Rare K decays with NA48

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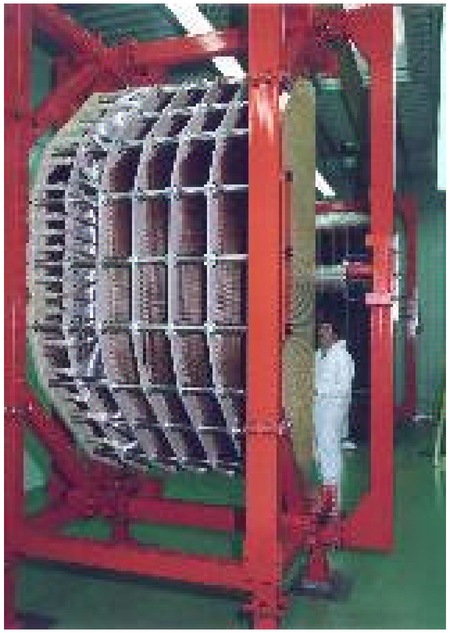
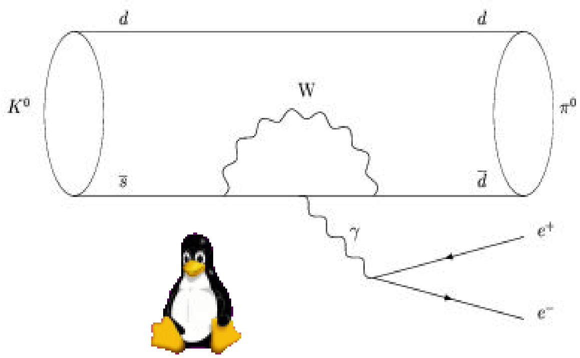
Outline

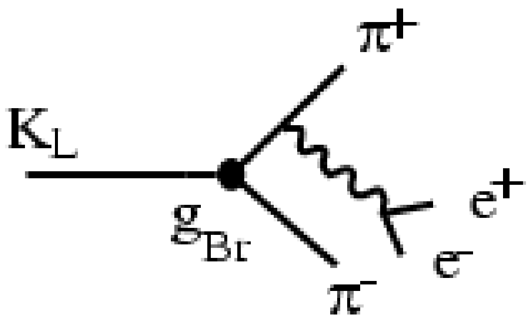
- NA48 experiment
- $K_L \rightarrow \pi^0\gamma\gamma$ decays
- $K_S \rightarrow \pi^0\gamma\gamma$ decays
- Future prospects



CP Violation in Rare Decays

Decays into 2π are very prolific. Due to the large amount of data collected, NA48 can see CP violation effects in rare decays (branching ratios in the range 10^{-5} - 10^{-8} and, in the future, 10^{-9} - 10^{-10})

