Analysis of circular polarization of γ - quanta with energy 10 – 30 MeV using Compton-polarimeter

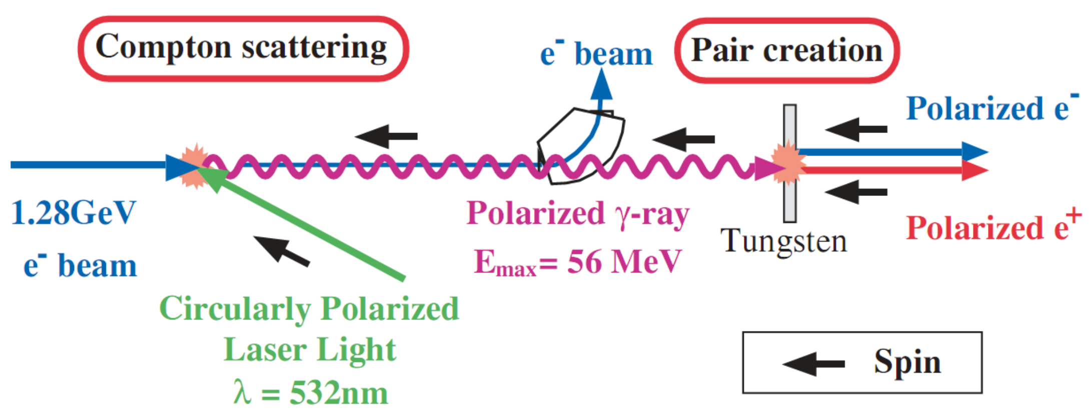
A.P. Potylitsyn, I.S. Tropin

Tomsk Polytechnic University,

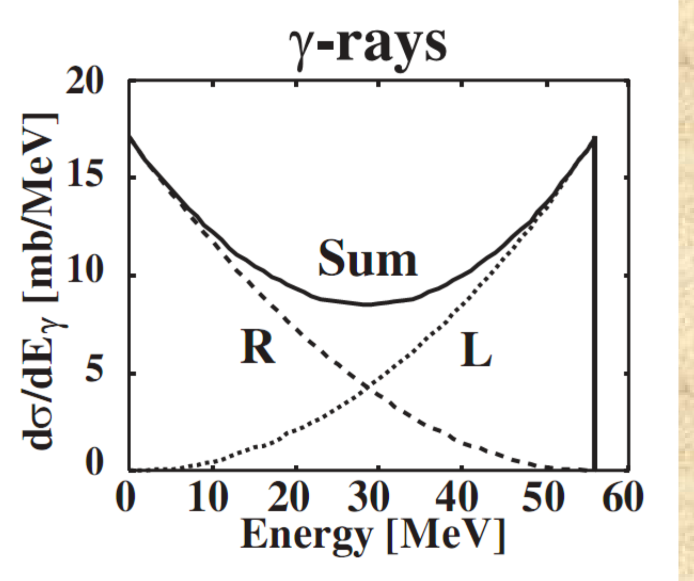
Lenin Ave. 30, 634050 Tomsk, Russia

Circularly polarized γ - beam

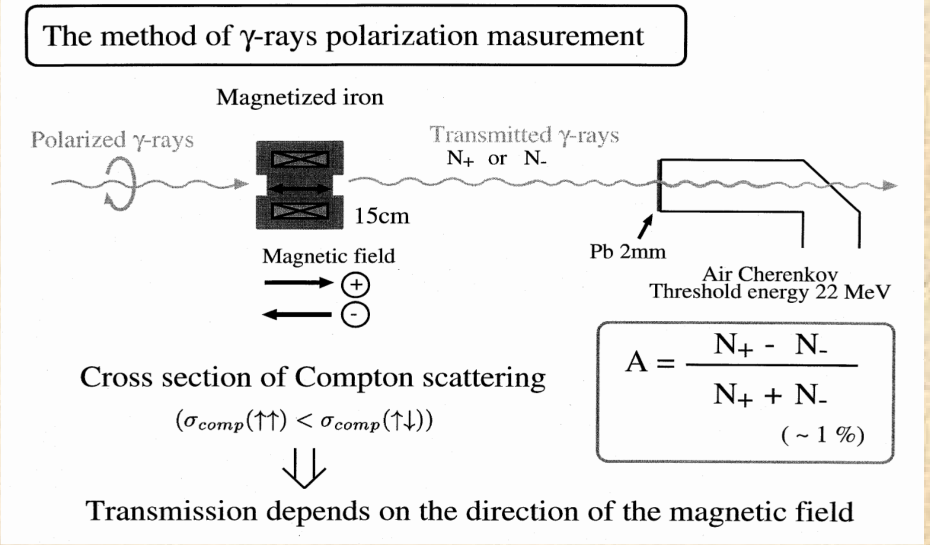
i) Compton scattering of laser photons by ultra relativistic electrons (KEK)



T. Omori. PRL, **96**, 114801 (2006)



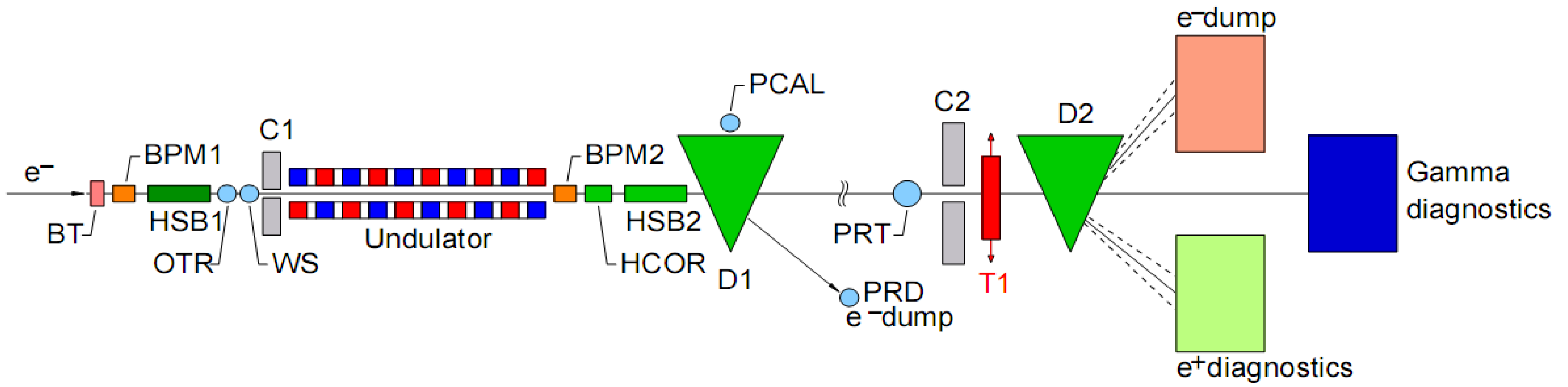
Differential cross section of the Compton scattering for right-handed polarized laser photons with wavelength of 532 nm backscattered off 1.28 GeV electrons as a function of the y-ray energy. The dashed and dotted curves correspond to the helicities of +1 and - 1 for the γ rays, respectively

