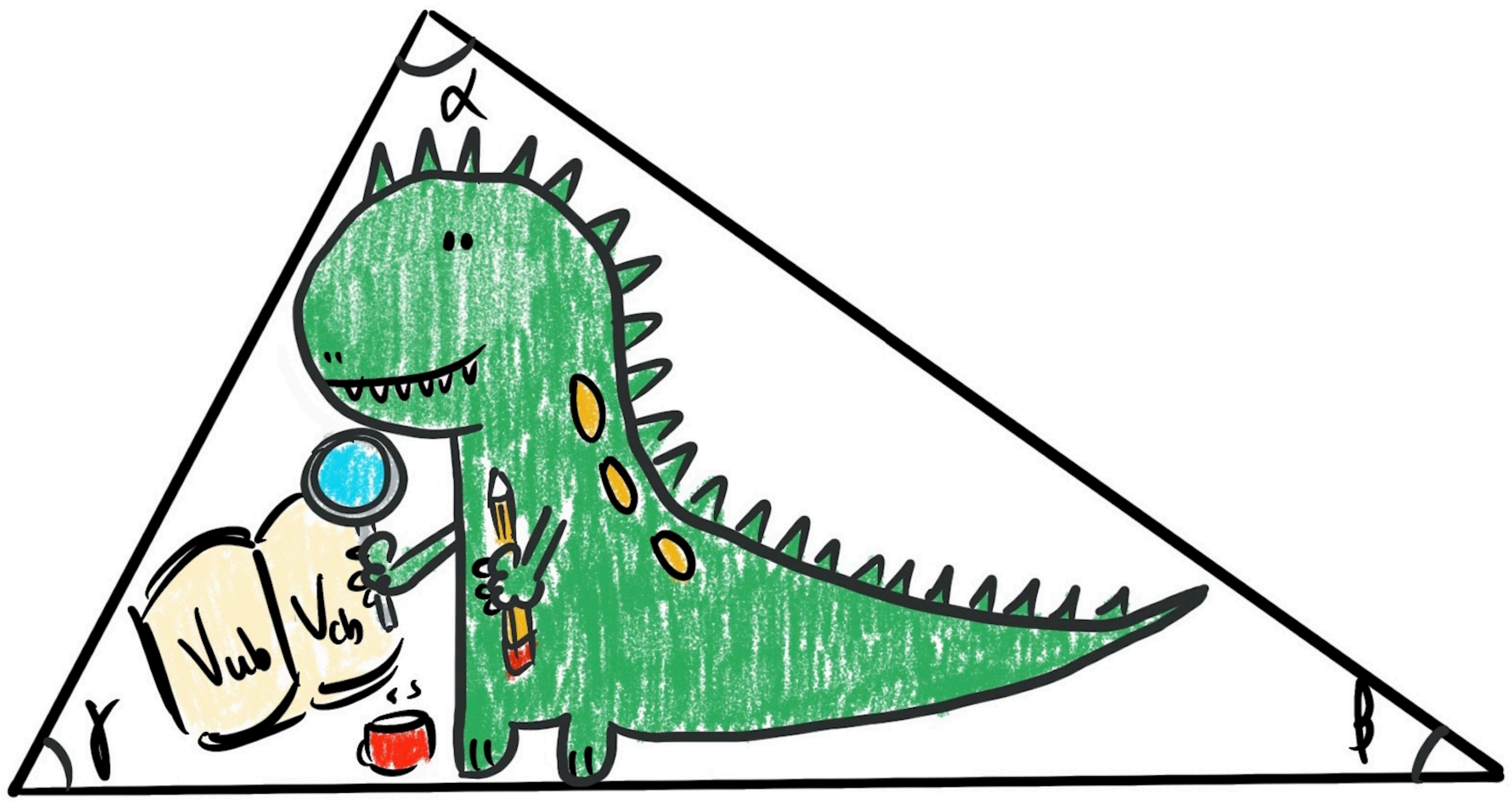


CKM physics hadronic machines

On behalf of the LHCb collaboration including results from ATLAS & CMS

18.09.2023

Yasmine Amhis

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

CERN

Recommendation for today's talk

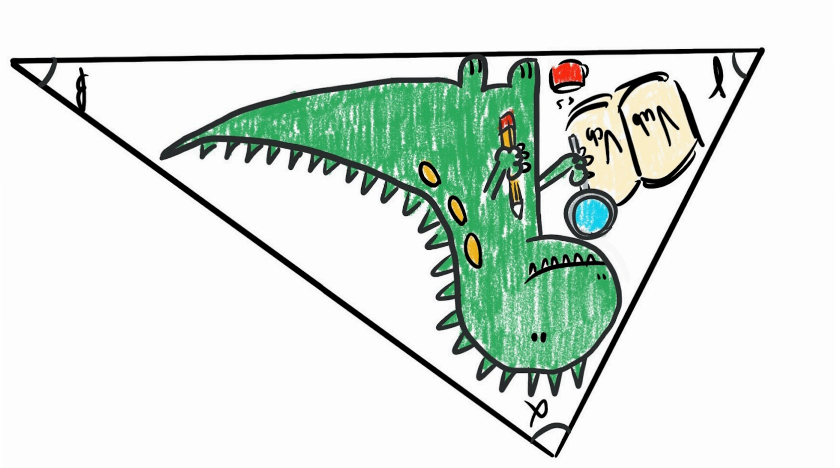
Talk about the Physics but don't give away the new results

Leave something for the summary speakers

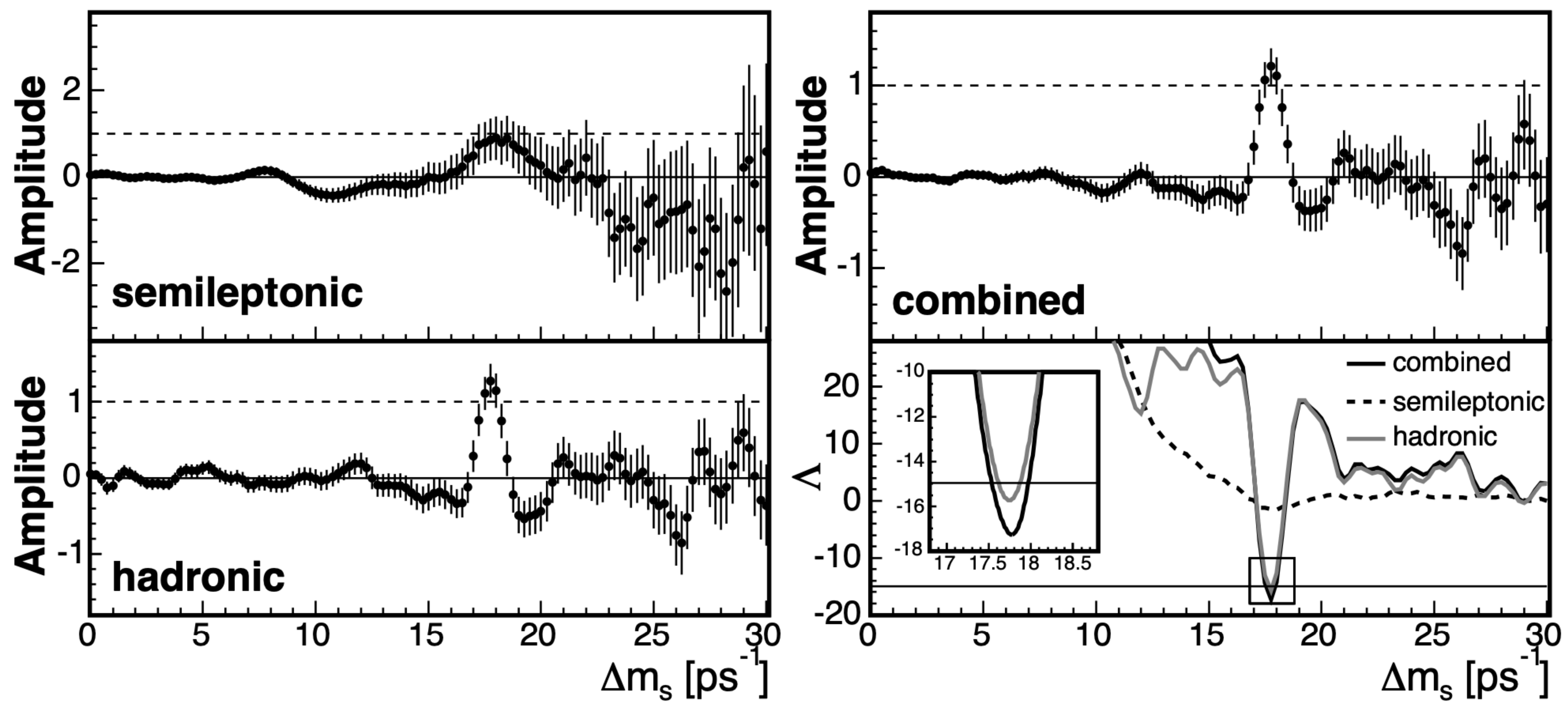
Don't go to far in History

No need to be hyper pedagogical this is a specialised workshop

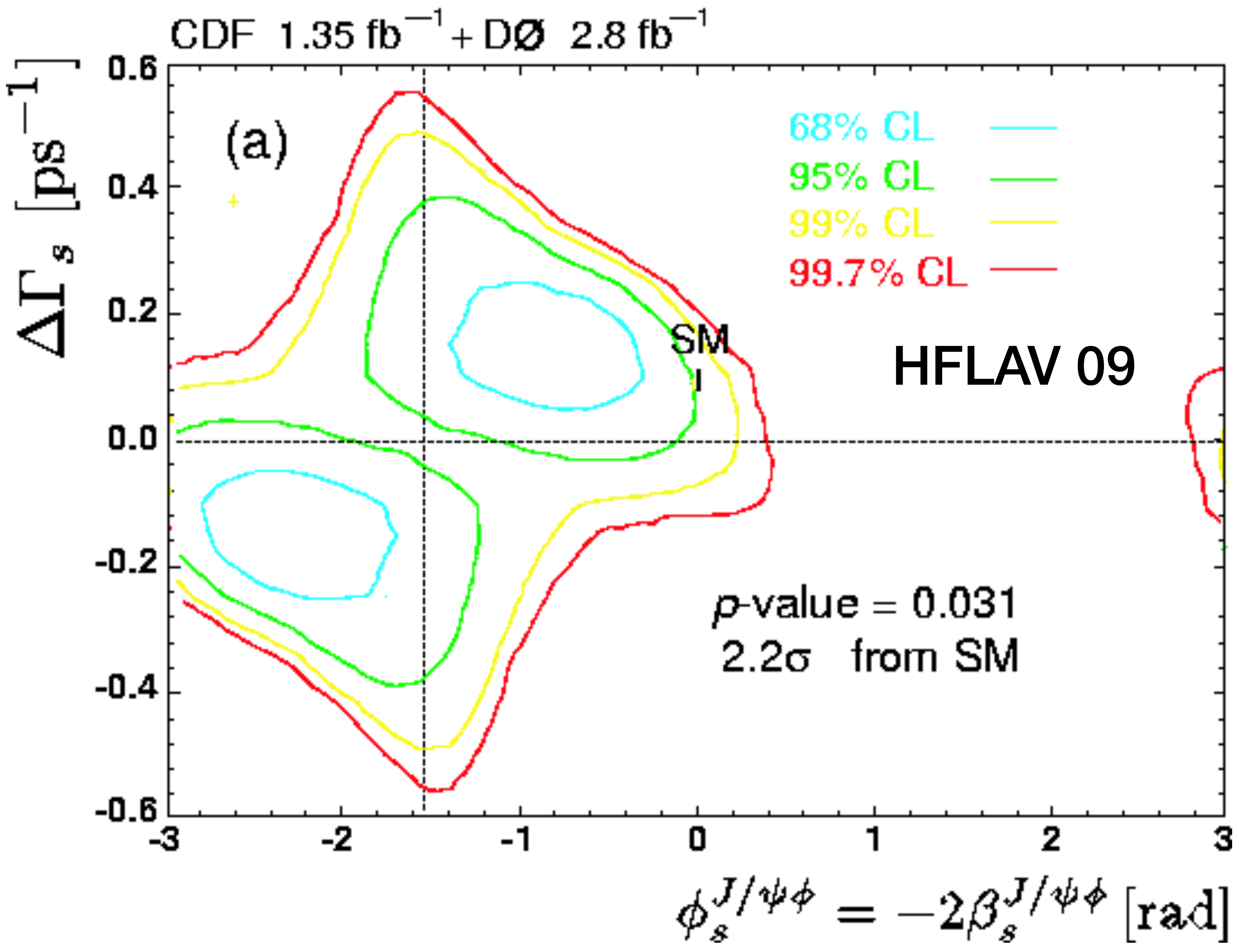
Don't wear a t-shirt form an other experiment



