LHCb Overview

Carla Marin
on behalf of the LHCb collaboration

LHCb Implications Workshop
28/10/2020

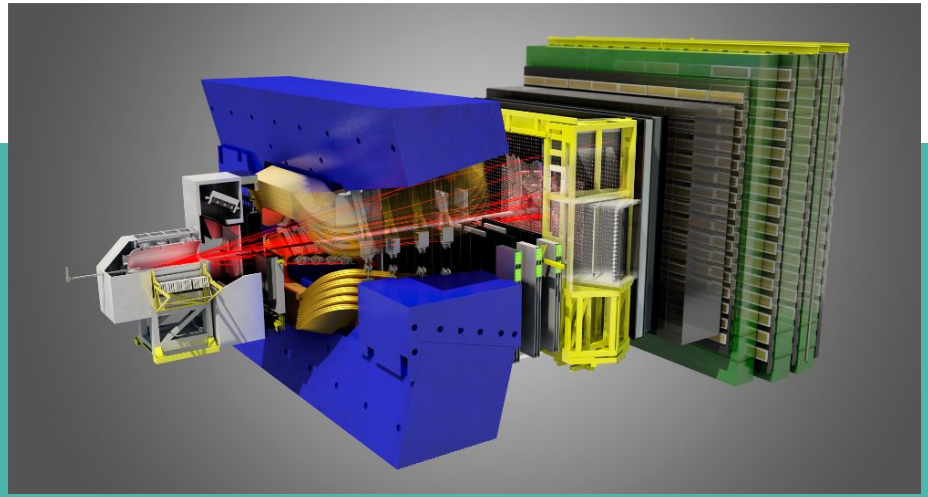
IJCLab Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

Outline

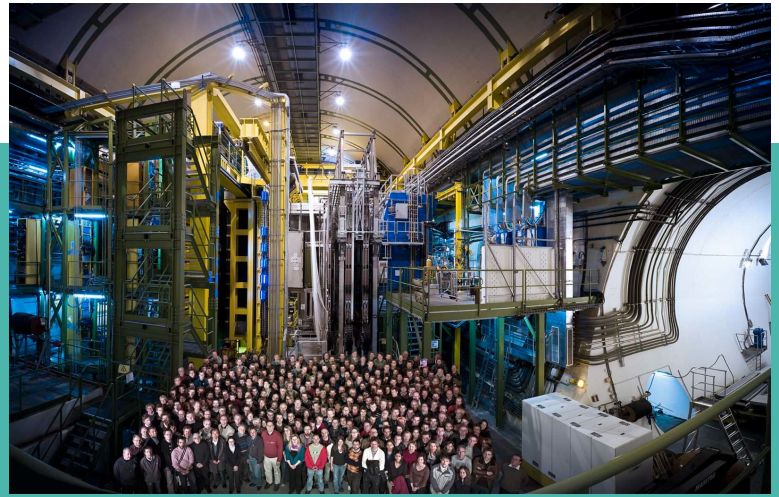
- The LHCb experiment
- Overview of new LHCb results in 2020
  - Spectroscopy
  - Rare decays
  - CPV
  - Exotica
- Future of LHCb
  - the renewed LHCb detector
  - physics prospects

Disclaimer: no time to cover everything, please check experimental talks in various streams for details

LHCb: Large Hadron Collider Beauty experiment



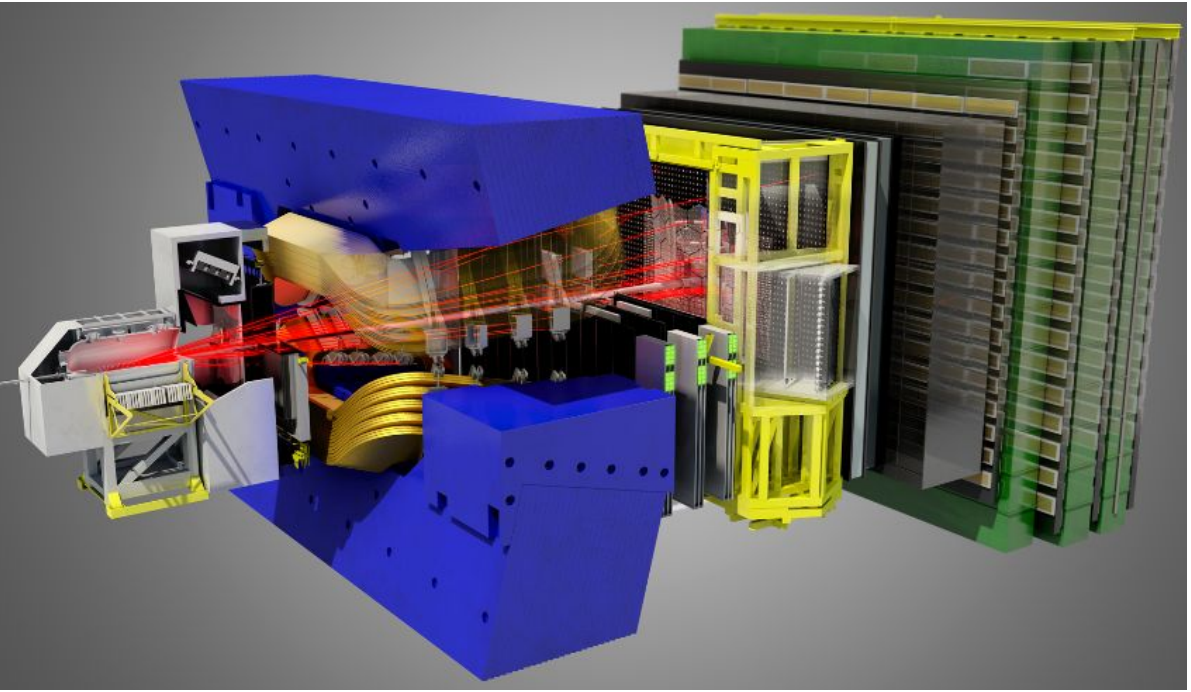
- Precision measurements heavy flavor physics
- Core physics: CPV and rare decays
- Much more: spectroscopy, QCD, heavy ions…



- > 900 authors and > 40 nationalities
- 87 institutes from 18 countries

JINST 3 (2008) S08005

LHCb detector at LHC



$\Delta p / p = 0.5 - 1.0\%$
$\Delta IP = (15 + 29/p_T[GeV])\ \mu m$

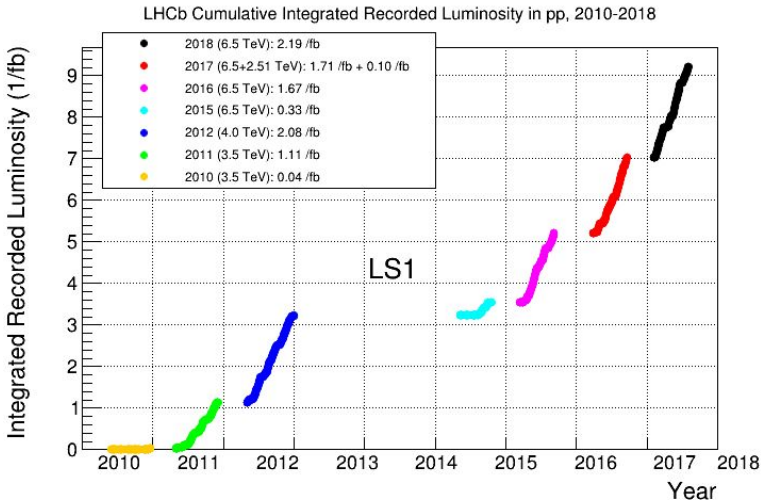
$\Delta E/E_{ECAL} = 1\% + 10\% / \sqrt{(E[GeV])}$

Electron ID ~90% for ~5% e→h mis-id probability

Kaon ID ~ 95 % for ~ 5 % π→K mis-id probability

Muon ID ~ 97% for 1-3% π→μ mis-id probability

LHCb dataset



Total recorded luminosity ~9 fb^{-1}:

- Run 1 (2010-2012) ~ 3 fb^{-1}
- Run 2 (2015-2018) ~ 6 fb^{-1}

All b-hadron species!

- B_s: $\frac{f_s}{f_d+f_u} = 0.122 \pm 0.006$ *
- Λ_b: $\frac{f_{\Lambda_b}}{f_d+f_u} = 0.259 \pm 0.018$

average over $p_T \in [4, 25]$ GeV and $\eta \in [2, 5]$ in pp collisions at 13 TeV [PRD100(2019)031102] and more: Ξ_b, Ω_b, B_c, B^* ...

*combination of LHCb results ongoing

$\sigma^{13TeV}(pp \to B^{\pm}X)/\sigma^{7TeV}(pp \to B^{\pm}X) = 2.02 \pm 0.02 \pm 0.12$
[JHEP 1712 (2017) 026] → almost x4 b-hadrons in Run 2

