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

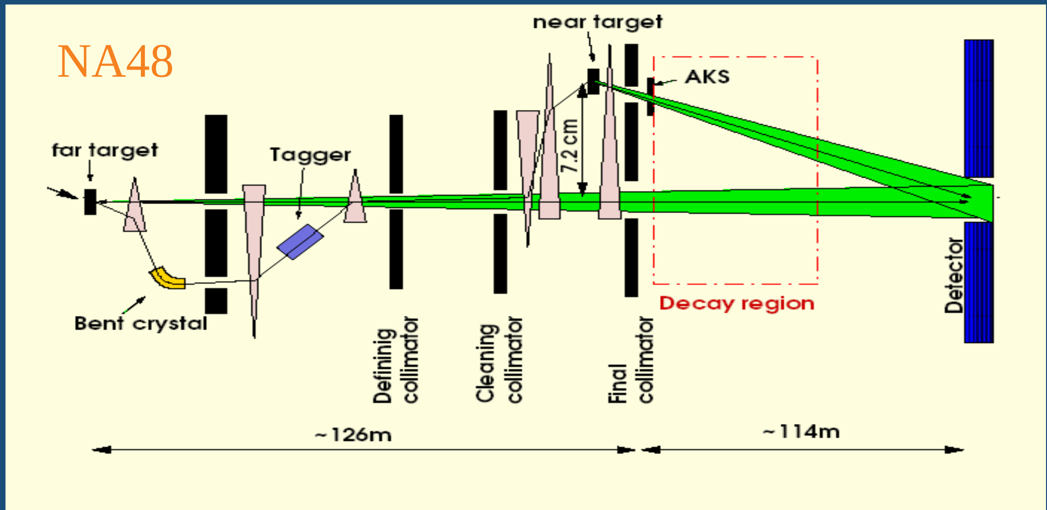
- ChPT is the effective field theory of the Standard Model at low energy (E <1 GeV region of non-perturbative QCD)
- Chiral symmetry of the QCD Lagrangian is spontaneously broken

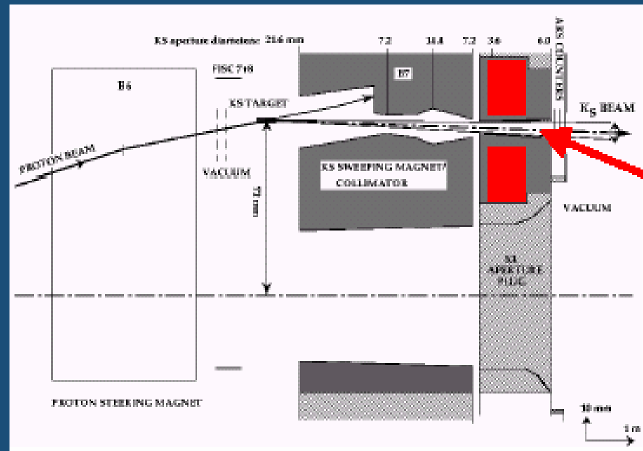
  $\Rightarrow$ degree of freedom of the theory are eight pseudoscalar Goldstone bosons (π , η , K)
- Processes described in perturbative expansion of momenta and masses
- Higher order boson loops are divergent, but compensated by counter-terms with (empirically determinated) effective couplings
- Rare kaon decays eg., $K_{L,S} \rightarrow \pi^0 \gamma\gamma$, $K_{L,S} \rightarrow \gamma\gamma$ are the ideal tool to probe ChPT ($m_K \sim 0.5$ GeV)

NA48/1

Unique opportunity :

