Curriculum Vitae

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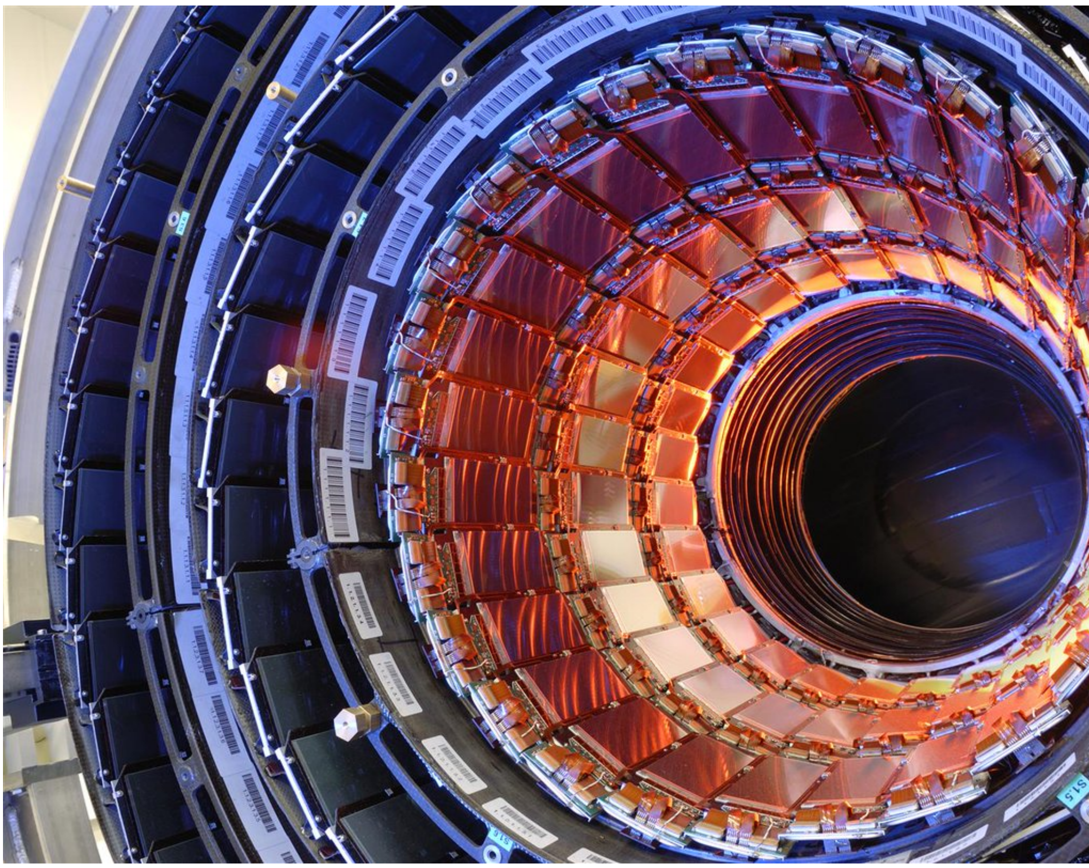

Contents

1 Academic career and present responsibilities and commitments

Lodovico Ratti joined the Electronic Instrumentation Group, led by prof. Pier Francesco Manfredi, in 1995 and graduated in Electronic Engineering, summa cum laude, in 1996 from the University of Pavia, Pavia, Italy. He received his PhD in Electrical, Electronic and Computer Engineering from University of Pavia in 1999, working on the optimization of front-end circuits in junction field-effect transistor technology for applications in harsh radiation environments. In 2000 he won a two year fellowship to work on the design of low noise integrated circuits in a detector-compatible technology, obtaining then a position as an assistant professor in 2001. In 2015 he became an associate professor of electronics with the Department of Electrical, Computer and Biomedical Engineering, University of Pavia. Since November 2021 he has been a full professor with the same department. His main interests are in the field of the design of low-noise analog circuits (in particular in CMOS technology) for the readout of radiation detectors, of the noise characterization of semiconductor devices and of the study and modeling of ionizing and non-ionizing radiation effects in microelectronic circuits and components. Lodovico Ratti

- is the head of the Electronic Instrumentation Group, and responsible for the Electronic Instrumentation Laboratory, Department of Electrical, Computer and Biomedical Engineering,
- is a senior member of the Institute of Electrical and Electronics Engineers (IEEE),
- is a member of the Radiation Instrumentation Steering Committee (RISC) of the IEEE Nuclear and Plasma Sciences Society,
- is secretary of the Nuclear and Plasma Sciences Italy Section,
- is a technology research fellow with the Italian Institute for Nuclear Physics (Istituto Nazionale di Fisica Nucleare, INFN),
- is a member of the Academic Board of the Ph.D. School in Microelectronics, University of Pavia,
- is a member of the board (giunta) of the Department of Electrical, Computer and Biomedical Engineering.

Lodovico Ratti is author or co-author of 280 among papers published in peer-reviewed journals or conference proceedings, works presented at international conferences and book chapters (from the Scopus database, as of March 2021: h-index=21, number of citations=3300 without self-citations). The research experience and the main scientific and teaching appointments are summarized in the following.

2 Scientific activity

As already briefly mentioned in the introduction to this document, Lodovico Ratti has been and is involved in the following research areas:

- design and characterization of low noise front-end circuits for radiation detectors, mostly based on integrated circuit technology;
- noise characterization of electronic and microelectronic devices and circuits, involving the development of specific interface stages for noise amplification and measurement;
- study and modeling of the damage induced by ionizing and non-ionizing radiation in semiconductor devices and circuits.

The research activity and the areas of interest are described in more details in the following. Reference is made, when deemed appropriate and useful, to the publications listed in section 7 of this document.

