Beam energy and electron polarization measurement

at Super c-tau factory

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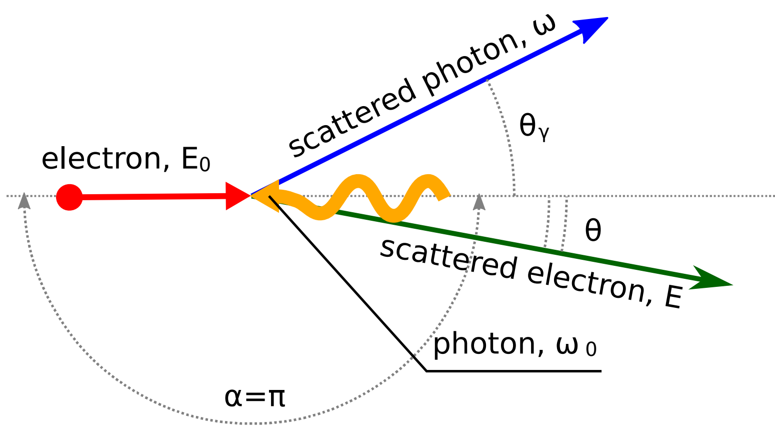
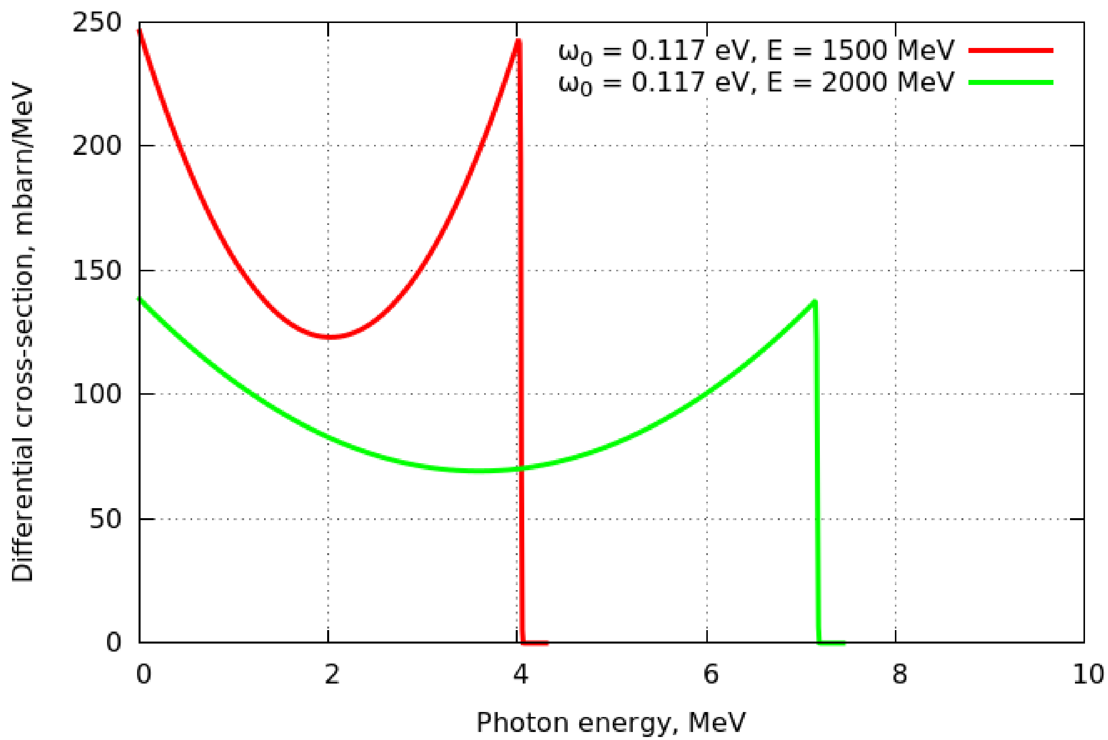
Challenges and approaches

- Beam energy measurement with accuracy of $10^{-3}...10^{-5}$ is needed.
  - Beam energy range: 1.0 to 2.5 GeV (CDR ver. 2)
    - below 2 GeV: energy measurement by Compton photons spectrum edge, well-established method
    - above 2 GeV - ???
  - Separate beamlines for electrons and positrons
    - 2 beam energy measurement systems
- Electron beam longitudinal polarization measurement in IP is needed.
  - It is delivered by photoelectron gun.
  - To make longitudinal polarization at the collision point, adjustment of Siberian snakes is needed.
  - To preserve polarization, longitudinal polarization is needed in wigglers.
  - No natural polarization by Sokolov-Ternov mechanism.
- Seems that Compton backscattering can solve these problems...

Compton backscattering (inverse Compton effect)

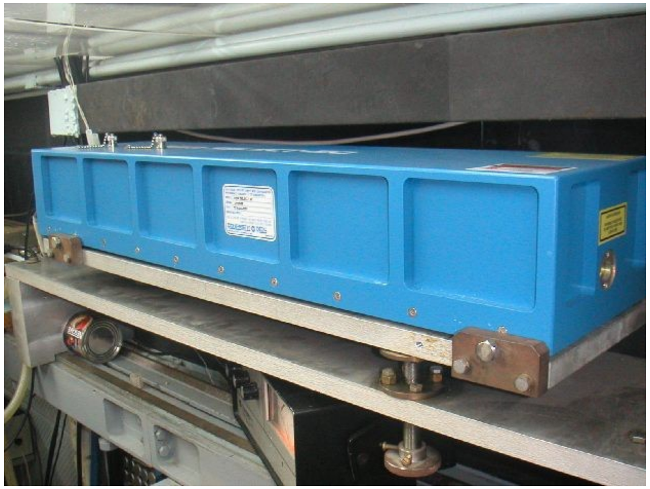




- Energy of the scattered photon strictly depends on scattering angle θ_γ.
- When $\theta_\gamma=0$ energy of the scattered photon is maximal (and the electron's one is minimal):

$$\omega_{max}=\frac{E_0\kappa}{1+\kappa}\overset{E_0\gg m\gg\omega_0}{\approx}4\gamma^2\omega_0\ ,\qquad \kappa=\frac{4E_0\omega_0}{m^2}\ ,\qquad E_{min}=\frac{E_0}{1+\kappa}$$

