RADMON Radiation Monitoring System for the LHC Machine and experimental caverns

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Acknowledgements :

Radiation facilities : UCL Louvain-La-Neuve, PSI Villingen, TSL Uppsala, CIS-BIO (CEA Saclay), Ljubljana, PROSPERO (CEA-Valduc)

Radiation community : Radecs community, ESA, JPL

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Electronics under irradiation

- **> 10.000 crates in tunnel ARCs/DSs, underground/expt. areas**
- **Equipment concerned :**

  Power Converters, QPS, Energy Extraction, Vacuum, BLM, BPM, Cryogenics, Survey, Electrical Distribution, Interlocks, Access, Ventilation, Fire detection, Oxygen deficiency, RF equipment, Beam Instrumentation (Pt4), …
- **All based on COTS components (not Radhard)**

QPS electronics (R. Denz)

CRYO electronics in UX85

(see talk A-L Perrot this workshop)

Radiation Tolerance Assurance

1. **Simulate radiation levels/spectra in specific areas**
2. **Design and implement shielding**
3. **Consider radiation as a constraint for**
   - Electronics integration
   - Component selection
   - System design
4. **Radiation testing before start series production**
5. **Monitor radiation during first years of LHC operation**

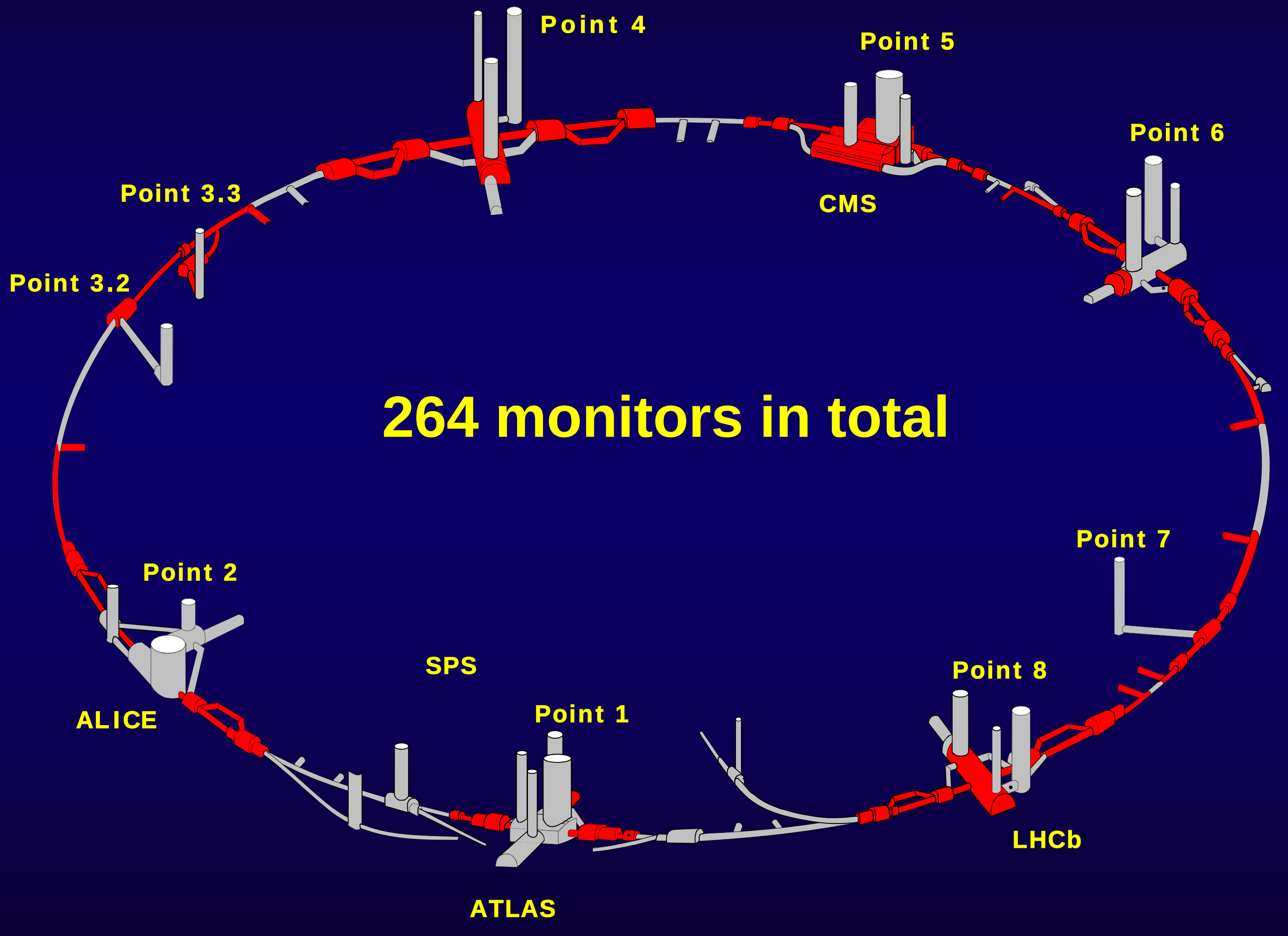
⇨ ***RADMON*** radiation monitoring system

