Challenge of polarized beams at future colliders

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on behalf of

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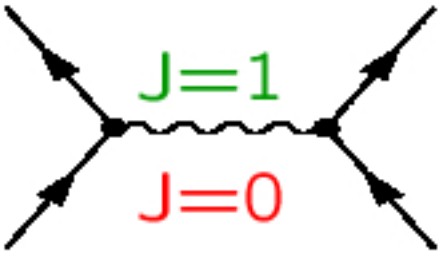
- **Introduction and physics motivation for polarized beams**
- **Polarized positrons at the ILC**
- **Spin tracking from source to IP**
- **Next steps and outlook**

Why are polarized beams useful?

- *Definition: Polarization = ensemble of particles with definite helicity λ = -½ left- or +½ right-handed*

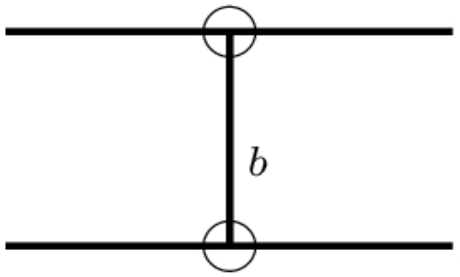
$$\mathcal{P} = \frac{\#N_R - \#N_L}{\#N_R + \#N_L}$$

- **Beam polarization fixes the initial state, if E and p known**



← **LR, RL: SM and(?) NP (γ, Z)**

← **LL, RR: NP !**



← **depends on P(e+)!**

helicity of e- not coupled with helicity of e+ !

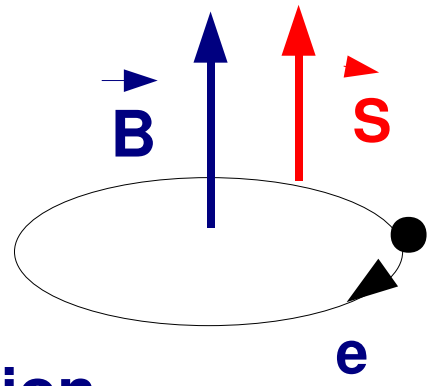
← **depends on P(e-) !**

→ **Access to couplings and the structure of interactions !**

Polarized beams at circular colliders

- **Overview:**
  - **Polarization of both beams via Sokolov-Ternov effect**

    (=spin-flip effect due to synchrotron radiation)



- **LEP: low polarization, used for energy calibration, not used for physics**
- **HERA: 27.6 GeV e vs. 920 GeV p, L up to $5 \times 10^{31} cm^{-2} s^{-1}$, excellent $e_{L/R}$ polarization 40% (70% non coll, mode), spin rotators to get longitudinally polarized beams**

Physics motivation for polarized e^- / e^+:

- **test of right-handed charged currents, electroweak couplings in the neutral currents, complementary information about PDF**
- **reference:** ***U. Klein (=U. Stoesslein), Ringberg Workshop, 2003***

Future plans for ep upgrades

- **eRHIC (BNL) ,eLIC (JLab):**
  - **(5 – 10 GeV) pol. e vs. (50-250 GeV) pol. p**
  - **lumi up to $10^{34}cm^{-2}s^{-1}$, pol. degree ~70%**

  Physics motivation for polarized beams:

  precise access to spatial and spin structure of gluons in p

  reference: ***Ptitsyn et al., EPAC06***
- **LHeC (CERN): 70 GeV e vs. 7 TeV p**
  - **lumi up to $10^{33}cm^{-2}s^{-1}$, highest Q^2 up to 10^6GeV^2**

  Physics motivation for maybe polarized e:

  revealing new physics at high Q^2, ew physics, proton structure

  reference: ***J. Dainton et al., 2006, JINST 1 P10001***

Polarized beams at linear colliders

- **Overview:**
  - synchrotron radiation due to longitudinal acceleration negligible
  - beams have to be polarized at the source !
- **at the SLAC Linear Collider (SLC): e^- polarization of about 78%**
  - led to precision measurement of the weak mixing angle:

    $\sin^2\Theta_{eff}$ =0.23098 0.00026 (SLD)

    (LEP: 0.23221 ±0.00029)
- **at the ILC:**
  - e^- of 80% - 90% in baseline, SLC scheme: no problems expected
  - e^+ with 30% (60% as upgrade): *see current RDR*
- **at CLIC under discussion: similar polarization schemes as for ILC, but e+ source less challenging than at ILC**

