Readout Electronics Radiation Tolerance in the Forward Region

CERN, 16 March 2004

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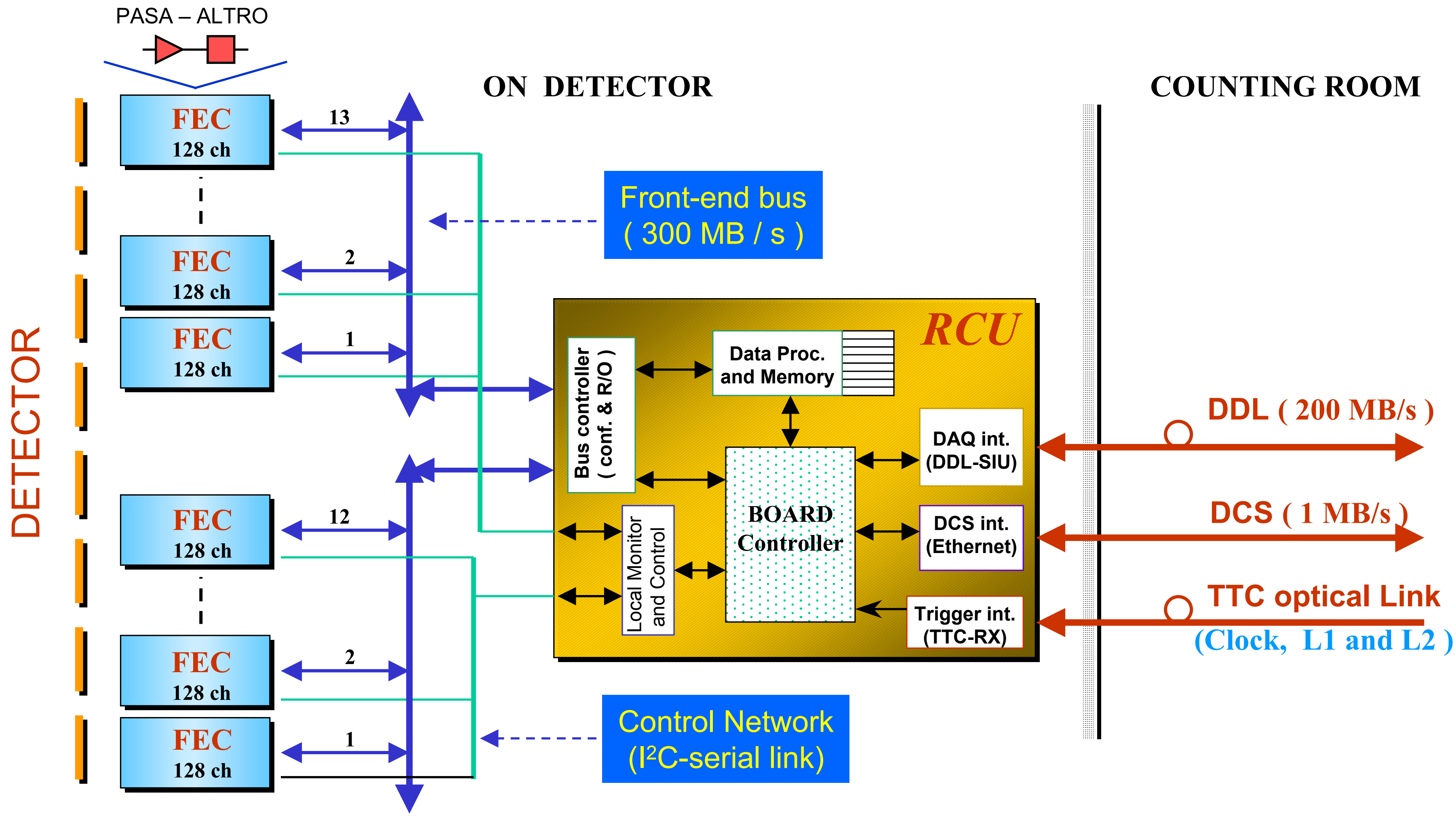
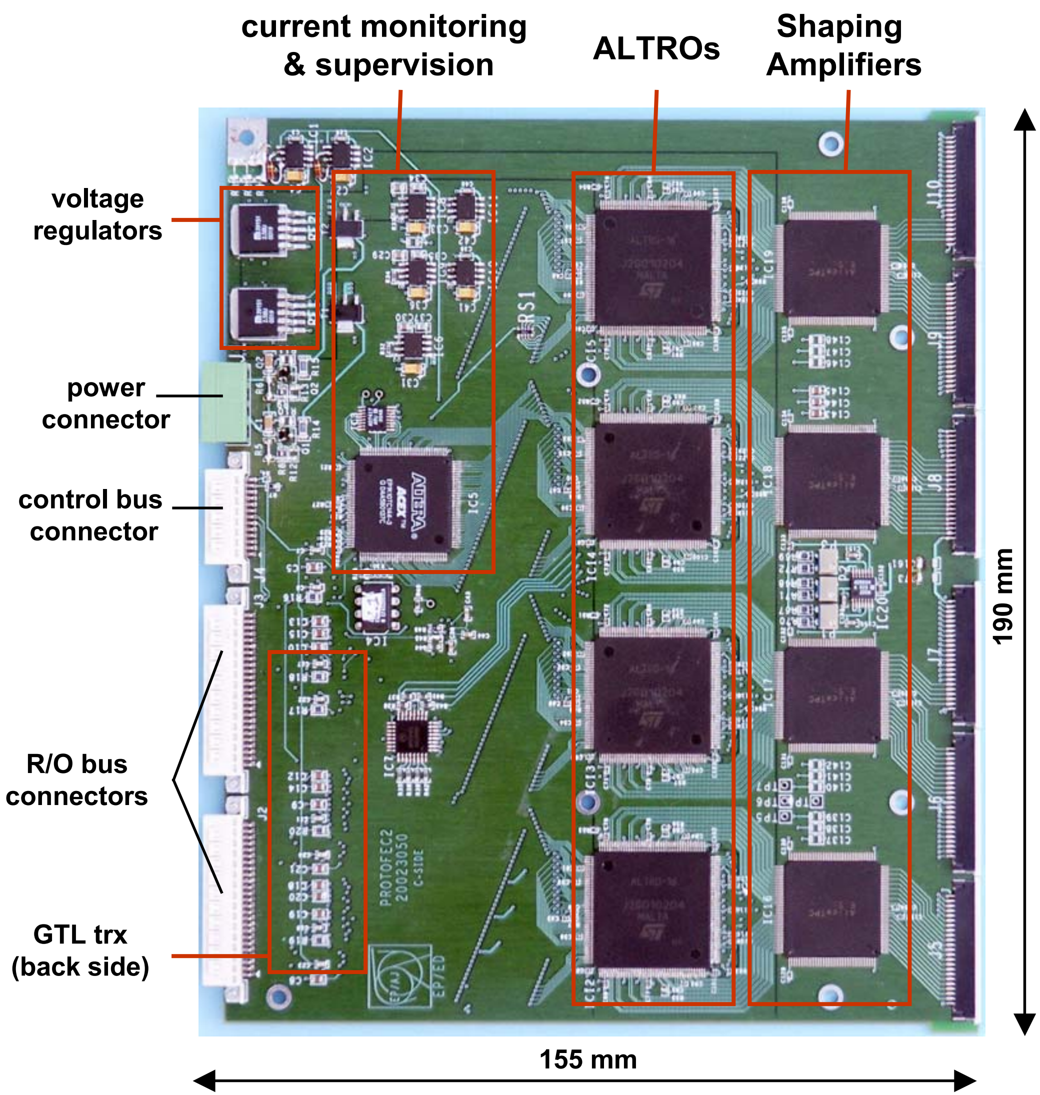
TPC FE AND READOUT ELECTRONICS

