KLOE data and prospects with 1.7 fb^{-1} for a_μ^{HLO}

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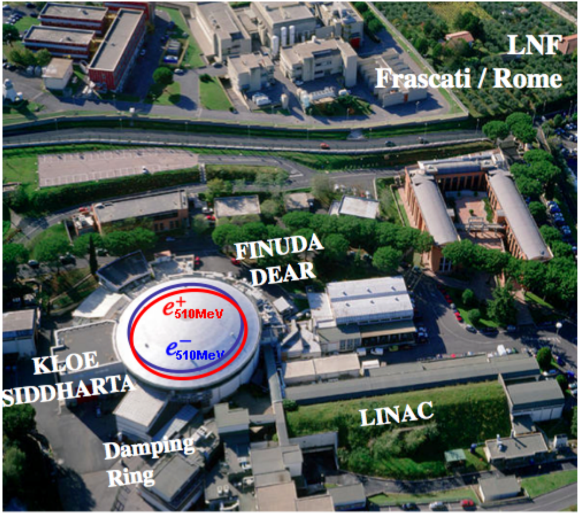
DRESDEN concept

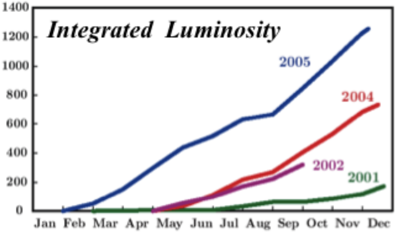
HZDR HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

DAΦNE: A ϕ factory



DAΦNE: A ϕ factory

e^+e^- collider with $\sqrt{s} = m_\phi \simeq 1.02$ GeV



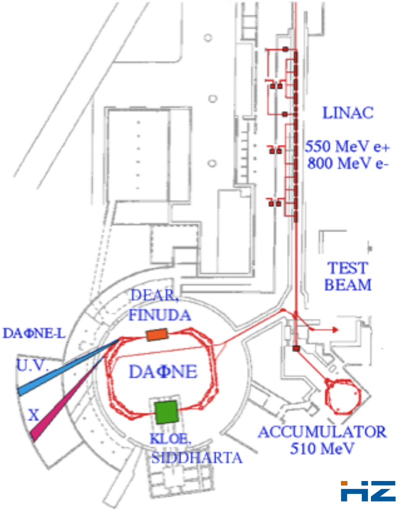
Peak luminosity $L_{\text{peak}} = 1.4 \cdot 10^{32} \text{cm}^{-2}\ \text{s}^{-1}$

Total KLOE int. luminosity:

$\int L dt \sim 2.1\ \text{fb}^{-1}$ (2001 - 2005)

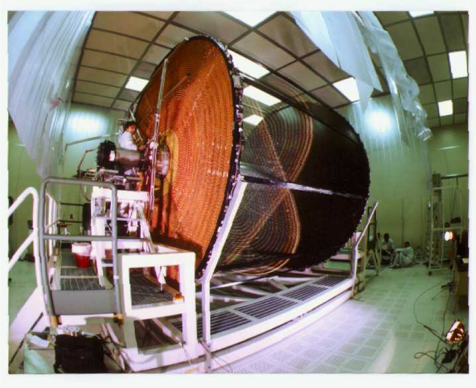
2006:

- Energy scan with 4 points around m_ϕ
- 250 pb^{-1} at $\sqrt{s} = 1$ GeV



The KLOE detector:

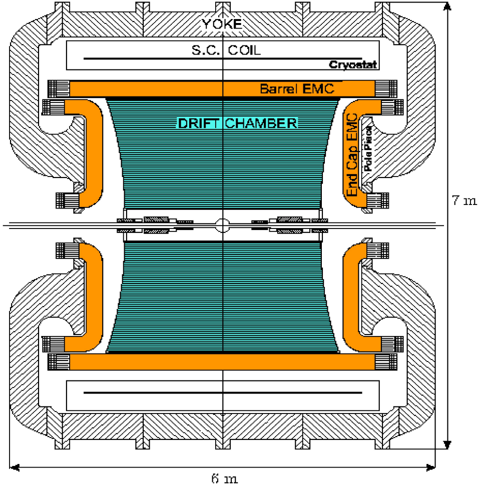
Driftchamber:



$$\sigma_{r\phi} = 150\mu m \,,\, \sigma_z = 2mm$$
$$\sigma_p/p = 0.4\%$$

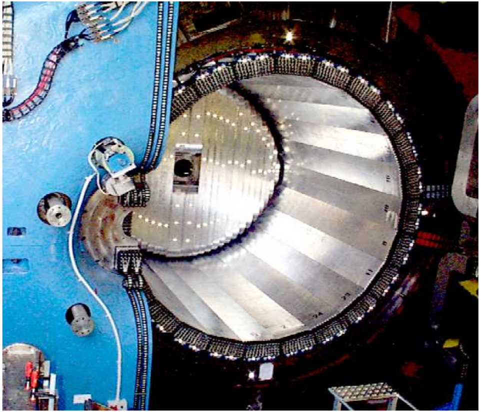
Excellent momentum resolution

KLOE Detector



The KLOE detector:

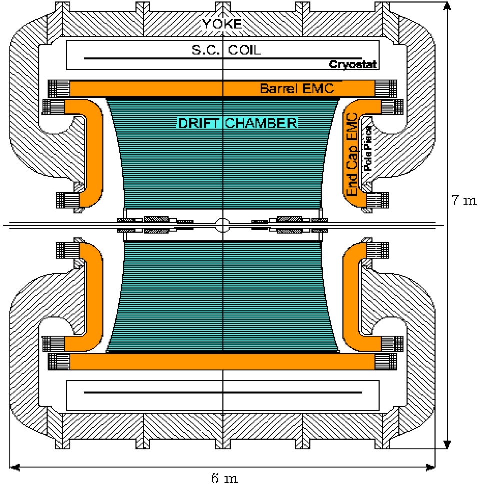
Electromagnetic Calorimeter



$$\sigma_t = 54\text{ps}/\sqrt{E(GeV)} \oplus 100\text{ps},$$
$$\sigma_E/E = 5.7\%/\sqrt{E(GeV)},$$

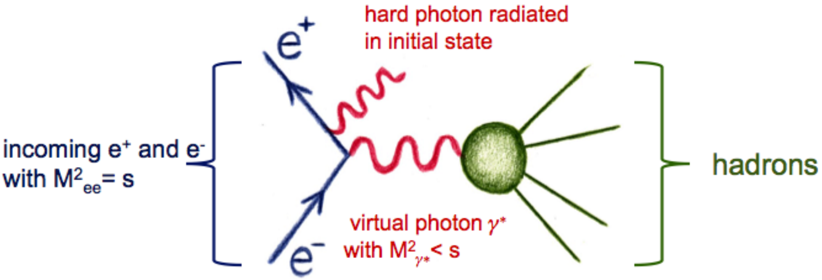
Excellent time resolution

KLOE Detector



Initial State Radiation

Particle factories measure hadronic cross sections as a function of the hadronic c.m. energy using a Radiative Return to energies below the collider energy $\sqrt{s}$.

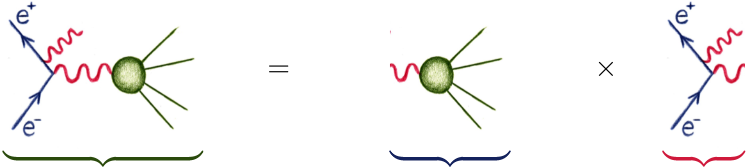


Emission of hard γ in the bremsstrahlung process reduces available energy to produce hadronic system.

Initial State Radiation

Relate measured differential cross section $\mathrm{d}\,\sigma_{\mathrm{had}+\gamma}/\mathrm{d}\,M^2_{\mathrm{had}}$ to hadronic cross section σ_{had} using radiator function $H(s, M^2_{\mathrm{had}})$:

$$\frac{\mathrm{d}\,\sigma(e^+e^- \to \mathrm{had} + \gamma)}{\mathrm{d}\,M^2_{\mathrm{had}}} = \frac{\sigma(e^+e^- \to \mathrm{had}, M^2_{\mathrm{had}})}{s} \times H(s, M^2_{\mathrm{had}})$$



measured cross section | resulting cross section | radiator function

Requires precise calculation of radiator function $H(s, M^2_{\mathrm{had}})$, e.g. from PHOKHARA Monte Carlo event generator.