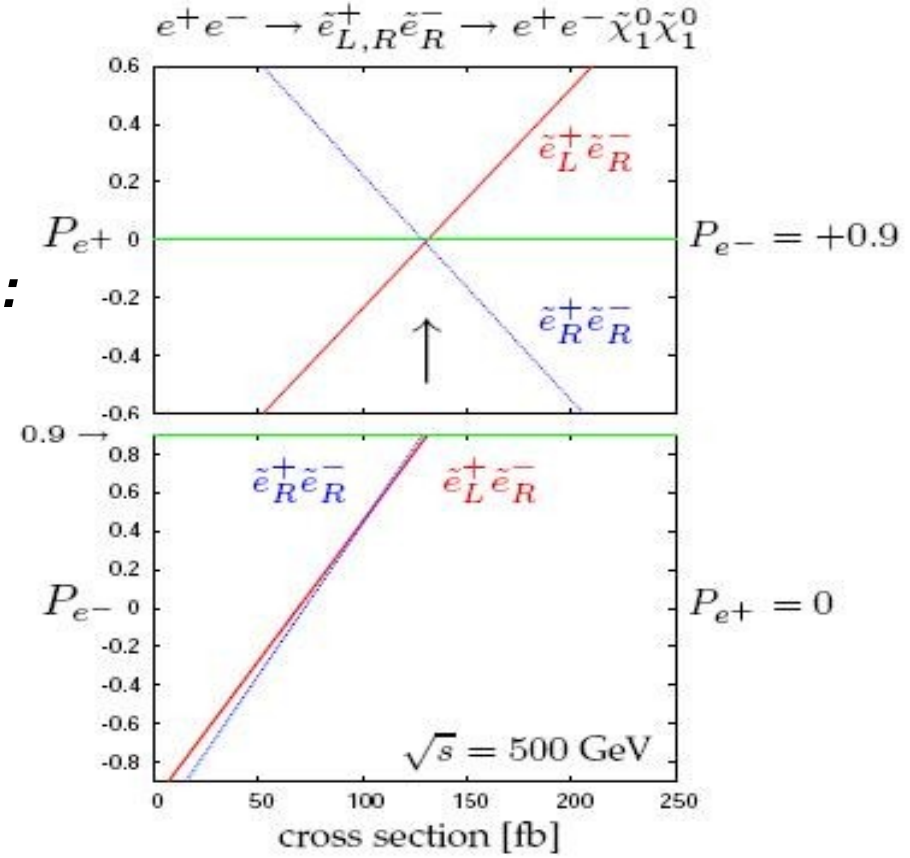
Physics case for pol. beams at ILC

- **Polarized beams required for**
  - improving **statistics**: enhancing rates, suppressing **backgrounds**
  - detecting new physics via deviations from Standard Model predictions in **high precision** measurements (e.g. at GigaZ)

- **Cases where pol. e+ mandatory**
  - *e.g. chiral properties of new particles: different cross section*
  - *see also summary table in*

reference: *GMP ea, hep-ph/0507011*

and *www/ippp.dur.ac.uk/~gudrid/source*



Features of the baseline source

- **ILC undulator: K~0.9, λ~1.15 cm, L~150 m**
  - **such a length is sufficient to produce pol. e^+ with P(e^+)~30%**

- **What is the gain with P(e^+)~30%?**
  - **'top couplings': gain factor 2 with (80%,30%) , ~3 with (80%,60%)**

    note: 'no' gain in case one had even P(e-)=100!
  - **'Higgs channels': gain factor 2 with (80%,30%), ~4 with (80%,60%)**
  - **'SUSY properties': gain factor 2 with (80%,30%), ~4 with (80%,60%)**

    note: there exist scenarios, where even P(e-)=100% not sufficient !
  - **Transversely polarized beams: ~ P(e^-)P(e^+)**
    'Extra dimensions': (80%,30%) = ½ of (80%,60%)

    note: these effects are only observable if both beams are polarized!

