NA48/1 Status Report

Augusto Ceccucci/CERN

CERN-NA48/1: Cambridge, CERN, Chicago, Dubna, Edinburgh, Northwestern, Ferrara, Florence, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Turin, Warsaw, Wien

Outline

- **Introduction**
  - Status of the Collaboration (PhD students, authors,…)
- **K_S results**
  - NA48/1 Phase I (SPS 2000 run)
    - $K_S \to 3\pi^0$ (Preliminary)
    - $K_S \to \gamma\gamma$ (shown already @SPSC in Nov. 2002, PLB 551)
    - $K_S \to \pi^0\gamma\gamma$ (CERN-EP/2003-052; hep-ex/0309022, accepted by PLB)
  - NA48/1 Phase II (SPS 2002 run)
    - $K_S \to \pi^0 ee$ (CERN-EP/2003-062; hep-ex/0903075, accepted by PLB)
    - $K_S \to \pi^0 \mu\mu$ (New preliminary result)
- **Neutral hyperons:**
  - Ξ^0 Semi-leptonic decays
  - Ξ^0 Radiative decays
- **Outlook**

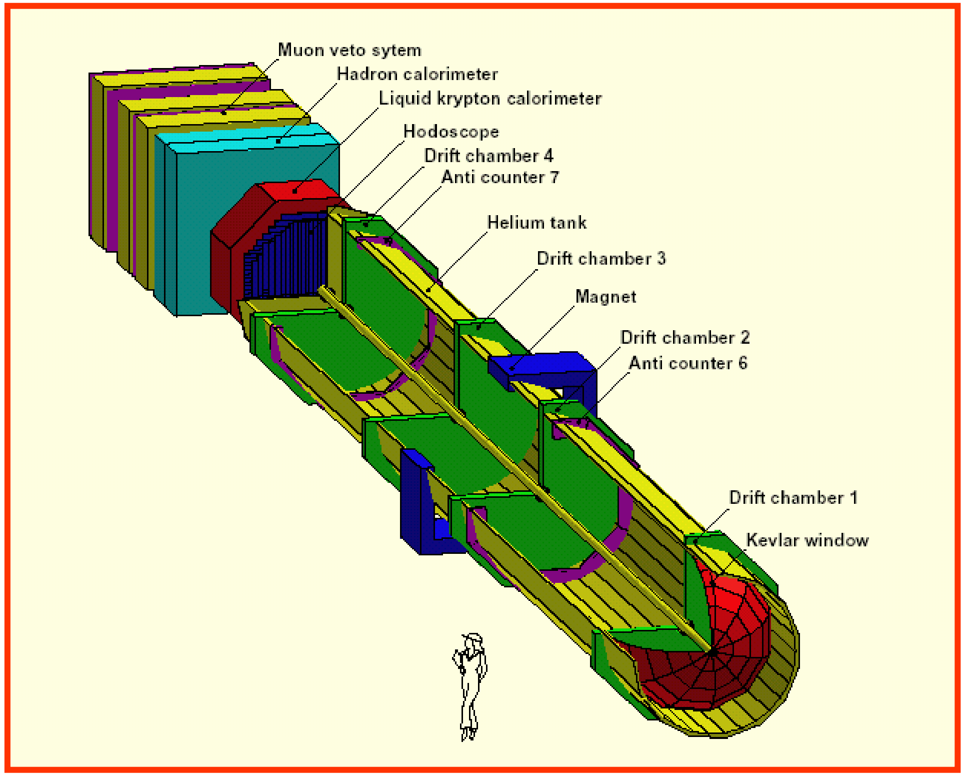
Collaboration Issues

- 114 Scientific authors
- Monthly analysis meetings
- Insist on independent analyses
- 12 PhD Students (either finished or quite advanced analyses)
  - Matthias Behler (Mainz)
  - Marco Clemencic (Torino)
  - Teresa Fonseca (Northwestern)
  - Guillaume Gouge (Saclay)
  - Andreas Hirstius (Mainz)
  - Ermanno Imbergamo (Perugia)
  - Venelin Kozhuharov (Dubna)
  - Peter Marouelli (Mainz)
  - Ulrich Moosbrugger (Mainz)
  - Mitesh Patel (Cambridge)
  - Mauro Piccini (Perugia)
  - Mark Slater (Cambridge)

+ Several Master/Diploma theses

NA48 Detector & Data Taking

1997	NA48: ε'/ε
1998	ε'/ε
1999	ε'/ε
2000	K_L no spectrometer; NA48/1 K_S
2001	ε'/ε lower inst. intensity
2002	NA48/1: K_S
2003	NA48/2: $K^{\pm}$



Kaons produced by 400 GeV protons from the CERN SPS on a Be target: E_K~110 GeV
NEAR (K_S) beam ~ 6.2 m long

Results from the 2000 data

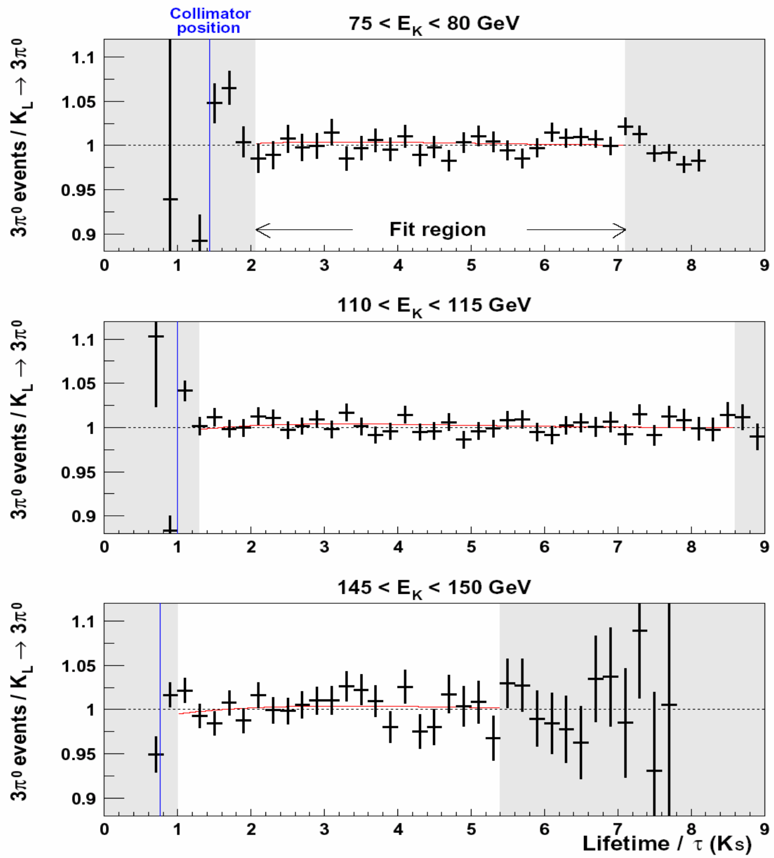
NA48/1 Phase I

Search for CP-violation in $K_S \to 3\pi^0$

$$\eta_{000} = \frac{A(K_S \to 3\pi^0)}{A(K_L \to 3\pi^0)}$$

CP-Violating
In SM $\eta_{000} \sim \varepsilon$

- **Near Beam**
  - NA48/1 (2000) ~6.5 10^6 $3\pi^0$
- **Far Beam:**
  - NA48 2000 > 10^7 $K_L \to 3\pi^0$
  - To normalise the acceptance
- **Analysis in bins of energy**

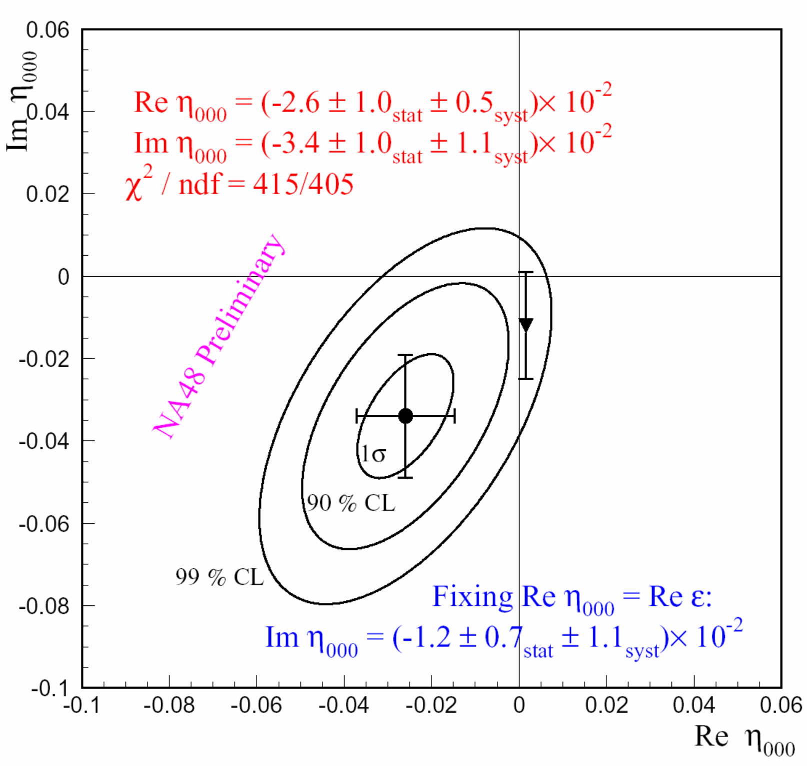


$$f(E,t) = \frac{NEAR}{FAR} =$$

$$A(E)\left[1 + |\eta_{000}|^2 e^{(\Gamma_L - \Gamma_S)t} + 2D(E) e^{\frac{1}{2}(\Gamma_L - \Gamma_S)t} \left(\mathrm{Re}\,\eta_{000} \cos \Delta m t - \mathrm{Im}\,\eta_{000} \sin \Delta m t\right)\right]$$

