PROSPECTS FOR ENERGY CALIBRATION AT DAΦNE

Mario Antonelli

Manuela Boscolo

Massimo Placidi

CONTENTS

- Aims and Motivation
- Radiative Polarization in e^+e^- Storage Ring
- Controlled Depolarization
  - Touschek IBS (Moller cross section)
  - Compton Scattering Polarimetry
- Perspectives for DAΦNE
- Outlook

MOTIVATION

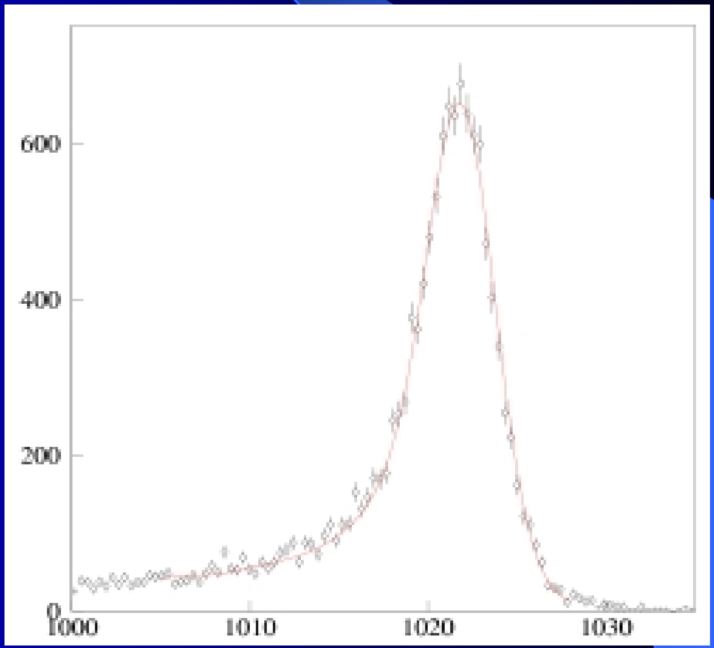
Measurement of W from KLOE

KLOE drift chamber to measure e^+e^- invariant mass in Bhabha's.

Absolute calibration ~10^{-4} (100 keV)

Work ongoing for improvements

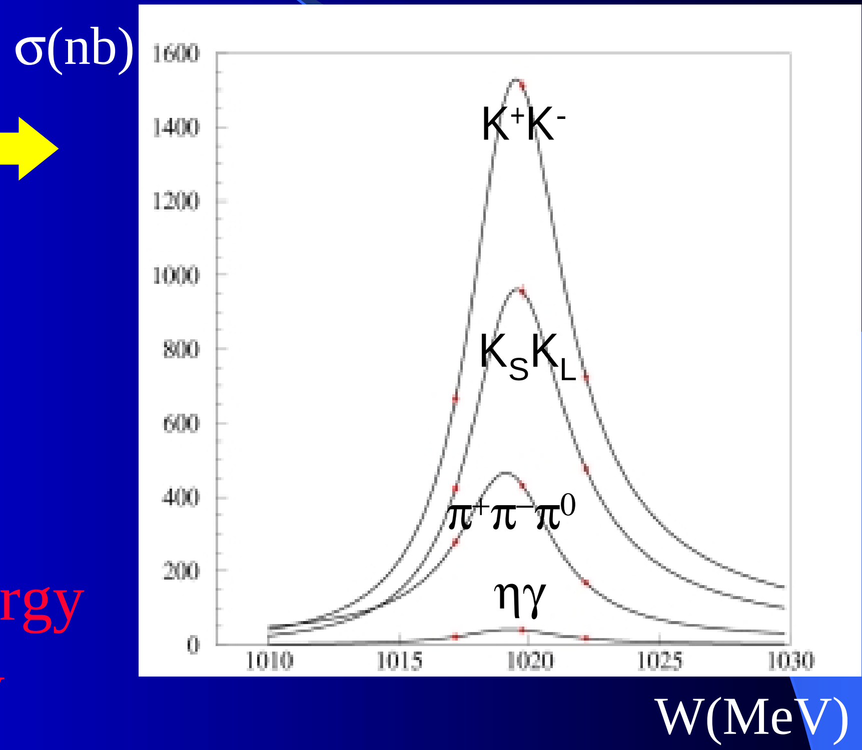
Limitation: momentum calibration



e^+e^- invariant mass (MeV/c^2)

MOTIVATION (cont'd)

- Precise measurement of the ϕ meson mass by a lineshape analysis



- Precise measurement of K_S and $K^{\pm}$ mass

AIM: knowledge of beam energy to a few 10^{-5} relative accuracy

Resonant Depolarization

Alternative to Magnetic Methods

- Record **accelerator physics effects** related to **polarization states** of the circulating beams: Controlled Depolarization
- Indirect: Spin-dependent large-angle intrabeam scattering (Touschek)
- Direct: Polarimetry and Resonant Depolarization

e^+e^- Radiative Polarization

(Sokolov-Ternov)

Quantum emission of Synchrotron Radiation naturally polarizes lepton beams in Storage Rings

