Hyperon physics in the experiment NA48/I at CERN

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On behalf of the NA48/I Collaboration

Cagliari Cambridge CERN Chicago Dubna Edinburgh Ferrara Firenze

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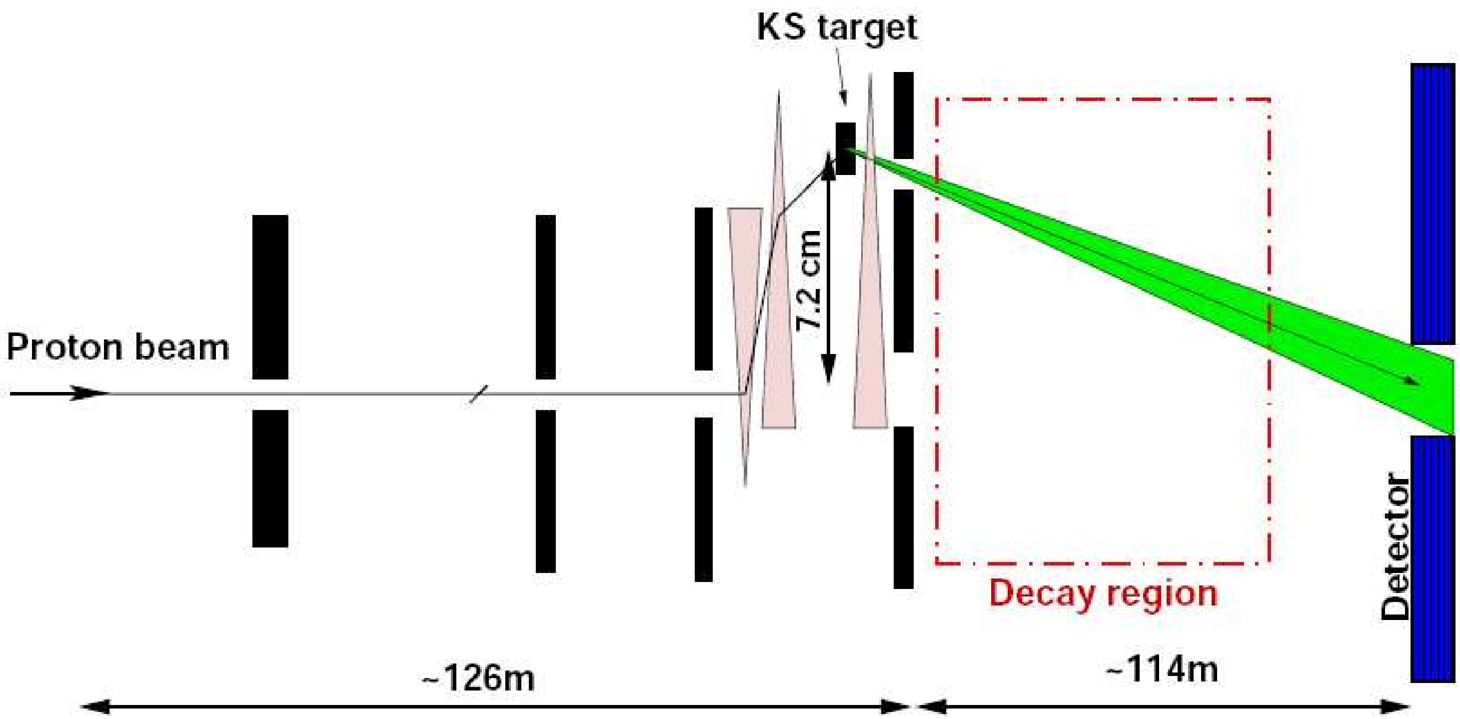
Outline

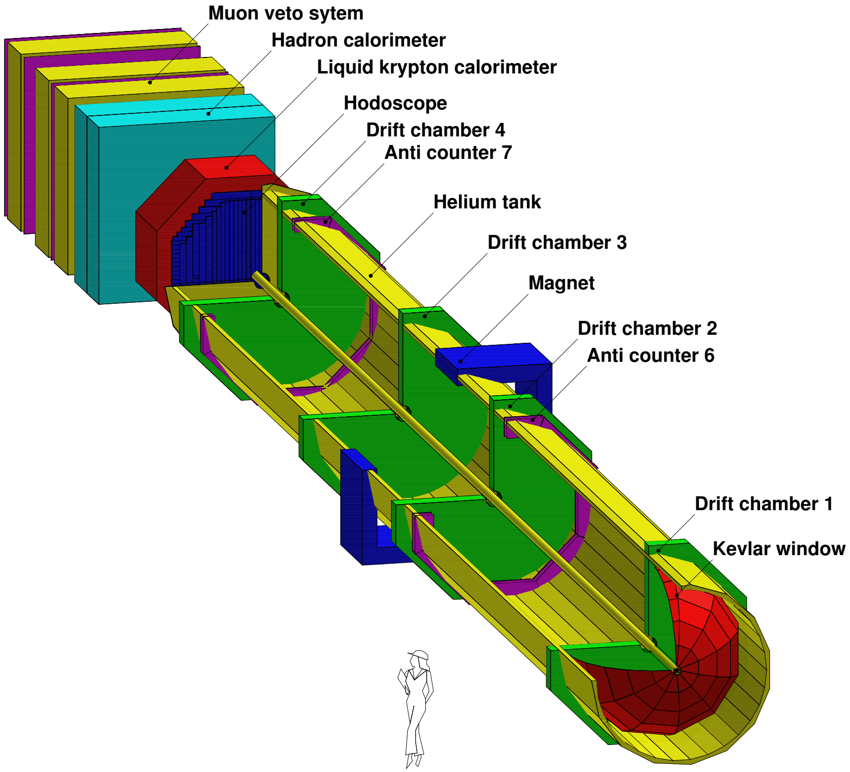
- The NA48/1 experimental set-up
- The NA48/1 cases of hyperon physics
- Decay asymmetries
  - *"a longstanding unsolved puzzle"*
  - Decay asymmetry on $\Xi^0 \to \Lambda\gamma$
  - Decay asymmetry on $\Xi^0 \to \Sigma^0\gamma$
- Ξ^0 semileptonic decays
  - $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$
  - $\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_\mu$
- Ξ^0 lifetime

