Physics Program at DAFNE

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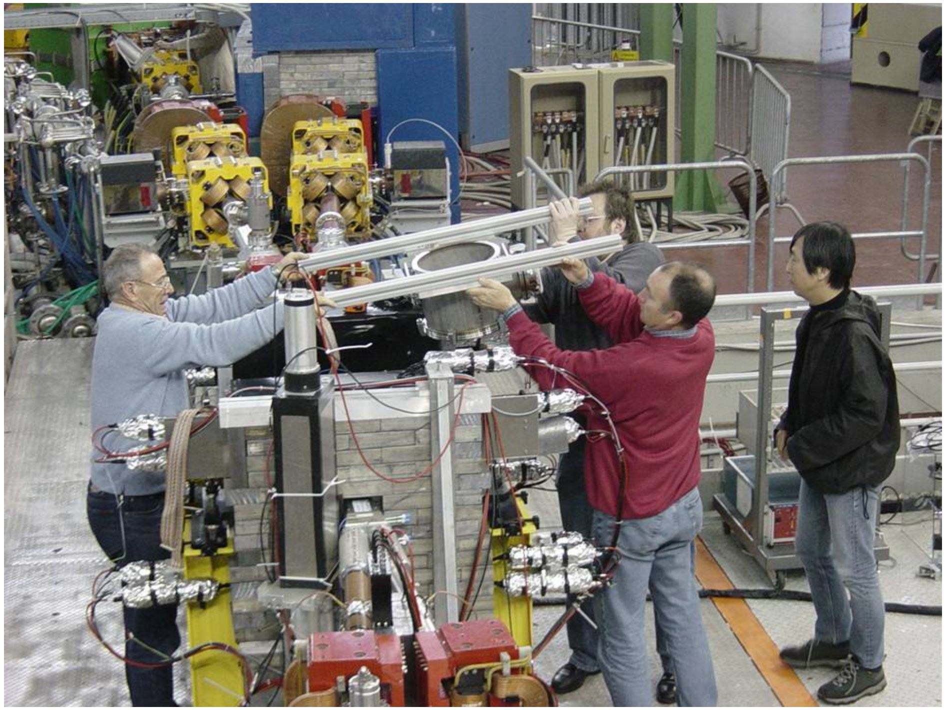
PHIPSI08

International Workshop on e+e- collisions from Phi to Psi

Laboratori Nazionali di Frascati, Italy, 7 - 10 April 2008

Plans

- Siddharta experiment on kaonic atoms, hydrogen and deuterium
- Measurement of the 1s-shift and line width by strong interactions at the eV level
- X-ray detection by SDD
- Day-One setup – ongoing 100 pb^{-1}



- Final setup - Precision measurement of kaonic hydrogen 400 pb^{-1}
- Final setup - Precision measurement of kaonic deuterium 600 pb^{-1}

Proposals

- KLOE/2 –
  - To improve and extend the results on kaon physics, ϕ radiative decays, $\gamma\gamma$ processes with $\int L \sim 50$ fb-1
  - To perform precision measurements of multihadronic cross sections with an energy scan up to $\sqrt{s} \sim 2.4$ GeV
- FINUDA -
  - To improve the results on hypernuclei spectroscopy and the searches for nuclear kaon clusters on the basis of 3 fb-1
- AMADEUS –
  - To search for deeply bound nuclear kaon structures with an ad-hoc target system installed inside the KLOE detector on the basis of $\int L \sim 10\text{-}20$ fb-1
- DANTE –
  - Study of p,n form factors with Dafne at $\sqrt{s} \sim 2.4$ GeV

Hypernuclei spectroscopy: the FINUDA proposal

- With the new run, 3 fb-1, FINUDA aims to
  - improve on the knowledge of the intermediate structures of ${}^{12}_{\Lambda}C$
  - perform ^{28}Si spectroscopy with K- stopping in the silicon modules
  - search for neutron-rich hypernuclei
  - improve the low-energy part of the proton spectra on ^{6}Li, ^{12}C

FINUDA, PLB622(2005)

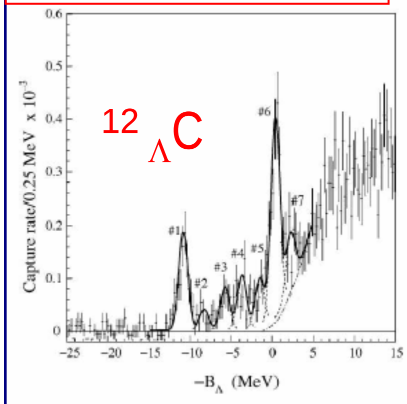
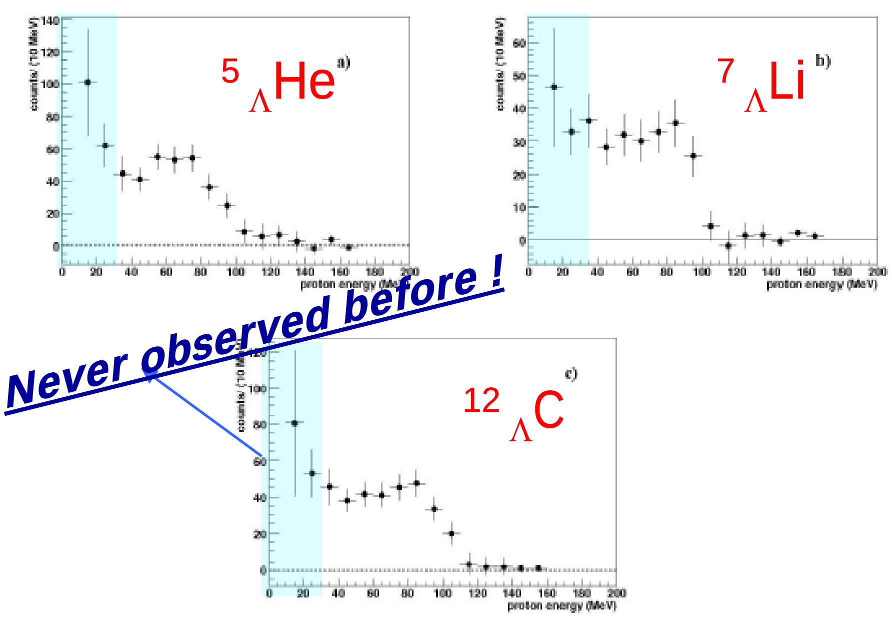