Fermilab paved the path of B_s physics

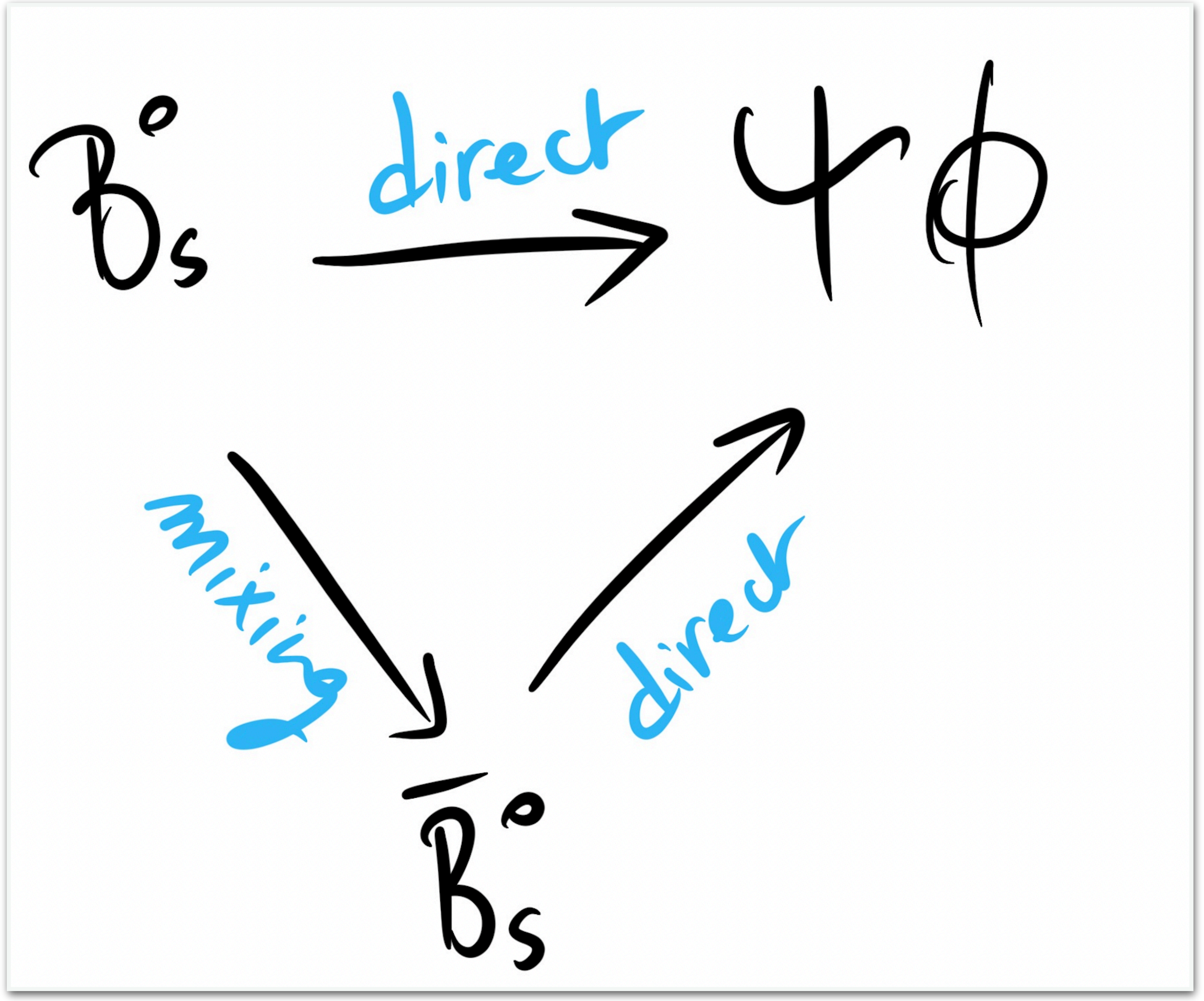


arXiv:0609040



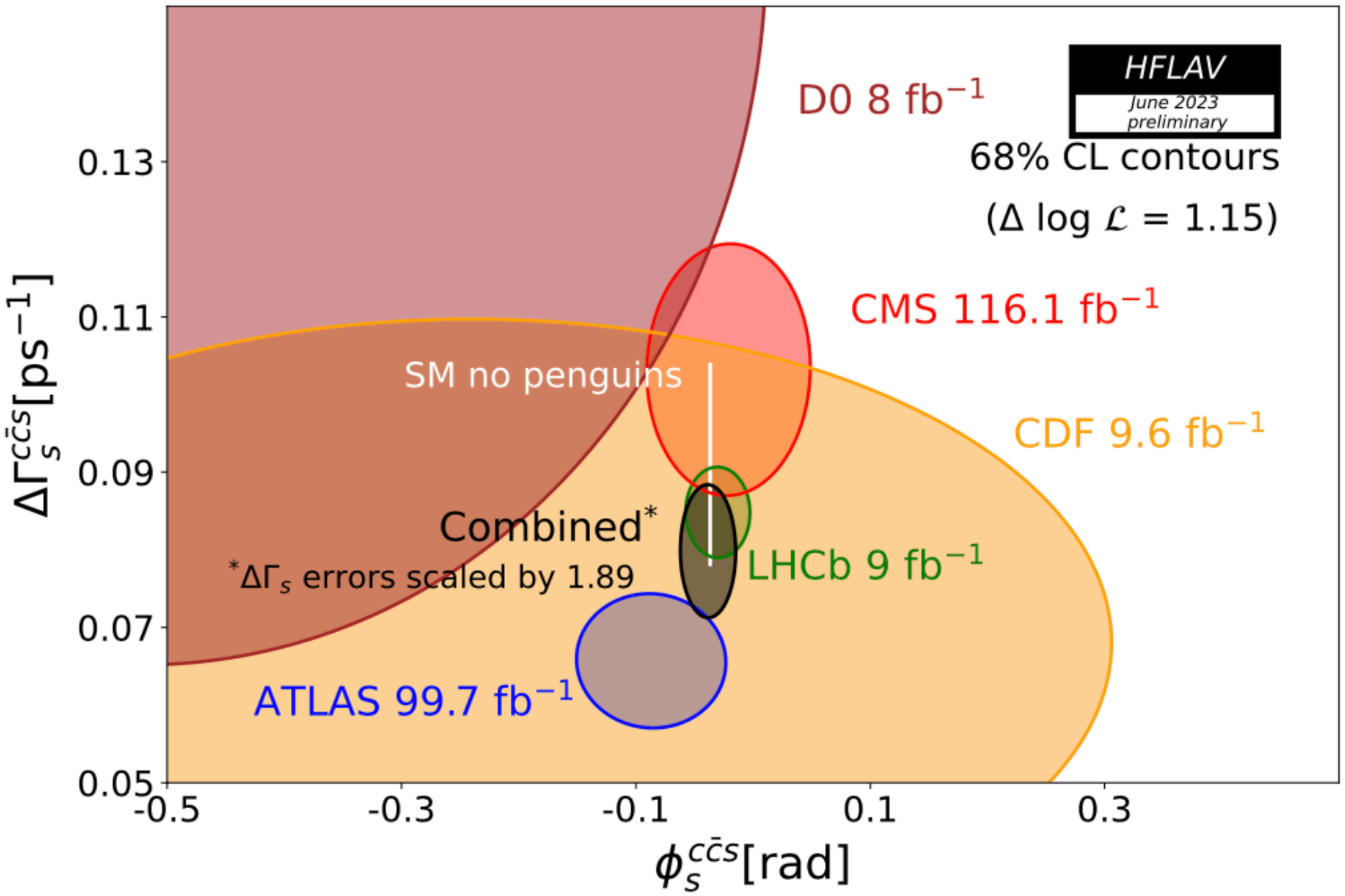
HFLAV 09

Fast forward to today



Melissa's talk

LHCb-PAPER-2023-016



What about the other observables?

