Horizon 2020 Framework Programme

HadronPhysicsHorizon (HPH)

TEMPLATE

for drafting a Proposal for a

Networking Activity or Joint Research Activity

Activity Descriptive Title:	Study of Avalanche Micro-Pixel Photo Sensors under Exposure to Ionizing Radiation
Activity Acronym:	**SiPM2020**
Leading Institution:	Helmholtz-Institute Mainz
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1. EXCELLENCE

1.4 AMBITION

[Describe the advance your proposal would provide beyond the state-of-the-art, and the extent to which the proposed work is ambitious. Your answer could refer to the ground-breaking nature of the objectives, concepts involved, issues and problems to be addressed, and approaches and methods to be used.
Describe the innovation potential which the proposal represents. Where relevant, refer to products and services already available on the market. Please refer to the results of any patent search carried out.]

The Geiger mode operated avalanche micro-pixel photo sensor matrix often just called **silicon photo multiplier** (SiPM) is ideally suited for photonics systems in a wide field of basic physical science, especially in hadron physics. It has the potential for novel, ground-braking applications in integrated cost-efficient technologies. This photo sensors combines performance features of traditional photomultiplier tubes like high quantum efficiency, intrinsic signal amplification, very fast response on even single photons with extremely important features like low-voltage operation and possibly electronics integration on the detector chip. It surpasses photomultiplier tubes in timing resolution, is insensitive to magnetic fields and, assembled on appropriate carriers, is mechanically robust thus suitable for harsh environments. Consequently, possible applications of these devices beyond hadron physics cover space research, analytical instrumentation, medical and non-medical diagnostic imaging non-destructive material testing, safety & security and eventually environmental technology.

Presently, the SiPM from any supplier has a very limited resilience when exposed to ionizing radiation. At a radiation flux above 10^{11} cm^{-2} destructive effects become measurable signaled through macroscopic properties, either noise increase, gain decrease or impair of single photon resolution. Intrinsic properties of the photo diode such as the breakdown voltage and/or the capacitance change as well.

In this project we want to perform studies of the resilience of SiPM against ionizing radiation using both hadronic as well as electronic particle beams. In addition, irradiation with nuclear reactor neutrons and very strong x-ray sources is planned. Such experiments can be performed at European laboratories (INFN, GSI, PSI, Giessen, Mainz, Prague).

We plan to take samples of sensors from different producers perform initial characterization and expose them to the radiation fields with gradually increasing strength. In between bench tests will allow to monitor the performance changes as a function of integrated applied dose. At the threshold of serious changes of the behavior or damage of performance also microscopic techniques of solid-state physics investigating defects in crystal structure etc will be applied. In addition, such sensors will be returned to the producer for further comparison with the parameters of a virgin sensor. In the ideal case damages can thus be identified and the wafer layout for production may be modified in the direction of higher radiation resilience. The innovation potential of this project could be further increased if the hardness against radiation could be enhanced similar to integrated electronics for use in space missions and accelerator neighborhood.

2. IMPACT

[Implement this Section by taking also advantage of what you have reported in Section B-Expected Impact of your original proposal,where the main challenges that you intend to master have been indicated.]

2.1 EXPECTED IMPACT

[Describe how your project will contribute to:

- *the expected impact set out in the work programme, under the relevant topic; in particular a structuring impact on the ERA and on the way research infrastructures operate, evolve and interact with similar facilities and with the users (including on a global level, where relevant);*
- *improving innovation capacity and the integration of new knowledge (strengthening the competitiveness and growth of companies by developing innovations meeting the needs of European and global markets[1]; and, where relevant, by delivering such innovations to the markets);*
- *any other environmental and socially important impacts (if not already covered above).*

Describe any barriers/obstacles, and any framework conditions (such as regulation and standards), that may determine whether and to what extent the expected impacts will be achieved. (This should not include any risk factors concerning implementation, as covered in section 3.2).]

On existing research infrastructures

The detection of photons in the visible, ultraviolet and infrared wavelength region is a key-technology in research, fundamental to the working principle of many detector systems in hadron physics. Silicon Photomultipliers will be increasingly used there and replace in many instances the traditional photo multiplier tube. The research infrastructure at accelerator laboratories is about to undergo a rapid change towards using SiPMs in calorimetric detectors replacing phototubes or avalanche photo detector. This trend can be seen timing signal detection as the SiPM has one of the fastest response time and is therefore ideal when coupled to fast organic scintillators and to Cherenkov radiation.

