Recent results in hyperon physics from NA48 and KTeV experiments

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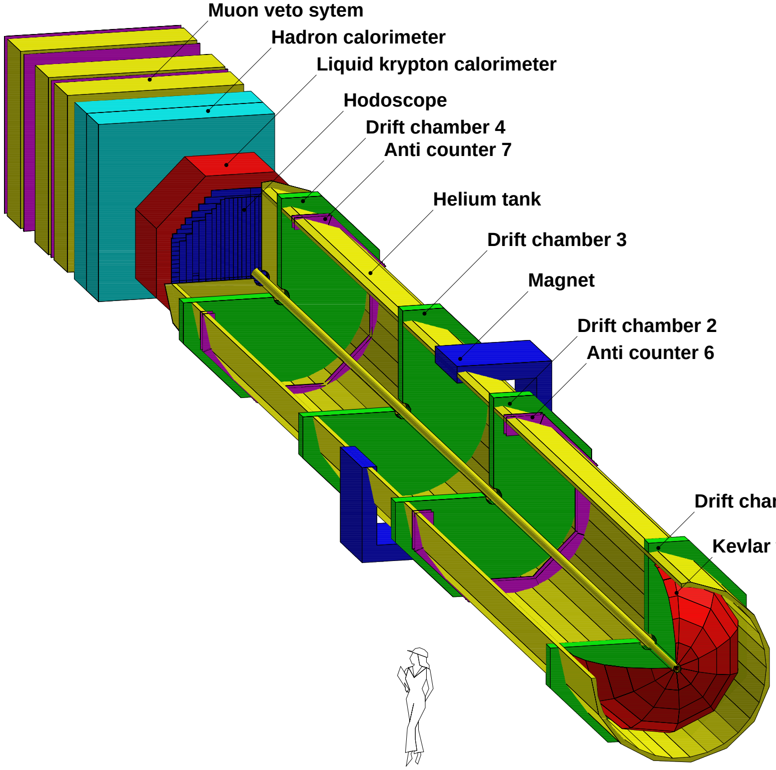
On behalf of the NA48 and KTeV Collaborations

Outline

- The NA48 and KTeV detectors
- Ξ^0 beta decays
  - $\Xi^0 \to \Sigma e \nu$ branching ratio, V_{us} extraction, $g_1(0)/f_1(0)$ (NA48 2005, prelim.)
  - $\Xi^0 \to \Sigma \mu \nu$ branching ratio (NA48 2005 prelim., KTeV Phys.Rev.Lett.95-2005)
- Decay asymmetry measurements:
  - $\Xi^0 \to \Lambda \pi^0$ (NA48 NEW, prelim.)
  - $\Xi^0 \to \Lambda \gamma$ (NA48 NEW, prelim.)
  - $\Xi^0 \to \Sigma \gamma$ (NA48 NEW, prelim.)
- Ξ^0 lifetime (NA48 NEW, prelim.)
- Conclusions

The NA48 detector



CHARGED PARTICLESS:

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

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

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

$$\sigma_{x,y}^{vtx} \simeq 2\ mm$$

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

NEUTRAL PARTICLES:

Quasi homogeneous Liquid Krypton electromagnetic calorimeter (LKr)

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

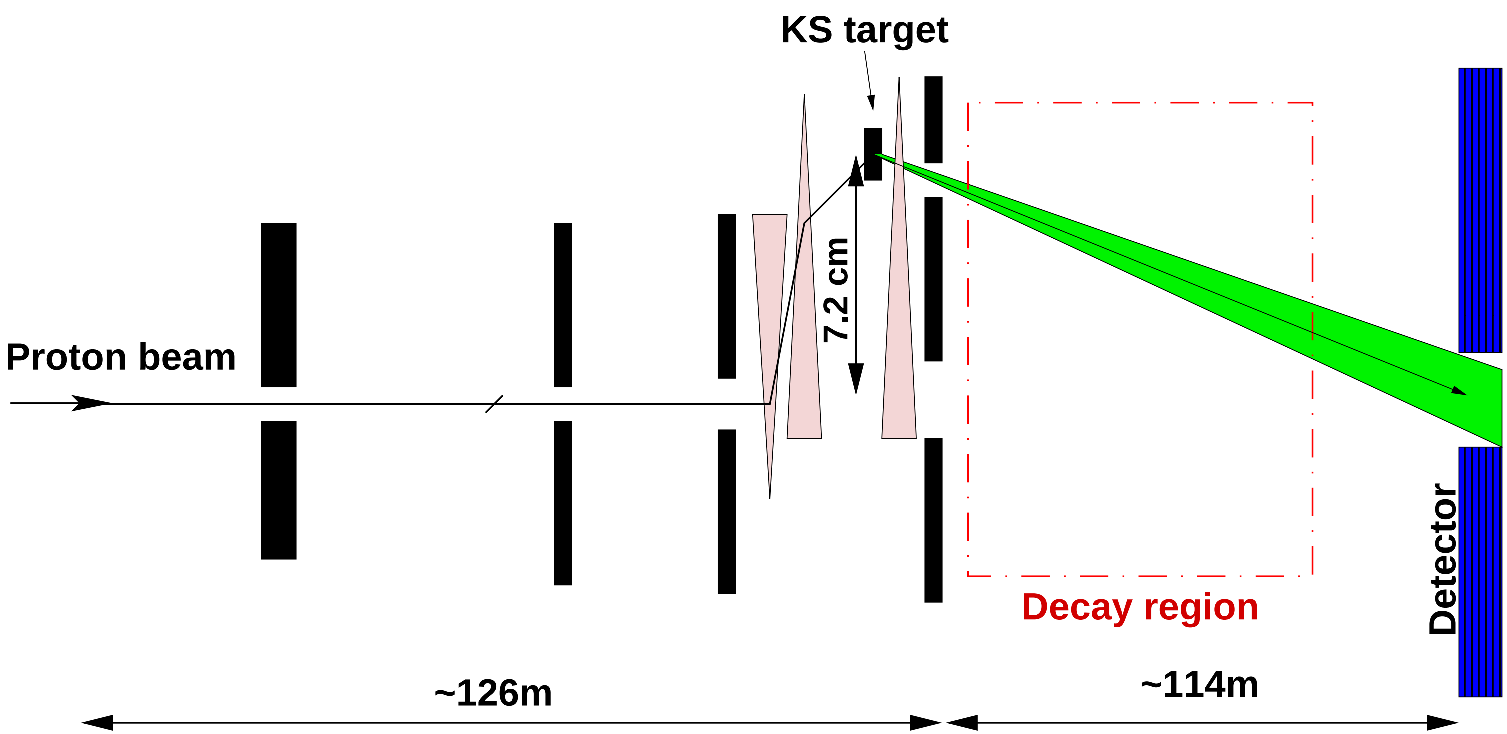
$$\sigma_{m_{\pi^0}} \simeq 1\ MeV/c^2$$

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

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

The NA48 K_S and hyperon beams

400 GeV/c secondary proton beam from the SPS T10 target, production angle of -4.2 $mrad \Rightarrow$ polarized Ξ^0

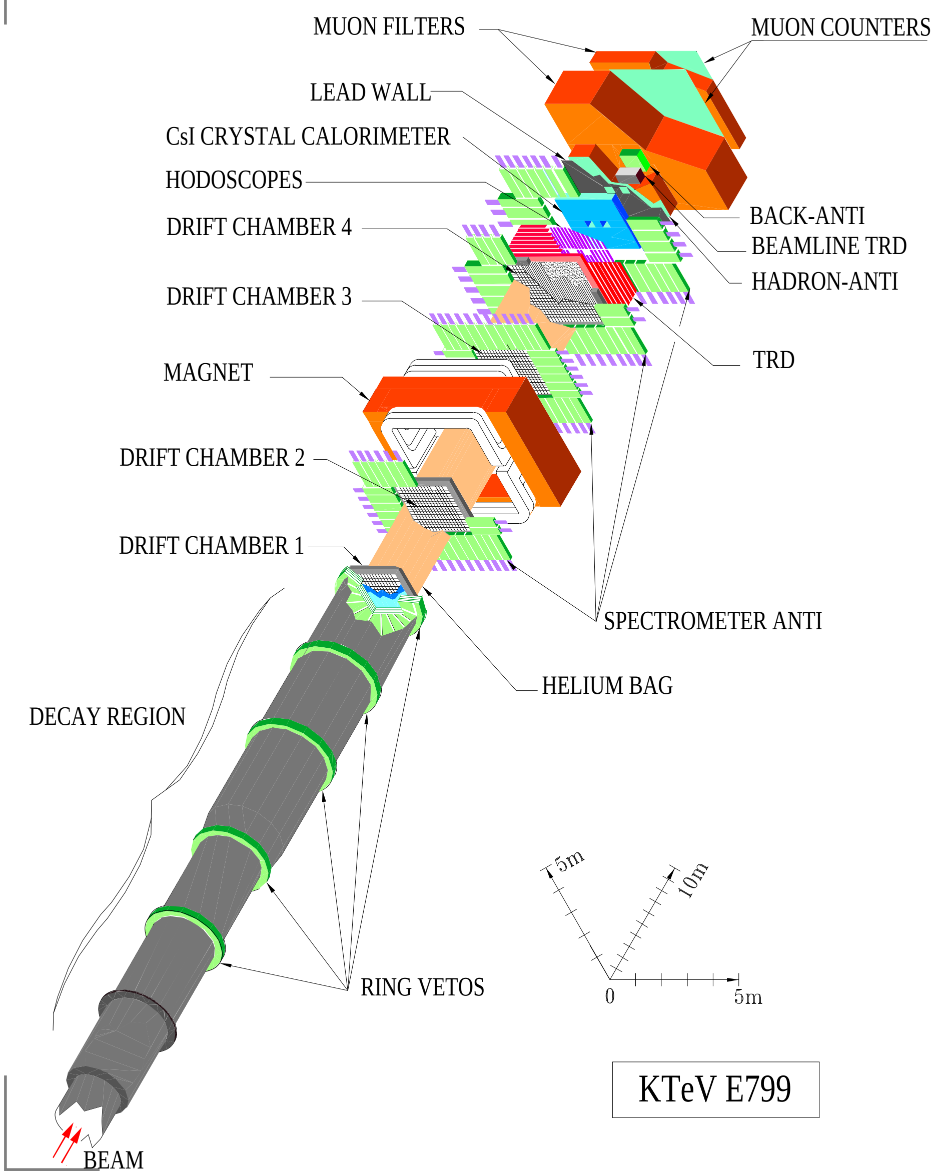


$70GeV \leq E_{\Xi^0} \leq 214GeV, \;\; 5m \leq z_{\Xi^0} \leq 50m$:

$N_{\Xi^0} = (2.422 \pm 0.003_{(stat.)} \pm 0.018_{(syst.)}) \times 10^9$

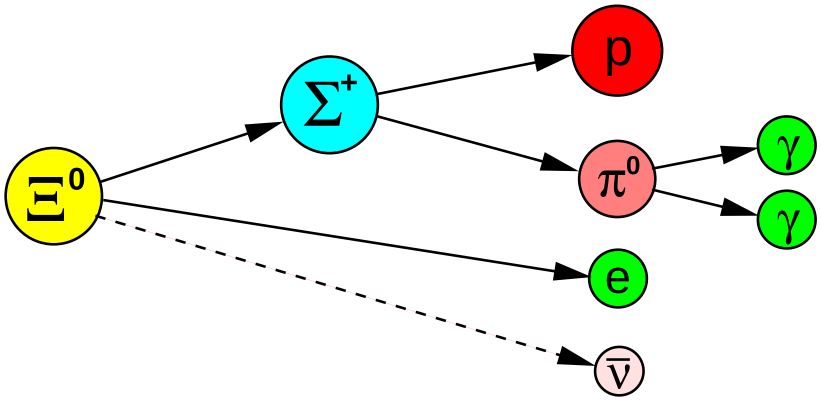
$N_{\bar{\Xi}^0} = (2.254 \pm 0.012_{(stat.)} \pm 0.017_{(syst.)}) \times 10^8$

The KTeV experiment



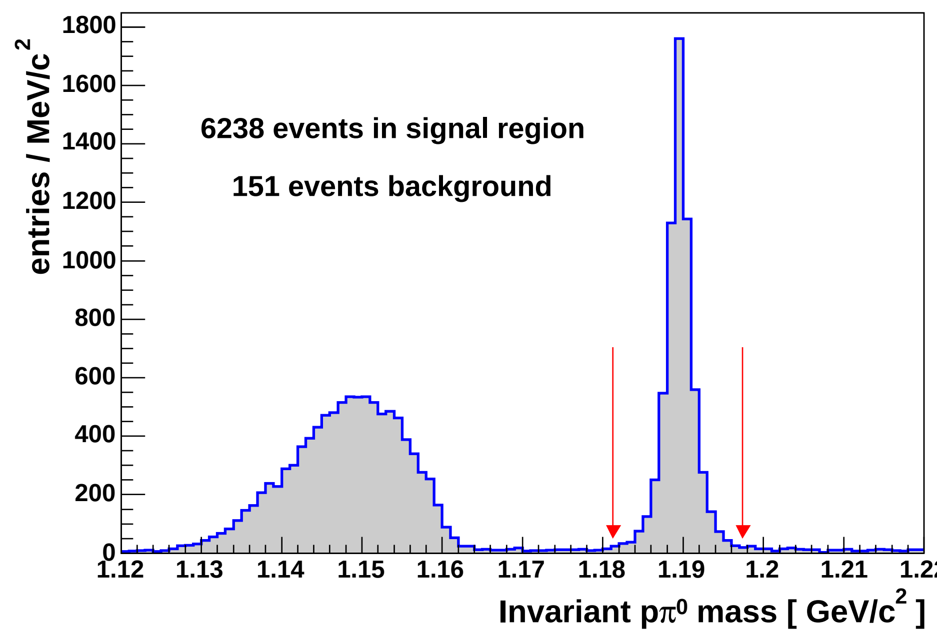
- 20MHz of neutron/kaons/hyperons in a 150:50:1 ratio
- Precision drift chamber spectrometer
- CsI electromagnetic calorimeter:1 mm spatial resolution, <1% energy resolution
- Optimised for Ξ^0 polarization measurement, half of data taken with each of the two vertical polarization states

NA48: $\Xi^0 \rightarrow \Sigma^+ e^- \nu$ decays



Reconstruct $\Sigma^+ \rightarrow p\pi^0$ and require additional electron

$\Xi^0 \rightarrow \Sigma^+ l^- \nu$ decays are only source of Σ^+ in the neutral beam



6238 signal events, 2.4% background

BR($\Xi^0 \to \Sigma^+ e^- \nu$)

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

Source	σ_{syst}/BR (%)
Trigger efficiency	± 2.2
Detector acceptance	± 3.0
Ξ^0 form factors g_1,f_2	± 1.0
Ξ^0 polarisation	± 1.0
Ξ^0 lifetime	± 0.5
Total systematics	± 4.2
Statistical uncertainty	± 1.2

BR=$(2.71 \pm 0.38) \times 10^{-4}$ KTeV published (176 events, 1999)

BR=$(2.54 \pm 0.11 \pm 0.16) \times 10^{-4}$ KTeV preliminary (625 events, 2000)

$|V_{us}|$ from Ξ^0 beta decays

Using $g_1/f_1 = 1.32^{+0.21}_{-0.17}{}_{stat} \pm 0.05_{syst}$ (KTeV 2000, 494 events), and following Garcia-Kielanowski prescription:

$|V_{us}| = 0.208 \pm 0.006^{+0.030}_{-0.025}{}_{g_1/f_1}$ (preliminary)

(neutron decay + SU(3): $g_1/f_1 = 1.267 \pm 0.035$, not used here)

$\rightarrow$ Agreement with SM expectation of $|V_{us}| = 0.2274 \pm 0.0021$

$\rightarrow$ Uncertainty dominated by experimental precision on form factor g_1/f_1

Extraction of g_1/f_1

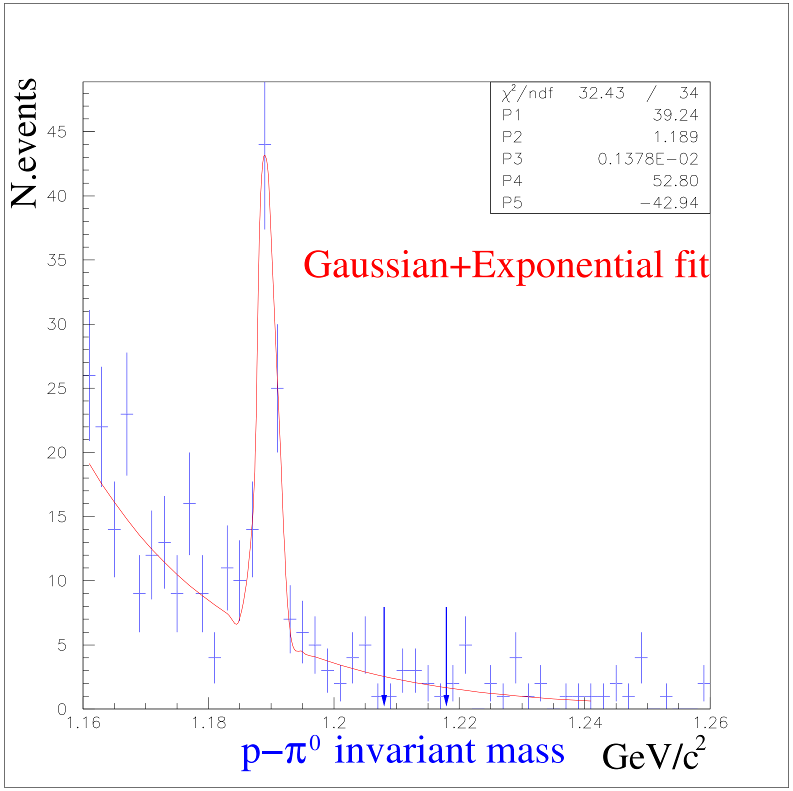
$g_1(0)/f_1(0)$ can be extracted from BR using $V_{us} = 0.2257$ from kaon decays (Blucher and Marciano, 2005):

$$g_1(0)/f_1(0) = 1.20 \pm 0.04_{br} \pm 0.03_{ext} \text{ (prelim.)}$$

where external uncertainty includes contributions from V_{us}, lifetime, and f_2/f_1

Agreement with exact SU(3) symmetry
Favours SU(3) breaking models that leave g_1/f_1 unchanged

NA48: $\Xi^0 \to \Sigma^+ \mu^- \overline{\nu_\mu}$



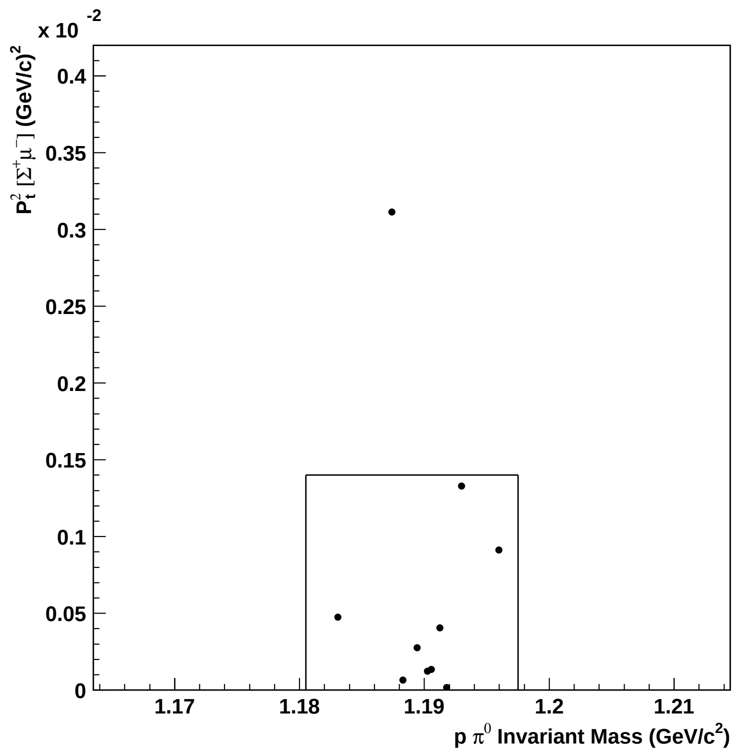
Normalised to electron mode

Same trigger, similar selection but require one muon (+1% correction for ID-inefficiency of low momentum muons)

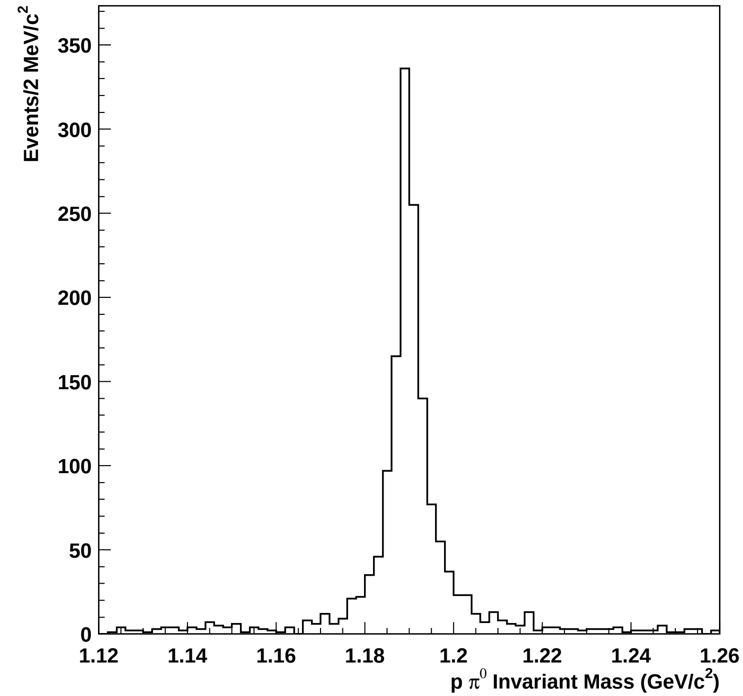
102 events with a background of (32 ± 3.0):

$BR(\Xi^0 \to \Sigma^+ \mu^- \overline{\nu}_\mu) = (2.2 \pm 0.3_{stat.} \pm 0.2_{syst.}) \times 10^{-6}$ (prelim.)

