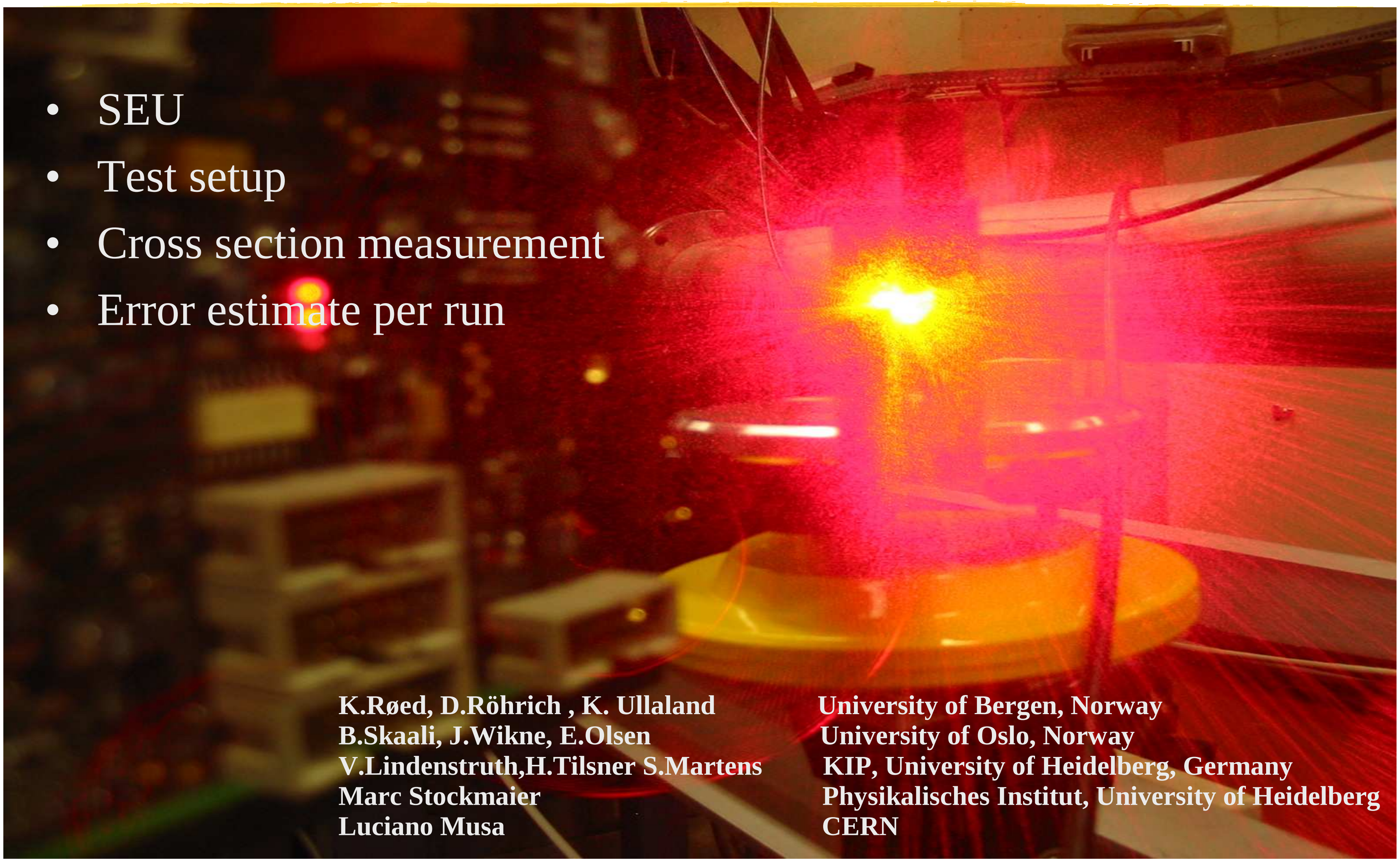
Irradiation results



- SEU
- Test setup
- Cross section measurement
- Error estimate per run

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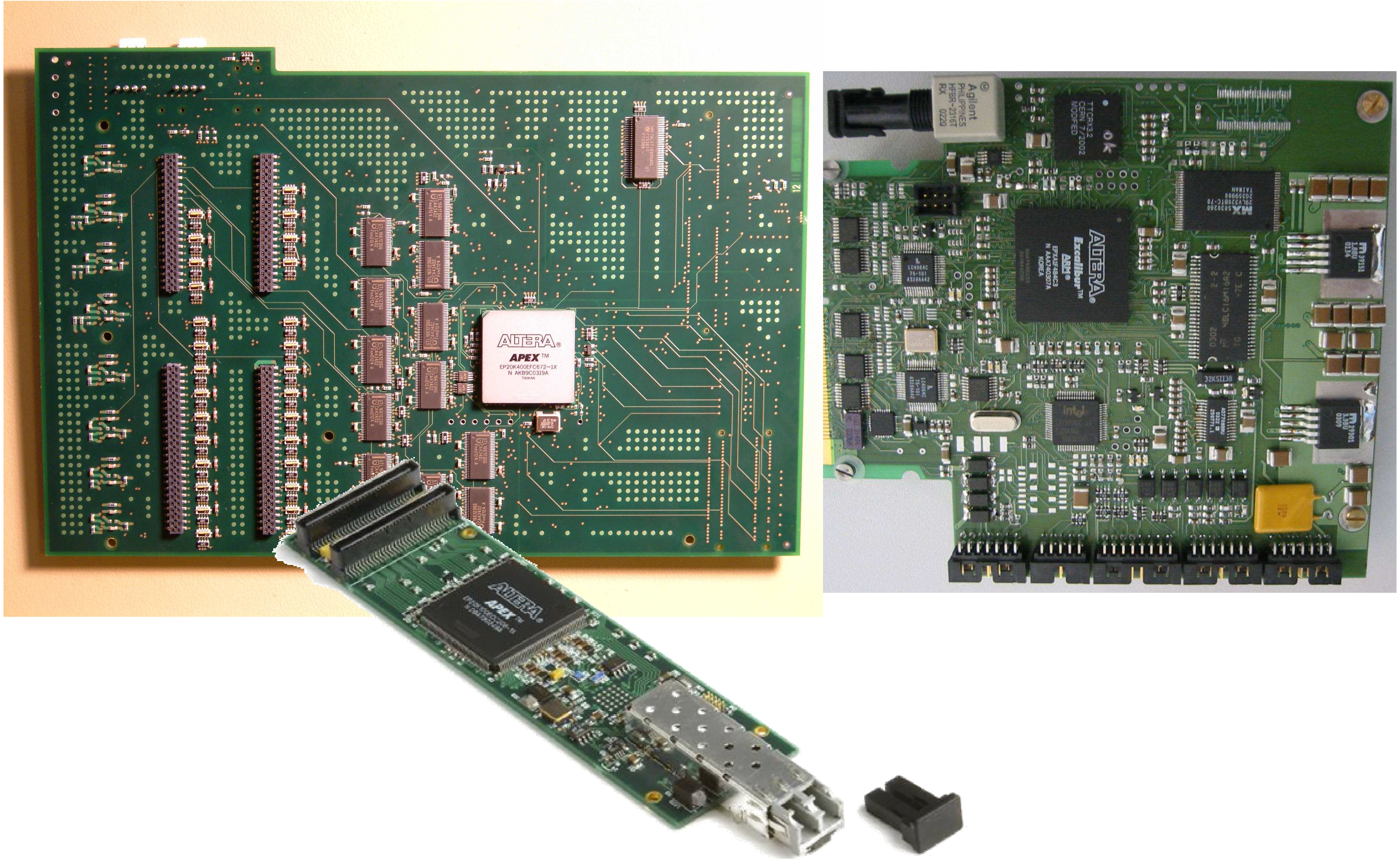
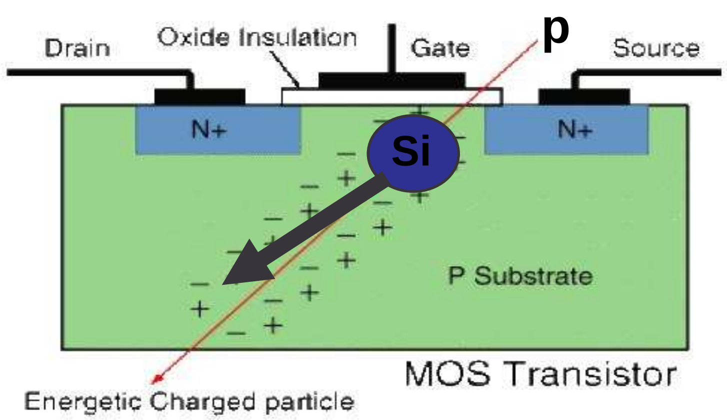
Luciano Musa — CERN

