Rare Kaons and Hyperons decays

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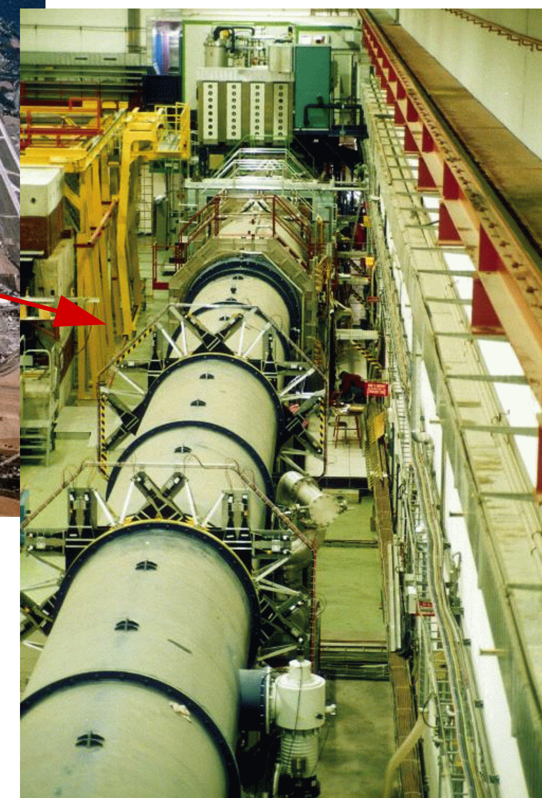
on behalf of the CERN NA48 collab.

Plan of the presentation

- The CERN Kaons/Hyperons facility: NA48
- $K_L \to e^+ e^- \gamma$
- $K_L \to e^+ e^- e^+ e^-$
- $K_S \to \pi^0 e^+ e^-$
- $K_S \to \pi^0 \mu^+ \mu^-$
- $\Xi^0 \to \Lambda \gamma$
- $\Xi^0 \to \Sigma^+ e^- \nu$

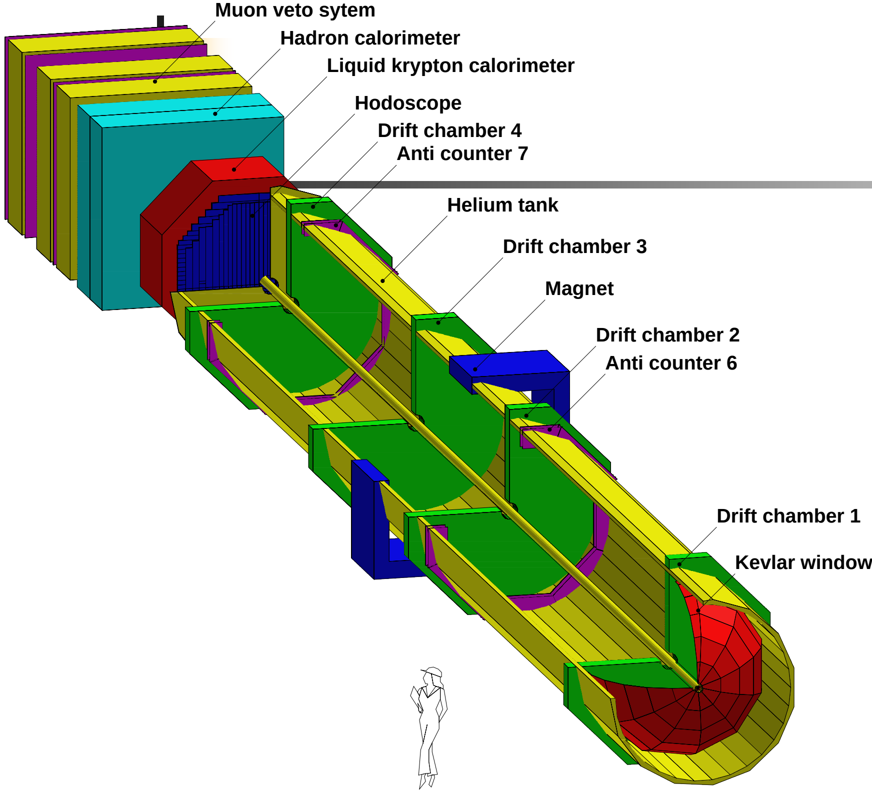
The CERN facility:NA48

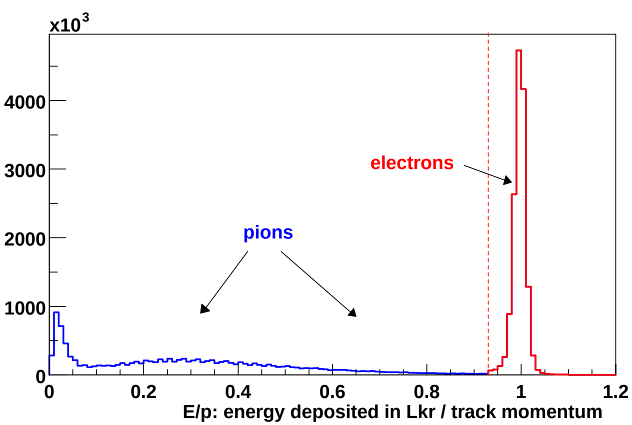
Fixed target experiment with 400-450 GeV protons from SPS



- Built for the precise measurement of direct CP violation in neutral Kaon decays (Re(ε'/ε))
- Goal reached in 2001, final (Re(ε'/ε)) in 2002
- Now: use detector to study K_L, K_S, $K^{\pm}$ and hyperon decays

The CERN facility:NA48 (II)



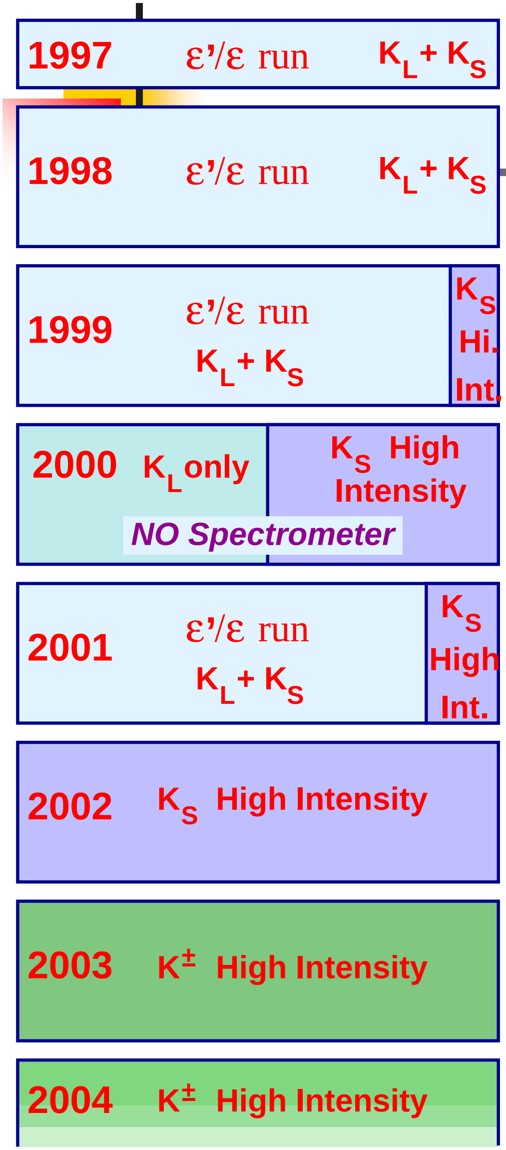


Main detector components:

- Magnet Spectrometer
  - Two drift chambers each before and after spectrometer magnet
  - Momentum resolution: ≤1% for 20 GeV/c tracks
- Anticounters for photons, muons
  - Liquid Krypton Calorimeter: energy resolution:

$$\frac{\Delta E}{E} = \frac{3.2\%}{\sqrt{E[GeV]}} \oplus \frac{90\ MeV}{E} \oplus 0.42\%$$

The CERN facility:NA48 (III)

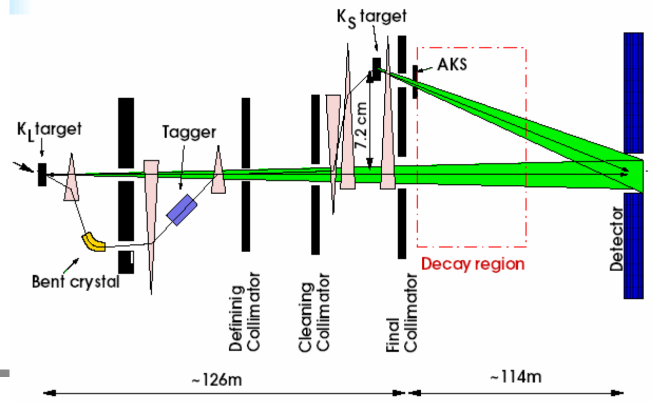


NA48: 1997-2001
- Direct CP violation ($Re(\varepsilon'/\varepsilon)$)
- K_L decays

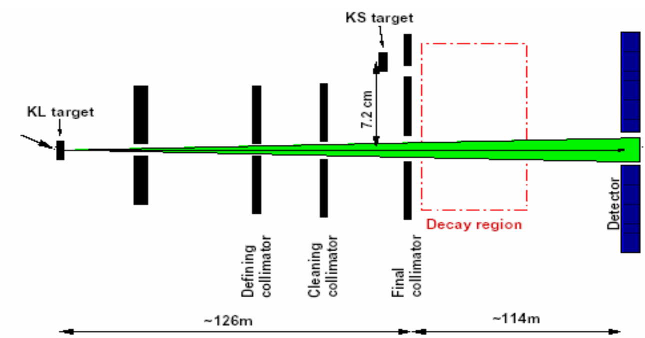
NA48/1: 2000,2002
- High intensity run for rare K_S decays
- Hyperon decays

NA48/2: 2003-2004
- Search for DCPV in $K^{\pm} \rightarrow 3\pi$ decays
- Rare $K^{\pm}$ decays
- Semileptonics $K^{\pm}$ decays