Each of the 36 TPC Sectors is served by 6 Readout Partitions

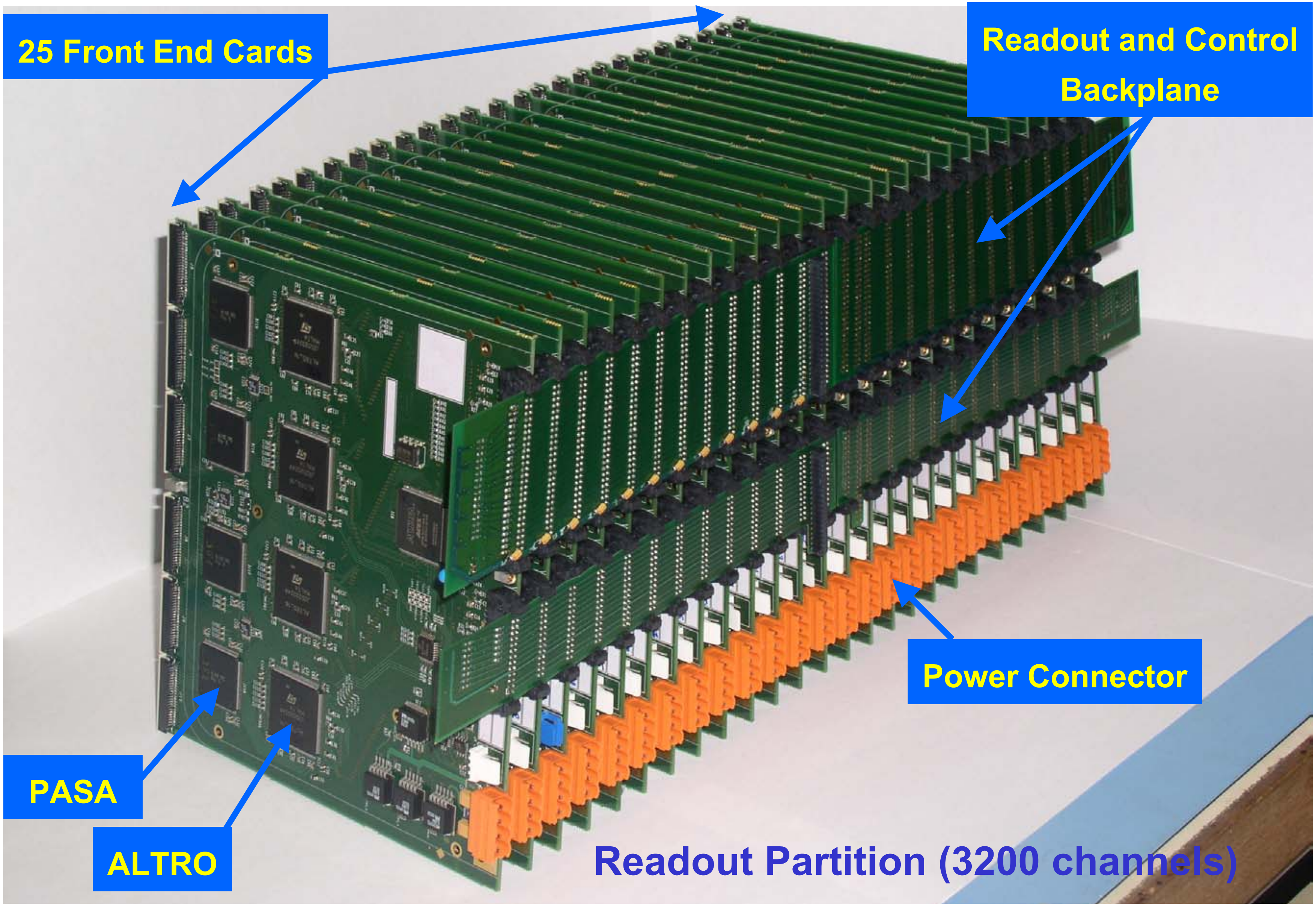


Overall TPC: 4356 Front End Card 216 Readout Partitions

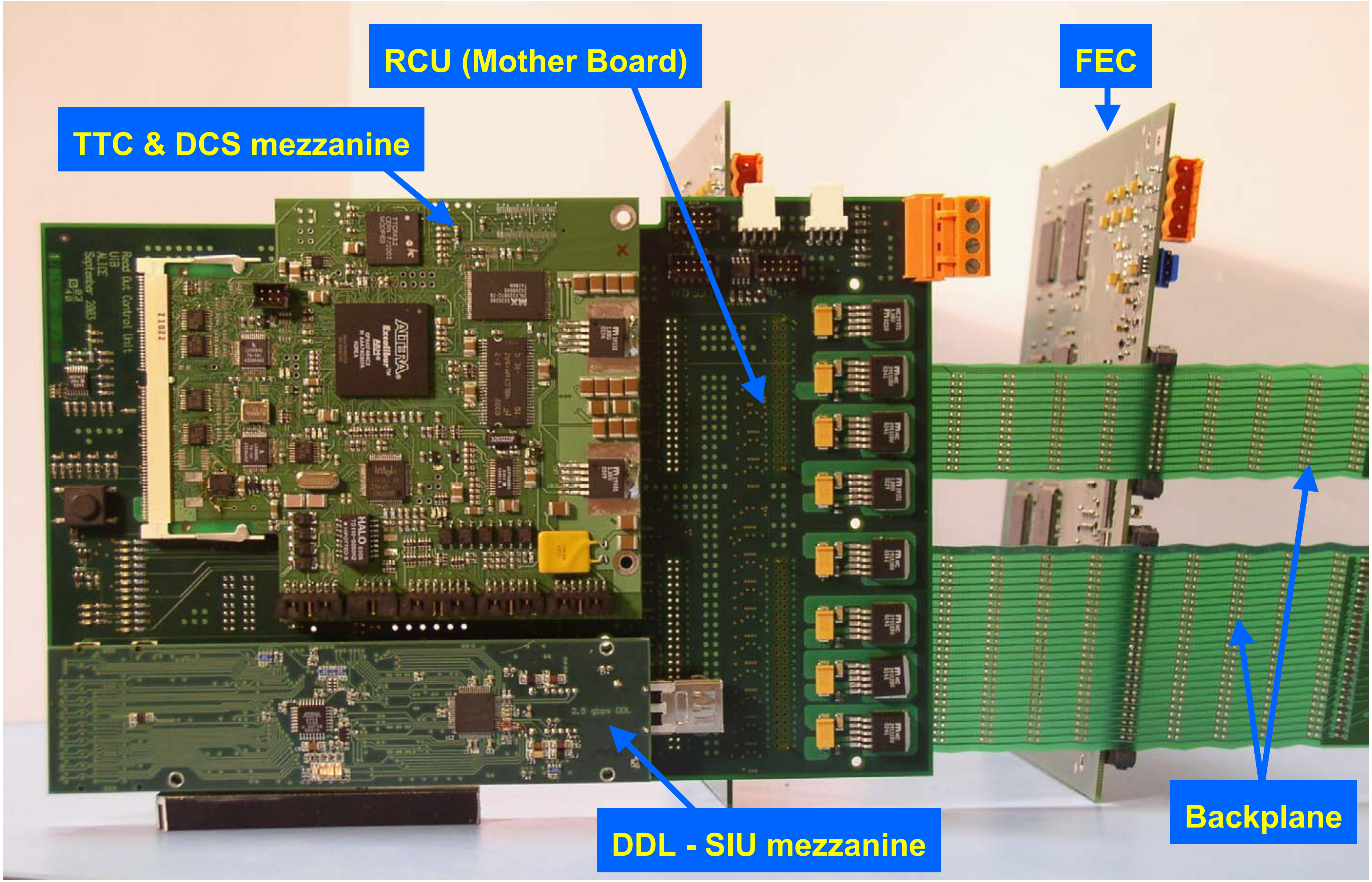
TPC Front End Card