The NA48/1 beam

- Neutral beam: mainly K_S^0, Ξ^0 and Λ
- Total flux: $3.5 \cdot 10^{10}$ K_S^0 and $2.4 \cdot 10^9$ Ξ^0 in the decay region
- Production angle: $-4.2\ mrad \Rightarrow$ polarized hyperons



The NA48/1 detector



CHARGED DECAYS:

magn. spectrometer and scintillator hodoscope ($p_T^{kick} \simeq 265\ MeV/c$)

$$\frac{\sigma(p)}{p} \simeq 0.5\% \oplus 0.009\%\ p\ (GeV/c)$$

$$\sigma^{hit}_{x,y} \simeq 90\ \mu m$$

$$\sigma_t \simeq\ 200\ ps$$

e.g. $\sigma_{M_{\Lambda\to p\pi^-}} \simeq 1\ MeV$

NEUTRAL DECAYS:

Quasi homogeneous Liquid Krypton electromagnetic calorimeter (LKr)

$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{0.10}{E} \oplus 0.5\%\ (E\ in\ GeV)$$

$$\sigma_{x,y} <\ 1.3\ mm$$

$$\sigma_t <\ 300\ ps\ above\ 20\ GeV$$

e.g $\sigma_{M_{\pi^0\to\gamma\gamma}} \simeq 1\ MeV/c^2$

Cases of Physics

decay channel	events	interest in
non-leptonic and radiative Ξ^0 decays:		
$\Xi^0 \to \Lambda\pi^0$	$3 \cdot 10^6$	lifetime, mass, decay asymmetry
$\Xi^0 \to \Lambda\gamma$	$4 \cdot 10^4$	BR, decay asymmetry
$\Xi^0 \to \Sigma^0\gamma$	$1 \cdot 10^4$	BR, decay asymmetry
semi-leptonic Ξ^0 decays:		
$\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$	$6 \cdot 10^3$	BR, V_{us}, decay form factors
$\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_\mu$	$1 \cdot 10^2$	BR
rare Ξ^0 decays:		
$\Xi^0 \to \Lambda e^+ e^-$	$1 \cdot 10^2$	search
$\Xi^0 \to p\pi^-$	-	search

Event topologies

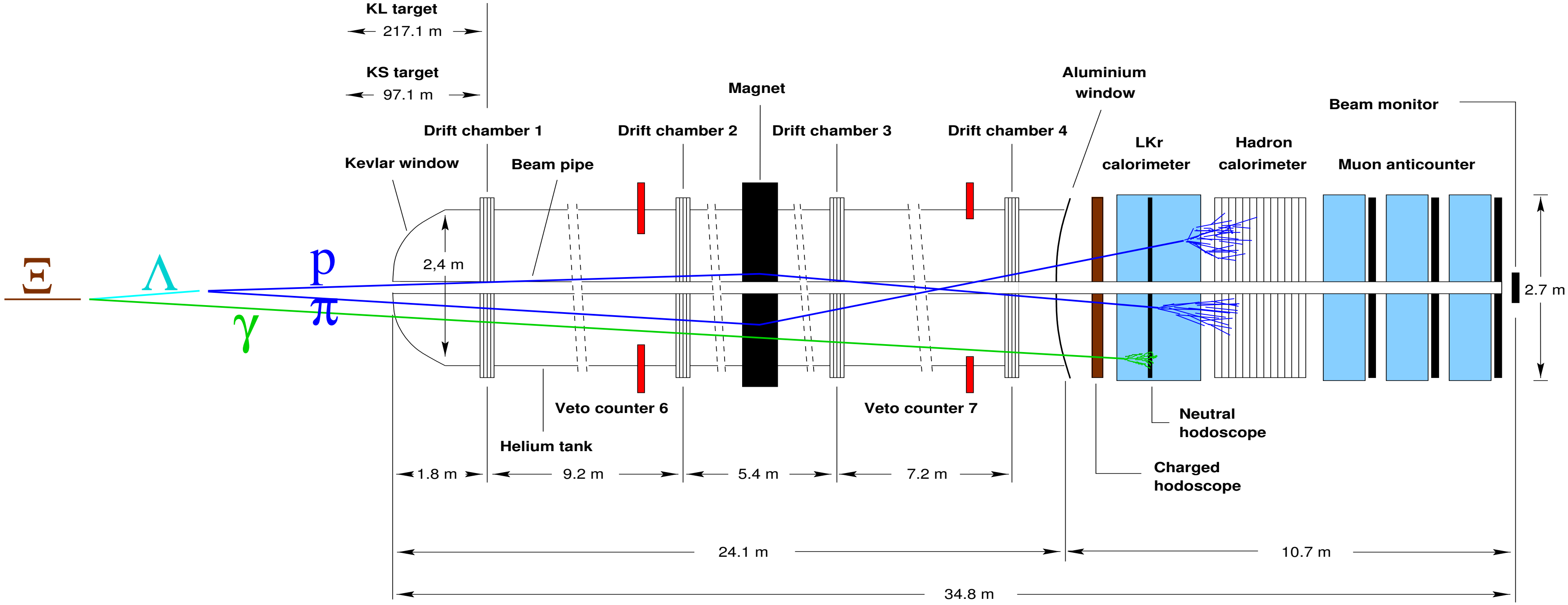
- Non-leptonic and radiative Ξ^0 decays:
  - $\Xi^0 \rightarrow \Lambda\gamma$
  - $\Xi^0 \rightarrow \Sigma^0\gamma$ with $\Sigma^0 \rightarrow \Lambda\gamma$
  - $\Xi^0 \rightarrow \Lambda\pi^0$ with $\pi^0 \rightarrow \gamma\gamma$

