Hyperon 99 Symposium Experimental Summary: A 40 Year Perspective

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29 Sept. 1999

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x_2	−100			
x_3	−2	−1		
x_5	46	−46	−1	
x_6	0	0	0	0
	x_1	x_2	x_3	x_5

Λ BRANCHING RATIOS

$\Gamma(p\pi^-)/\Gamma(N\pi)$ — $\Gamma_1/(\Gamma_1+\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.641±0.005 OUR FIT					
0.640±0.005 OUR AVERAGE					
0.646±0.008	4572	BALTAY	71B	HBC	$K^- p$ at rest
0.635±0.007	6736	DOYLE	69	HBC	$\pi^- p \to \Lambda K^0$
0.643±0.016	903	HUMPHREY	62	HBC	
0.624±0.030		CRAWFORD	59B	HBC	$\pi^- p \to \Lambda K^0$

1959

$\Gamma(n\pi^0)/\Gamma(N\pi)$ — $\Gamma_2/(\Gamma_1+\Gamma$

VALUE	EVTS	DOCUMENT ID		TECN
0.359±0.005 OUR FIT				
0.310±0.028 OUR AVERAGE				
0.35 ±0.05		BROWN	63	HLBC
0.291±0.034	75	CHRETIEN	63	HLBC

$\Gamma(n\gamma)/\Gamma_{total}$ — Γ_3

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.75±0.15 OUR FIT					
1.75±0.15	1816	LARSON	93	SPEC	$K^- p$ at rest
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.78\pm0.24^{+0.14}_{-0.16}$	287	NOBLE	92	SPEC	See LARSON 93

$\Gamma(n\gamma)/\Gamma(n\pi^0)$ — $\Gamma_3/$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2.86±0.74±0.57	24	BIAGI	86	SPEC	SPS hyperon beam

$\Gamma(p\pi^-\gamma)/\Gamma(p\pi^-)$ — $\Gamma_4/$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.32±0.22	72	BAGGETT	72C	HBC	π^- < 95 MeV/c

$\Gamma(pe^-\overline{\nu}_e)/\Gamma(p\pi^-)$ — $\Gamma_5/$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
1.301±0.019 OUR FIT					
1.301±0.019 OUR AVERAGE					

Very brief history

- PAST: 1947 discovery of ‘V’ particles in associated production led to development of strangeness as a quantum number, and ultimately to a theory of quarks.
- PRESENT: To this day the Fermilab program keeps this tight association between kaons and hyperons. Both fixed target experiments (HyperCP and KTeV) have compelling hyperon and kaon physics goals.
- FUTURE: If we wish to do more, we must develop an integrated program for hyperons. At Fermilab, asking for 800 GeV beam is asking to compete against the collider, so the 120 GeV and 3 TeV options must be kept in mind.

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

$\quad\quad\;\, \Sigma^+ \rightarrow p + \pi^0$

Branching Ratio Measurement

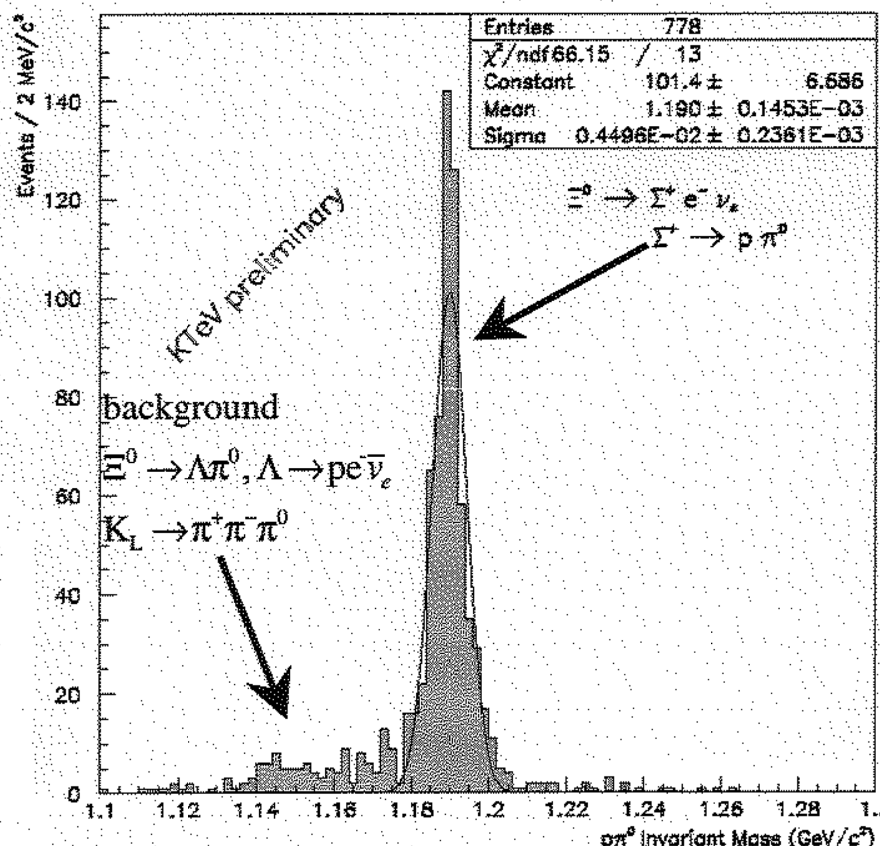
Signal = 626 ± 25 events

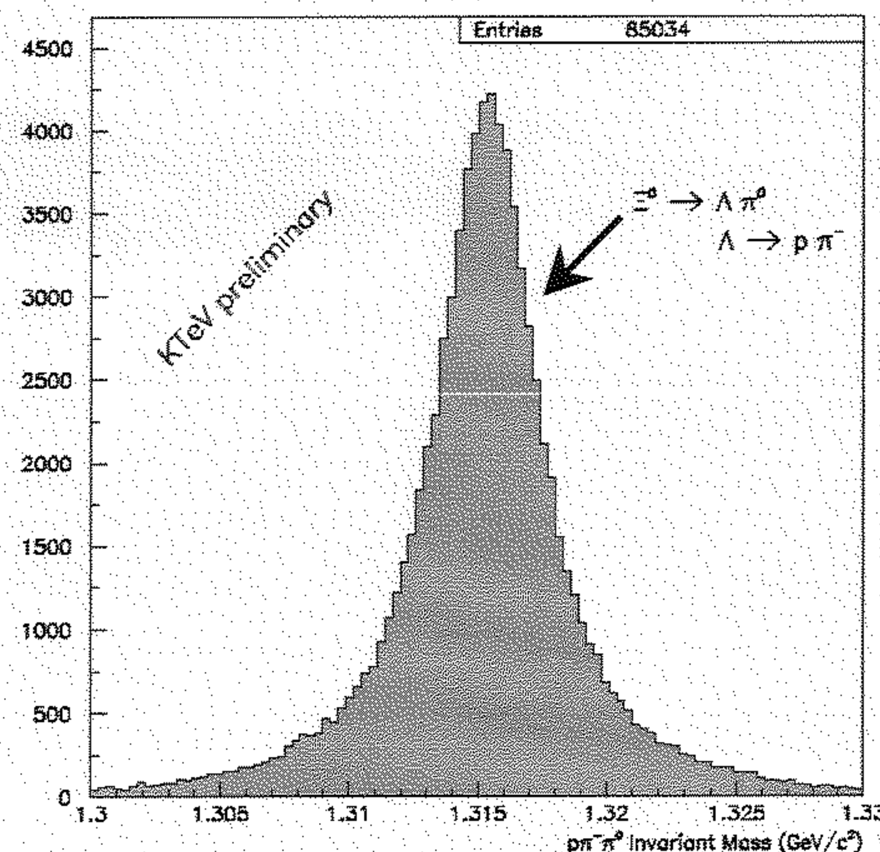
Background = 60 ± 8 events

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

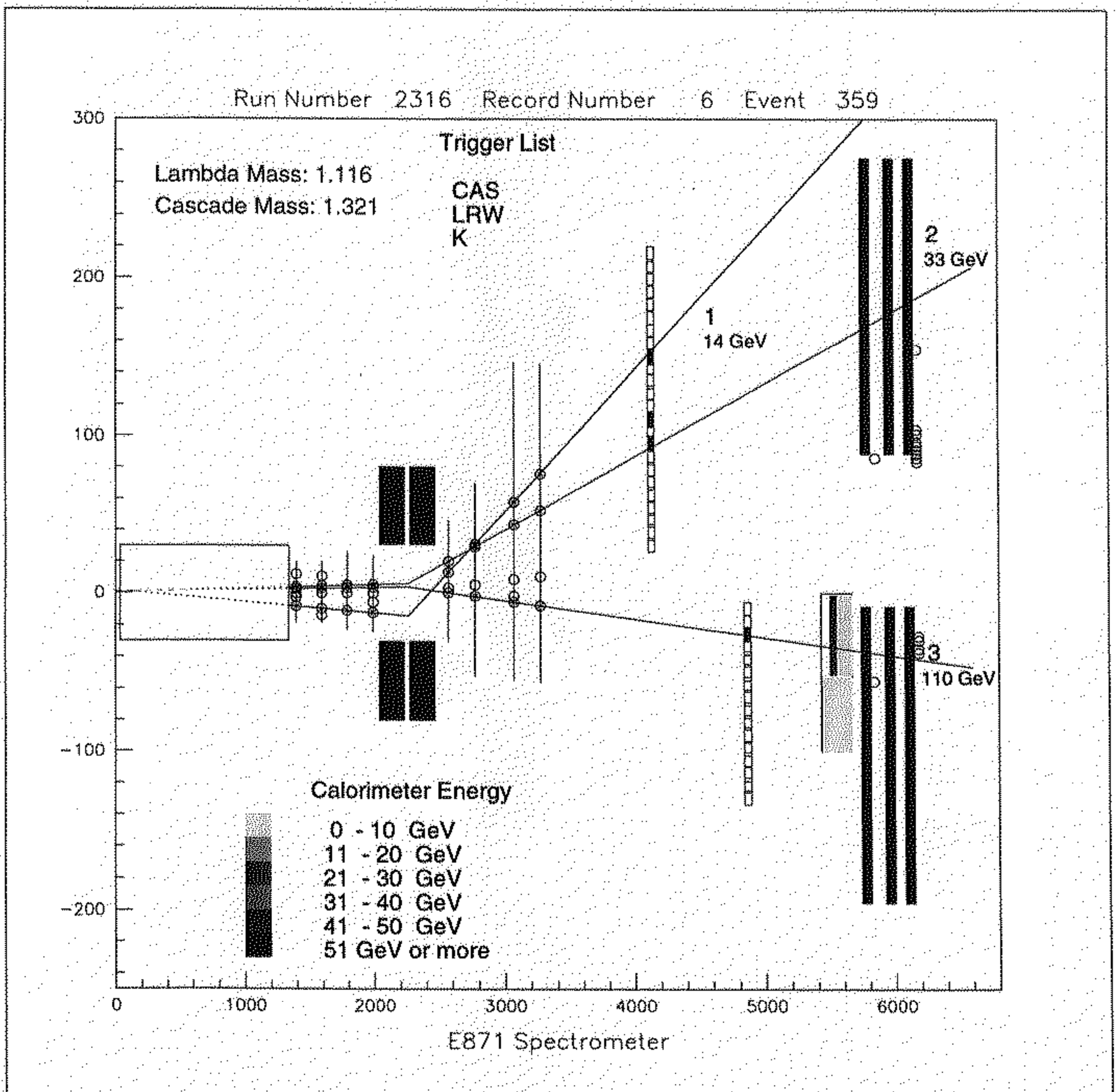
KTeV first measured B.R = (2.71 ± 0.22 ± 0.31) x 10^{-4}

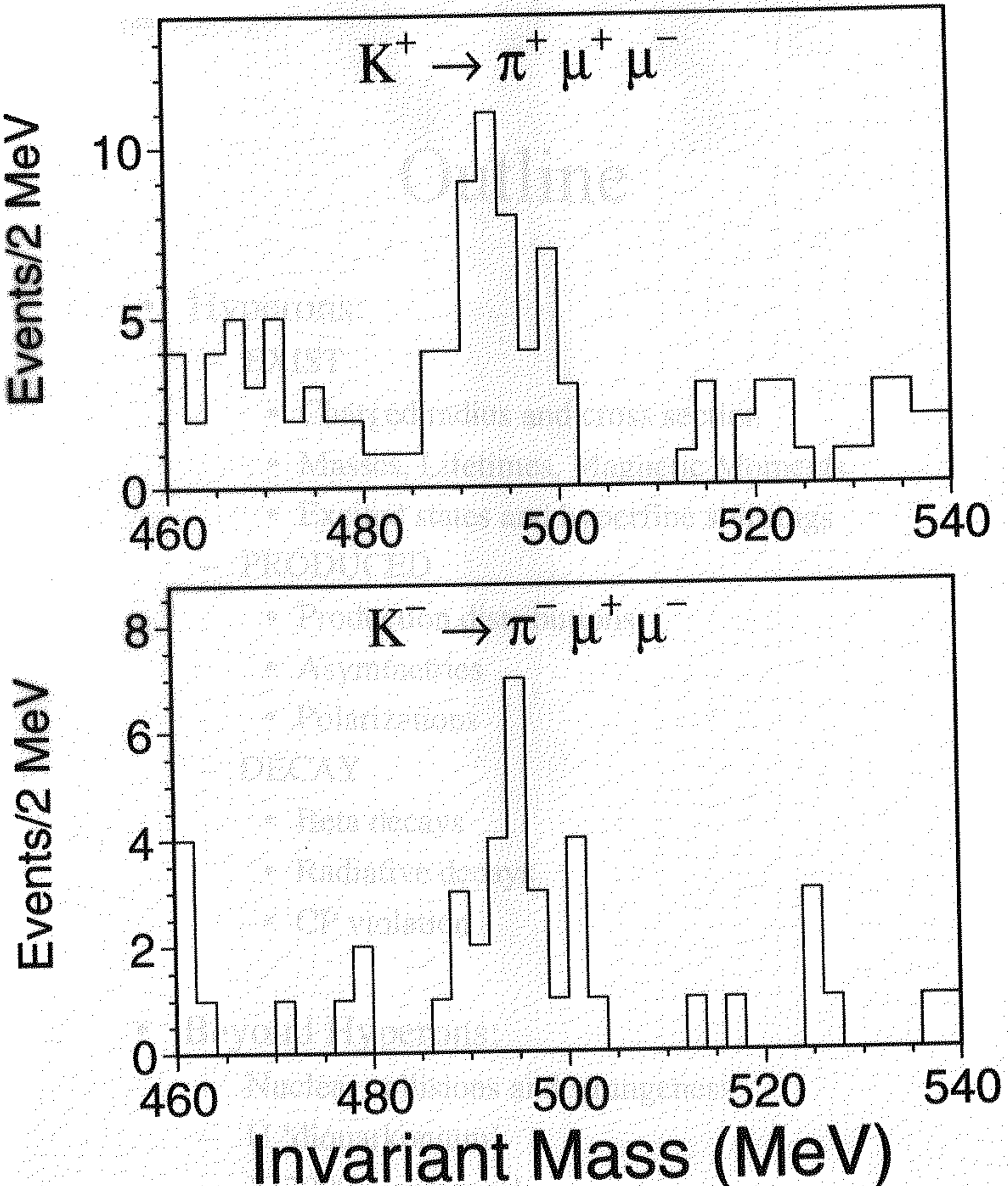
Theoretical (SU3) predicted B.R = (2.61 ± 0.11) x 10^{-4}





A TYPICAL EVENT DISPLAY



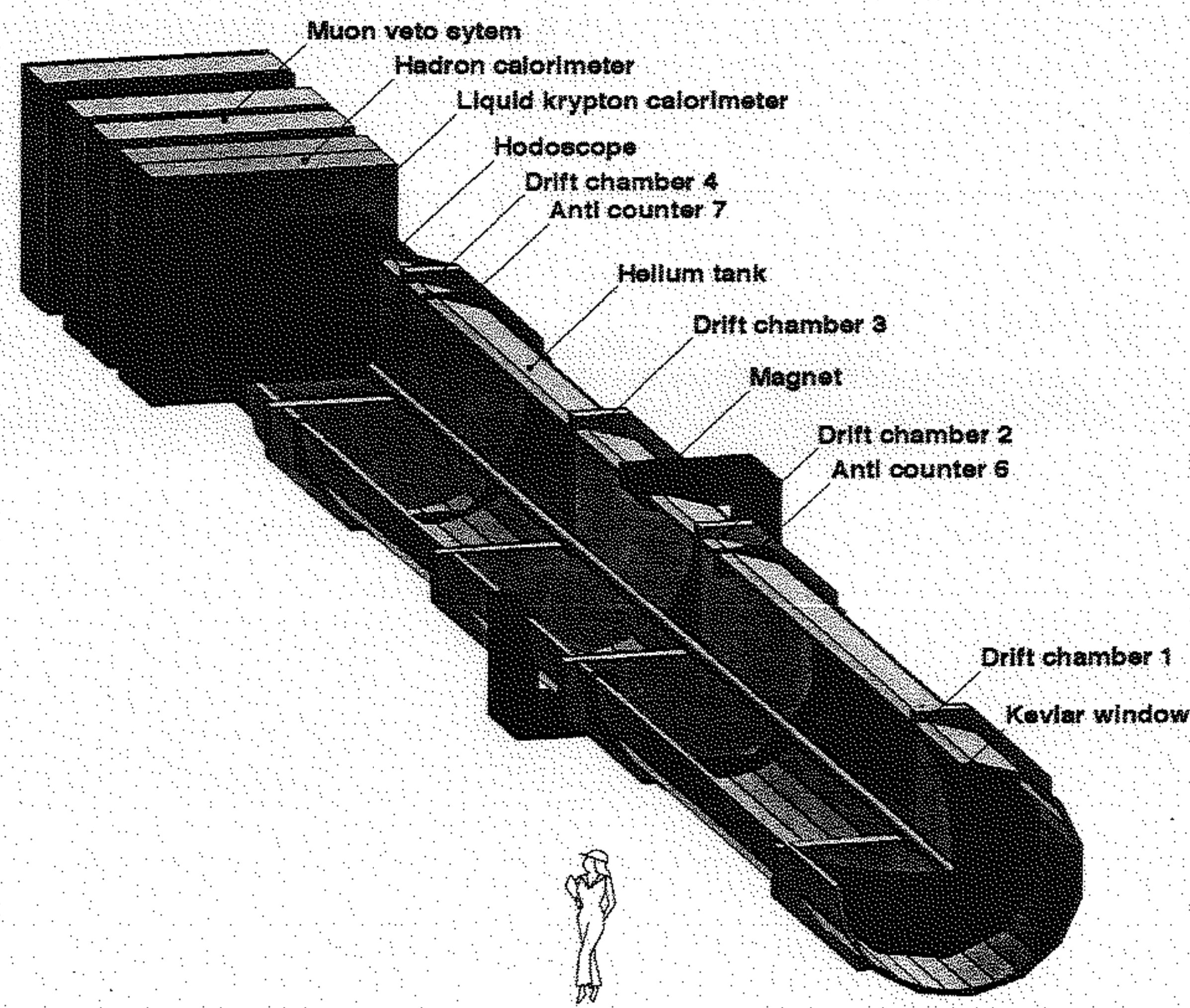


$K^+ \to \pi^+ \mu^+ \mu^-$
Events/2 MeV
0
5
10
460
480
500
520
540
$K^- \to \pi^- \mu^+ \mu^-$
Events/2 MeV
0
2
4
6
8
460
480
500
520
540
Invariant Mass (MeV)

Static Properties of Hyperons

- Masses - NA48
- Lifetimes - E761
- Magnetic moments
- Charge radius - SELEX
- Excited States - WA89
- Remarks on Σ/Λ mixing

NA48 - The Detector



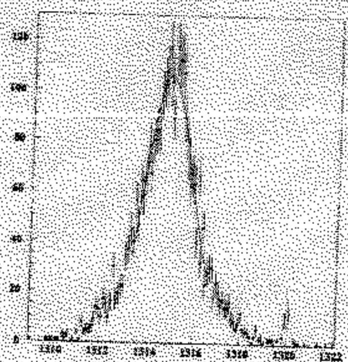
Mass

New Preliminary Result from NA48 from Lutz Kopke talk @ KAON99

Precision Ξ^0-mass

...Precise tracking and small uncertainty in momentum scale

- select $\Xi^0 \rightarrow \Lambda\pi^0$
- use π^0-vertex
- use nominal π^0 and Λ masses as constraints



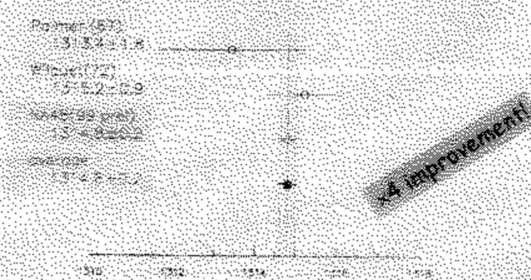
$m(\Lambda\pi^0)$ MeV

...Precision Ξ^0-mass

preliminary

$M_{\Xi^0} = 1314.83 \pm 0.06_{stat} \pm 0.20_{sys}$ MeV

...systematic error mainly due to ~50 cm uncertainty in vertex position



M_{Ξ^0} [MeV]

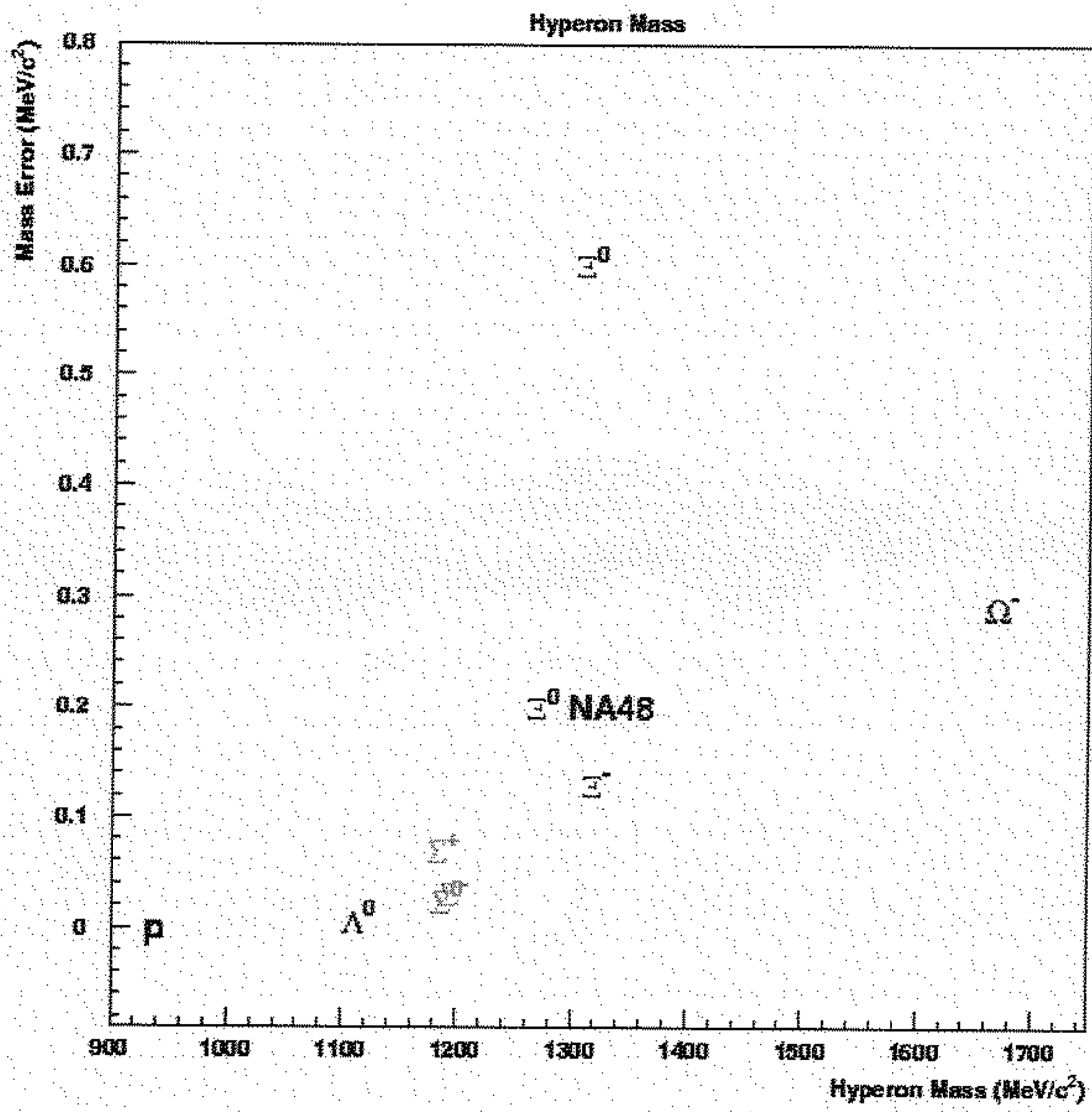
Mass

- The mass spectrum of the baryons is an enduring subject. The Coleman-Glashow relation(1961) is

  $M_n - M_p + M_{\Xi^-} - M_{\Xi^0} + M_{\Sigma^+} - M_{\Sigma^-} = 0 = -0.37 \pm 0.62$

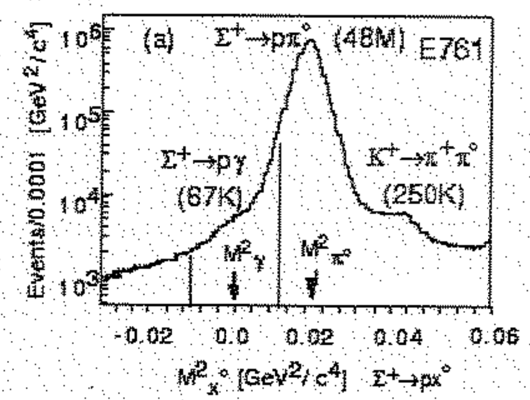
  dominated by the experimental uncertainty on M_{Ξ^0} .
- More recent theoretical works includes:
  - J. Rosner hep-ph/9707473v4
  - E. Jenkins hep-ph/9893349
- Improvements on M_{Ξ^0} can be expected from NA48 and perhaps KTeV. With the NA48 preliminary results the CG relation becomes -0.30 ± 0.25
- The next biggest uncertainty is in M_{Ξ^-} which HyperCP should be able to improve. Beyond this (0.1 MeV) the precision should limited by theory.
- The other sum rules predicted involve decuplet, charm or beauty state masses.