LHCb results

CPV

RD

SL

Charm

Spectroscopy

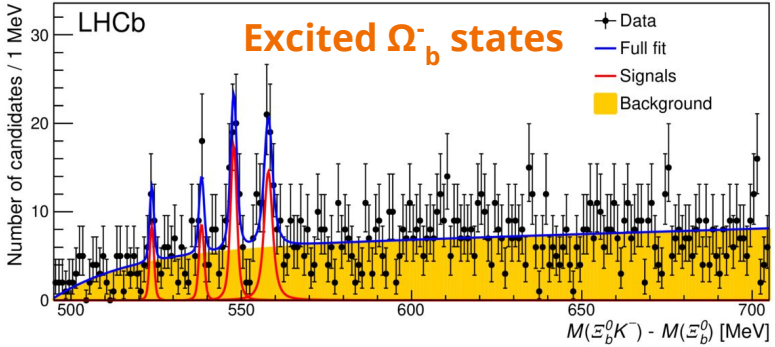
QCD, EW & exotica

Heavy ions

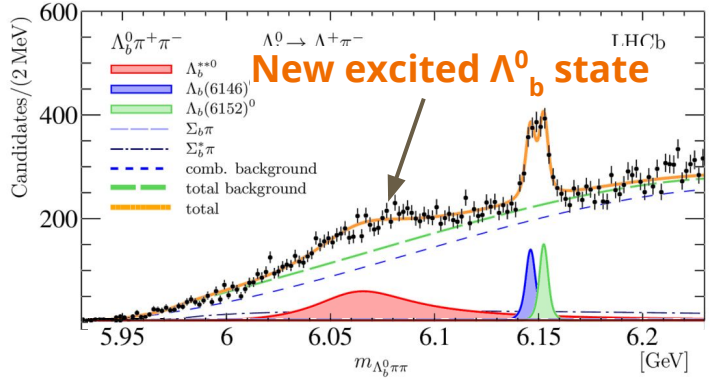
NEW 2020

A b-hadron factory

PRL 124 (2020) 082002

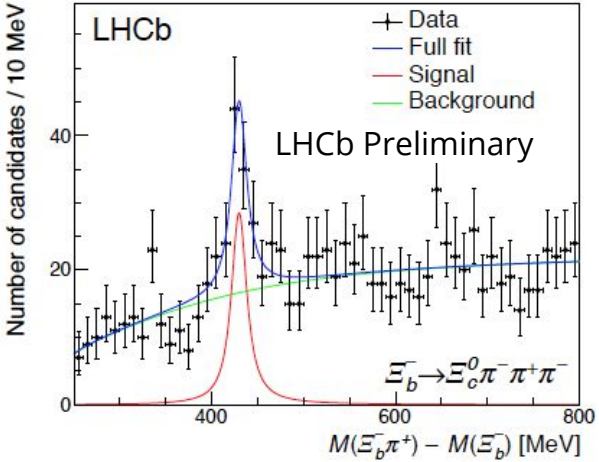


JHEP 06 (2020) 136

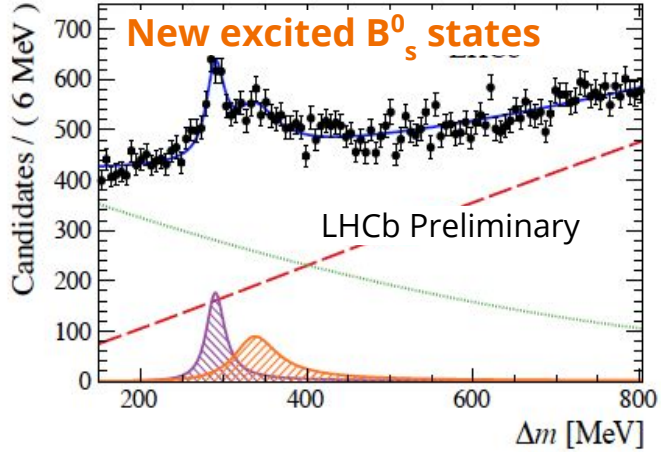


New excited Ξ^0_b state

LHCb-PAPER-2020-032



LHCb-PAPER-2020-026

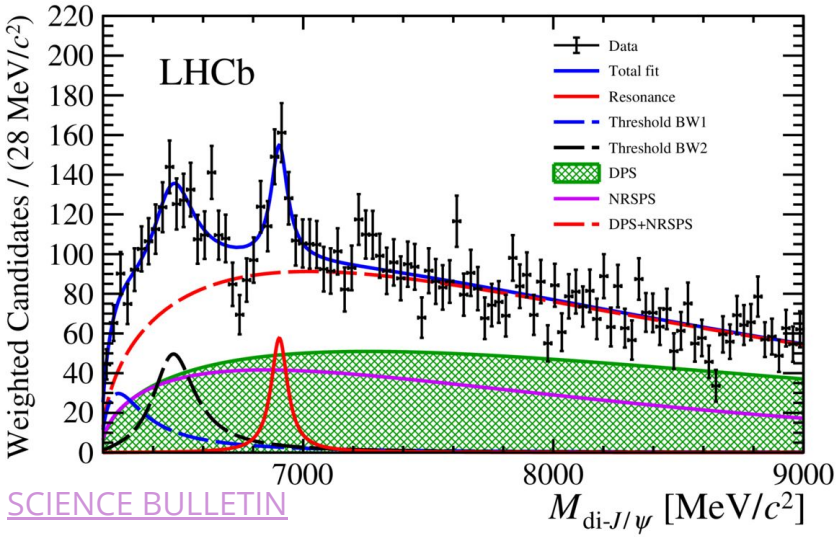


See talk by D. Craik for details and further studies

NEW 2020

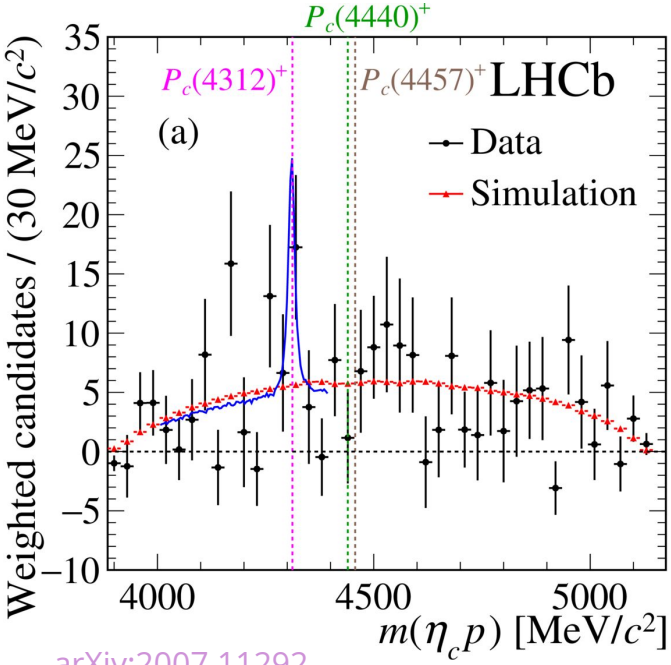
An exotic hadron factory!

Four-charm states in di-J/ψ spectrum?



SCIENCE BULLETIN

Observation of $\Lambda_b \to \eta_c p K^-$ and search for $P_c^+ \to \eta_c p$



arXiv:2007.11292

See talk by M. Wang for details and further searches: X(2900), X(4740), P_{cs}

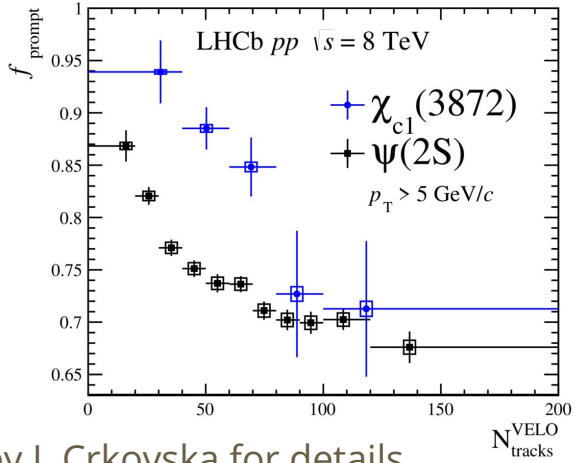
arXiv:2009.06619

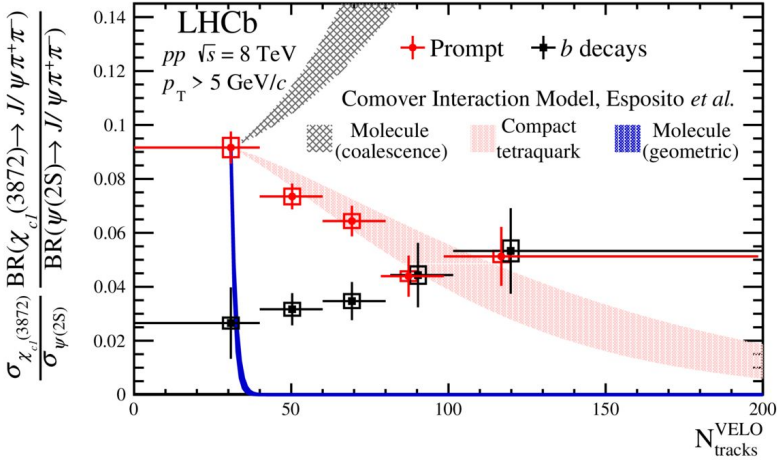
Multiplicity-dependent ψ(2S) & χ_{c1} production

Production of ψ(2S) and χ_{c1}(3872) studied in 8 TeV pp collisions, exploiting techniques from Heavy Ion physics

NEW 2020

- decrease of prompt fraction and ratio χ_{c1}(3872)/ψ(2S) with multiplicity

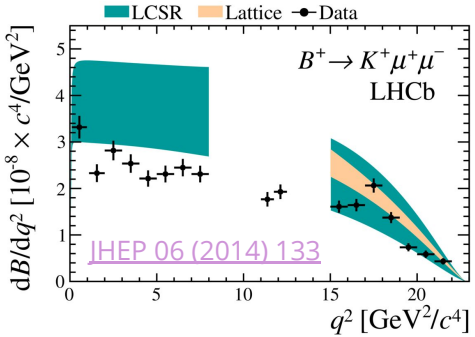




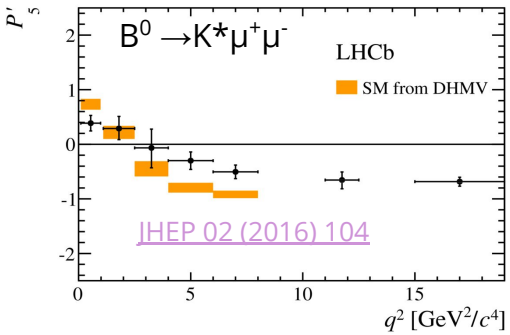
See talk by J. Crkovska for details

Intriguing deviations in rare B decays

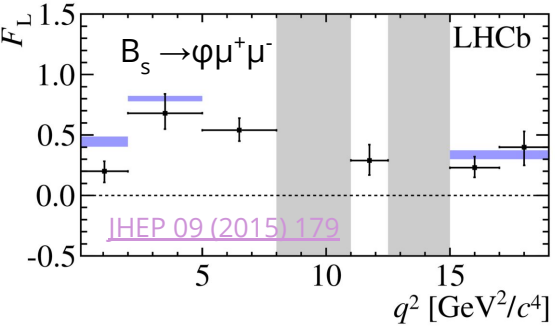
Differential BR and angular distributions



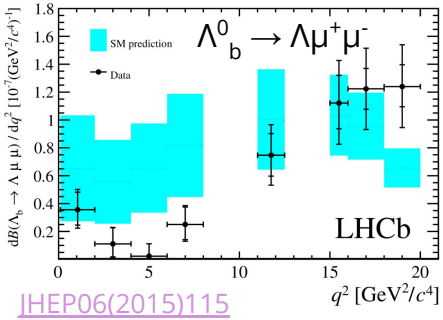
JHEP 06 (2014) 133



JHEP 02 (2016) 104

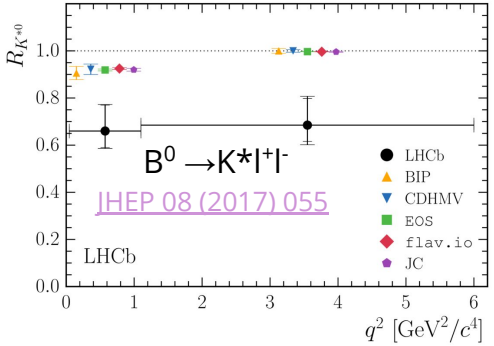


JHEP 09 (2015) 179

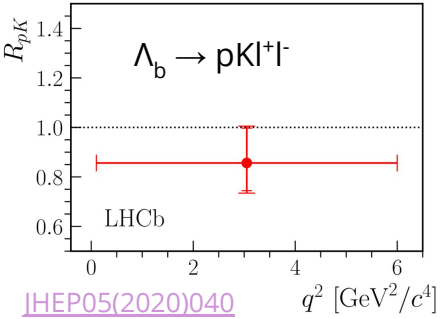


JHEP06(2015)115

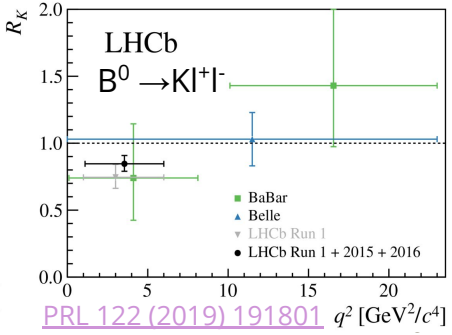
Lepton Universality tests



JHEP 08 (2017) 055



JHEP05(2020)040

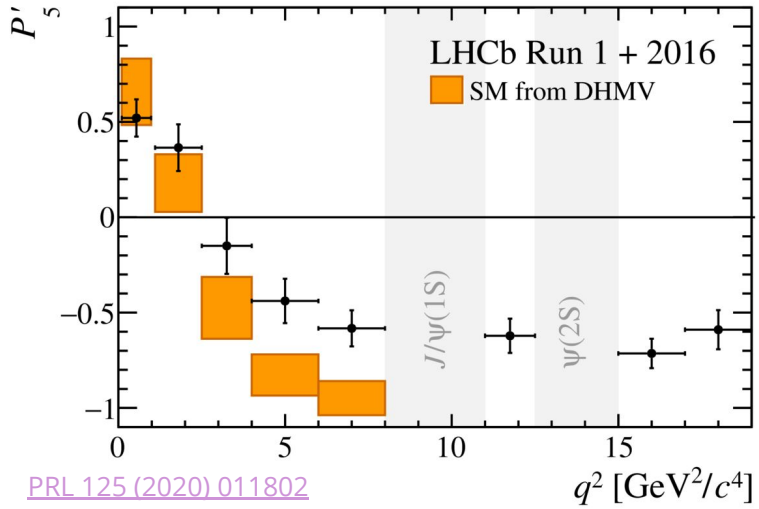


PRL 122 (2019) 191801

Angular analyses of $B \to K^* ll$

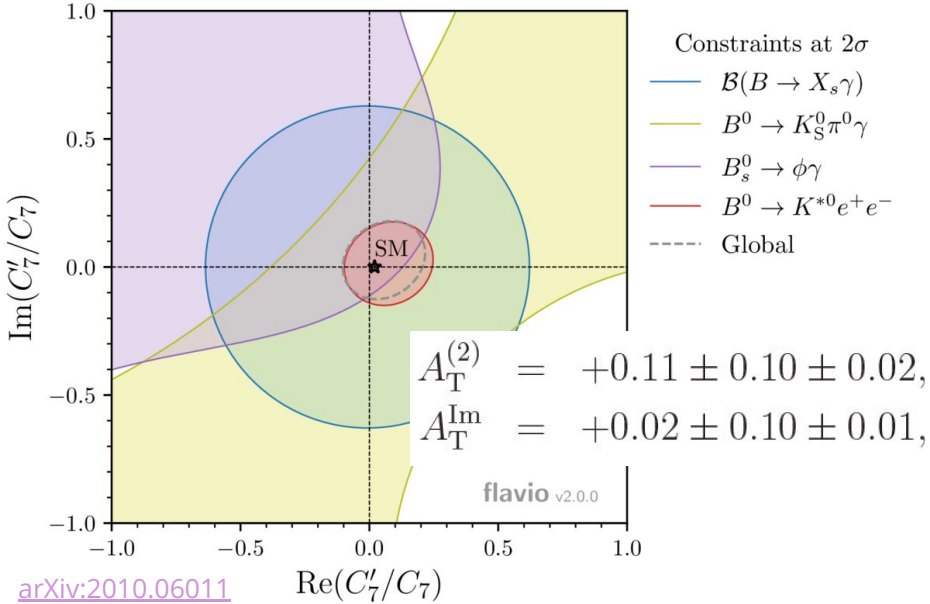
NEW 2020

New $B^0 \to K^* \mu^+ \mu^-$ results: tension with SM 3.3σ



PRL 125 (2020) 011802

$B^0 \to K^* e^+ e^-$ low q^2: strong constraints on C'_7



arXiv:2010.06011

See talk by D. Gerich for new results in B^+!

