Ultra High Fluence Radiation Monitoring Technology for the Future Circular Collider at CERN

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RADECS 2017
CERN, Geneva

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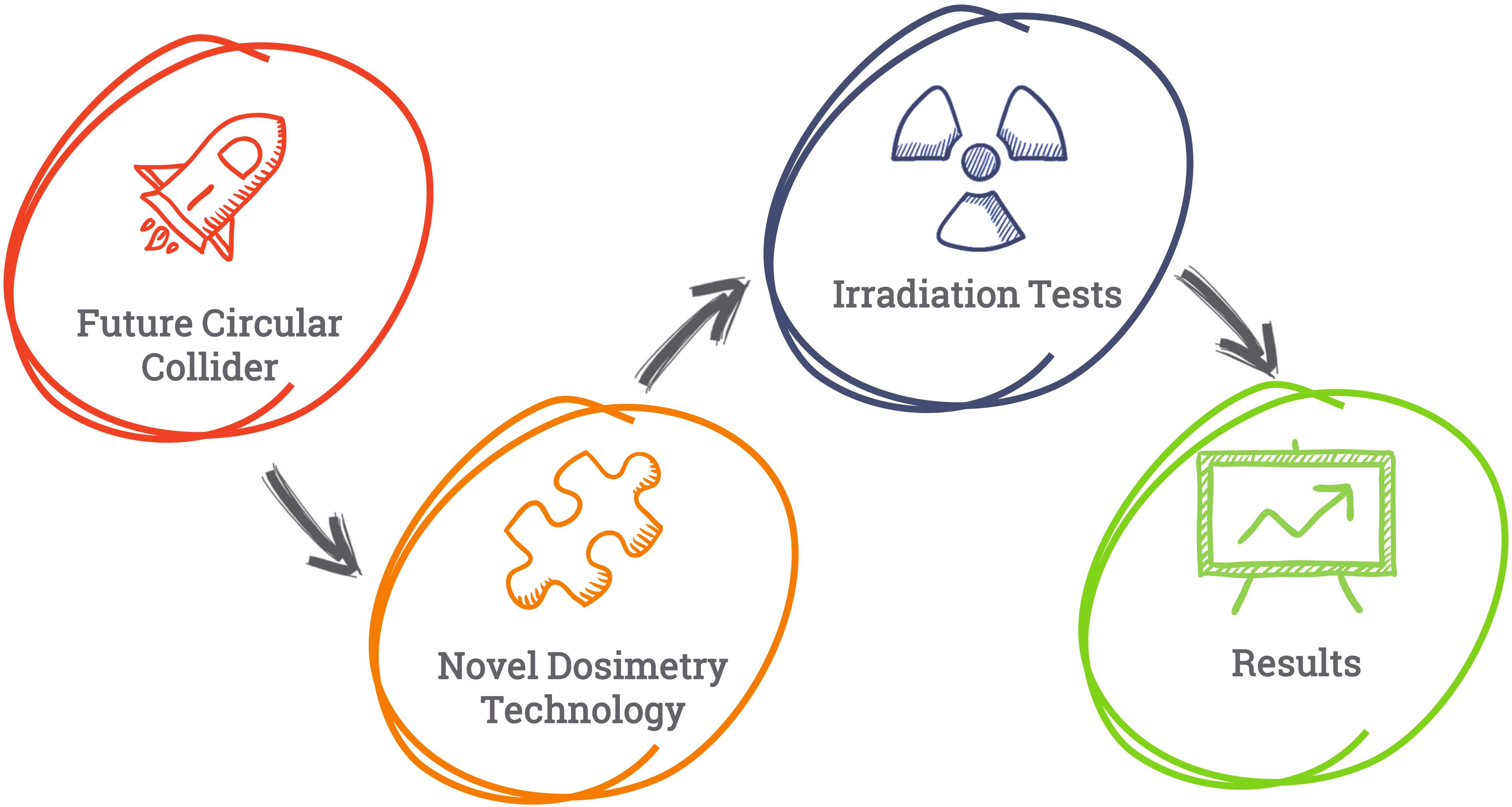
AIDA 2020

Outline


Future Circular Collider
Novel Dosimetry Technology
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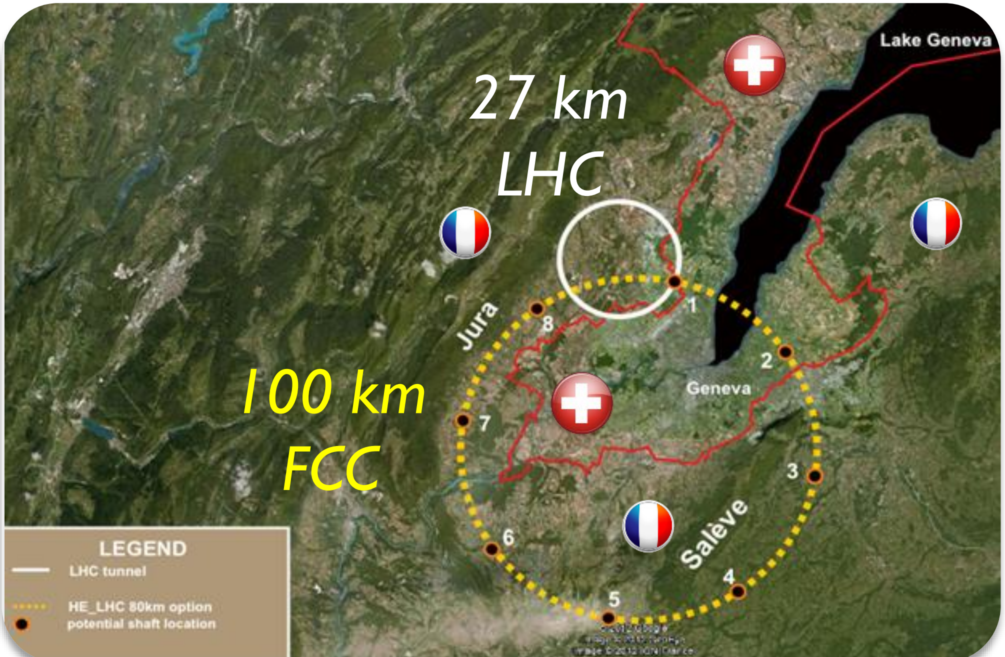
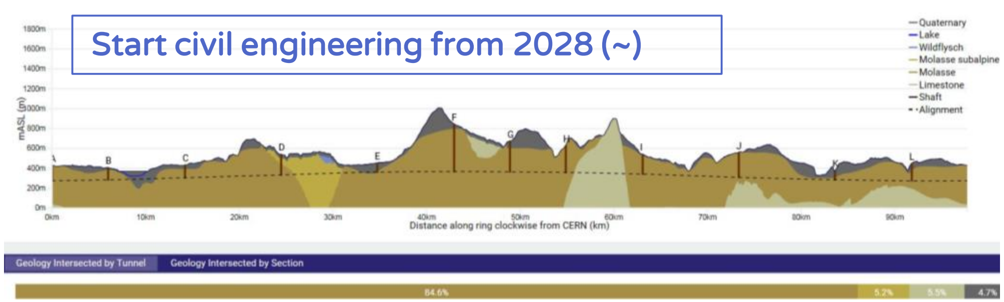
Future Circular Collider at CERN

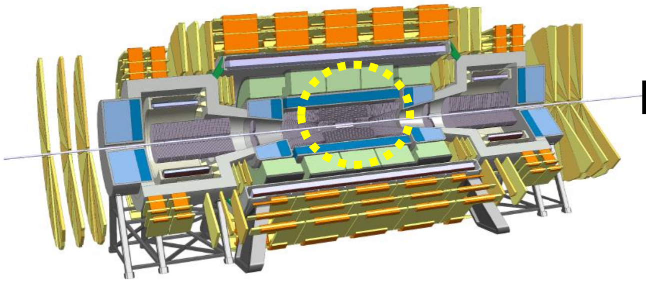


- International FCC collaboration.
- 100 TeV center-of-mass energy.
- Many challenges like:
  - ~100 km tunnel infrastructure
  - ~16 T magnets;
- HE-LHC with FCC-hh technology.
- Conceptual Design Report to the EU for end 2018.

