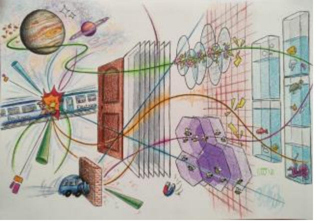


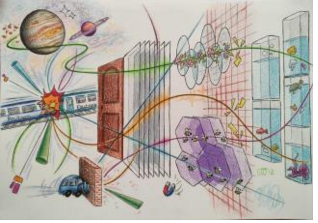
WG3: Radiation Damage & Extreme Fluences

Introduction to the WP – Scope – Community - Resources

Michael Moll

CERN EP-DT, Geneva, Switzerland

on behalf of the DRD3 proposal writing team



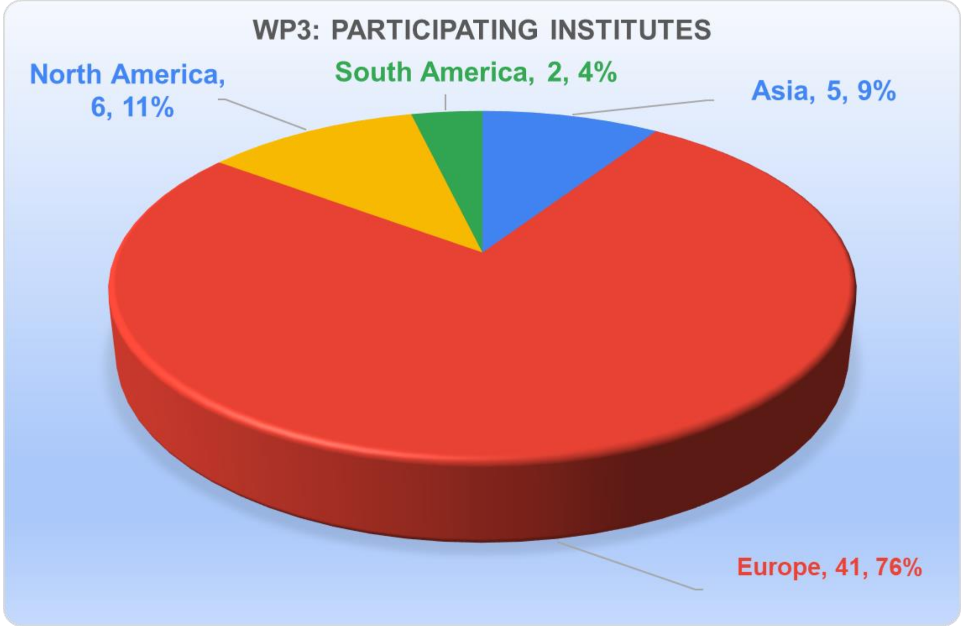
WG3: Community composition

Status: 19.3.2023 [88 institutes]
[*] Not all institutes provided numbers
No new strategic R&D included
[**] Extracted from research interest description in survey

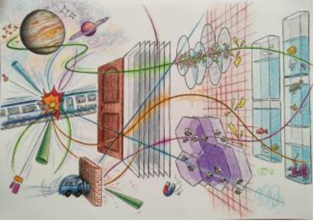
WG3 : radiation damage & ultrahigh fluences

- **54 institutes** (61% of 88*) allocated FTEs to the “radiation damage studies” theme in the survey
  - Indicated FTE*: **39 FTE senior** personnel and **48 FTE post-doc, students**

- **54 institutes**
  - from 4 different continents
    Asia, Europe,
    North America, South America
  - from 26 different countries
    Brazil, Canada, Chile, Croatia, Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Lithuania, Montenegro, Netherlands, Poland, Romania, Slovenia, Spain, Switzerland, Türkiye, UK, USA



- A large part of the “DRD3 community” (≈ 80-90%) is interested in radiation damage tests or studies**