On future research infrastructures

On the development of advanced theoretical methods

Understanding the avalanche process in a SiPM on the microscopic level needs theoretical models of the sensor. The simulations performed until now have to be refined with realistic boundary conditions. Such work implies sophisticated computational methods still to be developed. Using such advanced tools may lead to a description and better control of radiation defects in the production process.

On new opportunities for synergies

On applications

On collaboration with companies of mutual benefit

The topic of this JRA is bound to a strong collaboration with the producer. The radiation tolerance of the SIPM sensor can only be measured in the context of applications in the neighborhood of ionizing radiation such as hadron physics. On the other hand, the macroscopic and microscopic findings have to trigger feedback at the producer's side. We have therefore involved many producers to participate in this JRA with the hope of mutual benefit.

On education of young researchers

On partnership between Non-European and European institutes

2.2 MEASURES TO MAXIMISE IMPACT

a) Dissemination and exploitation of results

[Provide a draft 'plan for the dissemination and exploitation of the project's results'. In the case of Integrating Activities, these are typically the results of the joint research activities to improve the infrastructure services, the enhanced access provision, and/or common standards, protocols etc. resulting from networking activities. The plan, which should be proportionate to the scale of the project, should contain measures to be implemented both during and after the project.

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[1] For an Integrating Activity, this should be achieved via reinforcing the partnership with industry, through e.g. transfer of knowledge and other dissemination activities, as well as activities to promote the use of research infrastructures by industrial researchers.

Table 3.1a Work package Description
(maximum length of this table: 2 pages) In the following table, please include only beneficiaries which are receiving funds in this WP.

Work package number	JRA32		**Start date**	01/01/2015			
Work package title	Radiation Resilience of Avalanche Micro-Pixel Photo Sensors						
Participant number							
Short name of participant	GSI/HIM	OeAW	INFN	CUNI			
Person-months per participant	4	4	8	8			

Objectives

Radiation hardness is a very important issue to be addressed in order to use SiPM in nuclear physics where a high-intensity background radiation is present, with particular emphasis to high-energy hadrons, electrons and photons as well as epithermal neutrons. Generally, in silicon detectors irradiation causes lattice defects affecting the silicon performance in several ways. For instance defects with levels in the middle of the band-gap act as recombination/generation centers responsible for the increase in leakage current or as trapping centers reducing the charge collection efficiency.

Several radiation resilience studies have been conducted on SiPM since their first use as photo-detector in medium and high-energy physics and other nuclear applications. The major concerns regard their continued use and long-term exposure to radiation. Literature reports studies with positron beams and gamma rays, proton beams and mainly fast neutrons. In a comparative study devices different vendors have been irradiated up to 10^{10} particles/cm^2 with no sign of deleterious effect of breakdown voltage, PDE or gain. A common observation of all the previously cited studies is that both dark rate and leakage current increase linearly as a function of the total particle fluence and the damage dose not depends on the temperature or operating voltage. The damage results in the loss of the photon-counting capability due to baseline fluctuations and noise pile-up. This effect would be a problem for applications that involves low numbers of photons to be detected, as ring imaging Cherenkov. A pulse height resolution loss than can be explained as an increase of the after-pulse effect or change in gain uniformity among microcells. The deterioration in pulse height resolution is an issue in case of energy measurement applications such as in crystal calorimetry.

Concerning the damage recovery, part of the acute effects is not permanent but the speed and the extent of the annealing process strongly depends on the temperature and is faster and stronger at higher temperatures. Furthermore increasing the temperature of a damaged sample previously annealed at a given temperature brings further recovery. As a general indication in operating conditions, it seems the best to cool the SiPMs during exposure to minimize the effects of the increased dark rate. In addition, whereas possible, the devices should be heated during beam down times to anneal them and minimizes the noise increase.

All these studies must be faced in a systematic way by testing different types of samples from a number of vendors to investigate the end-points (dark rate, leakage current, single-photon resolution…) as a function of the dose of radiation with particular care toward the requirements of the applications. Another interesting aspect to be deeply investigated is the damage recovery and its dependence on temperature and on the operating conditions of the different hadron physics experiments.

