Physics with NA48/1 K_S Beam

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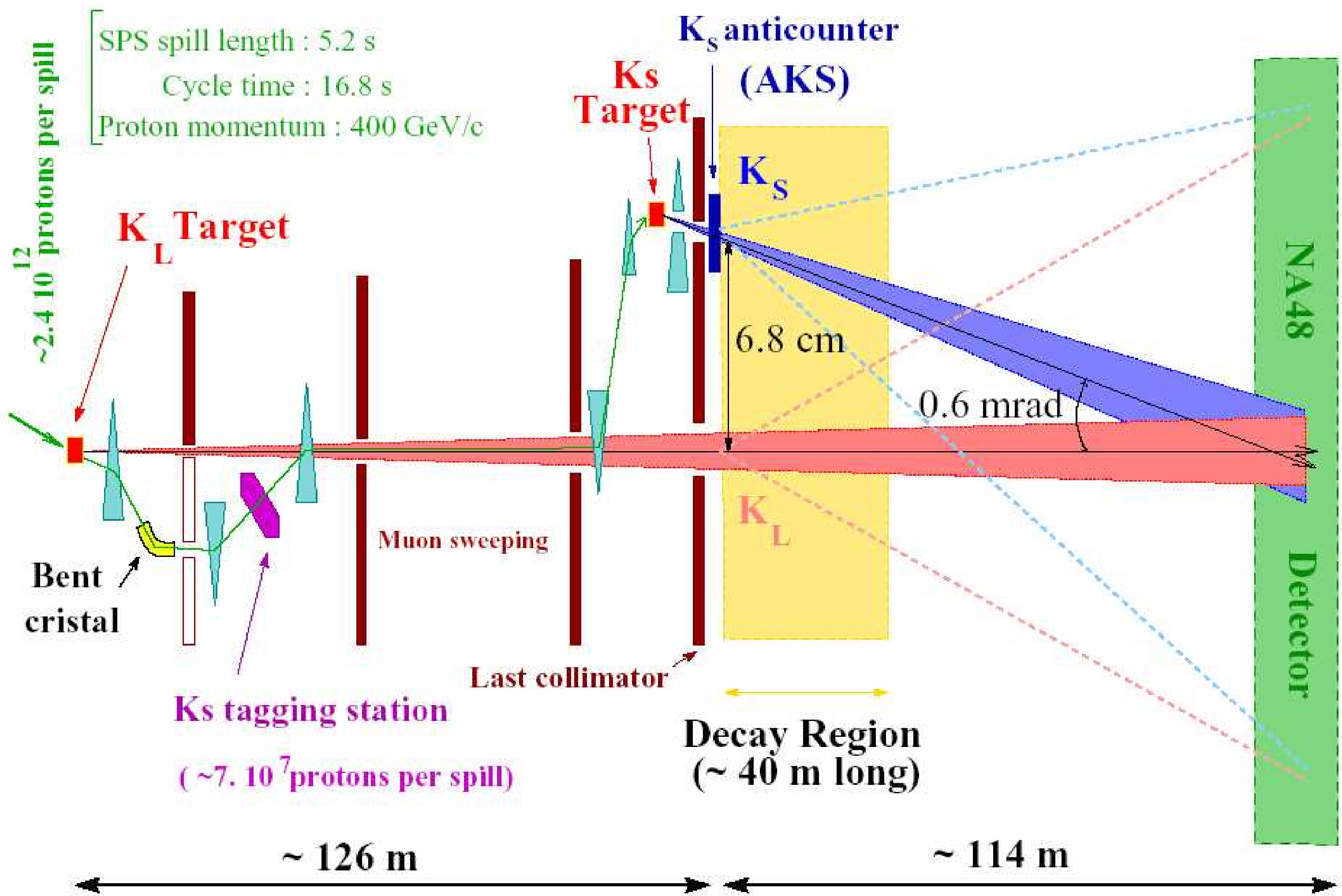
Overview