WG3: Needs for radhard devices

- Technology need and timeline evaluated during ECFA roadmap process

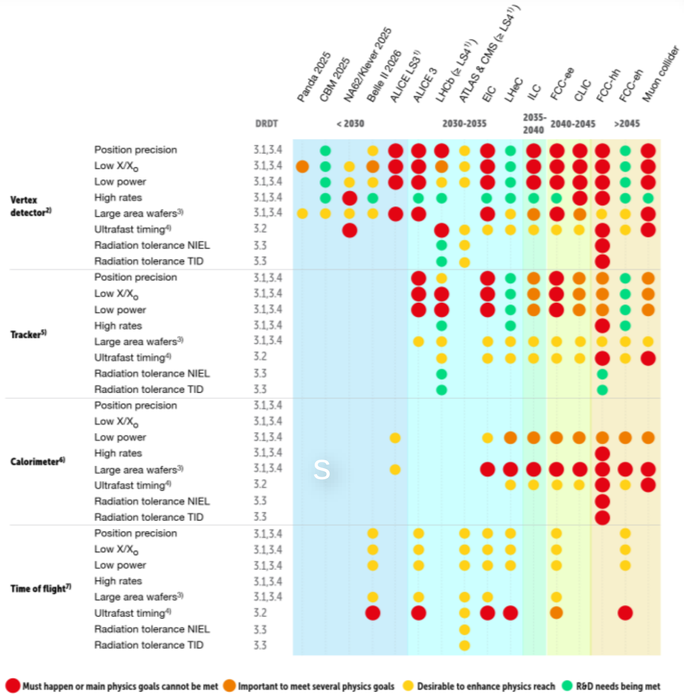
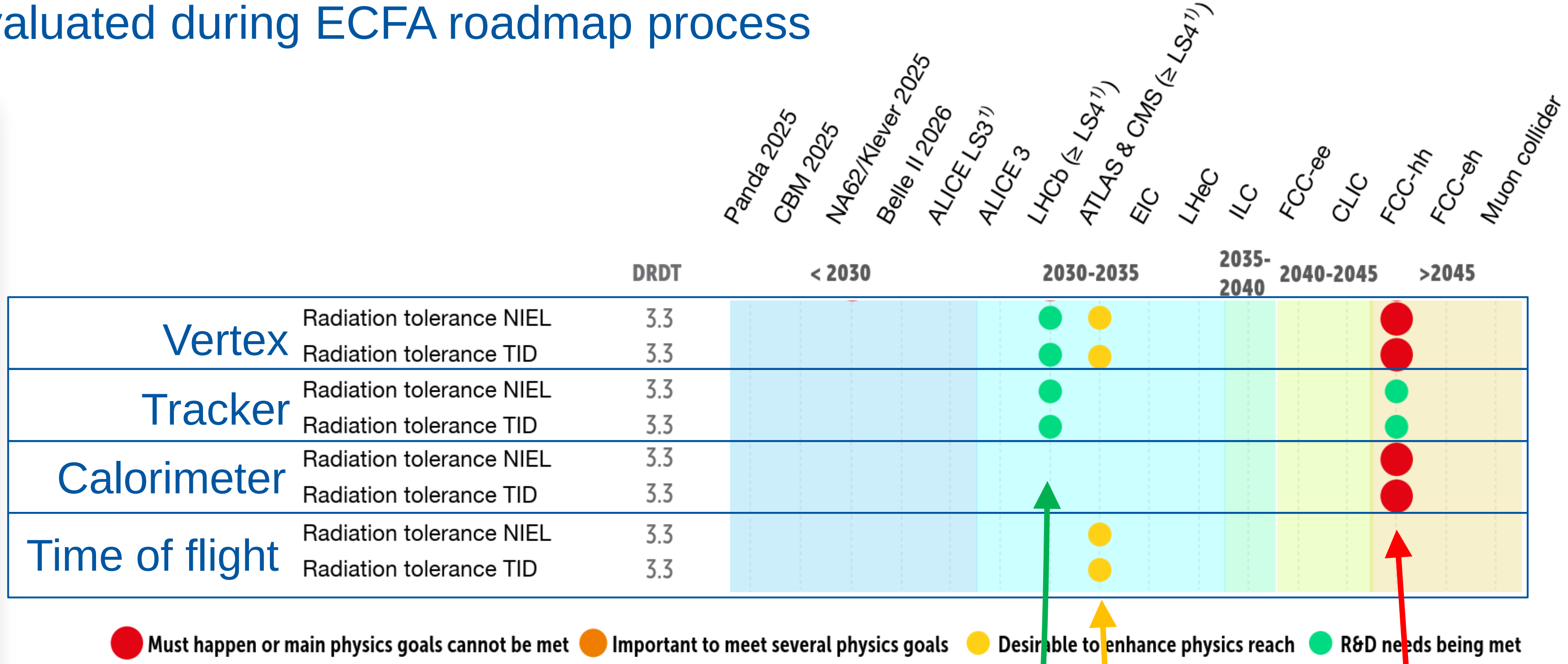


Figure 3.1: Schematic timeline of categories of experiments employing solid state sensors together with DRDTs and R&D tasks. The colour coding is linked not to the intensity of the required effort but to the potential impact on the physics programme of the experiment: Must happen or main physics goals cannot be met (red, largest dot); Important to meet several physics goals (orange, large dot); Desirable to enhance physics reach (yellow, medium dot); R&D needs being met (green, small dot); No further R&D required or not applicable (blank).