Beam energy measurement using Compton photon spectrum edge

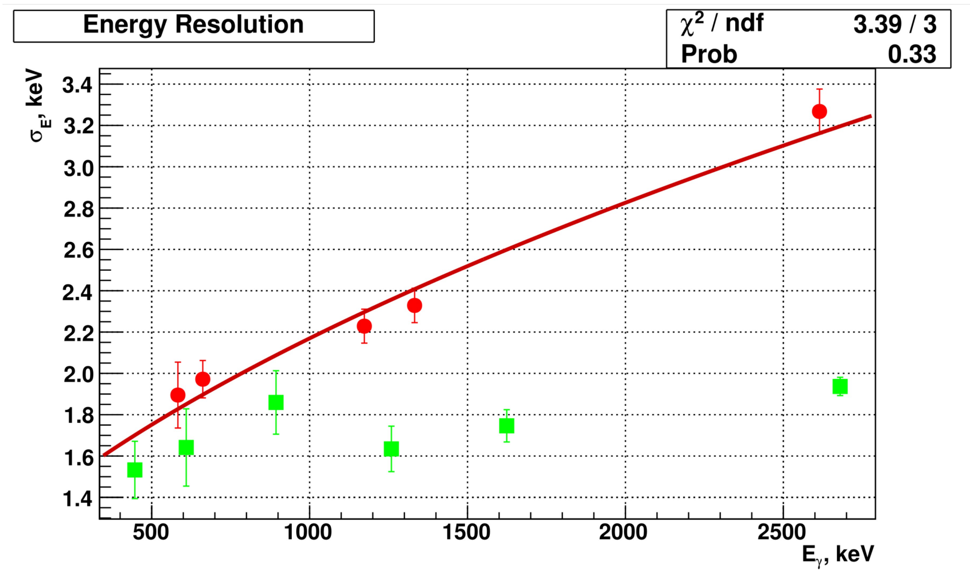


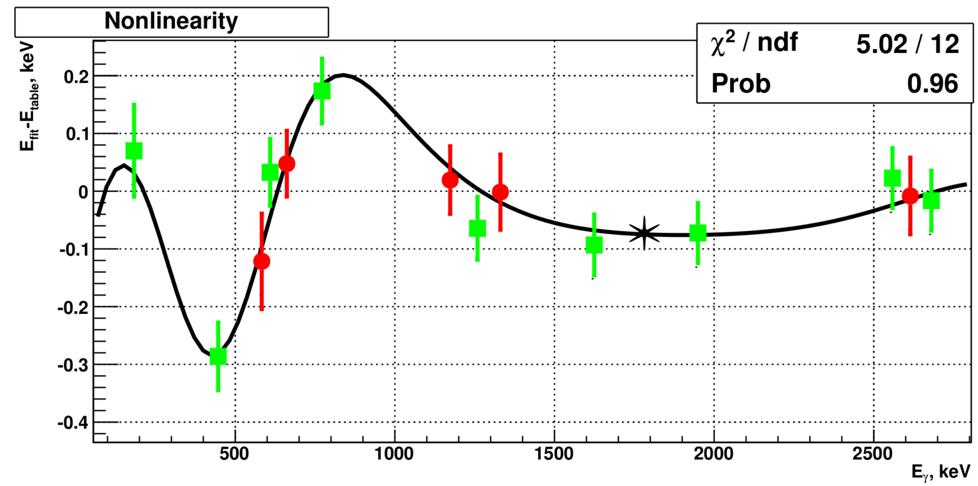
- Mid-IR laser interacts with electron and positron beams.
  - CO_2-laser: CW, λ=10.56 μm, ω_0 = 0.117 eV, P ~ 10 W.

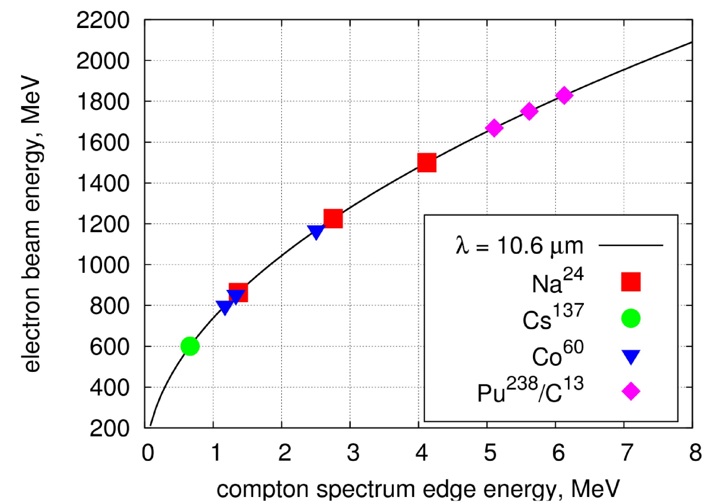
- Compton back-scattered photons (few MeV) are registered by high-purity germanium (HPGe) detector with excellent energy resolution.
  - Energy resolution 1-2 keV at 1 MeV, photon energies up to 6 MeV

Beam energy measurement using Compton photon spectrum edge

- HPGe detector energy scale is calibrated using photons with well-known energies from γ-active isotopes and precision pulse generator.







