First observation of the decay $K_S \longrightarrow \pi^0 e^+ e^-$

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On behalf of the NA48/1 Experiment :
Cambridge, Chicago, CERN, Dubna, Edinburgh
Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay,
Siegen, Torino, Warsaw, Wien

Overview

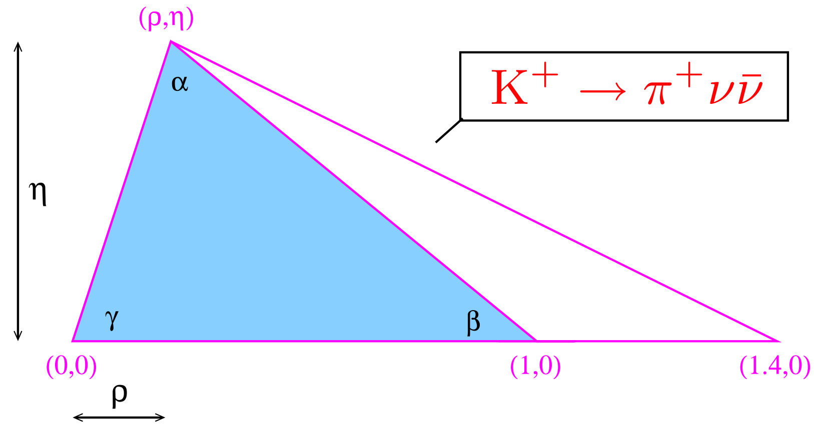
- Physics Motivation
- The NA48/1 beamline and detector in 2002
- $K_S \longrightarrow \pi^0 e^+ e^-$ selection
- Background Studies
- Preliminary result and conclusions

CP violation in rare kaon decays

A unitarity triangle in the kaon system :

$K_L \to \pi^0 \nu\bar{\nu}$

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



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

$K_L \to \pi^0 \nu\bar{\nu}$ and $K^+ \to \pi^+ \nu\bar{\nu}$ are theoretically clean

Theoretical error 2-5 %

Together determine unitarity triangle

Extremely difficult experiments

$K_L \to \pi^0 e^+ e^-$ experimentally more constrained (limited by background)

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

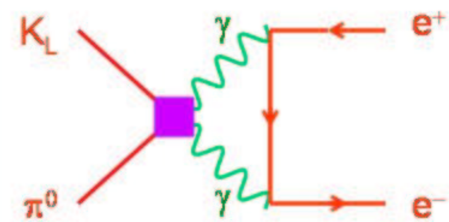
The decay $K_L \to \pi^0 e^+ e^-$ has three components :

- CP conserving

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

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

  [PL B536 229]

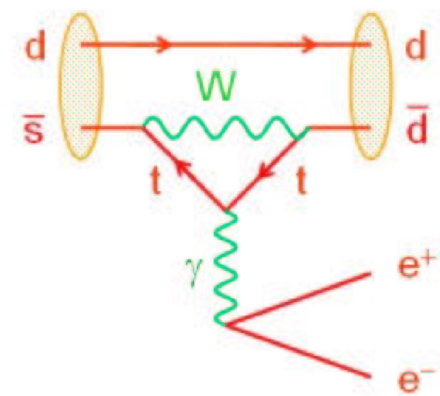


- direct CP violating

  Proportional to η or $\mathcal{I}m(\lambda_t)$

  $\mathcal{I}m(\lambda_t) = \eta A^2 \lambda^5 \qquad \lambda_t = V_{ts}^* V_{td}$

  $\to BR(K_L \to \pi^0 e^+ e^-)_{dir} \sim few \times 10^{-12}$



- indirect CP violating

  $\to BR(K_L \to \pi^0 e^+ e^-)_{ind} = |\epsilon|^2 (\frac{\tau_L}{\tau_S}) BR(K_S \to \pi^0 e^+ e^-)$

$BR(K_S \to \pi^0 e^+ e^-)$ and $BR(K_L \to \pi^0 \gamma\gamma)$ determine whether it will be possible to extract η from a measurement of $BR(K_L \to \pi^0 e^+ e^-)$

$K_L \to \pi^0 e^+ e^-$ *and* $K_S \to \pi^0 e^+ e^-$

Theory $BR(K_S \to \pi^0 e^+ e^-) = 5 - 50 \times 10^{-10}$

(Ecker, Pich, de Rafael [NP B291 692])

Direct/indirect CP violating components of $K_L \to \pi^0 e^+ e^-$ interfere :

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} = 1 \times 10^{-12} \left(15.3 a_s^2 \pm 6.8 \frac{\mathcal{I}m(\lambda_t)}{10^{-4}} |a_s| + 2.8 \left(\frac{\mathcal{I}m(\lambda_t)}{10^{-4}} \right)^2 \right)$$

$$BR(K_S \to \pi^0 e^+ e^-) = 5 \times 10^{-9} |a_s|^2 \qquad \Rightarrow \text{determines } |a_s|$$

(D'Ambrosio, Ecker, Isidori, Portoles [JHEP 08 (1998) 004])

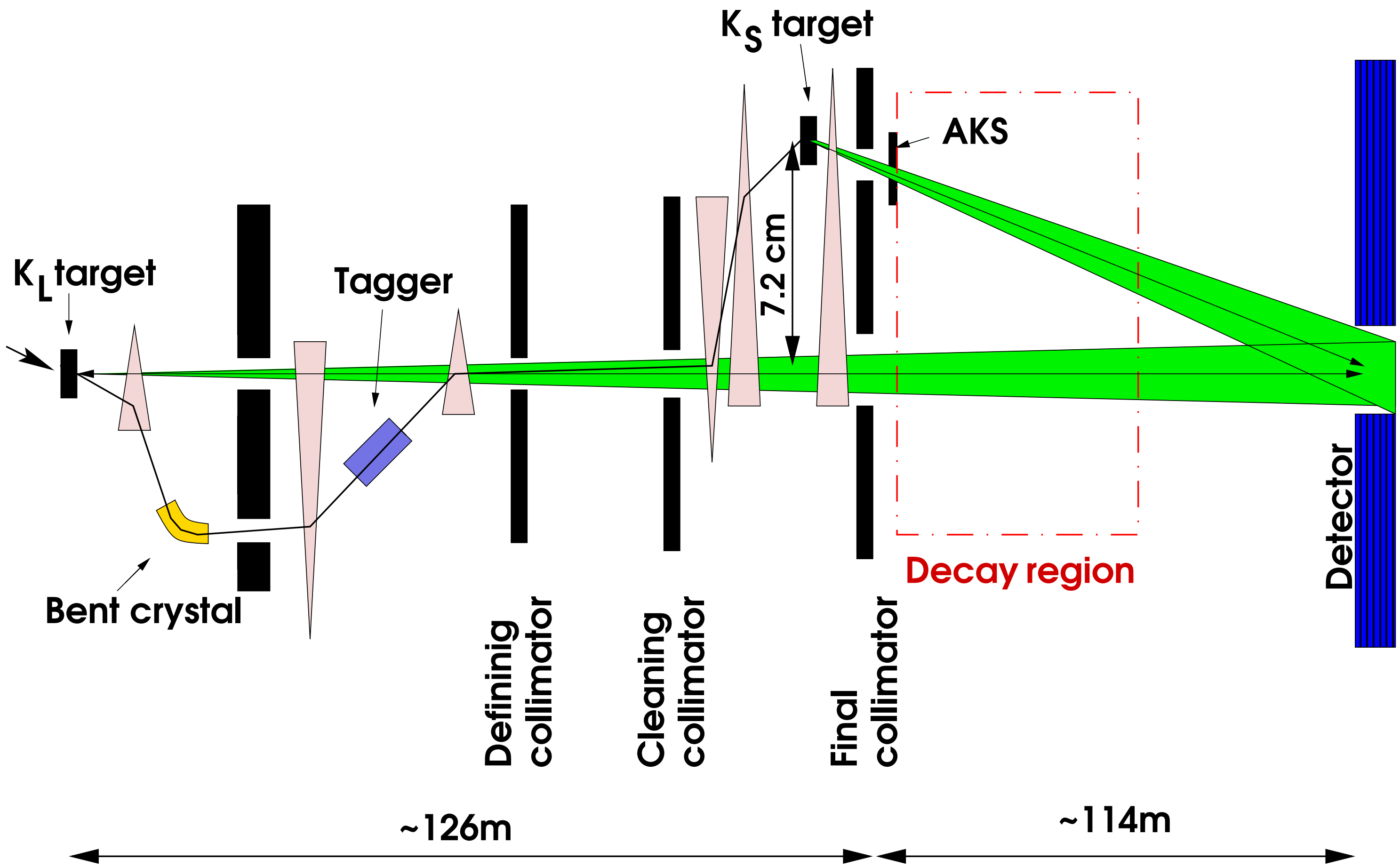
Current limits:

$BR(K_L \to \pi^0 e^+ e^-) < 5.1 \times 10^{-10}$ (KTeV, [PRL 86 397])
2 events with background of 1.1 event

$BR(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7}$ (NA48, [PL B514 253])
2-days test run in 1999

The NA48 simultaneous K_S and K_L beams

Used for $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement until 2001



2002 data-taking : K_S target only

2002 Beamline

5×10^{10} ppp from SPS in 4.8 s spill

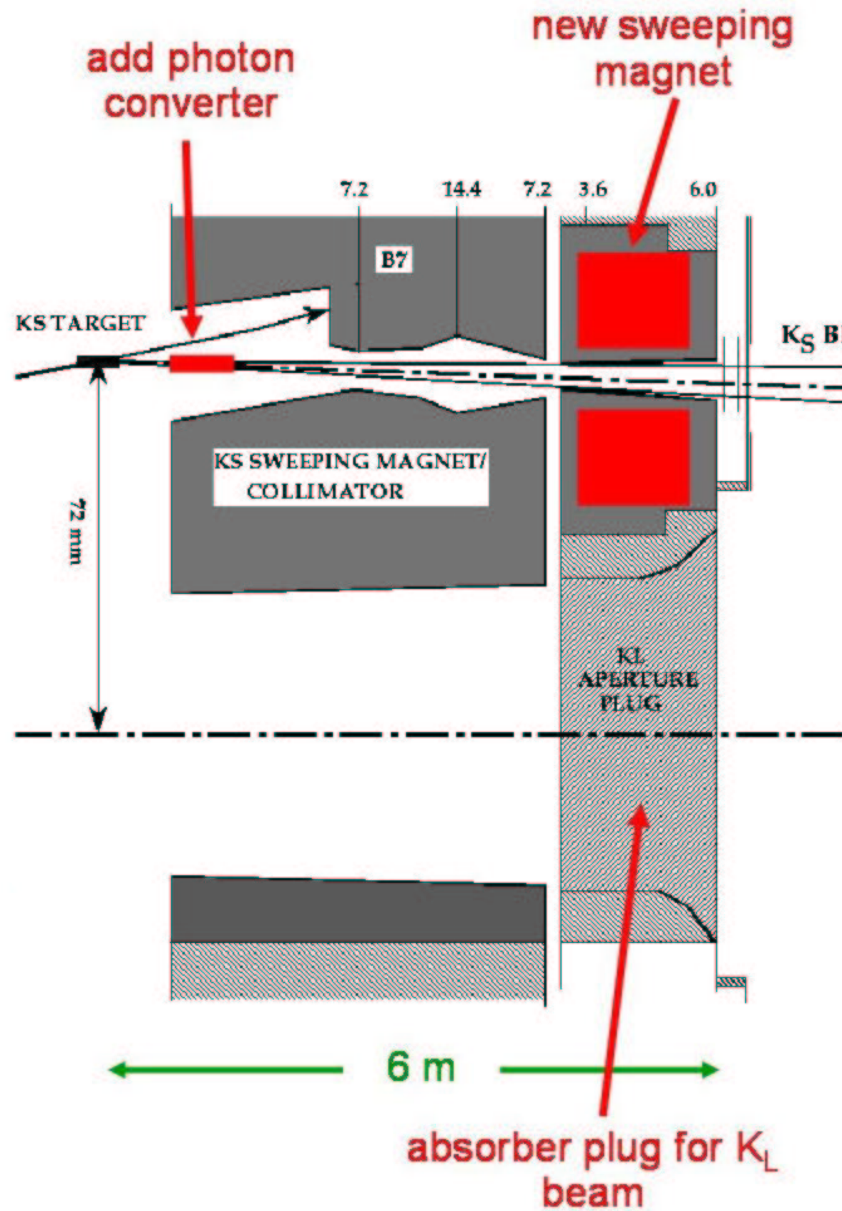
400 GeV/c protons onto 40 cm Beryllium target, 4.2 mrad production angle

Photon converter downstream of target and a sweeping magnet after the defining collimator

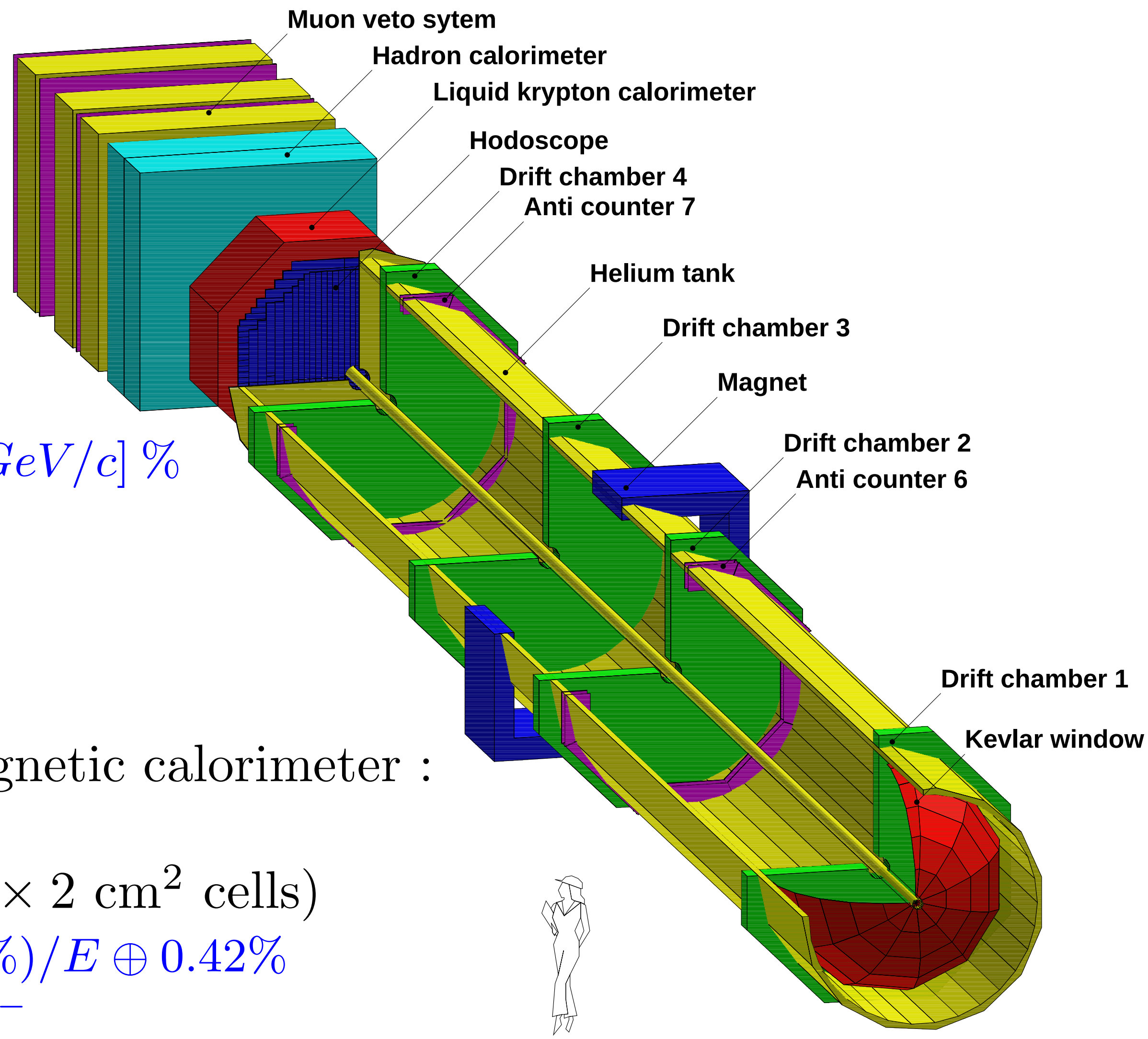
Intensity on target increased by factor ∼1000 compared to running conditions used for the measurement of ε'/ε

