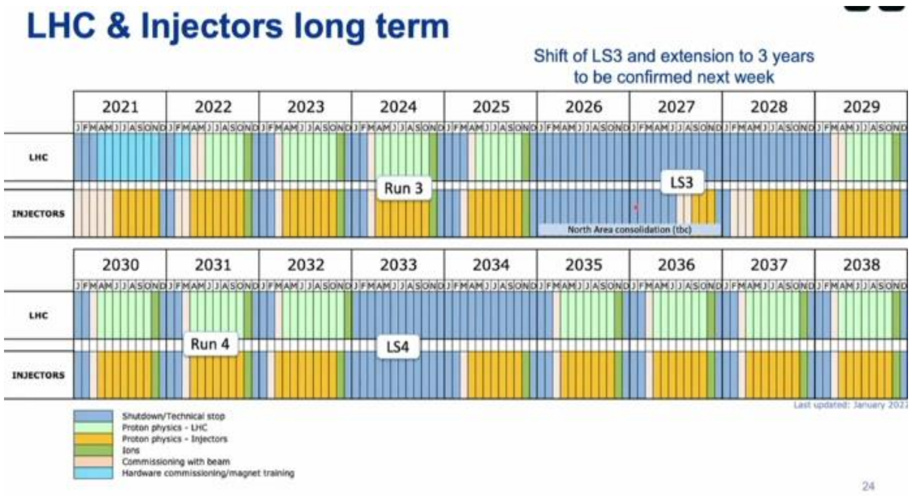
Gamma Factory

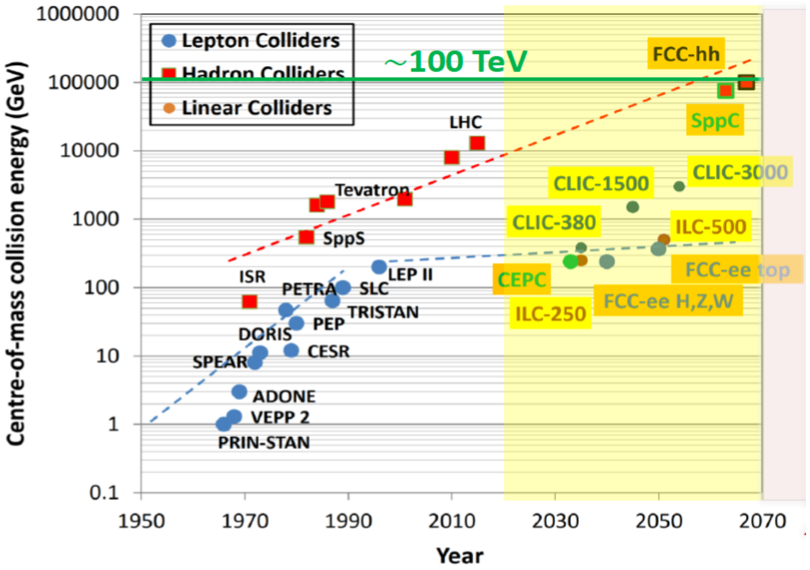
New research opportunities for CERN

Kyaik-Tiyo, Myanmar(Burma)

Corfu Workshop on the Standard Model and Beyond, Sept 2022

Mieczyslaw Witold Krasny, Gamma Factory study leader
LPNHE, CNRS and University Paris Sorbonne and CERN, BE-ABP





nature

NEWS | 08 August 2022

Particle physicists want to build the world's first muon collider

Instead od introduction:

A lesson from the past –

the Electron-Ion Collider (EIC) project path

THE ONLY LARGE SCALE (>10^9 EURO) ACCELERATOR PROJECT –

OUT OF THOSE CONSIDERED IN THE 90-TIES:

TESLA, ELFE, ENC, ELOISATRON, EIC

-- WHICH IS BEING CONSTRUCTED at BNL

The fist steps towards the EIC project (1994-1998):

Hamburg, 11.07.1996.

Memorandum

To: B. Wiik, A. Wagner, DESY

From: M.W. Krasny, LPNHE - Paris

- to build an "A-tunable" ion injector system and collide at HERA electrons with nuclei. The ePb collisions would have the world record center-of-mass energy (if realized before RHIC becomes operational) and, apart from several merits which I tried to explain in my summary talk of the HERA workshop, would provide the largest effective luminosity for photon-photon interactions in the intermediate W range. It is worth noticing that several physicists became interested in the nuclear option for HERA after introducing to the program of the Paris HERA workshop, back in 1995, a parallel session on nuclei and that this physics received some attention during the DESY workshop this year.

- to design a dedicated experiment for HERA for the "low Q^2" ($Q^2 \leq 100\ GeV^2$) domain optimized both for the ep and eA interactions. Let me note, as an example, that neither the upgraded H1 experiment nor the ZEUS experiment will be able to measure structure functions, in particular σ_L/σ_T, with the precision comparable to that of SLAC experiments of 70-ties, despite the energies and angles of the scattered electrons are, in this Q^2 range, similar. Such a detector would have to measure the energies and angles of particles produced over the large domain of η, covering in particular the proton (nucleus) fragmentation region, which still remains a "terra incognita". It should use large β rather than small β optics because the physics advocated here requires modest luminosities and high detection quality of particles emitted at small angles. I failed, back in 1991, to persuade the spokesman of the HERMES experiment that the first component of such an experiment could be the HERMES electron spectrometer used in the colliding beam mode.

DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

NOTKESTR. 85 - 22607 HAMBURG, TEL. 040/89 98-24 07 - TX 2 15 124 desy d - TTX 40 31 73=DESY - FAX 040/89 94 43 04

Der Vorsitzende des Direktoriums

Dr. M.W. Krasny
Universites Paris 6 +7
LPNHE
4, Place Jussieu, Tour 33
F-75252 Paris Cedex 05

August 19, 1996

Dear Dr. Krasny,

Thank you very much for your contribution to the HERA workshop and for your remarks to the HERA programme.

I agree with you that HERA will make a solid contribution to strong interaction physics and that colliding electrons with nuclei may open up new vistas and should be explored further. Indeed we want to do this in collaboratoin with GSI and I hope that you will be able to participate and contribute to this work. In order to carry out a prgramme in this direction there must be a well reasoned physics programme, a strong support including funds from the community, and GSI must be interested in a collaboration.

I'm not so sure that I agree with your comments concerning the luminosity frontier - at least I would feel somewhat uneasy if we neglected this frontier.

With my best wishes

Björn H. Wiik

Why EIC was not constructed at DESY?

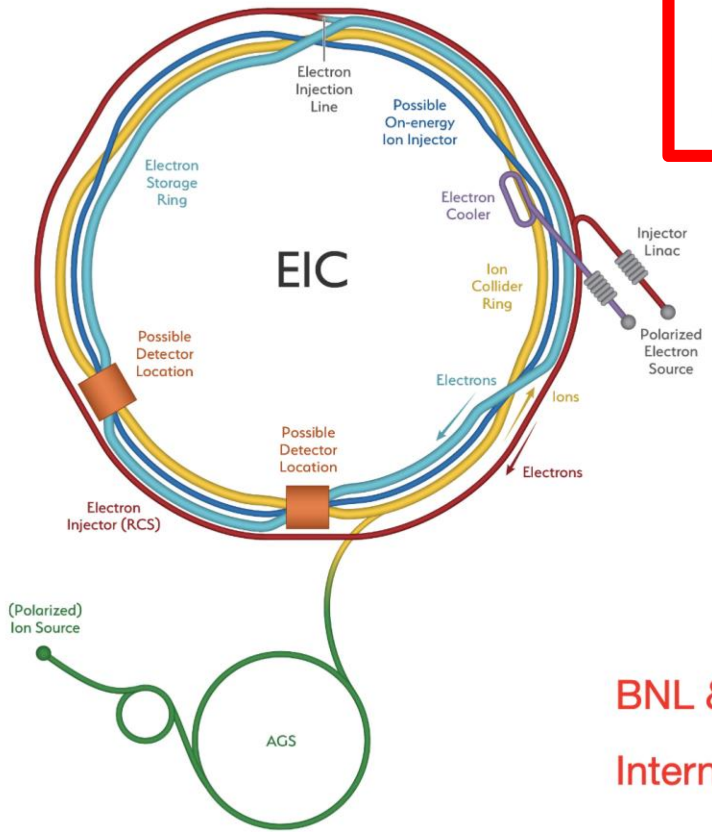
- *1999 - B. Wiik's unfortunate accident --*
  TESLA project loses its momentum and is finally abandoned

- *GSI works towards a local FAIR PROJECT (low energy),*
  ELFE groups join the CEBAF (TJNAF) program

- *DESY decides to to continue with the luminosity-upgraded HERA which turns out to be the dead-end road, closing its accelerator-based HEP programme*

- *The electron-ion collider concept moves to US (thanks to a strong commitment to this project by Peter Paul – the new BNL director)*

U.S.-based Electron-Ion Collider



EIC will be constructed at Brookhaven National Laboratory

EIC is well on its path towards realization (CD-1 in June 2021)

Now in the detector design and collaboration formation phase

Start of operation expected ~2031

BNL & TJNAF (Jefferson Lab) partnership

International facility, large EU involvement

"*Gamma Factory*" proposal (2015) and studies

"*Gamma Factory*" proposal and studies

The Gamma Factory proposal for CERN †

† An Executive Summary of the proposal addressed to the CERN management.