Why HPGe detector?
Ultimate resolution +
possibility of calibration

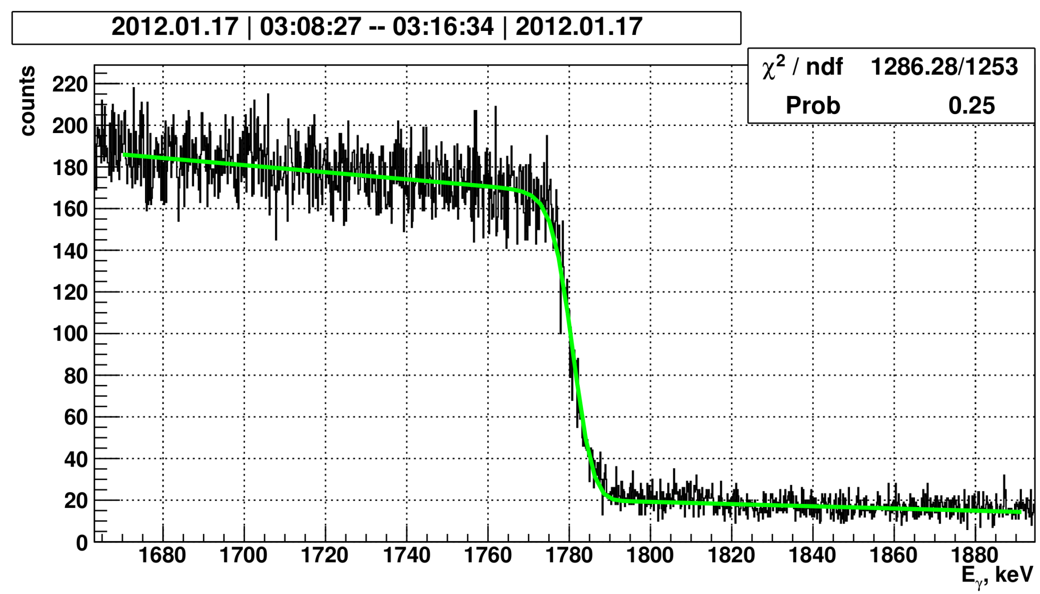
Beam energy measurement using Compton photon spectrum edge

- The energy of Compton spectrum edge is found and the beam energy is calculated.

$$E_0 = \frac{\omega_{max}}{2}\left(1+\sqrt{1+\frac{m^2}{\omega_0\,\omega_{max}}}\right) \approx \frac{m}{2}\sqrt{\frac{\omega_{max}}{\omega_0}}$$

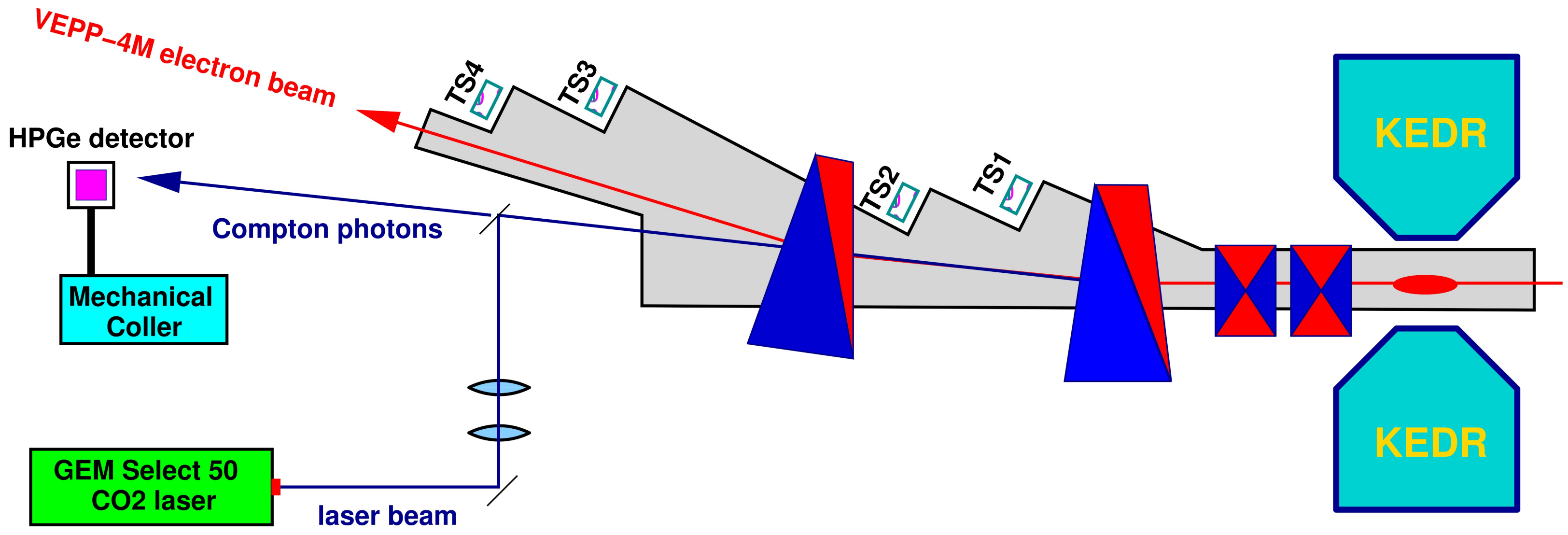
- Uncertainty:

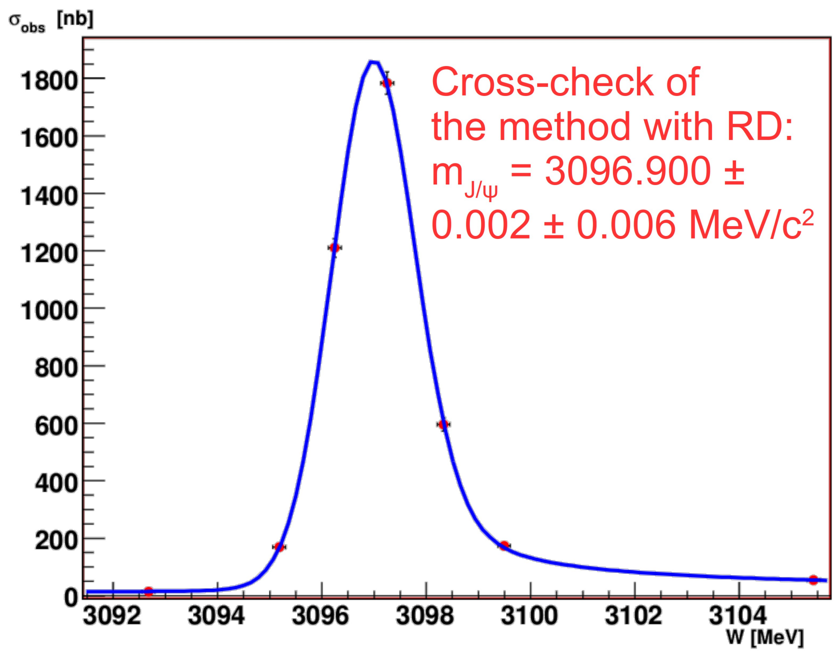
$$\Delta\frac{E_0}{E_0} \simeq \underbrace{\frac{1}{2}\frac{\Delta\omega_{max}}{\omega_{max}}}_{\substack{\text{detector resolution},\\ \text{calibration},\\ \text{beam energy spread},\\ \text{etc.}}} \oplus \underbrace{\frac{1}{2}\frac{\Delta\omega_0}{\omega_0} \oplus \frac{\Delta m}{m}}_{<10^{-7}}$$

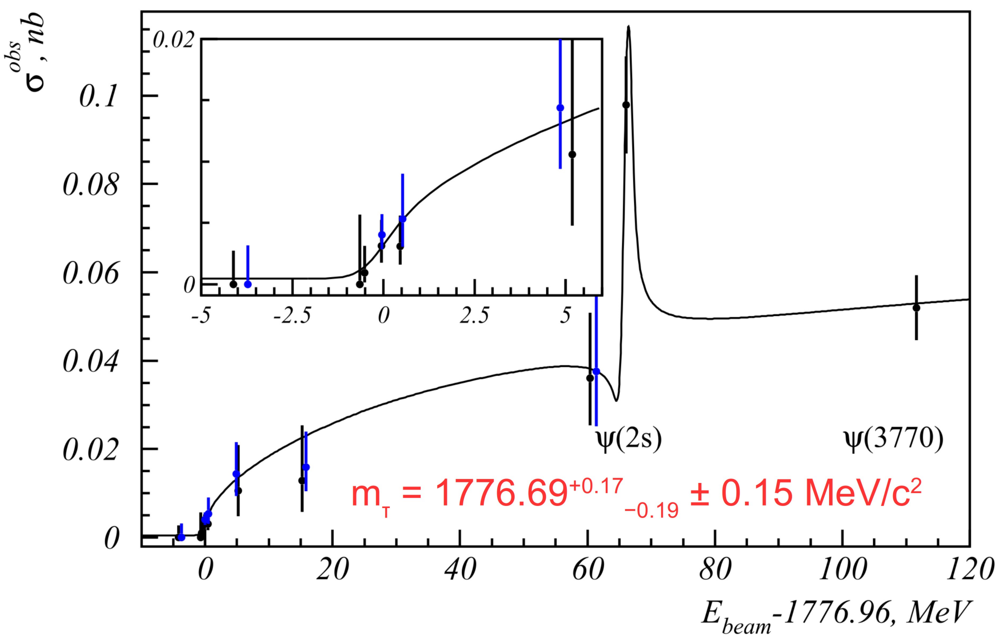


- Typically $5\cdot10^{-5}$
- Beam energy spread can be also measured (10% accuracy)
- Successfully implemented at VEPP-4M, VEPP-3, VEPP-2000, BEPC-II.