$\sim 4\times10^{10}$ K_S decays in 89 days with energy 40-240 GeV and within 2.5 K_S lifetimes from the final collimator

(proposal: 3×10^{10} K_S in 105 days; 8% loss due to duty cycle but factor 2 gain in readout)



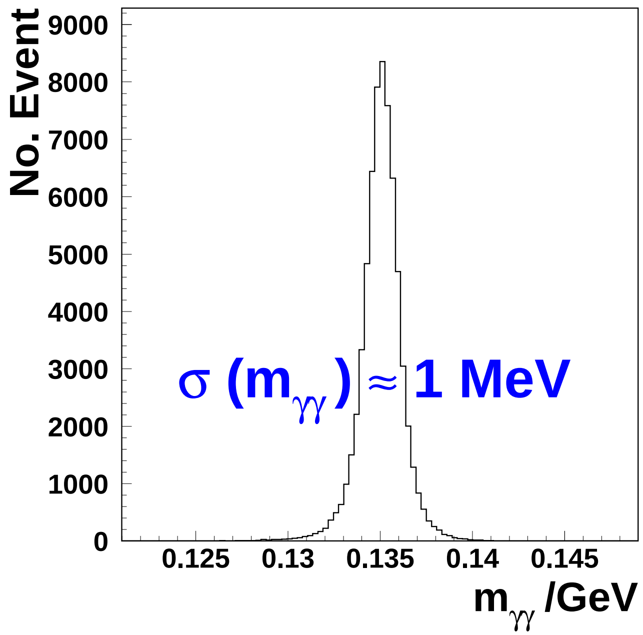
NA48 Detector

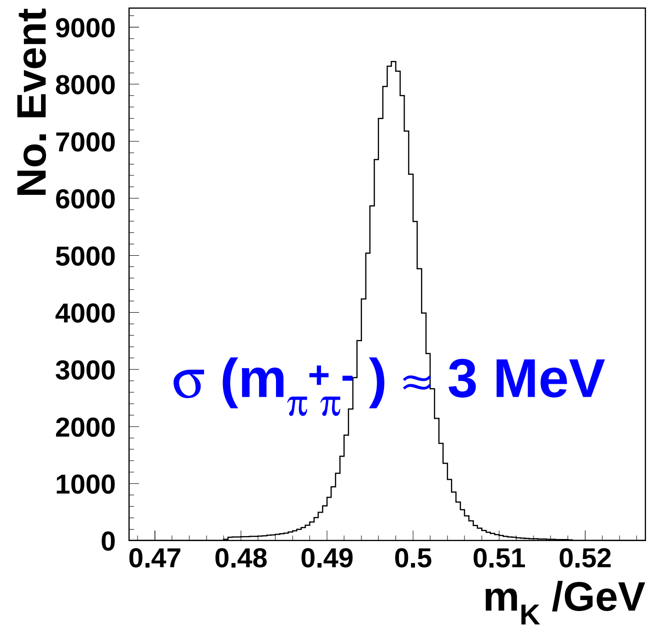


- Magnetic spectrometer :
  charged particles
  $\sigma(p)/p \simeq 0.5\ \% \oplus 0.009\ p[GeV/c]\ \%$
  $(\mathrm{P}_{\perp}{}^{kick} \sim 265\mathrm{MeV}/c)$

- Liquid Krypton electromagnetic calorimeter :
  photons and electrons
  high granularity (13212 2×2 cm^2 cells)
  $\sigma(E)/E = 3.2\%/\sqrt{E} \oplus (9\%)/E \oplus 0.42\%$
  $\sigma(t) \simeq 265ps$ for 50 GeV e^-

- Detector performance





- 50k events read out per burst :

  40 MHz read-out ±100 ns

  LKr electromagnetic calorimeter read-out upgraded

  New drift chamber read-out : removal of dead time due to read-out overflow

  Active Level III trigger reduced data volume 120 TB → 40 TB

Trigger

The trigger used to select $\pi^0 e^+ e^-$ candidates required :

- Energy deposited in LKr $>$ 30 GeV
- Energy centre of gravity $<$ 15 cm from beam axis at LKr
- Proper decay time < 6 K_S lifetimes from the end of the final collimator
- Number of hits in DCH1 compatible with at least one track

Trigger efficiency measured using $\pi^0 \pi^0_D$ events : 99.0%

Analysis Strategy

Rare decay analysis strategy $\Rightarrow$ understand and minimise all possible background processes, without cutting away the signal

"Blind analysis procedure" $\rightarrow$ signal and control regions masked :

Signal region : $2.5\sigma_{m_K} \times 2.5\sigma_{m_{\pi^0}}$

Control region : $6.0\sigma_{m_K} \times 6.0\sigma_{m_{\pi^0}}$

Study backgrounds using the data and a Monte Carlo simulation

Fix analysis cuts on the basis of these studies

Unmask control region $\rightarrow$ final background estimate

Unmask signal region $\rightarrow$ result

$K_S \to \pi^0 e^+ e^-$ *signal selection*

Select decays within 2.5 K_S lifetimes of final collimator and with energy 40$< E_{kaon} < 240\,\mathrm{GeV}$:

- 4 clusters in calorimeter within 3 ns of the average time
- 2 tracks, one +, one - forming a good vertex
- Charged vertex downstream of collimator region
- Electron id : $0.95 < \frac{E}{p} < 1.05$
- No signal from muon detector
- Energy centre of gravity (cog) $<$ 6 cm from beam axis at LKr
- No energy deposited in hadron calorimeter
- Remove events with additional clusters/tracks in-time
- $m_{ee\gamma\gamma} = m_{kaon}$ assuming $\gamma\gamma$ originate from charged vertex
  $2.5\sigma_{m_K}$ cut used ($\sigma_{m_K} = 4.7\,\mathrm{MeV}$)
- $m_{\gamma\gamma} = m_{\pi^0}$ assuming $\gamma\gamma$ originate from vertex reconstructed imposing m_K
  $2.5\sigma_{m_{\pi^0}}$ cut used ($\sigma_{m_{\pi^0}} = 1.0\,\mathrm{MeV}$)

Backgrounds to the search for $K_S \to \pi^0 e^+ e^-$

K_S decays

- $K_S \to \pi^0 \pi^0_{Dalitz}$
- $K_S \to \pi^0 \pi^0_D$ + conversion(s)
- $K_S \to \pi^0 \pi^0_{DalitzDalitz}$
- $K_S \to \pi^0 \pi^0 (e^+ e^-)$
- $K_S \to \pi^0_{Dalitz} \pi^0_{Dalitz}$

K_L decays

- $K_L \to \pi^0 \pi^+ \pi^-$
- $K_L \to \pi^0 \pi^\pm e^\mp \nu$
- $K_L \to ee\gamma$ + bremsstrahlung
- $K_L \to ee\gamma\gamma$

Ξ^0 decays

- $\Xi^0 \to \Lambda(p\pi^-)\pi^0$
- $\Xi^0 \to \Lambda(pe^-\nu)\pi^0$
- $\Xi^0 \to \Sigma^+(p\pi^0)e^-\nu$

Overlapping fragments of two decays

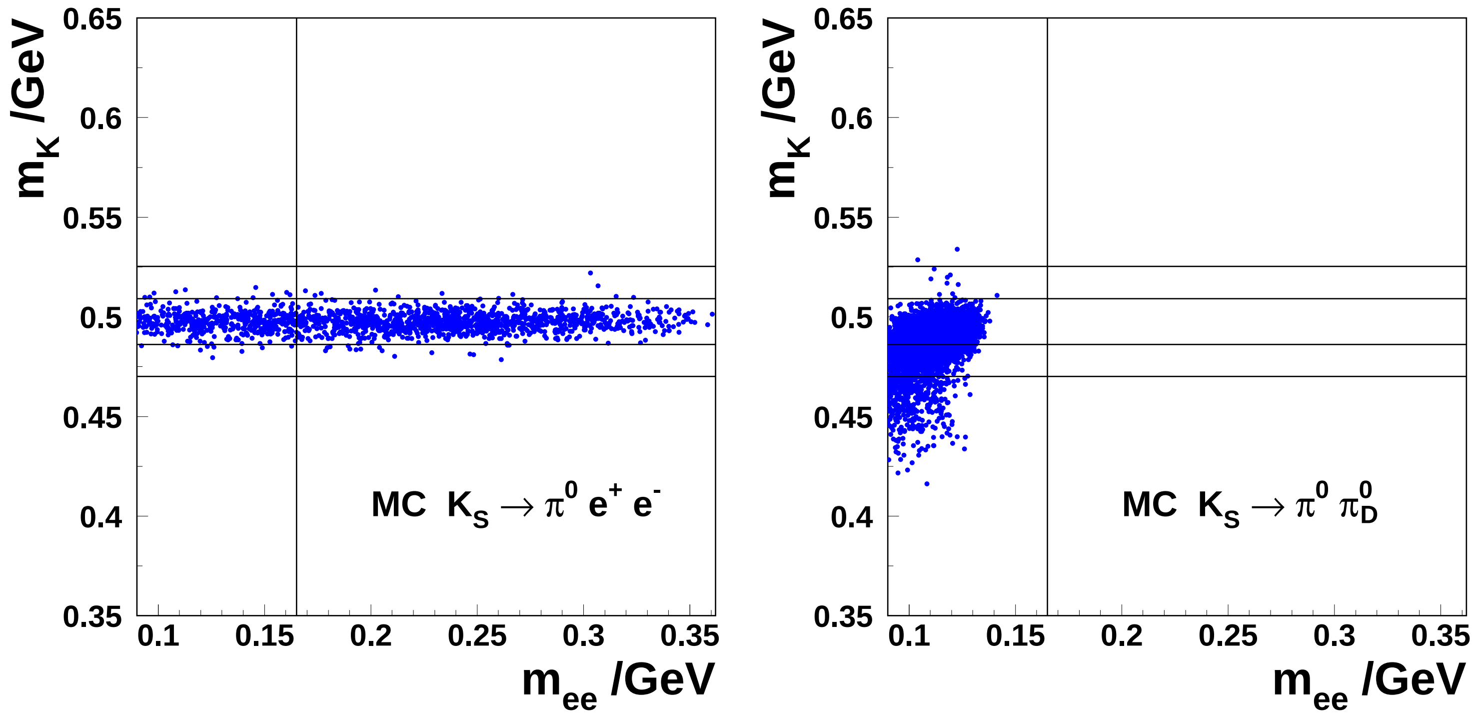
- from the same proton interaction
  - p$\to$ $\phi(K_S K_L)$
- from different proton interactions
  - p$\to K_S$ p$\to K_L$

Background from $K_S \to \pi^0 \pi^0_{Dalitz}$

$3 \times 10^8\ K_S \to \pi^0 \pi^0_{Dalitz}(e^+ e^- \gamma)$ decays in $0 < \frac{c\tau}{c\tau_S} < 2.5$

Rejected using :

- extra γ ⇔ m_K cut / additional activity cut
- $\theta_{e^+e^-}$ small ⇔ track separation at 1st drift chamber > 2 cm
- $m_{ee} < m_{\pi^0}$ ⇔ require $\pi^0 e^+ e^-$ candidates have $m_{ee} > 0.165\,\mathrm{GeV/c^2}$



Background from $K_S \to \pi^0 \pi^0_D$ (cont'd)

m_{ee} resolution studied extensively with both data and Monte Carlo

- 'regular' $\pi^0\pi^0_D$ events :

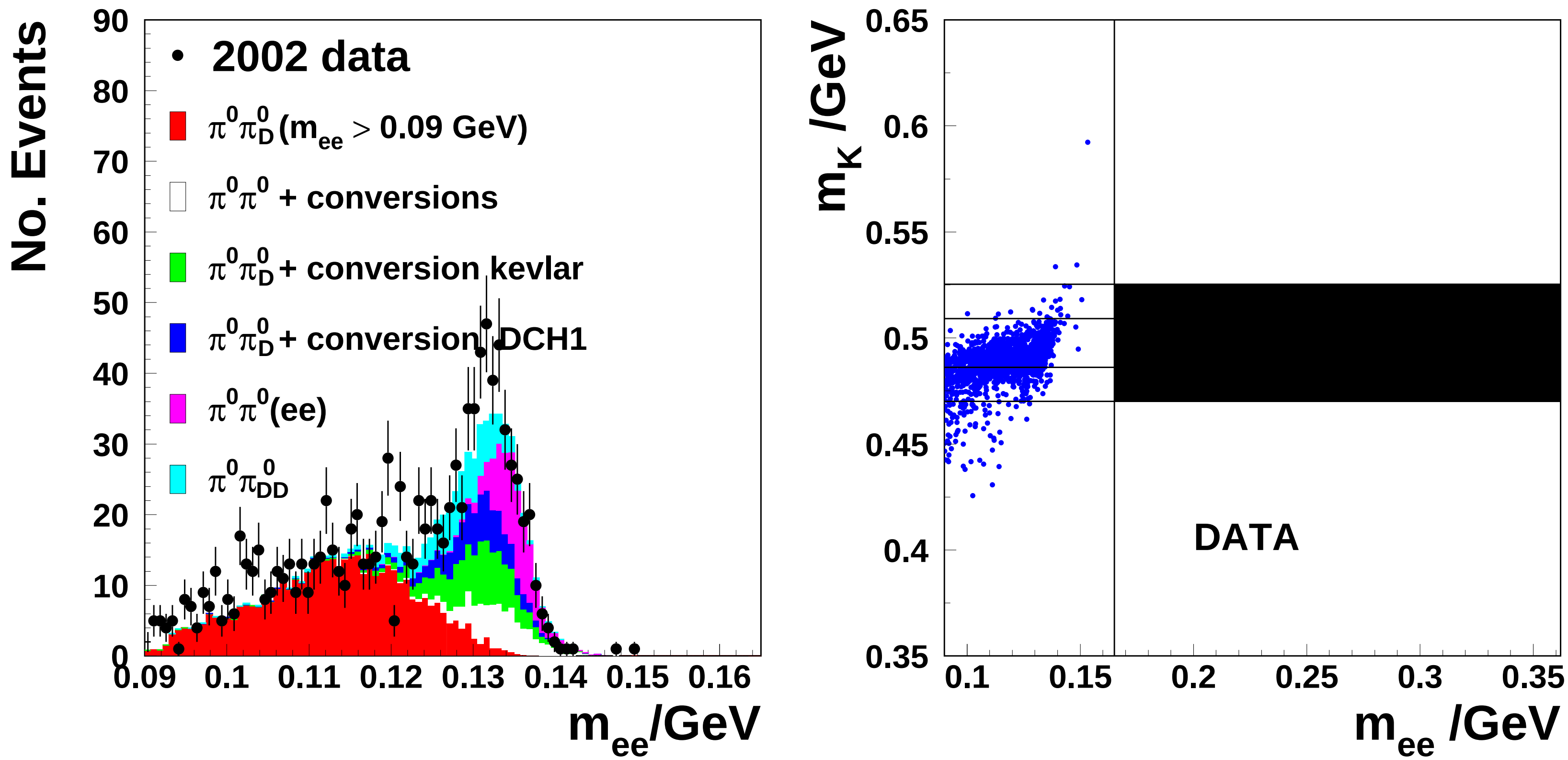
$$K_S \longrightarrow \begin{cases} \pi^0 \longrightarrow \begin{cases} \gamma \\ \gamma \end{cases} \\ \\ \pi^0_D \longrightarrow \begin{cases} \cancel{\gamma}\ \text{(lost)} \\ e \\ e \end{cases} \end{cases}$$

