# SPEAR2 Compton polarimeter

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2021-12-21

Questions:

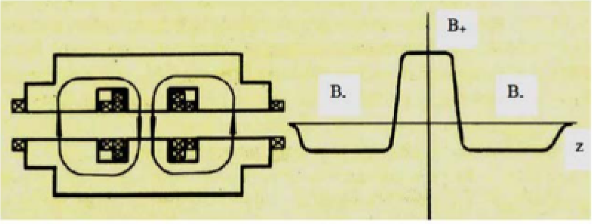
http://ias.ust.hk/program/shared_doc/2020/202001hep/conf/20200121_lt_Jie_GAO.pdf

# CEPC Self Polarization at Z-pole with Asymmetric Wigglers

- **Special wigglers to speed up self-polarization:**

| $N_w$ | $B_+$ | $L_+$ | $B_-$ | $L_-$ | $\frac{\tau_p}{\tau_p^w}$ | u | $\frac{\Delta E_w}{\Delta E}$ | $\frac{P_0^w}{P_0}$ |
|---|---|---|---|---|---|---|---|---|
| 10 | 0.6T | 1m | 0.15T | 2m | 13.4 | 0.34 | 3.2 | 0.99 |

u: Fraction of radiation energy loss enhancement. :Factor of beam energy spread enhancement.

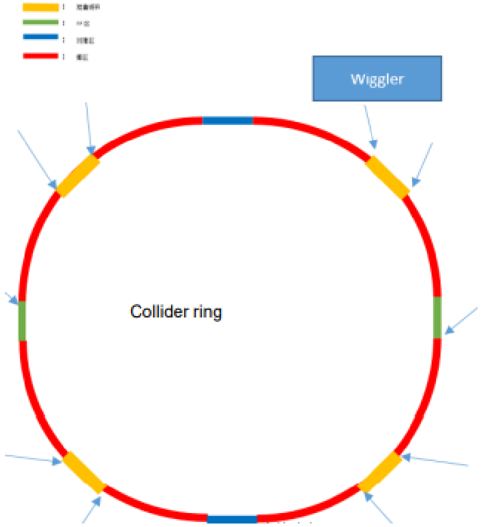



$P(t) = P_0^w(1 - e^{\frac{-t}{\tau_p^w}})$

$\tau_p^w = 19.6h, P(t) = 5\%, P_0^w = 0.913,$

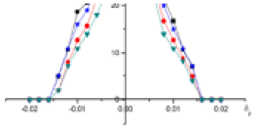
$t = 1.10h$

**5% is enough for energy calibration.**




In collaboration
wi
of

CEPC运行在Z-pole能量时可以通过正负电子横向自极化(5%~10%极化率)对撞来进行精确达$10^{-6}$的能量标定。为了提高自极化速度，需要在对撞环中加装10台左右的特种扭摆磁铁。为了进一步实现Z-pole能量下的高极化度(>50%)水平极化



DA

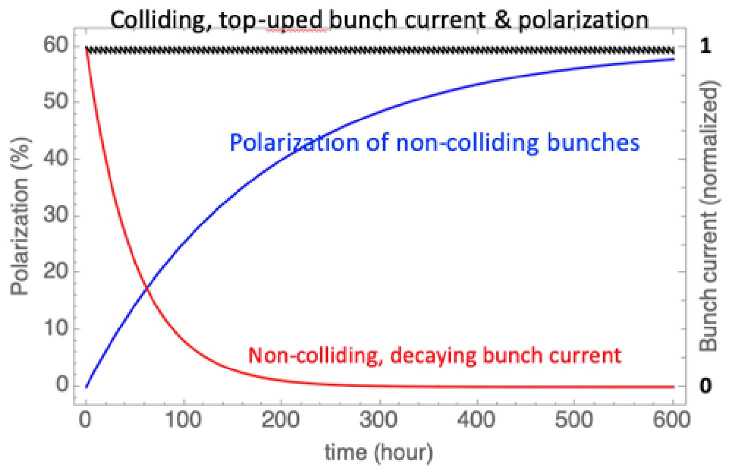
**Longitudinal polarized beam collision and full plozrization injection scheme are under studies**

1. Wigglers 共需要10个吗？
2. 在CEPC上具体的design

Questions: https://indico.ihep.ac.cn/event/14938/other-view?view=standard

# How to polarize the e+/e- beam?

| | Non-colliding bunches | Colliding bunches |
|---|---|---|
| Beam lifetime | 20~100 hours, a high bunch current is not necessary | ~2 hours |
| Injection frequency | Every 20~100 hours | Top-up injection, every ~ 10 seconds |
| Evolution of beam polarization | Exponential build-up<br>Time scale ~ several hundred hours | Saw-tooth near the level of injected beam polarization |
| Usage | Resonant depolarization | Colliding beam experiments |
| Method to realize desired beam polarization | Use asymmetric wigglers to reduce self-polarization build-up time | Inject polarized beam |




Note: injection of polarized beam for colliding experiments, enables resonant depolarization measurement of some colliding bunches, which could help reduce the systematic errors of RD on non-colliding bunches only.

