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Dosimetry for ultra-high fluence and challenges for irradiation experiments at FCC radiation levels

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FCC Radiation Environment and Challenges



As previously shown by <u>A. Infantino</u> and <u>R. Garcia</u> for the accelerators, and <u>G. Borghello</u> for the detectors, a very harsh radiation environment is expected in the FCC.



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RDR irradiation tests

Neutron Irradiation:

- TRIGA Mark II Research Nuclear Reactor at Jožef Stefan Institute (JSI), Ljubljana.
- Central channel flux: 7.2x10¹² n_{tot}/cm²/s.
- Cumulated ~1x10¹⁸ n_{tot}/cm² during 5 days of irradiation (40h).

Proton Irradiation:

- PS-IRRAD Proton Facility at CERN, Geneva.
- 23 GeV p⁺ beam with about 6x10¹¹ p⁺/spill every 10 s.
- Cumulated ~5.2x10¹⁶ p⁺/cm² during 3 months irradiation.

Radiation Dependent Resistors can be used!

Cu samples have shown the best sensitivity, while Al and Cr samples exhibited a much lower response. [G. Gorine, IEEE Trans. Nucl. Sci., 2018]













New neutron irradiation (performed in March 2018) and proton irradiation (from April 2018).

- Towards a full sensor with readout based on rad-hard transistors:
 - Extend a novel technology of nano-sized Vacuum Transistors to the HEP field.

Ongoing and Future R&D in Dosimetry for FCC

- Focus research on Copper RDR:
 - Microfabrication of new RDRs with thinner Copper layers (500, 50, and 5 nm), and fabrication techniques.
 - Study of radiation damage on Monolayers of Copper produced with ALD (Atomic Layer Deposition).
 - Evaluate new devices with irradiation experiments:
 - Test with ionizing radiation (ongoing at CERN AD GBAR LINAC).
 - Test in mixed field radiation (ongoing in LHC-TAN, BRAN location).







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Towards A Full Sensor...Vacuum Transistor



NASA realized and tested Vacuum Triodes:

- No implementation of real transistor (with saturation region)
- Intrinsically rad-hard, but never tested for HEP applications!



Manufacturing of Platinum VFET at CMi/EPFL



Future fabrication in Silicon:

Proposal **accepted** for Ascent transnational access



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Irradiation Facilities at CERN





HiRadMat (protons)



... and several X-Ray Irradiation Facilities





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FCC driven Facilities Upgrades



How CERN irradiation facilities can deal with FCC tests?

- TID qualification of COTS in CHARM:
 - At ~200 Gy/week → ~5 months to reach 4 kGy;
- TID test of FETs in X-Ray Facility at CERN:
 - At ~16 MGy/week → ~2 months to reach 90 MGy;
- DD test of RDR dosimeters in IRRAD:
 - At ~7x10¹⁵ p/cm²/week (5x5 mm²) → ~10 months to reach 2.8x10¹⁷ p/cm²;

Clear TIME ISSUE!

- No space due to dimension (bigger experiments), and quantity (100 km tunnel)
- CERN Irradiation facilities not capable to deliver required dose/fluence.
 - Expand CERN testing capabilities in terms of size and availability,
 - When possible, **external partners** will be fundamental!





Irradiation facilities database

Supported by AIDA2020, a unified entry point for irradiation facilities at CERN, in EU, and Worldwide.

- http://cern.ch/irradiation-facilities
- More than 200 facilities already registered!
- Auto-maintenance feature to avoid outdated information:
 - Automatic (annual) update requests sent to facility coordinators.
- Allows a "look into the future":
 - which facilities could be used by FCC community?













Testing Challenges at FCC levels



Irradiation tests at the MGy level (and >10¹⁷ p/cm²) require careful choice of material and test preparation!

DUT: specific PCBs, wire bonding, cables, etc..