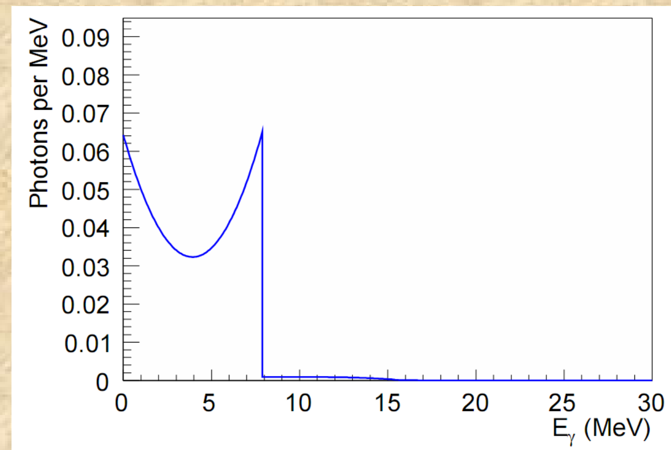


M. Fukuda. PRL, **91**, 164801 (2003)

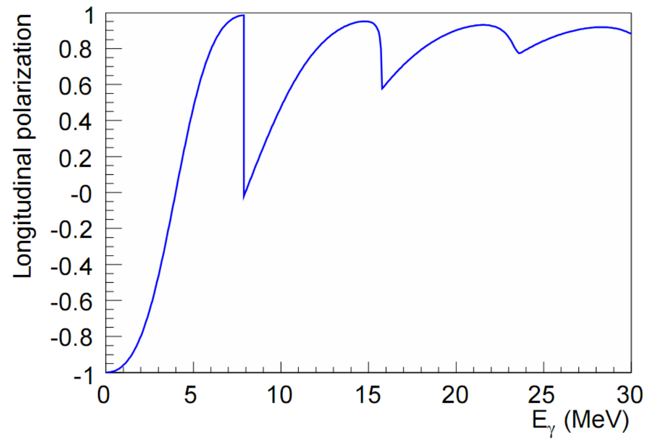
ii) Undulator radiation (SLAC)

Conceptual layout (not to scale) of the experiment to demonstrate the production of polarized positrons in the SLAC FFTB





The number of photon N(E_γ) of undulator radiation as a function of photon energy E_γ integrated over angle, for electron energy E_γ = 46.6 GeV, undulator period λ_u = 2.54 mm, and undulator-strength parameter K = 0.17. The peak energy E_1 of the first-harmonic (dipole) radiation is 7.89 MeV



The longitudinal polarization P(E_γ) of the undulator radiation as a function of photon energy for an undulator with a right-handed helical winding

G. Alexander et al. SLAC-PUB-13605

Polarimeter is based on the compton scattering process of circularly polarized photons by longitudinally polarized electrons in a magnetized iron.

The cross-section of this process:

$$\frac{d\sigma}{d\omega} = \frac{1}{2}\cdot r_0^2 \cdot \frac{\omega^2}{\omega_0^2}\cdot\left\{\left[\frac{\omega_0}{\omega}+\frac{\omega}{\omega_0}-\sin^2\theta\right]+\mathrm{P_c}\cdot\mathrm{P_e}\cdot\left[\left(\frac{\omega_0}{\omega}-\frac{\omega}{\omega_0}\right)\cdot\cos\theta\right]\right\} = \frac{d\sigma_0}{d\Omega}\left\{1+\mathrm{P_c}\cdot\mathrm{P_e}\cdot\mathrm{R}\right\} \quad (1)$$

ω_0 (ω) – energy of initial (scattered) photons, θ – photon scattering angle,

$\mathrm{P_c}$ – degree of photon circular polarization, $\mathrm{P_e}$ – degree of longitudinal electron polarization

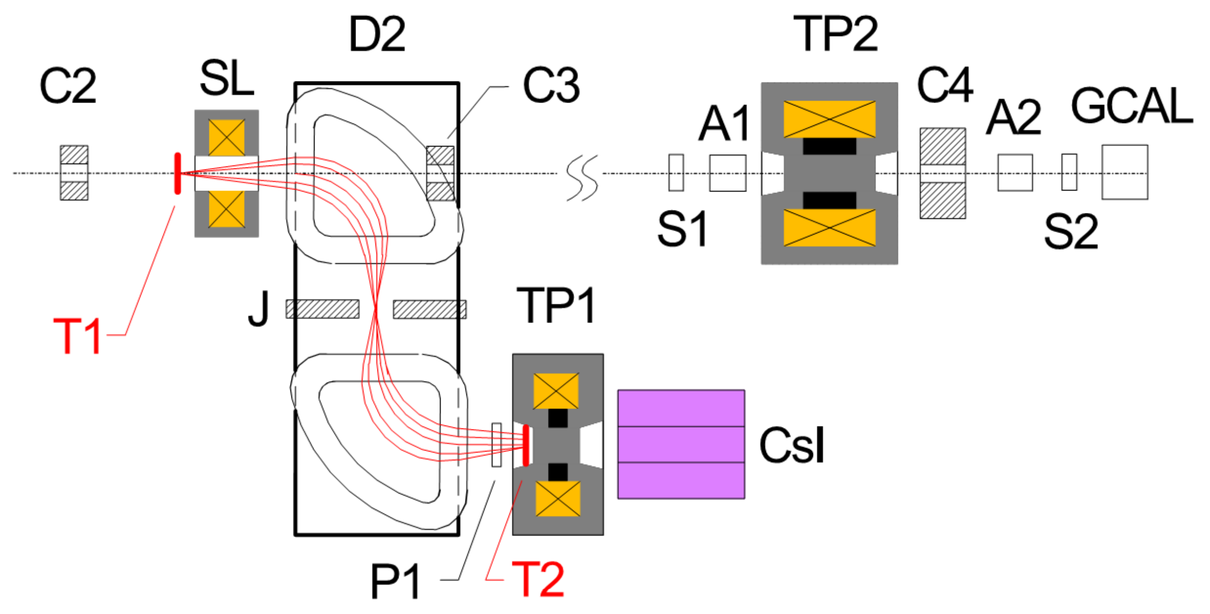
$$\frac{d\sigma_0}{d\Omega} = r_0^2\cdot\left(\frac{\omega}{\omega_0}\right)\cdot\left\{\frac{\omega_0}{\omega}+\frac{\omega}{\omega_0}-\sin^2\theta\right\} \quad (2)$$

