

Results from K_s and neutral hyperons decays from NA48/1

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*New trends in high energy physics
May 24-31, 2003 – Alushta, Crimea, Ukraine*

On behalf of the NA48 Collaboration

Plan of the presentation

- Introduction
- Results on rare decays and ChPT tests
 - ➡ Precision measurement of $K_{S,L} \rightarrow \gamma\gamma$ decays
 - ➡ Precision measurement of $K_L \rightarrow \pi^0\gamma\gamma$ decay
 - ➡ First observation of $K_S \rightarrow \pi^0\gamma\gamma$ decay
- Results on hyperons (Ξ^0, Λ) decays
- Outlook and Summary

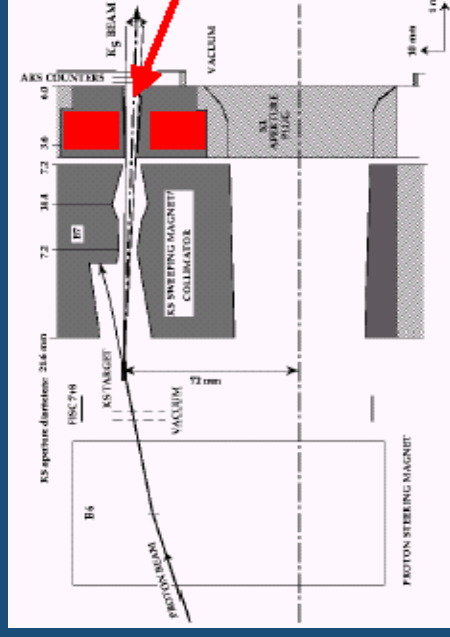
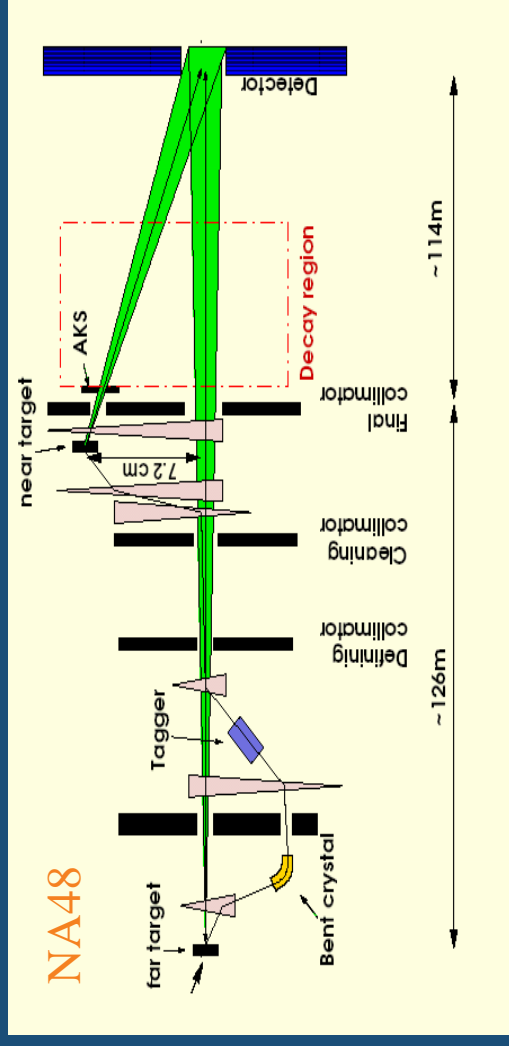
Chiral Perturbation Theory

- ChPT is the effective field theory of the Standard Model at low energy ($E < 1 \text{ GeV}$ region of non-perturbative QCD)
- Chiral symmetry of the QCD Lagrangian is spontaneously broken
 \Rightarrow degree of freedom of the theory are eight pseudoscalar Goldstone bosons (π, η, K)
- Processes described in perturbative expansion of momenta and masses
- Higher order boson loops are divergent, but compensated by counter-terms with (empirically determined) effective couplings
- Rare kaon decays eg., $K_{L,S} \rightarrow \pi^0 \gamma \gamma$, $K_{L,S} \rightarrow \gamma \gamma$ are the ideal tool to probe ChPT ($m_K \sim 0.5 \text{ GeV}$)

NA48/1

Unique opportunity:

- Use NA48 detectors with modified beam line and upgraded read-out systems
- More than 50 times the K_S world statistics, improved collimator technique



Proposal

December 1999
 3×10^{10} K_S (120 SPS days)

Phase I : approved

March 2000
45 day in 2000 SPS run
Final states only with γ

Phase II : approved

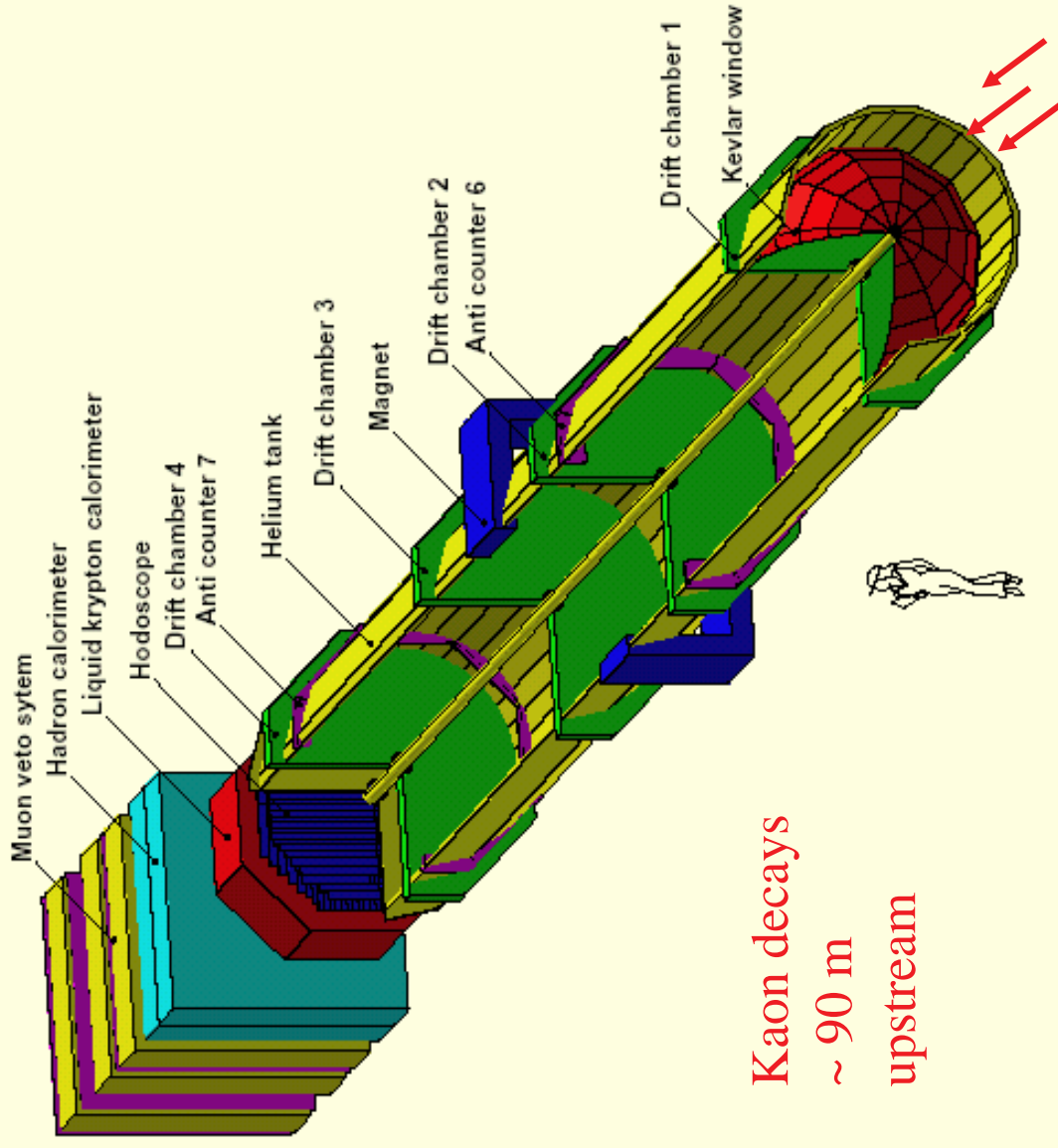
November 2000
Data taken in 2002

History:

28/5/2003

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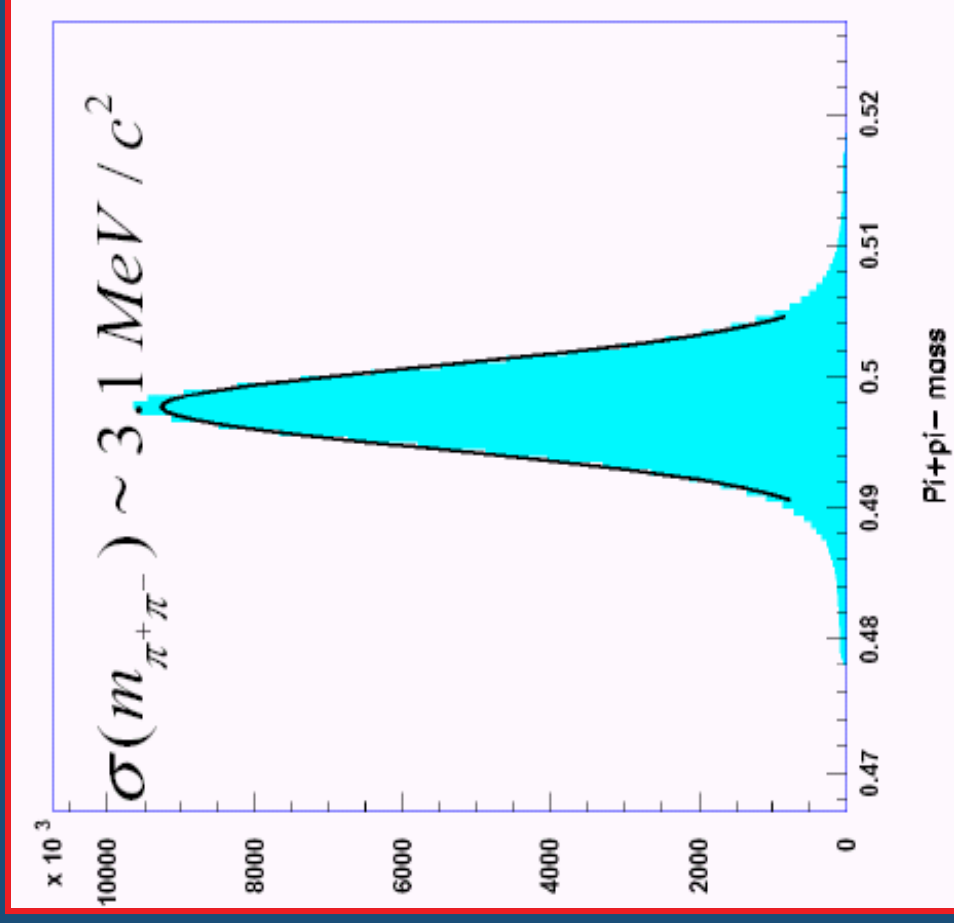
NA48 Detector



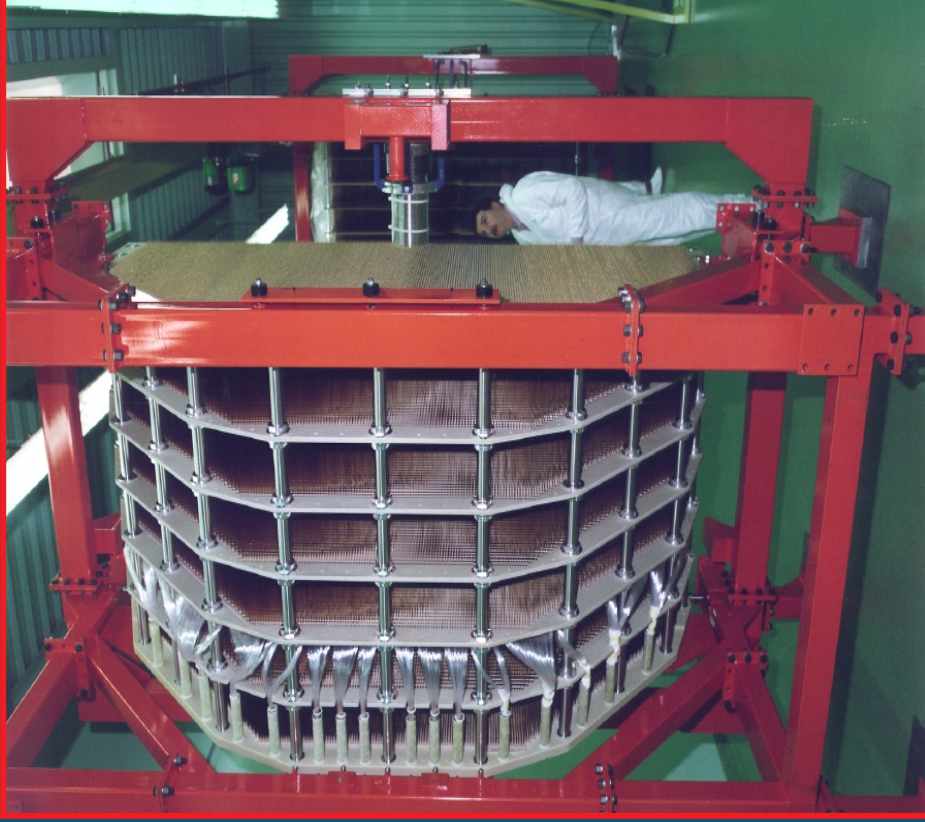
Kaon decays
~ 90 m
upstream

Performance of the Spectrometer

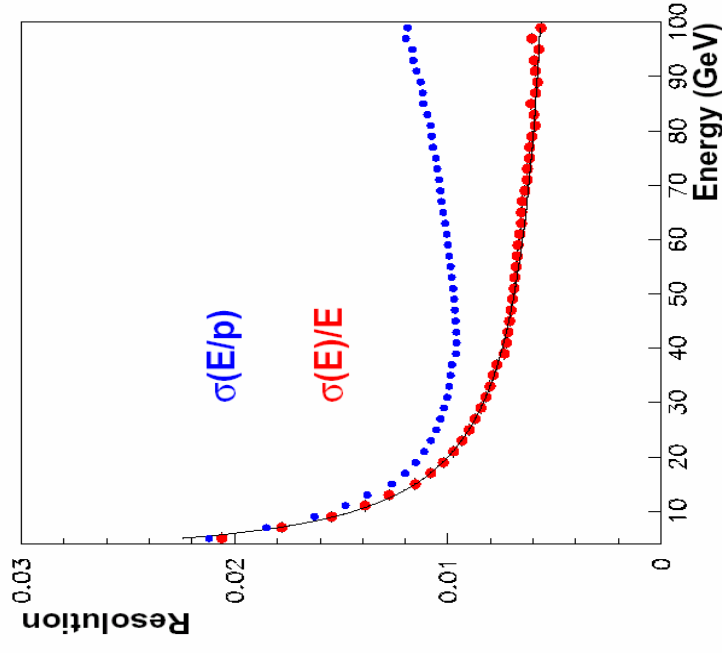
- **HV = 2200 V** (Ar-Ethane 50-50)
 1. 2300 V during ϵ'/ϵ era
 2. 2250 V during 2001 Ks tests
- $\pi^+\pi^-$ mass resolution worsens from **2.5 to 3.1 MeV/c²**
- Good enough for rare decays
- Stable during the run



Liquid Krypton Calorimeter

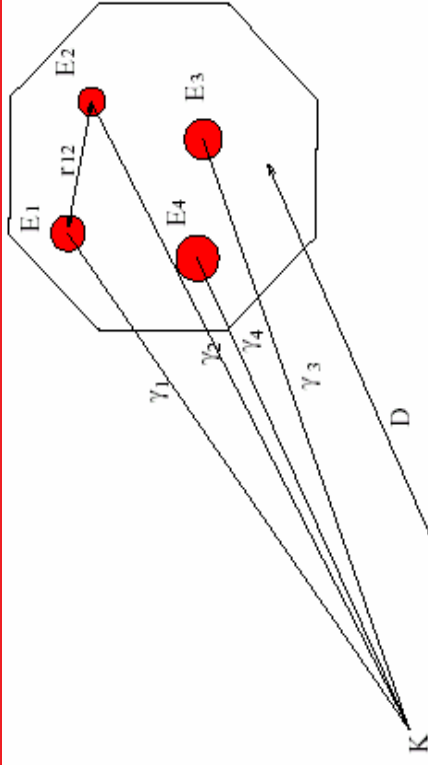


10 m³ of Lkr (13212 cells)
1.25 m depth (27 X₀)