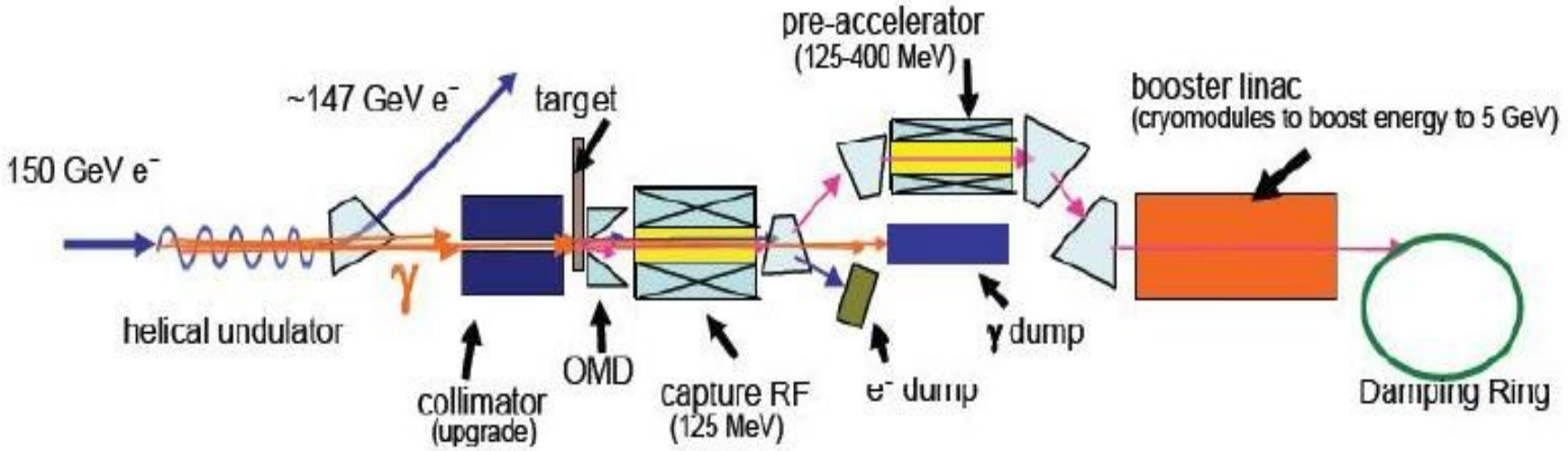
Physics requirement

- **High accuracy required:**
  - for most physics studies $\Delta P/P=0.5\%$ sufficient
  - for precision measurements $\Delta P/P<0.1\%$ required
  - polarization@IP = lumi-weighted polarization ≠ polarization@polarimeter
- **Expected for the ILC**
  - Compton polarimetry with up to $\Delta P/P< 0.5\%$,..,0.25%
  - higher precision only via Blondel scheme, needs polarized e+
- **Precise spin tracking from source to IP required**
  - sort out all possible depolarization effects
  - *...source, damping ring, main linac, beam-beam...*

see also Jeff Smith, 2006

ILC baseline design

- **Challenge: e^+ source has to deliver 5.2 x 10^{13} e^+/pulse**
  - **~3 orders of magitude higher than e^+ source of SLC !**
- **Undulator-based source has been chosen**
  - **higher yield, less demands for capture issues in DR, less radiation damage at target** ***A. Ushakov ea, EUROTeV-Report-2006-052***
  - **target prototypes:** ***please visit Leo Jenner and his poster!***
    reference: ***I. Bailey, EUROTeV-Report-2006-044***
  - **layout:**



