Measurement of the $e^+e^-$ hadronic cross section at DAME via radiative return (for the KLOE collaboration)
The nature of the difference in the two theoretical evaluations of $\tilde{a}_\mu$ has to be understood in order to claim a discrepancy between (SM-)theory and experiment. More and better information on the hadronic contribution to the SM calculation of $\tilde{a}_\mu$ could help to clarify this difference and (together with a further reduction of the experimental error) give the claim a higher significance.

Status on $(g-2)$: 

$\tilde{a}_\mu$: Disagreement between $e^+e^-$ based and $t$ based evaluations.

The nature of the difference in the two theoretical evaluations of $\tilde{a}_\mu$ has to be understood in order to claim a discrepancy between (SM-)theory and experiment.
Particle factories have the opportunity to measure the cross section \( s(e^+ e^- \rightarrow \text{hadrons}) \) as a function of the hadronic c.m.s energy \( M_{\text{hadrons}}^2 \) by using the radiative return. This method (S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999) is a complementary approach to the standard energy scan.

Disadvantage

Requires precise calculations of Initial State Radiator. Requires good suppression of Final State Radiator. Systematic errors from luminosity, elt ...

Advantage

Data comes as by-product of standard program.
KLOE and DEAR/FINUDA

- two interaction points
- accumulator for efficient injection into main rings
- two separate rings to minimize beam-beam-effects
- e+e- collider with $\sqrt{s} = 1.020$ GeV

(a) Double Annular F-Factory for Nice Experiments

<table>
<thead>
<tr>
<th>BRs for selected decays</th>
<th>K^+K^-</th>
<th>K_SK_L</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>49.1%</td>
<td>34.1%</td>
</tr>
<tr>
<td>e+e- decay</td>
<td></td>
<td></td>
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</tbody>
</table>
Peak Luminosity @ KLOE IP:
2000 run: 4.5 pb⁻¹
2001 run: 7.5 x 10⁷ f⁻¹ cm⁻²
2002 run: 9.0 x 10⁸ f⁻¹

Max int. Luminosity in one day:
2000 run: 4.5 pb⁻¹
2001 run: 7.8 x 10³ f⁻¹ cm⁻²
2002 run: 9.0 x 10⁸ f⁻¹

DAΦNE Backgr. reduced

2002 run: 300 pb⁻¹ x 10⁷
2001 run: 190 pb⁻¹ x 10⁸
2000 run: 25 pb⁻¹ x 10⁷

Peak Luminosity @ KLOE IP:
2000 run: 4.5 pb⁻¹
2001 run: 7.5 x 10⁷ f⁻¹ cm⁻²
2002 run: 9.0 x 10⁸ f⁻¹

Max int. Luminosity in one day:
2000 run: 4.5 pb⁻¹
2001 run: 7.8 x 10³ f⁻¹ cm⁻²
2002 run: 9.0 x 10⁸ f⁻¹

DAΦNE Performance
KLOE: (KLOE Experiment)

- Magnet:
  - Superconducting coil (B=0.5 T)

- EM Calorimeter:
  - Lead/Scintillating fibres

- Drift chamber:
  - 12782 Sense Wires
  - 52140 Wires in total

- Beryllium Beampipe:
  - R=10 cm, 0.5 mm thick

- Drift chamber:
  - 4880 Pm
Electromagnetic Calorimeter

Drift Chamber

\[
\frac{E}{E} = 5.7\% / E(GeV) \quad \frac{T}{E} = 54\text{ ps} / E(GeV) \quad \oplus 50\text{ ps (Bunch length contribution subtracted from constant term)}
\]
Signal selection:

- $400 < \theta < 1400$°
- $150 < \theta < 1650$°
- $\theta > 1650$°

Pion tracks are measured at angles $40^\circ > \theta > 140^\circ$

Photons cannot be detected efficiently with $\text{EmC}$, untagged measurement in which we cut on the direction of the missing momentum.

The choice of this kinematical region was motivated by:

- Small relative contribution of FSR
- Reduced background contamination

Photons are required to be within $\theta > 150^\circ$ and $\theta < 1650^\circ$.
FSR suppression:

**ISR + FSR**

M2

pp

\(\%\)

\(\text{nb}/(\text{GeV})^2\)

\(dS_{(ISR+FSR)}\)

\(dM_{pp}^2\)

100 \(\times dS_{(FSR)}\)

\(dM_{pp}^2\)

Contribution of FSR < 1% for our selection cuts (i.e., model dependence negligible).

Initial State Radiation and Final State Radiation have been evaluated with MC (Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999):

Our approach is to treat Final State Radiation of the pions as a "background" and suppress it in the measurement using kinematical cuts.