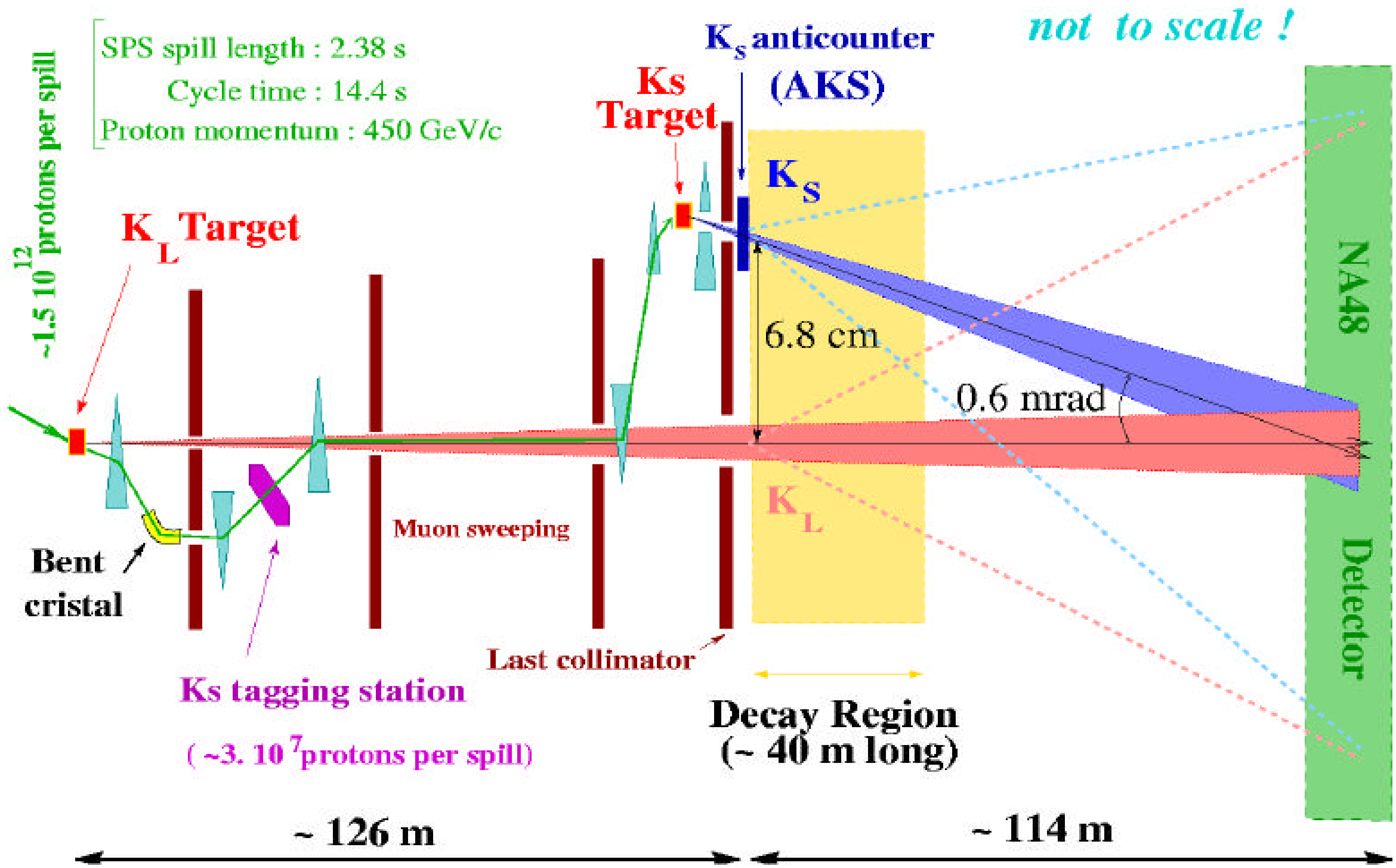




Chiral Perturbation Theory

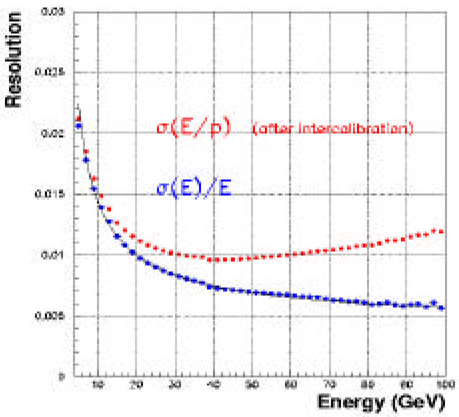
- χPT is the effective theory of the Standard Model at low energies (E < 1 GeV).
- The chiral symmetry of the QCD Lagrangian is spontaneously broken to $SU(3)_V$.
  - The degrees of freedom of the theory are the octet of pseudoscalar mesons (π,K,η). They are massive because of breaking terms proportional to the quark masses.
- At order $O(p^4)$ the flavour-changing chiral effective Lagrangian contains dozens of unknown couplings.
- Rare K decays are the ideal tool to probe χPT.