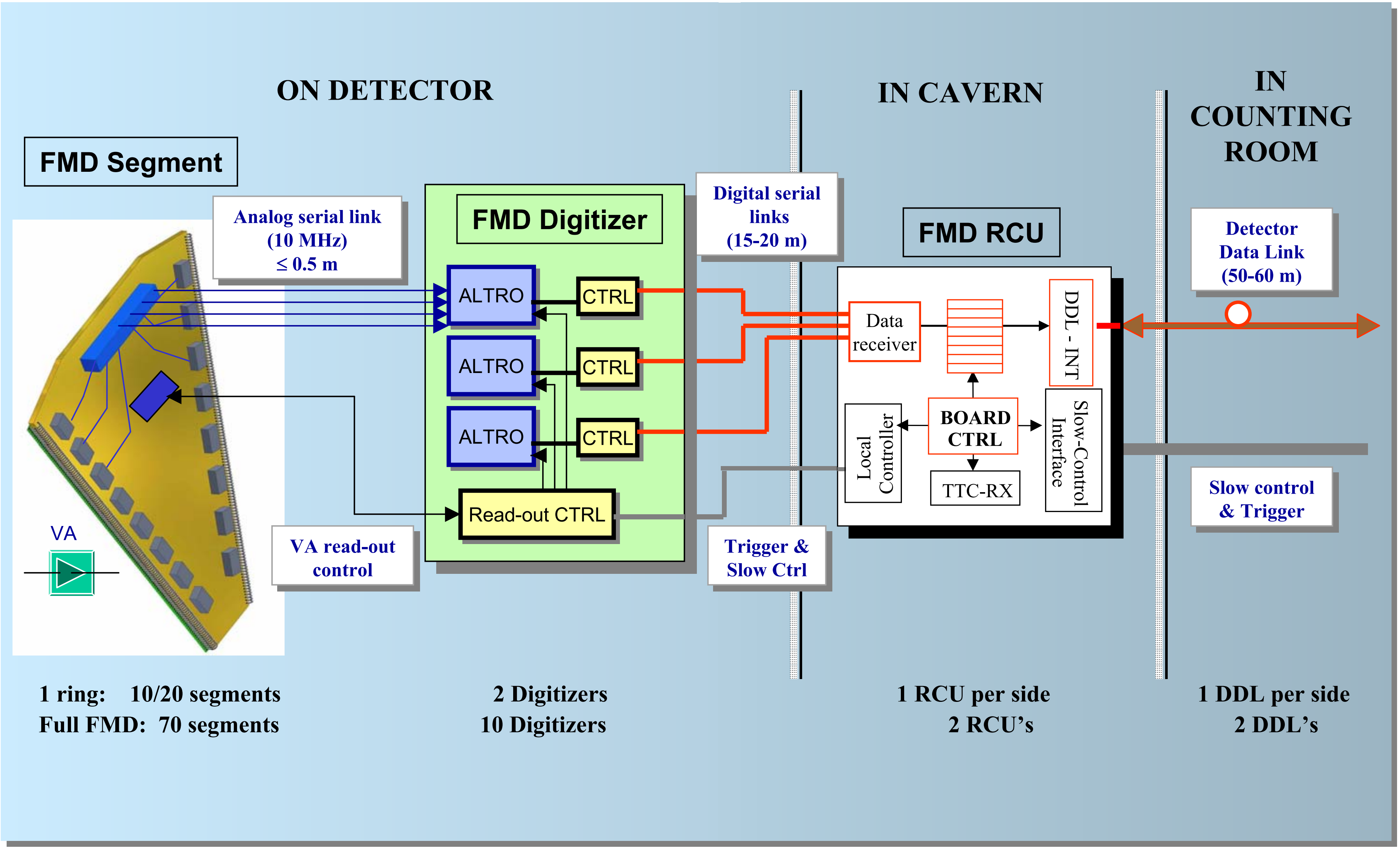
TPC Readout Partition



FEC – RCU Aseembly

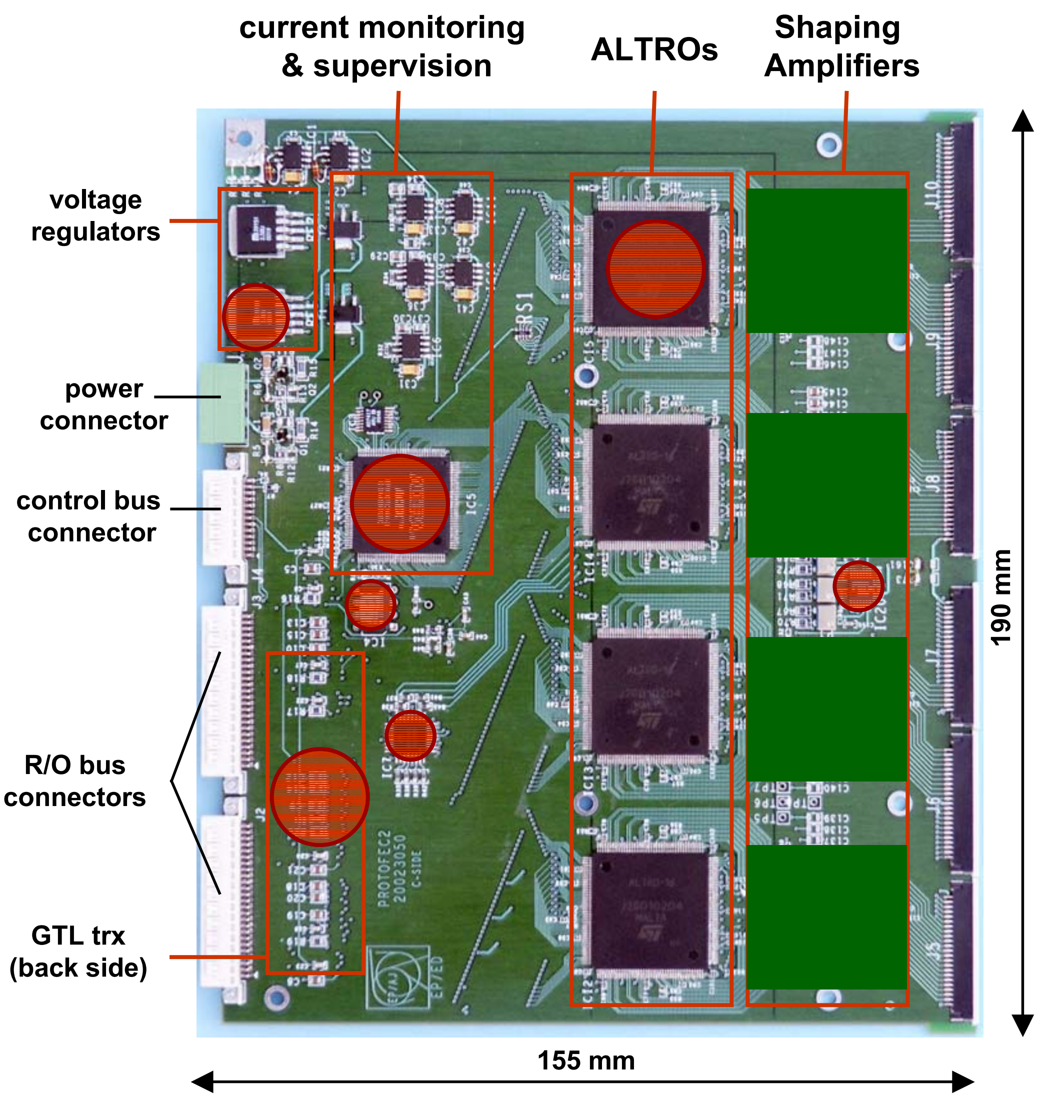


FMD READOUT AND CONTROL ELECTRONICS



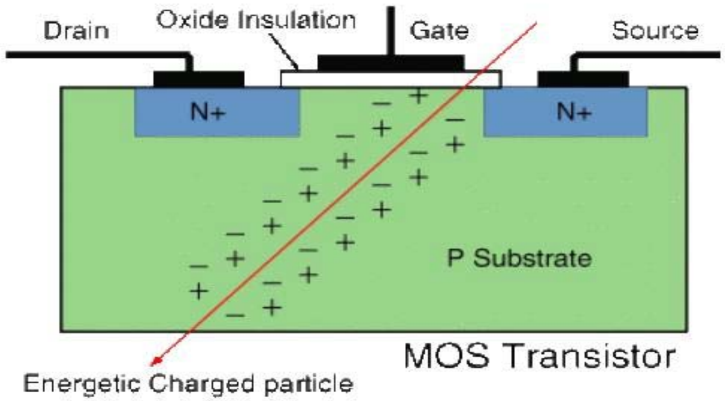
FMD digitizer card based on the TPC FEC

