Study of the Λ^* resonances in $\Lambda_b \rightarrow \Lambda^*(p^+K^-)\gamma$ decay, using Helicity Formalism

- developing a method to re-weight a sample -

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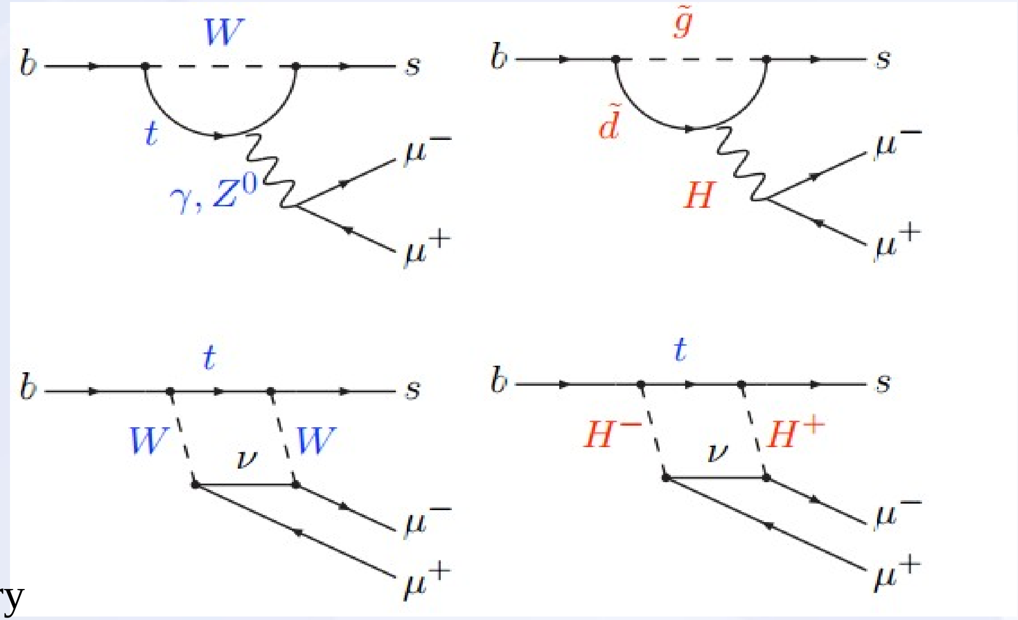
General physics motivation

LHCb looks to test and to extend the Standard Model by performing precise measurements on the i.e branching ratios (BR), angular distributions, CP asymmetries, etc. on the rare radiative decays of the b-flavored hadrons.

→ loop processes, described by Feynman-penguin diagrams.

→ in extensions to the SM these processes can receive contributions from "new" virtual particles.

→ flavour changing b→s and b→d transitions only occur at loop order in the SM.



Main rare decays studied within LHCb:

→ $B^0 \rightarrow K^* \gamma$
→ $B_s \rightarrow \Phi \gamma$ ► BR and CP studies

→ $B^0 \rightarrow \mu^+\mu^-$ ► Isospin asymmetries

→ $\Lambda_b \rightarrow \Lambda^* \gamma$ ► Polarization studies

→ $\Lambda_b \rightarrow J/\psi K^- p$ ► Pentaquark discovery

1. Introduction

Motivation of this study:

→ reduced technical and computing resources => a more efficient way in obtaining results of interest

→ability to analyze in detail the decay channels of interest, which may arise as a strong source of background in the analyzed signals