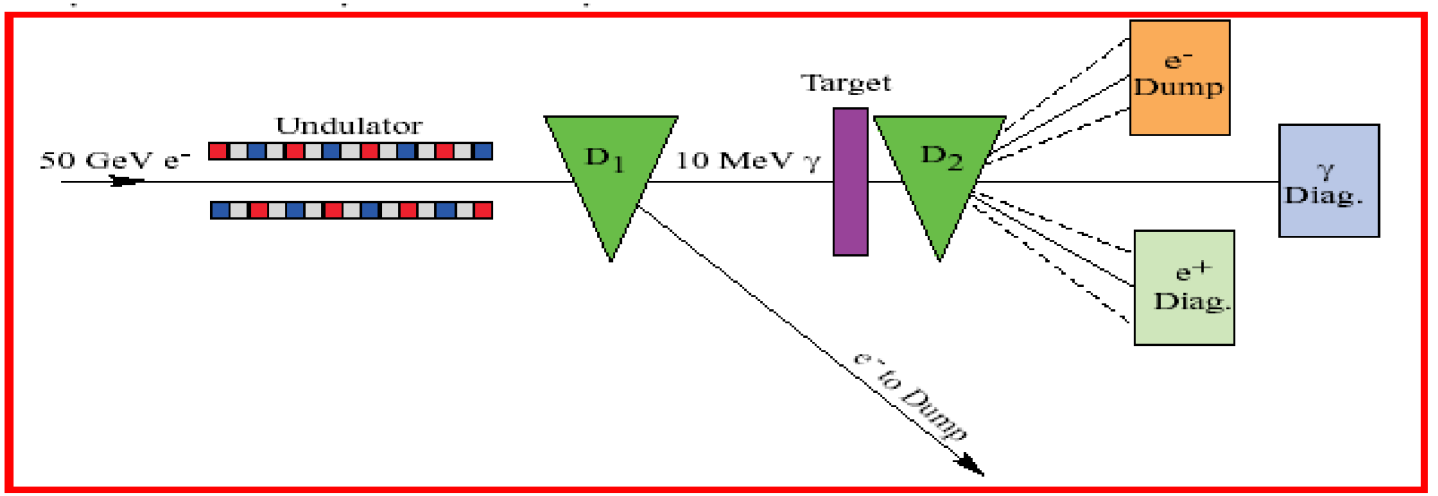
Prototype work: E166

- **Run in 2005 at SLAC: 1m helical undulator in FFTB → pol. e+**

L=1m

K=0.19

λ=0.25 cm



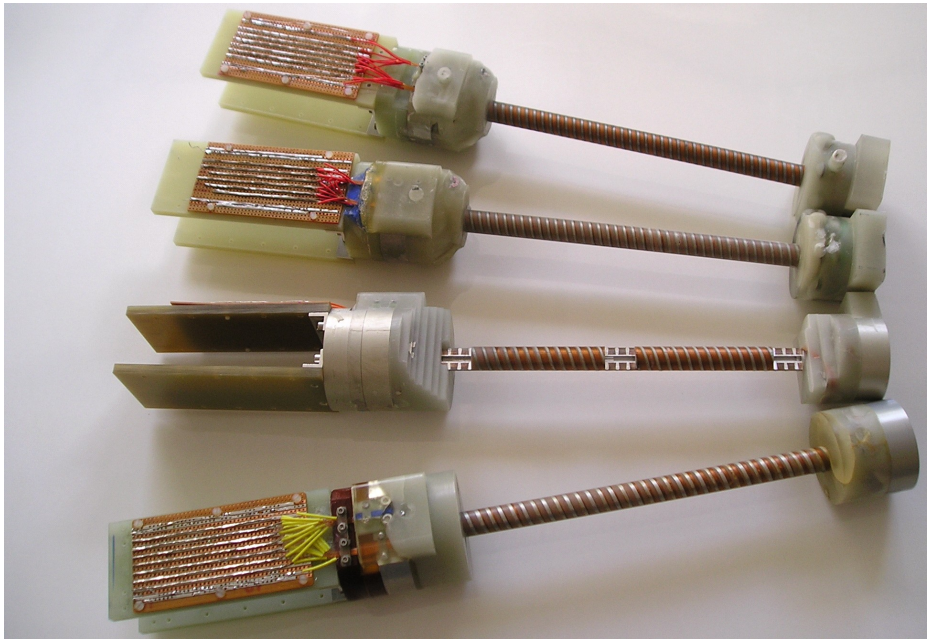
- **successful: both photon and e+ asymmetries measured**
- **e+ data analyzed at 6 different energies of spectrometer**
- **asymmetries in range [0.6%,1%] → pol. in range of [40%, 90%]**

