Gamma angle measurement in $B^- \to D^0(\to K_s\pi^+\pi^-\pi^0)K^-$ (Generalized GGSZ)

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Université Clermont-Auvergne, LPC

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The CKM Matrix, the Unitary Triangle and ɣ angle

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\sum_{i=1}^{3} V_{ji}V_{ki}^{*} = \sum_{i=1}^{3} V_{ij}V_{ik}^{*} = 0$$

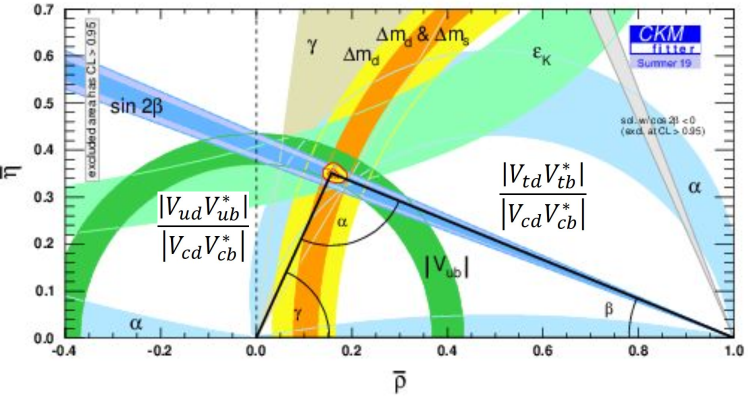
- The CKM Matrix elements can been determined from experiment -> Parameterization with 4 independent parameters

- Goal : Sensitivity to BSM effects if Unitarity triangle different in direct and indirect measurements

- The current state of ɣ measurements (CONF-2022-003-001) :

Direct : $\gamma = (63.8^{+3.5}_{-3.7})^\circ$ -> Tree Level

Indirect : $\gamma = (65.66^{+0.9}_{-2.65})^\circ$ -> Loops / Pinguin diagrams



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Couplings	NP loop order	Scales (in TeV) probed by B_d mixing	Scales (in TeV) probed by B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti}V_{tj}^*\rvert$	tree level	17	19
(CKM-like)	one loop	1.4	1.5
$\lvert C_{ij}\rvert = 1$	tree level	2×10^3	5×10^2
(no hierarchy)	one loop	2×10^2	40

TABLE II. The scale of the operator in Eq. (2) probed by B_d and B_s mixings at Stage II (if the NP contributions to them are unrelated). The impact of CKM-like hierarchy of couplings and/or loop suppression is indicated.

-> Test of global validity of the CKM formalism in tree level diagrams

- The CKM Matrix elements can been determined from experiment -> Parameterization with 4 independent parameters
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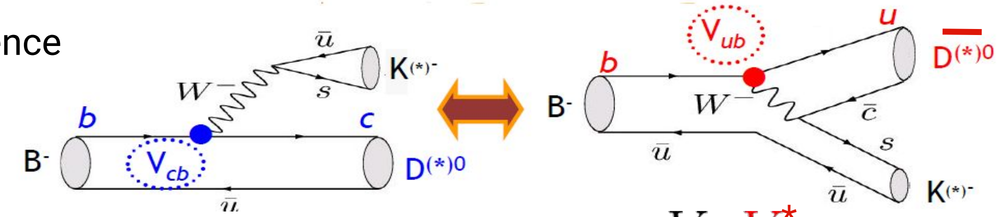
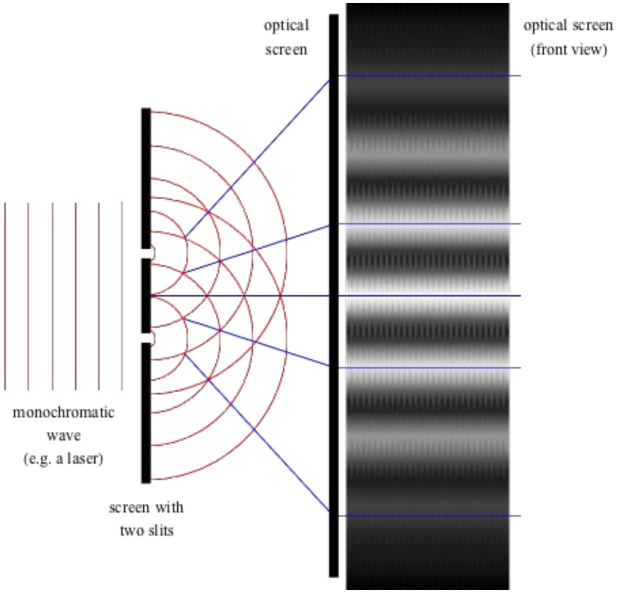
- According to CKMfitter group, a 1° precision on direct measurement test SM up to dozens of TeV energy scales
  -> **Only possible in association of multiple analysis**

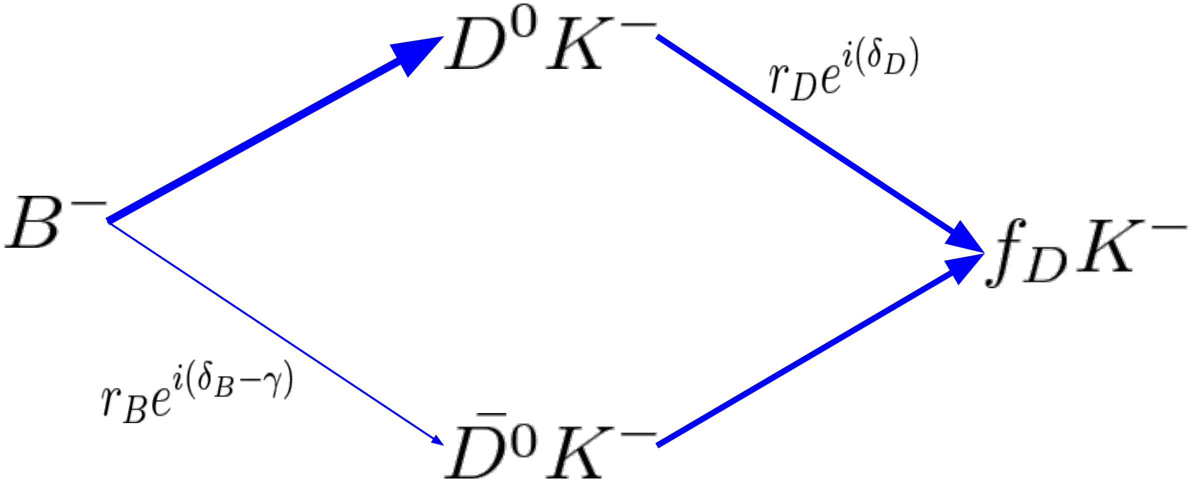
Measuring ɣ

- Relative weak phase ɣ measured in the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$ transitions by amplitude modulation
  -> Possible analogy with Young slits



