Hyperon Physics at KTEV

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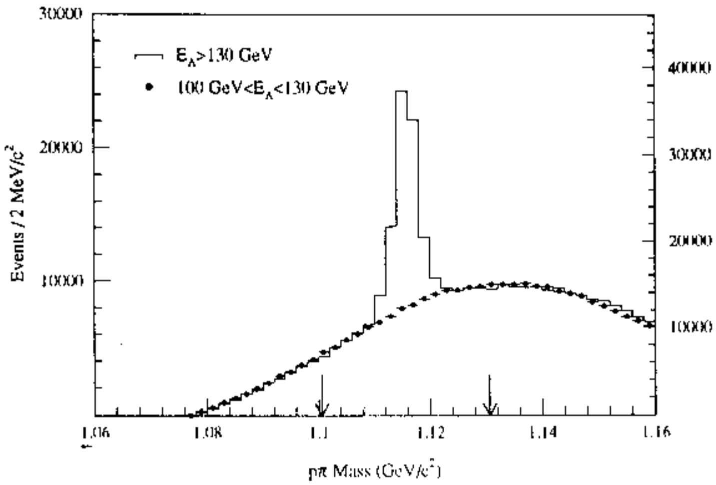
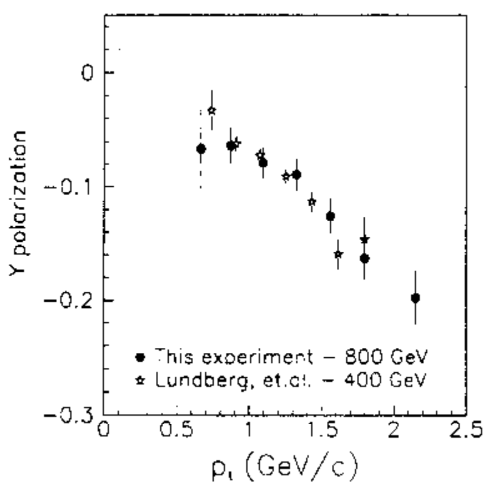
- A Short History
- The Data Set
- Beta Decays
- Radiative Decays

Hyperons in the Fermilab Kaon Program

In E731, Λ's were considered only as background:



In E799I, we did some interesting physics:



In KTEV, we have more physics than we can handle!

THE KTeV COLLABORATION

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Triggers

β Decay Trigger:

- 2 charged tracks, with a stiff track down the beamhole
- $\geq$2 clusters of energy in the calorimeter
- Total energy of about 25 GeV or more in the calorimeter
- Approximately 2×10^6 $\Xi^0 \rightarrow \Lambda\pi^0$ decays seen in this data sample
- Veto on hadronic showers (biases against π^- from Λ decay)

Normalization Trigger:

- 2 charged tracks, with a stiff track down the beamhole
- Total energy of about 16 GeV or more in the calorimeter
- Prescaled by 50:1
- About 80,000 $\Xi^0 \rightarrow \Lambda\pi^0$ decays seen in this data sample (unbiased)

Physics Motivation For Cascade Beta Decay

$\Xi^0 \rightarrow \Sigma^+ e^- \nu$ **(ssu → suu)** $\Xi^0 \rightarrow \Sigma^+ \mu^- \nu$

- ✓ SU(3) copy of $n \rightarrow p e \nu_e$ **(ddu → duu)**

- ✓ Cabibbo Model explains HBDs based on effective V-A currents
- ✓ SU(3) symmetry may be broken in HBDs?

- ✓ Large V&A form factor amplitudes.

- ✓ ~ 100% equivalent polarized Ξ^0 beam .