S-T polarization time $\tau_{ST} = c_{ST}\left(\frac{\rho_{eff}^3}{\gamma_e^5}\right)$

$$c_{ST}(e^{\pm}) = \frac{8}{5\sqrt{3}}\frac{m_e}{\hbar\, r_e} = 2.832\cdot 10^{18}\, s\, m^{-3}$$

$$(\rho_{eff}^3)^{-1} = \frac{1}{C}\oint\frac{ds}{|\rho(s)|^3} \equiv \frac{I_3}{C}$$

Radiation integral from magnetic structure

Numerical examples for τ_{ST}

- LEP : 320 / (19) min (Z^o / W)
- PEP II : 260 min (LER) / 220 min (HER)
- DAΦNE : 580 / 20 min (0.51 / 1 GeV)

Polarization time evolution

- Time evolution: $P(t) = \frac{8}{5\sqrt{3}} \frac{(1 - e^{-t/\tau_{eff}})}{\tau_{ST}/\tau_{eff}}$

- Effective Polarization time: $\frac{1}{\tau_{eff}} = \frac{1}{\tau_{ST}} + \frac{1}{\tau_d}$

- Equilibrium level defined by depolarizing time τ_d

Depolarizing Effects

- Single beam
  - Spin-orbit coupling
  - Spin diffusion
  - Solenoidal fields
- Beam-beam

Spin Dynamics

Thomas, Bargmann-Michel-Telegdi

- Dynamics of spin vector **S** along the magnetic structure described by Thomas-*BMT* equation

$$\frac{d\mathbf{S}}{dt} = \Omega_{BMT} \times \mathbf{S}$$

$$\Omega_{BMT} = -\frac{e}{m_e\gamma_e}\left[(1+a_e\gamma_e)\mathbf{B}_\perp + (1+a_e)\mathbf{B}_\parallel - \left(a_e + \frac{1}{1+\gamma_e}\right)\beta_e\gamma_e \times \frac{\mathbf{E}}{c}\right]$$

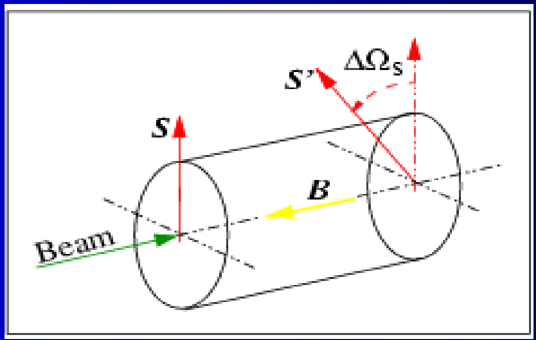
- Spin vector **S** precesses around **B** and **E** directions with angular frequency $\boldsymbol{\Omega}_{BMT}$

Spin Dynamics (cont'd)

- Precession around Vertical magnetic field in Storage Rings smeared by spin kicks from Horizontal and Solenoidal fields
- Horizontal fields from vertical off-center orbit in Quadrupoles.

➡ refine vertical closed orbit !!!

- Spin rotation in Solenoids:



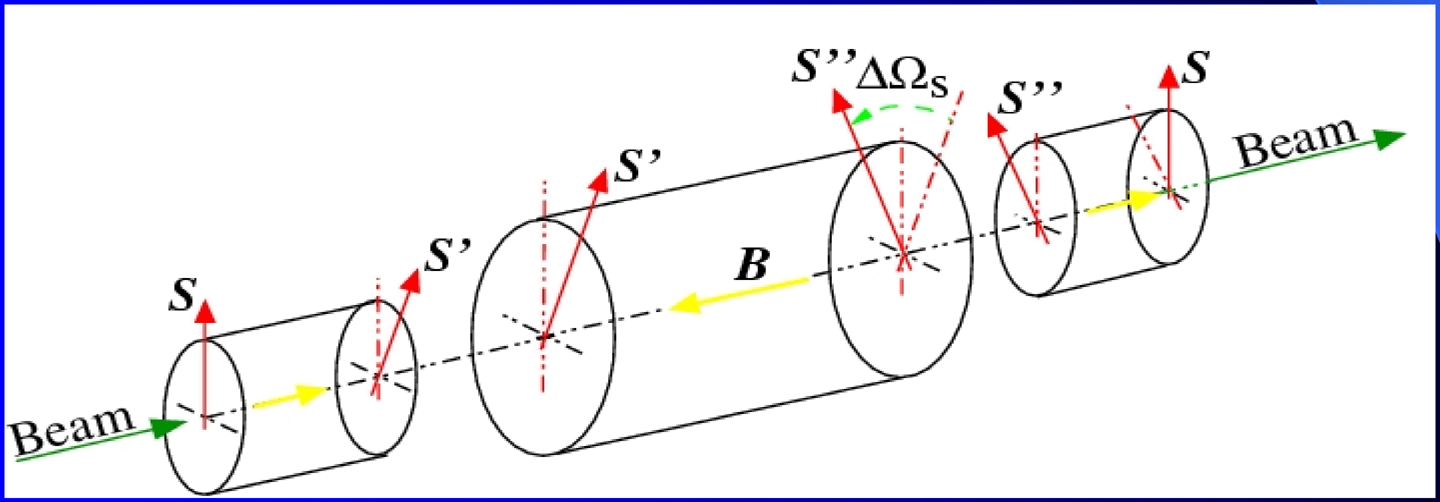
$$\Delta\Omega_s = \frac{e(1+a_e)}{m_e\gamma_e}\int B_s\,ds$$

SolSpin Compensation

Spin rotation from main solenoid compensated in anti-solenoids

Skewed trajectories might require additional orbit bumps

Spin bumps required in absence of anti-solenoids (LEP)



Intrinsic Depolarization

BMT: Horizontal and Longitudinal magnetic fields cause the spin vector to deviate from vertical orientation along guide field in main dipoles.

