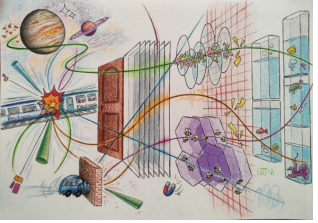
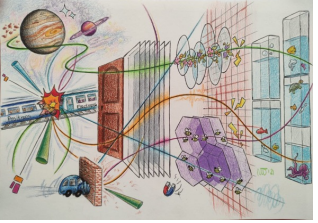


WG3: Radiation damage characterization and sensor operation at extreme fluences

Ioana Pintilie
Jörn Schwandt

DRD3 WG3 First Meeting
3rd June 2024

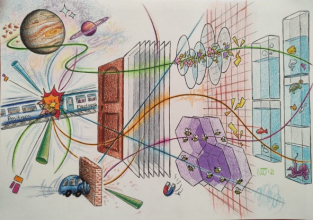


Detector R&D Theme

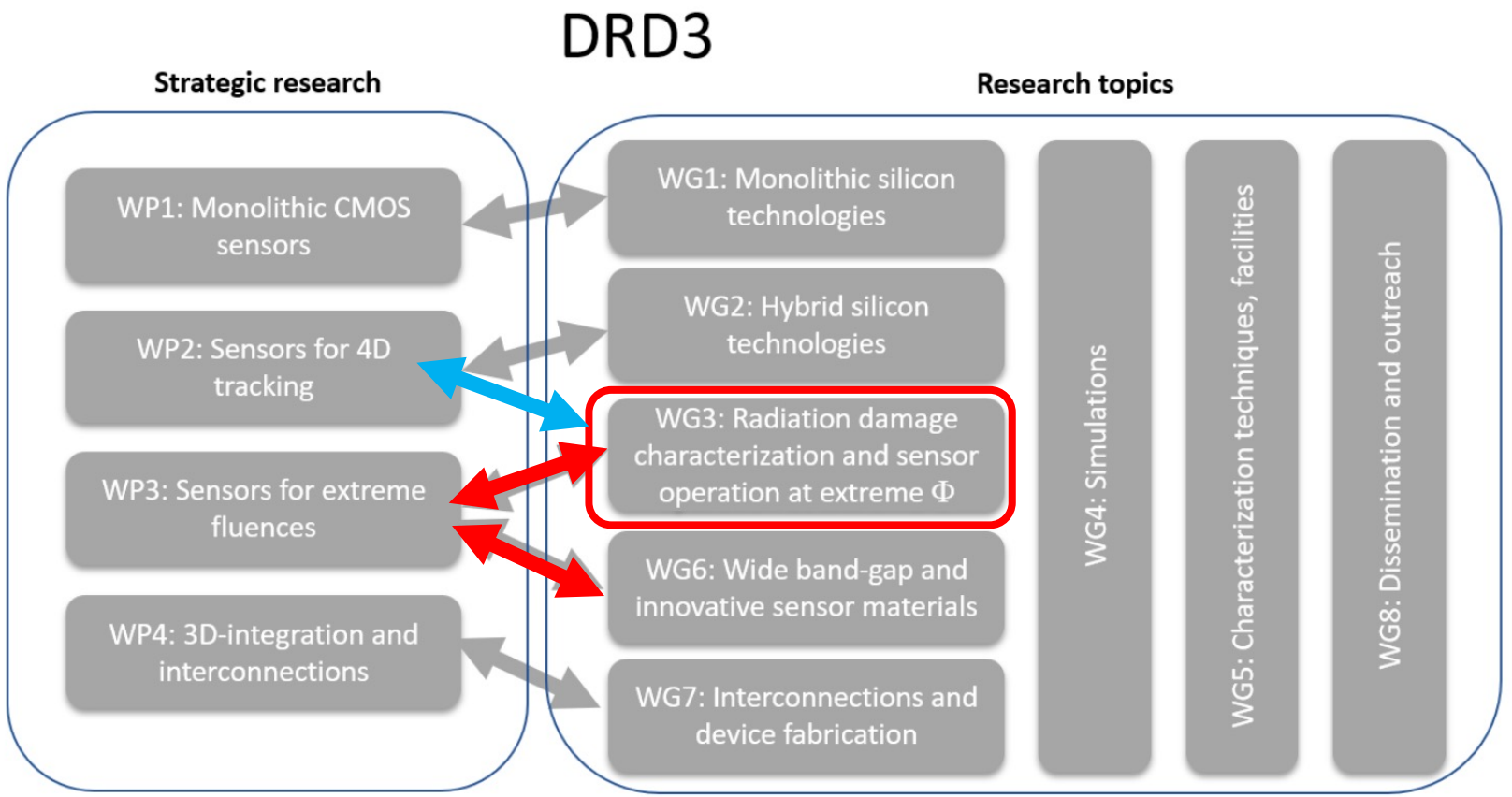
DRDT 3.3 - Extend capabilities of solid-state sensors to operate at extreme fluences

