Gamma Factory

Physics Beyond Colliders Annual Workshop

January 2019

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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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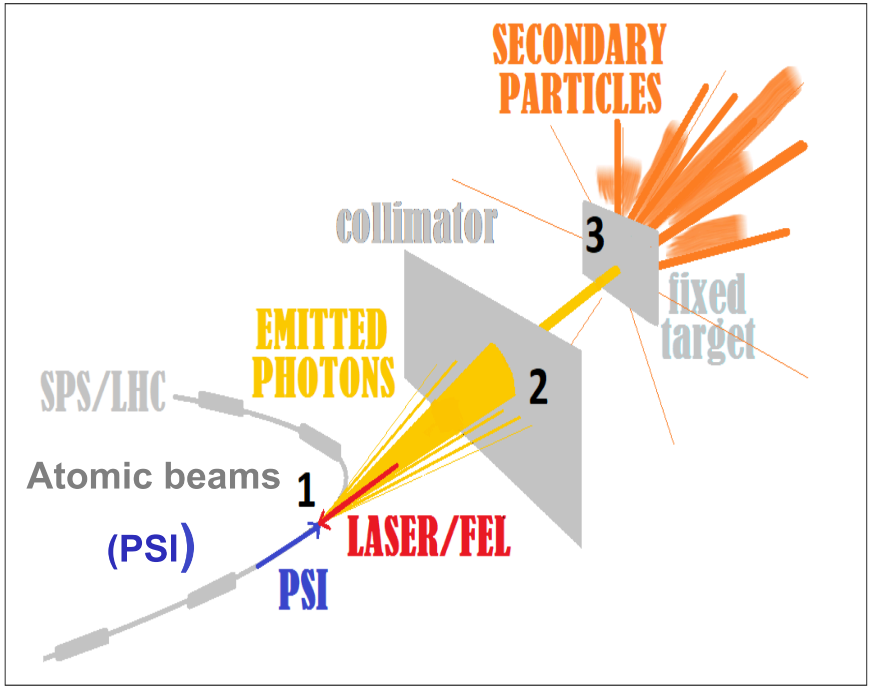
Gamma Factory research tools:
primary and secondary beams



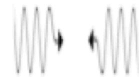
primary beams:

- 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

γ–p(A), ep(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 → **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.*

Gamma Factory research programme targets

Physics

- **Particle** — *basic symmetries, **DM,** EW precision measurements with PSI, ion, μ and ν beams…*
- **Nuclear** — *nuclear charge and spin structure**, neutron skin**, QCD confinement studies, photo-fission*
- **Accelerator** — ***beam cooling,** plasma wake field acc., high-int. polarized e & μ sources…*
- **Atomic** — *physics of highly charged electronic and muonic atoms: strong EM fields**,** EW effects…*
- **Applied** — *accelerator driven energy sources , cold? & warm fusion, medical isotope production…*