***D(E)* is the $K^0\,\bar{K}^0$ dilution (from NA31)**

$K_S \rightarrow 3\pi^0$



CPT TEST: $K_L \sim (\varepsilon+\delta_{CPT})K_1 + K_2$

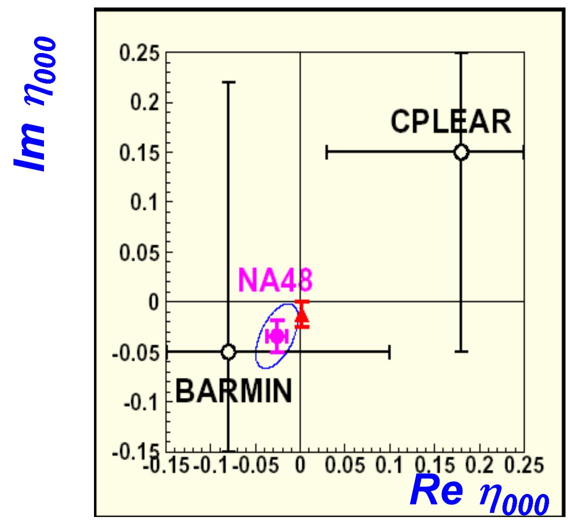
$K_S \sim K_1 + (\varepsilon-\delta_{CPT})K_2$

From the 2 parameter fit, using BS unitarity relation:

Im δ_{CPT} = $(-1.2 \pm 3.0) \times 10^{-5}$

Assuming CPT conservation in decay:

$M(K^0) - M(\overline{K^0}) = (-1.7 \pm 4.2) \times 10^{-19}$ GeV/c^2



From one parameter fit:

$BR(K_S \rightarrow 3\pi^0) < 3.0 \times 10^{-7}$ 90%CL

$BR_{SM} \sim 1.8 \times 10^{-9}$

First Observation of $K_S \to \pi^0 \gamma \gamma$

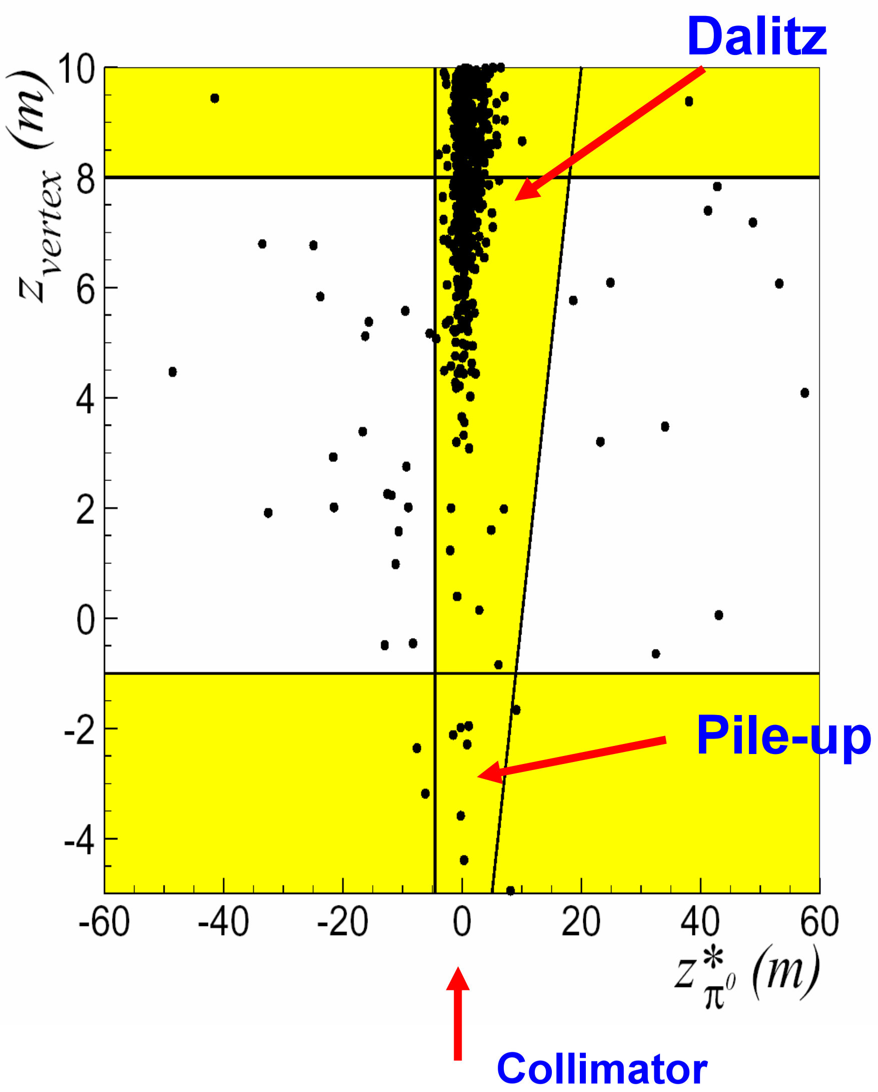
- The rejection of the Dalitz decays is complicated since no drift chambers were available in 2000
- Impose M_K to reconstruct decay vertex z_{vertex}
- Decays with missing particles are reconstructed downstream

Keep a short fiducial region:

$-1 < z_{vertex} < 8$ m

- $z_{\pi 0}$ = decay vertex reconstructed pairing 2 γ assuming a π^0 decay
- The $z_{\pi 0}$ closest to the exit of the collimator is $z^*_{\pi 0}$

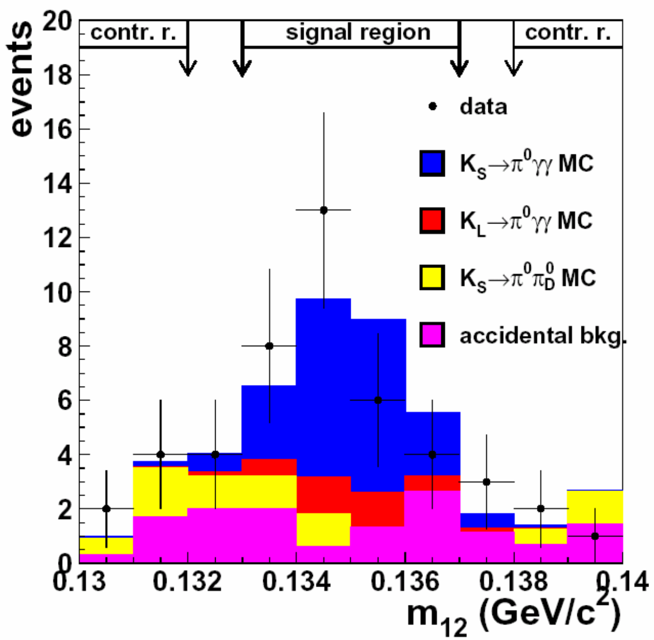
The events with small $z^*_{\pi 0}$ are rejected

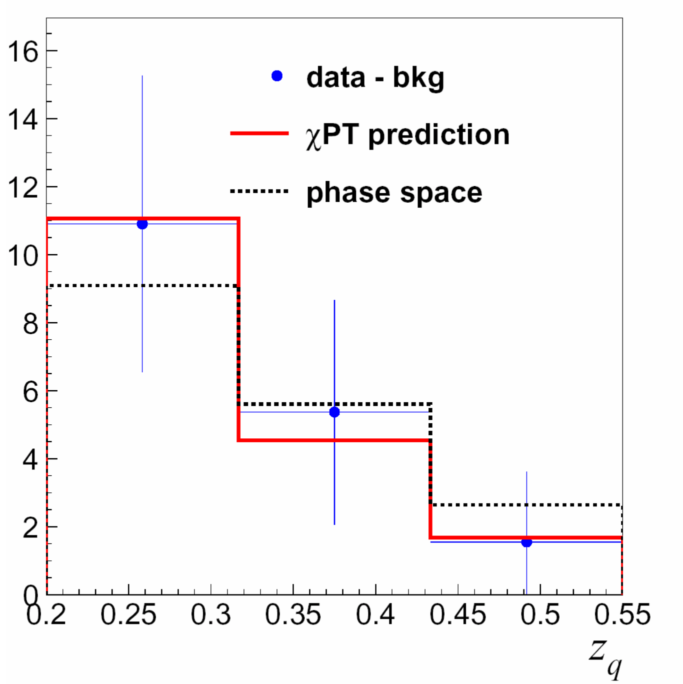


$K_S \to \pi^0\gamma\gamma$

first observation

CERN-EP/2003-052 (hep-ex/0309022)





$Z_q = q^2/M_K^2$

$$BR(K_S \to \pi^0\gamma\gamma,\ z_q > 0.2) = (4.9 \pm 1.8) \times 10^{-8}$$

CHPT predicts (Ecker, Pich and PLB 189 1987): $BR(K_S \to \pi^0\gamma\gamma)_{zq > 0.2} = 3.8 \times 10^{-8}$

