Gamma Factory in the CERN landscape

MITP Gamma Factory workshop, Nov.-Dec. 2020

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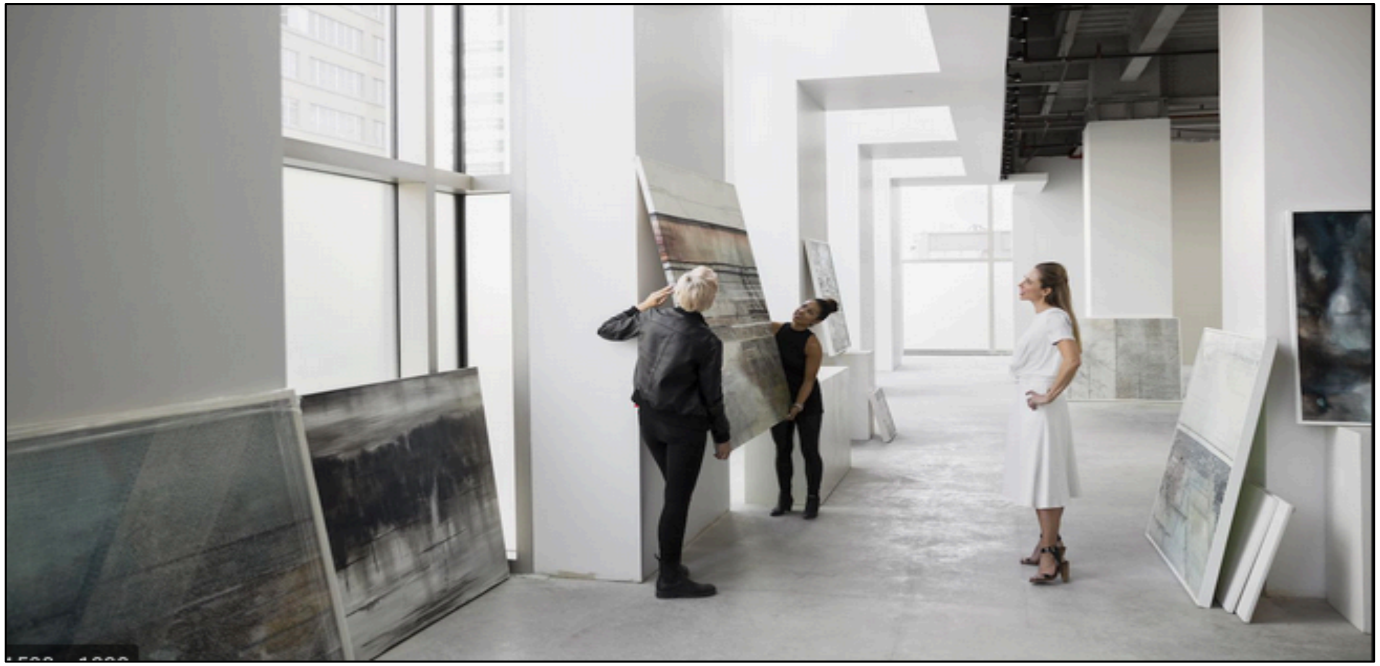
LPNHE, CNRS and University Paris Sorbonne and CERN, BE-ABP

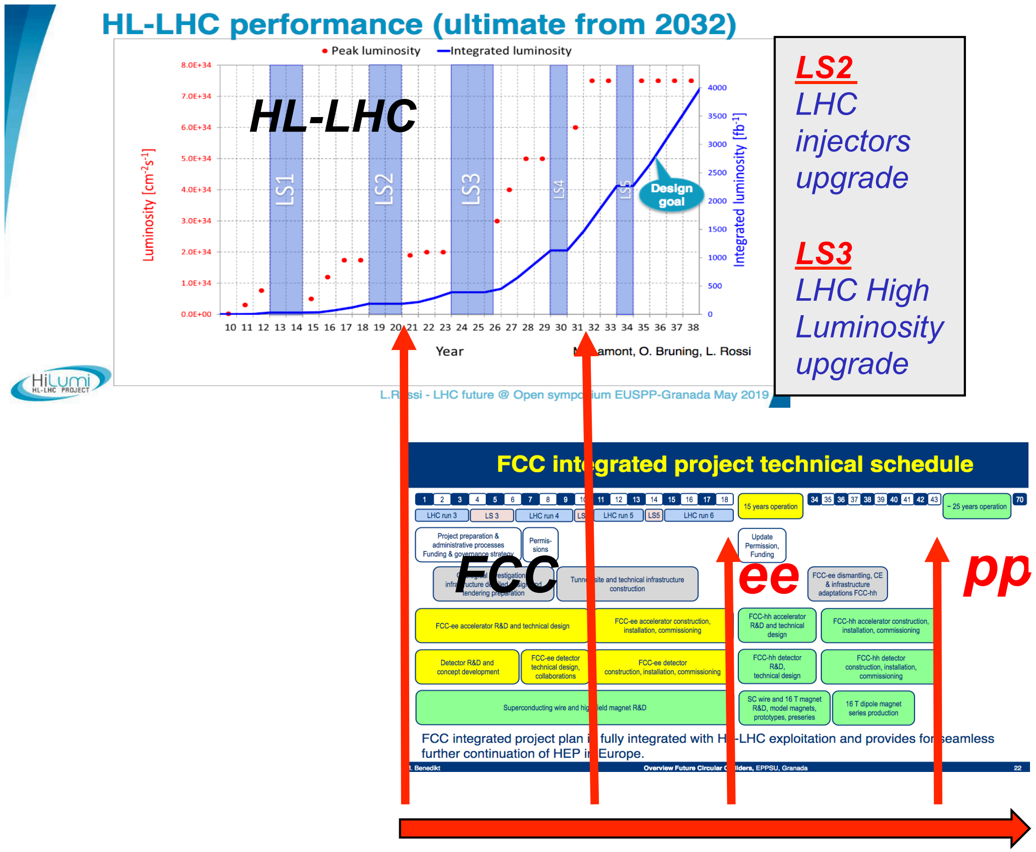
Outline of the talk

- *Our place in the CERN landscape*
- *Gamma Factory tools*
- *Gamma Factory milestones – status report*
- *Challenges*
- *Conclusions*

Our place in the CERN landscape



On-going and future CERN research programme



Year: 2021 2032 2040? …2065?

CERN priorities
(ESPP recommendations)

- ❑ Full exploitation of LHC including high-luminosity upgrade
  - Vast physics reach for **all** experiments
  - Physics and technology milestone towards a future collider

  Note: no future for CERN if HL-LHC is not successful

- ❑ Investigation of technical and financial feasibility of FCC

  ESPP gives direction for future collider at CERN*, but prudent approach: feasibility study first

- ❑ Reinforced R&D on accelerator technologies: **high-field superconducting magnets**, high-gradient accelerating structures, and plasma wakefield, muon colliders, ERL, etc.

  To prepare a broad and solid future for HEP, including alternatives to FCC if not feasible.

  ESPP recommends development of Accelerator R&D roadmap by European community.

- ❑ Support of scientific diversity programme and long-baseline neutrino (in particular LBNF/DUNE)

  Diversity is **keyword** in the absence of clues on E-scale and couplings of new physics

Fabiola Gianotti, CERNs DG

A potential place of Gamma Factory in the future CERN research programme

- *The **next** CERN **high-energy frontier** project may take **long time** to be approved, built and become operational, … unlikely before 2045 (FCC-ee) or 2050+ (μ-collider)*

- *The **present** LHC **research programme** will certainly reach **earlier** (>2032) its discovery **saturation** (little physics gain by a simple extending its pp/pA/AA running time)*

- *A strong **need** will certainly arise for a **novel** multidisciplinary programme which could **re-use** ("co-use") the **existing** CERN facilities (including LHC) in **ways** and at **levels** that were **not** necessarily **thought** of when the machines were **designed***

***The Gamma Factory** research programme (> 2032) could fulfil such a role. It can exploit **the existing world unique opportunities** offered by the CERN accelerator complex and CERN's scientific infrastructure **(not available elsewhere**) to conduct new, diverse, and vibrant research.*

Gamma Factory (PBC) study group

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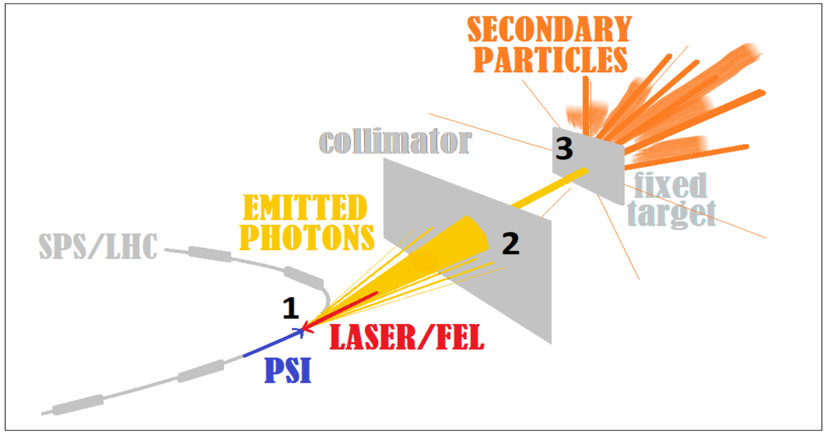
*The Gamma Factory proposal (arXiv:1511.07794 [hep-ex]) led to creation, by the CERN management (February 2017,) **the Gamma Factory study group**, embedded within the Physics Beyond Colliders studies framework.*

*~90 physicists from 35 institutions have contributed so far to the development of the project. **The GF group is open for everyone who wants to contribute.***

(contact: mieczyslaw.witold.krasny@cern.ch)

*We acknowledge the crucial role of the CERN **PBC** framework in bringing our accelerator tests, the PoP experiment design, software development and physics studies to its present stage!*

Gamma Factory Tools



The Gamma Factory in a nutshell

- *The infrastructure and the operation mode of the CERN accelerators allowing to:*
  - *produce, accelerate, cool, and store beams of highly ionised atoms*
  - *excite their atomic degrees of freedom by laser photons to form high intensity secondary beams of gamma rays*
  - *produce plug-power-efficient diverse tertiary beams*
- *The research programme in a broad domain of science enabled by the "Gamma Factory tools"*

Gamma Factory: *"Novel research tools made from light"*

1. *Atomic traps of highly charged atoms*

2. *Electron beam for ep collisions in the LHC interaction points*

3. *High intensity photon(γ)-beams*

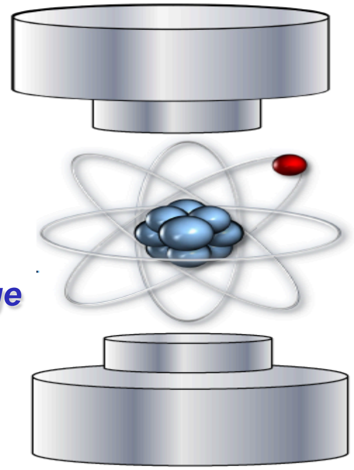
4. *Laser-light based cooling methods of high-energy hadronic beams*

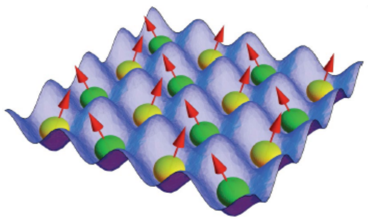
5. *Sources of polarised electrons, polarised positrons, polarised muons, neutrinos, neutrons and radioactive ions*

1.Atomic traps of highly-charged atoms

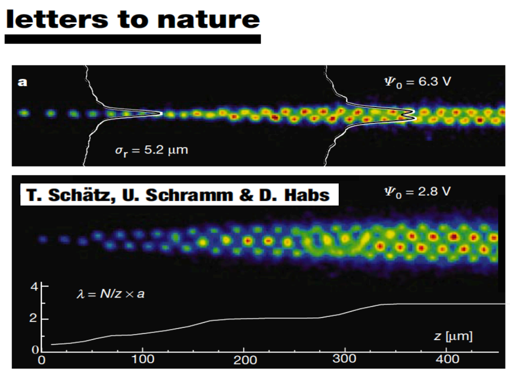
Atomic rest-frame

Trapped stationary atoms Exposed to pulsed magnetic and electric fields of the storage ring





Crystalline beams?



