Physics requirements for positron polarization

Sabine Riemann (DESY)

GDE Baseline Assessment Workshop (BAW-2)

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Outline

- Introduction
- Positron polarization at ILC
  - **polarized positrons at ILC (RDR, SB2009)**
  - **Precision measurements with e+ polarization (s-channel processes)**
  - **Requirements to use e+ polarization for physics**
  - **Increase of positron polarization**
- Unpolarized positrons?
- Polarimetry
- Summary

Physics Goals of ILC

Observe, determine and precisely reveal the structure of the underlying physics model

- Standard Model
  - **What is the mechanism of electroweak symmetry breaking?**
  - **Understanding the Higgs boson (mass, couplings and self-coupling)**
  - **Top quark, W boson physics**
- New discoveries beyond the Standard Model:
  - **New gauge bosons**
  - **SUSY particles**
  - **Extra dimensions**
  - **Cosmological connections**

ILC = High precision frontier

- **High luminosity**
- **Flexible energy, up to high values**
- **Polarization ⇔ initial state is known and fixed**

→ Experimental flexibility ⇔ be prepared for the unexpected

Positron polarisation is upgrade option, not baseline

Is P(e+) indispensable for a future linear collider?

- new physics signals are expected at the LHC; they can be interpreted and fixed with substantially higher precision if positron polarization is available

  → distinction of new physics models

What are the physics requirements to have positron polarisation?

- Overview of physics goals: see Moortgat-Pick et al., Phys.Rept. 460(2008)131

Precision Measurements in the nineties

Lessons from LEP/SLC:

- **LEP: Unpolarized beams, $17x10^6$ Z events**

  → leptonic weak mixing angle measured with relative precision of $1.3x10^{-3}$

- **SLC: Polarized electron beam, $5x10^5$ Z events**

  → leptonic weak mixing angle measured with relative precision of $1.1x10^{-3}$

Gedankenexperiment:

SLC with 40% positron polarization

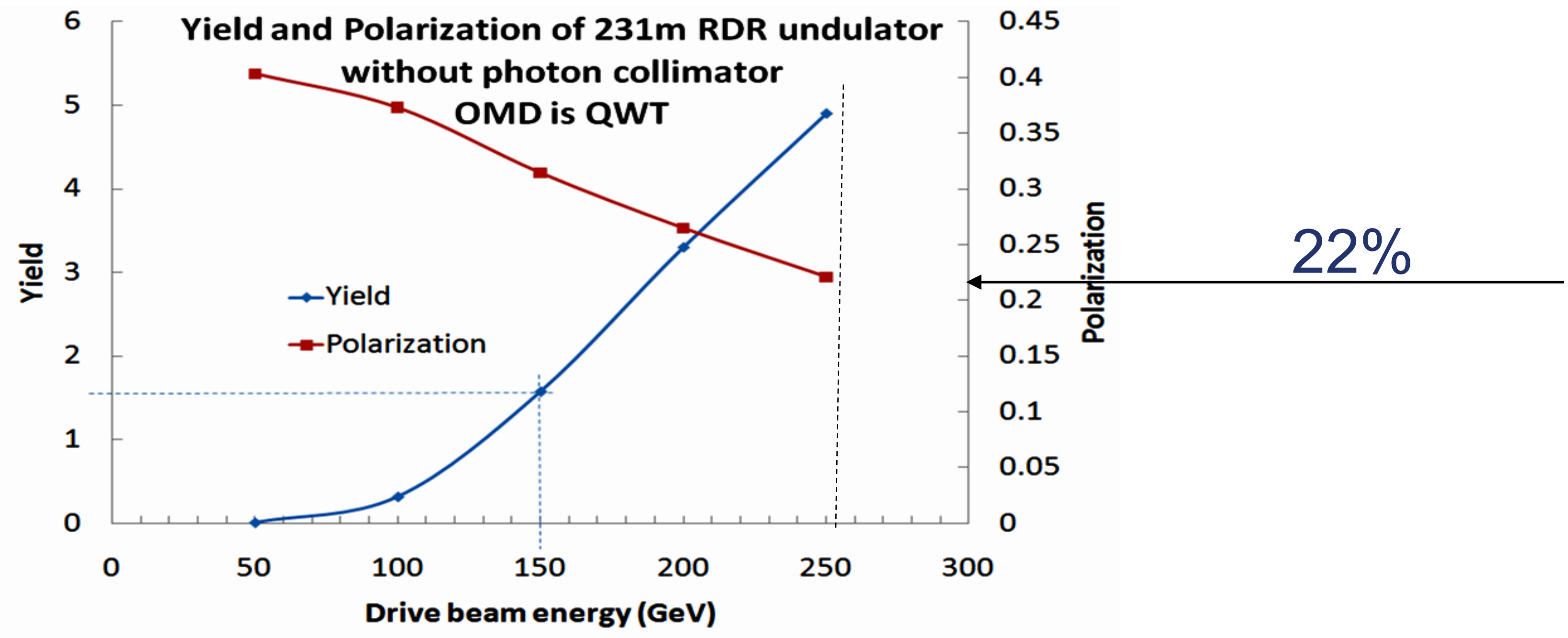
→ leptonic weak mixing angle measured with relative precision of $5x10^{-4}$

Yield of Polarized Positrons at ILC

Helical undulator, no photon collimator → RDR design → e+ polarization ~34%

SB2009 → e+ polarization ~22%

SB2009 Proposal Document:



