Exploring Spin Effects in Lambda B Production and Decay

$$p+p \rightarrow \Lambda_b + X$$

$$\Lambda_b \rightarrow J/\Psi(\mu\mu) + \Lambda_0(\pi p)$$

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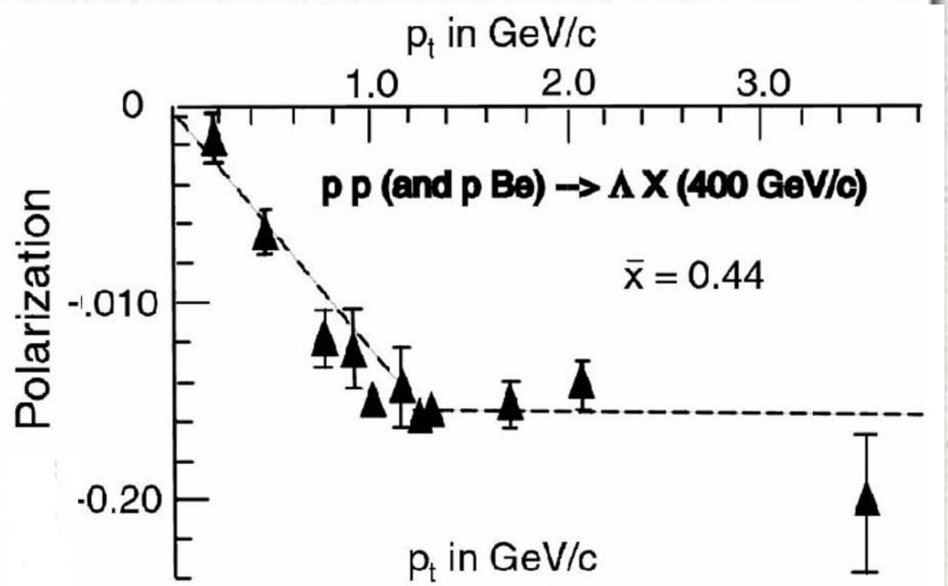
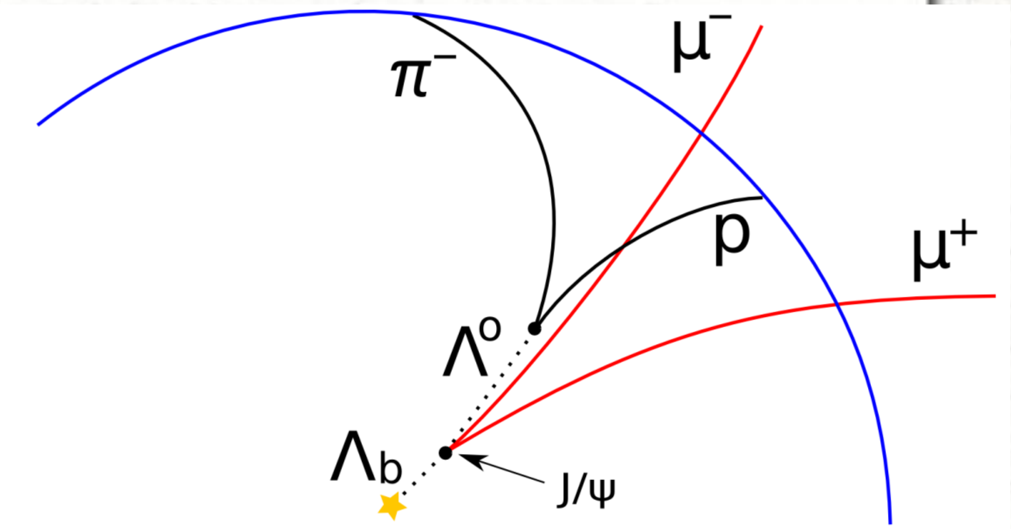
Polarized Surprises

- Physicists expected spin effects to play no role at higher energy
- In 1976 non-zero polarization was found for $p + Be \rightarrow \Lambda_0 + X$
  - Inclusiveness made polarization more mysterious
- Also found for other targets (p,Pb)



Why Study Λ_b?