2.1 Low noise front-end design for radiation detectors

Most of Lodovico Ratti's research activity has been carried out in the field of low noise design of analog readout circuits for radiation detectors. The design activity has been mainly based on integrated circuit processes, although some early work relied on discrete component technologies. During his career, Lodovico Ratti has been working on the development of electronics both for hybrid and monolithic sensors, in standard planar and three-dimensional, vertically integrated technology. Recently, he has been involved in the development of low-noise single photon avalanche diodes (SPADs) for charged particle detection.

2.1.1 Development of readout circuits in discrete component technology

Lodovico Ratti worked on the design of a four-channel, discrete component front-end circuit with Si-Ge bipolar transistor input for the four-quadrant gas detector of the Large Hadron Collider (LHC) beam monitor at CERN, Geneva, Switzerland [**J172**]. The activity was carried out in collaboration with the Accelerator Technology and Applied Physics Division, Lawrence Berkeley National Laboratory, Berkeley, USA. The purpose of the measurement system is that of optimizing the accelerator operating condition through a closed loop control of the main geometrical parameters of the beam. To avoid the effects from the very high levels of radiation in the surroundings of the detector, the front-end electronics needs to be located far away from the beam interaction points. Connection between the readout electronics and the detector is ensured by a coaxial cable, whose impedance matching is achieved by means of the so called cold resistance method, taking advantage of the dynamic input impedance of the first stage of the channel, the charge preamplifier, and guaranteeing low noise readout of the signal. The high collision rate of the LHC beam (40 MHz) and the demanding noise specifications of the application require that bipolar transistors with very high transition frequency and low base spreading resistance be used in the charge preamplifier [**J157, J154**]. The latter specification was met by using four devices in parallel as the input device. The system was successfully tested at the CERN

Super Proton Synchrotron facility and at the Advanced Light Source of the Lawrence Berkeley National Laboratory [**J147, J142**].
In the framework of the AUGER project [**J137**], involving several research groups from Europe, USA and South America, Lodovico Ratti was involved in the development of the front-end channel for a fluorescence detector, consisting of a photomultiplier tube pixel camera. The AUGER research program aims at studying cosmic ray sources with energies exceeding 10^{18} eV. The front-end electronics transmits the PMT signals to the ADCs, retaining the timing and amplitude information carried by signals which span a wide (15-16 bit) dynamic range. The analog processing channel consists of a low-noise linear section, including an antialiasing filter, followed by a circuit of original conception, performing a high accuracy bilinear compression of the signal dynamic range [**J169, J167, J166**]. This makes it possible to work with a 12 bit ADC. Quantization errors are minimized by suitably choosing the compression parameters.

2.1.2 Front-end circuits for microstrip detectors

Lodovico Ratti contributed to the design and characterization of the AToM (A Time-over-Threshold Machine) chip, a mixed analog and digital circuit fabricated in a 0.8 μm CMOS radiation tolerant technology [**J170**]. The chip, to be used in the vertex detector of the BaBar experiment [**J158**], conducted by an international collaboration at the e^+e^- linear collider of the Stanford Linear Accelerator Center (SLAC), Menlo Park, USA, includes 128 channels capable to process the signals delivered by the same number of microstrip detectors. Overall 150000 channels have been installed in the detector. The channel, including a charge preamplifier, a second order, semi-Gaussian unipolar shaper with programmable peaking time (from 100 to 400 ns), a comparator and a counter, makes it possible to directly digitize the signal amplitude through the so called Time-over-Threshold (ToT) technique. The chip has been demonstrated to tolerate total ionizing doses up to 2.4 Mrad(SiO_2) with no significant performance degradation [**J173**].
The silicon microstrip detector for the BTeV experiment at Fermi National Accelerator Laboratory, Batavia, USA, was conceived to include a total of 129000 channels, split in 7 stations, each including 3 silicon strip planes. In order to readout the signal from the strips, a full-custom integrated circuit, called the FSSR (Fermilab Silicon Strip Readout) chip [**J133, J126, J106**], was designed in a 0.25 μm CMOS process. Lodovico Ratti contributed to the design and characterization of the chip, including 128 channels, each consisting of a charge preamplifier, an RC^2-CR shaper with programmable peaking time (from 65 to 130 ns), a baseline restorer, a comparator and a 3-bit flash ADC. N-channel transistors in the circuit were designed using a hardening-by-layout approach, based on an enclosed layout technique, for improved radiation tolerance [**C75**]. The design was carried out in collaboration with the Particle Physics Division, Fermi National Accelerator Laboratory.
Lodovico Ratti also contributed to the design of the readout channel for microstrip sensors to be used in the vertex detector of the SuperB experiment [**J53**].

2.1.3 Development of monolithic sensors in detector-compatible processes

Integration of the readout electronic circuit, or of part of it, in the same substrate with the microstrip detectors the circuit has to read out, can improve the mechanical stability of the detection system. This solution can also beneficially impact on the noise performance of the detector by minimizing the stray capacitance in the interconnection between the sensor and the readout circuit. Starting from these considerations, Lodovico Ratti, in collaboration with groups from Bergamo, Pisa, Trieste and Trento Universities, worked on the development of mixed analog and digital circuits in a detector-grade process with high resistivity substrate [**J165, J156, J155, J152, J135, J134, J121, J117, J104, J39**]. The research program has led to the fabrication of fully monolithic JFET/CMOS circuits, including an analog section, with a charge preamplifier followed by a shaper, and a digital one consisting of a decoder and a multiplexer. Different reset techniques were implemented in the charge preamplifier with the purpose of optimizing the noise performance [**J145**]. Radiation hardness tests with ionizing radiation and proton sources, which were instrumental in qualifying the developed technology, proved the intrinsic radiation tolerance of junction FETs [**J146, J136**].

