18 – 21 April 2011 Vienna, Austria

Quarkonium Production
Probing QCD at the LHC

Prompt J/Ψ polarization at LHCb experiment

Emanuele Santovetti*
on behalf of the LHCb Collaboration

- Physics Motivation
- Measurement methods
- Systematics and statistics consideration
- Conclusions

Physics motivation

- Model (CSM, COM) give clear prediction of prompt J/Ψ polarization that provides an important theory test. But...
  - Feeddown from higher charmonium state must be understand
  - Good understanding of detector acceptance needed
- Polarization knowledge helps to decrease the error on the cross section measurement
- Possible comparison with previous measurements (CDF and HERA-B) and other LHC experiments

Polarization measurement

- The full angular dependence is (normalization apart):

$$\frac{d^2N}{d\cos\theta\, d\phi} = 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

$$\frac{dN}{d\cos\theta} = 1 + \lambda_\theta \cos^2\theta$$

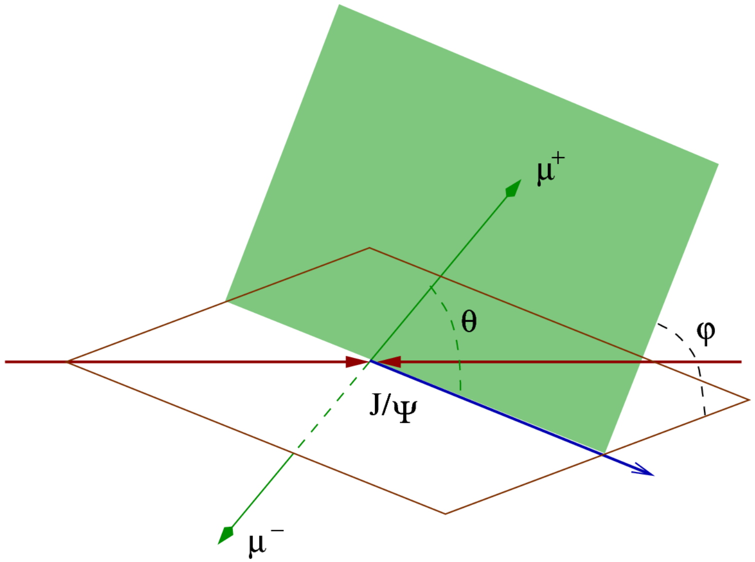
$$\frac{dN}{d\phi} = 2 + \frac{1}{3}\lambda_\theta + \frac{4}{3}\lambda_\phi \cos 2\phi$$

Helicity Frame

θ is the polar angle between the μ^+ momentum and the J/ψ fly direction, in the J/ψ rest frame

φ is the azimuthal angle between the J/ψ production plane (beam axis and J/ψ momentum) and the μ^+ decay plane (beam axis and μ^+ momentum)

