CERN

The LHC beam dumping system and its radiation hardness

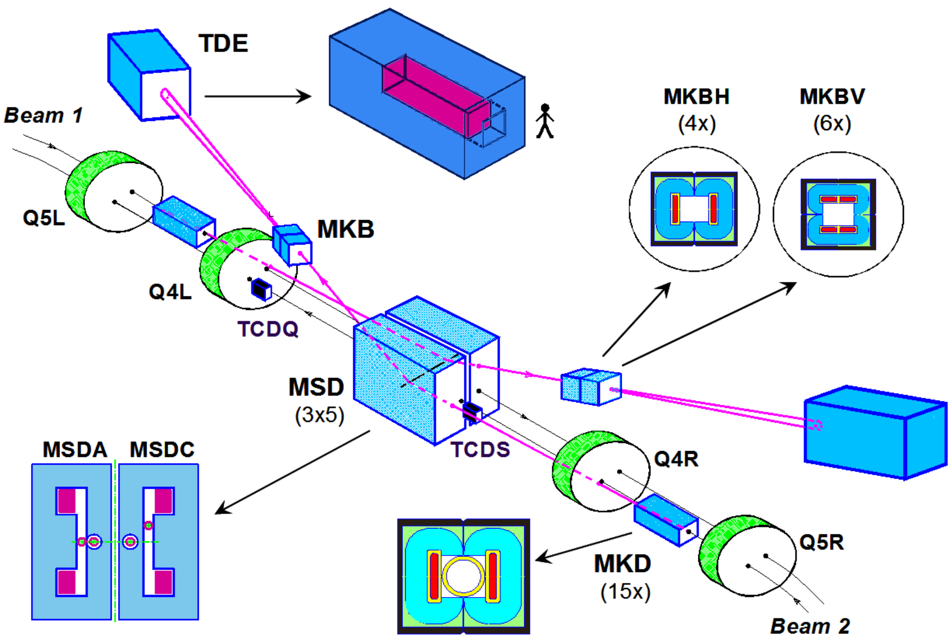
V. Senaj et al, CERN

Outline

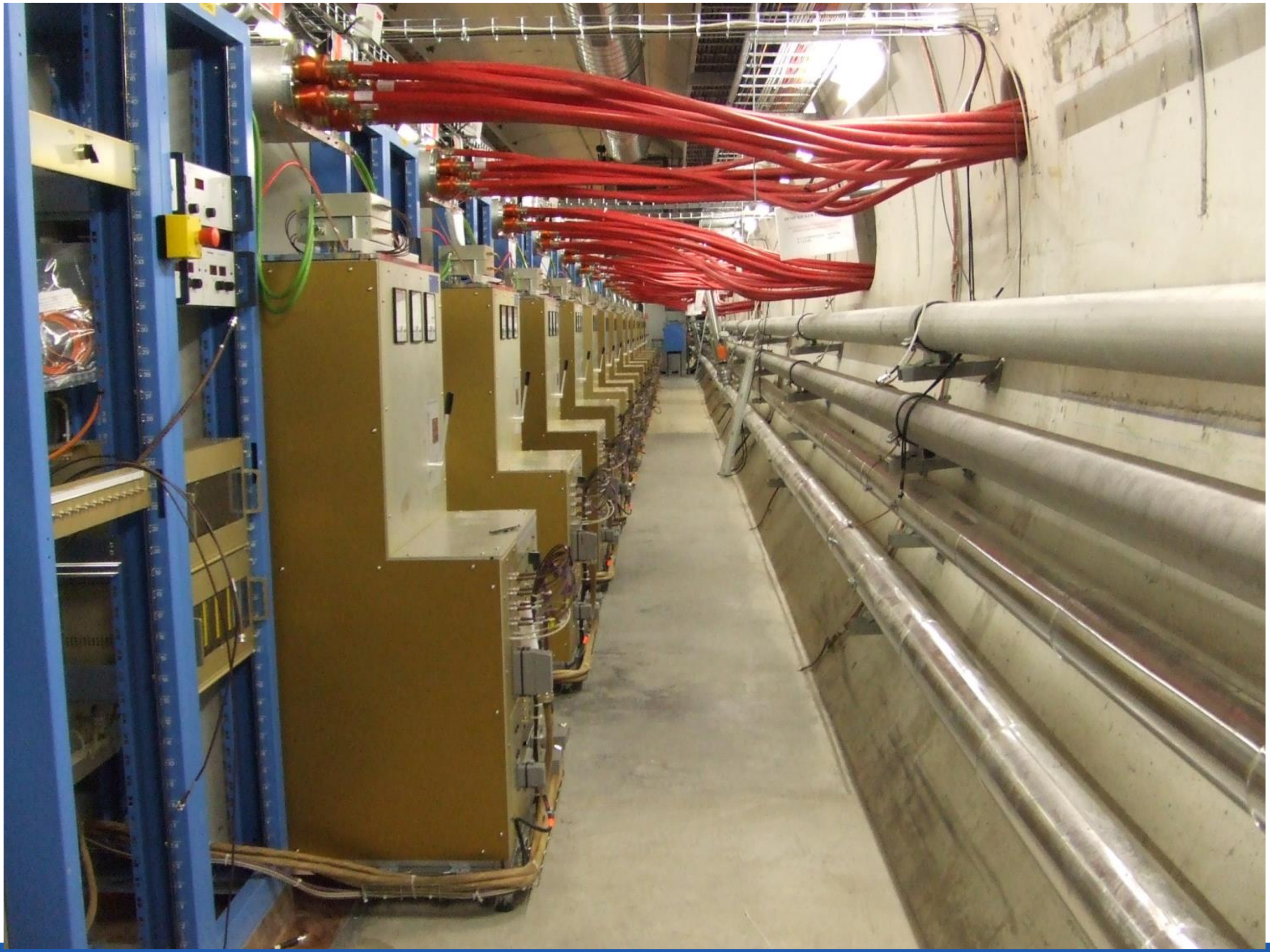
- LHC beam dumping system description
- Extraction and dilution generators
- HV switch
- R2E related items
- Non-destructive SEB test
- SEB cross section measurements
- SEB related failure rate evaluation
- Conclusion