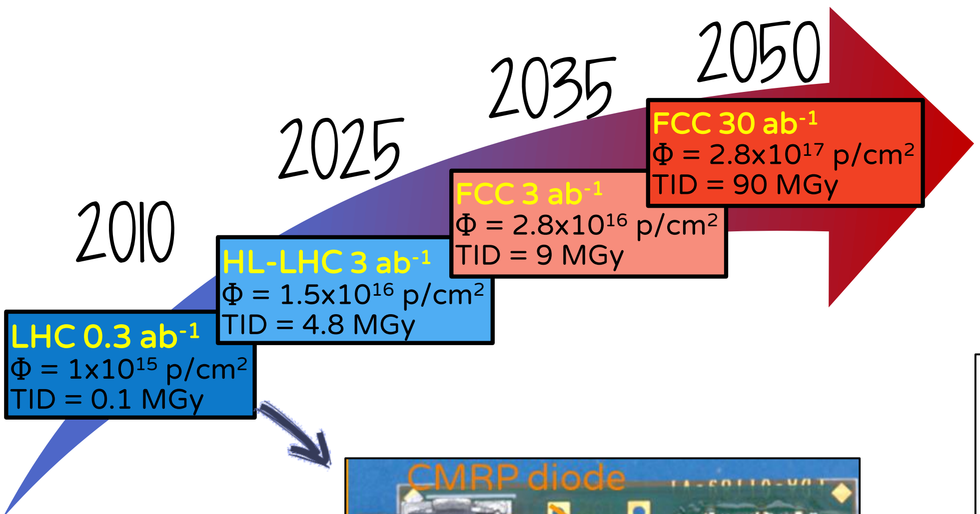


[Annual Review Meeting, Berlin, FCC Week 2017]

FCC Detectors: Radiation Environment

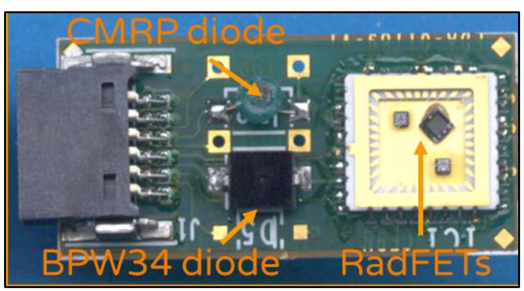


100TeV Collisions ≈

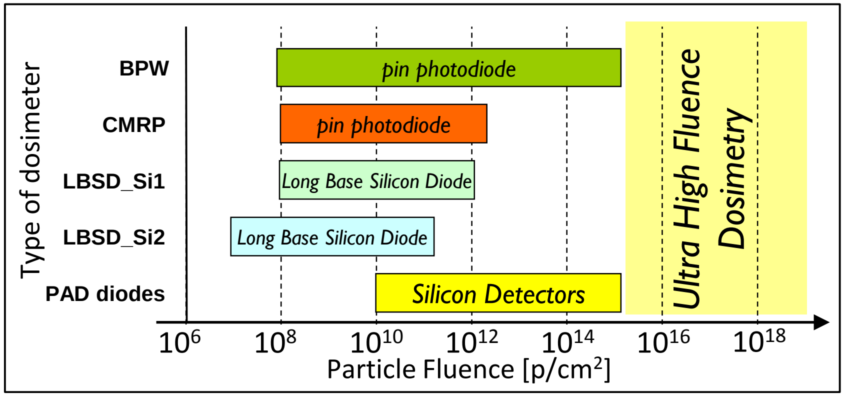


During 10 years of operation, in the **detectors** of FCC (30 ab^{-1}):

- ⚠ Extreme fluence up to **~3×10^{17} p/cm²**
- ⚠ Very high dose of **~100 MGy**
- ✖ **No solutions today** for dosimetry at such high levels!



[F. Ravotti]



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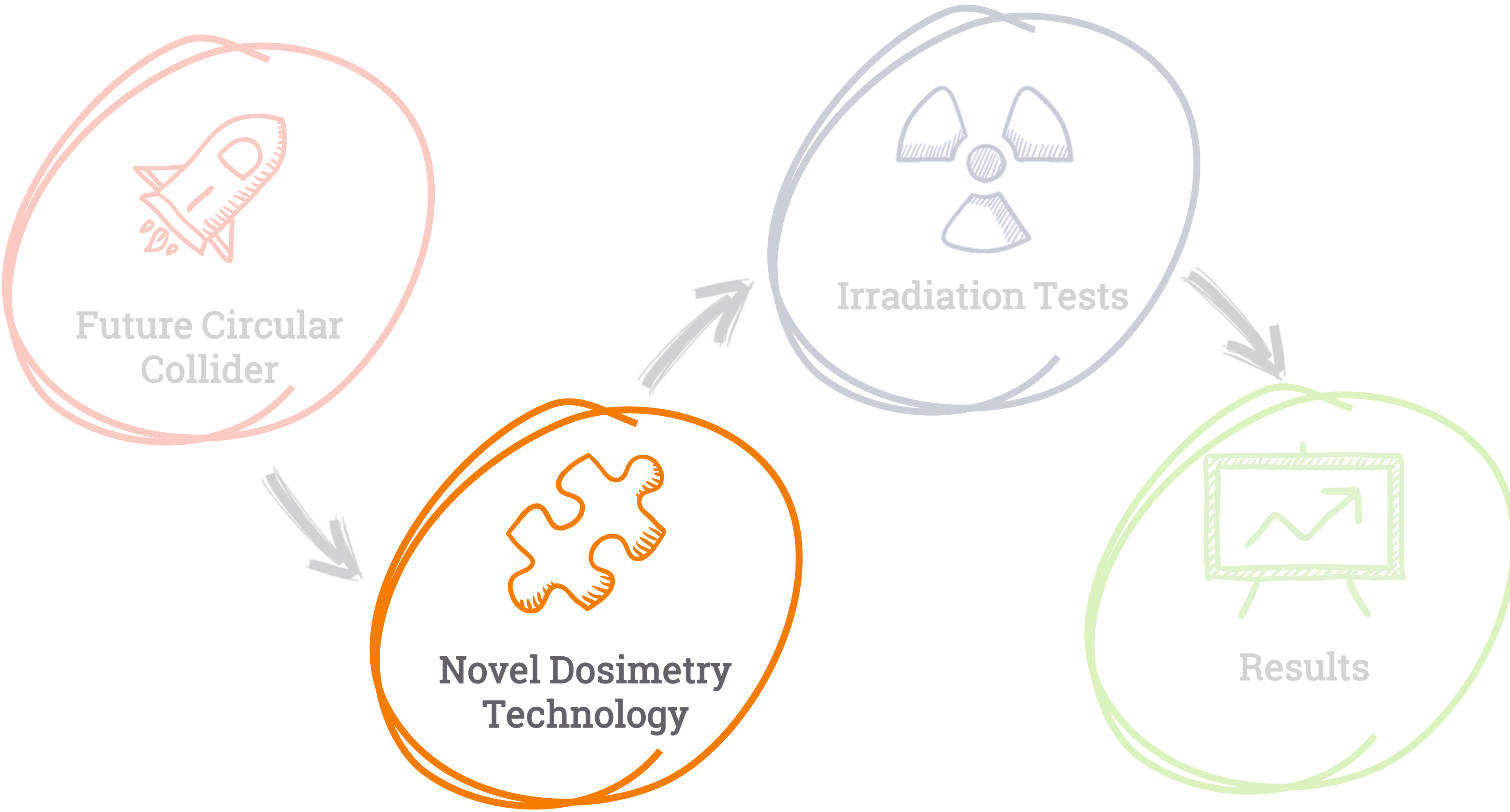