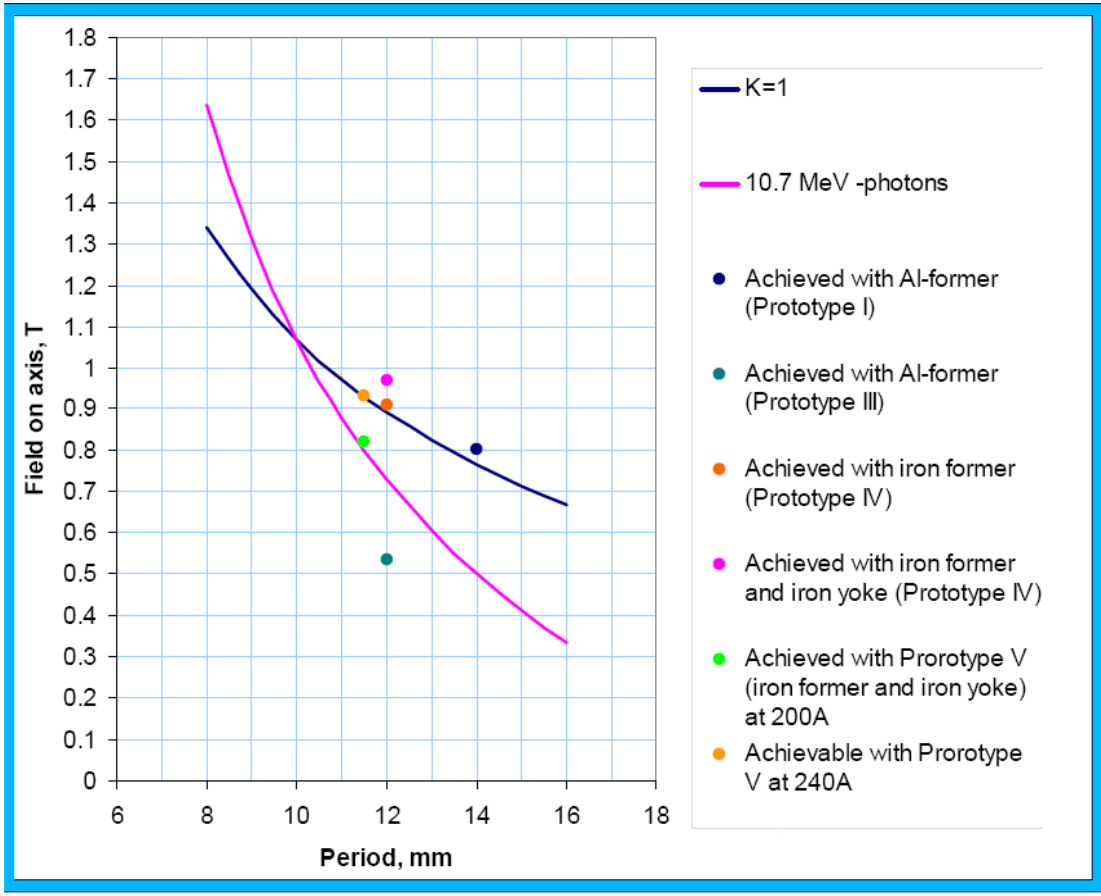
Reference: ***P. Schueler, SPIN06 and final publ. of E166 under work***

- **spin-off: polarization now in GEANT4, important for future coll.**
  - **Reference:** ***A. Schaelicke, EPAC06 and GEANT4 collaboration***

ILC undulator prototypes

- **ILC undulators: several short prototypes tested at ASTeC, UK**





- **SC magnet design chosen**
- **Impacts on emittance and energy spread studied: negligible**

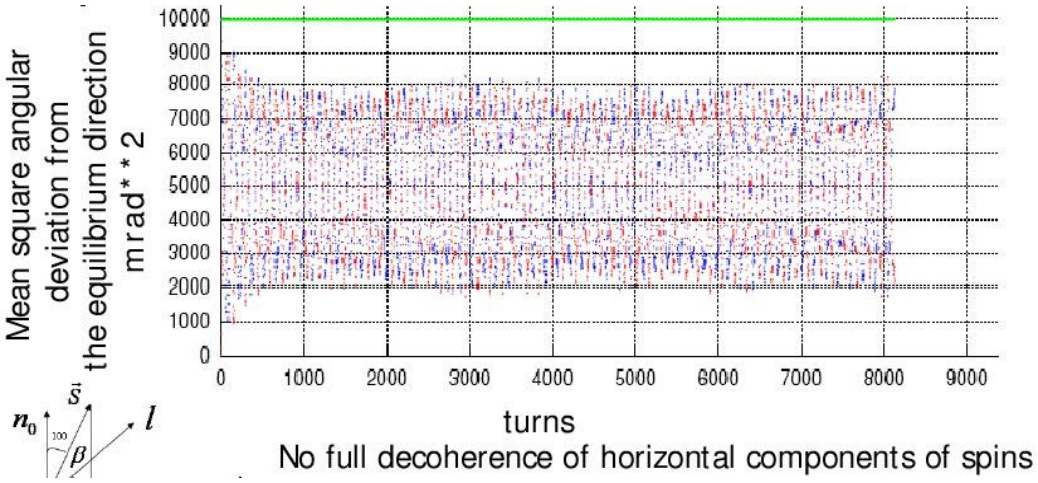
Reference: ***D. Scott, PAC07, EUROTeV-Report-2006-084, -085, -2007-007***