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

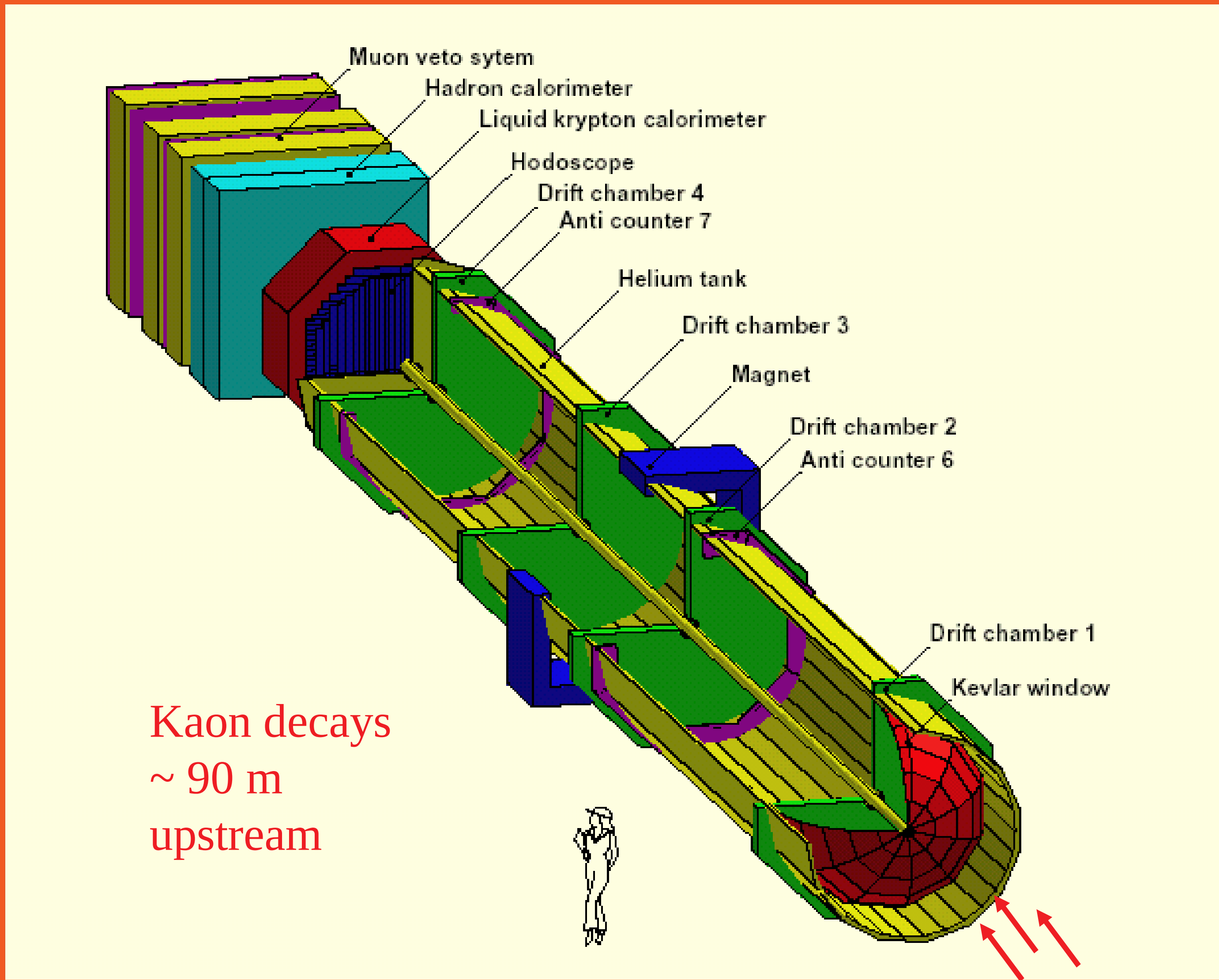




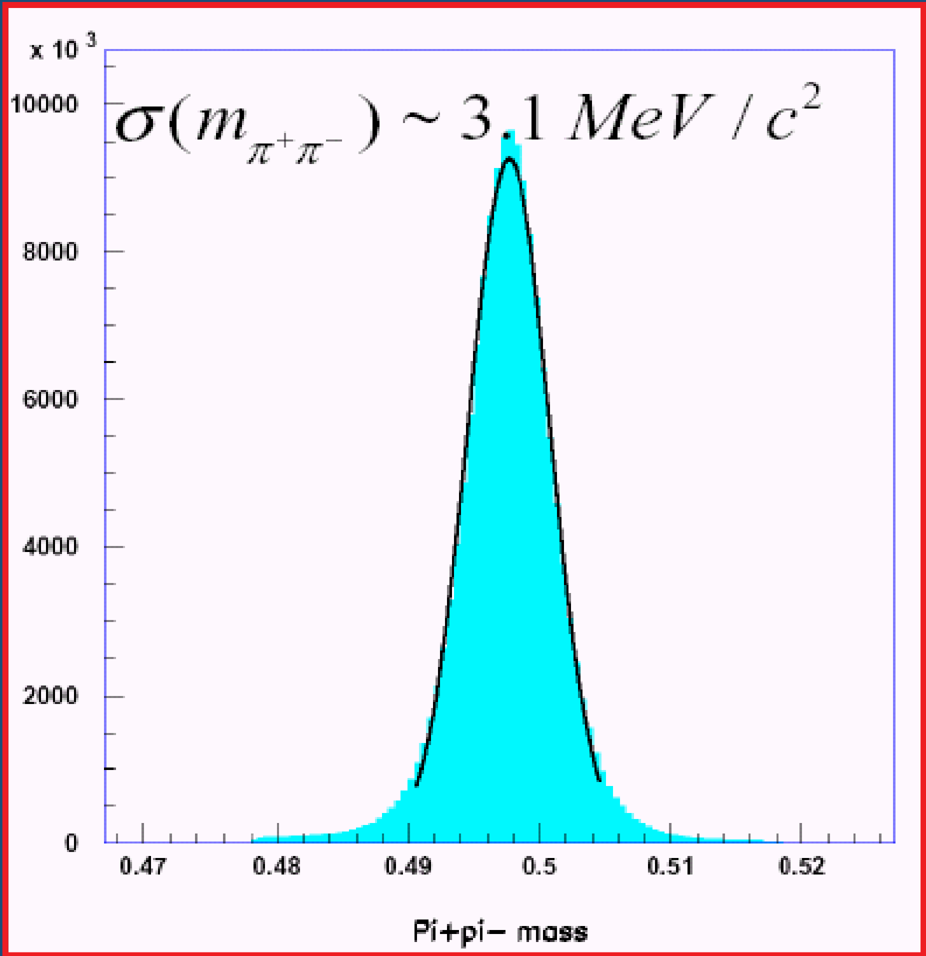
History :

Proposal	Phase I : approved March 2000	Phase II : approved November 2000
December 1999	45 day in 2000 SPS run	Data taken in 2002
3×10^{10} K_S (120 SPS days)	Final states only with γ	

NA48 Detector



Performance of the Specrometer

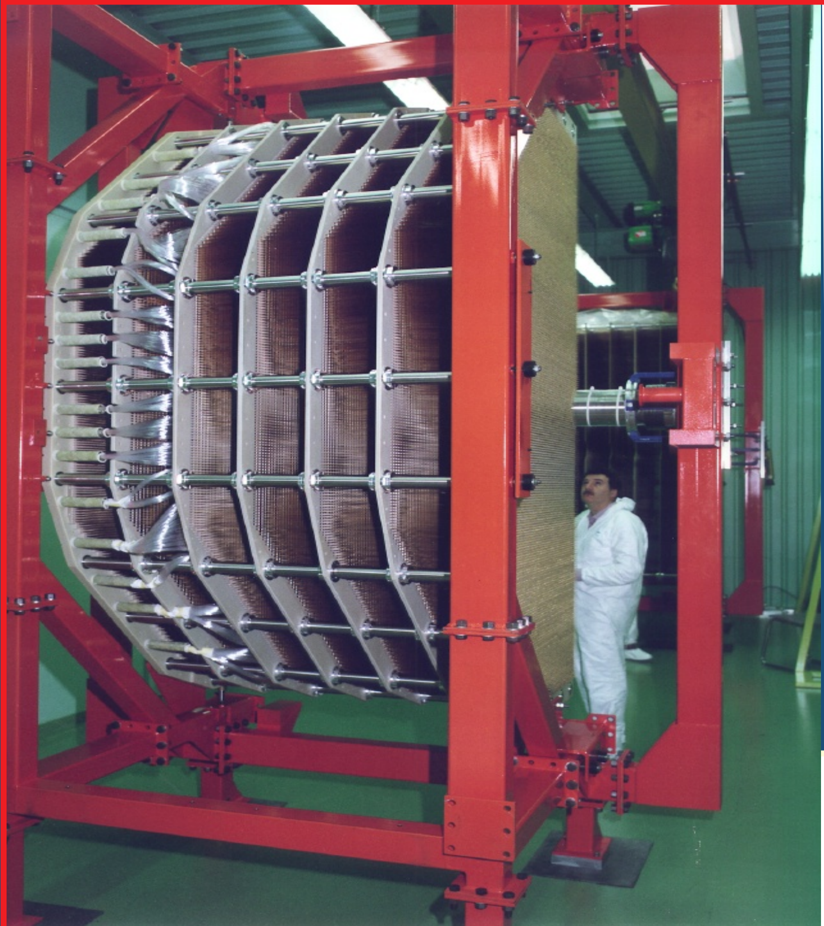


- HV = 2200 V (Ar-Ethane 50-50)
  1. 2300 V during ε′/ε era
  2. 2250 V during 2001 Ks tests

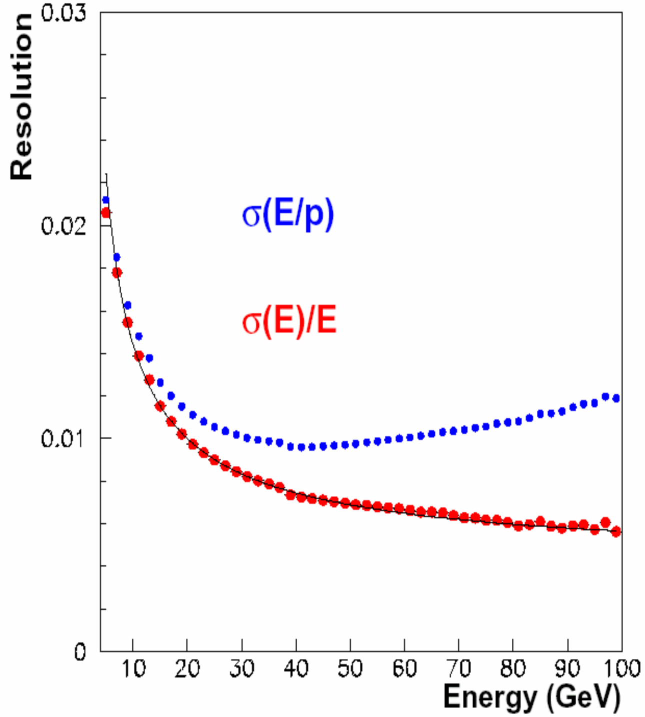
- π+π– mass resolution worsens from 2.5 to 3.1 MeV/c^2

- Good enough for rare decays
- Stable during the run

Liquid Krypton Calorimeter

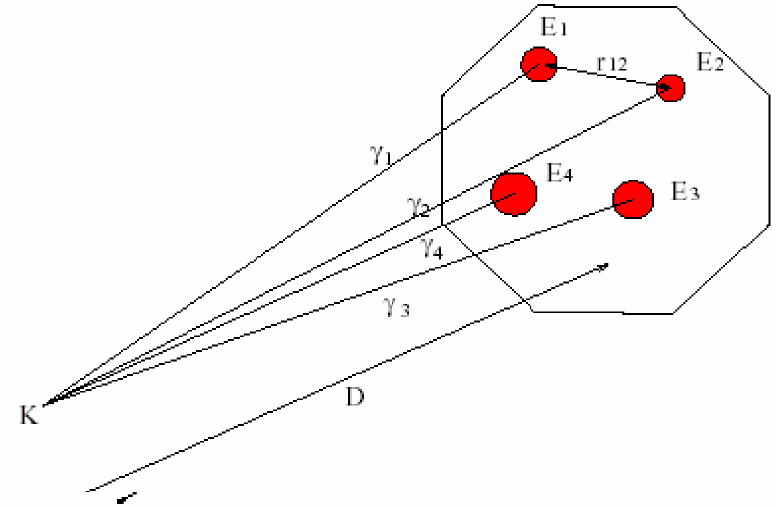


10 m^3 of Lkr (13212 cells)
1.25 m deph (27 X_0)