- ✓ No competing two body decay with the same final state baryon

  ($\Xi^0 \not\rightarrow \Sigma^+ \pi^-$)

  Unique possibility to probe this kind of decay at KTeV

Semi-Leptonic Decay of Baryons

$$A(p_A) \rightarrow B(p_B) + l + \nu \quad , \quad q = p_A - p_B$$

$$\underline{M} = 2^{1/2}\, G <B|\, J^{\mu}(0)\, |A> \bar{u}_l(p_l)\, \gamma_{\mu}(1+\gamma_5)\, v_{\nu}(p_{\nu})$$

$$<B\,|\,J^{\mu}(0)\,|\,A> = \bar{u}_B \; \{ f_1(q^2)\gamma^{\mu} + i\,\frac{f_2(q^2)}{M}\sigma^{\mu\nu} q_{\nu} + \frac{f_3(q^2)}{M} q^{\mu}$$

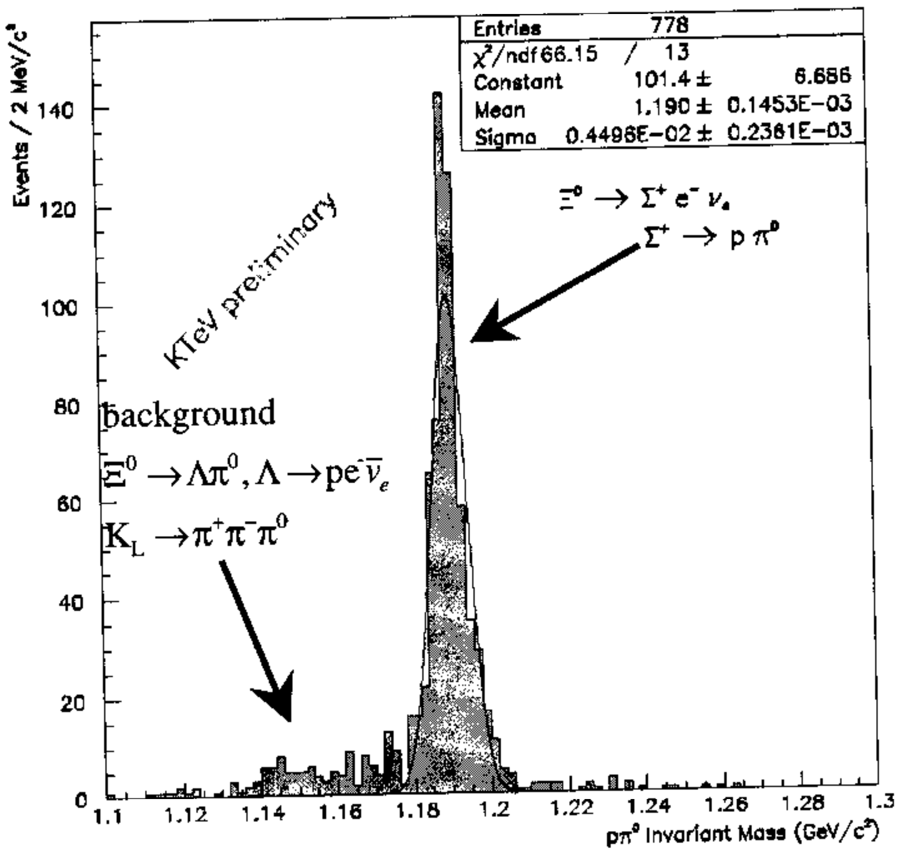
$$g_1(q^2)\gamma^{\mu}\gamma_5 + i\,\frac{g_2(q^2)}{M}\sigma^{\mu\nu}\gamma_5 q_{\nu} + \frac{g_3(q^2)}{M}\gamma_5 q^{\mu} \; \} u_A$$

