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A Project for a Compton Photon Source at the SKIF Synchrotron Facility

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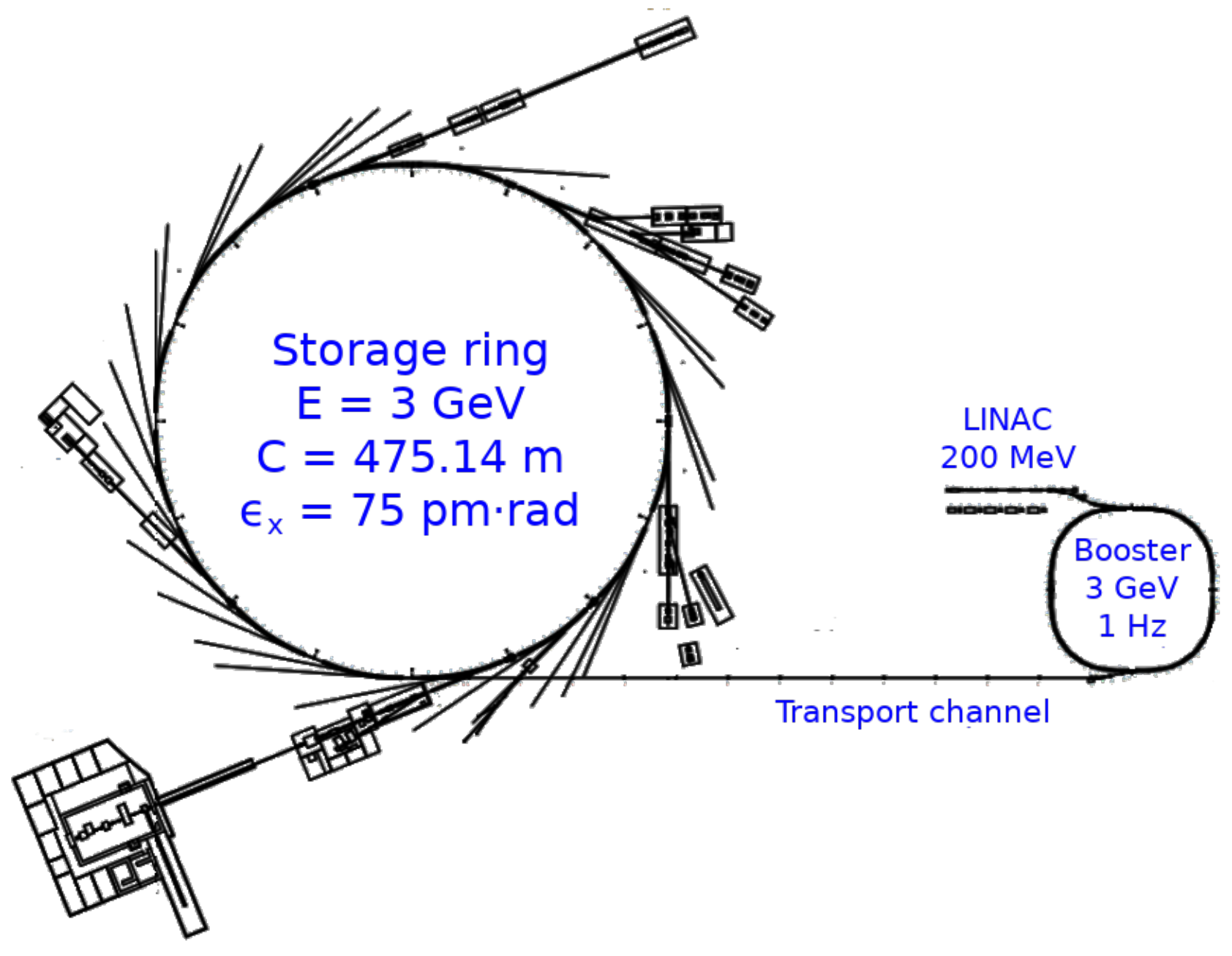
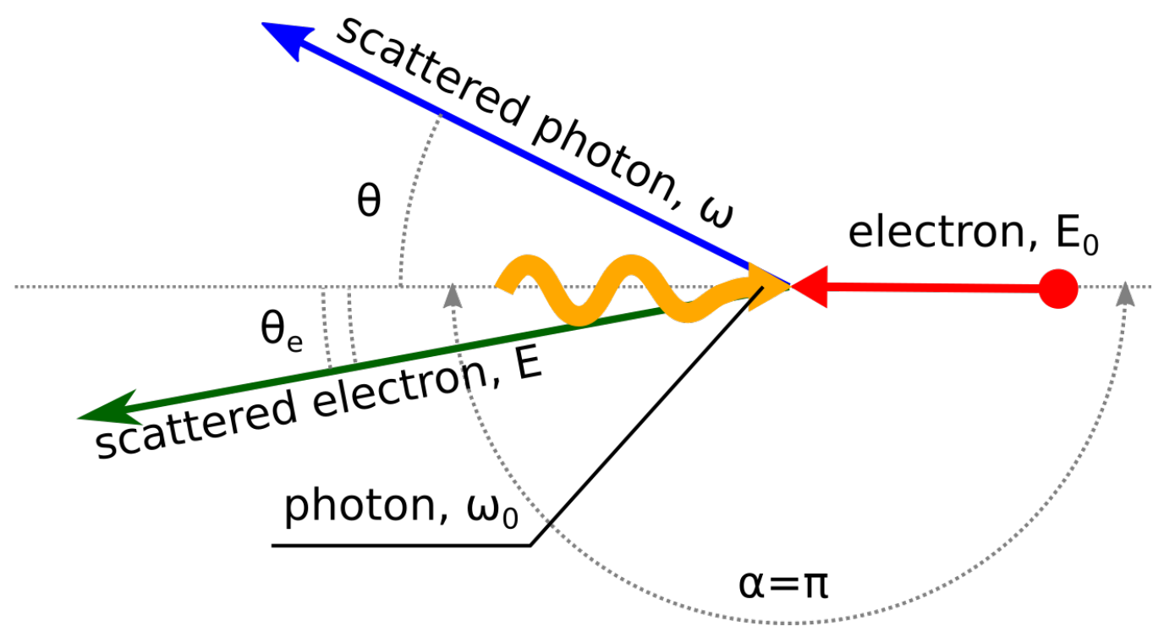
SKIF

