

# New EM polarisation library

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# Outline

## Motivation

- The International Linear Collider
- Use-cases

## Implementation

- Physics picture
- The new EM polarisation library

## Validation

- Comparison with calculation and simulation
- The E166 experiment

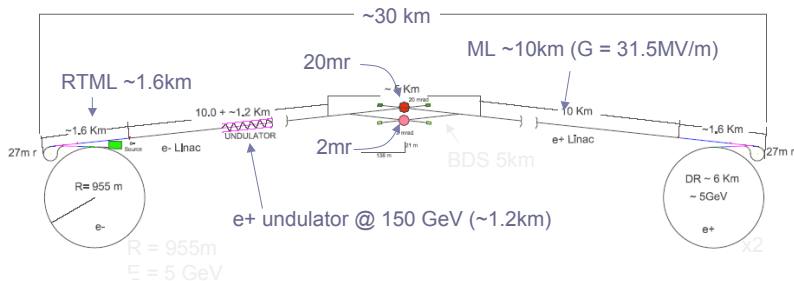
## Summary

- Summary & Outlook

# Motivation – The International Linear Collider

- ▶ luminosity  $\mathcal{L} = 2 \cdot 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ ,  $E_{\text{cms}} = 500 \dots 1000 \text{ GeV}$   
(remember LEP1  $\mathcal{L} = 2.4 \cdot 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ )
- ▶ goal integrated luminosity in first 4 years :  $500 \text{ fb}^{-1}$
- ▶ nominal operation: 1ms bunch trains with 2820 bunches,  
5Hz repetition rate (bunch interval 308 ns)
- ▶ option to have both, **positron** and electron beam, **polarised**

F. Asm/SLAC 11-28-2005



# 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 foreseen)
- ▶ 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 :

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

Jones vector :

$$|a_1|^2 + |a_2|^2 = 1 \quad \mathbf{a} = \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \quad \sigma_1 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Spin density matrix :

$$\rho = \mathbf{a} \otimes \mathbf{a}^* = \begin{pmatrix} a_1 a_1^* & a_1 a_2^* \\ a_2 a_1^* & a_2 a_2^* \end{pmatrix} = \frac{1}{2} (1 + \boldsymbol{\xi} \boldsymbol{\sigma}) \quad \sigma_2 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_3 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}$$

Stokes parameter :

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

► describes arbitrary lepton or photon polarisation states

# Matrix formalism

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

$$\begin{pmatrix} I \\ \xi \end{pmatrix} = T \begin{pmatrix} I_0 \\ \xi_0 \end{pmatrix}$$

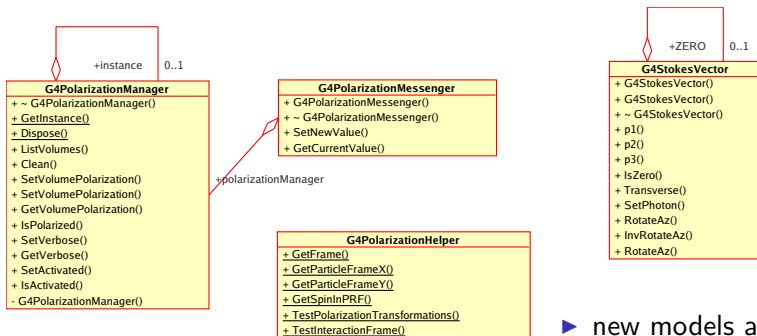
- ▶ relates incoming Stokes vector(s)  $\xi_0$  to outgoing Stokes vector(s)  $\xi$
- ▶  $I$  gives differential distribution (intensity)

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 EM Polarisation Library – helper classes

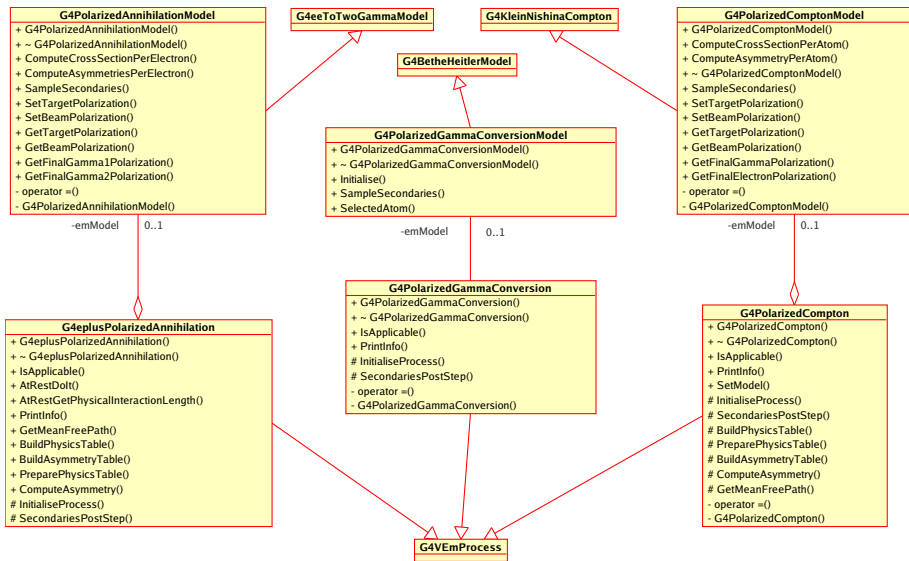


- ▶ new EM polarisation library
- ▶ provides polarised QED processes
- ▶ helper to **assign polarisation to any logical volume**

