New results from NA48 on rare neutral K decays
$K_L \to \pi^0\gamma\gamma$ and $K_{L,S} \to \pi^+\pi^-e^+e^-$

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Outline

- NA48 beam and detector

- $\mathrm{K_L} \to \pi^0\gamma\gamma$
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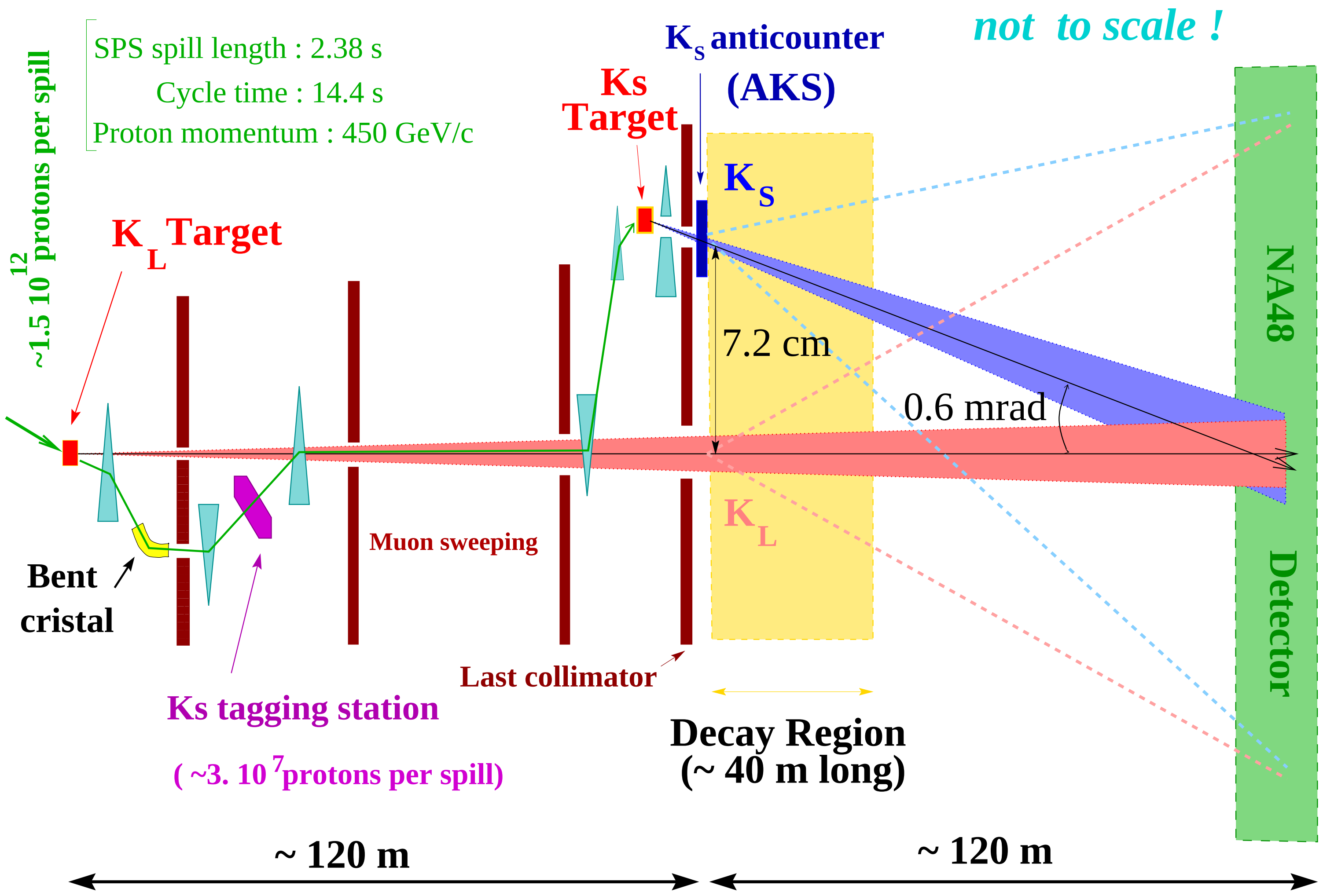
  - Selection criteria
  - Background rejection
  - Results

- $\mathrm{K_{L,S}} \to \pi^+\pi^-\mathrm{e^+e^-}$
  - Motivation
  - Selection criteria
  - Background rejection
  - Results for $\mathrm{K_L} \to \pi^+\pi^-\mathrm{e^+e^-}$
  - First evidence of $\mathrm{K_S} \to \pi^+\pi^-\mathrm{e^+e^-}$

- Conclusion

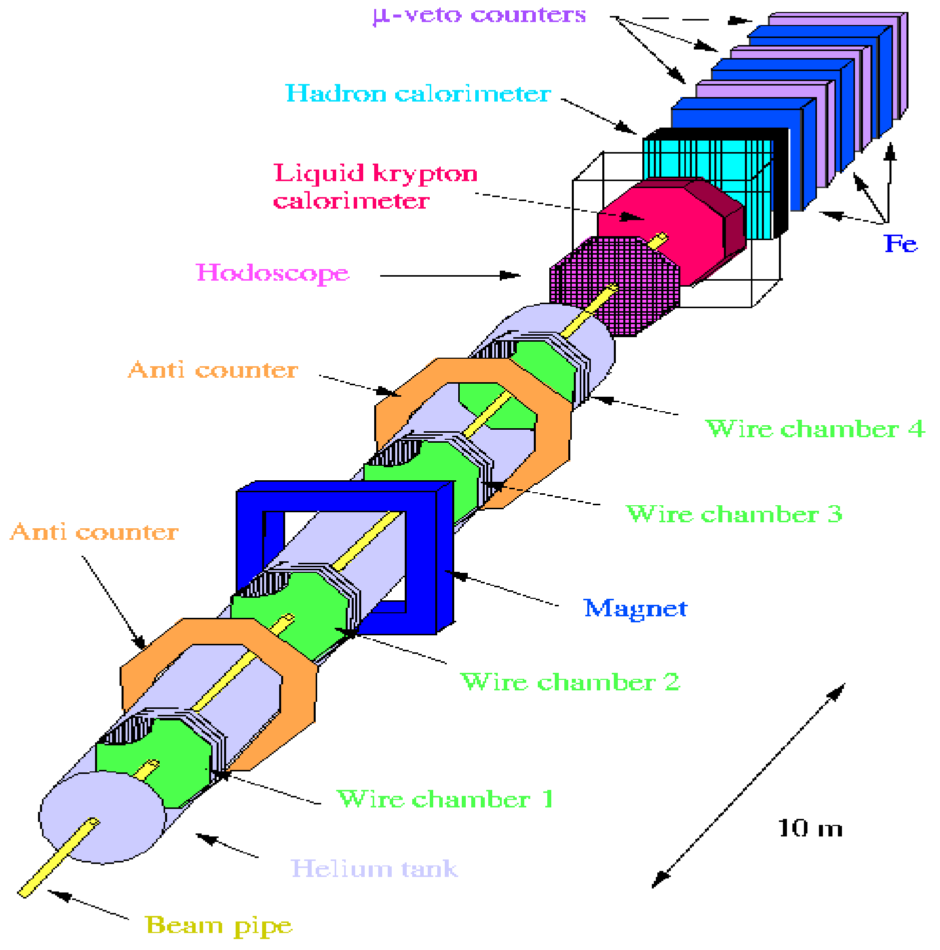
The NA48 Simultaneous K_S and K_L Beams



K_S are distinguished from K_L by tagging the time of flight of protons upstream of the K_S target

