Λ_b polarization in the decay

$$\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\Lambda(p^+\pi^-)$$

21/05/2015

R. Reyes, R. Rabadan, I. Heredia, H. Castilla,
CINVESTAV Mexico, Physics Dept.

Outline

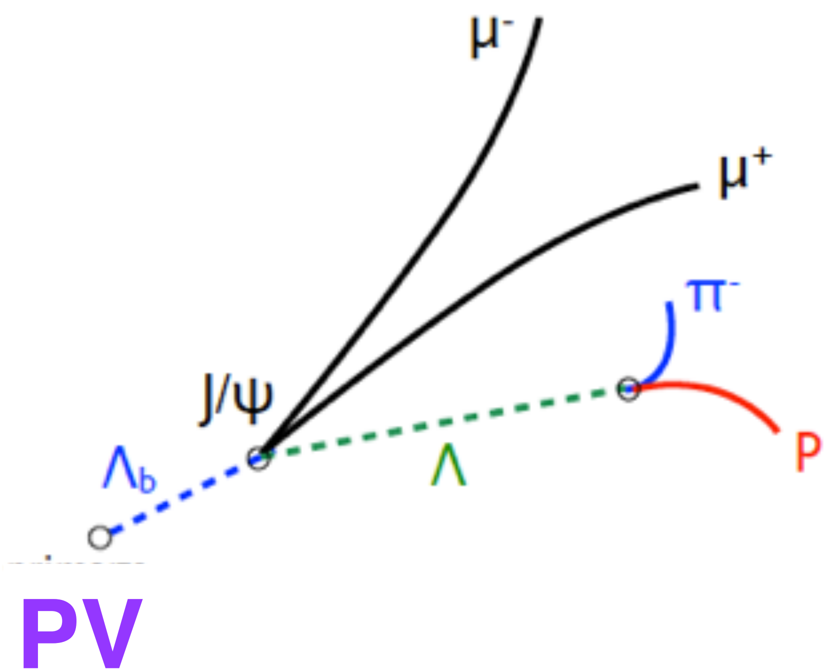
- Motivation
- Strategy to measure the Λ_b polarization
- Event Selection
- Likelihood fit
- Results
- Systematic Uncertainties
- Conclusions and plans

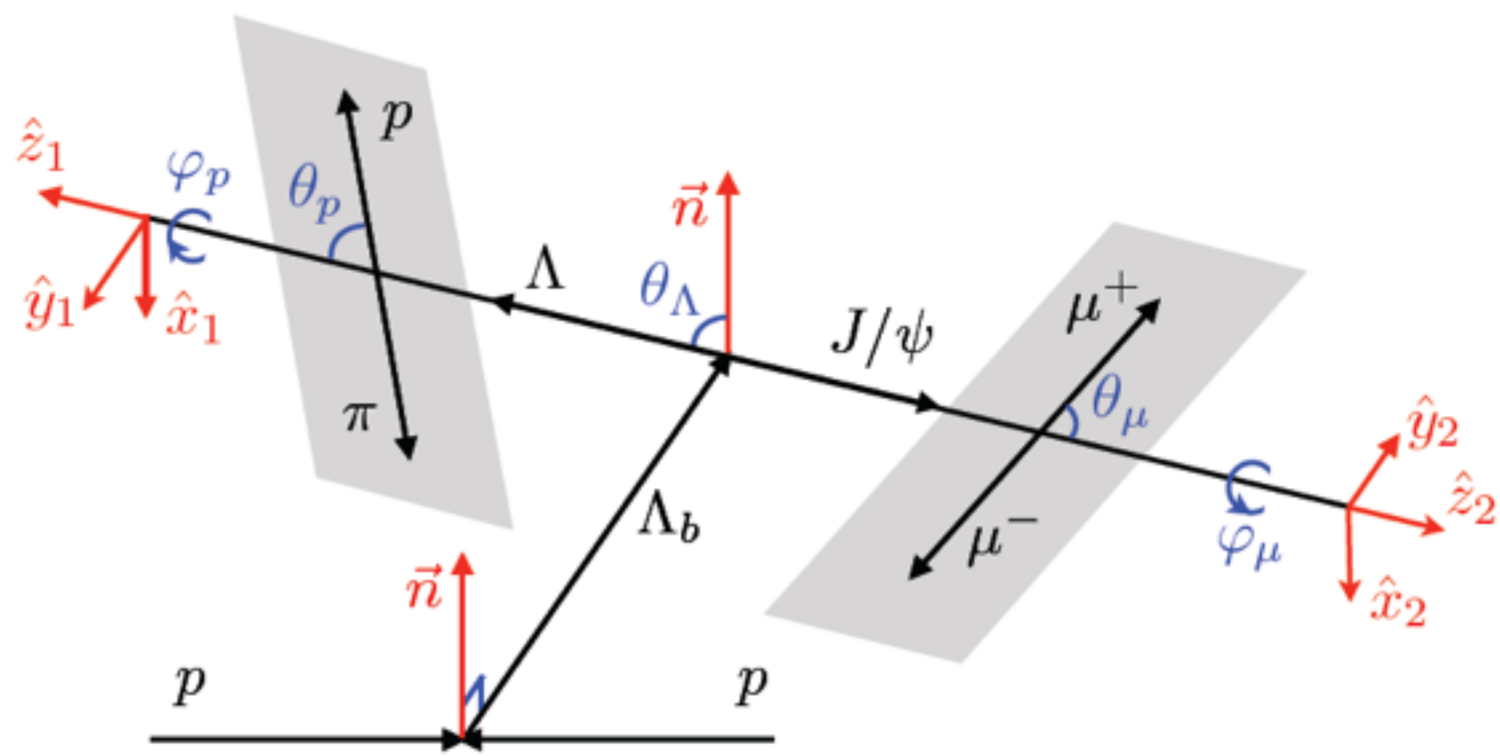
Motivation

- Predictions based on heavy-quark effective theory (HQET) augur for Λ_b baryons a large fraction of the transverse b-quark polarization to be retained after hadronization ~ 77% at 5.7 standard deviations. **arXiv:hep-ph/0412116.**
- A previous LHCb measurement in 2013 published in **Physics Letters B 724 (2013) 27.** where they exclude a tranverse polarization at the order of 20% at 2.7 standard deviations.

Strategy to measure the polarization

The decay





Strategy to measure the polarization

$$\frac{\mathrm{d}^5\Gamma}{\mathrm{d}\Omega_5}(\theta_\Lambda, \theta_p, \theta_\mu, \varphi_p, \varphi_\mu) \sim \sum_{i=1}^{20} \eta_i(T_{++}, T_{+0}, T_{-0}, T_{--})\; c_i(P, \alpha_\Lambda)\; f_i(\theta_\Lambda, \theta_p, \theta_\mu, \varphi_p, \varphi_\mu)$$

Observable angles — Helicity Amplitudes — Polarization and asymmetry parameter

- **Assuming a uniform detector acceptance over the azimuthal angles**

$$\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\Omega_3}(\theta_\Lambda, \theta_p, \theta_\mu) = \int_{-\pi}^{\pi}\int_{-\pi}^{\pi} \frac{\mathrm{d}^5\Gamma}{\mathrm{d}\Omega_5}(\theta_\Lambda, \theta_p, \theta_\mu, \varphi_p, \varphi_\mu)\, \mathrm{d}\varphi_p\, \mathrm{d}\varphi_\mu$$

$$\sim \sum_{i=1}^{8} \eta_i(T_{++}, T_{+0}, T_{-0}, T_{--})\; c_i(P, \alpha_\Lambda)\; f_i(\theta_\Lambda, \theta_p, \theta_\mu)$$