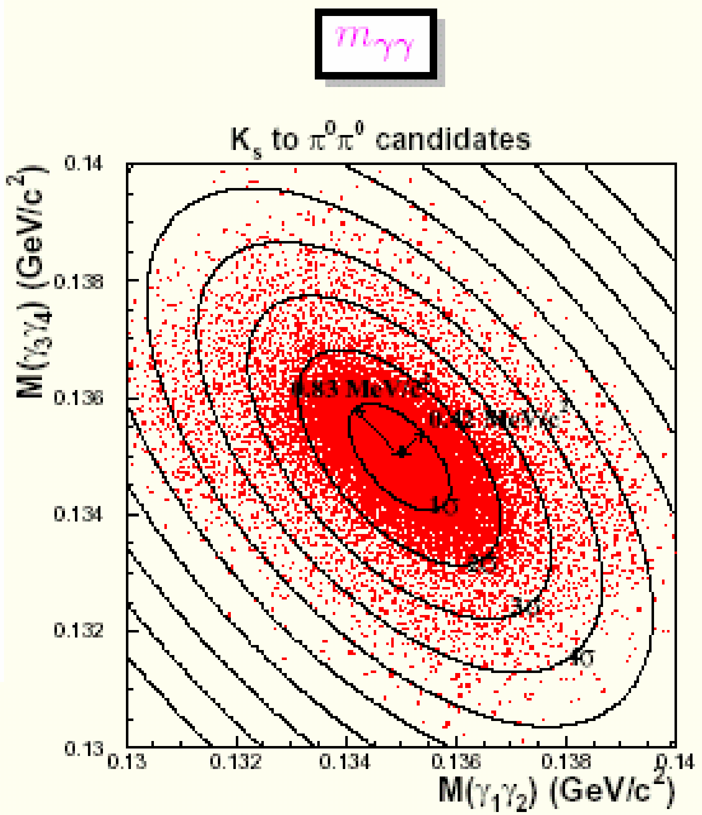


$\sigma(E)/E = 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$

Liquid Krypton Calorimeter



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



➡ LKr calorimeter resolutions:

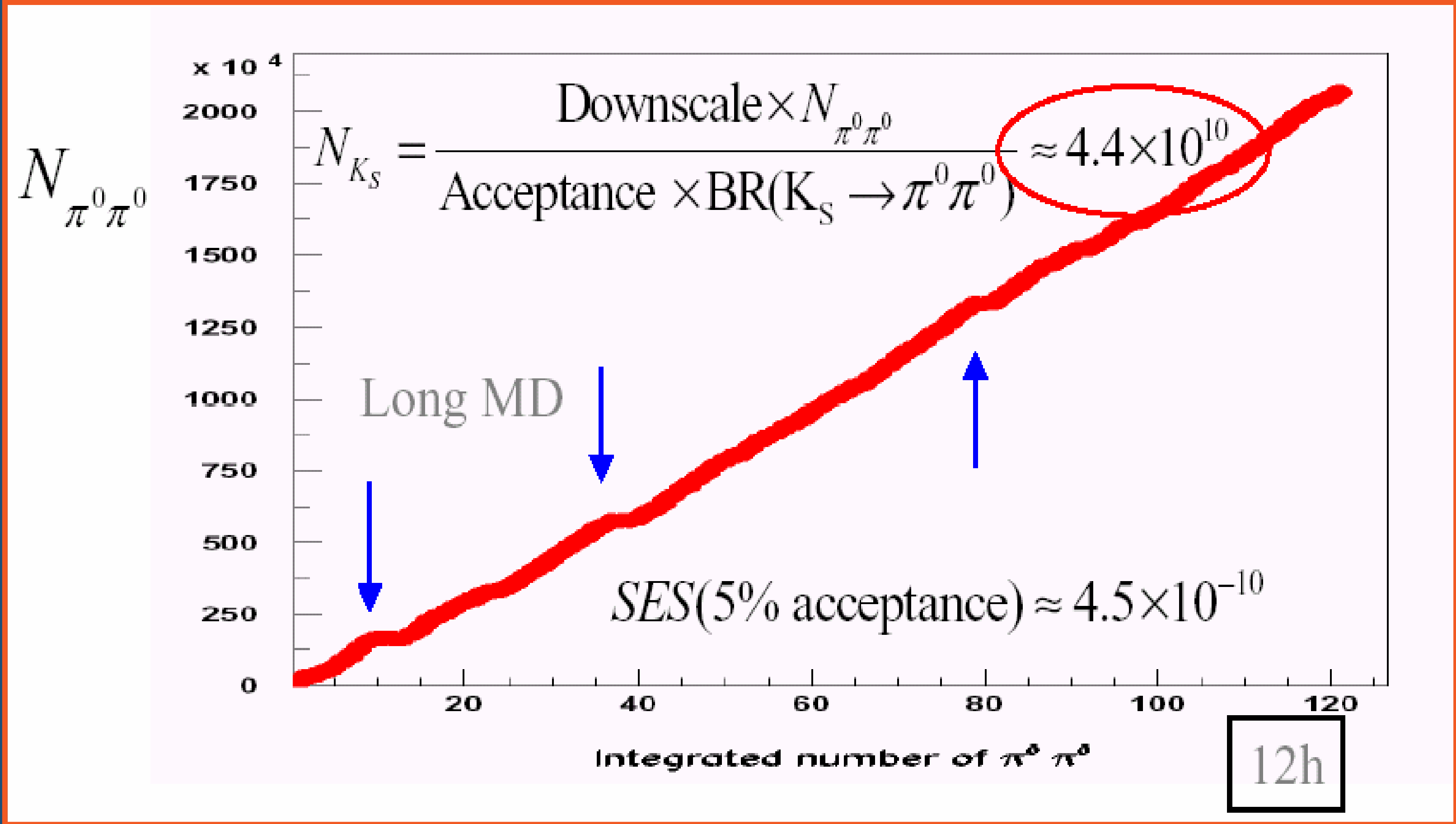
energy $\lesssim 1\%$ for >25 GeV photons

position $\lesssim 1$ mm for >25 GeV photons

time ~ 0.22 ns/$\pi^0\pi^0$

Run 2001

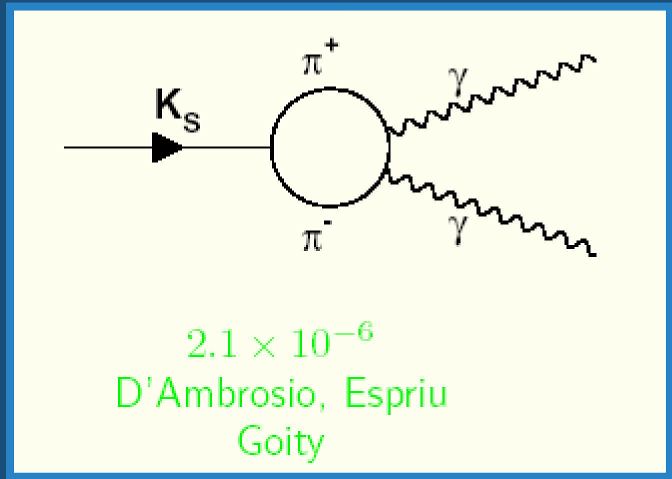
- 89 days of run, improved readout $\Rightarrow$ 50 K events/burst
- Data taken at high intensity (5×10^{10} ppp) from July 18 onward



$K_S \to \gamma\gamma$ decay

- Decays into neutral final states : $O(p^2) = 0$

- $O(p^4)$ unambiguosly predicted by ChPT loop diagram to better than 5% without counter terms

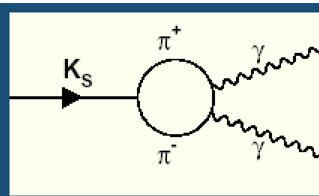


- Old NA48 measurement of $K_S \to \gamma\gamma$ branching ratio based on 2 days of test-run in 1999 with high intensity K_S :

$(2.6 \pm 0.4) \times 10^{-6}$ (PLB 493 2000, 29)

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

$K_S \rightarrow \gamma\gamma$ measurement



⇒ Data from 2000 near-target run, normalized to $K_S \rightarrow \pi^0 \pi^0$ decay rate

⇒ Principal background sources:

$K_S \rightarrow \pi^0 \pi^0$ with only 2 showers in the LKr calorimeter :

→ Reconstructed vertex moves downstream due to missing energy

→ 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

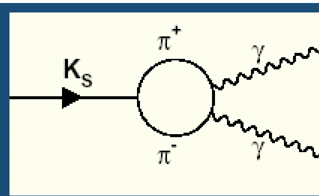
→ Use $K_L \rightarrow \pi^0 \pi^0 \pi^0$ to estimate the K_L flux