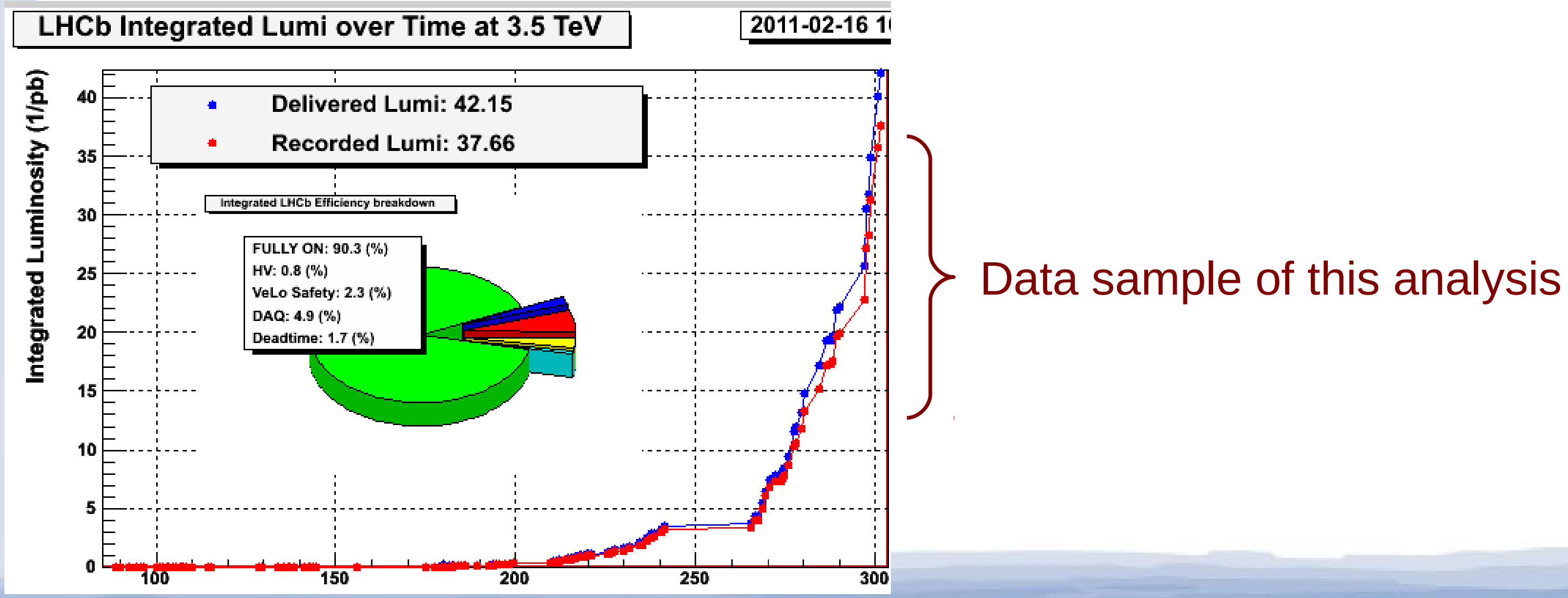
Measurement in CS frame in near future



Polarization measurement

- Polarization as a function of transverse momentum p_T
  - 15 bins in pt: $0 < p_T < 15$ GeV/c
  - Statistics not enough to bin in y (five bins $2 < y < 4.5$ under study)

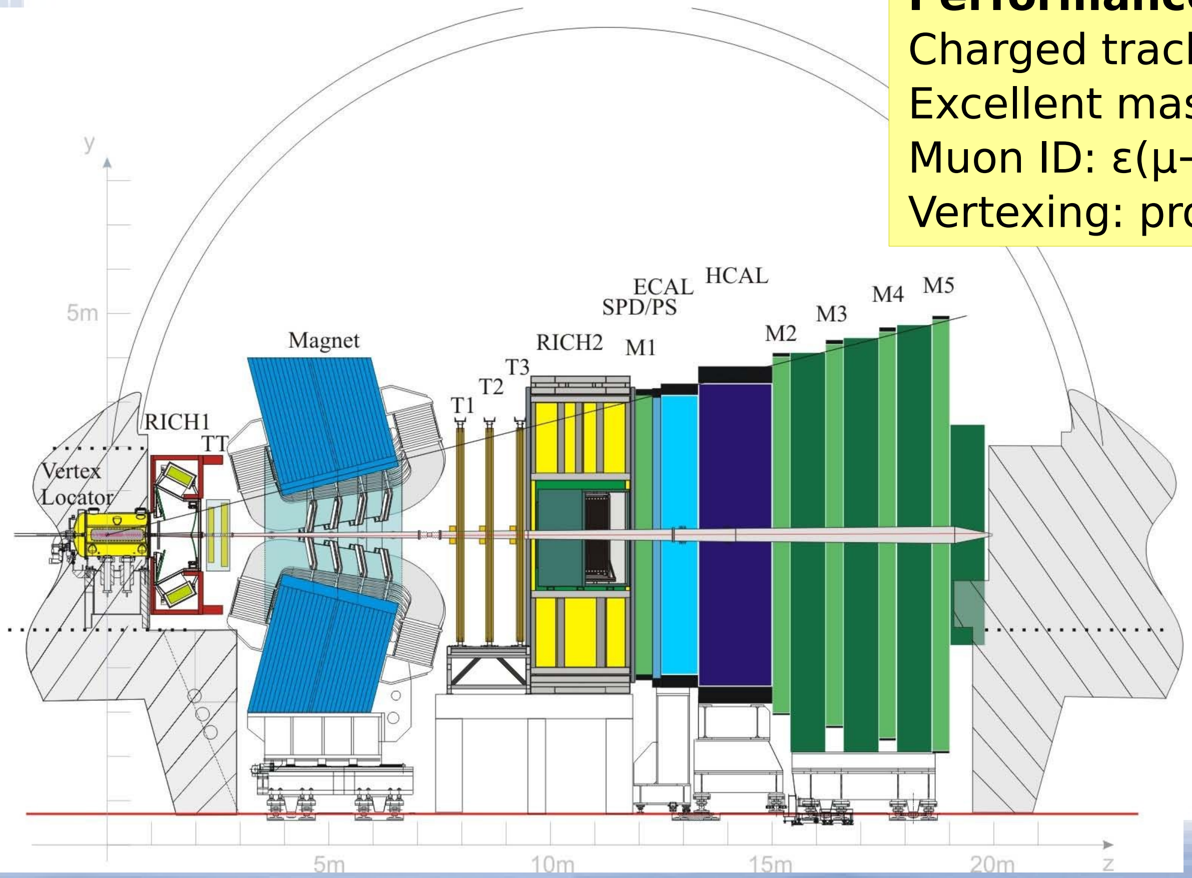
- Data: ~25 pb-1 (~70% of the full 2010 integrated luminosity)
  - ~ 2.8M J/Ψ (homogeneous trigger conditions)