- $\pi^0\pi^0_D$ decay + conversion in detector

$$K_S \longrightarrow \begin{cases} \pi^0 \longrightarrow \begin{cases} \gamma \\ \gamma \end{cases} \\ \\ \pi^0_D \longrightarrow \begin{cases} \gamma \xrightarrow{\text{conversion}} \begin{cases} \cancel{e}^{+-}\ \text{(lost)} \\ e^{-+} \end{cases} \\ e^{+-} \\ \cancel{e}^{-+}\ \text{(lost)} \end{cases} \end{cases}$$

- Analogous processes *e.g.* $\pi^0\pi^0_{DD}$, $\pi^{\mathbf{0}}(\gamma\gamma)\pi^{\mathbf{0}}(\gamma_{conv}(e\cancel{e})\gamma_{conv}(e\cancel{e}))$

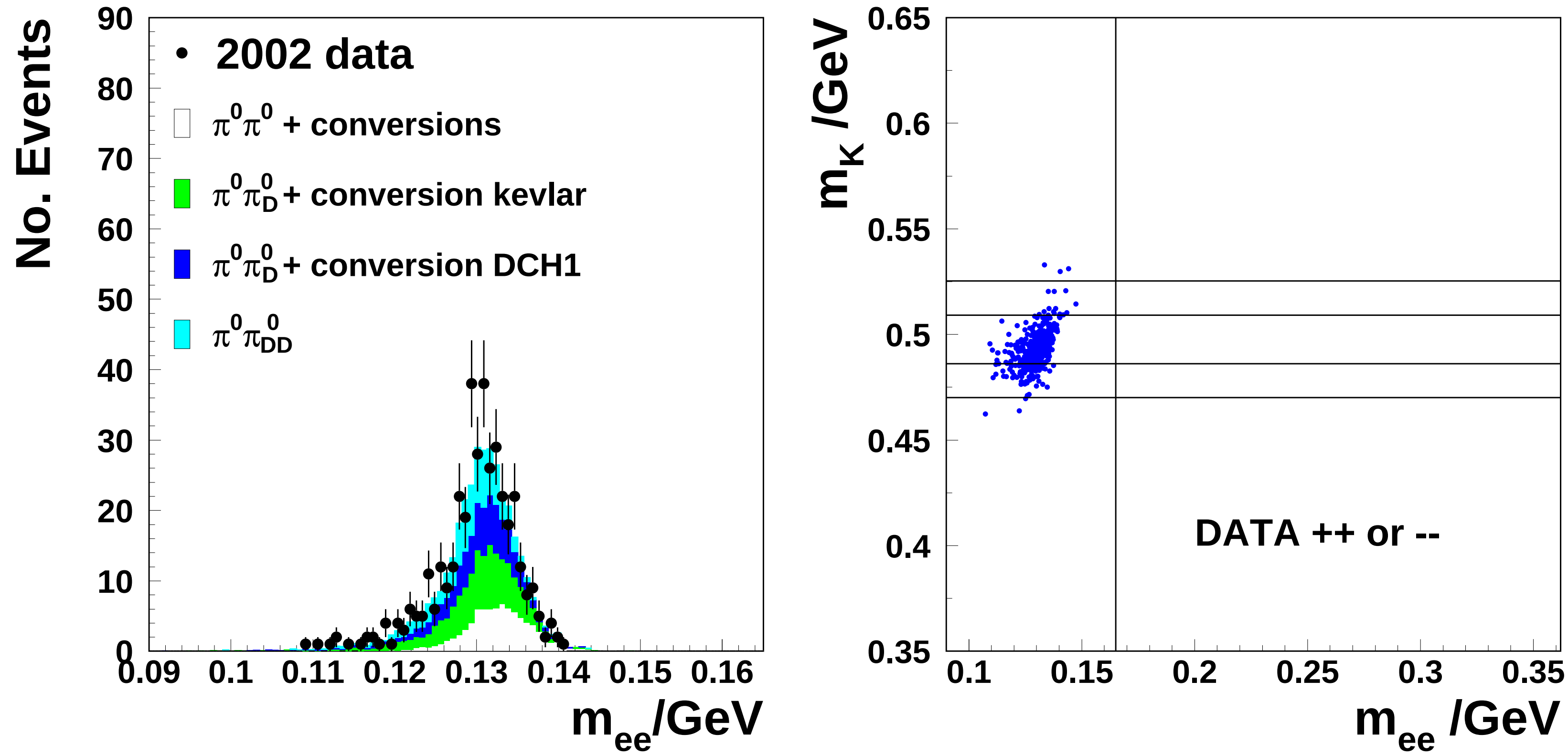
Background from $K_S \to \pi^0\pi^0_D$: Data/MC in low m_{ee} region



Events with m_{ee} mis-measured : $m_{ee} > m_{\pi^0} \to m_{ee\gamma\gamma} > m_K$

Apply conservative cut $m_{ee} > 0.165\,\mathrm{GeV}$

Background from $K_S \rightarrow \pi^0\pi^0_D$*: Same sign data*



Events with $m_{ee} \sim m_{\pi^0}$ contain $e^+e^-e^+e^-$

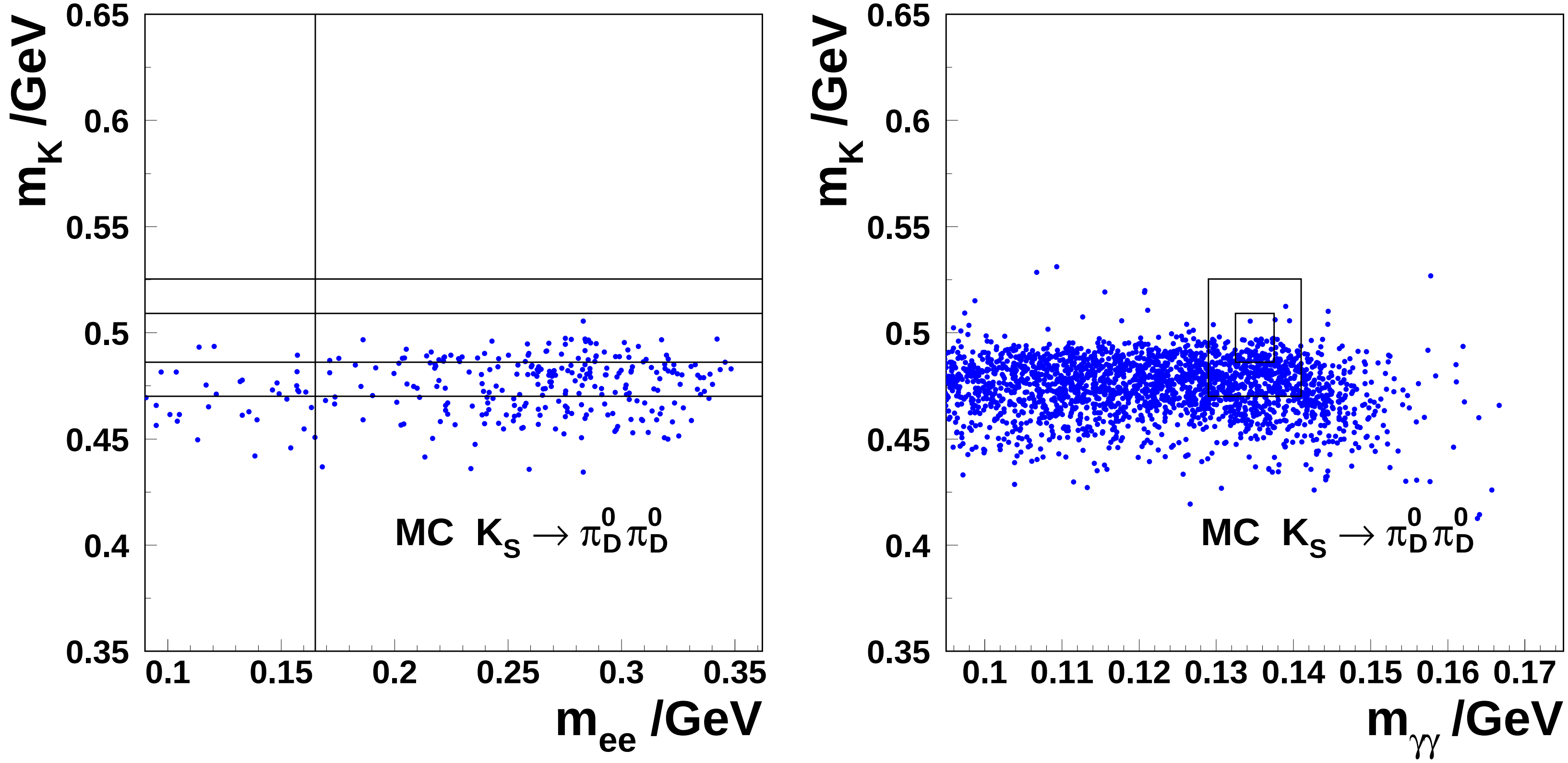
Check m_{ee} distribution of $\pi^0 e^+ e^+$ and $\pi^0 e^- e^-$ events :

- worse m_{ee} resolution
- have high m_{ee}

$\rightarrow$ same sign events used as a check of m_{ee} tail before freezing analysis cuts and unmasking control and signal regions

Background from $K_S \to \pi^0_D \pi^0_D$

$2{\times}10^6\ K_S{\to}\pi^0_D(e^+e^-\gamma)\pi^0_D(e^+e^-\gamma)$ decays in $0< \frac{c\tau}{c\tau_S} < 2.5$



e^+ and e^- lost from different π^0_D decays can have $m_{ee}{>}m_{\pi^0}$

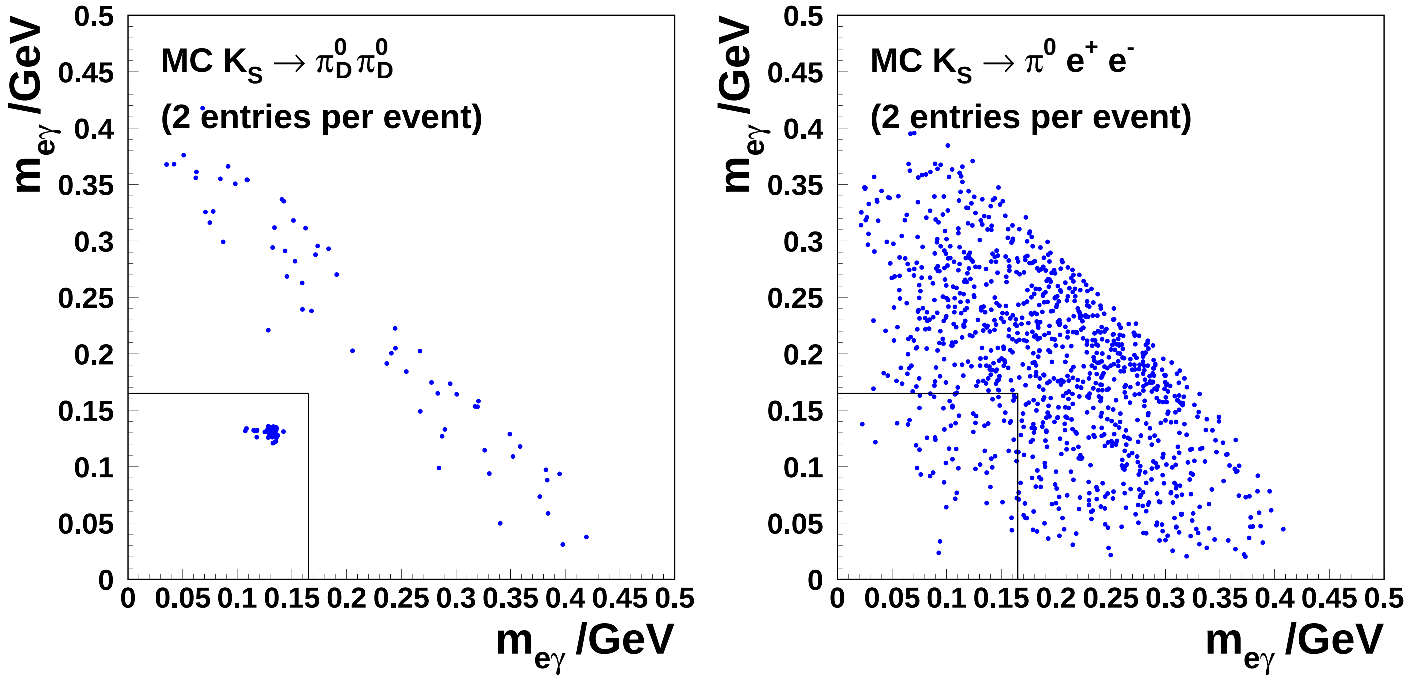
Suppressed by requirement $m_{\gamma\gamma}{\sim}m_{\pi^0}$

Background from $K_S \to \pi^0_D \pi^0_D$ (cont'd)

Lost e^+, e^- low energy $\Rightarrow$ $m_{ee\gamma\gamma} \sim m_K$

m_K cut $\Rightarrow$ $(m_{e\gamma}, m_{e\gamma}) \sim (m_{\pi^0}, m_{\pi^0})$

$\pi^0_D \pi^0(\gamma\gamma)+$ conversion $\Rightarrow$ tails $m_{e\gamma} < m_{\pi^0}$



Reject events with $(m_{e\gamma}, m_{e\gamma}) < 0.165\,\mathrm{GeV/c^2}$

No events found in the signal region in 30 $\times$ 2002 statistics

1 event found in control region

Background summary so far ...

