Polarisation in Geant4

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Outline

Motivation

- Geant4 version 8.2
- Use-cases

Implementation

- Physics picture
- The new Geant4 polarisation library

Applications

- The E166 experiment
- ILC positron source
- LEPOL

Summary

- Summary & Outlook

Geant4 release 8.2

appeared

- December 15th 2006

available at

- `http://geant4.web.cern.ch/`

includes

- polarised QED processes
- documentation available in Geant4 Physics Reference Manual
- usage illustrated in a simple example `examples/extended/polarisation/Pol01/`

Use-cases

1. Polarisation-Transfer

   e.g. a circularly polarised photon beam hits a thin target:
   What is the degree of polarisation of

   - the outgoing photon beam
   - the produced electron/positrons

   needed for Target studies for the ILC positron source optimisation and especially the E166 experiment

2. Polarimetry

   if a polarised beam hits a polarised target,

   - asymmetries in total cross sections
     (example E166 Compton transmission polarimeter), and
   - asymmetries in distribution
     (low–energy Polarimeter for the ILC)

   can be observed.

Use-cases

Interactions of polarised Electrons, Positrons and Photons

- main focus on logitudinal (or circular) polarisation (extension to transverse polarisation is forseen)
- envisaged energy domain is 1MeV . . . 10 MeV (E166 experiment, positron source) or up to 5GeV (ILC low-energy polarimeter)

Polarisation needed in

- Pair–production
- Bremsstrahlung
- Compton scattering
- Møller/Bhabha scattering
- Positron annihilation into two photons

Good news: Everything described by QED.

Stokes parameter

G. Stokes, Trans. Cambridge Phil. Soc. **9** (1852) 399

Wave function :

$$\Psi(\boldsymbol{x}, t) = a_1 \Psi_1 + a_2 \Psi_2$$

Jones vector :

$$|a_1|^2 + |a_2|^2 = 1 \qquad \boldsymbol{a} = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix}$$

Spin density matrix :

$$\rho = \boldsymbol{a} \otimes \boldsymbol{a}^* = \begin{pmatrix} a_1 a_1^* & a_1 a_2^* \\ a_2 a_1^* & a_2 a_2^* \end{pmatrix} = \frac{1}{2}(1 + \boldsymbol{\xi}\boldsymbol{\sigma})$$

$$\sigma_1 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \quad \sigma_2 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \quad \sigma_3 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

Stokes parameter :

$$\boldsymbol{\xi} = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix} = \boldsymbol{a}^\dagger \boldsymbol{\sigma}\, \boldsymbol{a}$$

- describes arbitrary lepton or photon polarisation states

Matrix formalism

W. H. McMaster, Rev. Mod. Phys. **33** (1961) 8

$$\begin{pmatrix} I \\ \boldsymbol{\xi} \end{pmatrix} = T \begin{pmatrix} I_0 \\ \boldsymbol{\xi}_0 \end{pmatrix}$$

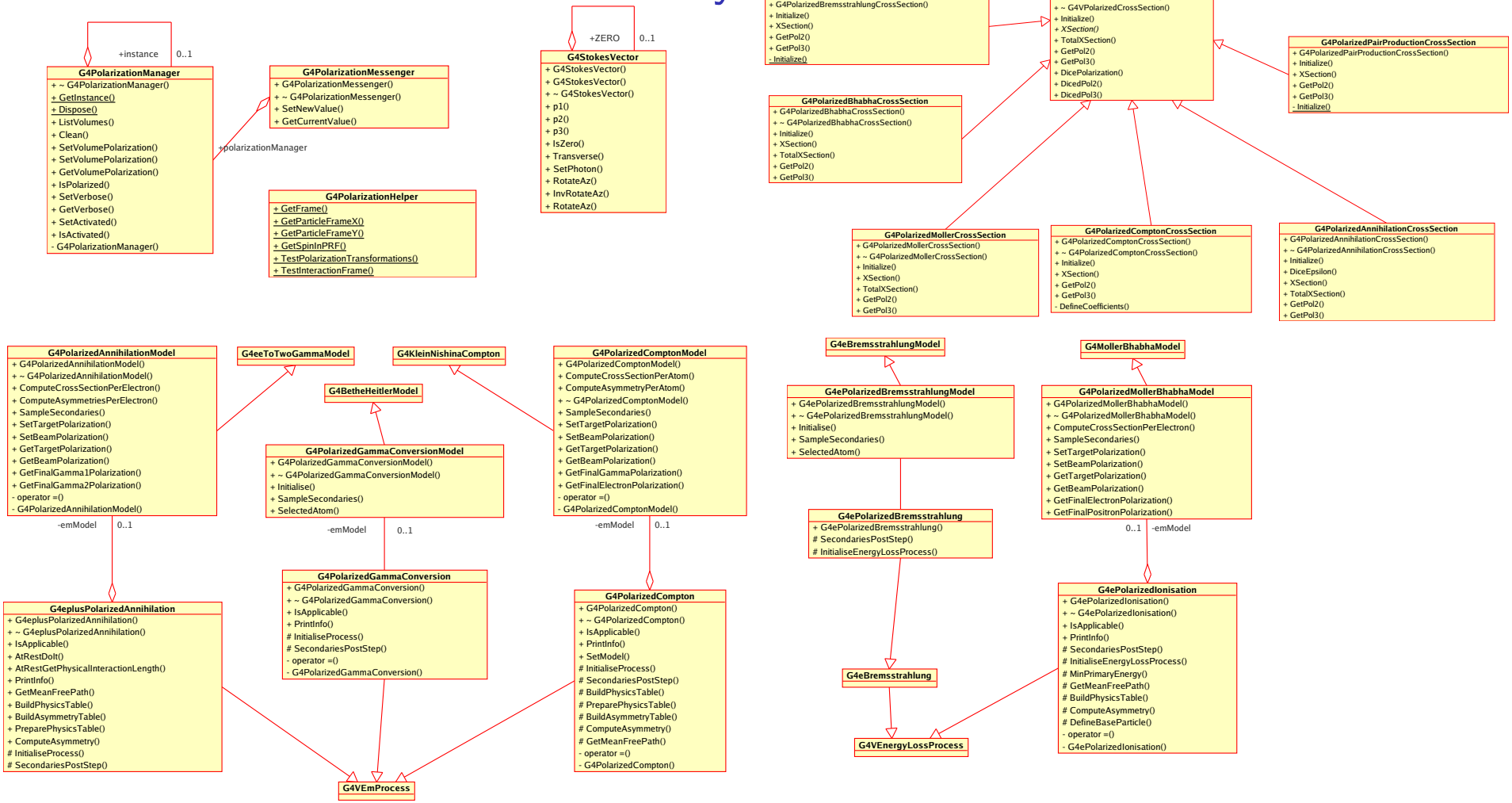
- relates incoming Stokes vector(s) $\boldsymbol{\xi}_0$ to outgoing Stokes vector(s) $\boldsymbol{\xi}$
- I gives differential distribution (intensity)