Table 6.3. *Baryon semileptonic decays*

Transition			Cabibbo's hypothesis			
ΔS		Branching ratio		C_V	C_A	Experiment
0	$n \rightarrow pe^-\bar{\nu}$	100%	$\cos\theta_1$	1	$D+F$	$C_V = 1,\ C_A = 1.25,\ C_A/C_V = 1.25,$
	$\Sigma^- \rightarrow \Sigma^0 l^-\bar{\nu}$	—	$\cos\theta_1$	$\sqrt{2}$	$\sqrt{2}F$	—
	$\Sigma^- \rightarrow \Lambda^0 l^-\bar{\nu}$	$e^-0.60(06) \times 10^{-4}$	$\cos\theta_1$	0	$\sqrt{\tfrac{2}{3}}D$	$C_V/C_A = 0.24(23)$
	$\Sigma^+ \rightarrow \Sigma^0 l^+\nu$	$e^+2.02(47) \times 10^{-5}$	$\cos\theta_1$	0	$\sqrt{\tfrac{2}{3}}D$	—
	$\Xi^- \rightarrow \Sigma^0 l^-\bar{\nu}$	—	—	-1	$D-F$	—
1	$\Sigma^- \rightarrow nl^-\bar{\nu}$	$e^-1.08(04) \times 10^{-3}$ $\mu^-0.45(04) \times 10^{-3}$	$\sin\theta_1$	-1	$D-F$	e^-: $C_A/C_V = 0.385(070)$
	$\Lambda^0 \rightarrow pl^-\bar{\nu}$	$e^-8.13(29) \times 10^{-4}$ $\mu^-1.57(35) \times 10^{-4}$	$\sin\theta_1$	$\sqrt{\tfrac{3}{2}}$	$-\sqrt{\tfrac{1}{6}}(D+3F)$	$C_V = 1.229(035),\ C_A = -0.903(046),$ $C_A/C_V = -0.734(031)$
	$\Xi^- \rightarrow \Lambda^0 l^-\bar{\nu}$	$(0.69 \pm 0.18) \times 10^{-3}$	$\sin\theta_1$	$\sqrt{\tfrac{3}{2}}$	$-\sqrt{\tfrac{1}{6}}(D-3F)$	—
	$\Xi^0 \rightarrow \Sigma^+ l^-\bar{\nu}$	1.1×10^{-3}	$\sin\theta_1$	1	$D+F$	—
	$\Xi^- \rightarrow \Sigma^0 l^-\bar{\nu}$	—	$\sin\theta_1$	$\sqrt{\tfrac{1}{2}}$	$\sqrt{\tfrac{1}{2}}(D+F)$	—
	$\Omega^- \rightarrow \Lambda e^-\bar{\nu}_e$	$\sim 10^{-2}$	$\sin\theta_1$	—	—	—

Commins and Bucksbaum, Weak interaction of leptons and quarks, 1983.

Ξ^0 Beta Decays



$B.R = (2.54 \pm 0.11 \pm 0.16) \times 10^{-4}$
Stat Sys

KTeV first measured $B.R = (2.71 \pm 0.22 \pm 0.31) \times 10^{-4}$

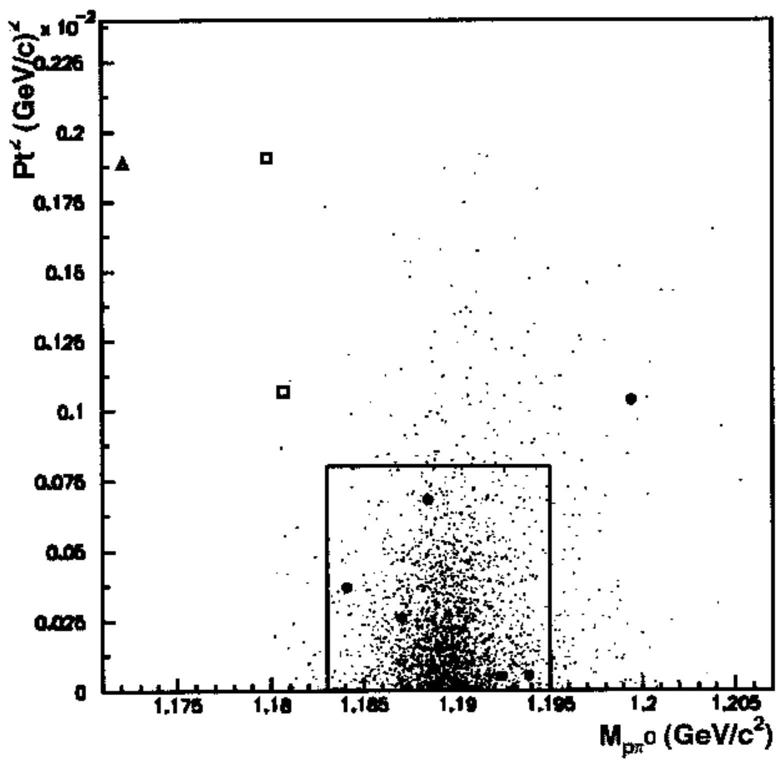
Theoretical (SU3) predicted $B.R = (2.61 \pm 0.11) \times 10^{-4}$