Depolarization effects at the DR

- **Precise Monte-Carlo simulations done including full 3-D spin motion (code SLICKTRACK):** *D.P. Barber, Cockcroft-04-01*
  - **No significant depolarization effects have been detected even for a positron beam with its large energy spread and transverse dimensions**
- **However, absence of full decoherence of the horizontal components of the spin observed in simulations:**
  - **longitudinal polarization can survive!**

→ **Spin rotators needed for 30%!**

L. Malysheva, EUROTeV-Report-2007-038



Please visit Ian Bailey and his poster!

Beam-beam interaction in CAIN

- **Two sources of depolarization effects:**
  - **Spin Precession (T-BMT equation) and spin-flip effect (ST effect)**
  - **have been treated in code CAIN (analytically-based code, quasiclassical approximations have been used)**
- **QED background processes have also to be taken into account (coherent and incoherent processes)**
  - **equivalent photon approximation used, no full polarization included, no second order processes had been included**
- **News: CAIN modified, i.e. virtual photon polarization included for incoherent processes, full polarization for Breit-Wheeler x-section, polarization of final states, qc-approximations have been checked**

Incoherent processes

- **Breit-Wheeler: 2 real γ's (basis process)**
- **Other processes treated in equivalent photon approximation:**
  - **Bethe-Heitler (1 real and 1 virtual γ), Landau-Lifshitz (2 virtual γ's)**
  - **Bremsstrahlung (1 electron and 1 virtual γ)**
- **After inclusion of polarization in BW process and for virtual γ's and final states in BH-, LL- and BS-processes:**
  - **Full polarizations show 10-20% less pair particles**
  - **Also effect on luminosity has been checked: remains unchanged, i.e. less pairs due to lower BW x-section....so far overestimated?**
  - **comparison with MC Guinea-Pig under work**

Reference: ***A. Hartin, EUROTeV-Report-2007-040 and -2006-073***

also C. Rimbault et al, Phys.Rev.ST Accel.Beams 9, 2006

Spin precession in strong fields

- **T-BMT equation:**

$$\frac{d\boldsymbol{S}}{dt} = -\frac{e}{m\gamma}\left[(\gamma a+1)\boldsymbol{B}_T + (a+1)\boldsymbol{B}_L - \gamma(a+\frac{1}{\gamma+1})\beta\mathbf{e}_v\times\frac{\boldsymbol{E}}{c}\right]\times\boldsymbol{S}$$

  - 'a' refers to anomalous magnetic moment of electron
  - higher-order effect, radiative corrections to eeγ–vertex
  - measured up to accuracy of 10^{-11}

- **What has to be taken into account in strong fields?**
  - 'a' gets corrections
  - so far derived only in quasi-classical approximation

Reference: *Baier, Katkov, Phys.Lett.A280, 2001 and GMP ea. 2007*

Laser-Compton-based e+ source

- Scheme has been chosen as alternative pol. e+ ILC source:
  - circularly-polarized γ via laser-backscattering
- Successful prototype experiment run at ATF in 2006
  - measured photon as well as e^+ asymmetries:
  - P(e+)=73% ±15 % (stat) ± 19% (syst) *T. Omori, Phys.Lett.96 (2006)*
- Large range of possible applications and schemes:
  - SuperB factories
  - CLIC
  - ERL
  - BNL CO_2 Lasers
- Exciting news ahead!

Next steps and outlook

- **Polarization will be an important issue at future colliders!**
- **Not covered today: polarimetry issues**
  - **flipping of helicities e- and e+ needed to access the gain of polarized e+ beams ! ..... required frequency under work**

S. Riemann, LCWS07

- **ILC positron source group**
  - **covers all positron tasks, preparation for EDR**
  - **next meeting at ANL, Argonne, Sept 17-19**
  - **decisive contributions from the heLiCal collaboration (undulator, target, spin tracking)**
- **further information:see also *www.ippp.dur.ac.uk/~gudrid/source/***