A1 **Titolo dell'attività di ricerca**
(*GRUPPO FISICA DEI PLASMI E APPLICAZIONI INTERDISCIPLINARI*)

Study of the collective and nonlinear excitation mechanisms of wake fields (large amplitude regime) for scientific and technological applications finalized to acceleration and manipulation of relativistic charged particle beams and to generation of EM radiation in laboratory and space/astrophysical plasmas.

A2 **Responsabile**
(aggiungere eventuale referente del Dipartimento se il Responsabile non è un afferente ad esso)

Responsabile **Renato Fedele**
Referente per il Dip.

A3 **Personale Dipartimento di Fisica** (Professori e Ricercatori)

Prof. Ordinari:
Prof. Associati: **Renato Fedele**
Ricercatori universitari:
RTDA:
RTDB:

A4 **Collaborazioni con altri enti/altri dipartimenti dell'Ateneo Federiciano**

CNR: **Dr. Sergio De Nicola** (SPIN-CNR, Unità di Napoli)
CNR: **Dr. Leonida Antonio Gizzi** e **Dr. Paolo Tomassini** (INO-CNR, Pisa)
Dip. di Matem. e Appl. C/O Univ. di Napoli "Federico II": **Gaetano Fiore** (P.A.)
Dip. di Fisica C/O Università di Torino: **Miguel Onorato** (P.A.)
INAF Bologna: **Pasquale Londrillo**
INFN Sezione di Milano: **Dr. Dario Giove**
Dip. di Scienze di Base e Applicate per l'Ingegneria, Sapienza Univ. di Roma: **Luigi Palumbo** (P.O.) e **Mauro Migliorati** (P.O.)
Inst. of Physics, Univ. Belgrade (Serbia): **Dusan Jovanovic** (Research Professor)
Istituto Superior Tecnico, Lisbone (Portugal): **J. Tito Mendonca** (Full Professor)
P.N. Lebedev Physical Institute, Moscow (Russia): **V.I. Man'ko**, **M.A. Man'ko**

A5 **Personale strutturato ricercatore o tecnologo altri enti convenzionati**

A6 **Altro personale di ricerca (Assegnisti, Borsisti)**

Assegnisti:
Borsisti Post-doc: **Tahmina Akhter** (da Luglio 2017), presso INFN Sezione di Napoli
Borsisti:

A7 **Dottorandi di Ricerca**

Dottorato in Fisica 31° Ciclo: **Davide Terzani**, presso Dipartimento di Fisica

B1 **Breve descrizione della linea di ricerca**
(max 1000 caratteri)

A plasma can sustain large amplitude electric and magnetic fields by means of suitable external actions that provide therein the creation of a charge separation between ions and electrons and the generation of an electric current. This takes place both in laboratory and astrophysical plasmas and can be provided by intense relativistic charged particle beams coming from outside plasma. While propagating, the beam interacts with the surrounding plasma which generates a large amplitude plasma wave which moves behind the beam as a "wake" with phase velocity equal to beam velocity. Beams long compared to the plasma wavelength experience a number of strong electromechanical actions and the wiggling of the beam particles, leading to radiation emission with very small wavelengths (f.i., X rays). The initial spontaneous emission can become very intense and eventually coherent.
We are going to study the above effects by using theoretical approaches based on kinetic description provided by the Vlasov-Poisson-type pair of equations. This will constitute the common framework and the common methodological platform to study the above physical mechanisms in laboratory and astrophysical plasmas.

B2 **Descrizione attività svolta nel triennio 2014-2016**
(max 2000 caratteri)

We have carried out a theoretical investigation on the self-modulated dynamics that takes place when a *nonlaminar*, relativistic, charged particle beam is travelling through a magnetized plasma while experiencing a strong interaction with the latter. This has been accomplished by developing the kinetic theory of the plasma wake field excitation. We have specialized the 3D Vlasov-Poisson-type equations to a 2D purely transverse system and to a 1D purely longitudinal system to describe the transverse and the longitudinal dynamics, respectively.
In the transverse dynamics, we have implemented the 2D Vlasov-Poisson-type equations for a cylindrically symmetric driving beam with the related virial equations. This has allowed us to find some constant of motions and to obtain ordinary differential equations for the time evolution of the beam spot size (envelope equations), that have been easily integrated analytically and/or numerically. The use of the method of pseudo potential or Sagdeev potential has been very helpful to carry out a qualitative analysis of the beam envelope self-modulation.
In the longitudinal dynamics, we have used the Landau approach to the longitudinal Vlasov-Poisson-type pair of equations. In fact, after linearizing this system around an unperturbed state, and taking the Fourier transformation of the resulting equation, we have obtained a set of algebraic equation in frequency and wave number domain. From the latter, we have easily found the Landau-type dispersion relation. The results we have obtained can be summarized as follows. We have:

- developed the kinetic theory of the PWF excitation that provides the generalized Vlasov-Poisson-type pair of equations for the diverse conditions of plasma and beam;
- provided the self-modulated beam dynamics analysis in both purely transverse and purely longitudinal cases;
- provided a satisfactory model for the self-modulation instability in the transverse case, by implementing the Vlasov-Poisson-type equations with the related virial description (envelope equations);
- carried out an instability analysis within the linearized kinetic theory of the self-consistent beam-plasma interaction, in the purely longitudinal case within two approaches based on Landau theory.
- Introduction of the novel concept of coupling impedance in the plasma wake field excitation to schematize the beam-plasma interaction

B3 **Descrizione attività programmata nel triennio 2017-2019**
(max 2000 caratteri)

We are going to investigate on the existence of stationary configurations of the relativistic charged particle *helicoidal bunch*. This can be accomplished within the framework of the hydrodynamic model of the system *bunch + plasma* that can be derived by the Vlasov-Poisson-type system of equations in the presence of the plasma wake field excitation mechanism. The subject is new and takes place from some preliminary considerations concerning the propagation of a relativistic beam in the presence of an external magnetic field. We assume that the bunch has a *helicoidal* shape and that it is rotating with a constant angular velocity, i.e. that it looks like *fusilli* or *cavatappi*. In terms of simple physical considerations we can easily see that the bunch parameters become governed by a nonlinear dispersion relation and fully determined by the angular velocity. Then, we easily obtain a stability criterion for the bunch. If one locally displaces a bunch from its original position and let it spin, it can survive only if its radial dependence has conformed with the aformentioned nonlinear dispersion relation. In order to obtain a full temporal dependence, we are going to solve numerically a 2D nonlinear partial equation with a fusilli-shaped initial condition, by approaching hopefully the problem in full rigor. The preliminary results are very encouraging, because they seem to be relevant to a study carried out at UCLA [1,2], where they have shown the formation of microbunching structures of electron beams that are wiggling into a device which is a combination of helical magnetic undulator and an axisymmetric input laser beam to produce tunable sources of coherent light with orbital angular momentum.

_____

[1] E. Hemsing and J. B. Rosenzweig, J. Appl. Phys. 105, 093101 (2009).
[2] E. Hemsing, P. Musumeci, S. Reiche, R. Tikhoplav, A. Marinelli, J. B. Rosenzweig, and A. Gover, Phys. Rev. Lett. 102, 174801 (2009).

C1 **Pubblicazioni scientifiche nel triennio 2014-2016**
(indicare il numero complessivo nel triennio e elencare le più significative (max 10))

N. complessivo: 17

Pubblicazioni più significative: 14

1. Fedele, R., Akhter, T., De Nicola, S., Migliorati, M., Marocchino, A., Massimo, F., Palumbo, L., *The concept of coupling impedance in the self-consistent plasma wake field excitation*, Nucl. Instr. Meth. Phys. Res. A **829**, 397-402 (2016)
2. Akhter, T., Fedele, R., De Nicola, S., Tanjia, F., Jovanovic, D., Mannan, A., *Self-modulated dynamics of a relativistic charged particle beam in plasma wake field excitation*, Nucl. Instr. Meth. Phys. Res. A **829**, 426-431 (2016)
3. Jovanovic, D., Fedele, R., Belic, M., De Nicola, S., *Semi-analytical fluid study of the laser wake field excitation in the strong intensity regime*, Nucl. Instr. Meth. Phys. Res. A **829**, 413-417 (2016)
4. Tanjia, F., Fedele, R., De Nicola, S., Akhter, T., Jovanovic, D., *Formation and*

stability of a hollow electron beam in the presence of a plasma wake field driven by an ultra-short electron bunch, Nucl. Instr. Meth. Phys. Res. A **829**, 130-136 (2016)

5. C Castaldo, A Di Siena, R Fedele, F Napoli, L Amicucci, R Cesario G Schettini, *Influence of collisions on parametric instabilities induced by lower hybrid waves in tokamak plasmas*, Nuclear Fusion **56** (1), 016003 (2015)
6. D Jovanović, R Fedele, M Belić, S De Nicola, *Semianalytical study of the propagation of an ultrastrong femtosecond laser pulse in a plasma with ultrarelativistic electron jitter*, Physics of Plasmas **22** (4), 043110 (2015)
7. Mannan A, Fedele R, Onorato M., De Nicola S, D Jovanovic, *Ring-type multisoliton dynamics in shallow water,* Phys. Rev. E 91, 012921 (2015)
8. JT Mendonça, R Fedele, *Photon mirror acceleration in the quantum regime*, Physics of Plasmas **21** (12), 123105 (2014)
9. G Fiore, R Fedele, U de Angelis, *The slingshot effect: a possible new laser-driven high energy acceleration mechanism for electrons*, Physics of Plasmas **21** (11), 113105 (2014)
10. R Fedele, A Mannan, S De Nicola, D Jovanović, T Akhter, *Vlasov's kinetic theory of the collective charged particle beam transport through a magnetized plasma in the strongly nonlocal regime*, European Physical Journal D **68** (9), 1-9 (2014)
11. R Fedele, T Akhter, D Jovanović, S De Nicola, A Mannan, *Transverse evolution of a long relativistic electron beam governed by the Vlasov-Poisson-type pair of equations within the plasma wake field dynamics in the local regime*, European Physical Journal D **68** (7), 1-8, (2014)
12. D Jovanović, R Fedele, M Belić, *Dynamics of the wakefield of a multi-petawatt, femtosecond laser pulse in a configuration with ultrarelativistic electrons*, EPL **107** (4), 44004 (2014)
13. Mannan A, Fedele R, Onorato M., De Nicola S, D Jovanovic, *Ring localized structures in nonlinear shallow water wave dynamics,* J. Phys. Conf. Series **482**, 012030 (2014)
14. Renato Fedele, Margarita A. Man'ko, Vladimir I. Man'ko, Sergio De Nicola, *The role of the Wigner function in charged-particle beam transport*, EPJ Web of Conf. **78**, 04003 (2014)