Mass   Present PDG values

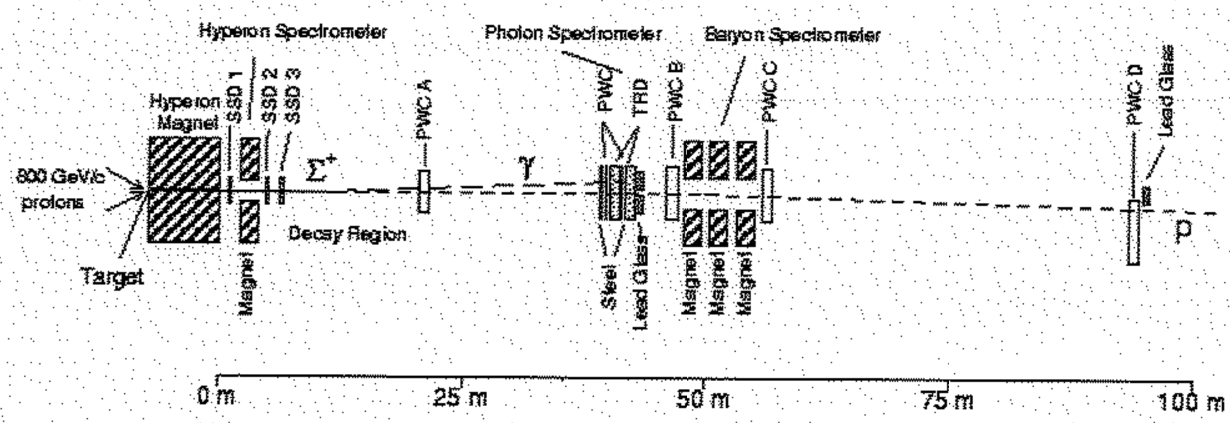


CPT Tests   New Σ^+ and $\bar{\Sigma}^-$ Lifetimes from E761

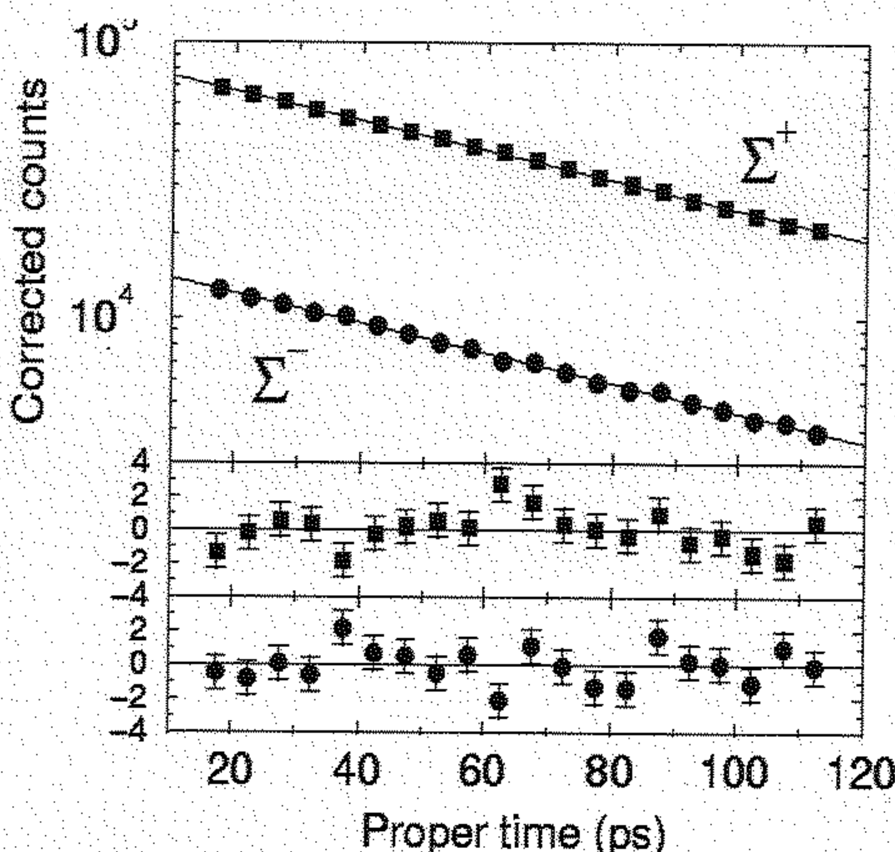
- E761 Data in the 1990 fixed target run in PC4



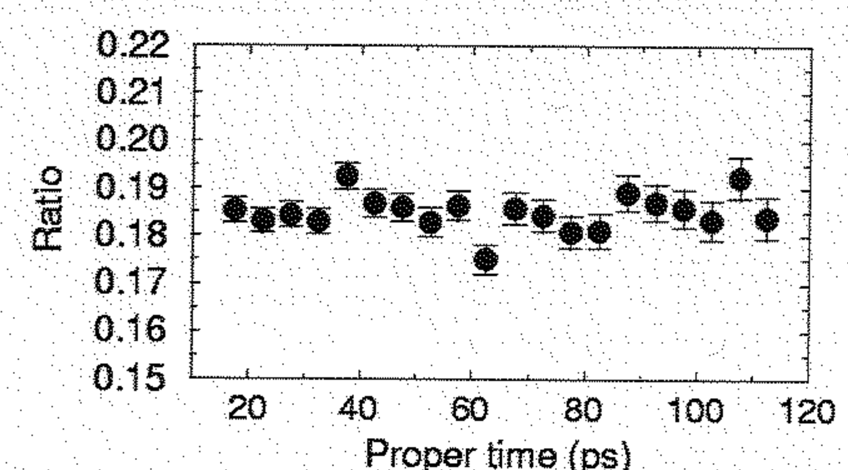
- Physics goals :Br and α_γ for $\Sigma^+ \to p\,\gamma$, $\Xi^- \to \Sigma^-\gamma$
- This new result is the *last* E761 paper (?)
  R.F. Barbosa *et.al.* - To be submitted to PRL



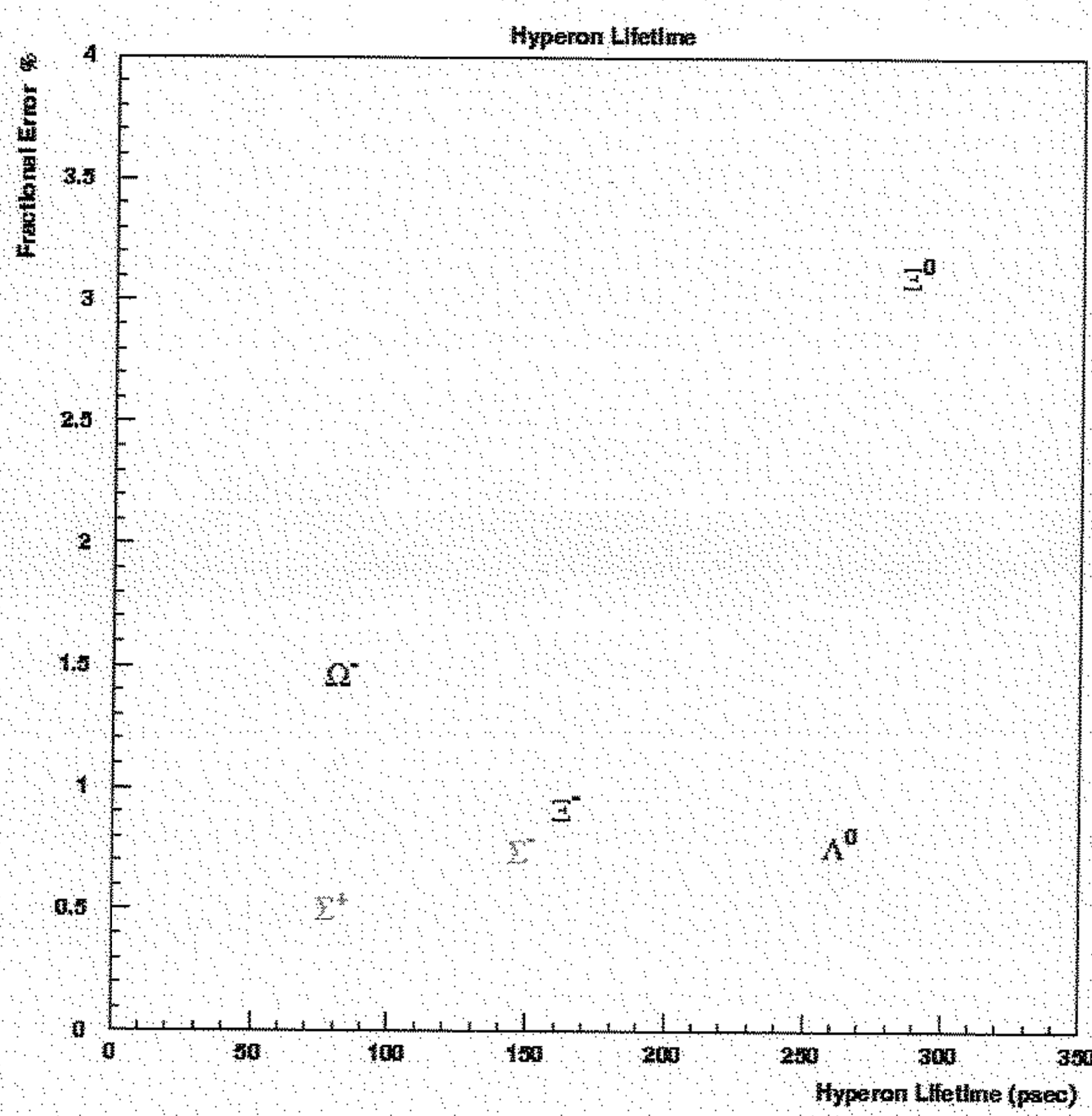
- Data sets used are 375 GeV/c Σ's produced by 800 GeV/c protons on Cu
  - 132K $\Sigma^- \to p\pi^0$ after cuts
  - 640K $\Sigma^+ \to p\pi^0$ after cuts - small subset of total data sample
  - Both data sets taken with same apparatus geometry - just sign reversal
- Acceptance corrections with a full GEANT simulation



- Results
  - $\tau[\Sigma^+] = 80.38 \pm 0.40 \pm 0.14$ psec
  - $\tau[\Sigma^-] = 80.43 \pm 0.80 \pm 0.14$ psec
  - $\Delta\tau/\langle\tau\rangle = -0.06 \pm 1.12\%$
- Best baryon lifetime CPT test
  - Λ^0 4.4 ± 8.5 %, Ξ^- 2 ± 18 %



Lifetime   Present PDG values



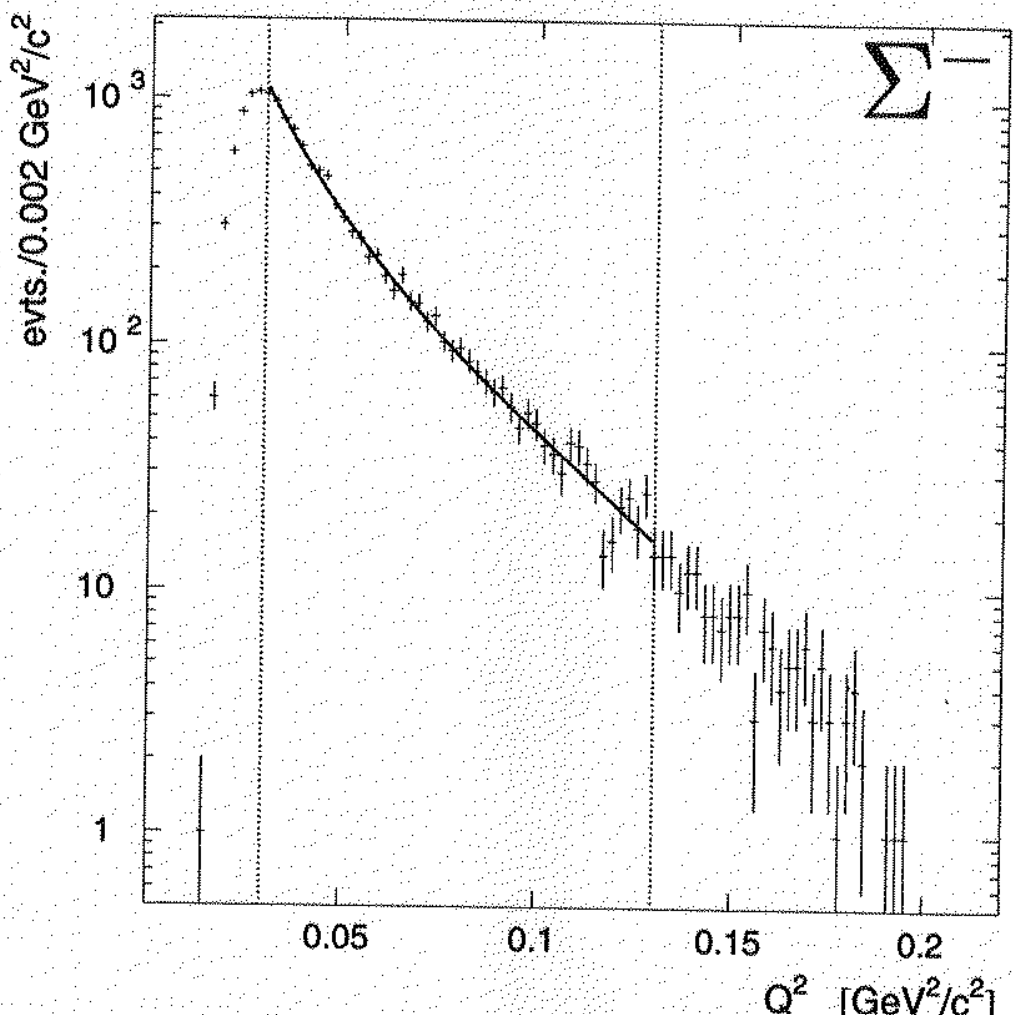
Magnetic Moments

- All the Hyperon magnetic moments are now measured with high precision (<~1%).
- The SU6 quark model fits the data to ~5-10%. The deviations are all very well measured (~10σ)
- ~100 papers latter no other model does much better!
- We're done until theory builds a better baryon.

Hyperon magnetic moments [NM]

Hyperon	Moment	Quark Model	Difference
p	+2.792847	fixed	—
n	-1.913043	fixed	—
Λ°	-0.613(04)	fixed	—
$\Sigma+$	+2.458(10)	+2.67	-0.210(10)
$\Sigma^\circ \rightarrow \Lambda^\circ$	-1.610(80)	-1.63	+0.020(80)
$\Sigma-$	-1.160(25)	-1.09	-0.070(25)
Ξ°	-1.250(14)	-1.43	+0.177(14)
$\Xi-$	-0.6517(25)	-0.47	-0.161(03)
$\Omega-$	-2.024(56)	-1.84	-0.184(56)

Preliminary Results



	SELEX $\langle r^2\rangle[fm^2]$	$\langle r^2\rangle[fm^2]$
Σ^-	$0.60 \pm 0.08 \pm 0.08$	
p	$0.70 \pm 0.06 \pm 0.06$	0.72 ± 0.01 [a]
π^-	$0.50 \pm 0.06 \pm 0.06$	0.44 ± 0.01 [b]

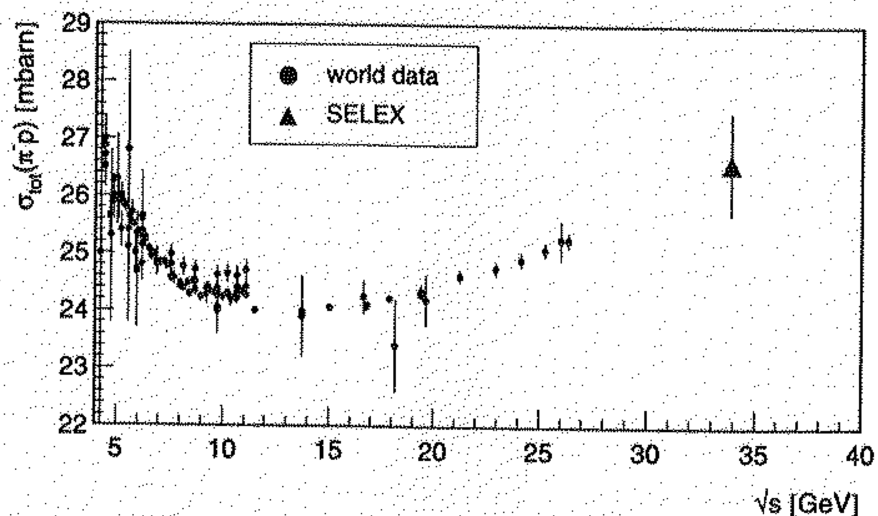
[a] Mergell *el al*, Nucl.Phys.A **596**, (1996) 596

[b] Amendolia *el al* [NA7 Collaboration], Nucl.Phys.B **277**, (1986) 168

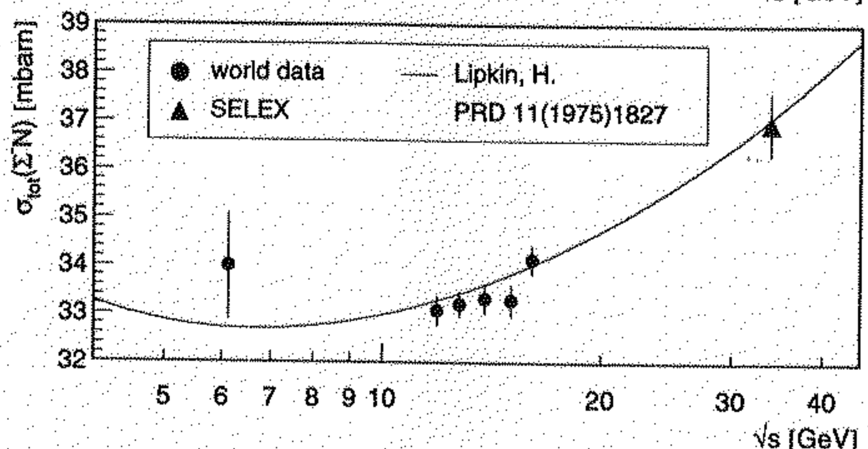
H KRUGER - E781

π^--N and Σ^--N Total Cross Sections

π^-



Σ^-



$p_{lab} = 610$ GeV/c ($\sqrt{s} = 33.9$ GeV/c)

method	$\sigma_{tot}(\Sigma^- N)$ [mb]	$\sigma_{tot}(\pi^- N)$ [mb]
CH2-C difference	33.7 ± 3.1	26.0 ± 2.1
σ_{tot}(Be target)	37.4 ± 1.3	27.1 ± 1.5
σ_{tot}(C taget)	37.0 ± 0.8	26.4 ± 1.3
total result	37.0 ± 0.7	26.6 ± 0.9

Table 1. The status of the Λ and Σ resonances. Only those with an overall status of *** or **** are included in the main Baryon Summary Table.

Particle	$L_{I \cdot 2J}$	Overall status	Status as seen in — $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	P_{01}	****		F		$N\pi$(weakly)
$\Lambda(1405)$	S_{01}	****	****	o	****	
$\Lambda(1520)$	D_{03}	****	****	r	****	$\Lambda\pi\pi, \Lambda\gamma$
$\Lambda(1600)$	P_{01}	***	***	b	**	
$\Lambda(1670)$	S_{01}	****	****	i	****	$\Lambda\eta$
$\Lambda(1690)$	D_{03}	****	****	d	****	$\Lambda\pi\pi, \Sigma\pi\pi$
$\Lambda(1800)$	S_{01}	***	***	d	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(1810)$	P_{01}	***	***	e	**	$N\overline{K}^*$
$\Lambda(1820)$	F_{05}	****	****	n	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	D_{05}	****	***	F	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	P_{03}	****	****	o	**	$N\overline{K}^*, \Sigma(1385)\pi$
$\Lambda(2000)$		*		r	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2020)$	F_{07}	*	*	b	*	
$\Lambda(2100)$	G_{07}	****	****	i	***	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2110)$	F_{05}	***	**	d	*	$\Lambda\omega, N\overline{K}^*$
$\Lambda(2325)$	D_{03}	*	*	d		$\Lambda\omega$
$\Lambda(2350)$		***	***	e	*	
$\Lambda(2585)$		**	**	n		

PDG 1998

T. RUSS

New Decay Channel $\Xi^0(1690) \to \Xi^-\pi^+$

Ξ^* resonances (PDG 1998)

Table 1. The status of the Ξ resonances. Only those with an overall status of *** or **** are included in the Baryon Summary Table.

Particle	$L_{2I \cdot 2J}$	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	P_{11}	****					Decays weakly
$\Xi(1530)$	P_{13}	****	$\boxed{\text{****}}$				
$\Xi(1620)$		*	*				
$\Xi(1690)$		***	$\boxed{\text{new}}$	***	**		
$\Xi(1820)$	D_{13}	***	**	***	**	$\boxed{\text{**}}$	
$\Xi(1950)$		***	**	**		$\boxed{\text{*}}$	
$\Xi(2030)$	1	***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$	1	**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

****	Existence is certain, and properties are at least fairly well explored.
***	Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
**	Evidence of existence is only fair.
*	Evidence of existence is poor.

ΣΛ MIXING

- When isospin is not conserved:
  $\Lambda = \Lambda_8 \cos \varphi + \Sigma_8 \sin \varphi$
  $\Sigma = -\Lambda_8 \sin \varphi + \Sigma_8 \cos \varphi$
- $\sin \varphi = -(\mathrm{sqrt}(3)/4)*(m_d - m_u)/(m_s - m_{av}) = -0.015$
- Ref: Dalitz and von Hippel(1964) MacFarlane and Sudarshan(1964) Isgur(1980), Leutwyler et al(1982)
- review: Donoghue,Ann.Rev.Nucl(1989)

G. KARL

EFFECTS OF MIXING ON SEMILEPTONIC DECAYS

$$R(\phi) = \Gamma(\Sigma(+) \Rightarrow \Lambda \bar{e} \nu)/\Gamma(\Sigma(-) \Rightarrow \Lambda e \bar{\nu})$$

$$= R(0)*(1- 3.95\phi) = R(0)*(1-0.06)$$

$$=0.65$$

a six percent diminution relative to no mixing. Present data is not good enough to check this value.(**Exp:R=.645+/-.18)**

Ref:Karl,Phys.Lett.B328,149(1994)
Henley&Miller,Phys.RevD50,7077(1994)

Static Properties of Hyperons

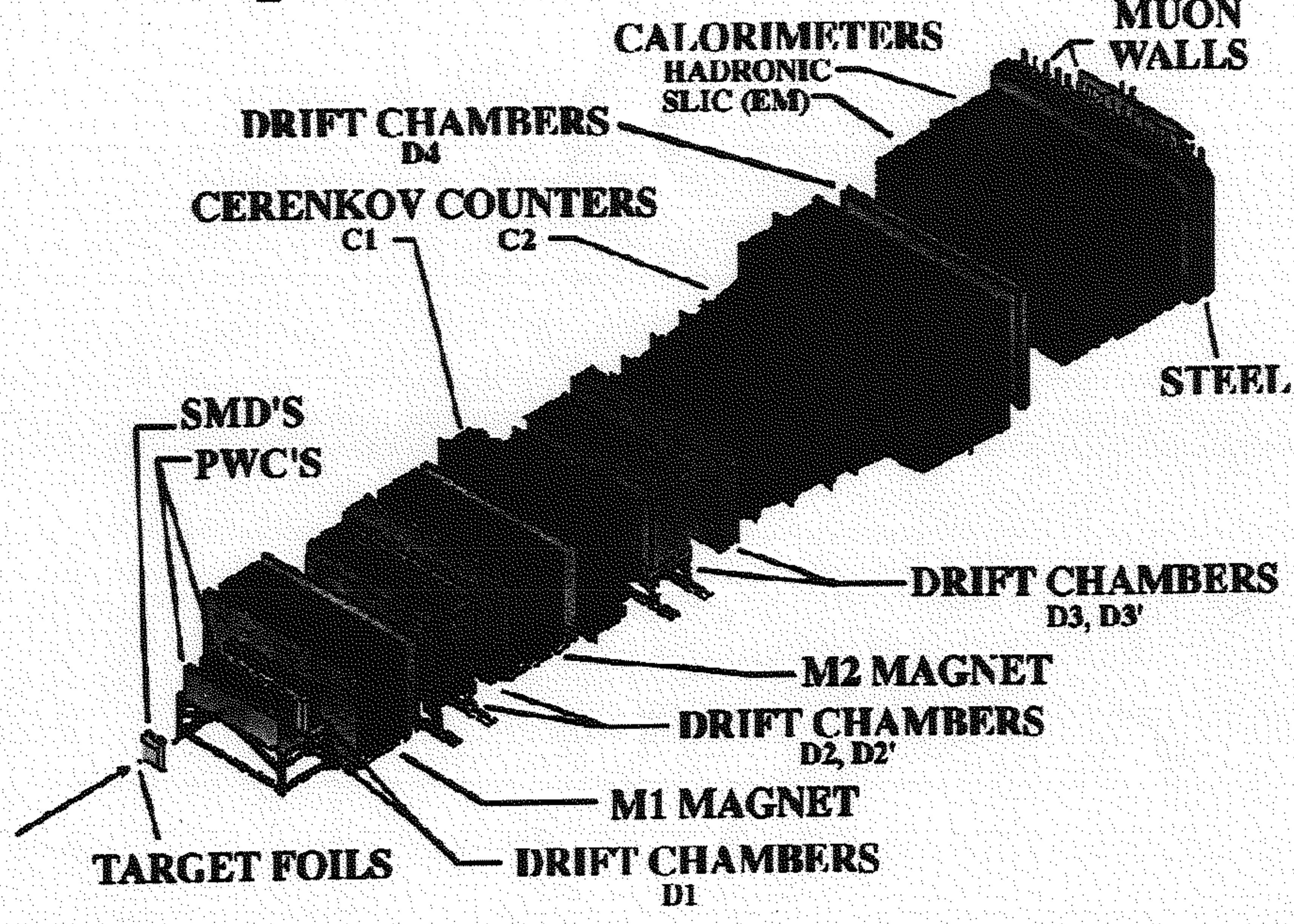
- Lessons we’ve learned:
  - High precision measurements of mass and magnetic moments are essentially complete. Theory cannot match their precision.

- Need to do:
  - Lifetime of Ξ^o
  - Measure Σ/Λ mixing ----> charged hyperon SLD

Hyperon Production

- E791 production spectra
- E791 asymmetries
- Polarization results:
  - E791
  - SELEX
  - KTeV
  - WA89
  - E690
- General remarks

E-791 Spectrometer

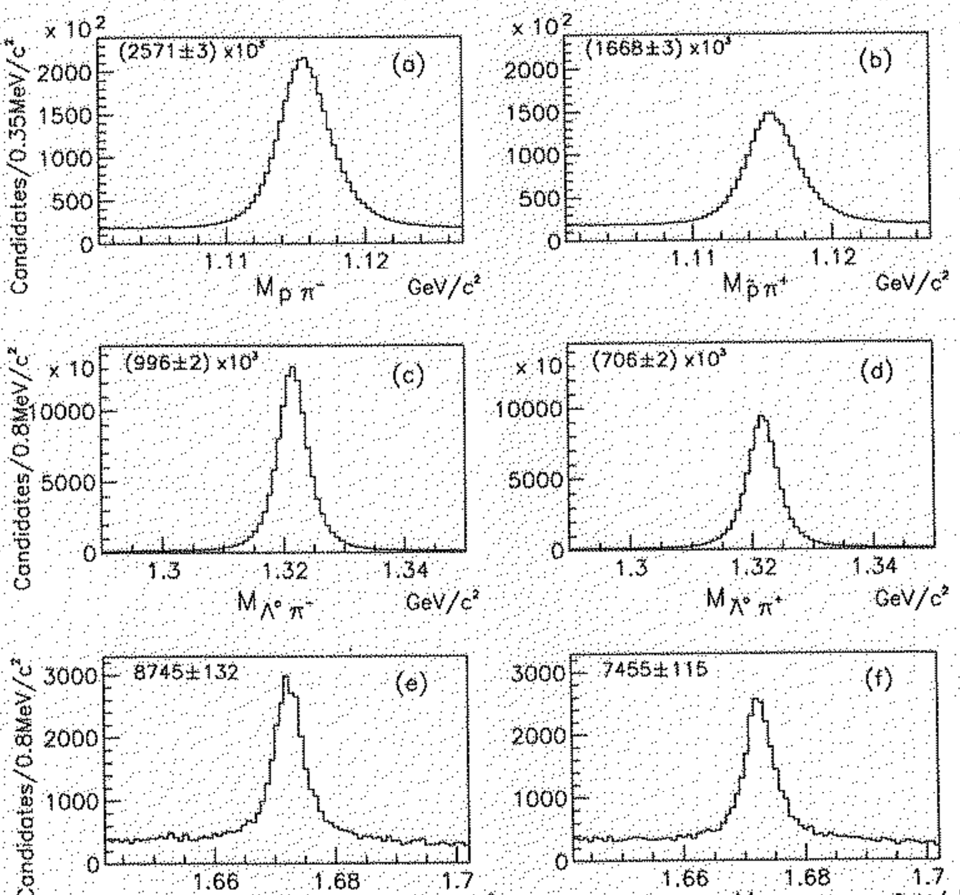


J. ANJOS - E791

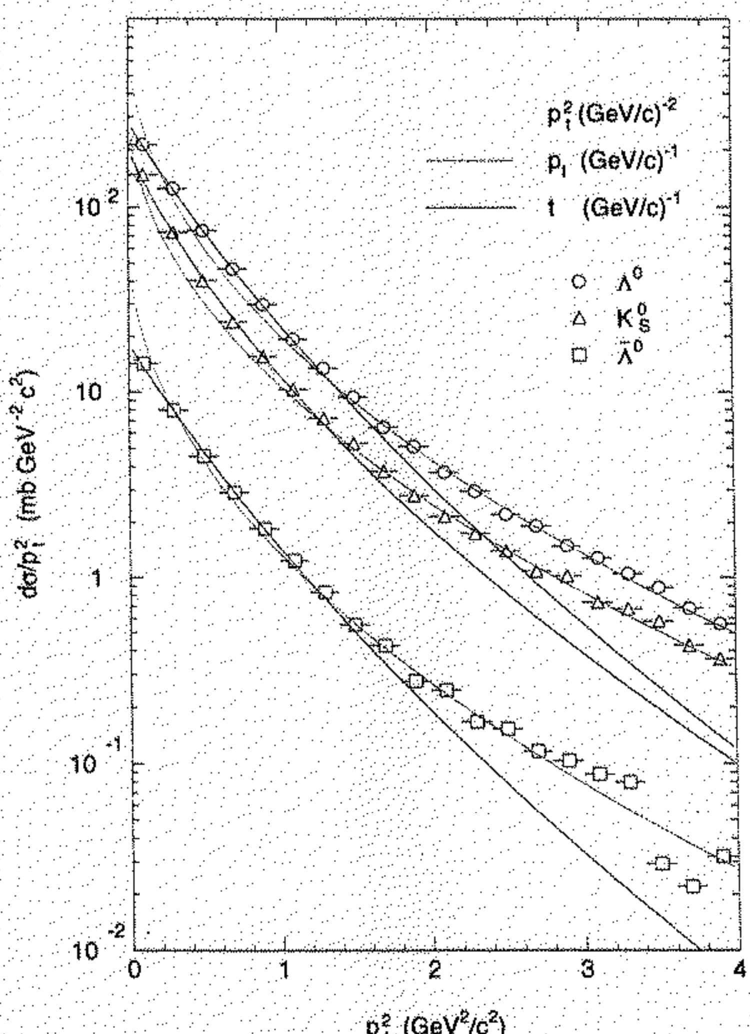
Final Data Sample

Signal Measurement

- Fit with Gaussian signal and linear background function for each interval of x_F and p_T^2.
- $2\,571\,700 \pm 3\,100$ Λ°'s and $1\,669\,000 \pm 2\,600$ $\bar{\Lambda}^\circ$'s,after background subtraction, taken from approximately 6.5% of the total E791 data sample
- $996\,200 \pm 1\,900$ Ξ^-, $706\,600 \pm 1\,700$ $\bar{\Xi}^+$, $8\,750 \pm 130$ Ω^-, and $7\,460 \pm 120$ $\bar{\Omega}^+$, with the 100% of E791 data

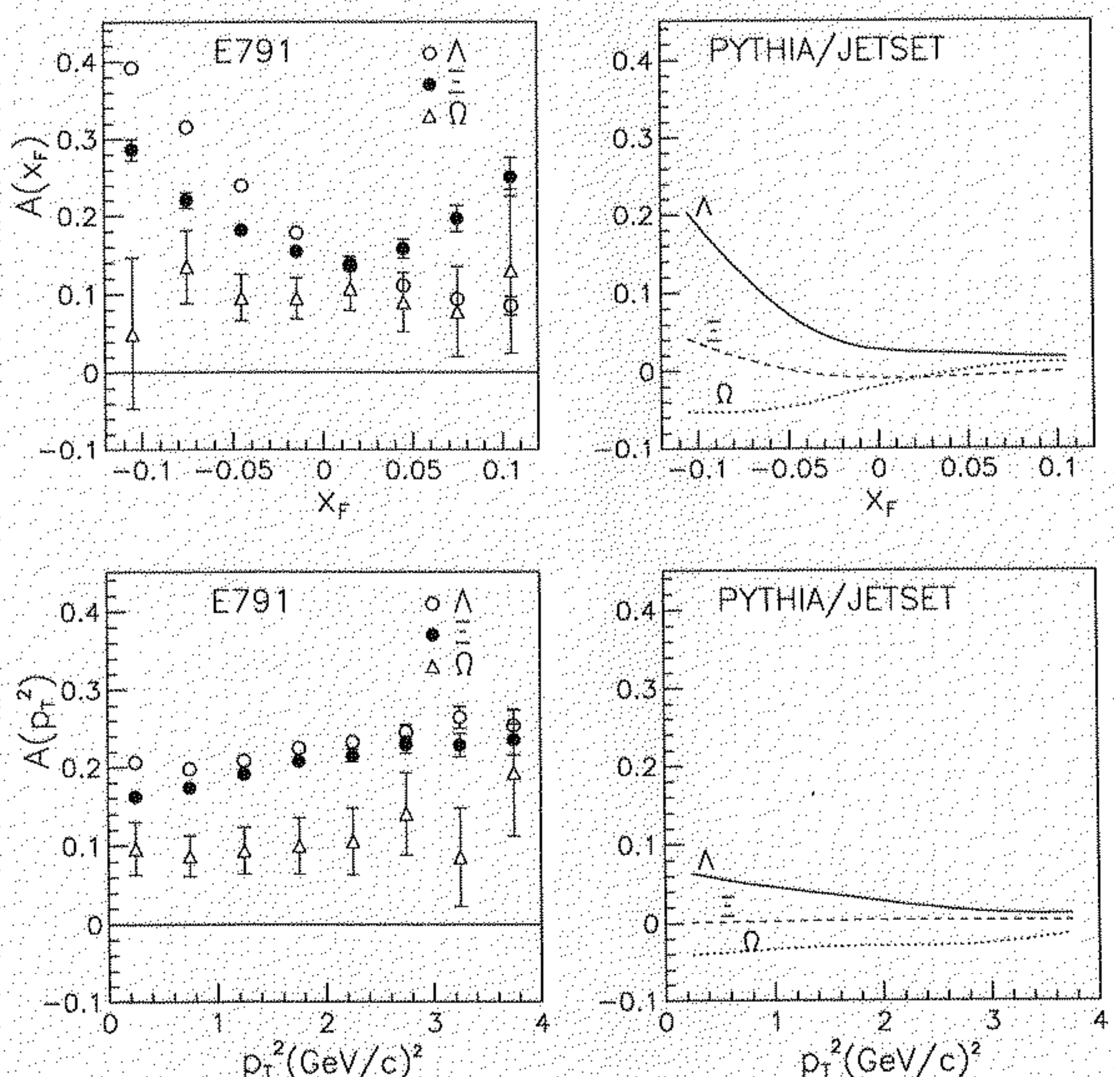


p_T^2 distributions for V^0 particles produced by Σ^-



The fitted curves indicate a strong (non-gaussian, non-thermal) enhancement at large transverse momenta.