- **Using the normalization constraint for the helicity amplitudes**

$$|T_{++}|^2 + |T_{+0}|^2 + |T_{-0}|^2 + |T_{--}|^2 = 1,$$

Strategy to measure the polarization

- **The distribution can be expressed in three parameters** →

$$\alpha_1 \equiv |T_{+\frac{1}{2}+1}|^2 - |T_{+\frac{1}{2}0}|^2 + |T_{-\frac{1}{2}0}|^2 - |T_{-\frac{1}{2}-1}|^2,$$
$$\alpha_2 \equiv |T_{+\frac{1}{2}+1}|^2 + |T_{+\frac{1}{2}0}|^2 - |T_{-\frac{1}{2}0}|^2 - |T_{-\frac{1}{2}-1}|^2,$$
$$\gamma \equiv |T_{+\frac{1}{2}+1}|^2 - 2|T_{+\frac{1}{2}0}|^2 - 2|T_{-\frac{1}{2}0}|^2 + |T_{-\frac{1}{2}-1}|^2$$

Note

Particle $\alpha_i = -\bar{\alpha}_i$, $\gamma = \bar{\gamma}$ **anti Particle**

i	η_i	c_i	f_i
1	1	1	1
2	α_2	α_Λ	$cos\theta_p$
3	$-\alpha_1$	P	$cos\theta_\Lambda$
4	$-(1+2\gamma_0)/3$	$\alpha_\Lambda P$	$cos\theta_\Lambda cos\theta_p$
5	$\gamma_0/2$	1	$(3cos^2\theta_\mu - 1)/2$
6	$(3\alpha_1 - \alpha_2)/4$	α_Λ	$cos\theta_p (3cos^2\theta_\mu - 1)/2$
7	$(\alpha_1 - 3\alpha_2)/4$	P	$cos\theta_\Lambda (3cos^2\theta_\mu - 1)/2$
8	$(\gamma_0 - 4)/6$	$\alpha_\Lambda P$	$cos\theta_\Lambda cos\theta_p (3cos^2\theta_\mu - 1)/2$

$$F_{sig}(\Theta, \alpha) \equiv \frac{d^3\Gamma}{d\Theta} = \sum_{i=1}^{8} c_i(\alpha) \cdot \eta_i(\alpha) \cdot f_i(\Theta).$$

$$\Theta = (\cos\theta_\Lambda, \cos\theta_p, \cos\theta_\mu)$$

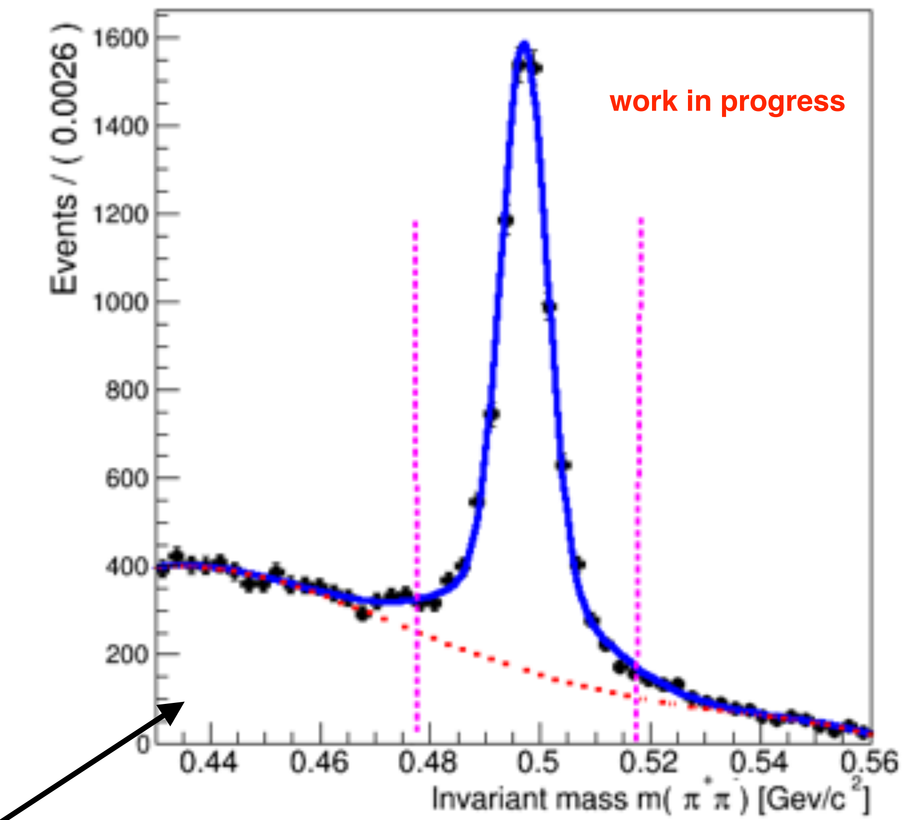
- **We use this approach as strategy to measure (P, α_1, α_2, γ) in a simultaneous fit. Taking the 2011 and 2012 data samples.**

Event Selection

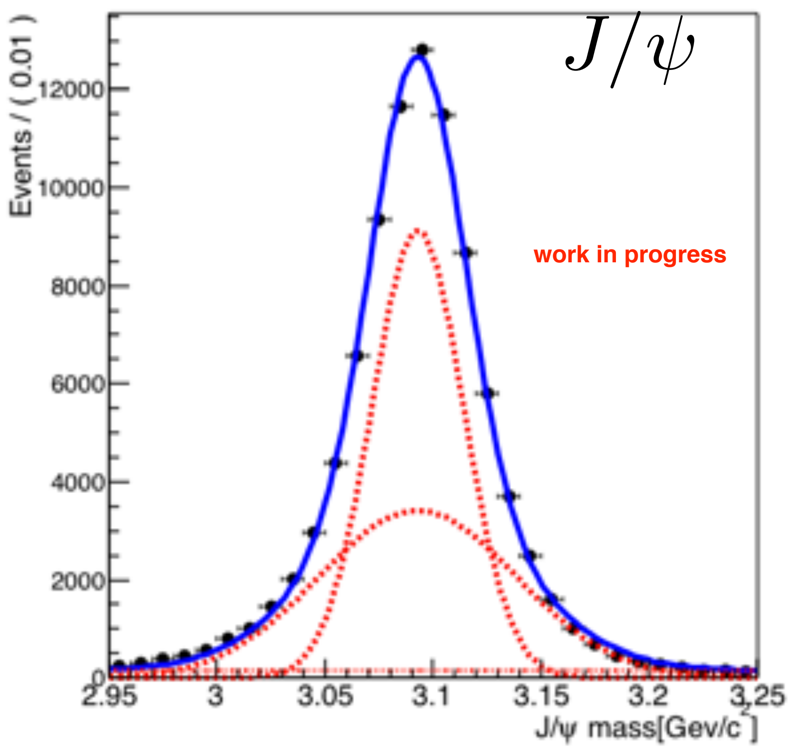
- **2011 and 2012 data at 7 TeV, 8 TeV corresponds to a integrated luminosity 5.2 (1/fb) and 19.7 (1/fb) respectively in pp collisions are reconstructed.**