see also talk of Wei Gai

ILC Parameters

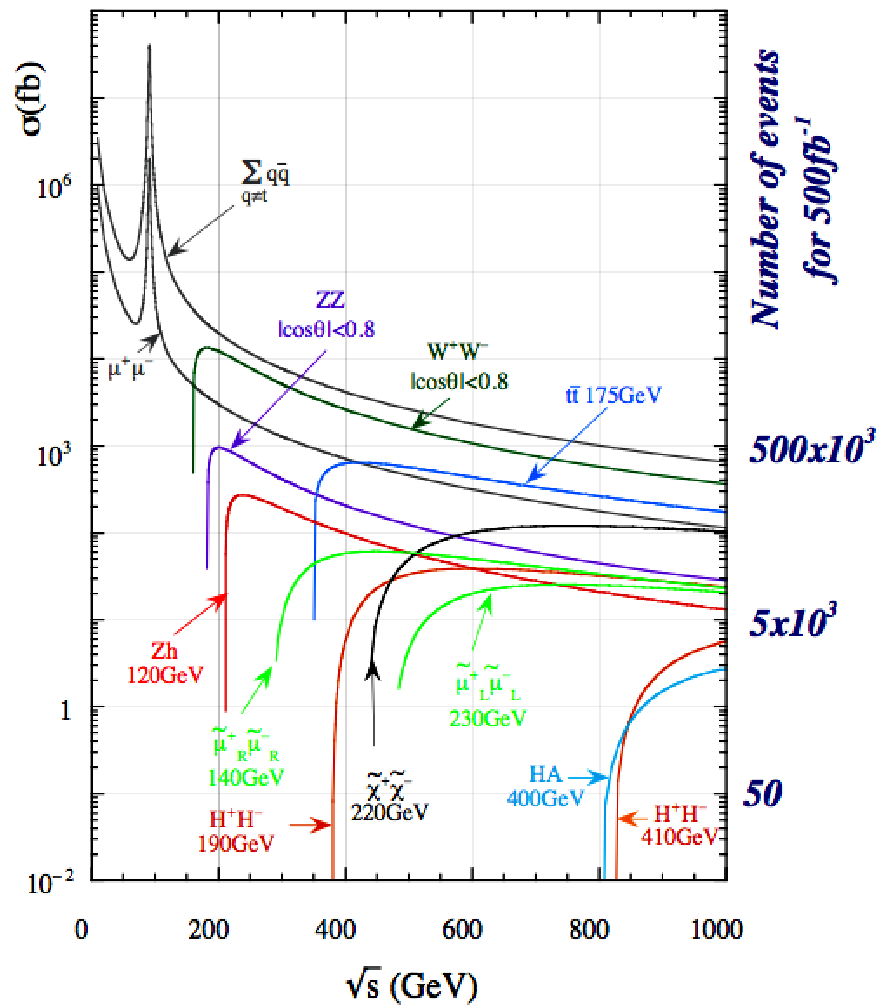
		RDR			SB2009	
		min	nominal	max	no TF	with TF
Bunch population	x 10^{10}	1	2	2	2	2
Number of bunches		1260	2625	5340	1312	1312
Linac bunch interval	ns	180	369	500	530	530
RM bunch length	µm	200	300	500	300	300
Normalized horizontal emittance at IP	mm-mr	10	10	12	10	10
Normalized vertical emittance at IP	mm-mr	0.02	0.04	0.08	0.035	0.035
Horizontal beta function at IP	mm	10	20	20	11	11
Vertical beta function at IP	mm	0.2	0.4	0.6	0.48	0.2
RMS horizontal beam size at IP	nm	474	640	640	470	470
RMS vertical beam size at IP	nm	3.5	5.7	9.9	5.8	3.8
Vertical disruption parameter		14	19.4	26.1	25	38
Fractional RMS energy loss to beamstrahlung	%	1.7	2.4	5.5	4	3.6
Luminosity	x 10^{34} $cm^{-2}s^{-1}$		2		1.5	2

- Potential concerns wrt. precision physics
  - **luminosity**
  - **Energy spread,**
  - **Beamstrahlung, depolarization**
  - **degree of positron polarization**

Physics potential of baseline machine

Positrons are polarized "for free"

– **Is this polarization useful for physics?**
  - Higgs measurements
  - SUSY searches
    (see talk of Mikael Berggren)
  - **Precision measurements**
    (ee→qq, μμ, tt, WW)
  - Searches and measurements of new gauge bosons, extra dim, …



– **Possibility of later upgrade to higher polarization (RDR and SB2009)**

ILC Baseline Machine (RDR/SB2009)

(See scope documents)

- Energy adjustable from 200 - 500 GeV, upgradable to 1 TeV
- Int. luminosity: L_{int} = 500 fb^{-1} (RDR: in 4 years,
  SB2009: stretch out, especially at lowest E)
- Energy stability and precision below 0.1%
- Electron polarization: P > 80%

→ expected statistics:

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

→ statistical cross section uncertainties at per-mille level !!

(stat. precision after 1st year ~ percent level)

$$\frac{\Delta L}{L}, \frac{\Delta E}{E}, \frac{\Delta P}{P}$$ must be measured with $O(10^{-3})$ or better

Precision physics with polarized beams

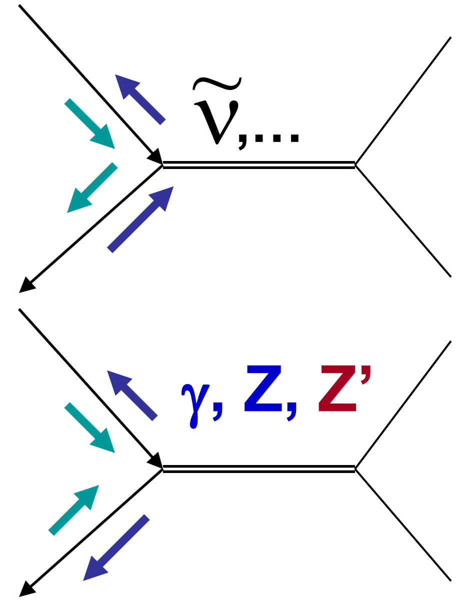
s-channel processes

	e^-	e^+	
σ_{RR}	⇒ (→)	(←) ⇐	$\frac{1+P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$
σ_{LL}	⇐ (→)	(←) ⇒	$\frac{1-P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$
σ_{RL}	⇒ (→)	(←) ⇒	$\frac{1+P_{e-}}{2}\cdot\frac{1-P_{e+}}{2}$
σ_{LR}	⇐ (→)	(←) ⇐	$\frac{1-P_{e-}}{2}\cdot\frac{1+P_{e+}}{2}$

J=0 (σ_{RR}, σ_{LL})

J=1 (σ_{RL}, σ_{LR})

SM



$$\sigma^{meas} = \sigma_0 \left(1 - P_{e-}P_{e+}\right)\left(1 + A_{LR}P_{eff}\right)$$

