Z-factory: polarization and lumi requirements

Some numbers, ideas and boundary conditions

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- Short summary
- Impact of polarization at the Z-pole
- Some technical issues of Z-factory@HERA

Physics: Z-pole data

- **Why do we need such data a.s.a.p.?**
  - **Discrepancy between A_{LR} and A_{FB}**

$$\text{SLD:} \quad \sin^2\theta_{\text{eff}} = 0.23098 \pm 0.00026 \quad (A_{LR}(\ell)),$$
$$\text{LEP:} \quad \sin^2\theta_{\text{eff}} = 0.23221 \pm 0.00029 \quad (A_{FB}(had)).$$

  - **,most sensitive tests of the Standard Model via measurements of the ew observables as $\sin^2\theta_{eff}$**

We do need it already now !!!

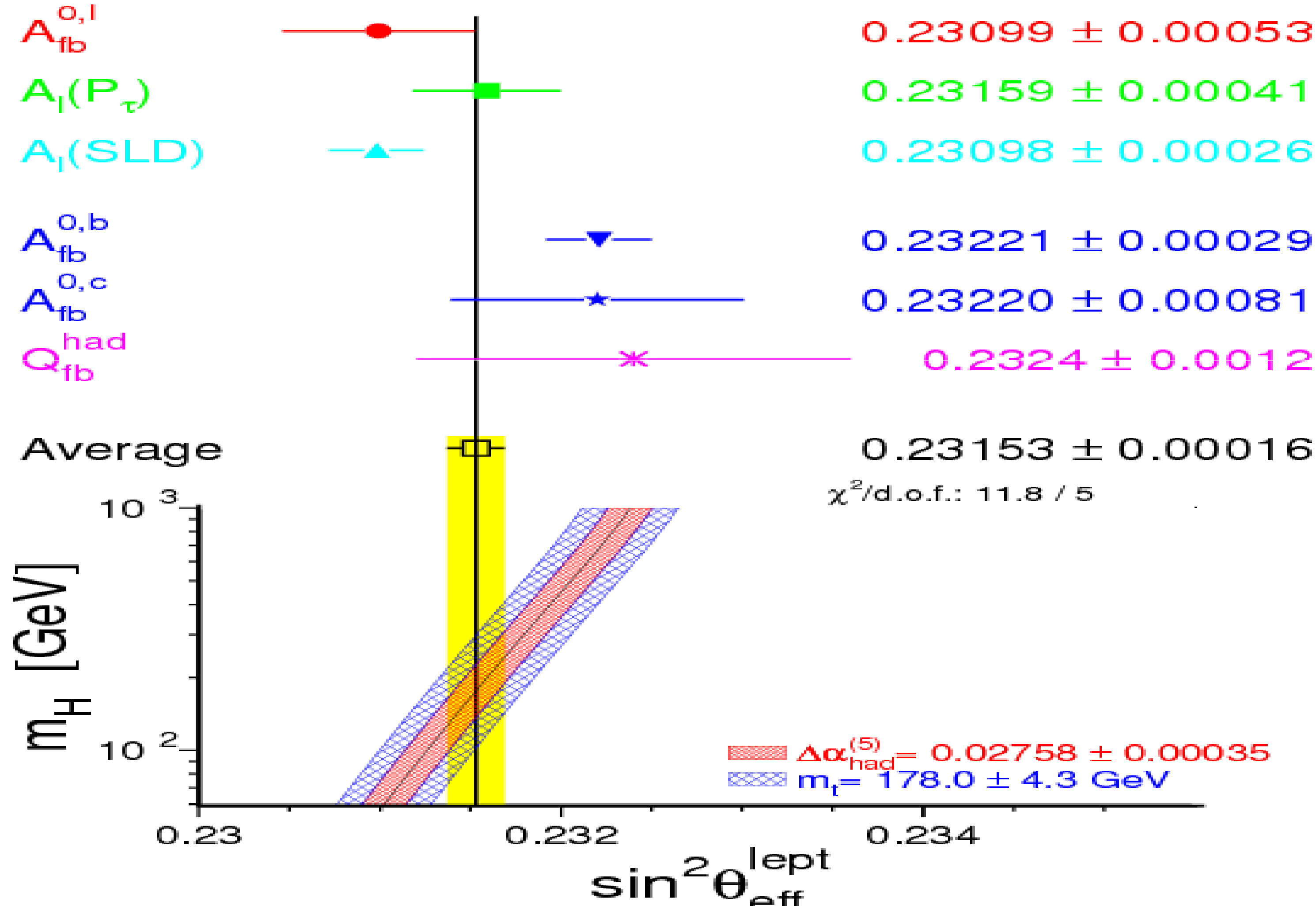
A_{LR} and $\sin^2\theta_{eff}$

- Accuracy in $\sin^2\Theta_{eff}$

$$A_{\rm LR} = \frac{2(1-4\sin^2\theta_W^{\rm eff})}{1+(1-4\sin^2\theta_W^{\rm eff})^2}$$

- precision in ALR directly transferred to $\sin^2\Theta_{eff}$
- GigaZ will provide $\Delta \sin^2\Theta_{eff} \sim 1.3 \times 10^{-5}$ (if Blondel scheme)
- only electron polarization at GigaZ: $\sim 9.5 \times 10^{-5}$
- current value: 16×10^{-5}
- What could we gain with a 'fraction' of GigaZ ?

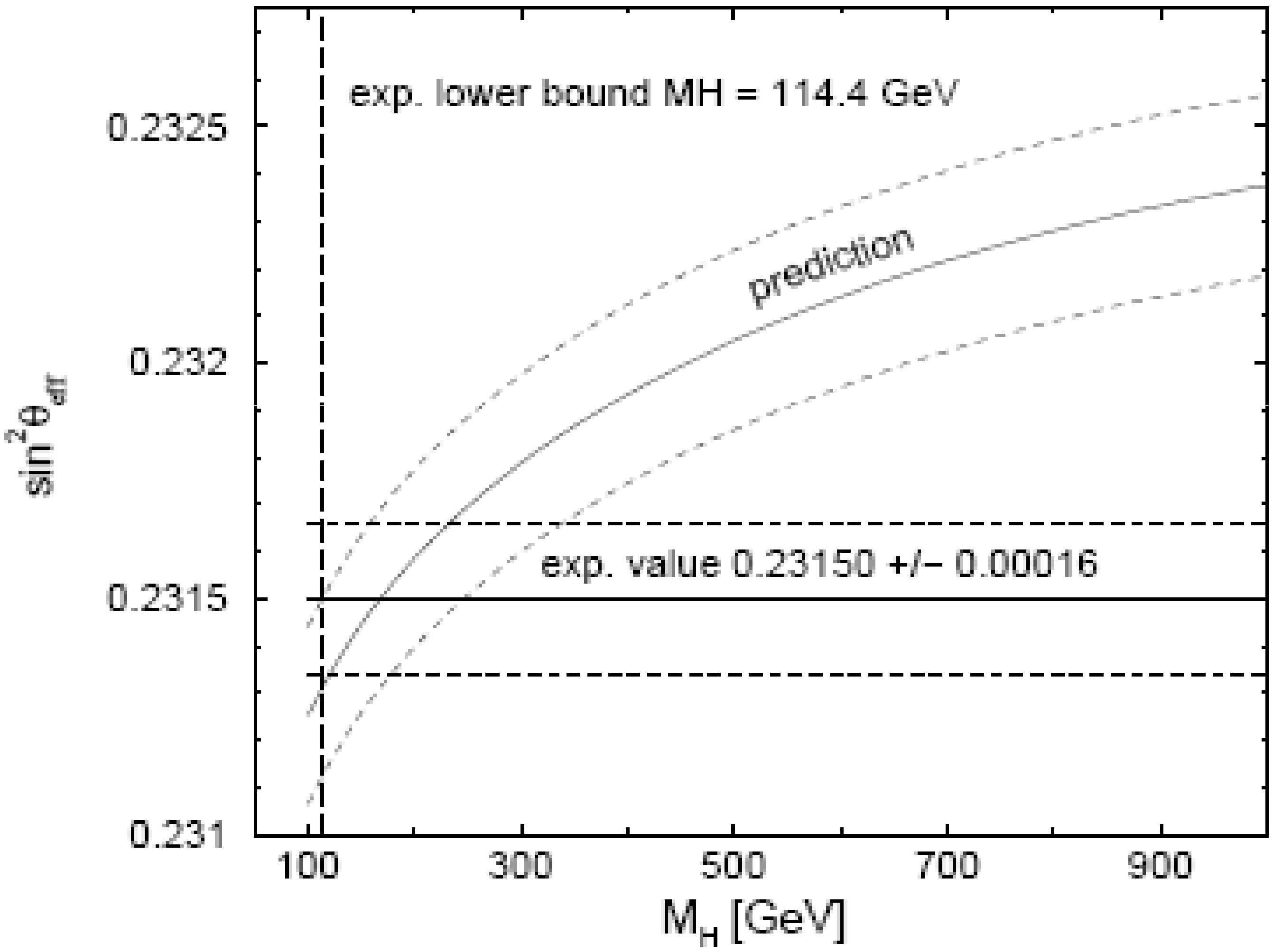
Relevance for 'Higgs'



