MightyLaser project

Iryna Chaikovska
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on behalf of MightyLaser collaboration

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MightyLaser project: French-Japanese collaboration:

- CELIA (CNRS, Bordeaux University)
- LAL (CNRS, University Paris Sud XI)
- LMA (CNRS, University Claude Bernard Lyon I)
- Hiroshima university (Hiroshima, Japan)
- KEK (Tsukuba, Japan)

Goal of MightyLaser is to demonstrate and to test the production of gamma rays by Compton scattering of the laser photons off the high energy electrons using a four-mirror Fabry-Perot cavity.

Activity consists of:
Laser system, Four-mirror Fabry-Perot cavity, Electronics, Detection system, Data taking and Data analysis...

For more information, please, refer to:
J. Bonis et al. Journal of Instrumentation, 7:P01017, 2012.
T. Akagi et al. Journal of Instrumentation, 7:P01021, 2012.

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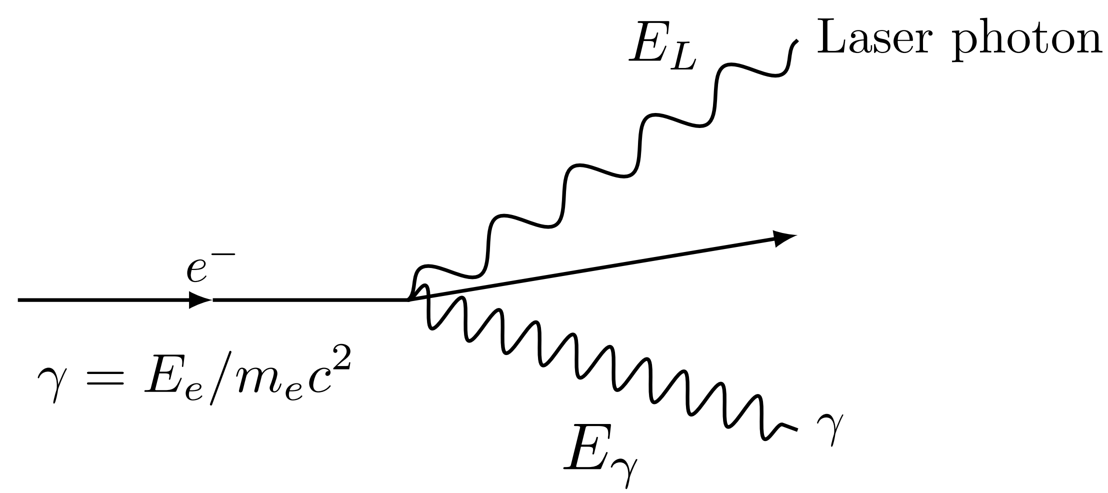
Inverse Compton scattering: $e^- + \gamma \rightarrow e^- + \gamma$

At low incident photon energies ($E_L \ll m_e c^2$) when the recoil of the electron can be neglected - Thompson Scattering (classical electromagnetism)

$$\sigma_T \equiv \frac{8\pi}{3}\left(\frac{e^2}{m_e c^2}\right)^2 \approx 6.65 \times 10^{-29} m^2$$



Interesting features of the ICS:

- Energy boost $E_\gamma^{max} \approx 4\gamma^2 E_L$, where γ is a Lorentz factor.
- Scattered gamma ray flux is concentrated at small angles $\sim 1/\gamma$ around the electron direction
- Angular dependence of Compton scattering $E_\gamma = f(\vartheta)$ allows to select the energy band by collimation of the scattered photons
- Since polarization in conserved, Compton scattering gives the possibility to produce polarized scattered gamma rays.

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Applications of Inverse Compton scattering