$$\gamma \equiv arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

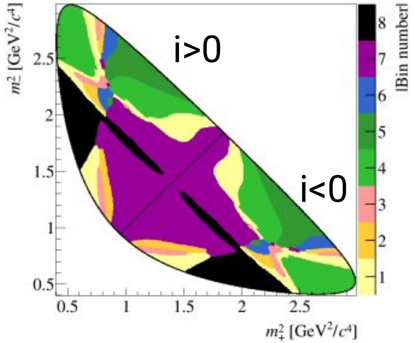


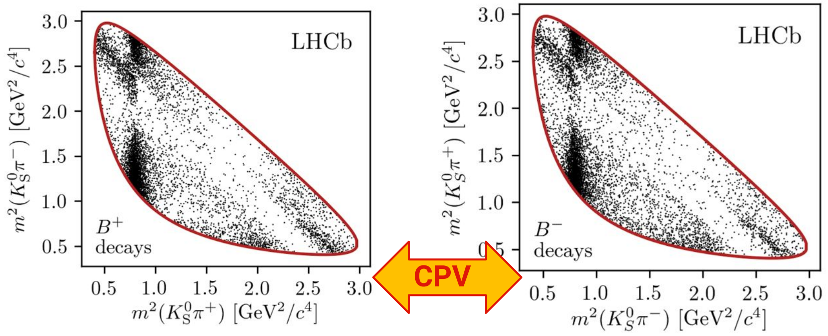


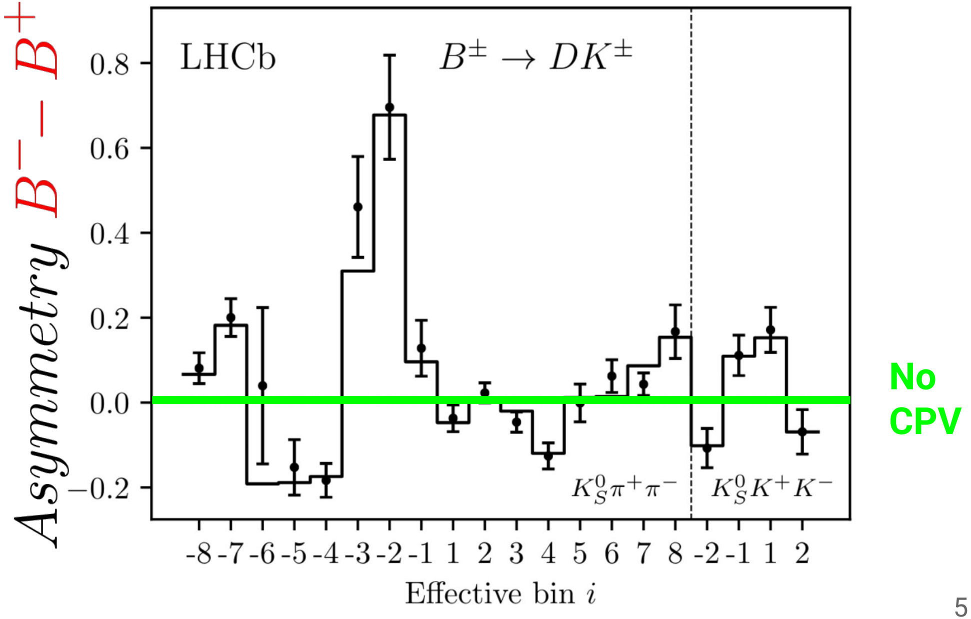
Measuring ɣ : GGSZ Method

- The 3-body decay mode used in GGSZ currently is one of the most precise ɣ measurement. The 4-body decay with π° still not measured in LHCb

$$B^{\pm} \to D^0(\to K_s^0\pi^+\pi^-)h^{\pm}$$







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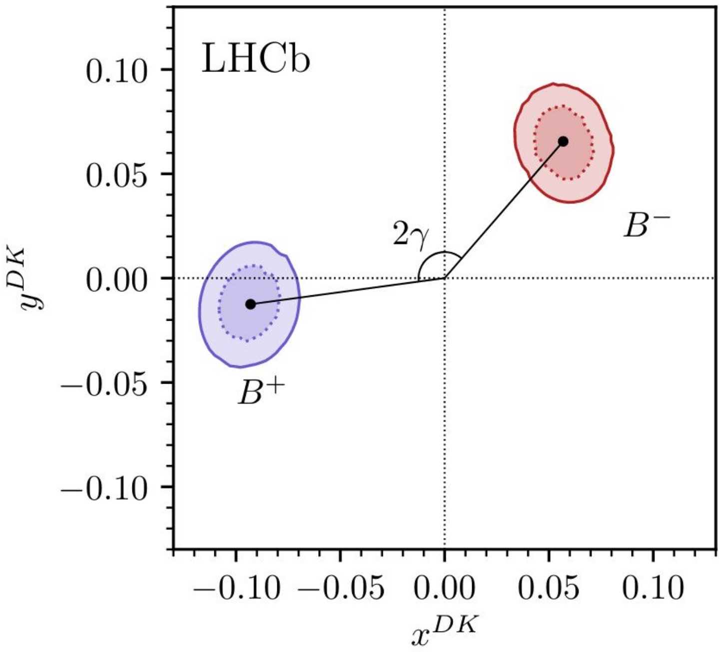
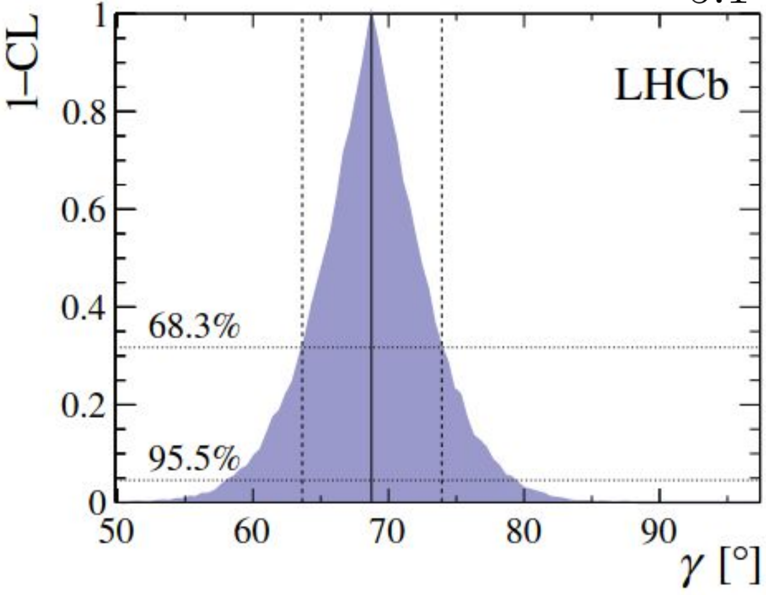


$$\gamma = (68.7^{+5.2}_{-5.1})^{\circ}$$



Measuring ɣ with decay $B^- \to D^0(\to K_s\pi^+\pi^-\pi^0)K^-$

- ɣ measurement depends on $\Delta\delta_D$, the strong phase difference between $D^0 \to f\ (\delta_D)$ and $\overline{D^0} \to f\ (\delta_{\bar{D}})$

Varies on Phase-Space of the 4-body decay $D^0 \to K_s^0\pi^+\pi^-\pi^0$

I will use a similar method to the one in JHEP 01 (2019) 82 (Belle, from Resmi P.K thesis)

-> Binned map of strong phase from JHEP 10 (2018) 178 (Resmi P.K, J. Libby, S. Malde, & G. Wilkinson - CLEO-c)