$\Xi^0 \rightarrow \Sigma^+ + \mu^- + \bar{\nu}_\mu$, $\Sigma^+ \rightarrow p + \pi^0$

Branching Ratio Measurement

- Five Candidate Events in the 90% cut box.
- $\Xi^0 \rightarrow \Sigma^+ + e^- + \bar{\nu}_e$ Used as the normalization mode.

$$BR = (2.6 \, {}^{+2.7}_{-1.7}\,(\text{Stat}) + 0.6\,(\text{Sys})) \times 10^{-6}$$

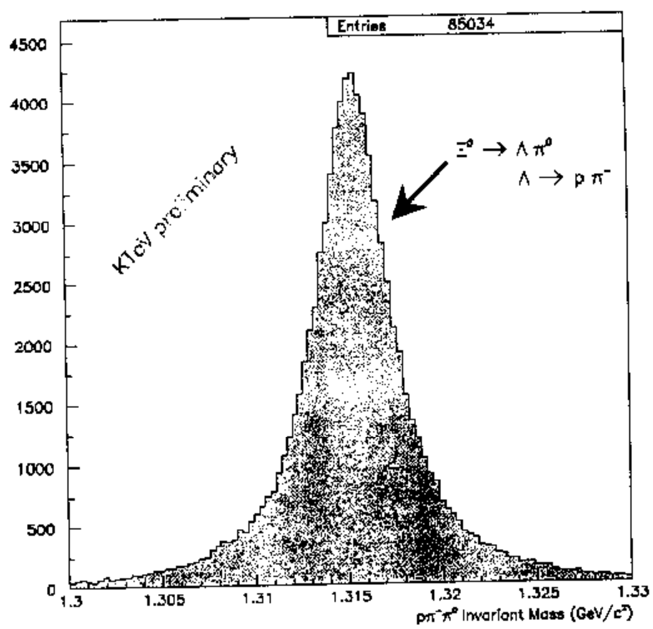


Theoretical (SU3) Prediction:

2.3×10^{-6}

$\Xi^\circ \to \Lambda\pi^\circ$ Decays

We obtain the Ξ° decay point by assuming two neutral clusters come from π° decay. We then plot the reconstructed Ξ° mass using this decay vertex:



The Ξ° hyperon has the poorest measured mass:

$$m_{\Xi^\circ} = 1314.9 \pm 0.6 \text{ MeV}$$

KTeV is interested in testing the relation:

$$M_n - M_p + M_{\Xi^-} - M_{\Xi^\circ} = M_{\Sigma^-} - M_{\Sigma^+}$$

which is resistant to SU(3) symmetry breaking (Rosner; PRD 57; 1998)

Weak Radiative Ξ° Decays

- They are of the form: $H \to B\gamma$.
- Straightforward measurements can be made of the only two unknowns: the branching ratio and asymmetry.
- Despite Hara's prediction of no asymmetry in this decay, the only significant measurement (in the decay $\Sigma^+ \to p\gamma$) shows a highly negative value.
- A simple SU(3) symmetry breaking model predicts a positive asymmetry.
- KTeV has world class samples of two modes:
  $\Xi^\circ \to \Sigma^\circ\gamma$ (5000 events)
  $\Xi^\circ \to \Lambda\gamma$ (1000 events)

