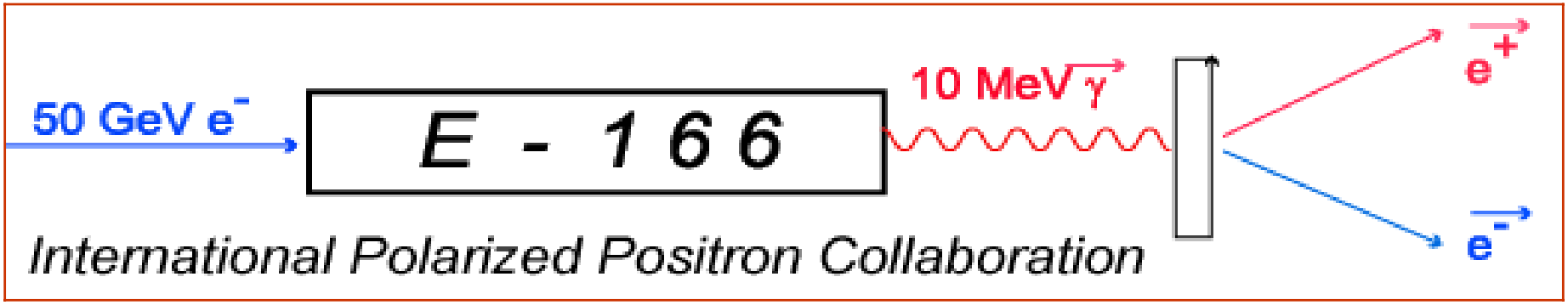

E-166
Undulator-Based Production of Polarized Positrons
An experiment in the 50 GeV Beam in the SLAC FFTB

K.T. McDonald
Princeton University

American Linear Collider Workshop
Cornell U., July 15, 2003

Undulator-Based Production of Polarized Positrons

E-166 Collaboration

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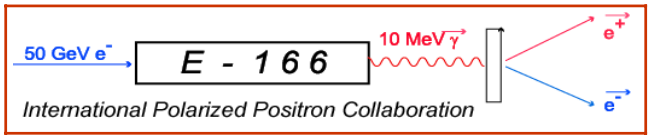
(45 Collaborators)



Undulator-Based Production of Polarized Positrons

E-166 Collaborating Institutions

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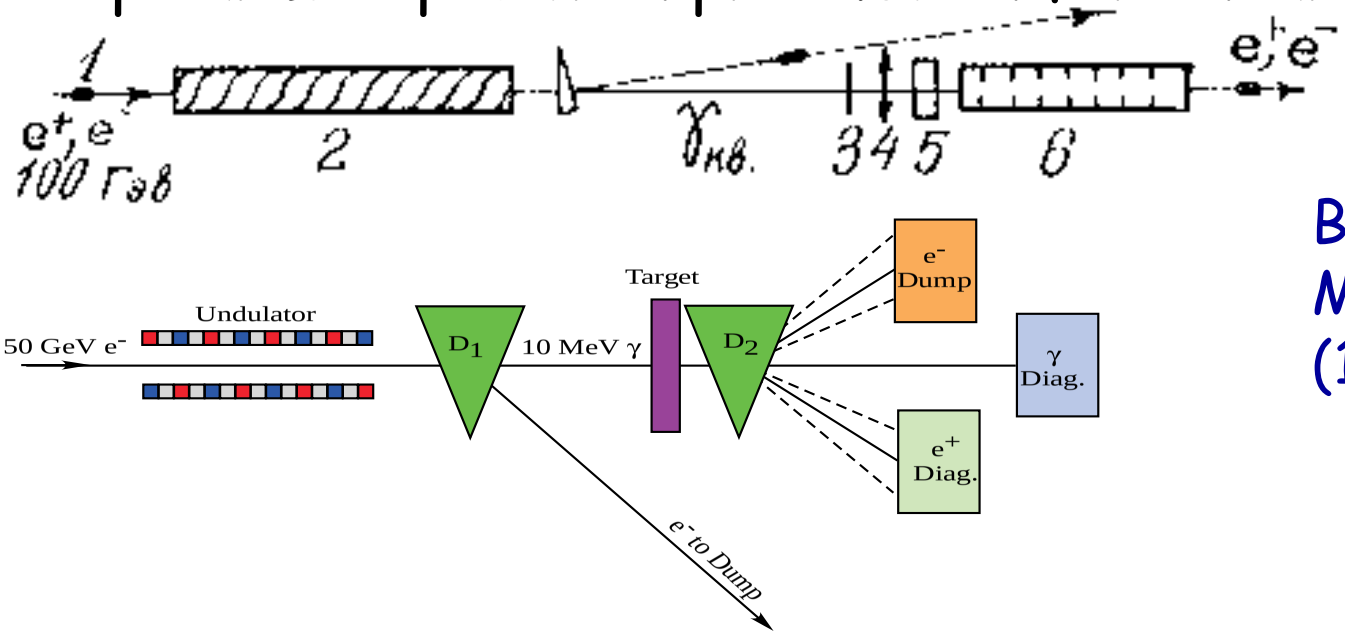
(15 Institutions)

E-166 Experiment

E-166 is a demonstration of undulator-based polarized positron production for linear colliders



Balakin and Mikhailichenko (1978)

- E-166 uses the 50 GeV SLAC beam in conjunction with 1 m-long, helical undulator to make polarized photons in the FFTB.
- These photons are converted in a ~0.5 rad. len. thick target into polarized positrons (and electrons).
- The polarization of the positrons and photons will be measured.

The Need for a Demonstration Experiment

Production of polarized positrons depends on the fundamental process of polarization transfer in an electromagnetic cascade.

While the basic cross sections for the QED processes of polarization transfer were derived in the 1950's, experimental verification is still missing

The Need for a Demonstration Experiment

Each approximation in the modeling is well justified in itself.

However, the complexity of the polarization transfer makes the comparison with experiment important so that the decision to build a linear collider w/ or w/o a polarized positron source is based on solid ground.

Polarimetry precision of 5% is sufficient to prove the principle of undulator based polarized positron production for linear colliders.

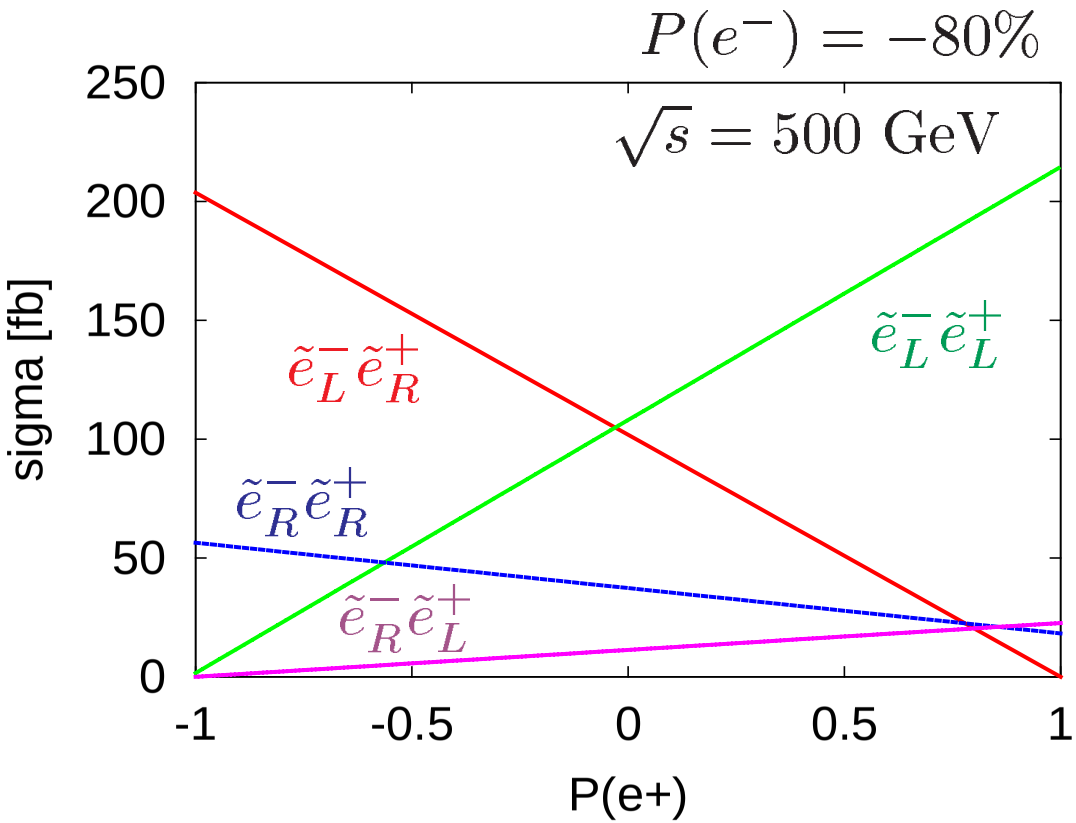
Physics Motivation for Polarized Positrons

