Physics Motivation for polarised e^- and e^+ Beams

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Polarisation Session
Paris, 'LCWS 2004 ' 20/04/2004

- Introduction: general remarks about coupling structures
- Beam polarisation for
  - $\longrightarrow$ search of new physics
  - $\longrightarrow$ discriminating the models
  - $\longrightarrow$ revealing the structure of the model
  - $\longrightarrow$ precision test of the Standard Model
- Further examples in Working group report: 'Polarisation Write-Up' (http://www.ippp.dur.ac.uk/~gudrid/power/)

Introduction

Goal of the Linear Collider

'Precision and discovery physics in the energy range up to O(1 TeV)'

Being prepared for the 'Unexpected'!

$\Rightarrow$ polarisation of e^- and e^+ beams is an important tool:

a) analysing the structure of the underlying (new) physics
  $\longrightarrow$ proof of the predicted properties
  $\longrightarrow$ determination of parameters
  $\longrightarrow$ distinguishing new physics models
b) discovery tool for new physics searches: 'S/B'
  $\longrightarrow$ also stat. arguments: P_{eff}, $\mathcal{L}_{eff}$
c) precision arguments: e.g. GigaZ

There are $n \rightarrow (n+1)$ reasons for $P(e^-)$ and $P(e^-)$: only a few today

(and also *Omori, '99, GMP, Steiner '00, GMP '03, see also the 'Write-Up' ...*)

Overview

History: First polarised e^- beam at a LC: 3-km SLC at SLAC
$\rightarrow P(e^-) = [60\%, 78\%]$

Planned design for a future LC:

- polarised electron source: similar design as for SLC!
  $\rightarrow$ strained photocathode technology
  $\Rightarrow P(e^-) \approx 90\%$ expected $\rightarrow$ *Talk by M. Yamamoto*

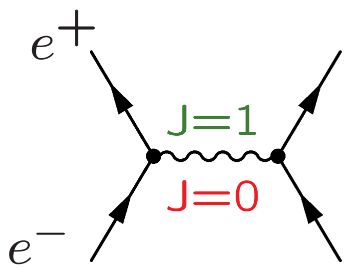
- polarised positrons at a LC: complete novelty!
  $\rightarrow$ laser Compton based source $\rightarrow$ *Talk by T. Omori*
  $\rightarrow$ helical undulator based source $\rightarrow$ *Talk by T. Schweizer*
  $\rightarrow$ polarised $\gamma \rightarrow$ photoproduction of polarised e^+:
  $\Rightarrow P(e^+) \geq 60\%$ expected

- Measurement of polarisation: (Talks tomorrow)
  Compton polarimetry: $\Delta P(e^\pm) \leq 0.5\%$ $\rightarrow$ *Talks by P. Schüler, M. Woods*
  'Physics measurements for Polarimetry': high precision polarimetry, Blondel Scheme
  $\rightarrow$ *Talk by K. Moenig*

General remarks about the coupling structure

Def.: left-handed $\equiv P(e^{\pm}) < 0$ right-handed $\equiv P(e^{\pm}) > 0$

Which configurations are possible in principle?
s–channel:

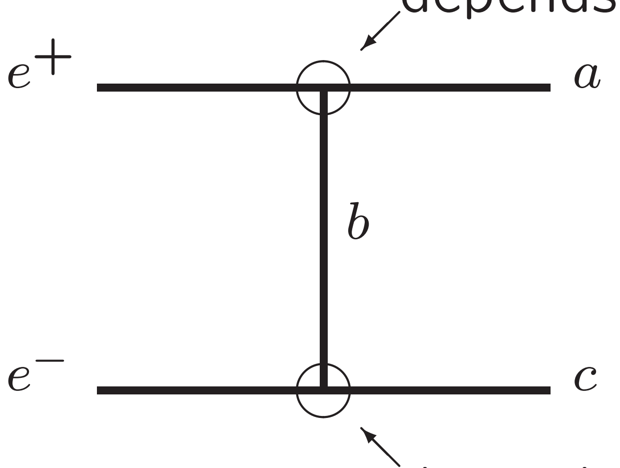


$\leftarrow$ only from RL,LR: SM (γ, Z) and NP(?)
$\leftarrow$ only from LL,RR: NP!

$\Rightarrow$ In principle: $P(e^-)$ fixes also helicity of e^+!