Relevance for 'Higgs'

$$\sin^2\theta_{\text{eff}} = 0.23098$$

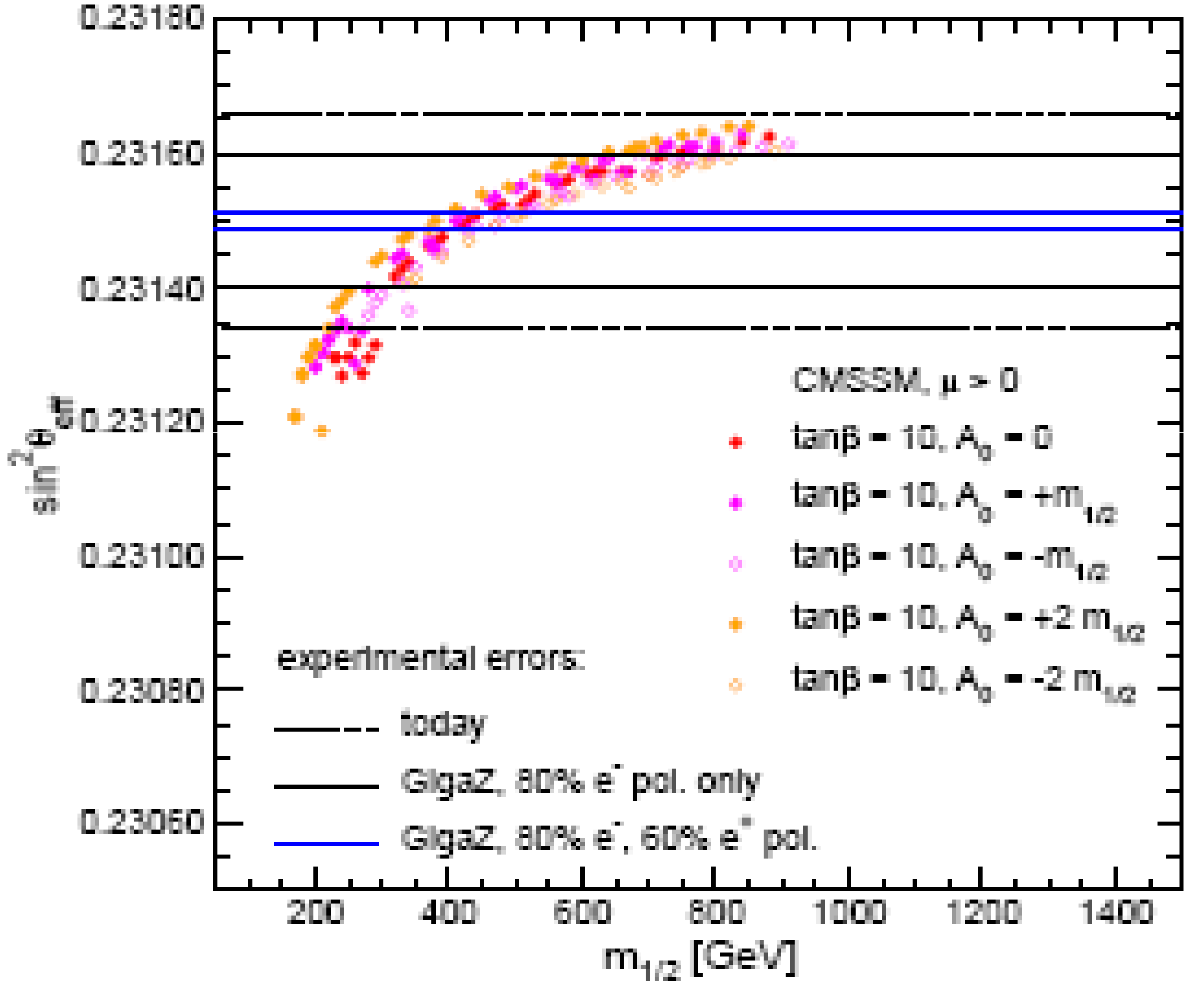
$$\sin^2\theta_{\text{eff}} = 0.23221$$



Relevance for SUSY/New Physics

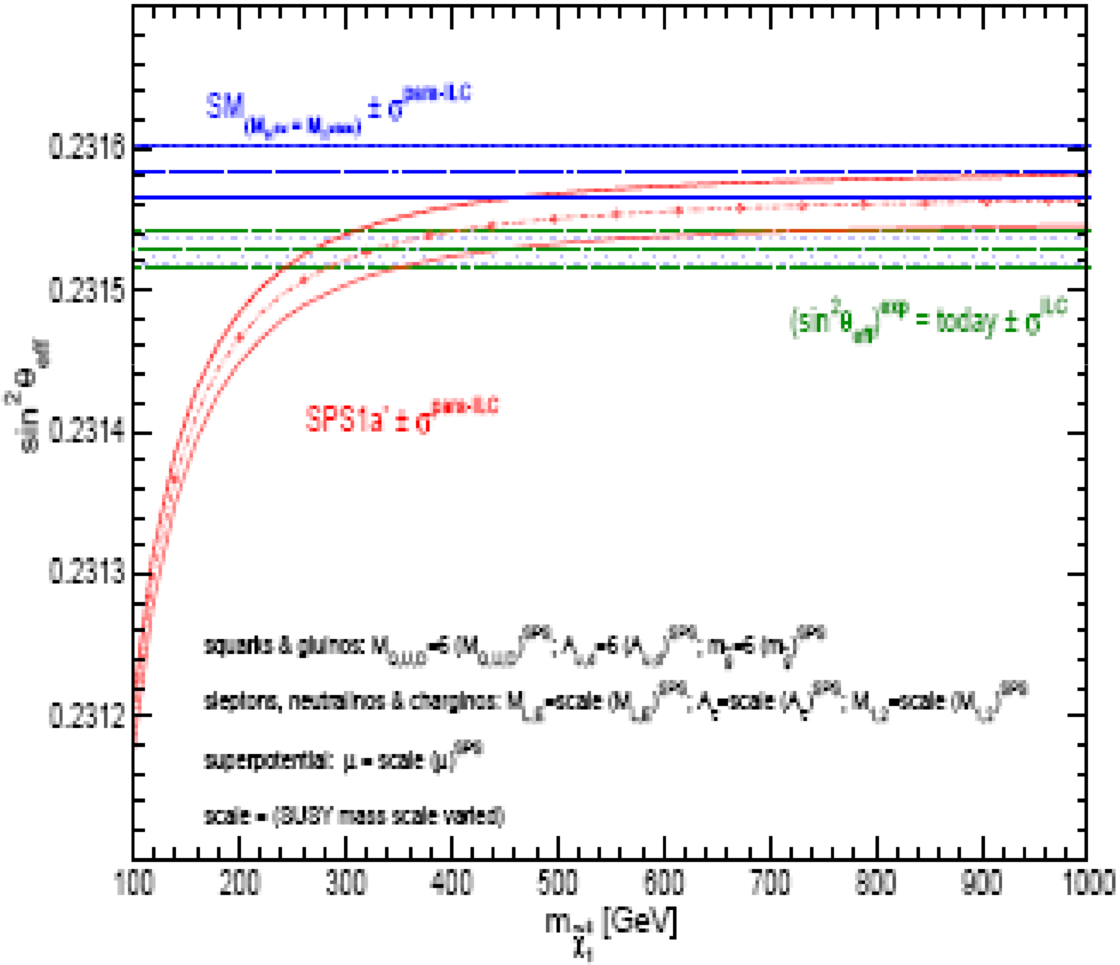
$\sin^2\theta_{\text{eff}} = 0.2309$

$\sin^2\theta_{\text{eff}} = 0.2322$



Relevance in worst case scenarios

- **Hints for new physics in worst case scenarios:**
  - Only Higgs @LHC
  - No hints for SUSY