Backgrounds from K_S decays $\rightarrow$ additional cuts :

$m_{ee} > 0.165\,\mathrm{GeV}$ $\qquad$ $(m_{e\gamma}, m_{e\gamma}) > 0.165\,\mathrm{GeV/c^2}$

$\Rightarrow K_S \rightarrow \pi^0_D \pi^0_D$ contributes 0.007 event in $\pm 2.5\sigma$ signal region

Now consider backgrounds from K_L decays :

K_L decays

- $K_L \rightarrow \pi^0 \pi^+ \pi^-$
- $K_L \rightarrow \pi^0 \pi^\pm e^\mp \nu$
- $K_L \rightarrow ee\gamma$ + bremsstrahlung
- $K_L \rightarrow ee\gamma\gamma$

Backgrounds from K_L decays

$\sim 5\times 10^8$ K_L decay in the $0 < \frac{c\tau}{c\tau_S} < 2.5$ fiducial region

K_L decay primarily to final states with $\pi^\pm$ rather than $e^\pm$
$\rightarrow$ need efficiency of electron id : $0.95 < E/p < 1.05$

Pions can charge exchange in calorimeter : $\pi^- p \rightarrow \pi^0 n$
$\rightarrow$ pions mis-identified as electrons

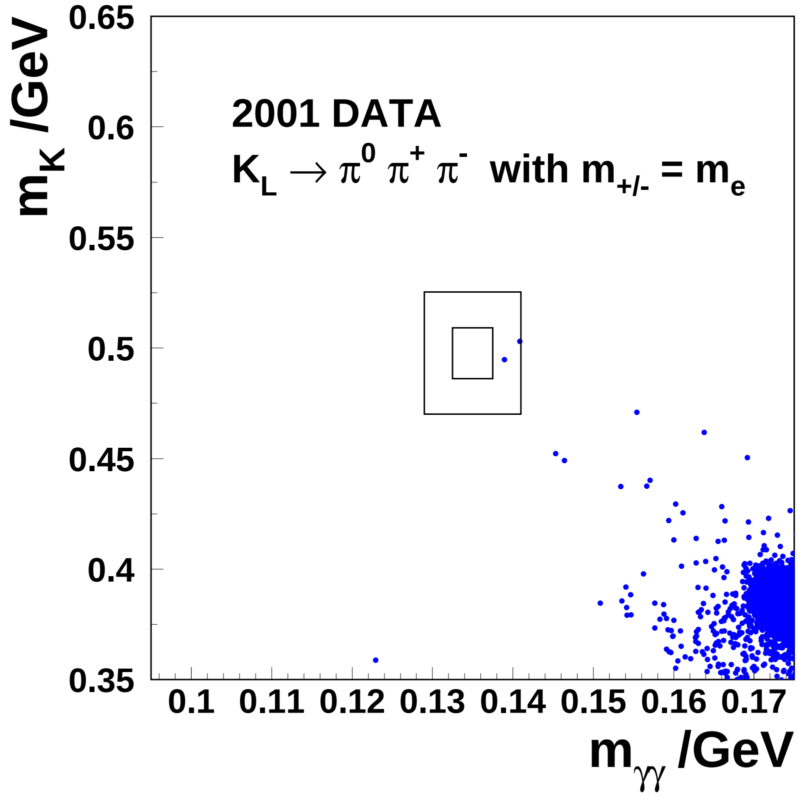
Select $K_L \rightarrow \pi^0\pi^+\pi^-$ decays from 2001 data :
Measure mis-identification probability $\rightarrow$ $\sim 10^{-2}$
Study kinematic rejection
using events from data

Starting from 5×10^8 K_L decays we expect :
6×10^3 $\pi^0\pi^+\pi^-$ decays
2×10^6 $\pi^0\pi^\pm e^\mp \nu$ decays
with two charged particles that look like e^+e^-

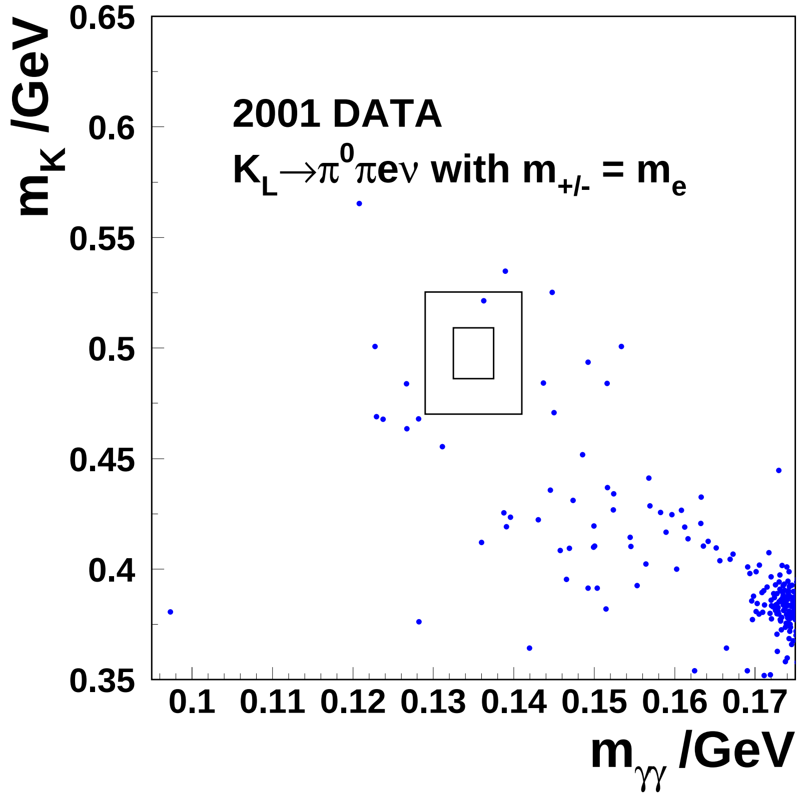
Backgrounds from $K_L \to \pi^0\pi^+\pi^-$ *and* $K_L \to \pi^0\pi^\pm e^\mp\nu$

To study rejection from kinematics, selected $\pi^0\pi^+\pi^-$ and $\pi^0\pi^\pm e^\mp\nu$ from 2001 data :

200 × 2002 statistics



60 × 2002 statistics



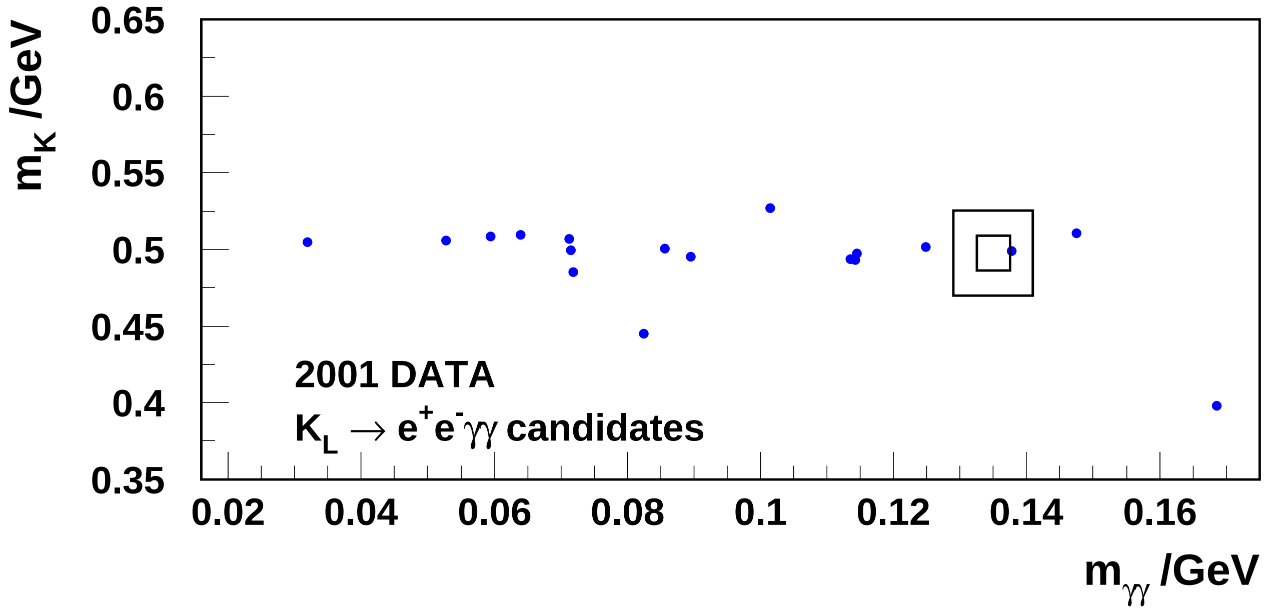
No events were found in the signal region in either channel

$Background\ from\ K_L \rightarrow ee\gamma\gamma$

Expect 300 $K_L \rightarrow ee\gamma\gamma$ decays in $0 < \frac{c\tau}{c\tau_S} < 2.5$ $(BR = 6{\times}10^{-7})$

Strongly suppressed by $m_{ee} > 0.165\,\mathrm{GeV}$ requirement and $m_{\gamma\gamma} = m_{\pi^0}$ cut ($\sigma_{m_{\pi^0}} = 1\,\mathrm{MeV}$ in $K_S \rightarrow \pi^0 e^+ e^-$)

$K_L \rightarrow ee\gamma\gamma$ candidates selected from 2001 data (K_L beam) used to estimate background (10 $\times$ number of K_L decays in 2002 data)



Extrapolate from low $m_{\gamma\gamma}$ region to signal region (assuming flat in $m_{\gamma\gamma}$)

Background summary so far ...

Backgrounds from K_S decays :

$\Rightarrow K_S \rightarrow \pi^0_D \pi^0_D$ contributes 0.007 event in $\pm 2.5\sigma$ signal region

Backgrounds from K_L decays :

Mis-identification $\pi^{\pm} \Leftrightarrow e^{\pm}$, kinematic rejection studied with data

$\Rightarrow K_L \rightarrow ee\gamma\gamma$ contributes 0.075 event in $\pm 2.5\sigma$ signal region

Now consider backgrounds from Ξ^0 decays :

Ξ^0 decays

$\Xi^0 \rightarrow \Lambda(p\pi^-)\pi^0$

$\Xi^0 \rightarrow \Lambda(pe^-\nu)\pi^0$

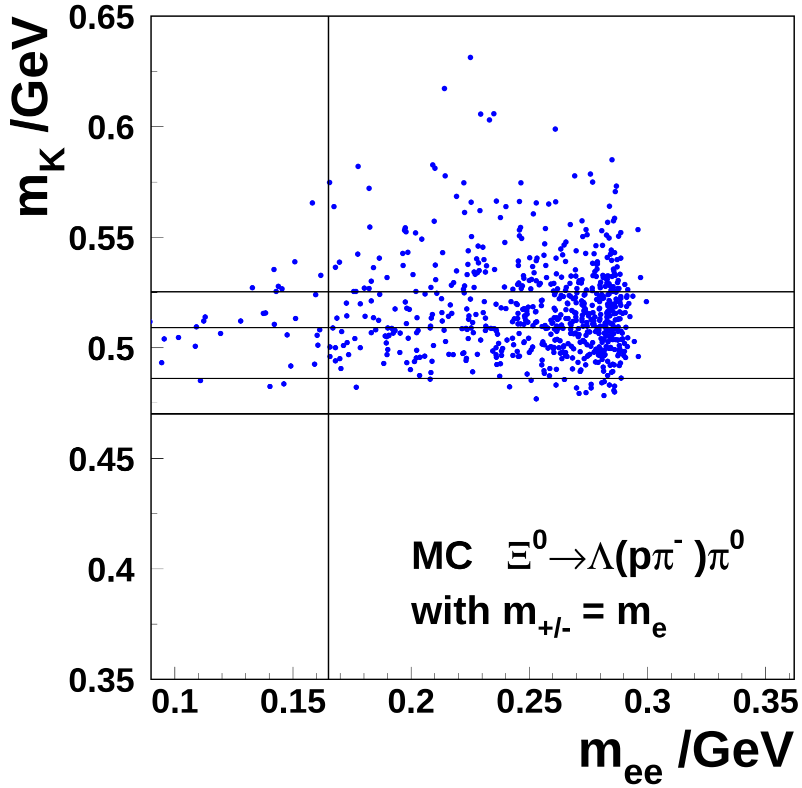
$\Xi^0 \rightarrow \Sigma^+(p\pi^0)e^-\nu$

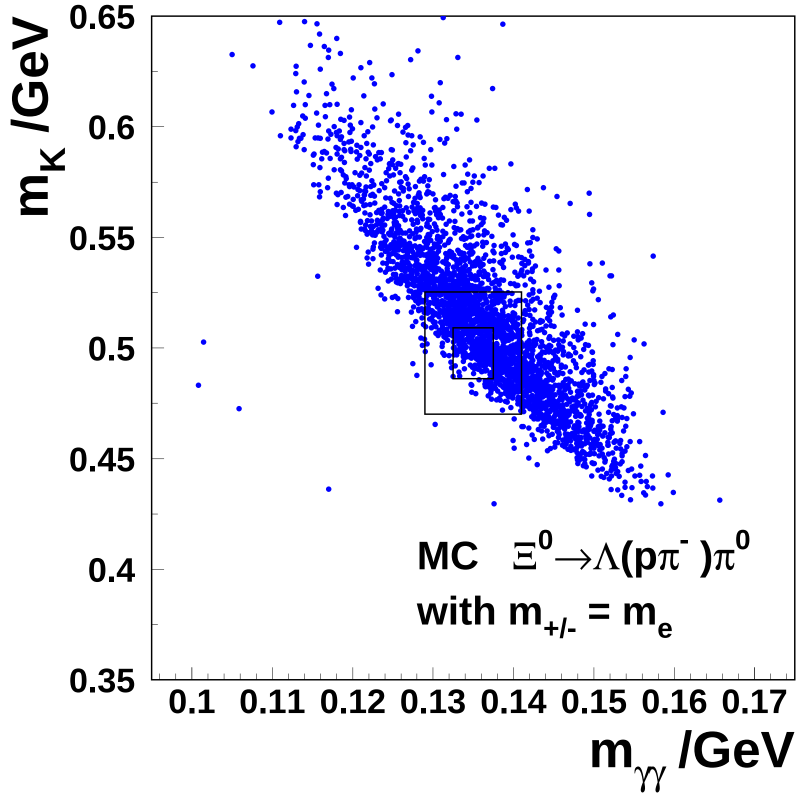
Backgrounds from Ξ^0 decays

Expect $\sim 2\times10^9$ $\Xi^0 \rightarrow \Lambda(p\pi^-)\pi^0$ decays in $0 < \frac{c\tau}{c\tau_S} < 2.5$

Probability of proton mis-identification as e^+ measured from 2001 data using Λ decays $\rightarrow$ $\sim 10^{-4}$

Expect 2×10^3 $\Xi^0 \rightarrow \Lambda(p\pi^-)\pi^0$ decays in 2002 data with two charged particles that look like e^+e^-





Backgrounds from Ξ^0 decays (cont'd)

