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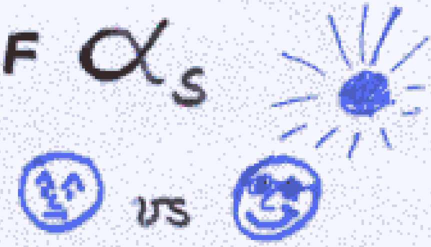
Determination of α_s at Giga-Z



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Outline

- Z observables vs α_s
- ADLO performances
- Improvement forecasts:
  - $q\bar{q}$ selection
  - $\mu^+\mu^-$ & $\tau^+\tau^-$ selections
  - luminosity determination
- TESLA potential for $\alpha_s(M_Z^2)$
- Summary - Conclusion

? how much may ΔR_ℓ be reduced ?

? which improvement fom Γ_Z and σ_0^h ?

Motivations for α_s determinations

- Fundamental parameter

- Essential to test gauge structure of strong interactions

- Allows to test hypotheses on nature well above exp$^{\underline{tal}}$ energy range (GUT)

- Enters theoretical prediction of many observables measured/used in future exp$^{\underline{ts}}$

Sensitivity of Z Observables to α_s

- $\Gamma_h = \Gamma_h^0 (1 + \delta_{QCD})$ where $\delta_{QCD} \sim \frac{\alpha_s}{\pi} \lesssim 4\%$

  $\hookrightarrow R_\ell = \frac{\Gamma_h}{\Gamma_\ell}$

- $\Gamma_Z = \Gamma_L + \Gamma_h = \Gamma_Z^0 + \Gamma_h^0 \delta_{QCD} \simeq \Gamma_Z^0 (1 + \underbrace{0.7\,\delta_{QCD}}_{\lesssim 3\%})$

- $$\sigma_0^h = \frac{12\pi \Gamma_\ell}{M_Z^2} \cdot \frac{\Gamma_h^0 (1+\delta_{QCD})}{\left[\Gamma_L + \Gamma_h^0 (1+\delta_{QCD})\right]^2} = \frac{12\pi \Gamma_\ell \Gamma_h^0}{M_Z^2 (\Gamma_Z^0)^2} \cdot \frac{1+\delta_{QCD}}{1 + 2\left(\frac{\Gamma_L \cdot \Gamma_h^0}{(\Gamma_Z^0)^2} + \left(\frac{\Gamma_h^0}{\Gamma_Z^0}\right)^2\right)\delta_{QCD}}$$

  $$\simeq \sigma_0^{h0} \cdot \frac{1+\delta_{QCD}}{1+1.4\,\delta_{QCD}} \simeq \sigma_0^{h0} (1 - \underbrace{0.4\,\delta_{QCD}}_{\sim 1.5\%})$$

► goals:

	R_ℓ	Γ_Z [MeV]	σ_0^h [nb]
S.M.	20.740	2495.7	41.479
ADLO	20.767 ±0.025	2495.2 ± 2.3	41.541 ±0.037
QCD corr.	~ 0.760	~ 65	~ 0.640
$\delta\alpha_s = 0.001 \Rightarrow$	~ 0.006	~ 0.55	~ 0.005

$$\alpha_s^{ADLO}(M_Z^2) = 0.1200 \pm 0.0024 + \underbrace{0.0029 - 0.000}_{M_H = 100^{+900}_{-0}\ \text{GeV}}$$

ADLO performances

- $\frac{\Delta\varepsilon_h}{\varepsilon_h} \oplus \frac{\Delta bg_h}{bg_h} = 0.04 - 0.10\%$

- $\frac{\Delta\varepsilon_\mu}{\varepsilon_\mu} \oplus \frac{\Delta bg_\mu}{bg_\mu} = 0.09 - 0.31\%$

- $\frac{\Delta\varepsilon_\tau}{\varepsilon_\tau} \oplus \frac{\Delta bg_\tau}{bg_\tau} = 0.18 - 0.65\%$

