A new constraint for matter/antimatter asymmetries

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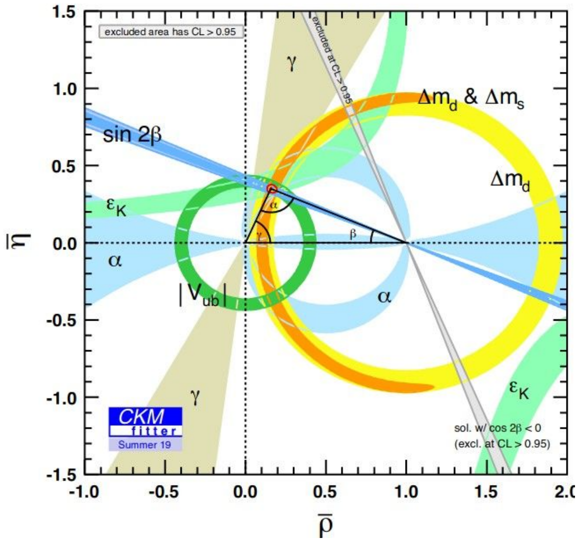
CP Violation in the Standard Model

- In the Standard Model the CP violation is due to complex phase in the Cabibbo-Kobayashi-Maskawa (CKM) matrix, that describes the charged-current weak interactions

$$\mathcal{L}_{cc} = \frac{g}{\sqrt{2}} \left(\bar{u} \quad \bar{c} \quad \bar{t}\right) V_{\text{CKM}} \gamma^{\mu} \frac{(1-\gamma^5)}{2} \begin{pmatrix} d \\ s \\ b \end{pmatrix} W^{+}_{\mu} + h.c..$$

- **Why do we measure CPV?**
  - SM alone can’t explain observed matter-antimatter asymmetry -> new physics must be there.



- The unitarity of the CKM matrix lead to

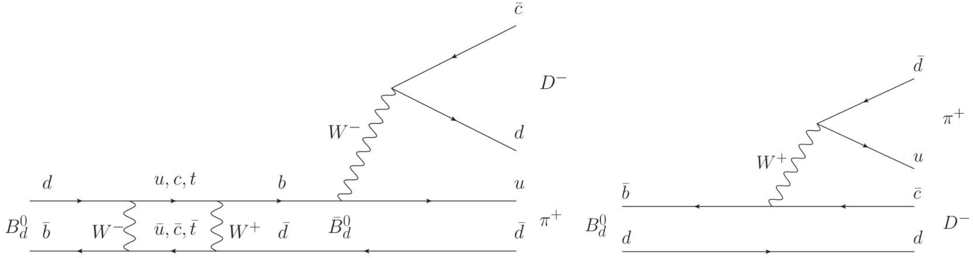
$$V_{ud}V^{*}_{ub} + V_{cd}V^{*}_{cb} + V_{td}V^{*}_{tb} = 0$$

- That can be represent in an unitary triangle in the complex plane
- The area of this triangle is proportional to the CPV

Time dependent CP asymmetries and γ

- The time dependent the CP asymmetries allow to constrain the gamma angle of the CKM matrix
- The CPV in $B^0 \to D^-\pi^+$ $B^0 \to D^+\pi^-$ appears in the interference between the decay with the mixing and the decay without mixing at tree level

$$\gamma \equiv \arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$$



- The decay time dependent CP asymmetries in these decays can be measured by analysing the decay rates of a function of B^0 mesons of know initial flavor.

