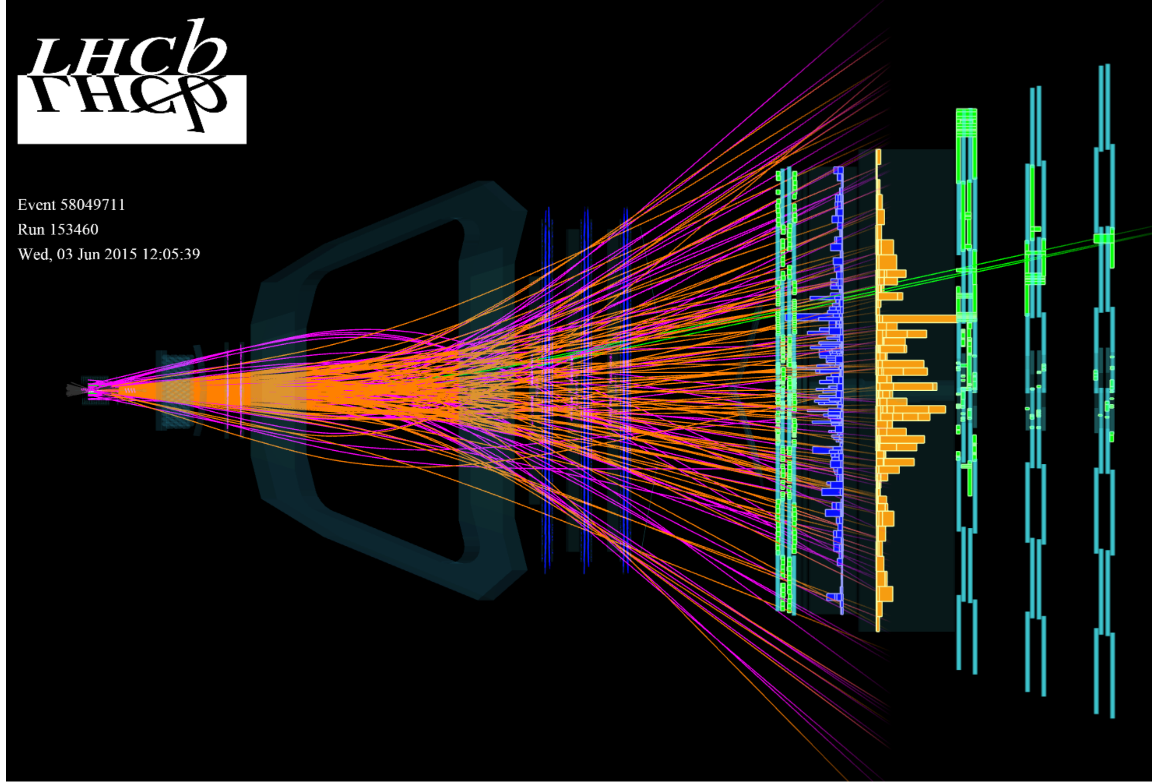


Highlights from the LHCb experiment

EPS 2019, July 10-17 2019

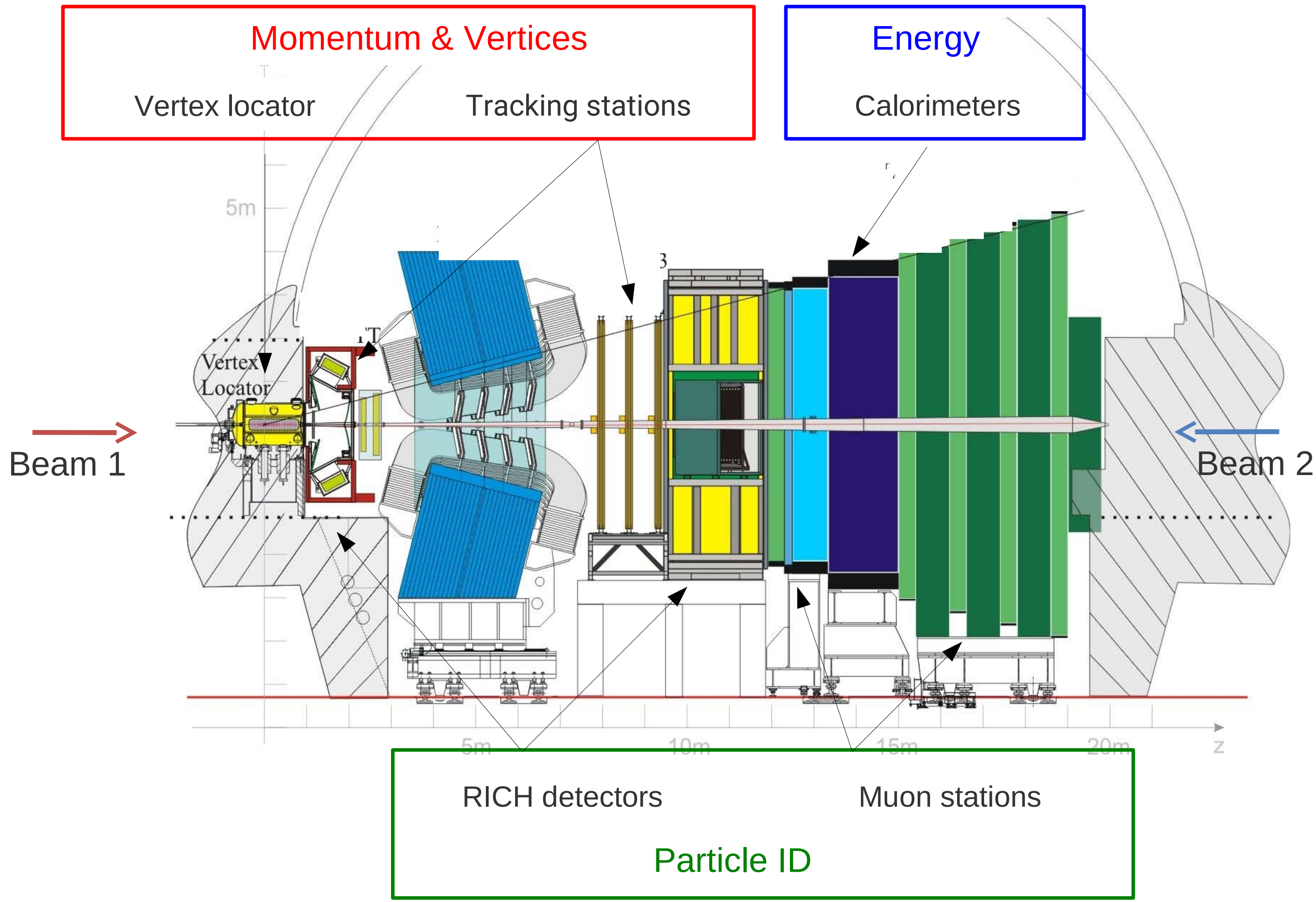
Katharina Müller
on behalf of the LHCb collaboration
Physik Institut, University of Zurich

University of Zurich UZH

LHCb detector

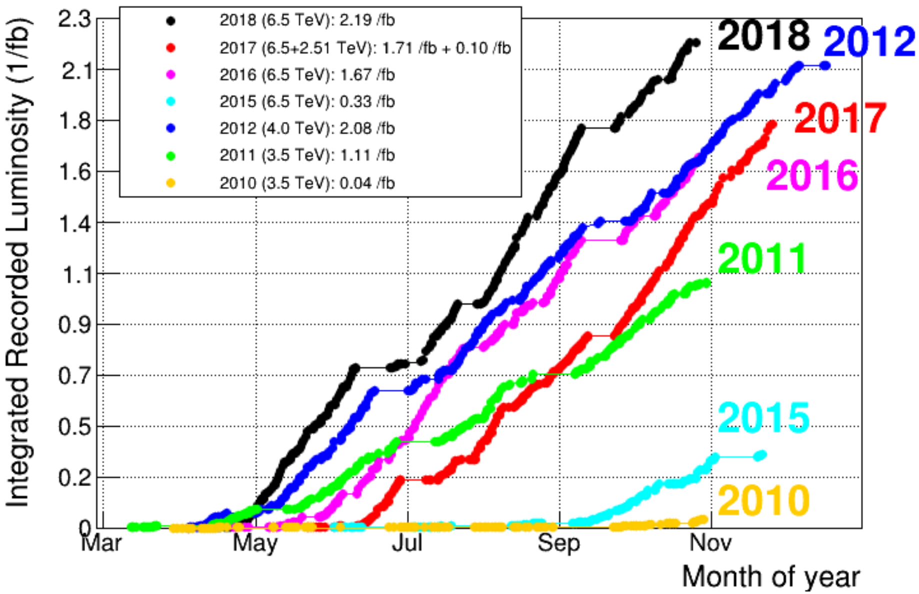
[Int. J. Mod. Phys. A30 (2015)1530022]

forward arm spectrometer for precision measurements ($2<\eta<5$)



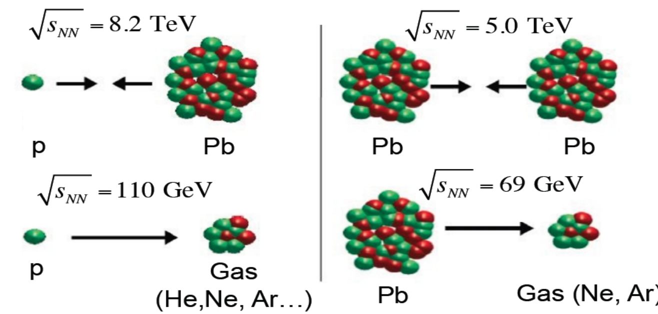
- good vertex and impact parameter resolution ($\sigma(IP)= 15 \pm 29/p_T$ μm)
- excellent momentum resolution ($\sigma(m_B) \sim 25$ MeV/c^2 for 2-body decays)
- excellent particle ID (μ ID 97% for ($\pi \rightarrow \mu$) misID of 1-3%)
- stable running conditions constant μ
- trigger on small p_T and low mass objects
- real time analysis alignment and calibration fully automated

LHCb dataset



Collider mode

Fixed target mode



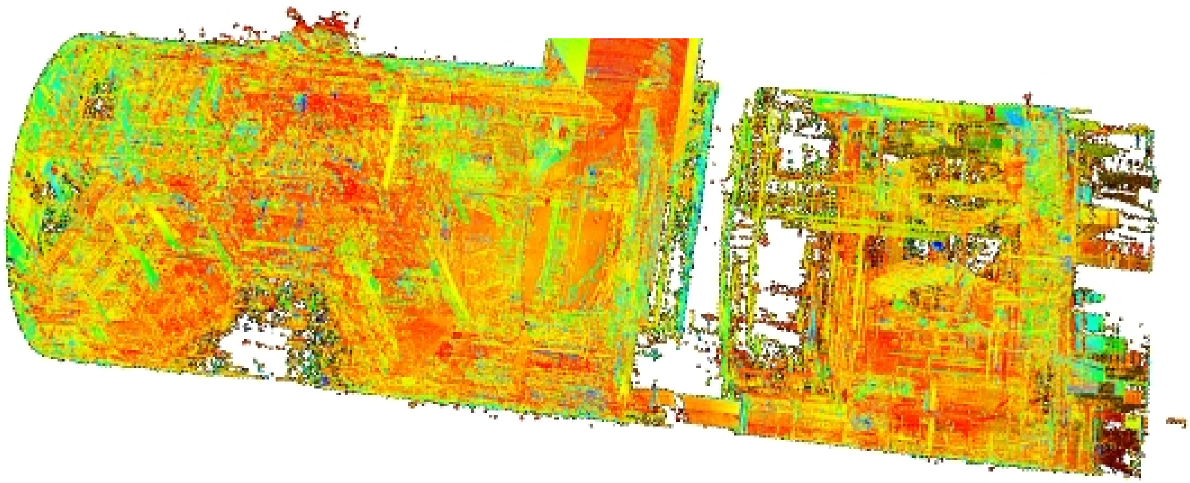
LHCb has recorded about 9 fb^{-1} of pp collisions

1 fb^{-1} @ 7 TeV
2 fb^{-1} @ 8 TeV – Run 1
6 fb^{-1} @ 13 TeV – Run 2

plus various datasets of proton-lead, lead-lead collisions as well as fixed target datasets: pNe, pHe, pAr, PbAr

→ LHCb a multipurpose detector in the forward region

Charming results



charm

rare decays

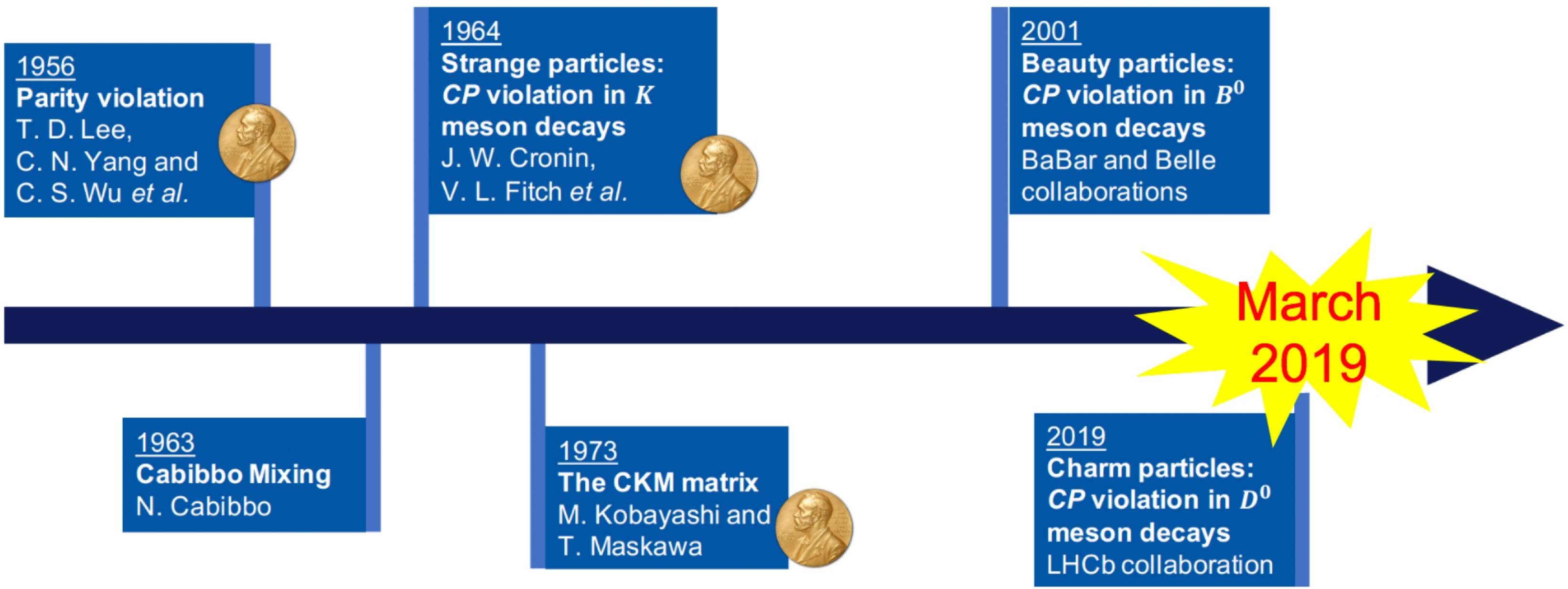
spectroscopy

heavy ion
fixed target

upgrade

- Observation of CP violation in charm [Phys. Rev. Lett. 122 (2019) 211803]
- Oscillations of charm mesons [Phys. Rev. Lett 122 (2019) 231802]
- A_Γ in $D^0 \rightarrow K^+K^-$, $\pi^+\pi^-$ [LHCb-CONF-2019-001]

History of CP violation

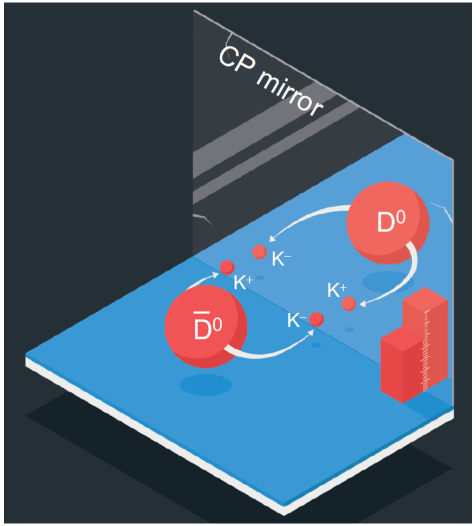


- CPV in Kaons and B mesons is well established – both are down type quarks
- charm contains an up-type quark
- SM predicts it to be at 10^{-3} - 10^{-4} level
- LHC is a charm factory, with billions of charm decays in LHCb

Observation of CP violation in charm

[Phys. Rev. Lett. 122 (2019) 211803]

charm decays allow CP violation to be probed in the up-sector
→ complementary to studies in K and B systems



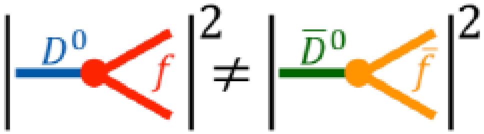
expected to be very small in the SM (10^{-3} - 10^{-4} level),
but theory predictions are not very precise (large long distance effects)

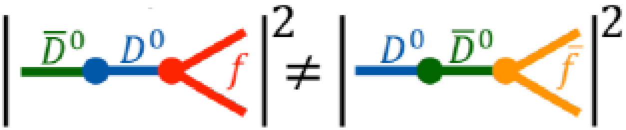
time dependent CP asymmetries

$$A_{CP}(f;t) = \frac{\Gamma(D^0(t) \to f) - \Gamma(\overline{D}^0(t) \to f)}{\Gamma(D^0(t) \to f) + \Gamma(\overline{D}^0(t) \to f)}$$

sensitive to

- direct CP-violation (a_{CP}^{dir})
- indirect CP-violation (a_{CP}^{indir})
  (CP-violation in mixing or in the
  interference between mixing and decay)





Observation of CP violation in charm

[Phys. Rev. Lett. 122 (2019) 211803]

