Measurement of the hadronic cross section at KLOE

- Introduction
- Large photon angle analysis (in progress)
- Conclusion
Hadronic contribution to \((g-2)_\mu\)

Magnetic momentum: \(\bar{\mu} = g_\mu \frac{e\hbar}{2m_\mu c} \bar{s}\) with \(\mu = (g_\mu - 2)/2\)

Due to quantum corrections:
\[
a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{had}} + a_\mu^{\text{EW}}
\]

\(a_\mu^{\text{had}}\) includes contributions not evaluable in pQCD, but it can be provided by \(\sigma(e^+ e^- \rightarrow \text{hadrons})\) by means of dispersion relation:

\[
a_\mu^{\text{had}} = \int \frac{ds \sigma^{\text{had},\exp}(s) K(s)}{4\pi^2 (4m^2)}
\]

\(K(s)\) is a steady function that goes with \(1/s\), enhancing low energy contributions of \(\sigma^{\text{had}}(s)\)

In energy range <1 GeV, \(e^+ e^- \rightarrow \pi^+ \pi^-\) contributes to more than 60% to \(a_\mu^{\text{had}}\)
σ(e⁺e⁻ → π⁺π⁻) with Radiative Return

Particle factories (fixed c.m. energy) have the opportunity to measure the cross section \( \sigma(e^+ e^- \rightarrow \text{hadrons}) \) as a function of the hadronic c.m. energy \( M^2_{\text{hadrons}} \) by using the **radiative return**.

\( \sigma(e^+ e^- \rightarrow \text{hadrons}) \) with Radiative Return

\[ M^2_{\text{hadr}} \frac{d\sigma(e^+ e^- \rightarrow \text{hadrons} + \gamma)}{dM^2_{\text{hadrons}}} = \sigma(e^+ e^- \rightarrow \text{hadrons}) H(M^2_{\text{hadr}}) \]

This method is a **complementary approach** to the energy scan.

Precise knowledge of ISR - process:
Radiation function \( H(Q^2, \theta, M^2_{\phi}) \)

MC generator: Phokhara


"Radiative Return" to \( \rho(\omega) \) resonance \( e^+e^- \rightarrow \rho(\omega) \gamma \rightarrow \pi^+\pi^-\gamma \)
Small angles analysis

- Acceptance
  \(50^\circ < \theta_\pi < 130^\circ, \theta_{\text{miss}} < 15^\circ\) and \(\theta_{\text{miss}} > 165^\circ\)
- No photon tagging

Event analysis and background evaluation:

\[
\frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\Delta M_{\pi\pi}^2} \times \frac{1}{\varepsilon_{\text{Select.}}} \times \frac{1}{L}
\]

- Division by the radiator function, and correction for the vacuum polarization and FSR contribution

Cross section

\[
\sigma(e^+e^- \rightarrow \pi^+\pi^-)
\]

Low relative FSR contribution and background contamination

Drift Chamber

EM Calorimeter

Hadronic cross section @ KLOE

D. Leone

... see talk of A. Denig
(T 112 Eingeladene Vorträge II tomorrow 15:30)
Result of small angles analysis


KLOE data 2001
$L_{\text{int}} = 140 \text{ pb}^{-1}$

its impact on $a_\mu$

DEHZ’03 [e+e- based]
DEHZ’03 [$\tau$ based]

New

Based on CMD-2 and KLOE-Measurements

Theory:
DEHZ’04 [e+e-]

BNL-E821 04
208 ± 5.8

Experiment E821

$a_\mu = 11 659 000 \cdot 10^{-10}$

A. Höcker @ ICHEP04: hep-ph/0410081

KLOE and CMD-2 in fair agreement in $\rho$ peak region.

Hadronic cross section @ KLOE

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Large photon angles analysis

Motivations

- At large photon angles it is possible to investigate the low $M_{\pi\pi}$ region (20% contribution to $a_\mu$).
- The relative amount of FSR is very big $\Rightarrow$ possibility to test the model used in MC to simulate it.

