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KLOE

Towards a New KLOE Luminosity Measurement

Particle Physics Annual Meeting 2026

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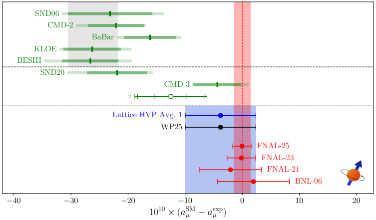
The current situation of a_μ

- Anomalous magnetic moment of the muon

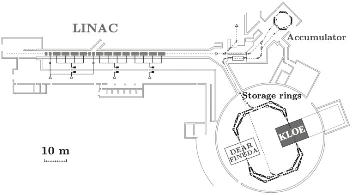
$$a_\mu = \frac{g-2}{2}$$

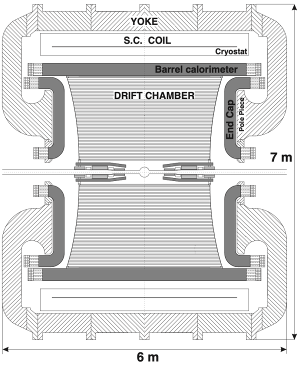
- Precision measurements from $g-2$ at Fermilab show a persistent discrepancy with the dispersive Standard Model prediction of a_μ
- Recent lattice results reduce the tension, but are in tension with dispersive results
- The main source of uncertainty lies in the hadronic contribution:
  - **Dispersive approach:** Uses $e^+e^- \to$ hadrons data
  - **Lattice QCD:** First-principles numerical calculation
- Dispersive approach is used at KLOE to determine the leading-order hadronic contribution a_μ^{HLO}



Physics Reports 1143 (2025) 1-158

DAΦNE and KLOE





The DAΦNE (*Double Annular Φ-factory for Nice Experiments*) is an e^+e^- collider located in Frascati near Rome, Italy, running at the ϕ peak at $\sqrt{s} = 1020\,\text{MeV}$

KLOE (K Long Experiment) detector consisting of an inner drift chamber surrounded by an electromagnetic calorimeter

Measuring a_μ^{HLO} at KLOE

- The leading-order hadronic contribution, a_μ^{HLO}, cannot be computed perturbatively and must be determined from data
- It is obtained via a dispersion relation connecting a_μ^{HLO} to the hadronic cross section:

$$a_\mu^{\mathrm{HLO}} = \frac{\alpha^2}{3\pi^2} \int_{m_\pi^2}^{\infty} ds \, \frac{K(s)}{s} \, \frac{\sigma(e^+e^- \to \mathrm{hadrons})}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

- $a_\mu^{HLO} \propto \frac{1}{s}$ means low-energy contributions are weighted more strongly
- KLOE measures the dominant contribution, $a_\mu^{\pi\pi}$, by:

$$e^+e^- \to \pi^+\pi^-\gamma$$

- Using initial-state radiation (ISR), the effective centre-of-mass energy is reduced, enabling a scan over a range of energy

Previous KLOE analyses

KLOE has published three a_μ^{HLO} results in the past: KLOE08, KLOE10 and KLOE12.

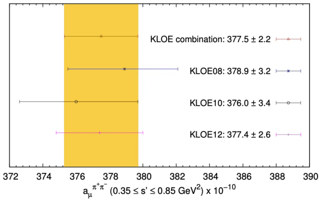
- KLOE08 and KLOE10 measured $\sigma(\pi\pi(\gamma))$ by normalizing to the integrated luminosity (**absolute approach**):

$$s\,\frac{d\sigma(\pi\pi(\gamma))}{ds_\pi} = \sigma_{\pi\pi}(s_\pi)\,H(s_\pi, s)$$

- KLOE12 measured $\sigma(\pi\pi(\gamma))$ by normalizing the $\pi\pi\gamma$ sample to the $\mu\mu\gamma$ sample (**ratio approach**):

$$\sigma_{\pi\pi(\gamma)} = \sigma_{\mu\mu(\gamma)}\,\frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}$$

With this approach, the luminosity and several systematics cancel, however, an additional analysis of muon events is required



Combination of results gives a value of

$$a_\mu^{\pi\pi}(0.10 < s' < 0.95\,\mathrm{GeV}^2) = (489.8 \pm 5.1) \times 10^{-10}.$$