$$\Gamma_{B^0\to\bar{f}}(t) \propto e^{-\Gamma t}\left[1 + C_{\bar{f}}\cos(\Delta m\, t) - S_{\bar{f}}\sin(\Delta m\, t)\right], \qquad \Gamma_{B^0\to f}(t) \propto e^{-\Gamma t}\left[1 + C_f\cos(\Delta m\, t) - S_f\sin(\Delta m\, t)\right],$$

$$S_f = -\frac{2r_{D\pi}\sin[\delta - (\gamma + 2\beta)]}{1 + r^2_{D\pi}}, \qquad S_{\bar{f}} = \frac{2r_{D\pi}\sin[\delta + (\gamma + 2\beta)]}{1 + r^2_{D\pi}},$$

$$D_f = -\frac{2r_{D\pi}\cos[\delta - (\gamma + 2\beta)]}{1 + r^2_{D\pi}}, \qquad D_{\bar{f}} = -\frac{2r_{D\pi}\cos[\delta + (\gamma + 2\beta)]}{1 + r^2_{D\pi}},$$

$$C_f = -C_{\bar{f}} = C = \frac{1 - r^2_{D\pi}}{1 + r^2_{D\pi}},$$

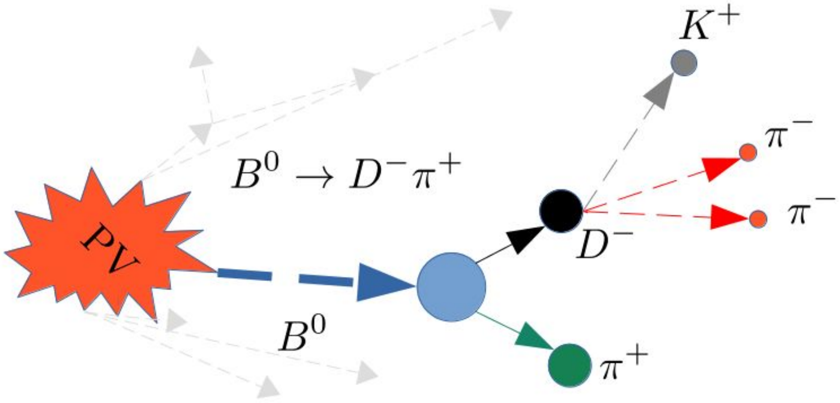
$$r_{D\pi} = |A(B^0 \to D^+\pi^-)/A(B^0 \to D^-\pi^+)|$$

- Measuring these parameters, we can extract the gamma angle using an external input for the beta angle and $r_{D\pi}$

Selection

- Dataset: 2015, 2016, 2017, 2018 LHCb Data corresponding to $\mathscr{L} \sim 6 fb^{-1}$
- Decay chanel: $B^0 \to D^-\pi^+$ $B^0 \to D^+\pi^-$
- The semileptonic decays were not taken into account

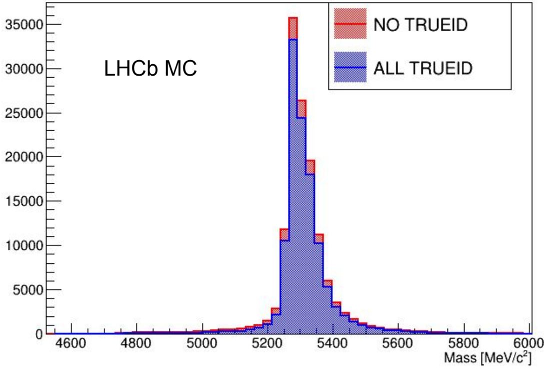
- To identify the B decay:
  - The $D^- \to K^+\pi^-\pi^-$ candidates are reconstructed from charged particle tracks with high **P** and **P_T** and from a common displaced vertex.
  - The invariant mass of this particles together is required to be within 35 MeV/c^2 of the known value of the D^-
  - Particle identification is used to select kaon and pion candidates.
  - This candidates are combined with a pion to form the B vertex displaced from any PV



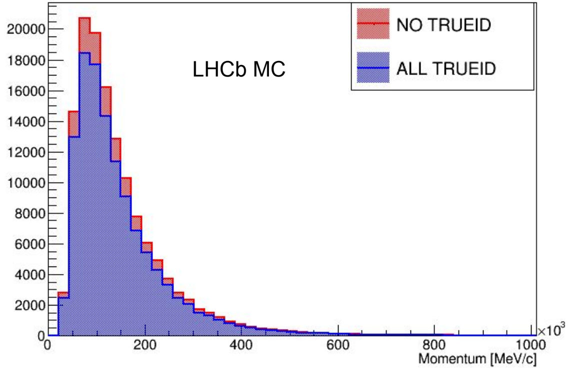
- The selection is based on:
  - Software and hardware trigger,
  - Vetos for misidentify background wrongly associated primary vertex
  - Cut based preselection
  - Boosted decision tree (machine learning algorithm) to increase the signal purity