WEAK RADIATIVE HYPERON DECAYS

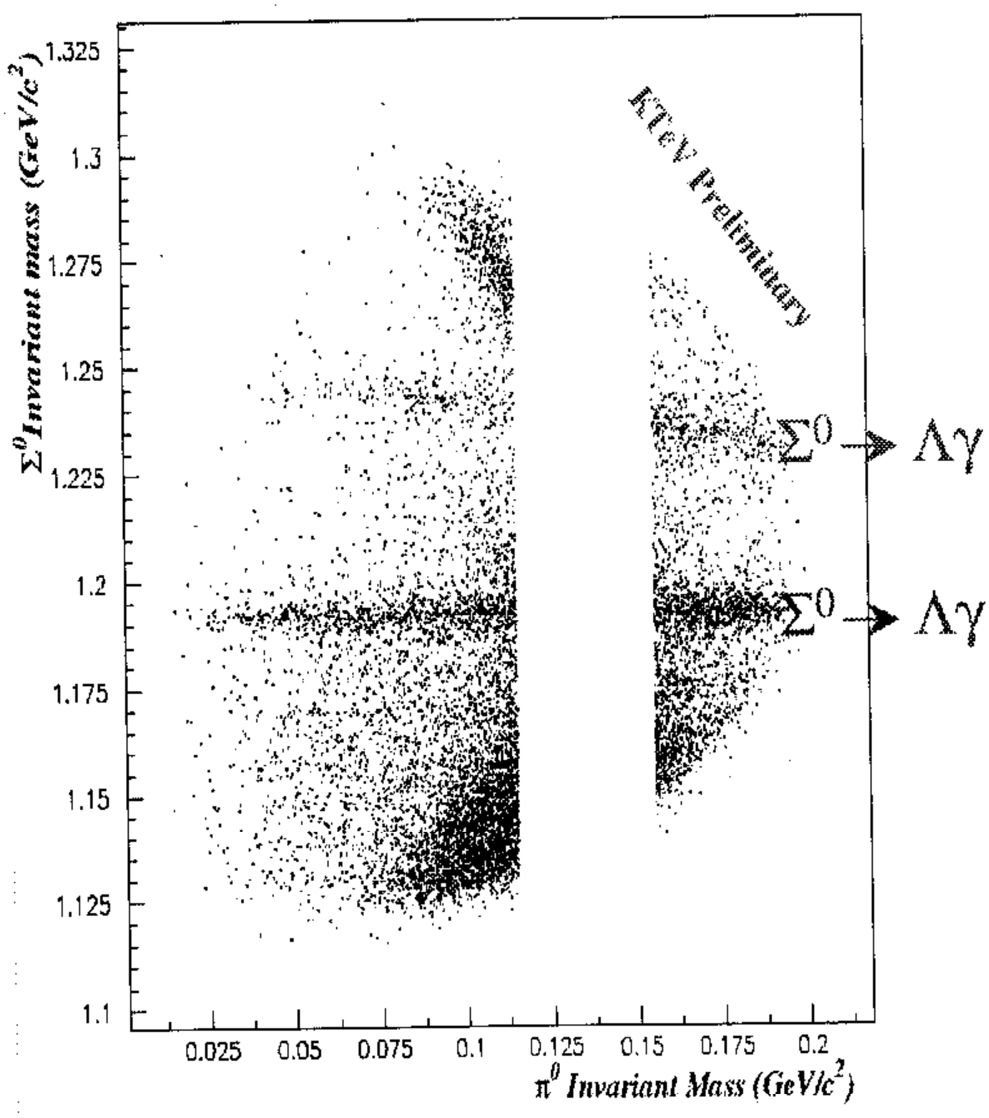
Table 2.1. Hyperon radiative decay measurements.