Experiment designed for measuring $\mathrm{Re}(\varepsilon'/\varepsilon)$

The NA48 Detector



- **Magnetic Spectrometer:**
  - $\sigma(p)/p \simeq 0.5\,\% \oplus 0.009\,p[GeV/c]\,\%$
  - $\sigma_{X,Y} = 100\ \mu m$
- **Liquid Krypton Calorimeter:**
  - high granularity (13212 $2 \times 2\,cm^2$ cells)
  - $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (100\,MeV)/E \oplus 0.5\%$
  - $\sigma(t) \simeq 265\,ps$ for $50\ GeV\ e^-$
  - $\sigma_{X,Y} = 1\,mm$

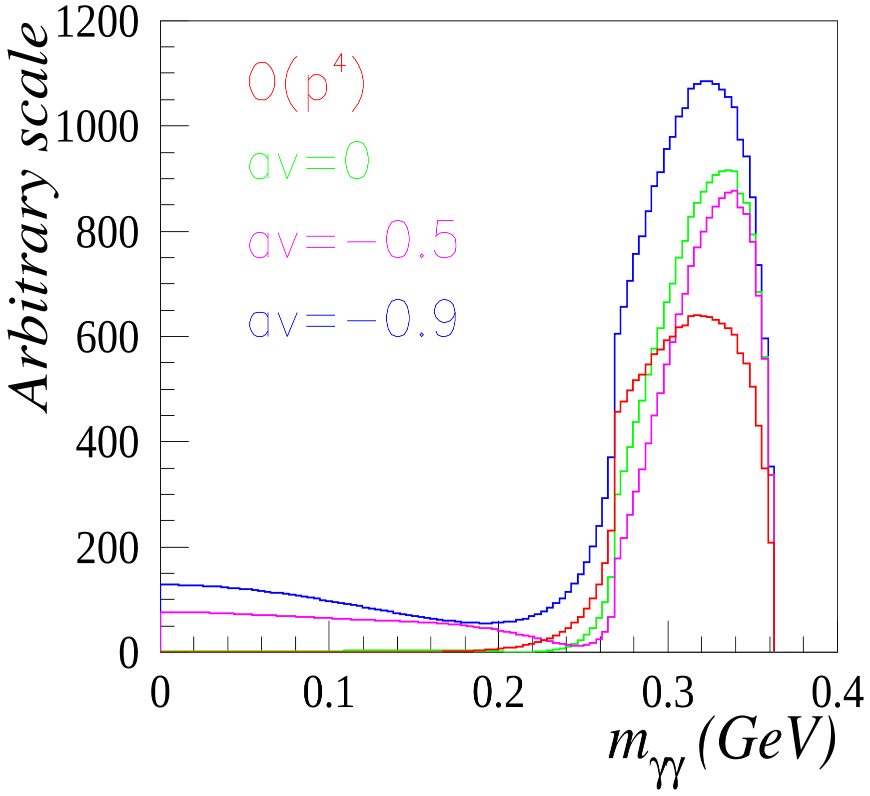
$\mathrm{K_L} \to \pi^0\gamma\gamma$: *Physics motivation*

- To verify the predictions of Chiral Perturbation Theory (χPT)

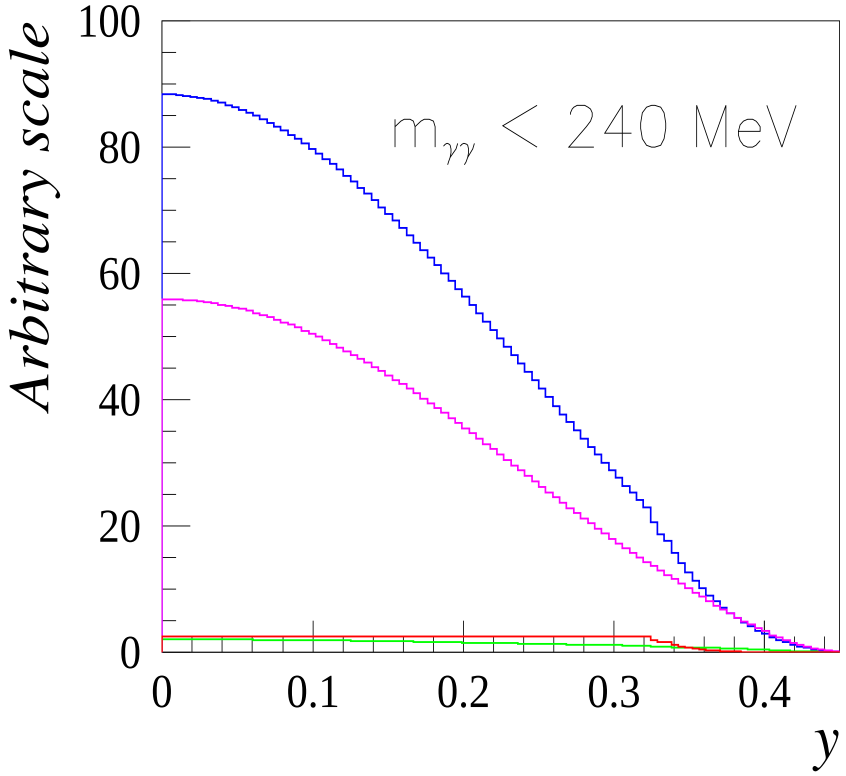
  - branching ratio and spectra of kinematic variables are not predicted together by χPT without introducing a contribution from Vector Meson Dominance
  - VMD relative strength is expressed by A_V parameter
  - bounds must be put on A_V experimentally
  - enhancement expected in $m_{\gamma\gamma}$ spectrum for $m_{\gamma\gamma} < 240\,MeV$ if $A_V \neq 0$

- To estimate $\mathrm{K_L} \to \pi^0\gamma\gamma$ CP-conserving amplitude via $\mathrm{K_L} \to \pi^0\gamma^*\gamma^* \to \pi^0 e^+e^-$

$K_L \to \pi^0\gamma\gamma$: *Physics motivation*

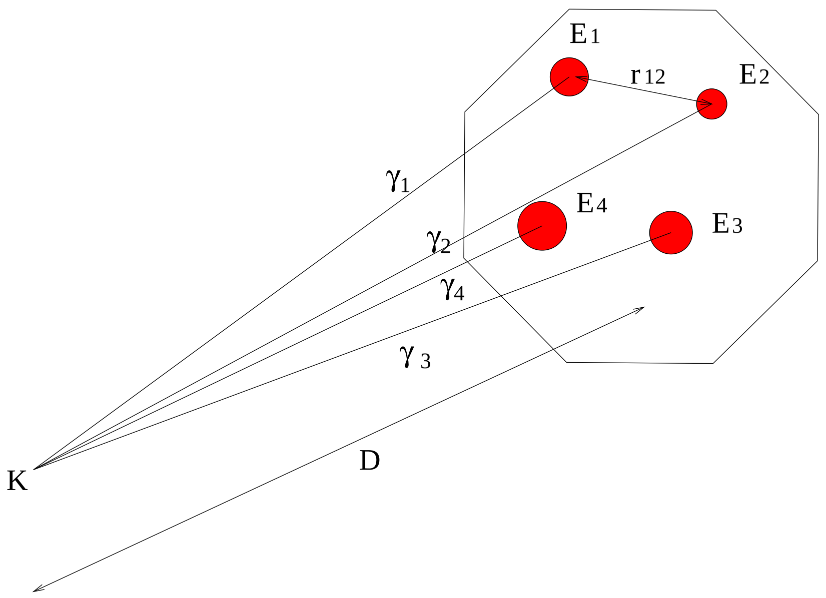


$m_{\gamma\gamma}$



$y = |E_{\gamma_1} - E_{\gamma_2}|/m_K$

NA48: The neutral reconstruction



- Reconstruction of $K_{\mathrm{L,S}} \to 2\pi^0 \to 4\gamma$
  - Vertex position along beam line found by imposing kaon mass

$$D = Z_{LKr} - Z_{decay} =$$
$$= \sqrt{\sum (E_i E_j \times r_{ij})^2} \; / M_K$$