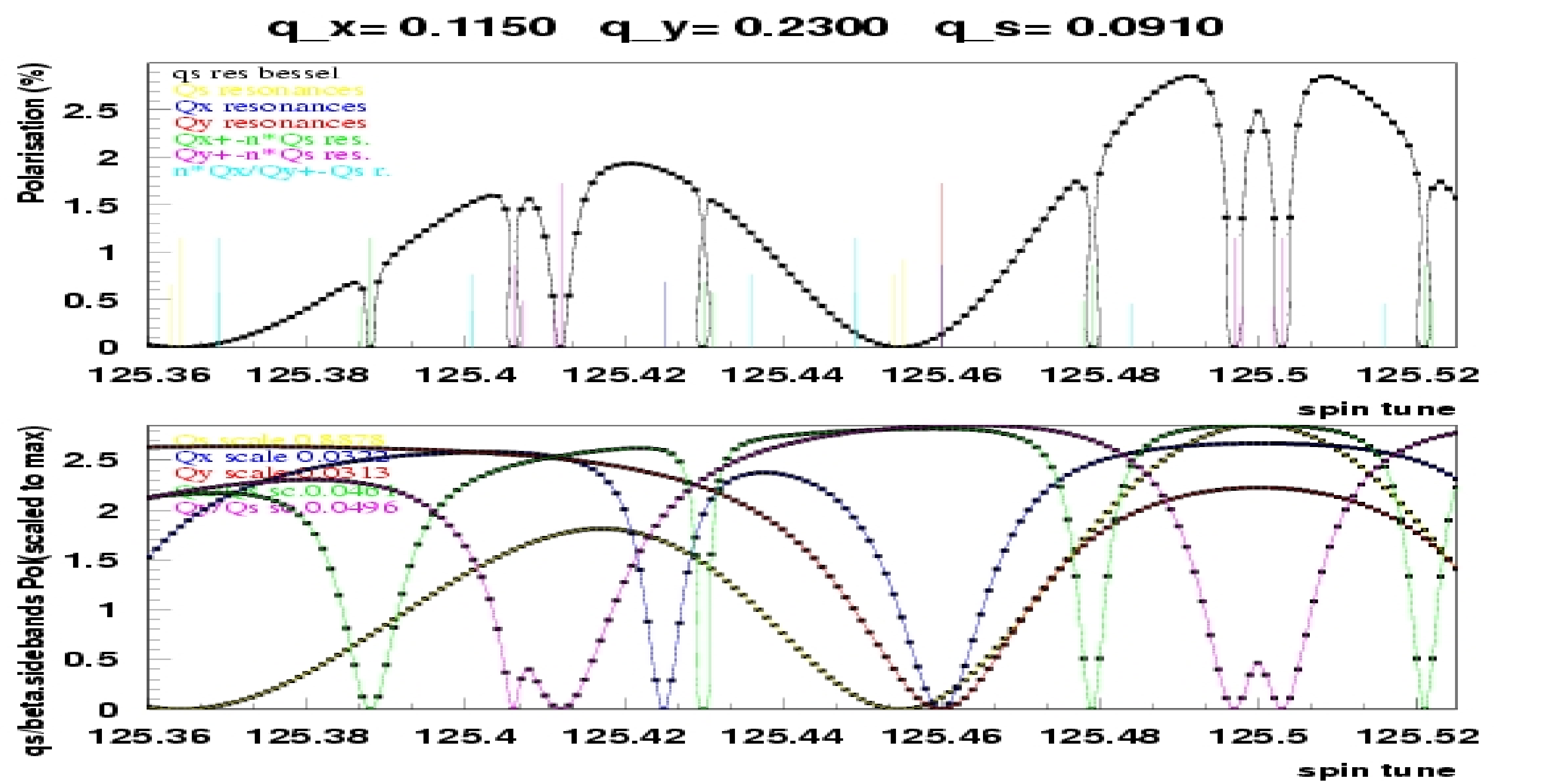
Spin-orbit coupling resonances occur whenever the spin tune ν is commensurate with any combination of tunes **Q**

$$\nu = k + k_x Q_x + k_y Q_y + k_s Q_s, \quad k, k_x, k_y, k_s \in \mathcal{Z}$$

