Measuring the CKM angle γ in open charmed B decays at LHCb

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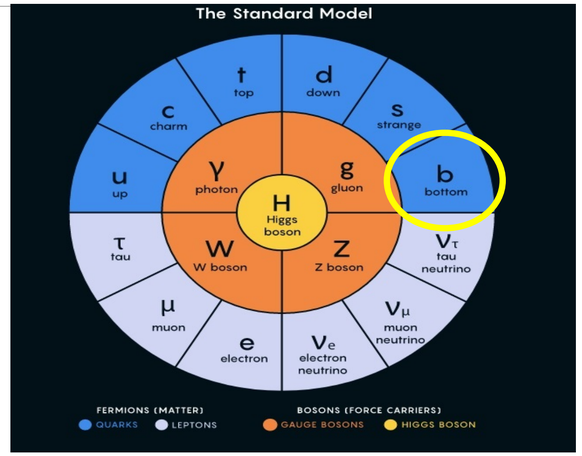
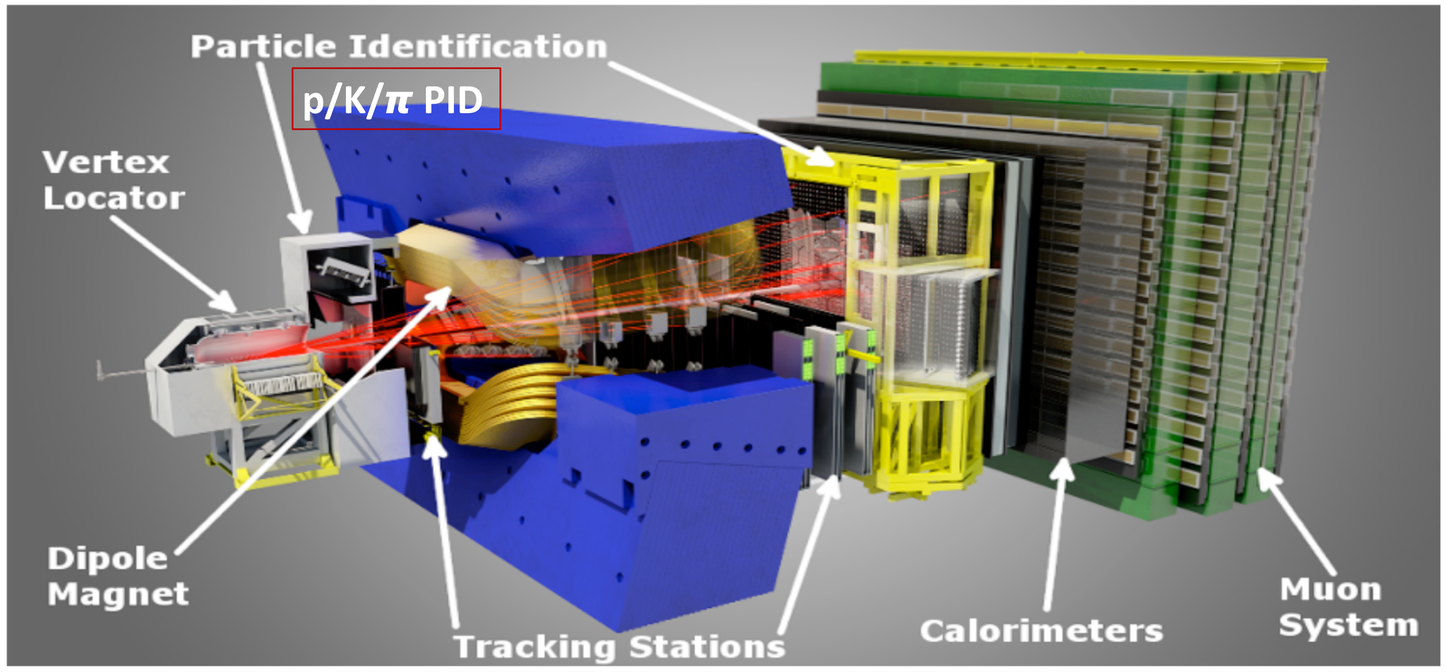
LHCb: Large Hadron Collider Beauty Experiment

- General purpose of spectrometer in the forward direction covering $2 < \eta < 5$
- **Goal:** Designed for the precision measurements of particles with beauty and charm sector in particular CP violation and search for indirect evidence of New Physics
- Precise particle identification and reconstruction
- Physics program involves Flavour physics, EW, exotic and heavy ions…





- Center of mass energy :

Run 1 (7-8 TeV collisions) (2011-2012)
Run 2 (13 TeV collisions) (2015-2018)

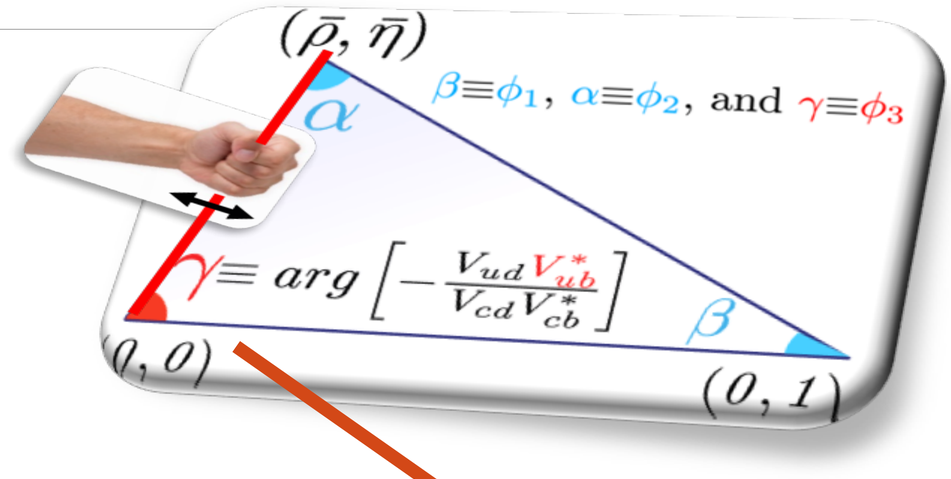
Luminosity collected :

$$\mathcal{L}_{inst} = 4 \times 10^{32} cm^{-2} s^{-1}$$

- 3 (Run 1) + 6 (Run 2) fb^{-1}

MOTIVATION

- The weak phase γ is the least accurately measured constraint of the CKM Unitarity Triangle.
- Measuring it precisely is one of the key goal of the **Flavour Physics**.
- γ can be measured from the processes mediated
  - Only angle easily accessible at **Tree-level** (direct measurement)
    - theoretically clean
    - "**Standard Candle**" of the Standard Model
    - Sensitivity determine by the interference between **favoured b→c** and **suppressed b→u** quark transitions in the tree level.
  - **Loop-level** (indirect measurement) – sensitive to NP



