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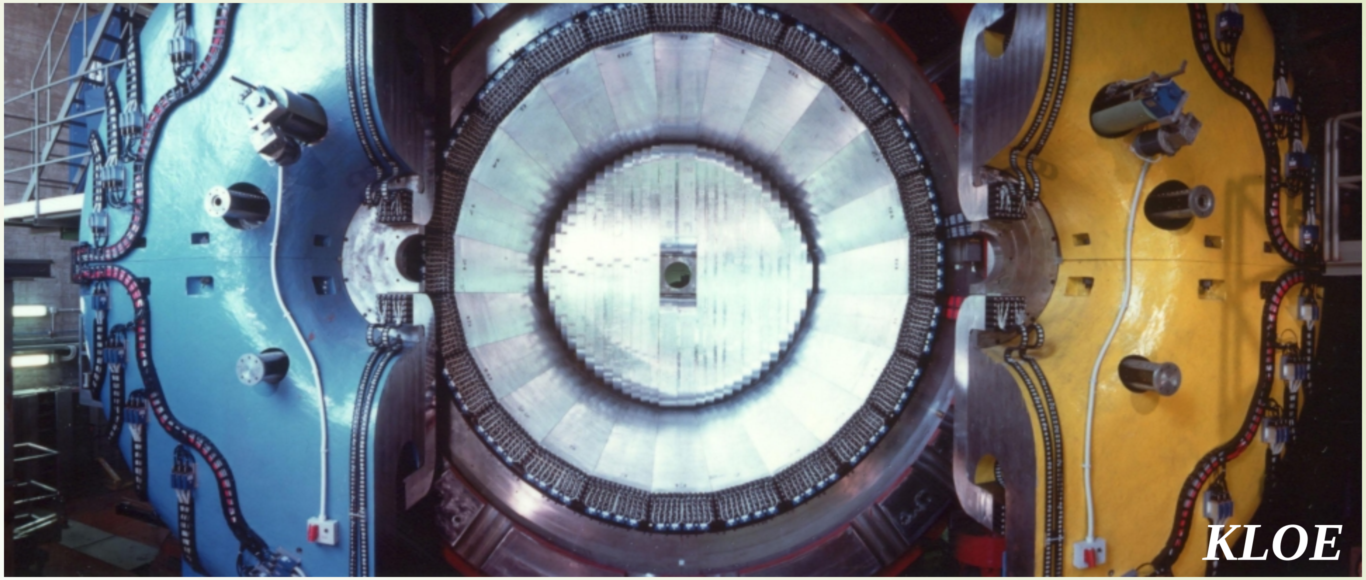
DESY - Kolloquium
July 6 th 2004
Hamburg

Recent Results from KLOE at the Electron-Positron-Collider DAΦNE



Content:

- Physics at DAΦNE with the KLOE Detector
- Kaon Physics
- Hadronic Cross Section
- Summary and Outlook

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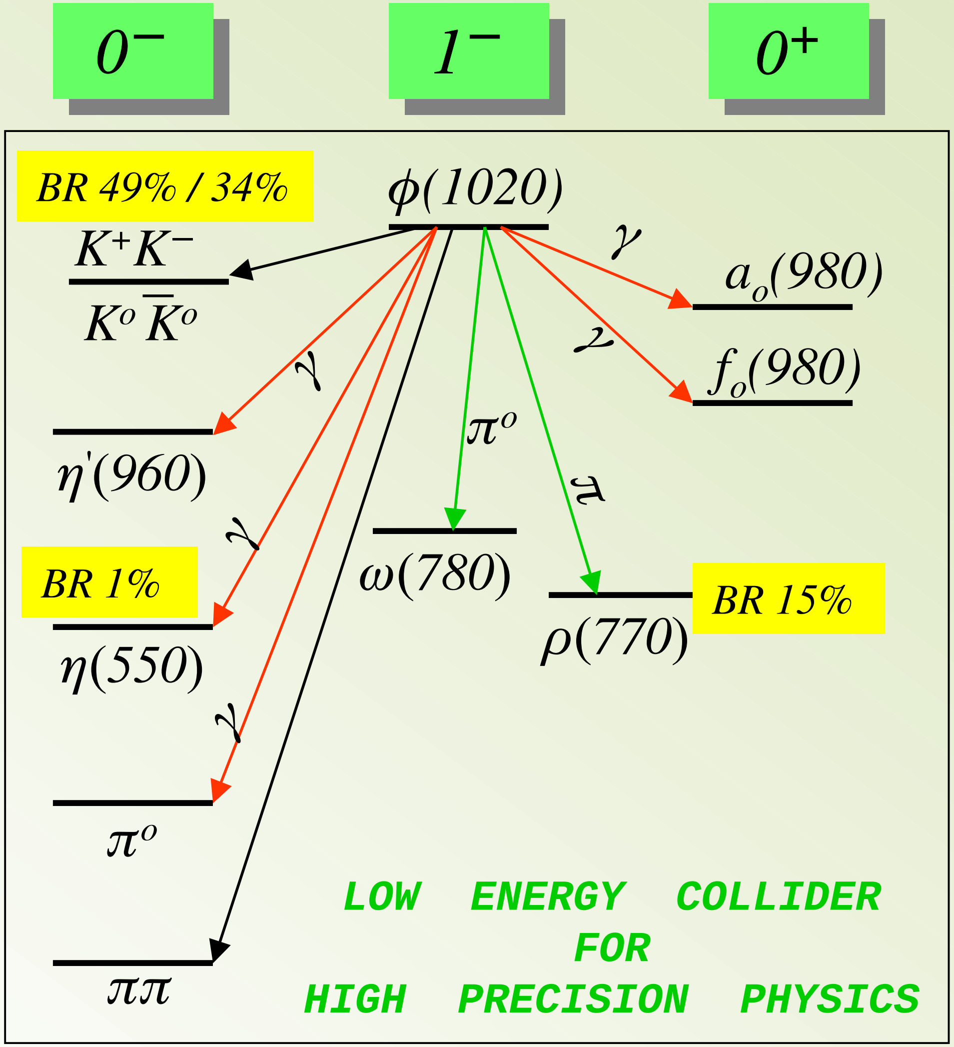
Physics at DAΦNE with the KLOE Detector

What is DAΦNE ?

Electron-positron-collider on
ϕ(*1020*)-Resonance in Frascati/Rome
Production ϕ – cross section:
$\sigma_\phi \approx 3\,\mu b$

1.5 kHz ϕ–**Rate** at design $\mathcal{L}$



Program:

- DAΦNE is a 'Kaon Factory'
  CP, CPT – Tests
- Strong source of ρ, η , (η') and scalars $f_o(980)$, $a_o(980)$
- Continuum physics: $e^+e^- \rightarrow \pi^+\pi^-$

Kaon Pairs

Kaon pairs are in a well defined ($t = 0$) quantum state, which is given by the quantum numbers of the $\phi(1020)$-meson: $C(\phi) = C(\gamma) = -1$

$$\left|K^o\ \overline{K}^o\right\rangle = \frac{1}{\sqrt{2}}\left(K^o_{\vec{p}}\ \overline{K}^o_{-\vec{p}} - \overline{K}^o_{\vec{p}}\ K^o_{-\vec{p}}\right)$$

! Minus sign

$$\left|K^o\ \overline{K}^o\right\rangle = \frac{1}{\sqrt{2}}\left(K^L_{\vec{p}}\ \overline{K}^S_{-\vec{p}} - \overline{K}^S_{\vec{p}}\ K^L_{-\vec{p}}\right)$$

! Minus sign

Quantum Interference!

This leads to quantum mechanical interference which can be observed at DAΦNE .

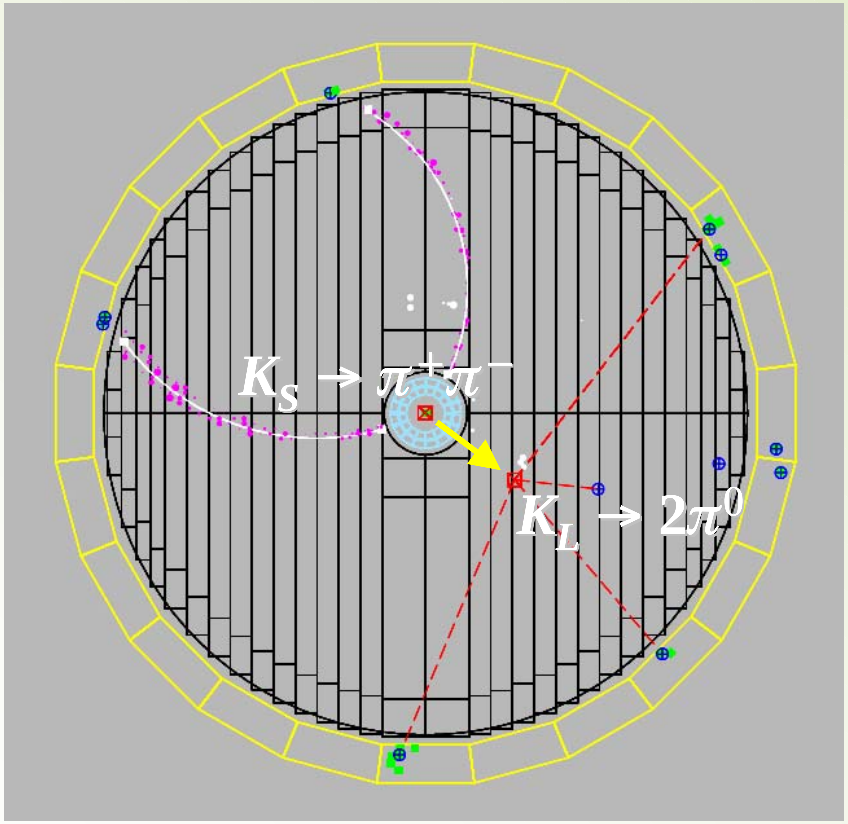
Kaon pairs, produced at a ϕ - factory, are:

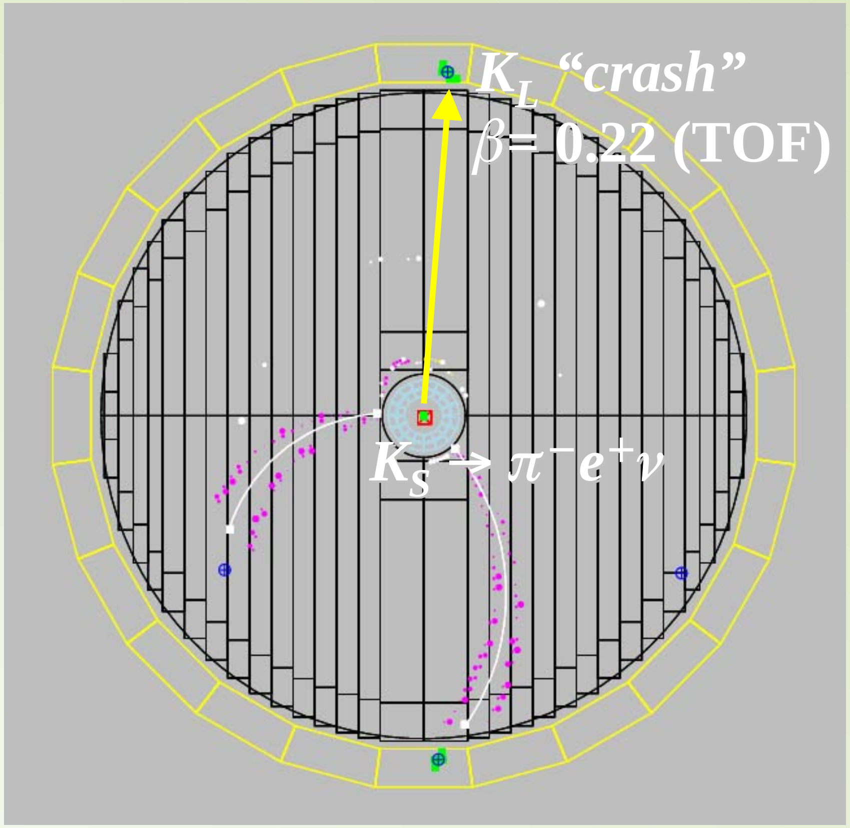
- Back-to-back
- Monochromatic
- K_S / K_L separated due to life times $\lambda(K_S) = 6$ mm, $\lambda(K_L) = 3500$ mm

Detection of a K_S (K_L) guarantees the presence of a K_L (K_S) with well defined momentum and direction of flight

Tagging !

Tagged K_L- and K_S-"Beams"





K_L tagged by $K_S \to \pi^+\pi^-$ vertex at IP

Efficiency ~ 70% × BR($K_S \to \pi^+\pi^-$)