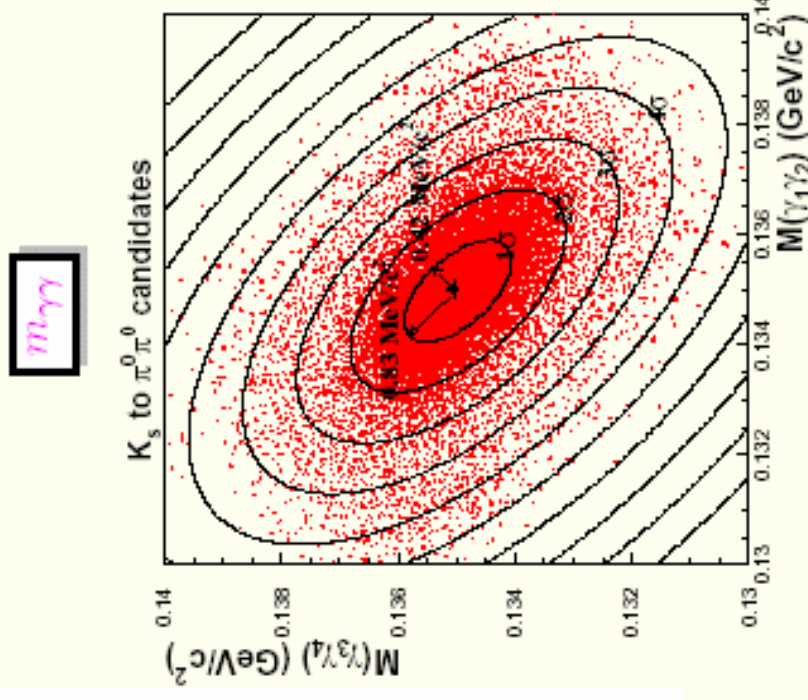
$$\sigma(E)/E = 3.2\%/\sqrt{E} \oplus 9\% / E \oplus 0.42\%$$

Liquid Krypton Calorimeter



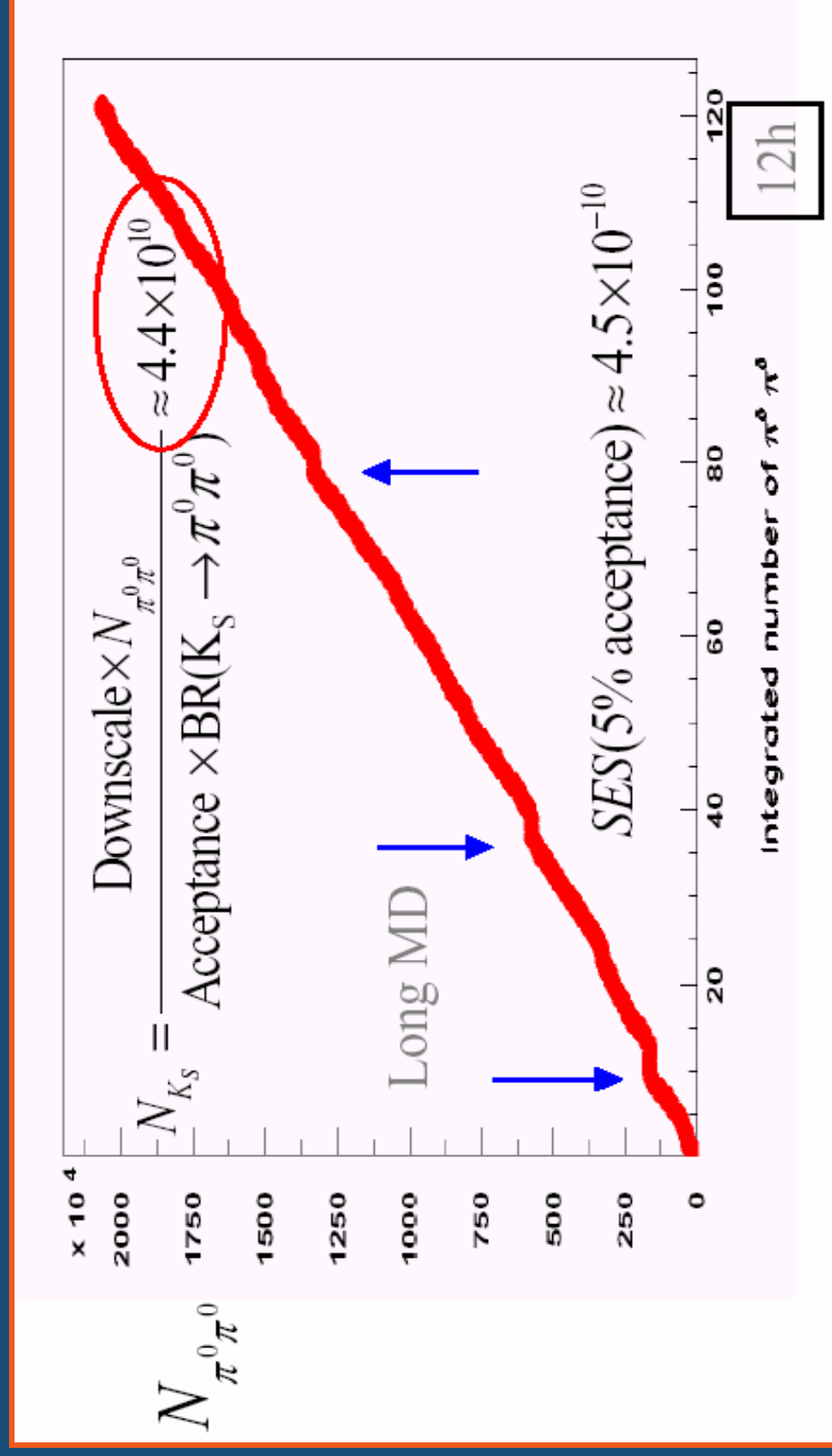
$$D = \sqrt{\sum E_i E_j} \times r_{ij}^2 / M_K \quad m_{ij} = \sqrt{E_i E_j r_{ij}^2} / D$$

 LKr calorimeter resolutions:
 energy $\lesssim 1\%$ for > 25 GeV photons
 position $\lesssim 1$ mm for > 25 GeV photons
 time ~ 0.22 ns/ $\pi^0 \pi^0$



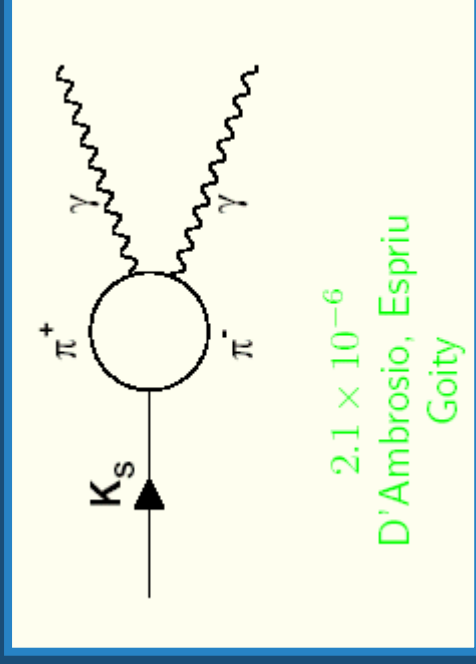
Run 2001

- 89 days of run, improved readout \Rightarrow 50 K events/burst
- Data taken at high intensity (5×10^{10} ppp) from July 18 onward



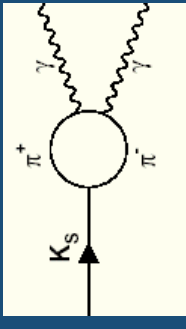
$K_S \rightarrow \gamma\gamma$ decay

- ◆ Decays into neutral final states : $O(p^2) = 0$
- ◆ $O(p^4)$ unambiguously predicted by ChPT loop diagram to better than 5% without counter terms
- ◆ Old NA48 measurement of $K_S \rightarrow \gamma\gamma$ branching ratio based on 2 days of test-run in 1999 with high intensity K_S :
 $(2.6 \pm 0.4) \times 10^{-6}$ (PLB 493 2000, 29)



not yet conclusive about possible $O(p^6)$ contributions

$K_S \rightarrow \gamma\gamma$ measurement



- \Rightarrow Data from 2000 near-target run, normalized to $K_S \rightarrow \pi^0 \pi^0$ decay rate
- \Rightarrow Principal background sources:

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

with only 2 showers in the LKr calorimeter :

- \rightarrow Reconstructed vertex moves downstream due to missing energy
- \rightarrow choose decays in the $-1m < z_{vertex} < 5m$ wrt collimator exit.