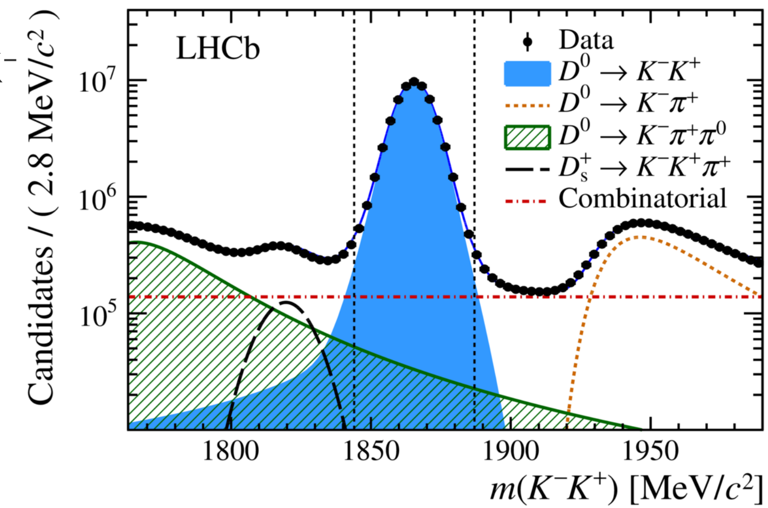
full Run 2 data 5.9 fb^{-1}

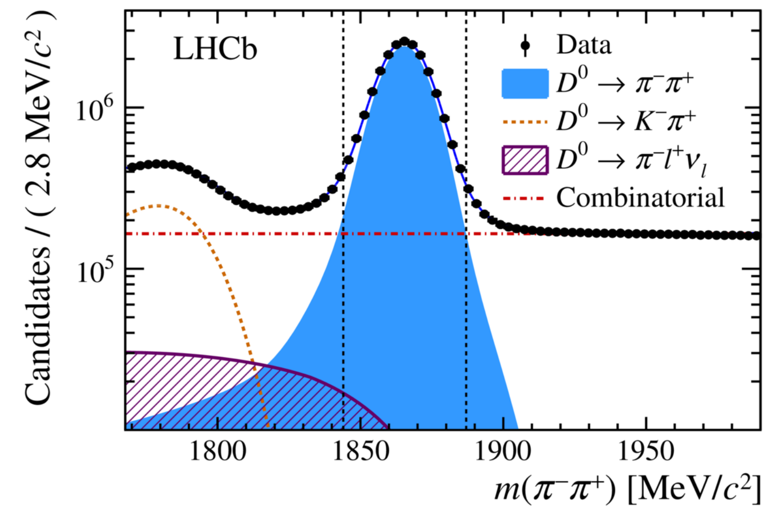
count how many D^0 and anti-D^0 decay into $\pi^+\pi^-$ and K^+K^-
should be equal if matter = antimatter

experimentally: easier to measure (time integrated) difference in CP asymmetry:

$$\Delta A_{CP} = A_{CP}(K^- K^+) - A_{CP}(\pi^- \pi^+)$$

- many systematics cancel at first order
- initial flavour of D meson tagged by charge of π in prompt decays ($D^{*+} \rightarrow D^0\pi^+$), and by the muon charge in secondary production ($B^0 \rightarrow D^0\mu^- X$)





Prasanthkrishnan Padmalayammadam
Flavour Physics, Thu, 16:30

Observation of CP violation in charm

[Phys. Rev. Lett. 122 (2019) 211803]

Run 2 result:

ΔA_{CP} =(-18.2 ± 3.2 (stat) ± 0.9 (syst))10^{-4} π-tag

ΔA_{CP} =(-9 ± 8 (stat) ± 5 (syst))10^{-4} μ-tag

compatible with previous LHCb result and world average

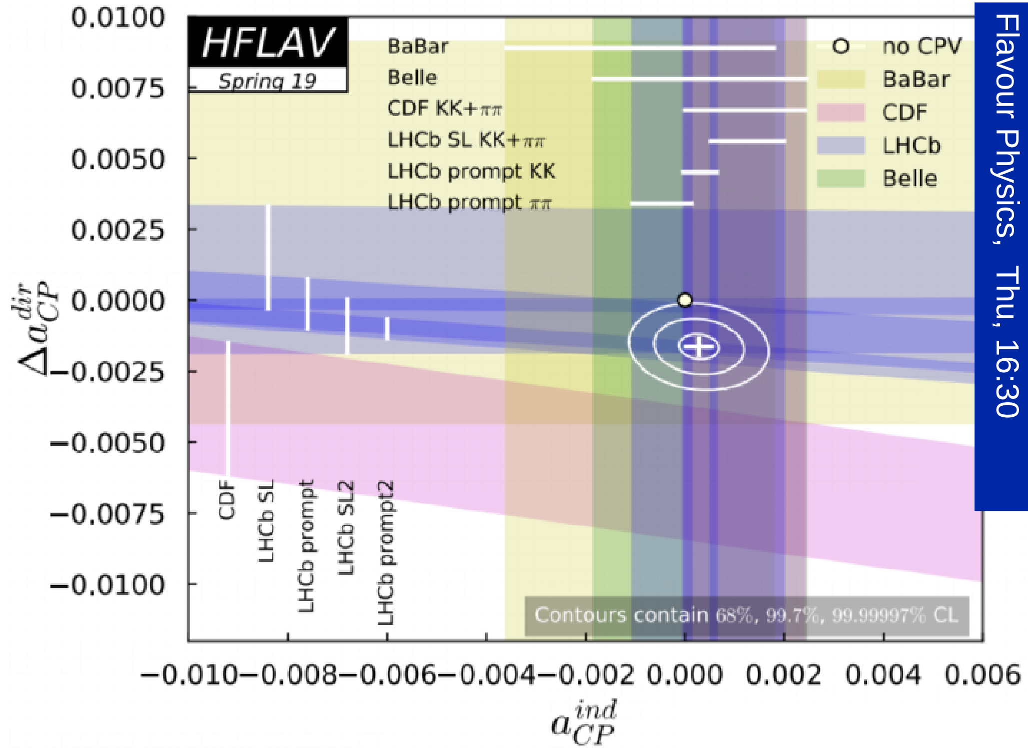
combination with Run 1 result

ΔA_{CP} =(-15.4 ± 2.9)10^{-4}

→ 5.3 σ difference from 0

→ roughly compatible with SM predictions
WA dominated by LHCb

uncertainties of SM predictions larger than data



Prasanthkrishnan Padmalayammadam
Flavour Physics, Thu, 16:30

→ new window opened to investigate matter-antimatter asymmetry

Oscillations of charm mesons in $D^0 \to K_S^0\pi^-\pi^+$

[Phys. Rev. Lett 122 (2019) 231802]

neutral flavoured mesons can oscillate between their particle and antiparticle states

→ the physical mass eigenstates are linear combinations of the weak eigenstates

$$|D_{1,2}\rangle \equiv p|D^0\rangle \pm q|\overline{D}^0\rangle$$

with masses m_1 and m_2 and decay widths Γ_1+Γ_2

mixing parameters $x \equiv (m_1-m_2)c^2/\Gamma$ and $y \equiv (\Gamma_1-\Gamma_2)/\Gamma$ $(\Gamma=(\Gamma_1+\Gamma_2)/2)$

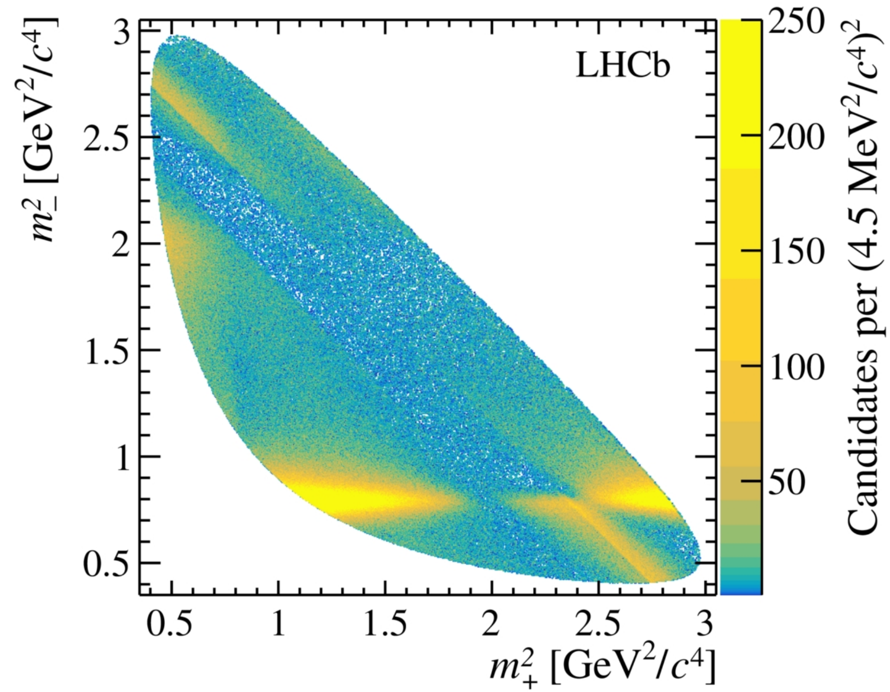
x determines the oscillation rate

x is very small for charm mesons but x and CPV can be enhanced by the presence of new particles beyond the SM

CPV can occur in the mixing → oscillation rates differ for mesons and antimesons

LHCb Run 1, decay: $D^0 \to K_S^0\pi^-\pi^+$

yields: prompt 1.3M, secondary 1M candidates



Prasanthkrishnan Padmalayammadam
Flavour Physics, Thu, 16:30

Oscillations of charm mesons in $D^0 \rightarrow K_S^0 \pi^- \pi^+$

[Phys. Rev. Lett 122 (2019) 231802]

model independent approach (bin-flip method)

→ most precise determination of CP averaged normalized mass difference $x=(m_1-m_2)c^2/\Gamma$ by a single experiment

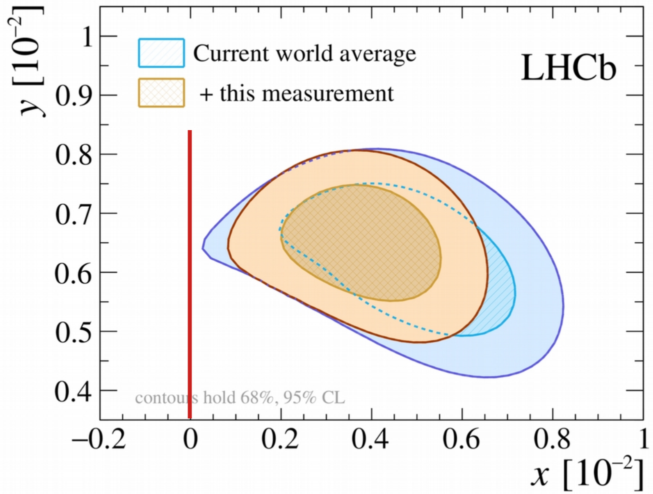
$x_{CP} = [2.7 \pm 1.6 \pm 0.4] \times 10^{-3}$

$y_{CP} = [7.4 \pm 3.6 \pm 1.1] \times 10^{-3}$

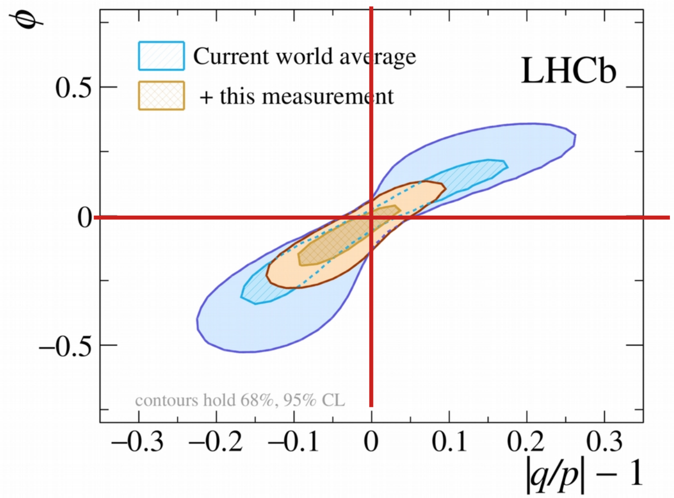
if CP symmetry in mixing and interference is conserved:
$x_{CP} = x$, $y_{CP} = y$

$x_{CP} = (3.9^{+1.1}_{-1.2}) \times 10^{-3}$ new world average

→ new world average provides first evidence of mass difference between the neutral charm mesons



CPV parameters



Prasanthkrishnan Padmalayammadam Flavour Physics, Thu, 16:30

Measurement of CPV parameter A_Γ in $D^0 \to K^+K^-$, $\pi^+\pi^-$

[LHCb-CONF-2019-001]

A_Γ probes CPV in mixing and interference

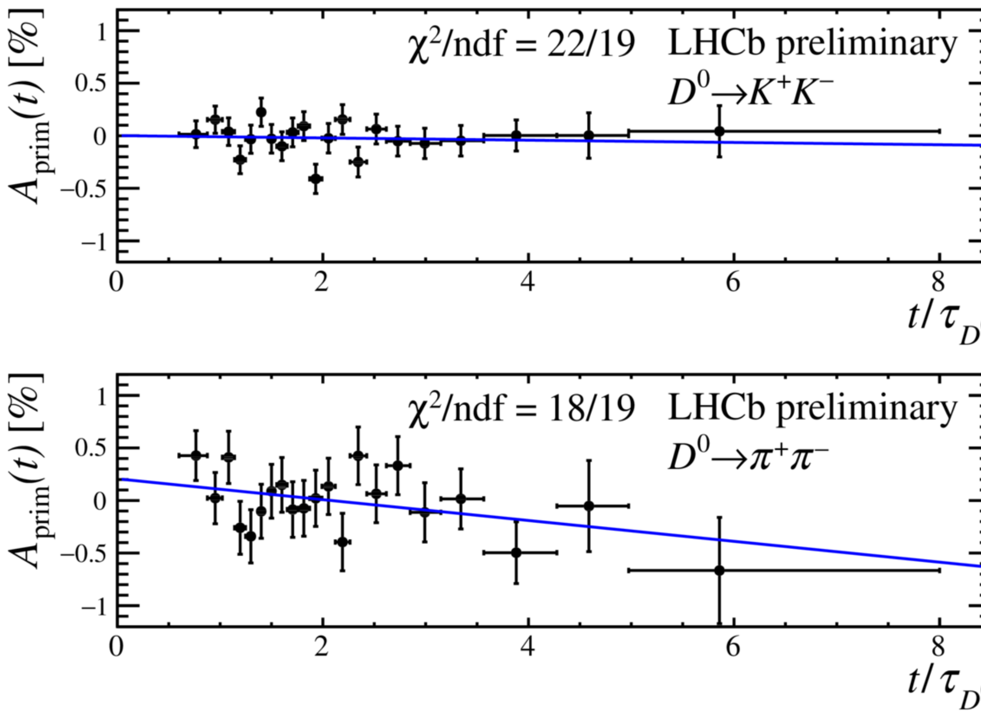
$$A_{CP}(f,t) \approx A_{CP}^{decay} - A_\Gamma(f)\frac{\langle t\rangle_f}{\tau_D^0}$$

SM predictions: ≈ 3 x 10^{-5} [arXiv:1812.07638]

A_Γ required input to measure CPV in decay from ΔA_{CP}

→ measure time dependent CP asymmetry

$$A_\Gamma(K^+K^-) = (1.3 \pm 3.5 \pm 0.7)10^{-4}$$
$$A_\Gamma(\pi^+\pi^-) = (11.3 \pm 6.9 \pm 0.8)10^{-4}$$



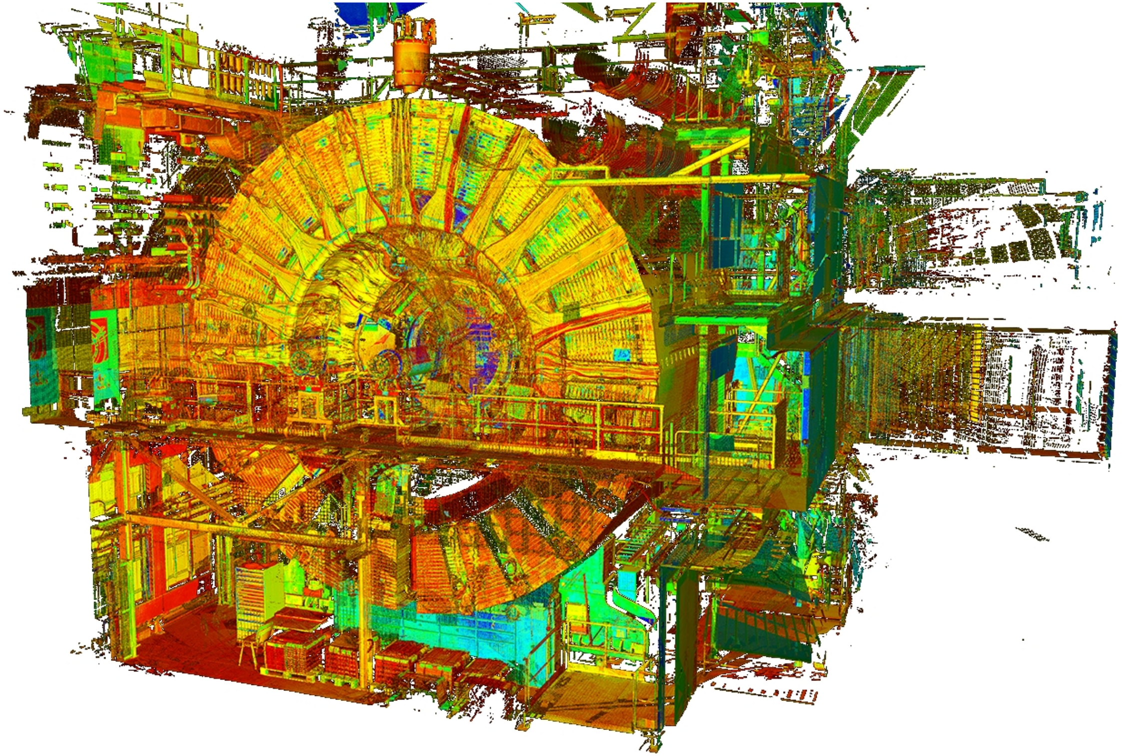
combined with previous LHCb result

$$A_\Gamma(\pi\pi + KK) = (0.9 \pm 2.1 \pm 0.7)10^{-4}$$
$$\Delta A_\Gamma = A_\Gamma(KK) - A_\Gamma(\pi\pi) = (-8.6 \pm 5.0 \pm 0.5)10^{-4}$$

analysis based on 2 fb^{-1} Run 2 data, still 4 fb^{-1} to be analysed, statisticallylimited
→ need Upgrade II to reach sensitivity of SM