Which configurations are possible in the crossed channels?

t–channel:

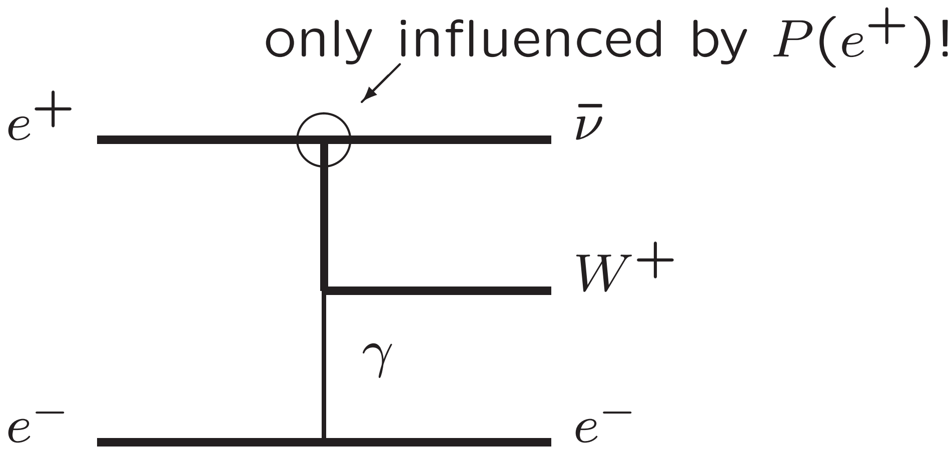


⇒ helicity of e^- not coupled with helicity of e^+!

⇒ $P(e^+)$ excellent tool for analysing couplings & interaction of any kind of physics, in general!

Two SM examples:

a) Single W production



b) Bhabha scattering

⇒ γ, Z exchange in s–channel: selects LR, RL

⇒ γ, Z exchange in t–channel: LL,RR possible!

unpolarised	4.50 pb
$P_{e^-} = -80\%$	4.63 pb
$P_{e^-} = -80\%$, $P_{e^+} = -60\%$	4.69 pb
$P_{e^-} = -80\%$, $P_{e^+} = +60\%$	4.58 pb

Task of the LC: Revealing the structure of the new physics

⇒ Example for NP: Minimal Supersymmetric Standard Model

Why Susy as an example for New Physics?

→ strongly motivated ... worked out very well ... (and only 15 minutes time

Questions:

- How to test in experiment the Susy properties?
  E.g. spin, quantum numbers, Yukawa couplings of Susy particles
- Since Susy is broken: at least 105 parameters (in MSSM)
  ⇒ How to derive the fundamental parameters without assuming a specific Susy breaking scheme?
- Which accuracy, theoretically and experimentally, is possible?
  → $O(\%)$ level possible, even if only light Susy particles accessible

⇒ Beam polarisation of both beams is decisive!

Example for NP: Minimal Supersymmetric Standard Model

SM particle + its superpartner: supermultiplets

$$\text{'Vector':}\ \binom{\text{Spin}1}{\text{Spin}\frac{1}{2}} \;=\; \binom{g_\mu^{a=1,\ldots,8}}{\tilde{g}_\mu^{a=1,\ldots,8}}, \binom{W_\mu^{i=1,2,3}}{\tilde{W}^{i=1,2,3}}, \binom{B_\mu}{\tilde{B}}$$

$$\text{'Chiral':}\ \binom{\text{Spin}\frac{1}{2}}{\text{Spin}0} \;=\; \binom{q_{L,R}}{\tilde{q}_{L,R}}, \binom{\ell_{L,R}}{\tilde{\ell}_{L,R}}, \binom{\nu_\ell}{\tilde{\nu}_\ell}$$

⇒ all Susy particles have to carry same quantum numbers as SM partner (except the spin)...... 'chiral' scalars?

⇒ experimental proof needed!

Enlarged Higgs sector – Two doublets H_1, H_2:

$$\text{'Higgs':}\ \binom{\text{Spin}0}{\text{Spin}\frac{1}{2}} \;=\; \binom{H_1}{\tilde{H}_1}, \binom{H_2}{\tilde{H}_2}$$

⇒ Physical states: h^0, H^0, A^0, $H^\pm$

Polarised beams e.g. for proving Susy quantum numbers

Test of the SUSY assumption:

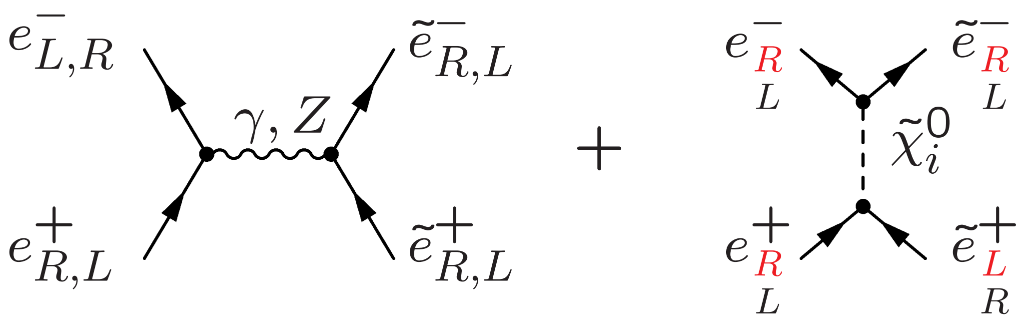
SM $\leftrightarrow$ SUSY have same quantum numbers!

