E-166 as Motivation for polarized processes in GEANT4

R. Dollan[1], K. Laihem[2], T. Lohse[1], S. Riemann[2],
A. Schaelicke[2], P. Starovoitov[3]

Humboldt University, Berlin[1]

DESY[2]

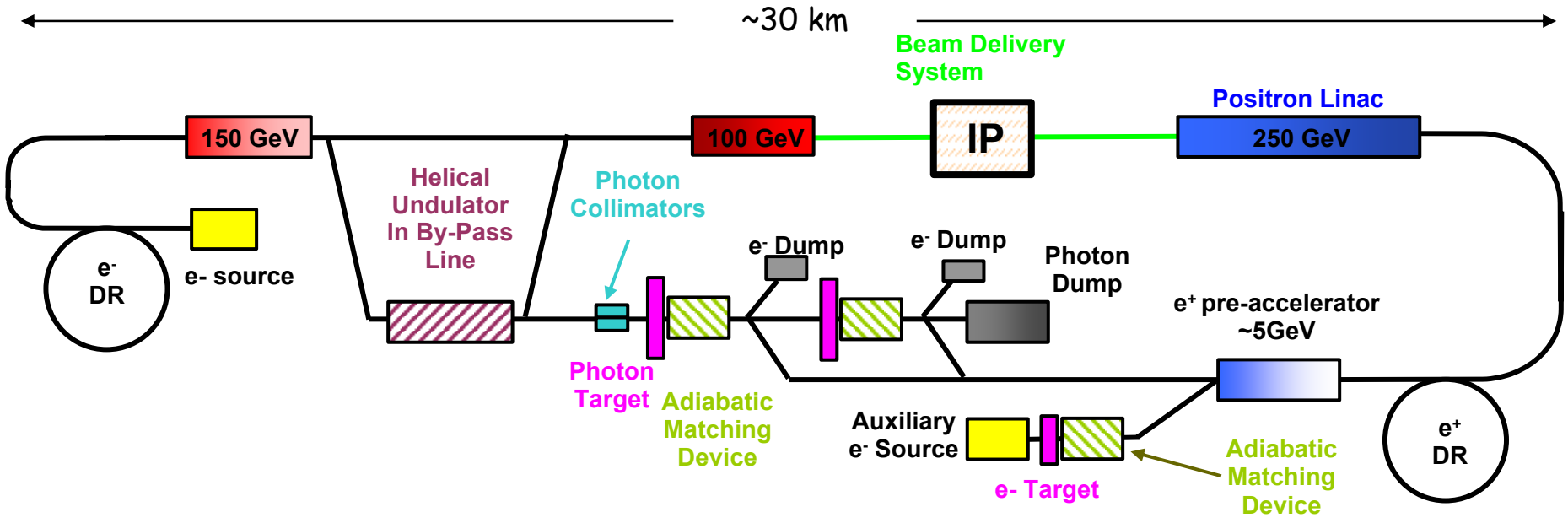
IHEP Minsk[3]

Outline

- Motivation
  - ILC
  - Positron polarization
- E166
  - The helical undulator
  - Polarimetry
  - Experimental results
- Simulation
  - "polarized" processes
  - Simulation results

The International Linear Collider - ILC

- Electron-Positron Collider
- E_{CMS}: 500 – 1000 GeV
- Luminosity: L= 2* 10^{34} $cm^{-2}s^{-1}$ (1st 4 years: 500 fb^{-1})
  (compare to LEP I L=2.4*10^{31} $cm^{-2}s^{-1}$)
- 1 ms bunch trains w. 2820 bunches at 5 Hz (interval 308ns)

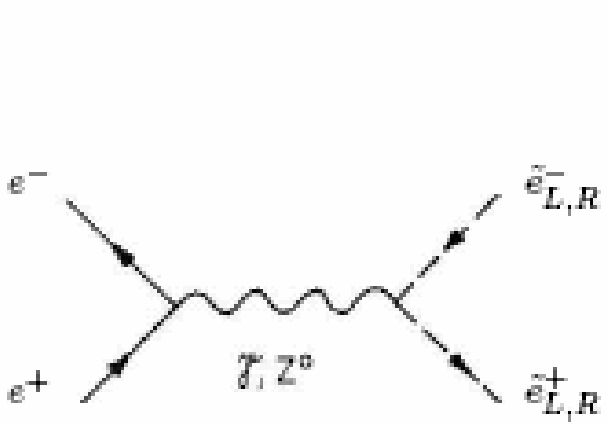


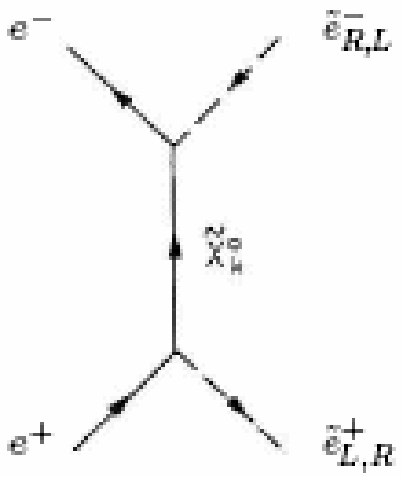
Wy both beams polarized at the ILC ?

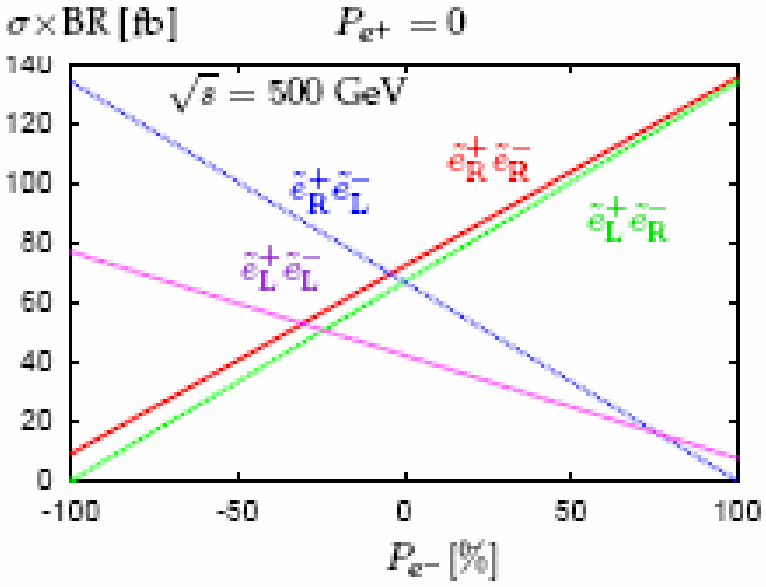
- enhancement of the effective luminosity
- higher effective polarization
- improved accuracy in measuring the polarization
- increased signal to background in studies of SM-Physics
- Precise analysis of many kinds of non-standard couplings (larger reach for non-SM physics searches)

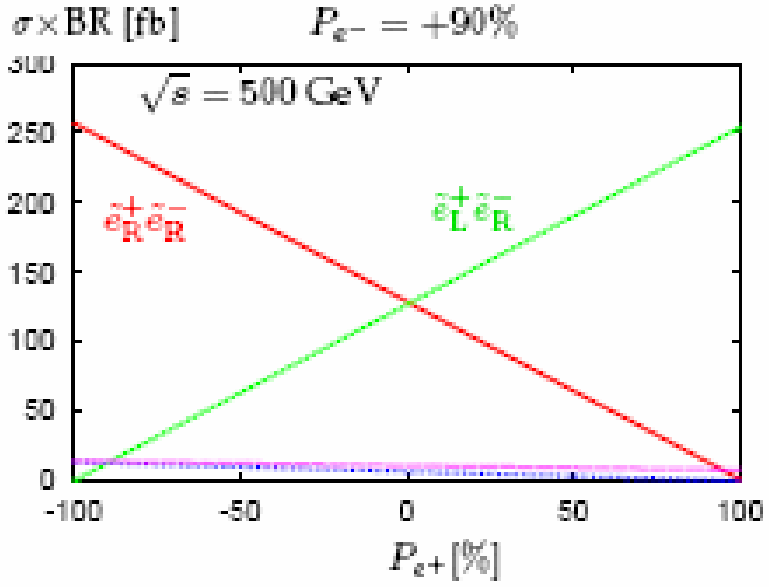
http://www.ippp.dur.ac.uk/~gudrid/source/

