Determine The Running of α_{QED} from Small Angle Bhabha Scattering

A. Arbuzov
D. Haidt
C. Matteuzzi
M. Paganoni
L.T.

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The Problem of Luminosity at LEP

1989 Expected Experimental Accuracy on the Luminosity $\frac{\Delta\mathcal{L}}{\mathcal{L}} \simeq 2 \div 4\,\%$.

1994 $\frac{\Delta\mathcal{L}}{\mathcal{L}} \simeq 0.08 \div 0.1\,\%$

Dominated by the theoretical error

$\sqrt{s} = M_{Z^0}$ $\quad \mathcal{L} = \frac{N_{Bhabha}}{\sigma^{Th}_{Bhabha}}$ $\quad N_{Bhabha} \leftarrow 0.09\%$, $\quad \sigma^{Th}_{Bhabha} \leftarrow 0.25\%$?

Precision Physics at LEP

"Internal"

↓

Line Shape
Decay Widths
Asymmetries
⋮

"External"

↓

Luminosity Determination

$N_a = \mathcal{L}\, \sigma_a$

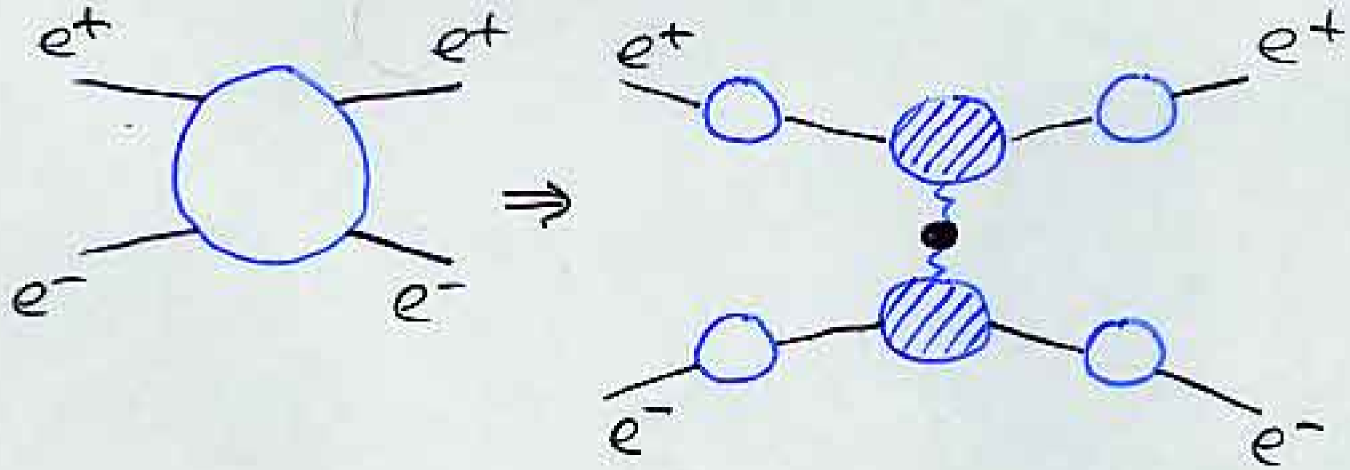
Luminosity $\longleftrightarrow$ Small Angle Bhabha Scattering