$\Rightarrow e^-_{L,R} \leftrightarrow \tilde{e}^-_{L,R}$ and $e^+_{L,R} \leftrightarrow \tilde{e}^+_{R,L}$

Scalar partners $\leftrightarrow$ chiral quantum numbers!

How to test this association?

Strategy: $\sigma(e^+e^- \to \tilde{e}^+_{L,R}\tilde{e}^-_{L,R})$ with polarised beams



$\Rightarrow$ t–channel: unique relation between chiral fermion $\longleftrightarrow$ scalar partner

Use e.g. $e^+_R e^-_R$
- $\rightarrow$ t-channel: $\tilde{e}^+_L \tilde{e}^-_R \longrightarrow \tilde{e}^+_L \leftrightarrow \tilde{e}^-_R$
- $\rightarrow$ no s–channel

Physics Case for $P(e^+)$: Tests of Susy quantum numbers

- precise analysis of non–standard couplings

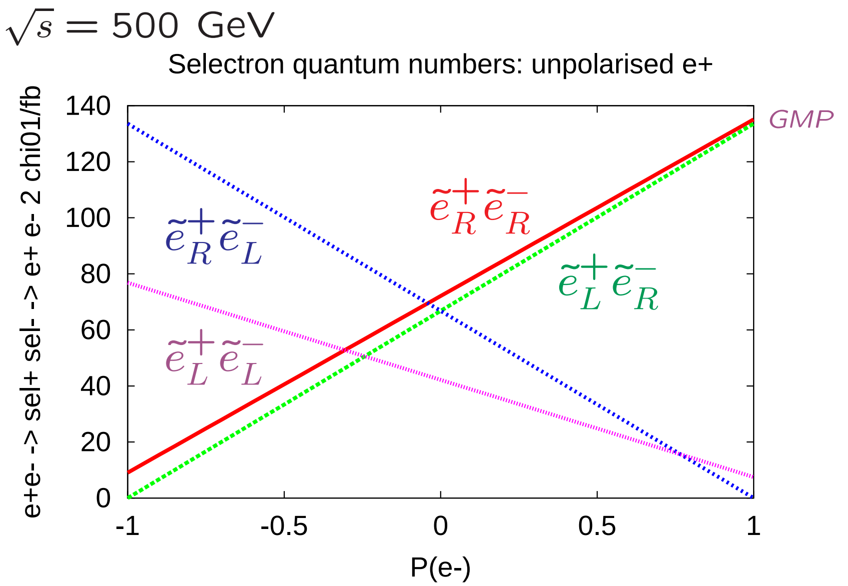
Polarised cross sections: $\sigma(e^+e^- \to \tilde{e}^+_{L,R}\tilde{e}^-_{L,R})$

Tricky case: $m_{\tilde{e}_L}$ $m_{\tilde{e}_R}$ close together:

$m_{\tilde{e}_L} = 200$ GeV, $m_{\tilde{e}_R} = 195$ GeV

$\longrightarrow$ same decay kinematics!

$\Rightarrow$ No separation of $\tilde{e}^+_R\tilde{e}^-_R$, $\tilde{e}^+_L\tilde{e}^-_R$ even for high $P(e^-)$!

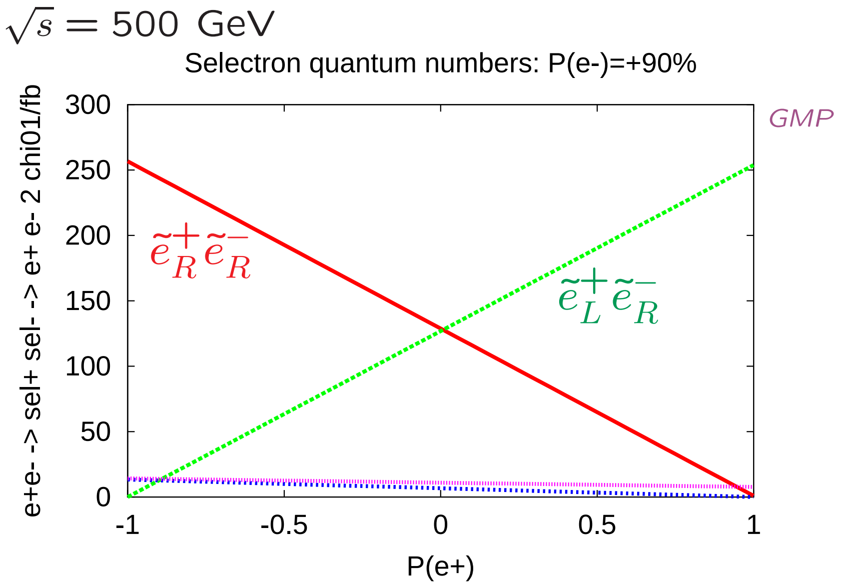


- could additional $P(e^+)$ help?