Radiation Monitoring

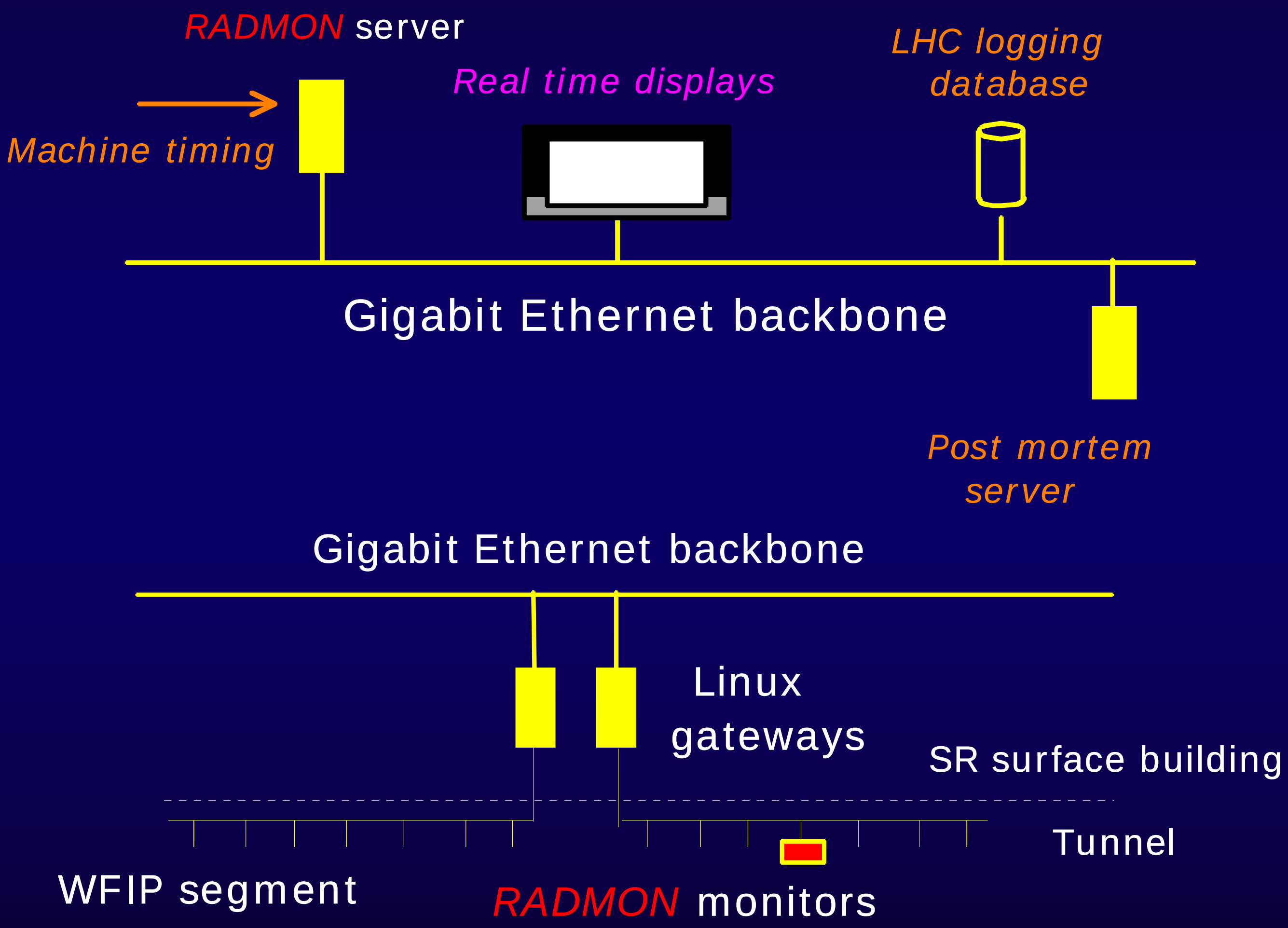
The *RADMON* system has been designed to measure the radiation levels at the location of equipment to :

- **Provide an early warning if levels are high**
- **Identify radiation induced failures**
  - *Type of damage (SEE, Cumulative)*
  - *Cause (accidental or systematic)*
- **Study variation of radiation levels as a function of**
  - *Position, time*
  - *Beam parameters*
  - *Machine condition*
- **Cross check Monte Carlo simulations**
- **Improve shielding**
- **Schedule preventive maintenance**
- **Estimate remnant dose rate equipment**