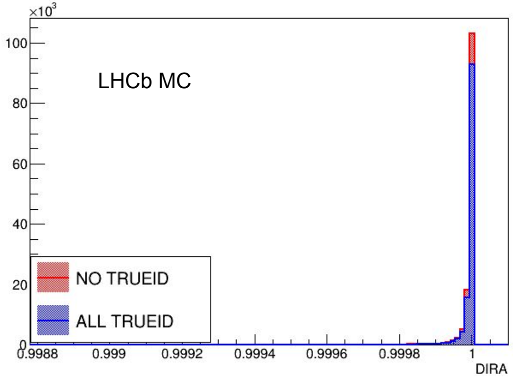
Cut based selection

- We defined these selections requiring on the simulated samples the Monte Carlo truth: these variables ensure that we have considered the correct simulated sample



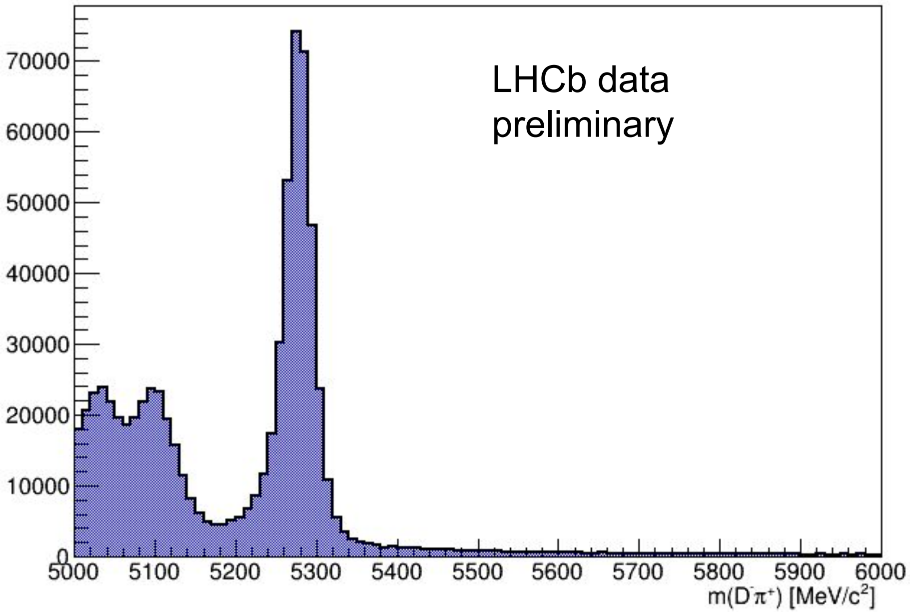
Description	Requirement
Trigger requirements	Hlt1TrackAllL0 && (Hlt2IncPhi || Hlt2Topo2(3)BodyBBDT)
BDTG response	> 0.1
$m(D^- \pi^+)$ mass	$[5000, 6000]$ MeV/c^2
$m(K^+ \pi^- \pi^-)$ mass	$[1830, 1920]$ MeV/c^2
D^- lifetime wrt. to B^0	> 0 ps
D^- vertex separation wrt. B^0	> 9
$m(K\pi)$	< 840 MeV/c^2
$B \to D^0 K\pi$, $D^0 \to K\pi$ veto	
$m(D^-\pi)$ with π misID as K	$\notin [1850, 1890]$ MeV/c^2
semileptonic backgrounds veto:	
PIDμ	< 2
$B \to D^*(D^0\pi)\pi$, $D^0 \to K\pi$ veto:	
$(m_{D^-} - m(K\pi))$	> 200 MeV/c^2
Λ_c^+ veto:	
p veto for pions	PID$p < 0$, or
D^- under Λ_c^+ hypothesis	$\notin [2255, 2315]$ MeV/c^2
D_s veto:	
kaon veto for pions	PID$K > 0$, or
D^- under D_s hypothesis	$\notin [1950, 2030]$ MeV/c^2





Cosine of the angle between the momentum of D meson and the direction of the best PV to the decay vertex.

