

The High Intensity Gamma Source for CERN: Physics Highlights and Technical Challenges

by Mieczyslaw Krasny (Directeur de Recherche, LPNHE, University Pierre et Marie Curie, Paris)

Thursday, 19 November 2015 from 14:15 to 15:30 (Europe/Zurich)
at CERN (30-7-018 - Kjell Johnsen Auditorium)

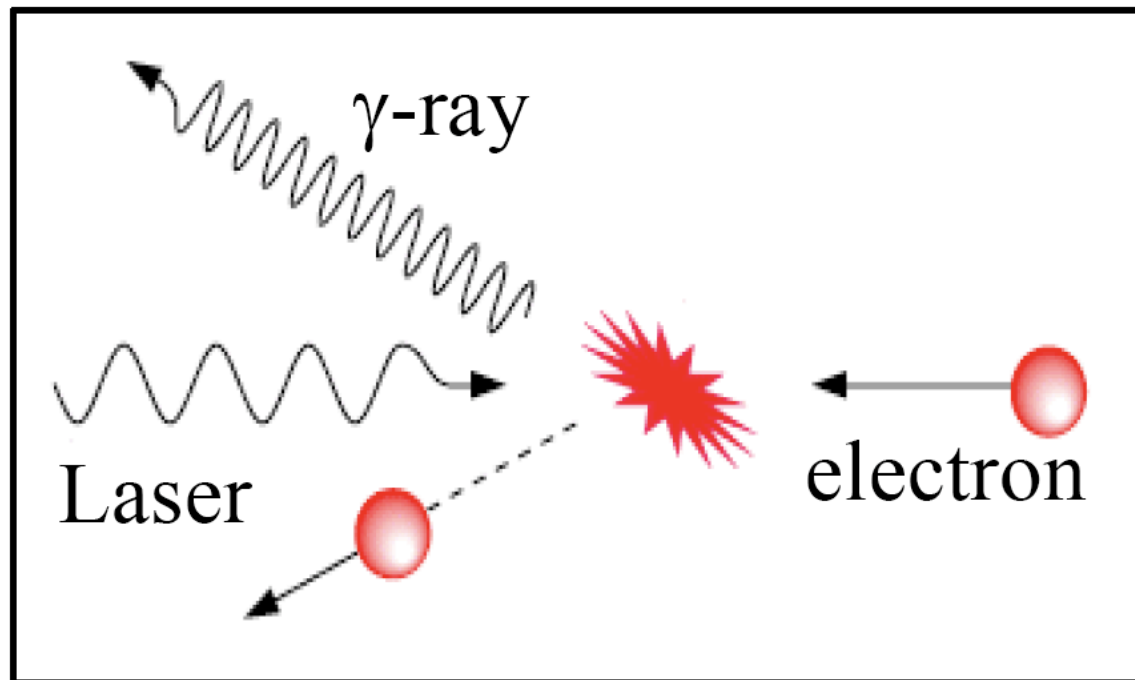
Description The ongoing discussions on the future CERN scientific program reflect the vision of its mission to be the particle-physics energy-frontier centre. They are focussed mainly on CERN's very high energy collider projects: FCC and CLIC. What, if the present and the future LHC hints for new physics at the FCC/CLIC energy scales will turn out to be not strong enough to assure the funding of the new, high-cost, energy frontier collider, ...or if its R&D and construction time will be longer than the life-time of the ongoing LHC research program? Should we not consider, already now, complementary research proposals broadening the use of the already existing CERN accelerator infrastructure to new research and technological application domains?

In this seminar an example of such a research proposal will be discussed. Its departure point is a new concept of the High Intensity Gamma Source which could be realized at CERN by mastering the storage of partially stripped ion beams and by profiting from the recent progress in laser technologies. The increase of the intensity limit of the present gamma sources by at least 6-7 orders of magnitude, in the energy domain which is inaccessible for the FEL based technologies, could provide new and fascinating research opportunities in the domains of:

- particle physics (studies of the basic symmetries of the universe, dark matter searches, precision-support measurements for the LHC),
- nuclear physics (confinement phenomena, link between the quark-gluon and nucleonic degrees of freedom, photo-fission research program),
- accelerator physics (beam cooling techniques, low emittance **hadronic beams**, high intensity photon beams, plasma wakefield acceleration, high intensity polarized positron and muon sources, secondary beams of radioactive ions and neutrons),
- atomic physics (electronic and muonic atoms)
- applied physics (AdS, transmutation of nuclear waste, fusion research, medical applications).