$P(e^-) = +90\%$, $P(e^+) = +60\%$:

excellent separation of $\tilde{e}^+_R\tilde{e}^-_R$, $\tilde{e}^+_L\tilde{e}^-_R$!

$\Rightarrow$ Test of association of chiral quantum numbers to $\tilde{e}$!



$\Rightarrow$ $P(e^+)$ absolutely needed!

start-up: stop/stau mixing angle

Process: $e^+e^- \to \tilde{t}_1\tilde{t}_1,\ \tilde{\tau}_1\tilde{\tau}_1$

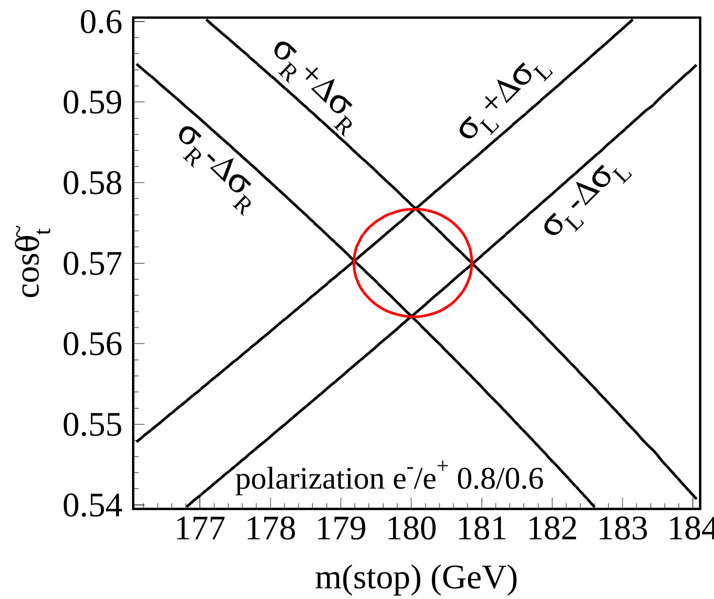
Unknown parameter: $m_{\tilde{t}_1}$ and $\Theta_{\tilde{t}}$

$\tilde{t}_1 = \tilde{t}_L \cos\Theta_{\tilde{t}} + \tilde{t}_R \sin\Theta_{\tilde{t}}$

How to derive the mixing angle?

⇒ pol. cross sections $\sigma = f(m_{\tilde{t}_1}, \Theta_{\tilde{t}})$

⇒ precise measurement of mass and mixing angle!!!



Keränen, Nowak, S

Bartl, Eberl, Kram

Majerotto, Porod

Impact of $P(e^+)$?

→ study error reduction by 20%

→ may be important for resolving ambiguitites

Other Susy sectors, e.g. gauginos/higgsinos: a bit more complicated

→ beam polarisation needed for determining parameters, testing Yukawa couplings, etc..

Impact of $P(e^+)$?

→ error reduction

→ providing more observables, maybe crucial for statistics, resolving ambiguities, . . .

Separation between different Susy models: NMSSM

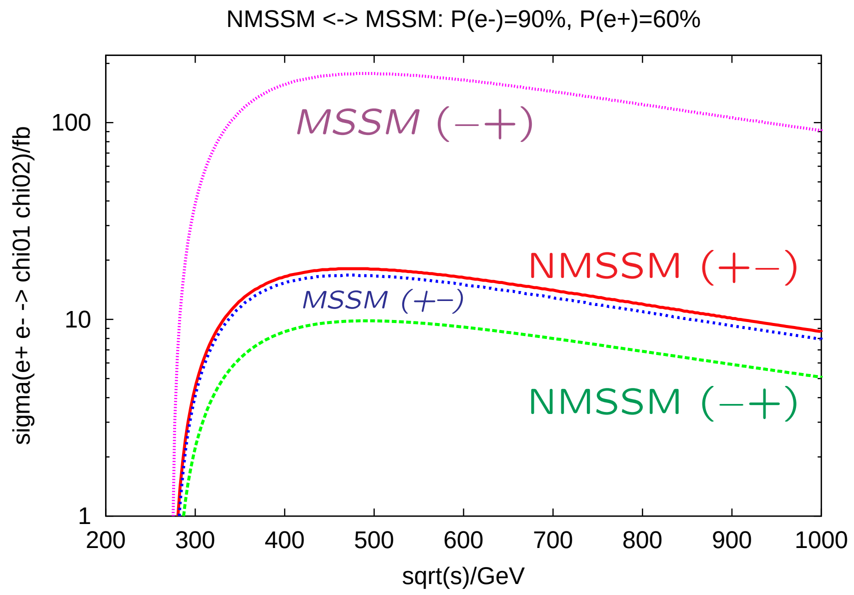
$\Rightarrow$ additional Higgs singlet leads to extended neutralino sector