- To study particle production mechanisms through spin effects
- To test model predictions of parity violation
- To test dependence of polarization on quark mass
- To look for new physics

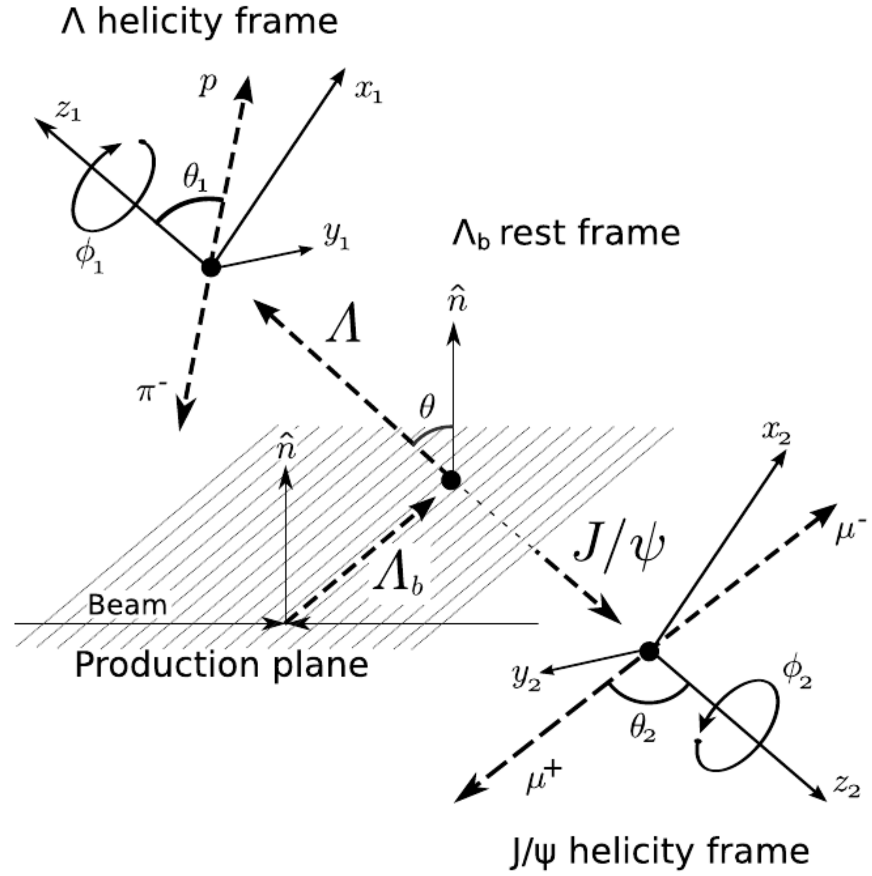


*Many thanks to Dan Scheirich for diagram on this slide

Λ_b Decay Angles Convention

- There are 5 angles in Λ_b decay.
- Using them the probability distribution function is:

$$\omega(\Omega) = \frac{1}{(4\pi)^3} \sum_i f_{1_i} f_{2_i} F_i$$



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Λ_b Decay Probability Distribution Function