$$E_\gamma^{max} \approx 4\gamma^2 E_L$$

$\lambda_L \sim 1\mu$, $E_e \sim$(20 - 100) MeV, $E_\gamma \sim$(10 - 100) keV

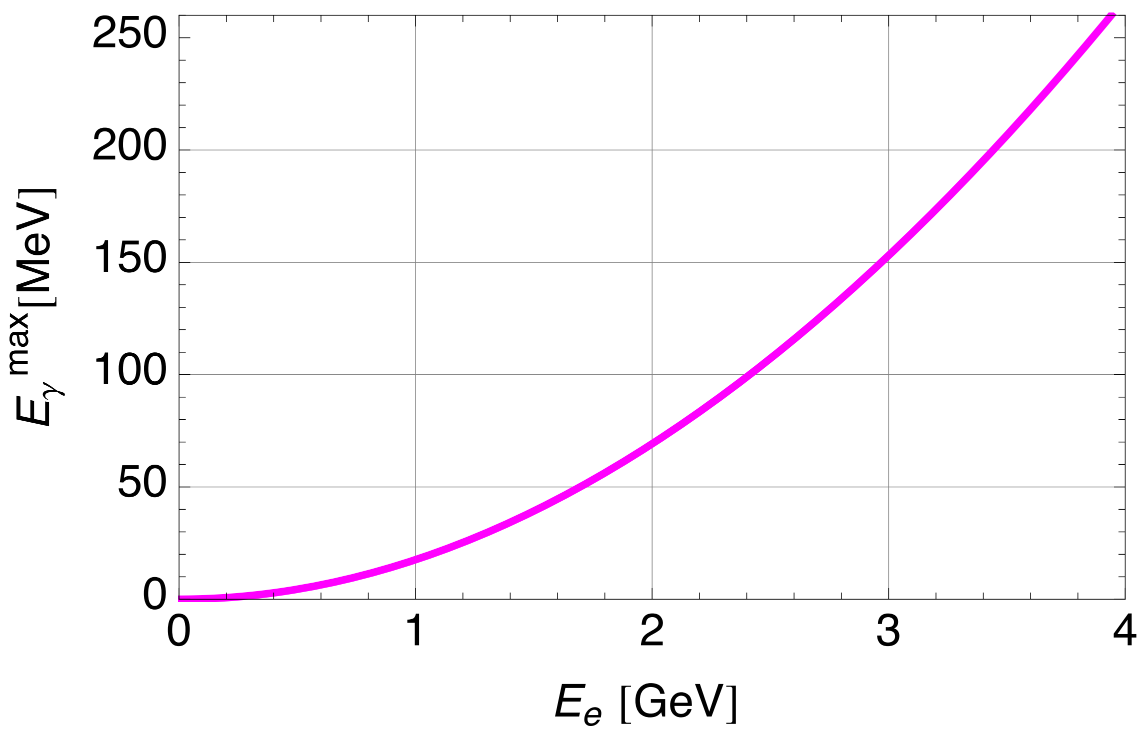
• Medical (radiography & radiotherapy), cultural heritage preservation, material science.

$\lambda_L \sim 1\mu$, $E_e \sim$(100 - 500) MeV, $E_\gamma \geq$ 1MeV

• Nuclear survey and nuclear waste treatment.

$\lambda_L \sim 1\mu$, $E_e \geq$ 1 GeV, $E_\gamma \geq$ 20 MeV

• Polarized positron source, Compton polarimeter, laser wire, γ-γ collider.



Compact X-ray Compton machine at Orsay (ThomX) to be built !!!!
$E_e \sim$ 50-70 MeV and $\lambda_L \sim 1\mu$ => $E_\gamma^{max} \sim$ 50-90 keV

See talk on Friday May, 24 at 11h50 by Alessandro Variola

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Inverse Compton scattering: summarizing

- Compton scattering is the exchange of energy that occurs when a photon collides with an electron.