	R ($\times 10^3$)	α	Events	Year	Group
$\Sigma^+ \to p\gamma$	$1.20 \pm 0.06 \pm 0.05$		31901	1994	Fermilab, Timm[36]
		$-0.720 \pm 0.086 \pm 0.045$	34754	1992	Fermilab, Foucher[8]
	$1.45 \pm 0.20^{+0.11}_{-0.20}$		408	1989	BNL, Hessey[37]
	1.30 ± 0.15	$-0.86 \pm 0.13 \pm 0.04$	190	1987	KEK, Kobayashi[38]
	1.27 ± 0.17		155	1985	CERN, Biagi[39]
	1.09 ± 0.20	$-0.53^{+0.38}_{-0.36}$	30 (R) 46 (α)	1980	CERN, Manz[25]
	1.42 ± 0.26	$-1.03^{+0.52}_{-0.42}$	31 (R) 61 (α)	1969	LBL, Gershwin[24]
	1.23 ± 0.06	-0.76 ± 0.08	Combined weighted mean		
$\Lambda \to n\gamma$	1.75 ± 0.15		1816	1993	BNL, Larsen[27]
	1.02 ± 0.33		24	1986	CERN, Biagi[29]
	1.63 ± 0.14		Combined weighted mean		
$\Xi^0 \to \Lambda\gamma$	$1.06 \pm 0.12 \pm 0.11$	0.43 ± 0.44	116 (R) 87 (α)	1990	Fermilab, James[32]
	5 ± 5		1	1974	BNL[34]
	1.06 ± 0.16	0.43 ± 0.44	Combined weighted mean		
$\Xi^0 \to \Sigma^0\gamma$	$3.56 \pm 0.42 \pm 0.10$	$0.20 \pm 0.32 \pm 0.05$ *	85	1989	Fermilab, Teige[33]
	< 8.0			1988	BNL, Bensinger[40]
	3.56 ± 0.43	0.20 ± 0.32	Combined weighted mean		
$\Xi^- \to \Sigma^-\gamma$	$0.122 \pm 0.023 \pm 0.006$	1.0 ± 1.3	211	1994	Fermilab, Dubbs[30]
	0.23 ± 0.10		~ 10	1987	CERN, Biagi[31]
	0.128 ± 0.023	1.0 ± 1.3	Combined weighted mean		
$\Omega^- \to \Xi^-\gamma$	< 0.46			1994	Fermilab, Albuquerque[35]
	< 2.2			1984	CERN, Bourquin[41]

* ASYMMETRY FOR $\Xi^0 \to \Sigma^0\gamma$ MEASURED INCORRECTLY

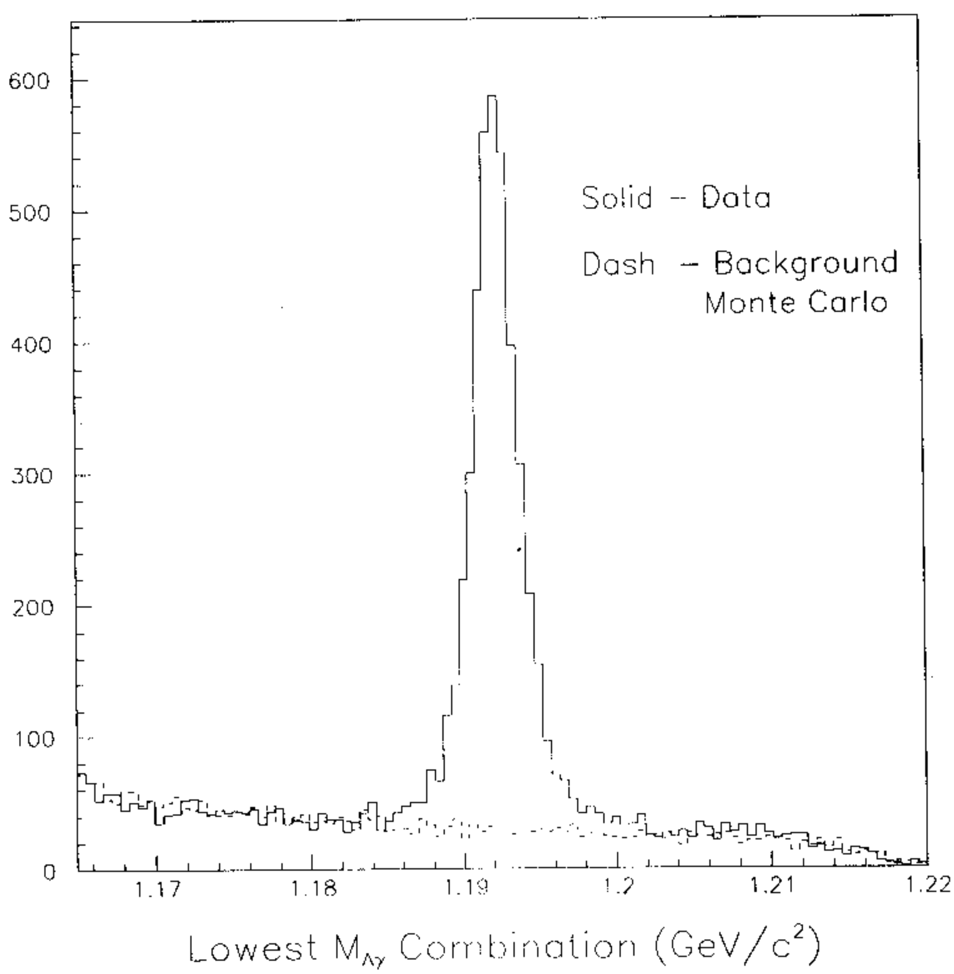
$\Xi^\circ \rightarrow \Sigma^\circ \gamma$