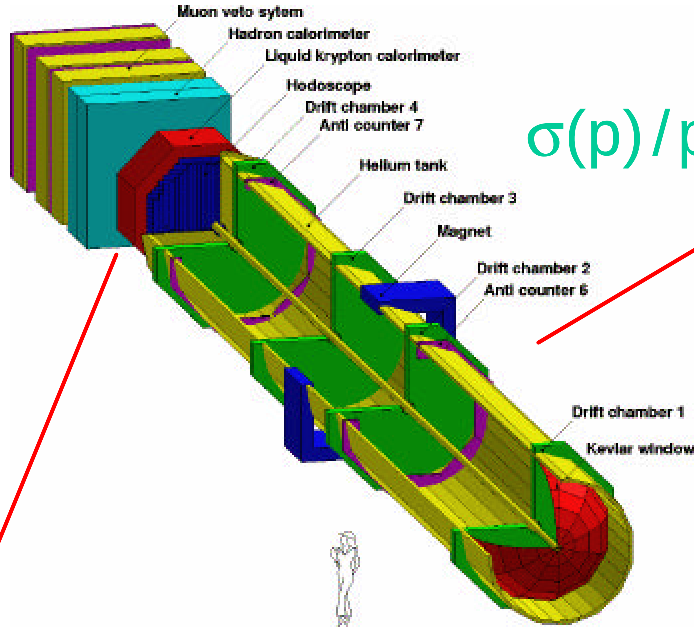
The K_L and K_S beams



The K_L and K_S beams

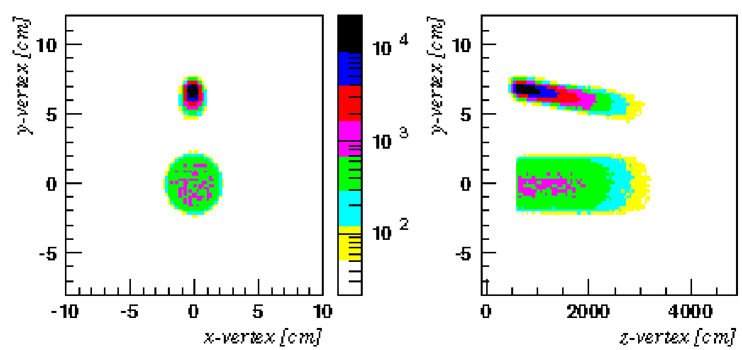
The Central Detector





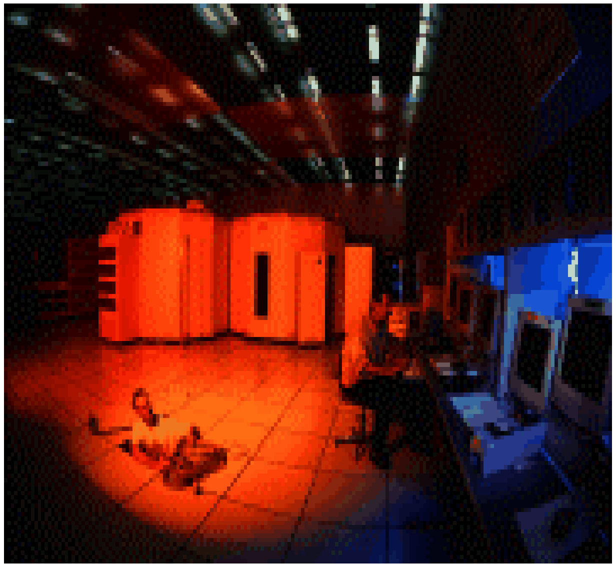
σ(p)/p =0.48% Å 0.009p%

σ(E)/E =0.032/E$^{-1/2}$
Å 0.1/E Å 0.005



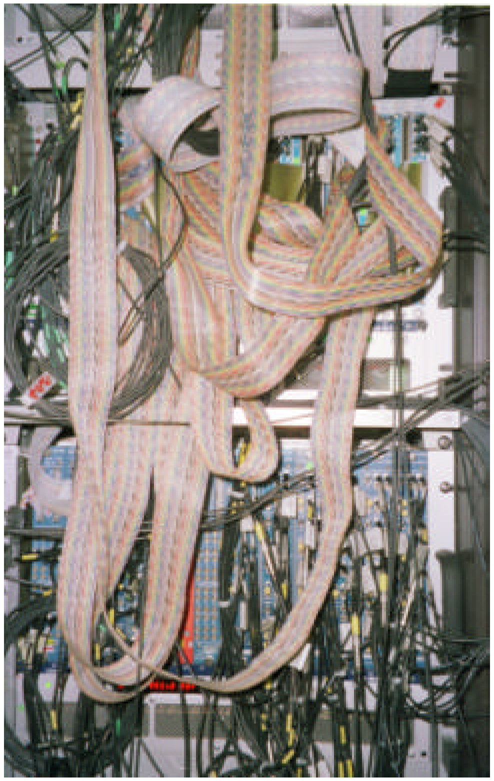
Data Collection

- Data taken in 1997-1999
  - 450 GeV protons from SPS
  - 1.2-1.4 x 10^{12} ppp on K_L target
  - 3 x 10^7 ppp on K_S target
  - duty cycle: 2.4 s/14.4 s
  - 3.2 x 10^{10} K_L decays/year
  - 6.5 x 10^7 K_S decays/year
- K_S only 1999 (2 days)
  - 6 x 10^9 ppp on K_S target
  - 3 x 10^8 K_S decays



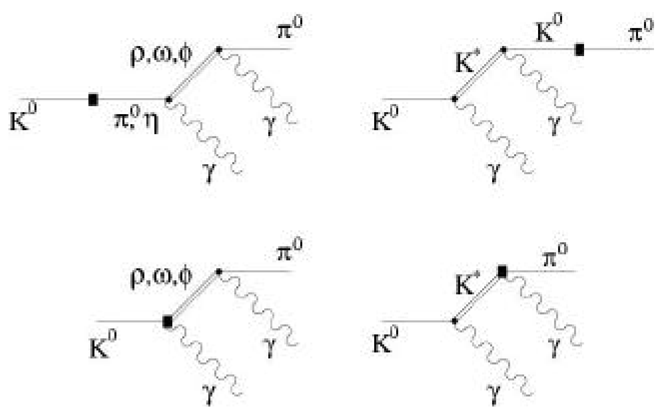
Data Collection

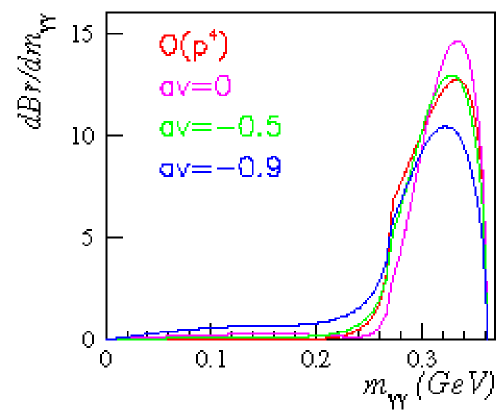
- K_S only 2000 (~45 days)
  - 400 GeV protons from SPS
  - 9 x 10^9 ppp on K_S target
  - duty cycle: 3.2 s/14.4 s
  - 1 x 10^{10} K_S decays
  - no drift chambers
- K_S only 2001 (~5 days)
  - full apparatus
  - same condition as 1999, larger statistics (~x2.5)
  - improved trigger



$K_L \rightarrow \pi^0\gamma\gamma$ - Motivation

- Decay rate is finite at one loop in χPT, but at $O(p^4)$ only 1/3 of measured rate is predicted.
- $O(p^6)$ calculations that include VMD reproduce the rate and predict a tail at low $m_{\gamma\gamma}$.



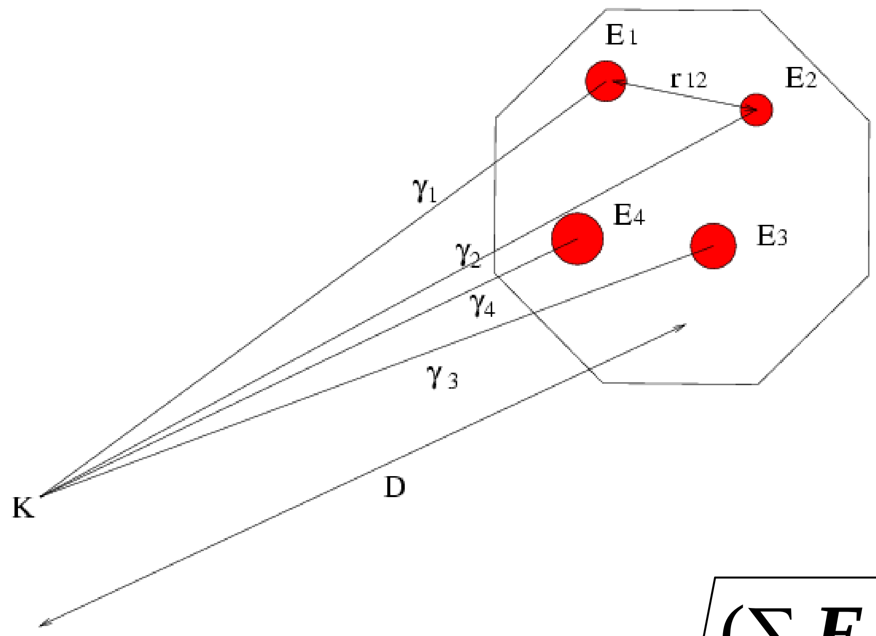


The VMD contribution are parameterised by a_V, to be measured.