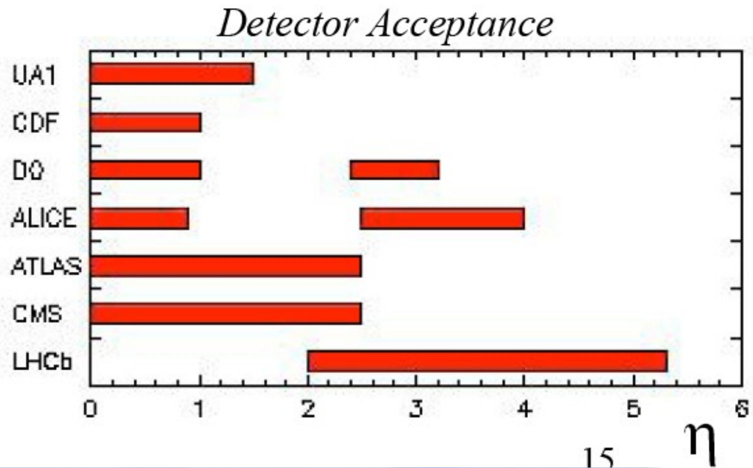


The LHCb detector

- Forward single arm spectrometer: large and correlated bb quark production in the forward region
- Coverage: 15-300 mrad
- Unique acceptance among the LHC experiments: can explore production properties in the forward region.

Performance numbers relevant to J/ψ analysis
Charged tracks Δp/p = 0.35 % - 0.55%
Excellent mass resolution
Muon ID: ε(μ→μ) = 97 %, mis-ID rate (π→μ) = 1-3 %
Vertexing: proper time resolution 30-50 fs





Trigger and selection

Trigger

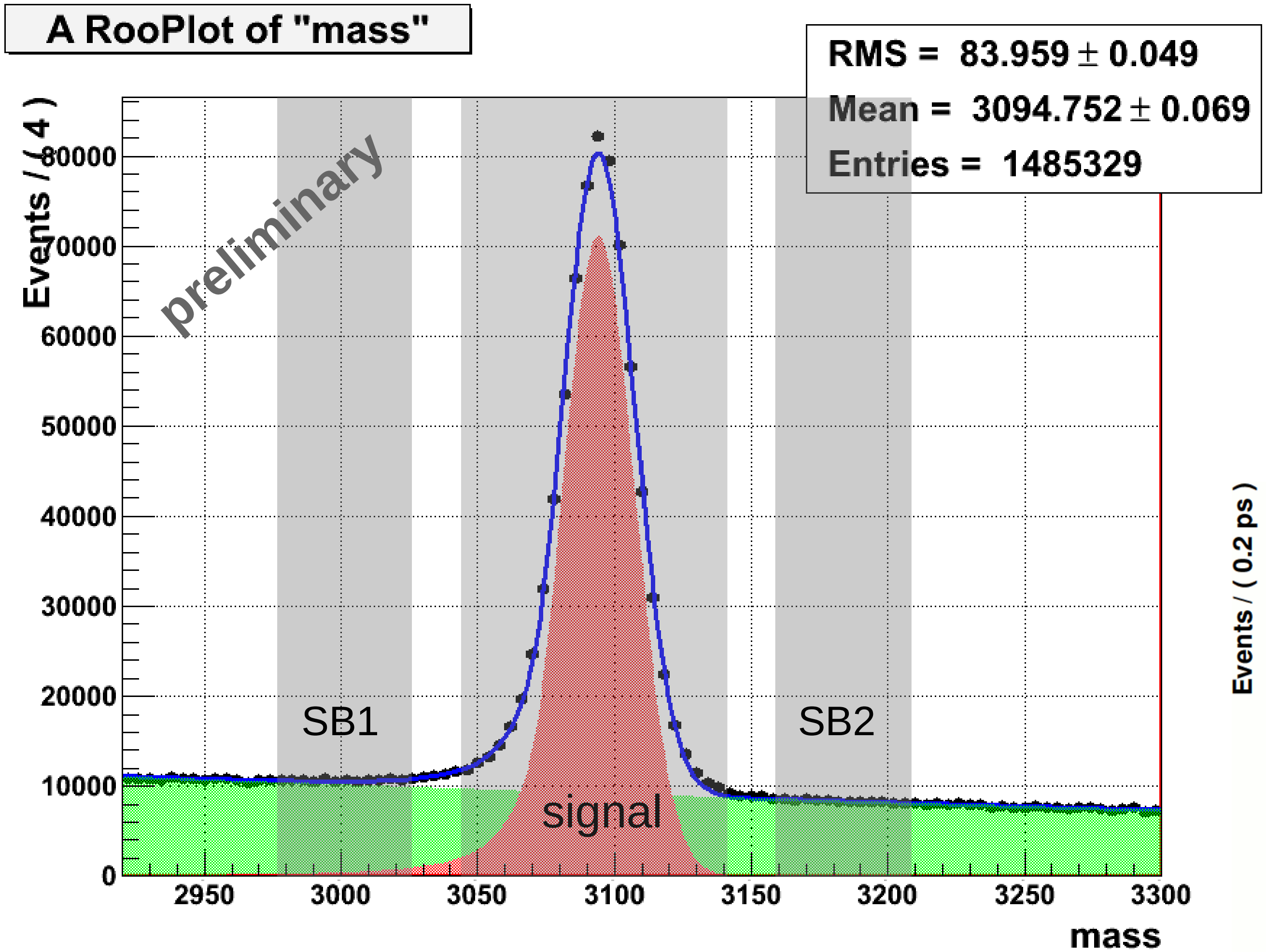
L0	Single Muon	p_T>1.4 GeV/c
	Di-Muon	$p_{T,1}$>0.56 GeV/c, $p_{T,2}$>0.48 GeV/c
HLT1	Single Muon	Confirm L0 single Muon and p_T>1.8 GeV/c (Pre-scaled in some lines by a foctor of 0.2)
	Di-Muon	Confirm L0 Di-Muon and Mμμ>2.5 GeV/c2
HLT2	Di-Muon	Mμμ>2.9 GeV/c2