One example: Selectron production in e^+e^-

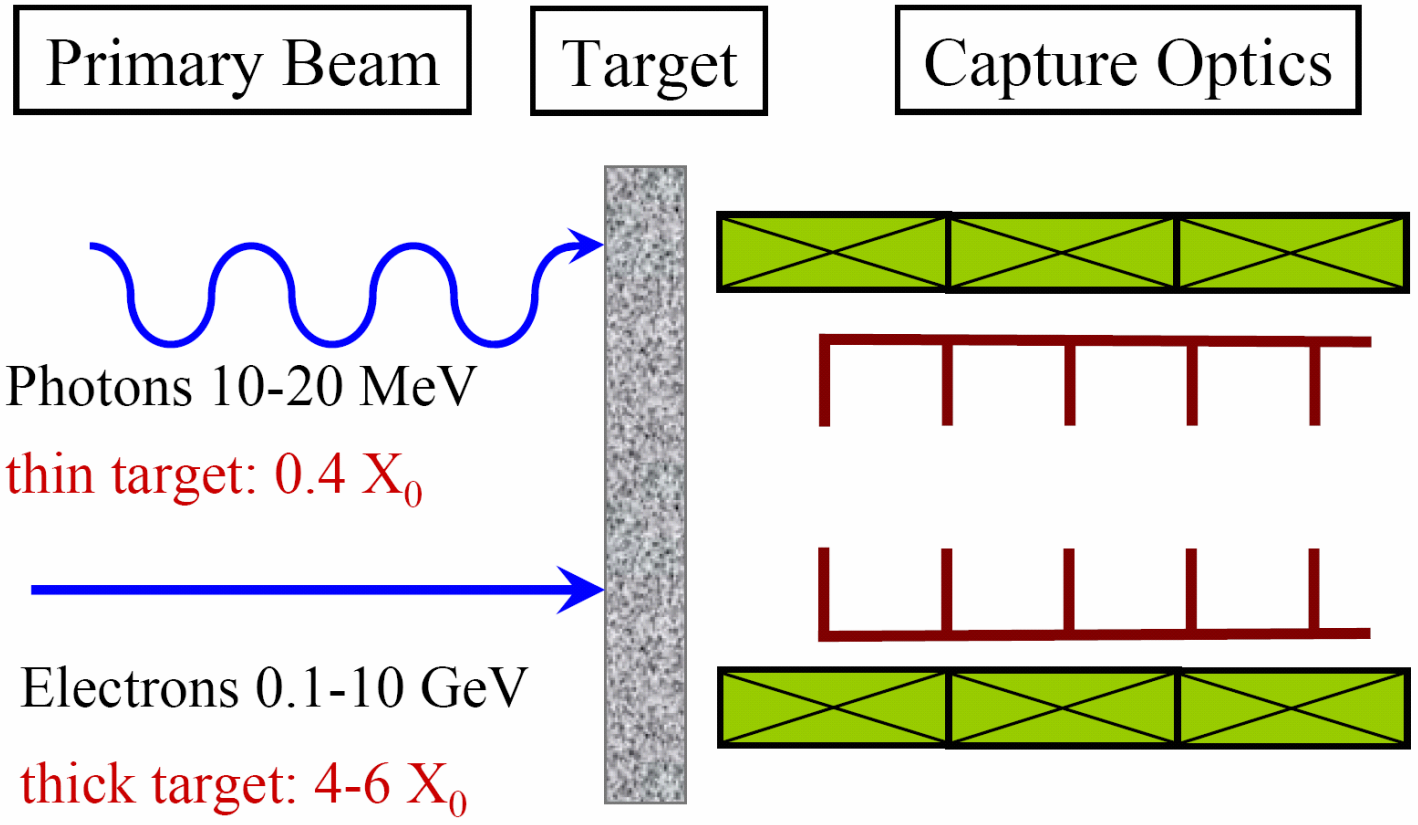






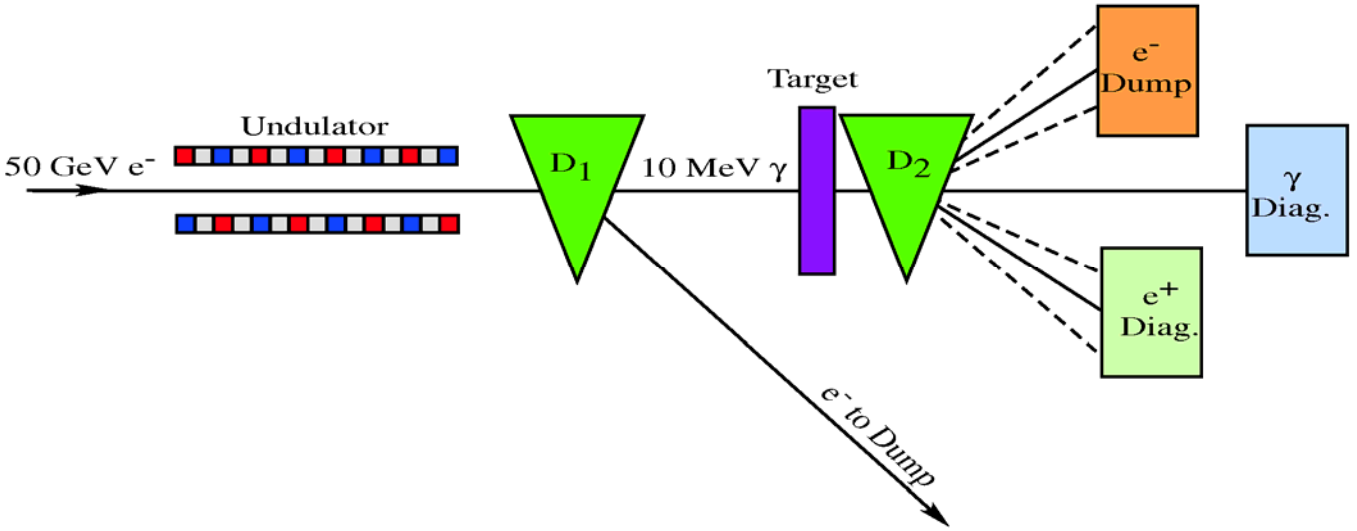


Positron production



E-166

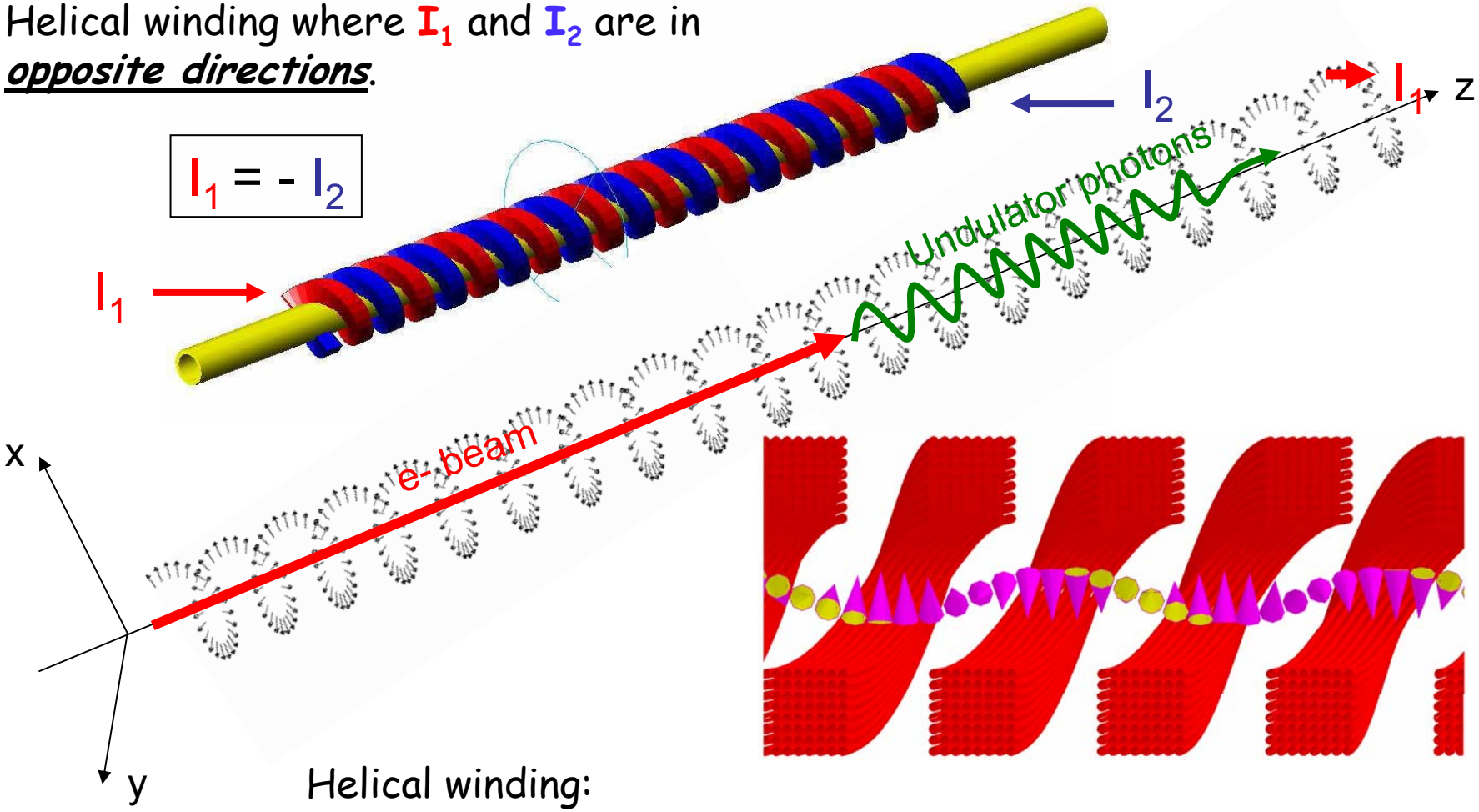
- Demonstration experiment to proof the possibility, to produce polarized positrons using a helical undulator
- Collaboration of >50 people from 3 continents
- In the final focus test beam (FFTB) at SLAC with ~50 GeV (unpolarized) electrons
- 1 m long helical undulator produces circular polarized photons
- Conversion of photons to longitudinally polarized positrons in thin W-target
- Measurement of polarization of photons and positrons by Photon transmission method



The helical Undulator

Helical winding where I_1 and I_2 are in ***opposite directions***.

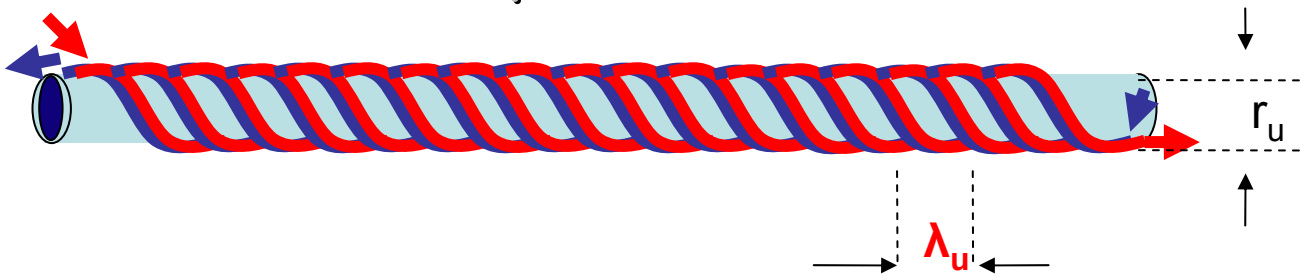
$I_1 = - I_2$



Helical winding:

- z component of the induced magnetic field cancels
- remaining magnetic field describes a helical profile

Undulator parameters



wound left handed

Parameter	Value
Period λ_u	**2.54mm**
On axis field	0.76 T
K factor	**0.18**
$E_0=\omega h$ (Energy cut-off 1st harmonic)	**9.4 MeV** (50GeV e-beam)
Feeding current	2.3 kA
Rate	up to 30 Hz
Heating/pulse	~3 degC

r_u Undulator aperture	0.89 mm

K - factor (Undulator strength)

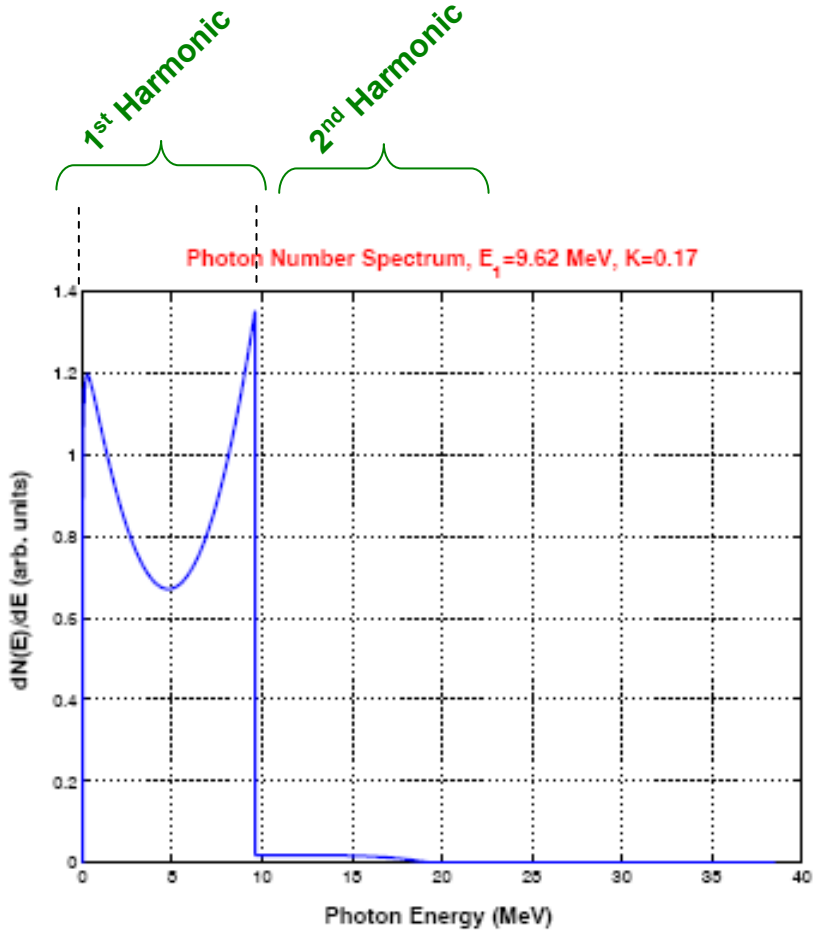
$$K = \frac{eH\lambda_u}{2\pi mc^2} \cong 93.4H[T]\lambda_u[m]$$

The average photon polarization depends on the angular photon selection (**K** factor) and also on the quality of the photon collimation (before the conversion target).

