FERMILAB-MISC-1992-01

Fermilab

Fermi National Accelerator Laboratory
P.O. Box 500 • Batavia, Illinois • 60510

Joint Experimental Theoretical Physics Seminar

Speaker: J. Duryea
University of Minnesota

Topic: "The Polarization and Magnetic Moment of the Cascade Minus Hyperon"

Date: Friday January 17, 1992

Time: 4:00 p.m.

Location: Fermi National Accelerator Laboratory
Wilson Hall
Curia II

–Wine and cheese will be served at 3:45 p.m.–

****PLEASE POST****

1

A PRECISION MEASUREMENT OF THE POLARIZATION AND MAGNETIC MOMENT OF THE Ξ^- HYPERON

FERMILAB E-756

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University of Minnesota

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Rutgers University

P. M. Ho, M. J. Longo, A. Nguyen
University of Michigan

C. James, K. B. Luk, R. Rameika
Fermilab

— grad students

— post docs

OUTLINE

(1) History and Theory

(2) Detection Apparatus

(3) Analysis Procedure

(4) Results and Conclusions

Spin polarization and magnetic moments are two related but separate phenomena

Polarization:

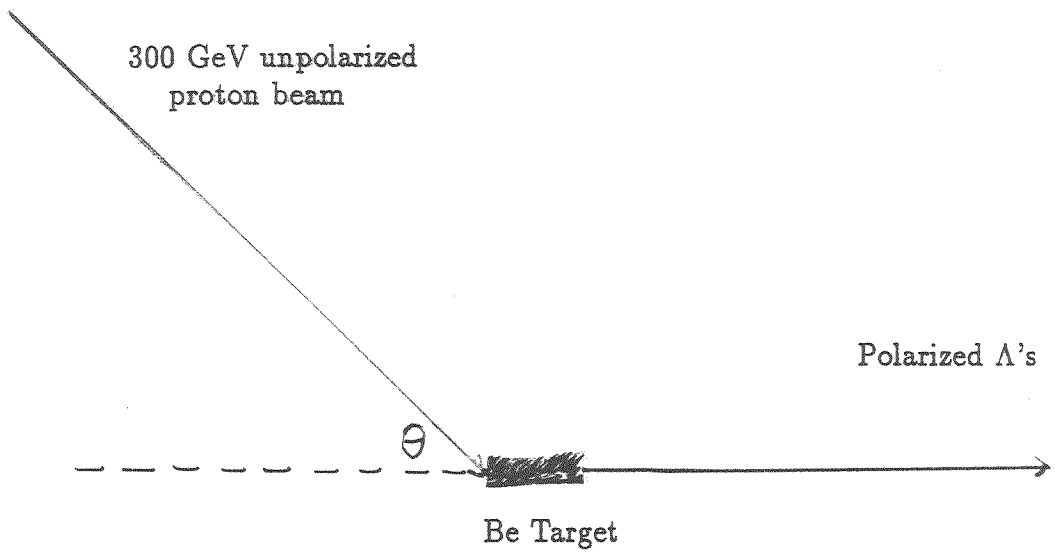
$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

Produced in an interaction.

Magnetic moment:

A static property which deals with quark confinement

FERMILAB E-8 DISCOVERS Λ POLARIZATION*



This is not expected!

Subsequently, this method has been used to make polarized Σ's, Ξ's Λ's, and $\bar{\Xi}^+$'s

* G. Bunce et. al., Phys. Rev. Lett. **36**, 1113 (1976)

$$P = \frac{(f^* g)}{f^2 + g^2}$$

f- spin independent part
g- spin dependent part

At low energies there are few dominant amplitudes but at high energies there are many.

So why are high energy hyperons polarized?

Kinematic Variables x_F and p_T

Inclusive reaction: $p + p \rightarrow \Xi^- + ?$

1) x_F:

$x_F = \frac{P_L}{P_{Lmax}}$ defined in c.o.m. frame

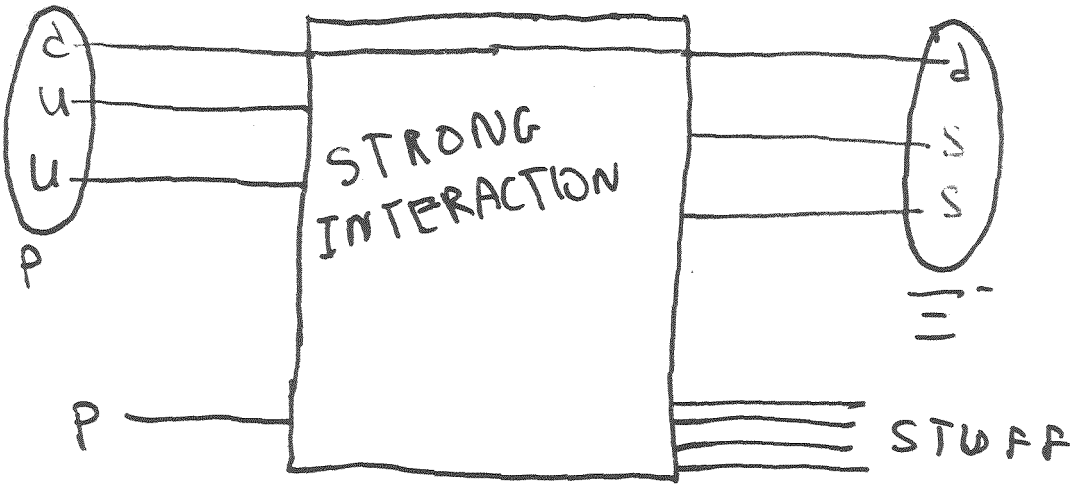
$x_F \approx \frac{P_{out}}{P_{beam}}$(lab) for $x_F > 0.2$

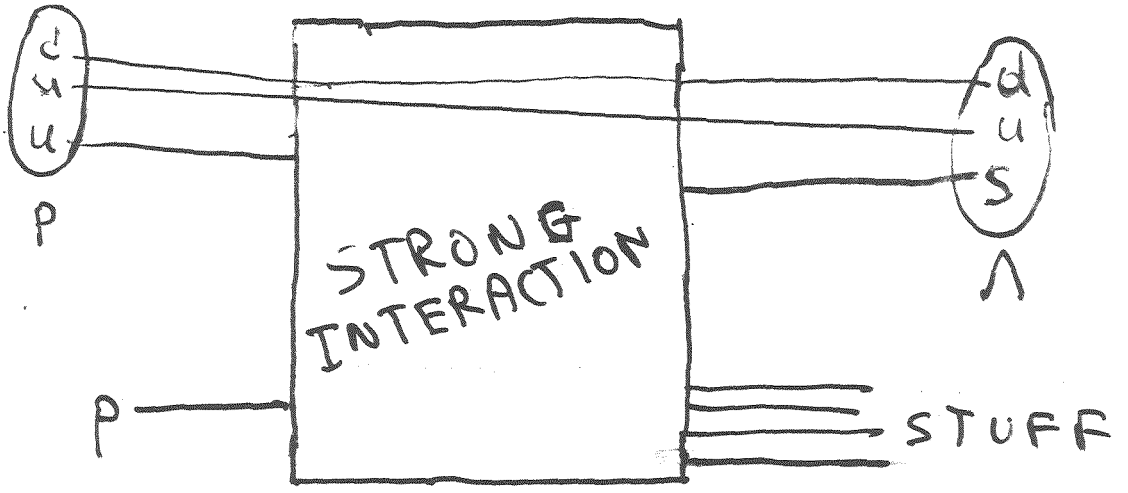
2) p_T: Transverse momentum

$p_T = P_{out} sin\theta_P = P_{out}\theta_P \qquad (sin\theta = \theta)$

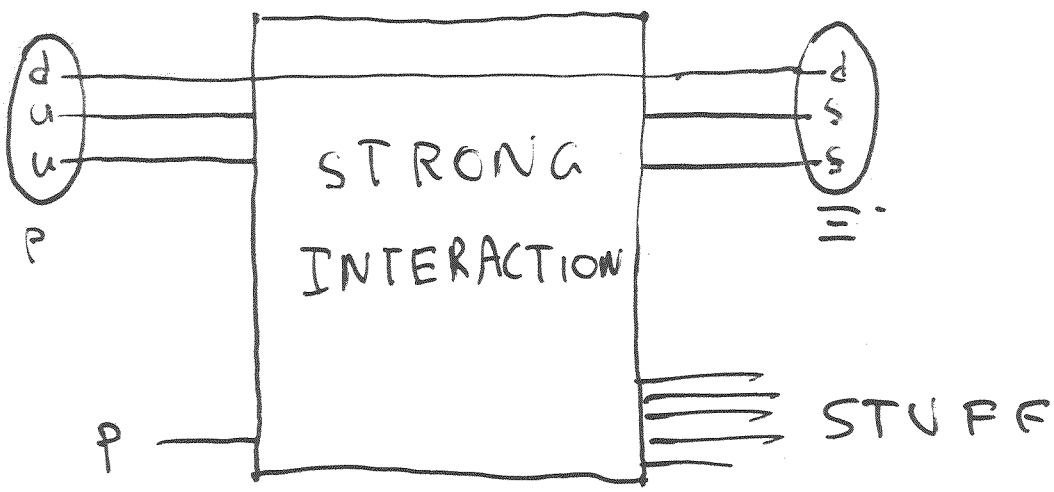
Tells how "hard" the interaction is.

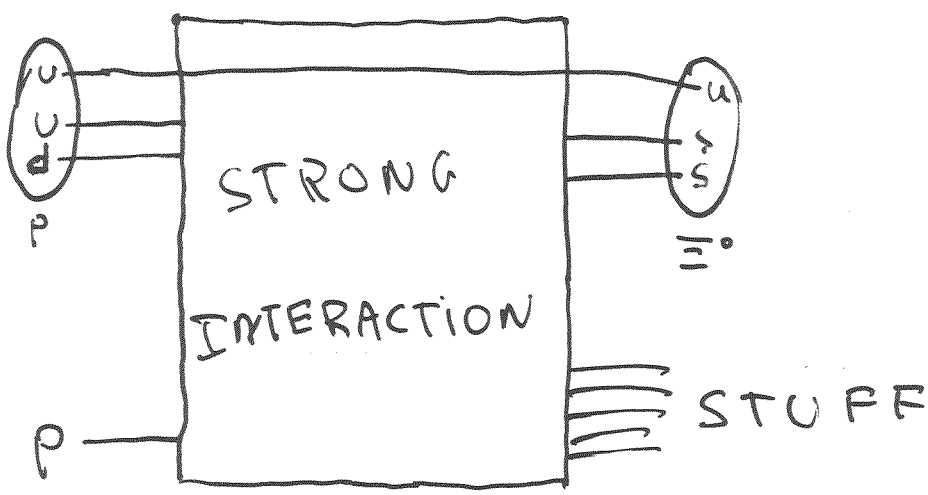
Ξ^- and Λ production





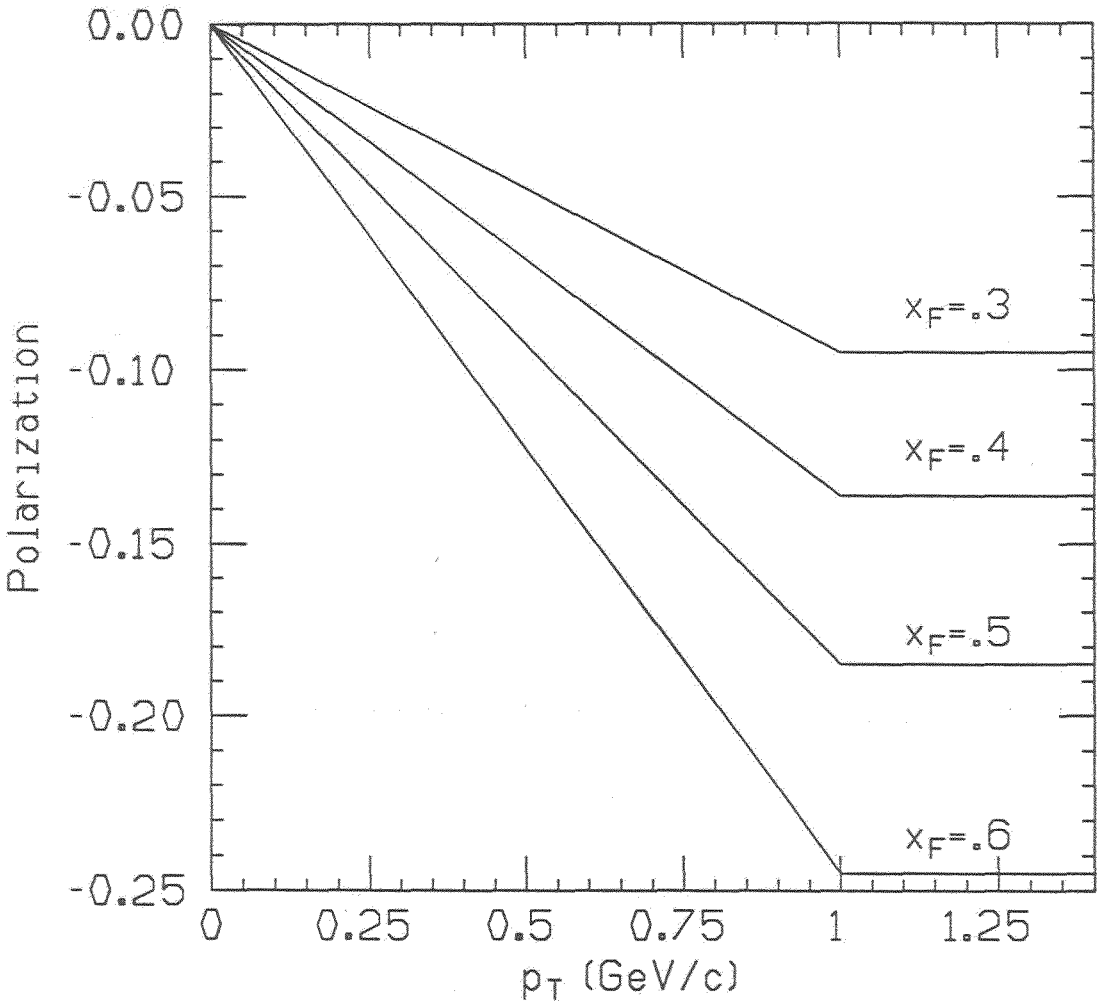
Ξ^0 and Ξ^- production





Models predict $P_{\Xi^-} = P_{\Xi^0}$

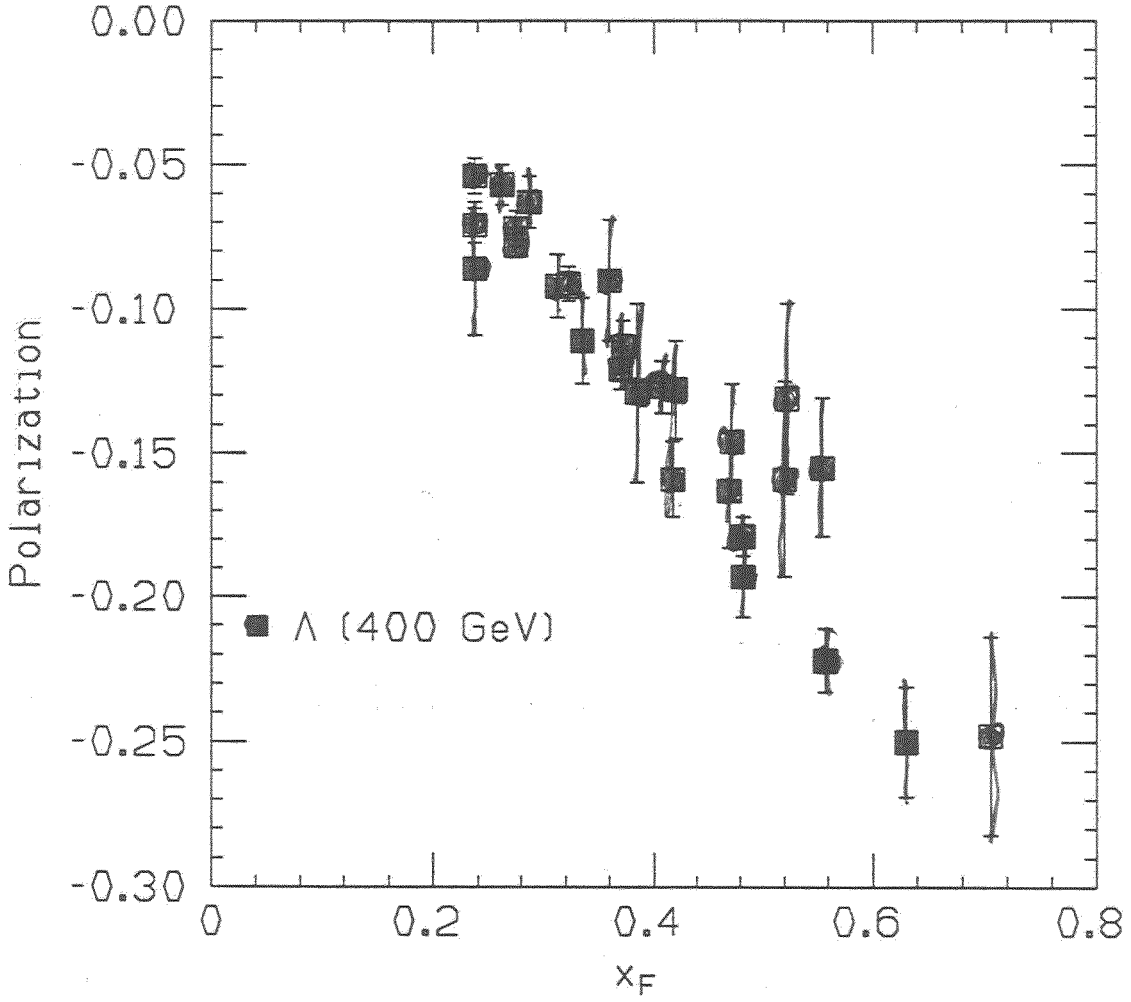
Schematic picture of P_Λ



What's so special about $p_T = 1$ GeV?