Polarized e^+ in addition to polarized e^- is recognized as a highly desirable option by the WW LC community (studies in Asia, Europe, and the US)

Having polarized e^+ offers:

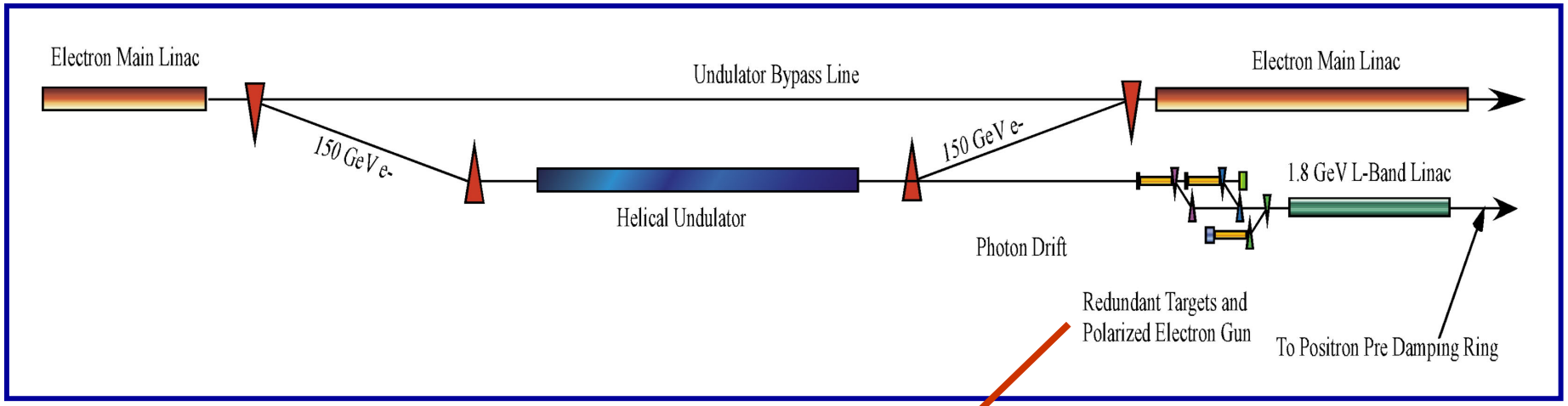
- Higher effective polarization -> enhancement of effective luminosity for many SM and non-SM processes,
- Ability to selectively enhance (reduce) contribution from SM processes (better sensitivity to non-SM processes,
- Access to many non-SM couplings (larger reach for non-SM physics searches),
- Access to physics using transversely polarized beams (only works if both beams are polarized),
- Improved accuracy in measuring polarization.

Physics Motivation: An Example

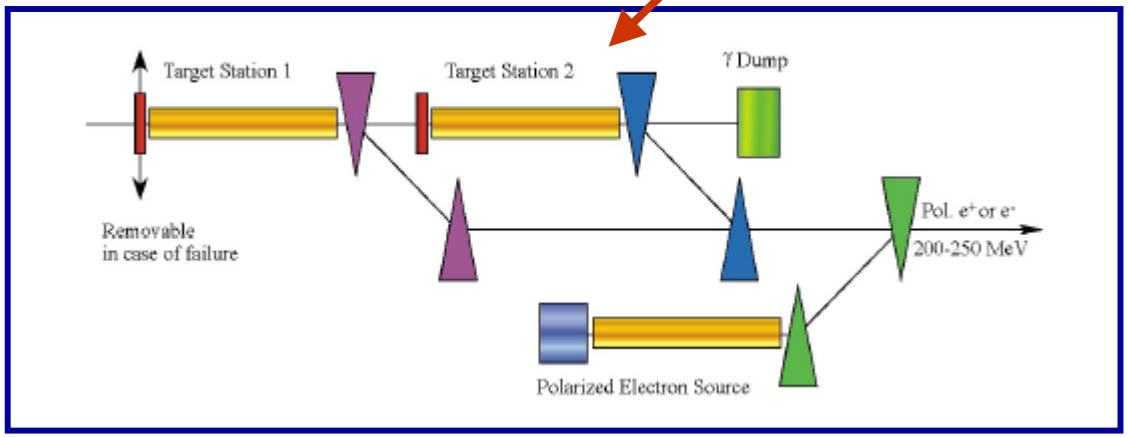


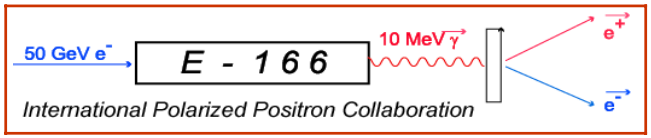
Separation of the selectron pair $\tilde{e}_L^- \tilde{e}_L^+$ in $e^+e^- \to \tilde{e}_{L,R}^- \tilde{e}_{L,R}^+$ with longitudinally polarized beams to test association of chiral quantum numbers to scalar fermions in SUSY transformations

NLC/USLCSG Polarized Positron System Layout



2 Target assembles for redundancy





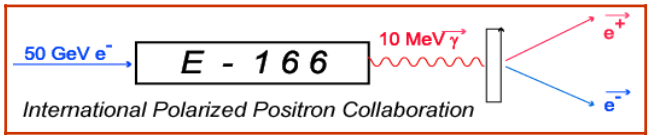
TESLA, NLC/USLCSG, and E-166 Positron Production

Table 1: TESLA, NLC/USLCSG, E-166 Polarized Positron Parameters

Parameter	Units	TESLA*	NLC	E-166
Beam Energy, E_e	*GeV*	150-250	150	50
N_e/bunch	-	3×10^{10}	8×10^{9}	1×10^{10}
N_{bunch}/pulse	-	2820	190	1
Pulses/s	*Hz*	5	120	30
Undulator Type	-	planar	helical	helical
Undulator Parameter, K	-	1	1	0.17
Undulator Period, λ_u	*cm*	1.4	1.0	0.24
1st Harmonic Cutoff, E_{c10}	*MeV*	9-25	11	9.6
dN_γ/dL	*photons/m/e-*	1	2.6	0.37
Undulator Length, L	*m*	135	132	1
Target Material	-	Ti-alloy	Ti-alloy	Ti-alloy, W
Target Thickness	*r.l.*	0.4	0.5	0.5
Yield	*%*	1-5	1.8†	0.5
Capture Efficiency	*%*	25	20	-
N_+/pulse	-	8.5×10^{12}	1.5×10^{12}	2×10^{7}
N_+/bunch	-	3×10^{10}	8×10^{9}	2×10^{7}
Positron Polarization	*%*	-	40-70	40-70

*TESLA baseline design; TESLA polarized e+ parameters (undulator and polarization) are the same as for the NLC/USLCSG

† Including the effect of photon collimation at $\gamma\theta = 1.414$.