LEP

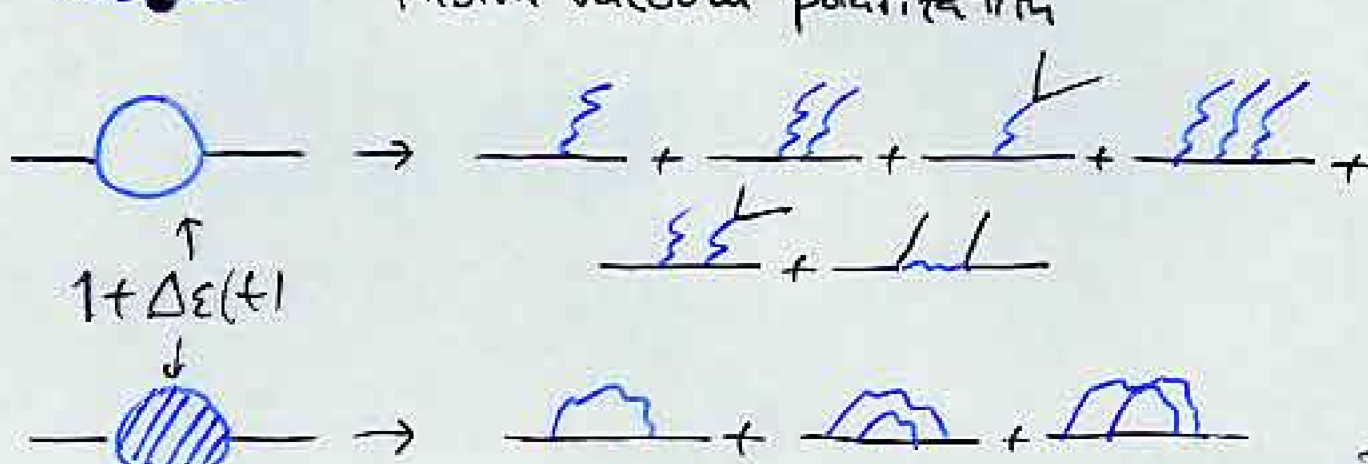
1994 → Increasing Accuracy to evaluate Radiative Corrections

- A Next-to-Next-to-Leading accurate determination of the Small Angle Bhabha Cross Section

$$\sigma^{\text{Bhabha}} = \sigma^{(0)}\left(1+\sigma_{\theta,W}+\sigma^{\gamma}+\sigma^{2\gamma}+\sigma^{e^+e^-}+\sigma^{3\gamma}+\sigma^{e^+e^-\gamma}\right)$$



 Photon vacuum polarization



1995 → Theoretical Accuracy $\simeq 0.11\%$
Small Angle Bhabha

$$\frac{d\sigma}{dt} = \frac{d\sigma^{(0)}}{dt}\left(\frac{\alpha(t)}{\alpha(0)}\right)^2 (1+\Delta\varepsilon(t))$$

$$\alpha(q^2) = \frac{\alpha(0)}{1-\Delta\alpha(q^2)}$$

Vacuum Polarization

- $\boxed{\Delta\alpha = \Delta\alpha^{\text{leptons}} + \Delta\alpha^{\text{quarks}\,*}}$ (* see figures)

$1+\Delta\varepsilon(t)$ All the Radiative corrections

$O(\alpha)$ $\alpha L^2, \alpha L, \alpha$ const.

$O(\alpha^2)$ $\alpha^2 L^4, \alpha^2 L^3, \alpha^2 L^2, \alpha^2 L$

- Neglected terms $\simeq O(10^{-4})$

  - Weak Radiative Corrections $O(10^{-5})$
  - QED corrections to weak contrib. $O(10^{-4})$
  - Interference $s \leftrightarrow t$ $O(10^{-5})$
  - Semi collinear configurations of pair production $O(10^{-4})$
  - Higher orders n photons $n>4$

⋮

The Standard Model

$SU(2) \otimes U(1)$

contains QED in an Effective Way

scales $q^2, t \ll M_Z^2, M_W^2$

- Small angle Bhabha scattering is a QED Process effectively*

  (*see table)