KTeV: $\Xi^0 \to \Sigma^+ \mu^- \overline{\nu_\mu}$



Norm.: 1139 $\Xi^0 \to \Sigma^+ e^- \nu$ events



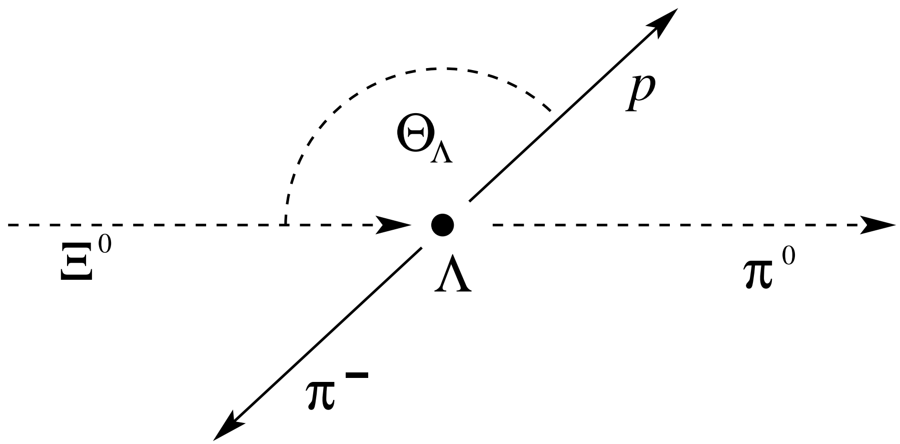
9 events found:

$\Gamma(\Xi^0 \to \Sigma^+ \mu^- \nu)/\Gamma(\Xi^0 \to \Sigma^+ e^- \nu) = (1.8^{+0.7}_{-0.5}(stat.) \pm 0.2(syst.)) \times 10^{-2}$

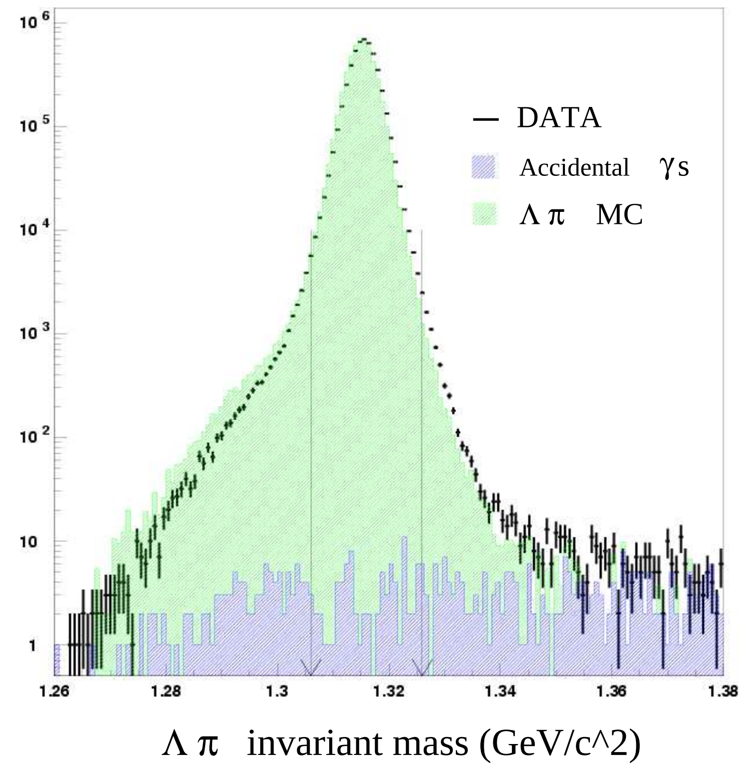
BR($\Xi^0 \to \Sigma^+ \mu^- \nu$)=$(4.7^{+2.0}_{-1.4}(stat) \pm 0.8(syst)) \times 10^{-6}$

(Phys.Rev.Lett. 95,2005)

NA48: $\Xi^0 \to \Lambda\pi^0$ decay asymmetry



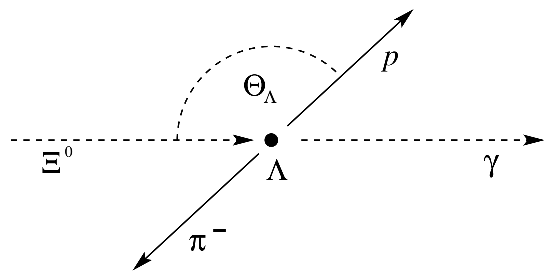
$$dN/dcos\Theta_\Lambda = N_0(1 + \alpha_\Xi\alpha_\Lambda cos\Theta_\Lambda)$$



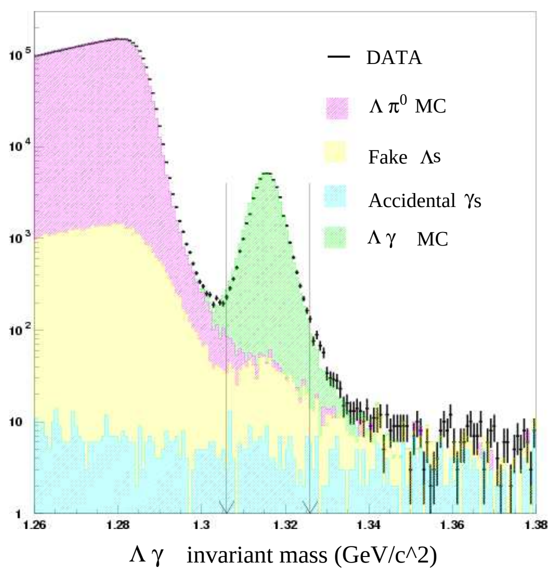
$\alpha_\Xi\alpha_\Lambda(\Lambda\pi^0) = -0.282 \pm 0.003_{stat} \pm 0.028_{syst}$ (prelim.)

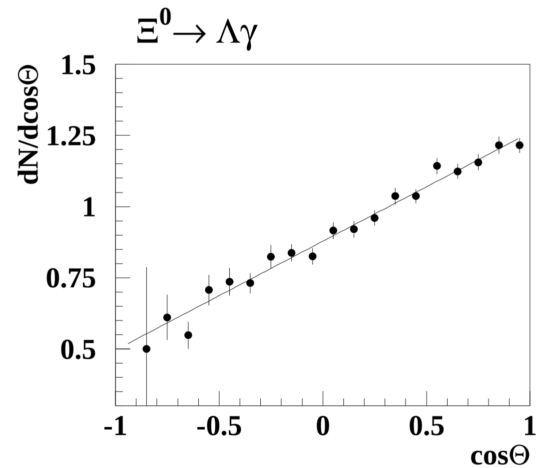
PDG: $\alpha_\Xi\alpha_\Lambda(\Lambda\pi^0) = -0.264 \pm 0.013$

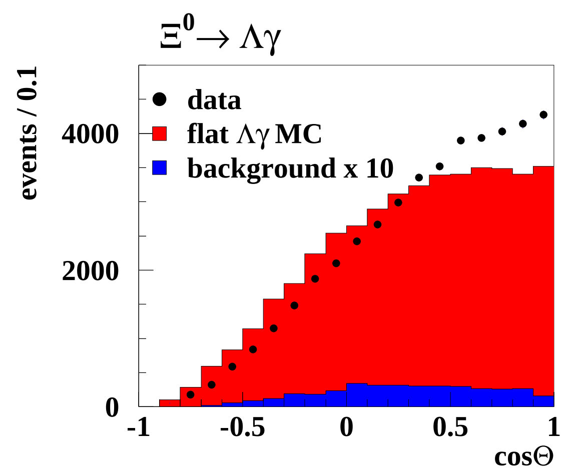
NA48: $\Xi^0 \to \Lambda\gamma$ decay asymmetry



$$dN/dcos\Theta_\Lambda = N_0(1 - \alpha_\Xi\alpha_\Lambda cos\Theta_\Lambda)$$



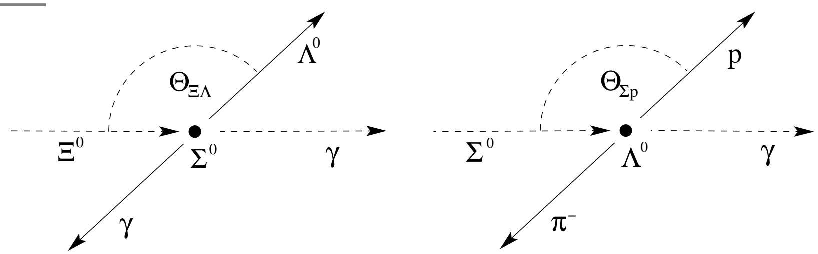




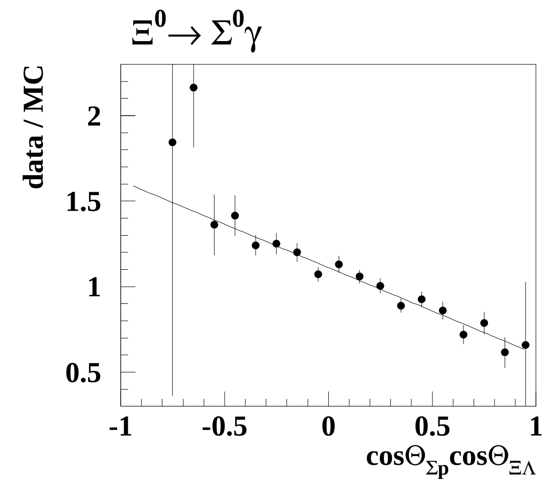
$\alpha_\Xi\alpha_\Lambda(\Lambda\gamma) = -0.439 \pm 0.013_{stat} \pm 0.038_{syst}$ (prelim.)

