Polarized Geant4 – Applications at the ILC

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DESY, Zeuthen

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Outline

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.

Physics picture

Base Stokes vectors $\boldsymbol{\xi}_i$

- representations of arbitrary photon/lepton polarisation states
- decomposition of Spin density matrix ρ

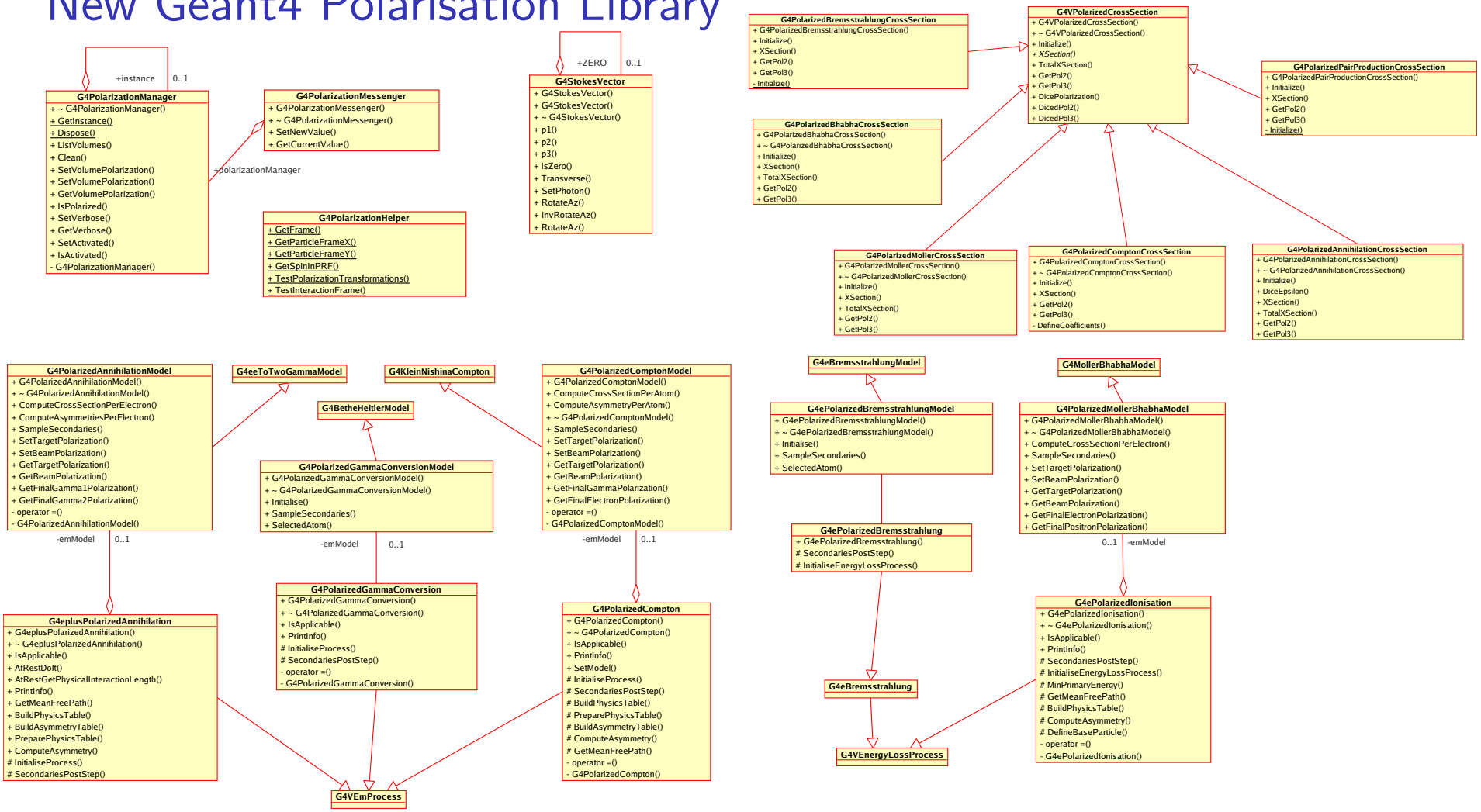
$$\boldsymbol{\xi} = \begin{pmatrix} \xi_1 \\ \xi_2 \\ \xi_3 \end{pmatrix} \qquad \rho = \frac{1}{2}(1 + \boldsymbol{\xi}\boldsymbol{\sigma})$$

Cross section is linear function of polarisation

$$\frac{d\sigma\left(\xi^{(1)},\xi^{(2)},\xi^{(3)},\xi^{(4)}\right)}{d\Omega} = \Phi\left(\xi^{(1)},\xi^{(2)}\right) + \boldsymbol{A}\left(\xi^{(1)},\xi^{(2)}\right) \cdot \boldsymbol{\xi}^{(3)} + \boldsymbol{B}\left(\xi^{(1)},\xi^{(2)}\right) \cdot \boldsymbol{\xi}^{(4)} + \boldsymbol{\xi}^{(3)^T} M\left(\xi^{(1)},\xi^{(2)}\right) \boldsymbol{\xi}^{(4)}$$

- describes asymmetries and
- polarisation transfer
- final state correlation $M\left(\xi^{(1)},\xi^{(2)}\right)$ is neglected

New Geant4 Polarisation Library



- provides (almost all) polarised QED processes

Comparison with Whizard/O'mega

- arbitrary initial polarisation
- final state helicity
- simple 2→2[a] processes
  - Compton
  - Møller/Bhabha
  - e^+e^-–annihilation

Checks:

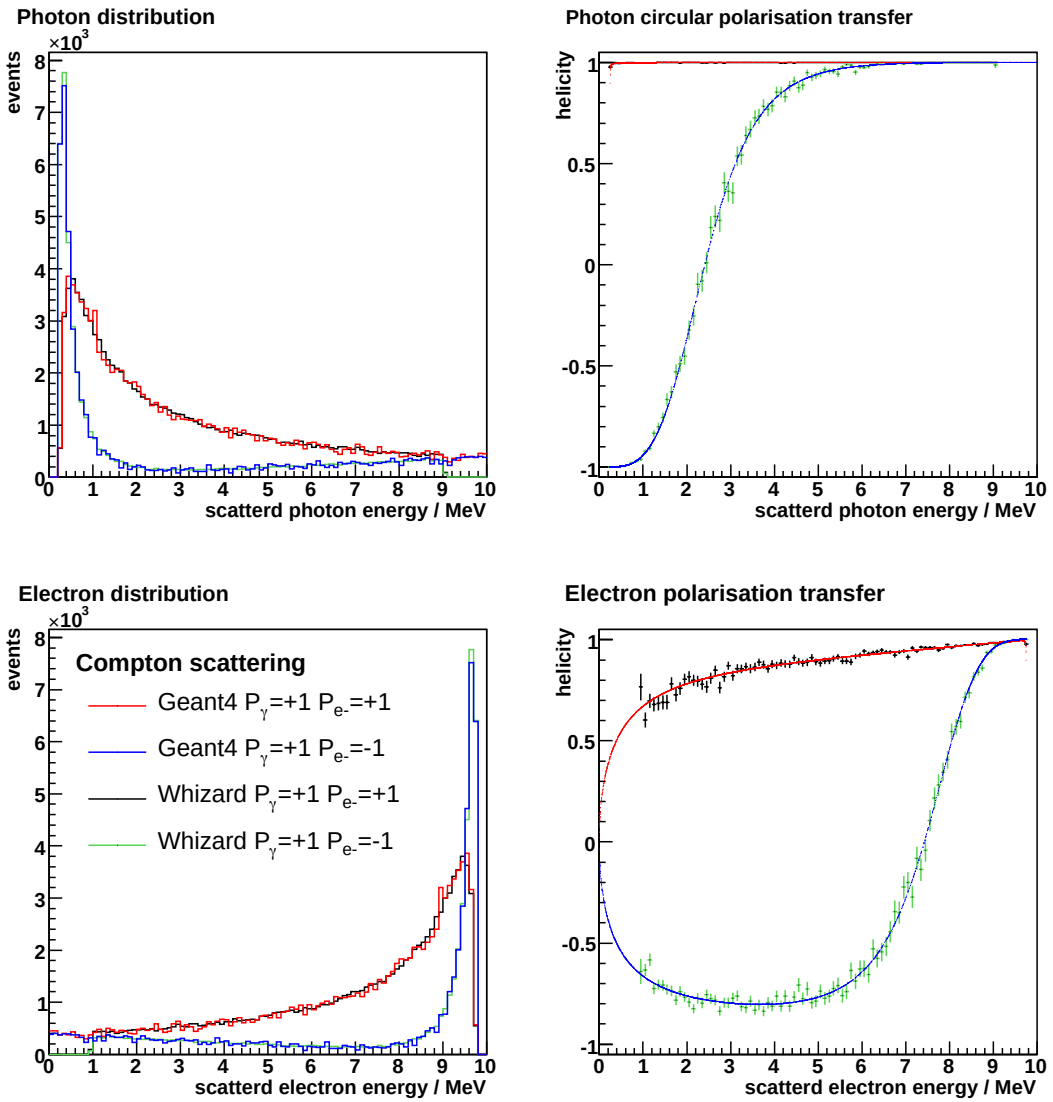
- Polarisation transfer
- Asymmetries

Missing:

- Interactions with nuclei

  e.g. Pair-Production

[a] Whizard/O'mega is not restricted to 2 final state particles



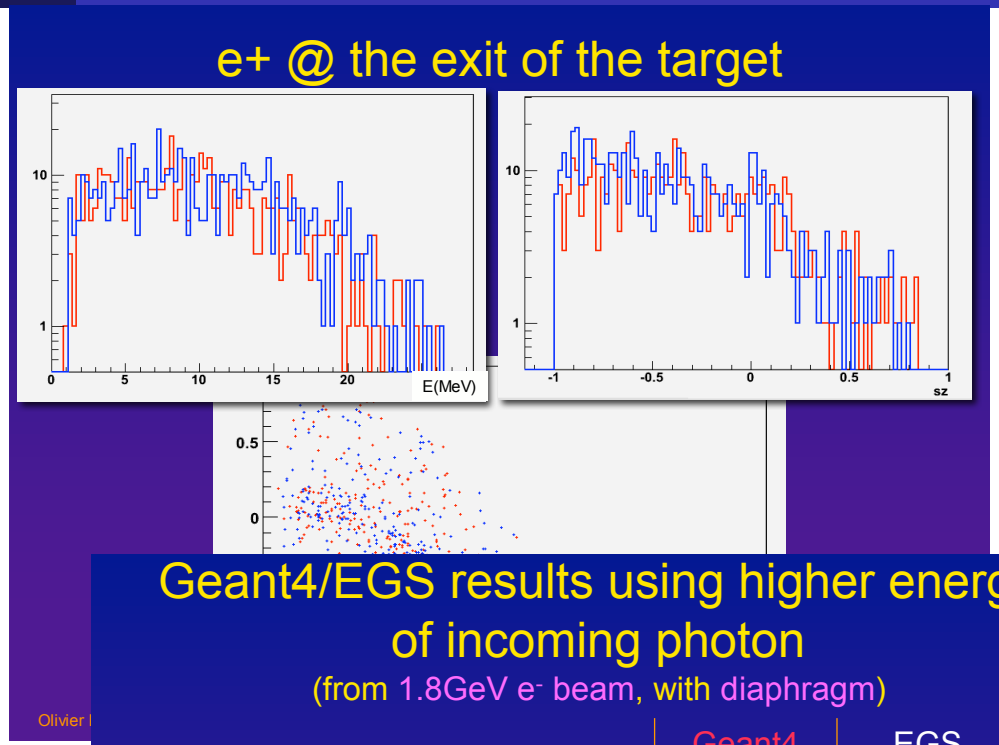
Comparison with EGS

EGS:

- polarisation implementation by K.Föttmann
- describes polarisation transfer
- no depolarisation via ionisation
- no target polarisation

Checks:

- good aggreement for polarisation transfer to high energetic positrons
- context of Compton based source (O.Dadoun)



Geant4/EGS results using higher energy of incoming photon

(from 1.8GeV e⁻ beam, with diaphragm)

		Geant4	EGS
γ	<E(MeV)>(RMS)	37.10(12.33)	37.08 (12.40)
	Sz (RMS)	-0.40 (0.60)	-0.40 (0.60)
e⁻	<E(MeV)>(RMS)	26.32 (8.48)	26.79 (8.55)
	Sz (RMS)	-0.50(0.37)	-0.45 (0.37) ?
e⁺	<E(MeV)>(RMS)	26.62 (8.73)	26.21 (8.30)
	Sz (RMS)	-0.54 (0.32)	-0.53 (0.32)

>15 MeV
Energy selection
For all particles

Olivier Dadoun EGS/Geant4 Benchmark

For γ e⁺ Sz: EGS = Geant4

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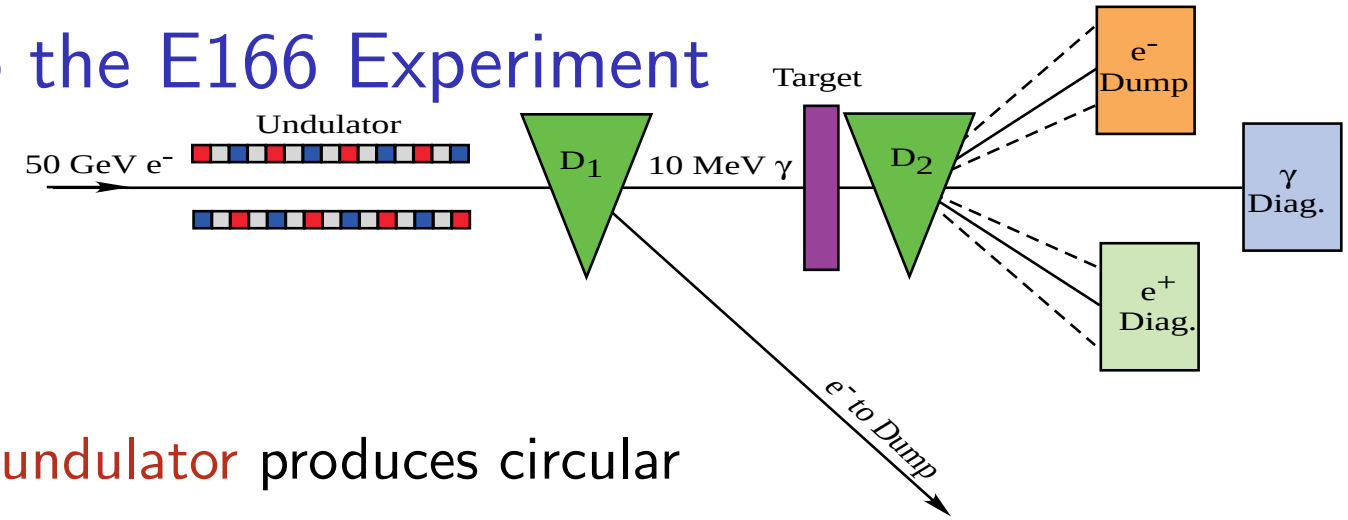
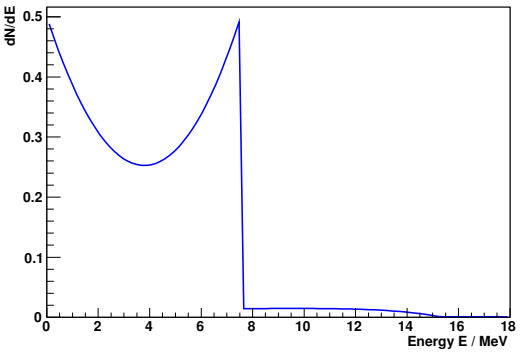
Application to the E166 Experiment



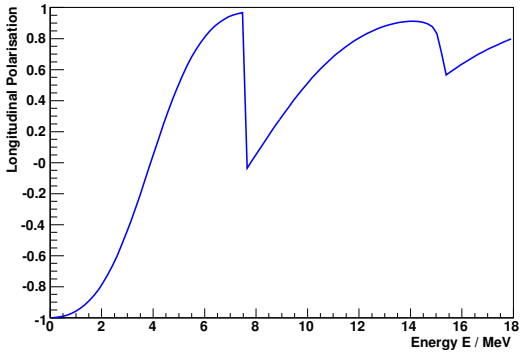
- 1 meter helical undulator produces circular polarised photons
- utilising 50 GeV electron final focus test beam (FFTB) at SLAC
- photons are converted to positrons in thin W-target
- measurement of photon and positron polarisation by Compton transmission polarimetry