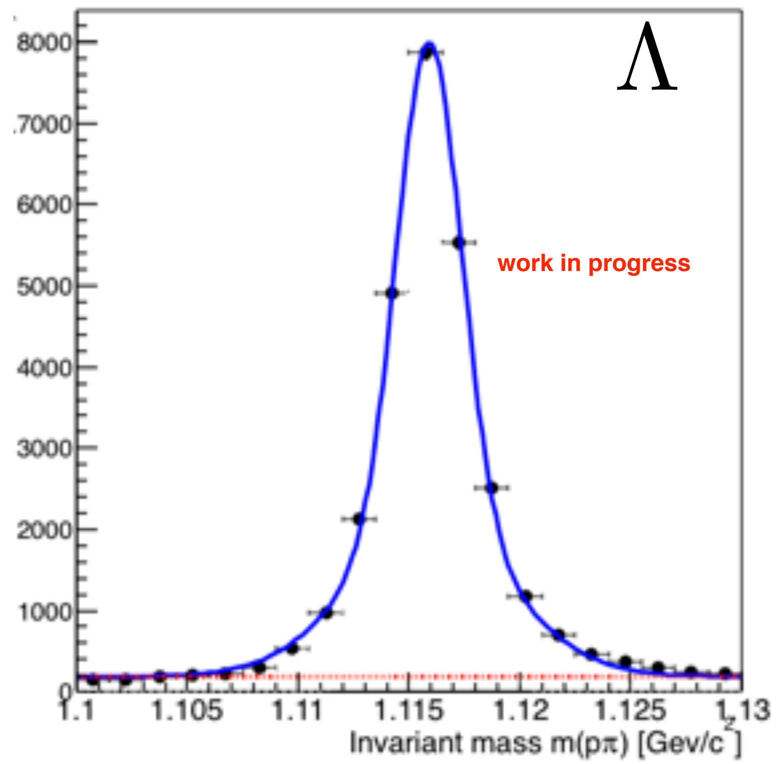
- **Cuts**

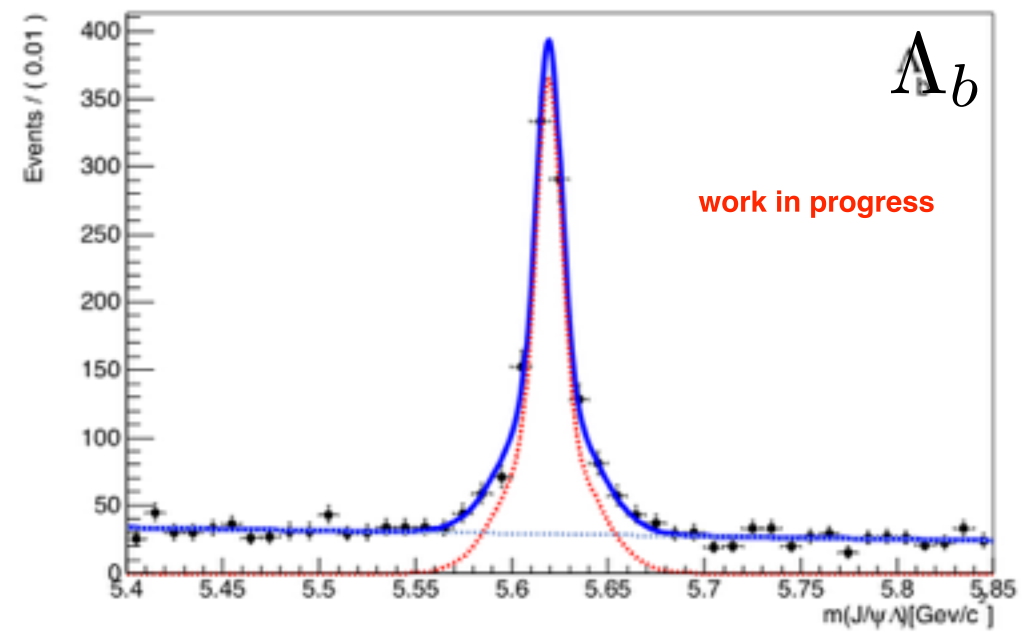
	Observable	cuts
J/ψ selection	$pT(\mu)$	$> 4GeV$
	vtx prob	$> 15\%$
	$\|\eta(\mu)\|$	< 2.2
	L_{xy}/σ	> 3
	$\cos(\alpha)$	> 0.95
	$pT(J/\psi)$	$> 8Gev$
	$m(J/\psi)$	$m_{PDG} \pm 150MeV$
Λ^0 selection	$p, \pi \# hits$	≥ 6
	track $\chi^2/ndof$	< 5
	track $d0$	$> 2\sigma$
	vertex χ^2	< 7
	L_{xy}/σ	≥ 15
	$pT(p)$	$> 1GeV$
	$pT(\pi)$	$> 0.3GeV$
	$pT(\Lambda)$	$> 1.3GeV$
	vtx prob(Λ)	$> 2\%$
	window mass $m(\Lambda)$	$m_{PDG} \pm 9MeV$
	$m(K_s)$ veto	$m_{PDG} \pm 20MeV$
on Λ_b candidates	$pT(\Lambda_b)$	$> 10GeV$
	vtx prob(Λ_b)	$> 3\%$



Event Selection







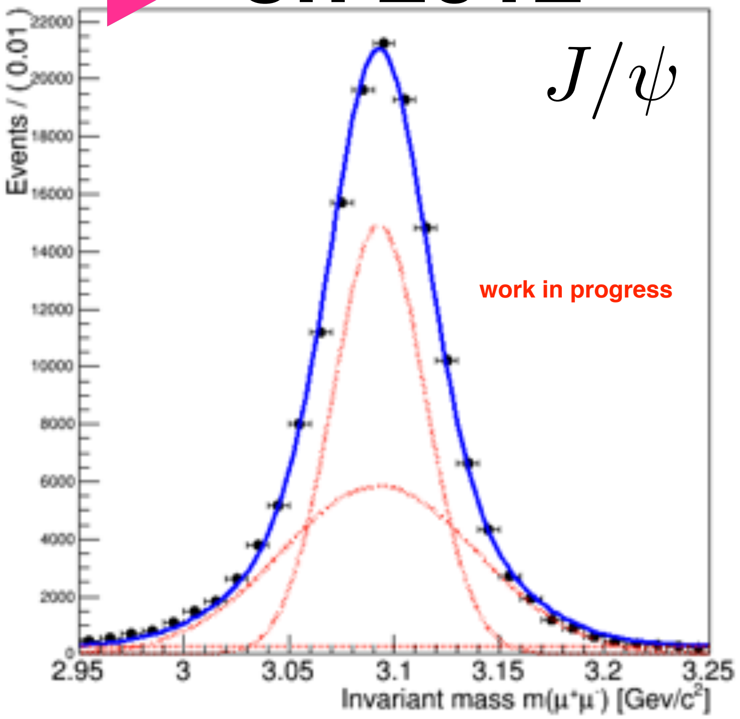
- **The Λ_b invariant mass signal and BKG is modelled by:**

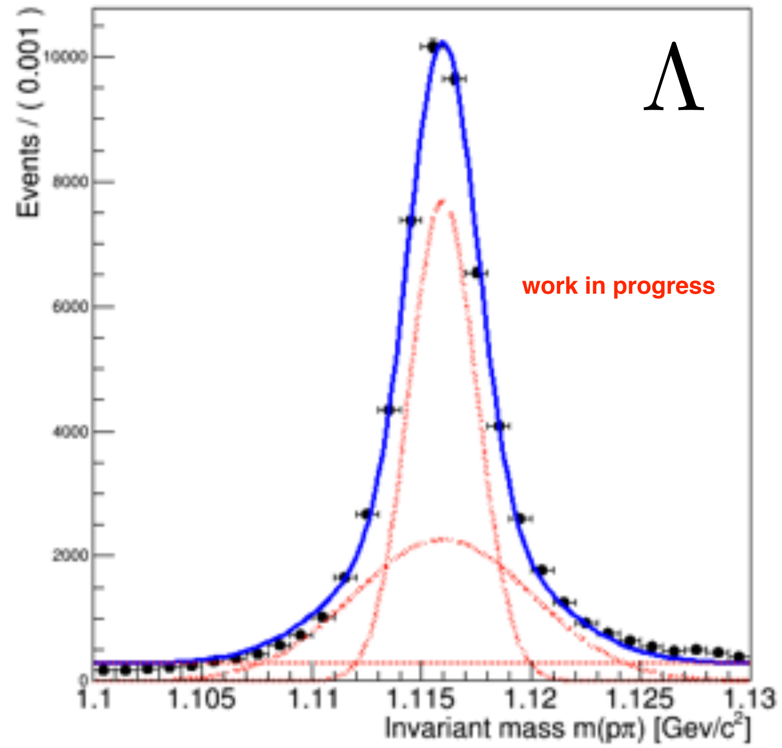
$$G(x;\mu,\sigma_1,\sigma_2,f) = f \bullet G_1(x;\mu,\sigma_1) + (1-f) \bullet G_2(x;\mu,\sigma_2) \quad Pol(x) = 1 + ax$$