E-166 Vis-à-vis a Linear Collider Source

E-166 is a demonstration of undulator-based production of polarized positrons for linear colliders:

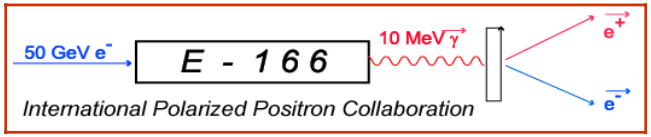
- Photons are produced in the same energy range and polarization characteristics as for a linear collider;

-The same target thickness and material are used as in the linear collider;

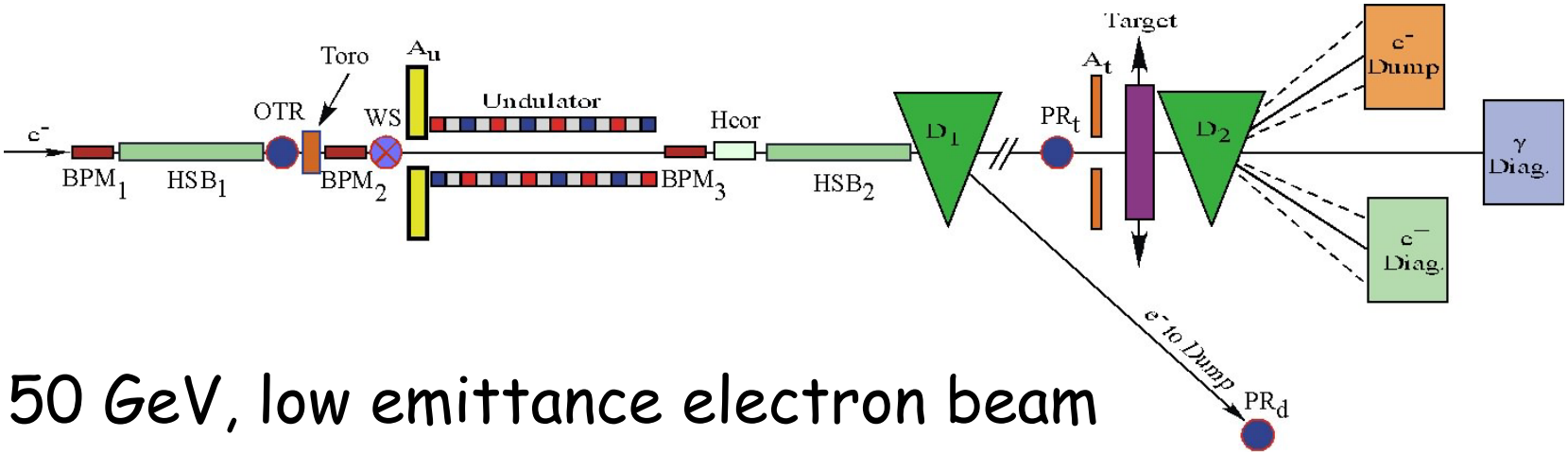
-The polarization of the produced positrons is expected to be in the same range as in a linear collider.

-The simulation tools are the same as those being used to design the polarized positron system for a linear collider.

- However, the intensity per pulse is low by a factor of 2000.



E-166 Beamline Schematic



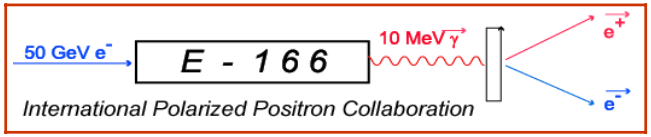
50 GeV, low emittance electron beam

2.4 mm period, K=0.17 helical undulator

0-10 MeV polarized photons

0.5 rad. len. converter target

51%-54% positron polarization



E-166 Helical Undulator Design, λ=2.4 mm, K=0.17

PULSED HELICAL UNDULATOR FOR TEST AT SLAC THE POLARIZED POSITRON PRODUCTION SCHEME. BASIC DESCRIPTION.

Alexander A. Mikhailichenko

CBN 02-10, LCC-106

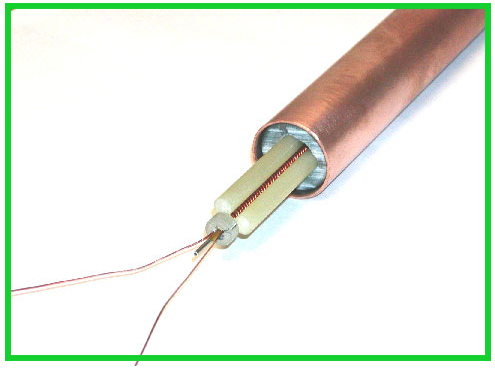
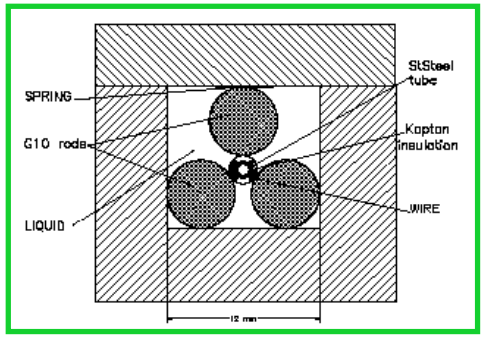


Table 3: FFTB Helical Undulator System Parameters

Parameter	Units	Value
Number of Undulators	-	1
Length	*m*	1.0
Inner Diameter	*mm*	0.89
Period	*mm*	2.4
Field	*kG*	7.6
Undulator Parameter, K	-	0.17
Current	*Amps*	2300
Peak Voltage	*Volts*	540
Pulse Width	*μs*	30
Inductance	*H*	0.9×10^{-6}
Wire Type	-	Cu
Wire Diameter	*mm*	0.6
Resistance	*ohms*	0.110
Repetition Rate	*Hz*	30
Power Dissipation	*W*	260
ΔT/pulse	^0C	2.7



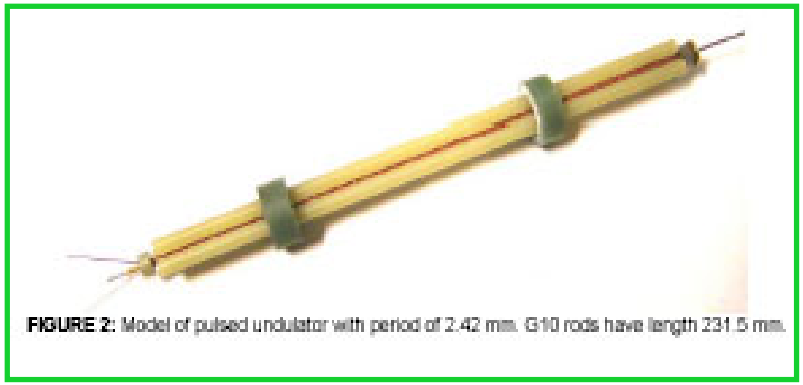


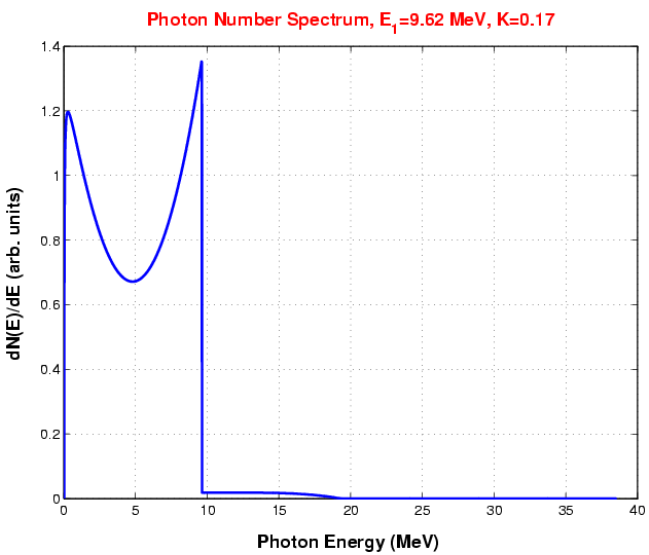
FIGURE 2: Model of pulsed undulator with period of 2.42 mm. G10 rods have length 231.5 mm.

