Polarized Positrons

Sabine Riemann (DESY)

September 18, 2007

ILC Positron Source Group Meeting, ANL

Outline

ILC physics after LHC: need polarized positrons

Current status: $P_{e+} \approx 30\%$ (baseline design)

- utilize the 30% for physics
- helicity reversal

Status G4 with polarization

Polarimetry at low energies

- Update of Bhabha polarimeter studies
- Compton polarimetry after DR?

Summary and outlook

RDR: Physics

Physics between 200 GeV and 500 GeV

Luminosity: Year 1-4: L_{int} = 500 fb^{-1}

1. year 10% → $L_{int} \approx$ 50 fb^{-1}
2. year 30% → $L_{int} \approx$ 150 fb^{-1}
3. Year 60% → $L_{int} \approx$ 300 fb^{-1}
4. year 100% → $L_{int} \approx$ 500 fb^{-1}

→ ee→HZ	at 350 GeV (mH≈120 GeV)	few 10^4
ee→ tt	at 350 GeV	10^5
ee → qq (μμ)	at 500 GeV	$5\cdot10^5$ $(1\cdot10^5)$
ee → WW	at 500 GeV	10^6

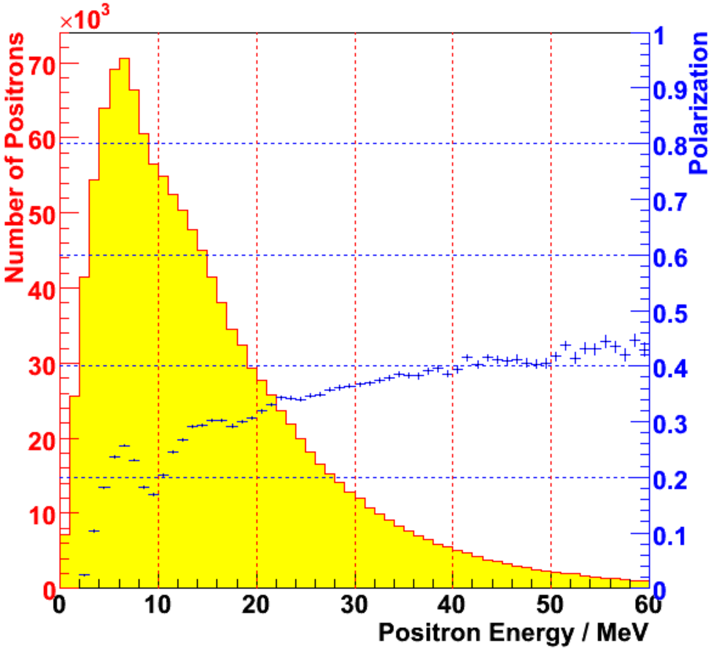
→ statistical uncertainties at per-mille level !!

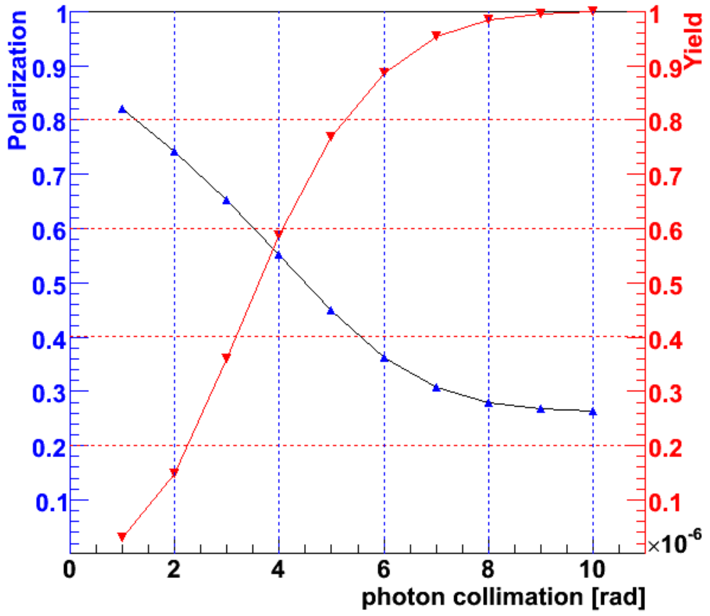
Uncertainties: $\Delta\sigma \propto \frac{1}{\sqrt{N}} \oplus \frac{\Delta L}{L} \oplus \frac{\Delta P}{P}$ → $O(10^{-3})$

ILC Baseline design: e+ Polarization

RDR: helical undulator ➔ ~30% e+ polarization

e+ spectrum





photon beam: distance undulator center ⬄target ~ 500m

s-channel cross sections with pol beams

Perform 4 independent measurements (s-channel vector exch.)

$$\sigma_{++} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(+P_{e^+} - P_{e-}\right)\right]$$
$$\sigma_{--} = \sigma_u \left[1 - P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} + P_{e-}\right)\right]$$

=0 (SM) if both beams 100% polarized

$$\sigma_{-+} = \sigma_u \left[1 + P_{e^+} P_{e-} + A_{LR}\left(-P_{e^+} - P_{e-}\right)\right]$$
$$\sigma_{+-} = \sigma_u \left[1 + P_{e^+} P_{e-} + A_{LR}\left(+P_{e^+} + P_{e-}\right)\right]$$

Standard Model

s-channel

SLC: σ_{-0} and σ_{+0} used for A_{LR} measurement

$$A_{LR} = \frac{\sigma_{-0} - \sigma_{+0}}{\sigma_{-0} + \sigma_{+0}} \cdot \frac{1}{P_{e^-}}$$

ILC:

$$A_{LR} = \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}} \cdot \frac{1 + P_{e^-} P_{e^+}}{P_{e^-} + P_{e^+}}$$
$$= \frac{\sigma_{-+} - \sigma_{+-}}{\sigma_{-+} + \sigma_{+-}} \cdot \frac{1}{P_{eff}}$$