2.1.4 Monolithic active pixel sensors in CMOS technology

In the framework of a few research programs funded by the Italian Ministry for Education, University and Research (Ministero dell'Istruzione, dell'Università e della Ricerca, MIUR) and by INFN, Lodovico Ratti worked on the development of CMOS monolithic active pixel sensors (MAPS) for charged particle detection, as a possible replacement for hybrid pixels in tracking applications. The most attractive feature of CMOS MAPS as to their use in particle physics lies in their relatively thin sensitive volume, minimizing multiple scattering through reduction of material budget in the beam interaction region and improving the system accuracy in particle momentum measurement. With respect to the standard 3 or 4 N-type transistor architecture of CMOS MAPS for applications in the visible spectrum, the device developed by Lodovico Ratti, known as deep N-well (DNW) or triple-well MAPS, relies on the integration of a full readout channel (including a preamplifier and a shaper) for capacitive detectors in a large area sensitive electrode, consisting of a deep N-well layer [**J127, J123, J122, J116, J115, J114, J100, J98, J97, J95**]. The front-end circuit, including both N- and PMOS FETs, can therefore be included in a digital readout architecture implementing sparsification techniques [**J93, J92**] to significantly reduce the amount of data to be delivered off chip. Different structures, fabricated in commercial 130 nm, 90 nm and 65 nm CMOS technologies [**J70, J66**] were fabricated and tested, proving the feasibility of the proposed approach. A180 nm CMOS process with both deep N-well and deep P-well options was exploited for the design of MAPS with small detector area (and accordingly small input capacitance) [**J65, J64**]. Vertical integration technologies, based on through silicon vias (TSVs) and wafer level, direct bonding techniques were also explored for the fabrication of small pitch, DNW-MAPS arrays with token-passing readout architecture [**J88, J80, J79, J78, J77, J75, J74, J68, J62, J59, J44**]. The effects of substrate thinning [**J52**] and ionizing and non-ionizing radiation [**J94, J89, J69, J63, J51, B1**] on the device performance were thoroughly analyzed. A simulation tool was also developed, capable of accurately predicting the degradation of the charge collection properties in MAPS exposed to neutrons [**J60**].

2.1.5 Front-end electronics for hybrid pixel detectors

In the frame of the PixFEL research program, Lodovico Ratti worked on the development of a readout channel for applications to X-ray diffraction imaging at free electron lasers (FELs) [**J45, J43, J37, J36**]. The circuit, designed in a 65 nm CMOS technology, was meant to read out the signal from slim edge pixel sensors with a 100 μm pitch [**J35, J27**], according to a hybrid detector approach. The analog front-end circuit can achieve an input dynamic range of 80 dB by leveraging a novel signal compression technique based on the non-linear features of MOS capacitors [**J42, J41, J17**]. Trapezoidal shaping is accomplished through a time-variant circuit, performing gated integration and correlated double sampling. A small area, low power 10 bit successive approximation register (SAR) ADC, operated in a time-interleaved fashion, is used for numerical conversion of the amplitude measurement. Operation at 5 MHz of the analog channel including the shaper was demonstrated. Also, the channel was found to be compliant with single 1 keV photon resolution at 1.25 MHz. The ADC provides a signal-to-noise ratio (SNR) of 56 dB, corresponding to an equivalent number of bits (ENOB) of 9 bits, and a differential non linearity smaller than 1 LSB at a sampling rate slightly larger than 1.8 MHz [**J32**]. A test structure including a 32 × 32 array of readout channels was designed, fabricated and fully characterized [**J33, C4**]. Radiation tolerance up to a 1 Grad(SiO_2) dose, as expected in applications to free electron lasers, was evaluated for the single blocks (charge preamplifier, shaper) making up the readout channel [**C10**].
The Italian research program CHIPIX65, funded by INFN, and the international RD53 collaboration, led by CERN and including several European research centers and universities, both aimed at the development of the pixel readout chip for the phase-2 upgrades of the CMS (a Compact Muon Solenoid) [**J49**] and ATLAS (A Toroidal LHC ApparatuS) [**J19**] experiments at the LHC. While the CHIPIX65 collaboration completed its campaign in 2018, at the time of writing this document, RD53 activity is in full swing, with tests running on the most recent chip prototypes. Lodovico Ratti in particular contributed to the design and characterization of the front-end channel for the upgraded version of the CMS pixel detector. The circuit design, carried out in a 65 nm CMOS technology, had to comply with extremely tight specifications in terms of power dissipation (<5 μW reserved for the analog section), area (about half of the overall pixel area, 50 μm × 50 μm), speed (peaking time smaller than 25 ns) noise occupancy (below 10^{-6}) and radiation hardness (tolerance to a total dose of 500 Mrad(SiO_2) is required) [**J28, J25, J24, J8**]. In order to minimize the area and the power dissipation, the channel was designed according to a shaper-less approach, where the filtering action of the circuit is incorporated into the charge preamplifier. A Krummenacher feedback stage was designed to comply with the expected radiation-induced increase in the detector leakage current after some time in the experiment. Signal amplitude is converted into digital through a high speed comparator, based on a transimpedance scheme [**C26**], and a counter, implementing the Time-over-Threshold method, mainly exploited to compensate for time walk effects. A local DAC is used for adjusting the comparator threshold in order to minimize threshold dispersion among channels [**J3**]. Radiation tolerance tests have been performed, both on single channels and on close to experiment-size chips, demonstrating their compliance with the application specifications [**J15**]. Lodovico Ratti also contributed to the development of IP blocks for the pixel readout chip, including bandgap voltage references [**J38**] and high speed drivers and receivers.