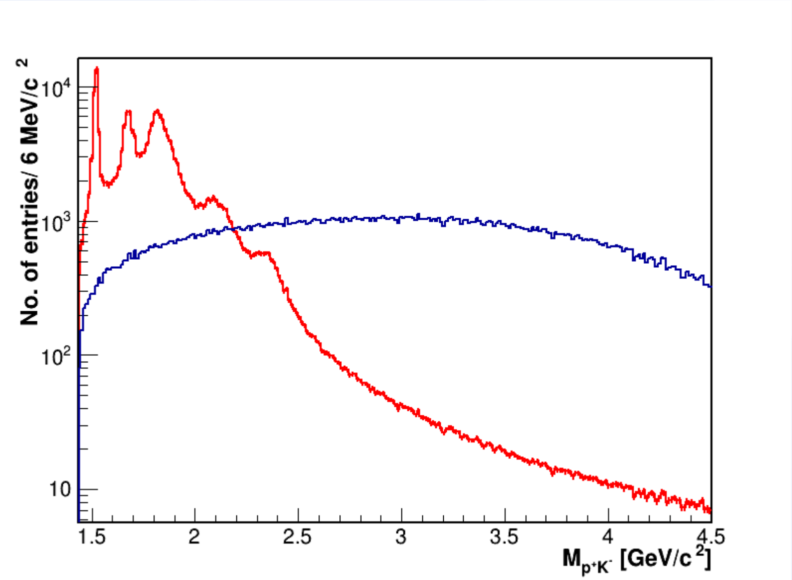
→ exposing the physics behind HelAmp (a method included in EvtGen to describe two-body decays in Helicity Formalism) in a simpler context and its extension to particles with spin higher than 3/2

→ useful to perform systematic error studies for LHCb future measurements and beyond.

1.1 Introduction

In this analysis:

→ a sample for the $\Lambda_b \rightarrow p^+K^-\gamma$ decay form was mapped in a sample of events describing the $\Lambda_b \rightarrow \Lambda^*\gamma$ decay by applying weights that emulates the resonances mass hypothesis and their angular distributions.



→ twelve resonances that may appear in the decay chain of Λ_b were considered to be completely polarized and investigated

Particles	p_T	p	Acceptance θ [mrad]
Λ	> 1 GeV/c	-	5-400
p	>0.3 GeV/c	>2 GeV/c	5-400
K	>0.3 GeV/c	> 2 GeV/c	5-400
γ	>1.2 GeV/c	-	5-400

→ a sample used generated with Pythia 8.1, the configuration optimized for LHCb

→ constraints over the particles

2. Physics frame. $\Lambda^* \rightarrow p^+K^-$ description in helicity basis

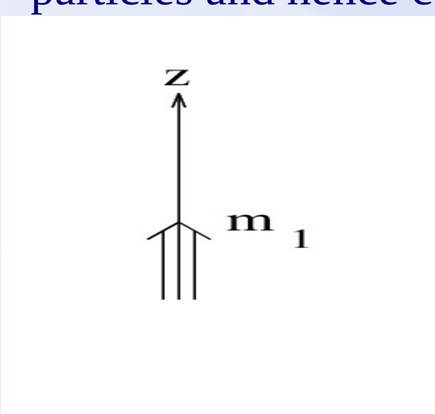
Helicity (λ): projection of total angular momentum along the direction of motion of a particle

$\vec{J}=\vec{L}+\vec{S}, \vec{L}=\vec{r}\ x\ \vec{p} \rightarrow m_l=0$

=> λ will be only the spin (s) projection along the momentum direction with $\lambda = s, s-1, \ldots, -s$

Advantages in using this frame:

→ no need to separate the total angular momentum J into orbital and spin parts and hence avoid the difficulties and complications that arise in the treatment of relativistic particles.
→ helicity λ is invariant under rotations and so states can be constructed with definite J and helicities.
→ the helicity states are directly related to individual polarization properties of the particles and hence convenient for the polarization study

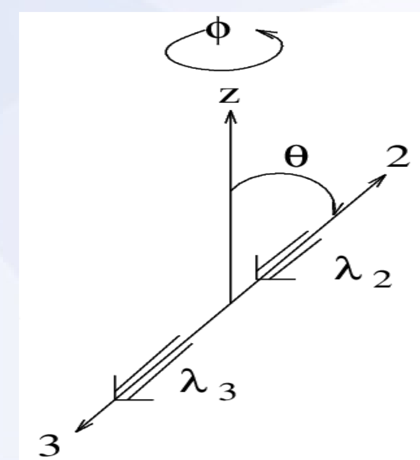


(a) Mother particle at rest: s_1 and m_1

$m_1=[j,-j]$

The measurements made on the final state particles (b) will be the direction of particle 2 (proton), specified on the z axis by $\Omega(\theta, \Phi)$ and the two helicities λ_2, λ_3

