Presence and future of K physics

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FrontierScience 2005, Milano

12-17 September 2005

Introduction

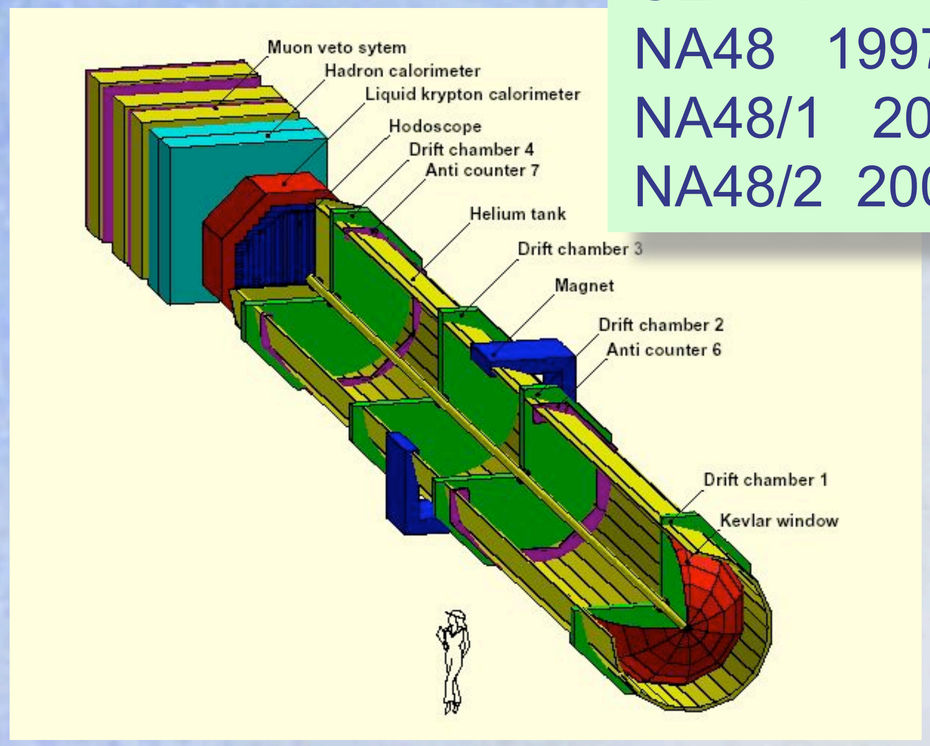
- K physics has been the laboratory of the founders of Standard Model (CP violation, GIM, 3 families, CKM, direct CP violation)

- K experiments today constantly deliver new results probing the limits of Standard Model

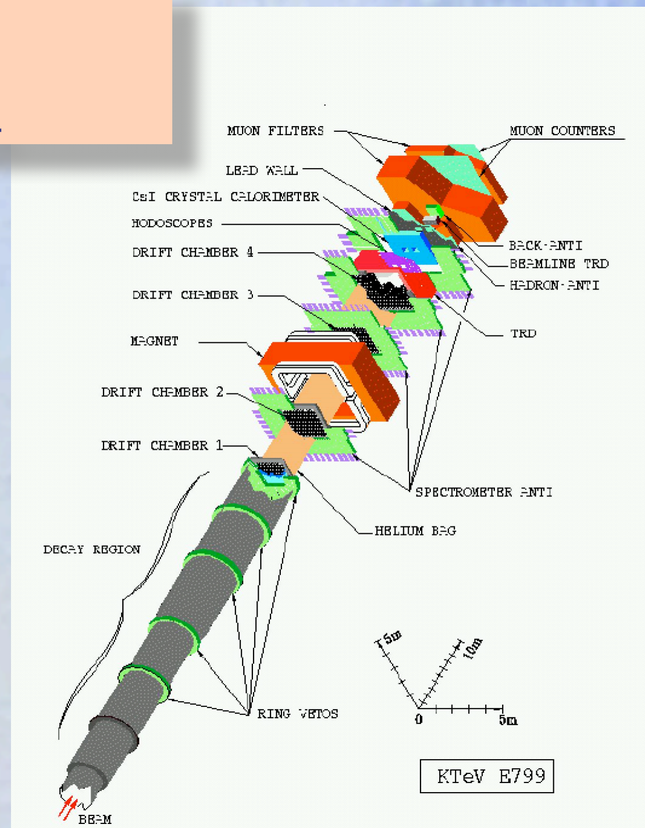
Overview

- Active K experiments
- V_{us} and related topics
- CP Violation
- Tests of low energy QCD
- Very rare decays
- Future projects

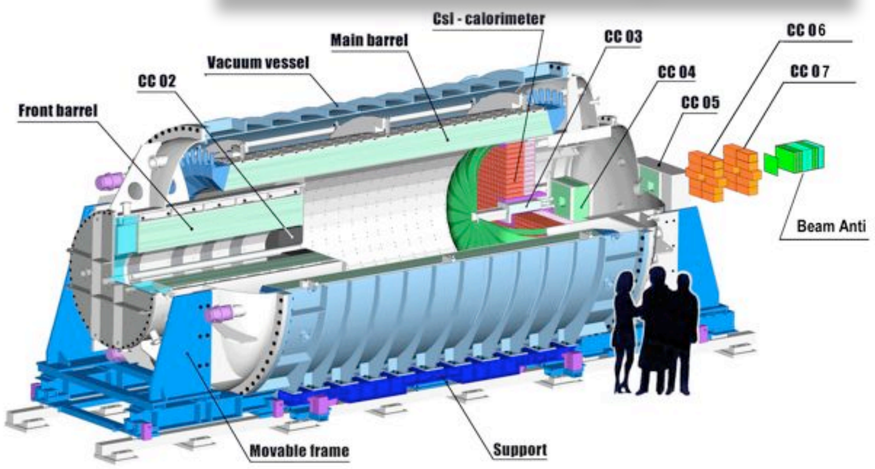
CERN:
NA48 1997-2001 K_L
NA48/1 2000,02 K_S
NA48/2 2003,04 $K^{\pm}$

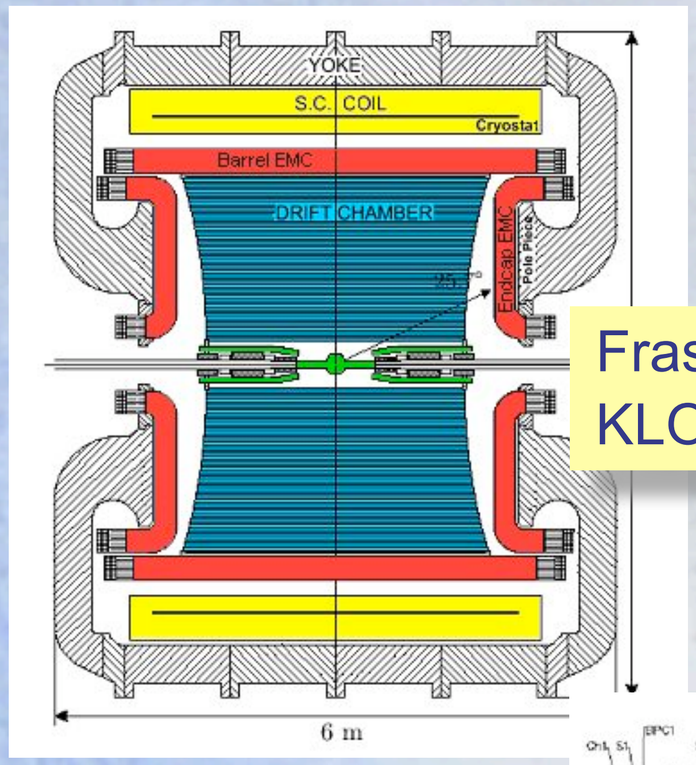


Fermilab:
KTeV 1997,99 K_L



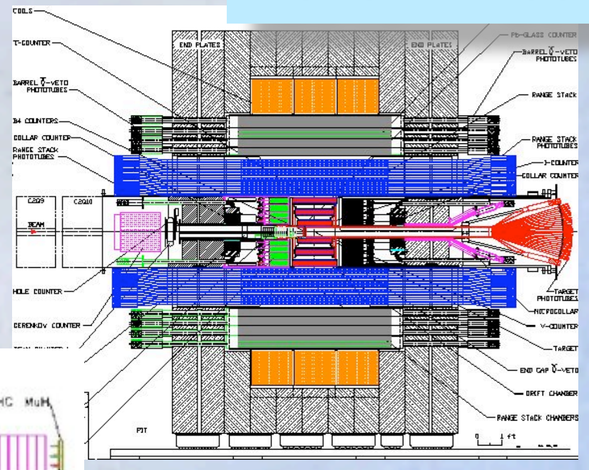
KEK-PS:
E391a >2004 K_L



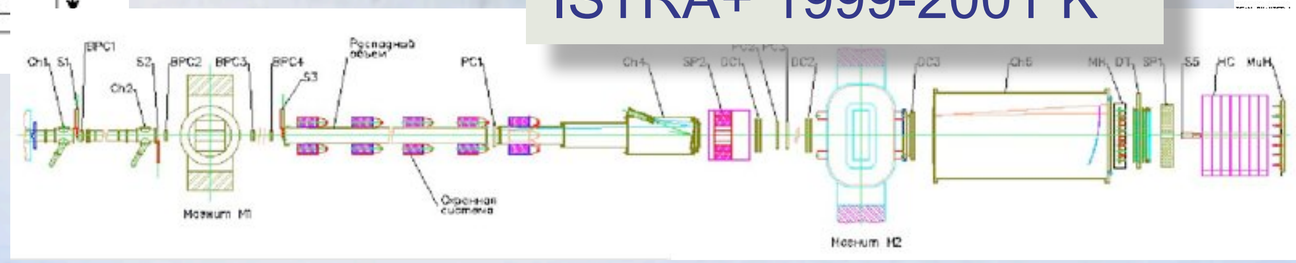


Frascati (Daϕne):
KLOE >2000 K_S,K_L, $K^{\pm}$

BNL:
E787 1995-99 K^+
E949 >2002 K^+



Protvino:
ISTRA+ 1999-2001 K^-



V_{us} and related topics

- BR's
- K_L life time
- Form factors

$|V_{us}|$ from semileptonic K decays

- 1st row - best test of CKM unitarity - PDG2002:

  $1-(|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2) = (4.3\pm1.9)\times10^{-3}$ ($>2\sigma$)

- **$K\to\pi l\nu$ (K_{l3})** decays – best determination of $|V_{us}|$
- 2σ "discrepancy" triggered many new results:

$$\Gamma(K_{l3}) \sim |V_{us}|^2 f_+^2(0)\,(\text{phase sp. integral})\,(\text{rad. corr.})$$

Experiment

$\text{Br}(K_L e3)$: KTeV, KLOE, NA48
$\text{Br}(K_L \mu 3)$: KTeV, KLOE
$\text{Br}(K_S e3)$: KLOE
$\text{Br}(K^\pm e3)$: E865, NA48, ISTRA+
τ_L: KLOE

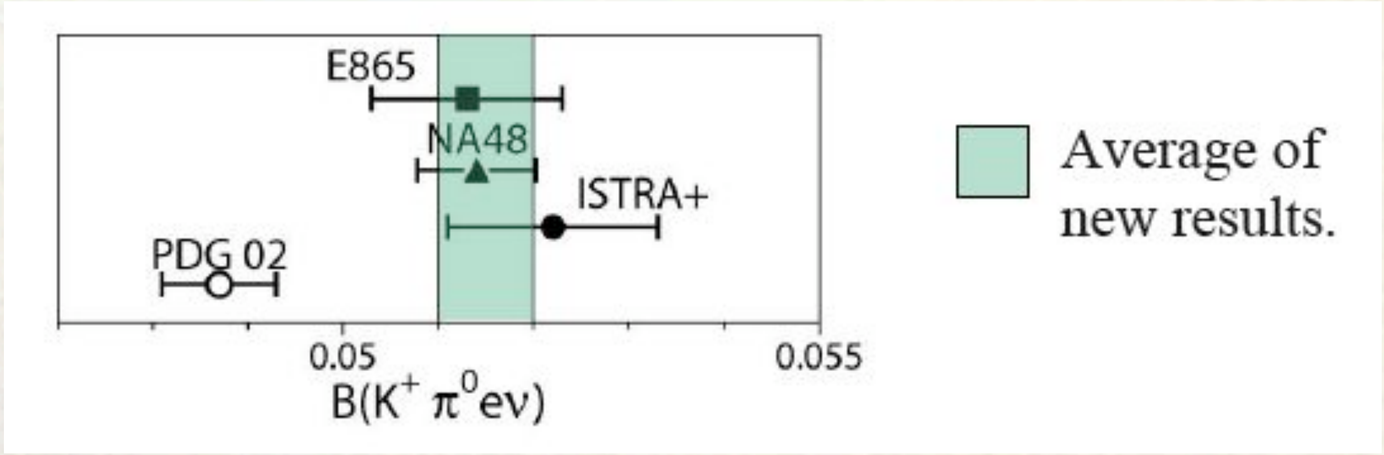
KTeV
KLOE
NA48
ISTRA+

Theory

χPT $O(p^6)$:
Bijnens, Talavera
Jamin at al.
Cirigliano et al.
Quenched Lattice:
Becirevic et al.