  - Pairing the photons to get the best π^0 combination

$$m_{ij} = \sqrt{E_i E_j \; r_{ij})^2} / D$$

  - Resolution on π^0 mass = 1 MeV

$K_L \to \pi^0\gamma\gamma$: *Event selection*

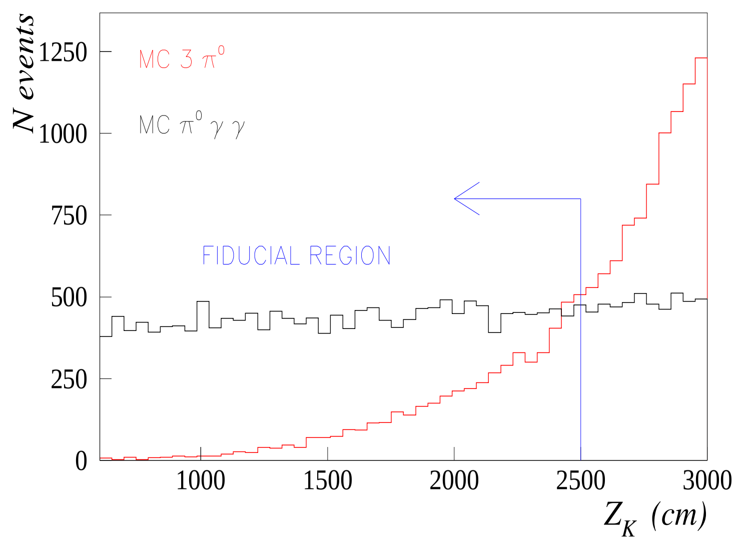
- Trigger requirements:
  - $E_{LKR} > 50\ GeV$
  - $c\tau_K < 4.5\ c\tau_{K_s}$
  - centre of gravity within 15 cm of beam axis
  - less than 6 gammas/projection (standard NA48 neutral trigger, efficiency for $2\pi^0 = 99.95\%$)

- Selection criteria:
  - $125 < m_{\pi^0} < 145\ MeV$
  - $m_{\gamma\gamma} < 130$ or $m_{\gamma\gamma} > 140\ MeV$
  - kaon selected as K_S by tagger
  - cluster energy $> 3\ GeV$
  - only 4 good clusters in time with the event
  - $70 < E_K < 170\ GeV$

$\mathrm{K_L} \rightarrow \pi^0\gamma\gamma$: *Background rejection*

- $\mathrm{K_L} \rightarrow \pi^0\pi^0$ background:
  Due to γ conversions or mis-reconstruction
  $\Rightarrow \chi^2_{2\pi^0} > 100$
  $\Rightarrow$ no DCH hits in time with the event
- $\mathrm{K_L} \rightarrow \pi^0\pi^0\pi^0$ background:

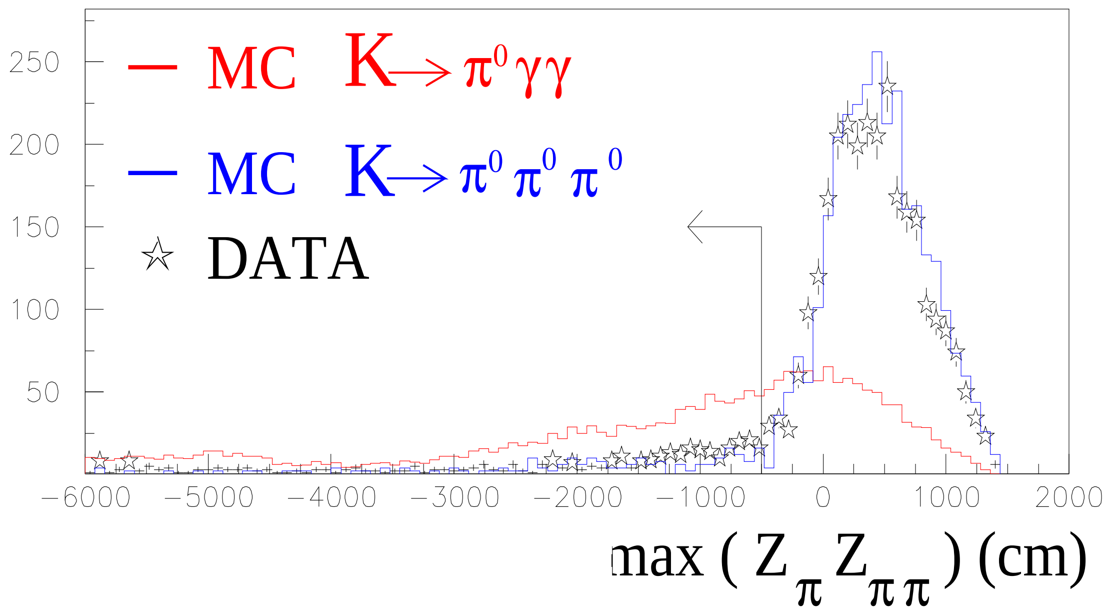
1) Due to lost γ(s):
   Position of the vertex overestimated
   $\Rightarrow$ No hits in the ring-vetoes in time with the event
   $\Rightarrow Z_{coll} < Z_K < 2500\ cm$



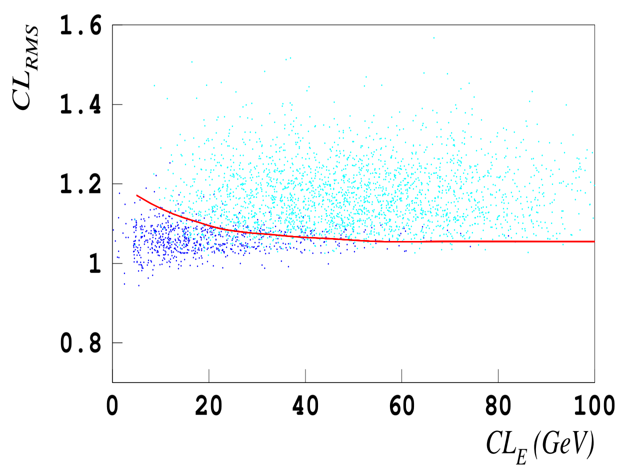
$K_L \to \pi^0\gamma\gamma$: *Background rejection*

- $K_L \to \pi^0\pi^0\pi^0$ background: (continued)

2) Due to overlapping γs:
π^0 mass hypothesis used to reject events with $Z_{\gamma\gamma}$ upstream of the kaon vertex