  $\Rightarrow$ one Λ and one or two γ
  with $\Lambda \rightarrow p\pi^-$
- Semi-leptonic Ξ^0 decays:
  - $\Xi^0 \rightarrow \Sigma^+ e^- \bar{\nu}_e$
  - $\Xi^0 \rightarrow \Sigma^+ \mu^- \bar{\nu}_\mu$

  $\Rightarrow$ one Σ^+ and one lepton
  with $\Sigma^+ \rightarrow p\pi^0$ and $\pi^0 \rightarrow \gamma\gamma$

All decays: 2 charged particles + 1 or 2 γs

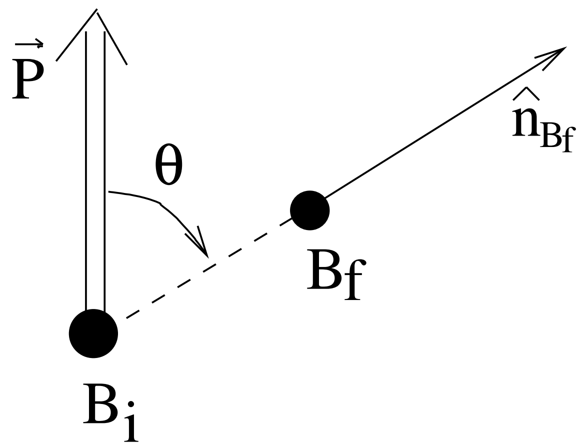
Event reconstruction ($\Lambda\gamma$ example)



- Ξ^0 decay vertex from closest distance of approach between Λ direction and Ξ^0 line of flight
- γ 3-momentum from Ξ^0 vertex and shower (γ) position-energy in the calorimeter

Decay asymmetry ($B_i \to B_f\gamma$)

For a sample of polarized hyperons (B_i), the direction of the polarization is a favorite direction for the emitted baryon (B_f):



$$\frac{dN}{dcos\theta} \propto 1 + \alpha_{B_i \to B_f\gamma} P \cos\theta$$

According to the apparently unshakable Hara theorem:
$\alpha(B_i \to B_f\gamma)$ should vanish in exact $SU(3)_f$ (1964)
from Gershwin (1969) $\alpha(\Sigma^+ \to p\gamma) = -1.0^{+0.5}_{-0.4}$
currently (PDG): $\alpha(\Sigma^+ \to p\gamma) = -0.76 \pm 0.08$
$\Rightarrow$ Discrepancy between data and theory (*"a longstanding unsolved puzzle"*)

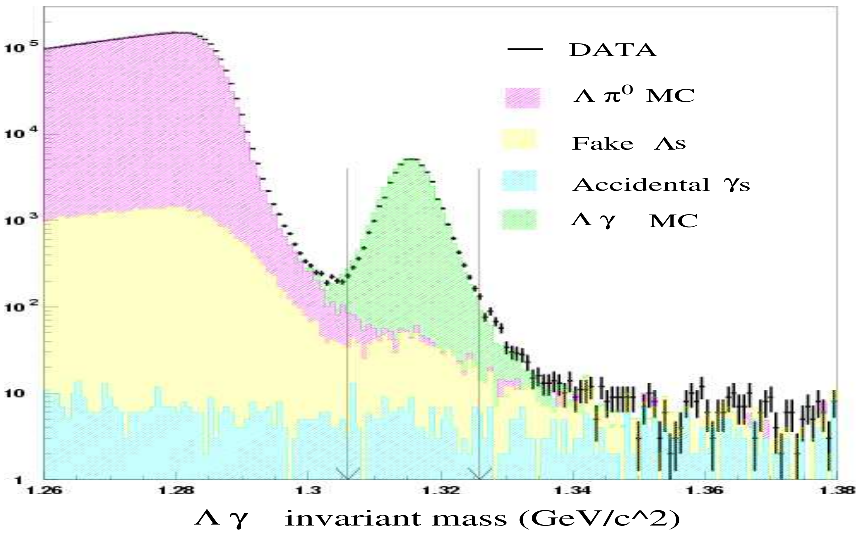
The two controversial approaches

How to connect $SU(3)_f$ breaking symmetry with the decay asymmetry?