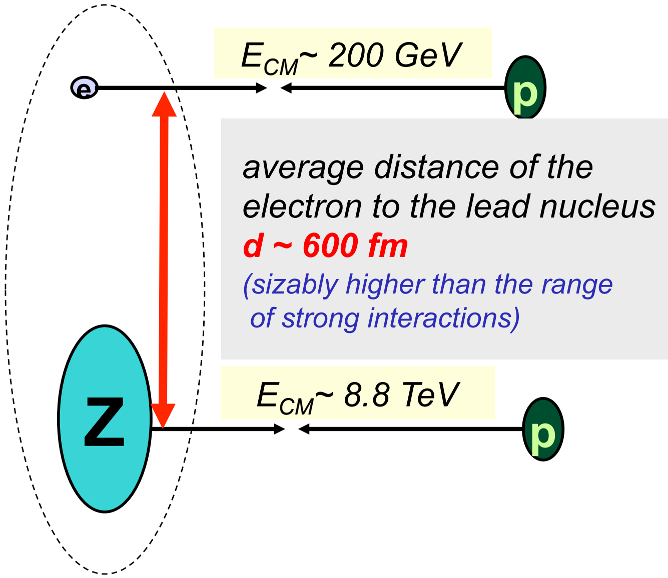
Opening new research opportunities in atomic physics:

- *Highly-charged atoms – very strong (~10^{16} V/cm) electric field (QED-vacuum effects)*
- *Small size atoms (electroweak effects)*
- *Hydrogen-like and Helium-like atomic structure (calculation precision and simplicity)*
- *Atomic degrees of freedom of trapped highly-charged atoms can be resonantly excited by laser photons*

2.Electron beam for ep collisions at LHC

(in the ATLAS, CMS, ALICE and LHCb interaction points)

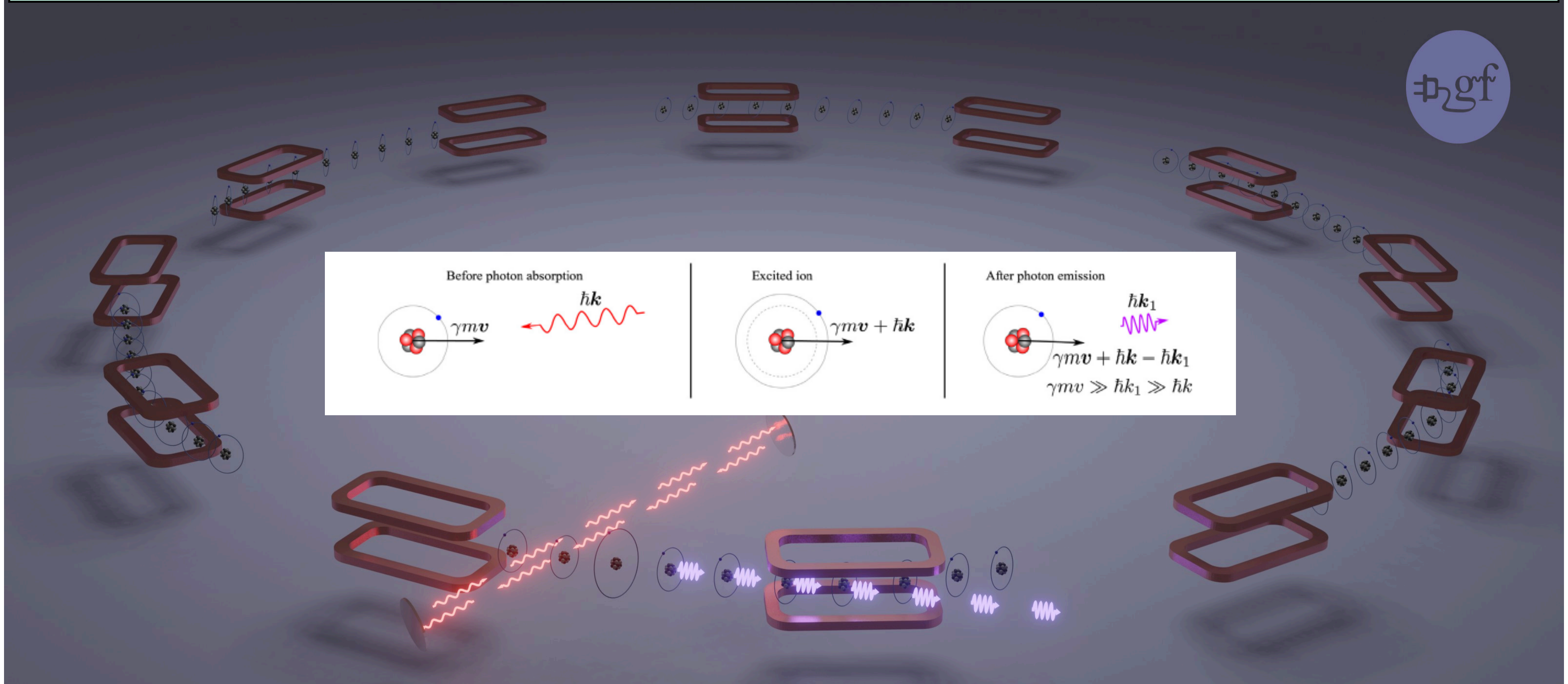
Hydrogen-like lead



*Atomic beams can be considered as **independent electron and nuclear beams** as long as the incoming proton scatters with the momentum transfer q >> 300 KeV!*

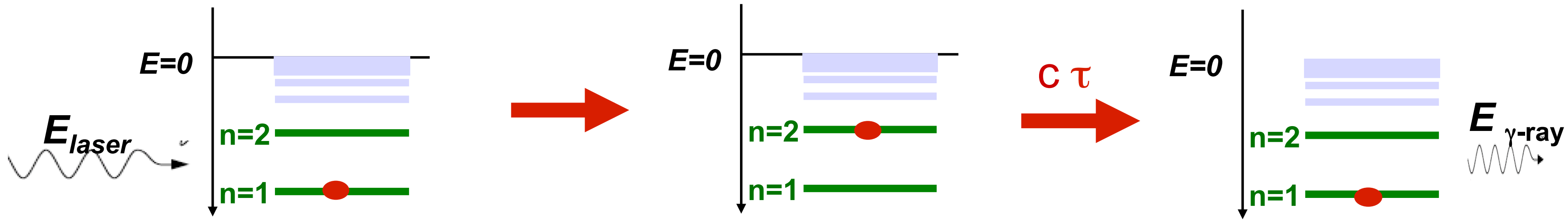
*Opens the possibility of collecting, by each of the LHC detectors, over one day of the **Pb+81–p** operation, the effective ep-collision luminosity comparable to the HERA integrated luminosity in the first year of its operation (1992) – in-situ diagnostic of the emittance of partonic beams at the LHC!*

3.Gamma Factory γ-source



Novel technology: *Resonant scattering of laser photons on ultra-relativistic atomic beam*

Source properties



1. Point-like:

➢ *For high-Z, hydrogen- and helium-like atoms:* ***decay length ($c\tau\gamma_L$) << 1 cm***

2. High intensity:

➢ ***Resonant*** *process. A leap in the intensity by* ***6–8 orders of magnitude*** *w.r.t. electron-beam-based Inverse Compton Sources (ICS) (at fixed γ_L and laser power)*

Source properties

High energy atomic beams play the role of **high-stability light-frequency converters**:

$$\nu^{max} \longrightarrow (4\,\gamma_L^{\,2})\;\nu_{Laser}$$

for photons emitted in the direction if incoming atoms, γ_L = E/M is the Lorentz factor for the ion beam

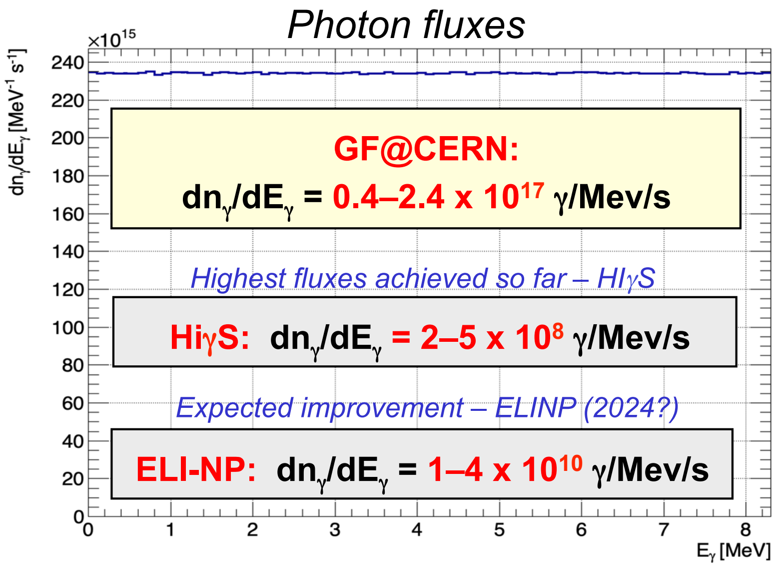
3.Tuneable energy:

- *The tuning of the beam energy (SPS or LHC), the choice of the ion, the number of left electrons and of the laser type allow to tune the γ-ray energy at CERN in the energy range of 10 keV – 400 MeV (extending, by a factor of **~1000**, the energy range of the FEL X-ray sources)*

4. Plug power efficient:

- *Atoms loose a tiny fraction of their energy in the process of the photon emission. Important: No need to refill the driver beam. The RF power is fully converted to the power of the photon beam*

A concrete example: *Nuclear physics application: He-like, LHC Calcium beam, $(1s \rightarrow 2p)_{1/2}$ transition, TiSa laser*

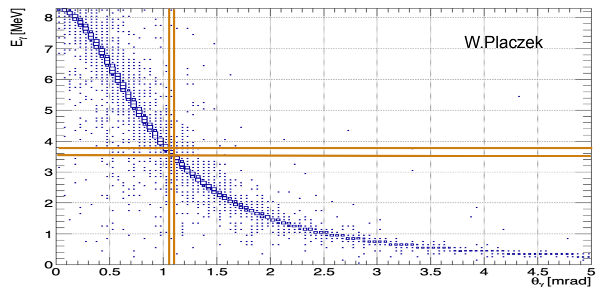


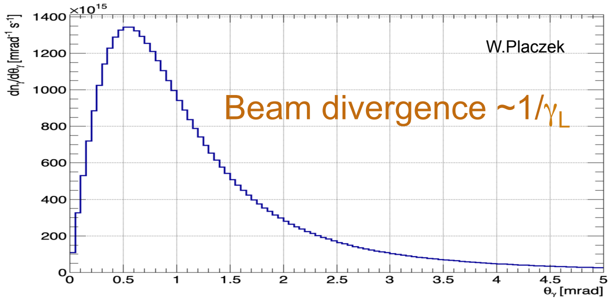
laser pulse parameters

- Gaussian spatial and time profiles,
- photon energy: E_photon = 1.8338 eV
- photon pulse energy spread: sigma_{omega}/omega = 2 x 10^{-4},
- photon wavelength: lambda = 676 nm,
- pulse energy: W_{l} = 5 mJ,
- peak power density 1.12 x 10^13 W/m^2
- r.m.s. transverse beam size at focus: sigma_{x} = \sigma_{y } = 150 um (micrometers),
- Rayleigh length: R_{L,x} = R_{L,y} = 7.5 cm,
- r.m.s. pulse length: l_{l} = 15 cm.