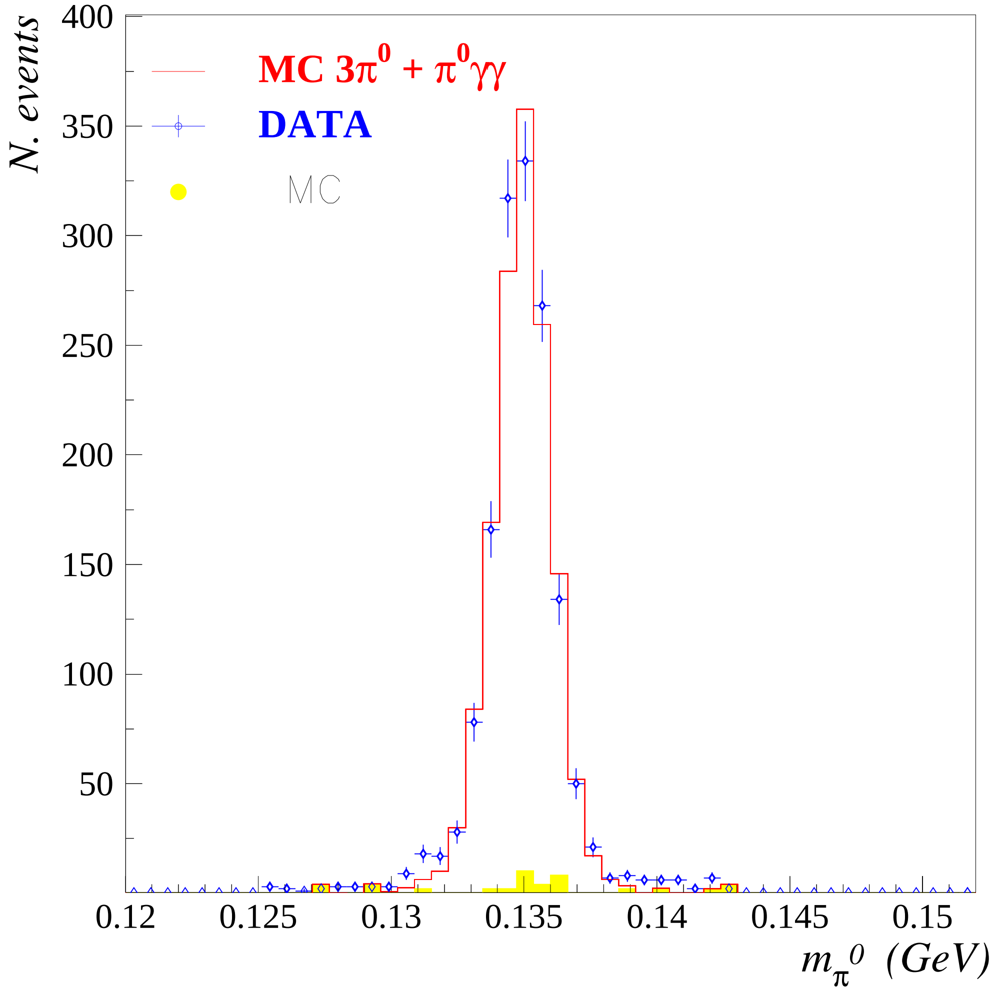
⇒ reject events with π^0 decay in the collimator zone



⇒ Cut on cluster RMS vs energy

$\mathrm{K_L} \to \pi^0\gamma\gamma$: *Result*

Preliminary (99 + fraction of 98)



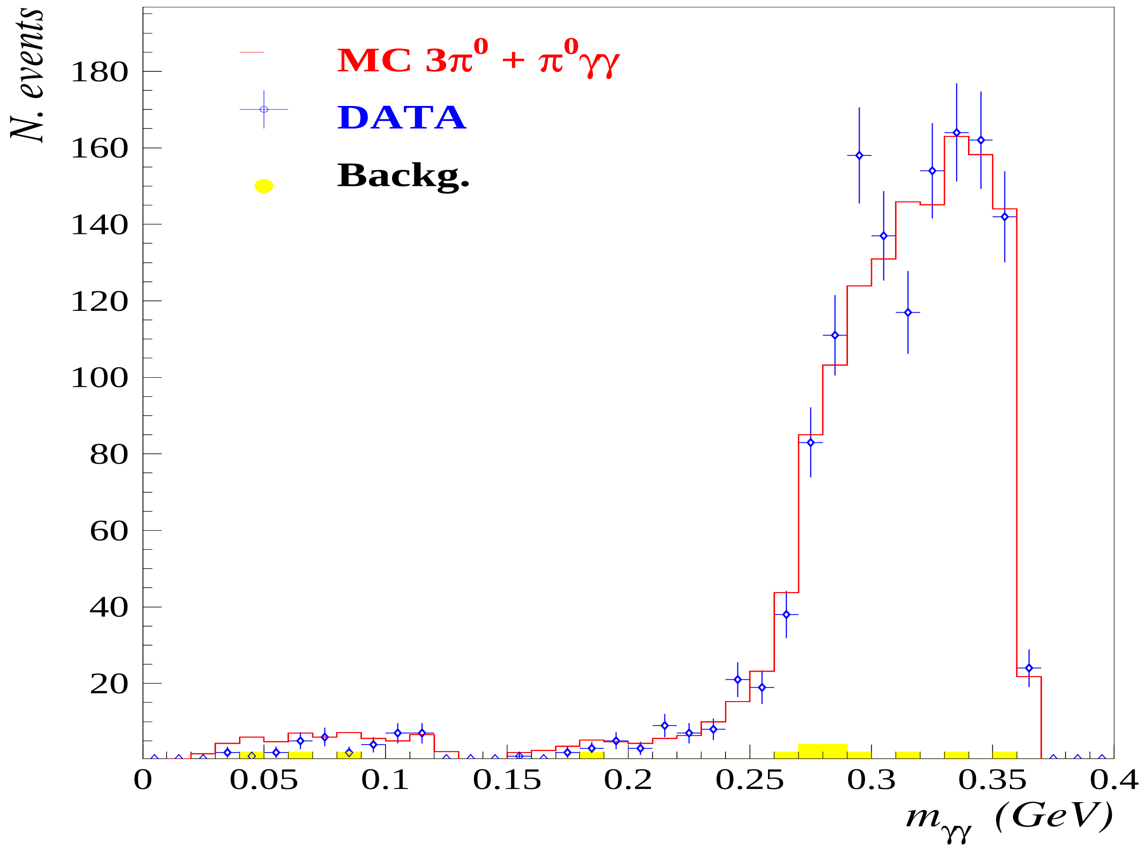
1397 candidates ($\sim$ 30 background)

with $A_V = -0.45$

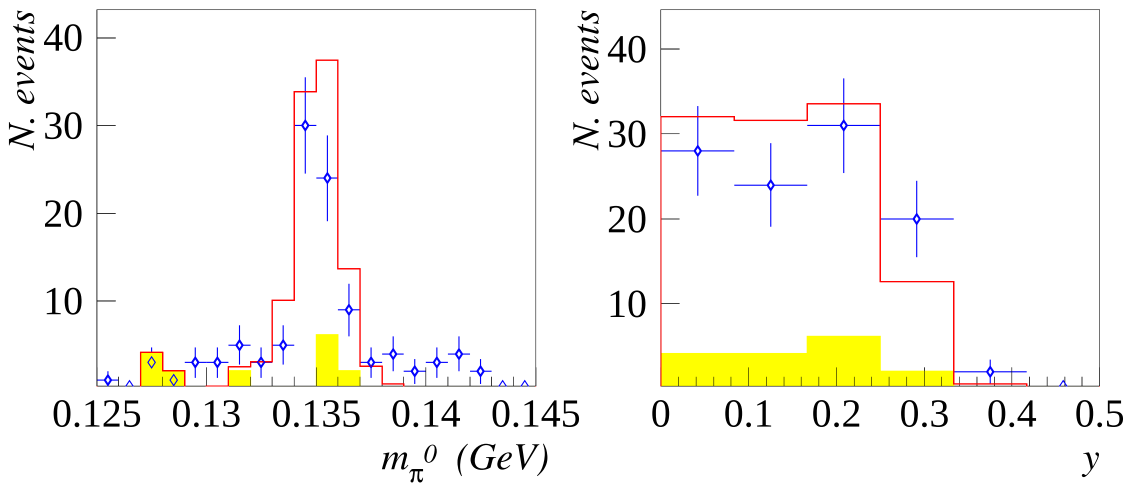
$$\mathrm{B}(\mathrm{K_L} \to \pi^0\gamma\gamma) =$$
$$(1.51 \pm 0.05\,(stat)\ \pm 0.20\,(sys)) \times 10^{-6}$$

