STATUS OF RADIATION ENVIRONMENT ASSESSMENT IN THE FCC-hh AND FCC-ee MACHINES

Francesco Cerutti on behalf of the EN-STI-BMI FLUKA team

and Ruben Garcia Alia, Salvatore Danzeca, Federico Faccio, Federico Ravotti

for the Radiation Hardness Assurance task

FCC week 2019, Brussels

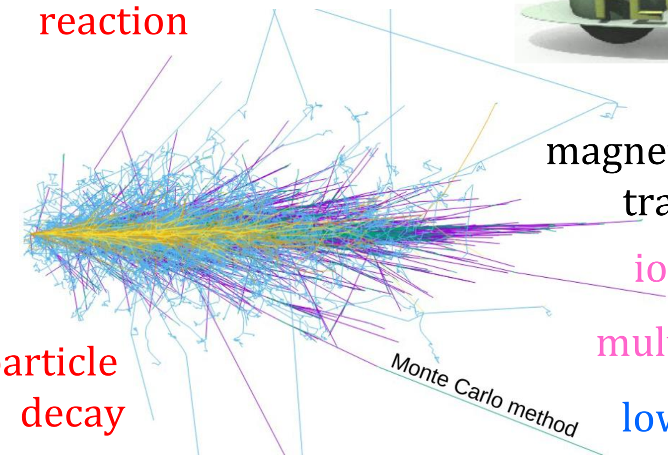
June 27th

OUTLINE

- Simulation tools
- Radiation level calculations:
    - FCC-hh arc — refreshed (J. Hunt talk, Thu morning 11.14 AM)
    - FCC-hh EIR (detector and machine)
    - FCC-hh betatron cleaning insertion — available (A. Infantino talk, FCC week 2018)
    - FCC-ee arc — to be updated
    - HE-LHC betatron cleaning insertion
    - FCC-hh extraction region — to be calculated
    - *HE-LHC arc*
    - *HE-LHC EIR* — *to be modelled*
- RHA work

MONTE CARLO SIMULATION OF BEAM-MACHINE INTERACTION

hadron-nucleus reaction



magnetic field tracking

ionization

multiple scattering

low energy neutron transport

particle decay

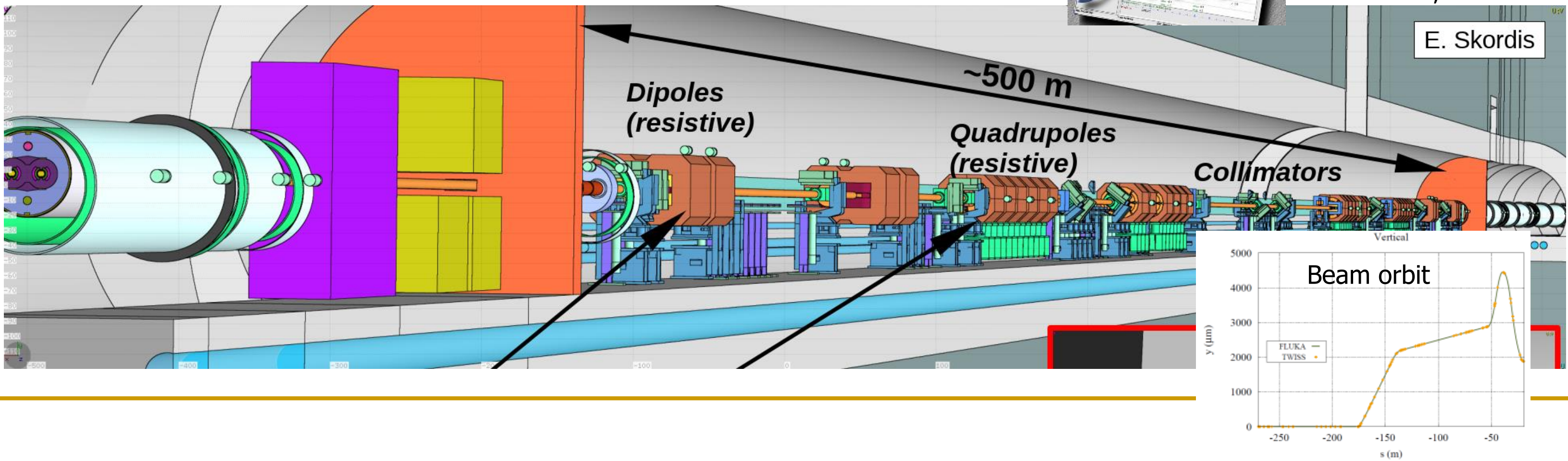
electromagnetic shower

FLUKA

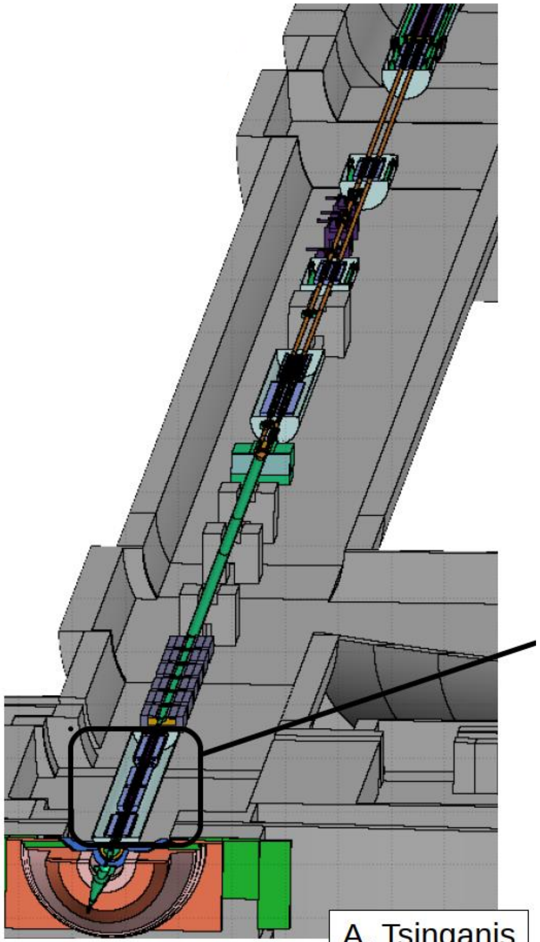
validation up to LHC Center-of-Mass energy (of the DPMJET event generator)

need for continuous development and benchmarking (model transition from 7 TeV to 50 TeV LAB energy)