Prasanthkrishnan Padmalayammadam
Flavour Physics, Thu, 16:30

Precision in beauty – covered in more detail in Johannes' talk



- charm
- **beauty**
- spectroscopy
- heavy ion fixed target
- upgrade

- Combination of γ measurements [LHCb-CONF-2018-002]
- B_s mixing phase Φ_s [arXiv:1903.05530, arXiv:1906.08356]
- Phase Φ^{sss} in $B_s \to \varphi\,\varphi$ decays [LHCb-PAPER-2019-019]
- New measurement of R(K) [Phys. Rev. Lett. 122 (2019) 191801]
- Search for Lepton flavour violating decays [arXiv:1905.06614, LHCB-PAPER-2019-022]

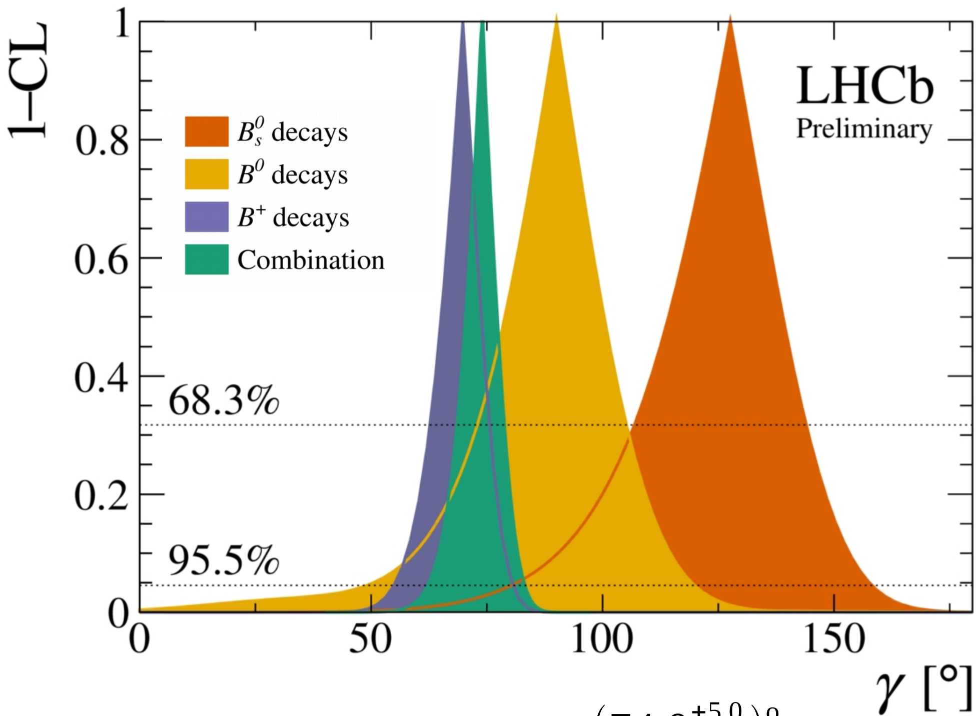
Combination of γ measurements

[LHCb-CONF-2018-002]
[arXiv:1906.08927]

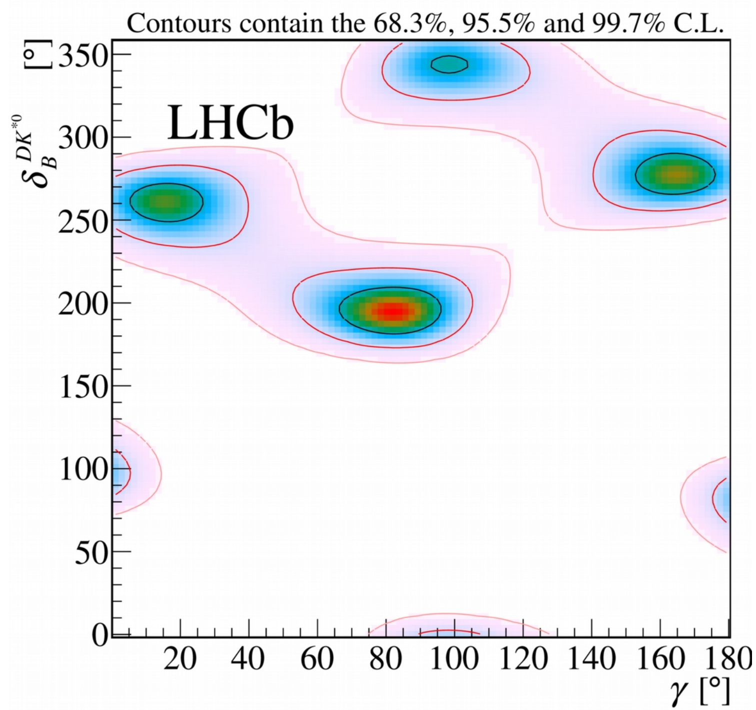
tension (2σ) between B^+ and B_s^0 results

tension (2σ) between direct measurements and indirect constraints from UT

LHCb: new measurement in $B^0 \to DK^{*0}$ ($D \to K\pi$, KK, $\pi\pi$) [arXiv:1906.08927]



$\gamma = (74.0^{+5.0}_{-5.8})^o$



HFLAV $\gamma = (71.1^{+4.6}_{-5.3})^o$

from UT (CKM fitter) $\gamma = (65.8^{+1.0}_{-1.7})^o$

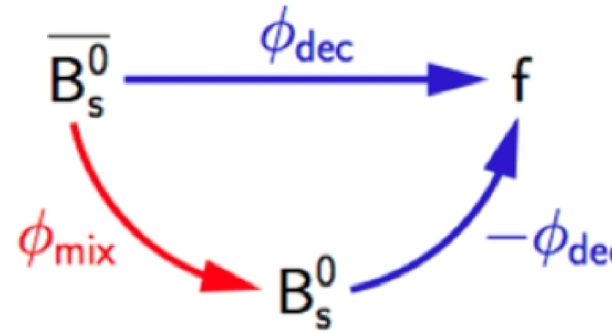
Alexandra Rollings
Flavour Physics, Thu, 10:10

B_s mixing phase Φ_s from $B_s \to J/\psi$ KK and $B_s \to J/\psi\pi\pi$

measure the phase difference between the two processes

SM prediction $\Phi_s = -36.8^{+9.6}_{-6.8}$ mrad (CKM Fitter)

highly sensitive to NP contributions



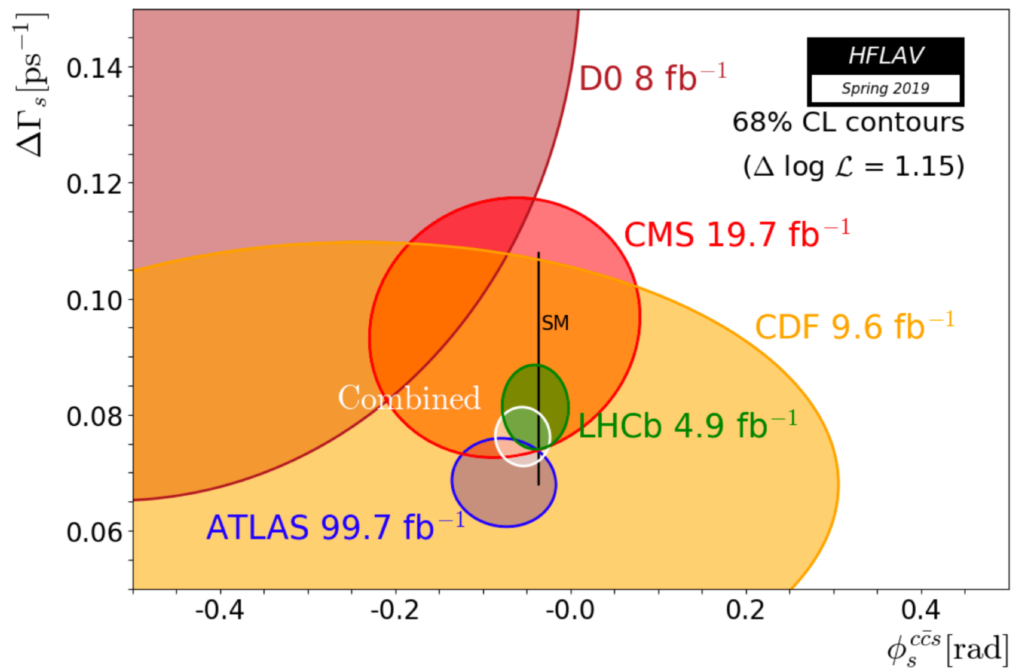
LHCb uses two channels:
$B_s \to J/\psi$ KK and $B_s \to J/\psi\pi\pi$

high yield, clean signature
→ very high precision measurements

flavour tagging from decay of other b hadrons in the event
analysis part of Run 2 (2 fb^{-1})

combined with Run 1
Φ_s = (-41 ± 25) mrad
(still 4 fb not analysed)

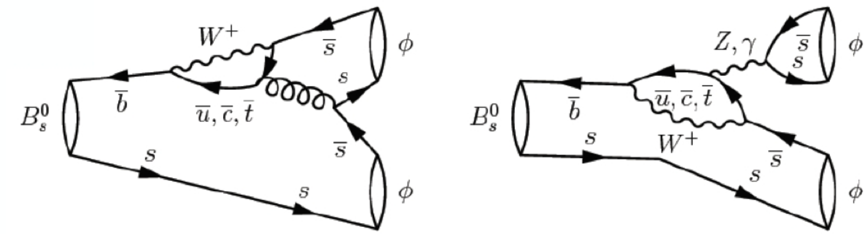
HFLAV combination:
Φ_s = (-55 ± 21) mrad



Measurement of CP violation in $B_s \to \Phi\Phi$

[LHCb-PAPER-2019-019]

Enhanced sensitivity to NP since decay is dominated by penguin loop



SM prediction $|\Phi_s^{sss}| < 20$ mrad

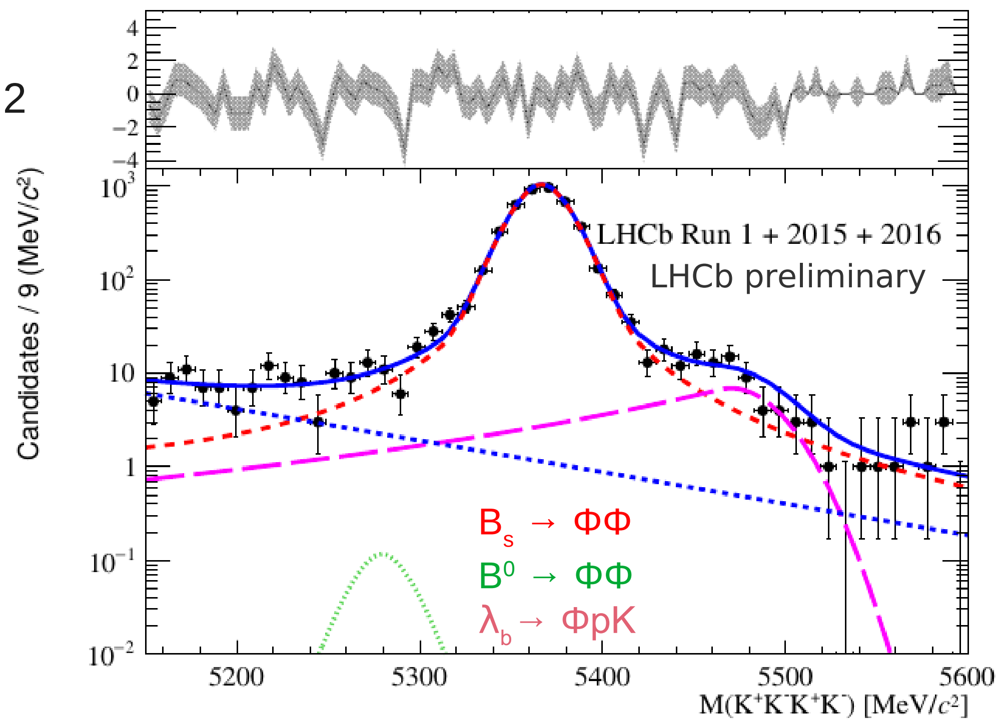
[arXiv:0810.0249 Phys.Rev.D80:114026,2009]

time dependent angular analysis, 2 fb^{-1} Run 2

$\Phi_s^{sss} = -73 \pm 115 \pm 27$ mrad

$|\lambda| = -0.99 \pm 0.05 \pm 0.01$

(LHCb preliminary)



Louis Henry
Flavour Physics, Thu, 11:40

Test of lepton flavour universality

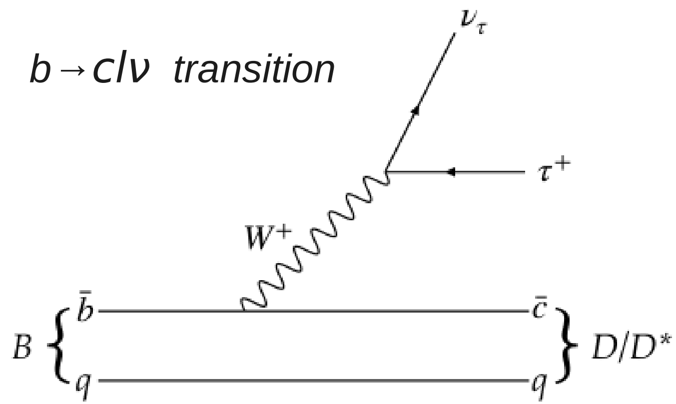
test of LFU in various B decays with leptons in the final state

Charged current (Semileptonic decays)

tree-level decays $b \to c l \nu$, testing third generation
BR of few %, precise prediction in SM

$$R(D^{(*)}) = \frac{BR(B \to D^{(*)} \tau \bar{\nu}_\tau)}{BR(B \to D^{(*)} \mu \bar{\nu}_\mu)} = 0.252 \pm 0.003\,(SM)$$

$b \to c l \nu$ transition



Neutral currents (Rare decays)

$b \to sll$

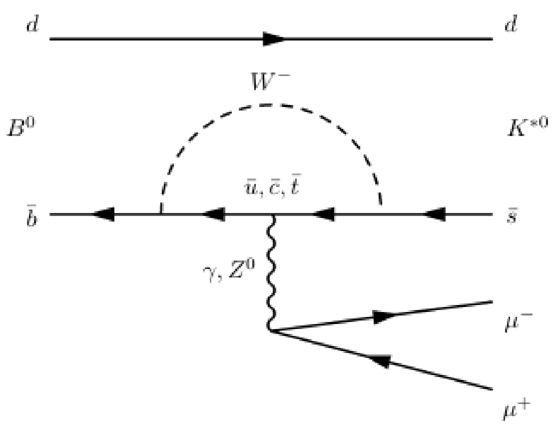
forbidden at tree-level in the SM
→ FCNC only at loop level → BR $10^{-7} \div 10^{-6}$

theoretically clean

$$R(K^{(*)}) = \frac{BR(B \to K^{(*)} \mu\mu)}{BR(B \to K^{(*)} e e)} = 1 \pm \underbrace{O(10^{-3})}_{\text{neglect lepton mass}} \pm \underbrace{O(10^{-2})}_{\text{QED}}$$

[EPJ C76 (2016) 8, 440]

$b \to sll$ transition

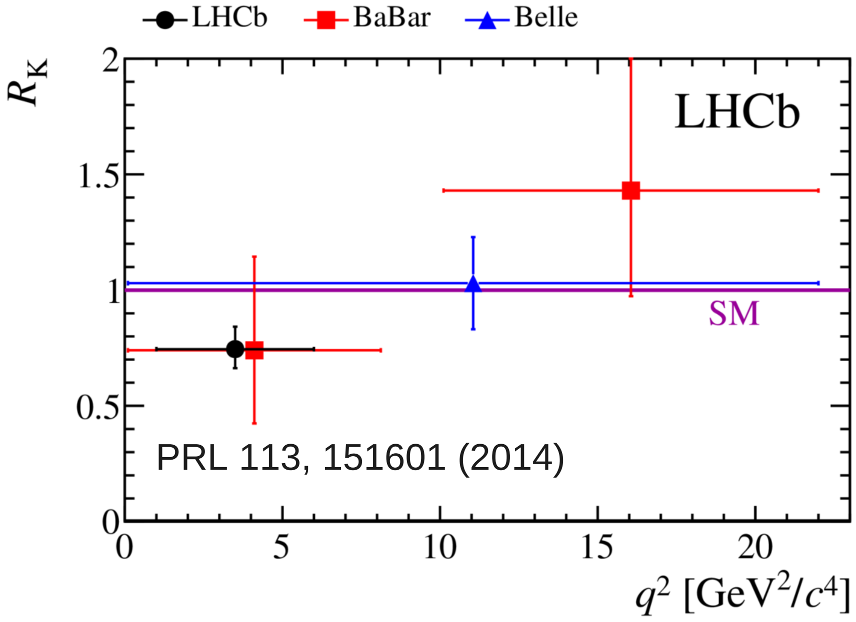


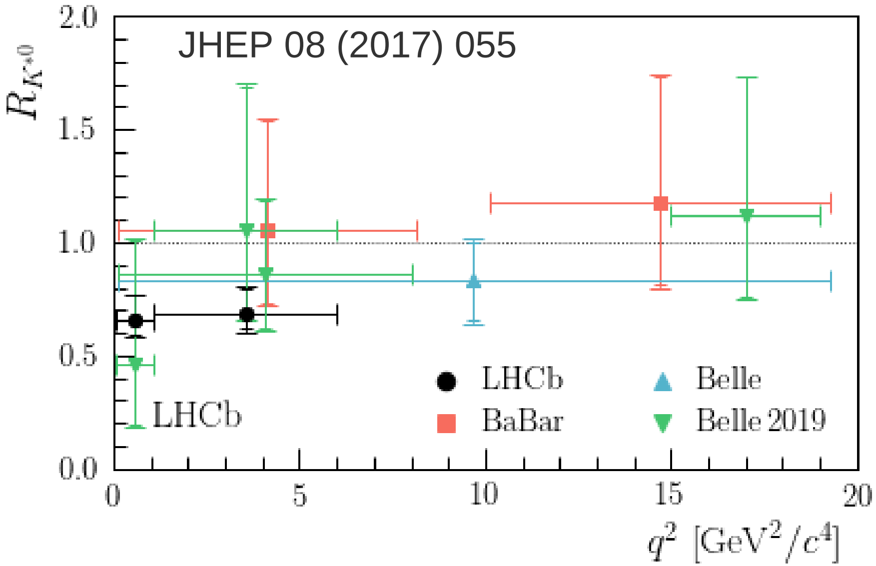
[PRL 113, 151601 (2014)]
[JHEP 08 (2017) 055]

test the LFU in FCNC decays $b \rightarrow s l^+ l^-$

Run 1 result: old results for R(K) and R(K*)

$$R(K^{(*)}) = \frac{BR(B \rightarrow K^{(*)} \mu\mu)}{BR(B \rightarrow K^{(*)} e e)} = 1 \pm \underbrace{O(10^{-3})}_{\text{neglect lepton mass}} \pm \underbrace{O(10^{-2})}_{\text{QED}}$$