LHC beam dump description

- 15 extraction generators (MKD) and 10 dilution generators (MKB) per beam
- Altogether 800 HV GTOs and 480 HV triggering IGBTs; 1 MA at 7 TeV
- Extraction generator current rise time < 2.7 µs; pulse duration > 91 µs
- Dilution generators – damped sine and cosine waveform with f ~ 13 kHz
- MKD: ~29 kV/19 kA
- MKBH/MKBV: 26kV/16 kV/ 24 kA
  Abort Gap (AG) duration = 3 µs
- Erratic on MKD = asynchronous dump (AD) = risk to downstream magnets and machine down time
- Erratic on MKB = partial dilution = risk to dump block and machine down time



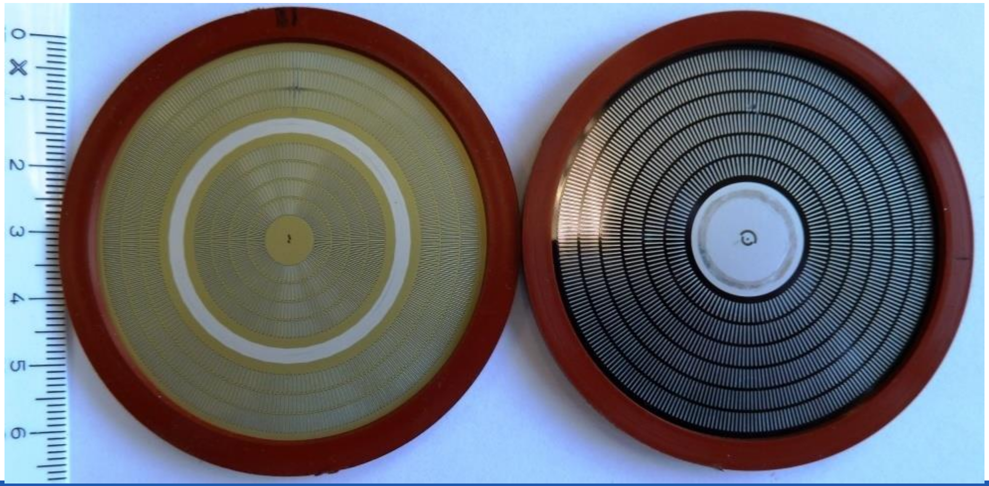
MKD generators: 15 per beam

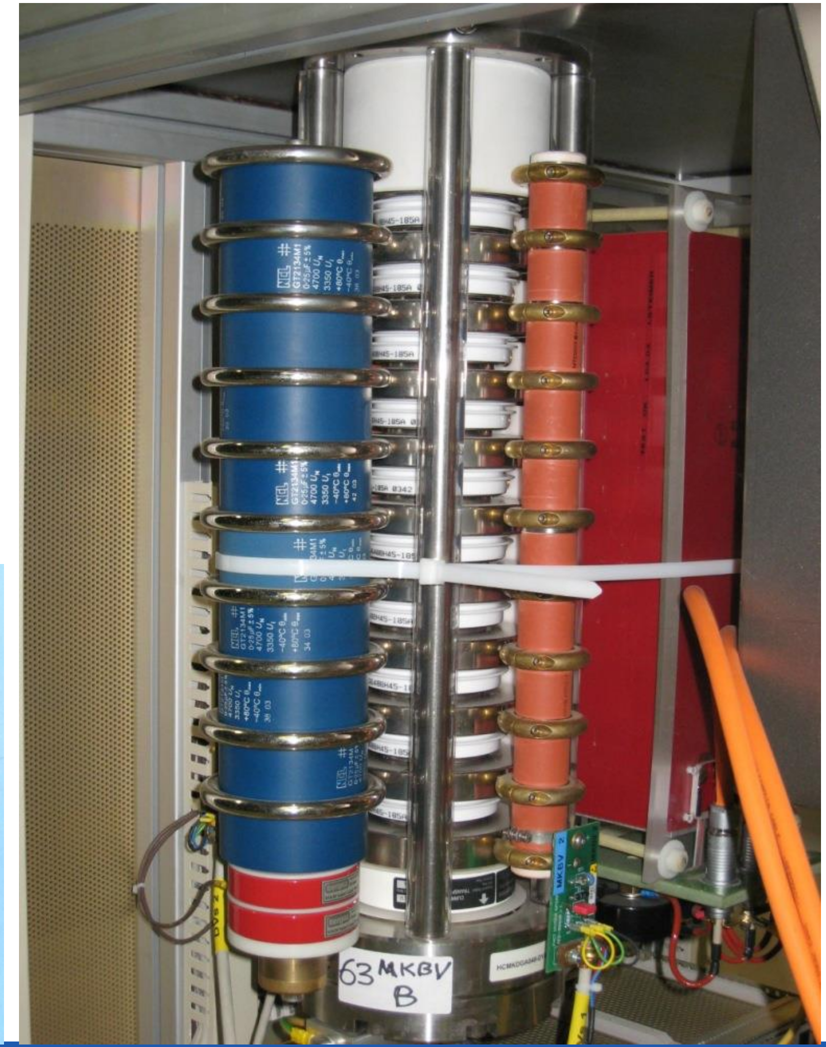


MKB generators: 10 per beam

HV switch - stack of 10 GTO-like thyristors

- ABB - 5STH20H4502
- DYNEX - DG648BH45-185
- Similar specifications for both:
  - Umax: 4.5 kV
  - Udc: 2.8 kV (100 FIT)
  - Imax: 80 kA
  - dI/dt: ~18 kA/µs
  - Load integral ~ 10^6 A^2s
  - wafer diameter ~ 60 mm