- The $\alpha(t)$ corresponds to the QED coupling evaluated at the scale t

for small angles

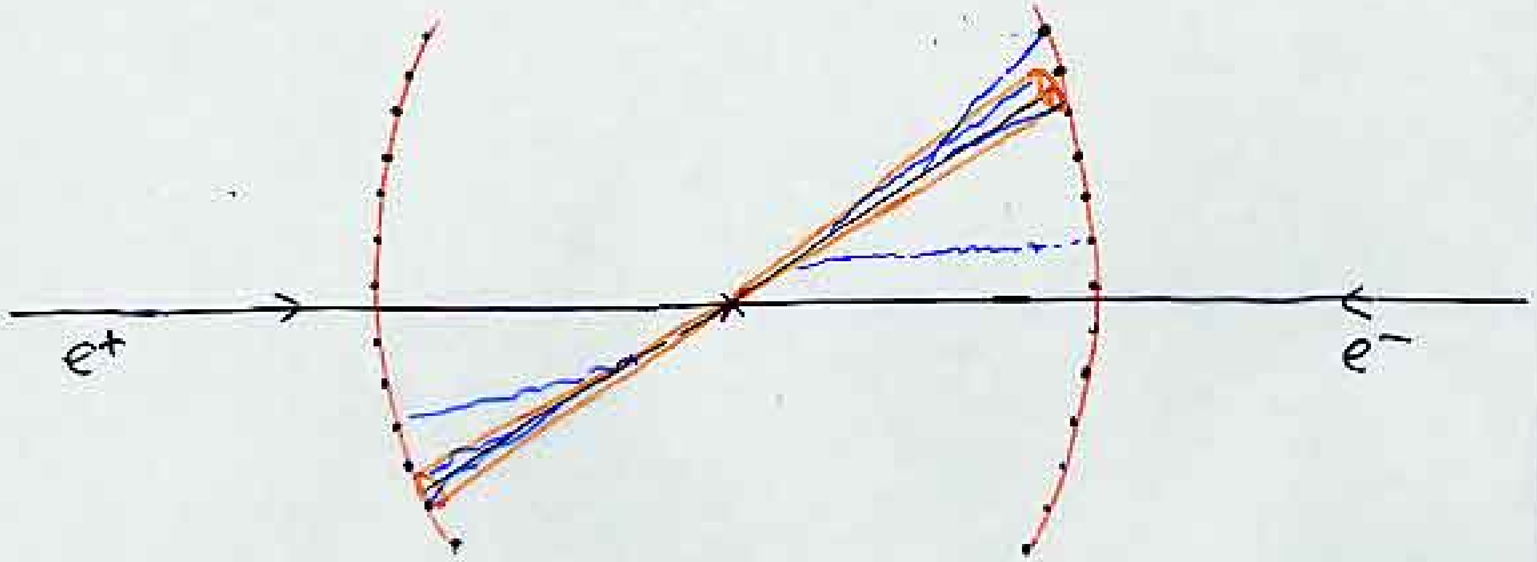
$$t = -\frac{s}{2}(1-\cos\theta) \cong -\frac{s}{2}\left(-\frac{\theta^2}{2}\right) \simeq \frac{s\theta^2}{4}$$

$\sqrt{s} = 91.187$

$\theta = 30$ mrad $\quad t = 2.2\ GeV^2$

$\theta = 150$ mrad $\quad t = 30\ GeV^2$

The Luminosity Data Sample



- Monte Carlo Codes

  – NLLBHA Semianalitical ($\alpha^2 L$)

  – LABSMC Monte Carlo for Small Angle Bhabba ($\alpha^2 L$)