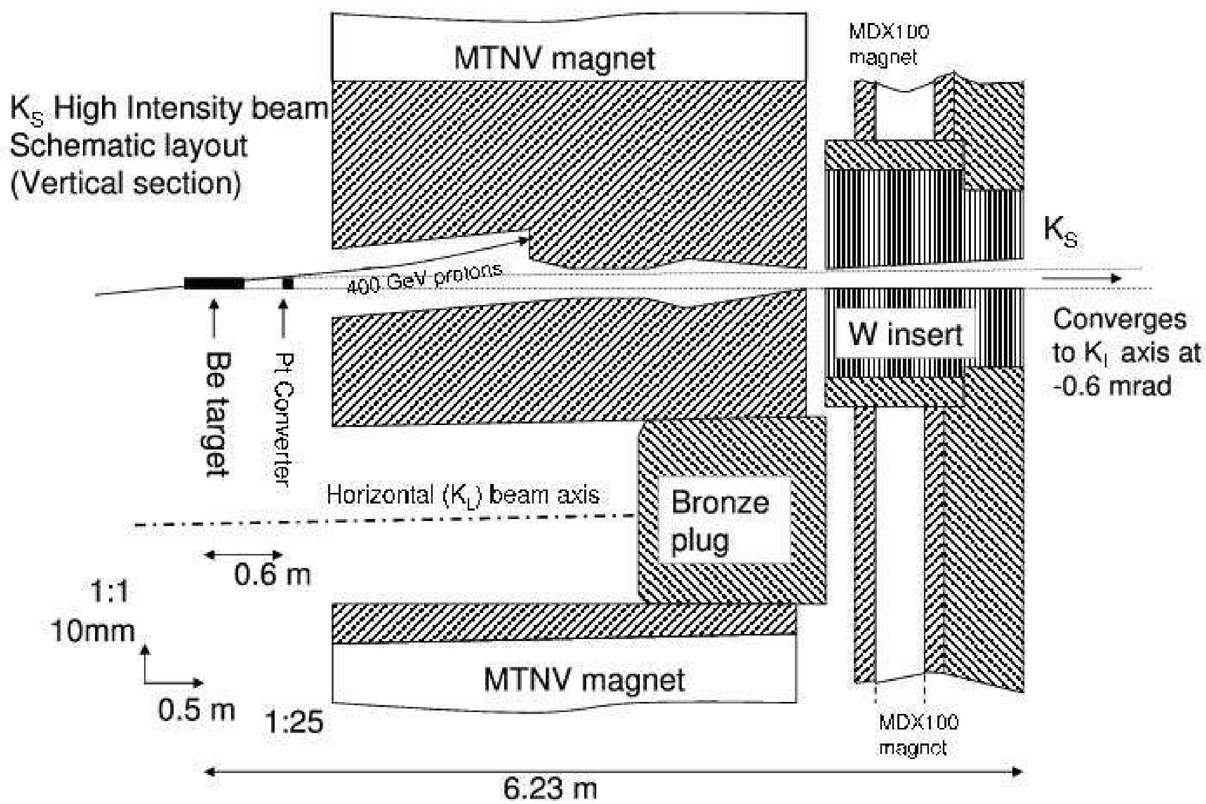
- NA48 Setup
- Data samples
- First observation of $K_S \to \pi^0 e^+ e^-$
- Status of the study of Ξ^0 β-decay