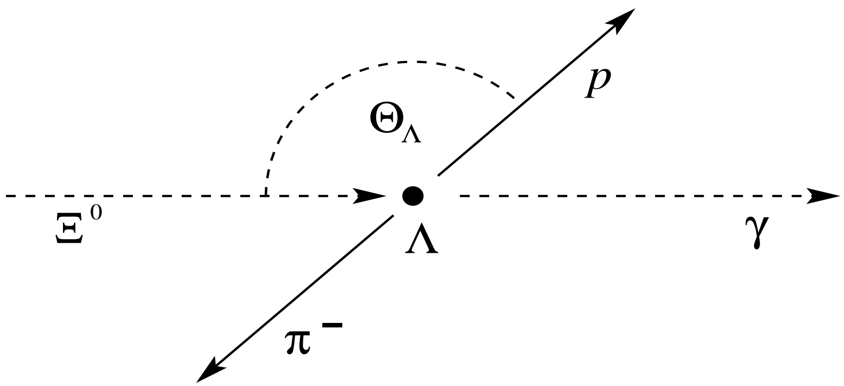
Asymmetry	Hara satisfied Pole models χPT models	PDG	Hara violated VMD models quark models
$\alpha(\Sigma^+ \to p\gamma)$	$-0.80^{+0.32}_{-0.19}$	-0.76 ± 0.08	-0.95
$\alpha(\Lambda \to n\gamma)$	-0.49	/	$+0.80$
$\alpha(\Xi^0 \to \Sigma^0\gamma)$	-0.96	-0.63 ± 0.09	-0.45
$\alpha(\Xi^0 \to \Lambda\gamma)$	-0.78	-0.78 ± 0.19(*)	$+0.80$

$\Rightarrow \alpha(\Xi^0 \to \Lambda\gamma)$ has the best power in differentiating between the two controversial approach

$\alpha(\Xi^0 \to \Lambda\gamma)$ (I)

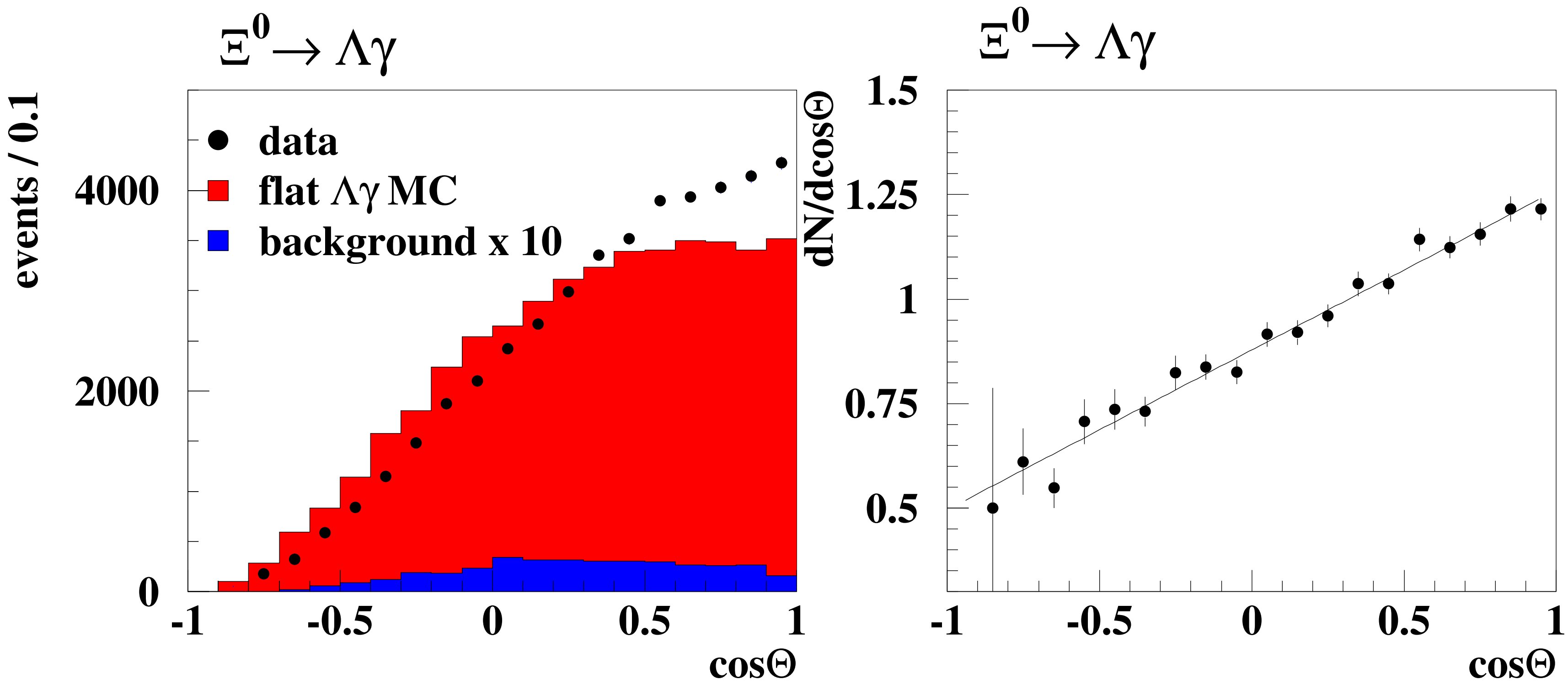


- 43814 $\Xi^0 \to \Lambda\gamma$ events selected
- 0.8% background



- use the $\Lambda \to p\pi^-$ as analyzer
- assume $\vec{P} \simeq \alpha_{\Xi^0}\vec{n}_{\Xi^0}$
- $dN/dcos\Theta \propto$
  $1 - \alpha_\Lambda \alpha_{\Xi^0} \cos\Theta_\Lambda$