- It can be used to boost low energy photons to higher energy by colliding them with the high energy electrons.
- But for X-/gamma ray source the Compton (Thomson) cross-section is very low (small flux of the scattered photons) - **main drawback of Compton scattering !!!!**

$$\mathcal{F} = \mathcal{L} \cdot \sigma_c \sim \frac{P_L I_e}{\sqrt{\sigma^2_{electron} + \sigma^2_{laser}}} \sigma_c$$

I_e: electron beam intensity
P_L: laser power
$\sigma_{electron}$: electron beam size r.m.s
σ_{laser}: laser beam size r.m.s
σ_c: Compton cross section

Therefore, it is important:
- To recycle laser beam and electrons: Storage Ring + High Average Power Laser amplified in a Fabry Perot cavity.
- To have small and stable laser and electron beam sizes at the Interaction Point.

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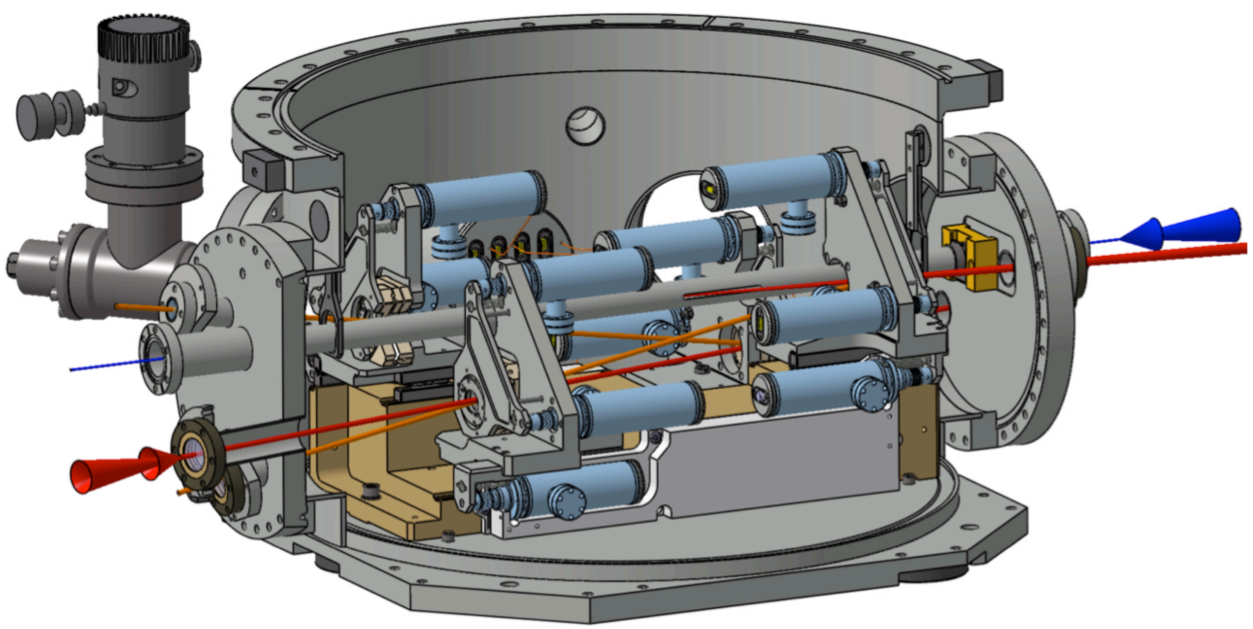
MightyLaser overview