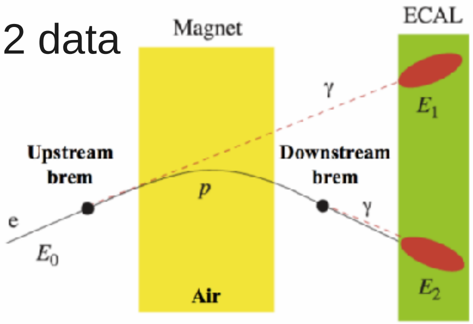


New measurement of R(K)

[Phys. Rev. Lett. 122 (2019) 191801]

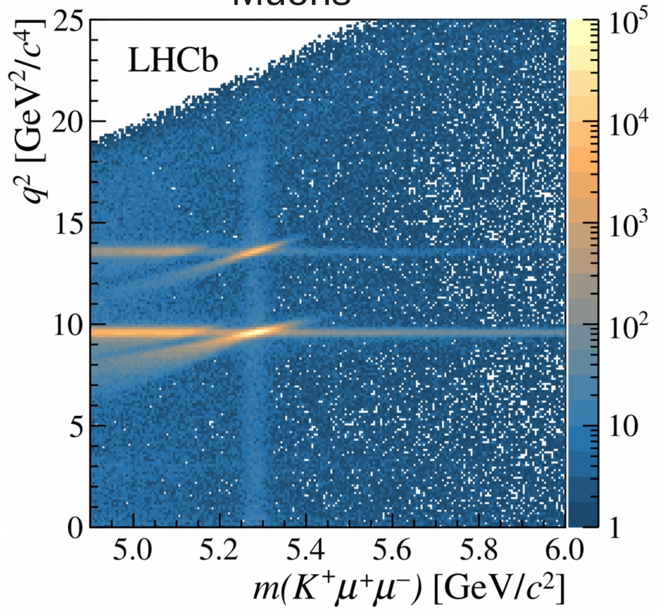
new measurement re-analysing Run 1 data and adding ~2 fb^{-1} of Run 2 data

$$R(K) = \frac{BR(B \to K\,\mu\,\mu)}{BR(B \to K\,e\,e)}$$

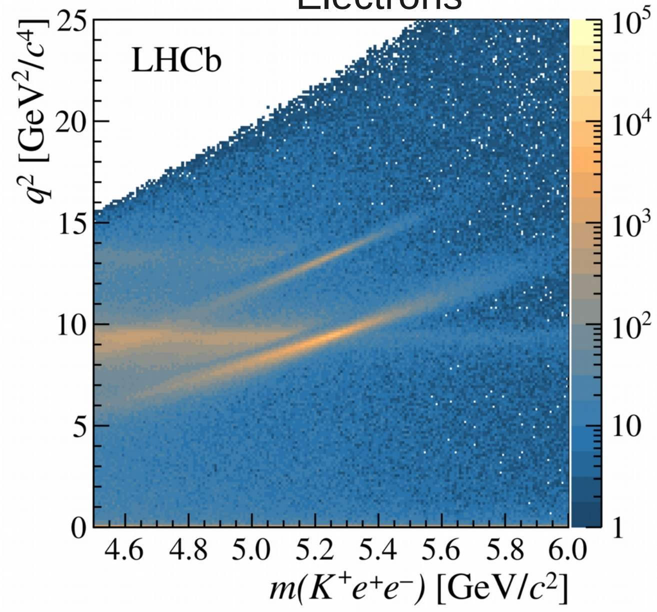


electrons are difficult to measure at LHCb: trigger, Bremsstrahlung …

Muons



Electrons



Vitalii Lisovskyi
Flavour Physics, Fri, 14:30

New measurement of R(K)

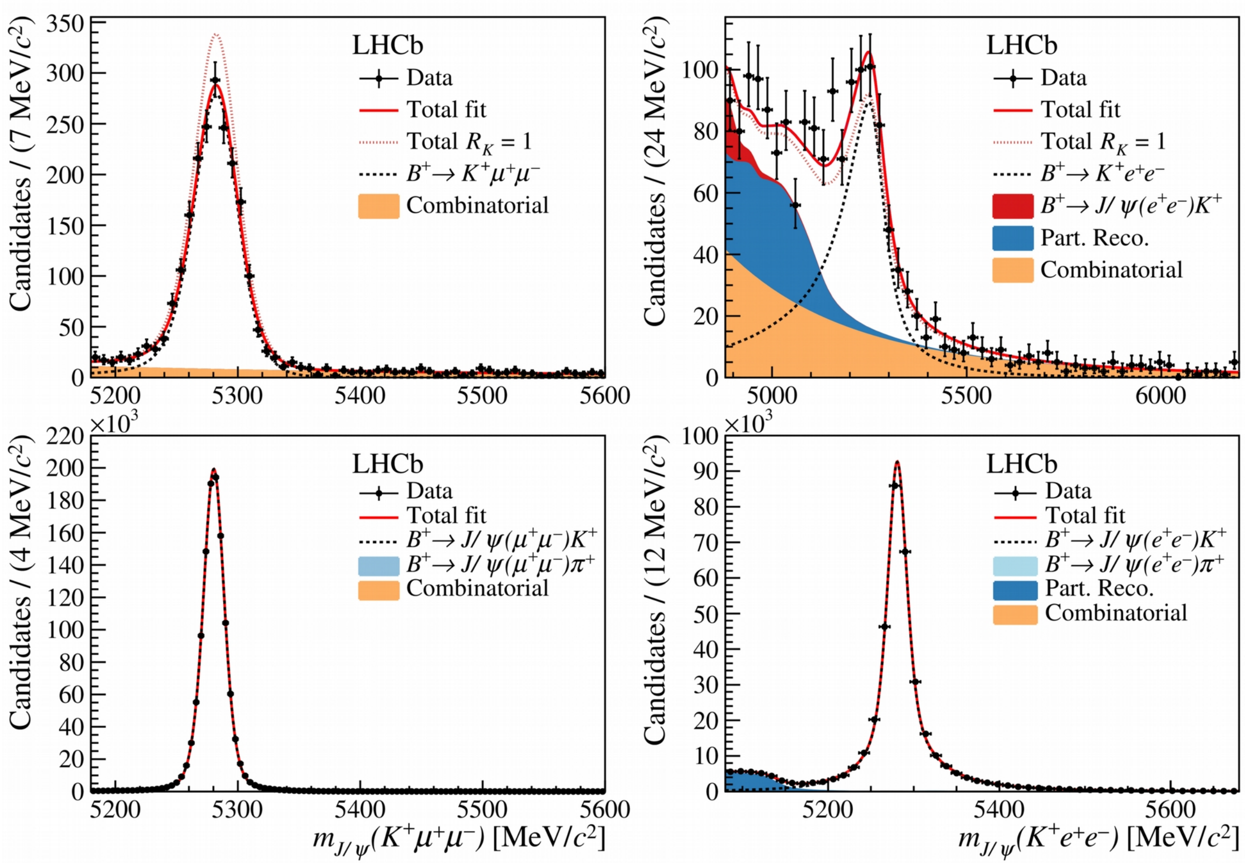
[Phys. Rev. Lett. 122 (2019) 191801]

Reduce systematic effects: normalise to B→ KJ/ψ
→ measure double ratio

$$R(K) = \frac{BR(B\to K\mu\mu)}{BR(B\to Kee)} \frac{BR(B\to K\,J/\psi(\to ee))}{BR(B\to K\,J/\psi(\to \mu\mu))}$$

Signal
$1.1<q^2<6$ GeV^2

Normalisation



Vitalii Lisovskyi
Flavour Physics, Fri, 14:30

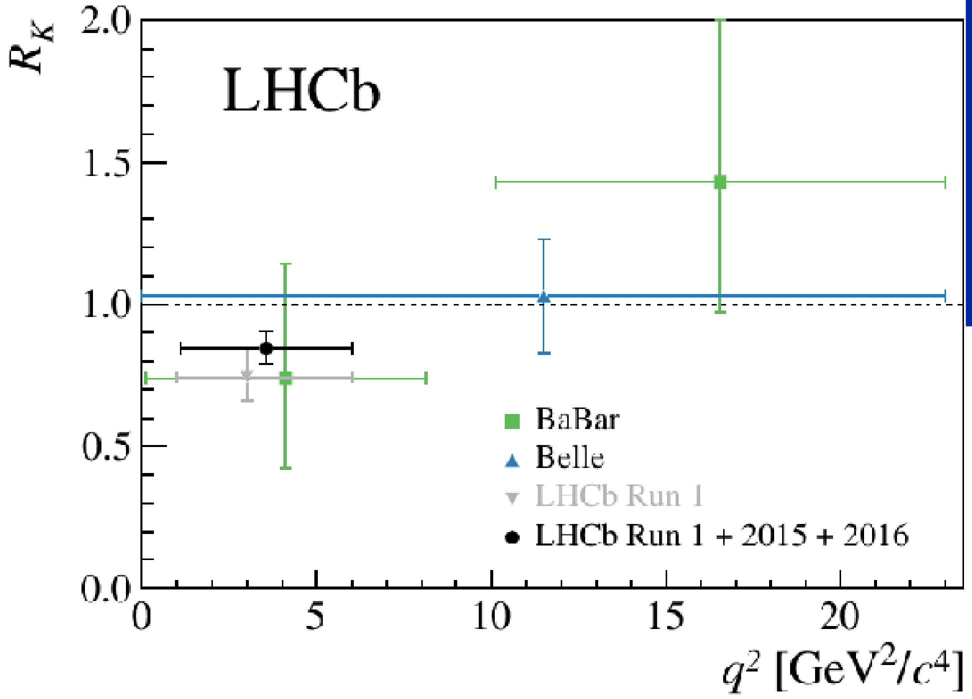
New measurement of R(K)

$$R(K) = 0.846^{+0.060}_{-0.054}(\text{stat})^{+0.016}_{-0.014}(\text{syst})$$

compatible with the SM at 2.5 σ
→ better precision but central value closer to the SM

→ need more data: inclusion of 2017+2018 data will double the statistics

other measurements in preparation:
R(pK), R(K*) and other decay channels



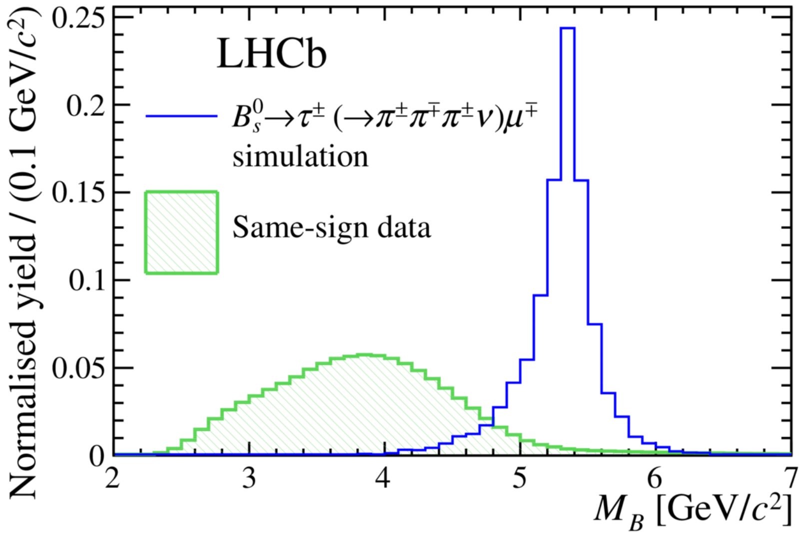
Vitalii Lisovskyi
Flavour Physics, Fri, 14:30

Search for Lepton flavour violating decays

$B^0_{(s)} \rightarrow \tau^{\pm}\mu^{\mp}$ [arXiv:1905.06614]

BR in SM highly suppressed: ~10^{-54}
can be strongly enhanced in NP models:
up to O(10^{-8} – 10^{-5})

$B(B_s \rightarrow \tau\mu) = 3.4\ 10^{-5}$ @ 90% CL (first limits)
$B(B^0 \rightarrow \tau\mu) = 1.2\ 10^{-5}$ @ 90% CL (best limits)



$B^+ \rightarrow K^+\mu^{\pm}e^{\mp}$ [LHCB-PAPER-2019-022]

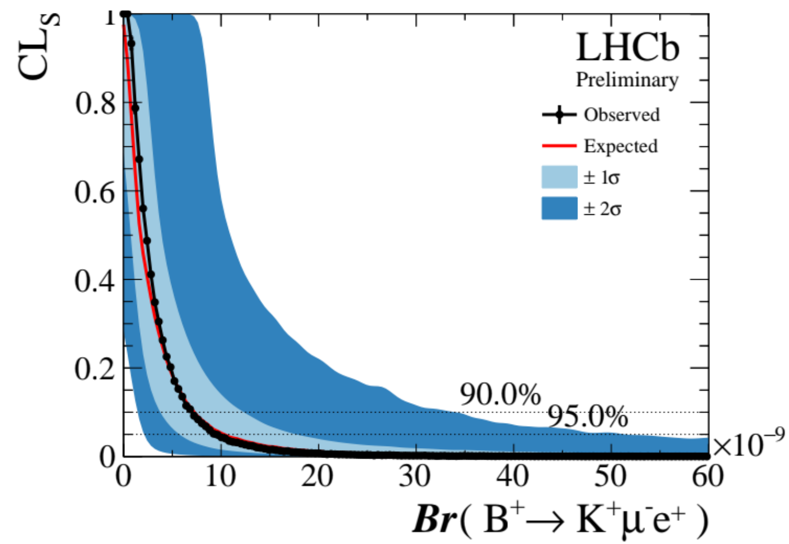
NP models including leptoquarks, extended gauge boson models or CP violation in the neutrino sector predict branching fractions
$10^{-8} - 10^{-10}$

search in full Run 1 dataset, no signal observed

$B(B^+ \rightarrow K^+\mu^-e^+) = 7.0\ 10^{-9}$ @ 90% CL

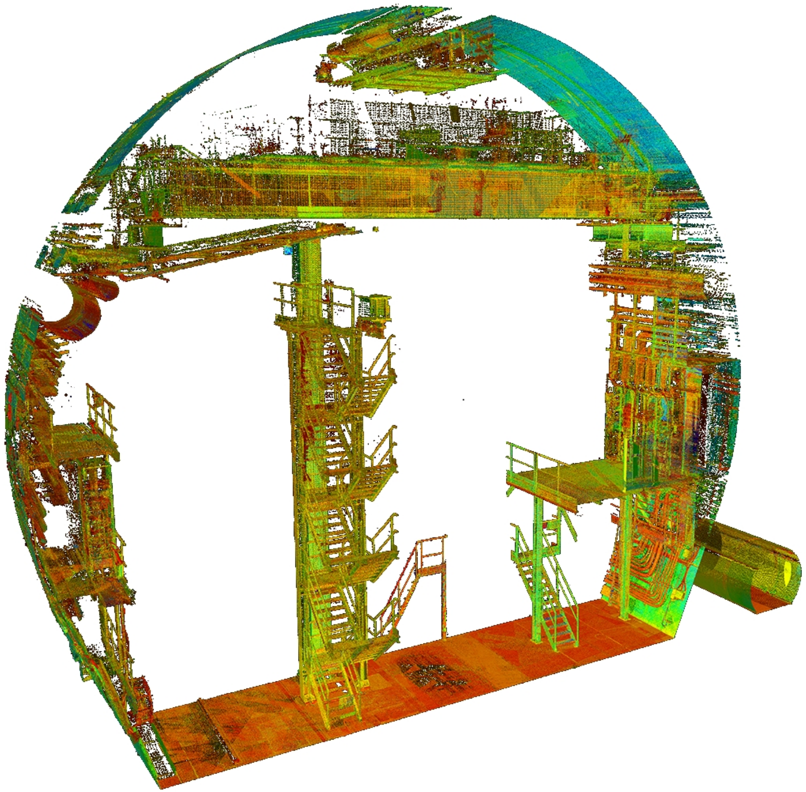
$B(B^+ \rightarrow K^+\mu^+e^-) = 7.1\ 10^{-9}$ @ 90% CL

→ limits improved by more than one order of magnitude



Marco Santimaria
Flavour Physics, Fri, 16:35

Beauty in Spectroscopy

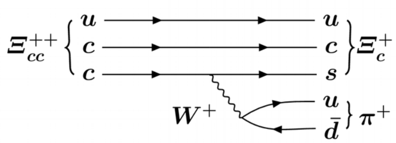


- charm
- beauty
- spectroscopy
- heavy ion fixed target
- upgrade

- Doubly charm baryons [Phys. Rev. Lett. 121 162002 (2018)], [PRL 121 (2018) 052002]
- Observation of a new state in DD mass spectrum [JHEP 07 (2019) 035]
- New resonances in the $\Lambda^0_b\pi^+\pi^-$ spectrum [LHCb-PAPER-2019-025]
- Observation of new pentaquark states [Phys. Rev. Lett. 122 (2019) 222001]

