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Gamma Factory

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Abstract

This contribution discusses the possibility of creating novel research tools by producing and storing highly relativistic atomic beams in high-energy storage rings, and by exciting their atomic degrees of freedom by lasers to produce high-energy photon beams. Their intensity would be, by several orders of magnitude, higher than those of the presently operating light sources, in the particularly interesting gamma-ray energy domain reaching up to 400 MeV. In this energy domain, the high-intensity photon beams can be used to produce secondary beams of polarised electrons, polarised positrons, polarised muons, neutrinos, neutrons and radioactive ions. The atomic beams, the photon beams and the above secondary beams are the principal research tools of the proposed Gamma Factory. New research opportunities in a wide domain of fundamental and applied physics can be opened by the Gamma Factory scientific programme.

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1 Scientific context

The Gamma Factory (GF) aim is to create new research tools, allowing to open new, cross-disciplinary research domains. This initiative was presented in [1] and endorsed by the CERN management through creation of the GF study group, embedded within the CERN Physics Beyond Colliders studies framework. The GF study group is quickly growing and includes now 79 physicists representing 32 research institutions.

2 Key principles

GF plans to create and store new types of relativistic atomic beams and to exploit their atomic degrees of freedom. In the CERN synchrotrons, atomic beams can be stored at very high energies over a large range of the Lorentz factor: $30 < \gamma_L < 3000$, at high bunch intensities: $10^8 < N_{\mathrm{bunch}} < 5 \times 10^9$, and at high bunch repetition rate of up to 20 MHz.

Lasers tuned to the atomic transition frequencies can be used to manipulate the primary beams directly, or for the production of secondary beams via the emitted photons. The resonant excitation of atomic levels is possible due to the large energies of the ions, which gives a Doppler boost of the laser frequency by a factor of up to $2\gamma_L$. The resonant absorption cross section is in the gigabarn range, and the high γ_L factors available in the SPS and the LHC open the possibility to excite atomic transitions even of high-Z ions with fairly conventional laser systems.

In addition, spontaneously emitted photons produced in the direction of the ion beam, when seen in the LAB frame, have their energy boosted by a further factor of $2\gamma_L$, so that the process of absorption and emission results in a frequency boost of the initial laser photon of up to $4\gamma_L^2$.

The selective photon absorption and random emission naturally opens the path to beam cooling.

3 Objectives – new research tools

3.1 Atomic beams

3.1.1 Beams for atomic, molecular and optical physics research

High-energy beams of highly charged high-Z atoms, such as hydrogen-, helium-, or lithium-like lead, are of particular interest for the Atomic, Molecular and Optical (AMO) physics community. They have, so far, never been technologically accessible as tools for AMO research [2].

3.1.2 Laser-cooled isoscalar ion beams for precision electroweak physics at LHC

Isoscalar nuclei such as Ca or O, are optimal for the LHC electroweak (EW) precision measurement program [3]. GF proposes to cool the partially-stripped atomic isoscalar beams in the SPS and to collide the low emittance beams in the LHC [4].

3.1.3 Electron beam for ep operation of LHC

The hydrogen-like or helium-like lead beams can be considered as the carriers of the effective electron beams circulating in the LHC rings. Collisions of such a beam with the counter propagating beam of protons can allow to observe the electron–proton collisions in the LHC detectors. LHC could thus be operating as an effective electron–proton(ion) collider [5].

3.1.4 Drive beams for plasma wake-field acceleration

High-intensity, laser-cooled atomic beams could be efficient driver beams for hadron-beam-driven plasma wake-field acceleration [6]. Electrons exploited initially in the cooling process of the driver beam can be subsequently used – following their stripping – to form a precisely synchronised witness bunch.

3.2 Photon beams

With the GF approach, the laser light excites a resonant atomic transition of a highly-charged relativistic ion resulting in a spontaneously emitted photon. The frequency boost is up to $4\gamma_L^2$, so that a photon beam in a broad energy range reaching up to $400\,\mathrm{MeV}$ can be driven by the high-γ_L CERN atomic beams. The resonant photon absorption cross section is up to a factor 10^9 higher than for the inverse-Compton photon scattering on point-like electrons. As a consequence, an atomic-beam-driven light source intensity can be higher than that of electron-beam-driven ones by a large factor.

3.3 Gamma-driven secondary beams

The Gamma Factory photon beam can be extracted from its production zone to produce secondary beams in collisions with an external targets.

3.3.1 Polarised electron, positron and muon beams

The high-intensity GF beam of photons could be converted into a high-intensity beam of positrons and electrons. The target intensity of the GF source of polarised electrons/positrons is 10^{17} positrons per second, assuming the present CERN accelerator infrastructure and presently available laser technology. The target intensity of the GF beam of polarised muons is 10^{12} muons per second.

3.3.2 High-purity neutrino beams

The low-emittance muon beams could be used to produce high-purity neutrino beams and antineutrino beams of precisely the same characteristics. Thanks to the initial muon polarisation and the $(V-A)$-structure of the week currents, muon-neutrino (muon-antineutrino) beams could be separated from the electron-antineutrino (electron-neutrino) ones on the bases of their respective angular distributions.

3.3.3 Neutron and radioactive ion beams

The energy of the GF photons could be tuned to excite the Giant Dipole Resonance (GDR) or fission resonances of large-A nuclei, providing abundant sources of: (1) neutrons with the target intensity reaching 10^{15} neutrons per second (first-generation neutrons), (2) radioactive and neutron-rich ions with the target intensity reaching 10^{14} ions per second.

4 Project milestones

The path towards the full feasibility proof of the GF concept is landmarked by the following six milestones:

1. Demonstration of efficient production, acceleration and storage of atomic beams in the CERN accelerator complex.
2. Development of the requisite GF simulation tools.
3. Successful execution of a GF Proof-of-Principle (PoP) experiment.
4. Realistic assessment of the performance parameters of the GF Research tools.
5. Building up the physics cases for the research programme and attracting wide scientific communities to use the GF tools in their respective research.
6. Elaboration of the GF Technical Design Report (TDR).

The first two of the milestones have been already reached [7–13]. At the moment we are working towards reaching the following 3 milestones. [14, 15].

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