SIBERIAN Circular Photon Source SKIF (rus: *«Сибирский кольцевой источник фотонов»*) [1] is a synchrotron radiation facility of "4+" generation under construction in Novosibirsk, Russian Federation. Its parameters make it possible to create a high-quality source of Compton photons on its basis.

Energy	3.0 GeV
Electron current	400 mA
Horizontal emittance	75 pm·rad
Revolution frequency	629.63 kHz
Number of bunches	567
Time between bunches	2.8 ns (84 cm)



Compton backscattering



The maximum photon energy when it scatters back ($\theta = 0$):

$$\omega_{\max} = \frac{E_0\kappa}{1+\kappa} \overset{\kappa\ll 1}{\underset{\alpha=\pi}{\approx}} 4\gamma^2\omega_0, \quad \kappa = \frac{4\omega_0 E_0}{m^2} \qquad (1)$$

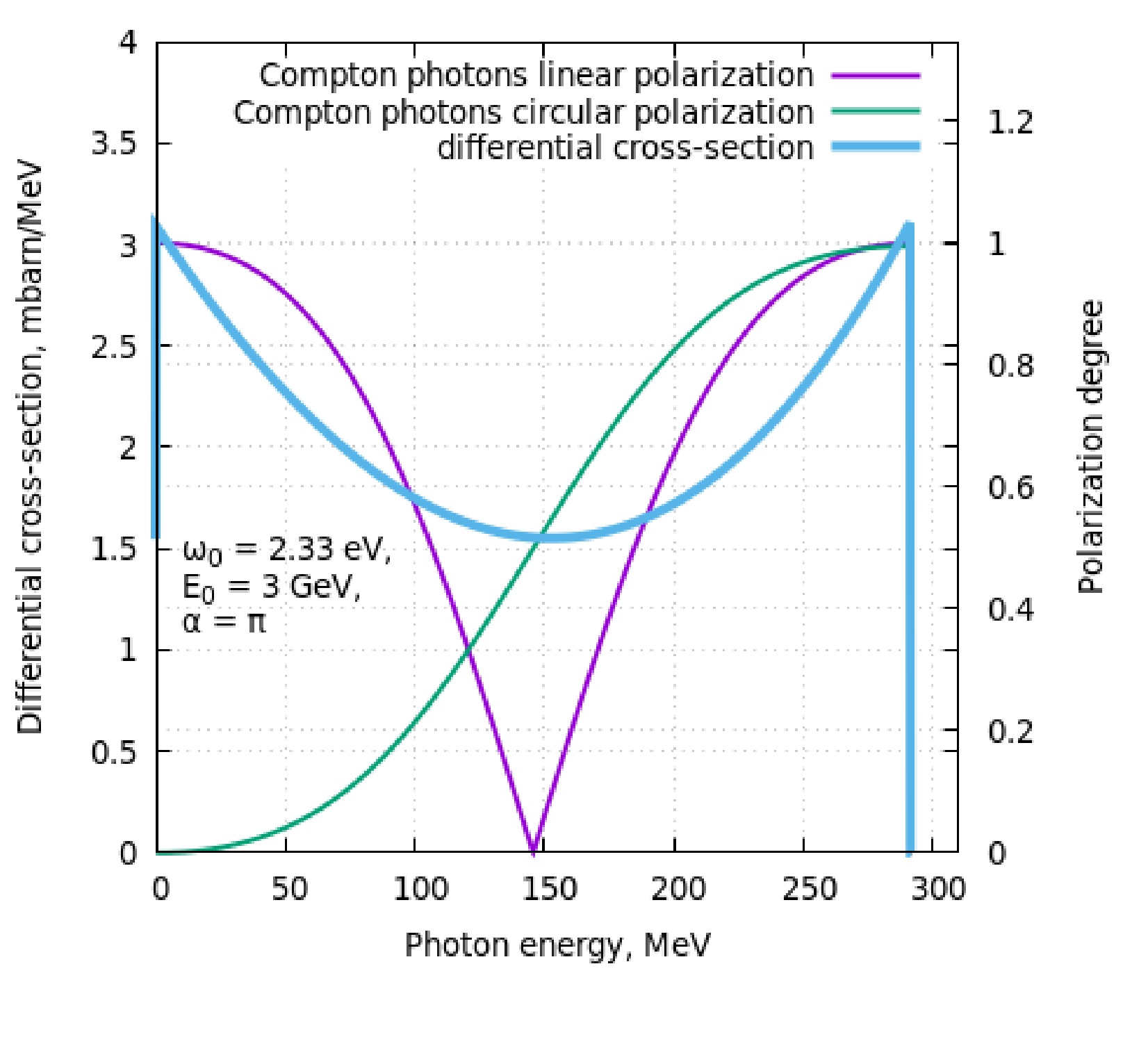
Energy depends on the scattering angle:

$$\omega(\theta) = \frac{\omega_{\max}}{1+(\theta/\theta_c)^2}, \quad \theta_c = \frac{m}{E_0}\sqrt{1+\kappa} \overset{\kappa\ll 1}{\approx} \frac{1}{\gamma} \qquad (2)$$