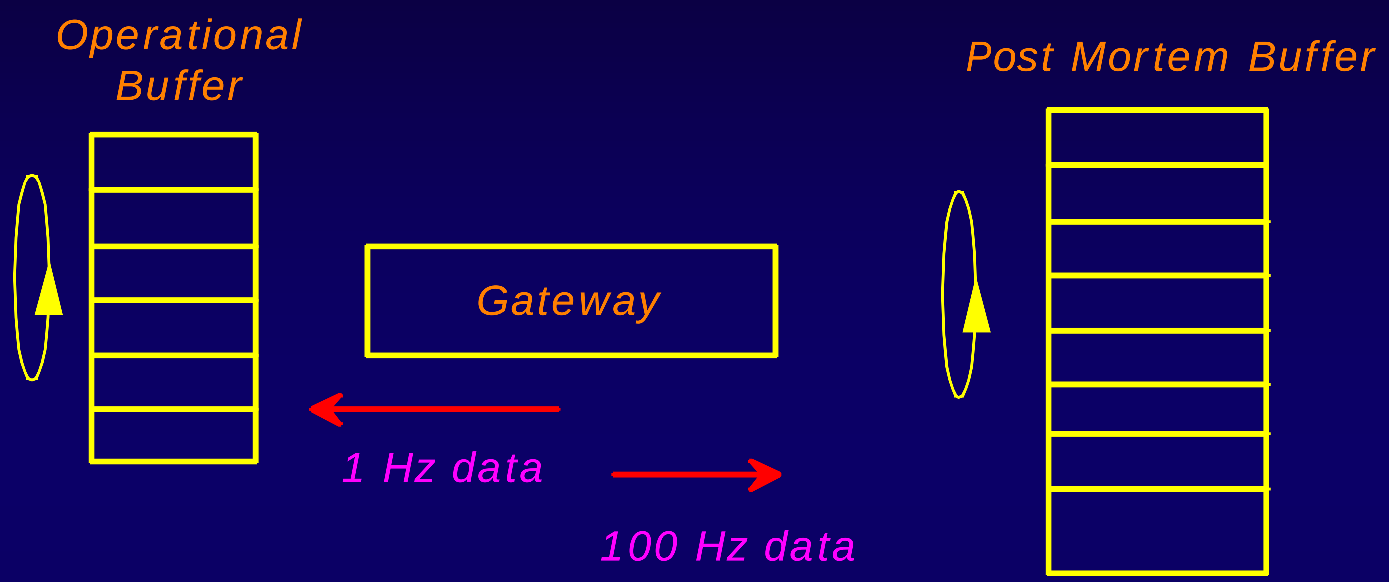
Tunnel layout



RADMON Architecture



Data acquisition – normal operation



Operational buffer :

- To LHC Logging database
- 1 hour autonomy
- Data taking only during operation

Post Mortem buffer :

- 30 min autonomy
- Freeze and remote readout :
    - automatically for machine transitions (injection, ramp, squeeze, physics)
    - on operator demand

LHC Radiation Fields

- **Radiation spectra are very similar**
- **Radiation levels in [cm^{-2} Gy^{-1}]**

  beampipe with cryostat

  6 x 10^{10} n > 100 keV

  4 x 10^{9} h > 20 MeV

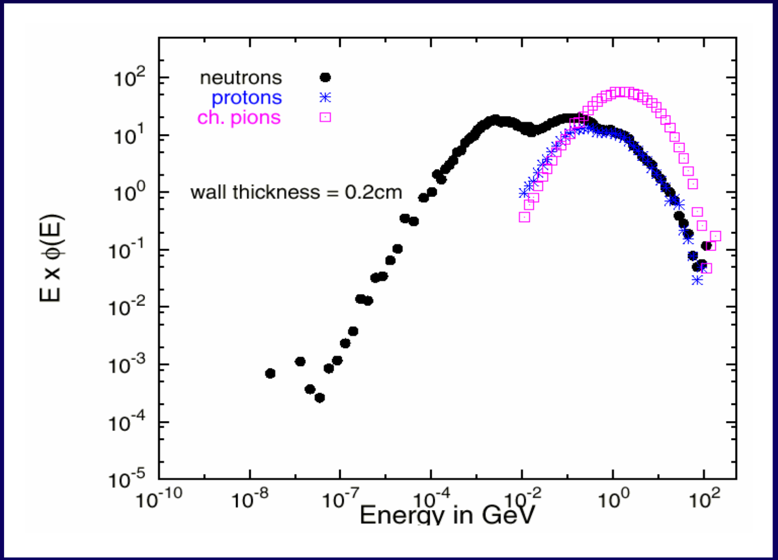
  2 x 10^{9} h > 100 MeV

  beampipe

  4 x 10^{9} n > 100 keV

  8 x 10^{8} h > 20 MeV

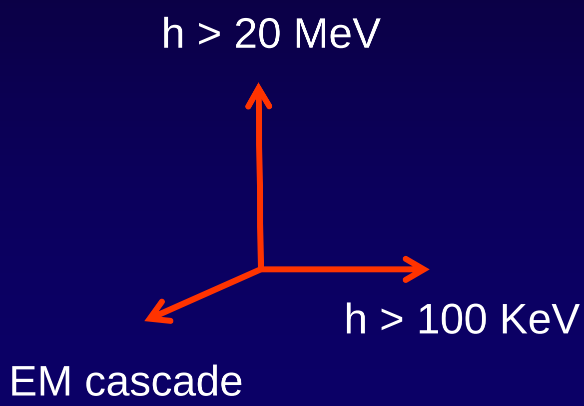
  5 x 10^{8} h > 100 MeV



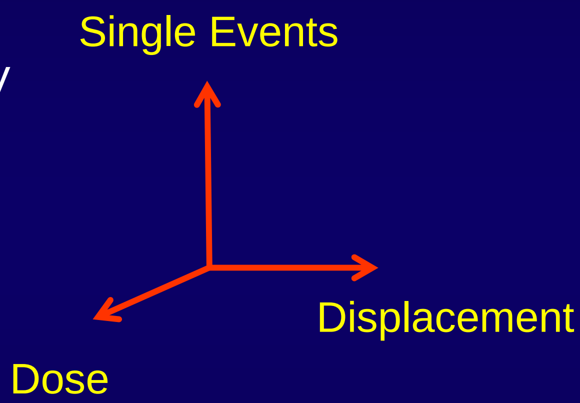
C. Fynbo, LHC seminar 22/11/01

- **Annual dose**
  - **1-2 Gy alongside magnets, 10-20 Gy in inter magnet gaps**
  - **35-150 Gy in dispersion suppressors, 9 kGy in cleaning sections**