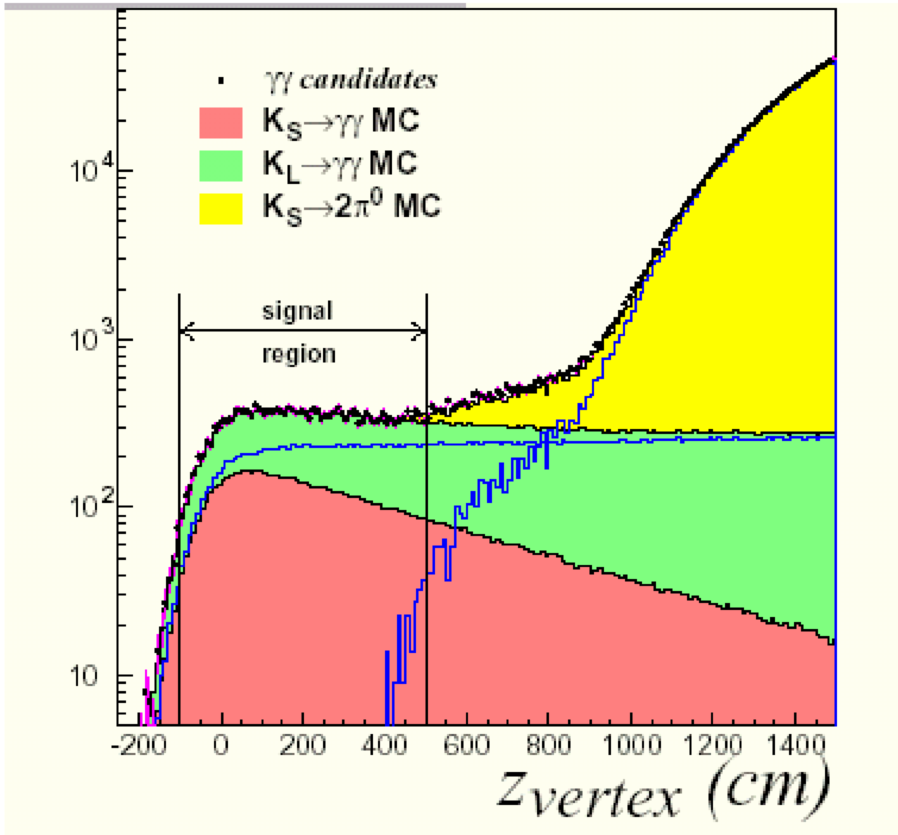
→ use 2000 far-target run to measure $\Gamma(K_L \rightarrow \gamma\gamma) / \Gamma(K_L \rightarrow \pi^0 \pi^0 \pi^0)$

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

This result has an accuracy 4 times better than the current PDG value:
$(2.77 \pm 0.08) \times 10^{-3}$

$K_S \to \gamma\gamma$ measurement





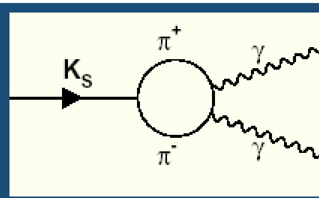
- Background from $\pi^0\pi^0$ subtracted using MC normalized to the flux obtained from fully reconstructed $\pi^0\pi^0$ events $\Rightarrow$ Background : $(0.8 \pm 0.2)\%$

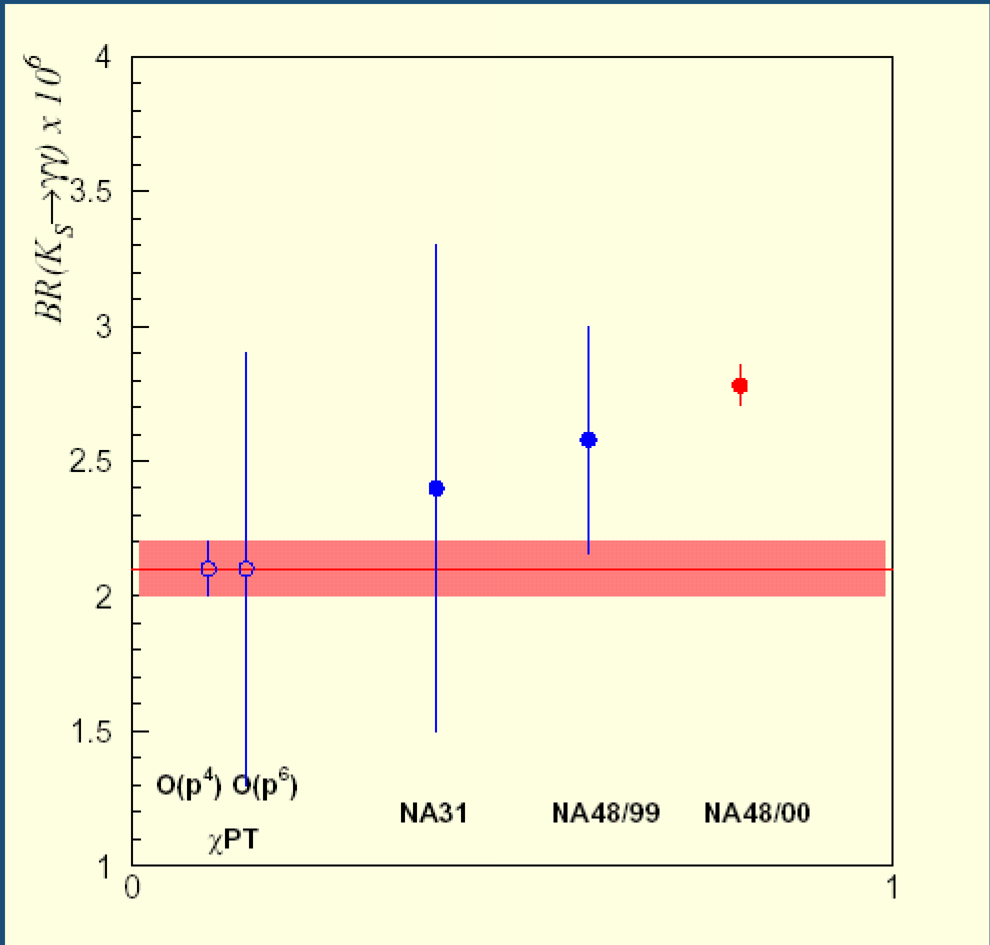
- Binned maximum likelihood fits to measure $\Gamma(K_L \to \gamma\gamma) / \Gamma(K_L \to \pi^0\pi^0\pi^0)$ and the $K_S \to \gamma\gamma$ branching ratio in 10 kaon energy and 6 vertex position bins

$BR(K_S \to \gamma\gamma) = (2.78 \pm 0.06_{stat} \pm 0.03_{syst} \pm 0.02_{ext}) \times 10^{-6}$