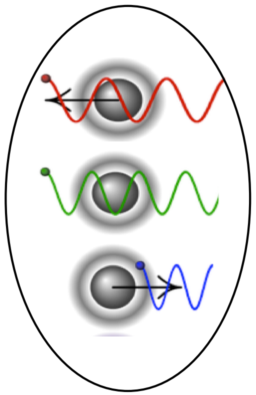
5. Highly-collimated monochromatic γ–beams:

- *the beam power is concentrated in a narrow angular region (facilitates beam extraction)*
- *the $(E_\gamma, \Theta_\gamma)$ correlation can be used (collimation) to "monochromatise" the beam*

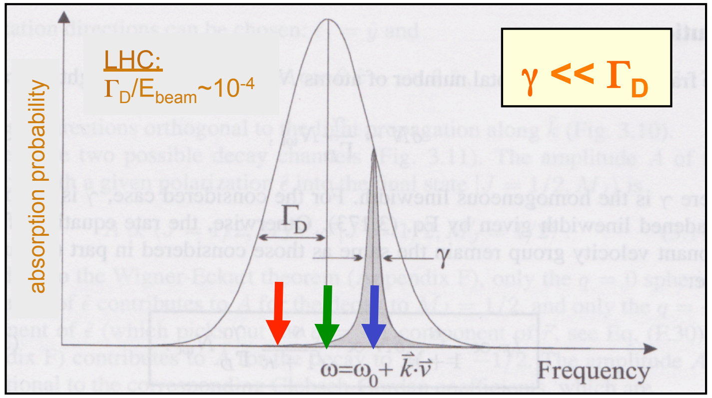


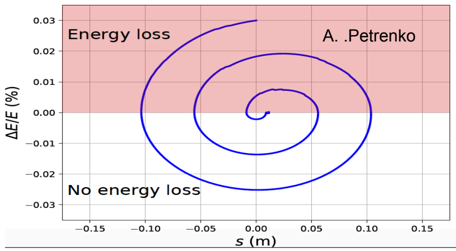


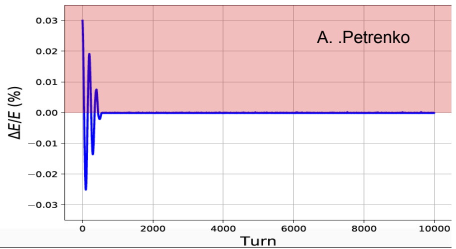
4.Doppler laser cooling methods of high energy beams



Bunch

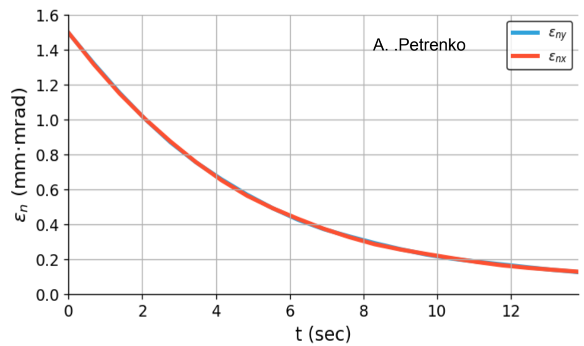






Beam cooling speed: *the laser wavelength band is chosen such that only the ions moving in the laser pulse direction (in the bunch rest frame) can resonantly absorb photons.*

Opens a possibility of forming at CERN hadronic beams of the required longitudinal and transverse emittances within a seconds-long time scale.



Simulation of laser cooling of the lithium-like Ca(+17) bunches in the SPS: transverse emittance evolution.

5.Tertiary beams' sources – *Intensity/quality targets*

- ***Polarised positrons*** – *potential gain of up to a factor of 10^4 in intensity w.r.t. the KEK positron source, satisfying both the LEMMA and the LHeC requirements*
- ***Pions*** – *potential, gain by a factor of 10^3, gain in the spectral density ($dN_\pi/dEdp_T dP$ [MeV^{-2} x MW] with respect to proton-beam-driven sources at KEK and FNAL (P is the driver beam power)*
- ***Muons*** – *potential gain by a factor of 10^3 in intensity w.r.t. the PSI muon source, charge symmetry ($N\mu^+ \sim N\mu^-$), polarisation control, no necessity of the muon beam cooling?*
- ***Neutrinos*** – *fluxes comparable to NuMAX but: (1) Very Narrow Band Beam, driven by the small spectral density pion beam and (2) unique possibility of creating flavour- and CP-tuned beams driven by the beams of polarised muons*
- ***Neutrons*** – *potential gain of up to a factor of 10^4 in intensity of primary MeV-energy neutrons per 1 MW of the driver beam power*
- ***Radioactive ions*** – *potential gain of up to a factor 10^4 in intensity w.r.t. e.g. ALTO*

Application domains of the Gamma Factory research tools

- ***particle physics*** *(studies of the basic symmetries of the universe, dark matter searches, precision QED and EW studies, vacuum birefringence studies, Higgs physics in $\gamma\gamma$ collision mode, rare muon decays, precision neutrino physics, …).*
- ***accelerator physics*** *(beam cooling techniques, low emittance hadronic beams, plasma wake field acceleration, high intensity polarized positron and muon sources, beams of radioactive ions and neutrons, very narrow band, and flavour-tagged neutrino beams).*

Wednesday, Friday sessions

- ***nuclear physics*** *(confinement phenomena, nuclear spectroscopy, nuclear photo-physics, fission research, gamma polarimetry, physics of rare radioactive nuclides,…).*
- ***atomic physics*** *(electronic and muonic atoms, pionic and kaonic atoms).*
- ***applied physics*** *(accelerator driven energy sources, cold and warm fusion research, medical isotopes' and isomers' production, …).*

Tuesday, Thursday, Friday sessions

Gamma Factory milestones – status report

Gamma Factory project milestones

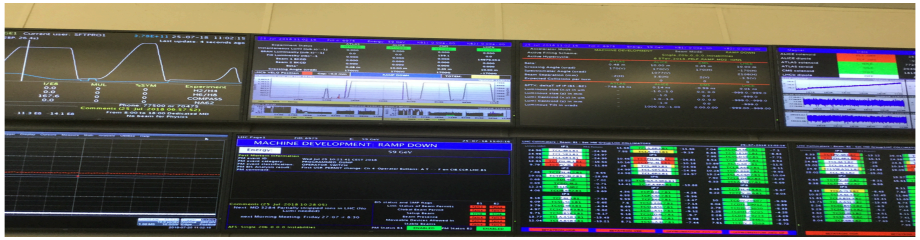
1. *Successful demonstration of efficient production, acceleration and storage of “atomic beams” in the CERN accelerator complex.* → *Done…*
2. *Development “ab nihilo” the requisite Gamma Factory software tools.* → *Done…*
3. *Building up the physics cases for the LHC-based GF research programme and attracting wide scientific communities to evaluate and use (in the future) the GF tools in their respective research.* → *Work on-going…*
4. ***Successful execution of the GF Proof-of-Principle (PoP) experiment in the SPS tunnel.*** → *LoI submitted to the SPSC on the 25th of September 2019, public presentation on the 13th of October 2020 → waiting for CERN’s approval*

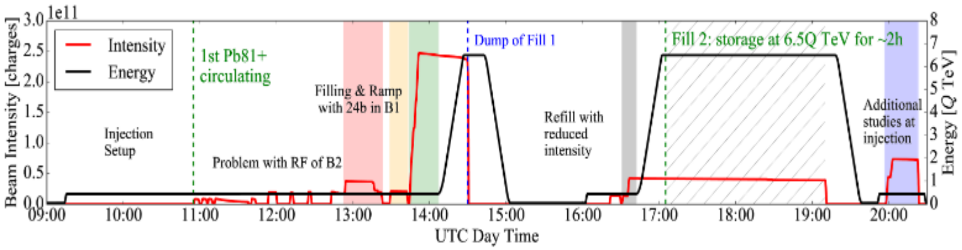
future

5. *Extrapolation of the PoP experiment results to the LHC case and precise assessment of the performance figures of the GF programme (prior to the next European Strategy Update).*
6. *Elaboration of the TDR for the LHC-based GF research programme.*

Milestone 1:

Successful demonstration and control of efficient production, acceleration and storage of atomic beams of partially stripped ions in the CERN accelerator complex..





July 2018

symmetry
dimensions of particle physics

topics

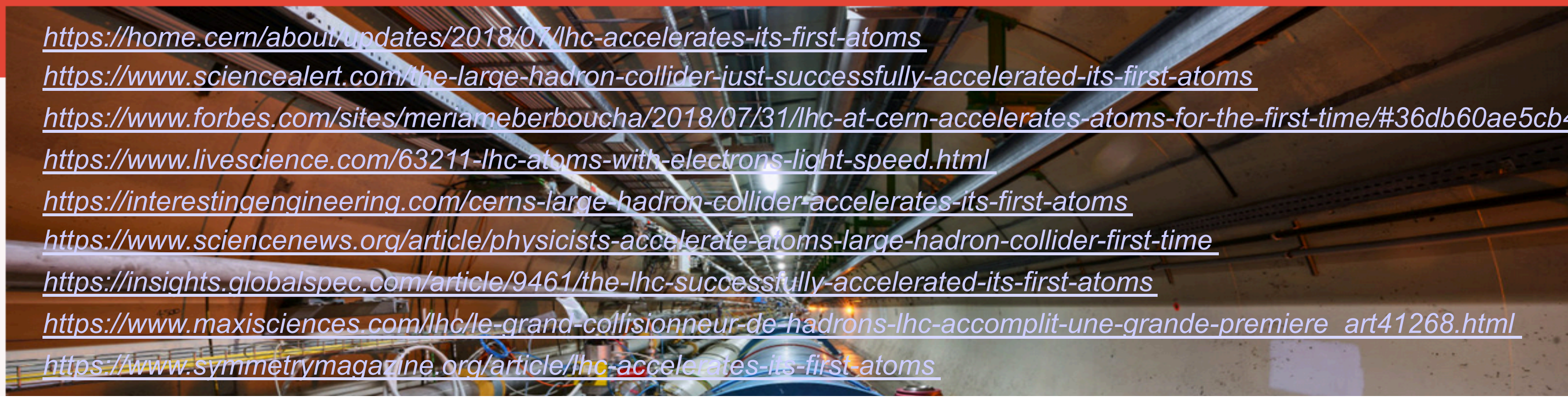
follow +

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.



