Gamma Factory

Physics Beyond Colliders Annual Workshop

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LPNHE, CNRS-IN2P3 and University
Paris Sorbonne, CERN BE-ABP division,
representing the Gamma Factory study group
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Today:
60 scientists
19 institutes
9 countries

GF study group is open to everyone willing to contribute to this initiative!
Gamma Factory EPPSU contributions

Gamma Factory for CERN
EPPSU COMPREHENSIVE OVERVIEW

Abstract
This contribution discusses the possibility of creating novel research tools at CERN by producing and storing highly relativistic atomic beams in its 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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Gamma Factory for CERN
EPPSU ADDENDUM

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Gamma Factory research tools: primary and secondary beams

**primary beams:**
- partially stripped ions
- electron beam (for LHC)
- gamma rays

**secondary beam sources:**
- polarised electrons
- polarised positrons
- polarised muons
- neutrinos
- neutrons
- vector mesons
- radioactive nuclei

**collider schemes:**
- $\gamma-\gamma$ collisions, $E_{CM} = 0.1 - 800$ MeV
- $\gamma-\gamma_L$ collisions, $E_{CM} = 1 - 100$ keV
- $\gamma-p(A)$, $e p(A)$ collisions, $E_{CM} = 4 - 200$ GeV

“Tools Made from Light”

A leap in production efficiency, intensity and purity
Gamma Factory beam intensity targets

- **Highly-ionised, highly-charged atoms** – new at relativistic energies.
- **Photons** – up to factor of $10^7$ gain in intensity w.r.t. present gamma sources.
- **Polarised positrons** – up to factor of $10^4$ gain in intensity w.r.t. KEK positron source.
- **Polarised muons** – up to factor $10^3$ gain in intensity w.r.t. to PSI muon source (low emittance beams $\rightarrow$ muon collider, high purity neutrino beams).
- **Neutrons** – up to factor of $10^4$ in flux of primary neutrons per 1 kW of driver beam power.
- **Radioactive ions** – up to a factor $10^4$ gain in intensity w.r.t. to e.g. ALTO.
Diverse and exciting research programme in many branches of science
Gamma Factory and the on-going (future) CERN research programme

- The next CERN high-energy frontier project may take long time to be approved, financed and built.

- If the present LHC research programme reaches earlier its discovery saturation (no further physics gain by extending its running time), a strong need will arise for a novel programme which could re-use (“co-use”) the existing CERN facilities (including the LHC) in ways and at levels that were not necessarily thought of when the machines were designed.

- Gamma Factory research programme could potentially fulfil such a role. It could exploit the existing, world unique opportunities offered by the CERN accelerator complex and its scientific infrastructure (not available elsewhere).

- It requires an extensive R&D to prove its feasibility. The Gamma Factory R&D timeline is tight to be ready at the time when such a need arises...
1. **Production, acceleration and storage** of “atomic beams” at CERN accelerator complex.

2. **Proof-of-Principle (PoP)** experiment in the SPS tunnel.

3. **Development** “ab nihilo” the requisite Gamma Factory **software tools**.

4. **Realistic assessment** of Gamma Factory **performance figures**.

5. **Physics highlights** of Gamma Factory based **research programme**.

6. Gamma Factory **TDR**.
Acknowledgement:

The successful **Gamma Factory** beam tests, with the Xe+39, Pb+80 and Pb+81 beams, over the year 2017 and 2018 involved dedicated work of the operation tams of the: Ion source, Linac, PS, SPS, LHC, the BE, EN groups responsible for the installations of the GF strippers, vacuum teams, RF-experts and numerous other individuals.

We (GF-group) acknowledge high quality of their work and their enthusiasm in making these tests a success story!
2018 highlight: Successful production, injection, ramp and storage of the hydrogen-like lead beam in LHC!

Beam lifetime ~ 40 hours

Intensity/bunch (~$7 \times 10^9$ charges), 6 bunches circulating.
July 2018: Birth of Atomic Physics research at CERN

LHC accelerates its first "atoms"

Lead atoms with a single remaining electron circulated in the Large Hadron Collider.

https://home.cern/about/updates/2018/07/lhc-accelerates-its-first-atoms
#36db60ae5cb4
https://interestingengineering.com/cerns-large-hadron-collider-accelerates-its-first-atoms
https://www.sciencenews.org/article/physicists-accelerate-atoms-large-hadron-collider-first-time
https://www.maxisciences.com/lhc/le-grand-collisionneur-de-hadrons-lhc-accomplit-une-grande-premiere_art41268.html
https://www.symmetrymagazine.org/article/lhc-accelerates-its-first-atoms
Lessons from of the 2017 and 2018 SPS and LHC GF beam tests

- Atomic beams can be formed, accelerated and stored using the existing LHC accelerator chain.