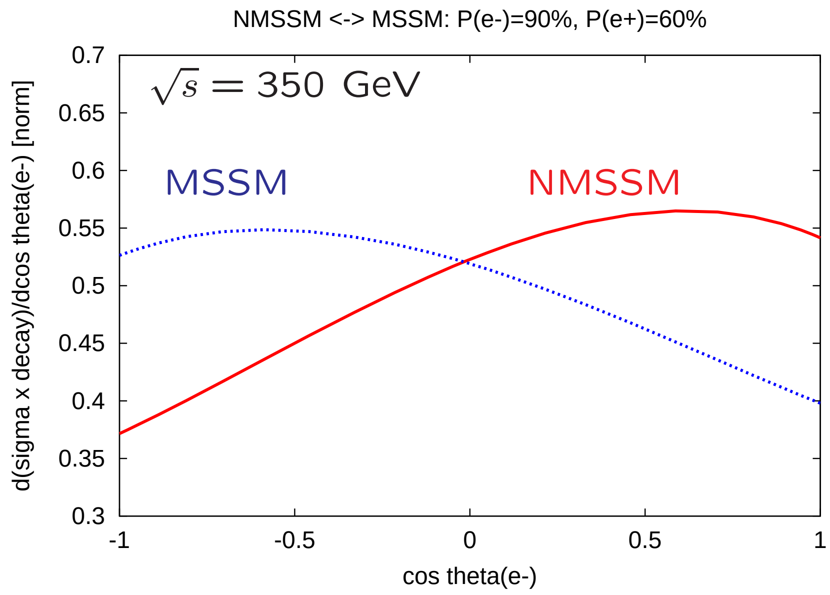
Process: $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2$

similar masses in both models: $m_{\tilde{\chi}^0_1} = 96$ GeV, $m_{\tilde{\chi}^0_2} = 176$ GeV

Strategy: polarised cross sections and angular distributions (incl. full spin correlations

Hesselbach, Franke, Fraas, GMP'99,'04, Hesselbach, Franke, Fraas'00, '01,'





$\Rightarrow$ similar mass spectra, but different polarisation dependence !

$\Rightarrow$ beam polarisation crucial for discovery (statistics!) and separation

Other example of New Physics: Large extra dimensions

- Separation with transversely polarised beams!

Rates are given by:

$$\sigma = (1 - P_{e^+}P_{e^-})\sigma_{unp} + (P^L_{e^-} - P^L_{e^+})\sigma^L_{pol} + P^T_{e^-}P^T_{e^+}\sigma^T_{pol}$$

$\Rightarrow$ only possible with both beam polarised!

Example here: $e^+e^- \to f\bar{f}$

Observable: azimuthal asymmetry

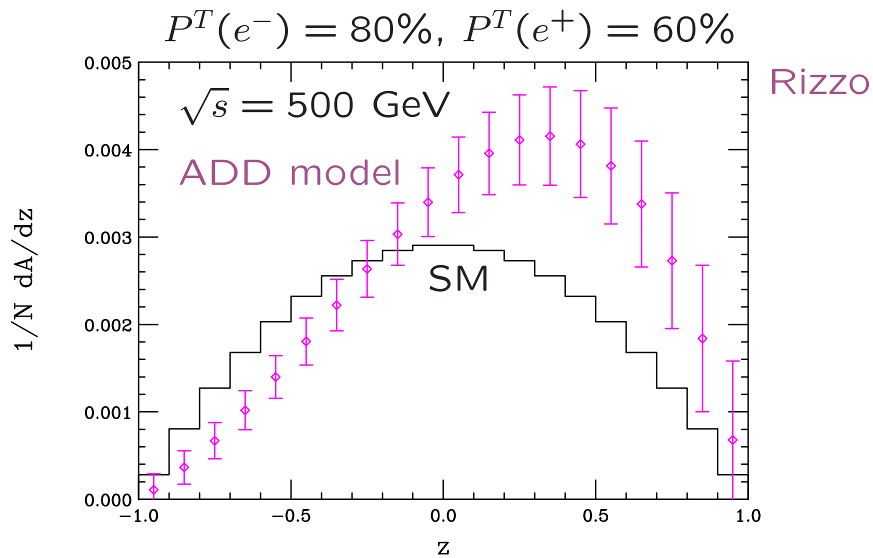
exact symmetric in the SM!

However: if e.g. large extra dimensions

$\rightarrow$ Graviton Spin=2 ('tensor') exchange

$\rightarrow$ asymmetric behaviour!!!!

$\Rightarrow$ clear separation of different models of NP



$\Rightarrow$ Polarised e^+ in addition to polarised e^- needed at a LC

Further examples: Tranverse beams and their impact on ...

