NA48/1: High sensitivity study of K_S and neutral hyperons: Status Report*

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Cambridge, CERN, Chicago, Dubna, Edinburgh,Northwestern, Ferrara, Florence, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Turin, Warsaw, Wien

*** Including some recent NA48 results**

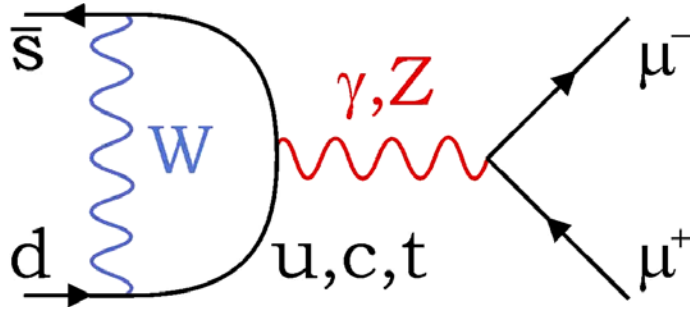
Introduction

- NA48/1 has collected data in 2000 and 2002
  - 2000: Phase I (no drift chambers)
  - 2002: Phase II
- The status report focuses on selected results that have appeared since October 2003
  - Rare Kaon Decays:
    - BR($K_S \to \pi^0 \mu^+ \mu^-$)
    - Implications
  - "Frequent" Kaon decays:
    - BR($K_L \to \pi e \nu$) $\to |V_{us}|$
    - BR($K_L \to \pi^0 \pi^0 \pi^0$)
  - Hyperon decays:
    - $\Xi^0 \to \Lambda \gamma$ decay asymmetry
    - BR($\Xi^0 \to \Sigma^+ e^- \nu$) (Preliminary)
- Outlook:
  - NA48/1 Phase III?

Rare Kaon Decays

$K^0_L \to \pi^0 e^+ e^-$ and $K^0_L \to \pi^0 \mu^+ \mu^-$

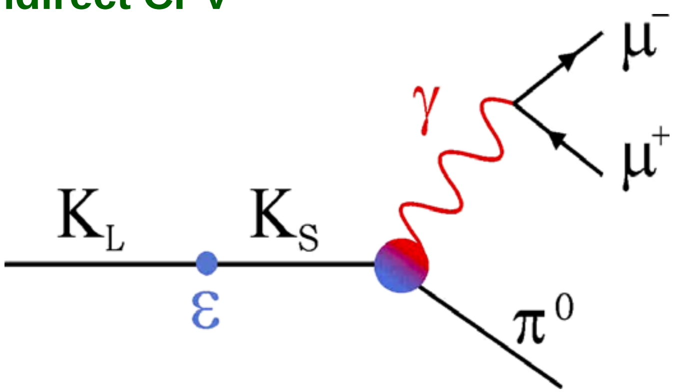
Study Direct CP-Violation

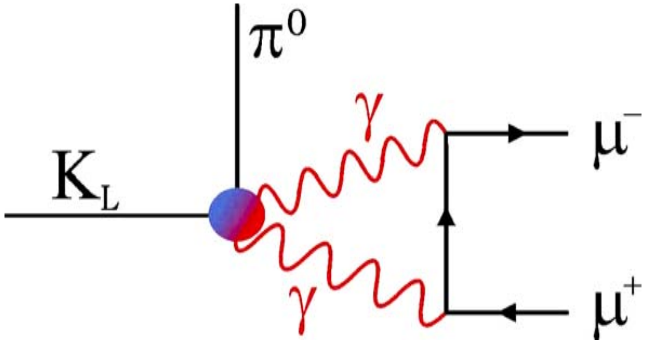


Direct CPV

- NA48/1 has measured the Indirect CP-Violating Contribution for both modes
- S-L Constructive Interference preferred
- CP-Conserving Contributions are negligible

