Physics requirements for GigaZ

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What is GigaZ?

Running on the Z with high luminosity for 10^9 recorded Z decays

- Reachable luminosity: $\mathcal{L} = 5 \cdot 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
  ➠ $\sim 50 - 100$ days for 10^9 Zs
- Beamstrahlung loss (outgoing beam): $\delta_b = 0.1\%$
- Depolarisation: $\Delta\mathcal{P} = 0.1\%$
  ➠ placement of polarimeters not really an issue
- Z-rate: 100-200 Hz
- Additional requirements (motivation in this talk)
  - polarised electron and positron beam
  - very high precision on polarisation and beam energy
  - very low beam energy spread

Physics motivation of GigaZ

- $\sin^2\theta^l_{eff}$: Want to measure $\sin^2\theta^l_{eff}$ from left-right asymmetry to $\mathcal{O}(10^{-5})$

- Z-lineshape: Improve Z-width by a factor two, cross section ratios by a factor three
(⇒ factor two on $\Delta\rho$, factor three on α_s)

- $\mathrm{Zb\bar{b}}$ couplings: improve factor 5-10 wrt. LEP

- m_W: measure m_W to 6 MeV

$\sin^2 \theta^l_{eff}$

Most sensitive observable is $A_{\rm LR}$, so only this is discussed

$$A_{\rm LR} = \frac{1}{\mathcal{P}} \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \mathcal{A}_{\rm e} = \frac{2 v_e a_e}{v_e^2 + a_e^2}$$

$$v_e / a_e = 1 - 4 \sin^2 \theta^l_{eff}$$

independent of the final state

Statistical error with 10^9 Zs: $\Delta A_{\rm LR} = 4 \cdot 10^{-5}$

(for $\mathcal{P}_{e^-} = 80\%$, $\mathcal{P}_{e^+} = 0$)

Crucial ingredient: polarisation measurement

Error from polarisation: $\Delta A_{\rm LR} / A_{\rm LR} = \Delta \mathcal{P} / \mathcal{P}$

- only electron polarisation with $\Delta \mathcal{P} / \mathcal{P} = 0.5\% \Rightarrow \Delta A_{\rm LR} = 8 \cdot 10^{-4}$
  (Still factor three to SLD, but few million Zs are sufficient)

- with positron polarisation $\mathcal{P}_{\rm eff} = \frac{\mathcal{P}_{e^+}+\mathcal{P}_{e^-}}{1+\mathcal{P}_{e^+}\mathcal{P}_{e^-}}$

  $\Rightarrow$ gain a factor four for $\mathcal{P}_{e^-}/\mathcal{P}_{e^+} = 80\%/60\%$ due to error propagation (even when error is 100% correlated between the polarimeters the gain is a factor three)