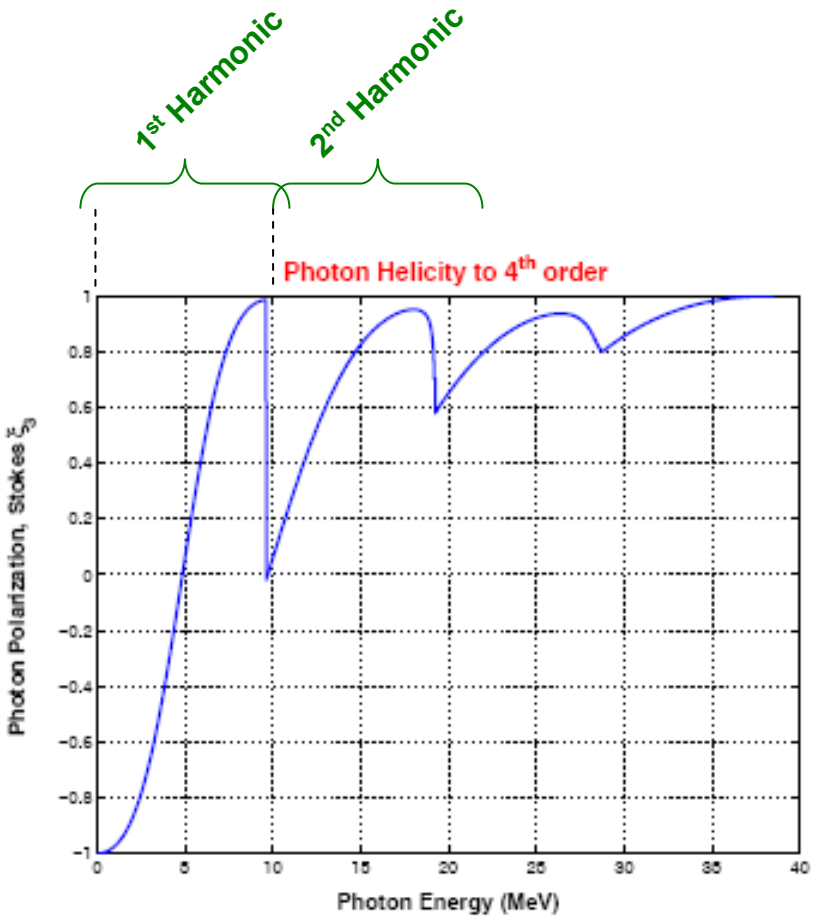
First harmonic Energy cut-off

$$E_0 \approx \frac{2\gamma^2 hc}{\lambda_u}$$

Photon Energy and Polarization

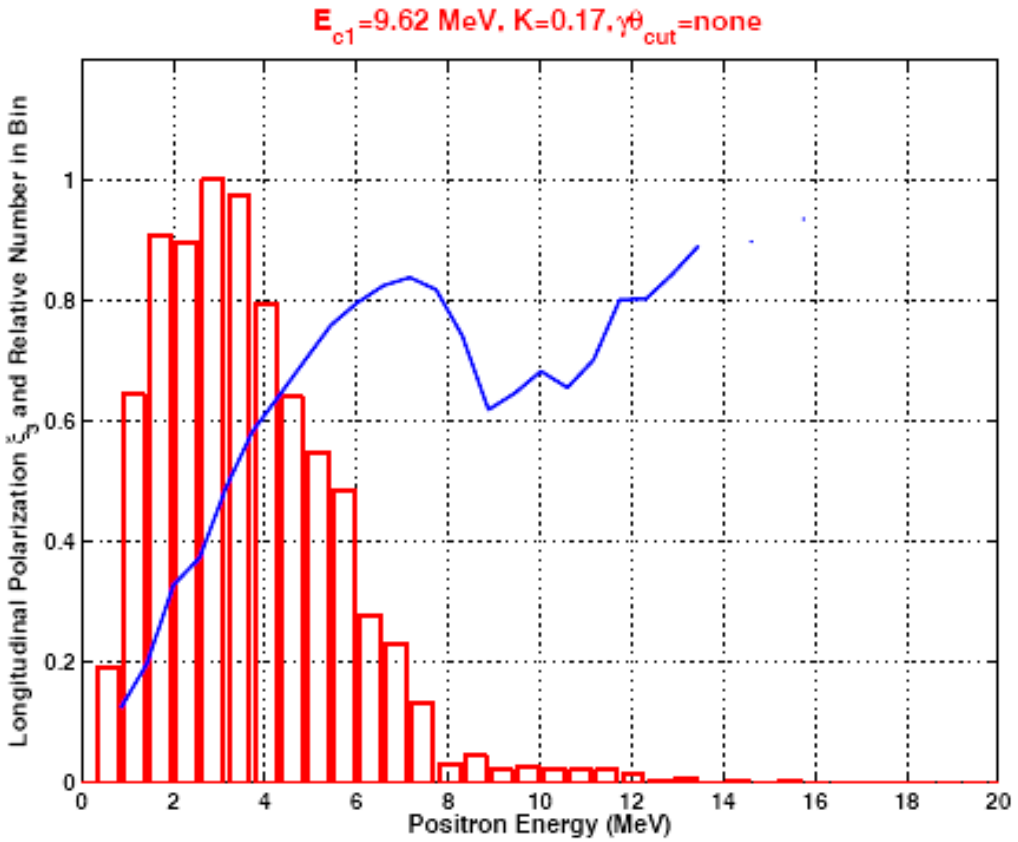


Undulator Photon energy spectrum



Undulator Photon degree of polarization

Expected Polarization



Expected positron polarization vs. positron energy

50 GeV e^- E - 166 10 MeV γ e^+ e^-

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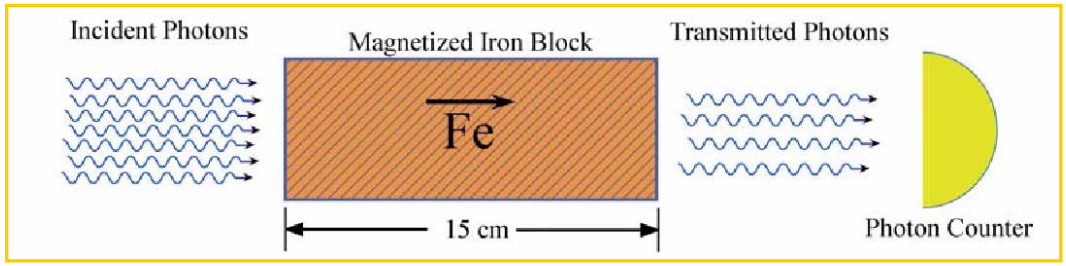
Transmission Polarimetry



$$\sigma_{tot} = \sigma_{phot} + \sigma_{comp} + \sigma_{pair} \qquad \text{with} \qquad \sigma_{comp} = \sigma_0 + P_\gamma P_e \sigma_{pol}$$

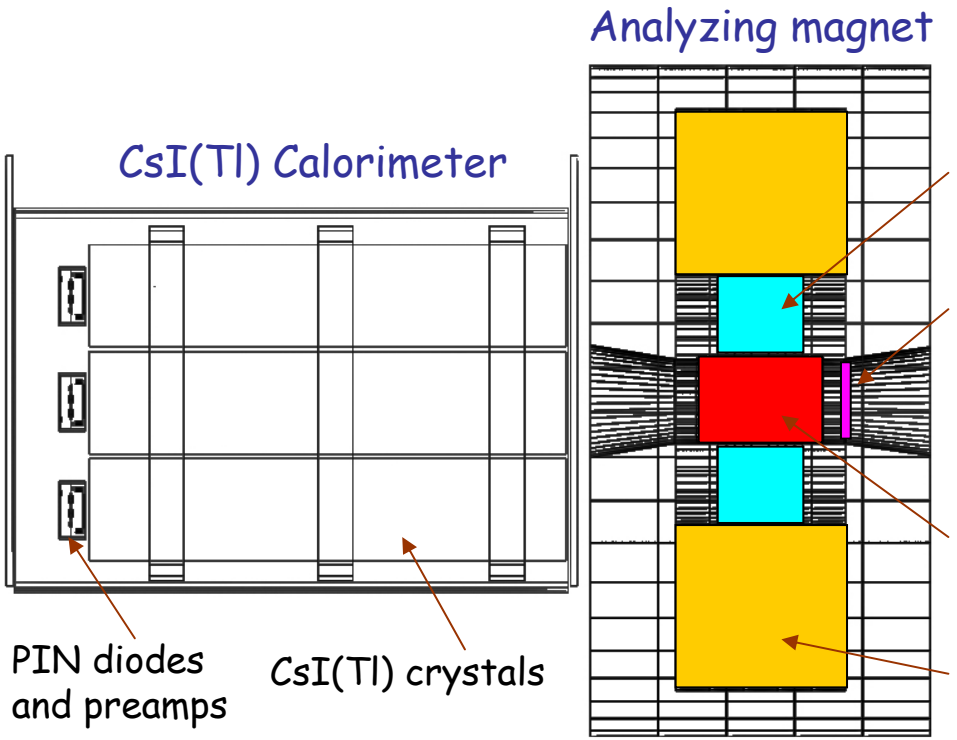
$$T^{\pm}(L) = e^{-nL\sigma} = e^{-nL(\sigma_{phot}+\sigma_{pair}+\sigma_0)} e^{\pm nLP_\gamma P_e \sigma_{pol}} \qquad \text{Transmission}$$

$$\delta(L) = \frac{T^+ - T^-}{T^+ + T^-} \approx nLP_e P_\gamma \sigma_{pol} \qquad \text{Asymmetry}$$

$$P_\gamma = \frac{\delta}{nL\sigma_{pol} P_e} = \frac{\delta}{A_\gamma P_e} \qquad \text{Photon Polarisation}$$

Analyzing Power

Polarimeter



- compare two Magnetizationstates of the analyzer magnet

e^+

$\vec{B}$ / $\overleftarrow{B}$

Measure $E_{dep}(\vec{B})$ and $E_{dep}(\overleftarrow{B})$ -> Asymetry = $\dfrac{E_{dep}(\vec{B}) - E_{dep}(\overleftarrow{B})}{E_{dep}(\vec{B}) + E_{dep}(\overleftarrow{B})}$

Expected Asymmetries

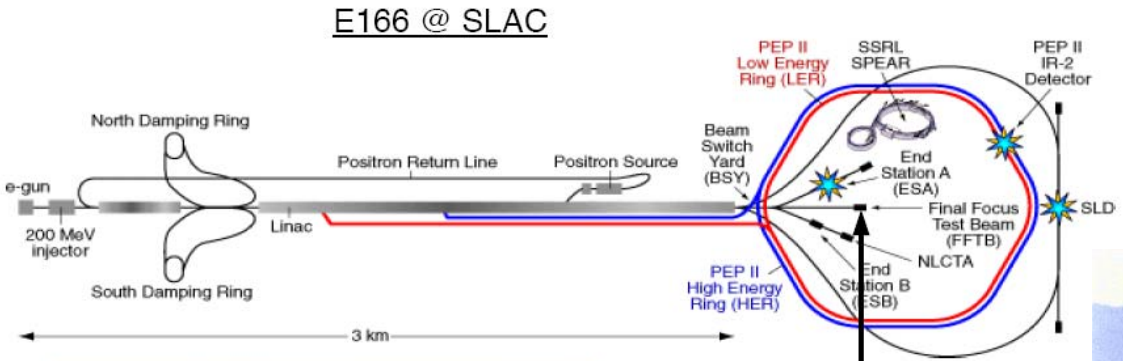
Positron Energy E_{e^+} (MeV)	Positron Polarisation P_{e^+} (%)	Positron Asymmetry δ (%)
3	42	0.55
4	61	0.84
5	69	0.82
6	78	0.87
7	84	0.93
8	77	0.82
9	64	0.63
10	68	0.66

Expected asymmetries power versus positron energy

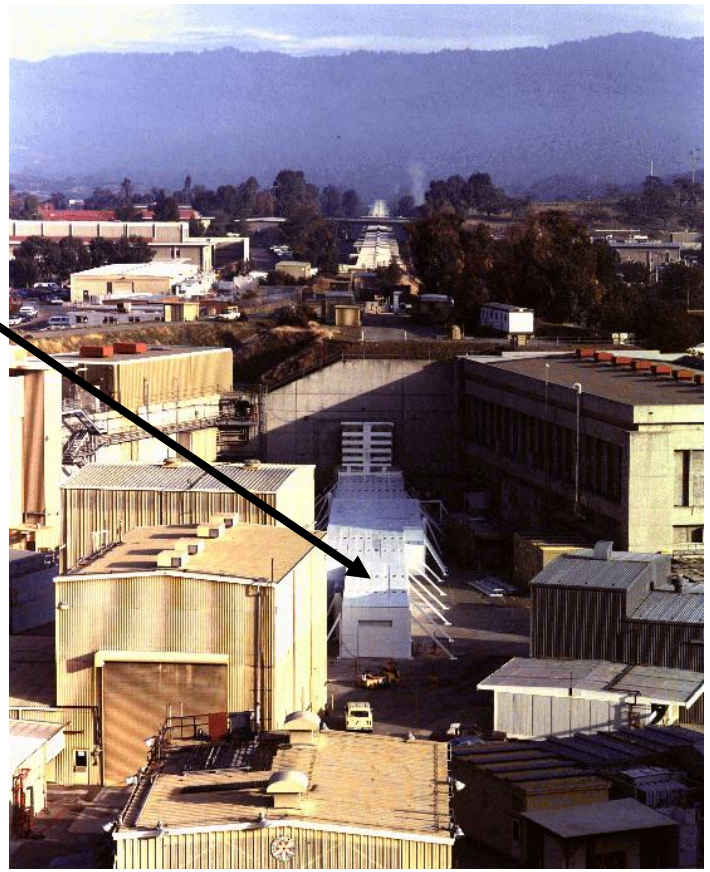
G3 simulation based on the experimental setup of the proposal

Most challenging task for E166
was to measure asymmetries ≤1% in the CsI - Calorimeter

E-166 in the FFTB

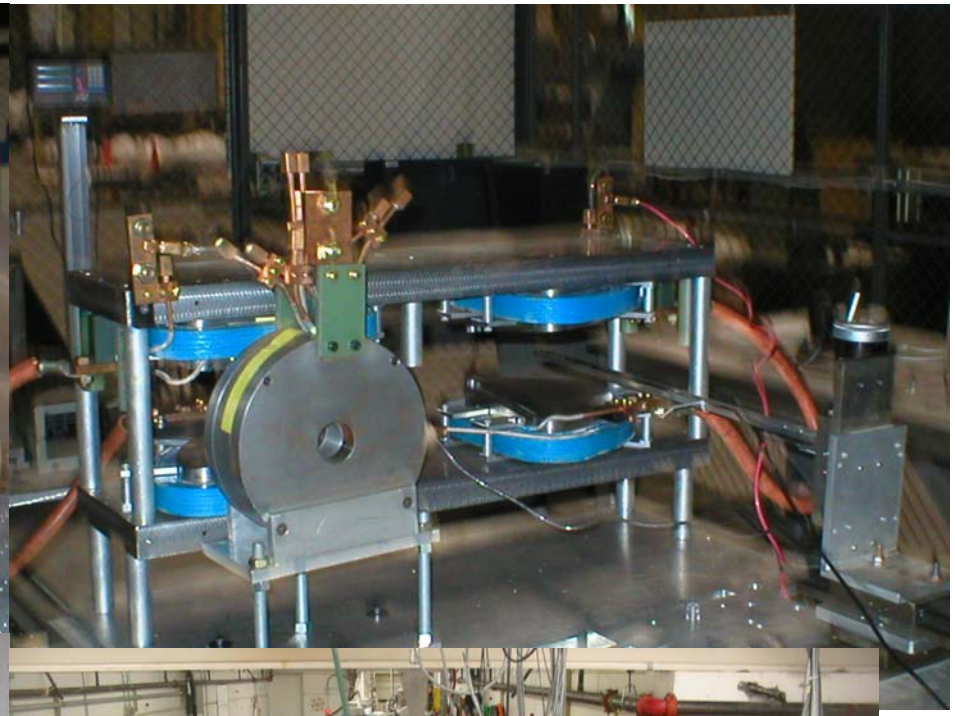


We are here !
(FFTB @ SLAC)