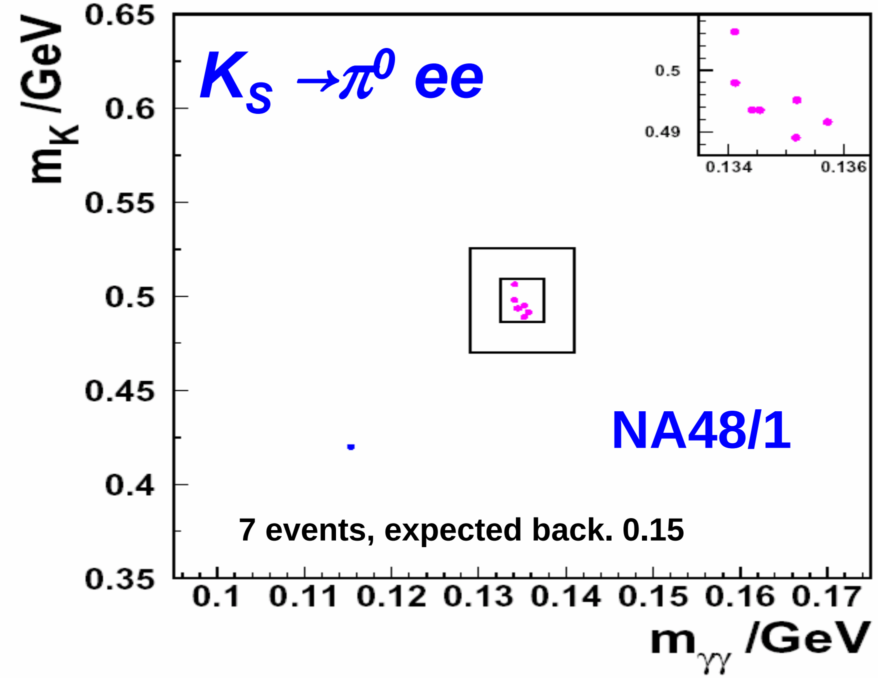
Indirect CPV

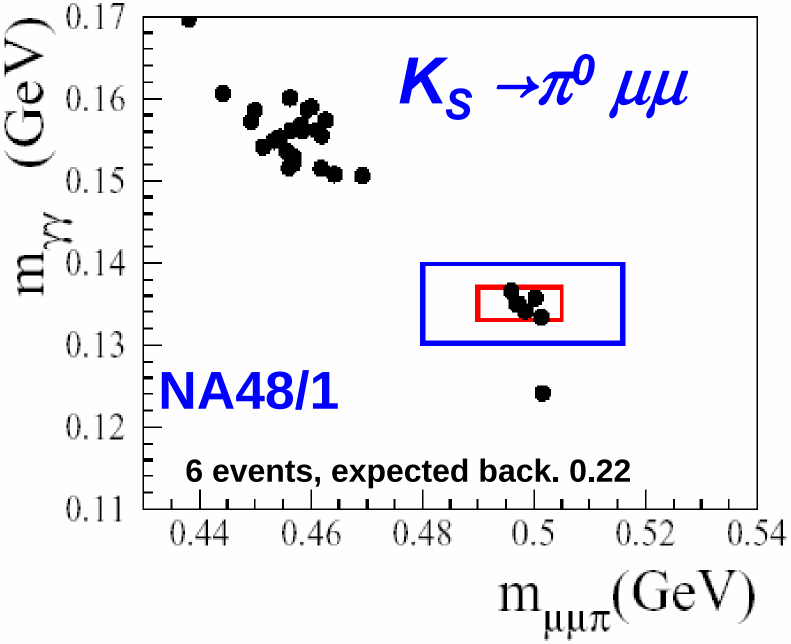




CPC

$K^0_S \to \pi^0 e^+e^-$ and $K^0_S \to \pi^0 \mu^+\mu^-$





$BR(K_S \to \pi^0 ee) \times 10^{-9}$ =
$5.8\ ^{+2.8}_{-2.3}(stat) \pm\ 0.8(syst)$

$|a_s| = 1.06^{+0.26}_{-0.21}\ (stat) \pm 0.07\ (syst)$
PLB 576 (2003)

$BR(K_S \to \pi^0 \mu\mu) \times 10^{-9}$ =
$2.9\ ^{+1.4}_{-1.2}(stat) \pm\ 0.2(syst)$

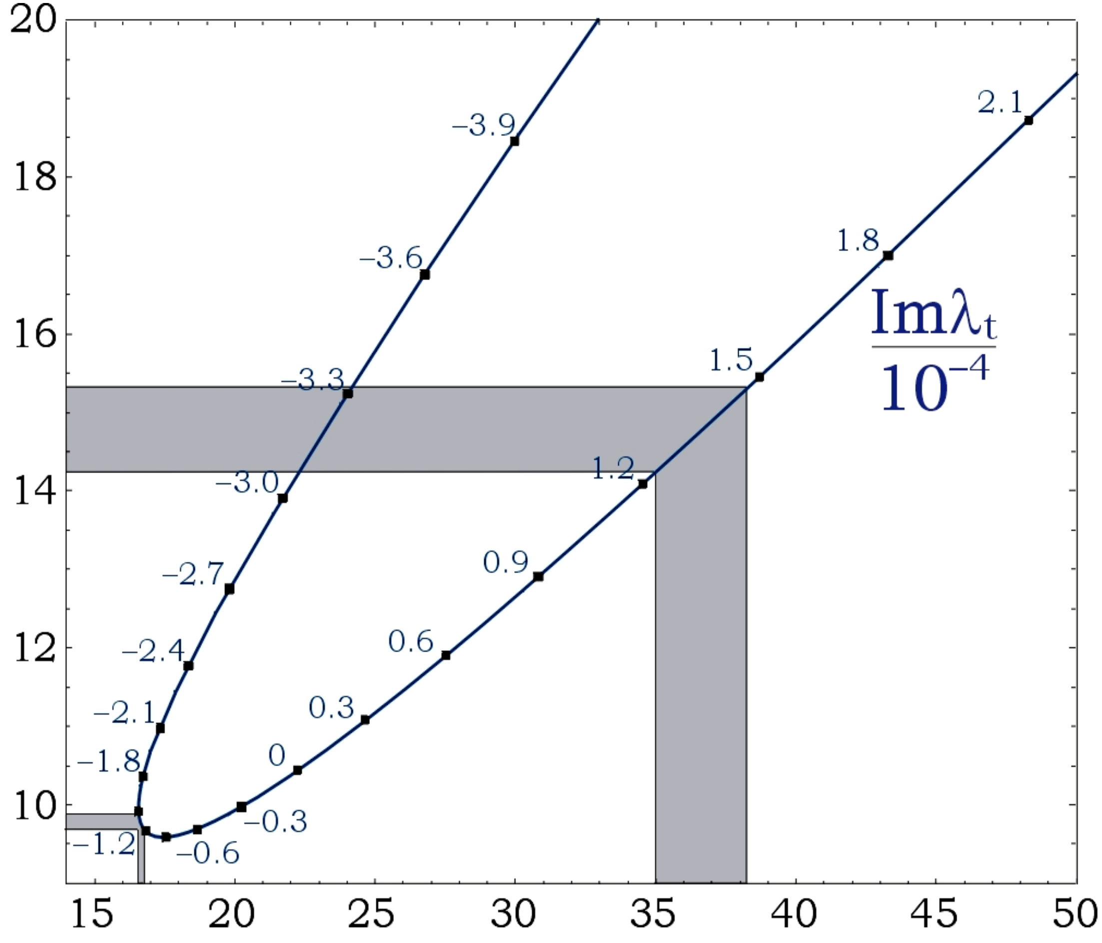
$|a_s| = 1.55^{+0.38}_{-0.32}\ (stat) \pm 0.05\ (syst)$

PLB 599 (2004)

$K^0_L \to \pi^0 ee\ (\mu\mu)$: SM Branching Ratios

Thank to the NA48/1 measurements, the KL BR can now be predicted

(Isidori, Unterdorfer, Smith)



Constructive

$$B_{e^+e^-} = 3.7^{+1.1}_{-0.9} \times 10^{-11}$$

$$B_{\mu^+\mu^-} = 1.5^{+0.3}_{-0.3} \times 10^{-11}$$

now favored by two independent analyses*

Destructive

$$B_{e^+e^-} = 1.7^{+0.7}_{-0.6} \times 10^{-11}$$

$$B_{\mu^+\mu^-} = 1.0^{+0.2}_{-0.2} \times 10^{-11}$$

*G. Buchalla, G. D'Ambrosio, G. Isidori, Nucl.Phys.B672,387 (2003)