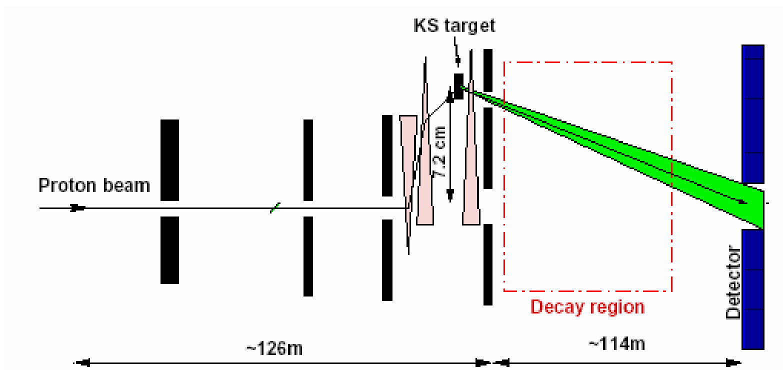
NA48
Beam lines



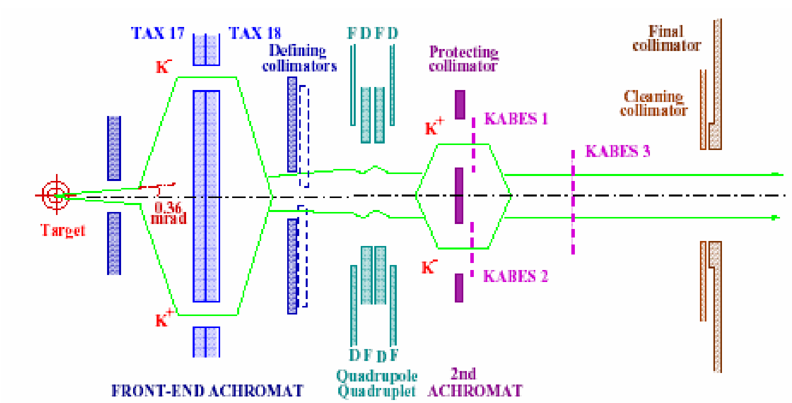
97,98,99,2001
NA48: Re(ε′/ε))



1999: K_L run (2 days)



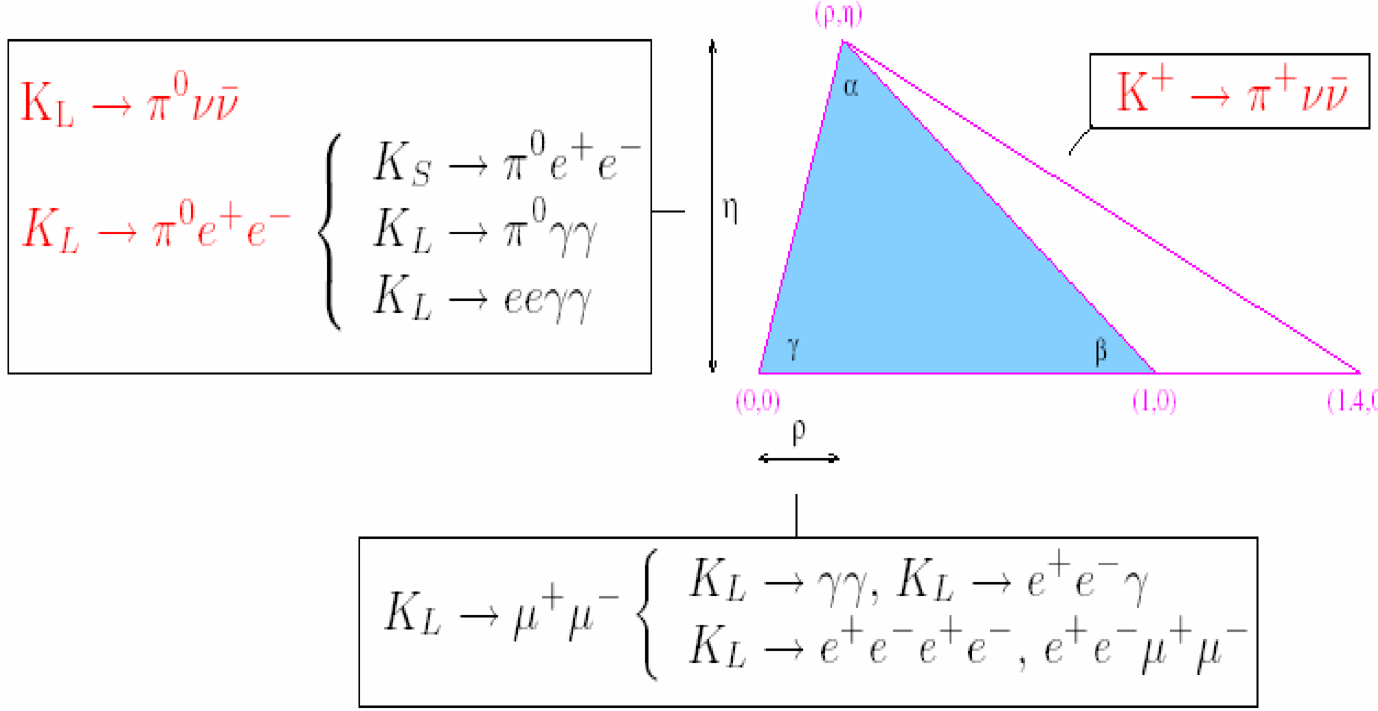
2002
NA48/1: K_S



2003-2004
NA48/1: $K^{\pm}$

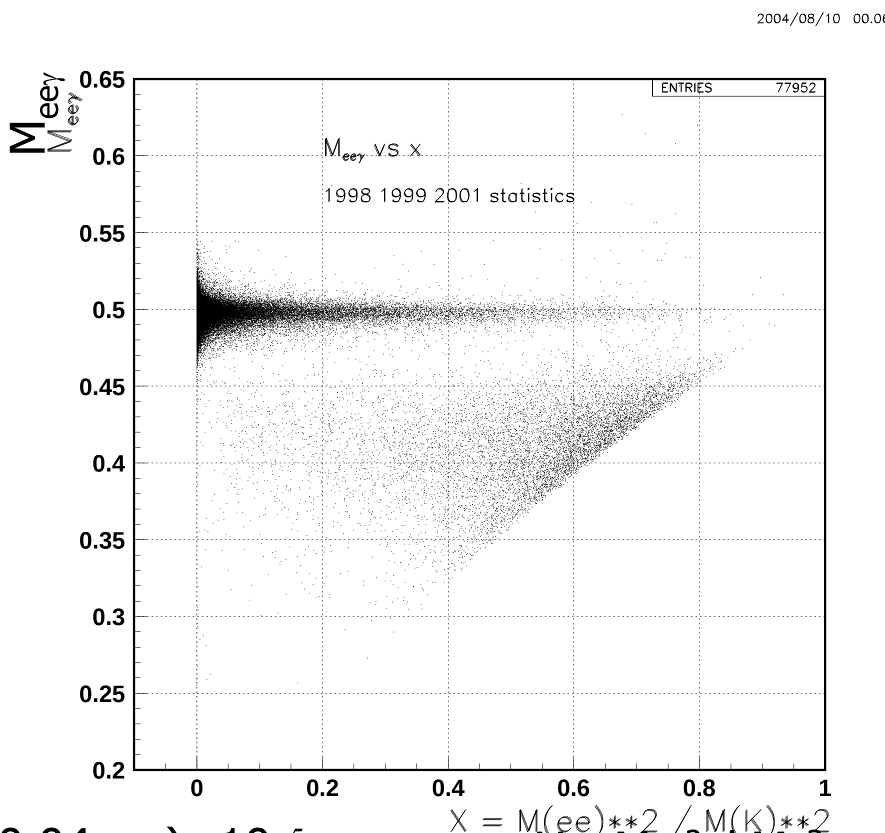
Why Kaons again?

A unitarity triangle in the kaon system :



$K_L \to e^+e^-\gamma$

- 1998, 1999, 2001 data
- 3 LKr cluster, two charged tracks
- electrons ID: E/P
- Main background: $\pi^0\pi^0_{Dalitz}$
- about 600000 events selected

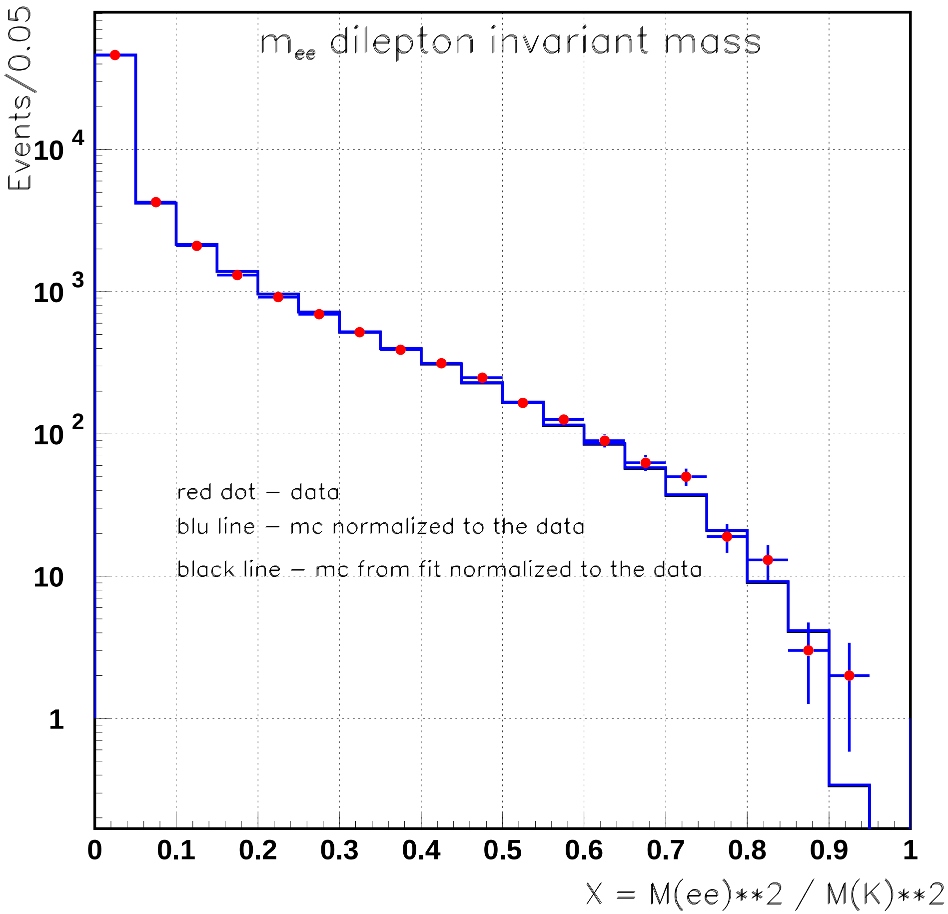


$X = M_{ee}^2 / M_K^2$

1997 data (7000 events):
$BR(KL \to e^+e^-\gamma) = (1.06 \pm 0.02_{stat} \pm 0.02_{syst} \pm 0.04_{norm}) \times 10^{-5}$