FPGAs on RCU mother/mezzanine boards



Single Event Upset (SEU)

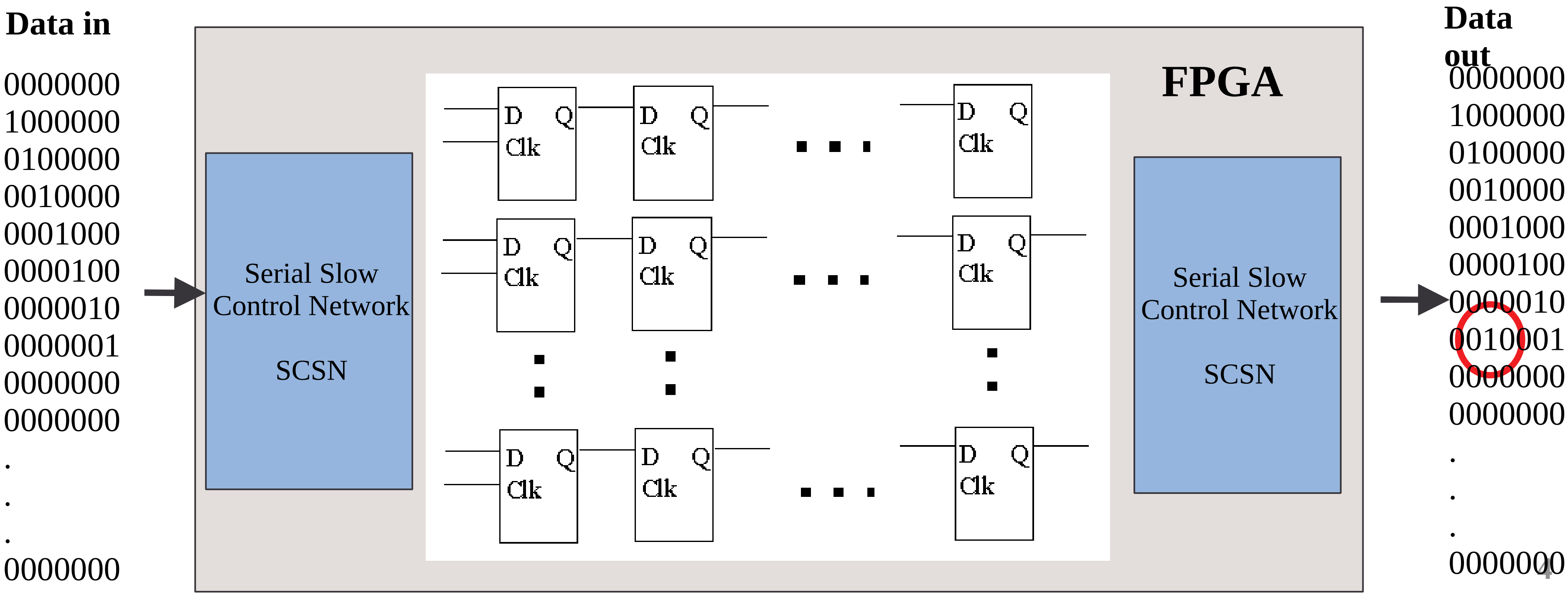
- High-energetic hadrons induce nuclear reactions in the silicon (E > 20 MeV - protons, neutrons, pions, kaons)
- Intermediate energy neutrons (2 MeV < E < 20 MeV) contribute little (10%) to SEUs
- (Almost) no effect due to thermal neutrons
- Heavy recoil ions from reactions ionize the material
- Charge deposition leads to a change in state of a transistor (SEU)
- Soft error – can be corrected (rewriting or reprogramming)