Cross-section for unpolarized particles

The asymmetry ratio R in (1) is expressed as

$$\mathrm{R} = \frac{\left(\frac{\omega_0}{\omega}-\frac{\omega}{\omega_0}\right)\cdot\cos\theta}{\frac{\omega_0}{\omega}+\frac{\omega}{\omega_0}-\sin^2\theta} \quad (3)$$

There were used transmission polarimeters in KEK and SLAC



In a magnetized iron $P_e \approx 0.07$

With taking into account the compton scattering process only, for polarized photon ($P_c=1$) transmission is described as:

$$N_{\uparrow\uparrow} = N_0 \cdot \exp\left\{-\sigma_{\uparrow\uparrow} \cdot \mathrm{L} \cdot \mathrm{n}\right\},$$

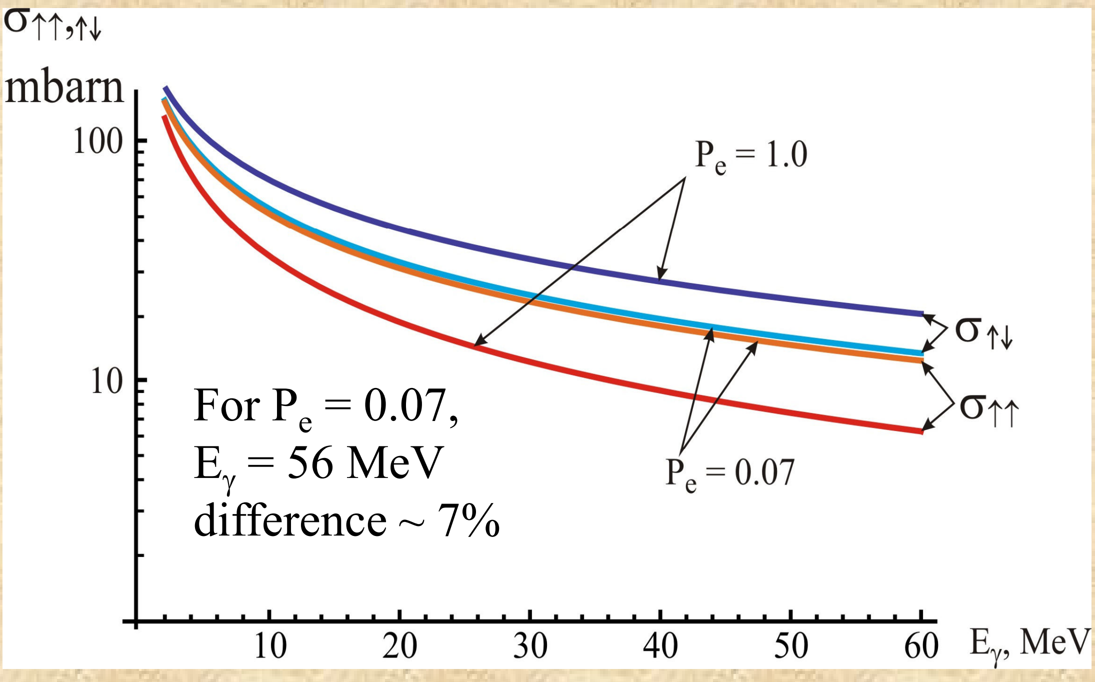
$$N_{\uparrow\downarrow} = N_0 \cdot \exp\left\{-\sigma_{\uparrow\downarrow} \cdot \mathrm{L} \cdot \mathrm{n}\right\},$$

$$\sigma_{\uparrow\uparrow(\uparrow\downarrow)} = \int d\Omega \frac{d\sigma_0}{d\Omega}\left(1 \mp \mathrm{P_e} \cdot \mathrm{R}\right) = \\ = \sigma_0\left(1 \mp \mathrm{P_e} \cdot \bar{\mathrm{R}}\right)$$

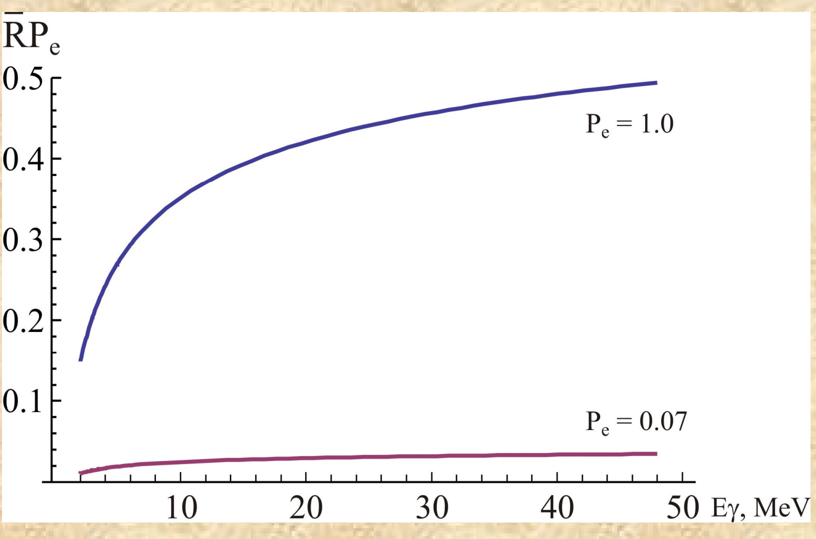
L – thickness, n - electron concentration