Signal and Background decays



- Signal: $B^0 \rightarrow D^- \pi^+$
- Backgrounds: all decays that can be confused with our signal. Because:
  - they have the same particles in the final state
  - their final state is a part of searched signal
  - one or more particle are misidentify

- In order to clean the data we need to identified background decays:
  - $B^0 \rightarrow \Lambda_c^- \pi^+$
  - $B^0 \rightarrow D_d^- K$
  - $B^0 \rightarrow D_d^- \rho$
  - $B^0 \rightarrow D_s^- \pi^+$
  - $B^0 \rightarrow D_s^* \pi^+$
  - Combinatorial Background: It's the background forms by random combination of tracks

- Pion-like decays have a peak at the know B mass 5279.65 ± 0.12 MeV/c^2 with a width of about 20 Mev/c^2

Analysis strategy

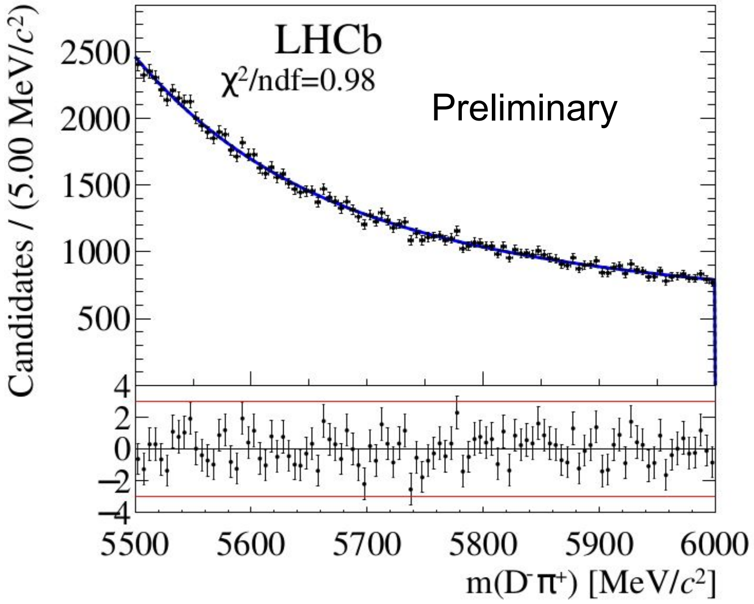
- Fit to the invariant mass distribution in order to extract the signal $B^0 \rightarrow D^-\pi^+$ $B^0 \rightarrow D^+\pi^-$ decays
  - The aim of my project: identify all processes that are not interesting for our analysis and parameterized these contributions with the most accurate shape

- Training calibration of algorithm necessary to infer the initial flavor of reconstructing B candidates

- Estimation of the CP parameters by means all a fit of the distribution of decay time observables