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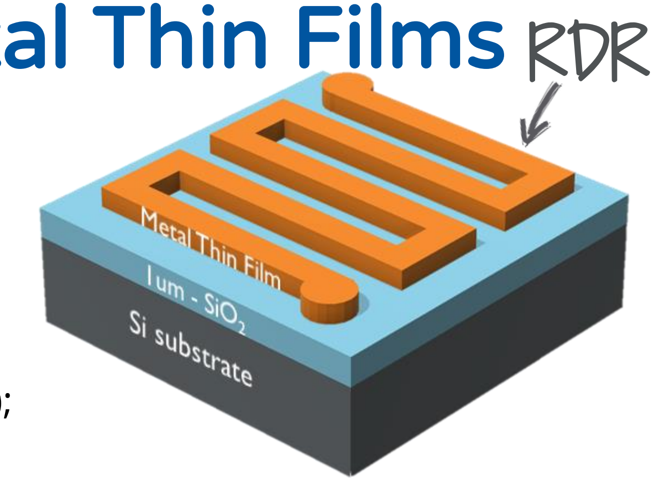
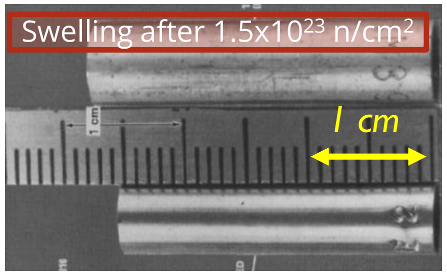
Proposed Technology: Metal Thin Films



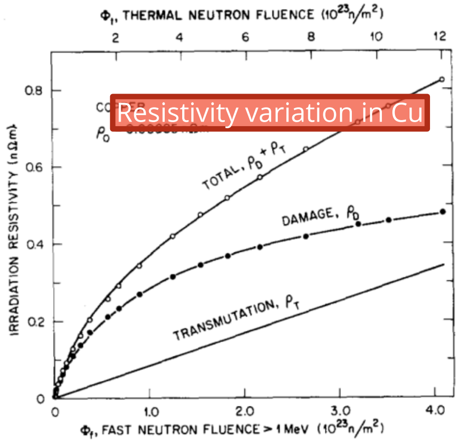
Novel dosimetry solution based on **metal thin film technology**.

- ✓ Metals were chosen because they are:
  - Unaffected by ionizing dose (only temporary internal heat);
  - Insensitive to low particle fluence (where current silicon dosimeters saturate).
- ✓ Documented sensitivity to very high fluence (bulk material damage):
  - *Dimensions*
  - *Mechanical properties*
  - *Chemical properties*
  - *Transmutation products*
  - *Physical properties:* increase of *electrical resistivity*.

✓ ***Proposed Idea: relate displacement damage to the variation of resistivity in metal thin films***



M. Eldrub, "Dose dependence of defect accumulation in neutron irradiated copper and iron"



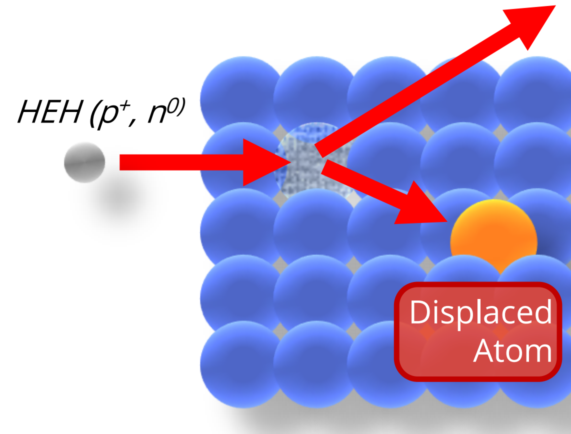
R.Chaplin, "Defects And Transmutations In Reactor-irradiated Copper".

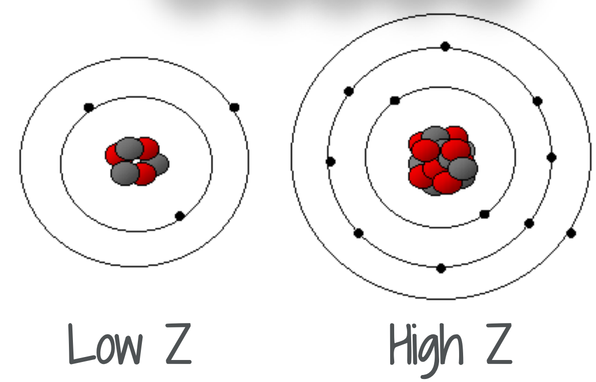
The Radiation Dependent Resistor (RDR)

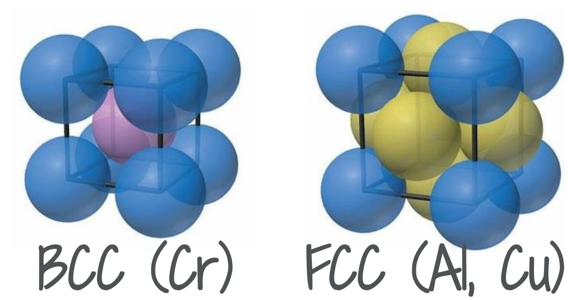
Three metals were selected:
Aluminium, **Chromium**, and **Copper**.

Material	DPA Neutrons [DPA/(n/cm²)]	DPA Protons [DPA/(p/cm²)]	Atomic Number	Lattice Structure
Aluminum	3.21×10^{-20}	0.75×10^{-21}	13	fcc
Chromium	1.91×10^{-20}	2.61×10^{-21}	24	bcc
Copper	1.74×10^{-20}	3.85×10^{-21}	27	fcc

- Monte Carlo simulations (FLUKA) on DPA generation also show different sensitivities.
- They have different **atomic number.**
- They have different **crystal orientation**
  (Face-Centered Cubic (fcc) open lattice vs Body-Centered Cubic (bcc)).
- But also because of **fabrication requirements:**
  (self-passivating, good adhesion with SiO_2, bondability, availability as targets for the sputtering machine, and relatively low level of induced radioactivity).