One of the main objectives will be collaborating with the commercial and non-commercial SiPM developers involved in this project to finally to provide new technologies of increased radiation tolerance addressing the requirements posed by the different applications

Description of work (where appropriate, broken down into tasks), lead partner and role of participants

In order to perform a comprehensive and systematic measurement with various radiations, we will have a meeting with all institutes at the beginning stage of the project to discuss and agree on the methodology of the measurements, e.g. initial dose and the fractional step size, the setups for the various irradiation facilities. In addition, we have to define control parameters to be monitored during beam time in order for those data measured by different groups at different facilities and with different setups to be comparable later on.

The selection of SiPMs for the study should be performed together with the specialists from industry experienced in production technology. For us the priority will have sensors to be used for planned large detectors in hadron physics such as optimized timing properties or high pixel density sensors for calorimetry. But the advice from the producer will be similarly important such that different engineering methods can be compared for radiation hardness including the associated electronics (e.g. dSiPM). The characterization of sensors after each irradiation step comprises i.e. gain, dark rate, leakage current, breakdown voltage, sensor capacitance and single-photon resolution. This work is performed in the leading labs respectively. Another interesting aspect to investigate is the damage recovery and its dependence on temperature and on the operating conditions.

The groups from Prague, CUNI (contractor) and FZU, will be the leading investigators for **neutron irradiation.** The two nearby reactors VR-1 named Sparrow (Czech Technical University) with thermal/fast neutrons (10^9n/cm^2

s and LVR-15 a more commercial reactor in Rez (Czech Academy of Science) with thermal (10^{14} n/cm^2 s) and epithermal neutrons (10^9 n/cm^2 s) can be accessed. OeAW and GSI will also participate in the neutron irradiation studies.
OeAW will be leading the **proton irradiation** part of the project. There is good contact to the PIF (proton irradiation facility) at PSI and the team has an experience with that facility. OeAW also worked in irradiation tests for SiPMs at COSY. One of the main interests of the INFN-Pisa group is the application of SiPMs to on-line dose monitoring in hadron therapy. To this aim, of particular importance will be the use of therapeutic beams. They will be available at the INFN Laboratori Nazionali del Sud in Catania (proton beams up to 60 MeV produced by a Superconducting Cyclotron) and also at the CNAO clinical facility in Pavia (proton beams up to 250 MeV produced by a Synchrotron). High-energy hadron beams (1 to 3 GeV) will be available at GSI as well. Beam time in parasitic mode can always be applied for.
INFN-LNF will be the principal investigator for **electron irradiation** tests to be performed at the BTF facility of LNF-INFN, where an electron beam with following characteristics is available: energy range from 25 to 750 MeV, a repetition rate up to 50 Hz with a pulse duration variable from 1.5 to 40 ns, with particles/pulse up to 10^{10} particles. INFN-PI, OeAW and GSI will also join the experiment and data evaluation.

Photon irradiation using a strong X-ray source can be performed at JLU Giessen. Access to this facility can be obtained on a rather informal basis and irradiation doses of 100 kGy and more are possible within reasonable exposure time. With this low energy irradiation the photosensitive layer will be studied independently from the silicon of the bulk material Leading investigator for this study will be GSI. INFN-PI is also very interested since similar radiation defects are likely to occur in medical applications such as PET.

A close contact with manufacturers is crucial in this study. FBK, KETEK and PHILIPS would offer test sensors and are ready to receive feedback. The aim of providing new prototypes and developing sufficiently radiation resilient sensor for hadron physics experiment, e.g. PANDA experiment, may become visible after this study. This goal is highly beneficial to both manufacturers and users. There is an additional aspect to the problem concerning the associated electronics. It is required to possess sufficient radiation tolerance as well, a fact that is intrinsically of concern for the PDPC digital variant from Philips. A separate irradiation of the electronic part and the sensor part of the chip will be planned. As a consequence, all participants of this JRA will get involved in this task.
We also plan to include sensors from HAMAMATSU as the present technology leader for conventional, surface type, analogue SiPM sensors.