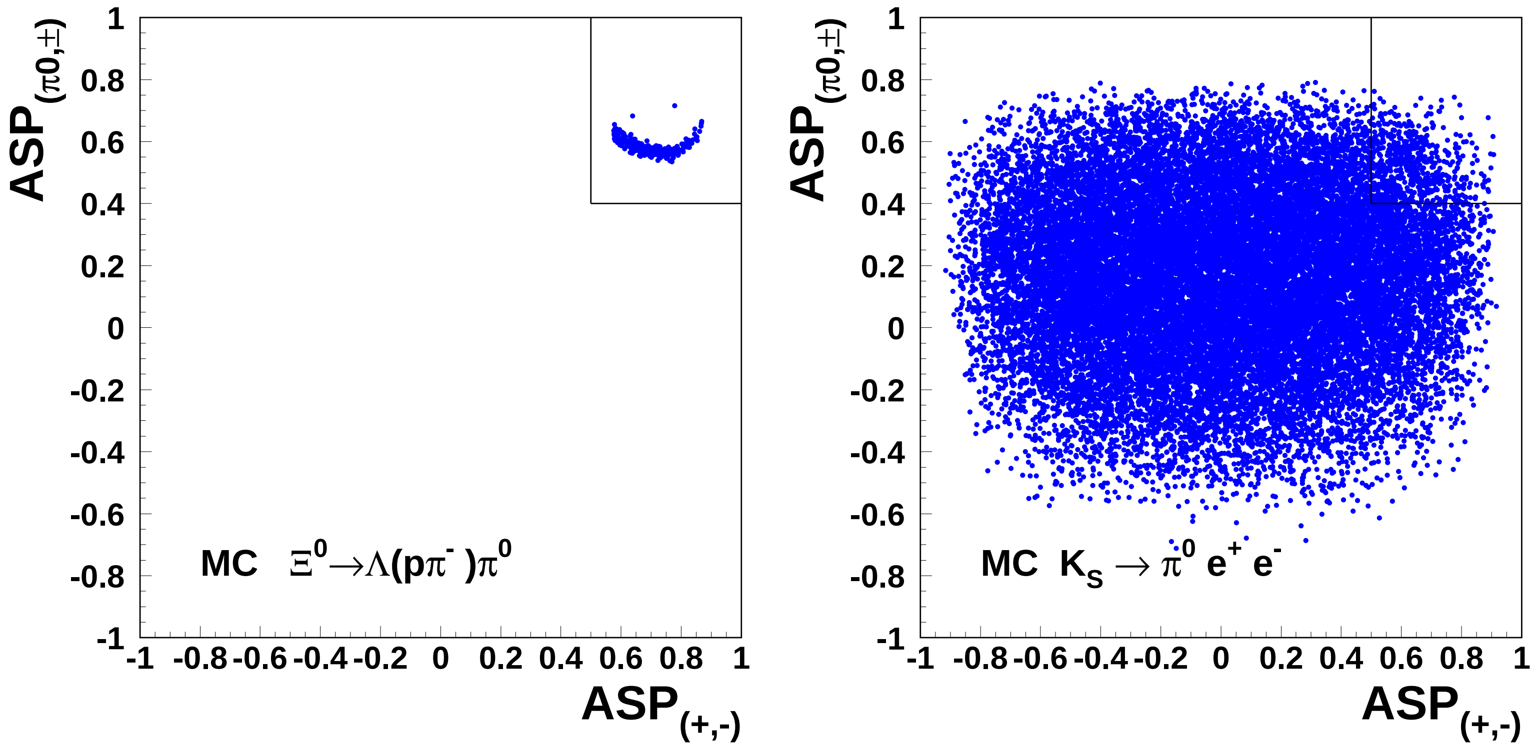
$\Xi^0 \rightarrow \Lambda(p\pi^-)\pi^0$ acceptance ~2 % ⇒ background already small

Exploit momentum asymmetry in Ξ^0 and Λ decay - additional cut on :

$$ASP_{(\pi^0,\pm)} = \frac{p_{\pi^0}-(p_+ + p_-)}{p_{\pi^0}+(p_+ + p_-)} \text{ and } ASP_{(+,-)} = \frac{p_+ - p_-}{p_+ + p_-}$$

reduces background to negligible level

$\Xi^0 \rightarrow \Lambda(pe^-\nu)\pi^0$, $\Xi^0 \rightarrow \Sigma^+(p\pi^0)e^-\nu$ decays rejected in same way



Background summary so far ...

Backgrounds from K_S decays :

$\Rightarrow K_S \rightarrow \pi^0_D \pi^0_D$ contributes 0.007 event in $\pm 2.5\sigma$ signal region

Backgrounds from K_L decays :

$\Rightarrow K_L \rightarrow ee\gamma\gamma$ contributes 0.075 event in $\pm 2.5\sigma$ signal region

Backgrounds from Ξ^0 decays $\rightarrow$ additional cut :

Cut on momentum asymmetry in Ξ^0 and Λ decay

$\Rightarrow$ Negligible contribution from Ξ^0 decays

Now consider backgrounds from overlapping fragments of two decays :

from different proton interactions

p$\rightarrow K_S$ p$\rightarrow K_L$

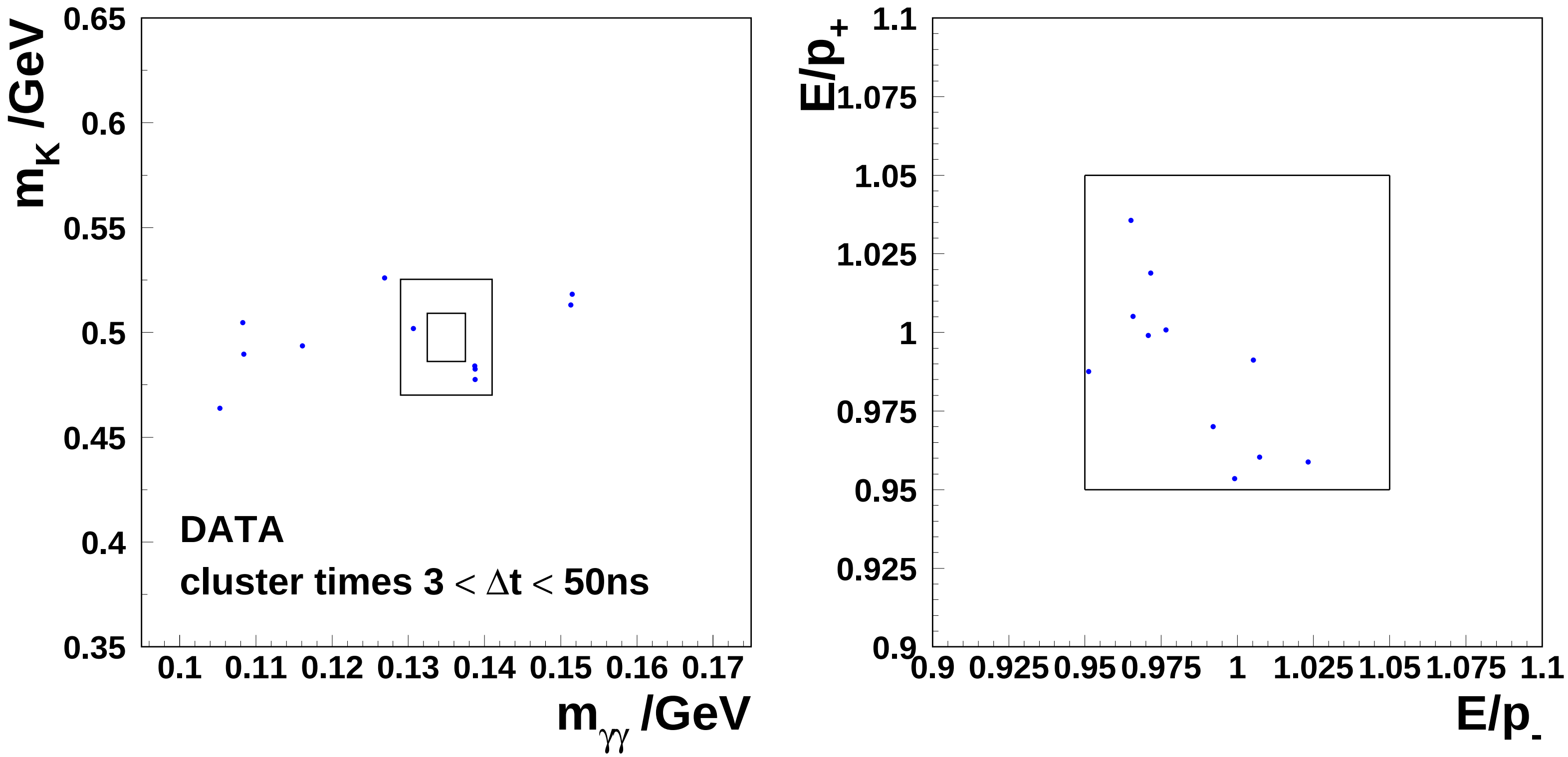
Background from overlapping fragments of two decays

Two p interactions accidentally close together in time look like one event : p_1+ Be $\rightarrow K_S$ +X and p_2+ Be $\rightarrow K_L$ +X

Rate measured using events with two fragments well separated in time

Control region : time between fragments Δt : $3 < \Delta t < 50\,\mathrm{ns}$

Signal region : $\Delta t < 3\,\mathrm{ns}$



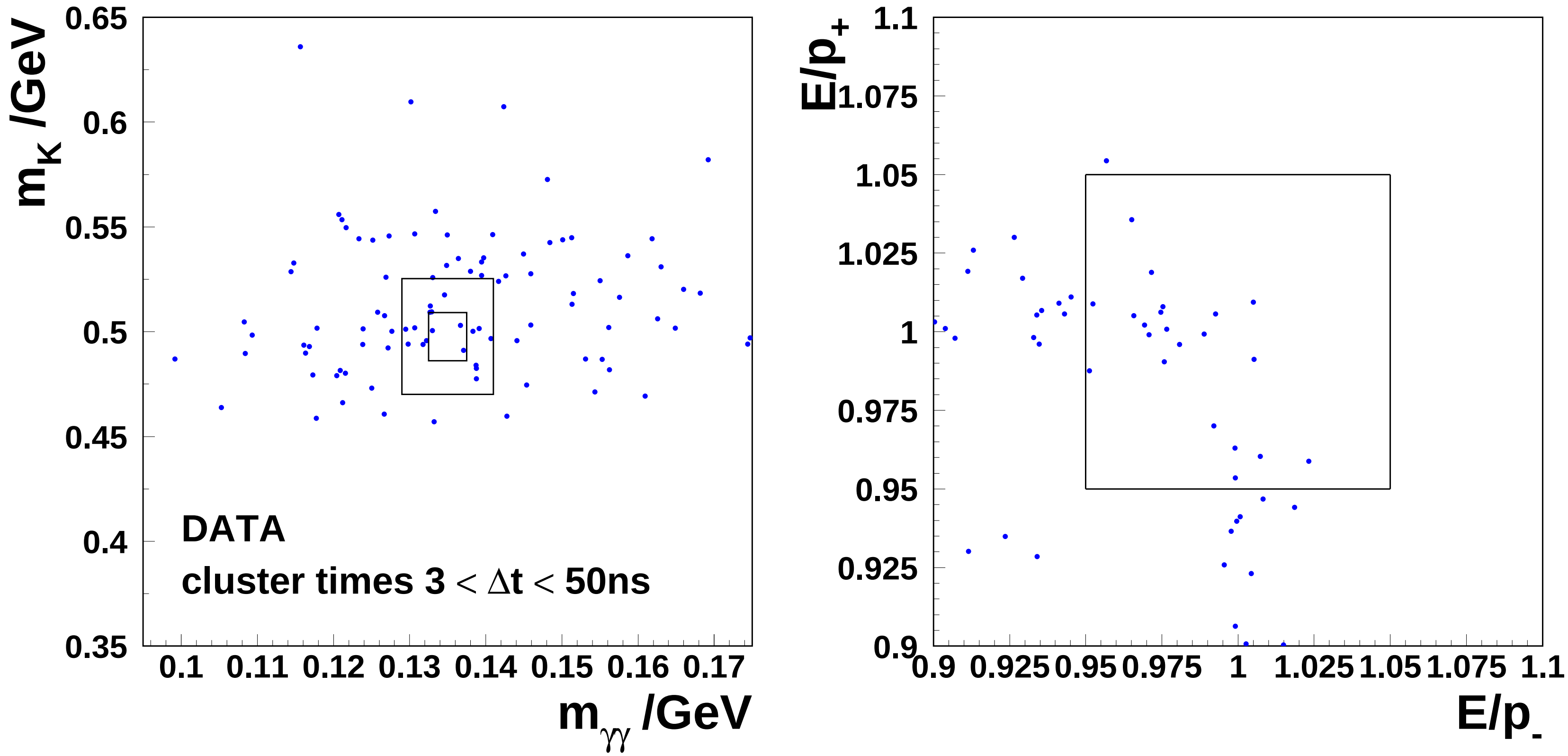
Extrapolate from out-of-time control region to in-time signal region

Background from overlapping fragments of two decays (cont'd)

Major component:

$$\mathrm{ee}(\pi^{\pm}e^{\mp}\nu) + \gamma\gamma(\pi^0\pi^0(\pi^0))$$

confirmed by relaxing E/p and $c\tau$



Background from overlapping fragments of two decays (cont'd)

No events in 2.5σ signal region in $(3 < \Delta t < 50\,\mathrm{ns})$ time sidebands

Toy MC $\Rightarrow$ (m_K, m_{π^0}) distribution of $(\pi^{\pm} e^{\mp} \nu) + (\pi^0 \pi^0 (\pi^0))$

Events in 6σ control region extrapolated into signal region using shape from toy MC

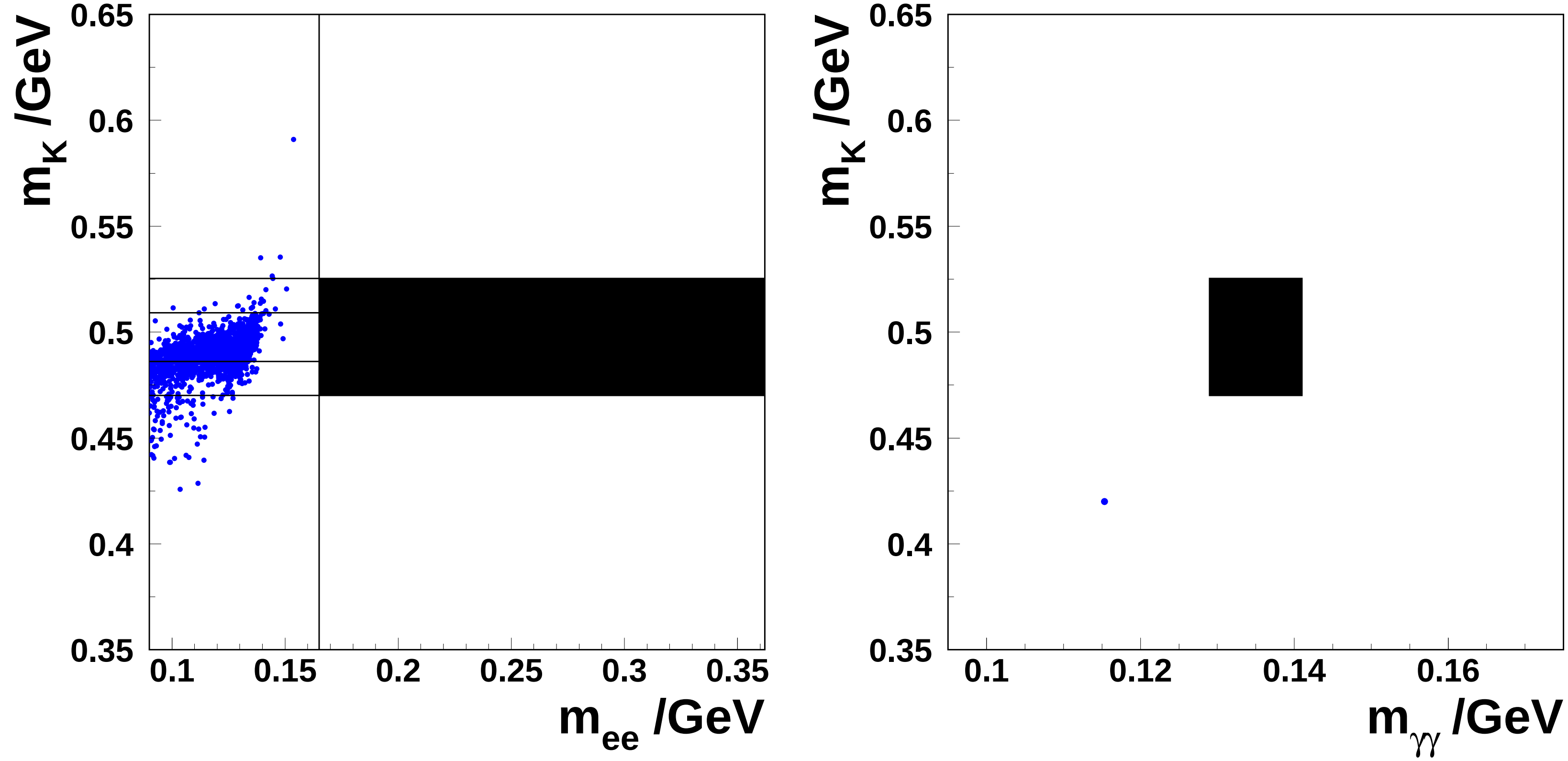
Linear extrapolation from $(3 < \Delta t < 50\,\mathrm{ns})$ time sidebands to $(\Delta t < 3\,\mathrm{ns})$ in-time signal region