*S. Friot, D. Greynat, E. de Rafael, hep-ph/0404136

$K^0_L \to \pi^0 ee\ (\mu\mu)$: Sensitivity to New Physics

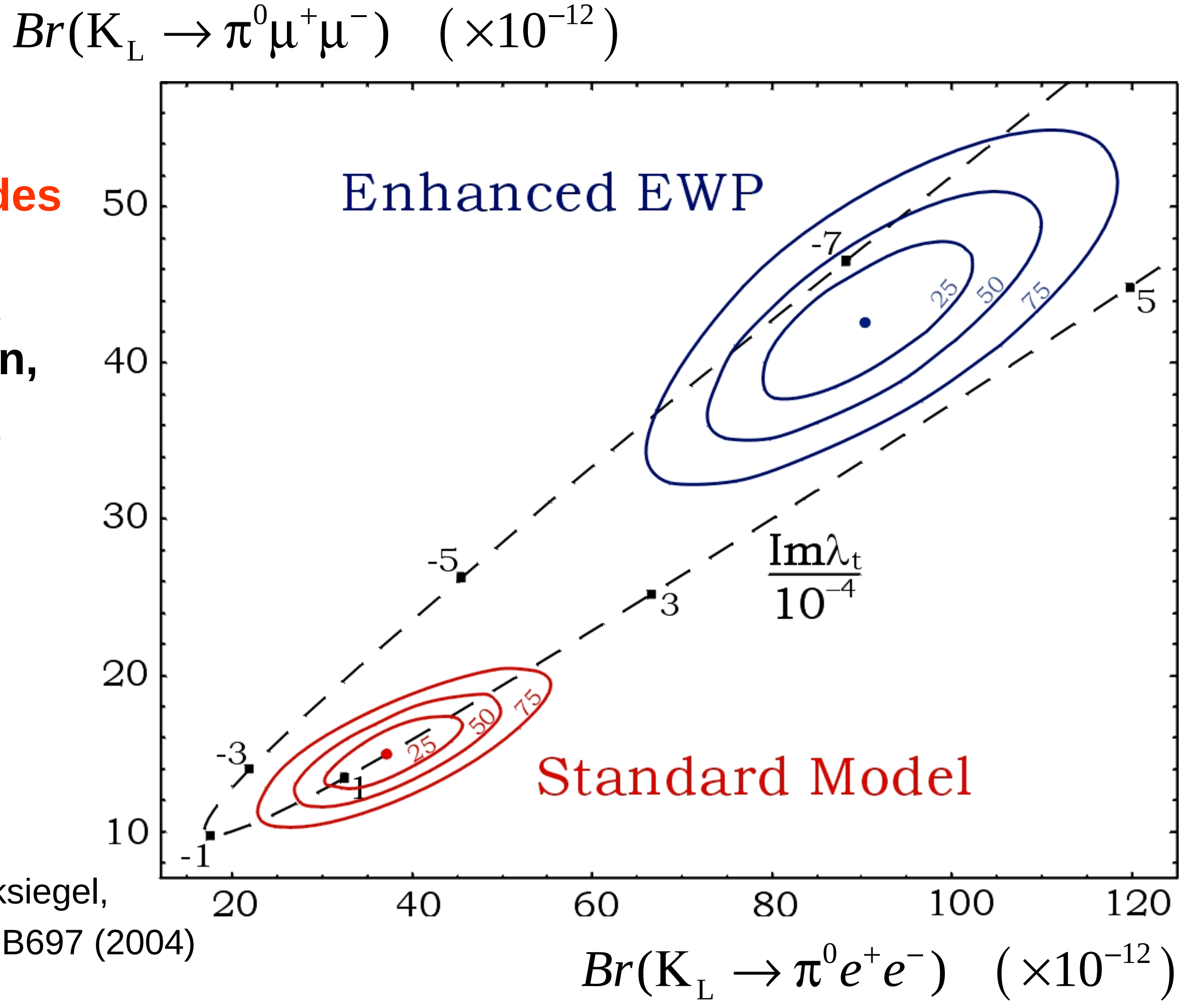
Isidori, Unterdorfer, Smith:

Fleischer theory:

Ratios of $B_d \to K\pi$ modes could be explained by enhanced electroweak penguins which, in turn, would enhance the K_L BR's:

$$B^{NP}_{e^+e^-} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B^{NP}_{\mu^+\mu^-} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$



•A. J. Buras, R. Fleischer, S. Recksiegel, F. Schwab, hep-ph/0402112, NP B697 (2004)

“Frequent” Kaon Decays

$BR(K_L \to \pi e \nu) \quad \to |Vus|$

$BR(K_L \to \pi^0 \pi^0 \pi^0)$

The puzzle

- The Unitarity of the CKM matrix requires for the first row: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$
- PDG04: $|V_{ud}| = 0.9738 \pm 0.0005 \quad |V_{us}| = 0.2200 \pm 0.0026$
  $|V_{ub}| = (3.67 \pm 0.47) \times 10^{-3}$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 - 1 = 3.3 \pm 1.5 \times 10^{-3}$$

⇓

$$2.2 \quad \sigma$$

- Semileptonic kaon decays are the best method to determine $|V_{us}|$:
  – protection from first order SU(3) symmetry breaking

NA48 $K_L \to \pi e \nu$ (Ke3) analysis

- Data from minimum bias run 1999 (80 M events)
- The basic measured quantity is the ratio R of decay rates of Ke3 decays relative to all decays with two charged tracks

$$R = \frac{N_e / a_e}{N_{2T} / a_{2T}}$$

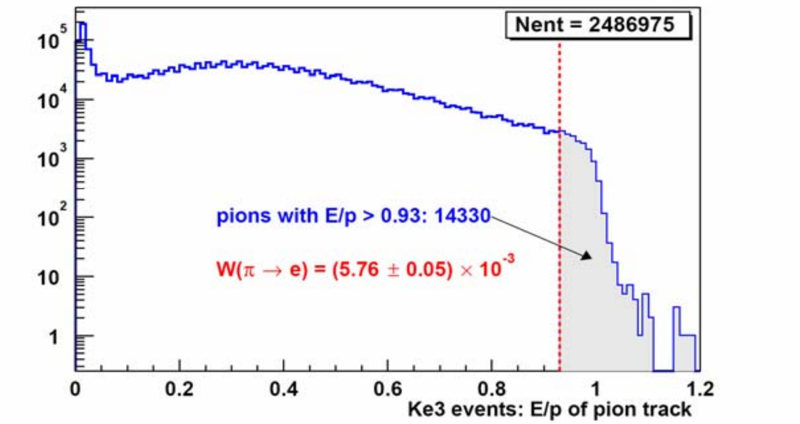
$$B(2T) = 1 - B(3\pi^0) + B(\pi^0\pi^0\pi^0_D) - B(2\pi^0) - B(2\gamma) - B(4T)$$
$$= 1.0048 - B(3\pi^0)$$

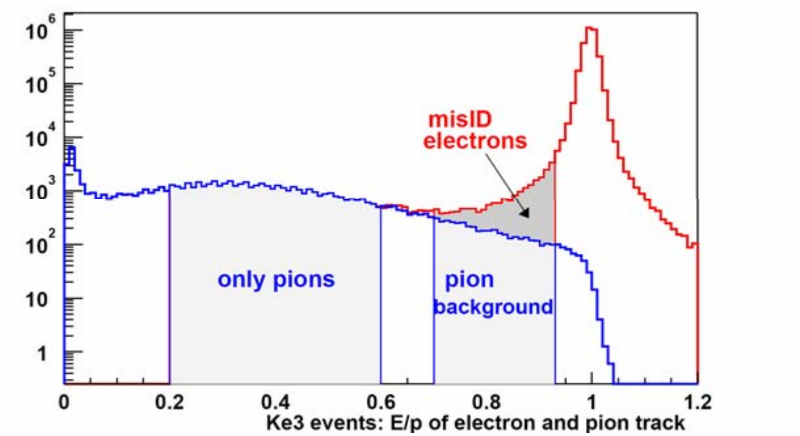
External input: *BR($K_L \to \pi^0 \pi^0 \pi^0$)*

$$B(Ke3) = R \times B(2T)$$

Electron Identification

Energy/Momentum (E/P)