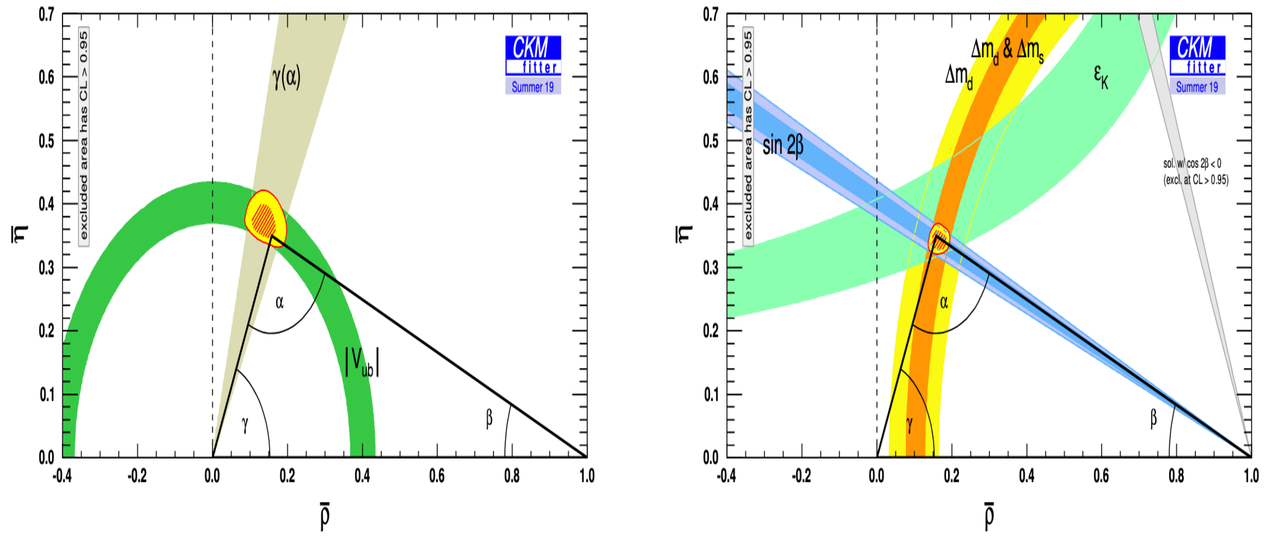
$$\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

Unitarity Triangle Measurement

- Discrepancy between these will indicate ”**New Physics**”

- Many different channels to study the sensitivity on $\boldsymbol{\gamma}$

- The decay modes we use for $\boldsymbol{\gamma}$ measurement :
  - $\boldsymbol{B_s^0 \to D^{(*)0}\phi(K^+K^-)}$, $\boldsymbol{D^{(*)0}}$ **decays to** $\boldsymbol{K^-\pi^+\pi^0}$
  - $\boldsymbol{B^- \to DK^{*-}}$ **where** $\boldsymbol{K^{*-}}$ **decays to** $\boldsymbol{K^-\pi^0}$ **(with GLW/ADS method)**



Tree only

Loop only

≠

NP

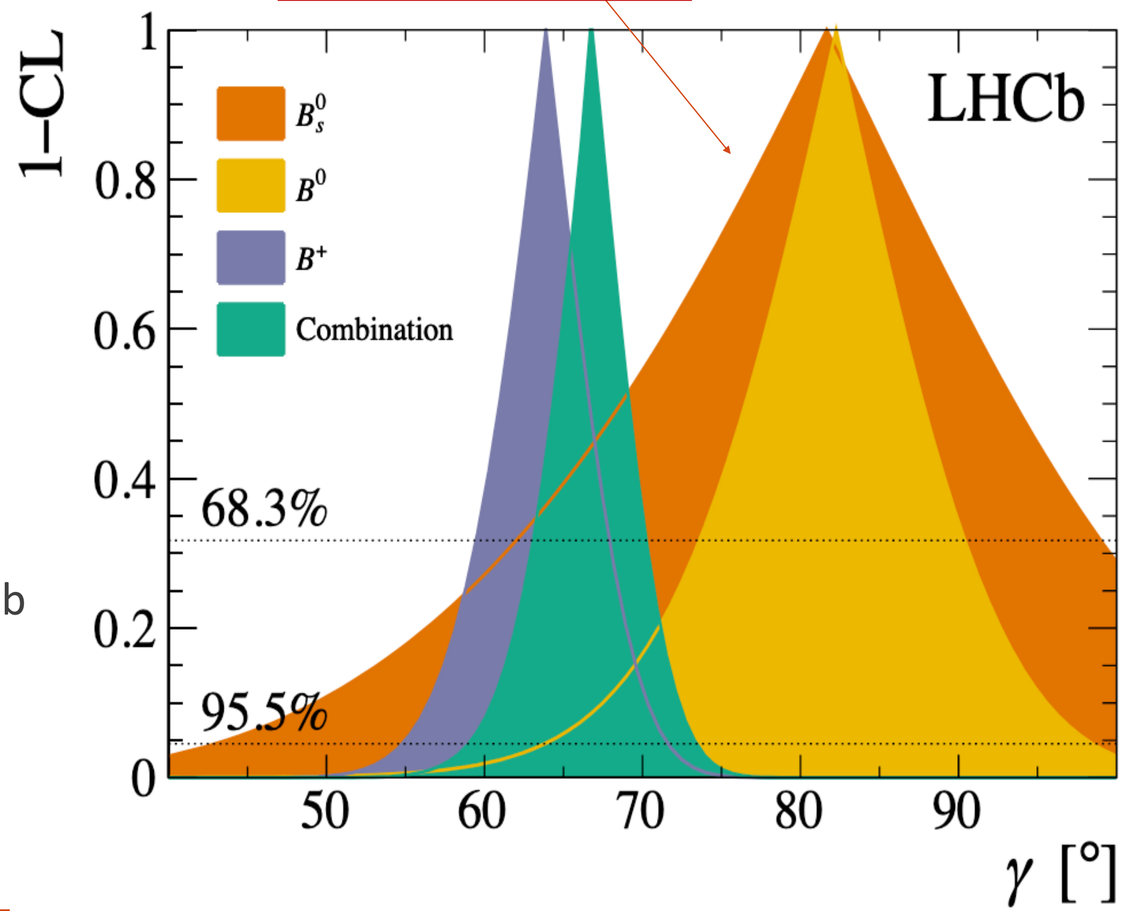
[CKMFitter]

γ Combination by LHCb

- Most precise determination of γ from a single experiment
- Different B modes agree at 2σ level
- B_s^0 decays in Run 1 and Run 2 analysis [LHCb-CONF-2020-003]
  - Constraint on $\gamma \sim 20^\circ$ level of precision
- Yields of D^0 modes can be used to study γ
  - $D^0 \to h^-h^+, D^0 \to K^-\pi^-\pi^+\pi^+, D^0 \to K^-\pi^+\pi^0$
- Combination of Unitarity Triangle angle γ measurements of the LHCb
  - **New average :** $\gamma = (67 \pm 4)^\circ$ [LHCb-CONF-2020-003] (direct measurement)