The principal goal of the seminar for the EN, TE and BE audience is to expose the technical challenges of this initiative, both on the path towards a proof of principle of the proposed scheme and on the path towards its practical realization.

Laser Compton Scattering as the source of MeV-range photons



The goal of the **HIGS@CERN** proposal
(*HIGS*= *H*igh *I*ntensity *G*amma *S*ource)

Increase the intensity of the present gamma ray
sources by at least 6-7 orders of magnitude

E_γ in the range $\sim 0.1 - 400$ MeV

The source of the proposal:
an “unconventional” use of the LHC and its detectors for
the ep(eA) collision programme



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Electron beam for LHC

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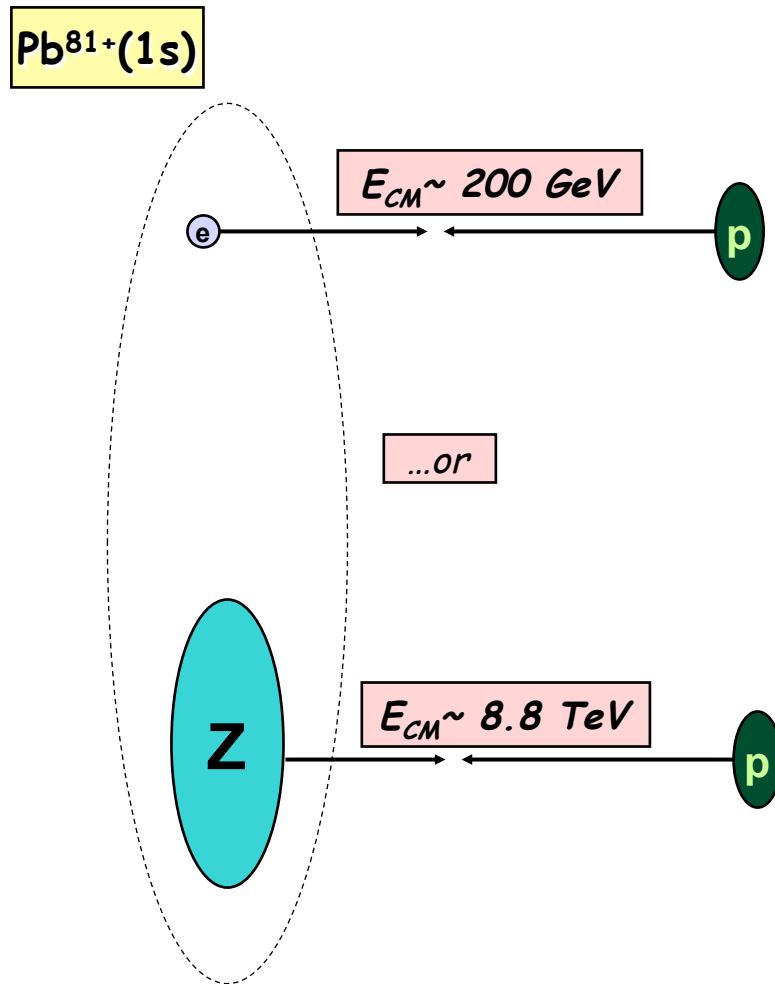
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Abstract

A method of delivering a small energy spread electron beam to the LHC interaction points is proposed. In this