Error propagation

➔ $\Delta P_{eff}/P_{eff} < \Delta P_{e+,e-} / P_{e+,e-}$

Cross section enhancement ~$(1+P_{e-}P_{e+})$

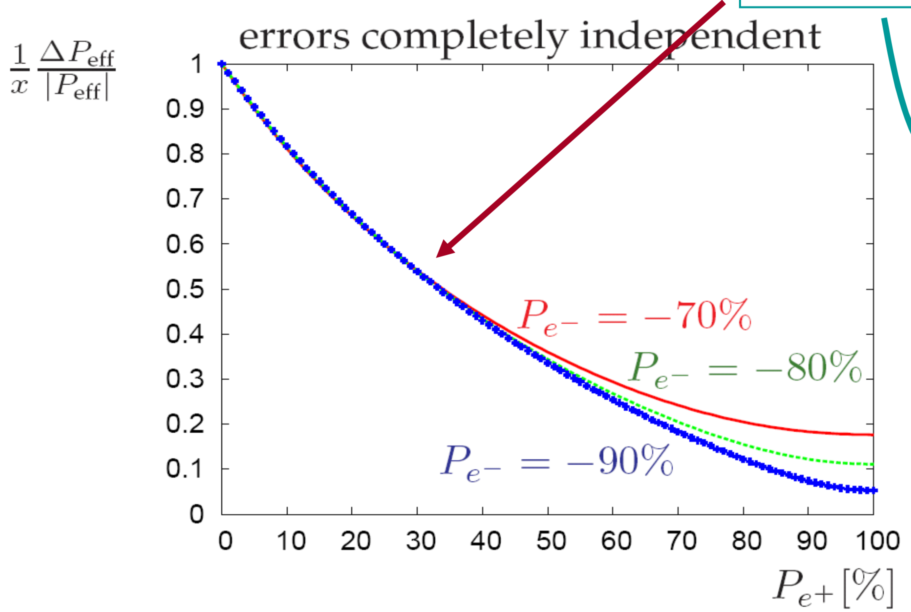
ΔP_{eff}

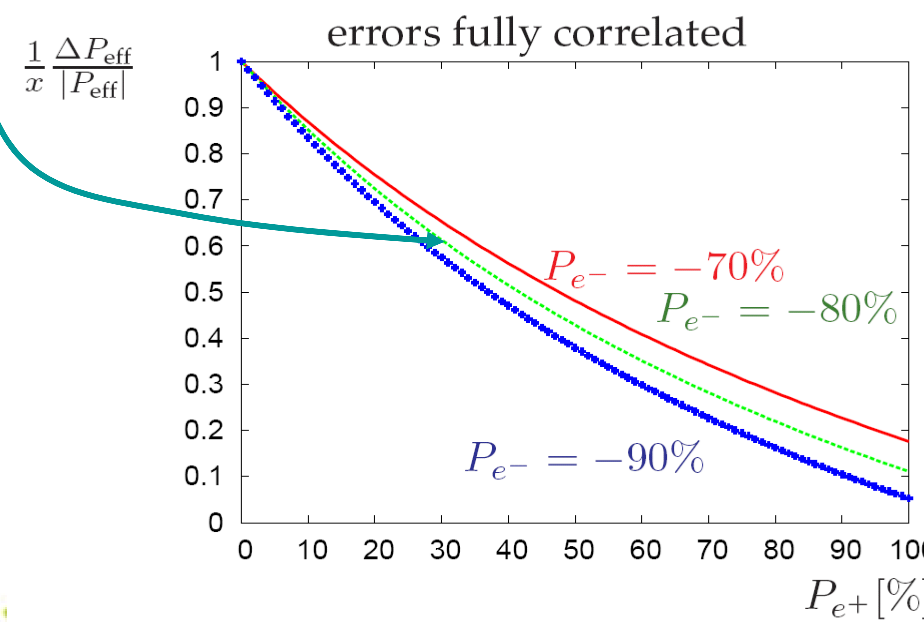
- Decrease of error on $P_{eff}=(P_{e-} + P_{e+})/(1+P_{e-} P_{e+})$

$$\frac{\Delta P_{eff}}{P_{eff}} = x\,\frac{\sqrt{\left(1-P_{e^+}^2\right)^2 P_{e^-}^2 + \left(1-P_{e^-}^2\right)^2 P_{e^+}^2}}{\left(P_{e^+}+P_{e^-}\right)\left(1+P_{e^+}P_{e^-}\right)}$$

$$x \equiv \frac{\Delta P_{e^-}}{P_{e^-}} = \frac{\Delta P_{e^+}}{P_{e^+}}$$

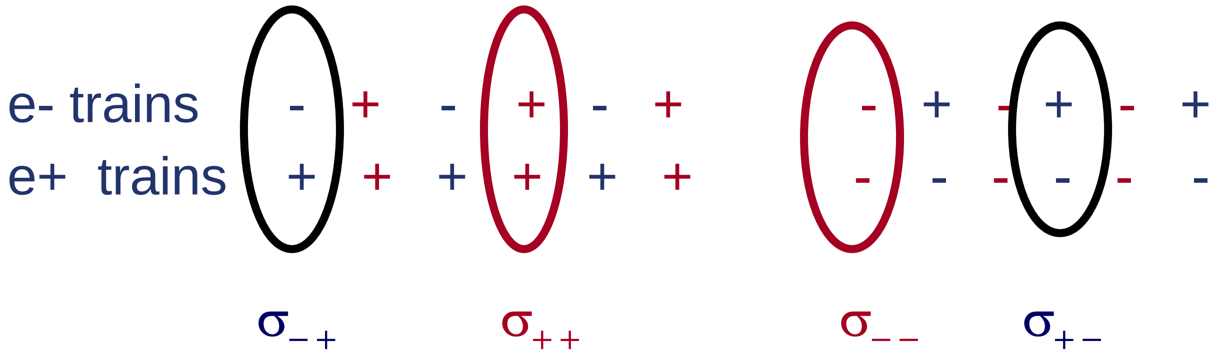
30%: Improvement by factor 2 (1.5)





e+ Helicity Reversal

e+ helicity flip less frequent than e- helicity reversal ?!



50% spent to ‘inefficient’ helicity pairing σ_{--} and σ_{++} ➔

- gain due to xs enhancement for J=1 processes with e+ pol is lost
- Improvement of ΔP_{eff} remains only for quite frequent reversal – if systematic errors known and small (intensity/polarisation tolerances)
- Corresponds to ‘slow’ Blondel scheme ⇔ determine P and A_{LR} simultaneously

$$\frac{\sigma_{-+}+\sigma_{--}-\sigma_{++}-\sigma_{+-}}{\sigma_{-+}+\sigma_{--}+\sigma_{++}+\sigma_{+-}} = P_{e^-} A_{LR} \qquad \frac{\sigma_{+-}+\sigma_{--}-\sigma_{++}-\sigma_{-+}}{\sigma_{+-}+\sigma_{--}+\sigma_{++}+\sigma_{-+}} = P_{e^+} A_{LR}$$

Polarization is an issue:

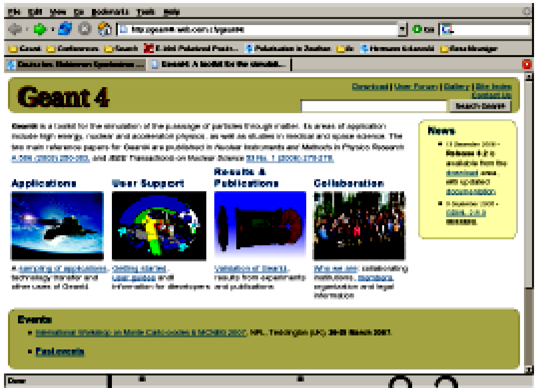
- The 30% positron polarization has to be brought to IP and used for physics (rotators, helicity reversal, design optimization for e+ pol)
- small polarization → no physics gain but more complicated measurement/analysis
- Collaboration with other groups necessary
- Spin tracking studies necessary

Geant4 with polarized processes

- Polarization has to be taken into account for
  - Pair-production
  - Bremsstrahlung
  - Compton scattering
  - Moller/Bhabha scattering
  - Positron annihilation into 2 photons
- Included since Geant4 release 8.2 (Dec 06)
  - Main focus: longitudinal (or circular) polarization (extension to transversal is foreseen)
  - Energy range of interest: MeV … ~5 GeV
- Applications:
  - Polarization transfer (target, E166)
  - Polarimetry (Bhabha/Moller, Compton transmission – e.g. E166)
  - ILC polarized positron source

Authors: A. Schälicke, K. Laihem, P. Starovoitov

Official Geant4 release



first appeared in version 8.2

- December 15th 2006

available at

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

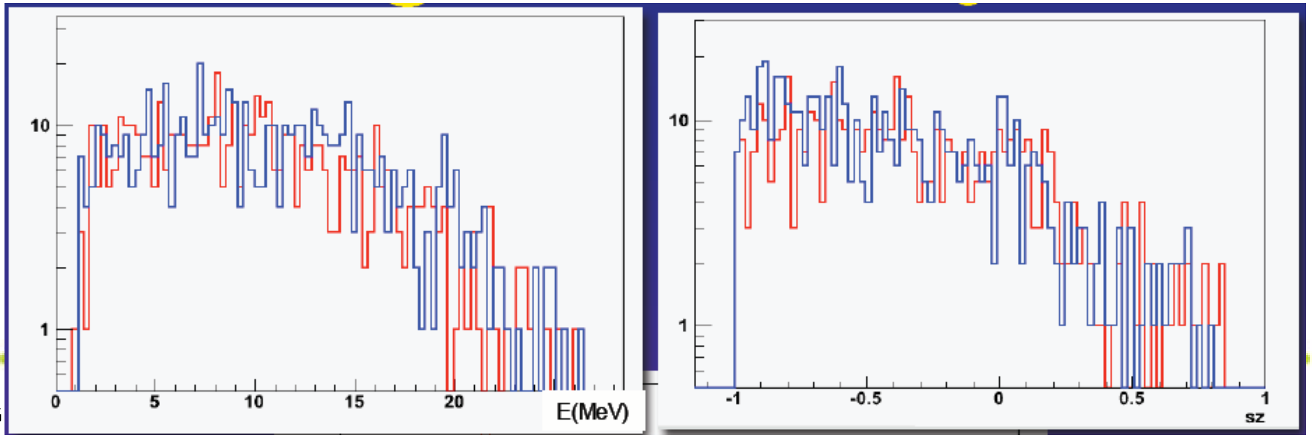
includes

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

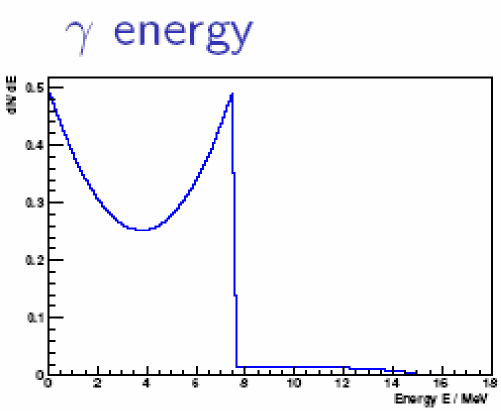
Verification of 'Polarized G4'