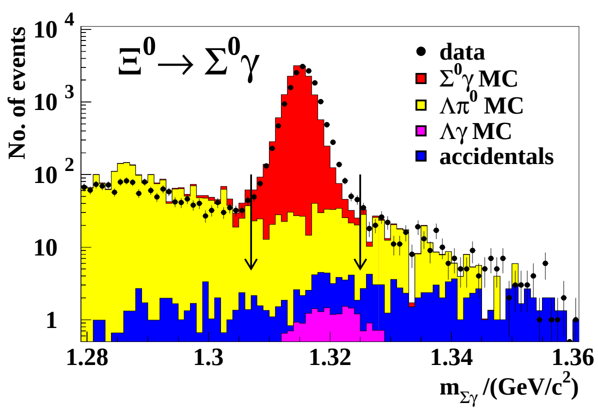
NA48(1999): $\alpha_\Xi\alpha_\Lambda(\Lambda\gamma) = -0.50 \pm 0.13$

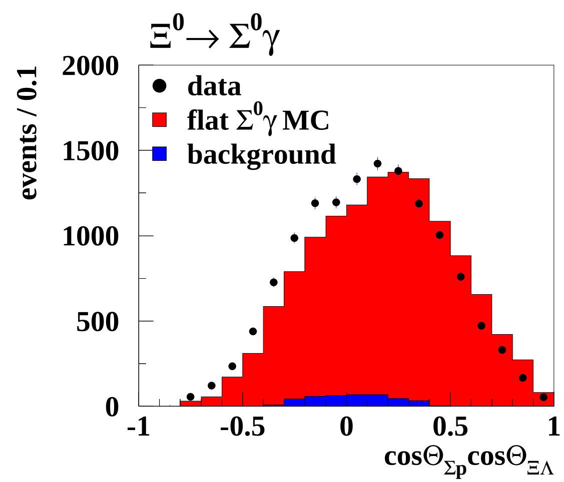
NA48: $\Xi^0 \to \Sigma\gamma$ decay asymmetry



$$d^2N/dcos\Theta_{\Xi\Lambda}dcos\Theta_{\Sigma p} =$$
$$N_0(1 + \alpha_\Xi \alpha_\Lambda cos\Theta_{\Xi\Lambda} cos\Theta_{\Sigma p} =$$
$$N_0(1 + \alpha_\Xi \alpha_\Lambda x)$$







$\alpha_\Xi \alpha_\Lambda(\Sigma\gamma) = -0.438 \pm 0.020_{stat} \pm 0.041_{syst}$ (prelim.)

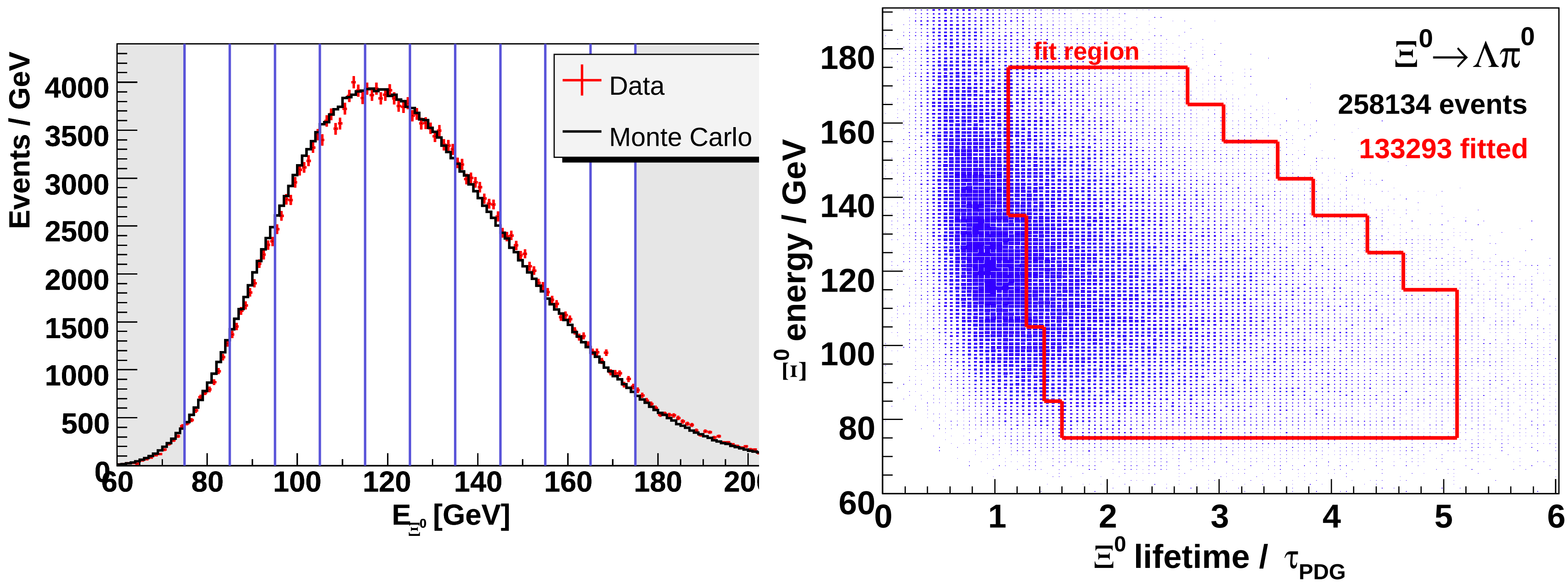
KTeV: $\alpha_\Xi(\Sigma\gamma) = -0.63 \pm 0.09 \Rightarrow \alpha_\Xi \alpha_\Lambda(\Sigma\gamma) = -0.40 \pm 0.06$

Ξ^0 radiative decays: systematics

Source	$\alpha_\Xi\alpha_\Lambda(\Lambda\pi^0)$	$\alpha_\Xi\alpha_\Lambda(\Lambda\gamma)$	$\alpha_\Xi\alpha_\Lambda(\Sigma\gamma)$
Trigger efficiency	± 0.001	± 0.016	± 0.024
Ξ^0 polarisation	± 0.002	-	-
Min radius DCH1	± 0.010	± 0.015	± 0.010
Track-cluster min. dist.	± 0.003	± 0.007	± 0.007
Min Z vertex	± 0.003	± 0.010	± 0.015
Min γ energy	± 0.004	± 0.008	± 0.007
Ξ^0 energy	± 0.025	± 0.025	± 0.025
Ξ^0 mass	± 0.004	± 0.010	± 0.002
MC $\tau(\Xi^0)$	± 0.003	± 0.001	± 0.007
MC $mass(\Xi^0)$	± 0.002	± 0.004	± 0.003
$\Lambda\pi^0$ background	-	± 0.001	-
Total systematics	± 0.028	± 0.038	± 0.041

NA48: Ξ^0 lifetime

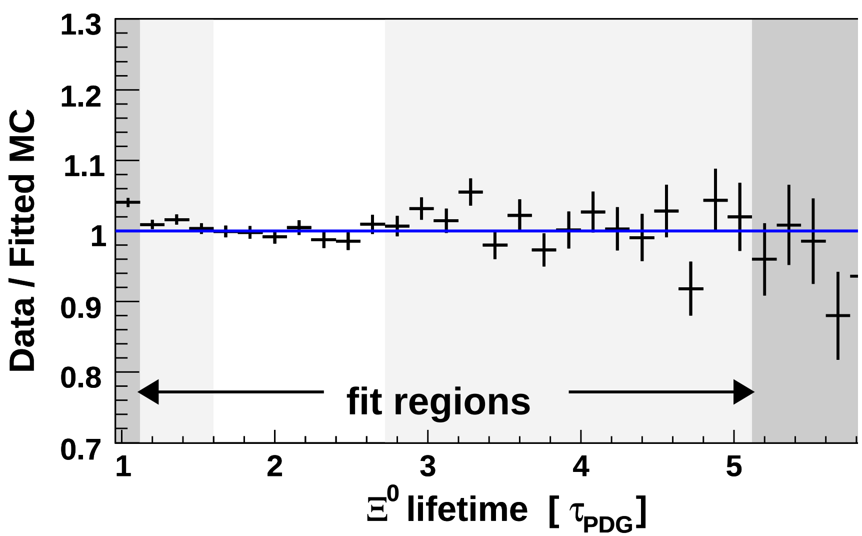
Large sample of $\Xi^0 \to \Lambda\pi^0$ with negligible background
lifetime is measured for Ξ^0 decaying outside final collimator

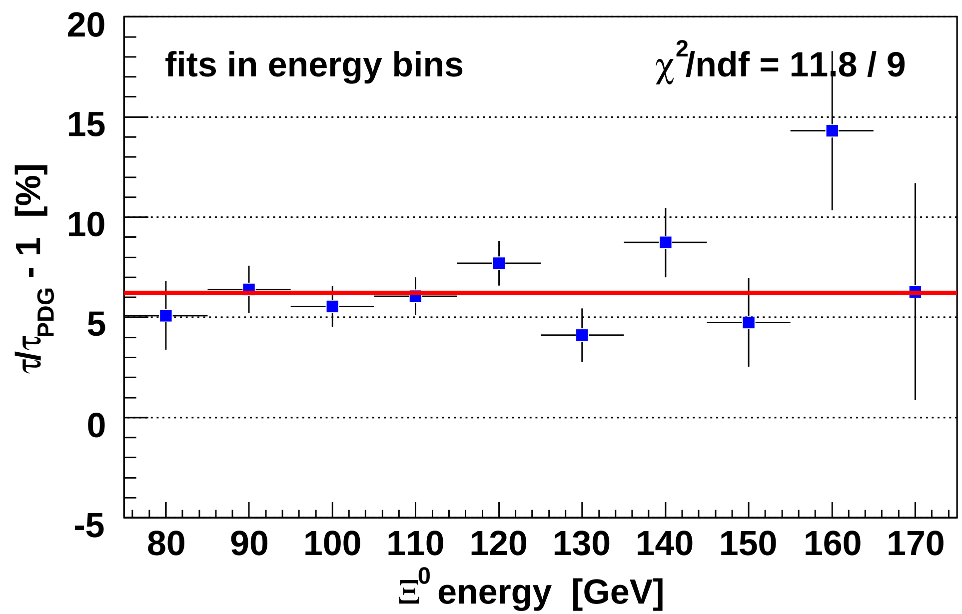


Ξ^0 lifetime, cont.