K_L angular resolution: ~ 1°

K_L momentum resolution: ~ 2 MeV

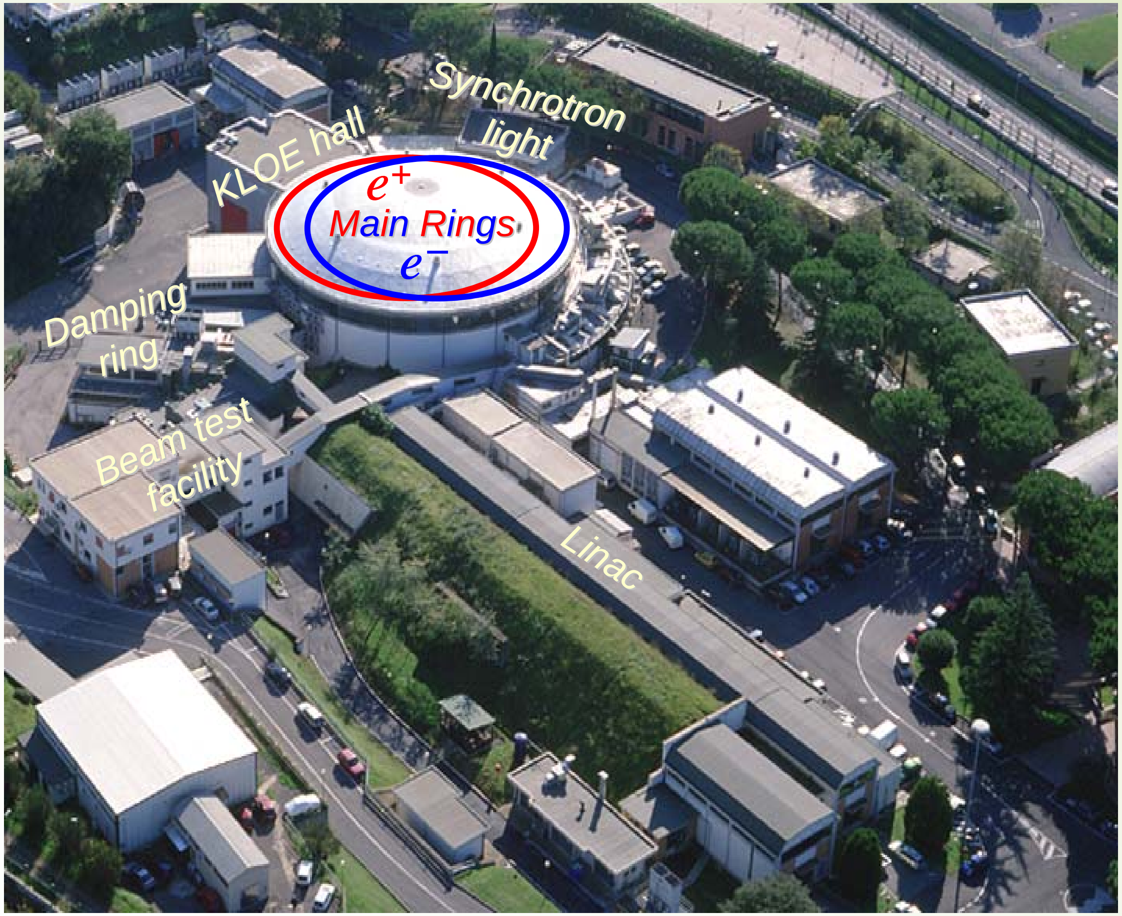
K_S tagged by K_L interaction in EmC

Efficiency ~ 30%

K_S angular resolution: ~ 1°

K_S momentum resolution: ~ 2 MeV

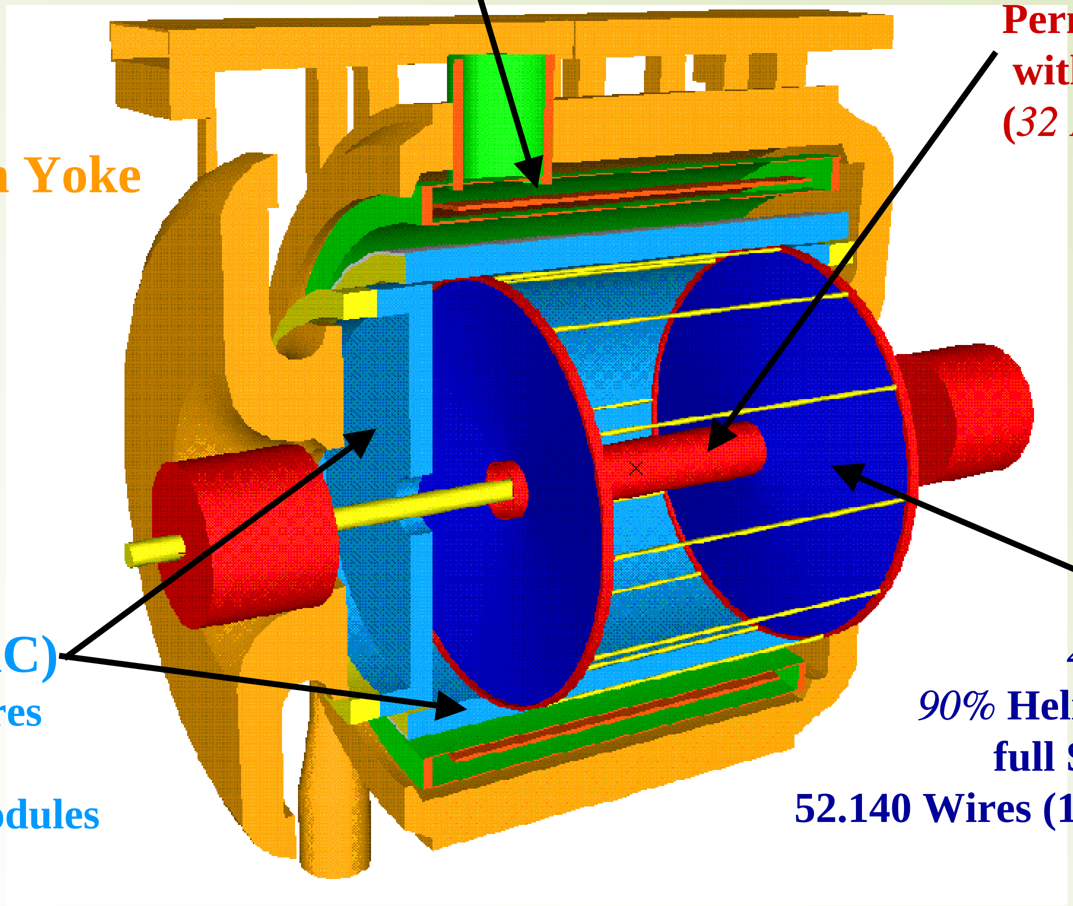
DAΦNE - Collider



Features

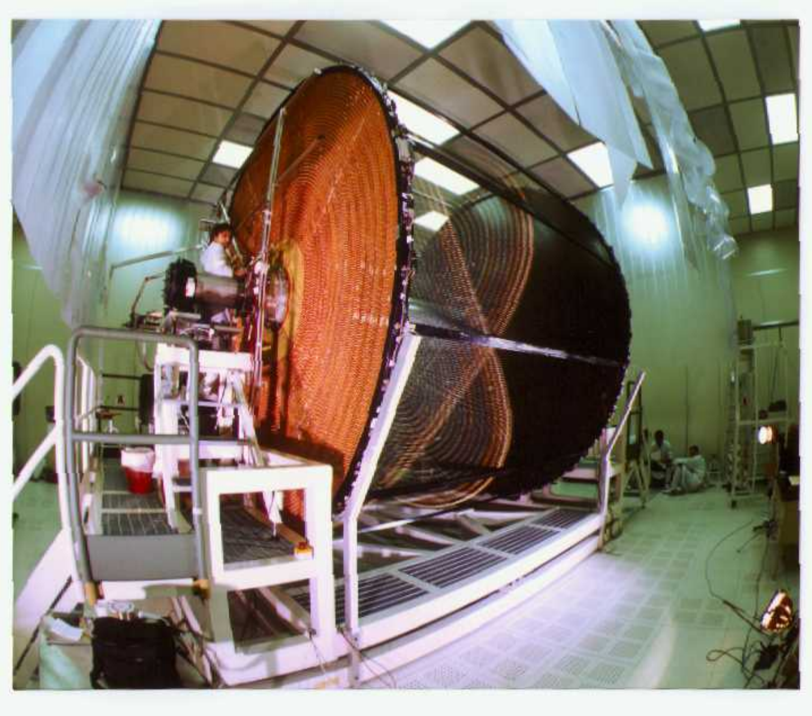
- ϕ – factory: $\sqrt{s}$ = 1.02 GeV
- 2 separate rings for e^+/e^-
  circumference ≈ 100m
- Concept
  ⇒ high # Bunches (120)
  ⇒ moderate single bunch $\mathcal{L}$
- 2 Interaction regions
  ⇒ KLOE
  ⇒ DEAR/FINUDA

KLOE - Detector



KLOE - Detector

Cylindrical Drift Chamber



$\sigma_{r\phi} = 150\ mm\ ,\ \sigma_z = 2\ mm$

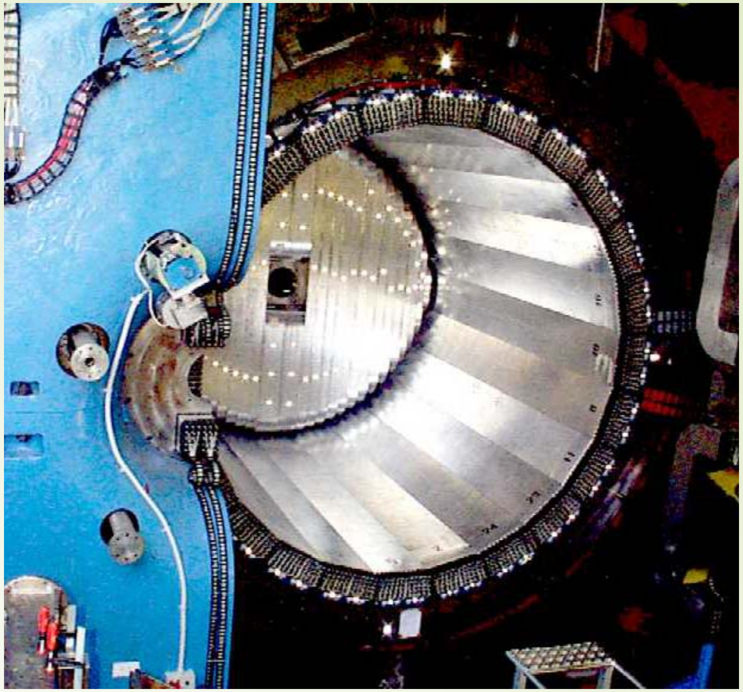
$\sigma_p / p = 0.4\%$ (for 90^o Tracks)

Very good Momentum Resolution

$\sigma_t = 54\ ps / \sqrt{E(GeV)} \oplus 50ps$

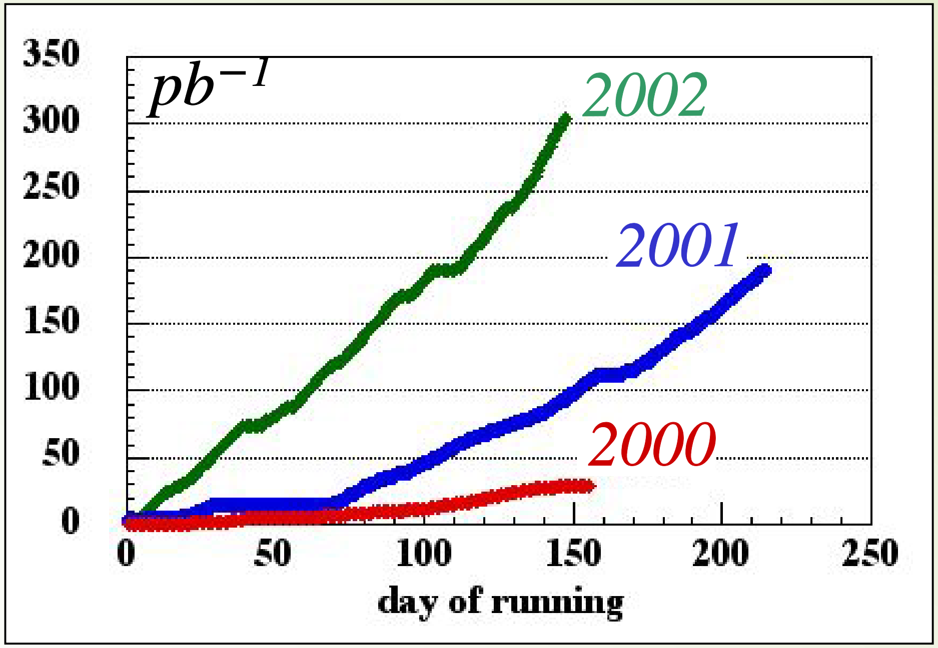
$\sigma_E / E = 5.7\% / \sqrt{E(GeV)}$

Excellent Time Resolution



Electromagnetic Calorimeter

Integrated Luminosity



2000 - 2002

> 1.5 Billion ϕ

$\int \mathcal{L} dt = 500\ pb^{-1}$

Parameters	**Design**	**2002**	**2004**
Max. bunches	120	51	110
Bunch current (mA)	40	20	20
$\mathcal{L}$, single bunch ($cm^{-2}s^{-1}$)	$4 \cdot 10^{30}$	$1.5 \cdot 10^{30}$	$2 \cdot 10^{30}$
$\mathcal{L}$, peak ($cm^{-2}s^{-1}$)	$5 \cdot 10^{32}$	$0.8 \cdot 10^{32}$	$2 \cdot 10^{32}$

Integrated Luminosity

2003: New KLOE IR + other DAΦNE upgrades

Goals for 2004:

$\mathcal{L}_{peak} = 2 \cdot 10^{32}\ cm^{-2}s^{-1}$

$\mathcal{L}_{int}$ / year = $2\ fb^{-1}$

Data taking started May '04

Parameters	**Design**	**2002**	**2004**
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KLOE Physics Program

2000 Statistics:

K_S **Physics:**

$BR(K_S \to \pi e \nu)$

$BR(K_S \to \pi^+\pi^-(\gamma)) / BR(K_S \to \pi^o \pi^o)$

ϕ **radiative Decays**

$\phi \to f_o \gamma, \phi \to a_o \gamma, \phi \to \eta' \gamma, \eta \gamma$

5 published results with *17 pb⁻¹*

2001+2002 Statistics:

- K_s – BR's, also rare decays
- Extraction *of* V_{us} semilept. Decays
- K_L – and $K^{\pm}$ - *BR's*
- $\phi \to \rho \pi \to \pi^+\pi^-\pi^o$
- Rare η - Decays
- η' - Physics
- Analysis of scalars f_o and a_o
- $\sigma(e^+e^- \to \pi^+\pi^-)$ via *ISR*
- *much more …*

This Talk !

Analysis with *500 pb⁻¹*

4 published results

Many more to come …

In Future ?

- Double Ratio for $\Re(\varepsilon'/\varepsilon)$
- Semileptonic Asymmetry (*CPT* Test)
- $K_L K_S$ Interferometry

In case of an improved DAΦNE luminosity

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Kaon Physics

Kaon Physics

This talk:

- $K_S \rightarrow \pi^0\pi^0\pi^0$ — preliminary results
- $K_S \rightarrow \pi e \nu$ — *Phys. Lett.* **B537**21 (2002), updated analysis
- K_L Lifetime — preliminary results

Other topics:

- $K_S \rightarrow \pi^+\pi^-(\gamma)$/ $K_S \rightarrow \pi^0\pi^0$ — *Phys. Lett.* **B538** 21 (2002)
- K_S mass — *KLOE Note 181* (http://www.lnf.infn.it/kloe)
- $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$ — hep-ex/0307054, submitted to *Phys. Lett.* **B**
- $K_L \rightarrow \gamma\gamma$ — *Phys. Lett.* **B566** 61 (2003)
- $K_S K_L$ interference — in progress
- $K^\pm \rightarrow \pi^\pm\pi^0$/ $K^\pm \rightarrow \mu^\pm\nu$ — in progress
- $K^\pm$ and K_L absolute BR’s — in progress
- $K^\pm$ Lifetime — in progress
- …

Motivation $K_S \to \pi^0 \pi^0 \pi^0$

- **Decay $K_S \to 3\pi^0$ is $\mathcal{CP}$-violating (direct and/or indirect)**

  PDG: $BR\,(K_S \to 3\pi^0) < 1.4 \cdot 10^{-5}$ @ 90%C.L.