i	f_{1i}	f_{2i}	F_i
0	$a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$	1	1
1	$a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$	P_b	$\cos\theta$
2	$a_+a_+^* - a_-a_-^* - b_+b_+^* + b_-b_-^*$	α_Λ	$\cos\theta_1$
3	$a_+a_+^* + a_-a_-^* - b_+b_+^* - b_-b_-^*$	$P_b\,\alpha_\Lambda$	$\cos\theta\,\cos\theta_1$
4	$-a_+a_+^* - a_-a_-^* + \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	1	$1/2\,(3\cos^2\theta_2 - 1)$
5	$-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	P_b	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta$
6	$-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	α_Λ	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta_1$
7	$-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	$P_b\,\alpha_\Lambda$	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta\cos\theta_1$
8	$-3Re(a_+a_-^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos\varphi_1$
9	$3Im(a_+a_-^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin\varphi_1$
10	$-\frac{3}{2}Re(b_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos(\varphi_1 + 2\,\varphi_2)$
11	$\frac{3}{2}Im(b_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin(\varphi_1 + 2\,\varphi_2)$
12	$-\frac{3}{\sqrt{2}}Re(b_-a_+^* + a_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
13	$\frac{3}{\sqrt{2}}Im(b_-a_+^* + a_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin\varphi_2$
14	$-\frac{3}{\sqrt{2}}Re(b_-a_-^* + a_+b_+^*)$	$P_b\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
15	$\frac{3}{\sqrt{2}}Im(b_-a_-^* + a_+b_+^*)$	$P_b\,\alpha_\Lambda$	$\cos\theta\,\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$
16	$\frac{3}{\sqrt{2}}Re(a_-b_+^* - b_-a_+^*)$	P_b	$\sin\theta\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
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18	$\frac{3}{\sqrt{2}}Re(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos(\varphi_1 + \varphi_2)$
19	$-\frac{3}{\sqrt{2}}Im(b_-a_-^* - a_+b_+^*)$	α_Λ	$\sin\theta_1\,\sin\theta_2\,\cos\theta_2\,\sin(\varphi_1 + \varphi_2)$

Probability Distribution Function

- The probability distribution function describes the probability with which Λ_b decays with specific angles
- a_+, a_-, b_+, b_- are probability amplitudes that Λ_b will decay into Λ and J/Ψ with spins (+½,0), (-½ ,0), (+½,1), (-½ ,1) respectively. These are called helicity amplitudes
- P_b is the polarization of Λ_b
- α_Λ is the parity violating term of the Λ_0 decay and is known

Toy Monte Carlo

- To test data analysis a Toy Monte Carlo generator was needed
  - Toy →Not Full Simulation → Fast
- Existing Toy Generator was modified
  - Ability to simulate either ideal or non-ideal detector using hard eta and p_t cuts
  - Converted such that generator can be compiled with g++ → Fast

Orthogonal Functions

i	f_{1i}	f_{2i}	F_i
0	$a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$	1	1
1	$a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$	P_b	$\cos\theta$
2	$a_+a_+^* - a_-a_-^* - b_+b_+^* + b_-b_-^*$	α_Λ	$\cos\theta_1$
3	$a_+a_+^* + a_-a_-^* - b_+b_+^* - b_-b_-^*$	$P_b\,\alpha_\Lambda$	$\cos\theta\,\cos\theta_1$
4	$-a_+a_+^* - a_-a_-^* + \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	1	$1/2\,(3\cos^2\theta_2 - 1)$
5	$-a_+a_+^* + a_-a_-^* + \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	P_b	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta$
6	$-a_+a_+^* + a_-a_-^* - \frac{1}{2}b_+b_+^* + \frac{1}{2}b_-b_-^*$	α_Λ	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta_1$
7	$-a_+a_+^* - a_-a_-^* - \frac{1}{2}b_+b_+^* - \frac{1}{2}b_-b_-^*$	$P_b\,\alpha_\Lambda$	$1/2\,(3\cos^2\theta_2 - 1)\,\cos\theta\cos\theta_1$
8	$-3Re(a_+a_-^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\cos\varphi_1$
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11	$\frac{3}{2}Im(b_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\sin\theta_1\,\sin^2\theta_2\,\sin(\varphi_1 + 2\,\varphi_2)$
12	$-\frac{3}{\sqrt{2}}Re(b_-a_+^* + a_-b_+^*)$	$P_b\,\alpha_\Lambda$	$\sin\theta\,\cos\theta_1\,\sin\theta_2\,\cos\theta_2\,\cos\varphi_2$
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Method of Moments