$m_p = .94$ GeV $\quad m_\Lambda = 1.1$ GeV

P_Λ for data with $p_T > 1$ GeV



Why measure μ_{Ξ}?

As for any particle, measuring μ should give some information about its internal structure and interactions.

Also, $\mu_{hyperon}$ measurements provide a testing ground for theoretical models.

Broken SU(6) Model

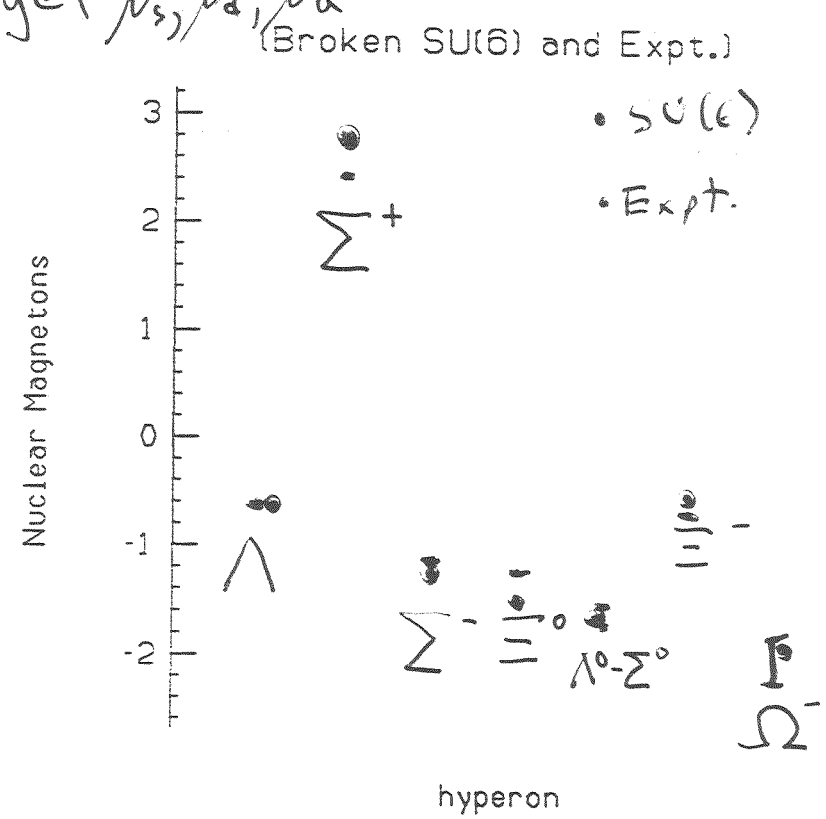
Baryon	Quark wave function
$p\uparrow$	$\sqrt{2/3}u\uparrow u\uparrow d\downarrow - \sqrt{1/6}\,(u\uparrow u\downarrow + u\downarrow u\uparrow)d\uparrow$
$n\uparrow$	$\sqrt{2/3}d\uparrow d\uparrow u\downarrow - \sqrt{1/6}\,(d\uparrow d\downarrow + d\downarrow d\uparrow)u\uparrow$
$\Lambda\uparrow$	$\sqrt{1/2}(u\uparrow d\downarrow - u\downarrow d\uparrow)s\uparrow$
$\Sigma^+\uparrow$	$\sqrt{2/3}u\uparrow u\uparrow s\downarrow - \sqrt{1/6}\,(u\uparrow u\downarrow + u\downarrow u\uparrow)s\uparrow$
$\Sigma^0\uparrow$	$\sqrt{2/3}u\uparrow d\uparrow s\downarrow - \sqrt{1/6}\,(u\uparrow d\downarrow + u\downarrow d\uparrow)s\uparrow$
$\Sigma^-\uparrow$	$\sqrt{2/3}d\uparrow d\uparrow s\downarrow - \sqrt{1/6}\,(d\uparrow d\downarrow + d\downarrow d\uparrow)s\uparrow$
$\Xi^0\uparrow$	$\sqrt{2/3}s\uparrow s\uparrow u\downarrow - \sqrt{1/6}\,(s\uparrow s\downarrow + s\downarrow s\uparrow)u\uparrow$
$\Xi^-\uparrow$	$\sqrt{2/3}s\uparrow s\uparrow d\downarrow - \sqrt{1/6}\,(s\uparrow s\downarrow + s\downarrow s\uparrow)d\uparrow$
$\Omega^-\uparrow$	$s\uparrow s\uparrow s\uparrow$

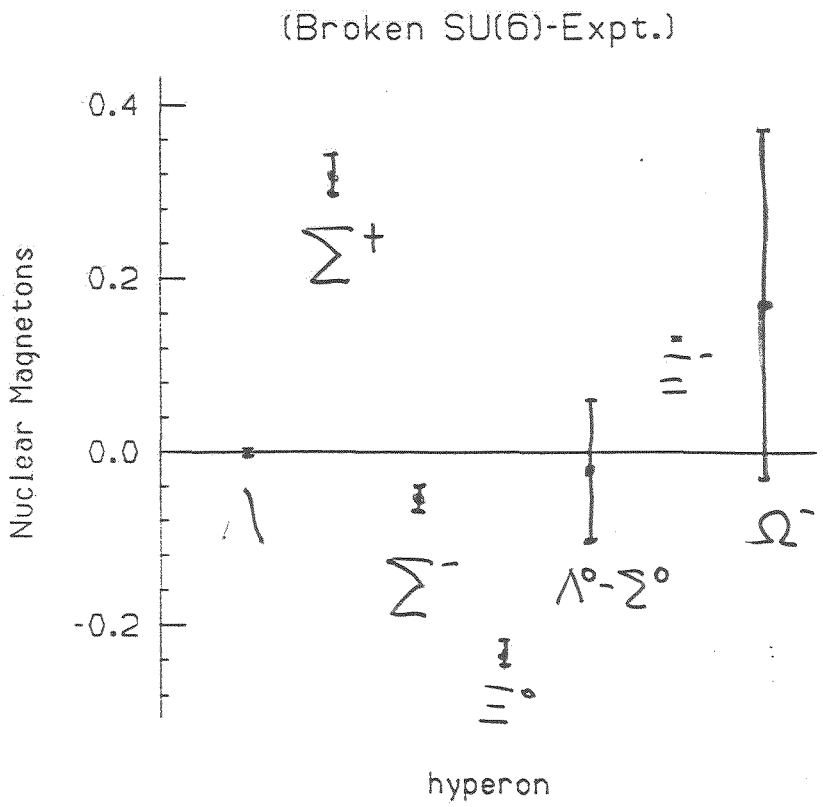
Table 1.1: The baryon SU(6) wave functions.

$$\mu_i = g\frac{q_i}{2m_i c}s_i$$

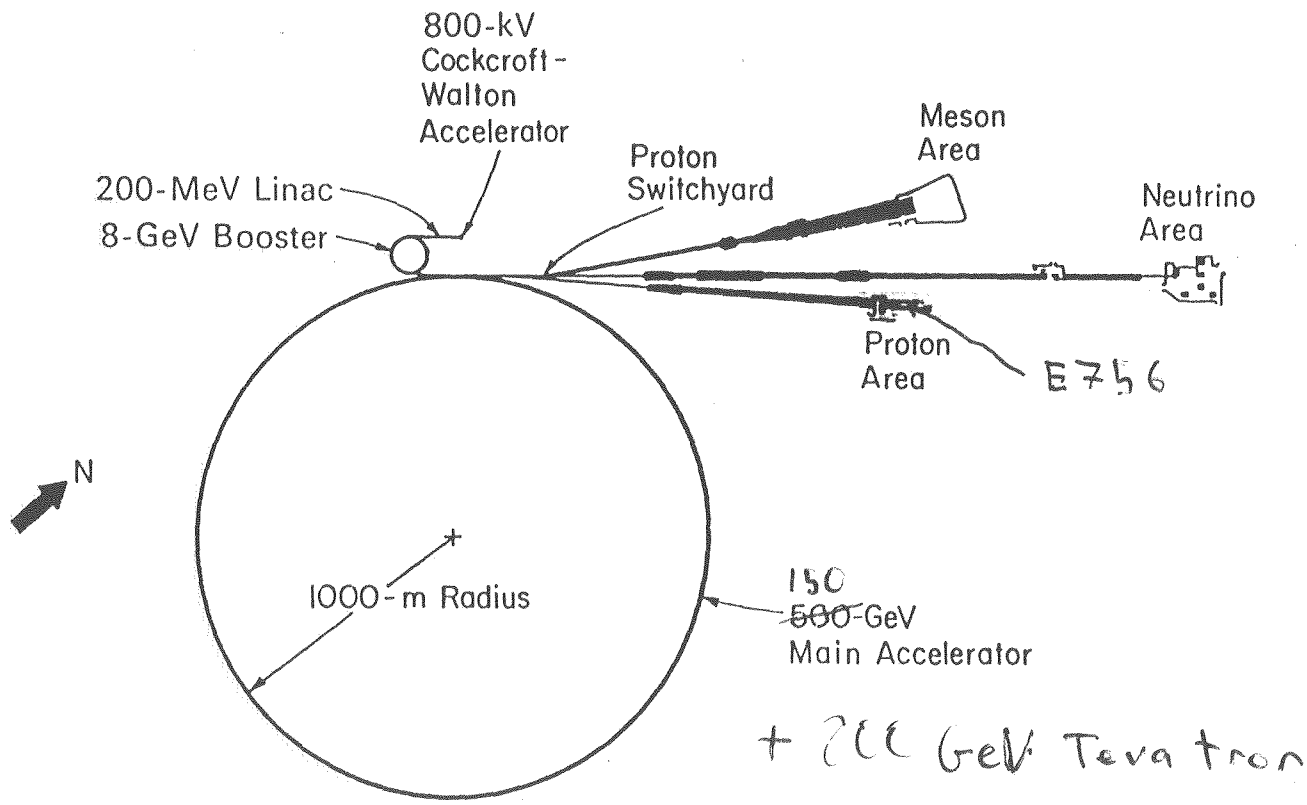
$$\mu_B = \langle B|\sum_i \vec{\mu}_i|B\rangle$$

μ_p, μ_n, and μ_Λ are used as input to get μ_s, μ_d, μ_u

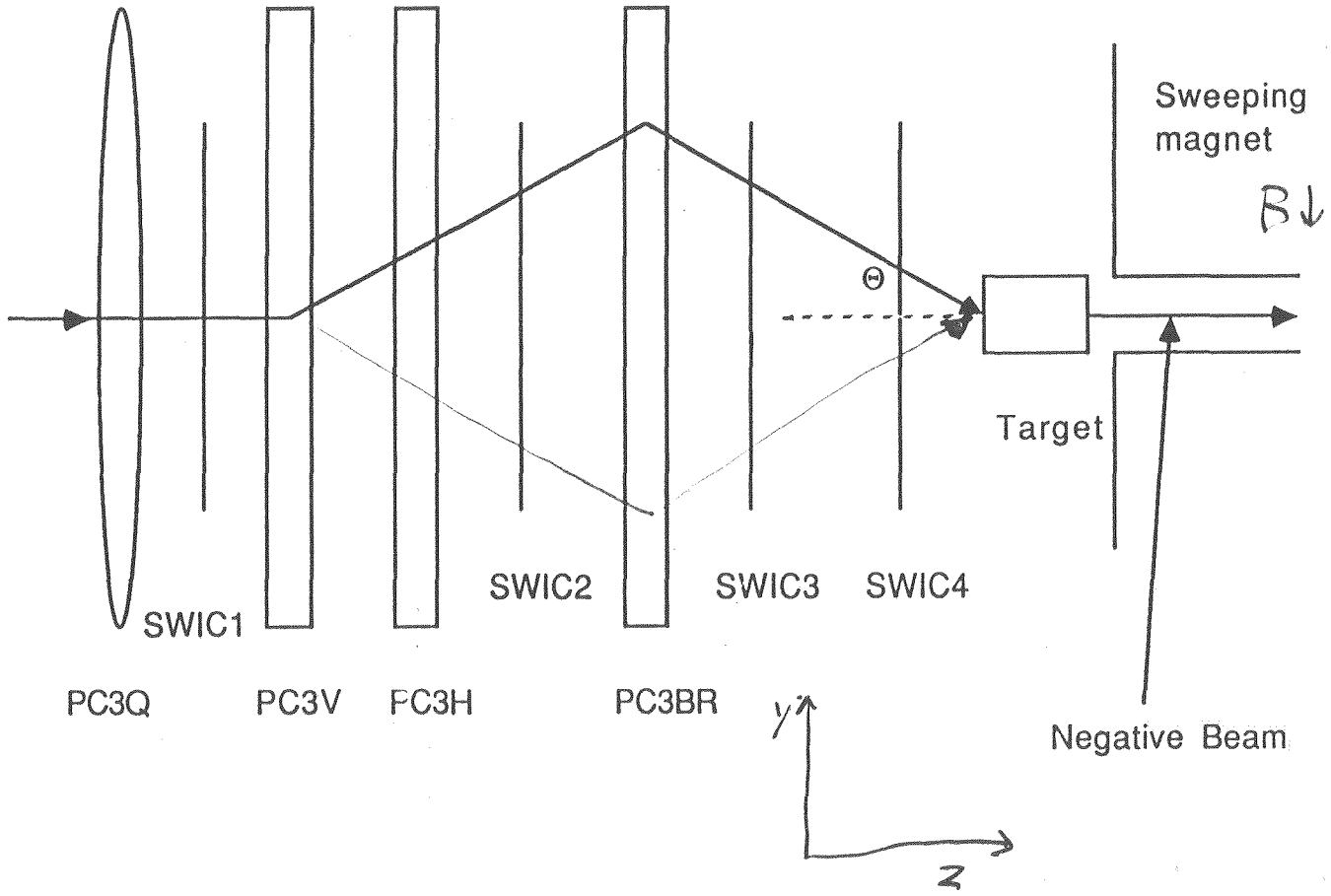




More sophisticated models don't do much better


800-kV
Cockcroft-
Walton
Accelerator
200-MeV Linac
8-GeV Booster
Proton
Switchyard
Meson
Area
Neutrino
Area
Proton
Area
E756
N
1000-m Radius
150
~~500~~-GeV
Main Accelerator
+ 200 GeV Tevatron