1. Collision bunch & non-collision bunch?

Questions:

https://www.sciencedirect.com/science/article/pii/S0920563202900058

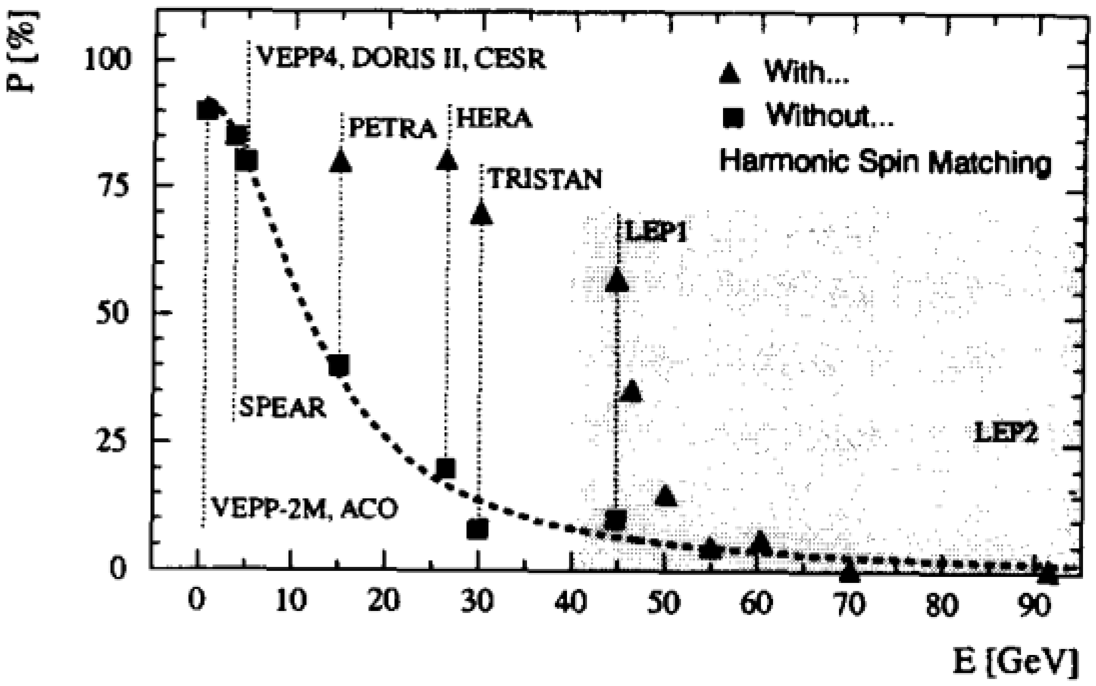



Figure 10. Maximum observed levels of polarization versus beam energy for different electron storage rings. The polarization level is indicated with (triangle) and without (square) Harmonic Spin Matching.

Questions:

- Spin rotator 转换效率
- Energy dependence?

# Outline

- Introduction of SPEAR
- Polarization in SPEAR
- Compton polarimeter method
- Compton polarimeter setup
  - Compton scattering
  - Polarimeter & Lattics
  - Detector
  - Data acquisition system
- Compton polarimeter result
- Discussion & Conclusion

# SPEAR Ⅱ

## Stanford Positron-Electron Asymmetric Rings

- SPEAR Ring machine at SLAC, completed in 1972.  1974~1975, upgrade to SPEAR Ⅱ, the maximum energy for operation can reach 4GeV. In 1990, the machine was dedicated to synchrotron radiation research. 2003, upgrade to SPEAR Ⅲ.
- A single bending magnet beam line, include the 234.1m electron storage ring and 10Hz synchrotron injector with 120MeV LINAC.

- Two particular SPEAR discoveries stand out: The first was the 1974 discovery of a particle J/psi. The second discovery was a new particle tau.

- The more usual Compton backscattering polarimeters were later installed in many $e^{+}\ e^{-}$ colliders (first at SPEAR.