Mieczyslaw Witold Krasny*

LPNHE, Universités Paris VI et VII and CNRS–IN2P3, Paris, France

e-Print: 1511.07794 [hep-ex]

~ 100 physicists form 40 institutions have contributed so far to the Gamma Factory studies

A. Abramov[1], A. Afanasev[37], S.E. Alden[1], R. Alemany Fernandez[2], P.S. Antsiferov[3], A. Apyan[4], G. Arduini[2], D. Balabanski[34], R. Balkin[32], H. Bartosik[2], J. Berengut[5], E.G. Bessonov[6], N. Biancacci[2], J. Bieroń[7], A. Bogacz[8], A. Bosco[1], T. Brydges[36], R. Bruce[2], D. Budker[9,10], M. Bussmann[38], P. Constantin[34], K. Cassou[11], F. Castelli[12], I. Chaikovska[11], C. Curatolo[13], C. Curceanu[35], P. Czodrowski[2], A. Derevianko[14], K. Dupraz[11], Y. Dutheil[2], K. Dzierżęga[7], V. Fedosseev[2], V. Flambaum[25], S. Fritzsche[17], N. Fuster Martinez[2], S.M. Gibson[1], B. Goddard[2], M. Gorshteyn[20], A. Gorzawski[15,2], M.E. Granados[2], R. Hajima[26], T. Hayakawa[26], S. Hirlander[2], J. Jin[33], J.M. Jowett[2], F. Karbstein[39], R. Kersevan[2], M. Kowalska[2], M.W. Krasny[16,2], F. Kroeger[17], D. Kuchler[2], M. Lamont[2], T. Lefevre[2], T. Ma[32], D. Manglunki[2], B. Marsh[2], A. Martens[12], C. Michel[40] S. Miyamoto[31] J. Molson[2], D. Nichita[34], D. Nutarelli[11], L.J. Nevay[1], V. Pascalutsa[28], Y. Papaphilippou[2], A. Petrenko[18,2], V. Petrillo[12], L. Pinard[40] W. Płaczek[7], R.L. Ramjiawan[2], S. Redaelli[2], Y. Peinaud[11], S. Pustelny[7], S. Rochester[19], M. Safronova[29,30], D. Samoilenko[17], M. Sapinski[20], M. Schaumann[2], R. Scrivens[2], L. Serafini[12], V.P. Shevelko[6], Y. Soreq[32], T. Stoehlker[17], A. Surzhykov[21], I. Tolstikhina[6], F. Velotti[2], A. Viatkina[9] A.V. Volotka[17], G. Weber[17], W. Weiqiang[27] D. Winters[20], Y.K. Wu[22], C. Yin-Vallgren[2], M. Zanetti[23,13], F. Zimmermann[2], M.S. Zolotorev[24] and F. Zomer[11]

Gamma Factory studies are anchored, and supported by the CERN Physics Beyond Colliders (PBC) framework.

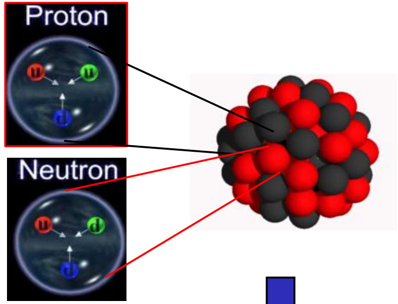
More info on the GF group activities:

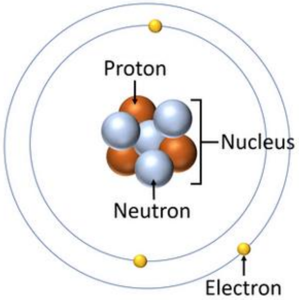
https://indico.cern.ch/category/10874

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

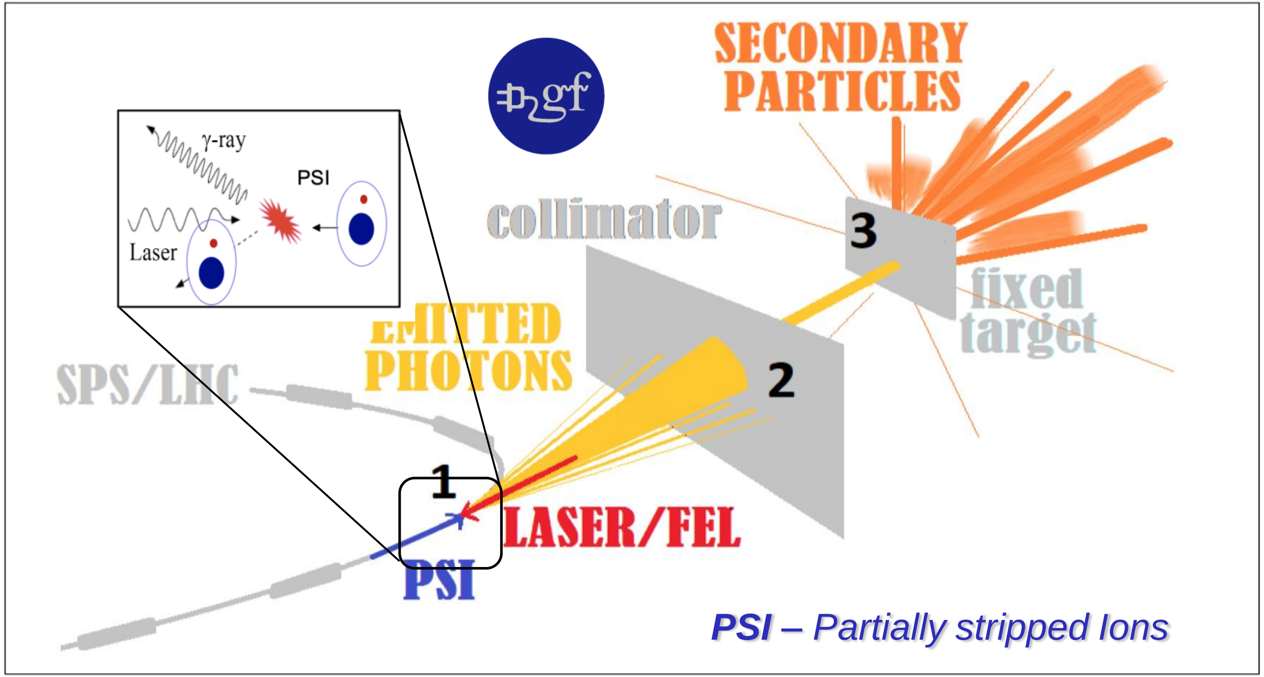
Gamma Factory: novel use of **existing** CERN's storage rings

LHC beams





- *Store **atomic beams of partially stripped ions** in the LHC*
- *Collide them with laser pulses **(circulating in Fabry-Pérot resonators)***

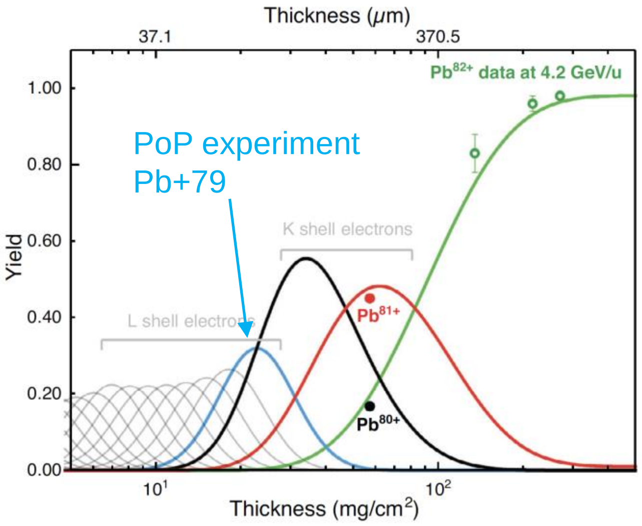


***PSI** – Partially stripped Ions*

Very recent technical developments:

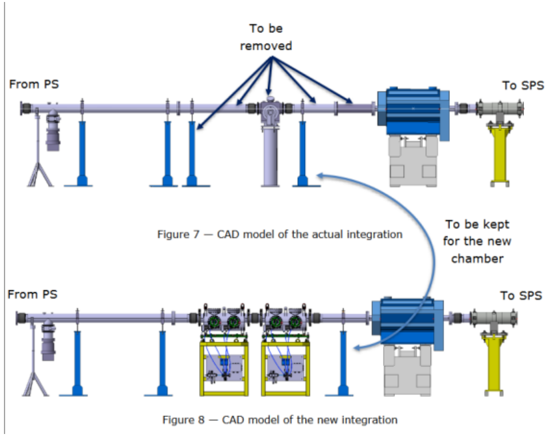
new TT2 stripper system

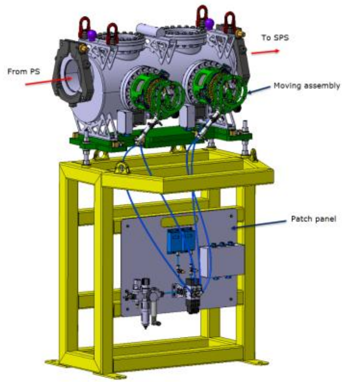
Stripping of Pb+54 ions in the TT2 PS-→ SPS transfer line



Charge-State Distributions of Highly Charged Lead Ions at Relativistic Collision Energies

Felix M. Kröger, Günter Weber, Simon Hirlaender, Reyes Alemany-Fernandez, Mieczyslaw W. Krasny, Thomas Stöhlker, Inga Yu. Tolstikhina, and Viacheslav P. Shevelko*