- CP violation search in incl. processes: $e^+e^- \to A + X$ *Ananthanarayan, Rindani '03*

  $\to$ only $S-$ or $T-$ currents lead to CP-odd observables (in s - channel)

  focused out by (only!) transverse polarisation in int. terms

  $\to$ no final state analysis necessary

  example: $e^+e^- \to t\bar{t}$ sensitive to scale $\Lambda \sim 10$ TeV at $\sqrt{s} = 500$ GeV
- CP violation search in $e^+e^- \to Z\gamma$ *Ananthanarayan, Rindani, Singh, Bartl'04*

  trans. pol. (only!) focusses out real part of CP-viol. vertex

$\to$ *Talk by S. Rindani in EW session*

- Further News: high Precision Tests of the SM

$\to$ transverse polarisation in WW prod. *Fleischer, Kolodziej, Jegerlehner'94*

simulation study for TGC: no gain compared to long pol. *F. Franco-Sollova'04*,

however sensitiv to one specifig TGC only with trans. pol.

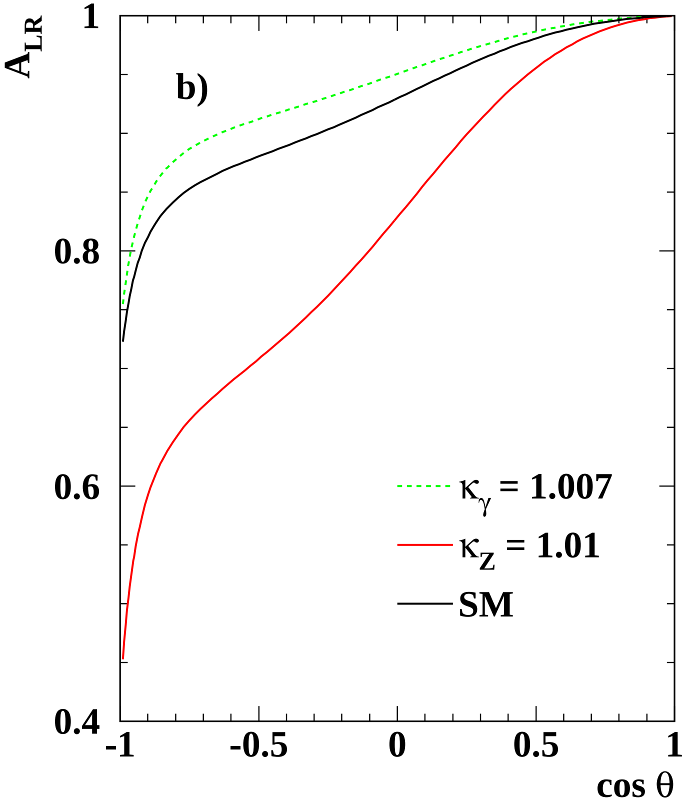
via optimal observable method *Diehl, Nachtmann, Nagel'03*

Longitudinal Beam Polarisation for high precision tests of the SM

I. Process: $e^+e^- \to W^+W^-$ at high $\sqrt{s}$

Test of anomalous gauge couplings: $\mathcal{L} \sim g_V^1 W^*_{\mu\nu} W_\mu A_\nu, \kappa_V W^*_\mu W_\nu F_{\mu\nu}, \lambda_V W^*_{\rho\mu} W_{\mu\nu} F_{\nu\rho}$

K. Moenig



Menges

error $[10^{-4}]$:	Δg_Z^1	$\Delta\kappa_\gamma$	λ_γ	$\Delta\kappa_Z$	λ_Z
unpolarised beams					
$\sqrt{s} = 500$ GeV	38.1	4.8	12.1	8.7	11.5
$\sqrt{s} = 800$ GeV	39.0	2.6	5.2	4.9	5.1
only electron beam polarised, $\lvert P_{e^-}\rvert = 80\%$					
$\sqrt{s} = 500$ GeV	24.8	4.1	8.2	5.0	8.9
$\sqrt{s} = 800$ GeV	21.9	2.2	5.0	2.9	4.7
both beams polarised, $\lvert P_{e^-}\rvert = 80\%$, $\lvert P_{e^+}\rvert = 60\%$					
$\sqrt{s} = 500$ GeV	15.5	3.3	5.9	3.2	6.7
$\sqrt{s} = 800$ GeV	12.6	1.9	3.3	1.9	3.0

$\Rightarrow$ beam polarisation needed for disentangling of the couplings

$\Rightarrow$ P_{e^-}, $[+P_{e^+}]$ improves sensitivity up to a factor 1.8 [2.5] and can save running time!

High precision tests of the SM, cont.

II. Process: $e^+e^- \to Z \to f\bar{f}$ at the Z-pole (s-channel)

Measurement of effective mixing angle $\sin\Theta^{\ell}_{eff}$ via A_{LR}:

$$\sigma = \sigma_u[1 - P_{e^-}P_{e^+} + A_{LR}(P_{e^+} - P_{e^-})], \qquad A_{LR} = \frac{2(1-4\sin^2\Theta^{\ell}_{eff})}{1+(1-4\sin^2\Theta^{\ell}_{eff})^2}$$

Gain in statistical power of ‘Z-factory’ only if $\Delta A_{LR}(pol) < \Delta A_{LR}(stat)$!

