INFN Position Paper for Snowmass'21 on Accelerators

Written by the Working Group "INFN-Accelerators" on behalf of the INFN Accelerator community, approved by the INFN Executive Board.
Contact persons: G. Bisoffi (giovanni.bisoffi@lnl.infn.it), L. Rossi (lucio.rossi@mi.infn.it)

INFN (Istituto Nazionale di Fisica Nucleare, Italy), with a long-standing tradition in the design, construction and operation of both lepton and hadron accelerator facilities and in the related accelerator technologies and R&D activities, expresses its deep interest in the accelerator R&D undertakings for Snowmass'21 and highlights herein the main domains, correlated with its Frontiers, where it pursues the common goal of advancing accelerator-based high energy physics. INFN actively contributes to both the European Strategy on Particle Physics and to coordinated initiatives funded by the European Union also on accelerator R&Ds. Hereinafter, contribution of INFN groups to R&D related to Snowmass Accelerator Frontiers is shortly outlined. Reference to specific LoI's is given.

AF1 - Beam Physics and Accelerator Education. Electron beam dynamics, theoretical and experimental studies on impedance, e-cloud effects and dynamical (cryogenic) vacuum [1,2,3] are central to the contribution of INFN groups at LNF (Laboratori Nazionali di Frascati), Napoli and Roma1 to HL-LHC, FCC-ee and CLIC projects: in particular, comparative study of electron and photon stimulated desorption in cryogenic environment and impact of new materials and metamaterials on impedance and e-cloud related issues. Other Beam Physics studies or experiments are included in the accelerator Projects and reported in the following AFs.

AF3 - Accelerators for EW/Higgs (and AF1, AF4, AF7-RF). Studies on the FCC-ee machine detector interface, background in the detector and injection system (damping ring and transfer lines) are being performed at LNF. Room temperature X-band technology (12 GHz) is the baseline technology for both EU-H2020 XLS-CompactLight and EuPRAXIA [4] projects, to drive a FEL with a compact RF linac (XLS) or with a plasma module (Eupraxia). The EuPRAXIA International Consortium of Eupraxia is applying to become a facility of the ESFRI Roadmap. INFN is deeply involved in both projects (for EuPRAXIA, see AF6). A new high power X-band RF stand, to test and condition CLIC and EuPRAXIA accelerating sections, is being commissioned at LNF in the frame of a collaboration between INFN and CERN. Developments on SRF cavities, in view and beyond of ILC project, in full Nb and novel materials, with strong involvement of industrial partners for cost optimization, are vigorously pursued at LNL (Laboratori Nazionali di Legnaro) and INFN-Milano.

AF4 – Multi-TeV Colliders (and AF1). A muon collider low-transverse-emittance source from a 45 GeV e^+ beam annihilating with e^- on a target close to threshold for pair creation (INFN-LEMMA [5]) is the option proposed by INFN as a Muon Collider source (see specific LoI'S on LEMMA general concept and R&D, and on the e^+ source). INFN teams investigate critical beam physics and design aspects of beams of e^+ and $\mu^{+/-}$ from the source to the interaction regions, as well as design of pulsed magnets for the muon chain. INFN participates in the International Muon Collider Collaboration, which is being set up under CERN leadership. INFN is leading a specific strategy network on muon colliders within the H2020 IFAST project (submitted to EU).

AF6 - Advanced Accelerator Concepts (and AF1, AF4). Novel particle acceleration techniques are actively pursued by several INFN groups in the frame of international collaborations. Acceleration based on particle driven and laser driven wake-fields in neutral plasmas is the most promising way towards compact lepton linear colliders with accelerating gradients exceeding 10 GV/m. Within the European collaboration EuPRAXIA, LNF is the site for the EuPRAXIA particle driven facility (see also AF3), hosting the Eupraxia@Sparc_Lab, the first user facility based on PWFA plasma acceleration aimed at driving a FEL in the soft X-rays wavelength. Beam physics studies to achieve the required high brightness beams and control the plasma acceleration process are critical for preserving beam quality and ensuring reproducibility (synergic with an R&D program for a future collider, AF4). A dedicated LoI is submitted to Snowmass'21. Production and acceleration of proton beams from high power lasers, illuminating metallic targets (TNSA), is being addressed mainly in INFN-Milano, LNS (Laboratori Nazionali del Sud, Catania, responsible for the diagnostic section of the ELIMAIA beamlines at ELI-Beamlines in Prague) and LNF. LNS and INFN-Milano are collaborating on the construction, at LNS, of the facility I-LUCE based on a high-power, short-duration (30J, 30fs) laser for ion acceleration and ion-plasma interaction studies. A strategy network within the H2020 I-

FAST project, with the participation of LNF and INFN-Milano, addresses laser drivers for plasma accelerators.