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ISR measurements at KLOE:

Two methods to obtain the 2π-cross section with **KLOE**:

- **Absolute normalization:** Normalize cross section from independent luminosity measurement using Bhabha events:

$$\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \frac{N^{\mathrm{sel}} - N^{bkg}}{\Delta M^2_{\pi\pi}} \cdot \frac{1}{\varepsilon_{sel}} \cdot \frac{1}{\int L dt}$$

The total cross section is then obtained from

$$\sigma_{\pi\pi}(M^2_{\pi\pi}) = s \cdot \frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} \frac{1}{H(s, M^2_{\pi\pi})}$$

ISR measurements at KLOE:

Luminosity is measured at KLOE using large angle Bhabha events:

$$55^o < \theta < 125^o$$

From the observed events, the integrated luminosity is evaluated via

$$\boxed{\int L\mathrm{d}t = \frac{N_{\mathrm{obs}} - N_{\mathrm{bkg}}}{\sigma_{\mathrm{eff}}}}$$

MC generator used for σ_{eff}: **BABAYAGA@NLO** [NPB758 (2006) 22]

- QED radiative corrections using Parton Shower approach
- Theoretical uncertainty around 0.1%
- Allows luminosity measurement at KLOE with 0.3% accuracy

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ISR measurements at KLOE:

Two methods to obtain the 2π-cross section with **KLOE**:

- **Normalization with muons:** Normalize $\pi\pi\gamma$ sample in each energy bin with $\mu\mu\gamma$ events:

$$|F_{2\pi}(s')|^2 = \frac{4(1+2m_\mu^2/s')\beta_\mu}{\beta_\pi^3} \cdot \frac{(d\sigma_{\pi\pi\gamma}/dM_{\pi\pi}^2)}{(d\sigma_{\mu\mu\gamma}/dM_{\mu\mu}^2)}$$

The cross section is then obtained from the formula

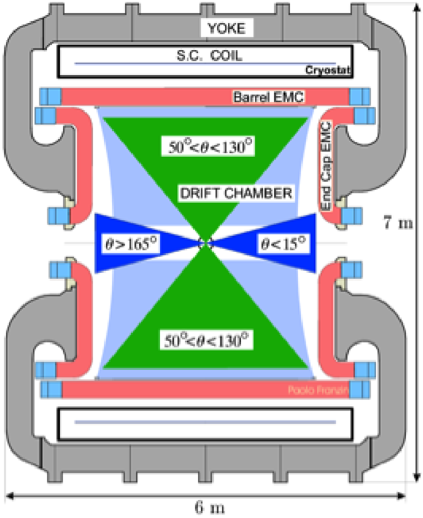
$$\sigma_{\pi\pi}(s') = \frac{\pi\alpha^2\beta_\pi^3}{3s'}|F_{2\pi}(s')|^2$$

Advantage: Cancellation of systematic effects and radiative corrections

Selection cuts for analyses:

2 pion (muon) tracks at large angles

$$50^o < \theta_{\pi,\mu} < 130^o$$



Selection cuts for analyses:

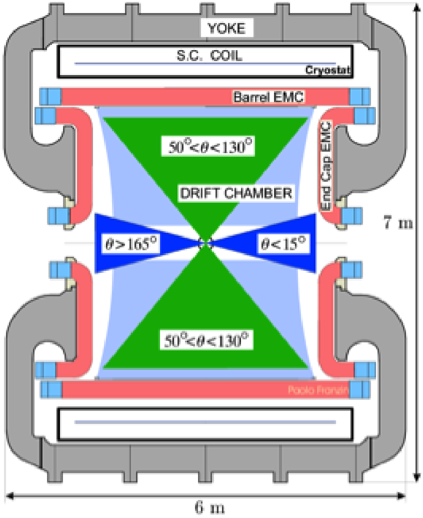
2 pion (muon) tracks at large angles

$$50^o < \theta_{\pi,\mu} < 130^o$$

- **Small angle cuts:**
  Photons at small angles

$$\theta_\gamma < 15^o \text{ or } \theta_\gamma > 165^o$$

  - high statistics for ISR events
  - low FSR contribution
  - suppression of $\phi \to \pi^+\pi^-\pi^0$ background
  - photon momentum from kinematics: $\vec{p}_\gamma = \vec{p}_{\rm miss} = -(\vec{p}_+ + \vec{p}_-)$
  - threshold region not accessible



