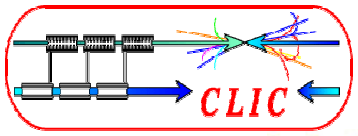
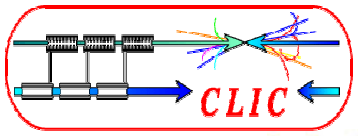


Indirect Sensitivity to New Physics at 1- 3 TeV

Sabine Riemann (DESY)

CLIC09 Workshop

CERN, October 14, 2009



Why Indirect sensitivity?

- LHC search reach up to 5 TeV ⇔ CLIC 1-3TeV
- LC will complete the study of phenomena (not) discovered with LHC ⇔ Sensitivity to effects beyond 3TeV

Outline

- Parametrization of NP and interpretation
- Sensitivity
- Scaling
- Depolarization

Advantage of e+e- : Precision

Required

- High luminosity
  - → statistical uncertainty few per-mille (0.5-1 TeV)
  - → percent level (3TeV)
- Stability & precision measurement of
  - **Luminosity**
  - **Energy**
  - **Polarisation**
- But: beamstrahlung, background 

Precision measurements allow indirect probes of new physics

Observable	Relative Stat. Accuracy $\delta\mathcal{O}/\mathcal{O}$ for 1 ab^{-1}
$\sigma_{\mu^+\mu^-}$	± 0.010
$\sigma_{b\bar{b}}$	± 0.012
$\sigma_{t\bar{t}}$	± 0.014
$A_{FB}^{\mu\mu}$	± 0.018
A_{FB}^{bb}	± 0.055
A_{FB}^{tt}	± 0.040

Marco Battaglia (LHC2FC 09), Gian Giudice (CLIC09)

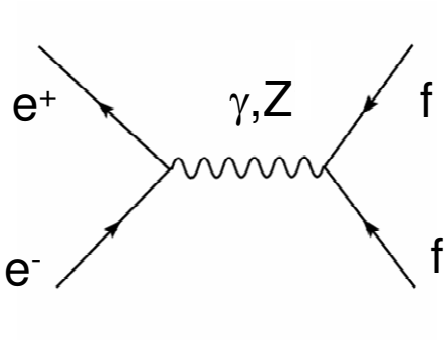
Sensitivity to New Physics

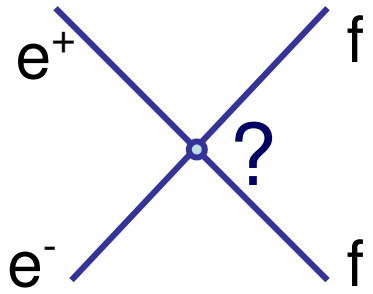
Fermion-Pair Production (s-channel)

Observables:

σ, A_{FB}, A_{LR}, A_{FBLR}

$$\frac{d\sigma}{d\cos\vartheta} = \sigma_{tot}\left[(1-P^+P^-)\left\{\frac{3}{8}(1+\cos^2\vartheta)+2A_{FB}\cos\vartheta\right\}\right] + \sigma_{tot}\left[(P^+-P^-)\left\{\frac{3}{8}(1+\cos^2\vartheta)A_{LR}+2A_{LR}^{pol}\cos\vartheta\right\}\right]$$