$K_L \rightarrow \pi^0\gamma\gamma$ - Motivation

- χPT theoretical prediction (FMV+BMS):
  - $B(K_L \rightarrow \pi^0\gamma\gamma) = 1.50 \times 10^{-6}$
  - $a_V = -0.7$
- A good measurement of a_V is fundamental to estimate the CP conserving amplitude for the process $K_L \rightarrow \pi^0 e^+ e^-$

Vertex Reconstruction



$$z_V = z_{LKr} - \frac{\sqrt{\sum E_i E_j d_{ij}^2}}{m_K}$$

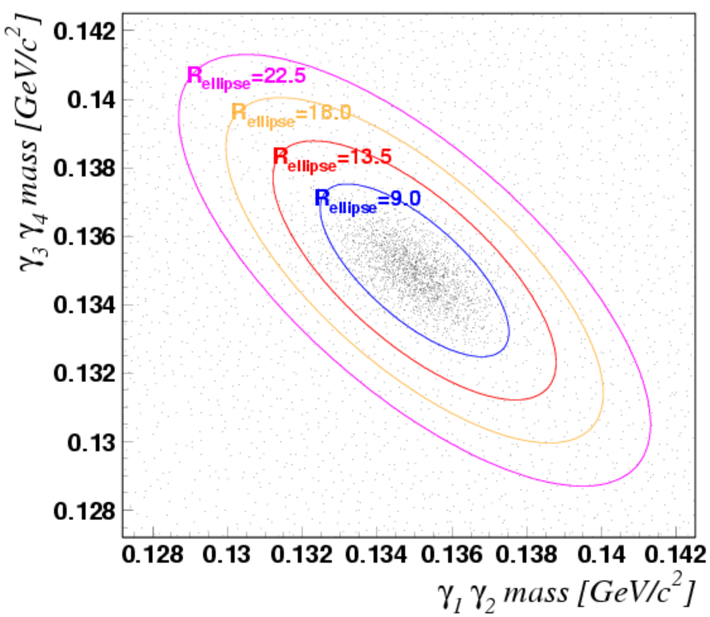
$$COG = \frac{\sqrt{(\sum E_i x_i)^2 + (\sum E_i y_i)^2}}{\sum E_i}$$

$K_L \rightarrow \pi^0\gamma\gamma$ - Selection

- Data collected in 1998 and 1999
- Trigger selection:
  - E_{LKr} > 50 GeV, COG < 15 cm, $\tau < 5.5\ \tau_S$, < 6 peaks in LKr projections
  - overall efficiency > 99.9 %
- Event quality:
  - Select tagged K_L
  - 4 clusters in time and within LKr acceptance
  - $3 < E_\gamma < 100$ GeV
  - $70 < E_K < 170$ GeV

$K_L \to \pi^0\gamma\gamma$ - Background

- Contributions from $K_L \to \pi^0\pi^0$ rejected with a χ^2-like variable and the requirements:
  - $\chi^2(\pi^0\gamma\gamma) > 300$
  - $|m_{1,2}-m_\pi| < 3$ MeV and $m_{3,4} \notin [110\text{-}160]$ MeV
  - DCH in veto
  - $P_{T,4} > 40$ MeV, where $P_{T,4}$ is the transverse momentum of the lowest energy γ of the unpaired photon



Residual $K_L \to \pi^0\pi^0$ background estimated using K_S-only runs: 4.1±2.1 events

$K_L \rightarrow \pi^0\gamma\gamma$ - Background

- Contributions from $K_L \rightarrow \pi^0\pi^0\pi^0$:
  - Missing photons
    - AKL veto
    - Restrict fiducial region to z < 30 m and R_{COG} < 4 cm
  - Missing and overlapping photons
    - Discrepancies between calculated π^0, $\pi^0\pi^0$ and K decay vertices (99% effective, at the expense of 49% of good events)
  - Overlapping photons
    - Energy dependent cut on shower width

