Gamma Factory:

Proof of Principle Experiment
SPSC-I-253

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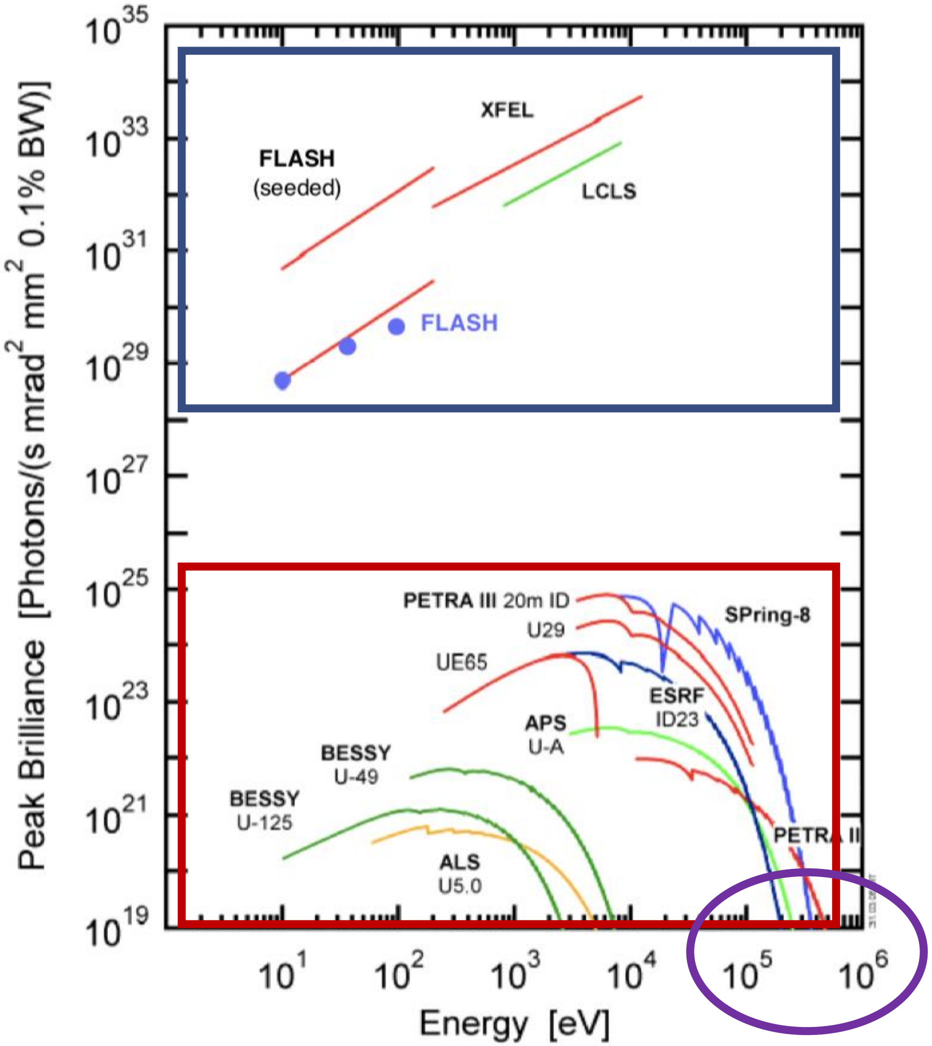
Outline

Gamma Factory

- Scientific context
- Why a Proof of principle experiment ?
- The Proof of principle experiment

Gamma Factory:
The scientific context

A striking fact

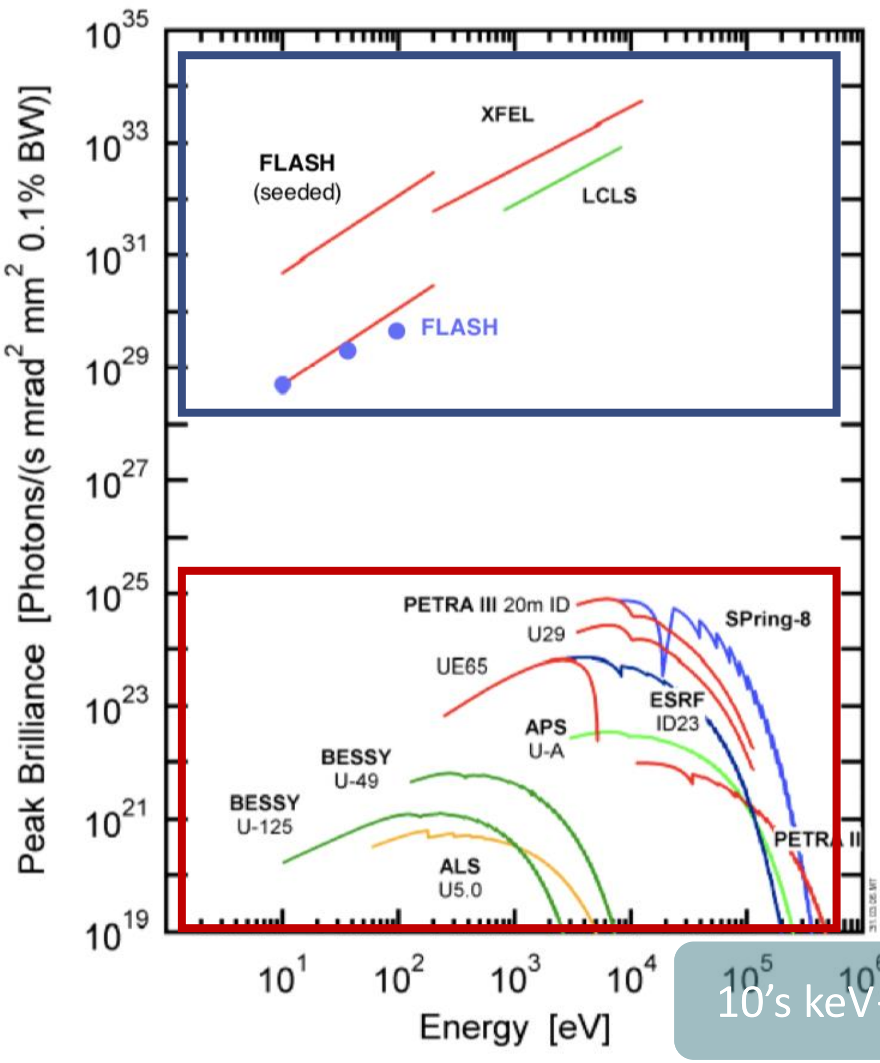


Weise, LINAC 2006 proceedings;

Few 100’s keV at most

A striking fact

Weise, LINAC 2006 proceedings;



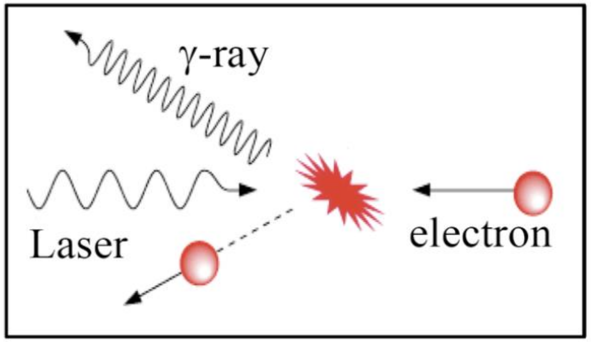
No bright photon source for nuclear and particle physics applications !

FEL and synchrotron impracticable

Inverse Compton scattering ?
Excellent monochromaticity but
O(1barn) cross-section is low !

ICS lie here

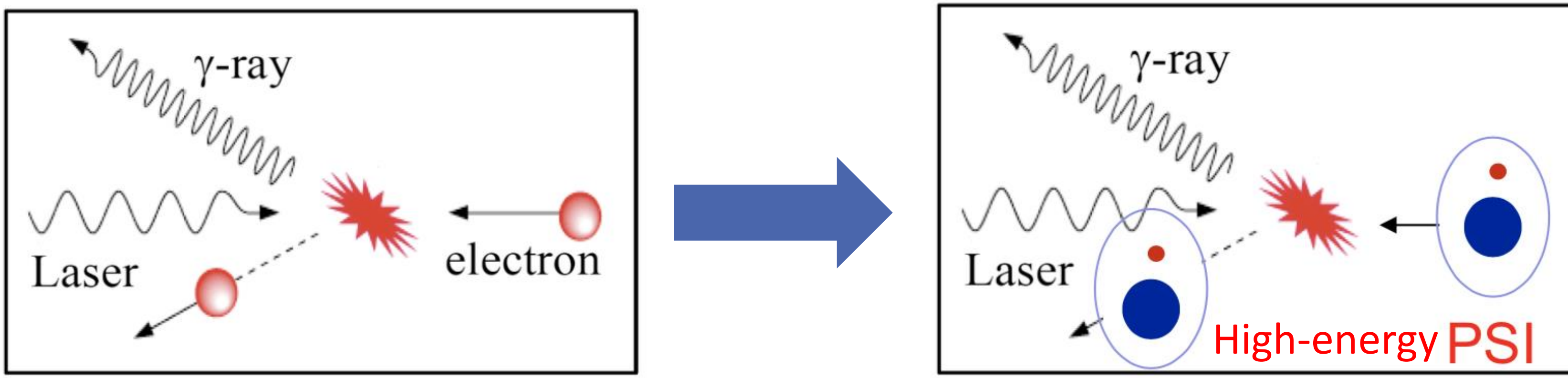
10's keV—100 MeV



Example : HIγS@Duke, 10^{10} ph/s, 1-100MeV

Physics concept

: Exploit high cross-section of atomic resonances & existing CERN accelerator complex



PSI: Partially stripped ions

Very similar with Inverse Compton scattering but O(10^9) larger cross-section !

For instance

Energy upshifting by a factor $4\gamma^2$

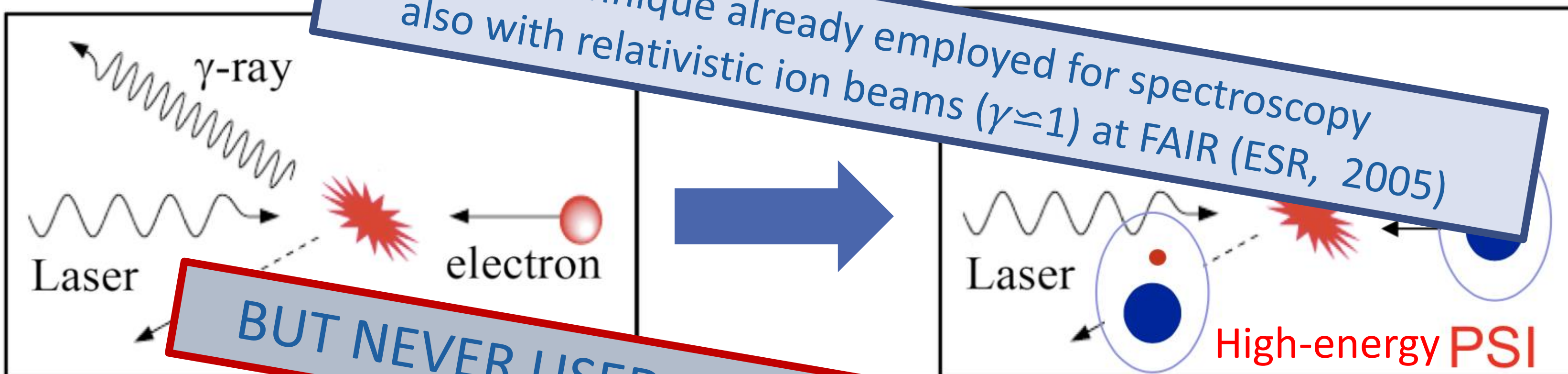
- H-like Xenon at LHC (γ=3000) → 180 MeV
- Li-like Calcium at SPS (γ=130) → 80 keV

E. J. Bessonov & K.J. Kim Phys. Rev. Lett. 76, 431, M.W. Krasny arXiv:1511.07794,
D Winters et al 2015 Phys. Scr. 2015 014048

Physics concept

: Exploit high c… …ection of atomic resonances & existing CERN accelerator complex

A technique already employed for spectroscopy
also with relativistic ion beams ($\gamma \simeq 1$) at FAIR (ESR, 2005)



PSI: Partially stripped ions

BUT NEVER USED AS A PHOTON SOURCE SO FAR !!!

Very similar with Inverse Compton scatter… …ection !