To ***evolve the design of solid-state sensors to cope with extreme fluences***, it is essential to measure the properties of silicon and diamond sensors in the fluence range $1x10^{16}$ - $5x10^{18}$ n_{eq}/cm^2 and to ***develop simulation models correspondingly including microscopic measurements of point and cluster defects***. All technologies will need improved radiation tolerance for use at future hadron collider experiments. ***Exploration of alternative semiconductors and 2D materials*** should timely start having as target the proper functioning at the extreme fluences present in the innermost parts of the detectors. A specific concern to address is the associated activation of all the components in the detector. Exploration of alternative semiconductors and 2D materials is desirable to push radiation tolerance further.

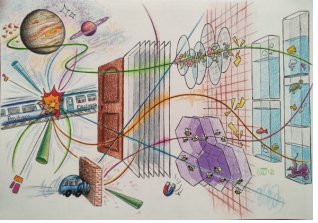
→ WP 3



Relationship between WPs and WGs

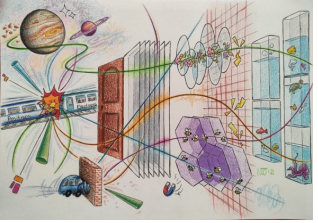


Close but not exclusive links
between corresponding WP and WG



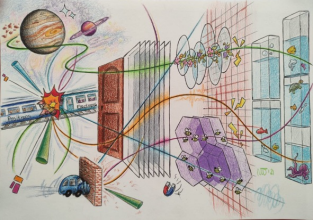
WG3 Research Goals

WG3 research goals <2027	
	Description
RG 3.1	Start of building up data sets on radiation-induced defect formation in WBG materials
RG 3.2	Continue developing silicon radiation damage models based on measured point and cluster defects
RG 3.3	Provide measurements and detector radiation damage models for radiation levels faced in HL-LHC operation
RG 3.4	Expand the measurements and models of silicon and WBG sensors properties in the fluence range 10^{16} to $1 \cdot 10^{18}$ n_{eq}/cm^2



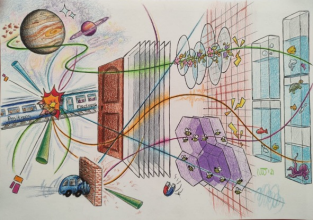
WP3 task, milestones, deliverables

WP	Task	MS or D	Description	2024	2025	2026	2027-2029	> 2030
2	2.2, 3.3	D2.4	Production of LGAD with radiation resistance up to $1{\cdot}10^{16}$ n_{eq}/cm^2				x	
3	3.3.	MS3.7	Fabrication and testing of different defect engineered Si sensors (enrichment with O, C and/or P) mimicking the gain layer in LGADs	x				
3	2.2, 3.3.	MS3.8	Understanding the effect of co-doping with O, C and/or P on the radiation hardness of gain layers in LGADs and develop defect engineered strategies for improving the radiation hardness (pin diodes 2026) and then segmented detectors (2029).			x	x	



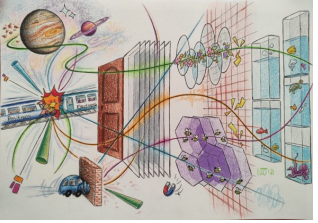
WP3 task, milestones, deliverables

WP	Task	MS or D	Description	2024	2025	2026	2027-2029	> 2030
3	3.3	D3.4	Report on microscopic and macroscopic investigations in irradiated defect engineered gain layers for Si based LGADs			x		
3	3.3	D3.5	Radiation damage studies on various silicon sensors up to $1{\cdot}10^{17}$ n_{eq}/cm^2 (2025) and up to $1{\cdot}10^{18}$ n_{eq}/cm^2 (2029)		x		x	
3	3.1	MS3.4	Understanding timing performance and validate simulation models of SiC detectors, before irradiation (2024) and at $1{\cdot}10^{15}$ n_{eq}/cm^2 (2030).			x		x
3	2.2, 3.1	MS3.5	SiC-LGAD (gain layer) proof of principle, simulation and first fabrication of devices with small areas (< 1 cm^2 in 2026) and in large areas (5 cm^2 after 2030).			x		x
3	3.1	MS3.6	Assess GaN devices as high-rate, high timing precision devices			x		