What have we learned from the SPS beam test:

(beam lifetime: Xe and Pb)

LIFETIME AND BEAM LOSSES STUDIES OF PARTIALLY STRIP IONS IN THE SPS ($^{129}Xe^{39+}$)

S. Hirlaender, R. Alemany Fernandez, H. Bartosik, N. Biancacci, T. Bohl, S. Cettour Cave, K. Cornellis, B. Goddard, V. Kain, M. Lamont, D. Manglunki, G. Papotti, M. Schaumann, F. Zimmermann, CERN, Geneva, Switzerland
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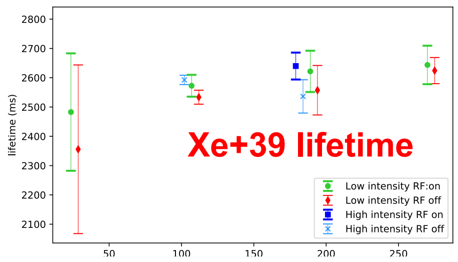
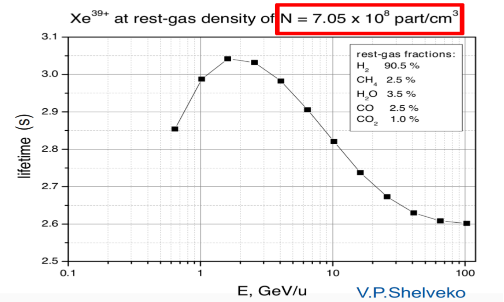
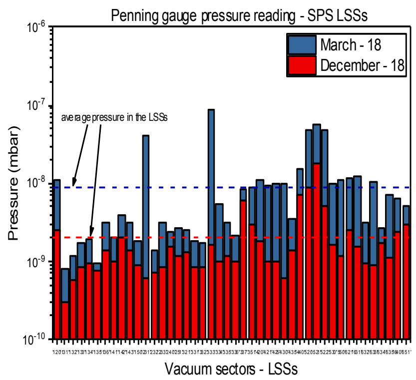
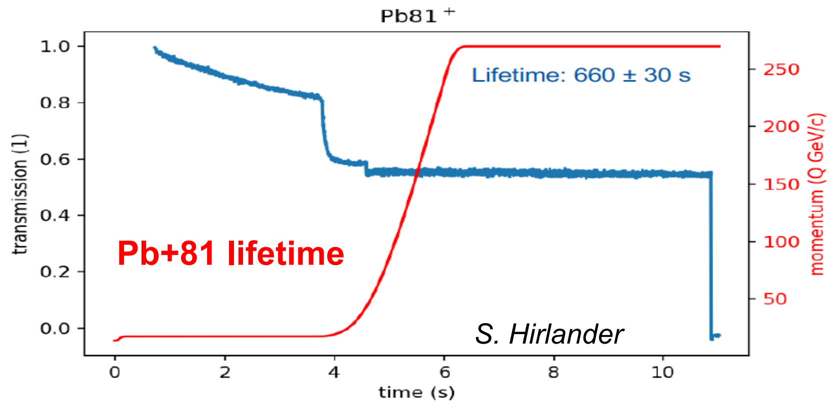


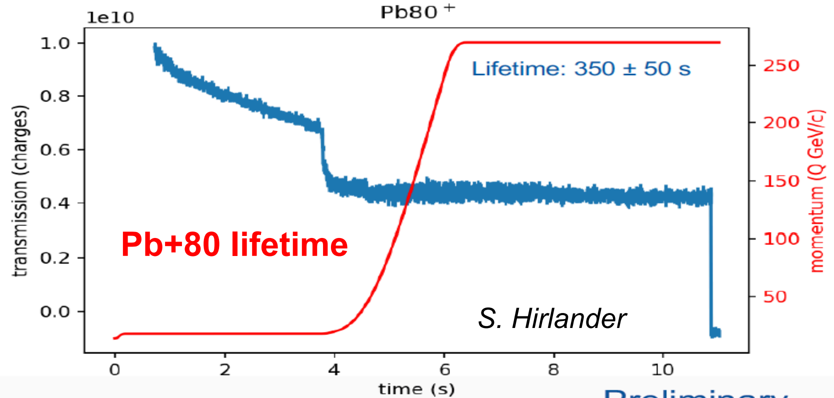


Residual gas density calibration



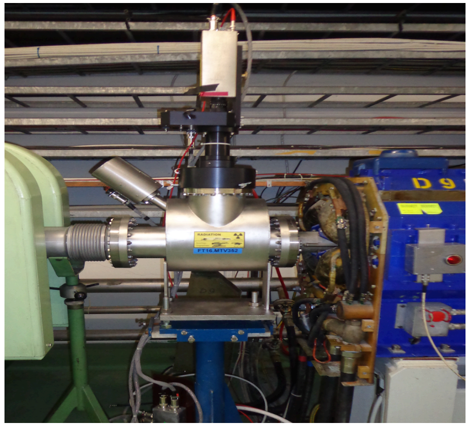
Pressure measurements campaign (2018)

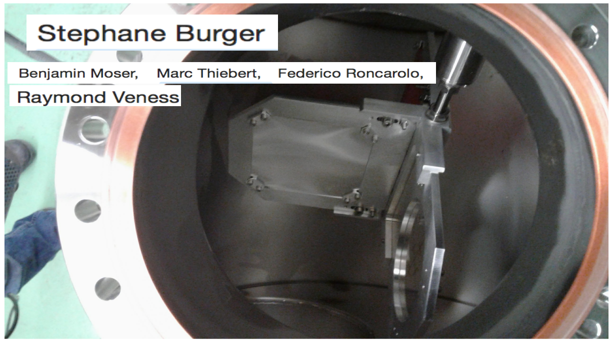


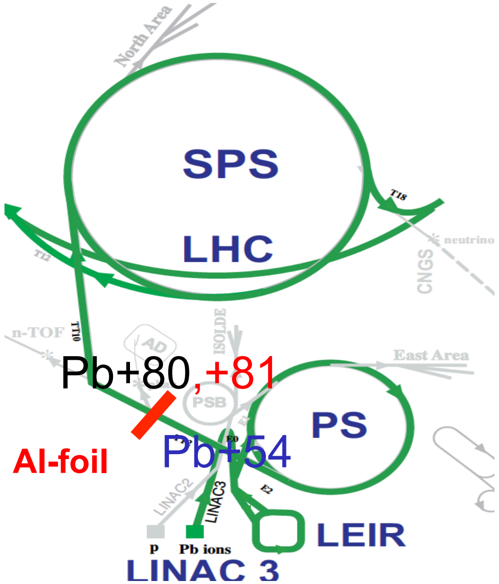


Preliminary

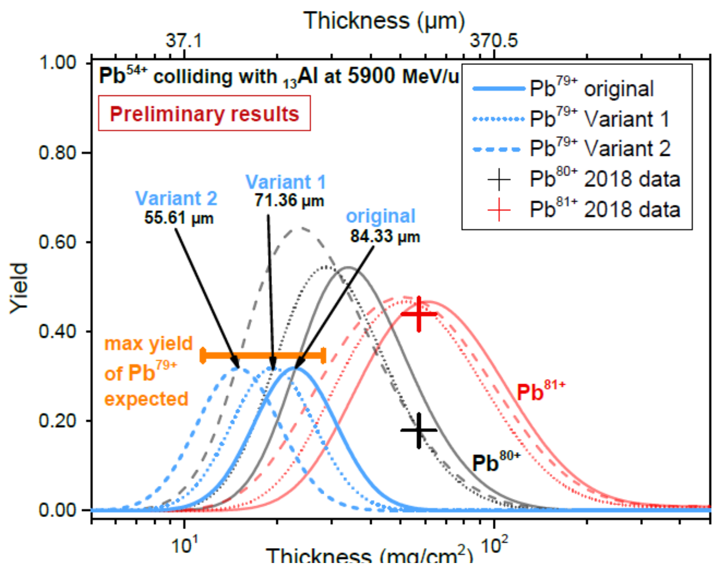
What we have learned form the LHC beam tests:
(optimisation of the electron stripping)







F.Kroeger. T. Stohlker. G. Weber.



Status of Upcoming SPARC Experiments Within FAIR Phase-0 / 46

Charge State Tailoring for Gamma Factory

Corresponding Author: felixkr1990@yahoo.de

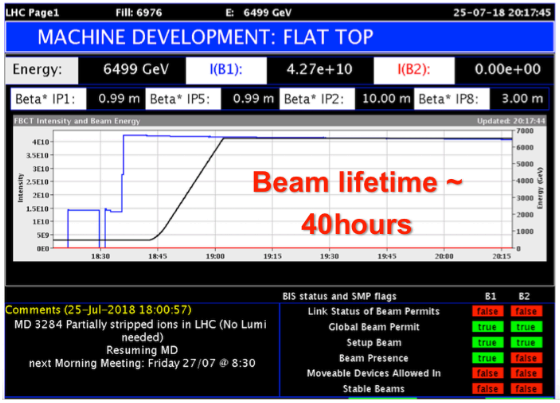
What have we learned form the LHC beam tests:

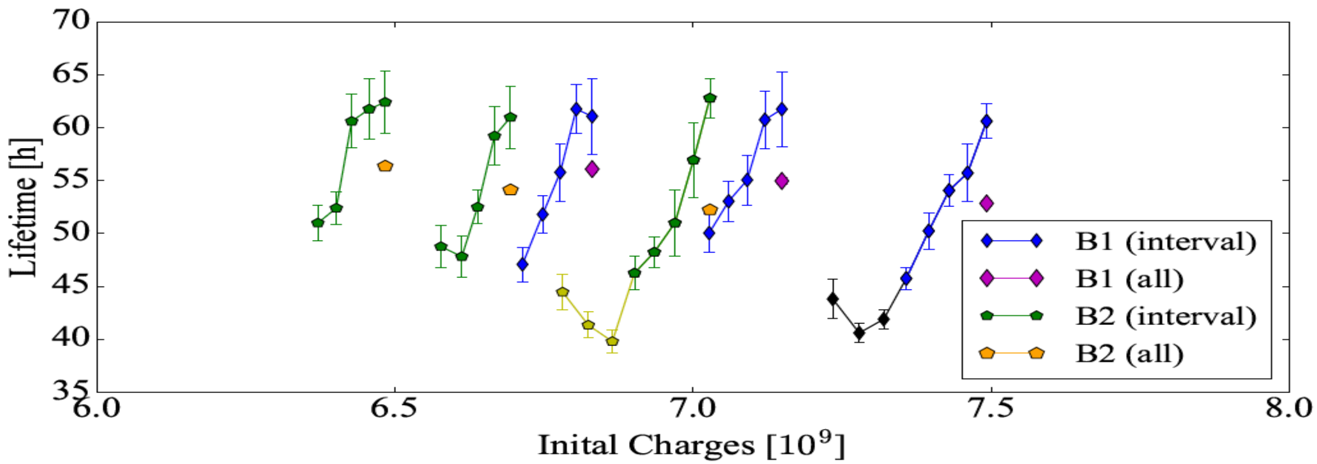
(LHC beam lifetime studies – hydrogen-like lead)

10th Int. Partile Accelerator Conf. IPAC2019, Melbourne, Australia JACoW Publishing
ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPRB055

FIRST PARTIALLY STRIPPED IONS IN THE LHC ($^{208}Pb^{81+}$)