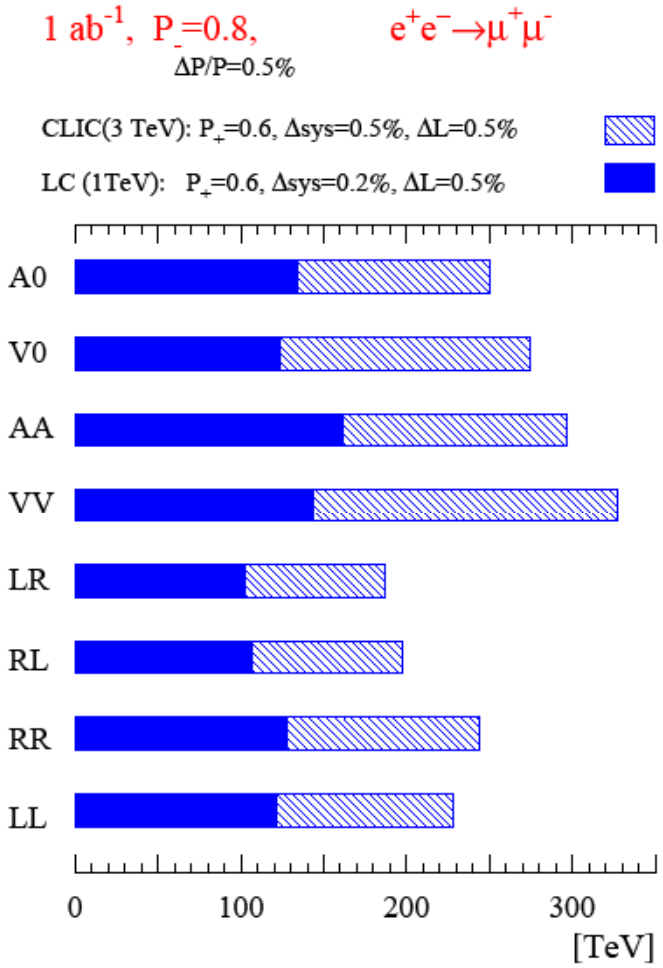
$$\sim \frac{\eta_{ij}\cdot s}{\Lambda^2}$$

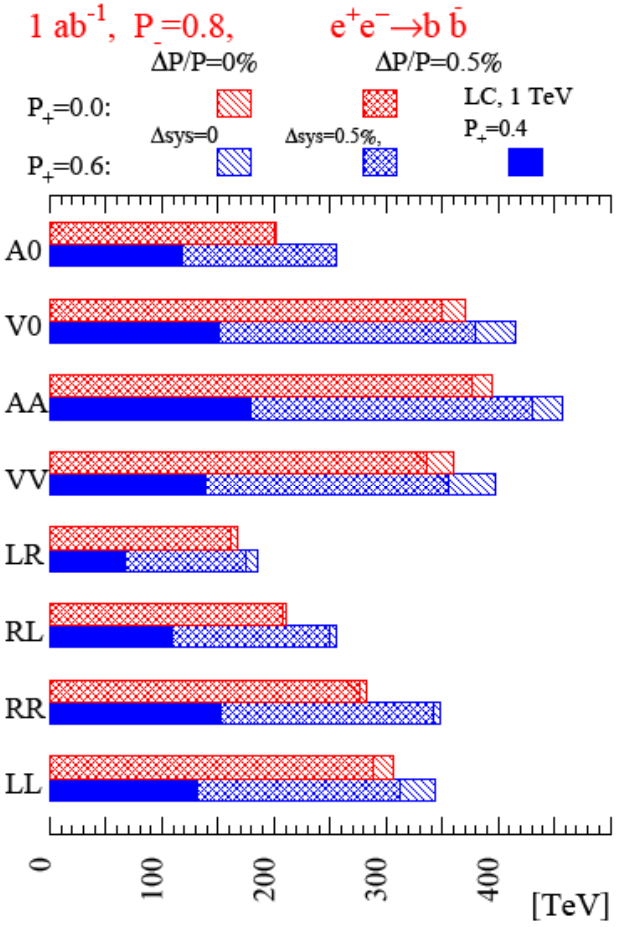
Four-fermion contact terms: effective parameterization of physics beyond the SM at 'low' energies, $s \ll \Lambda^2$

→ interference with SM

→ σ, A_{FB}, A_{LR}, A_{FBLR} ⇔ sensitivity to helicity amplitudes and their modification