- Same final state as $\Xi^\circ \rightarrow \Lambda \pi^\circ$
- Can be distinguished by $\Lambda\gamma$ and $\gamma\gamma$ mass



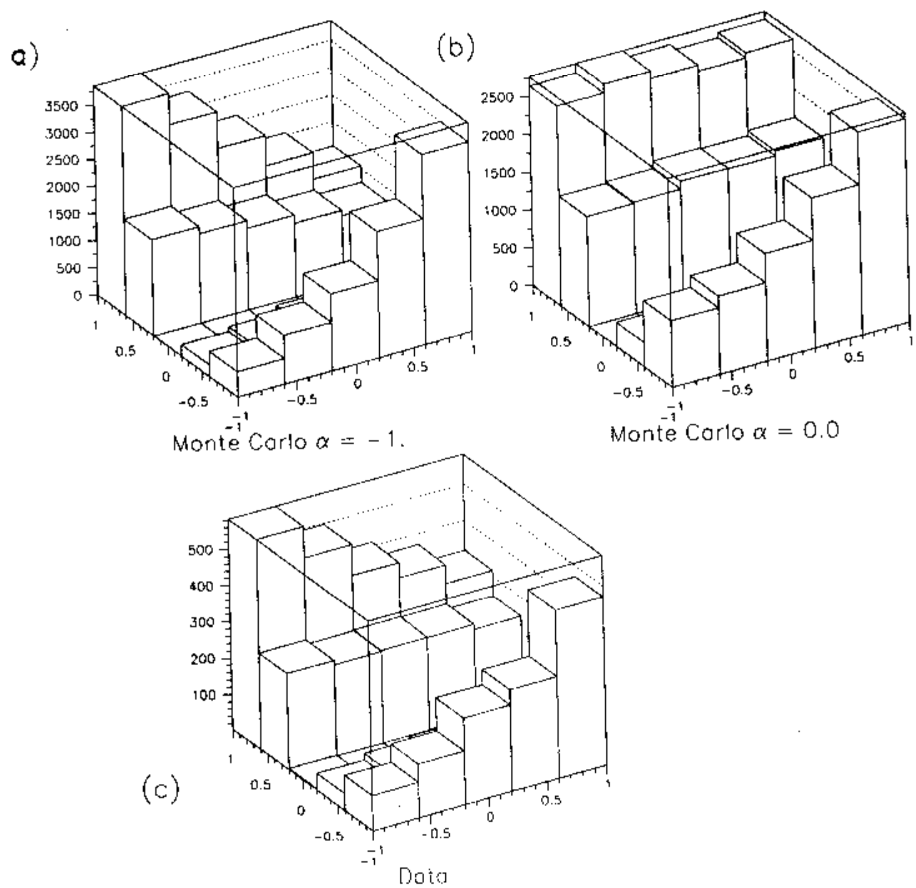
$\Xi^\circ \to \Sigma^\circ\gamma$ (cont.)

- KTeV has seen on the order of 5000 events of this mode
- Preliminary B.R. of $3.0 \pm .05 \pm .2 \times 10^{-3}$



$\Xi^\circ \to \Sigma^\circ\gamma$ (cont.)