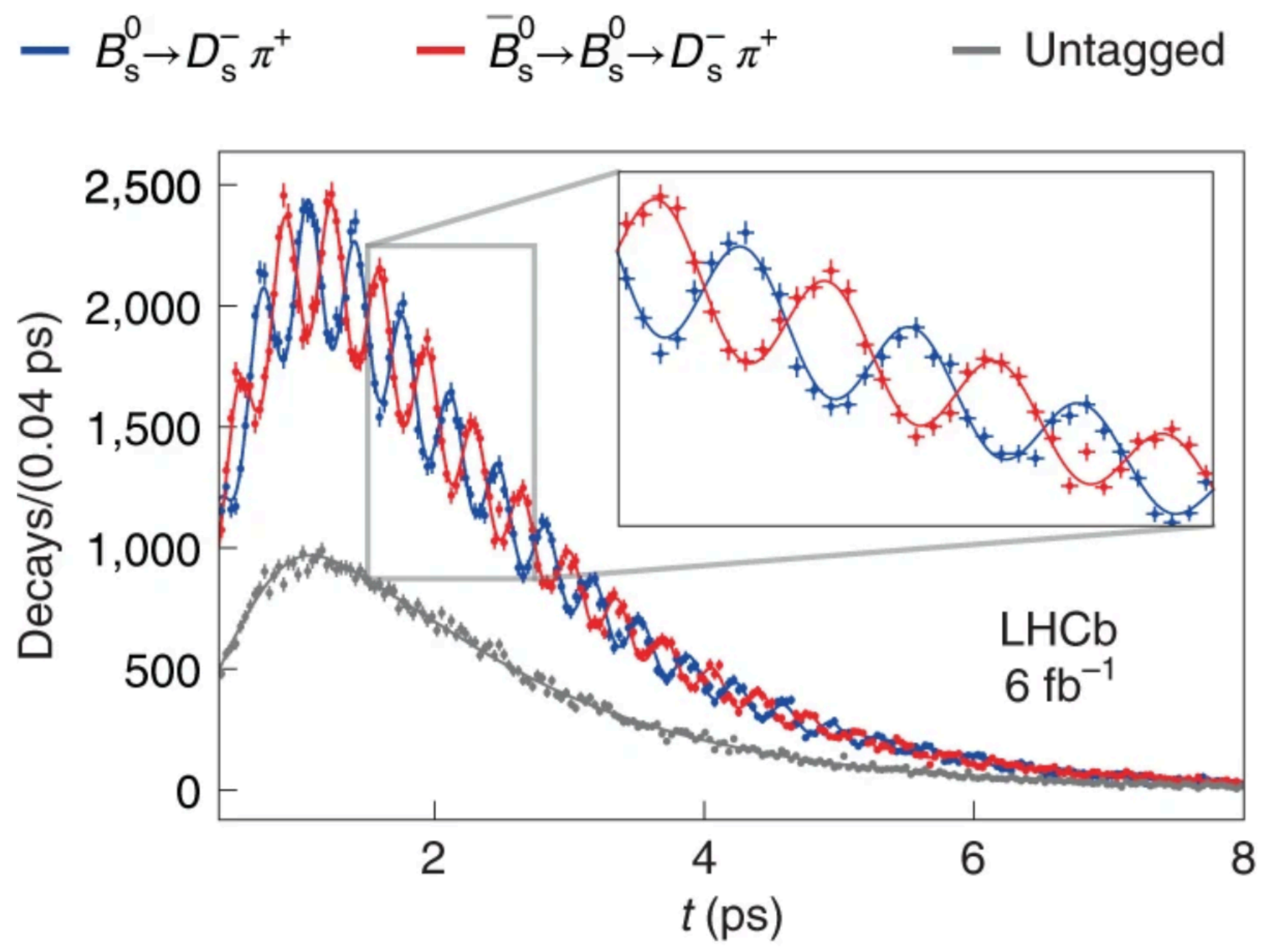
- $$i\frac{d}{dt}\begin{pmatrix}|B_q^0(t)\rangle\\ |\bar{B}_q^0(t)\rangle\end{pmatrix} = \mathcal{H}\begin{pmatrix}|B_q^0(t)\rangle\\ |\bar{B}_q^0(t)\rangle\end{pmatrix}$$

where $\mathcal{H} = \left(M - \frac{i}{2}\Gamma\right) = \begin{pmatrix}M_{11} & M_{12}\\ M_{12}^* & M_{22}\end{pmatrix} - \frac{i}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12}\\ \Gamma_{12}^* & \Gamma_{22}\end{pmatrix}$

(M: Mass Matrix; Γ: Decay Matrix)

$M = M^\dagger$ and $\Gamma = \Gamma^\dagger$, CPT $\Rightarrow M_{11} = M_{22} = m_q$ and $\Gamma_{11} = \Gamma_{22} = \Gamma_q$

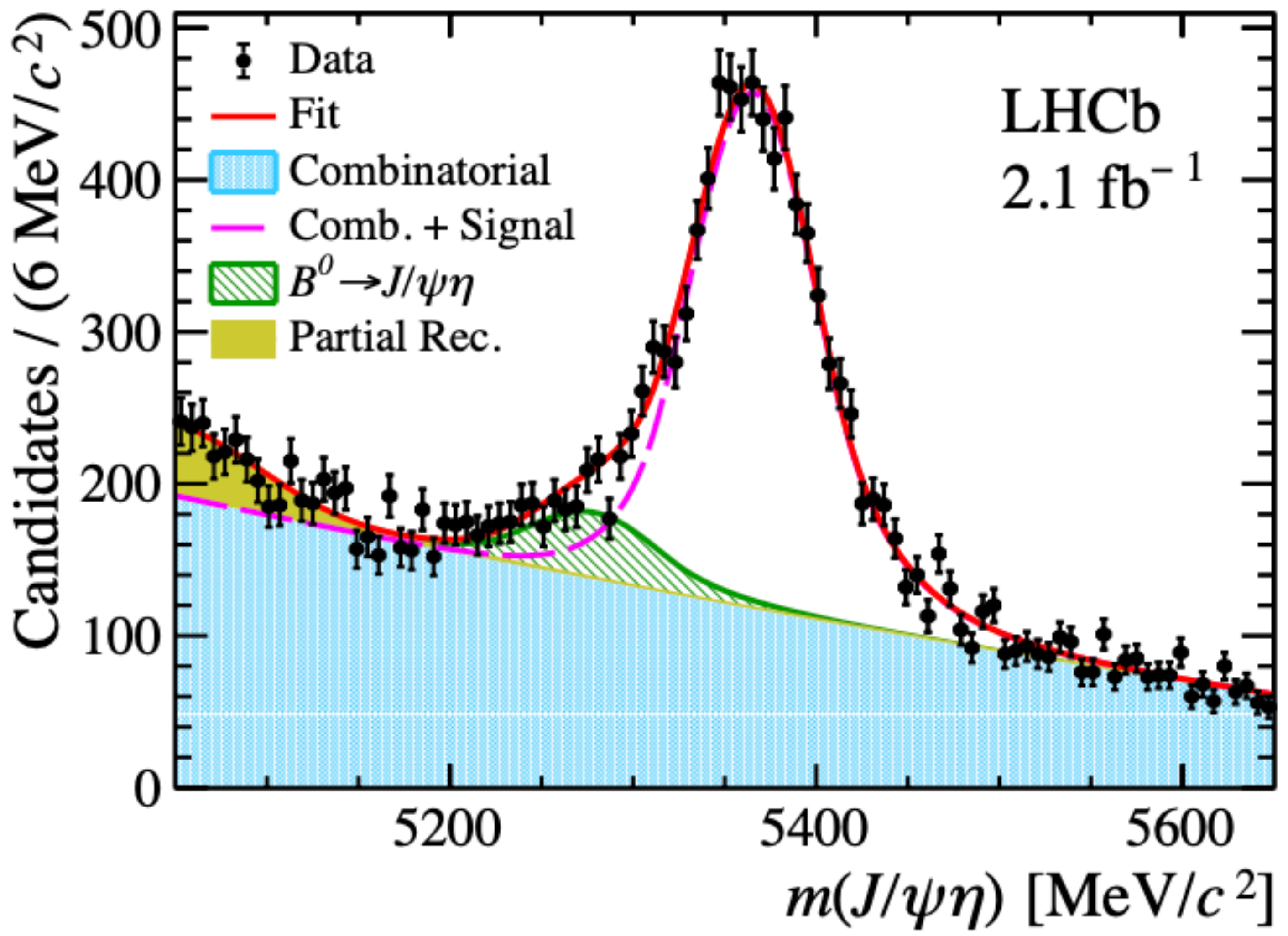
in case of mixing: M_{12} and Γ_{12} are non-zero