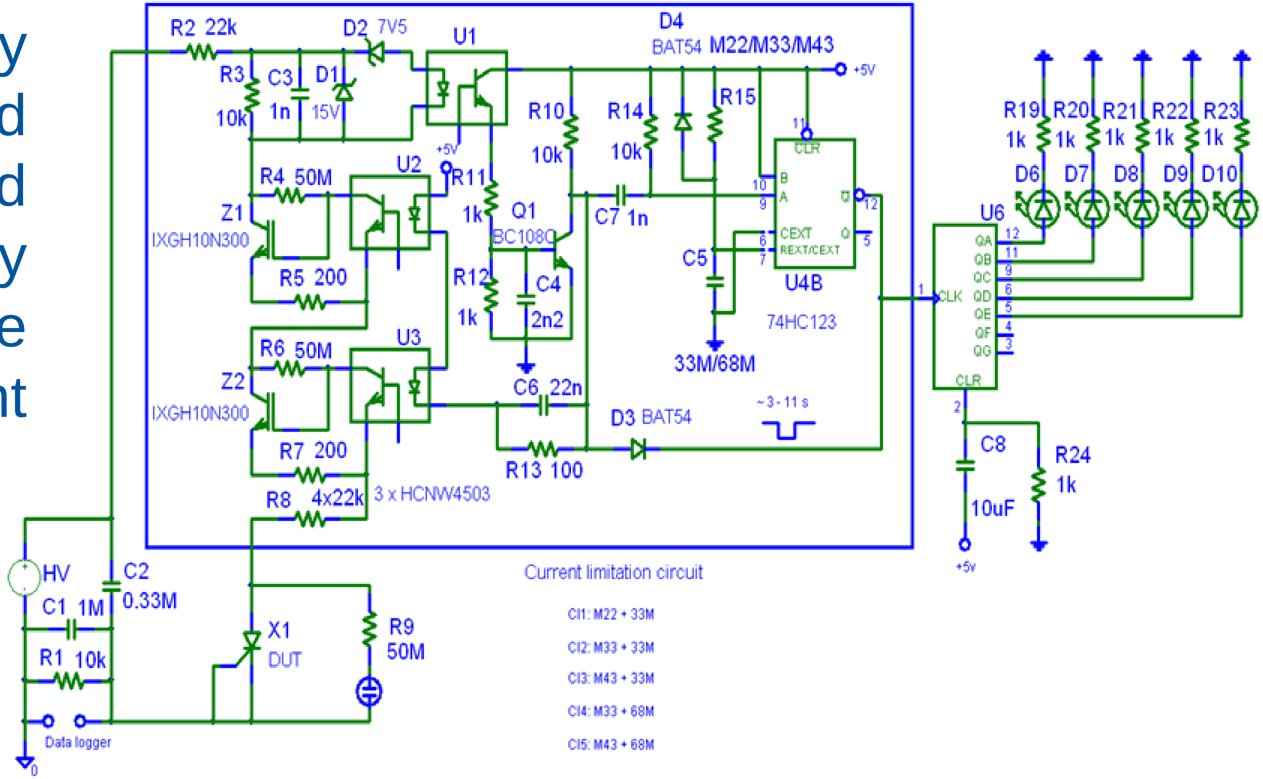


R2E related items

- LBDS generators are exposed to radiation leaking from tunnel to galleries via cable ducts
- High Energy Hadrons (HEH) can provoke Single Event Burnout (SEB) of HV semiconductors (IGBT, GTO)
- SEB = catastrophic failure leading very likely to erratic firing of the generator
- Probability of SEB – steep function of voltage; producer definition: 100 FIT at 2.8 kV due to cosmic rays at earth level
- HEH fluency in galleries not known; Fluka simulation: 1e6 HEH/cm2/y in front of cable duct;
- HEH fluency strongly reduced after LS1 – shielding of cable ducts (~5 t of iron rods per duct); today estimation: 5e4 HEH/cm2.y - very difficult to confirm; sensitivity of Batmons ~1count per 3e5 HEH/cm2
- Earth level cosmic rays ~1e5 HEH/cm2.y