Partially stripped ions as electron carriers

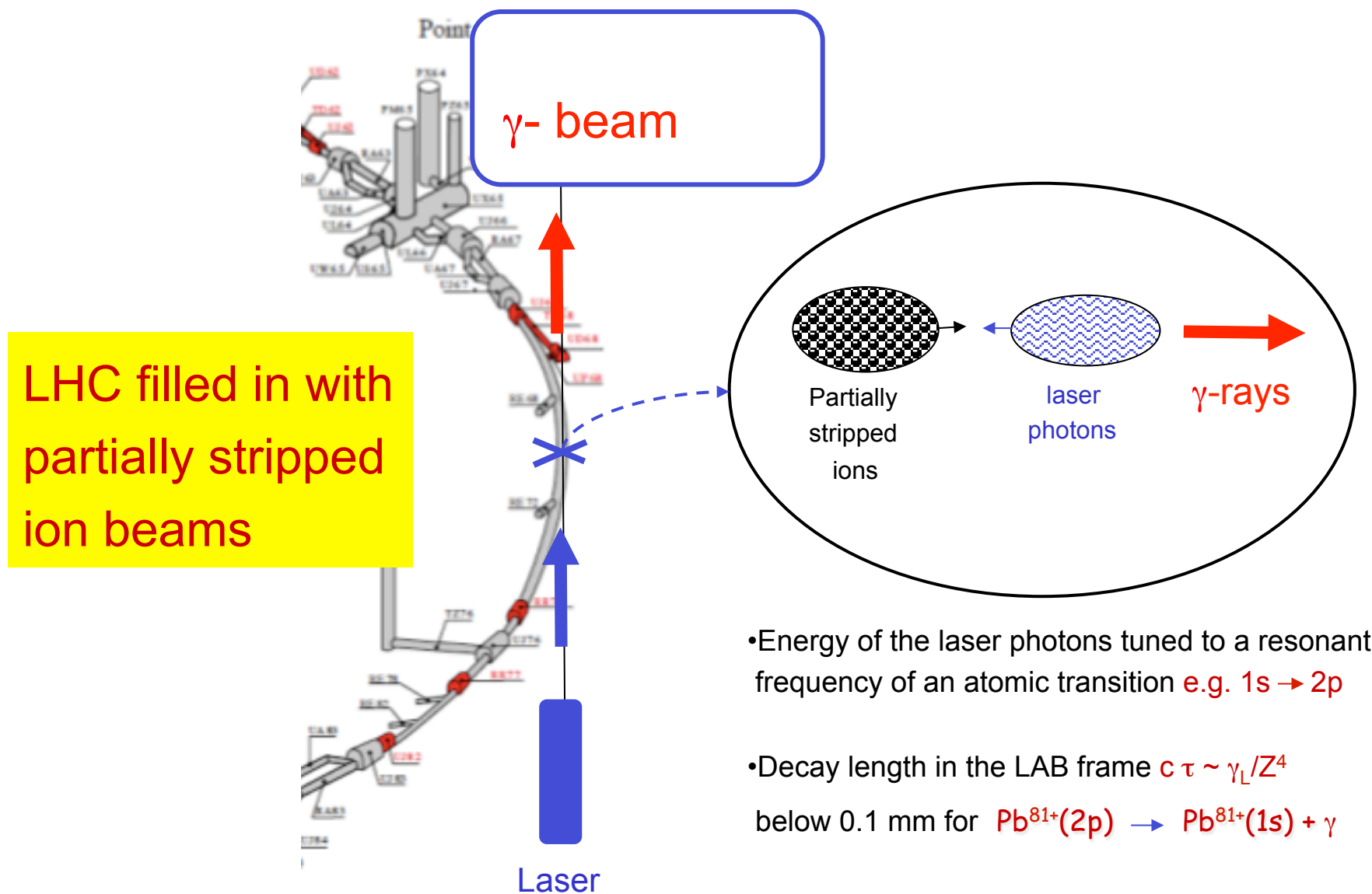


- average distance of the electron to the large Z nucleus $d \sim 600 \text{ fm}$ (sizably higher than the range of strong interactions)

- partially stripped ion beams can be considered as independent electron and nuclear beams as long as the incoming proton scatters with the momentum transfer $q \gg 300 \text{ KeV}$