Figure 2.7: FINUDA published results [5] for ${}^{12}_{\Lambda}$C.

Proton energy from hypernuclei decay

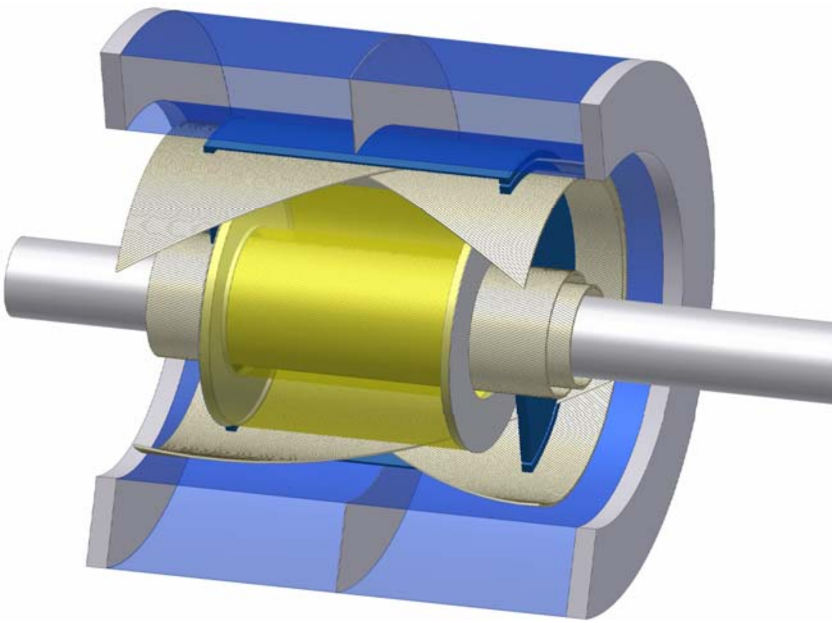


FINUDA, NPA(2008), doi:10.1016/j.nuclphysa.2008.02.003, arXiv:0803.1915v1 [nucl-ex]

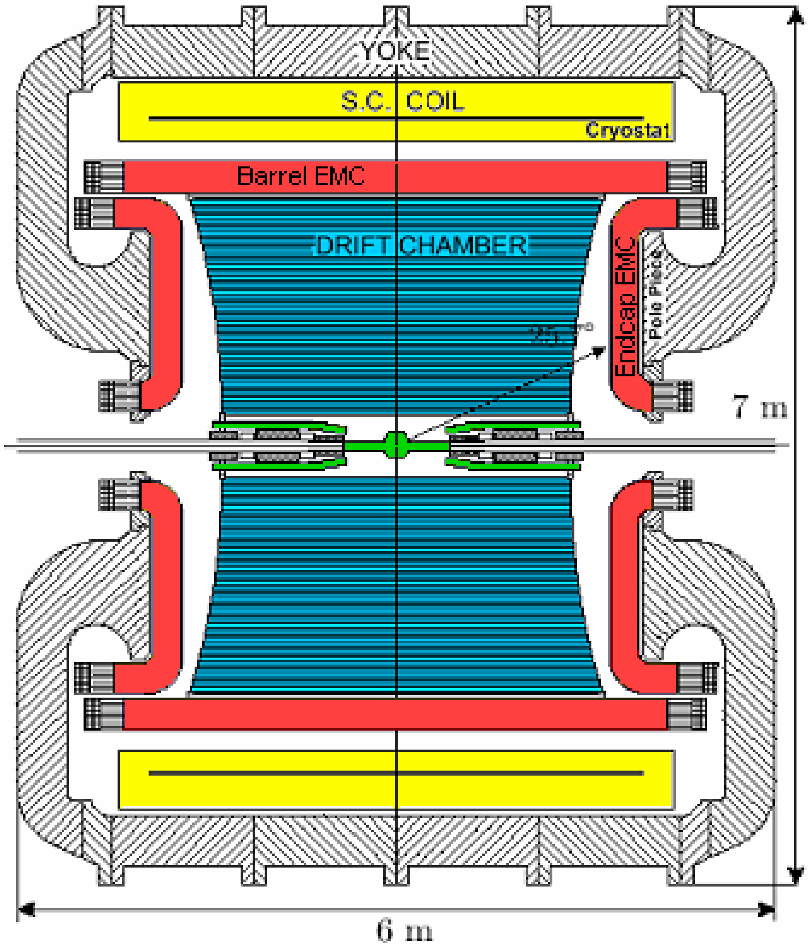
- search for deeply-bound states or nuclear kaon clusters on Li and ^{12}C, by the detection of deuterons and tritons and the study of their correlations with the Λ [PRL94(2005), PLB649(2007), EPJA33(2007)]