- **Deviations at Zpole**
  - Hints for SUSY

- **Discrepancy**

$$\text{SLD:} \quad \sin^2\theta_{\text{eff}} = 0.23098$$

$$\text{LEP:} \quad \sin^2\theta_{\text{eff}} = 0.23221$$

Tests of SM at quantum level

- What are the important input quantities?
  - **Impact of Mass of the top:**

current theoretical: intrinsic	$\Delta m_W^{\text{intr,today}} \approx 4$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{intr,today}} \approx 4.7 \times 10^{-5}$
parametric δm_t=1.2 GeV $\delta(\Delta\alpha_{\text{had}}) = 35 \times 10^{-5}$	$\Delta m_W^{\text{para},m_t} \approx 11$ MeV $\Delta m_W^{\text{para},\Delta\alpha_{\text{had}}} \approx 6.3$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{para},m_t} \approx 3.6 \times 10^{-5}$ $\Delta \sin^2\theta_{\text{eff}}^{\text{para},\Delta\alpha_{\text{had}}} \approx 12 \times 10^{-5}$
δm_Z=2.1 MeV	$\Delta m_W^{\text{para},m_Z} \approx 2.5$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{para},m_Z} \approx 1.4 \times 10^{-5}$

	future parametric		
LHC	δm_t=1 GeV	$\Delta m_W^{\text{para},m_t} \approx 6$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{para},m_t} \approx 3 \times 10^{-5}$
ILC →	δm_t=0.1 GeV	$\Delta m_W^{\text{para},m_t} \approx 1$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{para},m_t} \approx 0.3 \times 10^{-5}$
	$\delta(\Delta\alpha_{\text{had}}) = 5 \times 10^{-5}$	$\Delta m_W^{\text{para},\Delta\alpha_{\text{had}}} \approx 1$ MeV	$\Delta \sin^2\theta_{\text{eff}}^{\text{para},\Delta\alpha_{\text{had}}} \approx 1.8 \times 10^{-5}$

  - **$\delta\sin^2\theta \sim 1 \times 10^{-4}$ would be reasonable now!**

What's the role of polarization?

- **Derive the statistical uncertainty of A_{LR}**
  - **If only polarized electrons:**

    ΔA_{LR} determined by polarimeter uncertainty

    $$A_{LR} = 1 / P(e-) \times [\sigma_L - \sigma_R] / [\sigma_L + \sigma_R]$$

  - **Pure error propagation:**

    uncertainty depends on $\Delta\sigma_L$, $\Delta\sigma_R$, $\Delta P/P$

  - **For large statistics, σ (ee -> Z -> had) ~ 30 nb:**

    main uncertainty from ΔP/P~ 0.5 % maybe up to 0. 25%...

Blondel Scheme

- **Two polarized beams available**
  - **Express A_{LR} only by cross sections**

$$\sigma = \sigma_{\mathrm{unpol}}[1 - P_{e^-}P_{e^+} + A_{\mathrm{LR}}(P_{e^+} - P_{e^-})],$$

