Running TESLA on the Z-pole

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- Introduction
- Measurements of electroweak quantities on the Z
- B-physics on the Z
- Conclusions

LEP+SLD+TEVATRON measure electroweak observables on the permille level

Quantities:

- Z-lineshape: Partial widths of $\mathrm{Z} \to \mathrm{f\bar{f}}$, $\Delta\rho$, N_ν
- Asymmetries: Weak mixing angle in Z-decays, $\sin^2\theta^\ell_{\mathrm{eff}}$
- b-quark partial width and asymmetries (R_b, $\mathcal{A}_\mathrm{b}$) Mass dependent vertex corrections
- W-mass: Δr

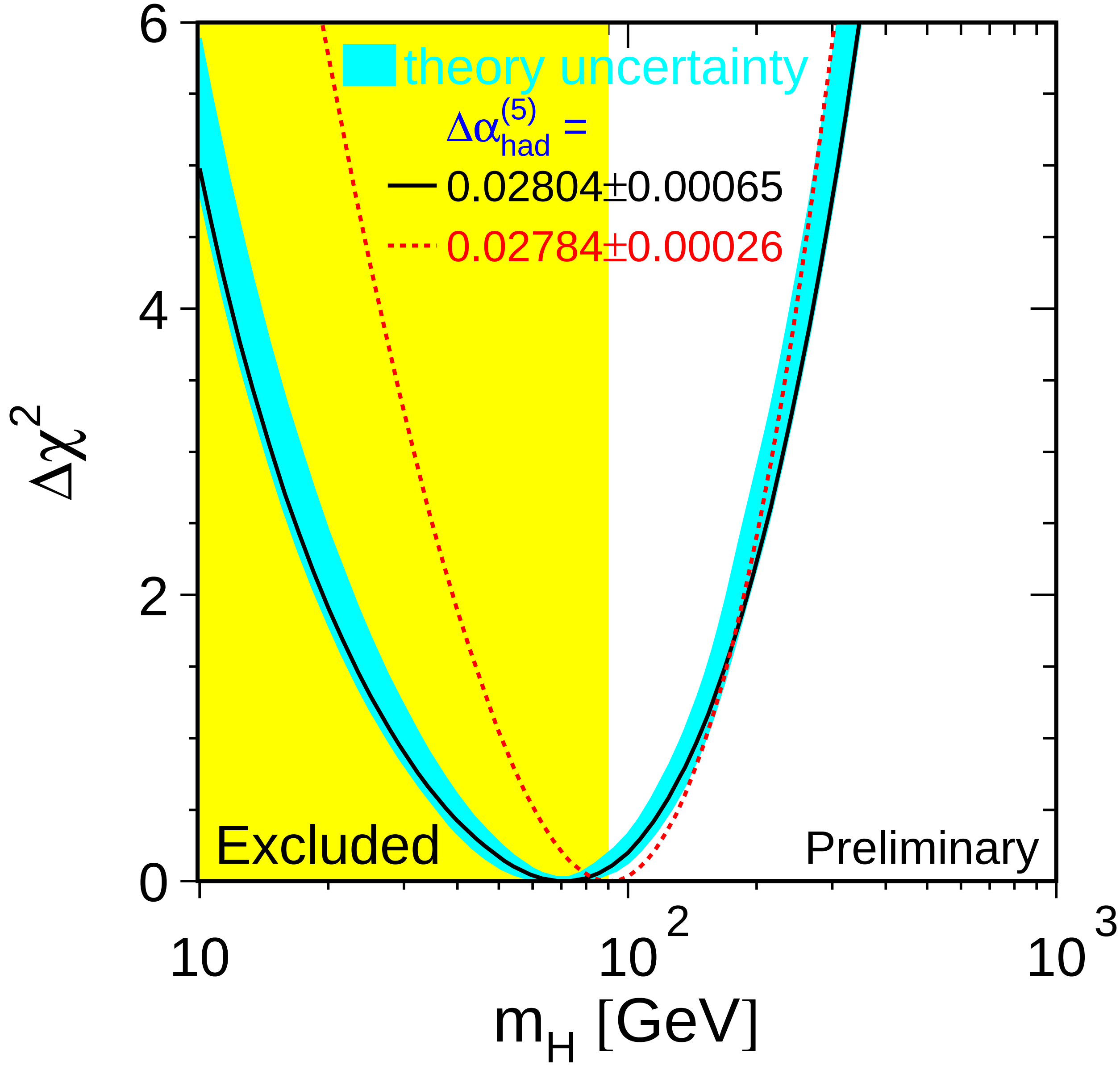
Present situation:

- LEP: $\sim 4 \times 4 \cdot 10^6$ Zs with unpolarised beams $\sim 4 \times 200\mathrm{pb}^{-1}$ above the W-threshold
- SLD: $\sim 5.5 \cdot 10^5$ Zs with $\mathcal{P} \sim 75\%$ electron polarisation

Objectives

- Test consistency of the theory on the loop level
- Try to "measure" unknown parameters in the theory

E.g. Higgs mass sensitivity of current precision data:



Assumptions

- The linear collider can produce $\sim 10^9$ Zs on resonance (corresponds to $\sim 30\text{fb}^{-1}$ or 50 days)
  $\mathcal{L} = 7 \cdot 10^{33}\text{cm}^{-2}\text{s}^{-1} \Rightarrow 230\,\text{Hz of Z} \rightarrow \text{q}\bar{\text{q}}$

- electrons and positrons can be polarised with $\mathcal{P}_{e^-} = \pm 80\%$, $\mathcal{P}_{e^+} = \pm 60\%$
  (corresponds to an effective polarisation of $\frac{\mathcal{P}_{e^+}+\mathcal{P}_{e^-}}{1+\mathcal{P}_{e^+}\mathcal{P}_{e^-}} \sim 95\%$)

- positive and negative polarisations can be switched randomly from bunch to bunch (or train to train) independent for electrons and positrons

- polarimeters are available for relative measurements

Lineshape parameters

LEP lineshape parameters:

m_Z, Γ_Z, $\sigma_0 \propto \frac{\Gamma_\ell \Gamma_{had}}{\Gamma_Z^2}$, $R_\ell = \frac{\Gamma_{had}}{\Gamma_\ell}$

- m_Z: probably taken as reference for E_b
- Γ_Z: $\Delta\Gamma_Z(LEP) = 2.4\,\text{MeV}$ from statistics and E_b, where E_b error is due to time dependences
  $\Rightarrow$ With a good spectrometer to measure E_b, this can go to 1 MeV
- σ_0: dominated by theoretical error on luminosity
  $\Rightarrow$ assume no improvement
- R_ℓ: Close to systematics dominated
  Lepton systematics is of statistical nature
  $\rightarrow$ assume 0.05% on R_ℓ from hadrons (LEP)
  $\Rightarrow \sim 70\%$ improvement

Physics quantities derived from the lineshape

	LEP	TESLA
m_Z	91.1867 ± 0.0021 GeV	± 0.0021 GeV
$\alpha_s(m_Z)$	0.1212 ± 0.0034	± 0.0016
$\Delta\rho$	$(0.42 \pm 0.12) \cdot 10^{-2}$	$\pm 0.05 \cdot 10^{-2}$
N_ν	2.994 ± 0.0011	± 0.0011

(For α_s and $\Delta\rho$ $N_\nu = 3$ is assumed)

- α_s and $\Delta\rho$ give an interesting improvement
- However did not exploit (yet) the ability of the better detector to classify events
- One should also think if lower statistics processes like large angle Bhabha or $e^+e^- \to \gamma\gamma$ could give a theoretically better understood luminosity determination

scale DELPHI analysis:

$$
\begin{aligned}
R_b = 0.21634 &\pm 0.00075\,(stat\,dat + MC)\\
&\pm 0.00028\,(uds - bg)\\
&\pm 0.00030\,(c - bg)\\
&\pm 0.00027\,(hem\ corr)
\end{aligned}
$$

DELPHI working point: $\varepsilon_b \approx 30\%$ purity $\approx 98\%$
Possible for TESLA: $\varepsilon_b \approx 40\%$ purity $\approx 99.5\%$