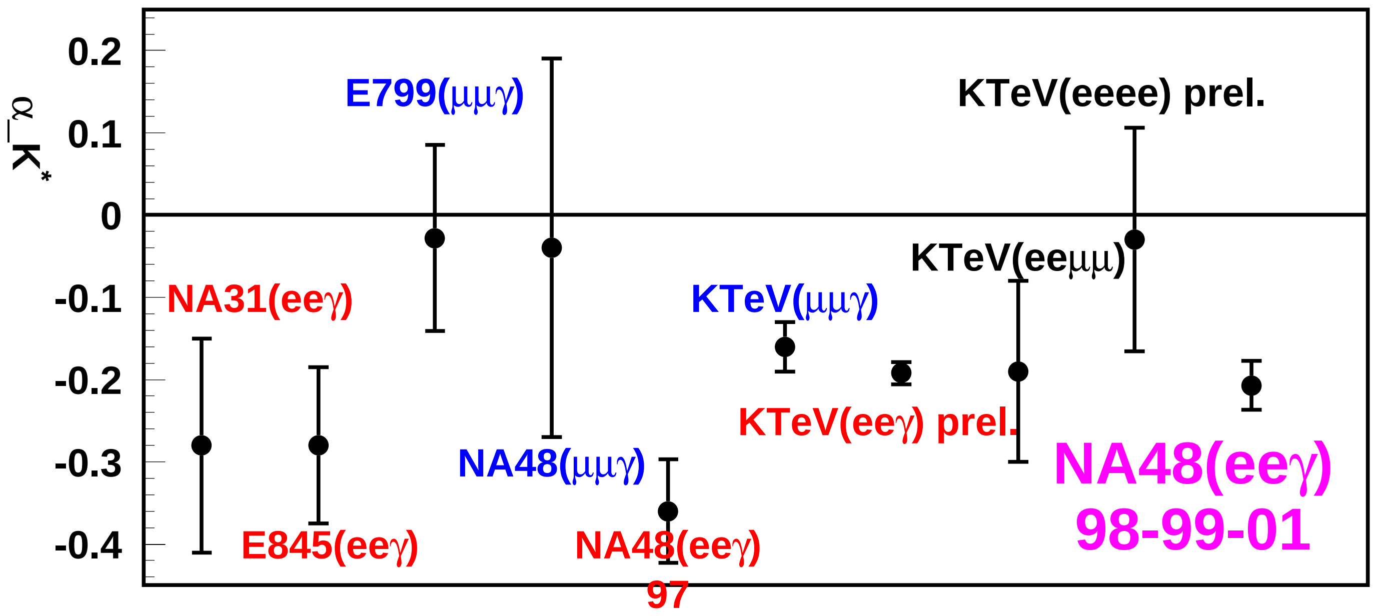
$K_L \to e^+e^-\gamma$ (II)

- Form factor measure structure of γ^* vertex
- In the BMS model: α_{K^*} measure the relative strenght of intermediate pseudoscalar and vector meson contribution
- α_{K^*} can be fitted from the x distribution



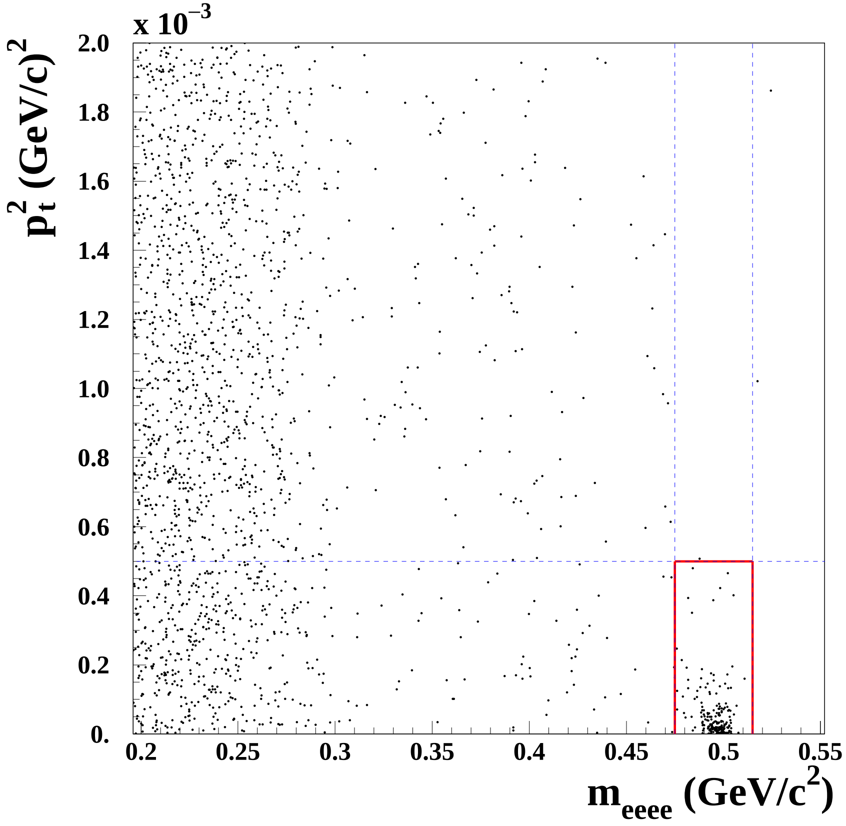
$K_L \to e^+e^-\gamma$ (III)

Preliminary: $\alpha_{K^*} = -0.207 \pm 0.019 \pm 0.017$



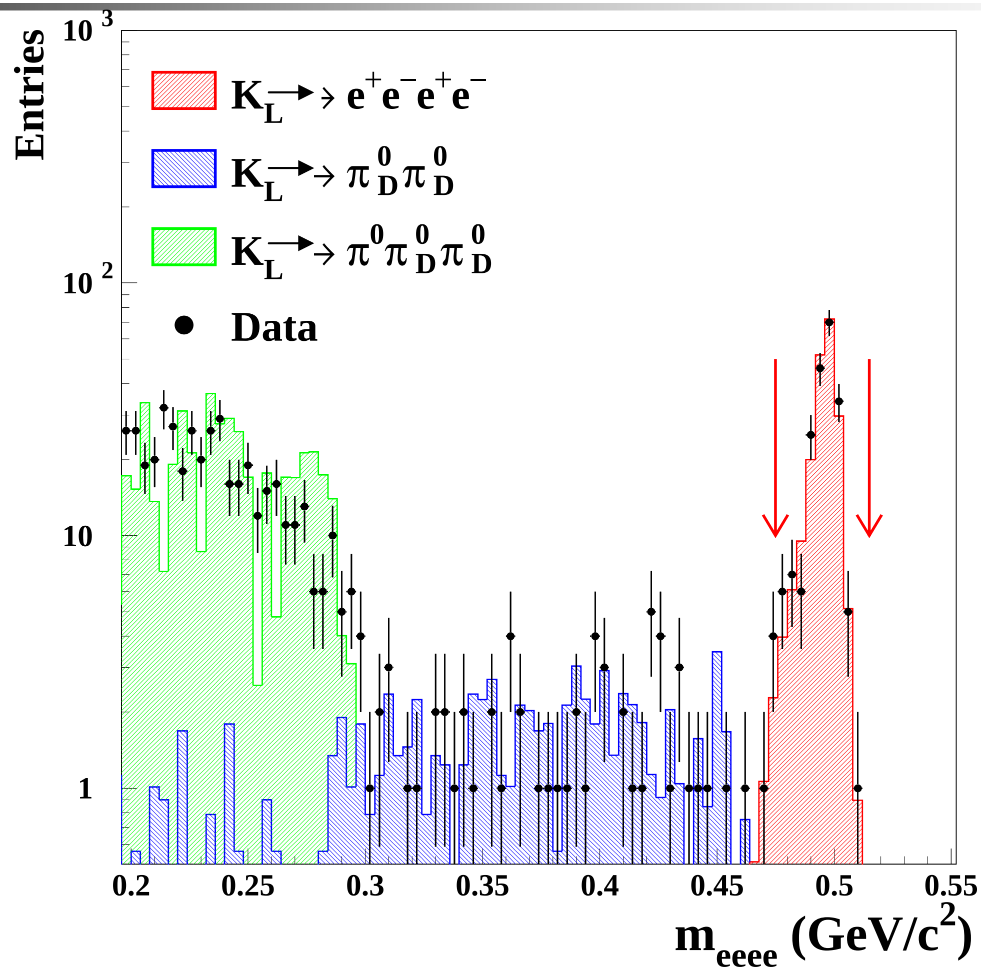
$K_L \to e^+e^-e^+e^-$

- 1998, 1999 data
- 4 LKr clusters, 4 charged tracks
- electrons ID: E/P
- about 200 events selected



$K_L \to e^+e^-e^+e^-$ (II)

$BR(K_L \to e^+e^-e^+e^-) = (3.30 \pm 0.24_{stat} \pm 0.14_{syst} \pm 0.10_{norm}) \times 10^{-8}$ [preliminary]



$K_S \to \pi^0 l^+ l^-$

- <u>CP conserving part:</u>

  NA48 measurement of BR($K_L \to \pi^0\gamma\gamma$):

  $\to$ BR$(K_L \to \pi^0 e^+ e^-)_{\text{CP cons.}} = 0.47^{+0.22}_{-0.18} \times 10^{-12}$

  $\to$ BR$(K_L \to \pi^0 \mu^+ \mu^-)_{\text{CP cons.}} \approx 10^{-12}$

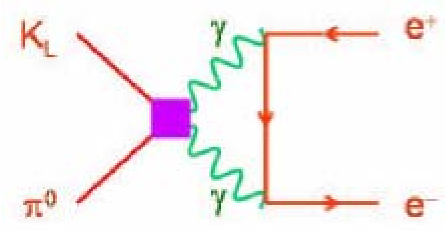
- <u>Direct CP violating part:</u>

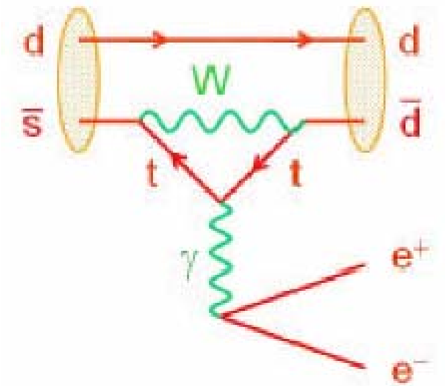
  proportional to η or Im(λ_t)