Cirigliano et al.
Andre
Moussallam,
Descotes

K^+_{e3} and K_{Se3} BR's



BR(K^+_{e3}):

In **K^+** decays a result by E865 (PRL91,261802) was confirmed by NA48 and ISTRA+ (KAON2005)

KLOE - at ϕ factory DAΦNE - takes advantage from direct K_S tagging using the opposite K_L in $\phi \rightarrow K_S K_L$ to measure precisely also BR(K_{Se3}) (HEP2005):

$$BR(K_{Se3}) = (7.09 \pm 0.08_{stat} \pm 0.05_{syst}) \times 10^{-4}$$

Can be used also to test $\Delta S = \Delta Q \Leftrightarrow \Gamma(K_{Se3})/\Gamma(K_{Le3}) = 1$

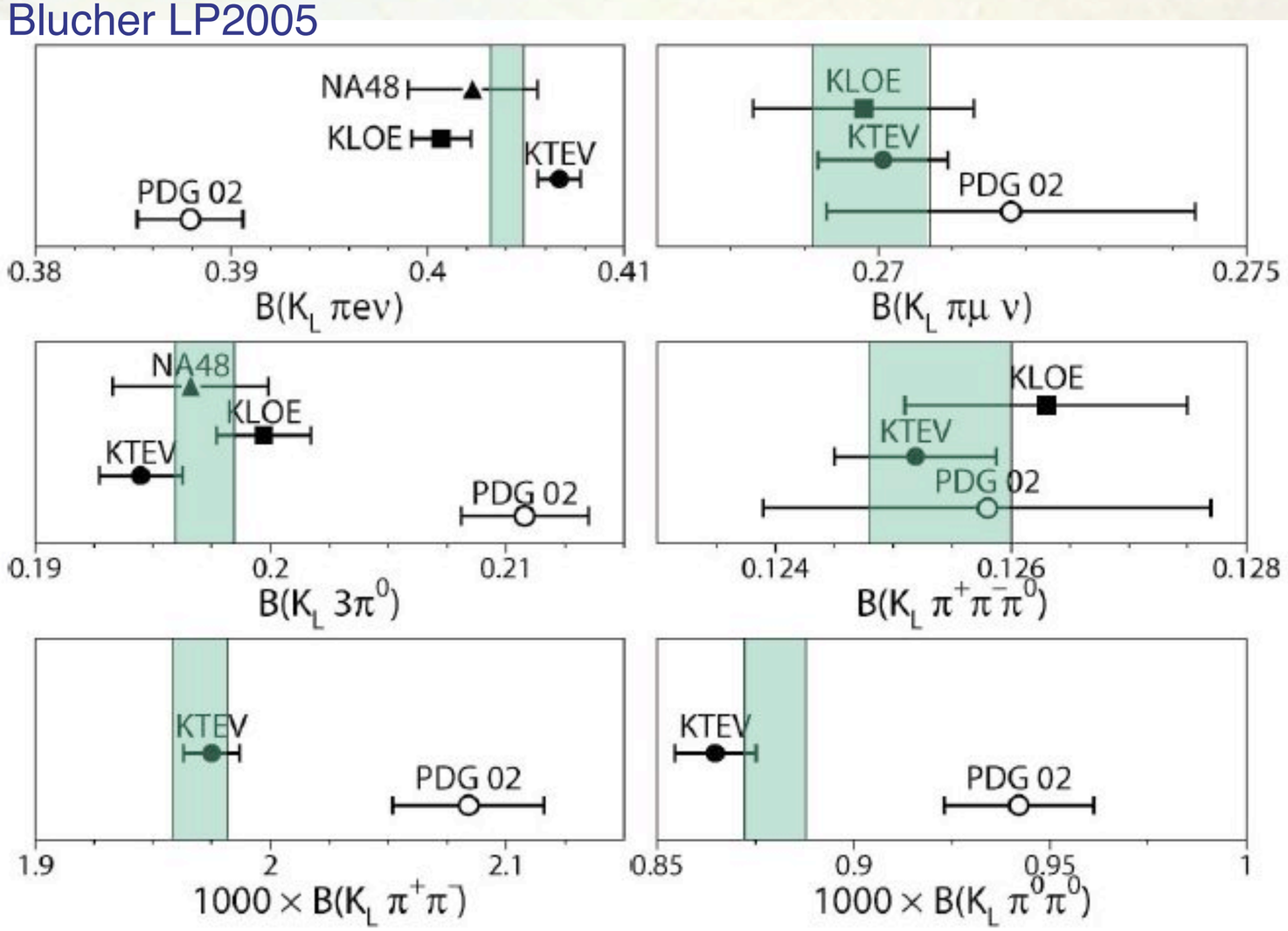
Note also a new preliminary result from NA48/1 (KAON2005):

$BR(K_{Se3}) = (6.8 \pm 0.2_{stat} \pm 0.2_{syst}) \times 10^{-4}$

K_L BR's

In 2004 most of main K_L BR in PDG had to be corrected!

Blucher LP2005



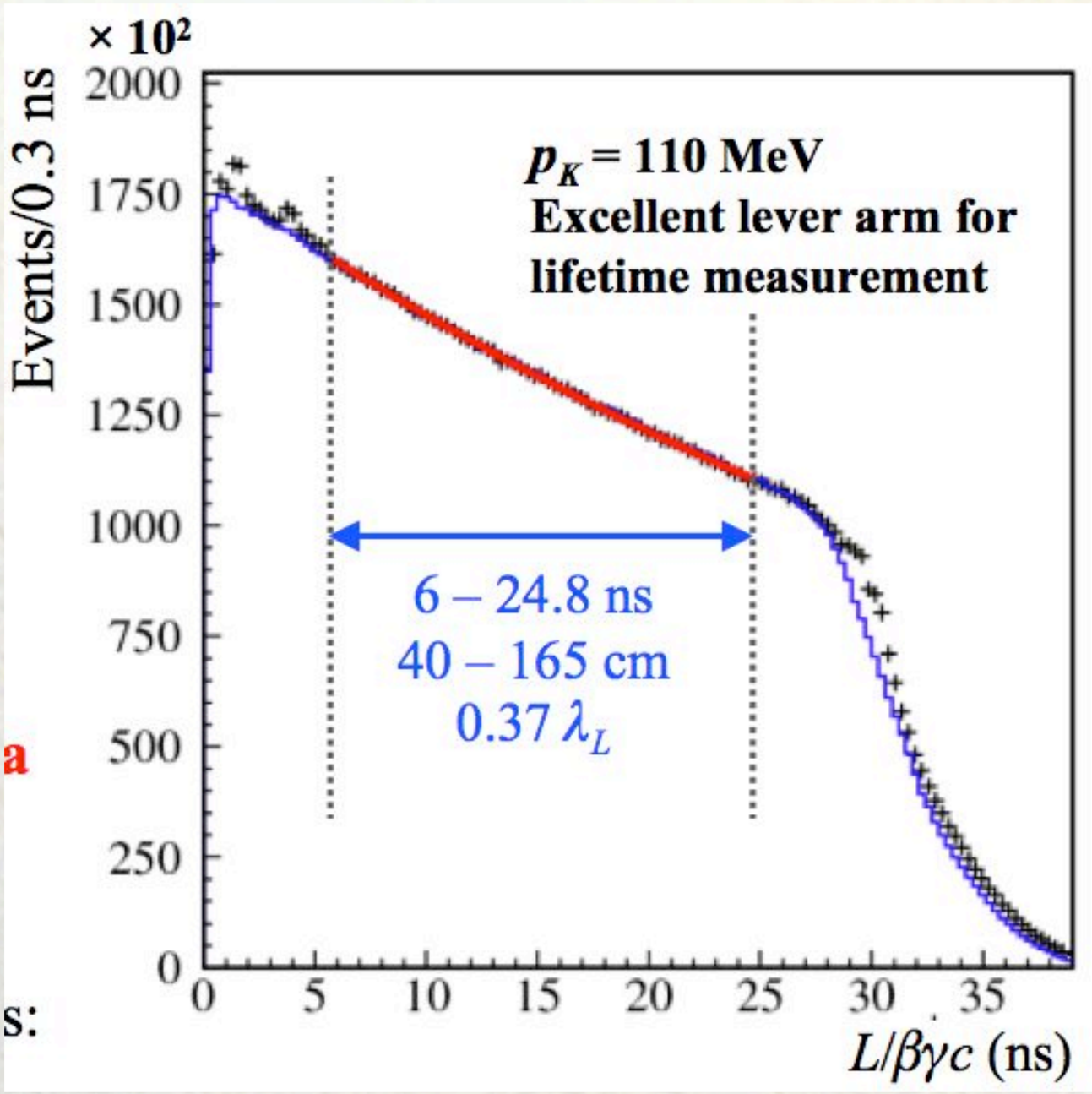
Value based on PDG-style fit to all new measurements (KTeV, KLOE, NA48)

Many new KTeV K_L BR's (PRD70,092006) in disagreement with PDG!

Confirmed by NA48 (PLB602,41; ICHEP04) and KLOE (hep-ex/0508027)

$BR(K_{Le3})$ shifts by 4%!