[1] *https://www-ssrl.slac.stanford.edu/content/spear3/spear-history*
[2] *http://ihep.cas.cn/kxcb/zmsys/200910/t20091030_2643482.html*

# Polarization in SPEAR

## ◻ Motivation

- These measurements were made to test theories of polarization and depolarization in high energy $e^+e^-$ storage rings
- To explore the influence of the beam-beam force on spin motion, where theory provides little guidance.
- Beam polarization affect angular distributions and production rates for many processes of interest. Control of beam polarization makes it possible to study effects that would be inaccessible or difficult to measure with unpolarized beams.
  - For example, transversely polarized beams were used to confirm the spin-l/2 behavior expected for quarks.
  - Longitudinally polarized beams should play an important role at higher energies where weak-electromagnetic interference phenomena are expected to become important.

## ◻ Method & feasibility

- Transverse polarization of positron beam is determined by measuring the up-down asymmetry via Compton polarimeter.
- If $e^-e^+$ beam polarization is to be useful for experiments, it must be possible to determine at what energies the polarization can be found and to monitor its value as a function of time and machine conditions. This requires a way of making polarization measurements on a time scale that is short compared with the polarization buildup time constant (~ 14 minutes at SPEAR). SPEAR can measure the beam polarization to a few percent in times of the order of 1 minute. *(引申CEPC 极化要求level, 及其要求)*

*https://doi.org/10.1016/0167-5087(83)90056-X*

# Compton polarimeter method

- A detector measured the vertical angular distribution of the backscattered gamma rays.
- An up-down asymmetry in the vertical distribution results from spin-dependent terms in the Compton cross section.
- Define A:

$$A = \frac{Up - Down}{Up + Down}$$

- To cancel certain possible asymmetries due to systematic effects, measurements for both left (L) and right (R) circular polarizations of the laser beam are averaged (with opposite sign):

$$\bar{A} = \frac{A_L - A_R}{2}$$

- The transverse polarization is :

$$\bar{A} = \Pi P_e$$

*Where $\Pi$ is the analyzing power.*

# Compton polarimeter setup

## ◆ 1. Compton scattering process

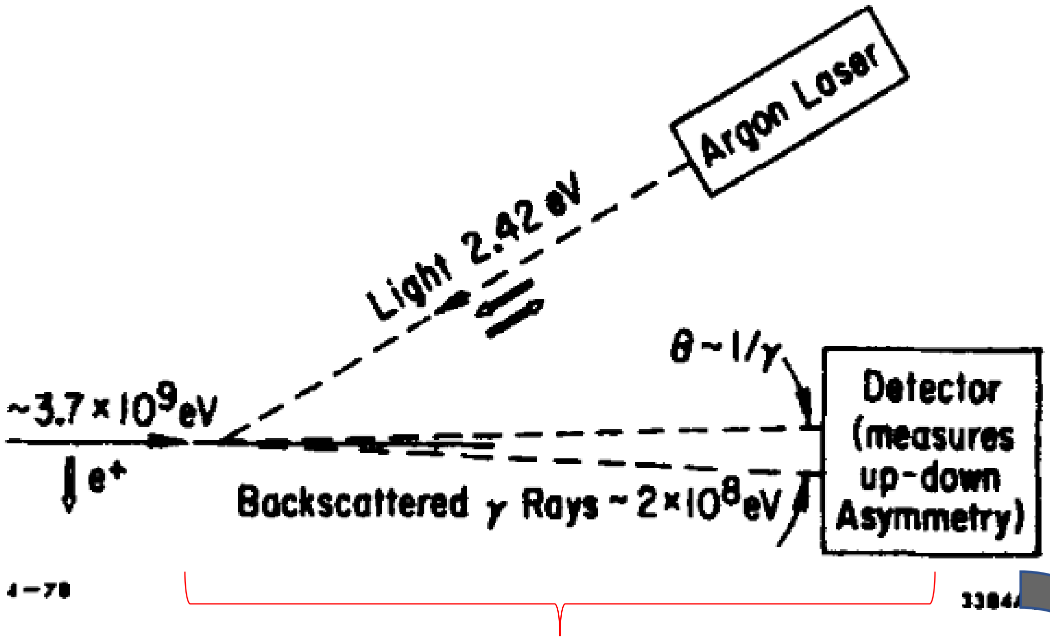



Fig. 1. Schematic layout of the experiment.