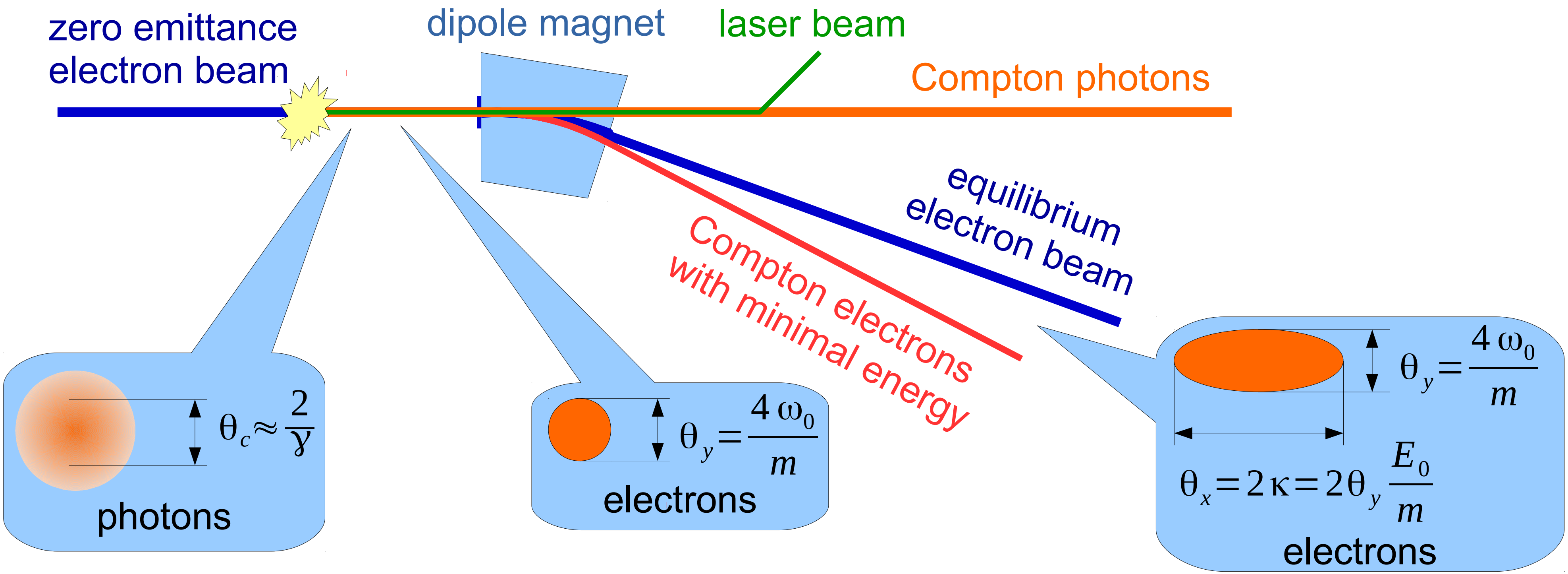
Example: VEPP-4M







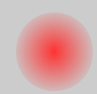
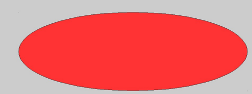
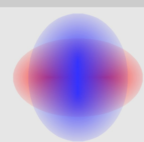
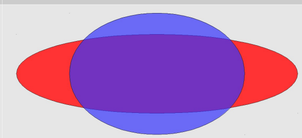
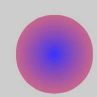
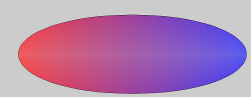
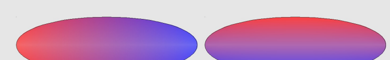
Compton backscattering: angular properties



- Due to nonzero emittance, electron/photon distributions are smeared out by the electron beam angular spread.
- Also a photon/electron spot in a coordinate detector is smeared out by the electron beam coordinate spread.

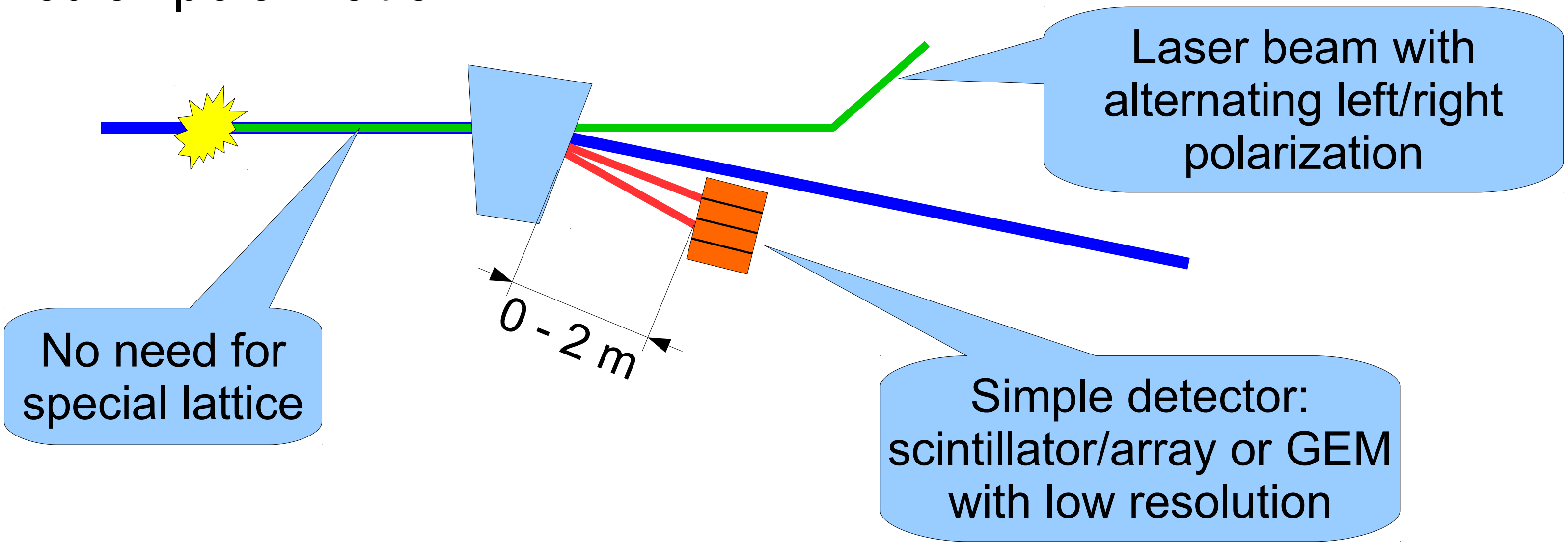
Compton backscattering: cross-section and polarization properties

- Light linear polarization (transverse, horizontal/vertical): $\xi_\perp, \ \varphi_\perp$
- Light circular polarization (longitudinal, left/right): $\xi_\parallel$
- Electron transverse polarization (horizontal/vertical): $\zeta_\perp, \ \psi_\perp$
- Electron longitudinal polarization: $\zeta_\parallel$
- Cross-section: $d\sigma = d\sigma_0 + d\sigma_+ + d\sigma_\parallel + d\sigma_\perp$

γ	e⁻	cross-section	photons	electrons	conditions
0	0	$d\sigma_0$ (non-polarized)			
$\perp$	0	$d\sigma_+ \sim \xi_\perp \cos 2(\varphi - \varphi_\perp) d\omega d\varphi$			$\xi_\perp = 1$, $\varphi_\perp = 0, \pi/2$
$\parallel$	$\parallel$	$d\sigma_\parallel \sim \xi_\parallel \zeta_\parallel d\omega d\varphi$ (integral ≠ 0)			$\xi_\parallel = \pm 1$
$\parallel$	$\perp$	$d\sigma_\perp \sim \xi_\parallel \zeta_\perp \cos(\varphi - \psi_\perp) d\omega d\varphi$			$\xi_\parallel = \pm 1$, $\phi_\perp = 0, \pi/2$

How to measure electron beam polarization at Super c-tau factory?