Final Results – Λ, Ξ and Ω



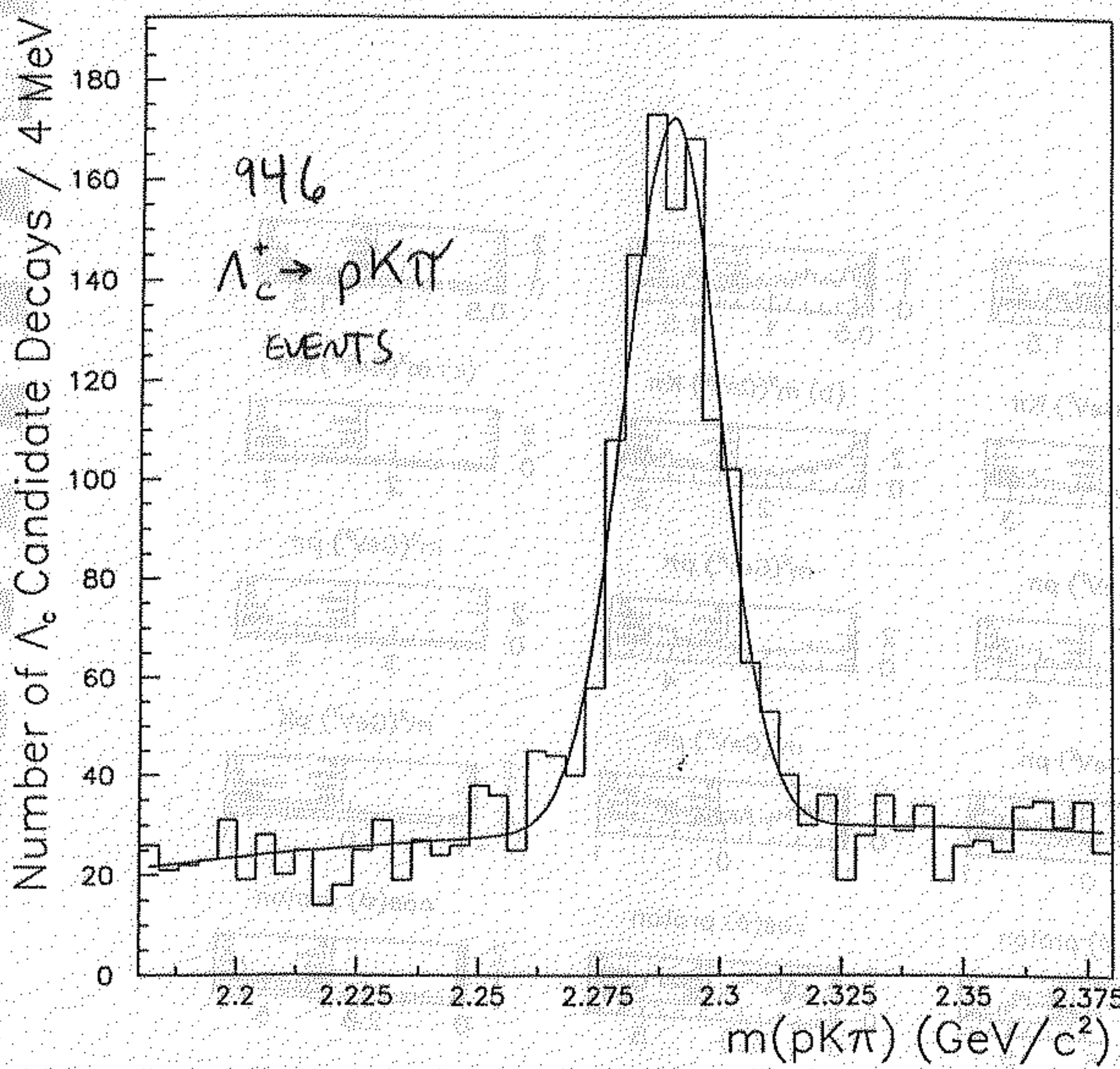
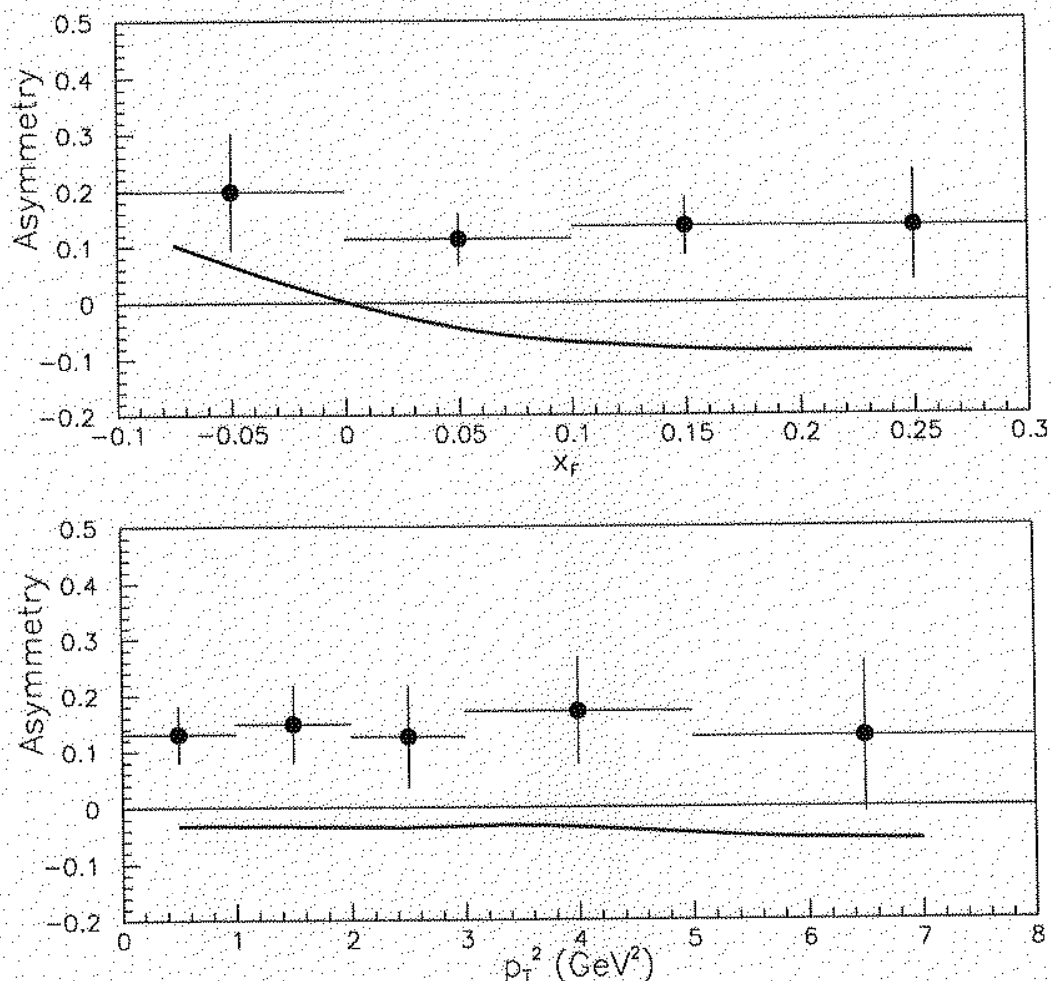


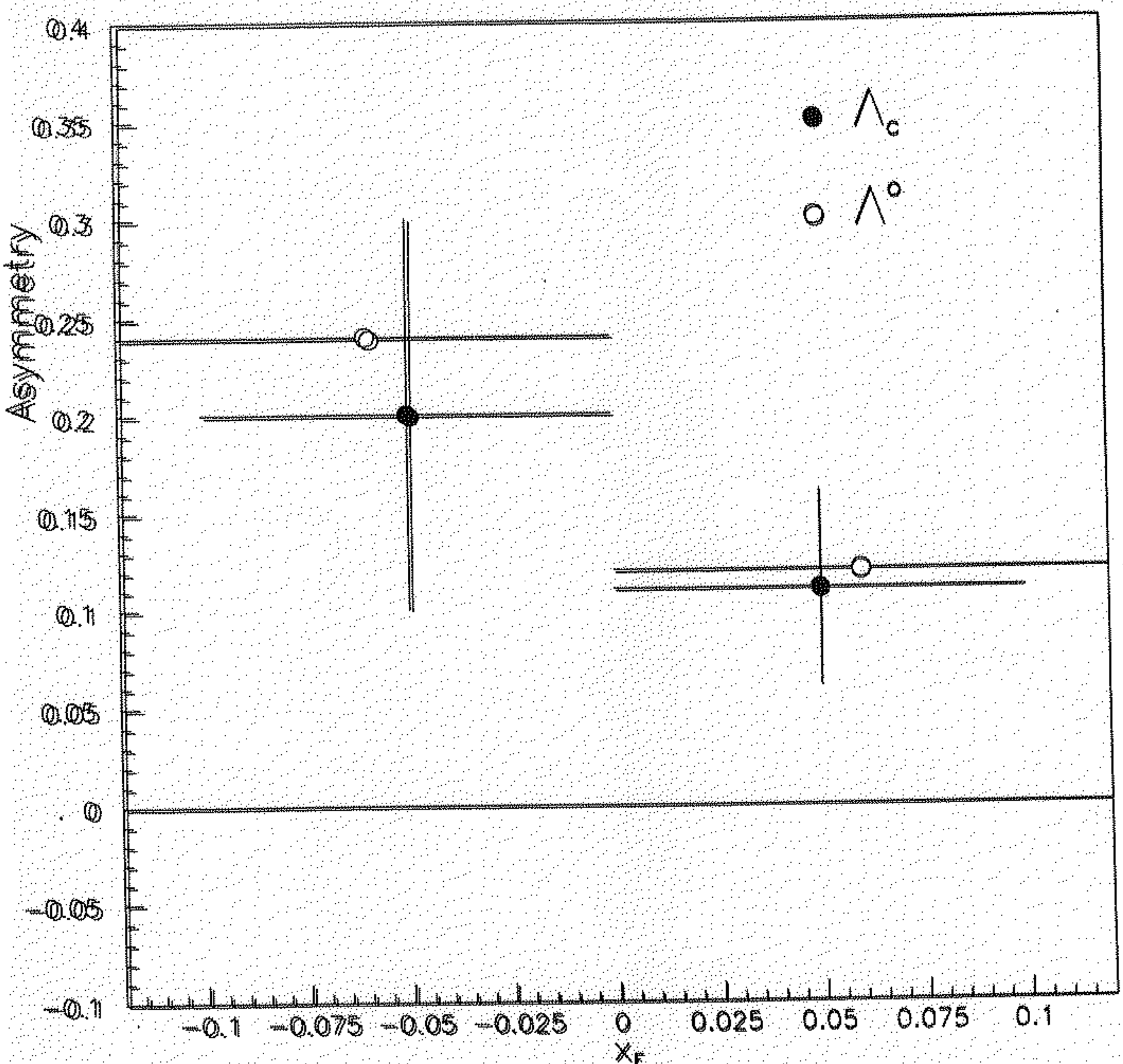
Figure 9.7: Mass(pKπ) of the real data set after Neural Net cuts and the MINUIT Fit 3. There are 946±38 signal events and 1324±43 background events assuming that the peak is Gaussian, the background is quadratic and the number of signal and background events are variables.

Λ_c's: Asymmetries as a function of x_F and p_T^2.



Full line: Pythia/Jetset predictions.

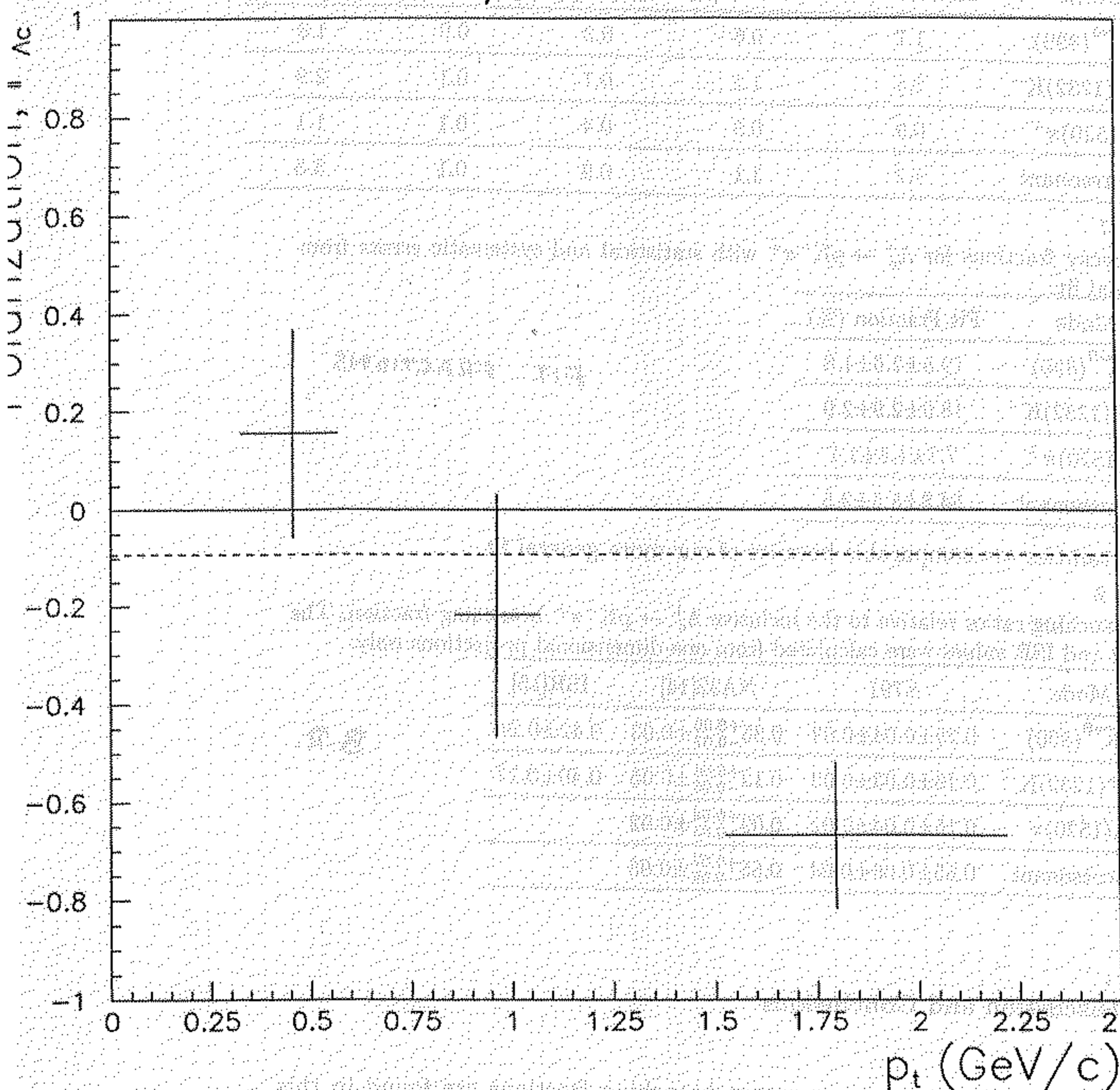
COMPAIRISON OF Λ_c AND Λ°
ASYMMETRIES



E791 VERY PRELIMINARY

$\Lambda_c^+ \to p K^- \pi^+$

POLARIZATION



$\langle P_{\Lambda_c} \rangle = -0.09 \pm 0.14$

$0 < p_T < 0.71$ GeV/c

$0.71 < p_T < 1.24$ GeV/c

$1.24 < p_T < 5.20$ GeV/c

E. McCLIMENT - E781

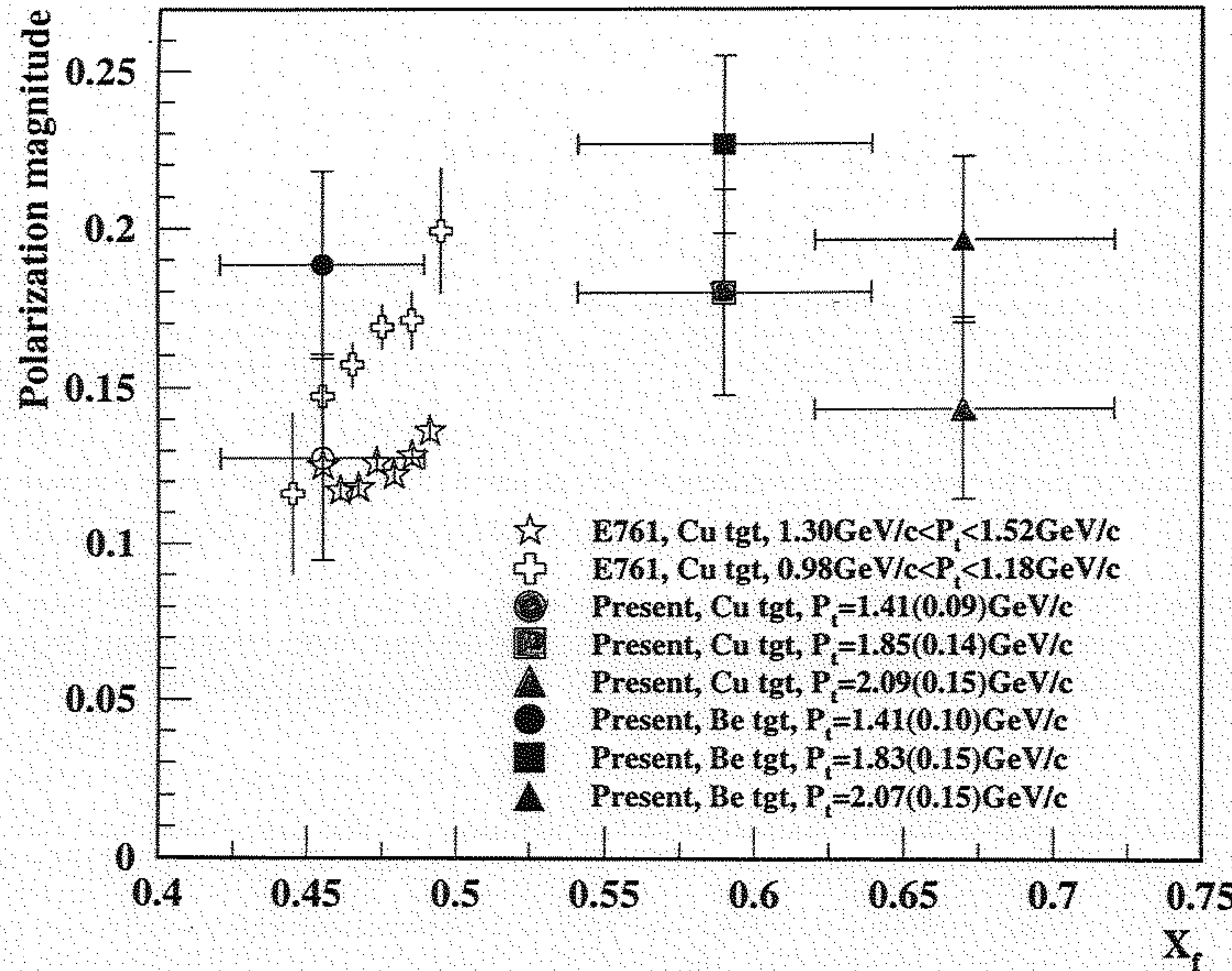


Figure 46: X_f dependence of the Σ^+ polarization (only statistical errors are shown). Open symbols correspond to the Cu production target, filled symbols – to the Be target. Open crosses and stars represent the E761 data [2] at $P_t \approx 1$ GeV/c and $P_t \approx 1.5$ GeV/c, respectively. Circles correspond to the present measurement at $P_t \approx$ 1.41 GeV/c. Boxes correspond to the present measurement at $P_t \approx 1.84$ GeV/c. And, finally, triangles correspond to the present measurement at $P_t \approx 2.08$ GeV/c. Horizontal error bars represent the widths (σ of the gaussian fit) of the corresponding

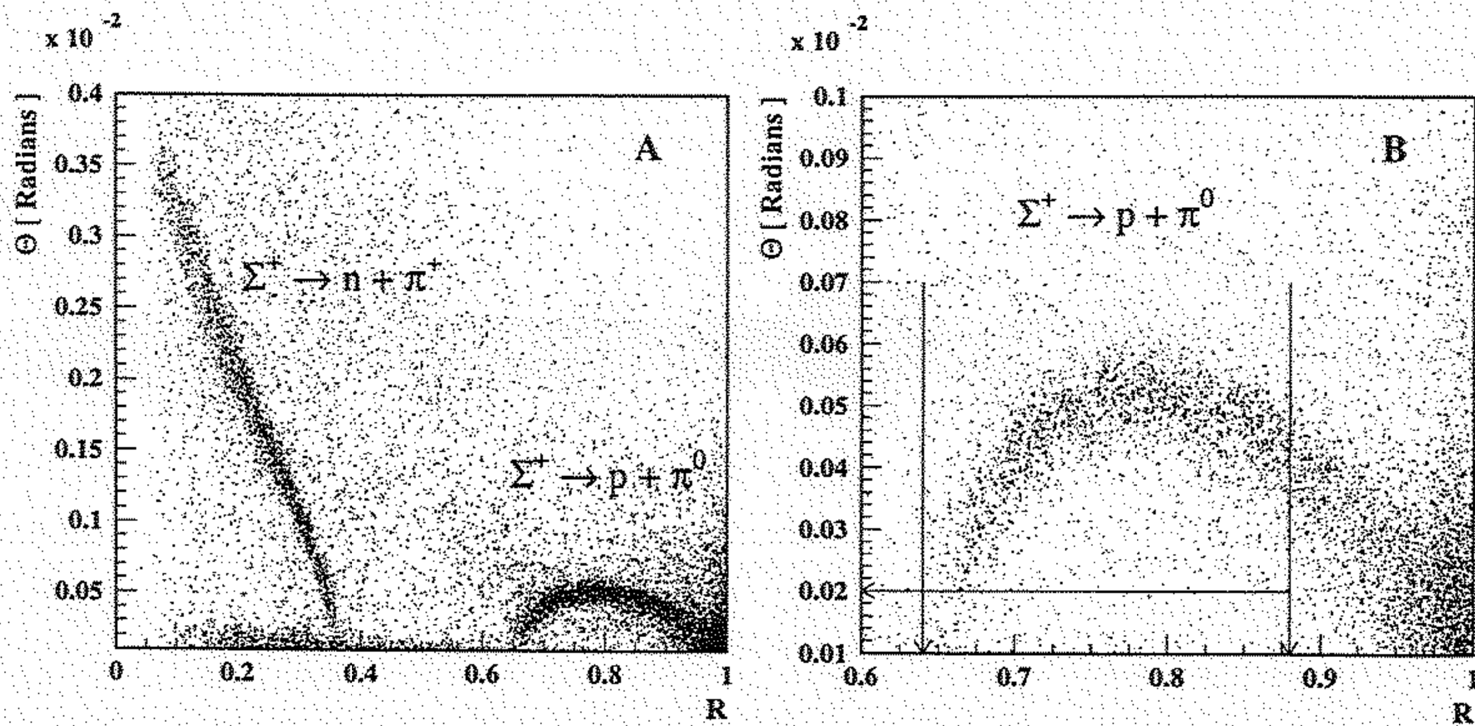
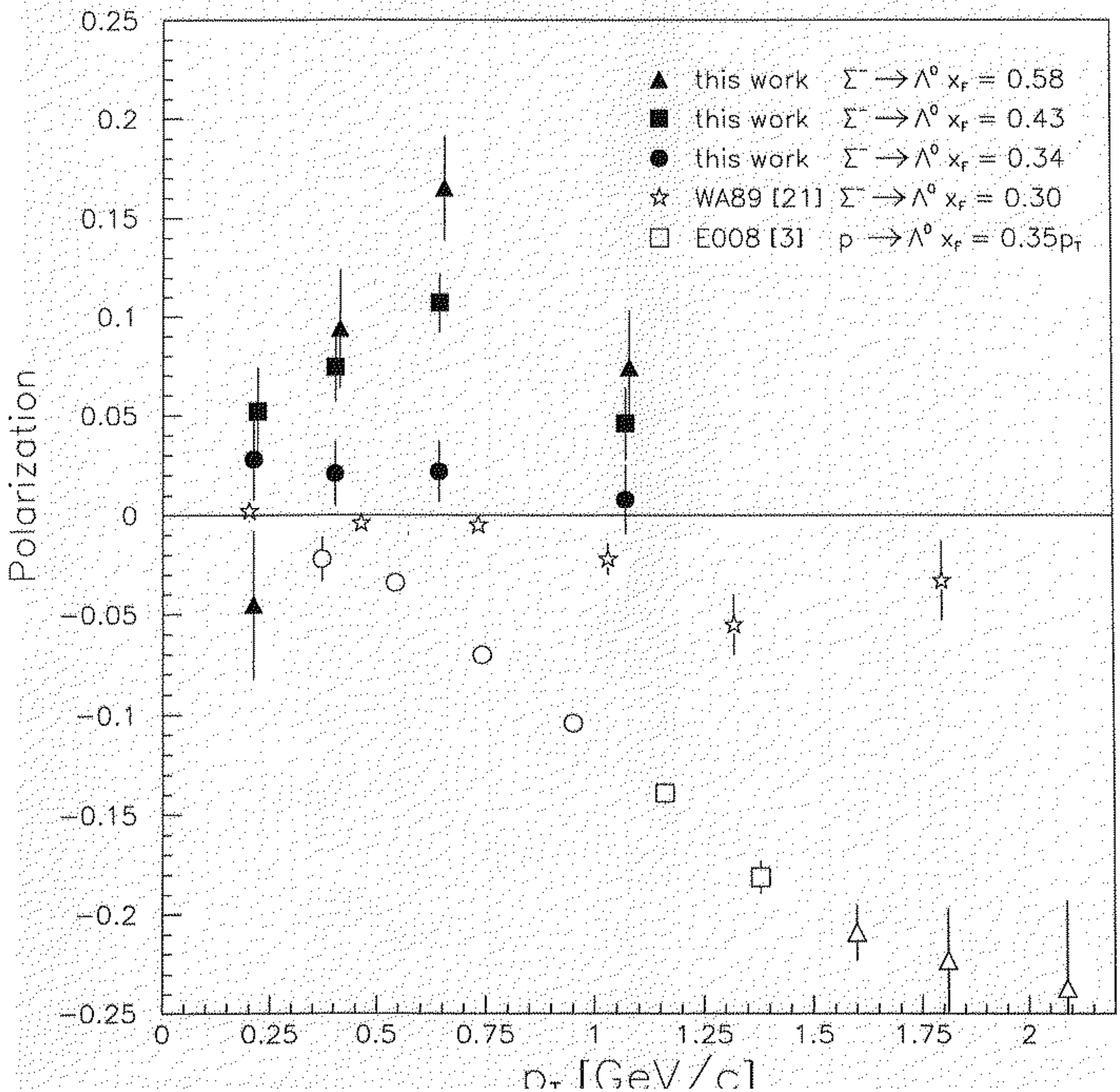