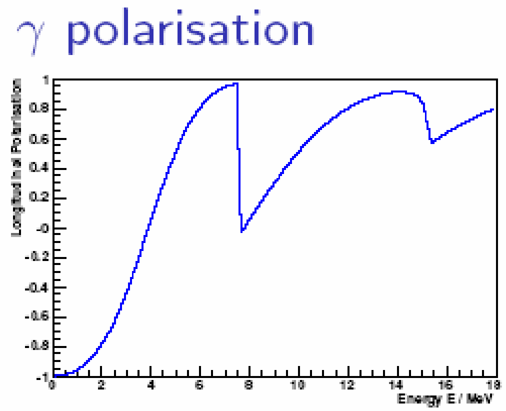
- Comparison other programs and with experiments
- Comparison with Whizard/O'mega:
  - **Checked: pol transfer, asymmetries (Compton, Moller/Bhabha, annihilation)**
  - **Missing: interaction with nuclei (e.g. pair production)**
- Comparisons with EGS
  - **EGS: polarization transfer**
  - **No depolarization via ionization, no target polarization**
  - **Good agreement for pol transfer to high energetic e+**
  - **Compton source: tests done/ongoing by O. Dadoun:**

e+ @ exit of target
EGS
Geant4
(Dadoun, Posipol 07)

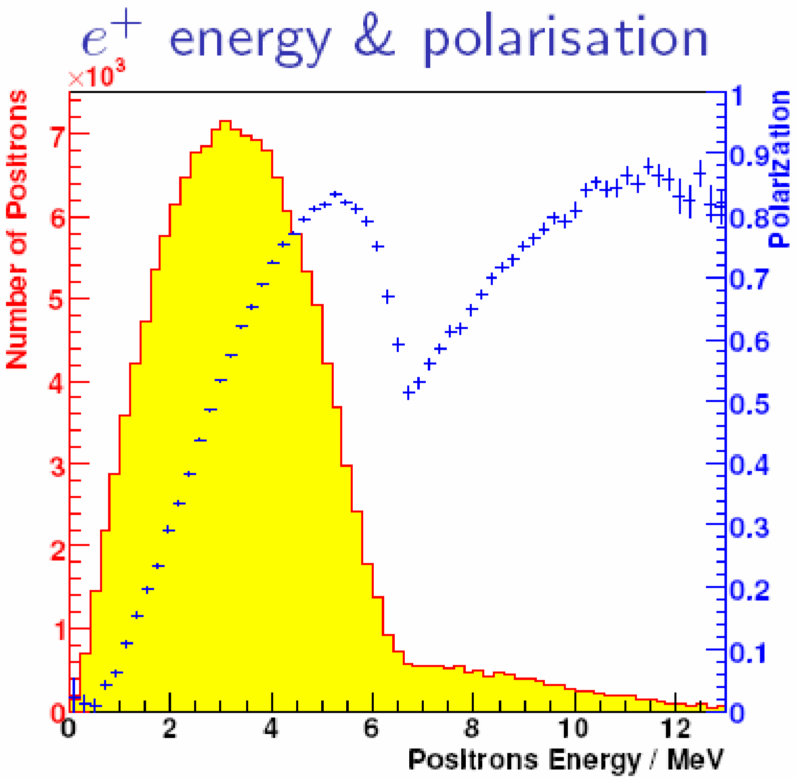


Geant4 & E166





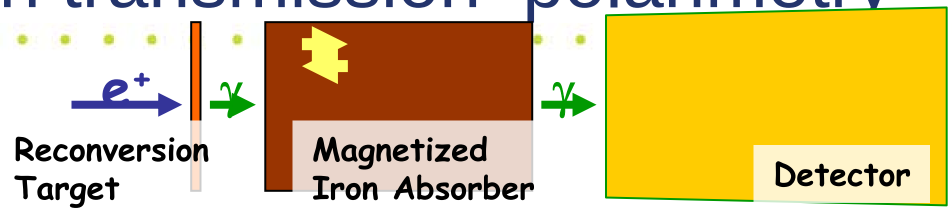
Input: energy and polarization of photons generated by helical undulator



Simulation of

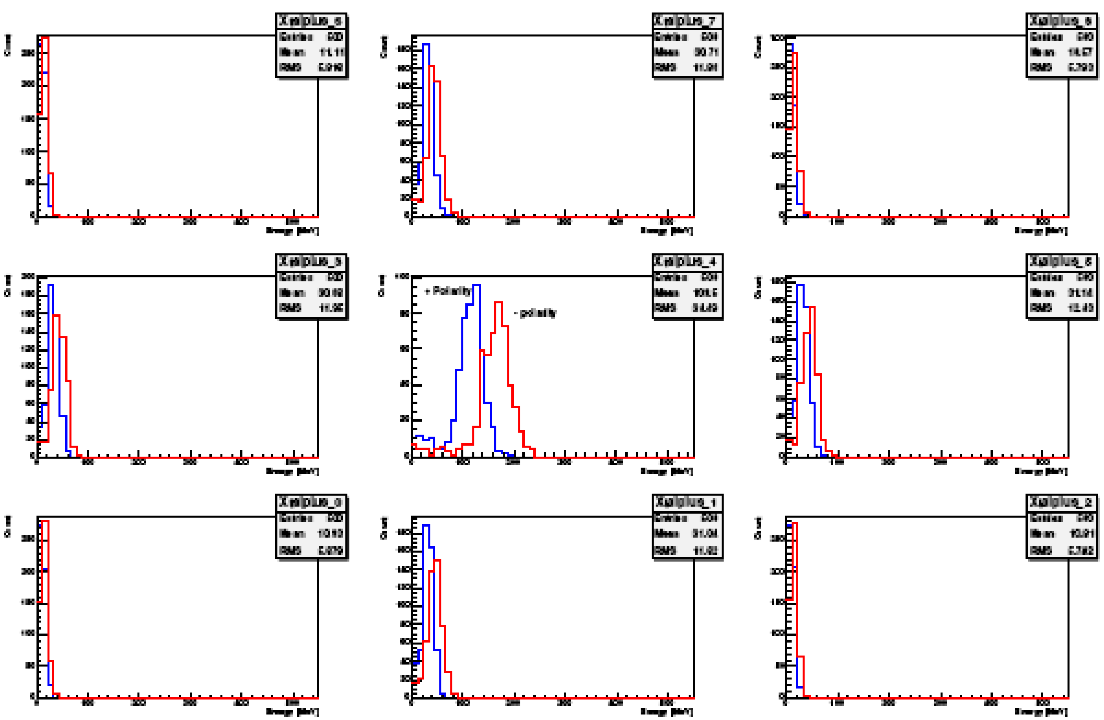
- Conversion into e+ e- pairs in thin W target,
- polarization transfer to high energetic leptons

G4: E166 Compton transmission polarimetry



- Reconversion of e+ to polarized photons (bremsstrahlung, annihilation)
- Transmission of photons through magnitized iron
- Polarization dependent Compton cross section → asymmetry for parallel/anti-parallel magnetized iron
- Measurement of transmission in CsI calorimeter (3x3 crystals)

K.Laihem



→Simulation of analyzing power for E166

ILC polarized positrons & Geant4

- ILC positron source studies:
  Target, spin transport in capture section (see Andriy's talk)
- Positron polarimeter @ source
  - **Bhabha polarimeter design studies**

Ongoing work / Plans:

- Implementation of T-BMT for spin tracking
- implementation of transverse spin polarization
- Validation