$\alpha(\Xi^0 \to \Lambda\gamma)$ (II)

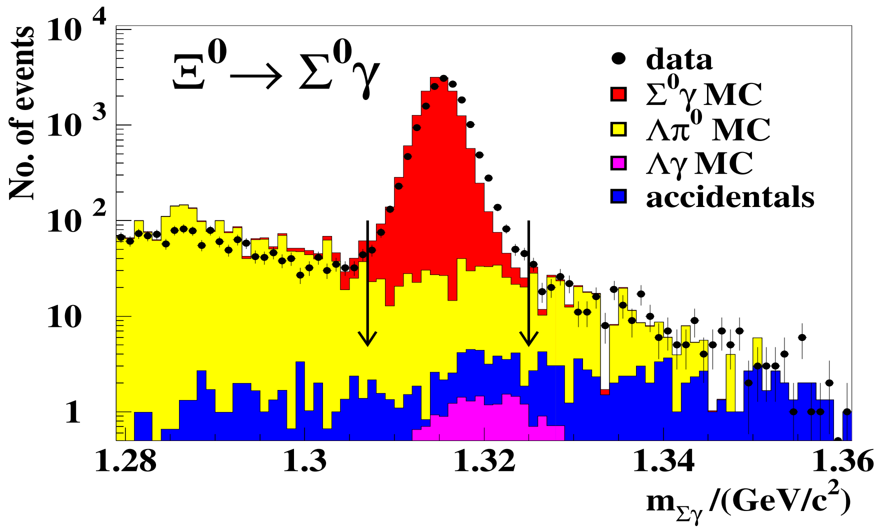


$\alpha(\Xi^0 \to \Lambda\gamma)\alpha(\Lambda \to p\pi^-) = -0.439 \pm 0.013_{stat} \pm 0.038_{syst}$

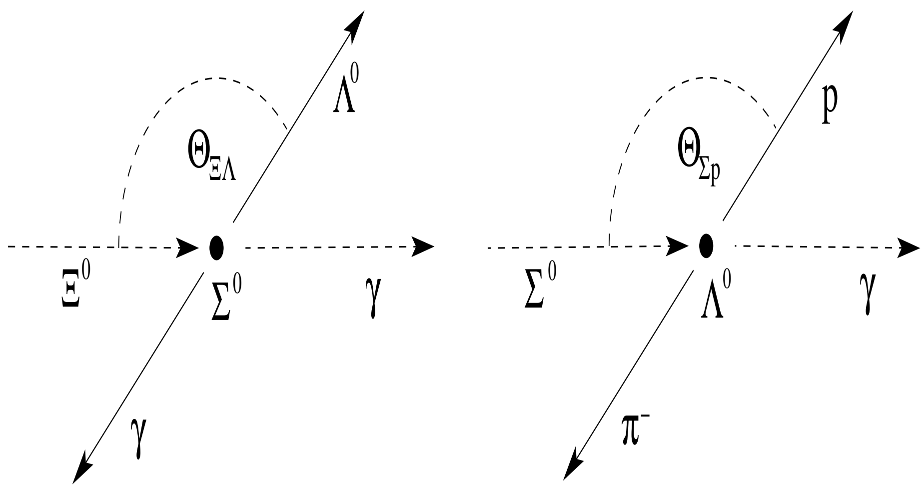
Using $\alpha(\Lambda \to p\pi^-) = 0.642 \pm 0.013$ (PDG)

$\Rightarrow \alpha(\Xi^0 \to \Lambda\gamma) = -0.684 \pm 0.020_{stat} \pm 0.061_{syst}$

$\alpha(\Xi^0 \to \Sigma^0\gamma)$ (I)