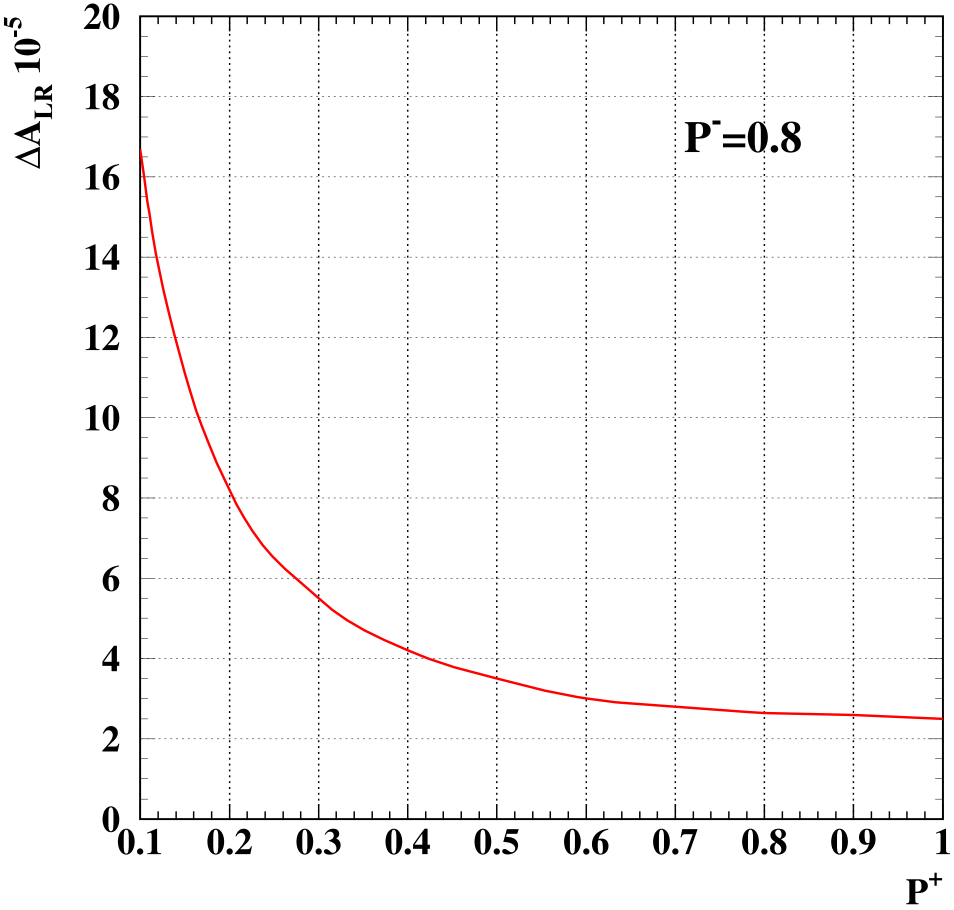
- even better with Blondel scheme:

$$\sigma = \sigma_u \left[1 - \mathcal{P}_{e^+}\mathcal{P}_{e^-} + A_{\rm LR}(\mathcal{P}_{e^+} - \mathcal{P}_{e^-})\right]$$

$$A_{\rm LR} = \sqrt{\frac{(\sigma_{++} + \sigma_{-+} - \sigma_{+-} - \sigma_{--})(-\sigma_{++} + \sigma_{-+} - \sigma_{+-} + \sigma_{--})}{(\sigma_{++} + \sigma_{-+} + \sigma_{+-} + \sigma_{--})(-\sigma_{++} + \sigma_{-+} + \sigma_{+-} - \sigma_{--})}}$$

  can measure $A_{\rm LR}$ independent from polarimeters with very small loss in precision and only 10% of the luminosity on the small cross sections

ΔA_{LR} as a function of the e^+ polarisation



For 10^9 Zs already 20% positron polarisation is better than a 0.1% polarimeter!

Crucial problem for Blondel scheme: Difference of absolute values of helicity states.

For $\mathcal{P} = \pm|\mathcal{P}| + \delta\mathcal{P}$: $\mathrm{dA_{LR}}/\mathrm{d}\delta\mathcal{P} = 0.5$ for e^- and e^+ separately

$\Rightarrow$ understand polarisation difference to $< 10^{-4}$

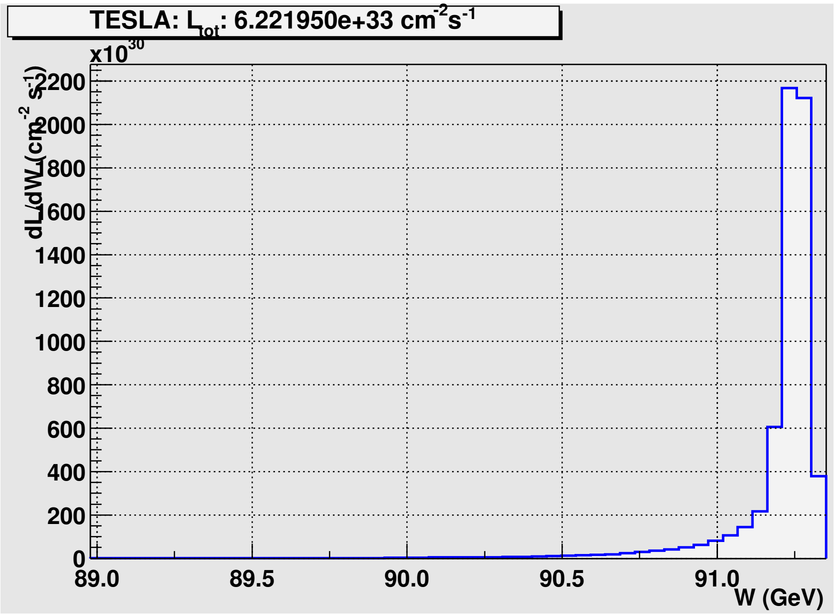
Many effects can be treated with a polarimeter with several channels with different analysing power