Results from 2002 data

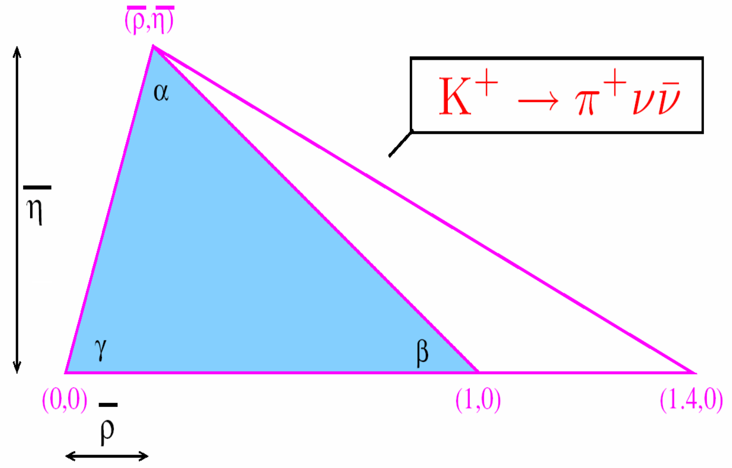
NA48/1 phase II

Kaon Rare Decays and the SM

CP-Violation

$K_L \rightarrow \pi^0 \nu \bar{\nu}$ **(holy grail)**

$K_L \rightarrow \pi^0 e^+ e^- \left\{ \begin{array}{l} K_S \rightarrow \pi^0 e^+ e^- \\ K_L \rightarrow \pi^0 \gamma\gamma \\ K_L \rightarrow ee\gamma\gamma \end{array} \right.$



$K_L \rightarrow \mu^+ \mu^- \left\{ \begin{array}{l} K_L \rightarrow \gamma\gamma,\ K_L \rightarrow e^+ e^- \gamma \\ K_L \rightarrow e^+ e^- e^+ e^-,\ e^+ e^- \mu^+ \mu^- \end{array} \right.$

J_{CP}=2×(Triangle Area) **is the unique measure of CP-Violation in SM**

$J_{CP} = Im(V_{ud}^* V_{us} V_{ts}^* V_{td}) \sim \cos\theta_c \sin\theta_c\ Im\ \lambda_t$

In the Wolfenstein parameterisation (λ, A, $\overline{\eta}$, $\overline{\rho}$):

$Im\ \lambda_t = A^2 \lambda^5 \overline{\eta}, \qquad Re\ \lambda_t = A^2 \lambda^5 \overline{\rho}$

$K_{L,S} \to \pi^0 ee\ (\mu\mu)$

- **Short Distance (Direct CP-Violation)**
  - From Standard Model fit: $Im\ \lambda_t = (1.36 \pm 0.12)\ 10^{-4}$
  - $B(K_L \to \pi^0 ee)_{CPV\text{-}dir} = (3.2 \pm 0.4) \times 10^{-12}$ (hep-ph/0308008)
- **Indirect CP-Violation**
  - $BR(K_L \to \pi^0\ ee)_{CPV\text{-}ind} \sim 1/330\ BR(K_S \to \pi^0\ ee)$

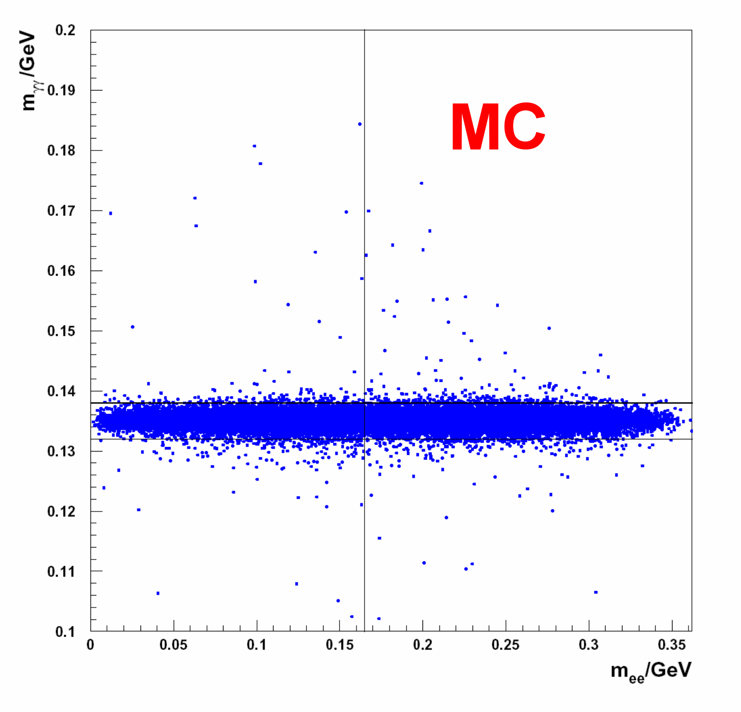
➡ **Essential to measure $BR(K_S \to \pi^0\ ee)$**

- **CP-Conserving contribution**
  - $BR_{CPC} < 3 \times 10^{-12}$ (hep-ph/0308008)
    - They fix the 3 counter-terms from $K_L \to \pi^0 \gamma\gamma$ and $K_S \to \gamma\gamma$

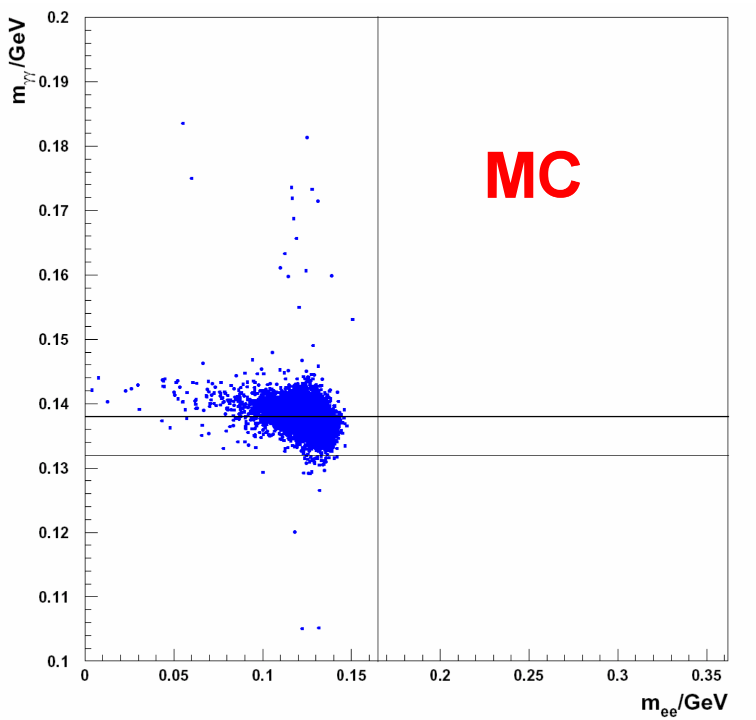
measured by NA48 and NA48/1

$K_S \to \pi^0 ee$

$K_S \to \pi^0 ee$



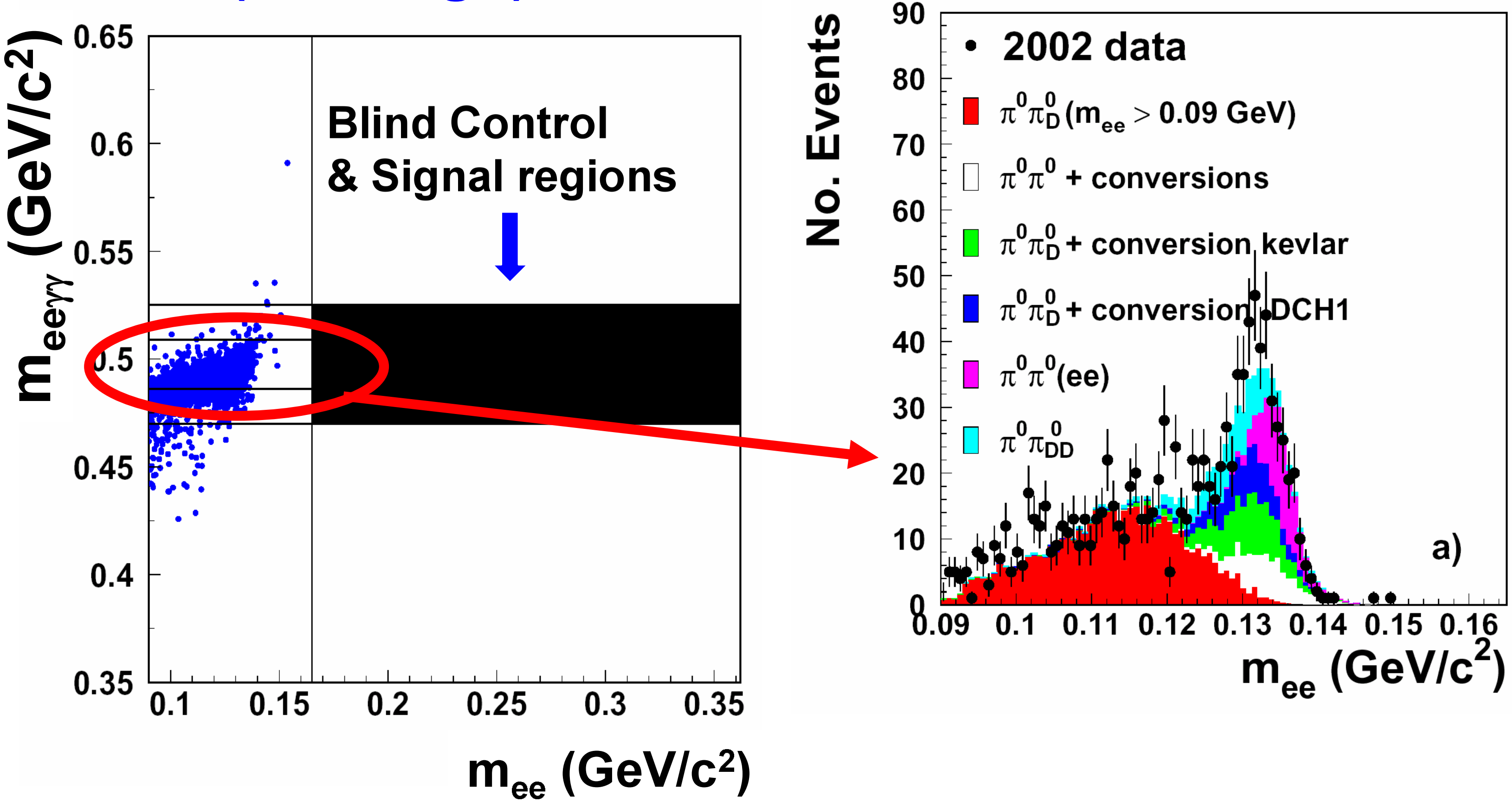
$K_S \to \pi^0 \pi^0_D \to \gamma\gamma ee(\gamma)$