to be compared with

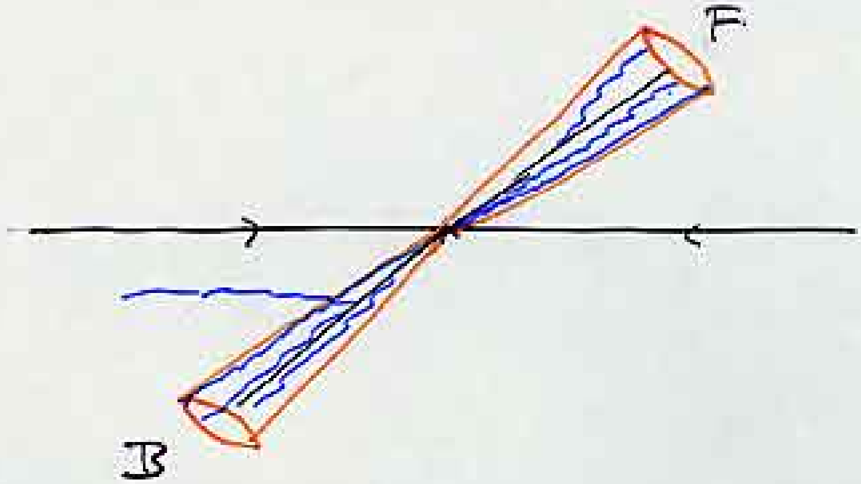
– BHLUMI

used to determine the Luminosity by the LEP Collaborations

NLLBHA, LABSMC: Contain EW Matrix Elements Born + O(α) QED

NLLBHA, LABSMC, BHLUMI: Describe all the small angle region with $\theta \gg \frac{m_e}{E_{beam}}$

Calorimetric type Measurement



1. The cluster is reconstructed
2. Find the cluster Center
3. Consider only the highest energy cluster in each emisphere F, B
4. Energy Cuts $\min(E_F, E_B) > 0.65\, E_{beam}$

   $\max(E_F, E_B) > 0.95\, E_{beam}$

   this suppresses the effects of the initial state radiation
5. Take the angle of the center of the most energetic cluster $\Rightarrow \theta$

6. This for several "rings" segmented detector to reproduce the differential distribution
7. Can be extended to NLC energies ?