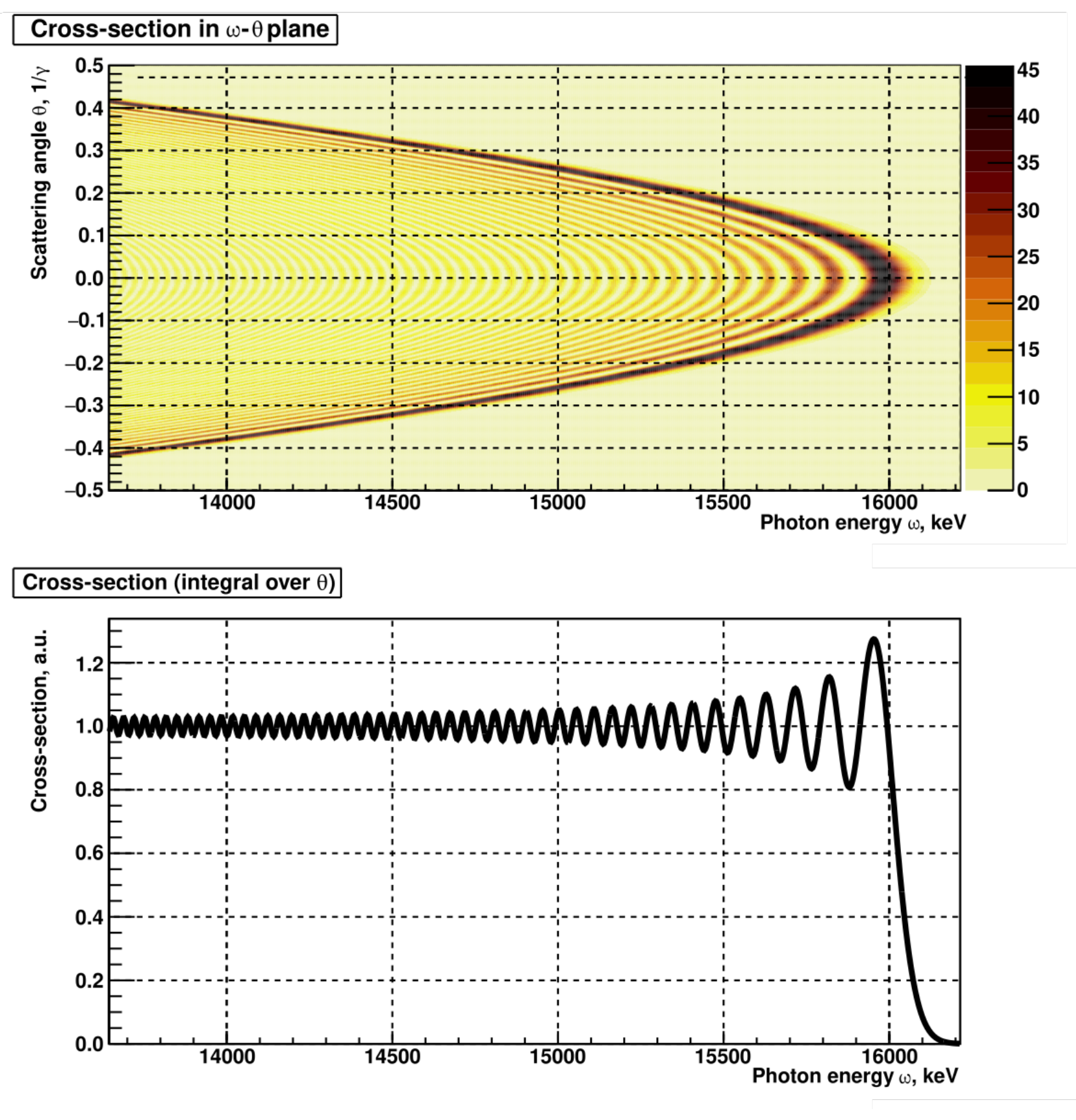
Electron recoil energy:

$$E = E_0 - \omega, \quad E_{\min} = E_0 - \omega_{\max} = \frac{E_0}{1+\kappa}. \qquad (3)$$