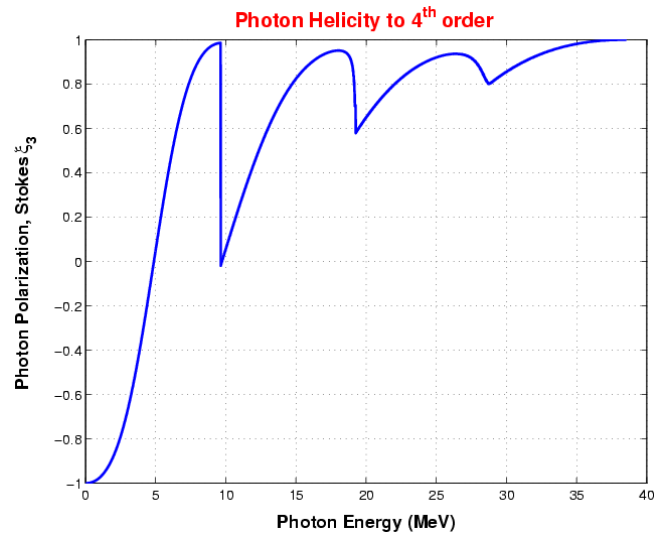
Helical Undulator Radiation

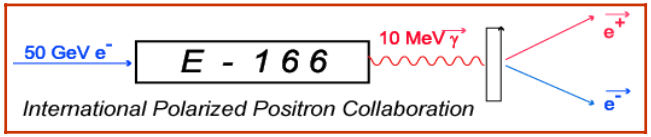
Circularly Polarized Photons

$$\frac{dN_\gamma}{dL} = \frac{30.6}{\lambda_u[mm]}\frac{K^2}{1+K^2}\ photons/m/e^- = 0.37\ photons/e^-$$

$$E_{c10} = 24[MeV]\frac{\left(E_e/50[GeV]\right)^2}{\lambda_u[mm]\left(1+K^2\right)} = 9.6\,MeV$$



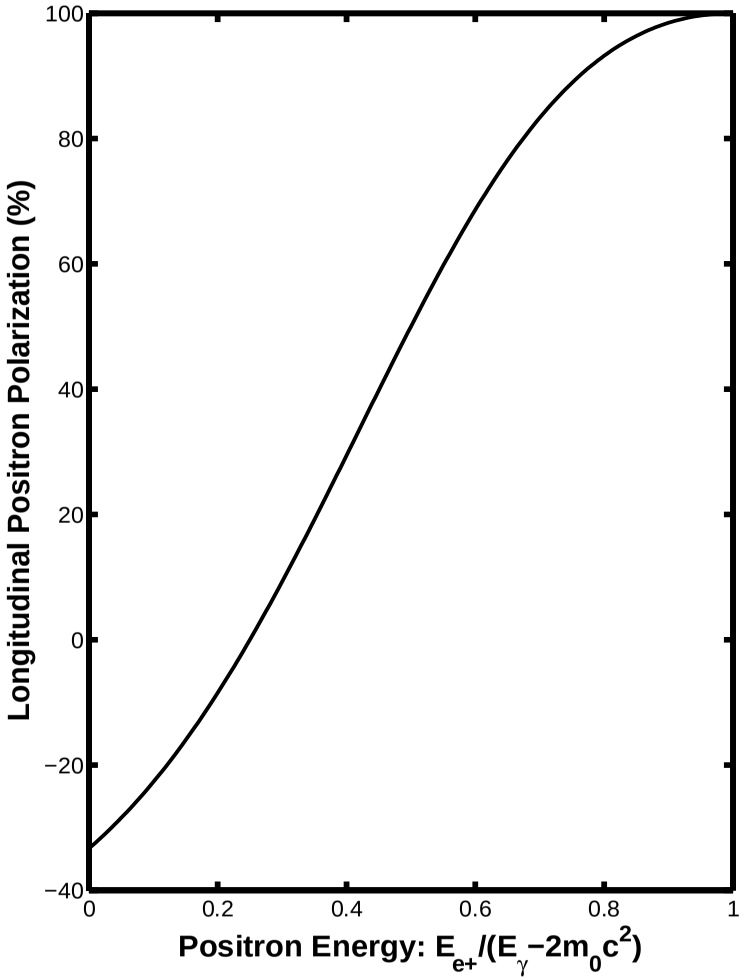




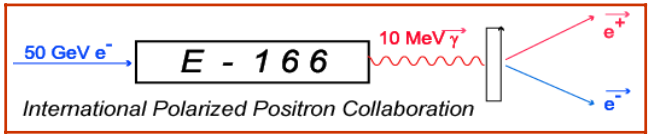
Polarized Positrons from Polarized γ's

Circular polarization of photon transfers to the longitudinal polarization of the positron.

Positron polarization varies with the energy transferred to the positron.



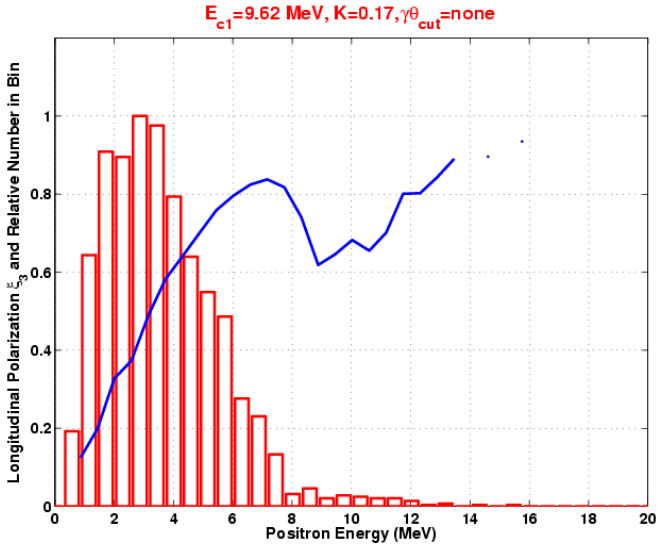
(Olsen & Maximon, 1959)

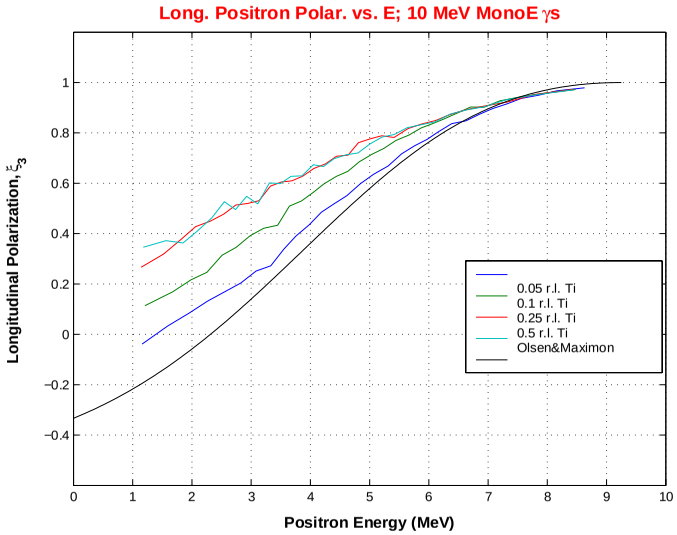


Polarized Positron Production in the FFTB

Polarized photons pair produce polarized positrons in a 0.5 r.l. thick target of Ti-alloy with a yield of about 0.5%.