- **Background to Ke3**
  - $K_{\mu3}/K_{3\pi}$ with pion mis-identified as electron
  - Tag e requiring E/P>1
  - Prob($\pi \rightarrow e$)=5.8×10^{-3}
- **Inefficiency of electron identification**
  - Estimated from K_{e3} data with identified pion
  - Prob($e \rightarrow \pi$)=4.9×10^{-3}

Acceptance

- MC simulation of detector acceptance for all 2-track channels. The most important channels are:

$K_L \to \pi e \nu$	0.2599
$K_L \to \pi \mu \nu$	0.2849
$K_L \to \pi^+ \pi^- \pi^0$	0.0975

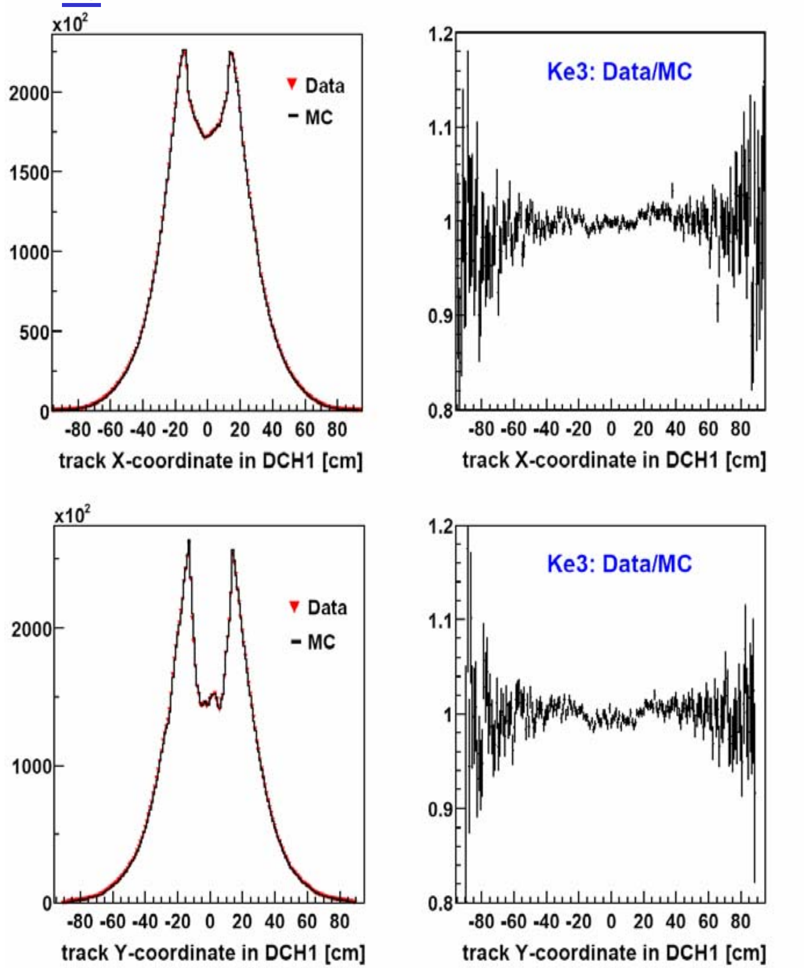
- Including radiative corrections
  - PHOTOS + Ginsberg
- Only ratios of BR enter In the calculation of the acceptance

  $\pi\pi\pi$ acceptance quite different from the semileptonic one, but BR is small