Deliverables (brief description and month of delivery)
Systematic study of radiation hardness for different sensor types: Investigation of parameter changes of a sensor after irradiation with ionizing radiation. An assessment of specific end-points (dark rate, leakage current, single-photon resolution, pulse-height resolution, etc.) will be performed with continuous feedback to developers. Possible redesign by our industrial partners involved in the network to improve the radiation tolerance based on the irradiation test results. Eventually, new production concepts for new sensors with increased radiation tolerance. The results of the comprehensive studies will be published.
The deliverables will be separate reports on each type of irradiation and finally a comprehensive publication of the experimental results (36)

(End of 2 pages maximum length.)

4. MEMBERS OF THE CONSORTIUM

⚠ *This section is not covered by the page limit.*
⚠ *The information provided here will be used to judge the operational capacity.*

4.1 PARTICIPANTS (APPLICANTS)

Please provide, for each participant, the following (if available):

- *a description of the legal entity and its main tasks, with an explanation of how its profile matches the tasks in the proposal.*
- *a curriculum vitae or description of the profile of the persons, including their gender, who will be primarily responsible for carrying out the proposed research and/or innovation activities;*
- *a list of up to 5 relevant publications, and/or products, services (including widely-used datasets or software), or other achievements relevant to the call content;*
- *a list of up to 5 relevant previous projects or activities, connected to the subject of this proposal.*

4.1.1 Participants not receiving funds in this work package

[Organizations not receiving EC funds in this work packages, but involved in the activities. Please provide, for each organization: - the full name of the organization - the activity leader - the person-months involved in the project]

Organization legal name *(in italics the Research Units)*	**Activity leaders**	**Human effort** *(person-months)*
Institute of Physics, Academy of Science of the Czech Republic (FZU), Prague	M. Lokajicek	8
KETEK GmbH, Munich (Germany) *KETEK SiPM-Technology*	F. Wiest	1
Philips Technology GmbH Innovative Technologies, Aachen (Germany *Philips Digital Photon Counting*	C. Degenhard	1
Fondazione Bruno Kessler, Trento (Italy) *Center for Information Technology*	C. Piemonte	1
Joint Institute for Nuclear Research (JINR), Dubna (Russia)	Z. Sadigov	1
Petersburg Nuclear Physics Institute (PNPI*),* Gatchina (Russia)	S. Belostotski	2
Justus-Liebig-Universitaet Giessen (JLU), Germany	R. Novotny, H.-G. Zaunick	1

4.2. THIRD PARTIES INVOLVED IN THE PROJECT (INCLUDING USE OF THIRD PARTY RESOURCES)

Please complete, for each participant, the following table (or simply state "No third parties involved", if applicable):

Participant: GSI

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)?	No
If yes, please describe and justify the tasks to be subcontracted	
Does the participant envisage that part of its work is performed by linked third parties[4]?	Yes
Photon irradiation facility at the Justus-Liebig University Giessen	

[4] A third party that is an affiliated entity or has a legal link to a participant implying a collaboration not limited to the action. (Article 14 of the Model Grant Agreement).

Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)?	No
If yes, please describe the third party and their contributions	

Participant: OeAW

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)?	No
If yes, please describe and justify the tasks to be subcontracted	
Does the participant envisage that part of its work is performed by linked third parties[5]?	Yes
Proton irradiation at the Paul-Scherrer Institut, Swizzerland	
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)?	No
If yes, please describe the third party and their contributions	

Participant: INFN

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)?	No
If yes, please describe and justify the tasks to be subcontracted	
Does the participant envisage that part of its work is performed by linked third parties[6]?	Yes
Catania, Pavia	
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)?	No
If yes, please describe the third party and their contributions	

Participant: CUNI

Does the participant plan to subcontract certain tasks (please note that core tasks of the project should not be sub-contracted)?	No
If yes, please describe and justify the tasks to be subcontracted	
Does the participant envisage that part of its work is performed by linked third parties[7]?	Yes
Research Nuclear Reactor Prague (REZ)	
Does the participant envisage the use of contributions in kind provided by third parties (Articles 11 and 12 of the General Model Grant Agreement)?	No

5 A third party that is an affiliated entity or has a legal link to a participant implying a collaboration not limited to the action. (Article 14 of the Model Grant Agreement).

6 A third party that is an affiliated entity or has a legal link to a participant implying a collaboration not limited to the action. (Article 14 of the Model Grant Agreement).

7 A third party that is an affiliated entity or has a legal link to a participant implying a collaboration not limited to the action. (Article 14 of the Model Grant Agreement).