Longitudinal polarization of the positrons is 54%, averaged over the full spectrum

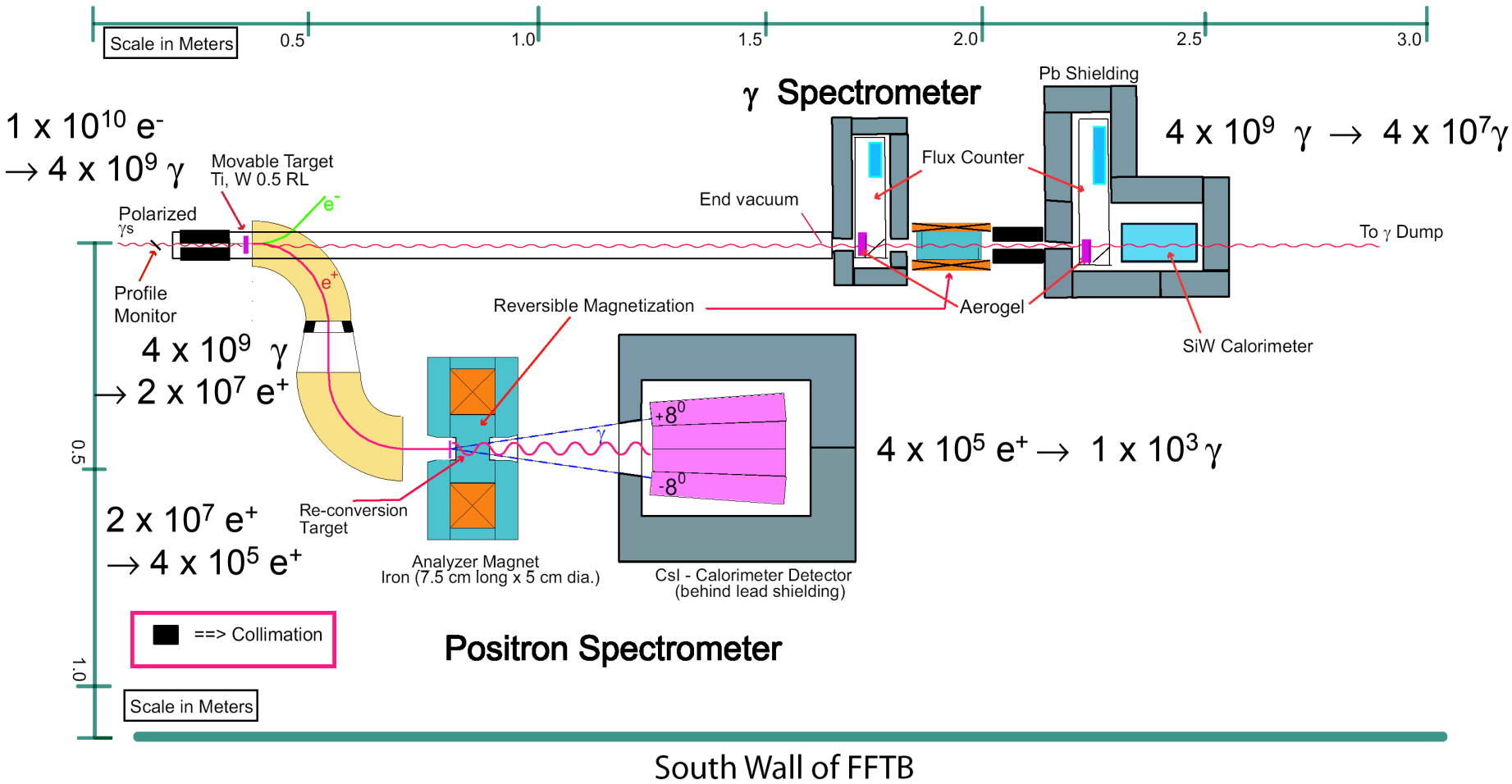




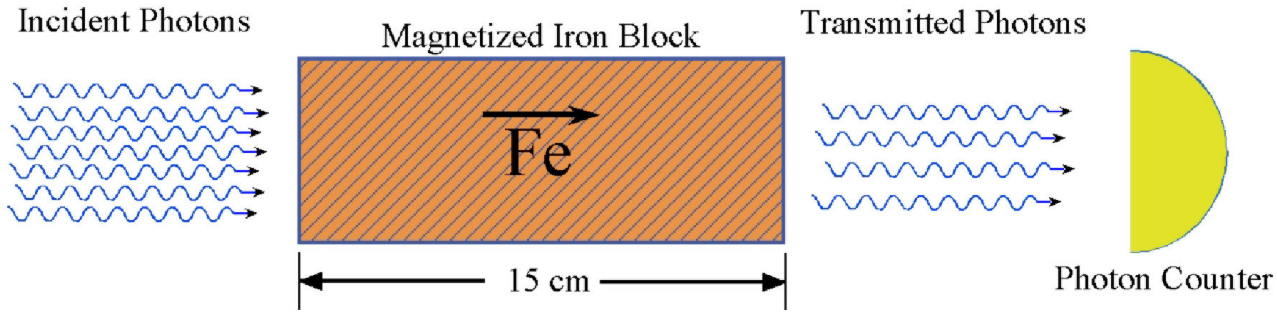
50 GeV e⁻ → E - 166 → 10 MeV γ → e⁺, e⁻

International Polarized Positron Collaboration

Polarimeter Overview



Transmission Polarimetry of Photons



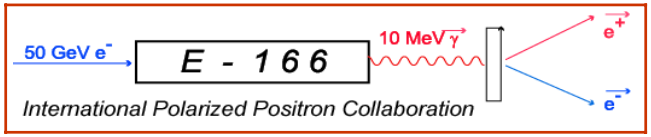
$$\sigma = \sigma_{phot} + \sigma_{comp} + \sigma_{pair}$$

$$\sigma_{comp} = \sigma_0 + P_\gamma P_e \sigma_P$$

$$T^{\pm}(L) = e^{-nL\sigma} = e^{-nL(\sigma_0+\sigma_{phot}+\sigma_{pair})}\, e^{\pm nLP_eP_\gamma\sigma_P}$$

$$\delta(L) = \frac{T^+(L) - T^-(L)}{T^+(L) + T^-(L)} = \tanh(nLP_eP_\gamma\sigma_P) \approx nLP_eP_\gamma\sigma_P, = P_e P_\gamma A_\gamma$$