Total background

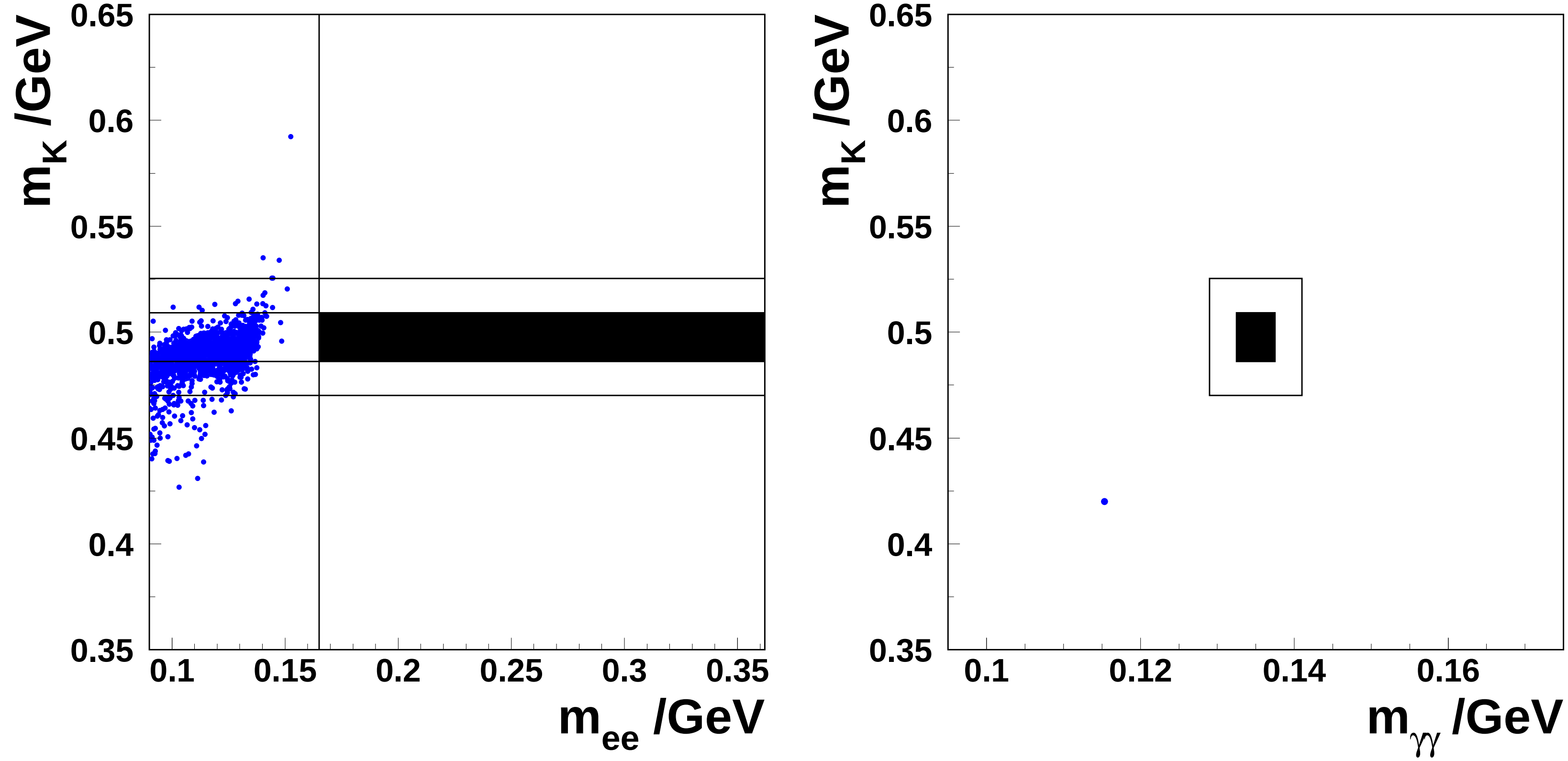
Significant contributions to the background in the signal region :

Source	control region	signal region
$K_S \to \pi^0_D \pi^0_D$	0.03	0.007
$K_L \to ee\gamma\gamma$	0.11	0.075
$(\pi^\pm e^\mp \nu) + (\pi^0 \pi^0 (\pi^0))$	0.19	0.069
Total background	$0.33^{+0.18}_{-0.11}$	$0.15^{+0.05}_{-0.04}$

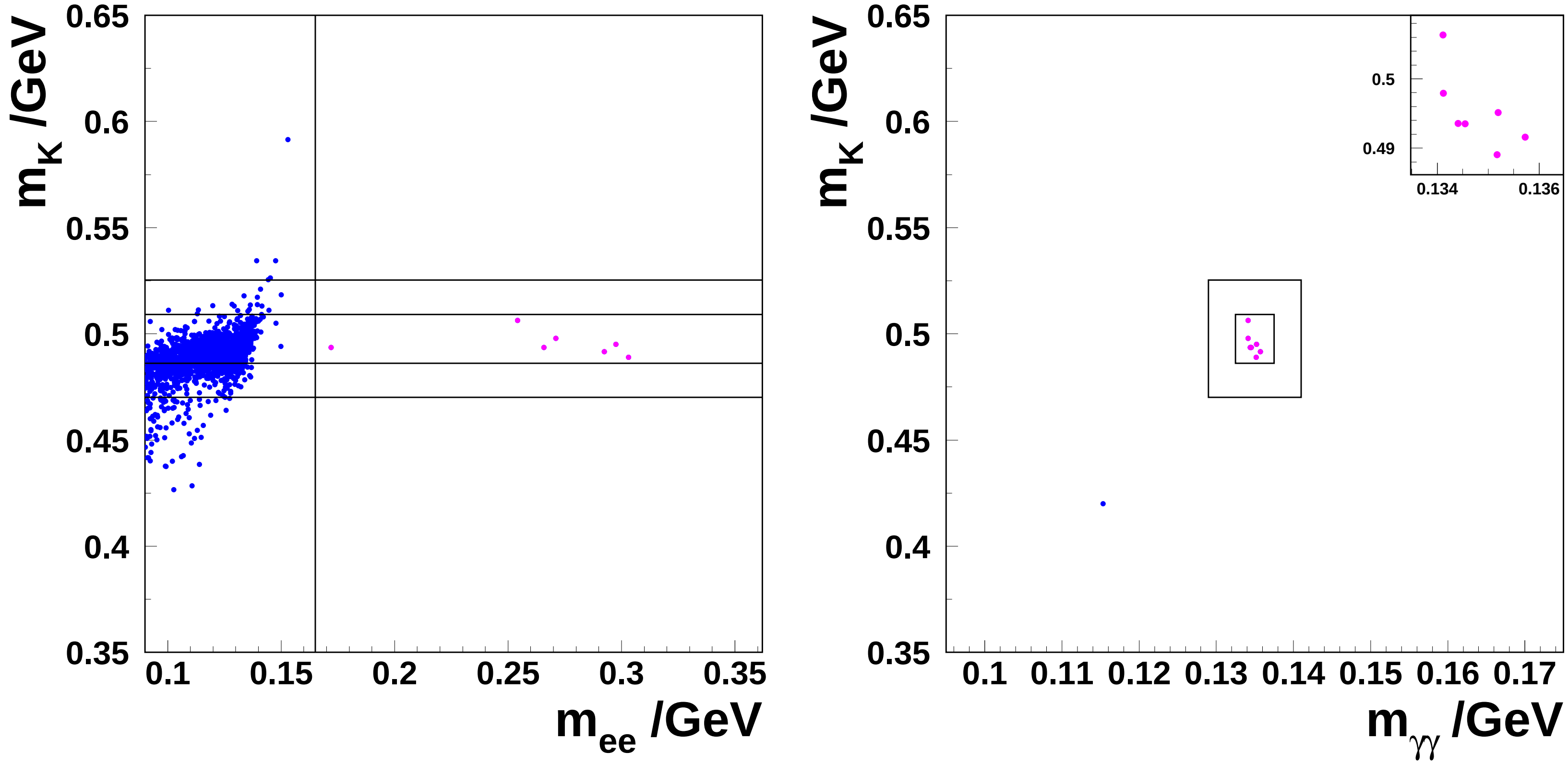
Toward opening the box ...



Unmasking the control region



Finally we can open the box !



7 events found in the signal region :

Negligible probability that all 7 events are consistent with background ($\sim 10^{-10}$)

$\rightarrow$ presence of signal well established

No events found in equivalent same sign distributions

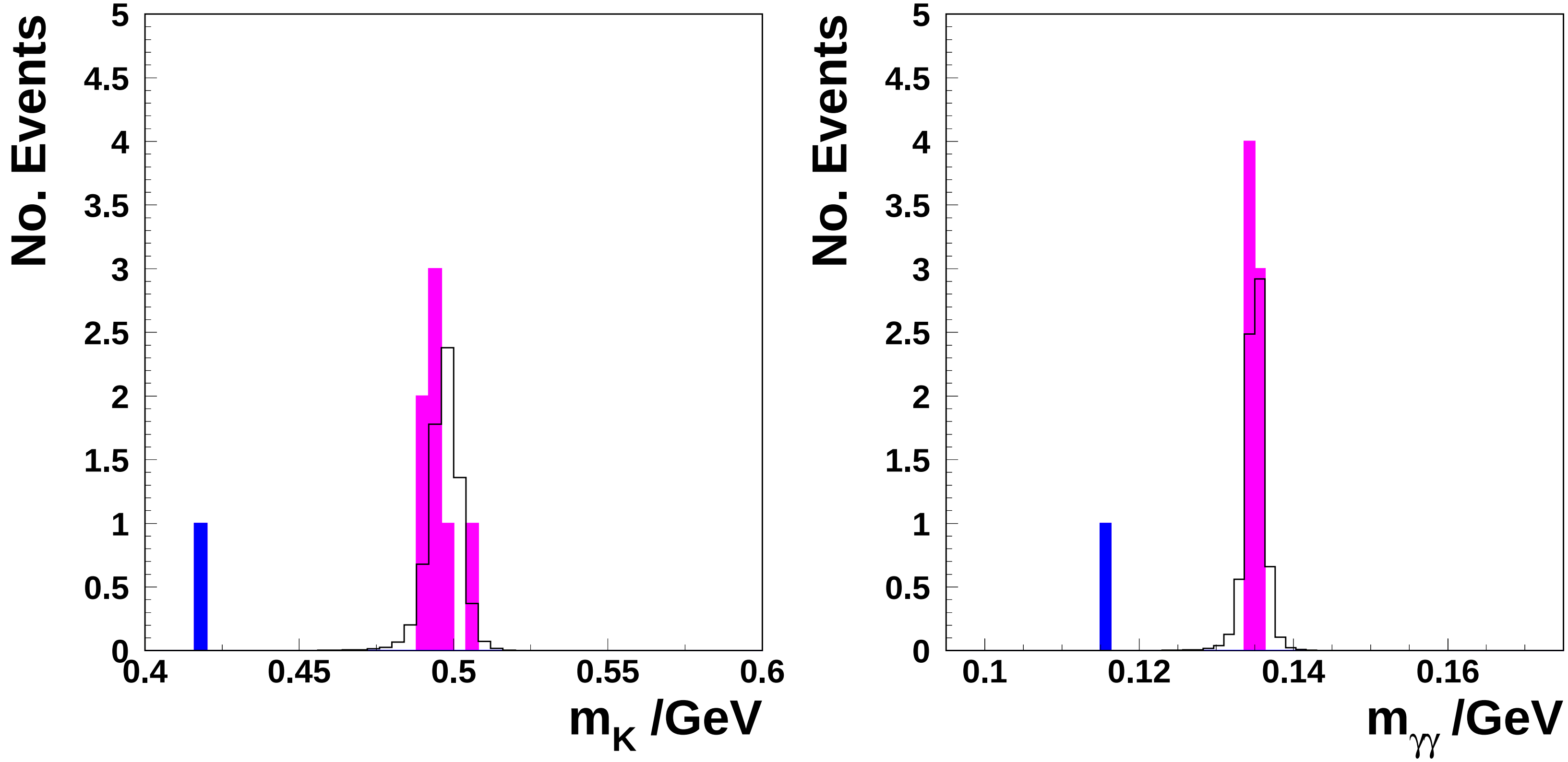
The box is open !

	control region	signal region
DATA	0	7
Total background	$0.33^{+0.18}_{-0.11}$	$0.15^{+0.05}_{-0.04}$

Have checked that there is no accumulation of background close to the signal region by relaxing cuts :

- E/p — $0.95 < E/p < 1.05$ $\longrightarrow$ $E/p > 0.85$
- $c\tau$ — $0 < \frac{c\tau}{c\tau_S} < 2.5$ $\longrightarrow$ $0 < \frac{c\tau}{c\tau_S} < 5$
- m_{ee} — $m_{ee} > 0.165\,\mathrm{GeV}$ $\longrightarrow$ $m_{ee} > 0.150\,\mathrm{GeV}$
- centre-of-gravity — $cog < 6\,\mathrm{cm}$ $\longrightarrow$ $cog < 10\,\mathrm{cm}$
- ASP cut — reversed : try to select Ξ^0 decays