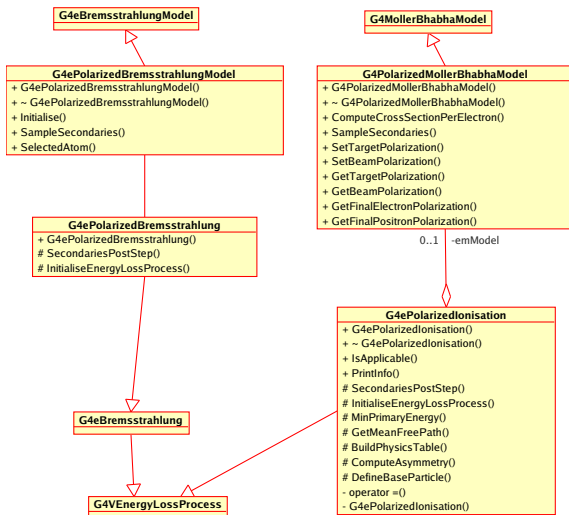
- ▶ new models are **derived from standard EM models**
- ▶ avoids duplication of code
- ▶ guaranties equivalence of unpolarised results



# New EM Polarisation Library – photon processes

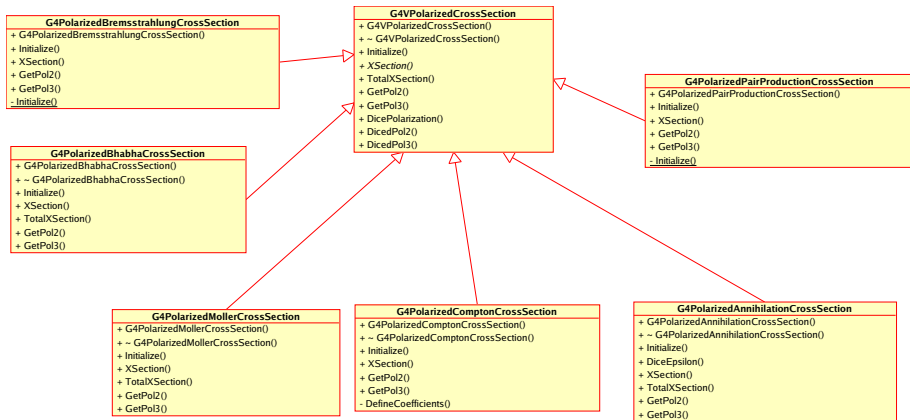


# New EM Polarisation Library – energy loss processes



- ▶ based on **standard energy-loss processes**
- ▶ polarisation results in change of total ionisation cross section

# New EM Polarisation Library – cross section classes



- ▶ polarised cross sections very complicated
- ▶ separated from models

# Validation

## Comparison with other simulation

- ▶ EGS, *polarisation extension by K. Flöttmann*
  - ▶ considers **polarisation transfer only**
  - ▶ simulates Pair production, Bremsstrahlung, Compton
  - ▶ suitable for target studies
- ▶ Geant3, *polarisation extension by V. Gharibyan/P. Schüler*
  - ▶ concentrates on asymmetries
  - ▶ simulates Bremsstrahlung, Compton (polarised target)
  - ▶ suitable for low-energy **Compton transmission polarimetry**

## Comparison with calculation

- ▶ based on ref. from '60s, recalculation of processes by P. Starovoitov
  - ▶ Bhabha/Møller cross section
  - ▶ Compton cross section
  - ▶ positron annihilation cross section

# Application to the E166 Experiment

## Proposal:

- ▶ Demonstration of polarised positron production with a helical undulator

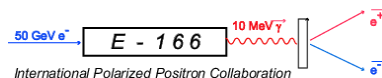
## Status:

- ▶ approved in June 2003
- ▶ two runs, June and September 2005
- ▶  $\approx 8.5$  million events on tape
- ▶ analysis is ongoing