$K_L \rightarrow \gamma\gamma$

Irriducible : $N(K_L \rightarrow \gamma\gamma) / N(K_S \rightarrow \gamma\gamma) \sim 1.5$ in decay volume

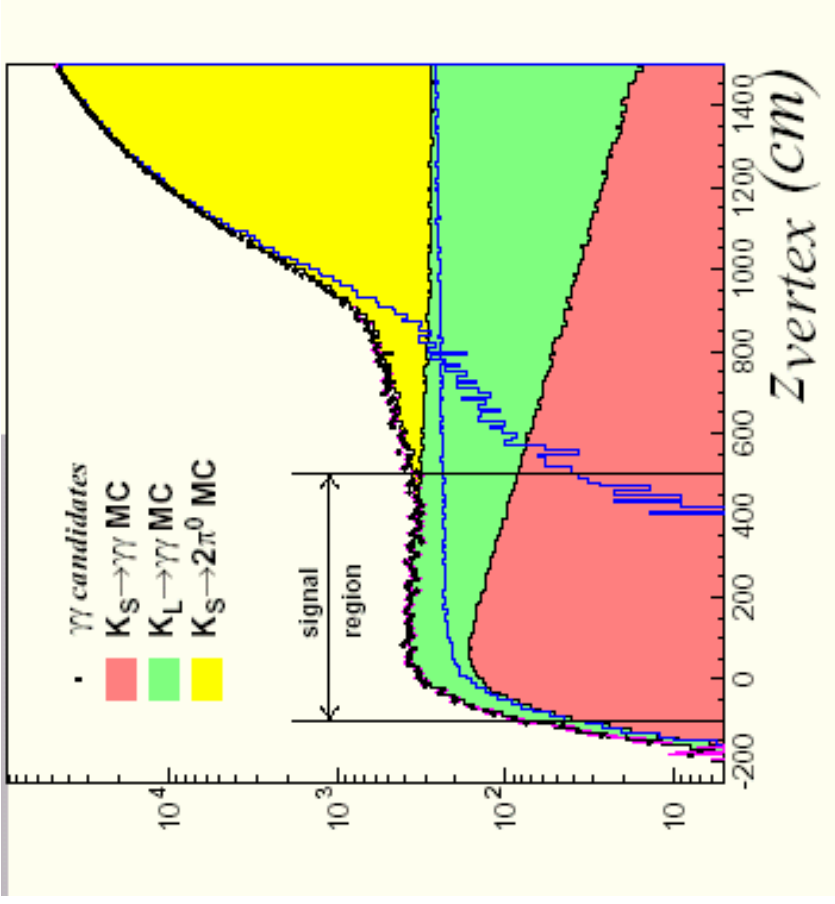
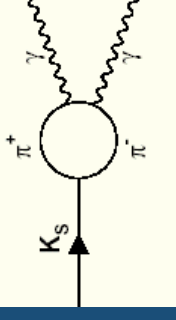
- \rightarrow Use $K_L \rightarrow \pi^0 \pi^0$ to estimate the K_L flux
- \rightarrow use 2000 far-target run to measure $\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0 \pi^0 \pi^0)$

$$\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0 \pi^0 \pi^0) = (2.81 \pm 0.01_{\text{stat}} \pm 0.02_{\text{syst}}) \times 10^{-3}$$

This result has an accuracy 4 times better than the current PDG value:

$$(2.77 \pm 0.08) \times 10^{-3}$$

$K_S \rightarrow \gamma\gamma$ measurement

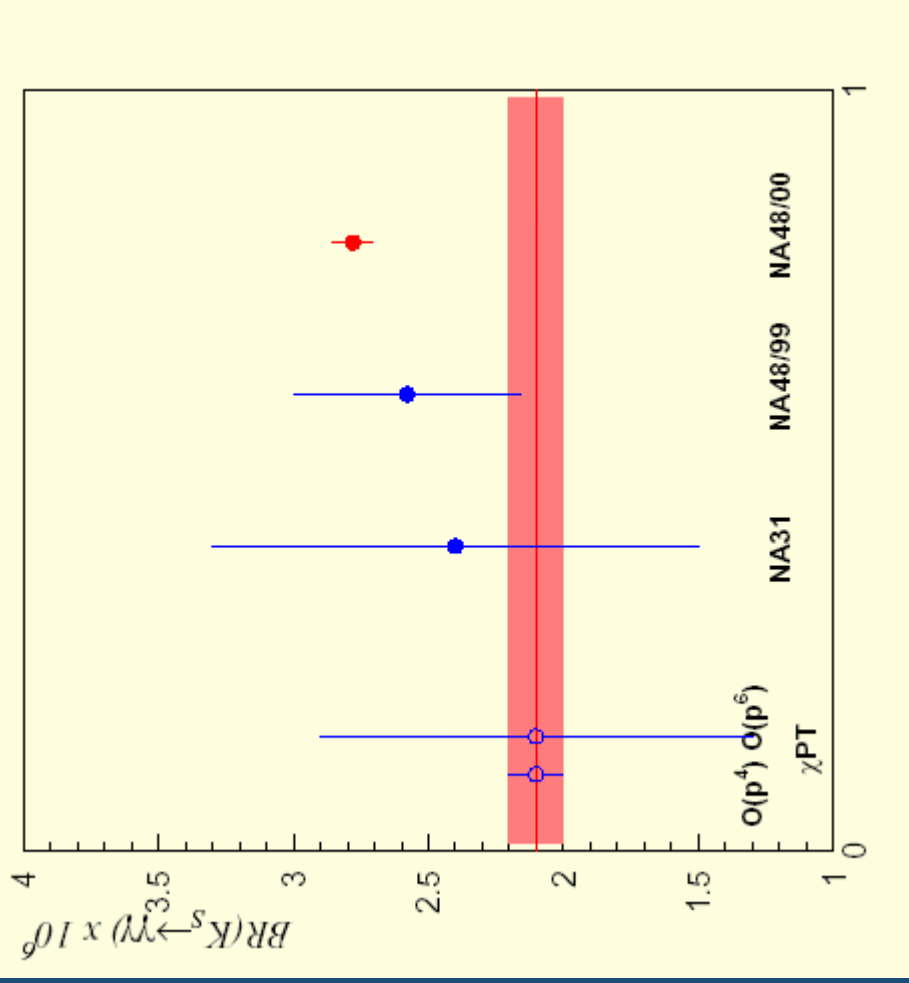
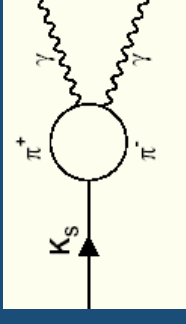


- ❖ Background from $\pi^0\pi^0$ subtracted using **MC normalized to the flux** obtained from fully reconstructed $\pi^0\pi^0$ events \Rightarrow **Background: $(0.8 \pm 0.2)\%$**
- ❖ Binned maximum likelihood fits to measure $\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0\pi^0\pi^0)$ and the $K_S \rightarrow \gamma\gamma$ branching ratio in 10 kaon energy and 6 vertex position bins

$$\text{BR}(K_S \rightarrow \gamma\gamma) = (2.78 \pm 0.06_{\text{stat}} \pm 0.02_{\text{syst}} \pm 0.02_{\text{ext}}) \times 10^{-6}$$

(Phys. Lett. B 551 (2003) 7)

$K_S \rightarrow \gamma\gamma$ measurement

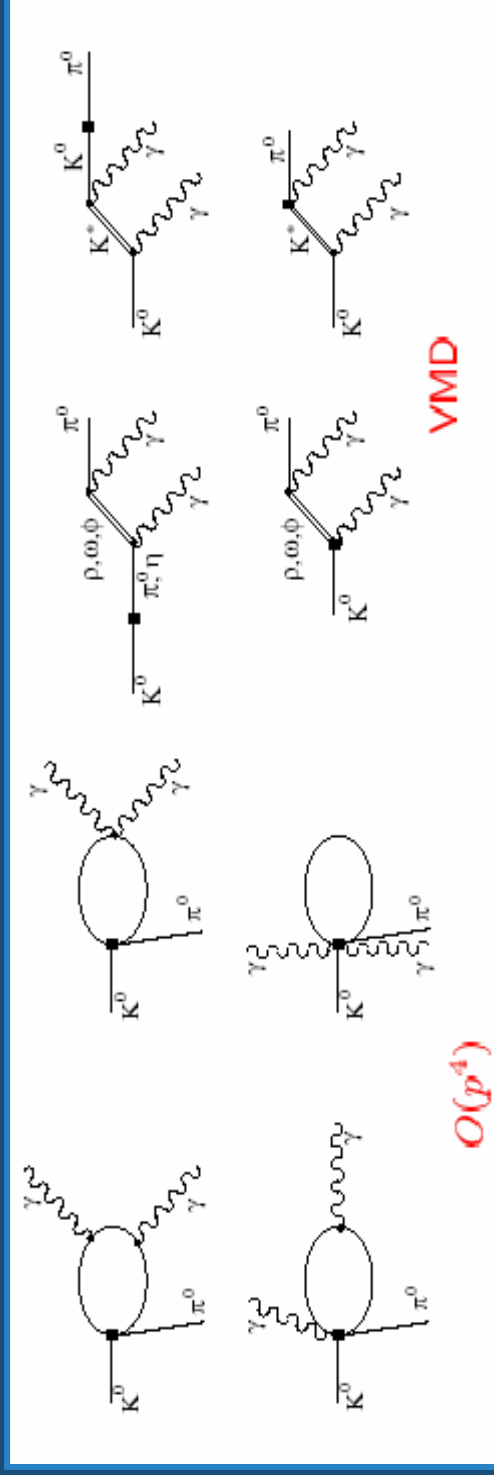
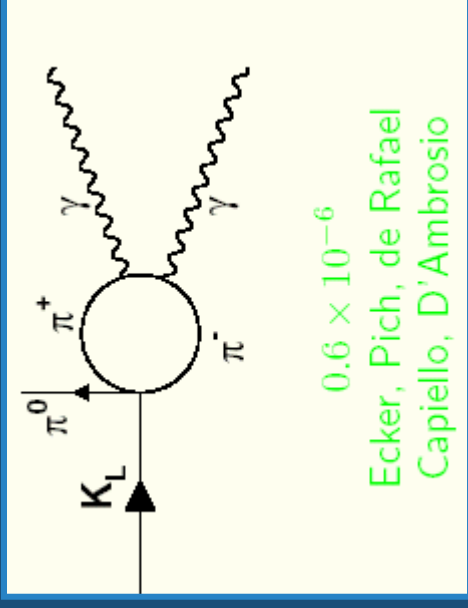