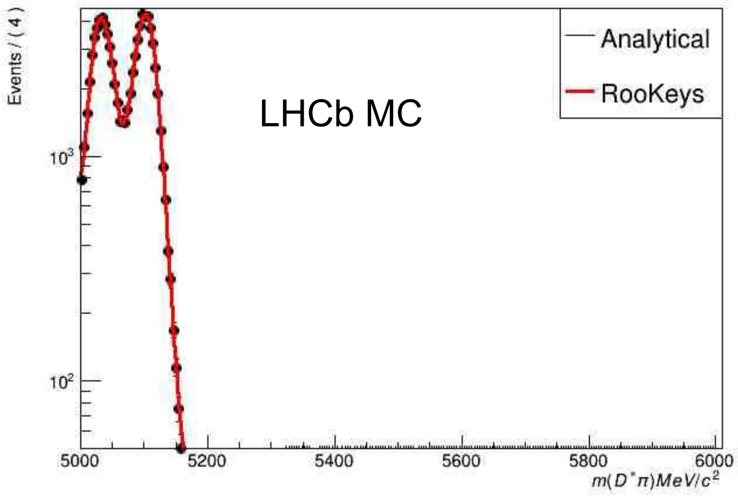
Backgrounds

Combinatorial background



- Data range: [5500,6000] MeV/c^2
- Shape: Double exponential

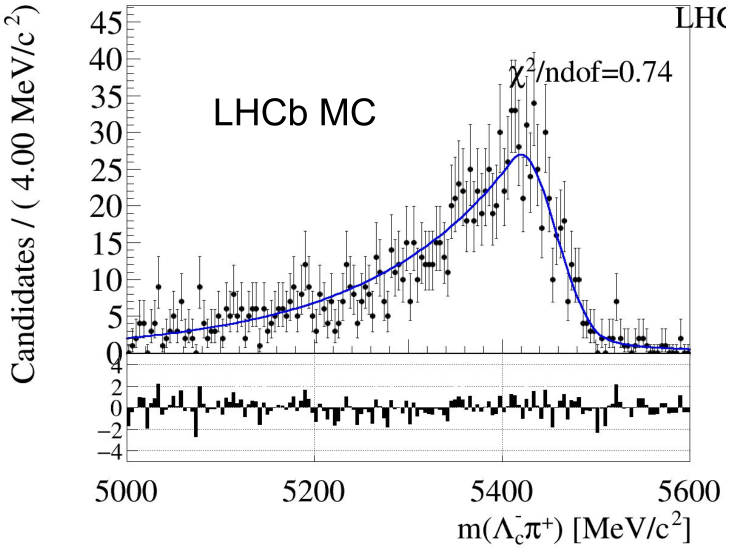
$B^0 \to D_s^* \pi^+$



- Shape: Kernel Estimation PDF
- RooKeysPDF: implements a kernel estimation p.d.f which model the distribution of an arbitrary input dataset as a superposition of Gaussian kernels, one for each data point, each contributing 1/N to the total integral of the pdf.