- $\frac{\Delta L^{exp}_{syst}}{L} = 0.033 - 0.09\%$

- $\frac{\Delta L^{th}_{syst}}{L} = 0.054\%$

$\mu^+\mu^-$ selection of ALEPH

$\varepsilon_{sel} \simeq 84\%$

present $\Delta^{A}_{syst} \sim \Delta^{TESLA}_{stat} \times 10$

↳ reduction is crucial

Source	$\Delta\sigma/\sigma$ (%)
Acceptance	0.05
Momentum calibration	0.006 (0.009)
Momentum resolution	0.005
Photon energy	0.05
Radiative events	0.05
Muon identification	$\simeq$ 0.001 (0.02)
Monte Carlo statistics	0.06
Total	0.10 (0.11)

→ track. eff.
$\cos\theta^*$ cut
ISR/FSR simul.

} $\mu^+\mu^-\gamma$

- tracking eff. can be better controled
- ISR/FSR simul. will improve (mat. budget!)
- acceptance knowledge ↗ with stat.
- $\mu^+\mu^-\gamma$ MC " " " " $ time
- ECAL response for γ will be ≫LEP calo.

⟶ Δ_{syst} can be reduced by 3-5(?)

$\tau^+\tau^-$ selection of ALEPH

$\varepsilon_{sel} \simeq 94\%$

"price" of ε_{sel} det.^{on}

Source	A	B	A⊕B
Acceptance	0.03	0.04	0.05
Efficiency			
Preselection cuts	0.05	0.04	0.07
$q\bar{q}$ cuts	0.06	0.09	0.11
Bhabha cuts	0.03	0.04	0.05
Dimuon cuts	0.03	0.03	0.05
Total Efficiency	0.08	0.11	0.14
Background			
$\gamma\gamma$	0.04	-	0.04
$q\bar{q}$	0.04	-	0.04
Bhabha	0.05	0.01	0.05
Dimuon	0.02	0.01	0.02
Total background	0.07	0.01	0.08
MC statistics	-	0.07	0.07
Total	0.12	0.13	0.18

scales $\sim \frac{1}{\sqrt{N}}$

many uncertainty components will follow the stat. accuracy of their estimate ...

$\longrightarrow$ may improve by $\gg 3$ (?)

Multi-Hadron selection of L3

$\varepsilon_{sel} \simeq 99.5\%$ for $\sqrt{s'} > 0.1\sqrt{s}$

Source		1993 – 1995
Monte Carlo statistics	[‰]	0.04 – 0.10
Acceptance ≡ fragm. on	[‰]	0.21
Selection cuts → move cut values	[‰]	0.30
Trigger	[‰]	0.12
Total scale	[‰]	0.39 – 0.40
Non-resonant background	[pb]	3
Detector noise	[pb]	1
Total absolute	[pb]	3.2

reduced by higher stat.
→ better tuning

better constrai
from higher stat.

Increase of stat by factor 200
⇒ all these uncertainties should go down by at least a factor 2-3 (possibly 5!)

Luminosity determination of OPAL

Rad. Metrology	$1.4\ 10^{-4}$	
Inner Anchor	$(1.4 \oplus 0.2)\ 10^{-4}$	
Background	$(0.8 \oplus 0.8)\ 10^{-4}$	*
Total External	$(2.2 \oplus 0.8)\ 10^{-4}$	
Energy	$(1.8 \oplus 0.1)\ 10^{-4}$	*
Beam param.	$(0.6 \oplus 0.6)\ 10^{-4}$	*
Clustering	$1.0\ 10^{-4}$	
MC stat.	$(0.8 \oplus 0.3)\ 10^{-4}$	
Total Simul.^{on}	$(2.3 \oplus 0.6)\ 10^{-4}$	

ALL $(3.2 \oplus 1.0)\ 10^{-4}$

- "geometrical" systematics will $\searrow$
- background (beam related) and ΔE_{LEP} may be difficult to squeeze

$\rightarrow (2 \oplus 1)\ 10^{-4}$?