Polarisation correlations:

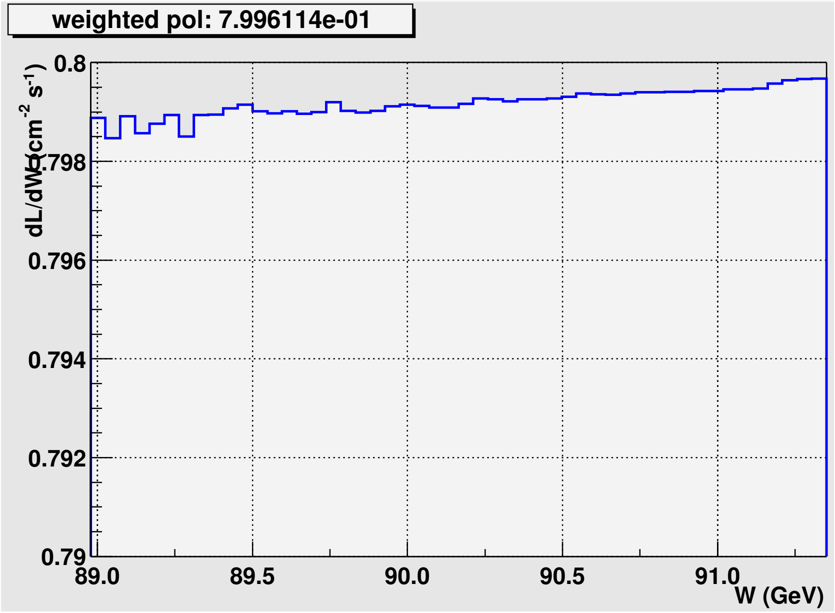
- the Blondel scheme assumes that the polarisations of the two beams are uncorrelated
- possible time correlations have to be tracked with polarimeters
- can there be spatial correlations from the beam transport?
- correlations from the beam-beam interactions are negligible (CAIN)