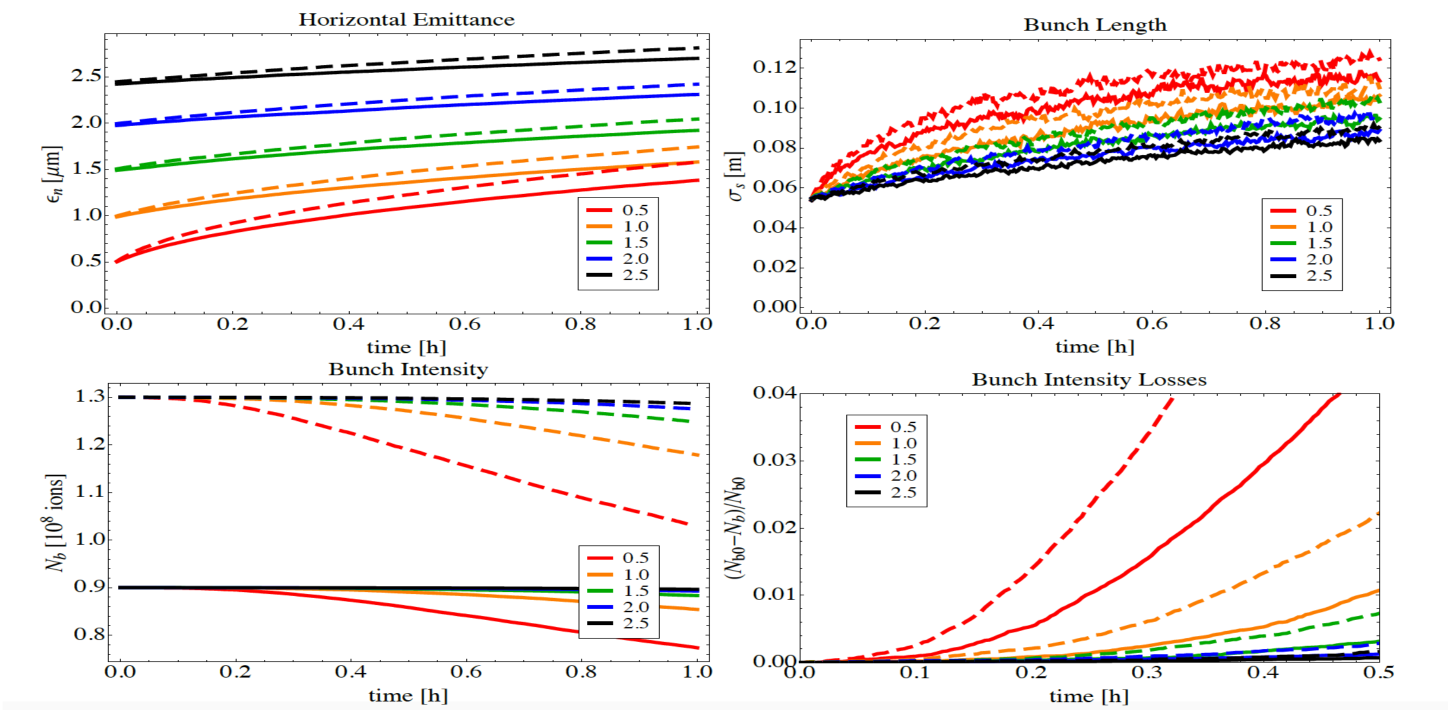
M. Schaumann*, R. Alemany-Fernandez, H. Bartosik, T. Bohl, R. Bruce, G.H. Hemelsoet,
S. Hirlaender, J.M. Jowett, V. Kain, M.W. Krasny, J. Molson, G. Papotti,
M. Solfaroli Camillocci, H. Timko, J. Wenninger, CERN, 1211 Geneva 23, Switzerland





What have we learned form the LHC beam tests:
(modelling of the LHC PSI bunch dynamics)

M. Schaumann



What we have learned form the LHC beam tests:

(collimation of PSI beams in the LHC rings)

PHYSICAL REVIEW ACCELERATORS AND BEAMS **23,** 101002 (2020)

Editors' Suggestion

Collimation of partially stripped ions in the CERN Large Hadron Collider

A. Gorzawski,[1,2,*] A. Abramov,[1,3,†] R. Bruce,[1] N. Fuster-Martinez,[1] M. Krasny,[1,4] J. Molson,[1] S. Redaelli,[1] and M. Schaumann[1]

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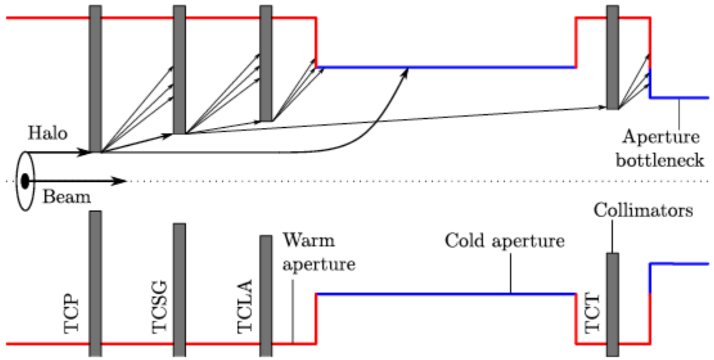
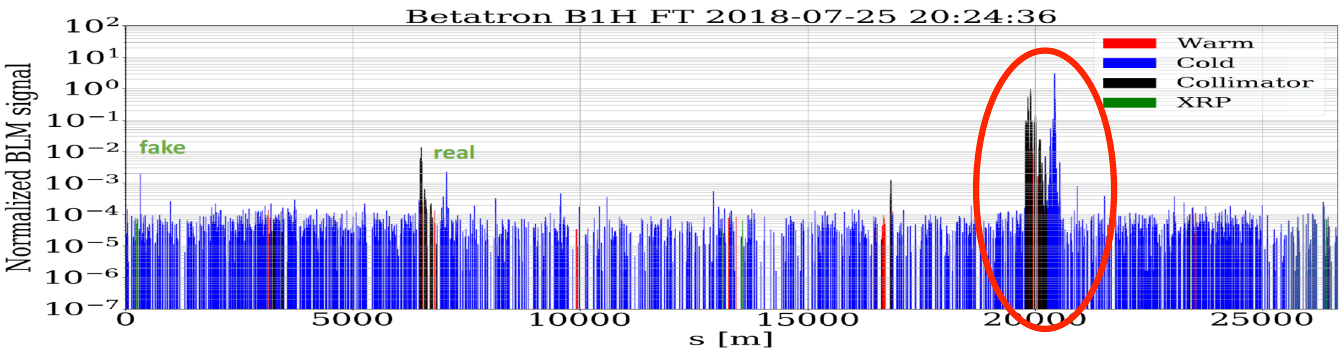
(Received 3 August 2020; accepted 5 October 2020; published 23 October 2020)



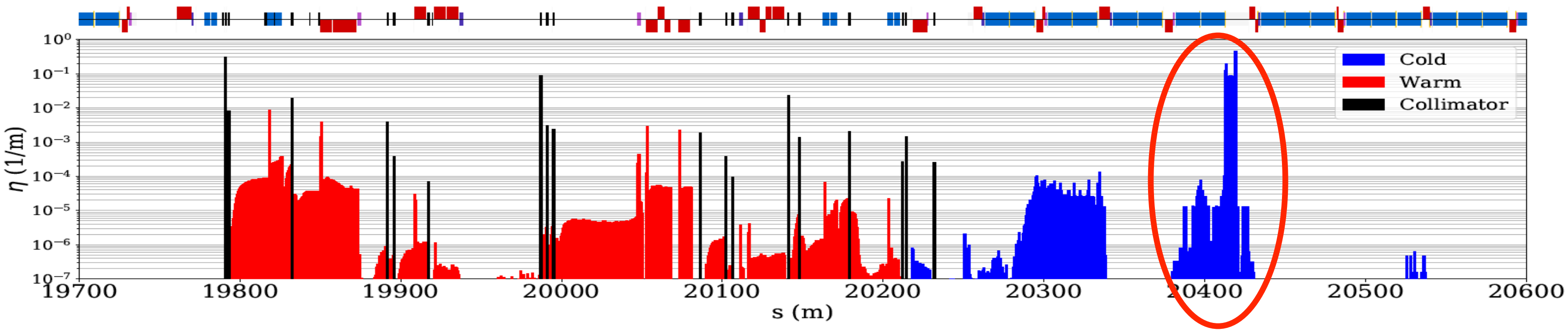
Observed LHC beam looses; hydrogen-like lead, LHC



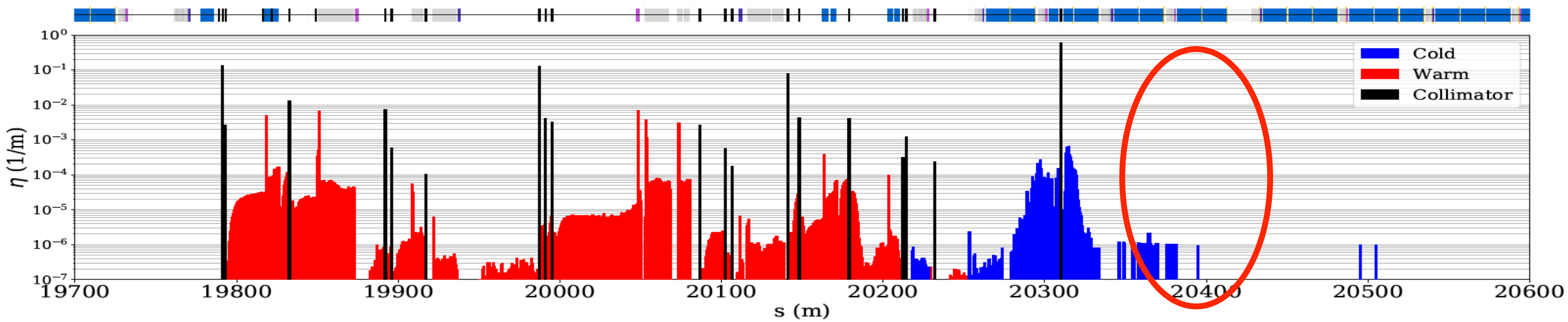
What we have learned form the LHC beam tests:

(collimation of the PSI beams in the LHC rings)

Simulation studies: present collimation system



Simulation studies: new collimators to be installed in LS3 period

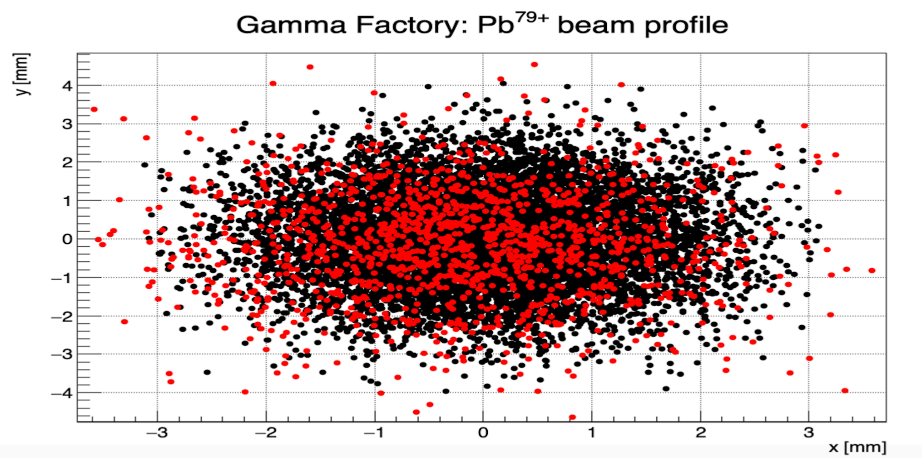


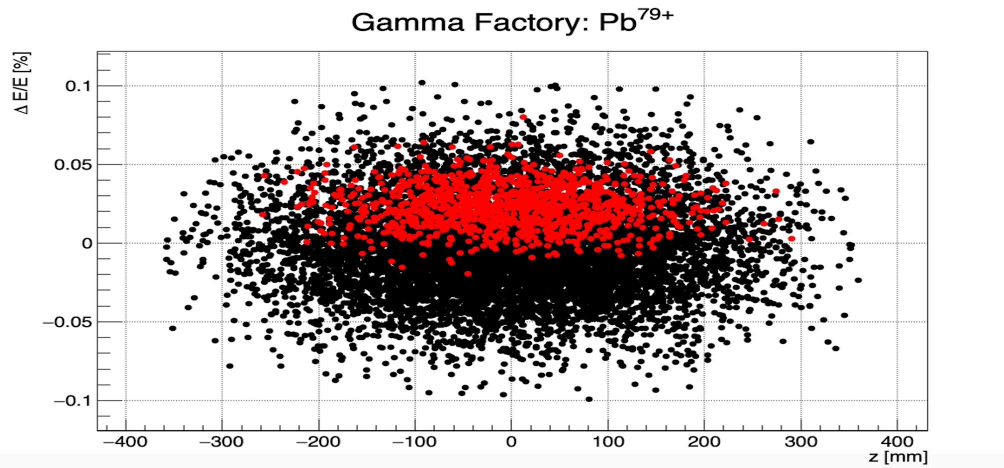
We have reached the first of Gamma Factory milestone:

- *We have demonstrated that we can efficiently produce, accelerate and store bunches of atomic beams of high Z, partially stripped ions in the CERN accelerator complex, with the requisite bunch intensities.*
- *We have identified and understood the dominant sources of beam losses over the full beam production, acceleration and storage cycles*

Milestone 2:

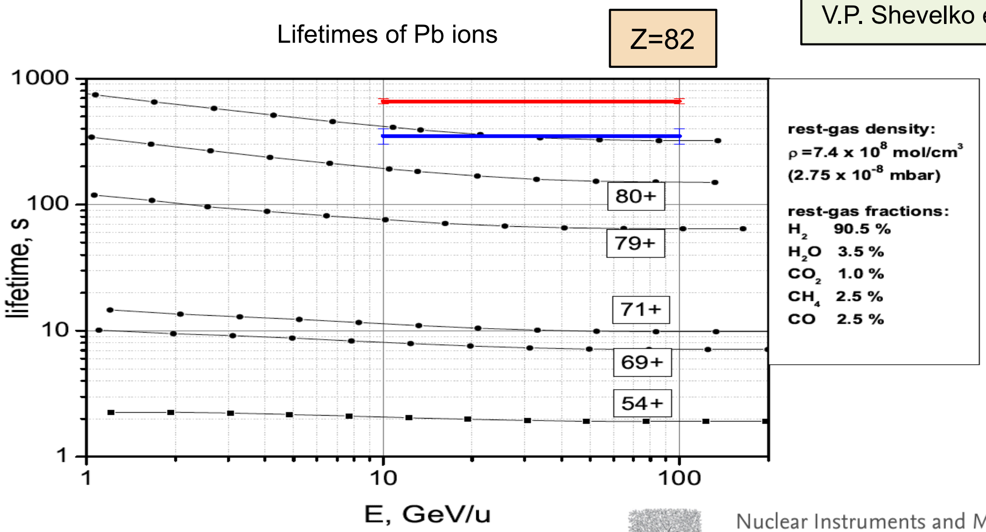
Development of the requisite Gamma Factory software tools.

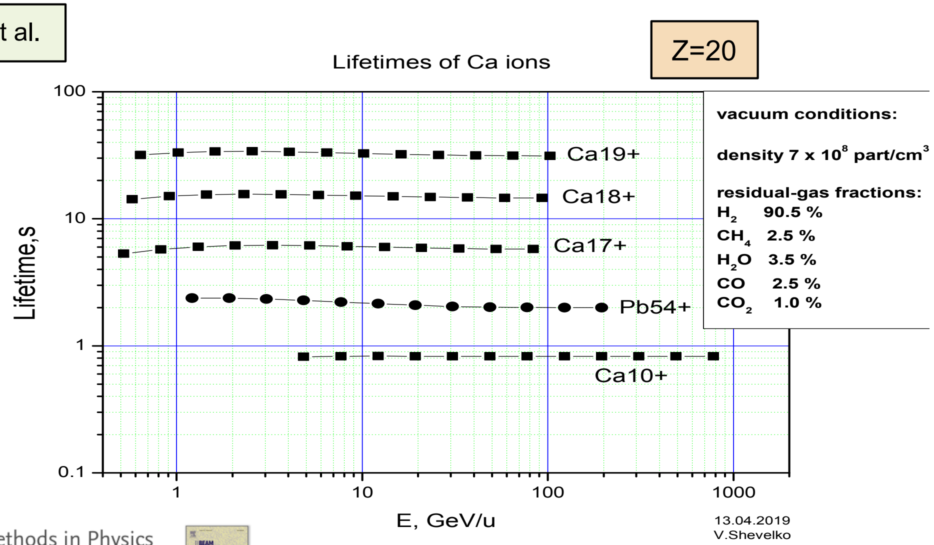




Example: Beam lifetime in the SPS

V.P. Shevelko et al.





ELSEVIER

Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms

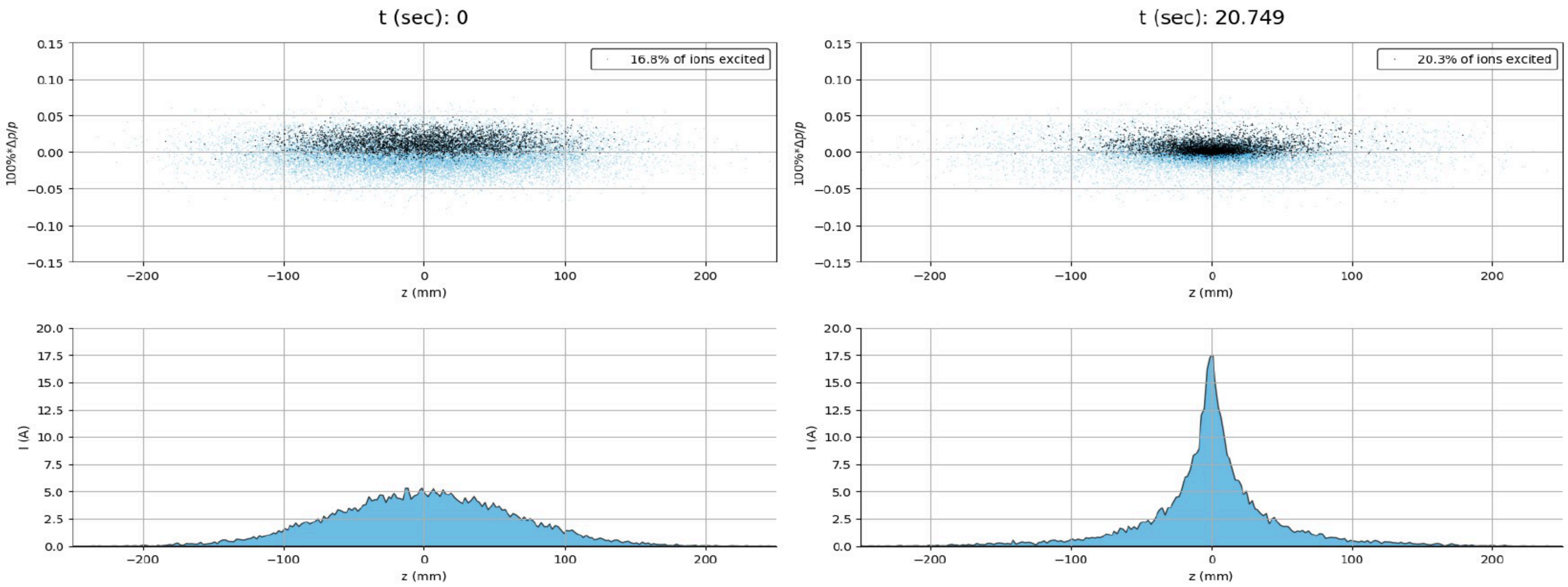
Volume 392, 1 February 2017, Pages 67-73

BREIT code: Analytical solution of the balance rate equations for charge-state evolutions of heavy-ion beams in matter

N. Winckler [a], A. Rybalchenko [a], V.P. Shevelko [b], M. Al-Turany [a, c], T. Kollegger [a], Th. Stöhlker [a, d, e]

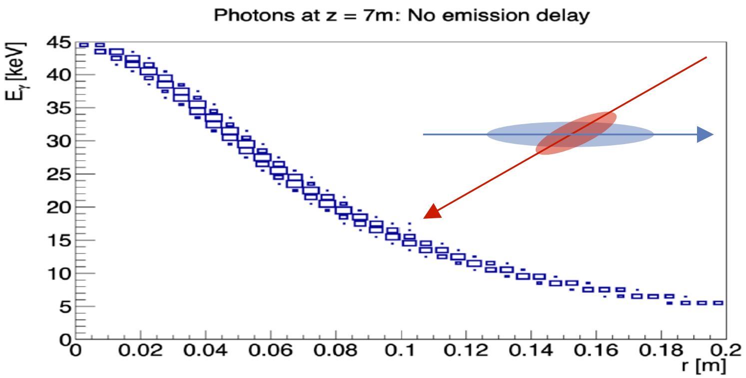
Example: Simulations of longitudinal cooling

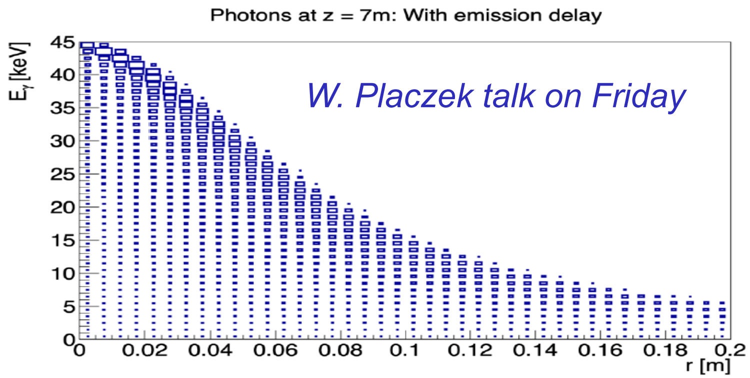
A. Petrenko



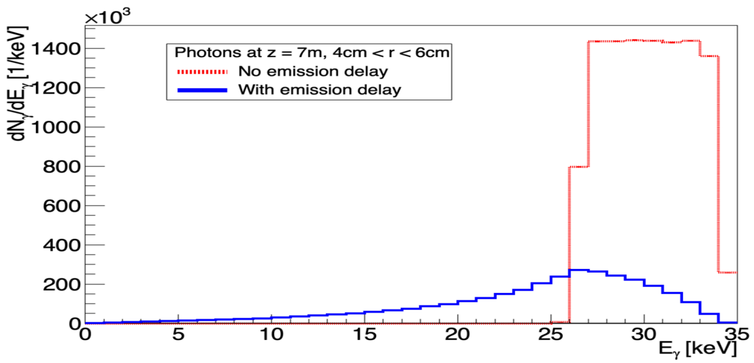
Example: Simulations of photon emission delay

(PoP experiment: Lithium-like lead beam and Yb-doped laser pulses)