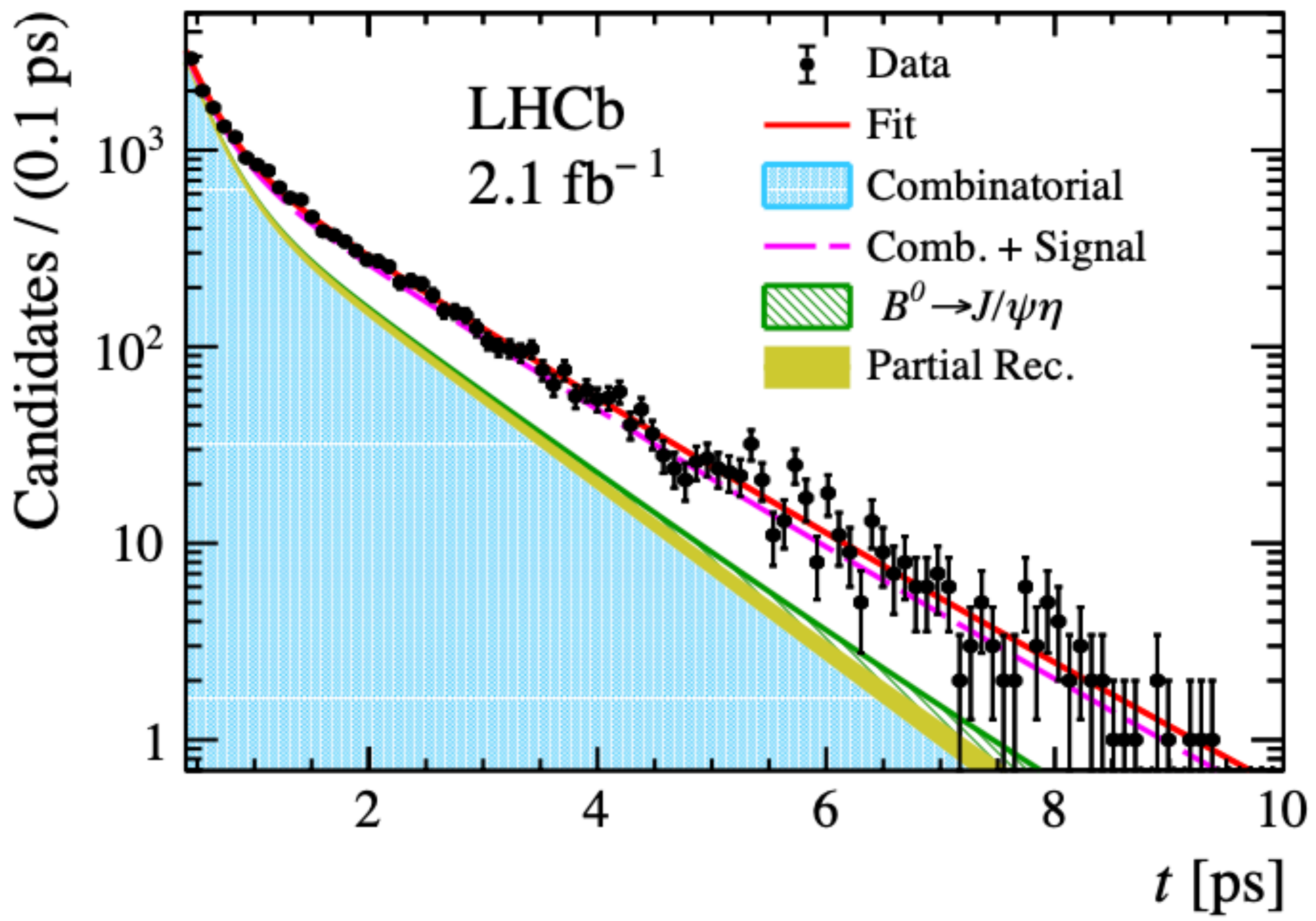


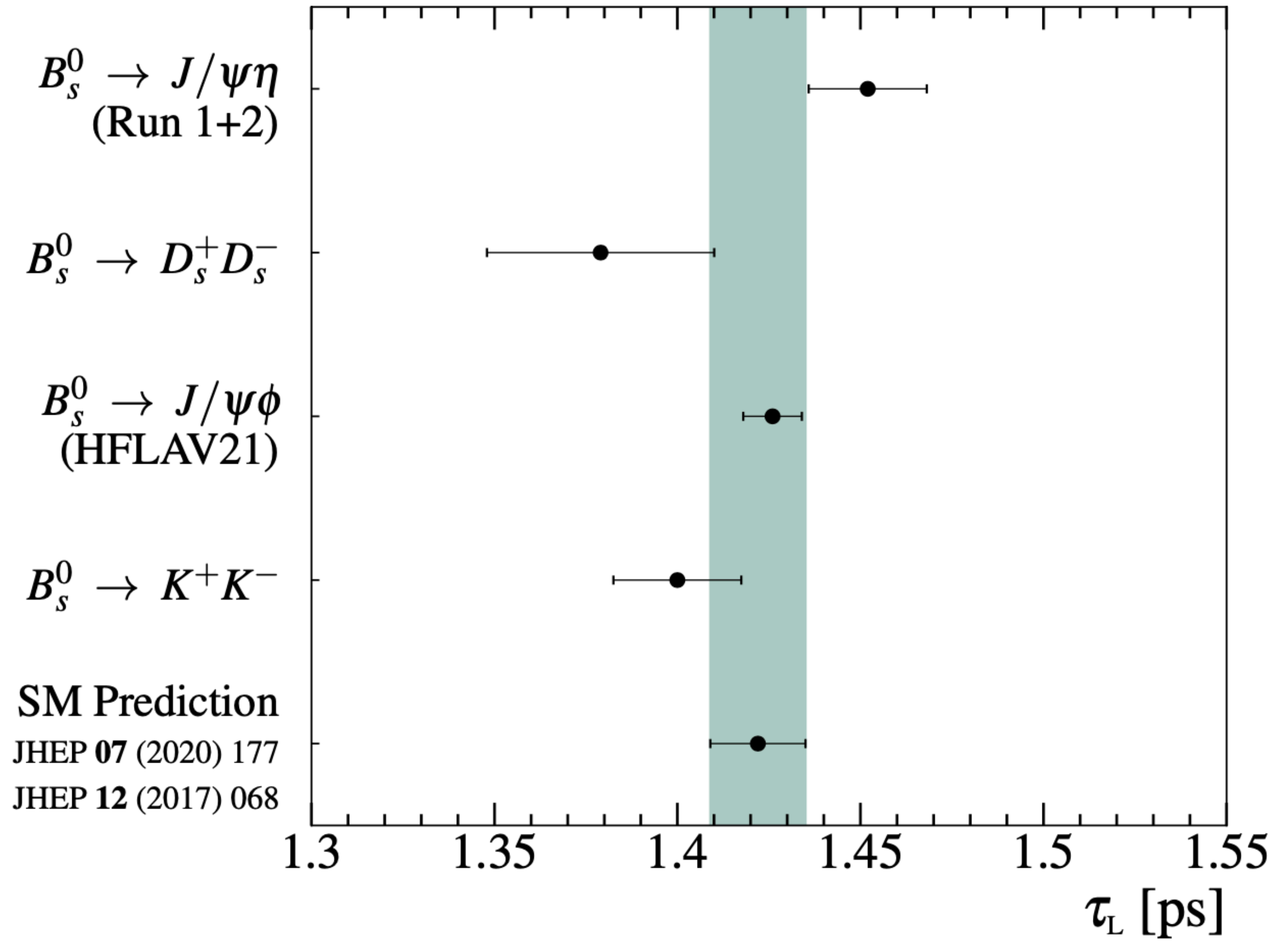
Nature Physics 18 2022 1-5

τ_L

Pure CP even







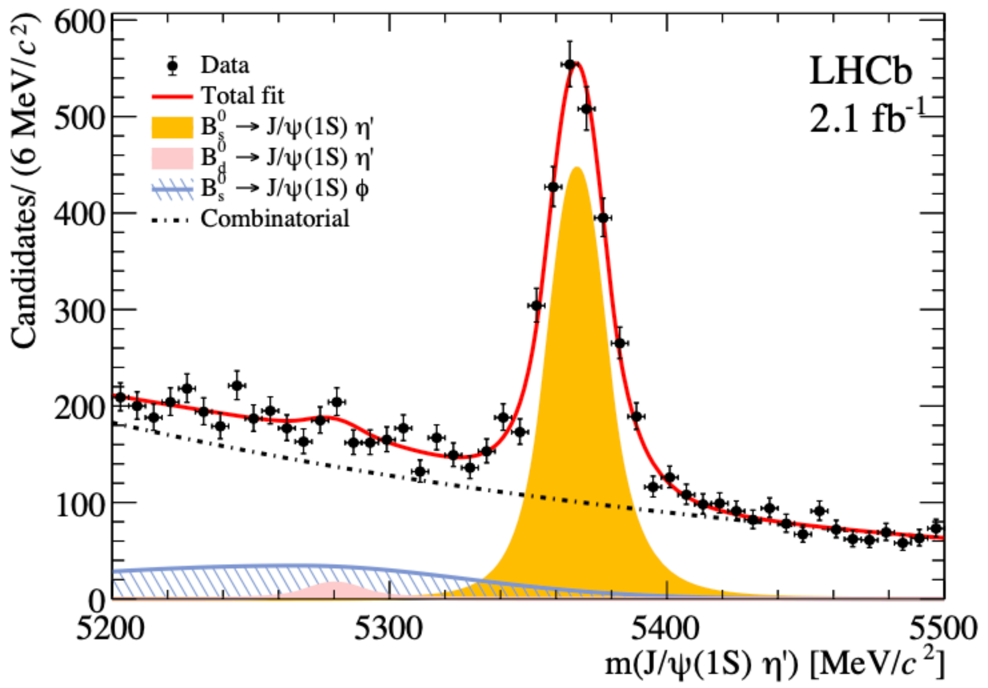
LHCb-PAPER-2022-010

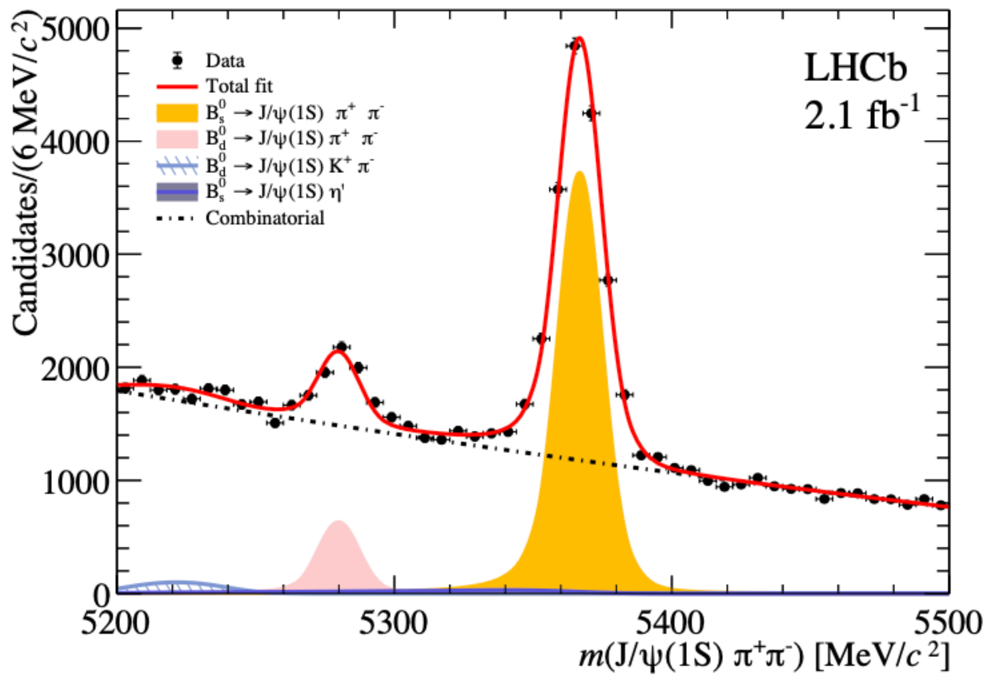
$\Delta\Gamma_s$

$$\Gamma(B_s^0(t) \to f) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) - \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right],$$

$$\Gamma(B_s^0(t) \to f) \propto e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + \sinh\left(\frac{\Delta\Gamma_s t}{2}\right)\right],$$

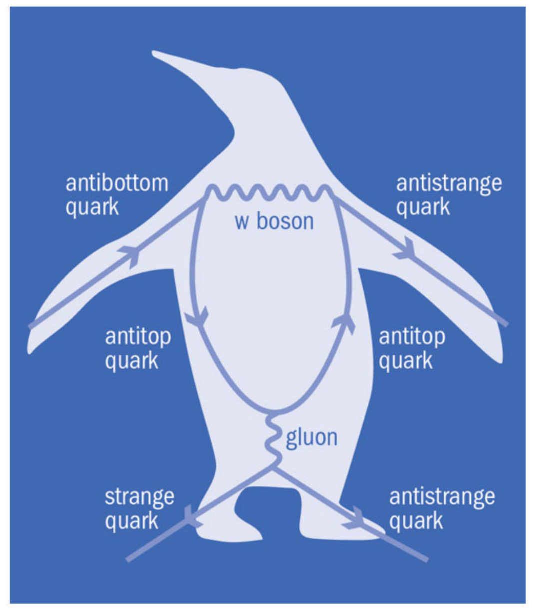
A counting experiment





Melissa's talk

LHCb-PAPER-2022-010



FLAVOUR PHYSICS | NEWS

New insights into CP violation via penguin decays

24 April 2023

A report from the LHCb experiment.