C2 **Presentazioni a Conferenze internazionali e nazionali**
(solo se lo speaker è tra il personale elencato nel punto A3)

R Fedele, *Classical and quantum aspect of the self-consistent charged particle beam-plasma interaction,* Joint ICTP-IAEA College on Advanced Plasma Physics, ICTP, Trieste, Italy, 18 – 29 August 2014 (invited lecture)

R Fedele, *Self-modulation and radiation emission of a long relativistic charged-particle beam interacting with a pump-driven plasma wave*, 100° Congresso

Nazionale SIF. Pisa, Italy, 22 - 26 Settembre 2014

R Fedele, T. Akhter, S. De Nicola, F. Massimo, A. Marocchino, Mauro Migliorati, L. Palumbo, *The concept of coupling impedance in the plasma wake field excitation as a new tool for describing the self-consistent interaction of the driving beam with the surrounding plasma*, *La Biodola, Isola d'Elba,* Italy, 13-19 September, 2015.

R Fedele, T. Akhter, S. De Nicola, F. Massimo, A. Marocchino, Mauro Migliorati, L. Palumbo, *The concept of coupling impedance in the plasma wake field excitation as a new tool for describing the self-consistent interaction of the driving beam with the surrounding plasma*, *FISMAT 2015*, 28 September - 02 October, 2015, Palermo, Italy

R Fedele, T. Akhter, S. De Nicola, F. Massimo, A. Marocchino, Mauro Migliorati, L. Palumbo, *The concept of coupling impedance in the plasma wake field excitation as a new tool for describing the self-consistent interaction of the driving beam with the surrounding plasma*, *101^0 Congresso Nazionale SIF*, 21-25 September, 2015, Roma, Italy

D Jovanović, **R Fedele**, M Belić, S De Nicola, *Semi-analytical fluid study of the propagation of an ultrastrong femtosecond laser pulse in a plasma with ultrarelativistic electron jitter*, 101^0 Congresso Nazionale SIF, 21-25 September, 2015, Roma, Italy

R Fedele, T Akhter, S. De Nicola, D. Jovanovic, D Terzani, *Self-consistent plasma wake field dynamics of a charged-particle beam: Vlasov vs Quantum-like approaches*, Fifth International Workshop on the Theory and Applications of the Vlasov equation **(**VLASOVIA 2016), Copanello, Italy, May 30 – June 2^{nd}, 2006

C3 **Presentazioni di brevetti internazionali e nazionali**

D1 **Progetti di ricerca attivi**
(Progetti di Enti di ricerca, Progetti Europei, Progetti MIUR, PON, POR, …)

1. COMB (Coherent plasma Oscillations excitation by Multiple electron Bunches). Nat. collab.: E Chiadroni, nat. resp.; R Fedele, loc. resp.

Aim: acceleration of high brightness electron beams by resonant plasma wakefields. A train of driver bunches, separated by a plasma wavelength resonantly excites a plasma wake, which accelerates a trailing witness bunch injected at the accelerating phase.

2. L3IA (Line for Laser Light Ions Acceleration). Nat. Collab.: D Giove (INFN, Milano) & L A Gizzi, nat. resp. (INO-CNR, Pisa); R Fedele, loc. resp.
Aim: to provide the laser-driven ion acceleration with the *Target Normal Sheath Acceleration* mechanism. A dense electron cloud at a distance of a few mm from the

target rear side is created upon the laser irradiation. A quasi-static electric field is, in turn, created. It field-ionizes the atoms on the target rear surface and accelerates them.

3. EUPRAXIA (European Plasma Research Accelerator with Excellence in Applications) The group takes part to a very wide European collaboration on plasma-based accelerators.
Aim: production of high-quality electron bunches in Laser Wake Field Acceleration relies on the possibility to inject ultra-low emittance bunches in the plasma wave; investigation of a new bunch injection scheme in which electrons extracted by ionization are trapped by a large amplitude plasma wave driven by a train of resonant ultrashort pulses.