  SM: $\Gamma_S = \Gamma_L \cdot |\eta_{000}|^2 \Rightarrow BR\,(K_S \to 3\pi^0) = 1.9 \cdot 10^{-9}$

  0.9 Events in 500pb^{-1}

$$\left| \frac{\mathcal{A}(K_S \to \pi^0\pi^0\pi^0)}{\mathcal{A}(K_L \to \pi^0\pi^0\pi^0)} \right| = \varepsilon + \varepsilon'_{000}$$

- **Accuracy on $\mathcal{A}(K_S \to 3\pi^0)$ is actually limiting the precision of $\mathcal{CPT}$-Tests:**

  Bell-Steinberger-Relation (Unitarity is valid also in case of ~~$\mathcal{CPT}$~~!)

$$(1 + i \tan\phi_{SW}) \mathrm{Re}\,\varepsilon - \Sigma_f \mathcal{A}^*(K_S \to f)\, \mathcal{A}(K_L \to f)/\Gamma_S = (-i + \tan\phi_{SW})\, \mathrm{Im}\,\delta$$

$$(\varepsilon_{S,L} = \varepsilon \pm \delta)$$

  $BR(K_S \to 3\pi^0) \sim 10^{-7}$ - Level leads to $|\mathrm{Im}\,\delta| < \sim 2 \times 10^{-5}$

  For $\Delta(M_{K^0} - M_{\bar{K}^0}) / M_{K^0}$ reduction of factor 2.5 down to ca. $8 \cdot 10^{-19}$

  up to now: $2 \cdot 10^{-18}$, $M_K/M_{Planck} \approx 4 \cdot 10^{-20}$

$K_S \rightarrow \pi^0 \pi^0 \pi^0$

Selection:
- K_S 'tagged' via '$K_{L,\text{crash}}$ –ID' (= nuclear K_L-interaction in EmC)
- 6 Photons (neutral clusters, TOF consistent with $\beta = 1$)
- No charged tracks from I.P.

Background:

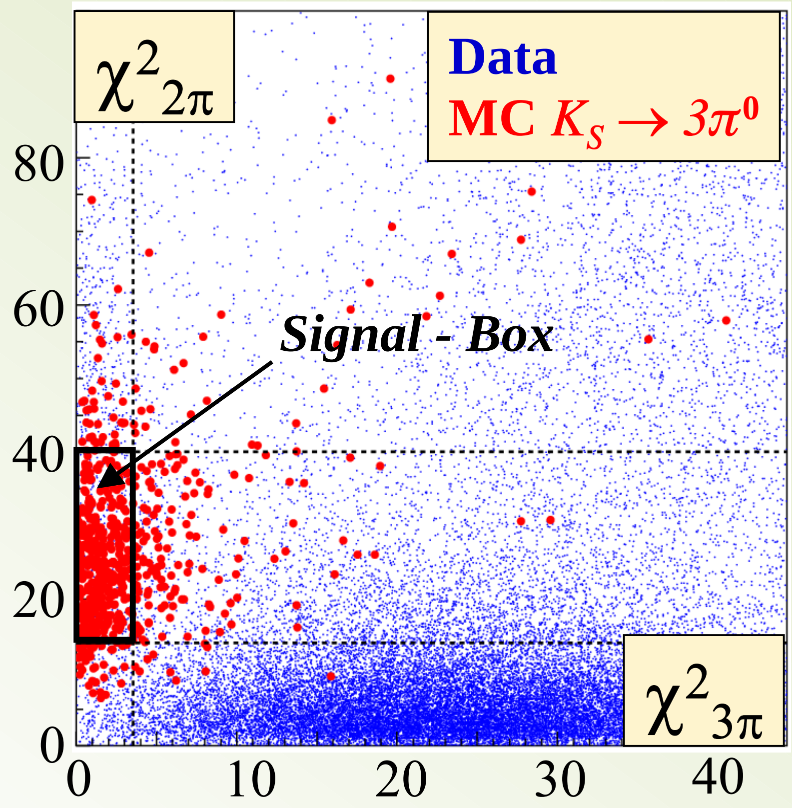
$K_S \rightarrow \pi^0\pi^0$ + 2 'fake' γ's

Kinematic Fit:

Compare *3π* vs *2π* hypothesis:

$\chi^2_{3\pi}$: 6γ - Cluster - Pairs with best π^0 - Mass - Results

$\chi^2_{2\pi}$: Pair 4 γ's out of 6 present: π^0 - Masses, $E(K_S)$, $\mathbf{p}(K_S)$, Angle btw. π^0s

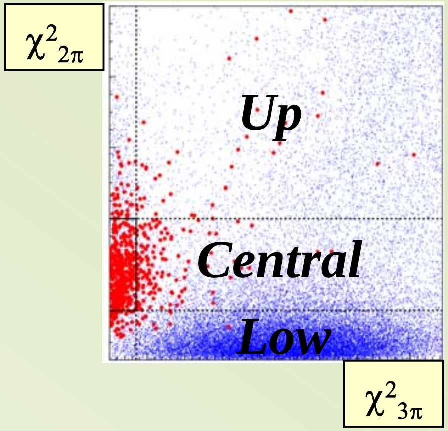


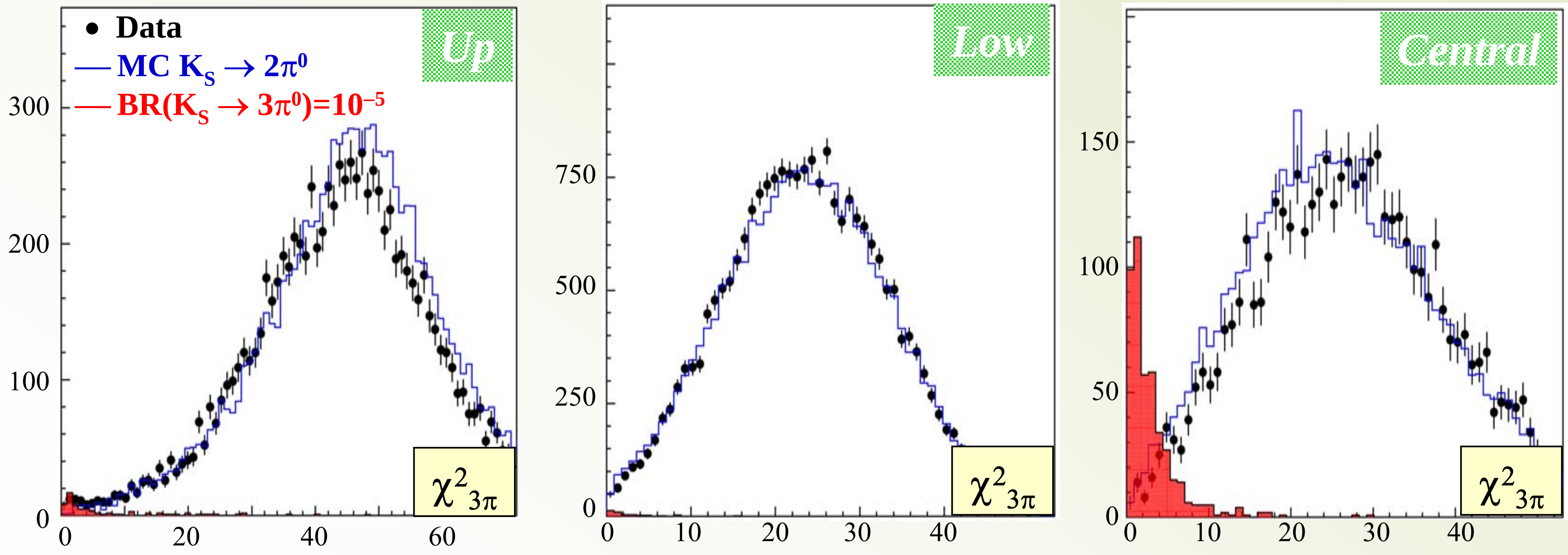
$K_S \to \pi^0 \pi^0 \pi^0$

Comparison Data – MC in ‘Side bands’

- Test of background-simulation for $K_S \to \pi^0\pi^0$
- Signal $K_S \to \pi^0\pi^0\pi^0$ simulated with actual *BR*-Limit 10^{-5}

$\Rightarrow$ Good agreement: systemat. differences < *10%*





Results $K_S \to \pi^0 \pi^0 \pi^0$

N_{sel}(data) = 4 Signal Events, Efficiency $\varepsilon_{3\pi} = 21\%$

N_{sel}(bkg) = $3 \pm 1.4_{stat} \pm 0.2_{syst}$ Background Events expected from MC

We conclude: **$N_{3\pi} < 5.8$ @ 90% CL**

- Normalize signal-events to $K_S \to \pi^0\pi^0$ Events in same data set ($38 \cdot 10^6$, $\varepsilon_{2\pi}$=92%):

$$\mathbf{BR}(K_S \to \pi^0\pi^0\pi^0) = \frac{N_{3\pi} / \varepsilon_{3\pi}}{N_{2\pi} / \varepsilon_{2\pi}} \mathrm{BR}(K_S \to \pi^0\pi^0) < 2.1 \cdot 10^{-7}$$

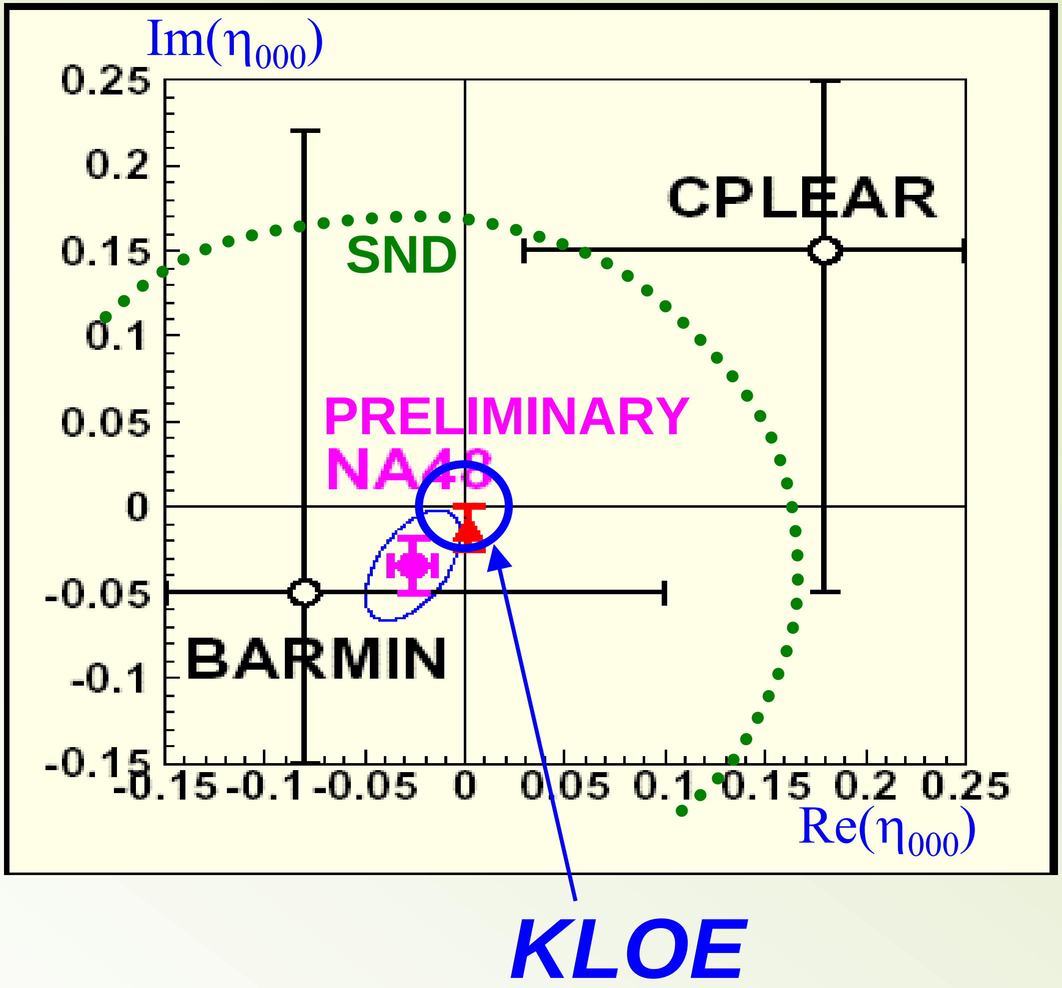
K L O E P R E L I M I N A R Y

- We obtain an upper limit on $|\eta_{000}| = \left| \frac{\mathcal{A}(K_S \to \pi^0\pi^0\pi^0)}{\mathcal{A}(K_L \to \pi^0\pi^0\pi^0)} \right| < 2.4 \cdot 10^{-2}$

@ 90% C.L.

Results $K_S \rightarrow \pi^0 \pi^0 \pi^0$

Comparison with CPLEAR, SND, BARMIN and NA48, which has a preliminary measurement of η_{000} (real and imaginary part) from K_S - K_L - interference



NA48 preliminary:

assuming *CPT* - conservation:

BR($K_S \rightarrow \pi^0\pi^0\pi^0$) < 3 · 10^{-7}

$$BR\,(K_S \rightarrow \pi\, e\, \nu\,)$$

Motivation for $K_S \rightarrow \pi e \nu$

- **Sensitivity for indirect** $\mathcal{CP}$ **through semilept. Charge Asymmetry** $\mathcal{A}_S$

$$\mathcal{A}_S = \frac{\Gamma(K_S \rightarrow \pi^- e^+ \nu) - \Gamma(K_S \rightarrow \pi^+ e^- \nu)}{\Gamma(K_S \rightarrow \pi^- e^+ \nu) + \Gamma(K_S \rightarrow \pi^+ e^- \nu)}$$

$\mathcal{CP}: \mathcal{A}_S = 2\,\Re\varepsilon_K$ $\mathcal{A}_S$ **never measured before**

- **Test of** $\mathcal{CPT}$ **through comparison of semileptonic Asymmetries** $\mathcal{A}_{S,L}$

$\mathcal{CPT}: \mathcal{A}_L - \mathcal{A}_S = 4\,\Re\delta_K$

$$\mathbf{K_S \propto K_1 + (\varepsilon_K - \delta_K)\, K_2}$$
$$\mathbf{K_L \propto K_2 + (\varepsilon_K + \delta_K)\, K_1}$$

- $BR(K_S \rightarrow \pi e \nu)$ **allows extraction of** V_{us} **and hence a stringent test of Unitarity in the first row of the CKM-Matrix (most precisely tested one!)**

$$|\mathbf{V_{ud}}|^2 + |\mathbf{V_{us}}|^2 + |\mathbf{V_{ub}}|^2 \sim |\mathbf{V_{ud}}|^2 + |\mathbf{V_{us}}|^2 \equiv \mathbf{1 - \Delta}$$