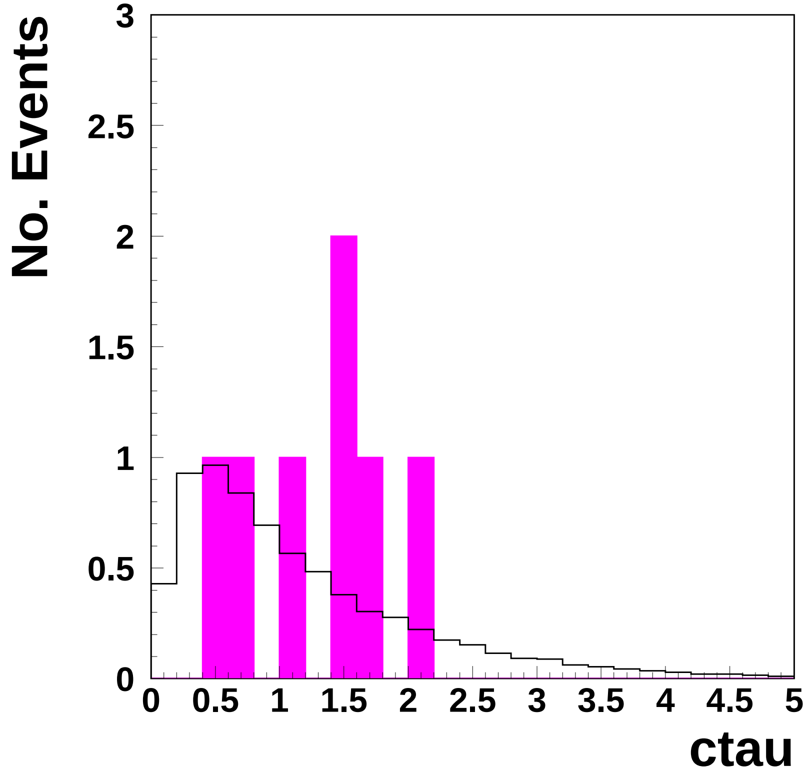
$K_S \to \pi^0 e^+ e^- \, events$

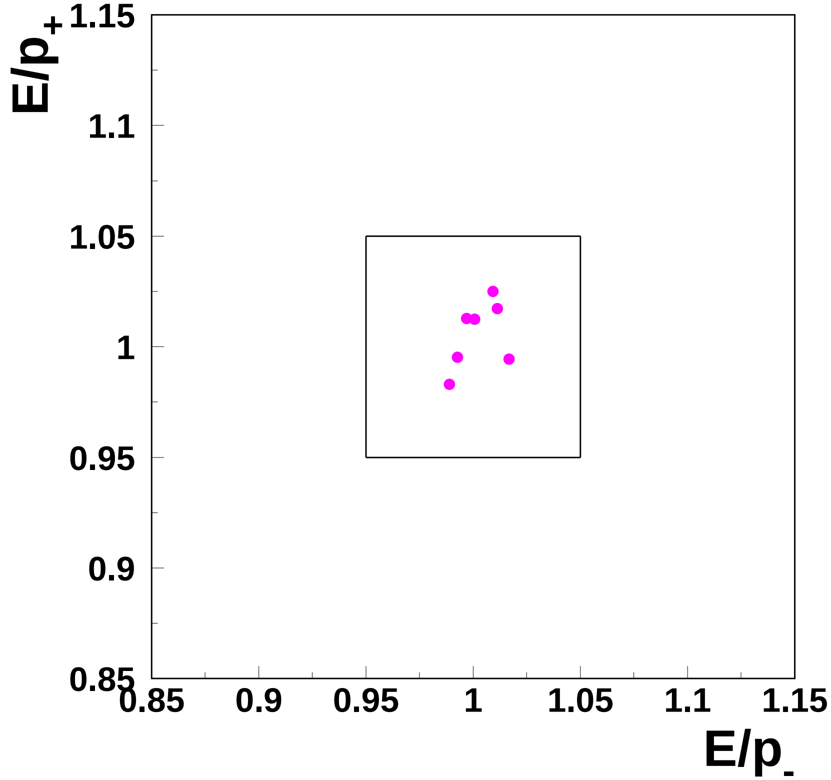


1 background event seen $17\sigma_{m_K}$, $20\sigma_{m_{\gamma\gamma}}$ from the signal region

Monte Carlo mass distribution : solid line

$K_S \rightarrow \pi^0 e^+ e^- \; events \; (cont'd)$





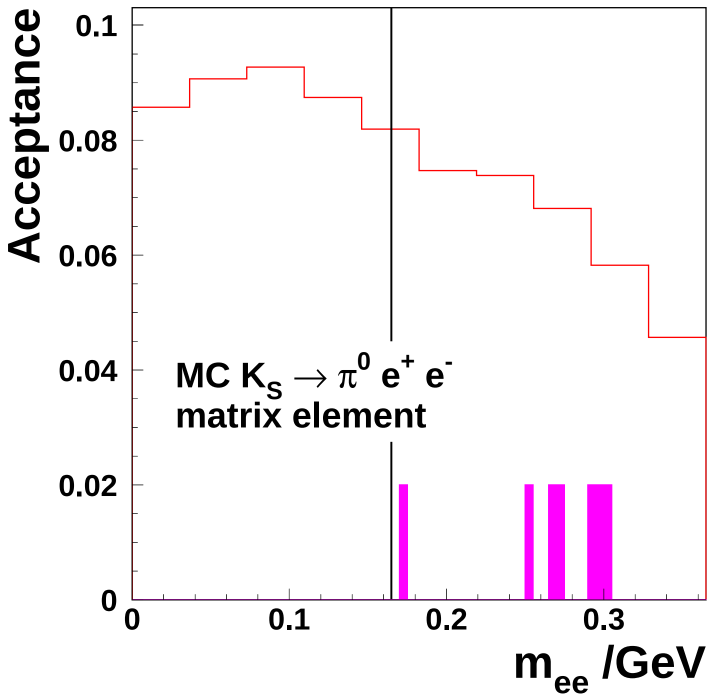
Branching ratio measurement - Acceptance

Model independent acceptance, α :

α computed in bins of m_{ee}

take weighted mean according to distribution of 7 $K_S \to \pi^0 e^+ e^-$ events found

$$\to \alpha(m_{ee} > 0.165\,\text{GeV}) = 6.6\%$$



Shape given by vector matrix element [JHEP 08 (1998) 004]

Branching ratio measurement - Flux

K_S flux measured using $K_S \to \pi^0 \pi^0_D$ decays :

- topologically similar to $K_S \to \pi^0 e^+ e^-$
- taken by the same trigger

Cross-checked using $K_S \to \pi^0 \pi^0$ decays

$\to$ Difference found between the two fluxes : 18.8%

Half the discrepancy is understood (common to $\pi^0 e^+ e^-$, $\pi^0 \pi^0_D$) :

- inefficiencies due to the drift chamber read-out (at start of run)
- accidental losses

To account for the remaining unexplained difference (10%) :

- K_S flux measured with $\pi^0 \pi^0_D$ decays increased by 5%
- systematic error of 5% assigned

Branching ratio measurement

7 events observed with a background 0.15 event

- Acceptance (m_{ee}>0.165 GeV)= 6.6 %
- Taking $\pi^0\pi^0_D$ flux

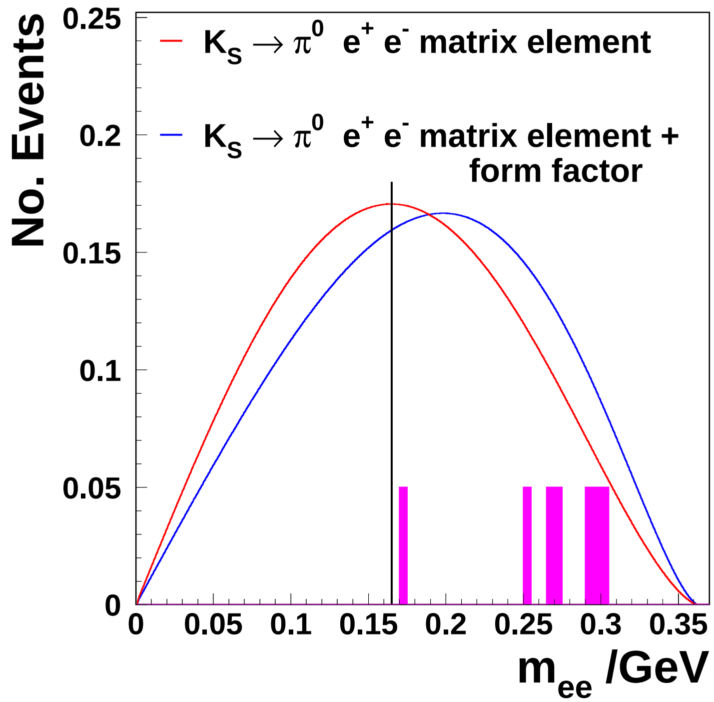
Preliminary result :

$$BR(K_S \rightarrow \pi^0 e^+ e^-)_{(m_{ee}>0.165 \text{ GeV})} =$$

$$(3.0^{+1.5}_{-1.2}(stat) \pm 0.2(syst)) \times 10^{-9}$$

Extrapolating to all m_{ee}

Acceptance calculated using vector matrix element
(D'Ambrosio, Ecker, Isidori, Portoles [JHEP 08 (1998) 004])



Form factor : $w(z) = (1 + \frac{b}{a}z)$ where $z = {m_{ee}}^2/{m_K}^2$, and $b/a = 1.12$
(from fitting $K^+ \to \pi^+ e^+ e^-$ including the $\pi\pi$ loop [PRL 83 (1999) 4482])

Extrapolation to full acceptance done using $w(z) = 1$

Preliminary results

Measured branching ratio :

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

Extrapolating to all m_{ee} (*) :

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

χPT prediction : $BR(K_S \to \pi^0 e^+ e^-) = 5 \times 10^{-9} |a_s|^2 \quad \to$
Preliminary measurement of $|a_s|$:

$$|a_s| = 1.08^{+0.26}_{-0.21}$$

---

* Matrix element from [JHEP 08 (1998) 004] used with form factor $w(z) = 1$

Implications for $K_L \to \pi^0 e^+ e^-$

Measurement of $|a_s|$ allows BR($K_L \to \pi^0 e^+ e^-$) to be predicted as a function of $\mathcal{I}m(\lambda_t)$ to within a sign ambiguity :

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} = \left(15.3 a_s^2 \pm 6.8 \frac{\mathcal{I}m(\lambda_t)}{10^{-4}} |a_s| + 2.8 \left(\frac{\mathcal{I}m(\lambda_t)}{10^{-4}}\right)^2\right) \times 10^{-12}$$

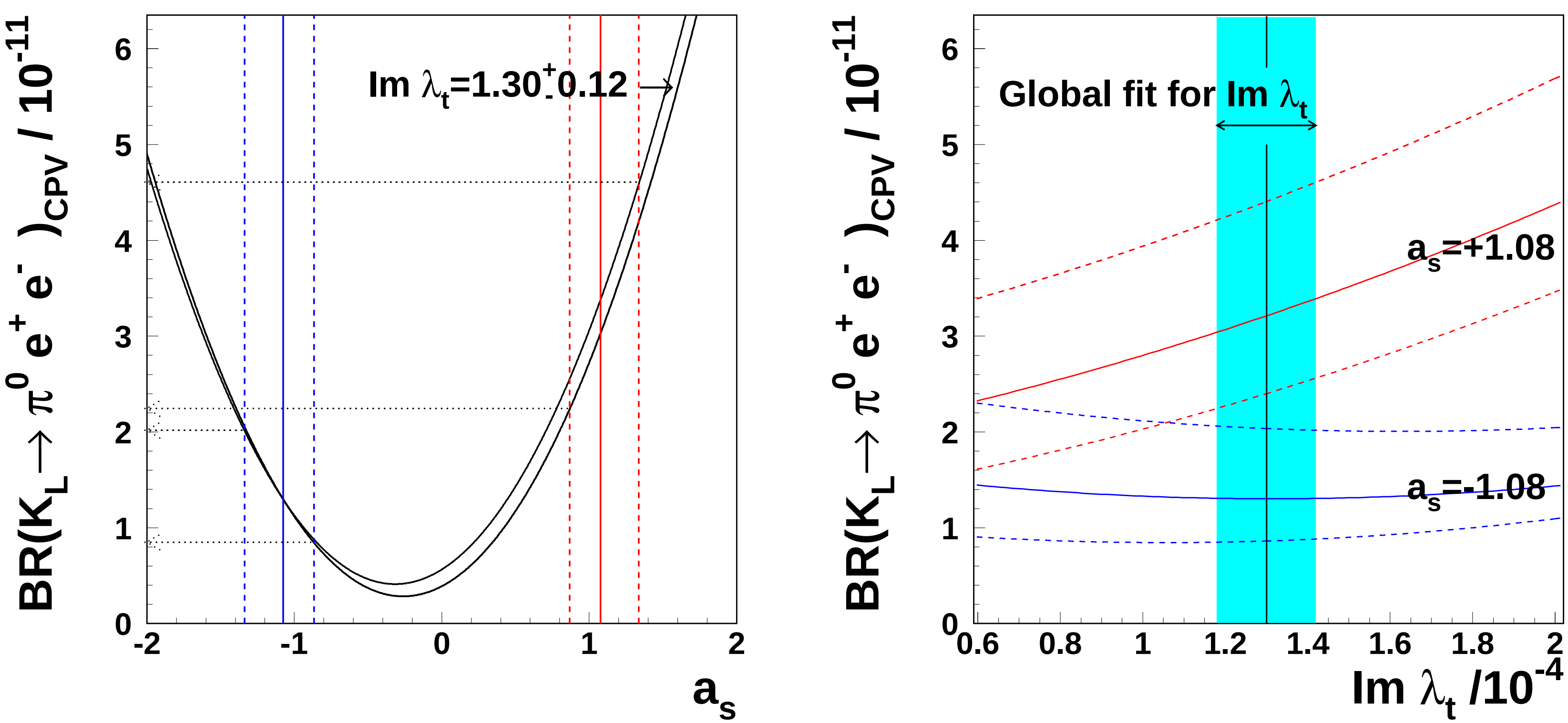
indirect interference direct

$$BR(K_L \to \pi^0 e^+ e^-)_{CPV} = (\ 17.7 \ \pm \ 9.5 \ + \ 4.7 \ ) \times 10^{-12}$$

(Global fit $\Rightarrow \mathcal{I}m(\lambda_t) = (1.30 \pm 0.12) \times 10^{-4}$ Kettell, Landsberg, Nguyen [hep-ph/0212321])

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

Implications for $K_L \to \pi^0 e^+ e^-$ (cont'd)



$$\Rightarrow BR(K_L \to \pi^0 e^+ e^-) = 1 - 4\times 10^{-11}$$

Conclusions

4.2×10^{10} K_S decays collected in the fiducial region during 89 days

7 $K_S \rightarrow \pi^0 e^+ e^-$decays found in region $m_{ee} > 0.165$ GeV with 0.15 event background

$\Rightarrow$ well established evidence for signal

Preliminary results :

Measured branching ratio :

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

Extrapolating to all m_{ee} :

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

$$|a_s| = 1.08^{+0.26}_{-0.21}$$

Spares

Background from overlapping fragments of two decays (cont'd)

Two fragments from a single proton interaction → always close together in time

Resonances → K+(K,Λ)   *e.g.* $\phi(K_S K_L)$

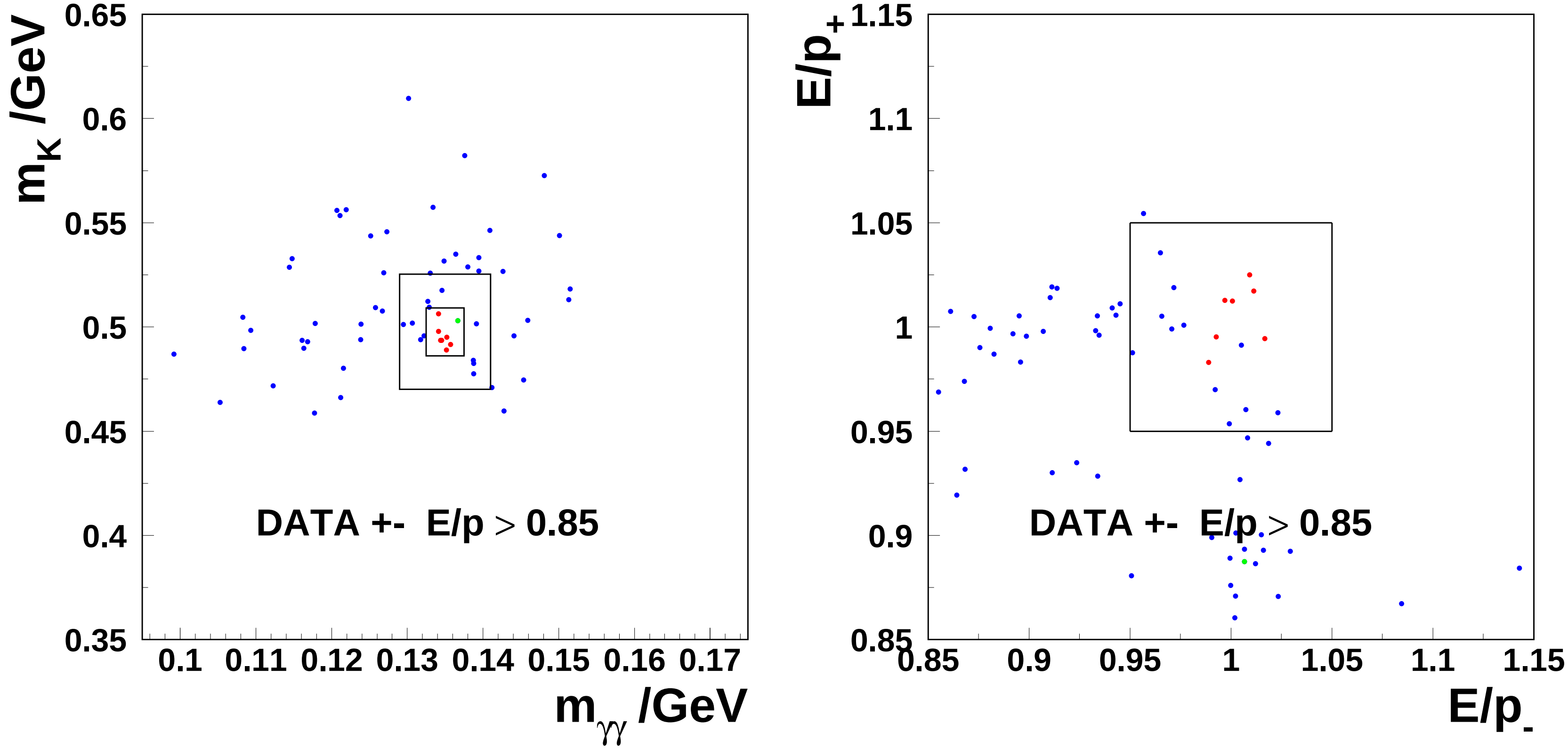
Estimated number of ϕ by searching for $K_S(\pi^+\pi^-)K_L(\pi^0\pi^0\pi^0)$ events in 2002 data