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…***

Gamma Factory project milestones

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**.*

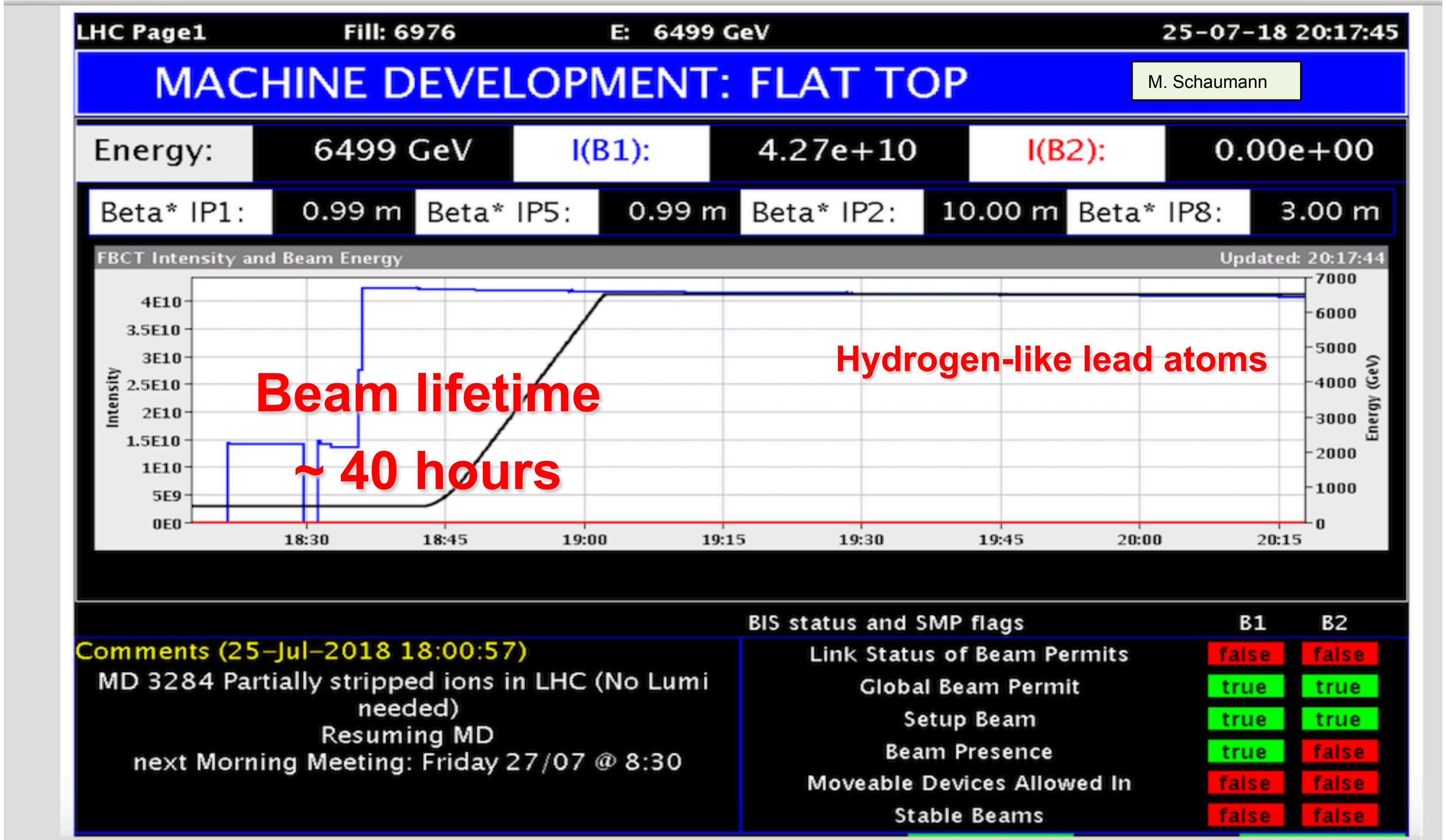
6. *Gamma Factory **TDR**.*

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 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!**