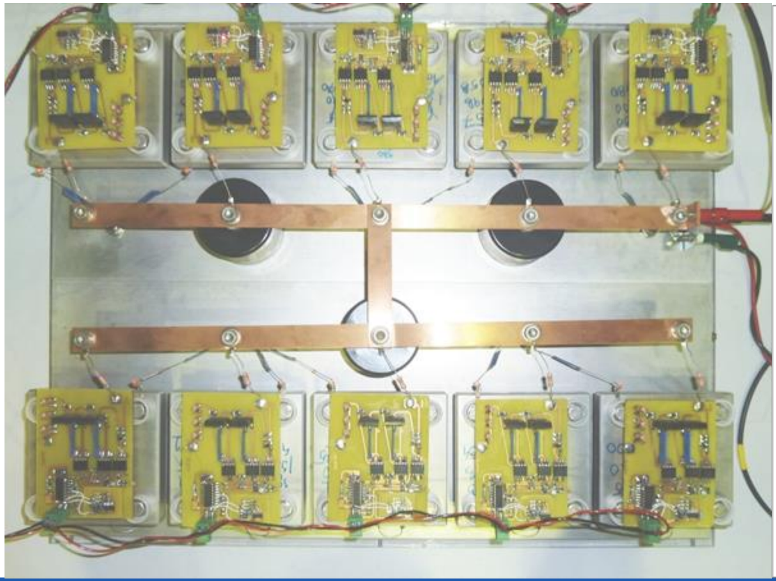
Non-destructive SEB test

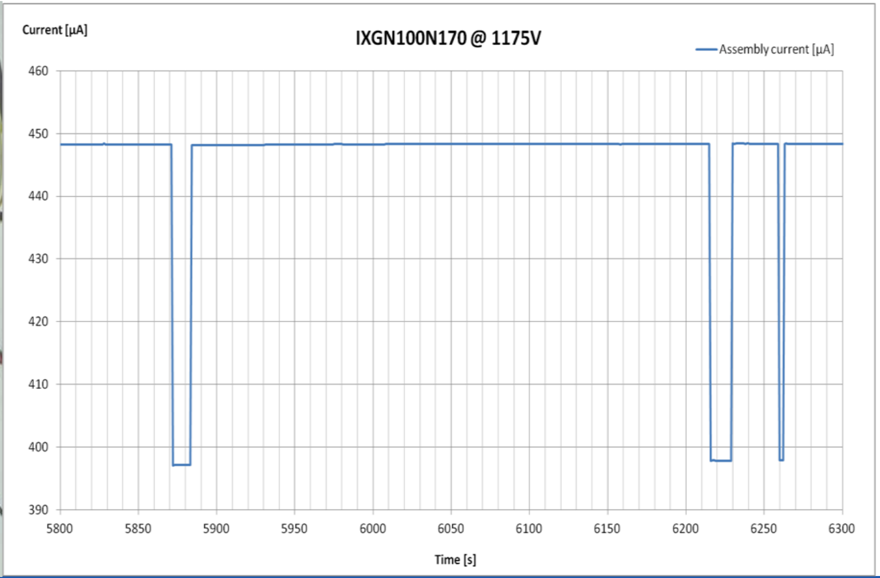
- SEBc-s measurement at nominal voltage (2.9 kV) necessary: due to the GTO cost (1kCHF) non-destructive SEB test was developed
- Multiple GTO in parallel with a current limiting circuit for each GTO
- SEB is counted by a local counter and remotely detected as a temporary decrease of the assembly current consumption