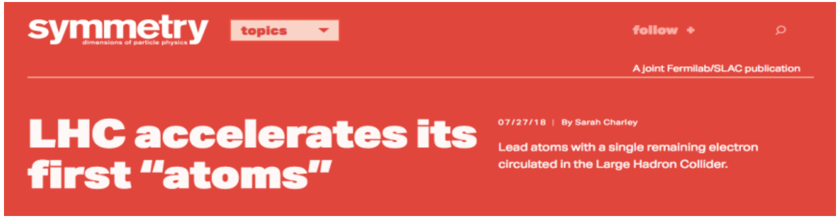


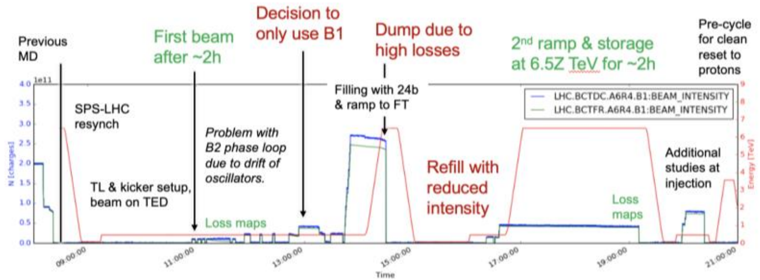


R. Alemany-Fernandez (BE.OP), E. Grenier-Boley and D. Baillard (SY.STI)

The two tanks of the new stripper system have been installed during YETS 2021-2022. The first of them is already one is equipped with two stripper foil mechanisms. The second will house additional two foil mechanism (installation in YETS 2022-20023)

Atomic beams in the LHC (Hydrogen-like Lead)





CERN-ACC-NOTE-2019-0012

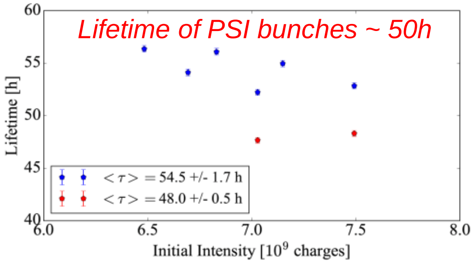
8 May 2019

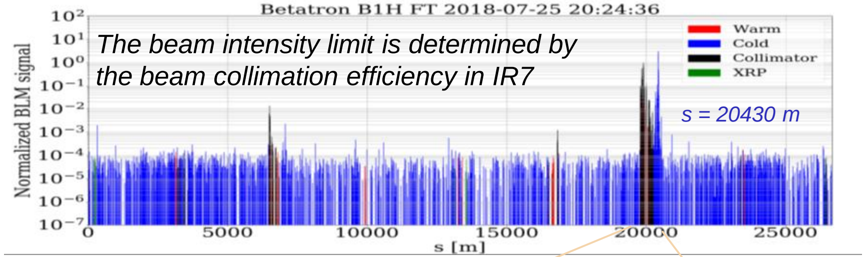
Michaela.Schaumann@cern.ch

MD3284: Partially Stripped Ions in the LHC

M. Schaumann, A. Abramov, R. Alemany Fernandez, T. Argyropoulos, H. Bartosik, N. Biancacci, T. Bohl, C. Bracco, R. Bruce, S. Burger, K. Cornelis, N. Fuster Martinez, B. Goddard, A. Gorzawski, R. Giachino, G.H. Hemelsoet, S. Hirlaender, M. Jebramcik, J.M. Jowett, V. Kain, M.W. Krasny, J. Molson, G. Papotti, M. Solfaroli Camillocci, H. Timko, D. Valuch, F. Velotti, J. Wenninger

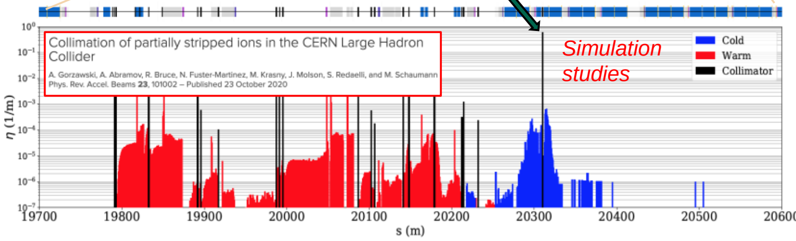
CERN, CH-1211 Geneva 23





Mitigation strategies:

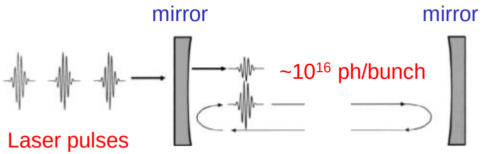
1. *Dispersion suppressor collimator (TCLD)*
2. *Crystal collimation*
3. *Laser collimation*

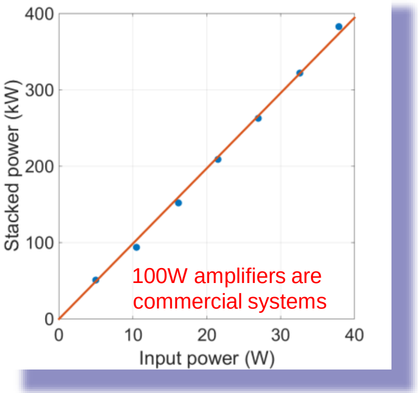


A dedicated LHC MD with crystal collimation of the PSI (H-like Pb) beam will be the next step…

Fabry-Pérot (FP) resonators
and their integration in the electron storage rings

Fabry-Pérot resonator

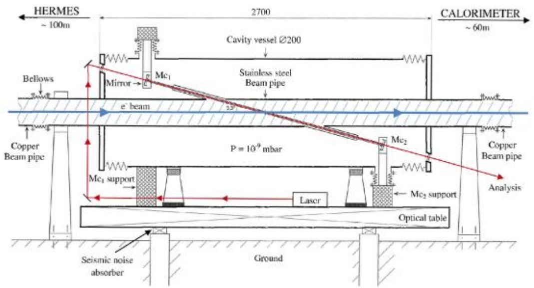




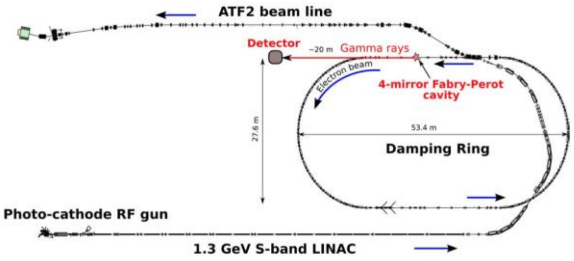
Amoudry L. et al., Applied Optics 59(2020)116

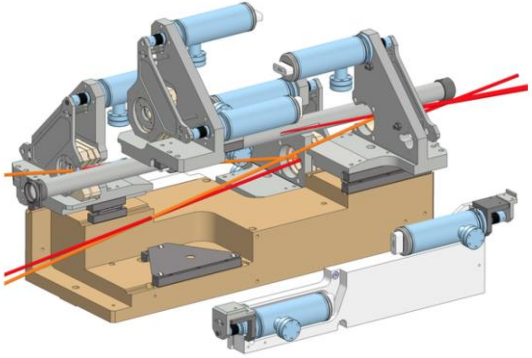
GF requirement:
< 5mJ pulses @ 40MHz,
(200kW photon beam)

HERA storage ring



KEK – ATF ring



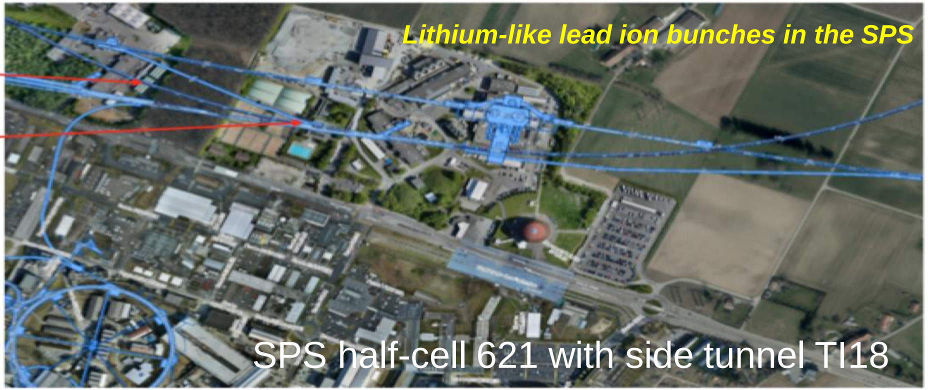


Towards the first integration of the FP resonator in the hadron storage ring →

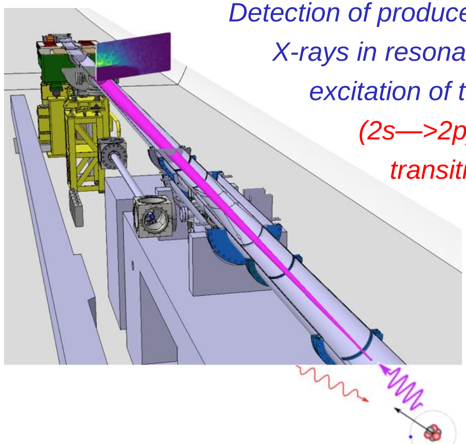
Gamma Factory Proof-of-Principle (PoP) SPS experiment