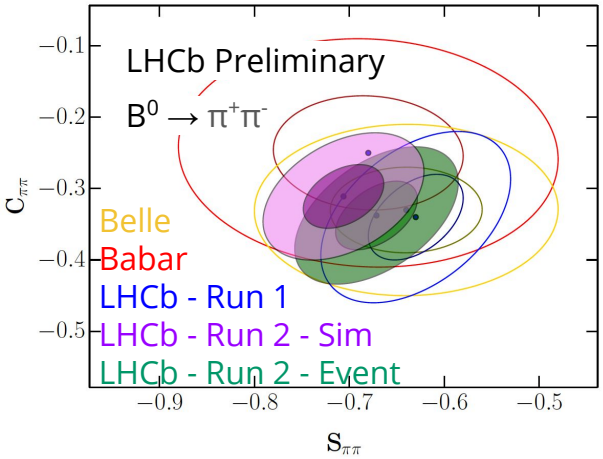
1st observation of TD-CPV in B_s decays

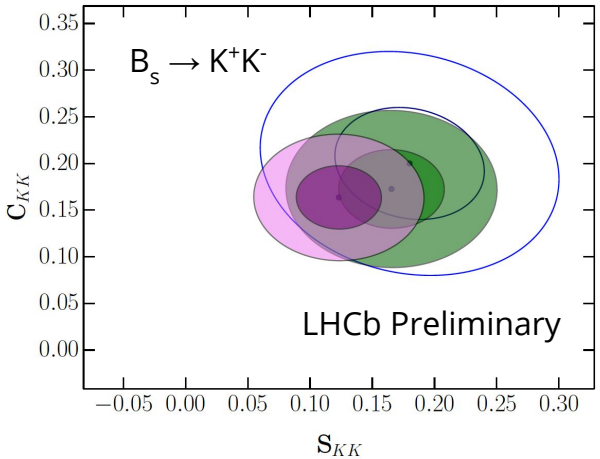
PRD98(2018)032004 826
LHCb-PAPER-2020-029

NEW 2020

New Run 2 analysis using 2.1 fb^{-1} and combination with Run 1 results

$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} = \frac{-C_f \cos(\Delta m_{d,s} t) + S_f \sin(\Delta m_{d,s} t)}{\cosh\left(\frac{\Delta\Gamma_{d,s}}{2}t\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_{d,s}}{2}t\right)}$$





LHCb Preliminary

$$\begin{aligned} C_{\pi\pi} &= -0.320 \pm 0.038 \\ S_{\pi\pi} &= -0.672 \pm 0.034 \\ C_{KK} &= 0.172 \pm 0.031 \\ S_{KK} &= 0.139 \pm 0.032 \\ \mathcal{A}^{\Delta\Gamma}_{KK} &= -0.897 \pm 0.087 \end{aligned}$$

$(C_{KK}, S_{KK}) \neq (0, 0)$ at 6.7σ

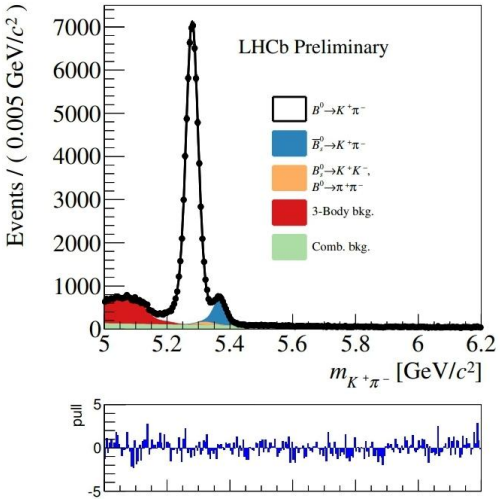
See talk by M. Torres for details and more results

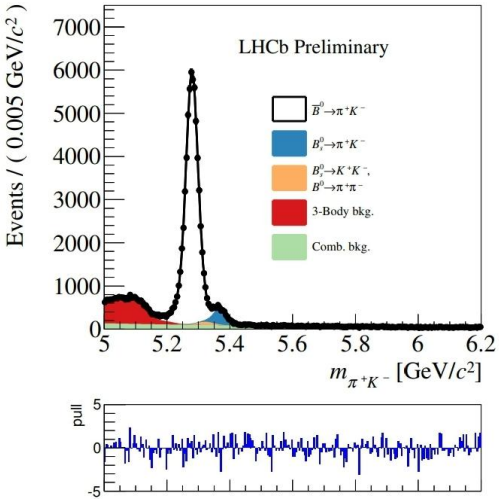
Direct CPV in $B_{(s)} \to K^+\pi^-$

PRD98(2018)032004 826
LHCb-PAPER-2020-029

NEW 2020

Measurement of A_{CP} in $B_{(s)} \to K\pi$ and relation as test of the SM





$$A_{CP}^{B^0} = -0.0831 \pm 0.0034$$
$$A_{CP}^{B_s^0} = 0.225 \pm 0.012$$

Most precise measurement from single experiment

$$\Delta = \frac{A_{CP}^{B^0}}{A_{CP}^{B_s^0}} + \frac{\mathcal{B}(B_s^0 \to \pi^+K^-)}{\mathcal{B}(B^0 \to K^+\pi^-)}\frac{\Gamma_s}{\Gamma_d} = 0$$

$$\Delta = -0.085 \pm 0.025 \pm 0.035$$

Comparible with 0 at 2σ

What about B^+ mode? See talk by W. Parker with new results!

NEW 2020

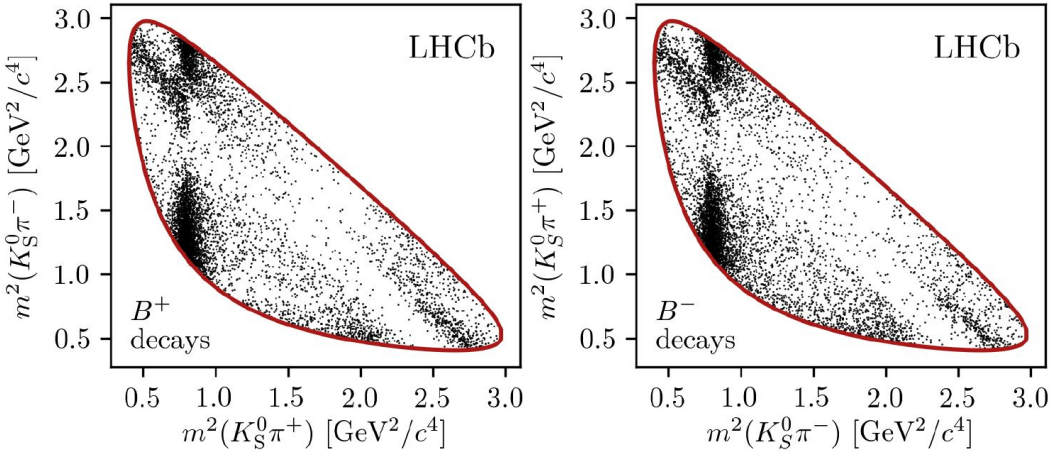
New constraints on γ

Less well-known angle Unitarity Triangle (δγ ~ 5°)

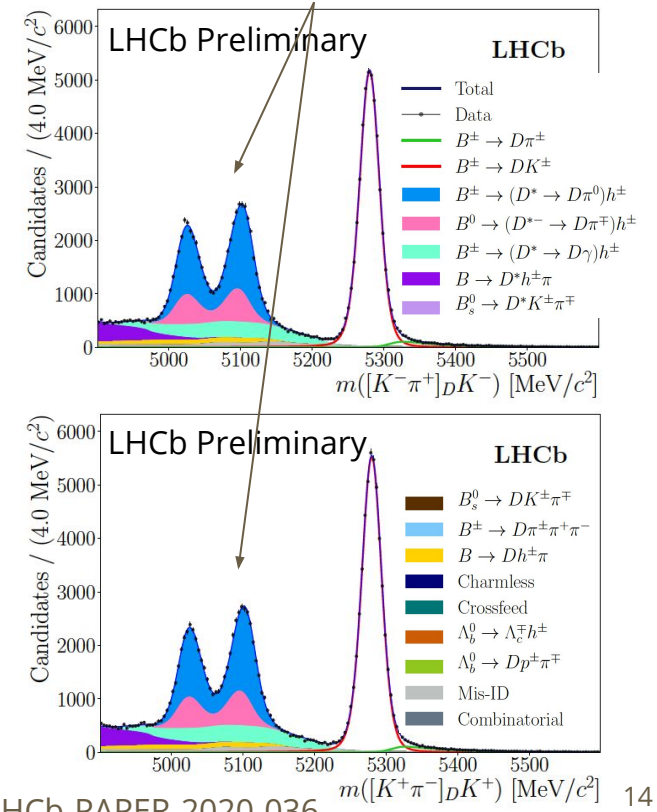
arXiv:2010.08483

$B^{\pm} \to Dh^{\pm}$, $D \to K_s h^+ h^-$

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



$B^{\pm} \to D^{(*)}h^{\pm}$, $D^* \to D\pi^0/\gamma$, $D \to h^+h^-$



LHCb-PAPER-2020-036

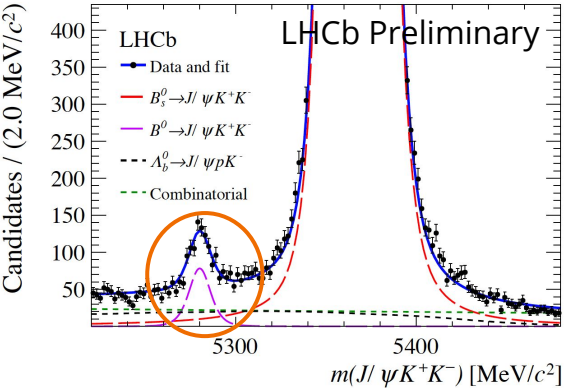
See talk by P. d'Argent for details, more results and new LHCb combination

Suppressed decays

NEW 2020

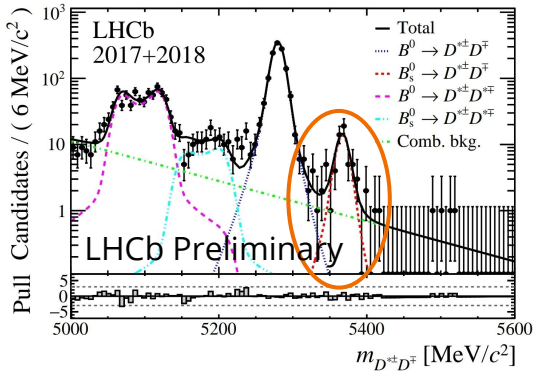
Searches for suppressed counterparts of well known decays

LHCb-PAPER-2020-033



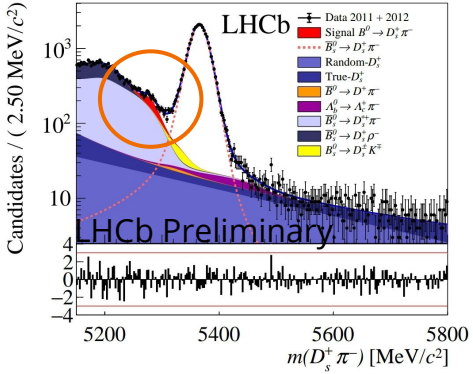
$BR(B^0 \to J/\psi\varphi) < 1.1 \times 10^{-7}$ @90% CL

LHCb-PAPER-2020-037



$$\frac{\mathcal{B}(B_s^0 \to D^{*\pm}D^{\mp})}{\mathcal{B}(B^0 \to D^{*\pm}D^{\mp})} = 0.137 \pm 0.017(\text{stat.}) \pm 0.002(\text{syst.}) \pm 0.006(f_s/f_d)$$

arXiv:2010.11986



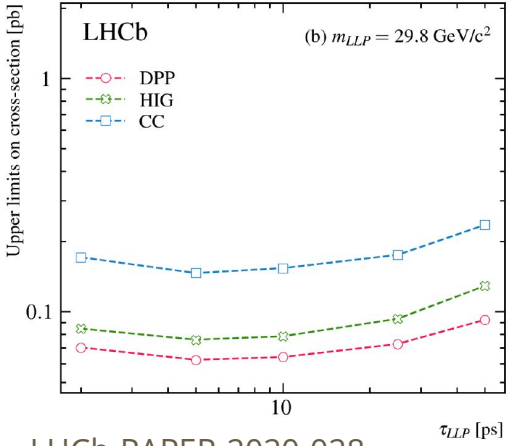
$$\mathcal{B}(B^0 \to D_s^+\pi^-) = (19.4 \pm 1.8 \pm 1.3 \pm 1.2) \times 10^{-6}$$

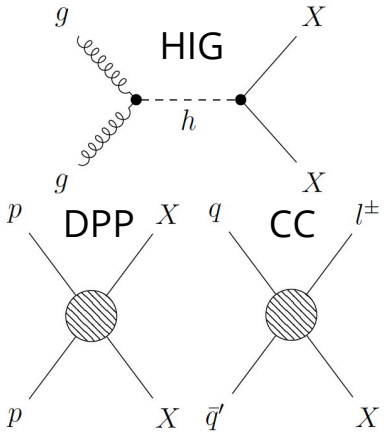
Search for New Exotic states

NEW 2020

Long-lived particles X → eμν

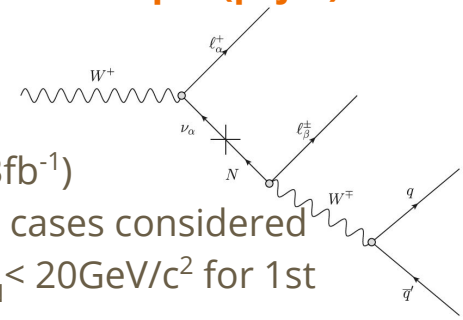
- Run 2 data (5.1fb^{-1})
- m∈[7, 50] GeV/c^2, τ∈[2, 50] ps