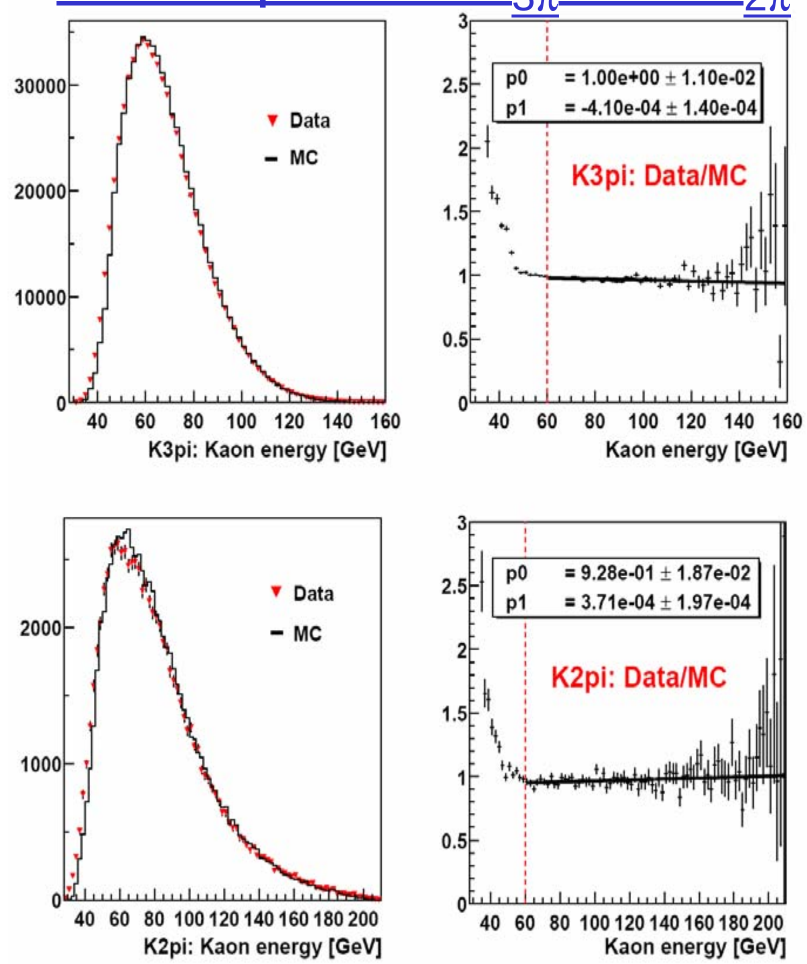
A(2T) = 0.2412

DATA-MC Comparison

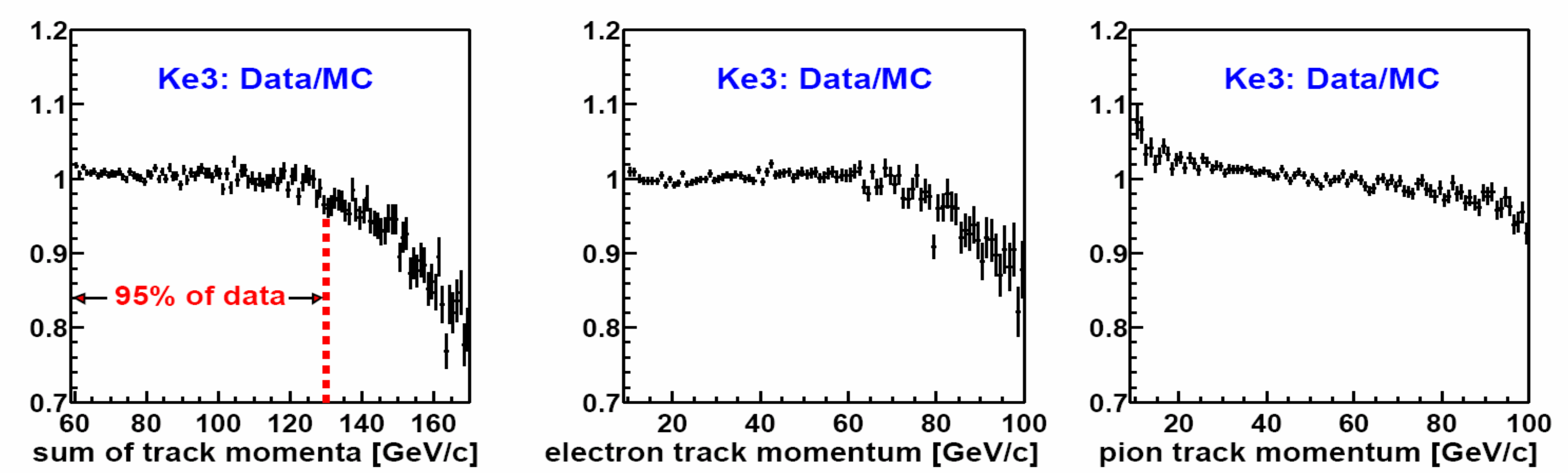
K_{e3} track co-ordinates at DCH1



Kaon spectra: $K_{3\pi}$ and $K_{2\pi}$



Momentum Spectra



- **Slight discrepancy data-MC for high track momenta**
  - **Only ~5% of statistics above 130 GeV/c**
  - **Uncertainty on R estimated by varying the accepted momentum range**

  → **Relative uncertainty: 0.67%**
  (largest exp. Systematics)

Experimental Result

$R = 0.4978 \pm 0.0035$

- **To compute BR(K3e) we need :** ***$BR(K_L \rightarrow \pi^0 \pi^0 \pi^0)$***
- PDG04: 0.2105 ± 0.0028
- **KTeV 04:** **0.1945 ± 0.0018**

Take average*: **0.1992 ± 0.0070**

➡ $5\,\sigma$!!

$BR(2T) = 0.8056 \pm 0.0070$

BR(Ke3) = R * BR(2T) = 0.4010 ± 0.028 ± 0.0035

***NA48/1 Internal cross check (Y2K data, see later) in good agreement with KTeV**

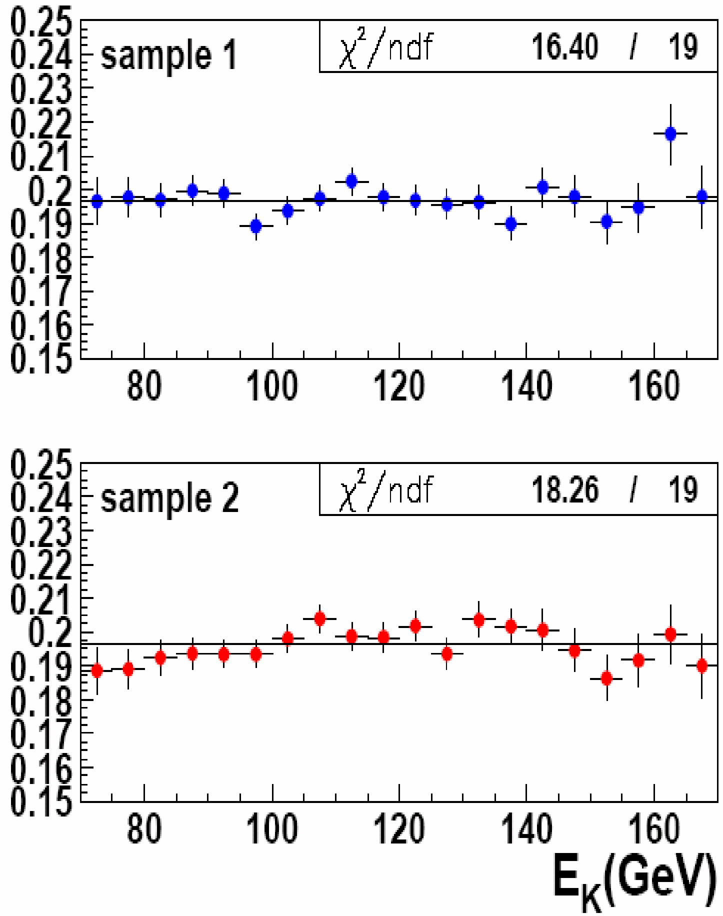
Internal NA48 cross-check

- $BR(K_L \to \pi^0 \pi^0 \pi^0)$ is the main uncertainty
  - PDG and new KTeV measurement inconsistent (5 sigma)
- Standard way:
  - Relative measurement between neutral and charged decays, with usual difficulties…
- NA48/1 way:
  - The same number of K_S and K_L are produced at the target
  - One can measure $BR(K_L \to \pi^0 \pi^0 \pi^0)$ with respect to the very well known $BR(K_s \to \pi^0 \pi^0)$ in the short neutral beam

Cross Check: $BR(K_L \to \pi^0 \pi^0 \pi^0)$

- **Small portion of 2000 data**
  - **200 000 K_L**
  - **600 000 K_S (D=50)**

Main Systematics:
LKr Energy scale: ± 0.0020
Effective target position: ± 0.0017
K_L lifetime: ± 0.0015



- **NA48/1 Preliminary:**

$BR(K_L \to \pi^0 \pi^0 \pi^0) = 0.1966 \pm 0.0006 \pm 0.0033$

In good agreement with KTeV

Extraction of V_{us}

$$|V_{us}| \cdot f_+^{K^0\pi^-}(0) = \sqrt{\frac{128\pi^3}{G_F^2 M_{K^0}^5 S_{EW} I_{K^0}} \cdot \Gamma(Ke3)}$$

