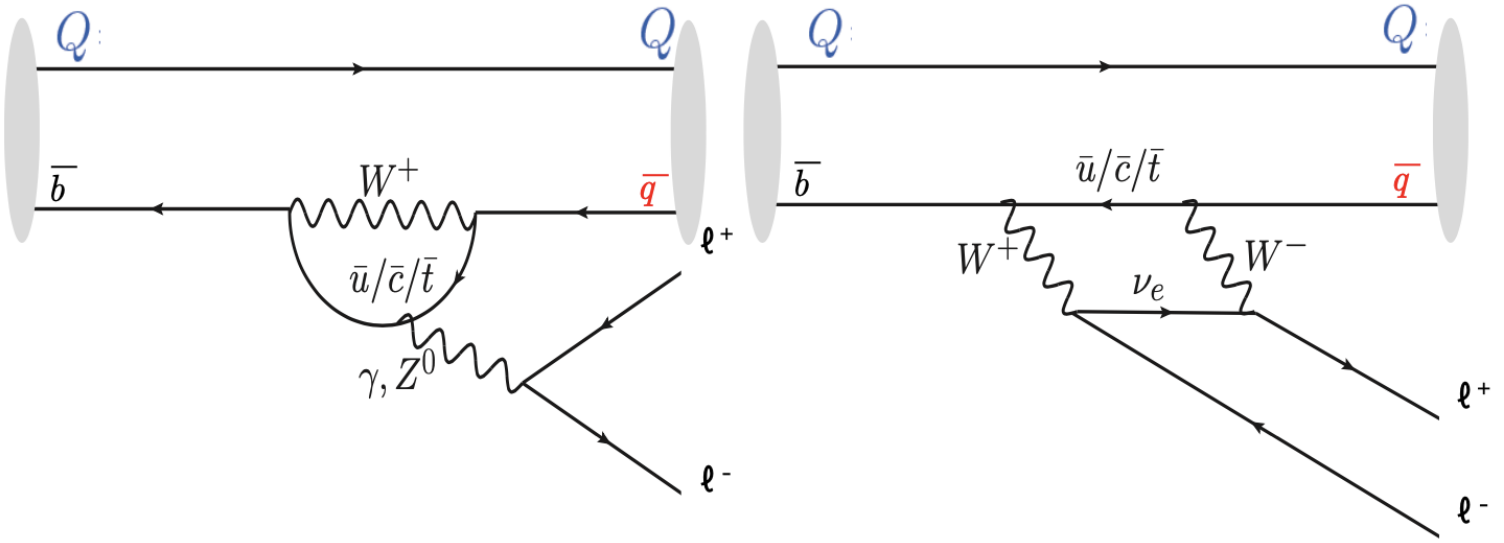
About $b \to d\ell\ell$ transitions and the B_c meson

Fabian Glaser

Marie-Helene Schune

Based on the work done by Khrystyna Trofimiuk (intern from Taras Shevchenko Univ 15/01/2025 – 15/03/2025) and still on-going



FCNC transitions are an ideal place to search for New Physics

$b \to s\ell\ell$ are reasonably well known and studied

$b \to d\ell\ell$ are much more rare (factor 1/20) → less well known

Focus on $\ell = \mu$ (at LHCb)

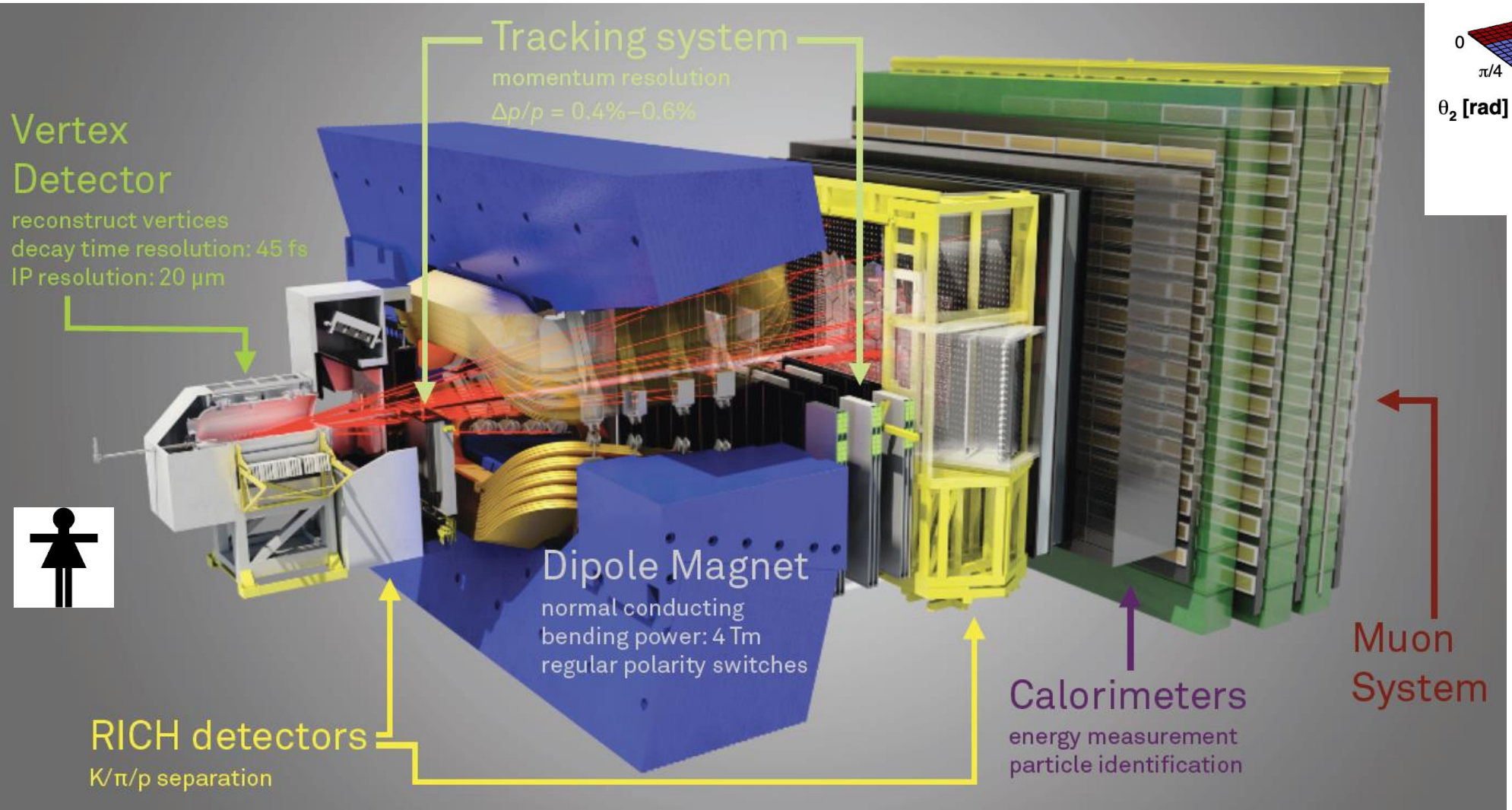
Powerful modes : B → Vector $\ell\ell$ but B → ρ^0 $\ell\ell$ challenging