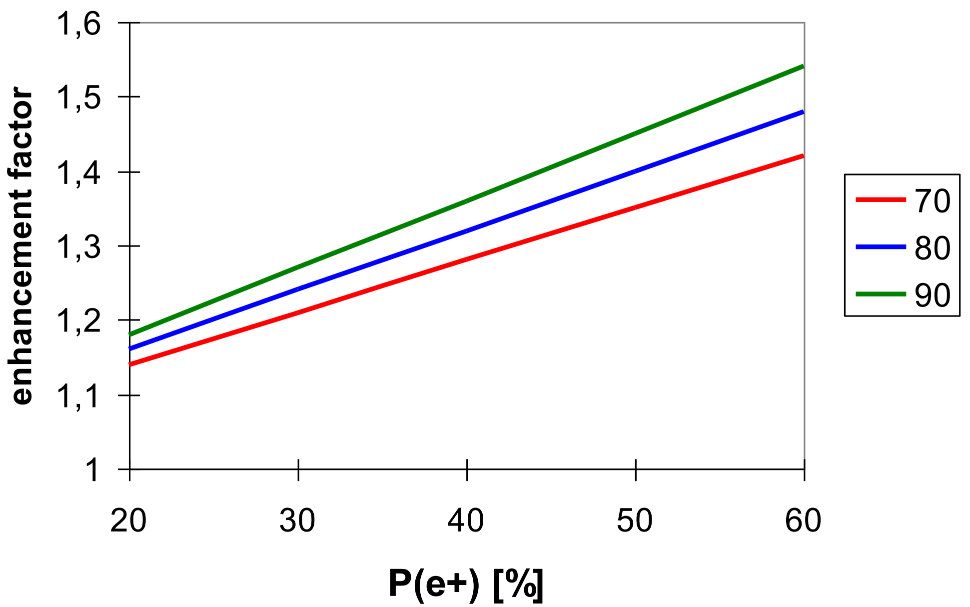
$$P_{eff} = \frac{-P_{e-} + P_{e+}}{1 - P_{e-}P_{e+}}$$

⟺

$\pm P_{e+}$, $\pm P_{e-}$ → enhancement or suppression of processes related to σ_{ij}

Precision physics with polarized beams

- enhancement of SM contributions by $(1-P_{e-}P_{e+})$ ⇔ enhancement of effective luminosity ⇨
  - **Enhancement factors:**
    (±80%,±60%) ⇔ 1.48 → δ_{stat} improved by 22%
    (±80%,±34%) ⇔ 1.27 → δ_{stat} improved by 13%
    (±80%,±22%) ⇔ 1.18 → δ_{stat} improved by 8%
    } **Could compensate reduced luminosity**
  - **Important for fermion-pair production, Higgs strahlung, TGC**



Left-right polarization asymmetry

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

$$\cong \frac{N_{LR} - N_{RL}}{N_{LR} + N_{RL}} \cdot \frac{1}{P_{eff}}$$

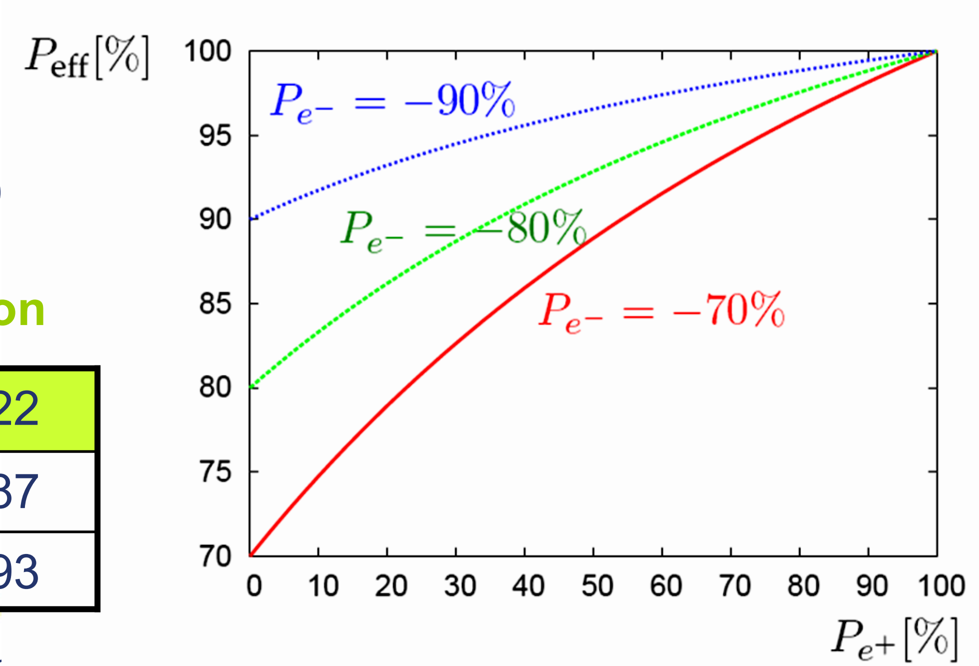
for measurements with equal luminosities for (LR) and (RL) pairing