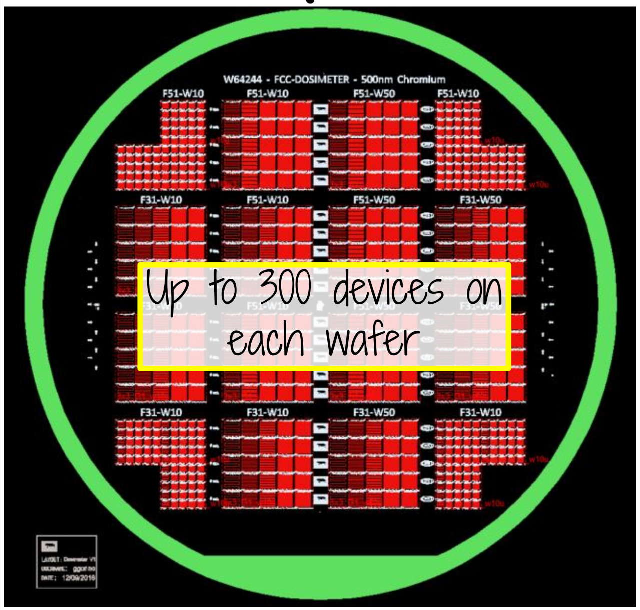


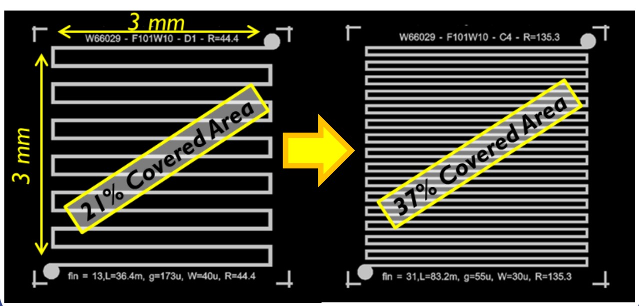




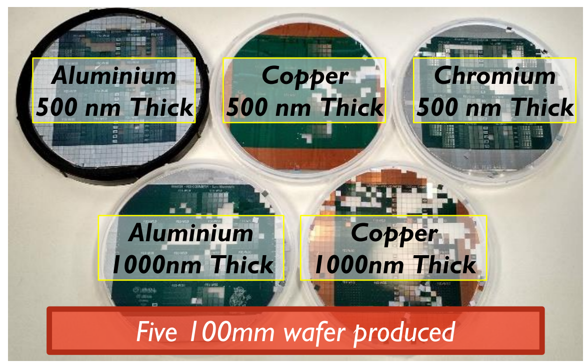
The Radiation Dependent Resistor (RDR)