Measuring γ with decay $B^- \to D^0(\to K_s\pi^+\pi^-\pi^0)K^-$

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Varies on Phase-Space of the 4-body decay $D^0 \to K_s^0\pi^+\pi^-\pi^0$

$$\Gamma_i^- = h\left(K_i + r_B^2\overline{K}_i + 2\sqrt{K_i\overline{K}_i}(c_i x_- + s_i y_-)\right)$$
$$\Gamma_i^+ = h\left(\overline{K}_i + r_B^2 K_i + 2\sqrt{K_i\overline{K}_i}(c_i x_+ - s_i y_+)\right)$$

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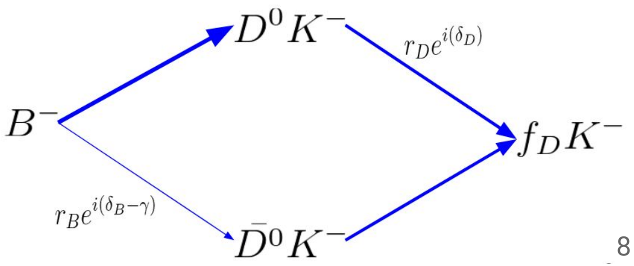
- $y_\pm = r_B sin(\delta_B \pm \gamma)$
- $x_\pm = r_B cos(\delta_B \pm \gamma)$
- $c_i = \overline{C}^i = \overline{cos(\Delta\delta_D)}^i$
- $s_i = \overline{S}^i = \overline{sin(\Delta\delta_D)}^i$

- K_i and $\bar{K}_i$ are fractions of $D^0/\bar{D}^0$ in bin i
- h is a normalisation factor
- $r_B = \dfrac{A_{B^- \to \bar{D}^0 K^-}}{A_{B^- \to D^0 K^-}}$



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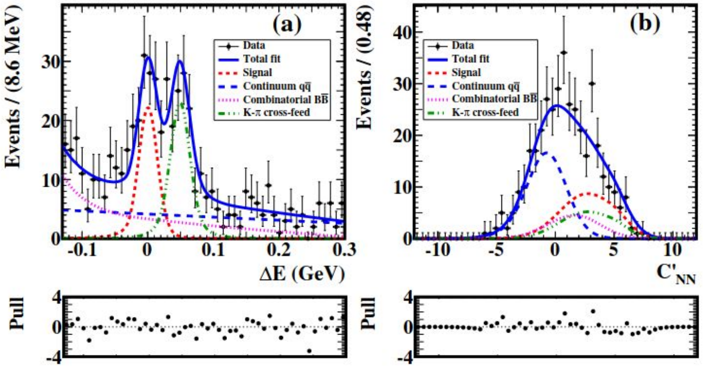
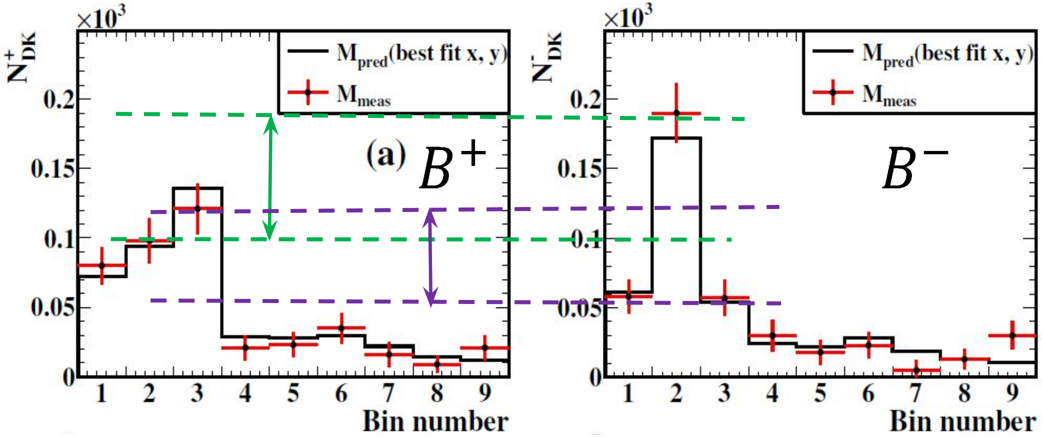
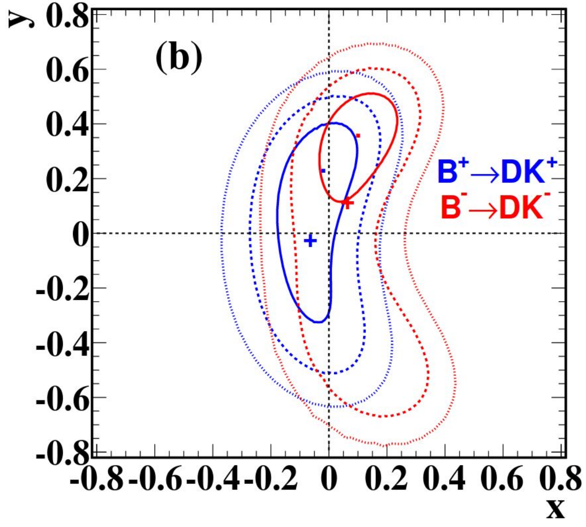


[JHEP 01 (2019) 82]

- In $B \to DK$: 815±51 events with ~60% purity at 2σ





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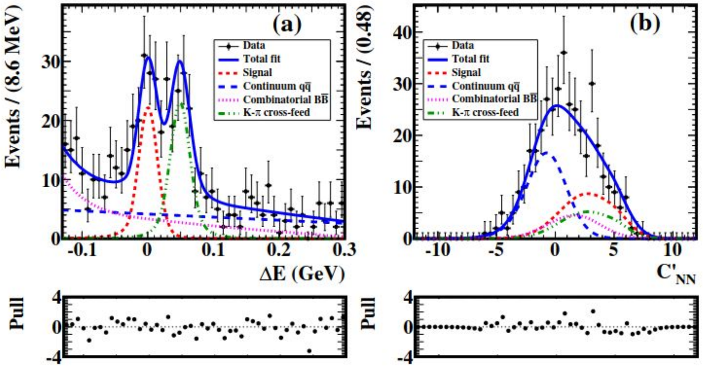
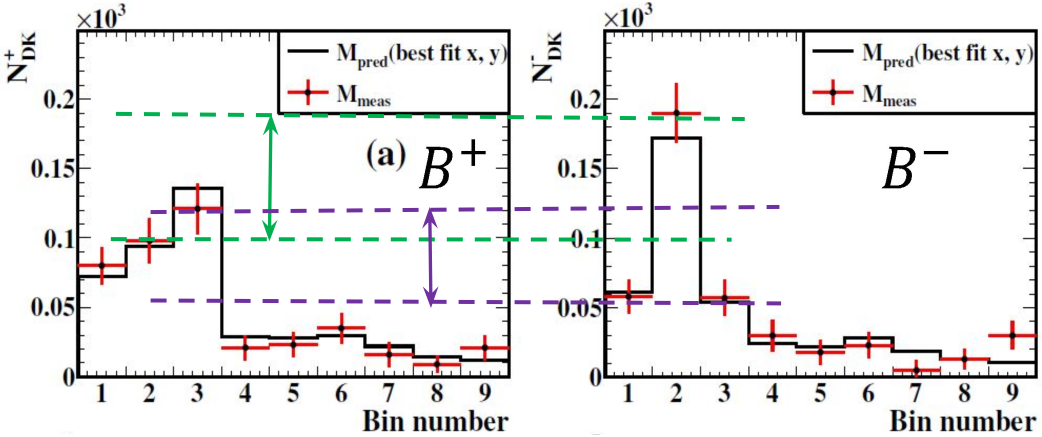
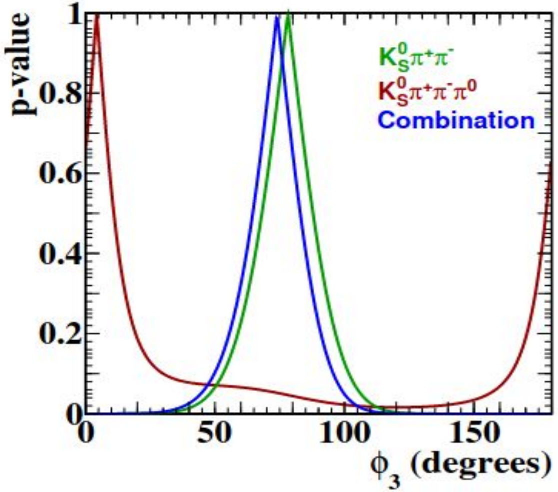