Experimental setup: *the beam lines*

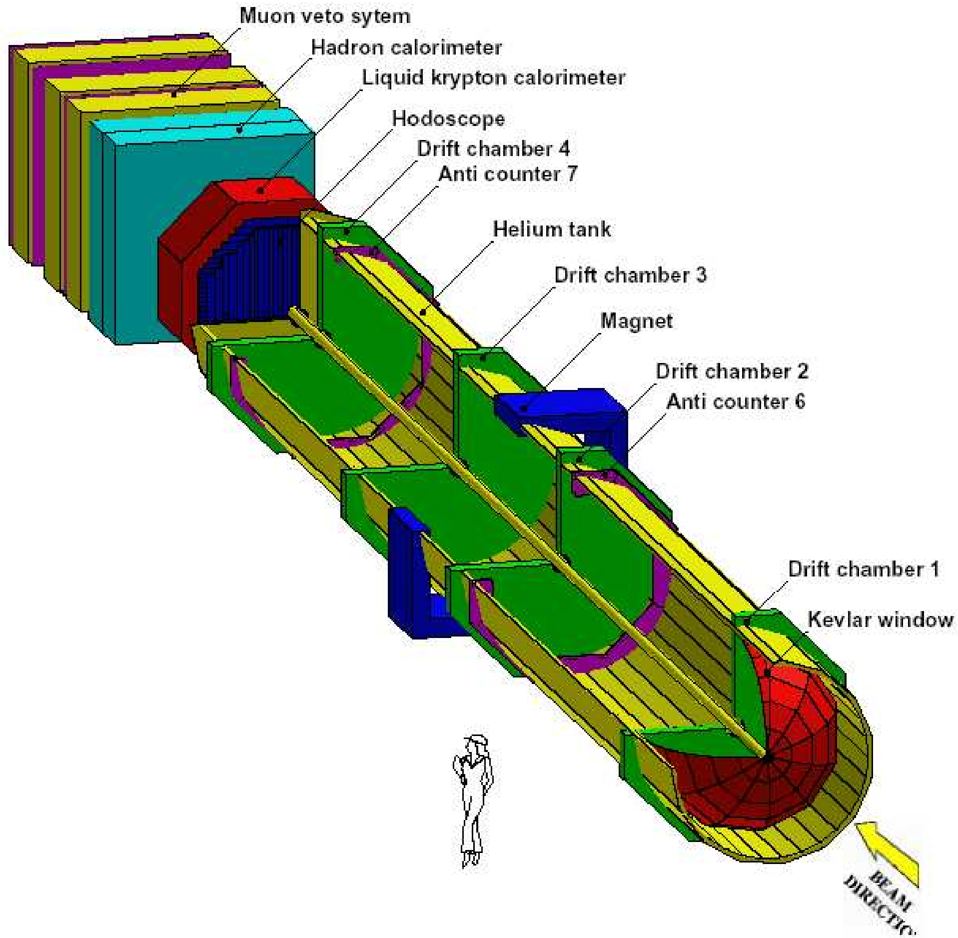


Experimental setup: *collimator*

New setup of the collimator region



Experimental setup: *the detector*



Magnetic Spectrometer

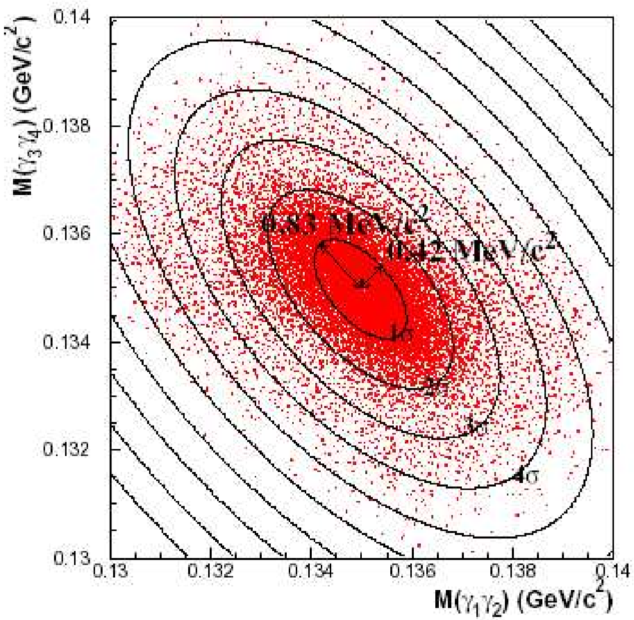
$$\frac{\sigma_p}{p}(\%) = 0.48 \oplus 0.009 \times p(\mathrm{GeV/c})$$

Liquid Kr e.m. spectrometer

$$\frac{\sigma_E}{E}(\%) = \frac{3.2}{\sqrt{E}} \oplus \frac{10.0}{E} \oplus 0.5(\mathrm{GeV})$$

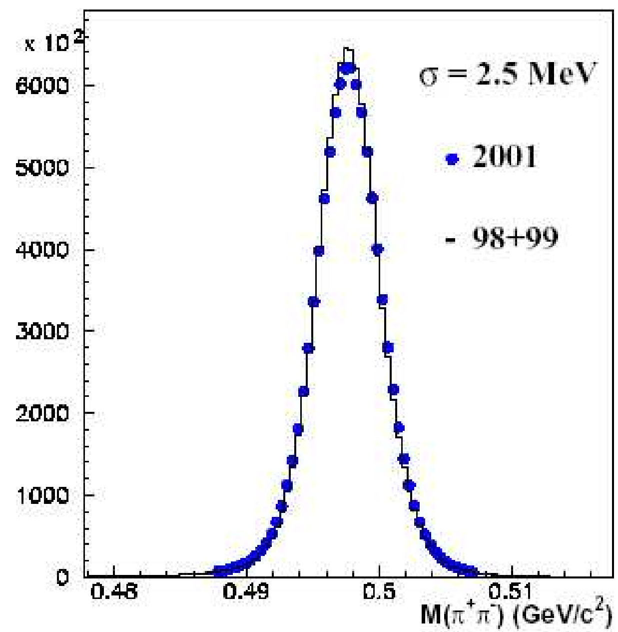
Experimental setup: *resolution*

LKr e.m. calorimeter



$\gamma\gamma$ invariant mass in
$K_S \rightarrow \pi^0\pi^0$ candidates

Spectrometer



Kaon invariant mass in
$K_S \rightarrow \pi^+\pi^-$ candidates

Data samples

1997	$\rightarrow$	ϵ'/ϵ run $(K_L + K_S)$
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1999	$\rightarrow$	ϵ'/ϵ run $(K_L + K_S)$ K_S high intensity
2000 (no spectr.)	$\rightarrow$	K_L only K_S high intensity
2001	$\rightarrow$	ϵ'/ϵ run $(K_L + K_S)$ K_S high intensity
2002	$\rightarrow$	K_S high intensity (NA48/1)
2003	$\rightarrow$	$K_+ + K_-$ (NA48/2)

First observation of

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

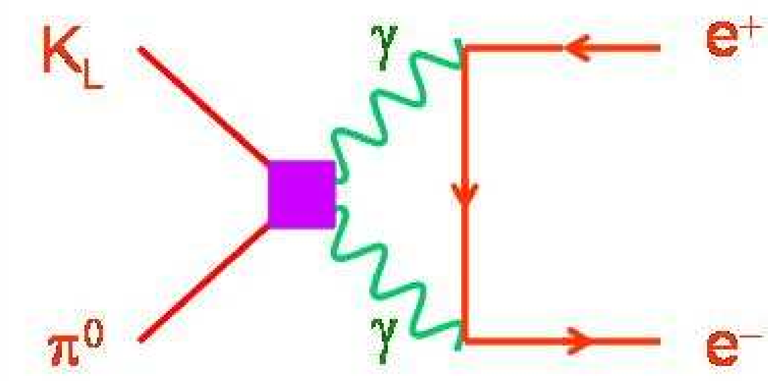
Motivation: $K_L \to \pi^0 e^+ e^-$

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

CP conserving

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

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



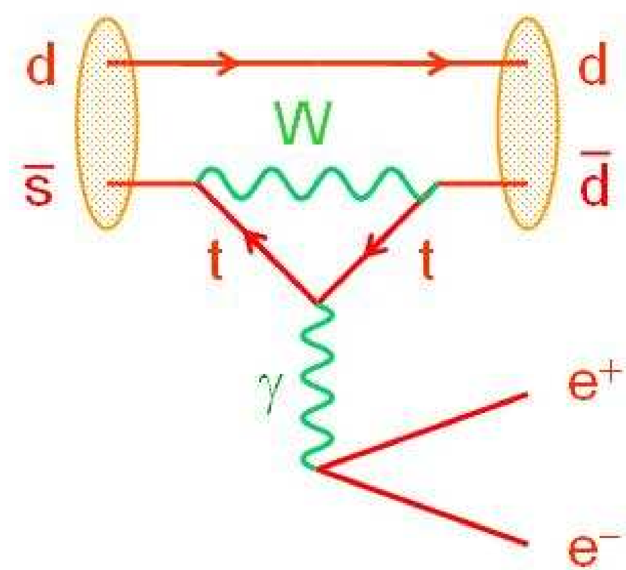
Motivation: $K_L \to \pi^0 e^+ e^-$ (2)