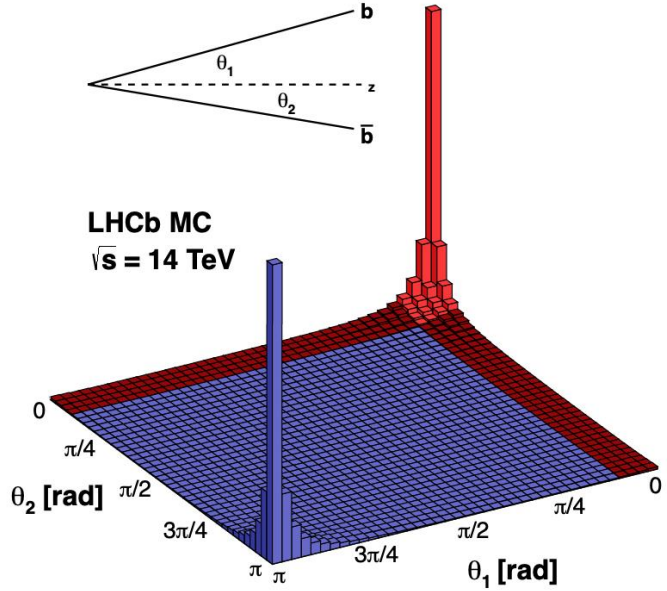
⇒ **$B_c \to D^*(\to D^0 \pi)\ell\ell$**

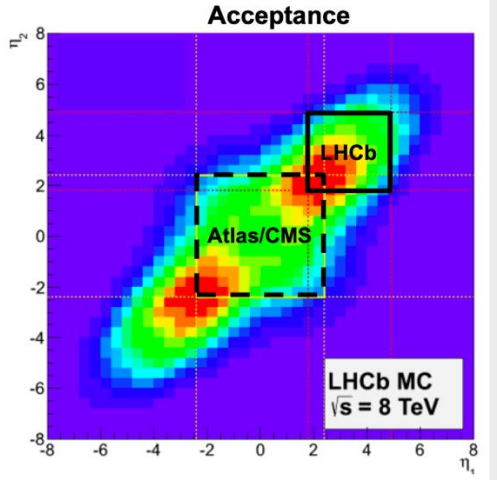
but : production of B_c with respect to $B_{u/d} = (7.26 \pm 0.08) \times 10^{-3}$

The LHCb detector

40% of the heavy quark production cross-section in 4% of the solid angle
All type of *b*-hadrons produced