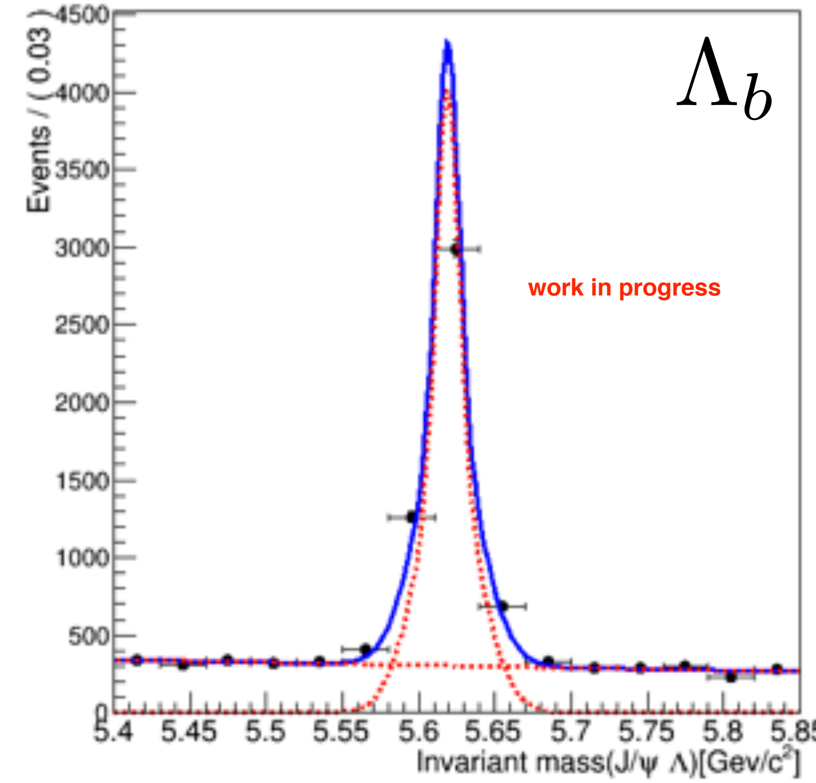
- **Mass fit results in the 2011 data sample**

Description	Parameter	Estimate Full sample $\Lambda_b + \bar{\Lambda}_b$	Estimate Λ_b	Estimate $\bar{\Lambda}_b$
Num. of bkg candidates	N_{bkg}	2325 ± 59 56	1300 ± 43	1018 ± 41
Num. of signal candidates	N_{sig}	1890 ± 55	981 ± 39	916 ± 40
Mean of Gaussian	μ (GeV)	5.61985 ± 0.00034	5.619 ± 0.00044	5.620 ± 0.00049
Width of Gaussian	σ_1 (GeV)	0.0214 ± 0.0024	0.0215 ± 0.0024	0.0240 ± 0.0059
Width of Gaussian	σ_2 (GeV)	0.00709 ± 0.00095	0.00637 ± 0.00092	0.0086 ± 0.00013
Double Gaussian fraction	f	0.539 ± 0.082	0.578 ± 0.074	0.41 ± 0.013
Bkg. coeff.	a	-0.1456 ± 0.0052	-0.14287 ± 0.0082	-0.14816 ± 0.0067

- **on 2012**







- **Mass fit results in 2012 data sample**

Description	Parameter	Estimate Full sample $\Lambda_b + \bar{\Lambda}_b$	Estimate Λ_b	Estimate $\bar{\Lambda}_b$
Num. of bkg candidates	N_{bkg}	4554 ± 80	2409 ± 58	1975 ± 53
Num. of signal candidates	N_{sig}	4122 ± 78	2072 ± 55	1974 ± 53
Mean of Gaussian	μ (GeV)	5.61909 ± 0.00025	5.61935 ± 0.00036	5.61885 ± 0.00036
Width of Gaussian	σ_1 (GeV)	0.0205 ± 0.001	0.0203 ± 0.0014	0.0203 ± 0.0015
Width of Gaussian	σ_2 (GeV)	0.00729 ± 0.0006	0.00765 ± 0.00083	0.00693 ± 0.00086
Double Gaussian fraction	f	0.635 ± 0.046	0.617 ± 0.067	0.655 ± 0.063
Bkg. coeff.	a	-0.13502 ± 0.0066	-0.1288 ± 0.0012	-0.13983 ± 0.0080

Full Likelihood Fit

- In order to obtain a polarization measurement an extended likelihood fit is done on the data sample, the likelihood function has the form

$$L = \exp(-\mathrm{N_{sig}} - \mathrm{N_{bkg}}) \prod_{\mathrm{j=1}}^{\mathrm{N}} [\mathrm{N_{sig}} \cdot \mathrm{PDF_{sig}} + \mathrm{N_{bkg}} \cdot \mathrm{PDF_{bkg}}]$$

Where the PDF of signal and background are:

Signal $PDF_{sig}^{+(-)} = F_{sig}^{+(-)}(\Theta, \alpha) \cdot \epsilon(\Theta)^{+(-)} \cdot G^{+(-)}(m; \mu, \sigma_1, \sigma_2, f).$

Angular distribution of the signal described above

Angular efficiency shape by the detector

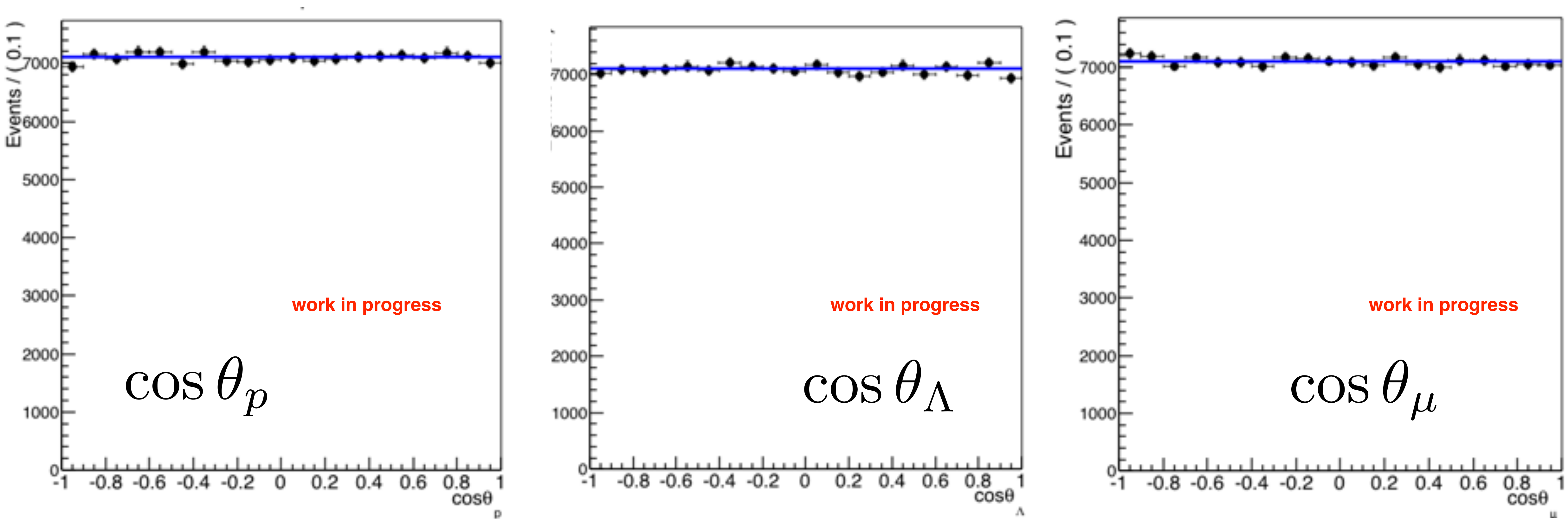
mass PDF described above

Note $+(-)$ Relative to particle and anti particle

Full Likelihood Fit

Efficiency shapes

Angular distribution are generated flat at truth level using phsp models in EVTGEN