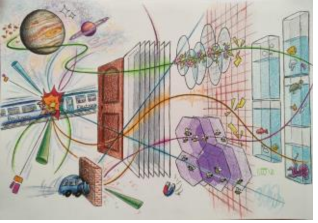
ECFA Detector R&D roadmap [CERN CDS]



LHCb (≥ LS4)
$6\times10^{16} n_{eq}/cm^2$, 10 MGy

FCC-hh
$1\times10^{18} n_{eq}/cm^2$, 300 MGy

ATLAS & CMS (≥ LS4)
$6\times10^{16} n_{eq}/cm^2$, 5 MGy

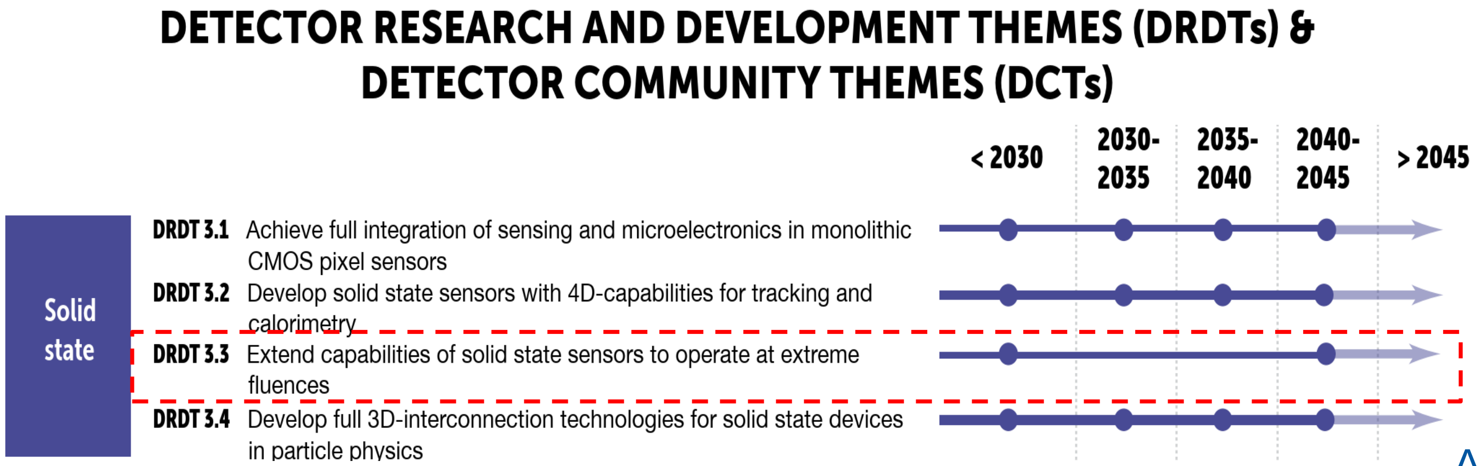


WG3: Recommendations for DRDT 3.3.

DRD3

ECFA R&D Roadmap

DRDT 3.3.
Extend capabilities of solid state sensors to operate at extreme fluences



Recommendations have been defined for DRDT3.3. and are fully in-line what we will propose:

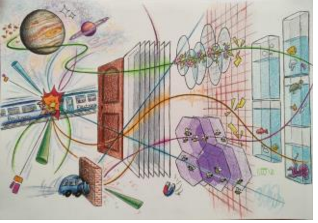
DRDT 3.3 - Sensors for extreme fluences.

- Measure the properties of silicon sensors in the fluence range $1\times10^{16}\ n_{eq}\,cm^{-2}$ to $1\times10^{18}\ n_{eq}\,cm^{-2}$. Map the limit of 3D sensors and evolve their design to cope with the highest possible fluences;
- Optimise the simulation models with the measurements at high fluence;
- Develop simulation models based on microscopically measured point and cluster defects (instead of a model based on "effective trap levels");
- Explore the use of WBG semiconductors as radiation detectors at high fluences;
- Develop innovative 2D-materials that can offer high radiation hardness and operate at room temperature.

Activity shared within DRD3

- with WG1 & WG2 sensors
- with WG4 Simulation
- with WG6: Non-silicon materials

ECFA Detector R&D roadmap [CERN CDS]



WG3: Expression of interest

Status: 19.3.2023 [88 Institutes]
Extracted from free text research interest description in survey

- **Evaluate and/or improve radiation hardness of sensors** [≈ 85%]
  - CMOS, LGAD, 3D, planar, ….
    (i.e. study radiation hardness of existing and newly developed sensor concepts)

see also WG1 & WG2 on sensors

- Explore the **extreme fluence** regime and/or study **radiation damage to WBG** sensors [≈ 65%]
  - Radiation damage up to extreme fluences (40 Institutes, 45%)
  - Radiation hardness of new materials (SiC: 26%, Diamond 17%, GaN 14%, Other 8%)

see also WG6 on WBG materials

- Study the radiation induced formation of **microscopic defects** and defect properties [≈ 10%]
  - Defect spectroscopic measurements (10 Institutes, 11%)