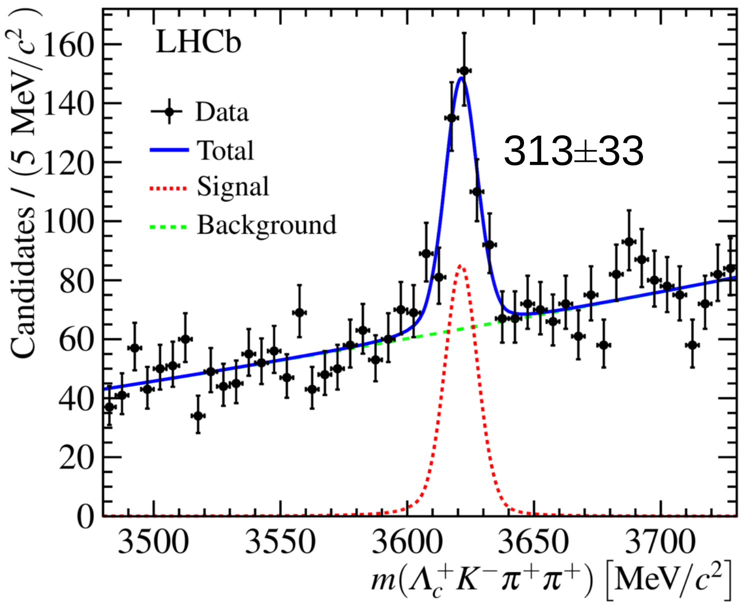
Doubly charmed baryons

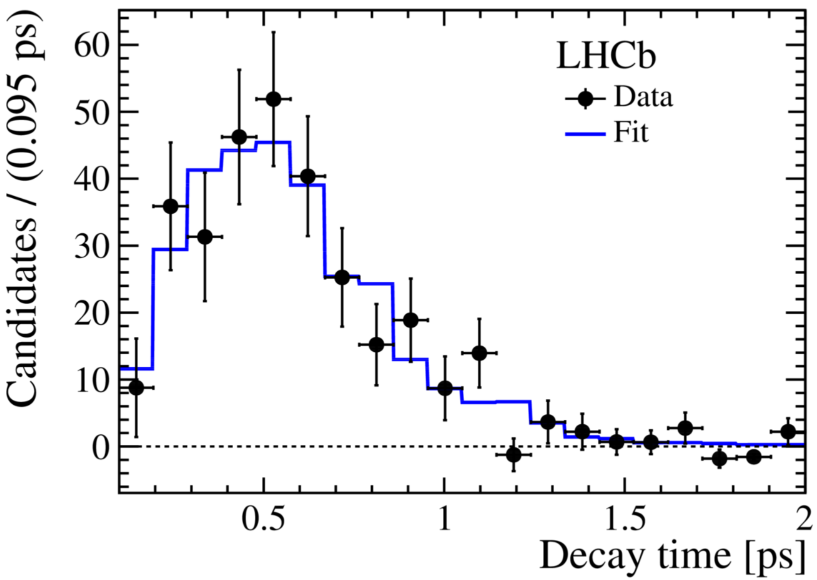
ground states: Ξ_{cc}^{++} (ccu), Ξ_{cc}^{+} (ccd) and Ω_{cc}^{+} (ccs)
only Ξ_{cc}^{++} discovered so far, search ongoing for Ξ_{cc}^{+} and Ω_{cc}^{+}



first observed by LHCb in decay: $\Xi_{cc}^{++} \rightarrow \Xi_c^{+}\pi^+$ final state $\Lambda_c^+ K^- \pi^+ \pi^+$ [Phys. Rev. Lett. 121 162002 (2018)]
m(Ξ_{cc}^{++}) = 3621. 40 ± 0. 72(stat) ± 0. 27 (syst) ± 0. 14 (Λ_c^+) MeV/c^2

weakly decaying: τ(Ξ_{cc}^{++})= 0. 256+0.024 −0.022(stat) ± 0. 014(syst) ps [PRL 121 (2018) 052002]
no signal found for: $\Xi_{cc}^{++} \rightarrow D^+ (\rightarrow K^-\pi^+\pi^+)\, pK^-\pi^+$ [arXiv:1905.02421]



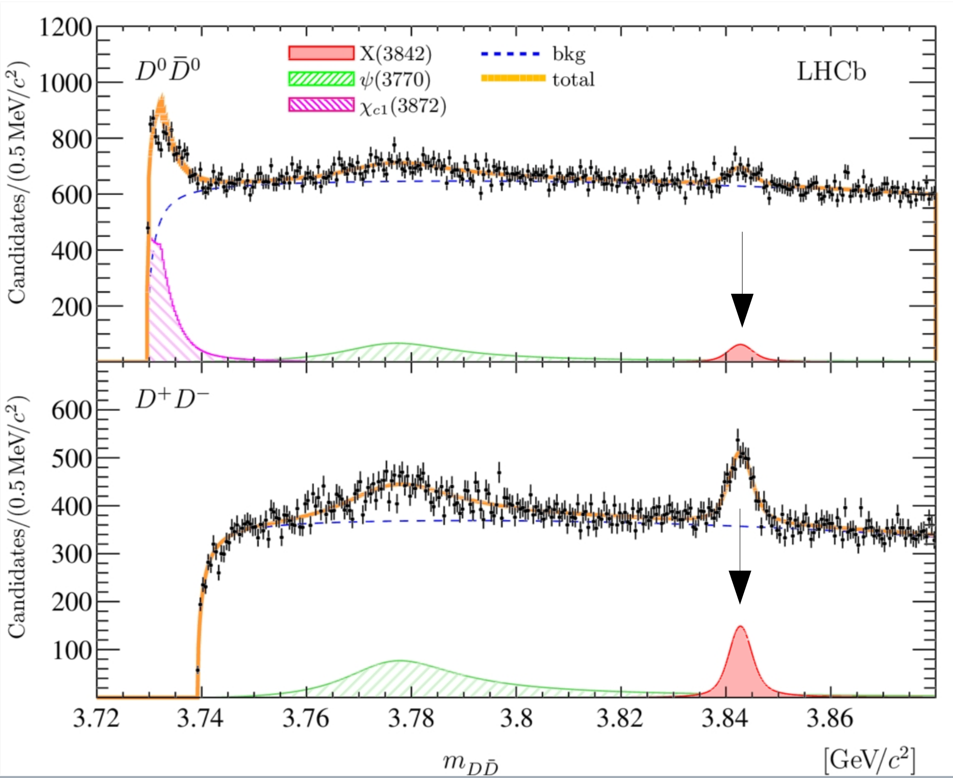


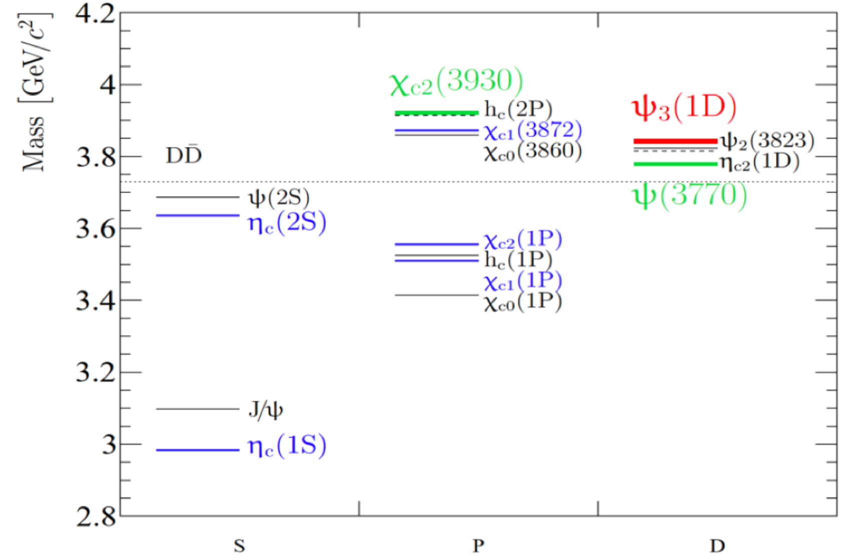
Observation of a new state in DD mass spectrum

[JHEP 07 (2019) 035]

full Run1+Run2 dataset

→ new narrow state observed in the invariant mass spectra of D^0D^0 and D^+D^-





$M_{X(3842)} = 3842.71 \pm 0.16 \pm 0.12$ MeV/c²

$\Gamma_{X(3842)} = 2.79 \pm 0.51 \pm 0.35$ MeV

narrow width → likely to be $\psi_3(1^3D_3)$ $J^{PC} = 3^{--}$

→ first observation of a spin-3 charmonium state

In addition: first observation of prompt hadroproduction of $\chi_{c2}(3930)$ and ψ(3770)

New resonances in the $\Lambda^0_b\pi^+\pi^-$ spectrum

[LHCb-PAPER-2019-025]

Full Run1+Run2 dataset
→ two new resonances in $\Lambda^0_b\pi^+\pi^-$ spectrum

- high mass state:
  decays via intermediate Σ_b and Σ_b^*
- low-mass state: decays Σ_b suppressed.

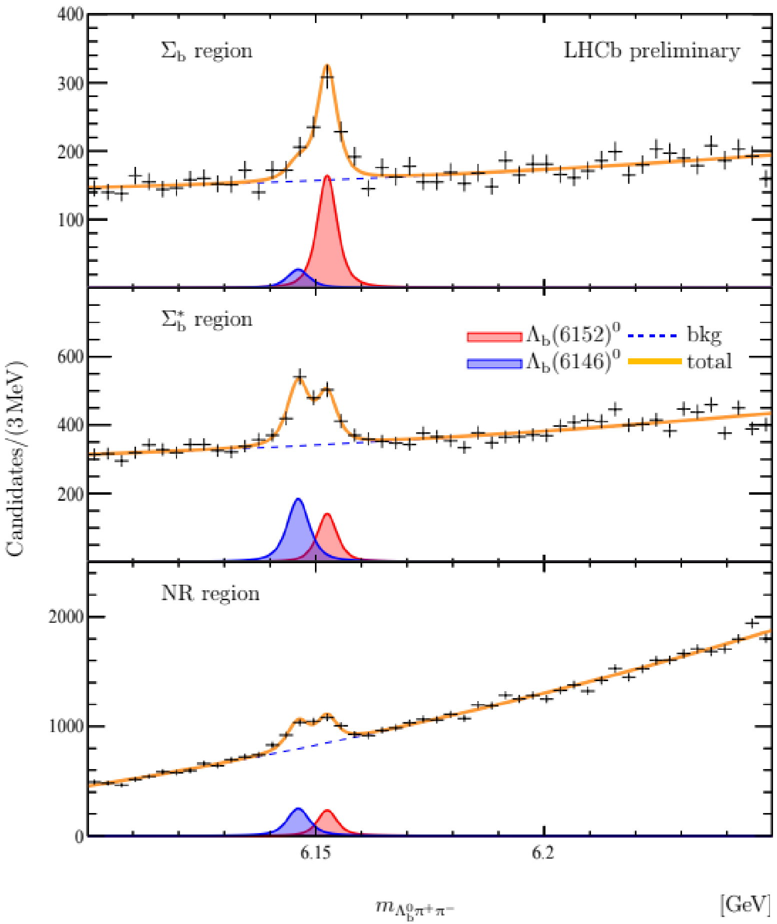
mass and mass-splitting are in very good agreement with expectation for Λ_b(1D)-doublet

LHCb preliminary

m(Λ_b(6152))=
6152.51 ± 0.26 ± 0.22 ± 0.16 MeV

M(Λ_b(6146))=
6146.15 ± 0.33 ± 0.22 ± 0.16 MeV

Γ(Λ_b (6152)) = 2.11 ± 0.81 ± 0.32 MeV
Γ(Λ_b (6146)) = 2.90 ± 1.28 ± 0.28 MeV



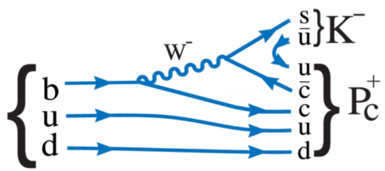
Andrii Usachov
QCD & Hadronic Physics, Sat 9:00

Observation of new pentaquark states

[Phys. Rev. Lett. 115 (2015) 072001]

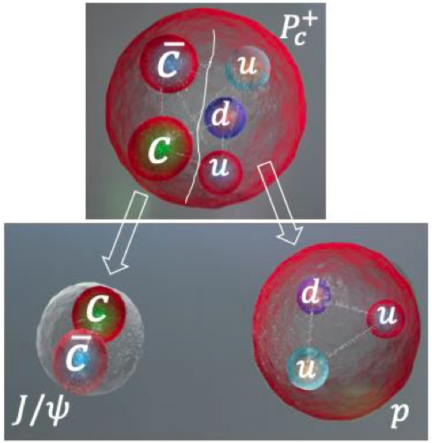
first pentaquarks observed by LHCb four years ago using $\lambda_b \rightarrow J/\psi Kp$

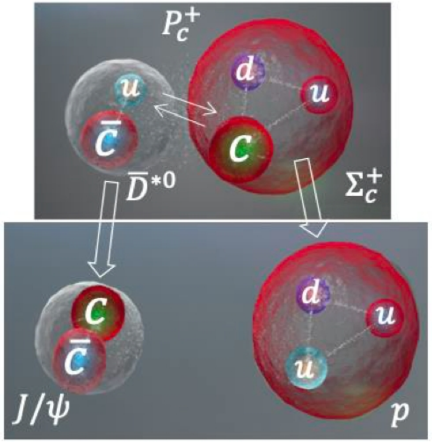
→ narrow $P_c(4450)^+$, broader $P_c(4380)^+$

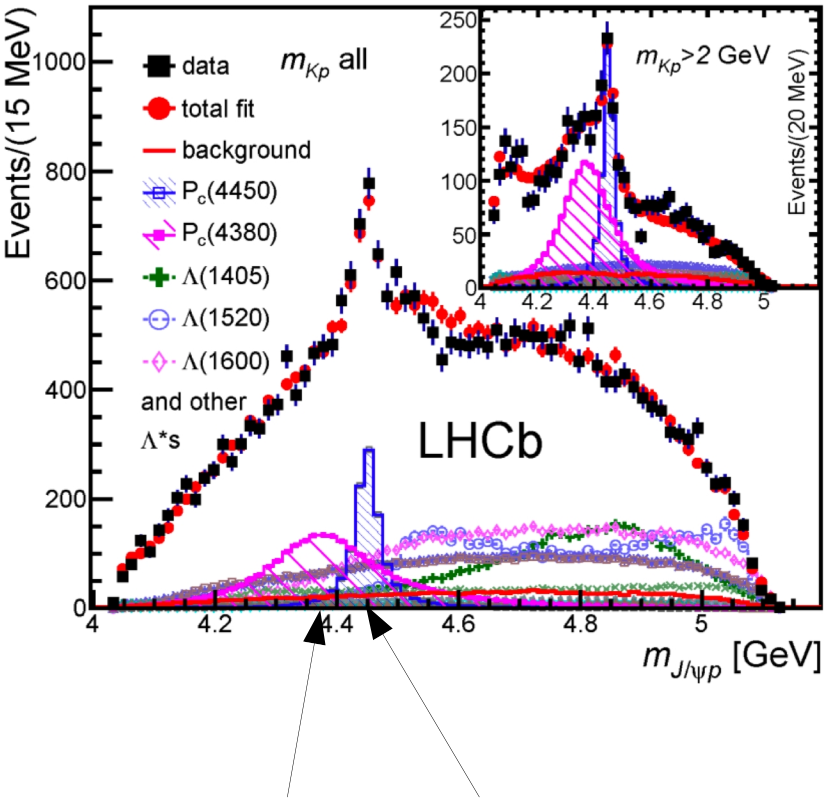


large theoretical interest in understanding the nature of the new states

tightly bound vs loosely bound molecular states







$P_c(4380)^+$ $P_c(4450)^+$

Biplab Dey
QCD & Hadronic Physics, Sat 10:30

Observation of new pentaquark states

[Phys. Rev. Lett. 122 (2019) 222001]

Update with full Run 2 statistics, 246'000 candidates

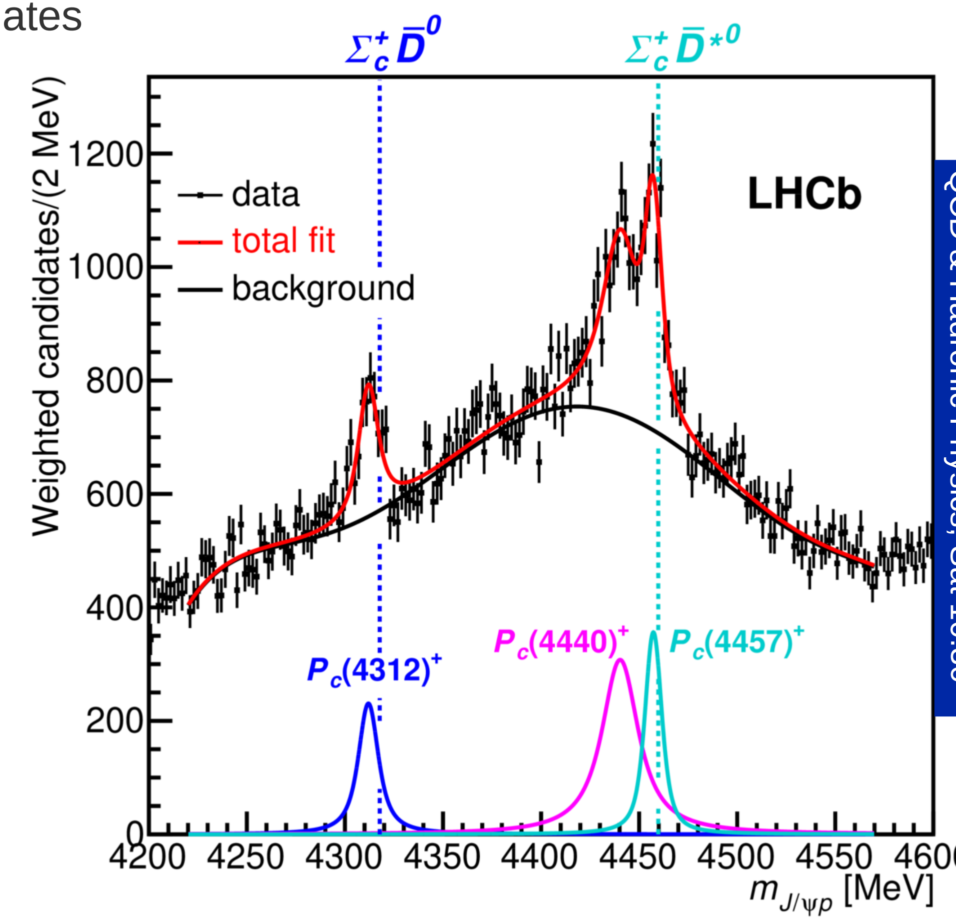
→ new peak at $P_c(4312)^+$ (7.3σ)

→ broad $P_c(4450)^+$ resolved as two narrow states (5.4σ): $P_c(4440)^+$ and $P_c(4457)^+$

minimal quark content duucc

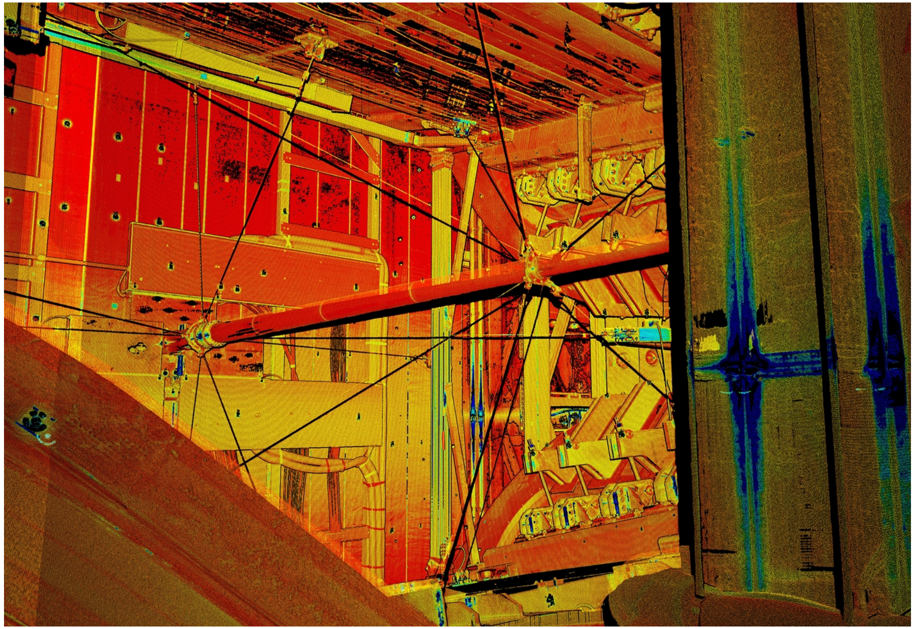
narrow and close to $\Sigma_c^+D^0$ and $\Sigma_c^+D^{*0}$ ([duc][uc]) mass thresholds