$K_L \rightarrow \pi^0\gamma\gamma$ - Background

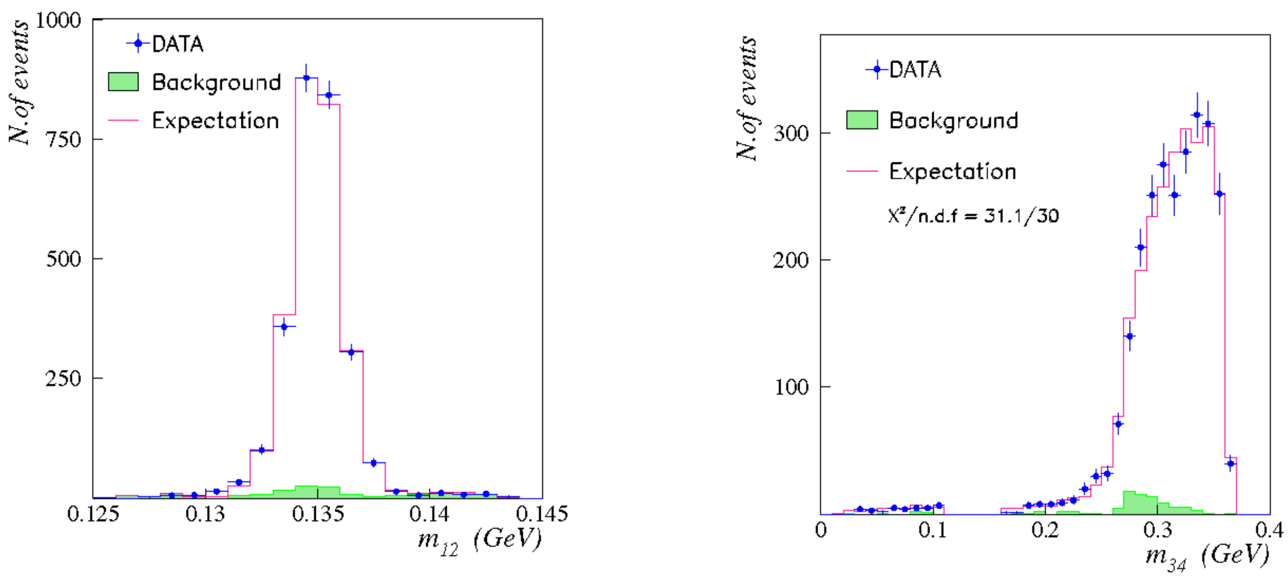
- Contributions from two overlapped in-time kaon decays:
  - Estimated comparing the normalised distributions of the center of gravity at the LKr for $K_L \rightarrow \pi^0\gamma\gamma$ candidates and for a good $2\pi^0$ data sample.

Overall background: 3.2%

Caveat: most of the events in the low $m_{3,4}$ mass region are genuine $K_L \rightarrow \pi^0\gamma\gamma$ where the wrong combination of photons was chosen. These events are used in the determination of the branching ratio but not to extract a value for a_V.

$K_L \rightarrow \pi^0\gamma\gamma$ - Result (Preliminary)

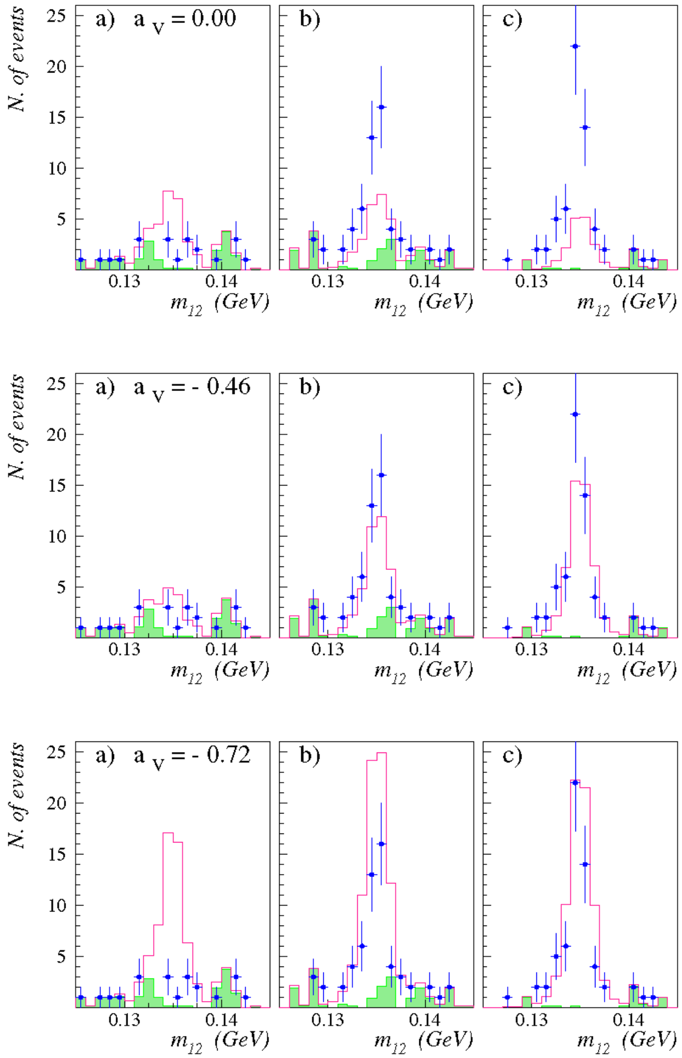
~2500 candidates in the signal region 132 < $m_{1,2}$ < 138 MeV



$B(K_L \rightarrow \pi^0\gamma\gamma) = (1.36 \pm 0.03(stat) \pm 0.03(syst) \pm 0.03(norm)) \times 10^{-6}$

KTeV: $B(K_L \rightarrow \pi^0\gamma\gamma) = (1.68 \pm 0.10) \times 10^{-6}$

$K_L \rightarrow \pi^0\gamma\gamma$ - Result (Preliminary)



a) $m_{3,4} \in$ [30,110] MeV

b) $m_{3,4} \in$ [160,240] MeV

c) $m_{3,4} \in$ [240,260] MeV

From a fit of the distribution of $m_{3,4}$ and $y(=|E_3-E_4|/m_K)$:

a_V= -0.46 ± 0.03(stat) ± 0.03(syst) ± 0.02(th)

KTeV:
a_V= -0.72 ± 0.05 ± 0.06

$K_L \rightarrow \pi^0\gamma\gamma$ - Result (Preliminary)