Definitely need positron polarisation to reach $\sin^2\theta^l_{eff}$ goal

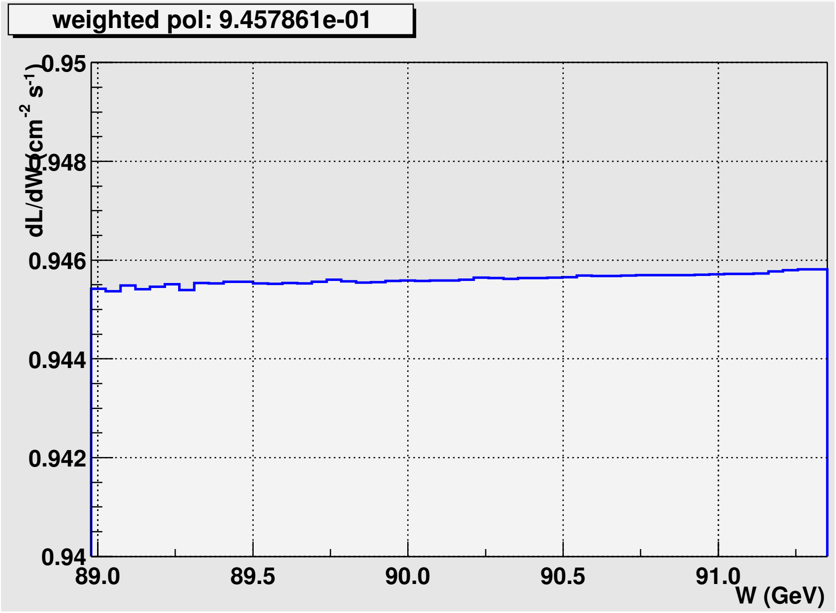
Luminosity spectrum



Electron polarisation



Effective polarisation



Other systematics

- Beam energy:
  - $\mathrm{dA_{LR}/d\sqrt{s}} = 2 \cdot 10^{-2} / \mathrm{GeV}$ from $\gamma - Z$-interference
  - ➠ need $\Delta\sqrt{s} \sim 1\,\mathrm{MeV}$ relative to m_Z
  - ➠ need possibility for (frequent) m_Z scans
  - ➠ Need spectrometer with 10^{-5} relative precision around m_Z
- Beamstrahlung: $\Delta A_\mathrm{LR} = 9 \cdot 10^{-4}$ (TESLA)
  - ➠ need to know beamstrahlung to a few %
  - (should be ok with Bhabha acolinearity)
  - However if beamstrahlung is the same in m_Z-scan and A_LR-running corrections are automatic
  - if really needed beamstrahlung can be reduced for the price of lower luminosity
- Other systematics should be small

In total $\Delta A_\mathrm{LR} = 10^{-4} \Rightarrow \Delta \sin^2\theta^\ell_\mathrm{eff} = 0.000013$ Factor 13 to LEP/SLD

Z-scan observables

Assumptions:

- relative beam energy error around Z-pole: 10^{-5}
  $\Rightarrow \Delta\Gamma_Z/\Gamma_Z = 0.4 \cdot 10^{-3}$ (from $0.9 \cdot 10^{-3}$ at LEP)
- selection efficiency for μs, τs, hadrons (and exp error on $\mathcal{L}$) improved by a factor three relative to the best LEP experiment
  $\Rightarrow \Delta R_\ell/R_\ell = 0.3 \cdot 10^{-3}$ (from $1.2 \cdot 10^{-3}$ at LEP)
- theoretical error on luminosity stays at 0.05%
  $\Rightarrow \Delta\sigma_0^{\mathrm{had}}/\sigma_0^{\mathrm{had}} = 0.6 \cdot 10^{-3}$ (from $0.9 \cdot 10^{-3}$ at LEP)
  (this assumption requires luminosity measurement $\leq$ LEP)

Effect of beamspread:

- $\Delta\Gamma_Z/\Gamma_Z = 7 \cdot 10^{-3}$ for $\sigma(E_b) = 0.1\%$
- $\Delta\sigma_0^{had}/\sigma_0^{had} = 5 \cdot 10^{-3}$ for $\sigma(E_b) = 0.1\%$
- effects go quadratic with $\sigma(E_b)$!

➠ Need $\sigma(E_b) < 0.1\%$ and understand $\sigma(E_b)$ to few %

Effect of beamstrahlung:

- $\Delta\Gamma_Z/\Gamma_Z = 10 \cdot 10^{-3}$ for TESLA default
- $\Delta\sigma_0^{had}/\sigma_0^{had} = 12 \cdot 10^{-3}$ for TESLA default
- effects go between linear and quadratic with beamspread depending on shape

➠ Need to know beamspread to few % as well

In principle both precisions are in reach for the Bhabha-acolinearity measurement

m_{W}

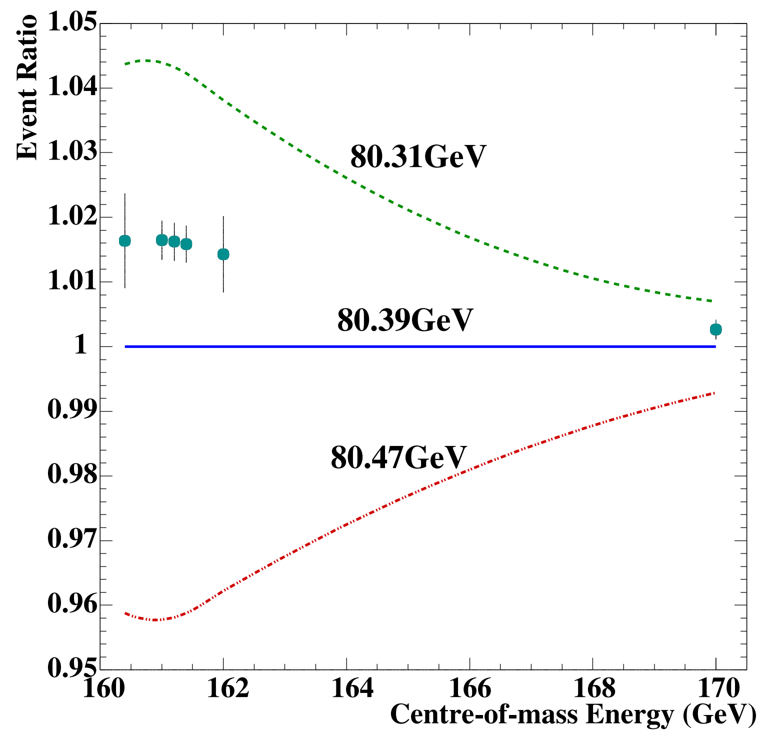
Threshold scan:

- Near threshold W-pair production is dominated by neutrino t-channel exchange

  $\Rightarrow$ β-suppression gives high sensitivity to m_{W}

  $\Rightarrow$ no (unknown) triple gauge couplings involved

- A six point scan around $\sqrt{s} =$ 161 GeV has been simulated with $\mathcal{L} = 100\ \mathrm{fb}^{-1}$ (one year!!!)



- Efficiencies/purities assumed as at LEP
- Polarisations used to measure background/ enhance signal
  - need $\Delta\mathcal{P}/\mathcal{P} < 0.25\%$
  - can use Blondel scheme on rad. ret. events if positron polarisation is available
  - $A_{\mathrm{LR}}^{f\bar{f}}(160)$ GeV large, rapidly changing with $\sqrt{s}$ and different for up- and down-type quarks

    $\Rightarrow$ need to understand left-right asymmetry for selected background very well

➽ $\Delta m_{\mathrm{W}} = 6\,\mathrm{MeV}$ possible with 0.25% error on luminosity and efficiencies

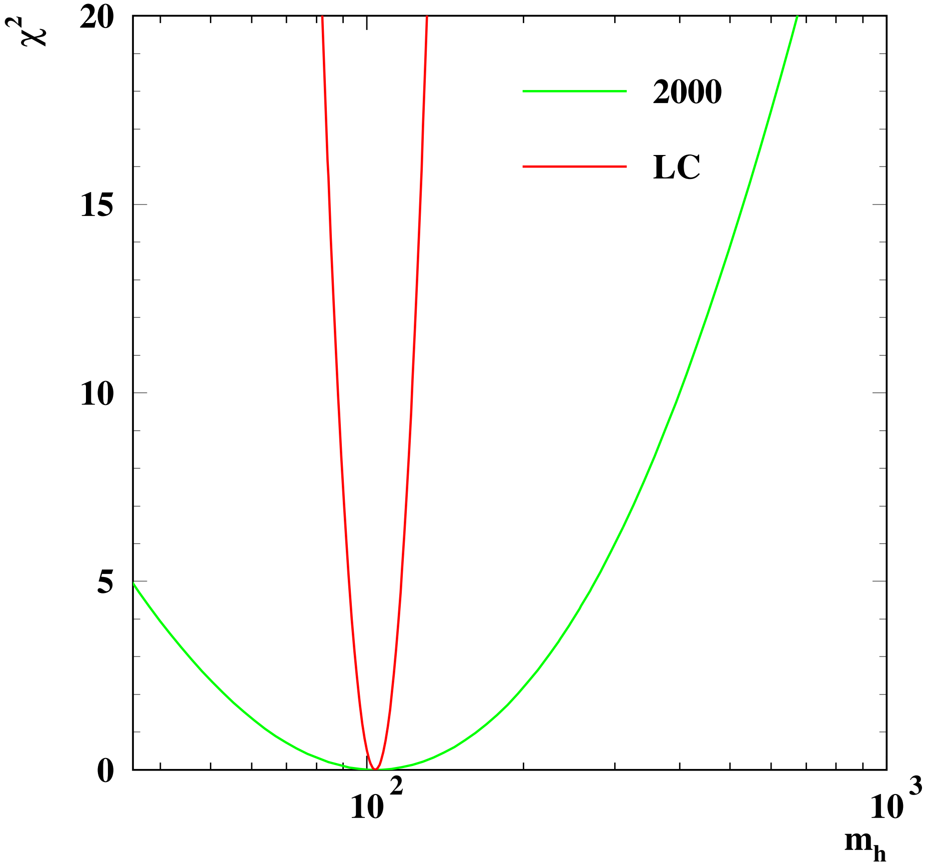
- error increases only to 7 MeV if efficiencies are fitted