- statistical error down by a factor 20
- c-background down by a factor 4
- uds-background mainly from gluon splitting to $b\bar{b}$ can be measured much better with TESLA
- hemisphere correlation is mainly QCD
  - detector resolution factor 10 better than LEP
  - losses are mainly due to mass cut (Lorenz invariant)
  - energy dependence should be much smaller
  - also this source should decrease by a factor 4-5
- $\Delta R_b = 0.00014$ should be possible (factor 5 to LEP)

Definition

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

with $\mathcal{P}_{e^+}$ ($\mathcal{P}_{e^-}$) longitudinal polarisations of the positrons (electrons)

$A_{\rm LR}$ measures weak mixing angle $\sin^2\theta^\ell_{\rm eff}$:

$$A_{\rm LR} = \mathcal{A}_\ell$$
$$\mathcal{A}_\ell = \frac{2 g_{Vl} g_{Al}}{g_{Vl}^2 + g_{Al}^2}$$
$$\frac{g_{Vl}}{g_{Al}} = 1 - 4|Q_l| \sin^2\theta^\ell_{\rm eff}$$

- $\sin^2\theta^\ell_{\rm eff}$ is a very sensitive variable to see loop corrections to the Z-couplings.
- $A_{\rm LR}$ is the variable most sensitive to $\sin^2\theta^\ell_{\rm eff}$

The (extended) Blondel scheme

Four independent measurements:
(4 combinations with positive/negative electron/ positron polarisation)

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

$\Longrightarrow$ A_{LR} can be measured without knowing $\mathcal{P}_{e^+}$, $\mathcal{P}_{e^-}$:

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

About 10% of the statistics is needed on the small cross sections

Only difference between $|\mathcal{P}^{+}_{e^\pm}|$ and $|\mathcal{P}^{-}_{e^\pm}|$ needs to be known from polarimetry

Can be brought under control with polarimeters a la SLD

Polarisation difference ($\Delta\mathcal{P}_{e^\pm} = |\mathcal{P}^+_{e^\pm}| - |\mathcal{P}^-_{e^\pm}|$):

- Need SLD like polarimeter
- Asymmetry in one polarimeter channel:
  $A_i = a_i \mathcal{P}_e \mathcal{P}_\gamma$ (a_i =analysing power)
- Laser polarisation can be switched pulse to pulse
- Allow for different laser currents dependent on the polarisation
- Need two polarimeter channels with different analysing power
- combined fit of Z-rates and polarimeter rates can get $\Delta\mathcal{P}_{e^\pm}$ and a_i as well
- However need polarimeter counting rates about 10 times the Z rate (ok for SLD)

Statistical precision:

$$\Delta A_{\mathrm{LR}} = 4 \cdot 10^{-5} \cdot \sqrt{\frac{10^9}{N_Z}}$$

Systematic uncertainties

- Beam energy: $\Delta A_{\mathrm{LR}} / \Delta\sqrt{s} \approx 2 \cdot 10^{-2} / \,\mathrm{GeV}$
  $\Rightarrow$ need $\Delta\sqrt{s} \approx 1\,\mathrm{MeV}$
- Luminosity difference: Only relative precision needed.
  Should be no problem if luminometer inside the mask is possible
- Backgrounds: To be kept below 10^{-4}
  According to LEP experience no problem
- Beamstrahlung: $\Delta A_{\mathrm{LR}} = 9 \cdot 10^{-4}$
  Needs to be known on the few percent level

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

Without polarised beams (LEP) the forward-backward asymmetries can be measured:

$$A^q_{FB} = \frac{\sigma^{(q)}_F - \sigma^{(q)}_B}{\sigma^{(q)}_T} = \frac{3}{4}\mathcal{A}_\mathrm{e}\mathcal{A}_\mathrm{q}$$

With polarised beams (SLD,TESLA) the left-right-forward-backward asymmetries can be measured:

$$A^q_{FB,LR} = \frac{\sigma^{(q)}_{L,F} - \sigma^{(q)}_{L,B} - \sigma^{(q)}_{R,F} + \sigma^{(q)}_{R,B}}{\sigma^{(q)}_L + \sigma^{(q)}_R} = \frac{3}{4}\mathcal{P}\mathcal{A}_\mathrm{q}$$