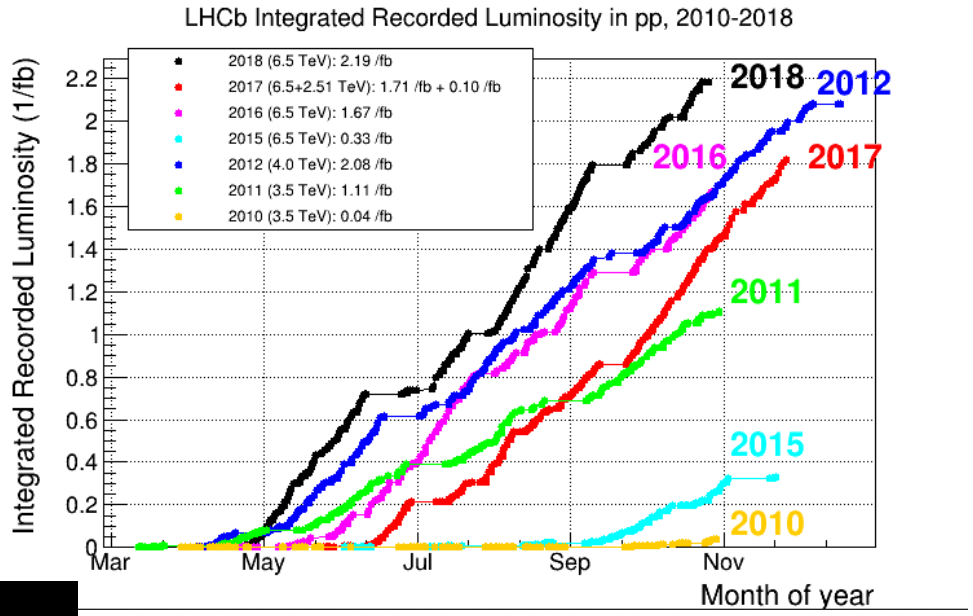


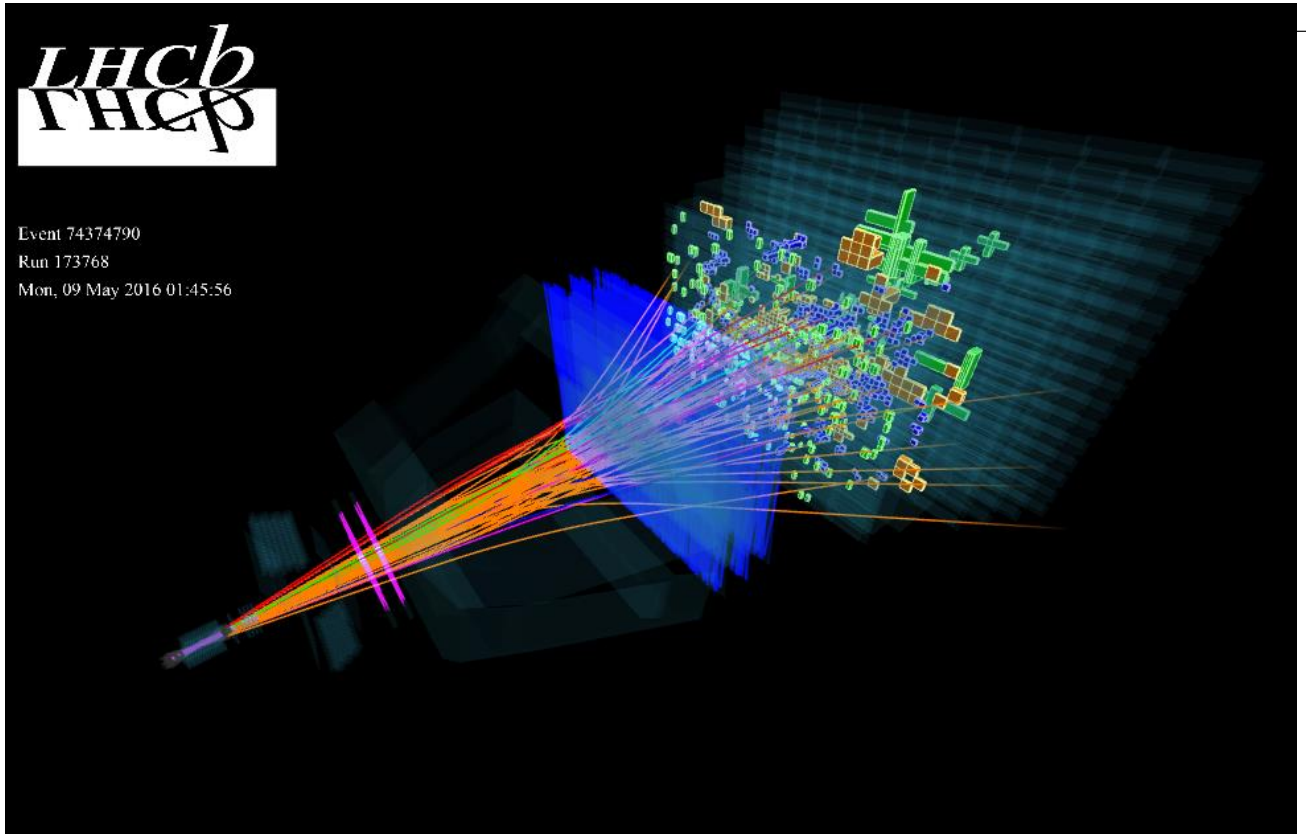


Data used for this analysis :

Run 1 (2011 – 2012 at 7 and 8 TeV): ~ 3 fb^{-1}

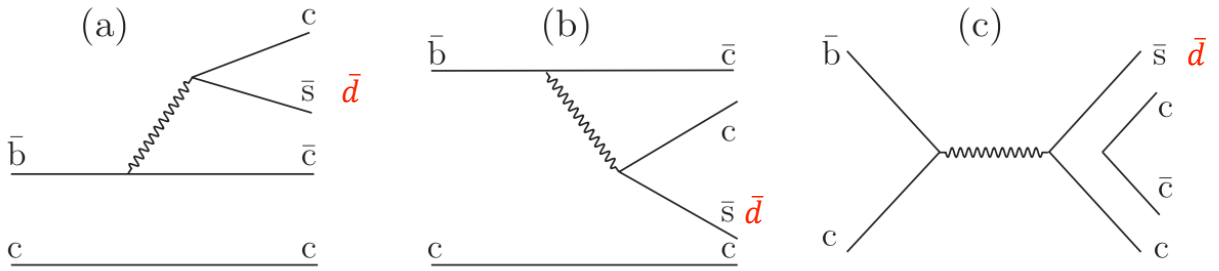
Run 2 (2015 – 2018 at 13 TeV): ~ 6 fb^{-1}