New K_L lifetime by KLOE



Direct measurement using $K_L \to 3\pi^0$ (hep-ex/0507088):

τ_{KL}=(50.92 ± 0.30) ns

Indirect measurement by summing main BR's (hep-ex/0508027):

τ_{KL}=(50.72 ± 0.36) ns

Combined lifetime:

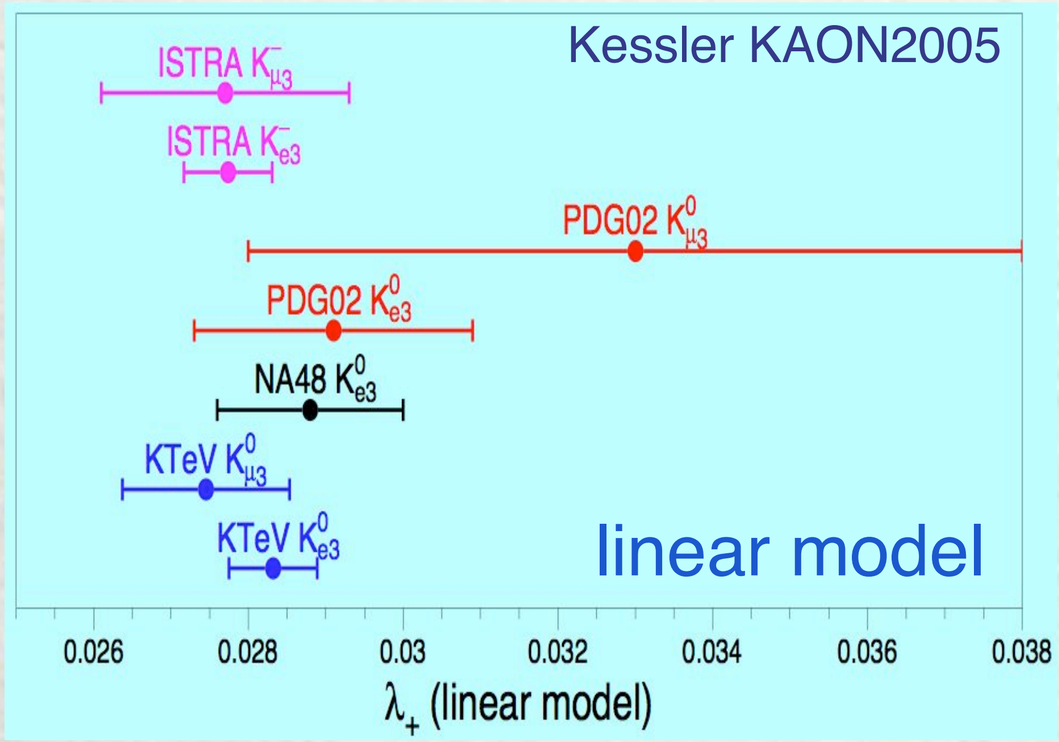
τ_{KL}=(50.84 ± 0.23) ns

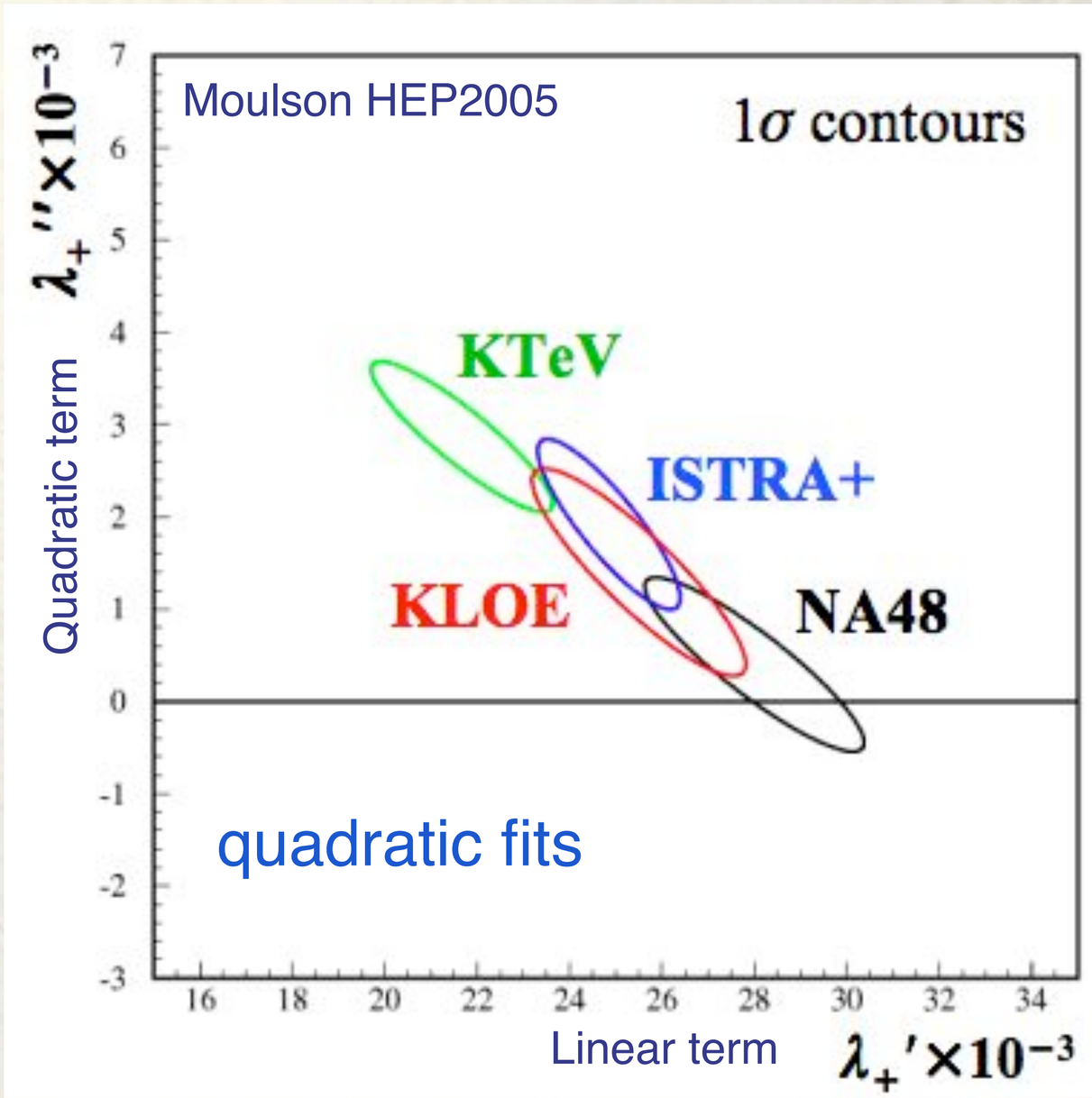
PDG was: (51.5 ± 0.4) ns

Form factor measurements

Needed to determine the phase space integrals (I_K)

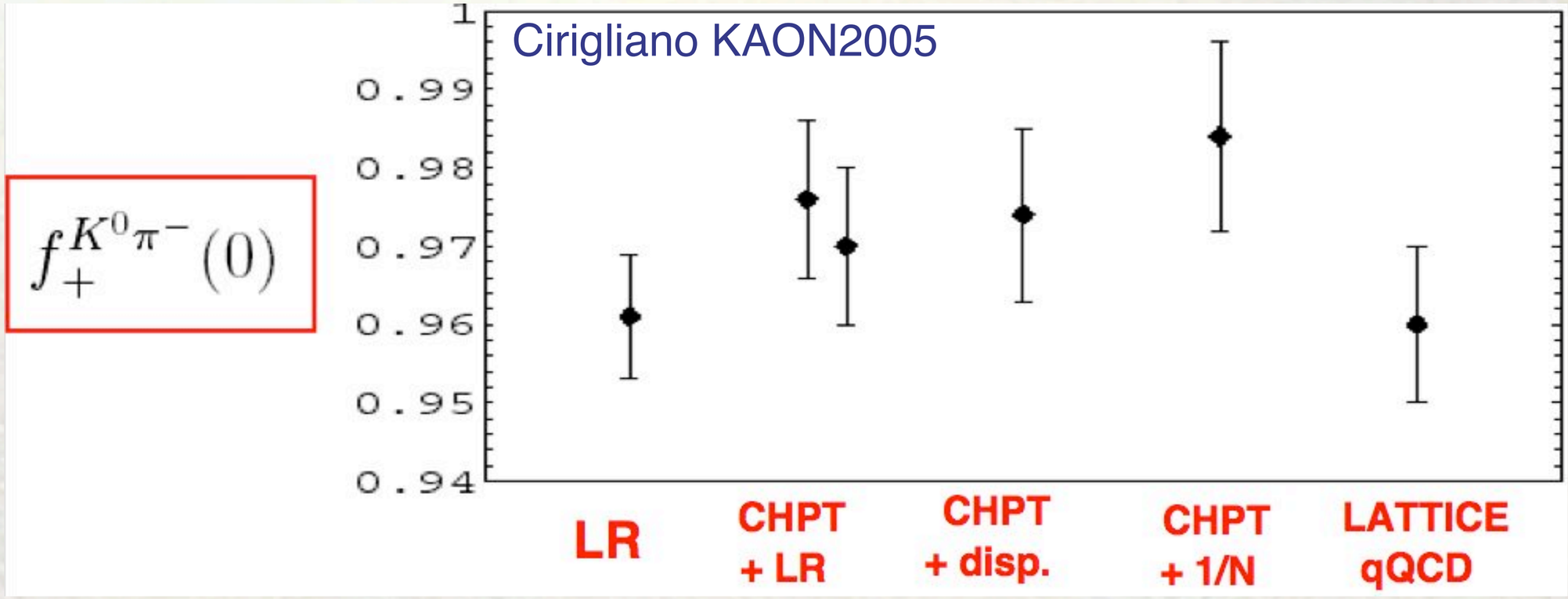
Fits to a linear model agree between experiments while quadratic fits are less consistent





$f_+(0)$ calculations

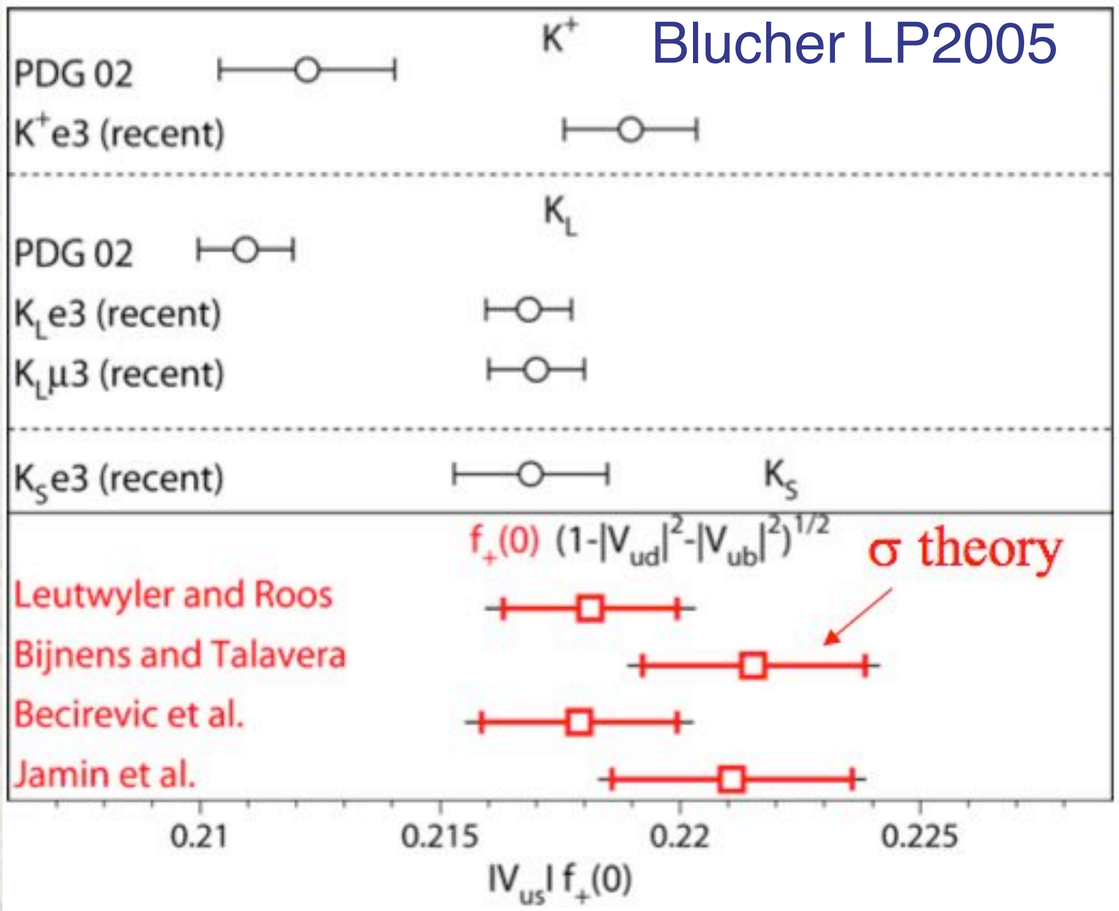
$f_+(0)$ - form factor normalisation - main source of theoretical uncertainty



- Original calculation by Leutwyler, Roos (LR) based on χPT at $O(p^4)$
- χPT with p^6 loops leads to increased $f_+(0)$
- Quenched Lattice calculations agree with LR
- Unquenched Lattice calculations awaited soon!