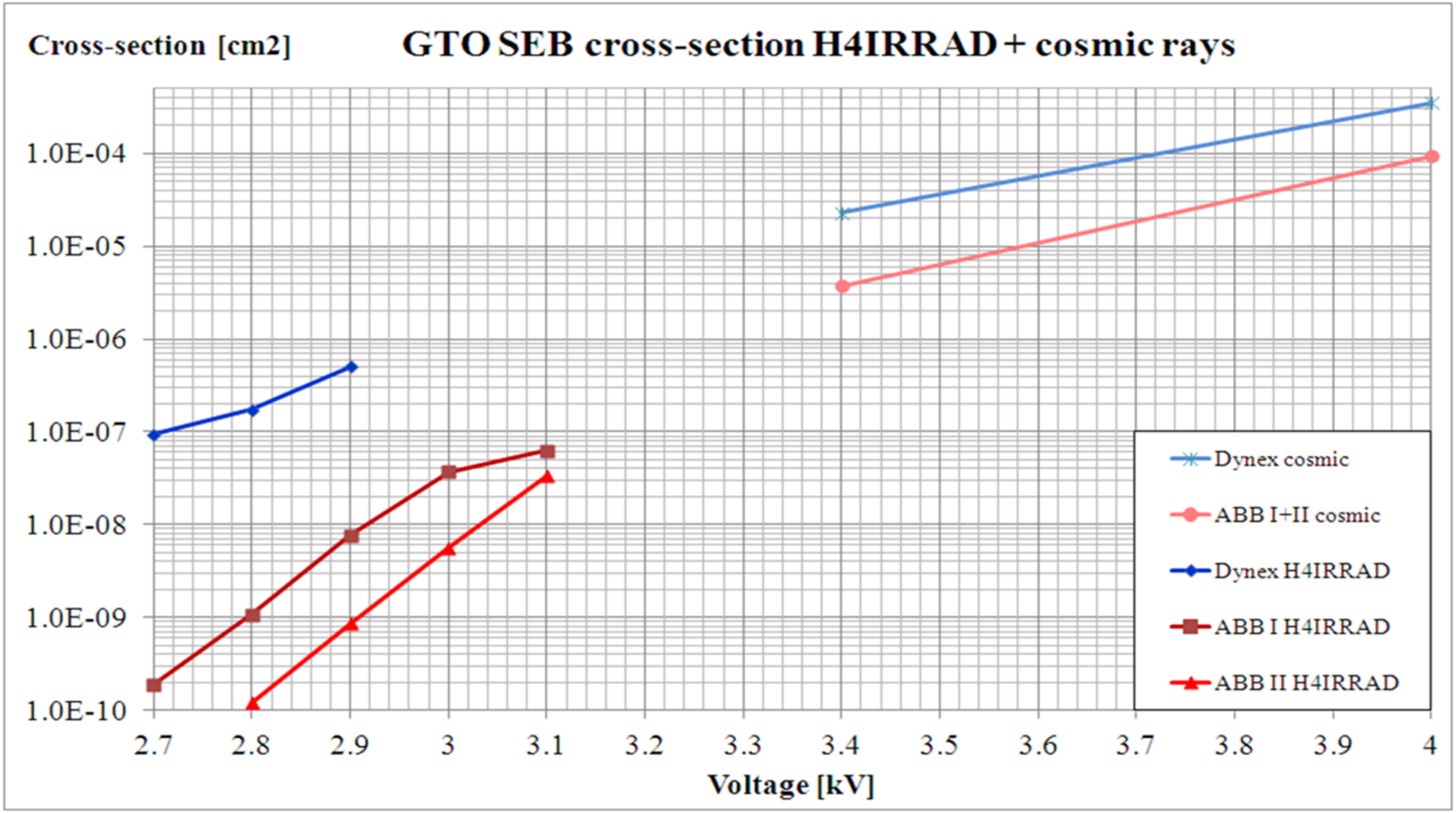
Non-destructive SEB test setup

- Non destructive SEB testing performed on GTO (maximum rating 4.5 kV tested up to 3.1 kV) and IGBT (1.2 kV and 1.7 kV rated tested up to 950V and 1.2 kV respectively)
- Simultaneous recording of the current consumption of 2 independent test assemblies (SEB detection) done by a low sampling speed data-logger accessed via Internet