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

$K_S \to \gamma\gamma$ measurement

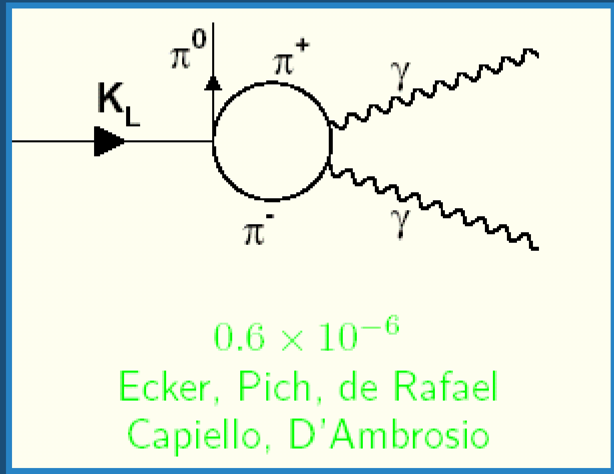


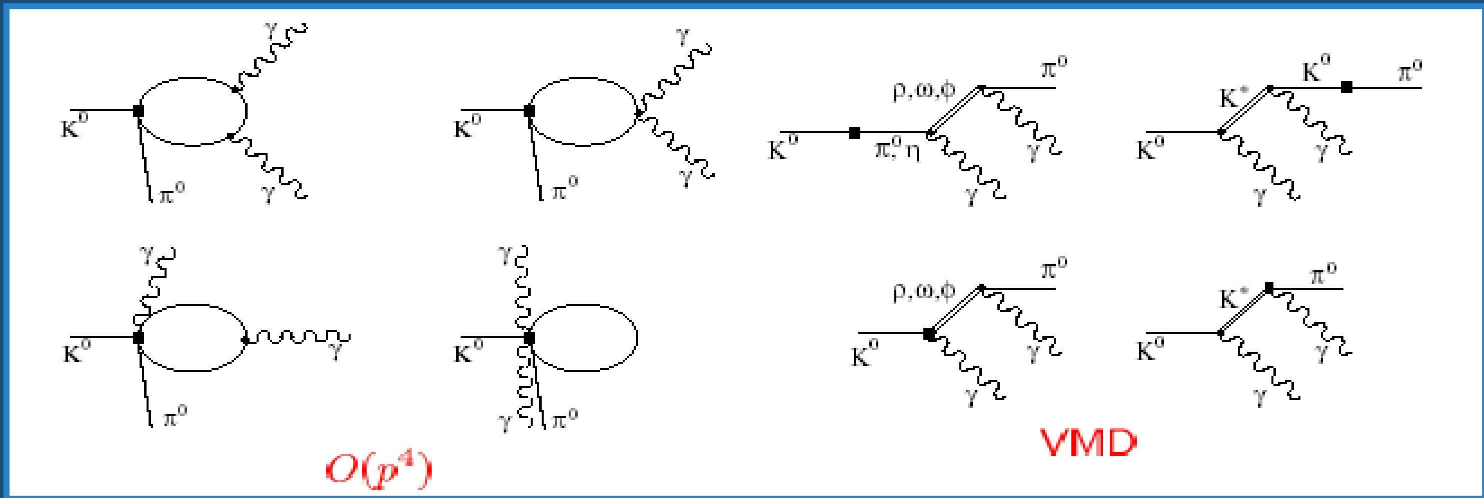


- The new result has an accuracy better than 3% and differs by 30% from $O(p^4)$ prediction of ChPT
- Indication of a large $O(p^6)$ contribution
- Compatible with previous measurements

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

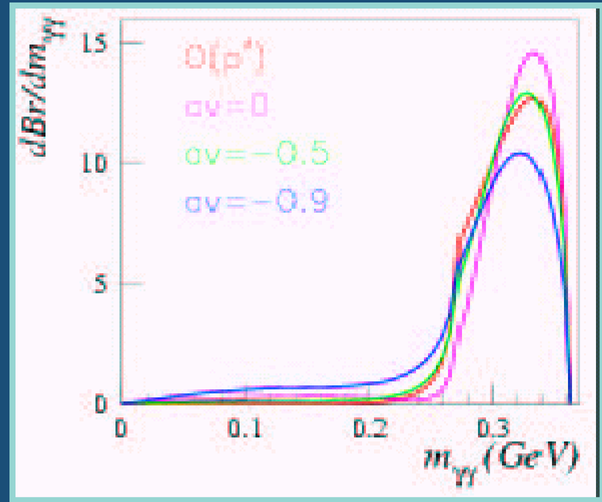
- Only 1/3 of the measured $K_L \rightarrow \pi^0 \gamma\gamma$ rate is predicted by $O(p^4)$.
- The rate can be reproduced at $O(p^6)$ including vector mesons exchange. The VMD contribution is parametrised by a_V, which has to be experimentally determinated.





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

- The a_v can be extracted from the tail $m_{\gamma\gamma} < 2 m_{\pi 0}$



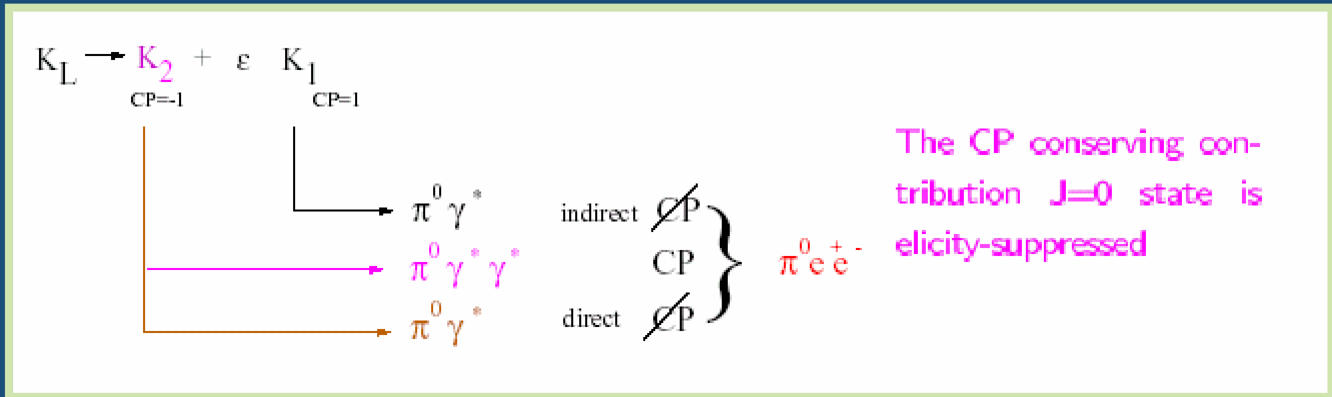
- The a_v contribution leads to a CP conserving component to $K_L \to \pi^0$ e+ e– :

BR($K_L \to \pi^0$ e+ e–)$_{CPC}$ = 1.24×10^{-12} for a_v = - 0.7

D'Ambrosio, Portoles NP B492 417

- The VMD mechanism could enhance the state J=2 for the two photons

⇨ sizeable CP conserving contribution for $K_L \to \pi^0$ e+ e–



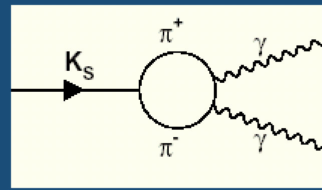
$K_L \rightarrow \pi^0 \gamma \gamma$ measurement

Rare process without a clear signature and a very high background

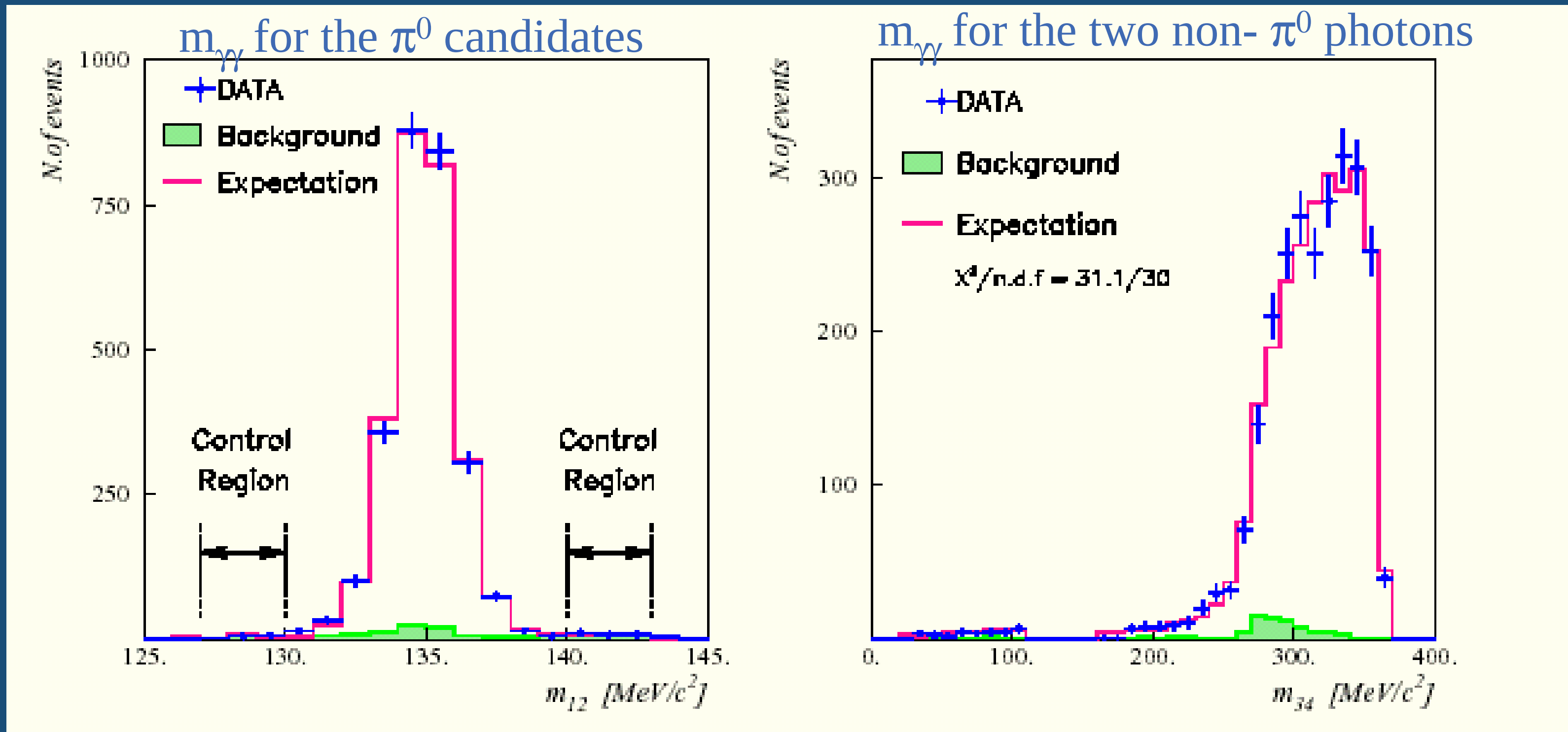
Data from 1998 and 1999 ε'/ε runs.