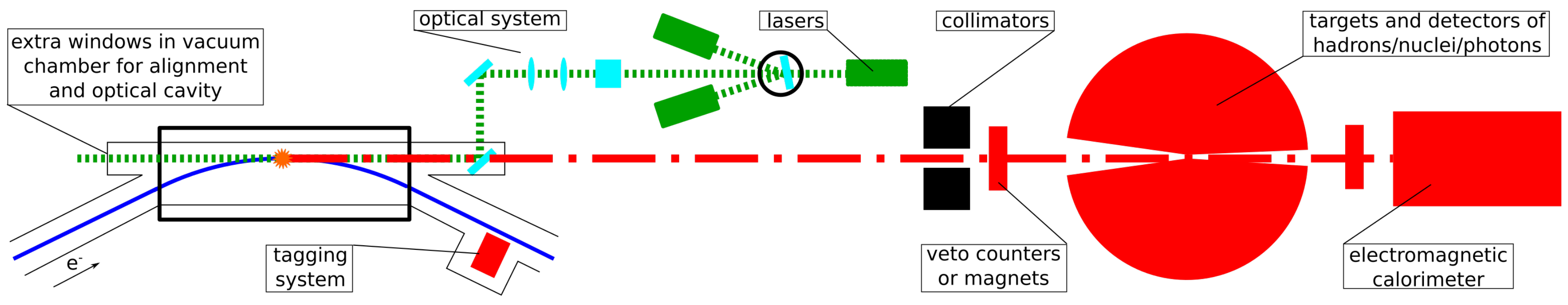
Cross-section and polarisation degree



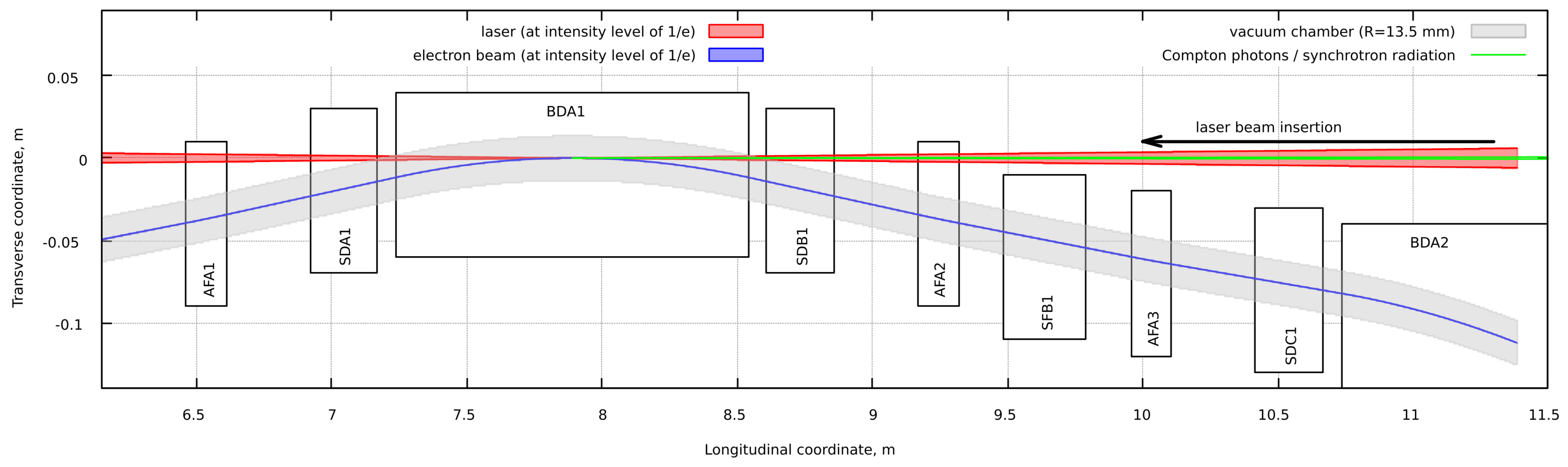
Cross-section of Compton bacscattering in a magnetic field [2]: $B = 0.56$ T, $E_0 = 3$ GeV, $\omega_0 = 0.117$ eV



Concept



Lasers: continuous wave (max. $3.57\cdot10^8$ Compton gamma-ray bursts per second) or pulsed <1 ns with jitter ∼ 0.1 ns (∼ 10^8 Compton gamma-ray bursts per second, it is the detector maximum rate). I, II, IV harmonics of Nd:YAG, CO_2, or tunable lasers with optical cavity inside the storage ring.
Interaction point is planned inside one of the soft-field dipole of supercell (BDA1).



Limitations

The main purpose of the storage ring is the generation of synchrotron radiation. Therefore significant deterioration of lifetime and electron beam quality is not allowed.

- Beam energy can not be changed:
  - Use many lasers or tunable lasers (at the cost of low power);
  - Use tagging system by recoil electrons;
- Rate of Compton photons is limited $\sim 4\cdot10^8\ \gamma/s$ by injection system if recoil electrons leave the equilibrium beam (most of recoil electrons from Nd:YAG lasers).
- Recoil electrons with energy loss up to 78 MeV (2.6% of the beam energy, all recoil electrons from CO_2 laser) remain in a storage ring and deteriorate emittance.