Layout

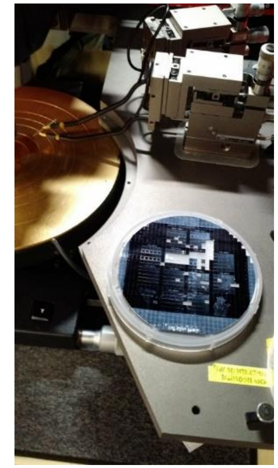


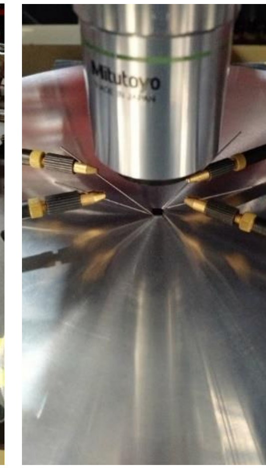


Microfabrication



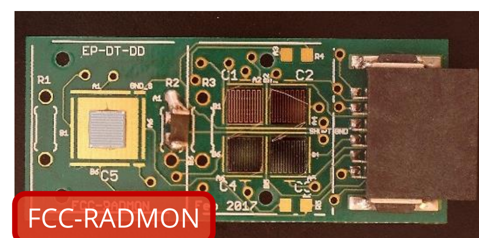
Characterization



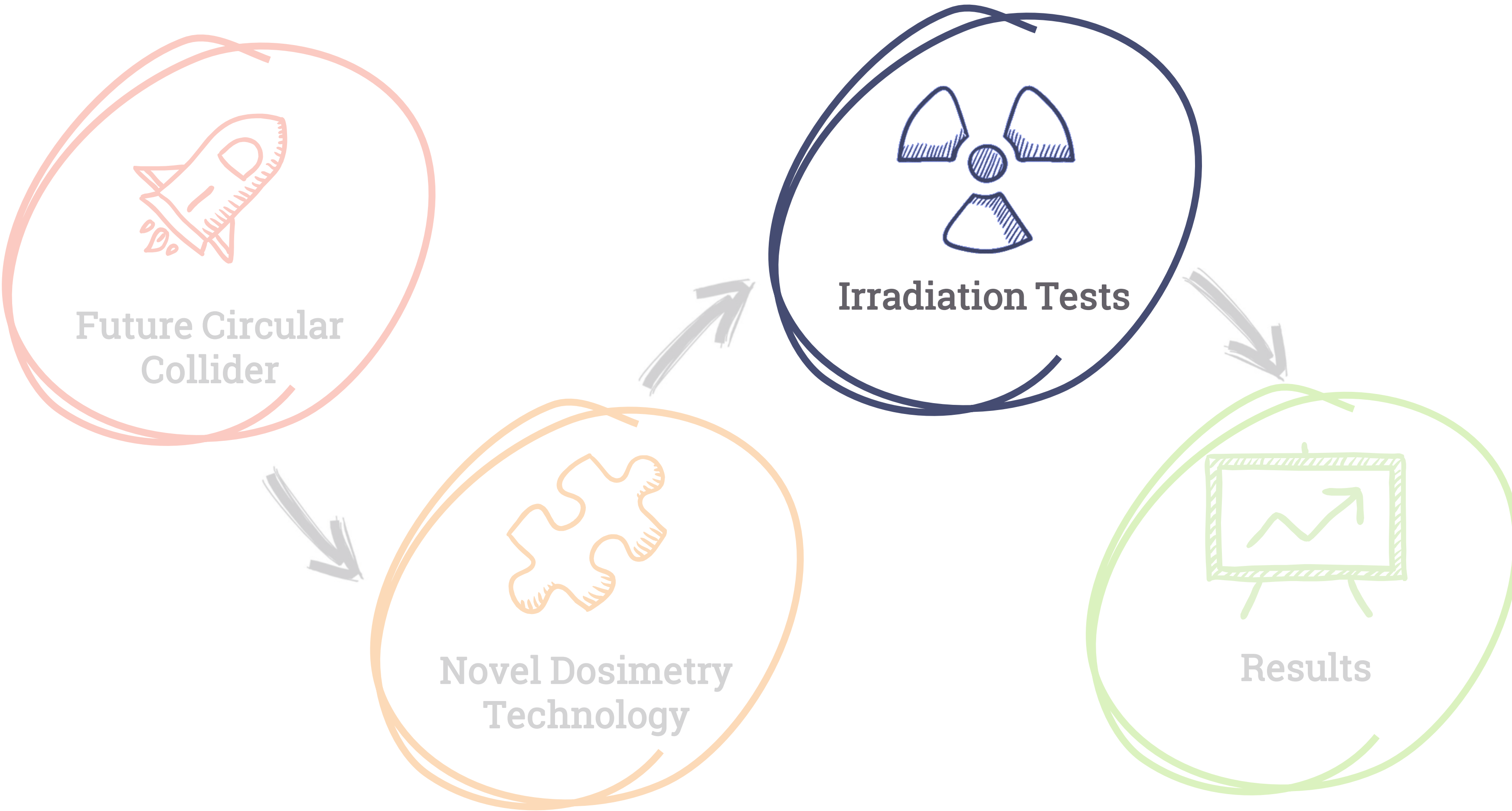


Property	Min	Max
# of Fingers	7	51
Finger Width	2 um	50 um
R range	few Ω	some kΩ

Geometrical and electrical properties



Outline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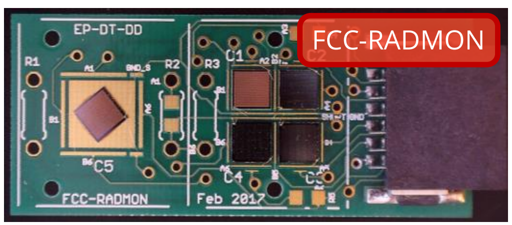
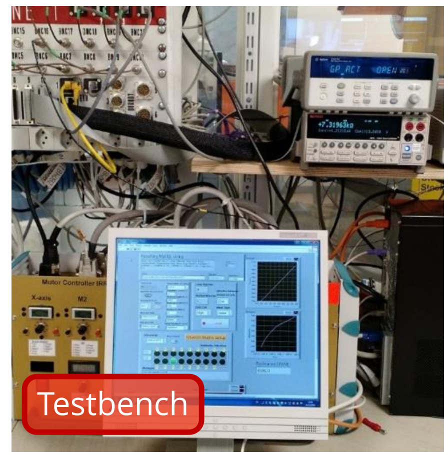
Irradiation Tests Details

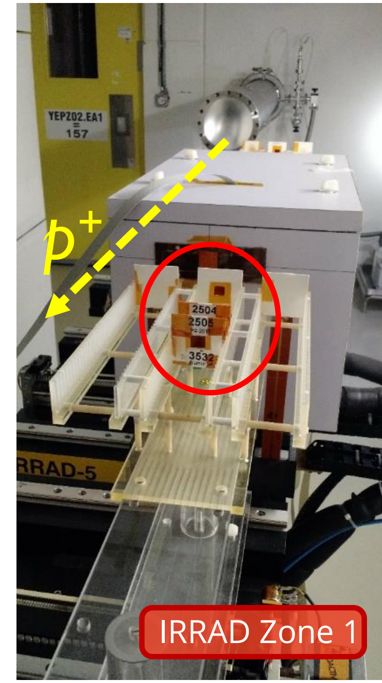
Neutron Irradiation



- Jožef Stefan Institute (JSI) in Ljubljana.
- Triga Mark II Research Nuclear Reactor.
- Central channel flux: $7.2\text{x}10^{12}$ n/cm^2/s.
- Cumulated ~$1\text{x}10^{18}$ n/cm^2 during 5 days of irradiation (40h).

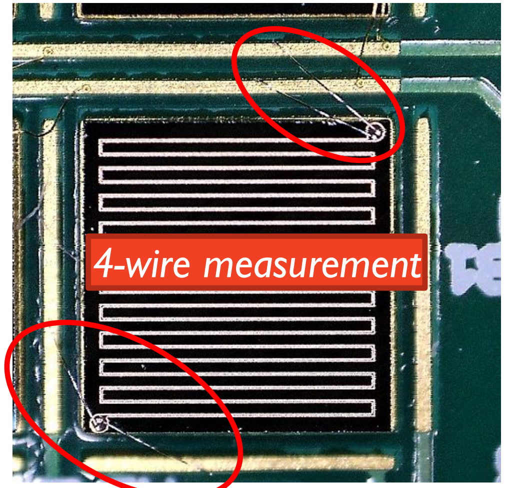
Proton Irradiation





- PS-IRRAD at CERN, Geneva.
- 23 GeV Proton beam from PS.
- About $6\text{x}10^{11}$ p^+/spill every 10 s.
- Cumulated ~$5.2\text{x}10^{16}$ p/cm^2 during 3 months irradiation.

Measurement Test-Bench

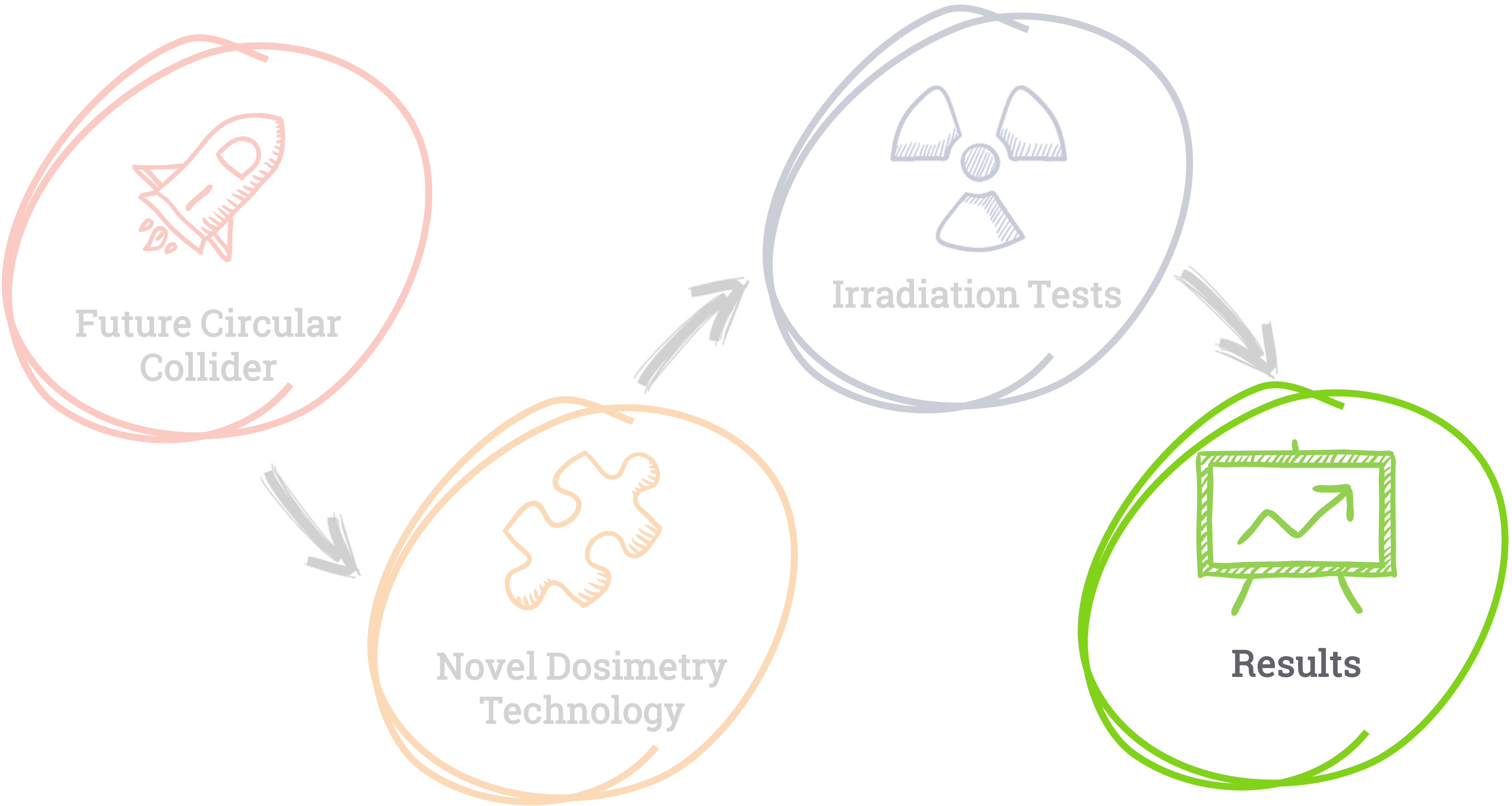


- Measurement setup based on **LabVIEW** + Keithley 2410 **SMU** + Agilent 34970A **Switch Matrix**.
- One sample every minute.
- Constant current readout with 50 uA.
- 4-wire Kelvin measurement (~15 m of cable).
- Interested in *Change in Resistance*:

Change in resistance [%]:

$$\% \, \Delta \boldsymbol{R} = \frac{\boldsymbol{R_t - R_0}}{\boldsymbol{R_0}} \times \mathbf{100}$$

Outline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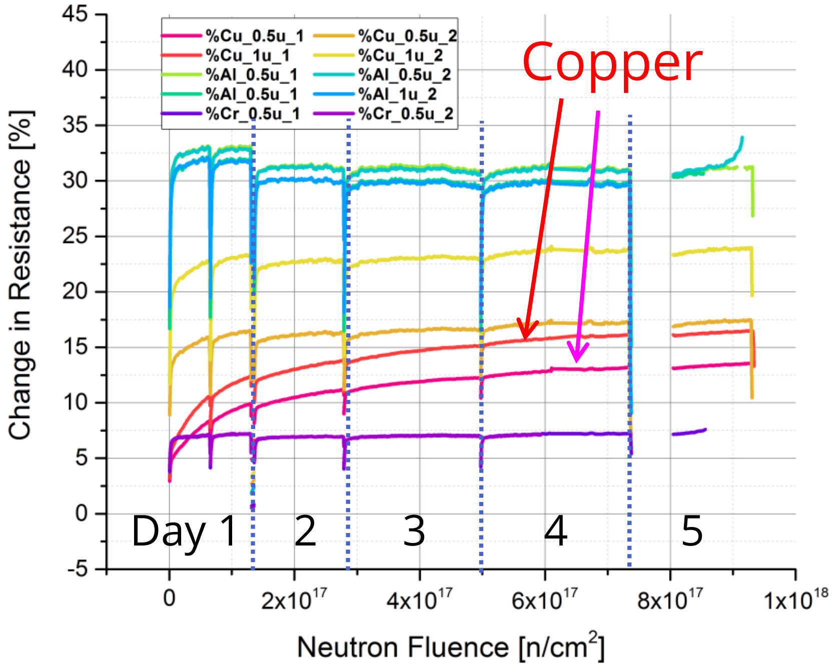
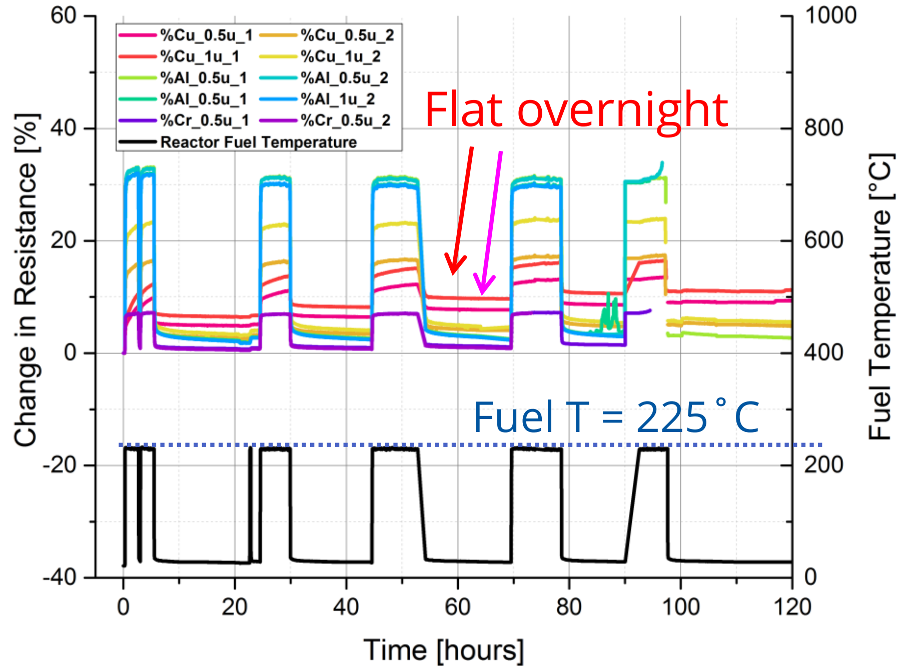
Neutron Irradiation - Results

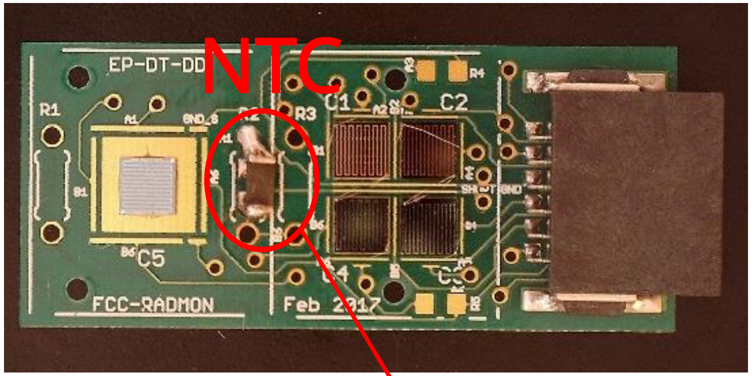
- All dosimeters have shown an increase.
  - RDR response is **temperature dominated**!
  - Temperature variation in the irradiation channel from 25˚C to >65˚C.
- Copper (pink and red) dosimeters rising during all the irradiation, and **no overnight annealing**.