- Note that F_i's are mutually orthogonal
  - Therefore

$$\int d\Omega\, F_i F_j = \delta_{ij}$$

- If ω is the distribution function then:

$$\int \omega F_j \, d\Omega = < F_j >_{events}$$

$f_{1i}f_{2i}$ can be calculated!

i	f_{1i}	f_{2i}	F_i
0	$a_+a_+^* + a_-a_-^* + b_+b_+^* + b_-b_-^*$	1	1
1	$a_+a_+^* - a_-a_-^* + b_+b_+^* - b_-b_-^*$	P_b	$\cos\theta$
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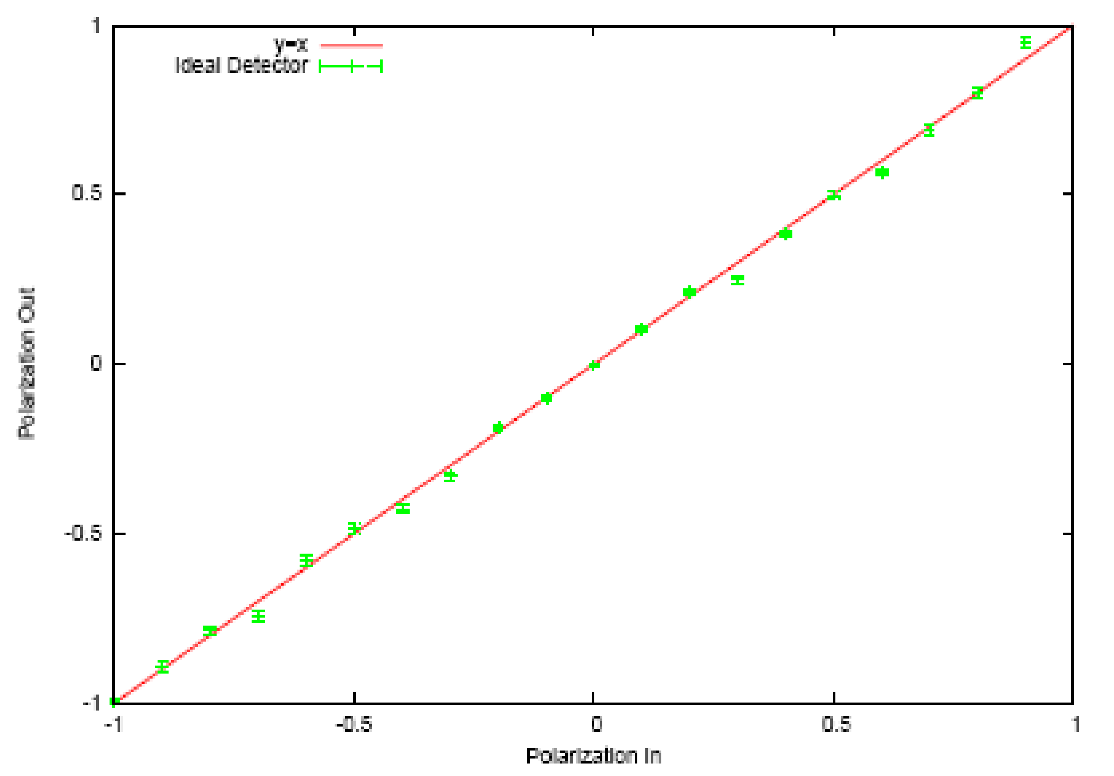
From Coefficients to Polarization

- The averaging process can determine all 20 products $f_{1i} f_{2i}$, which carry physically meaningful information
  - Thus giving 20 equations.
- The most convenient are first 8 (they are linear), which can determine magnitude of helicity amplitudes and polarization.
  - Note: 8 equations, 5 variables = over determined system
- There are 26 ways to calculate P → Use Weighted averages