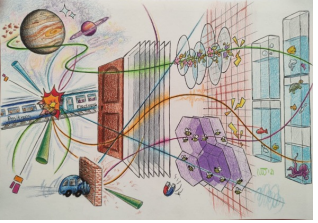


WG3 EOI

- Total number: 27 institutes (23 Europe, 2 North America, 1 Asia, 1 Middle East)
- All topics of WG3 covered:
  - Microscopic defect studies of Si, SiC, GaN (9 institutes mentioned DLTS)
  - Most institutes can perform macroscopic measurements
  - Radiation hard LGADs is mentioned explicitly by 9 institutes
  - 5 institutes with irradiation facilities



Running Projects related to WG3/WP3



RD50 project

DRD3

RD50-2023-05: PAB - Partial Activation of Boron to enhance the radiation tolerance of the gain implant

DRD3

- **Title:** "Partial Activation of Boron to enhance the radiation tolerance of the gain implant - PAB"
- **Project Leader:** Valentina Sola (Torino University)
- **Participating institutes: 12** (all RD50 members)
- **Indicated project cost: 52** keuros
- **Request to RD50: 27** keuros
- **Granted RD50 contribution: 27** keuros

Project description

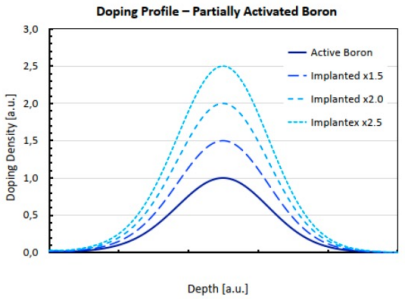


Figure 1: Profile of dopant density forming the gain implant of LGAD sensors exploiting partial activation of boron. Different doses of implanted boron are shown. The goal is to keep a constant dose of active dopant, indicated as dose 1, while studying the effect of different implant concentrations.

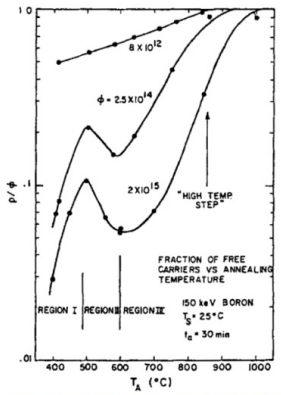


Figure 2: Isochronal annealing of boron. The fraction of activated boron, p/ϕ, is plotted against the annealing temperature, T_A, for different implant doses, ϕ. The annealing time is 30 minutes[3].

RD50 funding request

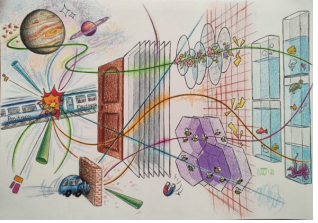
- Date: 15.11.2023 -

Title of project:	**Partial Activation of Boron to enhance the radiation tolerance of the gain implant – PAB**
Contact person:	V. Sola Torino University and INFN +39 011 670 7338 valentina.sola@to.infn.it

RD50 Institutes:

1. INFN Torino, V. Sola – valentina.sola@to.infn.it
2. Centro Nacional de Microelectrónica, G. Pellegrini – giulio.pellegrini@imb-cnm.csic.es
3. Fondazione Bruno Kessler, G. Paternoster – paternoster@fbk.eu
4. Jožef Stefan Institute, G. Kramberger – Gregor.Kramberger@ijs.si
5. Helsinki Institute of Physics, J. E. Brücken – jens.brucken@helsinki.fi
6. INFN Perugia, F. Moscatelli – moscatelli@iom.cnr.it
7. CERN, M. Moll – michael.moll@cern.ch
8. University of Montenegro, G. Medin – gordana.medin@gmail.com
9. National Institute of Materials Physics (Romania), I. Pintilie – ioana@infim.ro
10. Institut für Hochenergiephysik, T. Bergauer – Thomas.Bergauer@oeaw.ac.at
11. Vilnius University, T. Čeponis – tomas.ceponis@ff.vu.lt
12. Instituto de Física de Cantabria (CSIC), I. Vila Álvarez – ivan.vila@csic.es