For instance

Energy upshifting by a factor $4\gamma^2$

H-like Xenon at LHC (γ=3000) → 180 MeV

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Physics concept

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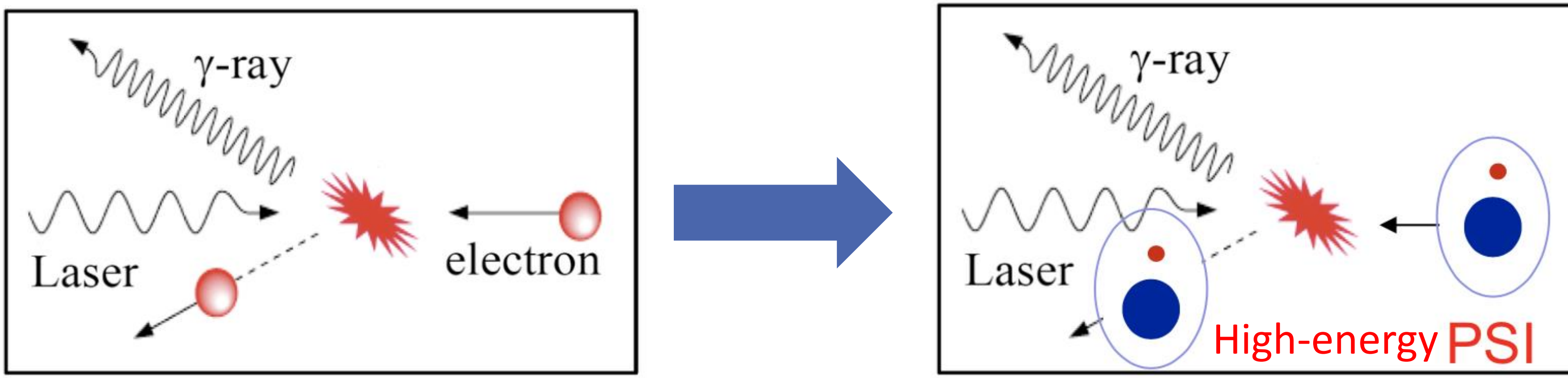


PSI: Partially stripped ions

Very similar with Inverse Compton scattering but $O(10^9)$ larger cross-section !

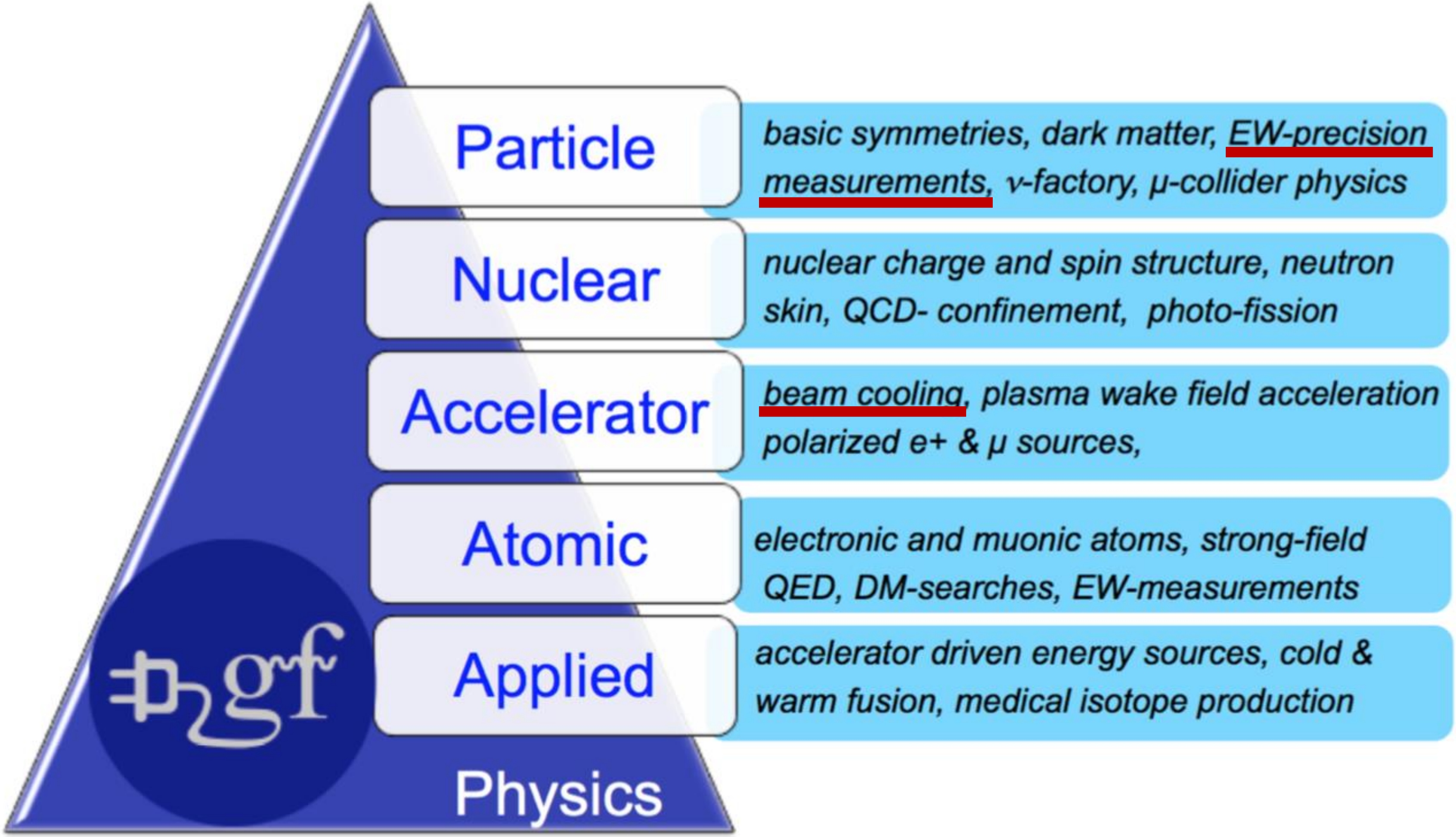
- PSI recycling in ring is very efficient (relative energy loss << beam energy spread)
- Energy tunability provided by PSI species choice and ion beam energy (<400MeV w/ LHC)

- Laser wavelength must be « tuned » to PSI species and beam energy
- Laser must be placed in a harsher environment (compared to e^- accelerators)

E. J. Bessonov & K.J. Kim Phys. Rev. Lett. 76, 431, M.W. Krasny arXiv:1511.07794,
D Winters et al 2015 Phys. Scr. 2015 014048

Implications of Gamma Factory

High potential to open new opportunities in many branches of physics



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Implications of Gamma Factory

High potential to open new opportunities in many branches of physics

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Review

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

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A R T I C L E I N F O

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A B S T R A C T

The existing CERN accelerator infrastructure is world unique and its research capacity should be fully exploited. In the coming decade its principal *modus operandi* will be focused on producing intense proton beams, accelerating and colliding them at the Large Hadron Collider (LHC) with the highest achievable luminosity. This activity should, in our view, be complemented by new initiatives and their feasibility studies targeted on re-using the existing CERN accelerator complex in novel ways that were not conceived when the machines were designed. They should provide attractive, ready-to-implement research options for the forthcoming *paradigm-shift* phase of the CERN research. This paper presents one of the case studies of the *Gamma Factory* initiative (Krasny, 2015) – a proposal of a new operation scheme of ion beams in the CERN accelerator complex. Its goal is to extend the scope and precision of the LHC-based research by complementing the proton–proton collision programme with the *high-luminosity* nucleus–nucleus one. Its numerous physics highlights include studies of the exclusive Higgs-boson production in photon–photon collisions and precision measurements of the electroweak (EW) parameters. There are two principal ways to increase the LHC luminosity which do not require an upgrade of the CERN injectors: (1) modification of the beam-collision optics and (2) reduction of the transverse emittance of the colliding beams. The former scheme is employed by the ongoing high-luminosity (HL-LHC) project. The latter one, applicable only to ion beams, is proposed in this paper. It is based on laser cooling of bunches of partially stripped ions at the SPS flat-top energy. For isoscalar calcium beams, which fulfil the present beam-operation constrains and which are particularly attractive for the EW physics, the transverse beam emittance can be reduced by a factor of 5 within the 8 seconds long cooling phase. The predicted nucleon–nucleon luminosity of $L_{NN} = 4.2 \times 10^{34}\,s^{-1}cm^{-2}$ for collisions of the cooled calcium beams at the LHC top energy is comparable to the levelled luminosity for the HL-LHC proton–proton collisions, but with reduced pile-up background. The scheme proposed in this paper, if confirmed by the future Gamma Factory proof-of-principle experiment, could be implemented at CERN with minor infrastructure investments.

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 ... See all authors

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Abstract

The Gamma Factory initiative proposes to develop novel research tools at CERN by producing, accelerating, and storing highly relativistic, partially stripped ion beams in the SPS and LHC storage rings. By exciting the electronic degrees of freedom of the stored ions with lasers, high-energy narrow-band photon beams will be produced by properly collimating the secondary radiation that is peaked in the direction of ions' propagation. Their intensities, up to 10^{17} photons per second, will be several orders of magnitude higher than those of the presently operating light sources in the particularly interesting γ-ray energy domain reaching up to 400 MeV. This article reviews opportunities that may be afforded by utilizing the primary beams for spectroscopy of partially stripped ions circulating in the storage ring, as well as the atomic-physics opportunities made possible by the use of the secondary high-energy photon beams. The Gamma Factory will enable ground-breaking experiments in spectroscopy and novel ways of testing fundamental symmetries of nature.

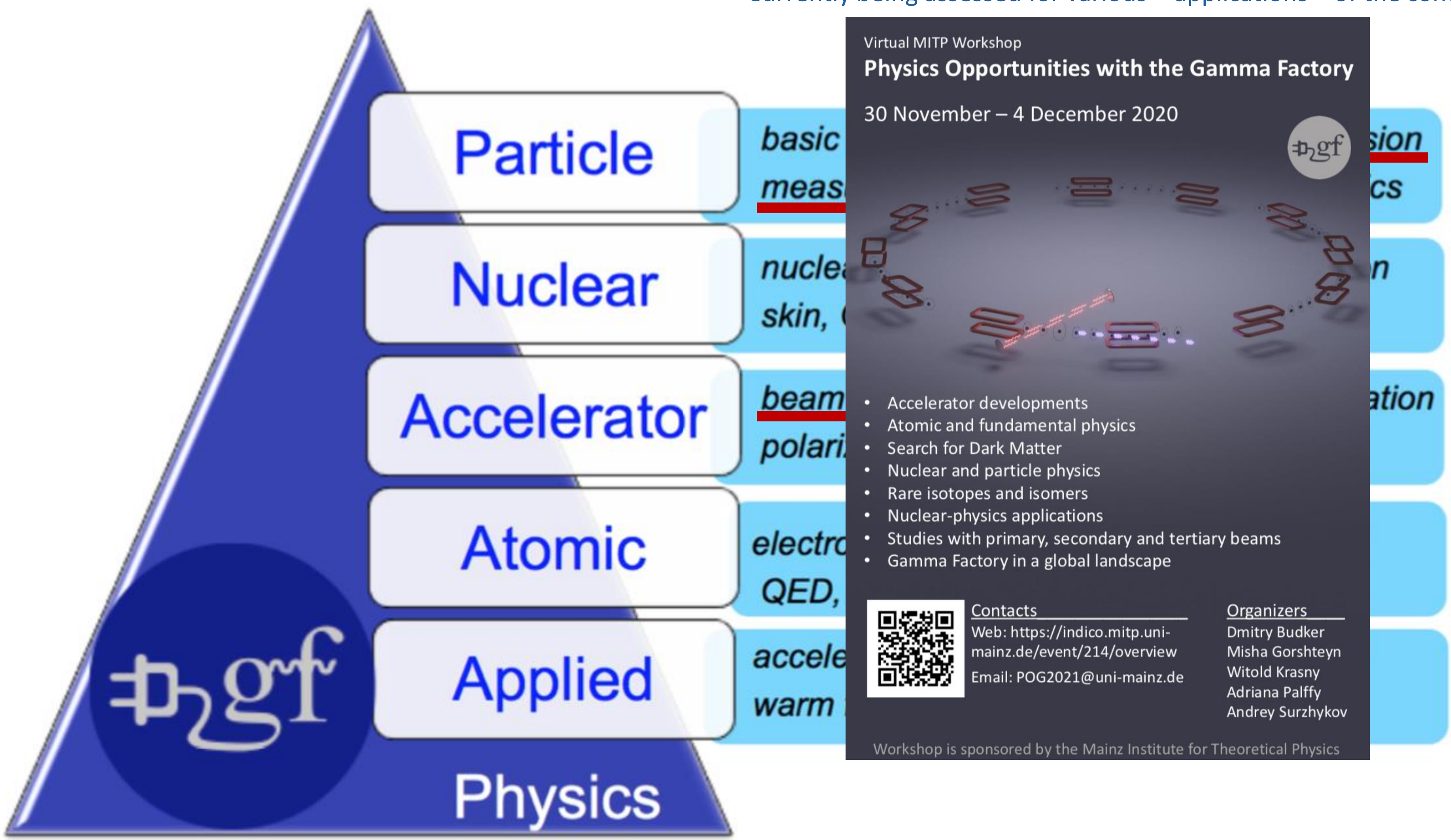
1 Introduction

M.W. Krasny et al., Progress in Particle and Nulcear Physics. 114 (2020) 103792,
D. Budker etal., Ann. Phys. (Berlin) 2020, 532, 2000204

Implications of Gamma Factory

High potential to open new opportunities in many branches of physics

Currently being assessed for various « applications » of the concept



Gamma Factory:

Why a Proof of Principle experiment ?