JHEP 01 (2019) 82

- In $B \to DK$: 815±51 events with ~60% purity at 2σ
- $\gamma = (5.7^{+10.2}_{-8.8} \pm 3.5 \pm 5.7)^\circ$
- 95% Confidence level : $\gamma \in (-29.7, 109.5)^\circ$





Selection

- Goal of the Selection : Keep the maximum efficiency on Signal while putting aside most of the Combinatorial and Physical background

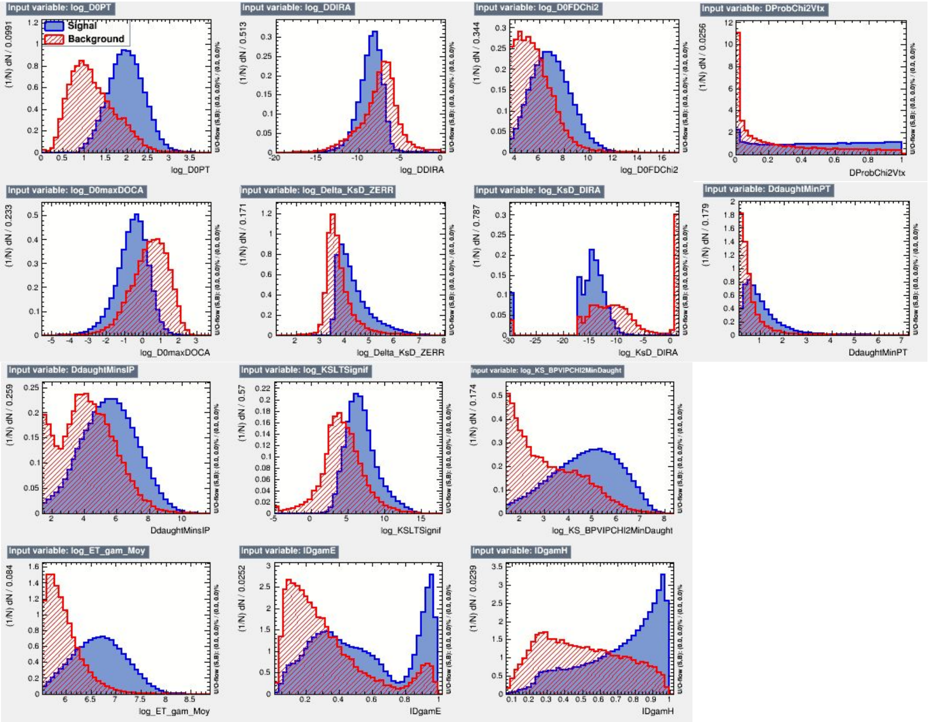
- Use of the reference mode $B^{\pm} \to D^0\pi^{\pm}$ that is topologically identical, statistically more interesting and less sensible to CP asymmetry

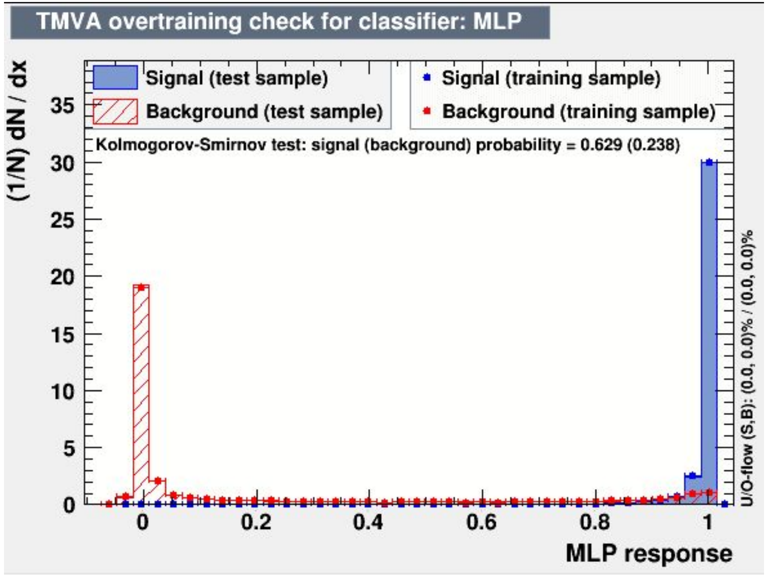
$$BR(B^{\pm} \to D^0\pi^{\pm}) \approx 12.7 \times BR(B^{\pm} \to D^0K^{\pm})$$

- Selection based on 2 Multivariate-Analysis and unidimensional cuts on particle masses :
  - First MVA : MLP method on geometrical and topological variables from D decay
  - Second MVA : MLP method on geometrical and topological variables from B decay
  - Unidimensional cuts on K°s, π° and D° masses

Selection

- Selection based on 2 Multivariate-Analysis and unidimensional cuts on particle masses using the reference mode $B^{\pm} \to D^0\pi^{\pm}$:
  - First MVA on D decay geometrical and topological parameters using a MLP method