2.1.6 SPAD detectors in CMOS technology

Single photon avalanche diodes can guarantee state-of-the-art space and time resolution in capturing weak optical signals while covering quite a large set of applications, including optical ranging, fluorescence lifetime imaging, positron emission tomography, Raman spectroscopy and single molecule fluorescence spectroscopy. In relatively recent times, CMOS SPAD technologies have been emerging as an extremely flexible solution for the design of sensor arrays with monolithically integrated processing electronics. Lodovico Ratti has been working on the design and characterization of low-noise CMOS SPADs for charged particle tracking based on vertically interconnected arrays of sensors [**J47, J23, J22, J14, J7, J2**]. The first prototype of a two-tier SPAD detector, providing a coincidence signal when a particle simultaneously strikes two overlapping sensors, was fabricated in a commercial 150 nm process and successfully tested. This solution leads to a strong reduction of the dark count rate (DCR), as the coincidence signals generated by concurrent random dark current pulses occurring in two overlapping pixels can be made a small fraction of the DCR from each individual sensor, depending on the duration of the coincidence window. With this approach, median dark count rates as low as 50 μHz/μm^2 have been obtained. Radiation effect studies performed on SPADs fabricated in different technologies, the already mentioned 150 nm one and a high-voltage, 180 nm CMOS process, provided interesting information about the damage mechanisms underlying dark count rate increase [**J13, J12, J11, J6**].

2.1.7 Optimum design criteria for low noise front-end circuits

Throughout his research activity on different subjects, Lodovico Ratti has been working on establishing criteria to enable the optimum design of readout channels for capacitive detectors under the constraints set by the experiment specifications and/or by the fabrication technology characteristics. Based on the noise features of a given technology, the resolution limits of the front-end circuit can be predicted based on considerations relevant to the ENC performance [**J150, J124, J112, J111, J87, J50**]. The different sensitivity to ionizing radiation of P- and N-channel JFETs can define a criterion for the choice of the polarity of the preamplifier input device according to the peaking time requirements set by the specific application [**J171**]. In the case of circuits in CMOS technology, operation of the input device of the charge preamplifier in moderate or weak inversion region may affect and modify the capacitive matching criterion for equivalent noise charge minimization [**J164, J162**]. Minimum ENC can be achieved by acting on the $I_C \times \tau$ (collector current $\times$ shaping time) product in the case of readout channels with bipolar transistor input [**J157**]. Again in CMOS technologies, compliance with radiation hardness specifications may impact on the design of the preamplifier input transistor (for instance, on the choice of the number of fingers, given the overall device width), when one takes into account ionizing radiation effects on 1/f noise [**J163, J101, J99, J90, J76**]. On the other hand, advance in CMOS technology, with the progressive reduction of the gate oxide thickness, can lead to a non negligible contribution from the noise in the gate current, which has to be taken into account for minimum noise design [**J96**]. For the purpose of minimizing the noise hit rate in a charge measuring system including a comparator for false event discrimination, the function to be minimized should actually take into account the impact of the input device design not only on the overall noise, but also on the offset at the comparator input [**J95**]. For this purpose, the design of the digital-to-analog converter typically included in multichannel readout chips to minimize the threshold dispersion among different channels can be optimized once the needed dynamic range (related to the pre-correction dispersion) or the available number of bits (related to the DAC complexity) are given [**J67**].

2.2 Noise characterization of semiconductor devices

Since the beginning of his career as a researcher, Lodovico Ratti has been working on the noise characterization of semiconductor devices with the purpose, on the one hand, of monitoring possible changes in the noise features of microelectronic processes with their evolution and, on the other hand, more from a designer point of view, of anticipating the fundamental limitations to the sensitivity of analog front-end circuits. Noise measurements can also be considered as a powerful tool to check the quality of a fabrication technology and to explain the mechanisms underlying radiation damage in semiconductor devices. Within this research activity, Lodovico Ratti developed noise amplifying circuits for accurate noise power spectral density measurement with commercial spectrum analyzers. Noise measurement campaigns were also carried out in collaboration with multinational semiconductor companies (STMicroelectronics, Marvell).

2.2.1 Noise measurement and modeling

Lodovico Ratti has been working on the measurement of the power spectral density of the noise in CMOS transistors belonging to bulk and SOI technology nodes ranging from 250 nm to 65 nm. Recently, devices from a 14 nm finFET technology have also been characterized. Data from measurement of the series noise, spanning a frequency range from 1 kHz to around 100 MHz, provided information about possible excess contributions at high frequency, for instance due to short channel effects, and about the features of flicker noise (amplitude and slope coefficient), typically dependent on the device polarity ad on the technology node [**J131, J120, J102, C5**]. Series noise measurements were also used to model the effects of radiation-induced accumulation of holes in the shallow trench isolations [**J113, J76**]. In the case of the more scaled technologies among those taken into consideration (from the 130 nm node on), noise in the gate current was measured, with emphasis on the different contributions to the overall shot noise originating from quantum tunneling effects [**J96**].
Noise measurements were also performed on bipolar transistors, on discrete components and on devices from a BiCMOS SOI technology as well, both in the collector and in the base current, confirming the behavior expected for the power spectral density of shot and 1/f noise contributions with the relevant quiescent current [**J144**].
In γ-ray irradiated JFETs from different technologies, noise measurements emphasized the emergence of one or more radiation-induced Lorentzian components with characteristic frequencies depending on the device polarity, therefore pointing to a device polarity related damage mechanism [**J174**]. Noise analysis of JFETs was also used for the qualification of a detector-grade fabrication process for monolithic sensors [**J146, J117, J105**].