Two sucessful running periods

- beam energy: 46.6 GeV
- rep. Rate: 10 Hz
- N_e^-/pulse: ~10^{10}



50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻

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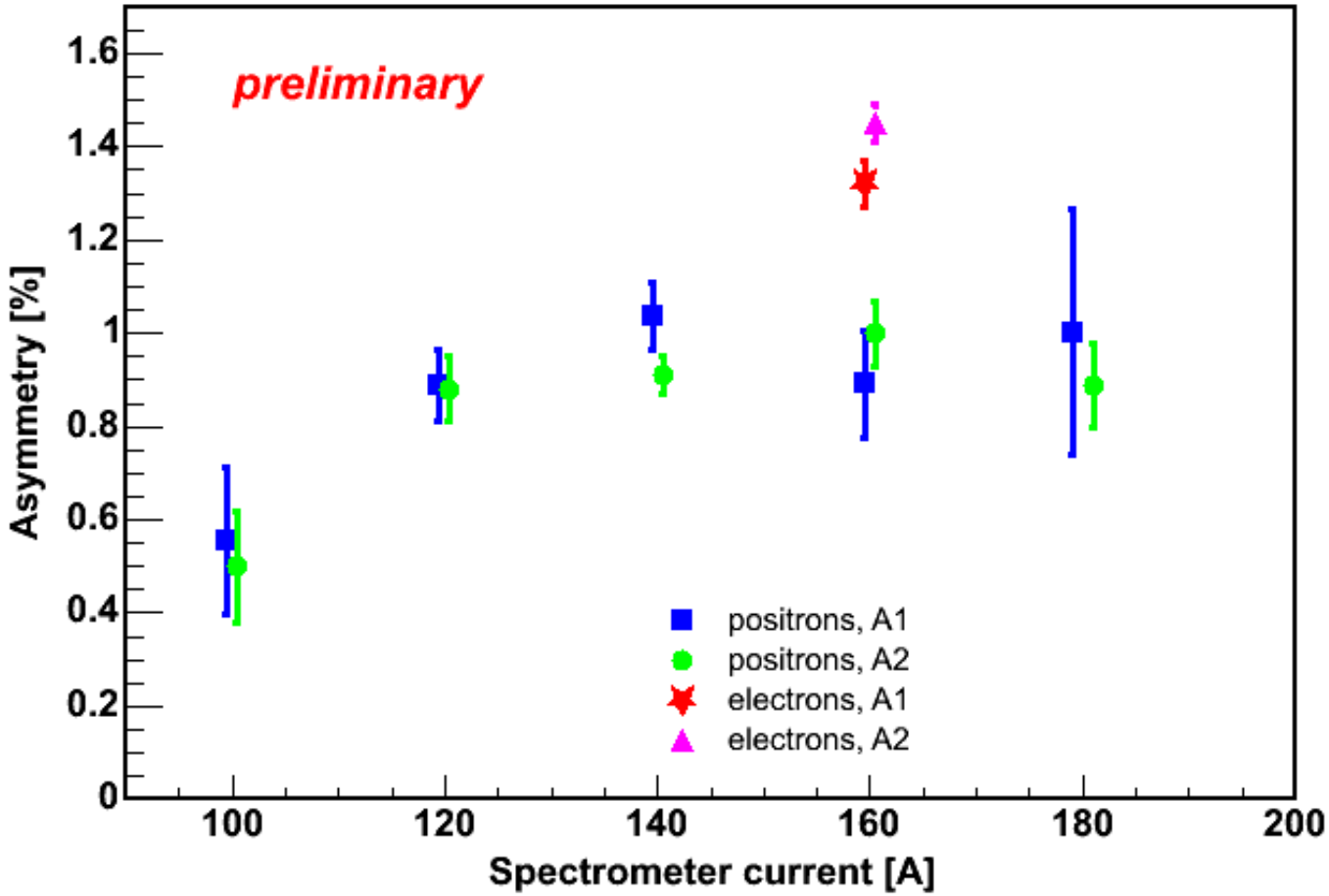
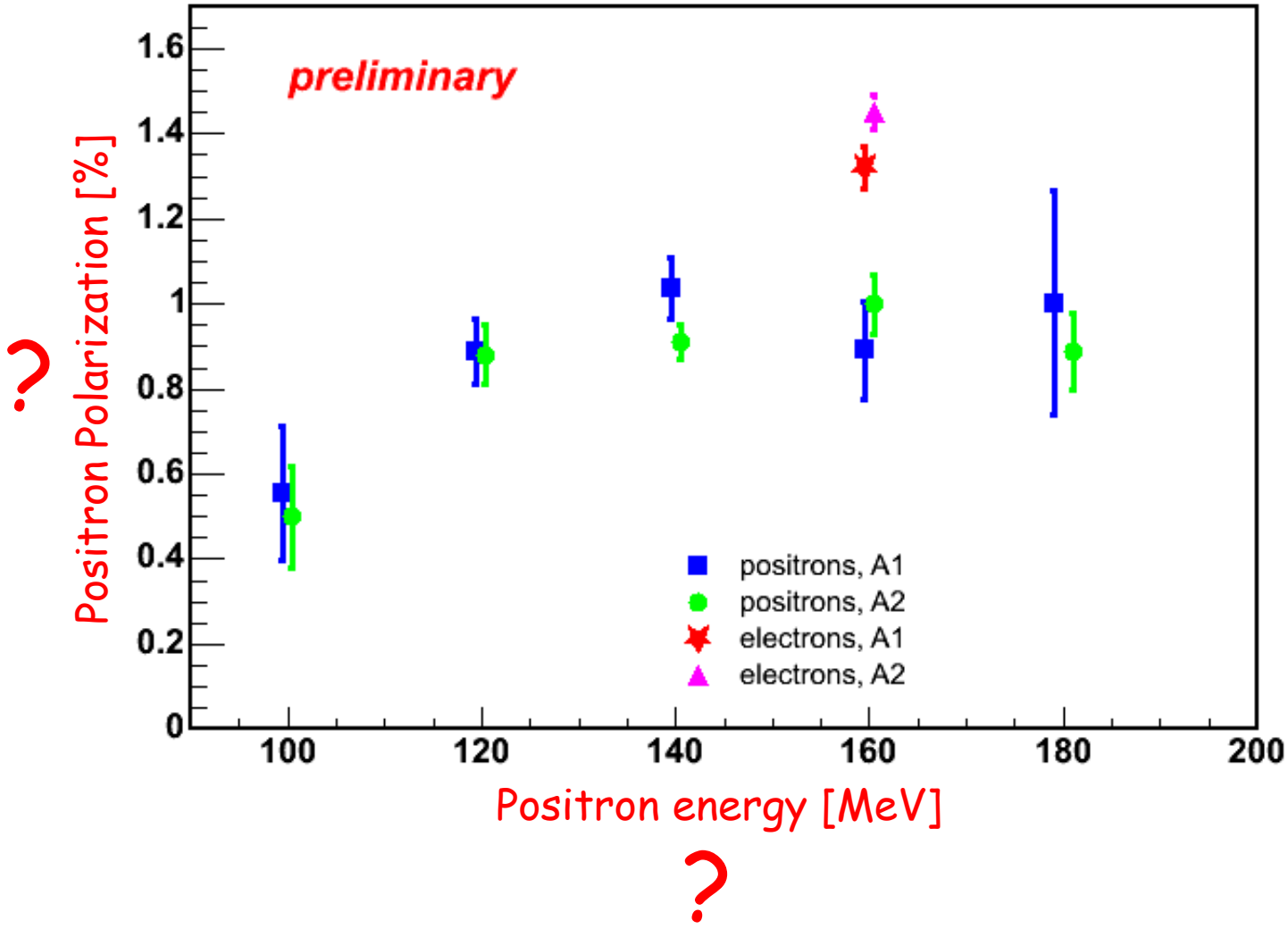
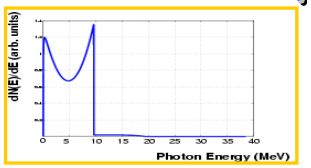
The Asymmetries



The Asymmetries



Polarization dependent processes



Conversion Target

G4ePolarizedBremsstrahlung

Polarized Photons

Undulator

G4PolarizedGammaConversion

G4ePolarizedIonisation
(G4PolarizedMollerBhabhaModel)

With the use of:
G4StokesVector
G4PolarizationHelper
G4PolarizationManager
G4PolarizationMessenger

Vacuum chamber

e+

e+

e+

e+

e+

G4PolarizedCompton

Analyzing Magnet

ReConversion
Target

CsI

G4eplusPolarizedAnnihilation

-> Wed Oct. 11, 8:30 EM Session

50 GeV e⁻ E - 166 10 MeV γ

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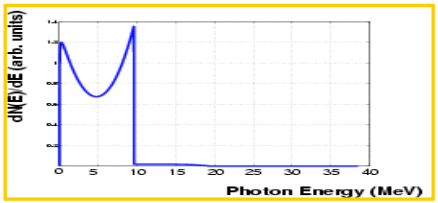
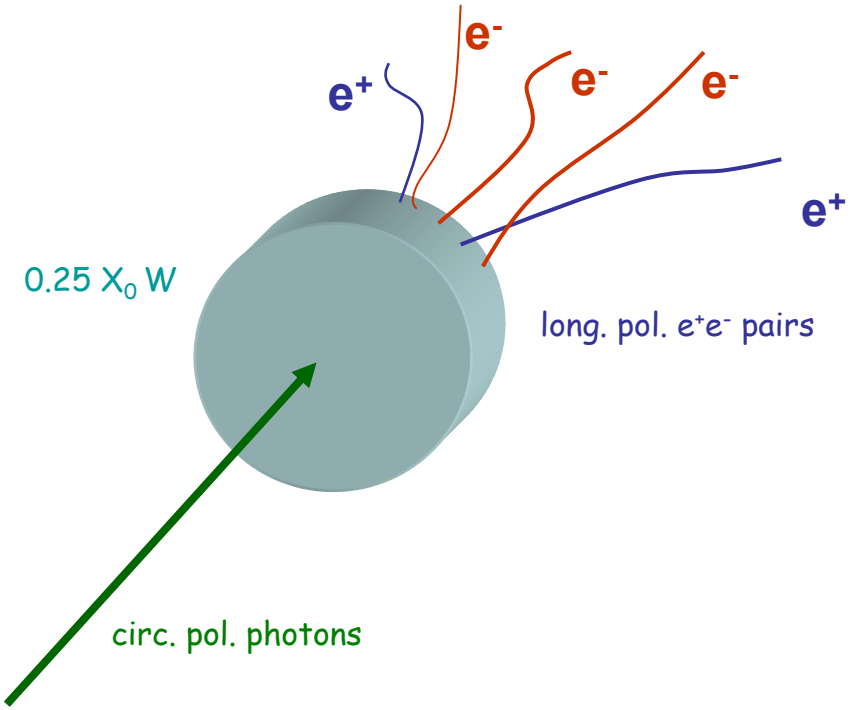
Positron production Target

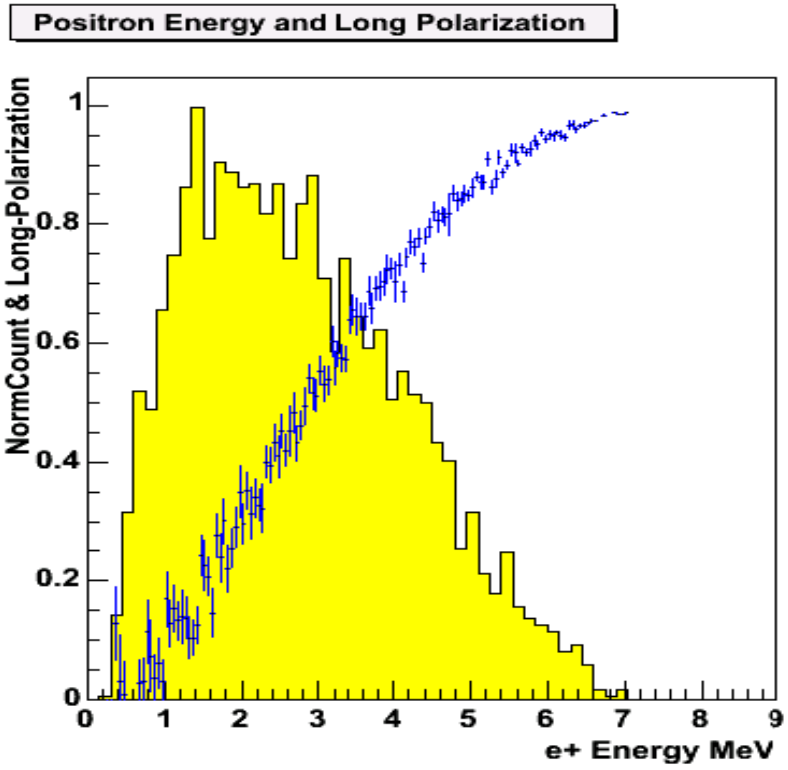
Input: undulator spectrum





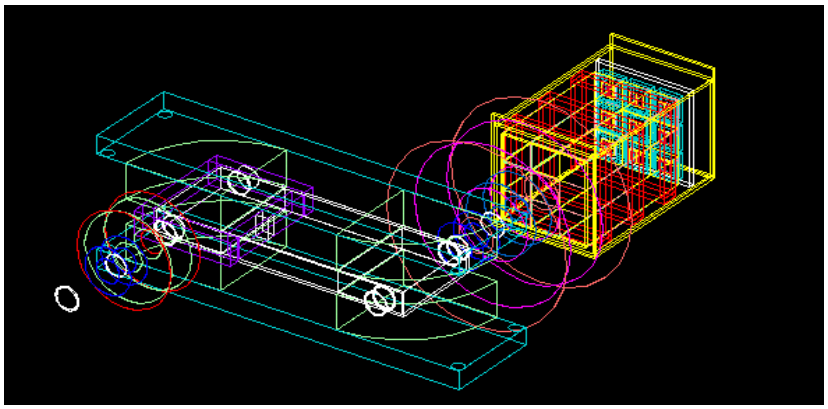
Polarization Transfer:
`G4PolarizedGammaConversion`