*The polar angle of the scattered photons:* $\theta_\gamma \sim \frac{1}{\gamma} = 0.138mrad$

*Detector dimension:* $L_1\theta_\gamma \sim \frac{L_1}{\gamma} = 1.17mm(a\ few\ milimeters)$


1. https://doi.org/10.1063/1.31758
2. https://doi.org/10.1016/0029-554X(79)90268-4


- Laser

- Circularly polarized photons from a laser
- Laser wavelength: $\lambda = \frac{hc}{w} = 514nm$ (可见光波段)
- Maximum backscattering photons: $w_{max} = 446keV$
- The laser is pulsed in synchronism with the rotation of the positron bunch;
- Width: 12-15ns
- Peak power: 80W

- Positron

- Energy: ~3.7GeV
- Cross angle: 8mrad
- The positron 0.5ns long

These small angles pose two problems for a polarization monitor.
First, the angular resolution of the detector must be line enough so that the polarization can be resolved.
Second, the angular divergence of the electron or positron beam must be small compared to typical backscattered gamma ray angles or else the polarization information will be lost.

# Compton polarimeter setup

## ◆ 2. Polarimeter & lattics

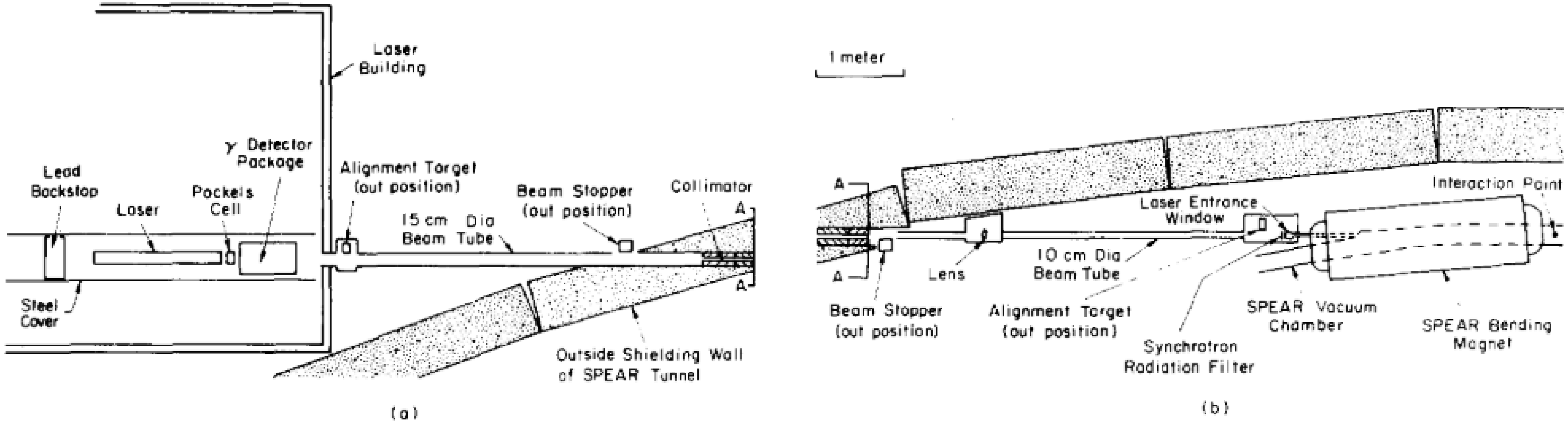



Fig. Plan view of the experimental layout (a) outside and (b) inside the SPEAR shielding tunnel

- 8 mrad to the plane of the storage ring. This angle provides the required separation between incident and backscattered beam lines, allowing about 10 cm clearance at the position of the gamma ray detector.
- Fine steering adjustments are made by translating the remotely movable lens located mid.

- Reduce the SR background: This aluminum (2 cm thickness) serves as a partial filter to reduce the background from synchrotron radiation. Additional filtering is provided by a 1.8 mm thickness of niobium placed in the backscattered beam line near the exit from the SPEAR vacuum chamber.

# Compton polarimeter setup

◆ 3. Detector

*a 1/2 radiation length tungsten converter plate to generate electron-positron pairs*