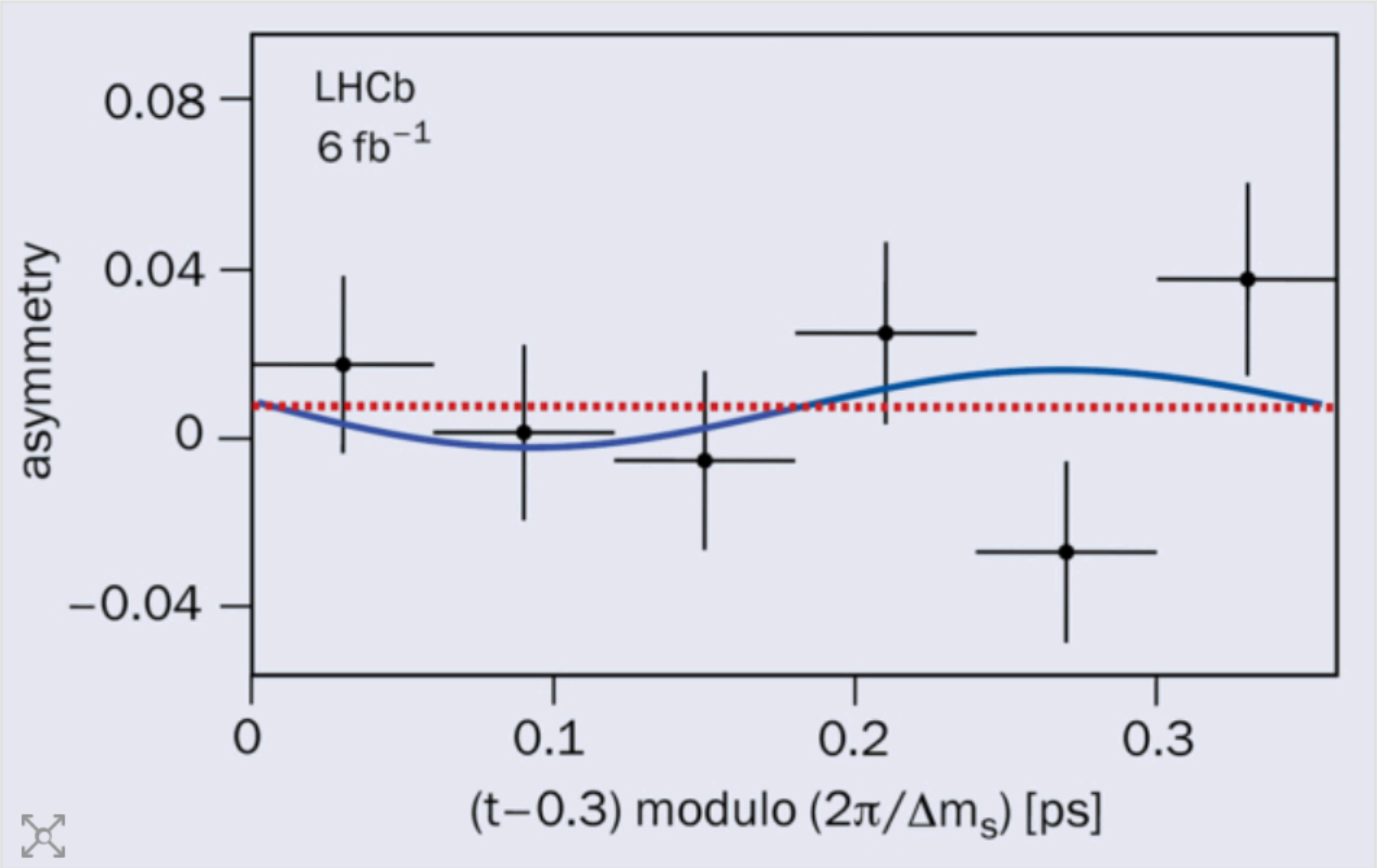
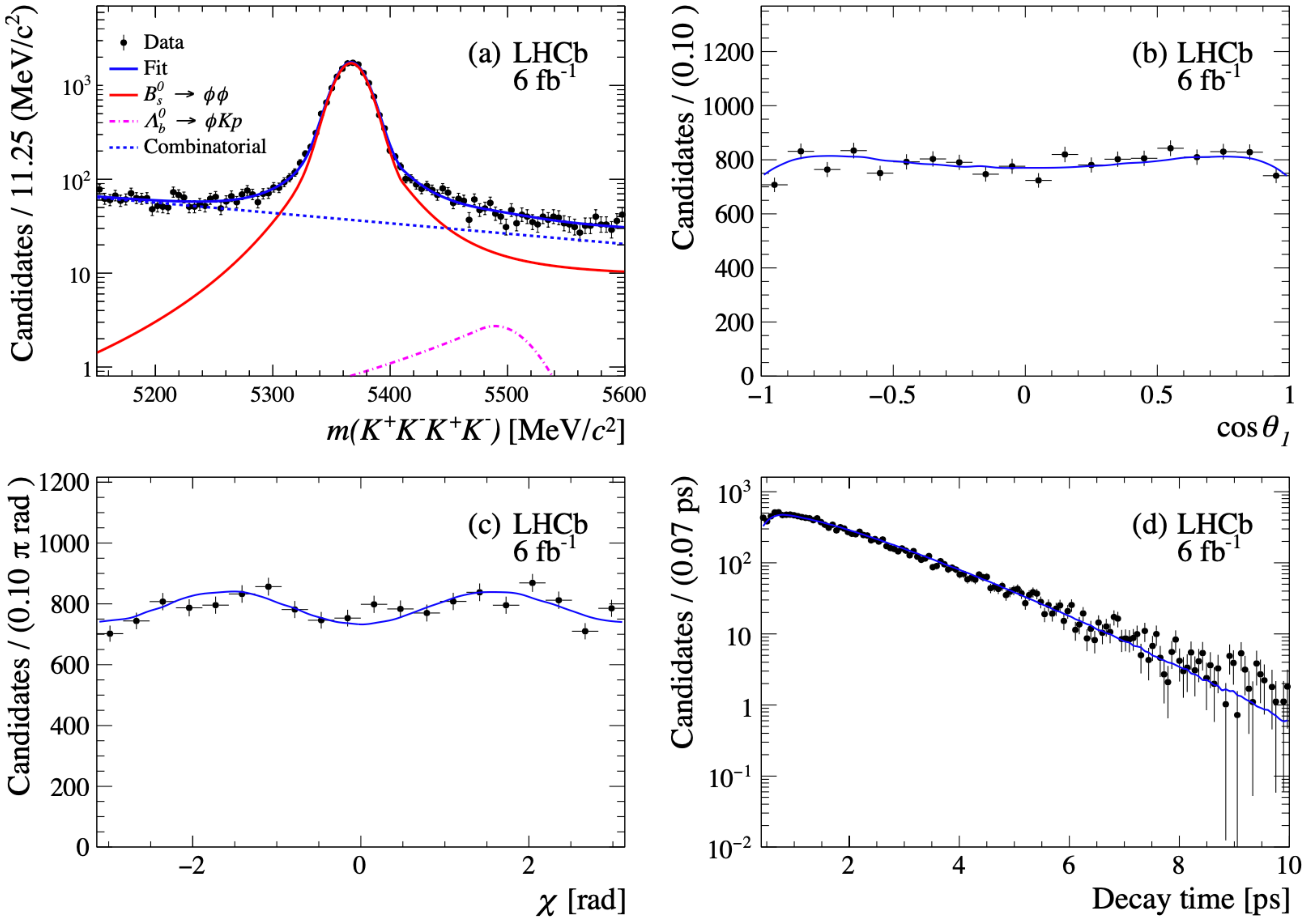


Fig. 1. Observed rate asymmetry between decays of flavour-tagged B^0_s or $\overline{B}^0_s$ mesons to a ϕϕ pair as a function of decay time, t, folded in a single oscillation period (black points) and overlaid with the projection of the best fit (blue solid line). The red dashed line corresponds to the hypothesis of CP symmetry. Source: LHCB-PAPER-2023–001

At the recent Moriond Electroweak conference, the LHCb collaboration presented a new, high-precision measurement of charge–parity (CP) violation using a large sample of $B^0_s \to \phi\phi$ decays, where the ϕ mesons are reconstructed in the K^+K^- final state. Proceeding via a loop transition ($\overline{b} \to \overline{s}s\overline{s}$), such "penguin" decays are highly sensitive to possible contributions from unknown particles and therefore provide excellent probes for new sources of CP violation. To date, the only known source of CP violation, which is governed by the Cabibbo–Kobayashi–Maskawa matrix in the