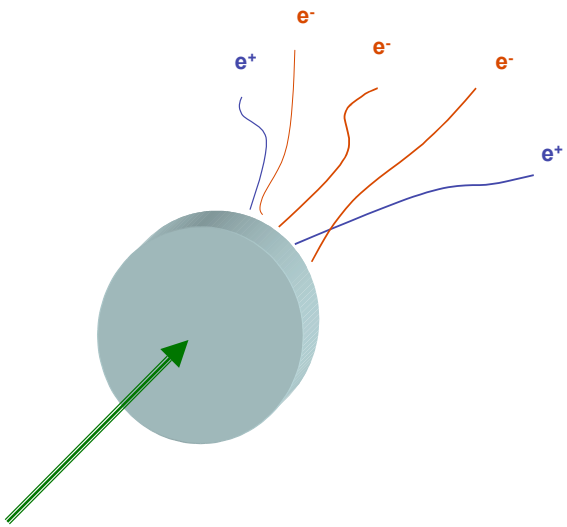
Target – Expected positron polarisation

γ energy



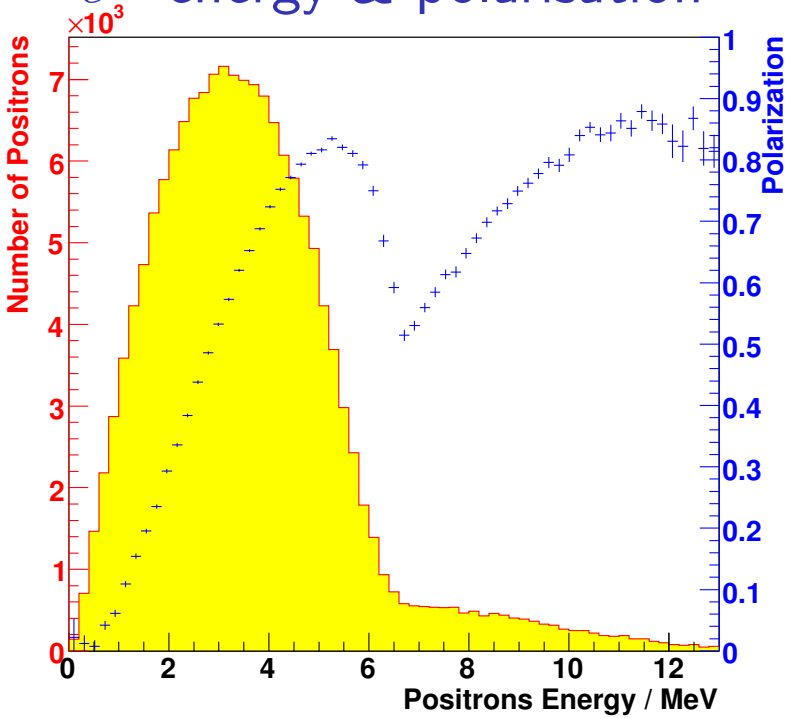
γ polarisation



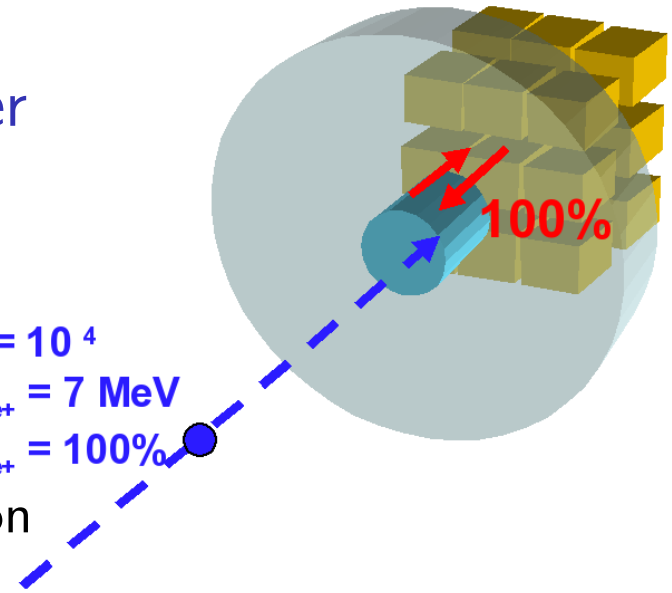


- input photon energy & polarisation generated by helical undulator
- conversion into electron–positron pairs in a thin W-target
- polarisation transfer to high energetic leptons
- simulation: expected energies and polarisation of produced positrons