Short distance factor S_{EW} = 1.0232

Phase Space Integral I_{K0}= 0.10339 ± 0.00063

Correction for radiative events: 0.99423

$$|Vus| \cdot f_+(0) = 0.2146 \pm 0.0016$$

Clearly above old measurements and in agreement with new KTeV value

Extaction of V_{us}

- Taking the latest calculation:
  - (Cirigliano et al., 2004) $f_+(0) = 0.981 \pm 0.010$

    $|V_{us}| = 0.2187 \pm 0.0028$

  still 2.4 from unitarity (0.2274)
- For comparison, if one takes the old Leutwyler and Ross value:
  - $f_+(0) = 0.961 \pm 0.008$

    $|V_{us}| = 0.2232 \pm 0.0029$

  one finds good agreement with unitarity

Neutral Hyperon Decays

$\Xi^0 \rightarrow \Lambda\,\gamma$ **decay asymmetry (data 1999)**

BR($\Xi^0 \rightarrow \Sigma^+ e^- \nu$**) (Preliminary) (data 2002)**

Weak radiative hyperon decays: a puzzle for the quark model

- Hara Theorem:
  - The Parity-violating amplitude of weak radiative hyperon decays vanishes in the SU(3) limit.
  - Accordingly, the decay asymmetry for weak radiative hyperon decays also vanishes.
- The violation of the Hara theorem is well established in

  $\Sigma^+ \rightarrow p\gamma$ decays where a large negative asymmetry is observed: $\alpha(\Sigma^+ \rightarrow p\gamma) = -0.76 \pm 0.08$

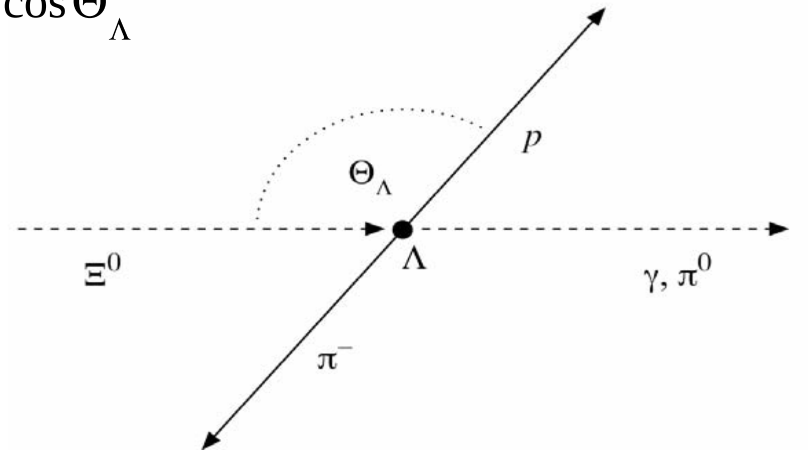
- The NA48 data (730 events collected in 1999) show the first evidence for negative decay asymmetry in $\Xi^0 \rightarrow \Lambda\gamma$:

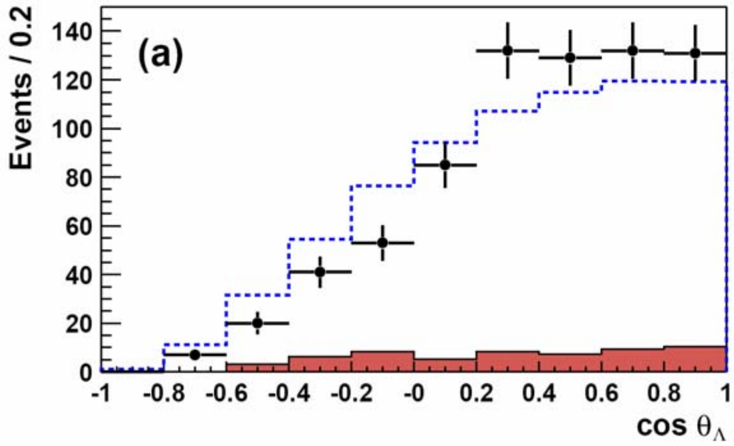
  $$\alpha(\Xi^0 \rightarrow \Lambda\gamma) = -0.78 \pm 0.18 \pm 0.06$$

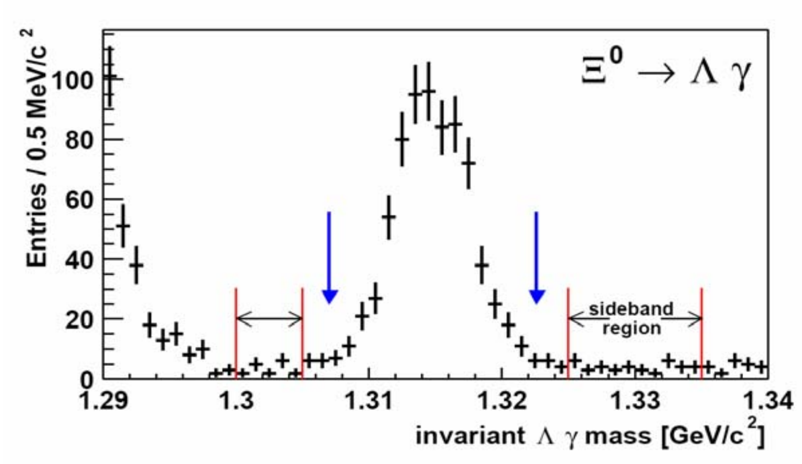
- With the NA48/1 data collected in 2002 we will reduce the statistical error to a negligible level.

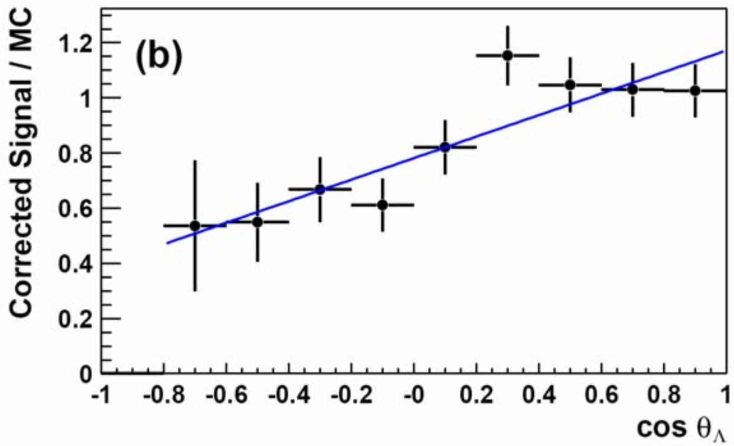
NA48 (1999) $\Xi^0 \to \Lambda\, \gamma$

$$\frac{dN}{d\cos\Theta_\Lambda} = N_0(1 - \alpha(\Lambda \to p\pi^-)\alpha(\Xi^0 \to \Lambda\gamma)\cos\Theta_\Lambda)$$