Request to RD50: € 27,000
Total project cost: € 52,000



RD50 project

DRD3

RD50-2023-06: Impact ionization parameterization at extreme fluences

DRD3

- **Title:** "Impact ionization parameterization at extreme fluences"
- **Project Leader: Gregor Kramberger** (Ljubljana)
- **Participating institutes: 5** (all RD50 members)
- **Indicated project cost: 52** keuros
- **Request to RD50: 25** keuros
- **Granted RD50 contribution: 25** keuros

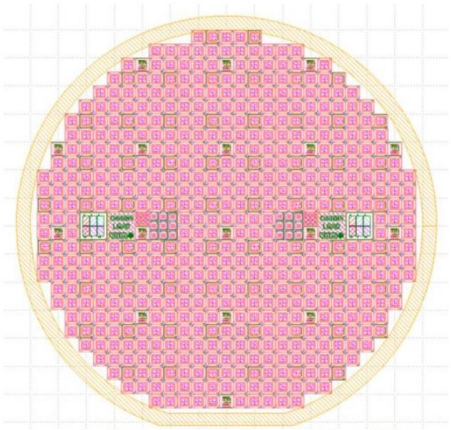


Figure 1: View of the wafer layout (6").

- 1, 2, 10, 100 a.u. (B+C LGADs)
- 1, 5, 20, 200 a.u. (B LGADs)
- 1 a.u. (C-implanted PINs)

RD50 funding request

- November, 2023 -

Title of project: Impact ionization parametrization at extreme fluences

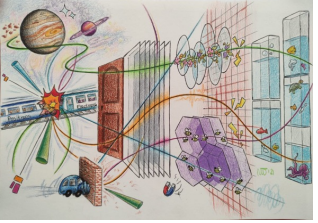
Contact person: *Gregor Kramberger*
Jožef Stefan Institute
+386 1 477 3159
Gregor.Kramberger@ijs.si

RD50 Institutes:

1. CNM, Giulio Pellegrini, giulio.pellegrini@imb-cnm.csic.es
2. JSI Ljubljana, Gregor Kramberger, <Gregor.Kramberger@ijs.si>
3. INFN-Torino, Valentina Sola <Valentina.Sola@cern.ch>
4. UCG, Gordana Medin <gordana.medin@gmail.com>
5. CERN, Michael Moll <Michael.Moll@cern.ch>

Request to RD50: 25000 €
Total project cost: 52000 €

We propose processing of several wafers of small size pin and LGAD samples (see Fig. 1) where the doping of the gain layer would be significantly higher than in presently produced LGADs (1e16-1e17 cm^{-3}) so that the produced LGADs would not be operational before irradiation, but would be become operational after irradiations when sufficiently large number of initial acceptors were removed to allow depletion of gain layer, establishing electric field in the bulk and not leading to the immediate break-down of the devices. That

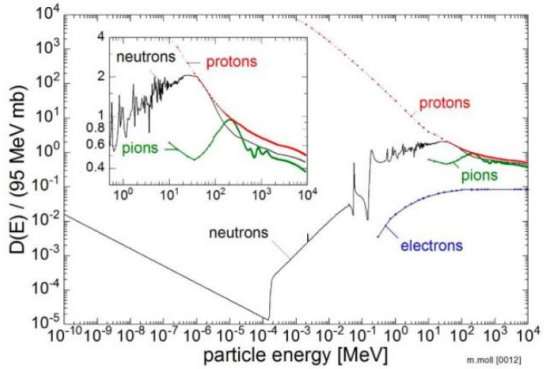


RD50 project

DRD3

RD50-2023-07: PIN sensors for dosimetry & NIEL studies DRD3

- **Title:** "PIN sensors for dosimetry and NIEL studies"
- **Project Leader: Michael Moll** (CERN)
- **Participating institutes: 4** (all RD50 members)
- **Indicated project cost: 40** keuros
- **Request to RD50: 20** keuros
- **Granted RD50 contribution: 20** keuros



RD50-2023-07

Project description:

The objective of this project is to produce n-in-p diodes in form of simple "pin sensors" that can be used as passive radiation monitoring devices by measuring the radiation induced leakage current in well-defined post-irradiation annealing and operational conditions.

The purpose of the project is two-fold:
[1] Dosimetry: The sensors will serve as dosimetric devices for radiation monitoring in irradiation campaigns at the JSI nuclear reactor and the CERN IRRAD facility in the context of RD50/DRD3 collaboration projects.