2.2.2 Instrumentation for noise measurements

The measurement of the power spectral density of the noise in a semiconductor device cannot be directly performed by means of a spectrum analyzer, whose intrinsic noise generally exceeds the noise under measurement. A circuit is needed, capable of biasing the device under test (DUT) in a well defined (possibly of users' choice) operating condition, while selectively amplifying the specified noise source and adding negligible noise to the overall measurement setup. The circuit architecture also depends on the DUT features.
For series noise measurements in MOSFET transistors, where the noise corner (the frequency at which flicker noise equals thermal noise) can be in the few MHz range, Lodovico Ratti contributed to the development of a transimpedance amplifier, with a bandwidth well in excess of 100 MHz. Both a BJT based, discrete component solution and one relying on commercial operational amplifiers with high gain-bandwidth product were proposed [**J161**].
Also in the case of parallel noise measurements in bipolar and MOSFET transistors, Lodovico Ratti developed an interface amplifier based on a transimpedance architecture. Use of a JFET as the input device of the noise amplifying circuit made it possible to achieve an input parallel noise as low as 0.3 $pA/\sqrt{Hz}$, while maintaining the operating frequency in the 10 Hz to 1 MHz range. Similar results were subsequently obtained in a circuit version based on a commercial amplifiier [**J144, C48**].

2.3 Analysis and modeling of radiation damage in semiconductor devices

Modeling radiation effects in semiconductor devices is of paramount importance to anticipate the performance degradation of front-end circuits for radiation detectors operated in harsh radiation environments, like the fundamental physics experiments to be carried out at hadronic particle colliders or at free electron lasers. For this purpose, Lodovico Ratti has been working on the study of the radiation tolerance of circuits and single transistors from different technologies. In particular, Lodovico Ratti studied the effects of ionizing radiation, at different dose rates and different integrated doses, on N- and P-chanell MOSFETs from different technology nodes [**J153, J151, J125, J107, J91**]. The results from the characterization of NMOS devices belonging to 130 nm, 90 nm and 65 nm processes were used to substantiate a model relating the increase in white and 1/f noise noise to the radiation-induced accumulation of holes in the shallow trench isolations [**J113, J103, J99, J76**]. Defect creation close to the gate oxide/channel interface was instead proven to be the main noise degradation mechanism in transistors exposed to extremely high doses of ionizing radiation, close to 1 Grad(SiO_2) [**J18**]. Effects of ionizing radiation was also studied in CMOS devices fabricated in a vertical integration technology [**J61**].
In junction field-effect transistors belonging to different fabrication processes, exposure to γ-rays, protons and neutrons was found to be responsible for the increase in 1/f noise and for the emergence of Lorentzian contributions, whose characteristic frequencies seem to depend on the device polarity and not on the technology [**J174, J171**]. Comparison between γ-ray and proton effects made it possible to ascertain that, in both cases, atomic displacement is the main mechanism underlying device performance degradation [**J136**].
The effects of the ionizing dose rate, of interest for the qualification of technologies in low dose rate environments such as in space applications, was studied in particular in bipolar transistors,

which are known to be subjected to the so called enhanced low dose rate sensitivity (ELDRS) effect [**J143, J132**].
CMOS SPADs have also been irradiated with X-ray doses up to 1 Mrad(SiO_2) and neutron fluences of 1 MeV equivalent neutrons up to 10^{11} cm^{-2} [**J12, J11, J6**]. In particular, in SPADs exposed to neutrons, the distribution of the dark count rate increase was found to be directly related with the distribution of the energy deposited in the active region of the device, in agreement with the NIEL (non-ionizing energy loss) hypothesis [**J13**].

2.4 Summary of the research experience, including ongoing activity

Following is a summary of the scientific activity in which Lodovico Ratti has been involved, from the beginning of his career, as a Ph.D. student, until these days.

2021 - present: development of front-end circuits and IP blocks in 28 nm CMOS technology for applications at future hadronic colliders (FALAPHEL call experiment with INFN);

2020 - present: development of a front-end circuit for pixel detectors to be used in X-ray diffraction imaging and ptychography applications at synchrotron light sources with almost continuous beam (FALCON project, in collaboration with the Detectors Group in the X-ray Science Division, Argonne National Laboratory, USA);

2020 - present: study of the gate current features in CMOS transistors from a 28 nm CMOS technology (FINFET16V2 R&D experiment with INFN);

2019 - present: study of the noise and radiation tolerance characteristics of a 110 nm CMOS technology for monolithic sensors with a high resistivity substrate; development of rad-hard IP blocks (bandgap voltage reference, high speed driver and receiver) in the same technology (ARCADIA call experiment with INFN);

2018: development of detectors based on a monolithic, fully depleted technology for X-ray imaging at FEL light sources (XDET R&D experiment with INFN);

2014 - present: development of dual-layer CMOS SPAD detectors with integrated electronics for thin, low power, low noise particle trackers (APiX and ASAP R&D experiments with INFN);

2014 - present: design of the front-end channel for the phase-2 upgrade of the CMS inner pixel tracker (CHIPIX 65 and CMS experiments with INFN, RD53 international collaboration);

2014 - 2017: development of building blocks and of the enabling technologies for fast X-ray imagers at the next generation FELs (PixFEL R&D experiment with INFN);

2013: activity within the research contract “Caratterizzazione dei dispositivi in tecnologia superscalata del gruppo Marvell” with Marvell;

2009 - 2013: design of the front-end electronics for the microstrip detector and of monolithic sensors (in planar and 3D technologies) for the innermost layer of the SuperB particle tracker (SUPERB experiment with INFN);

2006 - 2009: development of CMOS monolithic pixel sensors for the ILC vertex detector (P-ILC R&D experiment with INFN);

2004 - 2014: development of fast, low material budget hybrid and monolithic pixel detectors for particle tracking based on high density technologies, such as planar CMOS 130 and 65 nm and vertical integration CMOS processes, including radiation tolerance study (VIPIX and SLIM5 projects funded by INFN, PRIN calls funded by MIUR, AIDA FP7 project funded by the EU);

2004: activity within the research contract "Progetto di circuiti di lettura a segnali misti analogici e digitali per applicazioni rad-hard in una tecnologia BiCMOS SOI" with STMicroelectronics;

2002 - 2005: design and characterization of the front-end chip for the microstrip tracking detector of the BTeV experiment (BTEV experiment with INFN);

2001 - 2004: design of the front-end circuit reading the signal from a ionization chamber detector for the LHC beam monitor (BEAMON R&D experiment with INFN);

1999 - 2004: development of microstrip detectors in high resistivity substrate with integrated electronics (PRIN calls funded by MIUR);

1999 - 2001: design of a readout circuit with bilinear compression feature for the fluorescence detector of the Auger experiment (AUGER experiment with INFN);

1996 - present: noise and radiation hardness characterization of microelectronic technologies, including bulk and SOI CMOS and BiCMOS and JFET processes and development of ad hoc instrumentation (within several projects funded by INFN and PRIN and FIRB programs funded by MIUR);

1996 - 2001: design and characterization of the front-end chip for the microstrip tracking detector of the BaBar experiment (BABAR experiment with INFN).