SPS

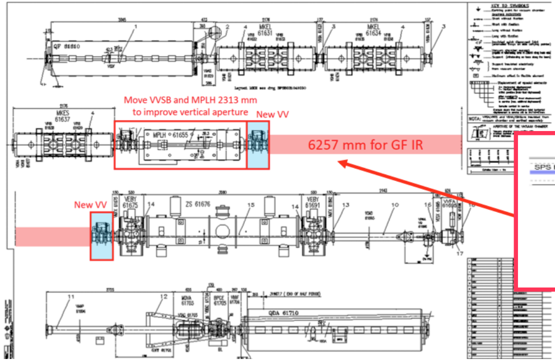
PoP location



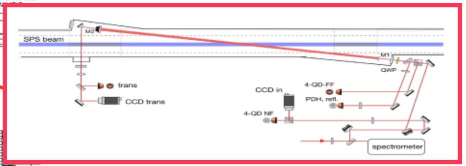
Detection of produced X-rays in resonant excitation of the $(2s \rightarrow 2p)_{1/2}$ transition



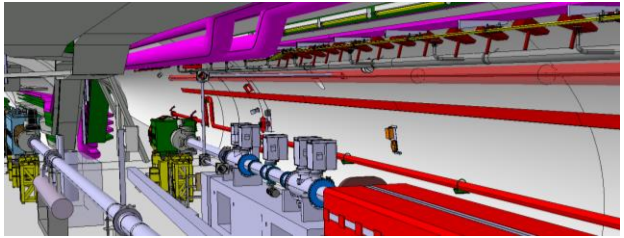
LSS6 zone



F-P cavity



F-P cavity – "in beam" position



***F-P cavity length – 3.75 m** -- vertically tilted by 2..6 deg*

Gamma Factory's novel research tools (examples)

1. *Atomic traps of highly charged, cold atoms*

2. *High intensity photon(γ)-beams*

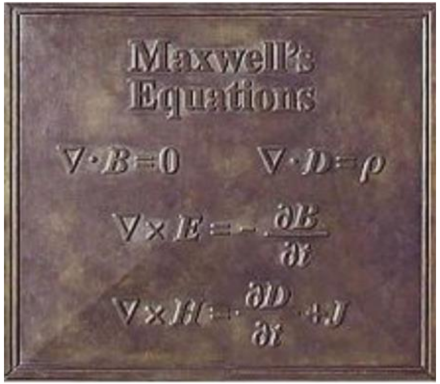
1. *Laser-light based cooling methods of high-energy hadronic beams*

2. *Unprecedented -intensity beams of polarised electrons, polarised positrons, polarised muons, neutrinos, neutrons and radioactive ions*

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

6. *Low emittance beams and electron source for plasma Wakefield acceleration*

Concepts and tools

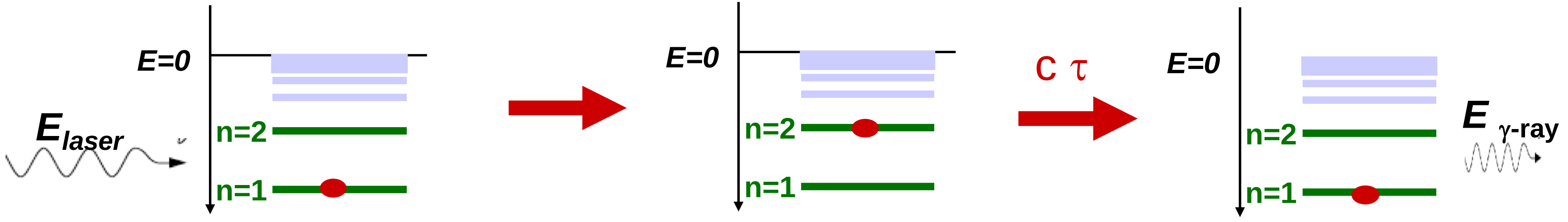


"New directions in science are launched by new tools much more often than by new concepts.

The effect of a concept-driven revolution is to explain old things in new ways.

The effect of a tool-driven revolution is to discover new things that have to be explained" - F. Dyson

Gamma Factory photon beam



Gigabarn cross section

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, $\gamma_L = E/M$ is the Lorentz factor for the ion beam

GF photon beams

1. Point-like, small divergence

- $\Delta z \sim l_{PSI\text{-}bunch}$, $\Delta x, \Delta y \sim \sigma^{PSI}{}_{x}, {}^{PSI}{}_{y}$, $\Delta(\theta_x), \Delta(\theta_y) \sim 1/\gamma_L < 1$ mrad

2. Huge jump in intensity:

- ***6–8 orders of magnitude*** *w.r.t. existing (being constructed) γ-sources*

3.Very wide range of tuneable energy photon beam :

- ***10 keV – 400 MeV --*** *extending, by a factor of* ***~1000****, the energy range of the FEL photon sources*

4. Tuneable polarisation:

- *γ–**polarisation transmission** from laser photons to γ-beams of **up to 99%***

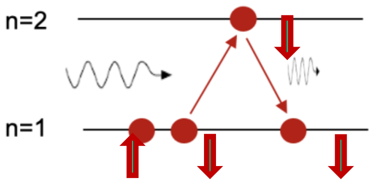
5. Unprecedented plug power efficiency (energy footprint):

- ***LHC RF power can be converted to the photon beam power.*** *Wall-plug power efficiency of the* ***GF photon source is*** *by a factor of* ***~300 better than that of the DESY-XFEL!***

(assuming power consumption of 200 MW - CERN and 19 MW - DESY)

Polarised beams in GF

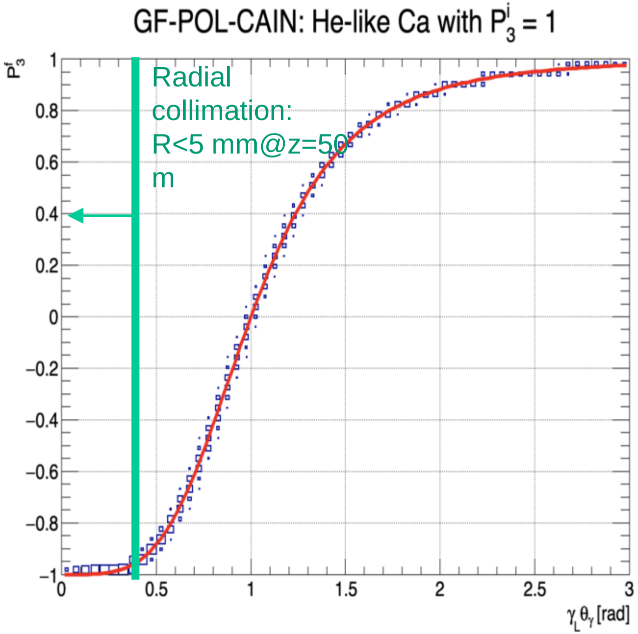
Example: He-like, Calcium beam, Er:glass laser (1522 nm)

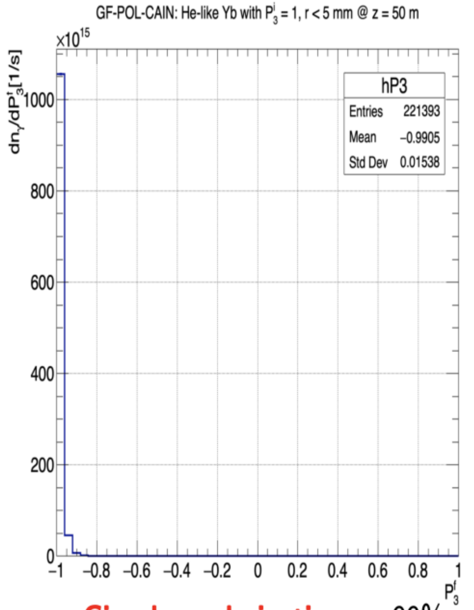


$nS_0 \rightarrow n'P_1 \rightarrow nS_0$

Closed transition in Helium-like atoms (n=1, n' =2) preserve initial polarisation of the laser light

A trick: $1s^2\ ^1S_0 \rightarrow 1s^1 2p^1\ ^1P_1$ transition in He-like atoms

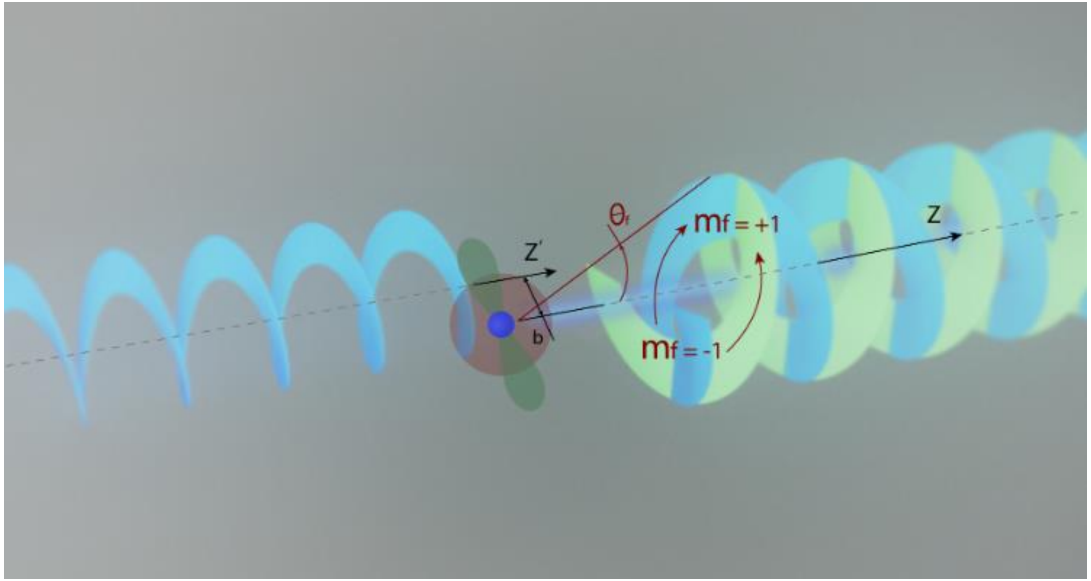




$\rightarrow$ Circular polarization $\approx 99\%$

For more details see presentations at our recent, November 2021, Gamma Factory workshop: https://indico.cern.ch/event/1076086/