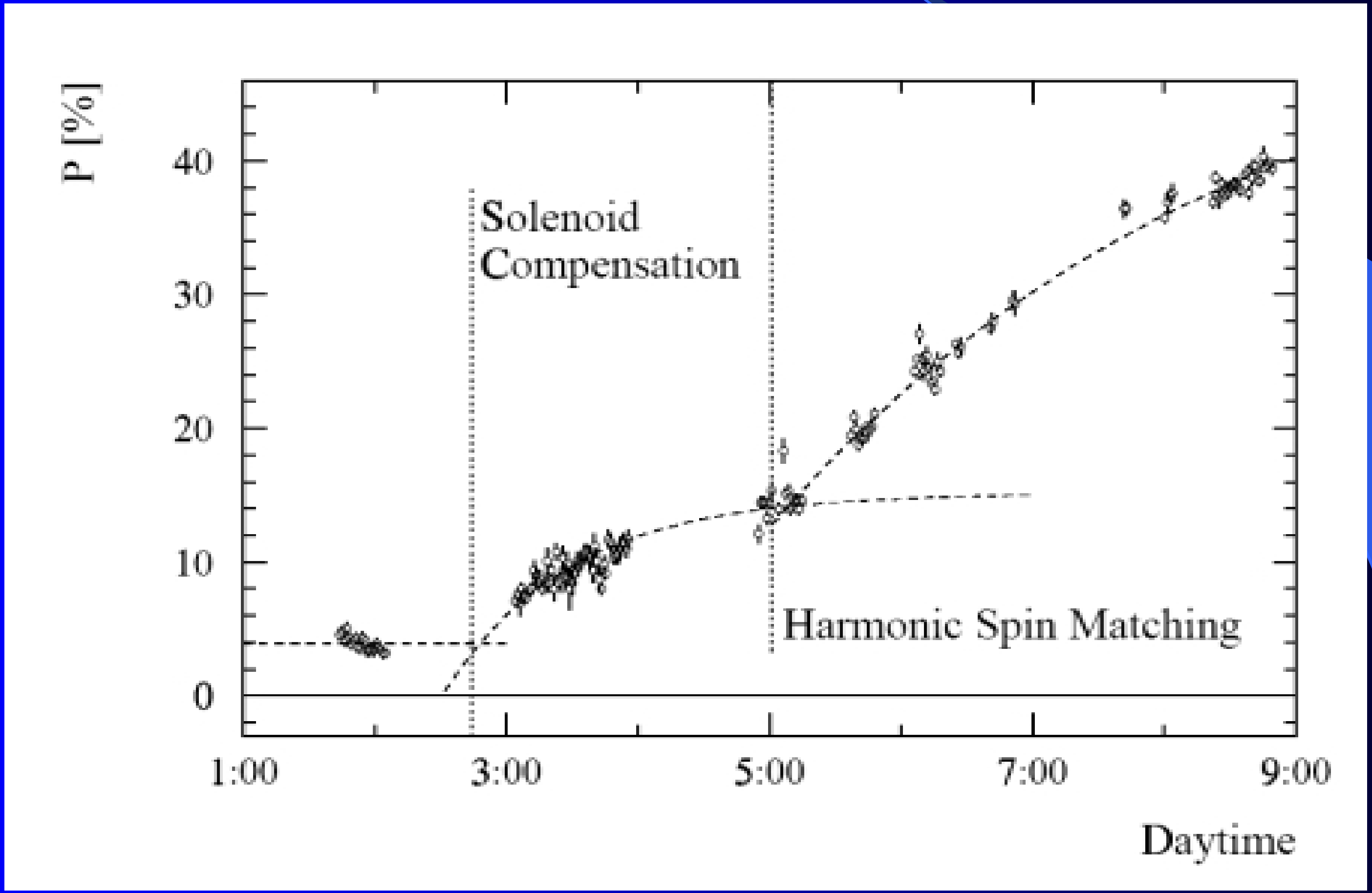
Compensation Strategies

- Careful choice of working point
  - Intrinsic and Beam-beam
- Clean vertical closed orbit and spurious dispersion
- Precession in solenoidal fields
- Harmonic Spin Matching
  - Orbit harmonics correction w. orbit bumps