- High average power laser system (4-mirror Fabry-Perot cavity) has been built by the collaboration at LAL.

- A non-planar geometry ensures that the stored laser pulses are circularly polarized (as needed for polarized positron production).



LASER photon energy	1.2 eV (1032 nm)
LASER frequency	178.5 MHz
Power stored in cavity	nominal 20 kW
LASER pulse energy	nominal 0.1 mJ
Crossing angle	8 deg.
LASER pulse length	nominal 20 ps
Cavity enhancement	~ 1000
Cavity length	1.7 m

- The set-up was installed at the Accelerator Test Facilities (ATF) at KEK in Japan during summer 2010.

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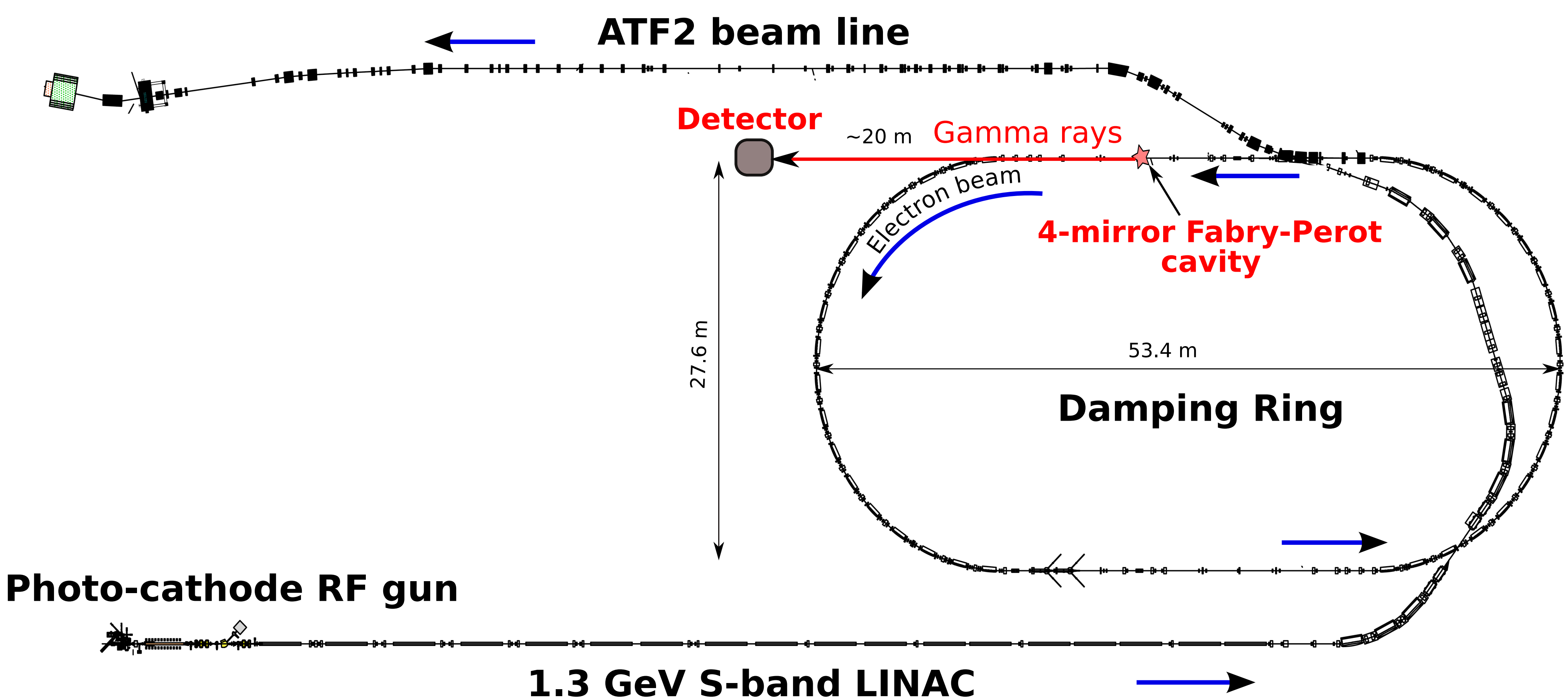
Accelerator Test Facility at KEK

- ATF is an electron accelerator used for R&D toward the Future Linear Colliders.