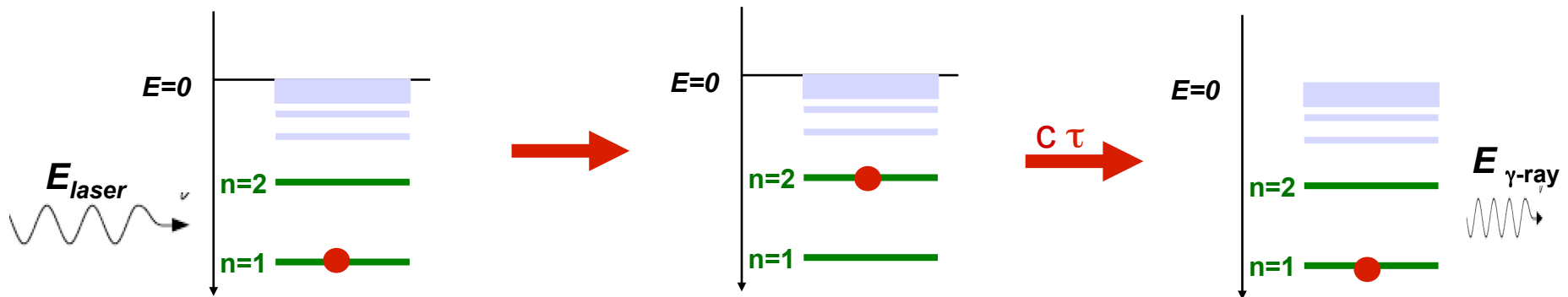
- both beams have identical bunch structure (timing and bunch densities), the same β^* , the same beam emittance – the choice of collision type can be done exclusively by the trigger system (no read-out and event reconstruction adjustments necessary)

LHC as a frequency converter of $O(1-10 \text{ eV})$ photons into $O(1 - 400 \text{ MeV})$ γ -rays



Scattering of photons on ultra-relativistic atoms

$$-E_n = 1\text{Ry } Z^2/n^2$$



$$E_{\text{laser}} = 1\text{Ry } (Z^2 - Z^2/n^2)/2\gamma_L$$

$$E_{\gamma\text{-ray}} = E_{\text{laser}} \times 4\gamma_L^2 / (1 + (\gamma_L \theta)^2)$$

Note: $(E_{\text{laser}}/m_{\text{beam}}) \times 4\gamma_L \ll 1$

Fine tuning of gamma ray energy: E_γ

scenario 2, $\lambda_{\text{laser}} = 1540 \text{ nm}$

Electrons:

$$\sigma_e = 6.6 \times 10^{-25} \text{ cm}^2$$

Partially stripped ions:

$$\sigma_{\text{res}} = 5.9 \times 10^{-16} \text{ cm}^2$$

...cross sections in the Giga-barn range!

Example: scenario 1, $\gamma_L = 2887$

Electrons:

$$E_{\text{beam}} = 1.5 \text{ GeV}$$

Electron fractional energy loss:
emission of 150 MeV photon:

$$E_{\gamma}/E_{\text{beam}} = 0.1$$

(electron is lost!)

Partially stripped ions:

$$E_{\text{beam}} = 574\,000 \text{ GeV}$$

Electron fractional energy loss:
emission of 150 MeV photon:

$$E_{\gamma}/E_{\text{beam}} = 2.6 \times 10^{-7}$$

(ion undisturbed!)

...stable ion beams, even in the regime of multi photon emission per turn!