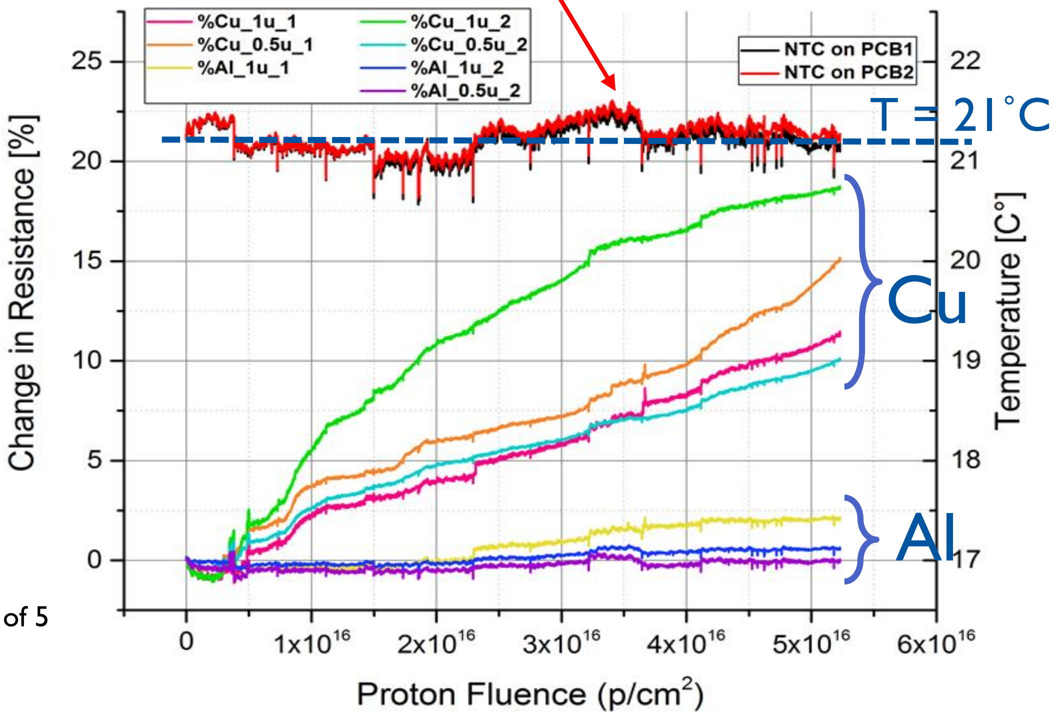




Proton Irradiation - Results

- All dosimeters have **shown an increase**.
- **Copper** dosimeters experienced higher resistance increase.
- **No temperature/annealing effects** *(constant T[°C] in the irradiation bunker)*
- Al samples 5x less sensitive then Cu as predicted in the DPA simulations.





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Copper	1.74×10^{-20}	3.85×10^{-21}

Ratio of 5

Conclusions

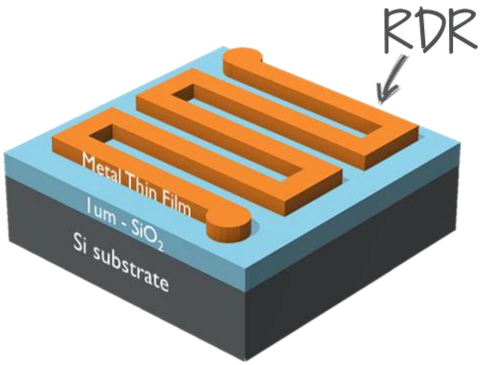
- Concept of dosimetry for very high particle fluence with Radiation Dependent Resistors was proven.

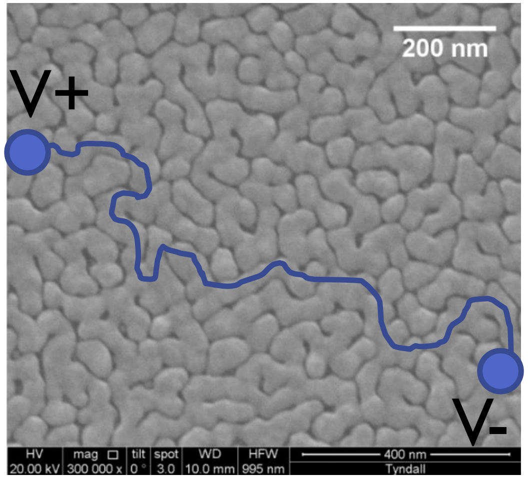
- Cu samples have shown the best sensitivity, while Al and Cr samples exhibited a much lower response.

- RDR sensitivity variation with geometry:
  - no influence due to thickness (500 nm vs. 1000 nm);
  - impact on sensitivity attributed to different geometry:
    - 51 vs 31 fingers (length) and 10 um vs 30 um width.

Future Work

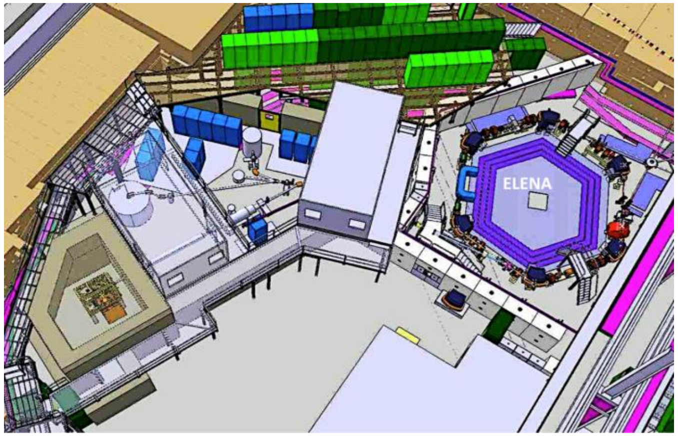
- Focus research on Copper RDR:
  - **Microfabrication:**
    - **Thinner Copper layers**. For now we tested 1000 nm and 500nm. Need to produce and test also 50nm and 5nm.
    - Try **different metal deposition techniques** and different **layout**.
    - **Monolayers of Copper** with ALD (Atomic Layer Deposition).
  - **Irradiation Tests:**
    - Continue irradiation in **IRRAD**.
    - Test with **Ionizing Radiation**.
    - New **Neutron Irradiation** only of Copper samples.
  - **Modeling:**
    - Understand and predict resistivity variation due to ***radiation enhanced electro-migration.***