The Amadeus project

- The scientific case of the so-called “deeply bound kaonic nuclear states” is hotter than ever, both in the theoretical (intensive debate) and experimental sectors.
- AMADEUS’s main aim is to perform the first full acceptance, high precision measurement of DBKNS both in formation and in the decay processes, by implementing the KLOE detector with an inner AMADEUS-dedicated setup, containing a cryogenic target and a trigger system,
- Two-Run scheme proposed: 3.5 fb-1 and 10-20 fb-1 with an upgraded inner detector region
- The first phase, with
  - 2 fb-1 of integrated luminosity with **He4** target in order to study the tribaryon DBKNS
  - 1-2 fb-1 of integrated luminosity with **He3** target in order to study the dibaryon DBKNS
  - 0.5 fb-1 of integrated luminosity for **low-energy kaon-nuclear** dedicated measurements



The KLOE2 proposal



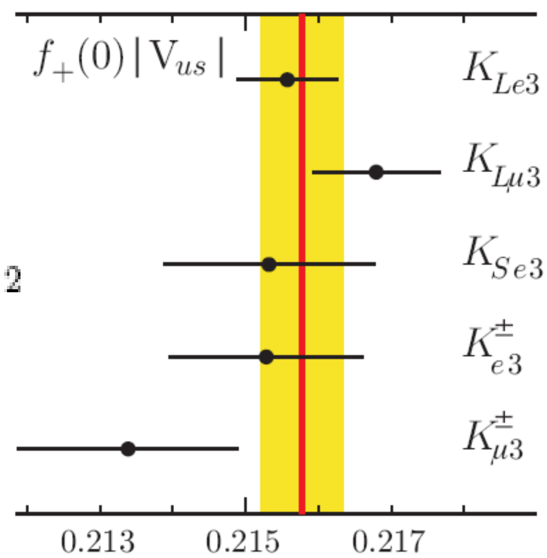
- We have proposed to prepare the KLOE detector for a new run in year 2009 (step 0) and then proceed with the installation of
  - a new inner-tracker for improving vertex resolution close to the interaction region
  - a new photon-veto system at small-angles
  - a new system for the quadrupole instrumentation
  - a new tagger system for γ–γ events
- In year 2009 we aim to integrate 5 fb^{-1} preparing the machine and the experiment for a longer data taking period
- The ultimate goal is to reach a statistics of 40-50 fb-1 in 3-4 years

Physics program with KLOE2

- Flavor physics
  - CKM unitarity test
  - Lepton universality
  - Search for Signals of new physics
  - New tests with Ks-KL QM-correlated pairs
- Low-energy QCD
  - Measurements in the Kaon sector
  - The η and η' pseudoscalars
  - The scalars
  - γ–γ processes

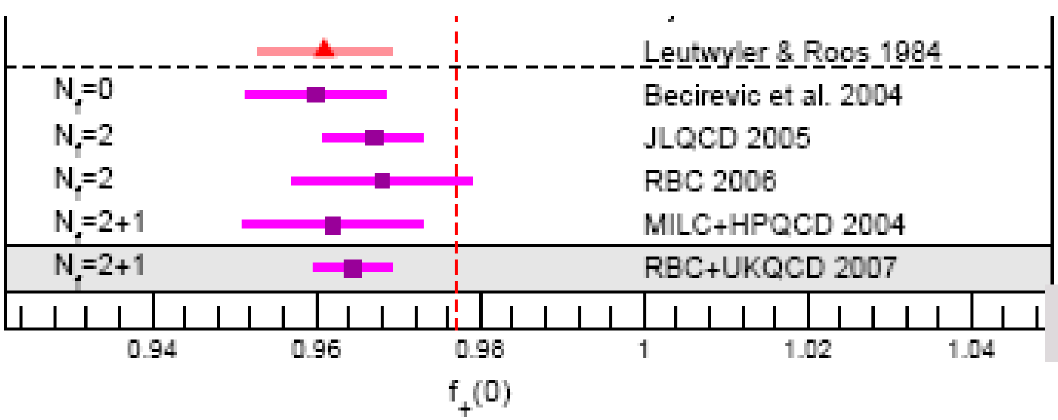
Vus determination with KLOE

- KLOE has measured the experimental inputs to Vus, Kaon branching ratios, lifetime, form factor dependence on the momentum trasfer (form factor slopes)
- Precision results on semileptonic decays of $K^{\pm}$, K_L , K_S and on the $K \to \mu\nu$ channel have been obtained
- The results on $|Vus\ f_+(0)|$ from all of the semileptonic decays are in good agreement showing the consistency of the measurements with SU(2) corrections



$$\Gamma_{K\to\pi l\nu} = C_K^2 \frac{G_F^2 m_K^5}{192\pi^3} I\, S_{EW}\left[1 + 2\Delta_{SU(2)} + 2\Delta_{EM}\right] |V_{us}|^2 |f_+(0)|^2$$