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

  - **Pure error propagation:**

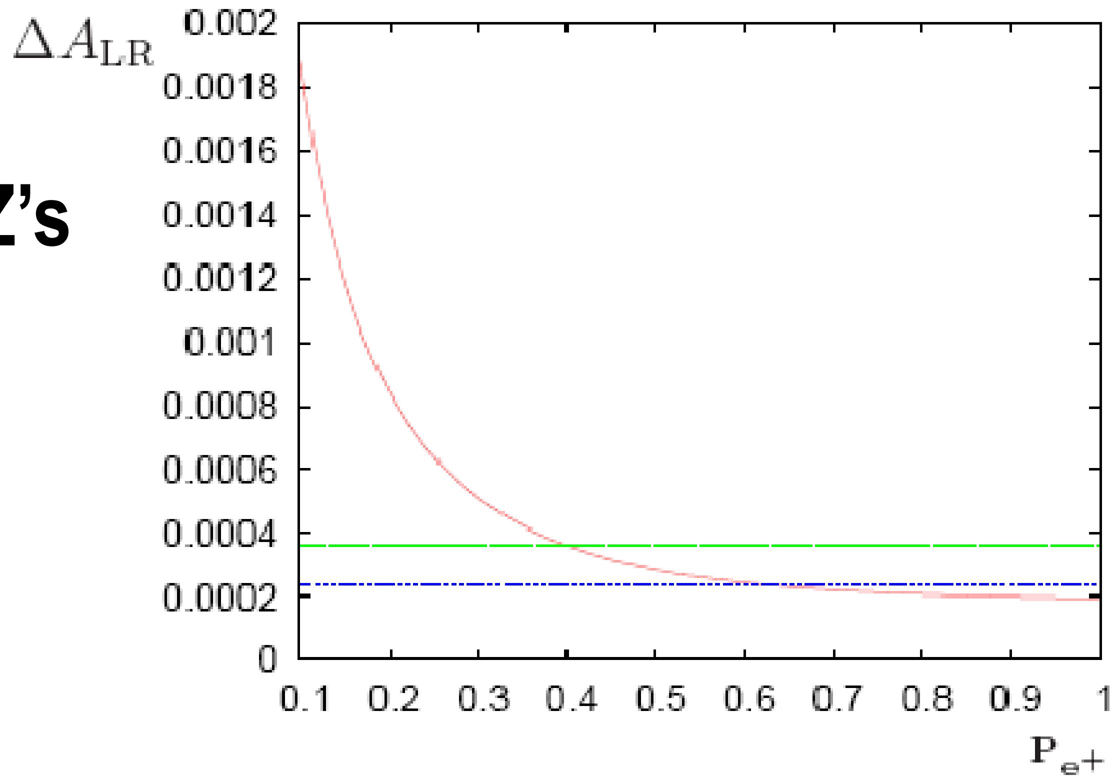
    uncertainty depends on $\Delta\sigma_{LL}$, $\Delta\sigma_{LR}$, $\Delta\sigma_{RL}$, $\Delta\sigma_{RR}$ not on $\Delta P/P$!
  - **Relative measurements wrt flipping polarization needed**

    $\Delta P / P = 0.5$ % sufficient
  - **Some calibration time in LL and RR required**

    about 10-20% of the time, optimum depends on polarization
  - **Different anal. powers: $\Delta A_{LR} = \Delta A^0_{LR} \times \sqrt{(1+8/x)}$, x~10=Ce/Ze**

Dependence of A_{LR} on $P(e^+)$

- **On basis of 27×10^6 Z's**
- **$P(e^+)$ very helpful**



No. of Z's and precision @ ILC calibration

$\int \mathcal{L}$	No. of Z's	$\int_{\text{days}} \mathcal{L}_{\text{cal}}$	$P(e^-)$	$P(e^+)$	ΔA^0_{LR}	ΔA_{LR}	$\sin^2\theta_{\text{eff}}$
6 pb^{-1}	1.8×10^5	1	90%	0	–	2.7×10^{-3}	3.4×10^{-4}
			90%	40%	3.3×10^{-3}	4.4×10^{-3}	5.6×10^{-4}
			90%	60%	2.2×10^{-3}	3.0×10^{-3}	3.8×10^{-4}
24 pb^{-1}	7.3×10^5	4	90%	0	–	1.5×10^{-3}	1.9×10^{-4}
			90%	40%	1.6×10^{-3}	2.2×10^{-3}	2.8×10^{-4}
			90%	60%	1.1×10^{-3}	1.5×10^{-3}	1.9×10^{-4}
60 pb^{-1}	1.8×10^6	10	90%	0	–	1.1×10^{-3}	1.4×10^{-4}
			90%	40%	1.0×10^{-3}	1.4×10^{-3}	1.8×10^{-4}
			90%	60%	7.0×10^{-4}	9.4×10^{-4}	1.2×10^{-4}
0.6 fb^{-1}	18×10^6	100	90%	0	–	8.1×10^{-4}	1.0×10^{-4}
			90%	40%	3.3×10^{-4}	4.4×10^{-4}	5.6×10^{-5}
			90%	60%	2.2×10^{-4}	3.0×10^{-4}	3.8×10^{-5}
0.9 fb^{-1}	27×10^6	150	90%	0	–	7.9×10^{-4}	1.0×10^{-4}
			90%	40%	2.7×10^{-4}	3.6×10^{-4}	4.6×10^{-5}
			90%	60%	1.8×10^{-4}	2.4×10^{-4}	3.1×10^{-5}
1.2 fb^{-1}	36×10^6	200	90%	0	–	7.9×10^{-4}	1.0×10^{-4}
			90%	40%	2.3×10^{-4}	3.1×10^{-4}	4.0×10^{-5}
			90%	60%	1.6×10^{-4}	2.1×10^{-4}	2.7×10^{-5}
1.8 fb^{-1}	54×10^6	300	90%	0	–	7.8×10^{-4}	1.0×10^{-4}
			90%	40%	1.9×10^{-4}	2.6×10^{-4}	3.2×10^{-5}
			90%	60%	1.3×10^{-4}	1.7×10^{-4}	2.2×10^{-5}