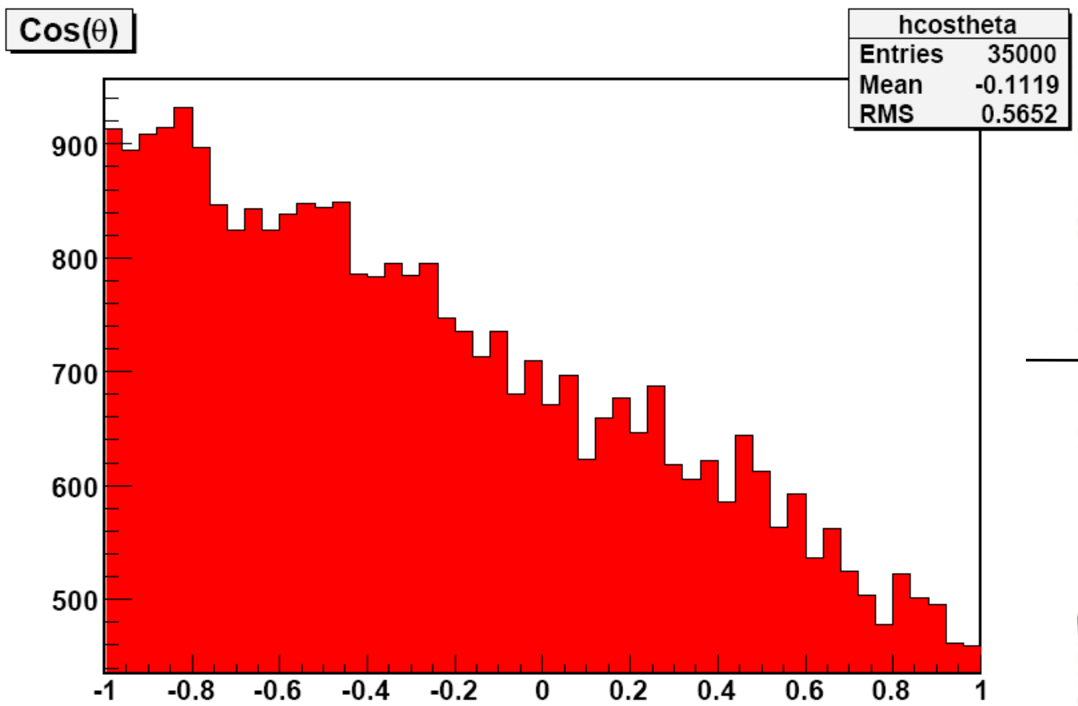
Ideal Detector Results

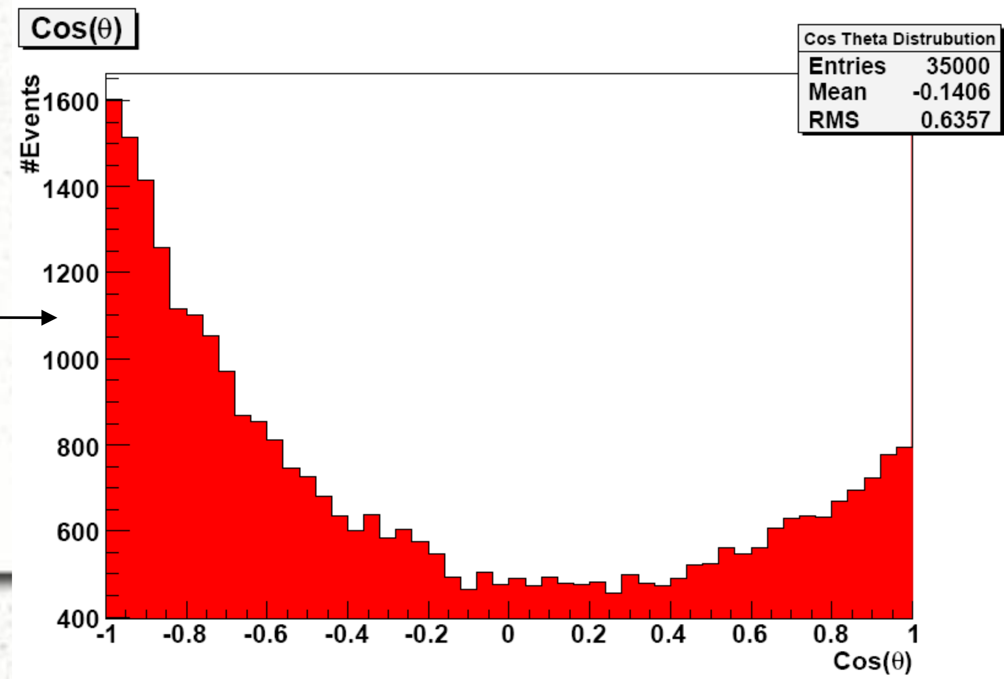
- For case of ideal detector this method works very well
- 35K events were generated with Toy Monte Carlo for various values of p
- Method of Moments Analysis was then performed