$m'=\lambda_2-\lambda_3$



2.1 D,d-Wigner functions, angular distributions

More detailes in "Study of the resonances structure appearance in the $\Lambda_b \rightarrow \Lambda^*(\rightarrow p^+K^-)\gamma$ decay using helicity formalism" accepted for publication in RJP and available at http://www.nipne.ro/rjp/accpaps/019-ElenaG_CDC0D9.pdf

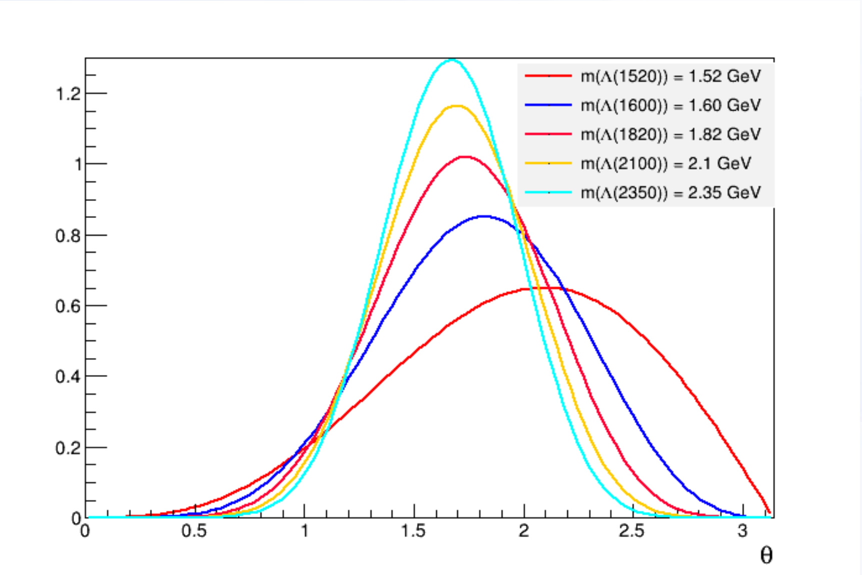
D- Wigner functions:

$$D^j_{m'm}(\alpha,\beta,\gamma)=e^{-i\alpha m'}d^j_{m'm}(\beta)e^{-i\gamma m}$$

→ contain angular informations about the entire process

→ tabulated in PDG for 1, 2, ½ and 3/2

→ available formula to calculate for greater spins in J.J Sakuray "Modern Quantum Mechanics", implemented in the computed code



Angular distribution formula: $\gamma=-\phi$

$$\frac{d\Gamma}{d\Omega_{m_1}\lambda_2\lambda_3}=\frac{2s_1+1}{4\pi}|D^{s_1}_{m_1\lambda_2-\lambda_3}(\phi,\theta,-\phi)|^2|A_{\lambda_2\lambda_3}|^2$$

$$=\frac{2s_1+1}{4\pi}|d^{s_1}_{m_1\lambda_2-\lambda_3}(\theta)|^2|A^2_{\lambda_2\lambda_3}|^2$$

The decay is symmetric over Φ angle, the D-Wigner are reduced to the d-Wigner, dependent only on θ

2.2 Λ^* properties

$\Lambda(X)$	J	Γ [MeV]	$\mathcal{B}_{N\overline{K}}$[%]	$\mathcal{B}_{\Lambda(X)\gamma}(10^{-5})$	$\mathcal{B}_{tot}(10^{-5})$
$\Lambda(1520)$	3/2	15.6	45	5.84	1.31
$\Lambda(1600)$	1/2	150	22	5.69	0.65
$\Lambda(1670)$	1/2	35	25	5.65	0.69
$\Lambda(1690)$	3/2	60	25	5.52	0.69
$\Lambda(1800)$	1/2	300	32	5.30	0.84
$\Lambda(1810)$	1/2	150	35	5.28	0.92
$\Lambda(1820)$	5/2	80	60	5.26	1.56
$\Lambda(1830)$	5/2	95	6	5.24	0.15
$\Lambda(1890)$	3/2	100	27	5.12	0.56
$\Lambda(2100)$	7/2	200	30	4.67	070
$\Lambda(2110)$	5/2	200	15	4.65	0.34
$\Lambda(2350)$	9/2	150	12	4.12	0.28