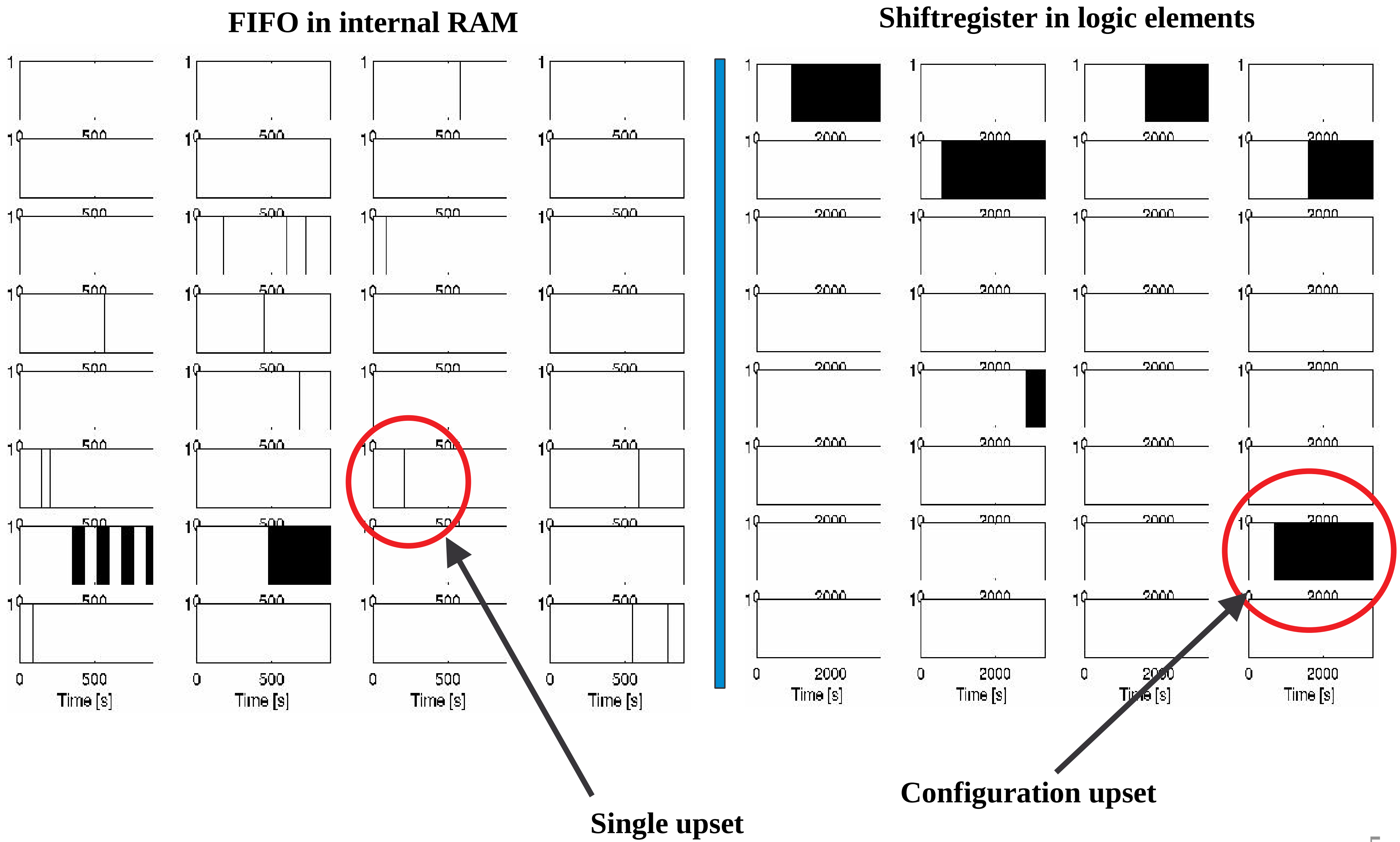
- Si(p,2p)Al
- Si(p,pα)Mg
- Si(n,p)Al
- Si(n,α)Mg

Upset detection in ALTERA FPGAs

- Two types of concern
  - Upsets in configuration SRAM cells
  - Single bitflips in register elements
- The APEX20K400E offers no direct readout of configuration SRAM
  - Indirectly detection of configuration upset through the VHDL design
  - Error observed reflects a change in logic due to a configuration upset, and not the configuration upset itself
  - A fixed pattern is shifted through and compared for setups when read out

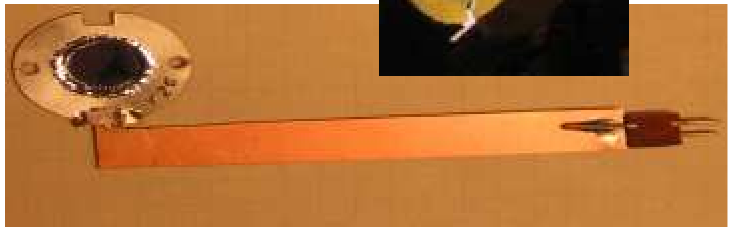


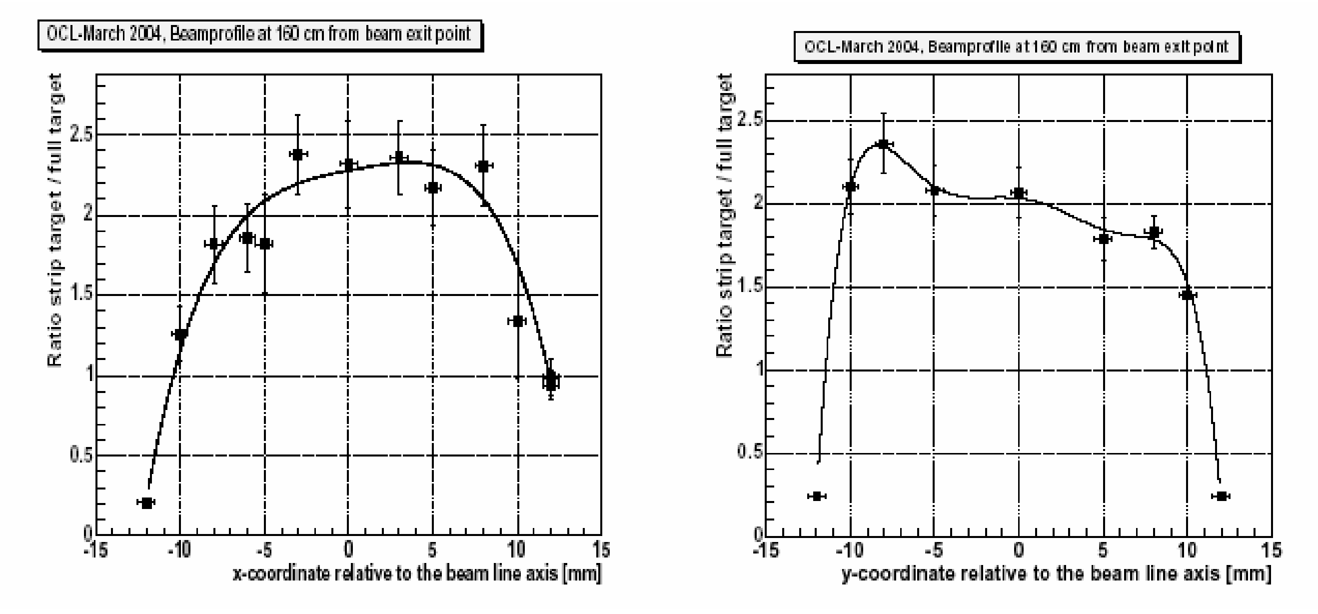
Example of analyzing data



Test setup (1)