Contact Interaction sensitivity CLIC 3TeV





➔ Sensitivity up to 200 - 400 TeV

Interpretation of contact terms

$$\frac{\eta_{ij}}{\Lambda^2} \Rightarrow \frac{g_i^X g_j^X}{s - m_X^2}$$

- Leptoquark, squark, sneutrino exchange

$$\frac{\eta^{ef}_{LL}}{\Lambda^2_{LL}} \cdot \frac{\eta^{ef}_{RR}}{\Lambda^2_{RR}} \neq \frac{\eta^{ef}_{LR}}{\Lambda^2_{LR}} \cdot \frac{\eta^{ef}_{RL}}{\Lambda^2_{RL}}$$

- New gauge bosons (Z')

$$\frac{\eta^{ef}_{LL}}{\Lambda^2_{LL}} \cdot \frac{\eta^{ef}_{RR}}{\Lambda^2_{RR}} = \frac{\eta^{ef}_{LR}}{\Lambda^2_{LR}} \cdot \frac{\eta^{ef}_{RL}}{\Lambda^2_{RL}} = \frac{g^e_L}{M_{Z'}} \cdot \frac{g^f_L}{M_{Z'}} \cdot \frac{g^e_R}{M_{Z'}} \cdot \frac{g^f_R}{M_{Z'}}$$

- KK excitation of gauge bosons

  Parameterization

$$V \equiv 2\sum_{\vec{n}} \left(\frac{g^2_{\vec{n}}}{g^2} \right) \frac{m_W^2}{\vec{n}^2 M_C^2}$$

$$\frac{\eta_{ij}}{\Lambda^2} \Rightarrow \left(Q_e Q_f + g^e_i g^f_j \right) \frac{\pi}{3M_C^2}$$

- Virtual graviton exchange

$$Q^{ef}_{ii} = Q^{ef\,SM}_{ii} - \frac{\lambda \cdot s^2}{4\pi\alpha M_S^4}(2\cos\theta - 1)$$

$$Q^{ef}_{ij} = Q^{ef\,SM}_{ij} - \frac{\lambda \cdot s^2}{4\pi\alpha M_S^4}(2\cos\theta + 1)$$

Search reaches LHC,ILC,CLIC

	LHC 100 fb^{-1}	ILC 800 GeV 500 fb^{-1}	SLHC 1000 fb^{-1}	CLIC 3 TeV 1000 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks [TeV]	2.5	0.4	3	1.5	2.5
Sleptons [TeV]	0.34	0.4		1.5	2.5
New gauge boson Z′ [TeV]	5	8	6	22	28
Excited quark q^* [TeV]	6.5	0.8	7.5	3	5
Excited lepton l^* [TeV]	3.4	0.8		3	5
Two extra space dimensions [TeV]	9	5–8.5	12	20-35	30–55
Strong W_LW_L scattering	2σ	-	4σ	70σ	90σ
Triple-gauge Coupling (95%)	.0014	0.0004	0.0006	0.00013	0.00008

from G.Giudice

Model-independent Z' Search

$$\frac{\eta_{ij}^{ef}}{\Lambda^2} \Rightarrow \frac{g_{Z',i}^{f} \cdot g_{Z',j}^{f}}{s - m_{Z'}^2}$$

$$a_N^f = a_f' \sqrt{\frac{s}{m_{Z'}^2 - s}}$$

$$v_N^f = v_f' \sqrt{\frac{s}{m_{Z'}^2 - s}}$$

normalized Z' coupling

ee → ll (+lepton universality)

