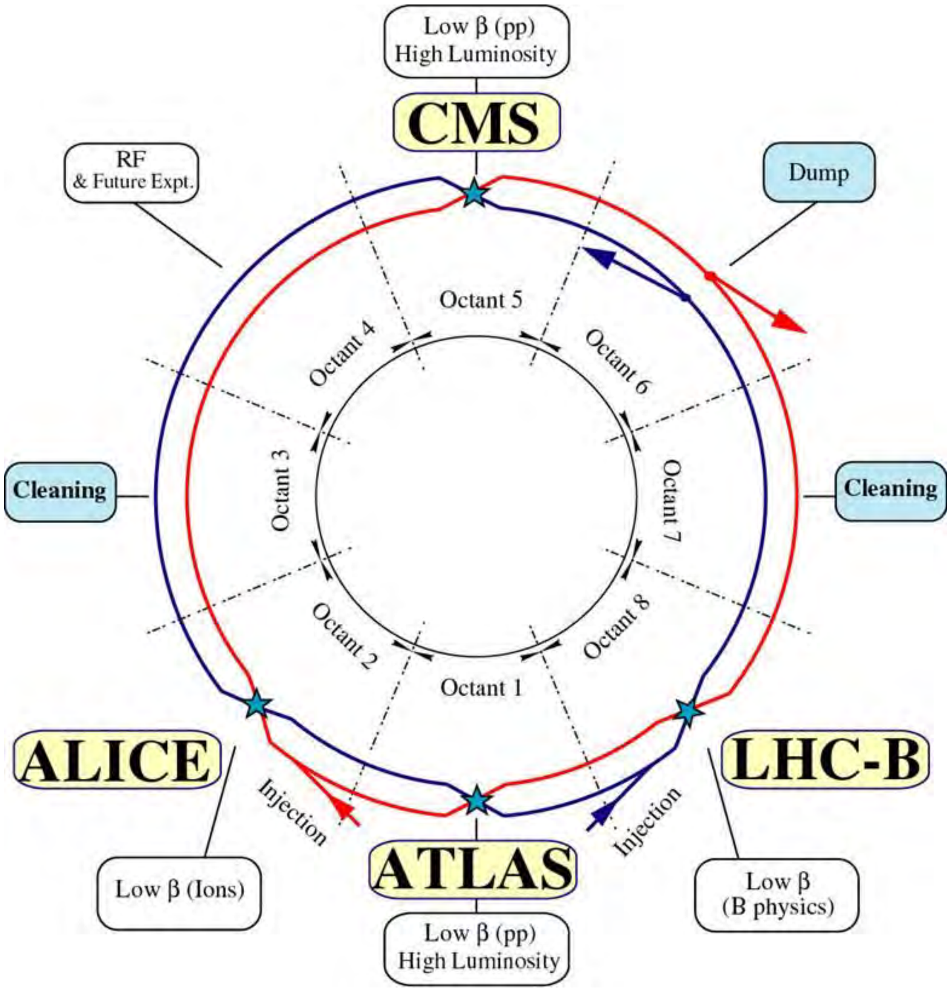
Why Are the Tests of Radiation Tolerance Needed?

- Dependable applications in common environment
  - Even natural radiation background can cause errors
  - Even a small probability of an error can be unacceptable for dependable devices
- High-radiation environment
  - Aircraft industry
  - Space applications
  - Medical applications
  - High-energy particle and nuclear physics experiments