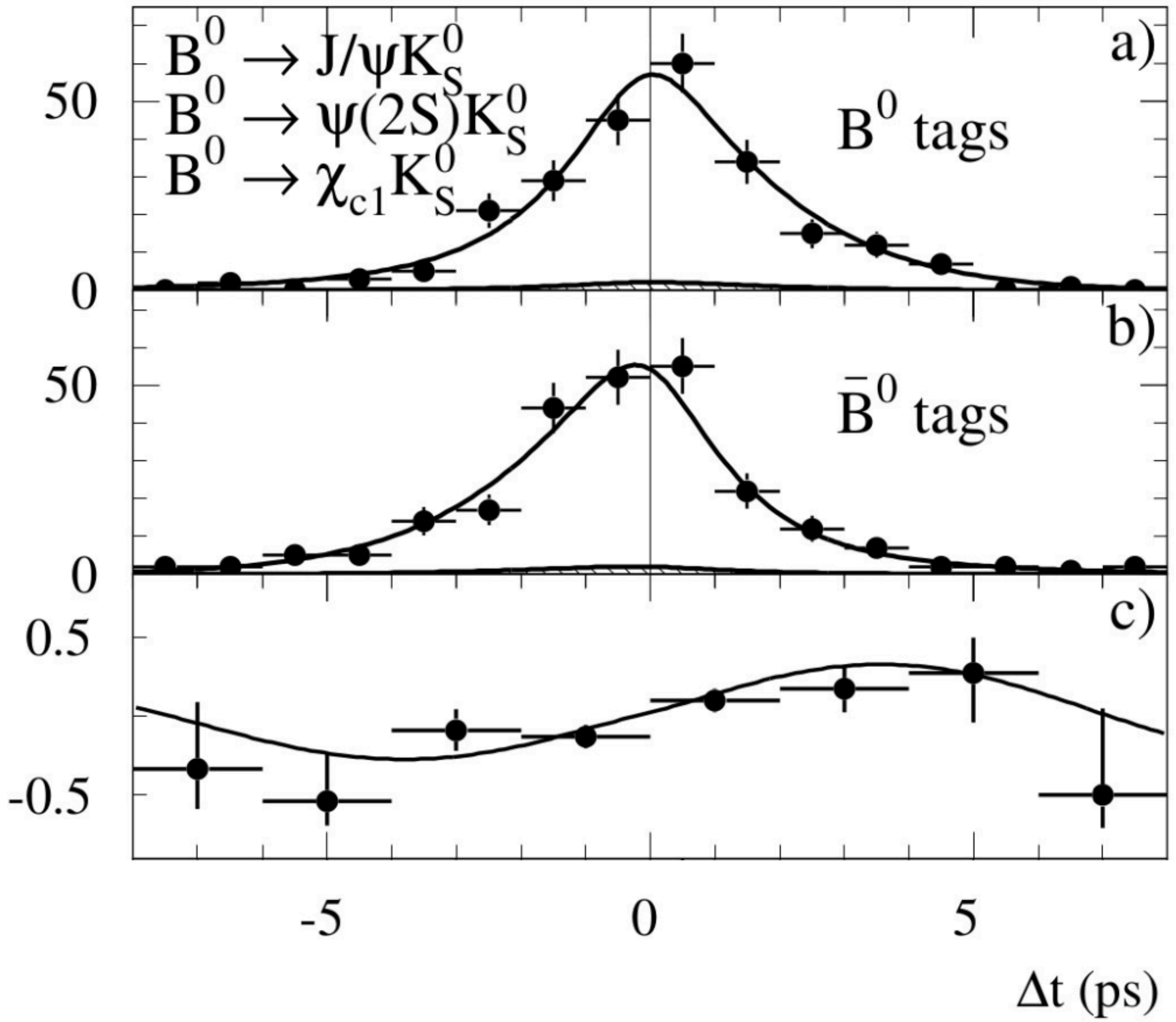
LHC-PAPER-2023-001



No evidence of CP violation

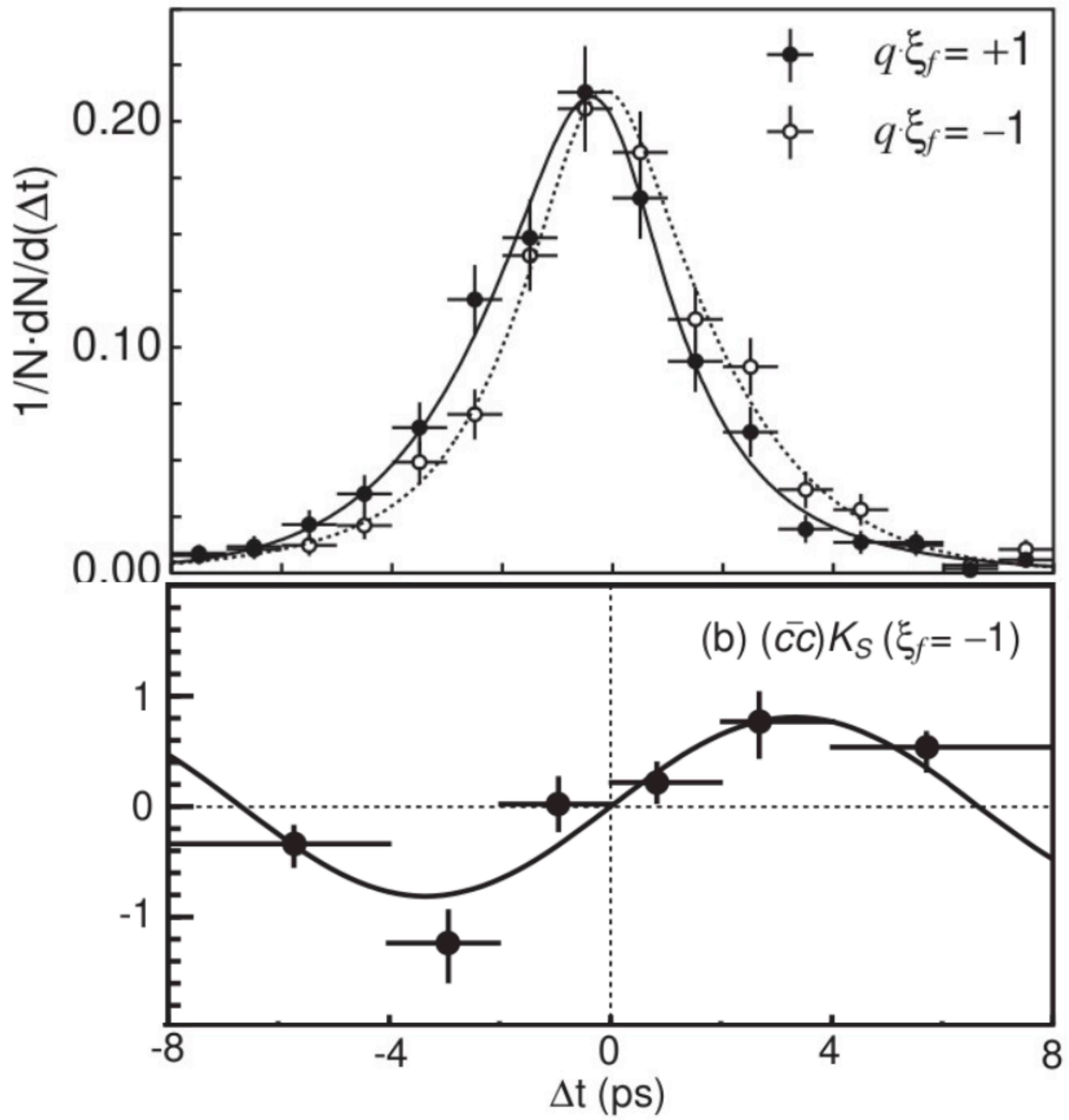
Where the B factories started

BaBar, PRL 87 (2001) 091801



$$\sin 2\beta = 0.59 \pm 0.14\ (\text{stat}) \pm 0.05\ (\text{syst}).$$

Belle, PRL 97 (2001) 091802

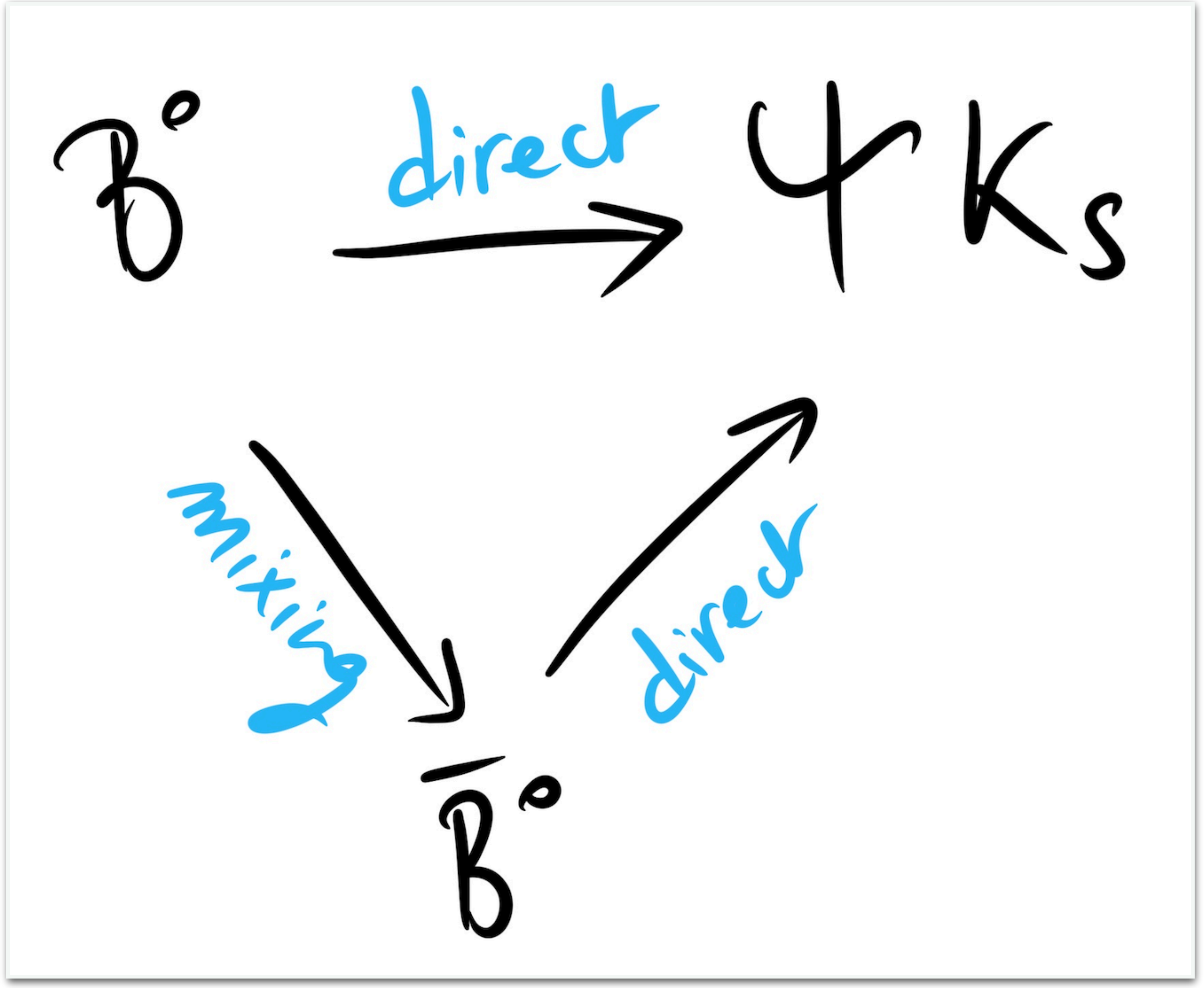


$$\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst}).$$

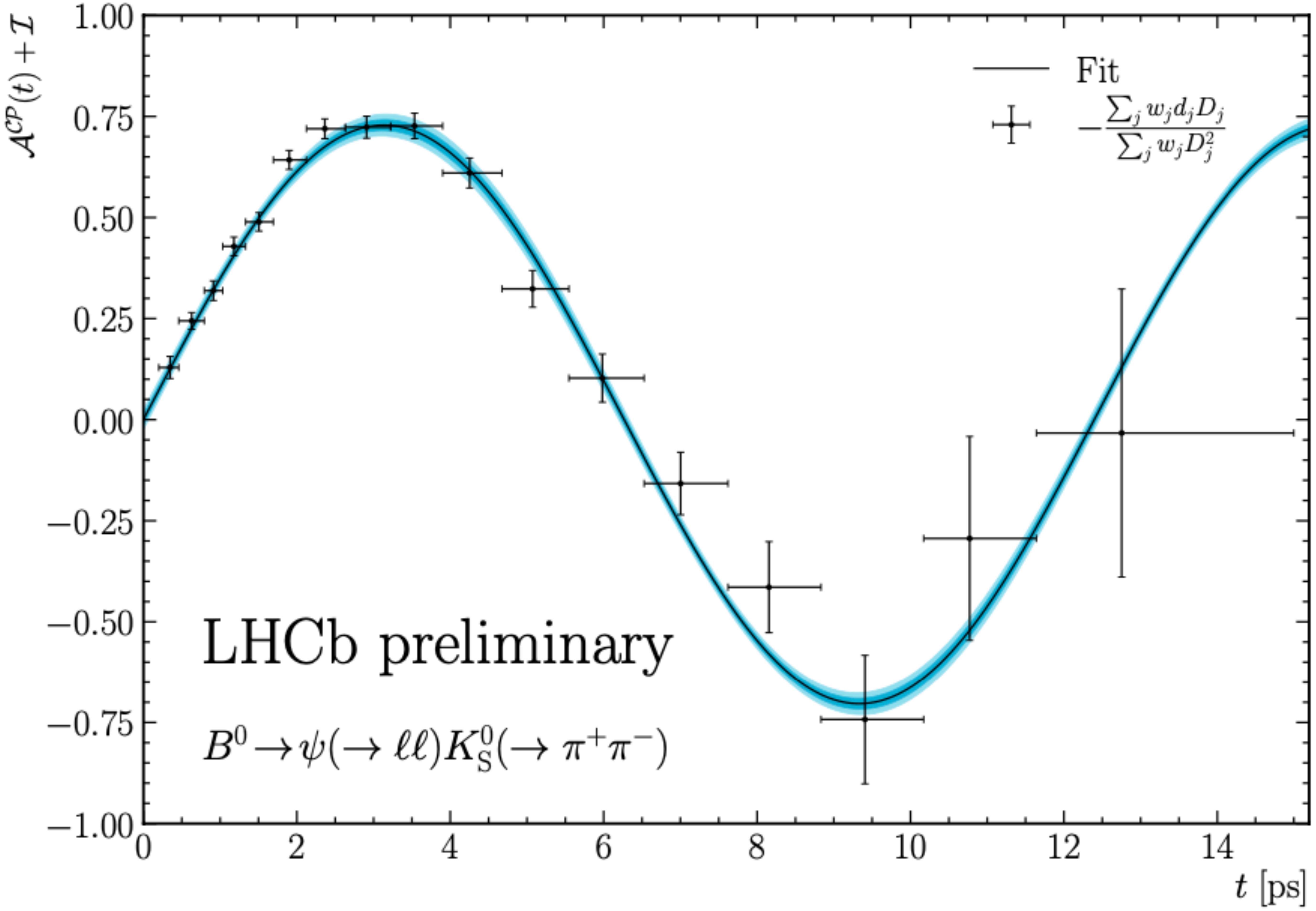
Jim et al's talks for the new results

An other fast forward

Combination of three decay modes
Including many way to reconstruct the Ks



An other highlight of the importance of Flavour Tagging



Tom Latham's talk

LHCb-PAPER-2023-013 in preparation

Question to my theory colleagues

Anatomy of New Physics in B–$\overline{B}$ mixing

A. Lenz[a,b], U. Nierste[c]

and

J. Charles[d], S. Descotes-Genon[e], A. Jantsch[f], C. Kaufhold[g], H. Lacker[h], S. Monteil[i], V. Niess[i], S. T'Jampens[g]

[CKMfitter Group]