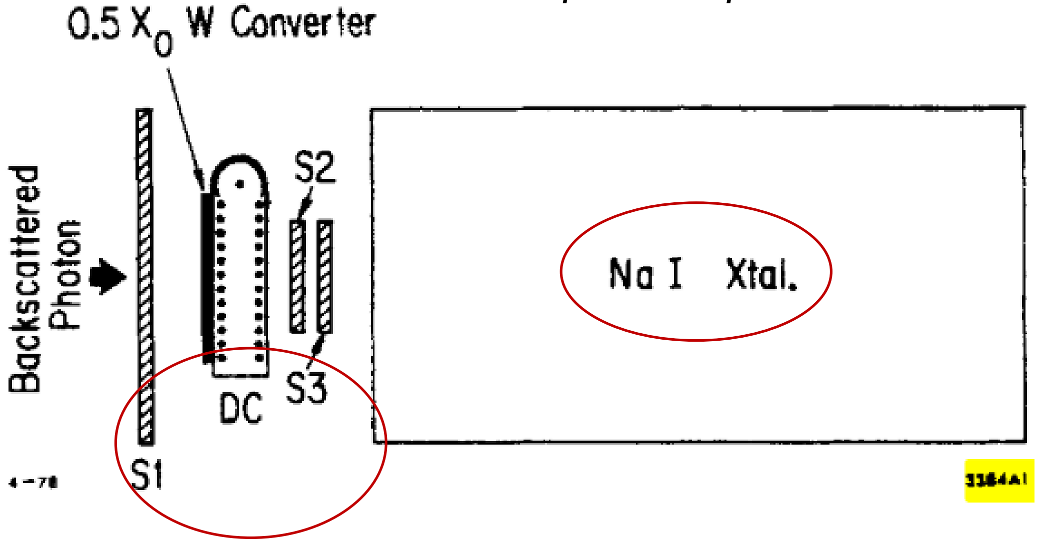



Fig. 2. Detector arrangement.

*The detector resolution of 200 pm*

Detector

- A photon trigger is crated with a telescope of three small scintillation counters:
  - S1 (7.6cm×7.6cm) vetoes charged particles
  - S2 and S3 (2.5cm×4.1cm) follow a tungsten converter plate and are put in coincidence.
  - *(The "start" pulse is obtained from the basic* $\overline{S1}S2S3$ *photon trigger; )*
  - A single small drift chamber (DC) (2.5cm×5cm active area) is placed immediately behind the converter to measure the vertical position of each detected photon.
- This arrangement is followed by a 3-inch diameter by 6-inch long Nal crystal to measure the photon energy.
- In the earlier stages of the experiment, a 1mm wire spacing proportional chamber was used as the detector, with satisfactory results.

https://doi.org/10.1063/1.31758

# Compton polarimeter setup

## ◆ 4. Data acquisition system

- The "start" pulse is obtained from the basic $\overline{S1}S2S3$ photon trigger;
- including a cut on photon energy from the NaI counter;
- the "stop" pulse comes from the drift cell.
- The events are accumulated in two different regions of the analyzer memory, selected according to the photon polarization state determined by the Pockels cell controller.

- The system can accept data at typical back-scattered rates of ~ 10 kHz without serious dead-time losses.
- A run is 2~3 min.