Z' obtained with σ_{tot} for

$$\left(\frac{v_l^N}{H_v}\right)^2 + \left(\frac{a_l^N}{H_a}\right)^2 \geq 1$$

$$H_{v,a} \sim \sqrt{\Delta\sigma_{tot}/\sigma_{tot}}$$

Z' obtained with A_{FB} for

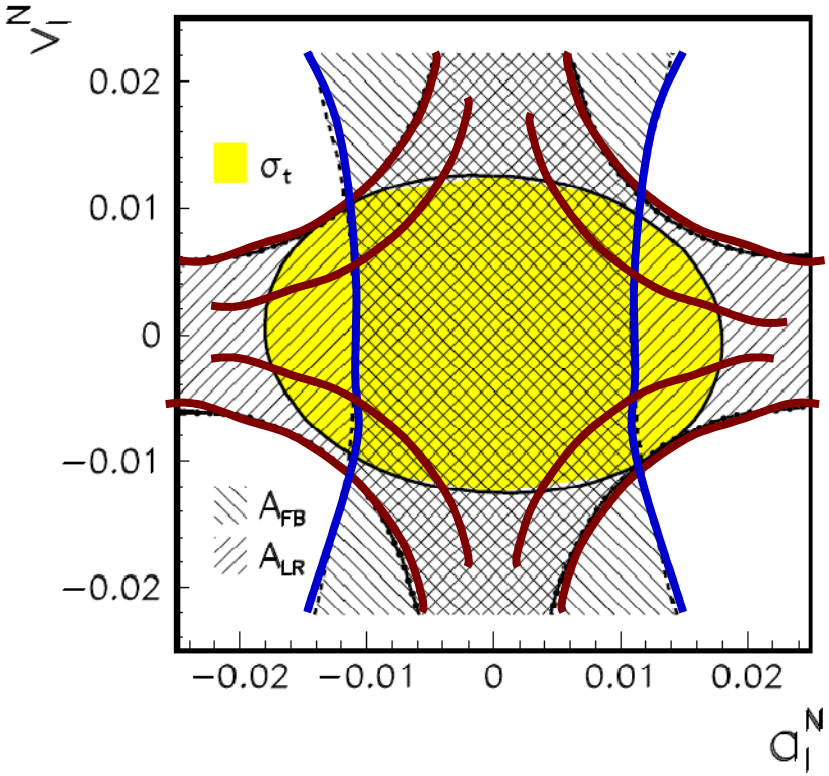
$$\left(\frac{v_l^N}{H_v'}\right)^2 - \left(\frac{a_l^N}{H_a'}\right)^2 \geq 1$$