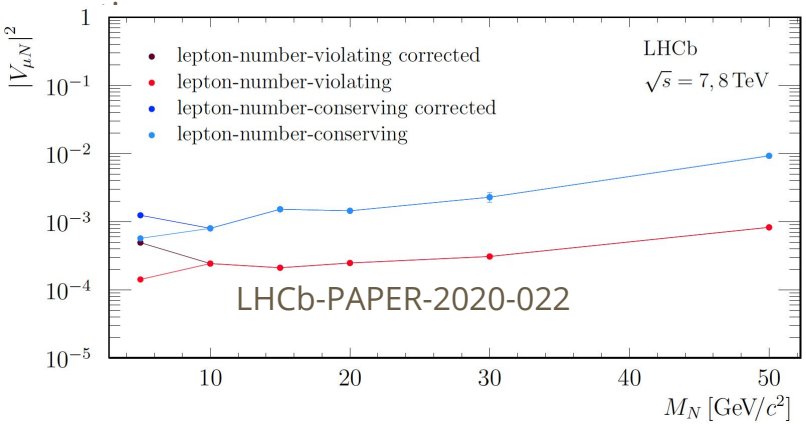


LHCb-PAPER-2020-028

Heavy Neutral Leptons in W → μ$^+$N(μ$^\pm$ jet)

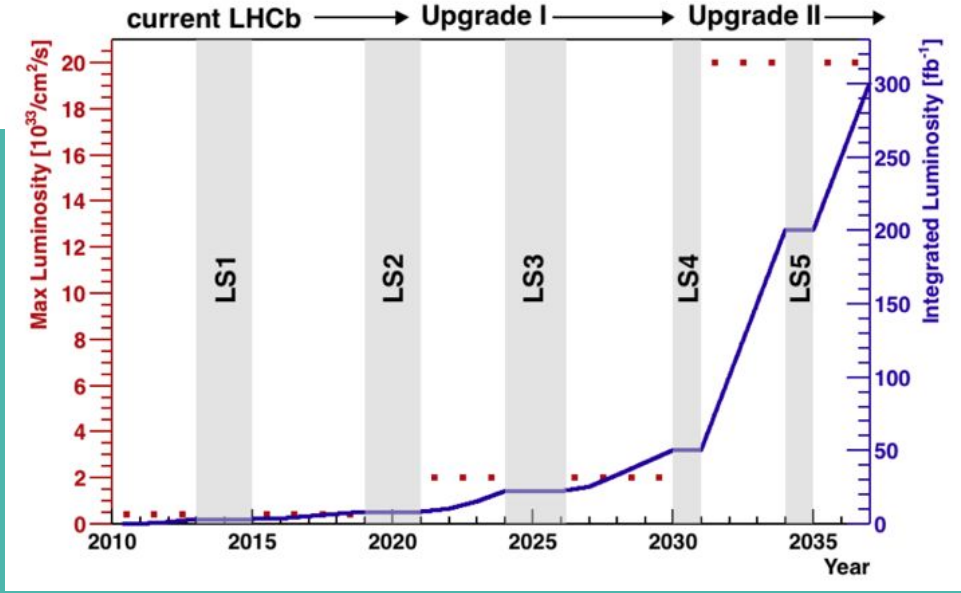


- Run 1 LHCb data (3fb^{-1})
- Pompt LN and LNV cases considered
- μμjet probed at M_N< 20GeV/c^2 for 1st