$$\gamma = (65.7^{+0.9}_{-2.7})^\circ \textbf{ (indirect measurement)}$$

Time-dependent and tagging analysis
$B_s^0 \to D_s^{\mp} K^{\pm}(\pi\pi)$



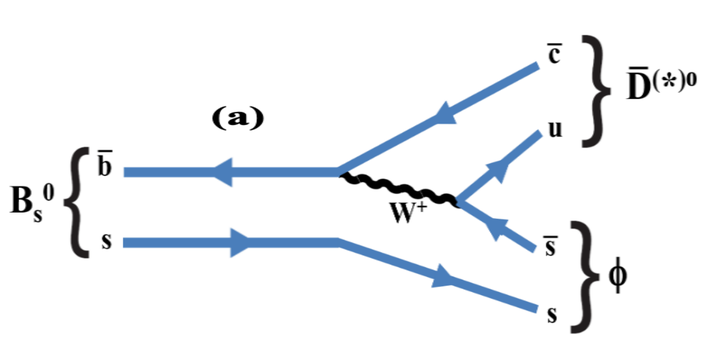
1. $B_s \to D^{0(*)}\phi$ Analysis

$B_s \to D^{0(*)}\phi$ Analysis

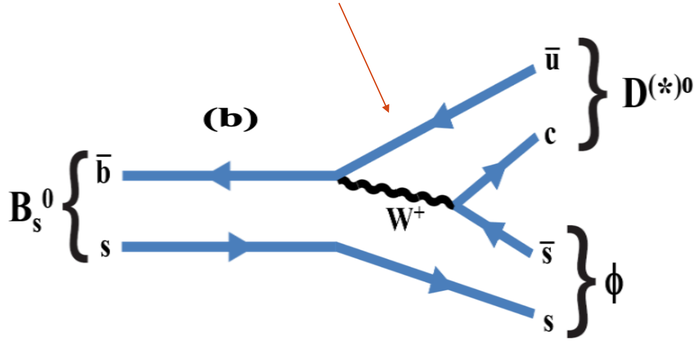
- The precise measurement of the γ angle through the $B_s^0 \to D^{(*)0}\phi(KK)$, where D-meson decay modes are: $K\pi, K\pi\pi\pi, K\pi\pi^0, KK, \pi\pi$ (**Phys. Rev. D 98, 071103(R)(2018)**), γ Sensitivity Paper (**Chinese Phys. C 45 023003 (2021)**)

- The sensitivity on γ obtained $\sim 8^\circ$ to 19° with Run1 & Run2 dataset

- Can proceed by leading-order interfering Feynman diagrams



"γ"



- Yields from the D^0->$K\pi\pi^0$ sub-decay mode used to study γ

Chinese Phys. C 45 023003 (2021)

- Combined other sub-decay modes ($K\pi, K\pi\pi\pi, KK, \pi\pi$) studied by Chinese colleagues to improve its sensitivity.

- **Goal:** Optimize the $B_S \to D^{0(*)}\phi$ channel to obtain a very high purity and the most abundant signal of $B_S \to D^0\phi$ to achive the best sensitivity on γ

$B_s \to D^{0(*)}\phi$ Analysis

- Preliminary analysis for $B_s \to D^{0(*)}\phi$, $D^{0(*)} \to K^-\pi^+\pi^0$ studied with MC, DATA Run1 (2011-2012) and DATA Run2 (2015-2016-2017) (not including 2018)

- **Datasets and selections used for the $B_s^0 \to D^{(*)0}\phi$ analysis for γ measurement**
  - Monte Carlo Run 1 (2011 - 2012) + Run 2 (2015-2018)
  - DATA Run 2 (2015-2018)
  - Stripping + trigger + pre-selections + PID Cut + MVA Cut

- **Re-optimize the selection on $B_s \to D^{0(*)}(K^-\pi^+\pi^0)\phi(K^+K^-)$**
  - **Deal with $D^{0(*)} \to K^-\pi^+\pi^0$**
  - **Pre-selections & MVA on $B_s \to D^{0(*)}(K^-\pi^+\pi^0)\phi(K^+K^-)$**

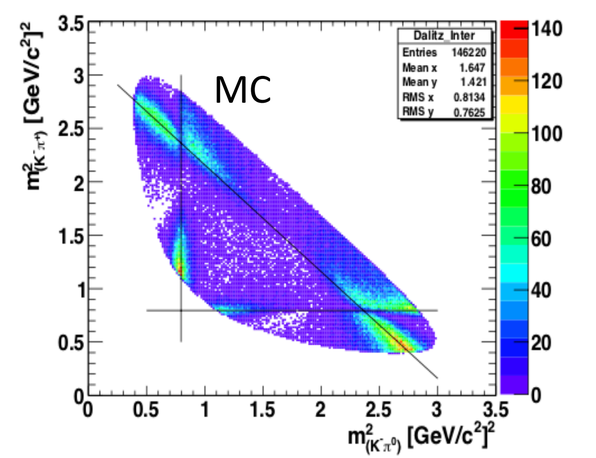
$B_s \to D^{0(*)}\phi$ Analysis

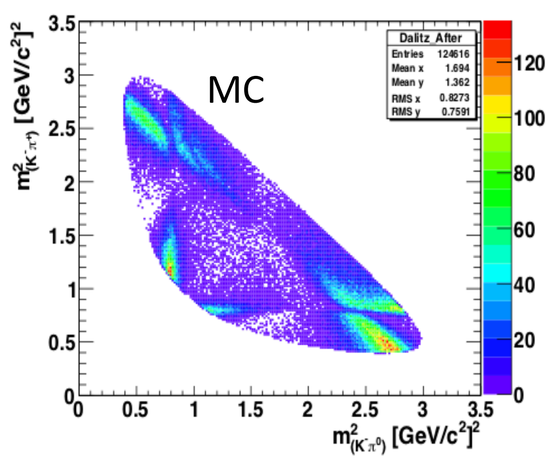
- Selection of sub-decay mode $D^0 \to K^-\pi^+\pi^0$ is complicated because of neutral pion π^0
  - Large backgrounds studied: Resolved $\pi^0 \to \gamma\gamma$ separately in ECAL

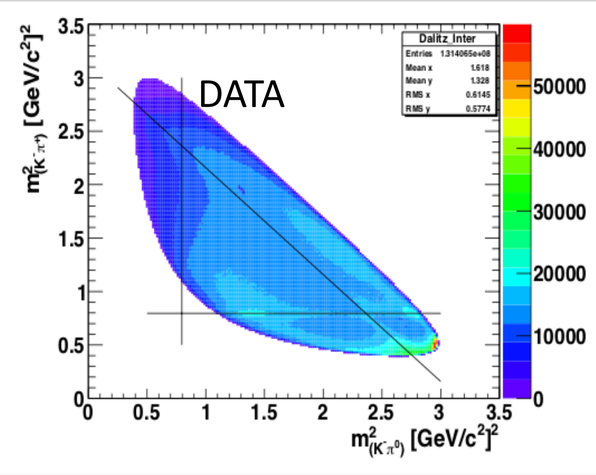
- **MC simulation:**
  - Amplitude model from E691 Experiment and confirmed by CLEO-C
  - involving resonant Spin-1 particles (K^{*0} (horizontal), K^{*-} (vertical), ρ^+ (anti-diagonal))

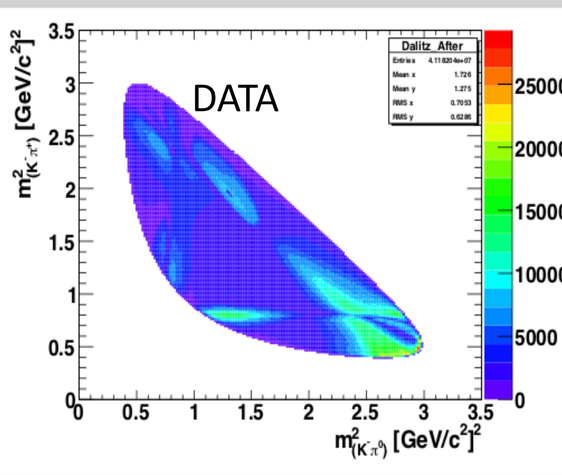
- **MVA Method: BDT to select π^0 (Selections)**
  - Dalitz weight, photon asymmetry, photon tranverse energy, probability for photons to be not electrons or hadrons to reduce the background

- **Optimization of the π^0**
  - **Signal Efficiency 85%**
  - **Background Rejection 80%**