If yes, please describe the third party and their contributions

GSI/HIM: GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt
Helmholtzinstitut, Mainz

GSI and HMI are strongly involved in hadron physics experiments. The major task of GSI is the development and operation of accelerators for heavy ions. It will become the campus for FAIR, the Facility of Antiproton and Ion Research in Darmstadt, a project that is just entering the central phase of its construction. The new instrumentation in this laboratory for hadron physics will be SIS100 (+SIS300), a proton synchrotron up to 30 GeV and a High Energy Storage Ring (HESR) for antiprotons. For the development of new detector components, as is proposed in this JRA, there exists a powerful infrastructure including technical support combined with the required expertise of specialists. The strong liaison with universities and the resources of young students from there make GSI/HIM a unique place for advancing physics and performing novel detector design.

Prof. Dr. Herbert Orth

Born: 22. October 1944, male
Physics Education: München and Heidelberg
1970: Diploma thesis in Heidelberg
1972: PhD thesis, Heidelberg, "Measurement of the nuclear quadrupole moments of Li^6 and Li^7 using the atomic double resonance technique"
Academic career and research activities:
1974-1976 Postdoctoral fellow Yale University (Max Kade), Muonium Experiments at Los Alamos Meson Physics Facility (LAMPF)
1976-1983 Wissenschaftlicher Assistent Univ. Heidelberg, Experiments at the Swiss Institute of Nuclear Research (SIN), Atomic and Solid State spectroscopy using muons, Muonic atoms.
1981 Habilitation at University Heidelberg "Spectroscopy of Muonium and the Muonic Helium Atom"
1983 Lehrstuhlvertretung Univ. Mainz
1984-1986 Associate Professor Yale University, New Haven, Experiments at LAMPF (Lamb shift in muonium, muonium- antimuonium conversion, muonic helium)
since 1986 Senior research scientist at GSI: Management responsibilities for accelerator upgrade to SIS18, Multifragmentation in heavy ion collisions (ALADIN, INDRA), HESR-PANDA, Participation in HadronPhysics EU-projects since 2005

JRAx: SiPM2020 REQUESTED EC CONTRIBUTION PER BUDGETARY ITEM AND PER BENEFICIARY						
Contr. No	**Contractor Acronym**	**Personnel (EUR)**	**Other costs (durables, consumables, travel, workshops) (EUR)**	**Total direct costs (EUR)**	**Indirect costs (EUR)**	**Requested EC contribution (EUR)**
	GSI	17,000	40,000	57,000	14,250	71,250
	OeAW	17,000	9,000	26,000	6,500	32,500
	INFN	34,000	13,000	47,000	11,750	58,750
	CUNI	34,000	12,000	46,000	11,500	57,500
	TOTAL	**102,00**	**74,000**	**176,000**	**44,000**	**220,000**

Table 3.1c List of deliverables

Deliverable (number)	Deliverable name	Work package number	Short name of lead participant	Type	Dissemination level	Delivery date
1	Neutron irradiation study	1.1	CUNI	R	PU	36
2	Proton irradiation study	1.2	OeAW	R	PU	36
3	Electron irradiation study	2.1	INFN	R	PU	36
4	Photon irradiation study	2.2	GSI	R	PU	36

KEY
Deliverable numbers in order of delivery dates.
Type (Use one of the following codes):
R: Document, report (excluding the periodic and final reports)
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc.

Dissemination level:
Use one of the following codes:
PU = Public, fully open, e.g. web
CO = Confidential, restricted under conditions set out in Model Grant Agreement
CI = Classified, information as referred to in Commission Decision 2001/844/EC.

Delivery date
Measured in months from the project start date (month 1)

Table 3.2.a List of milestones

Milestone number	Milestone name	Related work package(s)	Estimated date	Means of verification
JRA32.1	Intermediate results with neutron	JRA32	24	Presentation, decisions for next batch of samples
JRA32.2	Intermediate results with protons	JRA32	24	Presentation, decisions for next batch of samples
JRA32.3	Intermediate results with electrons	JRA32	24	Presentation, decisions for continuation at other facility
JRA32.4	Results with X-rays	JRA32	36	Presentation of photon results

KEY
Estimated date
Measured in months from the project start date (month 1)

Means of verification
Show how you will confirm that the milestone has been attained. Refer to indicators if appropriate. For example: a laboratory prototype that is 'up and running'; software released and validated by a user group; field survey complete and data quality validated.