Gamma Factory twisted photons

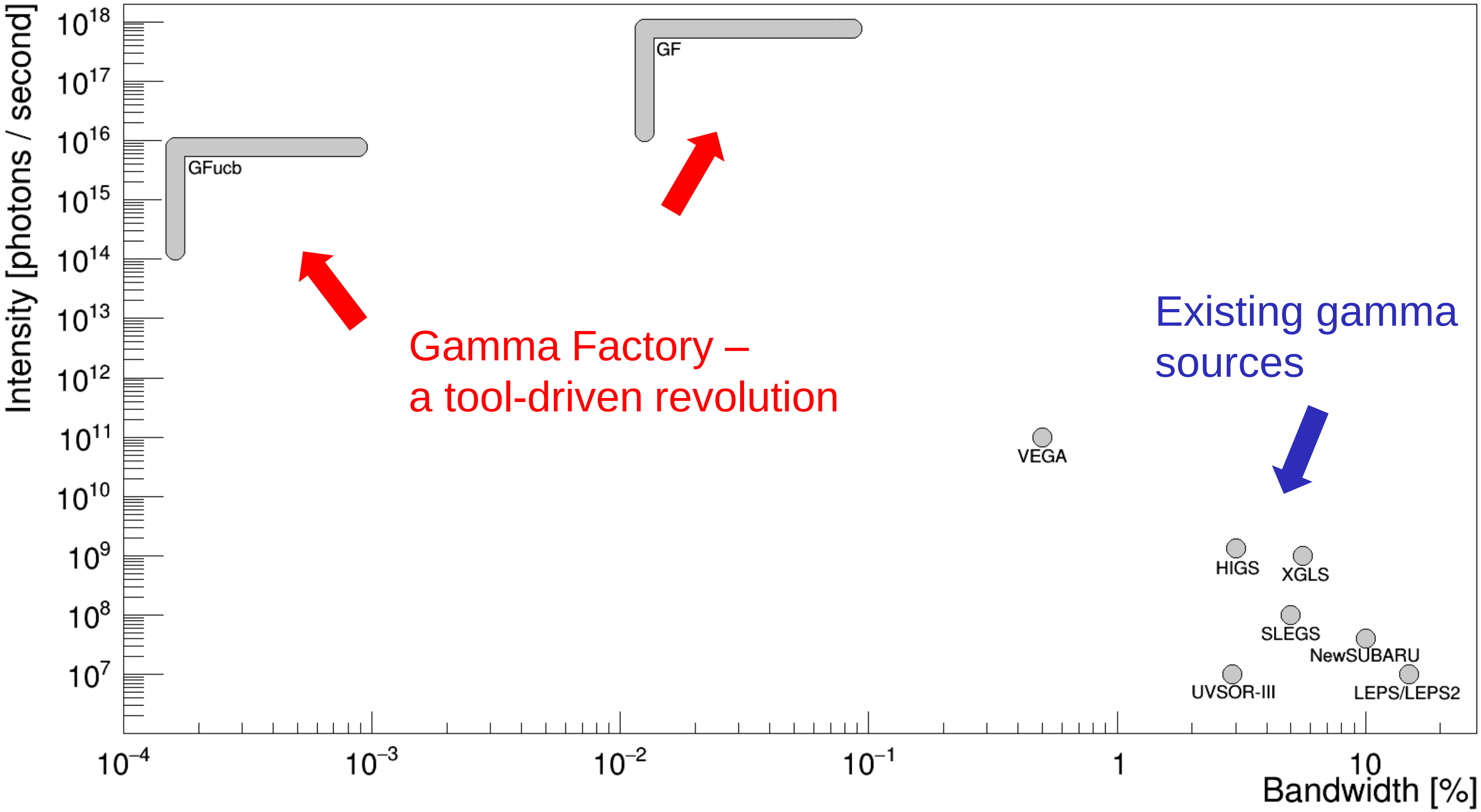


Resonant scattering of plane-wave and twisted photons at the Gamma Factory

Valeriy G. Serbo
Novosibirsk State University, RUS–630090, Novosibirsk, Russia and
Sobolev Institute of Mathematics, RUS–630090, Novosibirsk, Russia

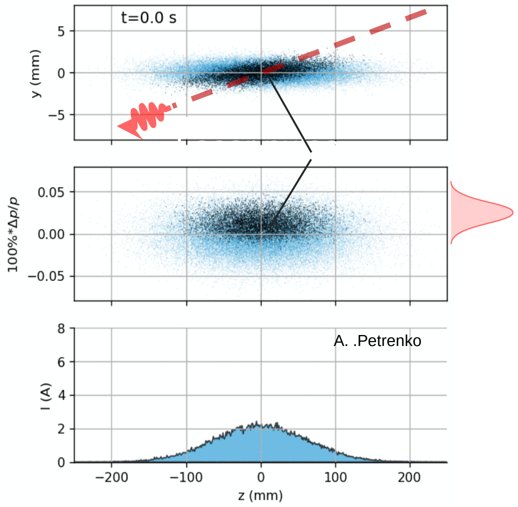
Andrey Surzhykov
Physikalisch–Technische Bundesanstalt, D–38116 Braunschweig, Germany
Institut für Mathematische Physik, Technische Universität Braunschweig, D–38106 Braunschweig, Germany and
Laboratory for Emerging Nanometrology Braunschweig, D-38106 Braunschweig, Germany

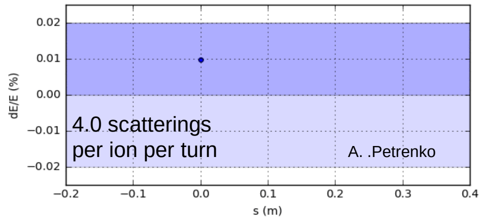
Andrey Volotka
School of Physics and Engineering, ITMO University, RUS–199034, Saint-Petersburg, Russia

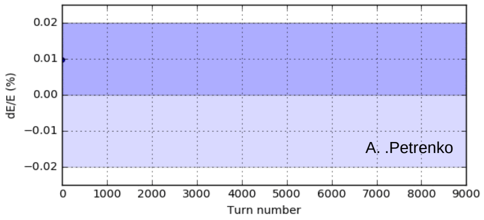

Intensity [photons / second]
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
GF
GFucb
Gamma Factory –
a tool-driven revolution
Existing gamma
sources
VEGA
HIGS
XGLS
SLEGS
NewSUBARU
UVSOR-III
LEPS/LEPS2
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
Bandwidth [%]

Laser cooling of high-energy hadronic beams

***Beam cooling*:**
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.

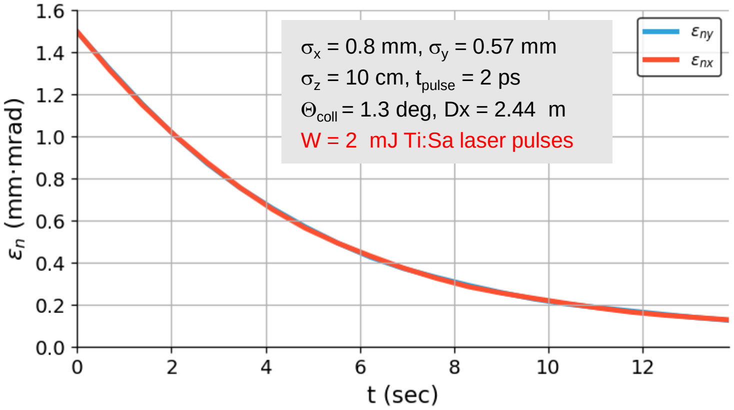






Opens a possibility of forming at CERN **high-energy** hadronic bunches of the required longitudinal and transverse emittances and population, (bunch merge + cooling) within a seconds-long time scale.

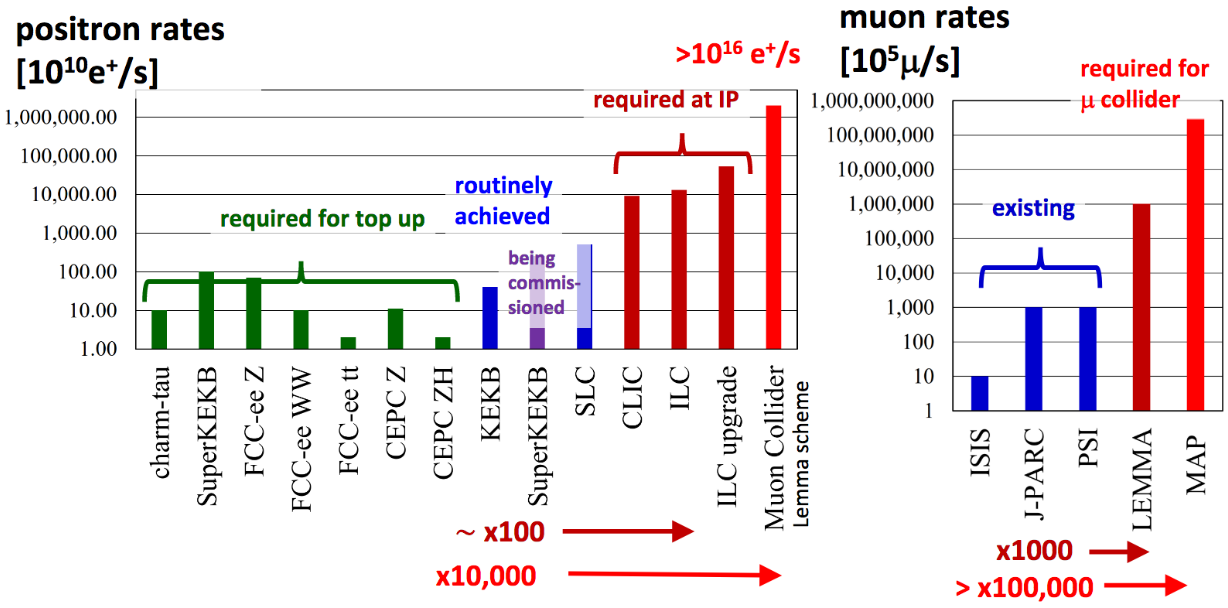
Prog.Part.Nucl.Phys. 114 (2020) 103792



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

Gamma Factory – presently the only technology capable to deliver the requisite power polarised positron source for the CLIC, ILC and for the Lemma scheme muon collider