Selection cuts for analyses:

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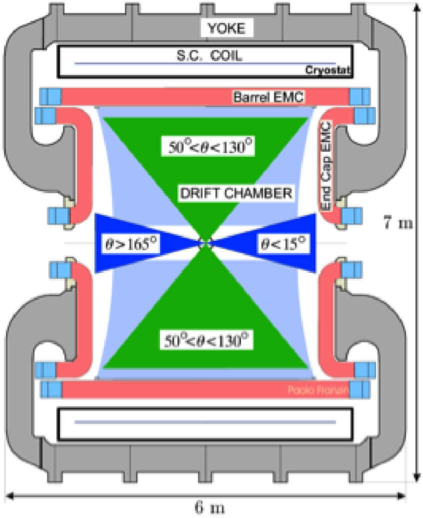
- **Large angle cuts:**
  Photons at large angles

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

  - lower signal statistics
  - higher FSR contribution
  - photon detection possible (4-momentum constraints)
  - threshold region accessible
  - more $\phi \to \pi^+\pi^-\pi^0$ background
  - irreducible background from $\phi \to f_0\gamma \to \pi^+\pi^-\gamma$



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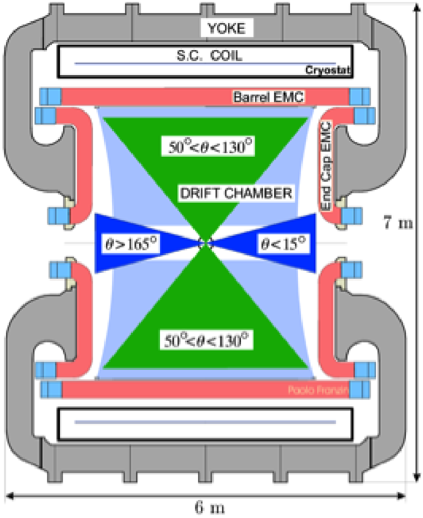
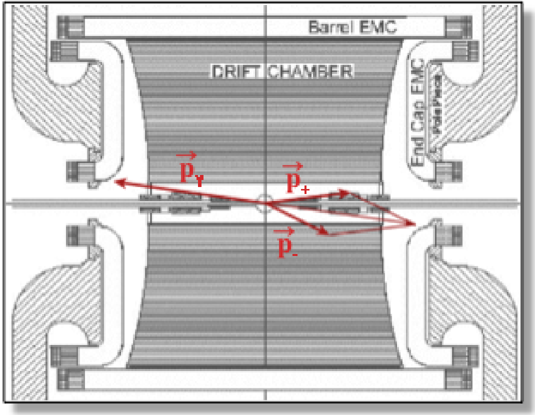
  - more $\phi \to \pi^+\pi^-\pi^0$ b... ...nd
  - irreducible ... from ... π γ

reduced using off-peak data



Threshold region:

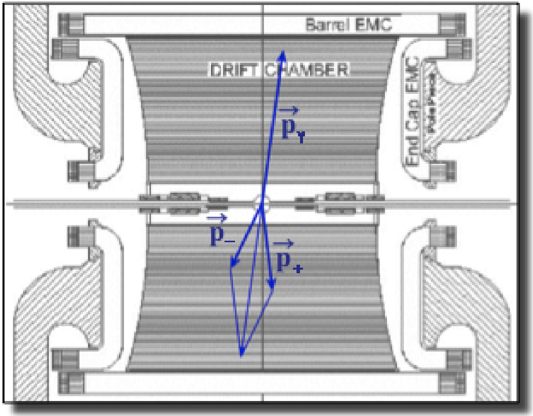
High energetic ISR photon (= small $M^2_{\pi\pi}$) at small angle forces also the pions to small angles, where they escape detection.
$\Rightarrow$ events with $M^2_{\pi\pi} < 0.35$ GeV^2 ($M_{\pi\pi} < 0.6$ GeV^2) are suppressed in small angle analysis.