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LHCb

cnrs dépasser les frontières IN2P3 Les deux infinis

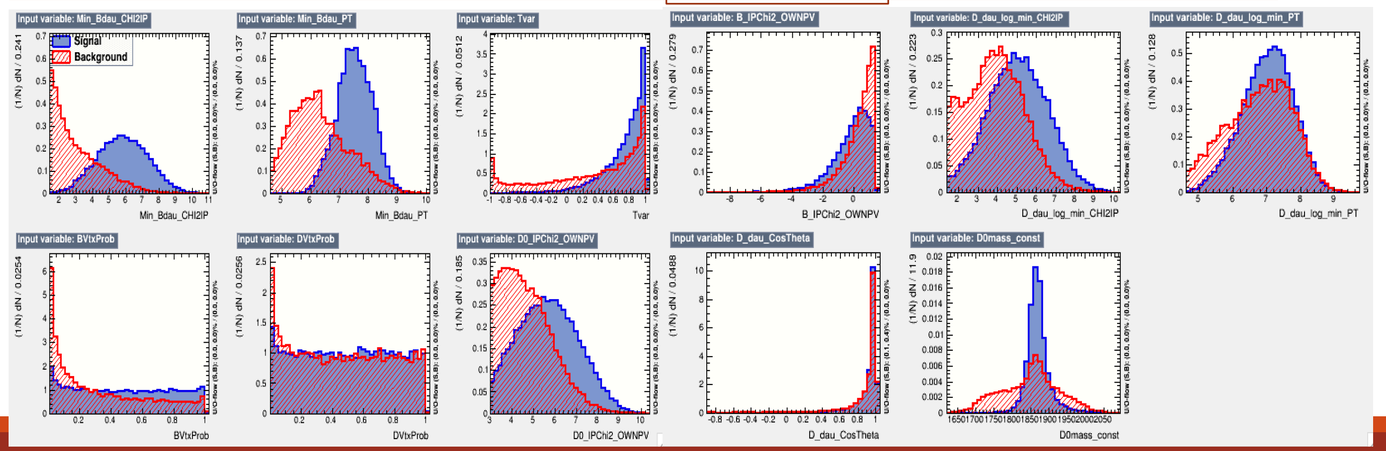
$B_s \to D^{0(*)}\phi$ Analysis

- **Pre-selections on $B_s \to D^{0(*)}\phi$** re-optimized to improve the statistical significance and to reduce the background [Phys. Rev. D 98, 071103(R)(2018)]

- Final selection MLP MVA giving the best optimization used to remove the combinatorial background
  - Topological and kinematic variables

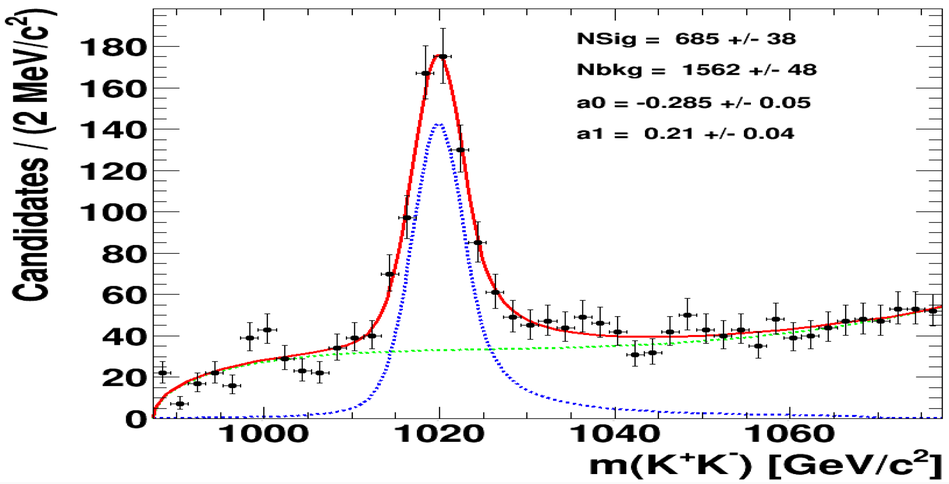
- Particle identification(PID) cuts for all tracks are applied

Candidates		Criteria
D^0	Invariant mass	[1765.0 , 1965.0] MeV/c²
B^0	Invariant mass	[5.1 , 6.0] GeV/c²
π^0		[116.0 , 160.0] MeV/c²
D^0	Vertex χ^2 / nDof	➢ < 6 to < 4
	BPVIPCHI2	> 20
D^0	SDB = $\frac{z_D - z_B}{\sqrt{\sigma_{z_D}^2 + \sigma_{z_B}^2}}$	➢ > 3 to ~ 1.25 (RUN1) ➢ > 3 to ~ 1.05 (RUN2) Charmless decay
B^0	Vertex χ^2 / nDof	< 4
	BPVIPCHI2	< 4
	$\cos(\theta_{dira})$(BPVDIRA)	> 0.99995
D^{*-} (2010) veto		$m_{D_\pi} - m_D \notin [140.621 , 150.221]$ MeV/c²
PID requirements for D^0 daughters (RICHs Identification)		
* π	ProbNN_π x (1 − ProbNN_K)x (1 − ProbNN_p)	➢ 2%
* K.	ProbNN_K x (1 − ProbNN_π)x (1 − ProbNN_p)	➢ 0.02% to 5%

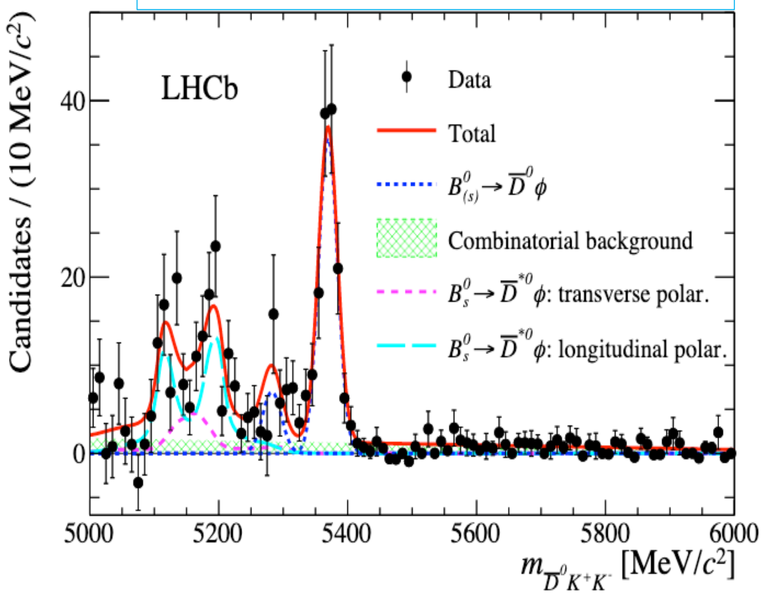


$B_s \to D^{0(*)}\phi$ Analysis

- Two-dimensional fit to m(DKK)
- Signal models
  - $B_s \to D^{0(*)}\phi$: Breit-wigner convoluted with Crystall-Ball