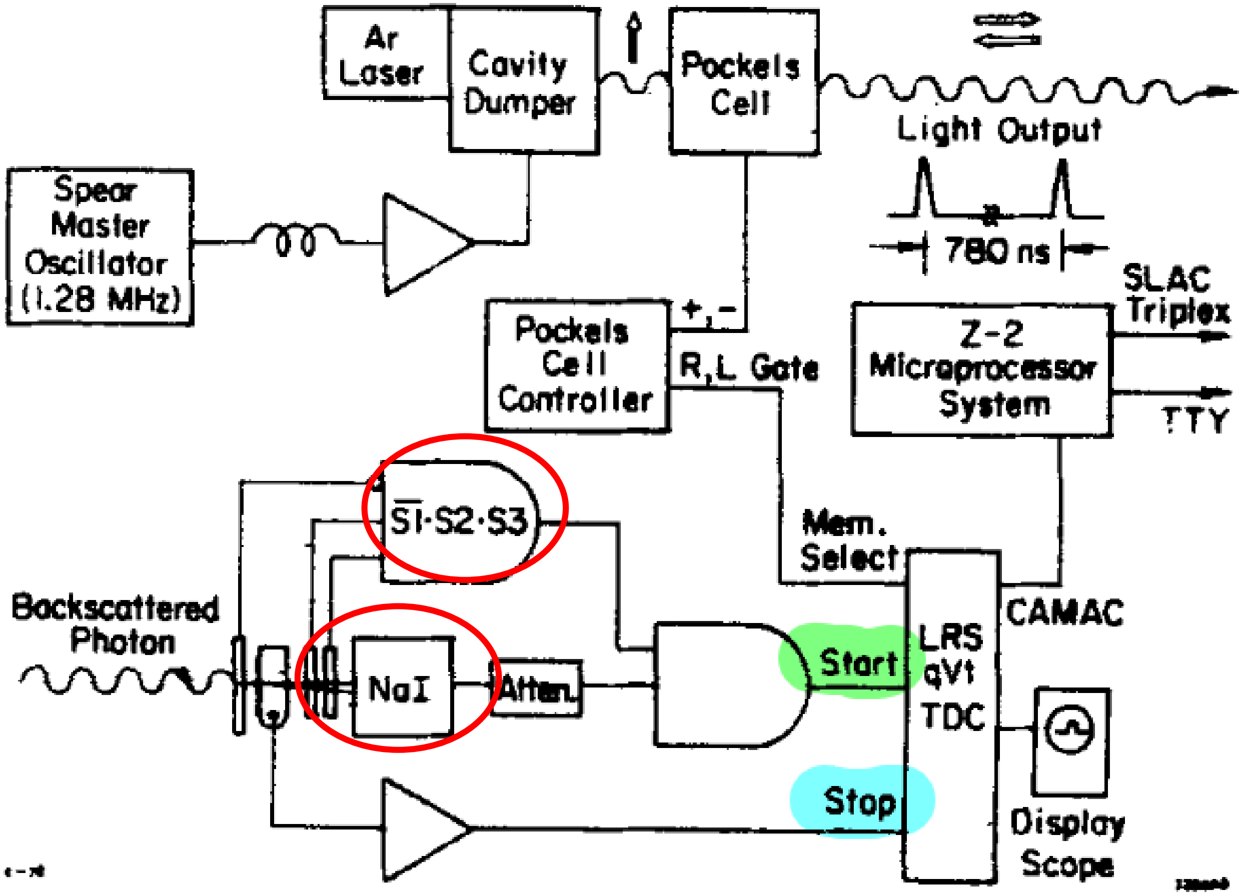



Fig. 3. Data acquisition system.

https://doi.org/10.1063/1.31758

# Compton polarimeter result

- At typical backscattered rates of 10~15 kHz, over $10^6$ events were normally accumulated in a two-minute run.

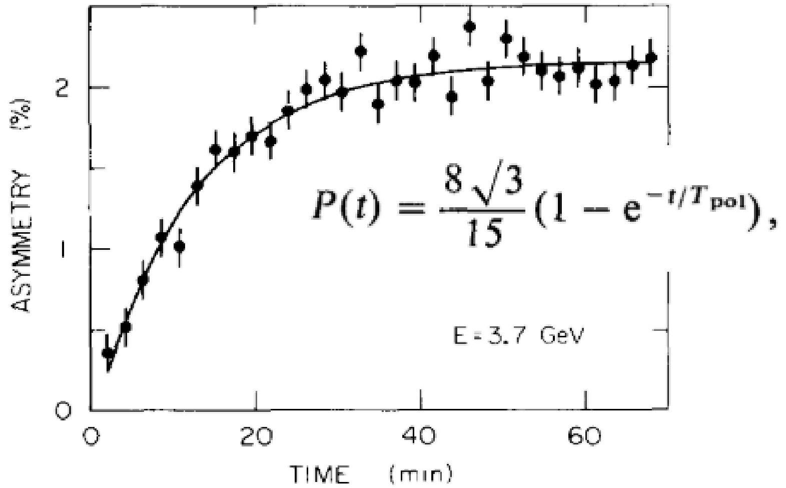



Fig. 11. Measured asymmetry versus time with 3.7 GeV positrons in SPEAR.

Fig. 11 shows an example of asymmetry measurements as a function of time during a single SPEAR fill. The time was defined to start from zero when the storage ring had finished ramping to its final energy of 3.7 GeV.

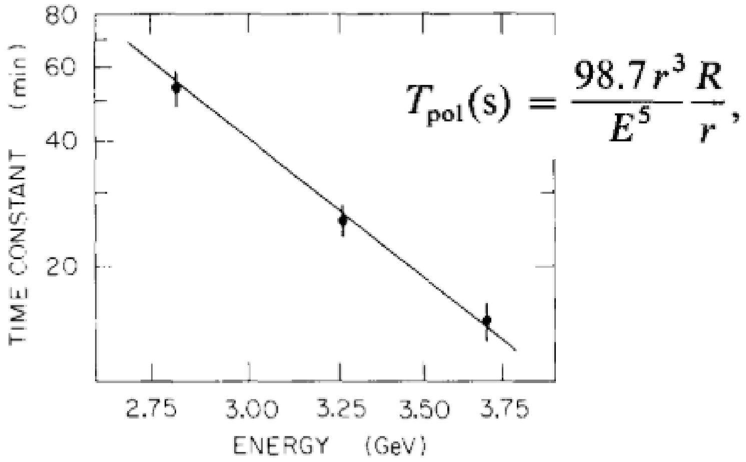



Fig. 12. Polarization time constant versus energy. The data points are the results of fits to the observed build-up of asymmetry at 3 energies. The solid line is the theoretically expected behavior.

For each energy, the time constant Tpol.at 2.82, 3.26 and 3.70 GeV. The solid line represents the theoretical expression from eq. (1). The agreement is excellent.