Threshold region:

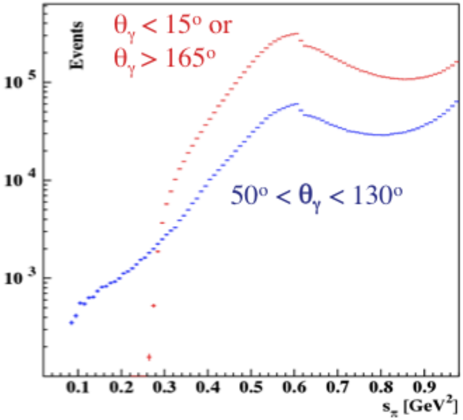
If the high-energy photon is emitted at large angles, also the pions will be at large angles, and can be detected.

$\Rightarrow 4m_\pi^2$ threshold reachable



Threshold region:

MC simulation (PHOKHARA):



The KLOE analyses:

- KLOE05: 60 points between 0.35 and 0.95 GeV^2,
  based on 141.4 pb^{-1} of data taken in 2001[a]
  (small angle photon cuts, normalization to Bhabha and PHOKHARA radiator)
- KLOE08: 60 points between 0.35 and 0.95 GeV^2,
  based on 240.0 pb^{-1} data taken in 2002[b]
  (small angle photon cuts, normalization to Bhabha and PHOKHARA radiator)
- KLOE10: 75 points between 0.1 and 0.85 GeV^2,
  based on 232.6 pb^{-1} data taken in 2006[c] with $\sqrt{s} = 1.00$ GeV
  (large angle photon cuts, normalization to Bhabha and PHOKHARA radiator)
- KLOE12: 60 points between 0.35 and 0.95 GeV^2,
  based on 240.0 pb^{-1} data taken in 2002[d]
  (small angle photon cuts, normalization to $\mu\mu\gamma$ events)

[a] Phys. Lett. B**606** (2005) 12
[b] Phys. Lett. B**670** (2009) 285
[c] Phys. Lett. B**700** (2011) 102
[d] Phys. Lett. B**720** (2013) 336

The KLOE analyses:

- KLOE05: 60 points between 0.35 and 0.95 GeV^2
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  Superseded by KLOE08!

- KLOE08: 60 points between 0.35 and 0.95 GeV^2,
  based on 240.0 pb^{-1} data taken in 2002[b]
  (small angle photon cuts, normalization to Bhabha and PHOKHARA radiator)

- KLOE10: 75 points between 0.1 and 0.85 GeV^2,
  based on 232.6 pb^{-1} data taken in 2006[c] with $\sqrt{s} = 1.00$ GeV
  (large angle photon cuts, normalization to Bhabha and PHOKHARA radiator)

- KLOE12: 60 points between 0.35 and 0.95 GeV^2,
  based on 240.0 pb^{-1} data taken in 2002[d]
  (small angle photon cuts, normalization to $\mu\mu\gamma$ events)

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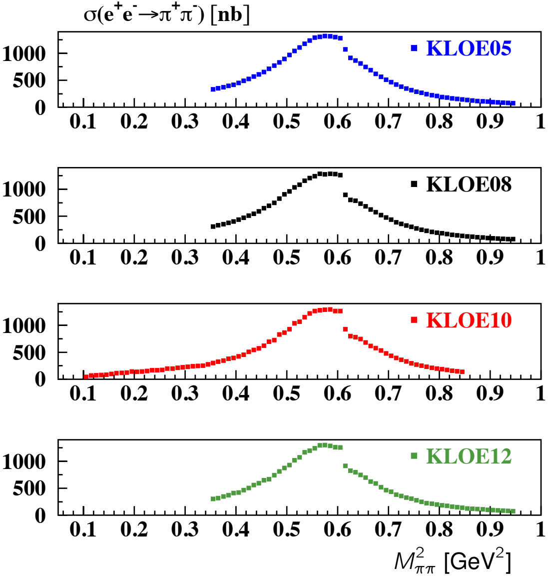
The KLOE analyses (2)