Offline selection

- Muon track well reconstructed and identified as muon
- Muon p_T > 0.75 GeV/c
- Muon track fit quality: χ^2/nDoF < 4
- J/ψ Mass > 2.9 GeV/c^2,
- J/ψ vertex fit quality: P(χ^2)>0.5%.

Signal selection

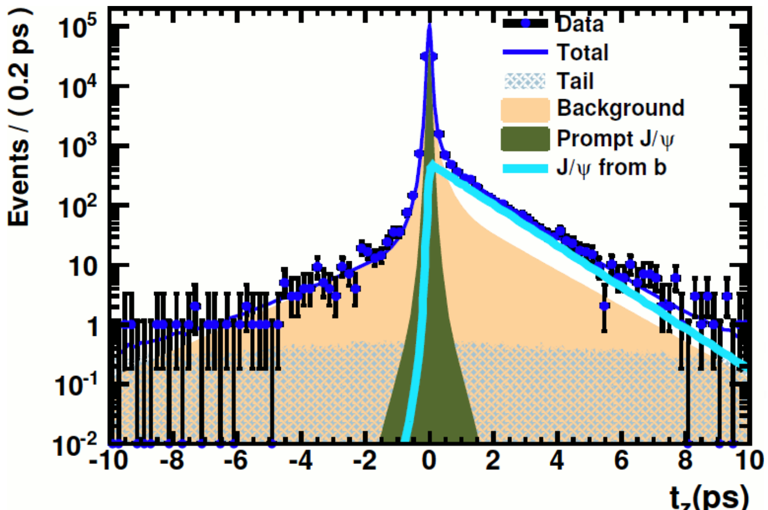
1 GeV < p_T < 2 GeV



- Fit with Crystal Ball function, signal distribution in ±50 MeV window
- Background evaluation from side bands analysis (two symmetric, 50MeV width windows)

SB choice is a compromise: not to close to the signal, to avoid signal contamination (radiative tail), not to far from the signal to be similar to the background under the signal

- ~2.5M J/Psi, <u>analysis only on prompt ones</u>: abs(t_z)<0.2 ps



Polarization measurement

- Three methods have been identified to measure the three parameters λ_θ, $\lambda_{\theta\varphi}$ and λ_φ
  - **Binned fit of the two dimensional angular distribution (φ – cosθ)**
  - **Binned fit of 1-dimensional distributions in φ, cosθ and a combination of them**
  - **Unbinned fit with a Likelihood method**

Binned fit method

- Find the $\cos\theta$, φ distribution (or separately the $\cos\theta$ and φ) in the signal fiducial region and in the side bands (SB)
- Subtract the Background (SB) distribution, properly normalized, from the signal one
- Apply the acceptance correction, dividing the signal data distribution by the MC acceptance function (distribution obtained from MC unpolarized sample)
- Fit the resulting distribution with the theoretical $f(\cos\theta, \varphi)$ function

futhermore...