Table 4: Lumi at Z-pole $\mathcal{L}_{\text{cal}} = 7 \times 10^{31}\ \text{cm}^{-2}\text{s}^{-1}$, $\sigma(e^+e^- \to Z \to had) \sim 30$ nb, $A_{\text{LR}} = 0.154$, $\Delta P/P = 0.5\%$, $\mathcal{L}_{++,--}/\mathcal{L} = 0.1$

'HERA' estimates

- Assuming only moderate lumi, see later:

  $L \sim 2 \times 10^{31} cm^{-2} s^{-1}$

- With 500 days: ~26 x10^6 Z's expected

$P(e^-)$	$P(e^+)$	$\delta \sin^2\theta$
30%	30%	5.6×10^{-5}
40%	40%	3.8×10^{-5}
80%	30%	4.9×10^{-5}

Further needs….

- *Details still under work, just brain storming*
  - **Stable energy: since $\Delta A_{LR} / \Delta\sqrt{s} \sim 0.2\% / GeV$**
  - **Low/well understood energy spread**
  - **Helicity flipping, well understood polarization**
  - **Maybe also scan and σ to get partial widths?**
  - **What else?**

A few technical remarks

- Option 1:

HERA storage ring with one ring

- – No new magnets needed for Z-pole energy !
- – Loss: About 660 MeV per turn …
- – Lumi: **L~2 x 10^{31} $cm^{-2}s^{-1}$** **(about LEP)**
- – Polarization…..? **Maybe resonance effects at the sides -> simulation required, but not excluded !**

  about 30%-40% (for both beams!) should be fine; spin rotators via dipoles
- – Energy width about 100 MeV **(at LEP ~70 Mev)**

More technical remarks….

- Option 2?
  - Maybe linac technology in straight sections?
    - **About 5 km ….should be enough for 45 km…**
  - Critical issue: luminosity?
  - Nice features: probably high e^- polarization should be available!
  - e^+ polarization: more difficult ….but not excluded.

And even more technical ideas

- Option 3: 'Straight' Z-factory?
  - High e^- polarization ~90% : should be possible
  - e+ polarization: not with undulator technology
    - Maybe via Laser-Compton backscattering?
    - Maybe via bremsstrahlung of polarized e-?
  - Maybe XFEL line exploitable?
    - **Probably lumi critical ?**

Conclusions

- Several technical options available
- Polarization, lumi, energy stab. is an issue !
- Physics case extremely good:
  - Sensitive to Higgs prediction
  - Sensitive zu SUSY effects, even if nothing@LHC
  - Sensitive to tests of SM at quantum level
- Very powerful option to test, treat and ‘determine’ new physics options!

Dependence of A_{LR} on L_{++} and L_{--}

- What is the optimum time running in (++) and (--) mode?
- Assume $P(e^+)$=40%
- Best value at about

 $(L_{++} - L_{--})/L_{int}$=25%

- But does not significantly reduce the uncertainty!