(KTeV: $(1.68 \pm 0.07\,(stat)\ \pm 0.08\,(sys)) \times 10^{-6}$)

$K_L \to \pi^0\gamma\gamma$: *Low* $m_{\gamma\gamma}$ *tail*



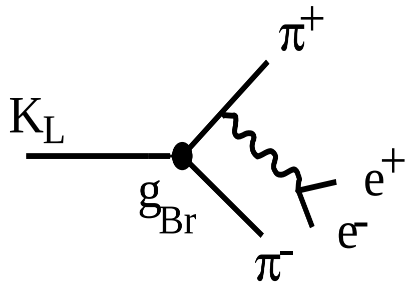
For $m_{\gamma\gamma} < 240\, MeV$:



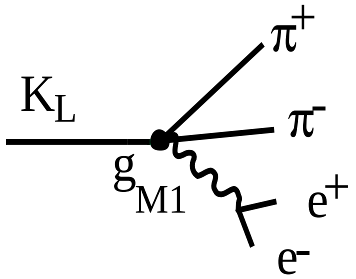
using $A_V = -0.45$

$K_{L,S} \rightarrow \pi^+\pi^-e^+e^-$: *Physics motivation*

K_L :

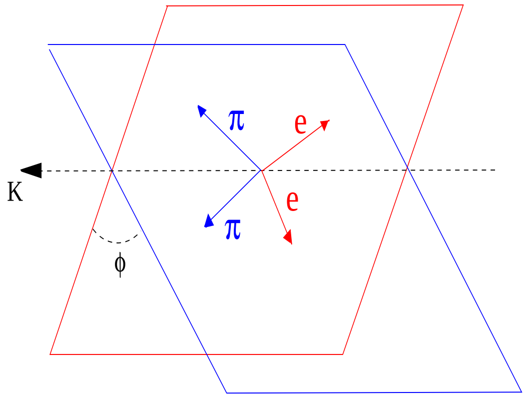


CP-violating bremsstrahlung



CP-conserving M1 γ emission

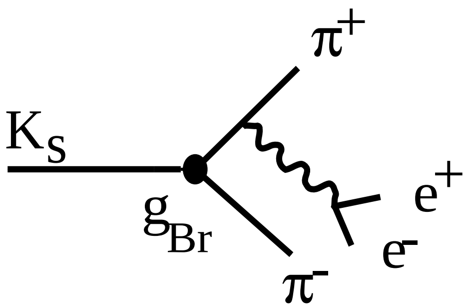
The interference between the two terms results in a CP-violating circular polarization of the γ^*



The effect is visible as an asymmetry in the decay rate

$$\frac{N_{\cos\phi\sin\phi>0} - N_{\cos\phi\sin\phi<0}}{N_{\cos\phi\sin\phi>0} + N_{\cos\phi\sin\phi<0}}$$

K_S :



CP-conserving bremsstrahlung

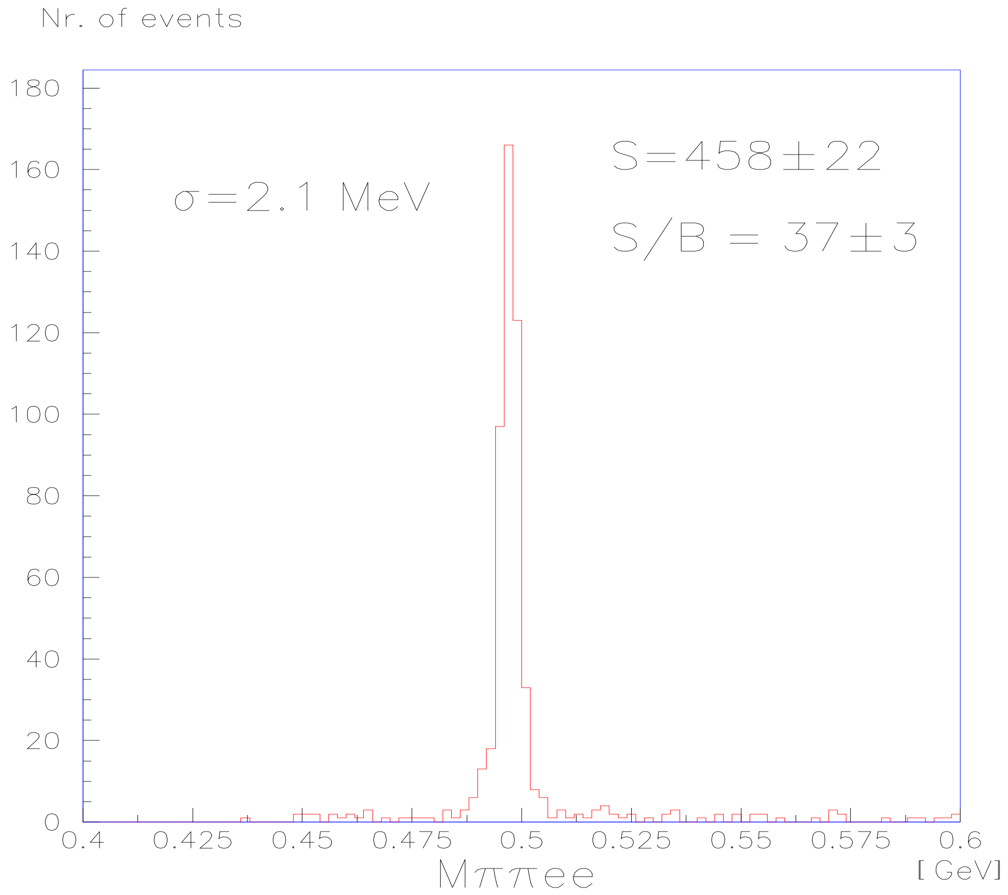
No CP-violating asymmetry expected

$\mathrm{K_{L,S}} \rightarrow \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-$: *Event selection*