direct CP violating

proportional to $\mathrm{Im}(\lambda_t)$

$$\lambda_t = V_{ts}^* V_{td}$$

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



Motivation: $K_L \to \pi^0 e^+ e^-$ (3)

indirect CP violating

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

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

Motivation: $K_{L,S} \to \pi^0 e^+ e^-$

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

$$\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{\mathrm{CPV}} \times 10^{12} \simeq$$

$$15.3 {a_s}^2 - 6.8 a_s \left(\frac{\mathrm{Im}(\lambda_t)}{10^{-4}}\right) + 2.8 \left(\frac{\mathrm{Im}(\lambda_t)}{10^{-4}}\right)^2$$

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) = 5.2 \times 10^{-9} {a_s}^2$$

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

Form the $K_S \to \pi^0 e^+ e^-$ decay it is possible to extract $|a_s|$.

Analysis

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- Blind Analysis strategy $\rightarrow$ signal and control region masked
  - Signal Region:
    - $|m_{\gamma\gamma} - m_{\pi^0}| < 2.5 \times \sigma_{m_{\gamma\gamma}}$
    - $|m_{ee\gamma\gamma} - m_K| < 2.5 \times \sigma_{m_{ee\gamma\gamma}}$
  - Control Region:
    - $3 \times \sigma_{m_{\gamma\gamma}} < |m_{\gamma\gamma} - m_{\pi^0}| < 6 \times \sigma_{m_{\gamma\gamma}}$
    - $3 \times \sigma_{m_{ee\gamma\gamma}} < |m_{ee\gamma\gamma} - m_K| < 6 \times \sigma_{m_{ee\gamma\gamma}}$

Backgounds Studied

- K_S decays
  - $K_S \to \pi^0 \pi^0_{\text{D}}$
  - $K_S \to \pi^0 \pi^0_{\text{D}}$ + conv.
  - $K_S \to \pi^0 \pi^0_{\text{DD}}$
  - $K_S \to \pi^0 \pi^0 (e^+ e^-)$
  - $K_S \to \pi^0_{\text{D}} \pi^0_{\text{D}}$

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  - $\Xi^0 \to \Lambda(p\pi^-)\pi^0$
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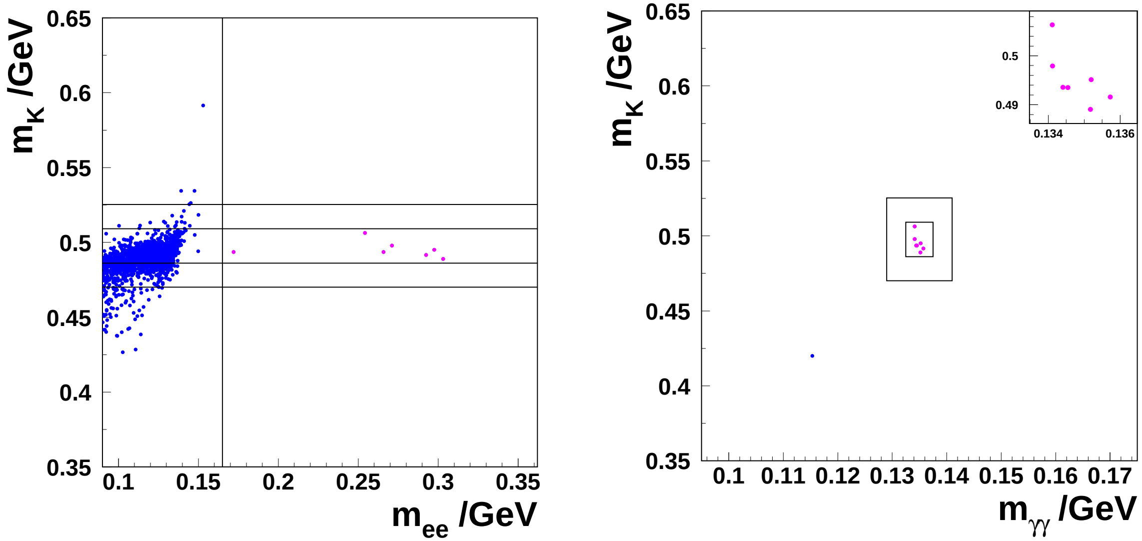
- Overlapping fragments of decays
  - from the same proton interaction
  - from different proton inteactions

Main Backgounds

Source	control region	signal region
$K_S \to \pi^0_{\mathsf{D}}\pi^0_{\mathsf{D}}$	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 backgound	$0.33^{+0.18}_{-0.11}$	$0.15^{+0.05}_{-0.04}$