- Effective polarization

  $P_{eff} = (-P_{e-} + P_{e+})/(1-P_{e-}P_{e+})$

  → **Higher than e- polarization**

P_{e-}	P_{e+}	0.6	0.34	0.22
0.8		0.95	0.90	0.87
0.9		0.97	0.95	0.93



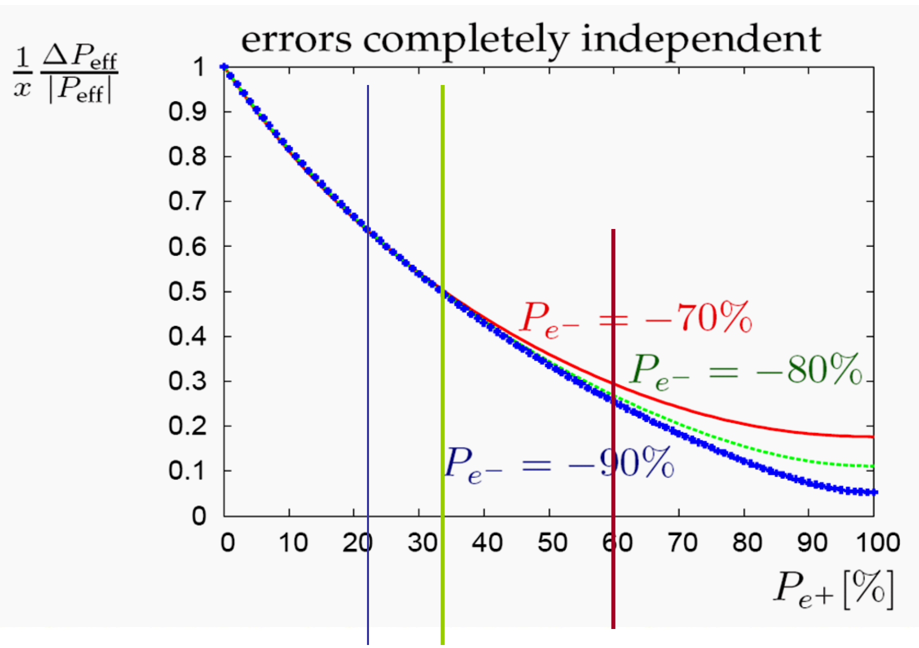
Uncertainty of eff. Polarization, ΔP_{eff}

- ΔA_{LR} can be dominated by error on polarization meas.
- error propagation → with e+ polarization ΔP_{eff} substantially smaller than δP_e

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

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

- no decrease with e- polarization only, even if P_{e-} = 100%



ΔP_{eff}

P_{e-}	P_{e+}	0.6	0.34	0.22
0.8		0.27 δP/P	0.50 δP/P	0.64 δP/P
0.9		0.25 δP/P	0.49 δP/P	0.64 δP/P

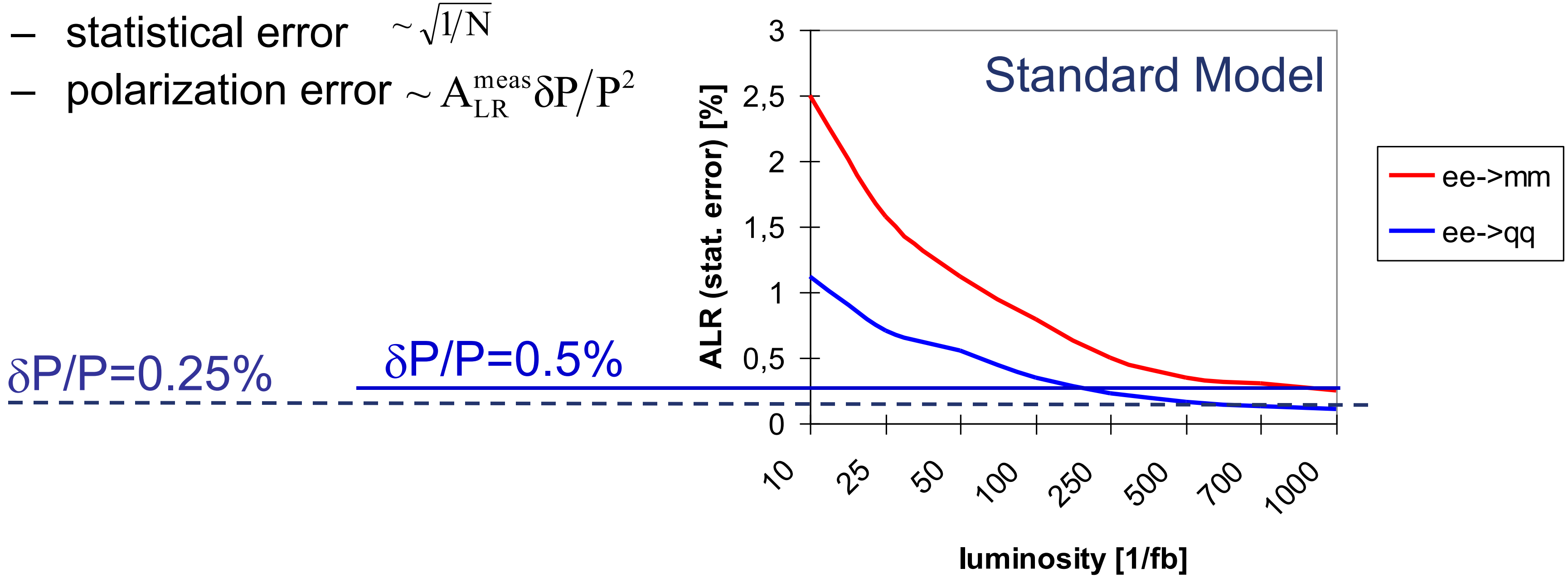
SLC: δP/P ~ 0.50% (Phys.Rept. **427**(2006)257)

ILC: δP/P = 0.25% (List et al., JINST 4:P10015,2009)

Uncertainty of A_{LR}

Contributions to uncertainty of Left-Right asymmetry:

– statistical error $\sim\sqrt{1/N}$
– polarization error $\sim A_{LR}^{meas}\,\delta P/P^2$



→ Reduction of A_{LR} uncertainty with positron polarization is important

→ **for high statistics, at new resonances (and at later for GigaZ)**

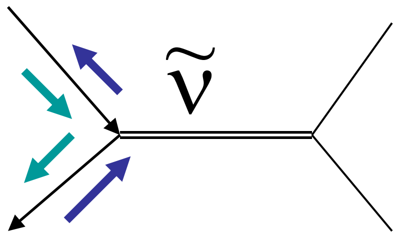
→ **for relatively large A_{LR} values**

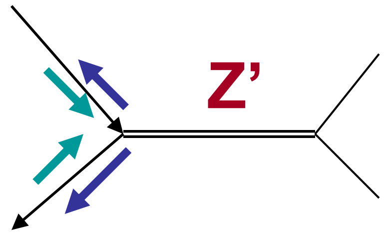
→ new physics at the TeV scale changes A_{LR} → positron polarization can increase substantially the sensitivity, and the potential to discriminate new physics models