# Compton polarimeter result

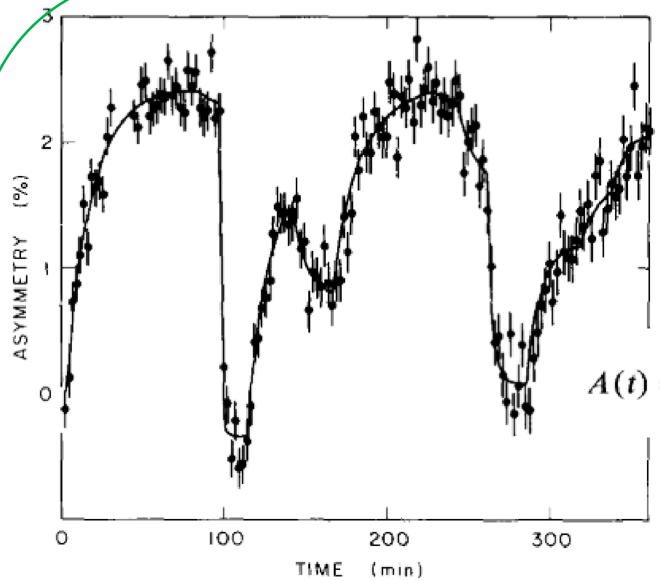



Fig. 13. Asymmetry measurements versus time, for approximately 2 MeV steps of SPEAR energy in the region of 3.60 to 3.64 GeV. The solid line is a fit to eq. (15).

$$A(t) = \frac{A_f}{1+x} + \left[A_i - \frac{A_f}{1+x}\right] \exp\left[-t(1+x)/T_{pol}\right]$$

$A_i$ is the asymmetry at the beginning of the segment;
$A_f$ is the asymptotic asymmetry in the case of no depolarization;
the quantity x is defined as $x = T_{pol}/T_{depol}$,
$T_{depol}$ is the depolarization time constant.
Fitting with x constrained to be positive and the entire curve required to be piecewise continuous. The value of $A_f$ is required to be the same for all segments, and $T_{pol}$ is calculated for each energy using eq. (1). The fitted x values for the full scan are plotted in fig. 14.

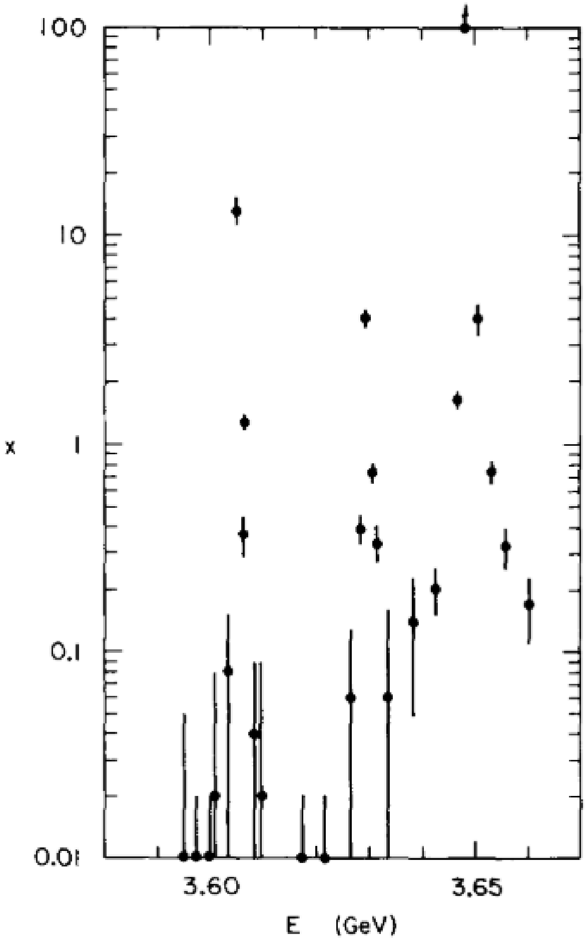



Fig. 14. Fitted values of $x$ from a SPEAR energy scan which includes the data shown in fig. 13.

The depolarization features shown in figs. 13 and 14 are due to resonant depolarization of the beam.

# Discussion & Summary

- The measurements presented above were obtained with a single beam of positrons in the storage ring.
- As indicated by the comparisons shown, the general features of the single-beam results obtained are in good agreement with theoretical expectations.
- Measurements with colliding beams have exhibited the expected tune shifts and broadening of single-beam resonances, but have also shown strong depolarization behavior that is not currently understood.
- Detailed studies of single beam and colliding beam depolarization are continuing and will be reported elsewhere.