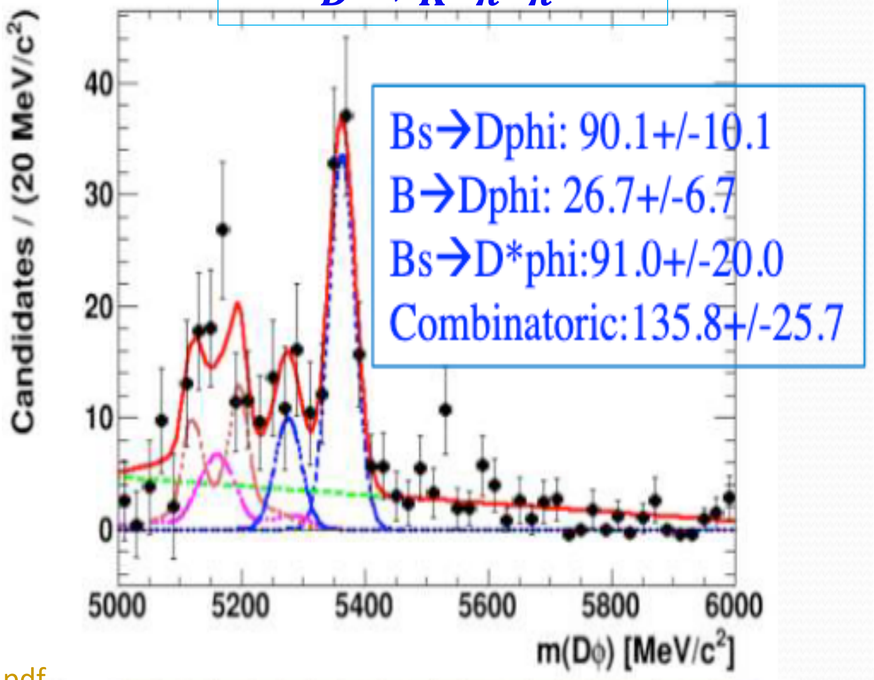


Published study on $D^0 \to K^-\pi^+$ Reference Channel

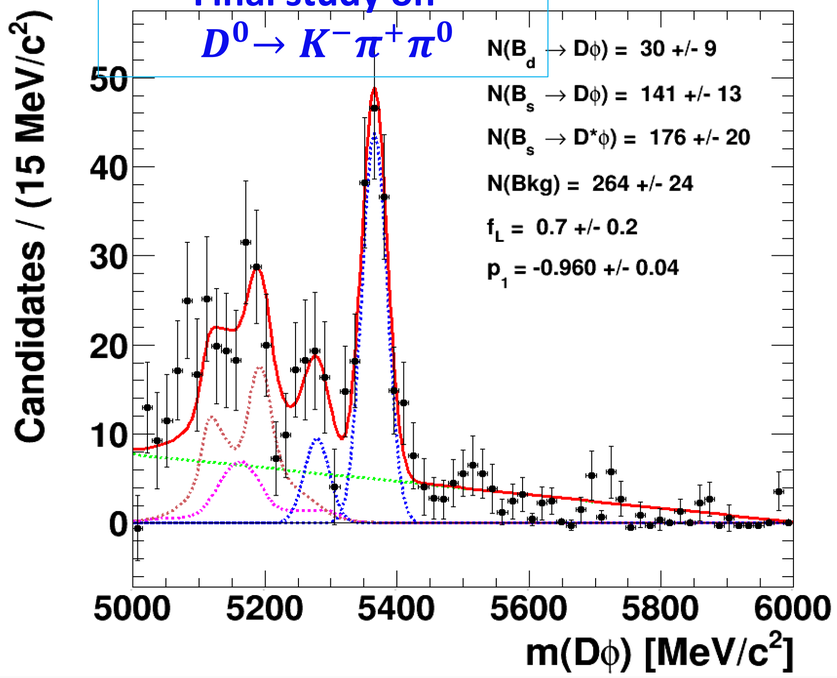


https://arxiv.org/pdf/1807.01892.pdf

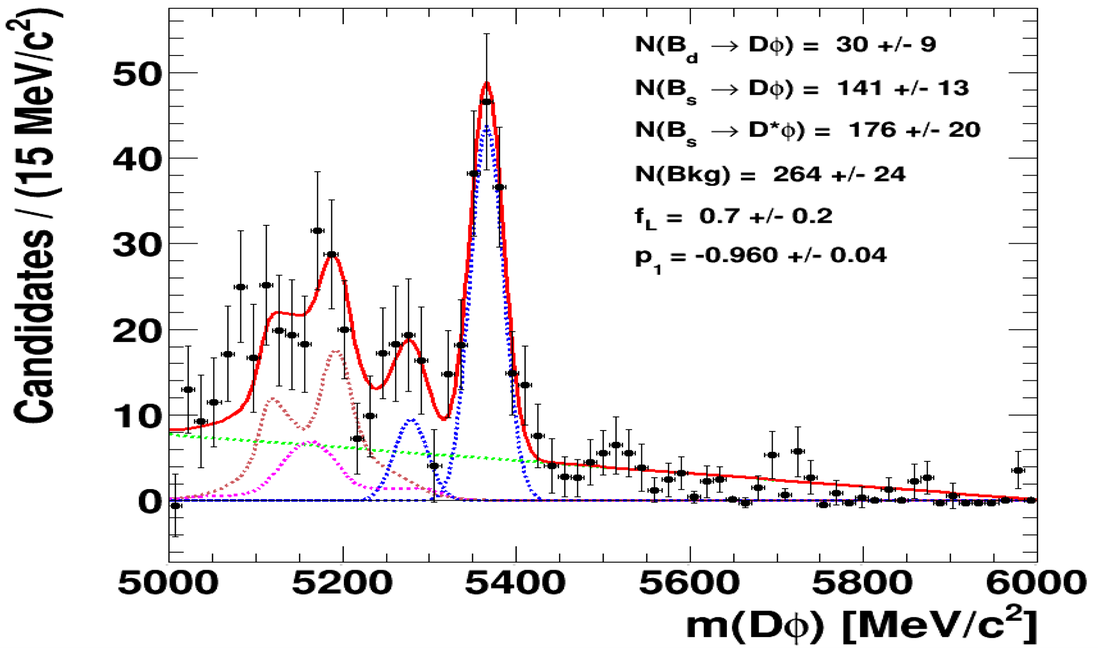
Preliminary study on $D^0 \to K^-\pi^+\pi^0$



Final study on $D^0 \to K^-\pi^+\pi^0$



$B_s \to D^{0(*)}\phi$ Analysis



- Measured yields

- The signal rate is improved !!!

Mode	$B_s^0 \to D^0\phi$	$B_s^0 \to D^{(*)0}\phi$
$K^-\pi^+$ (Run1) [https://arxiv.org/pdf/2008.00668.pdf]	58	34
$K^-\pi^+\pi^0$ (Run1+Run2) (Preliminary study)	90.1 $\pm$10.01	91.0 $\pm$20.0
$K^-\pi^+\pi^0$ (Run1+Run2) NEW RESULTS	141 $\pm$13	176 $\pm$20

- Time for the γ measurement!