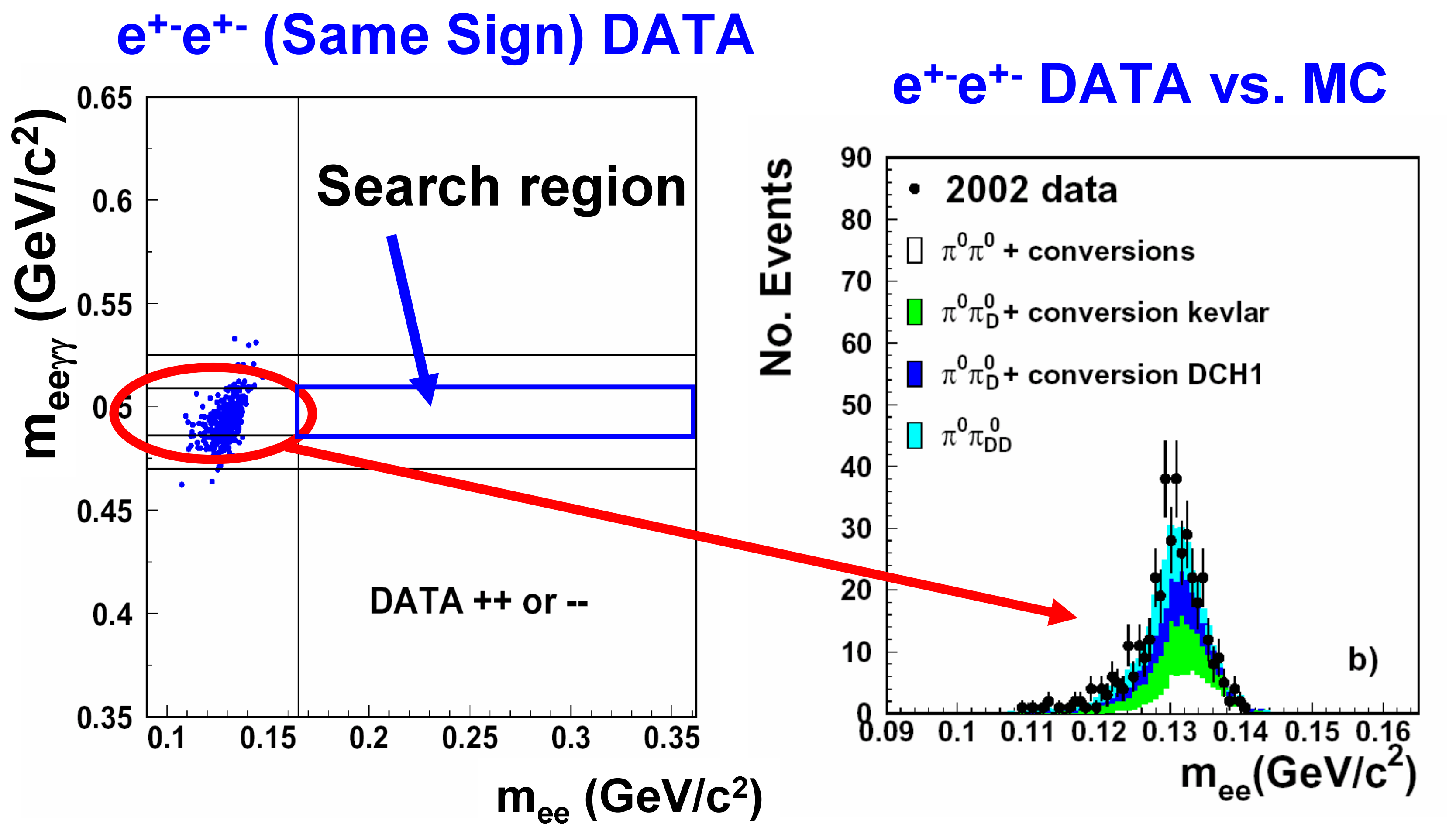
- **To reject the $K_S \to \pi^0 \pi^0_D$ decays that may mimic $K_S \to \pi^0 ee$ if a γ is lost, a cut $m_{ee} > 0.165\ GeV/c^2$ is applied**

$K_S \rightarrow \pi^0 ee$

$e^{+-}e^{-+}$ (Odd Sign) DATA | $e^{+-}e^{-+}$ DATA vs. MC



$K_S \to \pi^0 ee$



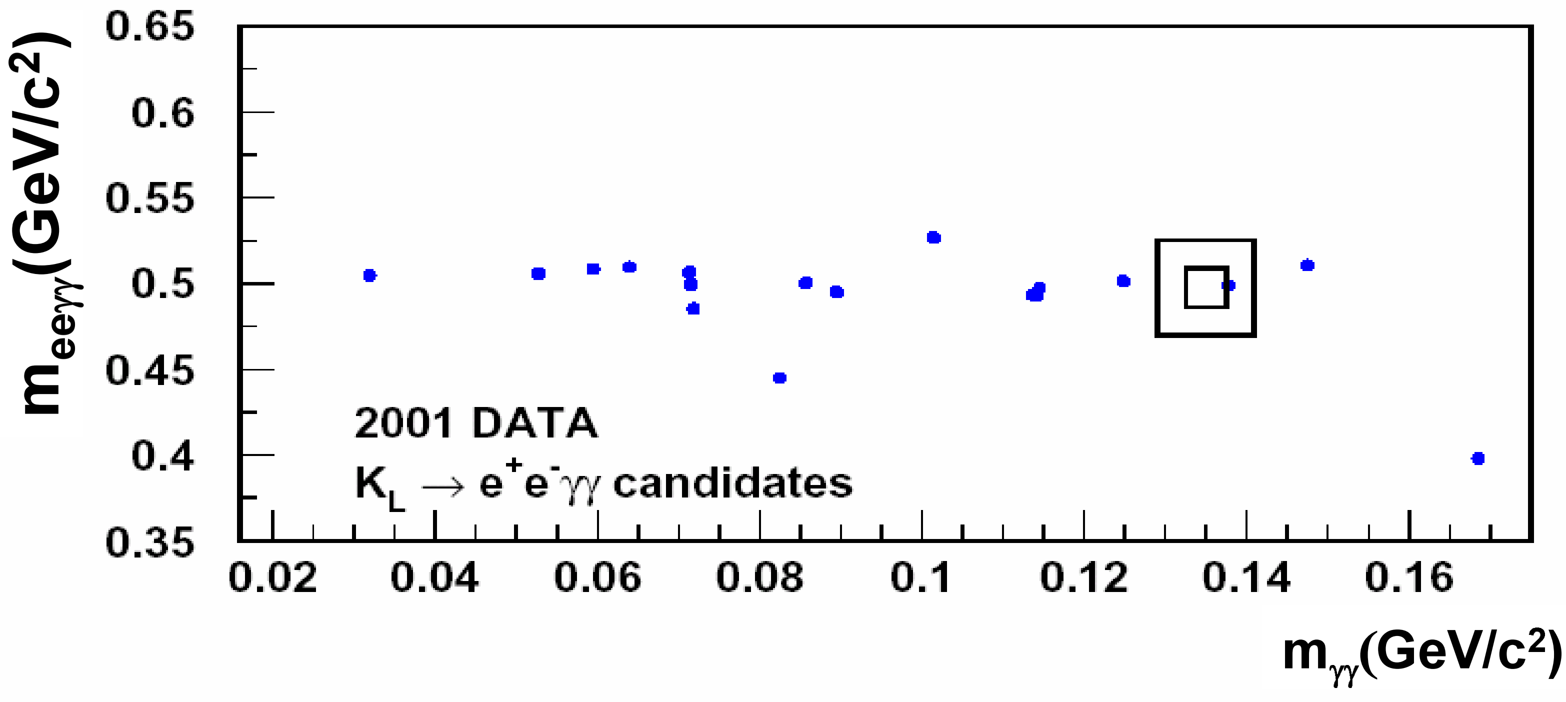
e+-e+- (Same Sign) DATA
Search region
DATA ++ or --
m_eeγγ (GeV/c²)
m_ee (GeV/c²)
e+-e+- DATA vs. MC
No. Events
2002 data
π0π0 + conversions
π0π0D + conversion kevlar
π0π0D + conversion DCH1
π0π0DD
b)
m_ee (GeV/c²)