- Fabry-Perot cavity is installed in one of the straight sections of the ATF DR.

- Gamma rays are detected by a detector about 20 m downstream the IP.

Electron energy	1.28 GeV
Electron charge	~1 nC
Revolution period	462 ns
Electron bunch length	25 ps
Electron beam size	~ 110/10 μm
RF frequency of the DR	714 MHz



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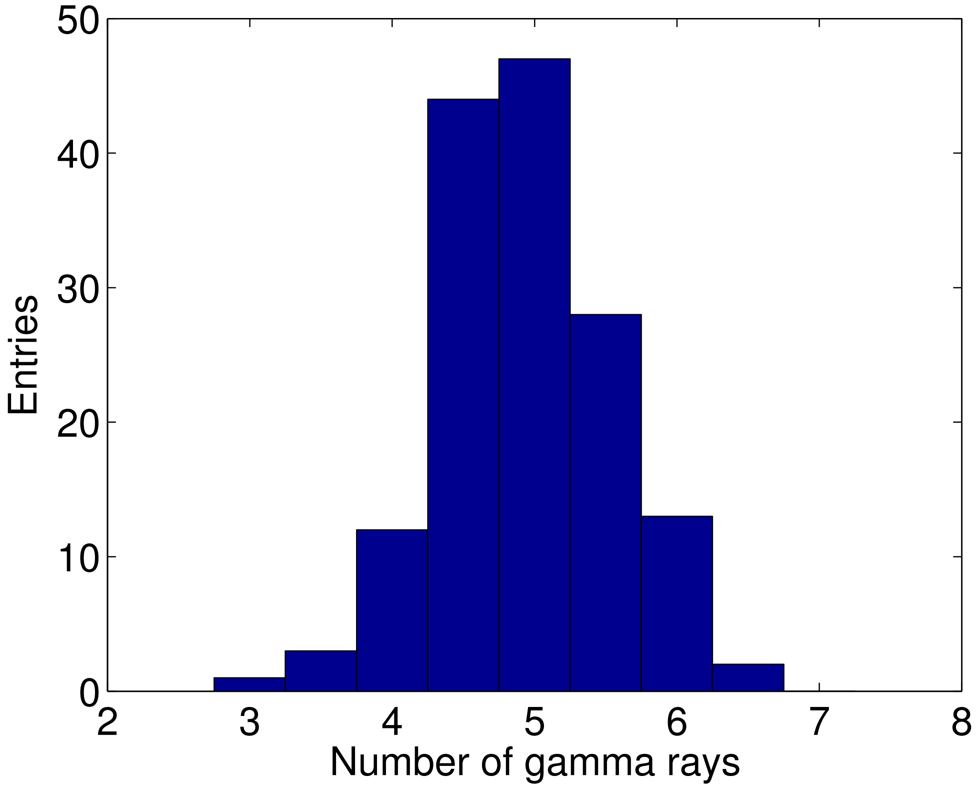
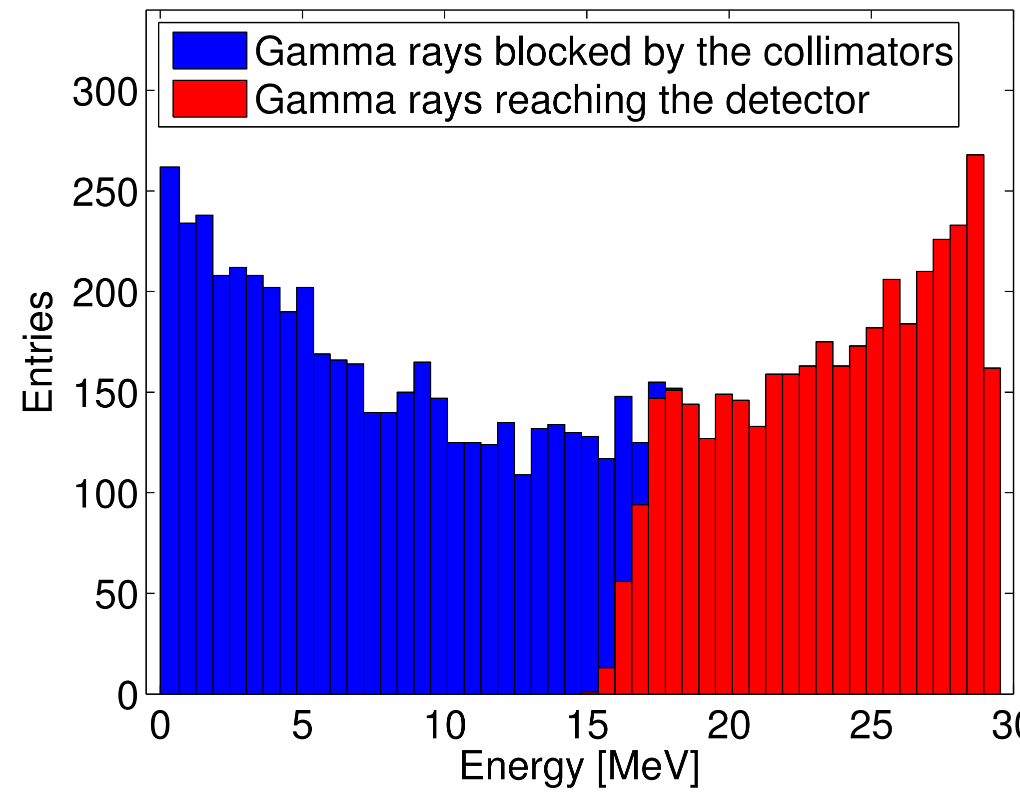
Gamma rays to detect

• From simulation we expect in average between 4 and 6 gamma rays per bunch crossing.