RADIATION SENSITIVE COMPONENTS

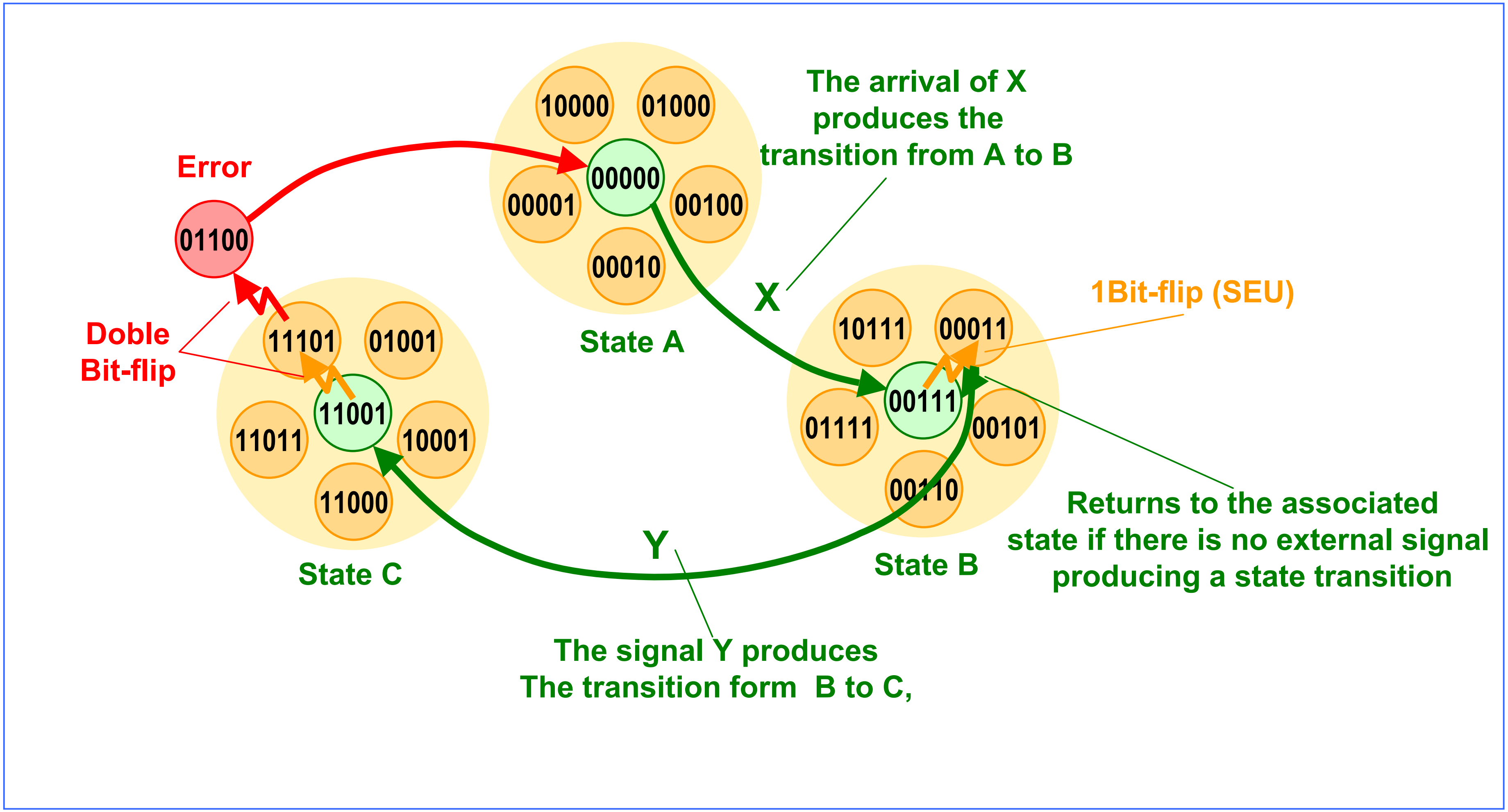


Single Event Upset (SEU)

- 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 ionise the material
- Protons do not deposit enough charge deposited by direct ionisation to cause a SEU
- Charge deposition leads to a change in state of a transistor (SEU)
- Soft error – can be corrected (rewriting or reprogramming)



- **Finite State Machine (FSM) protected by Hamming encoding**
  - **Basic principle**