- We have reached 0.3% precision in the $|Vus\ f_+(0)|$ average



- $f_+(0)$ calculation from Lattice has reached 0.5% accuracy

$f_+(0) = 0.9644 \pm 0.0049$

Vus determination with KLOE

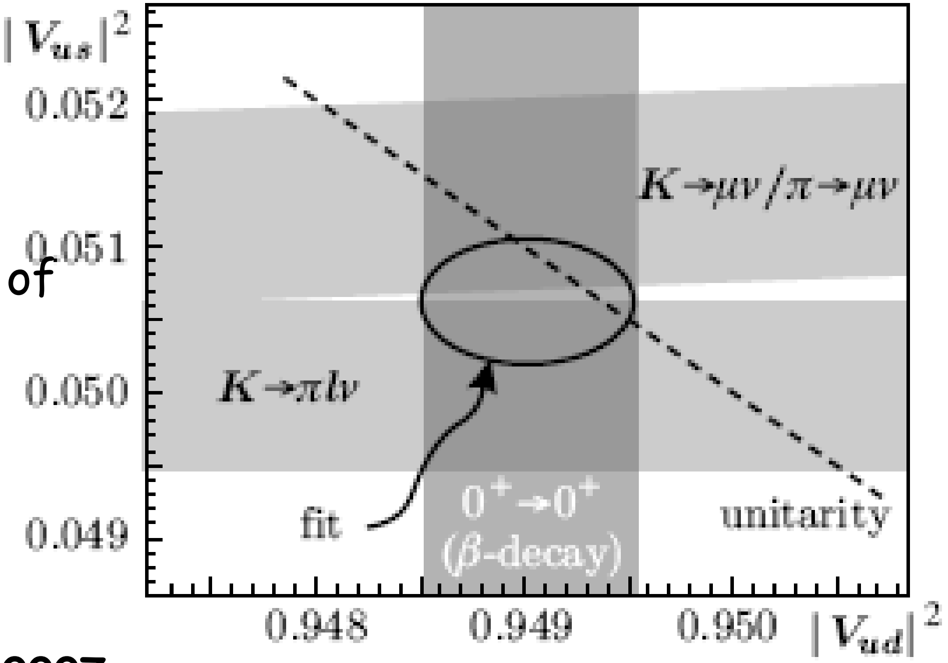
- Vus from the ratio of pseudoscalar K,π leptonic decays and the decay constants, f_K/f_π

$$\frac{\Gamma(K^{\pm}_{\ell 2(\gamma)})}{\Gamma(\pi^{\pm}_{\ell 2(\gamma)})} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2 m_K}{f_\pi^2 m_\pi} \left(\frac{1-m_\ell^2/m_K^2}{1-m_\ell^2/m_\pi^2}\right) \times (1+\delta_{\rm em})$$

- $\Gamma(K^{\pm}_{l2})/\Gamma(\pi^{\pm}_{l2})$ with 0.65% precision
- $|f_K/f_\pi|^2$ from lattice with 1.2% accuracy
- $|Vus/Vud|^2 = 0.0541 \pm 0.0007$
- The ratio of the two determinations of |Vus/Vud| is a test of LFC

$$R_{\ell 23} = \left|\frac{V_{us}(K_{\mu 2})}{V_{us}(K_{\ell 3})} \times \frac{V_{ud}(0^+ \to 0^+)}{V_{ud}(\pi_{\mu 2})}\right|$$

- From a fit to the measurements in figure:
  - **$1 - |Vus|^2 - |Vud|^2 = 0.0004 \pm 0.0007$**
- Further improvements in the experimental inputs in the prospect of Lattice QCD can progress as expected



A window on NP: the Ke2 case

- Lepton flavor conservation in the SM: opportunity for precision tests
- In the ratio $R_K = \Gamma(Ke2)/\Gamma(K\mu 2)$ theoretical uncertainties from non-perturbative QCD cancel out, giving the SM-prediction with 0.05% precision
- It is also an interesting window for NP signals
- SUSY LFV contributions have the potentiality to change these predictions at the percent level

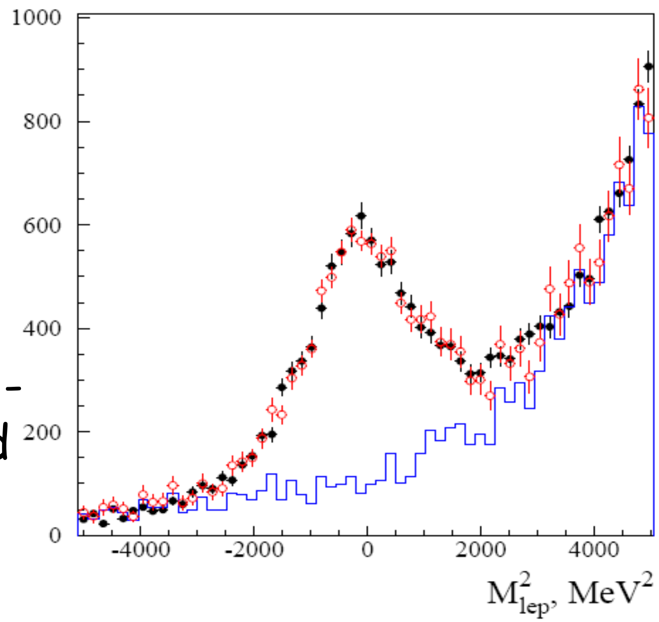
$$R_K^{LFV} \simeq R_K^{SM} \left[1 + \left(\frac{m_K^4}{M_H^4} \right) \left(\frac{m_\tau^2}{m_e^2} \right) |\Delta_R^{31}|^2 \tan^6\beta \right]$$

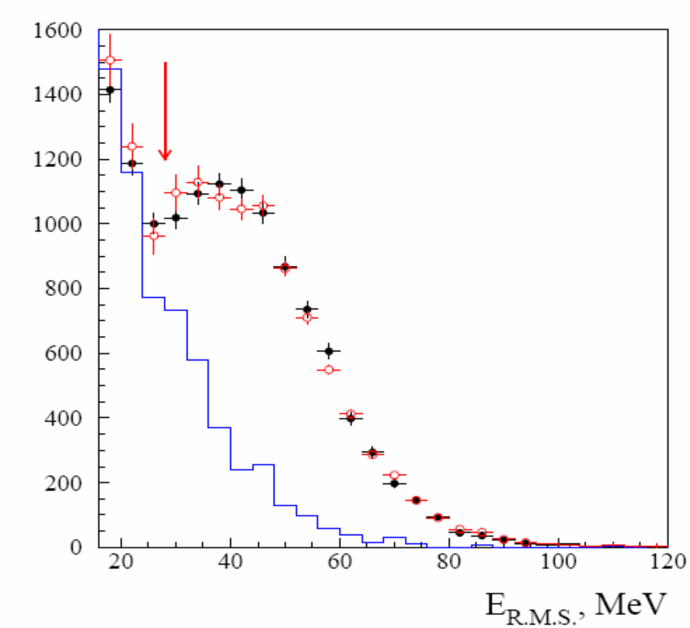
- Enhancement in the $\Gamma(Ke2)$ expected, $\Gamma(Ke2) = \Gamma(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)$