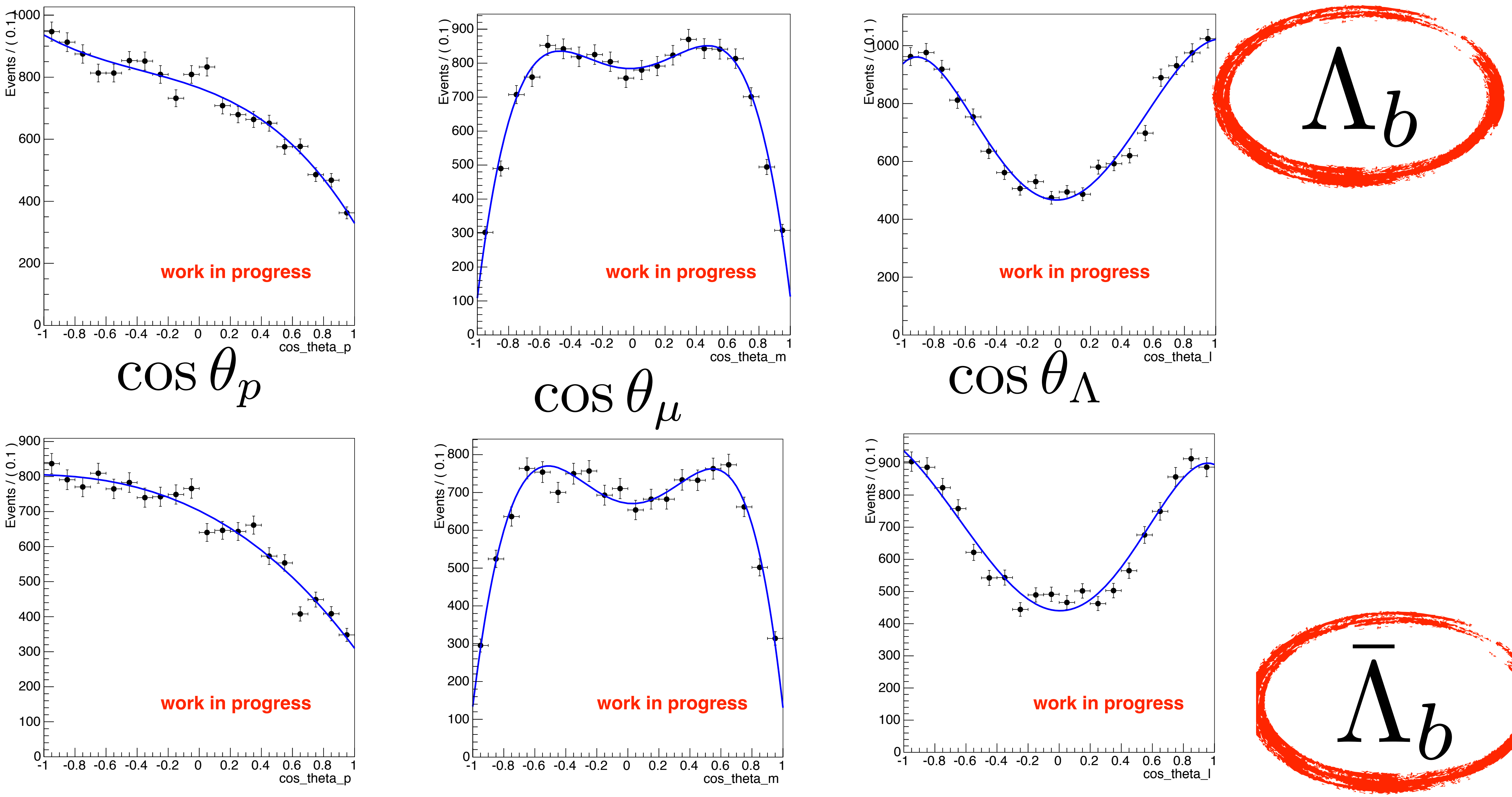


After detection, reconstruction and selection angular distributions are distorted drastically!.

Full Likelihood Fit

Efficiency shapes **modelled with Chebyshev polynomials.**

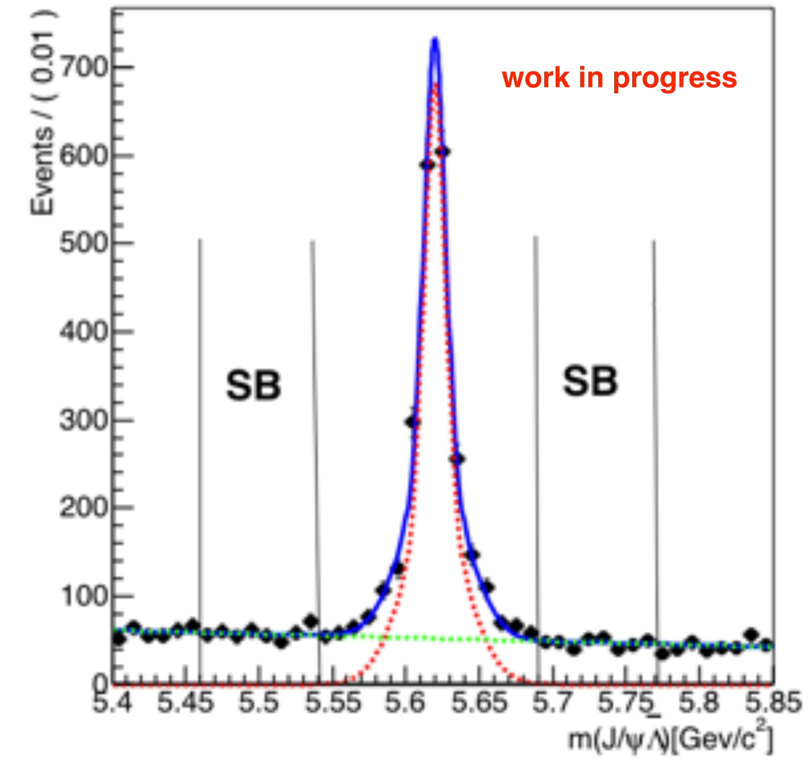
$$\epsilon(\Theta)^{+-} = \left(\sum_{i=1}^{6} A_i^{+-} \bullet T_i(\cos\theta_\Lambda)\right) \times \left(\sum_{j=1}^{3} B_j^{+-} \bullet T_j(\cos\theta_p)\right) \times \left(\sum_{k=1}^{6} C_k^{+-} \bullet T_k(\cos\theta_\mu)\right)$$



Full Likelihood Fit

Background PDF

$$PDF_{bkg}^{+(-)} = F_{bkg}^{+(-)} \cdot Pol^{+(-)}(m)$$



sidebands range $[5.46, 5.54]\bigcup[5.69, 5.78]$
corresponding $[\mu - 10\sigma, \mu - 5\sigma]\bigcup[\mu + 5\sigma, \mu + 10\sigma]$

- **The angular distribution for $\cos\theta_\mu$ and $\cos\theta_\Lambda$ are modeled by a superposition of Gaussian kernels one for each data point, by implementing RooFit's class RooKeysPdf.**