• Scattered rays pass through several collimators before entering the detector.

• 43% of the initial rays are accepted by the collimators and the average energy of the gamma rays reaching the detector is therefore 24 MeV (2–3   rays after collimation).

<u>Detector:</u> a fast scintillation detector made of BaF_2 coupled with a Photomultiplier Tube (PMT)

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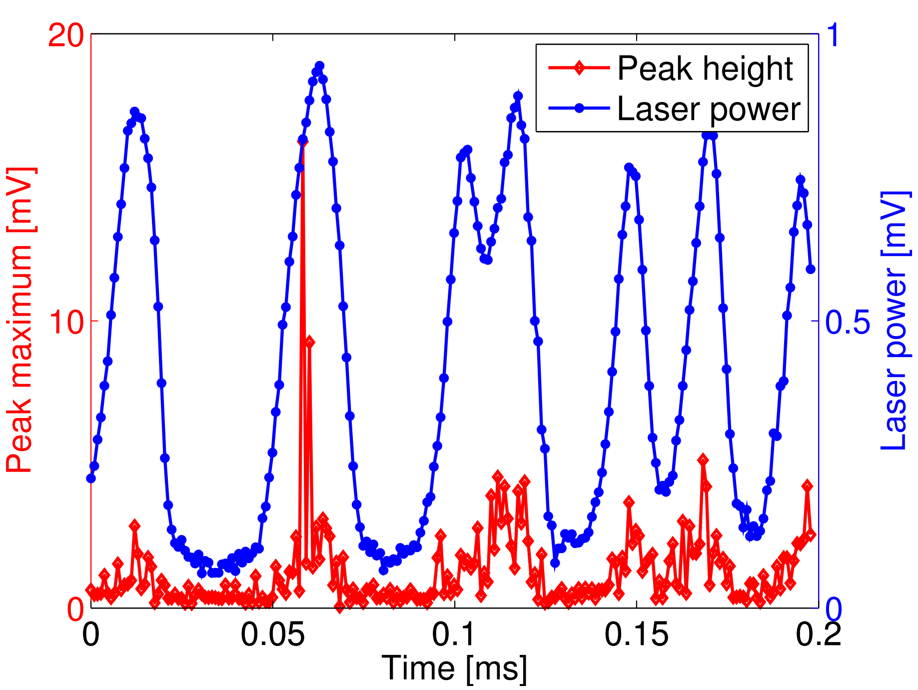
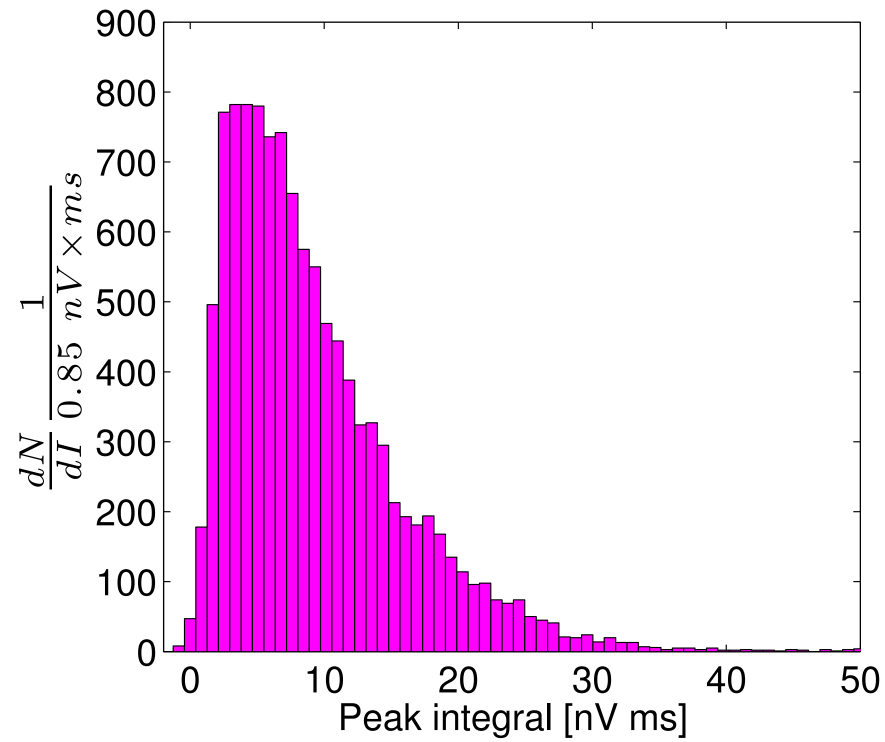
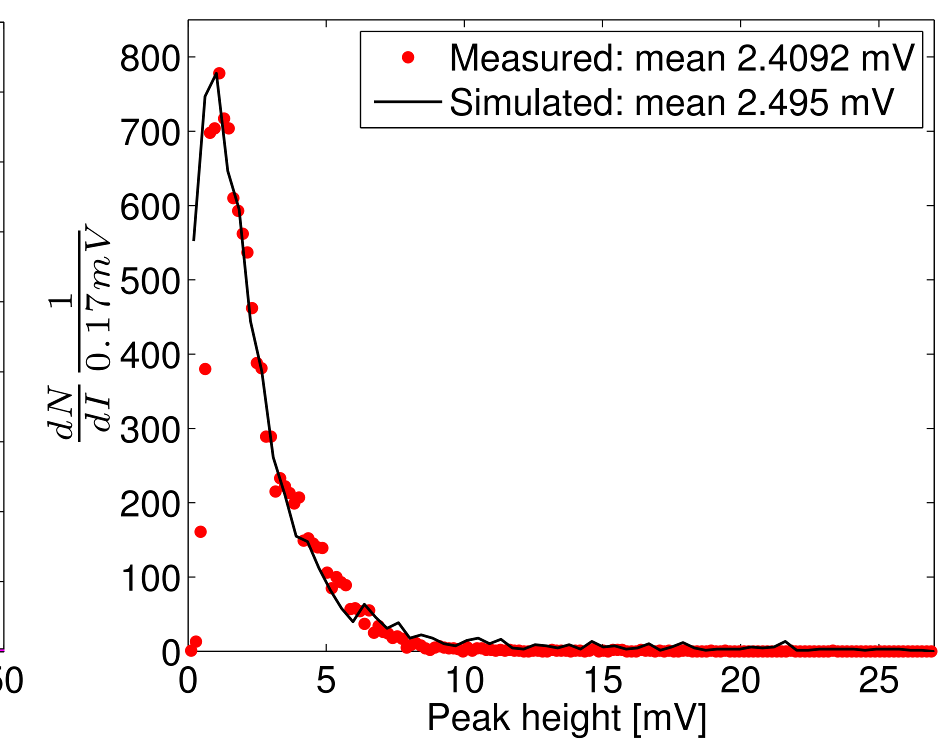
First data taking and first results