[2] Facility Intercomparison/NIEL study; The sensors will serve a measurement campaign for the cross-comparison of irradiation facilities. For the intercomparison of irradiation facilities, a set of sensors will be provided free of charge to interested irradiation facilities within the RD50/DRD3 collaboration for exposure at their facility under well controlled dosimetric conditions. After exposure, the sensors will then either be measured at the facility under well defined conditions (after annealing of 80 minutes at 60C at a specified bias voltage to be determined after processing of the sensors, with guard ring connected) or shipped to CERN were the corresponding measurements will be performed. The ultimate scientific goal is to evaluate the validity of the Non-Ionizing Energy Loss (NIEL) hypothesis by means of measuring the leakage current of the sensors after irradiation. This study is accompanied by simulation studies at CERN using FlUKA, GEANT4 and TRIM simulations to evaluate the expected Non-Ionising Energy Loss (NIEL) against the measured leakage current increase.

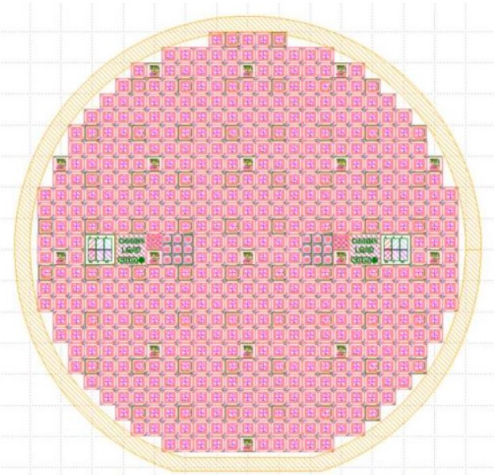


Figure 1: View of the wafer layout (6").

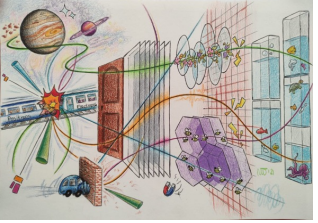
RD50 funding request
- November, 2023 -

Title of project: PIN sensors for dosimetry and NIEL studies
Contact person: *Michael Moll*
CERN, Geneva, Switzerland
+41 22 76 72495
michael.moll@cern.ch

RD50 Institutes:

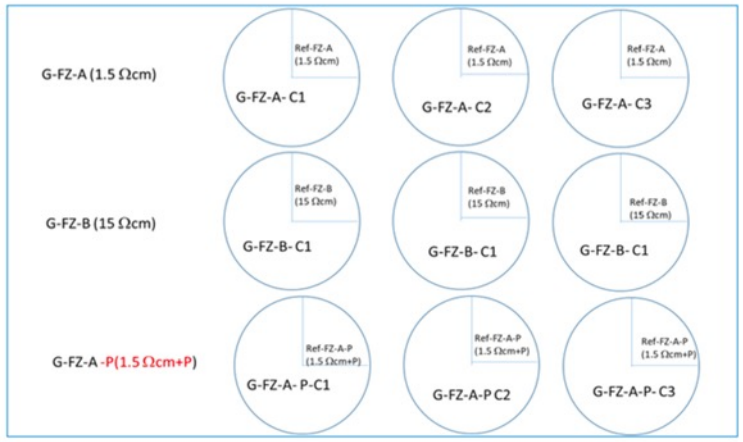
1. CERN, Michael Moll Michael.Moll@cern.ch
2. CNM, Giulio Pellegrini, giulio.pellegrini@imb-cnm.csic.es
3. JSI Ljubljana, Gregor Kramberger, Gregor.Kramberger@ijs.si
4. NIMP Bucharest, Ioana Pintilie ioana@infim.ro

Request to RD50: 20000 €
Total project cost: 40000 €



RD50 project

- **Title:** "Defect engineering in PAD diodes mimicking the gain layer in LGADs "
- **Project Leader:** Ioana Pintilie (NIMP, Bucharest)
- **Participating institutes: 7** (all RD50 members)
- **Indicated project cost:** 51.2 keuros
- **Request to RD50:** 26.7 keuros
- **Granted RD50 contribution: 26.7** keuros



… different Boron doped wafer type with/without Carbon and Phosphorous compensation

RD50 funding request **RD50-2022-01**

Date:
17.05.2022

Title of the project: *Defect engineering in PAD diodes mimicking the gain layer in LGADs*