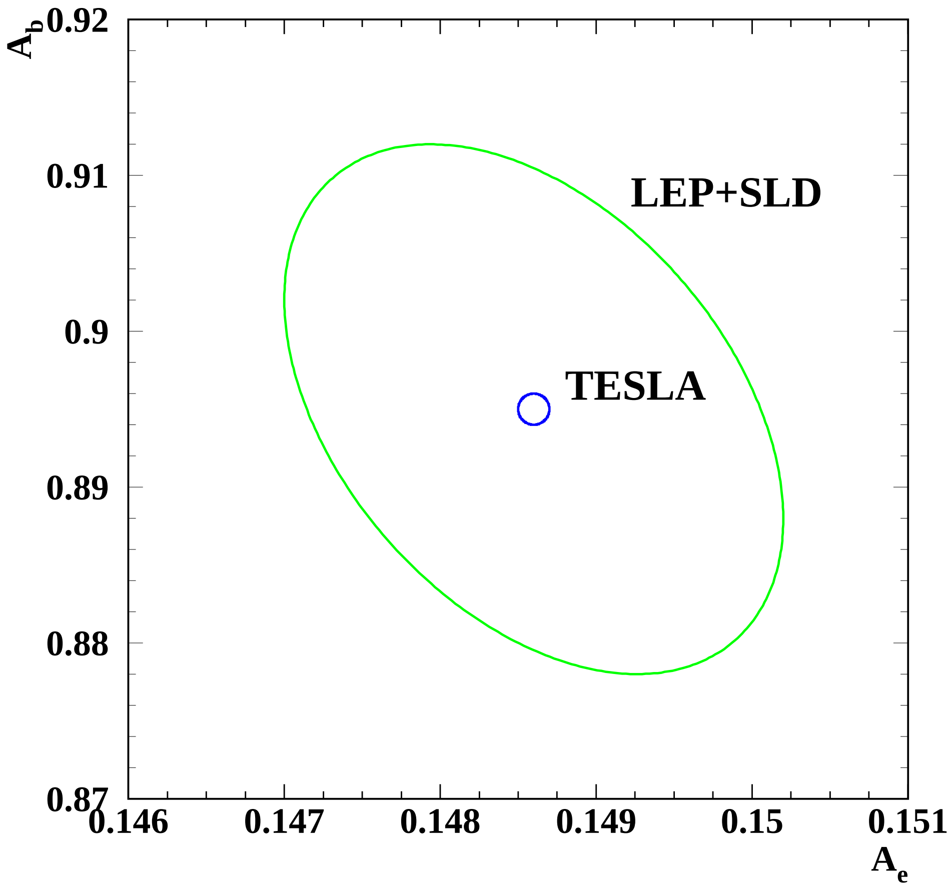
Statistically factor $\mathcal{P}/\mathcal{A}_\mathrm{e} \sim 6$ more sensitive to $\mathcal{A}_\mathrm{b}$