- Trigger:
  - on-line trigger for 4-track events
    ($\epsilon \sim 70\,\%\,(95\,\%)$ for 1998 (1999))
- Analysis selection:
  - 2 positive and 2 negative tracks in time
  - vertex in fiducial region ($6 < z < 87\,m$)
  - vertex near beam axis ($< 3\,cm$)
  - electron identification ($\mathrm{E/p} > 0.85$)
  - Low p_t ($< 0.01\,GeV$)
- Background rejection:
  - $\mathrm{K_L} \rightarrow \pi^+\pi^-\gamma$ with γ conversion $\rightarrow e^+e^-$
    $\Rightarrow$ Vertices in the vacuum volume
  - overlaid $\mathrm{K_L} \rightarrow \pi^-e^+\nu_e$ and $\mathrm{K_L} \rightarrow \pi^+e^-\bar{\nu}_e$
    $\Rightarrow$ Constraints to $\Delta t_{\pi^+\pi^-}$ and $\Delta t_{e^+e^-}$
  - $\mathrm{K_L} \rightarrow \pi^+\pi^-\pi^0_{\mathrm{D}}$ with $\pi^0_{\mathrm{D}} \rightarrow e^+e^-\gamma$
    $M_{ee\gamma}$ compatible with m_{π^0} and cut on kinematic variable
- Data used:
  - 1998 Normal ϵ' run
    reject large number of $\mathrm{K_S} \rightarrow \pi^+\pi^-\pi^0_{\mathrm{D}}$
    $\Rightarrow$ tagger and vertex information used
  - 1999 high intensity $\mathrm{K_S}$ run
    ($\sim$ 3 days, 200 times ϵ' intensity)
    No $\mathrm{K_L}$: much cleaner sample

$\mathrm{K_L} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-$: *Signal*

1998 DATA



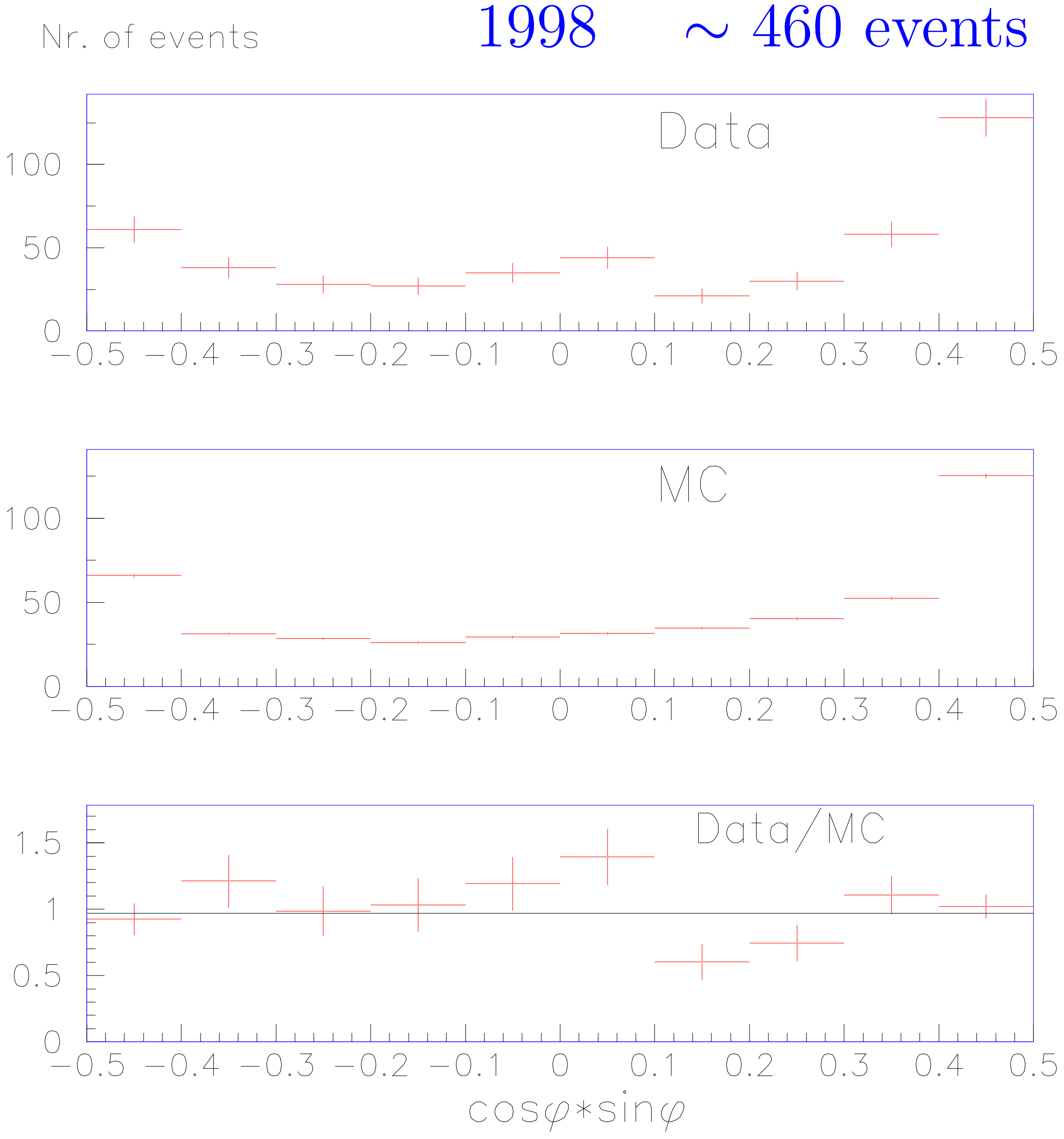
normalised to $\sim$ 1 million $\mathrm{K_L} \to \pi^+\pi^-\pi^0_D$

$$\mathrm{B}(\mathrm{K_L} \to \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-) =$$
$$(2.90 \pm 0.15\ (stat)\,) \times 10^{-7} \quad \textbf{(Prel)}$$

(KTeV: $(3.63 \pm 0.11(stat) \pm 0.14(sys)) \times 10^{-7}$)

$K_L \to \pi^+\pi^-e^+e^-$: *Asymmetry*

1998 $\sim$ 460 events



Asymmetry studies (preliminary):