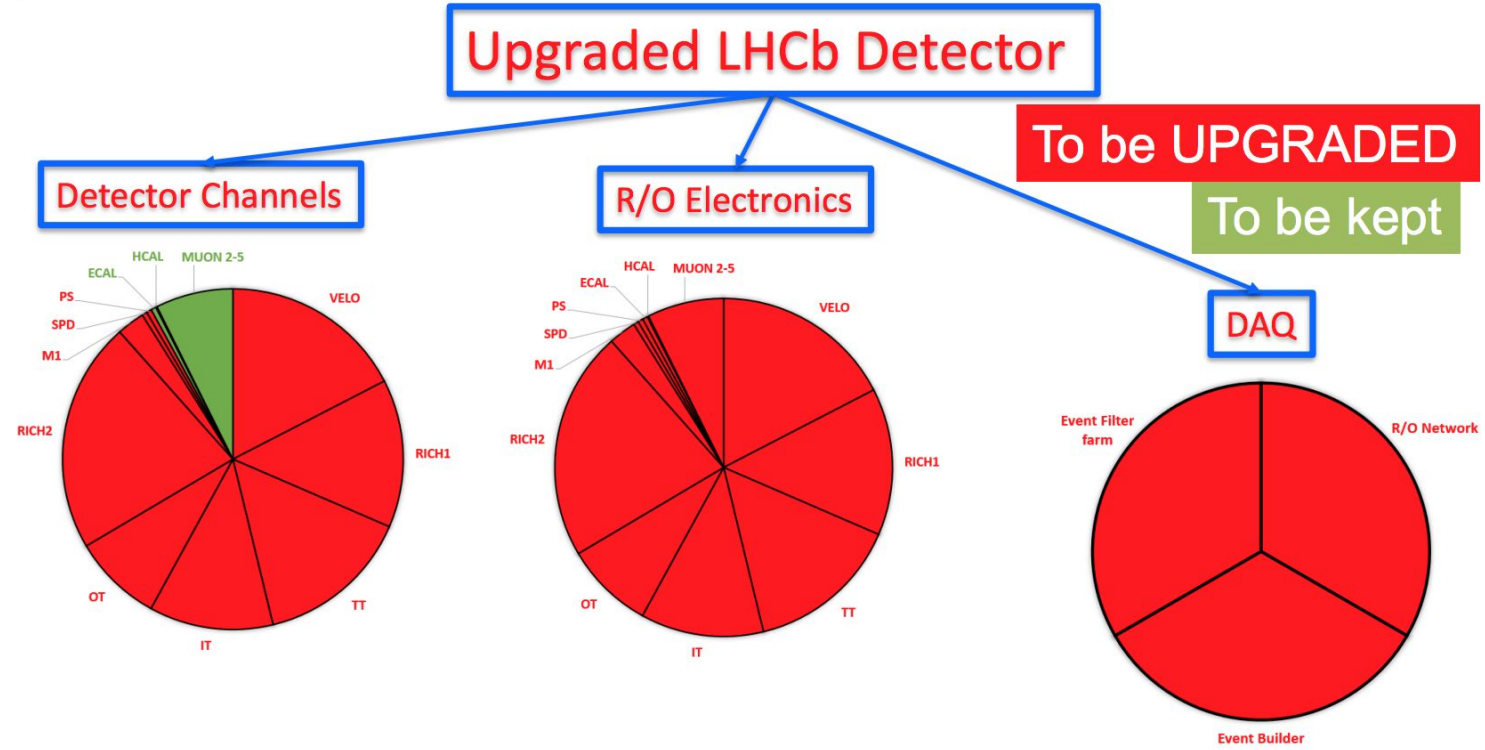


LHCb-PAPER-2020-022

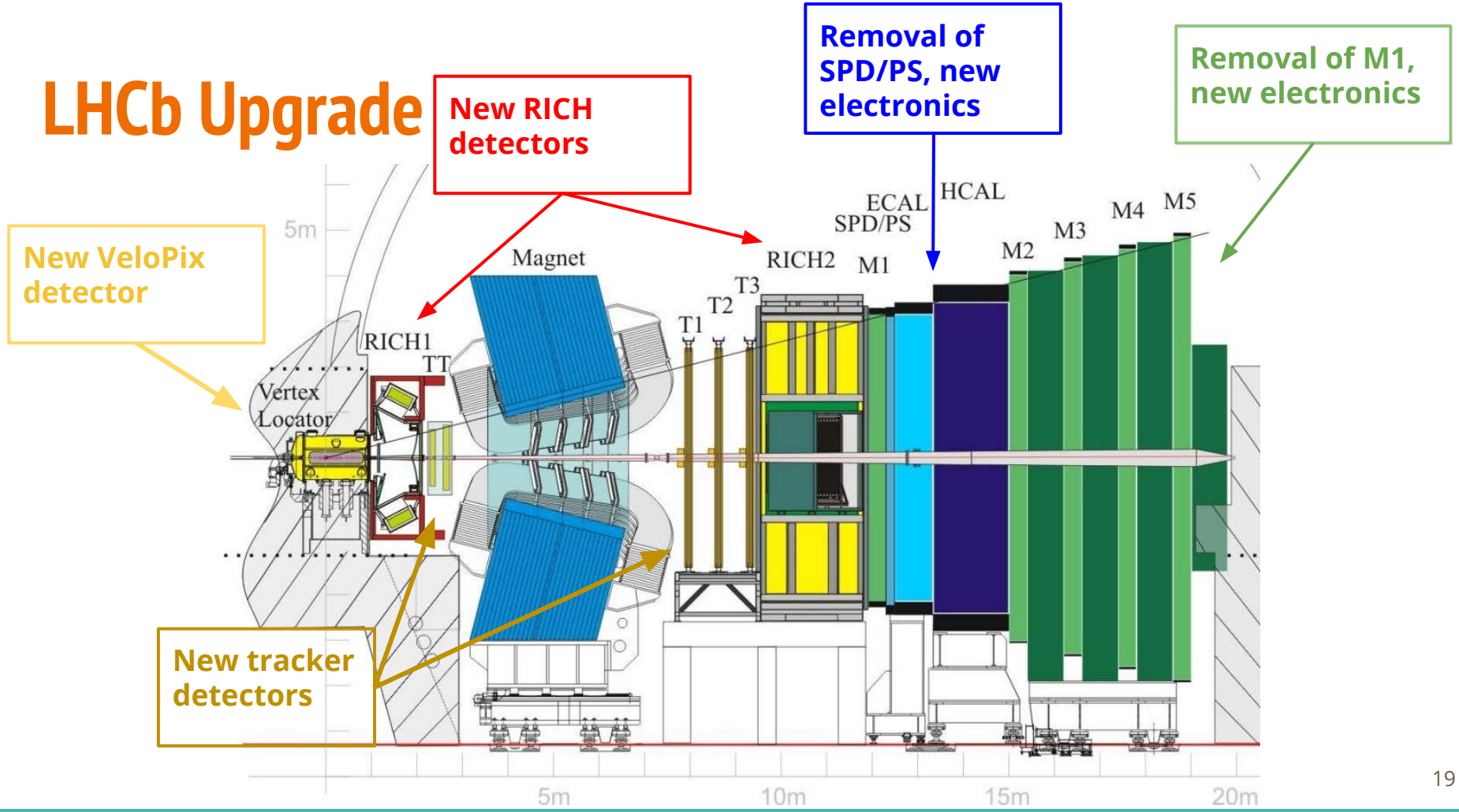
LHCb prospects



LHCb Upgrade: a quasi-new detector



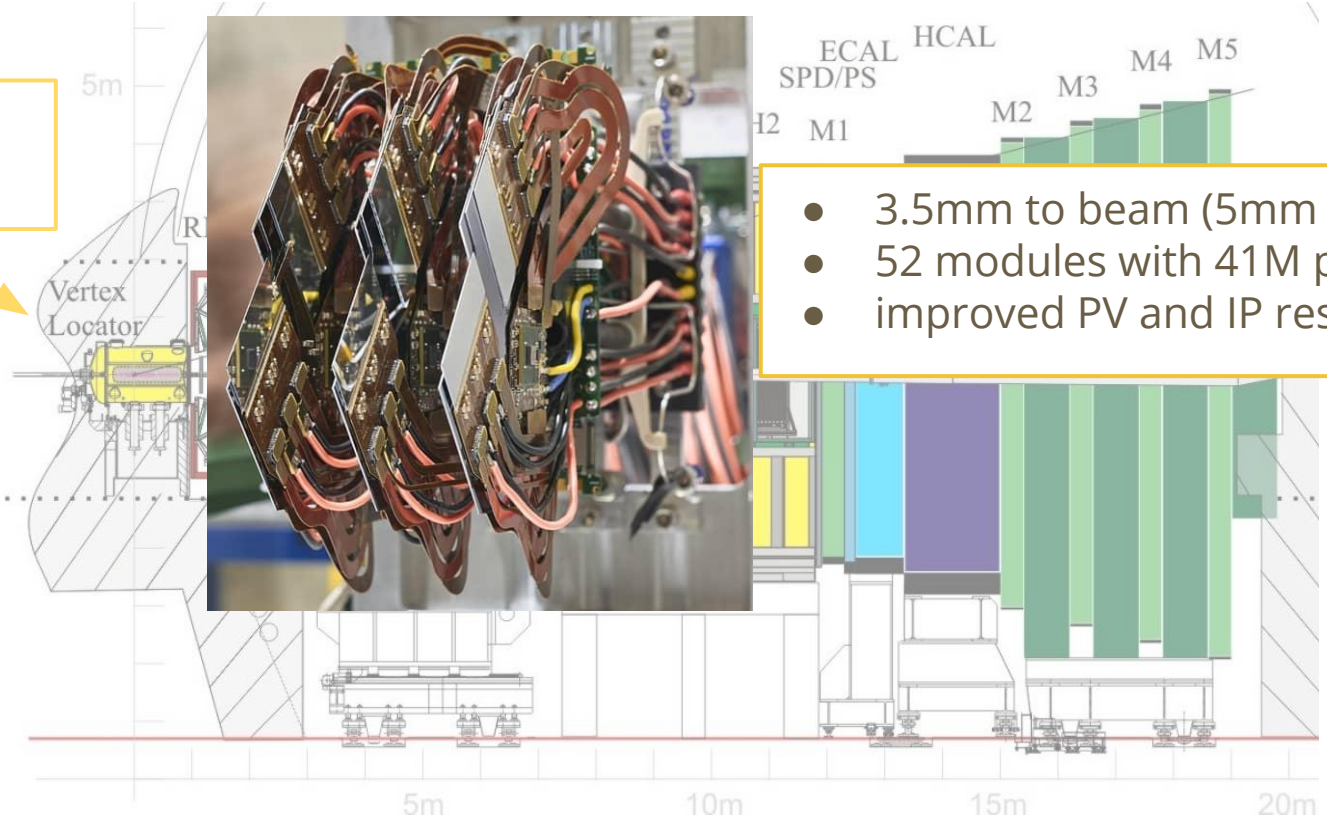
LHCb Upgrade



LHCb Upgrade

CERN-LHCC-2013-021

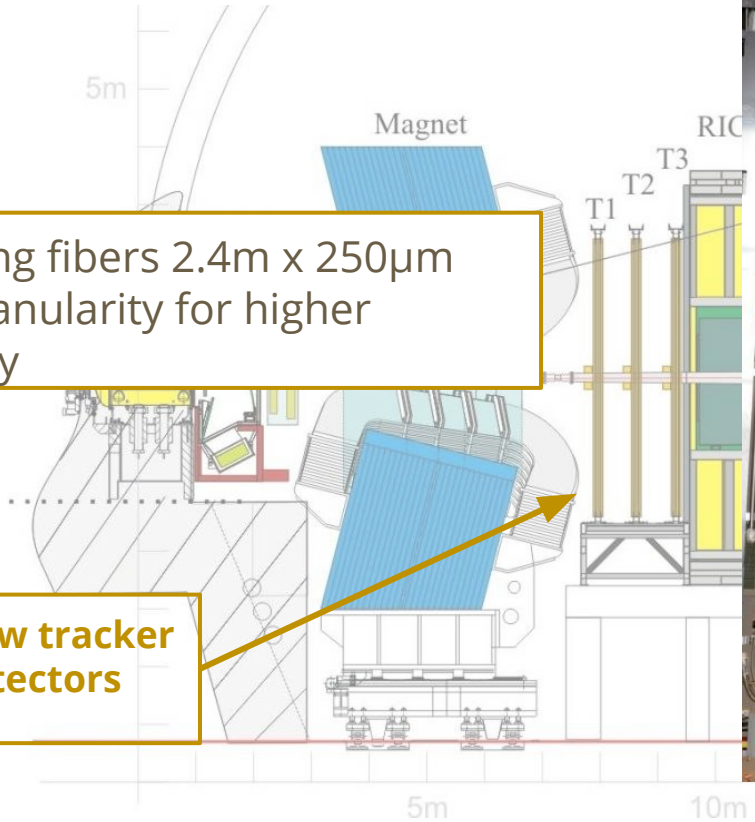
New VeloPix detector



- 3.5mm to beam (5mm Run1/2)
- 52 modules with 41M pixels
- improved PV and IP resolutions

CERN-LHCC-2014-001

LHCb Upgrade



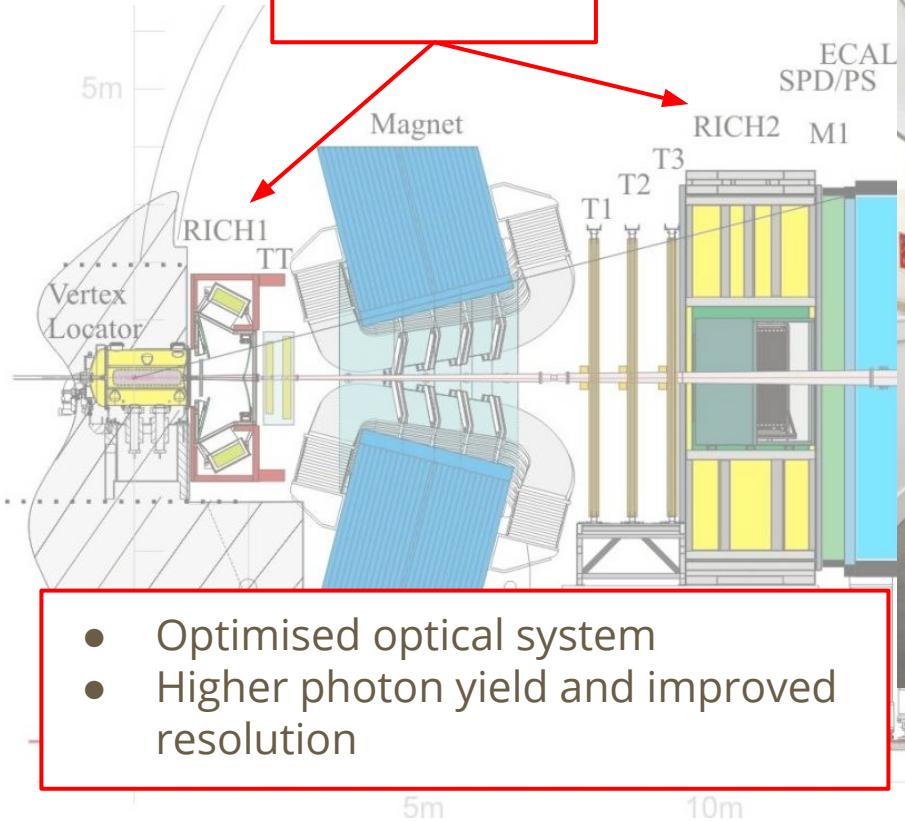
- Scintillating fibers 2.4m x 250μm
- higher granularity for higher occupancy

New tracker detectors

LHCb Upgrade

CERN-LHCC-2013-022

New RICH detectors



- Optimised optical system
- Higher photon yield and improved resolution

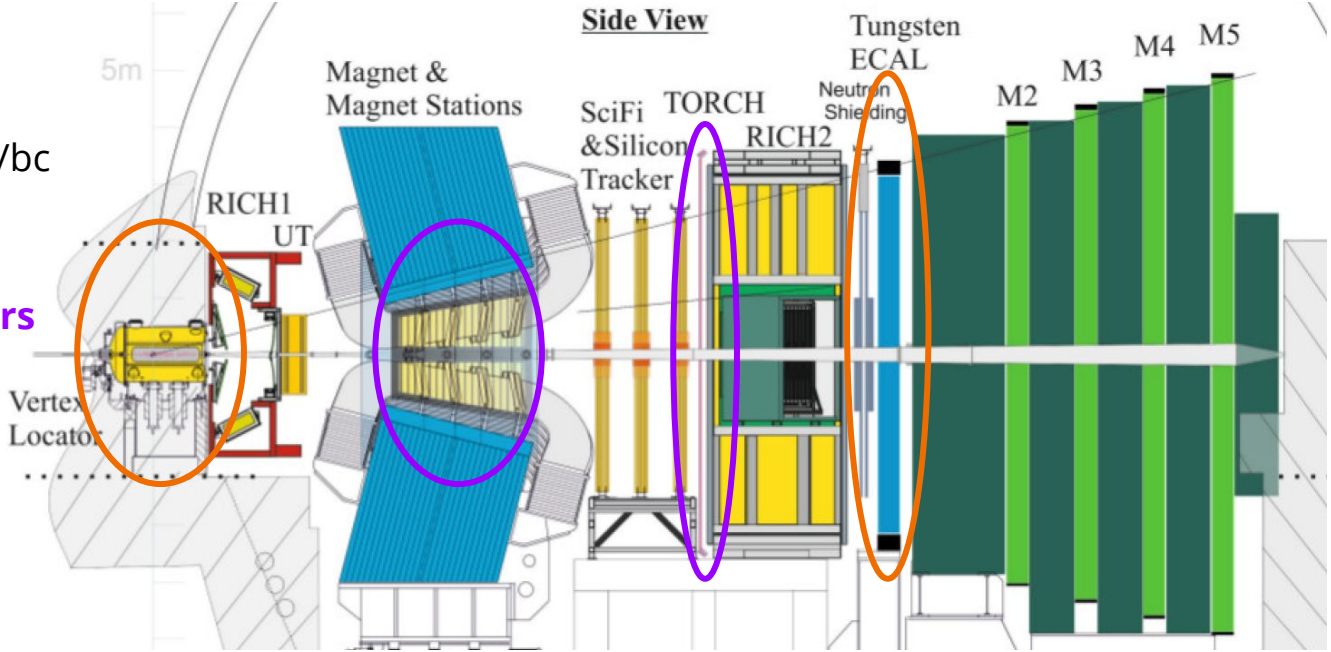
LHCb Upgrade II

CERN-LHCC-2017-003

To be installed in LS3+4: new sub-detectors and technology updates (timing)

Timing:
~50 collisions/bc

New detectors



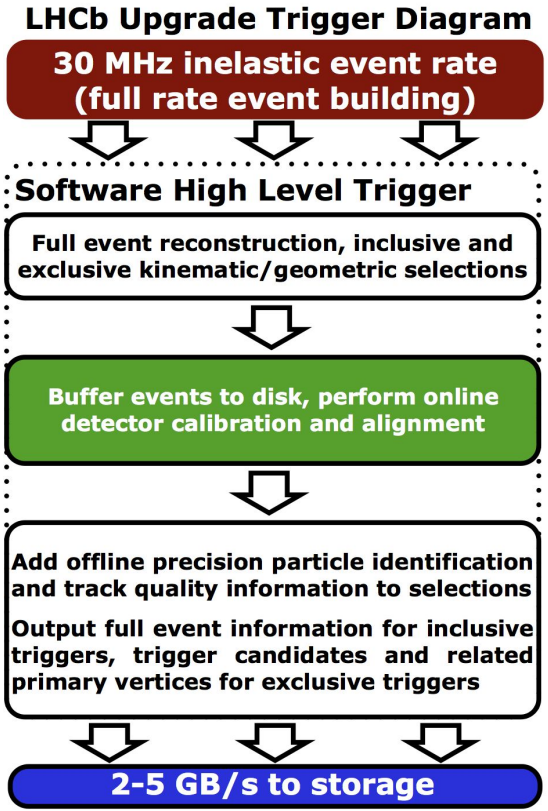
Trigger in Run 3 and beyond

Remove limitations of hardware trigger:

- remove tight p_T and E_T requirements
- x2 yields for fully hadronic decays

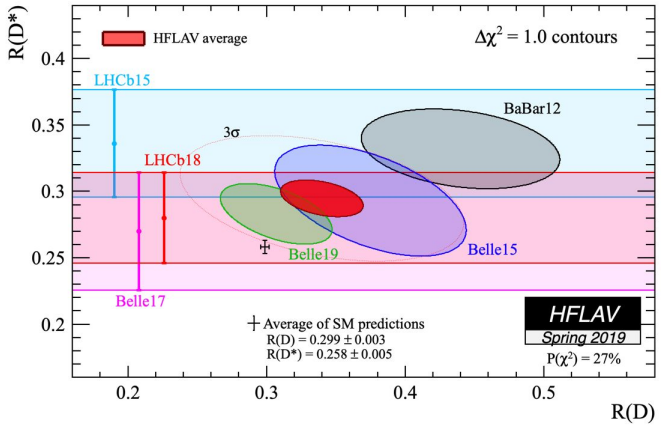
First level software trigger in GPUs:

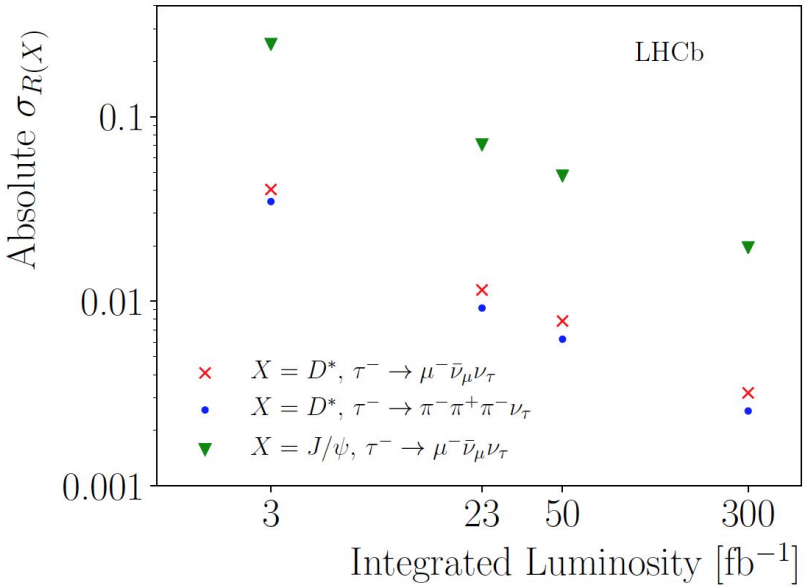
- increase complexity of tracking algorithms
- better performance at higher throughput



arXiv:1808.08865

Prospects for LU tests in b → clv decays





R(D)-R(D*) ongoing with current dataset

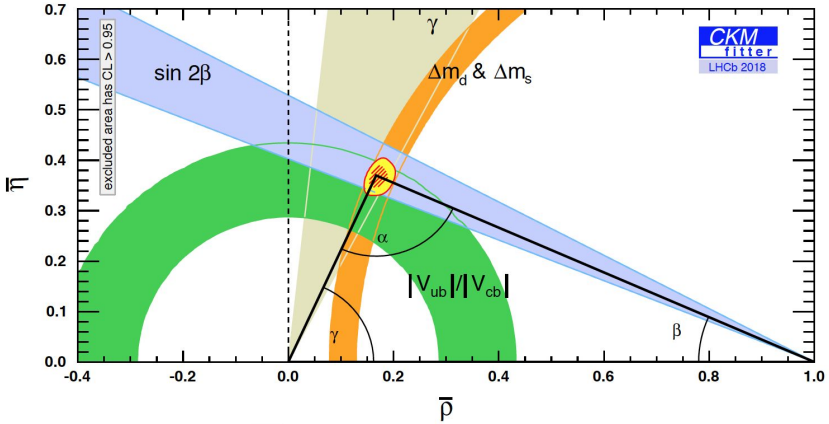
Also measurements with other b hadrons:

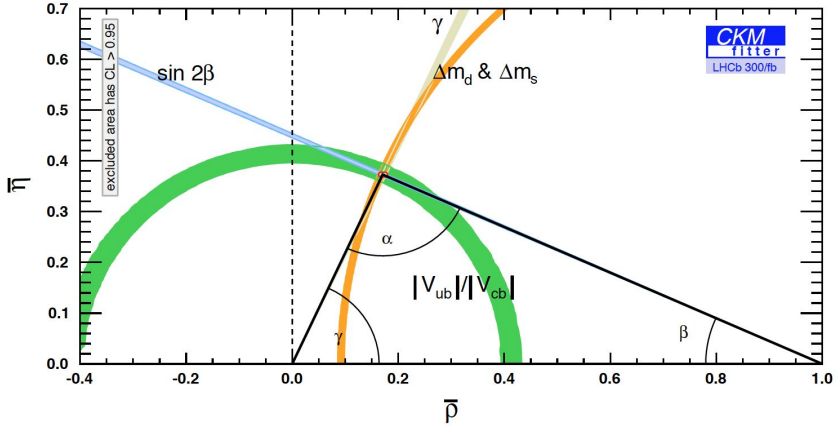
- $\sigma_{R(Ds)}$ < 6% (2.5%) and $R(D^{*(*)}{}_s)$
- $\sigma_{R(\Lambda c)}$ < 4% (2.5%) and R(pp) (b → ulν)

arXiv:1808.08865

Prospects for CKM measurements

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi \phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
$a_{\rm sl}^s$	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–



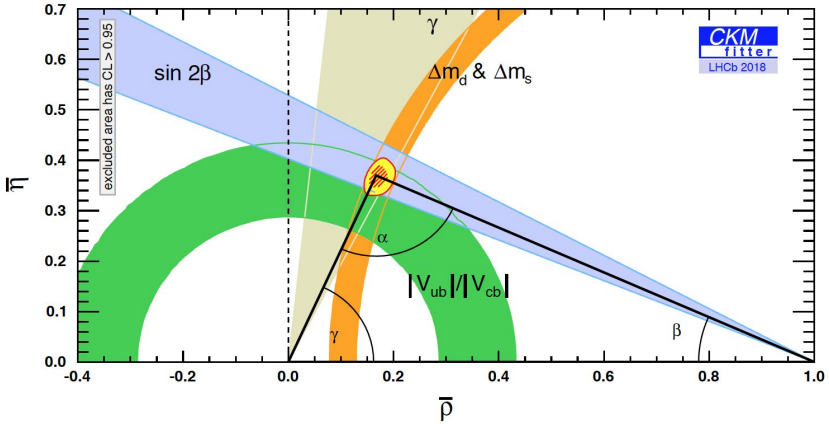


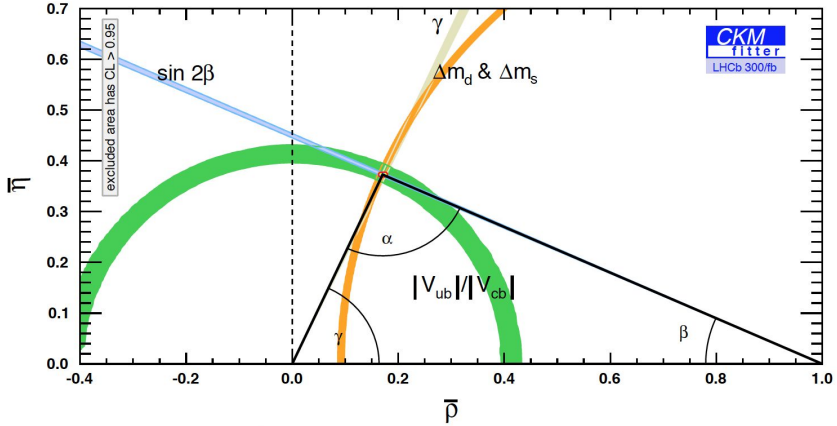
arXiv:1808.08865

Prospects for CKM measurements

Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
γ, with $B_s^0 \to D_s^+ K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0 \to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0 \to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0 \to D_s^+ D$					–
$\phi_s^{s\bar{s}s}$, with $B_s^0 \to \phi\phi$					Under study [611]
a_{sl}^s					–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$					–

Further measurement of $|v_{ub}|/|V_{cb}|$ from $B_S \to K^- \mu^+ \nu$?
See talk by B. Khanji!

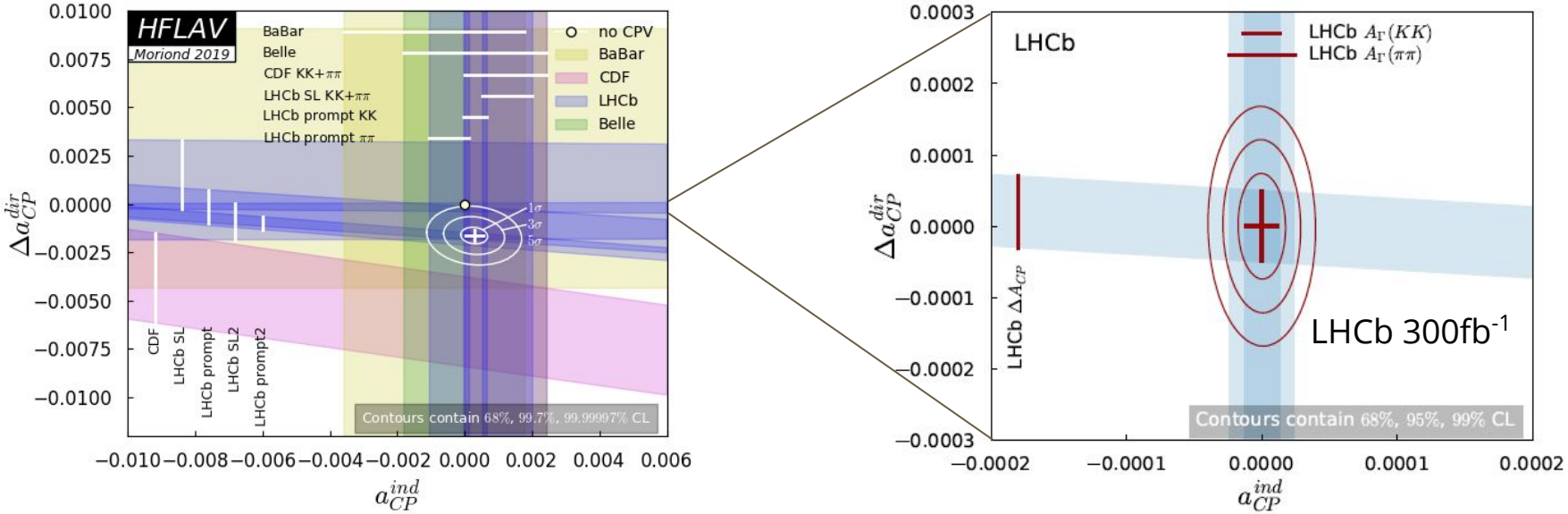




arXiv:1808.08865

Prospects for Charm physics

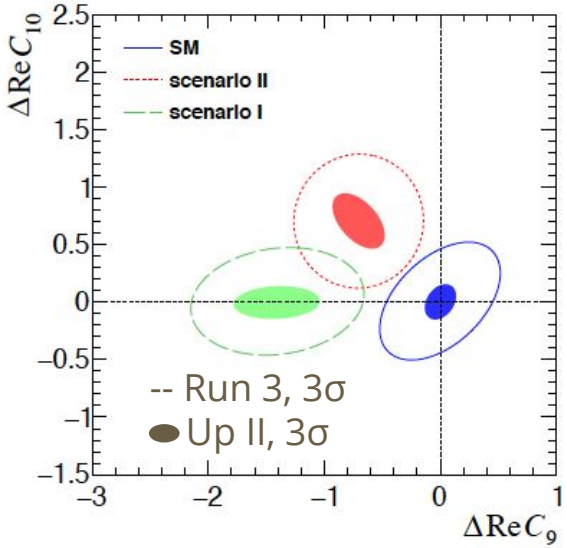
Large benefit from fully software trigger



arXiv:1808.08865

Prospects for Rare Decays

		Run 3	Run 4	Upgrade II
R_X precision	$9\,\mathrm{fb}^{-1}$	$23\,\mathrm{fb}^{-1}$	$50\,\mathrm{fb}^{-1}$	$300\,\mathrm{fb}^{-1}$
R_K	0.043	0.025	0.017	0.007
$R_{K^{*0}}$	0.052	0.031	0.020	0.008
R_ϕ	0.130	0.076	0.050	0.020
R_{pK}	0.105	0.061	0.041	0.016
R_π	0.302	0.176	0.117	0.047



See talk by M. Santimaria on Friday

Conclusions

LHCb is not only a b-factory (huge production of $B^{0/+}$, B_s, Λ_b...) but also a general purpose detector in the forward region

Wealth of new results this year and fresh ones for this workshop → details and more exciting results in dedicated talks

LHCb is being (will be) upgraded to collect x30 larger dataset in Run 3-5

Theory input is critical for interpretation of our results and development of new measurements to fully exploit potential of our data

Conclusions

LHCb is not only a b-factory (huge production of $B^{0/+}$, B_s, Λ_b...) but also a general purpose detector in the forward region

Wealth of new results this year and fresh ones for this workshop → details and more exciting results in dedicated talks

LHCb is being (will be) upgraded to collect x30 larger dataset in Run 3-5

Theory input is critical for interpretation of our results and development of new measurements to fully exploit potential of our data

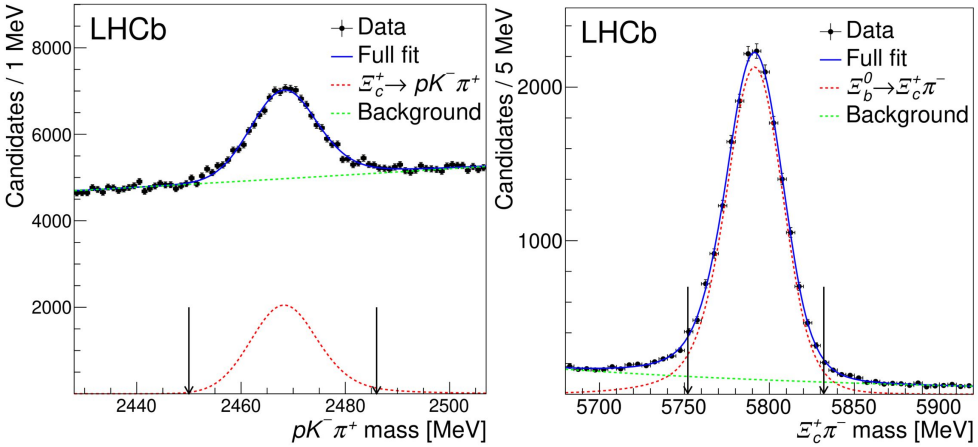
Looking forward to having lots of discussions in this workshop!