Line Builder
[A. Mereghetti et al., IPAC2012, WEPPD071, 2687]

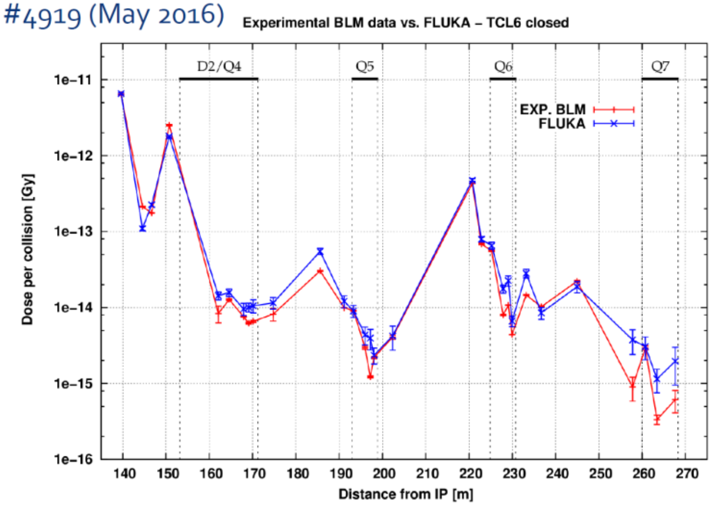


SIMULATION RELIABILITY

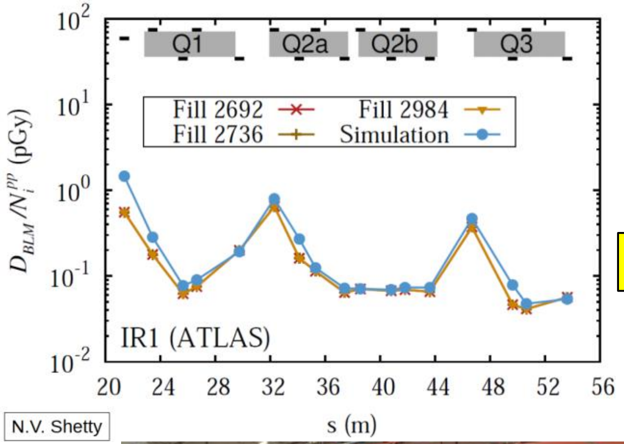


A. Tsinganis

- Fill #4919 (May 2016)



6.5 TeV beams



N.V. Shetty

4 TeV beams

RADIATION SOURCES

- *beam intercepting devices (targets, collimators, dumps, stoppers, stripping foils, …)*
  - *regular* ➡ loss quantification and distribution
  - *accidental: smearing failures, injection mis-steering, asynchronous beam dump, top-off*

- *diffused losses*
  - *synchrotron radiation, beam-gas interaction, gas bremsstrahlung*

    ➡ gas density profile

- *debris from regular collisions at the interaction points* ➡ luminosity scaling

- *unexpected obstacles (UFO, ULO, …)*

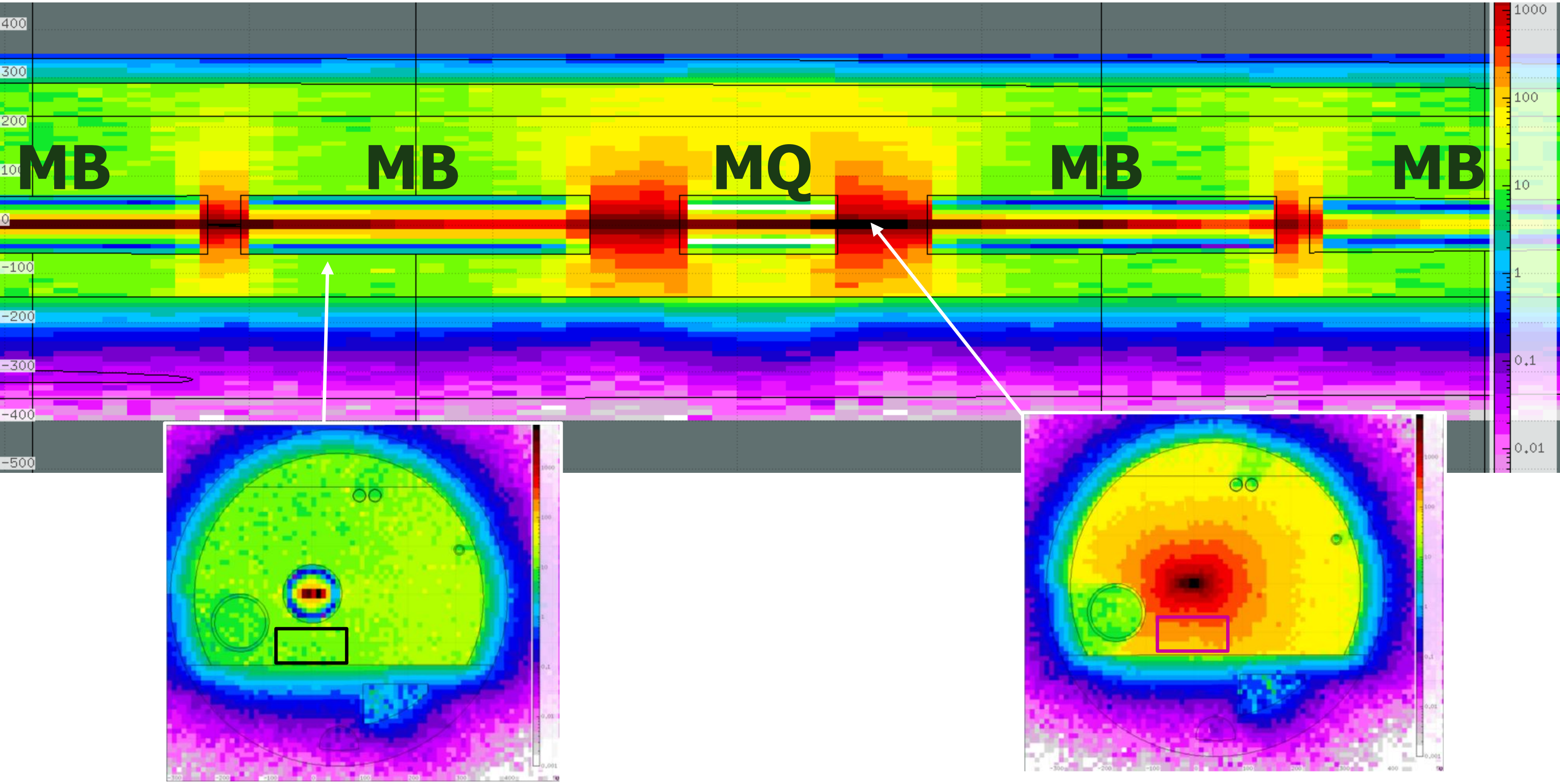
FCC-hh ARC [I]