Features

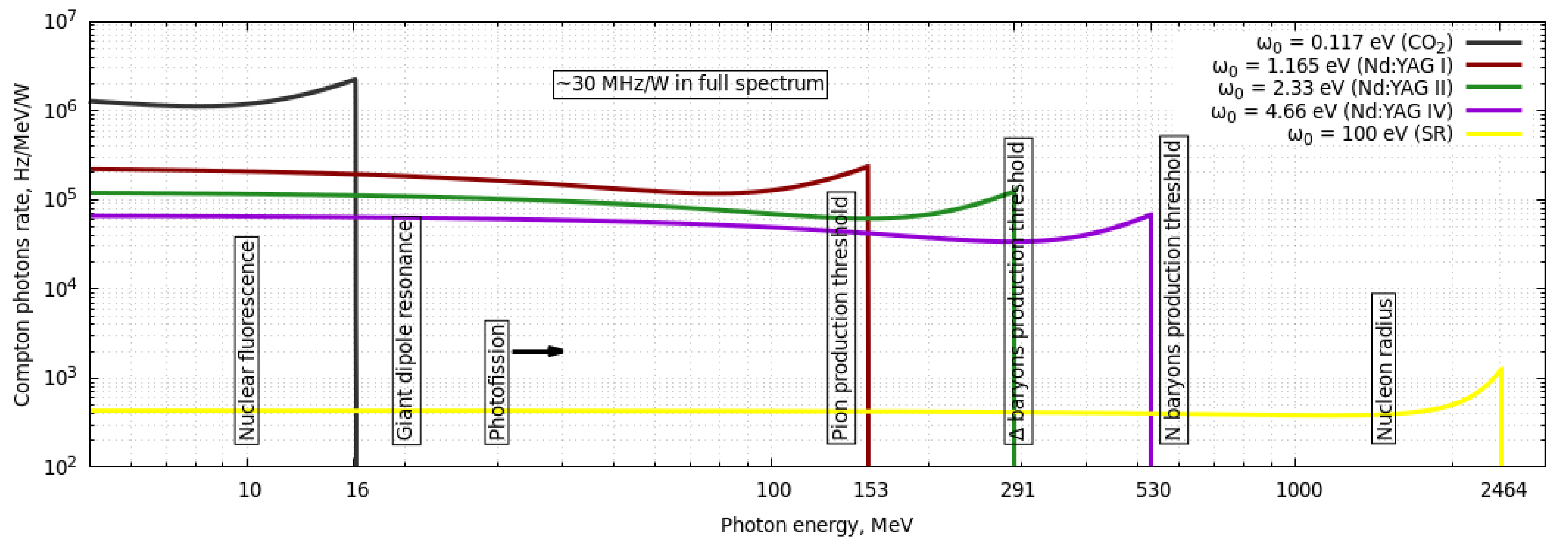
High bunch repetition rate: 357 MHz.

- Compton photon multiplicity is less then 1 → tagging system works with low pileup;
- Continuous wave or specialized pulsed lasers;

Low emittance and low angular/coordinate spread (the closest analogue is MAX-IV, Sirius).

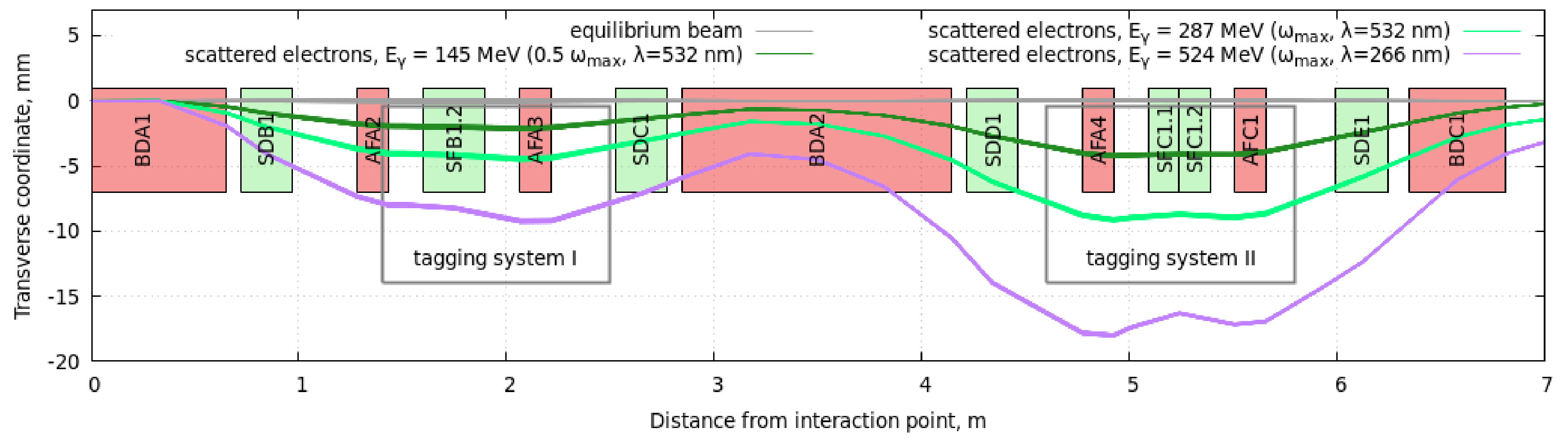
- Efficient collimation of Compton quanta for monochromatization and polarization selection;
- High tagging system energy resolution;
- High Compton photon polarization degree. Twisted Compton photons?