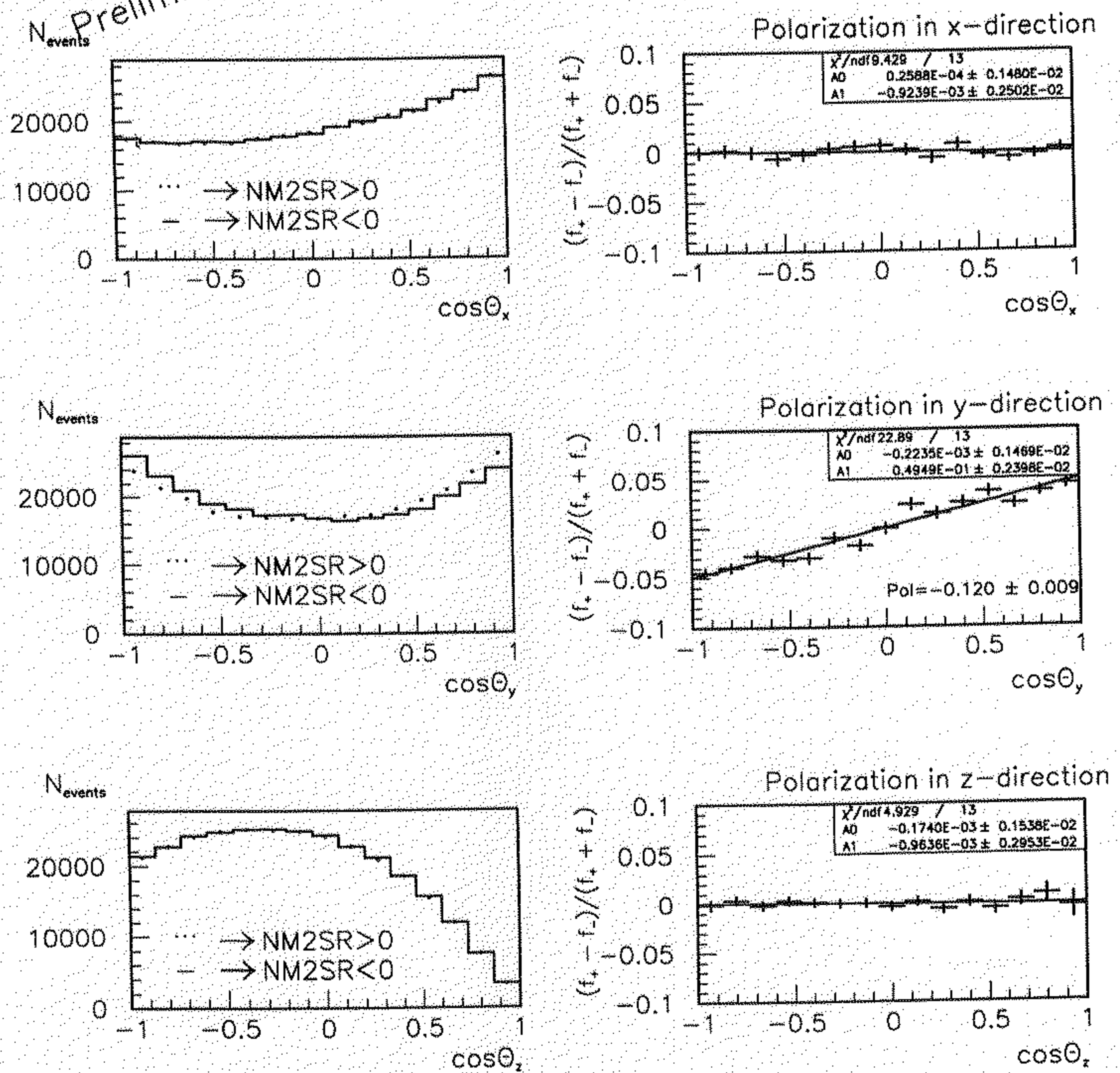
Figure 24: R vs. θ kinematic plot of the Σ^+ decay modes. Plot (A) shows both $\Sigma^+ \rightarrow p\pi^0$ and $\Sigma^+ \rightarrow n\pi^+$ decays modes. Plot (B) provides a closer view of the $\Sigma^+ \rightarrow p\pi^0$ region. $R = p_B / p_{\Sigma^+}$. θ is the decay angle.

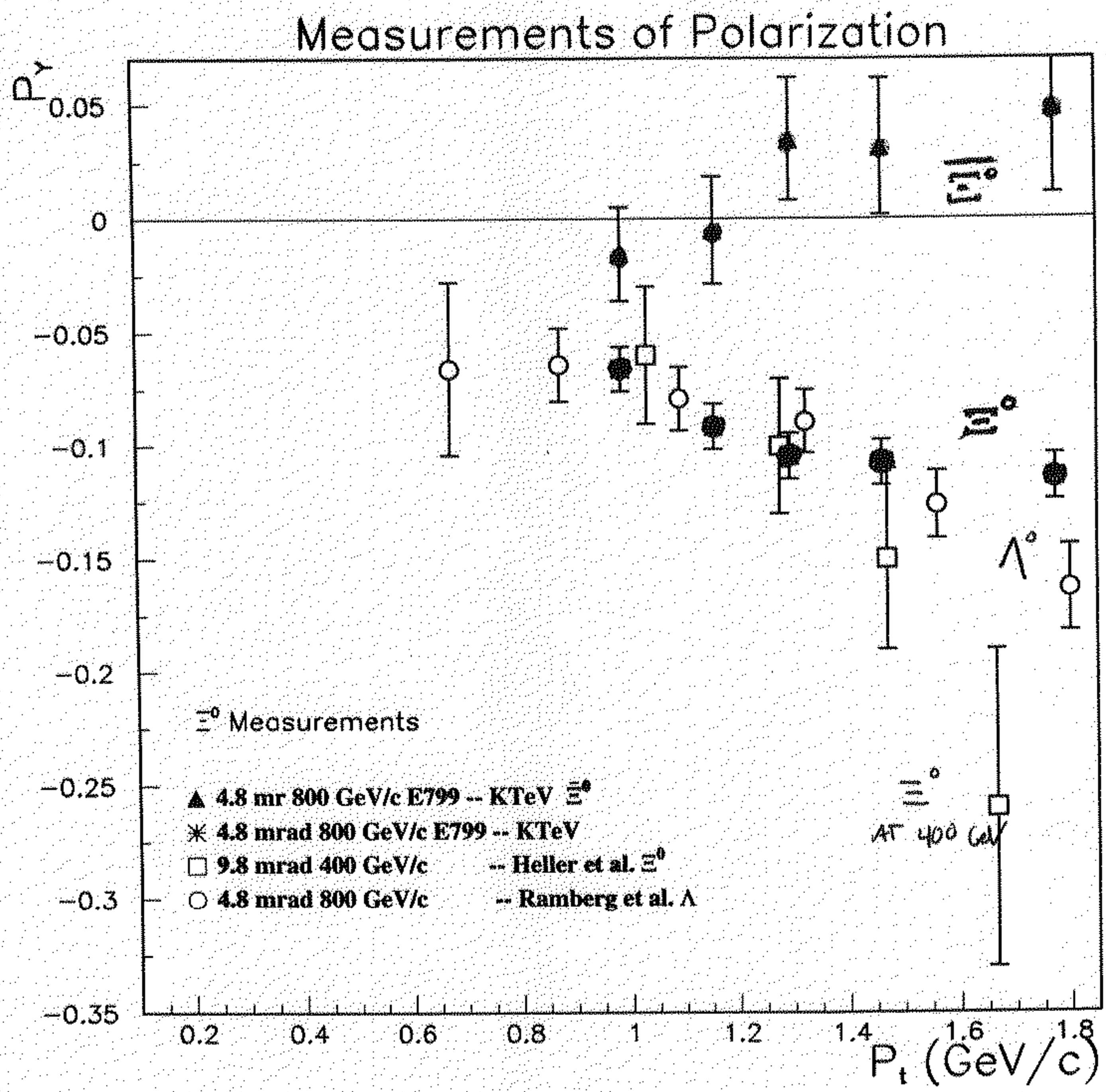
E. McCLIMENT - E781

E. McCLIMENT - E781

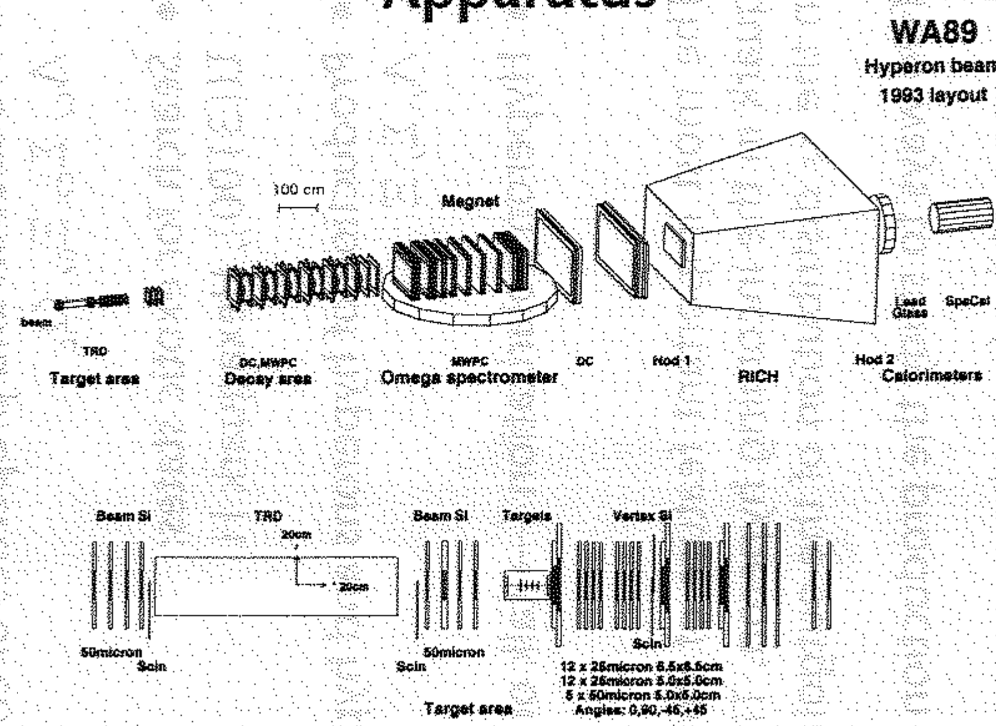


Preliminary Analysis Magnet NM4AN>0




Measurements of Polarization
P_Y
0.05
0
−0.05
−0.1
−0.15
−0.2
−0.25
−0.3
−0.35
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
P_t (GeV/c)
Ξ^0 Measurements
▲ 4.8 mr 800 GeV/c E799 -- KTeV Ξ^0
✳ 4.8 mrad 800 GeV/c E799 -- KTeV
□ 9.8 mrad 400 GeV/c -- Heller et al. Ξ^0
○ 4.8 mrad 800 GeV/c -- Ramberg et al. Λ
Ξ^0
Ξ^0
Λ^0
Ξ^0
AT 400 GeV

Apparatus



Setup of the WA89 experiment in the 1993 beam time.
The lower part shows an expanded view of the target area.

WA89 (1994) Preliminary

$\Sigma^- \to \Lambda$

$\pi^- \to \Lambda$

$n \to \Lambda$

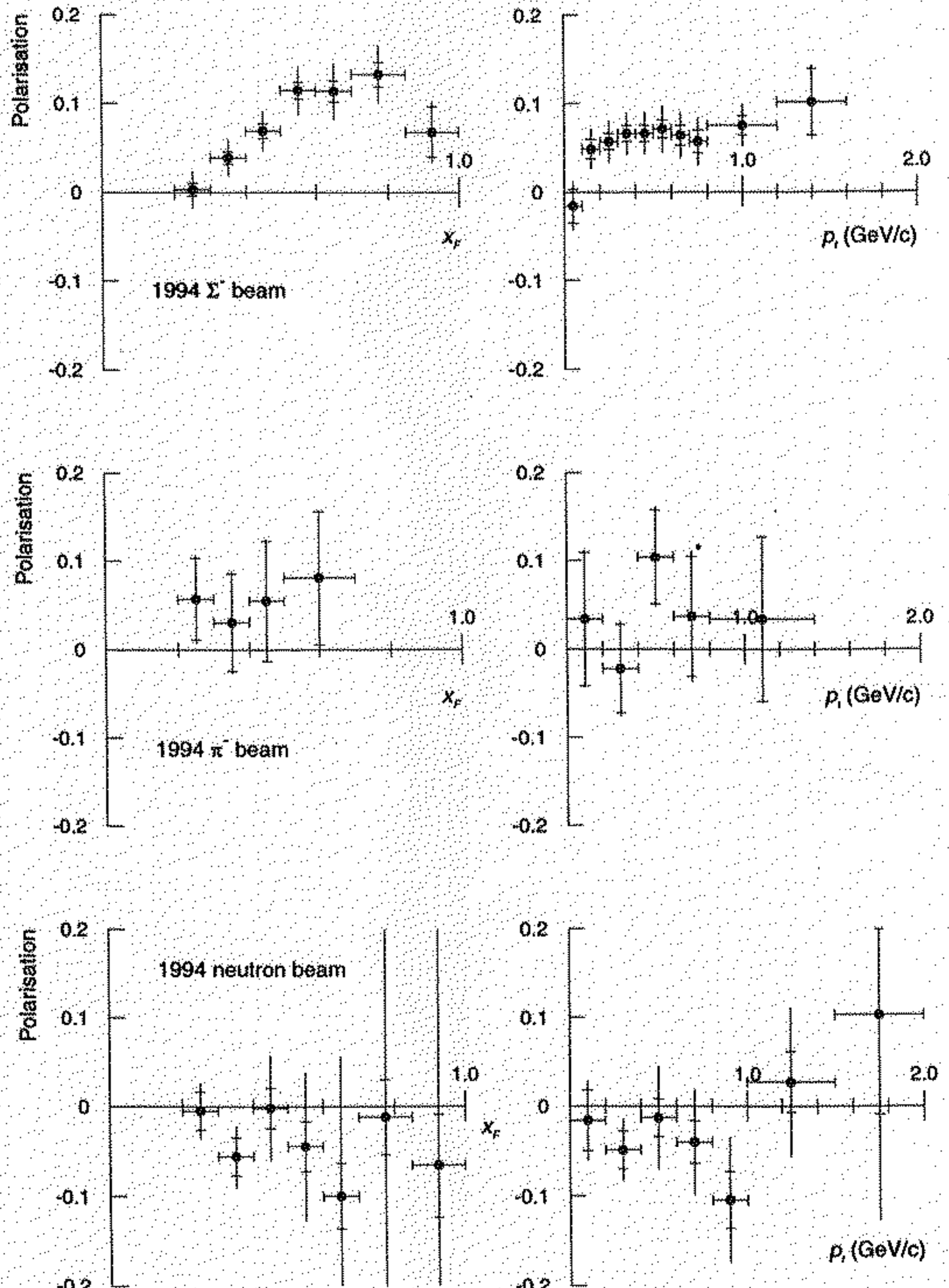


Figure 7.6: Polarisation measurements for Λ^0 produced from the 1994 Σ^-, π^- and neutron beams. The error bars within the cross-strokes indicate the statistical uncertainty, the whole length of the bars the combined statistical and systematic uncertainties. The Σ^- beam results are corrected for Σ^0 background.

WA89 Preliminary

$\Sigma^- \to \Sigma^0$

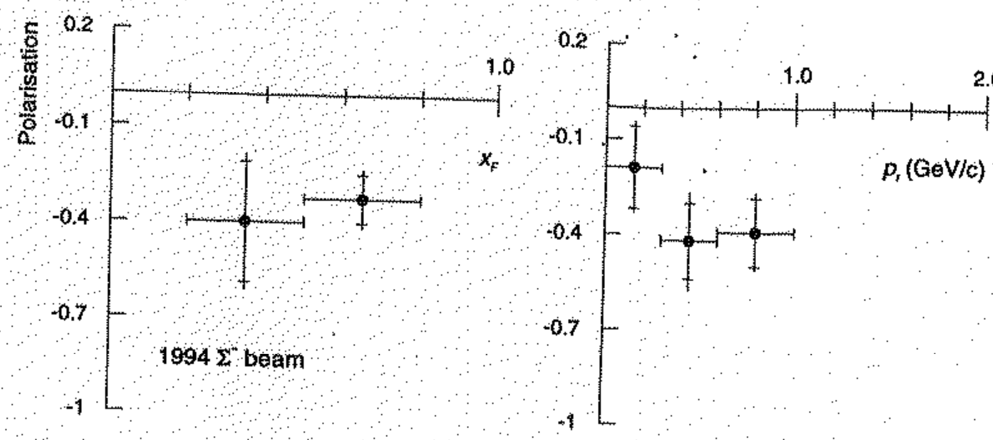


Figure 7.12: Polarisation measurements for Σ^0 produced from the 1994 Σ^- beam.

$\Sigma^- \to \Sigma^0$

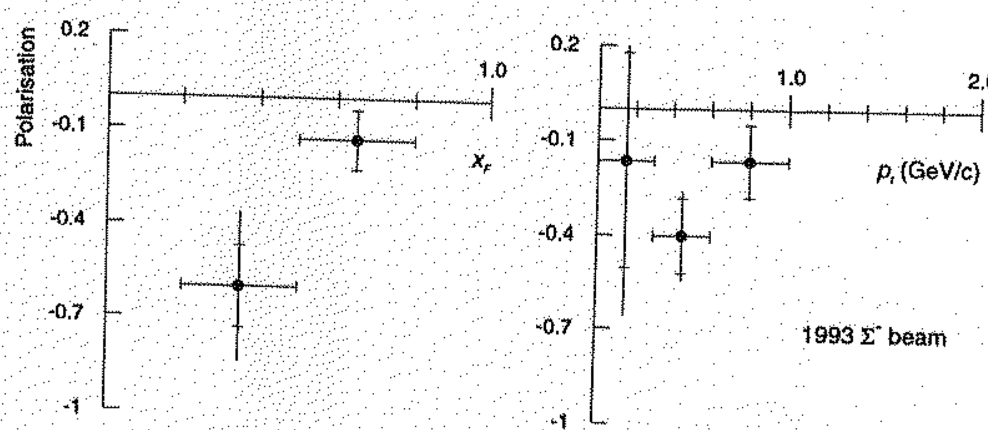


Figure 7.13: Polarisation measurements for Σ^0 produced from the 1993 Σ^- beam.

during the reconstruction was thus estimated to be $0.13 \pm 0.01\,(\text{stat.}) \pm 0.03\,(\text{syst.})$, avera over the whole kinematic range. Note that this number does not directly correspond to ratio of production cross-sections for the two hyperons, as it takes into account only the c tamination of Λ^0 passing the selection cuts; since the x_F spectrum of decay product Λ somewhat softer than that of the mother Σ^0, a large part of the daughter population was jected by the momentum cuts, and the ratio of cross-sections is expected to be somew higher than the above figure. For the purposes of background subtraction, the average construction efficiencies and Σ^0 polarisation were calculated for each kinematic bin in Λ^0 polarisation plots shown in Figures 7.6 and 7.7; since the number of data points for Σ^0 polarisation were small, the measurements were interpolated by fitting a second- or thi order polynomial function to the plots in Figures 7.12 and 7.13, constrained to pass throu

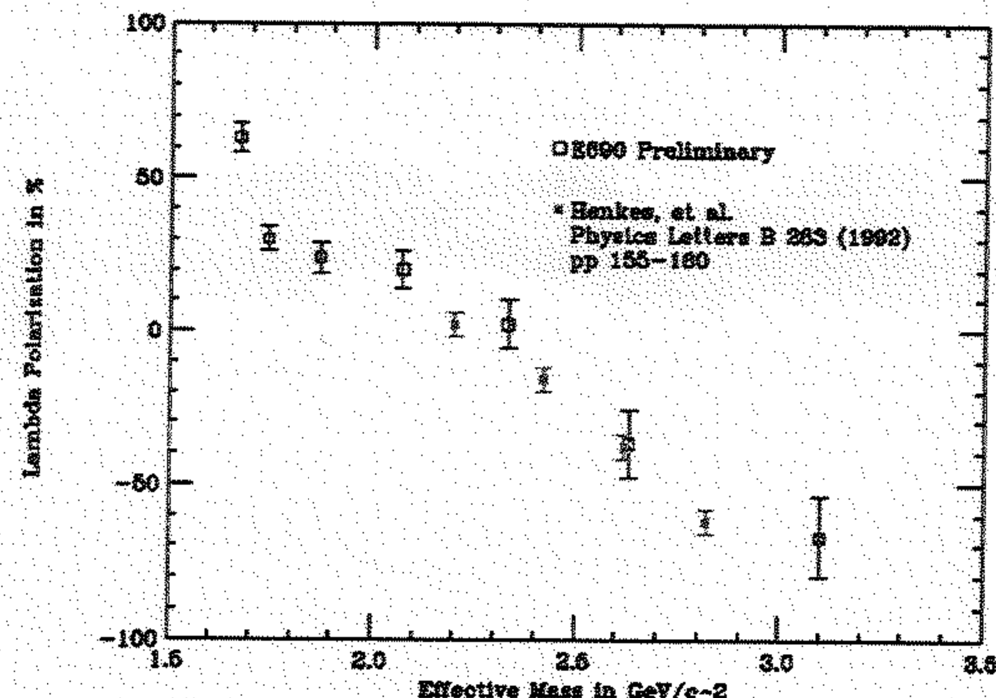
Λ polarization in bins of Λ x_F and p_T

	x_F (-.95,-.85]	x_F (-.85,-.75]	x_F (-.75,-.65]	x_F (-.65,-.55]
P_T (0.,0.1]		24% ± 13%	-17% ± 18%	
P_T (0.1,0.3]	7% ± 13%	35% ± 4%	38% ± 5%	23% ± 14%
P_T (0.3,0.5]	18% ± 37%	58% ± 6%	27% ± 5%	2% ± 12%
P_T (0.5,0.8]		67% ± 14%	21% ± 9%	-8% ± 15%
P_T > 0.8		-35% ± 25%	-49% ± 13%	-53% ± 17%

D. CHRISTIAN

Λ polarization in bins of ΛK^+ effective mass

ΛK^+ Effective Mass Range	(1.5,1.7] GeV/c^2	(1.7,1.8] GeV/c^2	(1.8,1.95] GeV/c^2	(1.95,2.2] GeV/c^2	(2.2,2.5] GeV/c^2	(2.5,2.8] GeV/c^2	(2.8,5.0] GeV/c^2
Λ Polarization	63%±5%	30%±4%	24%±5%	20%±6%	2%±7%	-37%±11%	-67%±13%



D. CHRISTIAN

Study of Λ^0 Polarization in Four Different Exclusive pp Reactions at 27.5 GeV/c

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We have measured the x_F and P_T dependence of the polarization of Λ^0 hyperons produced in exclusive final states $pp \to p\Lambda^0K^+\pi^+\pi^-$, $pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-$, $pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$, and $pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$ at 27.5 GeV/c. We present an empirical parametrization for Λ^0 polarization as a function of x_F and P_T: $\mathcal{P} = (-0.443 \pm 0.037)x_F P_T$ for $-1 \le x_F \le 1$ and $0 \le P_T \le 1.8$ GeV/c. This parametrization is independent of the final state and provides a good description of the data. We note that the mechanism responsible for Λ^0 polarization appears to be independent of the production mechanism. [S0031-9007(99)09536-8]

PACS numbers: 13.88.+e, 13.85.Hd, 14.20.Jn

The discovery that Λ^0 hyperons are produced polarized in high energy pp collisions [1] has posed an interesting puzzle for theories of particle production. This discovery, and subsequent observations that other hyperons are produced polarized as well [2], challenges the assumption that spin plays no role in high energy multiparticle production. Since multiparticle processes involve many final state particles and a correspondingly large number of amplitudes, it had been thought that coherent interference of spin-dependent amplitudes was precluded in these processes. However, the existence of polarization, which implies coherent interference of at least two spin-dependent amplitudes, may suggest that only a few spin-dependent amplitudes are involved in producing hyperons.

Although extensive experimental [3] and theoretical [4] efforts have addressed the polarization phenomenon during the past 20 years, an understanding of the mechanism responsible for polarization remains elusive. Various models that have been proposed do not fit the data well and tend not to have predictive power [4]. One of the impediments to understanding this fundamental process may be that most polarization measurements of hyperons in high energy collisions are based on inclusive measurements, in which a hyperon is included in a sample regardless of other particles produced in the collision. Exclusive measurements of specific final states, on the other hand, involve fewer amplitudes and provide a means to gain insight into the polarization phenomenon that is inaccessible to inclusive measurements. For example, the largest measured value for Λ^0 polarization comes from an analysis of $pp \to p\Lambda^0K^+$ events [5], in which the polarization is observed to increase to a value of -0.62 ± 0.04 as a function of the invariant mass of the diffractive Λ^0K^+ system.

In this paper, we present exclusive measurements from a study of Λ^0 polarization in a high statistics sample of the reactions

$$pp \to p\Lambda^0K^+\pi^+\pi^-, \tag{1}$$

$$pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-, \tag{2}$$

$$pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-, \tag{3}$$

$$pp \to p\Lambda^0K^+\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-. \tag{4}$$

This sample consists of fully reconstructed events in which all final state particles are measured and identified. A previous measurement has been published [6] for events belonging to reaction (2). We have reanalyzed these events for this paper to include them in our study of four specific final states.

The data for this study were recorded at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory in experiment E766, described in detail elsewhere [7–9]. A beam of 27.5 GeV/c protons interacted in a 30.5 cm long (5% interaction length) liquid-hydrogen target. The charged particles that were produced by pp interactions and those that resulted from the decays of short-lived particles were detected and measured in a six-station drift-chamber magnetic spectrometer. The momentum of the beam particle was measured in a separate spectrometer [10]. The data were reconstructed using a special computational system [11].

A detailed description of the event selection can be found elsewhere [7]. Here we mention details relevant only to the present analysis. Our data sample yielded $\sim 3 \times 10^6$ exclusive events. All of the events in this sample satisfied a kinematic constraint requiring that the

... was performed by measuring the polarization of K_S^0's produced in the reactions

$$pp \to ppK_S^0K^+\pi^-, \qquad (5)$$

$$pp \to ppK_S^0K^+\pi^-\pi^+\pi^-, \qquad (6)$$

$$pp \to ppK_S^0K^+\pi^-\pi^+\pi^-\pi^+\pi^-, \qquad (7)$$

$$pp \to ppK_S^0K^+\pi^-\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-. \qquad (8)$$

Events belonging to reactions (5), (6), (7), and (8) were required to satisfy the same selection criteria as events belonging to reactions (1), (2), (3), and (4), respectively, except that the invariant mass of the separated vertex (with two pions as the daughter particles) had to be consistent with the mass of the K_S^0.

The numbers of exclusive events satisfying our selection criteria are 5421, 51 195, 48 195, and 14 582 for reactions (1), (2), (3), and (4), and 4623, 47 352, 46 057, and 13 037 for reactions (5), (6), (7), and (8), respectively. Backgrounds for reactions (1)–(4) due to the kinematic ambiguity between Λ^0's and K_S^0's are small because (i) the mass resolution is excellent (the standard deviation of the Λ^0 mass distribution is 0.5 MeV$/c^2$ [8]) and (ii) an exclusive event must satisfy the additive conservation laws for charge, strangeness, and baryon number. Backgrounds from mismeasured, nonexclusive events are $\leq 5\%$ [9], and the requirement of 4-momentum balance reduces the background from events with $\Sigma^0 \to \Lambda^0 + \gamma$ decays to less than 2% (as determined by a Monte Carlo study).

In our study of Λ^0 polarization we explore the dependence of the polarization on the kinematic variables P_T and x_F [12] in each of the four final states (1), (2), (3), and (4). The variables are defined as follows: P_T is the Λ^0's transverse momentum with respect to the incident beam proton; and x_F is defined by $x_F = \frac{P_Z}{P_{Z\max}}$, where P_Z is the longitudinal momentum of the Λ^0 in the pp center of mass frame with the Z axis parallel to the direction of the beam proton, and $P_{Z\max}$ is the maximum value P_Z could have in this reference frame.

The angular distribution of the proton from the $\Lambda^0 \to p\pi^-$ decay in the Λ^0 rest frame is

$$dN/d\Omega = N_0(1 + \alpha\mathcal{P}\cos\theta), \qquad (9)$$

of x_F and P_T: $\mathcal{P} = \mathcal{P}(x_F, P_T)$. The parameters of this function are determined using the maximum likelihood method [13], with Eq. (9) as the probability distribution for having dN protons in a solid angle of $d\Omega$.