J. Hunt

beam-gas interaction

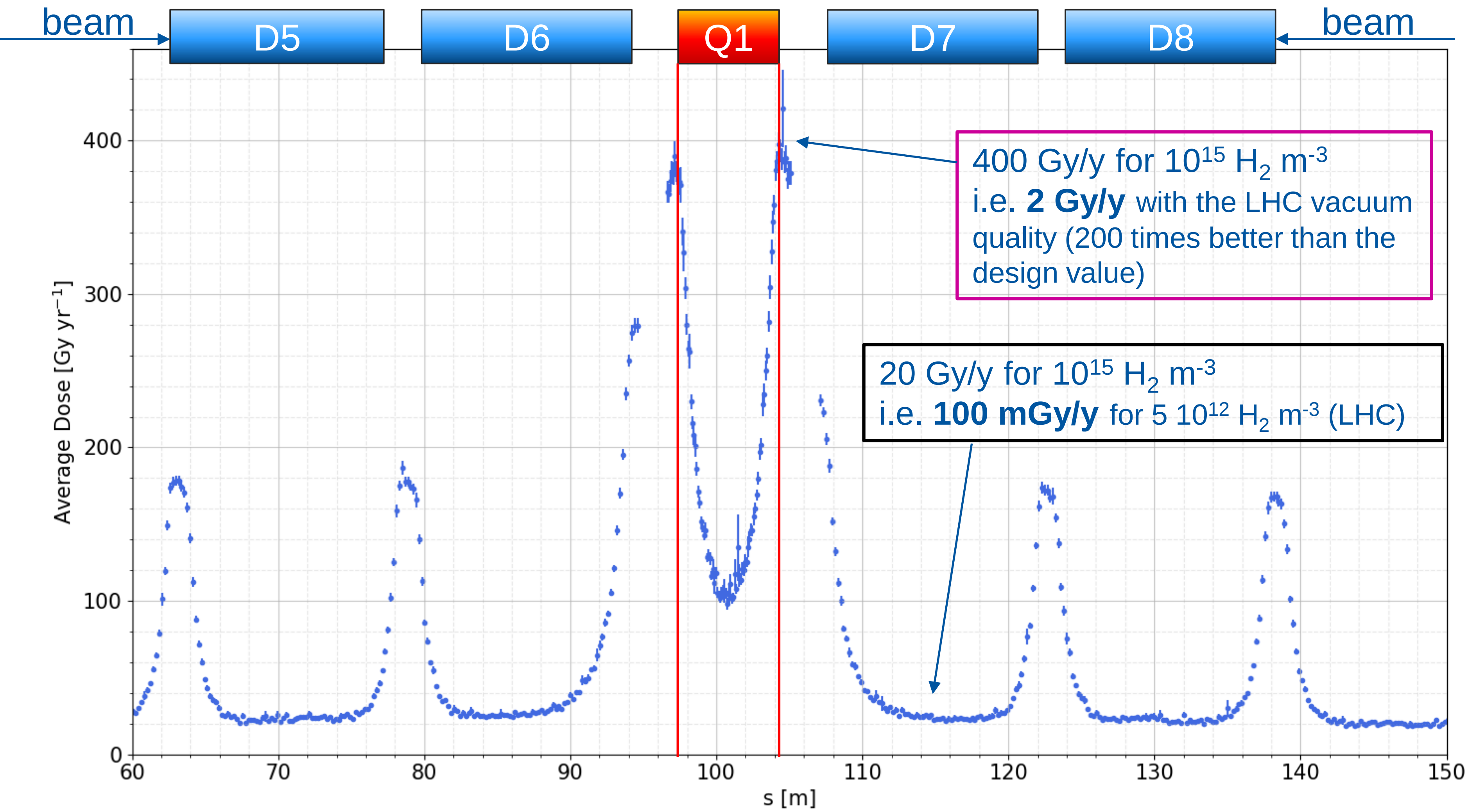
both beams

annual (10^7 s) dose [Gy/ y]
for 10^{15} H_2 m^{-3}



FCC-hh ARC [II]