LHC at CERN

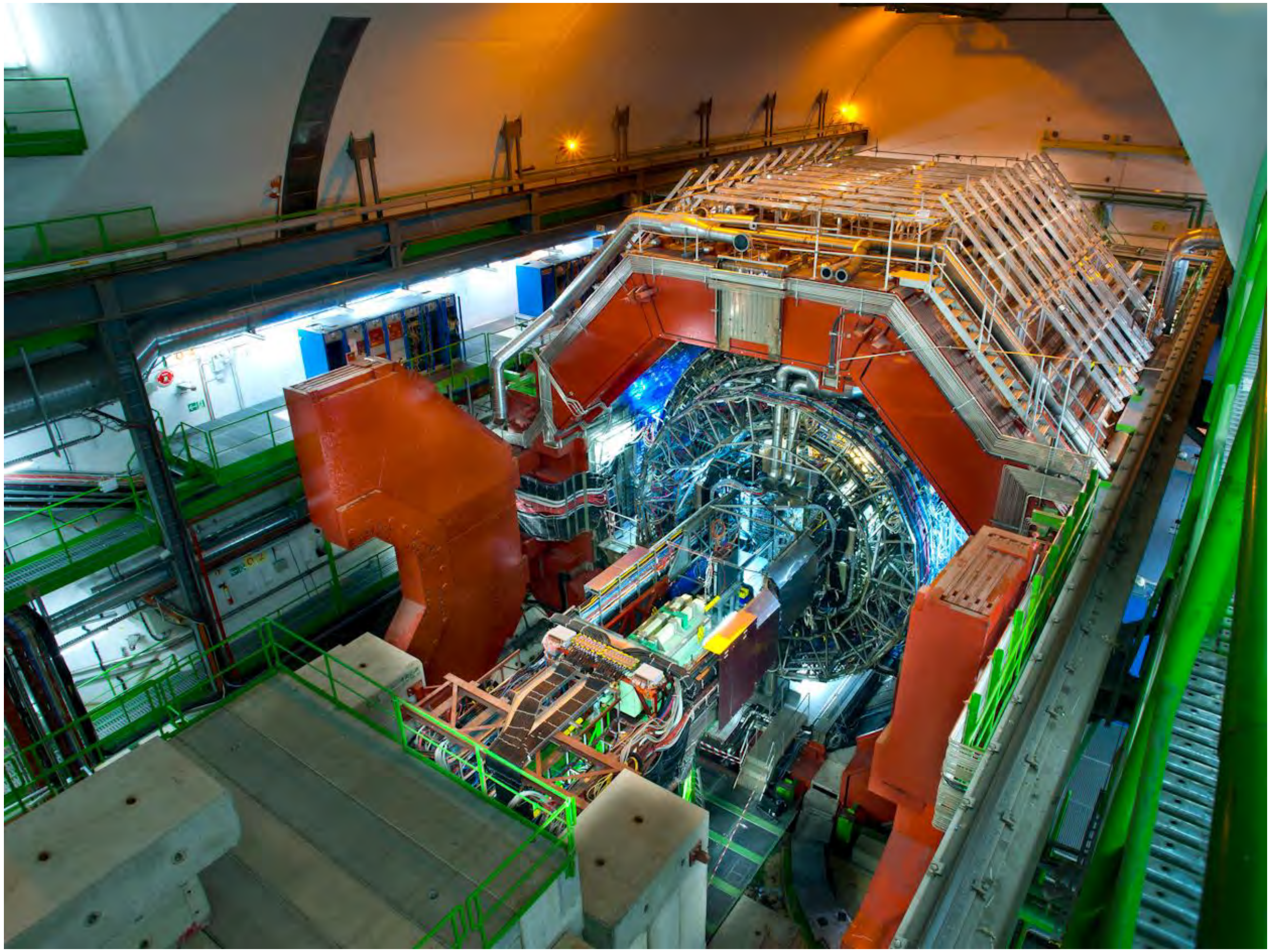

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km

The ALICE Experiment at the LHC

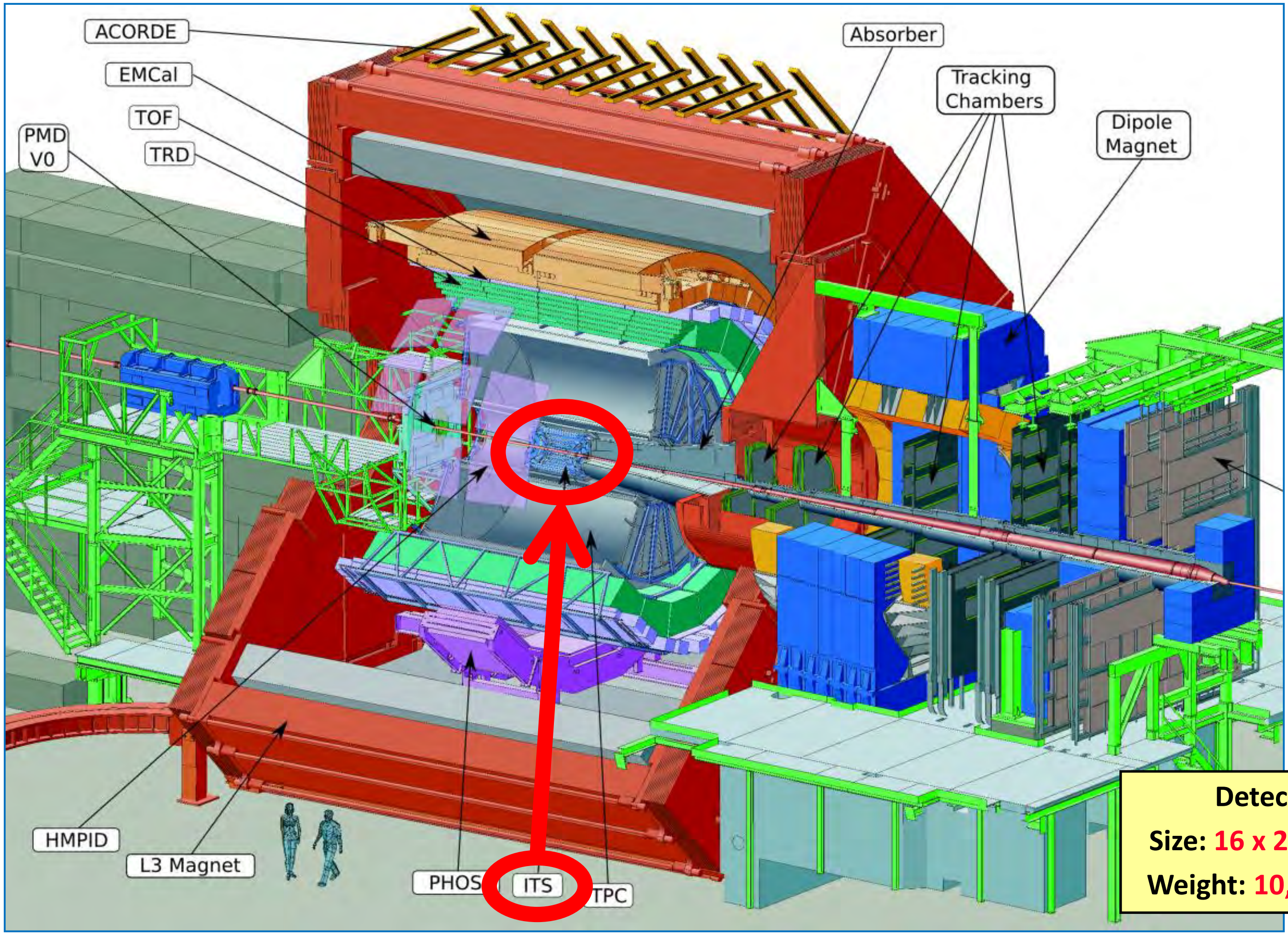


- LHC circumference: 27 km
- Two beams in opposite directions
- Energy up to 7 TeV (each beam)
- High particle currents (~mA)
- Beams collide on 4 places
- High-radiation environment

The ALICE Experiment



ITS at the ALICE Experiment



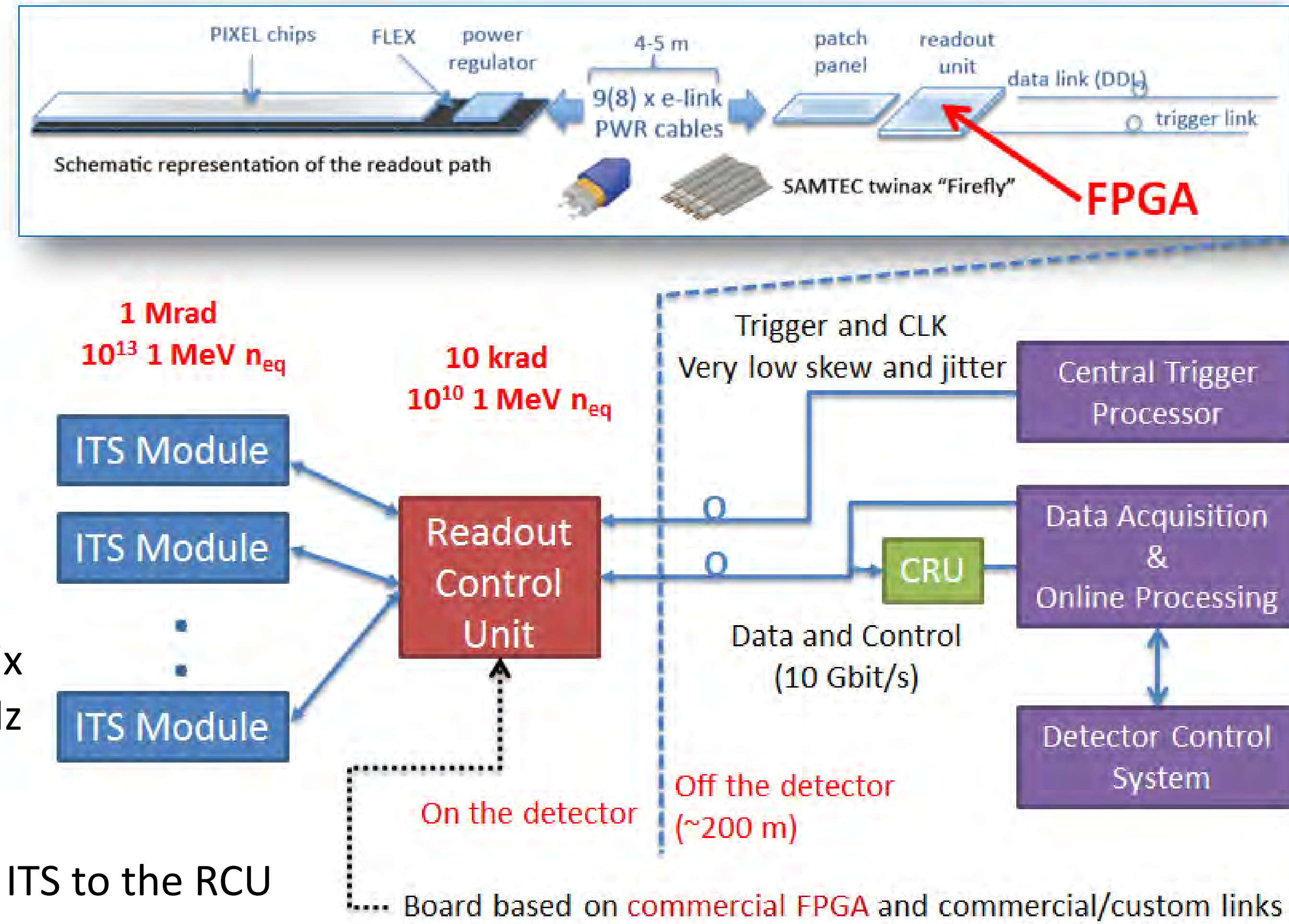
Detector:
Size: 16 x 26 meters
Weight: 10,000 tons