Without a theory for Λ^0 polarization the function $\mathcal{P}(x_F, P_T)$ must be determined empirically. For the maximum likelihood analysis we have chosen a function that represents the simplest bilinear combination of x_F and P_T:

$$\mathcal{P}_1(x_F, P_T) = -a x_F P_T. \qquad (10)$$

We have also investigated other functions with different P_T dependences by expressing $\mathcal{P}(x_F, P_T)$ as a power series expansion in P_T, but we do not find any other function with a solution that is significantly better than the solution we find for Eq. (10). Using Eq. (9), we define the probability for the extended likelihood as a function of $\cos\theta$ as

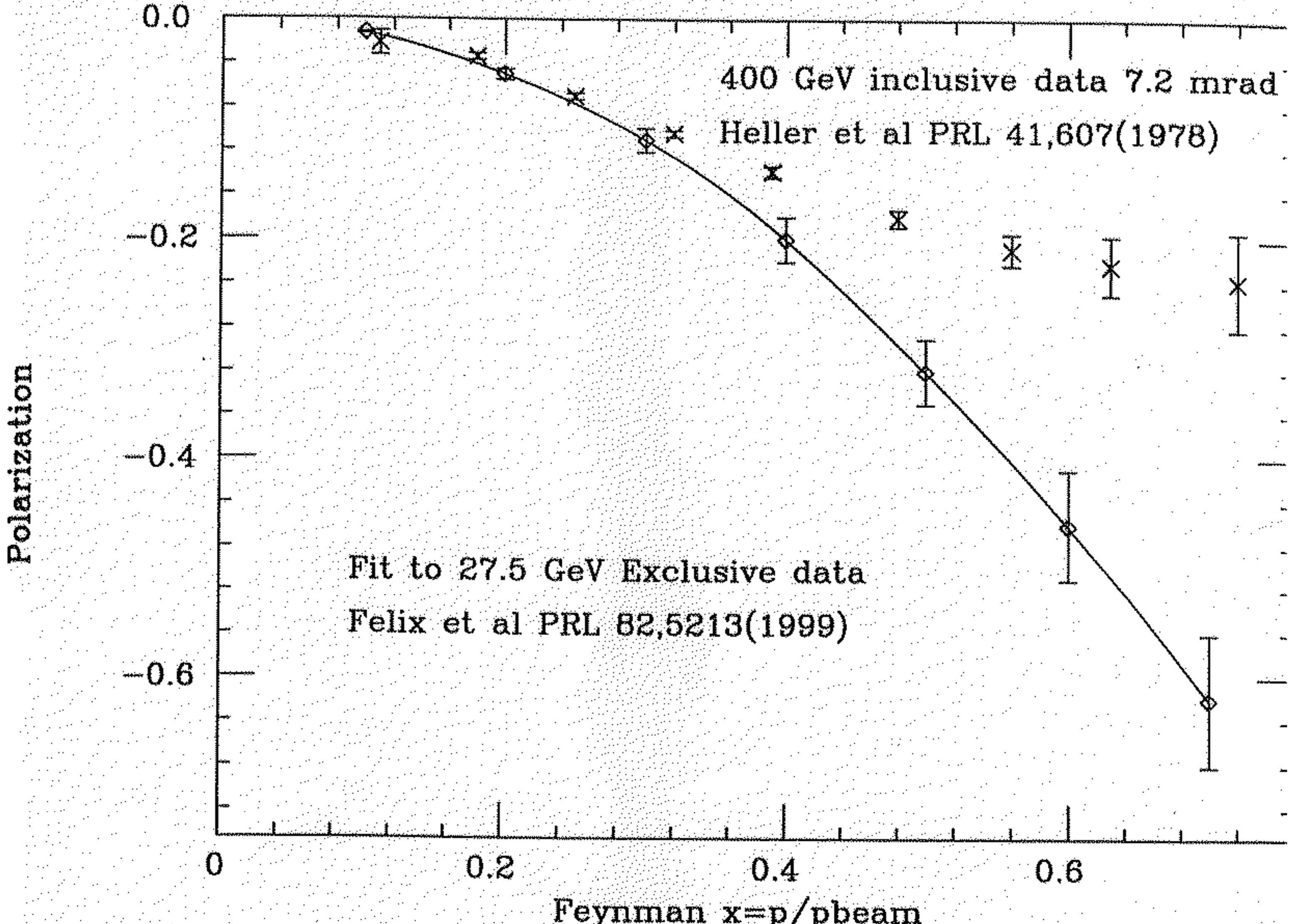
$$P_{ex}(\cos\theta) = C_0 A(1 + \alpha\mathcal{P}\cos\theta), \qquad (11)$$

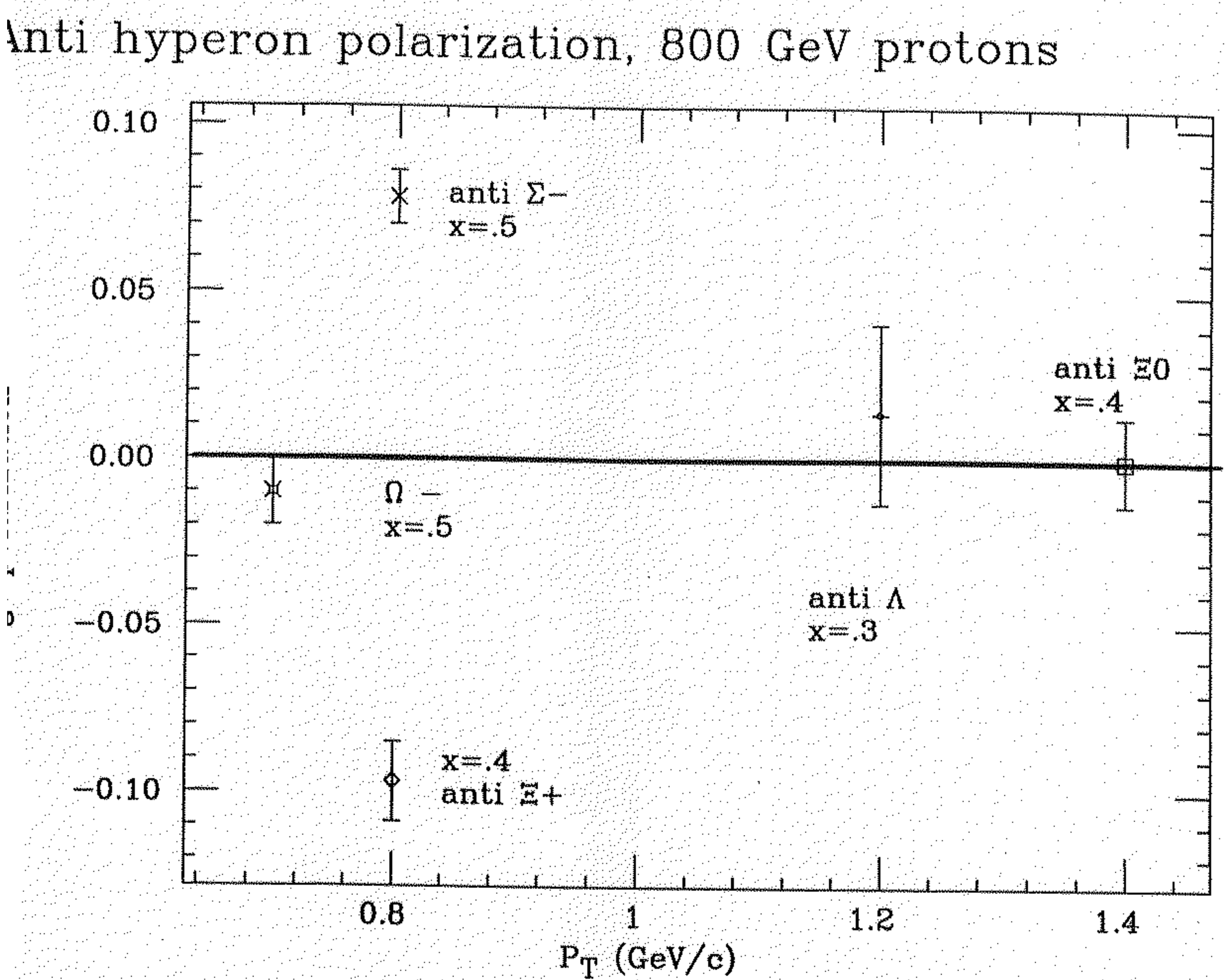
where C_0 is a normalization constant and A is the acceptance determined by a Monte Carlo analysis. The acceptance correction is symmetric in $\cos\theta$; therefore, our final results are presented without an acceptance correction. We determine the parameter a in Eq. (10) for each of the reactions numbered (1)–(4), and for the combined sample by minimizing the negative log of the extended likelihood. The results from this analysis are presented in Table I, which shows that, within errors, the dependence of Λ^0 polarization on x_F and P_T is independent of the reaction. Furthermore, the polarization for the combined sample is consistent with the results for the individual reactions. Using the value for the combined sample from

TABLE I. The values of parameter a in Eq. (10) as found by the maximum likelihood analysis for each reaction (1)–(4) and for the combined sample.

Reaction	a
1	0.390 ± 0.079
2	0.490 ± 0.051
3	0.366 ± 0.064
4	0.515 ± 0.143
All combined	0.443 ± 0.037

Polarization of Λ hyperons by protons




Anti hyperon polarization, 800 GeV protons
0.10
0.05
0.00
−0.05
−0.10
anti Σ−
x=.5
anti Ξ0
x=.4
Ω −
x=.5
anti Λ
x=.3
x=.4
anti Ξ+
0.8
1
1.2
1.4
P_T (GeV/c)

L. PONDROM

Experimental Data

$$Z \to \Lambda, \bar{\Lambda}\, X$$

$$\vec{P}_\Lambda \cdot \hat{n} \qquad \hat{n} = \vec{p}_\Lambda \times \vec{p}_{THRUST} / |\vec{p}_\Lambda \times \vec{p}_{TH}|$$

OPAL

p_T (GeV/c)	P_T^Λ (%)
< 0.3	$-1.8 \pm 3.1 \pm 1.0$
$0.3 - 0.6$	$0.4 \pm 1.8 \pm 0.7$
$0.6 - 0.9$	$1.0 \pm 1.9 \pm 0.7$
$0.9 - 1.2$	$0.8 \pm 2.2 \pm 0.6$
$1.2 - 1.5$	$0.0 \pm 2.7 \pm 0.6$
> 1.5	$1.8 \pm 1.6 \pm 0.5$
> 0.3	$0.9 \pm 0.9 \pm 0.3$
> 0.6	$1.1 \pm 1.0 \pm 0.4$

le 6: Measured transverse polarization of Λ baryons as a function of p_T (the transverse mentum of the Λ measured relative to the event thrust axis). The first error is statistical, second systematic.

Authors also found no effect with respect to scattering plane.

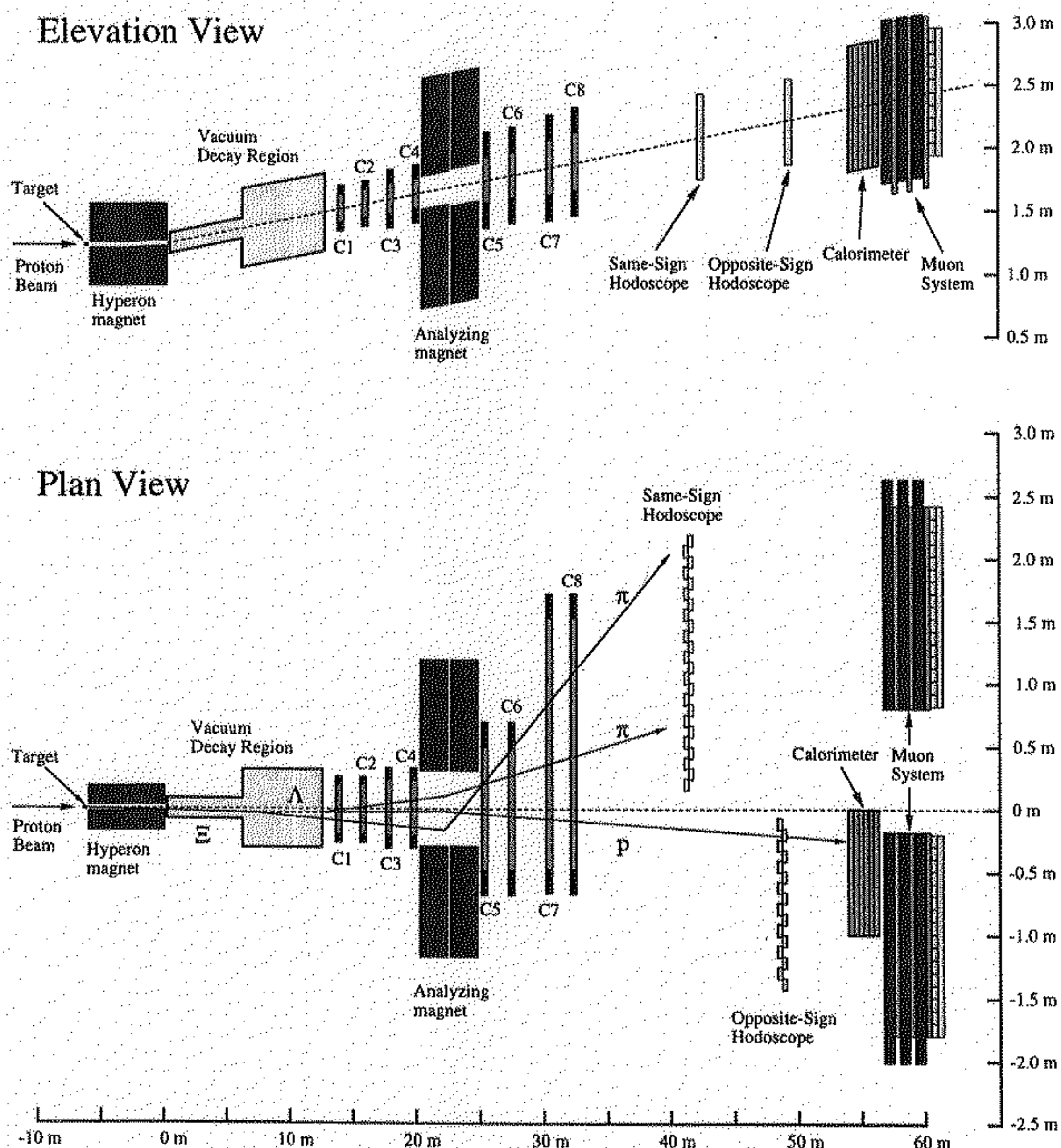
Hyperon Production

- Lessons we've learned:
  - Plethora of polarization data does not necessarily lead to answers. However, like money in the bank, it doesn't hurt to keep storing it up.
- Need to do:
  - Polarization in exclusive states looks promising!
  - Anti-hyperon polarization seems like the key to me -----> charged hyperon experiment

Hyperon Decays

- CP violation in Ξ^- decays - HyperCP
- Weak radiative Ξ^o decays - NA48 and KTeV
- Beta decay of Ξ^o – KTeV
  - general remarks on beta decays

The HyperCP Spectrometer



Secondary beam momentum $\approx 160\,\mathrm{GeV}/c$

Flip both $\vec{\mathbf{B}}$ fields $\Longrightarrow$ nearly symmetric acceptance.

The *HyperCP* Experiment at Fermilab

Obtain Ξ^- and $\overline{\Xi}^+$ hyperons having $\vec{\mathbf{P}}_{\Xi(\overline{\Xi})} = 0$ by selecting production at $0°$ in 800 GeV pN collisions.

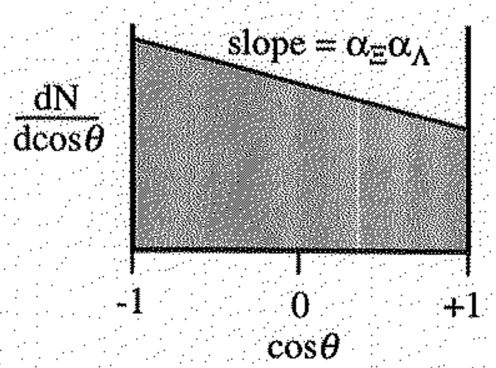
Subsequent $\Xi^- \to \Lambda\pi^-$ and $\overline{\Xi}^+ \to \overline{\Lambda}\pi^+$ yield Λ and $\overline{\Lambda}$ samples having polarization absolutely determined by the Ξ^- and $\overline{\Xi}^+$ decay parameters

$$\vec{\mathbf{P}}_\Lambda = \alpha_\Xi \hat{\mathbf{q}}_\Lambda \qquad \vec{\mathbf{P}}_{\overline{\Lambda}} = \alpha_{\overline{\Xi}} \hat{\mathbf{q}}_{\overline{\Lambda}}$$

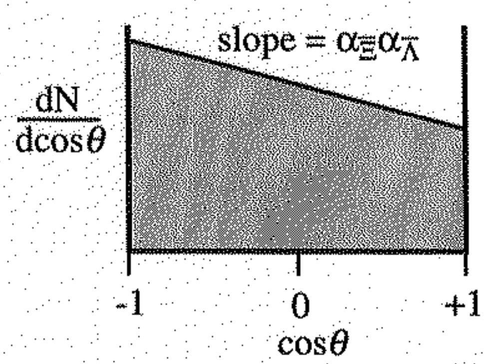
In the Λ and $\overline{\Lambda}$ helicity frames

$$\frac{dN_p}{d\cos\theta_{p\Lambda}} = 1 + \alpha_\Xi \alpha_\Lambda \cos\theta_{p\Lambda} \qquad \frac{dN_{\overline{p}}}{d\cos\theta_{\overline{p}\overline{\Lambda}}} = 1 + \alpha_{\overline{\Xi}} \alpha_{\overline{\Lambda}} \cos\theta_{\overline{p}\overline{\Lambda}}$$

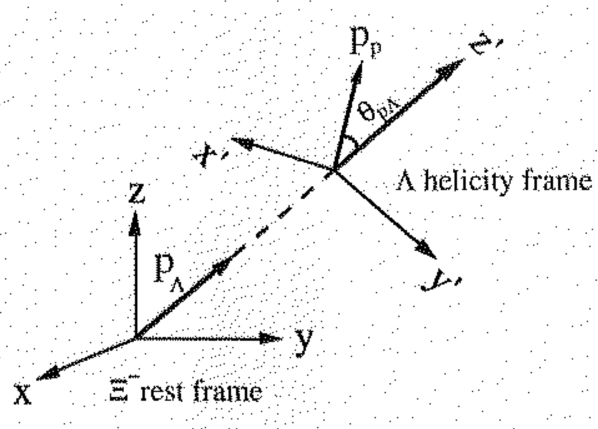
$\Xi^- \Rightarrow \Lambda\pi^- \quad \Lambda \Rightarrow p\pi^-$

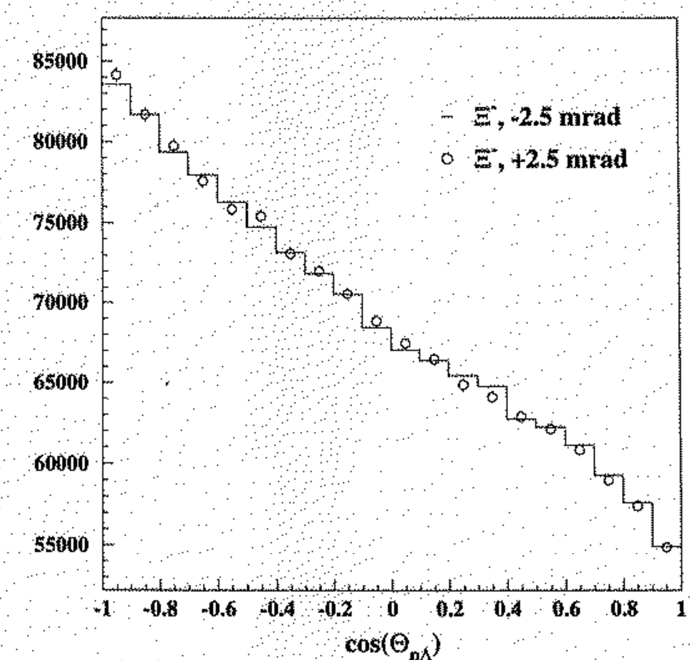


$\overline{\Xi}^+ \Rightarrow \overline{\Lambda}\pi^+ \quad \overline{\Lambda} \Rightarrow \overline{p}\pi^+$



Ξ^- (-2.5 mrad) vs Ξ^- (+2.5 mrad)





- **In the Λ helicity frame the effect of the small polarization on the $cos(\theta_{p\Lambda})$ distribution disappears**

K. NELSON HYPERCP

Expected Number of Reconstructed Events from '97 Run

	Channeled beam polarity $+$	Channeled beam polarity $-$	Total
$\Xi \to \Lambda\pi$	245×10^6	969×10^6	1.21×10^9
$K \to 3\pi$	204×10^6	75×10^6	279×10^6

Statistical sensitivity: $\delta A_{\Xi\Lambda} \approx 2 \times 10^{-4}$.

The *HyperCP* goal is to collect $\sim 4\times$ more events in 1999.

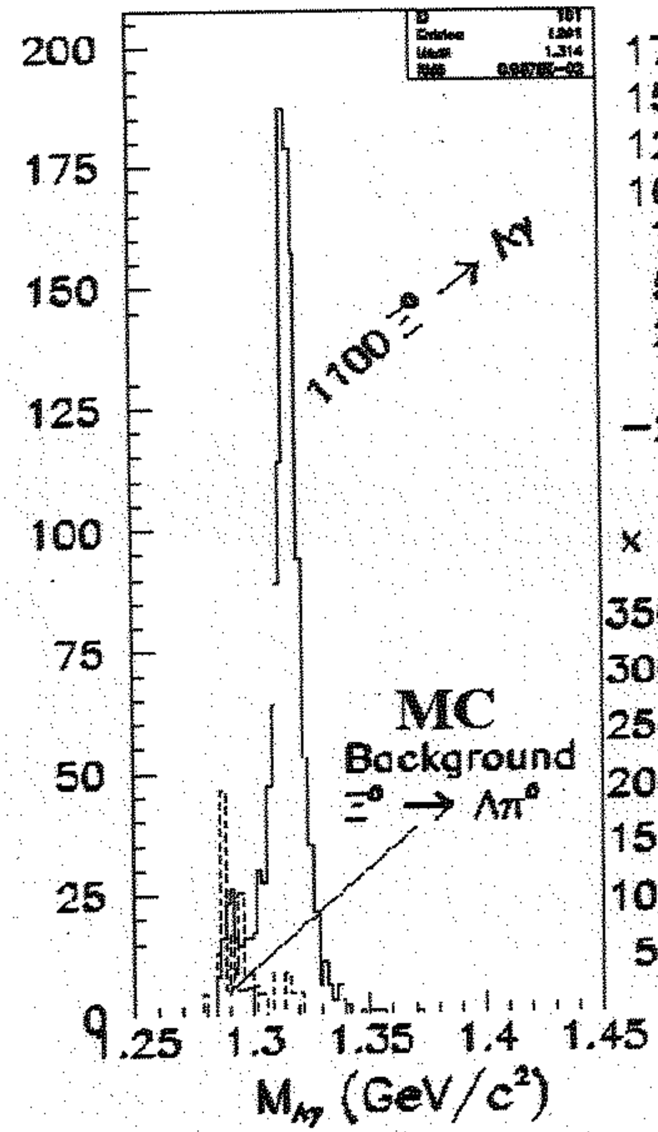
K. NELSON - HYPERCP

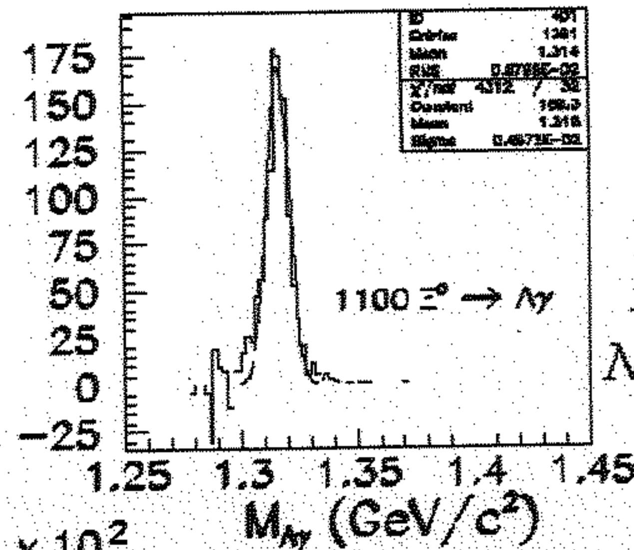
Experimental Results till 1998

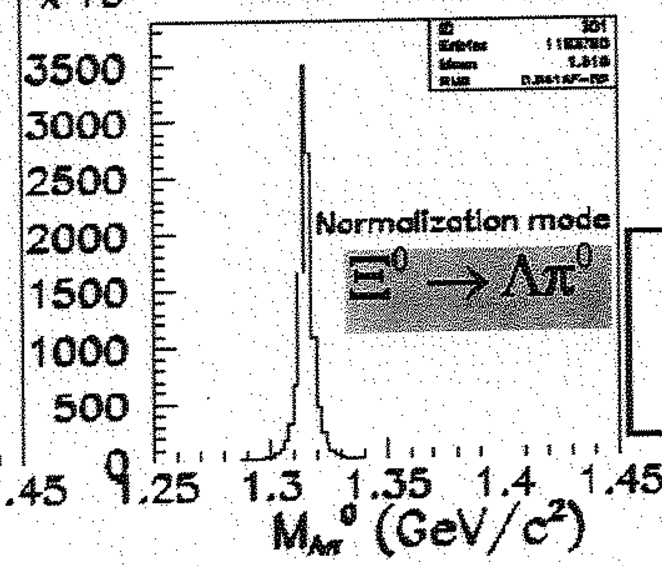
No. of events	Branching ratio (10^{-3})	Asymmetry parameter	Laboratory	Reference, Year
		$\Sigma^+ \to p\gamma$		
24	1.91 ± 0.41		BNL	Bazin [7] (1965)
31(61)	1.42 ± 0.26	$-1.03^{+0.54}_{-0.42}$	Berkeley	Gershwin [2] (1969)
45	1.08 ± 0.15		CERN	Ang [6] (1969)
30(46)	1.09 ± 0.20	$-0.53^{+0.38}_{-0.36}$	CERN	Manz [3] (1980)
155	$1.27^{+0.15}_{-0.18}$		CERN	Biagi [9] (1985)
190	1.30 ± 0.15	$-0.86 \pm 0.13 \pm 0.04$	KEK	Kobayashi [4] (1987)
408	$1.45 \pm 0.20^{+0.11}_{-0.22}$		BNL	Hessey [8] (1989)
(34754)		$-0.720 \pm 0.086 \pm 0.045$	Fermilab	Foucher* [13] (1992)
31901	$1.20 \pm 0.06 \pm 0.05$		Fermilab	This result*
		$\Xi^- \to \Sigma^-\gamma$		
11	0.23 ± 0.10		CERN	Biagi [14] (1987)
211	$0.122 \pm 0.023 \pm 0.006$	1.0 ± 1.3	Fermilab	Dubbs* [11] (1994)
		$\Xi^0 \to \Sigma^0\gamma$		
85	$3.56 \pm 0.42 \pm 0.10$	$0.20 \pm 0.32 \pm 0.05$	Fermilab	Teige [15] (1989)
		$\Xi^0 \to \Lambda\gamma$		
116(87)	$1.06 \pm 0.12 \pm 0.11$	0.43 ± 0.44	Fermilab	James [16] (1990)
		$\Lambda \to n\gamma$		
24	1.02 ± 0.33		CERN	Biagi [17] (1986)
287	$1.78 \pm 0.24 \pm 0.15$		BNL	Noble [18] (1992)
1816	1.75 ± 0.15		BNL	Larson [19] (1993)
		$\Omega^- \to \Xi^-\gamma$ Limits at 90% C.L.		
	<2.2		CERN	Bourquin [20] (1984)
	<0.46		Fermilab	Albuquerque* [12] (1994)

U. Koch - NA48

BR calculation of $\Xi^0 \longrightarrow \Lambda\gamma$







Winter'97 data

$$\frac{\alpha cc(\Lambda\gamma)}{\alpha cc(\Lambda\pi^0)} = 1.04$$

$N(\Lambda\gamma) = 1{,}100 \pm 33$ evts

$N(\Lambda\pi^0) = 1{,}130{,}000 \pm 1063$ evts

Preliminary

$$\frac{BR(\Lambda\gamma)}{BR(\Lambda\pi^0)} = (0.94 \pm 0.04^{(stat)}) \times 10^{-3}$$

$BR_{PDG} = [1.06 \pm 0.16] \times 10^{-3}$

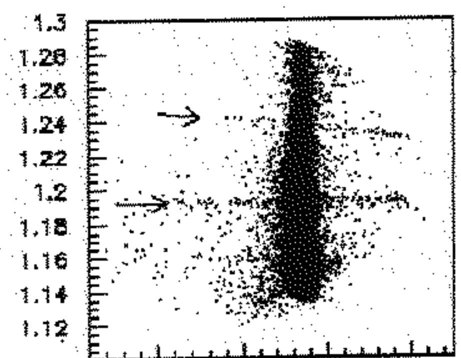
U. KOCH - NA48 -

KTeV - BR(Ξ -> $\Sigma\,\gamma$)