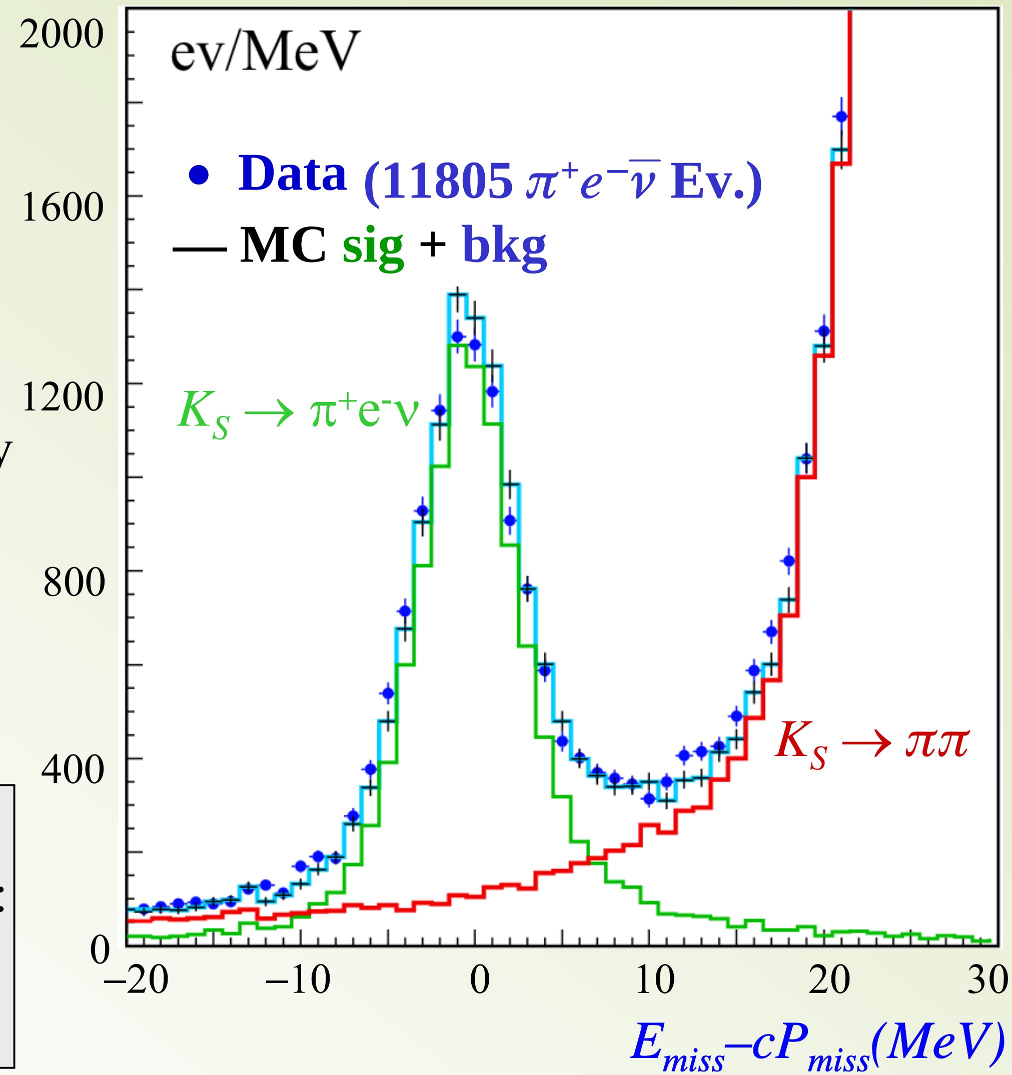
PDG02: $\Delta = 0.0042 \pm 0.0019$

V_{us} from > 20 year old BR-measurements!

$K_S \to \pi\, e\, \nu$

Analysis:

- K_S 'tagged' via '$K_{L,crash}$ –ID'
- TOF-PID thanks to the very good time resolution of the EmC suppress $\pi\pi$ and $\pi\mu\nu_\mu$ – Bkg.
- Signal- and normalizing-sample $K_S \to \pi\pi$ are further kinematically separated $E_{miss} - c{\cdot}P_{miss}$
- Obtain number of signal events via fit of data points to the sum MC-sum signal + Background



Signal-spectrum very sensitive to the presence of Final State Photons: **Radiative Correction simulated within MC** (w/o E_γ-cut off!)

Results $K_S \rightarrow \pi e \nu$

- Normalize counting rate to the BR($K_S \rightarrow \pi\pi(\gamma)$) measured in 2002 by KLOE

  BR($K_S \rightarrow \pi^- e^+ \nu$) = $(3.54 \pm 0.05_{stat} \pm 0.05_{syst})\ 10^{-4}$
  BR($K_S \rightarrow \pi^+ e^- \nu$) = $(3.54 \pm 0.05_{stat} \pm 0.04_{syst})\ 10^{-4}$

  BR($K_S \rightarrow \pi e \nu$) = $(7.09 \pm 0.07_{stat} \pm 0.08_{syst})\ 10^{-4}$

  K L O E
  P R E L I M I N A R Y

  Publ. Result: $(6.91 \pm 0.34_{stat} \pm 0.15_{syst})\ 10^{-4}$ [KLOE '02]

- Extract **semileptonic K_S - Asymmetry**

  $\mathcal{A}_S = (-2 \pm 9_{stat} \pm 6_{syst})\ 10^{-3}$

  Need 2 fb^{-1} $\rightarrow \sigma(\mathcal{A}_S) = 3 \cdot 10^{-3} = \mathcal{O}(\varepsilon) = \mathcal{O}(10^{-3})$

  Need 20 fb^{-1} $\rightarrow$ to extract ~~CPT~~ $- \delta$ with competitive precision
  via comparison of the K_S and K_L semileptonic asymmetries $\mathcal{A}_S - \mathcal{A}_L$
  [CPLEAR $\Re(\delta) = (-3.0 \pm 3.4) 10^{-4}$]

Test of CKM-Unitarity: V_{us}

Master-Formula:

Slope Factor

$$\Gamma(K \to \pi\, e\, \nu(\gamma)) \propto |V_{us}\, f_+^{K\pi}(0)|^2 \; I(\lambda_t)\,(1 + \Delta I(\lambda_t))(1 + \delta_{EM})$$

Measurement — **V_{us} * Formfactor** — **Radiative Corrections**

1) Measure semileptonic BR:

- PDG values from the 60's...70's

2) Calculate formfactor

- Leutwyler, Roos (1984)
  χPT p^4 + NNLO - Estimates
  $f_+(0)$ **= 0.961 ± 0.008**

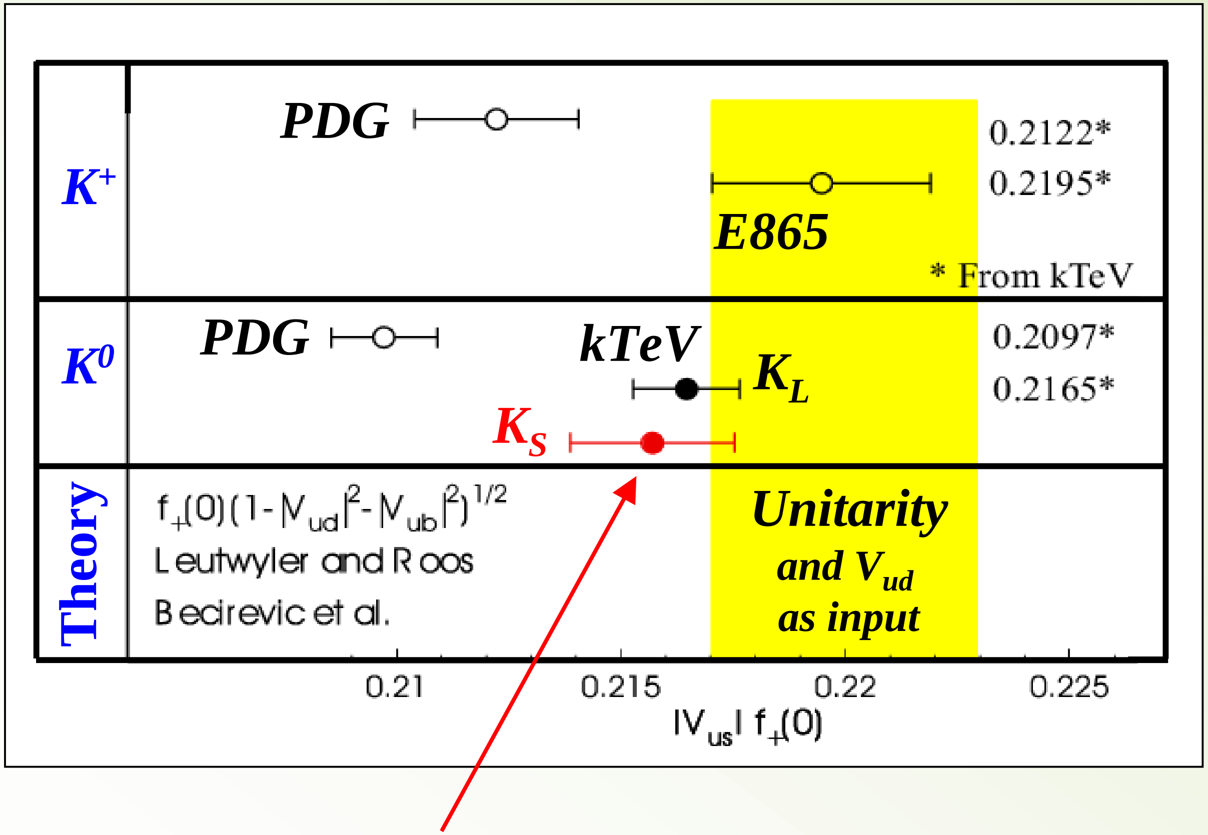
Recent experimental and theoretical work:

- **E865** (BNL \`03) K^+
- **kTeV** (FNAL \`04) K_L
- **KLOE** (LNF) K_S, K_L, $K^\pm$

- Cirigliano et.al. (2004) *elm. Isospin breaking*
  $f_+(0)$ **= 0.981 ± 0.010**
- Bijnens, Talavera (2003) *χPT p^6 – Loop, add this term to Leutwyler-Roos - formfactor*
- Becirevic et.al. (2004) *Quenched Lattice $K\to\pi$*
  $f_+(0)$ **= 0.960 ± 0.009**

Test of CKM-Unitarity: V_{us}

Comparison with "OLD" PDG & NEW data:



- New experiments kTeV and KLOE deviate from "old" PDG values and agree with E865 ($K^{\pm}$)!
- Taking "old" formfactor Roos & Leutwyler together with new data do not show considerable deviation from Unitarity!
- kTeV precision limited by knowledge of K_L life time.

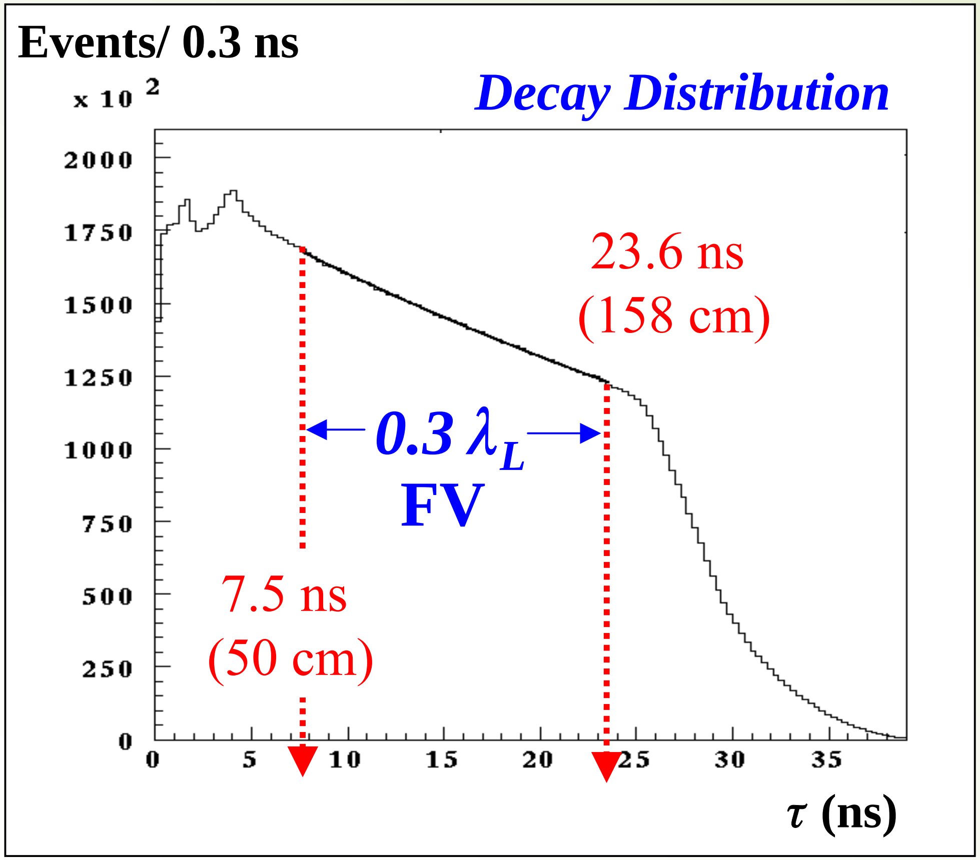
KLOE 2004:

$$V_{us} f_+^{K0\pi-}(0) = \mathbf{0.2177 \pm 0.0023}$$

K L O E   P R E L I M I N A R Y

K_L Lifetime

In KLOE the K_L momentum is well known, and 30% of the kaons decays inside the detector. Using 14.6 10^6 $K_L \to \pi^0\pi^0\pi^0$ events - tagged with $K_S \to \pi^+\pi^-$ - the neutral vertex is reconstructed using time of flight technique (σ~1.5 cm).



KLOE Result

$\tau\ (K_L) = (\ \dots \pm 0.20_{stat}\ )$ ns

τ (PDG) (fit) = (51.7 ± 0.40) ns

PRD 6 (1972), 1834

The systematic error is under evaluation:

- background estimate
- photon detection efficiency
- time-scale calibration
- Data vs MC comparison

Systematics < 0.6% at present limited by MC statistics.