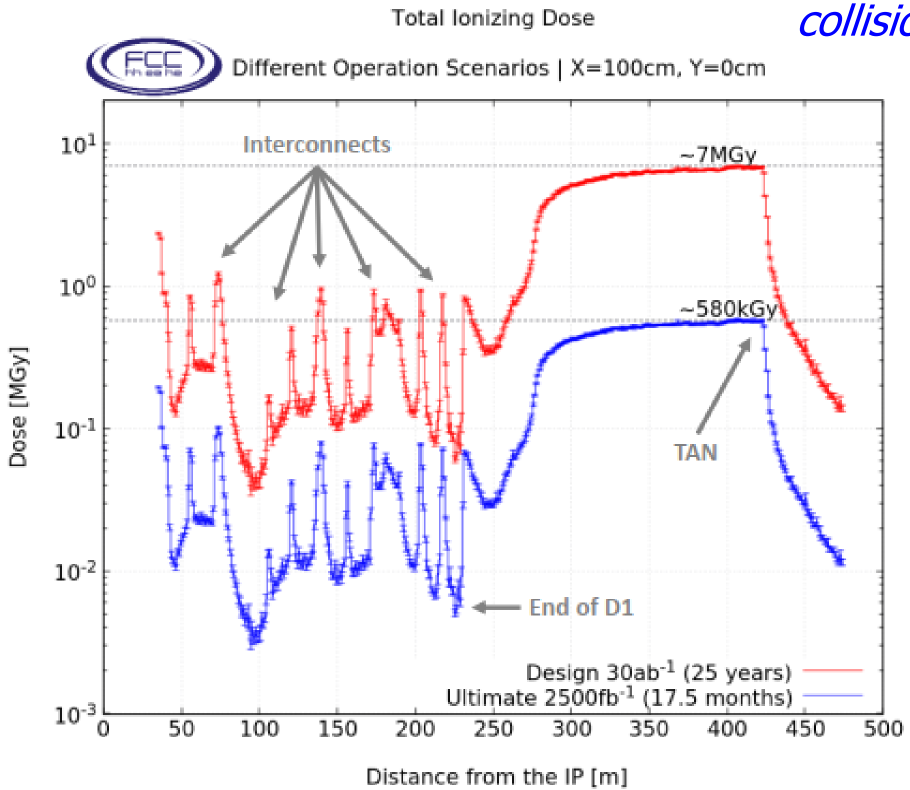
J. Hunt

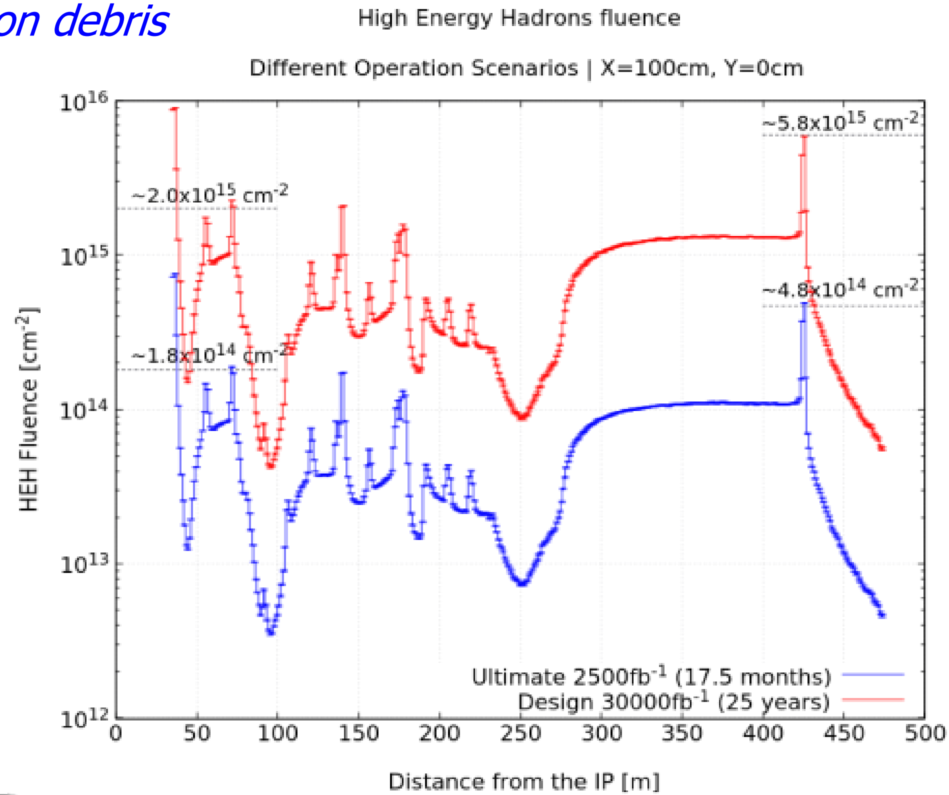


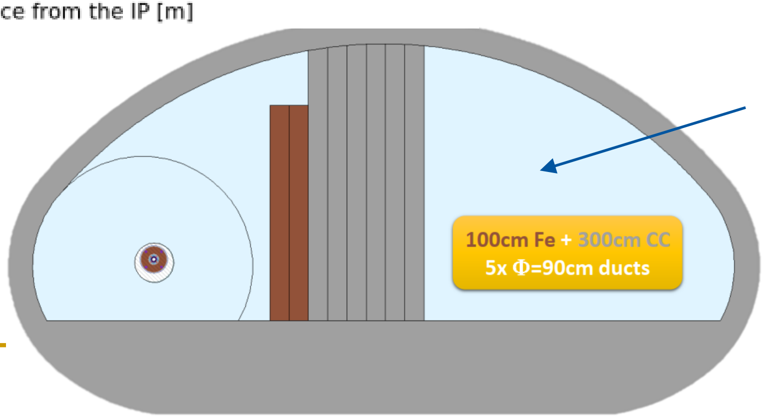
FCC-hh EIR

collision debris

A. Infantino



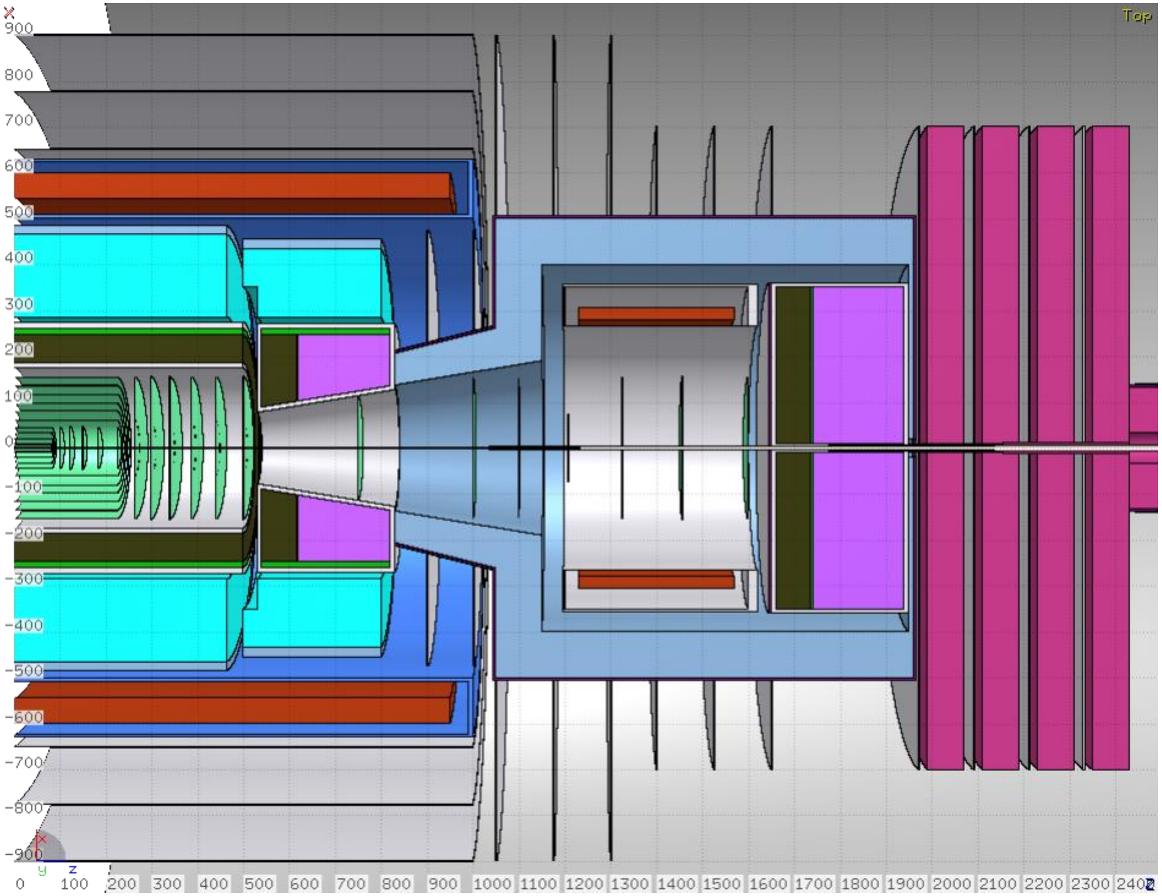




$10^8 – 10^9$ HEH cm^{-2} per 2.5 ab^{-1} as the annual (250 fb^{-1}) level in the HL-LHC UJ

FCC-hh DETECTOR [I]

M.I. Besana



FCC-hh DETECTOR [II]

M.I. Besana

collision debris

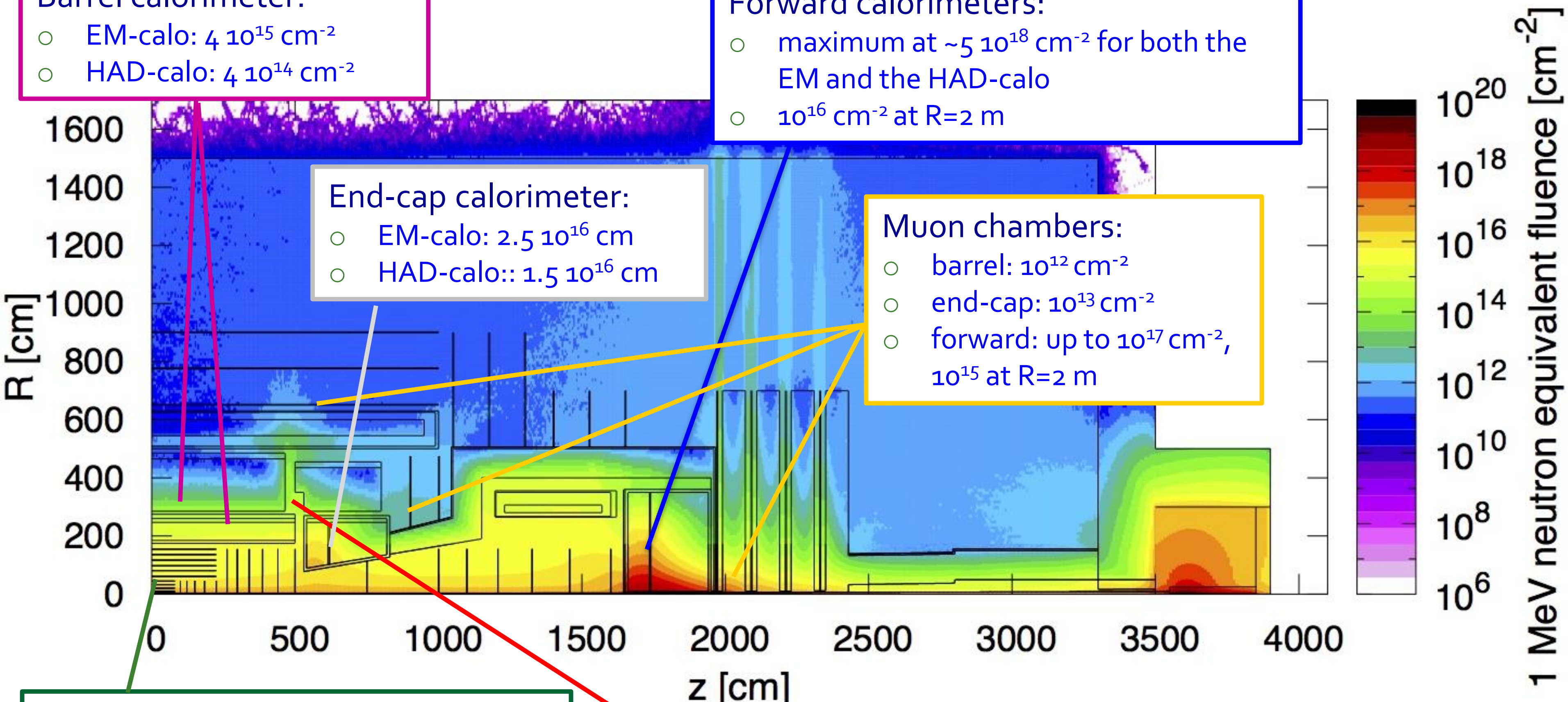
after 30 ab^{-1}

Barrel calorimeter:
- EM-calo: $4\ 10^{15}\ cm^{-2}$
- HAD-calo: $4\ 10^{14}\ cm^{-2}$

Forward calorimeters:
- maximum at $\sim 5\ 10^{18}\ cm^{-2}$ for both the EM and the HAD-calo
- $10^{16}\ cm^{-2}$ at R=2 m

End-cap calorimeter:
- EM-calo: $2.5\ 10^{16}$ cm
- HAD-calo:: $1.5\ 10^{16}$ cm

Muon chambers:
- barrel: $10^{12}\ cm^{-2}$
- end-cap: $10^{13}\ cm^{-2}$
- forward: up to $10^{17}\ cm^{-2}$, 10^{15} at R=2 m