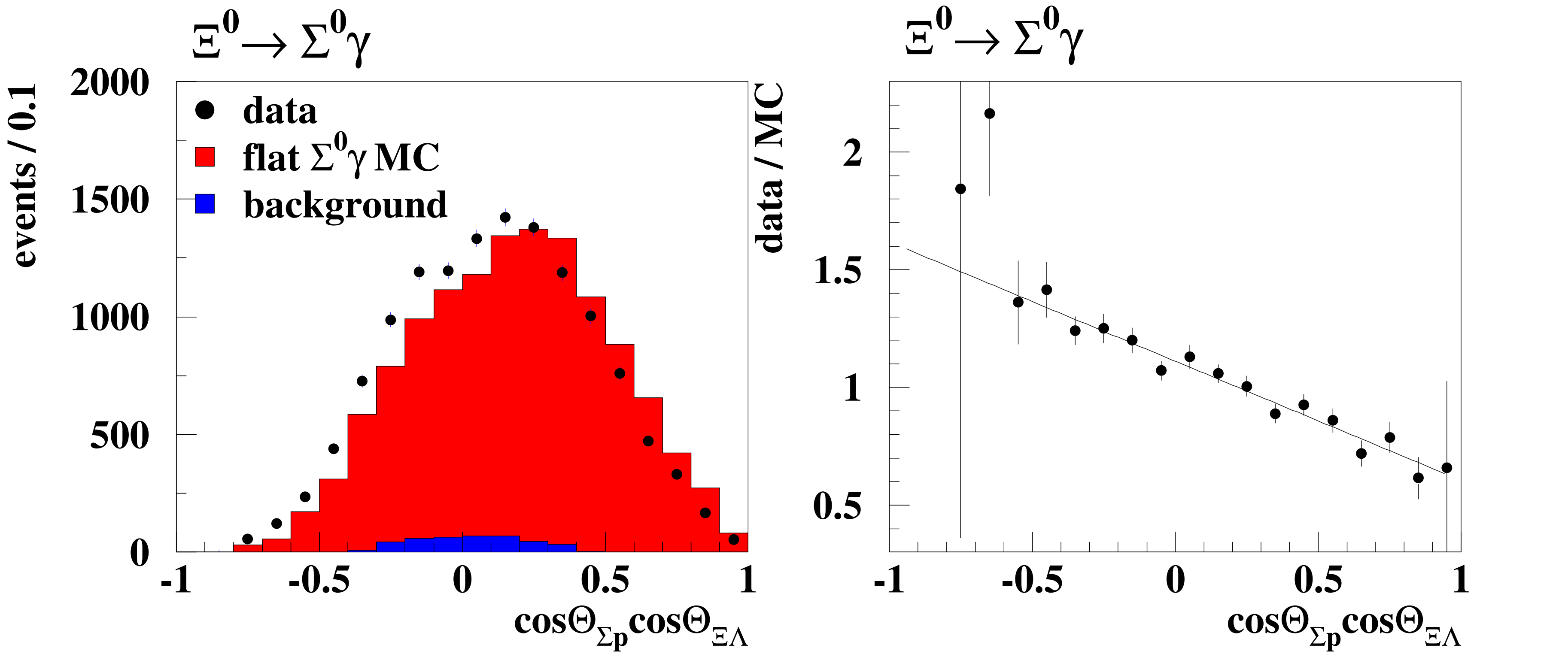


- 13068 $\Xi^0 \to \Sigma\gamma$ events selected
- 3% background



- again use the $\Lambda \to p\pi^-$ as analyzer but one more angle
- $dN^2/dcos\Theta_{\Xi\Lambda}dcos\Theta_{\Sigma p} \propto 1 + \alpha_\Lambda \alpha_\Xi \cos\Theta_{\Xi\Lambda} \cos\Theta_{\Sigma p}$

$\alpha(\Xi^0 \to \Sigma^0\gamma)$ (II)



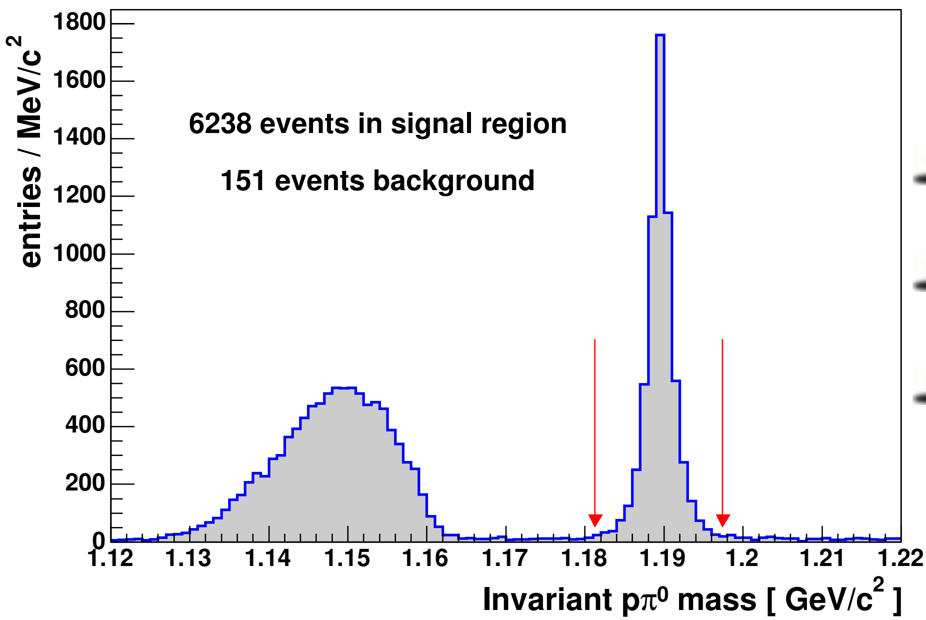
$$\alpha(\Xi^0 \to \Sigma^0\gamma)\alpha(\Lambda \to p\pi^-) = -0.438 \pm 0.020_{stat} \pm 0.041_{syst}$$

$$\Rightarrow \alpha(\Xi^0 \to \Sigma^0\gamma) = -0.682 \pm 0.031_{stat} \pm 0.065_{syst}$$

Semileptonics Ξ^0 decays

- The Ξ^0 β-decay $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$ is similar to the neutron β-decay $n \to p e^- \bar{\nu}_e$
  Since, in exact $SU(3)_f$ the Ξ^0 and n form factor should be the same, the measurement of Ξ^0 form factors is a check of the $SU(3)_f$ breaking.
- The measurement of the $BR(\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e)$ allows a determination of $|V_{us}|$ independent from the system of kaons, indeed:
  $$\Gamma = \frac{BR(\Xi^0 \to \Sigma^+ e - \bar{\nu}_e)}{\tau_{\Xi^0}} \approx G_F^2 |V_{us}|^2 \frac{\Delta m^5}{60\pi^3}[(1 - \tfrac{3}{2}\beta)(|f_1|^2 + 3|g_1|^2)]$$
  with $\Delta m = m_{\Xi^0} - m_{\Sigma^+}, \beta = \frac{\Delta m}{m_{\Xi^0}}$
- current PDG value of BR($\Xi^0 \to \Sigma^+ \mu^- \bar{\nu_\mu}$) can be improved with NA48/1 data