- The new result has an accuracy better than 3% and differs by 30% from $O(p^4)$ prediction of ChPT
- Indication of a large $O(p^6)$ contribution
- Compatible with previous measurements

$K_L \rightarrow \pi^0 \gamma \gamma$ decay

- Only 1/3 of the measured $K_L \rightarrow \pi^0 \gamma \gamma$ rate is predicted by $O(p^4)$.
- The rate can be reproduced at $O(p^6)$ including vector mesons exchange.

The VMD contribution is parametrised by a_V , which has to be experimentally determined.

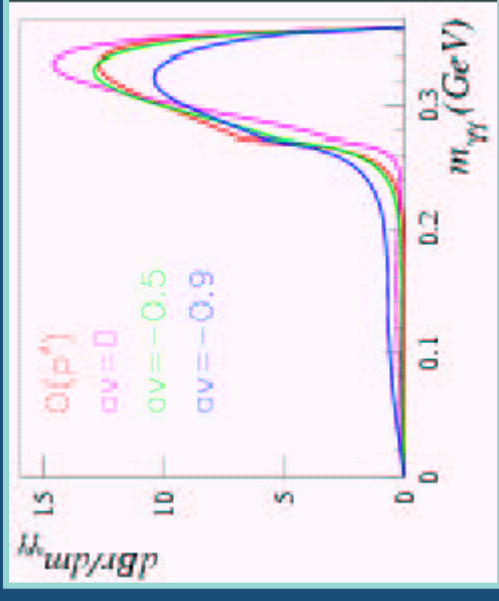


$K_L \rightarrow \pi^0 \gamma \gamma$ measurement

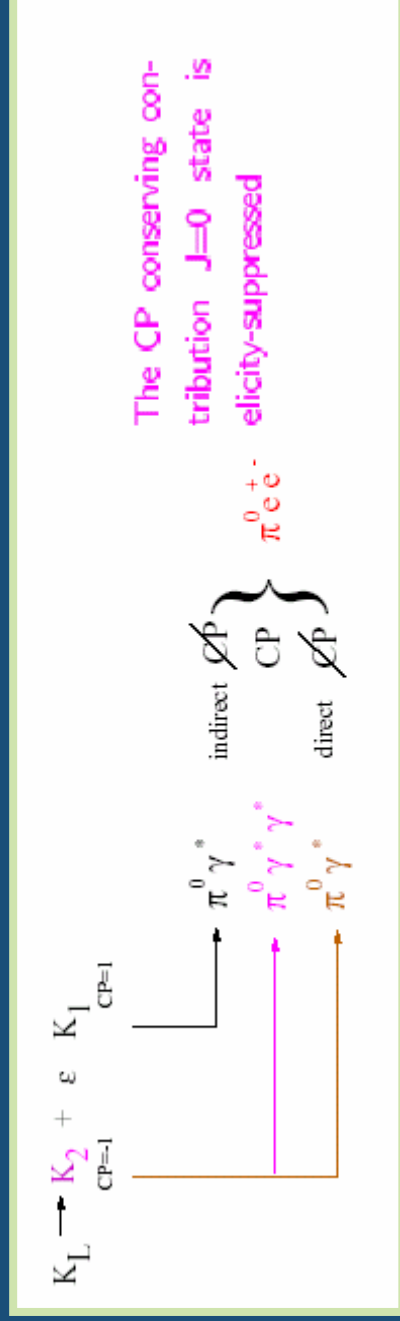
- The a_ν can be extracted from the tail $m_{\gamma\gamma} < 2 m_{\pi^0}$
- The a_ν contribution leads to a CP conserving component to $K_L \rightarrow \pi^0 e^+ e^-$:

$$BR(K_L \rightarrow \pi^0 e^+ e^-)_{CP} = 1.24 \times 10^{-12} \text{ for } a_\nu = -0.7$$

D'Ambrosio, Portoles NP B492 417



- The VMD mechanism could enhance the state $J=2$ for the two photons
 \Rightarrow sizeable CP conserving contribution for $K_L \rightarrow \pi^0 e^+ e^-$

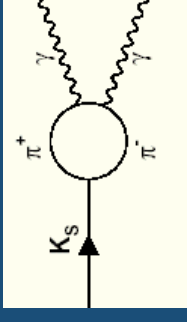


$K_L \rightarrow \pi^0 \gamma \gamma$ measurement

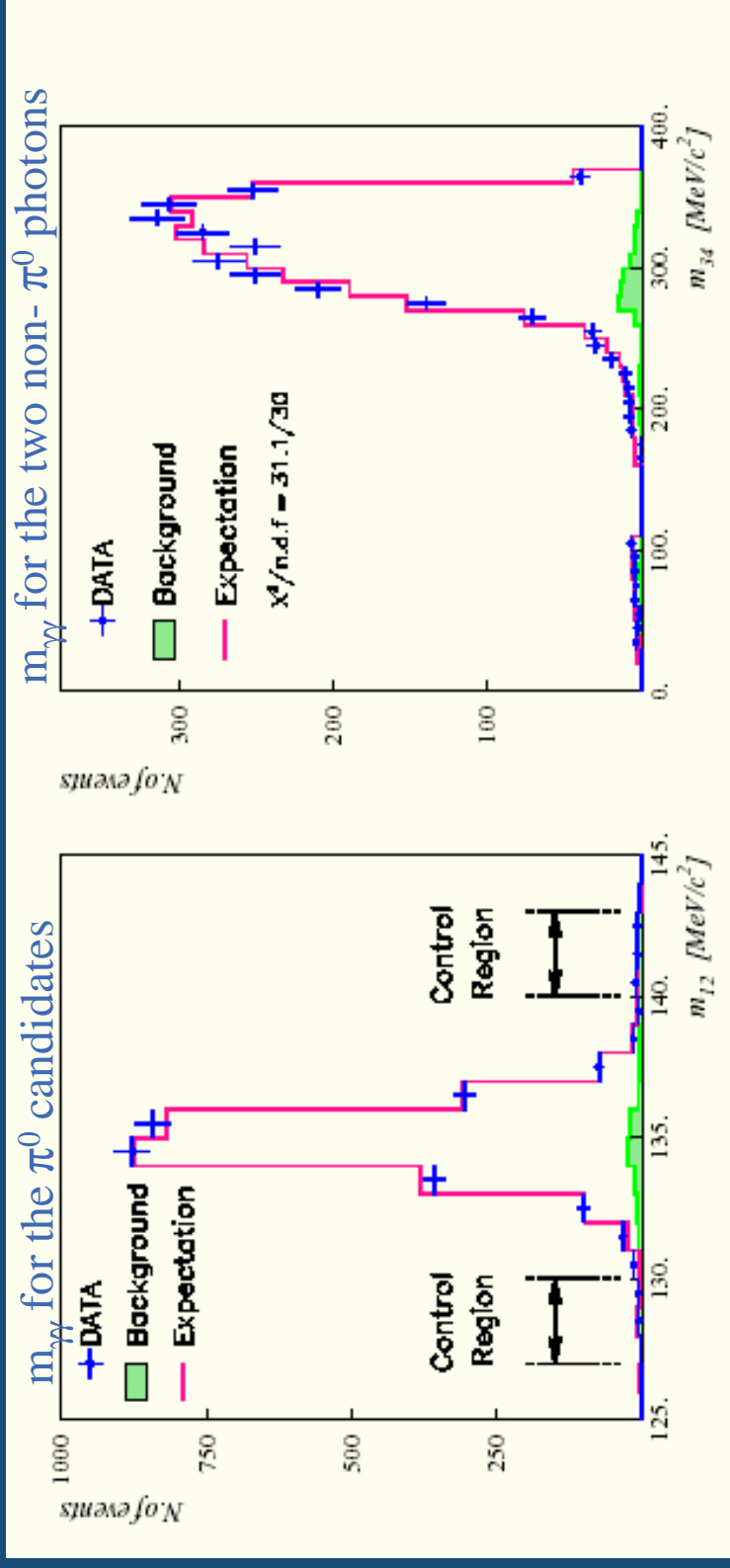
Rare process without a clear signature and a very high background
Data from 1998 and 1999 ϵ'/ϵ runs.