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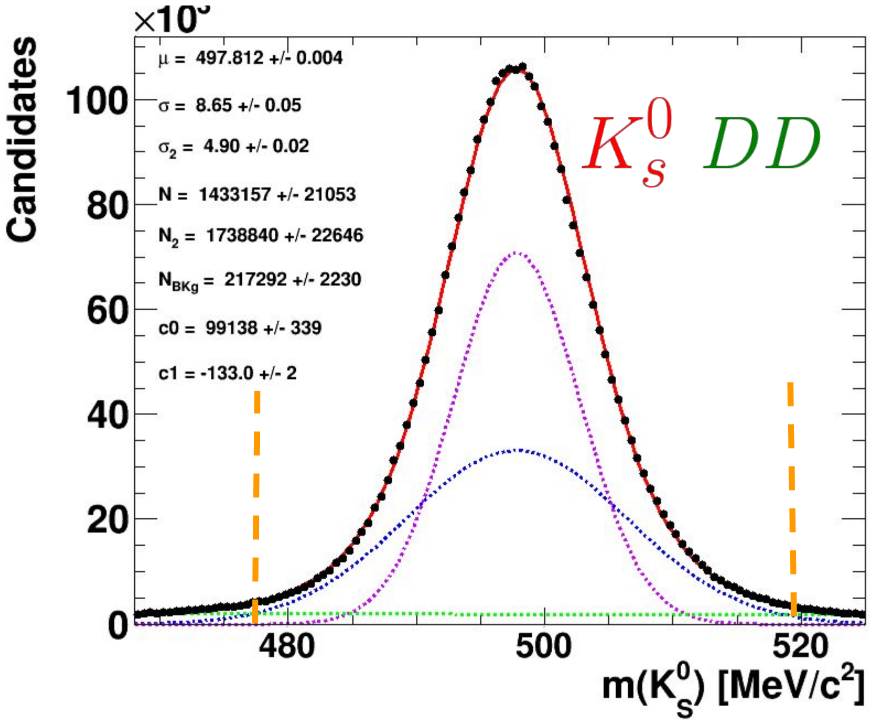
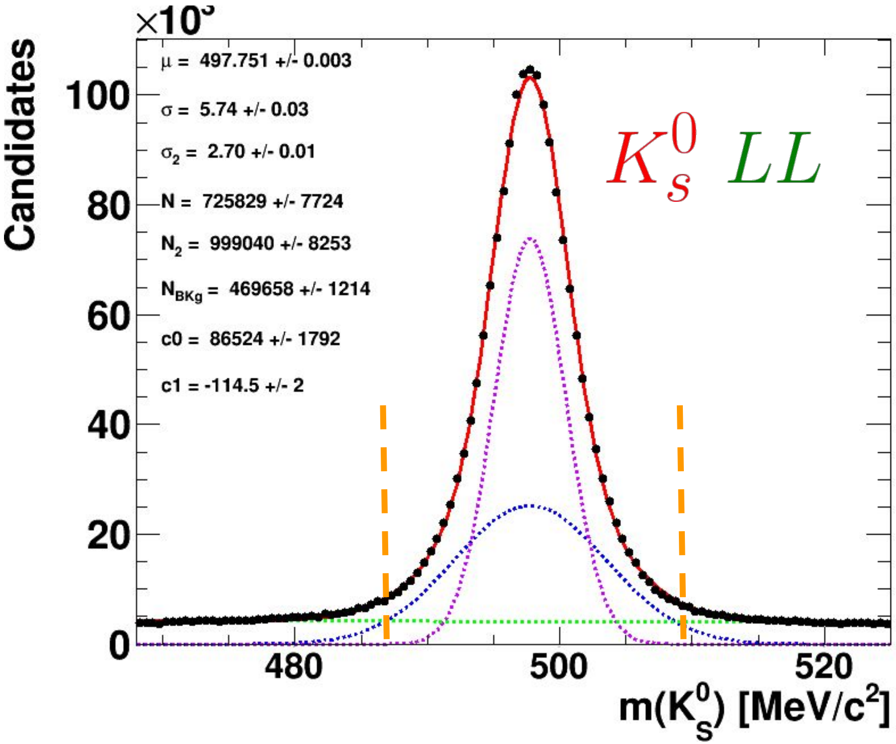
- $m(K_s^0)$ -> Selection by optimisation of $\frac{S}{\sqrt{S+B}}$ in left and right sides of the peak on DATA





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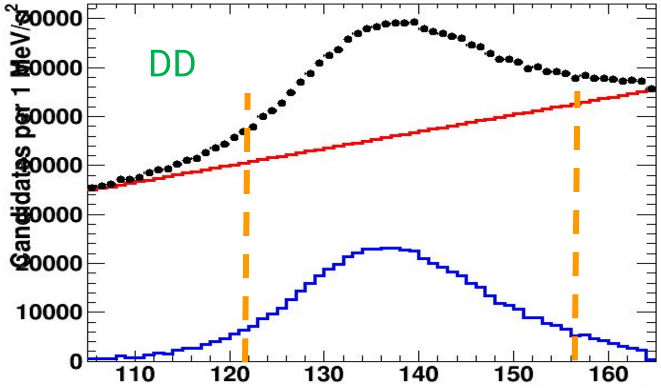
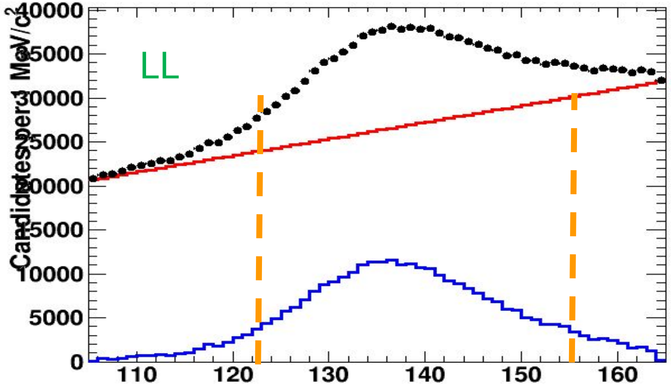
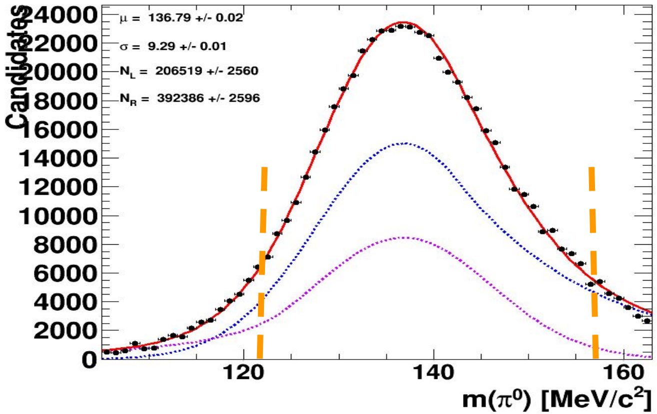
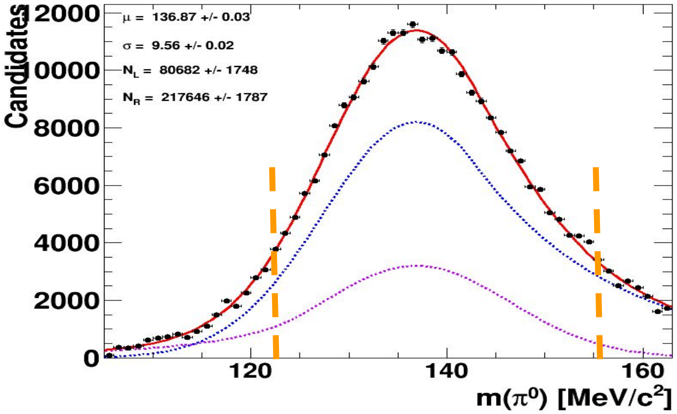
- $m(\pi^0)$ -> Selection by optimisation of $S/\sqrt{S+B}$ in left and right sides of the peak on DATA
  Combinatorial Background modelled with a technique where signal PDF is driven by MC