$\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$



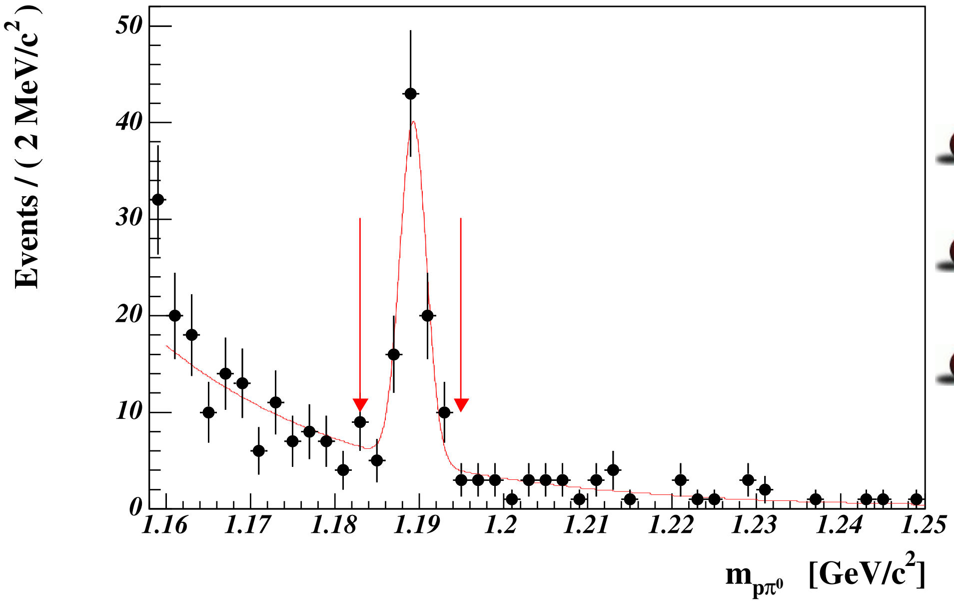
- 6238 events selected
- 2.4% background
- $\Xi^0 \to \Lambda\pi^0$ as normalization

$$BR(\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e) = (2.51 \pm 0.03_{stat} \pm 0.11_{syst}) \cdot 10^{-4}$$

$$V_{us} = 0.214 \pm 0.006_{BR} \,{}^{+0.030}_{-0.025}\,{}_{syst}$$

consistent with the PDG (from kaons) value $|V_{us}| = 0.2257 \pm 0.0021$

$\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_\mu$

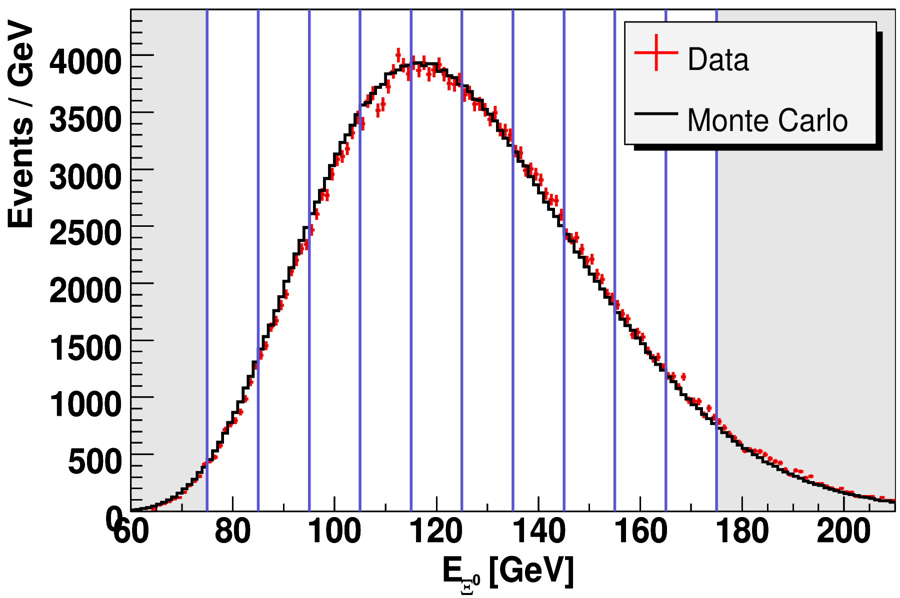


- 99 events selected
- 31% background
- $\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e$ as normalization