Two critical milestones

Demonstration at the SPS that there is no showstopper for the operation GF concept

The 'raison d'être' of the Gamma Factory Proof of principle experiment

Quantitative evaluation of the Gamma Factory potential for various branches of physics

On-going detailed case-by-case studies

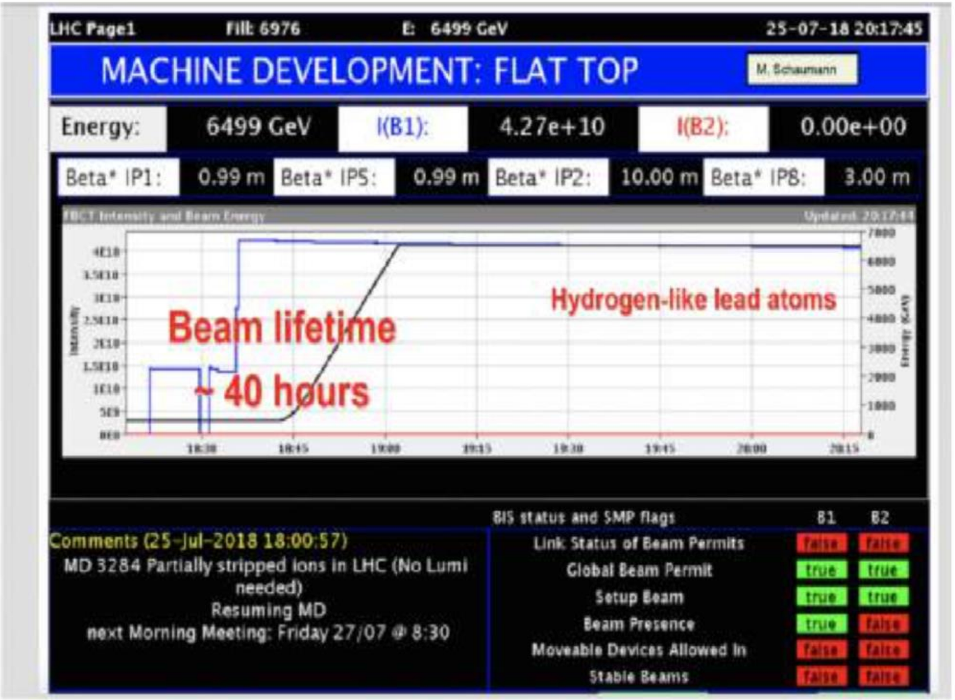
Necessary inputs to a further implementation at LHC

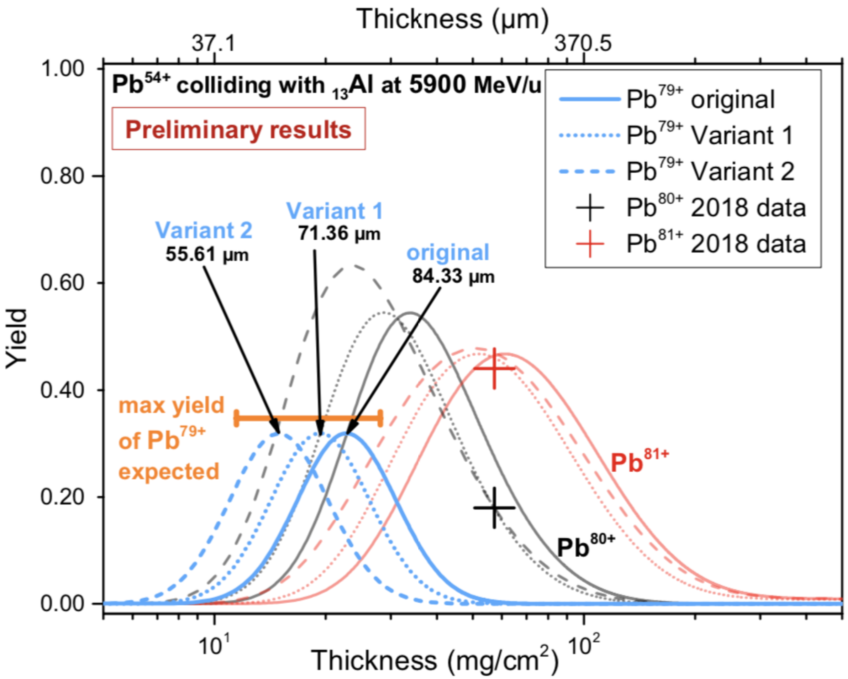
Atoms in the LHC !

1

- Demonstration of efficient production, acceleration and storage of atomic beams in the CERN accelerator complex

✓





2018 demonstration allowed us to estimate the Al-foil thickness optimized fo Pb^{79+}

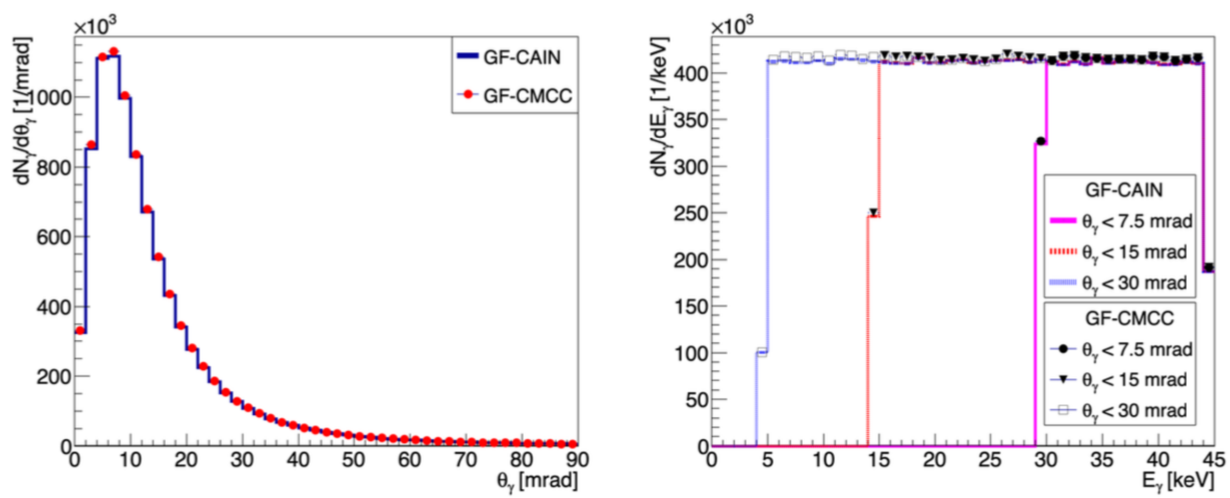
Simulation tools: cross-checked

1. Demonstration of efficient production, acceleration and storage of atomic beams in the CERN accelerator complex ✓

2. Development of the requisite GF research programme simulation tools. ✓

Two existing softwares improved for GF use + dedicated ones provide consistent

- Excitation rates
- Angular distributions
- Energy distributions
- Polarisation (on-going)



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Where do we stand ?

1. Demonstration of efficient production, acceleration and storage of atomic beams in the CERN accelerator complex ✓
2. Development of the requisite GF research program simulation tools. ✓
3. Successful execution of the GF PoP experiment in the SPS. — TODAY's subject to approval
4. Building up the physics cases for the LHC-based GF research program and attracting wide scientific communities to use the GF tools in their respective research.
5. Extrapolation of the SPS PoP experiment results to the (HL-)LHC case and realistic assessment of the performance figures of the LHC-based GF program.
6. Elaboration of the Technical Design Report (TDR) for the (HL-)LHC-based GF research program.

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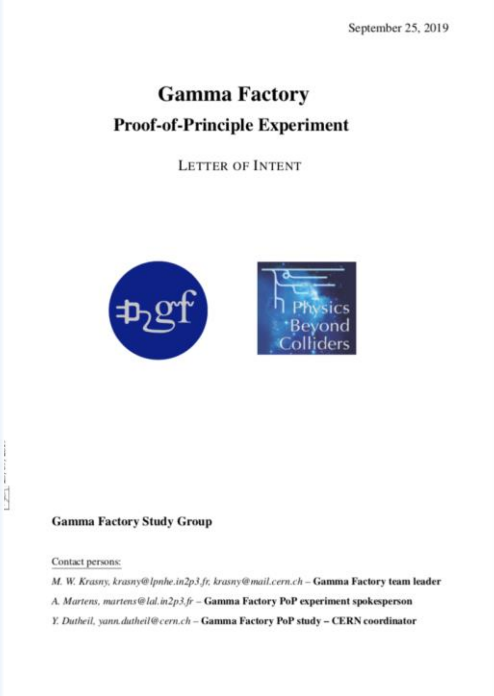
Gamma Factory:
The PoP experiment
Testing the concept with minimum cost and nuisance

LOI submission and review

M. W. Krasny et al. SPSC-I-253, M.W. Krasny arXiv:1511.07794


September 25, 2019

Gamma Factory

Proof-of-Principle Experiment

LETTER OF INTENT

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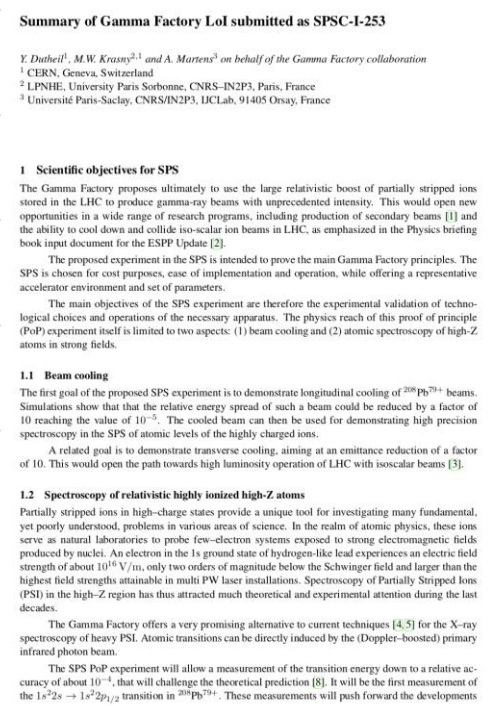
- 25/09/2019 — LOI submission
- 23/01/2020 — Questions received
- 18/02/2020 — answer document issued
- 08/05/2020 — Follow-up questions
- 28/05/2020 — updated answer document issued
- 12/06/2020 — invitation to SPSC meeting


Summary of Gamma Factory LoI submitted as SPSC-I-253

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1 Scientific objectives for SPS

The Gamma Factory proposes ultimately to use the large relativistic boost of partially stripped ions stored in the LHC to produce gamma-ray beams with unprecedented intensity. This would open new opportunities in a wide range of research programs, including production of secondary beams [1] and the ability to cool down and collide iso-scalar ion beams in LHC, as emphasized in the Physics briefing book input document for the ESPP Update [2].

The proposed experiment in the SPS is intended to prove the main Gamma Factory principles. The SPS is chosen for cost purposes, ease of implementation and operation, while offering a representative accelerator environment and set of parameters.

The main objectives of the SPS experiment are therefore the experimental validation of technological choices and operations of the necessary apparatus. The physics reach of this proof of principle (PoP) experiment itself is limited to two aspects: (1) beam cooling and (2) atomic spectroscopy of high-Z atoms in strong fields.

1.1 Beam cooling

The first goal of the proposed SPS experiment is to demonstrate longitudinal cooling of $^{208}Pb^{79+}$ beams. Simulations show that that the relative energy spread of such a beam could be reduced by a factor of 10 reaching the value of 10^{-5}. The cooled beam can then be used for demonstrating high precision spectroscopy in the SPS of atomic levels of the highly charged ions.