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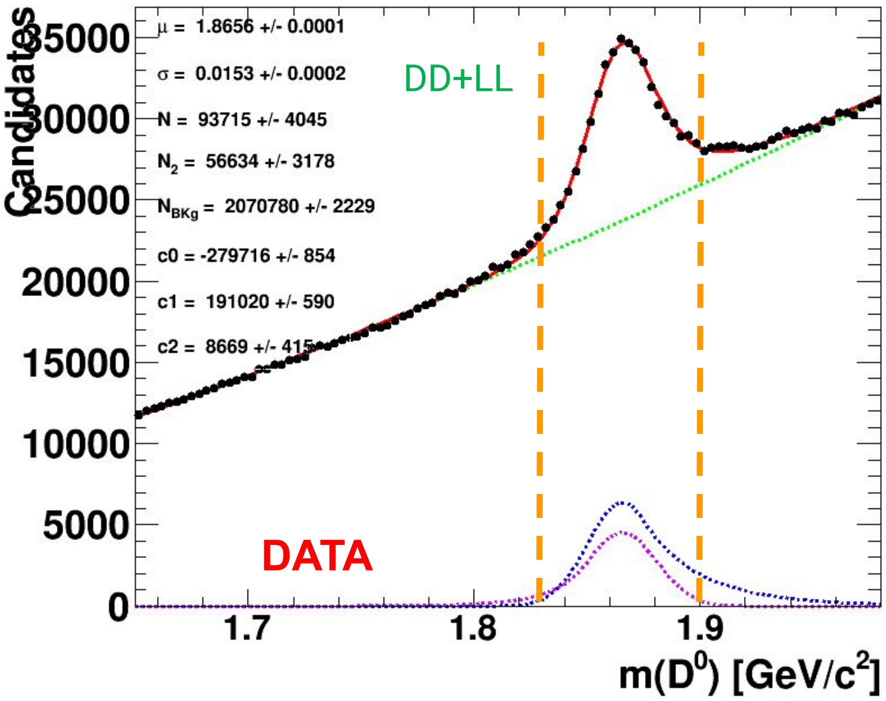

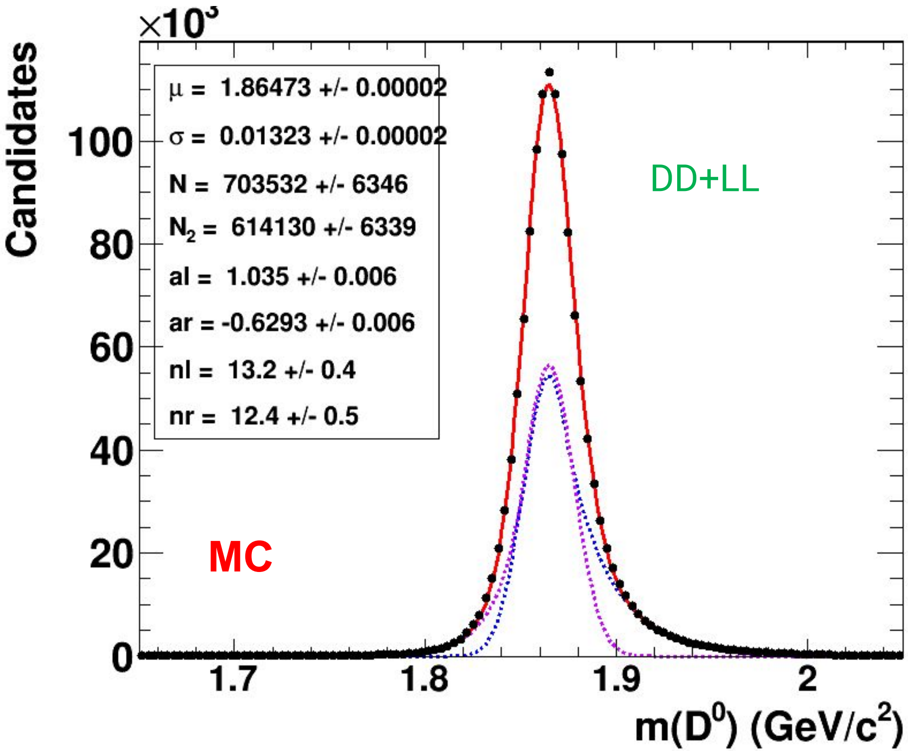

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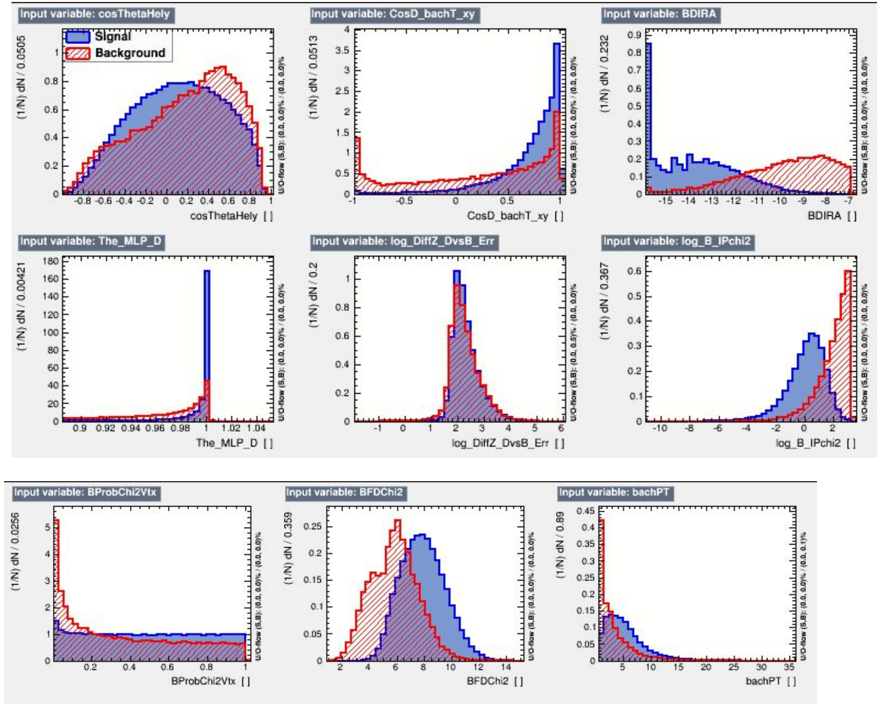

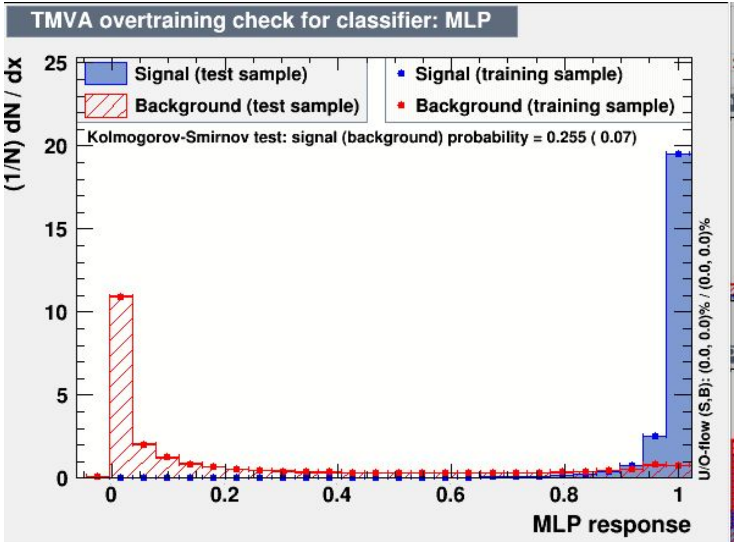

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- To limit misidentification of the bachelor track, we discriminate using a PID Likelihood Difference
  - ~71.5% signal efficiency / ~1.5% misidentification efficiency for $B \rightarrow D^0K^{\pm}$