FSR Suppression:
Background subtraction:

To reduce Bhabha contamination, a $p$-e-separation is performed using a Likelihood function based on:

- TOF of charged clusters
- Shape and energy deposition of charged clusters

The event is selected if one of the charged tracks is identified to be a pion.

\[
\begin{align*}
p &+ p^- \rightarrow e^- + e^- + g + g \\
\text{before cutting on likelihood function} &\quad \text{after cutting on likelihood function}
\end{align*}
\]
Background subtraction:

The track mass is the particle mass for the two tracks obtained by using the momentum-conservation and the assumption that both particles have the same mass $M_{\text{track}}$.

\[ g_2^q = M_{\text{track}}^2 - p_1^2 + p_2^2 \]

The signal is further selected by performing a cut in the kinematic variable $M_{\text{track}}$ in order to reduce the background. The track mass for the signal is further selected by a cut on $M_{\text{track}} = 120$ MeV.

$M_{\text{track}}$ (105 MeV) is selected by a cut on $M_{\text{track}} = 120$ MeV.

In order to reduce the background, another kinematic variable $M_{\text{track}}$ is performed a cut in the signal.
In a preliminary attempt to extract the pion form factor, we analyzed 73 pb$^{-1}$ of 2001 data according to the analysis items discussed after selection:

- 100,000 events with statistical error/bin < 1% for $M_{pp}^2 > 0.45$ GeV$^2$ after selection:
  - 100,000 events with statistical error/bin < 1%

For $M_{pp}^2 > 0.45$ GeV$^2$

- Statistical error/bin > 1%

After selection: 1,000,000 events analyzed items discussed.

For 73$^{rd}$ data according to the pion form factor, we analyzed.

In a preliminary attempt to extract the $M_{pp}^2$ spectrum:

\[
\frac{d}{dM_{pp}^2} N_{obs} \sqrt{N_{bkg}} = \frac{dM_{pp}^2}{dM_{pp}^2}
\]
Extraction of pion form factor:

$$F_p(M_{pp}^2) = \frac{d \sigma_{ppg}(M_{pp}^2)}{d \sigma_{ppg}}$$

We divide the $p^+ p^- g$ cross section by the cross section $p^+ p^- g$ for "pointlike" pions which is obtained from the MC generator by setting $F_p = 1$.

$$\frac{\langle \frac{d}{d^3W} \rangle_{F_p=1}}{\langle \frac{d}{d^3W} \rangle_{F_p}} = \frac{\langle \frac{d}{d^3W} \rangle_{F_p=1}}{\langle \frac{d}{d^3W} \rangle_{F_p}}$$

The MC was computed with 2*10^6 events of Monte Carlo with $F_p = 1$, which is obtained from the MC generator by setting $F_p = 1$. We divide the cross section by the cross section $p^+ p^- g$ for "pointlike" pions.

$$= (2.538 \pm 0.001) \text{ nb}$$

$$= (24.43 \pm 0.01) \text{ nb}$$
The next step is to refine the analysis with the full statistics of 2001 (ca. 170 pb⁻¹).

Current work is focused on:

- Efficiency estimation
- Luminosity
- Detector resolution (unfolding)
- Residual background subtraction

Pion form factor:

Correcting for efficiencies, normalizing to luminosity and dividing the spectrum $d^2F_p/dM^2$ by the radiation function $H(M^2_{pp})$, we get a preliminary extraction of the pion form factor.

$|F_p|^2$ for $M^2_{pp}$ (GeV):

No background subtraction has been performed on this first attempt.

KLOE PRELIMINARY
Theoret. Generators with rad. corrections

† Background

\[ L_{\text{diff}} = \frac{N_{\text{Bhabha}} (q) \cdot (1 - \text{Background})}{\text{MC} (E)} \]

KLOE uses "Large Angle Bhabhas" to measure the luminosity:

\[ \Delta \theta = 430 \text{ nb} \]

\[ E^+ > 400 \text{ MeV} \]

\[ \text{Accil.} > 9^\circ \]

\[ 55^\circ > \Delta \theta > 125^\circ \]
No limitation for luminosity precision > 1% found.

We use 2 independent theoretical generators to calculate the effective cross section for the actual selection cuts.

1) Berends (Drago, Venanzoni)
2) BABAYAGA (Calame, Montagna)

Agreement = (0.1 ± 0.1) %

Running Conditions:
Calibration of EMC and drift chamber
Changing s, p, beam position

Efficiencies (EMC, DC)
Acceptance
Difference DATA-MC:

Systematics

C.M.C. Calame et al.
The background is completely rejected by the trackmass cut, and the position go along the beampipe and can not be detected. From MC, we expect a background contribution at low values of $M^{2}_{pp}$.