The transmission asymmetry

$$\mathrm{T}_{est} = \frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}} = \frac{\exp\left\{\sigma_0 \cdot \mathrm{P_e} \cdot \bar{\mathrm{R}} \cdot \mathrm{L} \cdot \mathrm{n}\right\} - \exp\left\{-\sigma_0 \cdot \mathrm{P_e} \cdot \bar{\mathrm{R}} \cdot \mathrm{L} \cdot \mathrm{n}\right\}}{\exp\left\{\sigma_0 \cdot \mathrm{P_e} \cdot \bar{\mathrm{R}} \cdot \mathrm{L} \cdot \mathrm{n}\right\} + \exp\left\{-\sigma_0 \cdot \mathrm{P_e} \cdot \bar{\mathrm{R}} \cdot \mathrm{L} \cdot \mathrm{n}\right\}} = \tanh\left\{\sigma_0 \cdot \mathrm{P_e} \cdot \bar{\mathrm{R}} \cdot \mathrm{L} \cdot \mathrm{n}\right\}$$



For $P_e = 0.07$,
$E_\gamma = 56$ MeV
difference ~ 7%



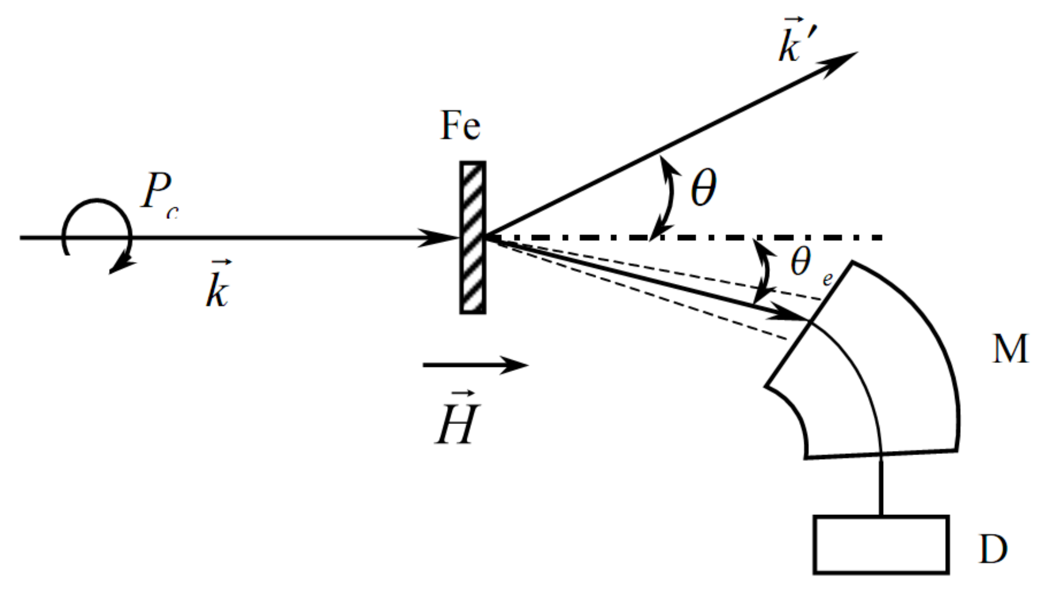
Exp	E_γ, MeV	σ_0, mbarn	$\bar{R}$	T_{est}	T_{sim}
KEK	**56**	**13.2**	**0.506**	**0.0153**	**0.013**
SLAC	**7.9**	**59.6**	**0.327**	**0.0446**	**0.034-0.036**

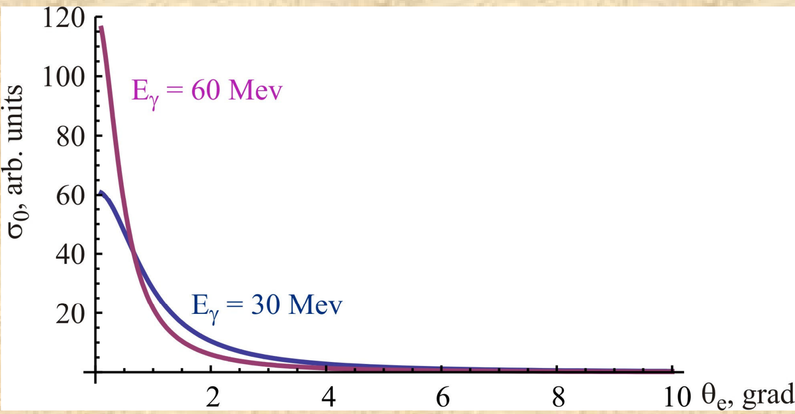
$$P_e = 0.07, n = 2.18 \cdot 10^{24}\ \text{cm}^{-3}, L = 15\ \text{cm}$$

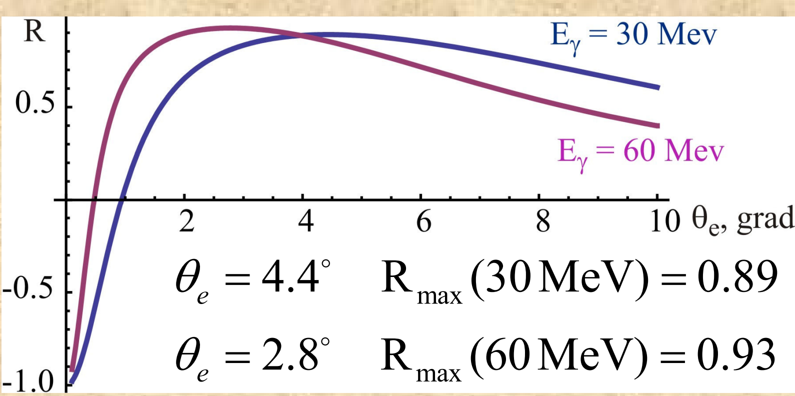
Transmission polarimetry:

- possible contribution from shower photons
- low rate due to large length of iron (photon attenuation length for $E_\gamma \approx 60$ MeV, $\lambda = 30$ g/cm^2 = 4 cm)
- low asymmetry ratio

The possible scheme for compton polarimeter without above mentioned disadvantages [A.S. Aryshev, A.P. Potylitsyn, M.N. Strihanov. IX Workshop on High Energy Spin Physics, SPIN01, Dubna, 373 (2001)]