A related goal is to demonstrate transverse cooling, aiming at an emittance reduction of a factor of 10. This would open the path towards high luminosity operation of LHC with isoscalar beams [3].

1.2 Spectroscopy of relativistic highly ionized high-Z atoms

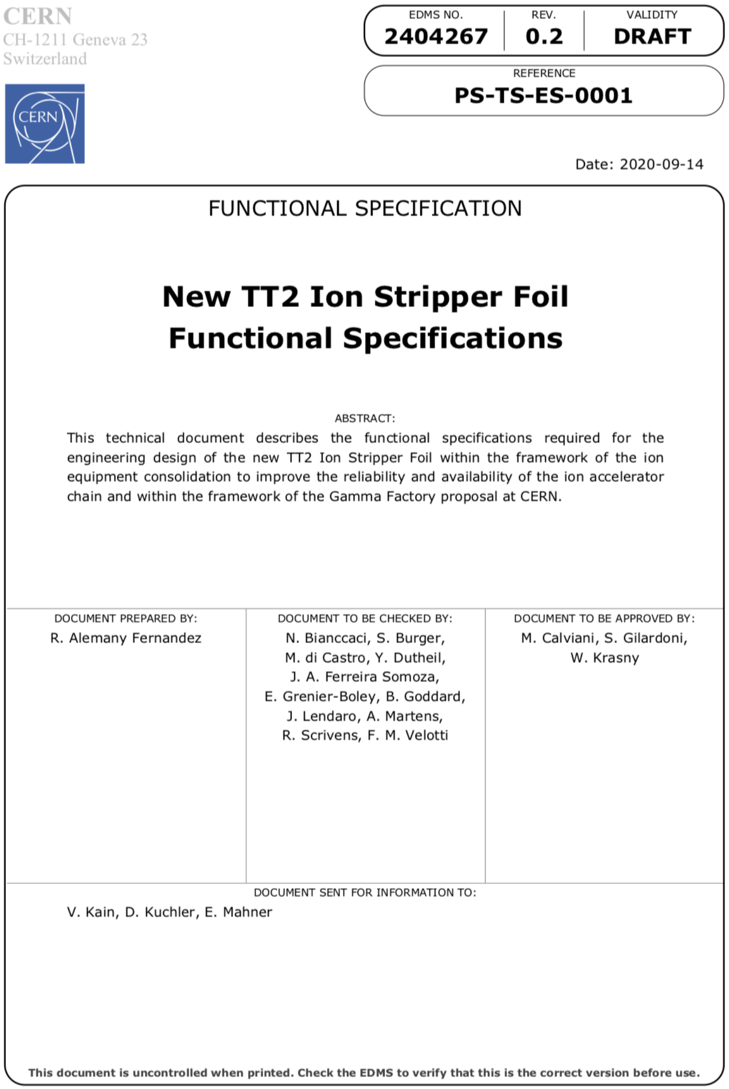
Partially stripped ions in high–charge states provide a unique tool for investigating many fundamental, yet poorly understood, problems in various areas of science. In the realm of atomic physics, these ions serve as natural laboratories to probe few–electron systems exposed to strong electromagnetic fields produced by nuclei. An electron in the 1s ground state of hydrogen-like lead experiences an electric field strength of about $10^{16}\,\mathrm{V/m}$, only two orders of magnitude below the Schwinger field and larger than the highest field strengths attainable in multi PW laser installations. Spectroscopy of Partially Stripped Ions (PSI) in the high–Z region has thus attracted much theoretical and experimental attention during the last decades.

The Gamma Factory offers a very promising alternative to current techniques [4,5] for the X–ray spectroscopy of heavy PSI. Atomic transitions can be directly induced by the (Doppler–boosted) primary infrared photon beam.

The SPS PoP experiment will allow a measurement of the transition energy down to a relative accuracy of about 10^{-4}, that will challenge the theoretical prediction [8]. It will be the first measurement of the $1s^2 2s \rightarrow 1s^2 2p_{1/2}$ transition in $^{208}Pb^{79+}$. These measurements will push forward the developments

Also presented @ 257th LHC Injector and Experimental Facilities Committee : https://indico.cern.ch/event/861645/

New ion stripper foils system



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REFERENCE
PS-TS-ES-0001

Date: 2020-09-14

FUNCTIONAL SPECIFICATION

New TT2 Ion Stripper Foil
Functional Specifications

ABSTRACT:
This technical document describes the functional specifications required for the engineering design of the new TT2 Ion Stripper Foil within the framework of the ion equipment consolidation to improve the reliability and availability of the ion accelerator chain and within the framework of the Gamma Factory proposal at CERN.

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R. Alemany Fernandez	N. Biancacci, S. Burger, M. di Castro, Y. Dutheil, J. A. Ferreira Somoza, E. Grenier-Boley, B. Goddard, J. Lendaro, A. Martens, R. Scrivens, F. M. Velotti	M. Calviani, S. Gilardoni, W. Krasny

DOCUMENT SENT FOR INFORMATION TO:
V. Kain, D. Kuchler, E. Mahner

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Common need with other experiments to add flexibility in stripping capability:

- 4 foils
- Angle (thickness) can be tuned
- Pulse to pulse operation !
- 35% stripping efficiency for Pb^{79+}

Will allow *parasitic* Gamma Factory Proof of principle operation

As extrapolated from 2018 run meassurements and ordinary SPS operations with ions

Beam parameters

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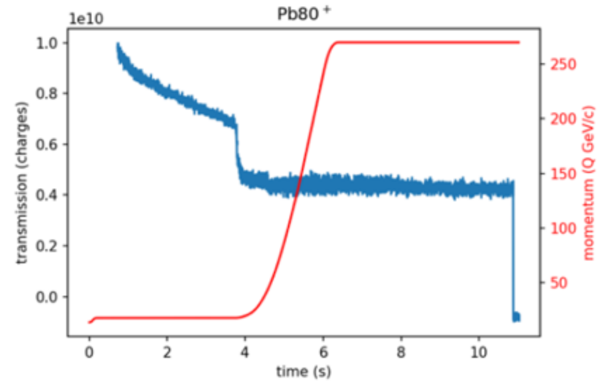
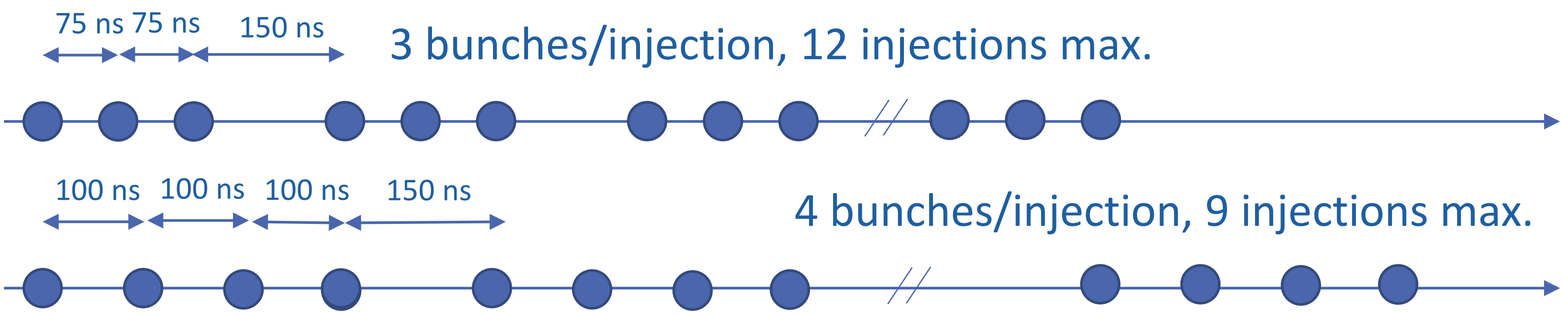
Lifetime is large enough at flat top for Pb^{80+}
→ Extrapolated for Pb^{79+}: about 100s



3 bunches/injection, 12 injections max.

4 bunches/injection, 9 injections max.



Common harmonic frequency=40MHz

Transverse normalised emittance	1.5 mm mrad
Bunch length	213 ps
Momentum spread	2×10^{-4}
Expected lifetime	100 s
Ions per bunch at injection	0.9×10^{8}
Maximum number of bunches in the ring	36

Collision scheme

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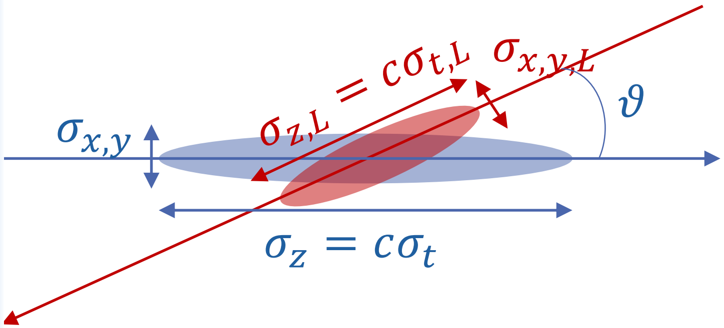


Beams must be aligned, synchronized

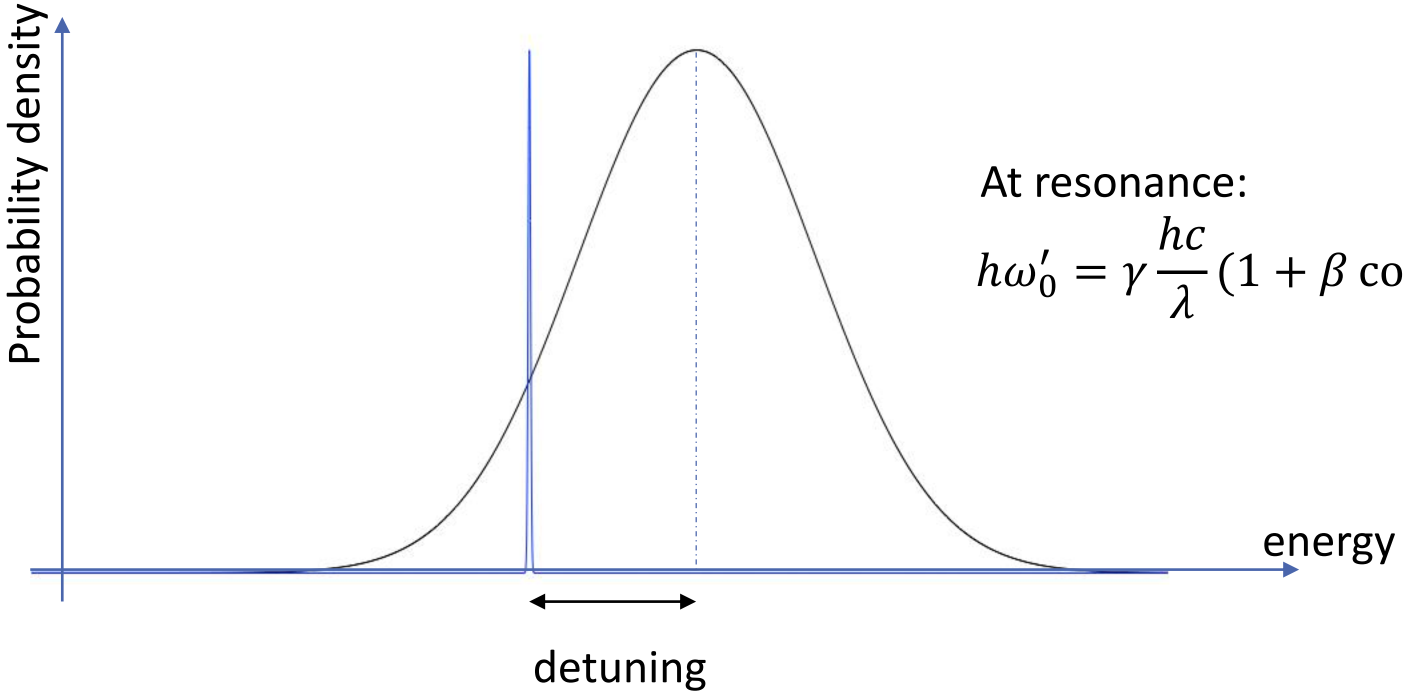
Not specific to Gamma Factory scheme

Table 3: SPS PoP experiment parameters.