Detector Acceptance

- Detector acceptance (the fact that not all events can be successfully recorded and reconstructed) makes the analysis much harder.
- Below is what happens to Cos(θ) distribution with just eta and pt cut (35K events at p=.75)





Correction Method 1

- Let $\epsilon(\Omega)$ be the acceptance function

$$\int \omega F_j \, d\Omega \Rightarrow \int \epsilon(\Omega)\omega F_j \, d\Omega$$

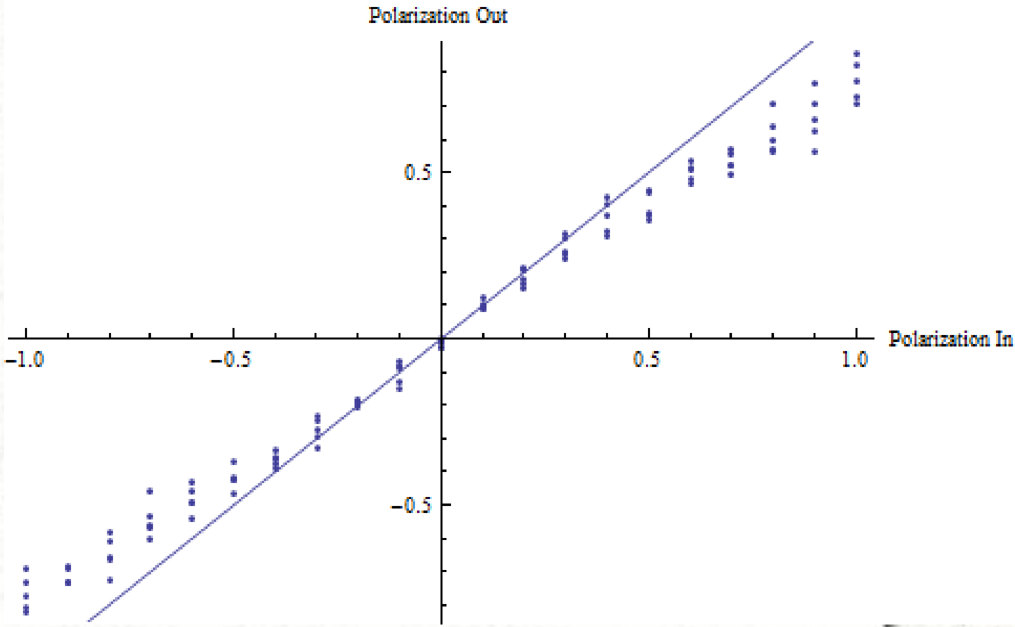
$$\int \frac{\omega F_j \epsilon(\Omega)}{\epsilon(\Omega)} \, d\Omega = < \frac{F_j}{\epsilon(\Omega)} >_{events}$$

Implementation of Correction Method 1

- The 5D space was subdivided into 10K bins
- Using 40M events at P=0 acceptance was calculated for each bin
- Linear Interpolation was used to smooth out the relatively wide range between centers of the bins.