Result



7 events in signal region

(probability of consistency with bg $\sim 10^{-10}$)

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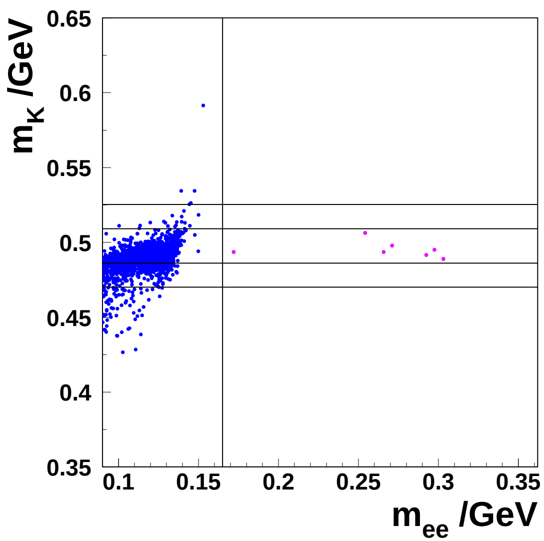

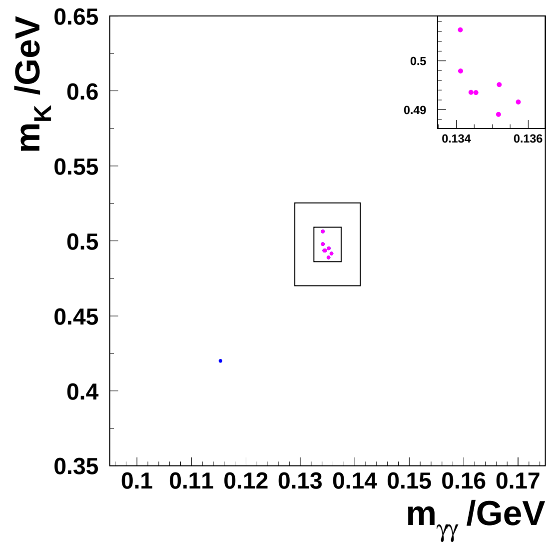

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$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) = (5.8^{+2.8}_{-2.3}(\text{stat}) \pm 2.3(\text{syst})) \times 10^{-9}$$

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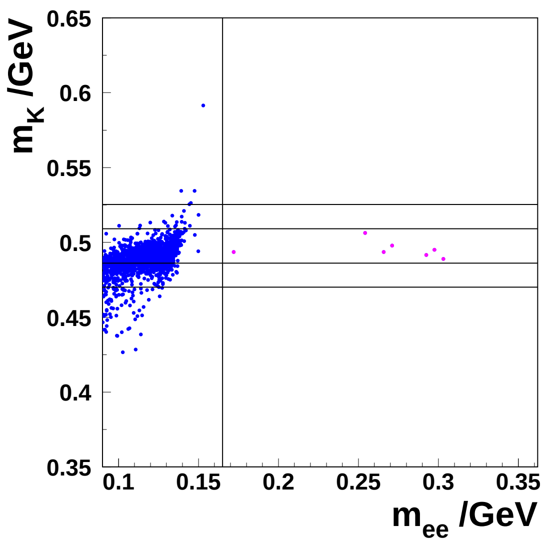

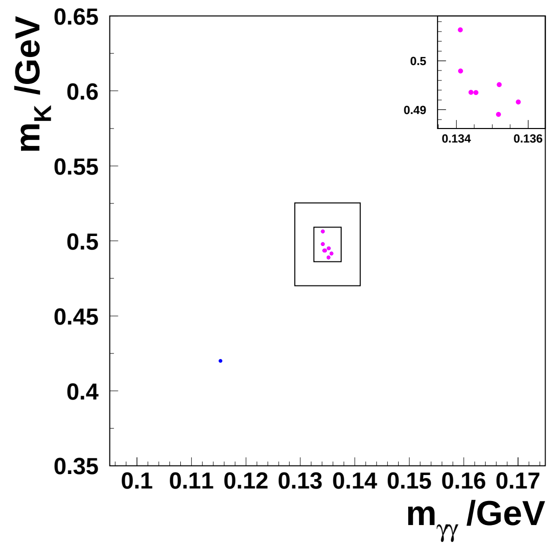

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$$|a_s| = 1.06^{+0.26}_{-0.21}(\text{stat}) \pm 0.07(\text{syst})$$

Status of Ξ^0 β-decay analysis

Motivation: *history*

In 1963, Cabibbo explained the differences between the coupling constants of the weak vertices of baryon and strange particles β-decays.

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The explanation was extended and translated in terms of three quark families by Kobayashi and Maskawa, with the use of a 3×3 unitary matrix (CKM matrix).

Motivation: *CKM matrix*

Current measurement of the CKM matrix elements

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} =$$

$$\begin{pmatrix} 0.9734(8) & \begin{matrix} 0.2196(23) K_{e3} \\ 0.2250(27) \text{hyp.} \end{matrix} & 0.0036(7) \\ 0.224(16) & 0.996(13) & 0.0412(20) \\ 0.004 \div 0.014 & 0.037 \div 0.044 & 0.94^{+0.31}_{-0.24} \end{pmatrix}$$

Motivation: *Unitarity*

The unitarity of the CKM matrix implies

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

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Ξ^0 β-decay has been observed only recently (KTeV) and has a large statistical uncertainty $\mathrm{BR} = 2.7(4) \times 10^{-4} \rightarrow$ can be improved.