PSI beam	$^{208}Pb^{79+}$
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 $^{208}Pb^{79+}$	$2s \rightarrow 2p_{1/2}$
$\hbar\omega_0'$ – 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

Spectrum matching

Linewidth of atomic resonance << bandwidth of laser spectrum (in ref. frame of atoms)

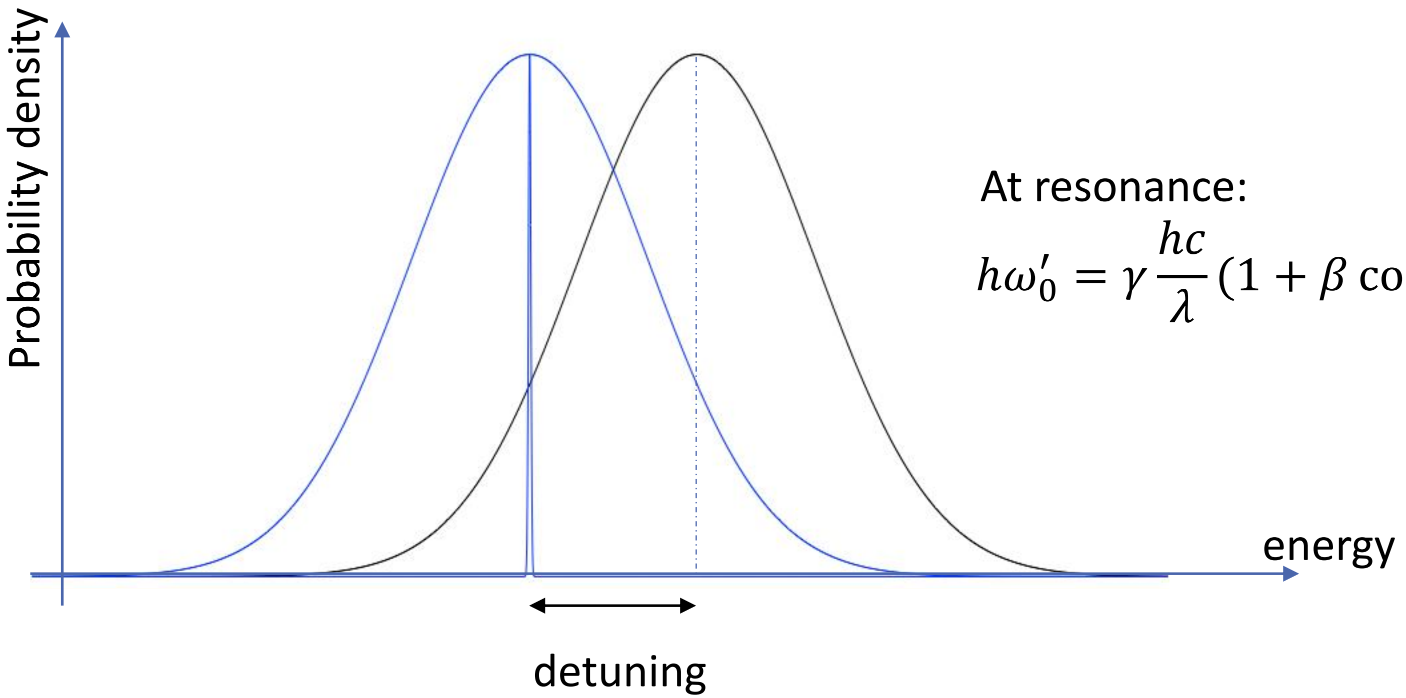


At resonance:

$$h\omega_0' = \gamma \frac{hc}{\lambda}(1 + \beta\cos(\vartheta))$$

Spectrum matching

Atomic (PSI) beam energy spread ≃ bandwidth of laser spectrum (in ref. frame of atoms)



At resonance:

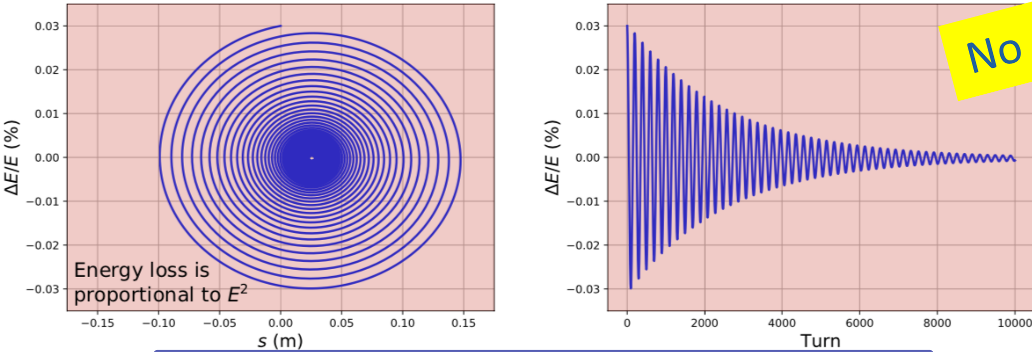
$$h\omega_0' = \gamma \frac{hc}{\lambda}(1 + \beta\cos(\vartheta))$$

- A relatively high laser energy is required to excite nearly all atoms
- Excitation rate of atoms depend on their position in the energy spectrum

Ultimately: 10^{17} ph/s

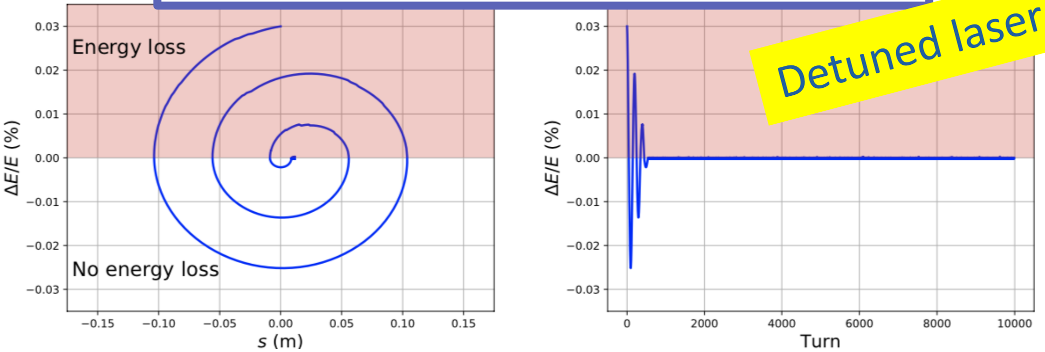
Ion beam cooling

No detuning

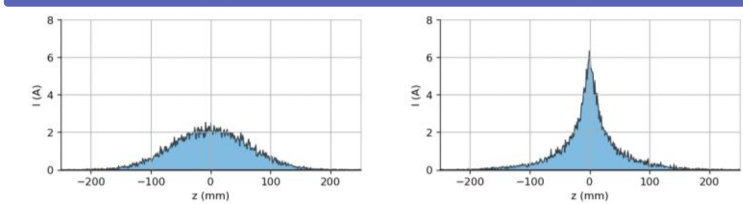


Ion beam efficiently cooled

Detuned laser spectrum



Observe it with wall current monitors



Large (horizontal) dispersion relation at the interaction point:
→ transverse cooling in a similar fashion by mis-aligning the beams

M. W. Krasny et al. SPSC-I-253

L. Amoudry et al., Applied Optics 59 (2020) 116; Chaikovska et al., Scientific Reports 6 (2016) 36569

Laser system at the state of the art

Fabry-Perot resonator to reach about 5mJ at 40MHz→ 200kW already exists

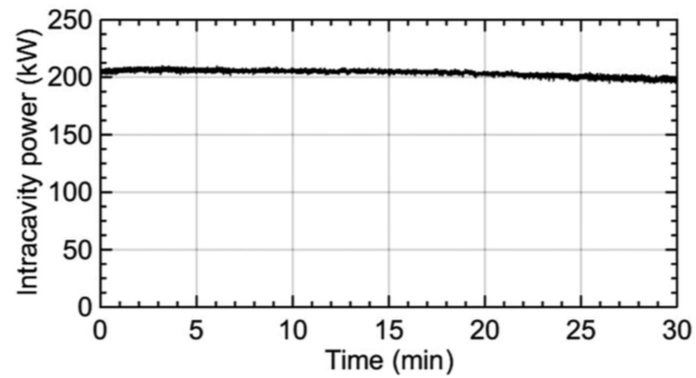


Fig. 7. Laser intracavity power for 30 min, measured by transmission of a cavity mirror.

Built and operated by IJCLab (Orsay) team

State of the art system, already operated in low emittance KEK ATF ring

But: need to ensure the system can be operated fully remotely

Synchronisation & alignment

Not specific to Gamma Factory

- Already realized in the past (for instance KEK ATF exp.)
- Alignment provided by BPMs on the girder of optical cavity
- Only needs to be adapted to SPS specifics

Cavity tuning range is limited

- Beam with constant revolution frequency at flat-top
- Varying transverse beam alignment: use existing orbit correctors

Similar to AWAKE

H. Damerau et al. IPAC2016-THPMY039; Chaikovska et al., Scientific Reports 6 (2016) 36569

Inputs from relevant experts at CERN : H. Damerau (RF) and V. Fedosseev (Laser)

Optical system: laser and amplifier

Required quality factor of optical cavity → very low phase noise laser

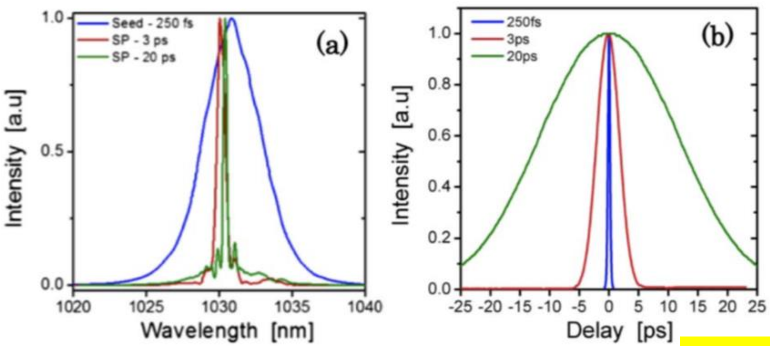
Unique provider !

Required laser power and robust performances

Tangor

Powerful, full-featured and versa[tile]
femtosecond laser

Industrial system exist !



Laser pulse duration/spectrum tunable

Pouysegur et al. Opt. Lett. 40, 5184-5187 (2015);

Radiation hardness

Ageing of laser system's components is not expected to be limitation if TID<150krad

Radiation hard mode-locked laser suitable as a spaceborne frequency comb

Gilles Buchs, Stefan Kundermann, Erwin Portuondo-Campa and Steve Lecomte*

Centre Suisse d'Electronique et de Microtechnique (CSEM), Jaquet-Droz 1, 2000 Neuchâtel, Switzerland
*steve.lecomte@csem.ch

Abstract: We report ground-level gamma and proton radiation tests of a passively mode-locked diode-pumped solid-state laser (DPSSL) with Yb:KYW gain medium. A total gamma dose of 170 krad(H_2O) applied in 5 days generates minor changes in performances while maintaining solitonic regime. Pre-irradiation specifications are fully recovered over a day to a few weeks timescale. A proton fluence of $9.76\cdot10^{10}$ cm^{-2} applied in few minutes shows no alteration of the laser performances. Furthermore, complete stabilization of the laser shows excellent noise properties. From our results, we claim that the investigated femtosecond DPSSL technology can be considered rad-hard and would be suitable for generating frequency combs compatible with long duration space missions.

Radiation hardening techniques for Er/Yb doped optical fibers and amplifiers for space application

Sylvain Girard,[1,*] Marilena Vivona,[2,3] Arnaud Laurent,[3] Benoît Cadier,[3] Claude Marcandella,[1] Thierry Robin,[3] Emmanuel Pinsard,[3] Aziz Boukenter,[2] and Youcef Ouerdane[2]

[1]*CEA, DAM, DIF, F91297 Arpajon, France*
[2]*Laboratoire Hubert Curien, UMR-CNRS, F42000 Saint-Etienne, France*
[3]*IXFiber SAS, F-22300 Lannion, France*
*sylvain.girard@cea.fr

Abstract: We investigated the efficiencies of two different approaches to increase the radiation hardness of optical amplifiers through development of improved rare-earth (RE) doped optical fibers. We demonstrated the efficiency of codoping with Cerium the core of Erbium/Ytterbium doped optical fibers to improve their radiation tolerance. We compared the γ-rays induced degradation of two amplifiers with comparable pre-irradiation characteristics (*~19 dB gain for an input power of ~10 dBm*): first one is made with the standard core composition whereas the second one is Ce codoped. The radiation tolerance of the Ce-codoped fiber based amplifier is strongly enhanced. Its output gain decrease is limited to ~1.5 dB after a dose of ~900 Gy, independently of the pump power used, which authorizes the use of such fiber-based systems for challenging space missions associated with high total doses. We also showed that the responses of the two amplifiers with or without Ce-codoping can be further improved by another technique: the pre-loading of these fibers with hydrogen. In this case, the gain degradation is limited to 0.4 dB for the amplifier designed with the standard composition fiber whereas 0.2 dB are reported for the one made with Ce-codoped fiber after a cumulated dose of ~900 Gy. The mechanisms explaining the positive influences of these two treatments are discussed.