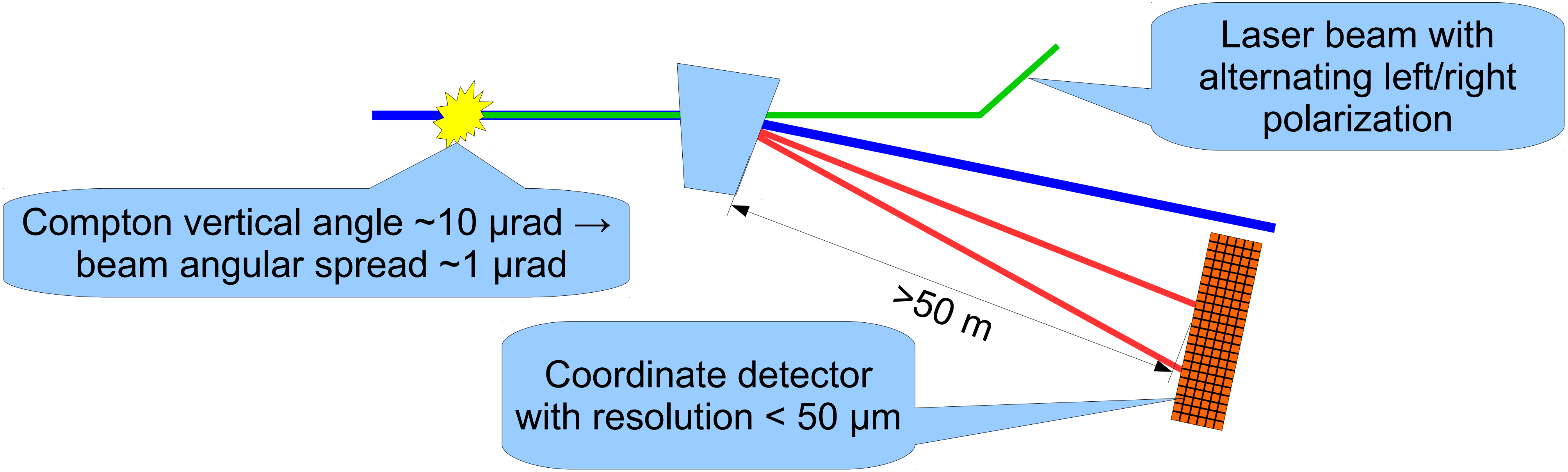
- “Easy” way: electron polarimeter without coordinate measurement.
  - Detects $\sigma_{\parallel}$: electron Compton rate changes (~3%) with sign of the light circular polarization.



  - Q-switched Nd:YAG or Nd:YLF laser (532 nm or 527 nm), <5 ns pulse duration, 2 W avg., would be a good choice.
  - Measures only longitudinal polarization: will be useful if installed in wigglers and IP.

How to measure electron beam polarization at Super c-tau factory?

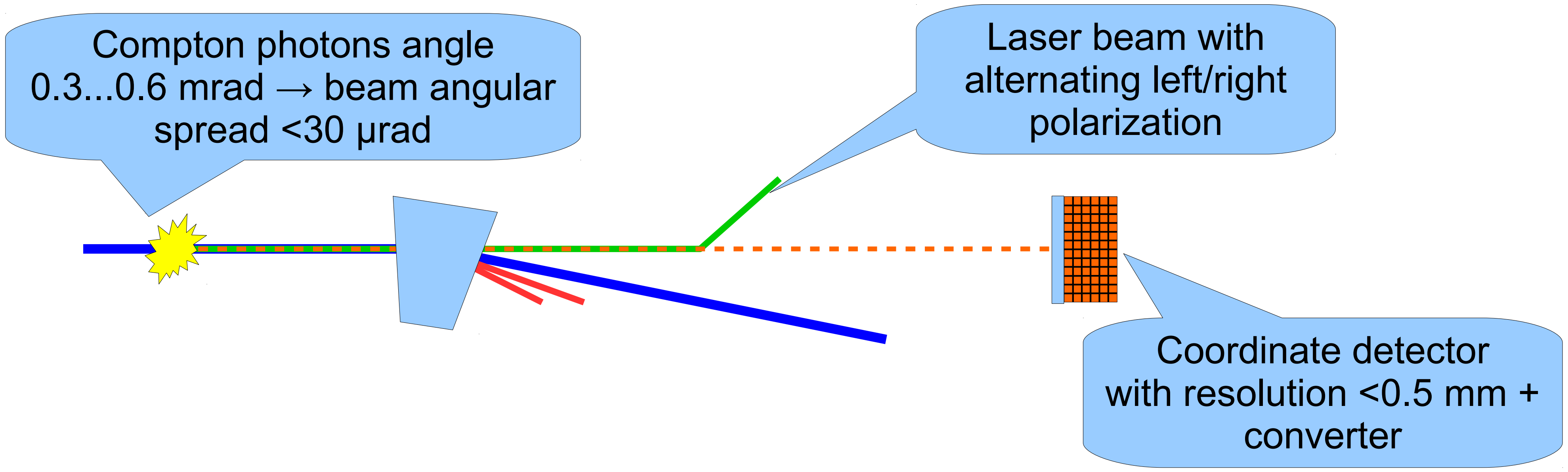
- “Hard” way: electron polarimeter with coordinate measurement.
  - Detects $\sigma_\perp$ (vertical and horizontal asymmetry), $\sigma_\parallel$ (horizontal asymmetry), horizontal and longitudinal polarizations are mixed.



  - Thorough study of possible location is needed.
  - Focusing system for scattered electrons?