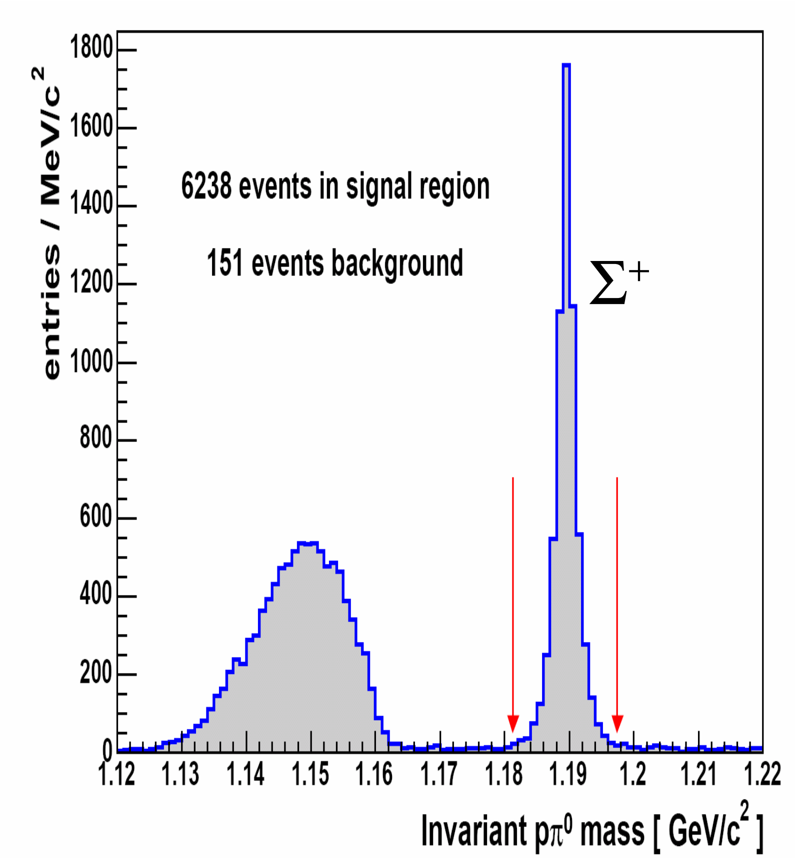


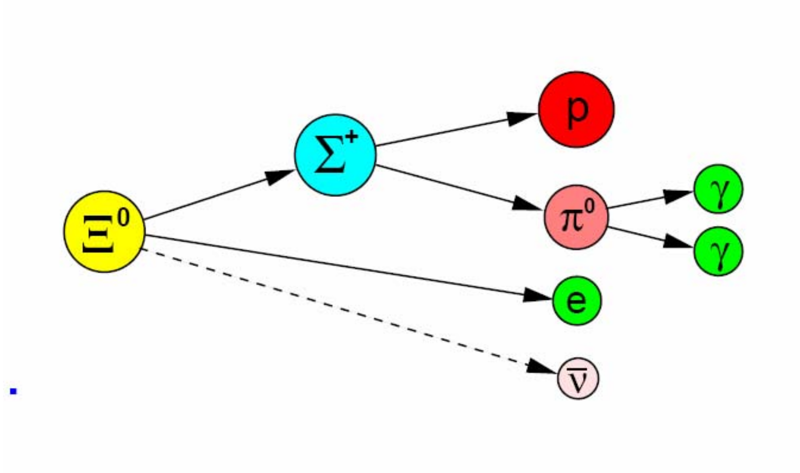






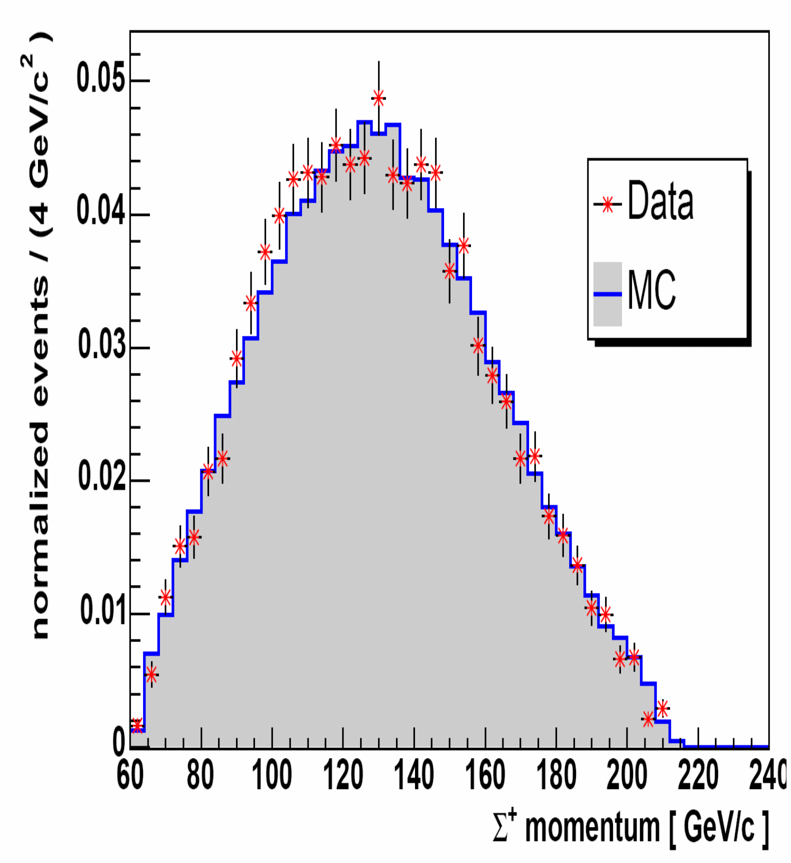
Semileptonic Ξ^0 decays

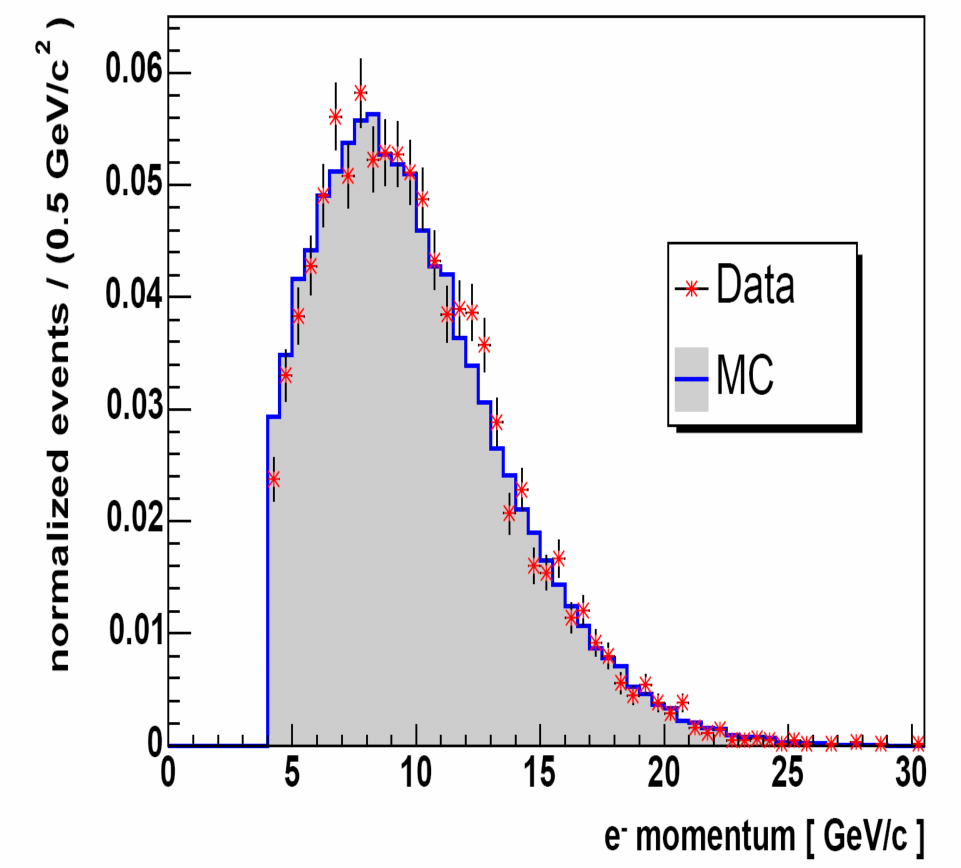




Ξ^0 semileptonic decay is the only source of Σ^+ in the neutral beam because $\Xi^0 \rightarrow \Sigma^+ \pi^-$ is kinematically forbidden

DATA-MC Comparison





Experimental Challange

- **Proton line-of flight very close to beam-pipe**
  - **Low acceptance**
  - **Sensitivity to detector geometry**
- **Hyperon trigger very tight to exclude online $K_S \to \pi^+\pi^-$, $\Lambda \to p\pi^-$ and radiative decays**
  - **Trigger computation based on minimum bias sample**
  - **Trigger efficiency: (83.8 ± 2.2) %**

Preliminary Result

- **Based on 6238 Ξ^0 β-decays:**

BR($\Xi^0 \rightarrow \Sigma^+ e^- \nu$)=(2.51 ± 0.03$_{sta}$ ±0.11$_{sys}$)×10^{-4}

Compare KTeV: (2.71 ± 0.38) ×10^{-4}

Systematics:

Trigger Efficiency	2.6 %
Acceptance	3.0 %
Ξ^0 ff (g$_1$ and f$_2$)	1.0 %
Ξ^0 Polarisation	1.0 %
Ξ^0 Lifetime	0.5 %
Tot systematics	4.2 %
Stat Uncertainty	1.2 %

NA48/1 Publications

1. PRECISE MEASUREMENTS OF THE K(S) ---> GAMMA GAMMA AND K(L) ---> GAMMA GAMMA DECAY RATES.
   A. Lai *et al*., CERN-EP-2002-074, Oct 2002. 10pp.
   Published in Phys.Lett.B551:7-15,2003
   e-Print Archive: hep-ex/0210053
2. FIRST OBSERVATION OF THE K(S) ---> PI0 GAMMA GAMMA DECAY.
   A. Lai *et al*., CERN-EP-2003-052, Aug 2003. 10pp.
   Published in Phys.Lett.B578:276-284,2004
   e-Print Archive: hep-ex/0309022
3. OBSERVATION OF THE RARE DECAY K(S) ---> PI0 E+ E-.
   J.R. Batley *et al*., CERN-EP-2003-062, Sep 2003. 13pp.
   Published in Phys.Lett.B576:43-54,2003
   e-Print Archive: hep-ex/0309075
4. OBSERVATION OF THE RARE DECAY K(S) ---> PI0 MU+ MU-.