2. $B^- \to D^0 K^{*-}$ Analysis

$B^- \to D^0 K^{*-}$ Analysis

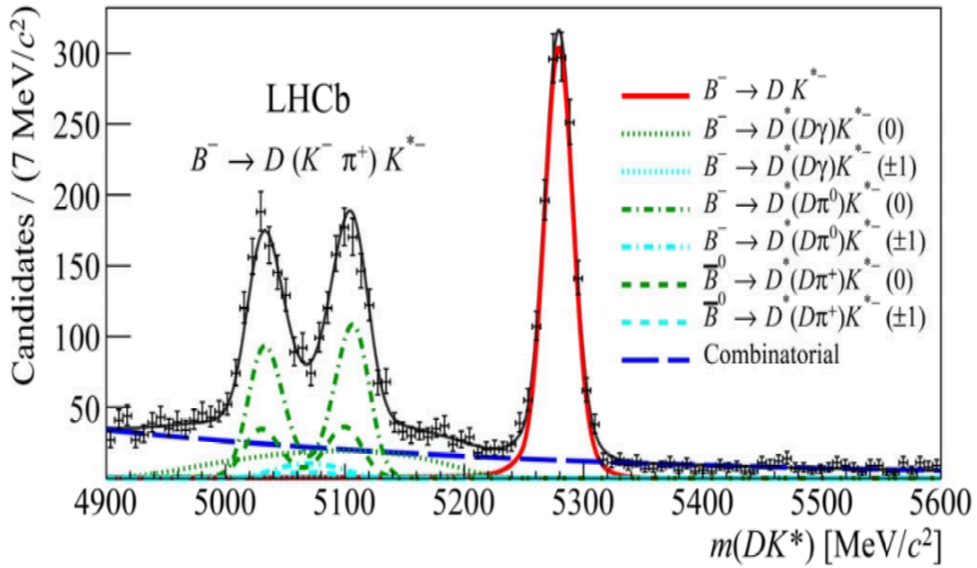
- Analysis on more conventional decay of $B^- \to D^0 K^{*-}$ and $K^{*-} \to K_S \pi^-$ has been done with RunI&RunII (2015-2016) data by A. Nandi & S. Malde(Oxford) & V. Tisserand [arXiv:1709.05855]

- The second part of the thesis will be to measure γ angle measurement with the decay of $B^- \to D^0 K^{*-}$, where $K^{*-} \to K^- \pi^0$
  - Only difference dealing with π^0

- Preliminary analysis on $K^{*-} \to K^- \pi^0$ done with Run1 & Run 2(not included 2018)

- **With current analysis to be used and improved**
  - **Full datasets**
  - **Same physics, i.e. r_B , δ_B**
  - **Selection optimisation(Pre-selections, MVA)**
  - **Efficieny measurement**
  - **Work on uncertainties**

- **Significance will be improved !**



Decay mode	B^- yield	B^+ yield
$B^\pm \to D(K^\pm\pi^\mp)K^{*\pm}$	996 ± 34	1035 ± 35
$B^\pm \to D(K^+K^-)K^{*\pm}$	134 ± 14	121 ± 13
$B^\pm \to D(\pi^+\pi^-)K^{*\pm}$	45 ± 10	33 ± 9
$B^\pm \to D(K^\mp\pi^\pm)K^{*\pm}$	1.6 ± 1.9	19 ± 7

$$R_{CP+} = 1.18 \pm 0.08 \pm 0.01$$
$$A_{CP+} = 0.08 \pm 0.06 \pm 0.01$$

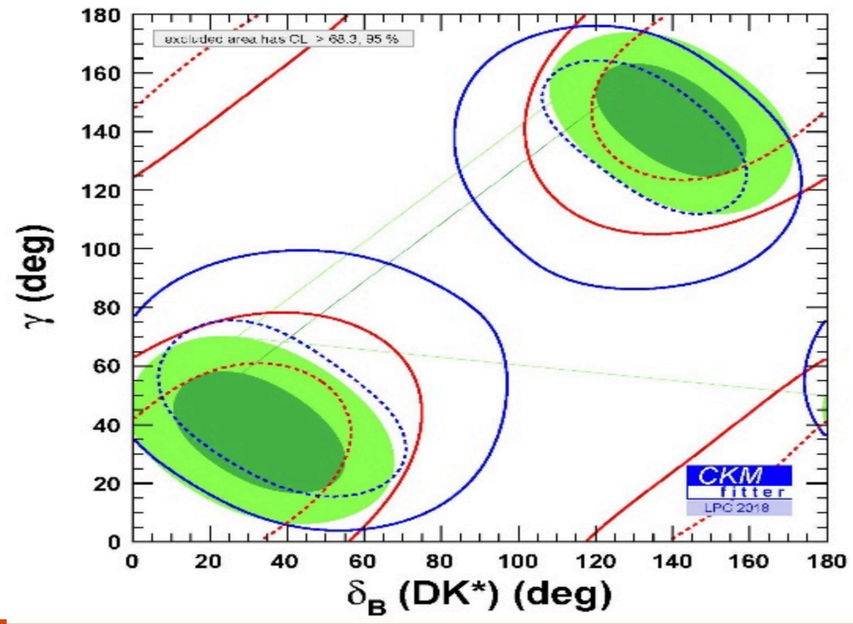
Statistical significance
4.2σ
[LHCb-PAPER-2017-030]

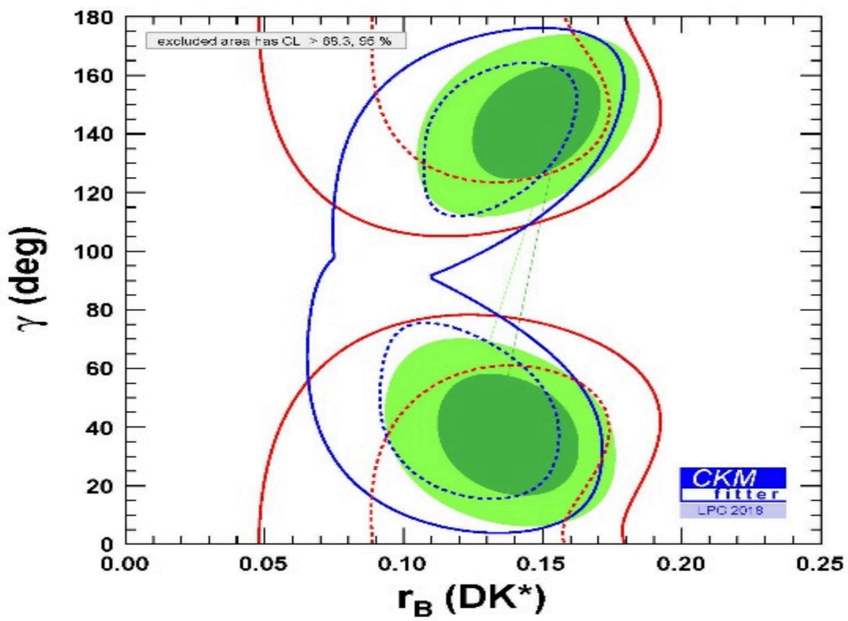
$B^- \to D^0 K^{*-}$ Analysis

- Measurements of all observables combined to determine r_B , δ_B , γ
- **Blue contour from the analysis of $B^- \to D^0 K^{*-}$ and $K^{*-} \to K_S \pi^-$** [LHCb-PAPER-2017-030]
- **Red contour from the preliminary analysis on $K^{*-} \to K^- \pi^0$**
- **Green zone correspond to the combination of two decay modes**