MC: $\text{FSR} / (\text{ISR} + \text{FSR})$

50% 30% 10% $M_{\pi\pi}^2$ [GeV$^2$]

Events $\theta_{\text{miss}} < 15^\circ$ or $\theta_{\text{miss}} > 165^\circ$

50$^\circ < \theta_{\text{miss}} < 130^\circ$

.....but

- statistic becomes an issue at threshold
- huge amount of background from $\pi^+\pi^-\pi^0$
Signal selection

Tracks: $50^\circ < \theta_\pi < 130^\circ$

In this region we detect photons tagged measurement

Event is selected if at least one photon has

$50^\circ < \theta_\gamma < 130^\circ$

$E_\gamma > 50$ MeV
Background rejection 1/2

The detection of photons is crucial in the rejection of $\pi^+\pi^-\pi^0$.

By cutting on the angle between the missing momentum $\vec{p}_\gamma = -\vec{p}_{\text{miss}} = -(\vec{p}_+ + \vec{p}_-)$ and the tagged photon $\Omega = a \cos \left( \frac{\vec{P}_\gamma \cdot \vec{P}_{\text{miss}}}{|\vec{P}_\gamma| |\vec{P}_{\text{miss}}|} \right)$ we have a powerful separation between $\pi^+\pi^-\gamma$ and $\pi^+\pi^-\pi^0$. 

![Diagram showing the angle distribution and separation between $\pi^+\pi^-\gamma$ and $\pi^+\pi^-\pi^0$ MC events.](image)
Further cuts for background rejection

Radiative Bhabhas $e^+e^- \rightarrow e^+e^-\gamma$ are separated by means of a Likelihood-Method (signature of EmC-Clusters and time of flight of particle tracks).

To reject $\mu^+\mu^-\gamma$ and $\pi^+\pi^-\pi^0$ background a cut in the plane $M_{trk}$ vs. $M_{\pi\pi}^2$ is applied. $M_{trk}$ is a kinematical variable obtained by solving

$$
\left(M_\phi - \sqrt{\vec{p}_1^2 + M_{trk}^2} - \sqrt{\vec{p}_2^2 + M_{trk}^2}\right)^2 - |\vec{p}_1 + \vec{p}_2|^2 = 0
$$
Preliminary spectrum

KLOE data 2001
$\int \nu = 140 \text{ pb}^{-1}$

The spectrum extends down to the 2-pions threshold
(10 times more statistics on tape!)

Hadronic cross section @ KLOE

After acceptance — $\pi^+\pi^+\gamma \text{ MC}$
$\pi^+\pi^-\pi^0 \text{MC}$

After the whole selection

Data

$\pi^+\pi^-\pi^0 \text{MC}$
Charge asymmetry

The final state in case of ISR or FSR is in an odd or even charge conjugation state respectively. At large photon angles, the amount of FSR is large and the interference between the two terms gives a sizeable effect in the charge asymmetry $A$

$$A(\theta) = \frac{N_{\pi^+}(\theta) - N_{\pi^-}(\theta)}{N_{\pi^+}(\theta) + N_{\pi^-}(\theta)}$$

**Preliminary**

Full range of $M_{\pi\pi}^2$

$2m_{\pi}^2 - 0.85 \text{ GeV}^2$

- **DATA**
- **MC (sQED)**

$\Rightarrow$ test the model of FSR (sQED) used in Montecarlo, by comparing data vs Montecarlo

Hadronic cross section @ KLOE

D. Leone
The charge asymmetry is also a very sensitive parameter for studying the presence and nature of the scalar particles $f_0(980)$ and $f_0(600)$ from $\phi$ radiative decays.

Czyz, Grzelinska, Kühn, hep-ph/0412239

Look at the charge asymmetry as a function of $M_{\pi\pi}$ we find large deviations from the prediction of sQED at the very high and low $M_{\pi\pi}$ region.
KLOE has published the first measurement of the $e^+e^-\rightarrow\pi^+\pi^-$ cross section with the radiative return, proving the feasibility and high precision of this new method.

A complementary analysis is in progress:
- measure the $e^+e^-\rightarrow\pi^+\pi^-$ cross section down to the 2-pions threshold region
- study the issue of FSR

In addition, an upgrade of the small photon angle analysis is in progress using 2002 data.

Measurement of $\sigma(e^+e^-\rightarrow\pi^+\pi^-\gamma)/\sigma(e^+e^-\rightarrow\mu^+\mu^-\gamma)$ (normalization to muons) $\Rightarrow$ direct measurement of $R$

This work is partly supported by:

Emmy Noether Programm
Deutsche Forschungsgemeinschaft DFG