➽ Need beam energy (relative to m_{Z}) to $< 5 \cdot 10^{-5}$

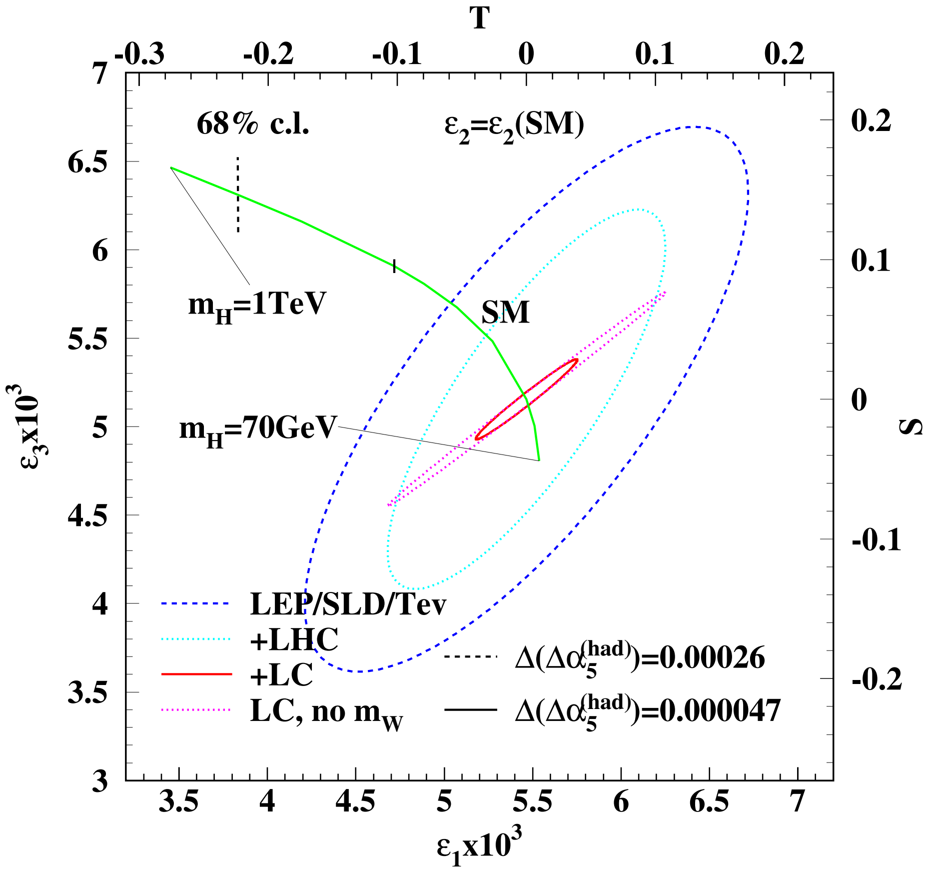
➽ Need (at least) full 4-fermion 1-loop at threshold from theory

Physics gain from GigaZ

Higgs mass prediction



ε (STU) analysis



- A_{LR}, lineshape parameters, m_{W} are important independent of each other

- Within the Standard Model (or SUSY) A_{LR} is the most important one

- For most extensions of the SM m_{W} has a high priority

- The lineshape parameters only get important for specific cases

Conclusions

- There exists a huge potential of GigaZ, especially in $\sin^2\theta^l_{eff}$ and $m_{\rm W}$
- However there are substantial requirements left:
  - positron polarisation
  - precision polarimetry
  - measurement of the beam energy
  - understanding of beamstrahlung and beamspread
  - understanding of > 1 Z multiplicities in a bunch train
  - understanding of theory and experimental input parameters ($\alpha(m_{\rm Z})$!!)
- ILC should be prepared to run in GigaZ mode not to miss a great opportunity