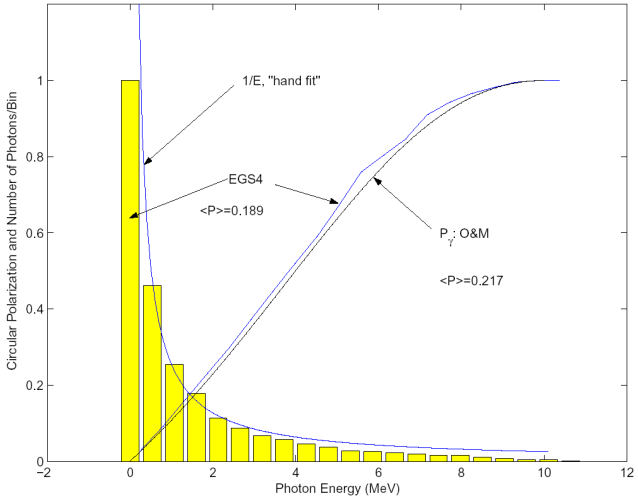
$P_e = 0.07$, $P_\gamma = 0.54$, $A_\gamma = 0.62$, $\Rightarrow \delta = 0.027$



Transmission Polarimetry of Positrons

2-step Process:

- re-convert e+ → γ via brems/annihilation process
  - polarization transfer from e+ to γ proceeds in well-known manner
- measure polarization of re-converted photons with the photon transmission methods
  - infer the polarization of the parent positrons from the measured photon polarization



Fronsdahl & Überall; Olson & Maximon; Page; McMaster

Experimental Challenges:

- large angular distribution of the positrons at the production target:
  - e+ spectrometer collection & transport efficiency
  - background rejection issues
- angular distribution of the re-converted photons
  - detected signal includes large fraction of Compton scattered photons
  - requires simulations to determine the effective Analyzing Power A_{e+}

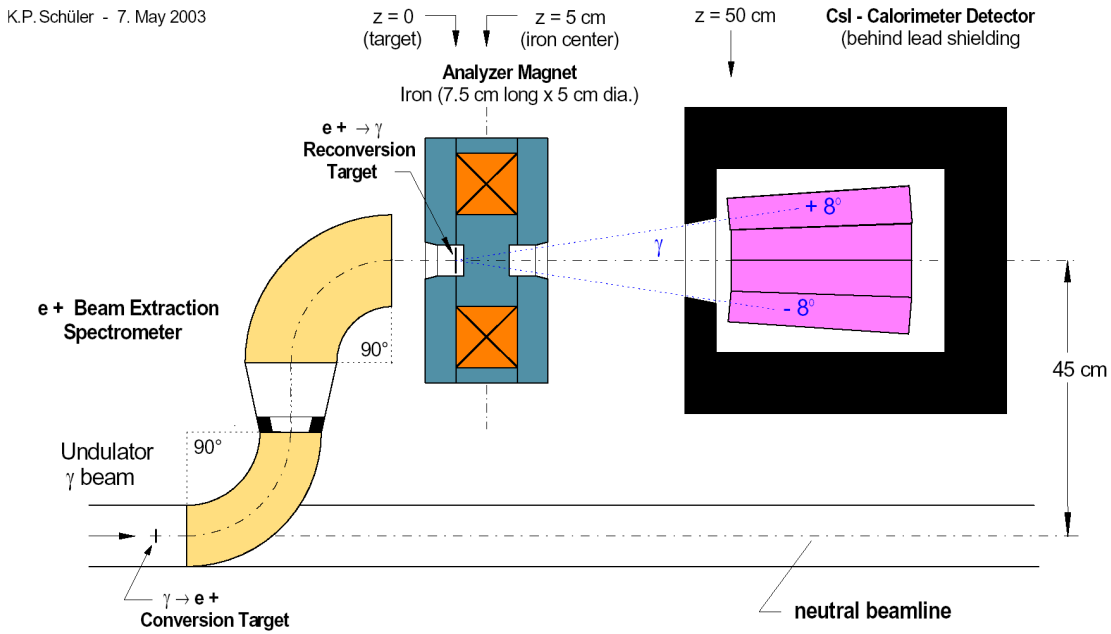
Formal Procedure:

$$P_{e^+} = \frac{\delta}{P_{e^-} A_{e^+}}$$

50 GeV e⁻ → E - 166 → 10 MeV γ → e⁺, e⁻

International Polarized Positron Collaboration

Positron Polarimeter Layout



e+ Energy spread	±20%
W Reconverter thickness	0.175 cm
Fe absorber thickness	7.5 cm
Fe absorber radius	2.5 cm
CsI Detector aperture	7 cm (radius)
Distance between reconverter and iron	1.25 cm
Distance between iron and CsI detector	41.25 cm

Positron Transport System

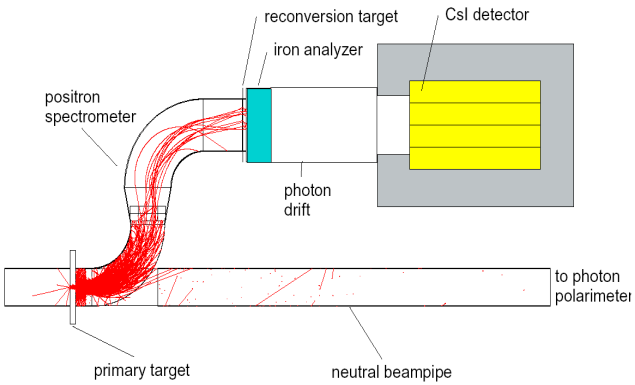
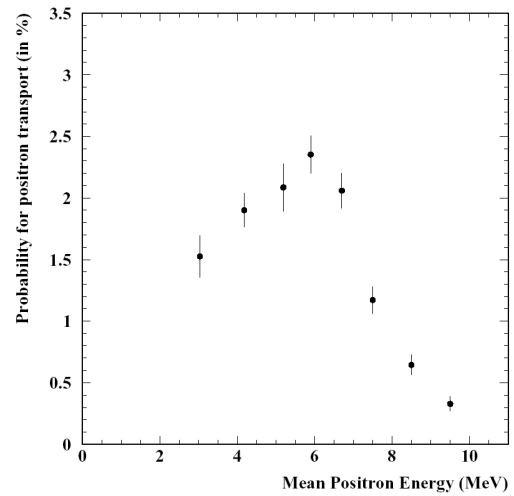


Figure 29: Examples of trajectories of positrons in the upstream part of the positron polarimeter.