ITS Readout

Over 25 000 pixel chips in 7 layers just next to the point of collision.

Resolution: ~25 Gpix
Readout rate: ~ MHz

Over 5000 2.5 GB/s
data channels from ITS to the RCU



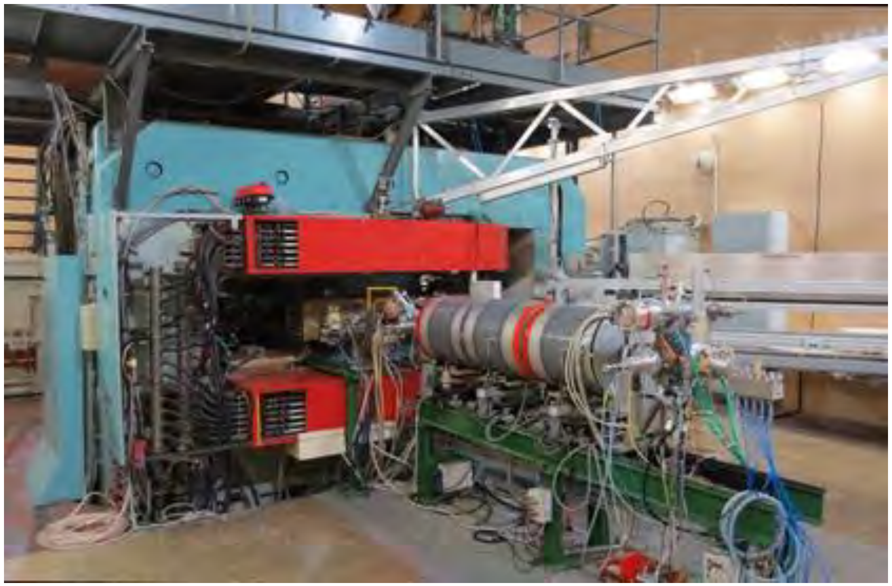
Which Parameters Need to Be Tested?

- Resistance to the total ionizing dose (TID)
  - Defects in a material due to the radiation effects
  - Changes are usually permanent and irreversible
- Single event effects (SEE) rate dependence on the flux
  - SEE is usually non destructive to the device
- Dependence on the type of radiation
  - Protons, Gamma, Neutrons
  - Each type of radiations has different effects on the device

What Are the Requirements for Radiation Testing?

- Source of the particles (beam)
- Adjustment and measurement of:
  - Particle energy
  - Particle intensity (flux)
  - Beam position
  - Beam profile
- Test setup
  - Design/device under test
  - Evaluation of the test

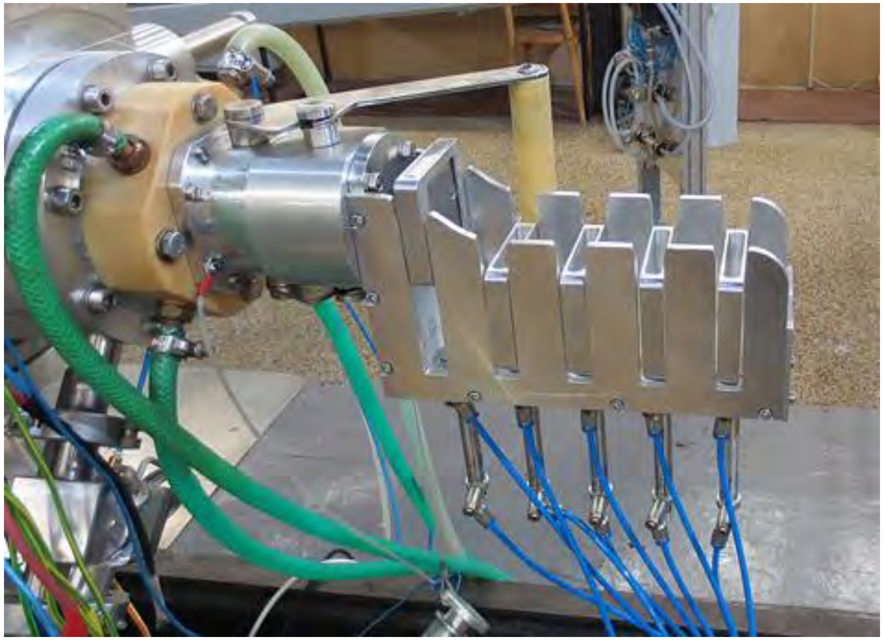
Source of the Particles: NPI Řež Cyclotron