- **The explicit form for $\cos\theta_p$ is a Chebyshev polynomial**

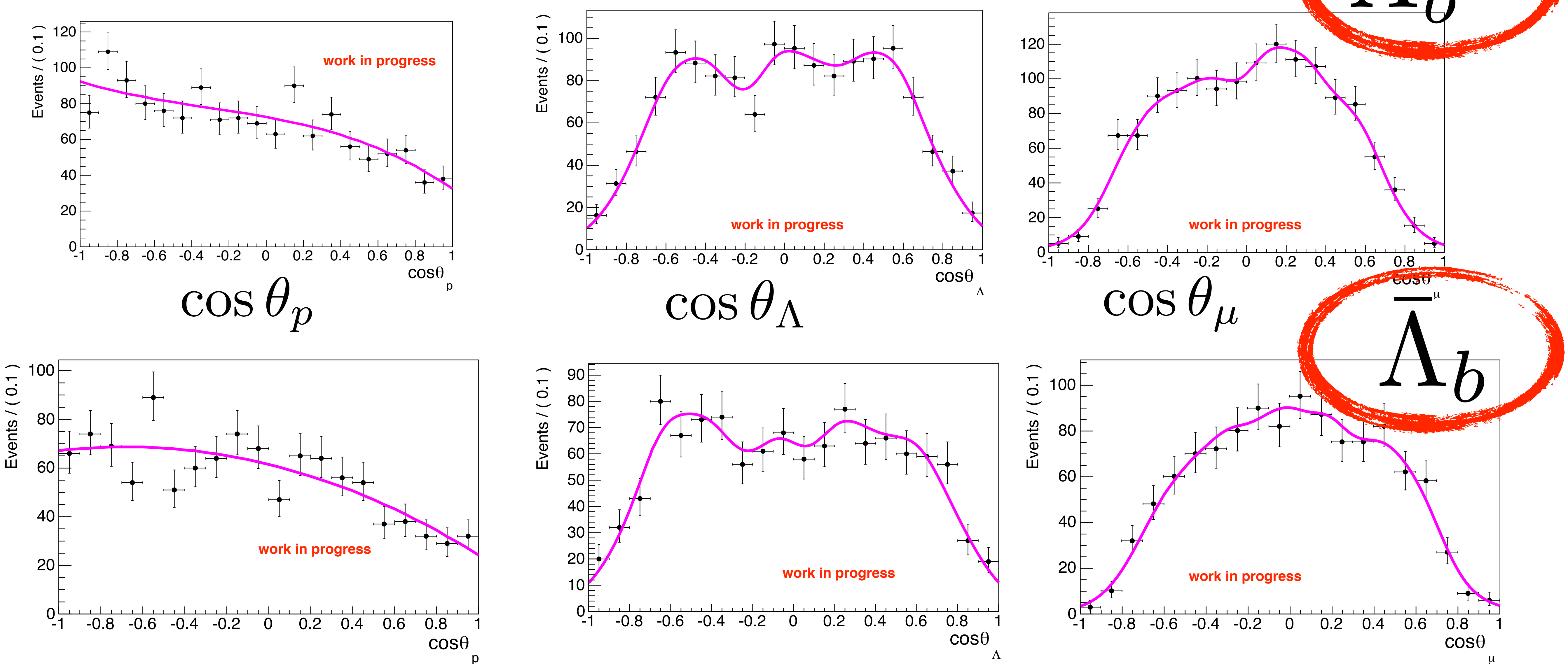
$$F_{bkg}^{+(-)}(cos\theta_p) = \sum_{i=0}^{3} B_i^{+(-)} \cdot T_i(cos\theta_p)$$