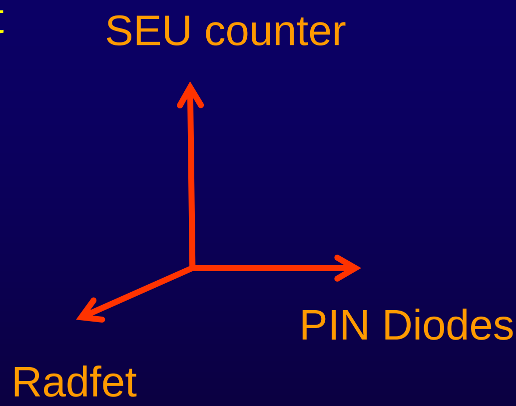
Parameterisation of a complex radiation field



nuclear cascade



radiation damage semiconductors



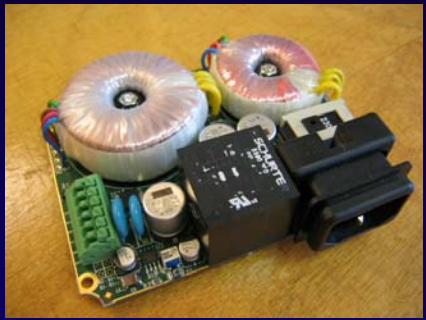
Radiation Monitor

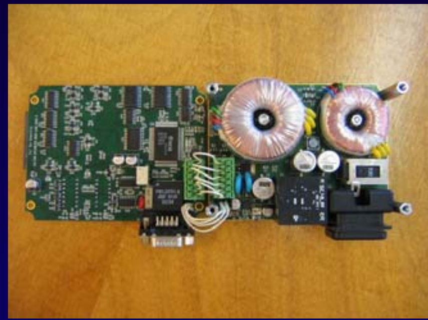
Radiation Sensors per monitor

- Dose, dose rate
  - Tyndall Radfets – 2 different types at a maximum of 1 rad/bit
- Hadron flux, hadron fluence
  - TC554001AF-70 SRAM – 4 x 4 Mbit gives 1 SEU per 1 10^6 n > 20 MeV
- 1 MeV eq. neutron fluence
  - SIEMENS BPW34FS – 3 diodes at maximum of 5 10^9 neutrons/bit (1 MeV)

	Inaccuracy	*Resolution*	*Range*
Dose [Gy]	±10 %	0.01	200
Dose Rate [Gy/hr]	±10 %	0.01	50
Neutron fluence [n/cm^2]	±15 %	5 10^9	1 10^{13}
Hadron fluence [h/cm^2]	±15 %	1 10^6	1 10^{12}
Hadron flux [h/cm^2.s]	±15 %	1 10^6	2.3 10^{11}