Precision expected from TESLA (1)

- Δ_{stat}
  - $4\,10^7 \mu\bar{\mu} + 4\,10^7 \tau\bar{\tau} \Rightarrow \frac{1}{\sqrt{N_{\mu\mu+\tau\tau}}} \simeq 1.1\,10^{-4}$ (add e^+e^- in barrel?)
  - $\sim 10^9 q\bar{q} \Rightarrow \frac{1}{\sqrt{N_{q\bar{q}}}} \simeq 3\,10^{-5}$ (negligible)
  - $2\text{-}3\,10^9$ small angle Bhabha $\rightarrow \Delta L_{stat}$ neglected
- Δ_{syst}
  - $\Delta_{syst}^{q\bar{q}} = \pm 3.9\,10^{-4}$ from L3
  - $\Delta_{syst}^{\ell^+\ell^-} = \pm 9\,10^{-4}$ from ALEPH
  - $\Delta L_{syst}^{exp} = \pm 3.3\,10^{-4}$ from OPAL
  - $\Delta L_{syst}^{th} = \pm 5.4\,10^{-4}$

$\longrightarrow$ consider improvements of :

- $\Delta_{syst}^{q\bar{q}}$, $\Delta_{syst}^{\ell^+\ell^-}$, ΔL_{syst}^{exp} by factor 3 and 5
- ΔL_{syst}^{th} by factor 2 and 3

Precision expected from TESLA (2)

- R_ℓ $[10^{-4}]$

$\Delta_{syst}^{q\bar{q}}$	$\Delta_{syst}^{\ell^+\ell^-}$	$\Delta_{stat}^{\ell^+\ell^-}$	ΔR_ℓ	$\Delta\alpha_s$
3.9	9	1.1	9.9	0.003
<3	<3	–	3.4	0.0011
<5	<5	–	2.2	0.0007

- σ_0^h $[10^{-4}]$

$\Delta_{syst}^{q\bar{q}}$	ΔL_{syst}^{exp}	ΔL_{syst}^{th}	$\Delta\sigma_0^h$	$\Delta\alpha_s$
3.9	3.3	5.6	7.5	0.0058
<3	<3	–	5.7	0.0045
<3	<3	<3	2.5	0.0019
<5	<5	<3	2.1	0.0016
<5	–	<3	3.9	0.0030

- Γ_Z $\quad \Delta\Gamma_Z = \pm 1\,\mathrm{MeV} \longrightarrow \Delta\alpha_s = \pm 0.002$ (if no effect from $\Delta\alpha_{em}$)

- combination (ignoring correlations)

$\Delta R_\ell / R_\ell$ $[10^{-4}]$	9.9	3.4	3.4	2.2	3.4
$\Delta\sigma_0^h / \sigma_0^h$ $[10^{-4}]$	7.5	5.7	2.5	2.1	3.9
$\Delta\alpha_s(M_Z^2)$ $\pm$	0.0016	0.0009_5	0.0008_6	0.0006	0.0009_2
best component	.002	.0011	.0011	0.0007	0.0011

Summary - Conclusion

- $\alpha_s(M_Z^2)$ likely to be determined at Giga-Z with $\sim 0.0015 - 0.0005$ accuracy

- the factor 2-5 improvement w.r.t. to LEP relies on:
  - $\Delta_{stat} < \Delta_{stat}^{LEP}/10$
  - better detector performance $\left(\begin{matrix}\text{tracking}\\ \text{calo.}\end{matrix}\right)$
  - better detector understanding (data stat., mat. budget, redundancy, align^{t}, ...)
  - more accurate simulations (gener., detector)
  - more precise S.M. predictions: $m_t, M_H \rightarrow \Delta\alpha_s \sim 0$ $(\Delta\alpha_{em}^{h}$, H.O.?)

$\Longrightarrow$ will need substantial effort!

- R_ℓ will be the most sensitive observable; Γ_Z and σ_0^h will reduce $\Delta\alpha_s$ by $\lesssim 20\%$

- present study needs refinement $\rightarrow$ end '00