- Normalization channel : $K_L \rightarrow \pi^0 \pi^0 \Rightarrow$ systematic effects cancel
- Background sources :
 - $K_L \rightarrow \pi^0 \pi^0$ with badly reconstructed showers; m_{π^0} mass cut ; residual background evaluated from the tagged $K_S \rightarrow \pi^0 \pi^0$ events (0.16 ± 0.08) %
 - $K_L \rightarrow \pi^0 \pi^0 \pi^0$ with missing or overlapping showers; shower width cut and vertex position cut assuming all events background; residual background evaluated from a MC sample of 3×10^9 events (2.74 ± 0.42) %
 - pile-up events e.g. two decays occurring within 3 ns; quantified from the tails of the R_{cog} distribution from good $\pi^0 \pi^0$ events (0.32 ± 0.21) %

$K_L \rightarrow \pi^0 \gamma \gamma$ measurement



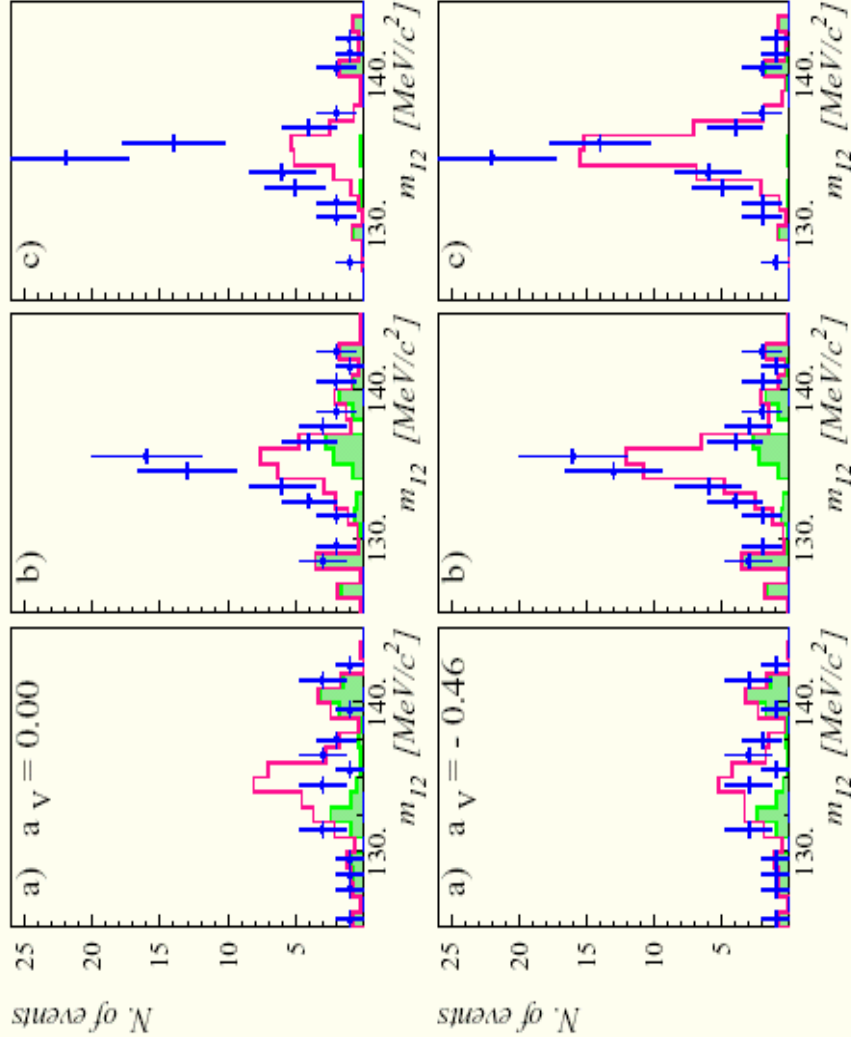
~ 2500 candidates in signal region $0.132 < m_{12} < 0.138$



$$a_v = -0.46 \pm 0.03_{\text{stat}} \pm 0.04_{\text{syst}}$$

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

$K_L \rightarrow \pi^0 \gamma \gamma$ measurement



$m_{34} \in [30-110]$ $m_{34} \in [160-240]$ $m_{34} \in [240-260]$

KTeV results (PRL 83 (99) 917):

$$a_V = -0.72 \pm 0.05_{stat} \pm 0.06_{syst}$$

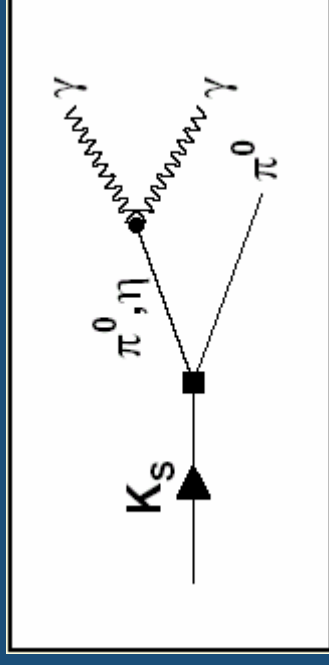
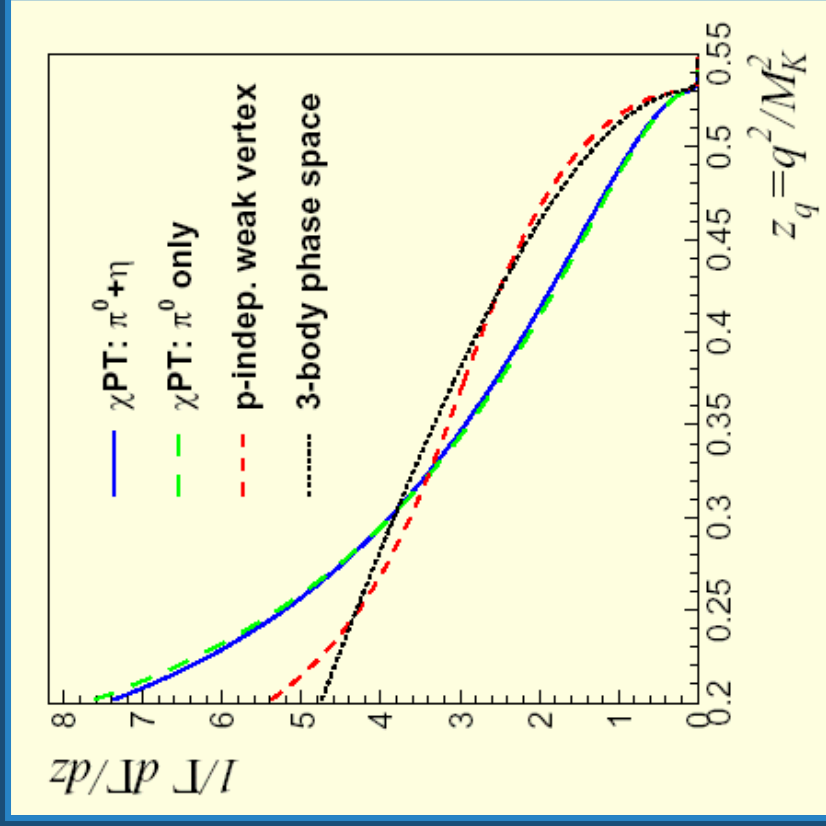
$$BR(K_L \rightarrow \pi^0 \gamma \gamma) = (1.68 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-6}$$

⇒ Implies negligible
CP conserving
amplitude in
 $K_L \rightarrow \pi^0 e^+ e^-$

$K_S \rightarrow \pi^0 \gamma \gamma$ measurement

- Up to now unobserved: NA48 placed recently the best limit to $BR(K_S \rightarrow \pi^0 \gamma \gamma)_{z_q > 0.2} < 3.3 \times 10^{-7}$ at 90% CL from 1999 test-run data.
- ChPT predicts (Ecker, Pich, De Rafael - Phys.LettB 189 (1987) 363):

$$BR(K_S \rightarrow \pi^0 \gamma \gamma)_{z_q > 0.2} = 3.8 \times 10^{-8}$$

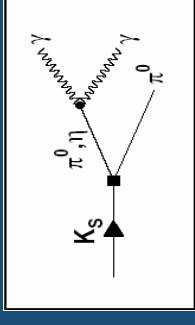


momentum dependence of the weak vertex

Chiral structure of the weak vertex is testable from shape of the $z_q = (m_{34}/m_K)^2$ distribution