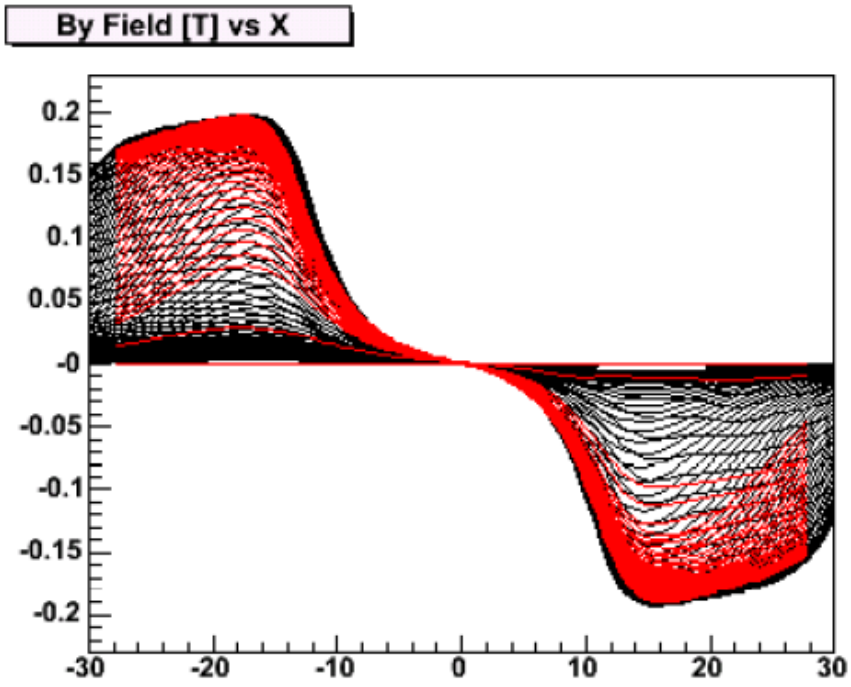
High energetic positrons
carry high degree of polarization

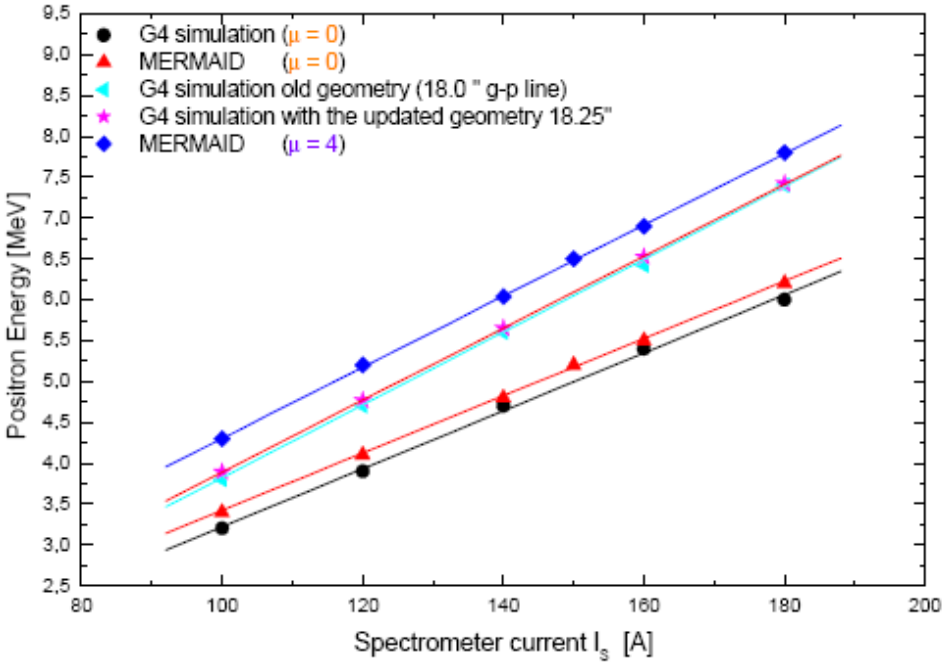


Spectrometer calibration

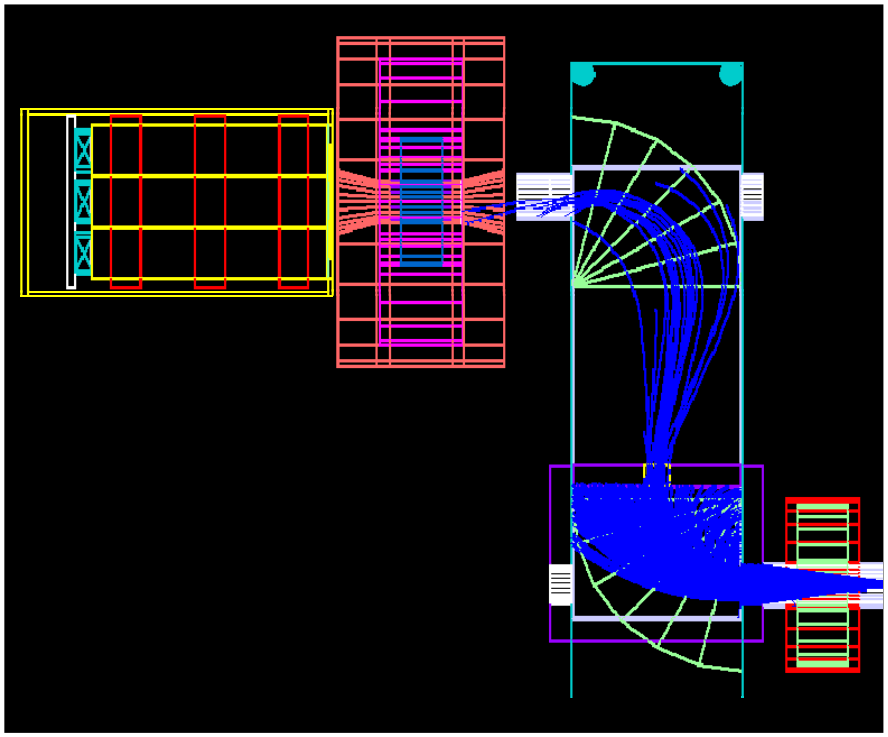
Calculated and measured field map were the input for the G4 Simulation