Fit performed in 10 energy bins of 10 GeV, from 75 GeV to 175 GeV

Summing all energy bins:



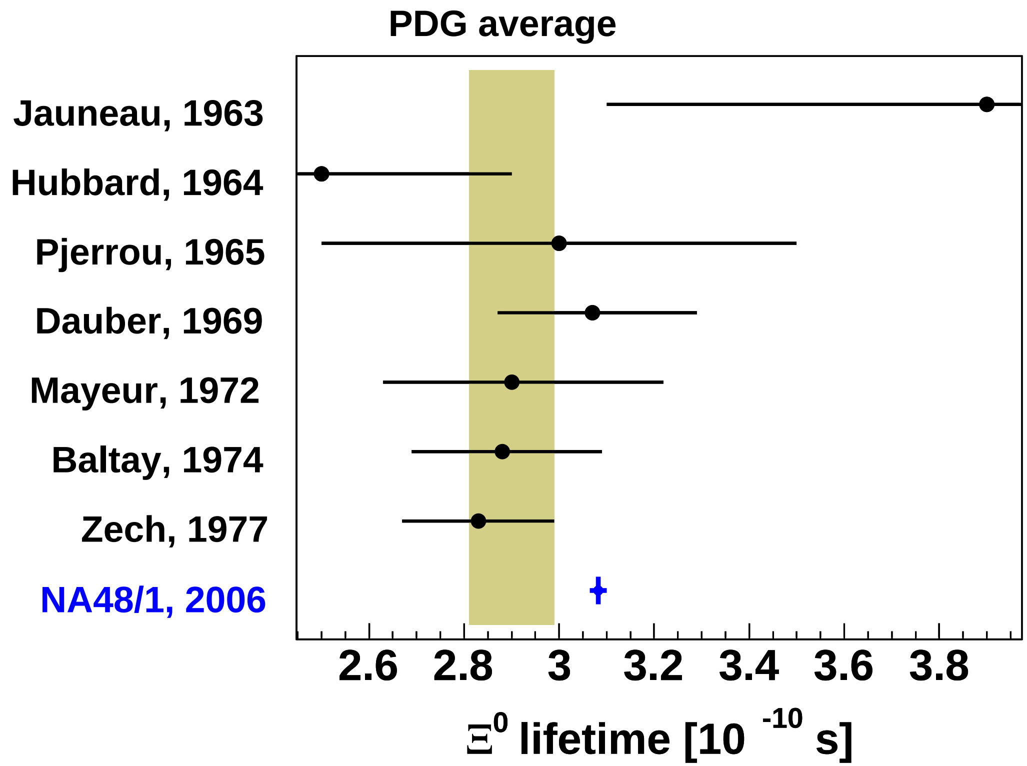


Ξ^0 lifetime, cont.

Source	$\sigma_{syst}/\ \tau$ (%)
Detector acceptance	± 0.30
Vertex resolution	± 0.08
Energy scale	± 0.14
Energy non-linearities	± 0.09
Ξ^0 polarisation	± 0.15
Ξ^0 mass	± 0.20
Λ lifetime	± 0.04
Total systematics	± 0.43
Statistical uncertainty	± 0.44

Ξ^0 lifetime, cont.

$$\tau_{PDG} = (2.9 \pm 0.09) \times 10^{-10} s$$



$$\tau(\Xi^0)/\tau_{PDG} = 1.0626 \pm 0.0044_{stat} \pm 0.0043_{syst}$$

$\tau(\Xi^0) = (3.082 \pm 0.013_{stat} \pm 0.012_{syst}) \times 10^{-10} s$ (prelim.)

Conclusions

Hyperon beta decays:

- BR($\Xi^0 \rightarrow \Sigma^+ e^- \nu$)=$(2.51 \pm 0.03_{stat} \pm 0.11_{syst}) \times 10^{-4}$
- $|V_{us}| = 0.208 \pm 0.006^{+0.030}_{-0.025}{}_{g_1/f_1}$, $g_1/f_1 = 1.20 \pm 0.04_{br} \pm 0.03_{ext}$
- $BR(\Xi^0 \rightarrow \Sigma^+ \mu^- \overline{\nu}_\mu) = (2.2 \pm 0.3_{stat.} \pm 0.2_{syst.}) \times 10^{-6}$
- KTeV: $BR(\Xi^0 \rightarrow \Sigma^+ \mu^- \overline{\nu}_\mu) = (4.7^{+2.0}_{-1.4}(stat.) \pm 0.8_{syst.}) \times 10^{-6}$

Asymmetries in Ξ^0 radiative decays

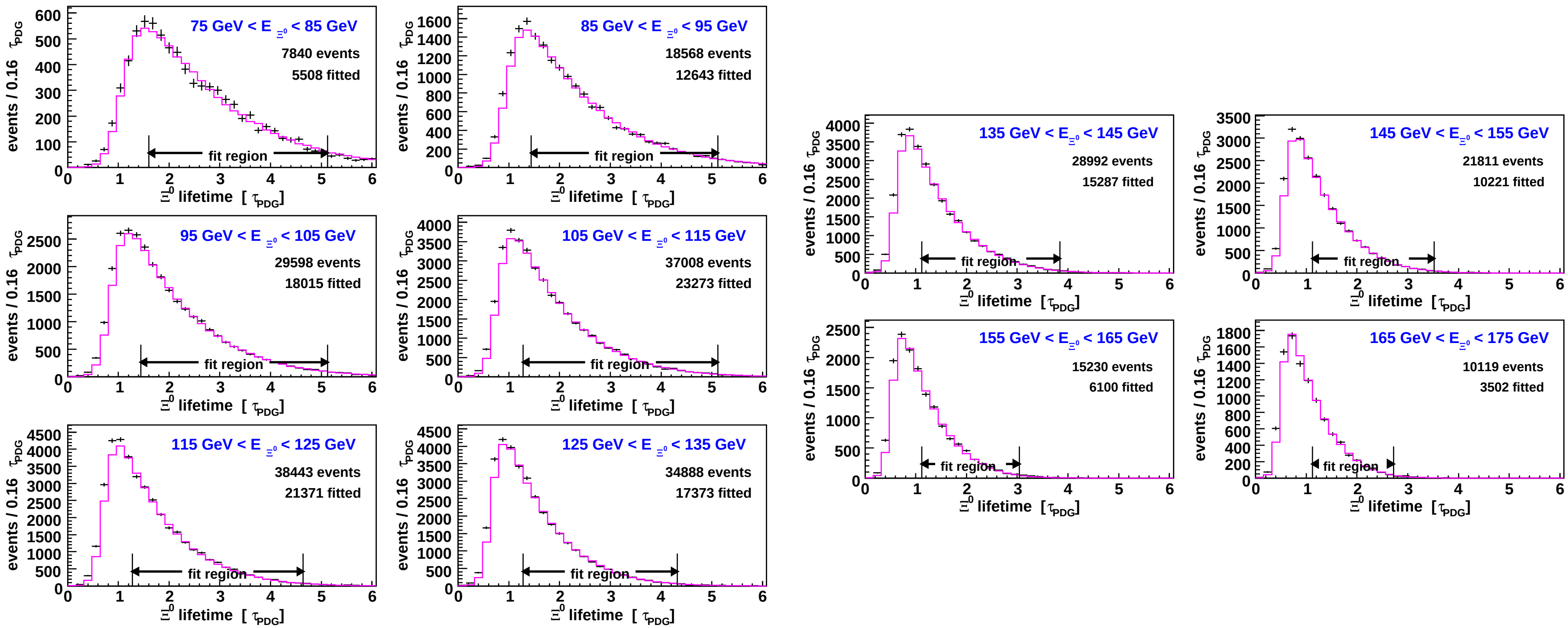
- $\alpha_\Xi \alpha_\Lambda(\Lambda\pi^0) = -0.282 \pm 0.003_{stat} \pm 0.028_{syst}$
- $\alpha_\Xi \alpha_\Lambda(\Lambda\gamma) = -0.439 \pm 0.013_{stat} \pm 0.038_{syst}$
- $\alpha_\Xi \alpha_\Lambda(\Sigma\gamma) = -0.438 \pm 0.020_{stat} \pm 0.041_{syst}$

Ξ^0 lifetime:

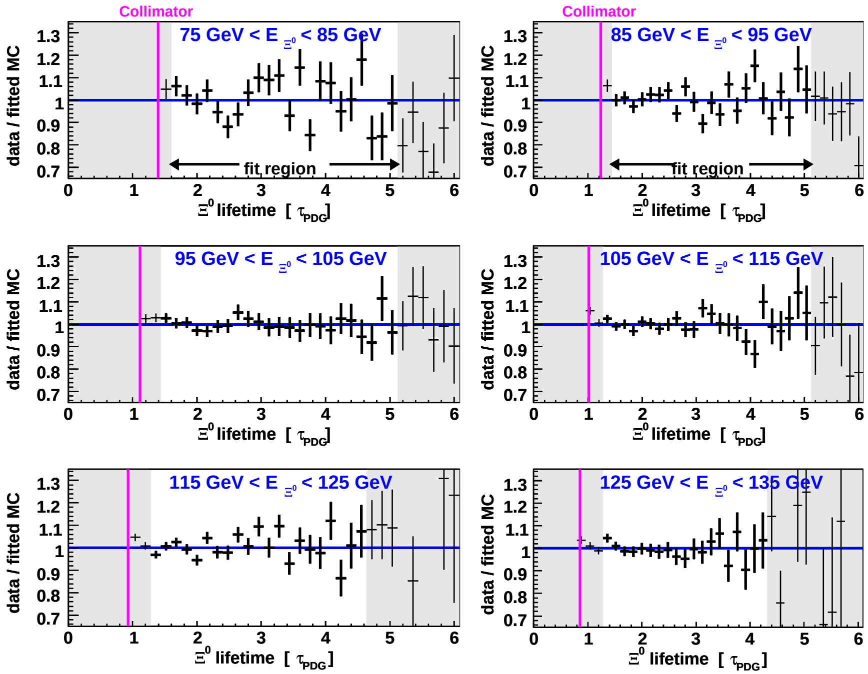
$$\tau(\Xi^0) = (3.082 \pm 0.013_{stat} \pm 0.012_{syst}) \times 10^{-10} s$$

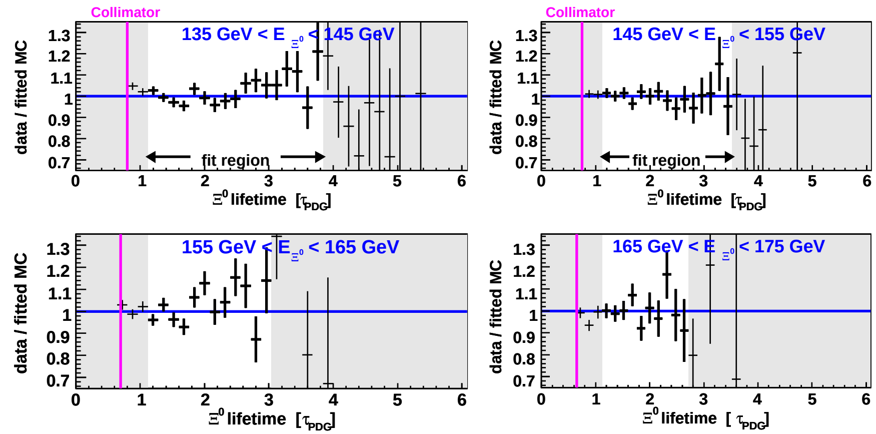
Spares

Ξ^0 lifetime, cont.