- Principal operation aspects for such beams have been successfully tested.

- Bunches of $\sim 10^8$ hydrogen-like lead atoms can be efficiently produced and stored at the top LHC energy with the lifetime and bunch-intensity reaching the GF requirements.

- The pivotal concept of the GF that stored relativistic atomic beams may serve as stable frequency converters of the laser photons to high-energy gamma rays has been experimentally proven.

Technological issues to be addressed in the future:
(1) collimation of PSI beams in the LHC, (2) SPS vacuum
What we want to learn/demonstrate with the GF Proof-of-Principle (PoP) experiment at the SPS?

1. How to integrate the laser and Fabry–Perot cavity system into the storage ring of high energy hadronic beam? (radiation hardness of the laser system, IP for high beam magnetic rigidity beam, beam impedance, vacuum, etc…)

2. How to maximise the rate of atomic excitations?

3. How to extract γ-rays from the collision zone?

4. How to collimate the γ-ray beam?

5. How to monitor/measure the flux of outgoing photons?

6. Demonstrate new cooling method of hadronic beams (Doppler Cooling).

7. Atomic Physics measurement programme.
**Choice of ion beam for the PoP experiment**

- **Lithium-like Lead: Pb+79**
  - Atomic ground state: $1s^2\ 2s^1\ 2S_{1/2}$
  - Choice of excited state: $1s^2\ 2p^1\ 2P_{1/2}$
  - Transition energy: $E = 230.76\ eV$
  - Lifetime (excited state): $\tau = 76\ ps$
  - Ion Lorentz factor: $\gamma_L = 96$
  - Pulsed laser: $\lambda_{\text{laser}} = 1030\ nm$

**Cooling time in the SPS**  
(~1 photon absorption/revolution/ion)

**Pb+79 beam life-time in the SPS**

$\tau_{\text{cooling}} < \tau_{\text{beam}}$
PoP experiment location – initial considerations:
LSS6: Laser–PSI interaction region: 616?

LSS6.616: present (post-LS2) layout

- Move VWSB and MPLH 2313 mm to improve vertical aperture
- New VV

6257 mm for GF IR

B. Goddard
GF software development

MC Cross-check

Beam cooling studies
Doppler cooling with narrow-band lasers

Laser and F-P optimisation studies

Maximising Nb of excited atoms

Selective atomic excitation

PoP photodetection studies

Beam cooling studies
4.4 scatterings per ion per turn
4 for gamma beam, 0.4 for cooling

Laser and F-P optimisation studies
The Gamma Factory timeline

**Phase 1 -- Initial beam tests and PoP experiment design**

<table>
<thead>
<tr>
<th>GF Phase 1: Initial Study</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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<tr>
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<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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<tr>
<td>SPS operation</td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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</tbody>
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Activities:
- Xe$^{39+}$ in SPS
- Pb$^{80/81+}$ in SPS
- Pb$^{80+}$ in LHC

Milestones:
- PBC GF Study Group formed
- Atomic beams accelerated and stored in SPS & LHC
- Proposal for PoP GF experiment in SPS

**Phase 2 -- SPS PoP experiment and GF performance studies**

<table>
<thead>
<tr>
<th>GF Phase 2: SPS PoP</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
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Activities:
- Radiation test
- Stripping construction
- Laser procurement
- Install in SPS
- SPS PoP MD beam tests
- SPS PoP MD beam tests
- TDR

Milestones:
- Validate Laser radiation tolerance
- All equipment ready for SPS installation
- System hardware and beam commissioned in SPS
- Proof of GF concept and TDR launch
Conclusions

- Over the last 2 years the Gamma Factory initial ideas developed into a well-defined project involving a group of 60 scientists from 19 institutes in 9 countries.
- It has passed its first and most important milestone: the proof that one can produce, accelerate and store atomic beams in the CERN accelerator complex.
- The Gamma Factory project has already entered its second phase: (1) developing the requisite software tools and (2) designing a GF Proof-of-Principle experiment at the CERN SPS.
- We have submitted two documents (Comprehensive overview and Addendum) to the European Particle Physics Strategy Update 2018–2020 and hope that the Gamma Factory will be retained as a possible future research programme for CERN.
- A Gamma Factory Yellow Report is currently in preparation.