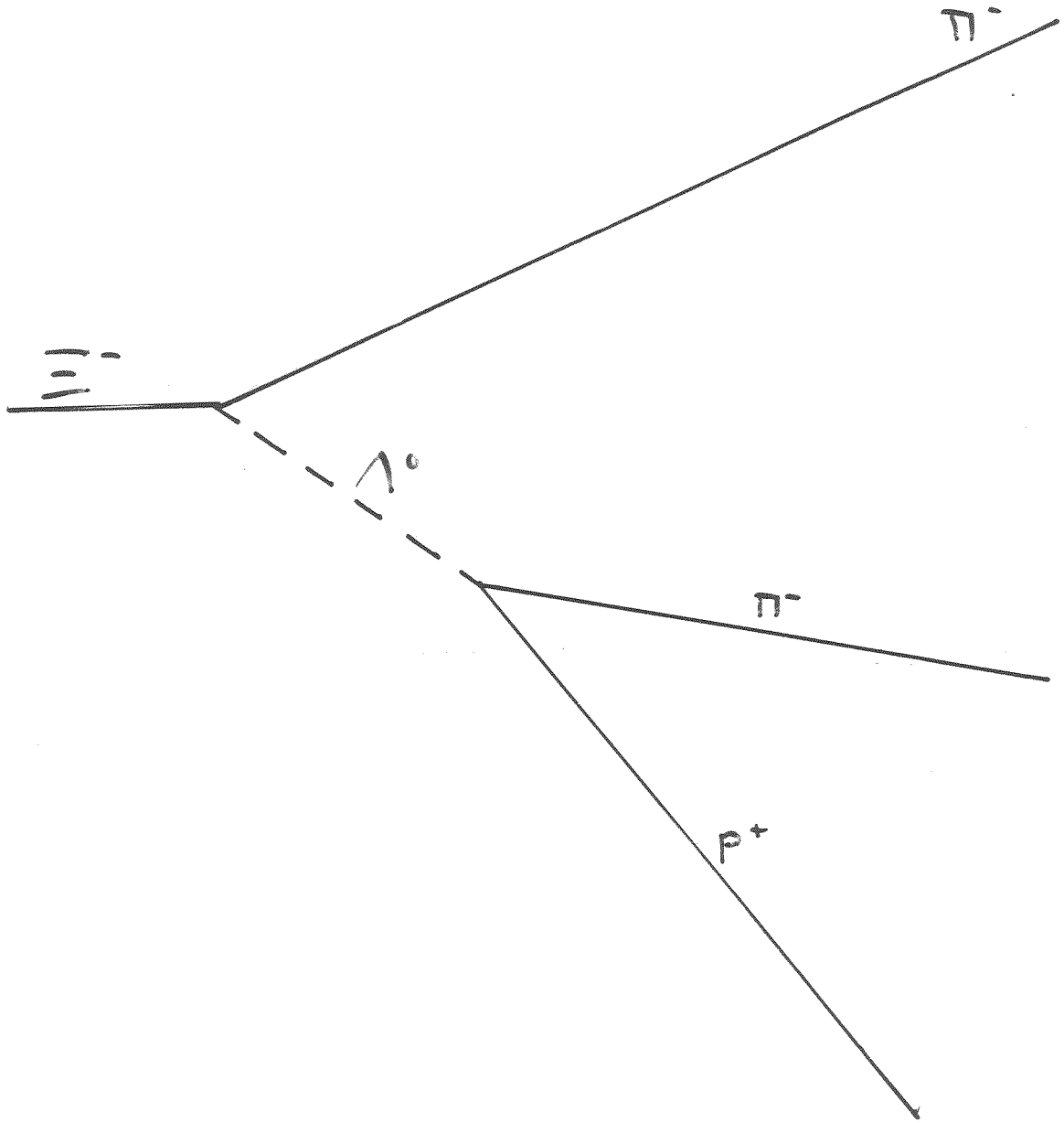
$\Theta = 2.4$ mrad



EVENT TOPOLOGY

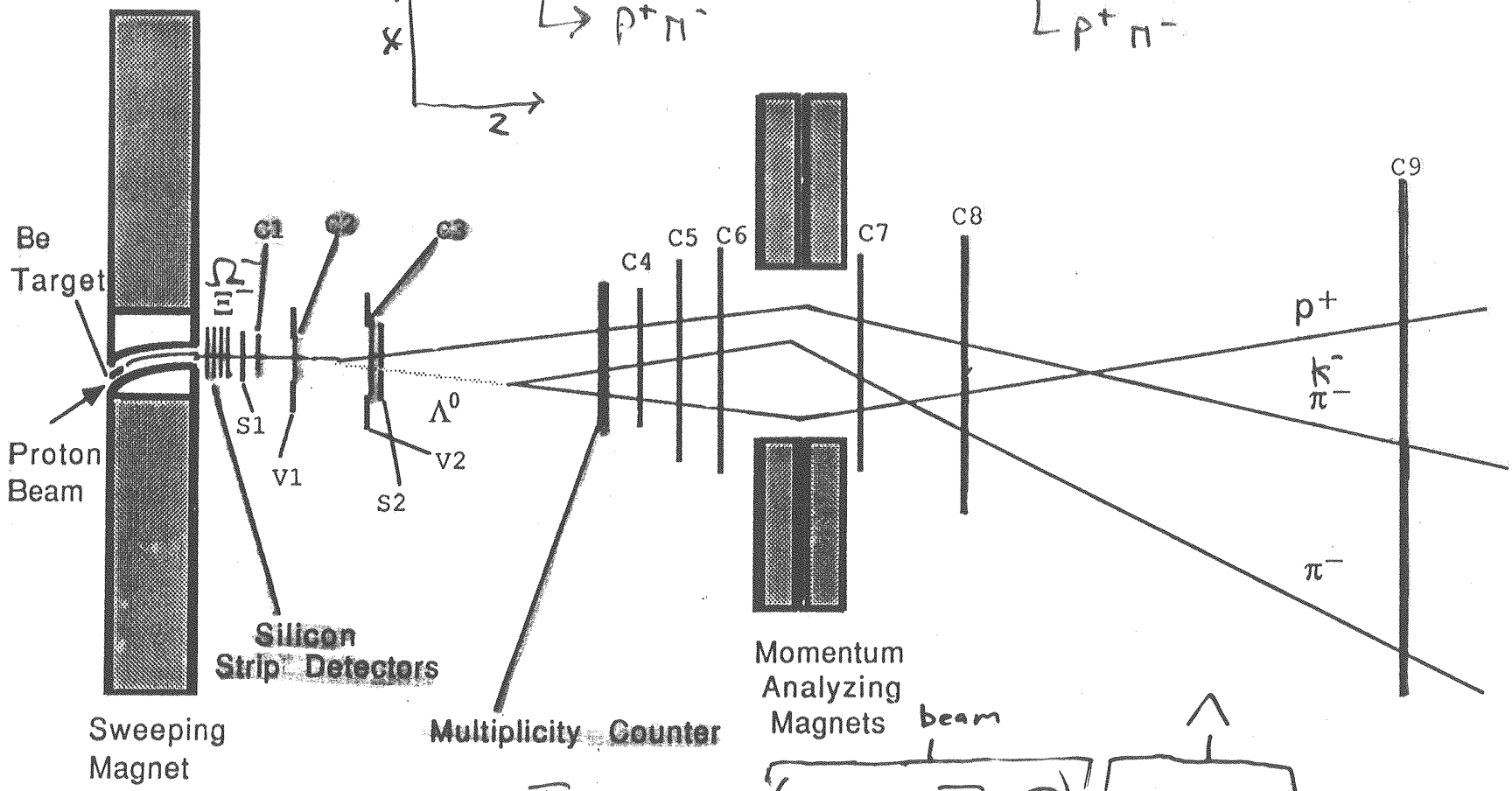
$\Xi^- \rightarrow \Lambda^0 \pi^-$

$\hookrightarrow p^+ \pi^-$



$\Xi^- \to \Lambda \pi^-$
$\hookrightarrow p^+ \pi^-$

$\Omega^- \to \Lambda K^-$
$\hookrightarrow p^+ \pi^-$



$$\text{Trigger} = \overbrace{(S1 \cdot S2 \cdot \overline{V1} \cdot \overline{V2})}^{\text{beam}} \cdot \overbrace{\underline{C8_{\pi}} \cdot \underline{C9_{p^+}}}^{\Lambda} \cdot M$$

Plan View of the E756 Spectrometer

RUNNING CONDITIONS

1) 5 Sweeper magnet fields. This means 5 different field integral values and momentum spectra

2) Use both signs of the analyzing magnets.

3) Change targeting angle.
   ± angle
   0 mrad targeting
   horizontal targeting

POLARIZATION ANALYSIS

1) $\vec{P}_\Lambda = \frac{(\alpha_\Xi + \hat{\Lambda}\cdot\vec{P}_\Xi)\hat{\Lambda} + \beta_\Xi(\vec{P}_\Xi \times \hat{\Lambda}) + \gamma_\Xi(\hat{\Lambda}\times\vec{P}_\Xi)\times\hat{\Lambda}}{1+\alpha_\Xi\hat{\Lambda}\cdot\vec{P}_\Xi}$

2) $\frac{dn}{dcos\theta_i} = \frac{1}{2}(1 + \alpha_\Lambda P_{\Lambda i} cos\theta_i)$

θ_i is the angle between the axis i and the proton direction in the Λ rest frame.

Additional points:

A) Use the Hybrid Monte Carlo technique to account for the acceptance.

B) Bias cancelation:

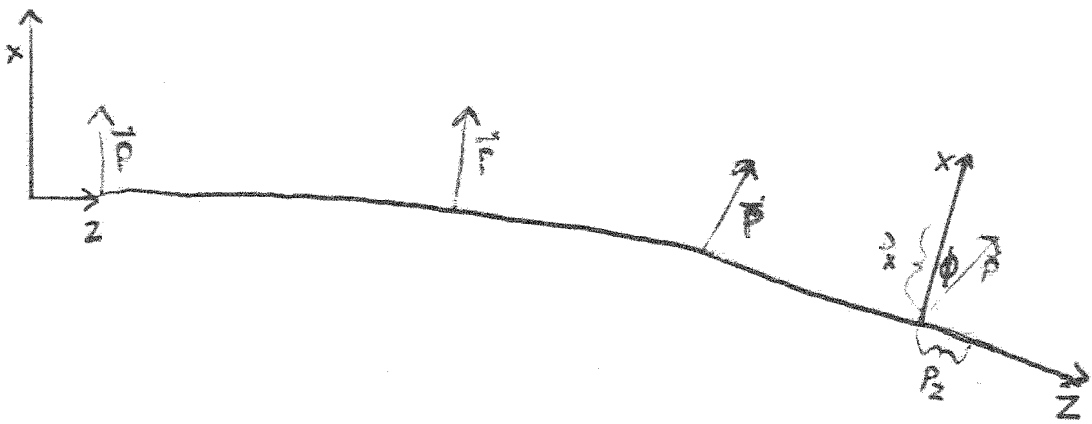
$A_+ = B + P$ $\qquad$ $A_- = B - P$

$P = \frac{A_+ - A_-}{2}$ $\qquad$ $B = \frac{A_+ + A_-}{2}$

MAGNETIC MOMENT ANALYSIS

$$\Phi = tan^{-1}\left(\frac{P_z}{P_x}\right) = \underbrace{\frac{q}{\beta m_\Xi c^2}\left(-\frac{\mu_\Xi m_\Xi}{\mu_N m_p} - 1\right)}_{\text{const}} \int B dl$$

$\beta = 1$, q=-e
m_p is the mass of the proton
μ_N is the nuclear magneton: $(e\hbar/2m_pc)$



But how can you tell whether $\vec{P}$ has rotated through an extra 360° or flipped its sign?

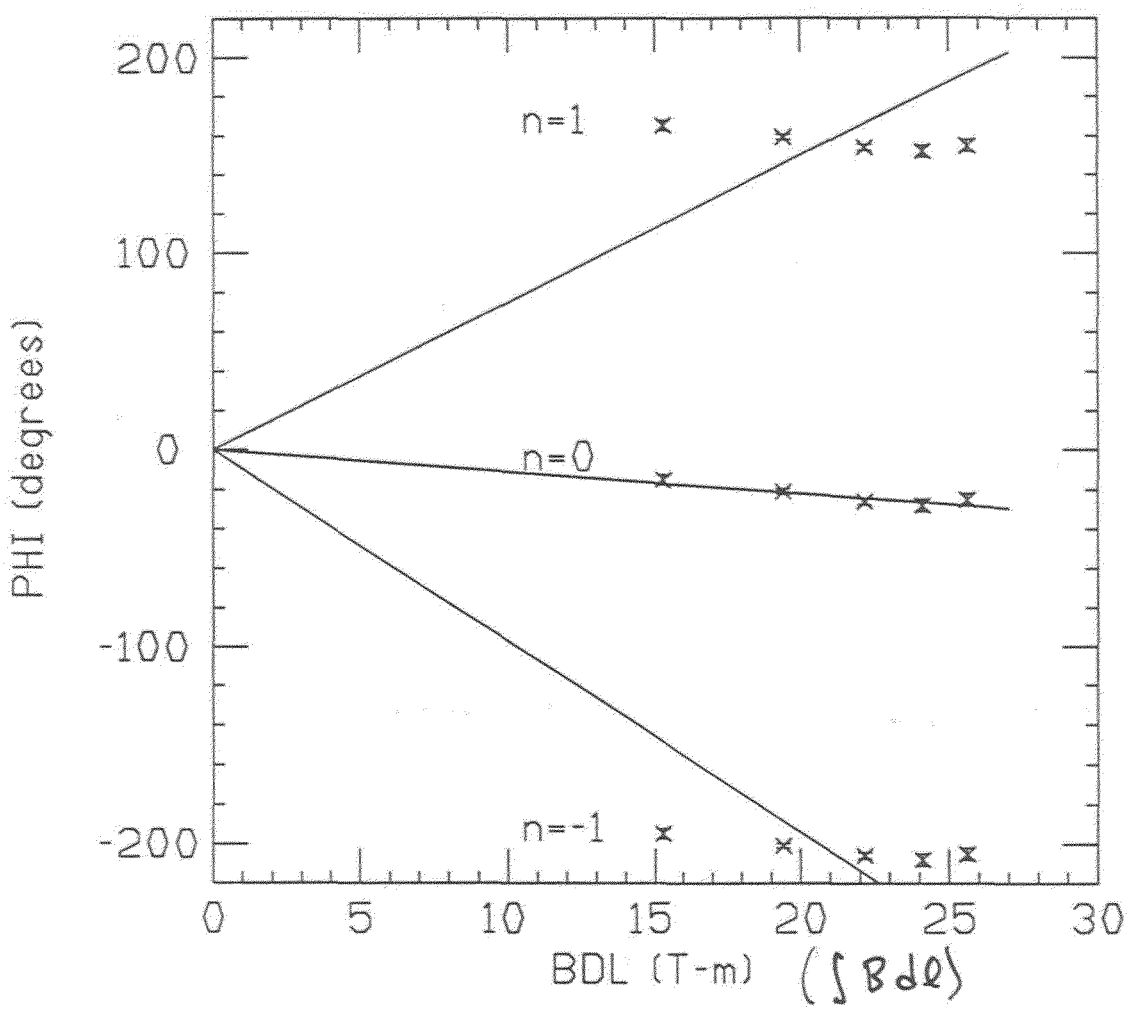
$$\Phi = \Phi \pm n180°$$

RESULTS

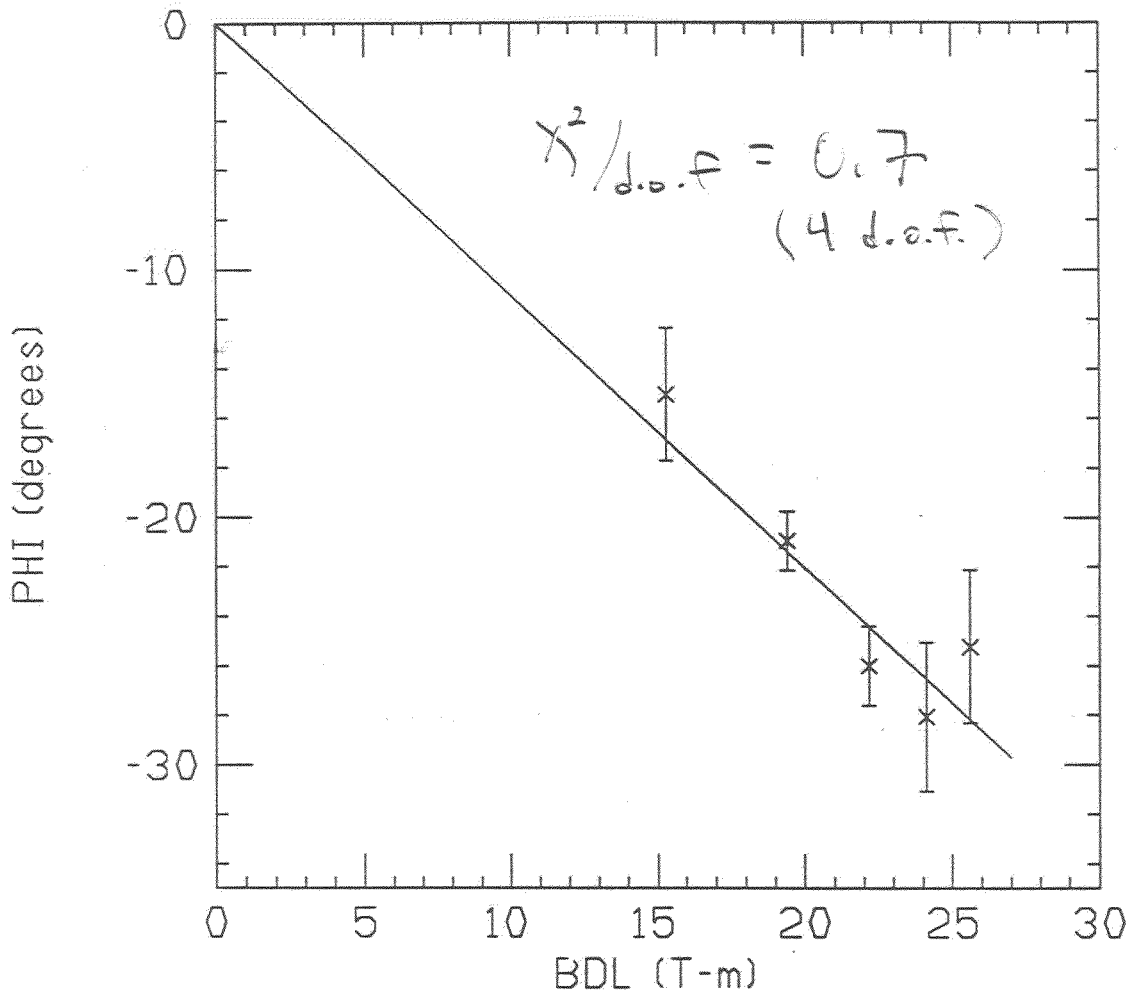
1) 4.37×10^6 Ξ^-'s produced with a vertical production angle