Backgrounds

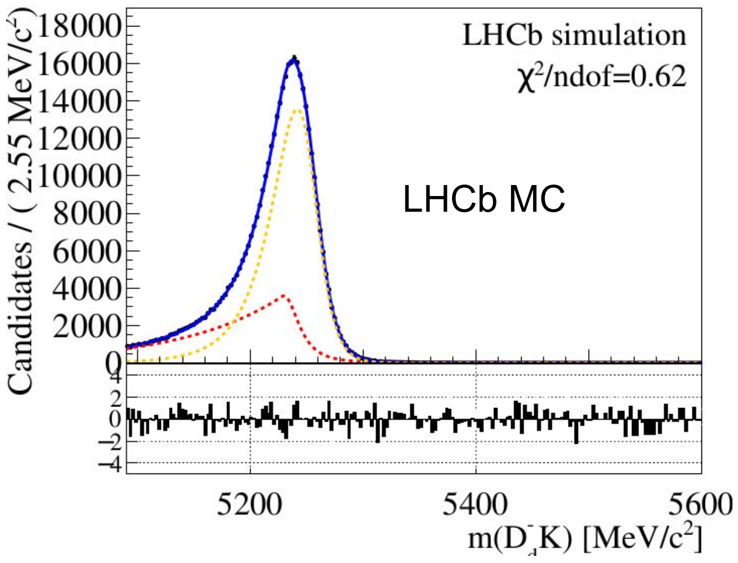
$B^0 \to \Lambda_c^- \pi^+$



- Shape: Double Hypatia function

$$H(m,\mu,\sigma,\lambda,\zeta,\beta,a_1,n_1,a_2,n_2) \propto \begin{cases} h(m,\mu,\sigma,\lambda,\zeta,\beta), & \text{if } \frac{m-\mu}{\sigma} > -a_1 \text{ or } \frac{m-\mu}{\sigma} < a_2, \\ \frac{h(\mu-a_1\sigma,\mu,\sigma,\lambda,\zeta,\beta)}{\left(1-m/\left(n\frac{h(\mu-a_1\sigma,\mu,\sigma,\lambda,\zeta,\beta)}{h'(\mu-a_1\sigma,\mu,\sigma,\lambda,\zeta,\beta)}-a_1\sigma\right)\right)^{n_1}}, & \text{if } \frac{m-\mu}{\sigma} \leq -a_1, \\ \frac{h(\mu-a_2\sigma,\mu,\sigma,\lambda,\zeta,\beta)}{\left(1-m/\left(n\frac{h(\mu-a_2\sigma,\mu,\sigma,\lambda,\zeta,\beta)}{h'(\mu-a_2\sigma,\mu,\sigma,\lambda,\zeta,\beta)}-a_2\sigma\right)\right)^{n_2}}, & \text{if } \frac{m-\mu}{\sigma} \geq a_2. \end{cases}$$

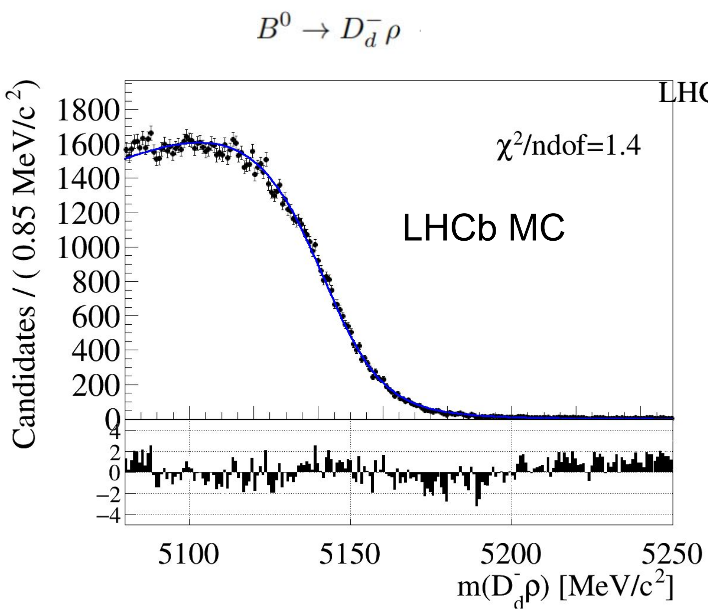
$B^0 \to D_d^- K$



- Shape: Double Hypatia plus Johnson function

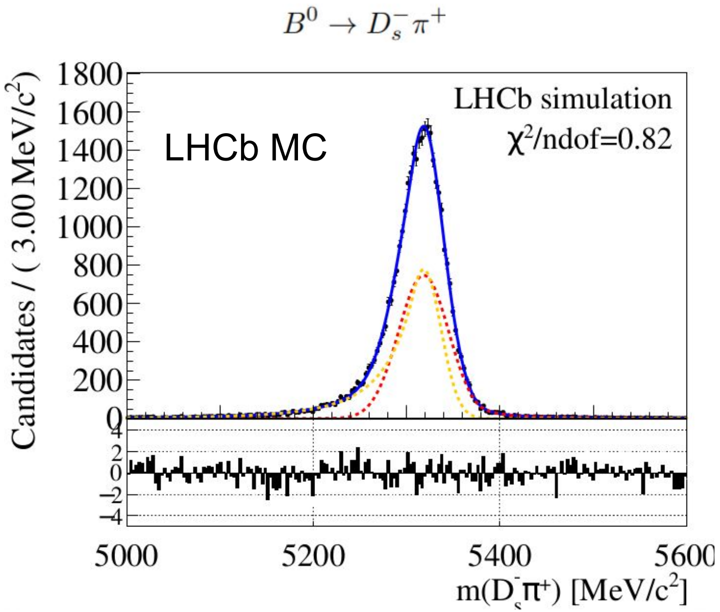
$$J(m,\mu,\sigma,\nu,\tau) \propto \frac{1}{2\pi c(\nu,\tau)\sigma} e^{-\frac{1}{2}r(m,\mu,\sigma,\nu,\tau)^2} \frac{1}{\tau\sqrt{z(m,\mu,\sigma,\nu,\tau)^2+1}}.$$