Conclusions Kaon Physics

Present status K_S:

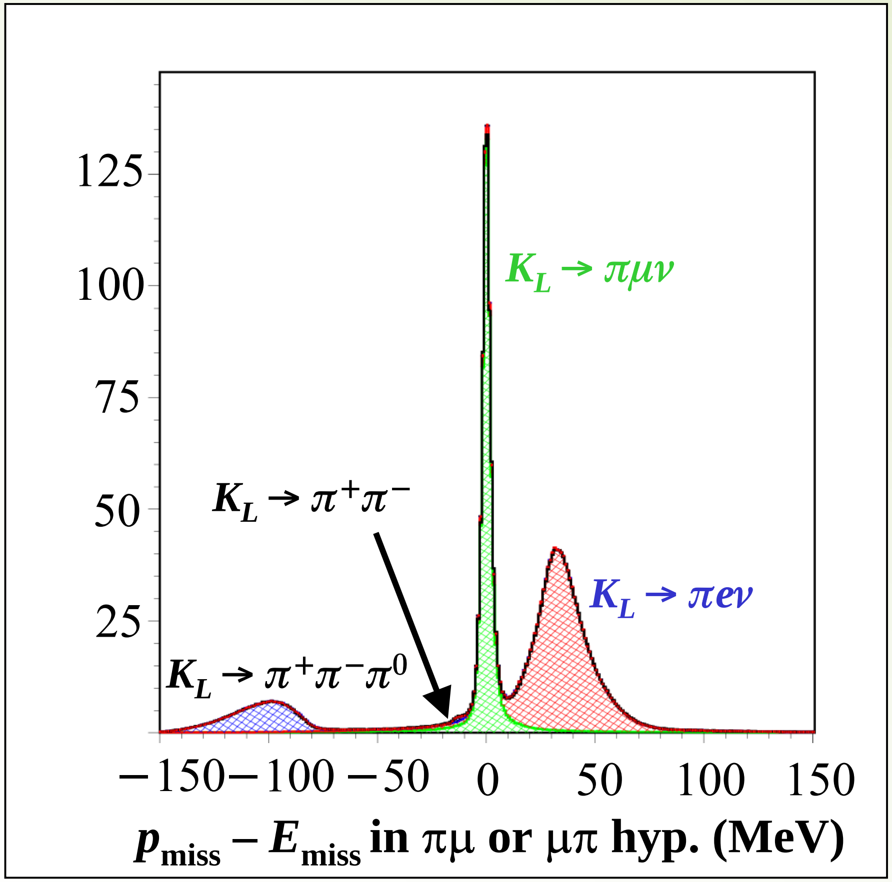
- Sensitivity to BR's at the 10^{-7} level (preliminary limit for $K_S \to 3\pi^0$)
- Measurement of K_{e3} mode at the % level
- Expect integrated luminosity of 2 fb^{-1} in 2004, would allow:
  - $\mathcal{A}_S$ with a total accuracy of $4\ 10^{-3}$, first test of SM prediction $\mathcal{A}_S = 2\ \mathrm{Re}\ \varepsilon$
  - Sensitivity to $K_S \to 3\pi^0$ at 10^{-8} level
  - Measurement of $BR(K_S \to \pi^+\pi^-\pi^0)$ with 20% relative uncertainty

In progress:

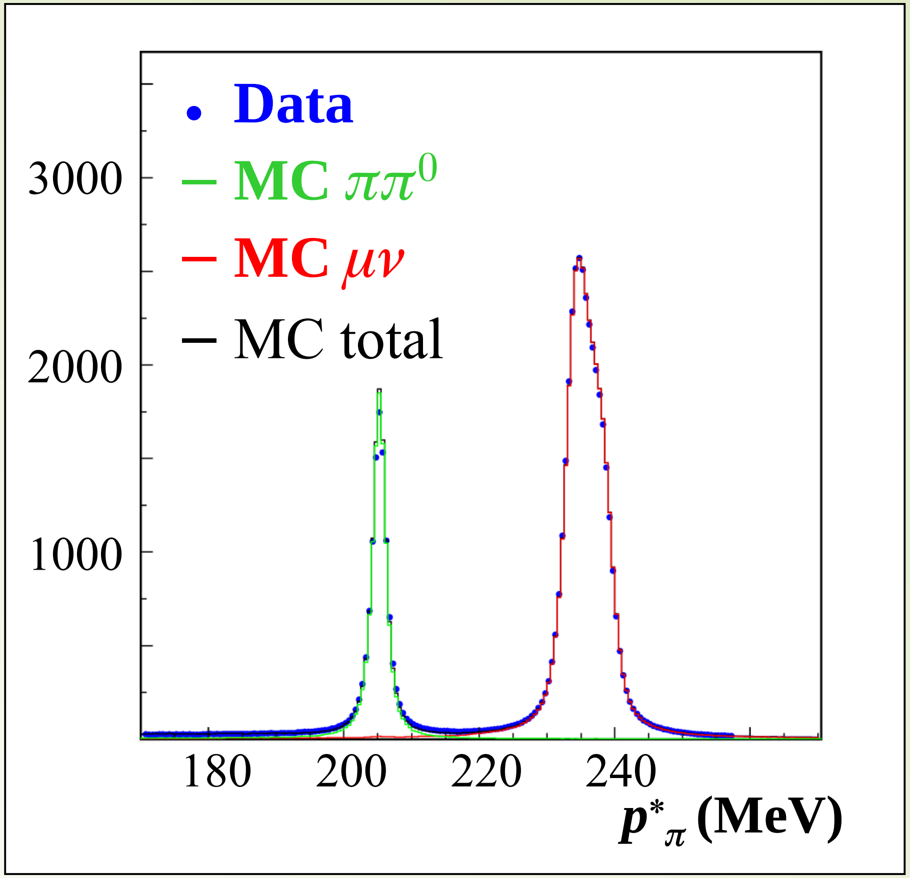
- Measurement of BR's for semileptonic K_L and $K^\pm$ decays
  Huge statistics: uncertainty will be limited by systematics
  $\Rightarrow$ Measurement of V_{us}
- Measurement of BR's of main decay channels of K_L and $K^\pm$ with a precision <1% (limited by systematics)

Conclusions Kaon Physics

Neutral Kaons: K_L



Charged Kaons: K^+



A first glance at Quantum Interference

Relative time distribution for decay to two given final states shows interference

Measure Γ_S, Γ_L, Δm, $\Re(\varepsilon'/\varepsilon)$, $\Im(\varepsilon'/\varepsilon)$, $\eta_{\pi\pi}$, δ_K

$K_S K_L \to \pi^+\pi^-\pi^+\pi^-$: $|A(\Delta t)|^2 \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos(\Delta m \Delta t)$

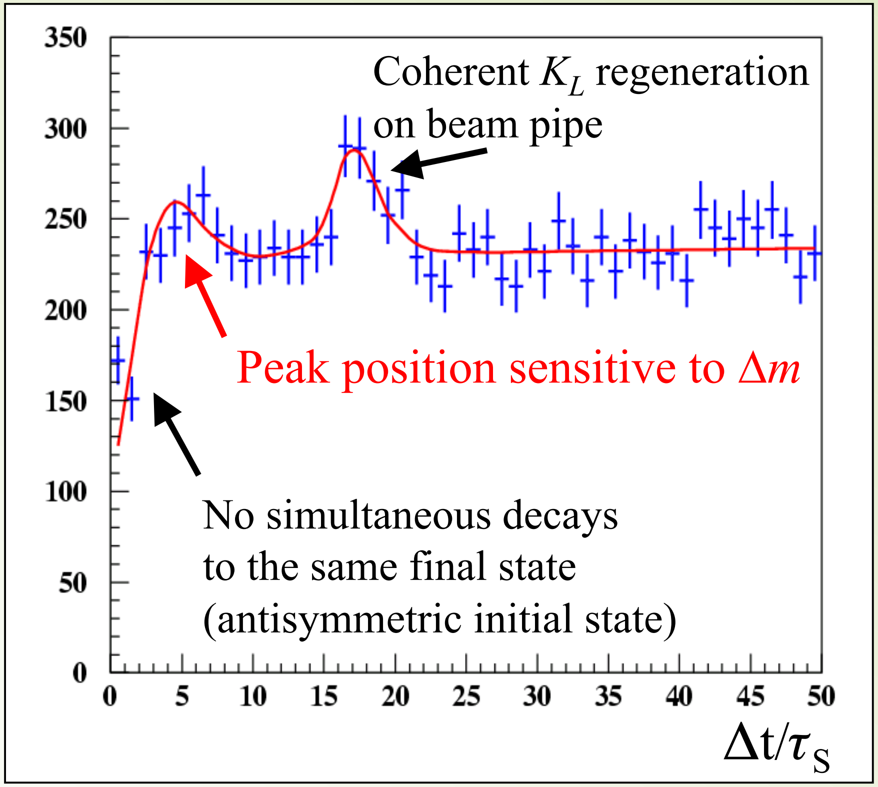
PDG '02:

$\Delta m = (5.301 \pm 0.016) \cdot 10^{-11}\,\hbar\,s^{-1}$

KLOE Preliminary :

$\Delta m = (5.64 \pm 0.37) \cdot 10^{-11}\,\hbar\,s^{-1}$

- 340 pb^{-1} '01+'02 data
- Fit with PDG values for Γ_S , Γ_L
- χ^2/d.o.f. = 43.7/47



First observation of quantum interference in relative decay-time distribution of K_S, K_L

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Hadronic Cross Section Measurement

Non - Kaon Physics

This talk:

Hadronic Cross Section	*Paper submitted to Phys. Lett.* **B**

Other topics:

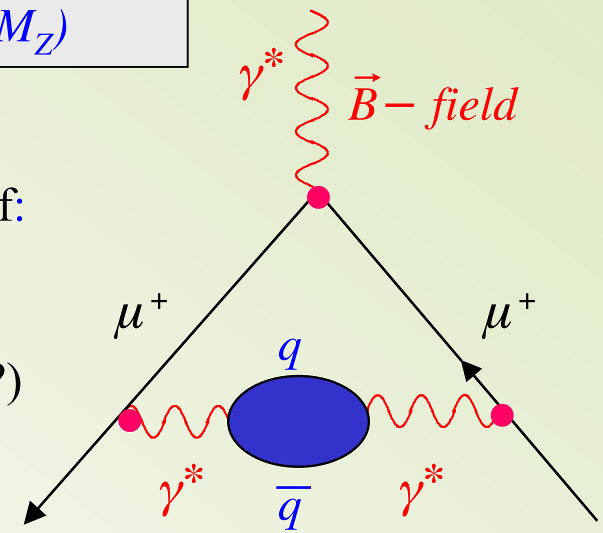
• $\phi \to f_0(980)\,\gamma$	*Phys. Lett.* **B536**(2002)209
• $\phi \to a_0(980)\,\gamma$	*Phys. Lett.* **B537**(2002)21
• $\phi \to \eta'\,\gamma,\ \eta\,\gamma$	*Phys. Lett.* **B541**(2002)45
• $\phi \to \rho\pi,\ \pi^+\pi^-\pi^0$	*Phys. Lett.* **B561**(2003)55
• Upper limit BR($\eta \to \gamma\gamma\gamma$)	*Phys. Lett.* **B591**(2004)45
• Dalitz plot $\eta \to \pi^+\pi^-\pi^0,\ \pi^0\pi^0\pi^0$	Preliminary results
• ϕ leptonic width	Preliminary results
• $\eta \to \pi^0\gamma\gamma$, other rare η – Decays	work in progress
• Updates $f_0(980)$, $f_0(980)$ analyses	work in progress
• Updates $\phi \to \eta'\,\gamma,\ \eta\,\gamma$ analyses	work in progress
• …	

Muon - Anomaly

Motivation: Determination of Hadronic Vacuum Polarization
= High Precision Test of the Standard Model

- Anomalous magnetic moment of the muon $a_\mu = (g-2)_\mu$
- Running fine structure constant at Z^0-mass $\alpha_{QED}(M_Z)$

Dirac-Theory: $(g-2) = 0$
Quantum corrections: $(g-2) \neq 0$ due to corrections of:
- electromagnetic interaction
- weak interaction
- strong interaction (and maybe **NEW PHYSICS** ???)



$$a_\mu = (g_\mu - 2)/2 = \alpha/2\pi + \ldots$$

$$a_\mu^{theor} = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak} + a_\mu^{new}$$

hadrons
Hadronic Vacuum Polarization

2nd largest contrib., cannot be calculated in *pQCD*

Error of hadronic contribution is dominating total error !

Hadronic Cross Section

Hadronic contribution to a_μ can be estimated by means of a dispersion integral:

$$a_\mu^{had} = \left(\frac{\alpha \, m_\mu}{3\pi} \right)^2 \int_{4m_\pi^2}^{\infty} ds \, \frac{R(s)\, \tilde{K}(s)}{s^2}$$

$$R(s) = \frac{\sigma_{tot}(e^+e^- \to \gamma^* \to q\,\bar{q} \to hadrons)}{\sigma_{tot}(e^+e^- \to \gamma^* \to \mu^+\mu^-)}$$

$1/s^2$ makes low energy contributions especially important:

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

in the range < *1 GeV* contributes to 70% !

- $K(s)$ = analytic kernel-function
- above sufficiently high energy value, typically *2…5 GeV*, use *pQCD*

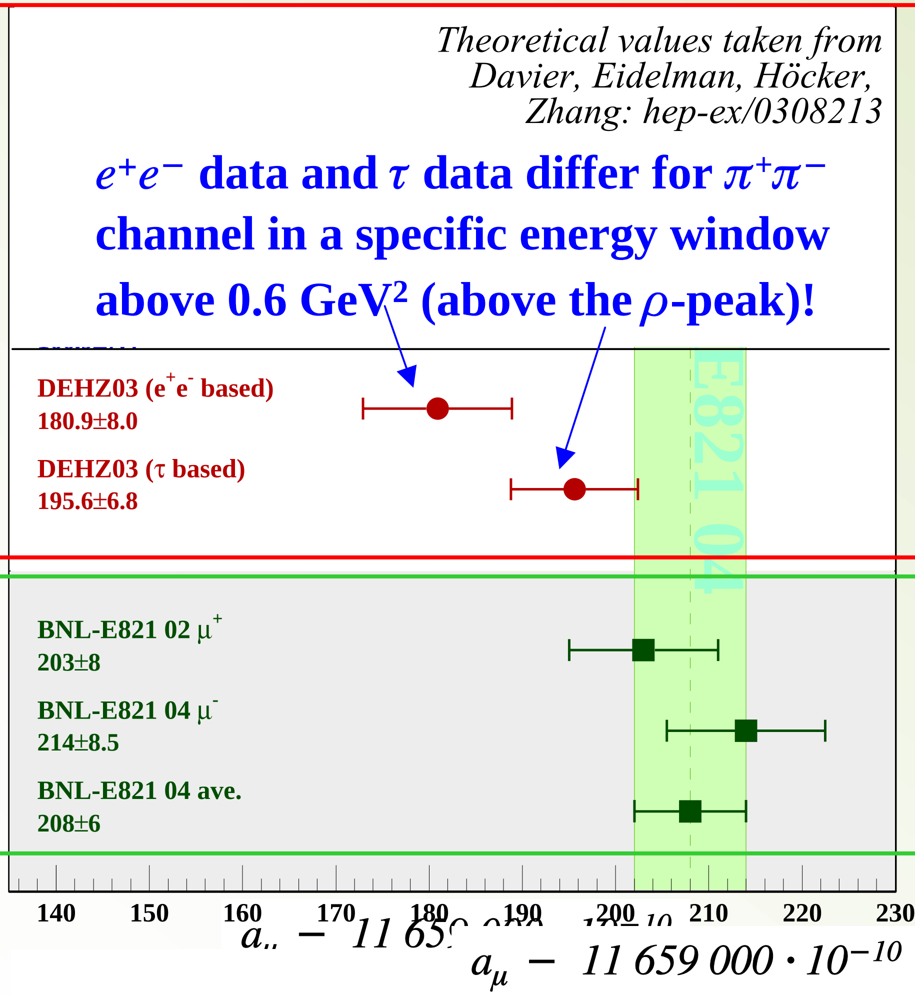
Input:

a) hadronic electron-positron cross section data

b) hadronic τ- decays, which can be used with the help of the *CVC*-theorem and an isospin rotation (plus isospin breaking corrections)

Muon-Anomaly: Theory vs. Experiment

THEORY '20/'03



Experiment '20/'04

Dispersion integral for hadronic contribution to a_μ evaluated for:

a) **e^+e^- - Data ONLY**

CMD-2 (VEPP-2M) measured $\pi^+\pi^-$ channel with *0.6%* precision < *1* GeV

2.7 σ – **Deviation**

b) **τ-Data ONLY if available**

ALEPH /OPAL/CLEO

1.4 σ – **Deviation**

Experiment BNL-E821

Values for μ^+(2002) and μ^-(2004) in agreement with each other.