- Experimental precision : 5%

$\Gamma(Ke2)/\Gamma(K\mu2)$

- With present statistics, thanks to the high efficiency of the on-going analysis, $\varepsilon \sim 0.25$, KLOE will reach 1% precision
- Fully reconstructed decays for the preliminary results
- N(Ke2) = 8090±156 from the fit with the MC-evaluated shapes for S and B
- The preliminary result is inclusive of the radiative decays with $E\gamma < 20$ MeV
  $\Gamma(Ke2)/\Gamma(K\mu2) = (2.55 \pm 0.05 \pm 0.05) 10^{-5}$
- Analysis in progress on Kaons decaying before entering the DC; a comparable amount of signal-events expected





- The KLOE-2 goal, with the first 5 fb-1, is to reach 0.5% precision

Decoherence and CPT in neutral Kaon pairs

$$I(\pi\pi,\pi\pi;|\Delta t|) \propto e^{-\Gamma_L|\Delta t|} + e^{-\Gamma_S|\Delta t|} - 2\cdot(1-\zeta)\cdot e^{-(\Gamma_S+\Gamma_L)|\Delta t|/2}\cos(\Delta m|\Delta t|)$$

interference term modified introducing a decoherence parameter ζ.

PLB 642(2006)315

$$\zeta_{K_S K_L} = 0.018^{+0.038}_{-0.035}$$

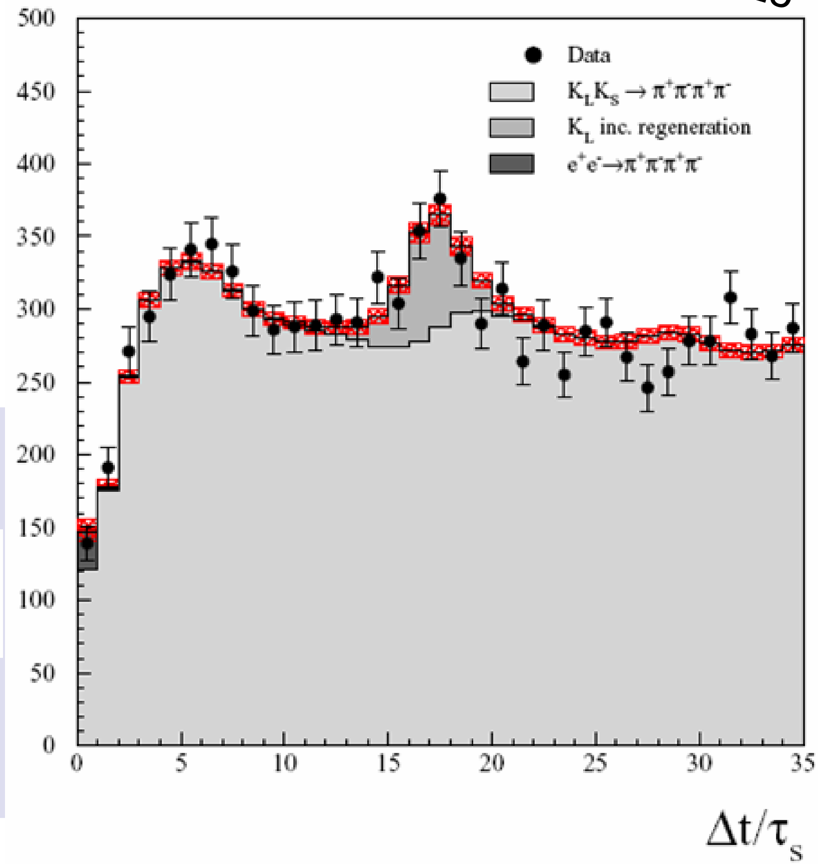
$$\zeta_{K^0\overline{K}^0} = \left(0.10^{+0.20}_{-0.18}\right)\times 10^{-5}$$

Systematics x10 better, completely negligible

$\zeta_{K_S K_L} < 0.085$

$\zeta_{K^0\overline{K^0}} < 0.44\ 10^{-5}$

@ 90% C.L.



CPT violation could also change initial state

$$|i\rangle = \frac{1}{\sqrt{2}}\left(\left[|K^0,\overline{K^0}\rangle - |\overline{K^0},K^0\rangle\right] + \omega\left[|K^0,\overline{K^0}\rangle + |\overline{K^0},K^0\rangle\right]\right)$$

$|\omega| < 2.1\ 10^{-3}$ @ 95% C.L:

Ks decays

- KLOE is the only experiment with Ks pure beams

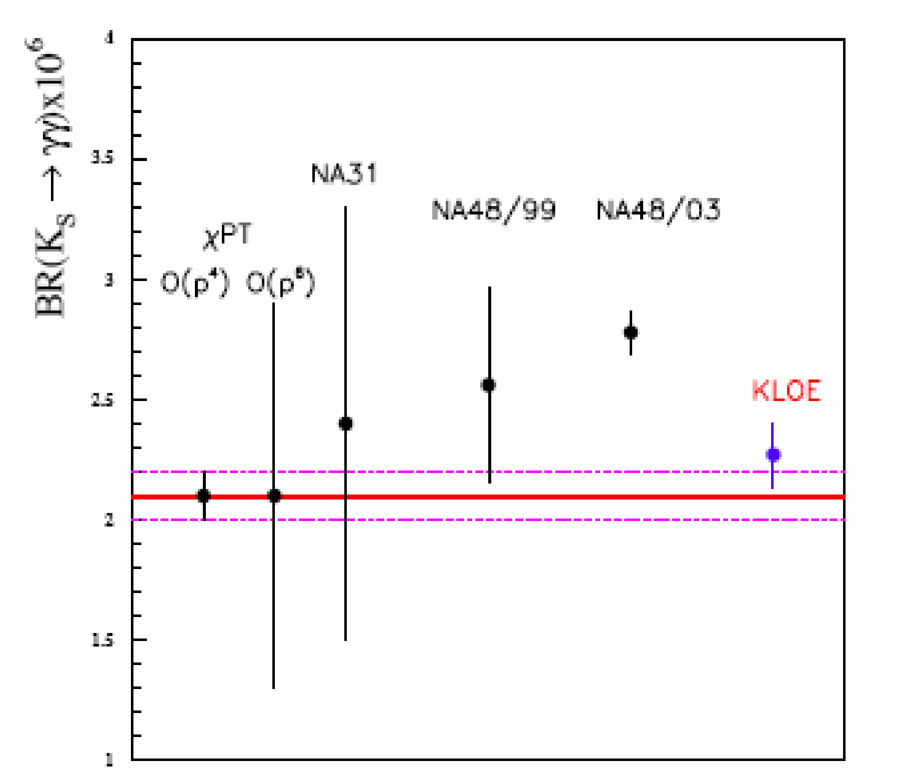
Channel	With present statistics	With 5 fb-1
$K_S \to \pi^+\pi^-, \pi^0\pi^0$	$\Gamma(\pi^+\pi^-)/\Gamma(\pi^0\pi^0)$ to ~0.25%	
$K_S \to \pi e \nu$	**BR to 1.3%, form factor slope, charge asymmetry (1/6 tot)**	
	BR to 0.5%	0.3%
$K_S \to \pi \mu \nu$	BR to 0.8-1%	0.5%
$K_S \to \gamma\gamma$	**BR to 6%**	4.5%
$K_S \to \pi^0\pi^0\pi^0$	**UL on BR to 10^{-7} (1/6 tot)**	
	UL on BR to few 10^{-8}	
$K_S \to \pi^+\pi^-\pi^0$	BR	30%
$K_S \to e^+e^-$	UL on BR to 2×10^{-8}	
$K_S \to e^+e^- \pi^+\pi^-$	UL on BR to 10^{-8}	

BR($K_S \to \gamma\gamma$)

- BR($KS \to \gamma\gamma$) = (2.26 ± 0.12stat ± 0.06syst) × 10^{-6}
- 3-σ discrepancy with NA48 measurement
- Our result indicates small O(p^6) ChPT contributions

- Even releasing the cut on QCAL used to reduce the BKG of a factor 3 .. We expect a ≈ 4.5% measurement of the BR with + 5 fb-1

- 1-2 % measurement error expected with larger statistics + upgraded QCAL



$K_S \to \pi e \nu$: BR, A_S, Re x_+

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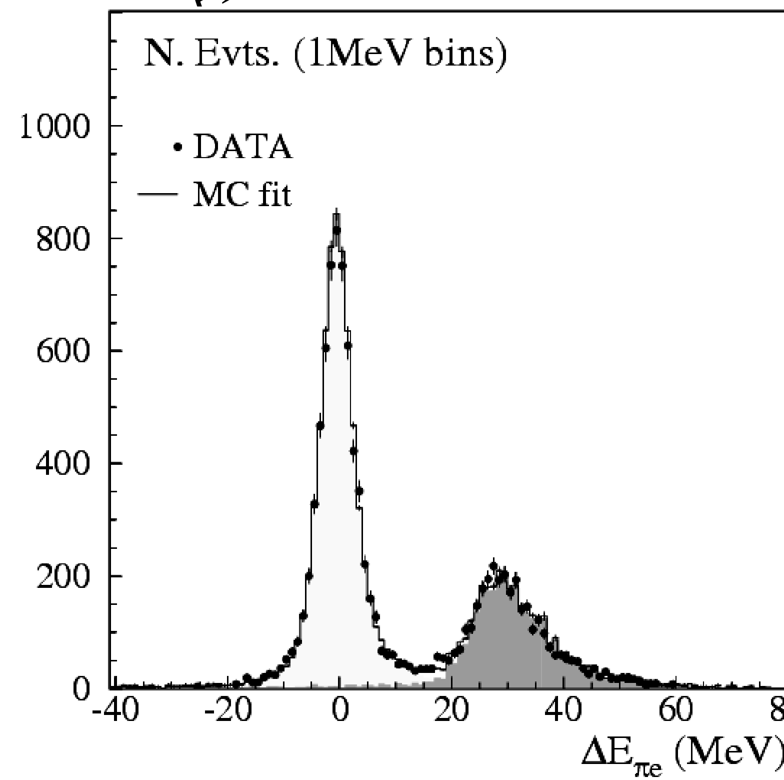
TOF e/π ID,
fit to E_{miss}- p_{miss} spectrum