→ extremely important result to shed light on the nature of these exotic states



Biplab Dey
QCD & Hadronic Physics, Sat 10:30

Heavy ion and fixed target



- charm
- beauty
- spectroscopy
- **heavy ion fixed target**
- upgrade

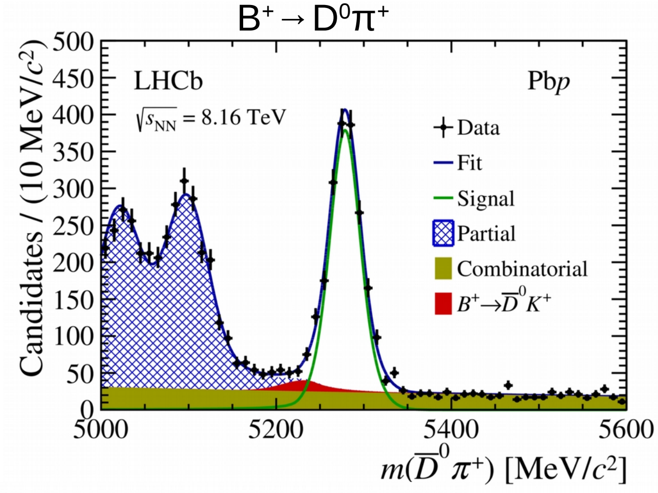
- b-hadron production in proton-lead collisions [Phys. Rev. D99 052011 (2019)]
- Charm production in fixed target collisions [PRL 122 (2019) 132002]

b-hadron production in proton-lead collisions

[Phys. Rev. D99 052011 (2019)]

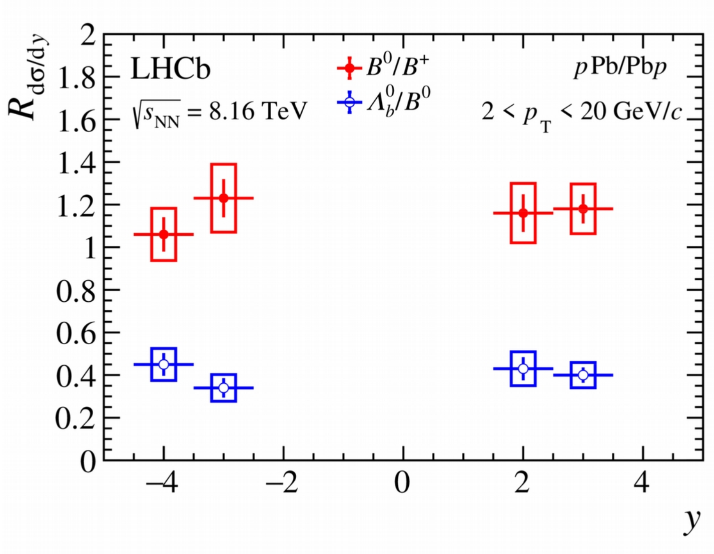
Production of B^0, B^+ and λ_b in proton-lead cm enery 8.16 TeV with exclusive decay modes

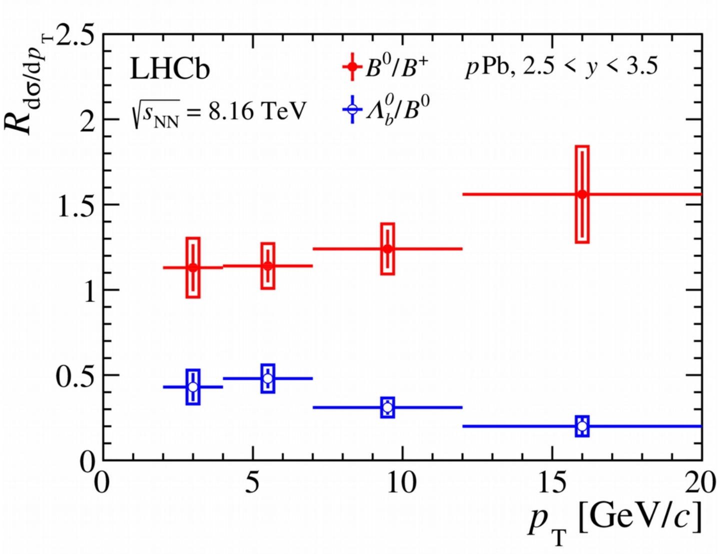
→ first measurement of beauty hadron production at p_T< mass of the hadrons in the forward region



→ input for fits of the nuclear PDFs

→ fragmentation models in nuclear environment





Yanxi Zhang
Heavy Ion Physics, Thu 16:30

Charm production in fixed target collisions

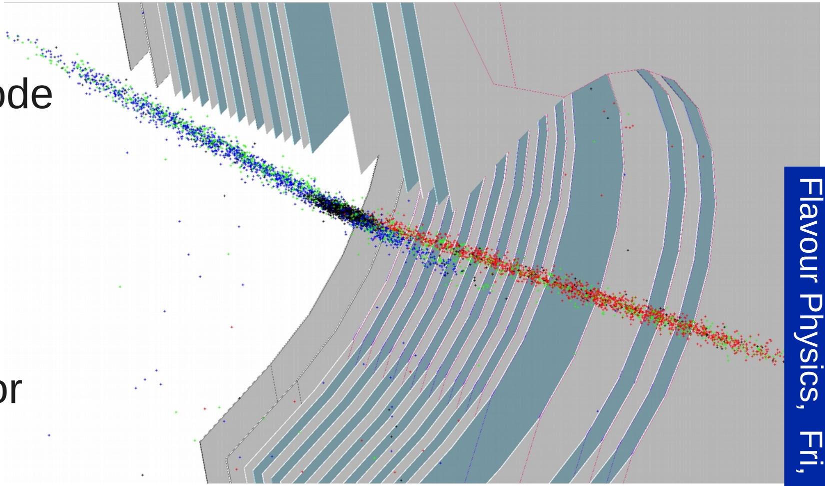
[PRL 122 (2019) 132002]

Unique opportunity for measurements in fixed target mode

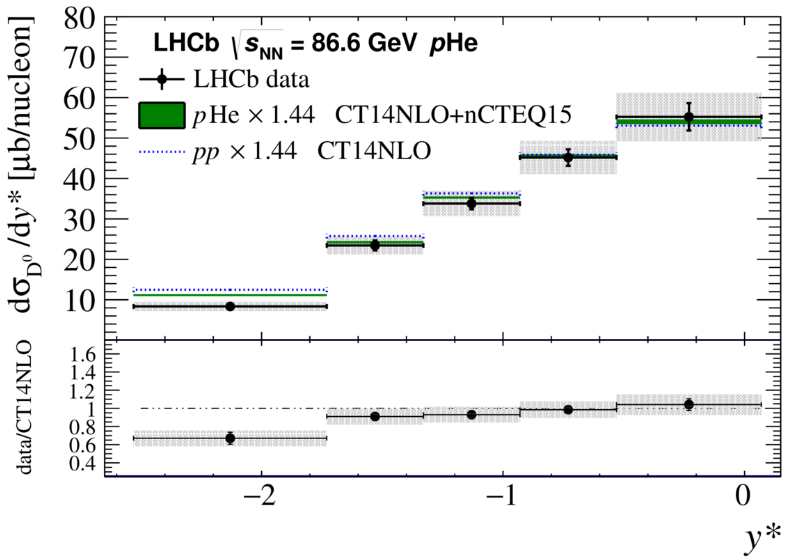
first measurement of J/ψ and D^0 production in
pHe @86.6 GeV pA @110.4 GeV

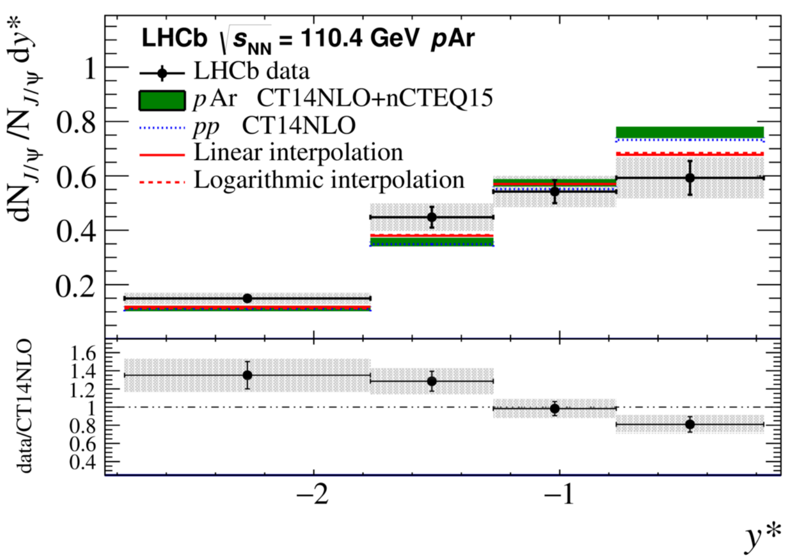
→ sensitive to large Bjorken-x, up to x=0.37 for D^0

D^0 good agreement in rapidity shapes → no evidence for significant contribution of valence-like intrinsic charm

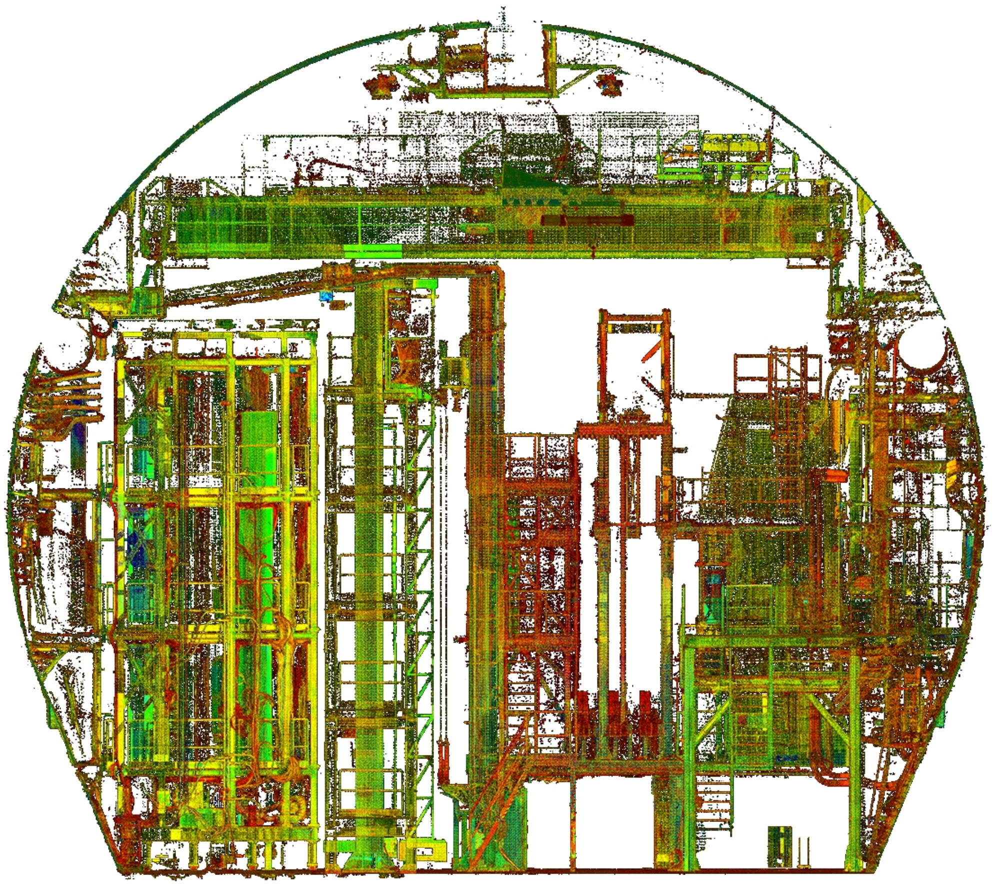


Felipe Rosales
Flavour Physics, Fri, 11:30





LHCb is transforming



charm

beauty

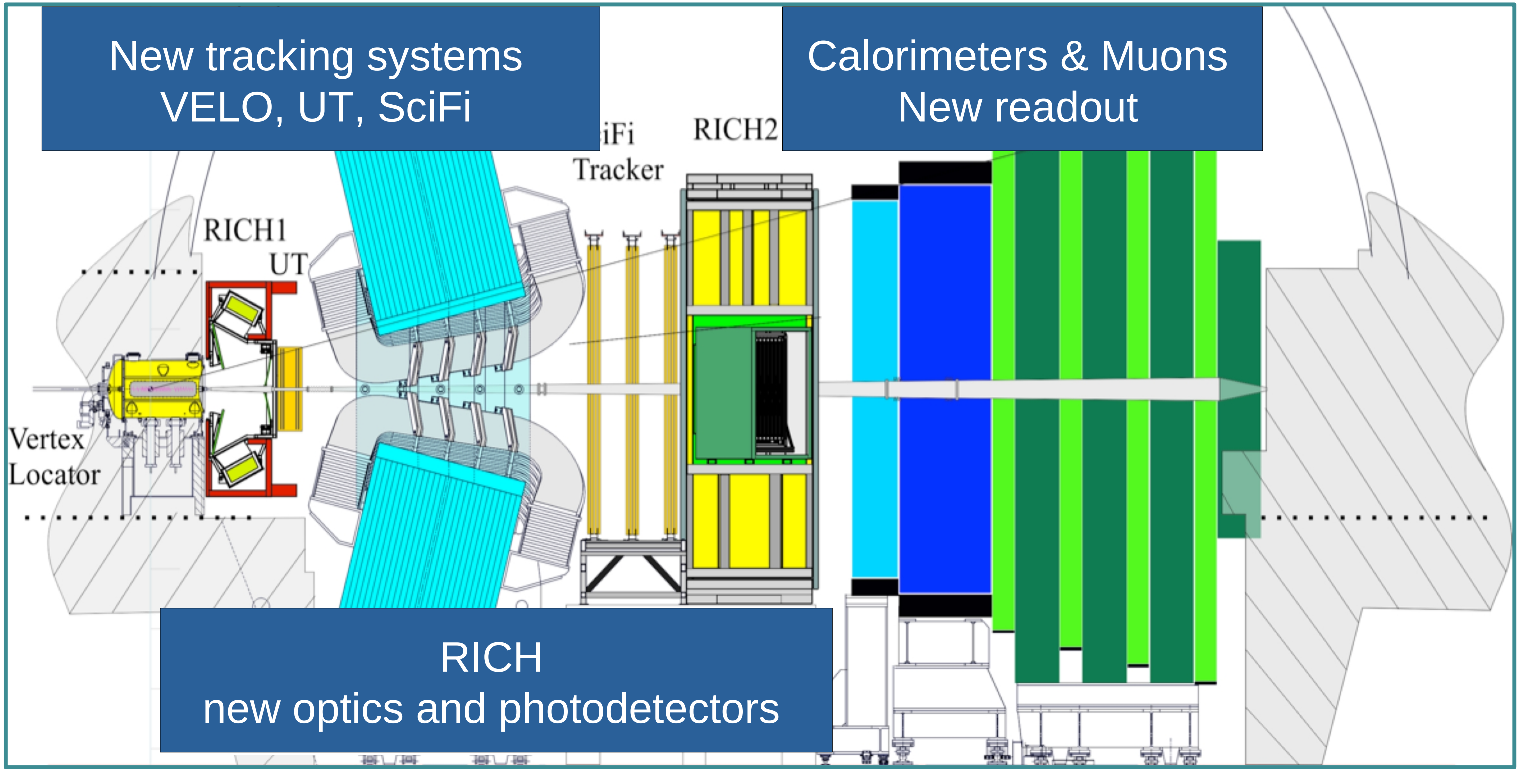
spectroscopy

heavy ion
fixed target

upgrade

LHCb upgrade – upgrade I

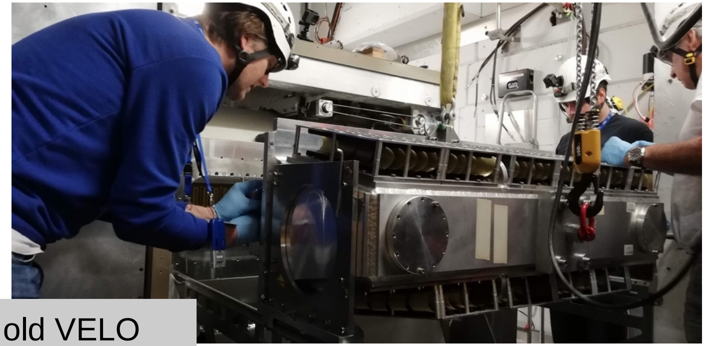
Going on right now!
remove the hardware trigger → all detectors read out at 30 MHz



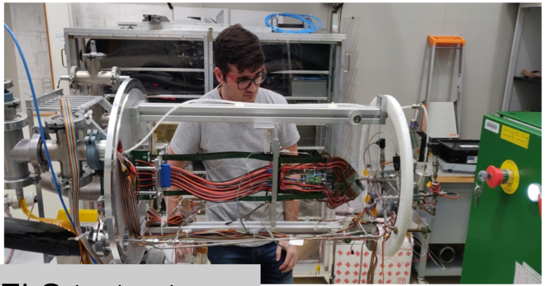
[CERN-LHCC 2014-001]
[CERN-LHCC 2014-016]
[CERN LHCC 2013-021]
[CERN-LHCC 2013-022]