BACK-UP

Observation of excited Ω^-_b states

PRL 124 (2020) 082002

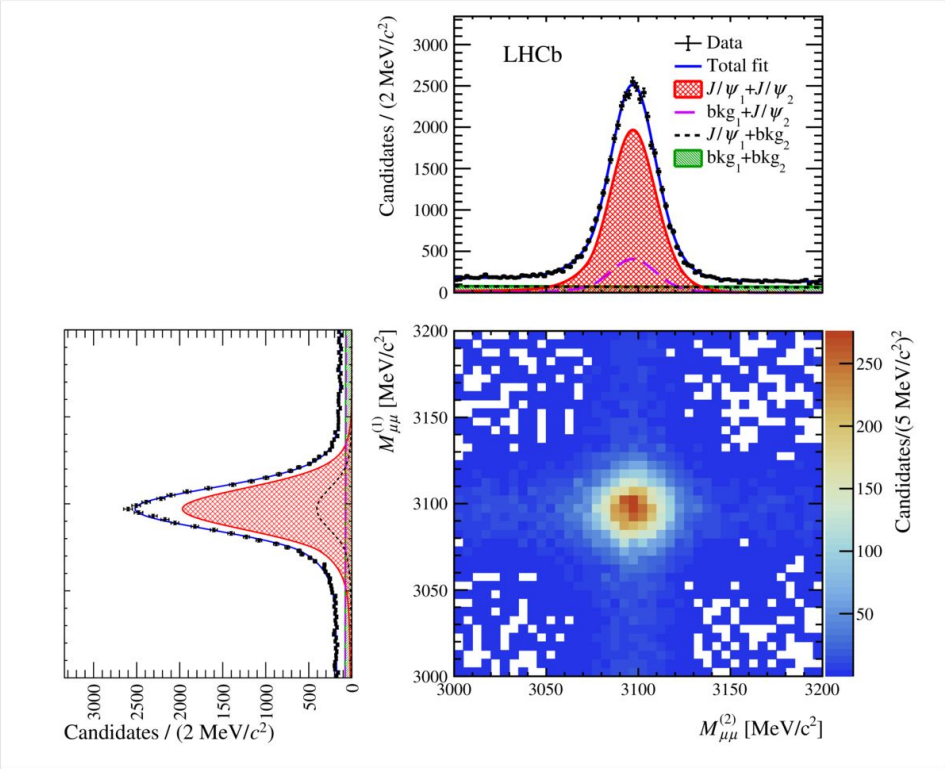
$\Omega_b \to \Xi^0_b K^-$ with $\Xi^0_b \to \Xi^+_c \pi^-$, $\Xi_c \to pK\pi$



Peak of δM [MeV]	Width [MeV]	Signal yield	Significances $[\sigma]$ Local	Global
523.74 ± 0.31	$0.00^{+0.7}_{-0.0}$	15^{+6}_{-5}	3.6	2.1
538.40 ± 0.28	$0.00^{+0.4}_{-0.0}$	18^{+6}_{-5}	3.7	2.6
547.81 ± 0.26	$0.47^{+0.6}_{-0.5}$	47^{+11}_{-10}	7.2	6.7
557.98 ± 0.35	$1.4^{+1.0}_{-0.8}$	57^{+14}_{-13}	7.0	6.2

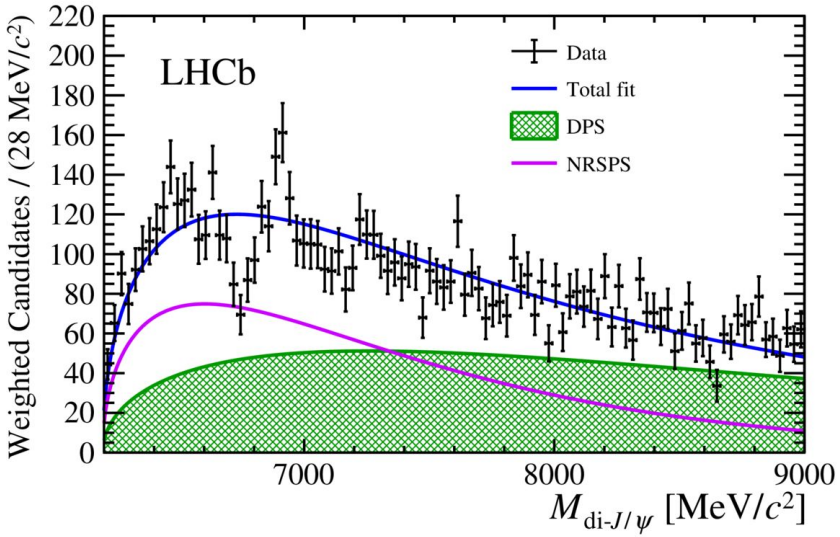
di-J/ψ candidates

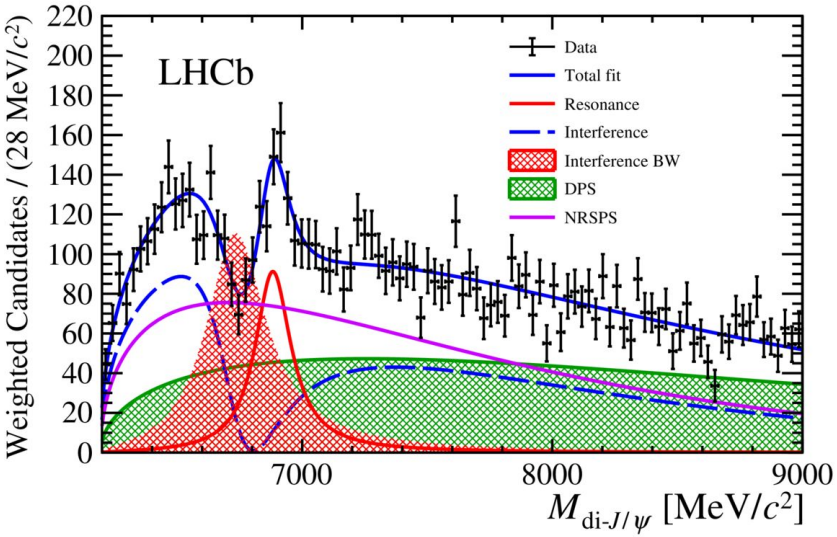
SCIENCE BULLETIN



Potential T_{cccc} candidates

SCIENCE BULLETIN





Angular analysis of $B \to K^* ll$

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^4(\Gamma+\bar{\Gamma})}{dq^2\,d\vec{\Omega}}\bigg|_{P} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K$$
$$+\tfrac{1}{4}(1-F_L)\sin^2\theta_K\cos 2\theta_l$$
$$-F_L\cos^2\theta_K\cos 2\theta_l + S_3\sin^2\theta_K\sin^2\theta_l\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_l\cos\phi + S_5\sin 2\theta_K\sin\theta_l\cos\phi$$
$$+\tfrac{4}{3}A_{FB}\sin^2\theta_K\cos\theta_l + S_7\sin 2\theta_K\sin\theta_l\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_l\sin\phi + S_9\sin^2\theta_K\sin^2\theta_l\sin 2\phi\Big],$$

Exploiting $b \to s e^+ e^-$ at very low q^2

arXiv:2010.06011

Angular coefficients $A_T^{(2)}$ and A_T^{Im} give access to C'_7:

$$\frac{1}{d(\Gamma+\bar{\Gamma})/dq^2}\frac{d^4(\Gamma+\bar{\Gamma})}{dq^2\, d\cos\theta_\ell\, d\cos\theta_K\, d\tilde{\phi}} =$$

$$= \frac{9}{16\pi}\Big[\frac{3}{4}(1-F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \left(\frac{1}{4}(1-F_L)\sin^2\theta_K - F_L\cos^2\theta_K\right)\cos 2\theta_\ell + \frac{1}{2}(1-F_L)\boxed{A_T^{(2)}}\sin^2\theta_K\sin^2\theta_\ell\cos 2\tilde{\phi} + (1-F_L)A_T^{Re}\sin^2\theta_K\cos\theta_\ell + \frac{1}{2}(1-F_L)\boxed{A_T^{Im}}\sin^2\theta_K\sin^2\theta_\ell\sin 2\tilde{\phi}\Big].$$

after folding Φ to reduce number of parameters

$$\boxed{A_T^{(2)}(q^2\to 0) = \frac{2\mathcal{R}e(\mathcal{C}_7\mathcal{C}_7'^*)}{|\mathcal{C}_7|^2+|\mathcal{C}_7'|^2}}$$

$$\boxed{A_T^{Im}(q^2\to 0) = \frac{2\mathcal{I}m(\mathcal{C}_7\mathcal{C}_7'^*)}{|\mathcal{C}_7|^2+|\mathcal{C}_7'|^2}}$$

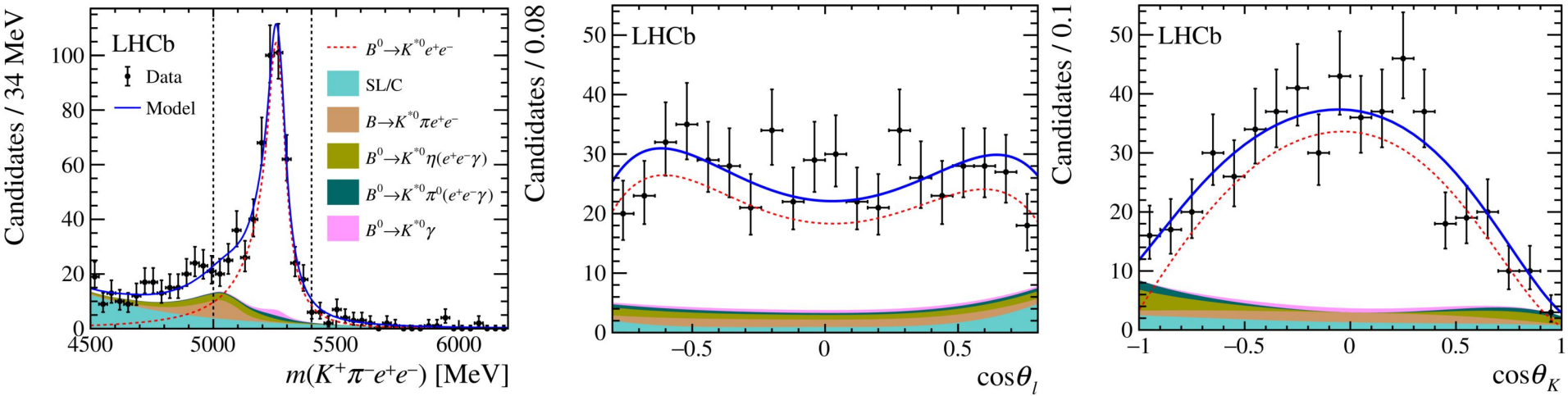
Pollution from $C_{9,10}$ when q^2 far from zero → analysis at very low q^2

- Run 1 analysis: $q^2 \in [0.002, 1.120]$ GeV^2/c^4
- Run 1+2: $q^2 \in [0.0008, 0.257]$ GeV^2/c^4

Exploiting $b \to s e^+ e^-$ at very low q^2

arXiv:2010.06011

Much cleaner selection achieved in new analysis



Mass shape, angular acceptance and model validated with $B \to K^* \gamma (\to e^+ e^-)$

Photon polarisation from $b \to s e^+ e^-$ low q^2

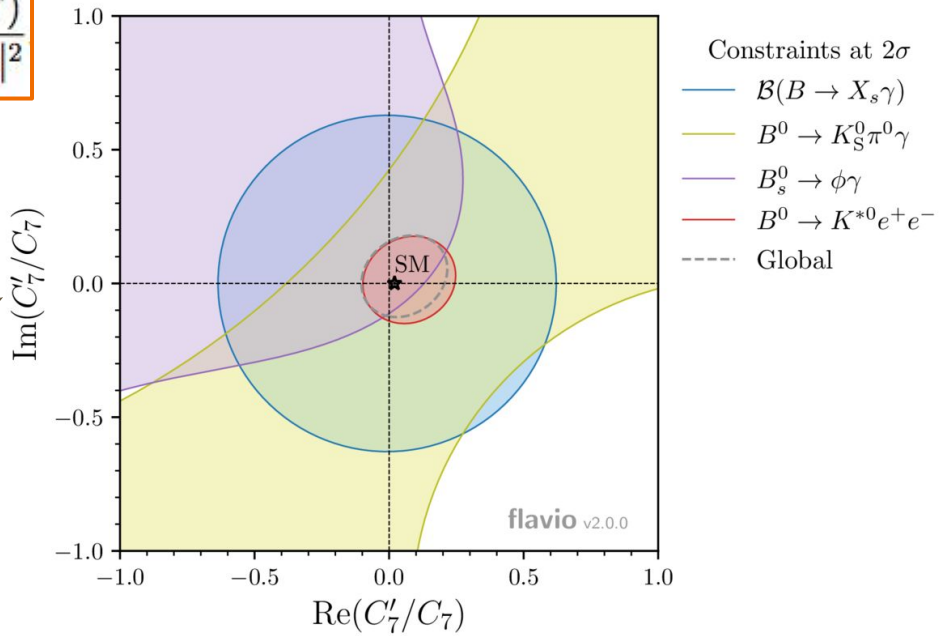
arXiv:2010.06011

Angular analysis of $B \to K^* e^+ e^-$ at very low q^2 with full LHCb dataset

$$A_T^{(2)}(q^2 \to 0) = \frac{2\mathcal{R}e(\mathcal{C}_7 \mathcal{C}_7'^*)}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$$

$$A_T^{Im}(q^2 \to 0) = \frac{2\mathcal{I}m(\mathcal{C}_7 \mathcal{C}_7'^*)}{|\mathcal{C}_7|^2 + |\mathcal{C}_7'|^2}$$