We analyse three different New Physics scenarios for $\Delta F = 2$ flavour-changing neutral currents in the quark sector in the light of recent data on neutral-meson mixing. We parametrise generic New Physics contributions to $B_q - \overline{B}_q$ mixing, $q = d, s$, in terms of

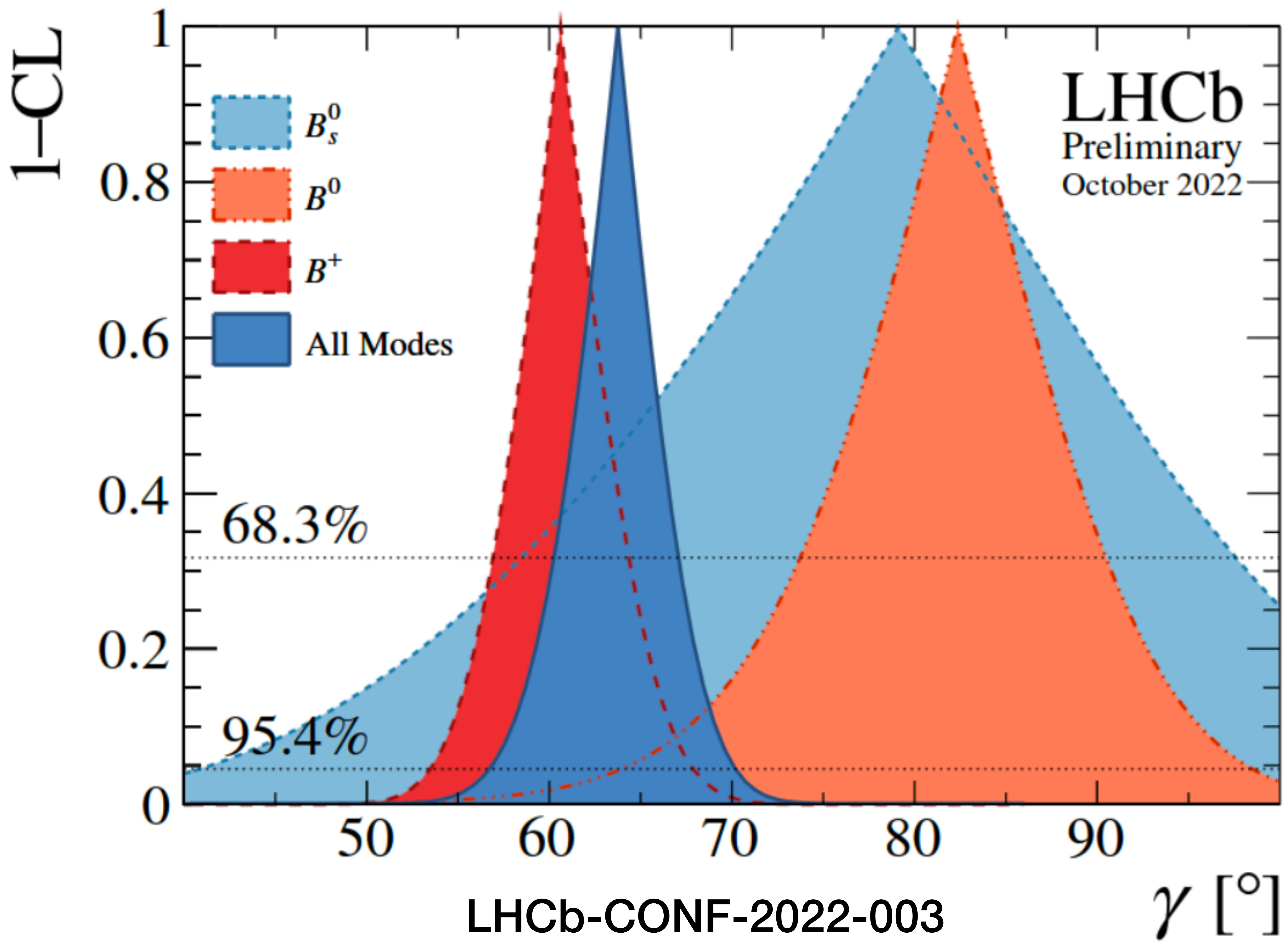
Alexander Lenz @alexlenz42 · 7h

Preparing for the pilgrimage to Santiago... I hope our expectations will be met...

1 6 369

Where do we stand today ?

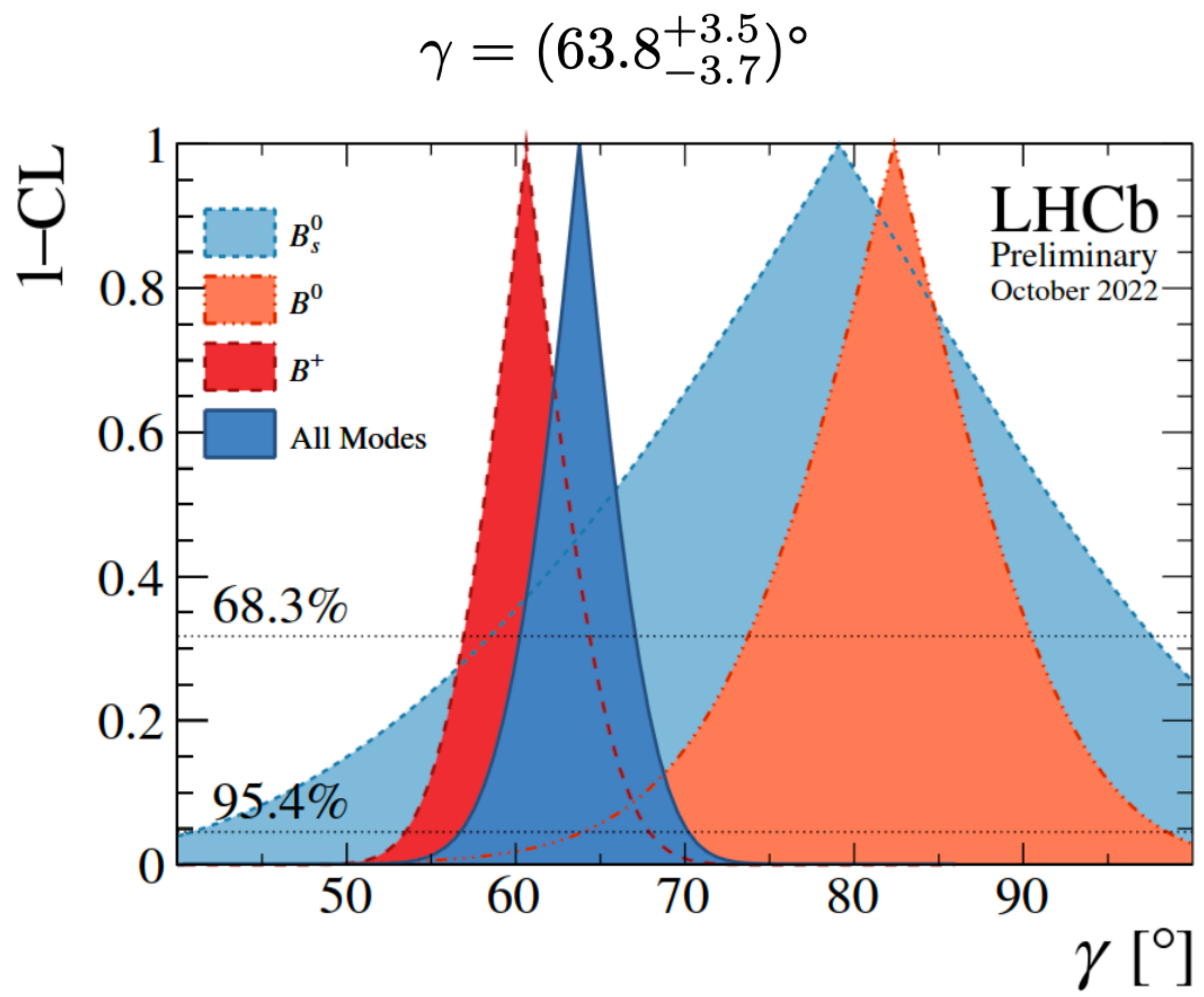
$$\gamma = (63.8^{+3.5}_{-3.7})^\circ$$



LHCb-CONF-2022-003

What do we make of this picture?

B decay	D decay	Ref.	Dataset
$B^\pm \to Dh^\pm$	$D \to h^+h^-$	[29]	Run 1&2
$B^\pm \to Dh^\pm$	$D \to h^+\pi^-\pi^+\pi^-$	[30]	Run 1
$B^\pm \to Dh^\pm$	$D \to K^\pm\pi^\mp\pi^+\pi^-$	[18]	Run 1&2
$B^\pm \to Dh^\pm$	$D \to h^+h^-\pi^0$	[19]	Run 1&2
$B^\pm \to Dh^\pm$	$D \to K^0_S h^+h^-$	[31]	Run 1&2
$B^\pm \to Dh^\pm$	$D \to K^0_S K^\pm\pi^\mp$	[32]	Run 1&2
$B^\pm \to D^*h^\pm$	$D \to h^+h^-$	[29]	Run 1&2
$B^\pm \to DK^{*\pm}$	$D \to h^+h^-$	[33]	Run 1&2(*)
$B^\pm \to DK^{*\pm}$	$D \to h^+\pi^-\pi^+\pi^-$	[33]	Run 1&2(*)
$B^\pm \to Dh^\pm\pi^+\pi^-$	$D \to h^+h^-$	[34]	Run 1
$B^0 \to DK^{*0}$	$D \to h^+h^-$	[35]	Run 1&2(*)
$B^0 \to DK^{*0}$	$D \to h^+\pi^-\pi^+\pi^-$	[35]	Run 1&2(*)
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	[36]	Run 1
$B^0 \to D^\mp\pi^\pm$	$D^+ \to K^-\pi^+\pi^+$	[37]	Run 1
$B^0_s \to D_s^\mp K^\pm$	$D_s^+ \to h^+h^-\pi^+$	[38]	Run 1
$B^0_s \to D_s^\mp K^\pm\pi^+\pi^-$	$D_s^+ \to h^+h^-\pi^+$	[39]	Run 1&2