- Multiple candidates are filtered, choosing the best candidate thanks to a MVA

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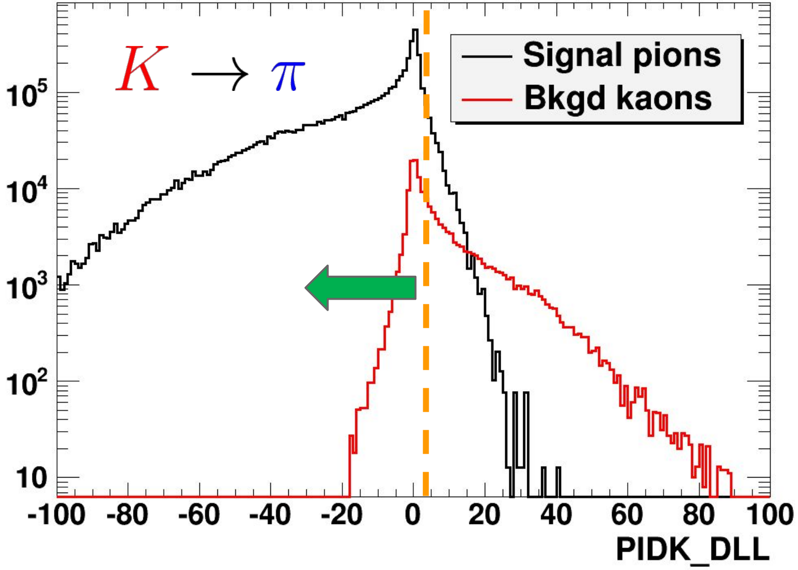

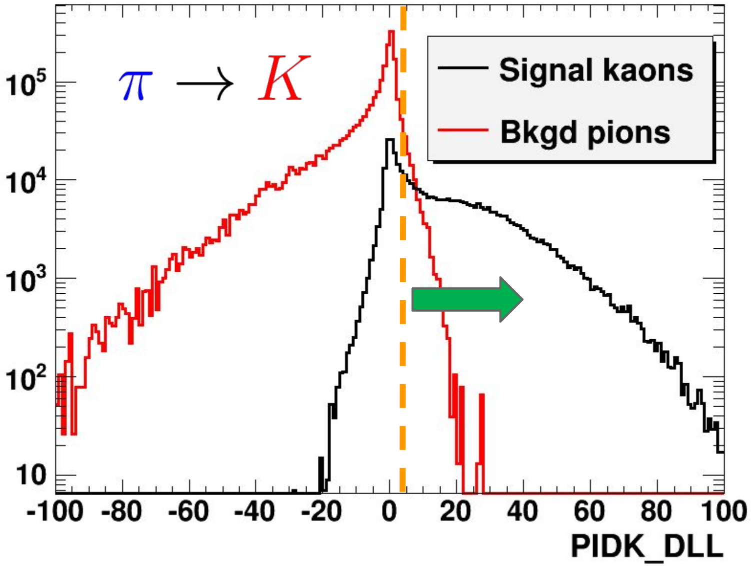

- To limit misidentification of the bachelor track, we discriminate using a PID Likelihood Difference
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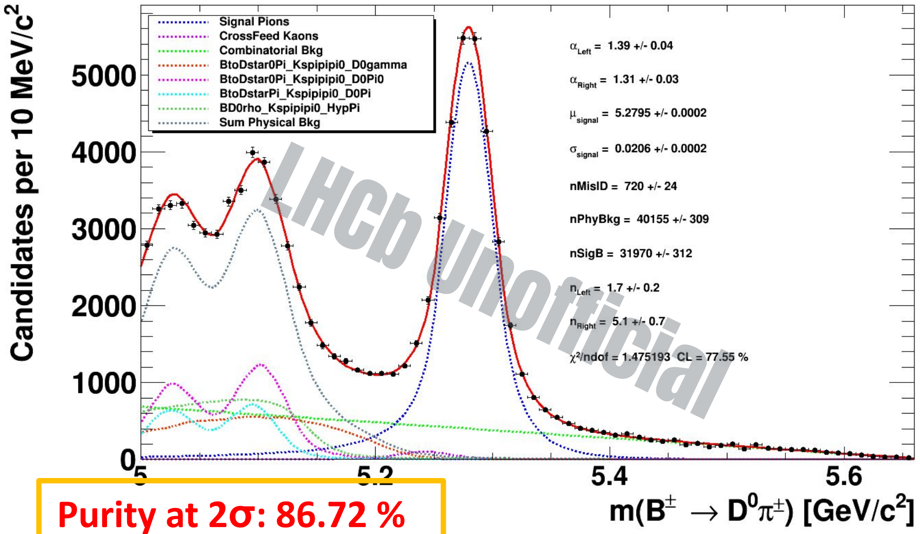
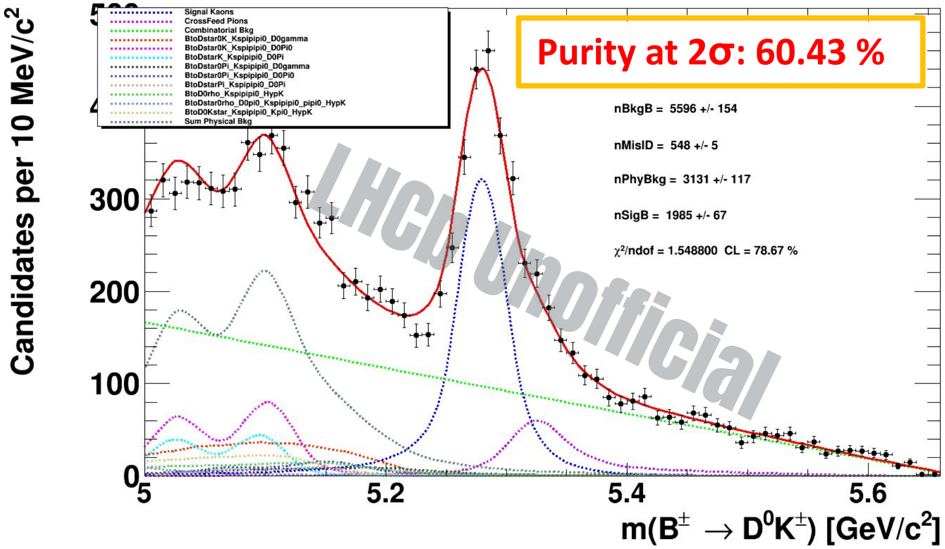
B± mass fit



Purity at 2σ: 86.72 %



Purity at 2σ: 60.43 %

At 2σ :

#Signal = 25784 ± 248

#CrossFeed = 403 ± 13

#Combinatorial = 3315 ± 67

#Phys. Bkg = 229 ± 2

At ±2σ :