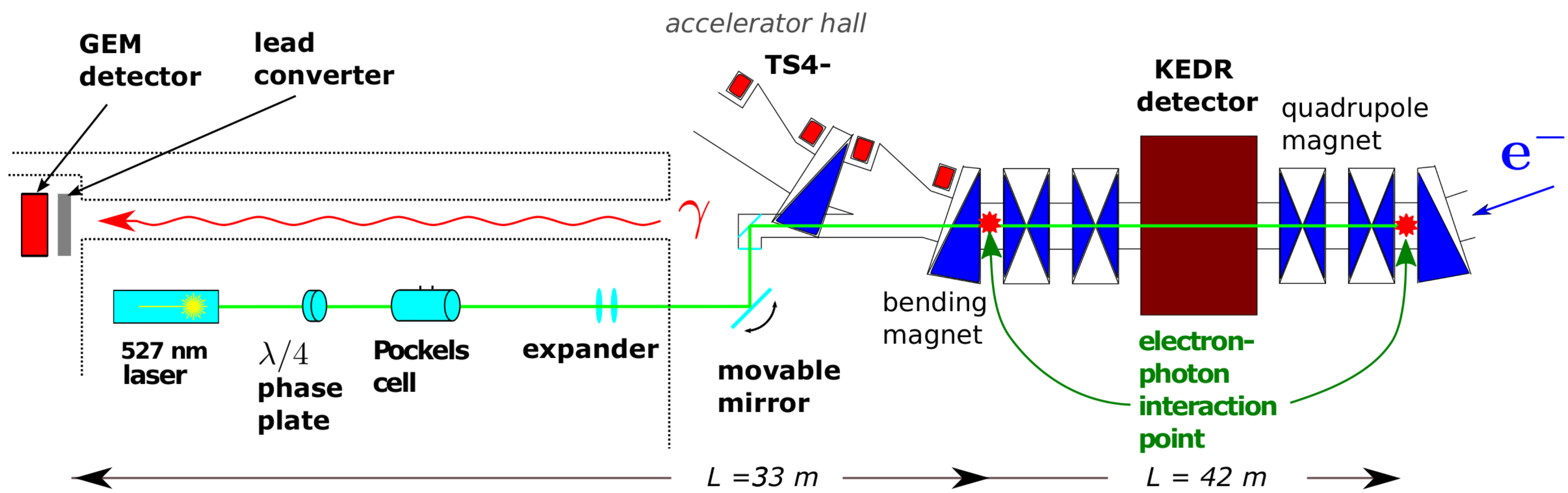
How to measure electron beam polarization at Super c-tau factory?

- “Approved” way: photon polarimeter with coordinate detector
  - Measures vertical and horizontal (asymmetry) and longitudinal polarization (by total cross-section).

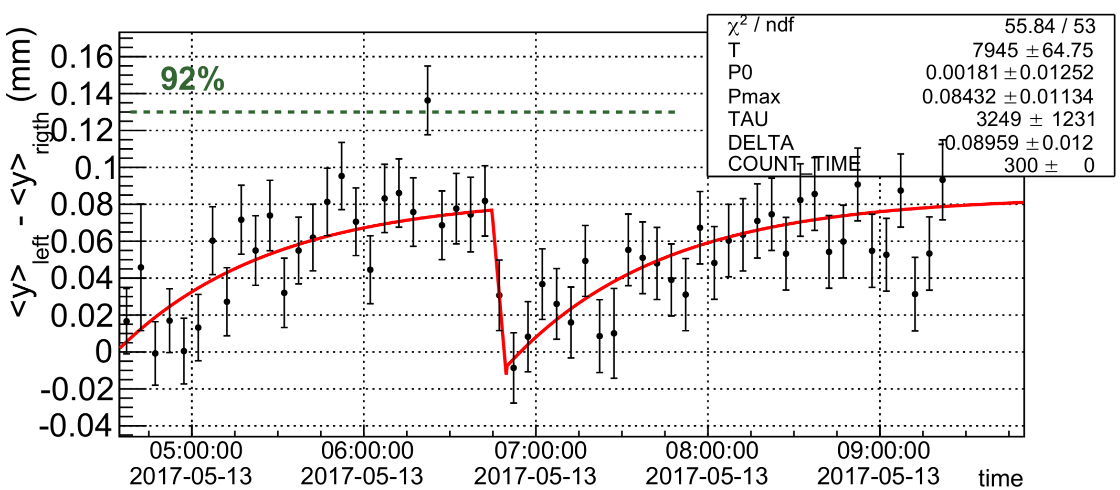


  - Low efficiency due to photon conversion (30-40%).
  - Implementation of the method at VEPP-4M is in progress now. Also it was used at LEP.

Compton (laser) polarimeter at VEPP-4M

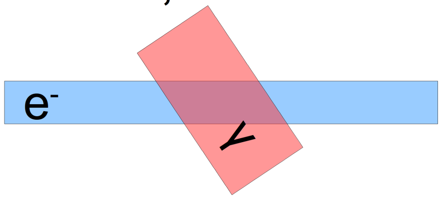


- Q-switching DPSS Nd:YLF laser (2nd harmonic): 5 ns pulse, 500 μJ/pulse, 2000 pulses/sec.
- Alternating right/left laser light polarization.
- Automated control and data acquisition system.



Beam energy measurement above 2 GeV

- Beam energy measurement using Compton photon spectral edge:
  - Longer wavelength laser: no reliable lasers with wavelength >10 μm.
  - Higher energy photon detector: no possibility for calibration, low efficiency.
  - Non head-on interaction: very low efficiency.