No evidence of signal in the region $m_{3,4} < m_\pi$
$\Rightarrow$ using events with $y < 2$ in 5 bins of $m_{3,4}$
between 30 and 110 MeV/c^2, we compute,
in a model-independent way, at 90% CL:

$$B(K_L \rightarrow \pi^0\gamma\gamma)_{m\in[30,110],y\in[0,2]} < 0.6 \times 10^{-8}$$

From this computation, using our measurement of a_V, we can predict the CP-conserving contribution to $K_L \rightarrow \pi^0 e^+ e^-$:

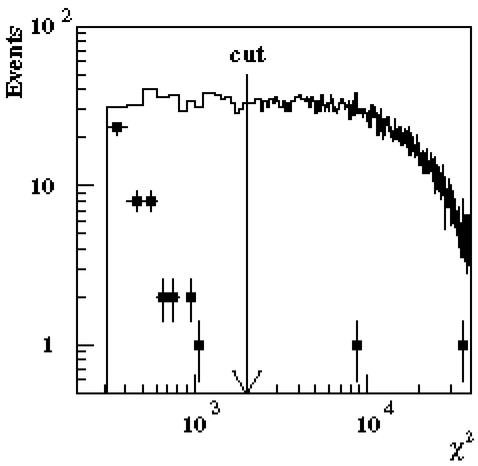
$$B(K_L \rightarrow \pi^0 e^+ e^-)_{CPC} = (4.7 \pm 2.2) \times 10^{-13}$$

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

- Again, χPT predicts the branching ratio for this mode, with the cut-off $z=(m_{\gamma\gamma}/m_K)^2>0.2$ (to avoid the region with pion pole):
  - $BR(K_S \to \pi^0\gamma\gamma) = 3.8 \times 10^{-8}$
- This mode has not been seen

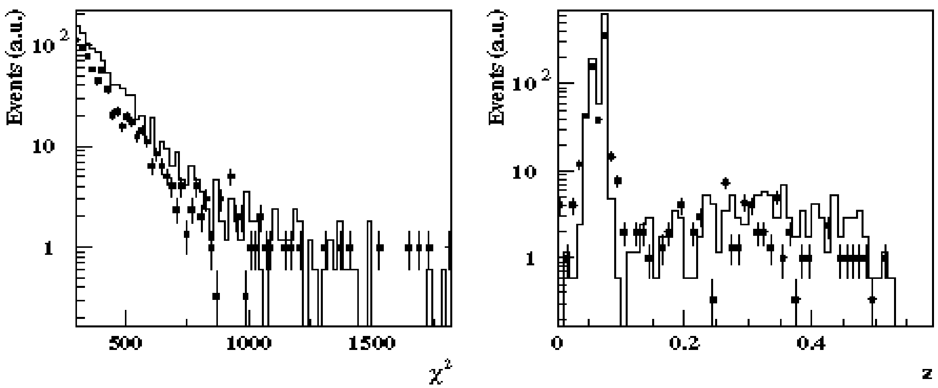
$K_S \rightarrow \pi^0\gamma\gamma$ - Selection

- Data from K_S high intensity run.
- No dedicated trigger was set up, so events satisfying $\gamma\gamma$ or $3\pi^0$ triggers were selected.
- Same event quality as for $K_L \rightarrow \pi^0\gamma\gamma$ except:
  - COG < 7 cm
  - $\chi^2(\pi^0\gamma\gamma) > 2000$
  - $z = (m_{\gamma\gamma}/m_K)^2 > 0.2$
  - $z_V < 8$ m



$K_S \rightarrow \pi^0\gamma\gamma$ - Background

- Background from misreconstructed $K_S \rightarrow \pi^0\pi^0$:
  – from MC, 0.1 ± 0.1 events are expected to contaminate the data after the selection cuts.

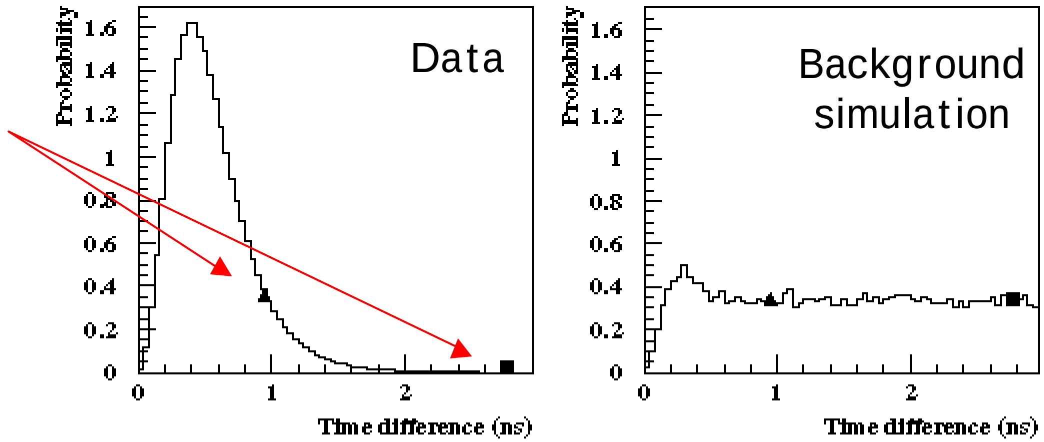


- Background from $K_S \rightarrow 3\pi^0$, $K_S \rightarrow \pi^0\pi^0$ and $K_L \rightarrow \pi^0\gamma\gamma$:
  – From simulation, about 0.14 events are expected to contaminate the data.