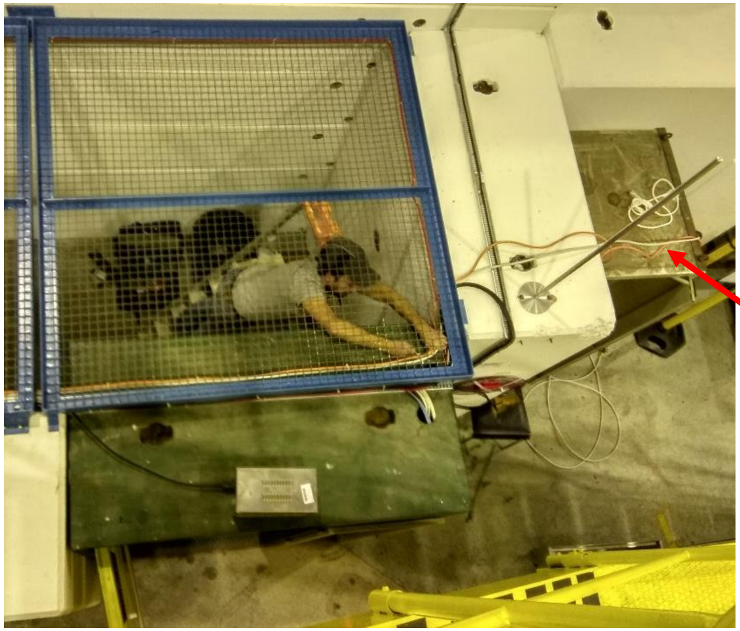


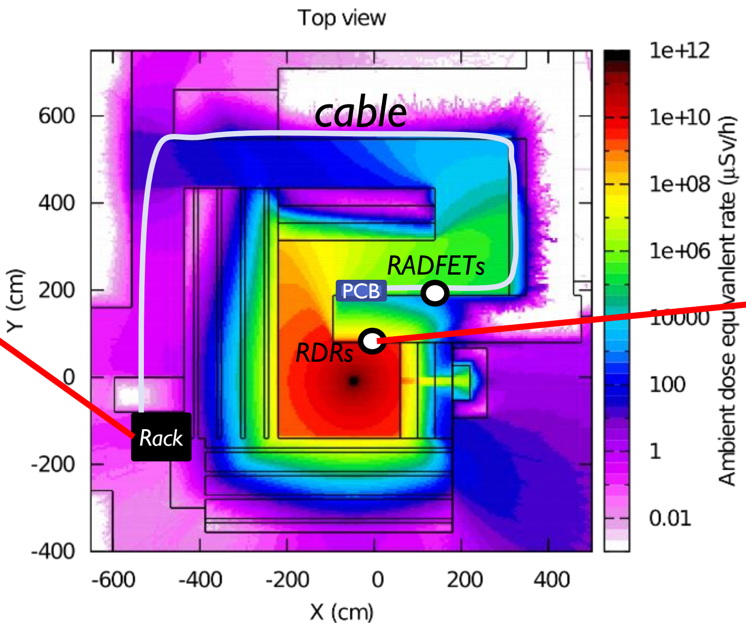
Ongoing work

- Ionizing Radiation irradiation in GBAR experiment
  - 3 RADMONs in parallel.
  - Hottest place has ~1MGy/hour!

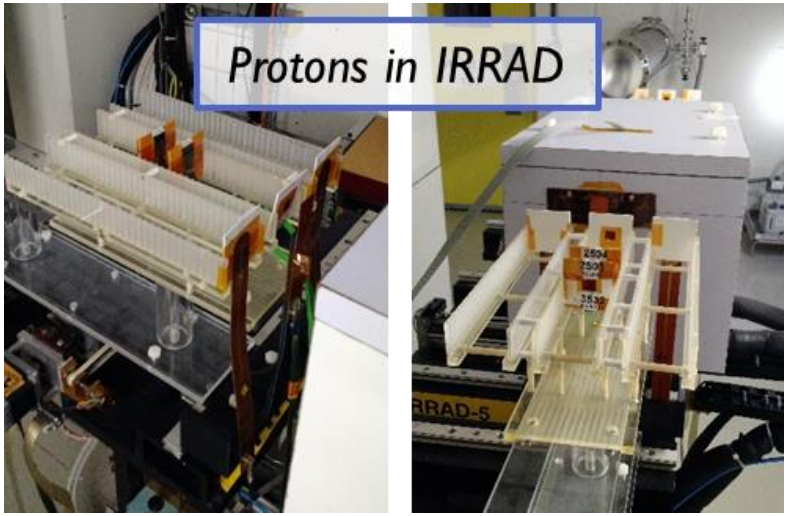


Gravitational Behaviour of Antihydrogen at Rest

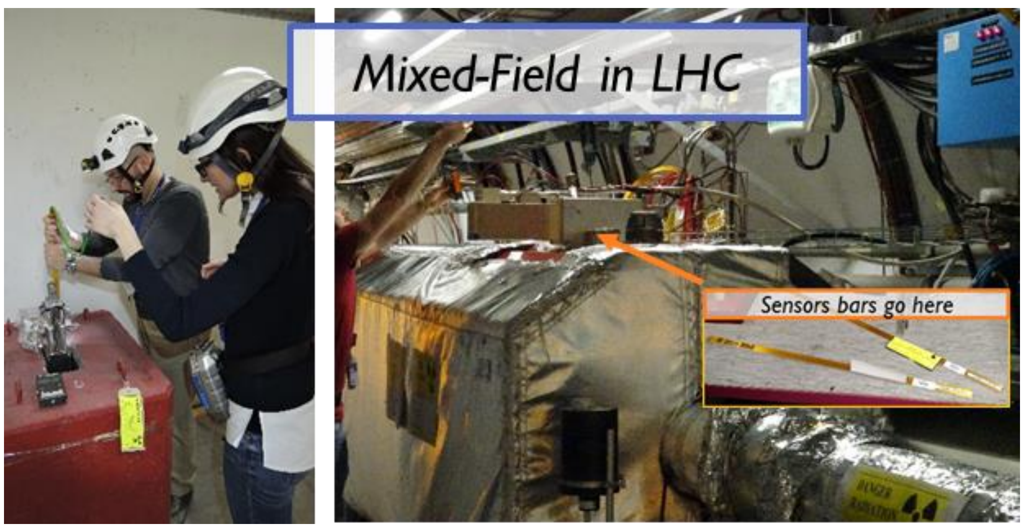




Ongoing work



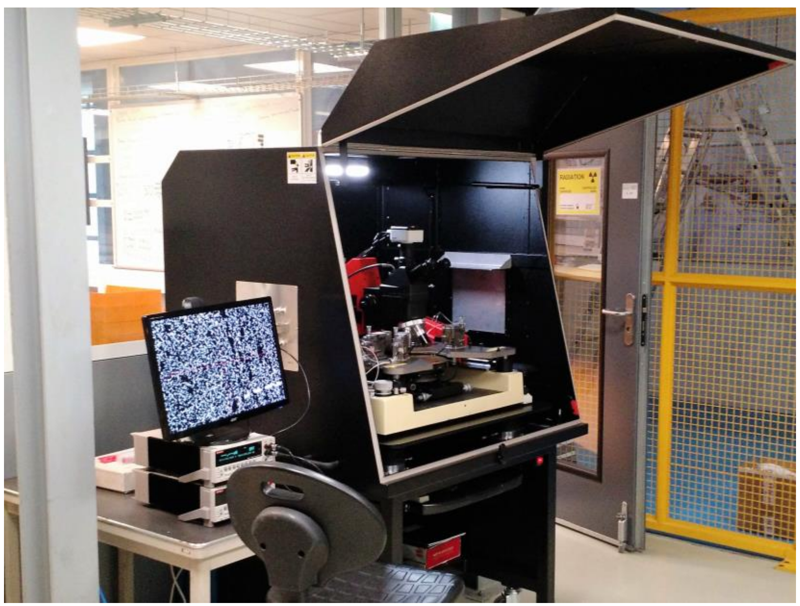
- Irradiation ends next Sunday reaching ~$1.2x10^{17}$ p/cm^2.
- Data analysis will follow.

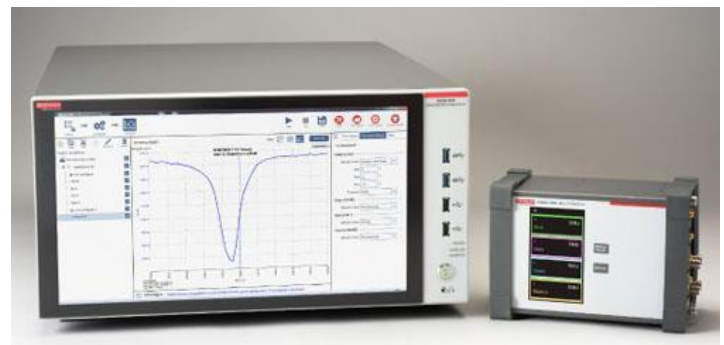


- Irradiation in LHC-TAN in point 1.
- Mixed field, using also standard dosimeters to characterize the radiation field.

One last thing…

- New state-of-the-art electrical characterization tools:
  - Suss PM8 Probe Station in IRRAD since June 2017
  - Keithley 4200A Semiconductor Parameter Analyzer from December 20th.
- Tool available to all of us. Write to IRRAD team to request measurement time.





Thanks for your attention!