Ξ^0 lifetime, cont.





$|V_{us}|$ from Ξ^0 beta decays

Using the new preliminary Ξ^0 lifetime from NA48, and $g_1/f_1 = 1.32^{+0.21}_{-0.17}{}_{stat} \pm 0.05_{syst}$ (KTeV 2000, 494 events), and following Garcia-Kielanowski prescription:

$|V_{us}| = 0.203 \pm 0.028$ dominated by g_1/f_1

(neutron decay + SU(3): $g_1/f_1 = 1.267 \pm 0.035$, not used here)

$\rightarrow$ Agreement with SM expectation of $|V_{us}| = 0.2274 \pm 0.0021$

$\rightarrow$ Uncertainty dominated by experimental precision on form factor g_1/f_1 and branching ratio

Extraction of $f_1(0)/g_1(0)$

Using the new preliminary Ξ^0 lifetime from NA48, $g_1(0)/f_1(0)$ can be extracted from BR using $V_{us} = 0.2257$ from kaon decays (Blucher and Marciano, 2005):

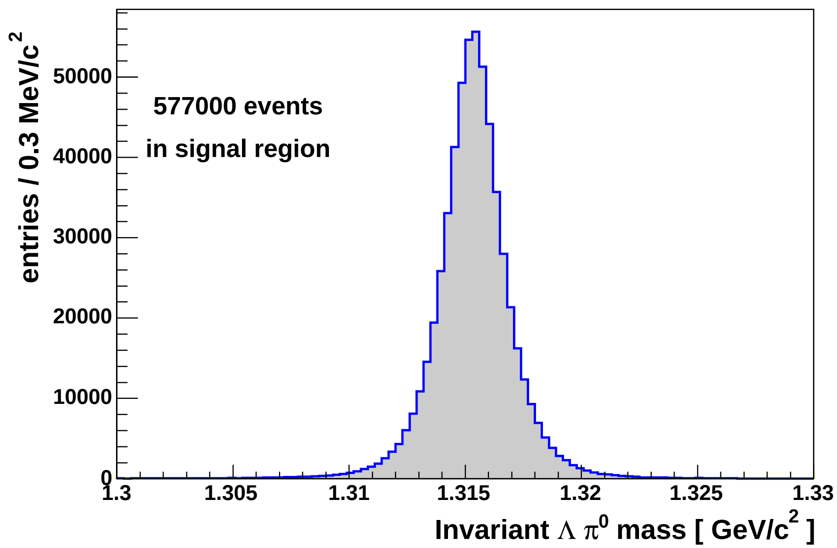
$$g_1(0)/f_1(0) = 1.16 \pm 0.04_{br} \pm 0.02_{ext}$$

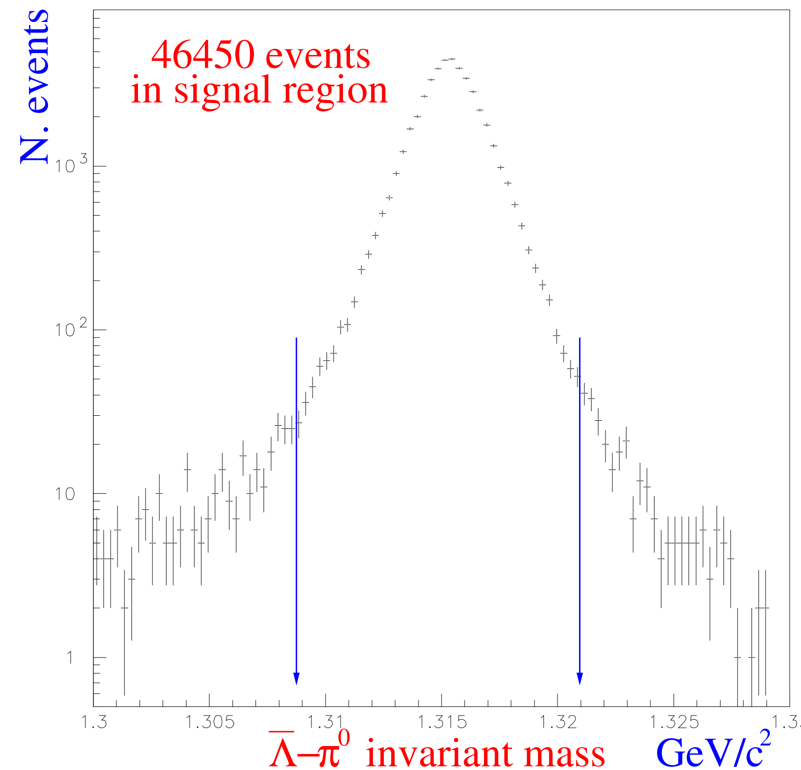
where external uncertainty includes contributions from V_{us}, lifetime, and f_2/f_1

Agreement with exact SU(3) symmetry within 2.5 sigma

Ξ^0 and $\overline{\Xi^0}$ in 2002

From minimum bias trigger (down-scaled by 35):