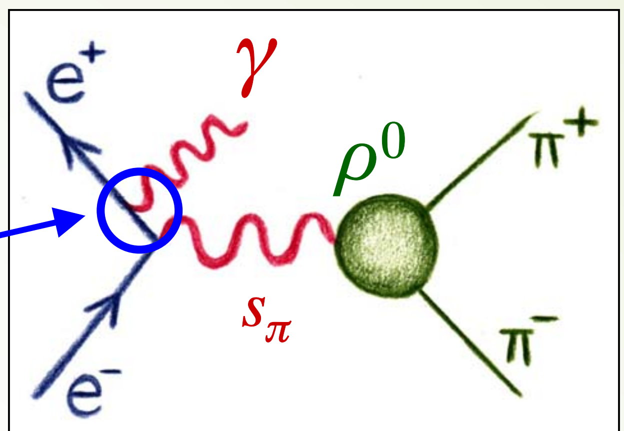
Precision: *0.5ppm*

Radiative Return

- Standard method for cross section measurement is the energy scan, i.e. the systematic variation of the c.m.s.-energy of the accelerator
- DAΦNE is a ϕ - factory and therefore designed for a fixed c.m.s.-energy: $\sqrt{s} = m_{\phi} = 1.019$ MeV; a variation of the energy is not foreseen in near future

Complementary approach:
Take events with Initial State Radiation (*ISR*)

ISR



"Radiative Return" to $\rho(\omega)$-resonance:

$e^+ e^- \rightarrow \rho(\omega) + \gamma \rightarrow \pi^+ \pi^- + \gamma$

Cross section as a function of the 2-Pion invariant mass $s_{\pi} = M_{\pi\pi}^2$

$$\frac{d\sigma(e^+ e^- \rightarrow \pi^+ \pi^- \gamma)}{dM_{\pi\pi}}$$

MC- Generator *PHOKHARA = NLO*
J. Kühn, H. Czyż, G. Rodrigo
Radiator-Function *H(s)*

$$M_{\pi\pi}^2 \frac{d\sigma_{\pi\pi\gamma}}{dM_{\pi\pi}^2} = \sigma_{\pi\pi}(s) \times H(s)$$

Selection $\pi^+\pi^-\gamma$

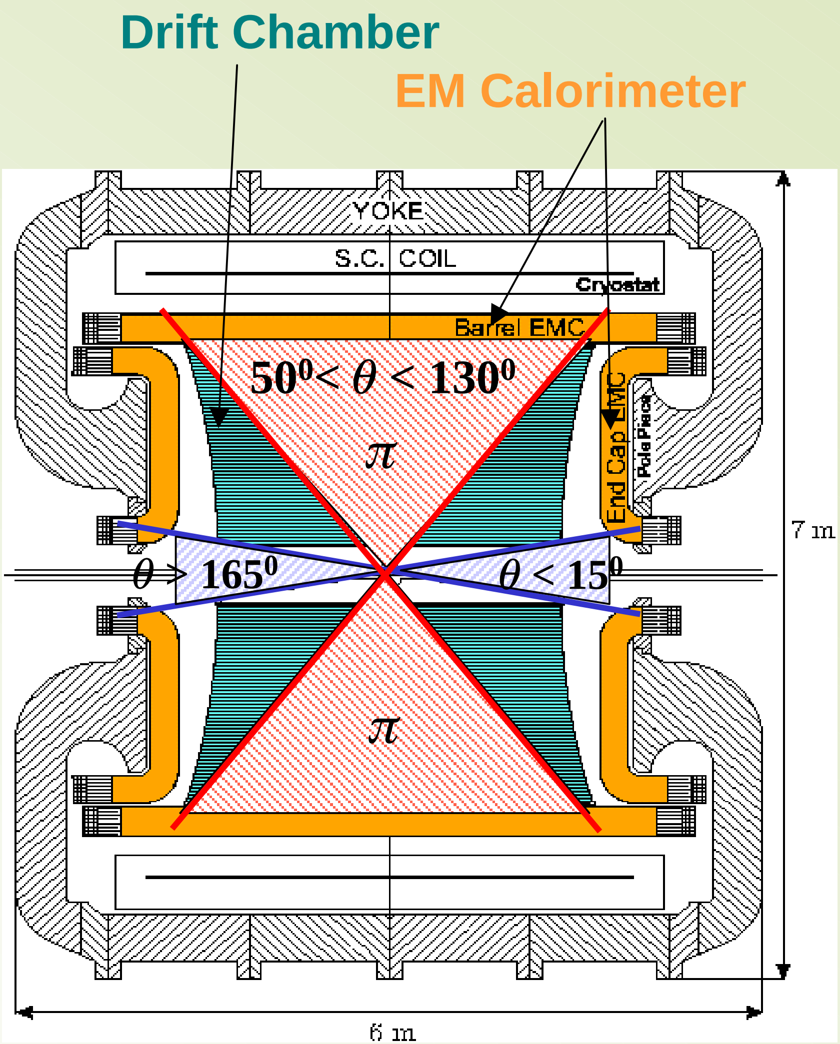
Pion tracks at large angles
$50^o < \theta_\pi < 130^o$

Photons at small angles
$\theta_\gamma < 15^o$ and $\theta_\gamma > 165^o$
are shadowed by
quadrupoles near the I.P.

NO PHOTON TAGGING

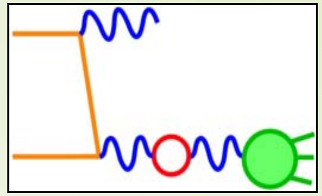
$$\vec{p}_\gamma = -\vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$$

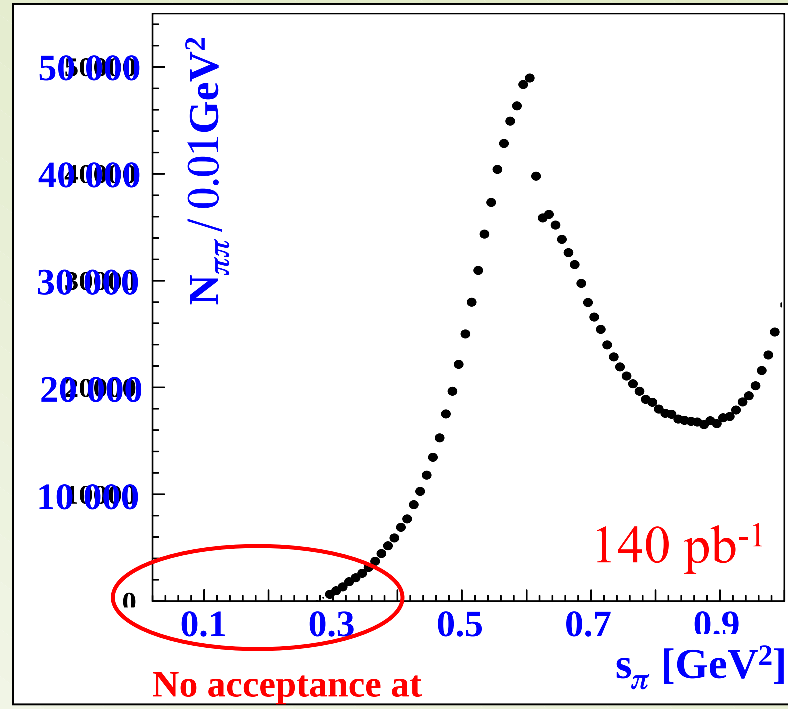
- High statistics for *ISR* events
- Reduced background contamination
- Low relative contribution of *FSR*



$\sigma(\pi\pi)$ *from the* $\pi\pi\gamma$ *Measurement*

$dN(\pi^+\pi^-\gamma) / dM_{\pi\pi}^2$
after acceptance cuts





No acceptance at threshold region

Event Analysis:
Efficiencies, Background
as a function of s_π

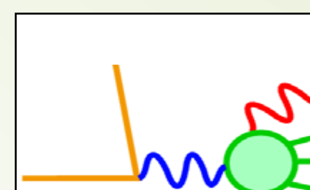
Normalize to Luminosity

Differential Cross Section
$d\sigma(\pi^+\pi^-\gamma)/dM_{\pi\pi}^2$

Divide by Radiator Function

Radiative Corrections

Cross Section
$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$



Background $\pi^+\pi^-\gamma$

1) Pion-Electron-Separation

Rad. Bhabhas $e^+e^- \to e^+e^-\gamma$ are separated by means of a Likelihood-Method (Signature of EmC-Clusters and TOF of particle tracks)

2) Kinematic Separation

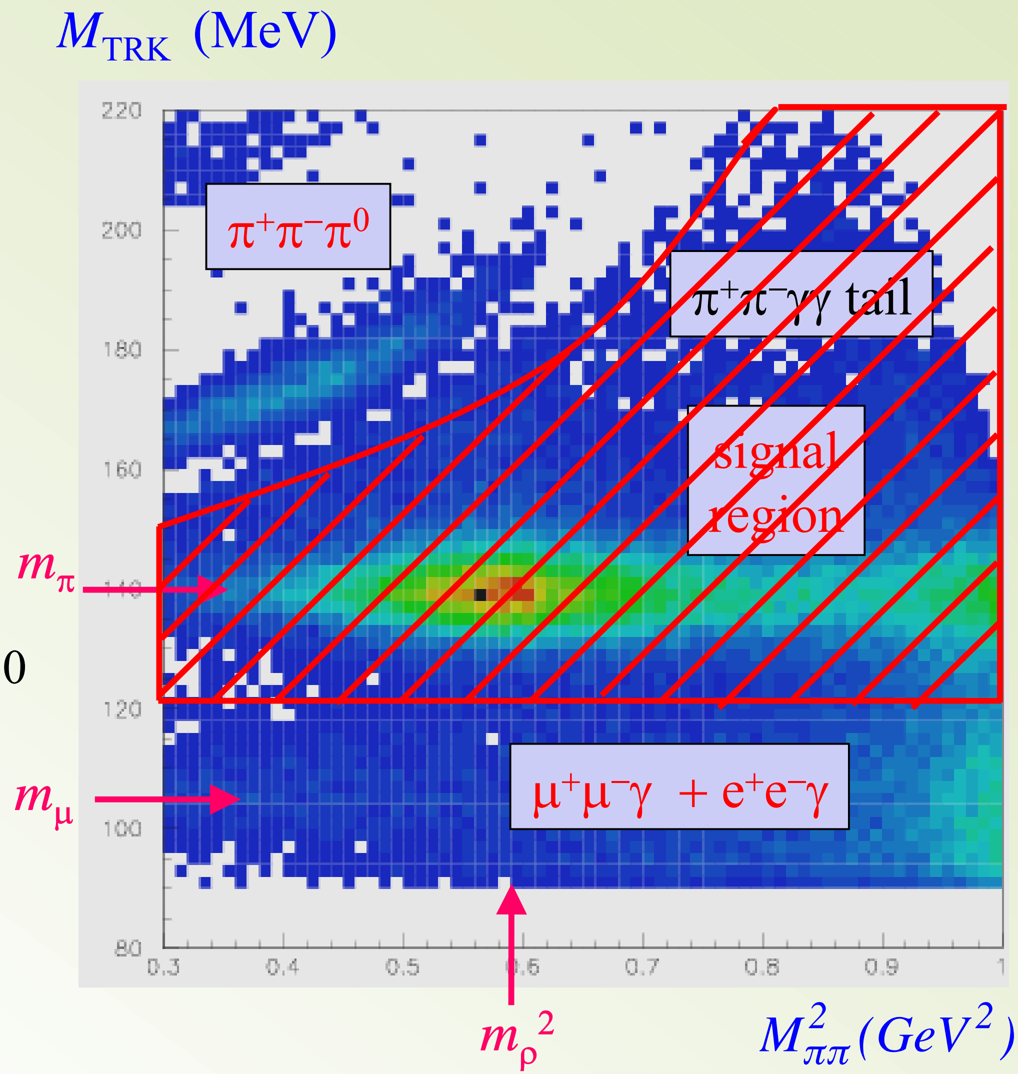
$\phi \to \pi^+\pi^-\pi^0$

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

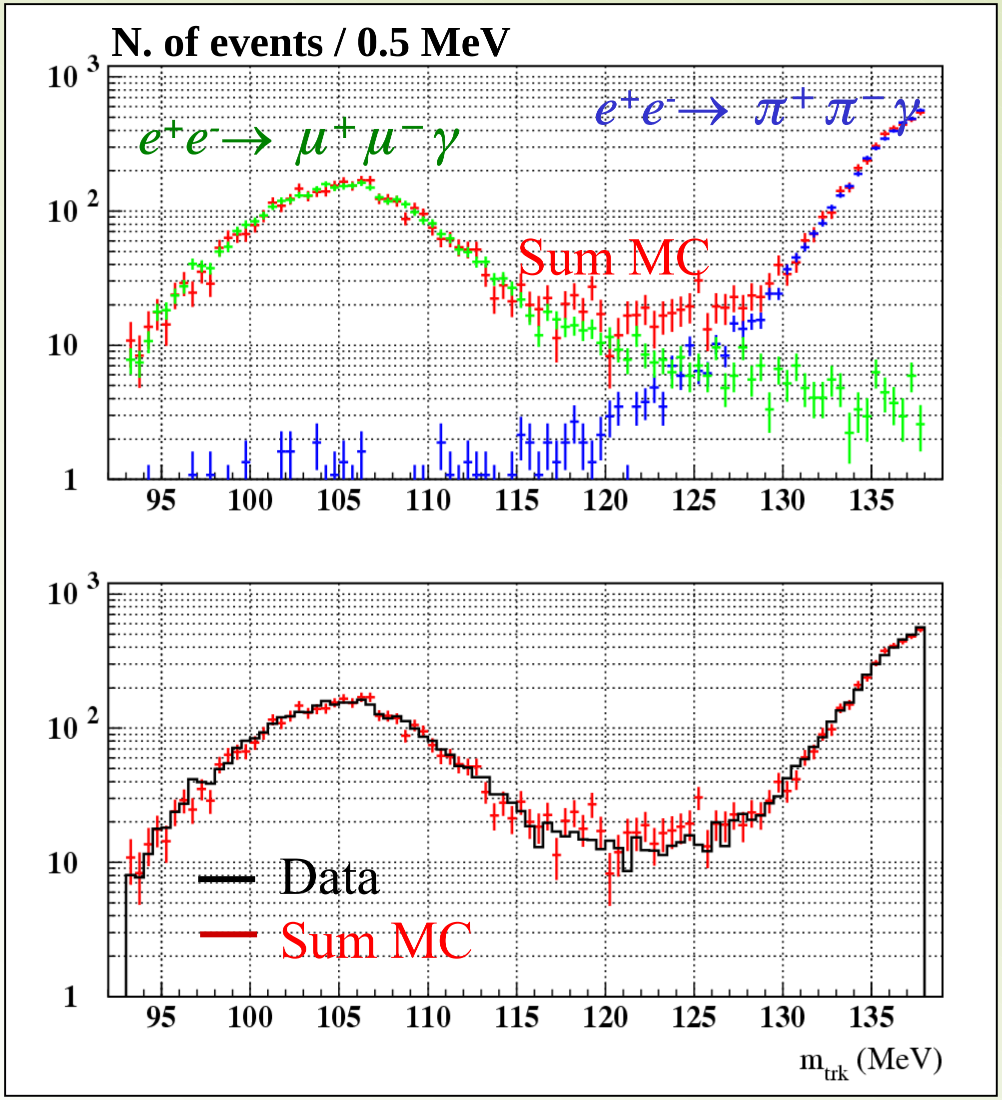
using „Trackmass"-variable

$$\left(M_\phi - \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} - \sqrt{\vec{p}_2^{\,2} + M_{trk}^2}\right)^2 - (\vec{p}_1 + \vec{p}_2)^2 = q_\gamma^2 = 0$$