Table 3.2.b Critical risks for implementation

Description of risk	**Work package(s) involved**	**Proposed risk-mitigation measures**

3.4 RESOURCES TO BE COMMITTED

Table 3.4.a ‘Other direct cost’ items

[Please complete the table below for each participant if the sum of the costs for ‘travel’, ‘equipment’, and ‘goods and services’ (other than related to provision of trans-national or virtual access) exceeds 15% of the personnel costs for that participant (according to the budget table in section 3 of the proposal administrative forms).]

Participant xxx/GSI	Cost (€)	Justification
Travel	4.000	Meetings of the SiPM2020 of the project participants. Visits to the partners from industry/producers. Presentation and discussion of results on conferences. Travel to the radiation facilities.
Equipment		
Other goods and services	36,000	Costs for engineering wafers with customs design and participation in technology runs at the producer (industry)
Access cost (if applicable)		
Travel and subsistence for trans-national access (if applicable)		
Total	40,000	

Participant xxx /OeAW	Cost (€)	Justification
Travel	3,000	Meetings of the SiPM2020 of the project participants, Travel to the radiation facilities, Presentation at conferences, Visits to the producers
Equipment		
Other goods and services	6,000	Material costs for test bench, Dosimetry material
Access cost (if applicable)		
Travel and subsistence for trans-national access (if applicable)		
Total	9,000	

Participant xxx/INFN	Cost (€)	Justification
Travel	5,000	Meetings of the SiPM2020 of the project participants, Travel to the radiation facilities, Presentation at conferences, Visits to the SiPM producers
Equipment		
Other goods and services	8,000	Material costs for experimental set-up
Access cost (if applicable)		
Travel and subsistence for trans-national access (if applicable)		
Total	13,000	

Participant xxx/CUNI	Cost (€)	Justification
Travel	4,000	Meetings of the SiPM2020 of the project participants, Travel to the radiation facilities, Presentation at conferences
Equipment		
Other goods and services	8,000	Material costs for radiation safety and dosimetry

Access cost (if applicable)		
Travel and subsistence for trans-national access (if applicable)		
Total	12,000	

Dissemination and exploitation measures should address the full range of potential users and uses including research, commercial, investment, social, environmental, policy making, setting standards, skills and educational training.
The approach to innovation should be as comprehensive as possible, and must be tailored to the specific technical, market and organisational issues to be addressed.
Explain how the proposed measures will help to achieve the expected impact of the project. Include a business plan where relevant.
Where relevant, include information on how the participants will manage the research data generated and/or collected during the project, in particular addressing the following issues:[2]

- *What types of data will the project generate/collect?*
- *What standards will be used?*
- *How will this data, including data generated by user projects, be exploited and/or shared/made accessible for verification and re-use? If data cannot be made available, explain why.*
- *How will this data be curated and preserved?*

Include information about any open source software used or developed by the project.
Outline the strategy for knowledge management and protection. Include measures to provide open access (free on-line access, such as the 'green' or 'gold' model) to peer-reviewed scientific publications which might result from the project[3].
Open access publishing (also called 'gold' open access) means that an article is immediately provided in open access mode by the scientific publisher. The associated costs are usually shifted away from readers, and instead (for example) to the university or research institute to which the researcher is affiliated, or to the funding agency supporting the research.
Self-archiving (also called 'green' open access) means that the published article or the final peer-reviewed manuscript is archived by the researcher - or a representative - in an online repository before, after or alongside its publication. Access to this article is often - but not necessarily - delayed ('embargo period') as some scientific publishers may wish to recoup their investment by selling subscriptions and charging pay-per-download/view fees during an exclusivity period.]