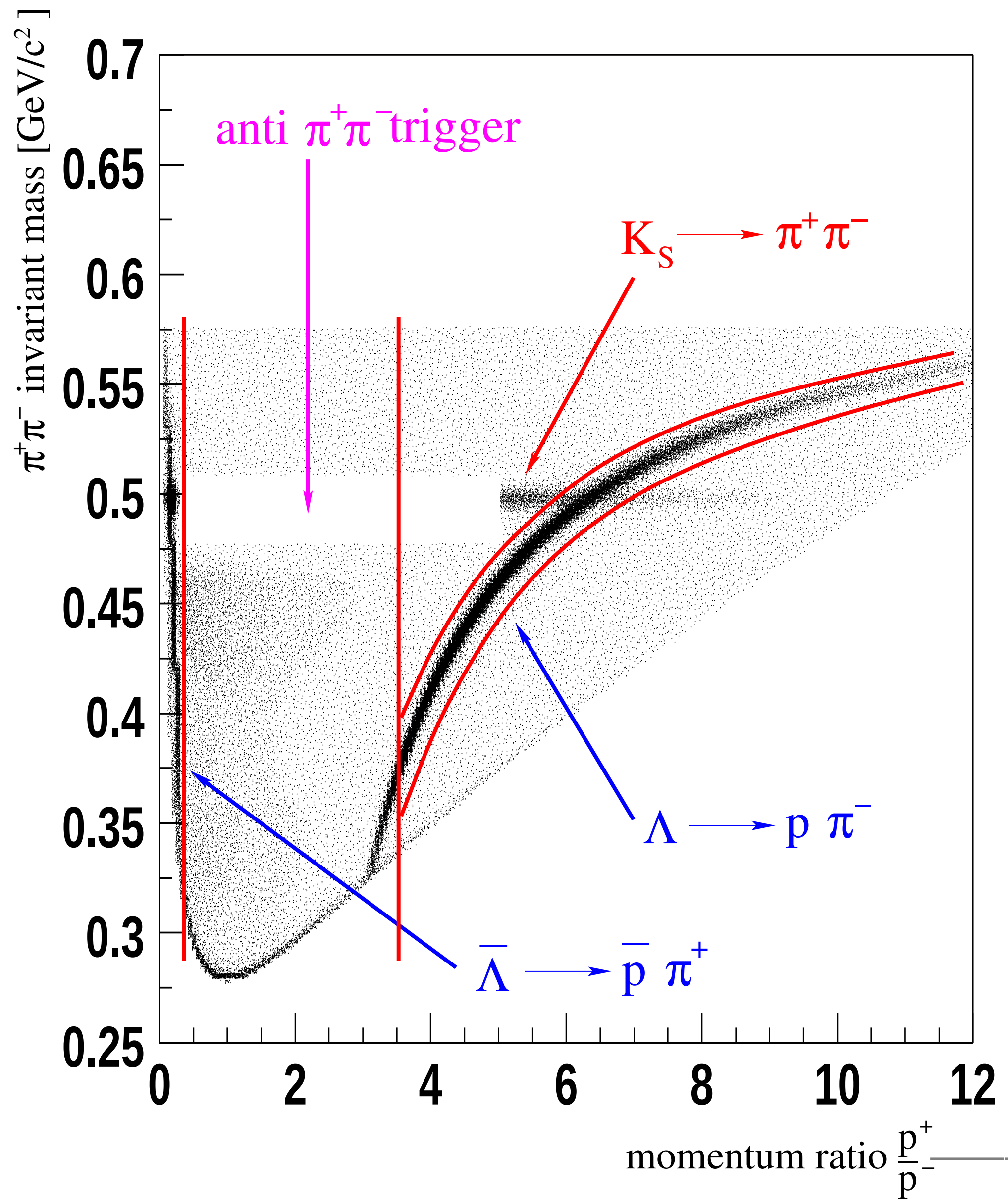


Used for normalisation purposes

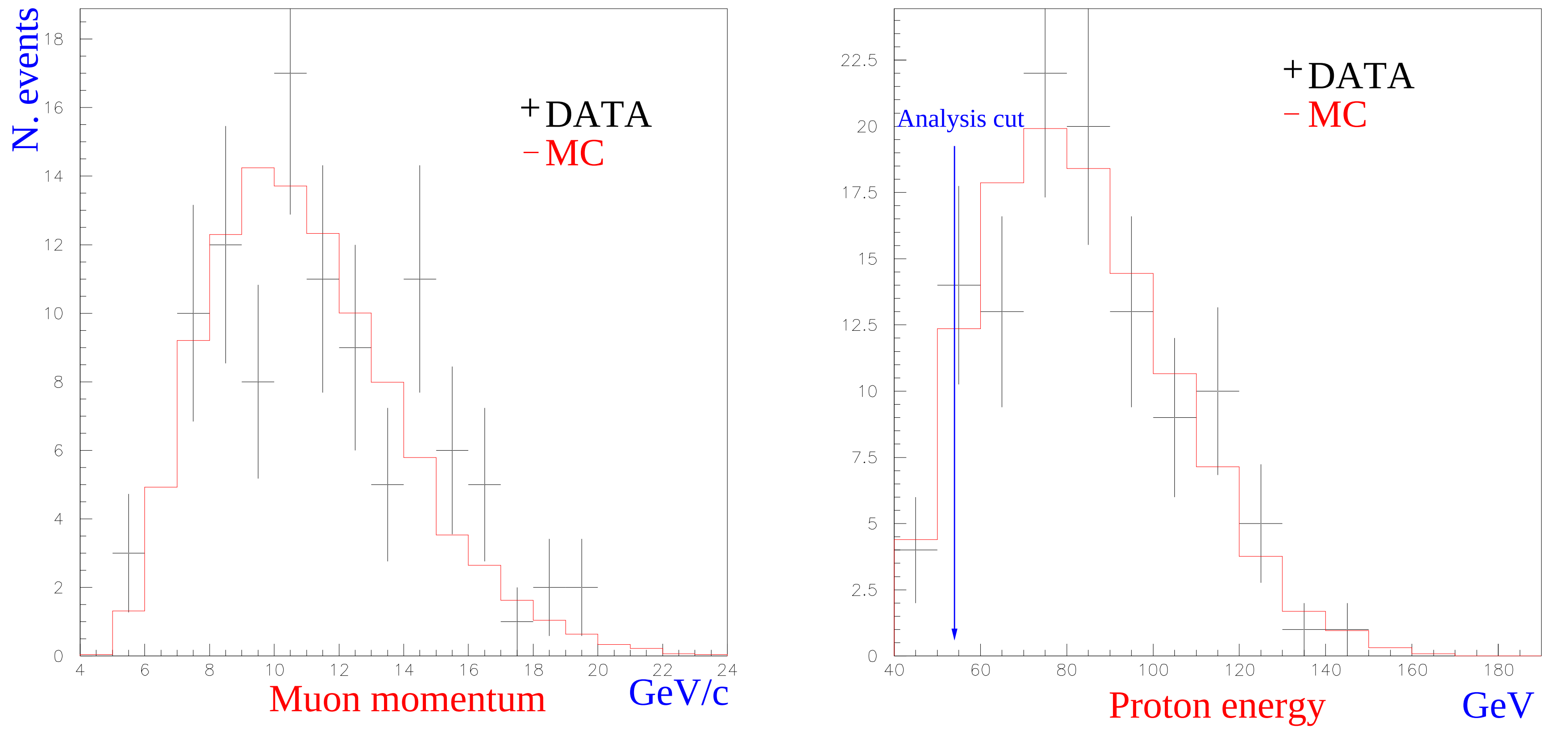
Experimental challenge

- Proton takes most of the hyperon momentum
  $\Rightarrow$ proton line-of-flight close to beam pipe
  $\Rightarrow$ low acceptance, sensitive to detector geometry
  $\Rightarrow$ accurate MC needed

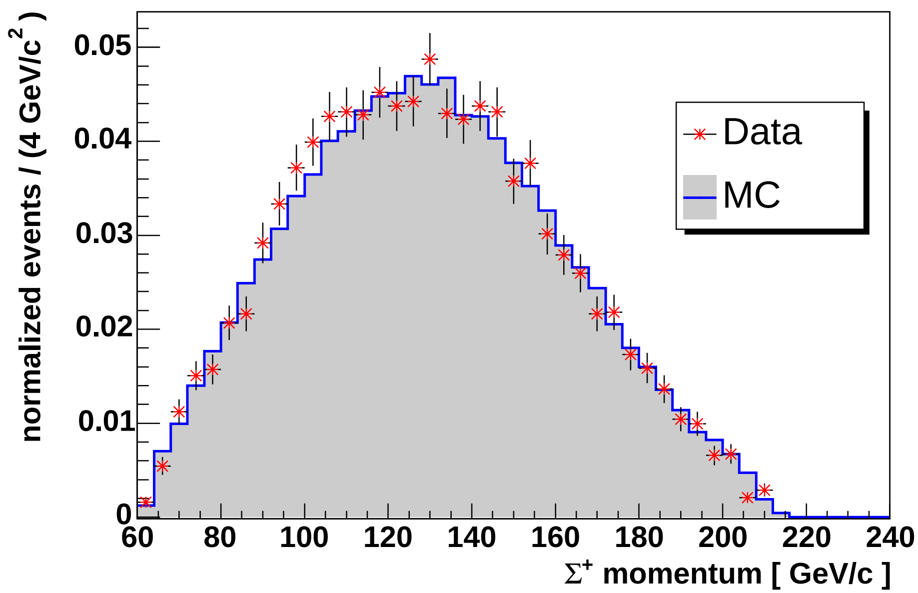
- Triggered by complex algorithm to exclude unwanted K_S and Λ decays

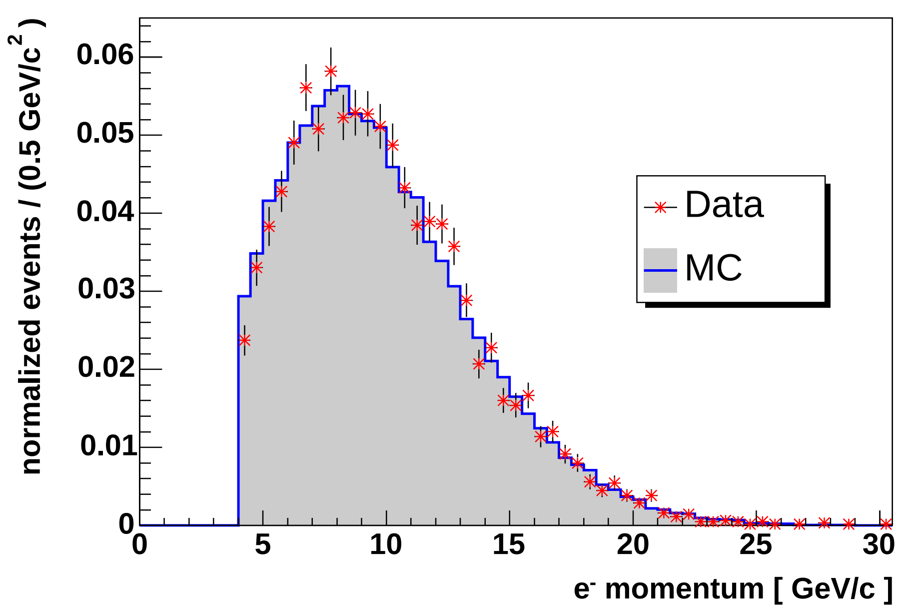


Data-MC comparison - μ channel

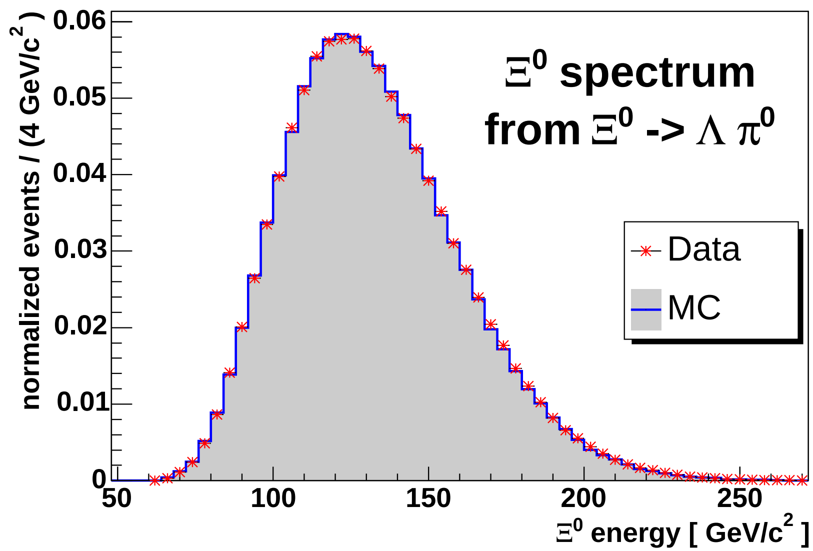


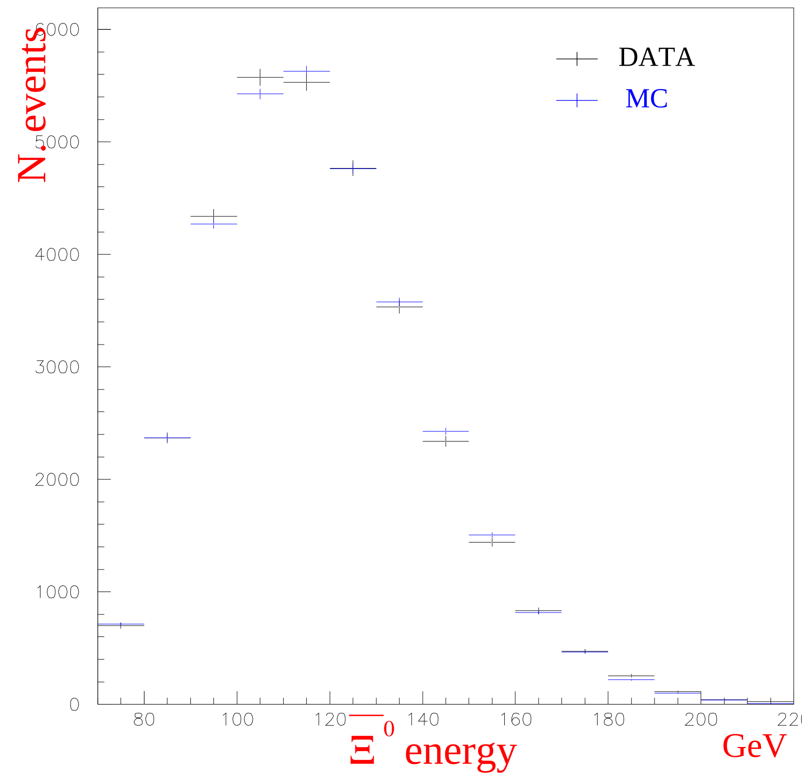
Data-MC comparison - e channel





Data-MC comparison - spectra





$|V_{us}|$ from Ξ^0 beta decays

Ξ^0 beta decay similar to neutron beta decay:
$\Xi^0(uss) \rightarrow \Sigma^+(uus)e^-\nu \qquad n(udd) \rightarrow p(uud)e^-\nu$