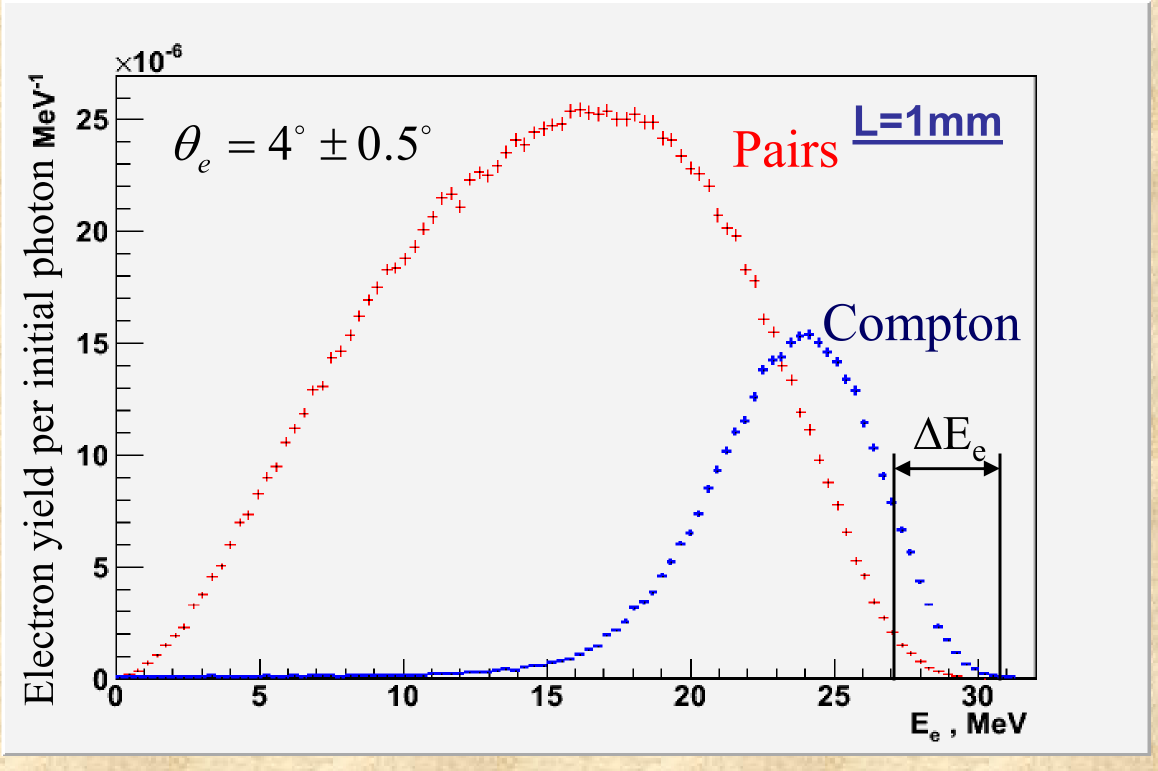


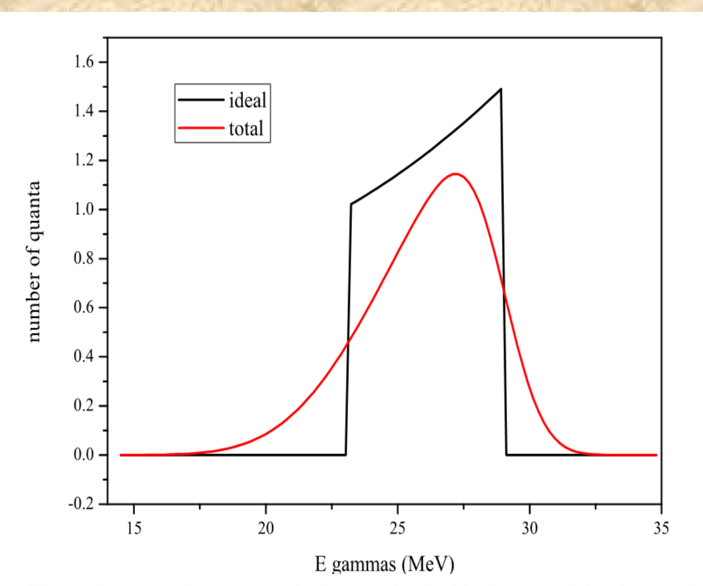


$\theta_e = 4.4^\circ$ $\quad R_{\max}(30\,\mathrm{MeV}) = 0.89$

$\theta_e = 2.8^\circ$ $\quad R_{\max}(60\,\mathrm{MeV}) = 0.93$

Monte-Carlo simulation





Collimated spectra of gammas. Black curve for the ideal case, red for simulated

$$\mathrm{T} = \frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}} = \frac{P_e P}{1 + N_p / N_c}$$

$$N_p = \int_{\Delta E} N_{pair}\, dE_e; \quad N_c = \int_{\Delta E} N_{compton}\, dE_e$$

$$\Delta E \rightarrow E_{e\min} = 27.5\ \mathrm{MeV},\ E_{e\max} = 31\ \mathrm{MeV}$$