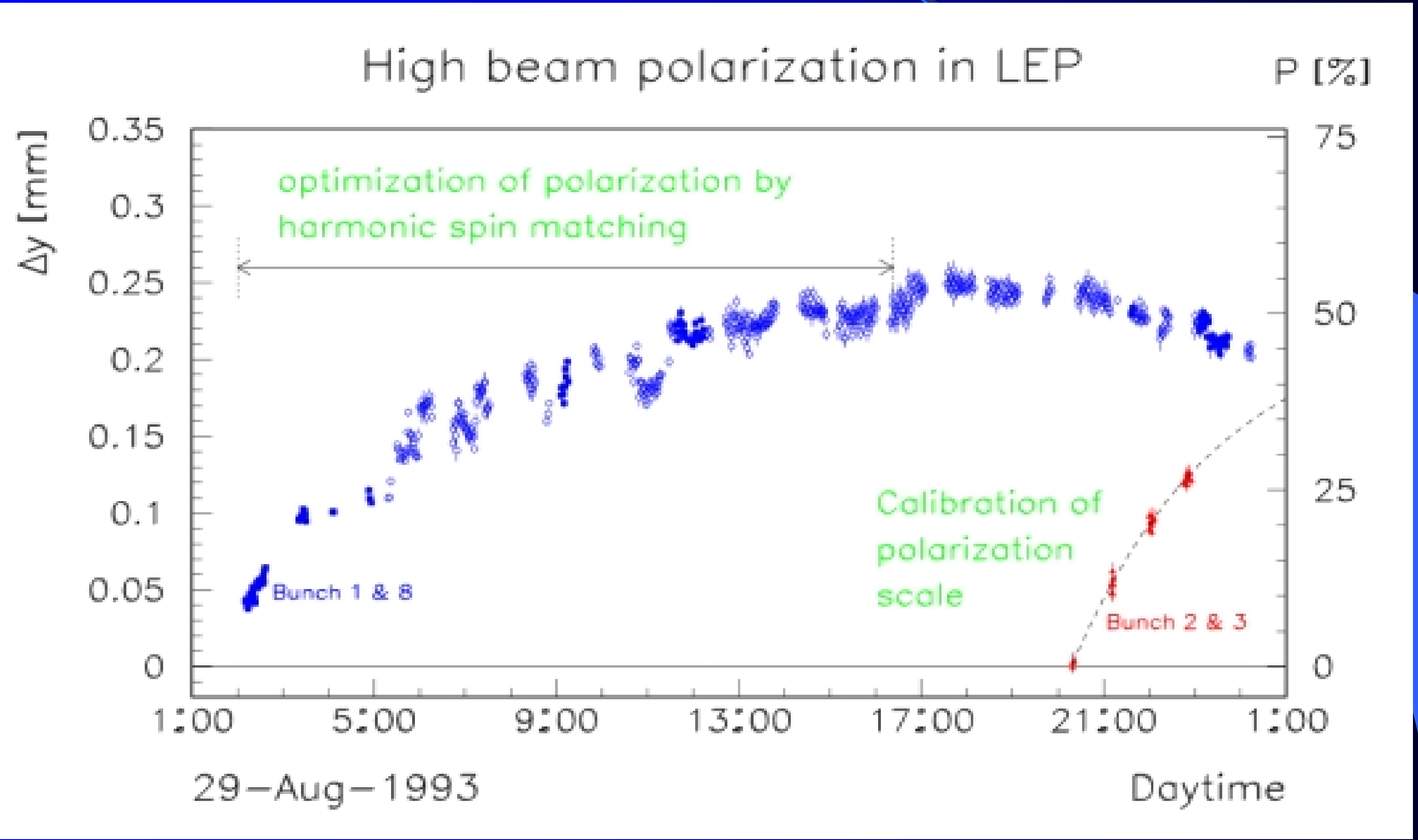
Simulated spin resonances
LEP @ 56 GeV



Polarization optimization
LEP @ 45.6 GeV



LEP optimization



Spin tune and beam Energy

- Spin tune : number of spin precessions per revolution

  only depends on Beam Energy

$$\nu = N_s + \delta\nu = a_e \gamma_e = \frac{E_{GeV}}{m_e c^2 / a_e}$$

$a_e = (g-2)/2$: electron gyromagnetic anomaly

$\frac{m_e c^2}{a_e} = 440.6486\ MeV$: energy shift for unitary spin change

Typical spin tune figures

- Integer part N_s of spin tune known from $\oint_C B_y(s)\,ds$
- Spin tune figures for some e^+e^- rings:

LEP (Z^0)	103.469
PEP II / HER	20.455
PEP II / LER	7.045
DAFNE (0.51 GeV)	1.157
DAFNE (1.019 GeV)	2.313

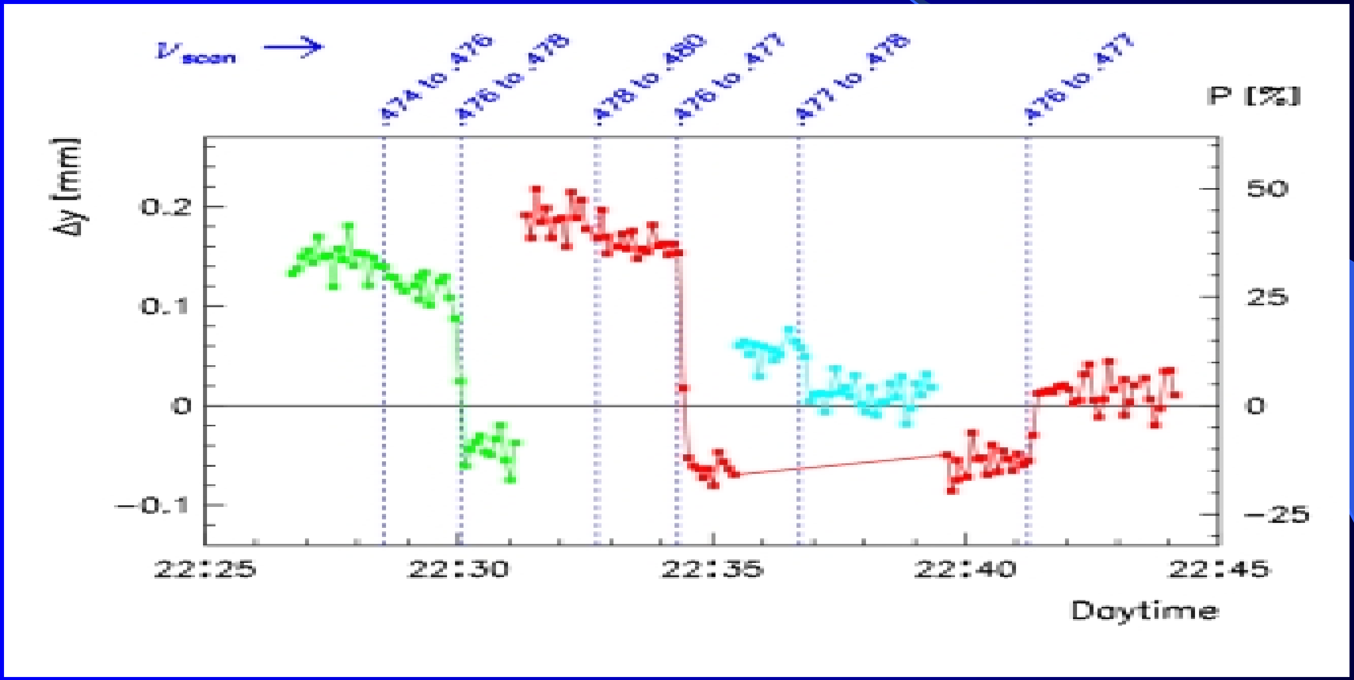
Resonant Depolarization

➡ Measure the Spin Precession Frequency

- Frequency-controlled radial RF magnetic field (vertical kicker) makes spin vector to precess away from vertical direction with spin kicks $\Delta\Omega_s \propto V_k \cos(\omega_k t)$
- Resonant Depolarization: $\omega_k^{res} \equiv \omega_s = 2\pi f_{rev}(\nu - N_s)$
- Beam energy:

$$\langle E \rangle_{GeV} = \nu \cdot \left(\frac{m_e c^2}{a_e} \right) = \left(N_s + \frac{f_k^{res}}{f_{rev}} \right) \times 0.4406486$$

Resonant Depolarization at LEP



M. Bassetti: Beam Energy function of azimuth due to quantum radiation.

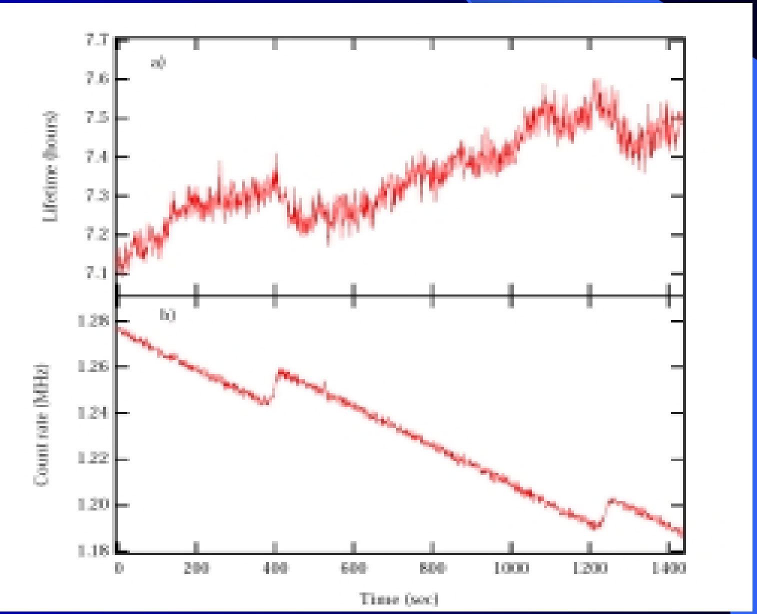
→ ***RD*** measures **E** at depolarizer point!

Spin-Dependent Beam Lifetime
(Touschek IBS)

- OBSERVABLE: Moller spin-dependent scattering rate in large-angle Intrabeam Touschek Scattering
- Larger lifetime / Smaller background for polarized beams

Beam lifetime at ALS
in presence of two partial
spin depolarizations.

Data: fast BCT and BLM



Spin-dependent IBS @ DAΦNE

Spin-dependence in Touschek IBS simulation at **DAΦNE** :

H. Brook prescription + Møller in non relativistic approximation

$$\frac{d\sigma}{d\Omega} = \frac{4r_0^2}{\beta^4}\left[\frac{4}{\sin^4\theta} - \frac{3+P^2}{\sin^2\theta}\right]$$

Simulated background results
(KLOE optics)

P	δRate/Rate
90%	9%
50%	2%
20%	0.3%

IBS&POL at DAΦNE

- Need high beam current to maximize BKG rates
- Very small effect (3×10^{-3}) at a possible P~20%
- A ~20% polarization level needs >120 minutes
- Fast background changes from orbit fluctuations

Compton Polarimetry demistified

Klein-Nishina total cross section in terms of electron and photon polarization states (Fano, Lipps and Toelhoek)

$$\frac{d\sigma_c(\vec{P}_e,\vec{\xi})}{d\Omega} = \left(\frac{r_e}{\sqrt{2}}\frac{k'}{k'_o}\right)^2 \left[\Phi_0 + \Phi_1(\vec{\xi}) + \Phi_2(\vec{\xi},\vec{P}_e)\right]$$

Bayer and Khoze laser polarimetry:
Circular light (ξ=0,0, ±1) on vertically polarized e+e- ($P_y = P_\perp$): **$\Phi_1 = 0$**.

Spin-dependent term Φ_2 generates an *up-down* Compton asymmetry in the vertical distribution of the backscattered photons.