Data: observed asymmetry $= (20 \pm 5)\%$

Simulation: generated $0\% \Rightarrow$ reconstructed 0%

generated $14\% \Rightarrow$ reconstructed 22%

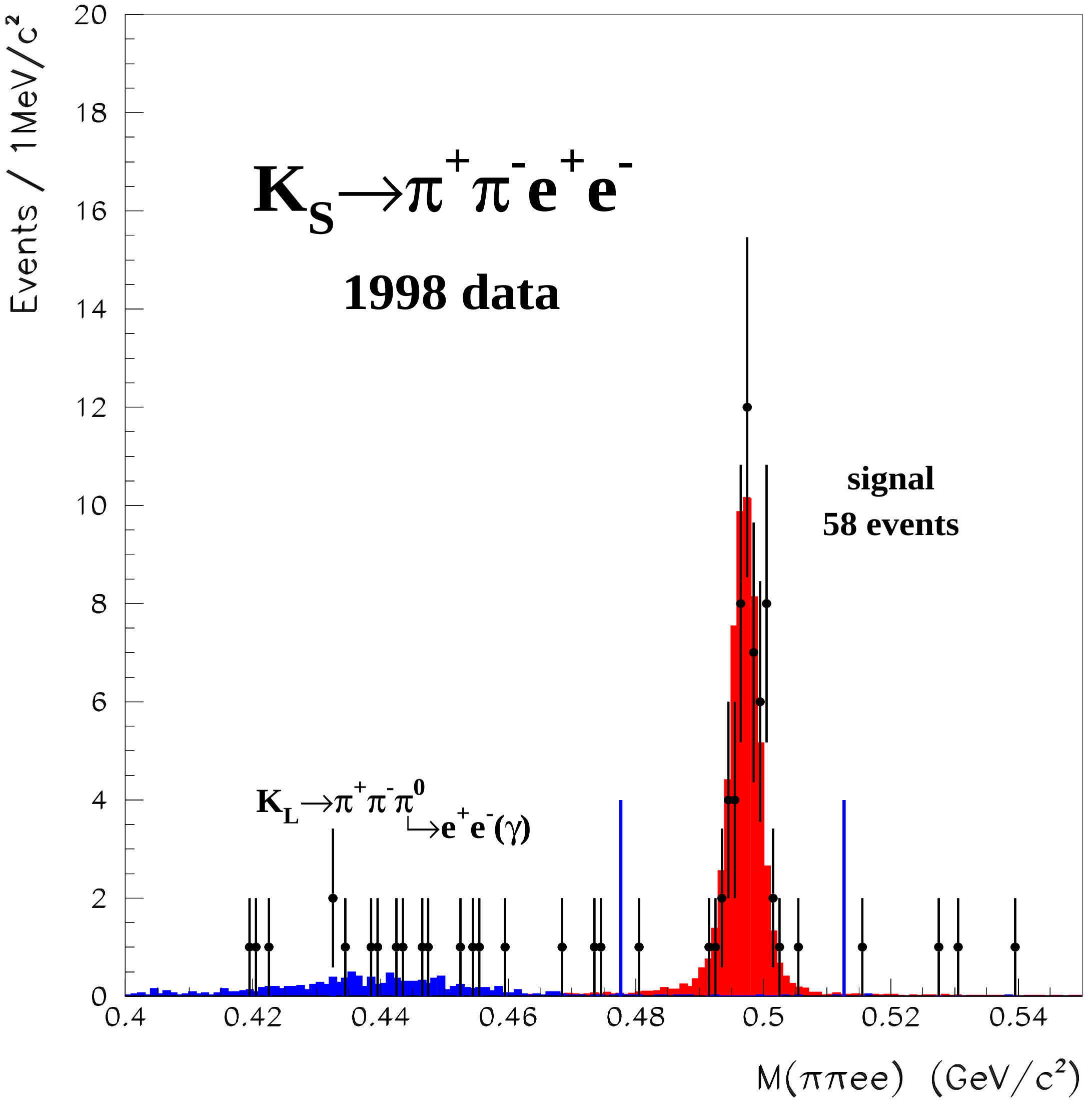
(KTeV: observed asymmetry $= 23.3 \pm 2.3\%$

acceptance corrected: $13.6 \pm 2.5(stat) \pm 1.2(sys)\%$)

$K_S \to \pi^+\pi^-e^+e^-$: *Result*

1998: First observation of $K_S \to \pi^+\pi^-e^+e^-$

Preliminary

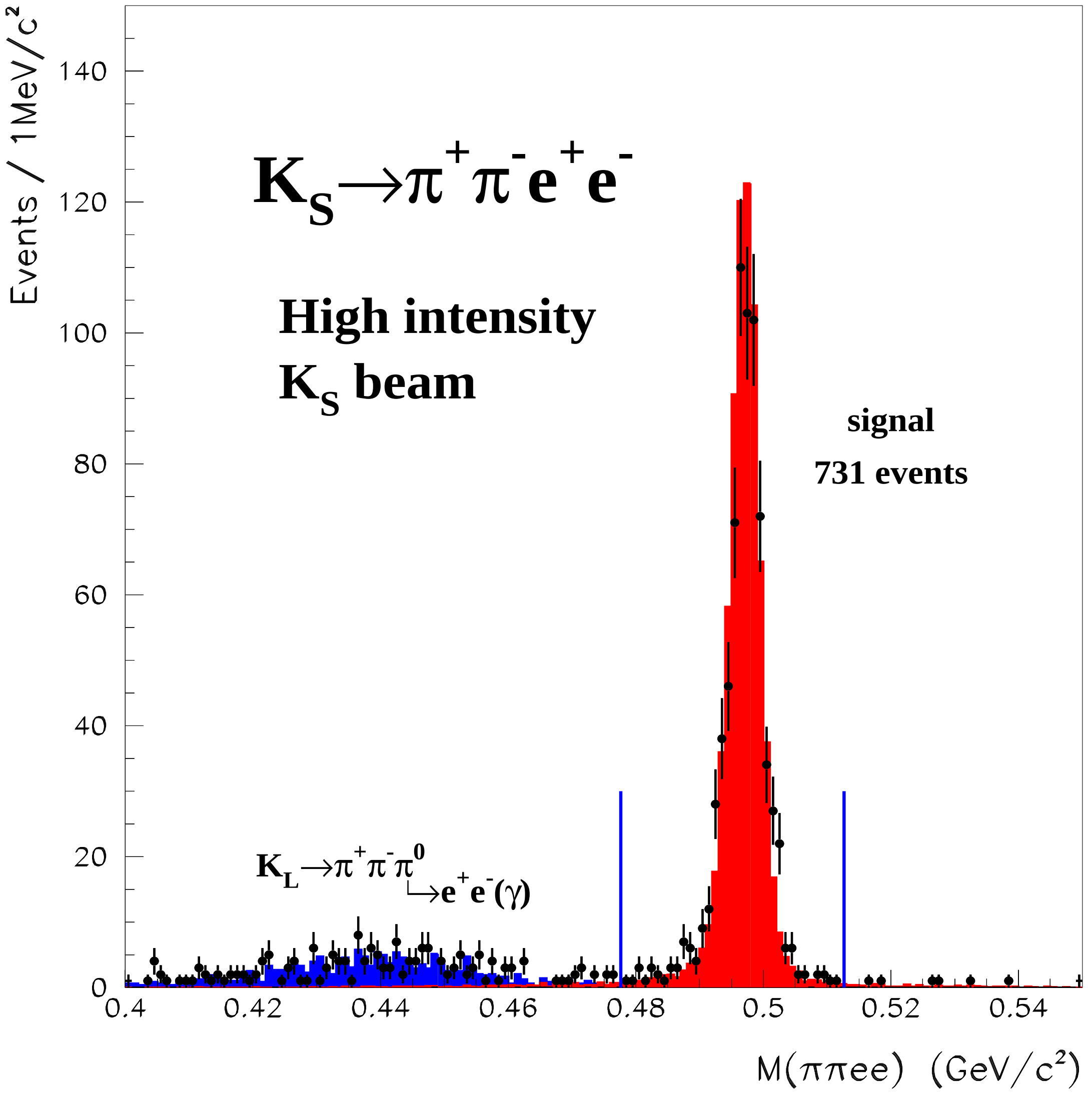


$K_L \to \pi^+\pi^-\pi^0_D$ from K_S target ($\sim$ 100 eV)
used as normalisation