Transformation Matrix :

$$T = \begin{pmatrix} S & A_1 & A_2 & A_3 \\ P_1 & M_{11} & M_{21} & M_{31} \\ P_2 & M_{12} & M_{22} & M_{32} \\ P_3 & M_{13} & M_{23} & M_{33} \end{pmatrix}$$

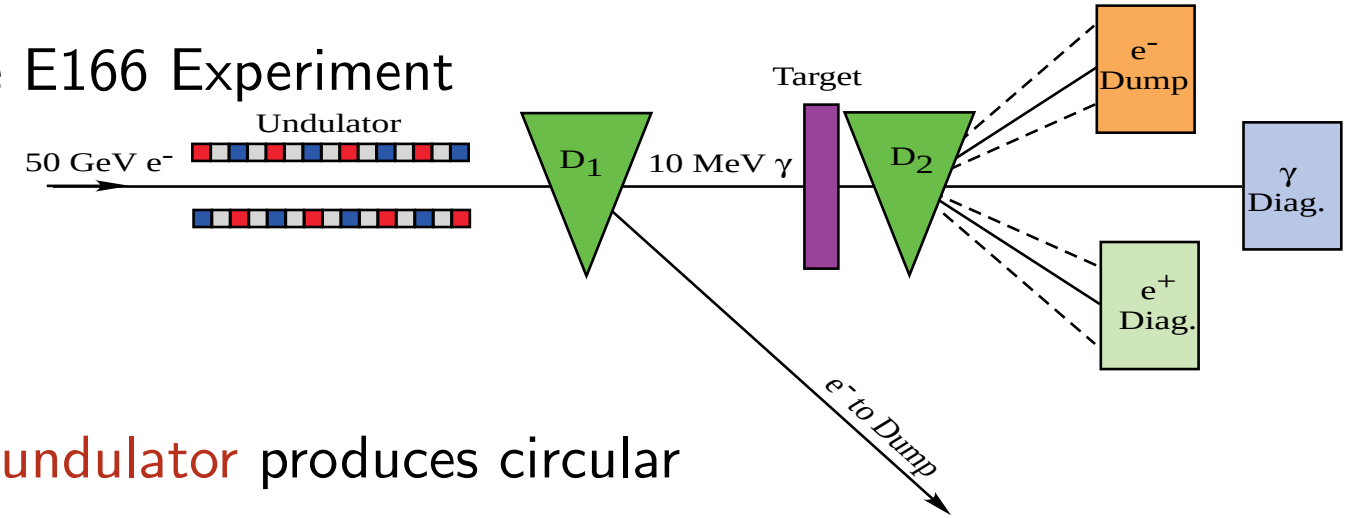
- Differential cross section
- Asymmetry
- Polarisation
- Depolarisation and polarisation transfer

New Geant4 Polarisation Library



- provides (almost all) polarised QED processes

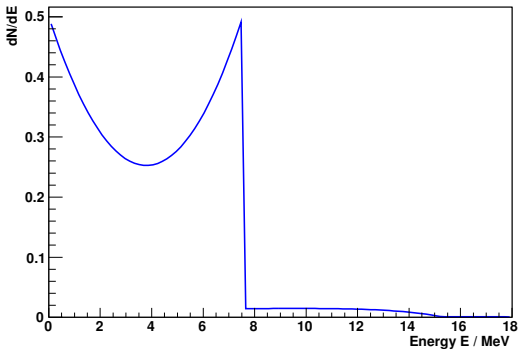
Application to the E166 Experiment



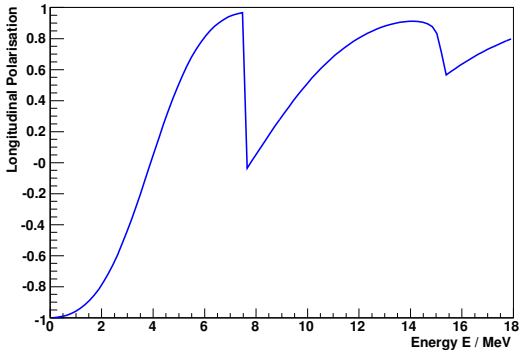
- 1 meter helical undulator produces circular polarised photons
- utilising 50 GeV electron final focus test beam (FFTB) at SLAC
- photons are converted to positrons in thin W-target
- measurement of photon and positron polarisation by Compton transmission polarimetry