HIGS as a source of high intensity secondary beams

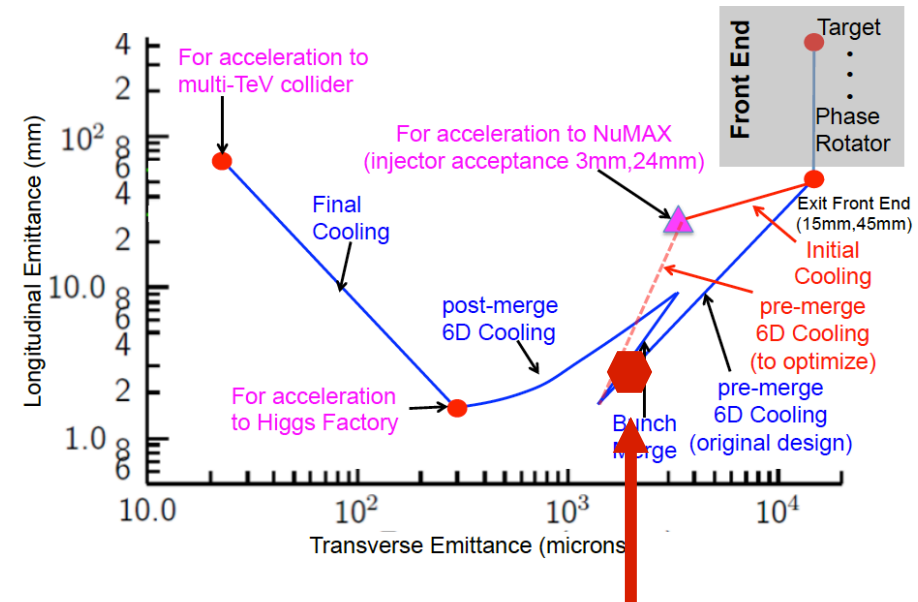
- *High Intensity highly polarised electron and positron beams ($\sim 10^{17}$ 1/s)*
- *Polarized muon and neutrino beams ($\sim 10^{12}$ 1/s and 4×10^{19} 1/year)**
- *High intensity monochromatic neutron beams (GDR in heavy nuclei as a source of neutron beam: $\gamma + A \rightarrow A-1 + n$) ($\sim 10^{15}$ 1/s)*
- *High intensity radioactive beams ($\sim 10^{14}$ 1/s)
(photo-fission of heavy nuclei: $\gamma + A \rightarrow A_1 + A_2 + \text{neutrons}$)*

**) for the quoted flux of the muons/neutrinos the LHC circumferential voltage would need to be increased from the present value of RF=16 MV and/or the number of stored ions (bunch population and bunch frequency) would have to be increased by e.g. the factors of 2, 2 and 3)
The power of the gamma-beam for the quoted fluxes would be ~ 4 MW.*

Possible application of HIGS for the $\mu^+ - \mu^-$ collider

(detailed studies by the muon collider experts would be most welcomed...)

| | | | | |
|------------------------------|-----------------|-----------------|-----------------|---|
| C of m Energy | 1.5 | 3 | 6 | TeV |
| Luminosity | 0.92 | 3.4 | 0.9 | $10^{34} \text{ cm}^2 \text{ sec}^{-1}$ |
| Beam-beam Tune Shift | ≈ 0.087 | ≈ 0.087 | ≈ 0.087 | |
| Muons/bunch | 2 (1.44 ?) | 2 | 2 | 10^{12} |
| Total muon Power | 9 | 15 | 3.7 | MW |
| Ring <bending field> | 6 | 8.4 | 8.4 | T |
| Ring circumference | 2.6 | 4.5 | 9 | km |
| β^* at IP = σ_z | 10 | 5 | 2.5 | mm |
| rms momentum spread | 0.1 (0.3 ?) | 0.1 | 0.1 | % |
| Required depth for ν rad | ≈ 20 | ≈ 200 | ≈ 200 | m |
| Proton Energy | 8 | 8 | 8 | GeV |
| Muon per proton | 0.16 | 0.16 | 0.16 | |
| Muon Survival | 7 | 6 | 5 | % |
| protons/pulse | 187 (134 ?) | 200 | 240 | Tp |
| Repetition Rate | 15 (21 ?) | 12 | 1.5 | Hz |



HIGS muon flux (factor 10 lower than required) up to 10^{12} polarized $\mu^+ \mu^-$ pairs [1/s] for 4MW RF power of the LHC cavities (For comparison: TLEP RF power ~ 300 MW)

muon-beam emittance (factor $\sim 10^4$ improvement* possible, counterbalance lower intensity?)