Decay rate :

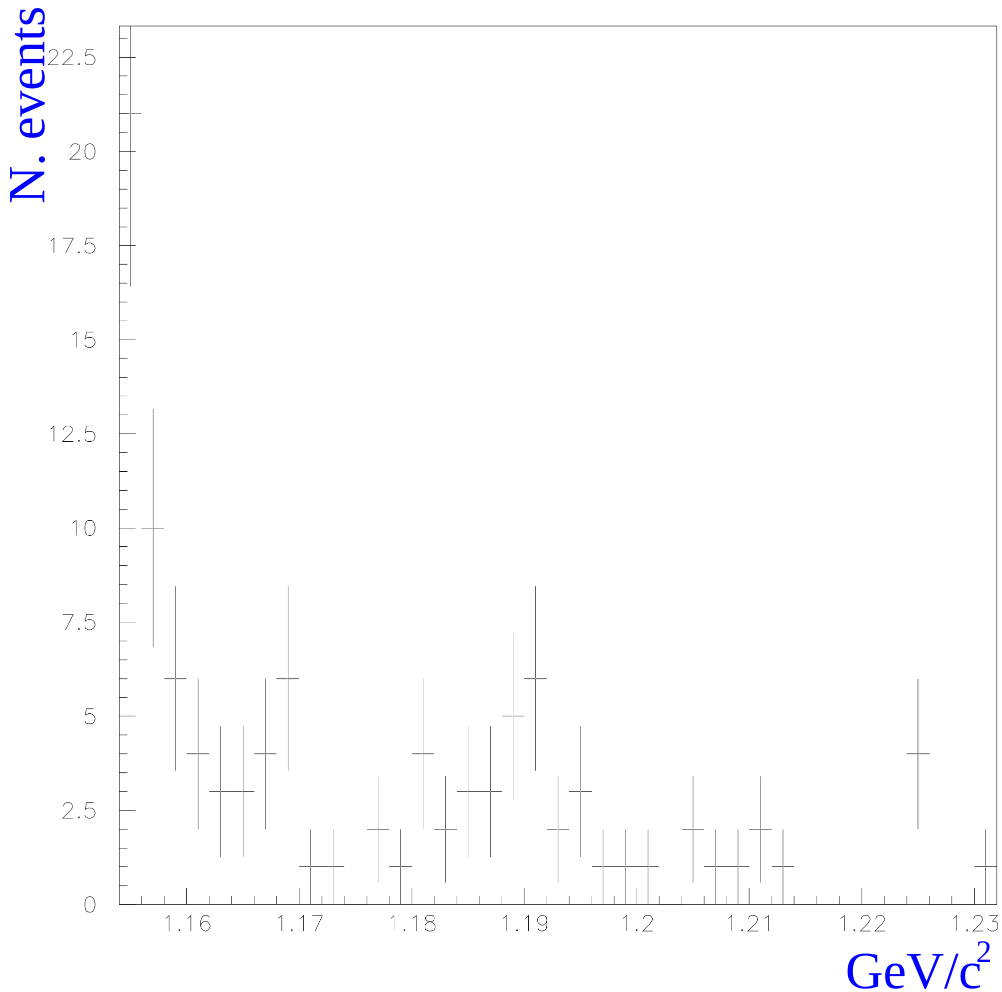
$$\Gamma = G_F^2|V_{us}|^2\frac{\Delta m^5}{60\pi^3}\left[(1-\tfrac{3}{2}\beta)(|f_1|^2+3|g_1|^2)\right]$$

$\Delta m = m_{\Xi^0} - m_{\Sigma^+}$, $\beta = \Delta m/m_{\Xi^0} = 0.095$
(slightly modified by radiative corrections and q^2 dependence)

- f_1 protected by Ademollo-Gatto theorem, $f_1 \approx 1$
- $g_1(\Xi^0) = g_1(neutron)$ if $SU(3)$ symmetry
- assume $g_2 = 0$ (non-existing second class currents)

Ξ^0 lifetime from PDG
$\Gamma(\Xi^0 \rightarrow \Sigma^+e^-\nu) = (8.66 \pm 0.38_{exp} \pm 0.27_{\tau}) \times 10^5 s^{-1}$

μ^+?



N. events
22.5
20
17.5
15
12.5
10
7.5
5
2.5
0
1.16
1.17
1.18
1.19
1.2
1.21
1.22
1.23
GeV/c2

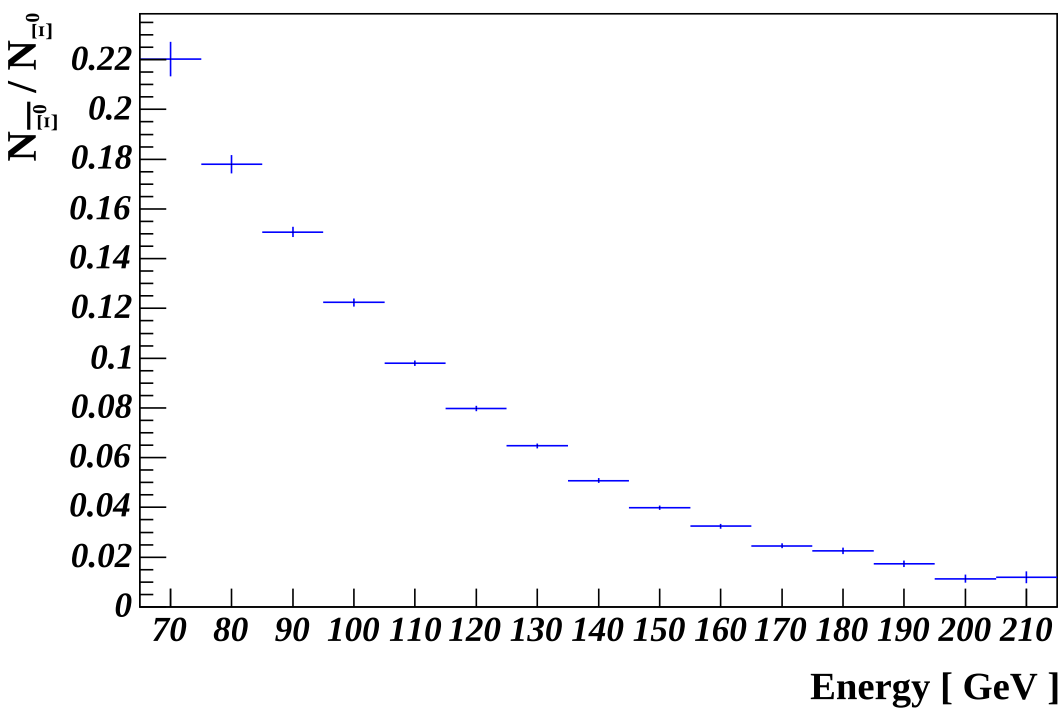
Ξ^0 and $\overline{\Xi^0}$ in 2002

Fiducial volume: $70GeV \leq E_{\Xi^0} \leq 214GeV, \;\; 5m \leq z_{\Xi^0} \leq 50m$

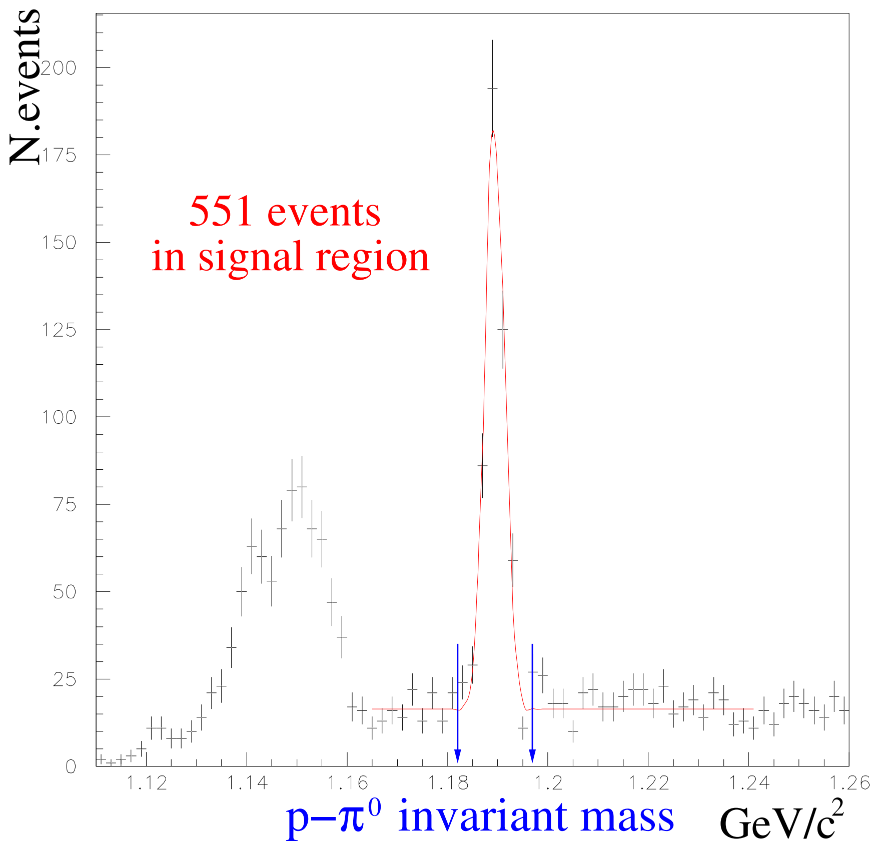
$$N_{\Xi^0} = (2.422 \pm 0.003_{(stat.)} \pm 0.018_{(syst.)}) \times 10^9$$

$$N_{\bar{\Xi}^0} = (2.254 \pm 0.012_{(stat.)} \pm 0.017_{(syst.)}) \times 10^8$$

$$N_{\bar{\Xi}^0}/N_{\Xi^0} = (9.31 \pm 0.05_{(stat.)} \pm 0.04_{(syst.)}) \times 10^{-2}$$



anti-Ξ^0 beta decay



Check for the BR measurement of the Ξ^0 decay

Same selection as for Ξ^0

551 events with a background of $(22.5 \pm 0.8)\%$:

$$BR(\overline{\Xi^0} \rightarrow \overline{\Sigma^+} e^+ \nu_e) = (2.57 \pm 0.12_{stat.} \ {}^{+0.10}_{-0.09}{}_{\ syst.}) \times 10^{-4}$$