- 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 occuring 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



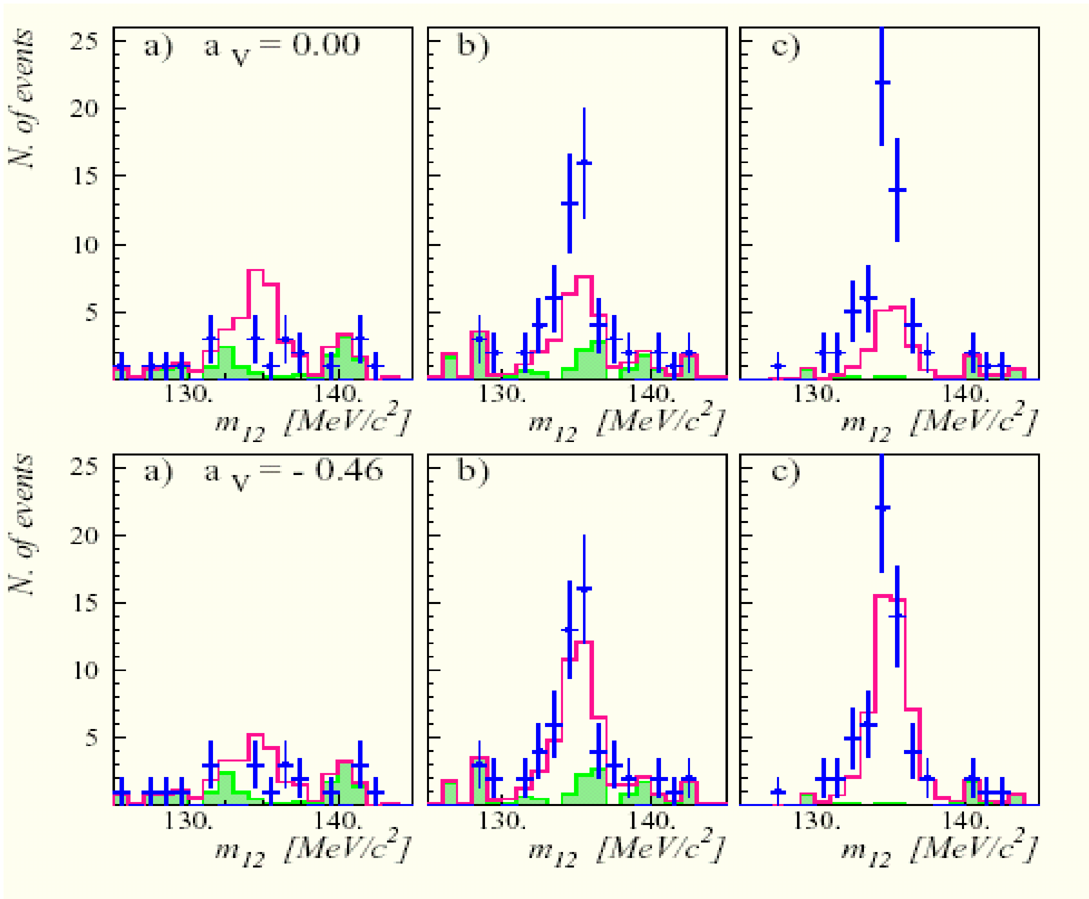
~ 2500 candidates in signal region $0.132 < m_{12} < 0.138$



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

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

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



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

KTeV results (PRL 83 (99) 917):

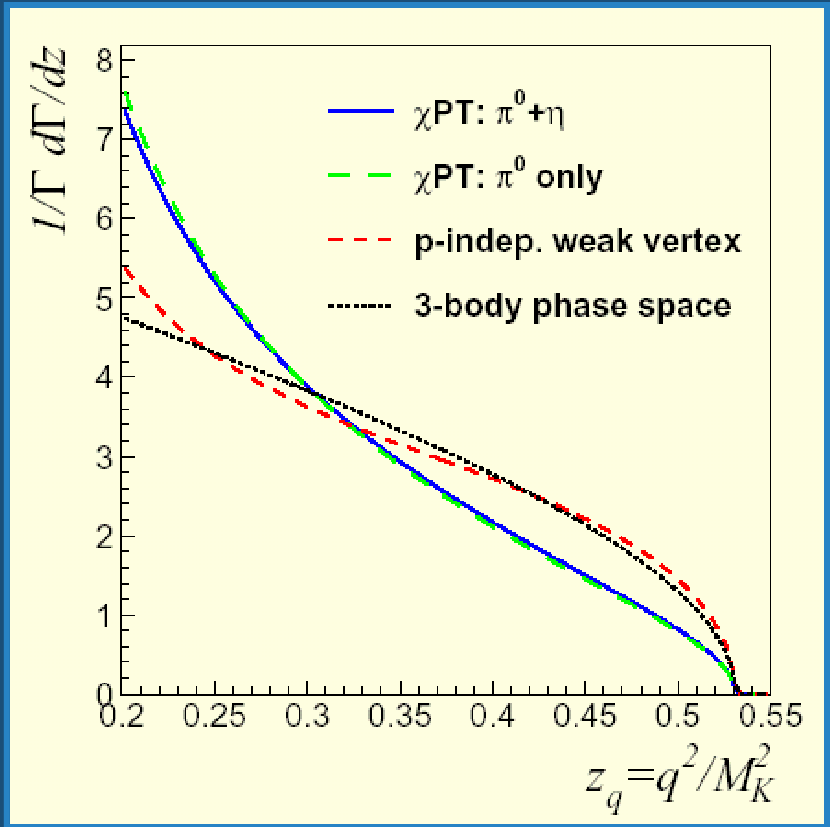
$$a_v = -0.72 \pm 0.05_{stat} \pm 0.06_{syst}$$
$$BR(K_L \to \pi^0\gamma\gamma) = (1.68 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-6}$$

$\Rightarrow$ Implies negligible CP conserving amplitude in $K_L \to \pi^0 e+ e-$

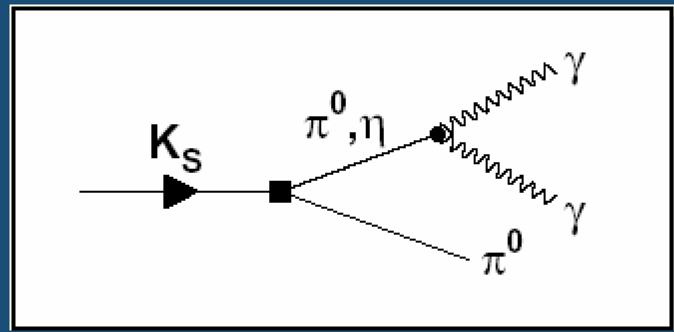
$K_S \to \pi^0\gamma\gamma$ measurement

- Up to now unobserved: NA48 placed recently the best limit to $BR(K_S \to \pi^0\gamma\gamma)_{zq > 0.2} < 3.3\times10^{-7}$ at 90% CL from 1999 test-run data.