→ this will be a new detector at LHCb

LHCb upgrade – work in progress


remove old VELO

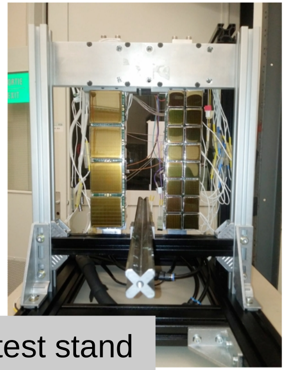

UT stave


VELO test setup


remove beampipe

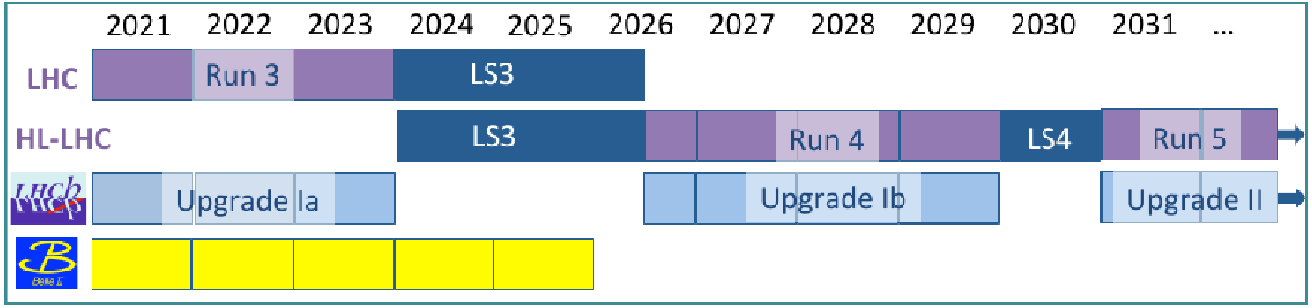

VELO RF boxes

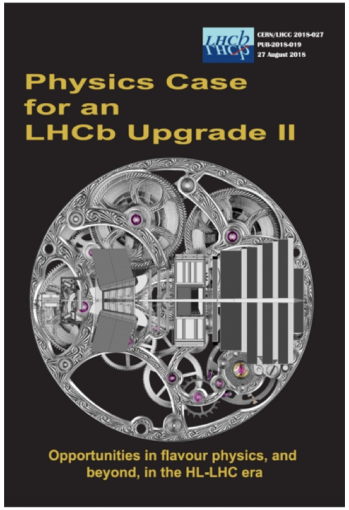

dismantling muon station


RICH test stand

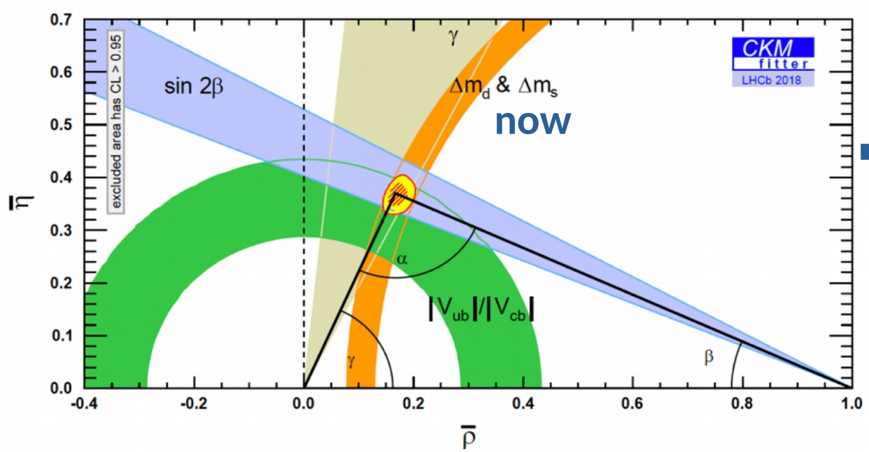

Event builder prototype

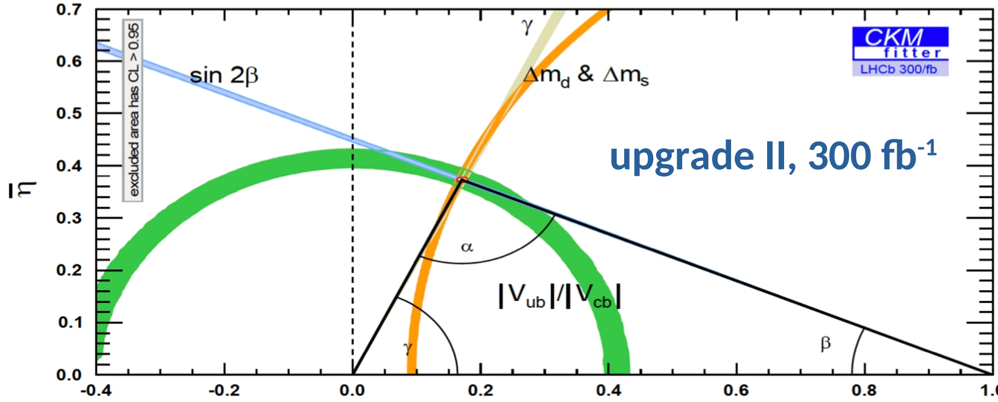
And looking further – upgrade II





- Aim to collect > 300 fb^{-1} at L = $2x10^{34}$, x10 with respect to Upgrade I
- Consolidate in LS3, major upgrade in LS4
- Expression of Interest issued in 2017, feasibility study [CERN-ACC-NOTE-2018-0038]
- Physics case document released [CERN-LHCC-2018-027]
- Green light from LHCC to proceed to TDRs (expected ~late 2020)

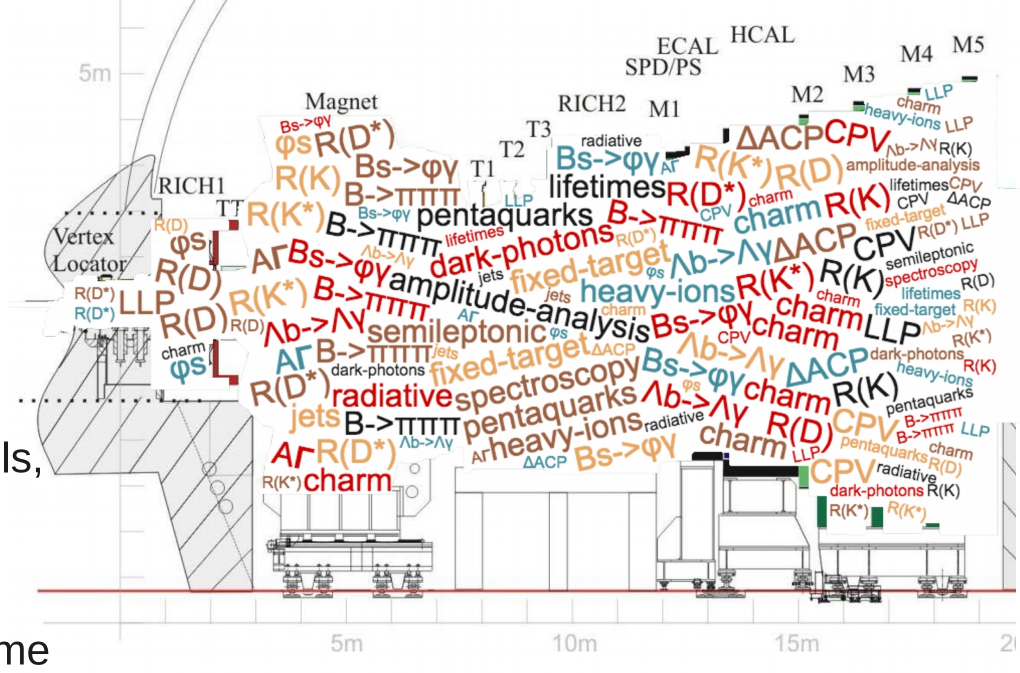




Conclusion and outlook

Plenty of interesting results still coming from LHCb Run1-2

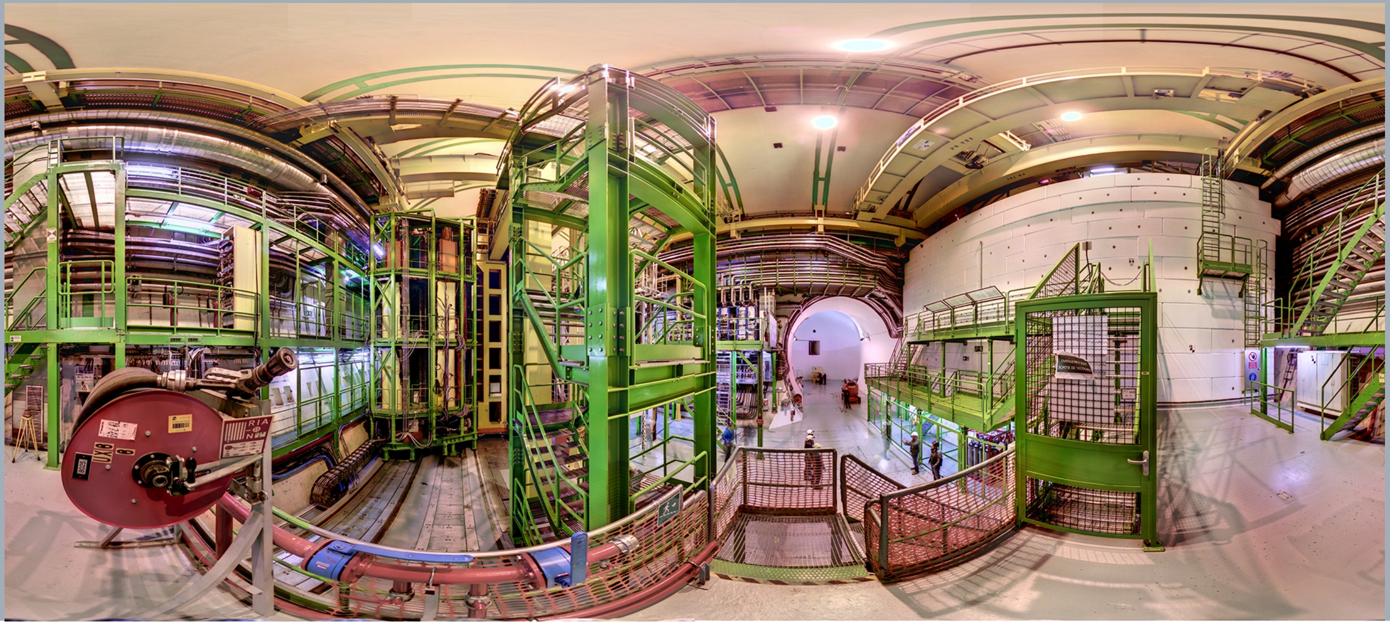
LHCb upgrade opens the door to many improvements in precision, so interesting times are ahead!



LHCb has a bright future

- Tensions on lepton flavour universality will be clear in a few years
- Sensitivity to NP in many interesting channels, more will open with upgraded detector
- Precision measurements of SM parameters
- Heavy Ion and fixed target physics programme has much to add

Backup

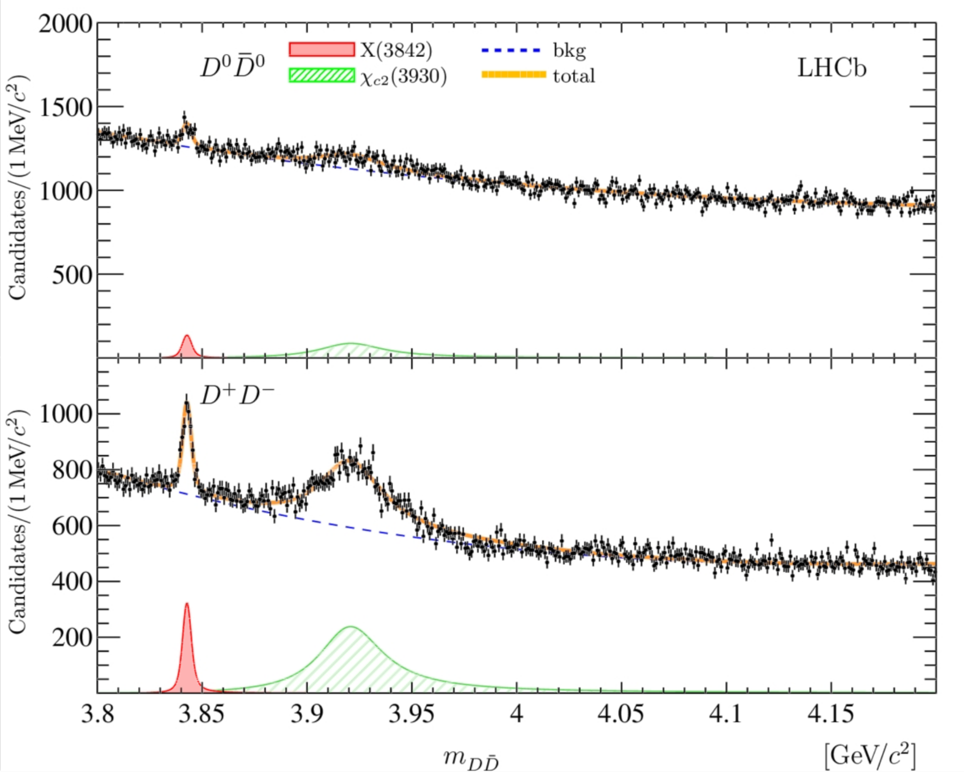


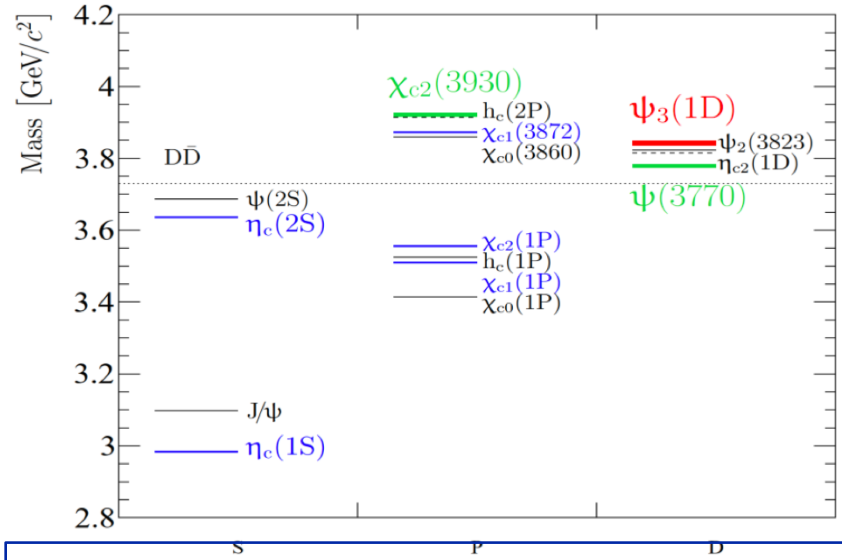
Observation of a new state in DD mass spectrum

[arXiv: 1903.12240]

Full Run1+Run2 dataset

New narrow state observed in the invariant mass spectra of D^0D^0 and D^+D^-





$M_{\chi c2(3930)}$=3921.9 ± 0.6 ± 0.2 MeV/c^2

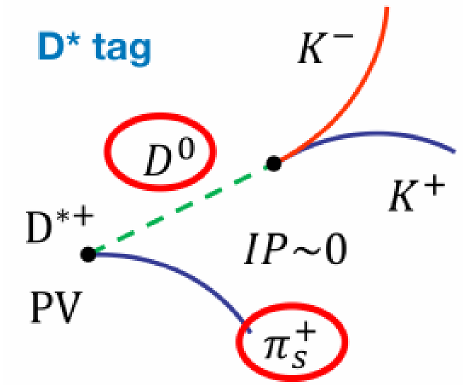
$\Gamma_{\chi c2(3930)}$ =36.6 ± 1.9 ± 0.9 MeV

→ first observation of prompt hadroproduction of $\chi_{c2}(3930)$

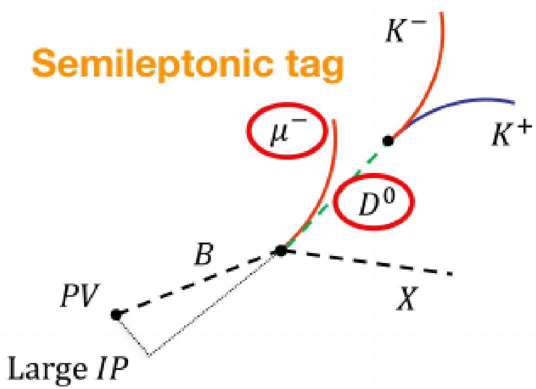
Tagging flavour of charmed meson

[Phys. Rev. Lett. 122 (2019) 211803]

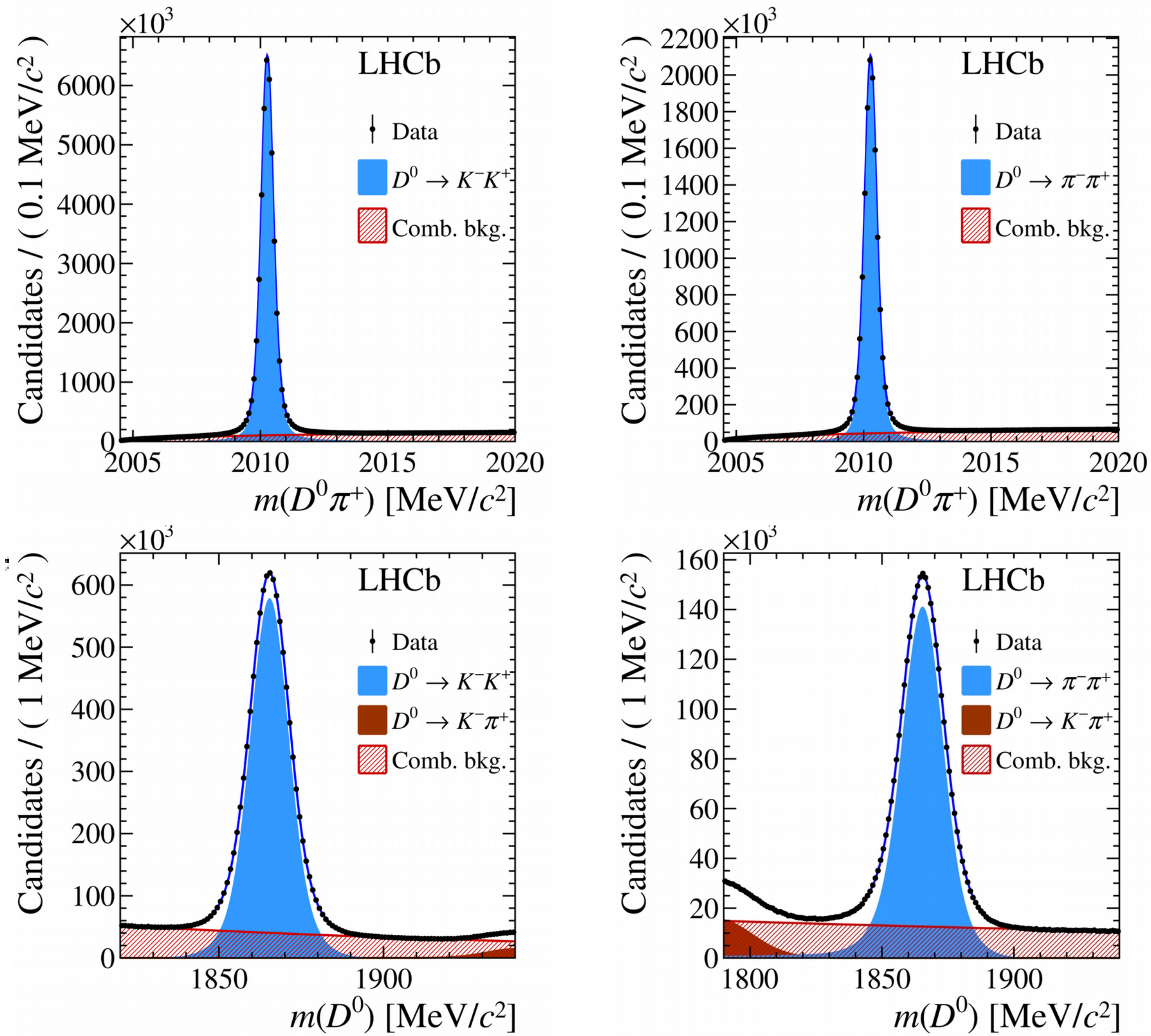
two independent ways



$$A_{\rm raw}^{\pi\text{-tagged}}(f) \approx A_{CP}(f) + A_{\rm D}(\pi) + A_{\rm P}(D^*),$$



$$A_{\rm raw}^{\mu\text{-tagged}}(f) \approx A_{CP}(f) + A_{\rm D}(\mu) + A_{\rm P}(B)$$