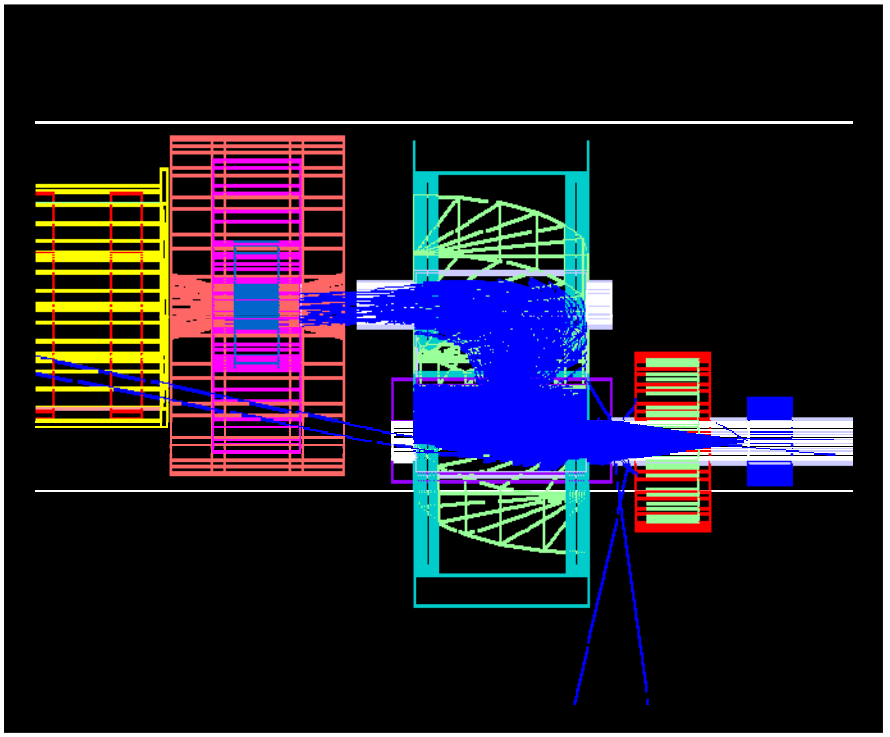




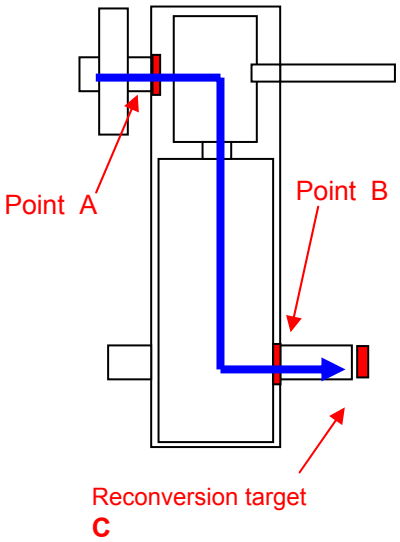


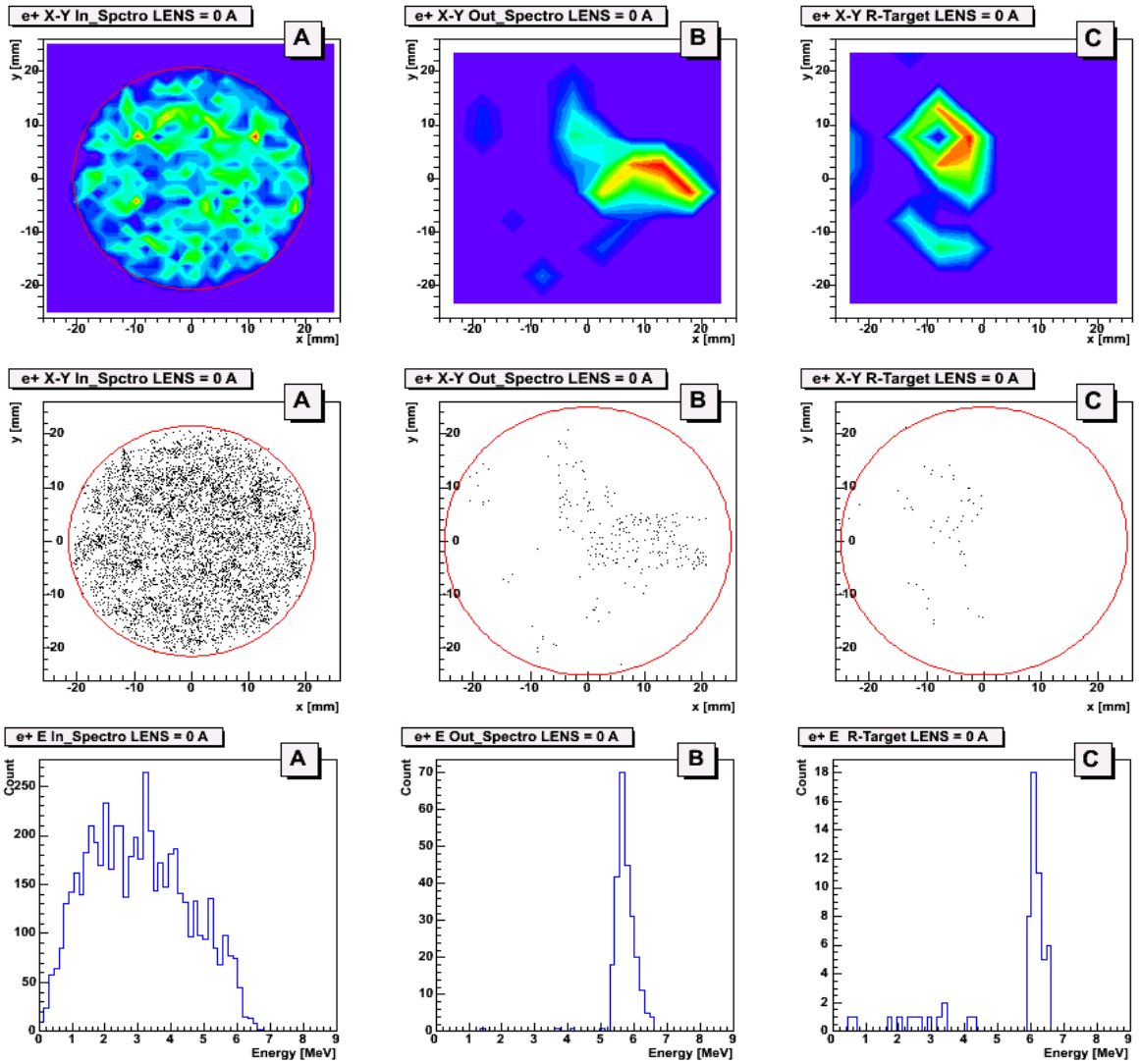
e^+ - Capture and Transport





e^+ - Capture and Transport





50 GeV e^- E - 166 10 MeV γ e^+ e^-

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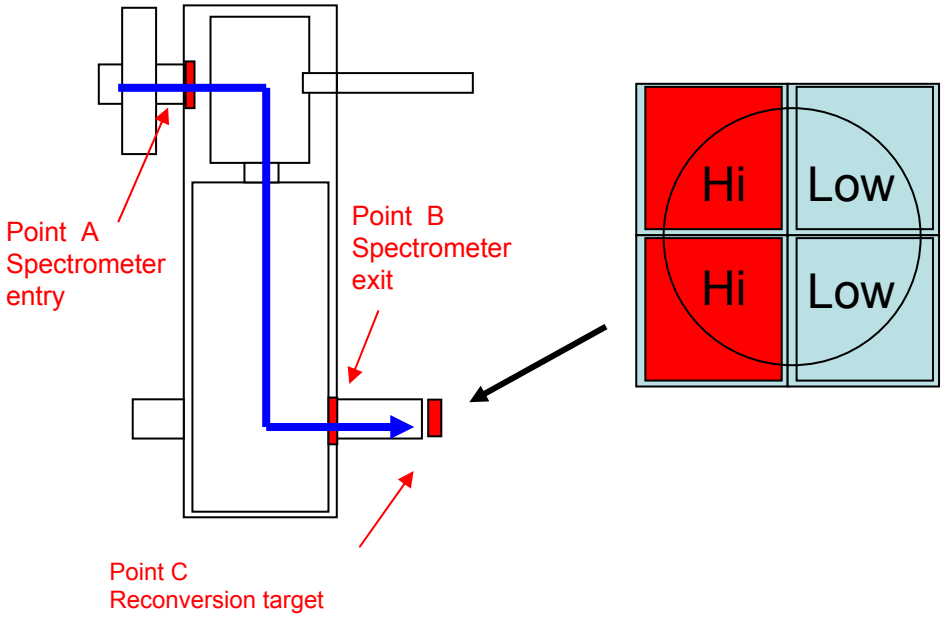
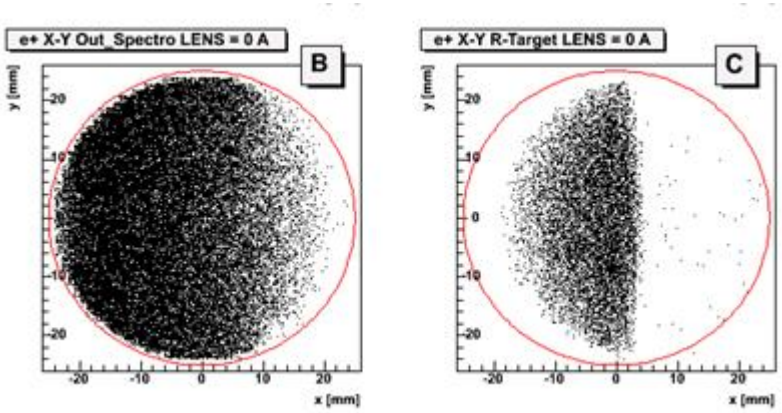
Understanding of experimental data

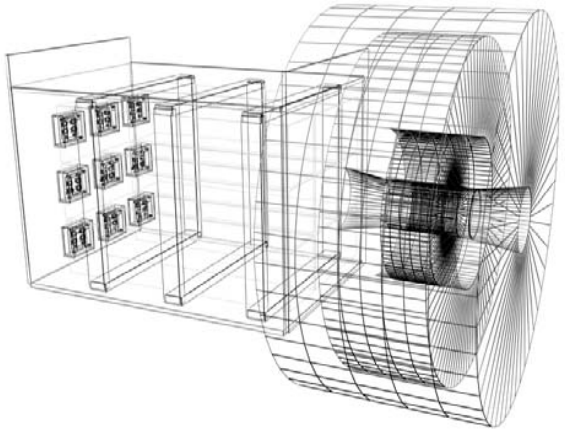


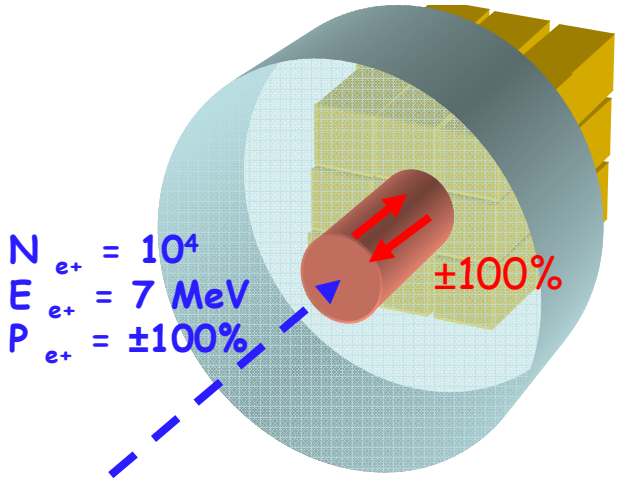
Unexpected distribution
in the Positron counter
at the conversion target

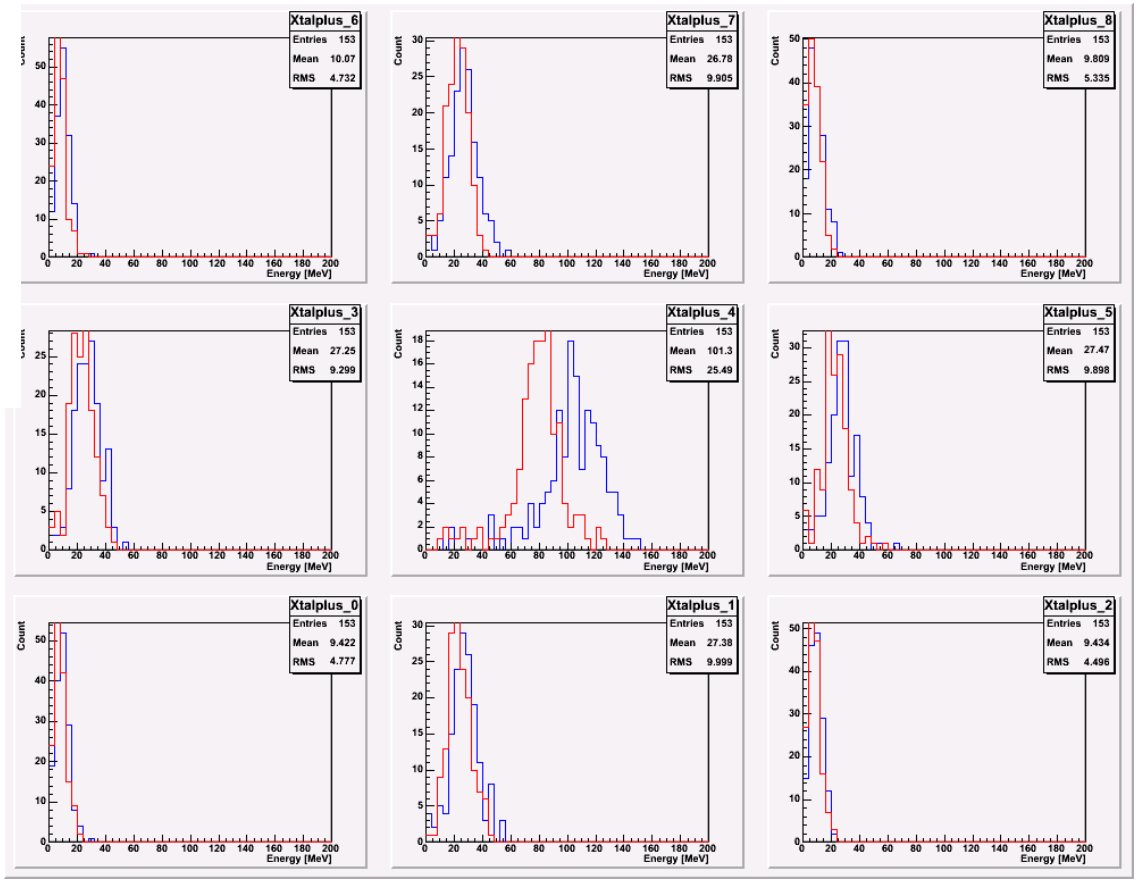
Confirmed by simulation -
Effect of the spectrometer geometry



Polarimeter Analyzing Power







50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻

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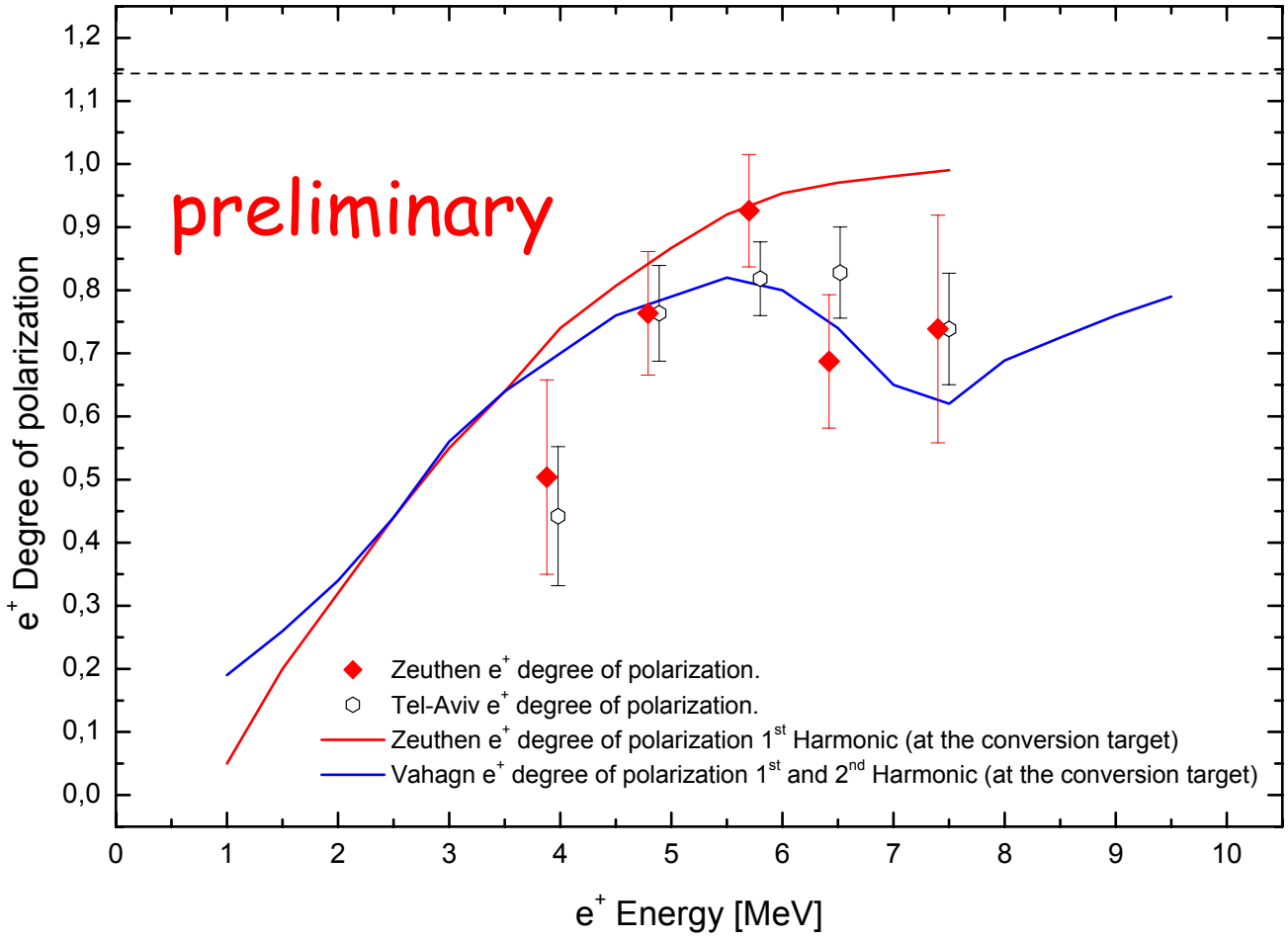
Preliminary results