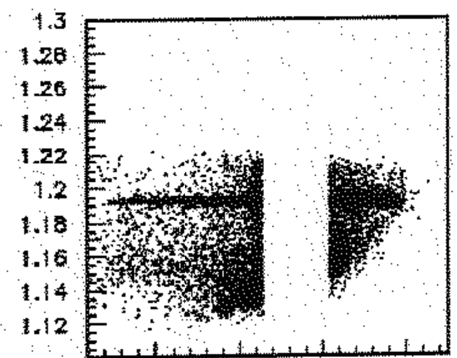
Same final state as the decay mode
Ξ -> $\Lambda\,\pi^0$ (99.95 %)

can be distinguished by $\Lambda\gamma$ and $\gamma\gamma$ mass

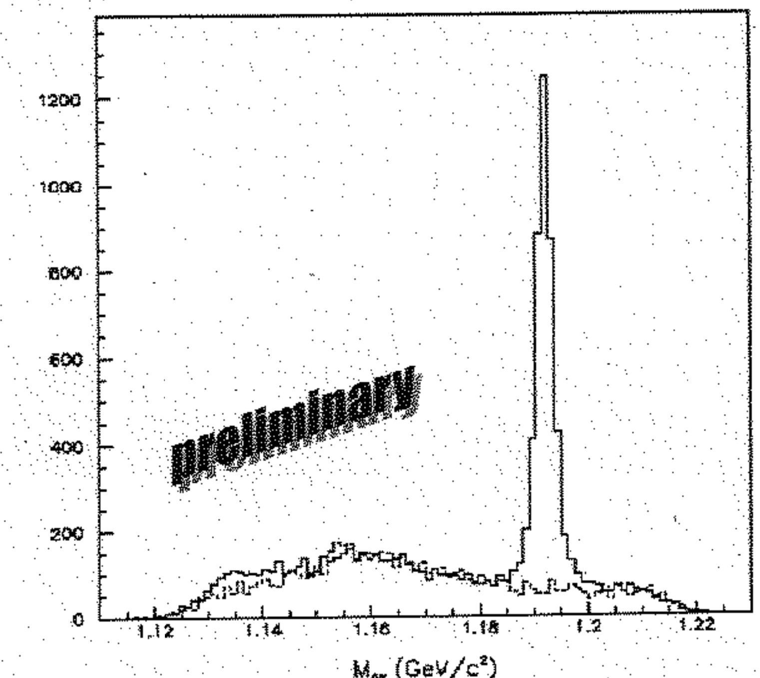
use Ξ -> $\Lambda\,\pi^0$ for normalization



Λ−γ mass vs. γ−γ mass



Λ−γ mass vs. γ−γ mass



Preliminary:

BR(Ξ -> $\Sigma^0\,\gamma$) = $(3.0 \pm 0.05 \pm 0.2) * 10^{-3}$

U. KOCH - NA48

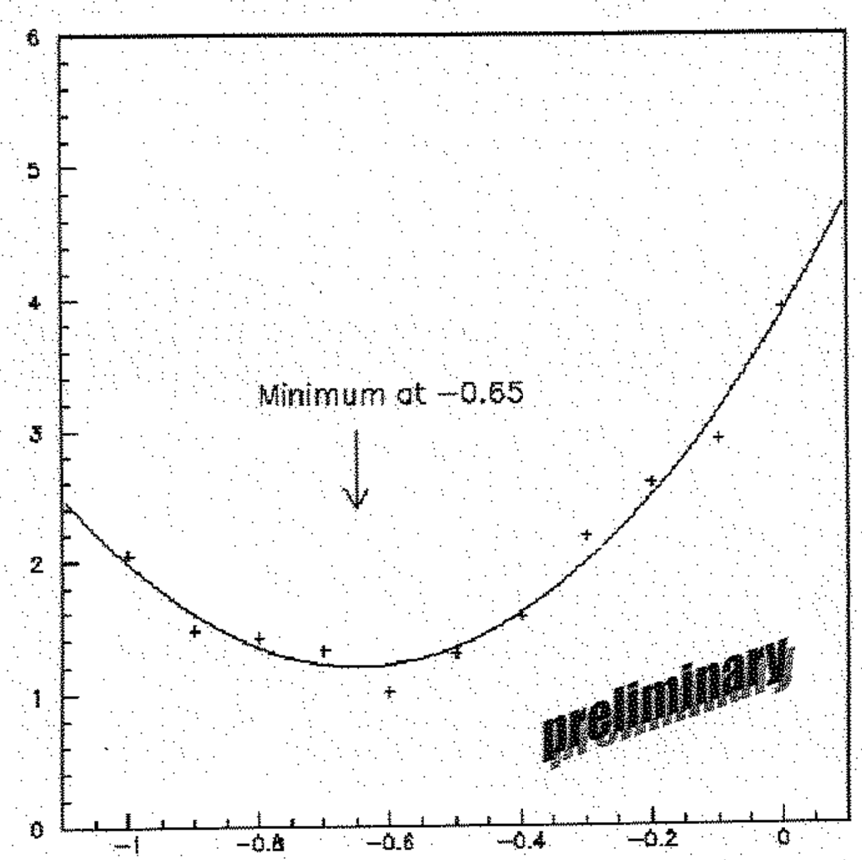
KTeV - $\Xi \to \Sigma^0 \gamma$ asymmetry

3 stages of decay have to be taken into account

2 dimensional cosine distribution of the data has been compared to 10 sets of MC data ranging from $\alpha = 0$ to $\alpha = -1$

The X^2/DOF comarison for each of this cases is shown in the right figure

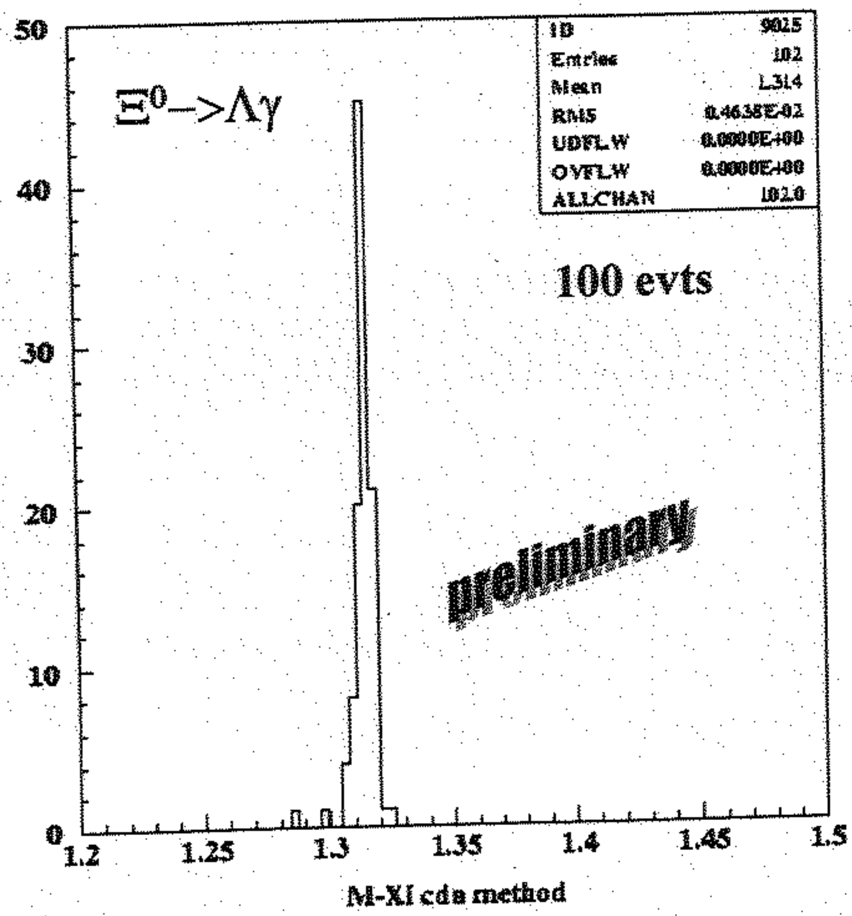
Preliminary Result:
$\alpha_\gamma = -0.65 \pm 0.13$

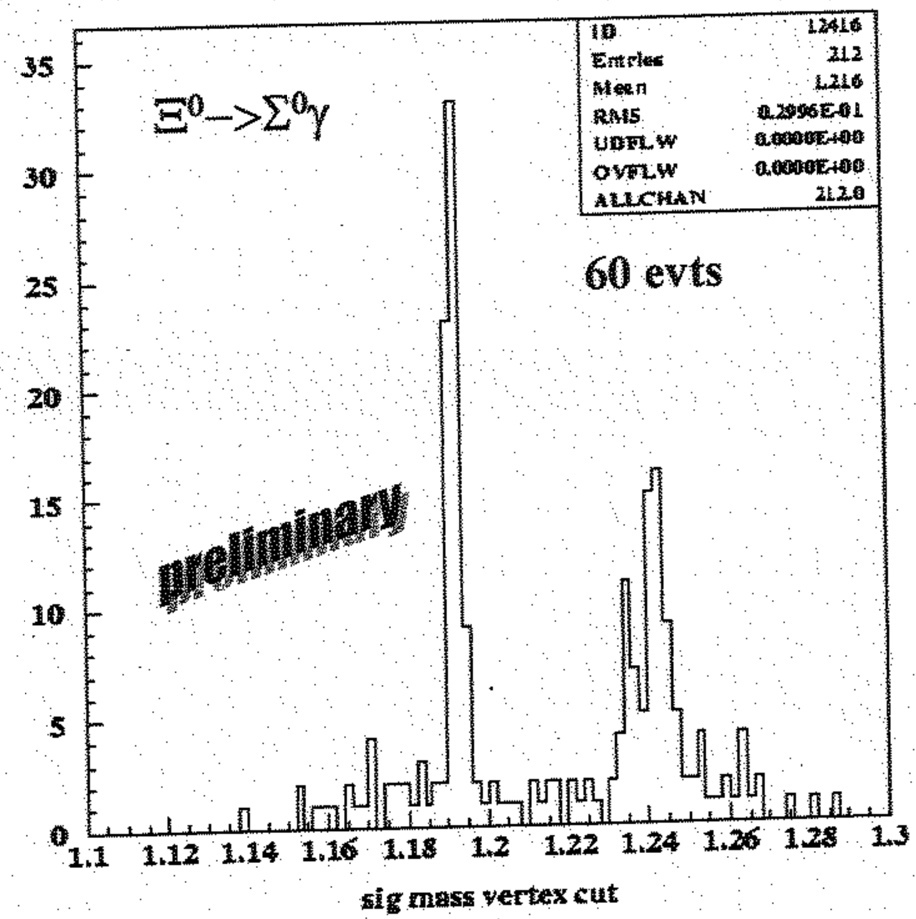


Chi2/DOF vs. Asymmetry

U. KOCH - NA48

Radiative Ξ decays (High Intensity K_S Test 1999)





U. KOCH - NA48

NA48 - High Intensity K_S Run

	measured rates 1999 8 hours, downscaling 10		expected rates 2000 24 hours downscaling 1		30 days
Decay modes	total	burst	total	burst	total
Λ-> p π	8,50E+05	425,00	2,13E+07	4250,00	6,38E+08
Λbar-> pbar π+	1,00E+05	50,00	2,50E+06	500,00	7,50E+07
Ξ->$\bar{\Lambda}\pi$0	1,70E+04	8,50	4,25E+05	85,00	1,28E+07
Ξ->$\Lambda\gamma$	1,00E+02	0,05	2,50E+03	0,50	7,50E+04
Ξ->$\Sigma\gamma$	6,00E+01	0,03	1,50E+03	0,30	4,50E+04
Ξbar->Λbar π0	1,20E+03	0,60	3,00E+04	6,00	9,00E+05

U. KOCH - NA48

Σ^0 – Physics at KTeV

Σ^0 Physics at KTeV

Can we do Σ^0 Physics with the KTeV detector?

Σ^0 decays EM, No direct Σ^0

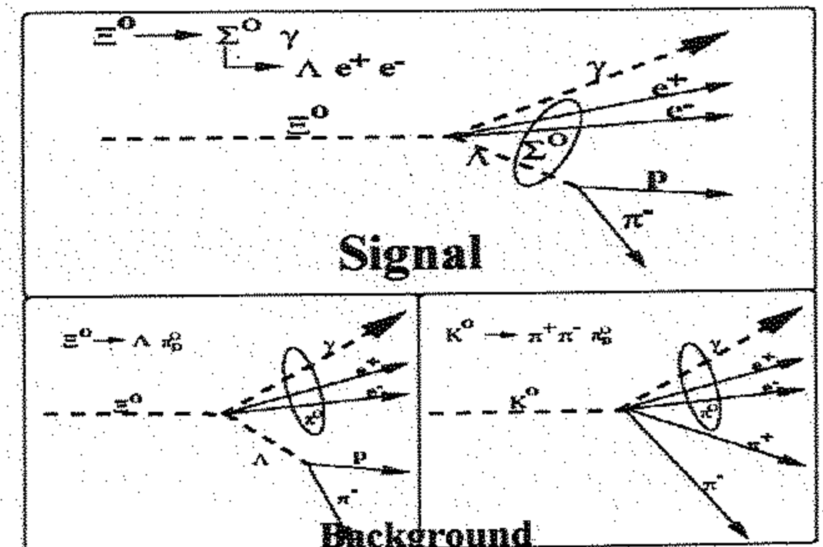
$$\Xi^0 \rightarrow \Sigma^0\gamma$$

$\rightarrow \Lambda\gamma$ — *BR=100%*

$\rightarrow \boxed{\Lambda e^+e^-}$ — *BR ~ 0.5 - 0.6%, theory*
Measure relative parity of Σ^0, Λ

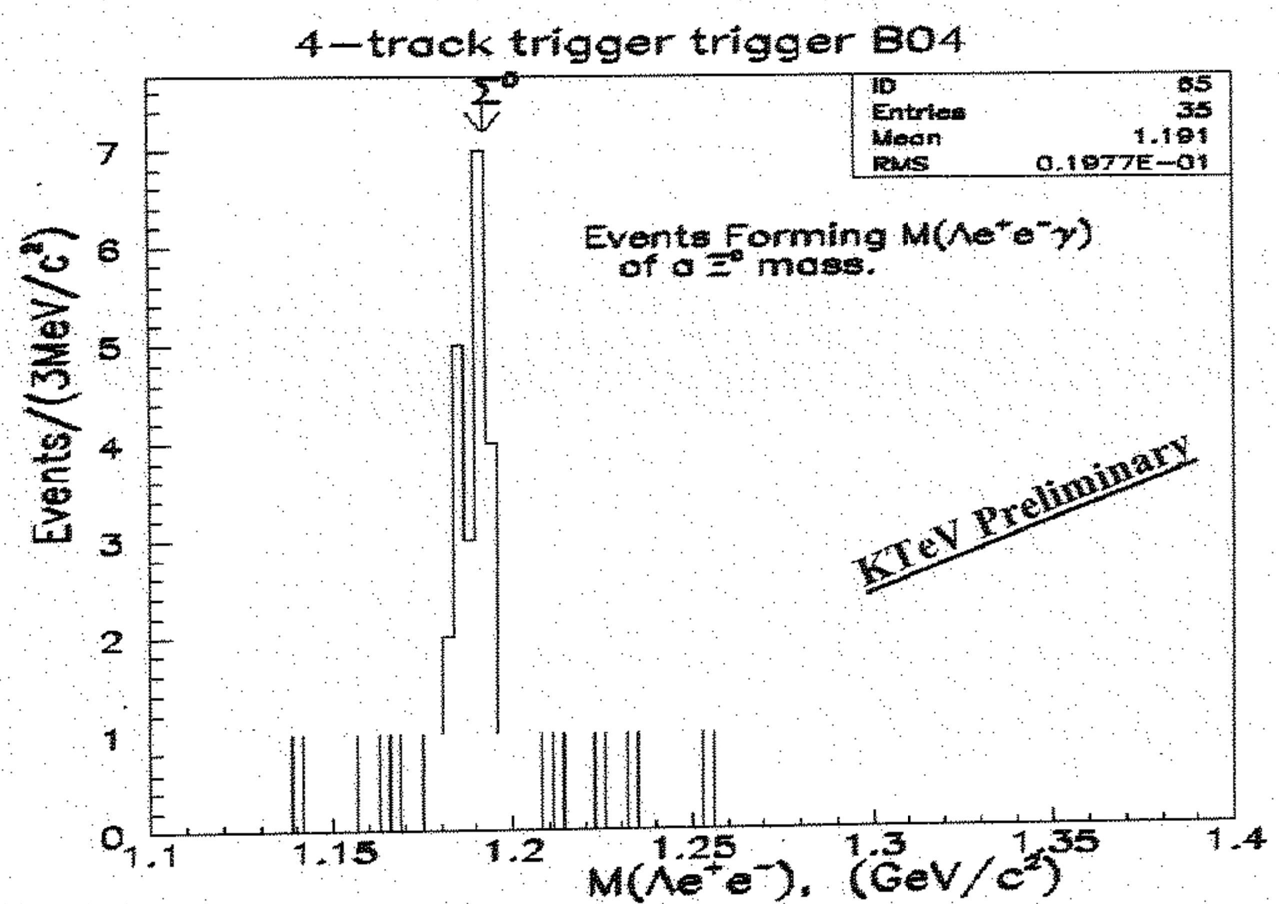
$\rightarrow \Lambda\gamma\gamma$ — *BR < 3%, 1975 result*
BR~10^{-7}??? Theory

Not observed yet



U. KOCH - NA48

KTeV - Signal for $\Sigma \to \Lambda e^+e^-$



U. Koch - NA48

KTEV Event Display

Run Number: 8387
Spill Number: 118
Event Number: 14718928
Trigger Mask: 200
All Slices

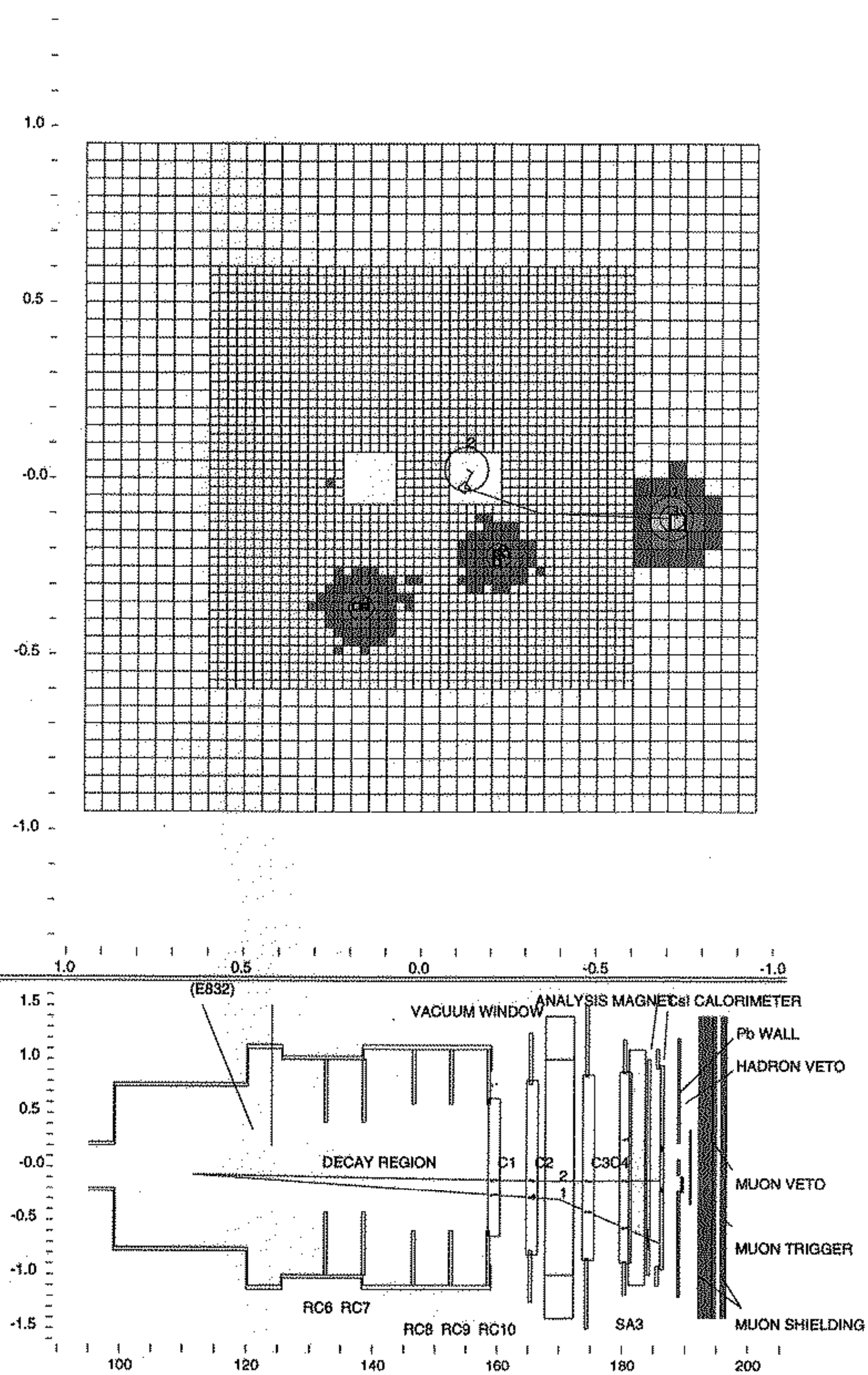
Track and Cluster Info
HCC cluster count: 3

ID	Xcsi	Ycsi	P or E
T 1:	-0.7063	-0.1142	-9.57
C 1:	-0.7092	-0.1137	9.50
T 2:	-0.1249	0.0260	+164.98
C 2:	-0.2179	-0.2197	19.41
C 3:	0.1739	-0.3658	25.03

Vertex: 2 tracks

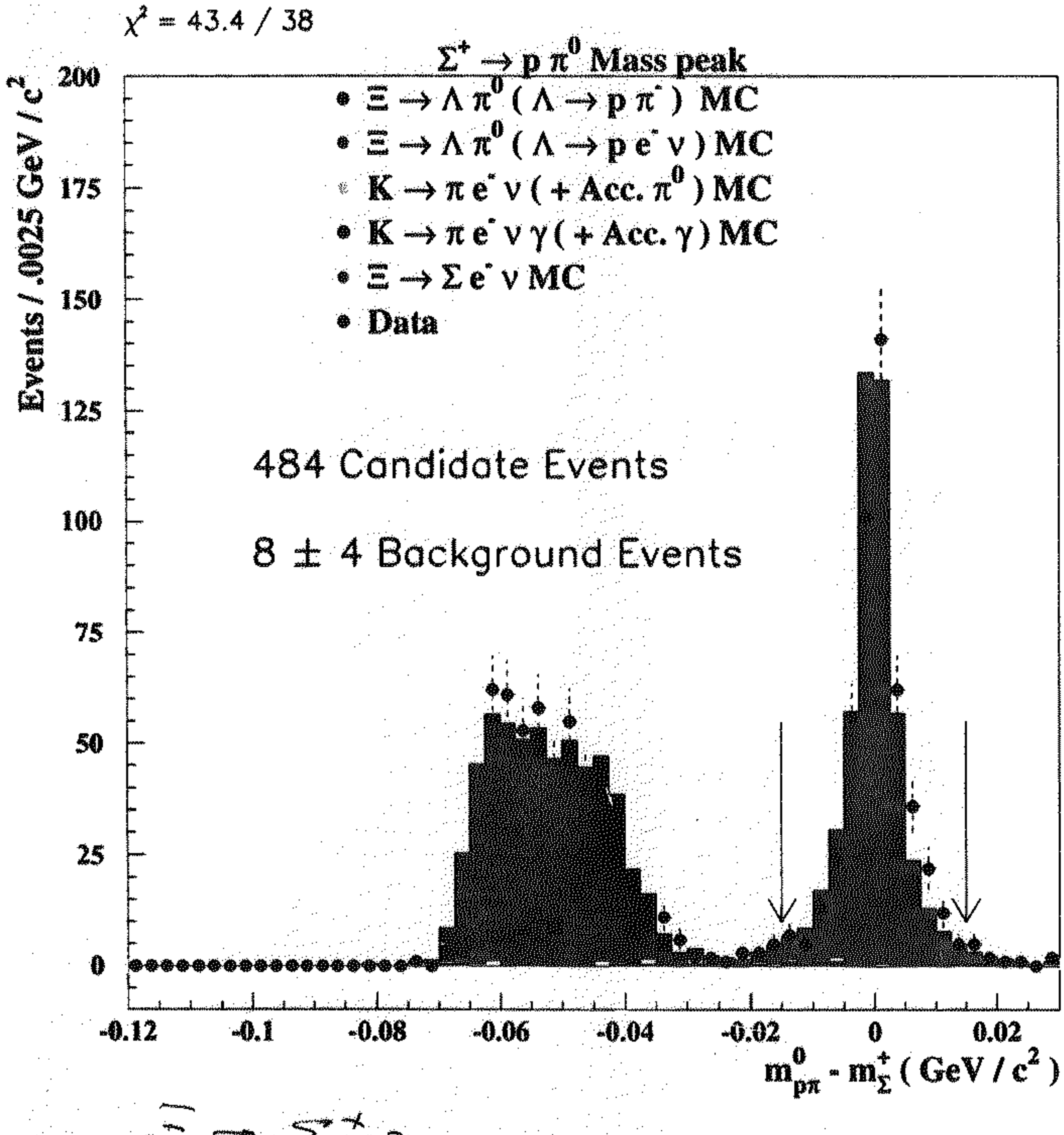
X	Y	Z
-0.0710	-0.0160	111.673

Mass=0.6285 (assuming pions)
Chisq=1.30 Pt2v=0.019142



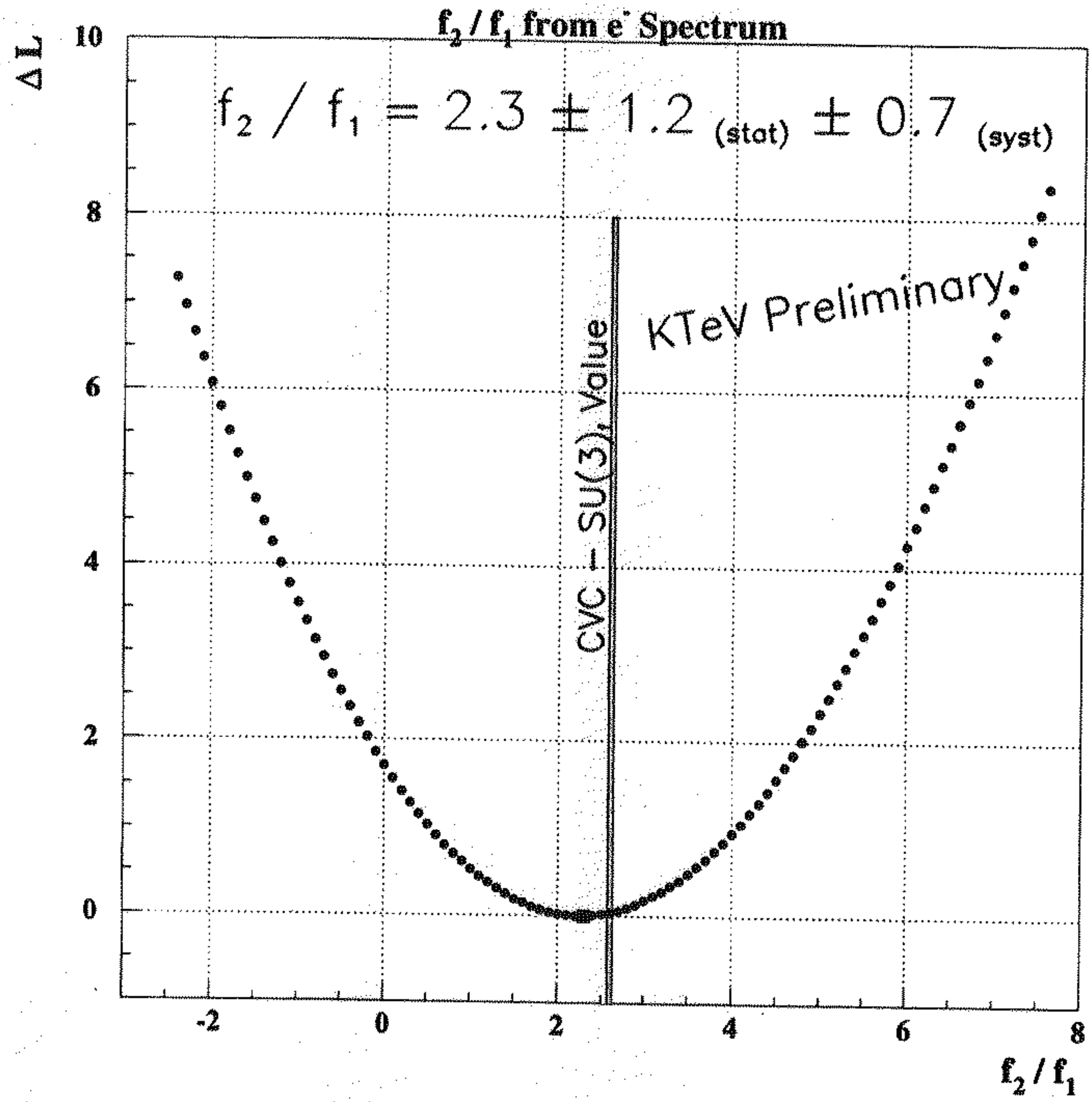
- Cluster
- Track
- 10.00 GeV
- 1.00 GeV
- 0.10 GeV
- 0.01 GeV