Model distinction with polarized beams

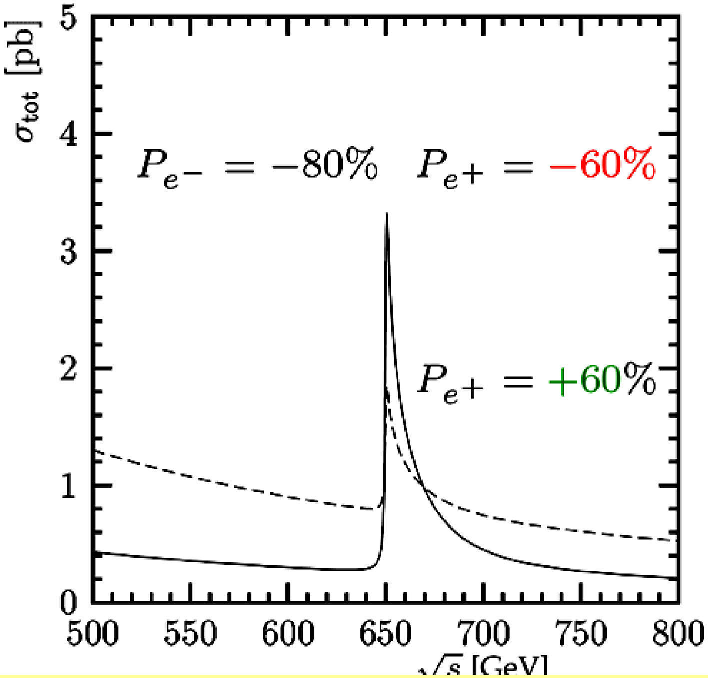
R-parity violating SUSY (spin-0) or Z' (spin-1) ?

- angular distribution
- helicities of initial e+ and e-

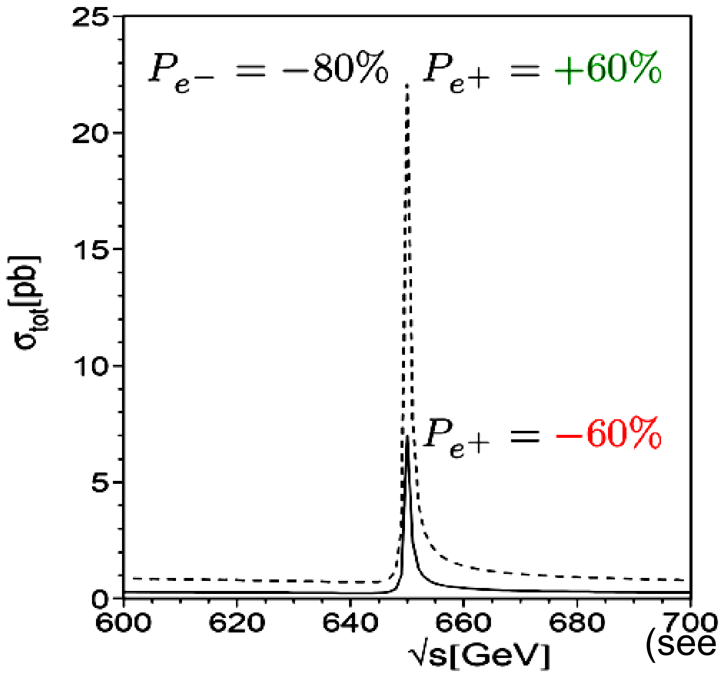


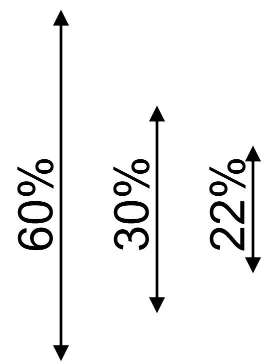


$e^+e^- \to \tilde{\nu}_\tau \to \mu^+\mu^-$



$e^+e^- \to Z' \to \mu^+\mu^-$



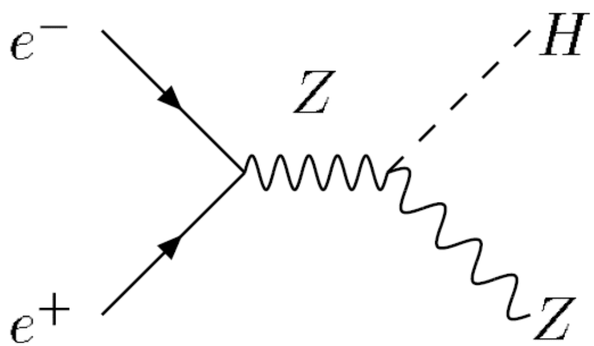


(see also POWER report)

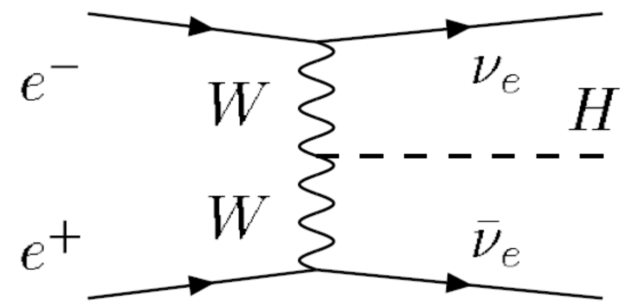
e+ polarisation improves substantially distinction between physics models – even below new resonances!

ILC as Higgs factory

Higgs Strahlung



WW Fusion



Configuration (P_{e^-}, P_{e^+})	Scaling factors $e^+e^- \to H\nu\bar{\nu}$	$e^+e^- \to HZ$
$(+80\%, 0)$	0.20	0.87
$(-80\%, 0)$	1.80	1.13
$(+80\%, -60\%)$	0.08	1.26
$(-80\%, +60\%)$	2.88	1.70

Enhancement of Higgs boson production by factor (1-Pe-Pe+)

→ 27% more Higgs bosons for 34% e+ polarization

(17% for P_{e+} = 22%)

Requirements to use P(e+) for physics

1. Bring the positron polarization to IP
   - **Spin rotation upstream e+ damping ring (long → vertical), and downstream turnaround (vertical → long.)**

2. Luminosity enhancement by factor $(1+|P_{e-}P_{e+}|)$
   - **Efficient pairing of initial states**

e- trains	**-**	**+**	**-**	**+**	**+**	**-**	**+**	**+**	**-**	**-**	**+**	**-**
e+ trains	**+**	**-**	**+**	**-**	**-**	**+**	**+**	**+**	**-**	**-**	**+**	**-**

→ 'interesting' SM processes — non SM

reversal of e+ helicity as fast as for electrons (pulse-to-pulse)

BUT:

- **direction of helical undulator windings determines sign of circular polarization of photons → '+' or '-' helicity of positrons**

→ Need facility for fast reversal to achieve desired initial states

- Fast kicker with 2 spin rotation lines (**K. Moffeit et al., SLAC TN-05-045, ILC-NOTE-2008-040)**

Requirements to use P(e+) for physics

Slow reversal of e+ helicity (run-to-run)

e- trains	-	+	-	+	-	+		-	+	-	+	-	+
e+ trains	+	+	+	+	+	+		-	-	-	-	-	-

→ **50% spent to 'inefficient' helicity pairing σ_{--} and σ_{++} (J=0)**

NO gain in effective luminosity!