2) $229K$ Ξ^-'s produced with a horizontal production angle of 1.3 mrad

3) $514K$ Ξ^-'s produced with a 0 mrad production angle

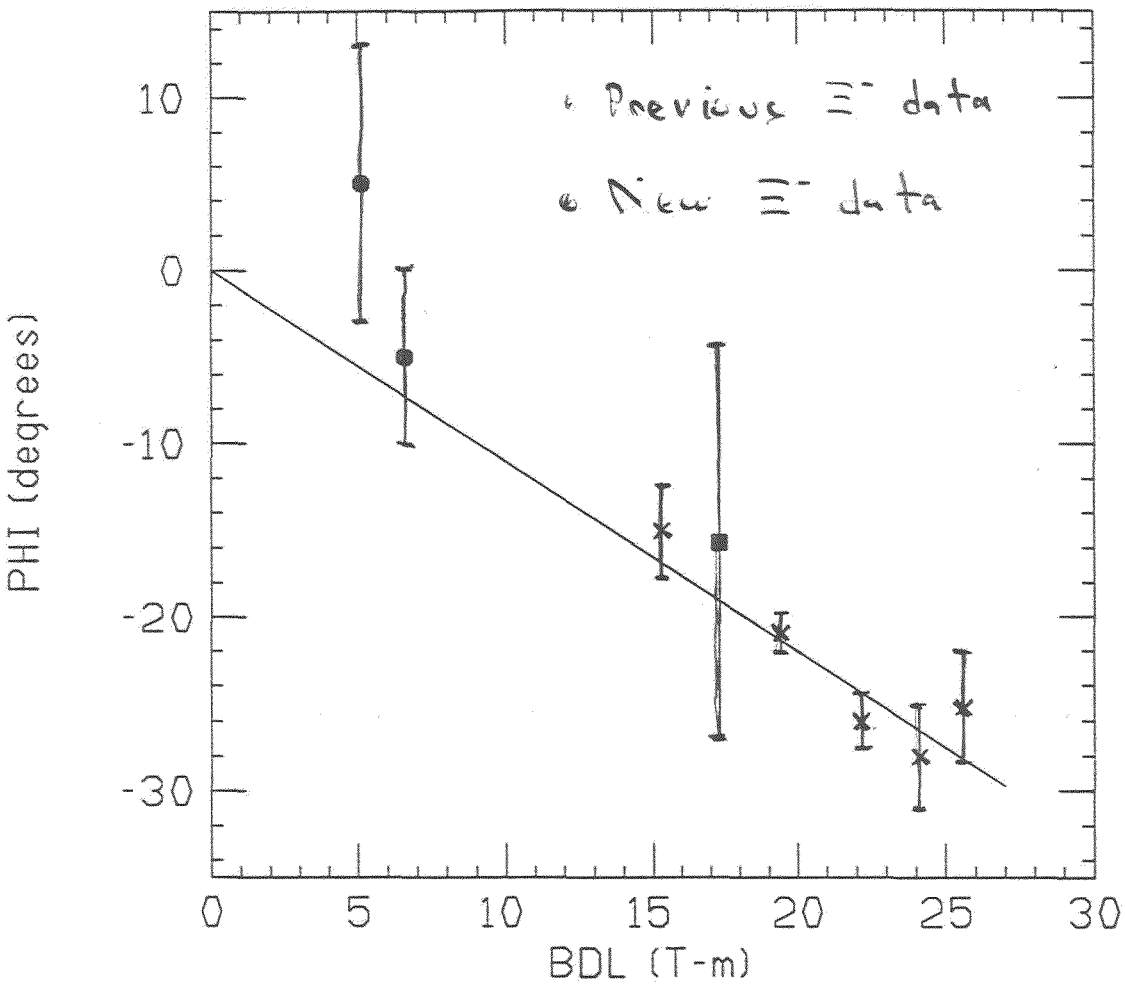


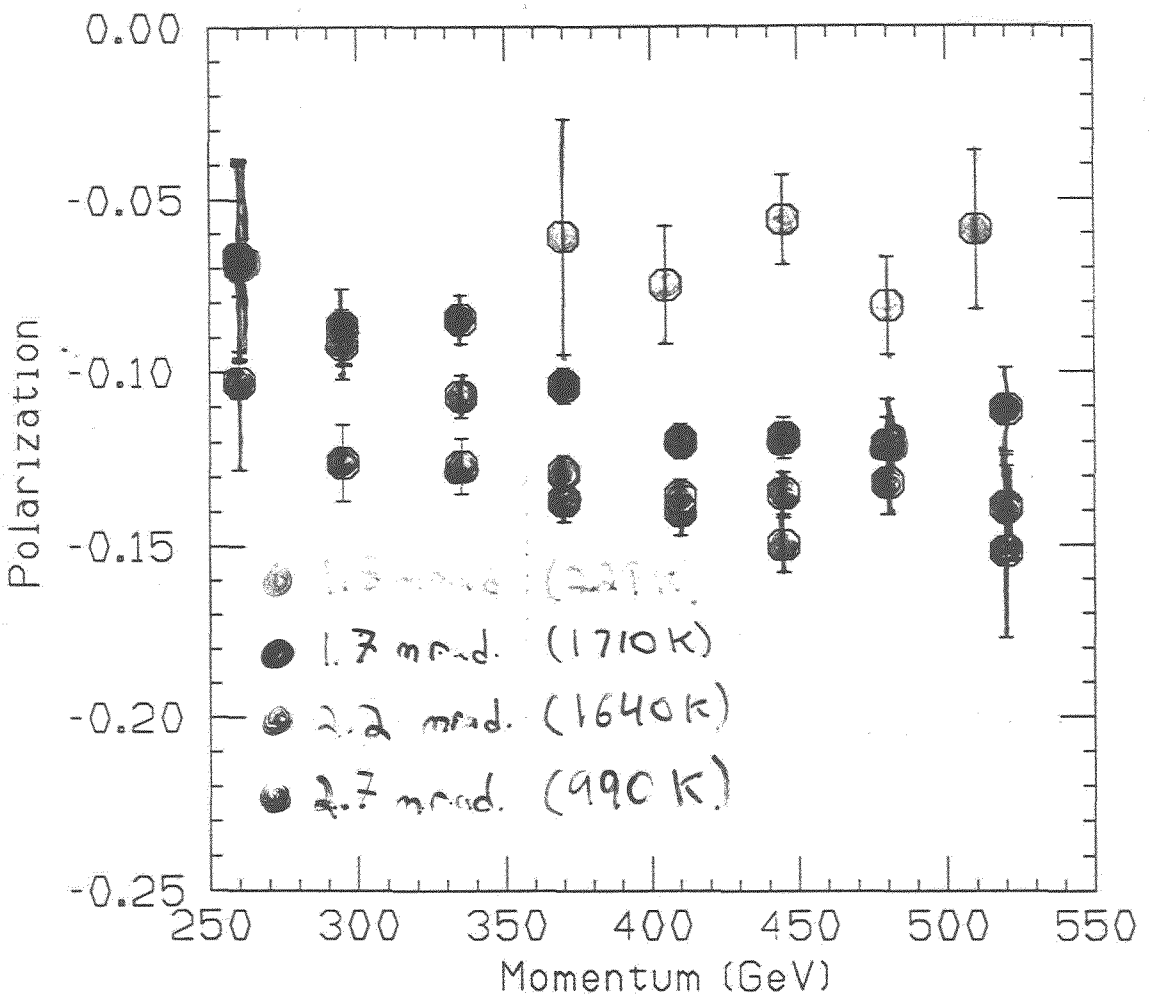
Best fit for n=0



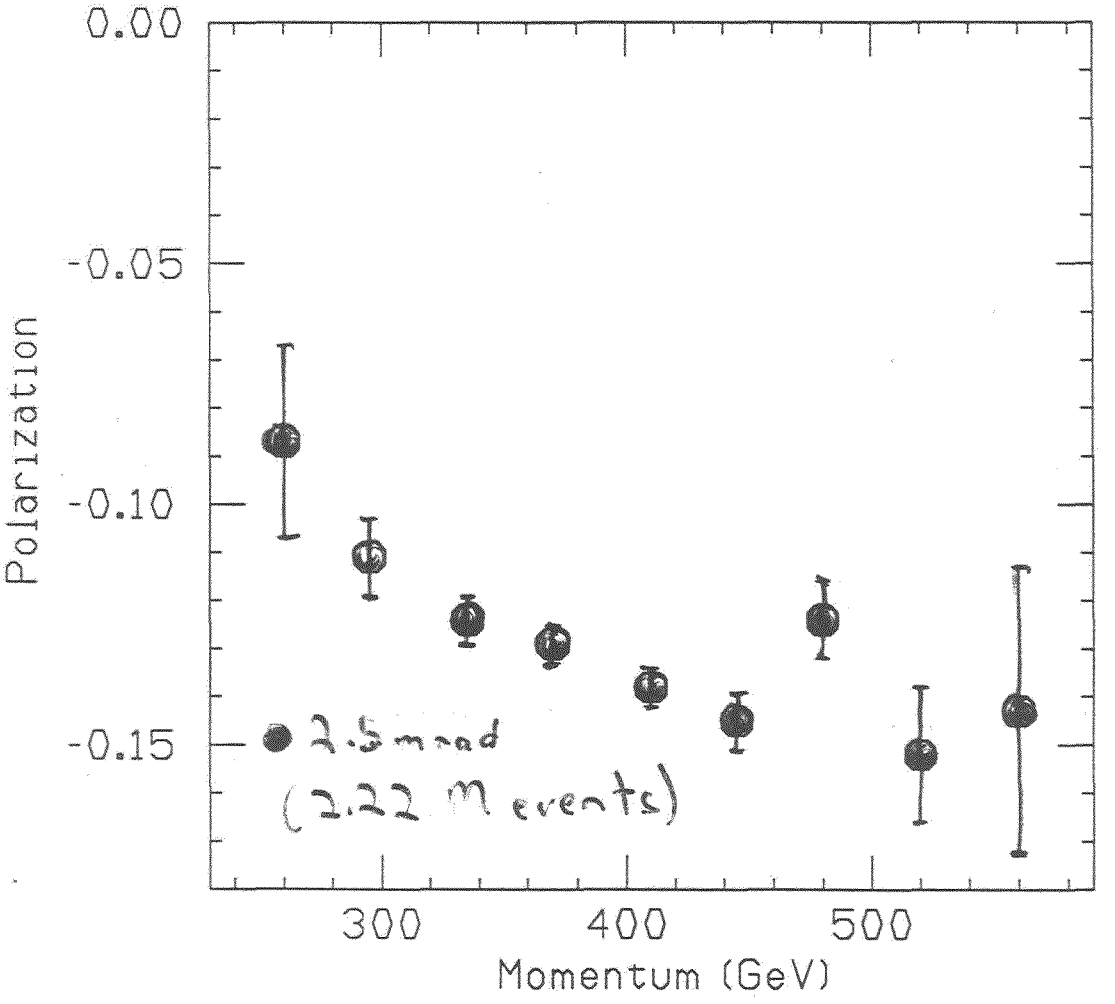
$U_{\Xi^-} = -0.6505 \pm .0025$ nm.

$\chi^2/d.o.f. = 1.3$ for 62 d.o.f.

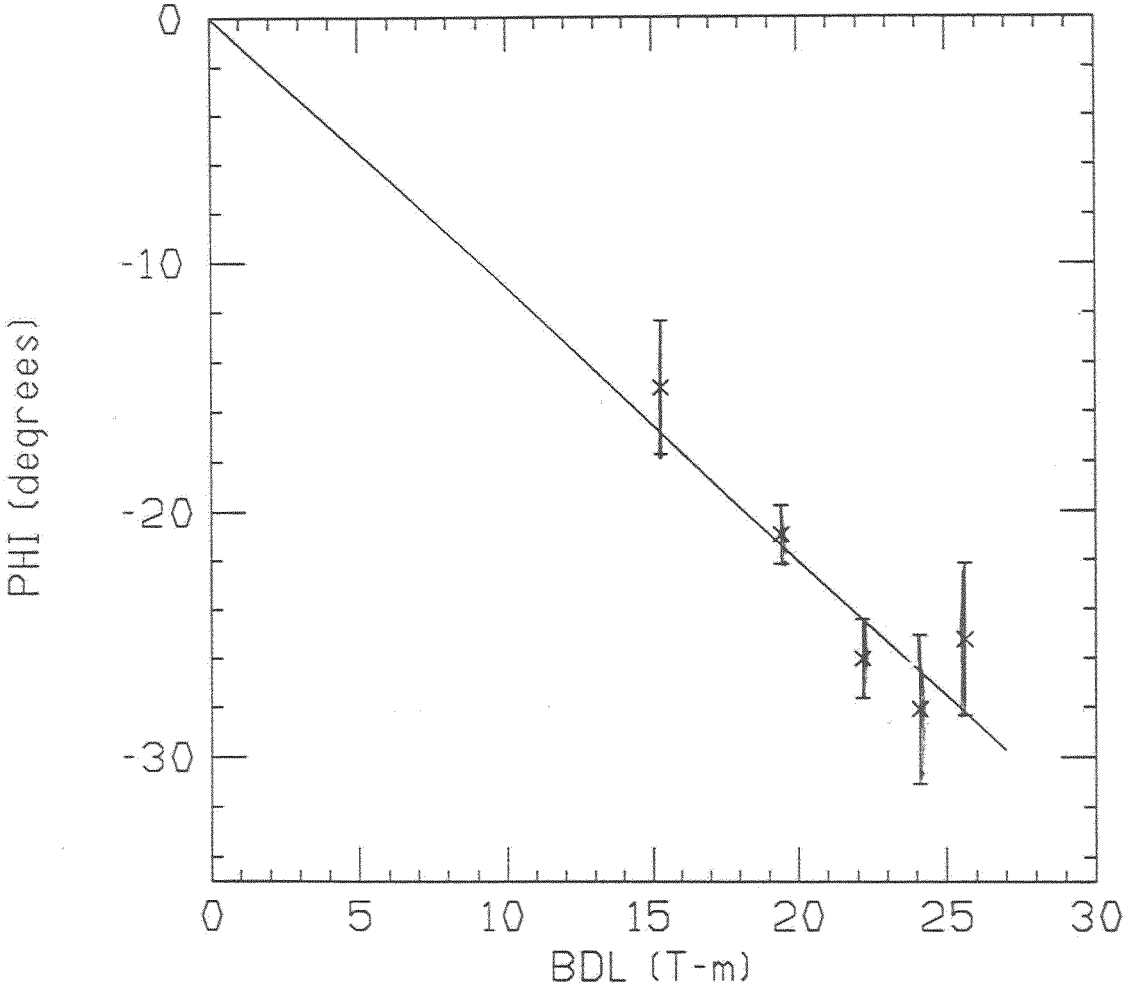

Previous Ξ⁻ data
New Ξ⁻ data
PHI (degrees)
BDL (T-m)
10
0
-10
-20
-30
0
5
10
15
20
25
30


0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Polarization
250
300
350
400
450
500
550
Momentum (GeV)
1.7 mrad. (1710 K)
2.2 mrad. (1640 K)
2.7 mrad. (990 K)

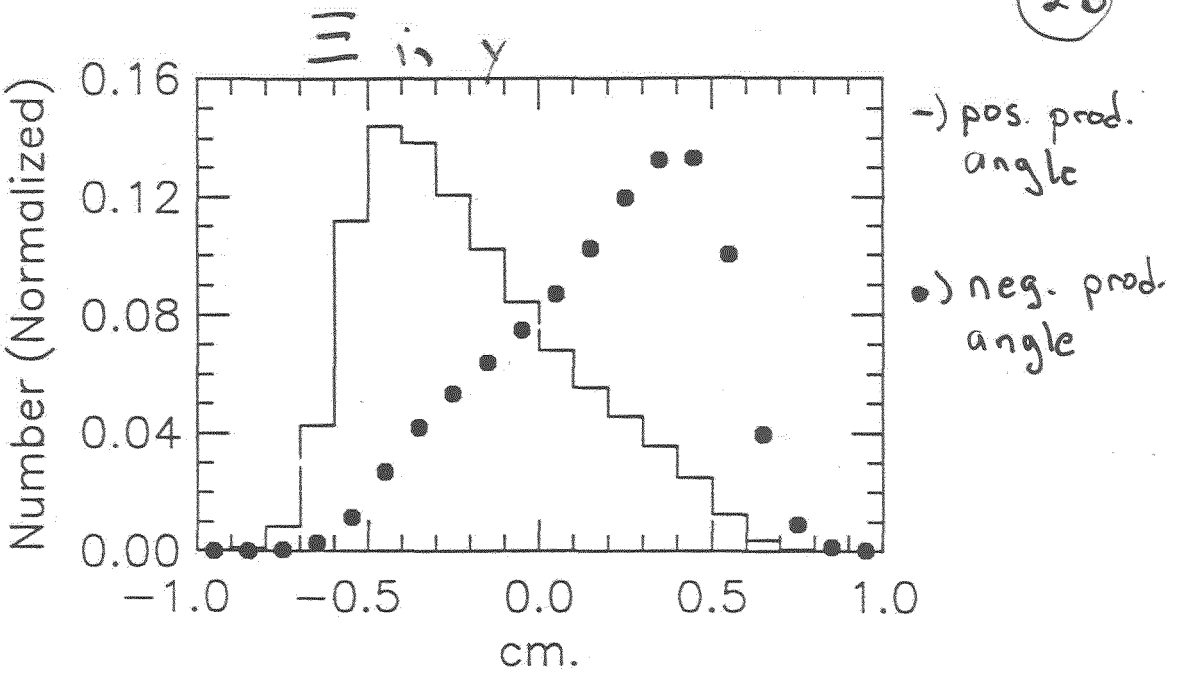
$P_T = \theta \rho$


0.00
-0.05
-0.10
-0.15
Polarization
300
400
500
Momentum (GeV)
2.5 mrad
(2.22 M events)