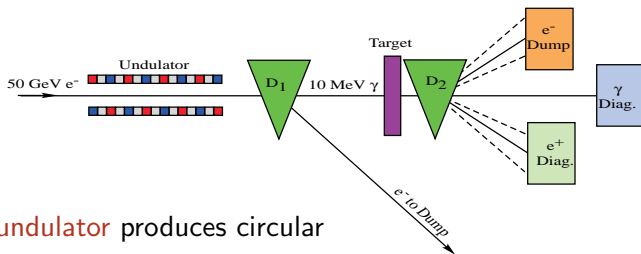
## Collaboration:

- ▶ about 50 people
- ▶ 15 institutes
- ▶ from 3 continents



G. Alexander *et al.*, 2003, SLAC-PROPOSAL-E-166.

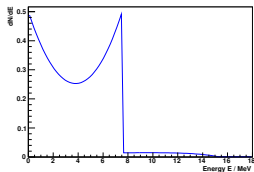
# Schematic layout



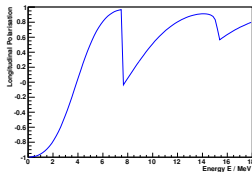
- ▶ 1 meter **helical undulator** produces circular polarised photons
- ▶ utilising 50 GeV electron final focus test beam (FFTb) at SLAC
- ▶ photons are converted to positrons in thin W-target
- ▶ measurement of photon and positron polarisation by Compton transmission polarimetry

## Target – Expected positron polarisation

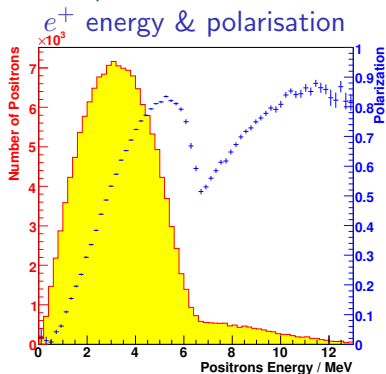
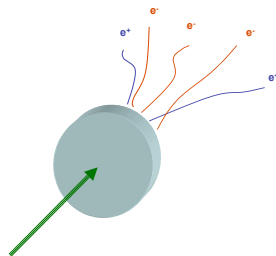
$\gamma$  energy



$\gamma$  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



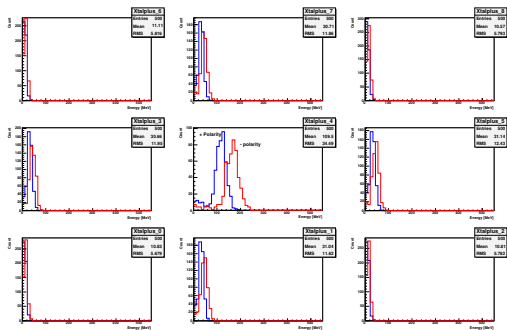
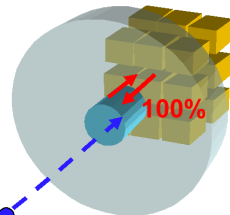
# Polarimeter – Simulation of Analysing Power

- ▶ 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 asymmetry
- ▶ simulation gives analysing power (conversion factor between measured asymmetry and polarisation of positrons)

$$N = 10^4$$

$$E_{e^+} = 7 \text{ MeV}$$

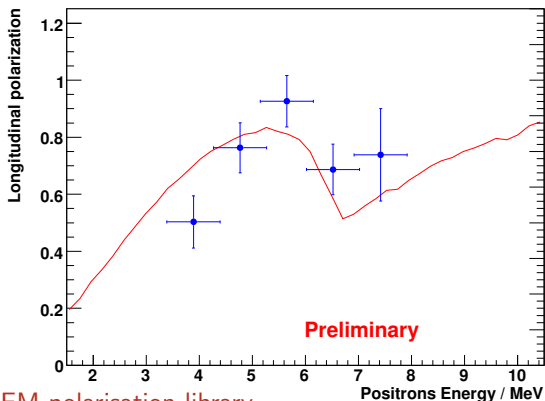
$$P_{e^+} = 100\%$$





## 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 ... this year!



# Summary & Outlook

- ▶ New EM polarisation library
  - ▶ uses **standard EM physics design**
  - ▶ fits requirements for optimisation of ILC **polarised positron source**
  - ▶ general scheme based on Stokes vectors
  - ▶ focused on longitudinal and circular polarisation (in the moment)
  - ▶ describes **polarisation transfer & asymmetry effects**
- ▶ Validation ongoing
  - ▶ independent calculation of polarised processes
  - ▶ comparison with EGS, and other software tools
  - ▶ data of the **E166 experiment**
- ▶ Future plans
  - ▶ **continue in validation**
  - ▶ work on efficiency optimisation
  - ▶ improve software framework (in cooperation with M.G.Pia)

## G4 polarisation group:

R. Dollan, K. Laihem, T. Lohse, S. Riemann, A.S., A. Stahl, P. Starovoitov  
in fruitful cooperation with **V. Ivantchenko and M. Maire**

**Thanks!**