- We achieved electron-laser collisions on the first attempt (October 2010).
- 2.7 ± 0.2 gamma rays are produced in average per bunch crossing (for an average laser power stored in the Fabry-Perot Cavity of about 160 W).
- The best instantaneous flux we measured corresponds to about 38 ± 3 gamma rays produced per bunch crossing.
- Very good agreement between the experimental data and simulations that confirms the production of 2.7 gamma rays rays per bunch crossing (corresponding to 6 gamma rays at the production).







Current status and Future Plans

- So far we have not yet reached our design performances.

- The previous data taking runs were postponed due to an incident on the RF modulator at the ATF, laser failure and a tragic earthquake that struck Japan in March 2011.

- The laser system is upgraded now to allow runs at higher power.

- Next data run will be in autumn 2013.

- To increase the luminosity we intend to upgrade the mirrors to reach the cavity enhancement of ~10000.

- We plan to upgrade the laser to reach 100W before injection (later 200W).

Summary

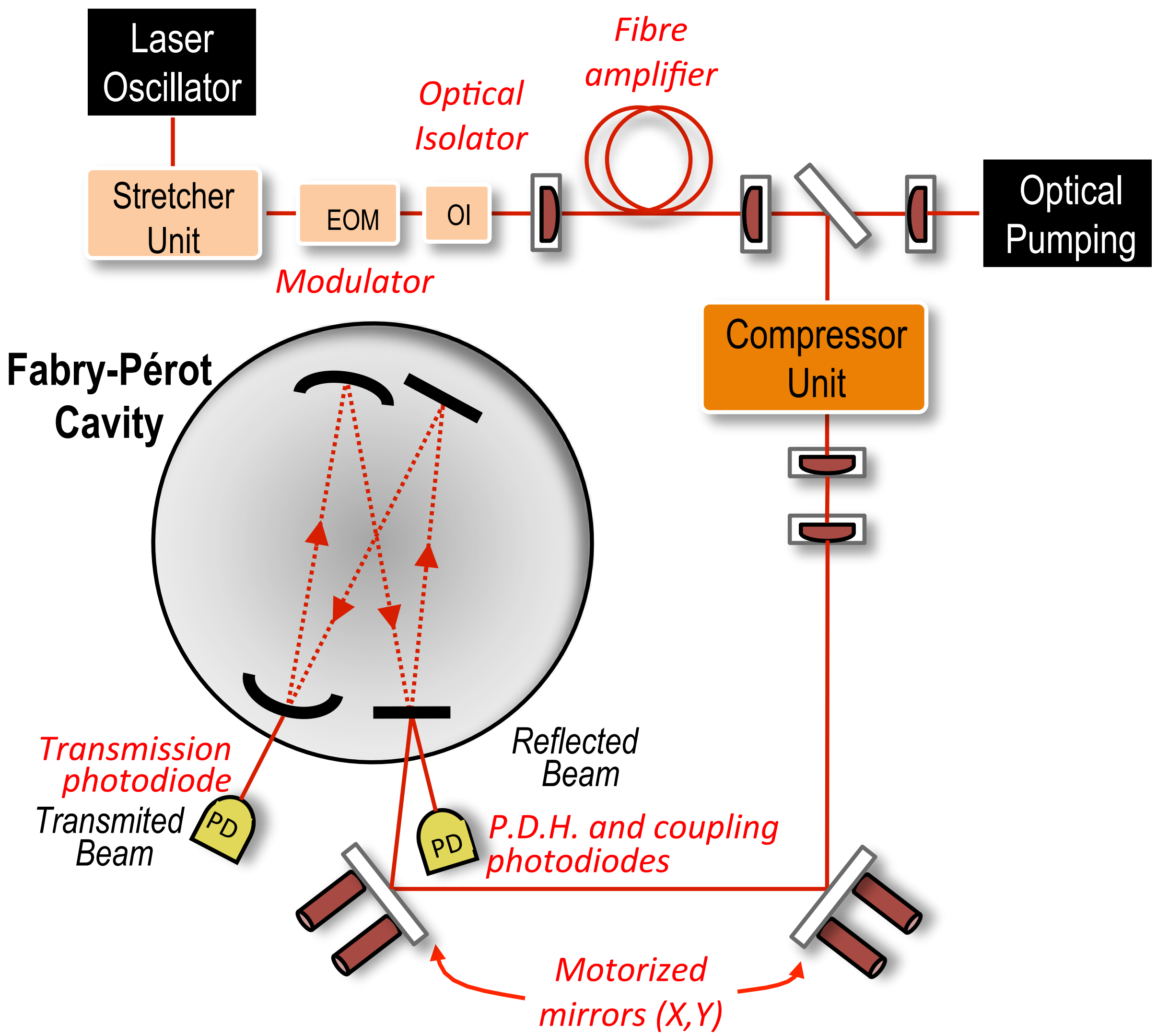
• The MightyLaser project has demonstrated the production of polarized gamma rays using a non-planar 4-mirror Fabry-Perot cavity.

• During the commissioning we measured for the first time the gamma ray flux of ~3×10^6 gammas/s with a 4-mirror Fabry-Perot cavity.

• This is an important step toward the feasibility of a Compton-based X-/gamma ray source for both polarized positron source at the Future Linear Collider and the compact Compton X-ray sources like ThomX.

• Now, high flux Compton X-/gamma ray source becomes more realistic due to the recent development in laser/cavity and amplification technologies.

Laser, Fabry-Perot cavity, feedback



- The laser should provide a stable, low phase noise pulses (laser oscillators deliver ~ hundreds of mW).
- Sophisticated laser amplification system before injection into the Fabry-Perot cavity.
- Design power: 50W (upgrade to higher power is foreseen). So far we obtained only 10W at the ATF under data taking conditions.

- For laser pulse stacking in the Fabry-Perot cavity each laser pulse should arrive in phase with those already stacked in the cavity
  1. <u>Feedback system needed between the seed laser and the cavity.</u>

- The laser pulse must cross the IP at the same time than the electrons
  2. <u>Feedback loop between the ATF clock and Fabry-Perot cavity is needed.</u>