e+ transmission (%) through spectrometer

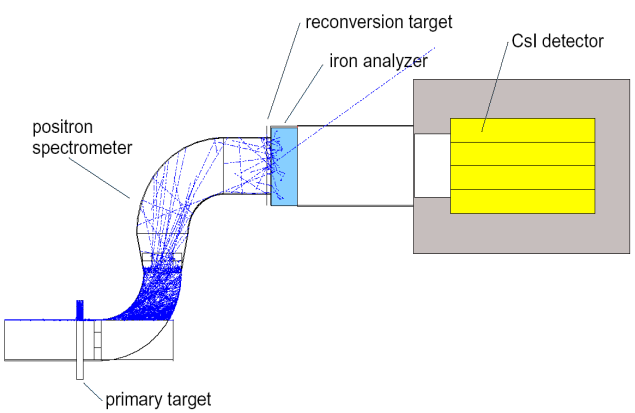
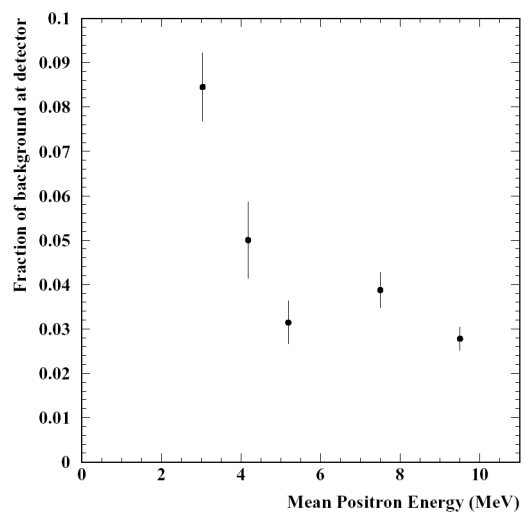
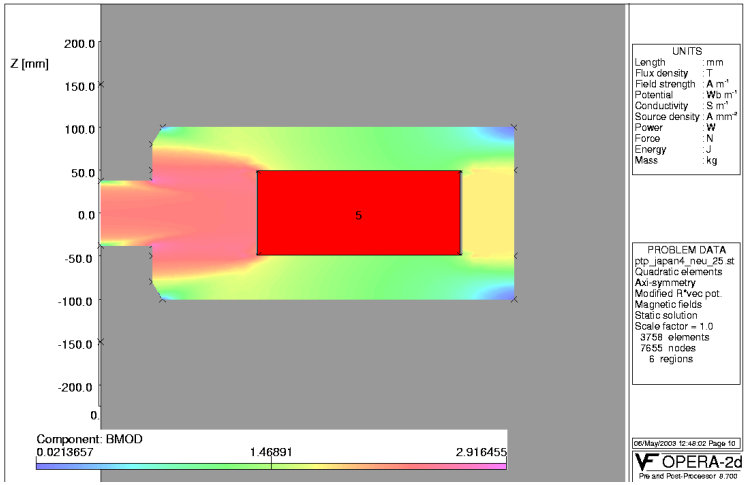


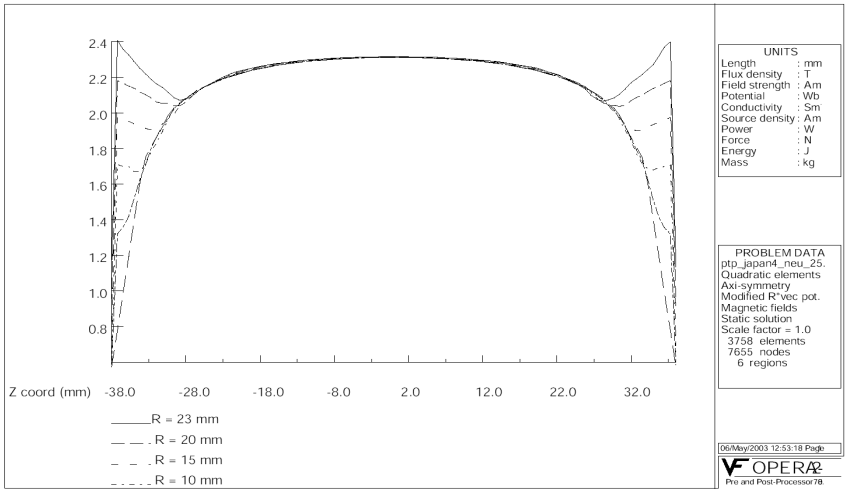
Figure 28: Examples of trajectories of photons in the upstream part of the positron polarimeter.



photon background fraction reaching CsI-detector

Analyzer Magnets





$$P_e = 2 \cdot \frac{g' - 1}{g'} \cdot \frac{M}{n\,\mu_B}$$

g' = 1.919 ± 0.002 for pure iron,
Scott (1962)

Error in e- polarization is dominated by knowledge in effective magnetization M along the photon trajectory:

$$P_e \approx 0.07$$

$$\Delta P_e / P_e \approx 0.05$$

	active volume
Photon Analyzer Magnet:	50 mm dia. x 150 mm long
Positron Analyzer Magnet:	50 mm dia. x 75 mm long

Photon Polarimeter Detectors

E-144 Designs:

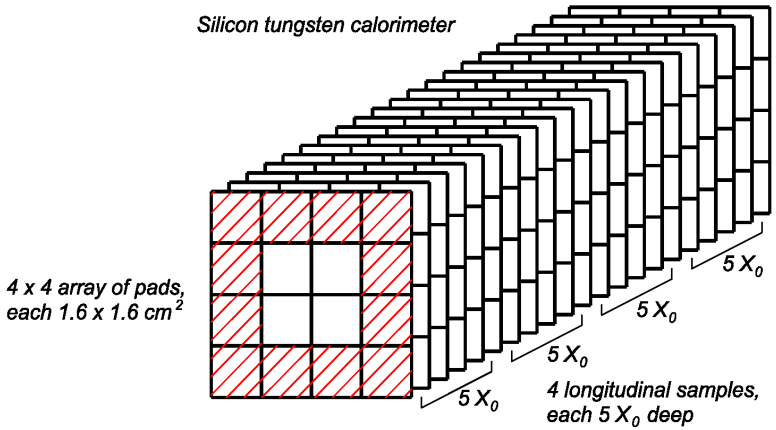


Figure 24: The silicon tungsten calorimeter consists of 20 longitudinal samples of 1 X_0 each, grouped into 4 segments of 5 X_0 each. The transverse sampling is via a 4×4 array of pads, each 1.6×1.6 cm^2 each.

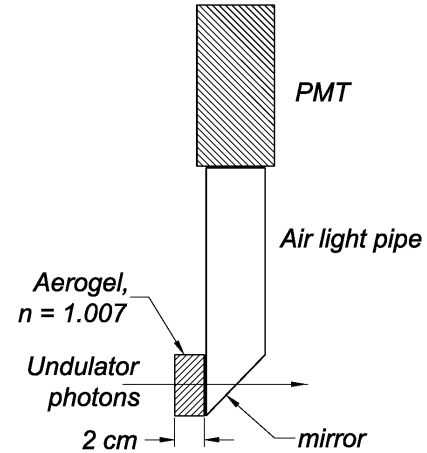


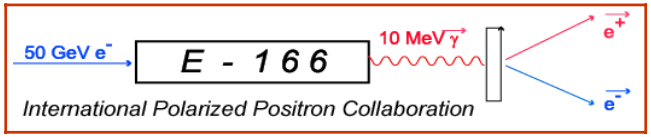
Figure 25: The photon flux counter, consisting of a 2-cm-thick block of aerogel of index $n = 1.007$, viewed by a photomultiplier tube at the end of an air light pipe.

Si-W Calorimeter

Threshold Cerenkov (Aerogel)