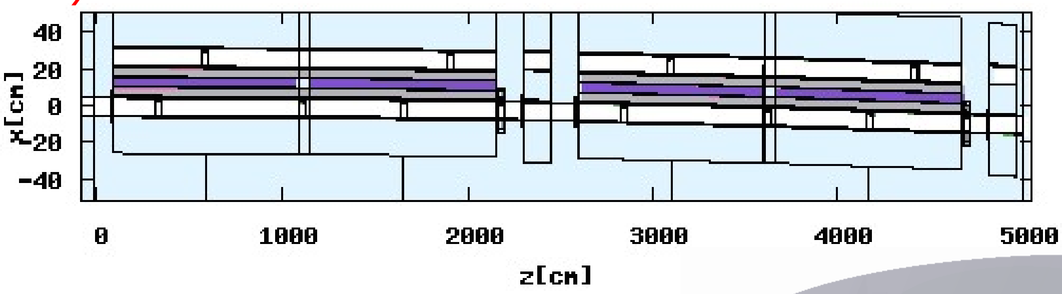
Central tracker:
- first IB layer (2.5 cm): $\sim 6\ 10^{17}\ cm^{-2}$
- external part: $\sim 5\ 10^{15}\ cm^{-2}$

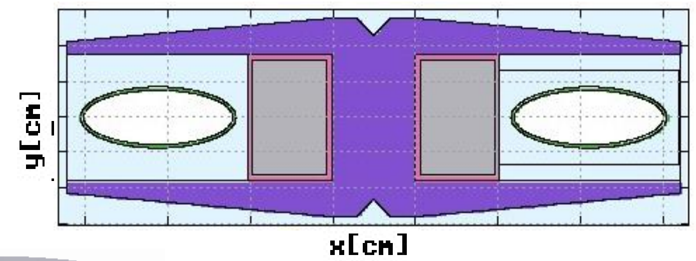
Calorimeter gap: from $10^{16}\ cm^{-2}$ to $10^{14}\ cm^{-2}$