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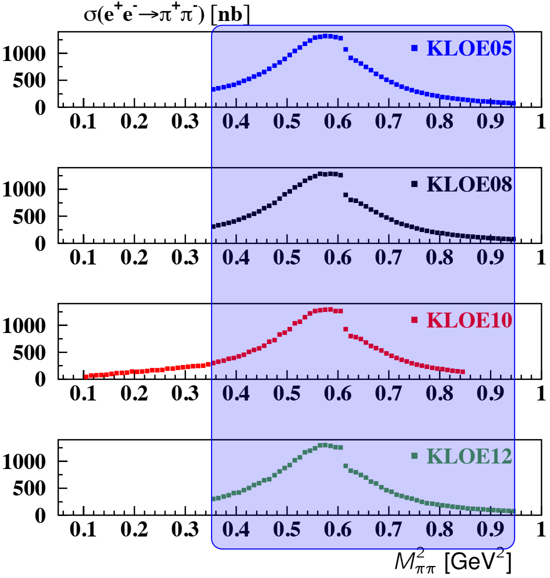

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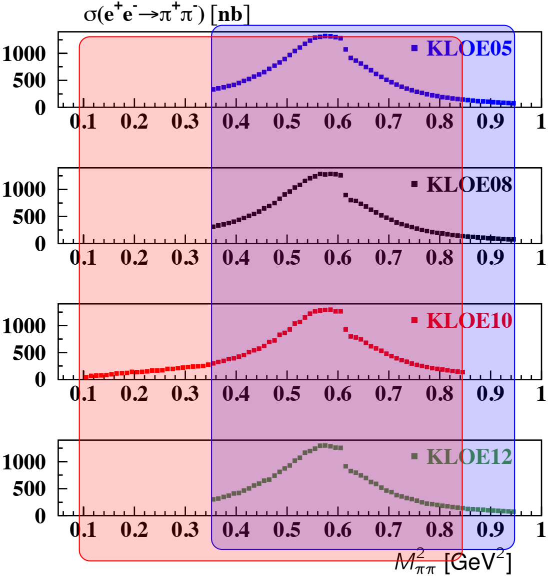
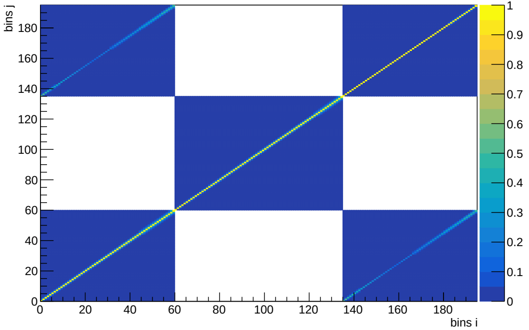


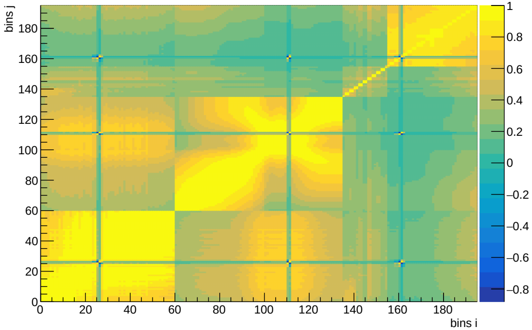
Combination of KLOE data

With the help of Alex Keshavarzi and Thomas Teubner, we managed to construct the statistical and systematic correlation matrices for the $60 + 75 + 60 = 195$ data points of the KLOE08, KLOE10 and KLOE12 analyses:

Statistical correlation matrix:



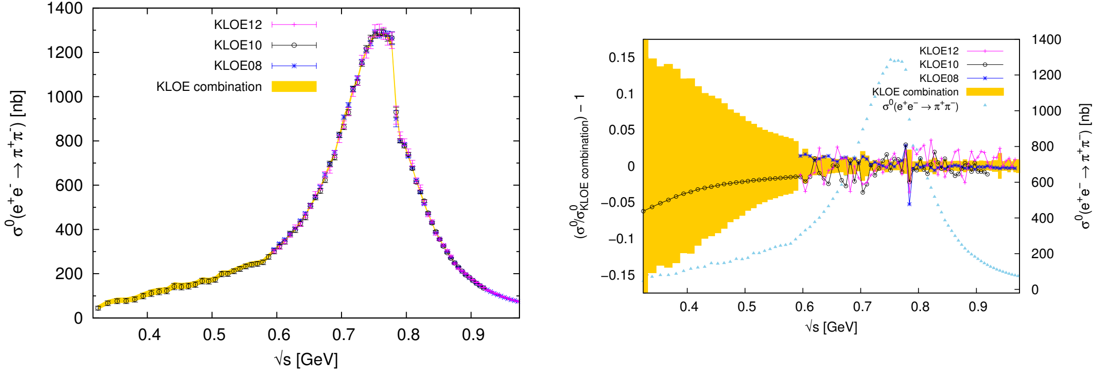
Systematic correlation matrix:



http://www.lnf.infn.it/kloe/ppg/ppg_2018/ppg_2018.html

Combination of KLOE data

Using the correlation matrices, it was possible to perform a combination of the three KLOE datasets (JHEP 1803 (2018) 173, arXiv:1711.03085):

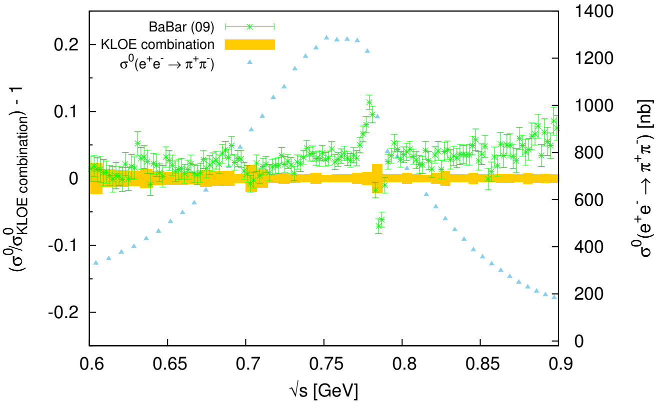


Plugging this in the dispersion integral for $a_\mu^{\pi\pi}$, one obtains in the range of $0.10 < s < 0.95$ GeV^2

$$a_\mu^{\pi^+\pi^-} = (489.8 \pm 1.7_{\text{stat}} \pm 4.8_{\text{sys}}) \times 10^{-10}$$

The BaBar-KLOE discrepancy

The tension between the two most precise measurements of the 2π-channel spoils the resulting uncertainty on a_μ^{HLO}:



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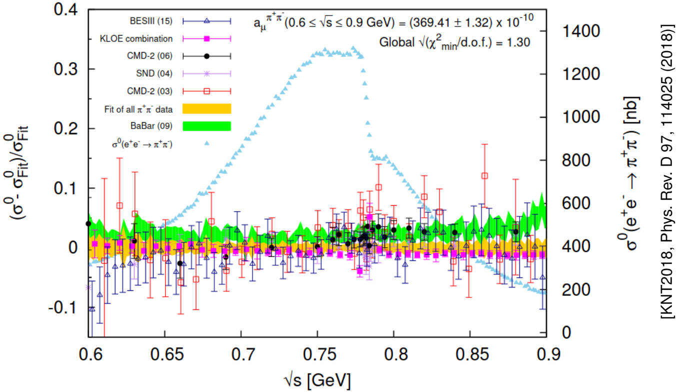

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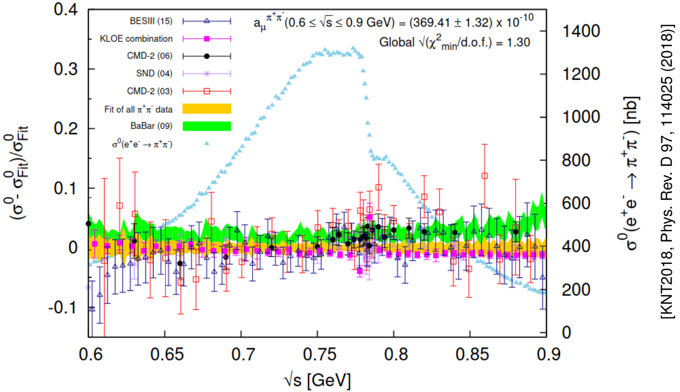
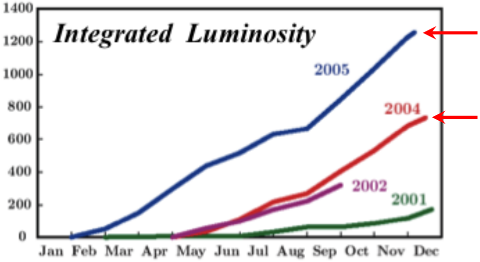