Compton Asymmetry

The Vertical distribution of the backscatteredCompton photons is shifted due to the azimuthal angle ϕ' by an amount $\Delta\tilde{y}$

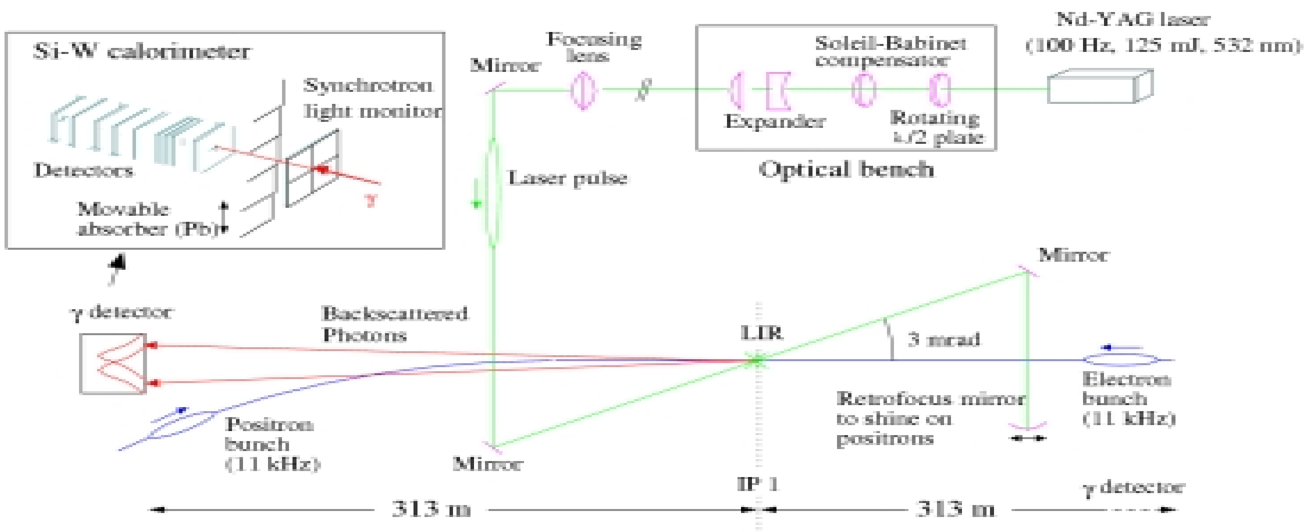
$$A_{\perp} = \frac{\Phi_2(\vec{\xi}, P_y)}{\Phi_0} = \xi_3 \, P_{\perp} \cdot \boldsymbol{\kappa}(\theta', \lambda_{ph}, \gamma_e) \, \mathbf{sin} \, \boldsymbol{\phi}' \propto \Delta\tilde{\boldsymbol{y}}$$

The amplitude of the shift $\Delta\tilde{y}$ under reversal of the photon helicity $(\xi_3 = \pm 1)$ is a measurement of the polarization level.

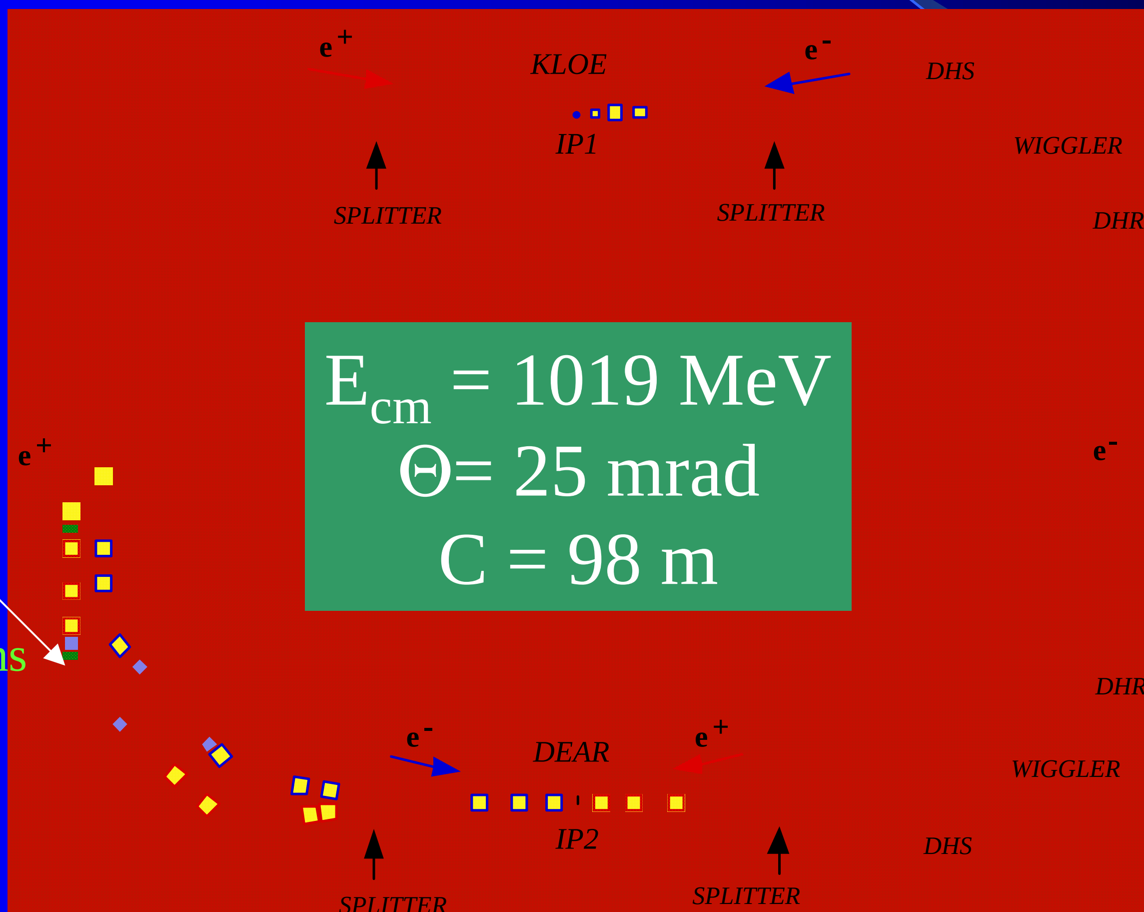
More on e-polarimetry: Handbook of Acc. Phys. & Engineering