PSI beam	$^{208}\mathrm{Pb}^{79+}$
m – ion mass	193.687 GeV/c^2
E – mean energy	18.652 TeV
$\gamma = E/mc^2$ – mean Lorentz relativistic factor	96.3
N – number ions per bunch	0.9×10^8
σ_E/E – RMS relative energy spread	2×10^{-4}
ϵ_n – normalised transverse emittance	1.5 mm mrad
σ_x – RMS transverse size	1.047 mm
σ_y – RMS transverse size	0.83 mm
σ_z – RMS bunch length	6.3 cm
Laser	Infrared
λ – wavelength ($\hbar\omega$ – photon energy)	1034 nm (1.2 eV)
σ_λ/λ – RMS relative band spread	2×10^{-4}
U – single pulse energy at IP	5 mJ
σ_L – RMS transverse intensity distribution at IP ($\sigma_L = w_L/2$)	0.65 mm
σ_t – RMS pulse duration	2.8 ps
θ_L – collision angle	2.6 deg
Atomic transition of $^{208}\mathrm{Pb}^{79+}$	$2s \rightarrow 2p_{1/2}$
$\hbar\omega_0'$ – resonance energy	230.81 eV
τ' – mean lifetime of spontaneous emission	76.6 ps
$\hbar\omega_1^{\max}$ – maximum emitted photon energy	44.473 keV

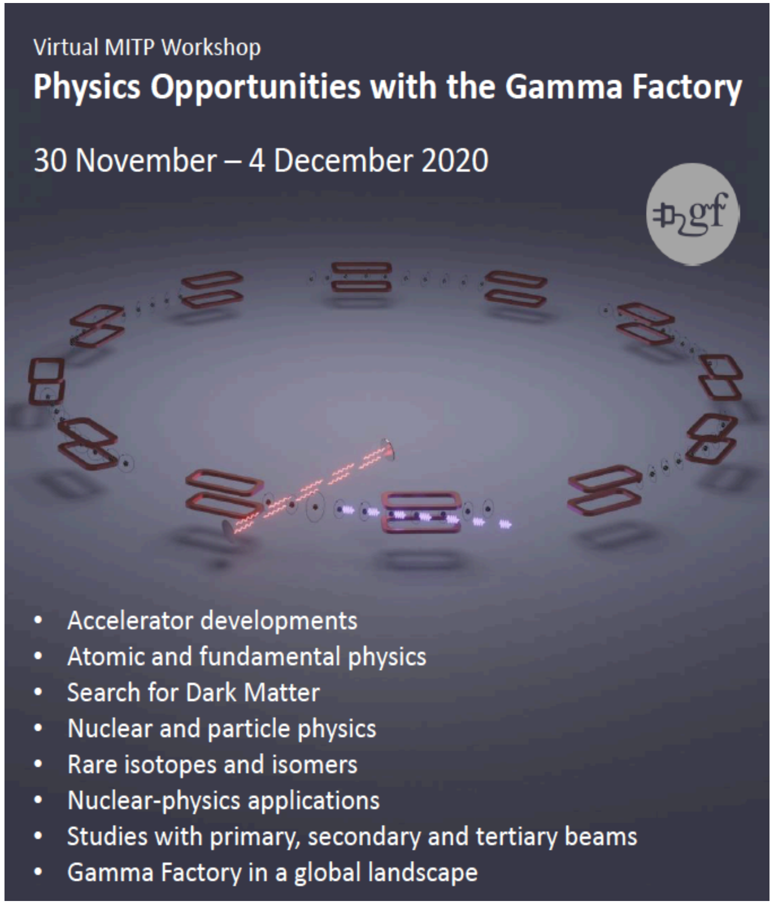


We have reached the second of the Gamma Factory project milestones:

- *We have developed software tools capable to extrapolate the results of the beam tests (stripping efficiency, beam loses) to the other particle species specified in terms of atomic number and the number of left over electrons*
- *We have developed the simulations tools to optimise the Laser-PSI Interaction Point (IP) design*
- *We have developed the simulation tools to study the multiturn PSI beam dynamics (including beam cooling)*
- *We have developed software tools to optimise the Fabry-Perot cavity design*

Milestone 3:

Building up the physics cases for the LHC-based GF research programme and attracting wide scientific communities to evaluate and use (in the future) the GF tools in their respective research (work on-going).



Physics cases for the LHC-based GF research programme (published and soon-to-be-published studies)

annalen der physik

Feature Article | Open Access

Atomic Physics Studies at the Gamma Factory at CERN

Dmitry Budker, José R. Crespo López-Urrutia, Andrei Derevianko, Victor V. Flambaum, Mieczyslaw Witold Krasny, Alexey Petrenko, Szymon Pustelny, Andrey Surzhykov, Vladimir A. Yerokhin, Max Zolotorev ... See fewer authors

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Progress in Particle and Nuclear Physics

Volume 114, September 2020, 103792

Review

High-luminosity Large Hadron Collider with laser-cooled isoscalar ion beams ☆

M.W. Krasny [a, b], A. Petrenko [c, b], W. Płaczek [d]

Show more

https://doi.org/10.1016/j.ppnp.202

To be presented at this workshop by Alexey Petrenko

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Electron beam for LHC

Mieczyslaw Witold Krasny

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Received 14 September 2004; received in revised form 19 November 2004; accepted 23 November 2004

Available online 22 December 2004

Expanding Nuclear-Physics Horizons with Gamma Factory

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(Dated: July 31, 2020)

To be presented at this workshop by Dragos Nichita

Radioactive Ion Beams (RIBs) production using the Gamma Factory source

D. Nichita[1,2], D.L. Balabanski[1], P. Constantin[1], W. Krasny[3]

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[1] Extreme Light Infrastructure – Nuclear Physics, "Horia Hulubei" National Institute for Physics and Nuclear Engineering, 077125 Bucharest Magurele, Romania

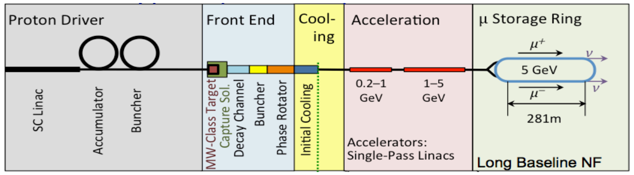
[2] Doctoral School in Engineering and Applications of Lasers and Accelerators, University Polytechnica of Bucharest, 060042 Bucharest, Romania

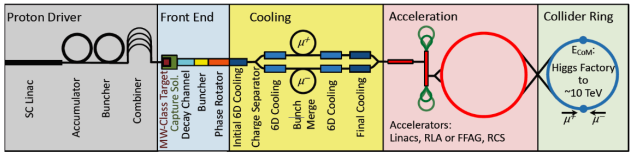
In preparation ...

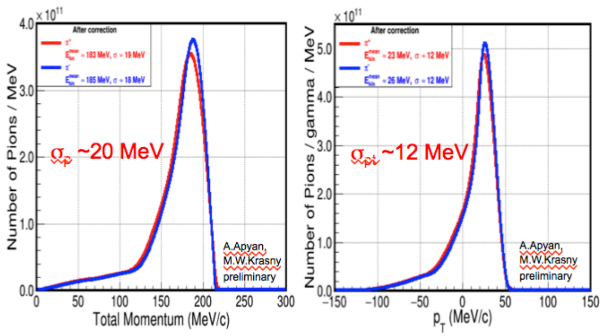
Physics cases for the LHC-based GF research programme

(on-going work)

The GF driven muon and neutrino source

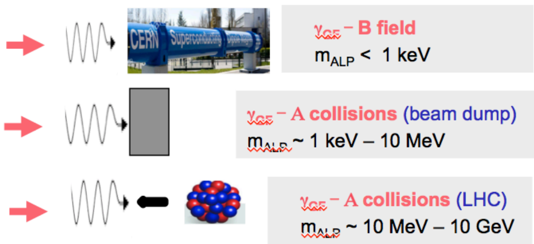


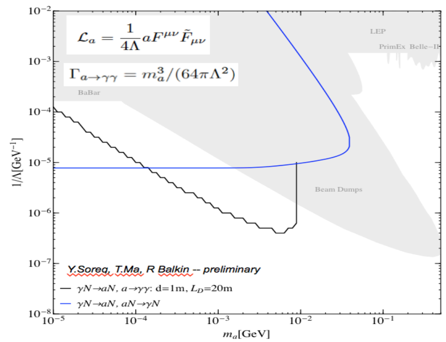




Dark Matter searches: ALP example

Search phase





Selective Nuclear-Waste transmutation

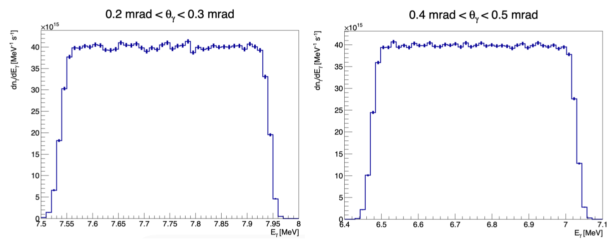
Proposal for selective isotope transmutation of long-lived fission products using quasi-monochromatic γ-ray beams

Takehito Hayakawa[a], Shuji Miyamoto[b], Ryoichi Hajima[a], Toshiyuki Shizuma[a], Sho Amano[b], Satoshi Hashimoto[b] and Tsuyoshi Misawa[c]

[a]Tokai Quantum Beam Science Center, National Institutes for Quantum and Radiological Science and Technology, Ibaraki, Japan; [b]Laboratory of Advanced Science and Technology for Industry, University of Hyogo, Hyogo, Japan; [c]Research Reactor Institute, Kyoto University, Osaka, Japan

Table 3. Selective isotope transmutation energy windows for each LLFP.

LLFP	SITEW (MeV)	Residual isotope	$T_{1/2}$	Other radioisotope	$T_{1/2}$
^{93}Zr	6.734–8.220	^{92}Zr	-	^{95}Zr	64 d
^{79}Se	6.914–9.914	^{78}Se	-	-	-
^{107}Pd	6.359–9.221	^{106}Pd	-	-	-
^{126}Sn	8.193–37.980	^{125}Sb	2.8 y	^{121}Sn	27 h
^{90}Sr	7.806–11.490	^{89}Sr	50.6 d	^{86}Rb	18.5 d
^{135}Cs	8.762–15.476	^{134}Cs	2.0 y	^{136}Cs	13.2 d
^{137}Cs	8.278–15.476	^{136}Cs	13.2 d	^{134}Cs	2.0 y
^{129}I	6.799–15.574	^{128}I	25 m	^{126}I	13.1 d
^{99}Tc	6.500–8.967	^{98}Mo	-	-	-



To be presented at this workshop by Armrn Apyan, Yotam Soreq and Takehito Hayakawa

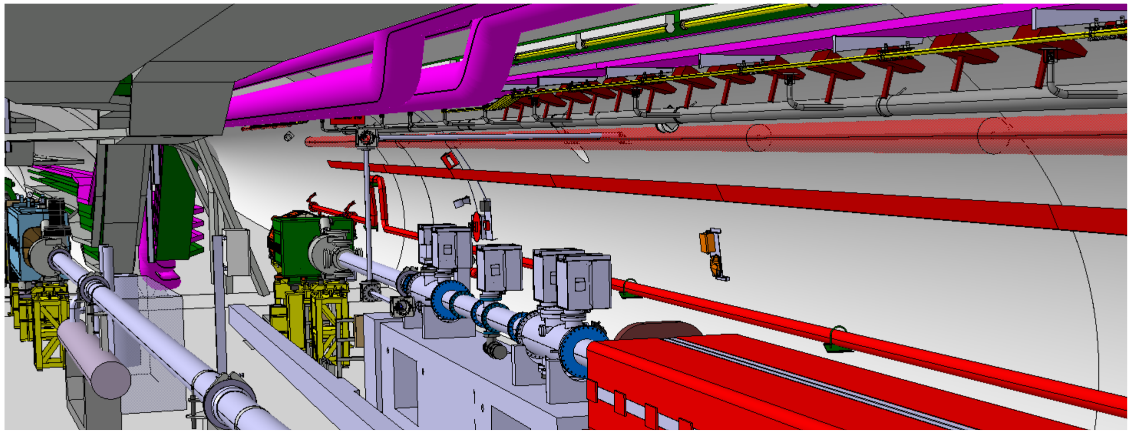
Physics cases for the LHC-based GF research programme
(new contributions)

Everybody is invited to contribute to the special issue of "Annalen der Physik" devoted to the physics opportunities offered by the Gamma Factory project!