$K_S \rightarrow \pi^0\gamma\gamma$ - Background

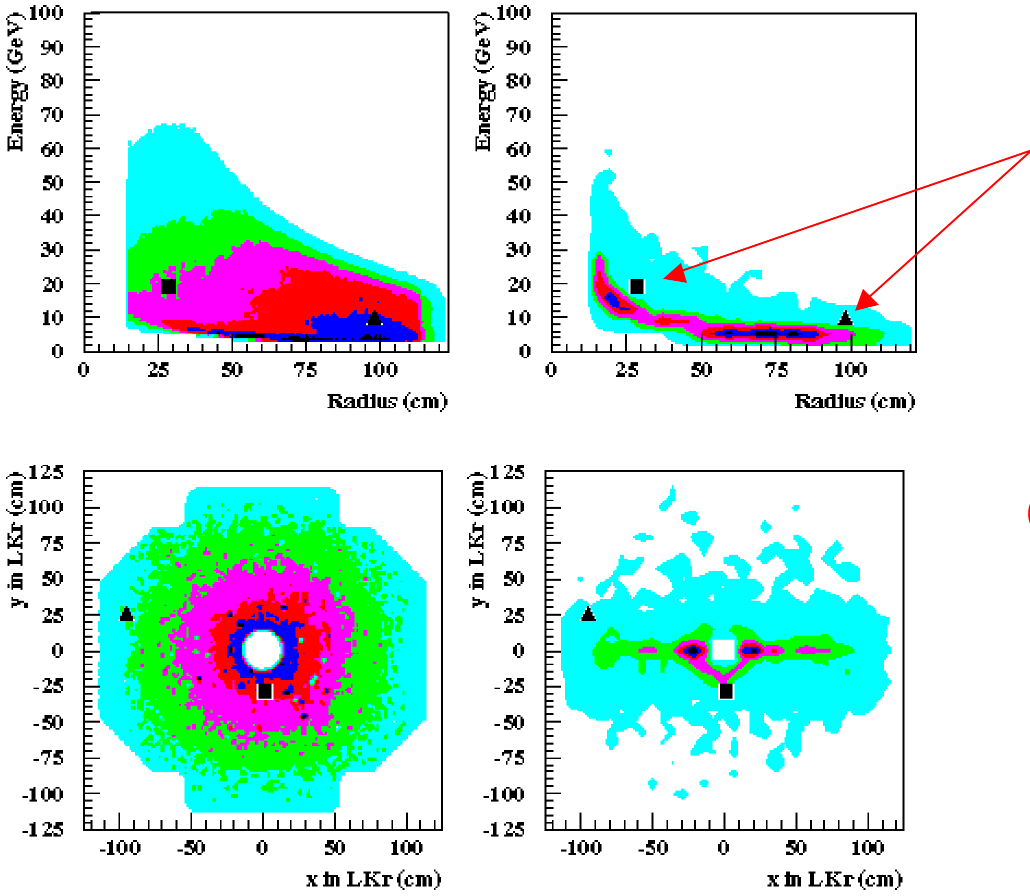
- Background from $K_S \rightarrow \pi^0\pi^0$ with three clusters into the acceptance and one random cluster accidentally in-time:

Furthest in time clusters wrt the event time for the two events surviving the cuts



The time distribution for random events is supposed to be flat; the two surviving events have cluster times consistent with random events

$K_S \to \pi^0\gamma\gamma$ - Background



Furthest in time clusters wrt the event time for the two events surviving the cuts

2.1 ± 0.1 background events of this kind are expected to contaminate the data

The limit to the background rejection comes from the low statistics of available random events

$K_S \rightarrow \pi^0\gamma\gamma$ - Result (Preliminary)

The total kaon flux was estimated from $K_S \rightarrow \pi^0\pi^0$ to be $(3.06 \pm 0.17) \times 10^8$

2 events survive the selection cuts, consistently with the expectation of 2.4 ± 0.2 background events

A total 6% of systematic uncertainty was calculated from various sources

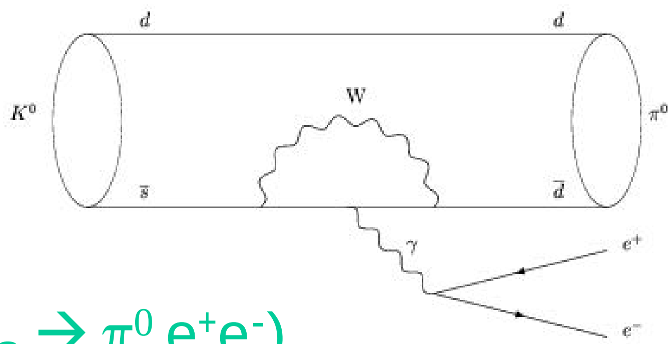
The upper limit to the branching ratio, at a 90% confidence level, for $(m_{\gamma\gamma}/m_K)^2 > 0.2$ is therefore:

$$B(K_S \rightarrow \pi^0\gamma\gamma) < 4.4 \times 10^{-7}$$

$K_{L,S} \rightarrow \pi^0 l^+ l^-$ - Motivation

$K_L \rightarrow \pi^0 e^+e^-$ has three components:

- CP conserving:
  - $B(K_L \rightarrow \pi^0 e^+e^-)_{CPC} \sim 10^{-13}$, dominated by two-photon processes $K_L \rightarrow \pi^0 g^* g^*$
- Direct CP violating:
  - $B(K_L \rightarrow \pi^0 e^+e^-)_{dir} \sim 4.5 \times 10^{-12}$
- Indirect CP violating:
  - $B(K_L \rightarrow \pi^0 e^+e^-)_{ind} \sim |\varepsilon|^2 \, \tau_L/\tau_S \, B(K_S \rightarrow \pi^0 e^+e^-)$