New combination of γ measurements

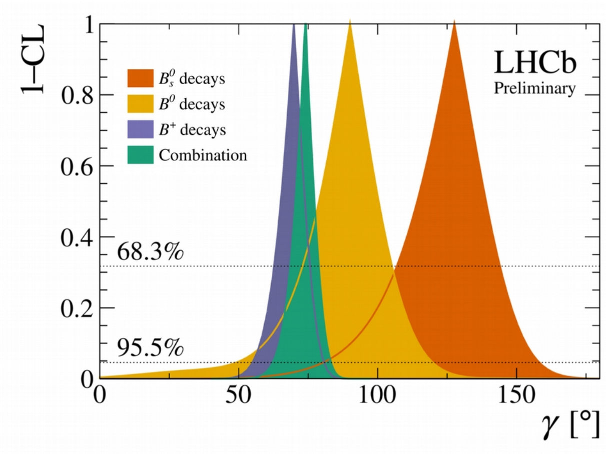
[LHCb-CONF-2018-002]

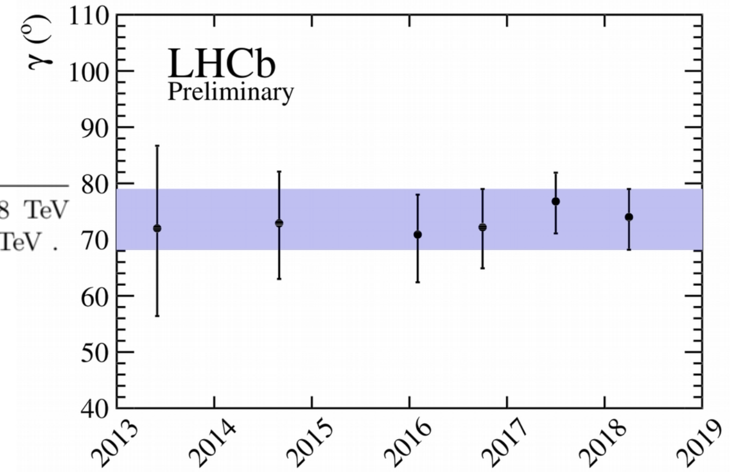
Combination of many tree level determinations

Using frquentist treatment

B decay	D decay	Method	Ref.	Dataset†	Status since last combination [3]
$B^+ \to DK^+$	$D \to h^+h^-$	GLW	[14]	Run 1 & 2	Minor update
$B^+ \to DK^+$	$D \to h^+h^-$	ADS	[15]	Run 1	As before
$B^+ \to DK^+$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[15]	Run 1	As before
$B^+ \to DK^+$	$D \to h^+h^-\pi^0$	GLW/ADS	[16]	Run 1	As before
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[17]	Run 1	As before
$B^+ \to DK^+$	$D \to K^0_S h^+h^-$	GGSZ	[18]	Run 2	New
$B^+ \to DK^+$	$D \to K^0_S K^+\pi^-$	GLS	[19]	Run 1	As before
$B^+ \to D^*K^+$	$D \to h^+h^-$	GLW	[14]	Run 1 & 2	Minor update
$B^+ \to DK^{*+}$	$D \to h^+h^-$	GLW/ADS	[20]	Run 1 & 2	Updated results
$B^+ \to DK^{*+}$	$D \to h^+\pi^-\pi^+\pi^-$	GLW/ADS	[20]	Run 1 & 2	New
$B^+ \to DK^+\pi^+\pi^-$	$D \to h^+h^-$	GLW/ADS	[21]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to K^+\pi^-$	ADS	[22]	Run 1	As before
$B^0 \to DK^+\pi^-$	$D \to h^+h^-$	GLW-Dalitz	[23]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	GGSZ	[24]	Run 1	As before
$B^0_s \to D_s^{\mp}K^{\pm}$	$D_s^+ \to h^+h^-\pi^+$	TD	[25]	Run 1	Updated results
$B^0 \to D^{\mp}\pi^{\pm}$	$D^+ \to K^+\pi^-\pi^+$	TD	[26]	Run 1	New

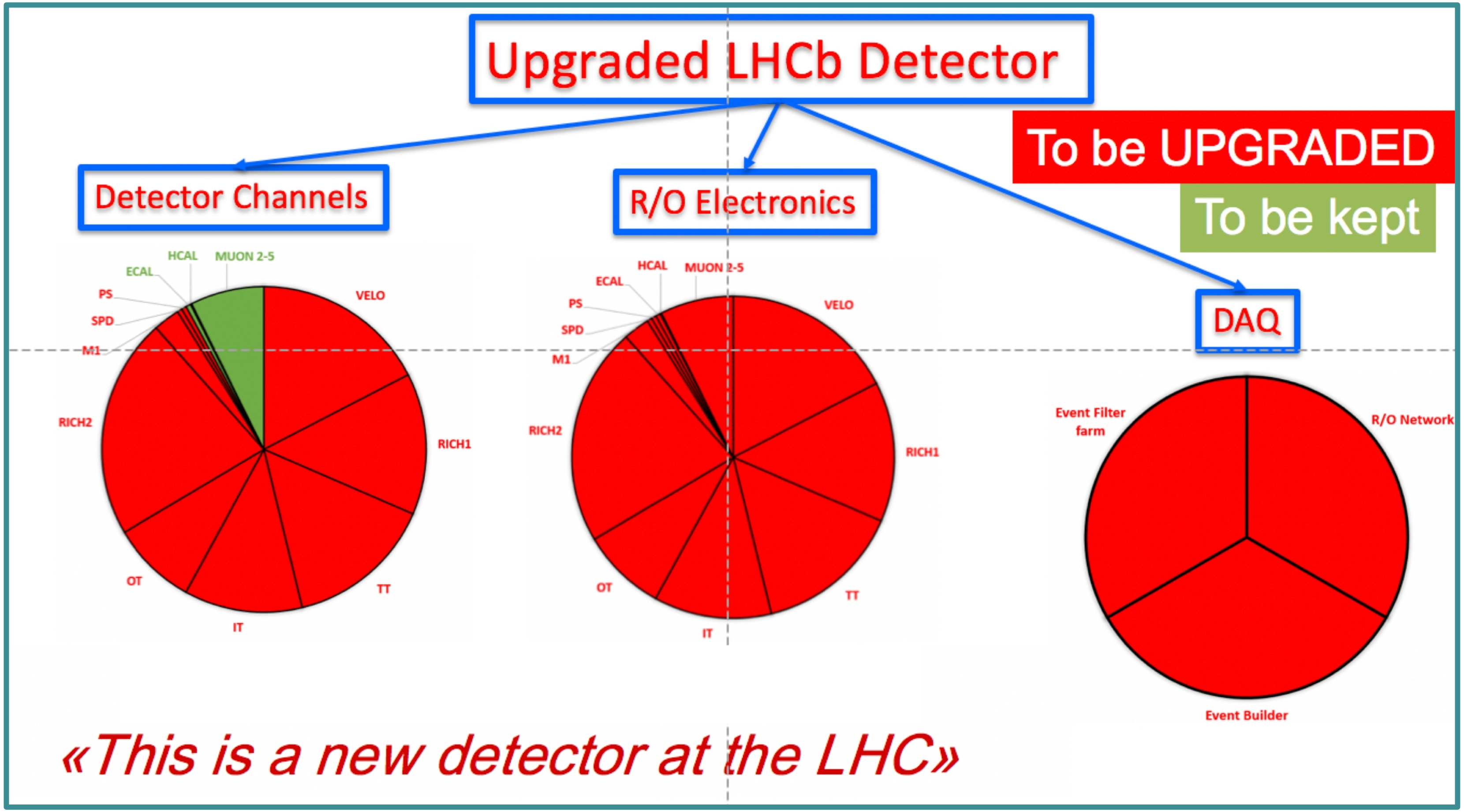
† Run 1 corresponds to an integrated luminosity of 3 fb^{-1} taken at centre-of-mass energies of 7 and 8 TeV . Run 2 corresponds to an integrated luminosity of 2 fb^{-1} taken at a centre-of-mass energy of 13 TeV .





Run 2 measurements with 2 fb^{-1} (4 fb^{-1} yet to be included)

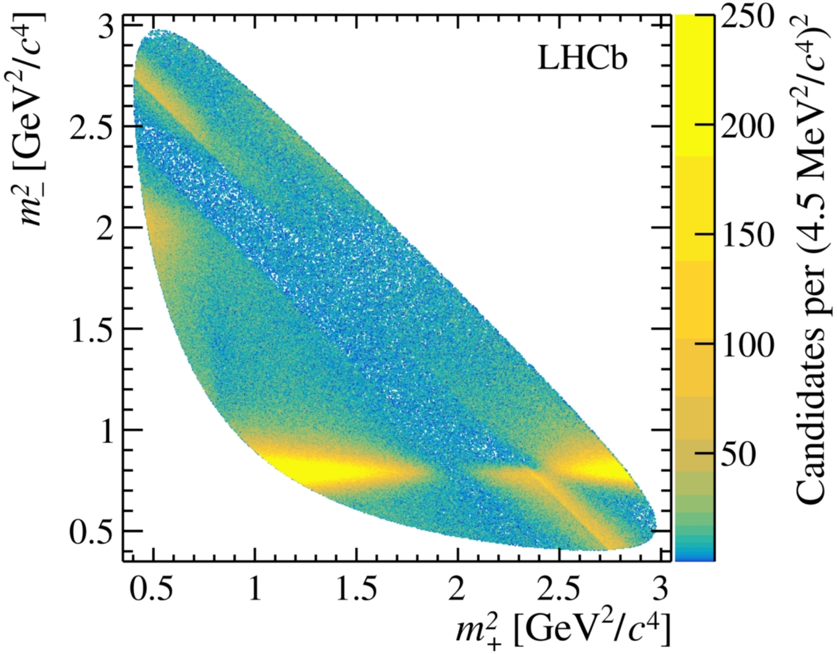
$$\gamma = \left(74.0^{+5.0}_{-5.8}\right)^{o}$$

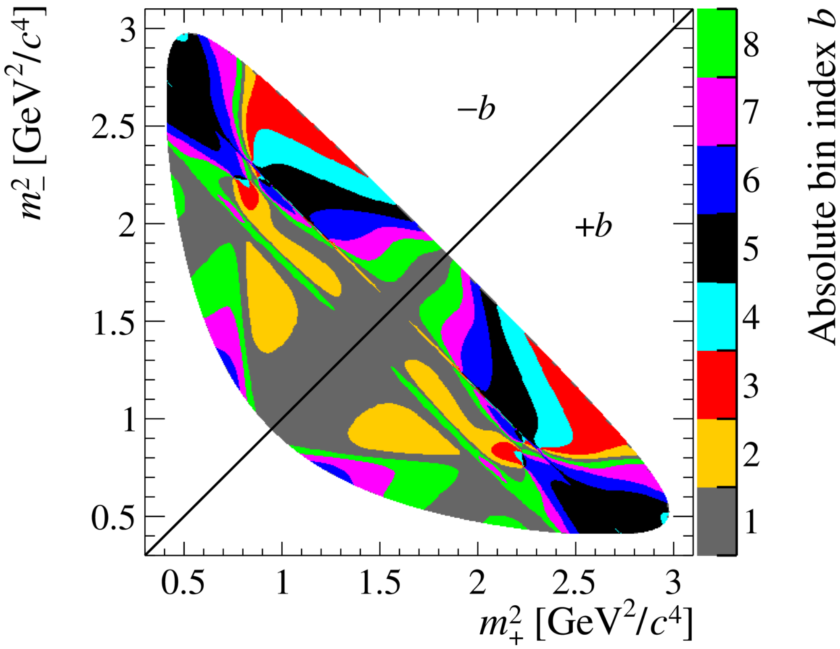

Upgraded LHCb Detector
Detector Channels
R/O Electronics
DAQ
To be UPGRADED
To be kept
HCAL
MUON 2-5
ECAL
PS
SPD
M1
VELO
RICH1
RICH2
OT
IT
TT
Event Filter farm
R/O Network
Event Builder
«This is a new detector at the LHC»

[Phys. Rev. Lett 122 (2019) 231802]

Model independent approach (bin-flip method)
Data is binned in Dalitz coordinates
binning scheme: approximately constant strong-phase differences

measure the yield ratio $R^{\pm}_{bj}$ between −b and b in bins of decay time





Phys. Rev. D99 (2019) 012007, arXiv:1811.01032l

[Phys. Rev. Lett. 122 (2019) 222001]

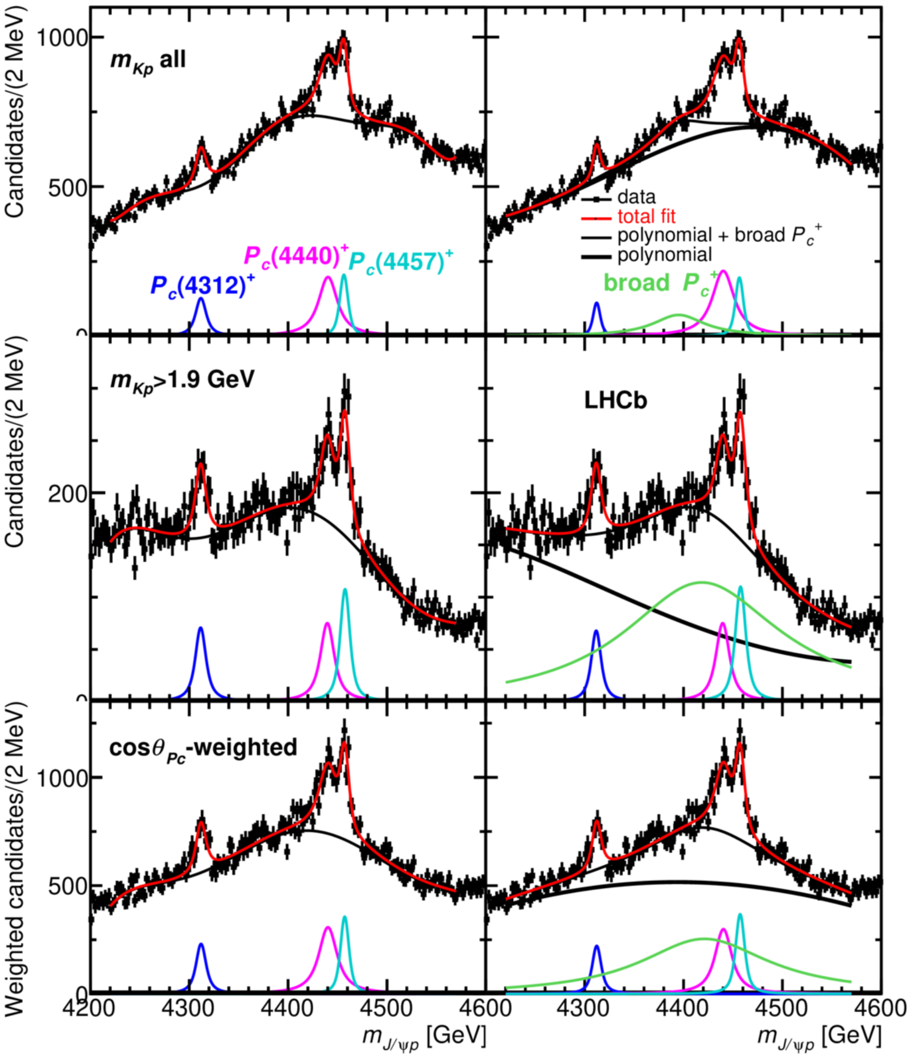
246’000 candidates

→ new peak at $P_c(4312)^+$ (7.3σ)

→ broad $P_c(4450)^+$ resolved as two narrow states (5.4σ): $P_c(4440)^+$ and $P_c(4457)^+$

m>1.9 GeV
remove λ*

Reweighted
to enhance
signal



LHCb – a multipurpose detector in the forward region

- Indirect searches for New Physics at the multi-TeV scale
  decays of beauty and charm hadron
  CP violation
- Understanding the details of QCD
  Heavy flavour production, pentaquark states,
  double heavy states, top physics, jets …
- Quark gluon plasma, cold nuclear effects in heavy ion collisions
  Heavy flavour production in p-Pb collisions, fixed target collisions

Doubly charmed baryons

[arXiv:1905.02421]

Search for: $\Xi_{cc}^{++} \to D^+ (\to K^-\pi^+\pi^+)\, pK^-\pi^+$

no signal found → $\mathcal{R} = \frac{\mathcal{B}(\Xi_{cc}^{++} \to D^+ pK^-\pi^+)}{\mathcal{B}(\Xi_{cc}^{++} \to \Lambda_c^+ K^-\pi^+\pi^+)} < 1.5 \times 10^{-2}$ @ 90% CL