- **Oslo Cyclotron**
  - 25 and 28 MeV external proton beam
  - flux ~ $10^7 – 10^8$ protons/s cm²
  - Flux measurements: Uranium fission target + TFBC
  - Intensity monitor: faraday cup
  - Beam profile: spot 1.5cm x 1.5cm

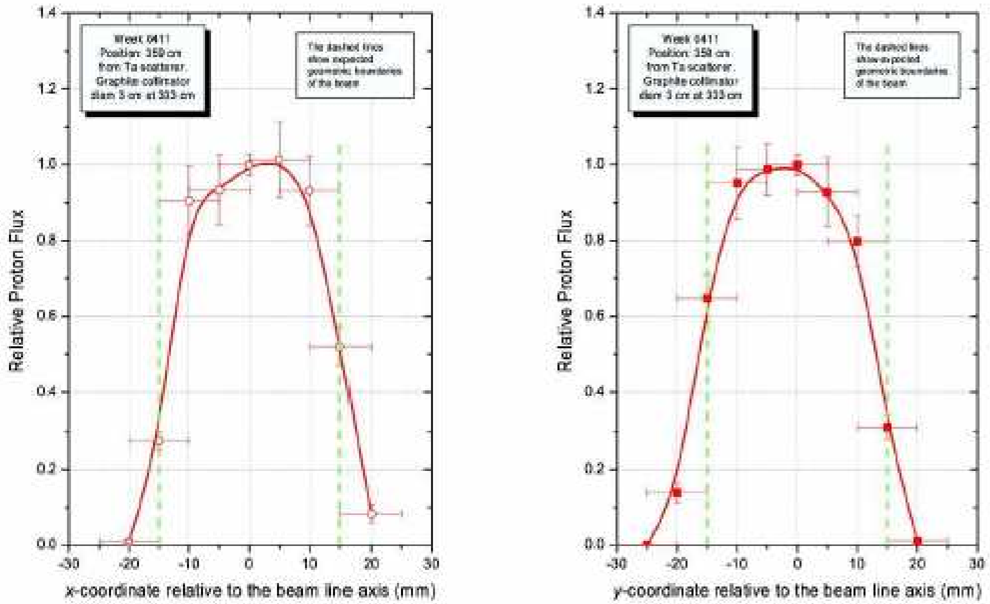




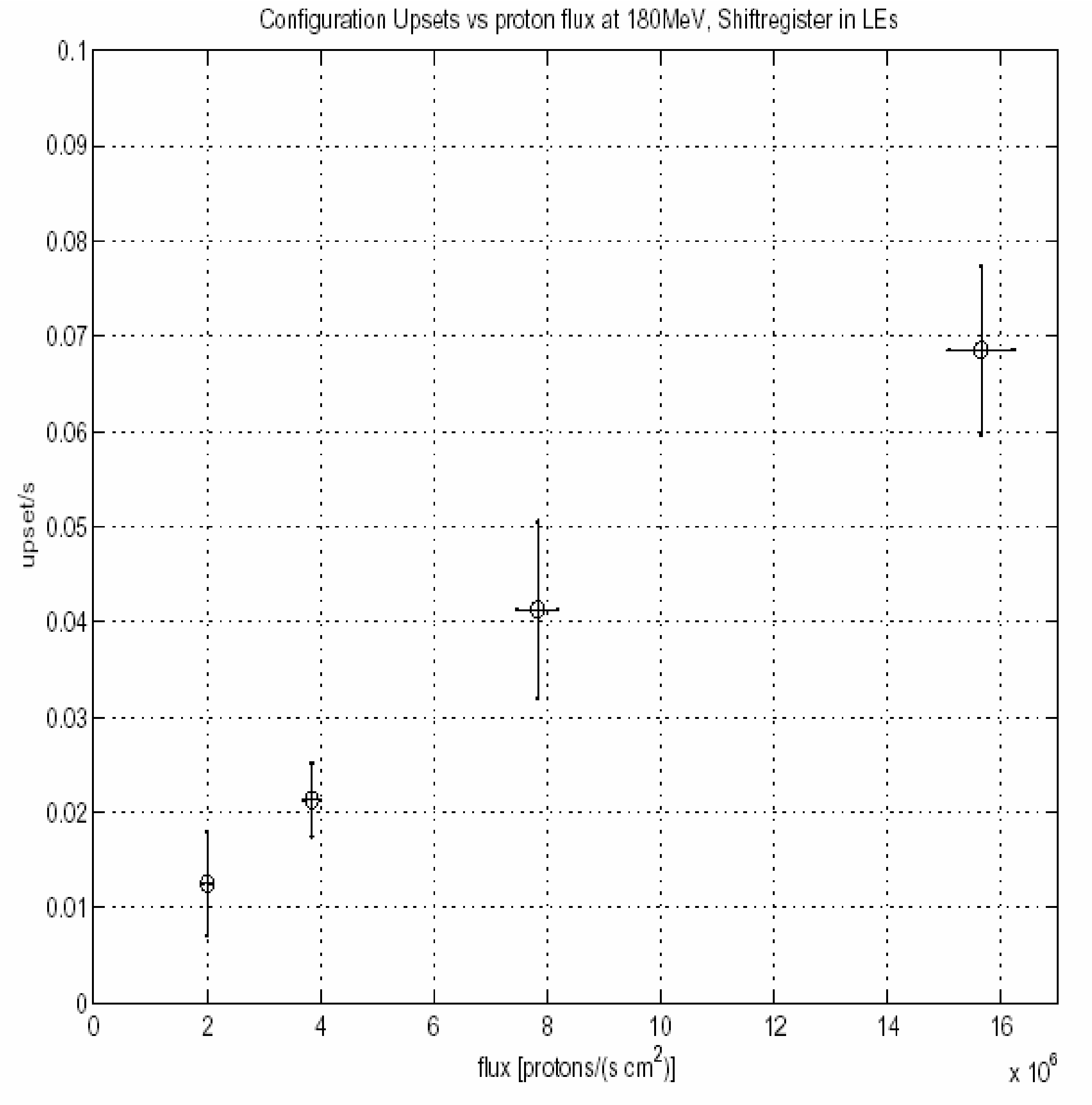
Test setup (2)

- **TSL (Uppsala)**
  - 38 and 180 MeV external proton beam
  - flux ~ 10^7 – 10^8 protons/s cm²
  - Flux measurements: Uranium fission target + TFBC

  - Intensity monitor
    - » scattered protons -> scintillator
  - Beam profile:
    - » spot ∅ 3cm