r_B: ratio of b→u and b→c amplitudes
δ_B : corresponding strong phase difference

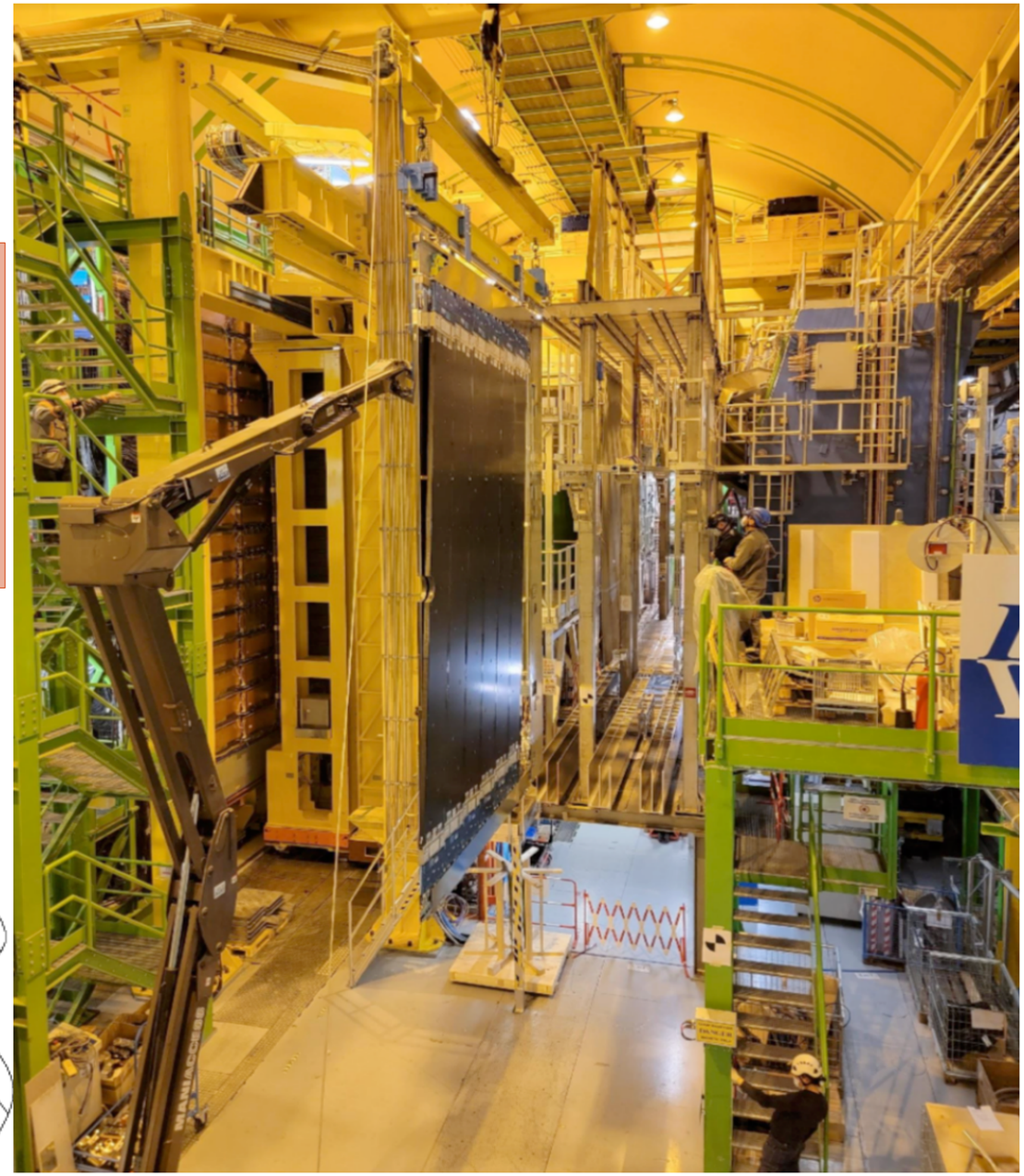
- **Precise determination of γ at 2σ level**
- **$K^{*-} \to K^- \pi^0$ Promising decay to study further**
- **To be improved with full dataset**

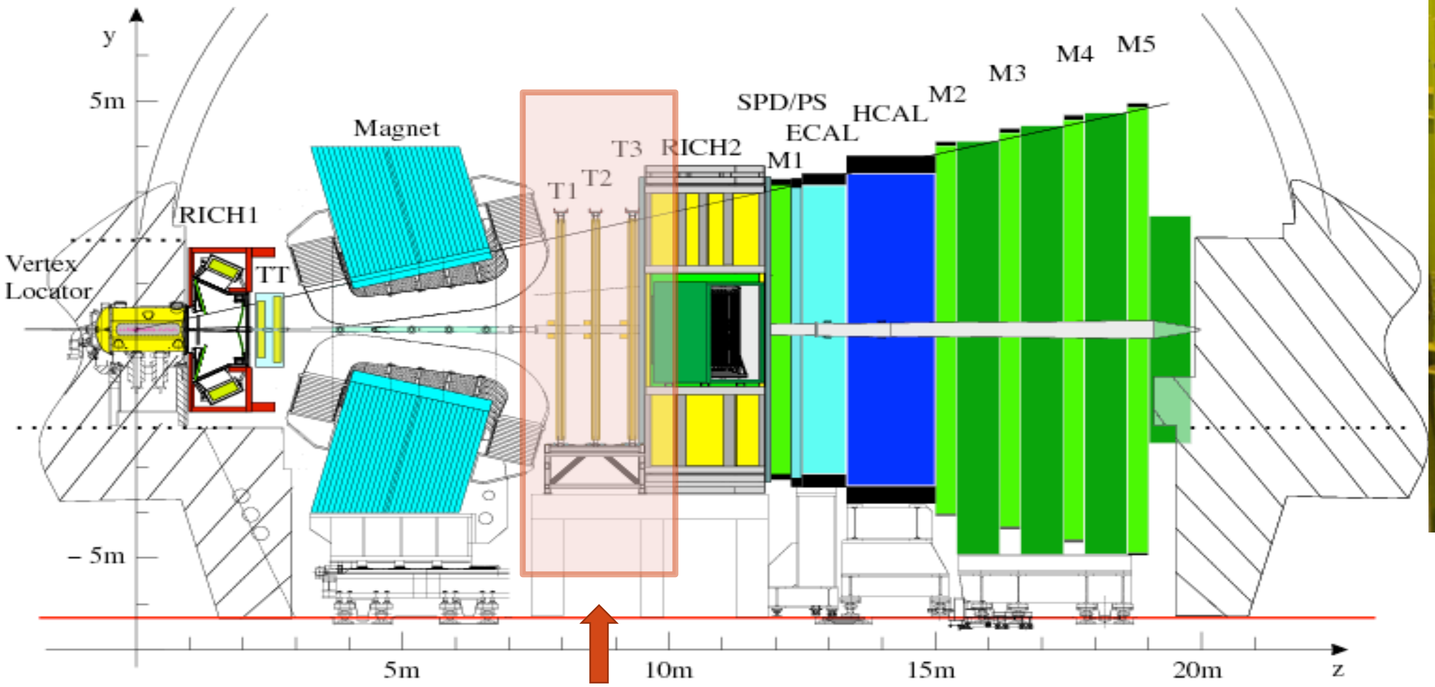




- LHCb Upgrade

Scintillating Fibre Tracker (SciFi)