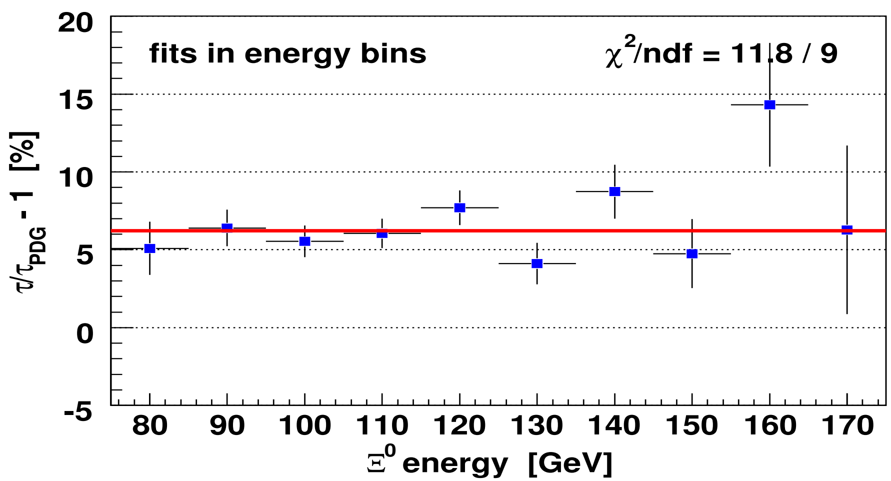
$$BR(\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_e) = (2.2 \pm 0.3_{stat} \pm 0.2_{syst}) \cdot 10^{-6}$$

it was $4.9^{+2.1}_{-1.6} \cdot 10^{-6}$ from KTev (based on 9 events)

Ξ^0 lifetime (I)

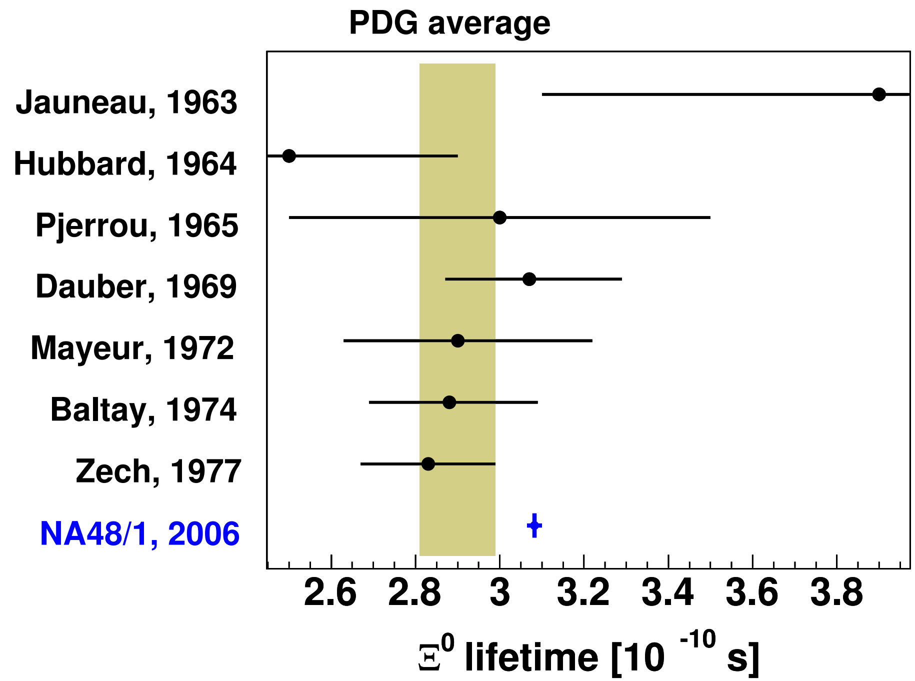


- About 130000 $\Xi^0 \to \Lambda\pi^0$ events selected for the measurement, with $75 < E_{\Xi^0} < 175\ GeV$
- $< 0.1\%$ background



- analysis in 10 bins of energy
- τ from data compared with τ from MC generated with $\tau_{\Xi^0}^{PDG}$

Ξ^0 lifetime (II)



- $\tau_{\Xi^0}^{PDG} = (2.90 \pm 0.09) \cdot 10^{-10} s$
- $\tau_{\Xi^0}^{NA48}$ is $\sim 2\sigma$ above PDG
- increased precision on τ_{Ξ^0} by a factor $\sim$ 5

$$\frac{\tau^{NA48}}{\tau^{PDG}} = 1.0626 \pm 0.0044_{stat} \pm 0.0043_{syst}$$

$$\Rightarrow \tau_{\Xi^0}^{NA48} = (3.082 \pm 0.013_{stat} \pm 0.012_{syst}) \cdot 10^{-10}$$

Conclusion

- NA48/1 results on decay asymmetries
  - $\alpha(\Xi^0 \to \Lambda\gamma) = -0.684 \pm 0.020_{stat} \pm 0.061_{syst}$
  - $\alpha(\Xi^0 \to \Sigma^0\gamma) = -0.682 \pm 0.031_{stat} \pm 0.065_{syst}$

  favorite the "Hara satisfied" approach to the problem of the Ξ^0 radiative decay asymmetries
- NA48/1 has provided a determination of V_{us} based on
  - $BR(\Xi^0 \to \Sigma^+ e^- \bar{\nu}_e) = (2.51 \pm 0.03_{stat} \pm 0.11_{syst}) \cdot 10^{-4}$

  $\Rightarrow V_{us} = 0.214 \pm 0.006_{BR}\ {}^{+0.030}_{-0.025}\ {}_{syst}$

  consistent with the determination from kaons.
- New measurements of
  - $\tau_{\Xi^0}^{NA48} = (3.082 \pm 0.013_{stat} \pm 0.012_{syst}) \cdot 10^{-10}$
  - $BR(\Xi^0 \to \Sigma^+ \mu^- \bar{\nu}_e) = (2.2 \pm 0.3_{stat} \pm 0.2_{syst}) \cdot 10^{-6}\ s$