$|V_{us}|$ summary

Tremendous experimental progress! (Also $K^+ \to \mu\nu$ by KLOE)



Average of all "recent" results accounting for correlations:

$$|V_{us}|\, f_+^{K^0\pi^-}(0) = 0.2173 \pm 0.0008$$

Uses updated $|V_{ud}| = 0.9739 \pm 0.0003$ (Hardy, Towner; Marciano,Sirlin -- Kaon 2005)

- Unquenched Lattice calculations should improve theoretical uncertainty
- Still some opened questions (consistency of K^0 and K^+ data, $K^+ \to \mu\nu$)

CP violation

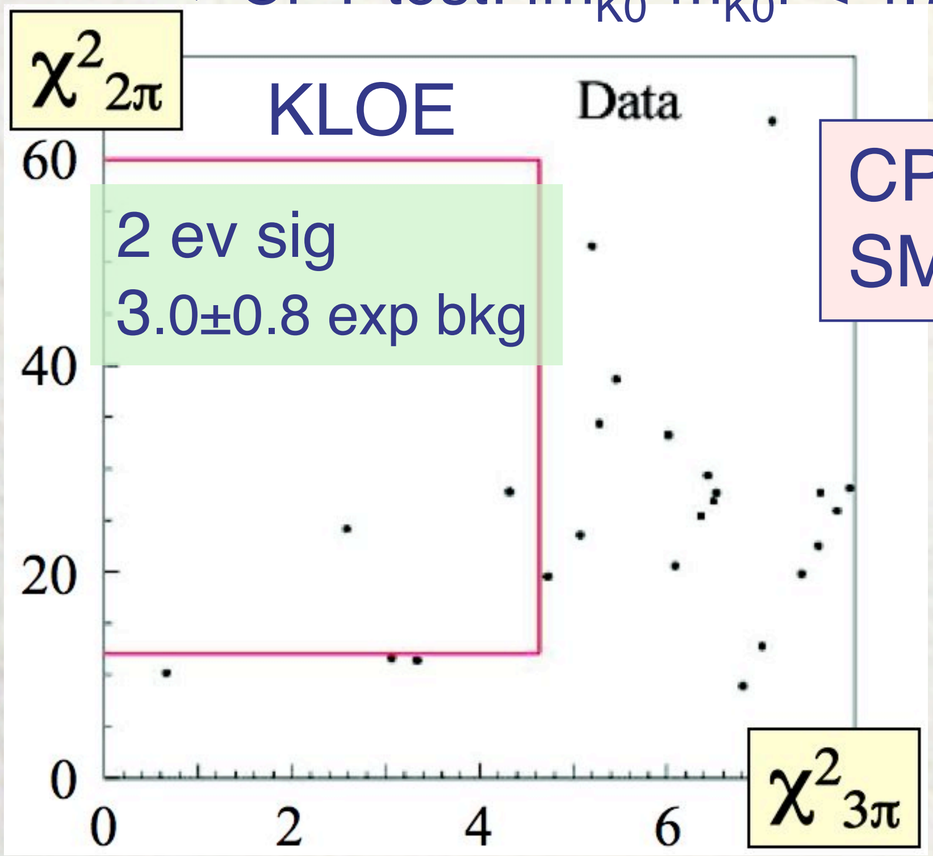
- Indirect
  - $K_S \rightarrow \pi^0\pi^0\pi^0$
  - $K_L \rightarrow \pi^+\pi^-$
- Direct
  - $K^\pm \rightarrow 3\pi$

Searches for $K_S \to \pi^0\pi^0\pi^0$

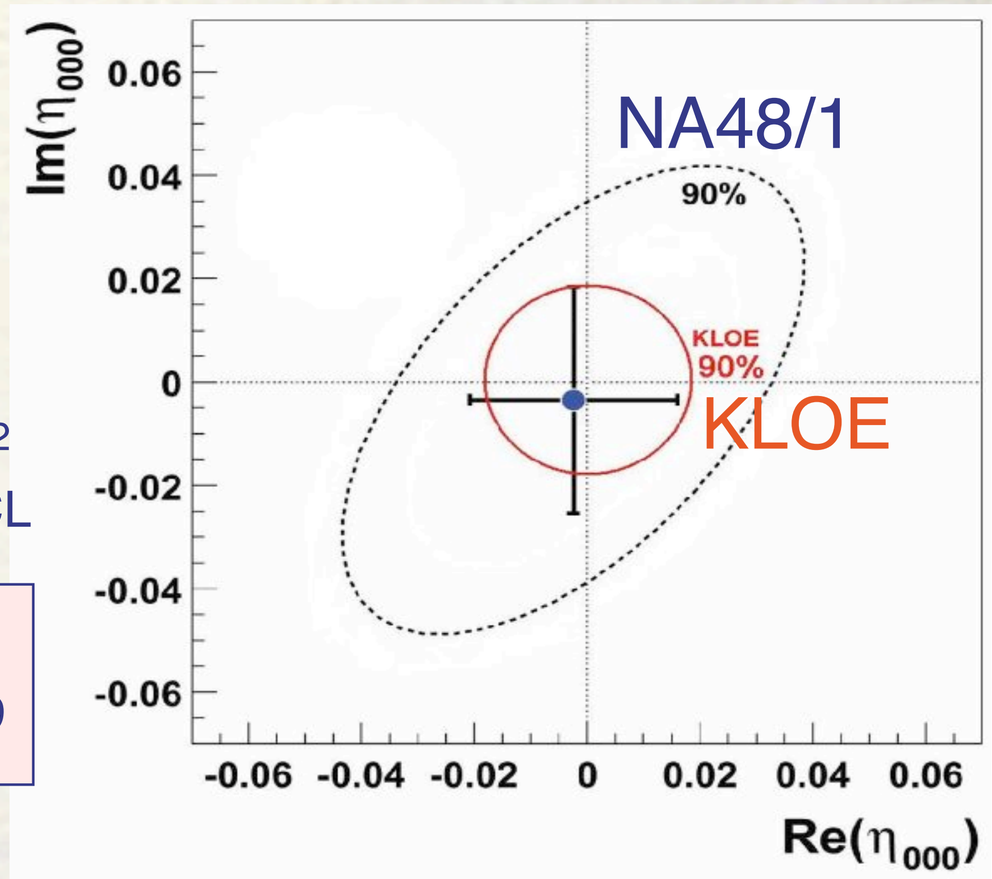
NA48/1: Indirect search - interference:
PLB610,165

$Re(\eta_{000}) = -0.002 \pm 0.019$
$Im(\eta_{000}) = -0.003 \pm 0.021$

$\Rightarrow BR(K_S \to 3\pi^0) < 7.4 \times 10^{-7}$ @90%CL
$\Rightarrow$ CPV test: $|m_{K0} - m_{\overline{K0}}| < 4.7 \times 10^{-19}$ GeV/c^2 @90%CL



CPV decay
SM BR≈2×10^{-9}



KLOE: Direct search - tagging with K_L
PLB619,61

$BR(K_S \to 3\pi^0) < 1.2 \times 10^{-7}$ @90%CL
$\Rightarrow |\eta_{000}| < 0.018$ @90%CL
Expect improvement of up to 10x

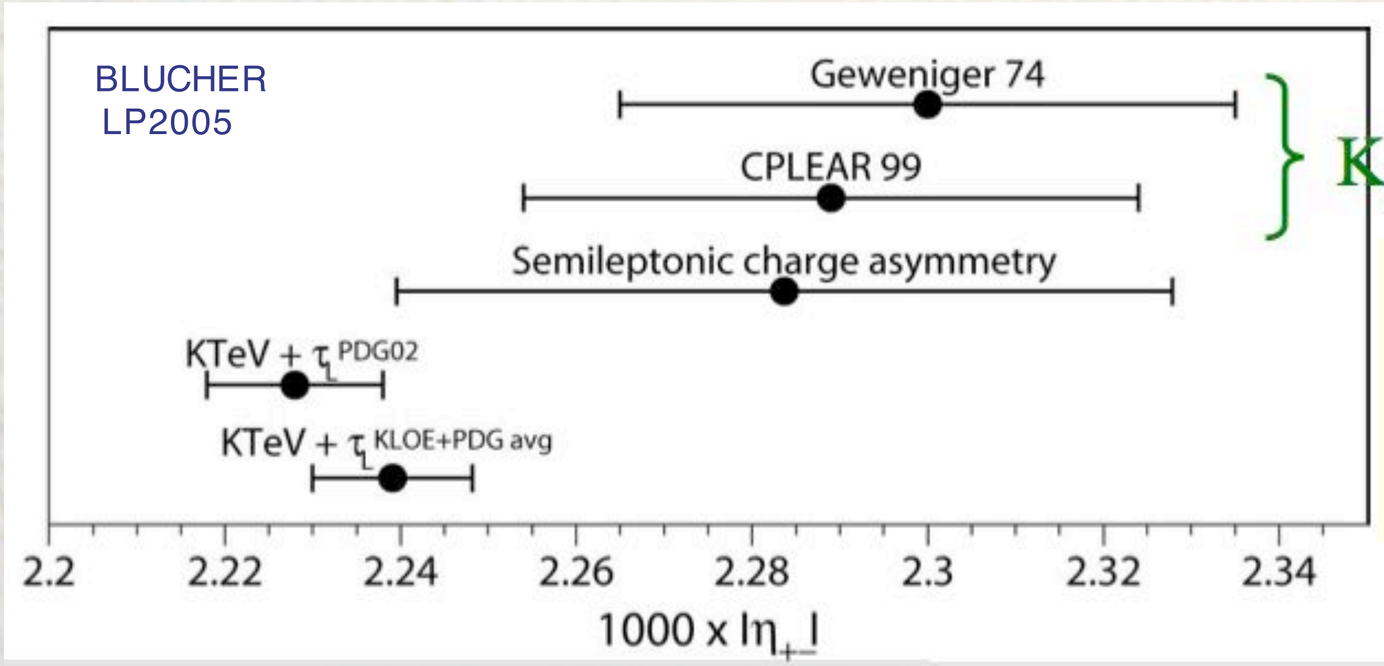
$|\eta_{+-}|$ measurement by KTeV

$$|\eta_{+-}|^2 = \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} = \frac{\tau_S}{\tau_L} \frac{B^L_{\pi^+\pi^-} + B^L_{\pi^0\pi^0}\left[1 + 6\,\mathrm{Re}(\varepsilon'/\varepsilon)\right]}{1 - B^S_{\pi\ell\nu}}$$

Assuming $\Gamma(K_S \to \pi e \nu) = \Gamma(K_L \to \pi e \nu)$

Published PRD70,092006 $|\eta_{+-}| = (2.228 \pm 0.005_{KTeV} \pm 0.009_{\tau KL}) \times 10^{-3}$

Using new τ_{KL} $|\eta_{+-}| = (2.239 \pm 0.005_{KTeV} \pm 0.008_{ext}) \times 10^{-3}$