# Back-up

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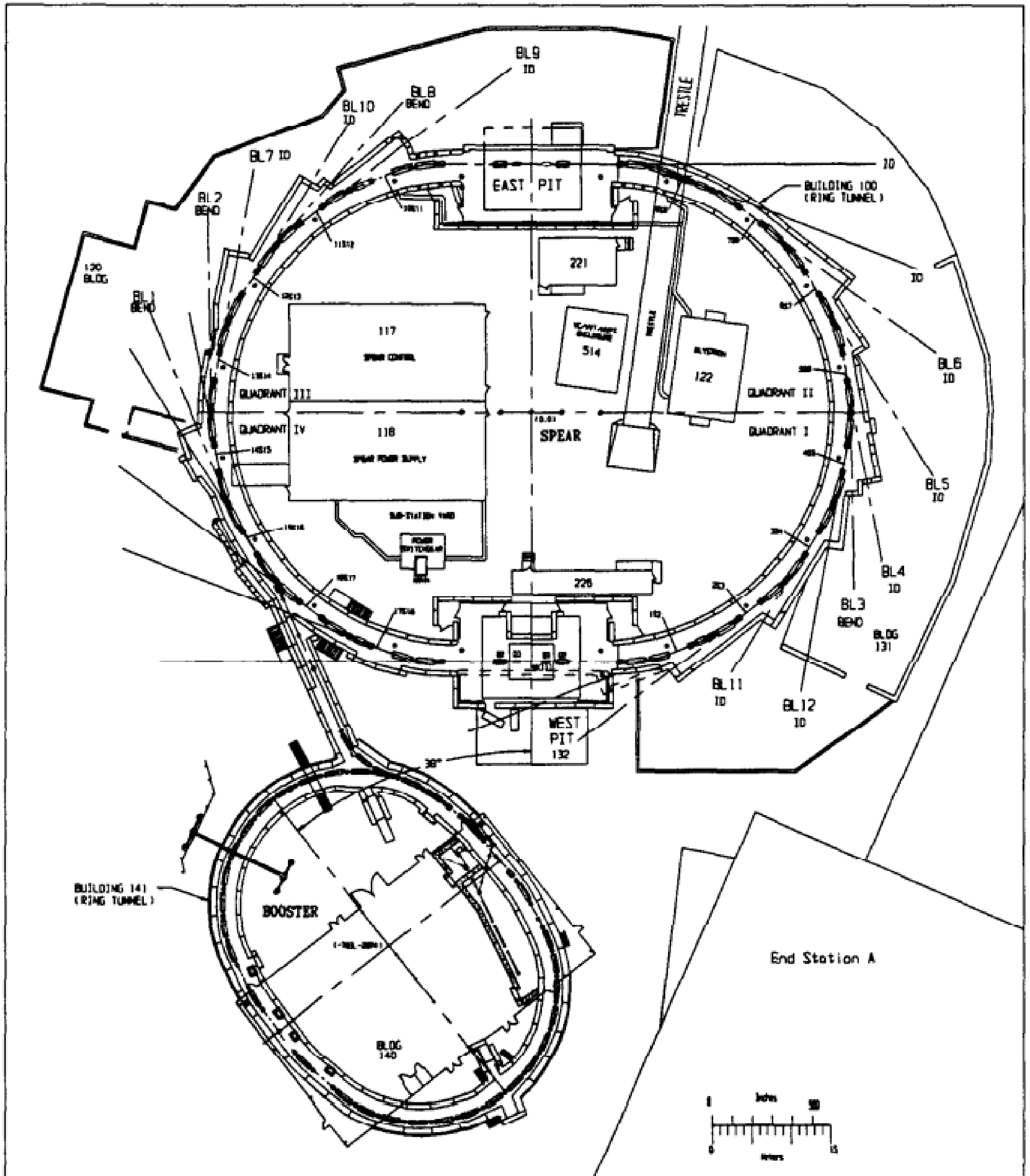
2021-12-21




Stanford Synchrotron Radiation Laboratory

**Table 2.1** Machine performance parameters for SPEAR 2 and SPEAR 3.

| | SPEAR 2 | SPEAR 3 |
|---|---|---|
| Emittance (with IDs) | 160 nm-rad | 18 nm-rad |
| Energy | 3 GeV | 3 GeV |
| Current | 100 mA | 200/500 mA† |
| Lifetime | 40 h @ 100 mA | >15 h @ 500 mA |
| Critical energy | 4.8 keV | 7.6 keV |
| Injection energy | 2.3 GeV | 3 GeV |

†. Initial 200 mA operation will be limited by some beam line components. The ring will be capable of 500 mA operation with beam lines closed.

*https://www.slac.stanford.edu/pubs/slacreports/reports09/slac-r-609a.pdf*