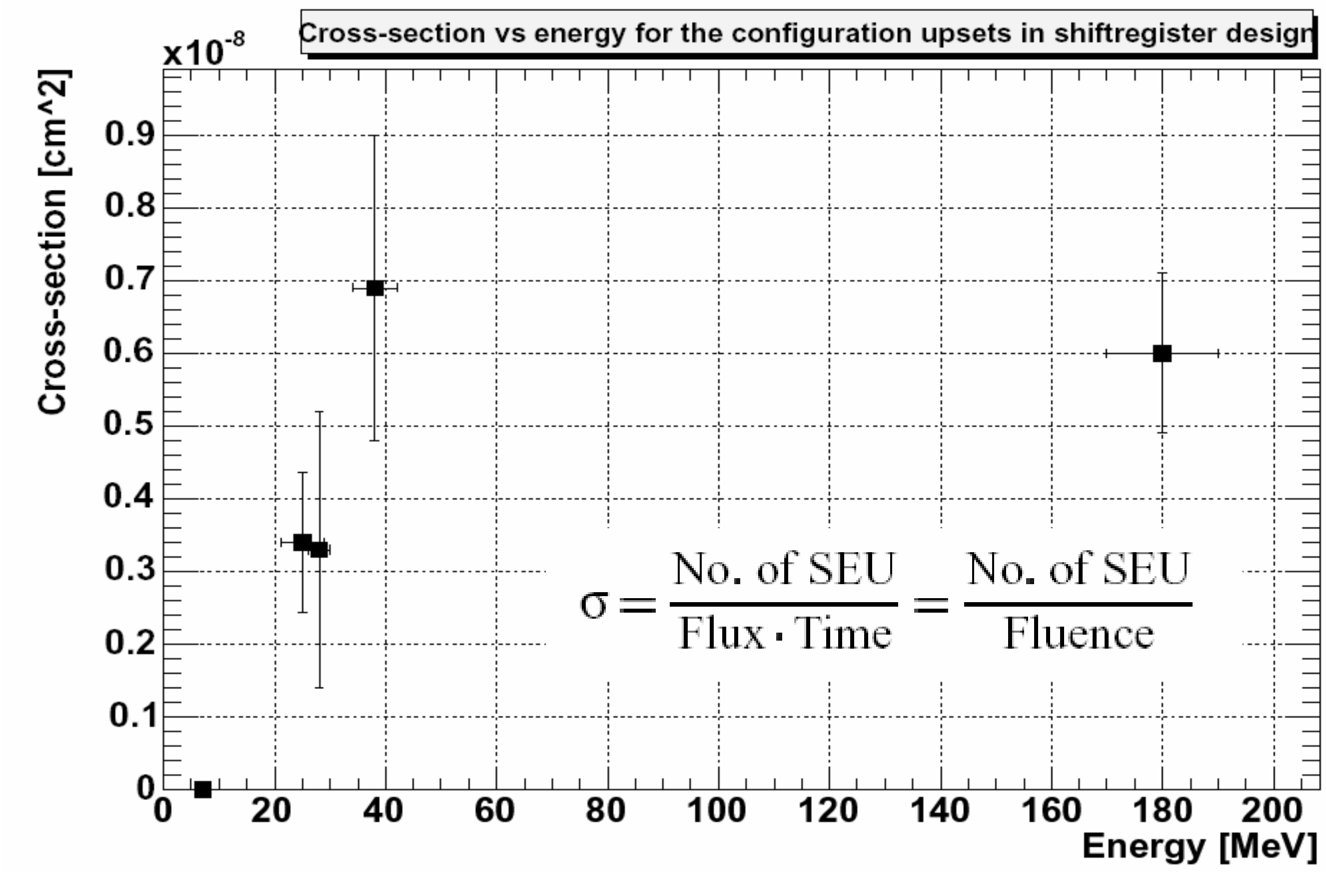
Results (1)



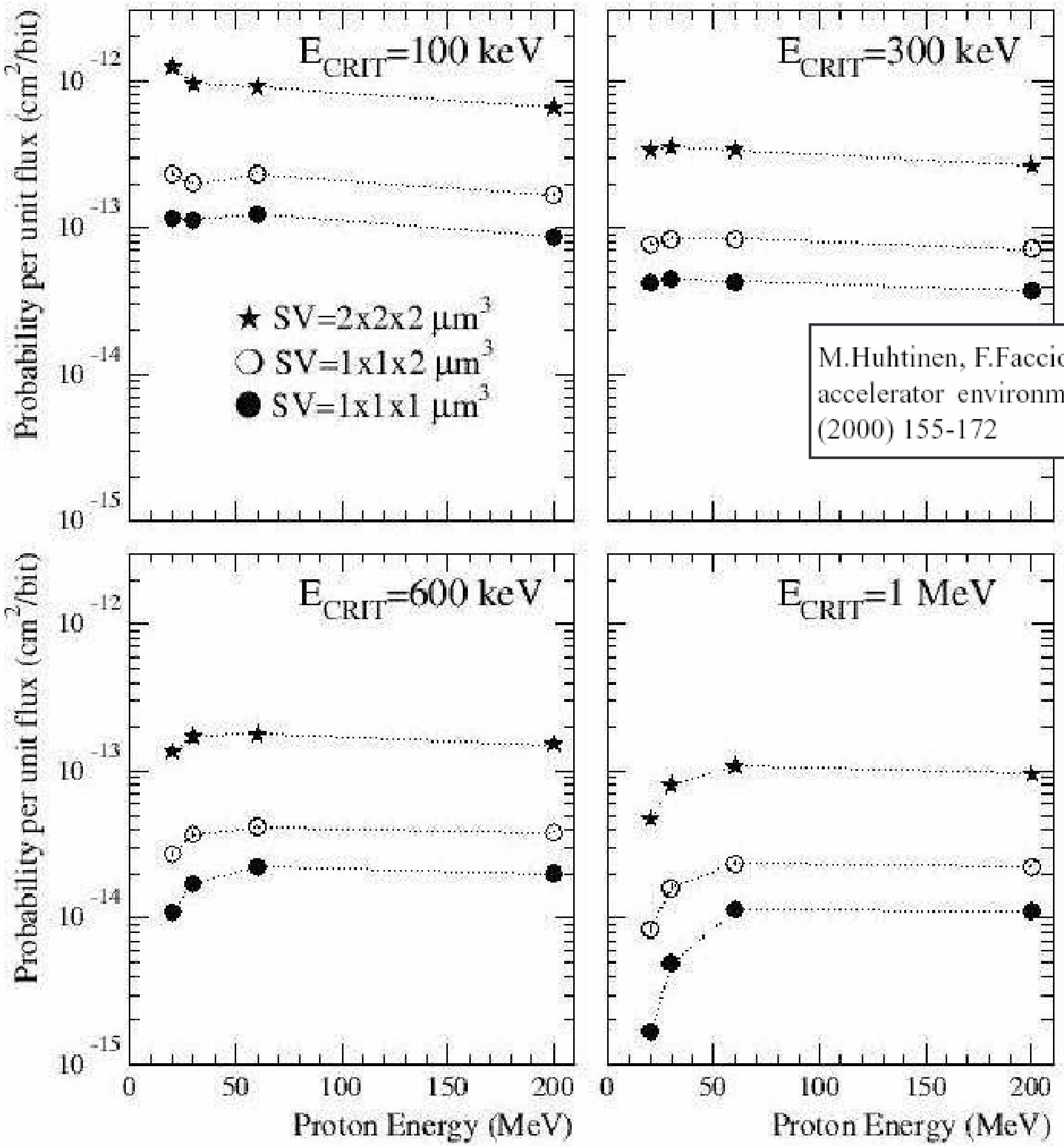
- **APEX20k400**
  - **configuration-SRAM upset rate**