Photon spectra and rates



The calculation is made for CW lasers of 1 W power and waist size of 50 µm in the interaction point ($\lambda =$ 527 nm): full-spectrum photon rate is ∼ 30 MHz.

Tagging system

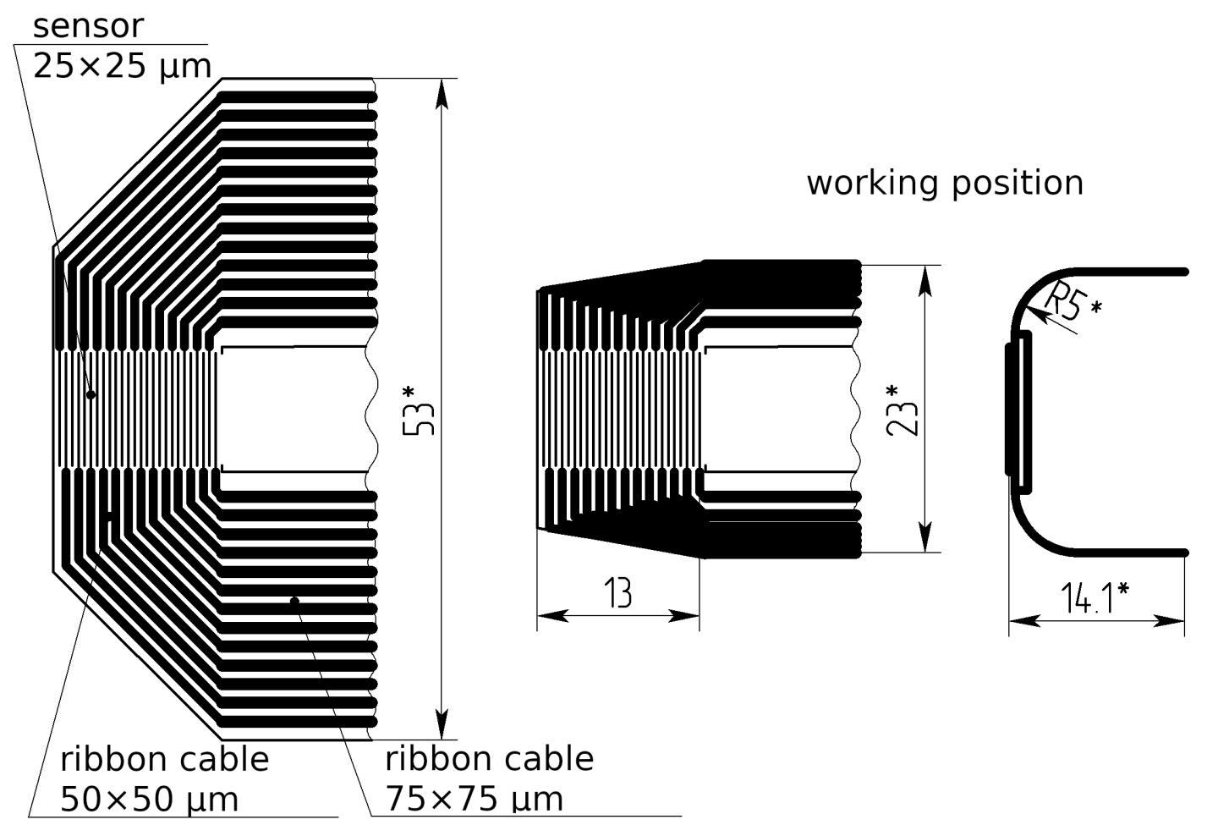


- Taking vacuum chamber radius of 13.5 mm into account, two tagging systems are necessary:

  I: for photons with energy up to 400 MeV, all Compton photons from Nd:YAG green laser;