➔ **Have to combine σ_{-+} and σ_{+-} measured in different runs with different luminosities**

→ **Larger systematic uncertainties due to**

luminosity variations
polarization variations
variations of detector efficiencies

3. e+ Compton polarimetry at IP

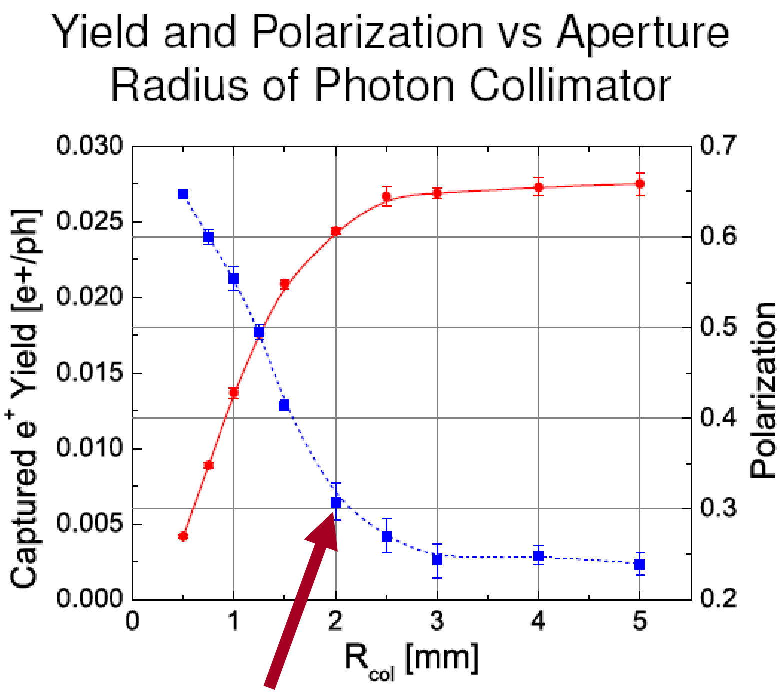
- **Also positron polarization has to be measured**

Positron polarization and SB2009

Only little gain for physics with 22% e+ polarization → better P(e+) >30%

Proposal:

Use photon collimator before positron production target:



Collimator with 2 mm aperture radius:

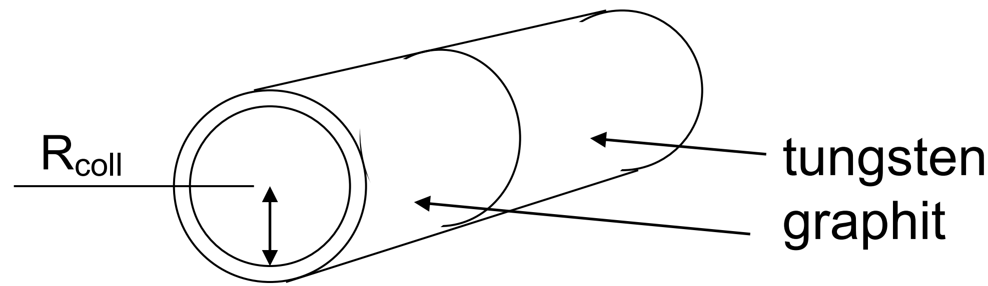
- increases polarization to ≈30%
- results in ≈12% yield reduction

A. Ushakov, IWLC 2010

Positron polarization and SB2009

Energy deposition in photon collimator

- Rough estimate of total energy deposition (E_{dep}) and peak energy deposition density (PEDD) in photon collimator (normalization 1.5e+/e-), using AMD
- Simplified collimator design:



	E=150GeV 2820 bunches/pulse		E=250GeV 1312 bunches/pulse	
R_{coll} [mm]	—	2.3	2	1.35
P[%]	34	45	30	45
E_{dep} [kW]	—	19.3	2.7	10.7
PEDD [J/(g·pulse)]	—	**290**	38.5	**200**
ΔT_{max} [K]/pulse in **tungsten**	—	**2150**	290	**1440**

Unpolarized positrons ?

1. Destroy the 22%÷34% positron polarization
   - **Need facility to depolarize e+ beam (damping ring is NOT sufficient,** see Barber, Malysheva**,** LCWS-2007-DR003-POL03**)**
   - **Need precision polarimeter to confirm zero polarization at IP**
2. Use planar undulator
   - **Planar instead of helical undulator → transversely polarized photons → unpolarized e+ (e-) beam**
   - **Photon yield of helical undulator is factor 1.5…2 times higher than that of planar undulator → lower luminosity**
3. Conventional positron source (unpolarized e- to target)
   - **Intense beam is a huge challenge for positron production target**
     - Several e+ targets – beam stability at the 0.1% level????
     - 300Hz option ?
   - **Polarization upgrade would require more effort**
   - **Reduced physics potential of the LC although we can do it much better!!**

Polarimetry at IP

Need high precision polarization measurement, $\delta P/P \sim 0.25\%(<0.5\%)$

- Upstream polarimeter
  - Clean environment
  - Stat. error 1% after 6μs
  - Machine tuning possible
- Downstream polarimeter
  - High background
  - Stat. error 1% after ~1min
  - Access to depolarization at IP

Combination of both polarimeters

- Cross checks ⇔ redundancy for high precision
- With collisions: depolarization at IP
- Without collisions: control spin transport in BDS