However most systematics scale with the asymmetry

Two main techniques: leptons and jetcharge

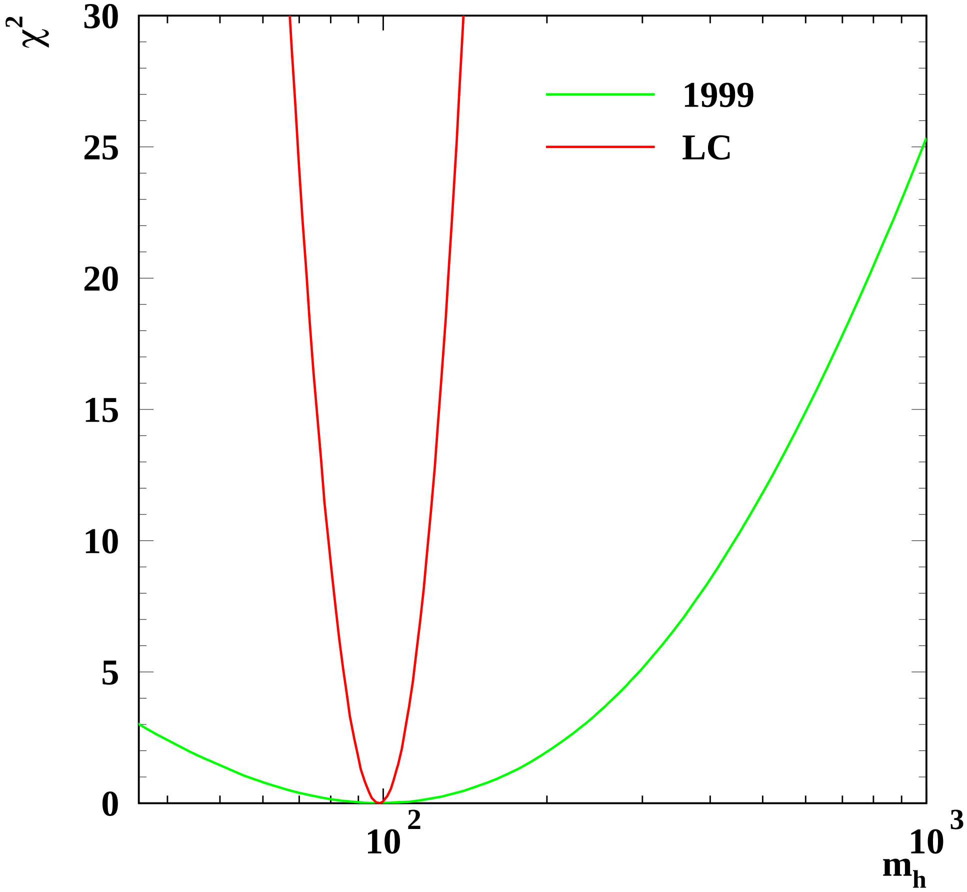
- Statistical error $\Delta\mathcal{A}_\mathrm{b} \sim= 4 \cdot 10^{-4}$ in both cases
- Light quark systematics can be reduced by a (harder) lifetime tag
- For jetcharge reduce hemisphere correlations by a thrust cut
- leptons will be dominated by $B\overline{B}$-mixing (statistical error!)
- A total error of $\Delta\mathcal{A}_\mathrm{b} = 1 \cdot 10^{-3}$ seems realistic