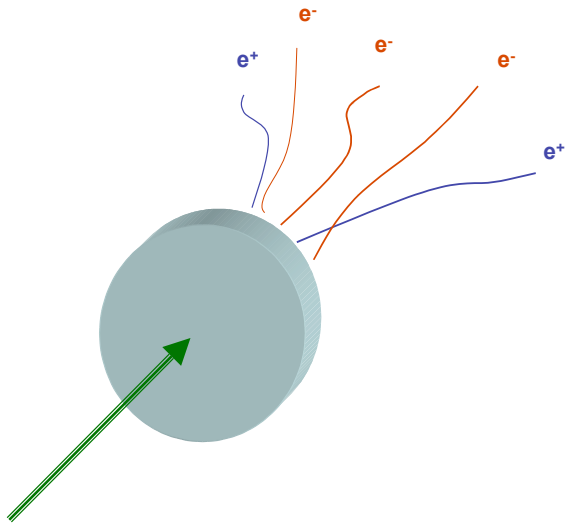
Target – Expected positron polarisation

γ energy



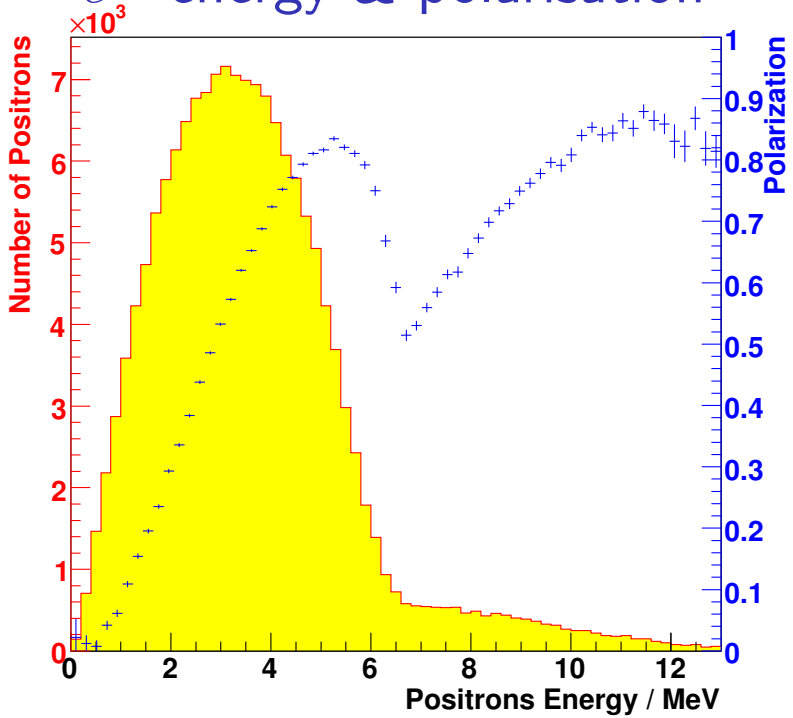
γ polarisation



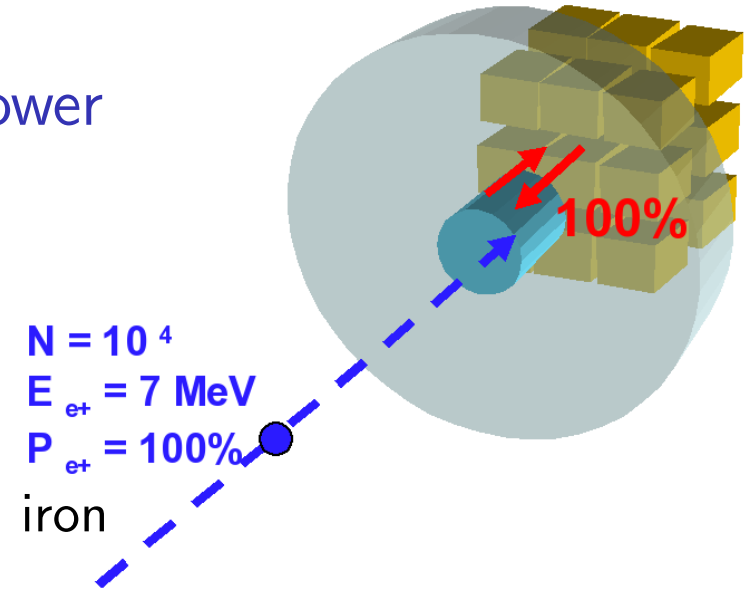


- input photon energy & polarisation generated by helical undulator
- conversion into electron–positron pairs in a thin W-target
- polarisation transfer to high energetic leptons
- simulation: expected energies and polarisation of produced positrons