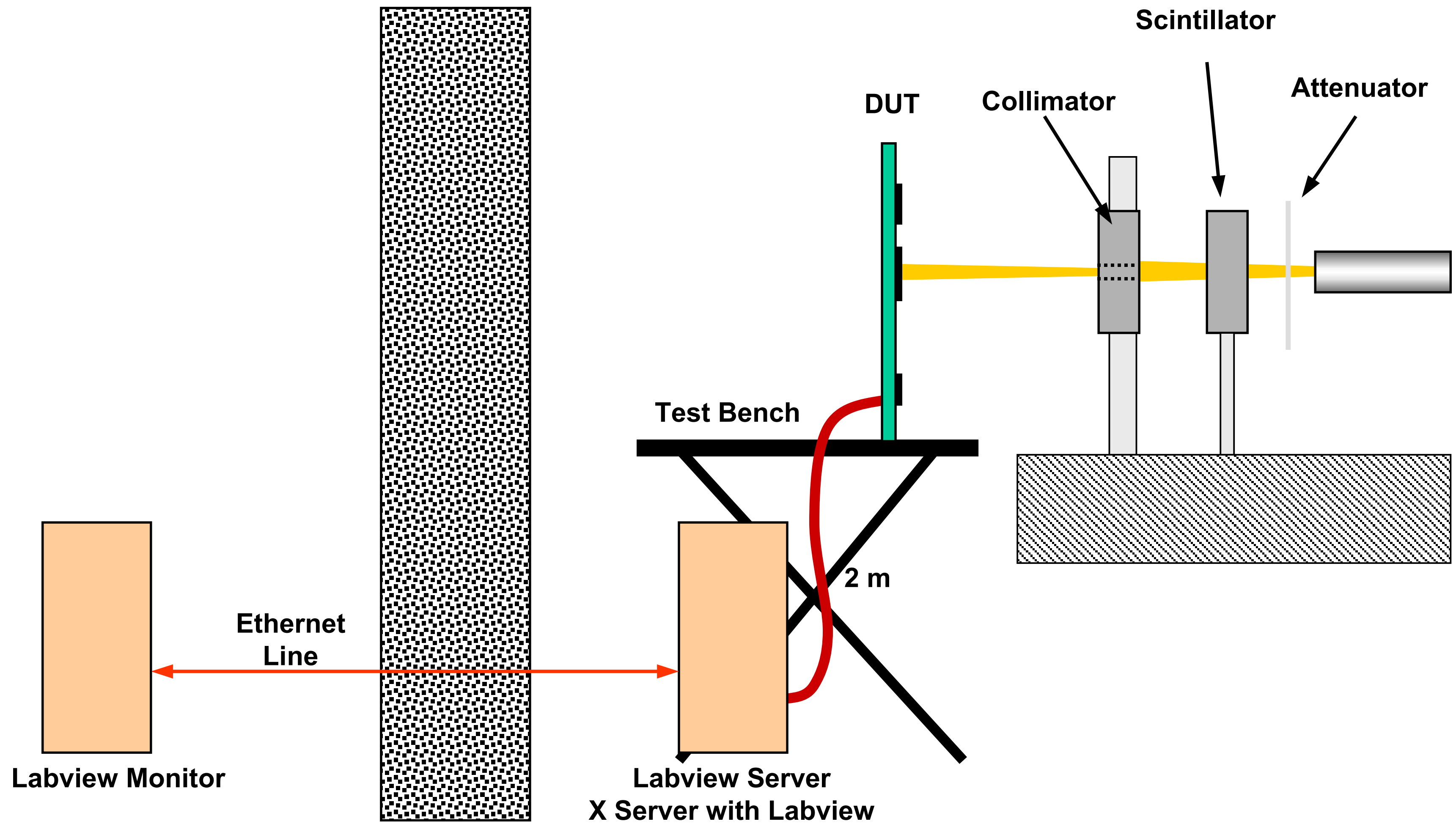
Irradiation Facilities at UCL Cyclotron

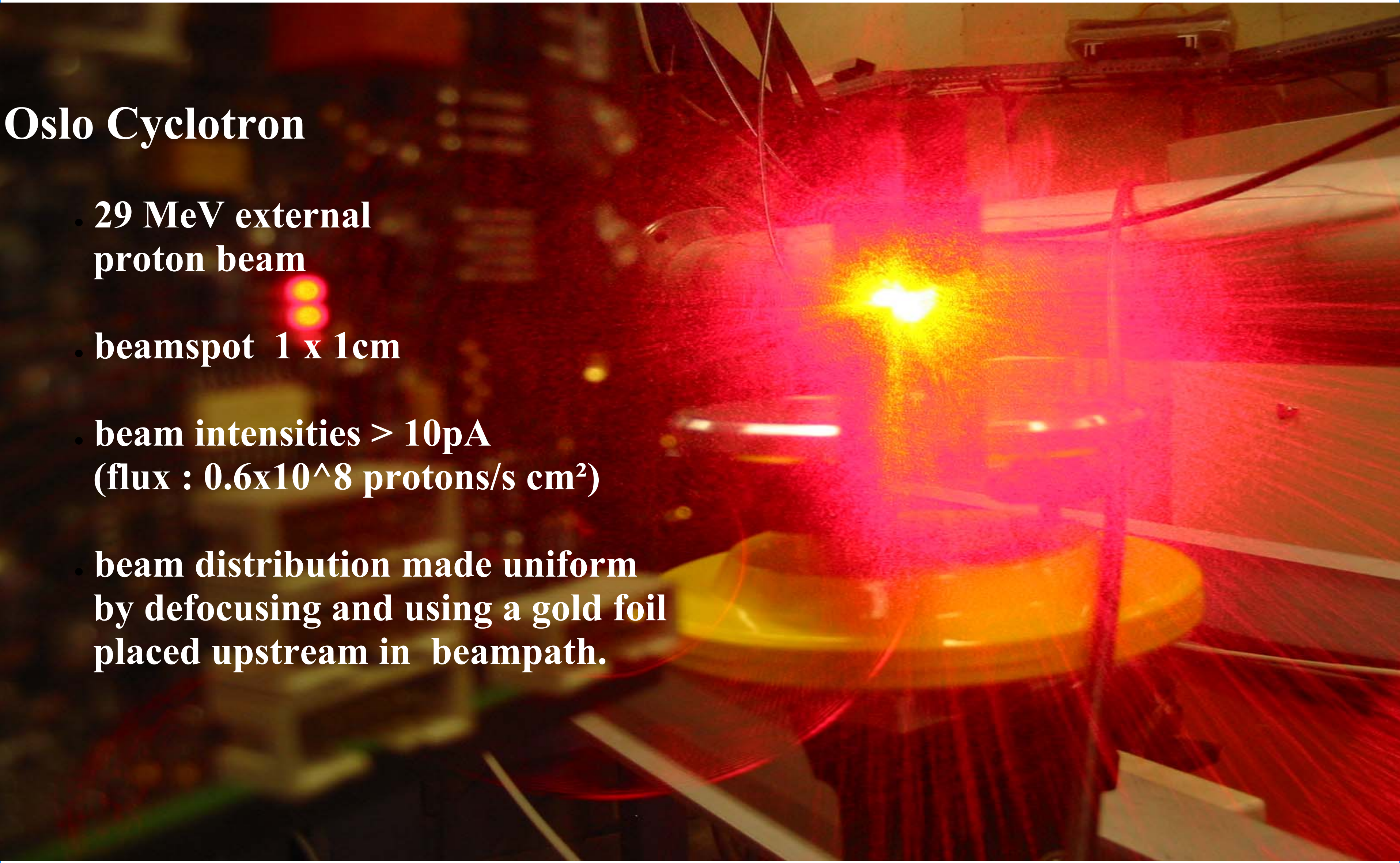
Test at UCL, Louvain-la-Neuve, Belgium

Beam Type: 65 MeV protons

Proton Flux: $1 \cdot 10^8$, $5 \cdot 10^8$ p cm^{-2} s^{-1}

100 krad in 30 min at this flux





Oslo Cyclotron

- 29 MeV external proton beam
- beamspot 1 x 1cm
- beam intensities > 10pA (flux : 0.6x10^8 protons/s cm²)
- beam distribution made uniform by defocusing and using a gold foil placed upstream in beampath.