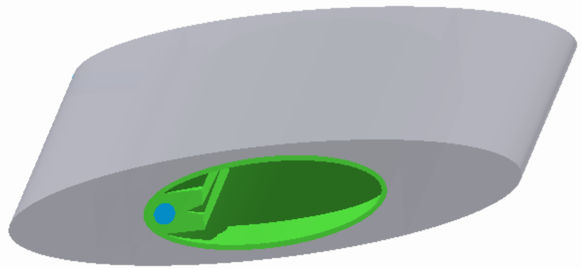
FCC-ee ARC

M.I. Besana ***(2016)***

synchrotron radiation from 175 GeV electrons





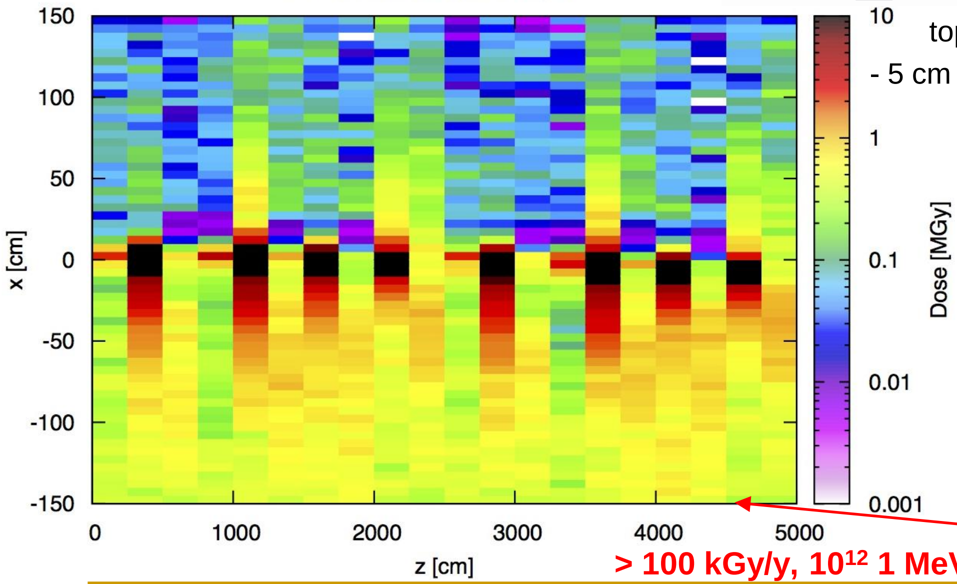


top view

- 5 cm < y < 5 cm

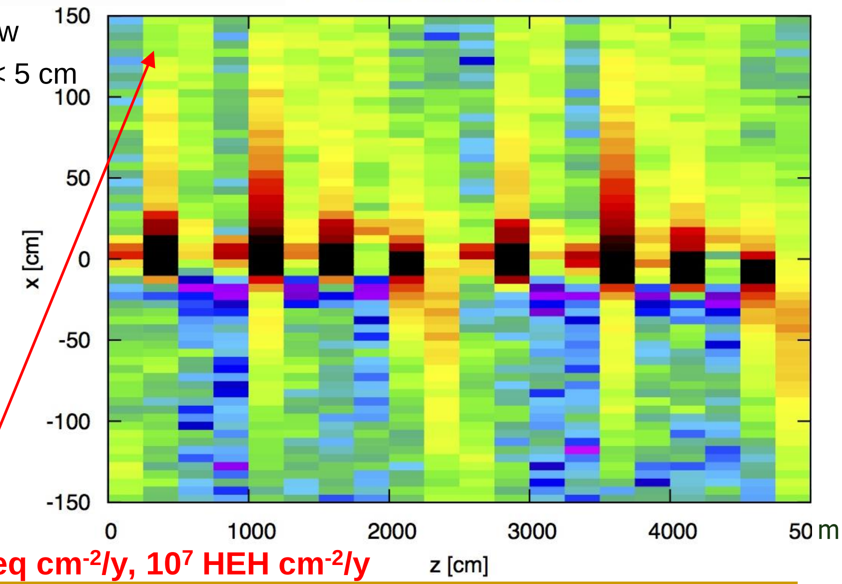
internal beam

Dose in the tunnel, 6.6 mA, 10^7 s



external beam

Dose in the tunnel, 6.6 mA, 10^7 s

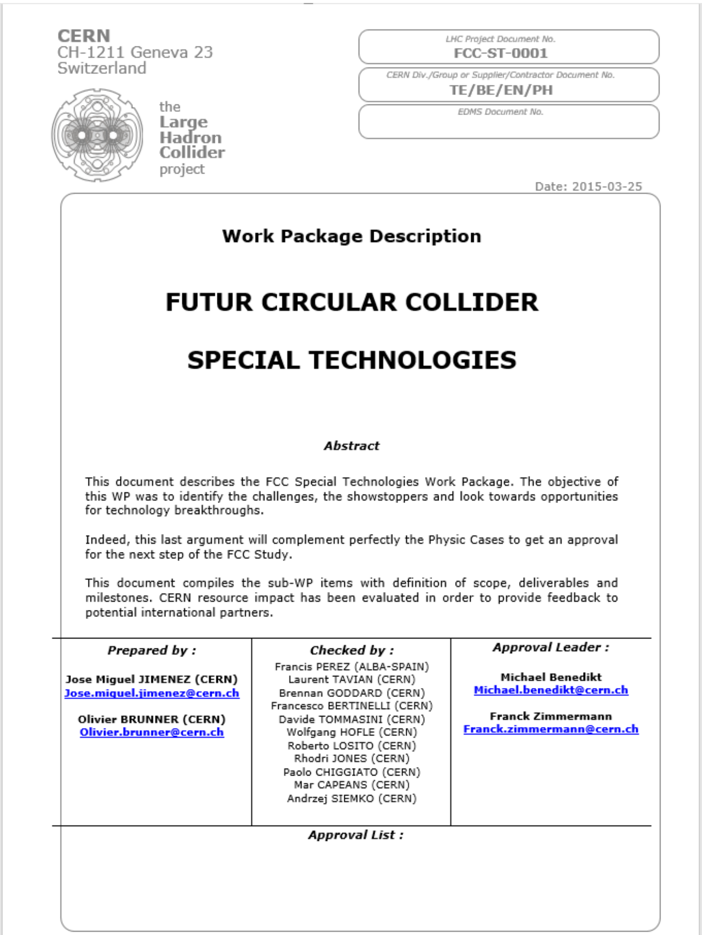


> 100 kGy/y, 10^{12} 1 MeV n eq cm^{-2}/y, 10^7 HEH cm^{-2}/y

ST WP: RADIATION HARDNESS ASSURANCE OF ELECTRONICS TASK

The **unprecedented radiation field expected** questions the possibility to **reliability operate** FCC and its experiments. An exploratory study on this crucial issue has been carried out, within the RHA task, on the following themes:

- **development of Rad-hard electronics**
  - study of radiation tolerance of new CMOS technologies for the design of Application-Specific Integrated Circuits (ASICs)
- **qualification of Rad-tol components**
  - no resources allocated
- **needs for adequate irradiation facilities**
  - identification and investigation of limitations for CERN facilities
- **development of suitable radiation monitoring systems** (for the components qualification and FCC operation)
  - focus on ultra-high level dosimetry



CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.
FCC-ST-0001

CERN Div./Group or Supplier/Contractor Document No.
TE/BE/EN/PH

EDMS Document No.

Date: 2015-03-25

Work Package Description

FUTUR CIRCULAR COLLIDER

SPECIAL TECHNOLOGIES

Abstract

This document describes the FCC Special Technologies Work Package. The objective of this WP was to identify the challenges, the showstoppers and look towards opportunities for technology breakthroughs.

Indeed, this last argument will complement perfectly the Physic Cases to get an approval for the next step of the FCC Study.

This document compiles the sub-WP items with definition of scope, deliverables and milestones. CERN resource impact has been evaluated in order to provide feedback to potential international partners.

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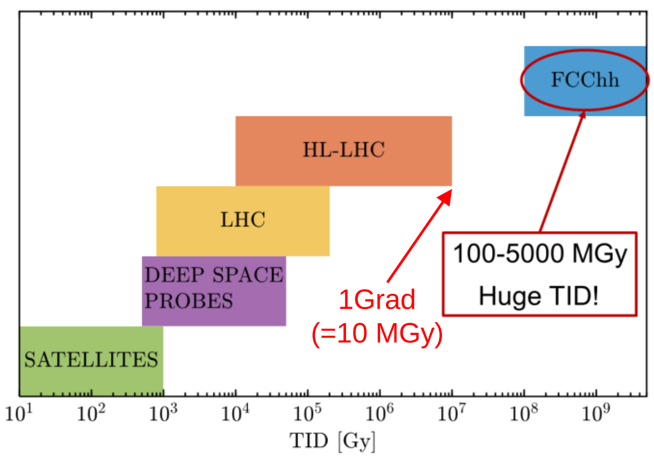
FCC Week 2018:
https://indico.cern.ch/event/656491/sessions/263078/#20180412

DEVELOPMENT OF RADIATION HARD ELECTRONICS

Application-Specific Integrated Circuits (ASICs) are designed in CMOS technologies and are composed almost exclusively by nMOS and pMOS transistors. Therefore, **the measurement of the radiation response of the transistors in different CMOS technologies is representative of the achievable level of radiation tolerance for the ASICs**.

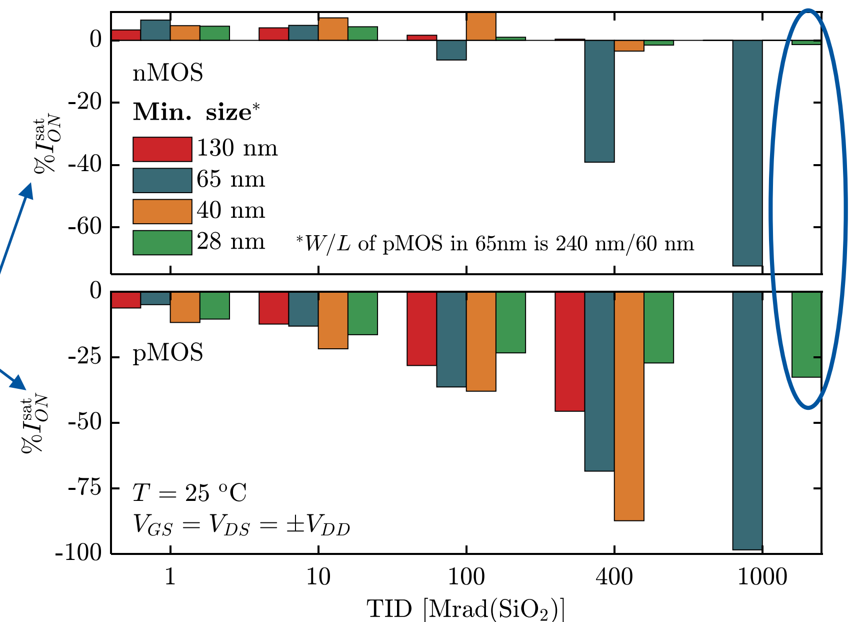
We have studied the **radiation tolerance of transistors in the CMOS technology nodes from 130nm to 28nm** (only TID).