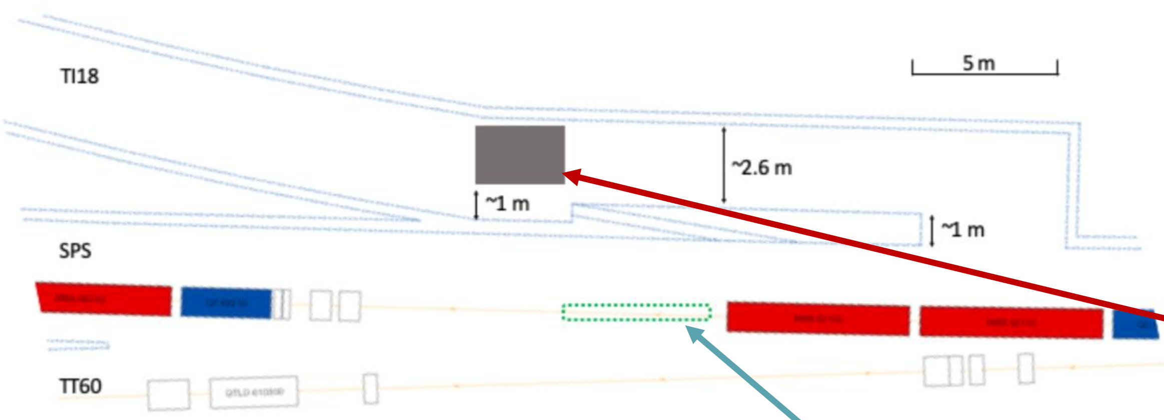
Gamma Factory PoP laser will only operate a few weeks a year

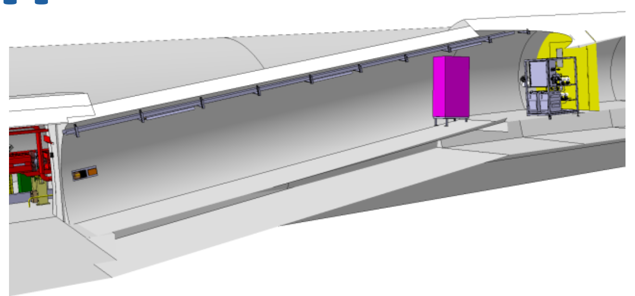
Sensitive laser-system must be shielded (side TI18 tunnel)

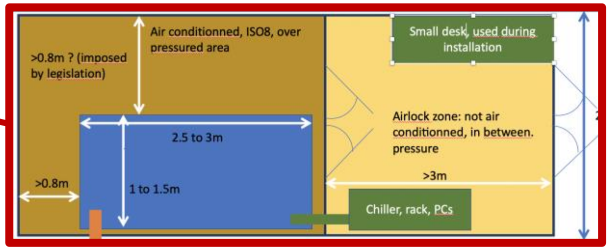
With R2E team: FLUKA simulations to be done to decide on the need of extra shielding or not

G. Buchs et al., Opt. Express 23 (2015) 9890 ; S. Girard et al., Opt. Express 20 (2012) 8457

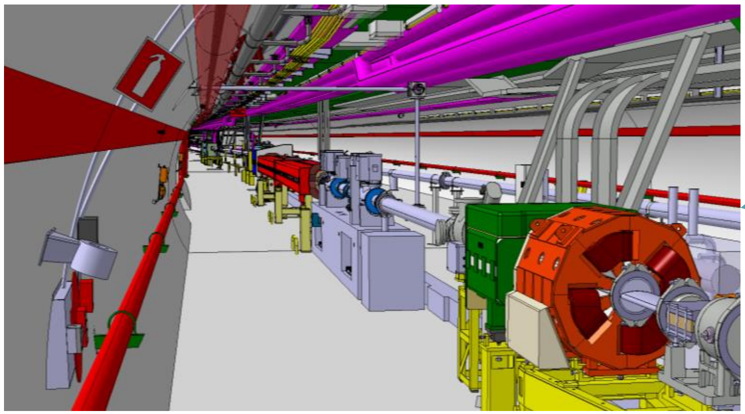
Optical system: integration

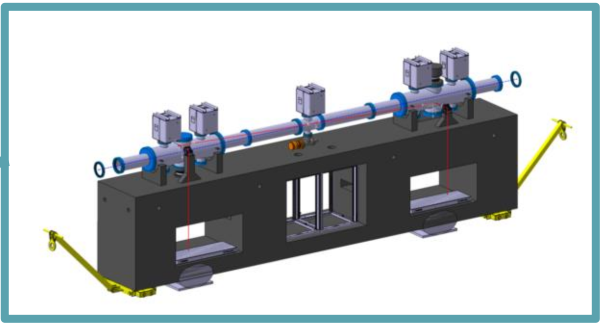






SPS half-cell 621 with side tunnel TI18



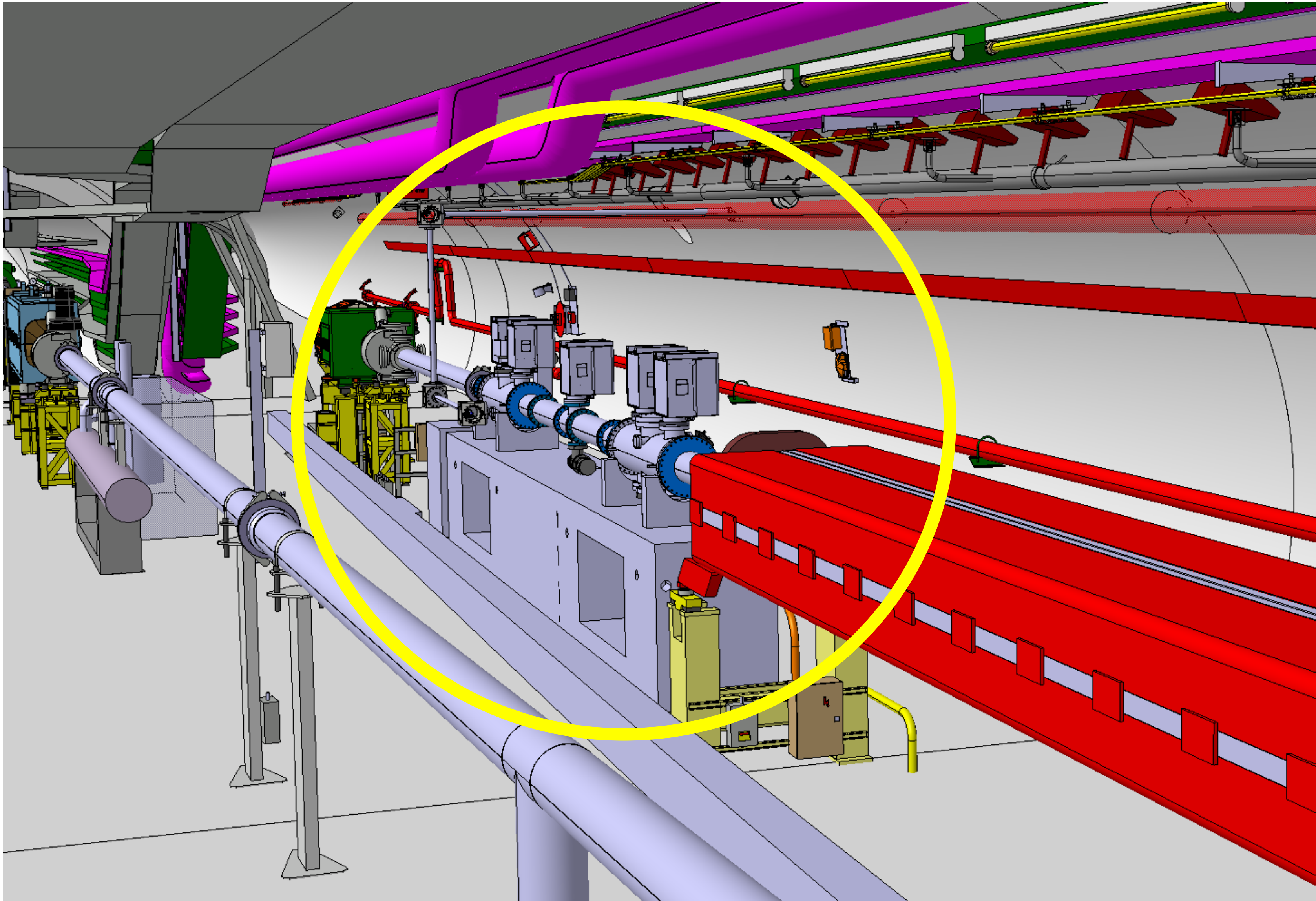


M. W. Krasny et al. SPSC-I-253

SPS half-cell 621 with side tunnel TI18

Optical system: integration

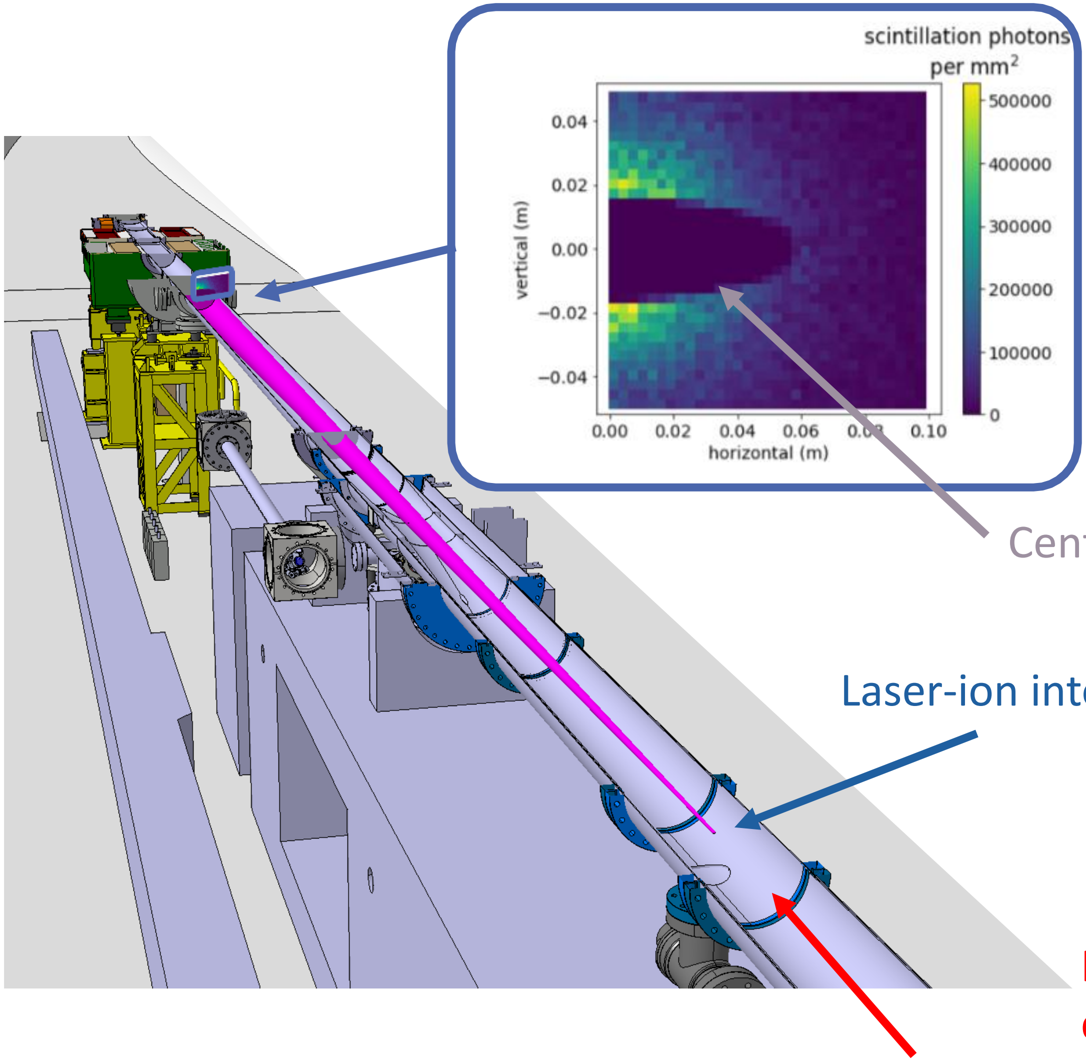
Thanks to Liam Dougherty for the help



Detection system

'BTV' system: YAG:Ce + camera

Remotely controlled manipulator



Central opening for ion beam passage

Laser-ion interaction Point

Ion beam direction

M. W. Krasny et al. SPSC-I-253

Impact on regular SPS operations

Vacuum

- Optical cavity requires similar or better vacuum compared to SPS
- Valves to break vacuum on a limited section of SPS → CERN experts