Results (2)

- **APEX20k400**
  - **Energy dependence of cross section**
  - **CS = 6.0 x $10^{-9} \pm 1.1$ x 10^{-9} cm^2 (E >30 MeV)**

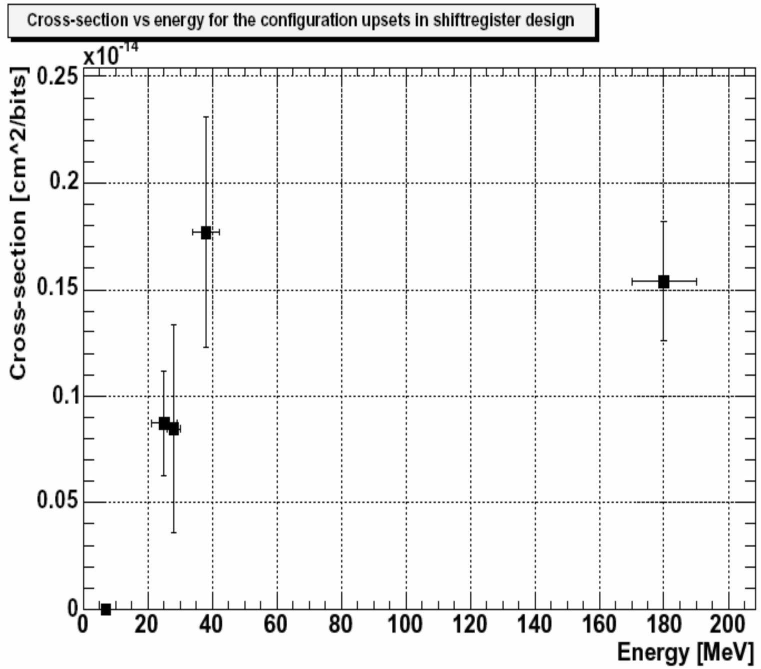


Results (3)



- **Energy dependence of cross section - comparison to simulations**

M.Huhtinen, F.Faccio, Computational method to estimate Single Event Upset rates in and accelerator environment, Nuclear Instruments & Methods in Physics Research, A 450 (2000) 155-172



Results (4)

- **APEX EP20K60E - SIU**

  See Trigger/DAQ/HLT/Controls-TDR, p. 142 (DAQ section)

Proton energy (MeV)	SEU cross section (cm^2)	CL cross section (cm^2)
180	1.56×10^{-9}	
100	1.70×10^{-9}	1.50×10^{-9}

Results (5)

- **ALTERA EPXA1F484C1 - ARM**

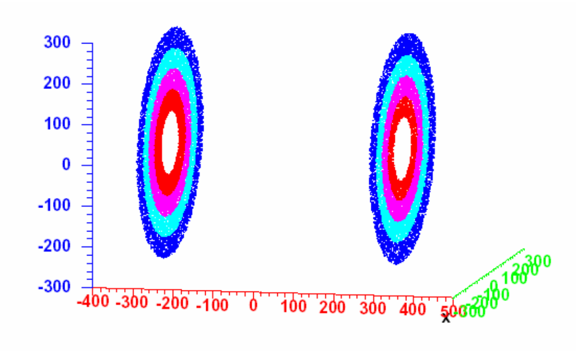
  See S. Martens, Diploma thesis, KIP (2003)

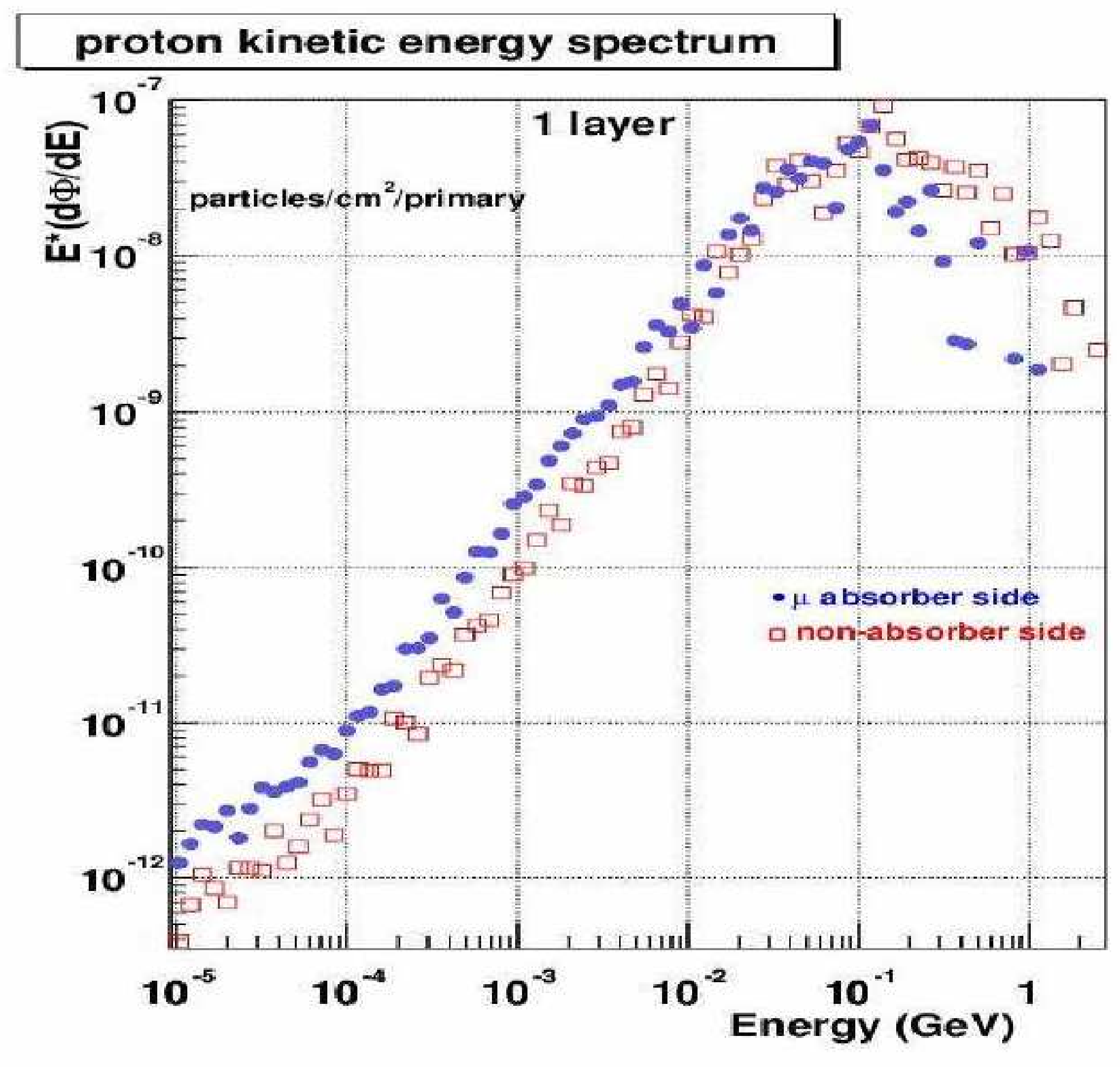
Flux @ 28 MeV (protons/s cm^2)	Mean time between failures (s)	cross section (cm^2)
3×10^6	360	1×10^{-9}
7×10^6	140	1×10^{-9}
2×10^7	50	1×10^{-9}