Subsequent publication of the Volume II of the Gamma Factory CERN Yellow report.

<u>Milestone 4:</u>

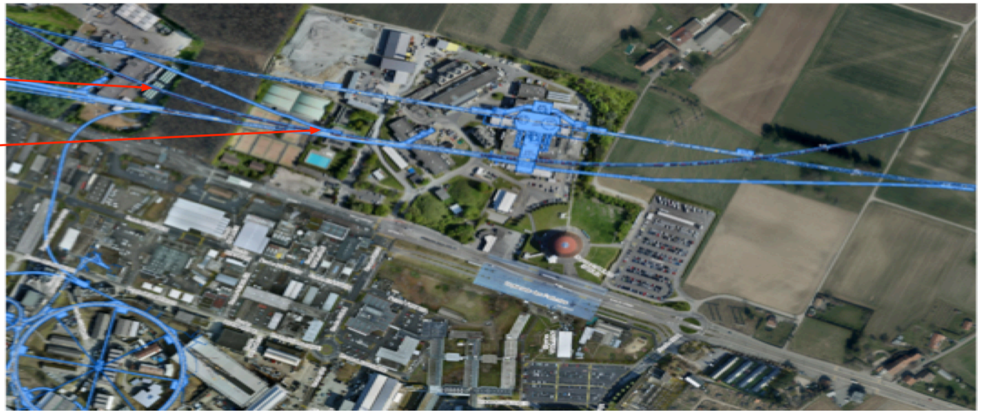
Successful approval by the SPSC and by the CERN Research Board), construction and execution of the GF Proof-of-Principle (PoP) experiment in the SPS tunnel (work on-going).

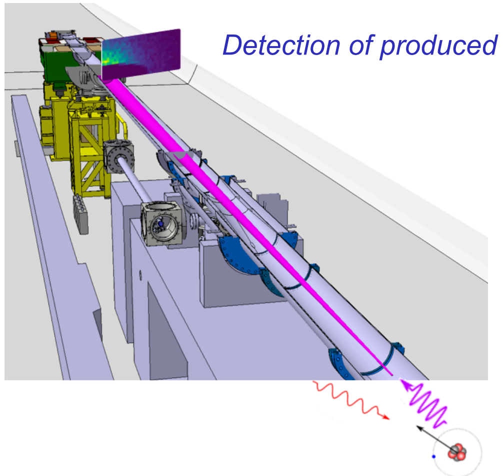


PoP experiment: integration (LSS6)

SPS

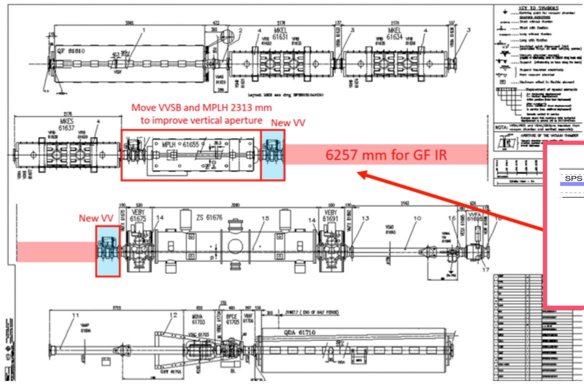
PoP location



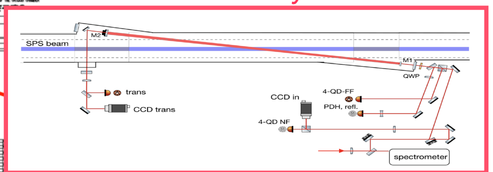


Detection of produced X-rays

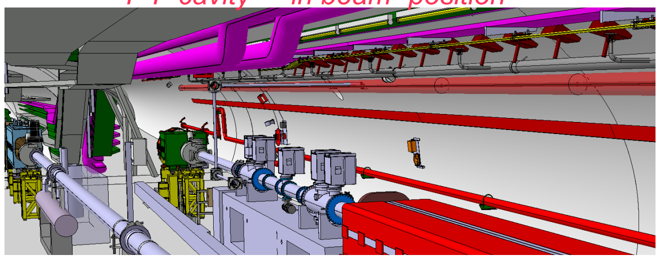
LSS6 zone



F-P cavity



F-P cavity – "in beam" position



Details of the PoP-experiment proposal and its status in Aurelien's talk…

…future

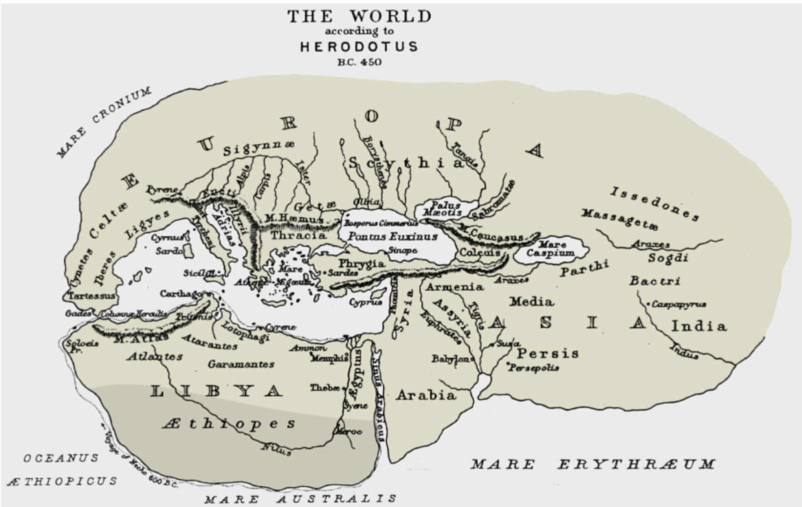
Milestone 5:

Extrapolation of the PoP experiment results to the LHC case and precise, quantitative assessment of the physics reach of the GF programme (should be finalised prior to the next European Strategy Update -2026?).

Milestone 6:

Elaboration of the TDR for the LHC-based GF research programme (If positive recommendation of the next ESPP).

Challenges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Scythia
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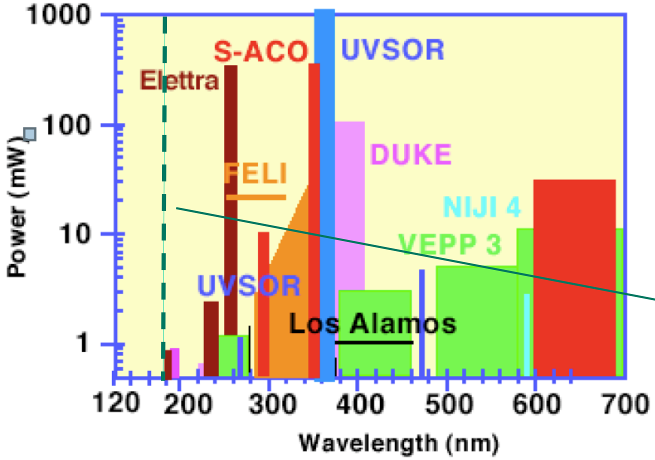
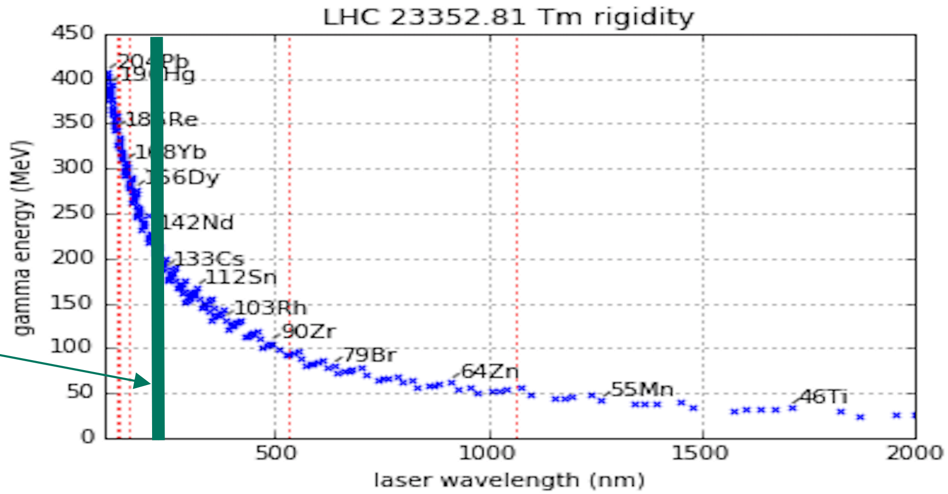
Massagetæ
Sogdi
Bactri
Parthi
Mare Caspium
Palus Mæotis
Pontus Euxinus
Thracia
Phrygia
Armenia
Media
ASIA
India
Persis
Persepolis
Babylon
Assyria
Syria
Arabia
LIBYA
Æthiopes
Garamantes
Atarantes
Atlantes
M. Atlas
Carthago
Cyprus
OCEANUS
ÆTHIOPICUS
MARE ERYTHRÆUM
MARE AUSTRALIS

- *GF PoP experiment*
    - *GF interactions with the SPSC and the approval process*
    - *How to find 2.5 MSFR to execute the experiment?*
    - *PoP- experiment collaboration, MoU, cost and manpower sharing*
    - *Grant application(s)*
    - *Timing*
- *Ion source(s) and new electron stripper construction and installation*
- *Mirror reflectivity and the frontier of the highest energy gamma-rays*
- *High repetition (~20 MHz) FEL as an alternative to conventional lasers*
- *Time-structure of laser pulses for the highest gamma-source intensity*
- *Production of polarised gamma-beams*
- *…..*

An example: maximal gamma energies –
LHC beams, 1s→ 2p transition, Hydrogen-like ions





Need optical cavities for (100 nm - 400 nm) wavelength. Multilayer mirrors using high refraction index materials (AL_2O_3, HFO_2, ZRO_2) and low refraction index material (SiO_2) deposited on silicium or sapphire. The roughness must be controlled to better than 1 angstrom. Very recent technological progress: Mackowski- Lyon, Jena (Germany)

… or a dedicated FEL to cover the wavelength range of 100-500 nm (initial studies by Vittoria Petrillo, Fabrizio Castelli and Luca Serafini).

Conclusions

- The target of the GF initiative is to develop a variety of novel research tools which could potentially open new research opportunities in a broad domain of basic and applied science.

- Over the last 3 years the Gamma Factory initial ideas developed into a well defined project involving a large group of ~90 physicists.

- Progress has been impressive. The next steps are clear.

- The Gamma Factory R&D studies enter now the crucial, decisive phase of its PoP SPS experiment.

- In parallel, we are intensifying our effort to propose and evaluate the physics cases for the LHC-based GF research programme and trying to attract various scientific communities to consider using the GF tools in their future research

Building the Gamma Factory project foundations