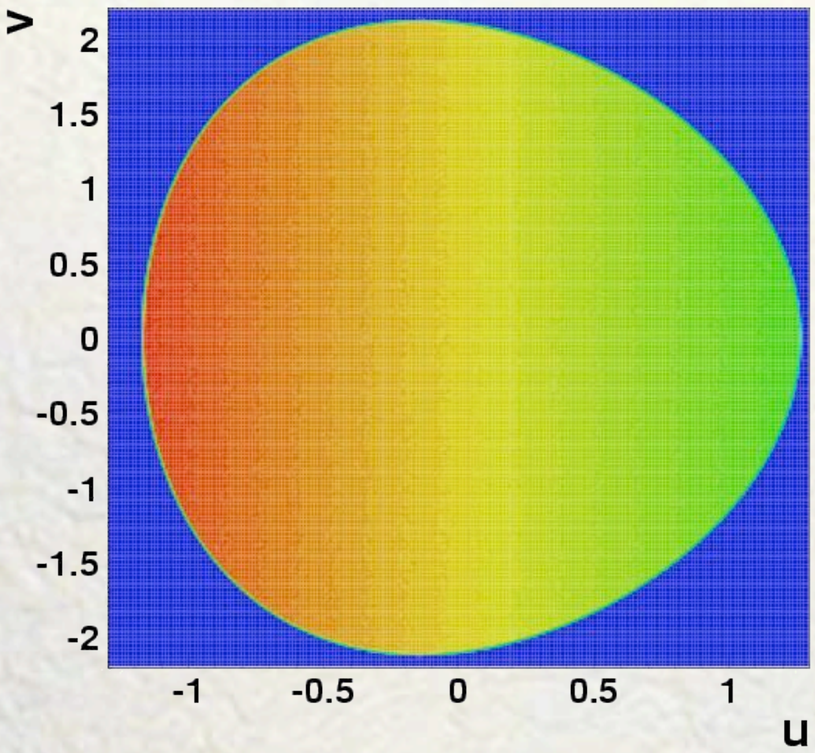


Slight disagreement with earlier interference measurements

New NA48 result soon

Search for direct CPV in $K^{\pm}\to 3\pi$ by NA48/2

$$|M(u,v)|^2 \sim 1 + gu + O(u^2,v^2)$$



u,v – Dalitz variables

- $K\to\pi^+\pi^-\pi^\pm$: g = -0.2154±0.0035
- $K\to\pi^0\pi^0\pi^\pm$: g = 0.652±0.031

Direct CP-violation:

$$A_g = (g_+ - g_-)/(g_+ + g_-) \neq 0$$

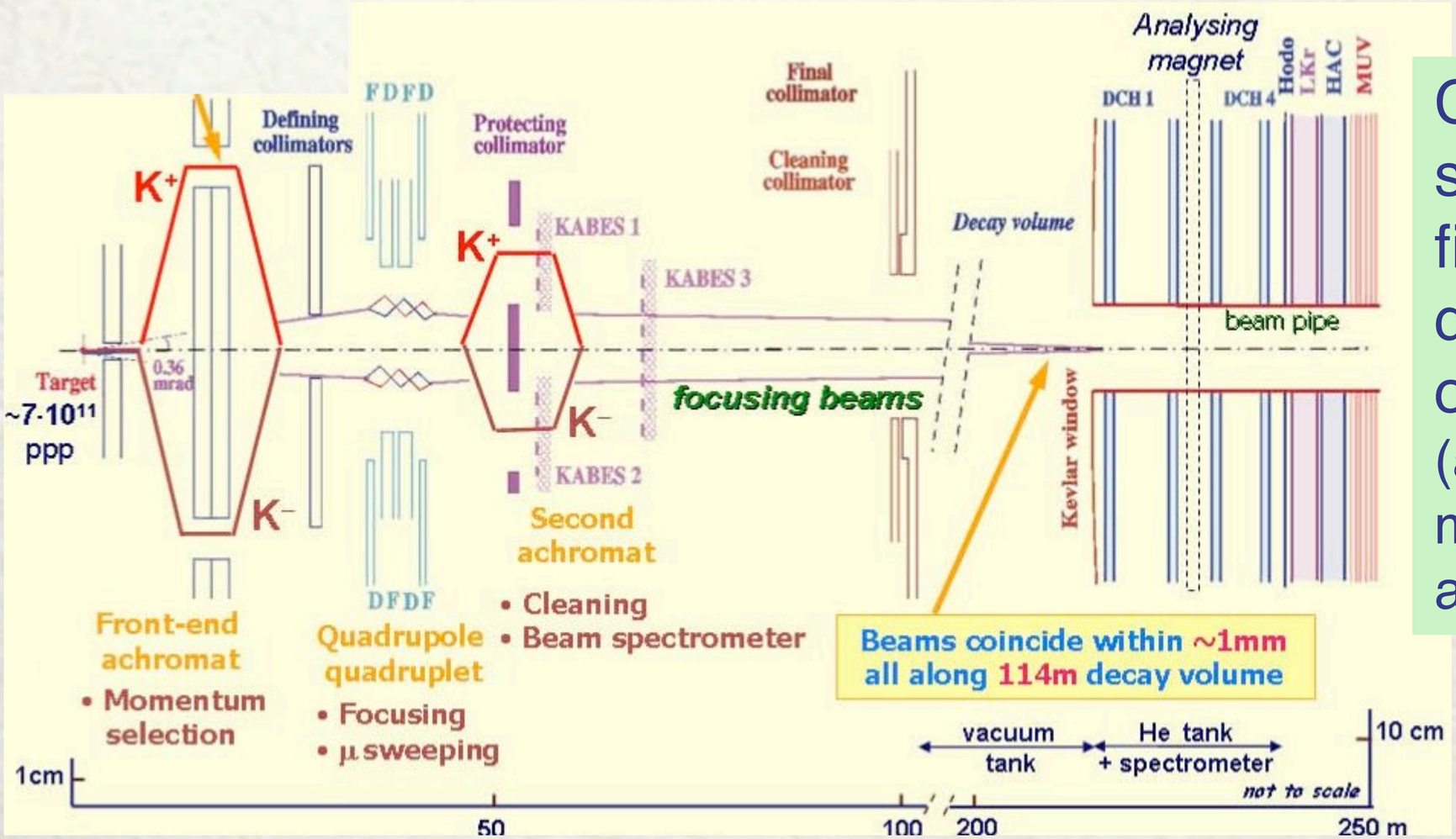
Measure:

$$R(u) = N(K^+\to 3\pi)/N(K^-\to 3\pi) \sim 1 + 2gA_g u$$

- NA48/2 Goal: measure A_g to better than 2×10^{-4}
- Previous experiments – precision at few x 10^{-3}
- SM predictions $A_g < 5\times10^{-5}$
- Substantial enhancements possible in models beyond SM

Search for direct CPV in $K^{\pm} \to 3\pi$ by NA48/2

- Simultaneous K+ and K- beams, superimposed in space with narrow momentum spectra
- Achromat and spectrometer magnet polarities alternated frequently



Cancellation of systematics by fitting only quadruple ratios of u-distributions (all possible magnet polarities are in ratio)

Search for direct CPV in $K^{\pm}\to 3\pi$ by NA48/2

New preliminary result (e.g. hep-ex/0505081) using 1.6 billions of $K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-}$ decays from 2003 run:

$$A_g = (0.5 \pm 3.8)\ x10^{-4}$$

- Expect ~3.5 billions $K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-}$ decays from full 2003+2004 run corresponding to statistical precision $\delta A_g^{stat}=1.6x10^{-4}$
- Expect ~0.1 billions (lower BR and acceptance) of $K^{\pm}\to\pi^{\pm}\pi^{0}\pi^{0}$ decays corresponding to similar precision due to better sensitivity

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Also new result by **TNF-IHEP** with 0.5 million $K^{\pm}\to\pi^{\pm}\pi^{0}\pi^{0}$ decays (EPJC40,343):

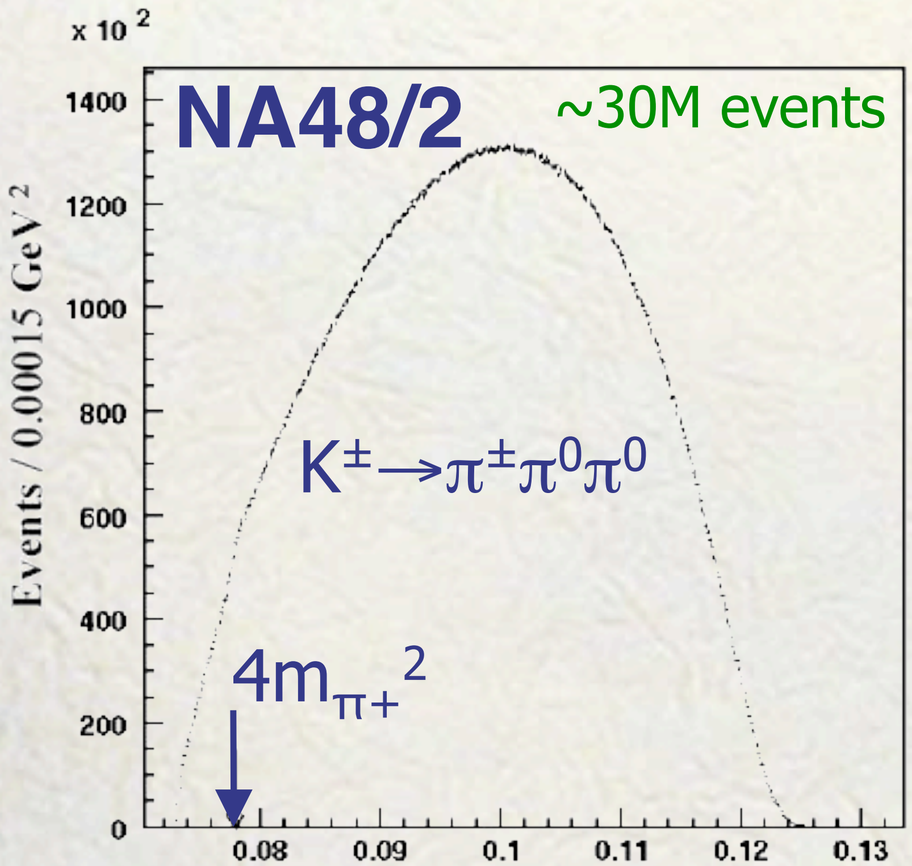
$$A_g=(2 \pm 19)\ x10^{-4}$$

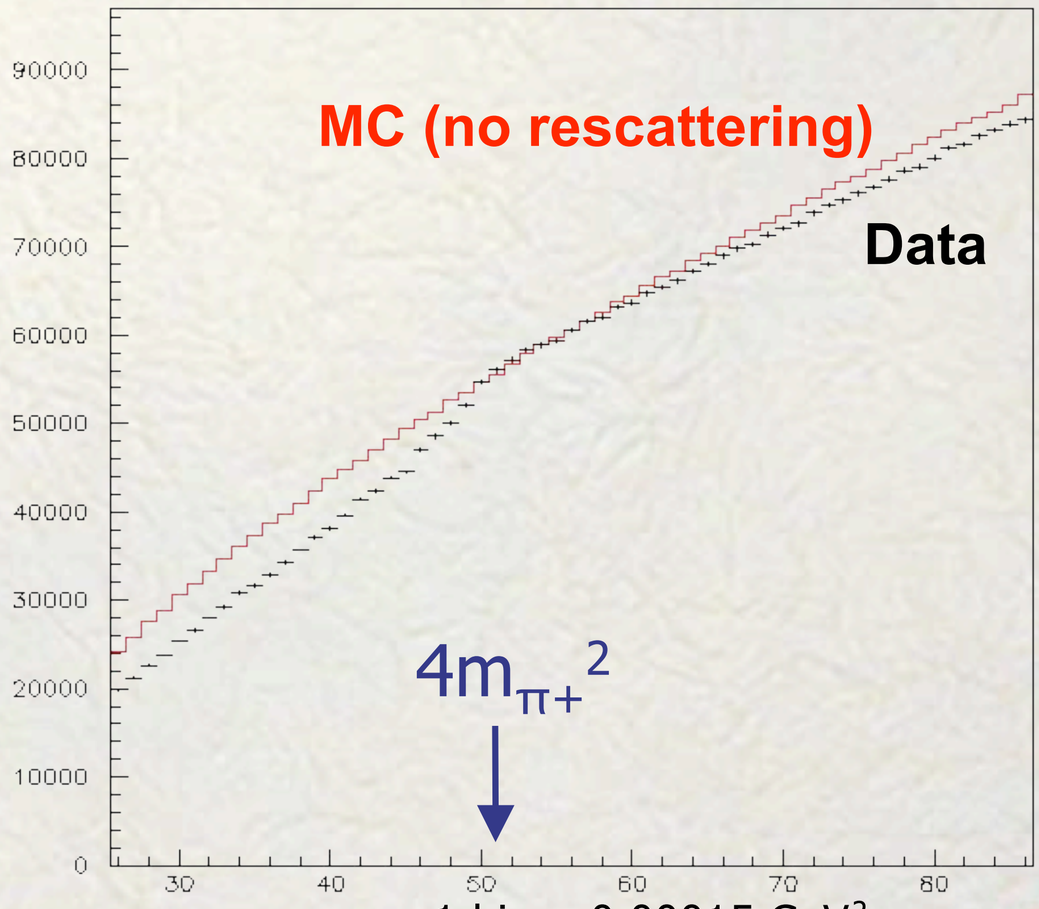
Tests of low energy QCD
(Chiral Perturbation Theory)