$K_S \to \pi^0\, ee$

Background from $K_{L,S} \to ee\gamma\gamma$:

measured using NA48 K_L data from 2001

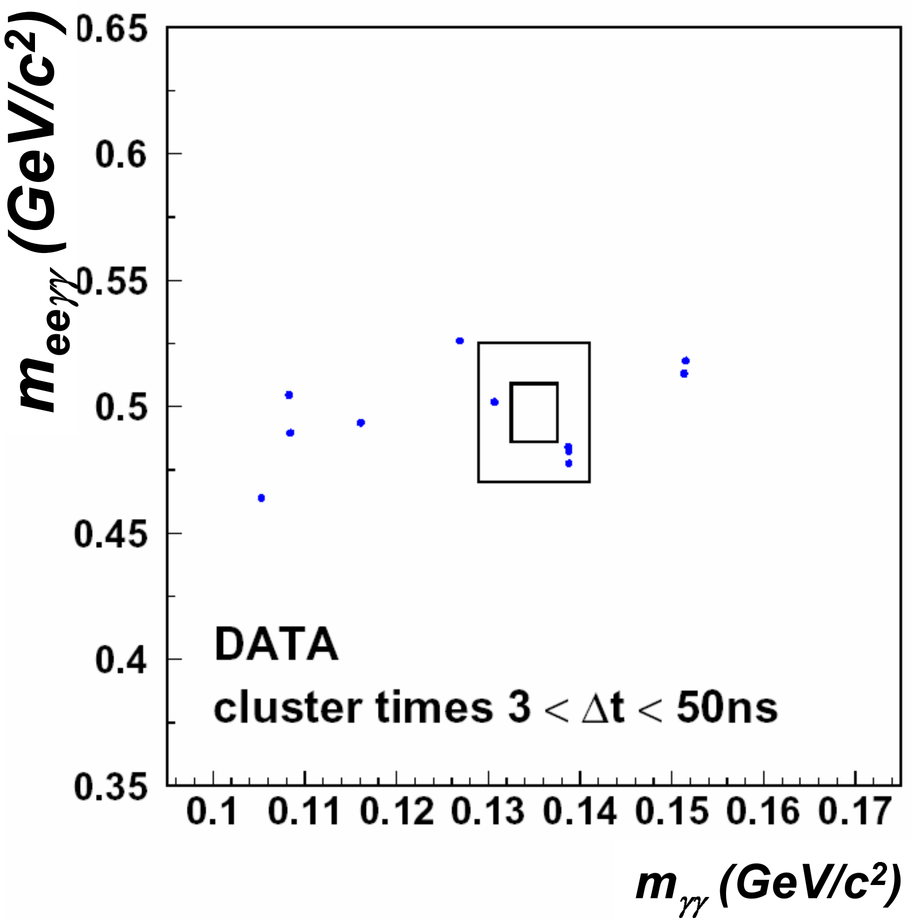
$N(K_L \to ee\gamma\gamma,\ 2001) \approx 10 \times N(K_{L,S} \to ee\gamma\gamma,\ 2002)$



$K_S \rightarrow \pi^0$ ee

Accidental backgrounds

- DC proton beam
- Read out window: ~ 200ns
- Use time side band to measure background from time-overlapping fragments from differ decays
- Major component:
  - $e\pi\nu + \pi^0(\pi^0)$
  - Confirmed relaxing E/P cuts



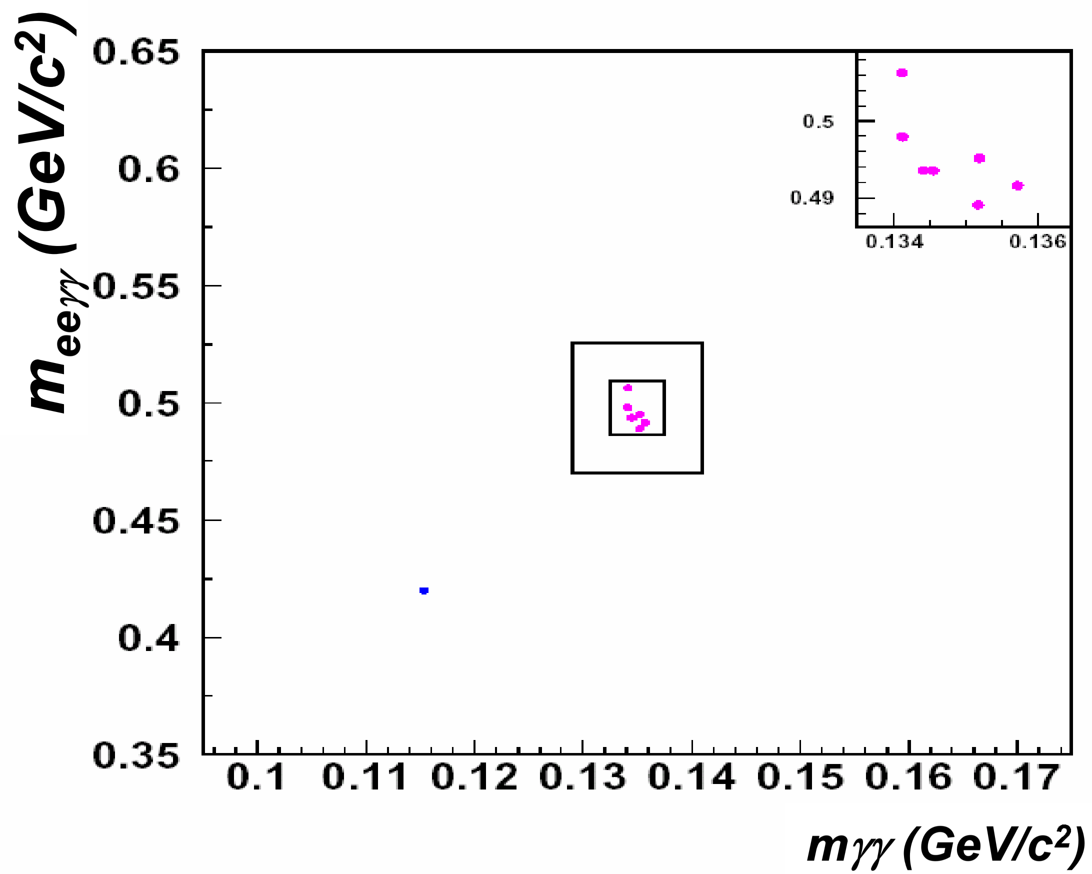
$K_S \rightarrow \pi^0 ee$

SUMMARY OF BACKGROUNDS:

Source	Control Region	Signal region
$K_S \rightarrow \pi^0_D \pi^0_D$	0.03	<0.01
$K_{L,S} \rightarrow ee\gamma\gamma$	0.11	0.08
$\pi e \nu + \pi^0(\pi^0)$	0.19	0.07
Total	0.33	$0.15^{+0.10}_{-0.04}$

- Many other sources investigated and found to be negligible (e.g. neutral cascade decays)
- Blind analysis: Control and signal region remained masked until the study of the background was finished

$K_S \to \pi^0$ ee



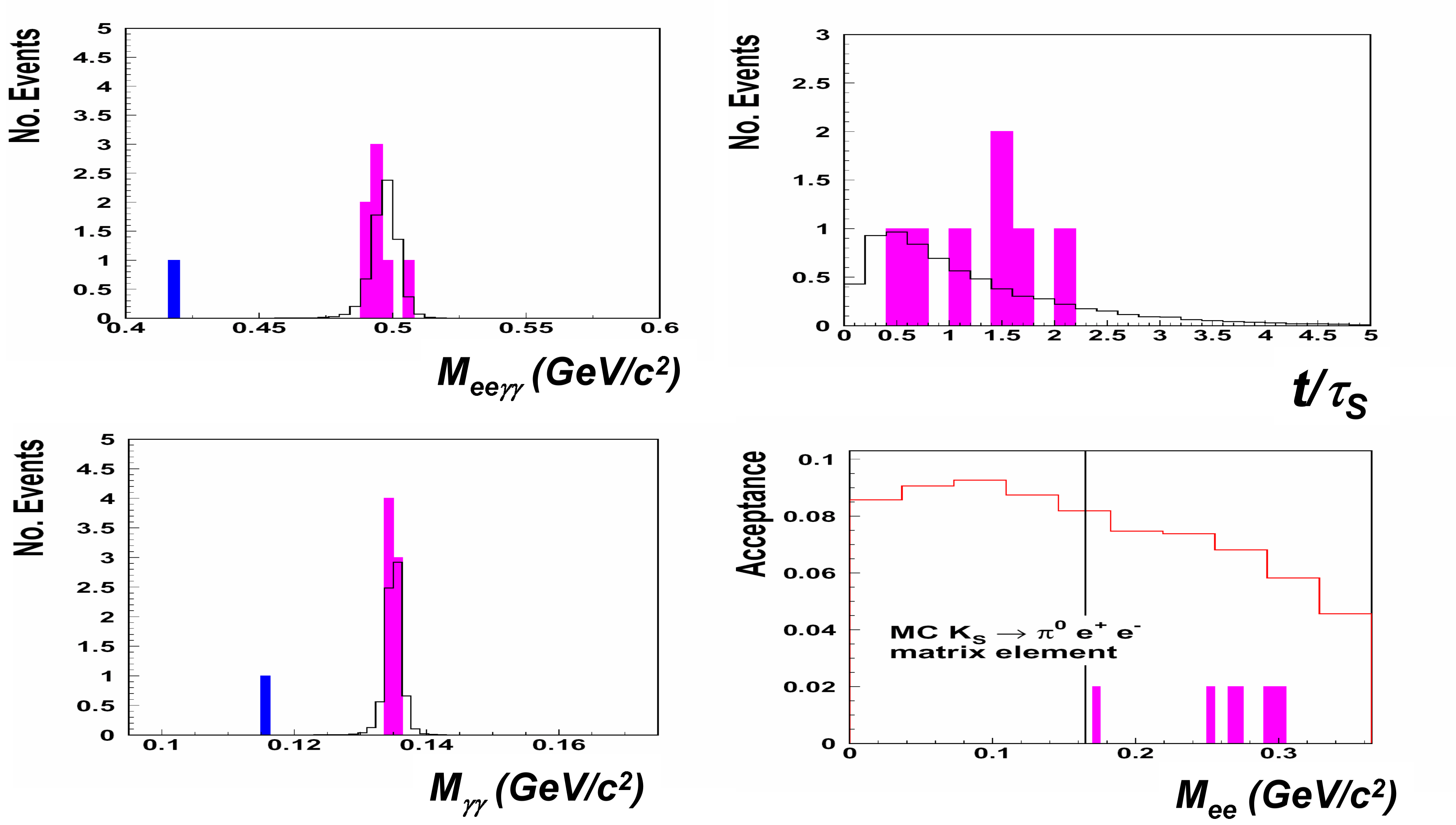
- **7 candidates in the signal region**

- **0 in control region**
- **Background 0.15**

The probability that all 7 events are background is ~10^{-10}

First observation of $K_S \to \pi^0$ ee

The 7 $K_S \to \pi^0 ee$ candidates



$K_S \to \pi^0 ee$

Accepted for publication by PLB

$$BR(K_S \to \pi^0 ee,\ m_{ee} > 165\ MeV/c^2) = (3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}$$