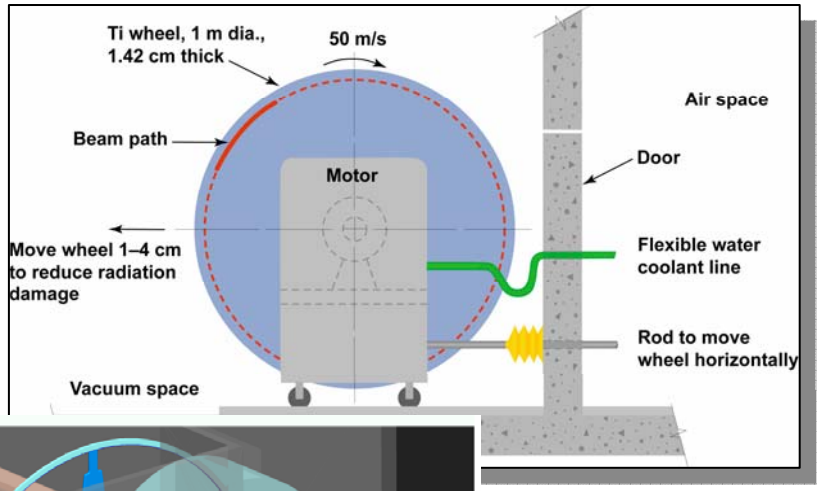


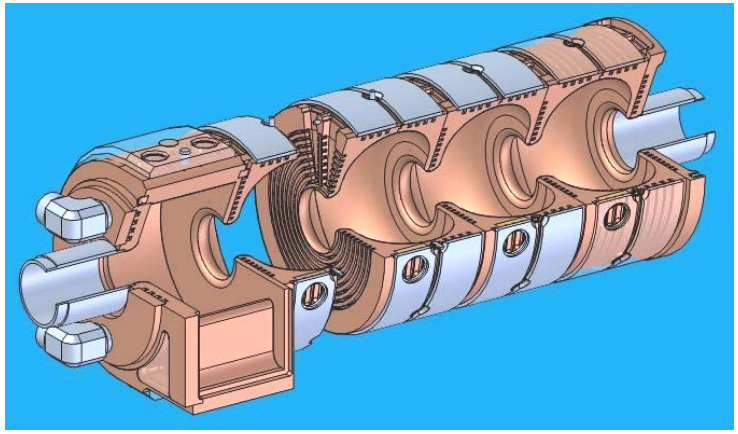
Summary

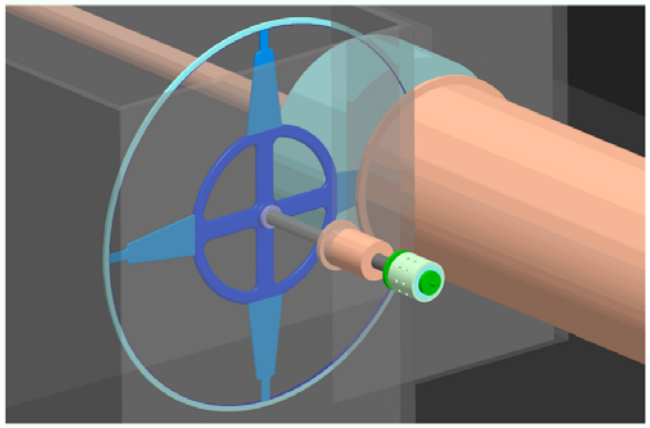
- E-166 produced data with good quality and has shown, that the helical undulator works
- The E166 asymmetries are in the expected range
- The E166 simulation made polarized processes in GEANT4 necessary
- Relevant polarization dependent processes have been implemented
- Full simulation is ongoing and used to test the implemented processes
- New polarized processes available in December

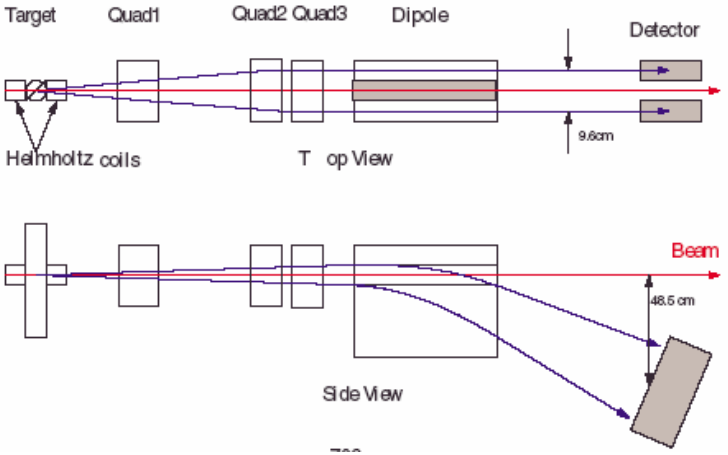
Next:

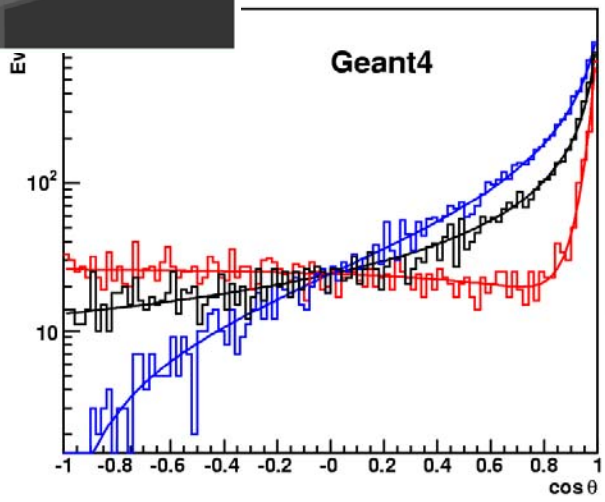
- Simulation studies of
  - Positron production-, capture- and transport system for the ILC
  - Low Energy Polarimeter options for the ILC – "LEPOL"











50 GeV e⁻ E - 166 10 MeV γ e⁺ e⁻

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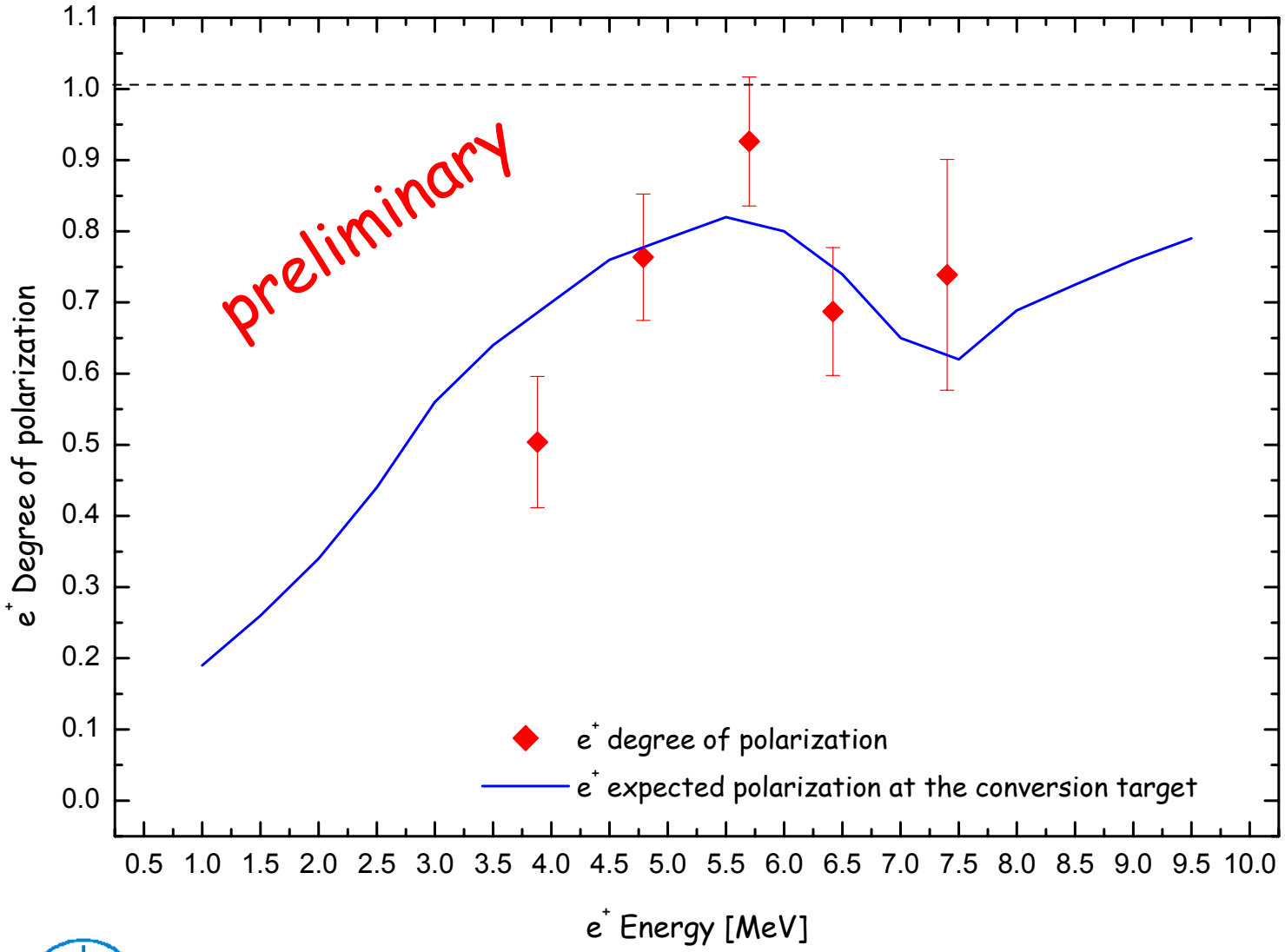
Preliminary Results



50 GeV e⁻ E - 166 10 MeV γ e+ e-

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E166 Helical undulator parameters vs. TESLA, NLC parameters

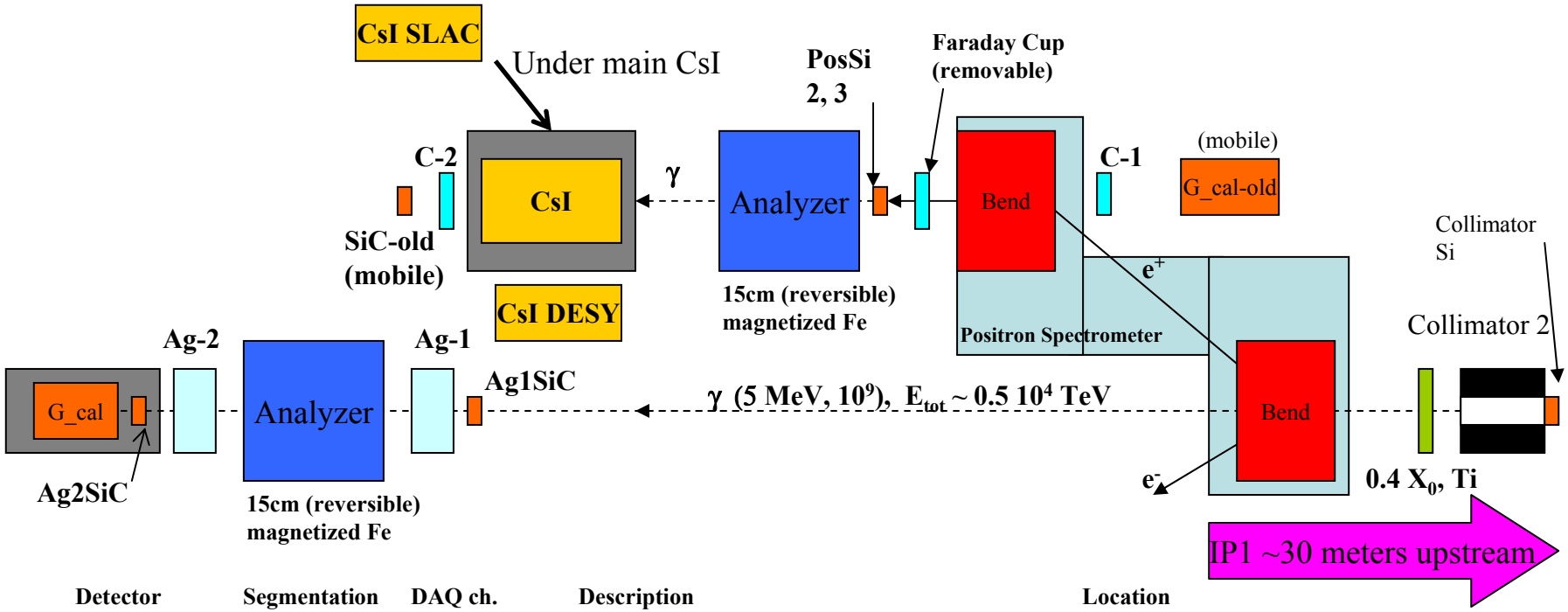
Table 1: TESLA, NLC/USLCSG, E-166 Polarized Positron Parameters