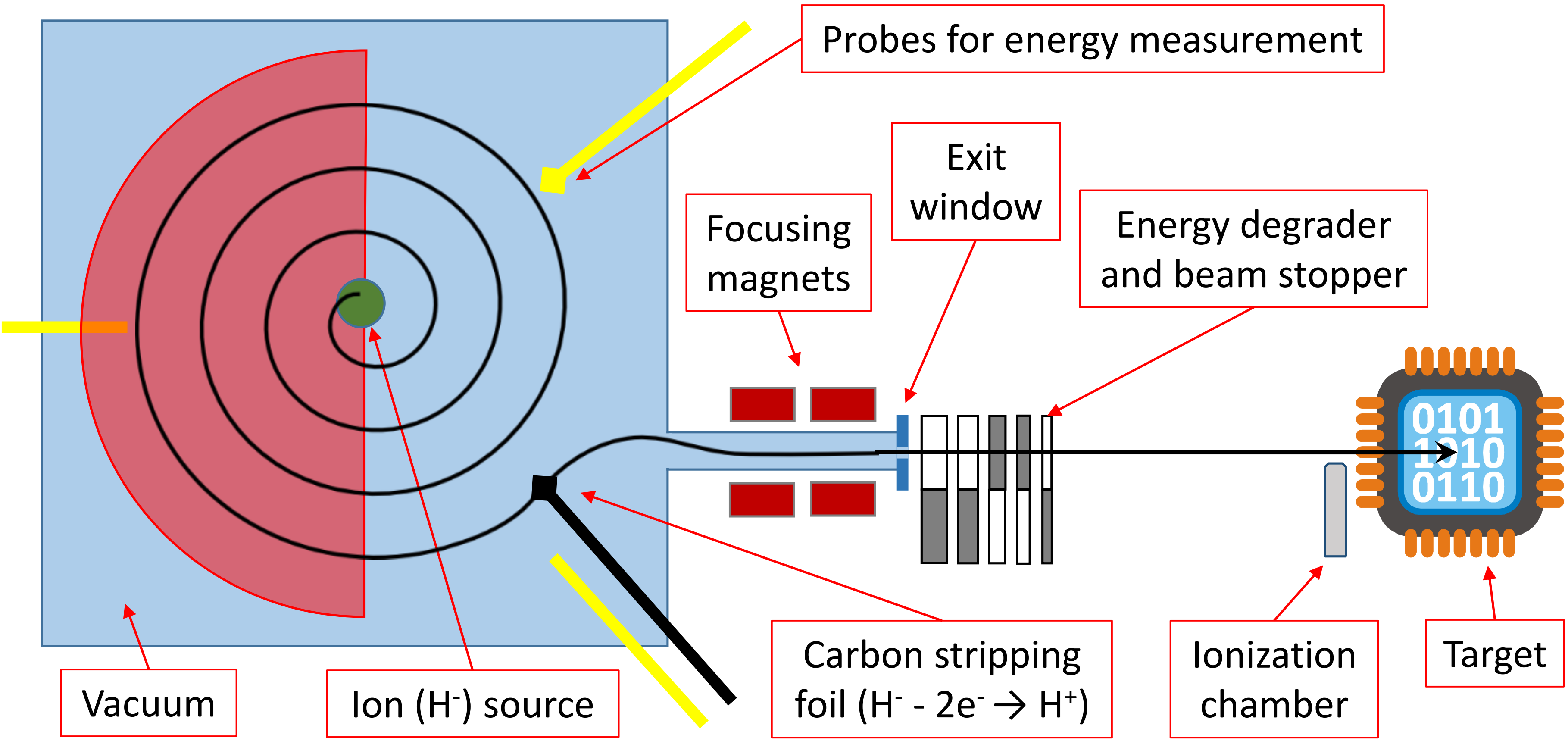
- Proton beam with tuneable energy 6 - 37 MeV
- Flux starting from 10^4 p/cm^2/s up to 10^{14} p/cm^2/s

Energy Adjustment and Measurement

- Cyclotron operates at the maximum energy
- Energy inside the cyclotron is measured
- Energy loss from the exit window to the target and the deposition in the target is calculated
- Energy can be adjusted (lowered) using the energy degrader



The Beam Route

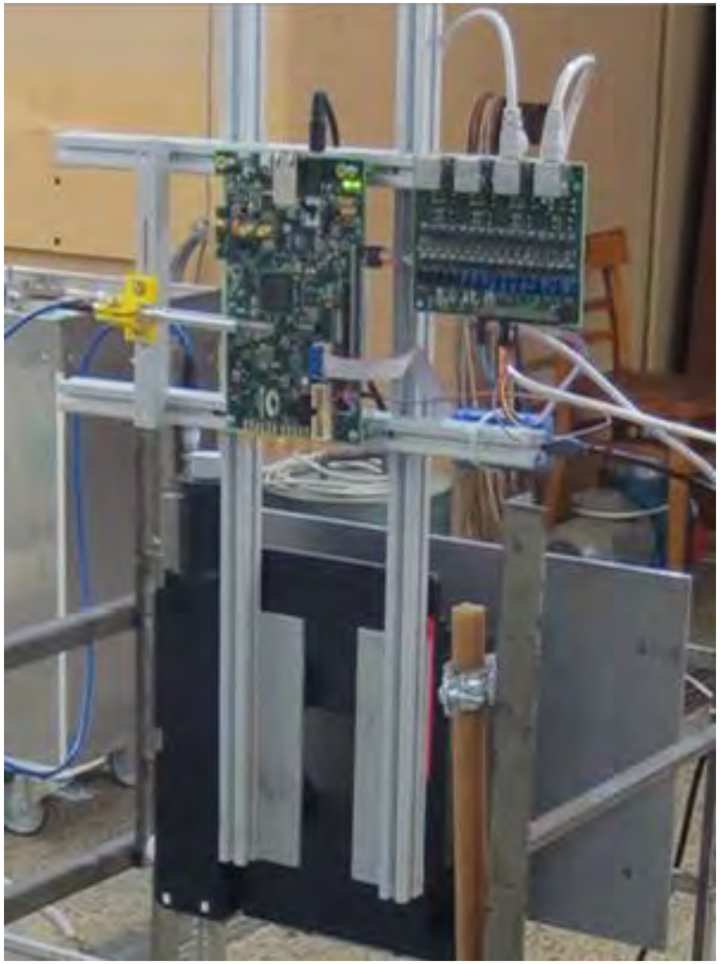


Particle Intensity (Flux) Measurement

- Ionization chamber placed next to the irradiated device
- Cross-calibrated using TimePix detector and GEANT4 simulations
- Scintillator-based monitoring development in progress