- Assuming vector interaction and unity form factor:

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

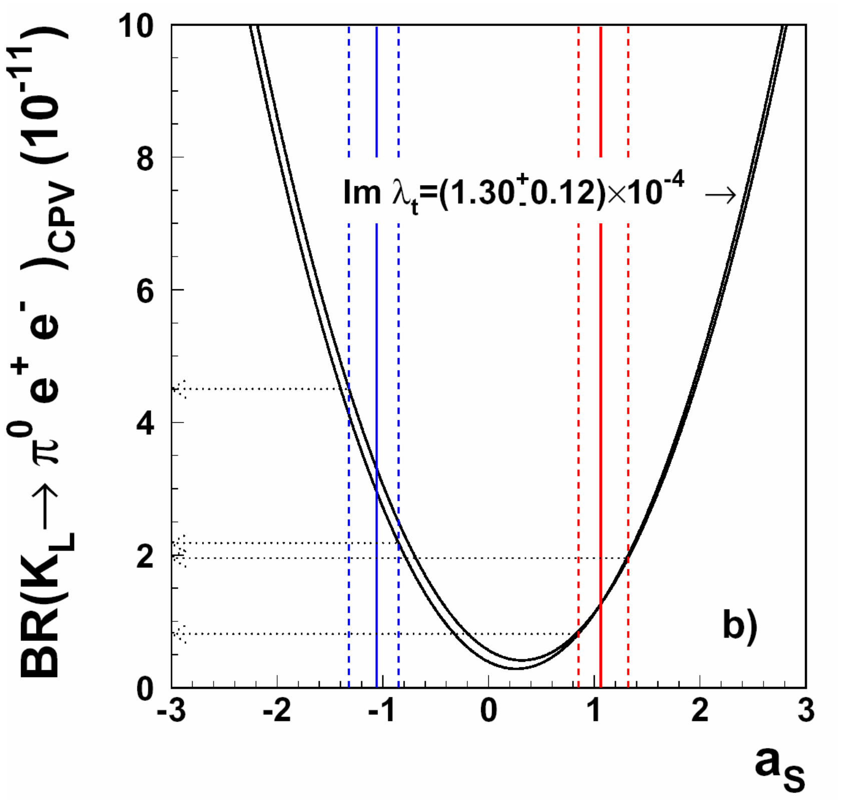
  – In remarkable agreement with L. Sehgal prediction: ~5.5 $\times 10^{-9}$ NP B19 (1970)

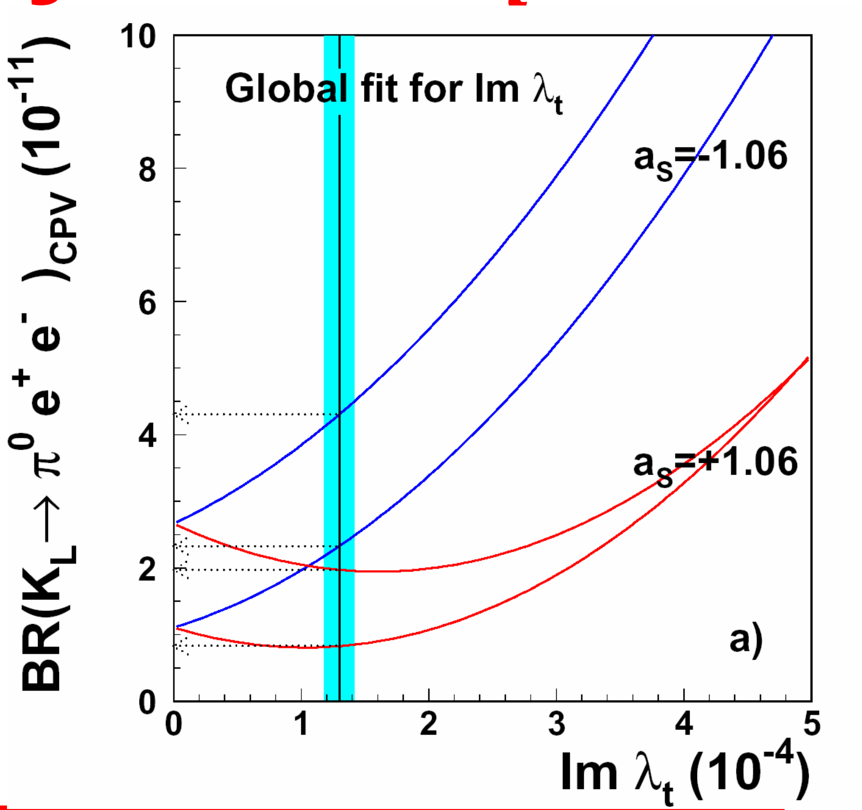
  – In the notation of D'Ambrosio et al. JHEP 08 (1998 004):

  – $BR(K_S \to \pi^0 ee) \sim 5\ |a_s|^2$

$$|a_s| = 1.06^{+0.26}_{-0.21}\ (stat) \pm 0.05\ (syst)$$

Sensitivity to *Im* λ_t

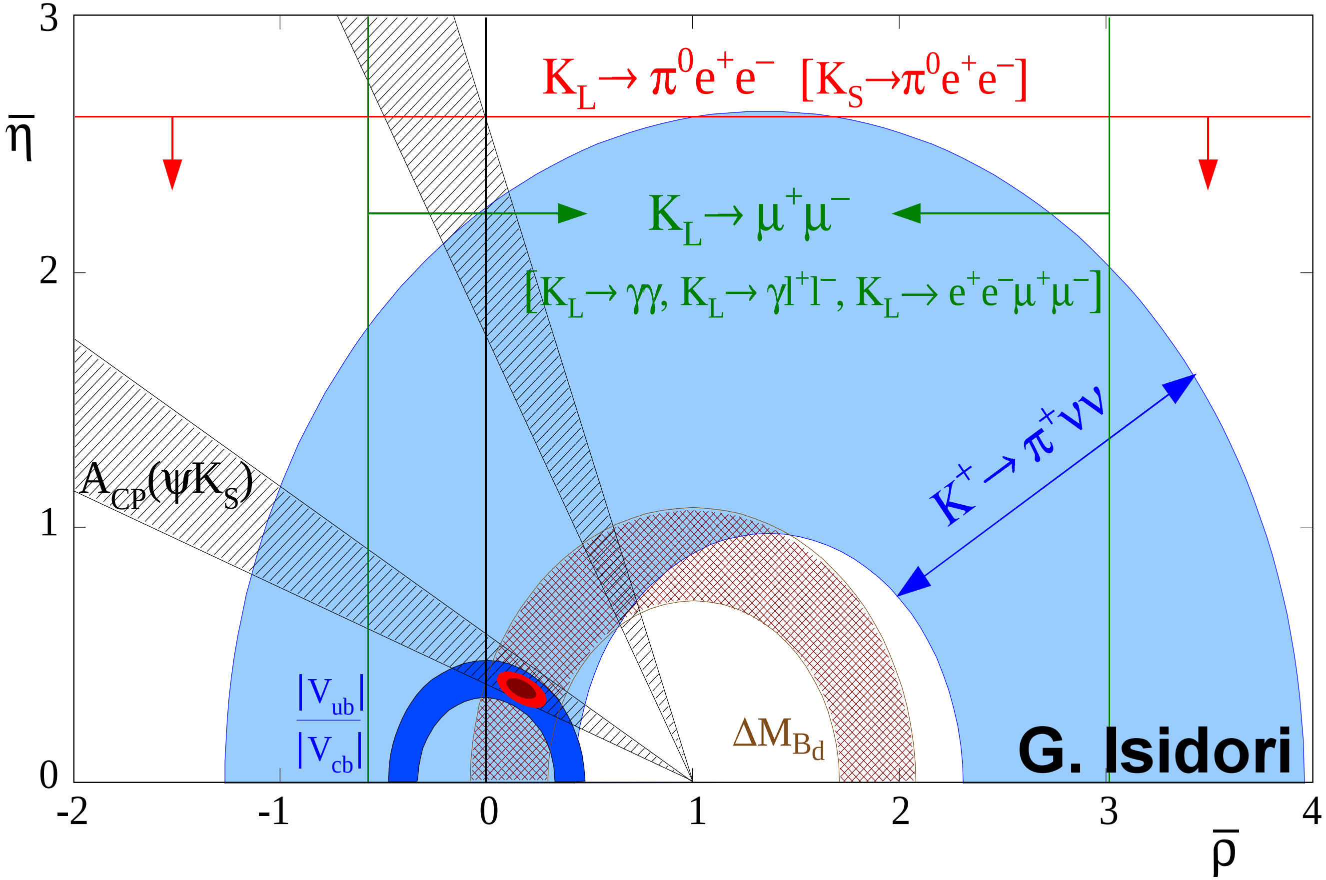




$$B(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{12} \approx 15.3 a_s^{\,2} - 6.8 a_s \frac{\mathrm{Im}(\lambda_t)}{10^{-4}} + 2.8 \left(\frac{\mathrm{Im}(\lambda_t)}{10^{-4}}\right)^2$$

IF the interference is constructive some sensitivity to *Im* λ_t is retained

The overall picture



STILL A LARGE WINDOW OF OPPORTUNITY EXISTS

NEW RESULT!!