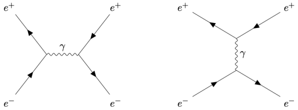
The current KLOE analysis: KLOE-NXT

- The ongoing KLOE-NXT analysis uses 1.7 fb^{-1} of data collected in 2004–2005, corresponding to ~ 25 million previously unanalysed $\pi\pi\gamma$ events
- First blinded KLOE analysis, reducing potential bias via random event removal that shifts the extracted a_μ
- Key improvements: significantly higher statistics, improved Monte Carlo generators, improved Data/Monte Carlo tuning, potential ML methods for background subtraction
- Target total uncertainty of 0.4%:

$$0.1\% \text{ (stat)} \oplus 0.2\% \text{ (th)} \oplus 0.3\% \text{ (sys)}$$

Luminosity study

- The ratio method requires a highly precise analysis of $\mu\mu\gamma$ events, demanding accurate knowledge of the integrated luminosity and associated systematic uncertainties
- Luminosity is measured with the KLOE detector using Very Large Angle Bhabha (VLAB) events, $e^+e^- \to e^+e^-$
  $\int \mathcal{L}dt = \frac{N_{\text{obs}} - N_{\text{bkg}}}{\sigma_{\text{eff}}}$, where σ_{eff} is taken from Monte Carlo simulation
- Advantages of Bhabha events:
  1. Very high statistics ($\sigma \sim 430\,\text{nb}$) for $55° < \theta_{\text{clu}} < 125°$
  2. Excellent theoretical precision of the process
  3. Clean and well-defined event topology



Luminosity study: Systematics and goals

- Previous luminosity study from 2006, based on 2001 data
- Dominant systematics arise from Data/Monte Carlo differences, which must be carefully evaluated and accounted for
- This analysis will:
  - Analyse 2002, 2004, and 2005 datasets individually
  - Use the updated BABAYAGA@NLO generator (C.M. Carloni Calame et al., Nucl. Phys. Proc. Suppl. 131 (2004) 48
  - Perform an independent cross-check using $e^+e^- \to \gamma\gamma$ events

	correction (%)	systematic error (%)
acceptance	$\delta_{accept} = +0.25$	$\Delta_{accept} = 0.25$
tracking	–	$\Delta_{track} = 0.06$
clustering	$\delta_{split} = +0.14$	$\Delta_{cluster} = 0.11$
background	$\delta_{bkg} = -0.55$	$\Delta_{bkg} = 0.08$
cosmic veto	$\delta_{cosmic} = +0.40$	–
dependence on $\sqrt{s}$	$\delta_{\sqrt{s}} = +0.10$	$\Delta_{\sqrt{s}} = 0.10$
E_{clu} drifts	–	$\Delta_{E_{clu}} = 0.10$
Total experimental	$\boldsymbol{\delta_{tot} = +0.34}$	$\boldsymbol{\Delta_{tot} = 0.32}$

Systematics from 2006 luminosity study

Eur.Phys.J.C 47 (2006) 589–596

VLAB event selection

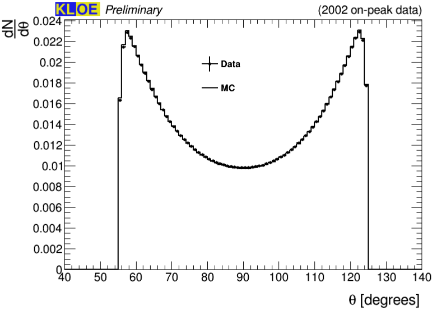
- **Pre-selection:** at least two energy clusters with $800\,\text{MeV} > E_{\text{clu}} > 240\,\text{MeV}$, within $4\,\text{ns}$, and separated by $d > 200\,\text{cm}$
- **LAB selection (calorimeter only):** two clusters with $800\,\text{MeV} > E_{\text{clu}} > 300\,\text{MeV}$ in the barrel region. The pair minimising the acollinearity

$$\zeta = |\theta_{\text{clu}_1} + \theta_{\text{clu}_2} - 180^\circ|$$

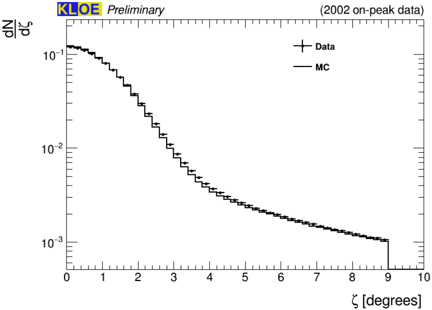
  is selected, with $\zeta < 10^\circ$
- **Final VLAB selection:** inclusion of drift chamber information to improve selection and suppress background. Two oppositely charged tracks are required with $|p| > 400\,\text{MeV}$, satisfying track quality cuts, as well as tighter angular requirements on the clusters