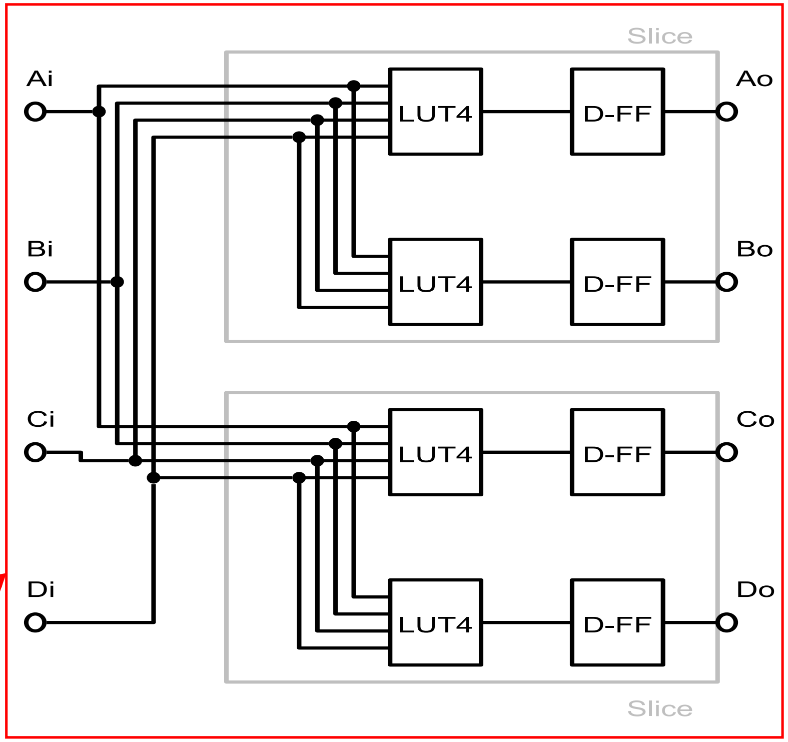
Positioning

- Remotely controlled X-Y moving platform
- The whole setup including the ionization chamber (flux monitoring probe) is attached on it
- Used to scan the beam profile and to put the irradiated device into it

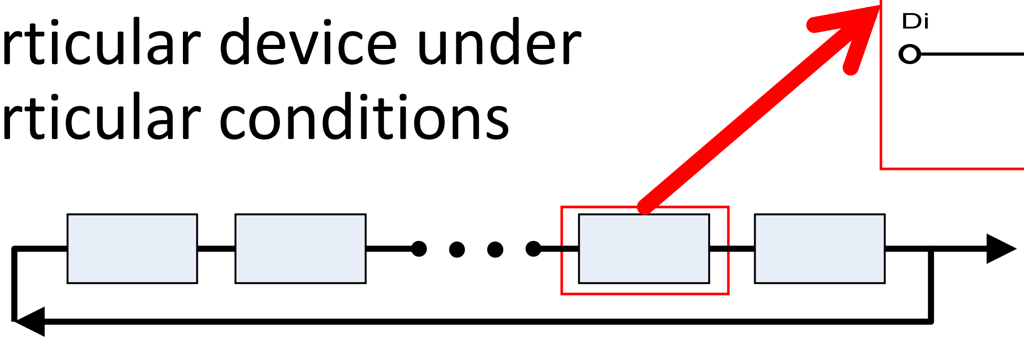


SEU Rate Measurement Circuit For Testing FPGAs

- Tests all LUTs and flip-flops
- Propagates any error to output
- Forms a long pipeline
- Is preloaded with data upon flip-flops reset
- Detects fault rate on the particular device under particular conditions



One pipeline stage



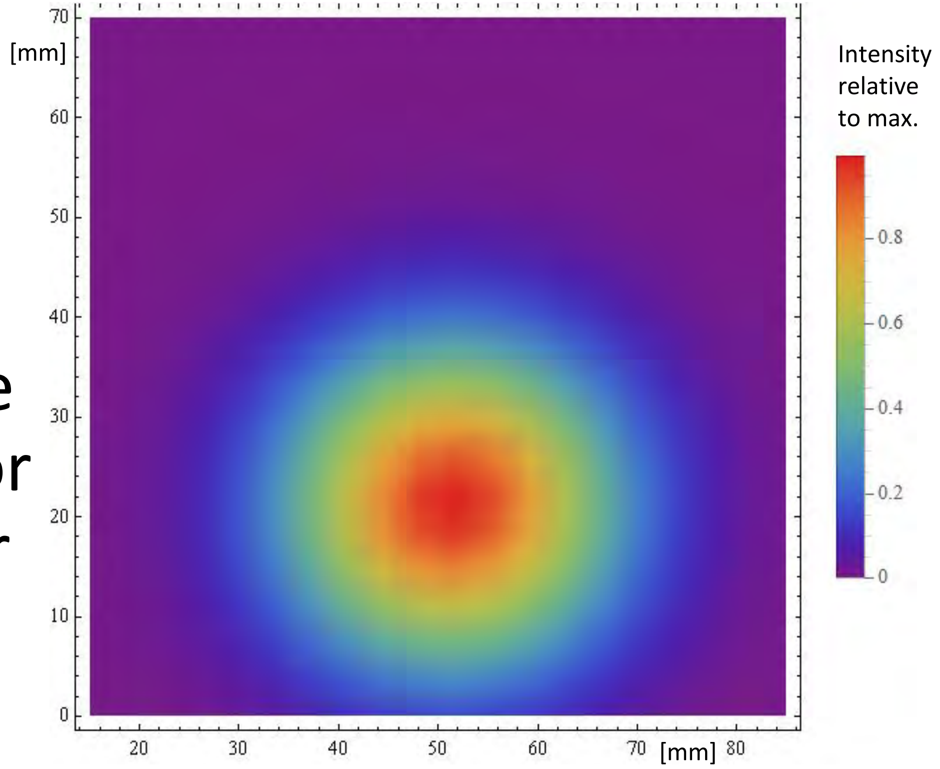
Pipeline

How Do We Do the Testing?

