Recent Activity of Polarized Positron Experiment in KEK-ATF

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BNL ; Brookheaven National Laboratory
Activity of Our Group

Conceptual Design of Polarized Positron Source for LC

Experiment at BNL - Development of $CO_2$ Laser
- Compton Scattering with $CO_2$ Laser
- Investigation of Non-linear Compton Scattering
- Research for New Technology (Plasma Channel)

Experiment at KEK - Proof of Principle
- Production of Polarized Positron Beam
- Measurement of their Polarization
Basic Conceptual Design

CO$_2$ Laser at BNL

Our Goal
30J/flush at 3ps (multi-bunch)

Achieved Values
5J/Flush at 200ps (single bunch)

Next Target Value
10J/flush at 3ps (single bunch)

Optional Plan: use of FEL
On-axis Short Focal Length Compton Chamber

Off-axis Parabolic Mirror was used as final focus.

History of KEK Experiment

JPY1995  First Laser-Beam collision at the end of KEK-ATF Linac
   - Master Thesis of T.Okugi

JPY1997  First positron production at KEK-ATF extraction Line
   - Master Thesis of Y.Sugiyama

Positron yield was too small to measure their polarization.
   -> We have concentrated to increase the number of Compton scattered gamma-rays.

JPY2000  on-axis collision with short focal length Compton chamber

JPY2002  Polarization measurement of Compton Scatterd gamma-rays
   with long focal length Compton chamber
   - M.Fukuda et al., to be published in Phys. Rev. Letters

JPY2003  Polarization measurement of pair created positrons is planned!!
Experimental Area

Experimental Area is at the KEK-ATF extraction line.
Apparatus around Laser-beam Collision

Old Short Focal Length Compton Chamber
-> Laser beam size was about 5 micron.
   - Difficult to make small electron beam size by limited optics condition
   - Difficult to make small laser spot by aberration
     (see I. Sakai et al., Phys. Rev. ST Accel. Beams 6, 091001 (2003))

Requirement of New Compton Chamber
Laser Beam: Make waist at the center
   Align to straight with respect to electron beam.
Electron Beam: Make the beam size small to laser spot size (100 micron)

For on-axis collision and
(electron beam size) << (laser spot size),
Luminosity is defined only by $M^2$ of laser.
Collision Point (Monitors)
Three Series Compton Chamber

Compton Chamber in the center has combined scanner.

**Screen**
for Position measurement of electron and laser

**Knife Edge**
for laser profile measurement

**Wire Scanner**
for electron beam size measurement

*Compton Chamber at the both sides has only screen*
for position and beam angle adjustment of electron beam with respect to the laser light.*
Three Series Compton Chamber

Wire Scanner and Knife Edge

Adjustment and measurement of electron and laser beam size.

Comparable to laser Rayleigh length

Screen Monitors

- Set the electron beam trajectories with respect to the laser light
- Set the laser waist at the center

Laser Light

Electron Beam
Measured Profiles

Laser Profile by Knife Edge

Horizontal Sigma = 154 micron

Electron Profile by wire scanner

Horizontal $\sigma = 87\mu m$

Vertical $\sigma = 72\mu m$

Vertical Sigma = 151 micron
Gamma-ray Counters

1) Silica Aerogel Cherenkov Counter
   Silica Aerogel is developed for the Belle Particle I/D

2) Si PIN Photo-diode
Gamma-ray Polarimeter

Cross Section of Compton Scattering as a function of incident photon energy

Polarization can be measured by the transmission in the magnetized iron
Analyzing Power

\[
\text{(Asymmetry)}_A = \frac{(T_{\text{para}} - T_{\text{anti}})(N_+ - N_-)}{(T_{\text{para}} + T_{\text{anti}})(N_+ + N_-)}
\]

\[
= \frac{(T_{\text{para}} - T_{\text{anti}})}{(T_{\text{para}} + T_{\text{anti}})} \cdot P
\]

\[
T; \text{Transmission} \\
N; \text{Number of Incident Photon} \\
P; \text{Polarization of Incident Photon}
\]

\[
A_{\text{power}} \rightarrow \text{Analyzing Power}
\]

Analyzing Power for 15cm Thickness Ideal Iron (Perfect Magnetized)

For 30-40MeV gamma-rays, analyzing power is only 2%.
Analyzing Power

Type A

Type B

Magnetization

Analyzing Power

\[ Mz / M_{\text{max}} \]

\[ \text{Analyzing Power} \]

\[ \text{Energy of polarized } \gamma [\text{MeV}] \]
Ideally, magnet thickness of 7cm is the best solution to get the small statistical error in the same measured period.

But we select the magnet thickness to be 15cm in order to reduce the systematic error.

(Even if we use the ideal magnet, the analyzing power is only 2%.)
Transmitted Gamma-ray Counter

Cross Section of Compton Scattering

Gamma-ray is highly polarized at high energy region.

→ Air Cherenkov counter is used for transmitted gamma-ray counter.
  (Threshold energy is 22MeV.)
### Experimental Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Electron</th>
<th>Laser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>1.28 GeV</td>
<td>2.33 eV (532nm)</td>
</tr>
<tr>
<td>Intensity</td>
<td>$0.65 \times 10^{10}$</td>
<td>400 mJ</td>
</tr>
<tr>
<td>Bunch Length</td>
<td>31 ps rms.</td>
<td>3.6 ns rms.</td>
</tr>
<tr>
<td>Beam Size in X</td>
<td>87 microns</td>
<td>154 microns</td>
</tr>
<tr>
<td>Beam Size in Y</td>
<td>72 microns</td>
<td>151 microns</td>
</tr>
</tbody>
</table>

(Expected Number of Generated Gamma-rays) = $1 \times 10^6$

(Expected Asymmetry) = 1.3%
Result - Number of Gamma-rays

- Low background in the experiment
- Consistent with expected value
Result - Polarization Measurement

(a) (Laser polarization) = -79%
\[ A = -0.93 \pm 0.15 \% \]

(b) (Laser polarization) = +79%
\[ A = 1.18 \pm 0.15 \% \]

Measured slope = 1.29 +/- 0.12 
Expected slope = 1.3

Good agreement!!
Next Step

Polarization Measurement of Pair Created Positrons

1) Replace laser system

Old laser : Q-switch Nd:YAG Laser
400mJ / 3.6ns $\rightarrow$ 100MW peak power
$M^2$ $\rightarrow$ 2.5 - 3.0

New laser : Mode-lock Nd:YAG Laser
200mJ / 200 ps $\rightarrow$ 1GW peak power
$M^2$ $\rightarrow$ 1.2

We expect the photon number increase by the factor 10(??).

- (Measured Energy of Positrons) 25-45MeV
- (Expected Number of Positrons) $= 3 \times 10^4$
- (Expected Polarization) $= 77\%$

2) Development of polarimeter of positrons
Summary

1) Our polarized positron group has 3 big themes.
   - Conceptual design     -> Done
   - Development of CO$_2$ laser  -> BNL, FEL
   - Proof of Principle     -> KEK

2) Polarization measurement of Compton scattered gamma-rays was succeeded in KEK.
   - We established the polarization measurement of short pulsed gamma-rays.
   - Number of gamma-ray was consistent with expectation.
   - Measured polarization was consistent with expectation.

3) We will start the polarization measurement of pair created positrons soon!
   - New mode-lock laser is ready !!
   - Positron spectrometer and polarimeter are ready !!