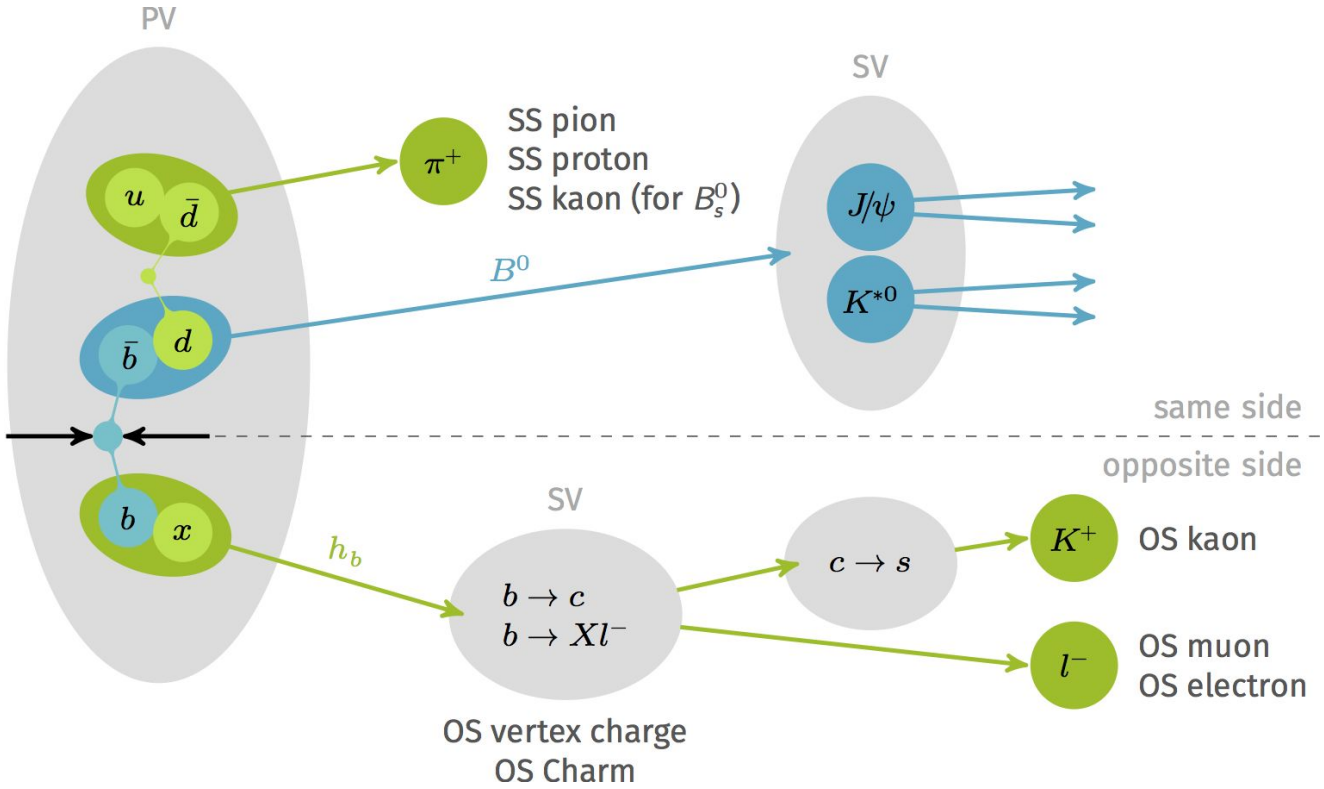
$$\begin{aligned} F_L &= 0.044 \pm 0.026 \pm 0.014, \\ A_T^{Re} &= -0.06 \pm 0.08 \pm 0.02, \\ A_T^{(2)} &= +0.11 \pm 0.10 \pm 0.02, \\ A_T^{Im} &= +0.02 \pm 0.10 \pm 0.01, \end{aligned}$$



Word-best constraints on C'_7

Very good agreement with SM

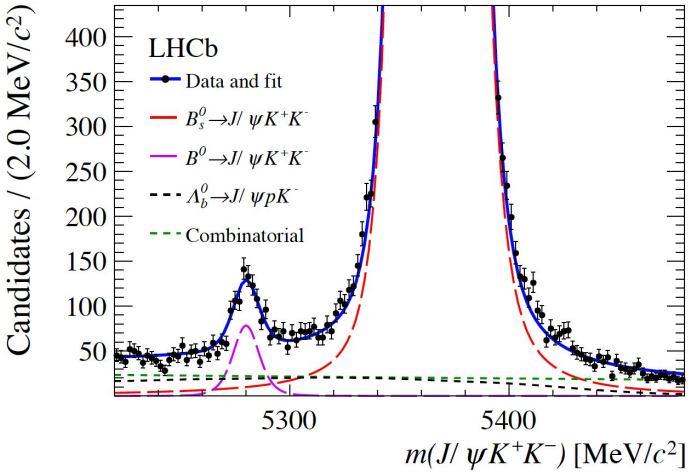
Flavour tagging at LHCb

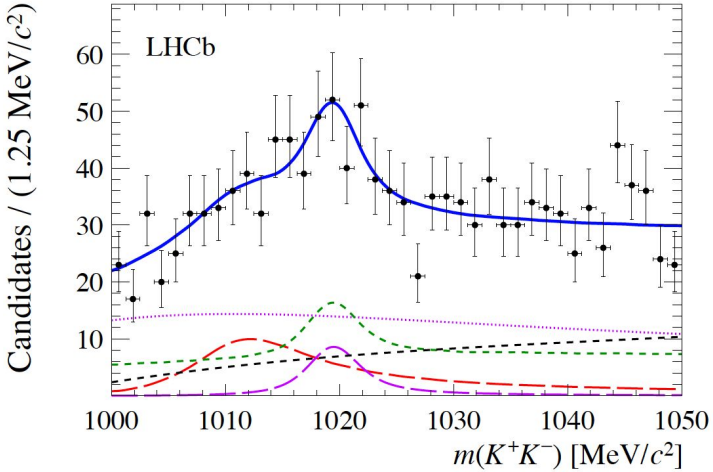


Search for B → J/ψφ

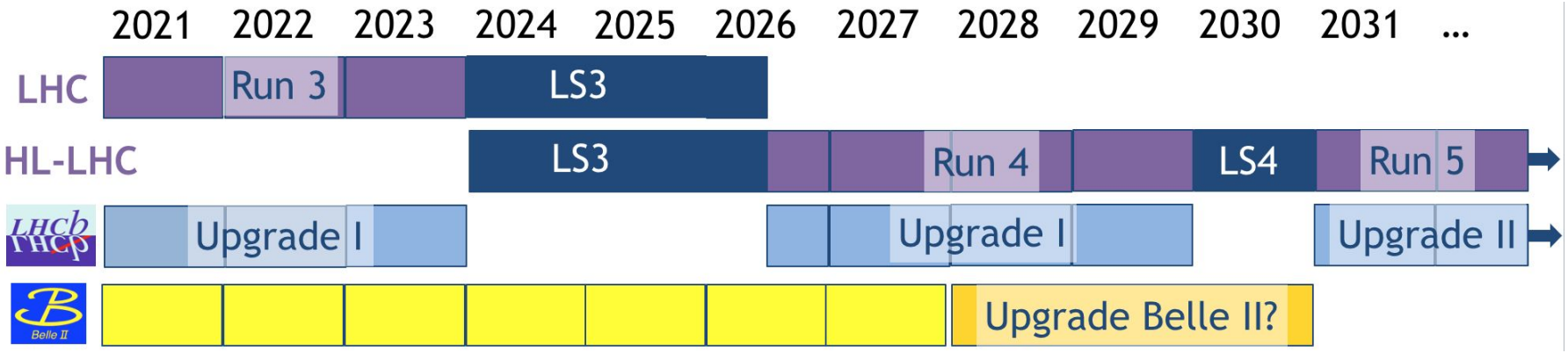
significance of 2.3σ, world-best limit

BR(B → J/ψφ) < 1.1 x 10^{-7} @90% CL

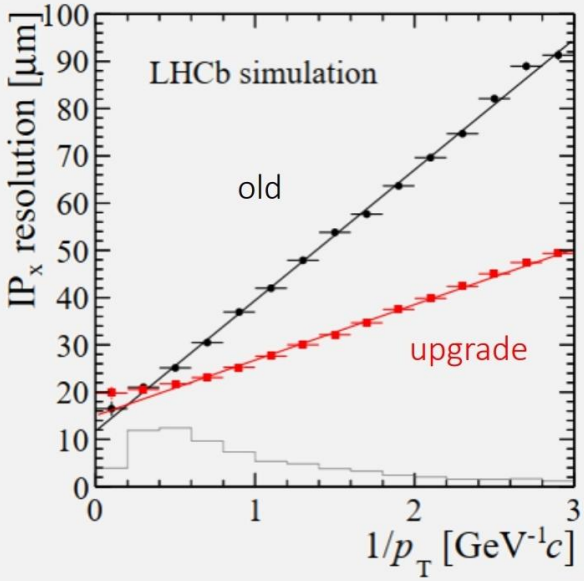




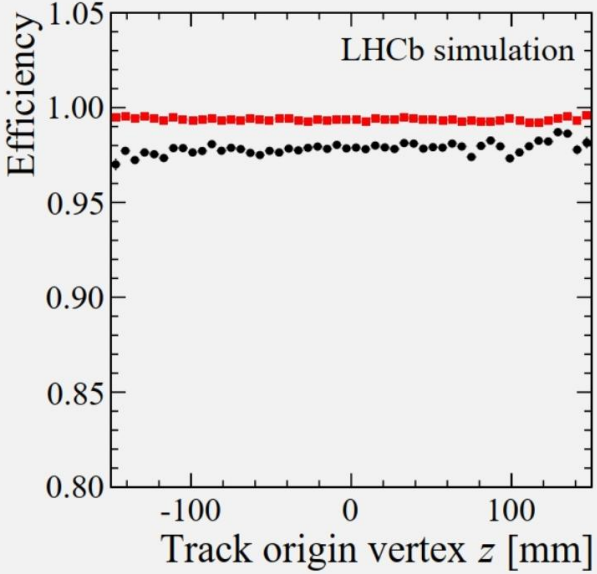
LHCb schedule overview



Velopix performance



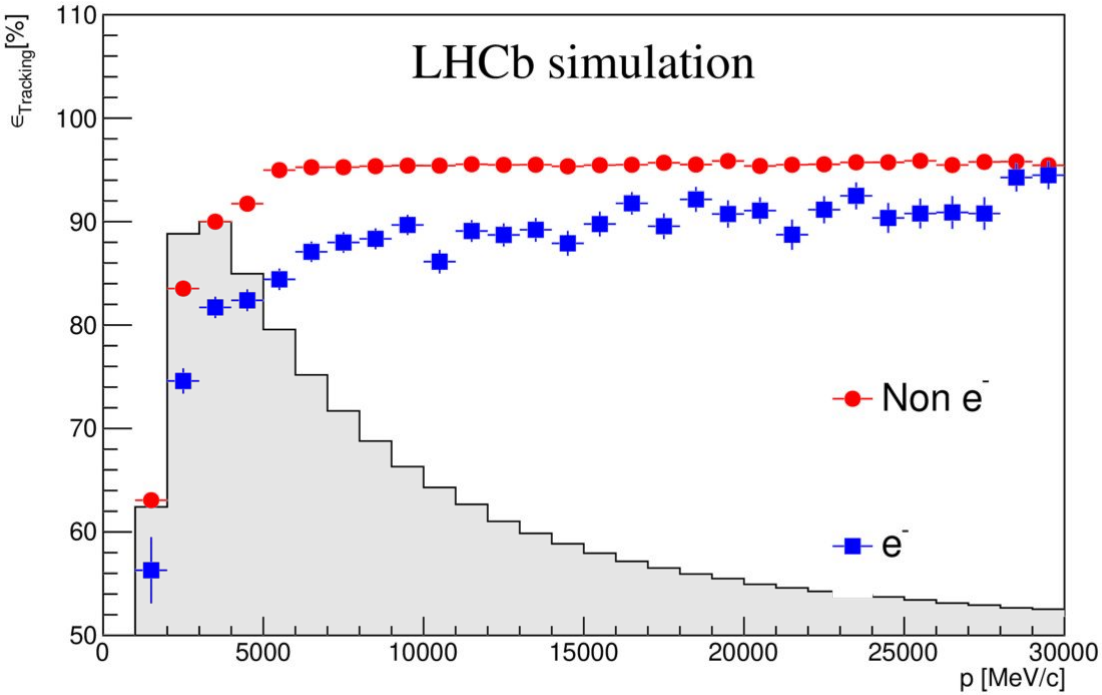
IP resolution



Average hit efficiency per track

Evaluated at ν = 7.6, √s = 14 TeV

Sifi performance



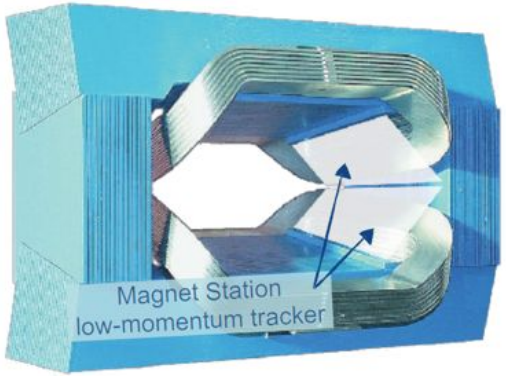
Upgrade 2 new detectors

Magnet stations

Measurement of low momentum particles:

- strange and charm physics, $\gamma \rightarrow e^+e^-$
- multi-body b decays, near-threshold

Scintillating fibers + SiPMs technology developed for Upgrade I



TORCH

Time-of-flight system in downstream region:

- reduce ghost rate, improve Λ^0 efficiency
- provide PID below 10 GeV (RICH1 limit)

1 cm quartz radiator + Micro-Channel Plate PMTs → ~15 ps/track