Cross section results - summary

	Cross section [cm^2]
RCU FPGA	$6.0 \times 10^{-9} \pm 1.1 \times 10^{-9}$
SIU	1.6×10^{-9}
DCS	2×10^{-9} (scaled to E > 30 MeV)

Radiation levels – simulation (1)





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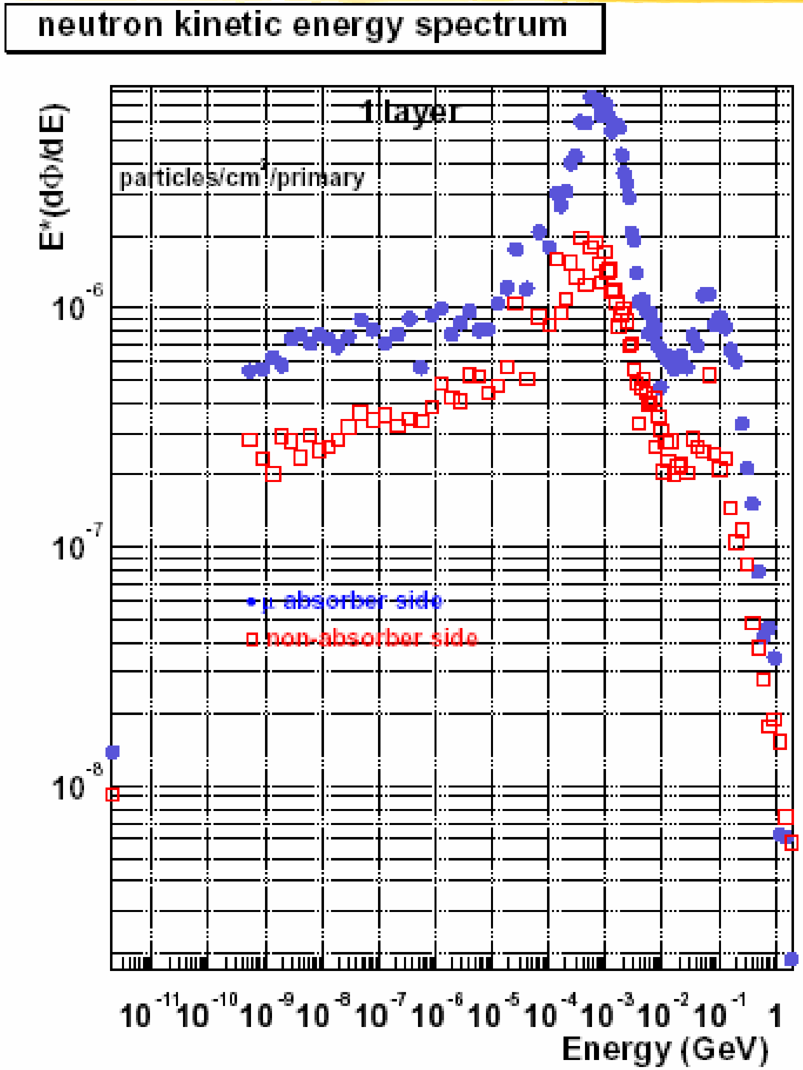
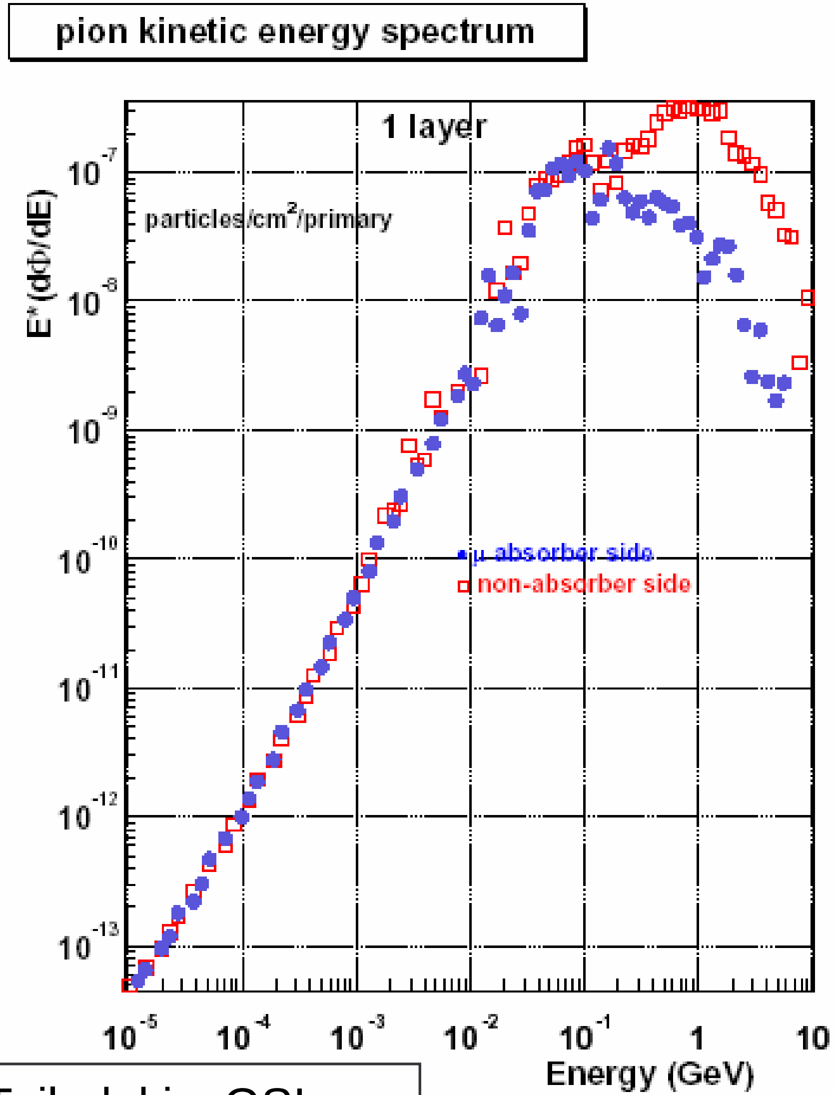
Radiation levels – simulation (2)