Let's focus first on $B_c \to D^* J/\psi(\to \ell\ell)$

Different diagrams, same final state



$B_c \to D_s^{(*)} J/\psi(\to \ell\ell)$ has been observed

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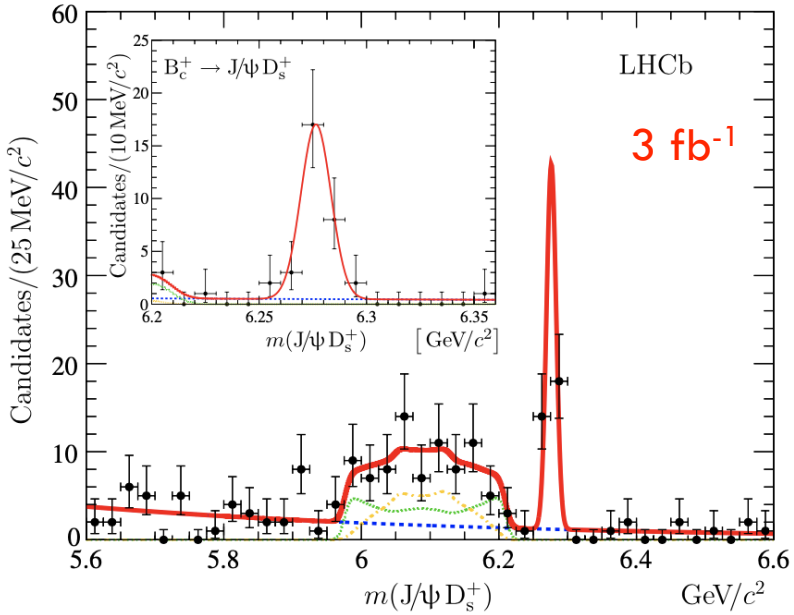

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} = 2.37 \pm 0.56 \pm 0.10$$

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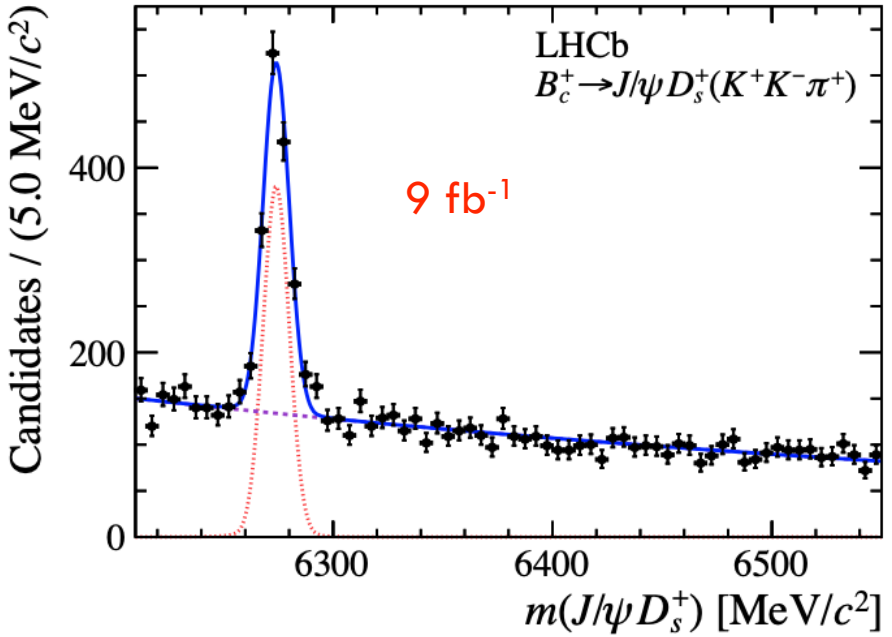

For now we will search for :

- $B_c \rightarrow D^* J/\psi(\rightarrow \mu\mu) \propto |V_{cd}|^2$ with $D^* \rightarrow D^0 \pi$ and $D^0 \rightarrow K\pi$ or $K3\pi$ **never seen**
- $B_c \rightarrow D_s J/\psi(\rightarrow \mu\mu) \propto |V_{cs}|^2$ with $D_s \rightarrow KK\pi$ for normalisation

$$\boldsymbol{BR(B_c \rightarrow D^* J/\psi) = BR(B_c \rightarrow D_s J/\psi) \times \frac{N_{D^* J/\psi}}{D_s J/\psi} \times \frac{N_{D^* J/\psi}}{N_{D_s J/\psi}} \times \frac{\epsilon_{D_s J/\psi}}{\epsilon_{D^* J/\psi}}}$$

Selection (in brief)