  $\to$ BR$(K_L \to \pi^0 l^+ l^-)_{\text{DCP viol.}} \sim$ few$\times 10^{-12}$

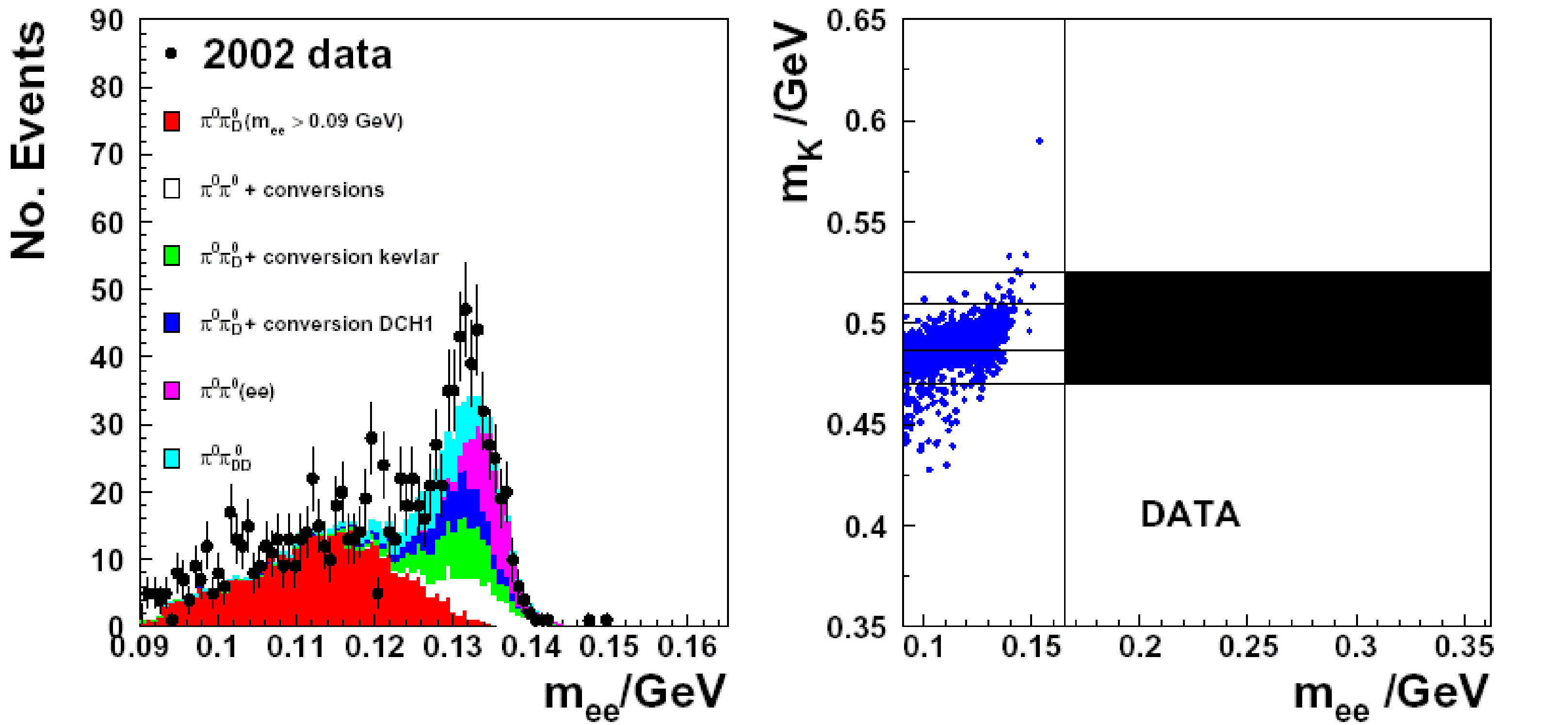
- <u>Indirect CP violating part:</u>

  $\to$ BR$(K_L \to \pi^0 l^+ l^-)_{\text{ICP viol.}} = |\varepsilon|^2 (\tau_L/\tau_S)$ BR$(K_S \to \pi^0 l^+ l^-)$





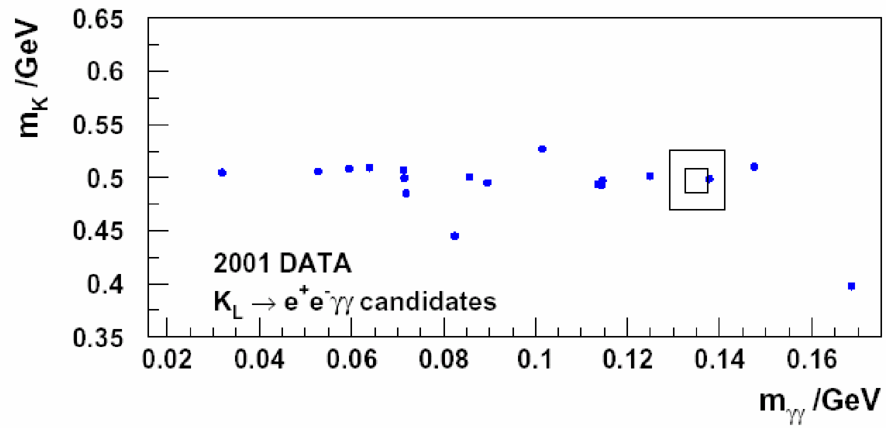
$K_S \to \pi^0 e^+ e^-$



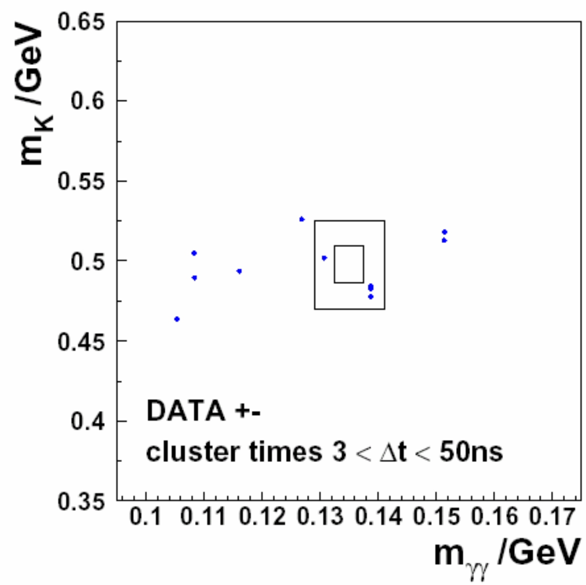
- Blind analysis: control and signal region masked
- Apply conservative cut $m_{ee} > 0.165$ GeV

$K_S \to \pi^0 e^+ e^-$ (II)

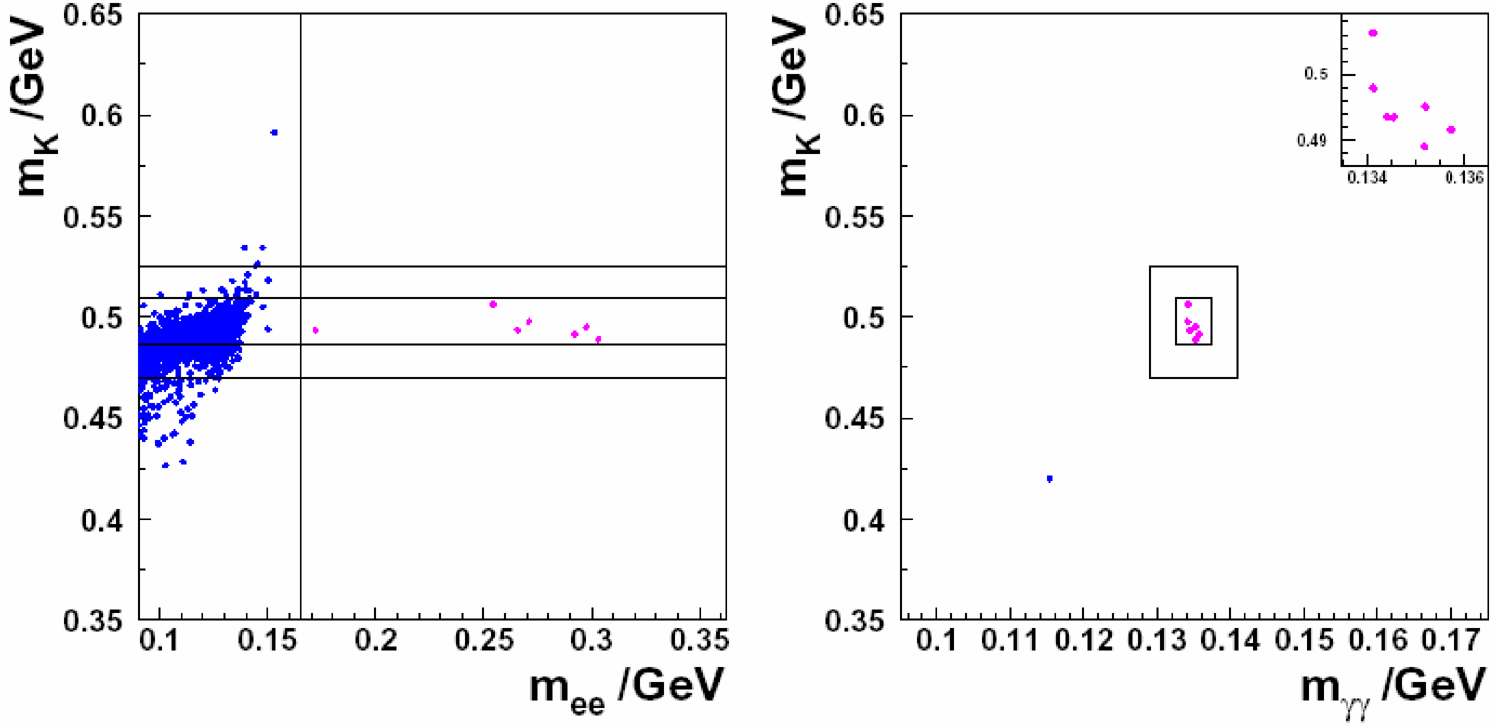
- Background from $K_L \to ee\gamma\gamma$: use 2001 data
  → 0.075 evts in signal region