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

Search for $K_S \to \pi^0 \mu\mu$

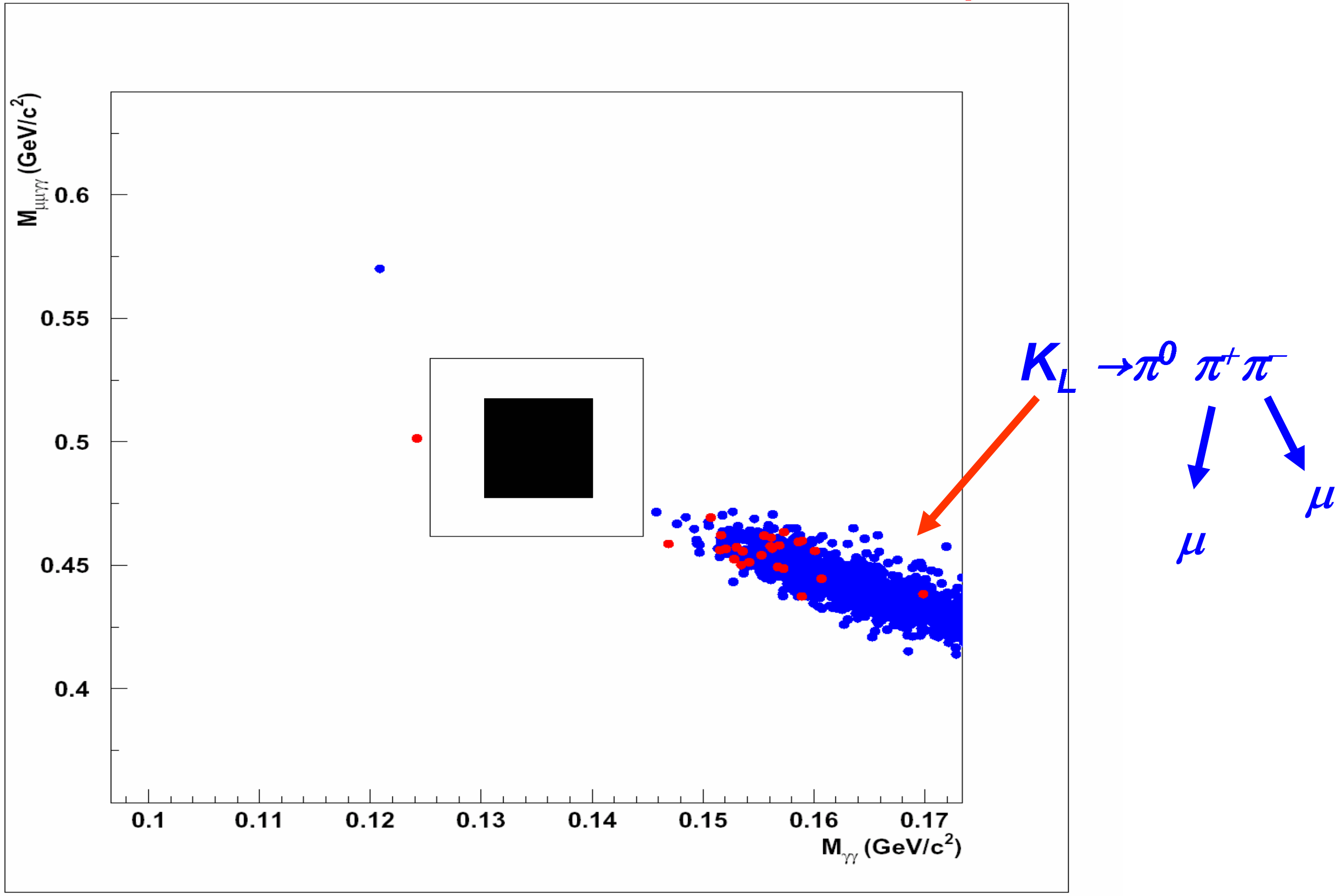
- The considerations made before for $K_L \to \pi^0 ee$ apply also to $K_L \to \pi^0 \mu\mu$ but the CP-conserving contributions need more attention
- A measurement of $K_S \to \pi^0 \mu\mu$ is quite complementary to the $K_S \to \pi^0 ee$ one
  - Different backgrounds
  - Larger acceptance (no Dalitz background)
  - In principle one can relate $K_S \to \pi^0 \mu\mu$ and $K_S \to \pi^0 ee$ to extract the form factor (for example the a_S and b_S parameters)

Backgrounds to $K_S \to \pi^0 \mu\mu$

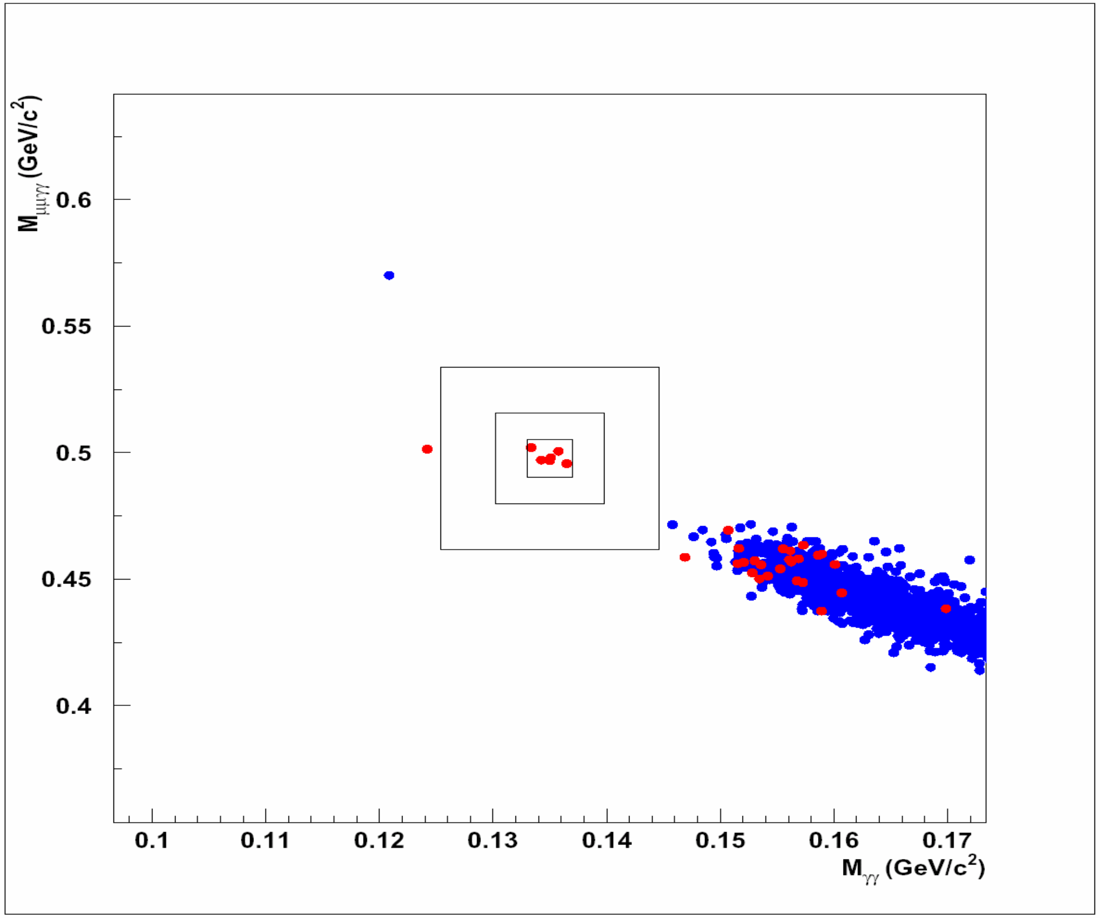
Source of Background	Expectation in signal region (# events)
$K_L \to \pi^+\pi^-\pi^0$	---
$K_{L,S} \to \mu^+\mu^-\gamma\gamma$	0.04
Neutral hyperons	---
Accidentals	0.20
In time background	---
Total	0.24

Ready to open box?