Full Likelihood Fit

Background PDF

Angular distribution from sidebands

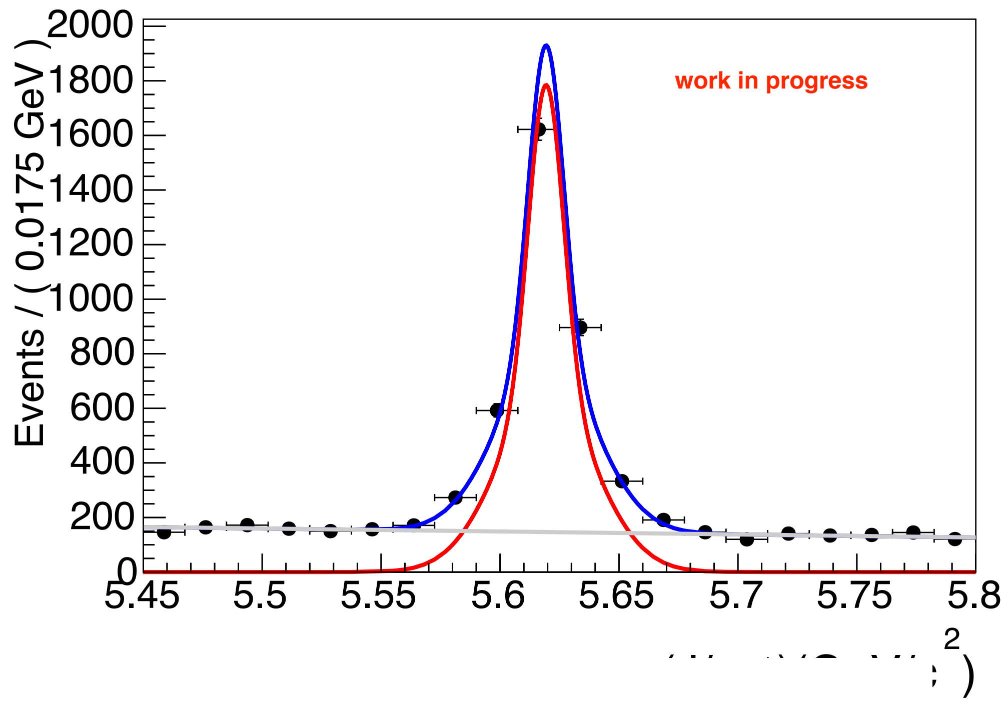
Λ_b

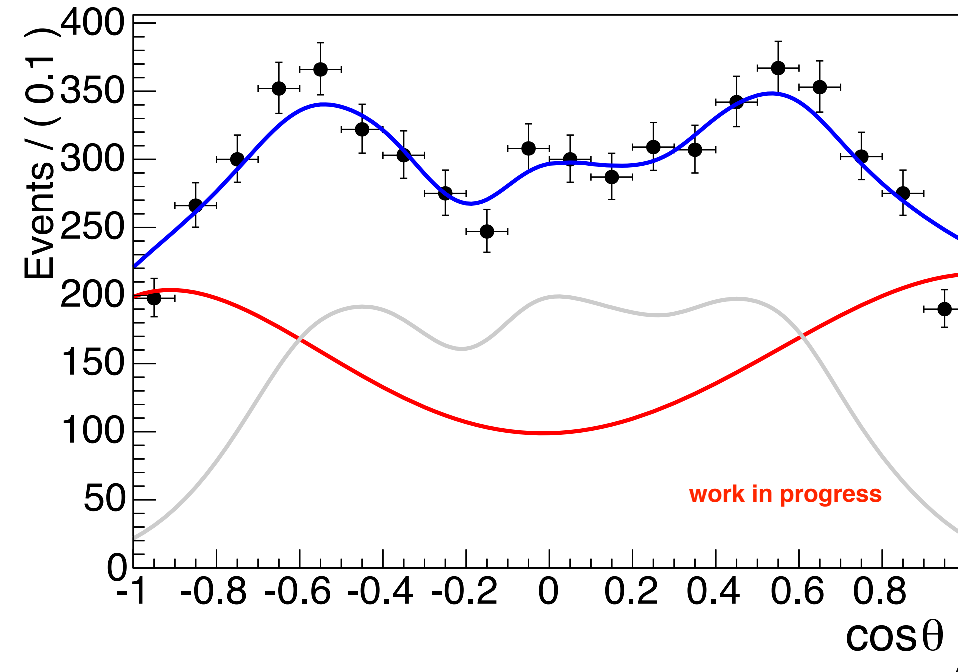


Region $[\mu - 10\sigma, \mu - 5\sigma] \bigcup [\mu + 5\sigma, \mu + 10\sigma]$

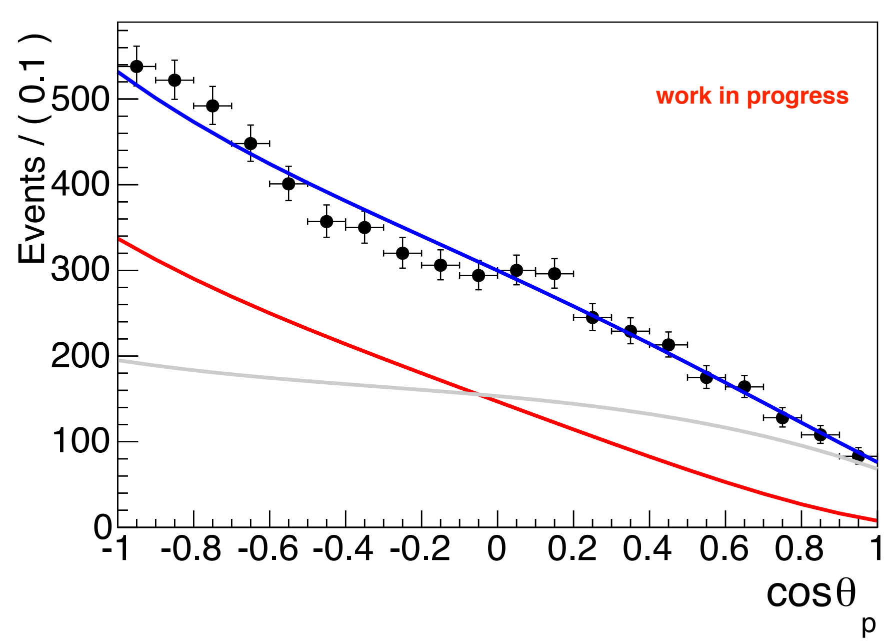
Results

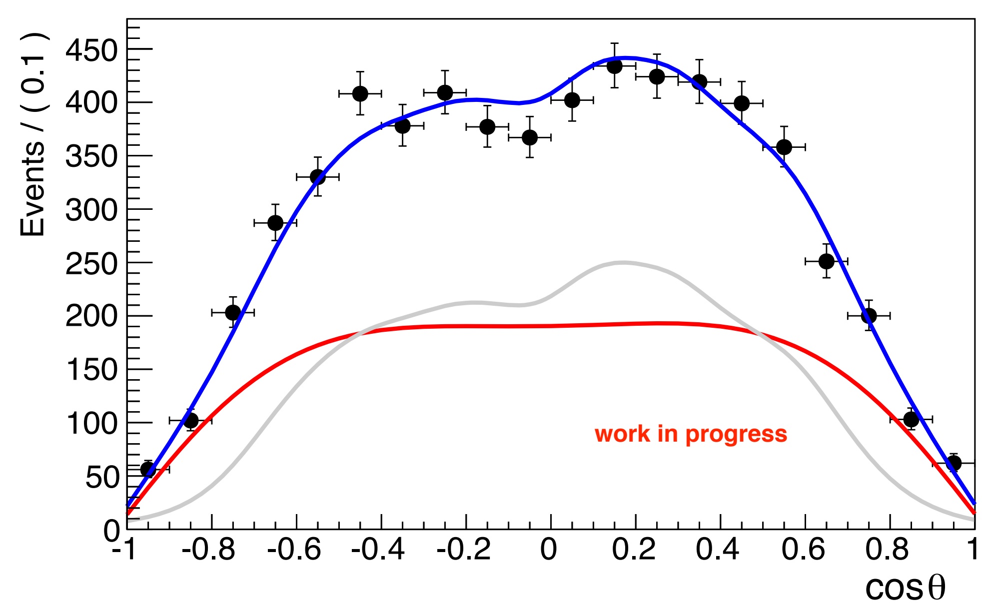
- **Finally an unbinned maximum likelihood simultaneous fit is applied to 2011 and 2012 data samples.**