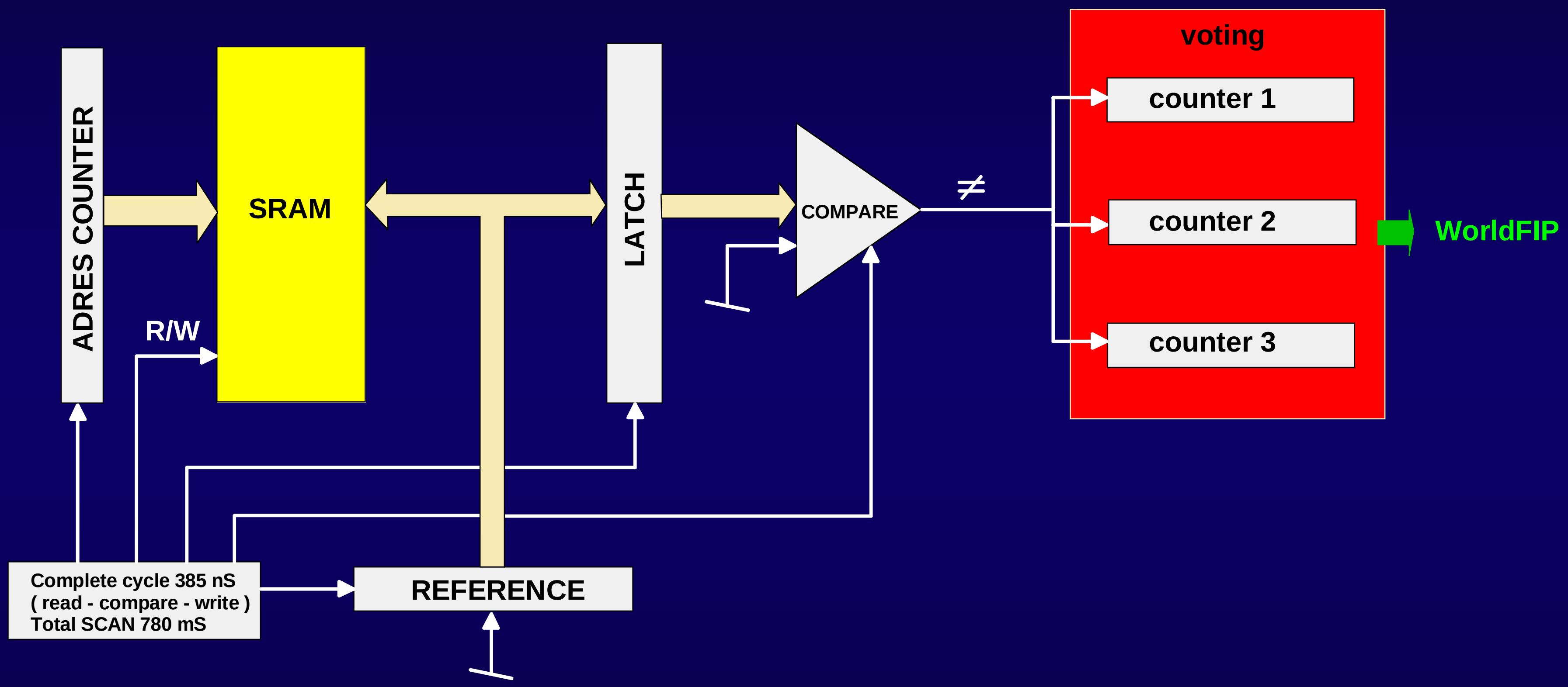
RADMON – monitor parts & assembly







RADMON – block diagram SEU counter

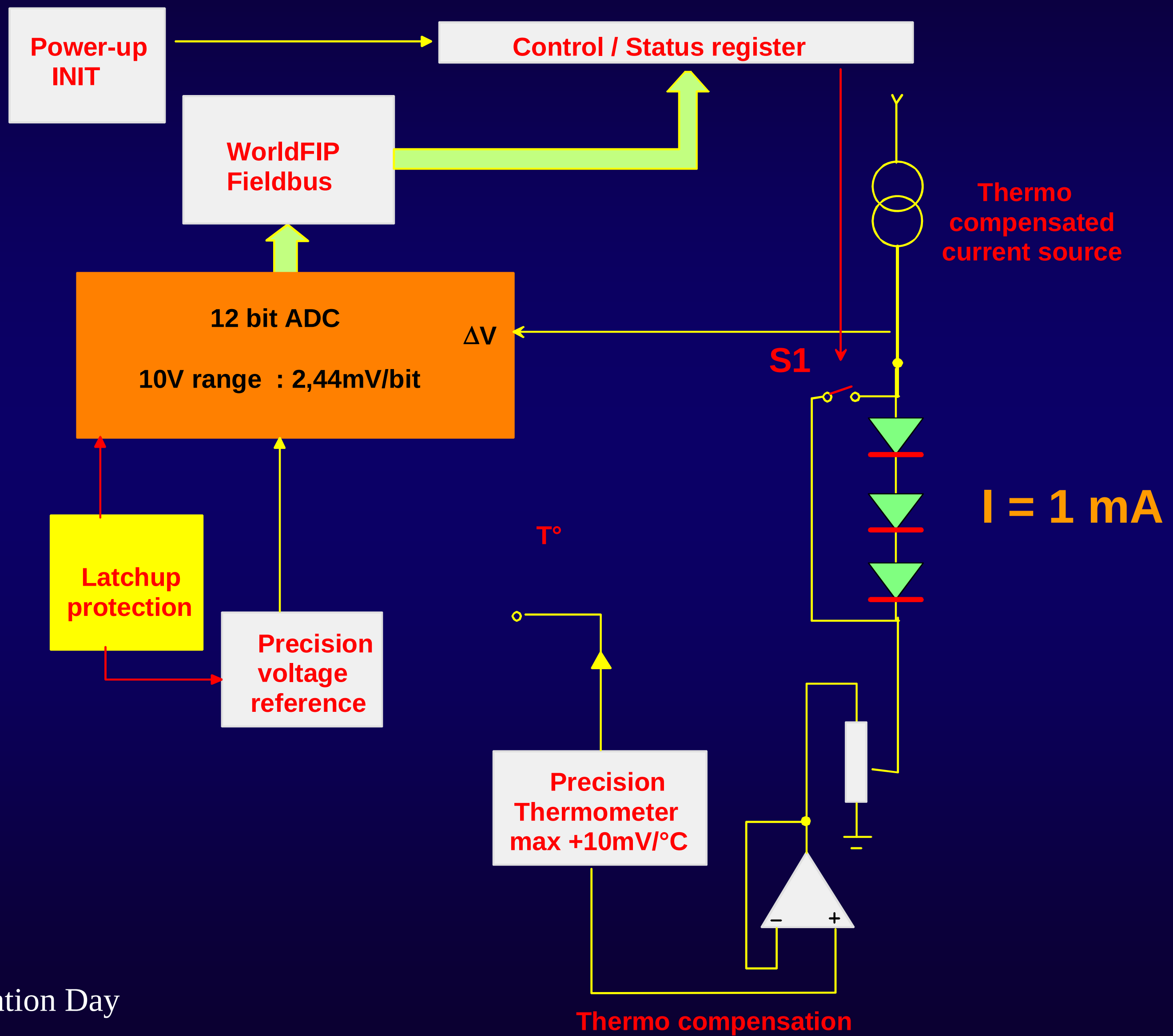


TC554001 SRAM – 4 x 524288 bytes

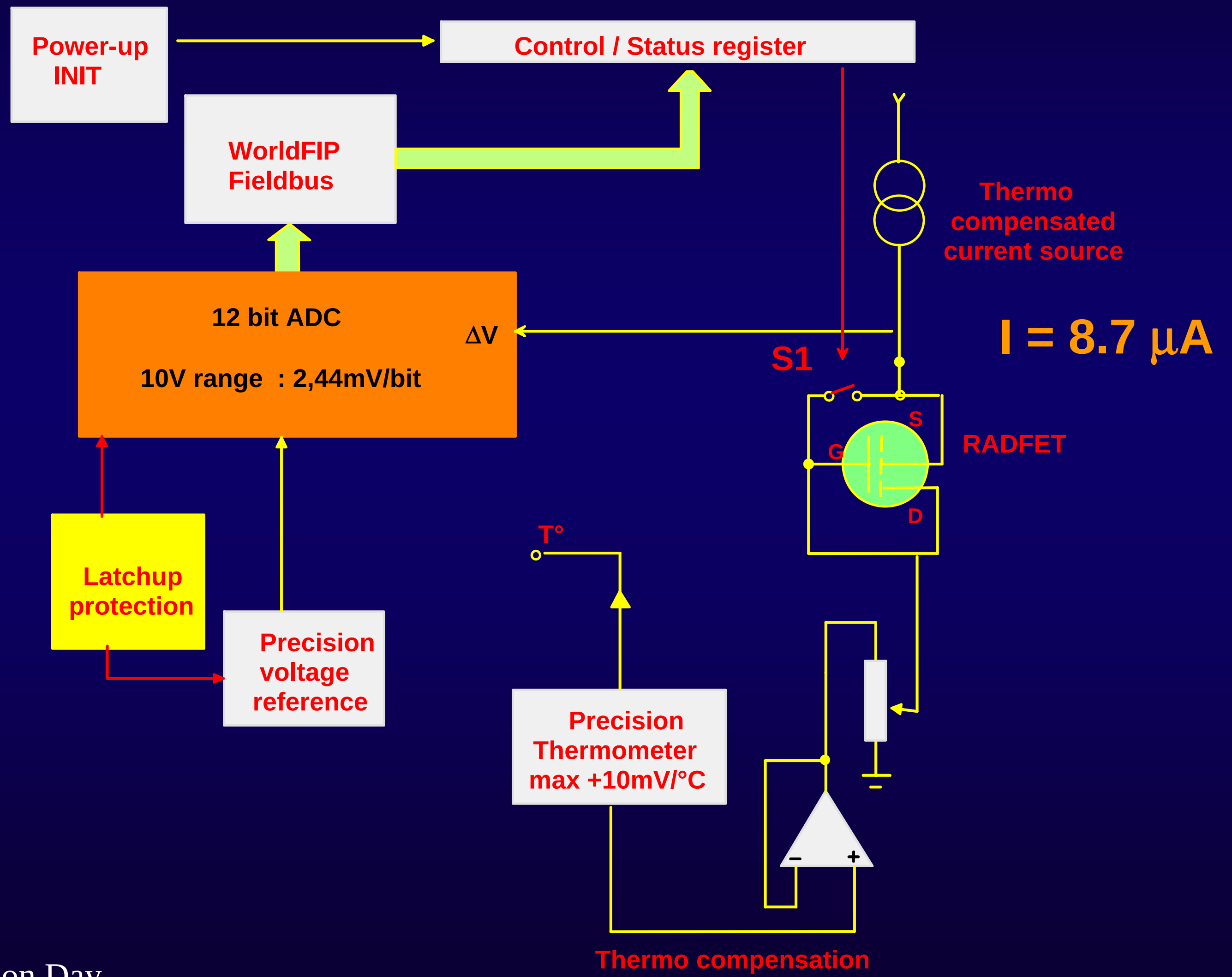
SEU counter design specifics

- **Comparison per “byte”, reference pattern “0”**
- **3 V or 5 V operation (3 V most sensitive)**
- **Cycle time variable (to deal with frequency effects in SRAM)**
  - read, write, compare
    215 nsec – 1 μs
  - total scan (16 Mbit SRAM)
    450 ms – 2100 ms
- **2 x Triple redundant counting registers**
- **Readout speed 3 counters via fieldbus over 2.5 km**
  (6 actions : LSB1 FREEZE - MSB1 – LSB2 - MSB2– LSB3 - MSB3)
  - 4 kHz - 1 monitor
  - 100 Hz - 32 monitors