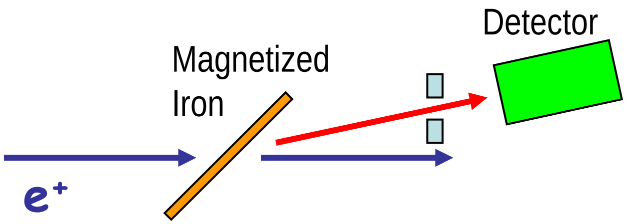
e+ polarimeter at/near the source

- Requirements:
  - **Suitable for energy range**
  - **Suitable for large positron beam size**
  - **Fast**
  - **Non-destructive**
  - **Accuracy O(few %)**
- Possibilities:
  - **Bhabha polarimeter (125-500 MeV)**
  - **Compton – after DR (beamsize!)**
- People:
  - DESY/HUB: R. Dollan, T. Lohse, S. Riemann, A. Schälicke, P. Schuler, A. Ushakov

    Minsk: P. Starovoitov, Tel Aviv U: G. Alexander

Bhabha Polarimetry

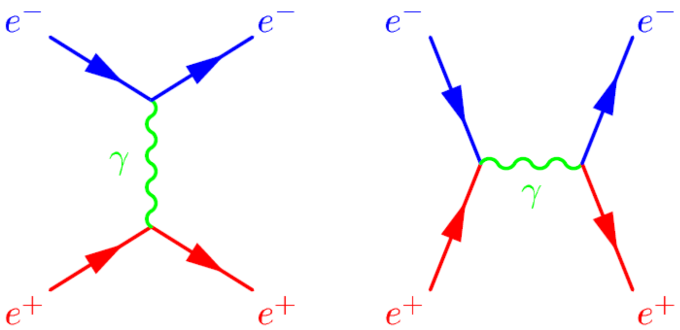
- As Møller polarimeter already widely used

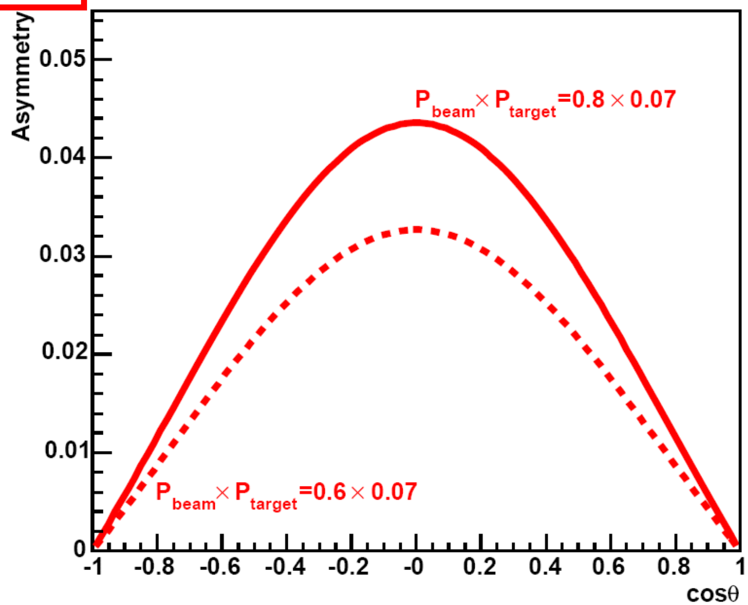


- Cross section:

$$\frac{d\sigma}{d\Omega} = r_0^2 \frac{(1+\cos\theta)^2}{16\gamma^2 \sin^4\theta}\left[\left(9+6\cos^2\theta+\cos^4\theta\right) - P_{e^+}P_{e^-}\left(7-6\cos^2\theta-\cos^4\theta\right)\right]$$

- e+ and e- must be polarized
- maximal asymmetry at 90°(CMS) ~ 7/9 ≈ 78 %

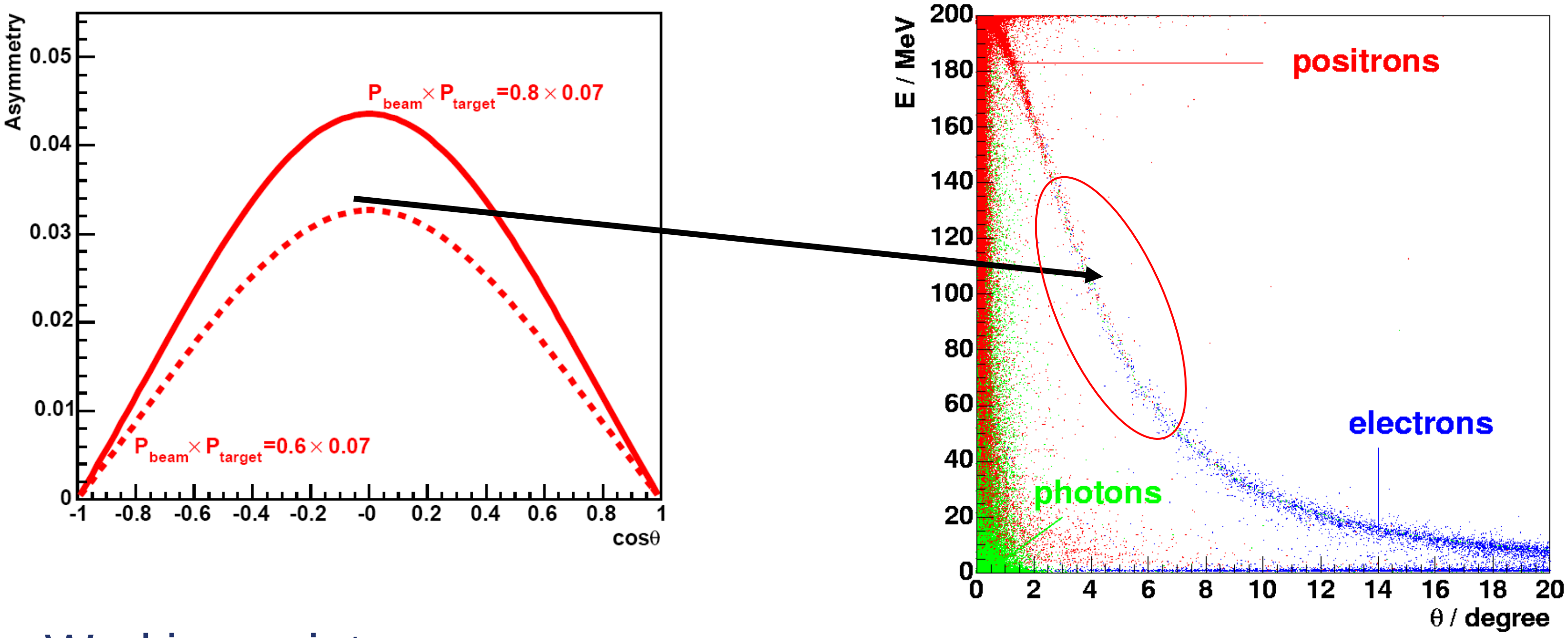




Example: P_{e+}= 80%, P_{e-}= 7% A_{max} ~ 4.4 %

Bhabha Polarimetry

Centre-of-mass system → Lab system



Working point:

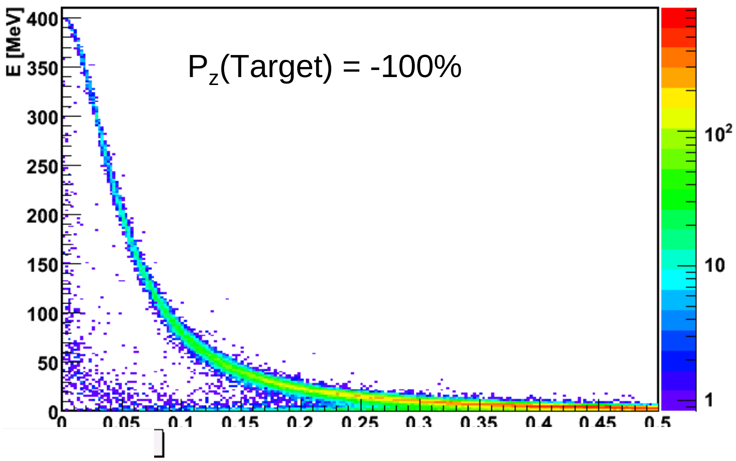
– After pre-acceleration (125 MeV –) 400 MeV