The dissemination and exploitation of the results gained in the proposed project will be guaranteed during and after the project period by different methods. In regular intervals, i.e. several times a year, there will be sub-groups meetings or even meetings of all participants of this project in order to present and discuss achieved results. The presentations will be collected and stored on free-access web-pages of this project, allowing full access to everybody.
Status reports and results will be presented on conferences, symposia, and on collaboration meetings of potential users of the developed technologies and results. These external presentations of the results and work plans guarantee a close contact with potential users of the technologies developed in this project. By this it is ensured that new requests and information from the scientific community can be considered in the running project. In addition, the scientific community will be informed about the ongoing research and expected outcome.
Similarly to the internal meetings here the presentations will be made available by open-access web-pages and/or via proceedings. Reached deliverables will be presented and discussed in written reports, which typically will be made accessible in, e.g., peer-reviewed journals (preferably open access publishing), in the electronic e-Print archive (arXiv), and in bachelor, master, and doctoral theses. In the latter case the theses will also be freely accessibly via the homepages of the corresponding University. In all cases the documents/codes will be stored as "machine-readable electronic copy". In order to allow for a validation of the scientific publications, the research data will be made accessible, e.g. by a data repository.

Experimental setups and devices developed within this proposed project will be made accessible for school pupils, students, and young researches for educational and scientific purposes, e.g. practical exercises and theses. Furthermore, the projects and experimental devices will be presented to the general public e.g. during open house days.
The software, which will be developed within this project, will be based if possible on commonly available standard languages such as C++, FORTRAN, LABVIEW. Furthermore, if possible also the data analysis programs will be developed by using open, free software such as ROOT and GNUPLOT.

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[2] For further guidance on research data management, please refer to the H2020 Online Manual on the Participant Portal.
[3] Open access must be granted to all scientific publications resulting from Horizon 2020 actions. This obligation applies to beneficiaries, not to trans-national access users. Further guidance on open access is available in the H2020 Online Manual on the Participant Portal.

Several of the proposed sub-projects require a close cooperation with the European industry since usually commercial products do not provide the full required functionality. Therefore, significant further developments of industrial products have to be made and the methods and results developed in this project can directly be made accessible to industry.

b) Communication activities

[Describe the proposed communication measures for promoting the project and its findings during the period of the grant. Measures should be proportionate to the scale of the project, with clear objectives. They should be tailored to the needs of various audiences, including groups beyond the project's own community. Where relevant, include measures for public/societal engagement on issues related to the project.
Describe how the impact of communication activities will be monitored to ensure optimum efficiency.]

In order to inform the scientific community and to attract the interest from industry and general public, status reports and recent results will be presented regularly on conferences, symposia, and on collaboration meetings of potential users of the developed technologies and results.
Experimental setups and devices developed within this proposed project will be made accessible for school pupils, students, and young researches for educational and scientific purposes, e.g. for practical exercises and theses. Furthermore, the projects and experimental devices will be presented to the general public, e.g. during open house days.
The groups involved in this proposed projects will prepare web-pages, e.g. at their home institutes, in order to inform the scientific community, industry, and general public about the project purposes as well as on their outcome. The presentation on these pages will cover both the needs of the scientific community, but will also be understandable for the general public.
The impact of communication activities can be monitored in different ways. In case of web-pages presenting the scope and results of the projects, it is possible to monitor the number of external accesses on this page. Furthermore, generally understandable and attractive short project summary movies can be made on broadly used platforms, such as YouTube. Here the number of accesses as well as the evaluation of the viewers can be observed. Similarly, in case of (electronically available) scientific publications the number of accesses as well as citations can be considered.

3. IMPLEMENTATION

[Definitions:
'Work package' means a major sub-division of the proposed project.
'Deliverable' means a distinct output of the project, meaningful in terms of the project's overall objectives and constituted by a report, a document, a technical diagram, a software etc.
'Milestones' means control points in the project that help to chart progress. Milestones may correspond to the completion of a key deliverable, allowing the next phase of the work to begin. They may also be needed at intermediary points so that, if problems have arisen, corrective measures can be taken. A milestone may be a critical decision point in the project where, for example, the consortium must decide which of several technologies to adopt for further development.]

(maximum length: ½ page)

3.1.2 Timing of the different work packages and their components

Work package number	JRA32
Work package acronym	SiPM2020
Work package title	Radiation Resilience of Avalanche Micro-Pixel Photo Sensors (SiPM)

TASKS/Subtasks	**2015**				**2016**				**2017**			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
1. Irradiation studies using hadrons												
1.1 Neutron Irradiation Studies								**1**				
1.2 Proton Irradiation Studies								**2**				
2. Irradiation studies using electrons and photons												
2.1 Electron Irradiation Studies								**3**				
2.2 Photon Irradiation Studies												**4**

(Timelines are indicate in grey, milestones with black boxes)