Preselection

$\mu^{\pm}$	isMuon $p_T > 500\,\mathrm{MeV}$ $3\,\mathrm{GeV} < \mathrm{p} < 200\,\mathrm{GeV}$
J/ψ	$\lvert m - m_{PDG}\rvert < 25\,\mathrm{MeV}$ $\chi^2_{Vertex} < 9$
D^0/D_s^+ daughters	$\chi^2_{Track} < 3$ $P_{Ghost} < 0.4$ $p_T > 200\,\mathrm{MeV}$ $ProbNN_h > 0.1$
D^0/D_s^+	$\lvert m - m_{PDG}\rvert < 25\,\mathrm{MeV}$ $p_T > 1.5\,\mathrm{GeV}$ / $p_T > 1.0\,\mathrm{GeV}$ $\chi^2_{Vertex} < 16$ BPVDLS > 3 $\sum_h \chi^2_{IP} > 9$ (not for $D^0 \to K\pi$) $c\tau_{J/\psi,D^0\,DTF} > 0$
D^{*+}	$\Delta m \in [141, 150]\,\mathrm{MeV}$ $p_T > 2000\,\mathrm{MeV}$ $\chi^2_{Vertex} < 9$
B_c^+	$\chi^2_{Vertex} < 9$ $\chi^2_{IP} < 25$ DIRA > 0.99

BDT (different ones for $D^0 \to K\pi$, $K3\pi$ and $D_s \to KK\,\pi$)

D^0/D_s^+: $\chi^2_{IP}(h^{\pm})$, $\sum_h \chi^2_{IP}(h^{\pm})$, $min(h^{\pm} p_T)$, $D_{(s)}$ flight distance
$\mu^{\pm}$: $min(\mu^{\pm} p_T)$
B_c^+ candidate: B_c^+ DIRA, B_c^+ flight distance, $\chi^2_{\mathrm{DTF\,fit}}$

Selection (in brief)

Preselection

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BDT

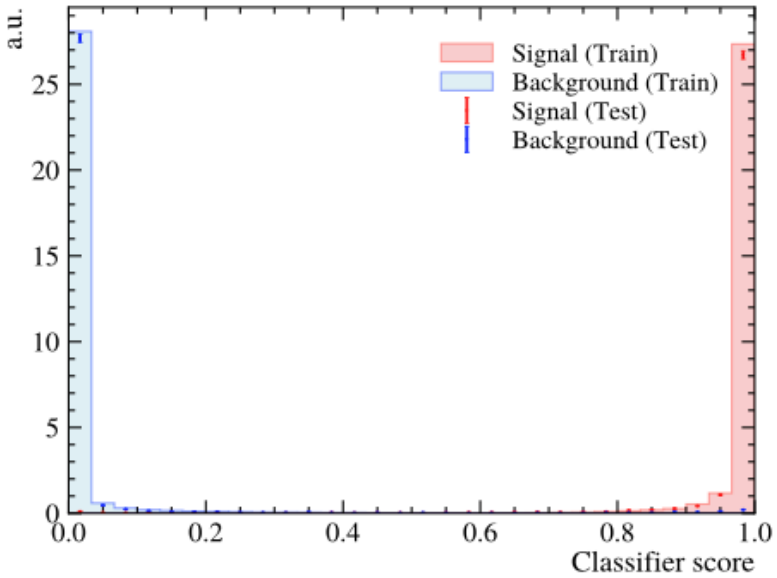
(different ones for $D^0 \to K\pi$, $K3\pi$ and $D_s \to KK\pi$)

Training samples :
Signal is MC
Background is B_c upper mass sideband (6400 – 7000) MeV

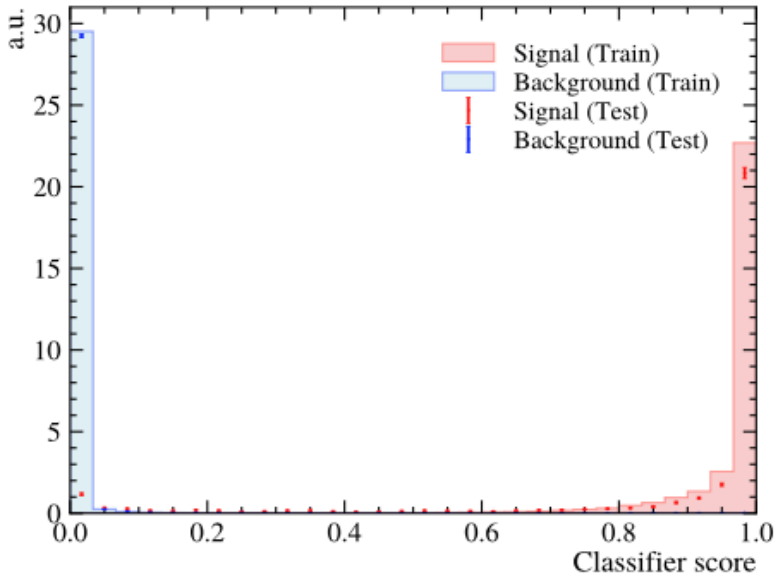
Use of k(=4)-folding technique

Training features are identical for all classifiers:
D^0/D_s^+: $\chi^2_{IP}(h^{\pm})$, $\sum_h \chi^2_{IP}(h^{\pm})$, $min(h^{\pm} p_T)$, $D_{(s)}$ flight distance
$\mu^{\pm}$: $min(\mu^{\pm} p_T)$
B_c^+ candidate: B_c^+ DIRA, B_c^+ flight distance, $\chi^2_{\mathrm{DTF\,fit}}$