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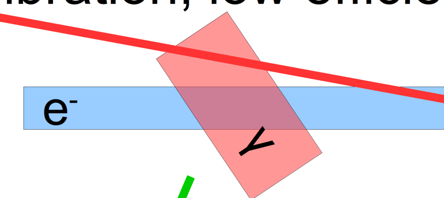
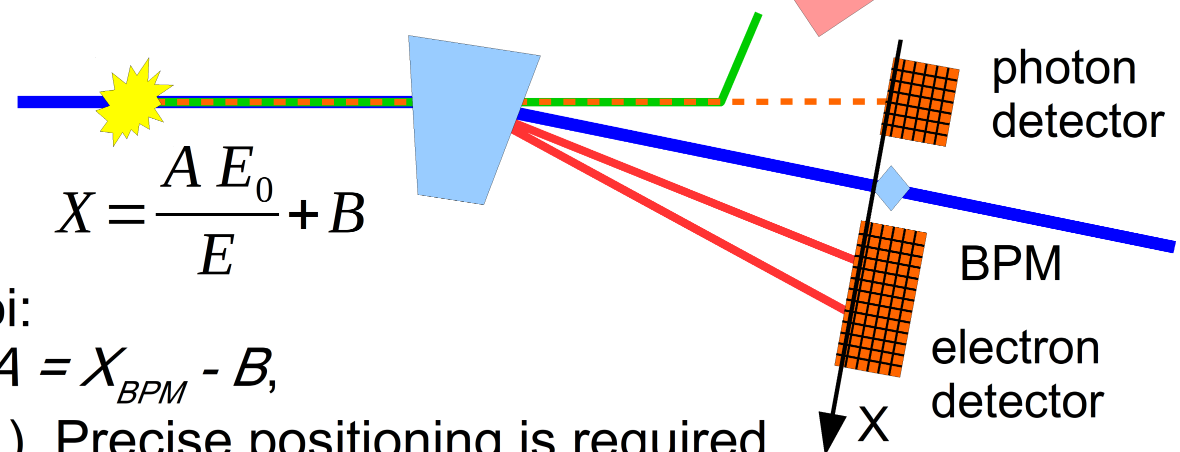


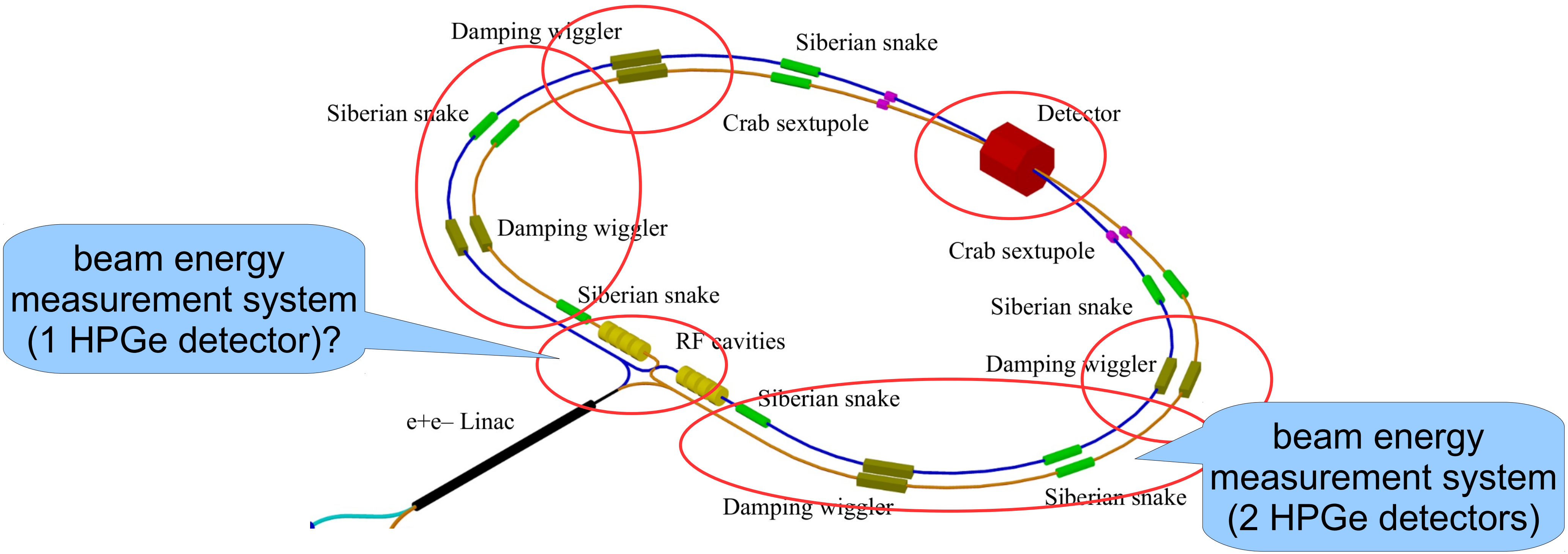
- “Compton spectrometer”:
  - If all the detectors are in one coordinate frame, B is a photon spot coordinate.

$$X = \frac{A\,E_0}{E} + B$$



  - Approach by N.Yu. Muchnoi: with one laser wavelength $A = X_{BPM} - B$, $E_0 = m^2 (X_e - B - A) / (4A\omega_0)$. Precise positioning is required.
  - Approach by V.V. Kaminskiy: “once” calibrate A, B in one coordinate frame with 2 laser wavelengths and precisely measured beam energy (<2 GeV or at narrow resonance). Use 2 laser wavelengths to calibrate A and E_0.
  - Precision: 10^{-4}. Why not do cross-checks and use both?

Where?



- BEMS utilizing Compton photon spectrum edge, more probably, will use 2 HPGe detectors.
- Super charm-tau factory has locations with low angular spread to place “advanced” electron polarimeter.
- To choose locations, a stable project of lattice and thorough study are needed.

Perspective

- Electron and positron beam energy < 2 GeV can be measured using Compton photons spectrum edge.
  - The method is well-established, BINP team has a large experience.
- Longitudinal electron beam polarization can be measured with "simple" electron polarimeter using alternating $\sigma_{\parallel}$ component of total Compton cross-section.
- Transverse electron beam polarization can be measured with Compton photon polarimeter.
  - The method was approved earlier at LEP and now its implementation is in progress at VEPP-4M.
- After careful study, "advanced" electron Compton polarimeter may be applied.
- Two polarimeters are preferred: near IP and near wigglers.
- These proposals need more thorough study.

Thank you for your attention!