If we define a new variable

$$\phi_\theta = \phi - \frac{3}{4}\pi \text{ for } \cos\theta < 0$$
$$\phi_\theta = \phi - \frac{\pi}{4} \text{ for } \cos\theta > 0$$

and substitute the new variable in the full angular distribution and integrate over cosθ

$$\frac{dN}{d\phi_\theta} = 1 + \frac{\sqrt{2}\lambda_{\theta\phi}}{3+\lambda_\theta}\cos\phi_\theta$$

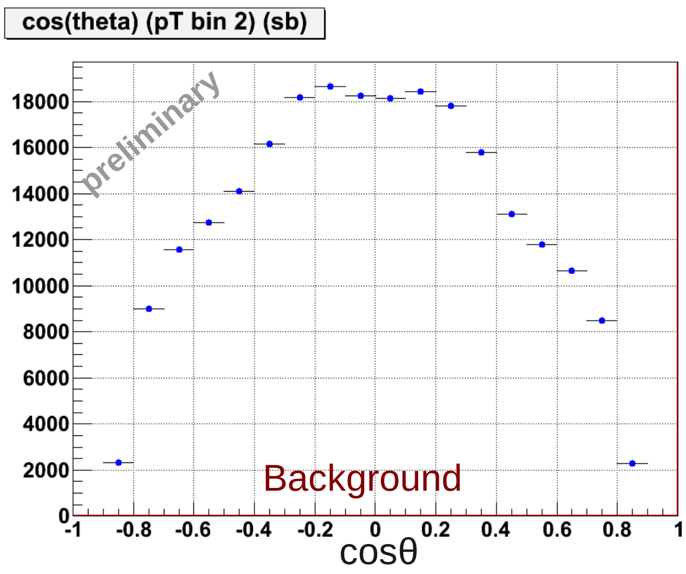
Get the three parameters from a simultaneous fit of the three distributions

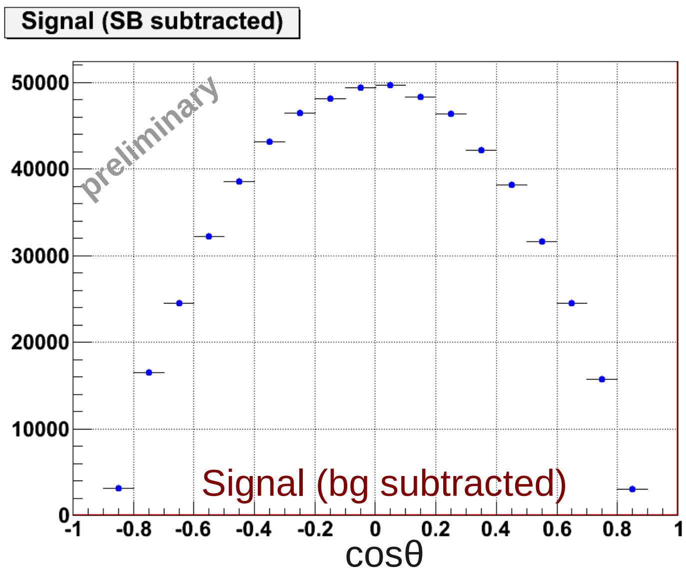
HERA-B collaboration, EPJ C 60 p. 517, 2009

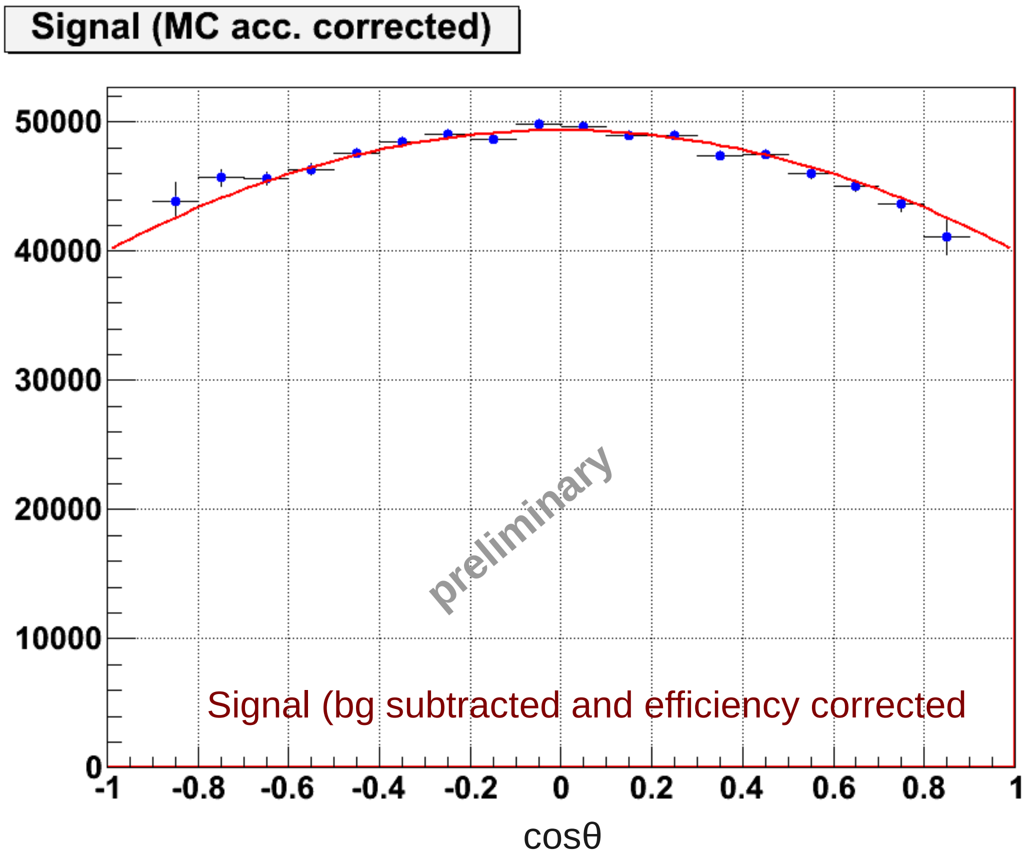
Example of measurement procedure in 1-dim case λ_θ