Beyond electron/ion plasma-based acceleration, INFN is also investigating miniaturized accelerating structures for sub-relativistic and relativistic particle acceleration aiming at gradients of the order of 1 GV/m, far beyond the present state-of-the-art of conventional RF structures ("Accelerator on a Chip" [6] collaboration recently tested acceleration of electrons [7,8]). Novel dielectric structures based on hollow-core photonic crystal waveguides [9,10,11] are actively investigated at LNS, INFN-Milano and LNF, and proposed in a dedicated LoI [12] to Snowmass'21.

AF7 – Accelerator Technology R&D - RF. INFN has played a pivotal role for SRF high gradient resonators and cryostats, being at the origin of the optimized design of 9-cell elliptical cavities and 8-cavity cryo-modules, baseline of the high energy SC linacs of the TESLA/ILC studies (TTF/FLASH, X-FEL projects). INFN-Milano has an established experience in coordinating and promoting qualified industrial large-scale production of SC cavities and cryomodules (frequencies 400 MHz, 1,3 and 3.9 GHz), the more recent ones for the XFEL and the ESS projects. LNL is developing promising new forming techniques (seamless elliptical resonators by mechanical spinning [13]), as well as improving the Nb_3Sn construction technology [14] and further advancing the Nb/Cu sputtering technique [15]. These activities may have relevant impact in AF3 and AF4, being fully synergic, for instance, with the ILC programme.

INFN LNF and Roma1 units are also involved in a collaboration program led by UCLA and SLAC on cryogenic normal-conducting Cu structures, to reduce the breakdown probability and allow operational gradients well beyond 100 MV/m [16]. This technology is being proposed as an alternative baseline for a normal-conducting Linear Collider beyond 1 TeV.

AF7 – Accelerator Technology R&D - Magnets. The target energy of $\approx$ 100 TeV envisaged for future hadrons colliders relies mainly on the capability of building large scale dipole magnets rated to $\geq$ 16 T magnetic field in a 50 mm bore, based on the Nb_3Sn technology or, possibly, on HTS. INFN Genova and Milano groups have a recognized expertise in magnet design and construction, from the critical contributions to the early R&D on LHC superconducting dipoles, construction of the SC coils for the two main LHC detectors (ATLAS and CMS) and strong participation to HiLumi LHC SC magnet construction. INFN has also a well-established relationship with the national industry for R&D and large-scale magnet production. A dedicated LoI has been requested to the INFN magnet groups for magnet technological development, recognizing the leadership in cos-theta layout design with bladder and key process. Recently a new project, co-funded by CERN and INFN, has started, aimed at the construction of a very high field single aperture short model. Named Falcon_D, it includes the development of the necessary new technologies, involving industry in this early R&D stage. In parallel, developments of HTS magnet started, aiming to put the basis of this technology for further increase of the magnetic field for accelerators, beyond 16T. INFN is also involved in designing the pulsed magnets of the accelerator chain of the Muon-C, in the frame of the MC International Collaboration, levering the experience gained with the FAIR SIS300 dipole prototype and the just started activity on pulsed magnets for hadron-therapy.

AF7 – Accelerator Technology R&D - Targets/Sources (and AF1). State-of-the-art microwave-discharge high current sources of monocharged ions (H+, H2+, D+, He+, …) are being developed at LNS, with high reliability and low emittance (e.g. 100 mA, 0.2 π mm mrad at 75 keV is the one built and commissioned for the ESS), implementing advanced beam diagnostics tools (optical emission spectroscopy). These diagnostics are also valuable for further development of plasma-based heavy ion sources. LNS and LNL are developing joint R&D, aimed at connecting plasma and ion source parameters, including emittance and shape of the beam.

A CDR on the first research infrastructure based on an optimized source for ultrafast spectroscopy and conceived for multi-disciplinary matter studies is being written by INFN-Milano and University of Milano (MARIX project). It is a forefront X-ray source based on an original cutting-edge system of combined electron accelerators. It enables generation of X-rays over a large photon energy domain by exploiting two different physics mechanisms, FEL and ICS (Inverse Compton Scattering). FEL generated X-ray beams will feature extremely short pulses ($<10^{-14}$s) with ultra-high brilliance, at a 1 MHz rep rate and 0.2÷8 keV energy. The novelty of this proposal is presented by its unique and unprecedented layout blending Energy Recovery Linacs (ERL) with arc compressors and recirculated acceleration. An R&D demonstrator (BriXSino) is being proposed. INFN Milano is also a scientific leader in the field of high rep-rate photocathodes.

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