Impedance

- Past experience on low emittance KEK ATF
- Require formal validation of final design by CERN experts

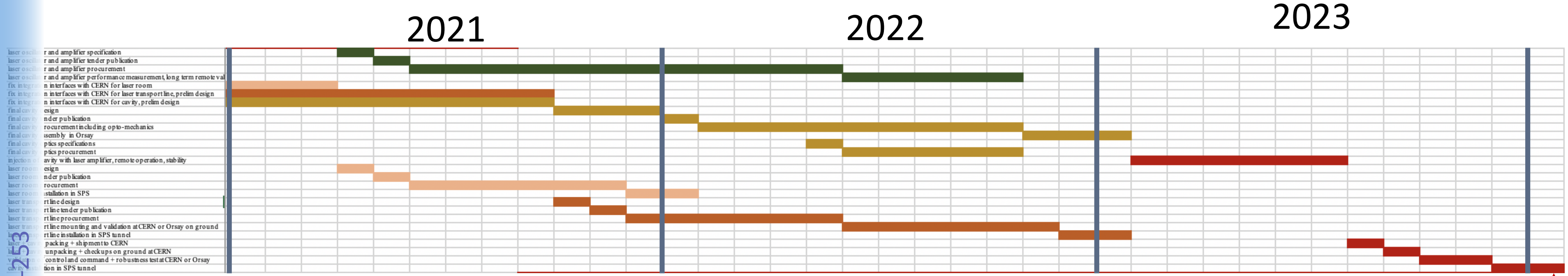
Remote operations

- Will be addressed during cavity and laser system implementation in lab

Parasitic operations

- Laser beam has no sizeable effect on proton/fully stripped hadronic beam

Project planning



Operational after 2023-2024 YETS

6 months of operation of optical cavity in lab

Installation of laser beam transport line in 2022-2023 YETS

optical cavity assembly in fall 2022

Laser room in TI18 during 2021-2022 YETS

PoP milestones and beam requests

In 2024

M. W. Krasny et al. SPSC-I-253

Resonance finding

- Commissioning with PSI before yearly ion run — 8h dedicated beamtime
- Realize synchronization, alignment — 4x8h in SPS supercycle // NA ops

Optimisation and characterisation

- Optimize interaction rate — 8h dedicated beamtime
- Stable measured rate of photons over >5s — 8h in SPS supercycle // NA ops

Cooling demonstration

- Show increase of beam current at constant charge — 2x8h dedicated beamtime
- Measure transverse beam size reduction — 8h in SPS supercycle // NA

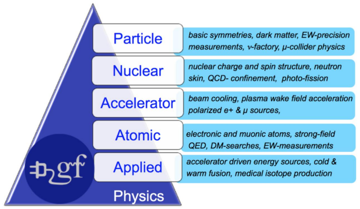
Atomic physics precision measurement

- First measurement of Pb79+ transition energy — 8h in SPS supercycle // NA
- Confront theory (strong field QED,...) to experiment — 8h dedicated beamtime

Summary

An international proto-collaboration of people

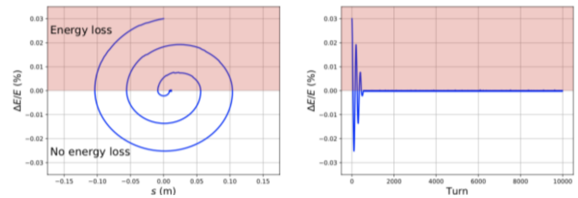
A. Abramov[1], S.E. Alden[1], R. Alemany Fernandez[2], P.S. Antsiferov[3], A. Apyan[4], D. Balabanski[34], H. Bartosik[2], J. Berengut[5], E.G. Bessonov[6], N. Biancacci[2], J. Bieroń[7], A. Bogacz[8], A. Bosco[1], R. Bruce[2], D. Budker[9,10], P. Constantin[34], K. Cassou[11], F. Castelli[12], I. Chaikovska[11], C. Curatolo[13], 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], R. Hajima[26], T. Hayakawa[26], S. Hirlander[2], J. Jin[33], J.M. Jowett[2], R. Kersevan[2], M. Kowalska[2], M.W. Krasny[16,2], F. Kroeger[17], D. Kuchler[2], M. Lamont[2], T. Lefevre[2], D. Manglunki[2], B. Marsh[2], A. Martens[12], S. Miyamoto[31] J. Molson[2], D. Nichita[34], D. Nutarelli[11], L.J. Nevay[1], V. Pascalutsa[28], A. Petrenko[18,2], V. Petrillo[12], W. Płaczek[7], 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.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]



with very broad physics interests in the Gamma Factory concept;

that would like to demonstrate before LS3 generation of unprecedented rates of photons

and ion beam cooling with laser,




adp 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 ... See all authors

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in order to trigger a new avenue for atomic measurements

and new opportunities for particle and nuclear physics


Contents lists available at ScienceDirect

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Review

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

M.W. Krasny, A. Petrenko, W. Płaczek

Summary

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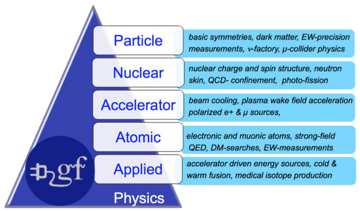
An international proto-collaboration of people

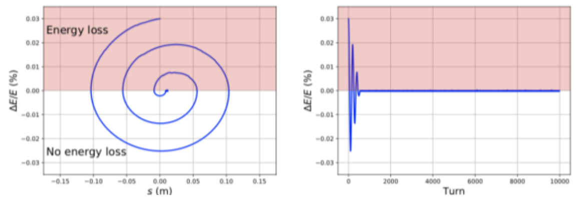


with very broad physics interests in the Gamma Factory concept;

that would like to demonstrate before LS... ...dented rates of photons

and io... ...;

The Proof of principle experiment for the Gamma Factory is a critical step to allow this very broad physics programme to happen



in order to trigger a new avenue for atomic measurements

and new opportunities for particle and nuclear physics

BACKUP

Project funding

Table 8: Preliminary material cost estimates for the Gamma Factory SPS PoP experiment.

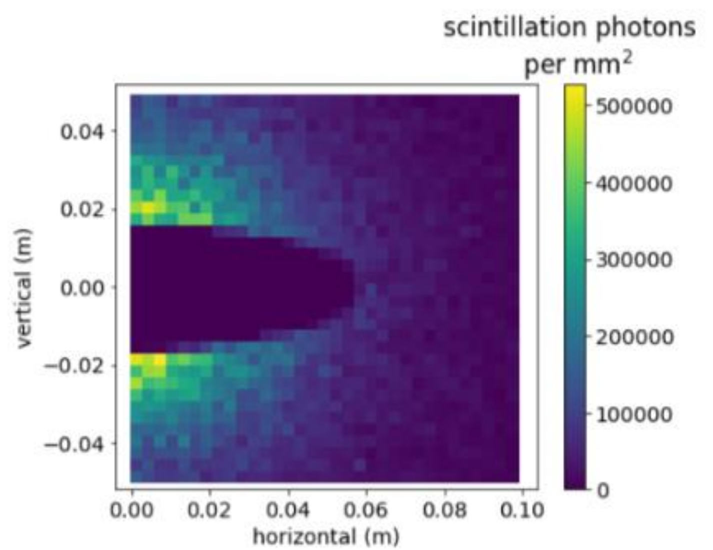
	Item	Cost [kCHF]
1	**Stripping foil** unit (design, assembly, tests, installation – in synergy with a foreseen stripper upgrade)	125
2	**FPC** (optics, support, interface, vacuum system)	180
3	**Laser system** (oscillator, amplifier, electronics, controls, assembly, lab tests, shipping, installation)	800
4	**Laser clean room and UHV transport line** (in SPS tunnel)	600
5	**Photon detection system** (design, detector, controls, vacuum chamber, assembly, tests, installation)	100
6	**Beam position monitor** (detector, cabling, electronics)	50
7	**Infrastructure and services** (cabling, supports, shielding)	80
8	**Manpower** (Doctoral Student/PDRA subsistence)	350
9	**Collaboration support** (travel, subsistence)	80
	Total	2365

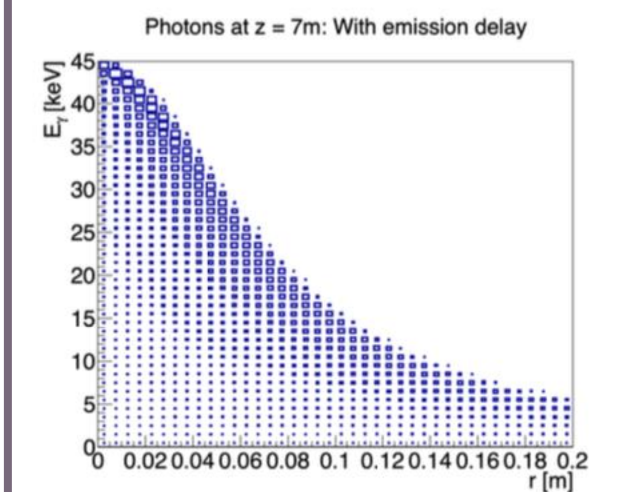
Already covered

X-ray detector

‘BTV’ system: YAG:Ce + camera

Remotely controlled manipulator to go to garage position for non GF operations





$>10^{11}$ visible photons/second

→ above sensitivity of standard camera

Post LS3 upgrade ability to mesaure energy-position correlations, timepix ?

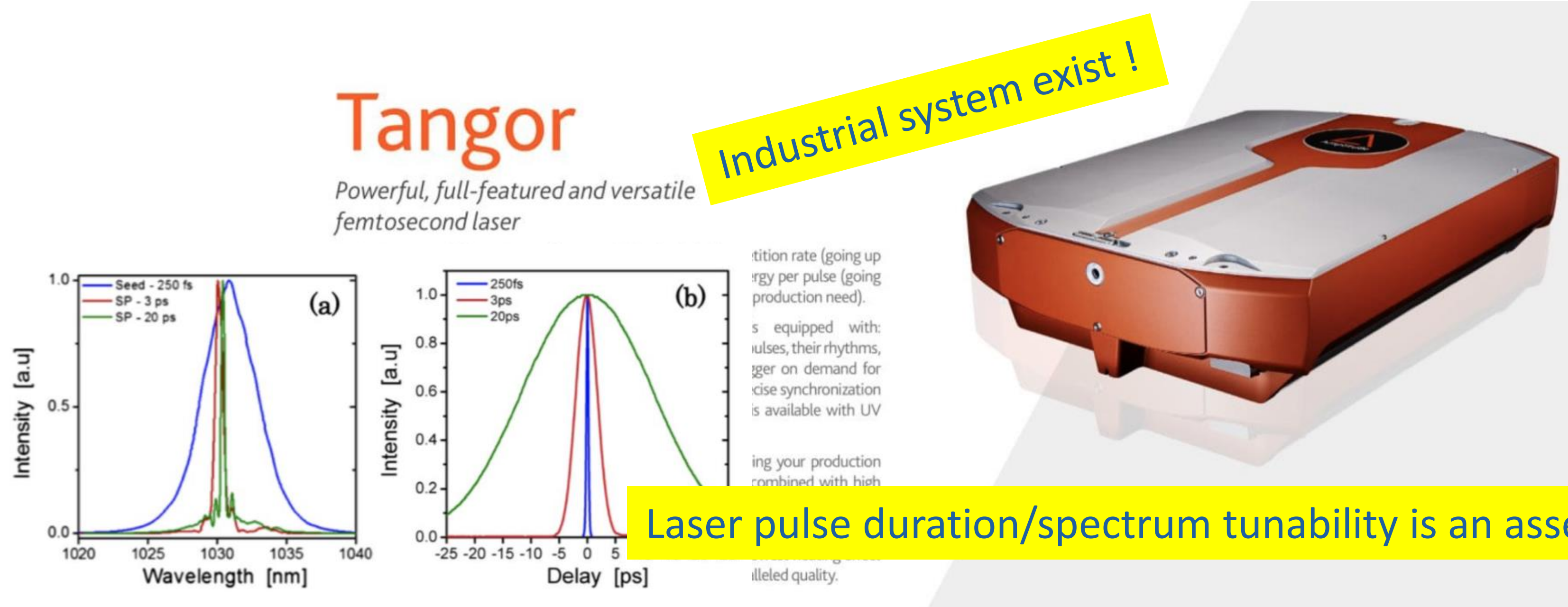
Optical system: laser and amplifier

Lock of laser to optical cavity of finesse 25k and length 7.5m → very low phase noise laser

Up to now: we know only one provider that delivered compliant performances

Risk mitigation:

1. reduce cavity selectivity i.e. finesse and gain (change coupling mirror, not expensive)
2. Use laser amplifier with higher average power to keep intracavity pulse energy high



Industrial system exist !