1 GeV < p_T < 2 GeV

$$\frac{dN}{d\cos\theta} = 1 + \lambda_\theta \cos^2\theta$$



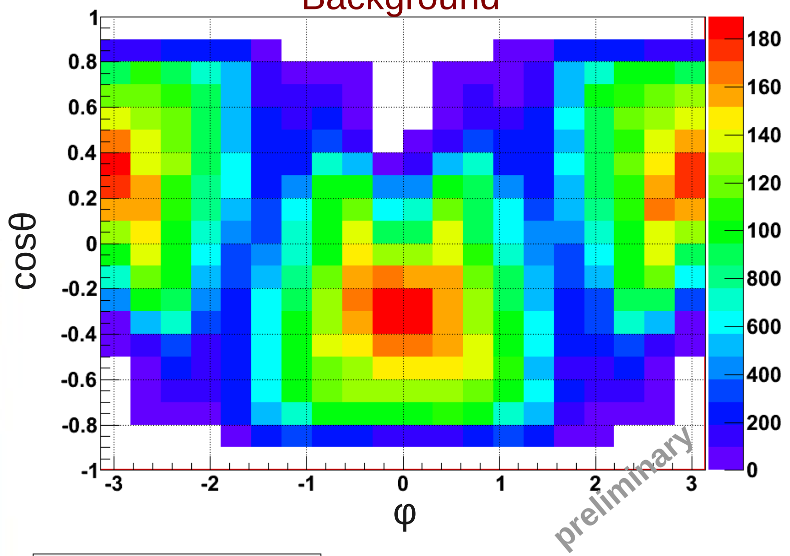




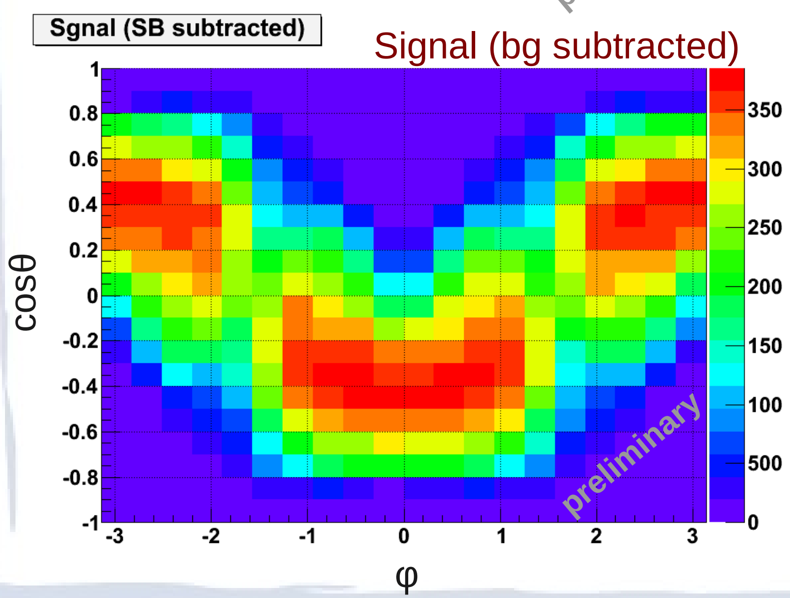
Example of measurement procedure in 2-dim case

$$\frac{d^2 N}{d\cos\theta\, d\phi} = 1 + \lambda_\theta \cos^2\theta + \lambda_{\theta\phi} \sin 2\theta \cos\phi + \lambda_\phi \sin^2\theta \cos 2\phi$$