Systematic Studies



an error of 1° in ϕ corresponds to a dP of about .002

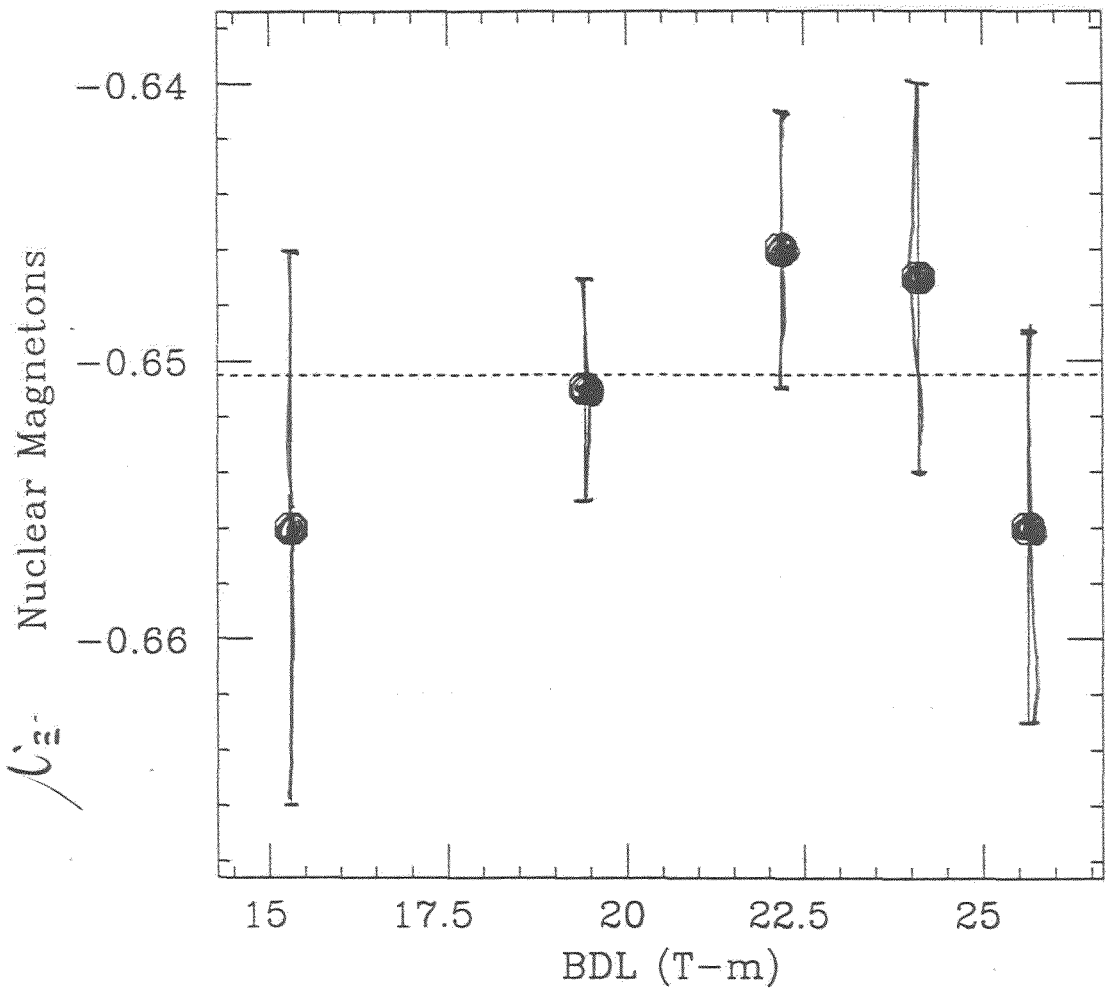


$P_y = 0.0005 \pm 0.0011$

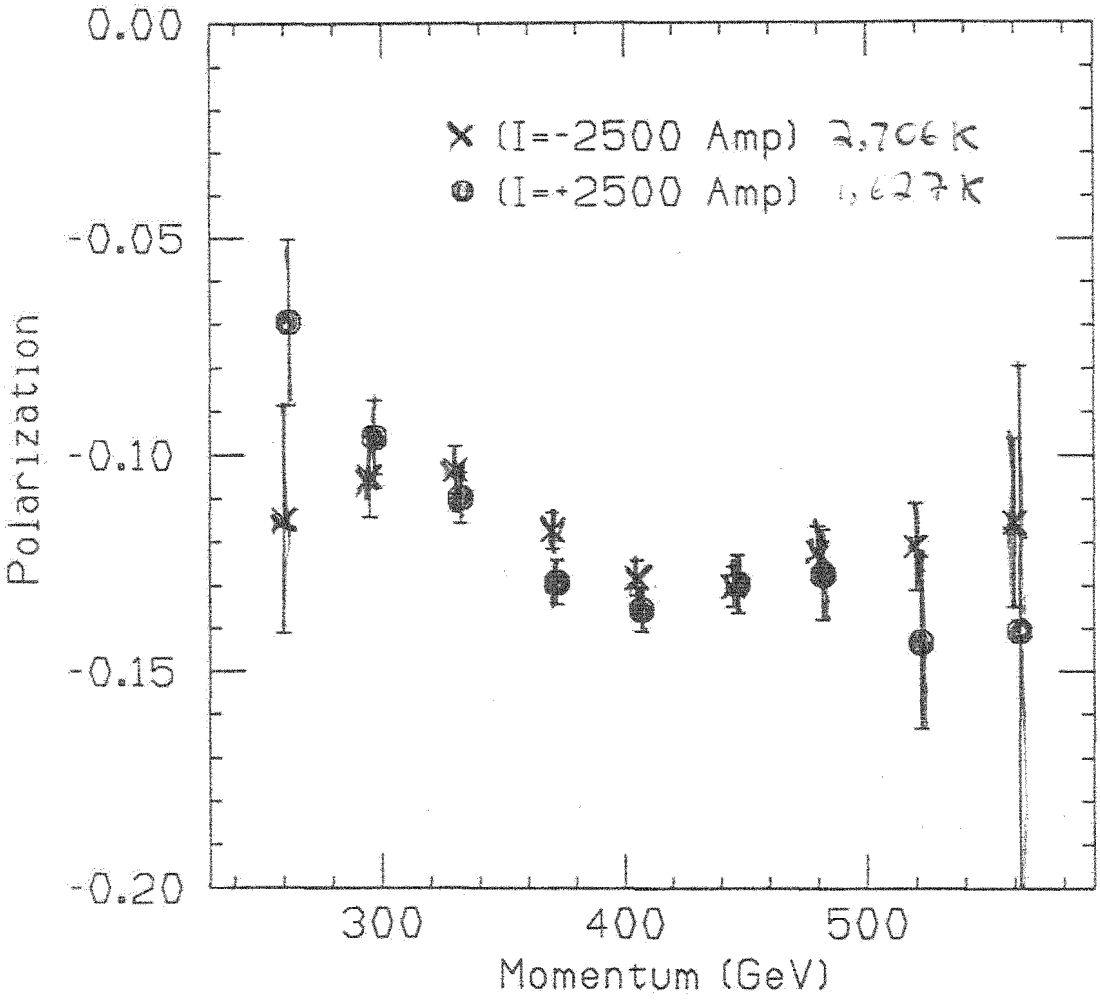
Since there's no component of P in the y view P_y should equal zero.

ν vs. $\int B\,dl$

$\phi = K(\nu) \int B\,dl$



$\chi^2/\text{d.o.f.} = 0.9$ for 9 d.o.f.

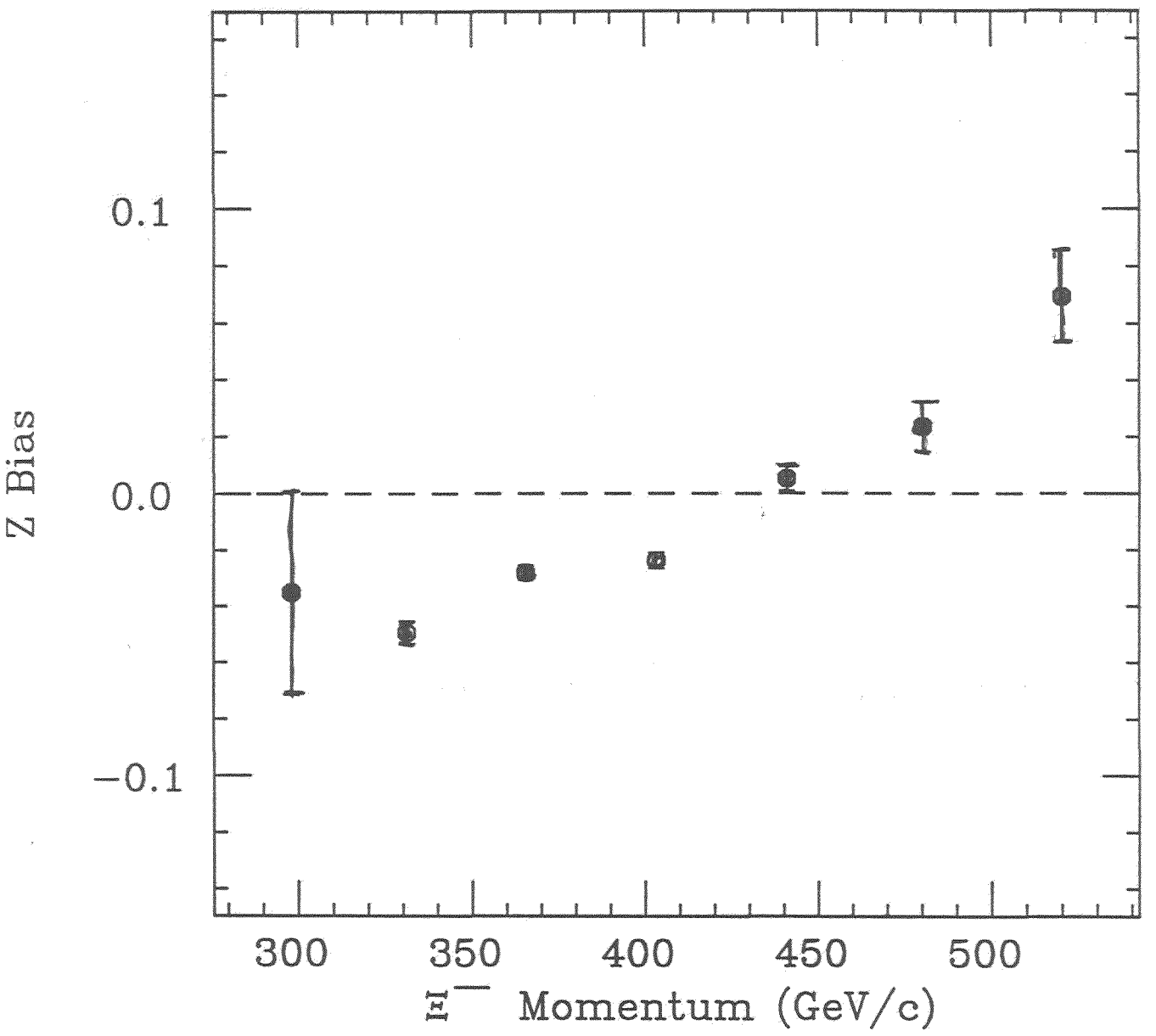


$\mu_\Xi = 0.6516 \pm .0036$ nm. (I=-2500 Amp)

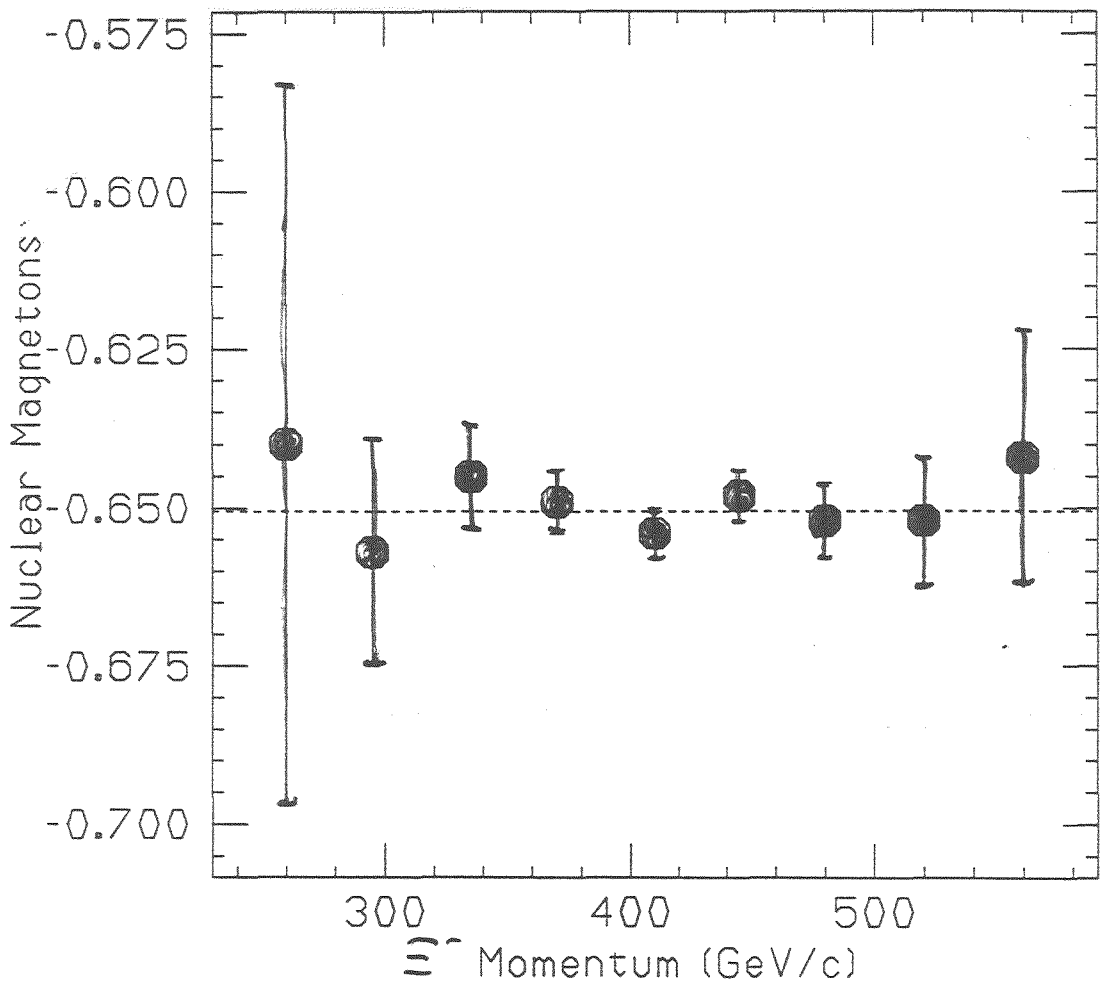
$\mu_\Xi = 0.6488 \pm .0037$ nm (I=+2500 Amp)

0.6σ

Z Bias



30.5


-0.575
-0.600
-0.625
-0.650
-0.675
-0.700
Nuclear Magnetons
300
400
500
Ξ⁻ Momentum (GeV/c)

How to compare 800 GeV to 400 GeV results?

$$x_F = \frac{P}{E}$$

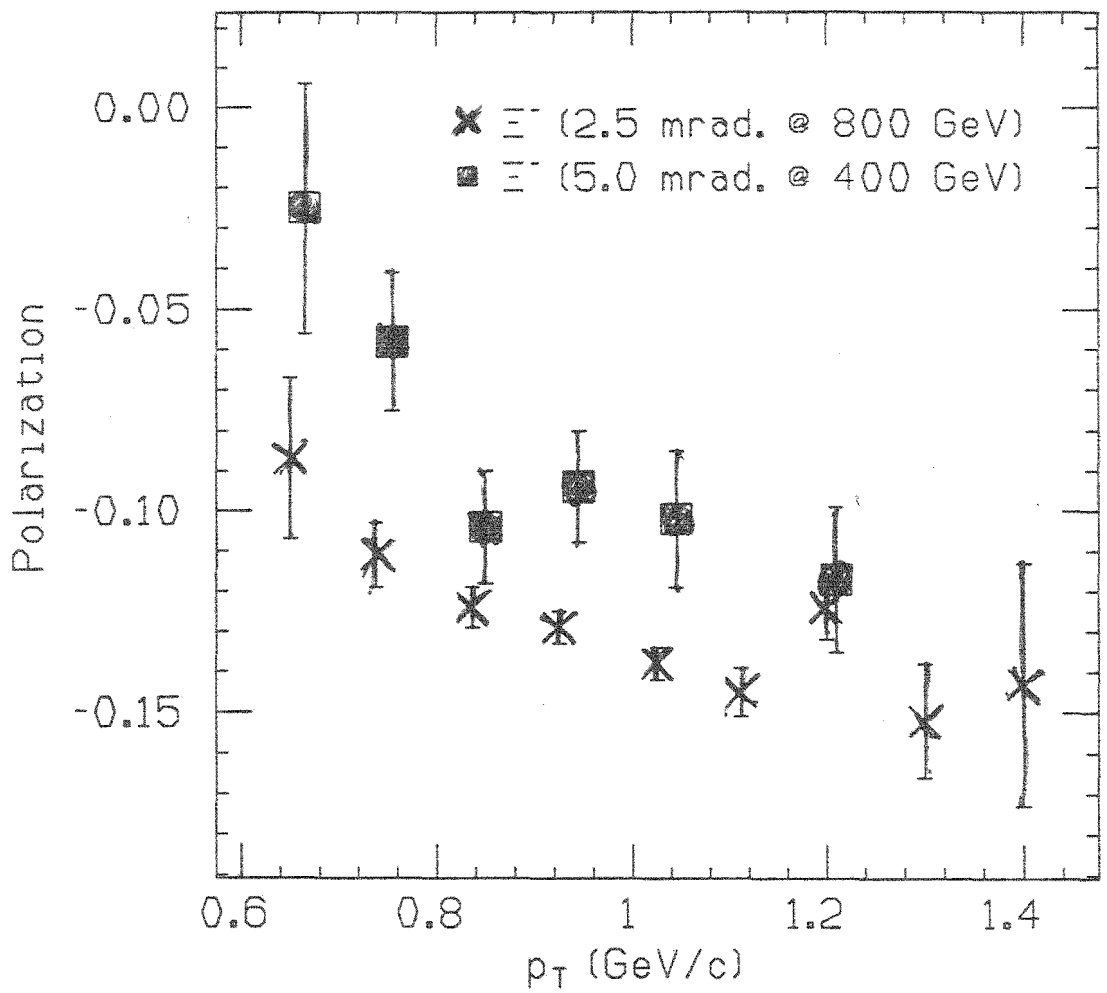
$$p_T = P\theta$$

so:

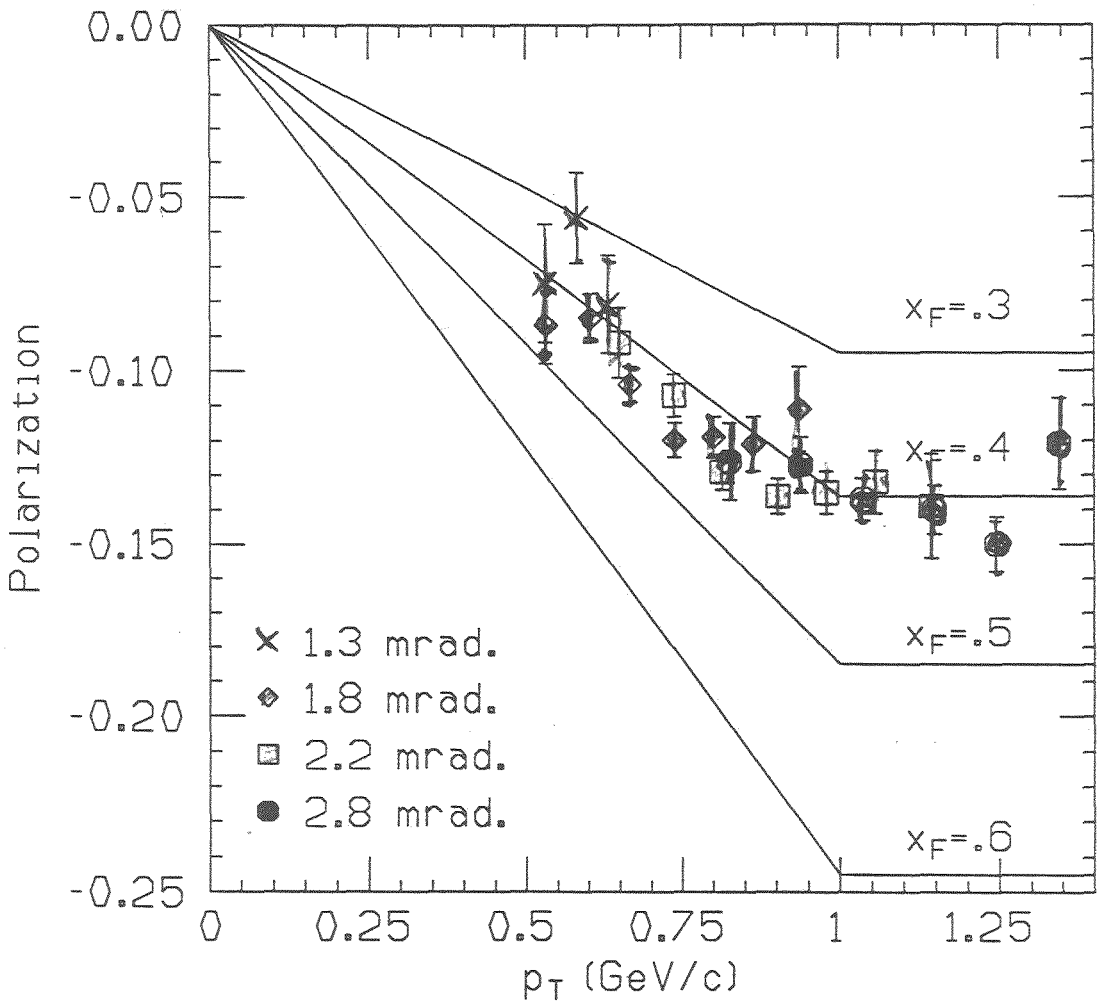
$$p_T = x_F \theta E$$

Hence, if you double E then use $\frac{\theta}{2}$

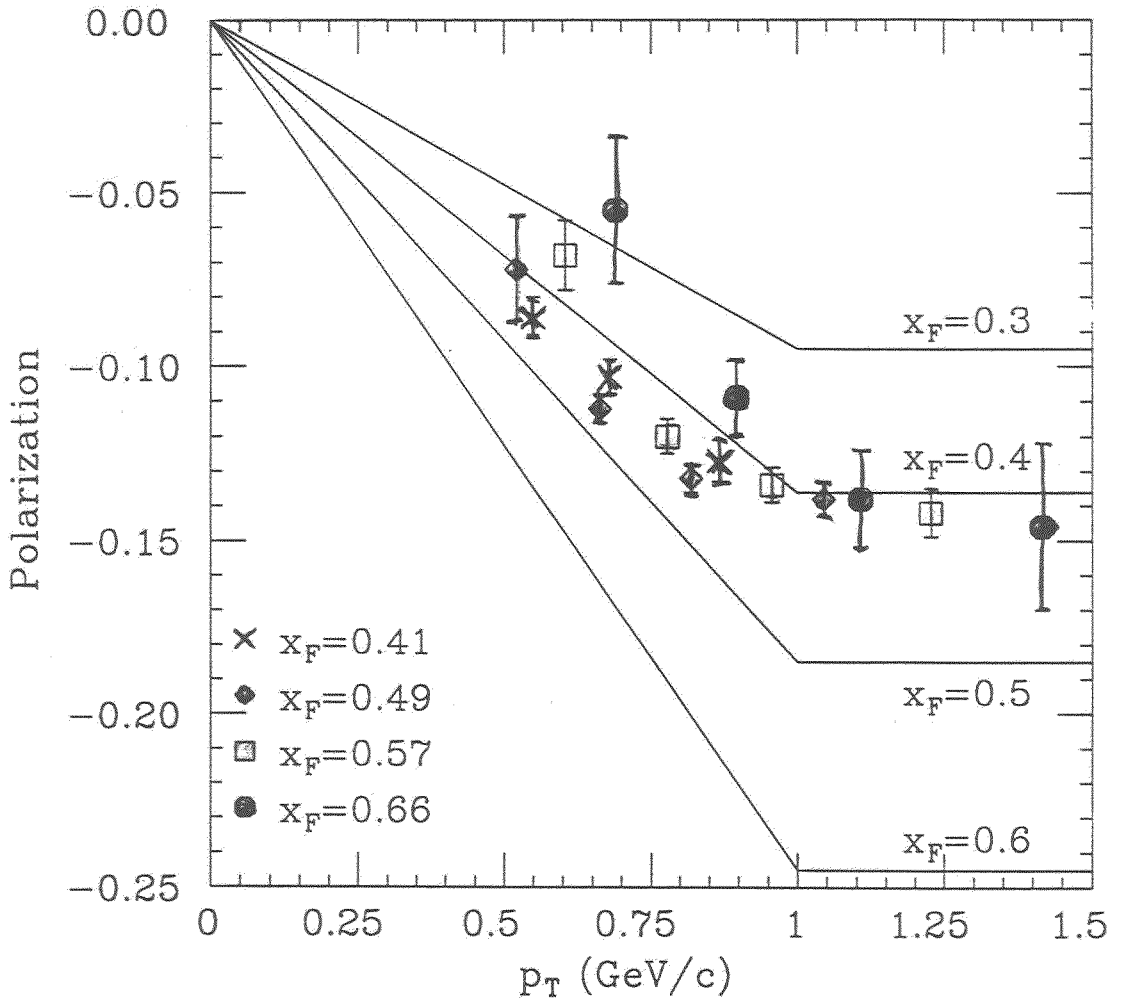
Energy Dependence



Compare to P_1



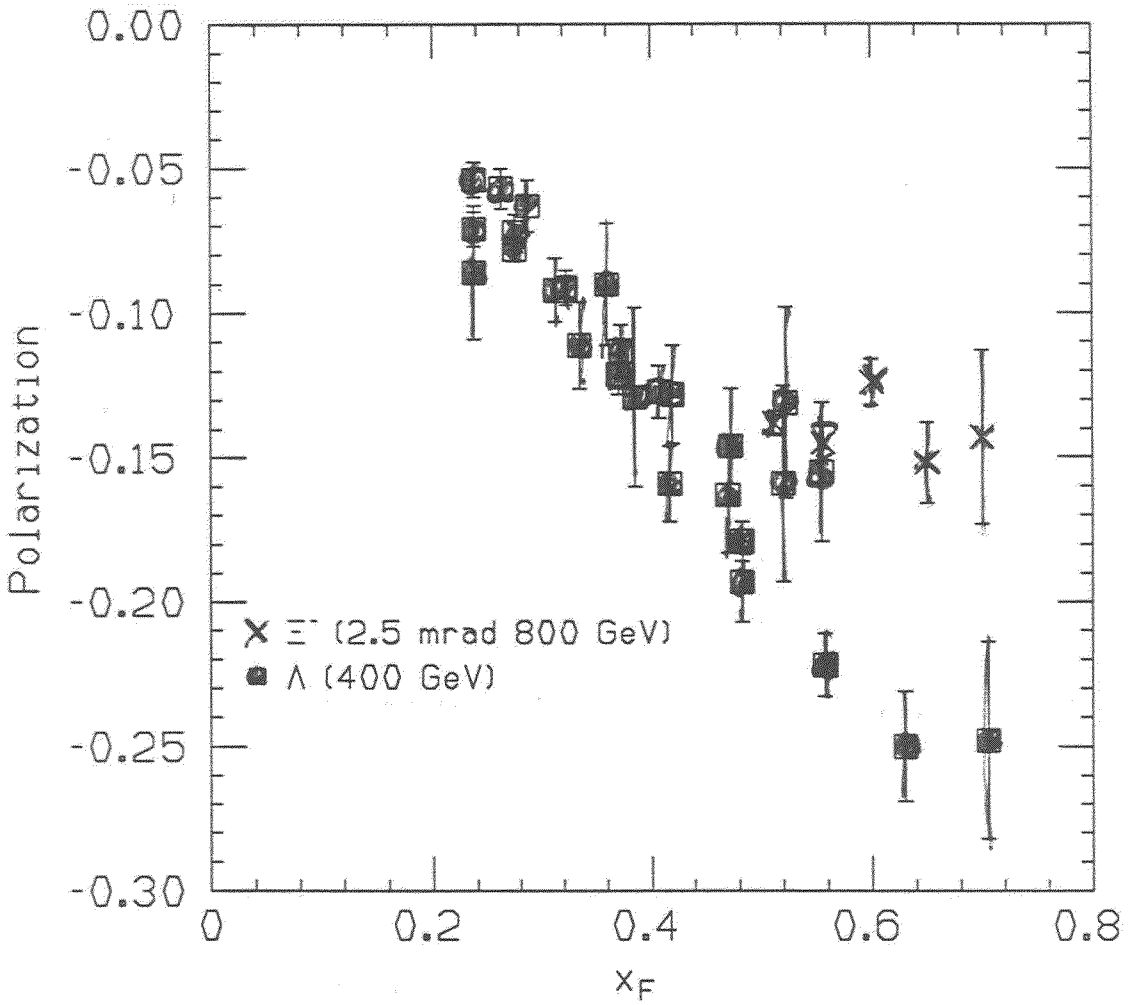
Compare to P_Λ

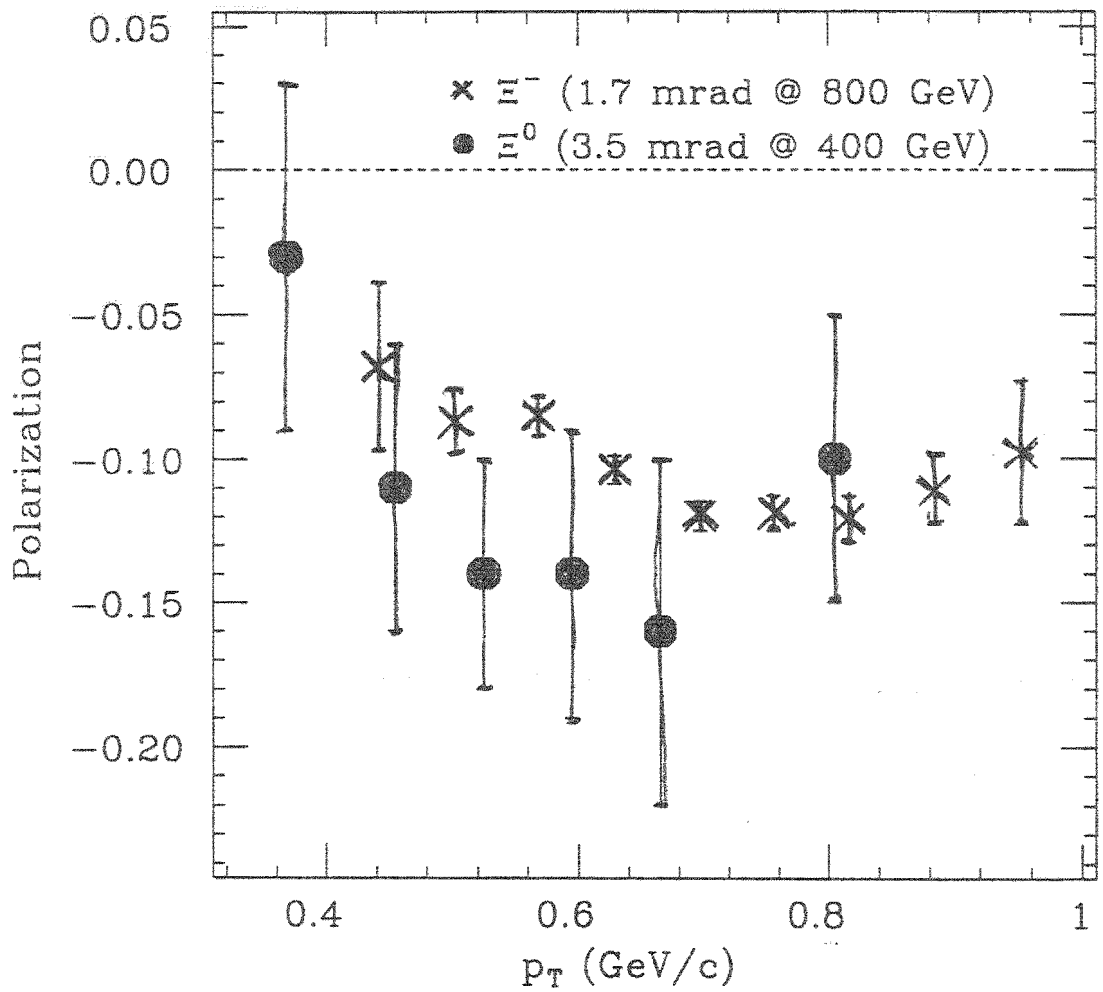


No x_F dependence!