→ main properties of the twelve considered resonances decaying in p^+K^-

→ Γ (Breit-Wigner) and B_{tot}, used to obtain the re-weighted mass spectrum

→ spins from ½ to 9/2

2.3 Weights calculus

The weights applied per each event depend on the angular distribution of the final state particles and a mass term associated to p^+K^-:

$$W = W(\theta) \times W(M_{p^+K^-})$$

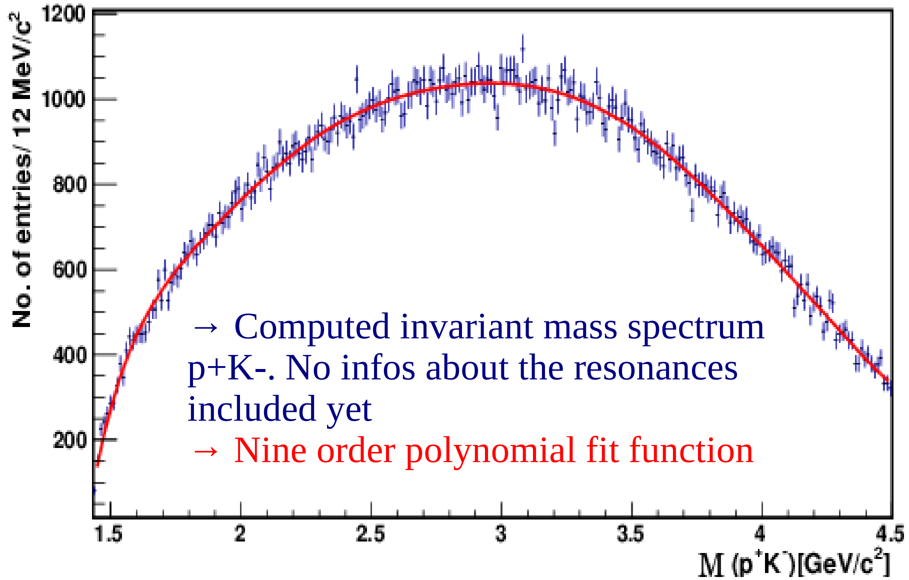
Mass weights: → event by event weight assignment which implies the mass-spectrum transformation from a continuous s-wave configuration to twelve resonances

→ resonances mass spectrum obtained by folding the S-wave spectrum assigned to the final state particles with its approx. inverse PDF (nine order polynomial function) and then folding it with the sum of twelve properly normalized to each other relativistic Breit-Wigner (BW) functions

Angular weights: → dependent on the resonance hypothesis decision (random method)

→ d-Wigner functions called to complete the calculus, containing spin and angular momentum informations about the decay process.