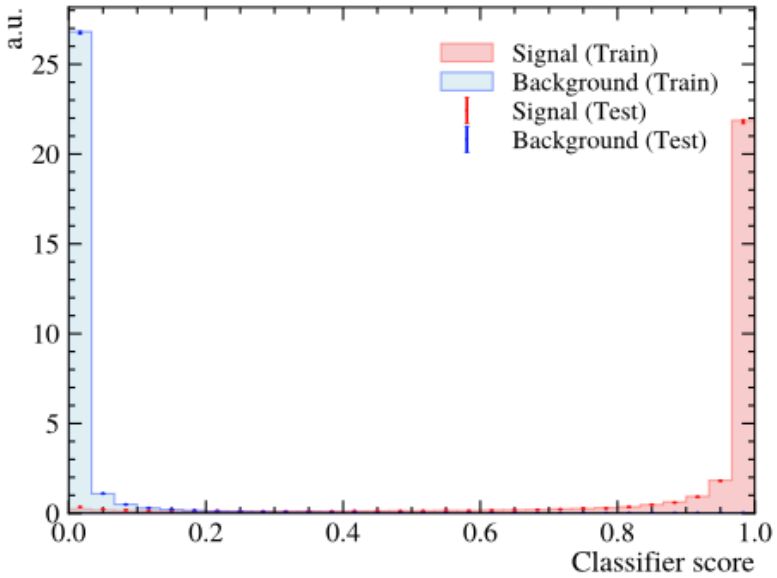
$D^0 \to K\pi$



$D^0 \to K3\pi$



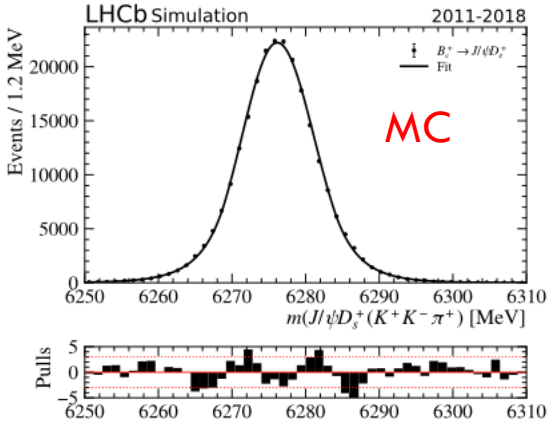
$D_s \to KK\pi$



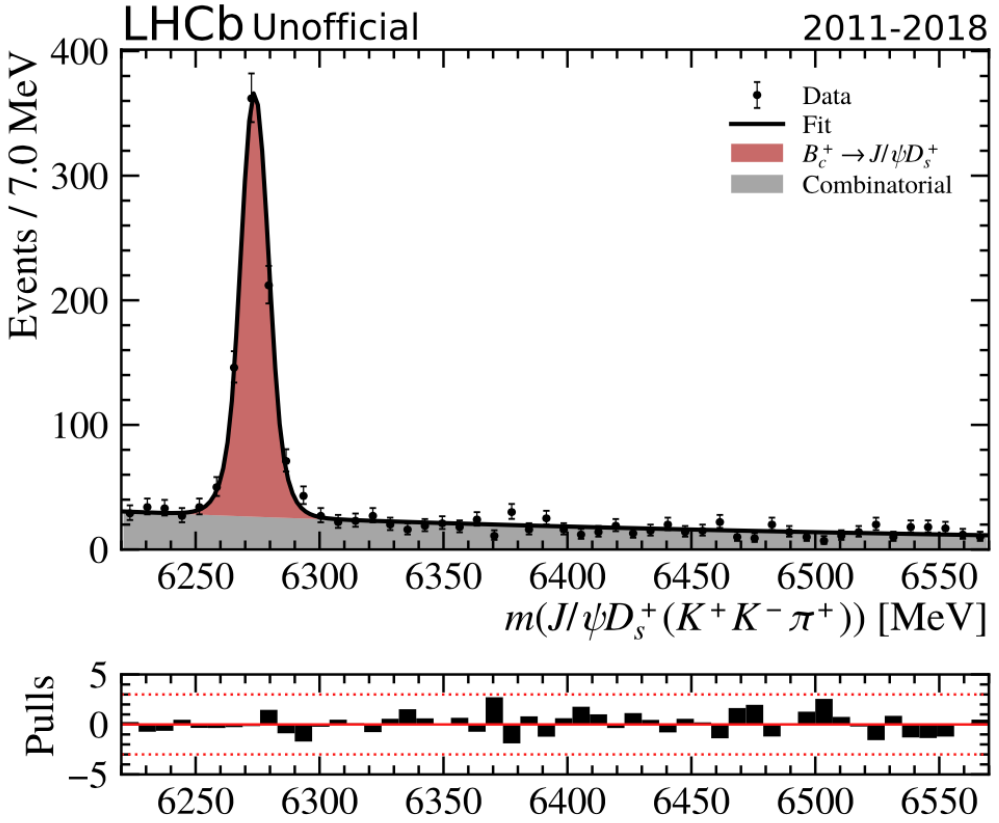
Clear difference between Signal and Background