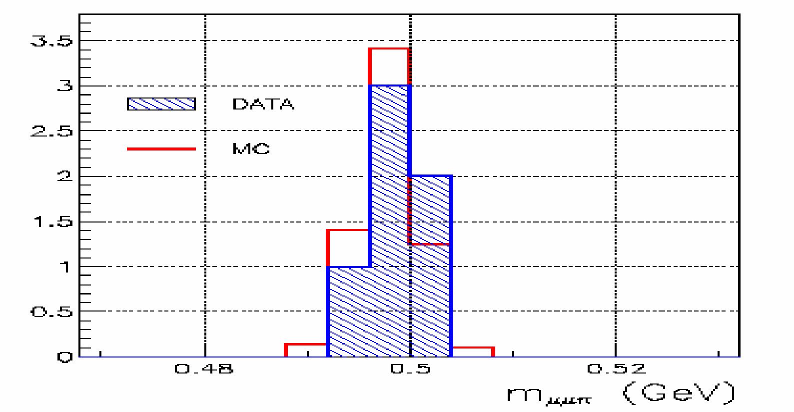
The red dots are the events passing $0 < \tau_K < 3\,\tau_S$

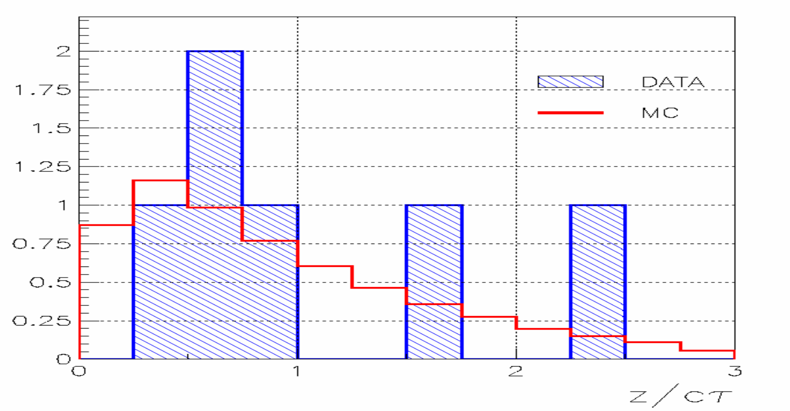


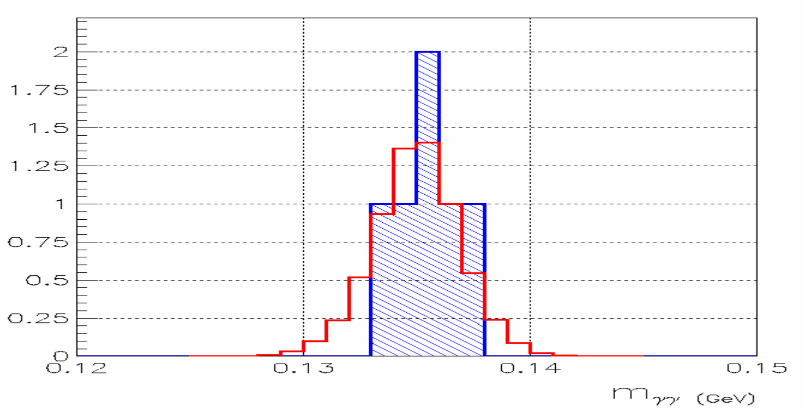
Six candidates!!



The six $K_S \to \pi^0 \mu\mu$ candidates







- Consistent with signal
- Measurement of BR in progress

Neutral hyperons

Admittedly, the run 2002 has not been optimised for hyperon physics:

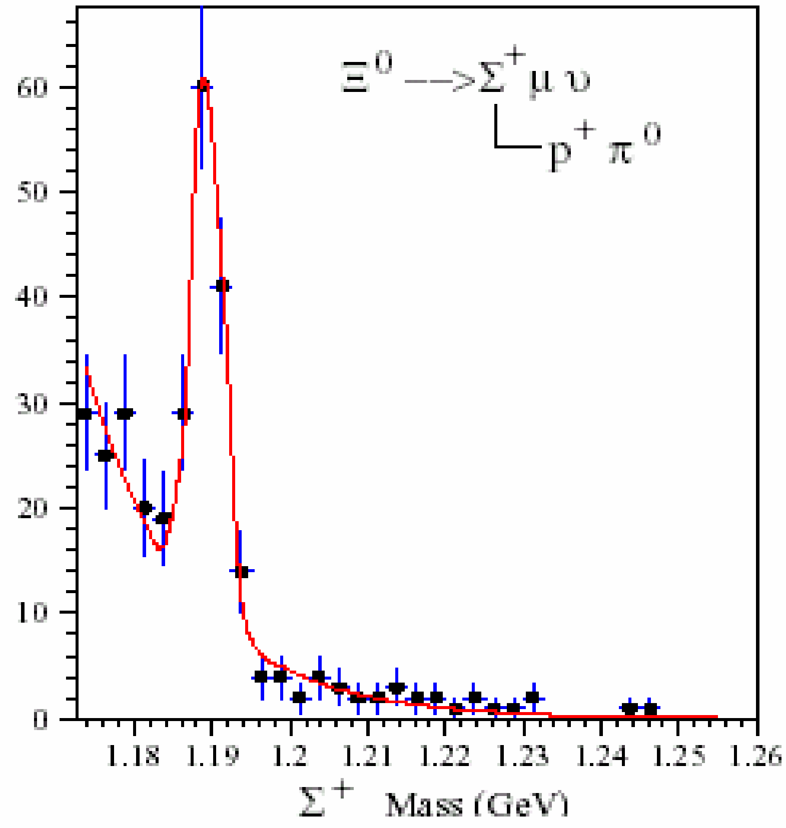
1. The production angle was not chosen to maximise the hyperon flux
2. There was no provision to rotate and flip the hyperon polarisation
3. The acceptance was limited by the lack of tracking in the beam pipe volume
4. A very selective trigger was employed to keep rate within assigned bandwidth
5. Large downscaling factor for the minimum bias was used for the same reason

Nevertheless:

- We accumulated a sample of semi-leptonic Ξ^0 decays which is at least four times the whole world statistics
- We have the first convincing observation of the decay $\Xi^0 \rightarrow \Sigma^+ \mu^- \nu$
- We have accumulated a high-statistic sample of Ξ^0 radiative decays

First Observation

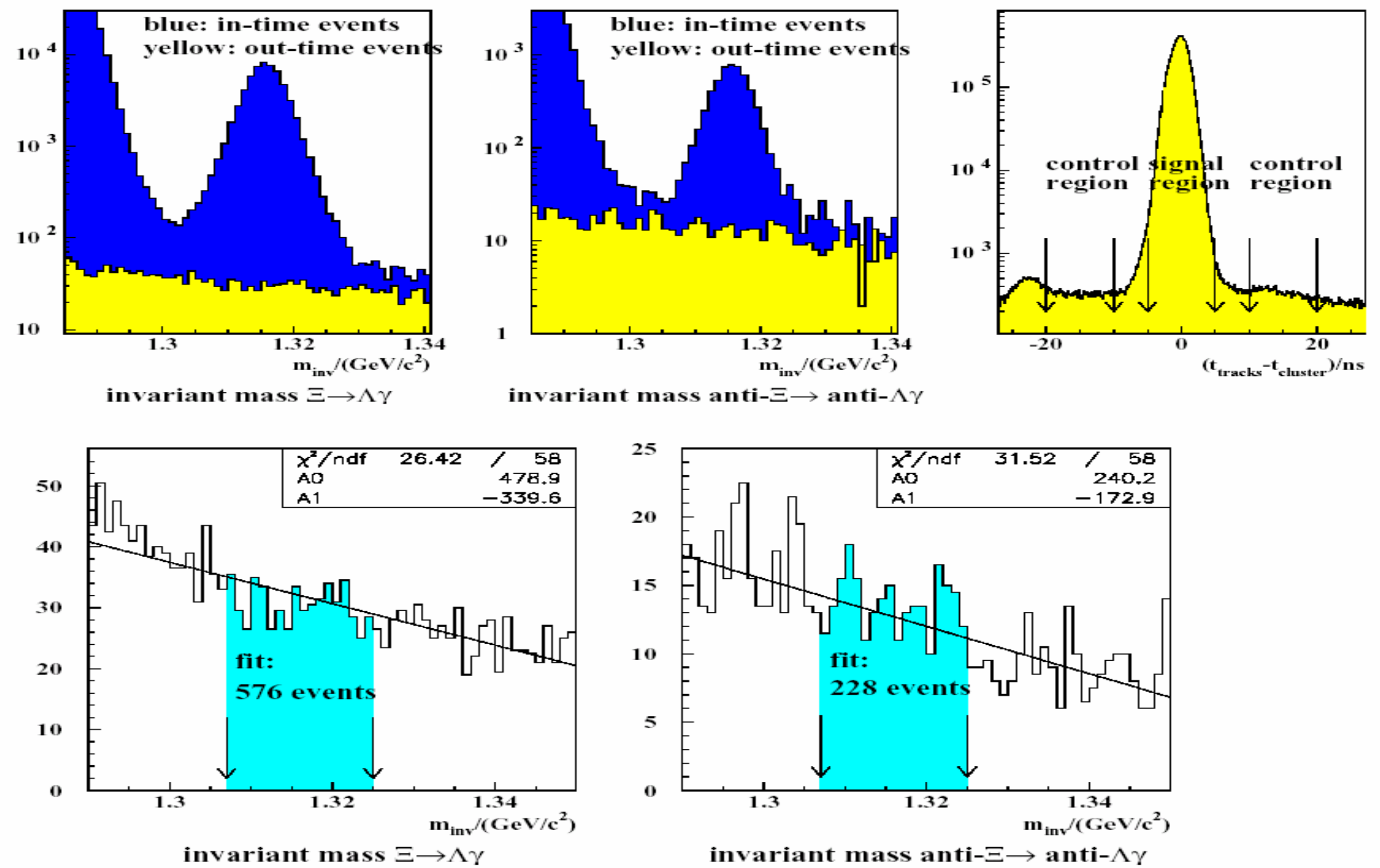
$$\Xi^0 \rightarrow \Sigma^+ \mu^- \nu$$



- The β decay of Ξ^0 is the only source of Σ^+ in the neutral beam
- The plot shows the $p\pi^0$ invariant mass for decays with one identified μ

Radiative decays: $\Xi^0 \to \Lambda \gamma$

- Precise measurement of decay asymmetry of $\Xi^0 \to \Lambda \gamma$ underway
- Nature of backgrounds under study



Outlook

- The analysis of the 2000 data is almost completed
- We are publishing the first observation of $K_S \rightarrow \pi^0 ee$ which was the main motivation of the 2002 run:
  - Indirect CP-violation in $K_L \rightarrow \pi^0 ee$ $(\mu\mu)$ is large and cannot be neglected!
  - To study the form-factor is interesting but significantly larger statistics should be accumulated
- The analyses of the neutral hyperon decays are advancing