FEC tested parts

Name	Type	No. Parts	Max. Dose (krad)	Test Method
ALTRO-16	CMOS	10	> 312	dynamic
MIC39151 (LDO) †	Bipolar	20	30	dynamic
MIC29371 (LDO) †	Bipolar	20	30	dynamic
GTL16612	Bi-CMOS	10	> 100	dynamic
MPC9109	CMOS	10	> 100	dynamic
OPA4364 †	Bipolar	10	> 30	dynamic
LM4040 †	Bipolar	10	> 30	dynamic
ACEX1K30	CMOS	10	> 100	dynamic
EPC1441	CMOS	8	> 10	powered
Electrolytic Cap	Tantalum	20	> 100	powered

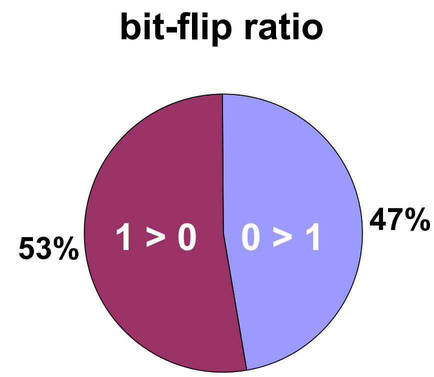
† Part malfunction at mentioned dose

ALICE dose over 10 years is 3 krad

ALTRO Radiation Test Results

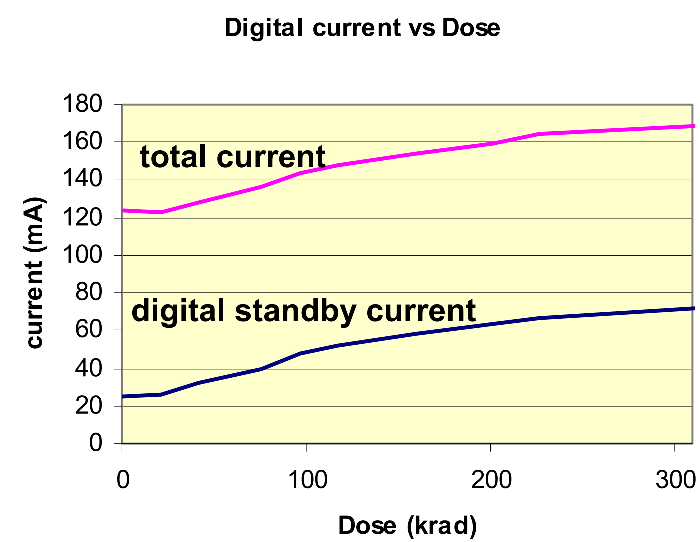
Error Cross Section

Memory Error Cross Section:	$1.10 \cdot 10^{-14}$	$cm^{-2}\ bit^{-1}$
Register Error Cross Section:	$7.02 \cdot 10^{-14}$	$cm^{-2}\ bit^{-1}$
Hamming Error Cross Section:	$9.50 \cdot 10^{-14}$	$cm^{-2}\ bit^{-1}$



Observations

- Slightly more flips from 1 to 0 than from 0 to 1
- Digital current increases with dose (leakage increases)
- Analog current stays the same
- ADC bit flips very rare
- Small spikes in analog part of ADC above 160 krad



ALTRO Radiation Test Results

Annealing

- After 2 weeks at room temperature: 43 mA standby current (+13.5% over total)
- After 3 months at room temperature: back to normal

- At a low flux, annealing and damage may compensate

All 4 irradiated chips continue to work today

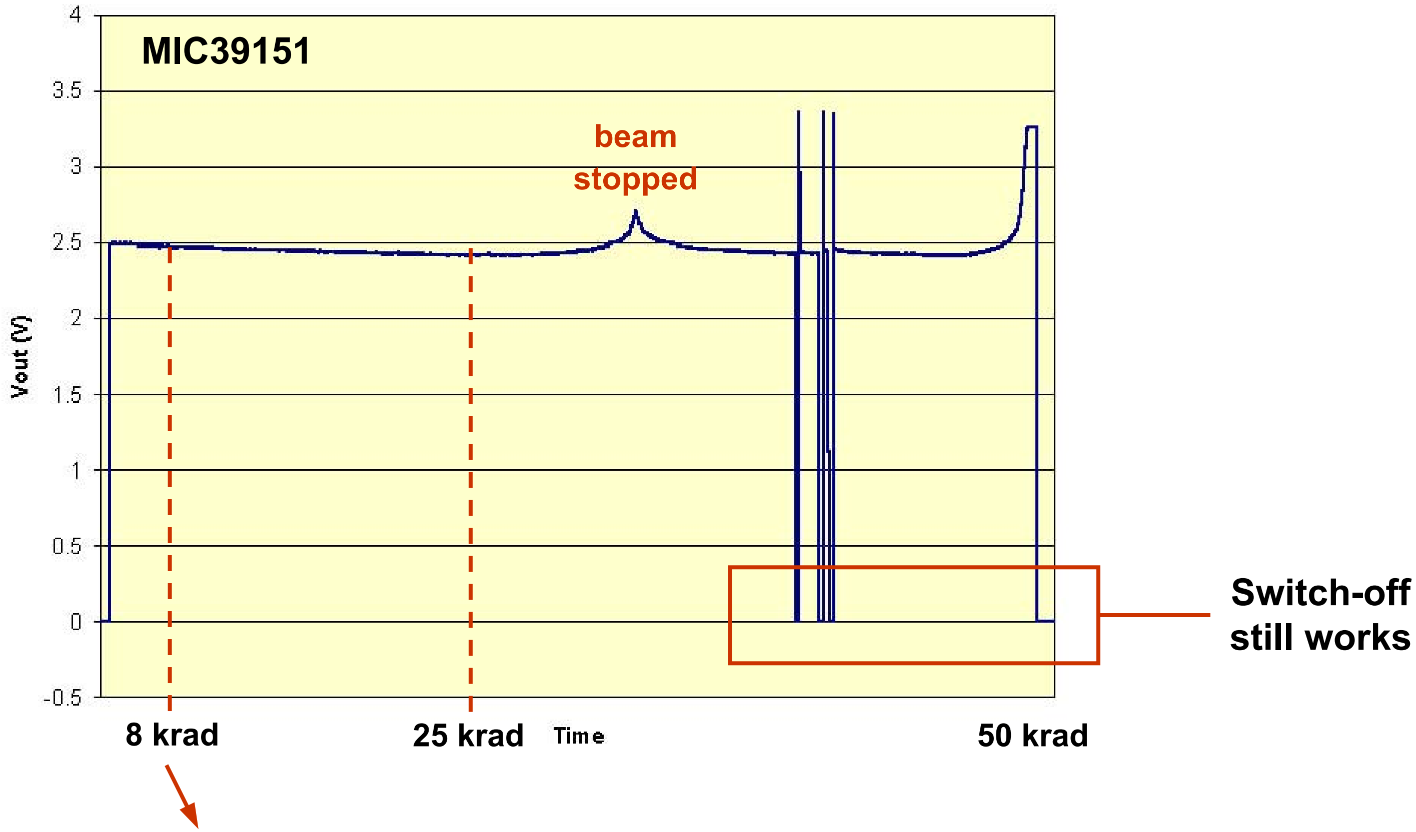
System-level Consequences

For an FMD Digitizer Card equipped with 3 ALTROs

	Registers	Pedestal Memory	Data Memory	Hamming Machines
SEU per hour	$3.45 \cdot 10^{-5}$	$5.4 \cdot 10^{-4}$	$2.1 \cdot 10^{-3}$	$1.05 \cdot 10^{-4}$
MTBF	1200 days	77 days	20 days	397 days