e^+ energy & polarisation

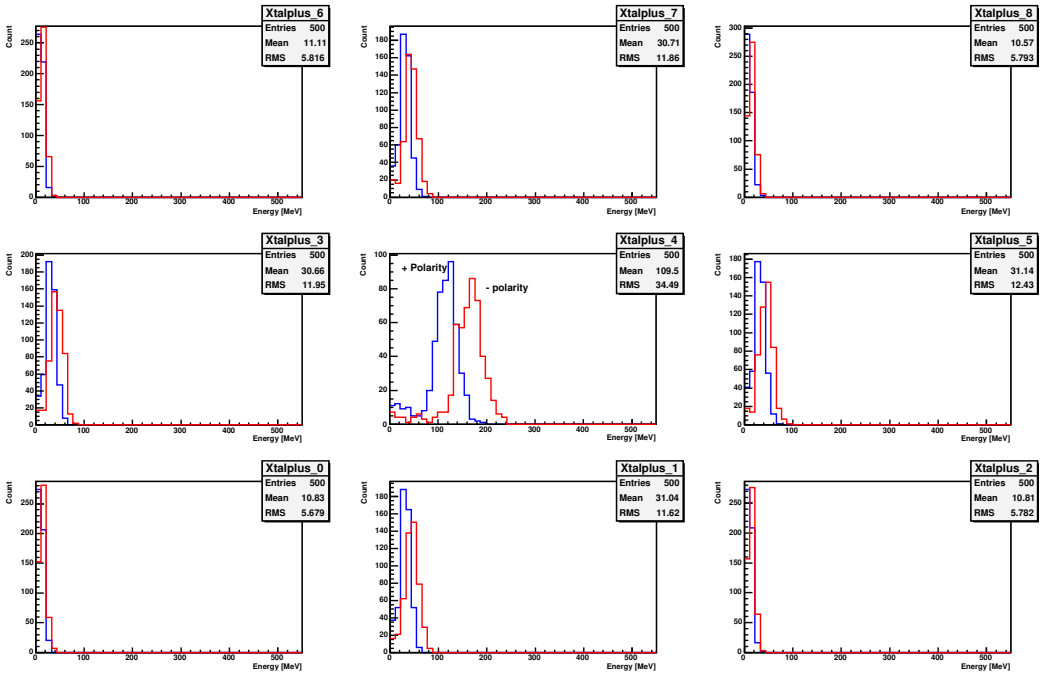


Polarimeter – Simulation of Analysing Power

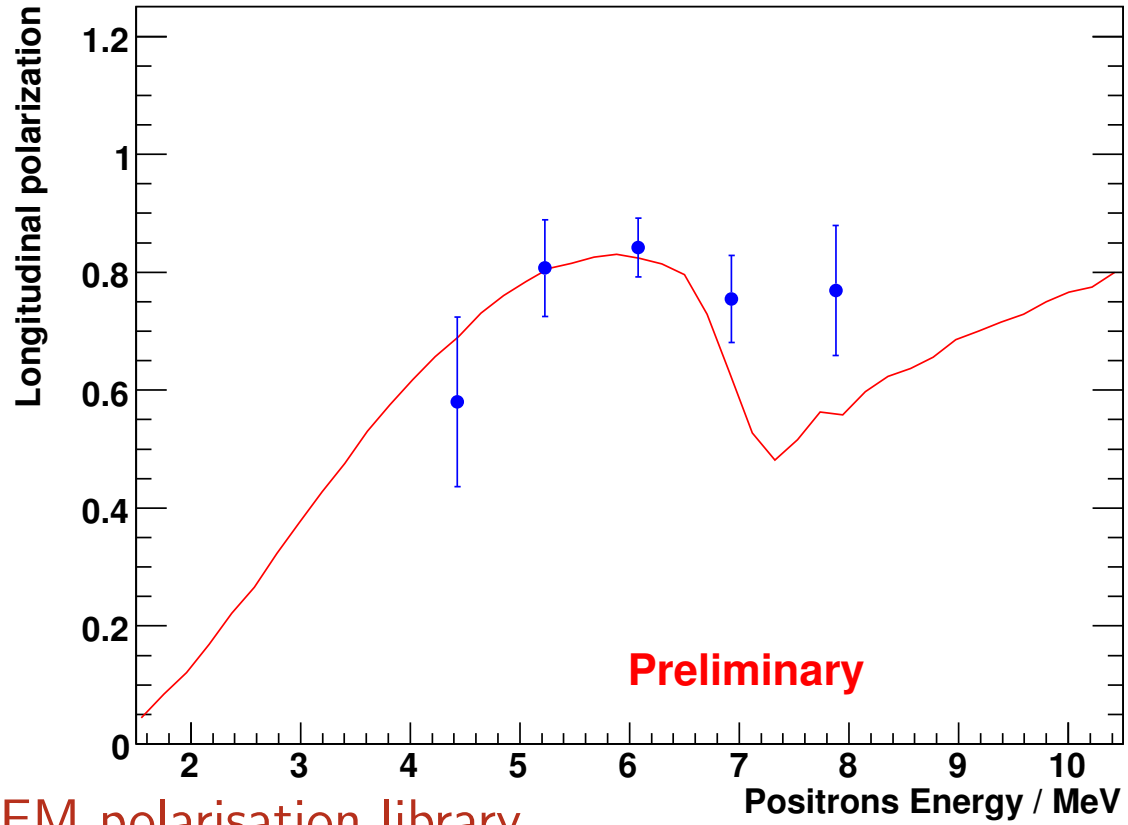


- reconversion of positrons into photons via Bremsstrahlung and annihilation
- transmission of photons through magnetised iron (magnetisation parallel or anti-parallel)
- measurement of transmission in a 9-crystal CsI calorimeter
- polarisation dependence of Compton cross section results in an asymmetry
- simulation gives analysing power (conversion factor between measured asymmetry and polarisation of positrons)

K.Laihem

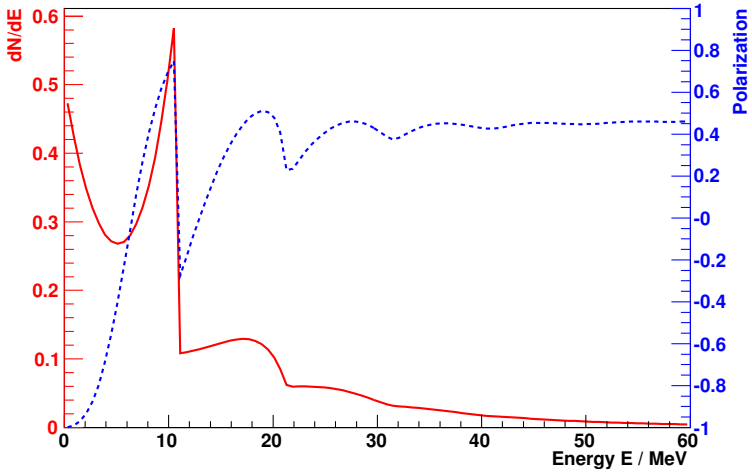


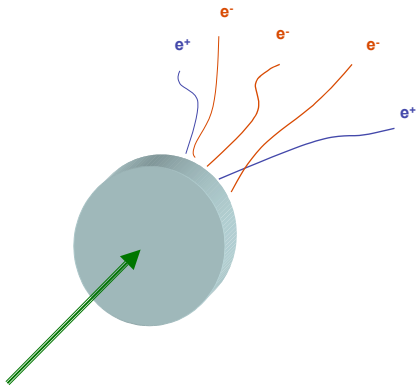
Positron polarisation – Preliminary results