e^+ energy & polarisation

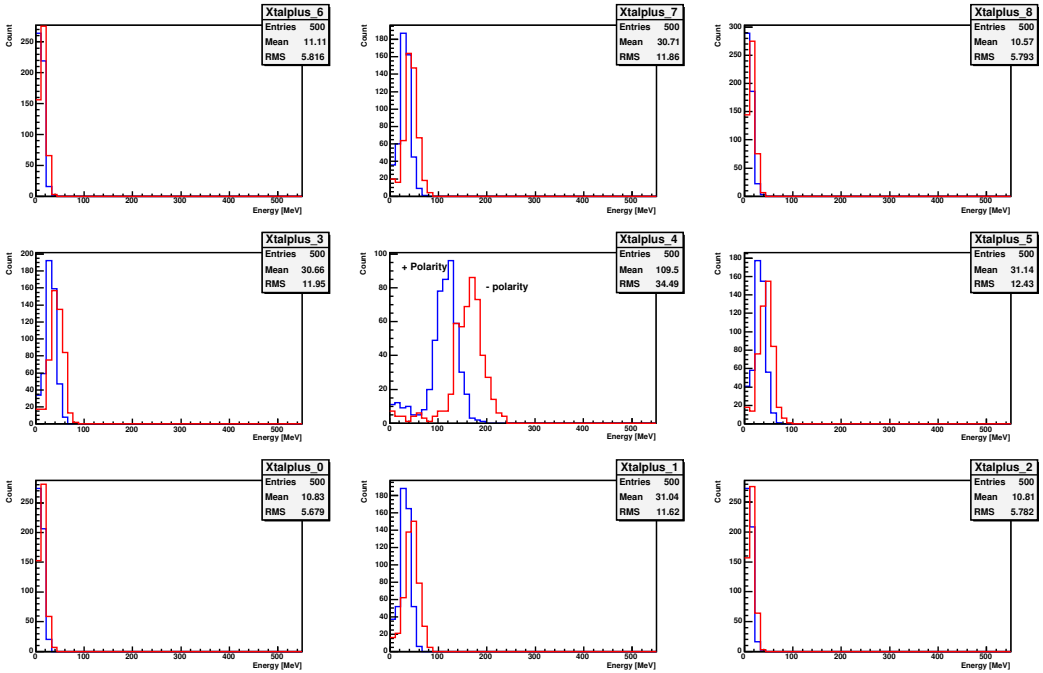


Polarimeter – Simulation of Analysing Power

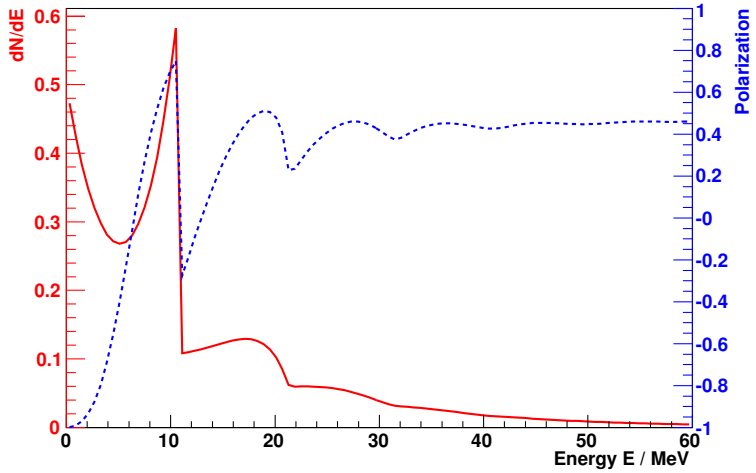


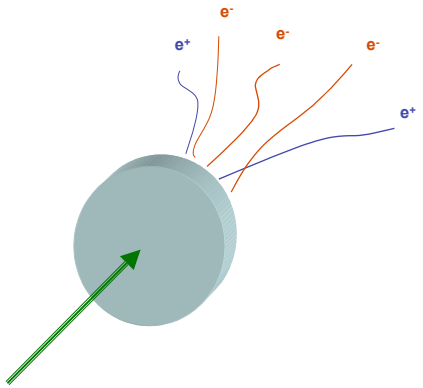
- reconversion of positrons into photons via Bremsstrahlung and annihilation
- transmission of photons through magnetised iron (magnetisation parallel or anti-parallel)
- measurement of transmission in a 9-crystal CsI calorimeter
- polarisation dependence of Compton cross section results in an asymmetry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

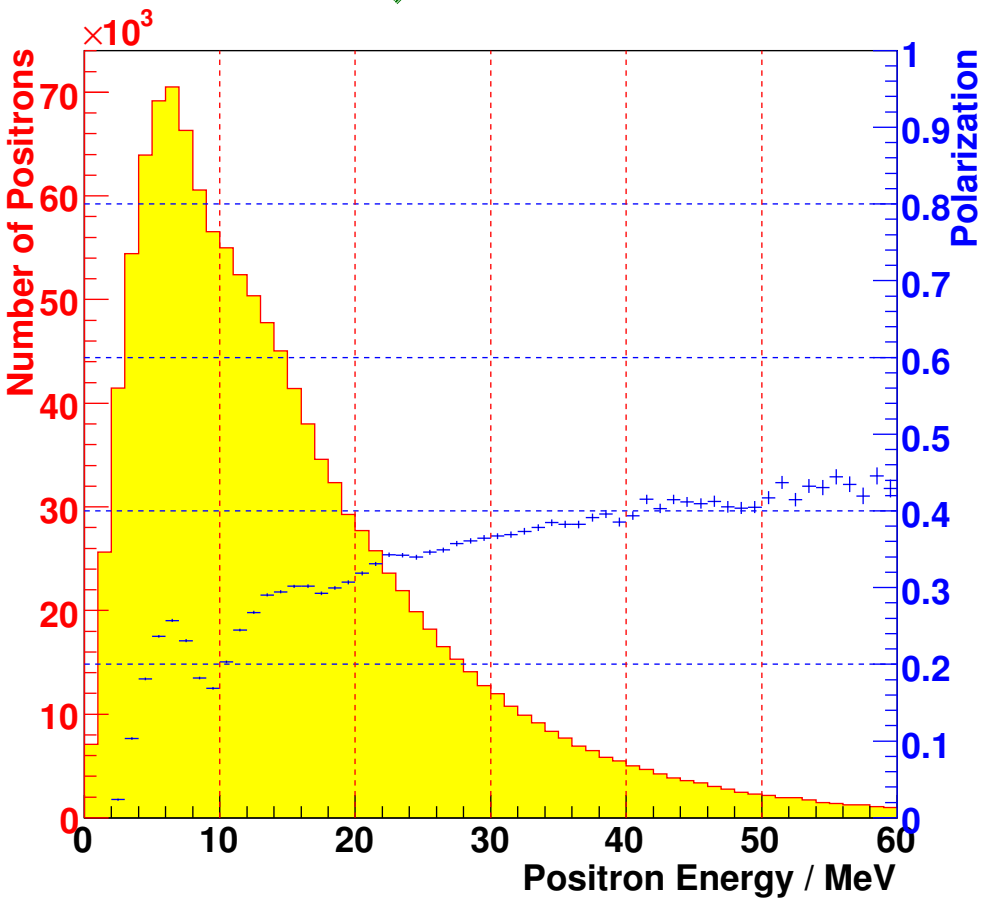
K.Laihem



ILC Positron source







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

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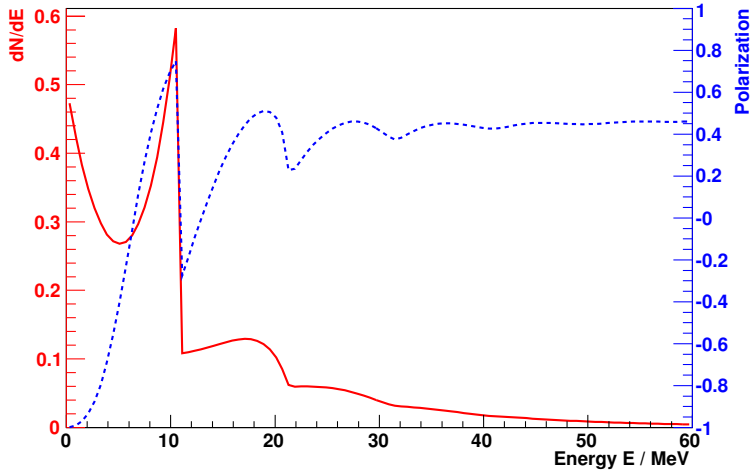