Frank Zimmermann – CERN seminar on challenges for future colliders



Gamma Factory: $N_{e+}^{\uparrow} > 10^{16}$ 1/s, $N_{\mu+} = N_{\mu-} > 10^{13}$ 1/s

Opening new possibilities

Examples of potential applications domains of the *Gamma Factory* research tools

- ***particle physics*** *(precision QED and EW studies, vacuum birefringence, Higgs physics in $\gamma\gamma$ collision mode, rare muon decays, precision neutrino physics, QCD-confinement studies, …);*
- ***nuclear physics*** *(nuclear spectroscopy, cross-talk of nuclear and atomic processes, GDR, nuclear photo-physics, photo-fission research, gamma polarimetry, physics of rare radioactive nuclides,…);*
- ***atomic physics*** *(highly charged atoms, electronic and muonic atoms, pionic and kaonic atoms);*
- ***astrophysics*** *(dark matter searches, gravitational waves detection, gravitational effects of cold particle beams, $^{16}O(\gamma,\alpha)^{12}C$ reaction and S-factors…);*
- ***fundamental physics*** *(studies of the basic symmetries of the universe, atomic interferometry,…);*
- ***accelerator physics*** *(beam cooling techniques, low emittance hadronic beams, plasma wake field acceleration, high intensity polarised positron and muon sources, beams of radioactive ions and neutrons, very narrow band, and flavour-tagged neutrino beams, neutron sources…);*
- ***applied physics*** *(accelerator driven energy sources, fusion research, medical isotopes' and isomers' production).*

GF papers published over the last year

Probing Axion-Like-Particles at the CERN Gamma Factory

*Reuven Balkin, Mieczyslaw W. Krasny, Teng Ma, Benjamin R. Safdi, and Yotam Soreq**

Ann. Phys. (*Berlin*) **2022**, *534*, 2100222

Delta Baryon Photoproduction with Twisted Photons

Andrei Afanasev and Carl E. Carlson*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100228

Double-Twisted Spectroscopy with Delocalized Atoms

Igor P. Ivanov

Ann. Phys. (*Berlin*) **2022**, *534*, 2100128

Vacuum Birefringence at the Gamma Factory

Felix Karbstein

Ann. Phys. (*Berlin*) **2022**, *534*, 2100137

Charge-State Distributions of Highly Charged Lead Ions at Relativistic Collision Energies

Felix M. Kröger, Günter Weber, Simon Hirlaender, Reyes Alemany-Fernandez, Mieczyslaw W. Krasny, Thomas Stöhlker, Inga Yu. Tolstikhina, and Viacheslav P. Shevelko*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100245

Access to the Kaon Radius with Kaonic Atoms

*Niklas Michel and Natalia S. Oreshkina**

Ann. Phys. (*Berlin*) **2022**, *534*, 2100150

Possible Polarization Measurements in Elastic Scattering at the Gamma Factory Utilizing a 2D Sensitive Strip Detector as Dedicated Compton Polarimeter

Wilko Middents, Günter Weber, Uwe Spillmann, Thomas Krings, Marco Vockert, Andrey Volotka, Andrey Surzhykov, and Thomas Stöhlker*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100285

Radioactive Ion Beam Production at the Gamma Factory

Dragos Nichita, Dimiter L. Balabanski, Paul Constantin, Mieczyslaw W. Krasny, and Wieslaw Płaczek*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100207

Electric Dipole Polarizability of Neutron Rich Nuclei

Jorge Piekarewicz

Ann. Phys. (*Berlin*) **2022**, *534*, 2100185

Resonant Scattering of Plane-Wave and Twisted Photons at the Gamma Factory

Valeriy G. Serbo, Andrey Surzhykov, and Andrey Volotka*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100199

Local Lorentz Invariance Tests for Photons and Hadrons at the Gamma Factory

B. Wojtsekhowski and Dmitry Budker*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100141

Optical Excitation of Ultra-Relativistic Partially Stripped Ions

*Jacek Bieroń, Mieczyslaw Witold Krasny, Wiesław Płaczek, and Szymon Pustelny**

Ann. Phys. (*Berlin*) **2022**, *534*, 2100250

Expanding Nuclear Physics Horizons with the Gamma Factory

Dmitry Budker, Julian C. Berengut, Victor V. Flambaum, Mikhail Gorchtein, Junlan Jin, Felix Karbstein, Mieczyslaw Witold Krasny, Yuri A. Litvinov, Adriana Pálffy, Vladimir Pascalutsa, Alexey Petrenko, Andrey Surzhykov, Peter G. Thirolf, Marc Vanderhaeghen, Hans A. Weidenmüller, and Vladimir Zelevinsky*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100284

Parity-Violation Studies with Partially Stripped Ions

Jan Richter, Anna V. Maiorova, Anna V. Viatkina, Dmitry Budker, and Andrey Surzhykov**

Ann. Phys. (*Berlin*) **2022**, *534*, 2100561

Polarization of Photons Scattered by Ultra-Relativistic Ion Beams

Andrey Volotka, Dmitrii Samoilenko, Stephan Fritzsche, Valeriy G. Serbo, and Andrey Surzhykov*

Ann. Phys. (*Berlin*) **2022**, *534*, 2100252

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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]

Gamma factory searches for extremely weakly interacting particles

Sreemanti Chakraborti, Jonathan L. Feng, James K. Koga, and Mauro Valli
Phys. Rev. D **104**, 055023 – Published 21 September 2021

Collimation of partially stripped ions in the CERN Large Hadron Collider

A. Gorzawski, A. Abramov, R. Bruce, N. Fuster-Martinez, M. Krasny, J. Molson, S. Redaelli, and M. Schaumann
Phys. Rev. Accel. Beams **23**, 101002 – Published 23 October 2020

Visions for the future accelerator infrastructure requirements for physics research

Mieczyslaw Witold Krasny

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

https://indico.cern.ch/event/1133593/timetable/?print=1&view=standard

Four examples

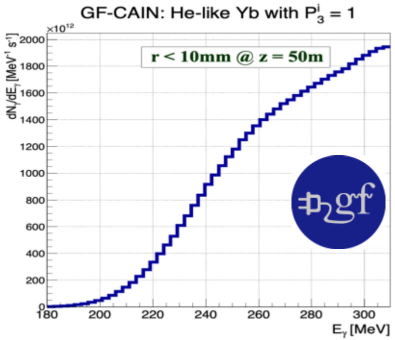
Particle Physics: GF low-emittance, high-intensity muon source

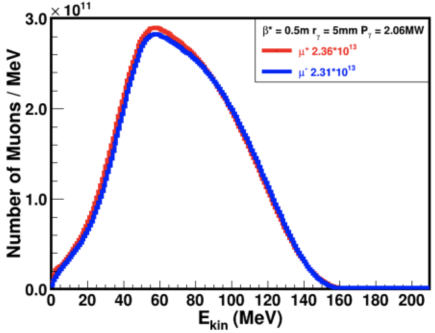
Existing and future muon sources: 10^8 (10^{10}) 1/s

Laboratory/ Beam line	Energy/ Power	Present Surface μ^+ rate (Hz)	Future estimated μ^+/μ^- rate (Hz)
PSI (CH)	(590 MeV, 1.3 MW, DC)		
LEMS	"	$4 \cdot 10^8$	
$\pi E5$	"	$1.6 \cdot 10^8$	
HiMB	(590 MeV, 1 MW, DC)		$4 \cdot 10^{10} (\mu^+)$
J-PARC (JP)	(3 GeV, 1 MW, Pulsed) currently 210 KW		
MUSE D-line	"	$3 \cdot 10^7$	
MUSE U-line	"		$2 \cdot 10^8 (\mu^+)$ (2012)
COMET	(8 GeV, 56 kW, Pulsed)		$10^{11} (\mu^-)$ (2019/20)
PRIME/PRISM	(8 GeV, 300 kW, Pulsed)		$10^{11-12} (\mu^-)$ (> 2020)
FNAL (USA)			
Mu2e	(8 GeV, 25 kW, Pulsed)		$5 \cdot 10^{10} (\mu^-)$ (2019/20)
Project X Mu2e	(3 GeV, 750 kW, Pulsed)		$2 \cdot 10^{12} (\mu^-)$ (> 2022)
TRIUMF (CA)	(500 MeV, 75 kW, DC)		
M20	"	$2 \cdot 10^6$	
KEK (JP)	(500 MeV, 2.5 kW, Pulsed)		
Dai Omega	"	$4 \cdot 10^5$	
RAL -ISIS (UK)	(800 MeV, 160 kW, Pulsed)		
RIKEN-RAL		$1.5 \cdot 10^6$	
RCNP Osaka Univ. (JP)	(400 MeV, 400 W, Pulsed)		
MUSIC	currently max 4W		$10^8 (\mu^+)$ (2012) means > 10^{11} per MW
DUBNA (RU)	(660 MeV, 1.65 kW, Pulsed)		
Phasatron Ch:I-III		$3 \cdot 10^4$	