- ***Intensity/bunch (~7 x 10^9 charges), 6 bunches circulating.***

July 2018: Birth of Atomic Physics research at CERN

symmetry
dimensions of particle physics

topics

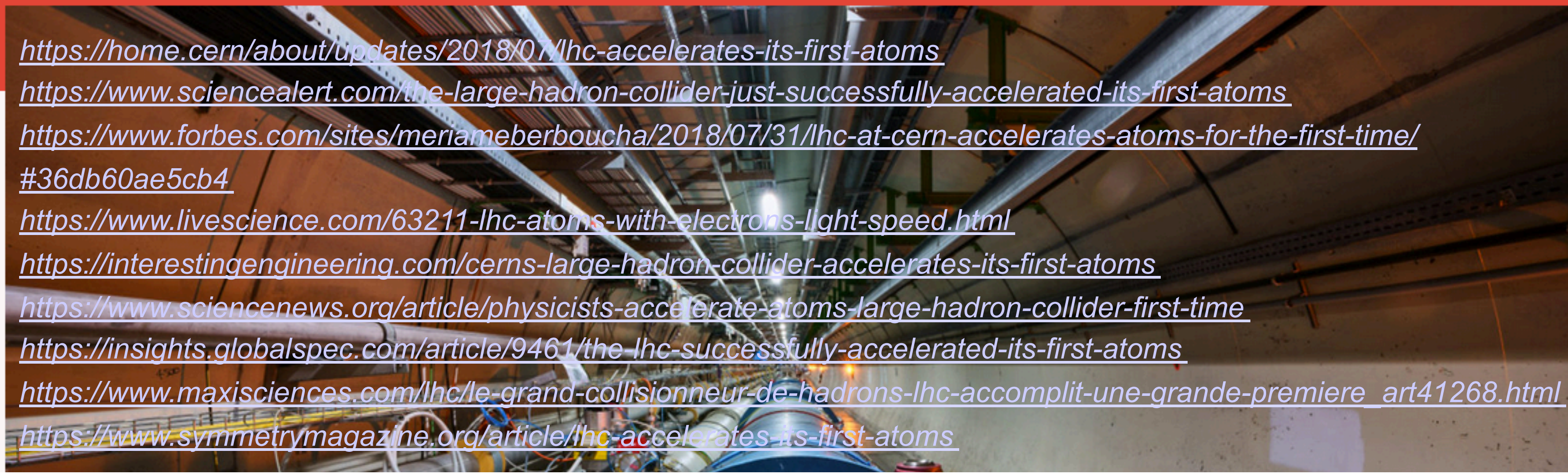
follow +

A joint Fermilab/SLAC publication

LHC accelerates its first "atoms"

07/27/18 | By Sarah Charley

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
https://www.sciencealert.com/the-large-hadron-collider-just-successfully-accelerated-its-first-atoms
https://www.forbes.com/sites/meriameberboucha/2018/07/31/lhc-at-cern-accelerates-atoms-for-the-first-time/#36db60ae5cb4
https://www.livescience.com/63211-lhc-atoms-with-electrons-light-speed.html
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://insights.globalspec.com/article/9461/the-lhc-successfully-accelerated-its-first-atoms
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 ~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**?*

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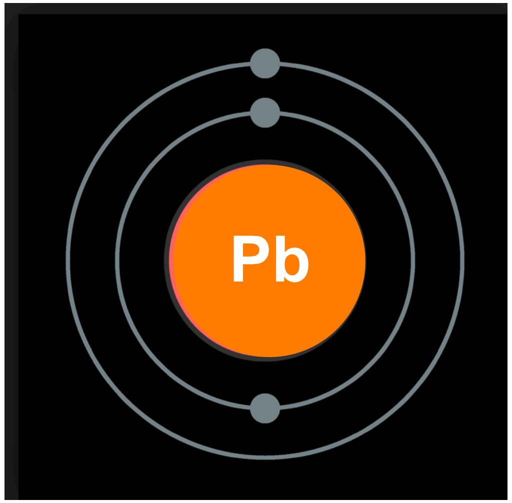
6. *Demonstrate **new cooling** method of **hadronic** beams (Doppler Cooling).*
7. ***Atomic Physics** measurement programme.*

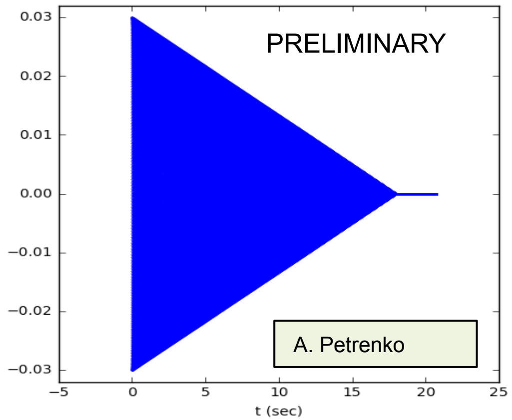
Choice of ion beam for the PoP experiment

➢ *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): **τ = 76 ps**
- ION LORENTZ FACTOR: **γ_L = 96**
- PULSED LASER: **λ_{laser} = 1030 nm**