Technologies tested up to >5x10¹⁷ n/cm²:

- 25um Gold wire bonds;
- 12-ch IDC cable;
- Kapton tape.

Support: material activation and radiation resistance studies



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Material tested up to >5x10¹⁷ n/cm²:

- Perfect support shows low activation and good stiffness after irradiation;
- Tested ULTEM-1000, Carbon fiber, PEEK, etc...



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Contribution to the CDR concerning Radiation Monitoring:

- We have proposed a new dosimetry technology for very high particle fluence monitoring, based on thin metal films (instead of silicon).
- The irradiation tests of the first prototypes of Radiation Dependent Resistors have confirmed our concept:
 - It's possible to relate Displacement Damage due to particle fluence with the variation of resistivity of a thin metal film.
- A second run of tests on Copper samples will give a wider understanding on the technology.
- Further development of the Vacuum Transistor for HEP applications, will allow building rad-hard circuitry for the FCC-RADMON.











Contribution to the CDR concerning Irradiation Facilities:

- The challenging radiation environment of the FCC will require extensive testing of all the equipment in the tunnel, as well as, unprecedented challenges in the development of detectors.
 - Current CERN infrastructure will not be sufficient (time, space, quantity)
 - Need of external partners \rightarrow Irradiation Facilities Database!
- A special know-how for irradiation testing at FCC-levels is required for the right selection of materials and supports.
 - A specific technical note will contain all the results from our material studies.











Thanks for your attention!

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CERN Irradiation Facilities



Name	Facility Characteristics		Main Purpose	FCC-driven targets (10 years operation)	Possible solution
IRRAD	Particle : p⁺ Momentum : 24 GeV/c	Flux: ~1-3×10 ¹⁰ p/cm ² /s TID: ~7-10 kGy/h	Study of IEL and NIEL effects on performance of detectors, calorimeters and FE electronics for HEP experiments.	<i>TID:</i> 90 MGy, <i>Φ:</i> 2.8×10 ¹⁷ p/cm ² . → one test takes ~1 year. <i>Issue</i> : low flux.	Increase flux to reach target fluence faster.
CHARM	Particle : mixed-field Energy : n ⁰ , HEH >100MeV	Flux: 10 ⁷ -10 ¹¹ HEH/cm ² /h TID: 0.01-100 Gy/h	Test of COTS electronics in an LHC-like environment for SEE evaluation such as failure cross sections and system sensitivity to radiation.	<i>TID:</i> 100 Gy, <i>Φ</i> : 7.9×10 ¹⁰ p/cm ² . → low levels, but 4x more systems for a 100 km FCC. Limit on parallel tests in ~1 year. <i>Issue</i> : not enough space.	Larger irradiation bunker to test more racks in parallel.
GIF++	Particles : γ + μ beam Energies : 0.662 MeV, 100 GeV	TID :~1Gy/h at 1m.(14TBq Cs137) / Flux : 10 ⁴ particles/spill (μ beam)	Evaluation of detection performance and aging of muon chamber detectors in ionizing dose environment.	<i>TID:</i> 10 kGy. → one test takes >1 years. Issue: both space and dose-rate.	Larger irradiation bunker to test bigger equipment + stronger gamma source.
CC60	Particles : γ Energy : 1.17 MeV, 1.33 MeV	TID :~1kGy/h at 5cm.(10TBq Co60)	Validation and test of electronic components and systems to ionizing radiation.	 TID: 10 MGy. → one test takes >1 year. Issue: both space and dose-rate. 	Stronger source.
VESPER	Particles : e ⁻ Energy : 200MeV	Flux: 10 ⁷ -10 ¹² e/cm ² /s TID: 17 kGy/s - 2.8 MGy/s	Characterizing electronic components to SEE, TID and DD, for the operation in a Jovian space-environment.	TID: 10 MGy. Issue : facility not equipped for wafer level testing, and small irradiation table.	Upgrade of testing infrastructure.

[Poster at FCC Week 2017]