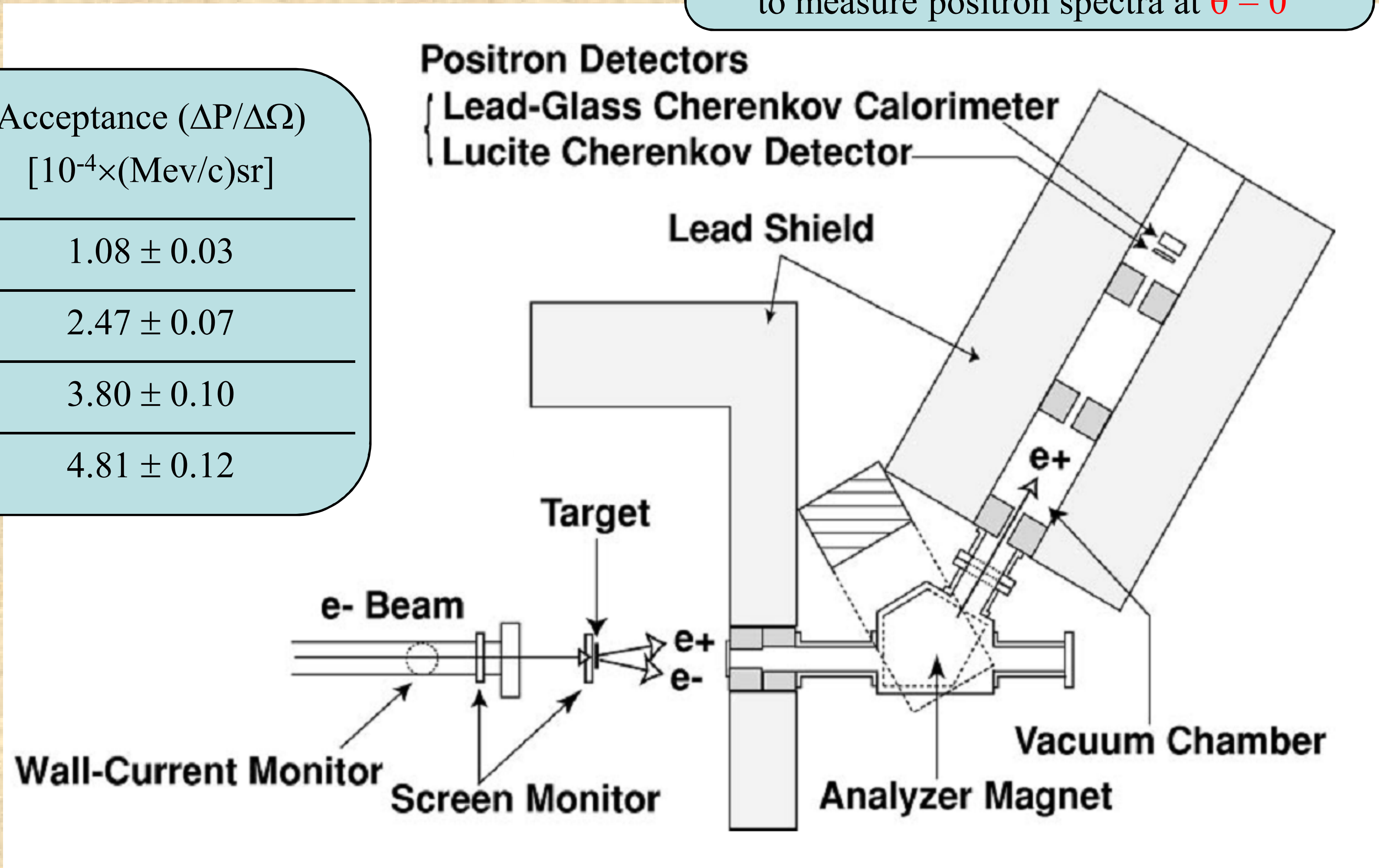
$$\mathrm{Yield} \sim 3 \cdot 10^2\ e^- / \mathrm{bunch}$$

$$N_p / N_c = 0.146; \quad \mathrm{T} = 0.055$$

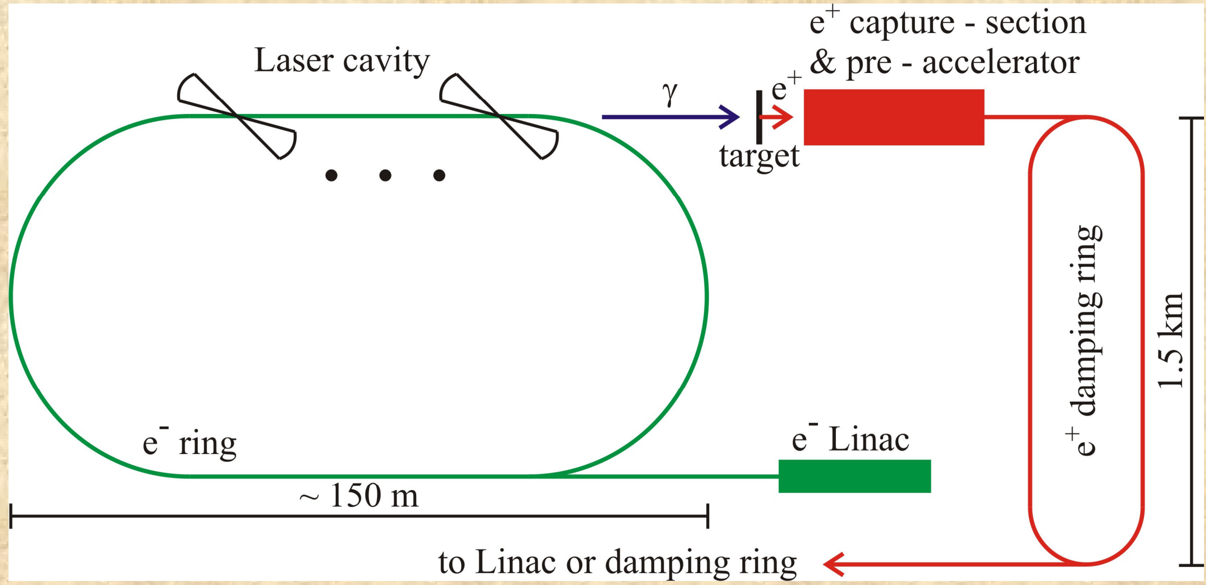
A spectral – angular selection of scattered electrons may provide significant increasing of an analyzer power

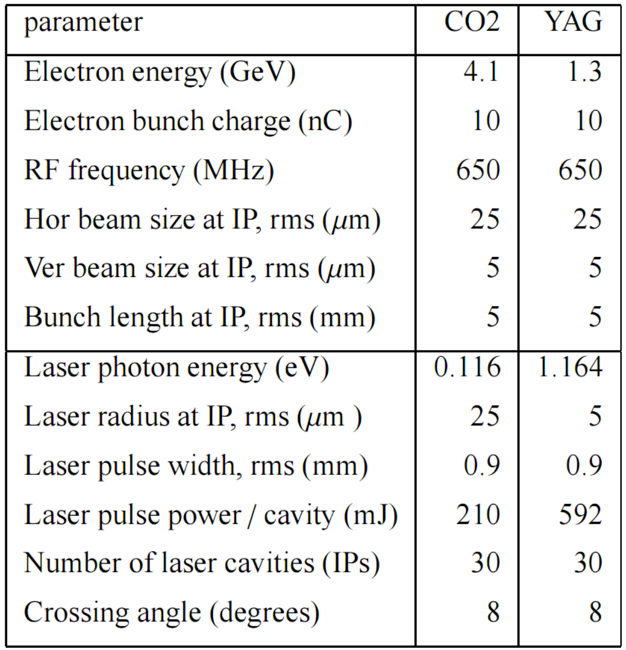
The Magnet Spectrometer was used in [T. Suwada et al. PRE, **67**, 016502 (2003)] to measure positron spectra at $\theta = 0°$