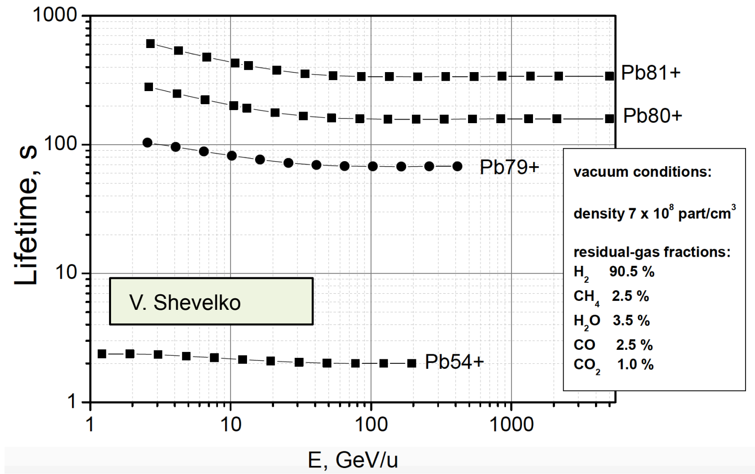


Cooling time in the SPS
(~1 photon absorption/revolution/ion)



$\tau_{cooling} < \tau_{beam}$

Pb+79 beam life-time in the SPS

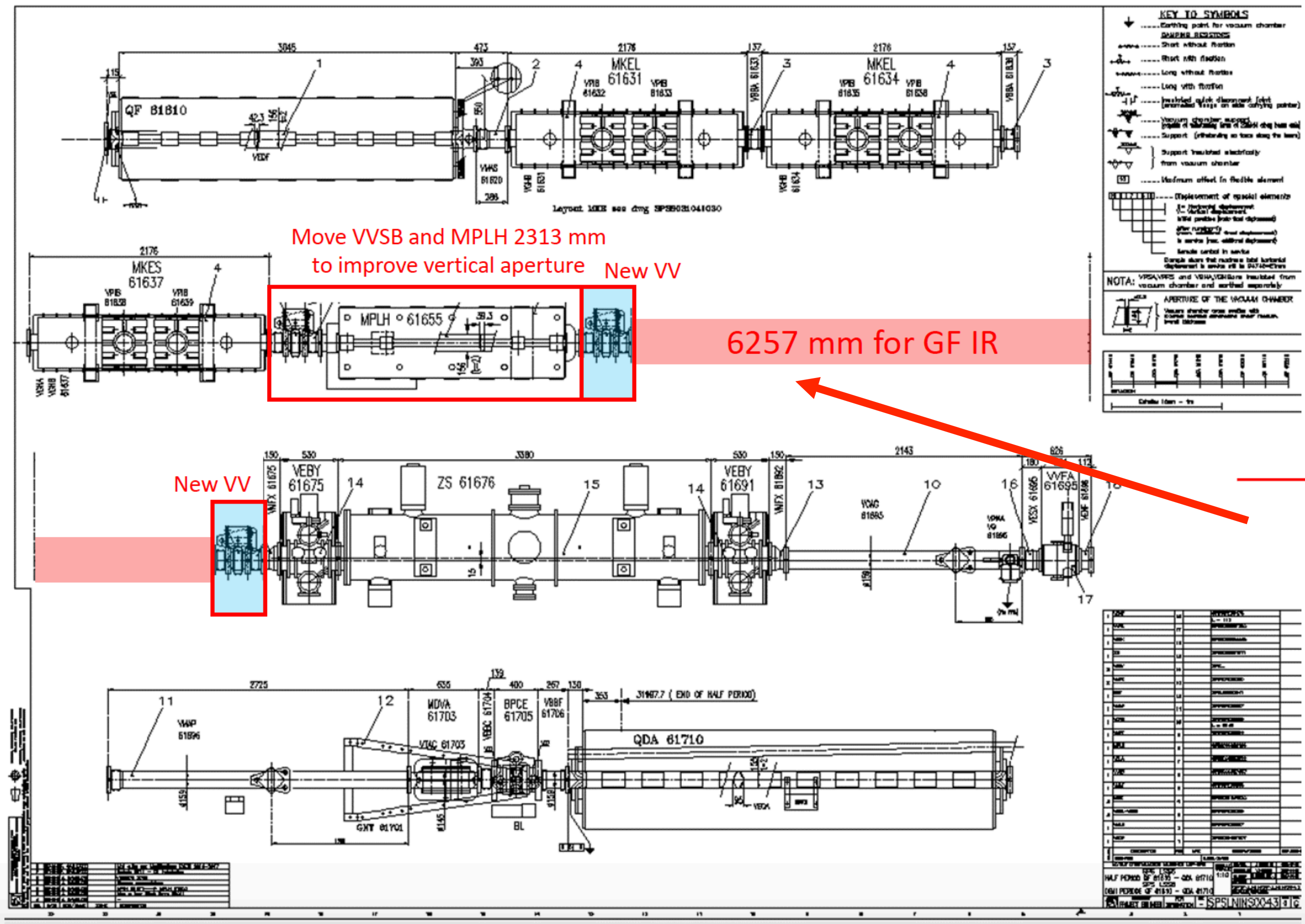


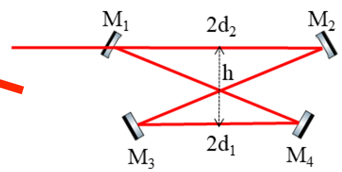
PoP experiment location – initial considerations:

LSS6: Laser–PSI interaction region: 616?