#Signal = 1601 ± 54

#Cross-feed = 170 ± 2

#Combinatorial background= 802 ± 22

#Phys. Bkg = 76 ± 3

Belle: 815±51 events
60% purity

Conclusion and perspectives

$$B^- \rightarrow D^0(\rightarrow K_s\pi^+\pi^-\pi^0)K^-$$

- Twice the Belle statistics with a similar purity -> We expect a statistical error of ~6-7°
- This Mode will also be used to participate to an Amplitude Analysis of D° decay
  - Common work with Tommaso Pajero who works on decay $B^\pm \rightarrow D^{*\pm}(\rightarrow D^0\pi)\mu\nu$
  - Creation of a continuous map of $\Delta\delta_D$
  - One can then redo the study independently from Cleo-c bins
  - Measure of $D^0 \rightarrow K^{*\pm}\rho^\mp$ branching ratio
  - Not measured since Mark III ….. 30 years ago

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- We expect a luminosity x5 during Run 3 that is just starting
  - With a L0 trigger from 1MHz on Runs 1&2 to 40MHz for Run 3
  - A new Vertex locator and tracker (SciFi) -> Very useful as the studied decay gets 5 charged tracks

    Note : I notably work on Scifi commissioning (Electronics Soft Control, Geometry description in software, Pacific Board Time-alignment)
  - Updates of most of the other sub-detectors
- About ɣ measurement -> expect combination of measurements to give a precision of 1-1.5° after Run 3 and 0.3-0.4° in the late 2030’

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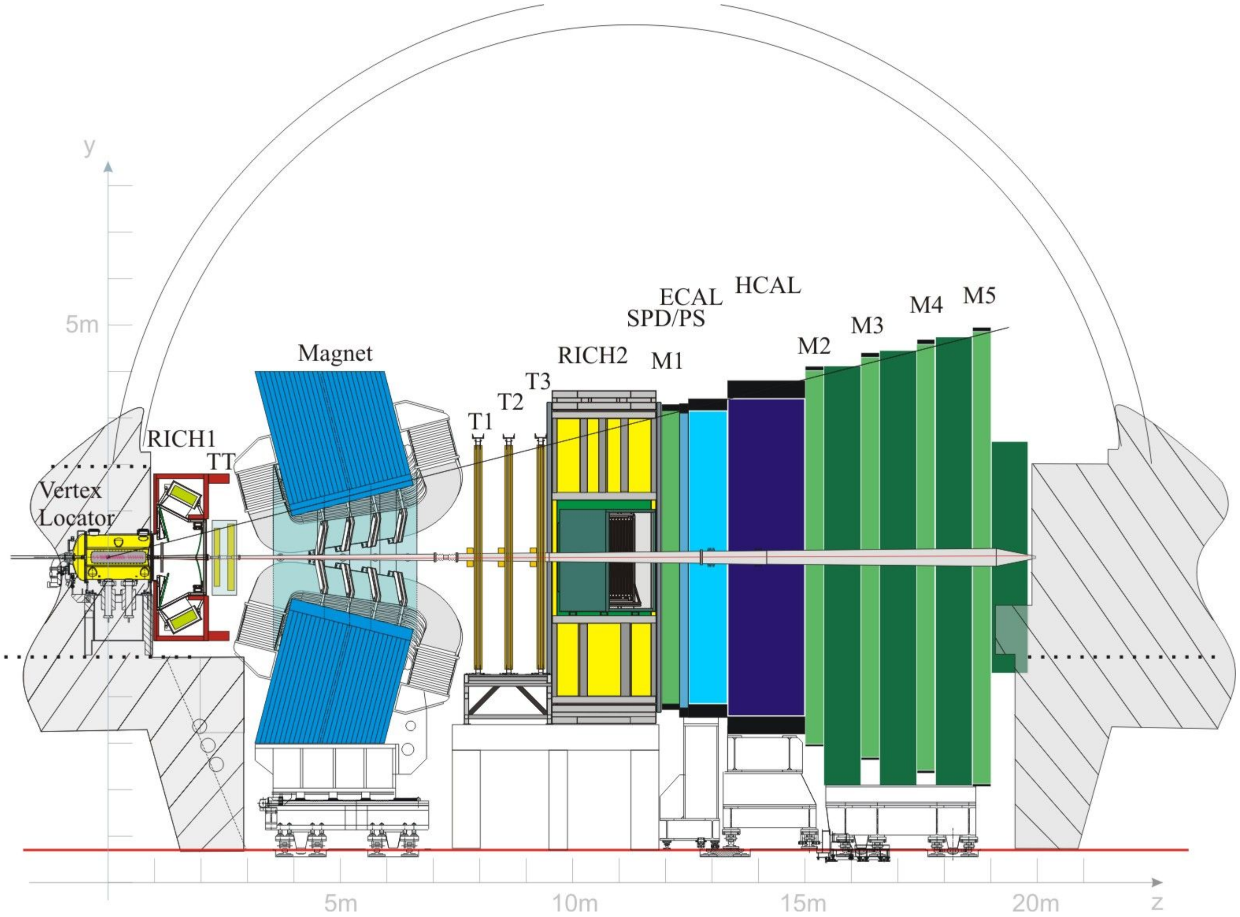
Thank you for your attention !

BACKUP

Backup : LHCb detector



Backup : Selection

MVA 1	
Nom de la variable	*Description*
Log_D0PT	Impulsion transverse de D0
Log_DDIRA	Alignement de l'impulsion reconstruite et de la direction de vol du candidat D
Log_D0FDchi2	Signification statistique de la distance du vertex du candidat reconstruit D par rapport au Primary Vertex
Log_D0maxDOCA	Distance maximum des plus courtes approches pour toutes les paires possibles de particules filles de D
Log_Delta_KsD_ZERR	Distance entre les candidats D et Ks le long de l'axe du détecteur (le candidat Ks doit être détecté plus loin que le candidat D)
Log_KsD_DIRA	Alignement de l'impulsion reconstruite et de la direction de vol du candidat Ks.
DProbChi2Vtx	Qualité du Vertex du D
DdaughtMinsIP	Minimum des paramètres d'impact des particules filles de D
Log_KSLTSignif	Signification statistique de la durée de vie (longue) du candidat Ks. Débarrasse des paires de pions du Primary Vertex se faisant passer pour des Ks
Log_ET_gam_Moy	Energie transverse moyenne des photons issus du candidat π^0
IDgamE	Probabilité que les candidats photons ne soient pas des électrons
IDgamH	Probabilité que les candidats photons ne soient pas des hadrons
Log_KS_BPVIPCHI2MinDaught	Minimum des paramètres d'impact des particules filles de Ks^0
DdaughtMinPT	Minimum des moments transverses des pions chargés issus du D

Backup : Selection

MVA 2	
Nom de la variable	*Description*
cosThetaHely	Angle d'hélicité entre D et B
CosD_bachT_xy	Angle ϑ_{HvsD} entre D et la trace célibataire H (π^- ou K^-) dans le plan transverse
BDIRA	Alignement de l'impulsion reconstruite et de la direction de vol du candidat B
B_PTasy_cone15	Asymétrie de l'impulsion transverse de B dans un cône de 1.5 rad
The_MLP_D	Variable de sortie du MVA 1
log_B_IPchi2	Log de la Signification du paramètre d'impact du candidat reconstruit B par rapport au PV
log_DiffZ_DvsB_Err	Log de la distance entre les candidats D et B le long de l'axe du détecteur
BProbChi2Vtx	Qualité du vertex du B
BFDChi2	Signification statistique de la distance du vertex du candidat reconstruit B par rapport au PV
bachPT	Impulsion transverse du bachelor track