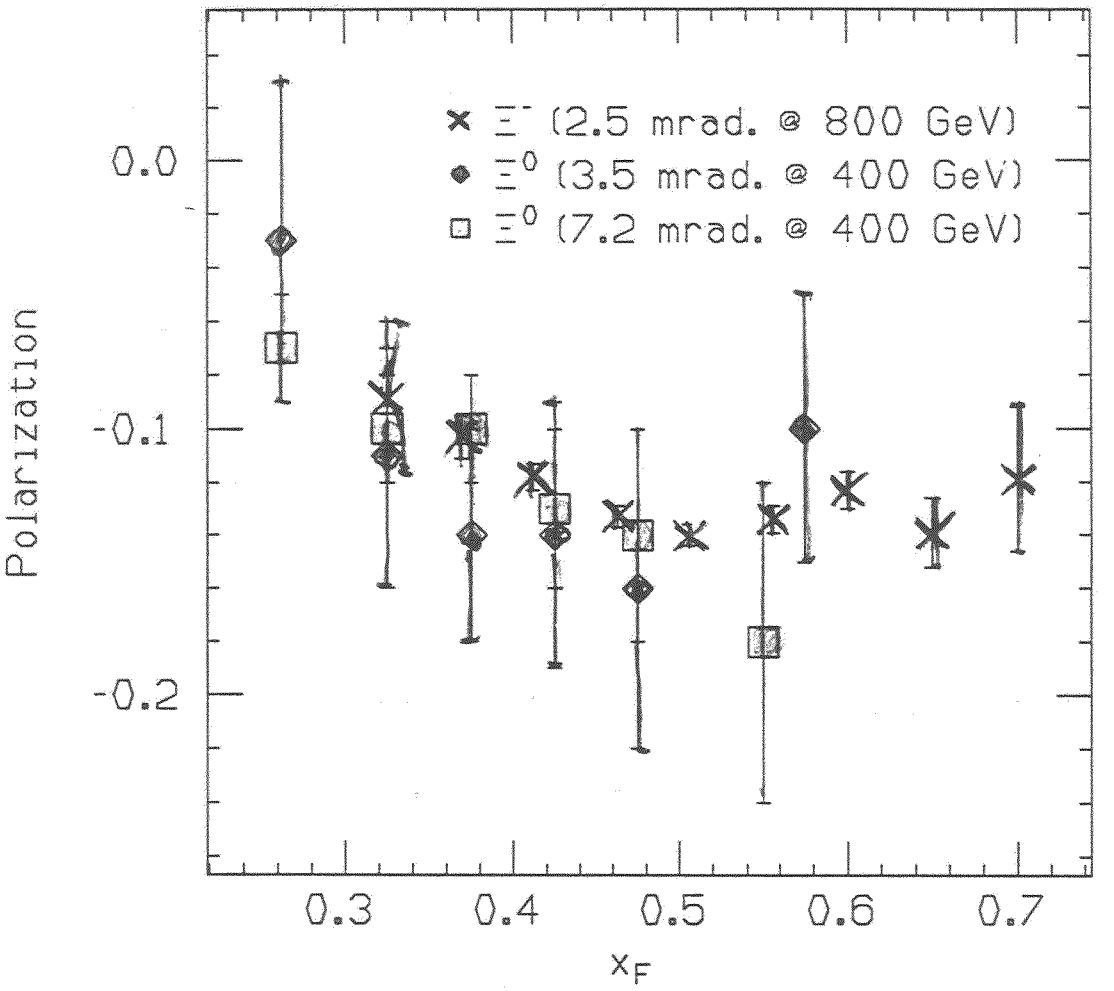
Compare to P_n

$p_T > 1$ GeV

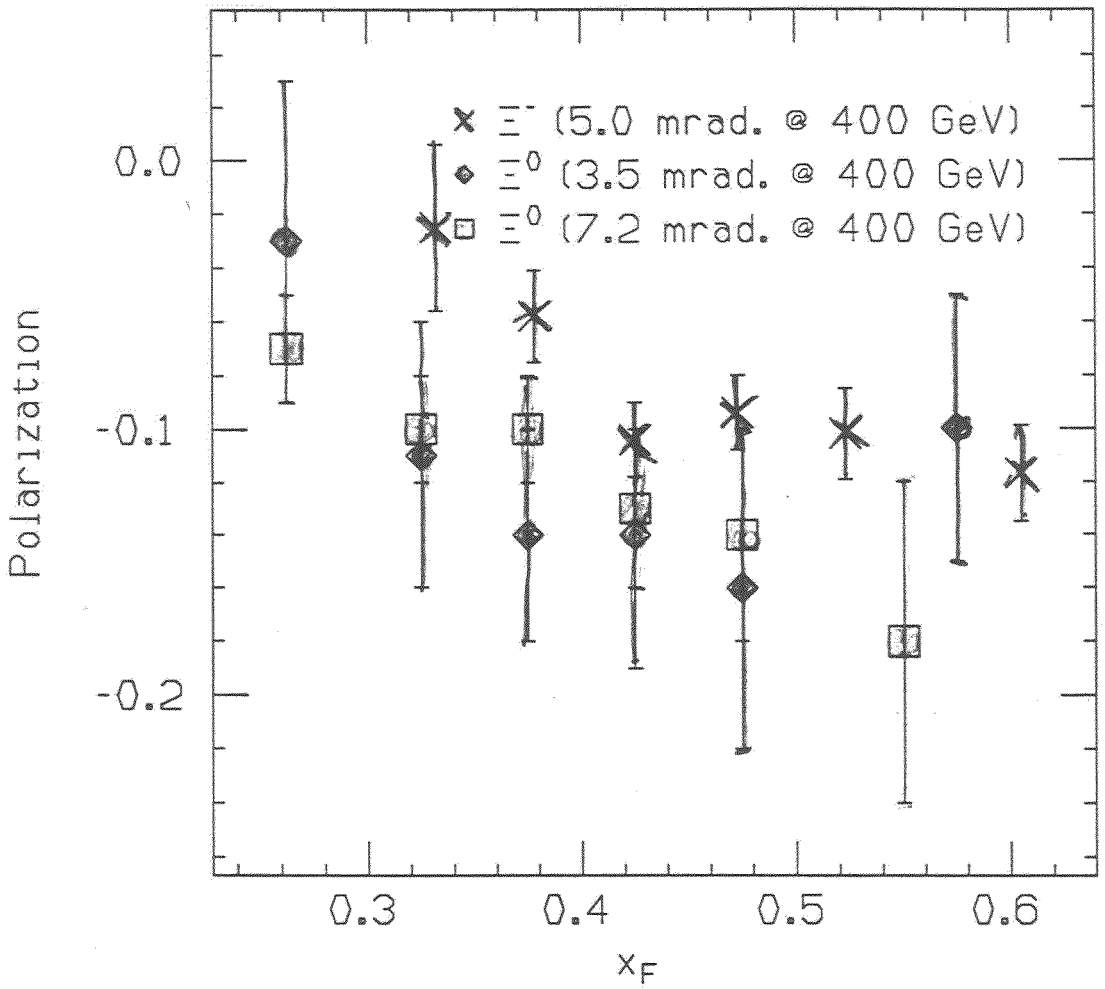



0.05
0.00
−0.05
−0.10
−0.15
−0.20
Polarization
0.4
0.6
0.8
1
p_T (GeV/c)
Ξ^- (1.7 mrad @ 800 GeV)
Ξ^0 (3.5 mrad @ 400 GeV)

P_{Ξ^-} vs. P_{Ξ^0}

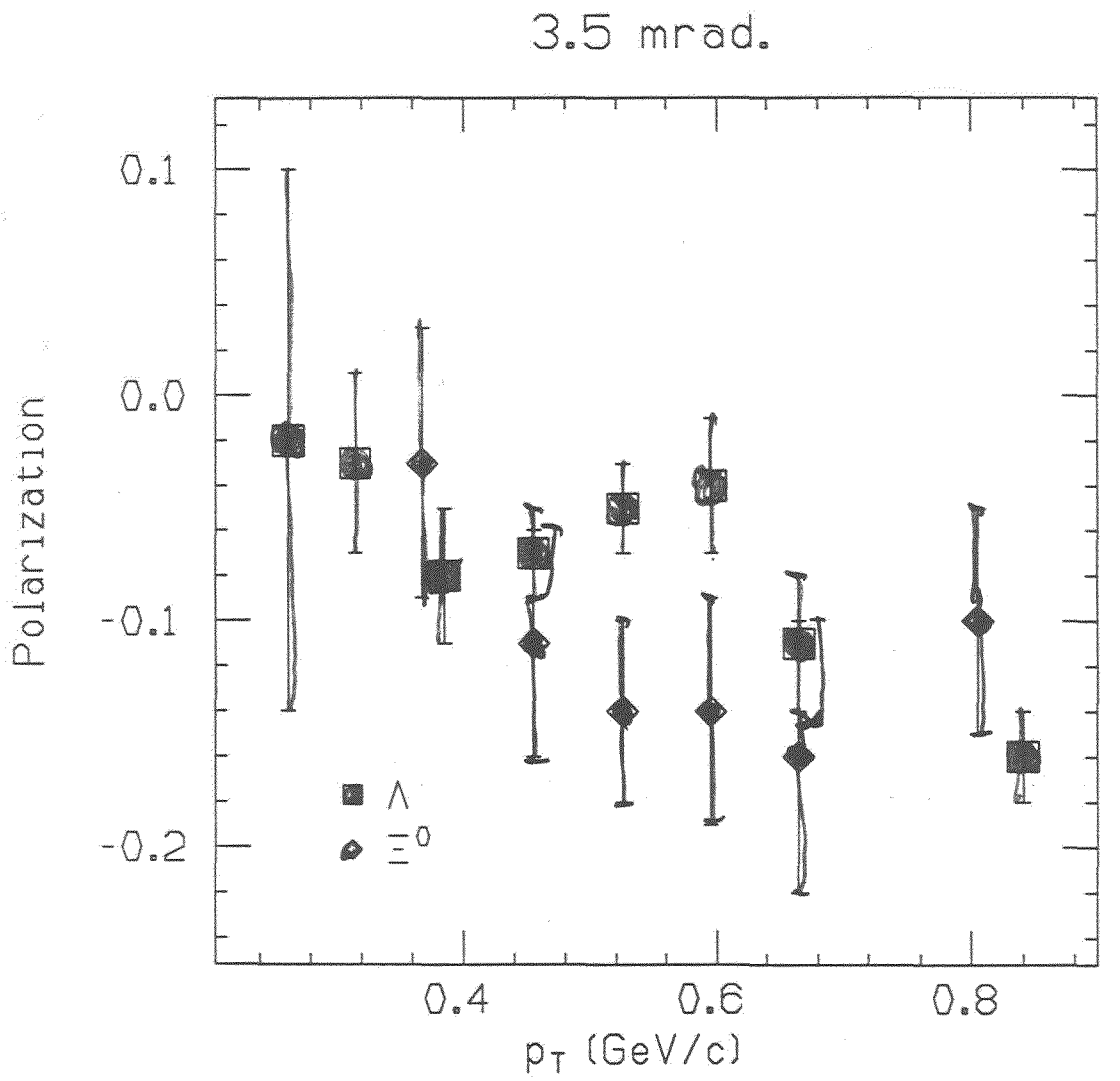

Ξ⁻ (2.5 mrad. @ 800 GeV)
Ξ⁰ (3.5 mrad. @ 400 GeV)
Ξ⁰ (7.2 mrad. @ 400 GeV)
0.0
-0.1
-0.2
Polarization
0.3
0.4
0.5
0.6
0.7
x_F

P_{Ξ^-} vs. P_{Ξ^0}

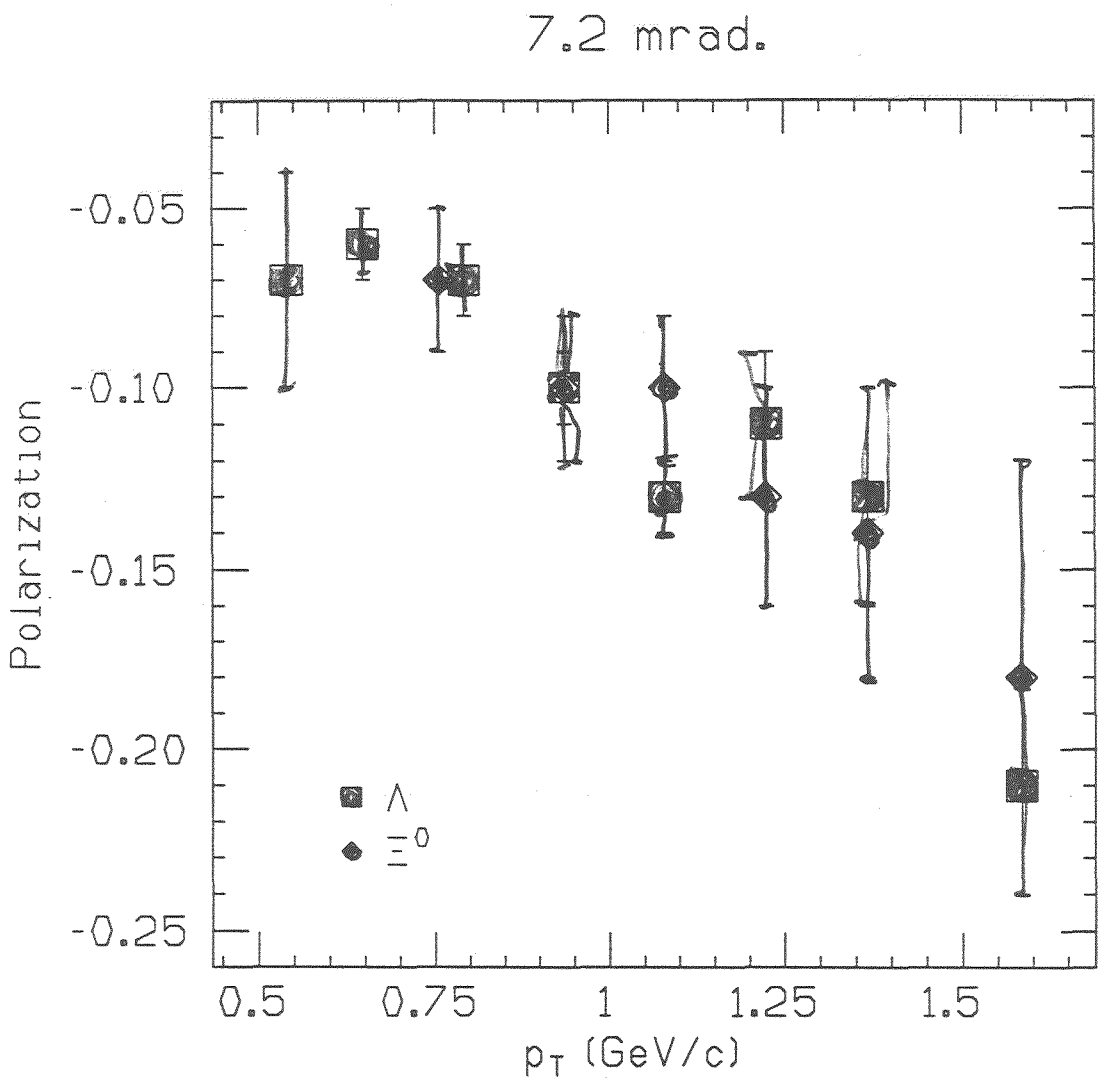

Ξ⁻ (5.0 mrad. @ 400 GeV)
Ξ⁰ (3.5 mrad. @ 400 GeV)
Ξ⁰ (7.2 mrad. @ 400 GeV)
0.0
-0.1
-0.2
Polarization
0.3
0.4
0.5
0.6
x_F