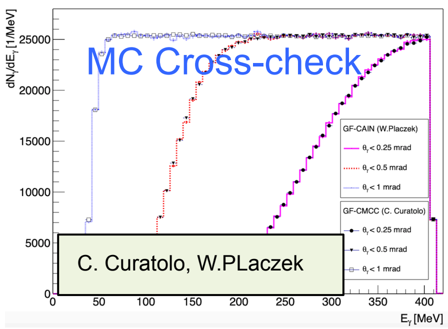
LSS6.616: present (post-LS2) layout

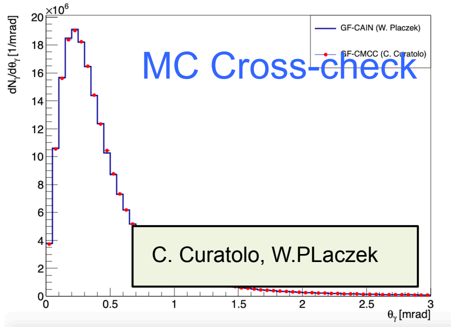
B. Goddard

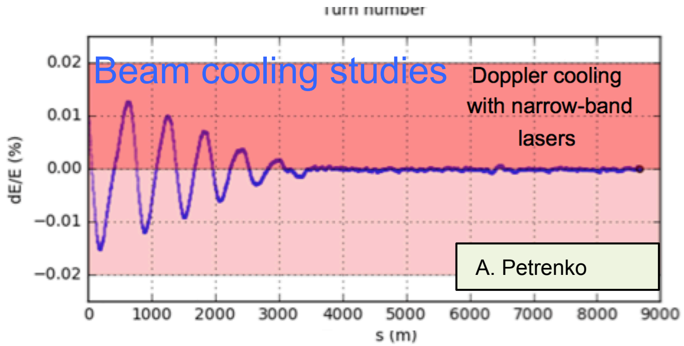


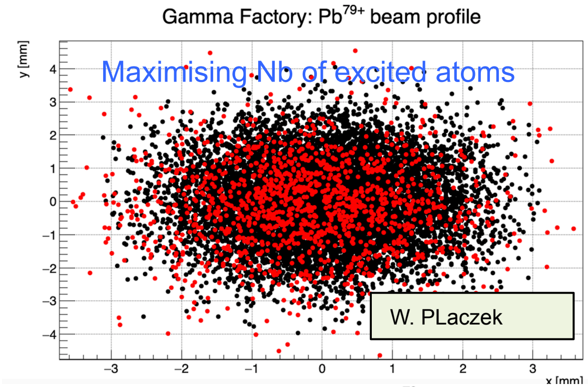


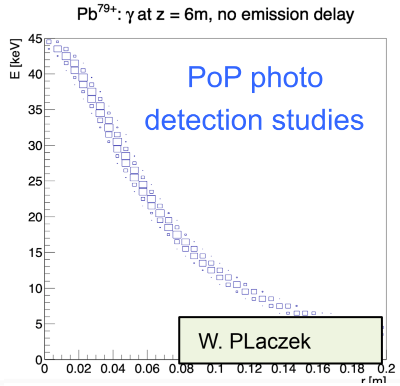