$\Rightarrow \Delta P_{eff} \sim 10^{-4}$ needed! ... not possible with only polarimetry.....

- Alternative Blondel Scheme:

$$A_{LR} = \sqrt{\frac{(\sigma^{RR}+\sigma^{RL}-\sigma^{LR}-\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}-\sigma^{LR}+\sigma^{LL})}{(\sigma^{RR}+\sigma^{RL}+\sigma^{LR}+\sigma^{LL})(-\sigma^{RR}+\sigma^{RL}+\sigma^{LR}-\sigma^{LL})}}$$

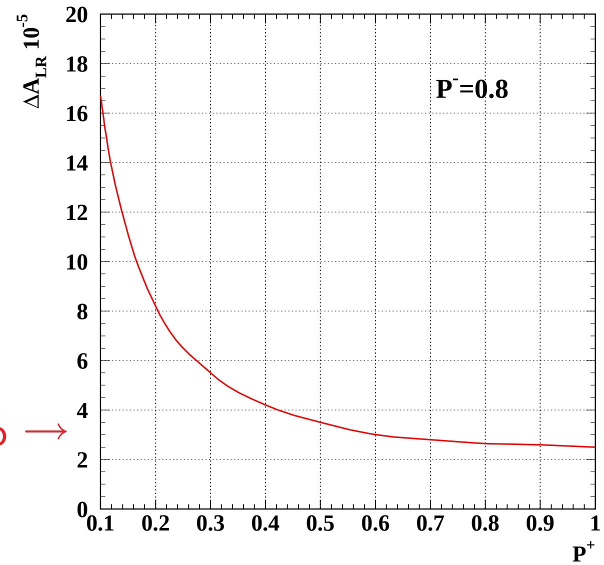
$\Rightarrow \Delta A_{LR} \sim 10^{-4}$, $\Delta \sin^2\theta^{\ell}_{eff} = 0.000013$!!!

Test:

$\Delta A_{LR}(80\%,0)/\Delta A_{LR}(80\%,60\%)$		
Two polarimeter	Blondel	Alt. Blondel
3.73	13.5	25

Alexander

$\Delta A^{stat}_{LR} 10^{-5}$



$P_{e^+} = 60\% \rightarrow$

P_{e^+}

Moenig

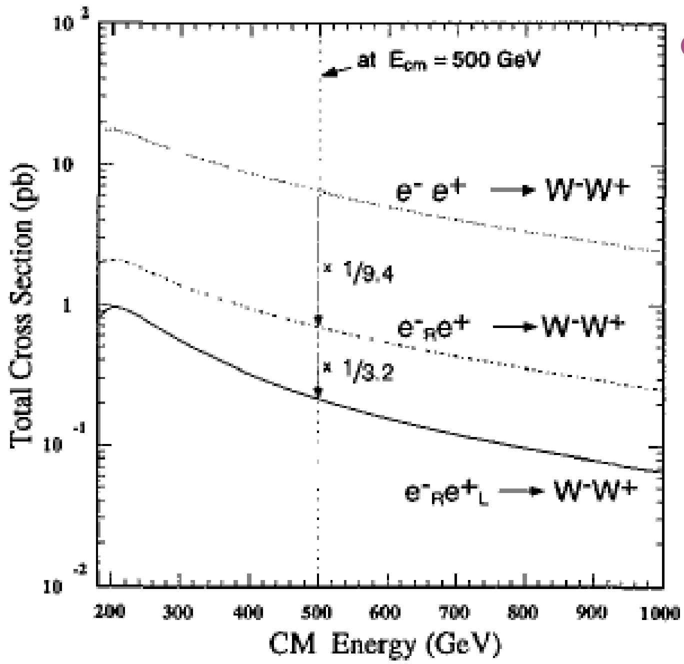
$\Rightarrow P(e^+)$ needed!

Last but not least:
Suppression of 'background' processes, e.g. WW production

WW, ZZ production = large background for NP searches!

W^- couples only left–handed:
$\Rightarrow$ WW background strongly suppressed with right polarised beams!