4c

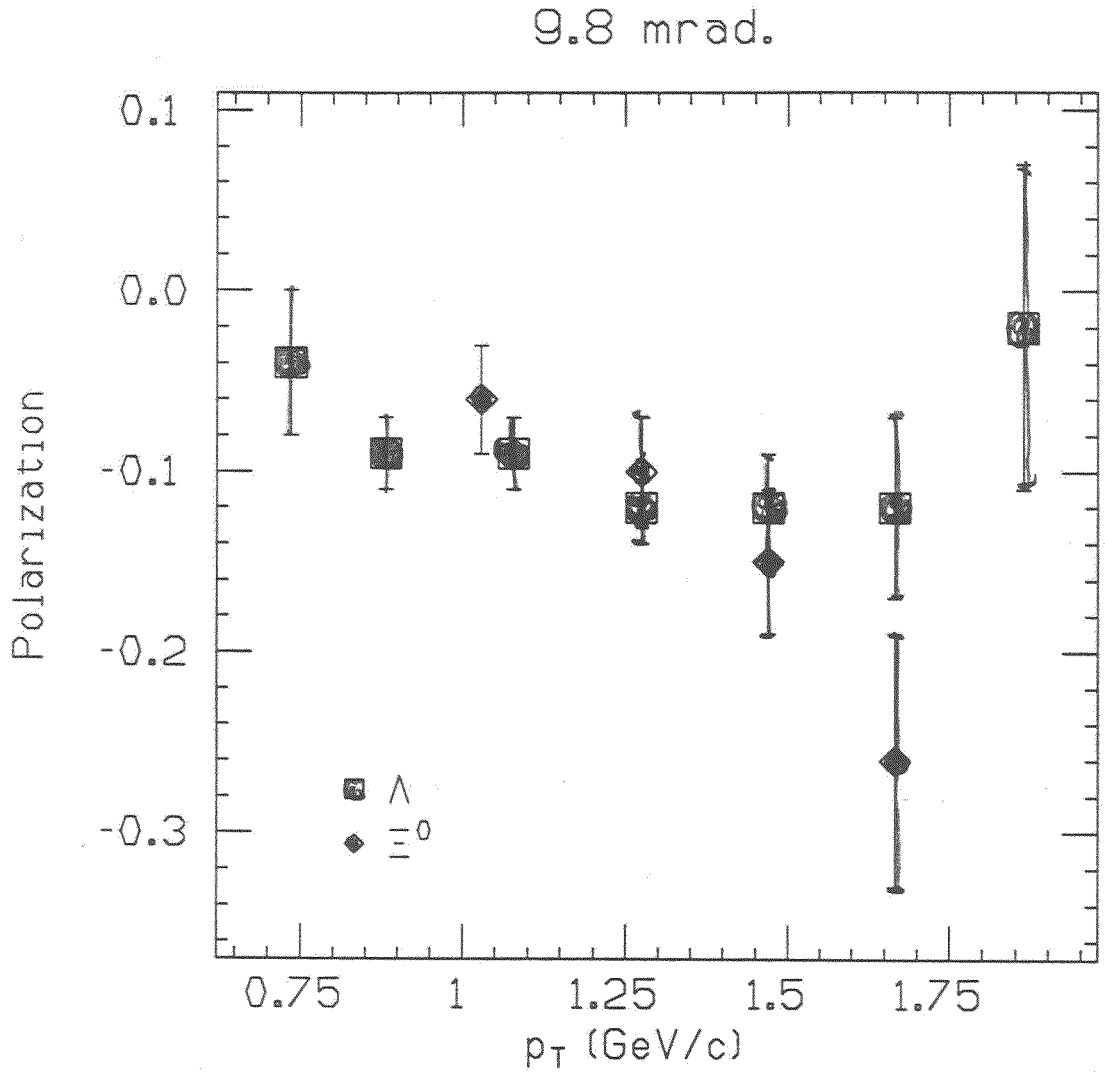
P_Λ vs P_{Ξ^0}



P_Λ vs. P_{Ξ^0}



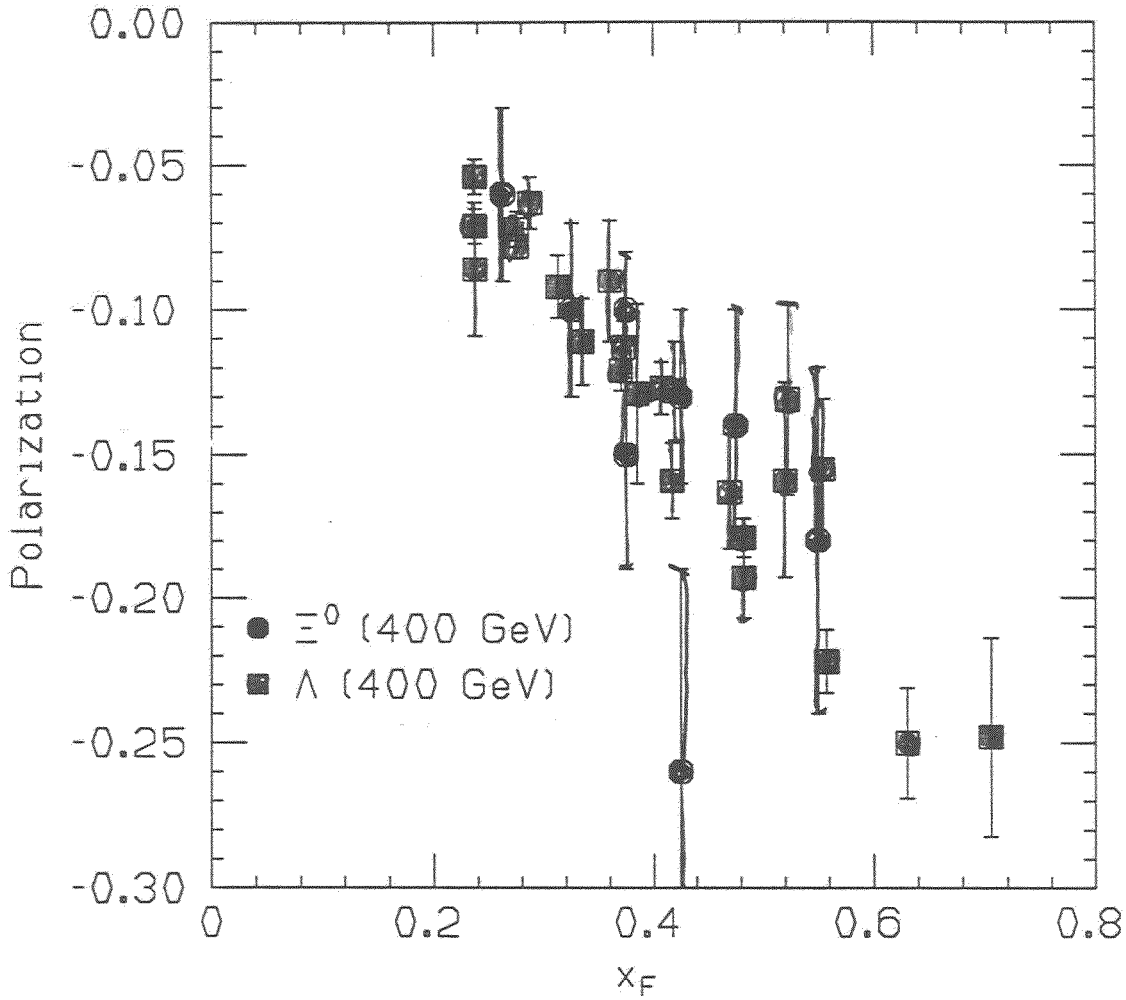
P_Λ vs. P_{Ξ^0}



P_Λ vs P_{Ξ^0}

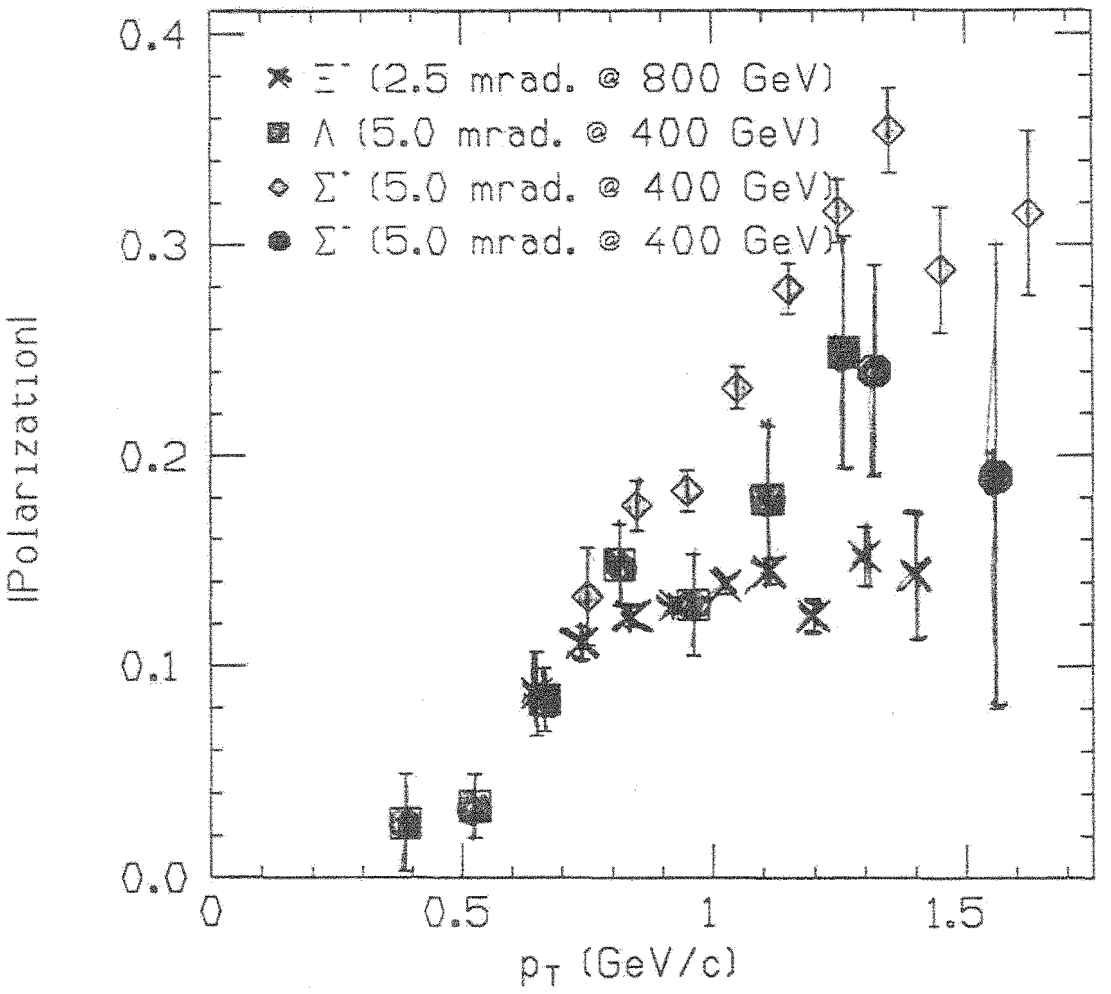
43

$p_T > 1$ GeV



Need to measure P_{Ξ^0} for $x_F > .6$ and $p_T > 1$ GeV

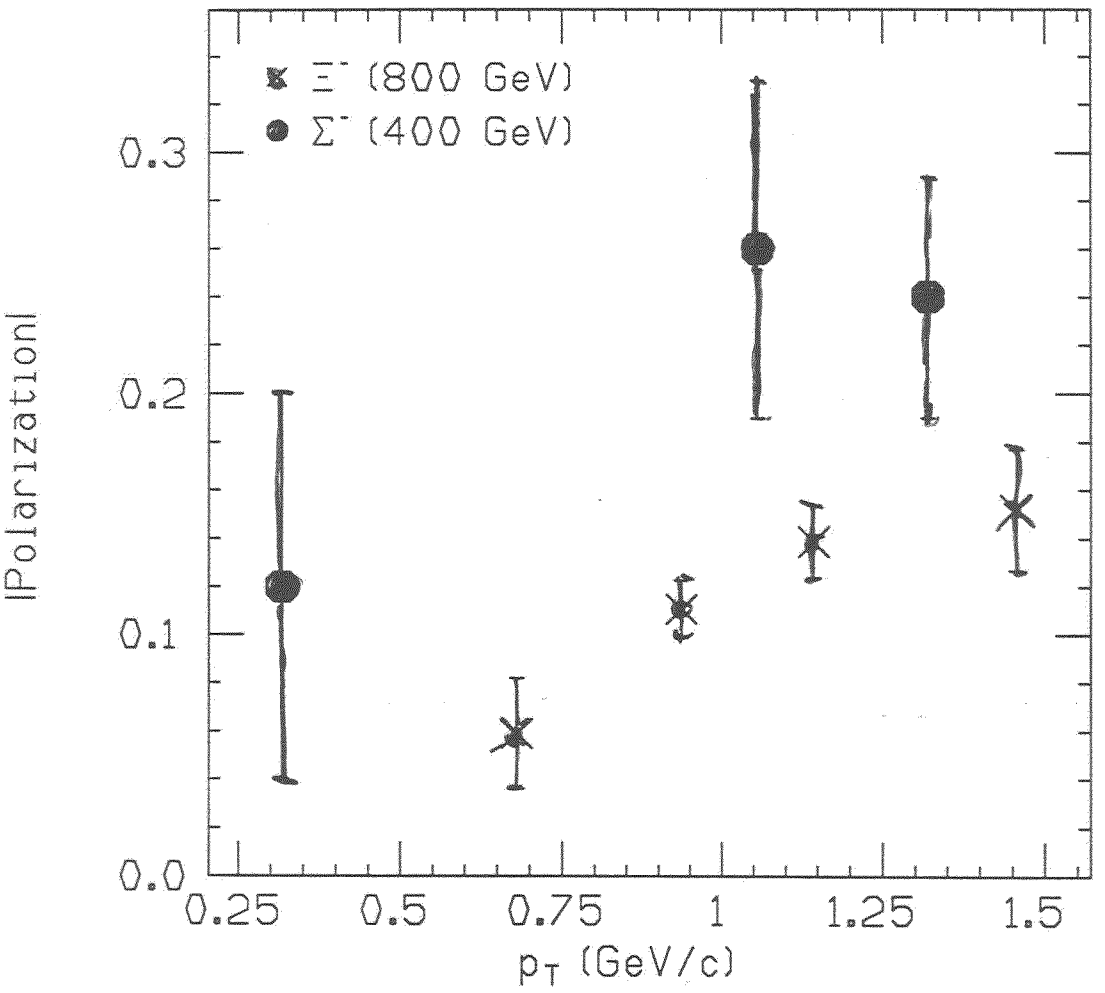
P_{Ξ^-} vs. P_{Σ}



P_{Ξ^-} vs. P_{Σ^-}

(45)

$X_F = .65$



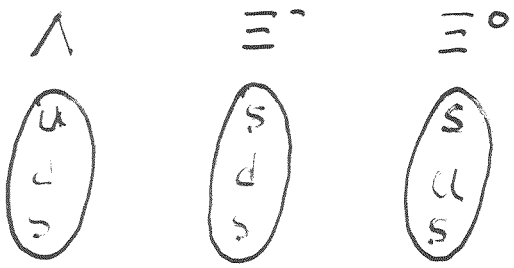
Summary of Polarization Results

1) P_{Ξ^-} is not energy independent.

2) Unlike P_Λ, P_{Ξ^-} is independent of x_F.

3) 800 GeV P_{Ξ^-} is consistent with 400 GeV P_{Ξ^0}.

4) P_Λ is consistent with P_{Ξ^0} in the kinematic region where P_{Ξ^0} is measured. What happens for $p_T > 1GeV$ and $x_F > 0.6$?



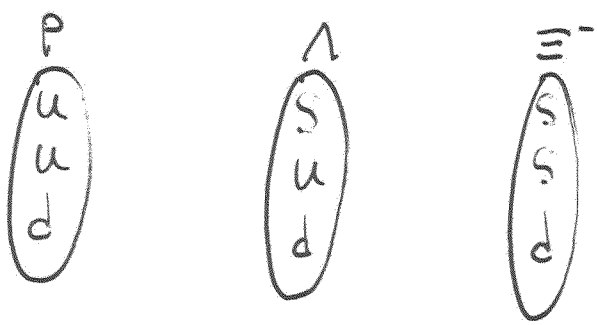
MAGNETIC MOMENT RESULT

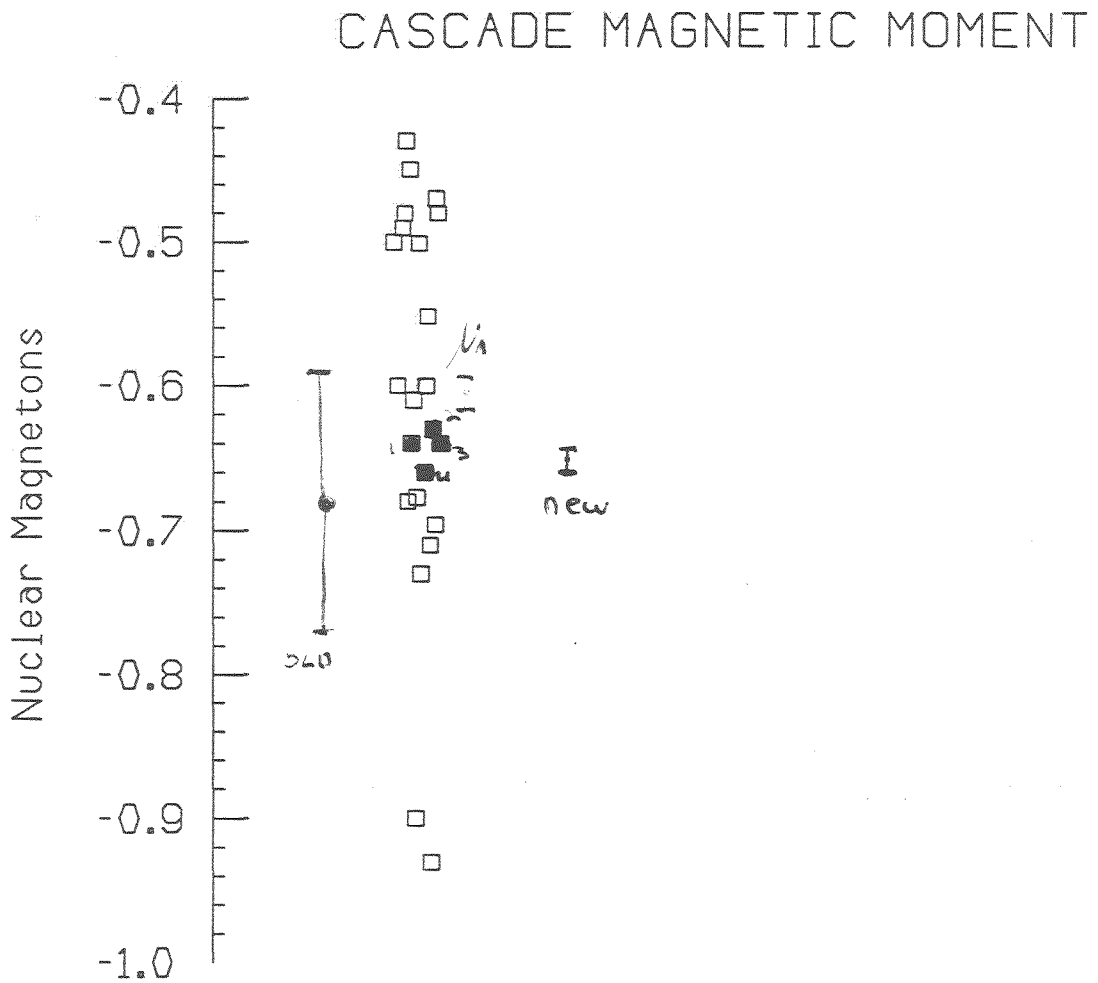
$$\mu_{\Xi^-} = -0.6505 \pm 0.0025\text{nm}$$

Best measurement of $\mu_{hyperon}$

Confirms somewhat controversial result. Earlier models predicted $|\mu_{\Xi^-}| < |\mu_\Lambda|$.
($\mu_\Lambda = -0.613 \pm 0.004\text{nm}$)

Three magnetic moments are very well measured ($< 1\%$ error): μ_{Ξ^-}, μ_Λ, and μ_{proton}

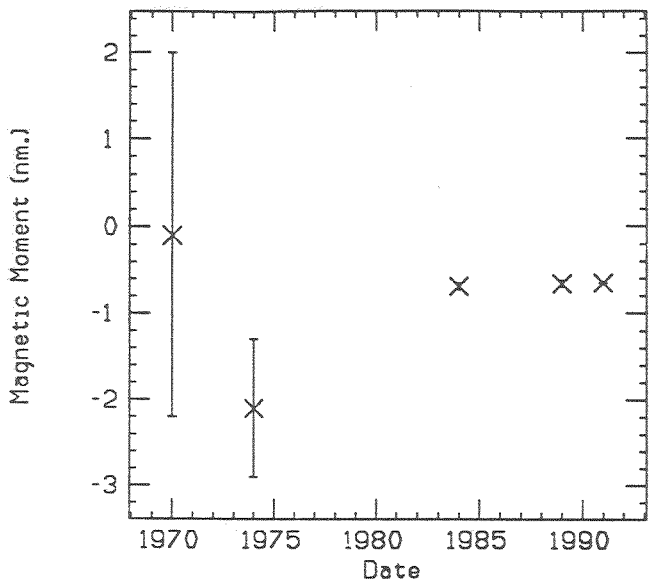


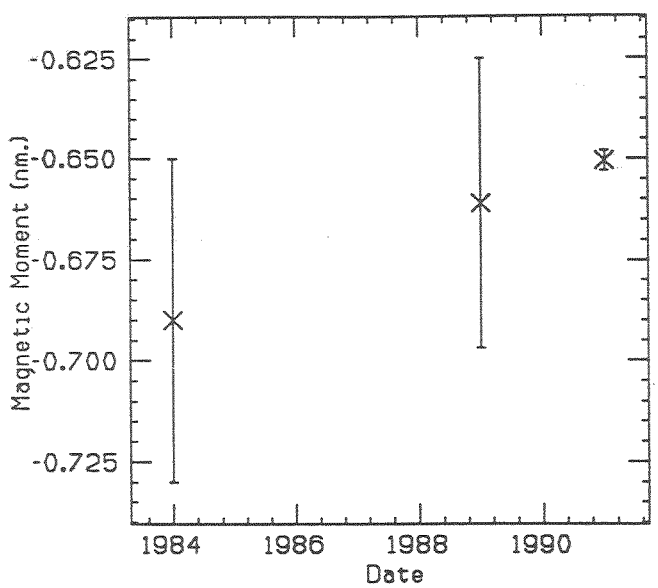


3σ uncertainties

1 De Grand P.R.D. 12 1156 (1975)
2 Bohm P.R.D. 25 223 (1982)
3 Dziembowski P. Lett. 200B 539 (1988)
4 Verma P. Lett. 183B 207 (1987)

μ_{Ξ^-} vs. date.


Magnetic Moment (nm.)
2
1
0
-1
-2
-3
1970
1975
1980
1985
1990
Date


Magnetic Moment (nm.)
-0.625
-0.650
-0.675
-0.700
-0.725
1984
1986
1988
1990
Date