➡ **LEP: min. polarization level for ECAL ~5-10%**

LEP Polarimeter



DAΦNE LAYOUT



Compton gammas

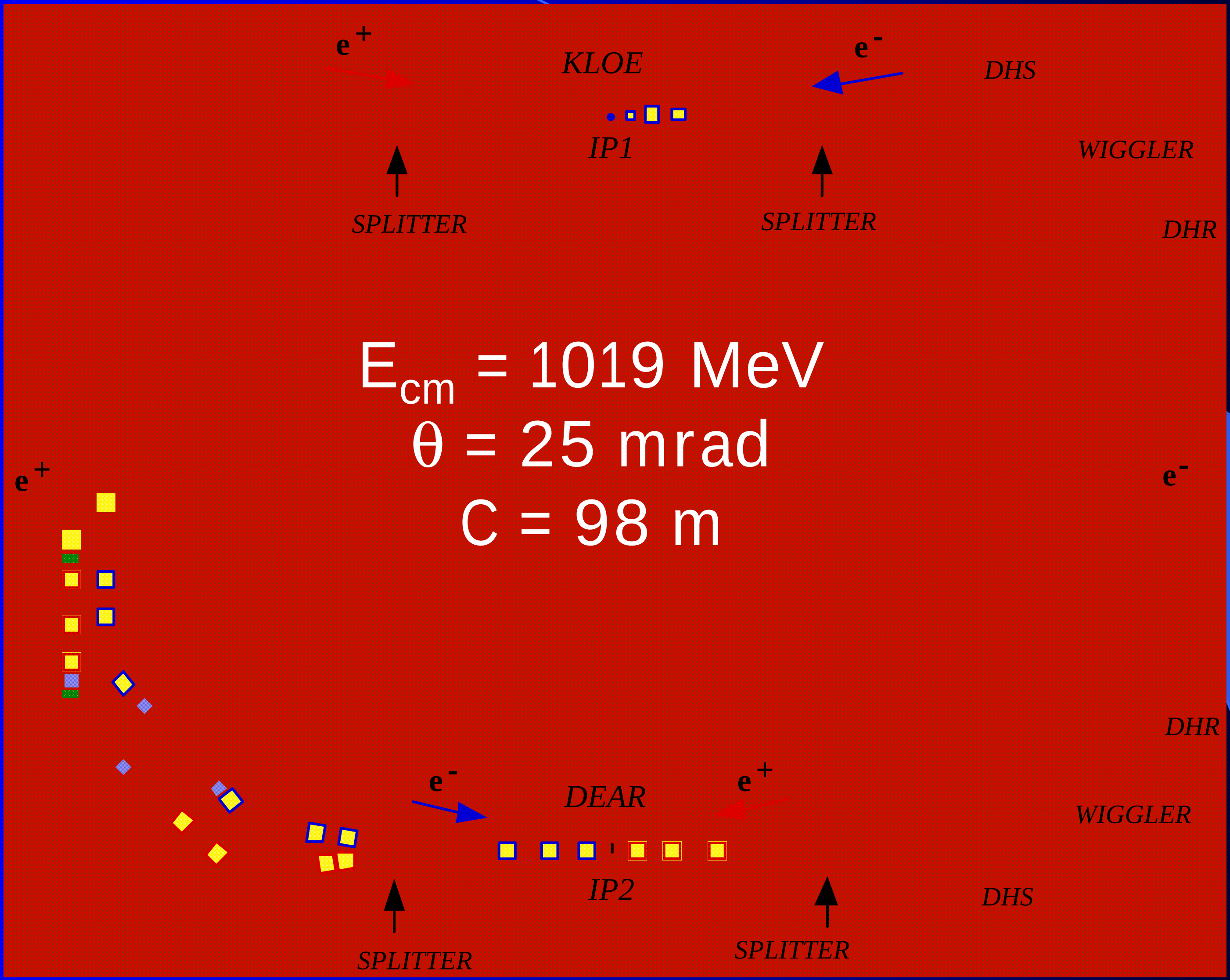
Laser photons

Cost Estimate

• Nd-YAG Laser - Frascati/CERN/LBNL expertise:	
any Solid State Laser (except your pointer)	50-80 k$
• Photon polarization control	15-25 “
• Photon steering (r.c. mirrors etc.)	10-20 “
• Si strip γ-detector	25-40 “
• Controls&Electronics	10-15 “
• **TOTAL**	**k$ 110 - 180**

OUTLOOK

- Accurate measurement of the **average beam energy** in DAΦNE achievable via measurement of Spin Precession Frequency which **only depends on energy**.
- Indirect methods exploiting spin-dependent terms in Touschek intrabeam scattering require **high P-level**.
- Direct observation of Controlled RD more challenging and costly but **more control** and **FUN with lower P**!



$E_{cm} = 1019$ MeV

$\theta = 25$ mrad

$C = 98$ m