RADMON – block diagram for PIN diodes

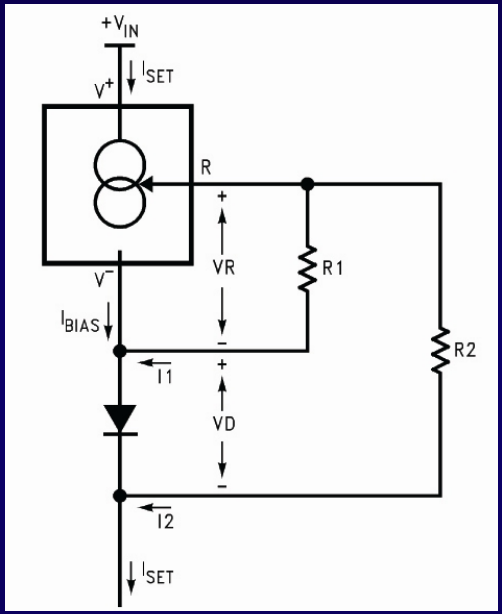


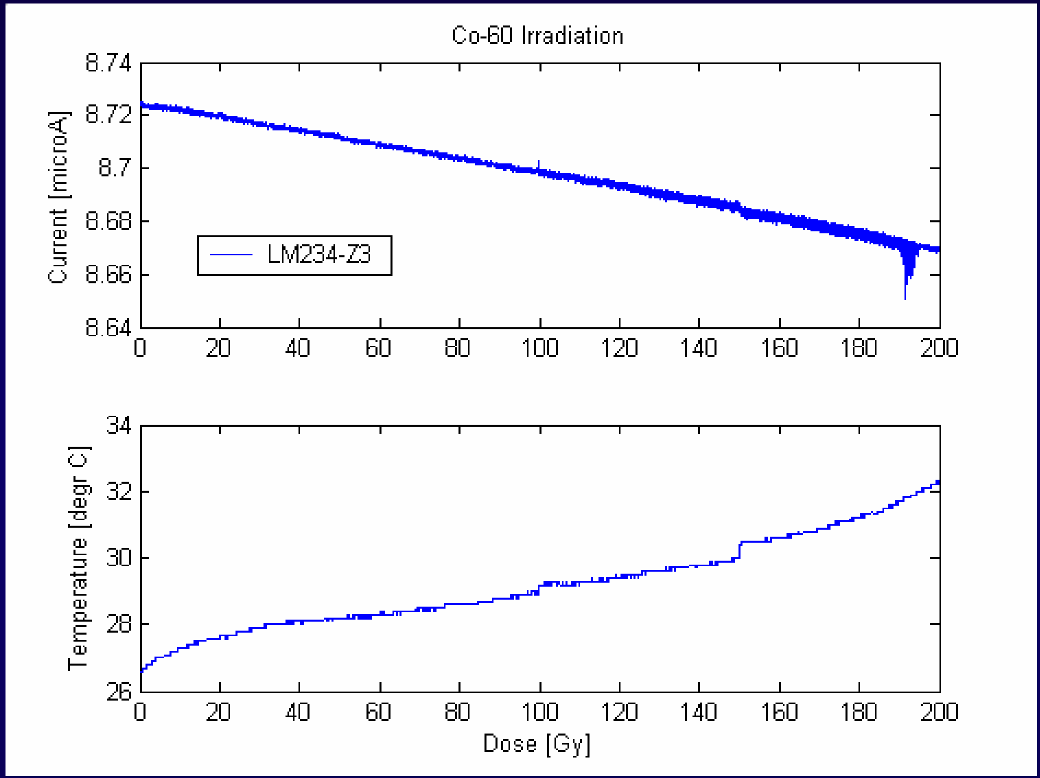
RADMON – block diagram for Radfets



Thermo compensated current source

LM234-Z3 (Nat.)





- **After 200 Gy (Co-60 at 50 Gy/hr)**
  - **60 nA drift (< 0.7 %)**
  - **Thermo compensation entirely intact**

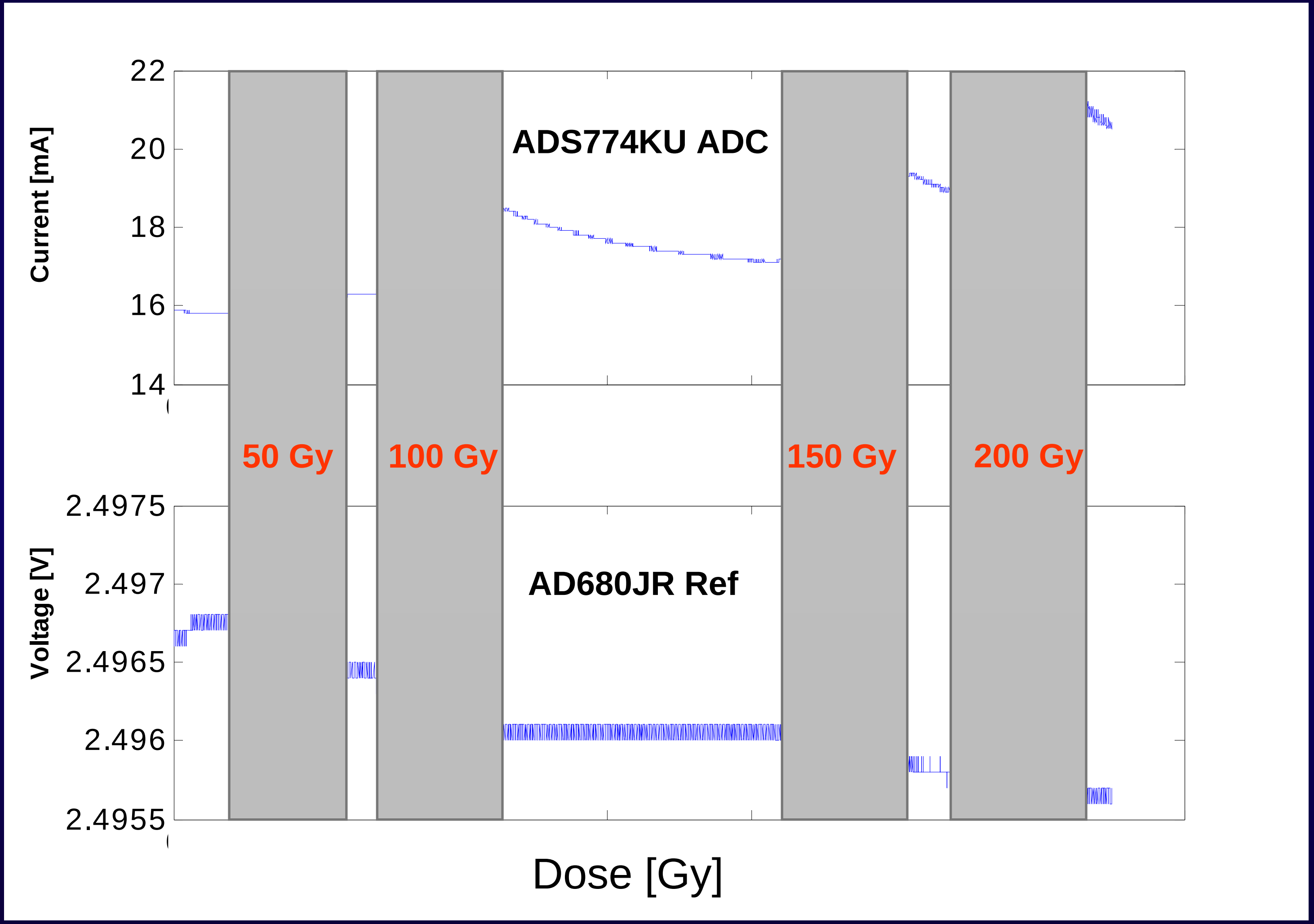
ADC design specifics

- **12 bit A/D converter ADS774KU**
- **External 2.5 V reference AD680JR**
- **A/D Conversion delay adjustable**