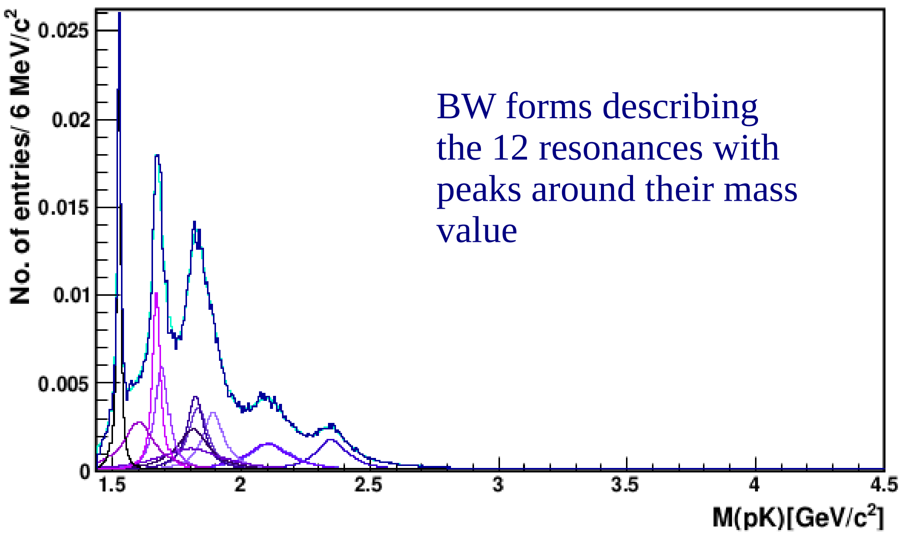
3. Results. Resonances mass spectrum

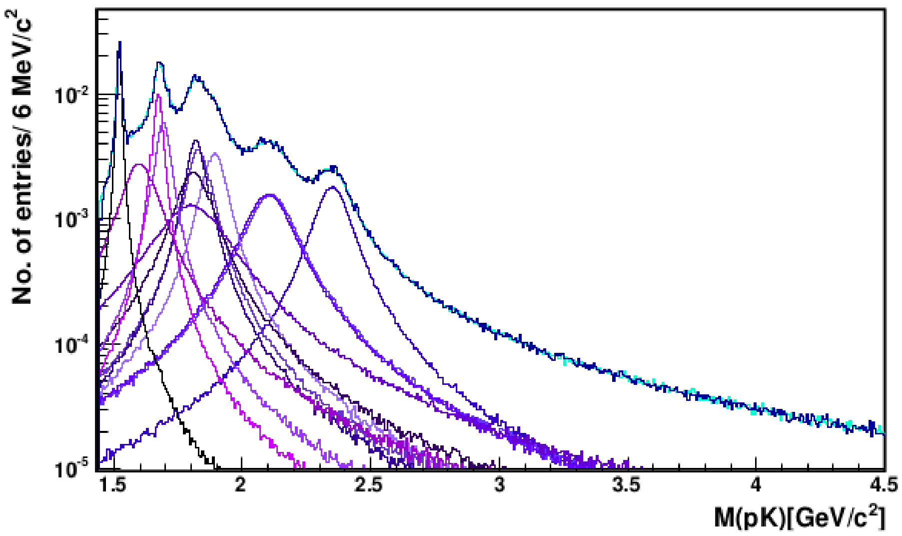


S-wave spectrum convoluted with $1/P_9$ and the sum of 12 relativistic BW functions, scaled with NF (BR of the $\Lambda_b \rightarrow \Lambda^0(1115)\gamma$ multiplied with a term dependent on the mass ratio $M(\Lambda^*/\Lambda_b)$ and B_{NK} assigned to the resonances

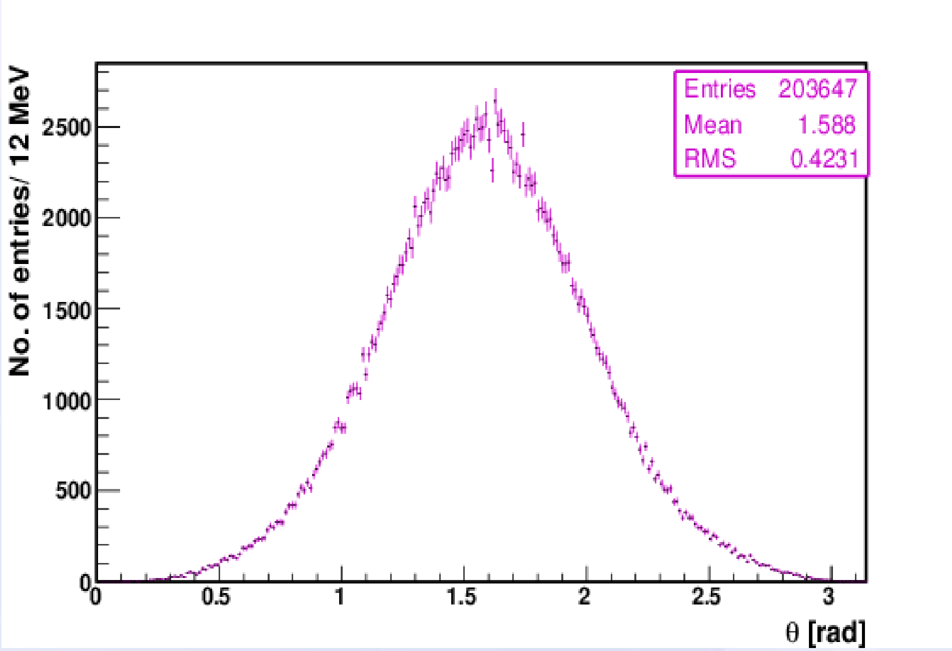
$$W(M_{p^+K^-}) = 1/P_9(M_{p^+K^-}) * \sum_{i=1}^{12} BW(M_{p^+K^-}) * NF$$