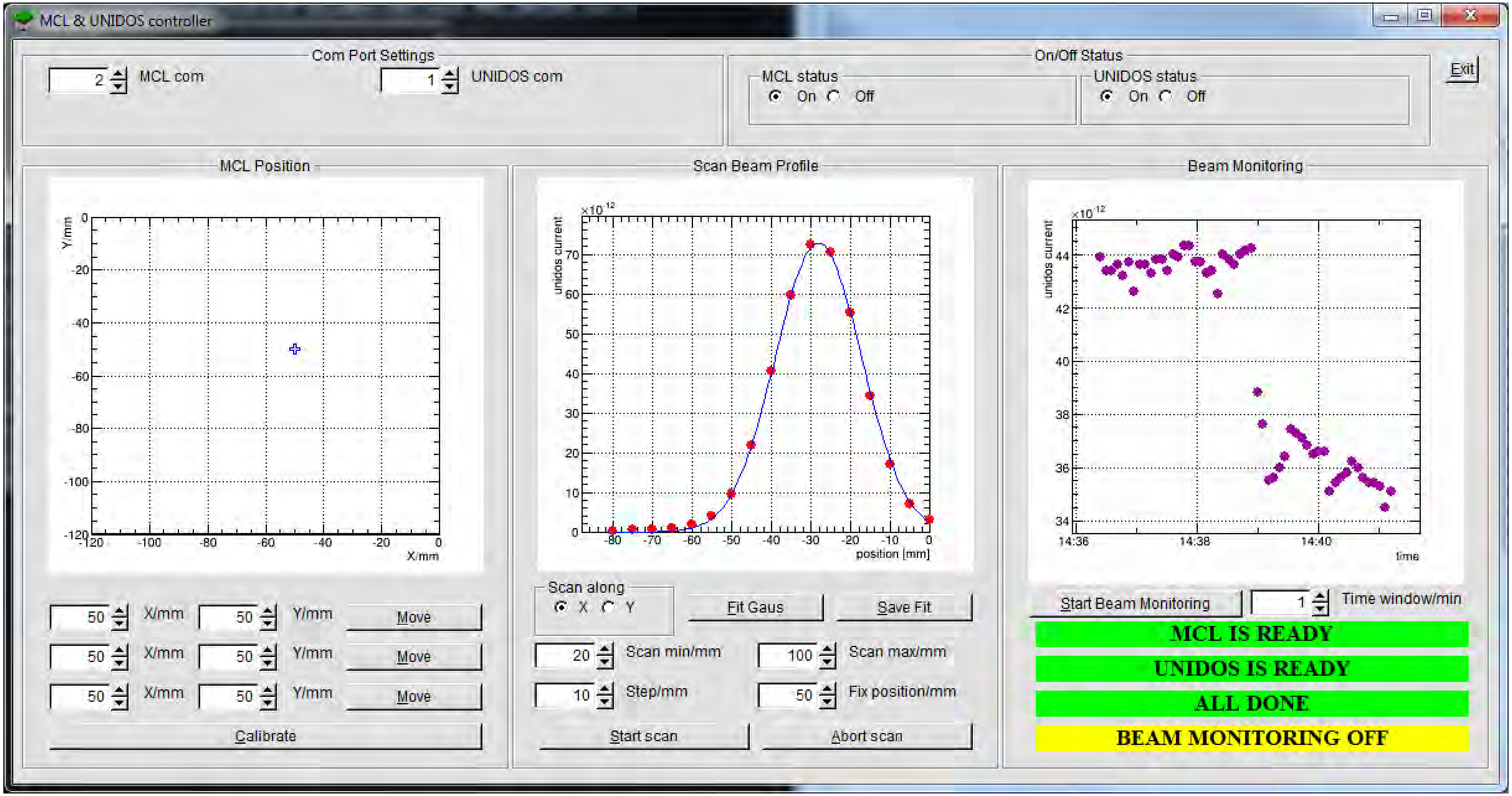
1. Place the setup in front of the cyclotron’s exit window
2. Precise placement of the ionization chamber next to the irradiated device on the setup
3. Start of the cyclotron and coarse tuning of the beam while the beam absorber is active

How Do We Do the Testing?

4. Remove the absorber and let the beam to the target
5. Scan the beam profile using ion. chamber on the moving platform
6. Place the ion. chamber into the beam and fine tune of the beam
7. Place the irradiated device into the beam and monitor the flux with ion. chamber on its edge