Results for Correction Method 1

- No satisfying method of estimating the errors was found
- The correction method's results worsen with p going away from zero
- More robust method was found. Therefore this method was abandoned



Correction Method 2

- The inclusion of acceptance function breaks the direct proportionality between calculable averages and coefficients. However, this proportionality can be restored using 20x20 matrix:

$$c_i = \int d\Omega \omega(\Omega)\epsilon(\Omega)F_i \qquad a_j = \int d\Omega \omega(\Omega) F_j$$

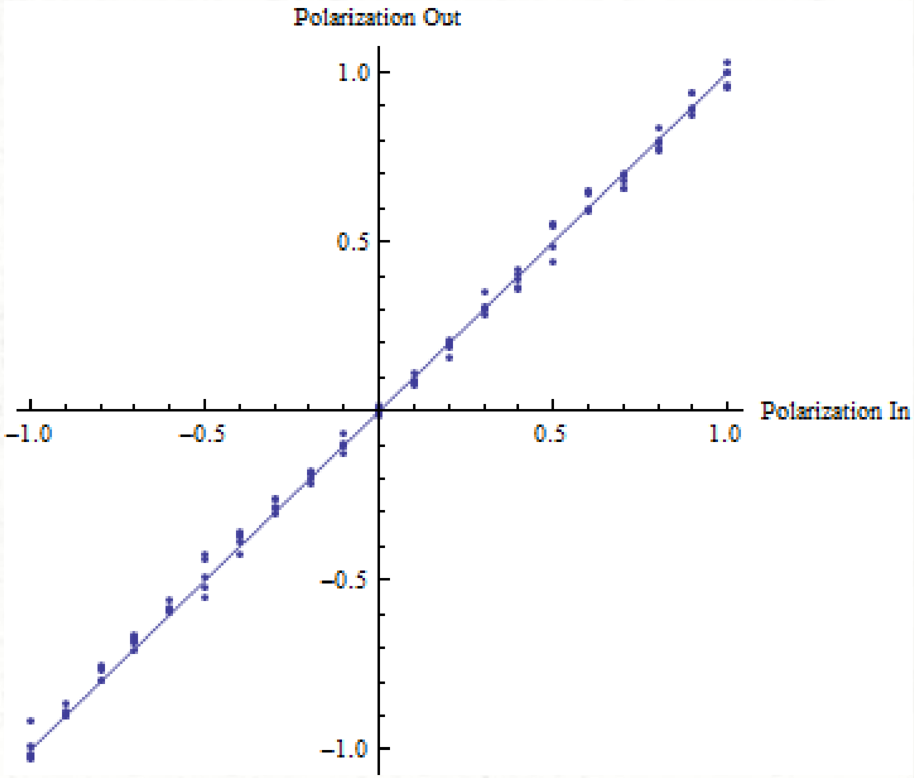
$$c_i = \int d\Omega \sum_j a_j F_j(\Omega)\epsilon(\Omega)F_i(\Omega) = \sum_j a_j \int d\Omega F_j(\Omega)\epsilon(\Omega)F_i(\Omega)$$

$$c_i = \sum_j a_j \epsilon_{ji} \qquad a_j = \epsilon_{ji}^{-1} c_i$$

$$\epsilon_{ij} = \int d\Omega\, \epsilon(\Omega)F_i(\Omega)F_j(\Omega) = \int d\Omega\, \frac{w(\Omega)\epsilon(\Omega)F_iF_j}{w(\Omega)} = < \frac{F_iF_j}{\omega(\Omega)} >_{events}$$

Results for Correction Method 2

- The correction matrix was calculated using 1M events at p=-.5
- The graph on the left shows p in vs. out for variety samples of 35K events at variety of P
- Method is very promising



Summary

- Data analysis is a highly complex task requiring utmost carefulness, especially with regard to detector acceptance
- The method of moments was shows as a viable candidate for extracting polarization of Λ_b with a promising method of correcting for detector acceptance.

Acknowledgments

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