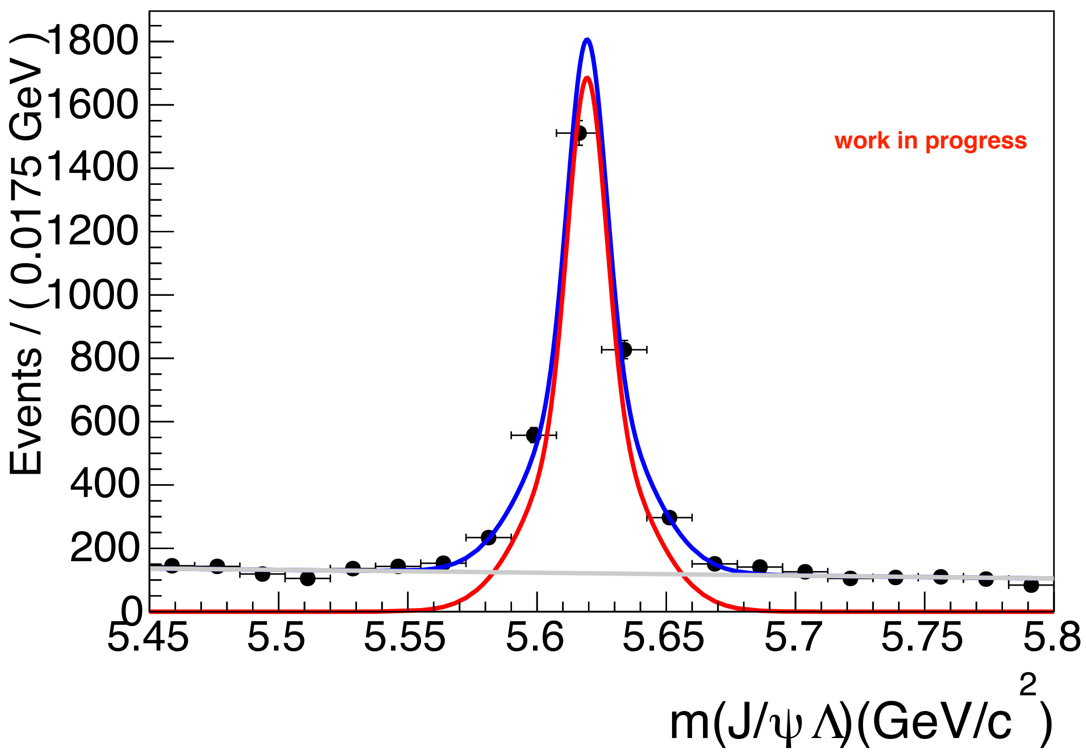


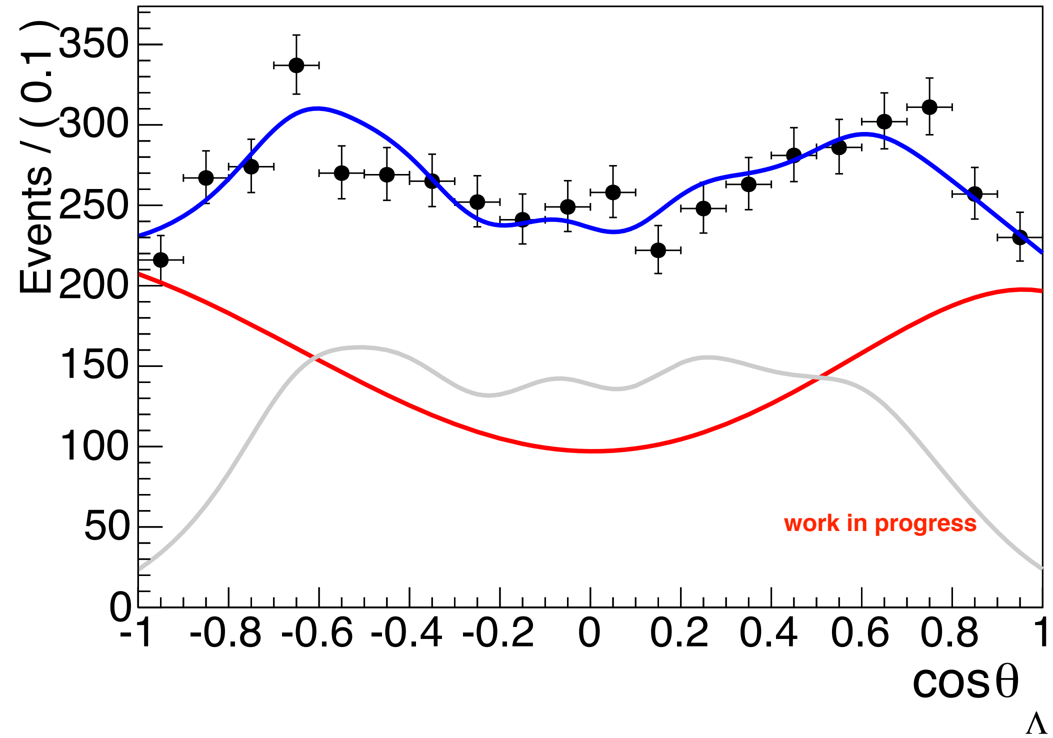
Λ_b

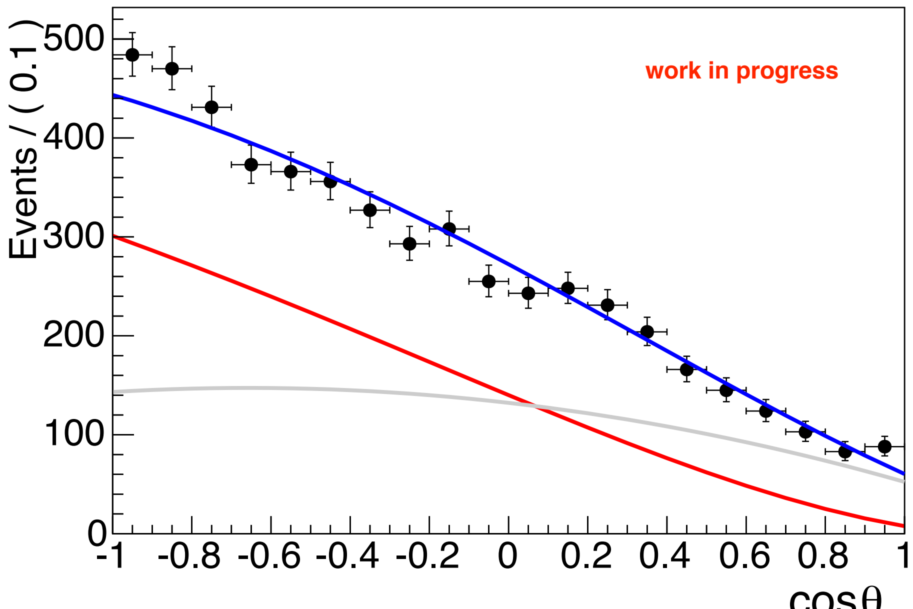


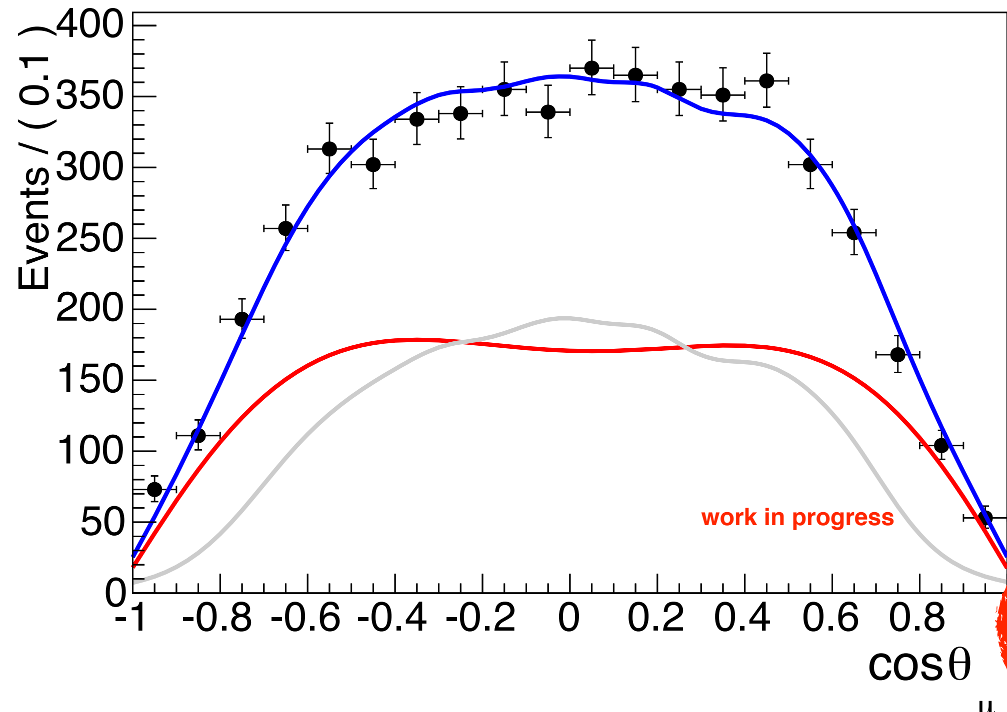


Results









$\bar{\Lambda}_b$

Solid red line represents the signal

Solid gray line represents the background

Solid blue line represents the fit

Results

LHCb results in 2013

Parameters	Fit Results
P	0.007 ± 0.034
α_1	0.45 ± 0.12
α_2	-1.371 ± 0.036
γ_0	-0.7203 ± 0.072

$$P_b = 0.06 \pm 0.07 \pm 0.02,$$
$$\alpha_b = 0.05 \pm 0.17 \pm 0.07,$$
$$r_0 = 0.58 \pm 0.02 \pm 0.01,$$
$$r_1 = -0.56 \pm 0.10 \pm 0.05,$$

Systematic uncertainties

* About the uncertainties, until now
* Background mass model Exponential function instead of a 1st. order polynomial.
* Signal mass model. We are using a model that uses only one convoluted Gaussian with and exponential function.
* Asymmetry parameter. The value of this parameter is varied within ±sigma of its measured value.
* Angular efficiency. estimate the systematic uncertainty by varying the values of the coefficients of the Chebyshev polynomials by ±sigma.
* Angular background. We are using alternative models to fit the three angular distributions and the difference with the nominal result is taken as systematic uncertainty.
* Fitting bias. the difference between the input and the fitted value is taken as the systematic uncertainty.

Systematic uncertainties

- The contributions from the different uncertainty sources are assumed to be independent .

- The total systematic uncertainty is calculated as the square root of the quadratic sum of all uncertainties.

Uncertainty source	P	α_1	α_2	γ_0
Background mass model	0.001	0.015	0.008	0.024
Signal mass model	0.003	0.009	0.037	0.021
α_Λ uncertainty	0.002	0.024	0.036	0.025
Angular Efficiency	0.010	0.018	0.008	0.040
Angular Background	0.000	0.022	0.013	0.046
Fit bias	0.001	0.003	0.012	0.002
Total	0.011	0.041	0.056	0.073

Conclusions and plans

- We measured Λ_b polarization using the 2011 and 2012 data by using an unbinned likelihood fit. The analysis it's almost complete.

- We are competitive with LHCb.

- We are working to calculate mising systematic uncertainties. the most significant uncertainties is:

    - The non uniformity in azimuthal efficiency shape

- Have to compute over again using official MC.