$$H_{v,a}' \sim \sqrt{\Delta A_{FB}^l}$$

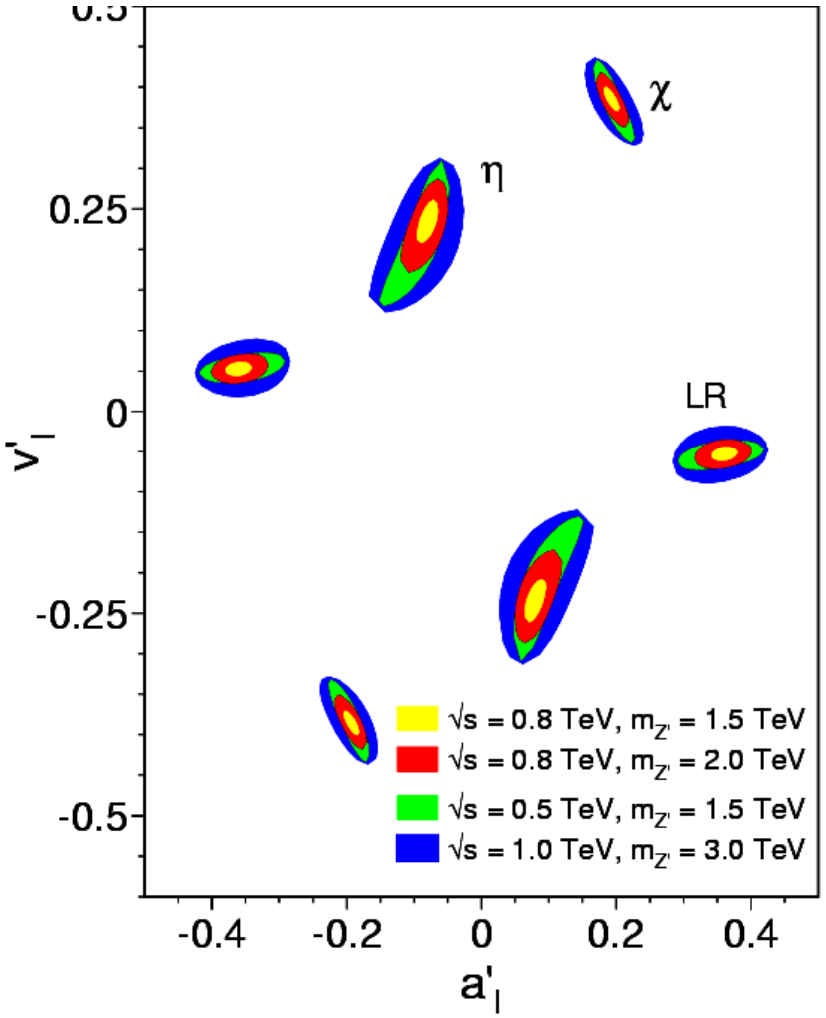
Z' obtained with A_{FB} for

$$\left(\frac{v_l^N}{H_v''}\right)^2 - \left(\frac{a_l^N}{H_a''}\right)^2 \geq 1$$

$$H_{v,a}'' \sim \sqrt{\Delta A_{LR}^l}$$



Z' coupling to leptons



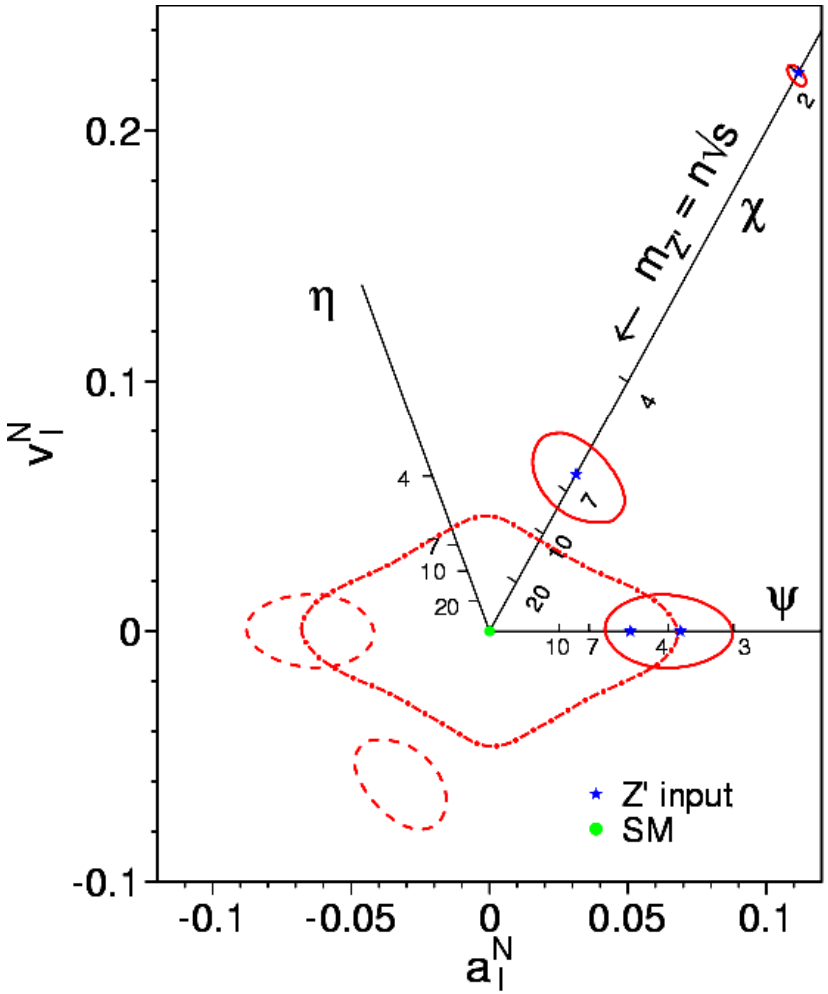
Z' mass measurement at LHC

→ Z' couplings with LC

- Model distinction up to $m_Z \sim 6\sqrt{s}$

Z' model distinction at LC

$e^+e^- \to l^+l^-$



$$a_N^f = a_f' \sqrt{\frac{s}{s - m_{Z'}^2}} \qquad v_N^f = v_f' \sqrt{\frac{s}{s - m_{Z'}^2}}$$