Gamma-Factory muon source: 10^{13} 1/s

A.Apyan, M.W.Krasny, W. Placzek, to be published



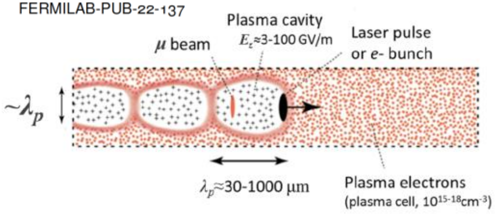


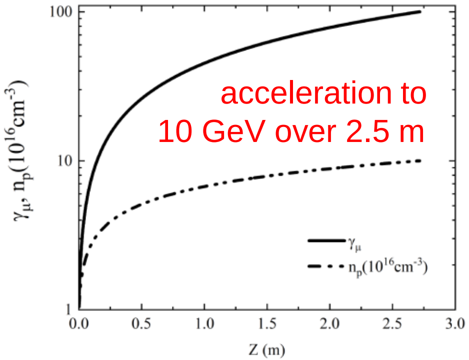
On Possibility of Low-emittance High-energy Muon Source Based on Plasma Wakefield Acceleration

Vladimir Shiltsev [a,1]

[a] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA*

FERMILAB-PUB-22-137





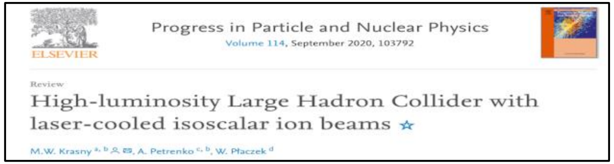
Particle Physics: Gamma Factory (complementary) path to HL-LHC

$$\mathcal{L} = f \frac{n_1 n_2}{4\pi \sqrt{\epsilon_x \beta_x^* \epsilon_y \beta_y^*}}$$

***Two complementary** ways to **increase** collider **luminosity** for fixed n_1,n_2,and f :*

- **reduce** β_x^* and β_y^*
- **reduce** ε_x and ε_y

***HL-LHC** – β* reduction by a factor of 3.7 (new inner triplet)*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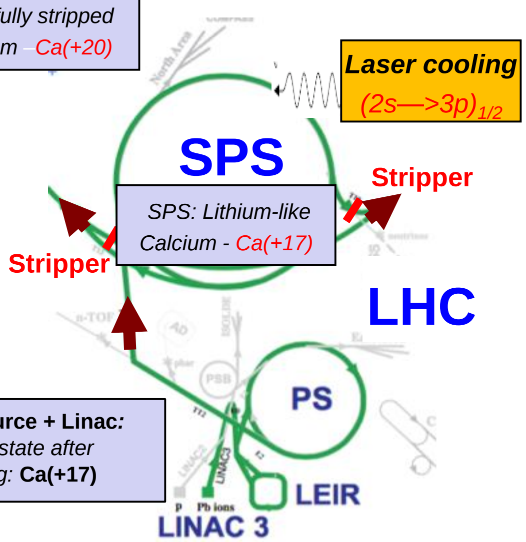
High-luminosity Large Hadron Collider with laser-cooled isoscalar ion beams ☆

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



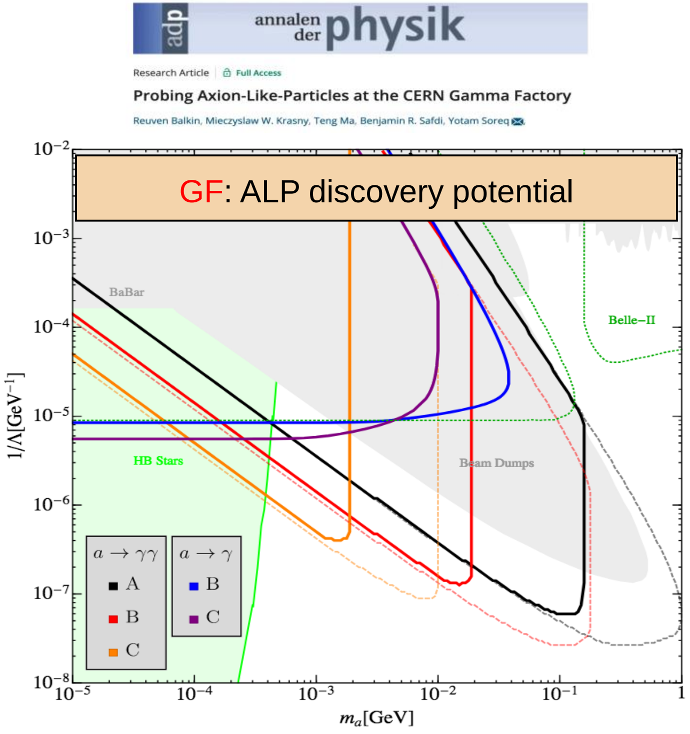
Reduction of the transverse x,y, emittances by a factor of 5 can be achieved in 9 seconds (<u>top SPS energy</u>)

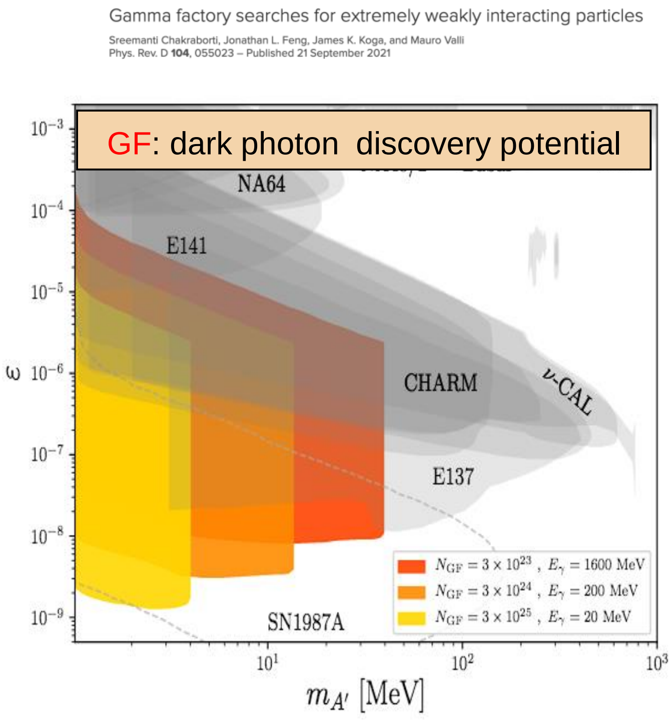
<u>The merits of cold isoscalar beams</u>

- *higher precision in measuring SM parameters (M_W, $\sin^2\theta_W$, …) in CaCa than in pp collisions,*
- *Possible unique access to exclusive Higgs boson production in photon–photon collisions,*
- *Lower pileup background at equivalent nucleon-nucleon (partonic) luminosity,*
- *New research opportunities for the EW symmetry breaking sector.*

If necessary:** add optical stochastic cooling time for the Ca beam at the LHC top energy t_{cool} ~1.5 hours **(V. Lebedev)

Astrophysics: Dark matter searches





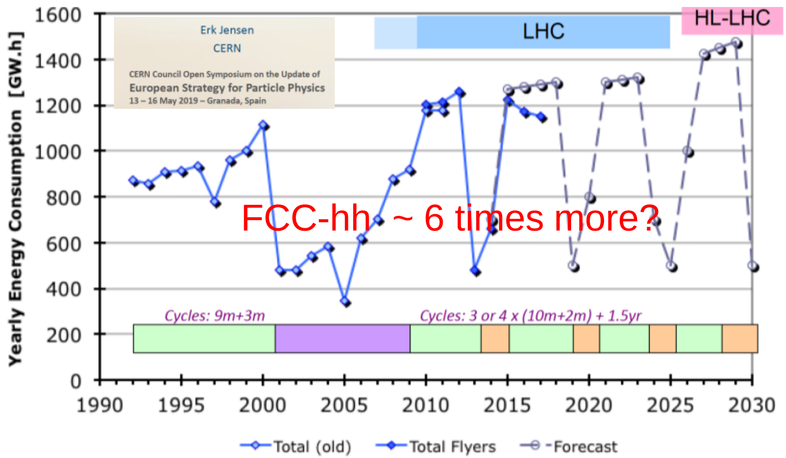
Significant discovery potential for Dark Matter particles with GF photon beams!

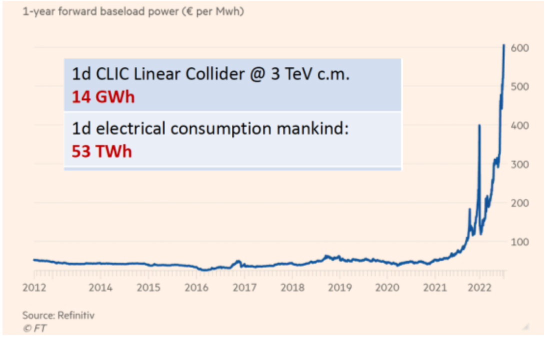
Applied physics: GF photon-beam-driven energy source

$N_A = 6{,}023 \cdot 10^{23}$

$N\gamma$/day = 5.4 x10^23

Is the present model of financing the running cost of the present and the future high energy frontiers accelerator infrastructures sustainable?





?