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

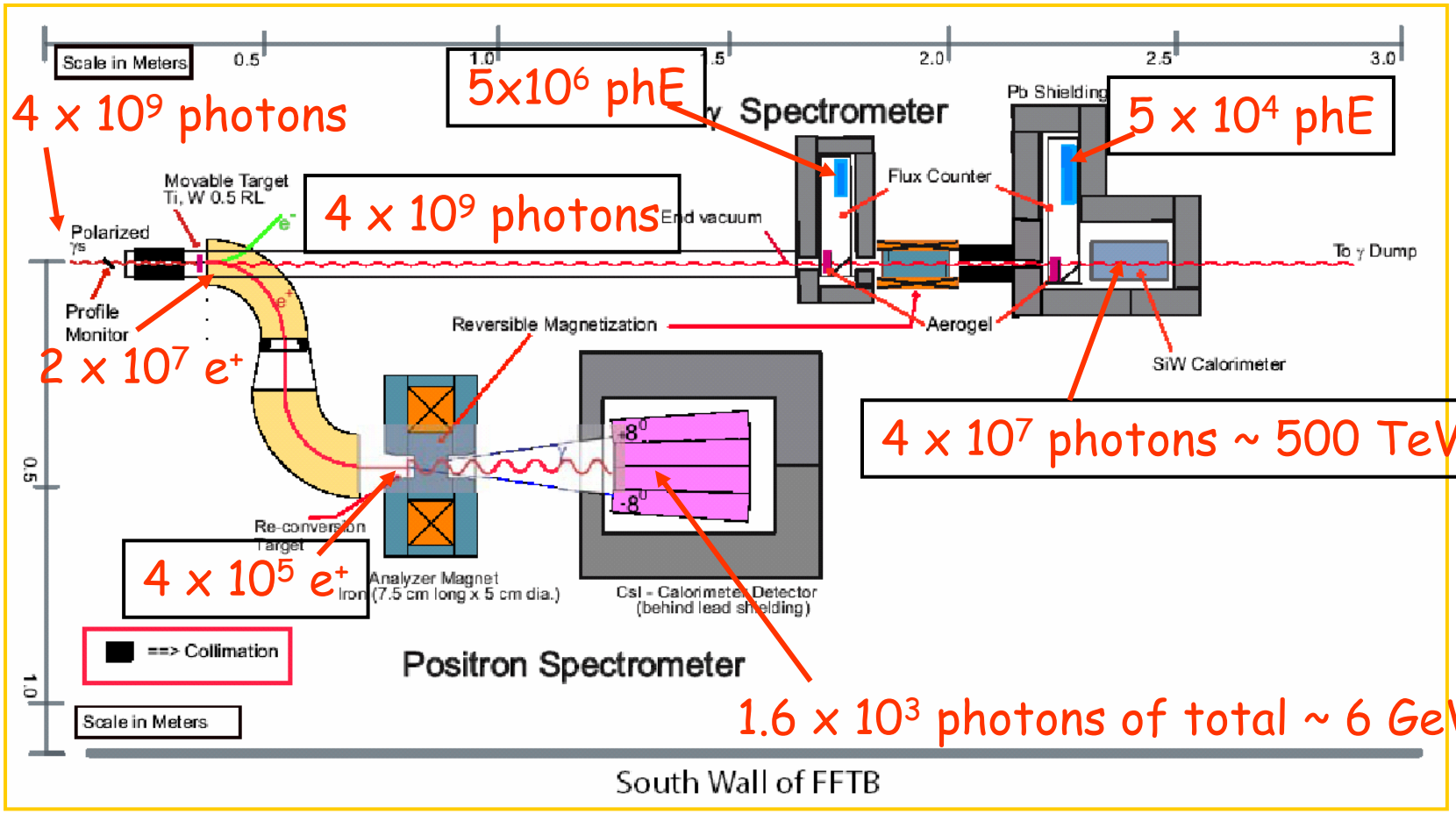
† Including the effect of photon collimation at $\gamma\theta = 1.414$.

E-166 Detector area (Top view)



Detector	Segmentation	DAQ ch.	Description	Location
1. Pcal	B, C, D, E(e-)	1, 2, 3, 4	4x4 arrays, 23 layer: 1X0W/Si/G10, xyz sum	above permanent dump magnets
2. Gcalold	1	8	12ch M1s, 23 layer: 1X0W/Si/G10, xyz sum	mobile (background)
3. SiCold	1	9	12ch M1s, 15 layer: Si/G10, xyz sum	mobile (background)
4. Ag2SiC	1	13	12ch. M1, 1 layer: 0.15X0W/G10/Si, xy sum	inside Gcal box
5. Gcal	Z1-4s	14-17	(s)ig:central 8ch M1s, Zsum| 1:1,2 2:3,4 3:5,6 4:7-9	Gcal box
	Z1-4b	18-21	(b)kgndl:corners 4ch M1s, Zsum| same as sig.	9 layers: 1X0W/G10/Si
6. PositronSi	1	22	12ch. M1, 1 layer Si/G10, xy sum	between Faraday cup and e+ magnet (June05 run)
6a.PosSi 2 or 3	4-BL,TL,TR,BR	88,89,90,92	(1) 2x2 array, 1 layer: Si only in beam,	between Faraday cup and e+ magnet (Sept05 run)
7. Ag1Si	1	23	12ch. M1, 1 layer 0.15X0W/G10/Si, xy sum	upstream of Ag1 in Al box
8. Collimator Si	4-T,R,B,L	84,85,86,87	4-M1, 12ch arrays w/ 1X0W, 3mm hole	aligned w/ collimator 3mm hole

Polarimeter setup



MERMAID field map implementation into E166_G4_SIM

$$
\begin{aligned}
B_x &= Blx_{i,j,k}(1-x)(1-y)(1-z) + Blx_{i,j,k+1}(1-x)(1-y)z + \\
&\quad Blx_{i,j+1,k}(1-x)y(1-z) + Blx_{i,j+1,k+1}(1-x)yz + \\
&\quad Blx_{i+1,j,k}x(1-y)(1-z) + Blx_{i+1,j,k+1}x(1-y)z + \\
&\quad Blx_{i+1,j+1,k}xy(1-z) + Blx_{i+1,j+1,k+1}xyz.
\end{aligned}
$$

$$
\begin{aligned}
B_y &= Bly_{i,j,k}(1-x)(1-y)(1-z) + Bly_{i,j,k+1}(1-x)(1-y)z + \\
&\quad Bly_{i,j+1,k}(1-x)y(1-z) + Bly_{i,j+1,k+1}(1-x)yz + \\
&\quad Bly_{i+1,j,k}x(1-y)(1-z) + Bly_{i+1,j,k+1}x(1-y)z + \\
&\quad Bly_{i+1,j+1,k}xy(1-z) + Bly_{i+1,j+1,k+1}xyz.
\end{aligned}
$$

$$
\begin{aligned}
B_z &= Blz_{i,j,k}(1-x)(1-y)(1-z) + Blz_{i,j,k+1}(1-x)(1-y)z + \\
&\quad Blz_{i,j+1,k}(1-x)y(1-z) + Blz_{i,j+1,k+1}(1-x)yz + \\
&\quad Blz_{i+1,j,k}x(1-y)(1-z) + Blz_{i+1,j,k+1}x(1-y)z + \\
&\quad Blz_{i+1,j+1,k}xy(1-z) + Blz_{i+1,j+1,k+1}xyz.
\end{aligned}
$$

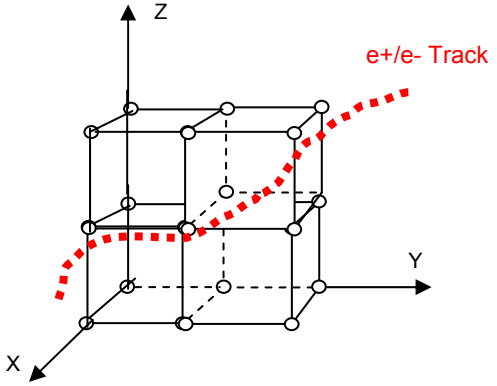


Figure 19. Scheme of one unitary segment for the 3D interpolation.

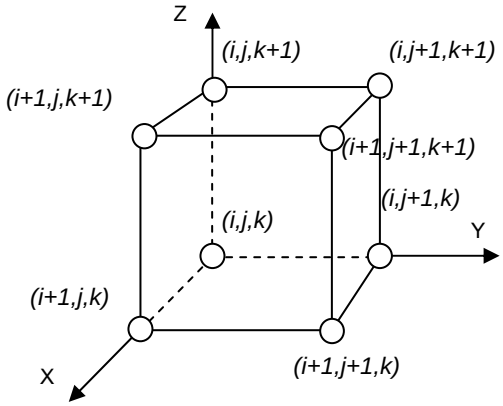
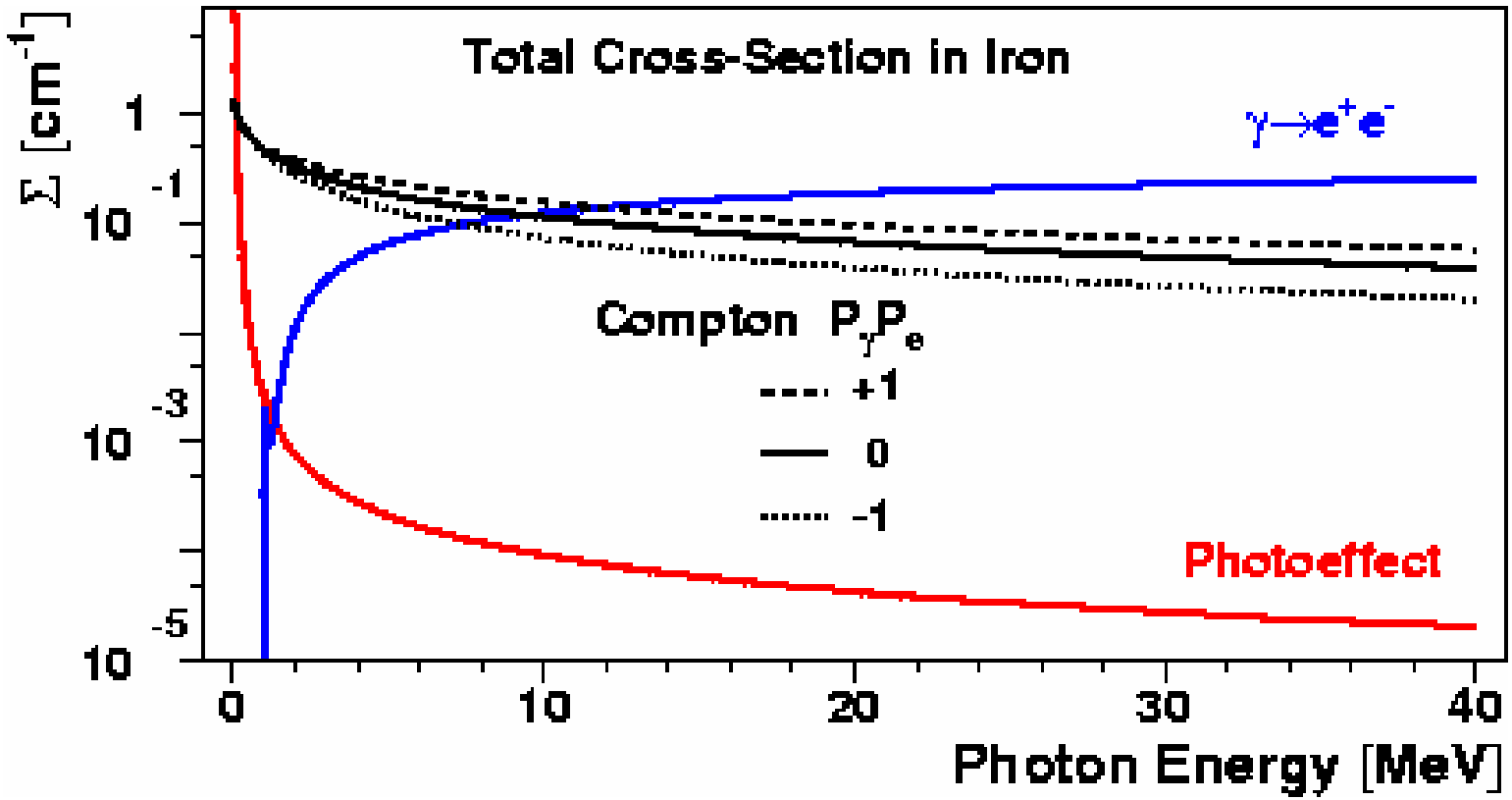
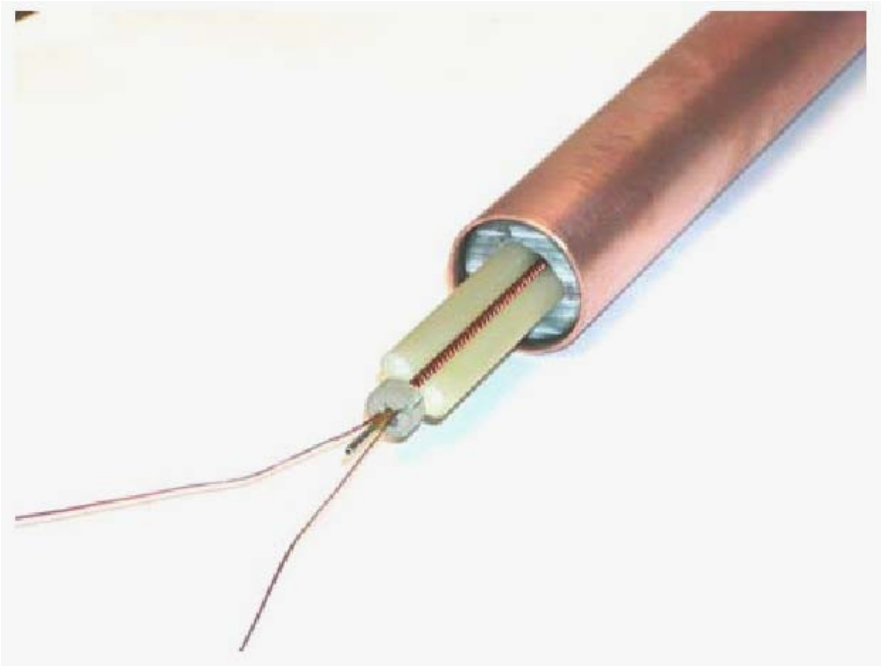


Figure 20. Scheme of the 3D segmentation using the unitary cube method for the field map implementation


Total Cross-Section in Iron
$\gamma \rightarrow e^+e^-$
Compton $P_\gamma P_e$
+1
0
-1
Photoeffect
Σ [cm^{-1}]
1
10^{-1}
10^{-3}
10^{-5}
0
10
20
30
40
Photon Energy [MeV]



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