P_{e+} (Mev/c)	Acceptance ($\Delta P/\Delta\Omega$) [$10^{-4}\times$(Mev/c)sr]
5	1.08 ± 0.03
10	2.47 ± 0.07
15	3.80 ± 0.10
20	4.81 ± 0.12

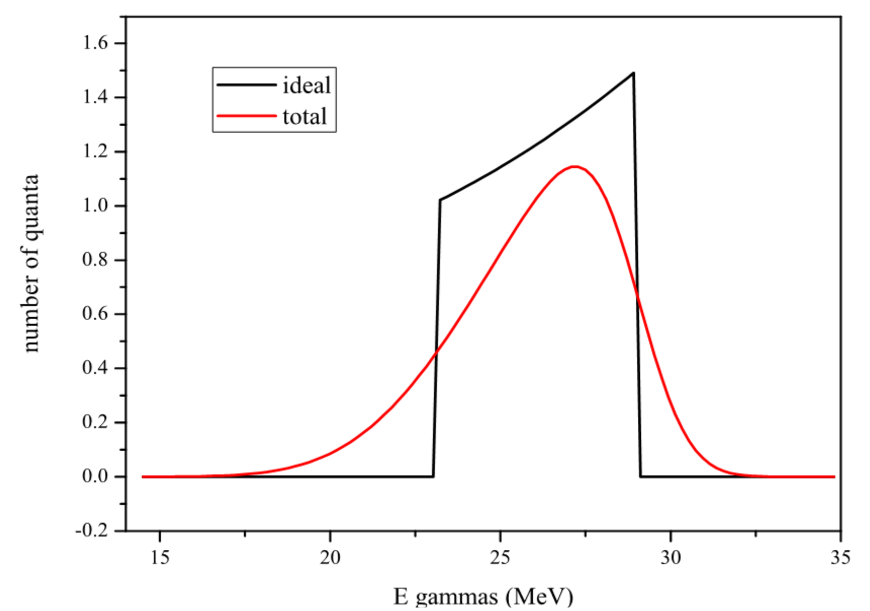


The ILC scheme proposed [S.Araki et al. Snowmass (2005)]





parameter	CO2	YAG
Electron energy (GeV)	4.1	1.3
Electron bunch charge (nC)	10	10
RF frequency (MHz)	650	650
Hor beam size at IP, rms (μm)	25	25
Ver beam size at IP, rms (μm)	5	5
Bunch length at IP, rms (mm)	5	5
Laser photon energy (eV)	0.116	1.164
Laser radius at IP, rms (μm)	25	5
Laser pulse width, rms (mm)	0.9	0.9
Laser pulse power / cavity (mJ)	210	592
Number of laser cavities (IPs)	30	30
Crossing angle (degrees)	8	8



Collimated spectra of gammas. Black curve for the ideal case, red for simulated

$n_{ph}(23.2\text{ MeV} \le E_\gamma \le 29\text{ MeV}) \sim 0.22$ per e^-

$\overline{n} = n_{ph}(0 \le E\gamma \le 29\text{ MeV}) \sim 0.9$ per e^-

There may be a needful for precise measurement of Pc.

The Poisson distribution for mean $\bar{n}$:

$$P_{\bar{n}}(n) = \exp(-\bar{n}) \frac{(\bar{n})^n}{n!}$$

(n = 0,1,2,…. – number of emitted photons by electron)

For $\bar{n} = 0.9$

n	$P_{\bar{n}}(n)$
0	0.41
1	0.36
2	0.17
3	0.05
4	0.01
5	….
	1

$U_m(\gamma_0,\gamma)$ – normalized electron energy distribution after emission of m photons ($mc^2 = 1$)

[A. Kolchuzhkin,A. Potylitsyn et al. NIMB, **201**, 207 (2003)]

$$U_m(\gamma_0,\gamma)=\int_0^{E_{\gamma\,\max}}\frac{d\sigma}{dE_\gamma}(\gamma_0,\hbar\omega_0,E_\gamma)U_{m-1}(\gamma_0-E_\gamma,\gamma)\,dE_\gamma$$

$$U_0(\gamma_0,\gamma)\to\exp\left\{-\frac{(\gamma_0-\gamma)^2}{2\sigma^2}\right\}$$