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Radiation levels – simulation (3)

Table 3.3: Particle fluxes (particles/cm ^{2}/s) for minimum bias Pb-Pb running (**absorber side**)[2]

Layers	**1**	**2**	**3**	**4**
Neutron Flux $[cm^{-2}s^{-1}]$	4377.6±1.6%	3289.6±0.3%	2726.4±0.9%	2368±0.5%
Neutron Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	334.1	204.8	134.4	959
Proton Flux $[cm^{-2}s^{-1}]$	13.2±26.7%	7.7±6.9%	5.0±10.6%	5.1±10.6%
Proton Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	12.7	7.5	4.9	5.0
Pion$^{\pm}$ Flux $[cm^{-2}s^{-1}]$	37.46±5.7%	55.9±3.1%	47.5±2.4%	28.5±2.8%
Pion$^{\pm}$ Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	37.2	55.8	47.5	1.3
Sum Flux with $E_{kin} > 10$ MeV	384	268	187	129

Table 3.4: Particle fluxes (particles/cm ^{2}/s) for minimum bias Pb-Pb running (**non-absorber side**)[2]

Layers	**1**	**2**	**3**	**4**
Neutron Flux $[cm^{-2}s^{-1}]$	1625.6±1.3%	1638.4±2.1%	1625.6±1.2%	1626±1.3%
Neutron Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	111.4	74.2	57.2	45.6
Proton Flux $[cm^{-2}s^{-1}]$	19.5±9.6%	9.2±11.5%	8.1±19.3%	4.6±8.5%
Proton Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	19.2	9.1	7.9	4.5
Pion$^{\pm}$ Flux $[cm^{-2}s^{-1}]$	114.4±1.0%	65.7±2.5%	46.7±4.0%	31.0±3.0%
Pion$^{\pm}$ Flux $[cm^{-2}s^{-1}]$ with $E_{kin} > 10$ MeV	114.3	65.4	46.6	31.0
Sum Flux with $E_{kin} > 10$ MeV	245	149	112	81

Error estimates per run

- **SEUs in RCU main FPGA**

Table 8.1: Expected numbers of SEUs for the different scoring regions in the TPC detector

	μ-absorber side					
Sector	1	2	3	4	5	6
SEU/(FPGA s) [x 10^{-6}]	2.4 ± 0.4	2.0 ± 0.4	1.6 ± 0.3	1.1 ± 0.2	0.9 ± 0.2	0.8 ± 0.1
	non-absorber side					
SEU/(FPGA s) [x 10^{-6}]	1.6 ± 0.3	1.3 ± 0.2	0.9 ± 0.2	0.7 ± 0.1	0.6 ± 0.1	0.5 ± 0.1

- **Errors per run (4 hours)**

	Errors per run (4 hours) per TPC system
RCU	**3.7**
SIU	**1.0**
DCS	**1.9**

Conclusion (1)

- SRAM based FPGAs
  - Error rate is so low that one can cope with it – if SEUs can be detected instantenously
  - ALTERA FPGAs do not provide real-time readback of configuration data nor disclose format of bitstream
  - Better choice: XILINX Virtex-II Pro FPGAs
    - » Real-time (= while running) readback of configuration data for verification
    - » Partial reconfiguration while running
    - » Existing infrastructure, running under linux (e.g. on DCS board), allowing full and high level control of the FPGA internals while running

Conclusion (2)

- Alternative: FLASH based FPGA (Actel)
  - ProASIC<u>Plus</u> FLASH Family FPGAs
  - Preliminary irradidation results
    - » Device: APA075
    - » Test method: reading back configuration
    - » Failure (probably latch-up) after a fluence of 3.7x 10^{11} protons/cm^2 ≅ dose (E_{dep} of 30 MeV protons in 300 µm Si) of 500 Gy (check!)
    - » Expected fluence in 10 years of ALICE: ~ 10^{11} protons/cm^2 (5.7 Gy)
    - » Further tests necessary

Table 8: Particle fluences and total absorbed doses per 10 ALICE years.

Scoring region of TPC electronics	Absorber side	Non-absorber side
Neutron Fluence [cm^{-2}]	(0.6-1.1)$\times 10^{11}$	0.4$\times 10^{11}$
Neutron Fluence [cm^{-2}] with $E_{kin} > 10$ MeV	(2.4-8.4)$\times 10^{9}$	(1.1-2.8)$\times 10^{9}$
Proton Fluence [cm^{-2}] with $E_{kin} > 10$ MeV	(1.2-3.2)$\times 10^{8}$	(1.1-4.8)$\times 10^{8}$
Pion Fluence [cm^{-2}] with $E_{kin} > 10$ MeV	(0.7-1.4)$\times 10^{9}$	(0.8-2.9)$\times 10^{9}$
Kaon Fluence [cm^{-2}] with $E_{kin} > 10$ MeV	(2.4-7.6)$\times 10^{7}$	(3.3-19.3)$\times 10^{7}$
Total Dose [Gy]	(0.8-2.5)$\times 10^{0}$	(0.3-5.7)$\times 10^{0}$

Next steps – a proposal

- Develop SEU detection strategies
- Decide to migrate RCU-FPGA to XILINX
- Select appropriate device w.r.t. resources (e.g. number of I/O cells)
- Decide to keep DCS board unchanged
- Keep Actel-FPGA as fallback solution
- Port RCU design to new develop environment
- Port existing reconfiguration scheme to DCS board
- Verify expected performance under irradiation
  - XILINX test @ OCL in June
  - System test @ TSL in fall with large beam spot (∅ 30cm)
- Update RCU-layout