- ChPT predicts (Ecker, Pich, De Rafael - Phys.LettB 189 (1987) 363):



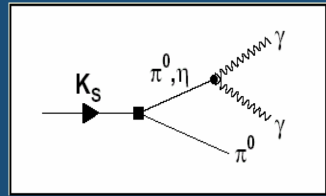
$BR(K_S \to \pi^0\gamma\gamma)_{zq > 0.2} = 3.8\times10^{-8}$



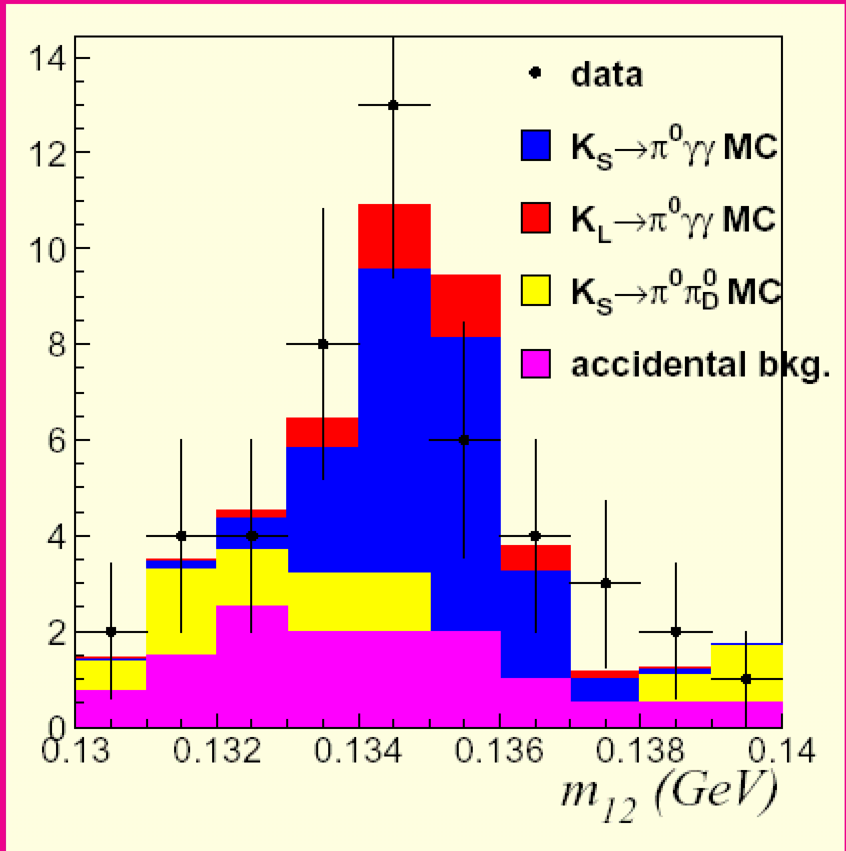
- momentum dependence of the weak vertex

→ 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

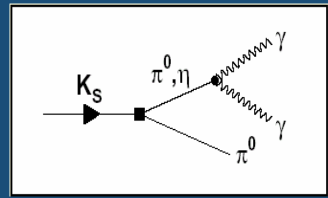
Normalized to $K_S \rightarrow \pi^0\pi^0$ decays