This process could create a background for our analysis if the electron and the positron go along the beampipe and can not be detected.
Conclusions:

- Last year we have performed an "attempt" on 73pb$^{-1}$ of data in order to test a method of getting the pion form factor from 2001 (170 pb$^{-1}$) and evaluating systematics of the measurement. We are in the final phase towards a publication of our results.

- Now we are refining this measurement using the full statistics from background contaminations, detector resolution, etc.

- Already with this reduced data sample, there are no limitations by statistics.

- Last year we have performed an "attempt" on 73pb$^{-1}$ of data in order to test a method of getting the pion form factor from a measurement utilizing the radiative return.
Isospin symmetry breaking effects have to be taken into account.

Isospin invariance assumed, one can relate the isovector cross sections to the spectral function

\[ \frac{W^2}{\sigma} \sum_{\lambda \tilde{\lambda}} s_{\lambda, \tilde{\lambda}} = \sum_{\lambda \tilde{\lambda}} W^2 \frac{\sigma_{\lambda, \tilde{\lambda}}}{s_{\lambda, \tilde{\lambda}}} \]

Specifically, to the

\[ s_{\lambda, \tilde{\lambda}} \]

isospin symmetry breaking effects have to be taken into account.

\[ \text{decays:} \]
Dispersion integral:

\[ \sigma_{\text{had}} \text{can be expressed in terms of } s_{\text{hadrons}} \text{ by the use of a dispersion integral:} \]

\[ \int ds_{\text{hadrons}} K(s) = \frac{4\pi^2}{\alpha^2} \]

\[ K(s) \text{ is a steady function that goes with } 1/s \]

\[ s \text{ is the c.o.m.-energy squared of the hadronic system} \]

\[ E_{\text{cut}} \text{ is the threshold energy above which } \text{QCD is possible} \]

\[ s_{\text{hadrons}} \text{ (e+e^- hadrons) by the use of a dispersion integral} \]
The region around the energy of the $\pi^-$-meson adds with ca. 72\% to the total value of a $\pi^- + e^- \rightarrow e^+ + p$. So in this energy region the $\pi^-$-meson decays to 100\% in $p^- + \bar{p}$, so in this energy region the

\[ (e^+e^- \rightarrow p^- + \bar{p}) \]

Low energy contribution: [Jegerlehner; hep-ph/0104304] The total value of a had. [Jegerlehner; hep-ph/0104304] The region around the energy of the $\pi^-$-meson adds with ca. 72\% to
The nature of the difference in the two evaluations of $a_{\text{had}}$ is currently not understood. The reduction of the error on the hadronic contribution to the SM calculation could (together with a further reduction of the experimental error) give this discrepancy between theory and experiment a higher significance.

The current status of $a_{\text{had}}$ from experiment and (SM-) theory:

$$\Delta a_{\text{exp}} - \Delta a_{\text{theor, SM}} = 0.9 - 3.0 \pm 0.0$$

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Based on $e^+e^-$ data
DEHZ hep-ph/0208177 v3
Nucl. Phys. B 76, 245

Based on $K^0\bar{K}^0$ decays

E821 hep-ex/0208001
```

The current status of $a_{\text{had}}$ from experiment and (SM-) theory:

$$g-2)$
Only statistical errors have been taken into account!

MC output has been interfaced with the detector simulation program (MC compared with the MC)

DATA compared with the MC

\( \frac{d^2}{dM^2}(nb/0.01GeV^2) \)

\( M^2 (GeV^2) \)
Pion form factor (prelim.):

Data points have been fitted with the Gounaris-Sakurai-Parametrization

\[ m_r, G_r, b, |d|, y_d \]

are free parameters of the fit, while

\[ m_w, G_w, m_r^*, G_r^* \]

are fixed to CMD-2 values

\[
\begin{align*}
  m_r &= 775.1 \pm 0.5 \text{ MeV} \\
  G_r &= 147.1 \pm 0.8 \text{ MeV} \\
  b &= -0.08 \pm 0.002 \\
  |d| &= (2.893 \pm 0.6) \times 10^{-3} \\
  y_d &= (124.8 \pm 9.0) \text{ MeV} \\
\end{align*}
\]

(G.J. Gounaris and J.J. Sakurai, Phys.Rev. Lett. 21 (1968), 244)

B+b+d+=rwwrp

Residual background

Data points have been fitted with the Gounaris-Sakurai-Parametrization

\[
\frac{1 + \frac{B}{BW_{GS}}(1 - \frac{1}{2} BW_{GS})}{1 + \frac{1}{BW_{GS}}} = \frac{F}{S}
\]

KLOE = KLOE data

KLOE Fit = KLOE fit