GF software development

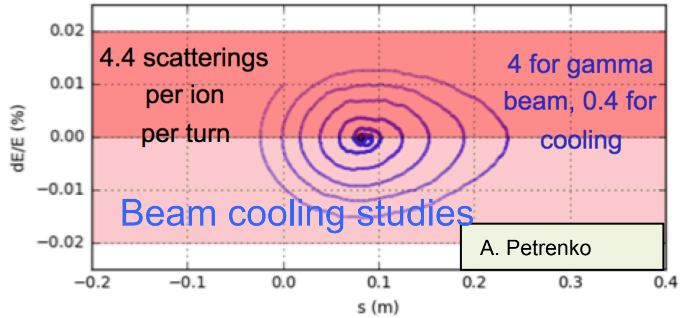


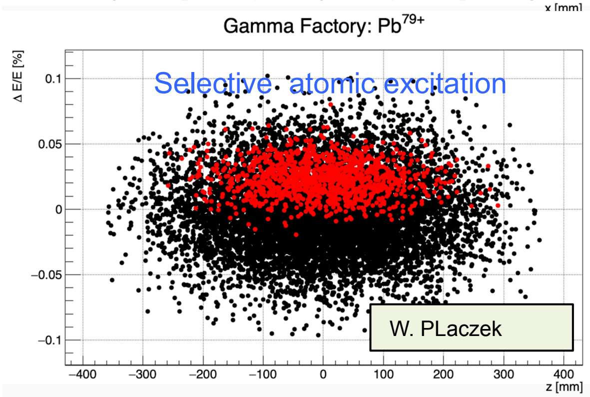


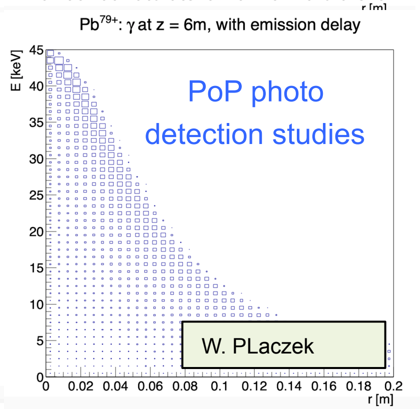


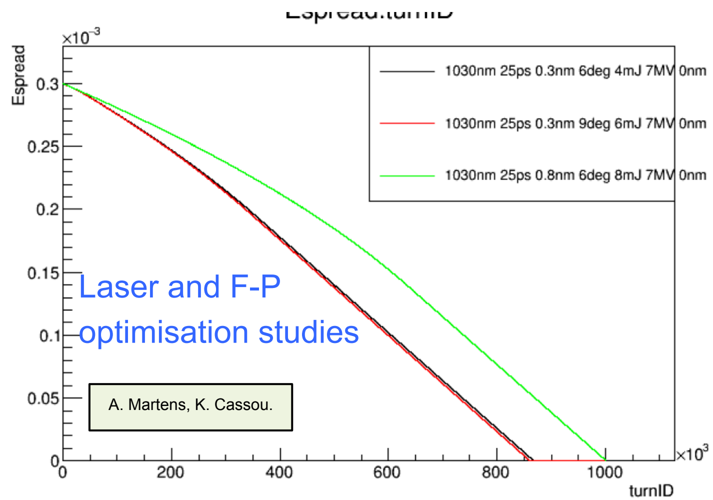






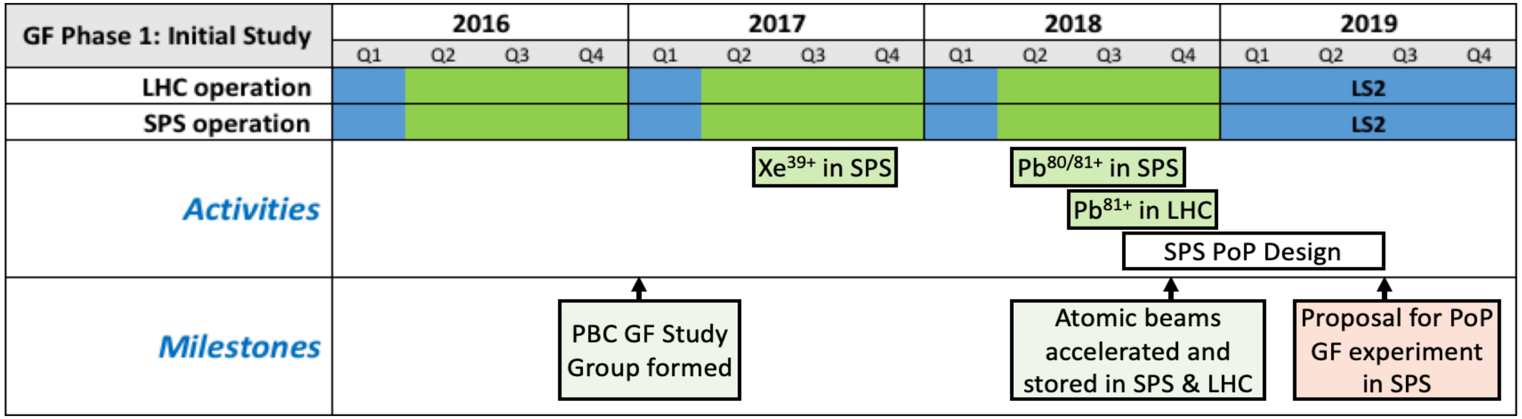