- $\pi\pi$ scattering length
- Other results

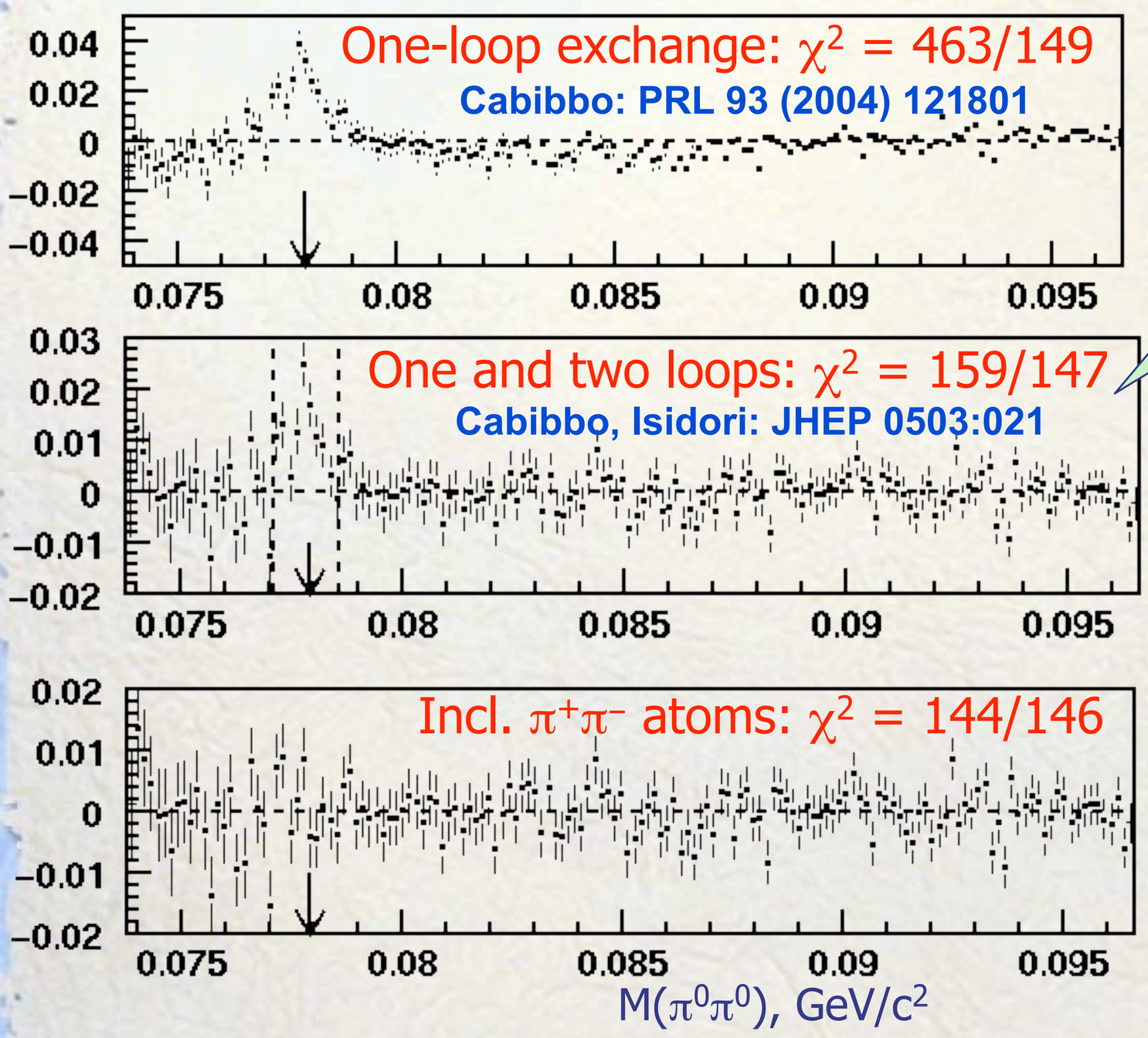
$\pi\pi$ scattering length from $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$

- Charge exchange process $\pi^+\pi^-\to\pi^0\pi^0$ not negligible under $2m_\pi$ threshold, destructive interference generates **a cusp** in the Dalitz plot, not seen earlier by lower precision experiments
- Can be used for extraction of $\pi\pi$ scattering length $\mathbf{a_0\text{-}a_2}$
  - precision test of χPT at few% level (Cabibbo PRL93,121801)





$\pi\pi$ scattering length from $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$



Two loop description was necessary to describe data

Preliminary result from NA48/2: MORIOND05

$(a_0-a_2)m_\pi = 0.281 \pm 0.016$

External uncertainty: ± 0.014

χPT prediction: 0.265±0.004

Colangelo hep-ph/0103088

Expect experimental uncertainty at the level of <3%!

Other results

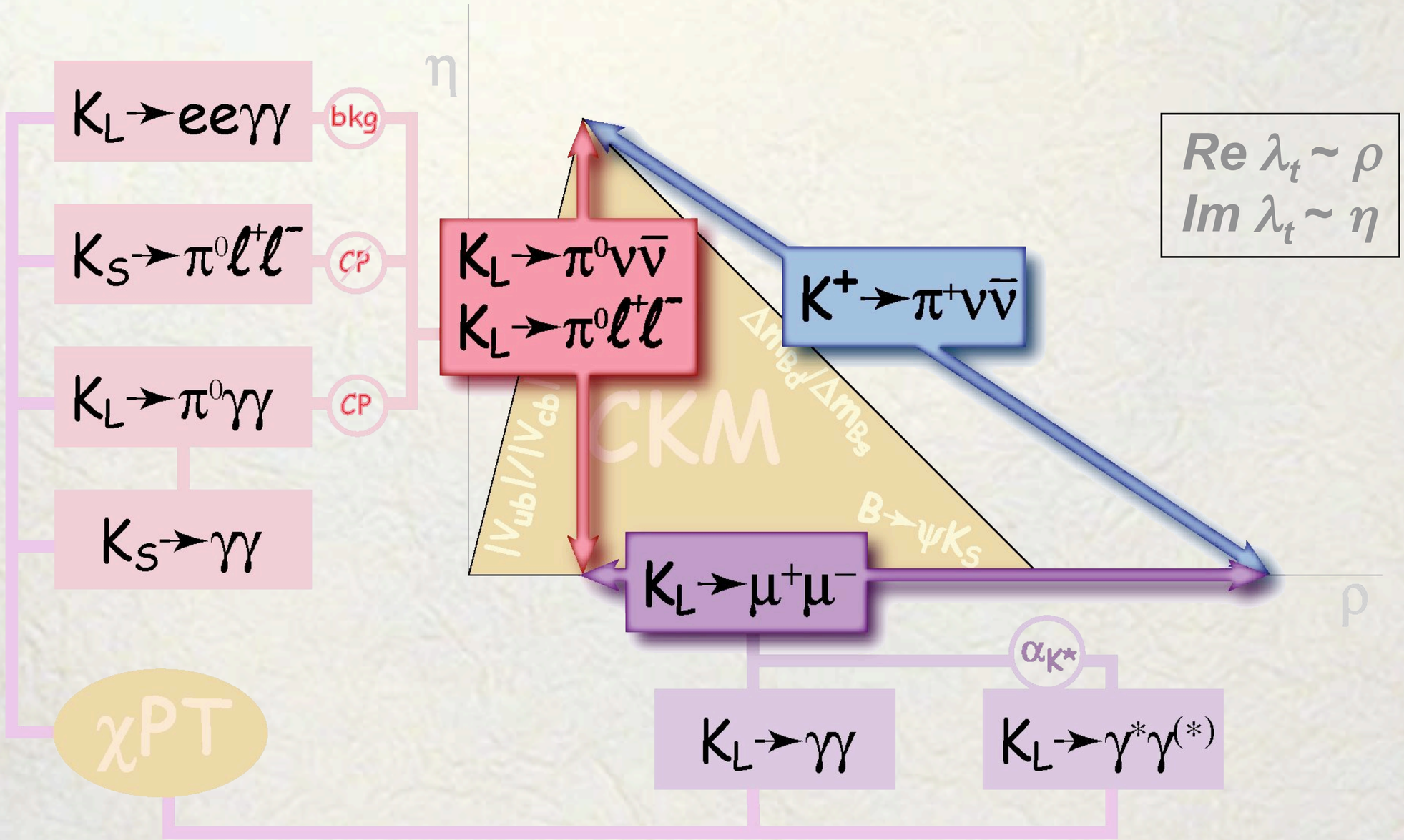
- Form factors and BR of the decay $K_L \to \pi^0\pi e\nu$ measured by **NA48** (PLB595,75)
- Search for $K^+ \to \pi^+\gamma\gamma$ in the π^+ momentum region P>213 MeV/c by **E949** (PLB623,192) and improved upper limit for $K^+ \to \pi^+\gamma$
- First observation and BR of $K^- \to \pi^0\mu^-\nu\gamma$ by **ISTRA+** (hep-ex/0506023)
- CP-conserving contribution to $K_S \to \pi^+\pi^-\pi^0$ measured by **NA48/1** (CERN-PH-EP/2005-037)
- Improved measurement of the Direct Emission component of the decay $K^+ \to \pi^+\pi^0\gamma$ by **E787** (KAON2005)
- First observation of $K_L \to \pi^+\pi^-\pi^0\gamma$ and $K_L \to \pi^+\pi^-\pi^0 ee$ by **KTeV** (KAON2005)

Very rare decays

- $K^+ \rightarrow \pi^+ \nu\nu$
- $K_L \rightarrow \pi^0 \nu\nu$

FCNC processes

- Highly sensitive to physics beyond SM
- Independent determination of CKM triangle - comparison to B physics