3 Scientific appointments

Following is a summary of the major Lodovico Ratti's scientific appointments.

PRIN MIUR projects:

2011 - 2013: head of the Pavia research unit in the PRIN 2009 project "High space-time resolution pixel detection systems";

2008 - 2010: head of the Pavia research unit in the PRIN 2007 project "Pixel systems for thin charged particle trackers based on high density microelectronic technologies".

INFN projects:

2018 - present: head of the Pavia research unit in the ASAP CSN5 R&D project "Array of silicon avalanche pixels";

2018: national scientific coordinator of the XDET CSN5 R&D project "Hybrid and monolithic pixel detectors for X-ray imaging at FELs and synchrotron light sources";

2014 - 2017: national scientific coordinator of the PIXFEL CSN5 R&D project "Enabling technologies, building blocks and architectures for advanced X-ray pixel cameras at FELs";

2014 - 2017: head of the Pavia research unit in the APIX2 CSN5 R&D project "Development of an avalanche pixel sensor for tracking applications";

2009 - 2012: head of the Pavia research unit in the VIPIX CSN5 R&D project "Pixel systems for thin charged particle trackers based on vertical integration technologies";

2006 - 2009: head of the Pavia research unit in the SLIM5 CSN5 R&D project "Silicon detectors with low interaction with material".

EU projects:

2011 - 2014: head of the INFN Pavia research unit in the AIDA FP7 INFRASTRUCTURE 2010 EU project "Advanced European Infrastructures for Detectors at Accelerators".

4 Research activity carried out abroad

Early in his academic career, Lodovico Ratti carried out part of his scientific activity at foreign research laboratories and institutions in the framework of international collaborations.

July-August 1999: feasibility study of a beam luminosity monitor for the Large Hadron Collider (LHC); the activity was carried out at the Lawrence Berkeley National Laboratory, Berkeley, USA.

November-December 1999: monitoring the data acquisition for the Online Prompt Reconstruction process in the frame of the BaBar experiment; the activity was carried out at the Stanford Linear Accelerator Center, Menlo Park, USA.

April 2000: characterization of the prototype readout channel for the fluorescence detector of the AUGER experiment; the activity was carried out at the Forschungszentrum Karlsruhe, Karlsruhe, Germany.

June-July 2000: test of the prototype luminosity monitor for the Large Hadron Collider (LHC); the activity was carried out at the Super Proton Synchrotron (SPS) facility, CERN, Geneva, Switzerland.

July-August 2000: characterization of the prototype readout channel for the ionizing chamber of the LHC luminosity monitor; the activity was carried out at the Lawrence Berkeley National Laboratory, Berkeley, USA.

July-August 2001: optimization of the beam luminosity monitor for the LHC; the activity was carried out at the Lawrence Berkeley National Laboratory, Berkeley, USA.

September 2001: test of a new version of the beam luminosity monitor for the LHC; the activity was carried out at the Super Proton Synchrotron (SPS) facility, CERN, Geneva, Switzerland.

July-August 2003: characterization of the Fermilab Silicon Strip Readout (FSSR) chip for the microstrip detector of the BTeV experiment; the activity was carried out at the Fermi National Accelerator Laboratory, Batavia, USA.

5 Editorial activity and conference organization

Lodovico Ratti

- is an associate editor with the IEEE Transactions on Nuclear Science;
- is a member of the Section Board for Microelectronics and Optoelectronics for the MDPI Electronics Journal;
- has been serving as a reviewer for the following journals (listed from the ones with which Lodovico Ratti has been more actively involved to the ones with which the collaboration has been less regular):
  - IEEE Transactions on Nuclear Science,
  - Elsevier Nuclear Instruments and Methods in Physics Research Section A,
  - IEEE Transactions on Circuits and Systems,
  - IEEE Transactions on Electron Devices,
  - IEEE Transactions on Instrumentation and Measurements,
  - IEEE Journal on Solid State Circuits,
  - Elsevier Microelectronics Journal,
  - Elsevier Microelectronics Reliability,
  - Springer Analog Integrated Circuits and Signal Processing,
  - Springer Nuclear Science and Techniques,
  - IOPscience Journal of Instrumentation,
  - MDPI Electronics Journal,
  - Frontiers in Physics,
  - IEEE Transactions on Radiation and Plasma Medical Sciences,
  - IEEE Sensors Journal,
  - IEEE Access,
  - Elsevier Alexandria Engineering Journal,
  - IET Journal of Engineering,
  - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering;
- is in the official reviewer list for the following international annual conferences:
  - IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS-MIC),
  - European Conference on Radiation Effects on Components and Systems (RADECS),
  - Nuclear and Space Radiation Effects Conference (NSREC),

  - European Symposium on Reliability of Electron Devices, Failure Physics and Analysis (ESREF),
  - PhD Research in Microelectronics and Electronics (PRIME) conference;

- has been a member of the organizing committee and of the scientific committee for the International VIPS (Vertically Integrated Pixel Detectors) 2010 Workshop, Pavia, Italy, April 22-24 2010;

- has been a member of the organizing committee for the 2011 Front-End Electronics Meeting (FEE2011), Bergamo, Italy, May 24-27 2011;

- has been a topic convener for the "Synchrotron, FEL and Beamline instrumentation" session of the 2017 and the 2018 IEEE Nuclear Science Symposium and Medical Imaging Conference;

- has been a session chair, mostly in sessions relevant to analog readout electronics and to radiation effects, in a number of editions of the IEEE Nuclear Science Symposium and Medical Imaging Conference;

- is a member of the program committee for the PRIME conference.