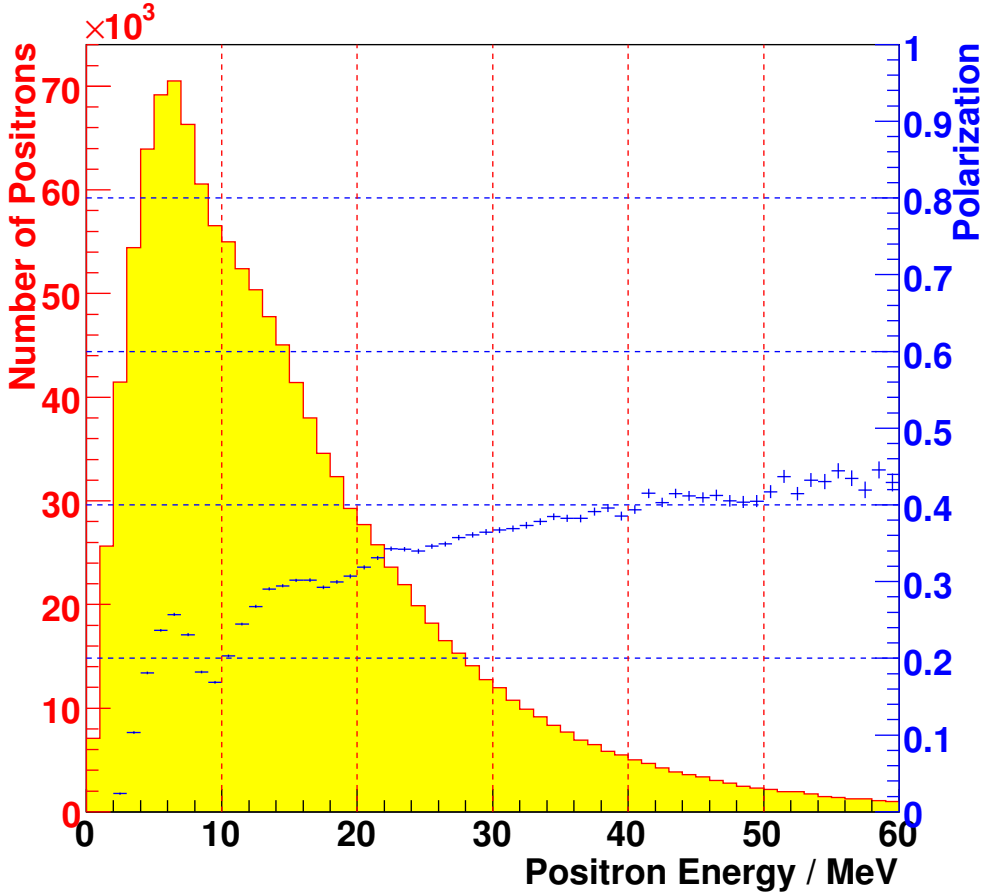


- measurements of small asymmetries ($\mathcal{O}(1\%)$) was a challenge
- measured positron polarisation at 5 energies
- simulations based on new EM polarisation library
- results consistent with expectation
- analysis ongoing
- final results expected . . . soon!

ILC Positron source







- simulation gives positron polarisation and yield
- colimation of photon beam gives higher polarisation
- simple acceptance model: 5-25 MeV, 20°
- optimisation of polarisation vs. yield

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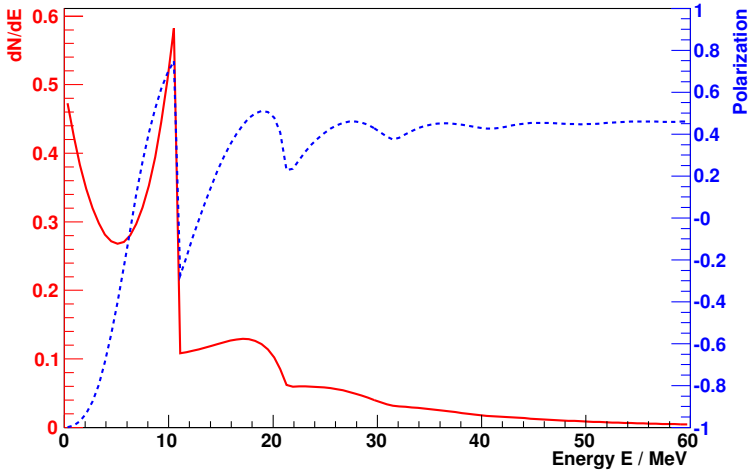