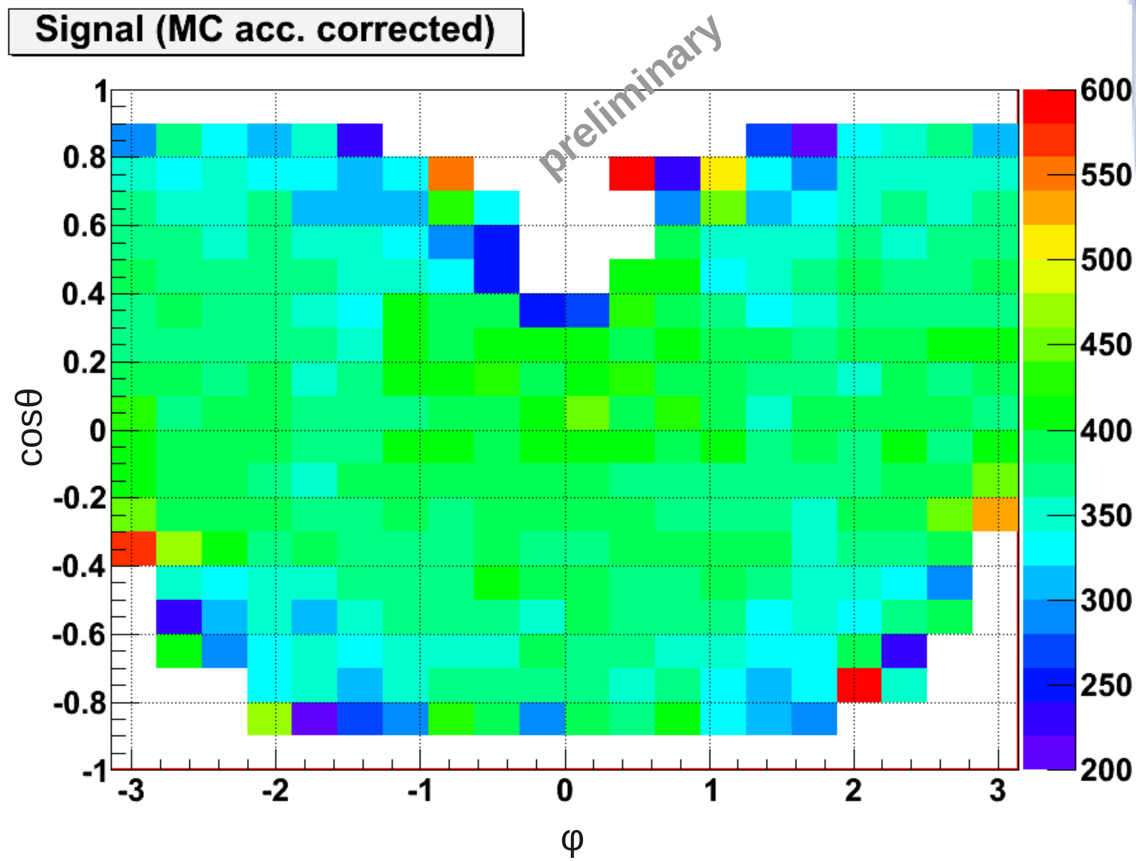
Background



Signal (bg subtracted)



Signal (bg subtracted and efficiency corrected



1 GeV < p_T < 2 GeV

Likelihood method

Angular distribution of μ+ in J/psi rest frame generation level.

$$\frac{d^2\sigma}{d\cos\theta d\phi} = (1 + \lambda_\theta \times \cos^2\theta + \lambda_{\theta\phi} \times \sin 2\theta \cos\phi + \lambda_\phi \times \sin^2\theta \cos 2\phi) \longrightarrow P(\cos\theta_i, \phi_i)$$

In building a probability we have to introduce the detector efficiency ε_{tot} and a normalization factor N(λ)

$$\epsilon_{tot}(\cos\theta_i, \phi_i) \quad \mathrm{Norm}(\lambda s)$$

For signal events the log Likelihood will be

$$\log L = \log \prod_{i=1}^{N_s} [\frac{P(\cos\theta_i, \phi_i) \times \epsilon_{tot}(\cos\theta_i, \phi_i)}{\mathrm{Norm}(\lambda s)}]$$

$$= \sum_{i=1}^{N_s} \log[\frac{P(\cos\theta_i, \phi_i) \times \epsilon_{tot}(\cos\theta_i, \phi_i)}{\mathrm{Norm}(\lambda s)}]$$

If we make the sum over all the events in the signal region we have also background events

Likelihood method (2)

We now extend the sum over the events also to the side bands and define a weight w_i for each event as:

+1 for signal region
-1 for SB region

$$\log L = \sum_{i=1}^{N_{\rm tot}} W(\rm{Mass_i}) \times \log[\frac{P(\cos\theta_i, \phi_i) \times \epsilon_{tot}(\cos\theta_i, \phi_i)}{\rm{Norm}(\lambda s)}]$$

<u>The background events cancel automatically</u>: for each background event in signal region (weight +1), there will be a background event in sideband region (weight -1), and they cancel.