- Sources of systematic errors
  - **Depolarization due to strong fields in crossing beams**
    - ILC RDR ~0.22%, SB2009 slightly higher (under study)
  - **Misalignment of spins in polarimeter and IP (should be parallel)**
- polarization measurement using annihilation data (ff, WW)
  - **but this measurement is slow (years)**
  - **ee → WW: e+ polarization does not improve precision (Marchesini, IWLC'10)**
  - **ee → ff: e+ polarization needed for measurement**

Summary and outlook

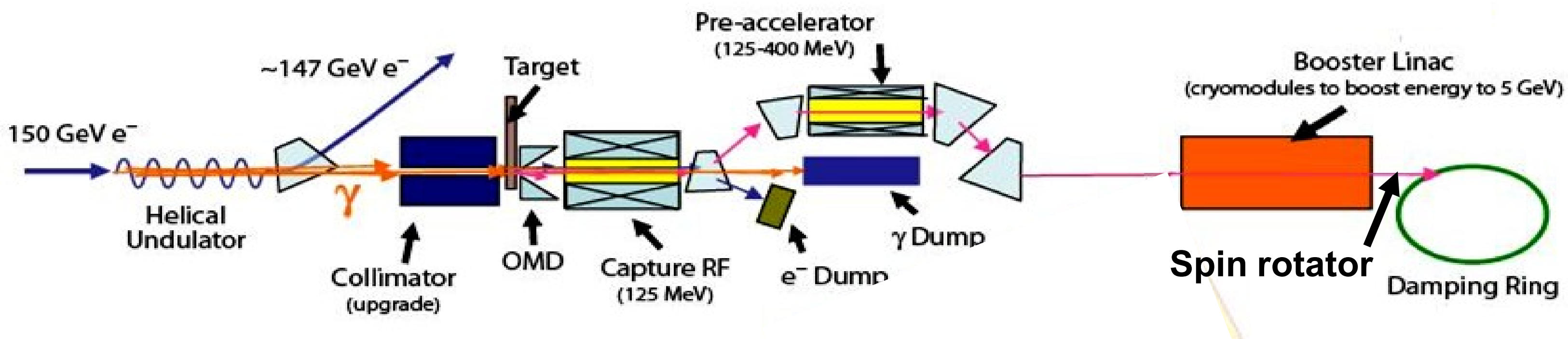
- Positron polarization
  - **Increases significantly the physics goal**
  - **will be available from the beginning with helical undulator as baseline design**
  - **Undulator at end of ML ⇔ some measures needed to take full advantage of e+ polarization**

- Under work:
  - **scenarios with polarization and consequences for physics precision**
  - **spin tracking from start to end for updated design**
  - **Depolarization effects at IP**
  - **Demonstrate target (and photon collimator) reliability**

Many thanks to the polarization group at DESY and Uni Hamburg, in particular Andriy Ushakov, Gudi Moortgat-Pick, Andreas Schälicke for contributions and discussions!

Backup

ILC Positron Source Layout



RDR (2007)

- Sc. Helical Undulator
  - **Located at the 150GeV point in electron linac**
  - **$\lambda = 1.15$cm, B=0.86T (K=0.92)**
  - **147m, aperture 5.85mm**
- Target
  - **Ti Alloy wheel**
  - **radius 1m, thickness 1.4cm**
  - **Rotating speed 100m/s (2000rpm)**
- Capture
  - **Flux concentrator (FC)**
- Keep Alive Source (KAS)
  - **Independent, conventional**
  - **10% intensity**

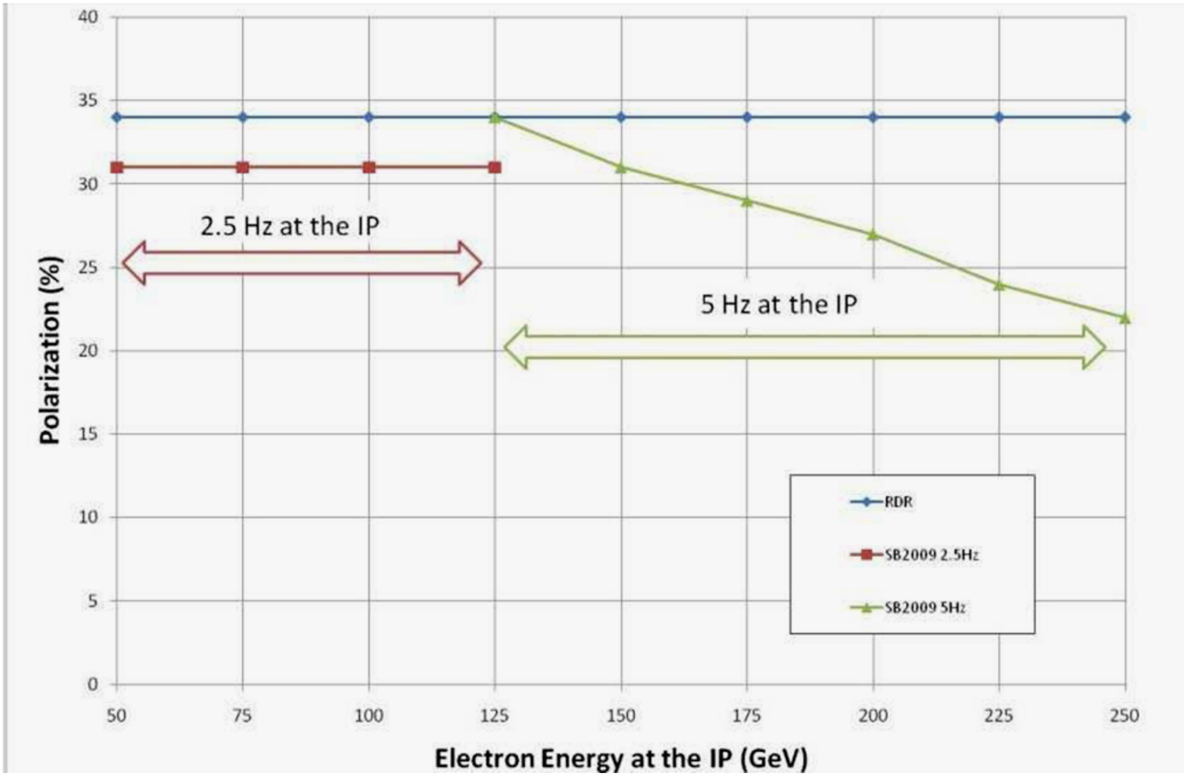
Under condsideration:
Strawman Baseline design 2009 **(SB2009)**