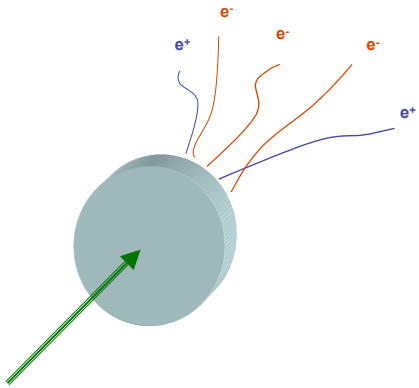

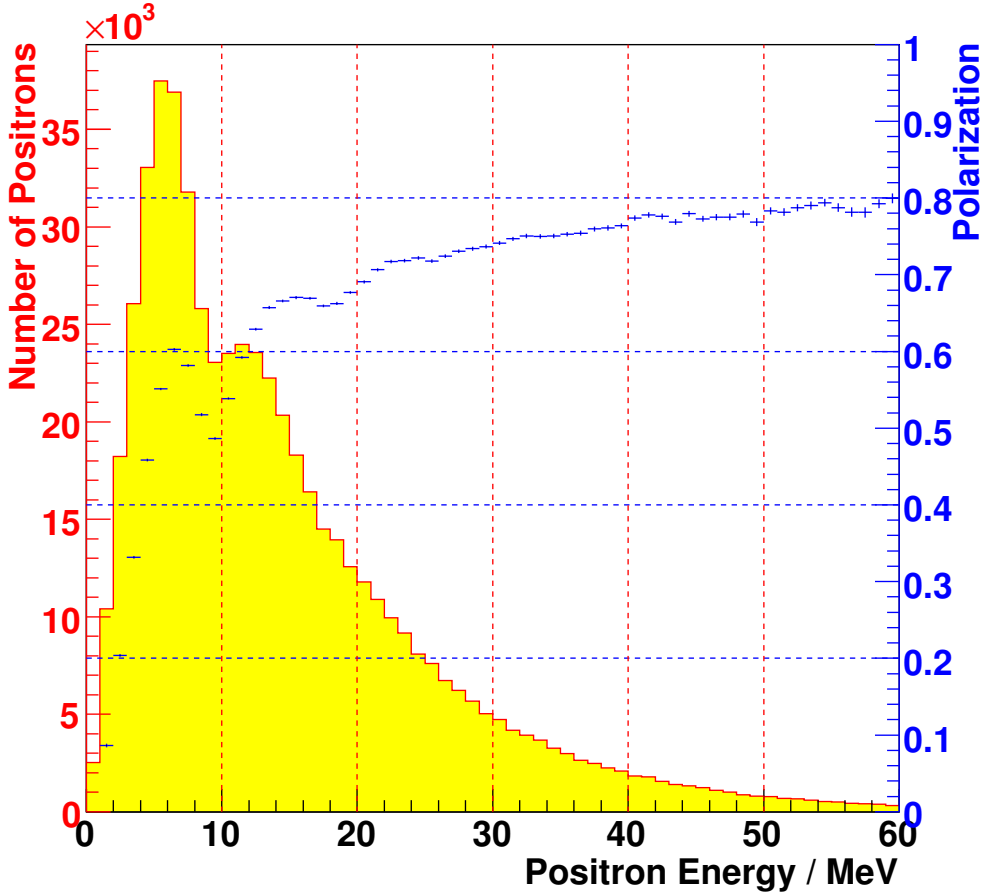

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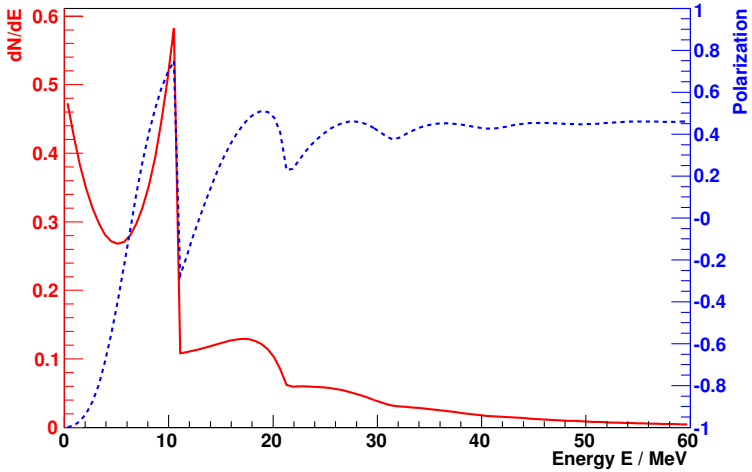