$K_S \to \pi^+\pi^-$ *events in the same sample for K_S counting*



Branching ratio

BR($\pi e \nu$) = (7.046 ± 0.077 ± 0.049) 10^{-4}

fractional error: $1.3\% = 1.1\%_{stat} \oplus 0.7\%_{syst}$

Charge asymmetry

A_S = (1.5 ± 9.6 ± 2.9) 10^{-3}

first measurement

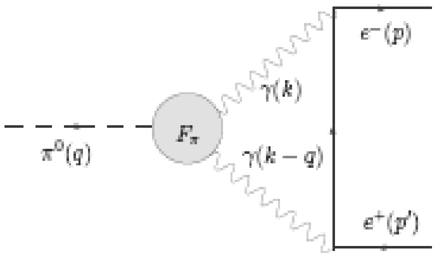
$$1 + 4\,Re(x_+) = \frac{\Gamma_S}{\Gamma_L} = \frac{BR(K_S \to \pi e \nu)\ \tau_L}{BR(K_L \to \pi e \nu)\ \tau_S}$$

13 10^{-3} 4.5 10^{-3} 4 10^{-3} 10^{-3}

Re x_+ = (–0.5 ± 3.1 ± 1.8) 10^{-3}

About $P \to l^+l^-$

- KTeV has recently published the measurement of BR($\pi^0 \to e+e-$) and theoretical predictions [Phys.Rev. D75 012004 (2007)]
- It is an helicity-suppressed decay probing $\pi^0\ \gamma^*\gamma^*$ coupling



- Dorokhov's presentation at this conference devoted to the 3-σ discrepancy between KTeV measurement of BR($\pi^0 \to e+e-$) and theoretical predictions [Phys.Rev. D75 114007 (2007)]

B	Unitary bound	CLEO bound	CLEO+OPE	Experiment
$B(\pi^0 \to e^+e^-) \times 10^8$	≥ 4.69	$\geq 5.85 \pm 0.03$	6.23 ± 0.09	7.49 ± 0.38 [1]
$B(\eta \to \mu^+\mu^-) \times 10^6$	≥ 4.36	$\leq 6.23 \pm 0.12$	5.11 ± 0.20	5.8 ± 0.8 [7, 32]
$B(\eta \to e^+e^-) \times 10^9$	≥ 1.78	$\geq 4.33 \pm 0.02$	4.60 ± 0.06	...

from Kahn et al., arXiv:0712.0007[hep-ph]

- With the first KLOE2 run we could reach 6% relative precision in the measurement of both, the BR($\pi^0 \to e+e-$) and the BR($\eta \to \mu+\mu-$), using π^0 from $\phi \to \pi+\pi-\pi0$, $K \to \pi+\ \pi0$, $KS \to \pi0\ \pi0$, $KL \to \pi0\ \pi0\ \pi0$

η decays

With 5 $fb^{-1} \rightarrow 2.0\ 10^8\ \eta$ produced

- χPT and most recent extensions call for precision measurements of BR's and photon (e^+e^-) spectrum in the radiative decays

Decay	BR (PDG04)	ε_{ana}	N_{exp}
$\eta \rightarrow \gamma\gamma$	(39.43 ± 0.26) %	70%	5.5×10^7
$\eta \rightarrow \pi^0\pi^0\pi^0$	(32.51 ± 0.29) %	45%	2.9×10^7
$\eta \rightarrow \pi^+\pi^-\pi^0$	(22.6 ± 0.4) %	36.5%	1.6×10^7
$\eta \rightarrow \pi^+\pi^-\gamma$	(4.68 ± 0.11) %	46%	4.3×10^6
$\eta \rightarrow e^+e^-\gamma$	$(6.0 \pm 0.8)\times 10^{-3}$	46%	5.5×10^5
$\eta \rightarrow \mu^+\mu^-\gamma$	$(3.1 \pm 0.4)\times 10^{-4}$	~10%	6.2×10^3
$\eta \rightarrow e^+e^-e^+e^-$	$< 6.9\times 10^{-5}$	~ 7%	
$\eta \rightarrow \pi^+\pi^-e^+e^-$	$(4.0^{+14.0}_{-2.7})\times 10^{-4}$	~ 7%	5.6×10^3

B.Borasoy and R.Nissler, hep-ph arXiv:0705.0954

$\eta \rightarrow \pi^+\pi^-\gamma$:

Tension in the old measurements of the γ spectrum

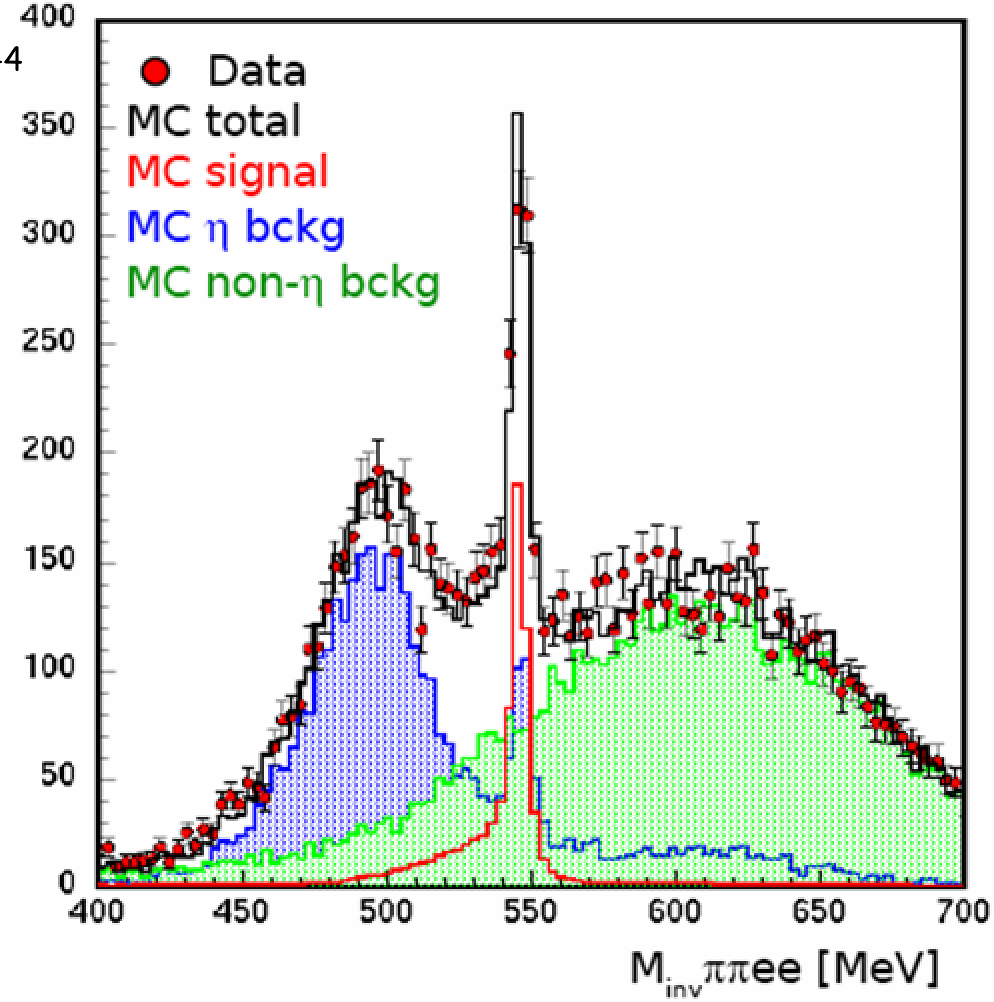
BR($\eta \rightarrow \pi^+\pi^-ee$)/

BR($\eta \rightarrow \pi^+\pi^-\gamma$):

Theor. accuracy: 1-2%

η rare decays: $\eta \to \pi^+\pi^- e^+e^-$

- On-going analysis
- Preliminary result with 700 selected events on 1/3 of the data sample
- BR($\eta \to \pi^+\pi^- e^+e^-$)= $(2.4\pm0.2\pm0.4)\ 10^{-4}$

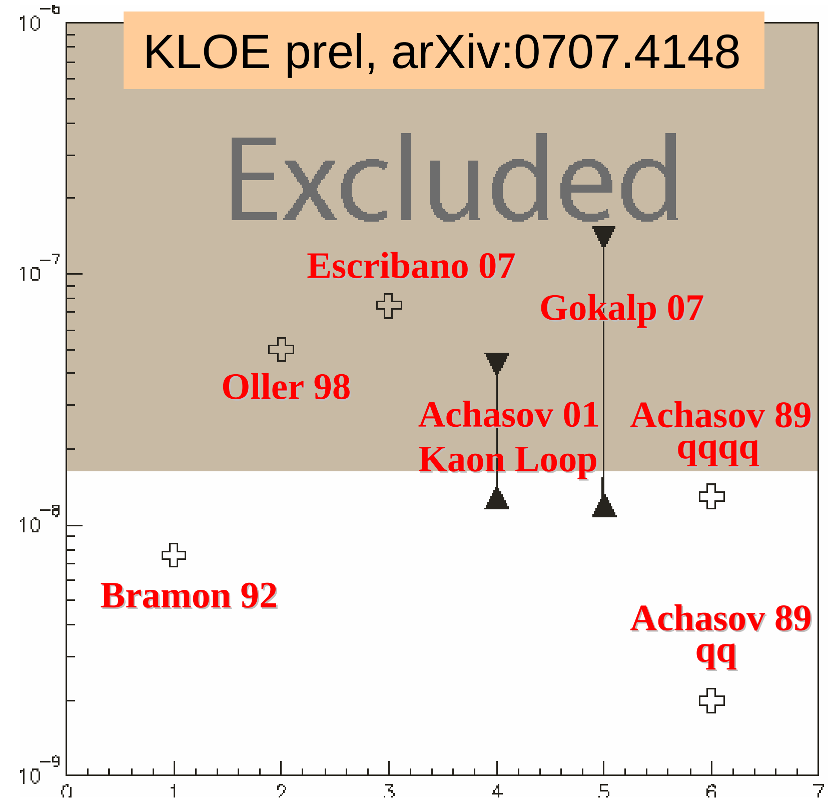


The possible reach for KLOE[2] Step-0 is 5000-10000 events i.e. BR at 1.5 % and δ(Acp) @ similar level!

Test unconventional CP mechanism

Search for $\phi \to (f_0/a_0)\gamma \to KK\gamma$

- $\phi \to [f_0(980)+a_0(980)]\,\gamma \to K^0 K^0 \gamma$ decay has never been observed
- Observation of this decay will constraint the gSkk coupling
- Signal search @KLOE in the clean topology $K_S K_S \gamma \to \pi^+ \pi^- \pi^+ \pi^- \gamma$
- Limit in the region where signal is expected with 2.5 fb-1
- Further improvements from the study of $K^+ K^- \gamma$ and $K_L K_L \gamma$ channels



Conclusions

- The results obtained with the upgrade of DAFNE are very promising
- We expect that the Siddharta experiment will experience a smooth, continuous increase of the rate of the integrated luminosity, approaching soon 600 pb-1 per month, together with the improvement of the running conditions, background levels and operation stability
- This opens new opportunities for improving on
  - Precision measurements of Vus
  - LFC tests and searches for NP signals
  - rare Ks and η decays
  - C, P, CP and CPT tests
  - the knowledge of low-mass scalars
- and on the nuclear physics program of hypernuclei spectroscopy and nuclear kaon cluster formation.