$M_{\pi\pi}$ – dependent M_{TRK}-Cut



Background $\pi^+\pi^-\gamma$



3) Residual Background

Fit MC-Spectra (Trackmass) for signal and background
with free normalization parameters

Analysis $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma)$

Efficiencies:

- Trigger & Cosmic veto
- Tracking, Vertex
- π- e- separation
- Reconstruction filter
- Trackmass-cut
- Unfolding resolution
- Acceptance

Errors:

0.9%

Background:

- $e^+ e^- \rightarrow e^+ e^- \gamma$
- $e^+ e^- \rightarrow \mu^+ \mu^- \gamma$
- $\phi \rightarrow \pi^+ \pi^- \pi^o$

0.3%

Luminosity:

Bhabhas at large angles

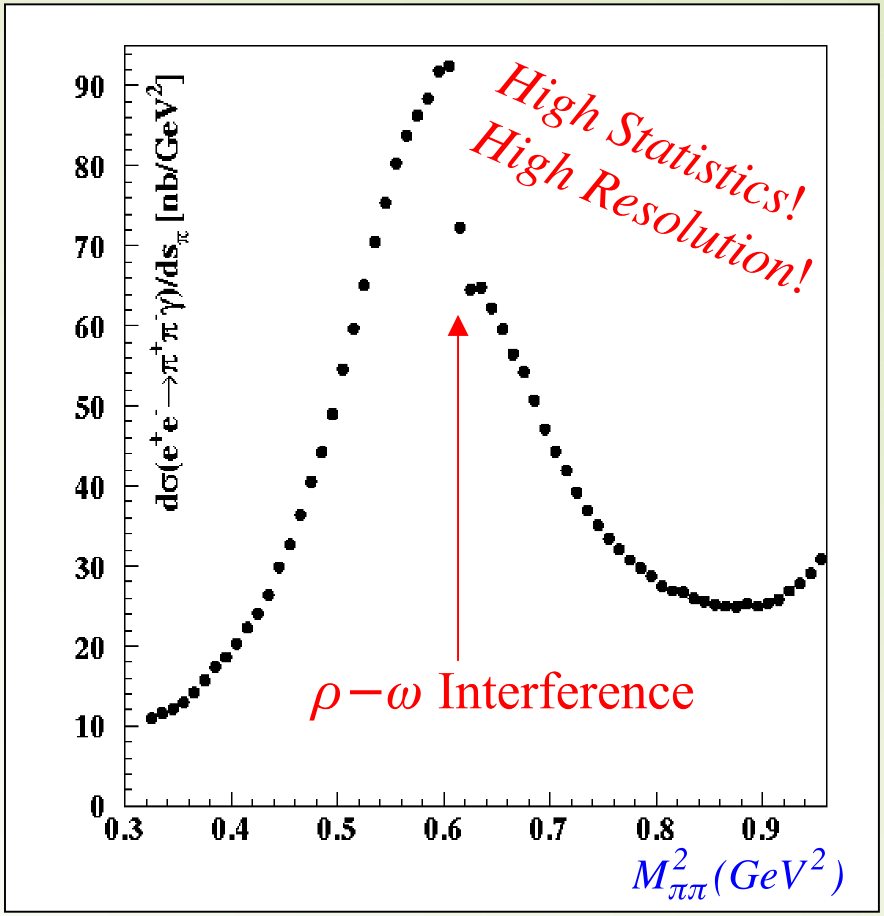
$> 55°, \sigma_{eff} = 430\ nb,$

$0.3\%_{exp}$

$0.5\%_{theo}$

Statistics: **141pb[-1] of 2001-Data**

1.5 Million Events



Luminosity

$$\mathcal{L} = N_{Bhabhas} / \sigma_{eff}^{MC}$$

Large Angle Bhabha Events > 55°, σ=430nb

Experimental precision:

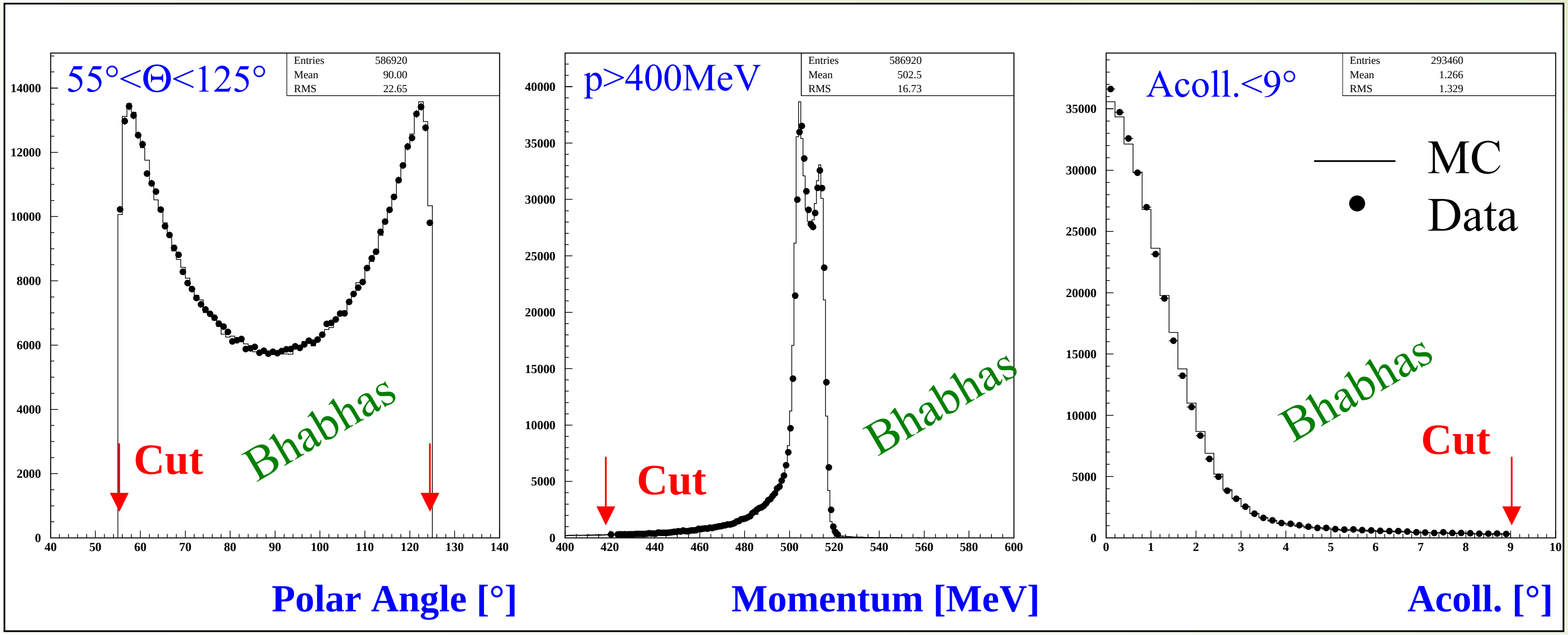
- Excellent agreement Data – MC for efficiencies and acceptance
- Background-"free" (0.5% $\pi^+\pi^-$)

⇒ **Uncertainty 0.3%**

Theory precision (radiative corrections):

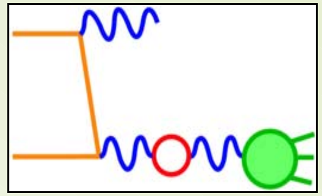
- BABAYAGA event generator (Pavia group)
- systematic comparison among other generators (Berends, KKMC, VEPP-2M), max. Δ=0.7%

⇒ **Uncertainty 0.5%** (=BABAYAGA error)



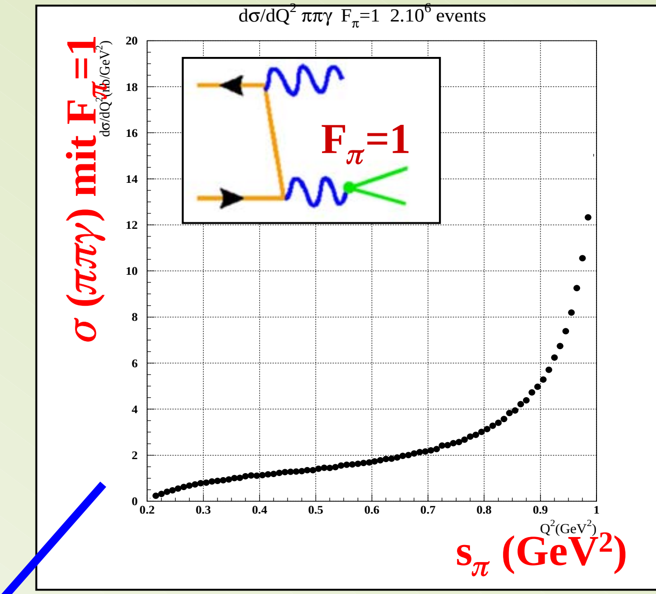
$\sigma_{\pi\pi}$ *from the* $\pi\pi\gamma$ *Measurement*

$dN(\pi^+\pi^-\gamma) / dM_{\pi\pi}^2$
after Acceptance Cuts



Event Analysis:
Efficiencies, Background

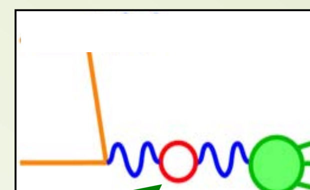
Normalize to Luminosity



We are here!

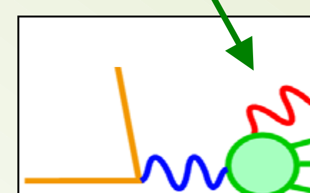
Differential Cross Section
$d\sigma(\pi^+\pi^-\gamma)/dM_{\pi\pi}^2$

Divide by Radiator Function



Radiative Corrections

Cross Section
$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

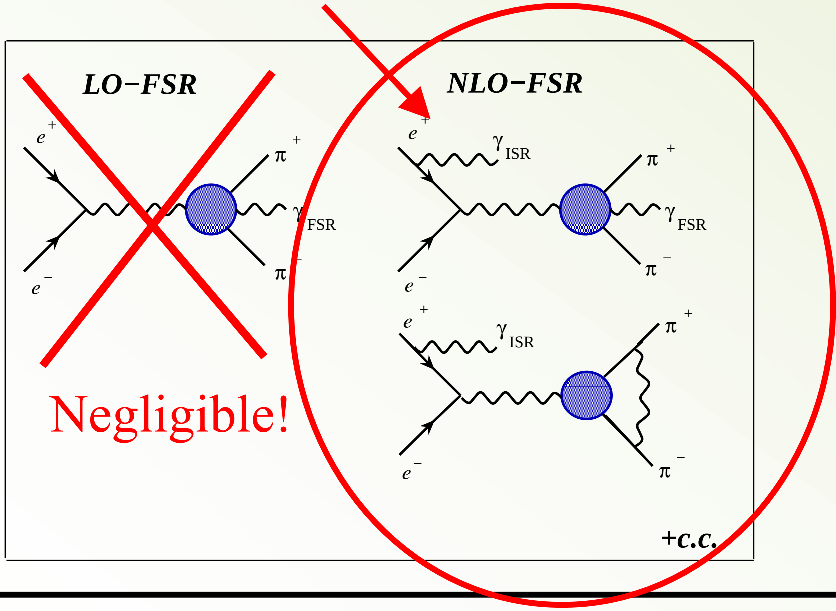


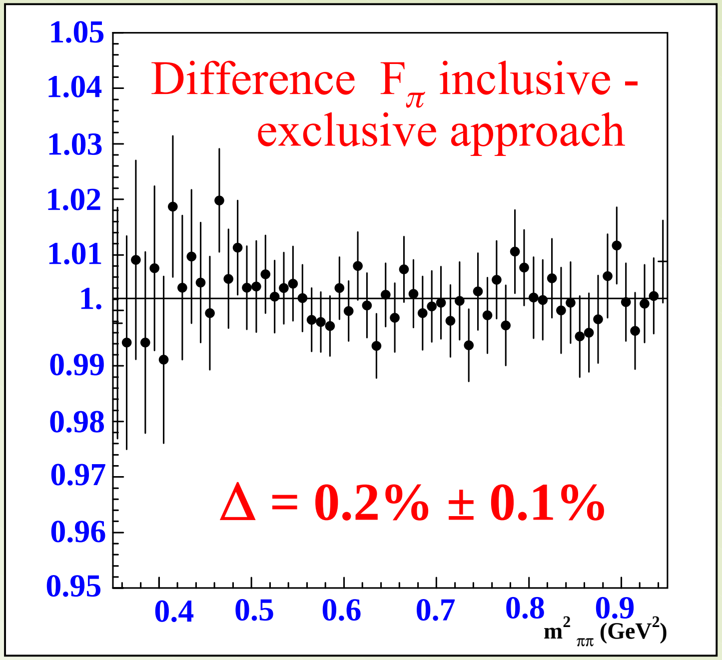
FSR Corrections

Cross Section $\sigma_{\pi\pi}$ must be incl. for FSR:

consider $\sigma_{\pi\pi\gamma}$ - Events with ISR-
and FSR-Photons = NLO-FSR

Efficiency for this kind of events has been analyzed according to 2 independent approaches!

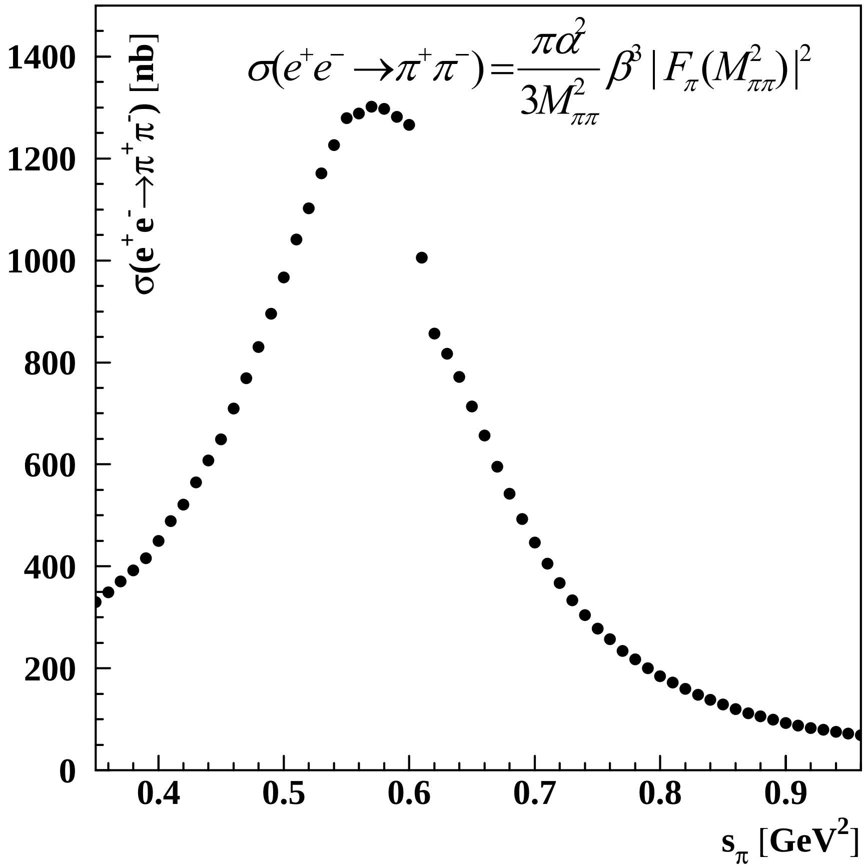




⇒ FSR-Corrections under control
⇒ Higher Order FSR-contributions negligible
⇒ Factorization-Ansatz correct
⇒ Model Dependence scalar QED!