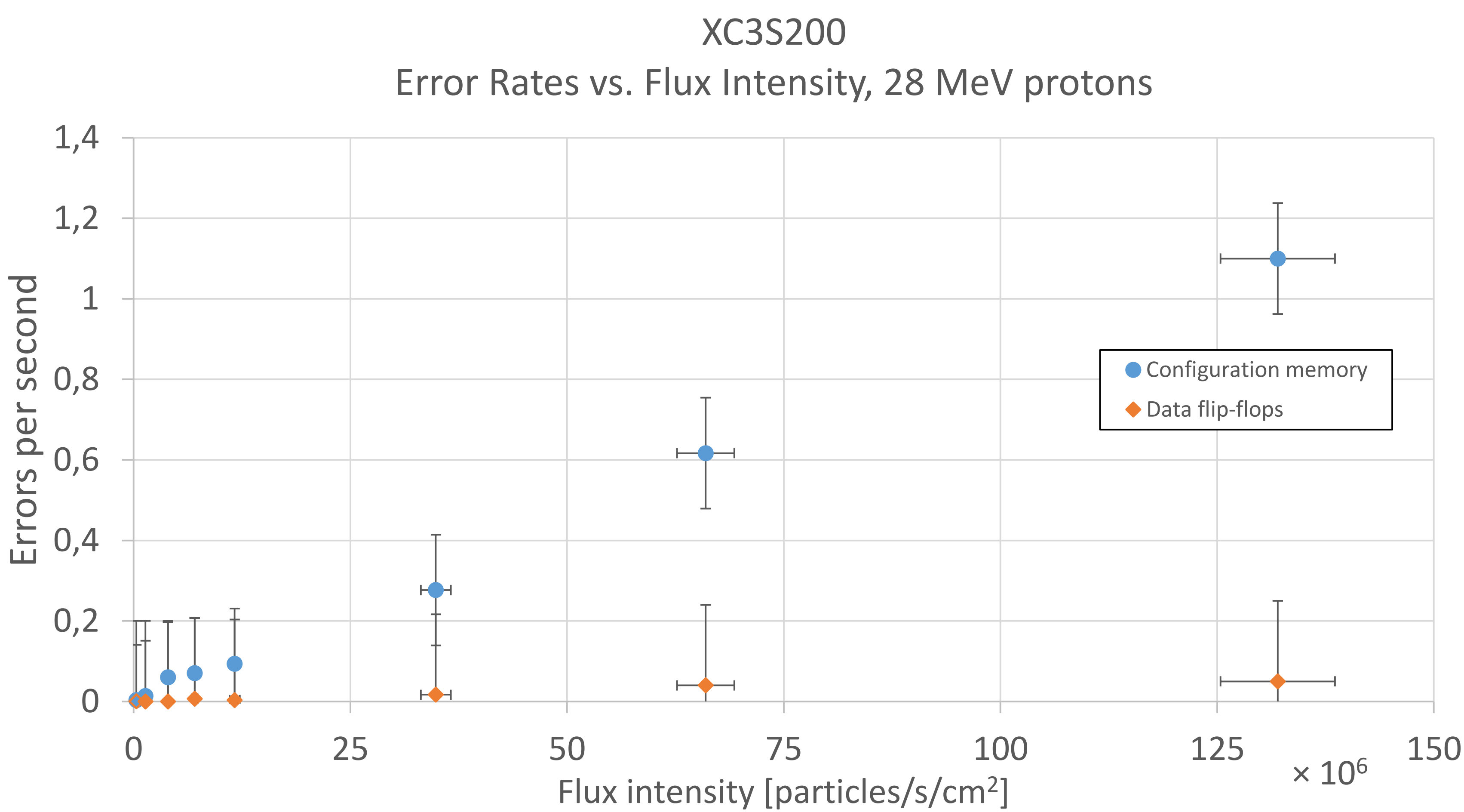
Monitoring Software



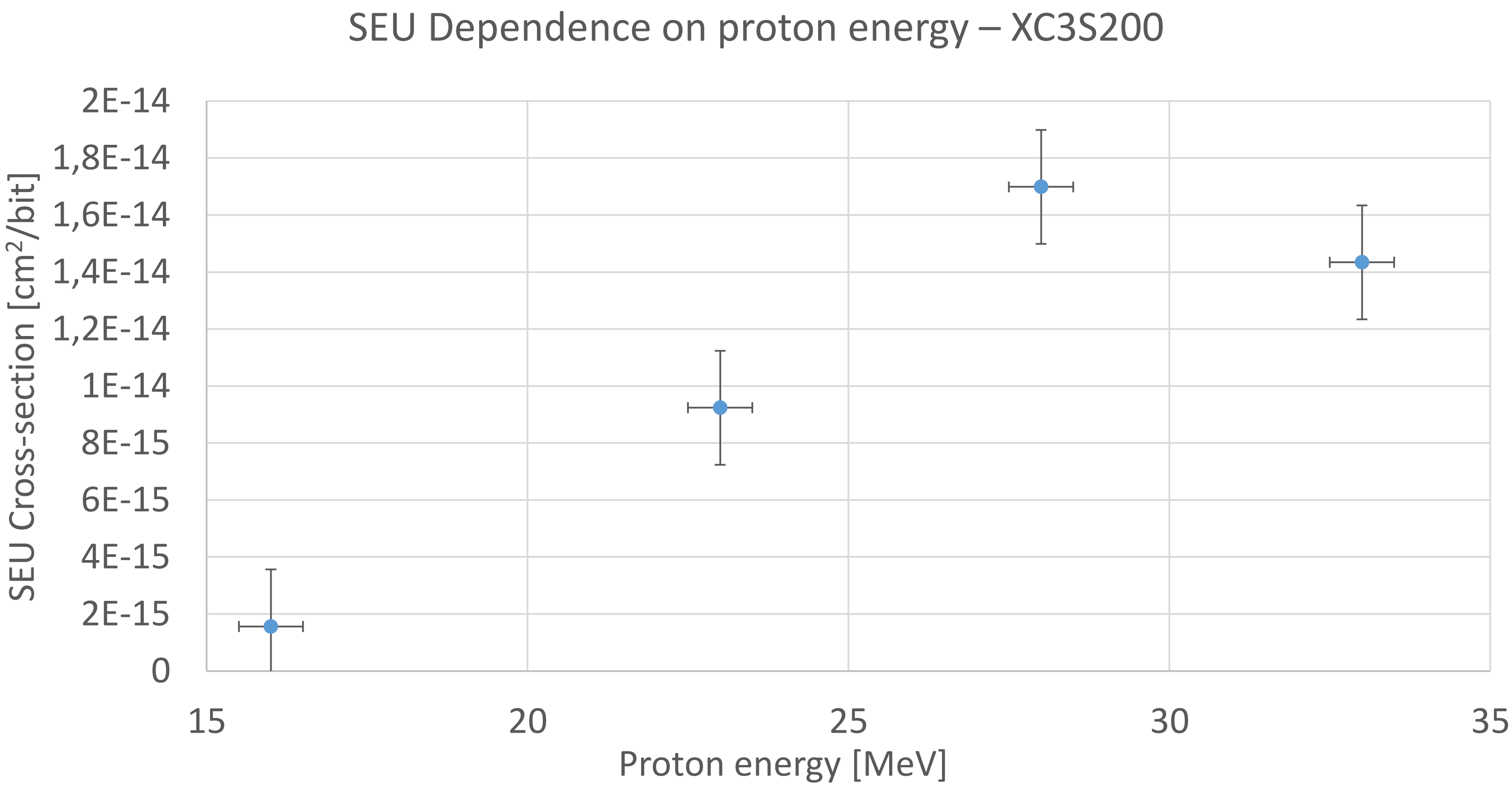
Results

- Already performed tests:
  - Spartan 3 TID resistance and SEU cross-section
  - Microsemi flash FPGAs TID resistance and SEU cross-section
  - Hi-speed coaxial cables TID resistance
  - Optical transceivers – bit error rates in radiation
  - Single event transients in Spartan 3 and ProASIC 3

SEU Dependence on the Proton Flux: Xilinx Spartan 3 (90 nm)



SEU Dependence on the Proton Energy: Xilinx Spartan 3 (90 nm)