$K_S \rightarrow \pi^0 \gamma \gamma$ measurement

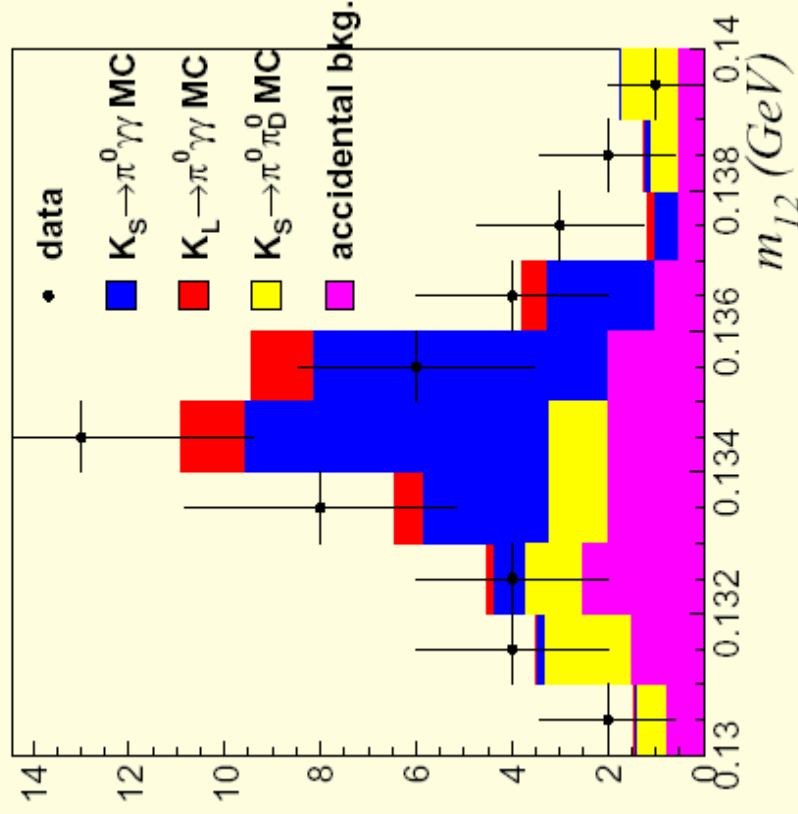
PRELIMINARY



2000 near-target data

Normalized to $K_S \rightarrow \pi^0 \pi^0$ decays

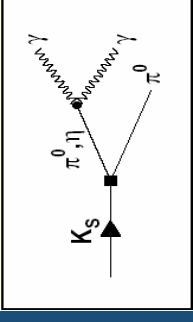
(31.0 ± 5.6) evts in signal region



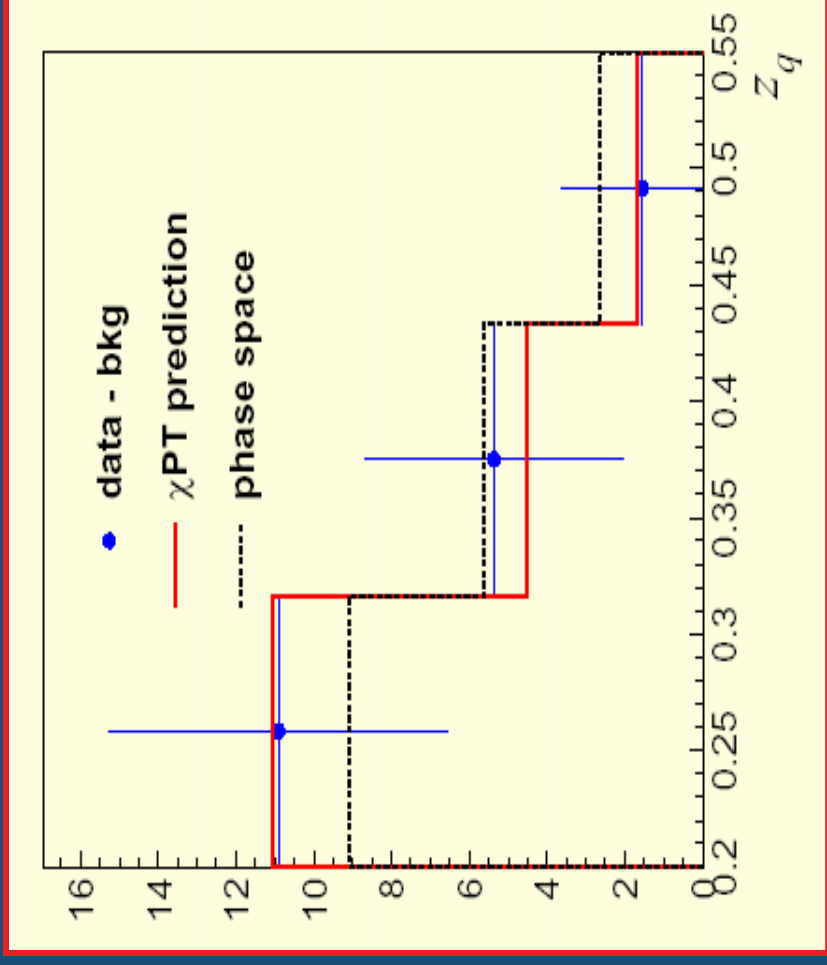
Background & Systematics	Estimated events
Beam activity	7.4 ± 2.4
$K_S \rightarrow \pi^0 \pi^0_D$	2.4 ± 1.2
$K_L \rightarrow \pi^0 \gamma \gamma$	3.8 ± 0.0
Acceptance	± 0.7
	13.6 ± 2.8

$$BR (K_S \rightarrow \pi^0 \gamma \gamma)_{zq>0.2} = (4.9 \pm 1.6_{\text{stat}} \pm 0.8_{\text{syst}}) \times 10^{-8}$$