Cross Section $\sigma(e^+e^- \to \pi^+\pi^-)$

Aim: Cross Section $e^+e^- \to \pi^+\pi^-$



Acceptance	0.3 %
Trigger	0.3 %
Reconstruction Filter	0.6 %
Tracking	0.3 %
Vertex	0.3 %
Particle ID	0.1 %
Trackmass	0.2 %
Background subtraction	0.3 %
Unfolding	0.2 %
Total exp systematics	0.9 %
Luminosity	0.6 %
Vacuum Polarization	0.2 %
FSR resummation	0.3 %
Radiation function ($H(s_\pi)$)	0.5 %
Total theory systematics	0.9 %

TOTAL ERROR 1.3%

- **Result published now**
- **Considerable improvement in near future**

2π Contribution to a_μ^{hadr}

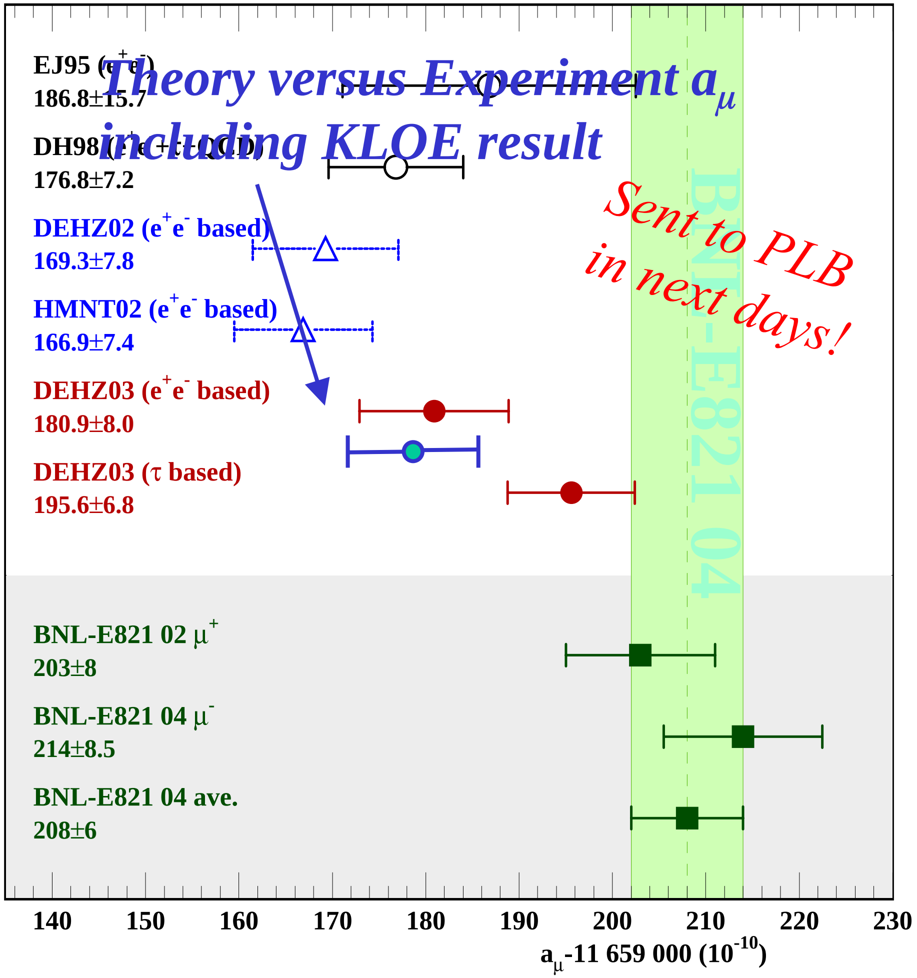
- We have computed the Dispersions Integral for the 2-Pion-Channel in the Energy Range $0.35 < M_{\pi\pi}^2 < 0.95\ \mathrm{GeV}^2$

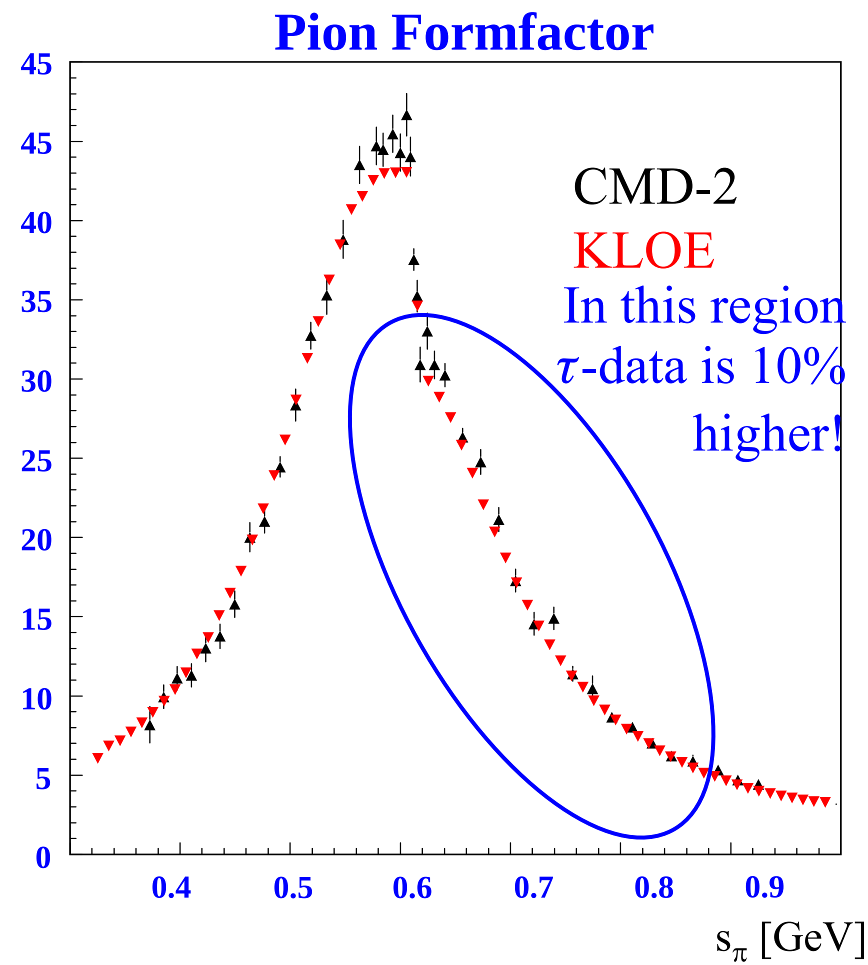
$$a_\mu^{\pi\pi} = 1/4\pi^3 \int_{0.35\mathrm{GeV}^2}^{0.95\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

$$a_\mu^{\pi\pi} = (388.7 \pm 0.8_{stat} \pm 3.5_{syst} \pm 3.5_{theo})\ 10^{-10}$$

- Comparison with CMD-2 in the Energy Range $0.37 < M_{\pi\pi}^2 < 0.93\ \mathrm{GeV}^2$

KLOE	$(375.6 \pm 0.8_{stat} \pm 4.9_{syst+theo})\ 10^{-10}$	*1.3% Error*
CMD2	$(378.6 \pm 2.7_{stat} \pm 2.3_{syst+theo})\ 10^{-10}$	*0.9% Error*





- At large values of s_π ($>m_\rho$) we see a large deviation with τ-Data! KLOE Data Points differentially are not in excellent agreement with CMD-2 (KLOE higher at low s_π and lower at large s_π).

Conclusions $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$

- KLOE has measured $\sigma_{\pi\pi}$ with 1.3% precision, very close collaboration with theory groups (Jegerlehner, Kühn)
- KLOE confirms a 3σ - deviation between the experimental and the theoretical value for the Muon-Anomaly!
- In the energy range above the ρ-peak the difference between KLOE- and τ-data is >10%!
- Speculations, whether Isospin - corrections for τ-data are completely understood (Mass-Shift ρ, F. Jegerlehner)?
  $\Rightarrow$ IF YES: e^+e^- - Data only basis for $(g\text{-}2)_\mu$?!

Outlook $\sigma(e^+e^- \to \pi^+\pi^-)$

Measure σ(ππ) in the region close to threshold, $M_{\pi\pi}$ < 600 MeV, responsible for ~20% of $a_\mu^{\pi\pi}$

- This region excluded by angular selection in small angle photon approach
- Complementary analysis at large photon angles

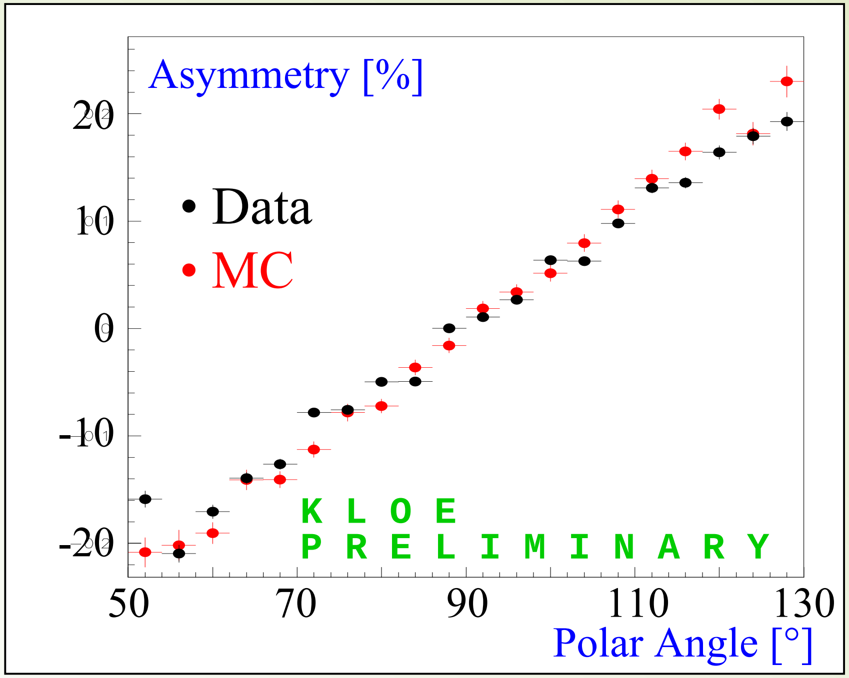
At large photon angles the amount of FSR is large!

⇒ test model of scalar QED (i.e. poinlike pions)

⇒ Measure Charge Asymmetry and compare data with MC

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

Charge asymmetry is due to different C-Parity of ISR- and FSR-amplitudes



4

Summary & Outlook

Summary

- KLOE experiment is providing relevant results, in particular in ***K_S physics*** and ***σ(hadronic)***
- Analysis of ***$K_{S,L}$ and $K^{\pm}$ decays*** with data on tape
- Investigate the nature of ***scalar mesons*** *$f_0(980)$, $a_0(980)$*
- So far DAΦNE has produced ***20 Million η - Mesons***
- New data taking just started, ***expectation for 2004: 2fb^{-1}***
  *… **more physics to come … especially** CP, CPT*

Wide **and** ***interesting physics program*** **@ 1GeV** **We are ready for the** ***femto-barn-era*** **!**

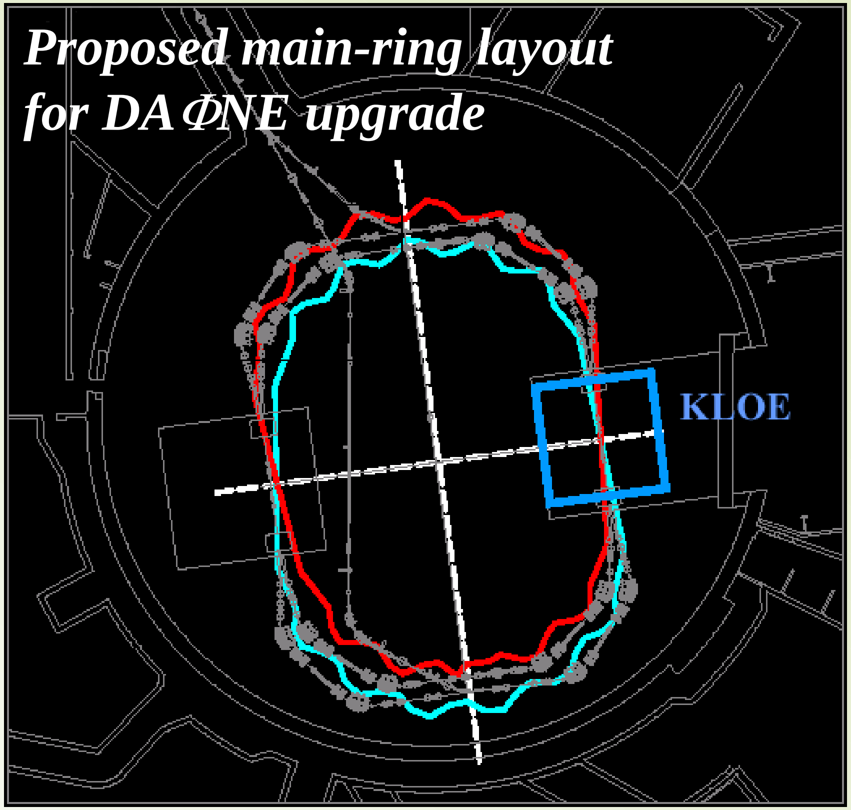
Outlook: Next generation DAΦNE

Next-generation DAΦNE ($\sqrt{s} = m_\phi$) with $\mathcal{L}$ up to 5×10^{34} cm^{-2} s^{-1} would allow competitive measurements of

- Rare K_S decays
- $\mathcal{CP}$ / $\mathcal{CPT}$ parameters via $K_S K_L$ interference

Would require a KLOE upgrade:

- Vertex detector
- New DC: higher segmentation
- Upgrade to EmC: added depth, higher readout granularity



Currently moving from discussion to proposal stage
Include the possibility to increase c.m.s. energy to 2 GeV