χPT: $B(K_S \rightarrow \pi^0 e^+e^-) = 5.2(a_S)^2 \times 10^{-9}$, $a_S \sim 1$

$K_S \rightarrow \pi^0 e^+ e^-$ - Result

No event survives the selection criteria in the 1999 data

Assuming for the simulation, from χPT, a form factor
$f_V(z) \sim 1 + z/r_V^2$, $r_V^2 = 2.5$,
the total acceptance for $K_S \rightarrow \pi^0 e^+ e^-$ is 7.5%

$B(K_S \rightarrow \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$ at 90% CL

(Phys.Lett.B514:253-262,2001)

$\Downarrow$

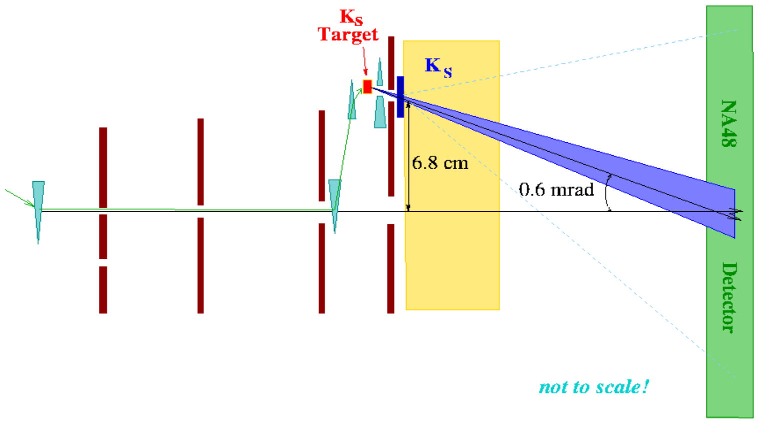
$a_S < 5.2$

$B(K_L \rightarrow \pi^0 e^+ e^-)_{CPC} < 4.4 \times 10^{-10}$

NA48/1 - Motivation

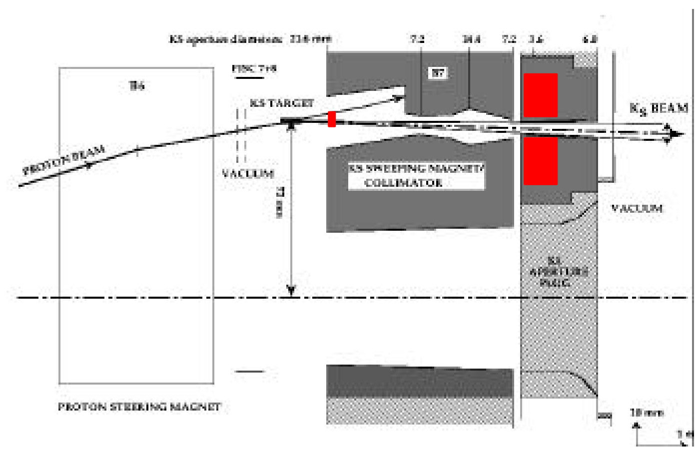
- $K_S \to \pi^0 l^+ l^-$, l=e,μ
  - Bound Indirect CP Violation in the decay $K_L \to \pi^0 l^+ l^-$ to $< 10^{-12}$
- Search for CPV in K_S decays
  - $K_S \to 3\pi^0$, $K_S \to \pi^+ \pi^- \pi^0$
- Study of time dependent CPV asymmetry in $K_{S,L} \to \pi^+ \pi^- \gamma^*$
- Test of Chiral Perturbation Theory
  - $K_S \to \gamma\gamma$, $K_S \to \pi^0 \gamma\gamma$, $K_S \to \pi^0 \pi^0 \gamma\gamma$
- Study K_S Dalitz and semi-leptonic decays
- Semi-leptonic and radiative neutral hyperon decays
  - $\Xi^0 \to \Sigma^+ e^- \nu$, $\Xi^0 \to \Sigma^+ \mu^- \nu$, $\Xi^0 \to \Sigma^0 \gamma$, $\Xi^0 \to \Lambda \gamma$
- ....

NA48/1 - Modifications



- Use NA48 detectors and beamline
- Beam Intensity can be increased hundreds of times wrt to double beam

- Improvement of the K_S target station
  - Installation of sweeping magnet
  - Provision for a photon converter (8-13 X_0)



NA48/1 - Modifications

- Upgrade of the Drift Chamber read-out
  - Minimise loss due to overflows (30% in 1999 test run)
- New readout procedure for LKr and upgrade of the online PC farm
  - Increase Level II bandwidth (currently limited by LKr)
  - Up to 1 Gbyte/burst

Sensitivity

- Instantaneous rate already achieved in 1999
  - 10^{10} ppp → 3×10^{10} K_S decays x 105 days
  - SES 6×10^{-10} for 5% acceptance x efficiency
- Upgraded Target Station (2002)
  - Expect x2 reduction in accidental rate
  - Increase beam intensity from 10^{10} ppp to 2×10^{10} ppp
  - SES → 3×10^{-10} for 105 days
- Upgraded Drift Chamber Readout (2002)
  - Recover 30% of events (overflows)
  - SES → 2×10^{-10} for 105 days

But we only have 78 days ⇒ hope in a better SPS efficiency!

Conclusions

- The NA48 rare decay program is providing interesting results in the field of χPT and CP violation in the neutral kaon sector
- NA48 has demostrated the capability to use the detector at high proton intensity
- We look forward to collecting K_S and neutral hyperon decays during the 2002 SPS proton run