$B_c \to D_s (\to KK\pi)\ J/\psi(\to \mu\mu)$

Choose the optimal BDT cut by optimizing S/√(S+B)



Ns = 847 ± 50



$B_c \to D^* (\to D^0 (\to K\pi \text{ or } K3\pi)\, \pi_{soft})\, J/\psi(\to \mu\mu)$

Expected yields :

assumption

$$\frac{\mathcal{B}(B_c^+ \to J/\psi D^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D^+)} = \frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} = 1.91 \pm 0.20 \pm 0.07$$ [JHEP 02 (2024) 032]

$$\Rightarrow \quad N_{exp}^{f} = N_{D_s^+} \frac{\mathcal{B}(B_c^+ \to J/\psi D_s^{*+})}{\mathcal{B}(B_c^+ \to J/\psi D_s^+)} \frac{|V_{cd}|^2}{|V_{cs}|^2} \frac{\mathcal{B}(D^{*+} \to D^0\pi^+)\mathcal{B}(D^0 \to f)}{\mathcal{B}(D_s^+ \to K^+K^-\pi^+)} \frac{\varepsilon_f}{\varepsilon_{D_s^+}}$$

$f = K\pi$ or $K3\pi$

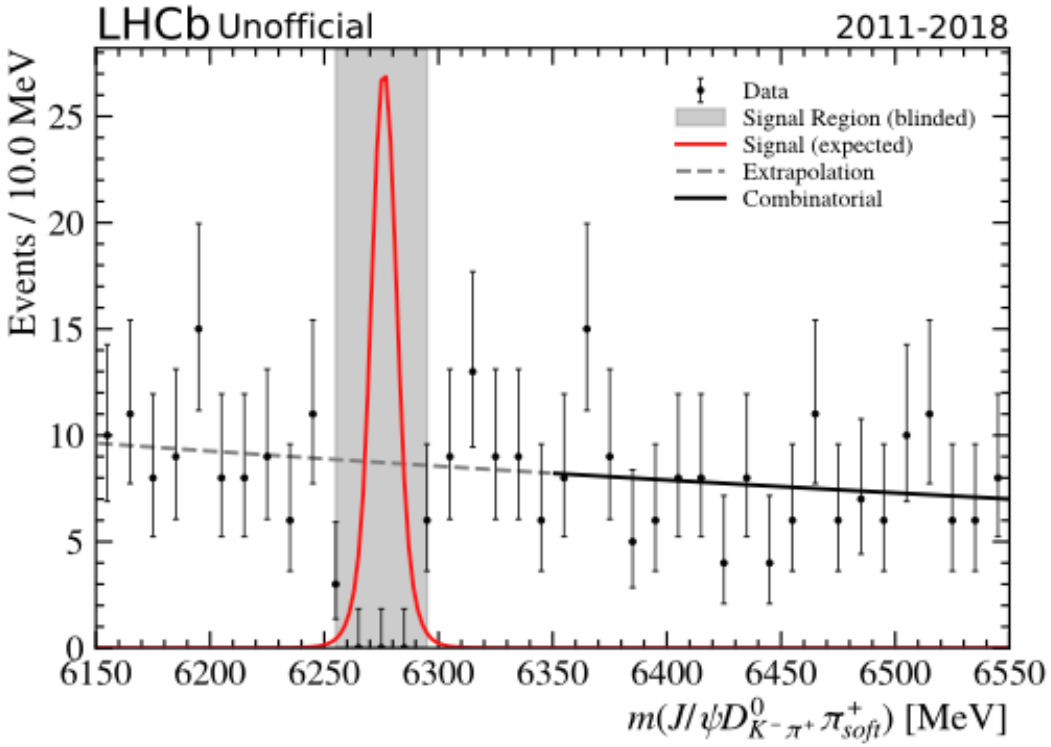
$$\Rightarrow \boxed{\begin{aligned} N_{exp}^{K\pi} &= 47 \pm 6 \\ N_{exp}^{K3\pi} &= 36 \pm 5 \end{aligned}}$$