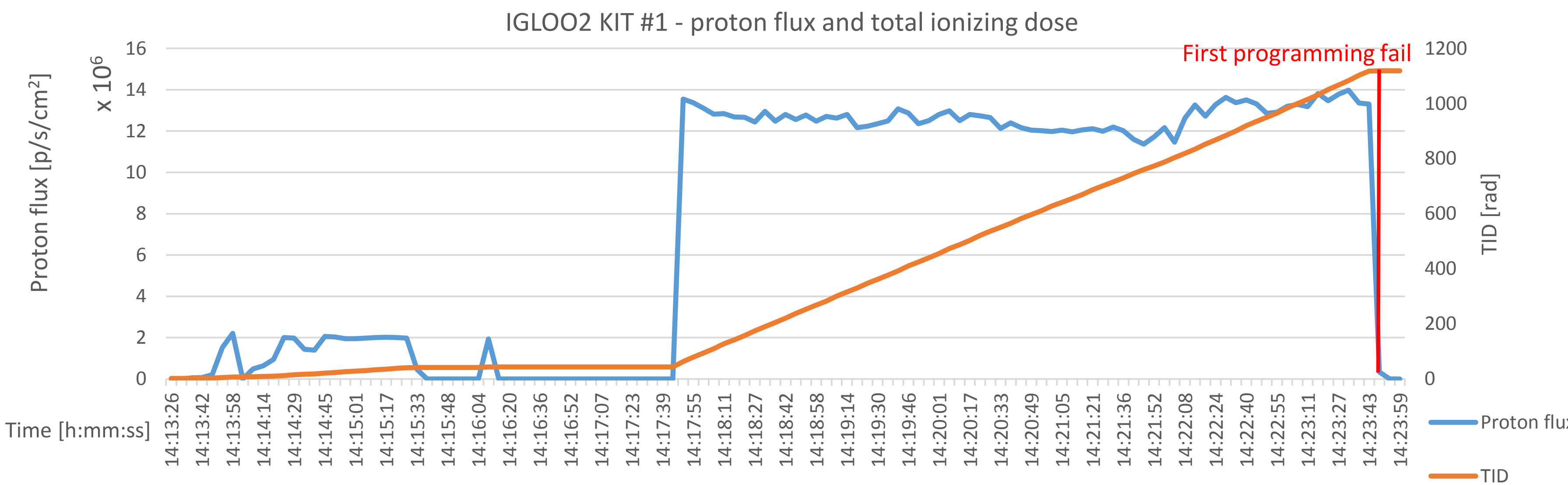
Flash-based FPGAs

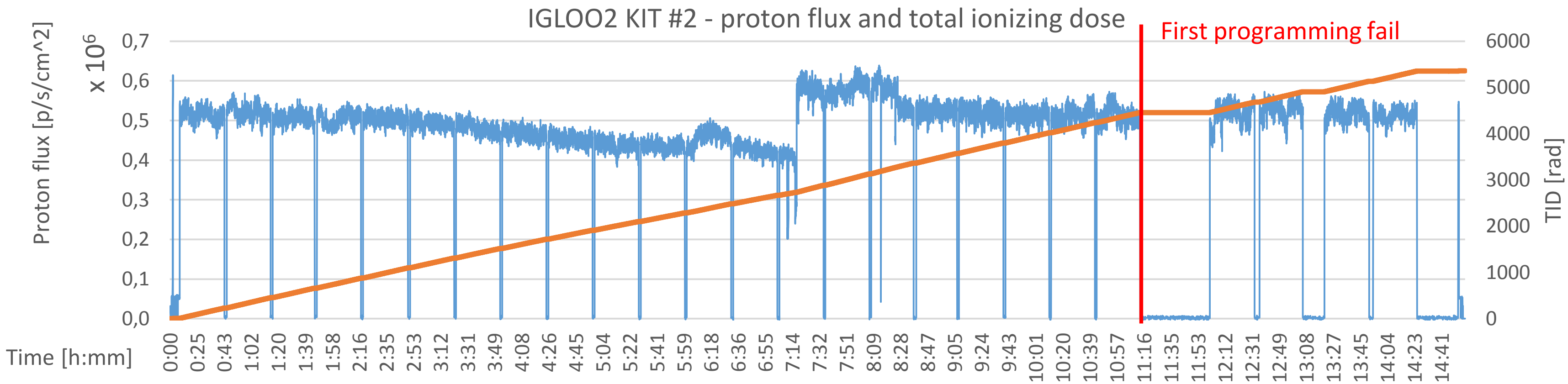
- Microsemi FPGAs – non-RT versions
  - SmartFusion 2, IGLOO 2 (65 nm)
  - ProASIC 3 (130 nm)
- Configuration memory is SEU safe
- SEUs in data memory
- Also some SEL (latch-ups) observed
- Programming issues observed after the measurement
  - Probably the charge pump transistors for Flash programming failed due to the material degradation

Determining the Programming Failure TID Threshold

- Depends on the technology
  - ProASIC3 lasted ~90 krad
  - SF2/IGLOO2 lasted ~7 krad
- Depends also on the dose rate:
  - For high dose rate the failure threshold is lower (~2 orders less flux → ~4 times higher threshold)
  - Recovery process exists
  - From some TID threshold, there is no recovery regardless the dose rate, by which it was achieved

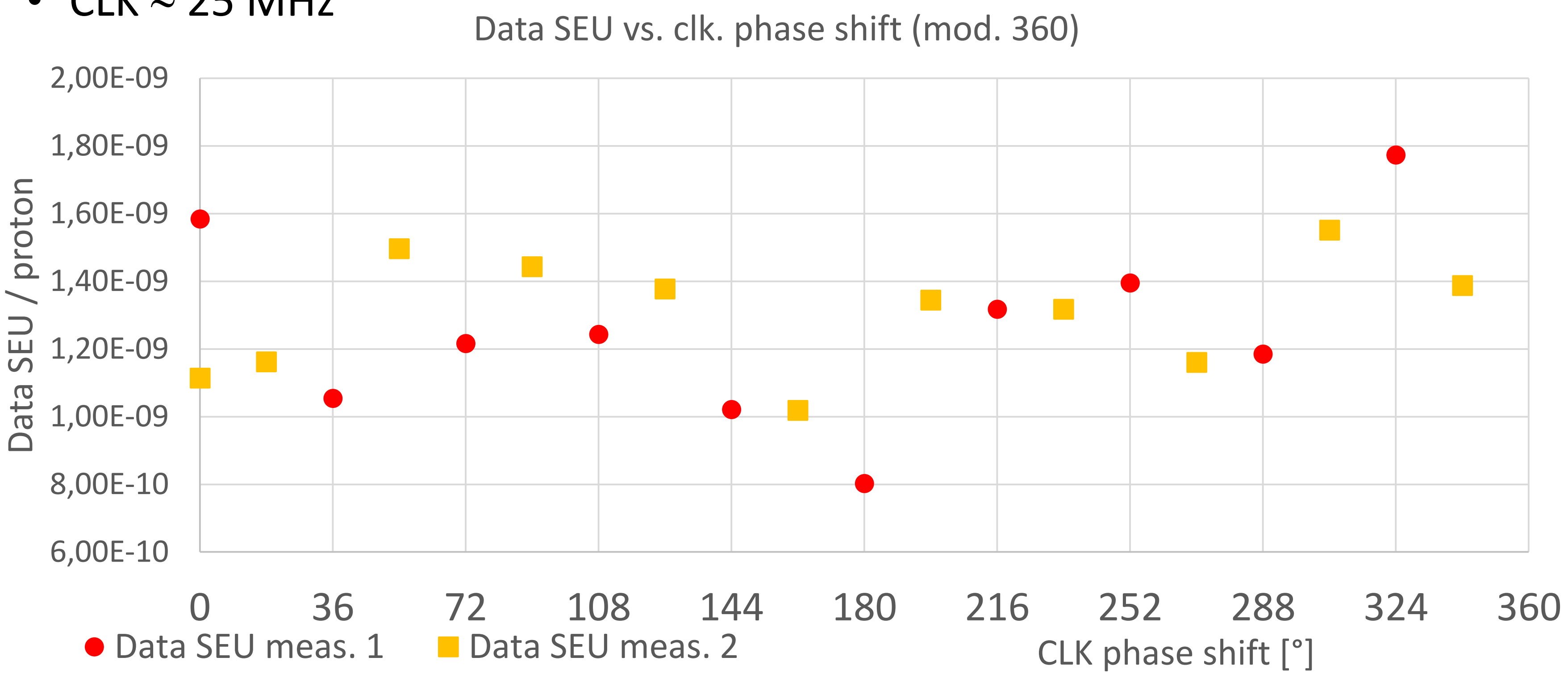
Determining the Programming Failure TID Threshold





Single Event Transient (SET) Measurement

- Xilinx Spartan 3 – Preliminary results
- Proton bunch width: ~6 ns,
- CLK ~ 25 MHz



Conclusions

- We have introduced a complete testing system and methodology for testing the FPGAs for the proton radiation induced errors
- Flash-based FPGA means configuration SEU safe, but not radiation tolerant
- Except SEU and SET, no performance issues were observed on SRAM based Xilinx Spartan 3 FPGAs up to 200 krad of TID

Acknowledgement: Measurements were carried out at the CANAM infrastructure of the NPI ASCR Řež supported through MŠMT project No. LM2011019