Motivation: *Form Factors*

The matrix element of a baryon β-decay can be written as

$$\mathcal{M} = \frac{G_F V}{\sqrt{2}} \overline{u_b}(O_\mu^V + O_\mu^A) u_B \overline{u_e} \gamma^\mu (1 + \gamma_5) u_\nu + h.c.$$

with

$$V \quad : \quad \text{appropriate element of CKM matrix}$$

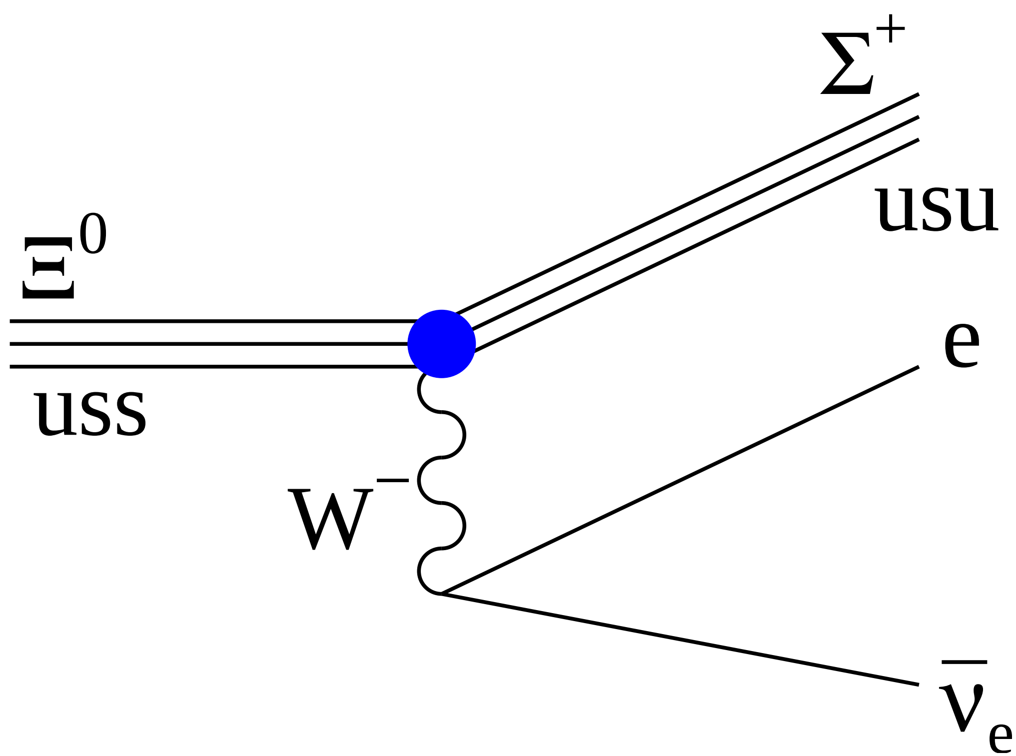
$$O_\mu^V = f_1(q^2)\gamma_\mu + \frac{f_2(q^2)}{M_p}\sigma_{\mu\nu}q^\nu + \frac{f_3(q^2)}{M_p}q_\mu$$

$$O_\mu^A = \left(g_1(q^2)\gamma_\mu + \frac{g_2(q^2)}{M_p}\sigma_{\mu\nu}q^\nu + \frac{g_3(q^2)}{M_p}q_\mu\right)\gamma_5$$

$f_i(q^2)$ and $g_i(q^2)$ are the form factors

Motivation: *SU(3) Breaking*

The form factors decribe the effect of the strong interaction between the components of the barion in the week vertex.



Motivation: *SU(3) Breaking* (2)

The values of the form factors of Ξ^0 β-decay are predicted by the theory, under the assumption of exact SU(3), to be the same of the neutron β-decay.