$$\gamma_0=1.3\ \text{GeV}/mc^2=2544$$

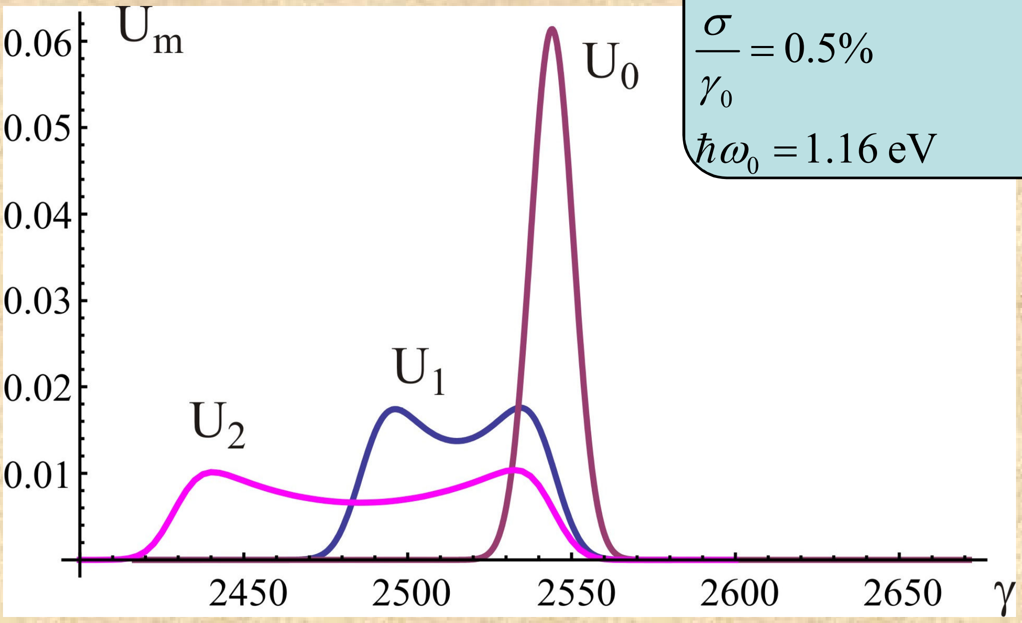
$$\frac{\sigma}{\gamma_0}=0.5\%$$

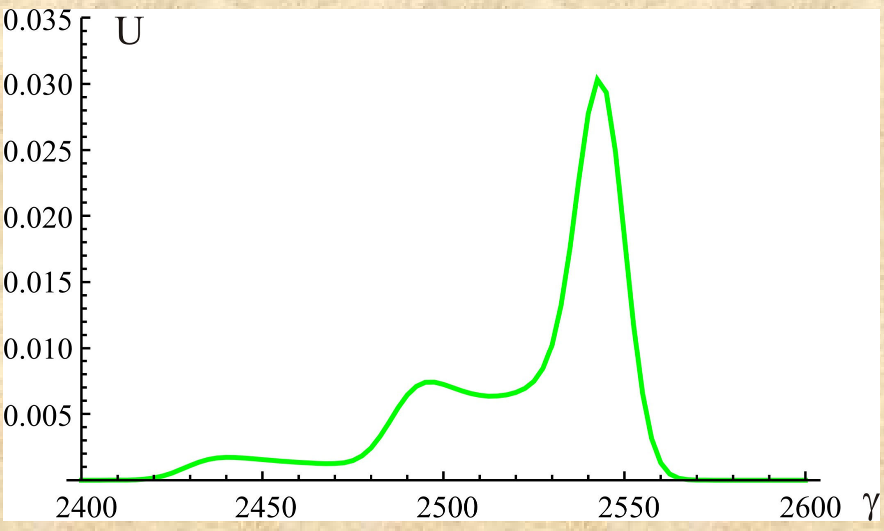
$$\hbar\omega_0=1.16\ \text{eV}$$

The result electron distribution

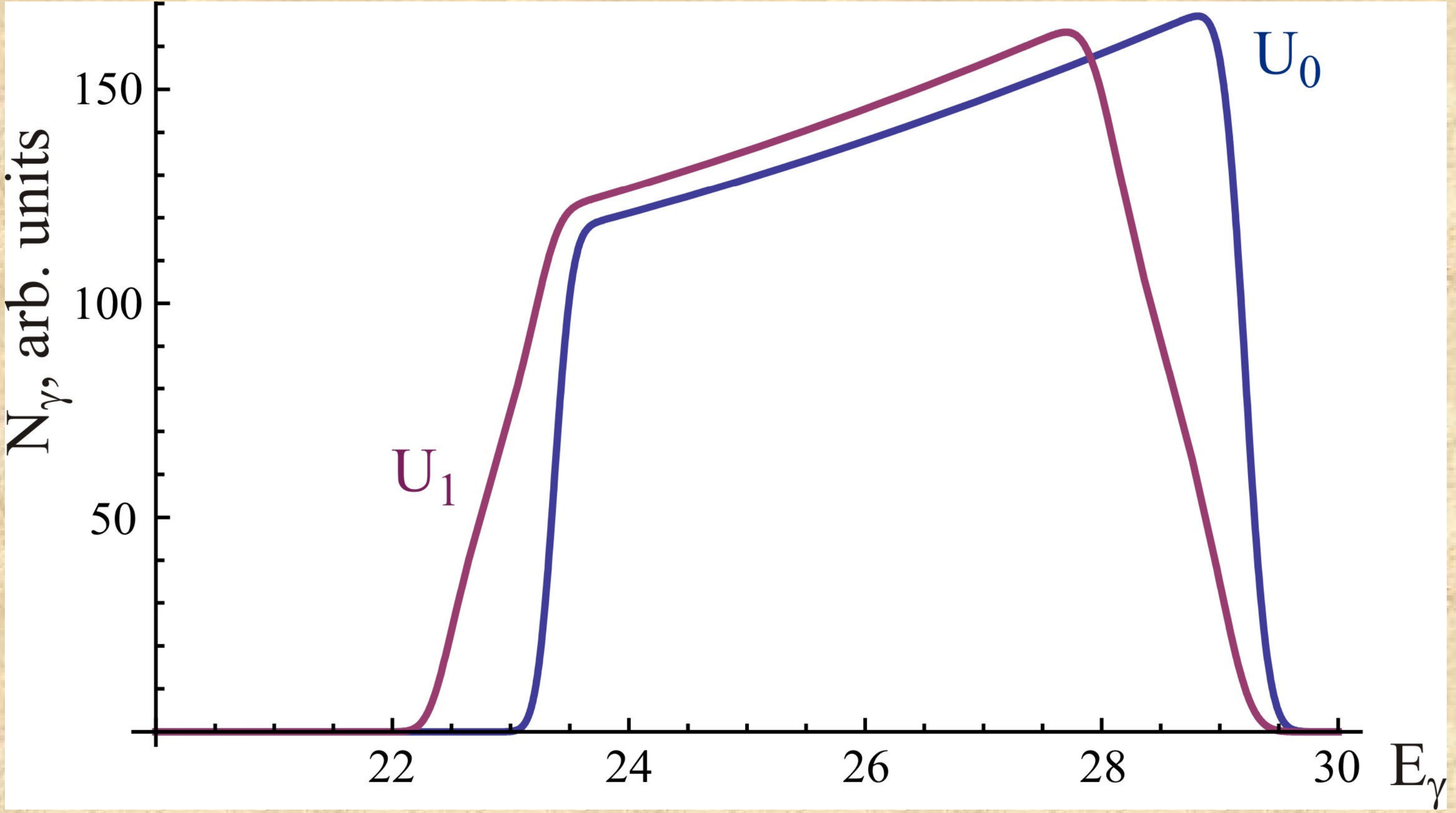
$$U_\Sigma(\gamma_0,\gamma)=\sum_{m=0}^{2}P_{\bar{n}}(m)U_m(\gamma_0,\gamma)$$

$$\int U_\Sigma(\gamma_0,\gamma)\,d\gamma=1$$





Photon spectra from electrons with U_0, U_1



CONCLUSION

- The polarimeter proposed may provide the increasing of analyzing power at list 4 times in comparison with a transmission polarimeter
- In order to decrease a systematic error the scheme proposed allows to change magnetization field H after passing of a few (< 10) bunches
- The intensity of detected electrons allows to achieve a statistical error ~ 10 % during a few seconds

Thank you for your attention!