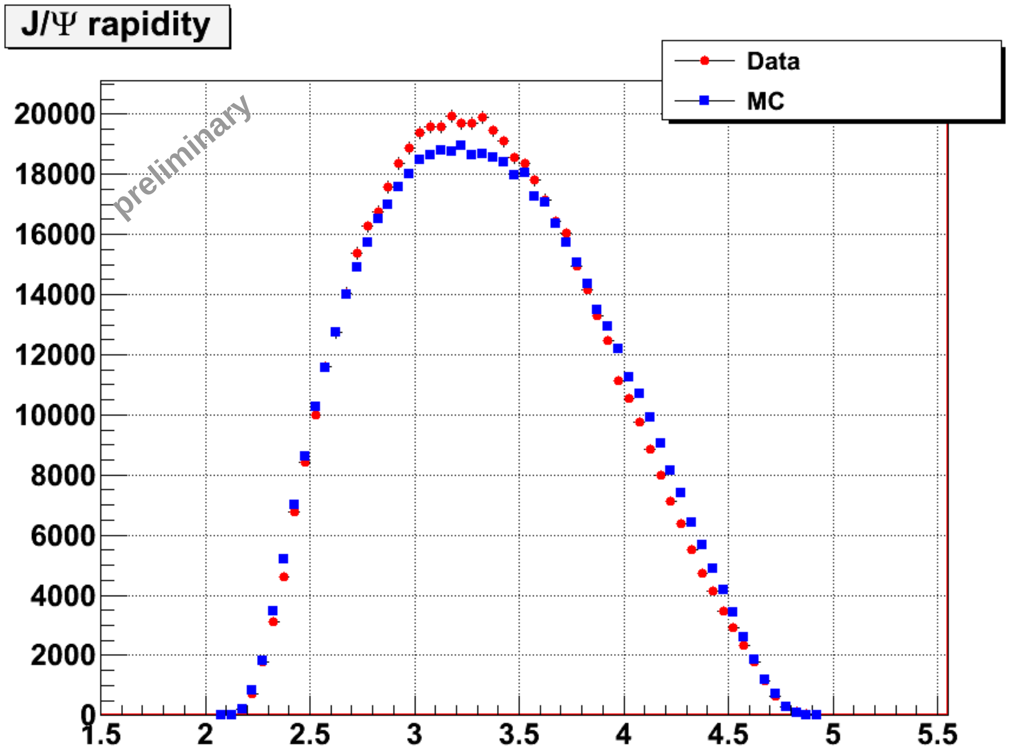
There is a further simplification because the ε term in the denominator does not contain λ and rules out

$$\log L = \sum_{i=1}^{N_{\rm tot}} W(\rm{Mass_i}) \times \log[\frac{P(\cos\theta_i, \phi_i)}{\rm{Norm}(\lambda s)}] + \sum_{i=1}^{N_{\rm tot}} W(\rm{Mass_i}) \times \log[\epsilon_{tot}(\cos\theta_i, \phi_i)]$$

We have now a right Likelihood function and we minimize -log(L) respect to the parameters λ, that enters through the normalization factor. <u>This factors can be easily evaluated with the MC events</u>

Rapidity distribution from data

- We integrate over all rapidity values but we know that the J/Ψ rapidity distribution is slightly different from data and MC. We correct for this using the J/Ψ rapidity distribution of data



1 GeV < p_T < 2 GeV

- Correction important: effect much larger than the statistical sensitivity

Statistical sensitivity

Statistical sensitivity of the different λ parameters depends on the p_T bin statistics and are similar for the three methods

parameter	min	max
λ_θ	0.01	0.16
$\lambda_{\theta\varphi}$	0.006	0.06
λ_φ	0.004	0.06

Systematic uncertainties

- Signal selection
  - The cuts we apply to select the signal (muon DLL, p_T and t_Z) can bias the results. For this reason they are as loose as possible. Furthermore a study of the signal and background retention on data and MC has been done to evaluate the MC in reproducing the cut
- Background subtraction
  - The Background subtraction procedure (SB and signal regions) is repeated with different choices of the side bands to evaluate the stability of the procedure
- Montecarlo efficiency correction
  - The reliability of the Montecarlo in reproducing data is checked by comparing muons pT and p distributions in different bins of J/Ψ pT and y
- Size of systematic expected to be similar to the statistical error

Conclusions

- Using the LHCb 2010 data, we will measure the prompt J/Ψ polarization (all parameters) in the range 0 < pT < 15 GeV/c (15 pT bins), with high accuracy (~0.01)
- Three different methods are pursued to measure polarization
- Systematics are under evaluation