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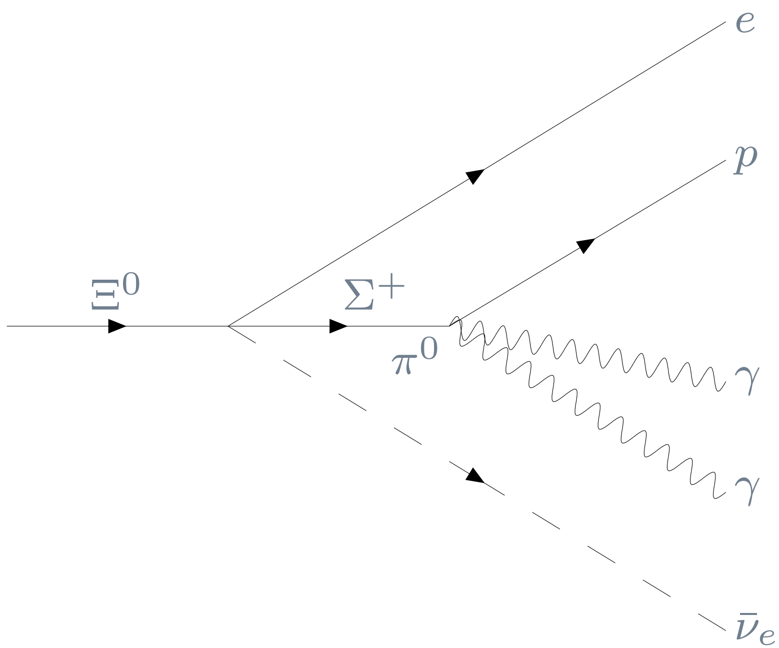
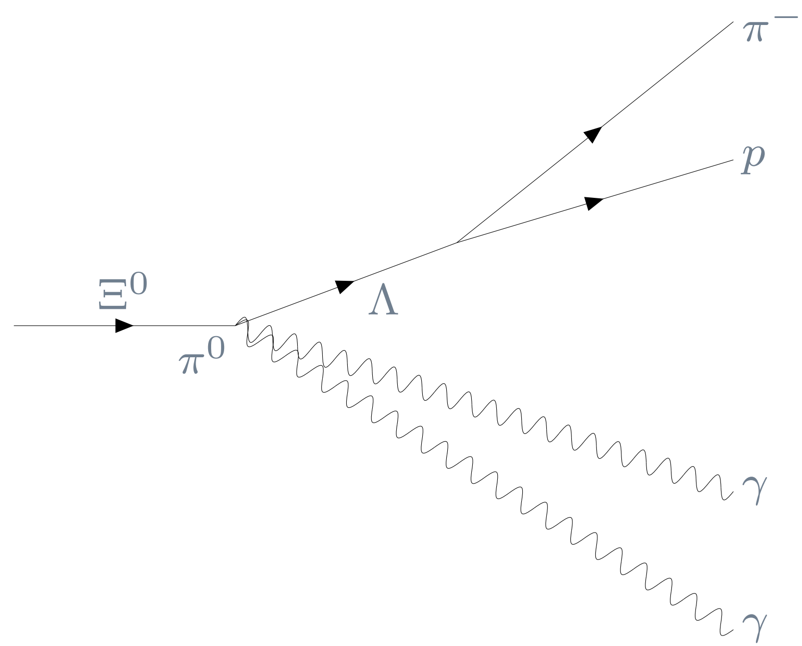
The effects of SU(3) symmetry breaking can be studied by comparing the two decays.

Events Signature

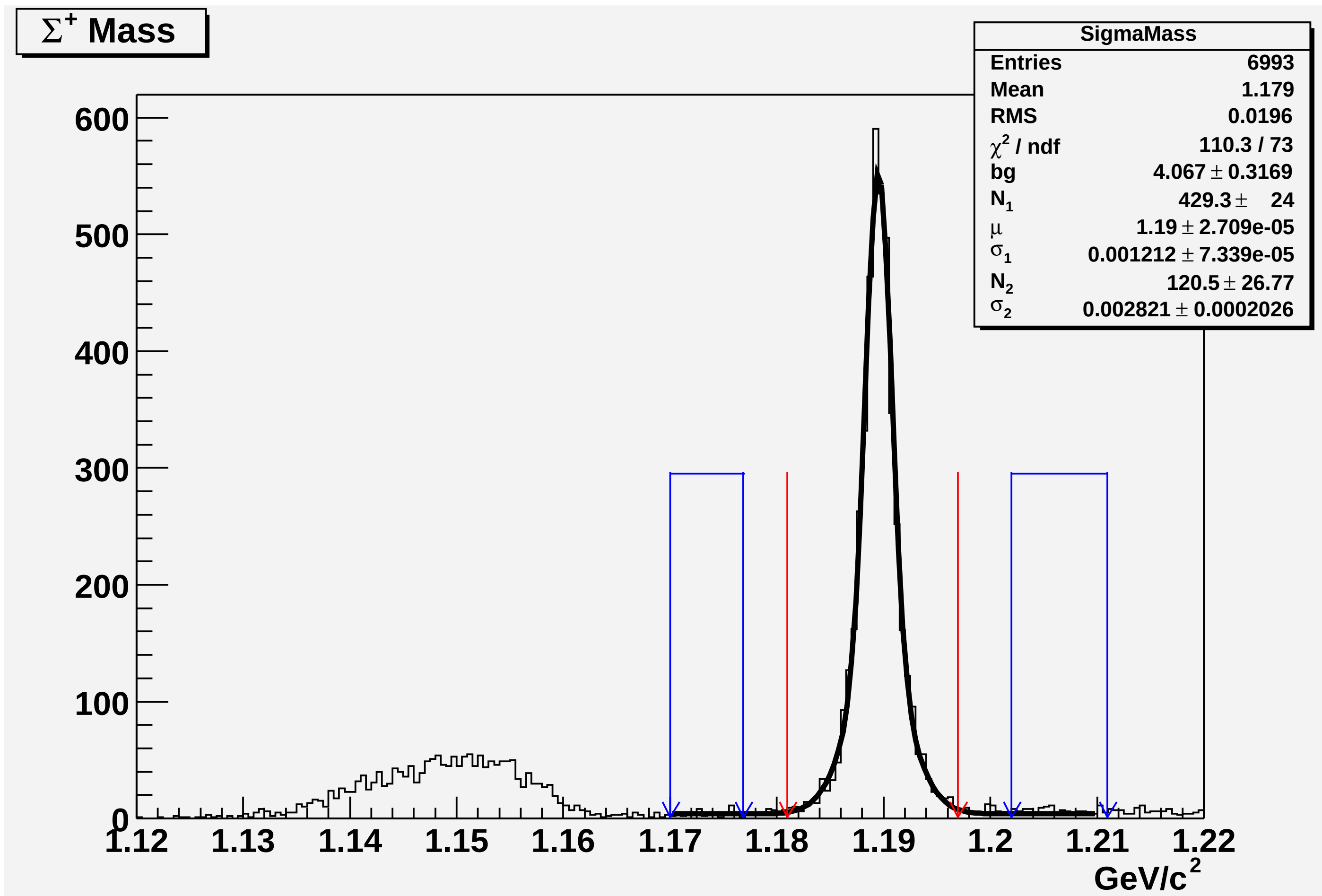
Signal	Normalization
$\Xi^0 \rightarrow \Sigma^+ e\,\bar{\nu}_e\,,\Sigma^+ \rightarrow p\,\pi^0$	$\Xi^0 \rightarrow \Lambda\, e\, \pi^0\,,\Lambda \rightarrow p\,\pi^-$