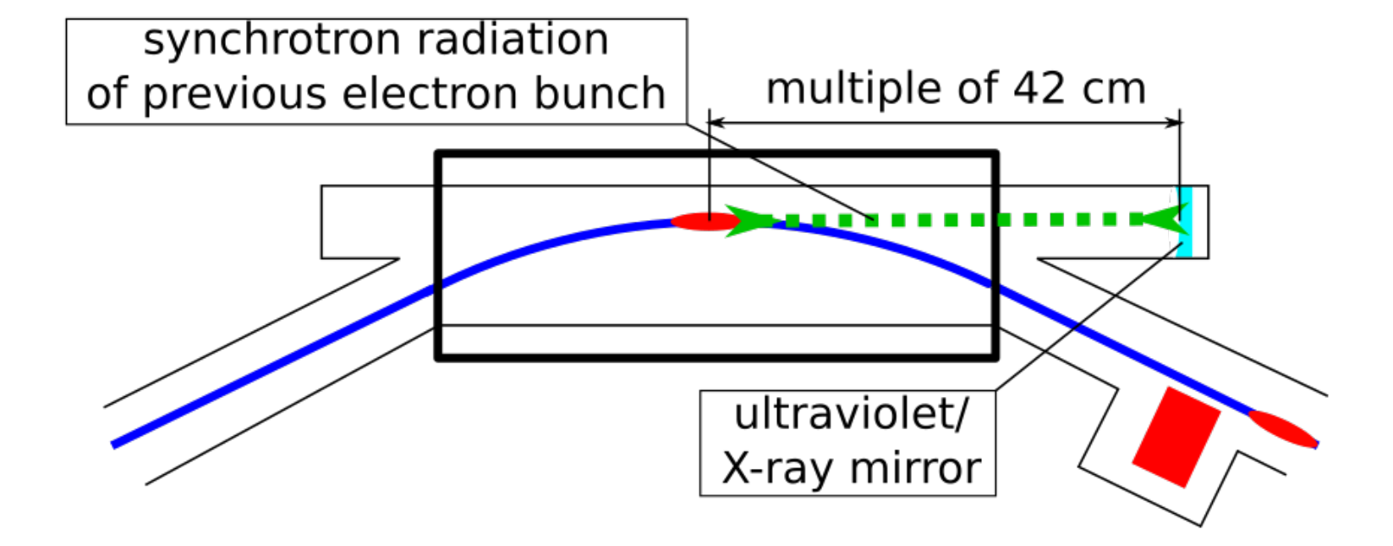
  II: for photons with energy up to 600 MeV, all Compton photons from UV lasers;

- Tagging system are placed in the same storage ring periodic cell, 1.2 . . . 2.4 m and 4.6 . . . 5.8 m from the interaction point.
- Two Si/GaAs strip sigle-coordinate movable detectors inside the vacuum chamber.



- Photon energy resulution from 0.6 to 0.8% beam energy (∼ 2 MeV photon energy resolution, detector strip pitch is 50 µm.
- Photon multiplicity <0.5 → no pileup (if the detector can operate at 357 MHz).

Obtaining very high-energy photons



With focusing mirror for synchrotron radiation at 100 eV (±2.5%) (12.4 nm) with reflection coefficient of 0.7 [3] we can obtain Compton photons with $\omega_{\max}$ = 2464 MeV and rate about 600 kHz (scattering cross-section is 29% of Thompson cross-section).

Possible experiments

Photonuclear reactions in "low-energy" range (units–tens MeV) e.g. nuclear fluorescence, pygmy resonances, problem of "bypassed" nuclei, etc. **are difficult** as the beam energy is constant and tagging system can not operate at such a low-energy recoil electrons.
Promising experiments:

- Photonuclear reactions in "mid-energy" range (hundreds MeV): nuclei photofission, production of hypernuclei, pions, hyperons, etc., nonlinear QED effects. Tagging system is usable;
- Energy scale calibration and energy resolution measurement of electromagnetic detectors;
- Gamma tomography, production of radioisotopes for nuclear medicine?

Methodical experiments:

- Optical cavity inside the storage ring vacuum chamber for higher radiation power;
- Using synchrotron radiation as a source of initial photons;
- Twisted Compton photons.

If tunable lasers with vacuum optical cavity is used, the monochromatization is possible for "low-energy" experiments.
First experiments: continuation of the experiments conducted in 1980s-1990s at VEPP-4 collider.

- Actinides nuclei photofission with 100–500 MeV photons [4]. Fissility of ^{237}Np appeared 60% larger than of ^{238}U defined as a sum of pion photoproduction at all nucleons of a nucleus, and this problem has not been finally solved yet [5].
- Nonlinear QED: Delbrück scattering [6] and photon splitting [7] in atomic fields.

Conclusion

- A draft design of a Compton source on a SKIF storage ring is proposed.
- Individual installation elements are being developed.
- Specialists in photonuclear physics and detectors for it are needed.
- Further ideas for a physical program are needed.

References

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