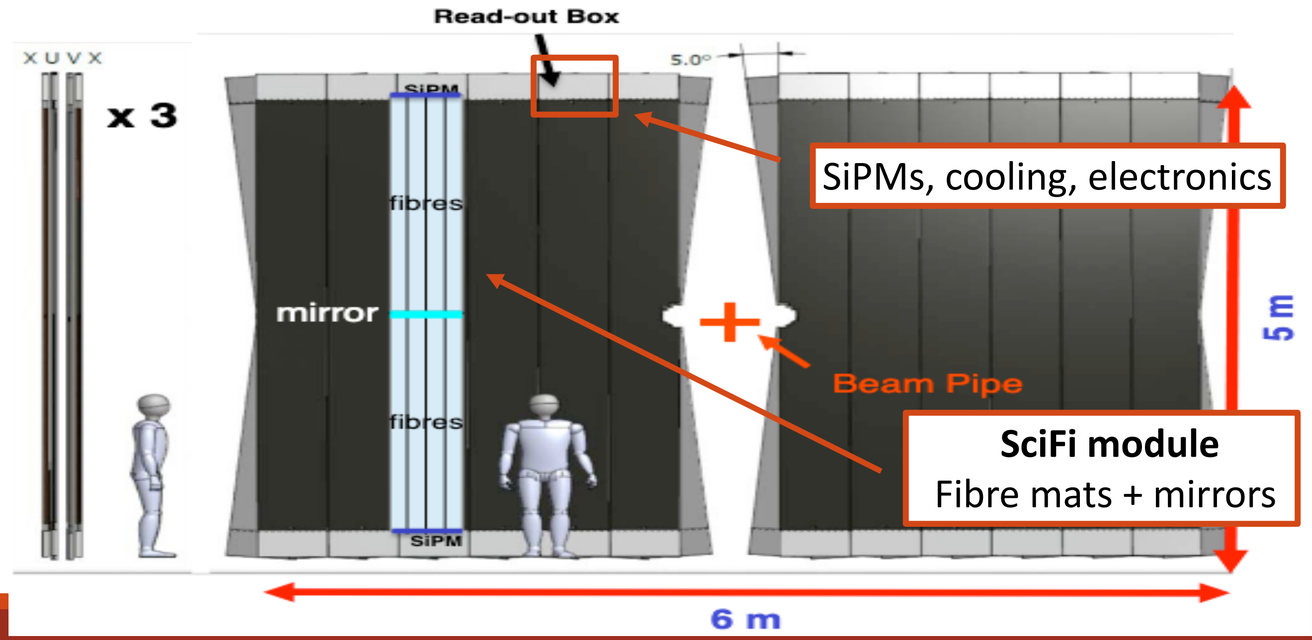
IT + OT → SciFi

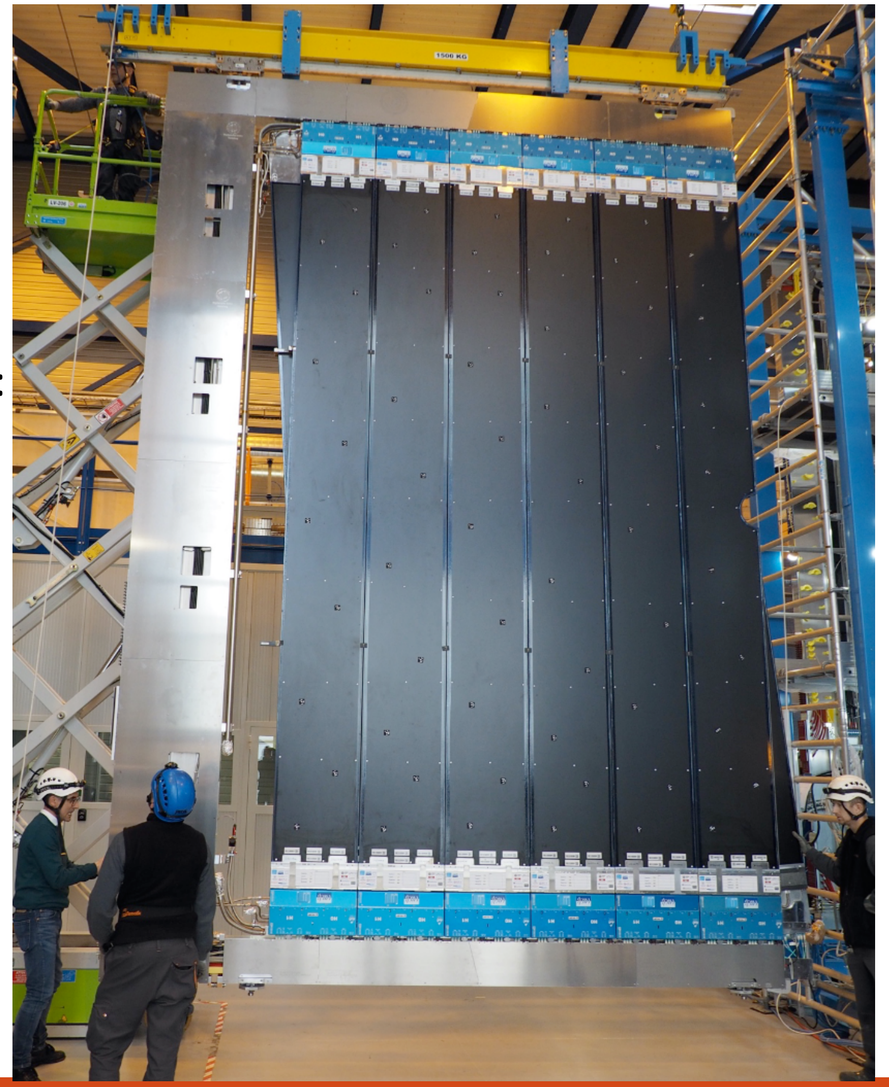
Scintillating Fiber Tracker (SciFi)

➢ **Motivation:**

Increase the instantaneous luminosity ($4.10^{32} cm^{-2} s^{-1} \rightarrow 2.10^{33} cm^{-2} s^{-1}$) and the data taking rate from 1MHz to 40MHz

- Hard to cope with faster data-taking with IT and OT
- Inner (IT) and Outer Tracker(OT) replaced by a single technology: **SciFi tracker** = scintillating fibres with SiPM readout





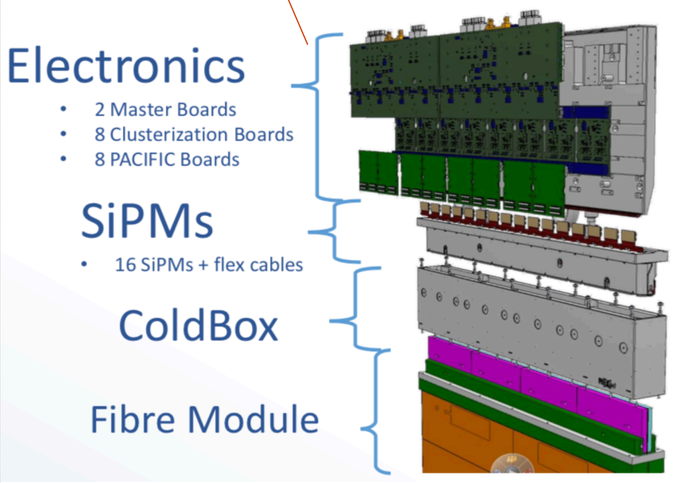
Scintillating Fiber Tracker (SciFi)

- Participate the construction and the commisioning of the new Scintillating Fibres (SciFi) tracker project.

- especially assembly of the **SciFi readout box**

- Contribute to the online monitoring and simulation of the behaviour of the environment sensors that monitor the changes of electronics **readout box**

- 6/12 C-Frames transported to the cavern.



Photos by S. Jacobsen – 101st LHCb Week

Conclusions

- Efficiency and the systematics studies on $B_s \to D^{0(*)}(K^-\pi^+\pi^0)\phi$ have been finalized

- **Currently working on:**

  - Combine with the other sub-decay modes($K\pi, K\pi\pi\pi, KK, \pi\pi$) and measure the ***γ*** angle
    - Soon to be published

- Measurement of γ through $B^- \to D^0 K^{*-}$($K^{*-} \to K^-\pi^0$) is in preparation

- Final transport for the C-Frames will be end of January.

Thank You For Your Attention!