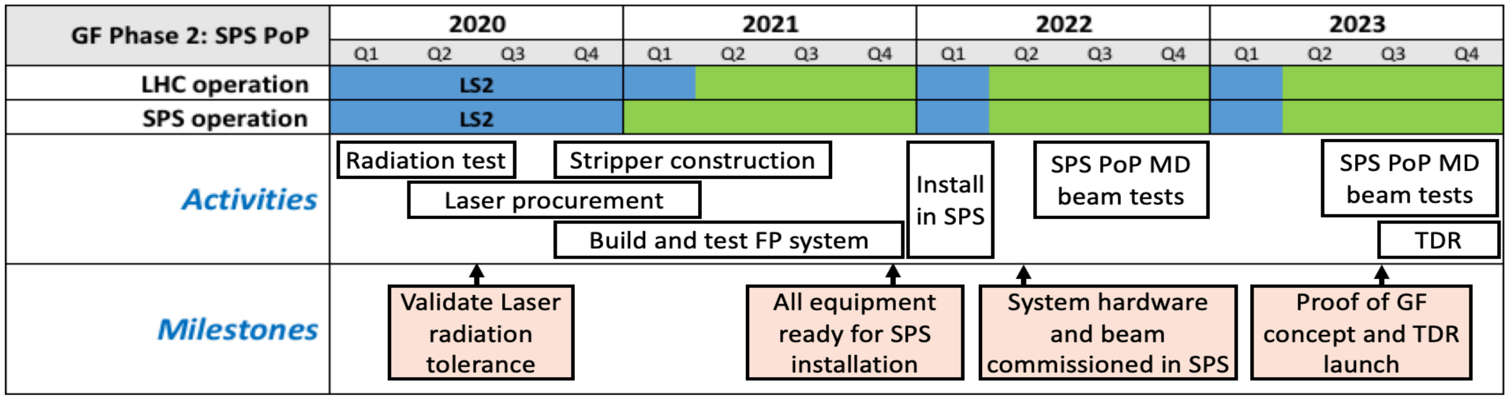


The Gamma Factory timeline

Phase 1 -- Initial beam tests and PoP experiment design



Phase 2 -- SPS PoP experiment and GF performance studies



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.