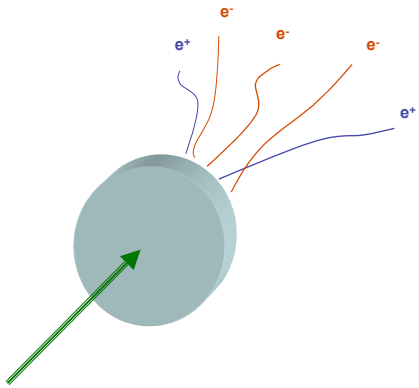

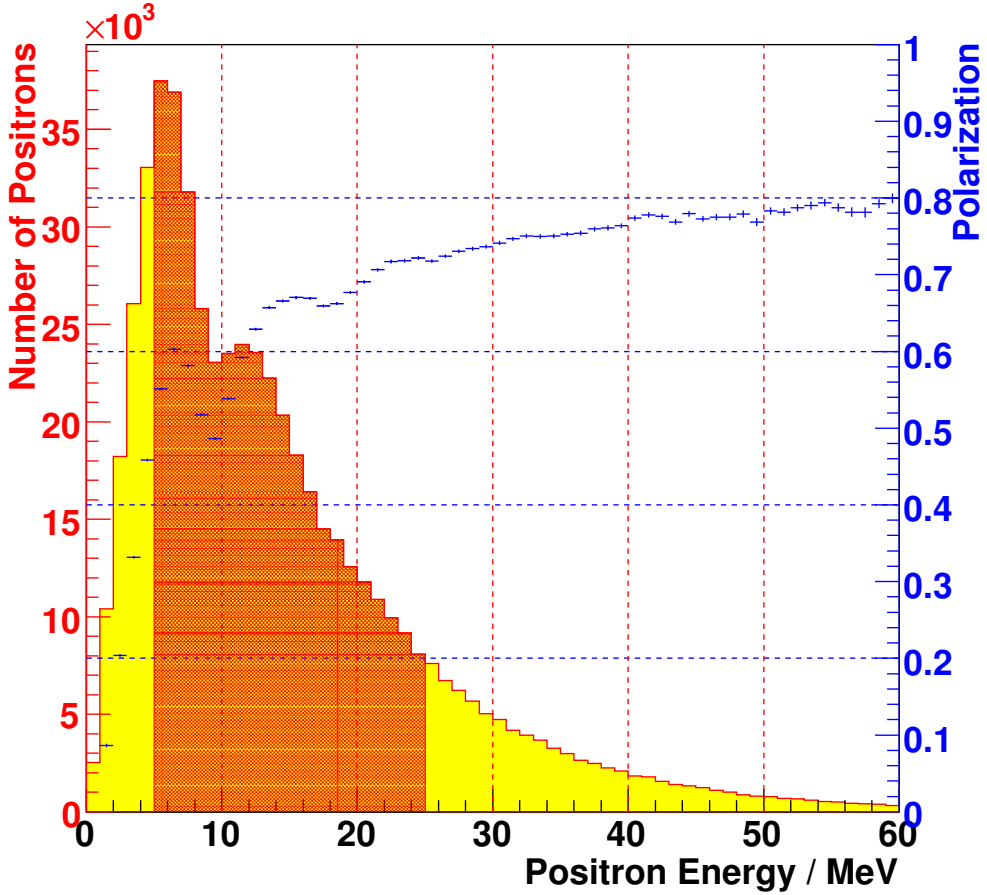

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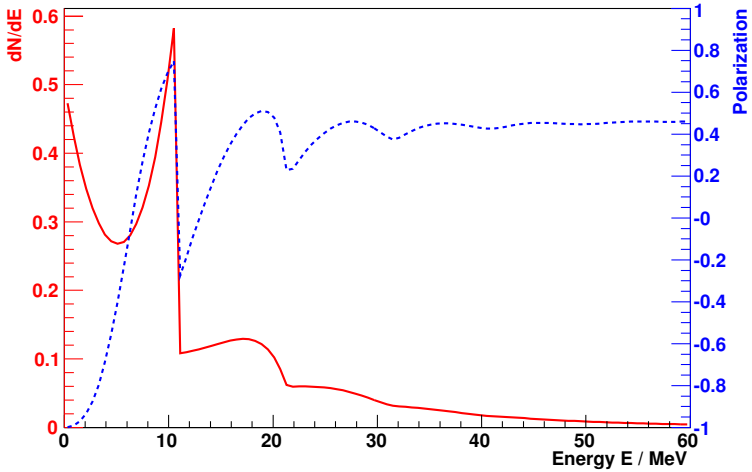