6 Teaching activity and participation in Ph.D. academic boards and final examination committees

6.1 Institutional teaching activity

Lodovico Ratti has been teaching several courses (some of them in English) in Electronics since 2001, when he became an assistant professor with the Electrical, Computer and Biomedical Engineering Department (at that time the Electronics Department). Since 2016 he is responsible for the"Pier Francesco Manfredi" Electronics Teaching Laboratory, serving a number of courses from different Bachelor's and Master's Degree Programs at the Engineering Faculty. Following is a more detailed list of the courses taught by Lodovico Ratti since his appointment as associate professor.

Academic Year 2014/2015:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **3 CFU** (33 hours);
- Elettronica II, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **1 CFU** (28 hours);
- Generazione, acquisizione ed elaborazione di segnali analogici, Certification Course for Secondary School Teachers - **3 CFU** (30 hours).

Academic Year 2015/2016:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **3 CFU** (33 hours);
- Elettronica I, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **3 CFU** (39 hours);
- Elettronica II, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **3 CFU** (50 hours).

Academic Year 2016/2017:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **3 CFU** (28 hours);
- Electronics for Industrial Measurements (in English), Master's Degree in Industrial Automation Engineering - **6 CFU** (68 hours);
- Elettronica II, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **3 CFU** (48 hours).

Academic Year 2017/2018:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **4 CFU** (34 hours);

- Electronics for Industrial Measurements (in English), Master's Degree in Industrial Automation Engineering - **6 CFU** (66 hours);
- Elettronica I, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **6 CFU** (70 hours);
- Elettronica II, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **1 CFU** (21 hours).

Academic Year 2018/2019:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **4 CFU** (32 hours);
- Electronics for Industrial Measurements (in English), Master's Degree in Industrial Automation Engineering - **6 CFU** (70 hours);
- Elettronica I, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **6 CFU** (70 hours);
- Elettronica II, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **1 CFU** (22 hours).

Academic Year 2019/2020:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **4 CFU** (32 hours);
- Electronics for Industrial Measurements (in English), Master's Degree in Industrial Automation Engineering - **6 CFU** (72 hours);
- Elettronica I, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **6 CFU** (88 hours).

Academic Year 2020/2021:

- Electronic Instrumentation and Technology (in English), Master's Degree in Electronic Engineering - **6 CFU** (51 hours);
- Electronics for Industrial Measurements (in English), Master's Degree in Industrial Automation Engineering - **6 CFU** (88 hours);
- Elettronica I, Bachelor's Degree in Electronics and Computer Science (Elettronica e Informatica) - **7 CFU** (in progress)

Over the last three academic years (from academic year 2017/2018 to academic year 2019/2020), Lodovico Ratti scored a CFU-weighted average of **9.14/10** in the university student survey on his teaching activity concerning the following three aspects: 1) whether he stimulates/motivates interest in the discipline, 2) whether he is clear in explaining the subject during the lectures, 3) whether he is available to students for clarification and consulting.

6.2 Ph.D., Master's and Bachelor's student supervision

Lodovico Ratti has been supervisor or co-supervisor of more than 40 among Bachelor's and Master's thesis students (4 of them currently under his supervision) and supervisor or co-supervisor of 12 Ph.D. students (3 of them currently under his supervision).

6.3 Seminars at national and international Ph.D. schools and Master's courses

Lodovico Ratti was invited to give seminars and teach courses at a number of national and international Ph.D. schools and Master's courses, as detailed in the following.

- "Radiation Effects in Electronic Devices and Circuits", Master in Nuclear and Ionizing Radiation Technologies, Istituto Universitario di Studi Superiori, Pavia, Italy, February 1 and 3 2010.
- "Total Dose Effects in Electronic Devices and Circuits", IV National School on "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics" - INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy, April 11-15 2011.
- "Mixed signal integrated circuits for semiconductor radiation detectors", International Doctoral School in Information and Communication Technology, Trento, Italy, February 11-12 2013.
- "Radiation effects in electronic devices and circuits", International Doctoral School in Information and Communication Technology, Trento, Italy, February 11-12 2013.
- "Ionizing Radiation Effects in Electronic Devices and Circuits", V National School on "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics", INFN, Laboratori Nazionali di Legnaro, Legnaro, April 15-19 2013.
- "Intelligent front-end for pixel based instruments: front-end and novel ideas", 1st International Summer School on Intelligent Front-End Signal Processing for Frontier Exploitation in Research and Industry (INFIERI), Oxford, UK, July 10-16 2013.
- "Front-end electronics for hybrid and monolithic particle detectors: new ideas and technologies", IDPASC School on Frontier Detectors for High Energy and Astroparticle Physics, Siena, Italy, October 4-6 2013.
- "Radiation effects in electronic devices and circuits", Master in Nuclear and Ionizing Radiation Technologies, Istituto Universitario di Studi Superiori, Pavia, Italy, December 12 2013.
- "Ionizing Radiation and Single Event Effects in Electronic Devices and Circuits", VI National School on "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics", INFN, Laboratori Nazionali di Legnaro, Legnaro, March 25 2015.