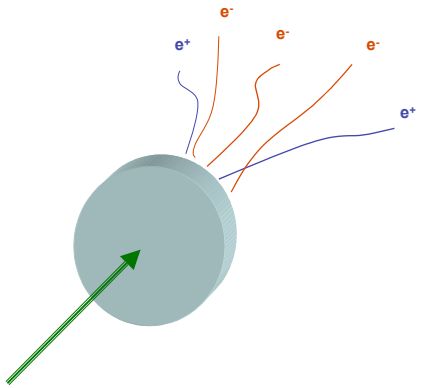

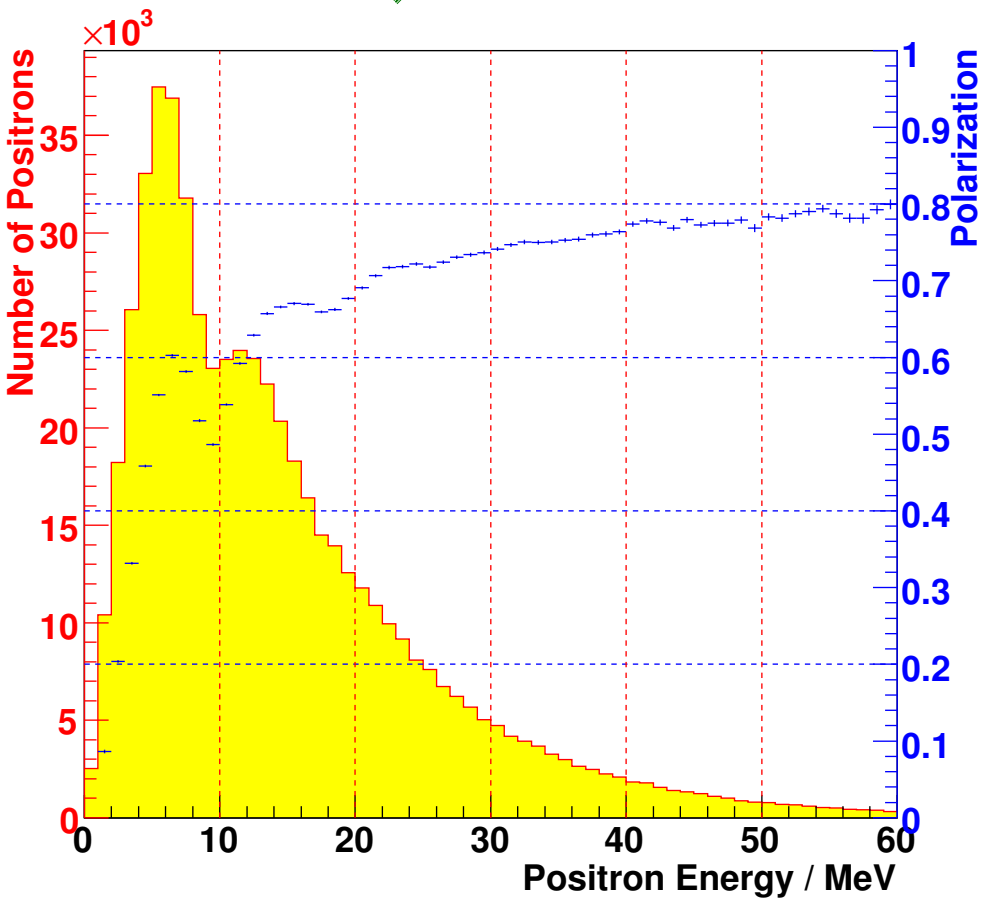

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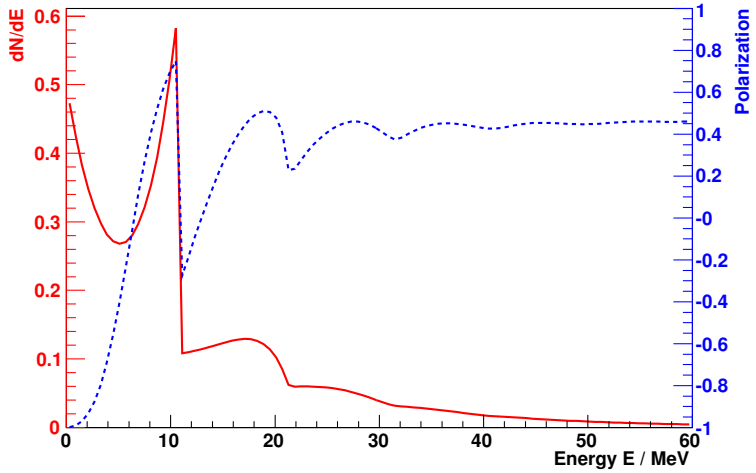