If no Z' information from LHC:

Z' model distinction for

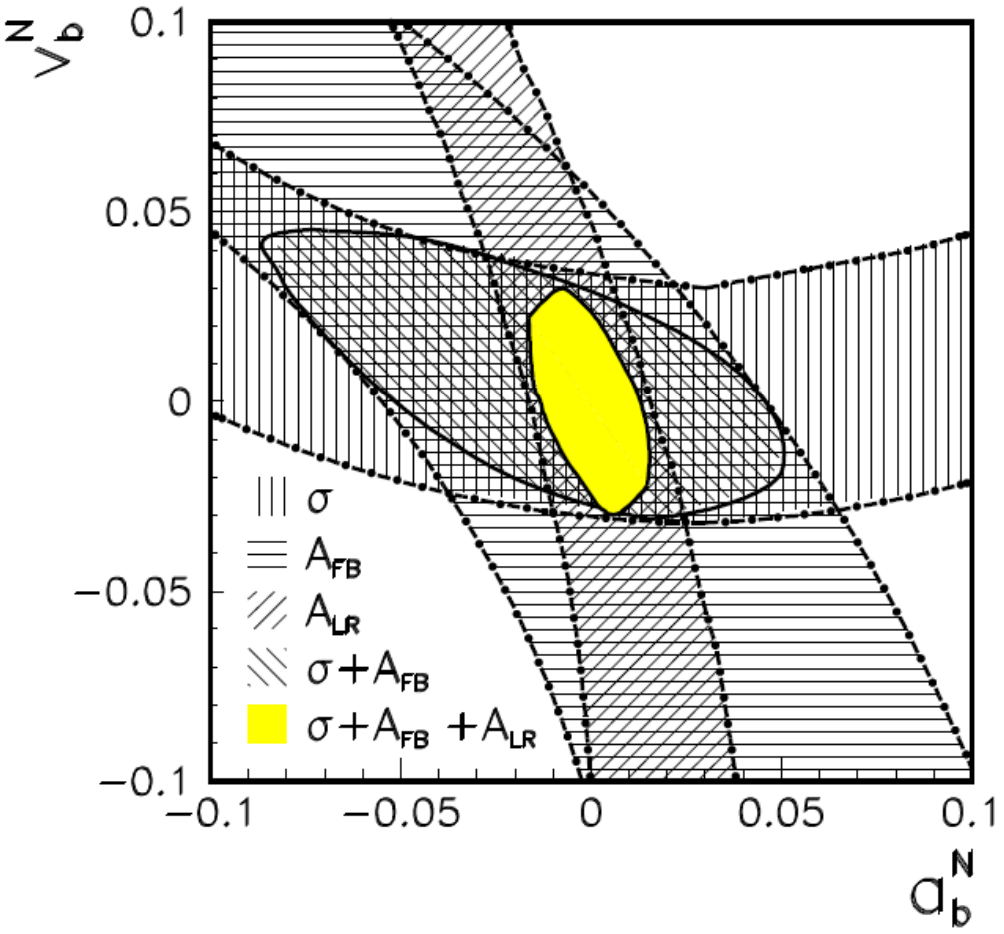
$m_{Z'} < 4 \div 8\sqrt{s}$

L_{int}=1ab-1 (±0.2%)
P-=0.8 (±0.5%)
P+=0.6 (±0.5%)
δ_{sys}^l=0.2%
δ_{sys}^b=0.5%

ee → γ,Z,Z' → bb

Z' coupling to leptons from measurement of leptonic final states

Good sensitivity with information using combination of all measurements



Scaling of sensitivity to contact terms

Scaling with energy and luminosity

$$\left(\frac{\sigma-\sigma_{SM}}{\delta\sigma}\right)^2 \le \chi^2_{CL}$$

$$\left(\frac{\sigma-\sigma_{SM}}{\delta\sigma}\right)^2 \approx L\cdot s\cdot\left(\sigma-\sigma_{SM}\right)^2 \propto L\cdot s\cdot T^2_{contact}$$