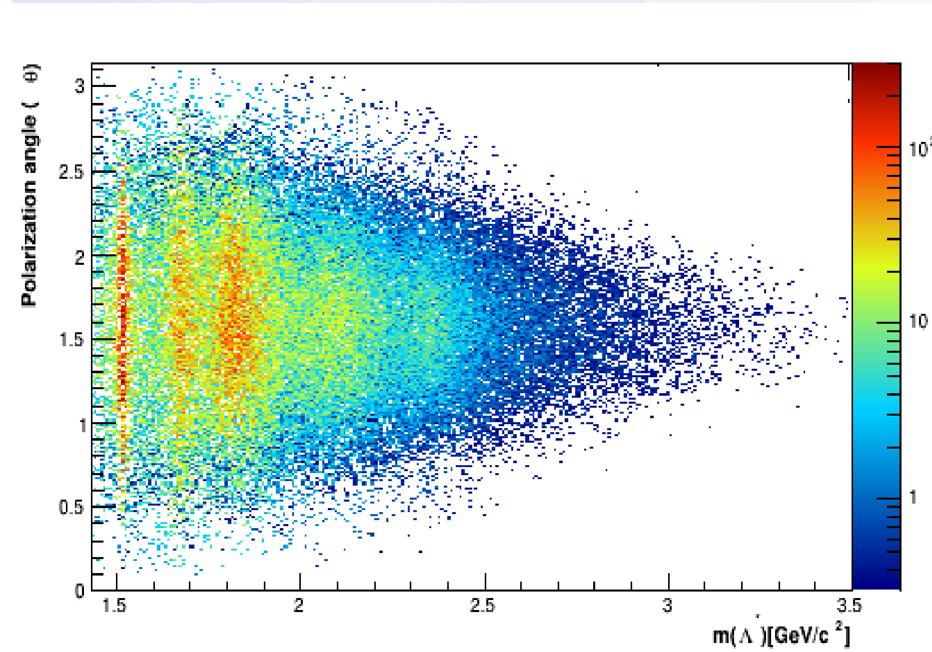
$$NF = 7.5 * 10^{-5} \text{ x } (1-(m^2_{\Lambda^*}/m^2_{\Lambda_b}))^3 * B_{N\bar{K}}$$





3.1 Angular distribution. 3D represenation, full weights





Projection of the polarization angle distribution

3D representation of the fully described resonances
→ band structures around their mass value
→ the clearest band associated to Λ(1520): → the closest to the the treshold mass
→ the narrowest BW distribution (Γ=1.5 MeV)
→ 12 resonances in 1.5-24 GeV range, some of them being described by the same quantum numbers => almost a continuous spectrum with only the Λ(1520) being clearly and distinctly visible.

3.2 Efficiency ratio

→ cuts over the p_T of the particles in decay, known as "reconstruction cuts"

→ selection done in order to improve the candidate reconstruction quality in the selected sample in parallel to increasing the purity of the final sample.

Reconstruction cuts	
Particles	p_T
Λ_b	> 3 GeV
p	> 1.2 GeV
K	> 0.5 GeV
γ	> 2.6 GeV

→ Systematic error coming from the physics differences, due to the developed algorithm

Affected by the algorithm

Generator	CP (err x 10^{-3})	η_{reco}/η_{gen} (err x 10^{-4})
Pythia LHCb Tune	0.362 +/- 2.707	0.392 +/- 9.403

Result: 0.392 +/- 9.403 x 10^{-4} (stat.) +/- 0.030 (syst.)

Unaffected by the weights calculus computed algorithm

4. Conclusions

A method to emulate physical effects in MC samples was developed:

→ by applying weights/event

→ from mathematical point of view: weights~ convolution+deconvolution

→ error propagation well done after each operation

→ spectra normalization after re-weighting procedure does not induce systematic effects

A method to “transform” a sample with no initial informations about the considered resonance into a sample with 12 full described resonances was developed by introducing weights dependent on their masses and their characteristic quantum numbers (stored in the d-Wigner functions)

→ full spectrum of the resonances in which the mass hypothesis and their angular distributions are stored in a 3D histogram; visible resonance structures obtained in 1.5 -2.35 GeV/c^2 range

→ systematic error coming from the differences induced by the physics introduced in the re-weighting algorithm calculated.

Thanks for your attention!