It appears that **the 28nm technology node has better radiation tolerance, suggesting that appropriately designed ASICs could survive radiation levels approaching 1Grad**. However, this radiation level is well below those expected in some locations at the LHC-hh experiments.



Best performer: 28nm CMOS

Figure-of-Merit: % decrease of max current in nMOS and pMOS transistors of minimum size



Increasing TID levels →

F. Faccio, G. Borghello PhD (CERN-EP)

RAD-TOL DESIGN AND QUALIFICATION FOR FCC

- **Present landscape for accelerator qualification of COTS-based systems:**
  - Critical electronic components are tested at device level, however final validation for reliable operation in representative radiation field is performed at **system level** (i.e. at the dedicated CHARM facility)
  - Approach already **at the limit of requirements** for distributed HL-LHC systems (e.g. power converters)

- **Evaluation and roadmap for FCC:**
  - Higher radiation levels, larger amount and complexity of systems, tighter reliability/availability requirements
  - System design/architecture considerations:
    - Importance of common building blocks, centralized versus embedded approach, degraded mode operation, failure self-diagnose, on-line hot-swap, remote handling capability, etc.
  - **Need of progressing in design, qualification and facility requirements and guidelines for FCC**
  - **Importance of international collaboration** with space and ground-level (e.g. server farms, automotive) applications

Maximum system size allowed at CHARM facility

R. Garcia Alia, S. Danzeca (CERN-EN)

LIMITATIONS OF CURRENT CERN IRRADIATION FACILITIES

Main shortcomings identified in current CERN infrastructure of irradiation facilities

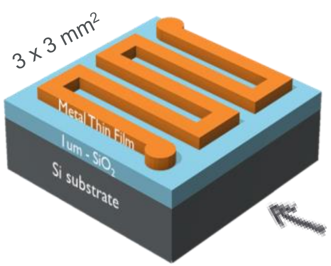
Name	Main Purpose	Issues w.r.t. FCC-driven targets (10 years operation)	Possible solution
IRRAD	Study of IEL and NIEL effects on performance of detectors, calorimeters and FE electronics for HEP experiments.	low particle flux.	Increase flux to reach target fluence faster.
CHARM	Test of COTS electronics in a LHC-like environment for SEE evaluation such as failure cross sections and system sensitivity to radiation.	not enough space.	Larger irradiation bunker to test more racks in parallel.
GIF++	Evaluation of detection performance and aging of muon chamber detectors in ionizing dose environment.	both limited space and low dose-rate.	Larger irradiation bunker to test bigger equipment + stronger gamma source.
CC60	Validation and test of electronic components and systems to ionizing radiation.	both limited space and low dose-rate.	Stronger source.
VESPER	Characterizing electronic components to SEE, TID and DD, for the operation in a Jovian space-environment.	facility not equipped for wafer level testing, and small irradiation table.	Upgrade of testing infrastructure.
X-ray generators	Characterizing electronic components (COTS, ASIC) to TID.	Insufficient dose-rate.	Unknown.

Database of irradiation facilities (EU-funded AIDA-2020 project) to boost international collaboration for FCC radiation testing. http://cern.ch/irradiation-facilities

ULTRA HIGH RADIATION DOSIMETRY

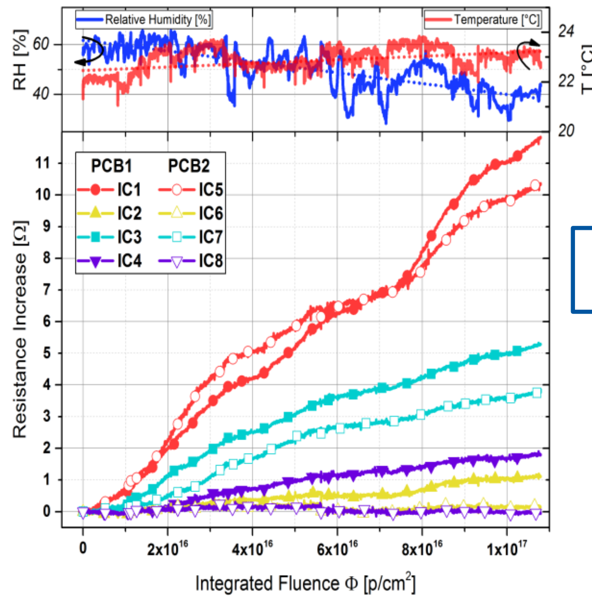
R&D on a new dosimetry technology based on nm-thick Copper thin films.

Design and Fabrication



Radiation Dependent Resistor

Irradiation and Measurement



Resistance increase during proton irradiation

Variation of electrical resistivity due to **Radiation Enhanced Oxidation** of copper exposed to radiation, tested up to 5×10^{17} p/cm^2.

Technology to further develop, potentially **suitable to build a FCC radiation monitor.**

F. Ravotti, G. Gorine PhD (CERN-EP)

[1] IEEE Trans. Nuc. Sci. 10.1109/TNS.2018.2797540
[2] RAD Journal, 10.21175/RadJ.2018.03.029
[3] AIP Advances, under review *Radiation enhanced oxidation of proton-irradiated copper thin-films*

STATUS OF RHA TASK RESOURCES IN ST WP

Task Leader: Rubén García Alía (EN/STI)

Deputy Task Leader: Federico Ravotti (EP/DT)

Activities (including FCC-funded PhDs and fellowships):

- **Radiation environment simulation** (Francesco Cerutti, EN/STI):
  - fellowship of Angelo Infantino finished in Jan 2019; fellowship of James Hunt (partially FCC funded) started in Mar 2019
- **Deep sub-micron CMOS tech. evaluation** (Federico Faccio, Giulio Borghello, EP/ESE):
  - PhD of Giulio Borghello finished in 2019. No further FCC resources allocated
- **Common building-block technologies** development and qualification (Salvatore Danzeca, EN/SMM):
  - synergies with R2E and RADSAGA activities but no dedicated FCC resources allocated so far
- **Test facilities and radiation monitoring** (Federico Ravotti, EP/DT):
  - PhD of Georgi Gorine finished in 2019. No further FCC resources allocated

PROSPECTS

- refocus the calculation effort according to refreshed priorities
- reprofile the RHA task activities on the basis of available resources