$B(K_S \to \pi^+\pi^-e^+e^-) \sim 4 \times 10^{-5}$

$K_S \to \pi^+\pi^-e^+e^-$: *Result*

$1999\ K_S \to \pi^+\pi^-e^+e^-$

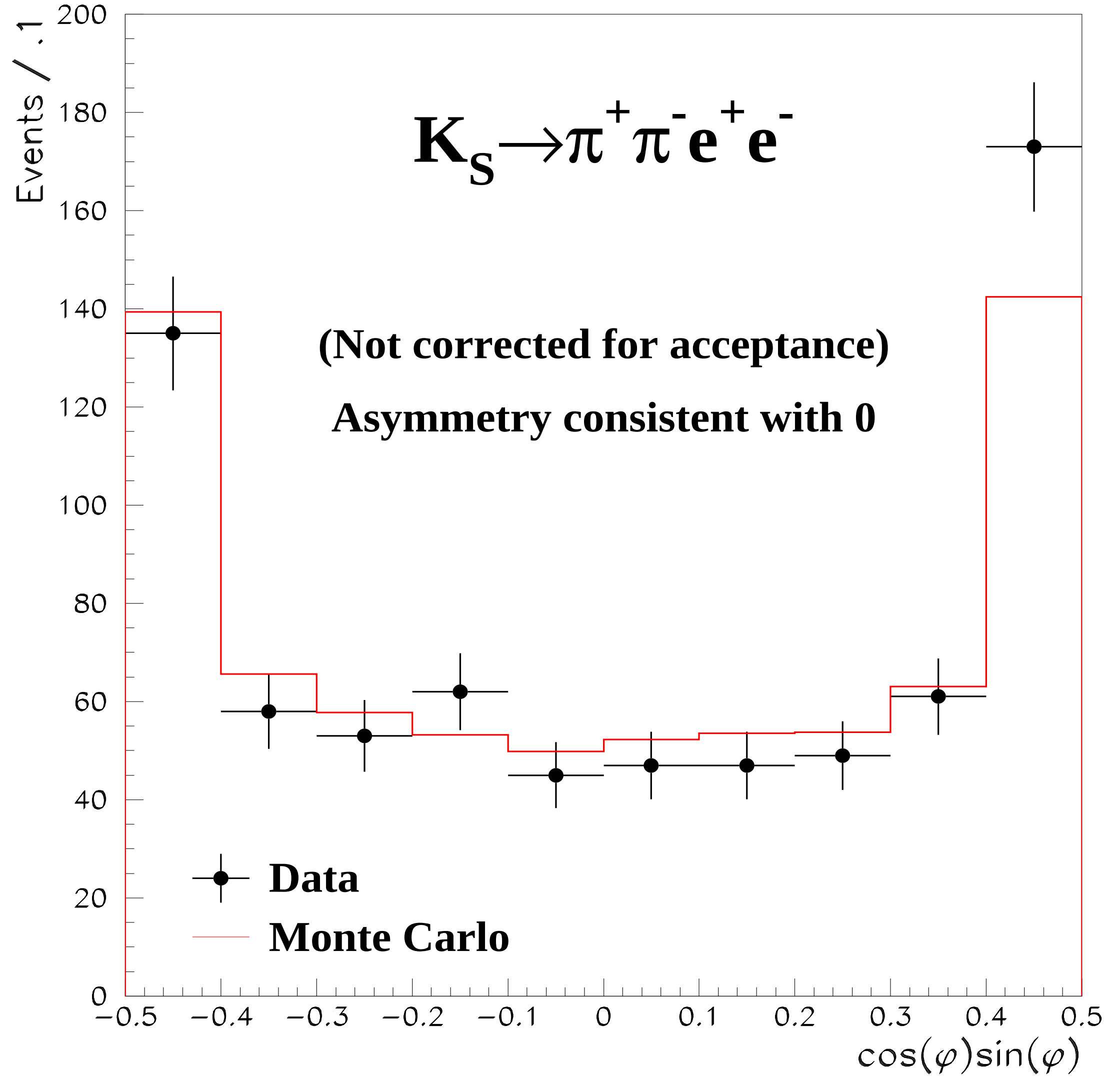


$731\ \ K_S \to \pi^+\pi^-e^+e^-$ candidates

$K_S \to \pi^+\pi^-e^+e^-$: *Asymmetry*

1999 $K_S \to \pi^+\pi^-e^+e^-$

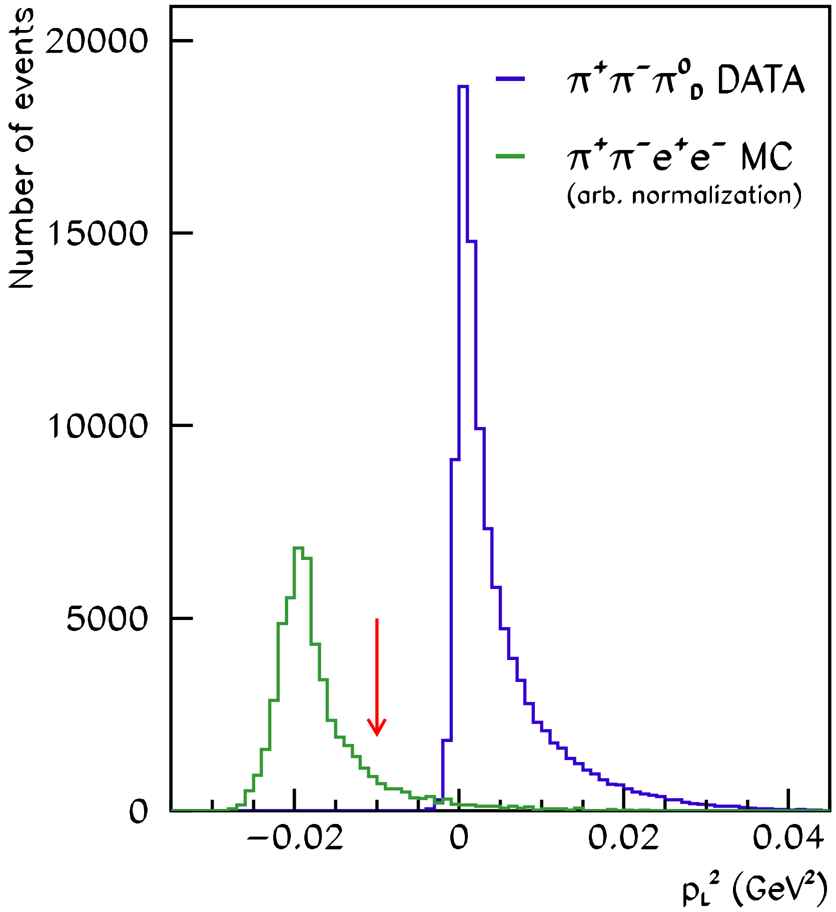
Preliminary



Conclusion

- Preliminary measurement of
  $\mathrm{B}(\mathrm{K_L} \rightarrow \pi^0\gamma\gamma) =$
  $(1.51 \pm 0.05(stat) \pm 0.20(sys)\ ) \times 10^{-6}$
  based on $\sim$ 1400 events
  with only $\sim$ 30 background events
- Evidence of low $m_{\gamma\gamma}$ tail
  with very low backgrounds
- Measured asymmetry in $\mathrm{K_L} \rightarrow \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-$
  consistent with theory
- First observation of $\mathrm{K_S} \rightarrow \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-$
- First measurement of
  $\mathrm{B}(\mathrm{K_S} \rightarrow \pi^+\pi^-\mathrm{e}^+\mathrm{e}^-)\ \sim\ 4 \times 10^{-5}$
  based on 58 events from 98 data
- Measured asymmetry consistent with zero
  within few percent

$\mathrm{K_{L,S}} \rightarrow \pi^+\pi^-\mathrm{e^+e^-}$: *kinematical cut*



Cut on:

$$P_L^2 \equiv \frac{(\mathrm{M_K^2}-\mathrm{M^2_{\pi^0}}-\mathrm{M^2_{\pi\pi}})^2-4\mathrm{M^2_{\pi^0}}\mathrm{M^2_{\pi\pi}}-4\mathrm{M_K^2}(\mathrm{P_T^2})_{\pi\pi}}{4[(\mathrm{P_T^2})_{\pi\pi}+\mathrm{M^2_{\pi\pi}}]}$$