F. Jegerlehner
DESY 99-07

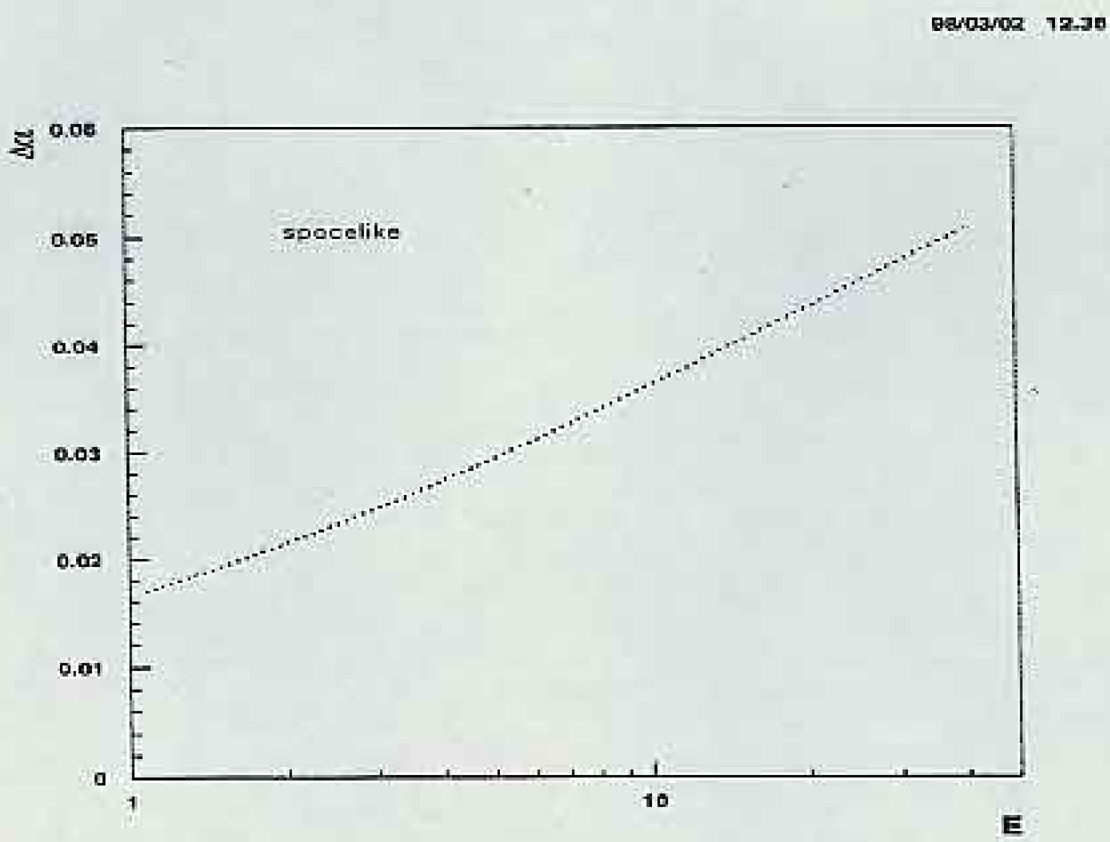


Figure 1: $\Delta\alpha$ versus $E=\sqrt{-t}$

F. Jegerlehner
DESY 99-07

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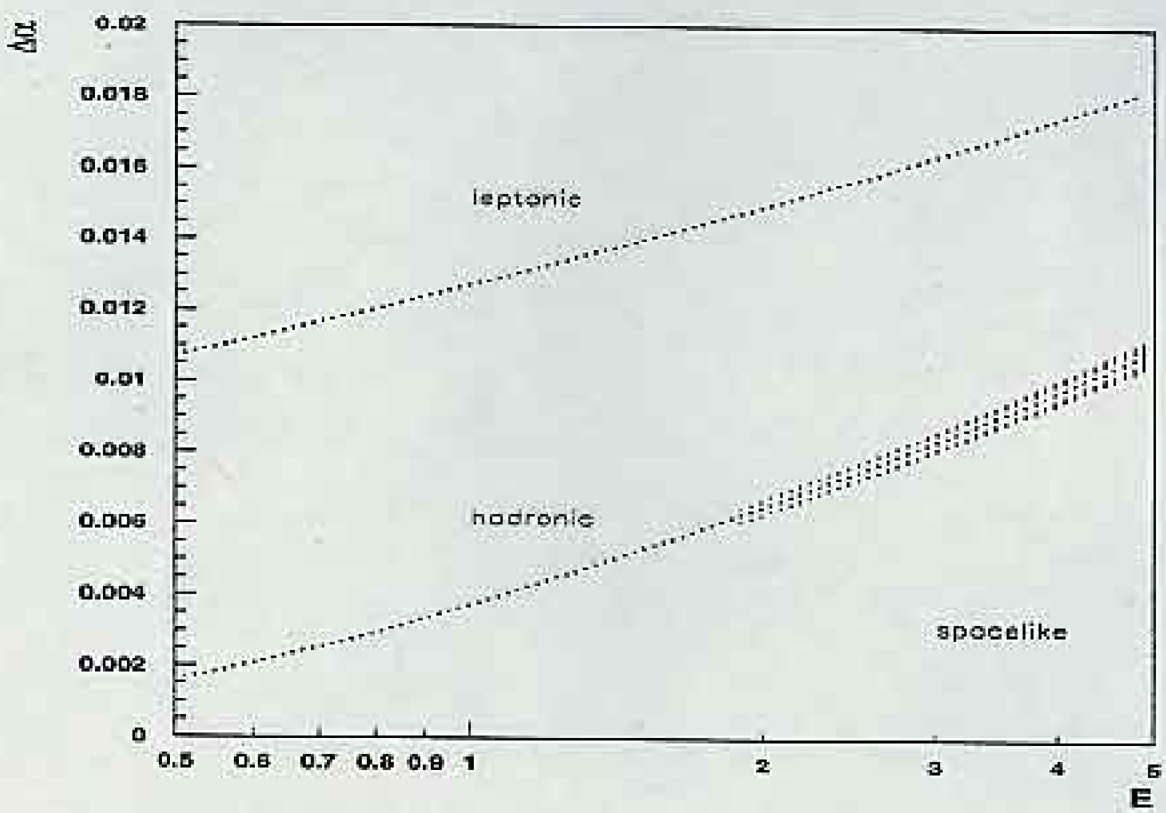

Figure 2: $\Delta\alpha$ *for leptons and hadrons versus* $E=\sqrt{-t}$

The cross section is integrated over angular range 45–110 mrad.