- No evidence for in-time peak above accidental background → assumed all decays found in-time from a ϕ (upper limit)
- Computed background from all partially reconstructed K_S+K_L decays modes

Also searched for in-time sources of K_S+K_S, K_S+Λ, K_L+Λ

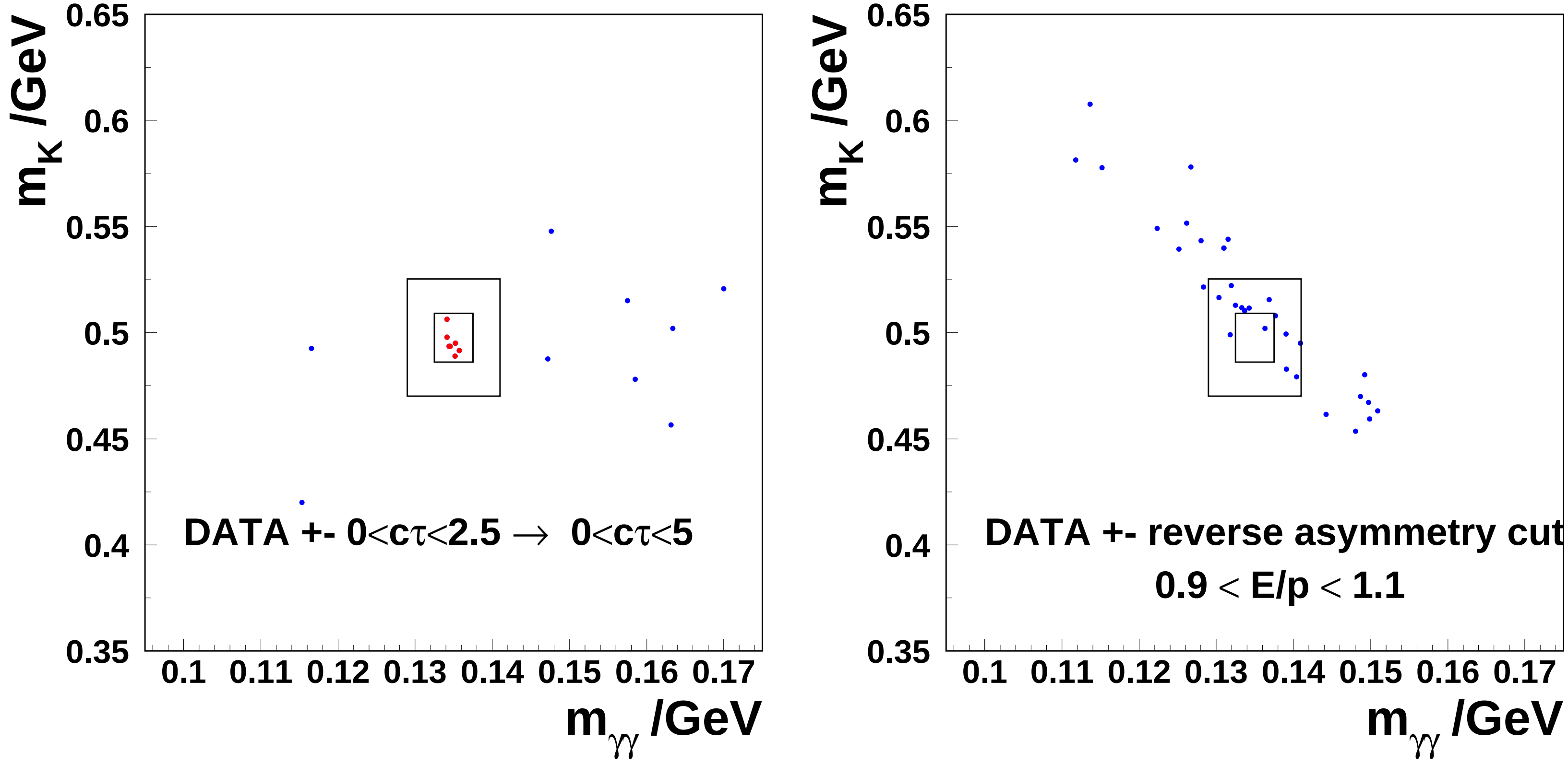
Total contribution to background negligible

Checks

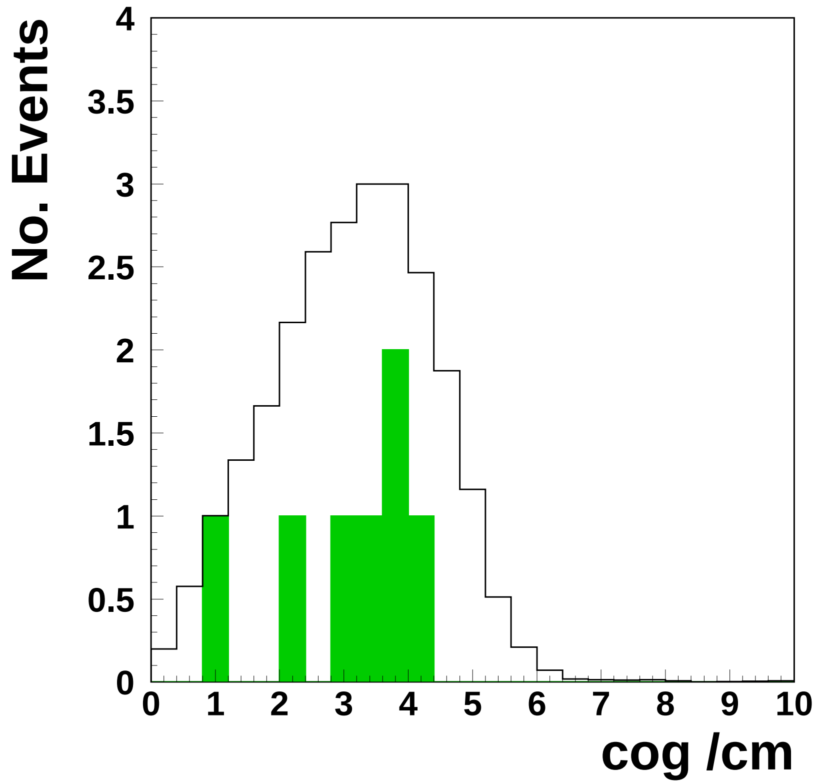


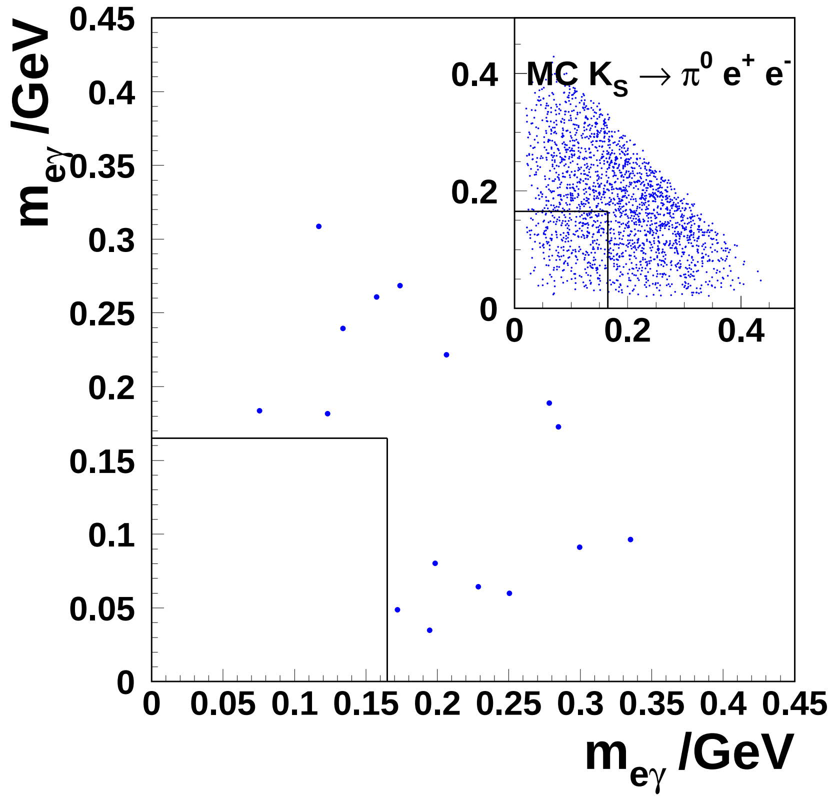
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.1 0.11 0.12 0.13 0.14 0.15 0.16 0.17
m_K /GeV
$m_{\gamma\gamma}$ /GeV
DATA +- E/p > 0.85
1.15
1.1
1.05
1
0.95
0.9
0.85
0.85 0.9 0.95 1 1.05 1.1 1.15
E/p_+
E/p_-
DATA +- E/p > 0.85

Checks (cont'd)



$K_S \to \pi^0 e^+ e^-$ *events (cont'd)*





$NA48$ and $KTeV$ measurements of $K_L \to \pi^0\gamma\gamma$

NA48 : $\mathrm{BR}(K_L \to \pi^0\gamma\gamma) = (1.36 \pm 0.05)\times 10^{-6}$ [PL B536 229]

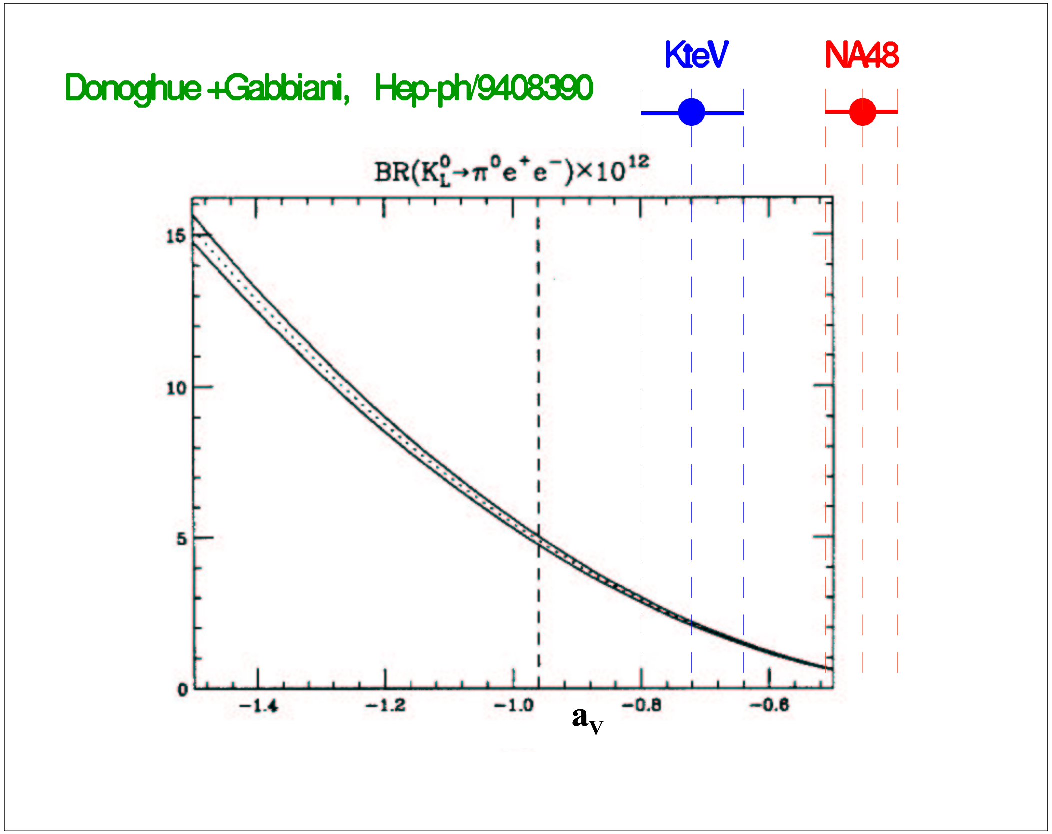
$\to a_V = -0.46 \pm 0.05$

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

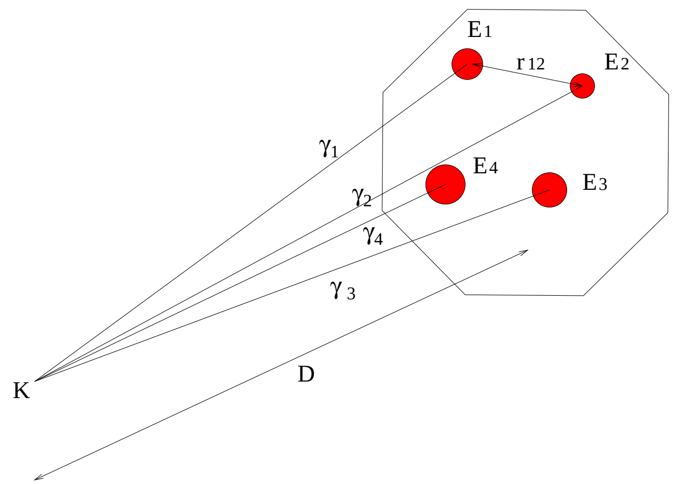
KTeV : $\mathrm{BR}(K_L \to \pi^0\gamma\gamma) = (1.68 \pm 0.10)\times 10^{-6}$ [PL 83 917]

$\to a_V = -0.72 \pm 0.08$

$\to BR(K_L \to \pi^0 e^+ e^-)_{CP\,cons} \sim 2\times 10^{-12}$



π^0 reconstruction



- Vertex position along beam line found by imposing the Kaon mass

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

Z_{vtx} resolution $\approx$ 50 cm

$\Rightarrow$ Correlation between Z_{vtx} and energy scale