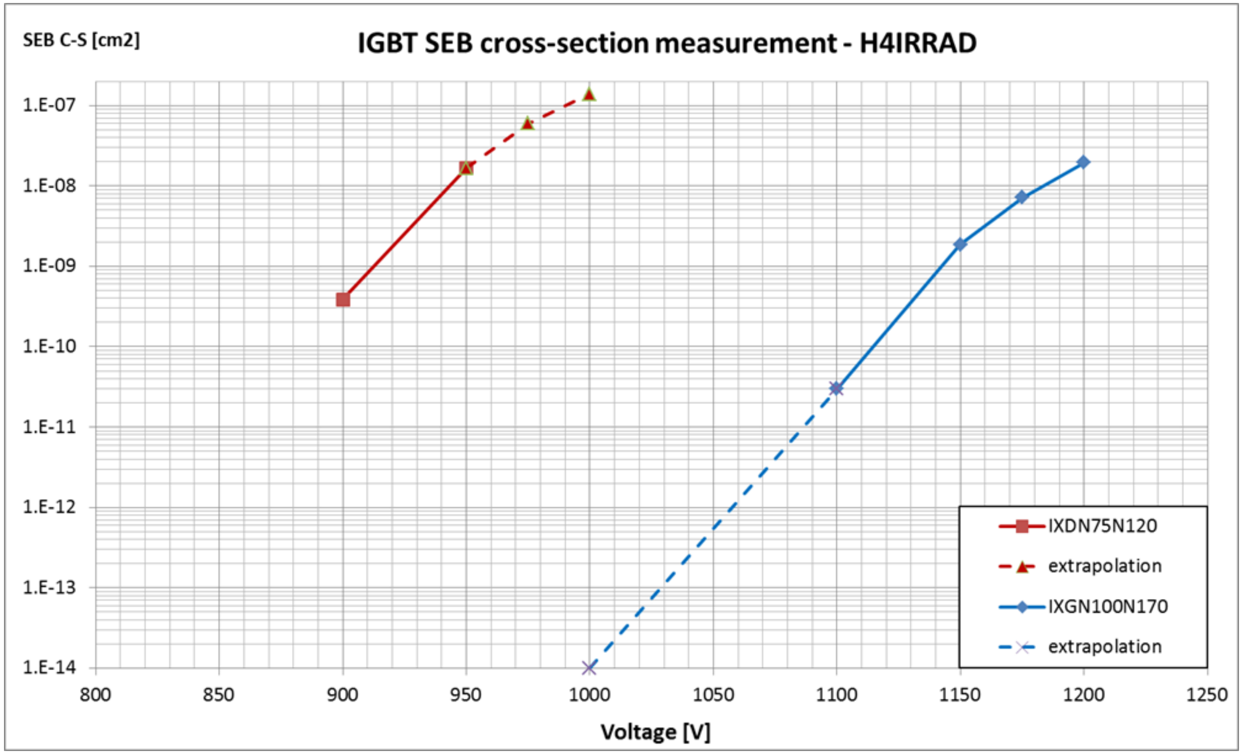




GTO SEB c-s measurement



Triggering IGBT SEB c-s: IXYS IXDN75N120 vs. IXGN100N170



SEB related failure rate evaluation

	6.5 TeV	7 TeV	7 TeV (without LS1 modifications)
	2.7 kV/GTO (MKD) 2.5 kV/GTO (MKBH)	2.9 kV/GTO (MKD); 2.7 kV/GTO (MKBH)	
ABB SEBc-s [cm^2]	2e-10	8e-9	8e-9
Dynex SEBc-s [cm^2]	3e-8	1e-7	1e-7 (5e-7 if used in MKD =2.9kV/GTO)
IXGN100N170 SEBc-s [cm^2]	5e-9	5e-9	1e-7 IXDN75N120
HEH fluence estimation [HEH.cm^{-2}.y]	5e4	5e4	4e5
	Failure probability		
MKD (GTO) [y^{-1}]	6e-3	0.2	61 (60 due to Dynex GTO)
MKD (IGBT) [y^{-1}]	9e-2	9e-2	15
MKBH (GTO) [y^{-1}]	0.12	0.4	3.2
MKB (IGBT) [y^{-1}]	3e-2	3e-2	5
Total AD (MKD GTO + IGBT) [y^{-1}]	0.1	0.3	76
Total SD (MKB GTO + IGBT) [y^{-1}]	0.15	0.43	7.2

Preliminary results

- No observed SEB on extraction generators (150 Dynex GTO replaced by less sensitive ABB ones)
- Shielding of galleries UA63/67 during LS1(~50t of iron) reduced HEH fluency from originally estimated 1e6 HEH/cm2.y down to today estimation 5e4 HEH/cm2.y; monitoring sensitivity (3e5 HEH/cm2/count) insufficient: no count in 2 years
- 2 suspected SEBs on dilution generators in 2 years (Dynex GTO) = factor of 10 higher than evaluation; suspected sensitivity of used GTO to thermal neutrons

Conclusion

- Method of non-destructive SEB testing for high power semiconductors (GTO&IGBT) developed in house allowed SEBc-s measurement at strongly reduced cost
- Based on SEBc-s measurements – mitigations done during LS1: replacement of GTO in extraction generators and IGBT in triggering circuit and shielding of galleries
- No SEB observed on extraction generators (most critical); 1SEB on dilution generator GTO per year (10x more than expected) – suspected sensitivity to thermal neutrons
- Measurement of Dynex GTO SEB sensitivity to thermal neutrons under preparation

CERN

www.cern.ch

Modified GTO stack