$K_S \rightarrow \pi^0 \gamma \gamma$ measurement

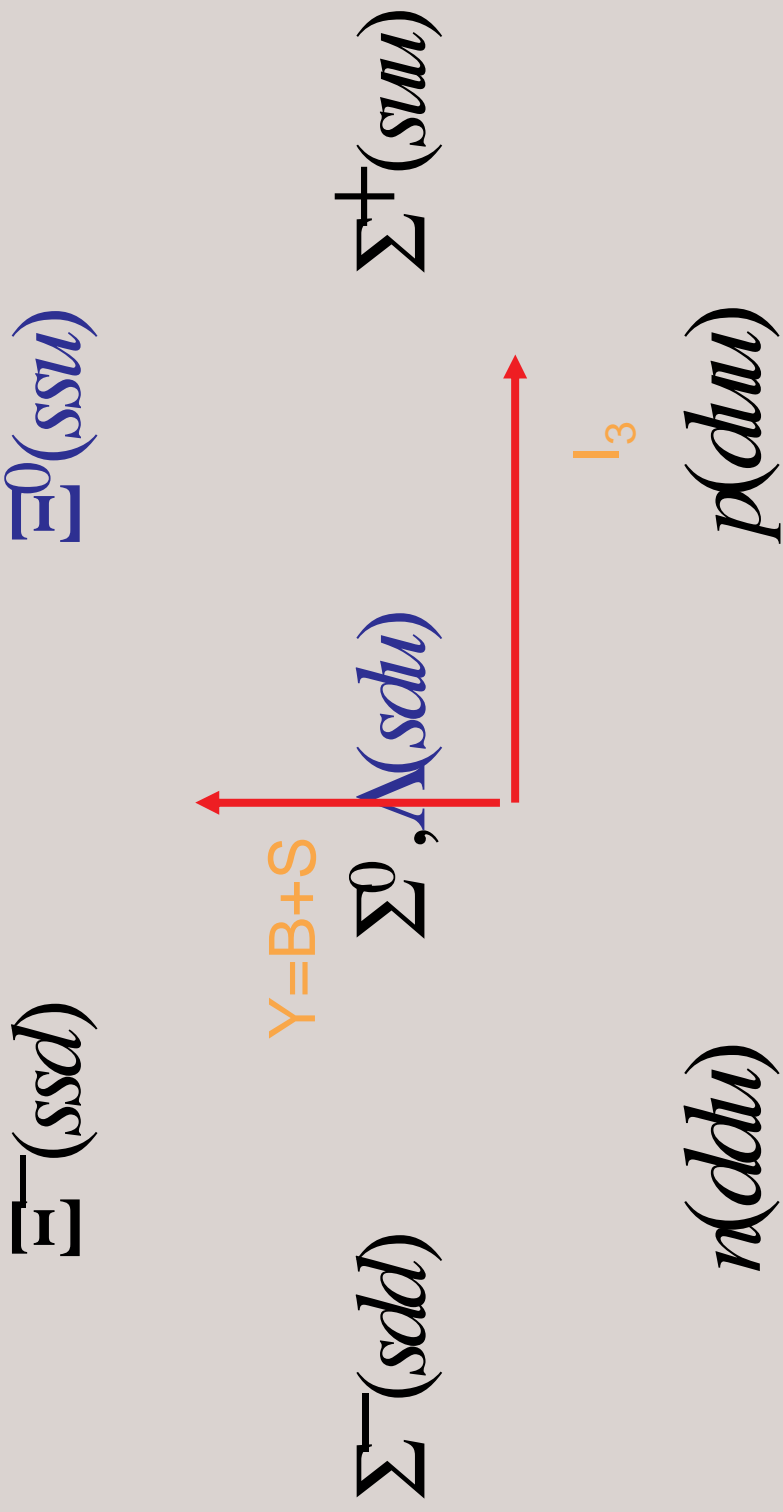


PRELIMINARY

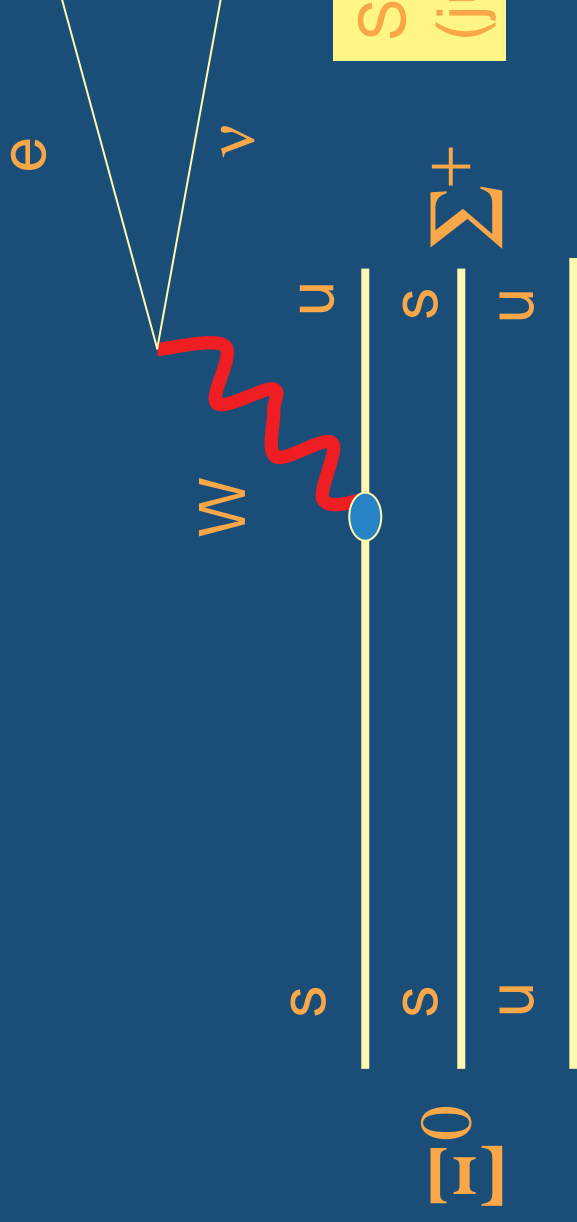


Statistic insufficient to test the chiral structure of the weak vertex

Hyperons



Hyperon Semi-leptonic decays



Same as the neutron
(just replace $d \leftrightarrow s$)

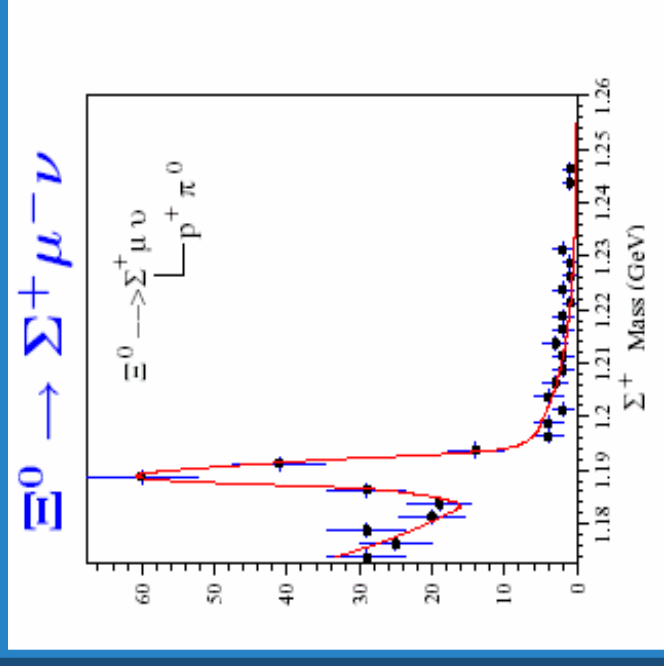
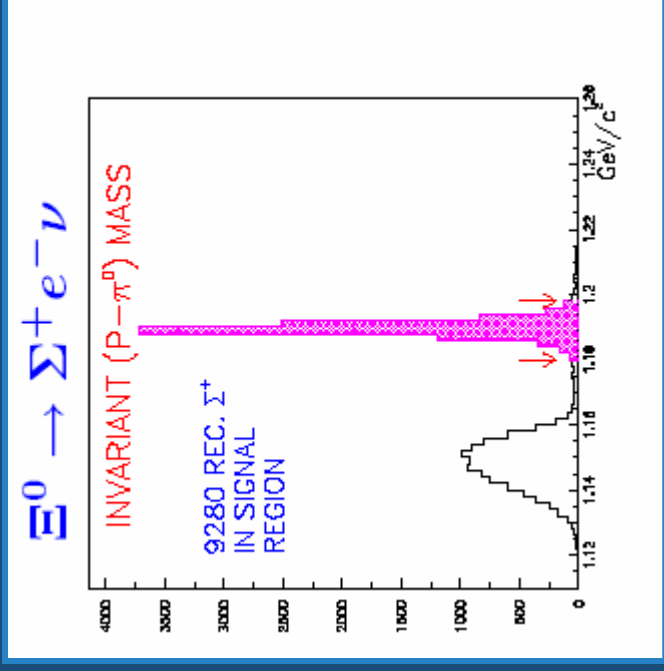
The W probes the weak structure of the hyperon

Rich phenomenology: BR, Angular correlations

Hyperon Semi-Leptonic Decay Rates

Decay	BR	Events	two-body
$\Lambda \rightarrow p \bar{e} \nu$	8.32×10^{-4}	20 k	Y
$\bar{\Sigma} \rightarrow n \bar{e} \nu$	1.02×10^{-3}	4.1 k	Y
$\Sigma \rightarrow \Lambda e \bar{\nu}$	5.73×10^{-5}	1.8 k	N
$\Sigma^+ \rightarrow \Lambda e^+ \nu$	2.0×10^{-5}	21	N
$\Xi^- \rightarrow \Lambda e \bar{\nu}$	5.63×10^{-4}	2868	N
$\Xi^- \rightarrow \Sigma^0 e \bar{\nu}$	8.7×10^{-5}	154	N
$\Xi^0 \rightarrow \Sigma^+ e \bar{\nu}$	2.71×10^{-4}	176	N
$\Xi^- \rightarrow \Xi^0 e \bar{\nu}$	$< 2.3 \times 10^{-3}$	0	N

Ξ^0 beta decays : $\Xi^0 \rightarrow \Sigma^+ l \nu$



Study of the rate and of the form-factors to extract V_{us}

- Run 2002 not optimized for hyperons
- $\Xi^0 \rightarrow \Sigma e \nu$ clean sample: Signal/Back ~ 40 , ~ 9000 events after cuts
- Too early to predict precision on BR and form factor
- **Currently published sample (KTeV)** BR 176 evts, FF 487 evts
- $\Xi^0 \rightarrow \Sigma \mu \nu$ first experimental evidence

Summary

- ➡ Precise measurement of $K_S \rightarrow \gamma\gamma$ decay indicates a significant $O(p^6)$ contribution and provides an input for higher loop calculations of ChPT.
- ➡ Precise measurement of $K_L \rightarrow \pi^0\gamma\gamma$ suggests a small vector meson contribution and a small CPC component in the $K_L \rightarrow \pi^0e^+e^-$
- ➡ Decay $K_S \rightarrow \pi^0\gamma\gamma$ was observed for the first time with BR in agreement with ChPT
- ➡ Interesting results on Hyperon semileptonic and radiative decays are coming soon.
- ➡ NA48 present activity : NA48/2

2003 run: NA48/2

New project called NA48/2 with simultaneous and high intensity **charged kaon beams**.

Main topics:

- Search of direct CP violation by measuring slope asymmetry in $K^{\pm} \rightarrow 3\pi$ decays
- $K^{\pm} e4$ decays
- $K^{\pm} 13$ decays
- Rare K^{\pm} decays

Run time:

Expected $\approx 3 \times 10^{11}$ K^{\pm} decays