Laser pulse duration/spectrum tunability is an asset

Pouysegur et al. Opt. Lett. 40, 5184-5187 (2015)

Bottomline: such an industrial system, with spectrum/pulse duration tunability should be very robust compared to any home made solution

Why a Proof of Principle experiment ?

1
- Demonstrate that an adequate laser system (5mJ@40MHz) can be (remotely) operated in the high radiation field of SPS and LHC.

2
- Demonstrate that very high rates of photons are produced : almost all PSI's excited for every bunch crossing

3
- Demonstrate stable and repeatable operation

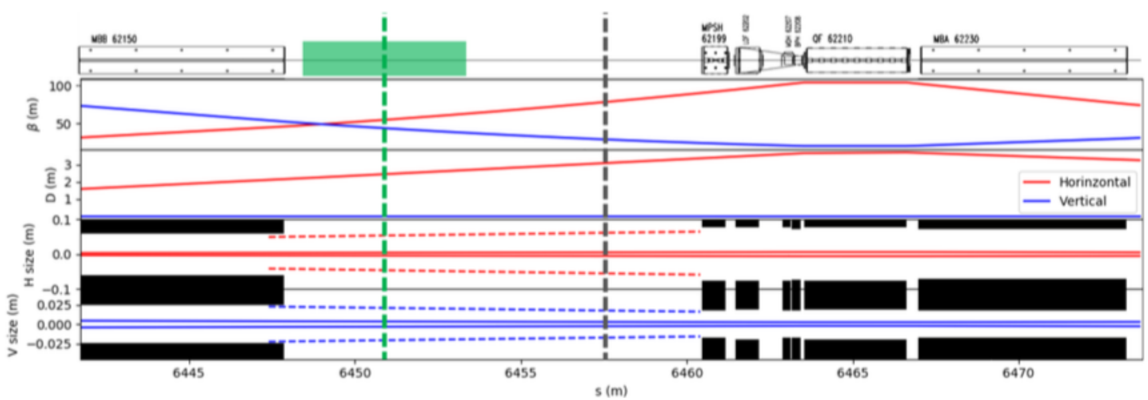
4
- Confront data to simulations

5
- Demonstrate ion beam cooling: longitudinal and then transverse

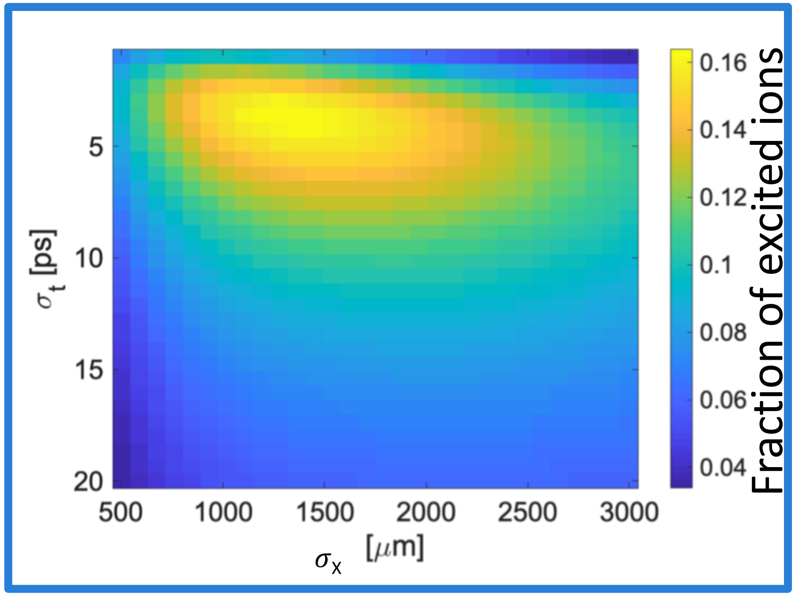
6
- Perform atomic physics measurement

Table 7: Optical parameters at the IP in the half-cell 621.

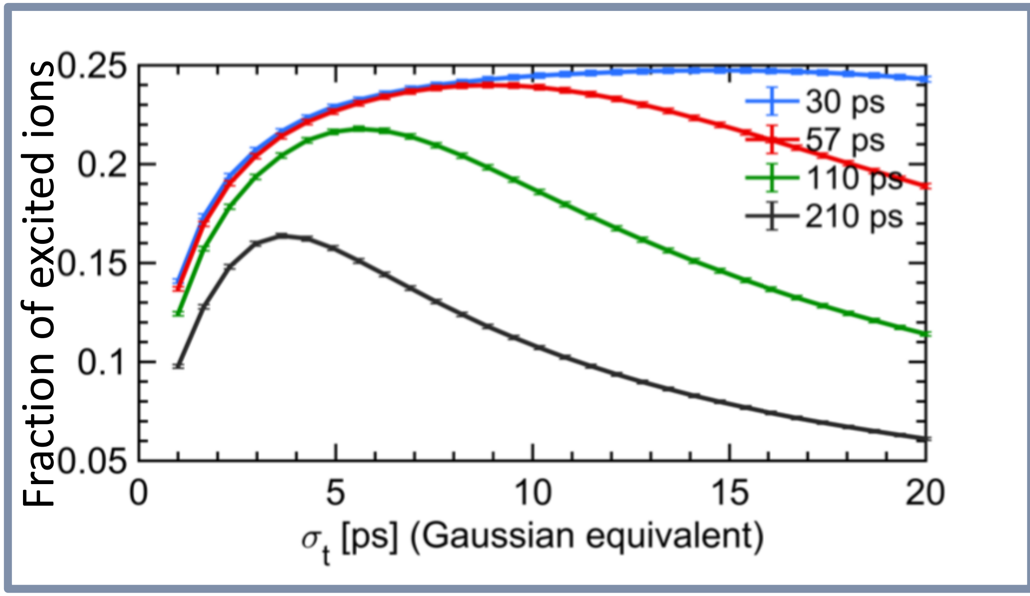
s Azimuthal position	6451 m
$\alpha_x = -\frac{1}{2}\delta\beta_x/\delta s$	-1.549
β_x	55.32 m
D_x	2.462 m
DP_x	0.0976
$\alpha_y = -\frac{1}{2}\delta\beta_y/\delta s$	1.301
β_y	43.87 m
D_y	0.0 m
DP_y	0.0
$\sigma_{px} = \sqrt{\epsilon_x\gamma_x + (\delta p/pDP_x)^2}$	3.66×10^{-5}
$\sigma_{py} = \sqrt{\epsilon_y\gamma_y + (\delta p/pDP_y)^2}$	3.09×10^{-5}
$\sigma_x = \sqrt{\epsilon_x\beta_x + (\delta p/pD_x)^2}$	1.05×10^{-3} m
$\sigma_y = \sqrt{\epsilon_y\beta_y + (\delta p/pD_x)^2}$	8.27×10^{-4} m



Optical system optimization



A muti-dimensional approach to optimize the laser beam parameters



Optimum parameters depend on ion-bunch length

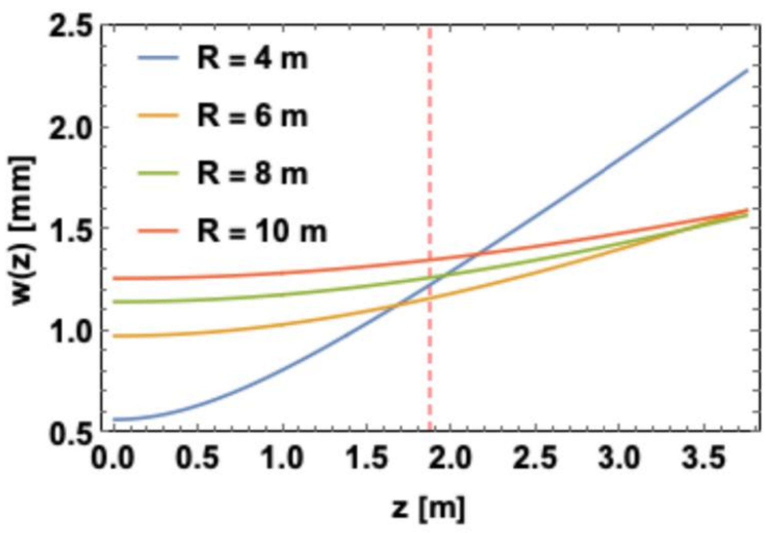
Laser pulse duration/spectrum tunability is an asset

Optical system: design

A several mJ pulsed laser at 40 MHz is a natural candidate:

- Compatible with the atoms filling schemes
- Compatible with what one would naturally expect for LHC operations
- State of the art technology: pulsed laser (freq. comb) + amplifier + resonant cavity

A 2-mirror (plano-concave) cavity is considered:
→ simpler operation, delivers naturally beam sizes close to optimum

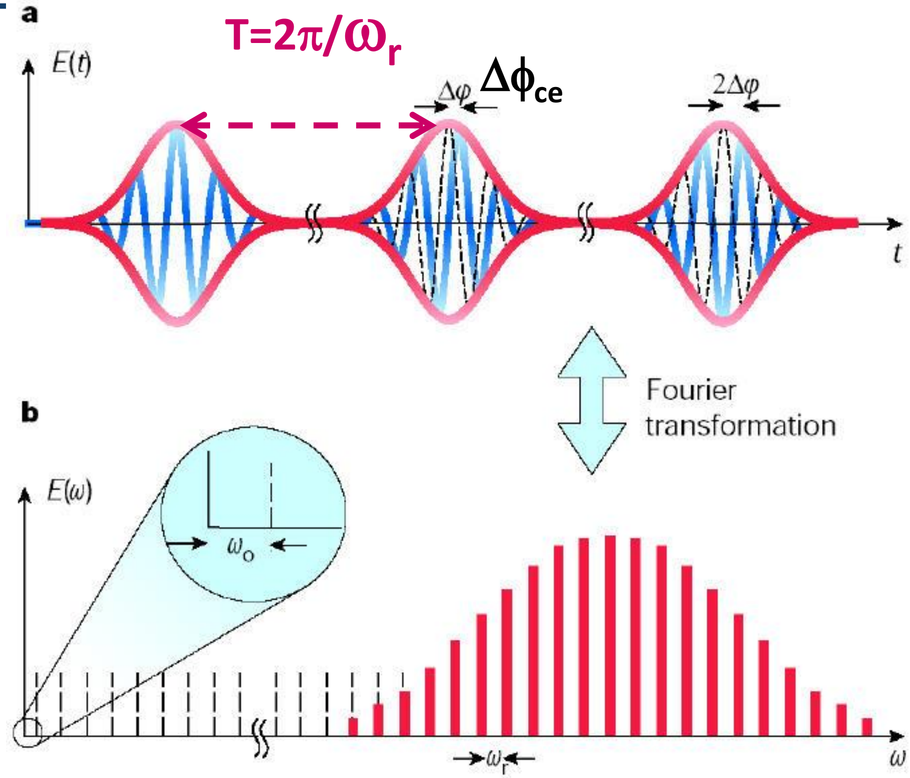


A 10m mirror Radius of curvature is preferred

We expect to operate the optical cavity with an enhancement factor >5000

>4.5mJ pulses @ 40MHz, 180kW in cavity

Laser phase noise



T. Udem et al. Nature 416 (2002) 233

The whole comb must be locked:
dilatation (f_{rep})
translation (f_{CEP})

$$F = \frac{\nu}{\Delta\nu} = 20000$$

$$\nu = 40MHz$$

$$\Delta\nu = 2kHz$$

Phase noise of the laser must be low to lock to a high finesse cavity

Noise limits coupling