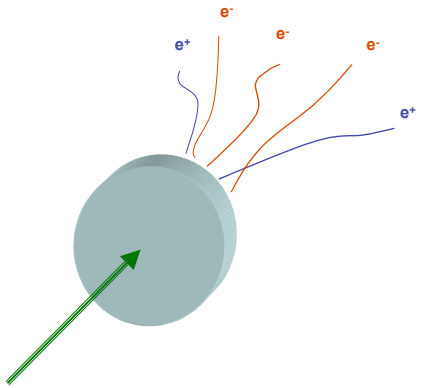

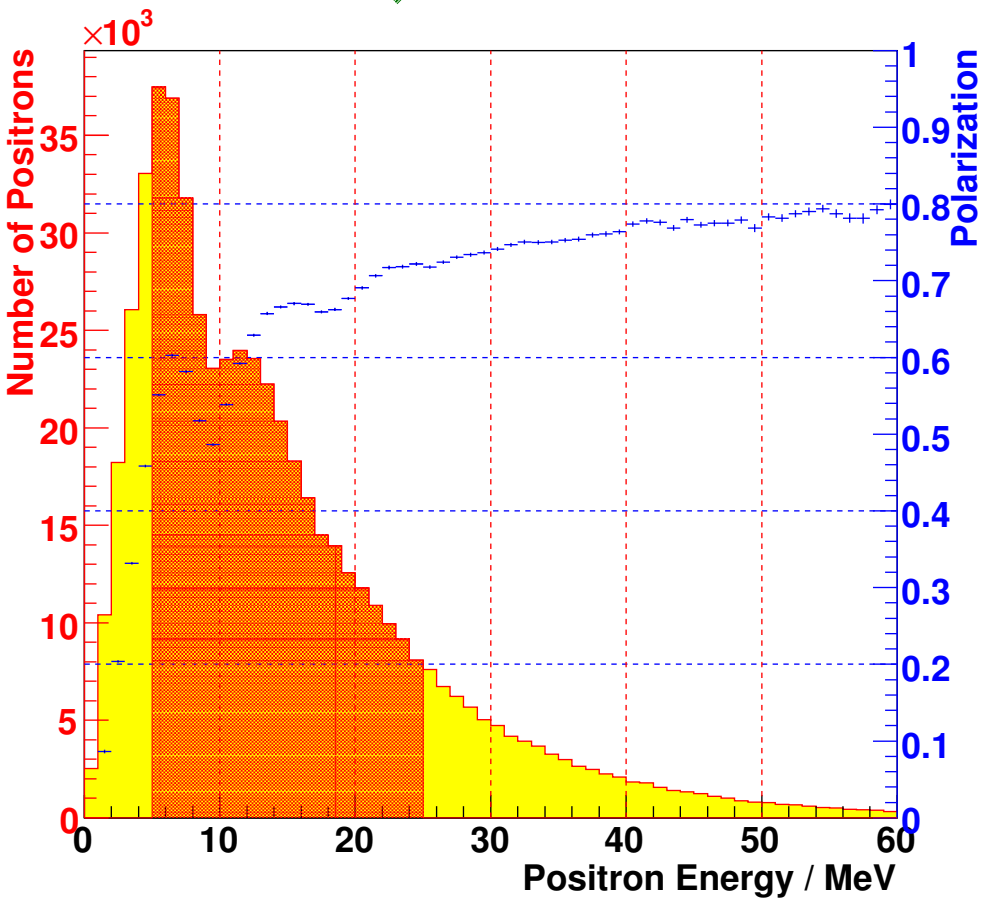

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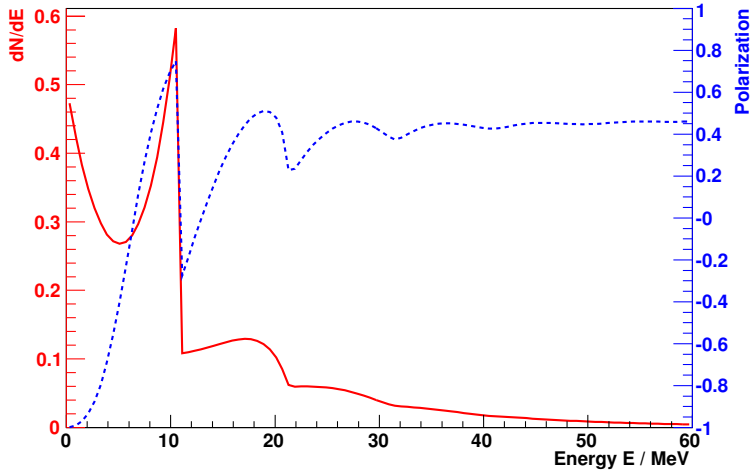