$\boxed{NC \quad \Xi^0 \rightarrow \Sigma^+ \pi^-}$

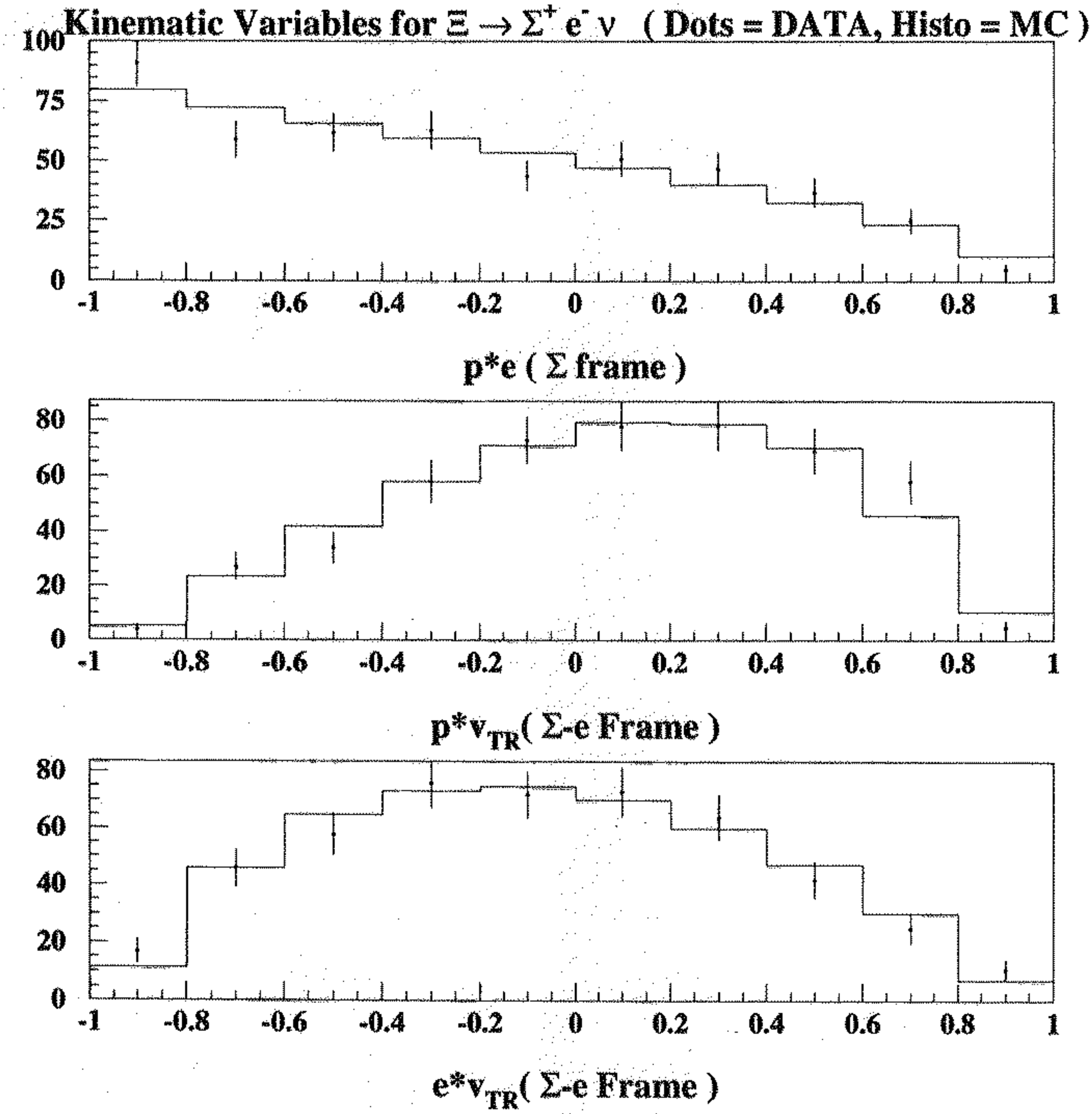


$\Xi \rightarrow \Sigma^+ e^- \nu$ ONLY SOURCE OF Σ^+

S BRIGHT - KTeV



S. BRIGHT - KTeV



S. BRIGHT - KTeV

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

KTeV measurements:

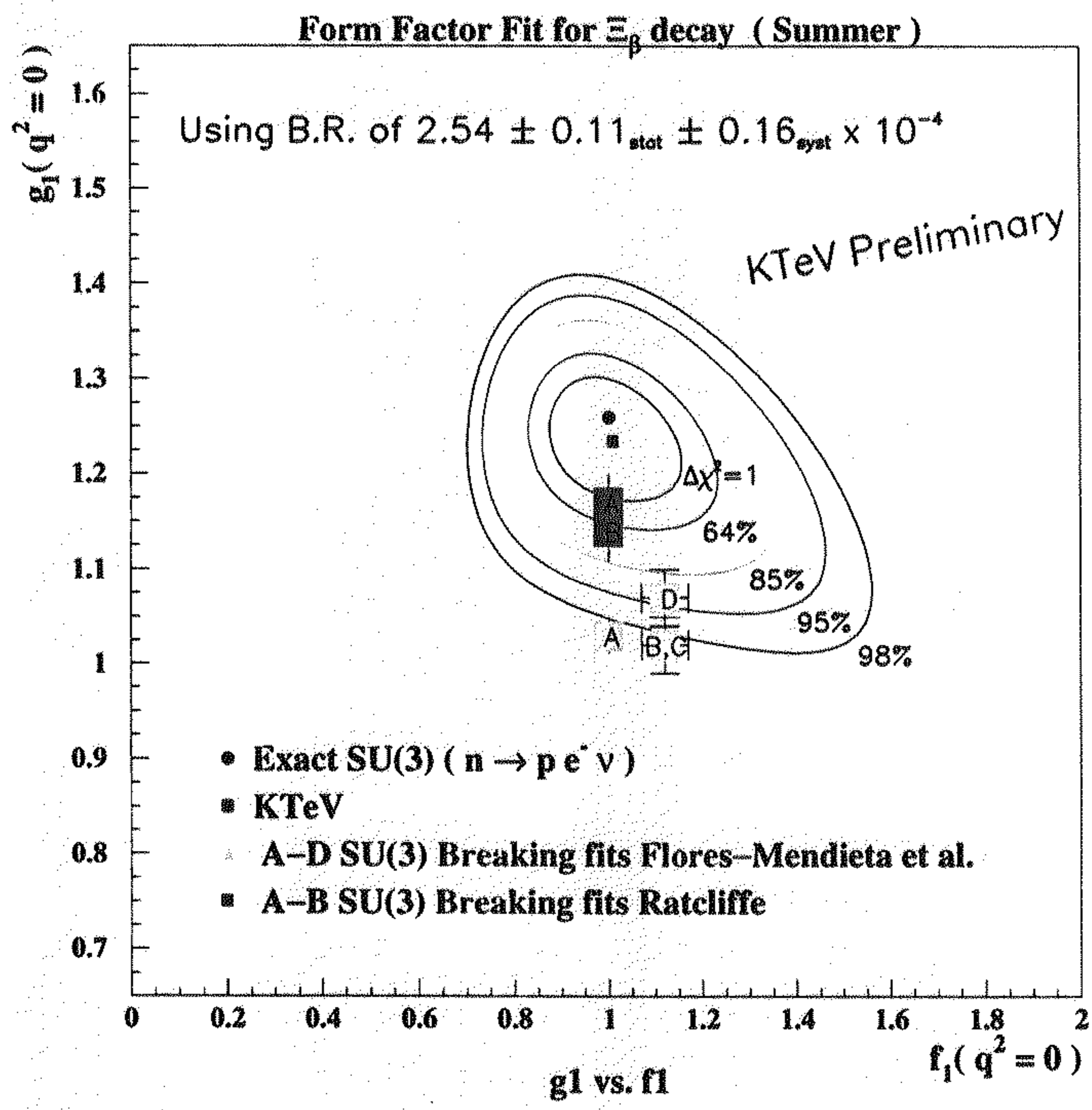
(DPF99) $\mathrm{B.R} = (2.54 \pm 0.11 \pm 0.16) \times 10^{-4}$

(S. Bright's talk) $\dfrac{g_1}{f_1} = 1.24^{+0.20}_{-0.17} \pm 0.07$

$$\frac{f_2}{f_1} = 1.9 \pm 1.3 \pm 0.7$$

$$\frac{g_2}{f_1} = -1.4^{+2.2}_{-1.9} \pm 0.5$$

A. ALAVI - KTeV



PRD 58 094028 (1998)

PRD 59 014038 (1999)

S. BRIGHT - KTeV

Semi-Leptonic Decay of Baryons

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

$$\underline{M} = 2^{1/2}\, G \langle B |\, J^{\mu} \,| A \rangle\, u_l(\bar{p_l})\, \gamma_{\mu}(1 + \gamma_5)\, v_{\nu}(p_{\nu})$$

$$\langle B \,|\, J^{\mu} \,|\, A \rangle = u_{\bar{B}} \{ f_1(q^2)\gamma^{\mu} + i\frac{f_2(q^2)}{M}\sigma^{\mu\nu} q_{\nu} + \frac{f_3(q^2)}{M} q^{\mu}$$

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

- All 6 form factors are real, assuming time reversal invariance.
- f_1 and f_2 can be fixed through the CVC hypothesis.
- $g_2 = 0$ in the SM (no second class currents).
- f_3 and g_3 are suppressed by the mass of the lepton and can be neglected in the case of electrons.
- q^2 dependence of f_1 and g_1 may need be to be considered.

A. ALAVI

Hyperon Beta Form Factors

Decay	scale	f_1	g_1
$n \rightarrow p e \nu$	V_{ud}	1	D+F
$\Lambda \rightarrow p e^- \nu$	V_{us}	$-\sqrt{3/2}$	$-\sqrt{1/6}$ (D+3F)
$\Sigma^- \rightarrow n e^- \nu$	V_{us}	-1	D-F
$\Sigma^- \rightarrow \Lambda e^- \nu$	V_{ud}	0	$\sqrt{2/3}$ D
$\Sigma^+ \rightarrow \Lambda e^+ \nu$	V_{ud}	0	$\sqrt{2/3}$ D
$\Xi^- \rightarrow \Lambda e^- \nu$	V_{us}	$\sqrt{3/2}$	$-\sqrt{1/6}$ (D-3F)
$\Xi^- \rightarrow \Xi^0 e^- \nu$	V_{ud}	-1	D-F
$\Xi^0 \rightarrow \Sigma^+ e^- \nu$	V_{us}	1	D+F
$\Xi^- \rightarrow \Sigma^0 e^- \nu$	V_{us}	$\sqrt{1/2}$	$\sqrt{1/2}$(D+F)

A. ALAVI

Hyperon Semi-Leptonic Decay Rates

Decay	BR	Events	two-body
$\Lambda \rightarrow p e^- \nu$	8.32×10^{-4}	20 k	Y
$\Sigma^- \rightarrow n e^- \nu$	1.02×10^{-3}	4.1 k	Y
$\Sigma^- \rightarrow \Lambda e^- \nu$	5.73×10^{-5}	1.8 k	N
$\Sigma^+ \rightarrow \Lambda e^+ \nu$	2.0×10^{-5}	21	N
$\Xi^- \rightarrow \Lambda e^- \nu$	5.63×10^{-4}	2868	N
$\Xi^- \rightarrow \Sigma^0 e^- \nu$	8.7×10^{-5}	154	N
$\Xi^0 \rightarrow \Sigma^+ e^- \nu$	2.71×10^{-3}	176	N
$\Xi^- \rightarrow \Xi^0 e^- \nu$	$<2.3 \times 10^{-3}$	0	N

A. ALAVI

CERN (WA2) Experiment

- Cabibbo fits on these measurements results in:
$F = 0.477 \pm 0.012$, $D = 0.756 \pm 0.011$

and $\sin\theta_C = 0.231 \pm 0.003$ (Bourquin et.al. 1983)

- Excellent fit with all measurements from a single experiment, within the error bars.

- Still a good fit when they added the n lifetime measurements.

- However, the measured Cabibbo angle disagrees with the K sector:

$$\mathrm{Sin}\,\theta_C = 0.2196 \pm 0.0023 \quad \text{(PDG98)}$$

P. Cooper (1994)

New Measurements

In the subsequent decade 5 of the 10 measurements have been improved by at least a factor of 2.

The one significant change is the lifetime of the neutron which has come down by 3.5 old standard deviations from the previous measurement.

[Note - The sign convention for g_1/f_1 used here is opposite that of the PDG.]

Hyperon Beta Decay Measurements.

Errors in the last digits are given in parentheses [()].

Decay	Old (1984)	New (1994)	New Error [%]	Diff/error [SD]	Error Improvement
g_1/f_1					
Λ° p	0.70(3)	0.718(15)	2.1%	0.6	2.0
Ξ^- Λ°	0.25(5)	0.25(5)	20.0%		
Σ^- n	-0.34(5)	-0.340(17)	5.0%	0.0	2.9
n p	1.258(9)	1.2573(28)	0.2%	-0.1	3.2
Br [x10^{-3}]					
Σ^- Λ°	0.0561(31)	0.0573(27)	4.7%	0.4	1.1
Λ° p	0.857(36)	0.832(14)	1.7%	-0.7	2.6
Σ^- n	0.960(50)	1.017(34)	3.3%	1.1	1.5
Ξ^- Σ°	0.087(17)	0.087(17)	19.5%		
Ξ^- Λ°	0.564(34)	.563(31)	5.5%	0.0	1.1
Lifetime [sec]					
n p	925(11)	887.0(2.0)	0.2%	-3.5	5.5 ←

FIT WITH NEW n DATA GIVES

$\sin\theta_c = 0.2214 \pm .0016$ BUT $\frac{\chi^2}{DOF} = \frac{35}{7}$

P. COOPER

Hyperon Decays

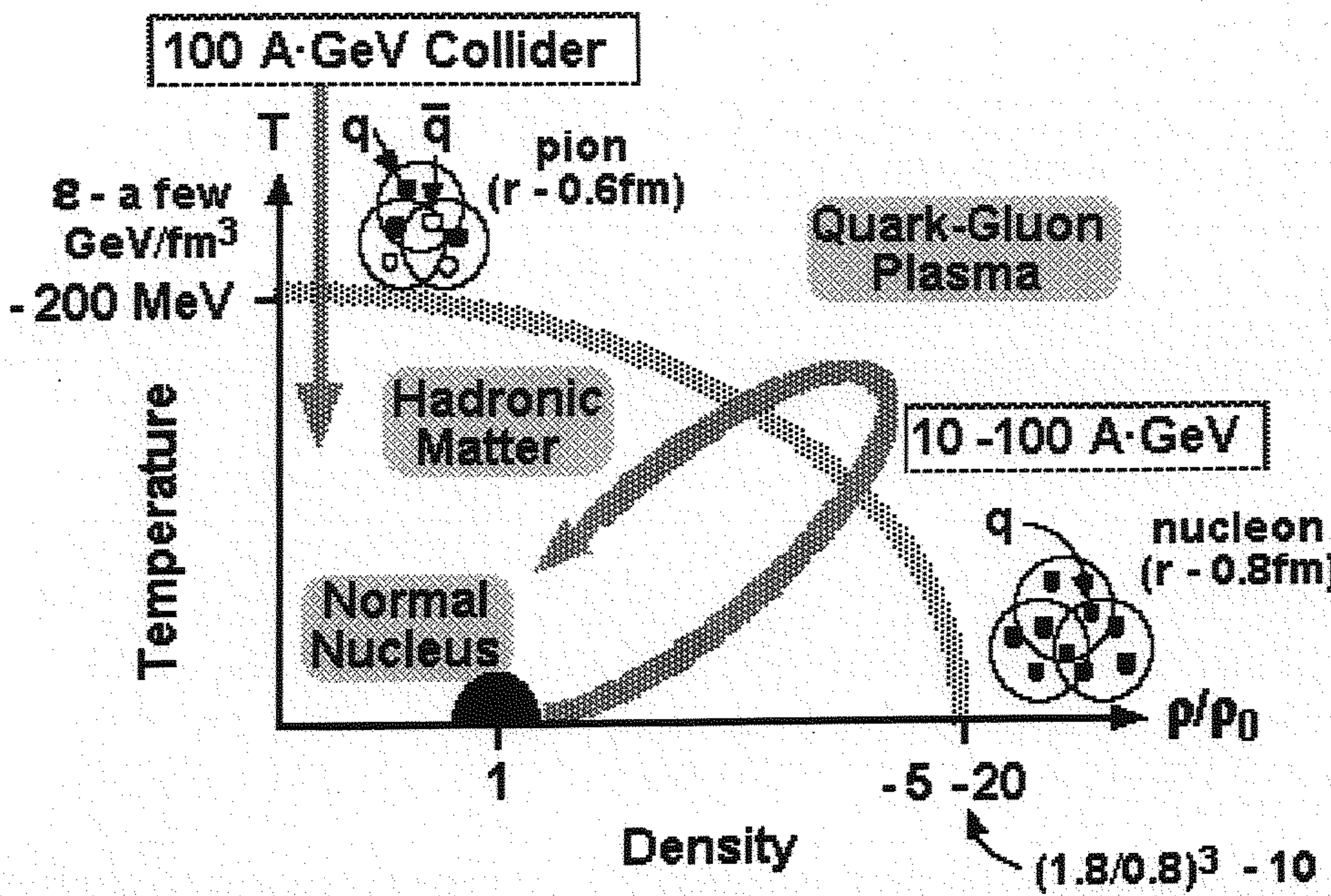
- Lessons we've learned:
  - Cabibbo model is VERY good. (Why are SU(3) effects so subtle in SLD but so large in static properties?)
- Need to do:
  - Finish $\Xi^o \rightarrow \Lambda\gamma$ measurement
  - Measure asymm in $\Lambda \rightarrow n\gamma$ from tagged Ξ^- decays
  - Measure $\Xi^- \rightarrow \Sigma^-\gamma$ with better precision
  - Observe $\Xi^- \rightarrow \Xi^o e\nu$
  - Measure $\Sigma^+ \rightarrow \Lambda e\nu$

-----> charged hyperon experiment

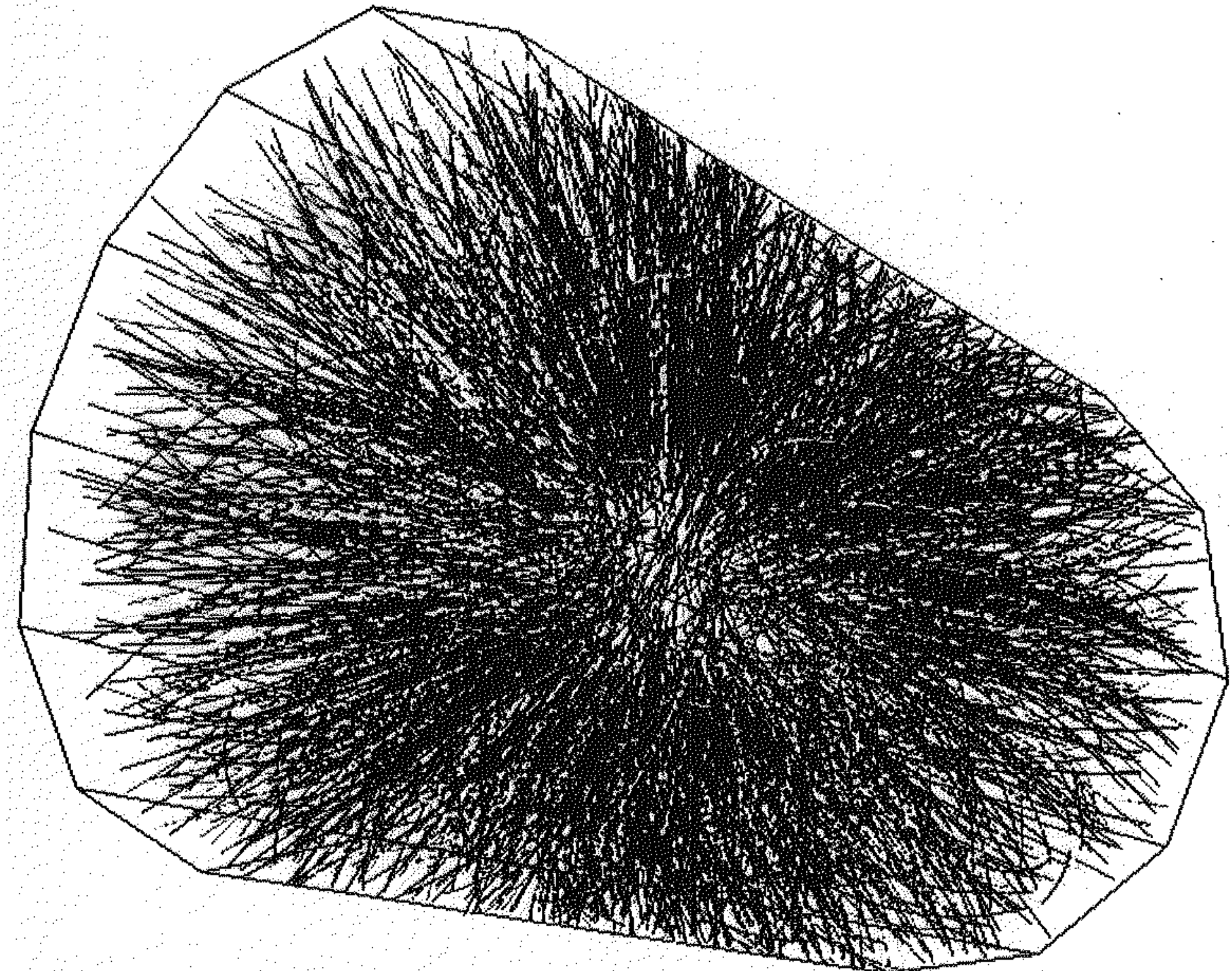
Beyond Hyperons

- Strangeness in Heavy Ion collisions
- U ‘diquarkonium’ states - WA89
- X(2000) ‘pentaquark’ state - SPHINX

Phase Diagram of Nuclear Matter & Nuclear Collisions



R. BELLWIED



Single Central Au–Au collision at RHIC (100 GeV/A + 100 GeV/A)

~10,000 charged particles produced

~2,500 charged particles detected and identified in STAR detector

R. BELLWIED

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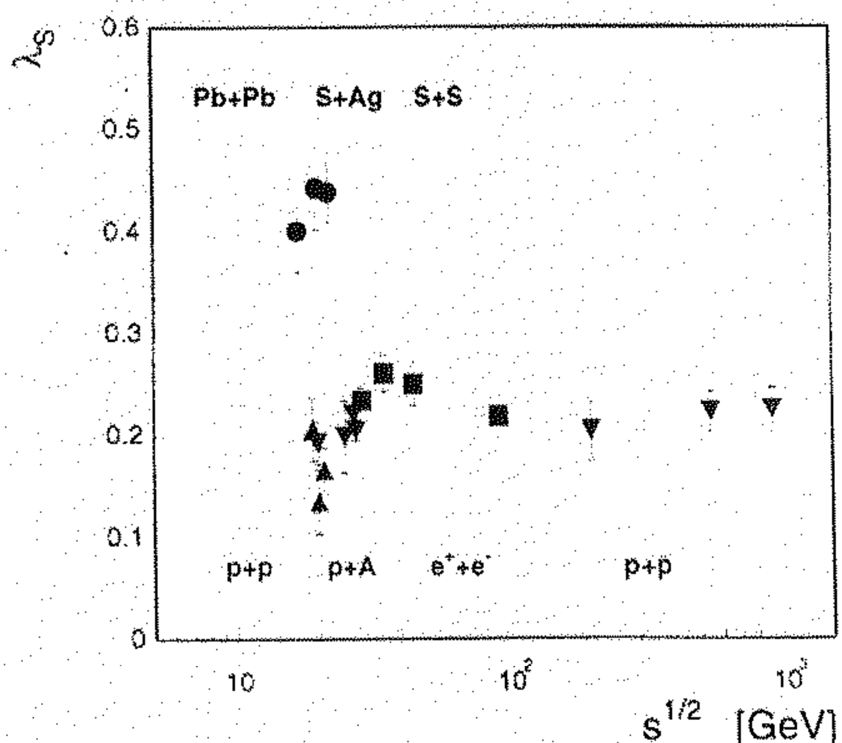
F. Becattini, M. Gazdzicki, J. Sollfrank
Eur. Phys. J. C5 (1998) 143

NA49/NA35 Pb+Pb, S+A
Total Strangeness Enhancement



$$\lambda_S = \left. \frac{2\langle s+\bar{s}\rangle}{\langle u+\bar{u}\rangle + \langle d+\bar{d}\rangle} \right|_{produced}$$

Strangeness Enhancement Unique Feature

of Nucleus - Nucleus Collisions

H–Dibaryon searches: Past, Present, Future

H - Search experiments

Laboratory		Reaction	
BNL *	9	(K^-, K^+), $\Delta S = -2$	6
CERN	1	Light Hadroproduction	9
FNAL	2	Relativ. Heavy Ions	4
FSU **	4		
KEK *	3		

Decay Mode		Results	
$H \to \Sigma N$	10	Negative (UL)	10
$H \to \Lambda\pi p$	3	"Positive"	4
Indep.	6	Analysing	2
		Running/Future	4

* Incl. running/future ** Former S.U.

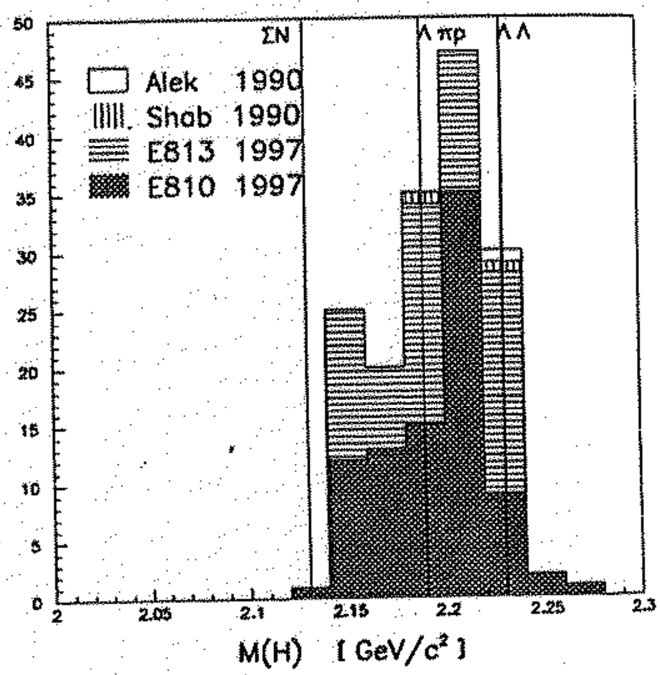


Figure 6: Observed events which may contain H candidates

Ongoing and Proposed Searches

We now list and very briefly describe ongoing and proposed experiments to search for the H dibaryon or for double-Lambda hypernuclei:

- <u>BNL E885:</u> Search for ${}^{A}_{\Lambda\Lambda}Z$ Hypernuclei. Used ${}^{12}C(K^-, K^+)\Xi^- X$, stop the Ξ to make ${}^{12}_{\Lambda\Lambda}B$ + n. Use SCIFI + CCD for tracking, detect neutrons. Data reduction completed, expect $\sim$ 20,000 stopped Ξ events. This should lead to $\sim$ 50 ${}^{12}_{\Lambda\Lambda}B$.
- <u>BNL E906:</u> Search for ${}^{A}_{\Lambda\Lambda}Z$ Hypernuclei. Use ${}^{9}Be(K^-, K^+)\Xi^- X$, stop Ξ to make ${}_{\Lambda\Lambda}{}^{5}H$. Use Cylindrical Detector System (CDS) for tracking, detect π^- from sequential decays: ${}_{\Lambda\Lambda}{}^{5}H \to {}_{\Lambda}^{5}He + \pi^-$; ${}_{\Lambda}^{5}He \to {}^{4}He + p + \pi^-$. Experiment started; expect to detect $\sim$ 500 coincident π^-.
- <u>BNL E896:</u> 11.6 × A GeV/c Au on Au target. Detect $H \to \Sigma^- p$, $H \to \Lambda\pi^- p$. Use sweeping magnet to remove charged particles and an analysing magnet to detect H decay products. Experiment started.
- <u>KEK E248:</u> $p + p \to K^+ K^+ X$, P(p) = 12.9 GeV/c. Use Asymmetric Double-Arm Spectrometer, measure m(X). Taking data since Feb. '97, expect 100pb sensitivity.