A better understanding of this "BaBar-KLOE"-puzzle would contribute to a reduced uncertainty in the a_μ^{HLO}-evaluation!

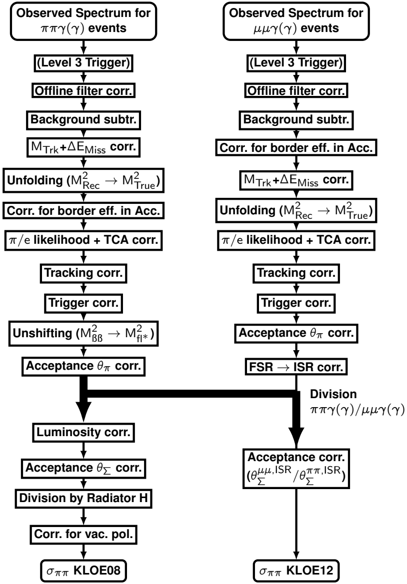
Future improvements using KLOE data

There are about 1.7 pb^{-1} of KLOE data taken in 2004 - 2005 on tape:



- data is taken at $\sqrt{s} = m_\phi$, which makes the large angle analysis cuts unfeasible
- essentially “replay” KLOE08 and KLOE12 analysis with the newer data
- use increased statistics to improve systematic uncertainties (old KLOE analyses are not limited by statistics)
- benefit from modern analysis techniques

KLOE08 and KLOE12 analysis flow



KLOE08 and KLOE12 systematic uncertainties on $a_\mu^{\pi\pi}$

Syst. errors (%)	KLOE08 $\Delta^{\pi\pi}a_\mu$ abs [4]	KLOE12 $\Delta^{\pi\pi}a_\mu$ ratio
Background Filter (FILFO)	negligible	negligible
Background subtraction	0.3	0.6
Trackmass	0.2	0.2
Particle ID	negligible	negligible
Tracking	0.3	0.1
Trigger	0.1	0.1
Unfolding	negligible	negligible
Acceptance ($\theta_{\pi\pi}$)	0.2	negligible
Acceptance (θ_π)	negligible	negligible
Software Trigger (L3)	0.1	0.1
Luminosity	0.3 ($0.1_{th} \oplus 0.3_{exp}$)	-
$\sqrt{s}$ dep. of H	0.2	-
Total exp systematics	0.6	0.7
Vacuum Polarization	0.1	-
FSR treatment	0.3	0.2
Rad. function H	0.5	-
Total theory systematics	0.6	0.2
Total systematic error	0.9	0.7

KLOE2 Public Document 6 - K2PD-6

Summary

- The KLOE experiment, with data taken in 2001/2002 and (off-peak) in 2006 has performed 4 analyses of the $e^+e^- \to \pi^+\pi^-$ cross section using the ISR method
- For the KLOE08, KLOE10 and KLOE12 results, the statistical and systematic covariance matrices have been constructed, which allows to perform a combination of the measurements
- When comparing the KLOE results with the result from the BaBar collaboration, a significant difference is found
  - *This difference introduces an additional uncertainty in the evaluation of the hadronic contribution to* a_μ
- There are about 1.7 fb^{-1} of additional KLOE data taken in 2004-2005 on tape
- New KLOE analyses of these data could help to settle the “BaBar-KLOE”- puzzle
  - *KLOE data is currently maintained by the KLOE-2 collaboration*
  - *Keep the same binning? Make it finer?* $M_{\pi\pi}$ *instead of* $M^2_{\pi\pi}$*?*
  - *Blinding strategies for the analyses?*
  - ...