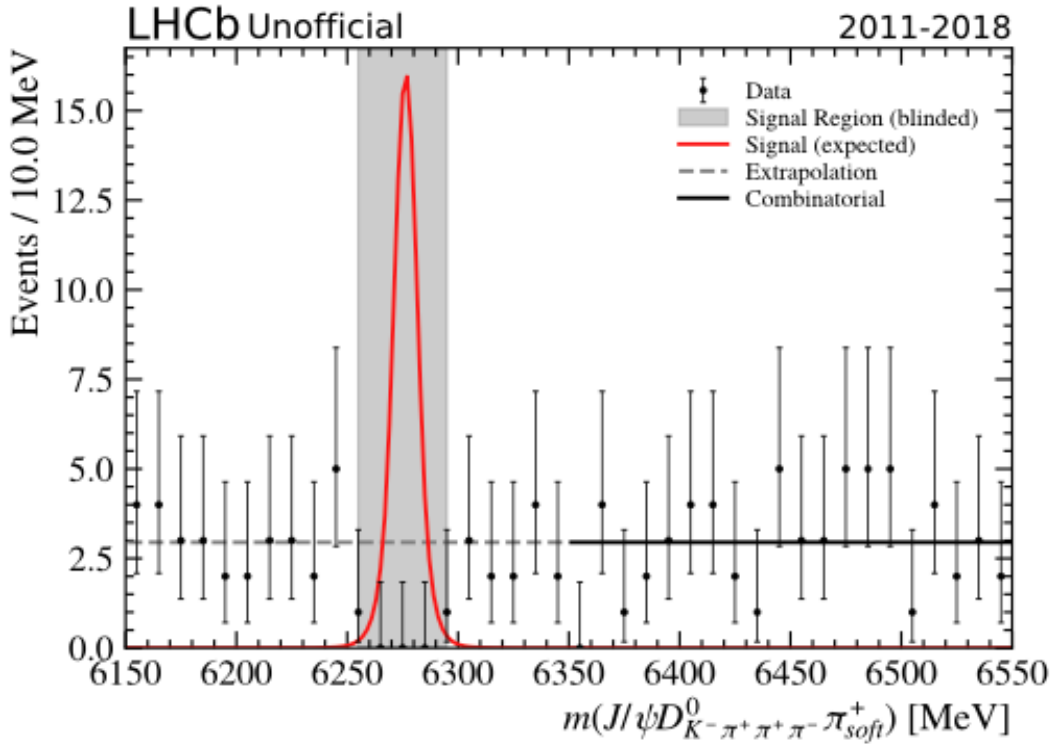
before the BDT

Choose the optimal BDT cuts by optimizing the S/√(S+B) FoM : S is obtained as previously explained and B is from upper mass sidebands

Preferred working points : $\epsilon_{BDT}^{K\pi} = 75$ % (FoM ~ 5) and $\epsilon_{BDT}^{K3\pi} = 56$ % (FoM ~ 4)

How it could look like :





Blinded zone

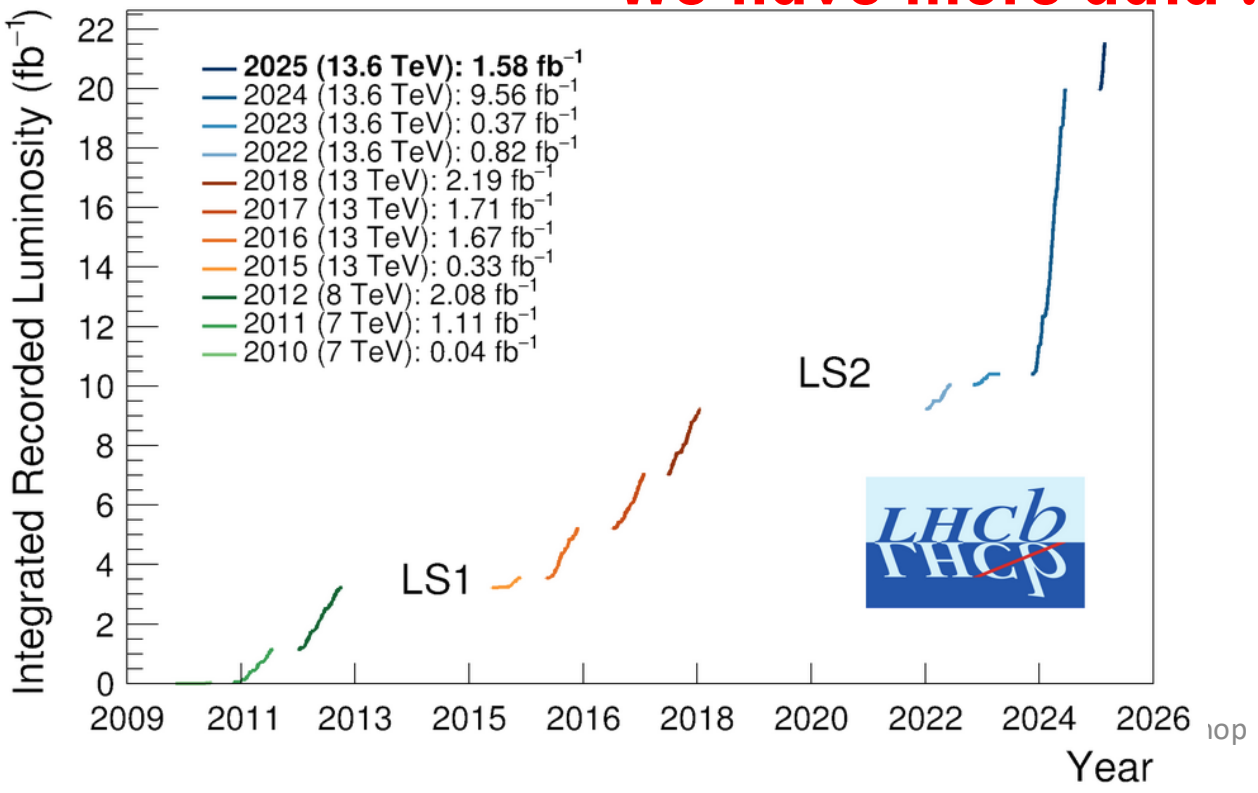
Conclusion

First search for the decay $B_c \rightarrow D^* (\rightarrow D^0 (\rightarrow K\pi \text{ or } K3\pi)\ \pi_{soft})\ J/\psi(\rightarrow \mu\mu)$

The analysis strategy is in place and the first signal estimate is promising

It will contribute to the better knowledge of the B_c meson

We have more data !



Stay tuned

Thank you for your attention