Regulator Test Results

MIC39151 died after 30 krad (switch-off still possible)



MIC39151 still usable for the TPC. Batch dispersion might be an issue

Upset detection in ALTERA FPGAs

Two types of concern

- Upsets in configuration SRAM cells
- Single bit-flips in register elements (can be avoided by design)

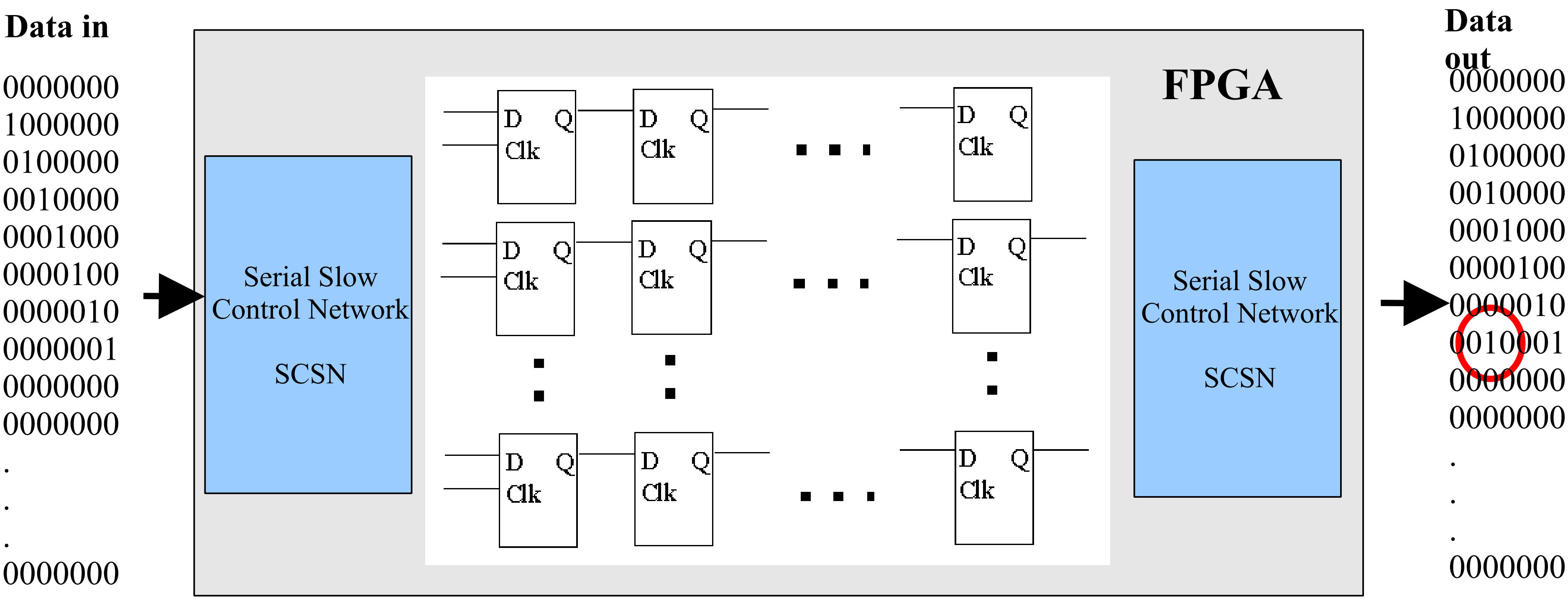
The APEX20K400E offers no direct readout of configuration SRAM

- Indirectly detection of configuration upset through the internal logic

Error observed reflects a change in logic due to a configuration upset, and not the configuration upset itself

Upset detection in ALTERA FPGAs

A fixed pattern is shifted through and compared for setups when read out.



Cross Section Results

Particle E > 10 MeV	Fluence [cm^{-2}] per 10 ALICE years (Simulation 1, non-absorber & absorber side)	Fluence [cm^{-2}] per 10 ALICE years (Simulation 2, incl. absorber side)
Protons	6×10^{8} 3×10^{8}	8.6×10^{8}
Pions, kaons	3.5×10^{9} 1.5×10^{9}	1.4×10^{9}
Neutrons (5%)	1.9×10^{9} 5×10^{9}	$\approx 10^{10}$? tbc

Particle E > 10 MeV	Flux [$sec^{-1}cm^{-2}$] (Simulation 1)	Flux [$sec^{-1}cm^{-2}$] (Simulation 2)
Protons	24 13	34
Pions, kaons	140 60	56
Neutrons (5%)	76 206	450? tbc

Error estimates per run

High Energetic Hadron Flux (@ TPCin): 250 – 550 hadrons / sec • cm^2

	Error rate per run (4 hours) per device
FEC	$3 \cdot 10^{-4}$
RCU	$1.5 \cdot 10^{-2}$
DCS	$3 \cdot 10^{-2}$

Conclusions (1)

- **ALTRO chip**
  - TID > 300krad
  - SEU: Control Logic is SEU free, Memories cross section too small to be a concern at the projected ALICE particle flux
- **FMD Digitizer (based on TPC FEC components)**
  - TID ~ 30krad
  - SEU (@ 500 hadrons / $cm^2 \cdot s$)
    failure rate per run (4hours) per device ~ 3×10^{-4}
- **FMD Digitizer (modified version based on CMOS LDOs and antifuse FPGA)**
  - TID > 100 krad
  - SEU free

Conclusions (2)

- **RCU (TPC actual version)**
  - TID ~ 30krad
  - SEU (@ 500 hadrons / cm^2 s)
    failure rate per run (4hours) per device ~ $5x10^{-2}$