E_{CM}	91.187 GeV	91.2 GeV	189 GeV	206 GeV
QED	51.428	51.413	11.971	10.077
QED_t	51.484	51.469	11.984	10.088
EW	51.436	51.413	11.965	10.072
$EW+VP_t$	54.040	54.016	12.743	10.745
EW+VP	54.036	54.013	12.742	10.744

add a column for 800 GeV and angular range 5 to 50 mrad

NLC, TESLA

$$\frac{d\sigma}{dt} = \frac{d\sigma^0}{dt}\left(\frac{\alpha(t)}{\alpha(0)}\right)^2(1+\Delta\epsilon(t))$$

In Table 2 we give the theoretical predictions for the ingredients of Eq. (3), averaged over the 7 rings:

$$\sigma_i^0 = \int^{R_i} \mathrm{d}t \frac{\mathrm{d}\sigma^0}{\mathrm{d}t}, \qquad \langle(\alpha(t)/\alpha(0))^2\rangle = \int^{R_i} \frac{\mathrm{d}t}{t_{\max} - t_{\min}} \left(\frac{\alpha(t)}{\alpha(0)}\right)^2,$$

$$\langle 1 + \Delta\epsilon(t)\rangle = \frac{1}{\sigma_i^0 \langle(\alpha(t)/\alpha(0))^2\rangle} \int^{R_i} \mathrm{d}t \frac{\mathrm{d}\sigma}{\mathrm{d}t}. \tag{1}$$

Table 1: Theoretical predictions for the averages over the rings.

No. of ring	1	2	3	4	5	6	7
	$E_{\mathrm{CM}} = 91.2$ GeV						
σ_i^0	20.078	7.8711	3.8737	2.1866	1.3534	0.8951	0.6224
$\langle(\alpha(t)/\alpha(0))^2\rangle$	1.0425	1.0475	1.0516	1.0551	1.0582	1.0609	1.0634
$\langle 1+\Delta\epsilon(t)\rangle$	0.9426	0.9439	0.9411	0.9395	0.9241	0.8918	0.7986
	$E_{\mathrm{CM}} = 189$ GeV						
σ_i^0	4.6745	1.8323	0.9016	0.5088	0.3148	0.2081	0.1446
$\langle(\alpha(t)/\alpha(0))^2\rangle$	1.0554	1.0613	1.0661	1.0702	1.0736	1.0767	1.0794
$\langle 1+\Delta\epsilon(t)\rangle$	0.9376	0.9387	0.9355	0.9322	0.9155	0.8846	0.7885
	$E_{\mathrm{CM}} = 200$ GeV						
σ_i^0	13.117	5.1422	2.5309	1.4284	0.8839	0.5846	0.4064
$\langle(\alpha(t)/\alpha(0))^2\rangle$	1.0565	1.0625	1.0673	1.0714	1.0749	1.0780	1.0807
$\langle 1+\Delta\epsilon(t)\rangle$	0.9374	0.9384	0.9347	0.9324	0.9150	0.8835	0.7881

$\leftarrow \pm\delta O(10^{-4})$

Conclusions

- A well established region of the phase space exists where it is possible to test QED and where weak effects are negligible

- The running of α can be measured directly within a pure QED framework at LEP and at NLC energies

- $\Delta\alpha = \Delta\alpha^{lept} + \Delta\alpha^{had}$, if the precision of the data allows, opens the possibility of separately determine $\Delta\alpha^{had}$ in an extended range of energies