Preliminary luminosity results: Clusters

Initial work studying 2002 dataset evaluating Data/Monte Carlo differences. Resolution differences were found in cluster variables and smearing applied to Monte Carlo in order to match resolution of data, by fitting the difference of the reconstructed cluster positions, to the extrapolated cluster positions from the tracks to the calorimeter

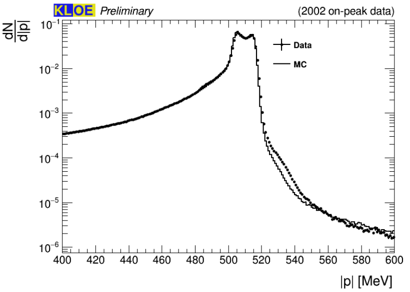


Polar angle of VLAB clusters after Monte Carlo smearing

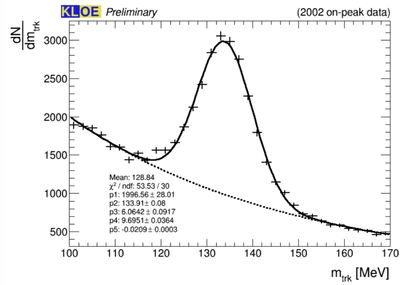


Acollinearity of VLAB clusters after Monte Carlo smearing

Preliminary luminosity results: Tracks



Track momentum of selected VLAB events



Background subtraction based on Gaussian fit of trackmass (m_{trk}) distribution of data with background due to collinear $\pi^+\pi^-$ events.

m_{trk} is evaluated from

$$\left(\sqrt{s} - \sqrt{|\mathbf{p}_+|^2 + M_{\rm trk}^2} - \sqrt{|\mathbf{p}_-|^2 + M_{\rm trk}^2}\right)^2 - (\mathbf{p}_+ + \mathbf{p}_-)^2 = 0$$

Conclusion

- Reducing uncertainties in the hadronic contribution is essential to clarifying the source of the discrepancy
- The KLOE-NXT result will provide precise input to the SM prediction of a_μ
- The new luminosity study is a key component of the KLOE-NXT analysis, aiming to improve the overall precision of the $\mu\mu\gamma$ analysis, with work currently in progress to evaluate all of the relevant associated systematic uncertainties

Thank you!

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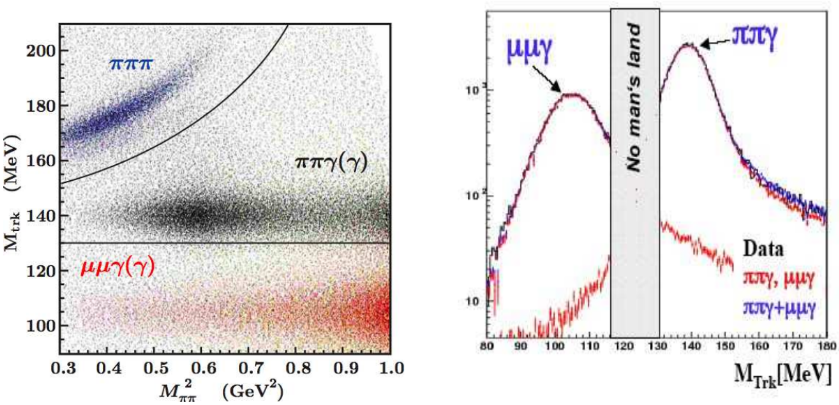
Backup

Pion/Muon separation



$$\left(\sqrt{s} - \sqrt{|\mathbf{p}_+|^2 + M_{\rm trk}^2} - \sqrt{|\mathbf{p}_-|^2 + M_{\rm trk}^2}\right)^2 - (\mathbf{p}_+ + \mathbf{p}_-)^2 = 0$$

Resolution smearing