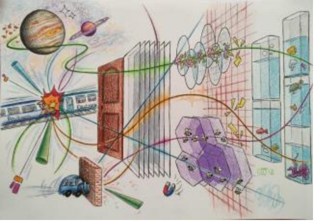
see also WG5 on characterization tools

- **Produce models** to simulate radiation damage on **material level** [≈ 10%]
  - Modelling of primary damage (Geant4, SRIM, NIEL,…) (6 institutes)
  - Modelling of defect kinetics and defect engineering approaches (4 institutes)

- **Produce models** to simulate radiation damage on **sensor level** [≈ 17%, 15 Institutes]
  - Produce/Improve sensor damage parameterization models (i.e. like "Hamburg model")
  - Produce reliable TCAD models with defects to simulate radiation damaged sensors

Note: Number of institutes that want to use simulation tools (TCAD/MC/…) including radiation damage but not necessary want to develop the damage models itself is much higher (see session on simulation!)

see also WG4 on simulations



WG3: Structuring of the WG

DRD3

- WG structured in 3 areas for the discussion (and proposal?)
- WG closely related to all other WGs

WG4: Simulations

Need for simulations in all areas

- on the material level
  Geant4, TRIM, NIEL, DFT, KMC, …
- on the device & system level
  TCAD, AP2, Signal & MC simulators, generic sensor parameter simulations (e.g. Hamburg model)
- extrapolation to extreme fluences
  do models still deliver reliable results?

WG5: Characterization techniques

Need for tools in all areas

- on the material level
  EPR, FTIR, PL, DLTS, TSC, …
- on the device & system level
  TCT, CV, IV, IBIC, test-beams, ….
- extrapolation to extreme fluences
  which tools still deliver reliable results?
  radiation facilities,…

WG3: Radiation Damage

Radiation hardening of material

understand fundamental damage process, defect formation, impact of defects on device performance (also non-silicon!), material and defect engineering

Radiation hardening of devices and systems

understand device operation with radiation damage, device engineering

Extreme fluences

understand physics, possibilities for operation of detectors

WG6: Non-silicon based detectors

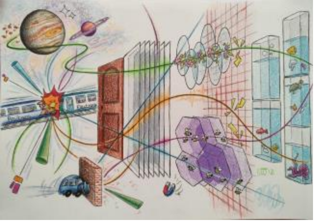
- Material & devices to be studied and understood as silicon in terms of radiation damage in all areas (simulations, material/sensor characterization, tool development)
- Developments for extreme fluence

WG1 & WG2: Silicon based detectors

- Radiation hardness evaluation of all sensors with exposure to radiation (existing and newly developed sensors/sensor concepts)
- Developments for extreme fluence

Synergies with other application areas in radiation fields

- Detectors for nuclear physics, space applications, fusion, medical applications, …



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WG3: Radiation Damage

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Talk: Ioana

Radiation hardening of devices and systems

understand device operation with radiation damage, device engineering

Talk: Sally

Extreme fluences

understand physics, possibilities for operation of detectors

Talk: Marko

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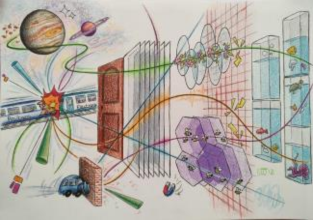

WP3: Milestones (for discussion)

WG3: Radiation Damage

Radiation hardening of material
understand fundamental damage process, defect formation, impact of defects on device performance (also non-silicon!), material and defect engineering

Radiation hardening of devices and systems
understand device operation with radiation damage, device engineering

Extreme fluences
understand physics, possibilities for operation of detectors

- Milestones for 3 years
  - Material studies and understanding
    - Develop radiation damage models based on microscopically measured point and cluster defects for irradiation fluences up to 10^{16} n_{eq}/cm^2 [also as input for NIEL and TCAD simulations]
    - Develop defect engineered optimized devices: Refine and optimize radiation damage models
    - Non-silicon: Build up data sets on defect formation in non-silicon materials
  - Devices and systems
    - Non-silicon: Build up dataset and produce improved or new models (i.e. parameterizations) for new materials including extreme radiation conditions; transfer of information from models to simulations
    - Improve radiation damage models for radiation levels up to the (HL-)LHC operation lifetime
      - sufficient test beam support required for this diverse program!
  - Measure the properties of silicon/silicon sensors in the fluence range 10^{16} to 10^{18} $n_{eq}cm^{-2}$
    - Sensors: Map the operational limits for different device types
    - Material: Characterize the defects and the material properties (e.g. carrier mobility)
    - Material: Map limits of defect spectroscopic tools and explore/develop tools for extreme fluences
    - Deliver input data for models & simulation tools (microscopic and macroscopic level)

- Milestone for 6 years
  - reliable availability of facilities for 10^{18} integrated fluence, charged and neutral.