- “Processing the signals from pixel detectors in X-ray imaging at FELs”, 3^{rd} International Summer School on Intelligent Front-End Signal Processing for Frontier Exploitation in Research and Industry (INFIERI), Hamburg, Germany, September 14-25 2015.
- “Processing the signal from pixel detectors in high energy physics and photon science”, Topics on Microelectronics 2016, Pavia, Italy, September 28-30 2016.
- “Advances on Pixel-Embedded Signal Processing Technology”, 4^{th} International Summer School on Intelligent Front-End Signal Processing for Frontier Exploitation in Research and Industry (INFIERI), San Paolo, Brazil, January 23 - February 3 2017.
- “Ionizing radiation effects on electronic circuits: from micro to nano, from mega to giga”, VII National School on “Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics”, INFN, Laboratori Nazionali di Legnaro, Legnaro, April 3-7 2017.
- ”Effects of ionizing and non-ionizing radiation on electronic devices and circuits”, VII National School on “Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics”, INFN, Laboratori Nazionali di Legnaro, Legnaro, April 1-5 2019.
- “Pixel-embedded signal processing for the next generation of radiation detectors at the LHC and FELs”, 5^{th} International Summer School on Intelligent Front-End Signal Processing for Frontier Exploitation in Research and Industry (INFIERI), Whuan, China, May 12-26 2019.

6.4 Participation in Ph.D. boards

Lodovico Ratti has been a member of the Academic Board of the Ph.D. School in Microelectronics, Università di Pavia, since its establishment in 2006. Before 2006 he was a member of the Academic Board of the Doctoral School in Electronics, Computer Science and Electrical Engineering.

6.5 Participation in Ph.D. final examination committees

Lodovico Ratti has been a member of Ph.D. committees for final examination at the following Ph.D. Schools:

- Dottorato di Ricerca in Informatica e Telecomunicazioni, Università di Trento, Italy, 2006;
- Dottorato di Ricerca in Ingegneria dell’Informazione, Università di Padova, Italy, 2015;
- Doctoral School in Microelectronics, Università di Pavia, Italy, 2016;
- Doctoral School in Information Technology, Politecnico di Milano, Italy, 2016;
- Ècole Doctoral Information, Structures et Systèmes, Université de Montpellier, France, 2018;

- Doctoral School in Materials, Mechatronics and Systems Engineering, Università di Trento, Italy, 2020;
- Doctoral School in Physics and Astronomy, Università di Milano Bicocca, Italy, 2020.

7 Publications

7.1 Papers published in international journals

[J1] L. Ratti et al. (CMS international collaboration), "The CMS Phase-1 pixel detector upgrade," *Journal of instrumentation*, vol. 16, no. 2, 2021. DOI: 10.1088/1748-0221/16/02/P02027.

[J2] L. Ratti, P. Brogi, G. Collazuol, G. F. Dalla Betta, P. S. Marrocchesi, L. Pancheri, A. Sulay, G. Torilla, and C. Vacchi, "Layered CMOS SPADs for Low Noise Detection of Charged Particles," *Front. Phys*, vol. 8, 2021. DOI: 10.3389/fphy.2020.607319.

[J3] L. Gaioni, M. Manghisoni, L. Ratti, V. Re, E. Riceputi, and G. Traversi, "Threshold tuning DACs for pixel readout chips at the High Luminosity LHC," *Nucl. Instrum. Methods A*, vol. 969, 2020. DOI: 10.1016/j.nima.2020.164025.

[J4] L. Ratti et al. (CMS international collaboration), "Beam test performance of prototype silicon detectors for the Outer Tracker for the Phase-2 Upgrade of CMS," *JINST*, vol. 15, P03014–P03014, 2020. DOI: 10.1088/1748-0221/15/03/P03014.

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[J9] L. Ratti et al. (CMS international collaboration), "The DAQ and control system for the CMS Phase-1 pixel detector upgrade," *JINST*, vol. 14, P10017–P10017, 2019. DOI: 10.1088/1748-0221/14/10/P10017.

[J10] L. Ratti et al. (RD53 international collaboration), "Test results and prospects for RD53A, a large scale 65 nm CMOS chip for pixel readout at the HL-LHC," *Nucl. Instrum. Methods A*, vol. 936, pp. 282–285, 2019. DOI: 10.1016/j.nima.2018.11.107.

[J11] M. Musacci, G. Bigongiari, P. Brogi, C. Checchia, G. Collazuol, G. F. Dalla Betta, A. Ficorella, P. S. Marrocchesi, S. Mattiazzo, F. Morsani, S. Noli, L. Pancheri, L. Ratti, A. Savoy Navarro, L. Silvestrin, F. Stolzi, J. Suh, A. Sulaj, C. Vacchi, and M. Zarghami, "Radiation tolerance characterization of Geiger-mode CMOS avalanche diodes for a dual-layer particle detector," *Nucl. Instrum. Methods A*, vol. 936, pp. 695–696, 2019. DOI: 10.1016/j.nima.2018.10.078.

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[J19] L. Gaioni, D. Braga, D. C. Christian, G. Deptuch, F. Fahim, B. Nodari, L. Ratti, V. Re, and T. Zimmerman, "A 65nm CMOS analog processor with zero dead time for future pixel detectors," *Nucl. Instrum. Methods A*, vol. 845, pp. 595–598, 2017. DOI: 10.1016/j.nima.2016.04.053.

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[J29] L. Gaioni, F. De Canio, M. Manghisoni, L. Ratti, V. Re, and G. Traversi, "Design and test of clock distribution circuits for the Macro Pixel ASIC," *Nucl. Instrum. Methods A*, vol. 824, pp. 287–289, 2016. DOI: 10.1016/j.nima.2015.10.046.

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7.3 Book chapters

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7.4 Paper awards

Lodovico Ratti was a co-recipient of the Outstanding Paper Award for the paper ”Channel Hot Carrier Stress on Irradiated 130-nm NMOSFETs: Impact of Bias Conditions During X-ray Exposure”, presented at the 9th European Conference on Radiation and Its Effects on Components and Systems (RADECS 2007), Deauville, France, September 10-14 2007.