1. Experimental evidence

V. MULLER – WA8

- **WA62**: Hyperon beam experiment at CERN-SPS

  135 GeV $\Sigma^- + Be$

  → Observed signal for charmed baryon decay

  $\Xi_c^+ \rightarrow \Lambda K^- \pi^+ \pi^+$

  Checked particle identification $K^- \leftrightarrow \bar{p}$ (thresh. Č)

  ⇒ Peaks in spectra $\Lambda \bar{p}$ + pions

  $m = 3100\ MeV/c^2$, $\Gamma < 30\ MeV$

$U^+ \rightarrow \Lambda \bar{p} \pi^+ \pi^+$

$S/B = 45/50$

$\sigma \cdot B = 4.8 \pm 1.4 \pm 0.8\ \mu b/Be$

for $x_F > 0.6$

$U^0 \rightarrow \Lambda \bar{p} \pi^+ \pi^+ \pi^-$

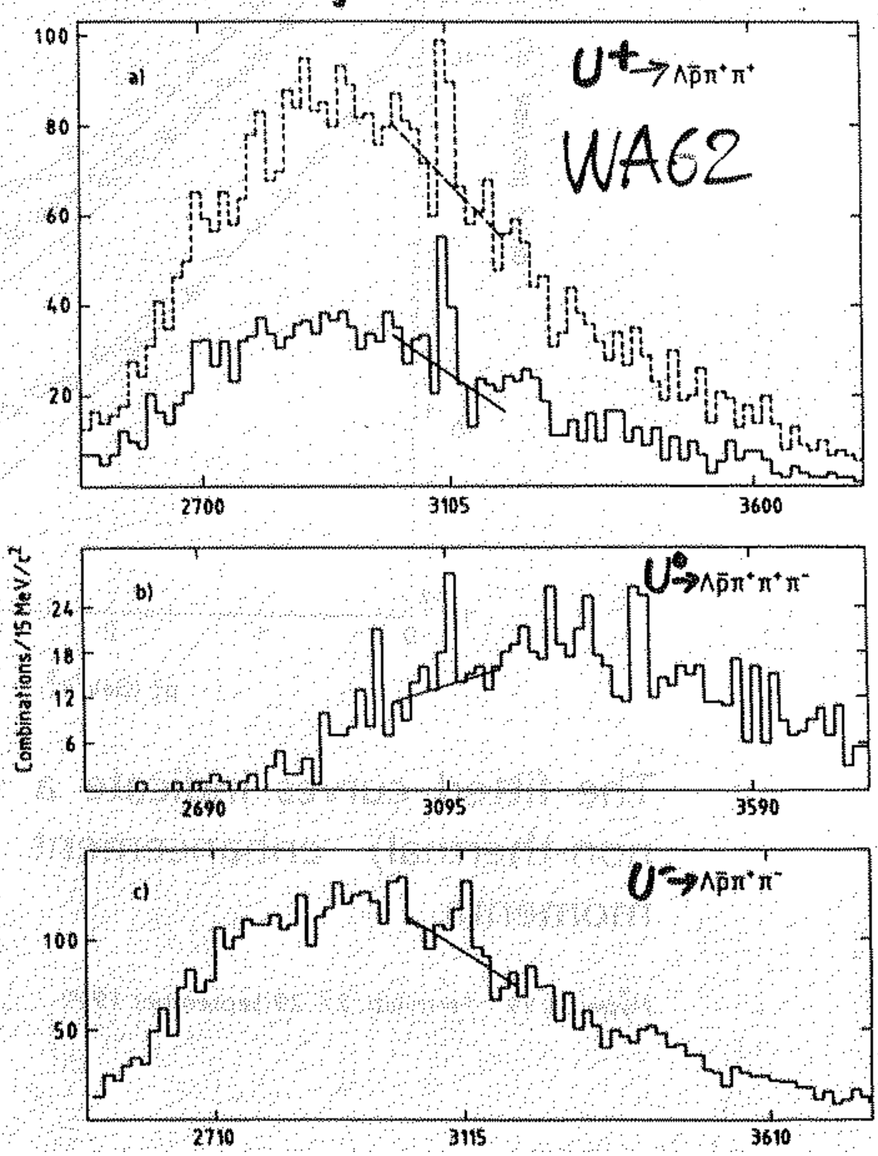
$S/B = 19/28$

$\sigma \cdot B = 1.2 \pm 0.7 \pm 0.2\ \mu b/Be$

$U^- \rightarrow \Lambda \bar{p} \pi^+ \pi^-$

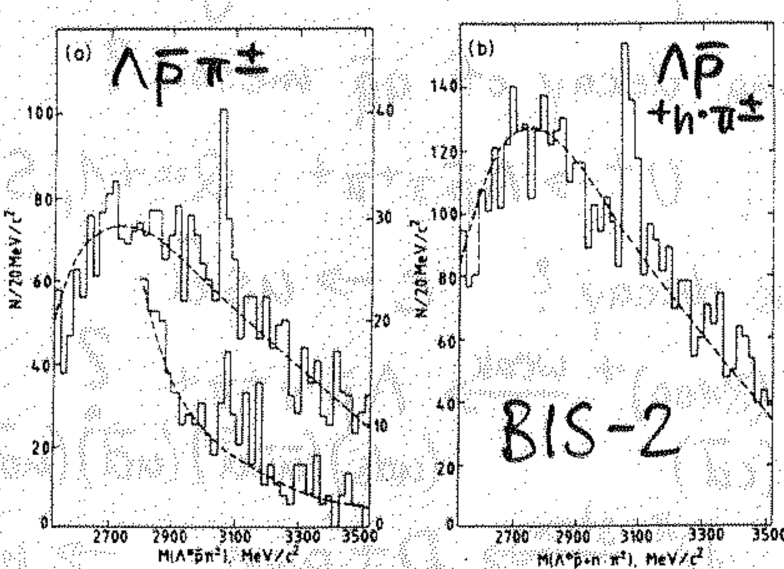
$S/B = 62/187$

$\sigma \cdot B = 3.0 \pm 1.7 \pm 0.5\ \mu b/Be$



- $\underline{\text{BIS-2}}$, Serpukhov

40 GeV $n + A$



→ Observed peaks in

$$\left.\begin{array}{l} U^+ \to \Lambda\bar{p}\pi^+\pi^+ \\ U^0 \to \Lambda\bar{p}\pi^+ \\ U^- \to \Lambda\bar{p}\pi^+\pi^- \\ U^{--} \to \Lambda\bar{p}\pi^- \end{array}\right\}$$

$\frac{S}{B} = \frac{242}{667}$ c.c.: $\frac{S}{B} = \frac{210}{921}$

$m = 3060\ \mathrm{MeV}/c^2$

$\sigma \cdot B = 1\,\mu b/N$ for $x_F > 0.2$

- $\underline{\text{E771}}$, Brookhaven

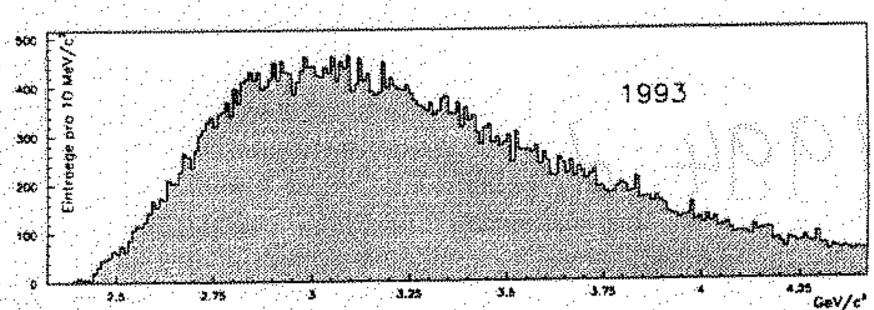
8 GeV $\bar{p} + p$

Looked for $\bar{\Lambda}p$ + pion states ⇒ no signal!

$\sigma \cdot B < 23\,nb$, $\bar{U}^0 \to \bar{\Lambda}p\pi^-$
$17\,nb$, $\bar{U}^+ \to \bar{\Lambda}p\pi^+\pi^-$
$12\,nb$, $\bar{U}^{++} \to \bar{\Lambda}p\pi^+$

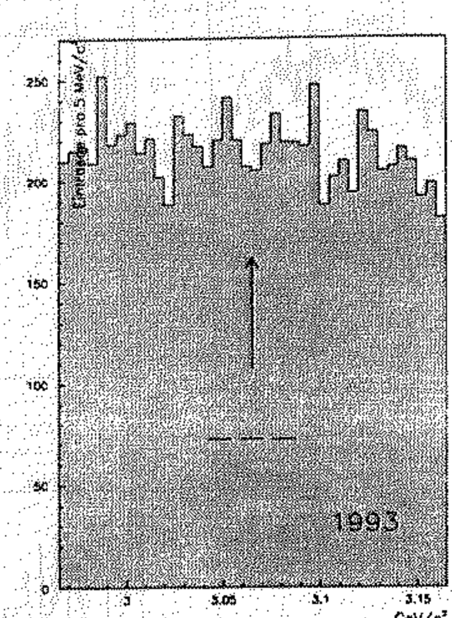
5. Upper limit for $\sigma \cdot B$ for $U^+ \to \Lambda \bar{p} \pi^+ \pi^+$

Use 1993 data set:

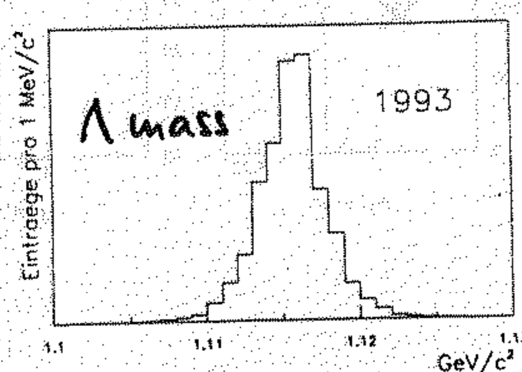


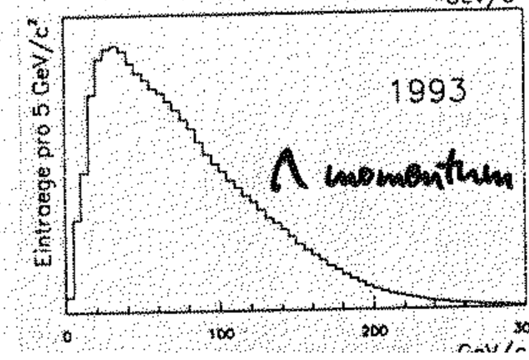
- **Cuts:**

Λ mass within 2.5σ
$\bar{p}$ momentum > 45 GeV/c
$\bar{p}$ RICH I.D
π^+ momenta > 5 GeV/c
π^+: K, p cand. excluded (RICH)
main vertex in target



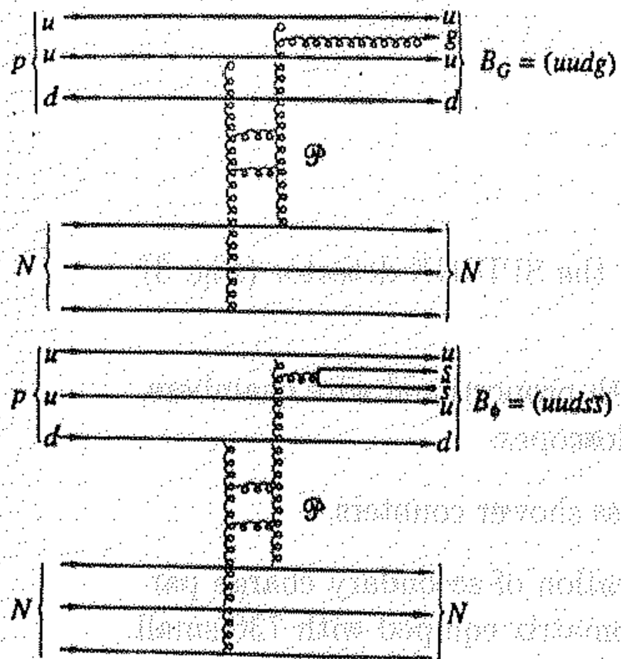
$$\boxed{\begin{array}{c}\sigma \cdot B < 0.18\ \mu b/\text{nucleon} \\ \text{FOR } U^+ \to \Lambda \bar{p} \pi^+ \pi^+\end{array}}$$

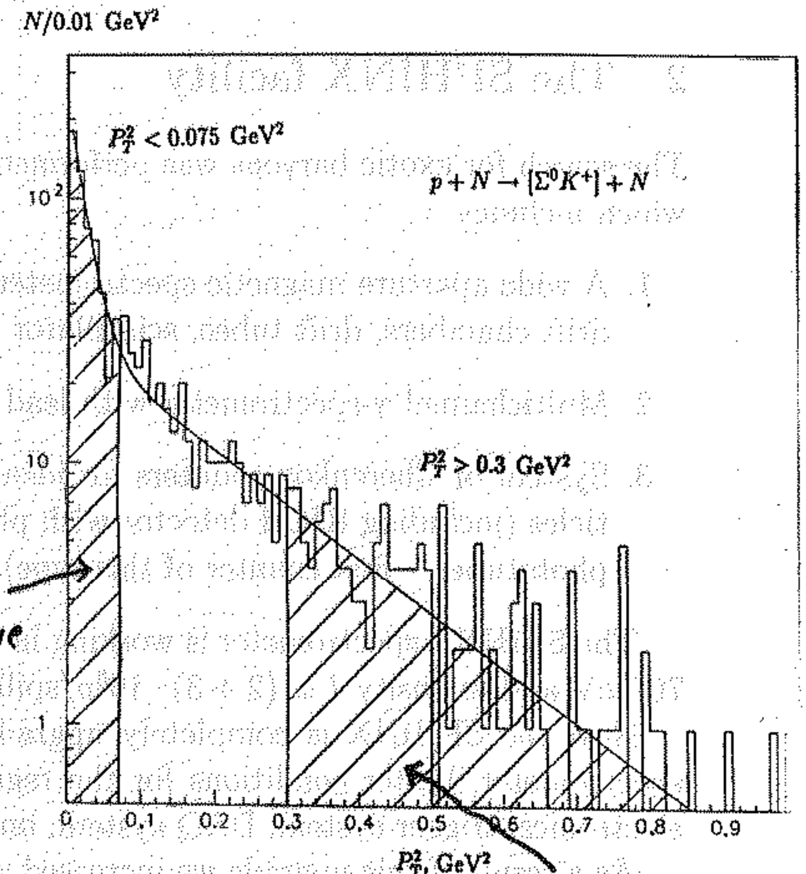




U. MULLER – WA89

Diffractive production

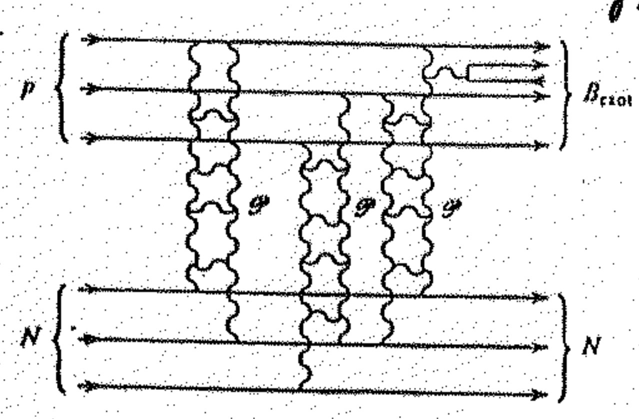


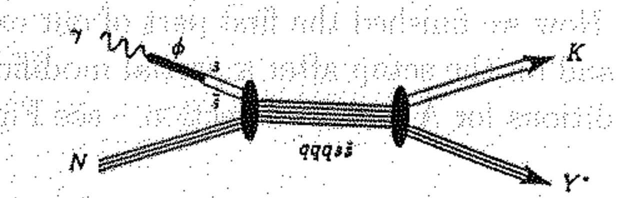


Diffractive coherent region

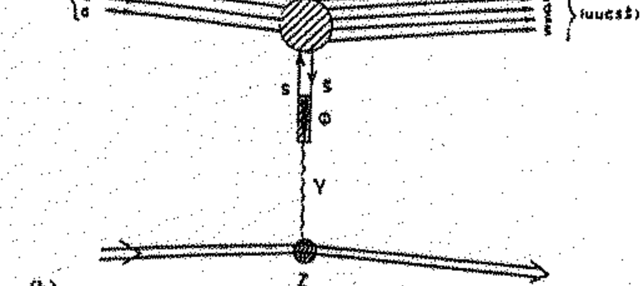
nonperipheral region

Nonperipheral production
(mechanism of pomeron rescattering)





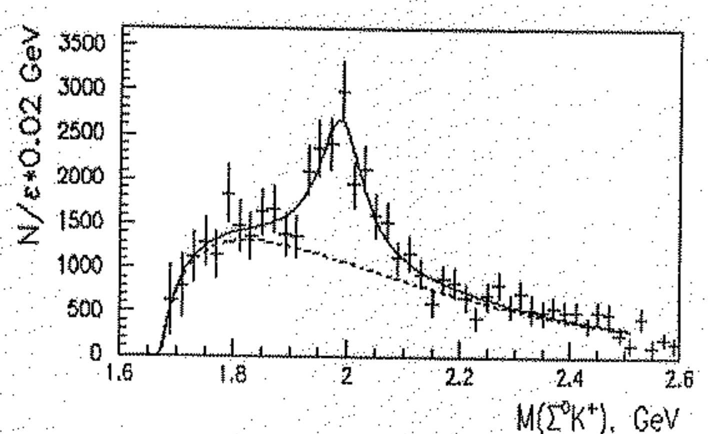
(a)



(b)

Search for exotic pentaquark baryons with hidden strangeness $|qqqs\bar{s}\rangle$ in diffractive production reactions $p + N \to Y^{*}K + N$

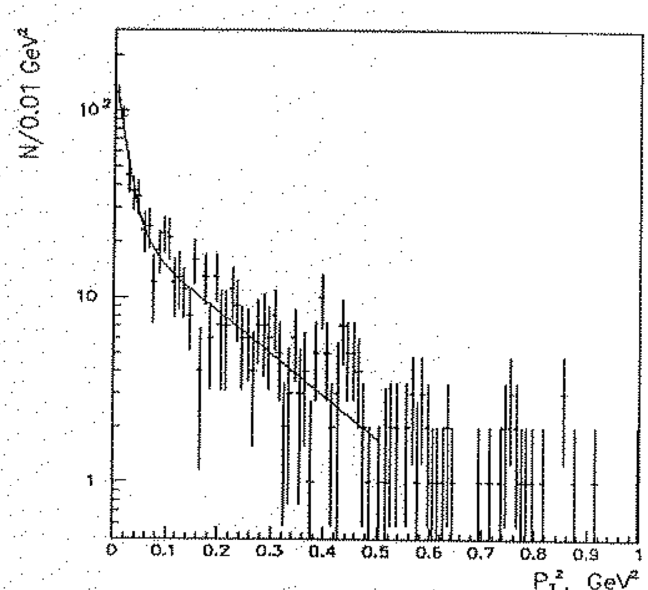
Experiment SPHINX at proton beam of IHEP accelerator with $E_p = 70\,\mathrm{GeV}$. Reaction $p + N \to [\Sigma^0 K^+] + N; \Sigma^0 \to \Lambda\gamma$ was separated (N-nucleon or C nucleus for coherent reaction).



$M(\Sigma^0 K^+)$ for all P_T^2 weighted with efficiency of the setup.

$X(2000) \to \Sigma^0 K^+ \left\}\begin{array}{lcl} M & = & 1989 \pm 6\,\mathrm{MeV} \\ \Gamma & = & 91 \pm 20\,\mathrm{MeV} \end{array}\right.$

This state is seen with high statistical level (> 10 s.d.).



dN/dP_T^2 – strong coherent production on C nuclei is observed ($b = 63 \pm 10\,\mathrm{GeV}^{-2}$)

Cross sections

$$\sigma[p + N \to X(2000) + N] \cdot BR[X(2000) \to \Sigma^0 K^+] = 95 \pm 20\,\mathrm{nb/nucleon}$$
$$\sigma[p + C \to X(2000) + C]_{\mathrm{coh.}} \cdot BR[X(2000) \to \Sigma^0 K^+] = 260 \pm 60\,\mathrm{nb}/C\ \mathrm{nucleus}$$

($\pm 20\%$ (system.) – Monte Carlo + absolute normalization)

Unusual dynamic properties of X(2000) state

a) $R = \frac{BR[X(2000) \to \Sigma K]}{BR[X(2000) \to \Delta(1232)\pi; p\pi^+\pi^-]} \gtrsim 1$

b) $\Gamma[X(2000)] \lesssim 100\,\mathrm{MeV}$

For usual $|qqq\rangle$ isobars:

a) $R \lesssim (\mathrm{few}) \cdot 10^{-2}$

b) $\Gamma(M \gtrsim 2000\,\mathrm{MeV}) \sim 300 \div 400\,\mathrm{MeV}$

X(2000) is serious candidate for pentaquark exotic baryon with hidden strangeness $|X(2000)\rangle = |uuds\bar{s}\rangle$

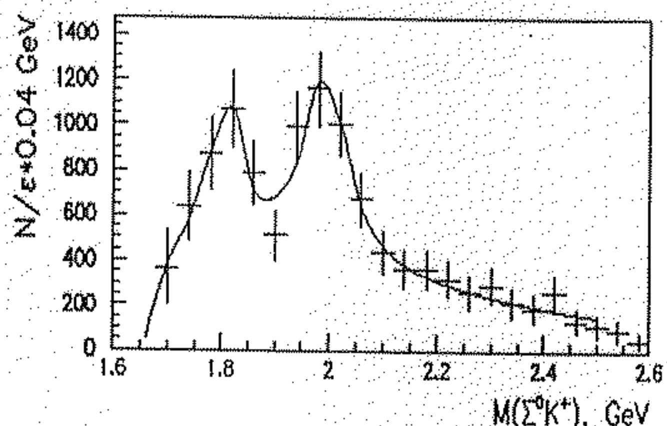
Study of coherent reaction $p + C \to [\Sigma^0 K^+] + C \ (P_T^2 < 0.1\,\mathrm{GeV}^2)$

In the $M(\Sigma^0 K^+)$ for this P_T^2 region the $X(2000)$ state and some threshold structure with $M \sim 1810\,\mathrm{MeV}$ are clearly seen (this structure is practically not seen in mass spectrum for all P_T^2 due to difficult background conditions). Study of the yield of $X(1810)$ as function of P_T^2 demonstrate that this state is produced only in the region of very small P_T^2 ($\lesssim 0.01\,\mathrm{GeV}^2$) where it is well defined:

$$X(1810) \to \Sigma^0 K^+ \left\{ \begin{array}{lcl} M & = & 1807 \pm 7\,\mathrm{MeV} \\ \Gamma & = & 62 \pm 19\,\mathrm{MeV} \end{array} \right.$$

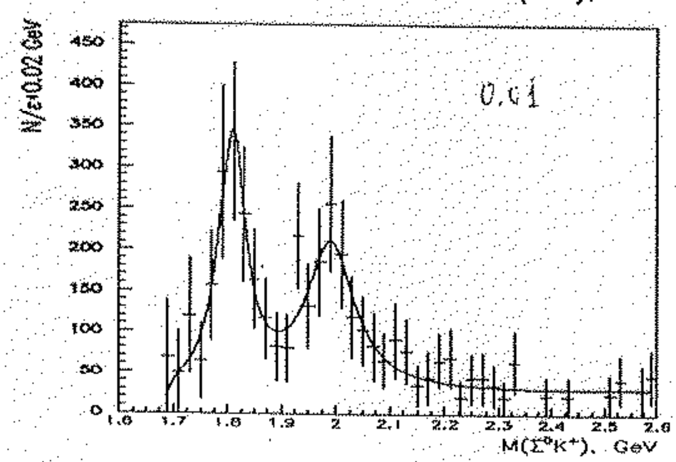
$$\sigma[p+C \to X(1810)+C]_{P_T^2<0.01\,\mathrm{GeV}^2} \cdot BR[X(1810) \to \Sigma^0 K^+] = 215 \pm 44\,\mathrm{nb} (\pm 30\%\,\mathrm{syst.})$$

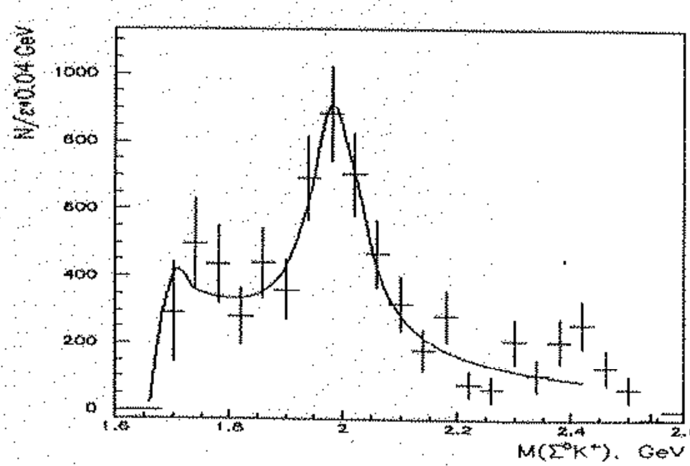
Possible explanation of unusual production properties of $X(1810)$: may be this is a Coulomb production process ? The value of the coherent cross section is not in contradiction with this hypothesis which is also supported by observation of $\Delta(1232)^+$ Coulomb production in the SPHINX experiment.

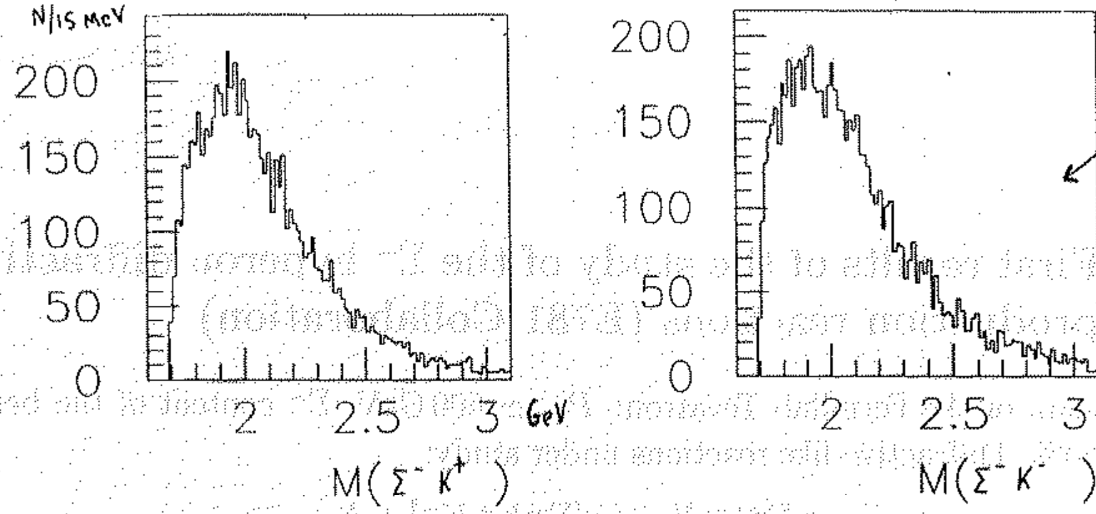


In the "restricted coherent region" $0.02 < P_T^2 < 0.1\,\mathrm{GeV}^2$ (without the influence of $X(1810)$ in $M(\Sigma^0 K^+)$ $X(2000)$ baryon is observed in the clearest way.

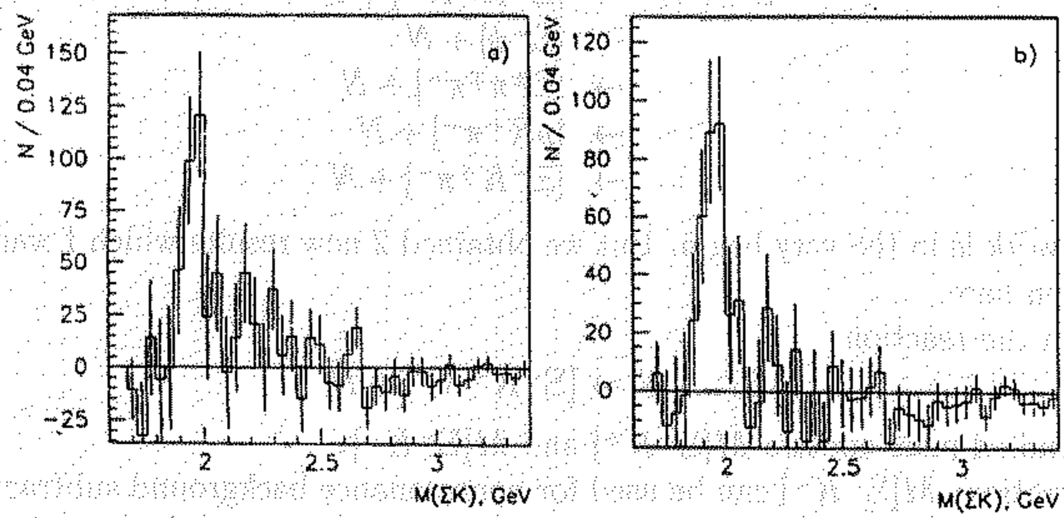
$\Downarrow$







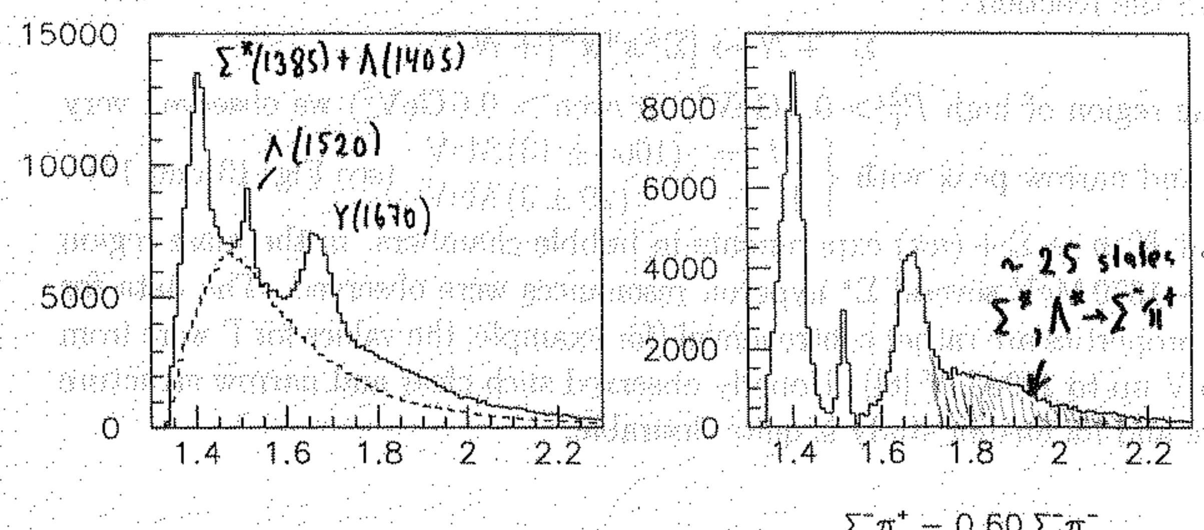
For nonresonance background evaluati



without $\phi \to K^+K^-$ band

Study of $M(\Sigma^- K^+)$ in the reaction $\Sigma^- + N \to [\Sigma^- K^+ K^-] + N$ in the SELEX experiment. Here the spectr $M(\Sigma^- K^-)$ with open exotic quantum number used for subtraction of nonresonance background in $M(\Sigma^- K^+)$ after so normalization. One presents in this figure $M(\Sigma^- K^+) - 0.95M(\Sigma^- K^-)$ (here 0.95 – normalization factor): (a) all events; (b) after subtraction of the events in ϕ band to suppress the influence of the reaction $\Sigma^- + N \to [\Sigma^- \phi] +$

$$\Sigma^- + N \to \Sigma^- \pi^+ \pi^- + N$$



Justification of background subtraction technique

Summary of summary

- Hyperon physics has matured very well in the last 40 years.
- It is still probing some of the best subjects in particle physics:
  - mixing
  - CP violation
  - SU(3) breaking
  - QCD
  - new states of matter
- Although there is a lot to do, do we have the willpower to get out of bed and face the issues at hand?