- Sc. Helical Undulator
  - **Located at end of electron linac (125…250 GeV)**
  - **231 m long, aperture 5.85mm**
- Capture
  - **Quarter wave transformer (QWT) ➔ lower e+ yield**
- Auxiliary Source
  - **3 GeV e- beam to positron target**

RDR and SB2009 e+ source parameters

Parameter	RDR	SB2009	Units
Positrons per bunch at the IP	2 x 10^{10}	1 to 2 x 10^{10} (see Figure 4.3.3 for details)	
Bunches per pulse	2625	1312	
Pulse repetition rate	5	5 (125 to 250GeV) 2.5 (50 to 125GeV)	Hz
Positron energy (DR Injection)	5	5	GeV
DR transverse acceptance	0.09	0.09	m-rad
DR energy acceptance	±0.5	±0.5	%
Electron drive beam energy	150	125 to 250	GeV
Electron energy loss in undulator	3	0.5 to 4.9 (see Figure 4.3.4 for details)	GeV
Required additional electron linac overhead	3	4.1	GeV
Undulator period	11.5	11.5	mm
Undulator strength	0.92	0.92	
Active undulator length	147 (210 after polarisation upgrade)	231 (maximum, not all used when >150GeV)	m
Field on axis	0.86	0.86	T
Beam aperture	5.85	5.85	mm
Photon Energy (1^{st} harmonic)	10	1.1 (50 GeV) to 28 (250 GeV)	MeV
Photon beam power	131	102 at 150 GeV (less at all other energies)	kW
Target material	Ti – 6%Al – 4%V	Ti – 6%Al – 4%V	
Target thickness	14	14	mm
Target power adsorption	8	8	%

Comparison RDR ⇔ SB2009: e+ polarization



SB2009

Figure 4.3.6: Positron polarisation vs electron energy for the RDR and SB2009 in the baseline configuration. Much higher polarisation levels are achievable in both layouts following a simple upgrade of the positron source.

undulator length ⇔ better positron capture using flux concentrator than quarter wave transformer to achieve high photon yield

No positron polarization….

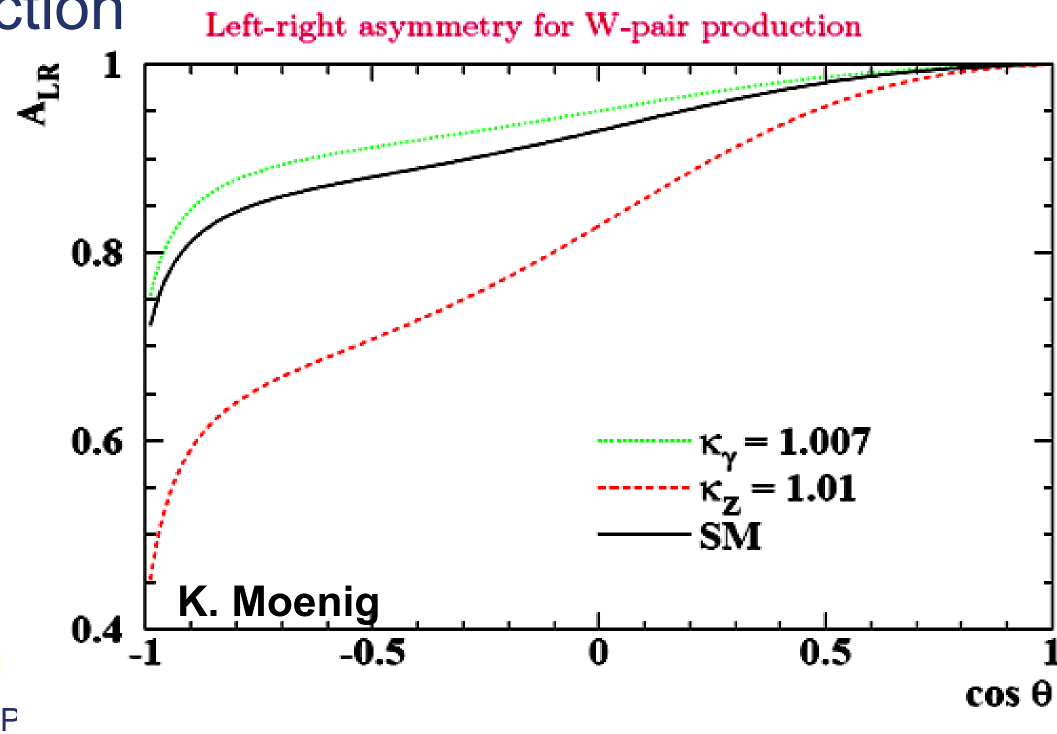
Electron polarization only:

$$\sigma_{+(-)} \sim \sigma_u \left[1 + A_{LR} P_e\right]$$

2 observables for 3 unknowns, independent measurements impossible

Include WW production – dominated by ν exchange in t-channel in forward direction

→ Quasi-independent determination of anomalous couplings and P_e



Precision Measurements with $P_{e+} > 0$

Left-Right asymmetry

$$A_{LR} \cong \frac{N_{-+} - N_{+-}}{N_{-+} + N_{+-}} \cdot \frac{1 - P_{e^-}P_{e^+}}{-P_{e^-} + P_{e^+}}$$

$1/P_{eff}$

Error propagation

→
→

$$\frac{\Delta P_{eff}}{P_{eff}} \cong F \frac{\Delta P_e}{P_e}$$

(80%,30%): F= 0.5
(80%,60%): F=0.25

Measurements with equal + - and - + pairing only (no - - , no ++) for

$$\sigma_u = \frac{1}{2} \cdot \frac{N_{+-} + N_{-+}}{L \cdot (1 + |P_{e-}P_{e+}|)}$$

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

→ (80%, 30%): ~25% gain in stat. but add. uncertainty $\delta\sigma_u$ ~0.3•δP/P[%]

→ (80%, 60%): ~50% gain in stat. but add. uncertainty $\delta\sigma_u$~0.44•δP/P[%]

→ (80%, 0%), e+ pol destroyed: add. uncertainty $\delta\sigma_u$~0.12%