$P(e^-) = +90\%$, $P(e^+) = -80\%$

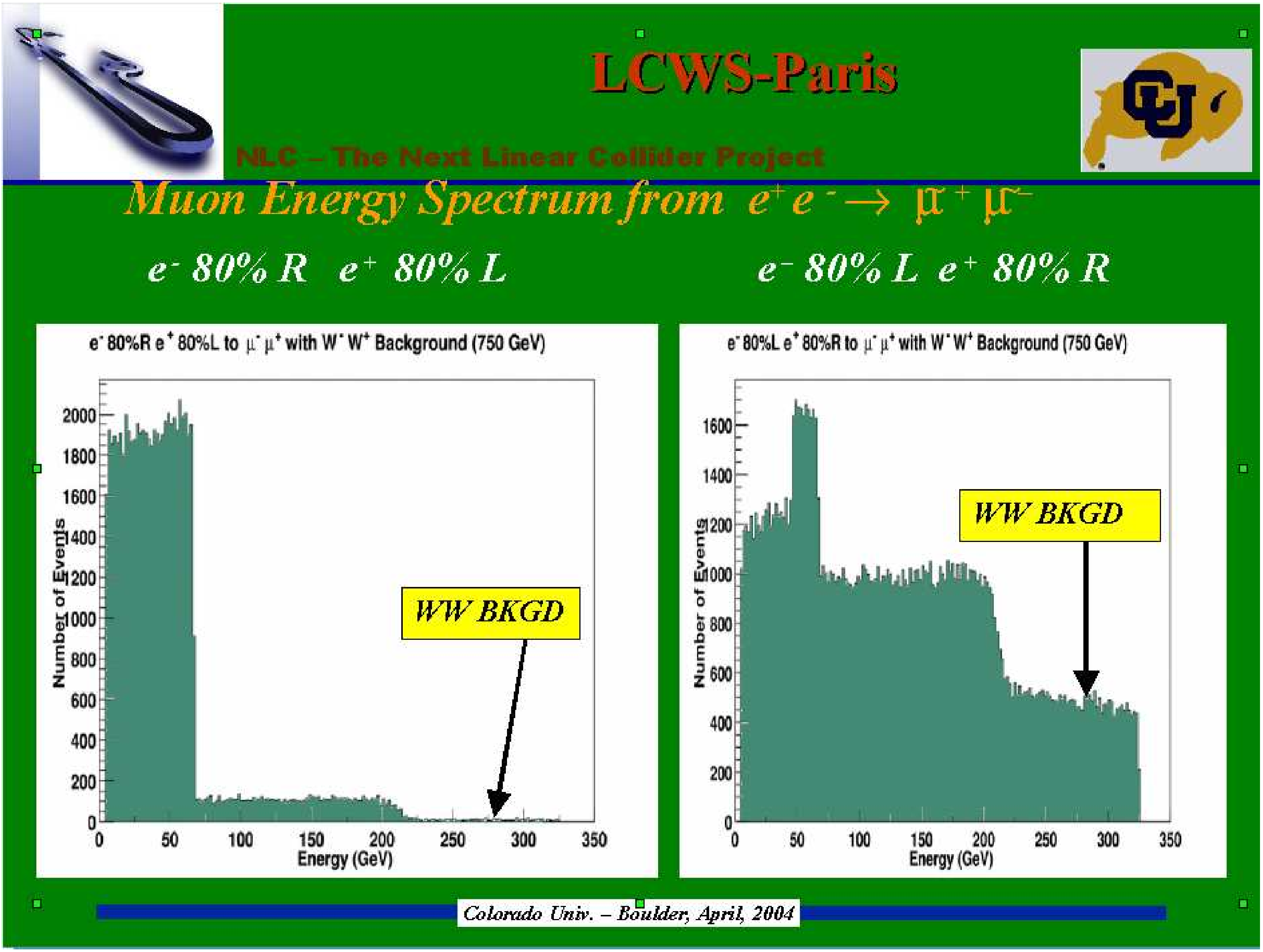


Omori

Scaling factor= $\sigma^{pol}/\sigma^{unpol}$ for WW and ZZ:

$P_{e^-} = \mp 80\%$, $P_{e^+} = \pm 60\%$	$e^+e^- \to W^+W^-$	$e^+e^- \to ZZ$
(+0)	0.2	0.76
(−0)	1.8	1.25
(+−)	0.1	1.05
(−+)	2.85	1.91

Suppression of ‘background’ processes for Susy searches, e.g. $\tilde{\mu}\tilde{\mu}$



‘Colorado Grou

Choi, Dobos, Dorlan

Erdos, Goodson, Gill

Gray, Hahn, Kuhn

Martinez, Miller, Pro

Smock and

U. Nauenberg

Beam polarisation of both beams: powerful tool at a future LC for being prepared for the 'Unexpected'

- Discovery and 'unveiling' of SUSY
  → test of SUSY assumptions
  → derive fundamental MSSM parameters without scheme assumption
- Discovery of other kinds of New Physics and Separation between different Susy models
- Use of transversely polarised beams
  → high potential in search for CP violating sources
  → sensitive to e.g. Spin=2 exchange (graviton) in ED
- Electroweak precision tests with unprecedented accuracy!
  → anomalous gauge couplings
  → option of using 'Blondel scheme' for measuring polarisation
- 'Polarisation Write-Up' under work, provides many more examples: will be finished for ECFA '04@Durham

Further news and information, please have a look:

POWER working group: close contact between Th/Exp/Machine

(→ http://www.ippp.dur.ac.uk/~gudrid/power)