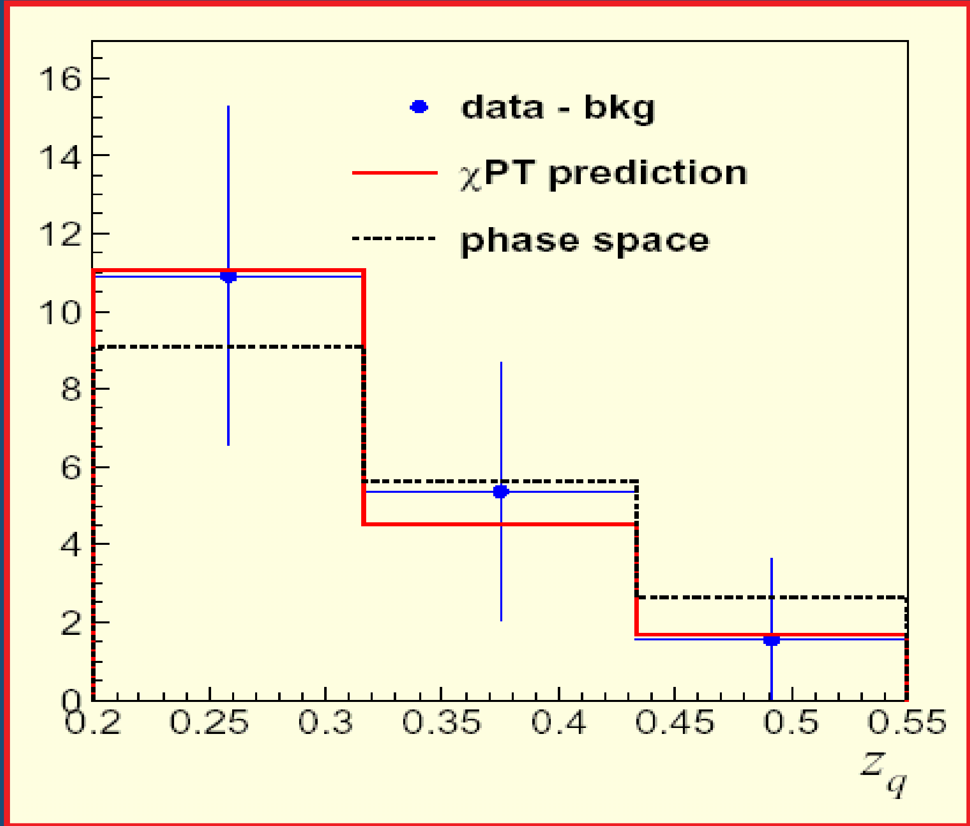
(31.0 ± 5.6) evts in signal region

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

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

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

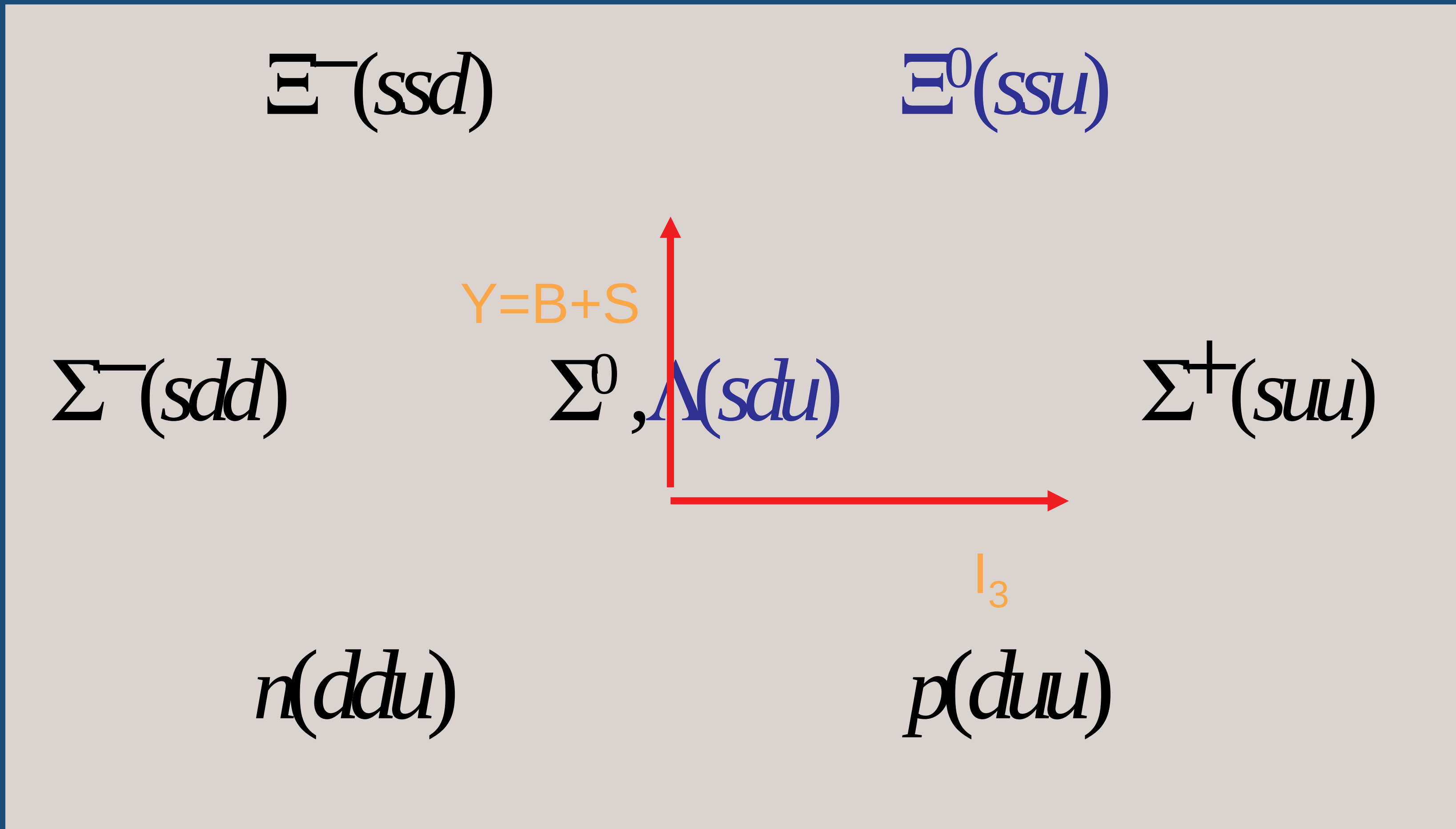




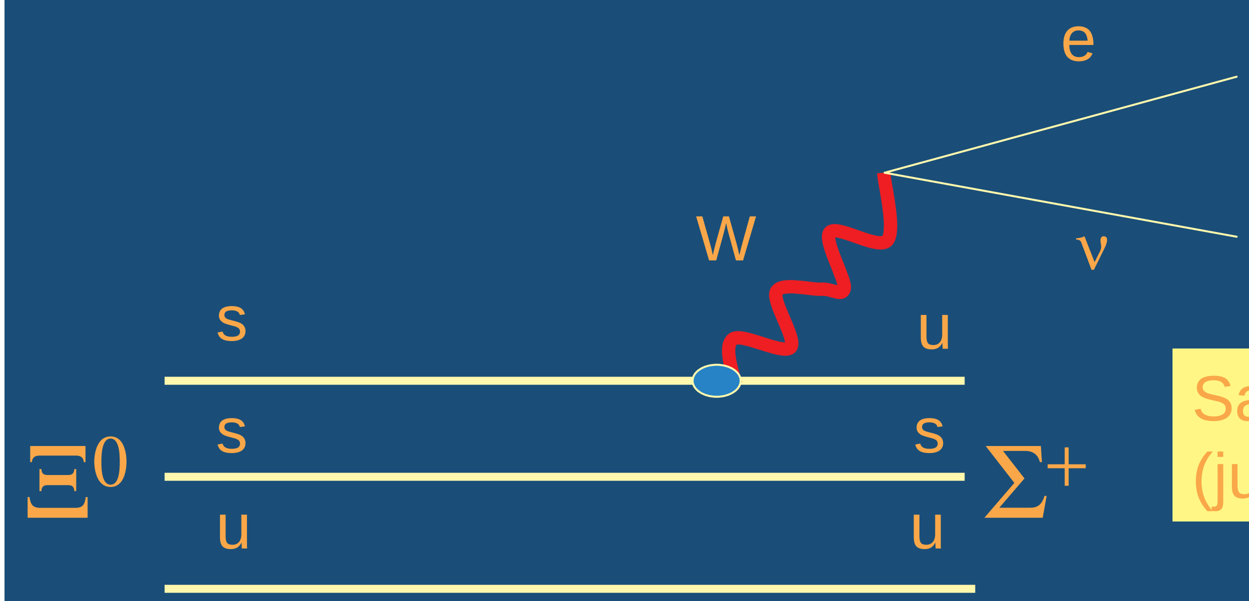
PRELIMINARY

Statistic insufficient to test the chiral structure of the weak vertex

Hyperons


$\Xi^-(ssd)$
$\Xi^0(ssu)$
Y=B+S
$\Sigma^-(sdd)$
$\Sigma^0, \Lambda(sdu)$
$\Sigma^+(suu)$
I_3
$n(ddu)$
$p(duu)$

Hyperon Semi-leptonic decays



Same as the neutron
(just replace d ⇔ s)

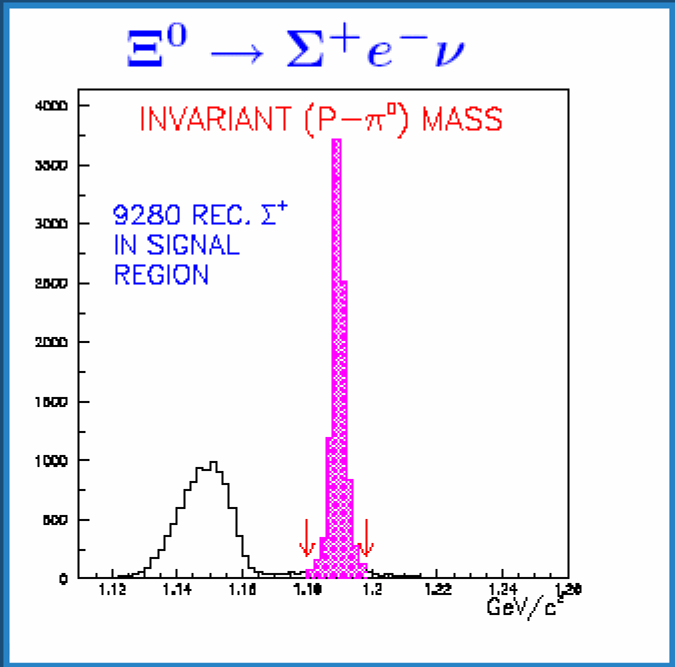
The W probes the weak structure of the hyperon

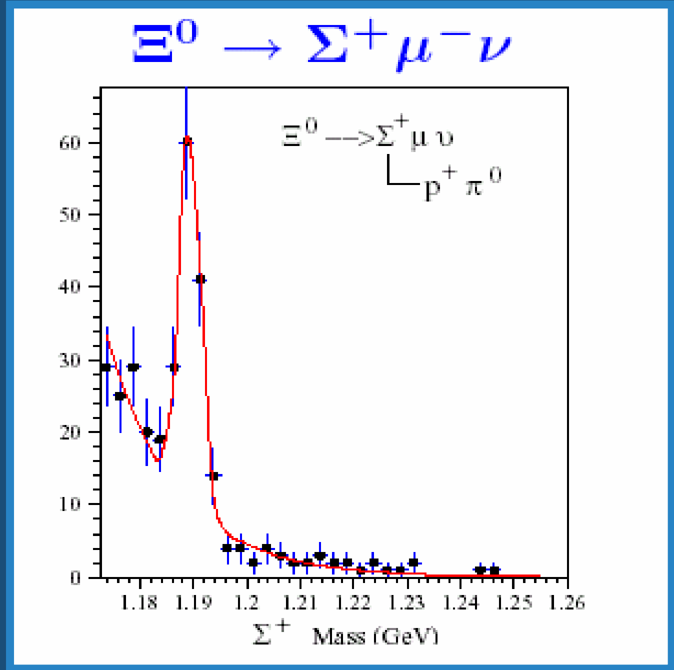
Rich phenomenology: BR, Angular correlations

Hyperon Semi-Leptonic Decay Rates

Decay	BR	Events	two-body
$\Lambda \rightarrow p\bar{e}\,\nu$	8.32×10^{-4}	20 k	Y
$\Sigma^- \rightarrow n e^-\nu$	1.02×10^{-3}	4.1 k	Y
$\Sigma^- \rightarrow \Lambda e^-\nu$	5.73×10^{-5}	1.8 k	N
$\Sigma^+ \rightarrow \Lambda e^+\nu$	2.0×10^{-5}	21	N
$\Xi^- \rightarrow \Lambda e^-\nu$	5.63×10^{-4}	2868	N
$\Xi^- \rightarrow \Sigma^0 e^-\nu$	8.7×10^{-5}	154	N
$\Xi^0 \rightarrow \Sigma^+ e^-\nu$	2.71×10^{-4}	176	N
$\Xi^- \rightarrow \Xi^0 e^-\nu$	$<2.3\times10^{-3}$	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 $K_S \to \gamma\gamma$ decay indicates a significant $O(p^6)$ contribution and provides an input for higher loop calculations of ChPT.
- Precise measurement of $K_L \to \pi^0\gamma\gamma$ suggests a small vector meson contribution and a small CPC component in the $K_L \to \pi^0 e^+e^-$
- Decay $K_S \to \pi^0\gamma\gamma$ 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
- $K^{\pm}$ l3 decays
- Rare $K^{\pm}$ decays

Run time:

Expected $\approx 3\times10^{11}$ $K^{\pm}$ decays