- Background from fragments of two decays:
  Δt = time between fragments
  Control region: $3<\Delta t<50$ ns
  Signal region: $\Delta t<3$ ns



$K_S \to \pi^0 e^+ e^-$ (III)

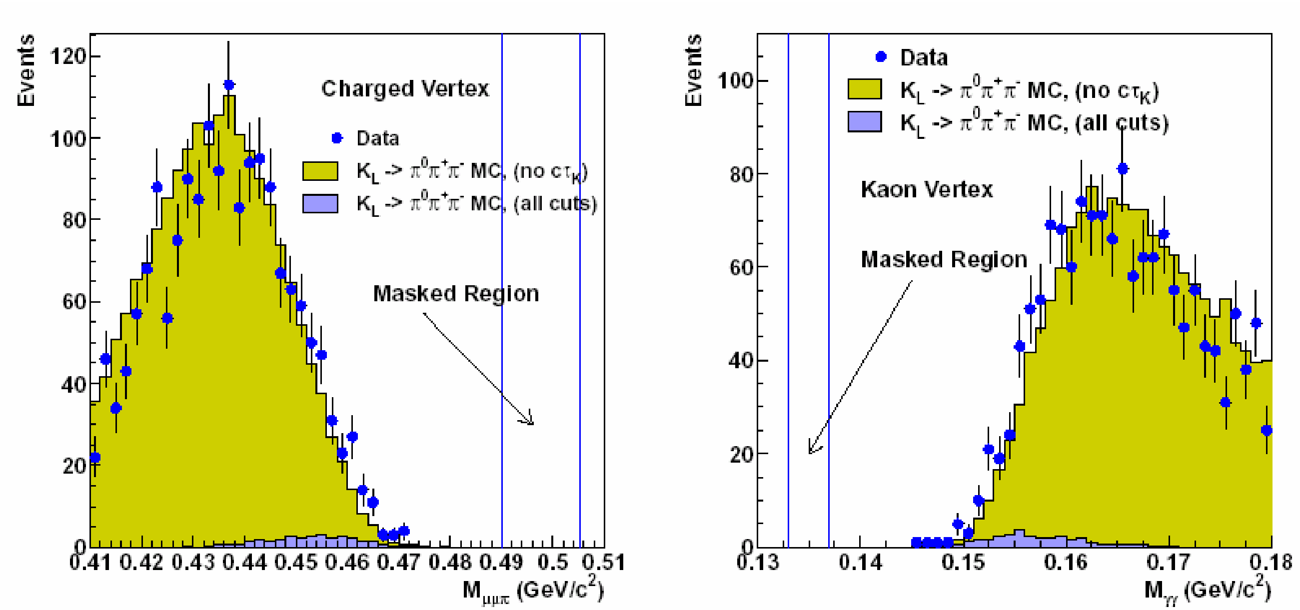


7 events found in the signal region with a background $0.15^{+0.05}_{-0.04}$

$$BR(K_S \to \pi^0 e^+ e^-)_{(m_{ee} > 0.165 GeV)} = \left(3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)\right) \times 10^{-9}$$

Published in PLB576(2003) 43

$K_S \to \pi^0 \mu^+ \mu^-$



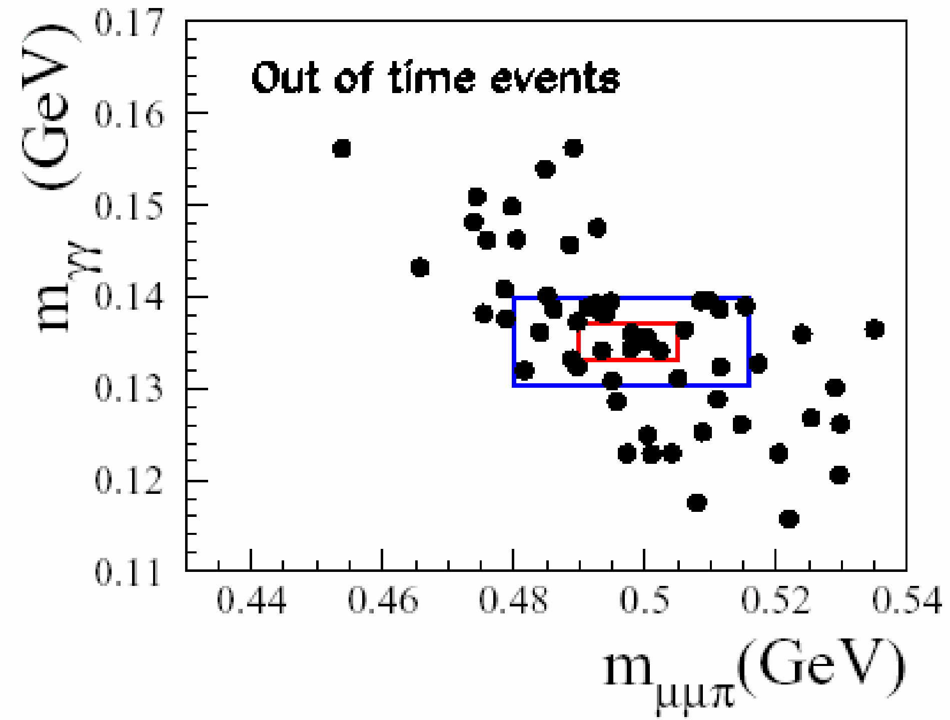
- Background from $K_L \to \pi^+ \pi^- \pi^0$ with pion decay in flight studied with MC and τ/τ_S cut removed
  $\to$ no MC evt in signal region (22×2002 statistics generated)
- Background from $K_L \to \mu^+\mu^-\gamma\gamma$ suppressed by BR($\approx 10^{-9}$) and pion mass cut
  $\to$ 0.04 ±0.04 evts expected in signal region

$K_S \rightarrow \pi^0 \mu^+ \mu^-$ (II)

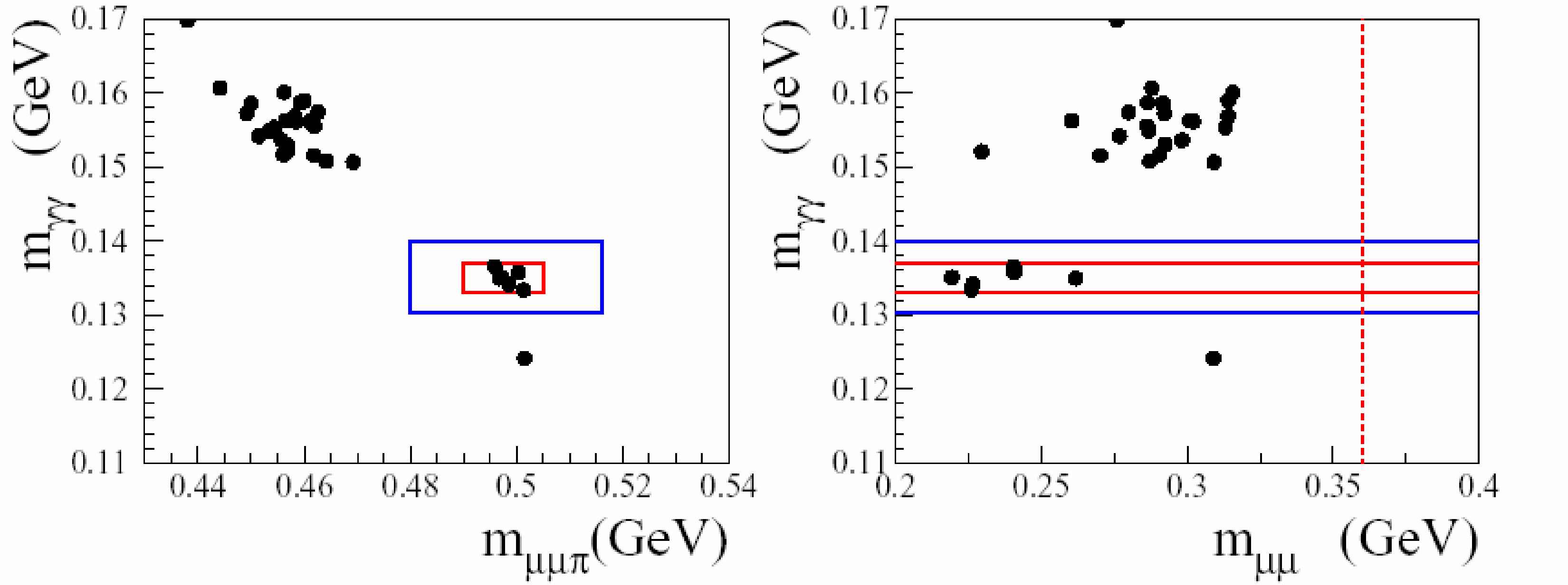
- Background from fragments of two decays ($\Delta t = t_{tracks} - t_{\gamma\gamma}$)

  Control region: $-115 < \Delta t < -3$ ns, $3 < \Delta t < 60$ ns

  Signal region: $-1.5 < \Delta t < 1.5$ ns



$K_S \to \pi^0\mu^+\mu^-$ (III)



6 events found in the signal region with a background $0.22^{+0.19}_{-0.12}$

$$BR(K_S \to \pi^0\mu^+\mu^-) = \left(2.9^{+1.5}_{-1.2}(\text{stat}) \pm 0.2(\text{syst})\right) \times 10^{-9}$$

Submitted to PLB

$K_S \rightarrow \pi^0 l^+ l^-$ (comments)

Assuming vector interaction and a unit form factor:

$$BR(K_S \to \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3}(stat) \pm 0.3(syst) \pm 0.8(theor)) \times 10^{-9}$$