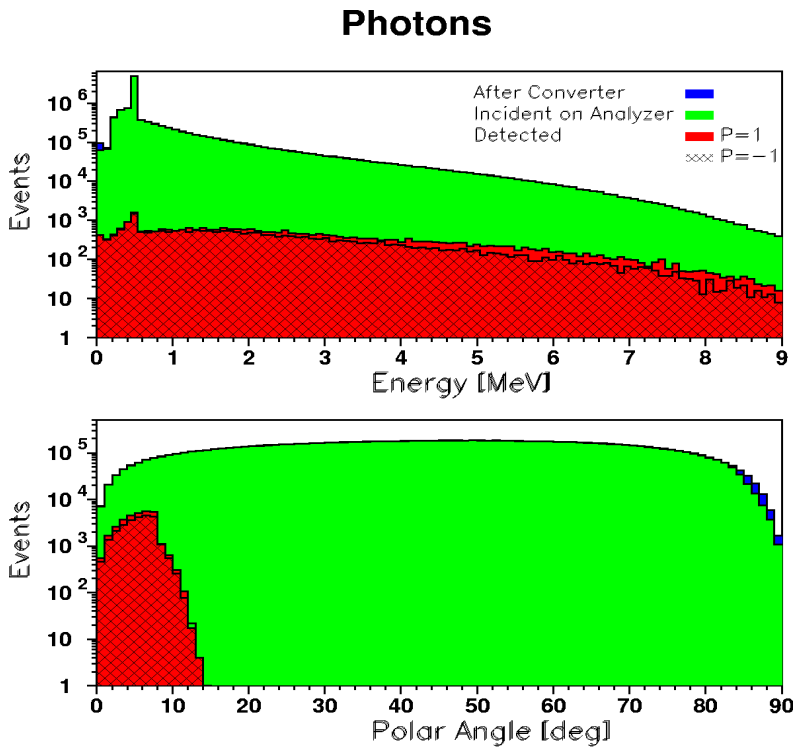
CsI Calorimeter Detector

Crystals:	from BaBar Experiment
Number of crystals:	4 x 4 = 16
Typical front face of one crystal:	4.7 cm x 4.7 cm
Typical backface of one crystal:	6 cm x 6 cm
Typical length:	30 cm
Density:	4.53 g/cm^3
Rad. Length	8.39 g/cm^2 = 1.85 cm
Mean free path (5 MeV):	27.6 g/cm^2 = 6.1 cm
No. of interaction lengths (5 MeV):	4.92
Long. Leakage (5 MeV):	0.73 %
Photodiode Readout (2 per crystal):	Hamamatsu S2744-08 with preamps

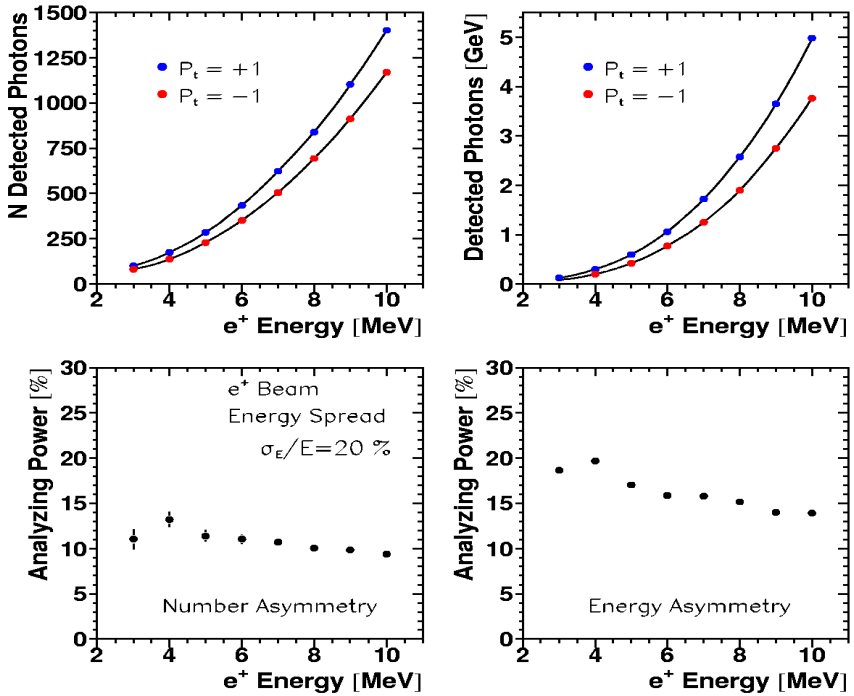


Expected Positron Polarimeter Performance

Simulation based on modified GEANT code, which correctly describes the spin-dependence of the Compton process

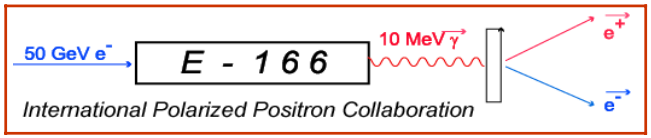


Photon Spectrum & Angular Distr.



Number- & Energy-Weighted Analyzing Power vs. Energy

10 Million simulated e^+ per point & polarity on the re-conversion target

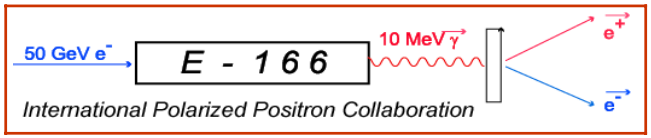


Expected Positron Polarimeter Performance II

$$P_{e^+} = \frac{\delta}{P_{e^-} A_{e^+}}, \qquad \Delta P_{e^+} = \frac{1}{P_{e^-} A_{e^+} \sqrt{N_\gamma}}$$

Positron Energy (MeV)	Positron Pol. P_{e^+} (%)	Positron Transport Eff. ϵ_{e^+} (%)	Photon Transport Eff. ϵ_γ (%)	Photon Asym. δ (%)	Analyzing Power A_{e^+} (%)	N_γ in 15 min	15 min Abs. Error ΔP_{e^+} (%)
3	42	1.5	0.045	0.55	18.6	3.7×10^6	4.0
4	61	1.9	0.078	0.84	19.7	8.0×10^6	2.6
5	69	2.1	0.12	0.82	17.0	1.45×10^7	2.2
6	78	2.3	0.20	0.87	15.9	2.44×10^7	1.8
7	84	1.7	0.28	0.93	15.8	2.59×10^7	1.6
8	77	0.9	0.38	0.82	15.0	1.86×10^7	2.2
9	64	0.4	0.50	0.63	14.0	1.09×10^7	3.1
10	68	0.3	0.64	0.66	13.9	1.04×10^7	3.2

Table 13



E-166 Beam Measurements

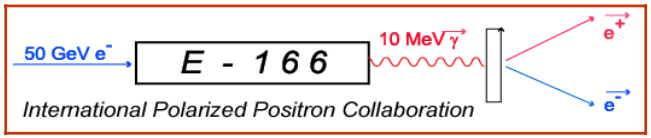
- Photon flux and polarization as a function of K (P_γ ~ 75% for E_γ > 5 MeV).

- Positron flux and polarization for K=0.17, 0.5 r.l. of Ti vs. energy. (P_{e^+} ~ 50%).

- Positron flux and polarization for 0.1 r.l. and 0.25 r.l. Ti and 0.1, 0.25, and 0.5 r.l. W targets.

- Each measurement is expected to take about 20 minutes.

- A relative polarization measurement of 5% is sufficient to validate the polarized positron production processes.



E-166 Beam Request

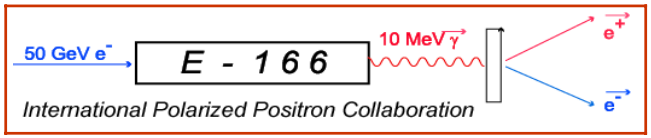
E-166 Beam Parameters

E_e	f_{rep}	N_e	$\gamma\varepsilon_x=\gamma\varepsilon_y$	β_x,β_y	σ_x,σ_y	σ_E/E
GeV	*Hz*	e^-	*m-rad*	*m*	μm	%
50	30	1×10^{10}	3×10^{-5}	5.2, 5.2	40	0.3

6 weeks of activity in the SLAC FFTB:

- 2 weeks of installation and check-out
- 1 week of check-out with beam
- 3 weeks of data taking:
  roughly 1/3 of time on photon measurements,
  2/3 of time on positron measurements.

E-166 was approved by SLAC in June, 2003, with proviso for a preliminary test run to study backgrounds in the FFTB.



E-166 Institutional Responsibilities

Electron Beamline	SLAC
Undulator	Cornell
Positron Beamline	Princeton/SLAC
Photon Beamline	SLAC
Polarimetry:	
Overall	DESY
Magnetized Fe Absorbers	DESY
Cerenkov Detectors	Princeton
Si-W Calorimeter	Tenn./ S. Carolina
CsI Calorimeter	DESY/Humboldt
DAQ	Humboldt/Tenn./S. Car.