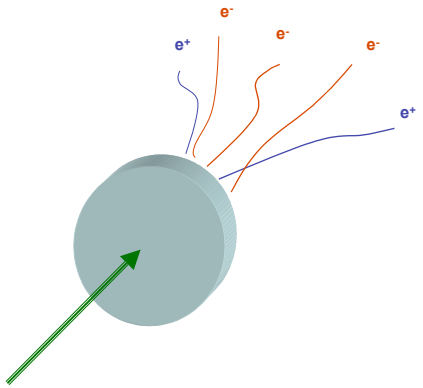

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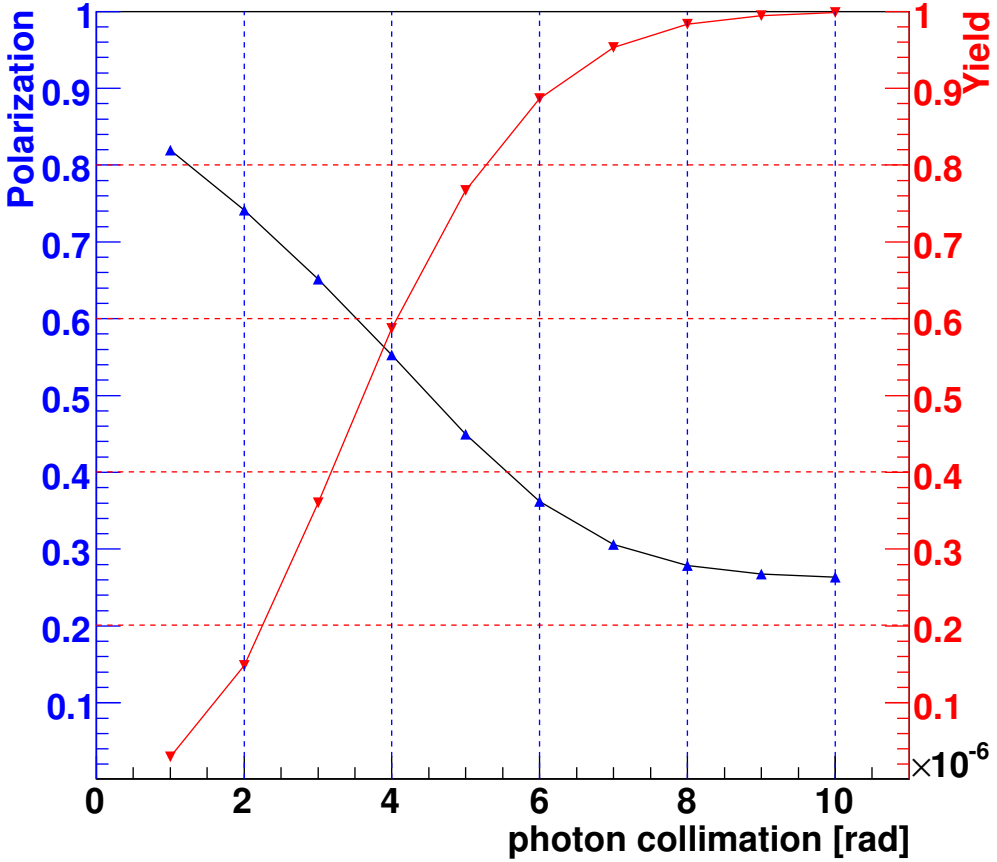
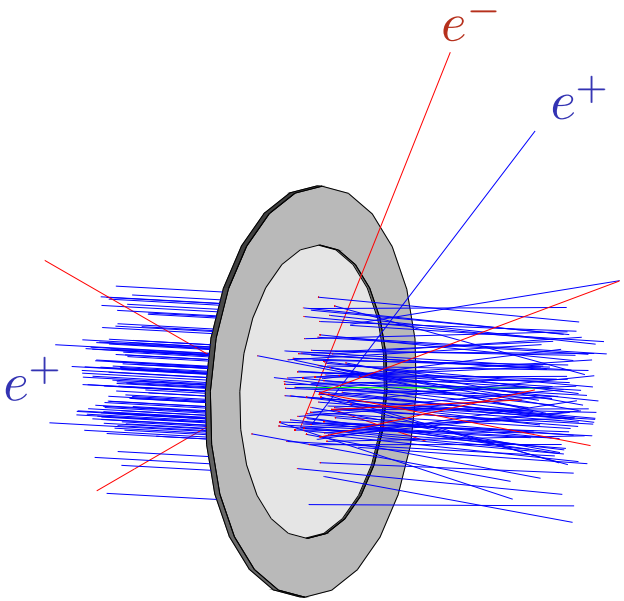
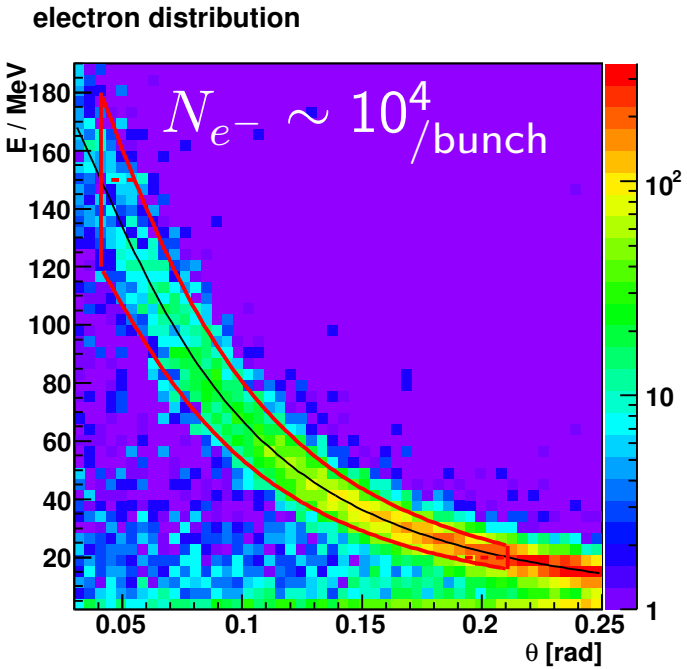
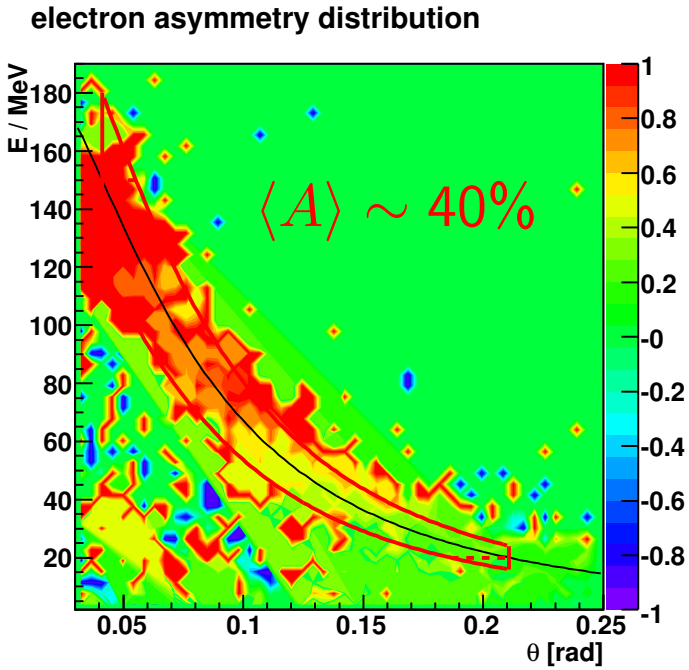


Bhabha Polarimeter



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





Official Geant4 release

first appeared in version 8.2

- 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/`

Further plans

- continue the validation

  utilising complementary computer codes

  (e.g. by V.Gharibyan, V.Strakhovenko, or A.Mikhailichenko)
- add new polarised processes (Photo-Electric effect in preparation)
- full implementation of transverse polarisation

  validation with existing implementations in Geant4
- work on efficiency optimisation
- improve software framework (in cooparation with M.G.Pia)

Summary

- 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 official Geant4 release since version 8.2

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