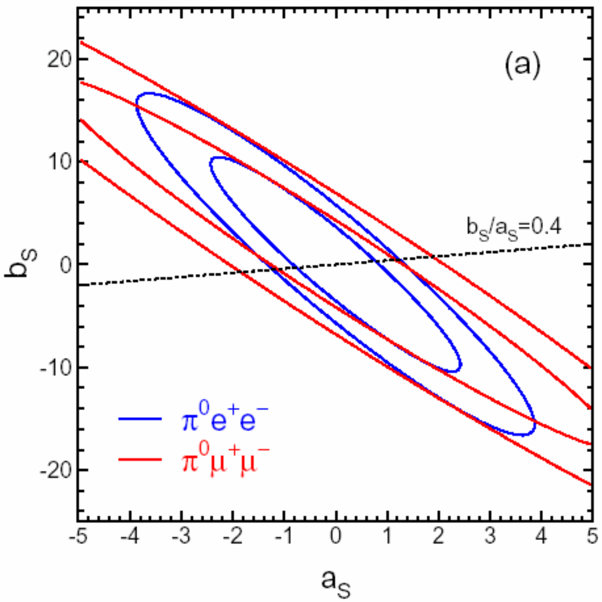
$$BR(K_S \to \pi^0 l^+ l^-) \propto |W(z)|^2 \qquad W(z) \sim (a_s + b_s\ m_{ll}^2/m_K^2)$$

Assuming Vector Meson Dominance: $b_s/a_s = m_K^2/m_\rho^2 = 0.4$

D'Ambrosio, Ecker, Isidori, Portoles JHEP08 (1998) 004

$$BR(K_S \to \pi^0 e^+ e^-) = 5.2 \times 10^{-9} |a_s|^2 \Rightarrow |a_s| = 1.06^{+0.26}_{-0.21} \pm 0.07$$

$$BR(K_S \to \pi^0 \mu^+ \mu^-) = 1.2 \times 10^{-9} |a_s|^2 \Rightarrow |a_s| = 1.54^{+0.40}_{-0.32} \pm 0.06$$



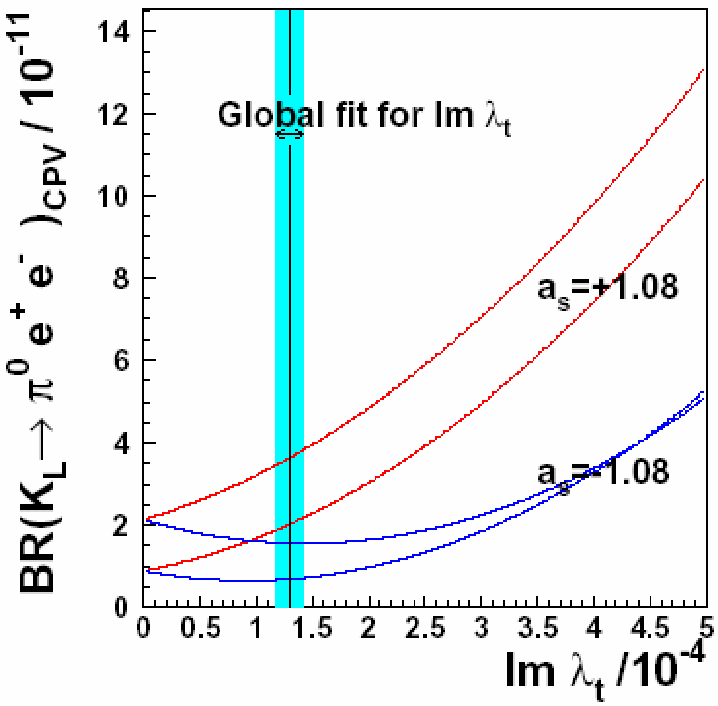
Leaving b_s and a_s free:

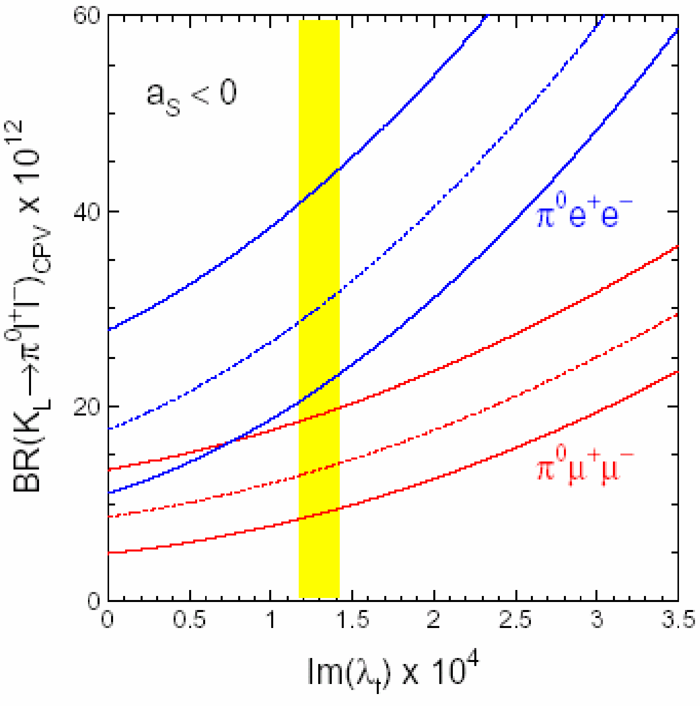
use both BR for a log-likelihood fit

Results compatible with each other and VMD

Statistics too low to determine bs

$K_L \to \pi^0 l^+ l^-$ (predictions)

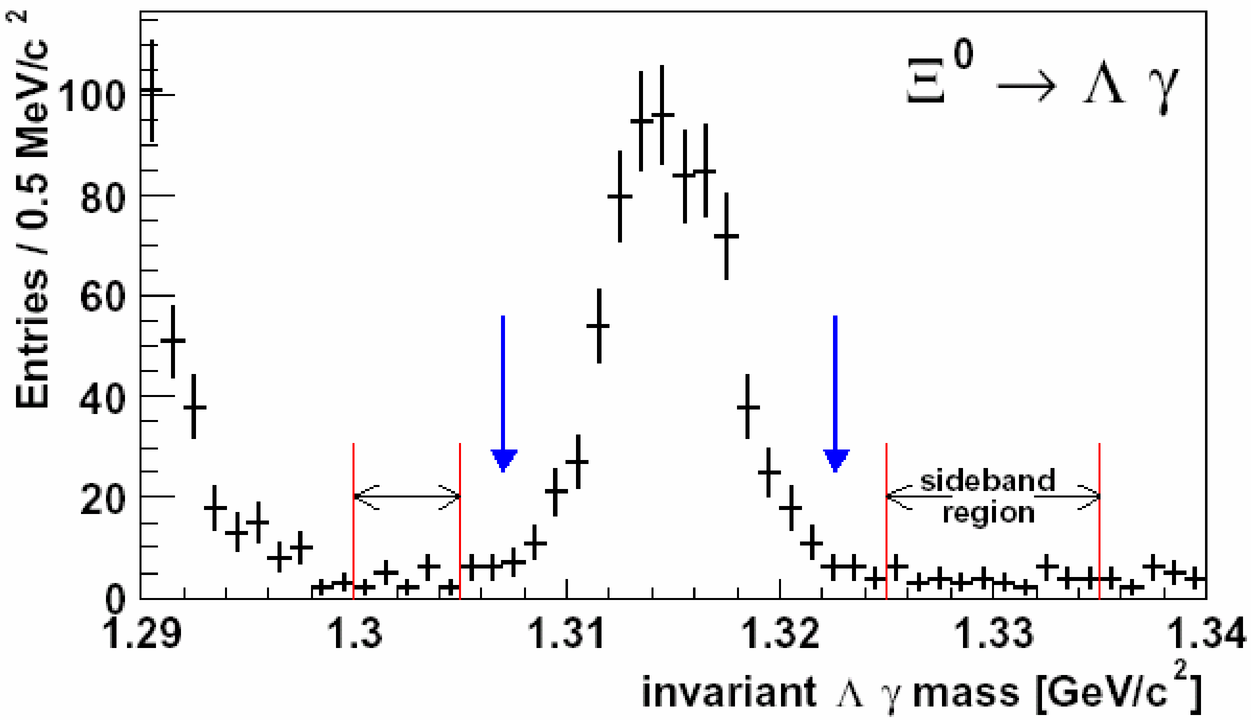




Construct. interf.

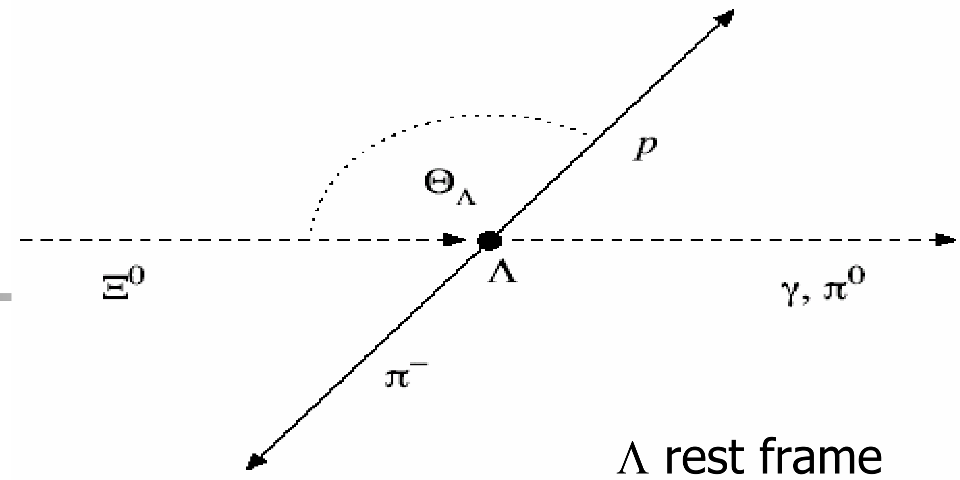
$\Xi^0 \rightarrow \Lambda\gamma$

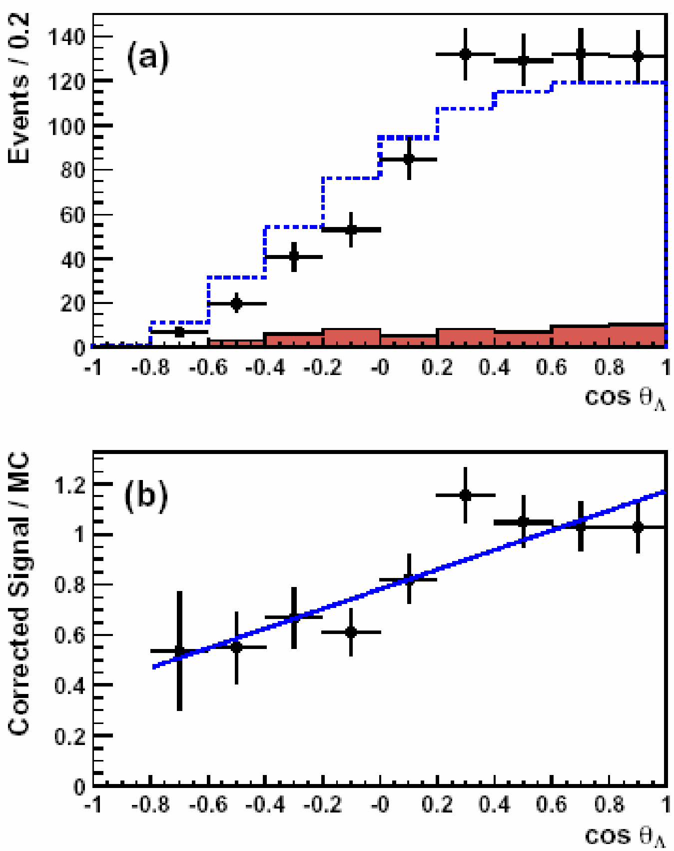
- 1999 High intensity K_S run (two days)
- 730 $\Xi^0 \rightarrow \Lambda\gamma$ with background of 58.2±7.8 evts



$$BR(\Xi^0 \rightarrow \Lambda\gamma) = (1.16 \pm 0.05_{stat} \pm 0.06_{syst}) \times 10^{-3}$$