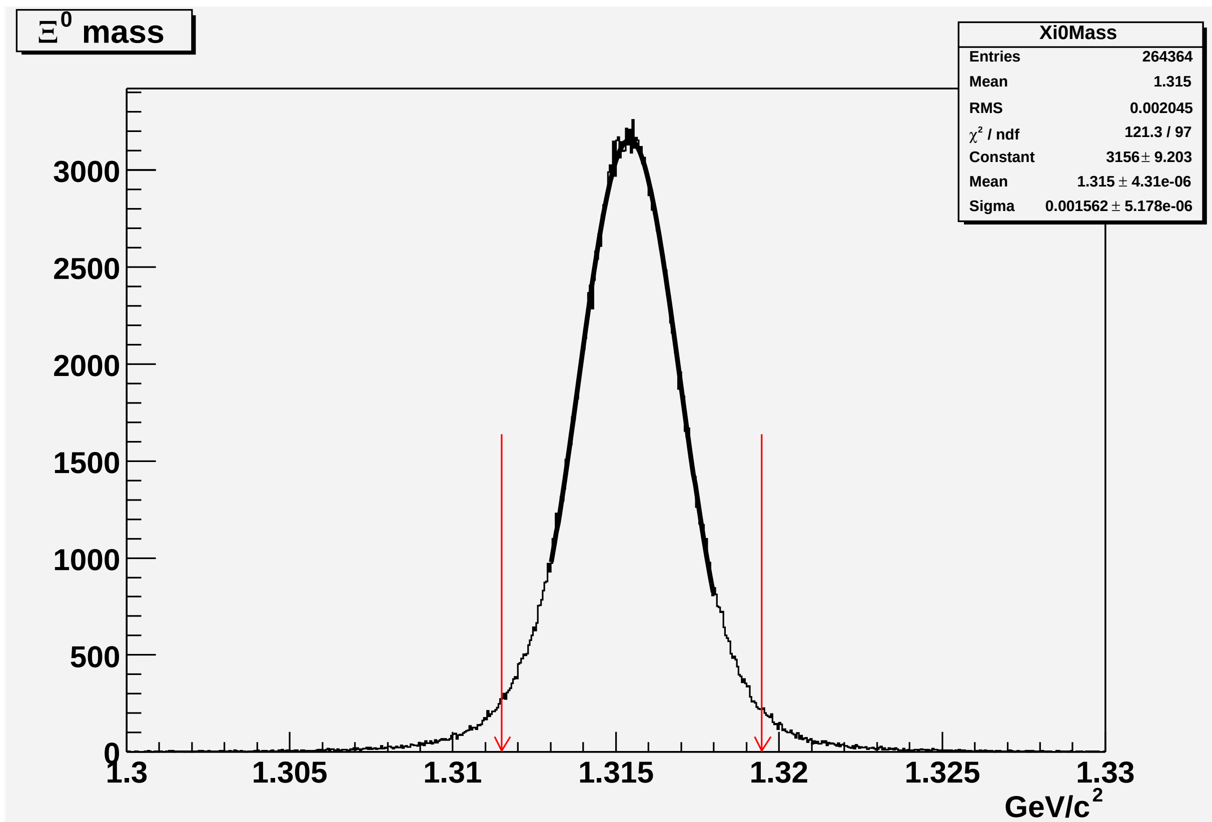
Signal

$\sim 4500\ \Xi^0\ \beta$-decays in signal region.



Normalization

$\sim 250000\ \Xi^0 \to \Lambda\pi^0$ decays in signal region.



Estimated flux: $7.5 \times 10^8\ \Xi^0$ decays in the fiducial volume.

Work in progress

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We will have

- better understanding of the sources of systematic error
- measurement of the polarization of the Ξ^0s produced
- measurement of the form factors

Work in progress (2)

Other interesting channels

- $K_S \to \pi^0 \mu^+ \mu^-$ almost done
- $\Xi^0 \to \Sigma^+ \mu \bar{\nu}_\mu$
- $\bar{\Xi}^0 \to \Sigma^- e^+ \nu_e$
- $\Xi^0 \to \Lambda \gamma$
- $\Xi^0 \to \Lambda \pi^0$, $\Lambda \to p e \bar{\nu}_e$
- . . . much more