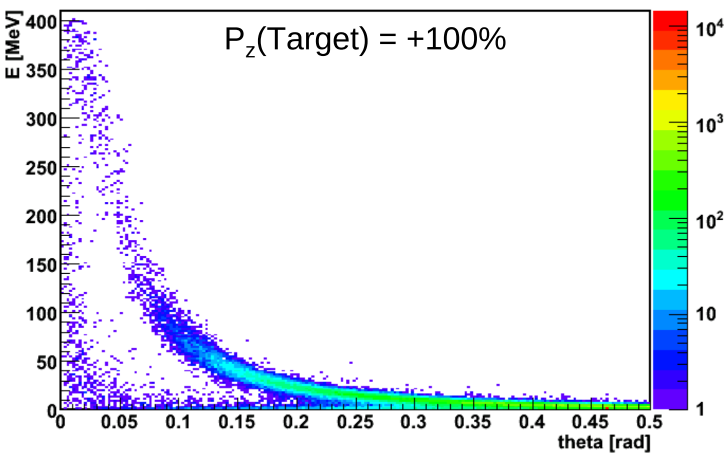
– First studies done for 200 MeV, 400 MeV

Example: e^- distribution and e^- asymmetry

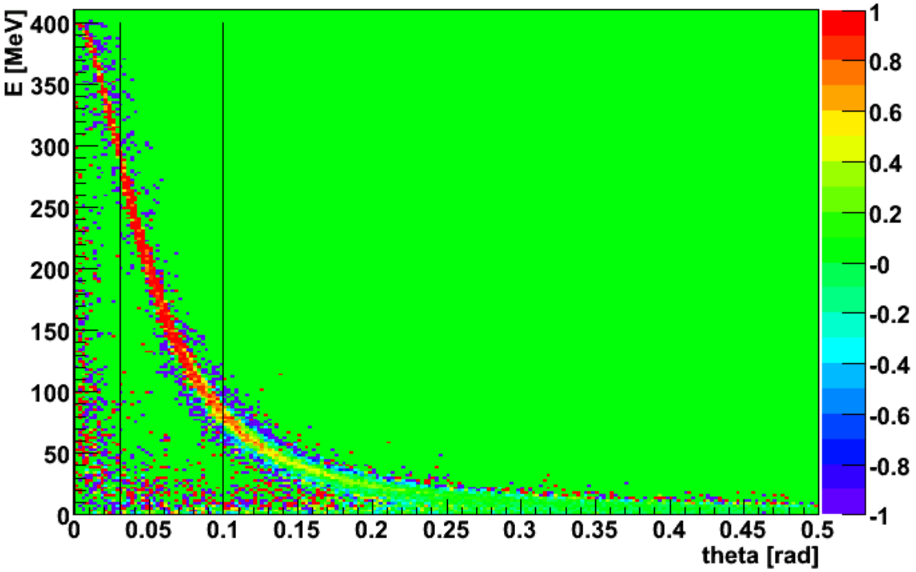
- 30 µm magnetized Fe-Foil
- E_{beam}: 400 MeV (10 % spread)
- Ang. Spread: 0.5º
- 100% e+ and e- polarisation assumed

e^- distribution





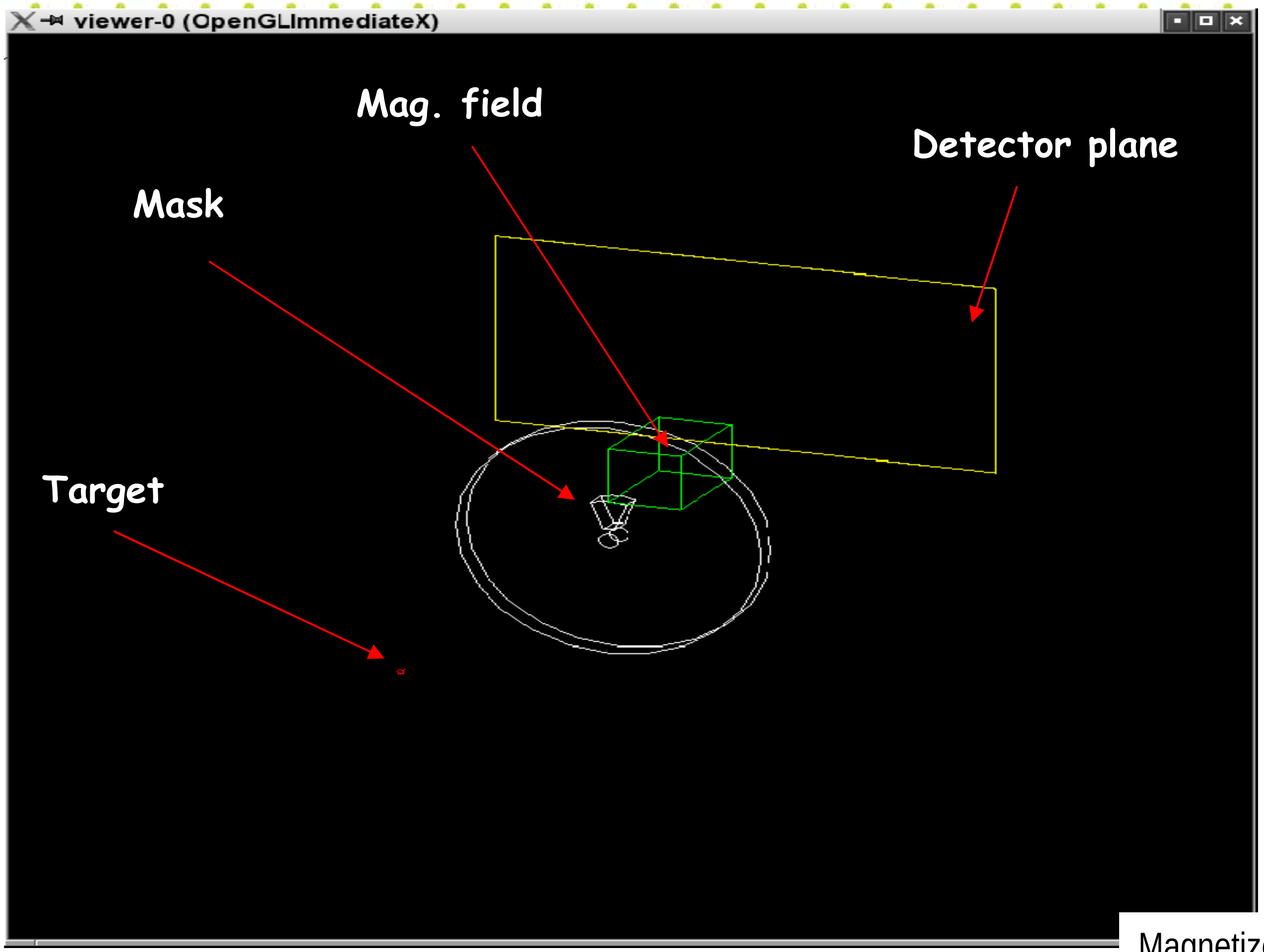
asymmetry (analyzing power)



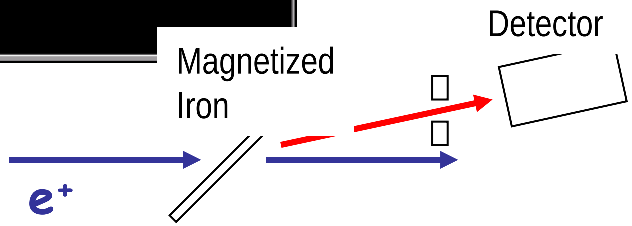
ang. range of interest: 0.03 – 0.1 rad

→ Asymmetry in the ang. range: A_{e-} ~50 % (A_{e+} ~5%, A_{γ} ~-15%)

Geometry



- detector ?
- mask ?
- magnet ?