  (to deal with variation in RADFET responsetime)
  - 500 µs – 10 ms
- **Operate in "command- response" mode**

  (to minimise probability of SEUs in ADC and registers)
  - A/D conversion – delay – latch in registers 2 ms
  - Readout via field bus (2 accesses) 60 µs

Co-60 Irradiation ADS774KU (50 Gy/hr)

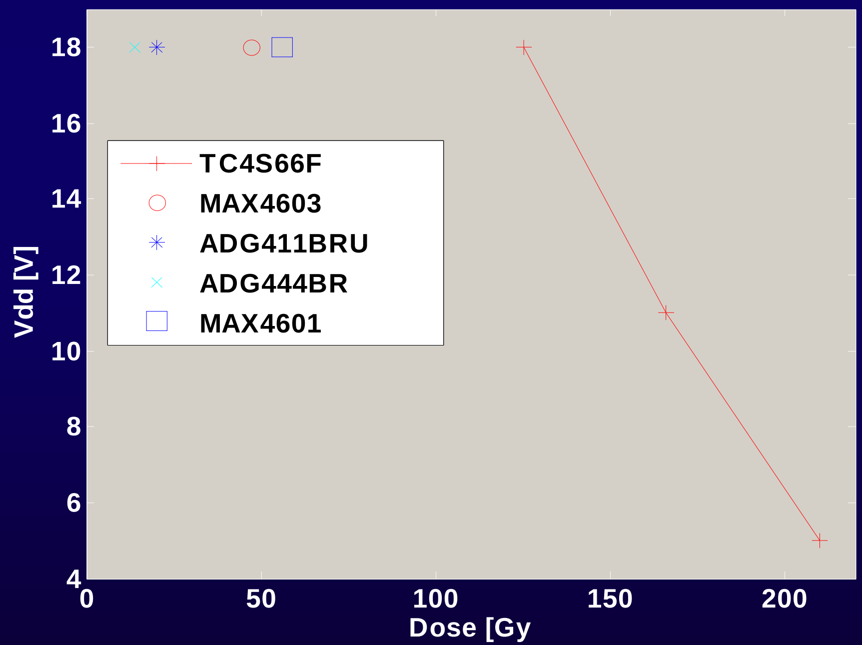


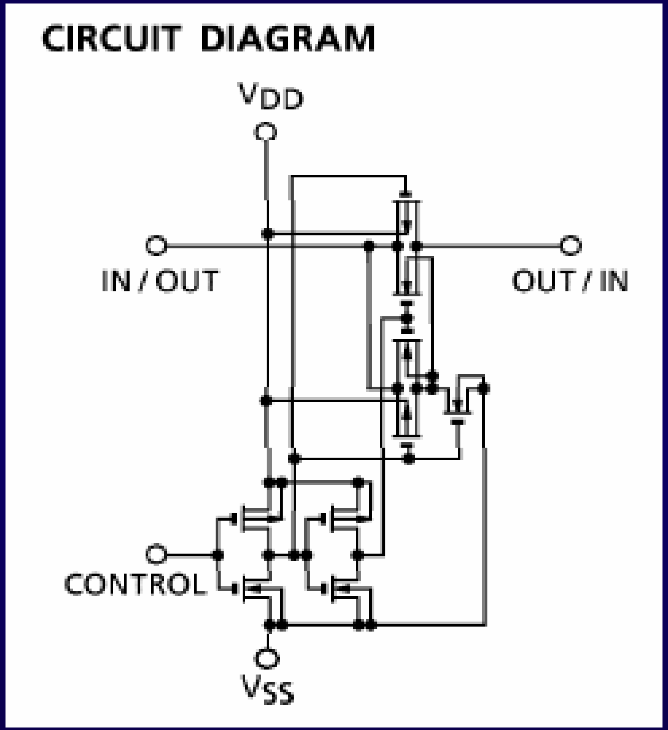
CMOS analog switches

- **Common Characteristics :**
  - **NO/NC switches (NO/NC = normally open/closed)**
  - **Logic input to open/close switch**
  - **$R_{OFF} > 10^9\ \Omega$ (open) $R_{ON} = 2 - 500\ \Omega$ (closed)**
  - **Maximum switching voltage equal to V_{DD}**
- **Common characteristics under irradiation :**
  - **TID is main damage effect, *sharp decrease* in R_{OFF}**
  - **TID ↓ if V_{DD} ↑**
  - **TID ↓ if switching frequency ↑**
  - **TID = for NO or NC**

CMOS Analog switches – Co-60 Irradiation

- ADG 411 BRU from AD
- ADG 444 BR from AD
- MAX4603, MAX4601 from MAXIM
- TC4S66F from Toshiba





TC4S66F

Summary

- **RADMON radiation monitors :**
  - *Remote, on-line radiation monitoring in complex HEP fields*
  - *3 sensors for EM shower, h > 100 keV, h > 20 MeV*
  - *Integrated measurements*
  - *Complementary to BLM, IAMs*
- **Study variation of radiation levels at the location of equipment :**
  - *Dependence on position, time*
  - *Dependence on beam and machine parameters*
- **Key components in radiation tolerant design :**
  - *Analog CMOS switches*
  - *Thermo compensated current source*
  - *1 Mbit/s μFIP Fieldbus interface*
  - *12 bit ADC with external voltage reference*