**) the theta/energy correlation of the muons produced by the photon conversions on high Z target would have to be exploited in the beam forming section*

Possible application of HIGS for the muon-based neutrino factory (detailed studies by the neutrino experts would be most welcomed...)

| Neutrino Factory parameters | | | | | | |
|-----------------------------|--|------|--------------------|------------------------|-----------------------|----------------------|
| System | Parameters | Unit | nuSTORM | NuMAX Commissioning | NuMAX | NuMAX+ |
| Performance | ν_e or ν_μ to detectors/year | - | 3×10^{17} | 4.9×10^{19} | 1.8×10^{20} | 5.0×10^{20} |
| | Stored μ^+ or μ^- /year | - | 8×10^{17} | 1.25×10^{20} | 4.65×10^{20} | 1.3×10^{21} |

Achievable neutrino flux (a factor 10 lower than that of NuMAX, a factor 50 higher than that of nuSTORM)

...but, if the initial muon polarization is preserved in the acceleration process \rightarrow ultra pure ν_μ ($\bar{\nu}_\mu$) beams of precisely equal fluxes (e.g. CP – violation measurements in the neutrino sector)

Problems which need to be solved:

- For e.g. $E_\gamma \sim 300 \text{ MeV}$, muons constitute only a small ($\sim 10^{-5}$) fraction of all the photon conversion pairs.

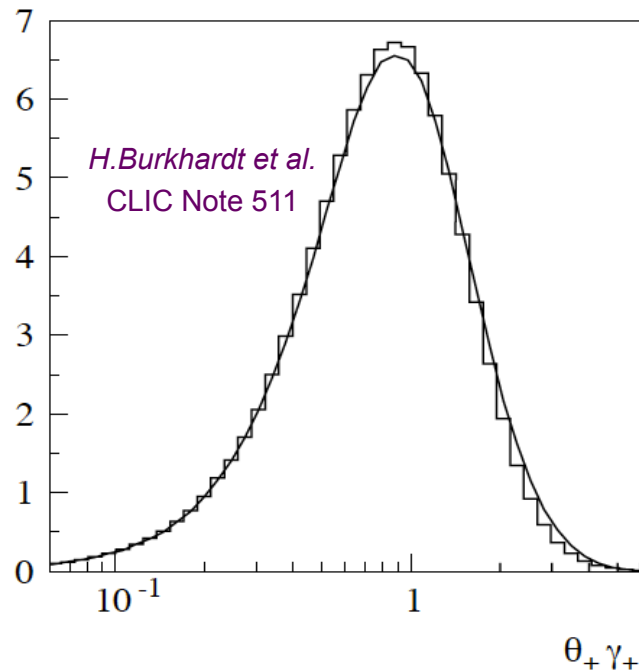
How to filter them out?

- Muons produced mainly at significantly larger angles than electrons and may be emitted at large angles ($\gamma_e \gg \gamma_\mu$).

How to collect them to preserve the small longitudinal and transverse bunch sizes of the parent photon bunches?

Hint1

The conversions, especially on high Z material lead to a simple relation between the outgoing muon energy and angle:



Hint2

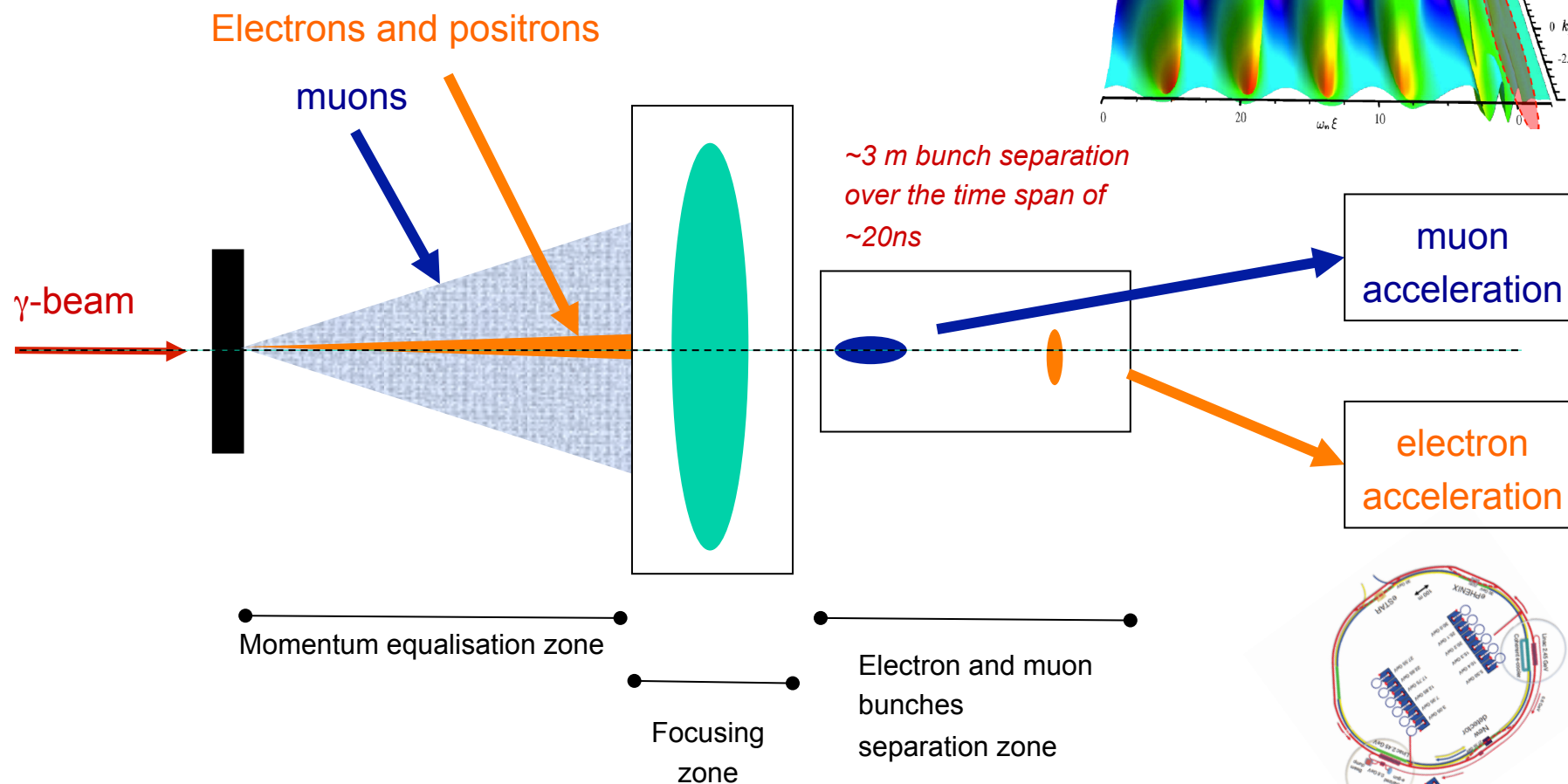
Electrons are relativistic,
muons are not:

$$\beta_e = 1, \langle \beta_\mu \rangle \sim 0.5$$

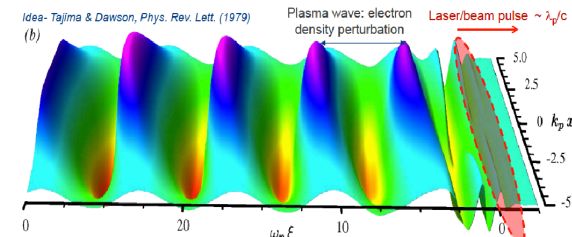
20 ns following the collision
of the photon bunch with the
conversion target, electron
and muon bunches are
separated by (on average)
200 cm allowing for their
efficient separation

initial ideas...

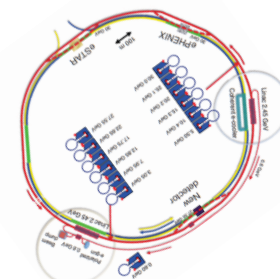
muon collider
neutrino factory



Plasma Waves



electron-ion collider



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More tomorrow...

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