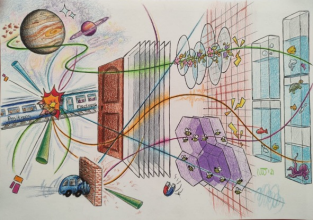
RD50 Institutes:
- NIMP, Ioana Pintilie, ioana@infim.ro
- CERN, Michael Moll, Michael.moll@cern.ch
- CiS, Kevin Lauer, klauer@cismst.de
- JSI, Gregor Kramberger, Gregor.Kramberger@ijs.si
- HH, Eckhart Fretwurst, Eckhart.fretwurst@desy.de
- INFN-Torino, Valentina Sola, sola.valentina@gmail.com
-Vilnius University, Tomas Ceponis, tomas.ceponis@ff.vu.lt

Request to RD50: 26665 EUR

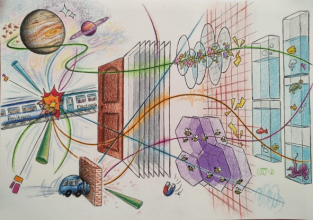
Total project costs: 51165 EUR

Project description:

The proposed project is focusing on the acceptor removal process (ARP) in the irradiated gain layer of LGAD sensors, aiming to understand it and parametrize it for various content of B, C and O impurities and irradiation fluences, in order to find proper defect engineering solutions to maximize the radiation hardness of the gain layers. The studies performed so far on LGAds show that in the p^+ layer of LGADs, the ARP can result in a complete disappearance of the gain at 1MeV neutron equivalent fluences higher than $2x10^{15}$ cm^{-2}. As major obstacles preventing the achievement of enough knowledge for characterizing and proposing feasible solutions for improving the performance of the gain layers in LGADS are:



New projects

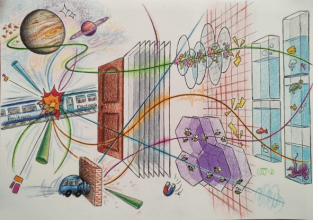


New projects are needed to achieve our research goals, especially for WBG materials

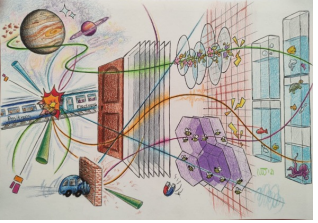
- All new WG6/WG2 productions should include samples for microscopic studies (collaborative work)
- Note that for fluences > $5x10^{15}$ n_{eq}/cm^2 the standard defect investigations techniques (DLTS, TSC) do not work. Some extension possible for quantitative evaluations via:
  - extended simulations starting from well determined defect introduction rates at lower irradiation fluences and *ab initio* modeling of different radiation induced defect structures
  - or/and fabrication of special doped samples.
- For fluences well above $10^{16}n_{eq}/cm^2$, other techniques, such as EPR (Electron Paramagnetic Resonance), FTIR (Fourier Transform IR Spectroscopy) or PA (Positron Annihilation) have to be employed.
- A Work Package Project template is available

Structure of the document/proposal

- **Title**
- **Project description**
  - Short abstract
  - Motivation and goals
    - main motivation (experiment, TB, demonstrator, engineering experiments …)
    - strategic goals directly addressed in project as specified in DRDT and DRDT scientific proposal
    - the expected results addressing other strategic goals (not necessarily important for the project)
  - execution of the project (description, *list of things to be included*)
- **Milestones, deliverables and timeline (in form of a table shown below)**
  - description
  - importance
  - risks associated to failing M&D
  - reporting
- **Collaborative work:**
  - required WG activities involved (e.g. WG5 -TB, WG4-TCAD…)
  - cross-DRD activities
  - **Potential synergies with similar projects**
- **Participants:**
  - List of already interested institutions with topics of interest
  - List of missing topics/not covered activities **(call for collaboration)**
- **Resources needed**
  - Available resources needed for completion of the project
    - time line for resources?
  - Missing/Requested resources - asked (key for strategic funding)
    - large equipment needed and missing (e.g. state-of-art oscilloscopes)
    - services cost (e.g. processing runs, SIMS, …)



Setting up WG3



- 3rd WG3 convenor still missing (volunteers?)
- Submit abstracts (scientific/project proposals) for the DRD3 week
- Identify common DRD3 projects
- WG3 Organisation:
  - No subgroups for the time-being
  - Proposed liaison persons for:
    - Simulation (WG4)
    - WBG (WG6)
    - LGAD (WG2)
    - Irradiations
  - Regular meetings in between the DRD3 workshops

Important e-mails:

- Convenors: drd3-wg3-conveners@cern.ch
- E-group: drd3-wg3-radiation