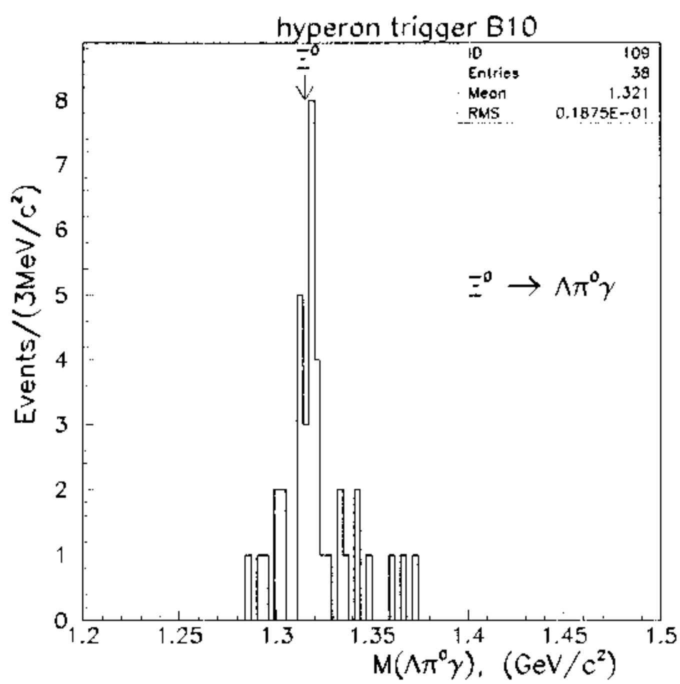
- Preliminary indication is that the asymmetry is highly negative:



Other radiative decays

- Preliminary evidence for first observation of

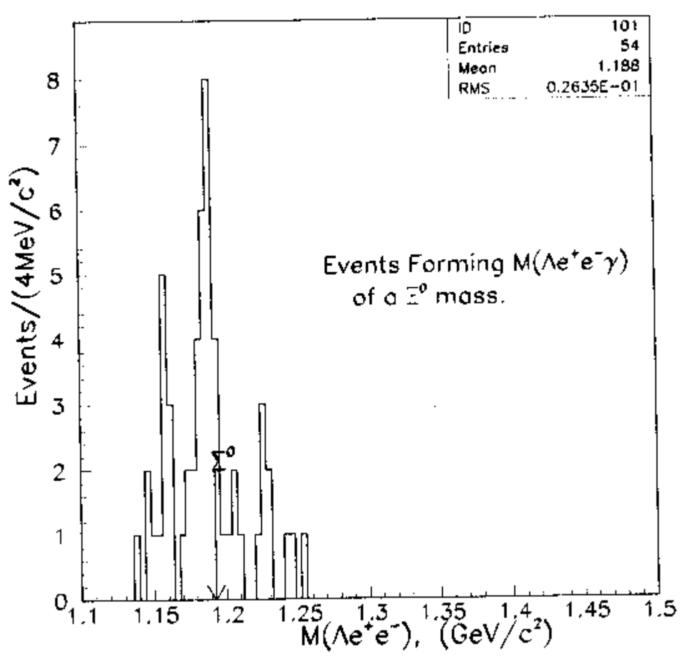
$\Xi^\circ \rightarrow \Lambda\pi^\circ\gamma$:



- An unusual radiative mode with a neutral final state with an unknown physics content. Theoretical guidance welcomed.

Other radiative decays (cont.)

- Preliminary evidence for first observation of $\Sigma^\circ \to \Lambda e^+ e^-$ from tagged decays of $\Xi^\circ \to \Sigma^\circ \gamma$:



- Relative $\Sigma^\circ - \Lambda$ parity can be measured.

Summary

- KTeV had a very succesful neutral hyperon program during the 1996-97 run.
- We made a first observation of Ξ° beta decays (both electron and muon modes)
- We have world class samples of the two Ξ° weak radiative decays.
- Tantalizing evidence for first observation of the decays: $\Xi^\circ \to \Lambda\pi^\circ\gamma$ and $\Sigma^\circ \to \Lambda e^+e^-$
- The 1999 run of KTeV will produce from 3-10 times as much data.