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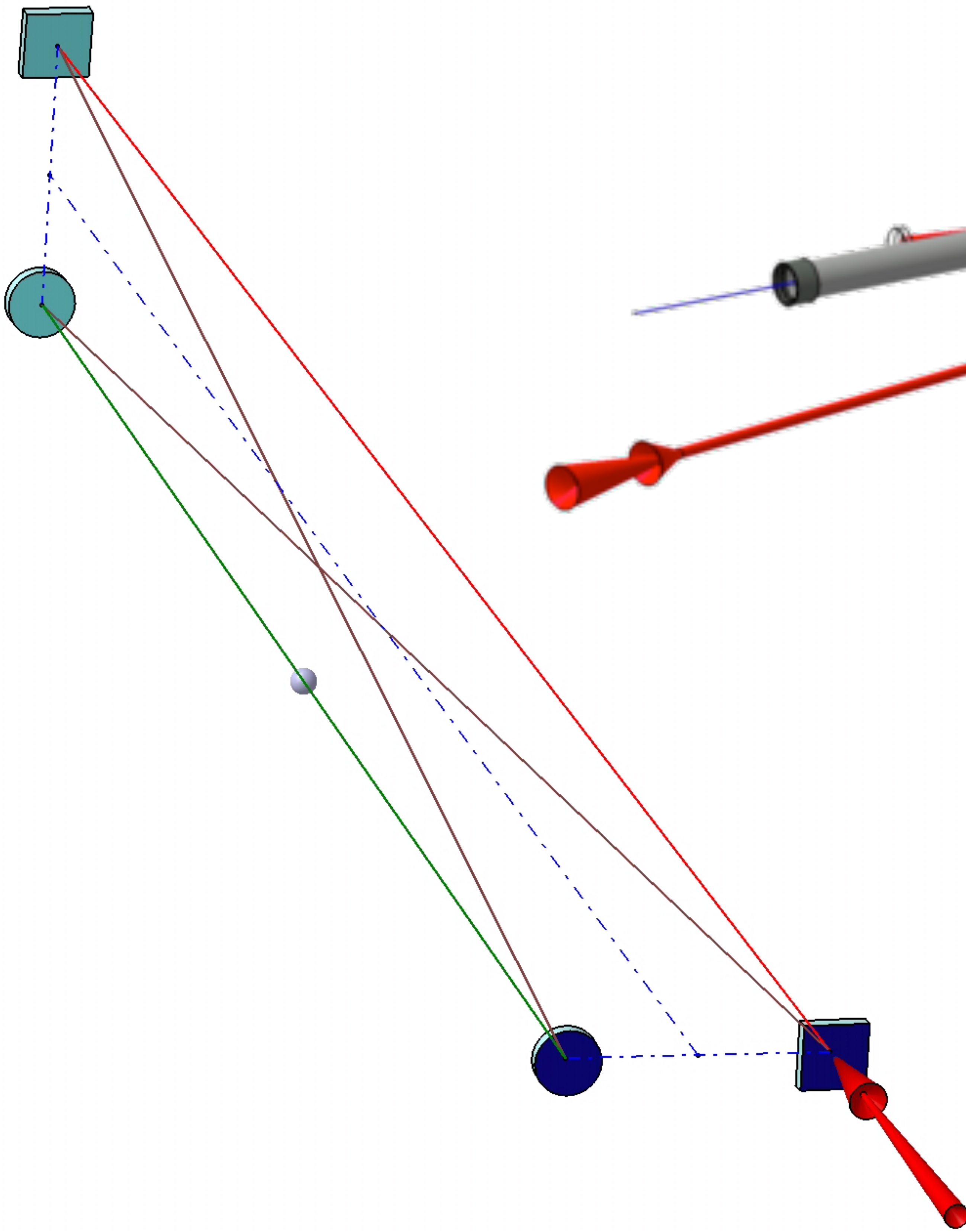
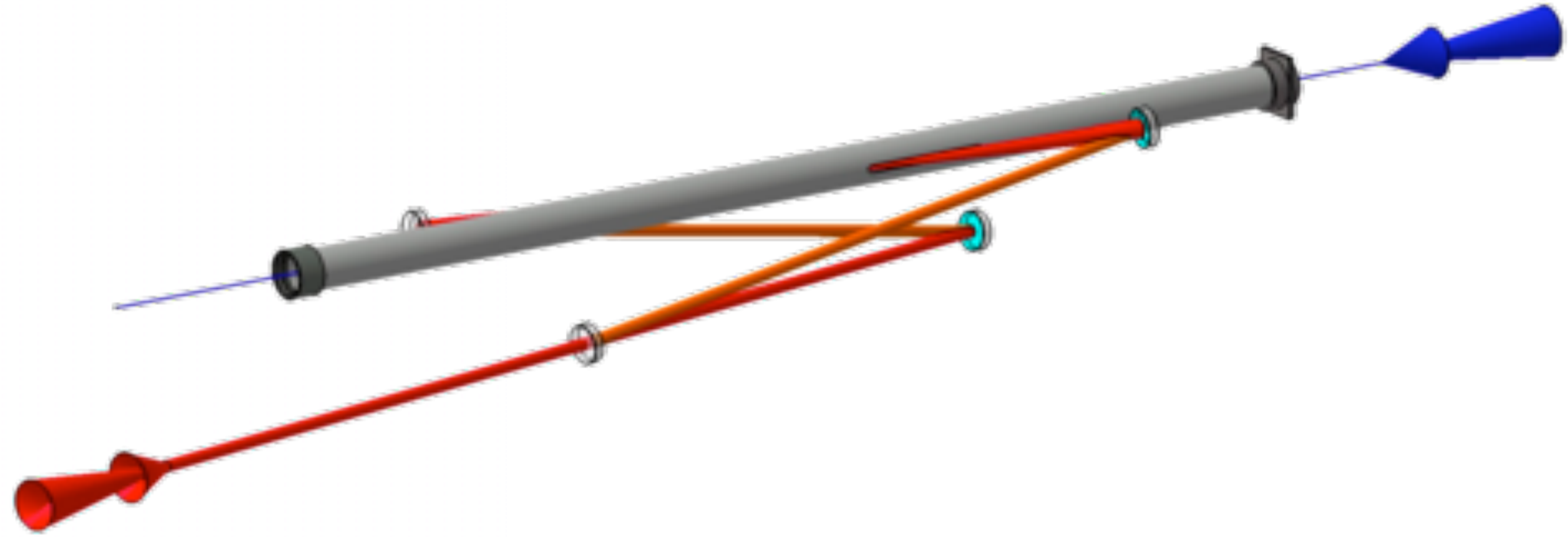
Fabry-Perot cavity





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