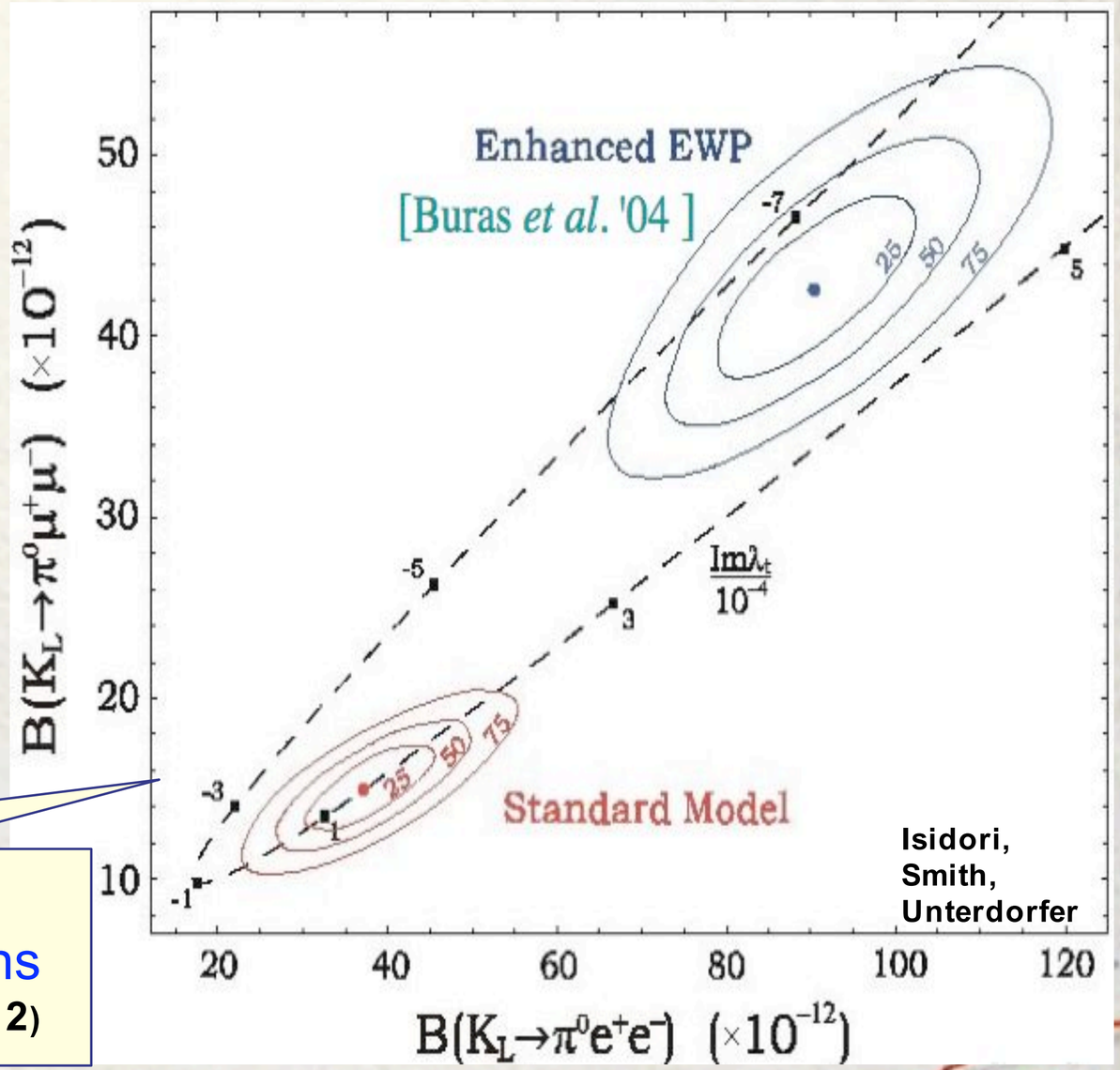
$Re\ \lambda_t \sim \rho$
$Im\ \lambda_t \sim \eta$

Importance of FCNC processes

- **$K \to \pi\nu\nu$** - pure short distance - precise theor. predictions (few%)
- **$K_L \to \pi^0 ll$** long distance admixtures have recently been determined by NA48/1 measuring **$K_S \to \pi^0 ll$**

  NA48/1: PLB576,43; PLB599,197
  Theor.: NPB672,387; EPJC36,57

- Different sensitivity to models BSM (MFV, MSSM, EEWP, Ext. Dim.) up to 20x (see e.g. KAON2005)
- Possibility to distinguish between models
- Complementary to energy frontier colliders and B-factories!



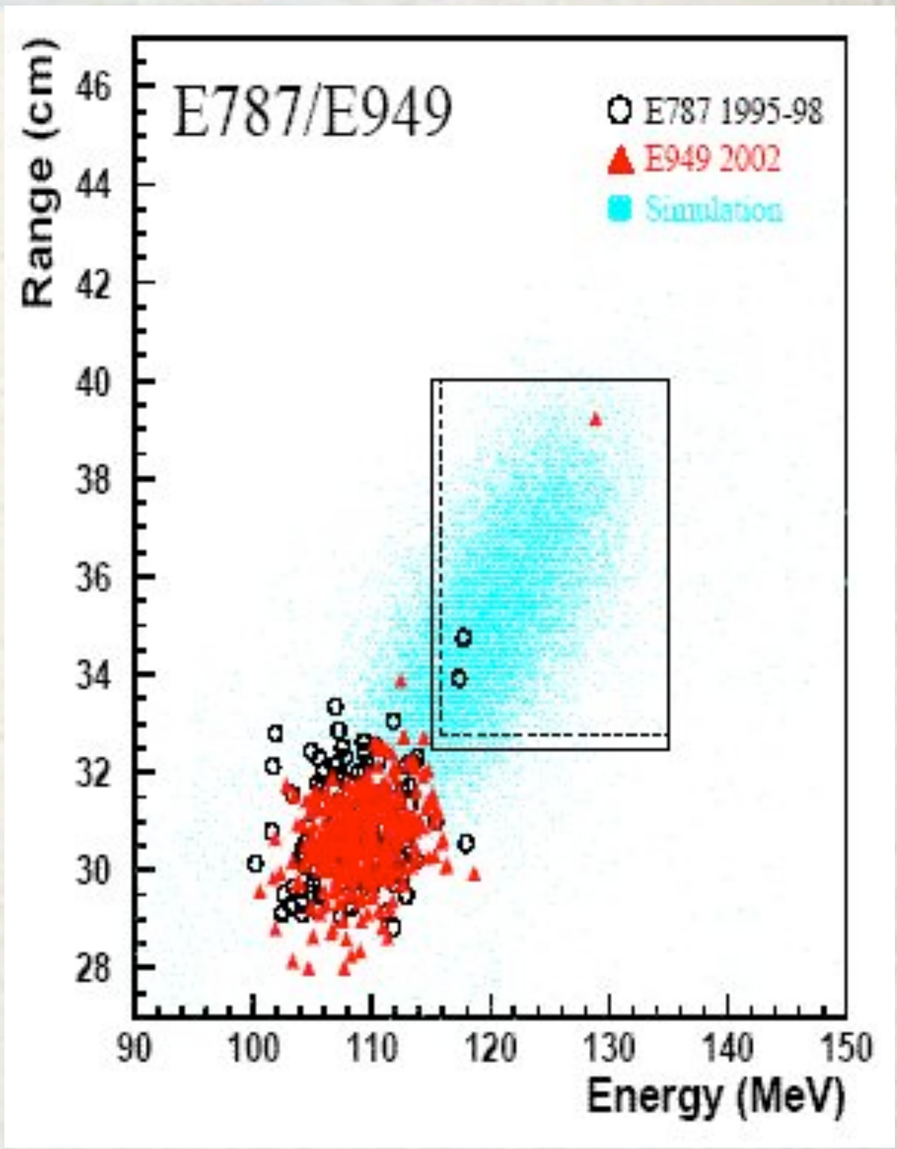
Example of sensitivity to New Physics:
Enhanced electroweak penguin contributions
(Buras, Fleischer, Recksiegel, Schwab, hep-ph/0402112)

Search for $K^+ \to \pi^+ \nu\nu$

- Very clean - pure short distance physics
- Precise SM prediction: BR=(0.8±0.1)x10^{-10}
- BNL **E787** took data 1995-98 - stopped K^+
- Successor **E949** got only 20% of allocated beam time in 2002

3 events observed up to now!

	sig	ex bkg
E787	2	0.14±0.05
E949	1	0.30±0.03



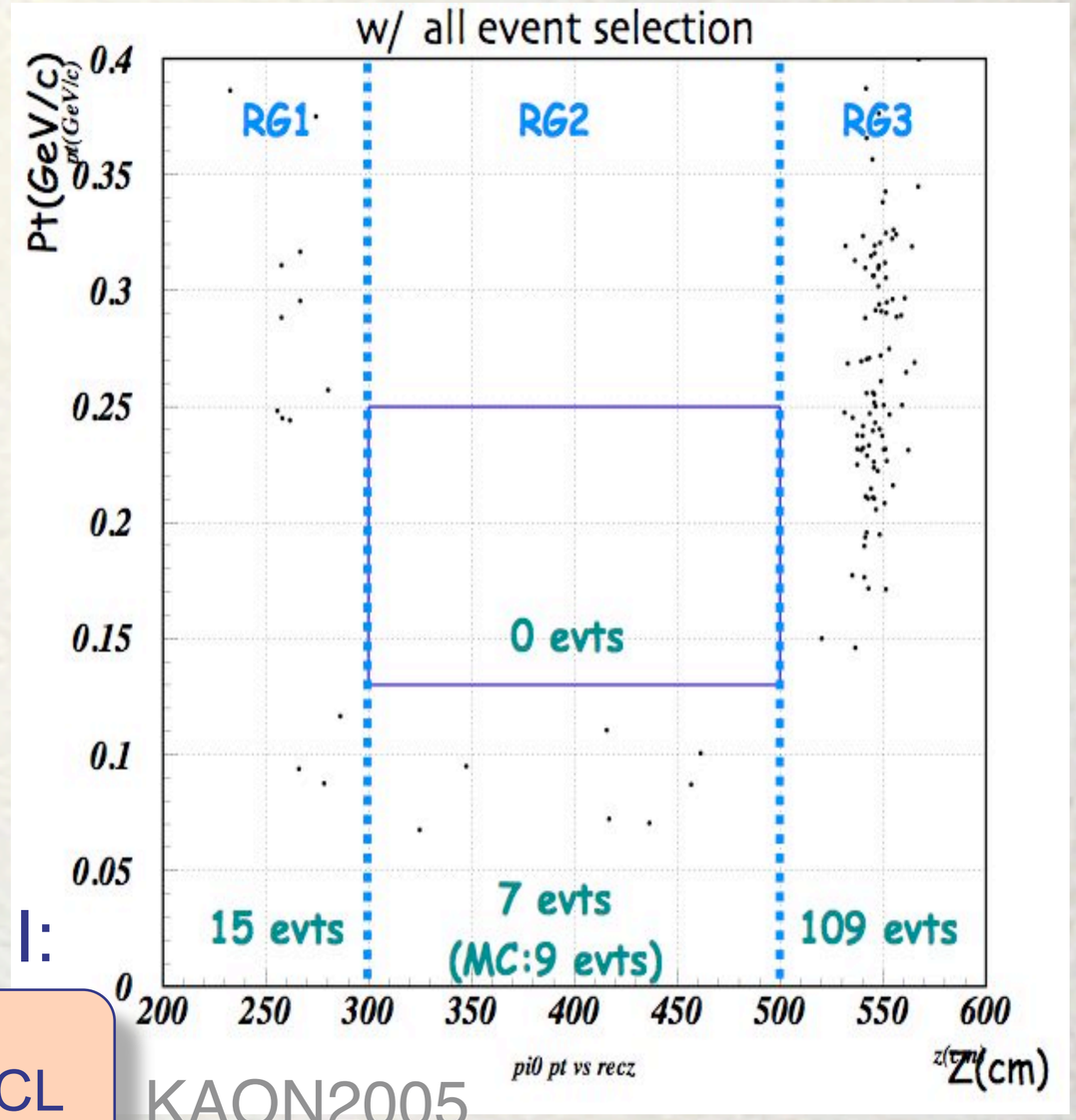
E787/E949 combined (PRL93,031801):

$$BR(K^+ \to \pi^+ \nu\nu) = (1.47^{+1.30}_{-0.89}) \times 10^{-10}$$

Search for $K_L \to \pi^0 \nu\nu$

- <2% theoretical uncertainty!
- SM BR ≈ 3.0×10^{-11}

- Experimentally very challenging
- First dedicated experiment **E391a** at KEK-PS started to take data 2004
- Using pencil neutral beam
- Expect to reach single event sensitivity of ~10^{-9}



First E391a preliminary result from Run I:

$BR(K_L \to \pi^0 \nu\nu) < 2.86 \times 10^{-7}$ @90%CL

KAON2005

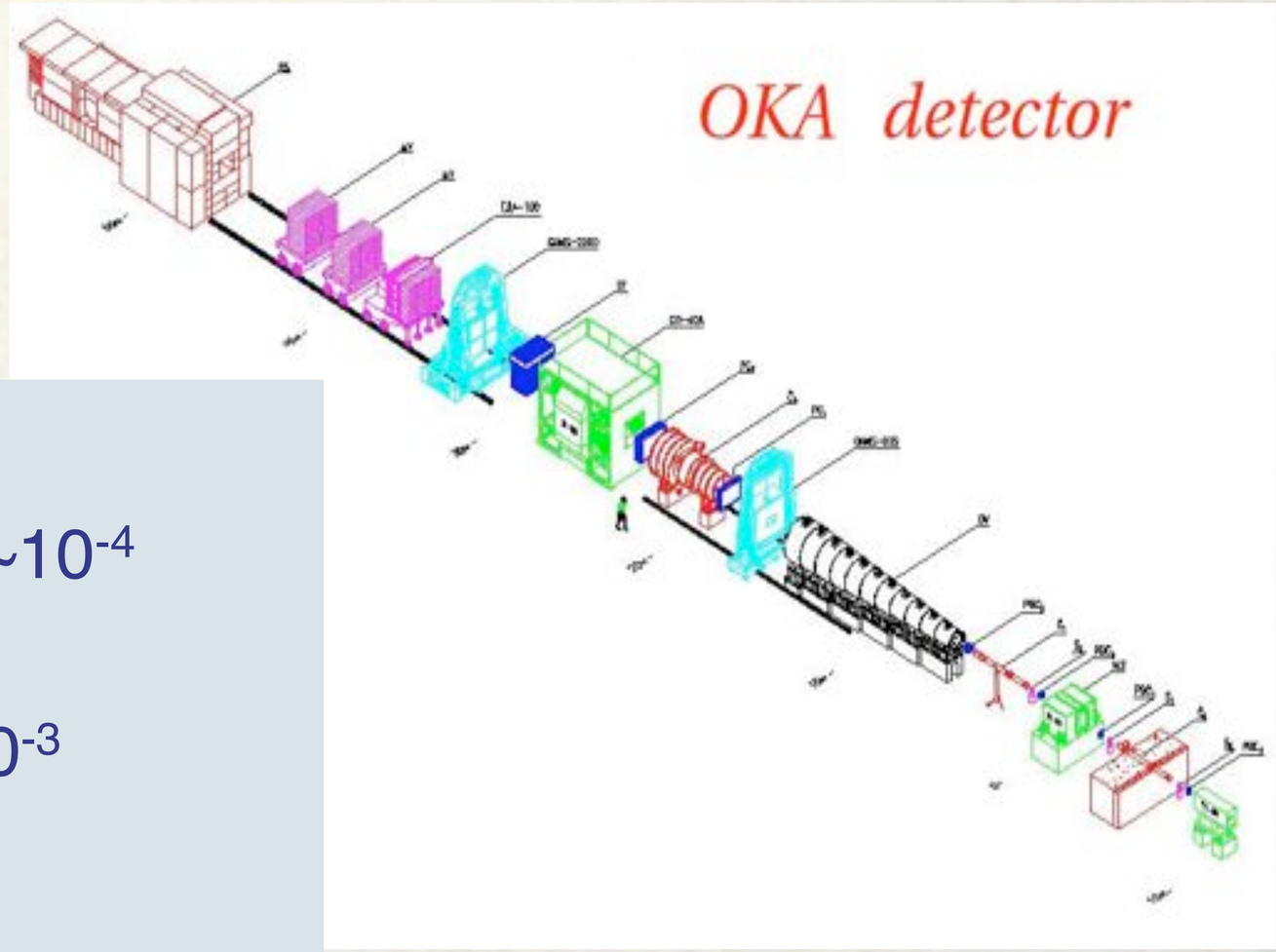
Old KTeV limit: $BR(K_L \to \pi^0 \nu\nu) < 5.9 \times 10^{-7}$ @90%CL

Future K projects

- OKA
- J-PARC
- P-326

OKA

- **OKA** experiment at Protvino **IHEP** - continuation of ISTRA+
- Commissioning of RF separated $K^{\pm}$ beam scheduled for December 2005.



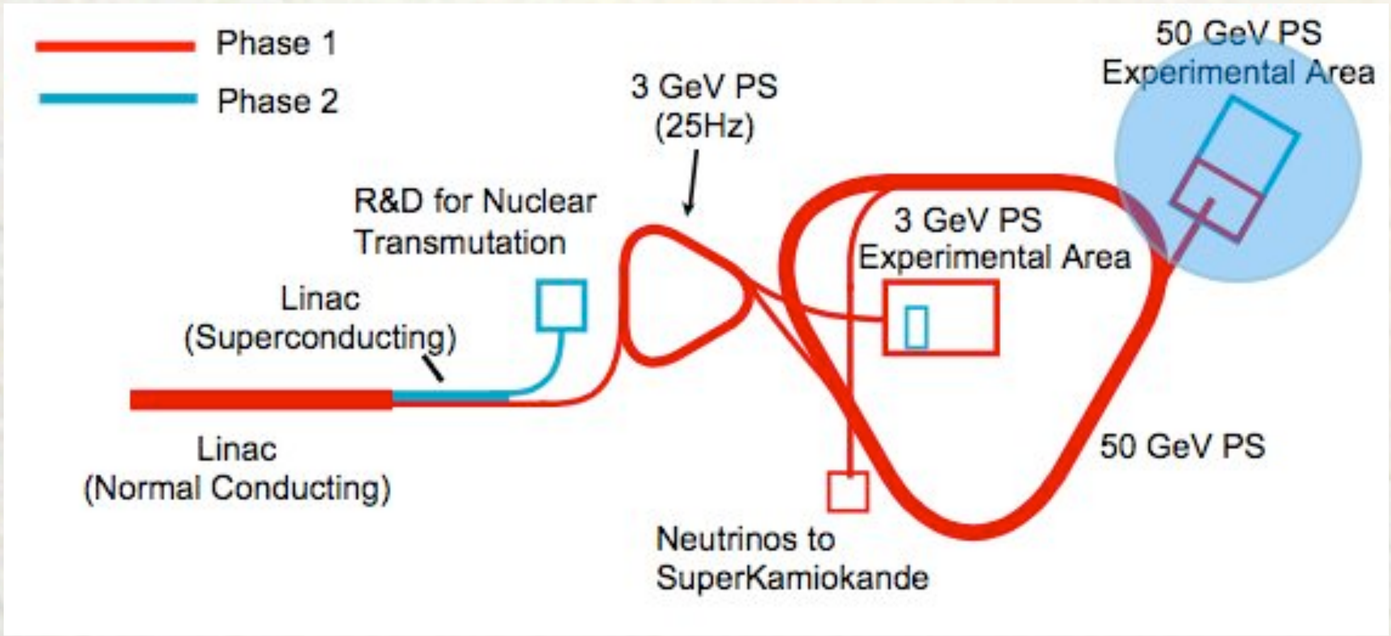
Physics goals:

- CP violation in $K^{\pm} \to 3\pi$: $A_g \sim 10^{-4}$
  sensitivity similar to NA48/2
- T violation in $K^{\pm}_{l3\gamma}$: $A_\xi < 2 \times 10^{-3}$
- Search for physics BSM in BR($K^{\pm}_{l2}$), and FF in $K^{\pm}_{l3}$

J-PARK

J-PARK: high intensity protons at 30-50GeV with $3x10^{14}$ ppp
Several K projects are planned at J-PARK facility in Japan
(LoI recommended):

- Search for $K_L \rightarrow \pi^0\nu\nu$ using modified E391a detector:



Phase I: start ~2008
goal ~20 events / 3y

Phase II: new detector

- Search for $K^+ \rightarrow \pi^+\nu\nu$ with stopped K^+ beam (goal 50 events)
- Search for T-violation in the transverse muon polarisation in decays $K^+ \rightarrow \pi^0\mu\nu$ or $K^+ \rightarrow \mu\nu\gamma$ (goal $\delta P_T \sim 10^{-4}$ sensitivity to some BSM)

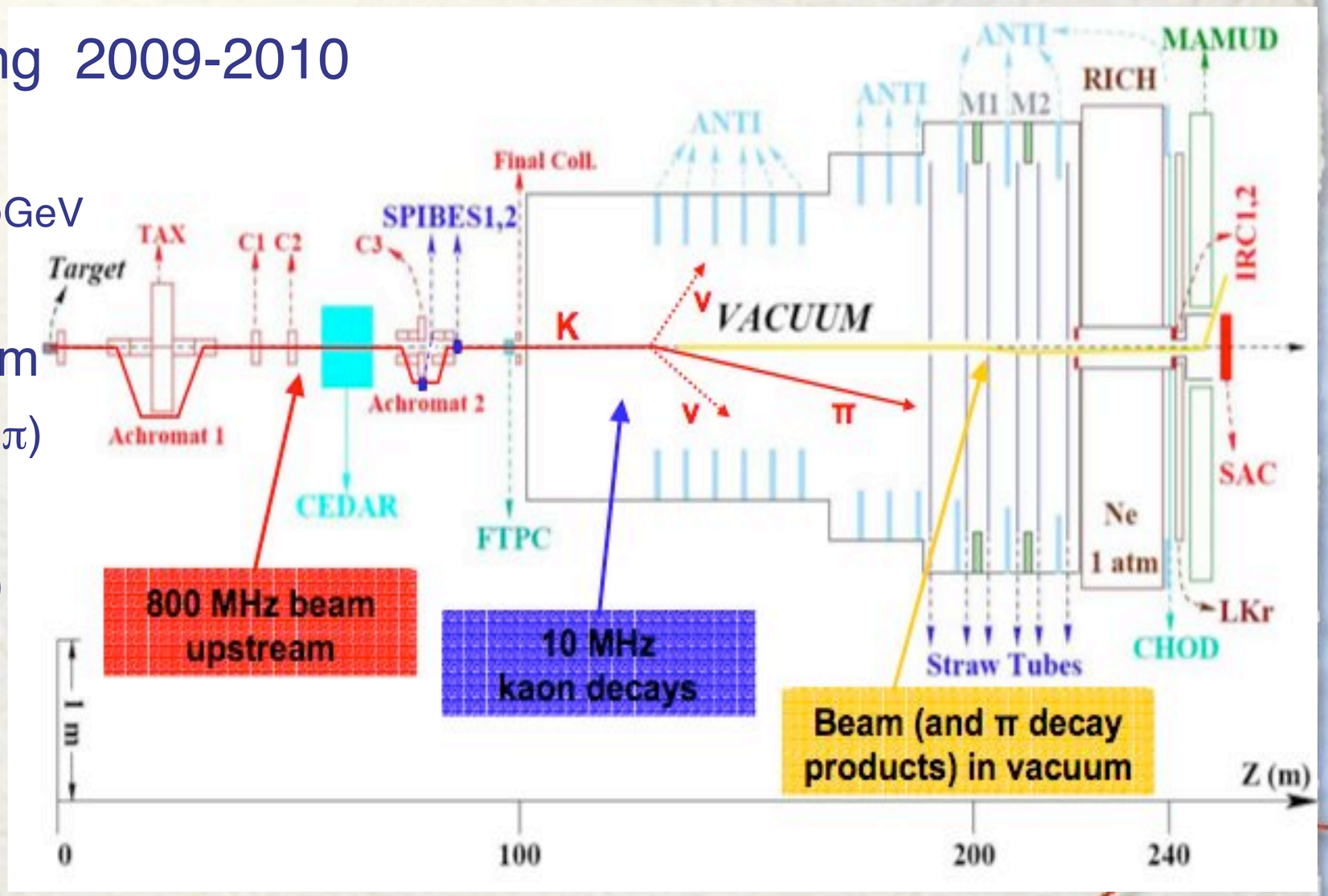
P-326

- **P-326** (former NA48/3) is a project to measure $K^+ \to \pi^+\nu\nu$ at **CERN** SPS: 400 GeV protons with 3×10^{12} ppp
- Proposal has been submitted to SPSC
- Intended data taking 2009-2010

Main features:

- Unseparated K^+ beam 75GeV
- Decay in flight
- Redundancy in momentum measurement (both K and π)
- High efficiency γ-vetoes
- Particle ID (RICH,MAMUD)

Goal ~80 events in 2 years



Summary

- Good progress in understanding CKM unitarity thanks to coherent efforts of most K experiments as well as theoretical groups.
- Present experiments and future projects concentrate on processes with strong contributions expected from models beyond SM.
- Notably, very rare K decays mediated by FCNC, due to differences in sensitivity depending on the model, have strong discriminative power.
- This makes K physics complementary to large colliders and B factories.
- The demise of the US K projects (KOPIO, CKM) leaves Europe and Japan to pursue K physics