Backgrounds



- Shape: Johnson function

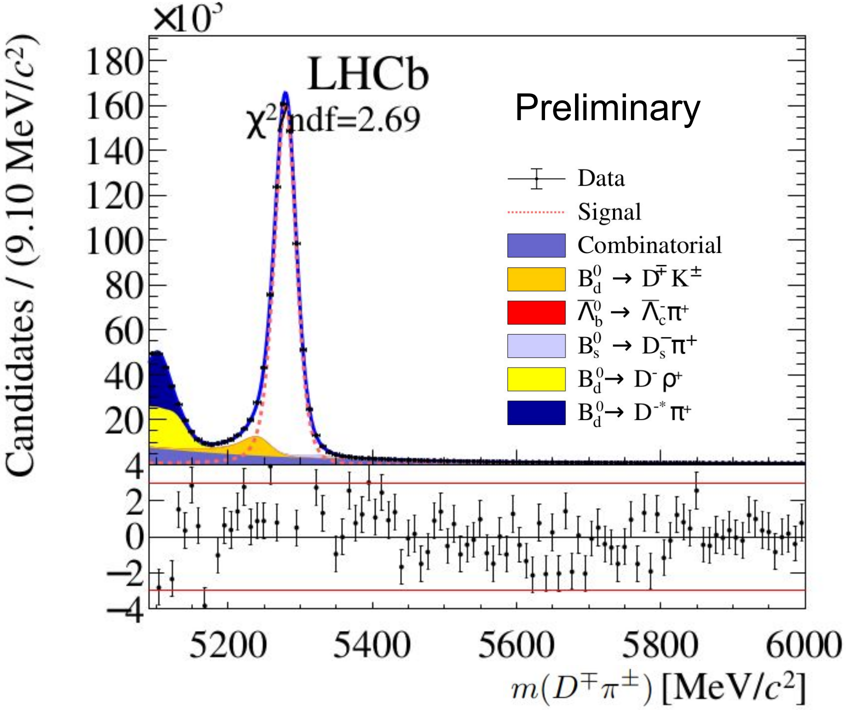
$$J(m,\mu,\sigma,\nu,\tau) \propto \frac{1}{2\pi c(\nu,\tau)\sigma} e^{-\frac{1}{2}r(m,\mu,\sigma,\nu,\tau)^2} \frac{1}{\tau\sqrt{z(m,\mu,\sigma,\nu,\tau)^2+1}}.$$



- Shape: Crystal ball function

$$CB(m,\mu,\sigma,\alpha,n) \propto \begin{cases} e^{-\frac{(m-\mu)^2}{2\sigma^2}}, & \text{if } \frac{m-\mu}{\sigma} > -\alpha, \\ A\left(B - \frac{m-\mu}{\sigma}\right)^{-n}, & \text{if } \frac{m-\mu}{\sigma} \leq -\alpha. \end{cases}$$

Fit the invariant mass distribution *m(Dπ)*



- Data: 2015, 2016, 2017, 2018
- Unbinned maximum likelihood fit implemented on URANIA LHCb package
- Signal: Hypatia plus Johnson
- Backgrounds:
  - Combinatorial: Double exponential
  - Decay backgrounds: Kernel estimation
- We measured $N_{B\text{->}D\pi}$ = *741424 ± 5157*

Conclusions and outlook

- During my project:
  - I defined the selection in order to filter the searched decays
  - I identified the background and I parameterized their shapes
  - I developed the unbinned maximum likelihood fit in order to extract the $B^0 \to D^-\pi^+$ $B^0 \to D^+\pi^-$

- Next step:
  - Perform the mass invariant fit using the analytic shapes
  - Develop the time dependent studies

Thanks for your attention.