   J.R. Batley *et al*., CERN-PH-EP-2004-025, Jun 2004. 19pp.
   Published in Phys.Lett.B599:197-211,2004
   e-Print Archive: hep-ex/0409011
5. SEARCH FOR CP VIOLATION IN K0 ---> 3 PI0 DECAYS.
   A. Lai *et al*., Aug 2004. 18pp.
   Submitted to Phys.Lett.B
   e-Print Archive: hep-ex/0408053

2004 NA48 Publications

1. MEASUREMENT OF THE XI0 ---> LAMBDA GAMMA DECAY ASYMMETRY AND BRANCHING FRACTION.
   A. Lai *et al.*, CERN-EP-2003-078, Jan 2004. 15pp.
   Published in Phys.Lett.B584:251-259,2004
   e-Print Archive: hep-ex/0401027
2. MEASUREMENT OF THE BRANCHING RATIO AND FORM-FACTORS FOR THE DECAY K(L) ---> PI+- PI0 E-+ NU(E)(ANTI-NU(E)).
   J.R. Batley *et al.*, CERN-PH-EP-2004-013, Apr 2004. 12pp.
   Published in Phys.Lett.B595:75-85,2004
   e-Print Archive: hep-ex/0405010
3. MEASUREMENT OF THE BRANCHING RATIO OF THE DECAY K(L) ---> PI+- E-+ NU AND EXTRACTION OF THE CKM PARAMETER |V(US)|.
   Lai *et al.*, CERN-PH-EP-2004-047, Sep 2004. 18pp. In Press Phys. Lett. B 21408

Outlook

- Some NA48/1 analyses under way:
  - $K_S \rightarrow \pi^+\pi^-\pi^0$
  - $K_S \rightarrow \pi e \nu$
  - Ξ^0 lifetime
  - $\Xi^0 \rightarrow \Lambda\, e^+ e^-$
  - $\Xi^0 \rightarrow \Sigma^+ e\, \nu$ form factors $\rightarrow |V_{us}|$
- Is there scope for NA48/1 Phase III?
  - K_S decays
    - Renewed interest following NA48/1 measurements
    - The predictions of the $K_L \rightarrow \pi^0\, ee\, (\mu\mu)$ BR would improve if K_S mode would be better known
    - To improve KS statistics by a factor of 10 one would need to run for ~180 days at three times the NA48/1 Phase II intensity
  - Ξ^0 semi-leptonic decays:
    - Improvements in trigger and optimisation of detector for neutral hyperon decays might lead to definitive measurements of form factors and BR
    - No reason to collect more radiative decays