<u>Prix kWh</u>

- Present CERN price ~ 0.06 euro (Jensen, ESPP Granada)
- EU average(2021) ~ 0.24 euro (https://ec.europa.eu/)
- Market price (last week) ~0.60 euro (Financial Times)

<u>Electricity cost (estimates per year) HL-LHC(FCC-hh);</u>

- Present CERN cost - ~90 (540) x 10^6 euro/year
- EU prices (2021) ~370 (2220) x 10^6 euro/year
- Market price (last week) ~ 900(5400) x 10^6 euro/year

(CERN yearly budget -- 1200 x 10^6 euro /year !)

In my view, <u>producing -- rather than buying --</u> the requisite plug-power may become soon a "sine qua non" (survival) condition for exploring the high energy frontier in a sustainable way!

Applied physics:

Gamma Factory, photon-beam-driven energy source?

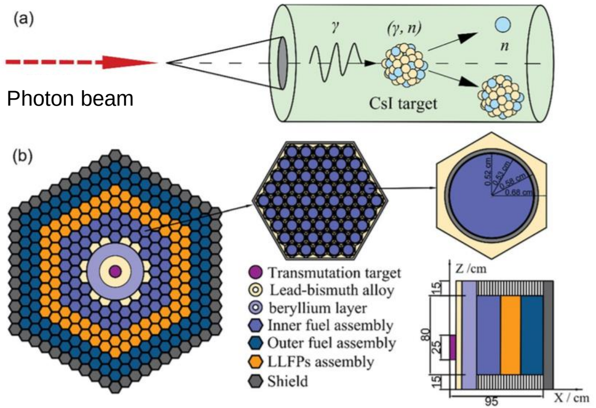
Nature:

Article | Open Access | Published: 09 February 2022

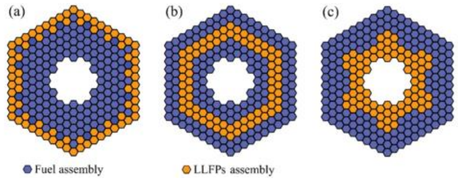
Transmutation of long-lived fission products in an advanced nuclear energy system

X. Y. Sun, W. Luo, H. Y. Lan, Y. M. Song, Q. Y. Gao, Z. C. Zhu, J. G. Chen & X. Z. Cai

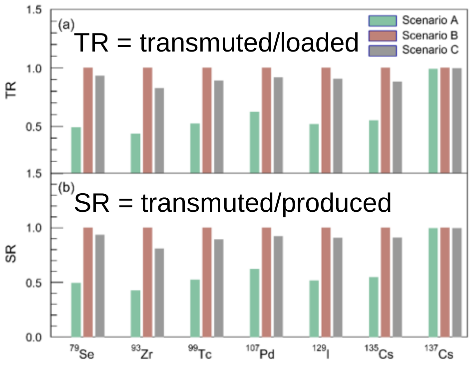
Scientific Reports **12**, Article number: 2240 (2022) | Cite this article



Main parameters	Data used in this study
Type of fuel	UO_2
Thermal power (MWt)	500
Electric power (MWe)	200
Core height (mm)	1100
Core diameter (mm)	1050
Number of fuel assemblies	60/102 (inner/outer)
Number of pins in each of fuel assembly	61
Pin diameter (mm)	5.8
Pellet diameter (mm)	5.2
^{235}U enrichment (%)	23.3
Number of LLFPs assemblies	78
Number of pins in each of LLFPs assembly	61
Number of shield assemblies	60

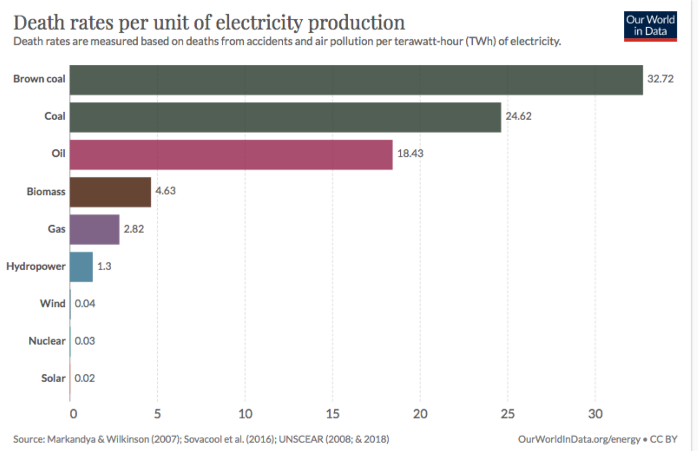


Physical quantity	Value
Effective multiplication factor (k_{eff})	0.979
Reactivity (ρ)	−0.019
Effective multiplication factor for prompt neutrons (k_p)	0.977
Eigenvalue (α)	−0.003
Effective delayed neutron fraction (β_{eff})	0.007
Neutron generation time (Λ) (μs)	0.523
Neutron worth of PNS (φ)	1.319
Sub-critical effective multiplication factor (k_s)	0.984



Potential merit of the GF-beam-driven sub-critical reactor.

Could provide the requisite plug-power for the present, and for the the future CERN's needs with one of the most safe (and clean!) sources of energy with resonant photo-transmutation of the long-lived nuclear waste isotopes!



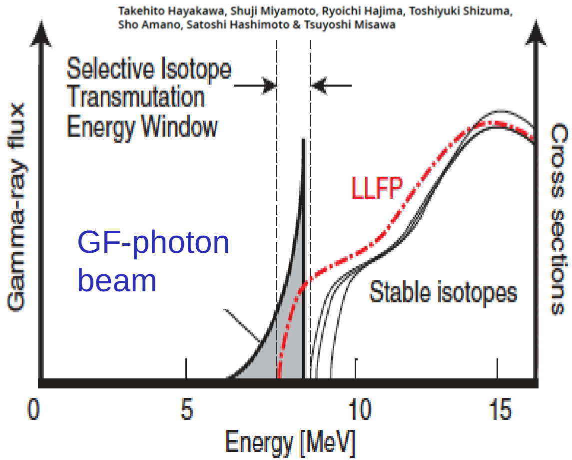


Table 1. Particle threshold energies and residual nuclei for even-*Z* elements including LLFPs.

Isotopes	$T_{1/2}$	E (MeV)	R.I.	$T_{1/2}$
^{90}Zr	-	8.355(p)	^{89}Y	-
^{91}Zr	-	7.195(n)	^{90}Zr	-
^{92}Zr	-	8.634(n)	^{91}Zr	-
^{93}Zr	1.61×10^{6} y	6.734(n)	^{92}Zr	-
^{94}Zr	-	8.220(n)	^{94}Zr	1.61×10^{6} y
^{96}Zr	-	7.854(n)	^{95}Zr	64 d
^{76}Se	-	9.508(p)	^{75}As	-
^{77}Se	-	7.418(n)	^{76}Se	-
^{78}Se	-	10.399(n)	^{77}Se	-
^{79}Se	2.95×10^{5} y	6.914(n)	^{78}Se	-
^{80}Se	-	9.914(n)	^{79}Se	2.95×10^{5} y
^{82}Se	-	9.276(n)	^{81}Se	18 m
^{104}Pd	-	8.658(p)	^{103}Ph	-
^{105}Pd	-	7.941(n)	^{104}Pd	-
^{106}Pd	-	9.347(p)	^{105}Rh	1.47 d
^{107}Pd	6.5×10^{6} y	6.359(n)	^{106}Pd	-
^{108}Pd	-	9.221(n)	^{107}Pd	6.5×10^{6} y
^{110}Pd	-	8.861(n)	^{109}Pd	13.7 h
^{117}Sn	-	6.945(n)	^{116}Sn	-
^{118}Sn	-	9.327(n)	^{117}Sn	-
^{119}Sn	-	6.485(n)	^{118}Sn	-
^{120}Sn	-	9.107(n)	^{119}Sn	-
^{122}Sn	-	8.814(n)	^{121}Sn	27 h
^{124}Sn	-	8.488(n)	^{123}Sn	40 m
^{126}Sn	2.3×10^{5} y	8.193(n)	^{125}Sn	9.6 d
^{88}Sr	-	10.614(p)	^{87}Rb	-
^{90}Sr	28.8 y	7.806(n)	^{89}Sr	50.6 d
^{133}Cs	-	6.085(p)	^{132}Xe	-
		8.987(n)	^{132}Cs	6.5 d
^{135}Cs	2.3×10^{6} y	6.751(p)	^{134}Xe	-
		8.762(n)	^{134}Cs	2.0 y
^{137}Cs	30 y	7.416(p)	^{136}Xe	-
		8.278(n)	^{136}Cs	13.2 d
^{127}I	-	6.206(p)	^{126}Te	-
@		9.143(n)	^{126}I	13.1 d
^{129}I	1.57×10^{7} y	6.799(p)	^{128}Te	-
		8.833(n)	^{128}I	25 m
^{99}Tc	2.11×10^{5} y	6.500(p)	^{98}Mo	-
		8.967(n)	^{98}Tc	4.2×10^{6} y

Conclusions

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

- *The **next** CERN **high-energy frontier** project (if ever constructed) may take **long time** to be approved, built and become operational, … unlikely before 2050-ties*
- *The **present** LHC **research programme** will certainly reach **earlier** (late 2030-ties?) its discovery **saturation** ($L_{int} \sim 0.5L_{goal}$) -- 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,** by a broad scientific communities*

__The Gamma Factory__ research programme 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 in particle, nuclear, atomic, fundamental, applied physics, and astrophysics __with novel research tools__

A vision of the LHC operation mode in in the post-HL-LHC phase