Similar improvement as for $\mathcal{A}_\mathrm{e}$



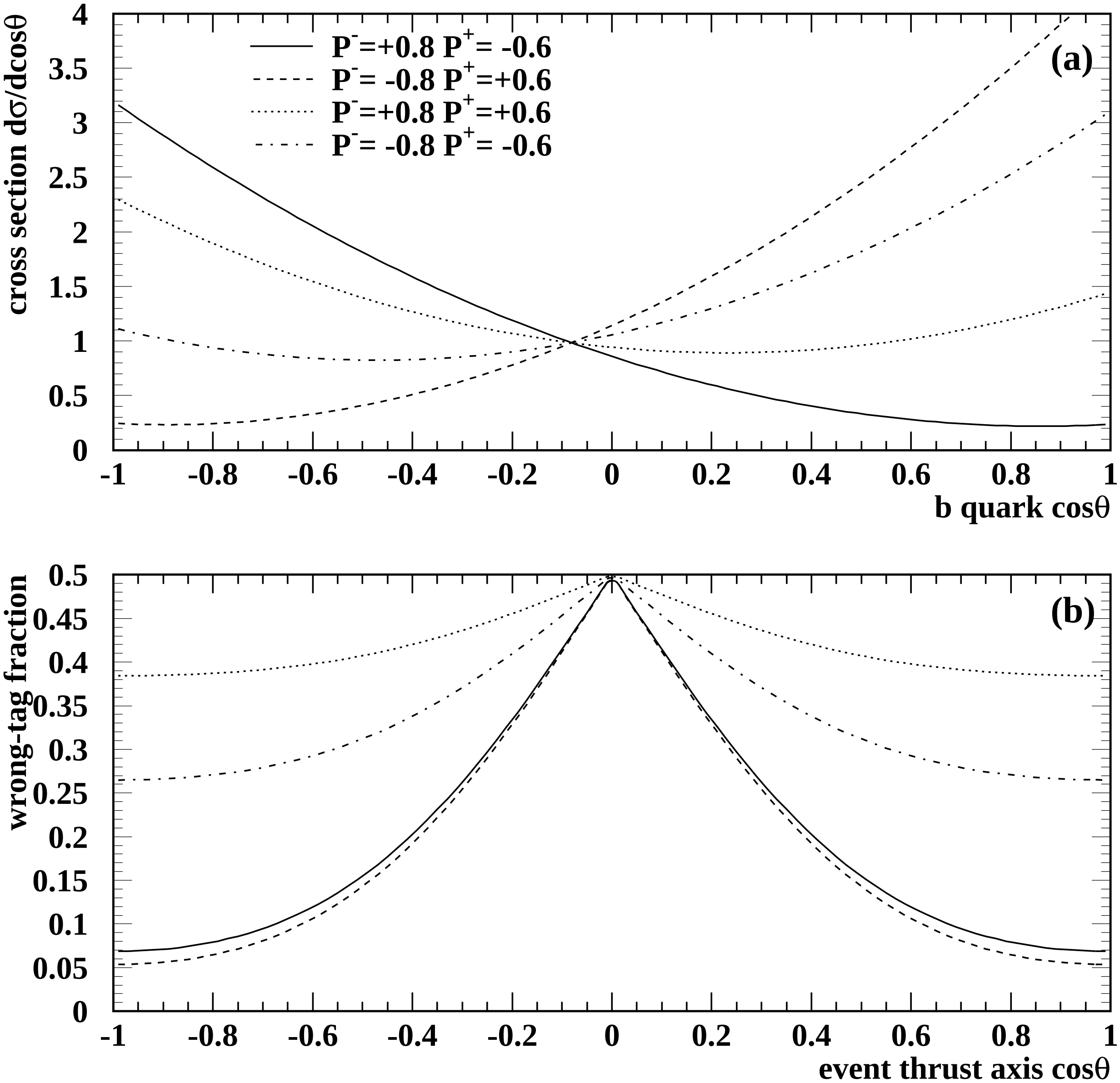
If no new physics found up to then:

Standard LEPEW Higgs fit:

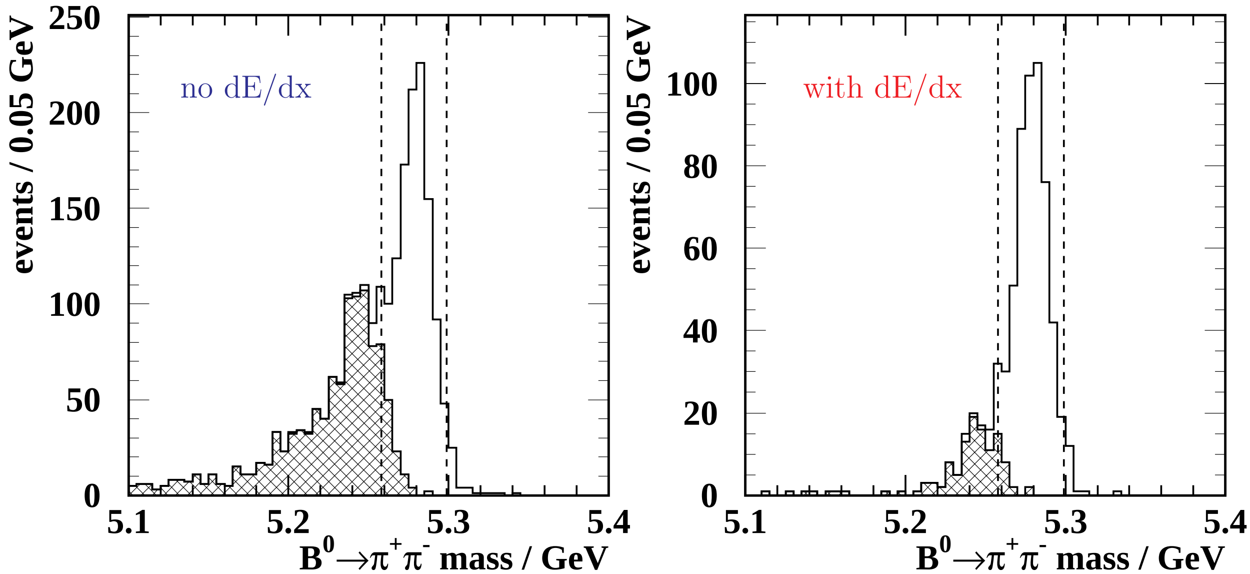


More theory: → S. Heinemeyers talk

- $4 \cdot 10^8$ b-hadrons
- Polarisation give primary flavour tagging "for free"



- Missing particle ID can be replaced by excellent momentum resolution



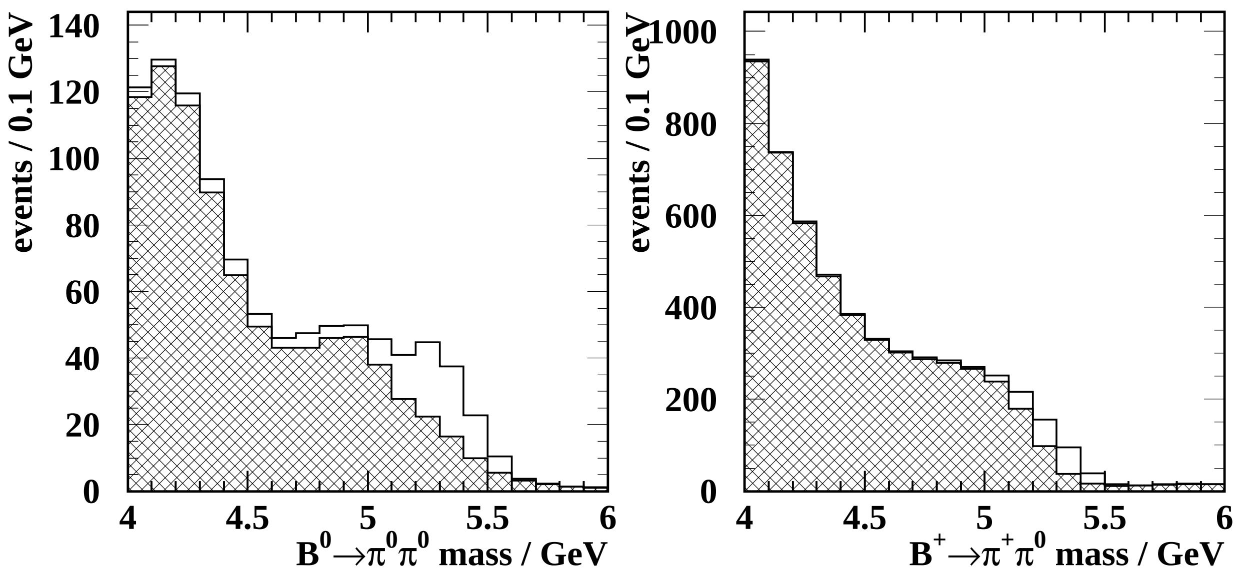
Results

	$\sin 2\beta$	"$\sin 2\alpha$"
BarBar	0.12	0.26
CDF	0.08	0.10
ATLAS	0.02	0.14
LHC-b	0.01	0.05
TESLA	0.04	0.07

Not the best, but interesting cross check!

Branching ratios $B^0 \to \pi^0\pi^0$, $B^+ \to \pi^+\pi^0$

- needed to disentangle direct from penguin contributions in $B^0 \to \pi^+\pi^-$
- only possible in e^+e^--machines
- can be done at LC with good calorimetry and good b-tagging/anti-b-tagging



- Competitive results to BarBar can be obtained

Conclusions

- With less than a year of running on the Z huge progress on $\sin^2\theta^l_{eff}$ can be made
- Also Zbb-couplings can be improved a lot
- Only modest improvement in Z-lineshape observables possible
- Some interesting cross checks in B-physics, however no "golden channel" (yet)