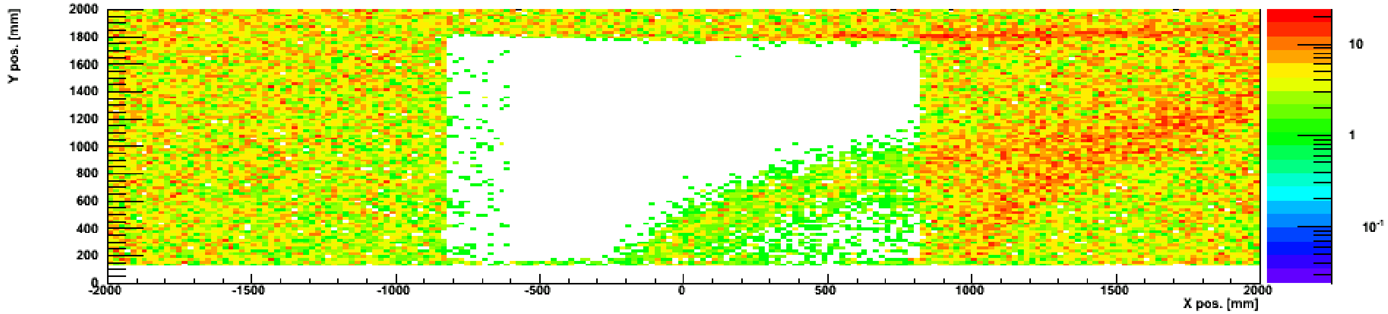


Detector plane, int. B-field 0.1 Tm

e^- distribution

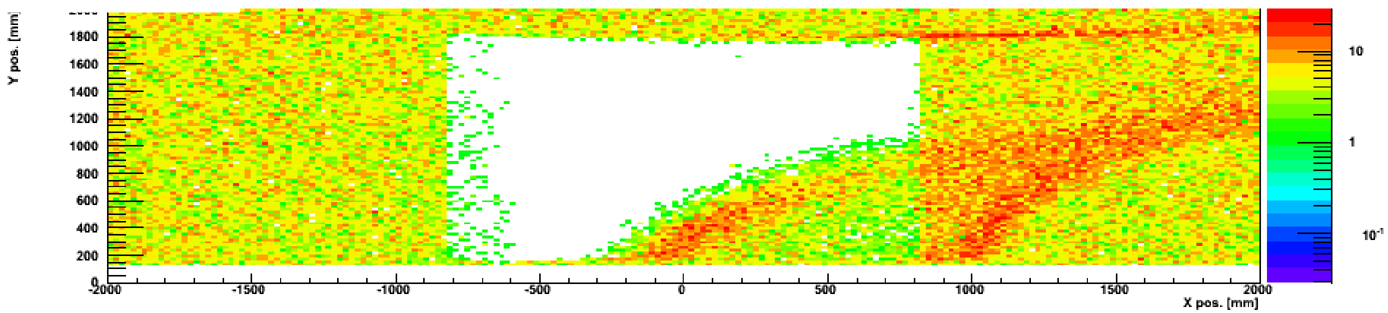
Distance analyzing magnet – detector ~ 5m

- run

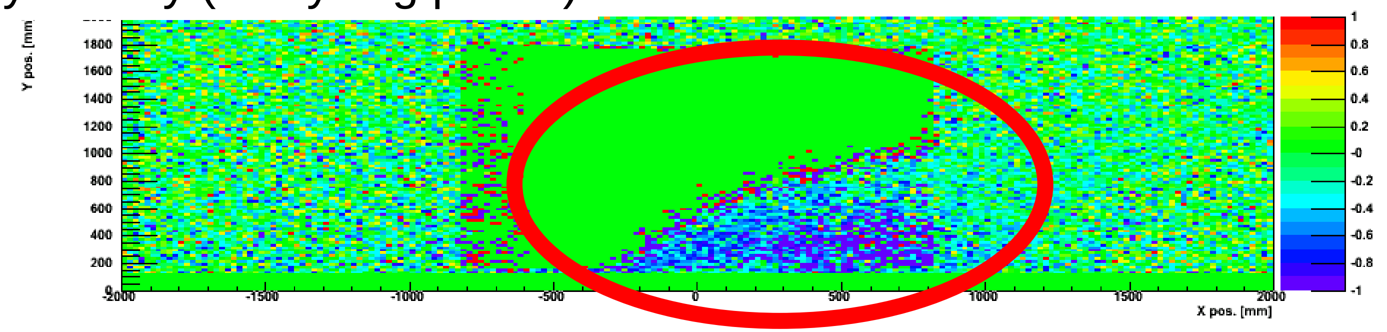


e^- distribution

+ run



asymmetry (analyzing power)



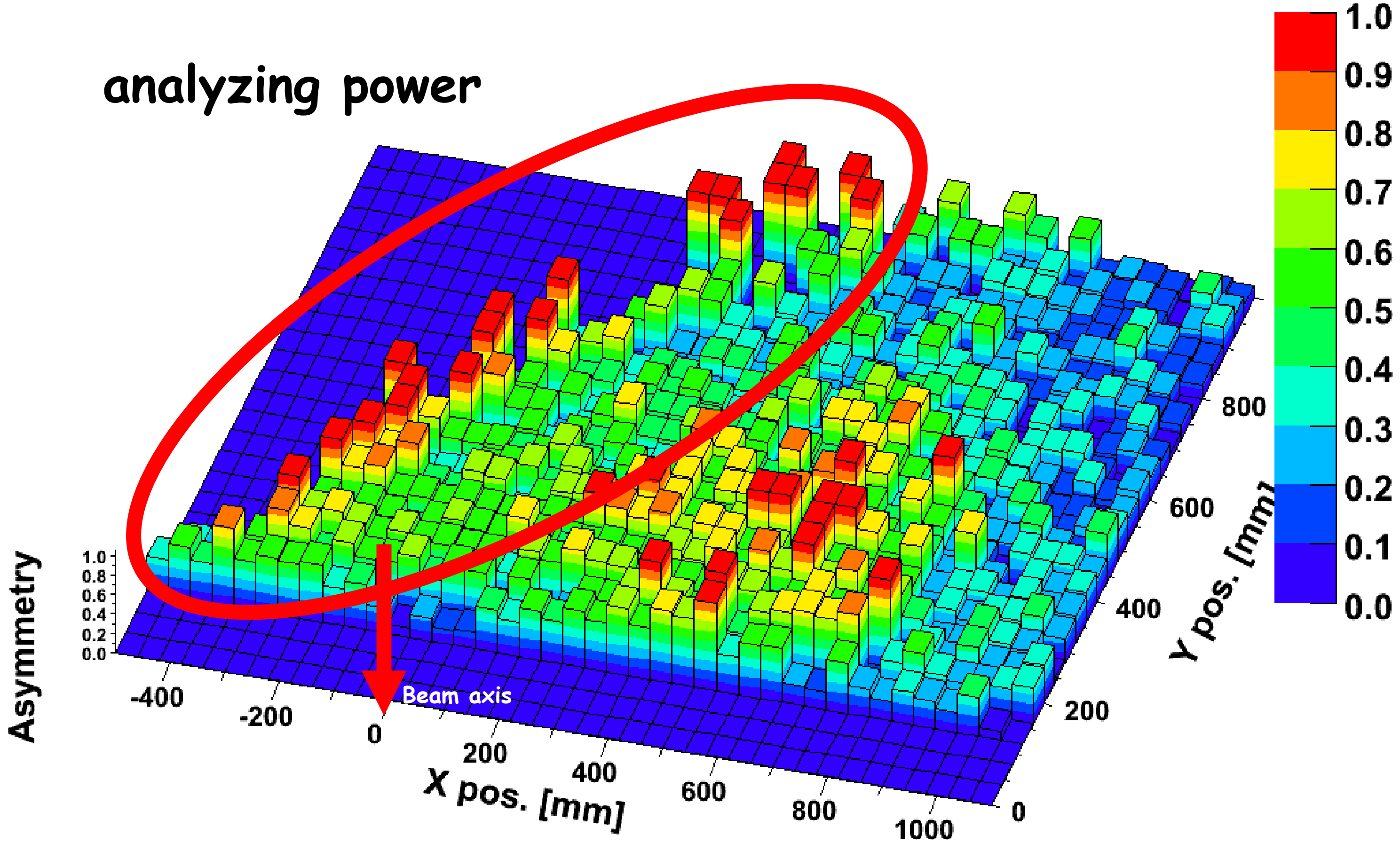
(beam: $1*10^9$ e^+, E: 400 MeV (10 % spread), ang spread: 0.5º