$\Xi^0 \rightarrow \Lambda\gamma$ (II)





- background subtraction: main systematics (use mass sidebands)
- use an isotropic MC distribution
- test the method with $\Xi^0 \rightarrow \Lambda\pi^0$

decay asymmetry:

$$\alpha(\Xi^0 \rightarrow \Lambda\gamma) = -0.78 \pm 0.18_{stat} \pm 0.06_{syst}$$

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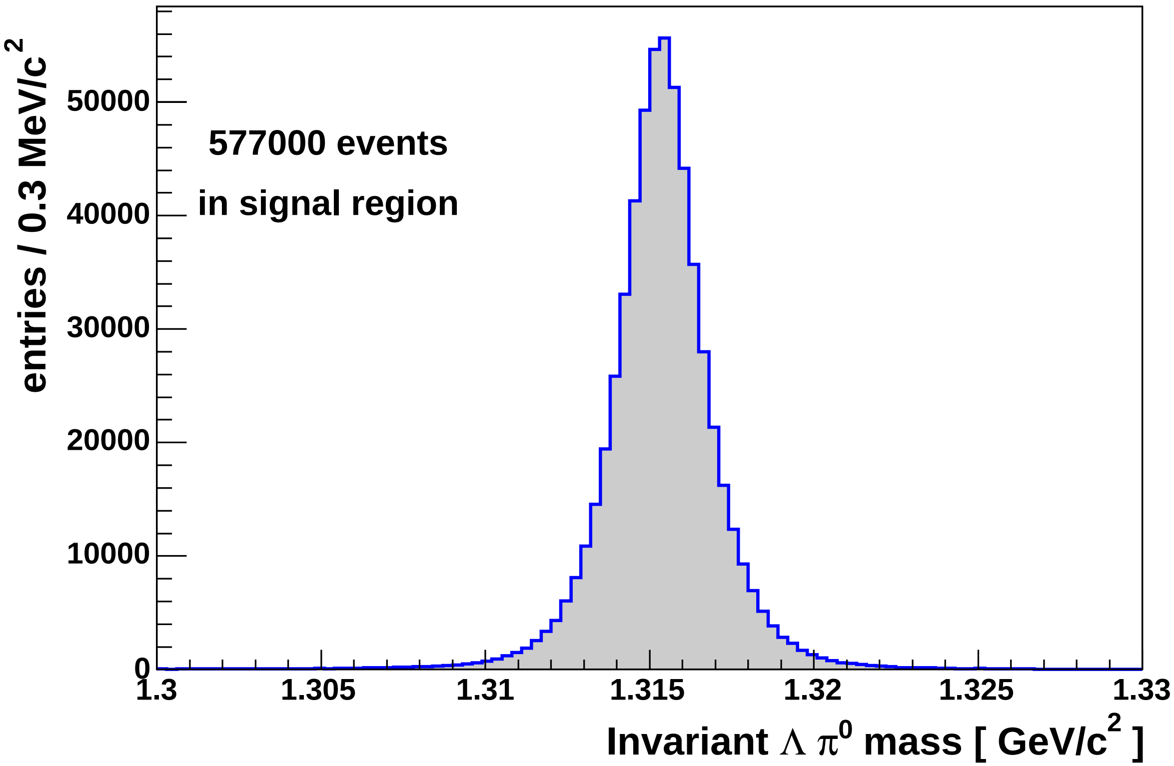
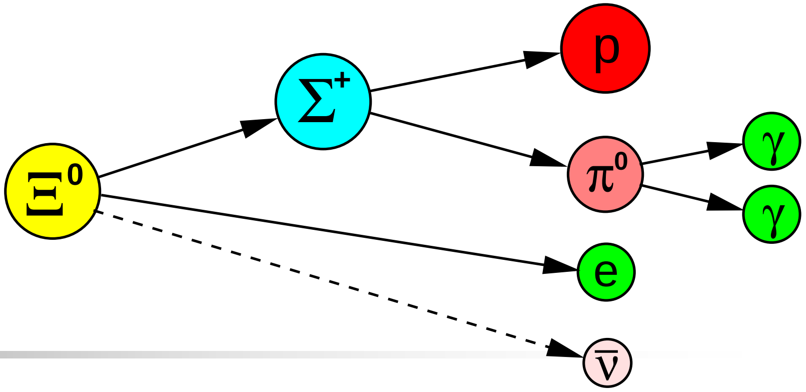
Ξ^0 Hyperons in 2002

- <u>2002 run period</u>
- Total flux: > 2×10^9 Ξ^0 decays in fiducial volume
- $\Xi^0 \to \Lambda\pi^0$ from min bias trigger (downscaled by 35, used for norm.)



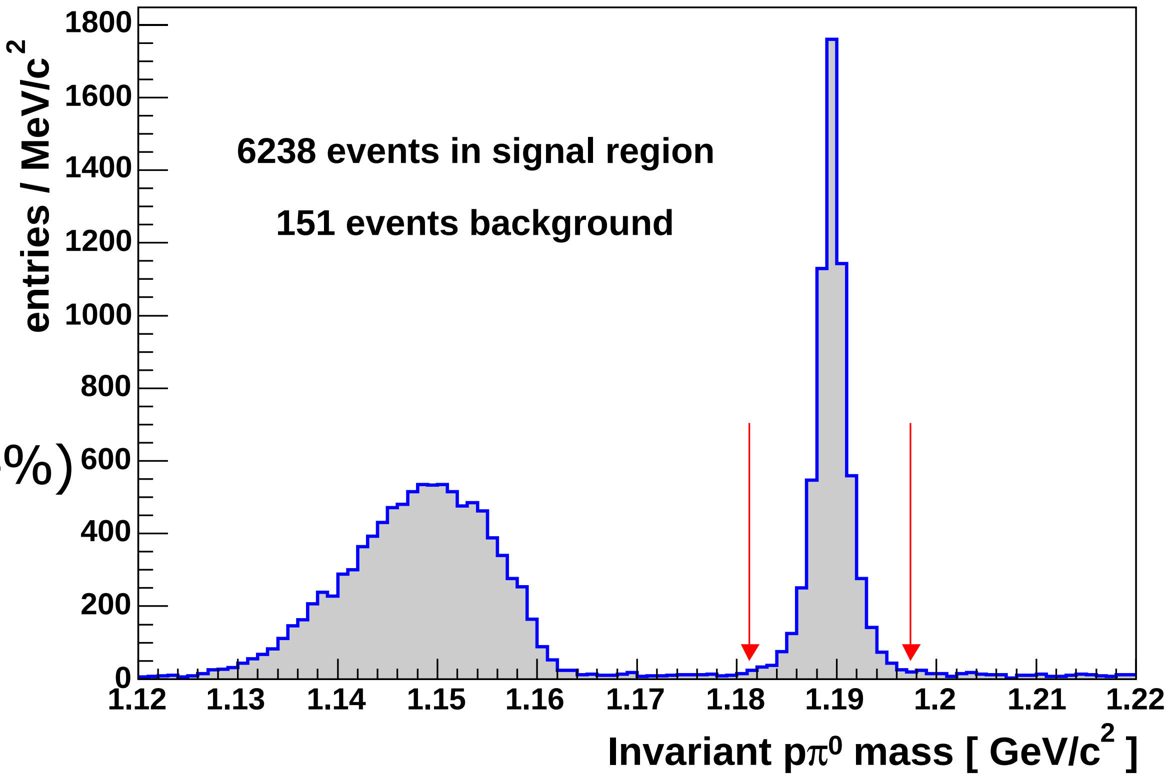
Ξ^0 beta decay



- Reconstruct $\Sigma^+ \rightarrow p\pi^0$
- Find an additional e^-

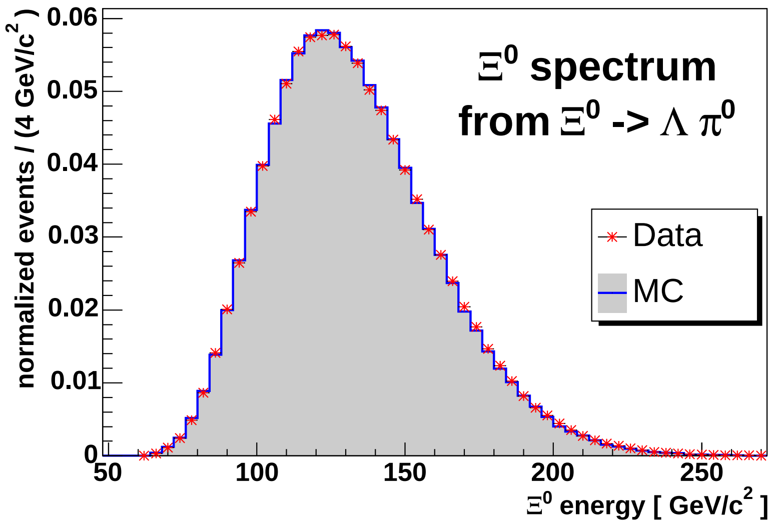
- Ξ^0 beta decay is the only source of Σ^+ in neutral beam
- 6238 signal events