- $T_{contact} = \frac{\eta_{ij}}{\Lambda^2};\ \frac{g_i g_j}{M_X^2} \Rightarrow \Lambda, M_X \sim (s\cdot L)^{1/4}$
  - to improve statistical uncertainty by factor 2 needs a factor 4 in luminosity → improves sensitivity by factor 1.4
  - Double energy increases sensitivity factor ~1.4
- $T_{contact} = \frac{\lambda\cdot s}{M_S^4} \Rightarrow M_S \sim (s^3\cdot L)^{1/8}$

(ADD model)

Scaling of sensitivity to CI with polarization

Scaling with polarization

$$\chi^2 \geq \left(\frac{\sigma - \sigma_{SM}}{\delta\sigma}\right)^2 \approx L \cdot s \cdot (\sigma - \sigma_{SM})^2 \propto L \cdot s \cdot T^2_{contact}$$

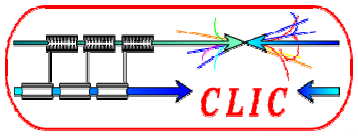
- Polarization of both beams increases luminosity

$$\Lambda \sim \left(1 + P^+ P^-\right)^{1/4}$$

- If polarization-dependent observables (A_{LR}, A_{LRFB}) dominate the sensitivity →

$$\Lambda \sim \sqrt{P_{eff}} = \left(\frac{P^+ - P^-}{1 - P^+ P^-}\right)^{1/2}$$

Improvement of sensitivity with positron polarization is not very large, but polarized beams are essential for model discrimination



Sensitivity with polarized beams

- Sensitivity to NP depends on uncertainty of observables
- Uncertainty of σ, A_{FB}, A_{LR}, A_{LRFB}
  - **depends on uncertainty of pol measurement, in particular, if both beams are polarized**
  - **ΔP should be ~0.5% to avoid dominating polarization error**
- Problem: beamstrahlung ⇔ depolarization
  - **CLIC beam sizes @ IP (hor./vert. in nm)**
    - 500 GeV:
      - 248 / 5.7 conservative
      - 202 / 2.3 nominal
    - 3 TeV
      - 83 / 2.0 conservative
      - 40 / 1.0 nominal (σ_z=45nm)
  - **ILC beam sizes @ IP (hor./vert. in nm)**
      - 640 / 5.7 (σ_z = 300 nm)

Depolarization

Bailey et al., EPAC08-MOPP024

Parameter set	Depolarization ΔP_{lw}		
	ILC 100/100	ILC 80/30	CLIC-G
T-BMT	0.17%	0.14%	0.10%
S-T	0.05%	0.03%	3.4%
incoherent	0.00%	0.00%	0.06%
coherent	0.00%	0.00%	1.3%
total	0.22%	0.17 %	4.8%

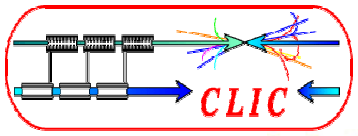
depolarization-studies with GP and CAIN: C. Rimbault, LCWS08:

- Lumi-weighted depol for ILC (500 GeV): $\Delta P_{lw} \sim 0.23 \pm 0.01$ %
- Depol depends strongly on horizontal beam size variations: uncertainty of 10% on beamsize → uncertainty on depolarization is larger than 20%

→ Increasing depolarization with increasing CLIC energy

→ **What is the uncertainty on depolarization at CLIC3TeV??**

Talk about polarimetry at CLIC by Tony Hartin, Thursday, WG5



Summary & conclusion

- Good indirect sensitivity to NP beyond LHC search reach
- need precise predictions from theory
- Scaling of sensitivities is only very rough estimate, for high CLIC energies detailed studies necessary
  - **Precision measurements of cross sections / asymmetries depend on uncertainty of polarisation**

    (and realistic lumi spectrum and energy…)

  → Check whether the NP limits are realistic