e⁻ asymmetry in detector pads

Pad size: 4cm x 4cm

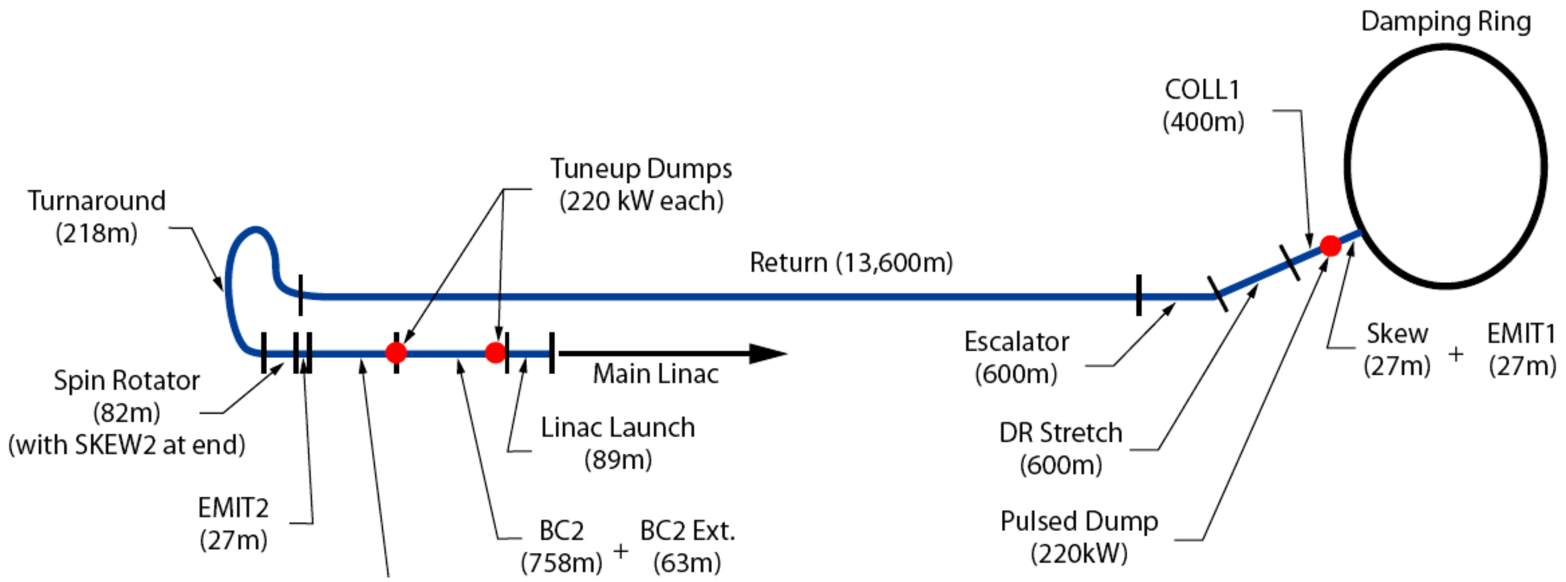
- run

analyzing power



Compton Polarimetry after DR

Large e+ beam size → no Compton polarimetry before the DR
After DR: → small beam size, 5GeV,
→ transverse pol (DR…Turnaround)
→ ~longitudinal pol (spin rotation after turnaround)
taking into account earth curvature



Compton Polarimetry after DR

Compton scattering on polarized lepton beam:

- Transverse polarization
  - Asymmetry in scattered azimuthal distribution
- longitudinal polarization
  - asymmetry in energy distribution

- Asymmetry measured using scattered photons
- Detection of e-, e+ more complicated, separation by chicane

Needs:

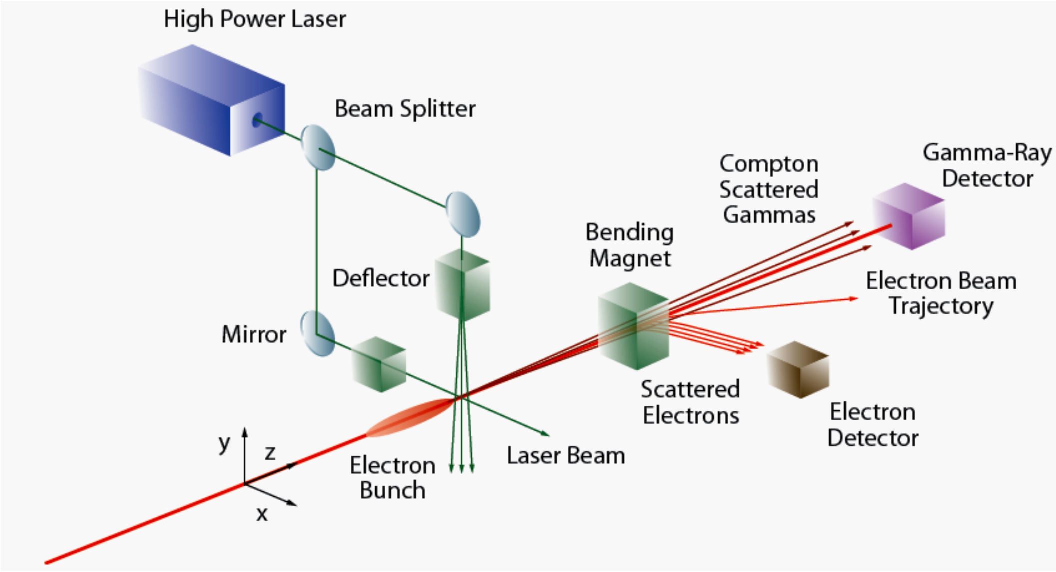
- Large Rate (Rate = Lumi • cross section)
- ‘reasonable’ asymmetry

Could the laser wire be used??

Compton Polarimetry after DR

Laser wire:

- $\pi/2$ **crossing angle between e and** γ
- **e beam size larger than laser beam waist**

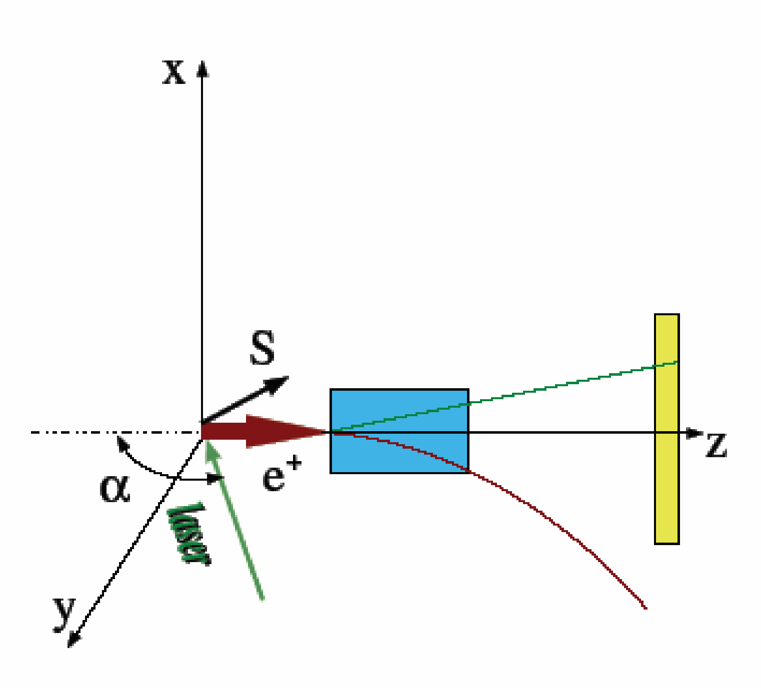


'Normal' Compton crossing angle: π

Use of LW facilities for polarimetry ??