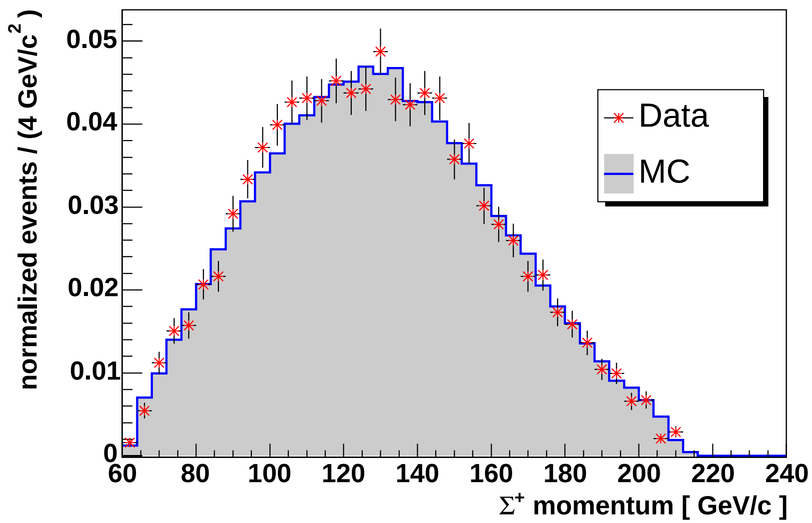
- Background ≈ 150 evts(2.4%) (from mass sidebands)

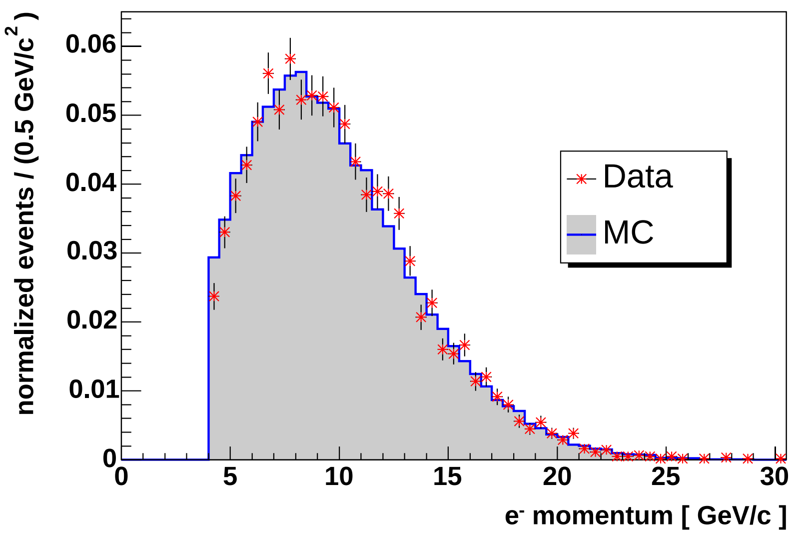


Ξ^0 beta decay (II)

Data-MC comparison







Ξ^0 beta decay (III)

Crucial items:

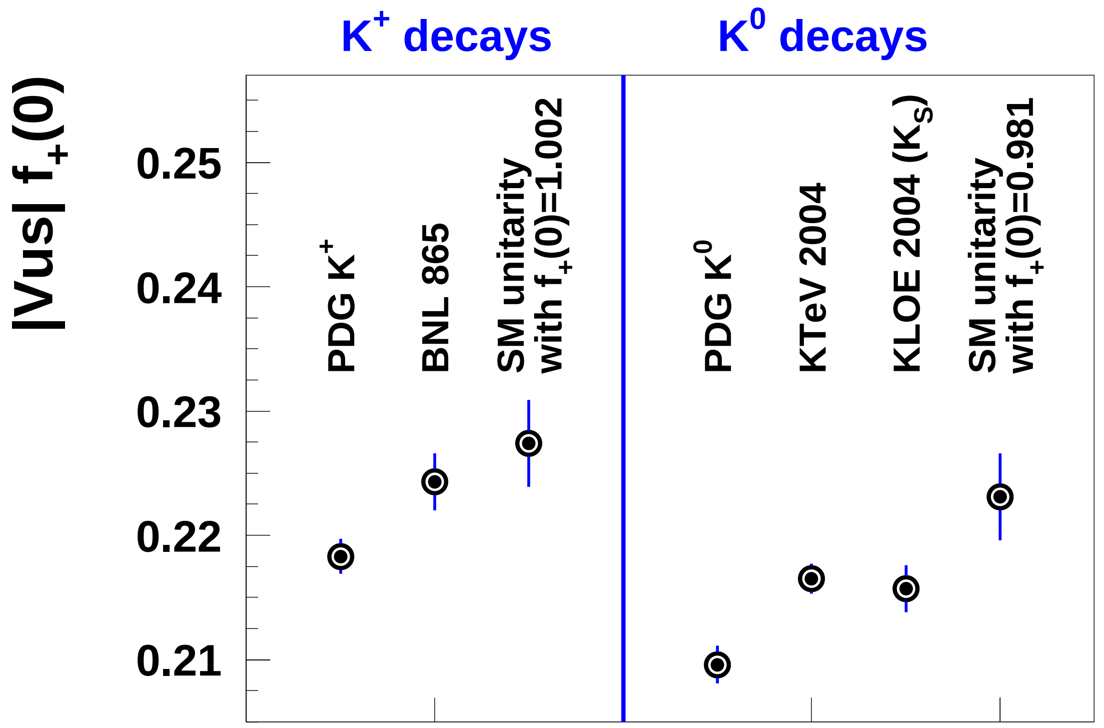
- Montecarlo simulation
- Trigger efficiency: (83.8±2.2)% [signal], 99.5% [normalization]

Preliminary NA48/1 result (6238 evts):

$BR(\Xi^0 \to \Sigma^+ e^- \nu) = (2.51 \pm 0.03_{stat} \pm 0.11_{syst}) \times 10^{-4}$

$|V_{us}|$ "crisis": is CKM matrix unitary?

Before....



NA48 $|V_{us}|$ measurements

- $K_L \to \pi e \nu$ (submitted to PLB): [1999 K_L 2-days run]

  $$\left|V_{us}\right|_{K^0_{e3}} = 0.2187 \pm 0.0028 \qquad \left[f_+(0) = 0.981 \pm 0.010\right]$$

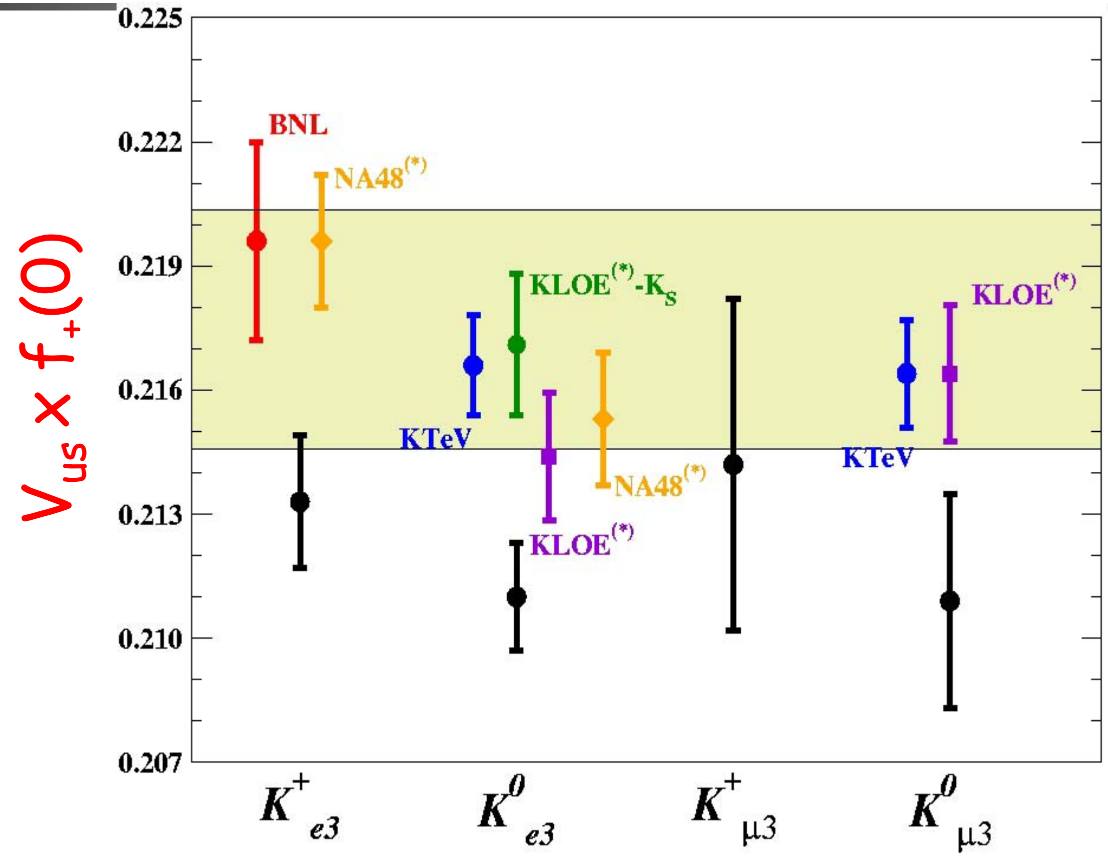
- $K^\pm \to \pi^0 e^\pm \nu$ (preliminary): [2003 run]

  $$\left|V_{us}\right|_{K^+_{e3}} = 0.2241 \pm 0.0026 \qquad \left[f_+(0) = 1.002 \pm 0.010\right]$$

- $\Xi^0 \to \Sigma^+ e^- \nu$ (preliminary): [2002 run]

  $$\left|V_{us}\right|_{\Xi^0_\beta} = 0.214 \pm 0.06^{+0.030}_{-0.025} \qquad \left[f_1(0) = 1; \quad g_1 / f_1 = 1.32^{+0.21}_{-0.17} \pm 0.05\right]$$

Slide borrowed by J.Ellis'talk in ICHEP04 in Beijing....



CKM unitarity 'crisis' has disappeared

Conclusions

- Kaons (and Hyperons) physics still alive
- Important contribution to Flavor physics (unitarity triangle, $|V_{us}|$)
- PV, CPV and DCPV first discovered in K
- Many results to be retrieved from NA48 data yet
- NA48 “far” future: $K^+ \rightarrow \pi^+ \nu\nu$