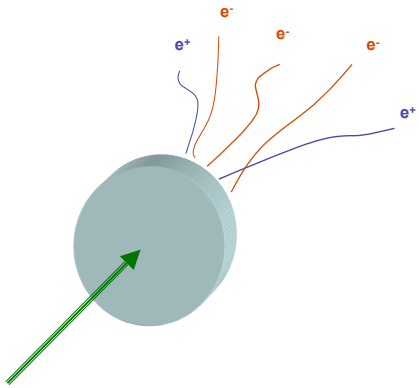

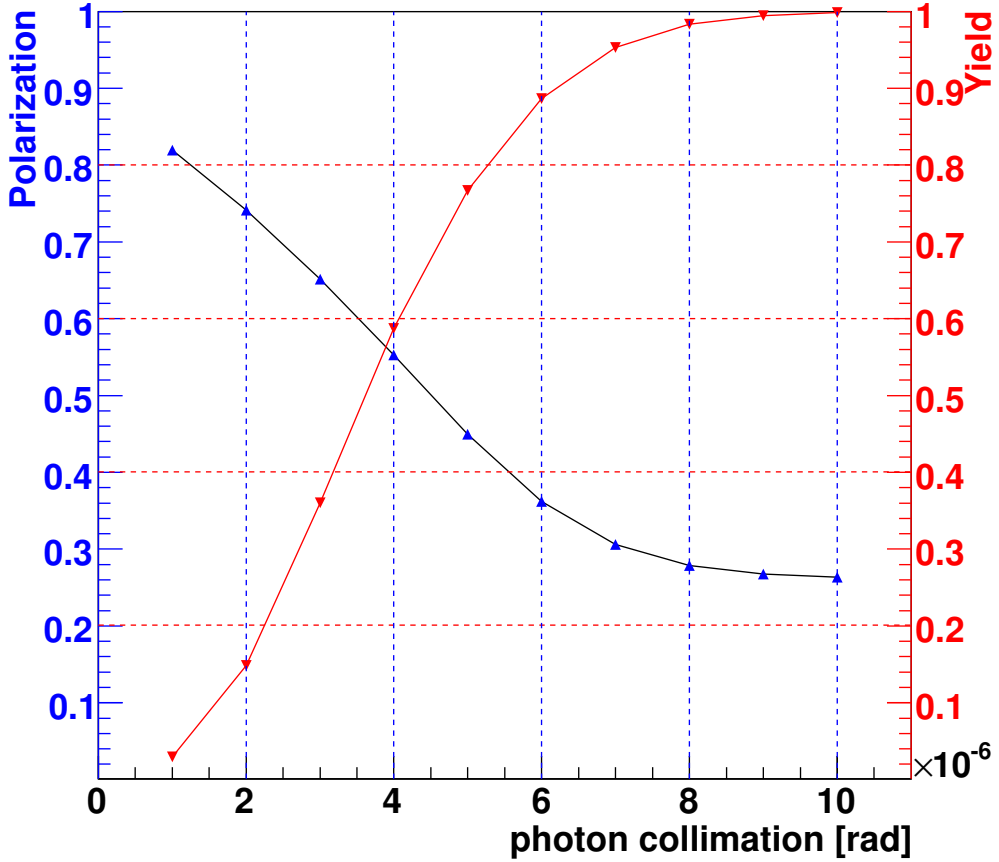

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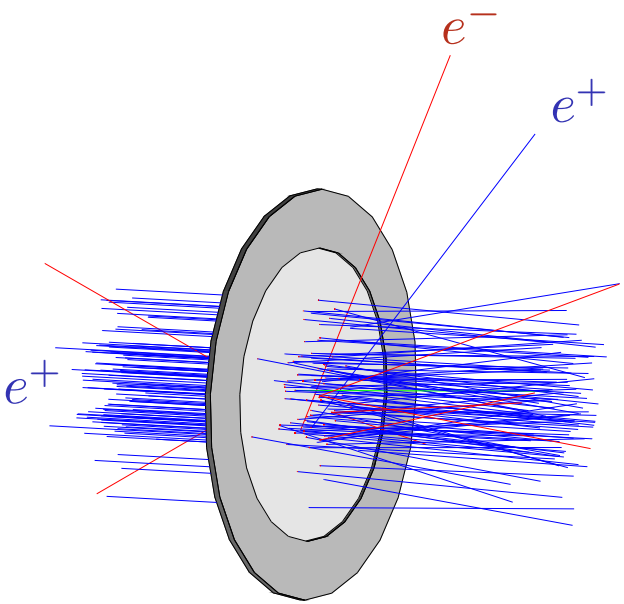
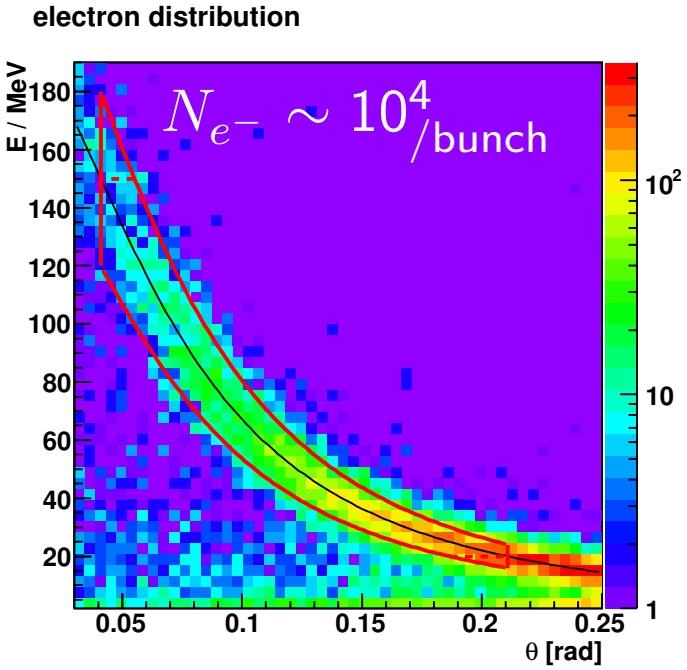
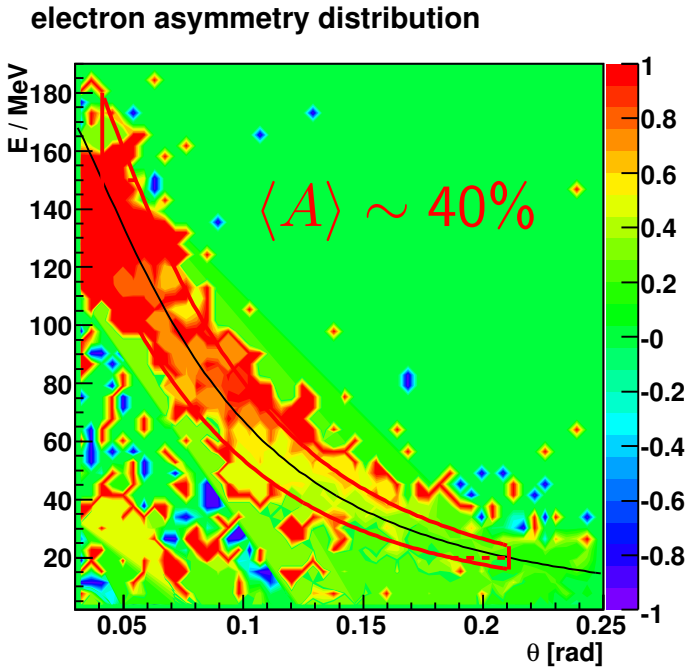
Bhabha Polarimeter



- e^+ beam, $E \approx 200$ MeV
- magnetised iron foil 30 μm
- simulation gives distribution and analysing power for e^+, e^- and γ





Summary & Outlook

- New EM polarisation library
  - fits requirements for optimisation of ILC polarised positron source
  - general scheme based on Stokes vectors
  - focused on logitudinal and circular polarisation (in the moment)
  - describes polarisation transfer & asymmetry effects
  - validated against other software tools and E166 data
  - included in Geant4 8.2 released in December 2006
- Future plans
  - continue the validation
  - extend the list of processes (Photoelectric effect)
  - fully implementation and validation of transverse polarisation
  - work on efficiency optimisation
  - improve software framework (in cooparation with M.G.Pia)

G4 polarisation group:
R. Dollan, K. Laihem, T. Lohse, S. Riemann, A.S., A. Stahl, P. Starovoitov
in fruitful cooparation with V. Ivantchenko and M. Maire