Some Compton Kinematic Studies

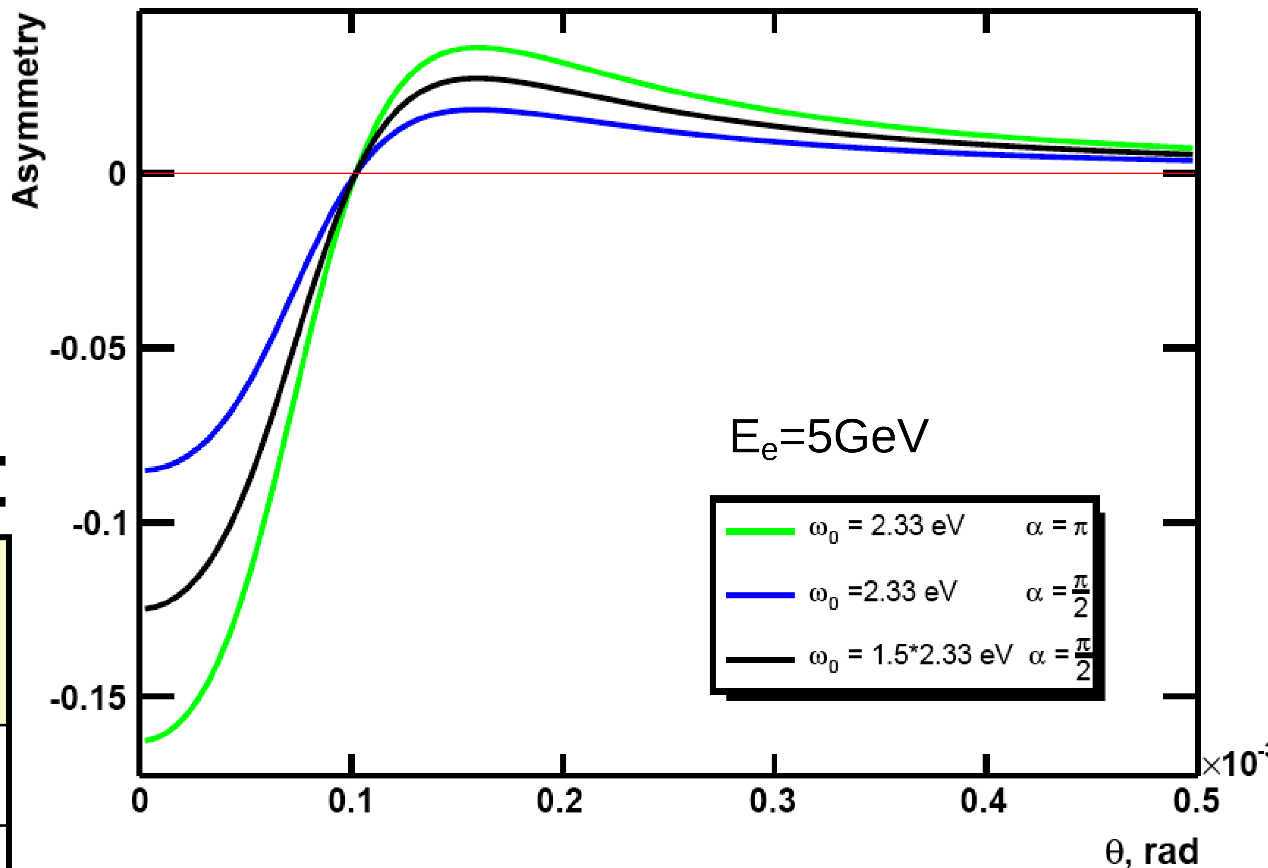
Done by P. Starovoitov



$$\gamma(k_1, \zeta) + e^+(k2, s) \rightarrow \gamma(p_1) + e^+(p_2)$$

Laser energy:	$\omega_0 = 2.33$ eV
Crossing angle:	$0 < \alpha < \pi$
Positron energy:	$E_0 = 5$ GeV
Positron spin:	$\vec{S} = (s_1, s_2, s_3)$

- Asymmetry dependence on crossing angle α of laser and lepton beam
- Asymmetries for trans/long polarization



Total asy [%]:

ω_0 [eV]	$\alpha=\pi/2$	$\alpha=\pi$
1.165	2	4
2.33	4	7.4
4.66	7.4	12

$2 \cdot A(\alpha=\pi/2) \sim A(\alpha=\pi)$

Transverse positron beam polarisation

Total asy [%]:

ω_0[eV]	$\alpha=\pi/2$	$\alpha=\pi$
1.165	1	2
2.33	2	3.7
4.66	3.7	6.5

A(trans) ~ 0.5 A(long)

➔ should measure with longitudinal polarized e+

G. Alexander, P. Starovoitov

Rough error estimate:

Assumptions: long. polarization

e-beam: σ_x=130μ σ_y=6.5μ

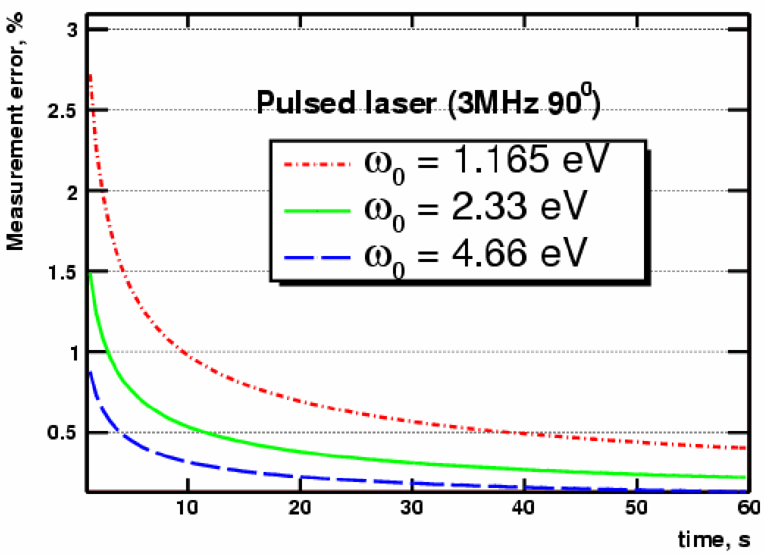
γ-beam: $\sigma_e \ll \sigma_\gamma$

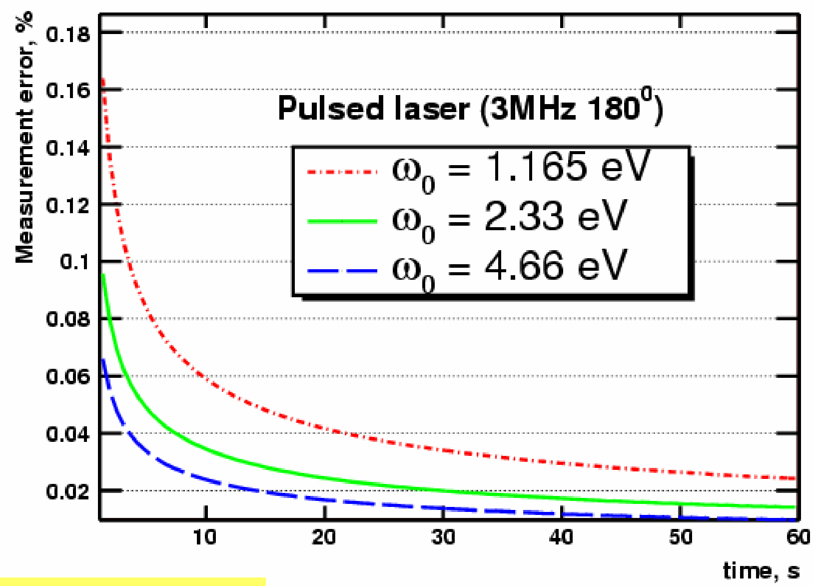
100% efficiency

calorimeter: 10% /√E

Laser: 3MHz

ω_0 (eV)	λ (nm)	Energy (μJ)	Pulse (ps)	$\mathcal{L}$umi ($cm^{-2}s^{-1}$)
1.66	1064	10	10	1.4×10^{31}
2.33	532	10	10	7.2×10^{30}
4.66	266	10	10	3.6×10^{30}





$\Delta(\alpha=\pi/2)\approx15\bullet\Delta(\alpha=\pi)$

e+ Compton Polarimetry after DR (~turnaround) is an option

Summary & Conclusion

- machine will be polarized
  ➔ consequences for design:
  ≥30% e+ polarization have to be kept
  ➔ interaction with IP (polarimeter, physics):
    - frequency of helicity reversal,
    - stability of intensity and polarization
- Tools for design/performance studies:
  - **G4 with polarization extension:**
    - validition,
    - spin tracking,
    - transverse pol.
- e+ polarimeter:
  - **Bhabha (~400 MeV),**
  - **Compton (5GeV, long polarization)**
    - Further studies in cooperation with machine and Lw people