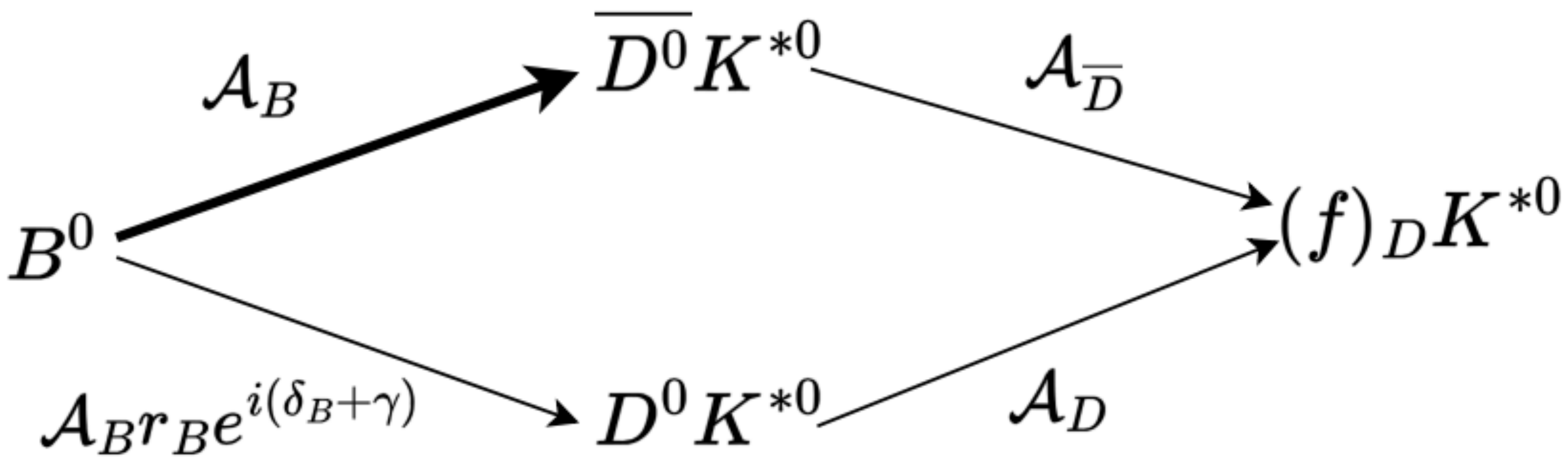


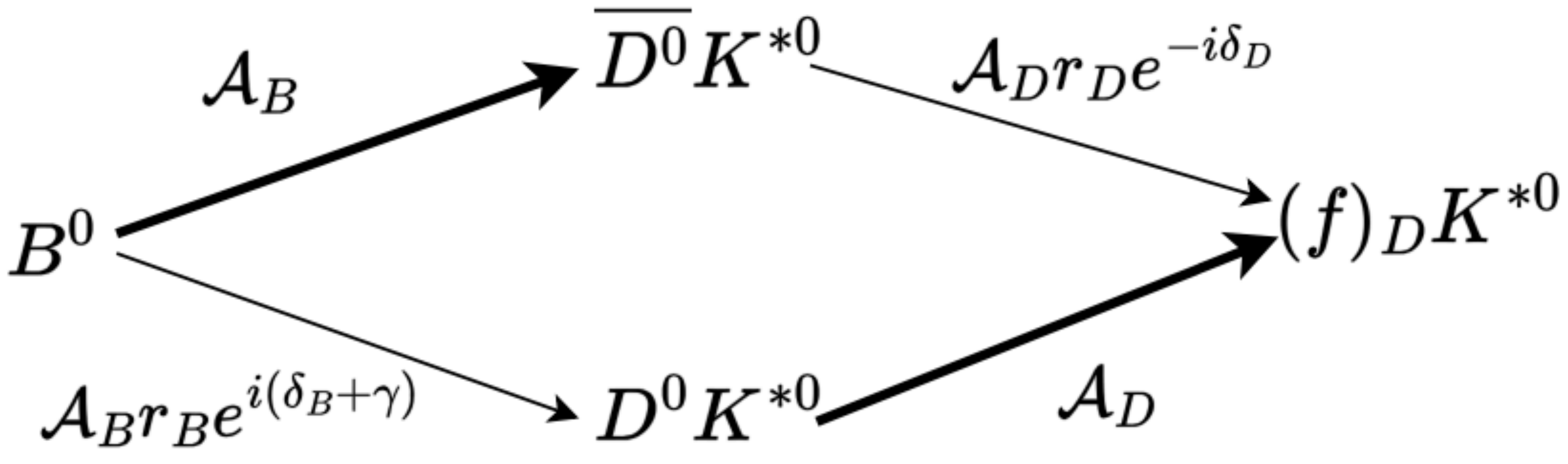
New results for CKM !

Innes, Seophine, Alex, Quentin's talks

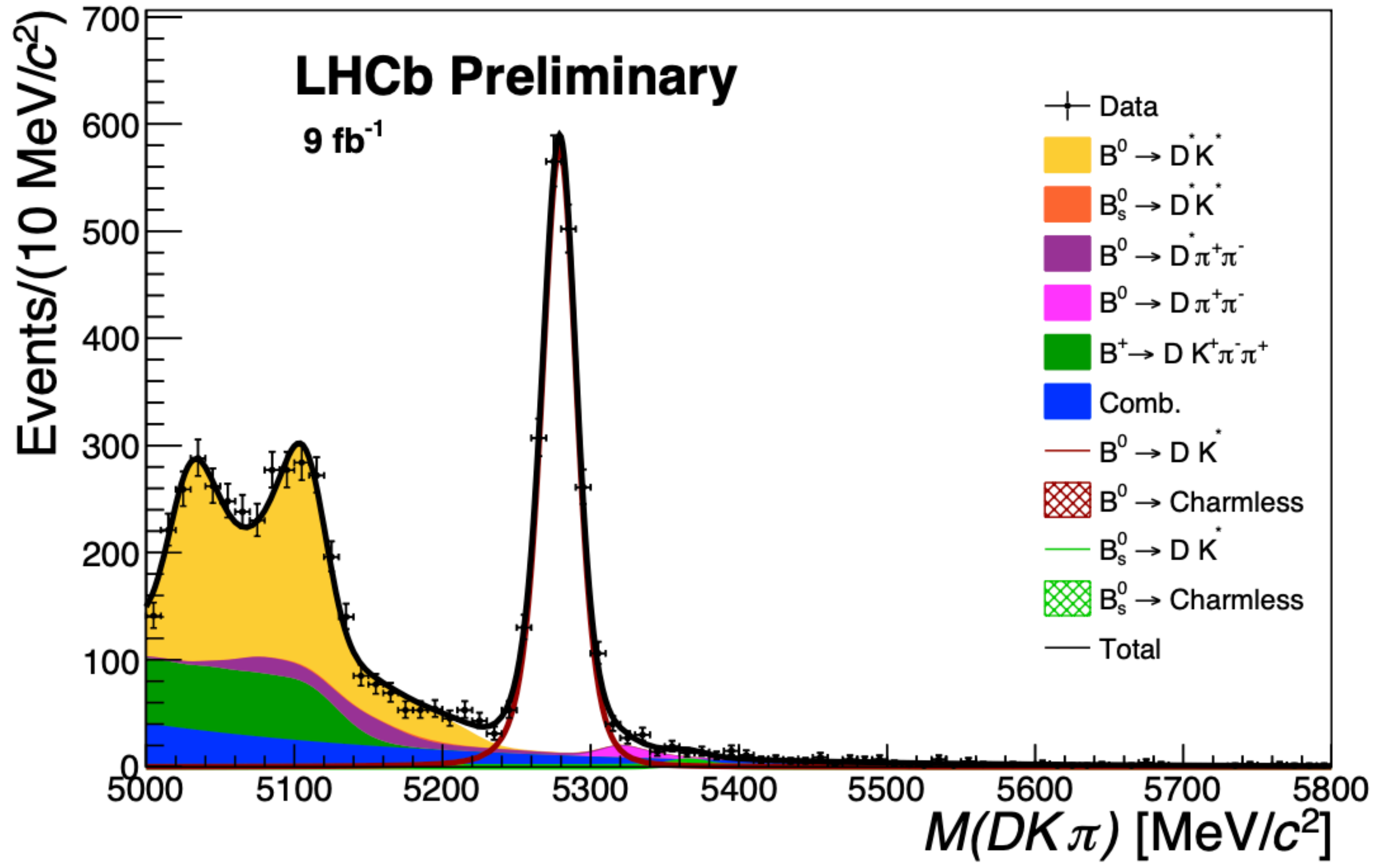
LHCb-CONF-2022-003

ADS/GLW techniques

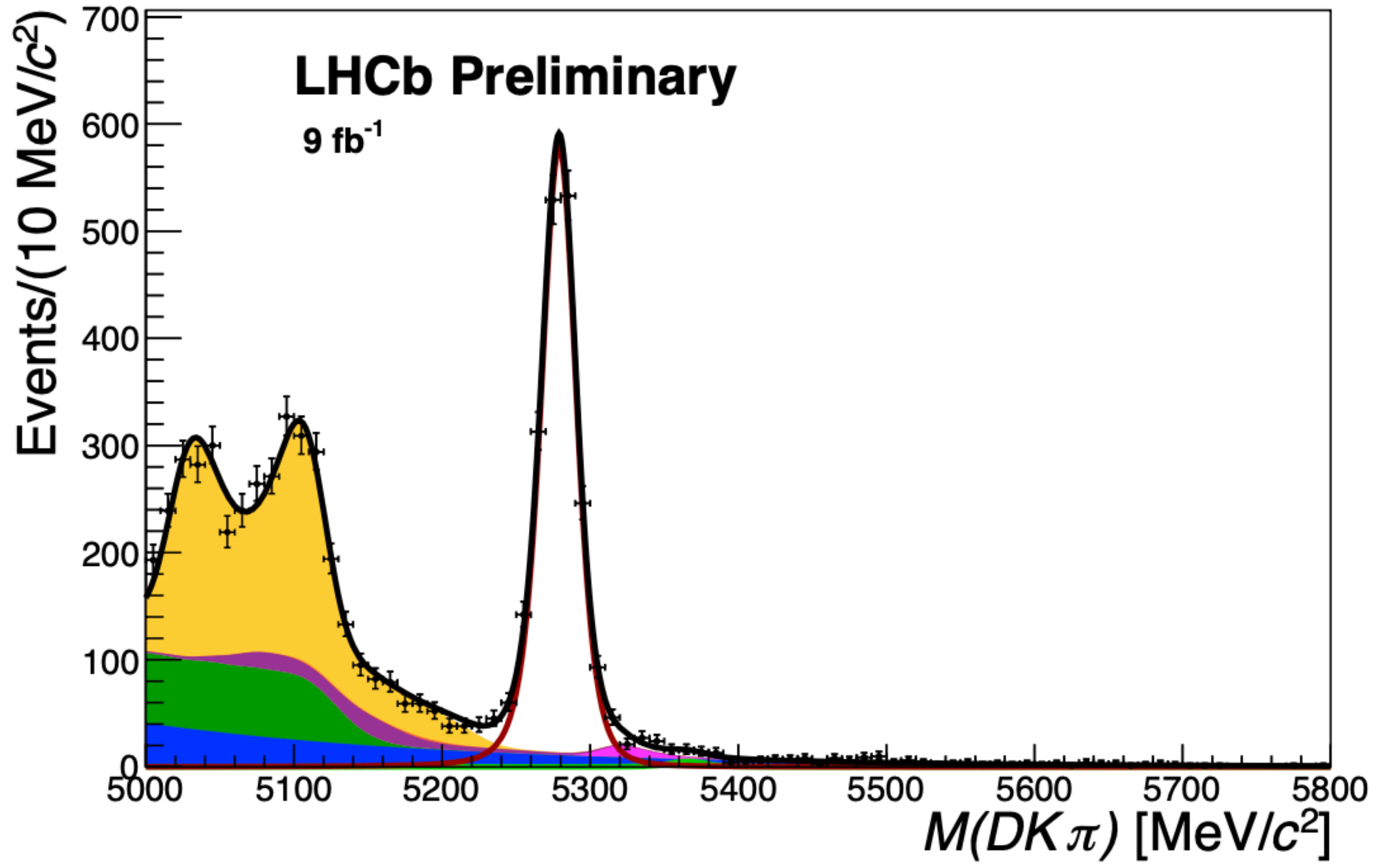




r_B gives the sensitivity to the angle ɣ



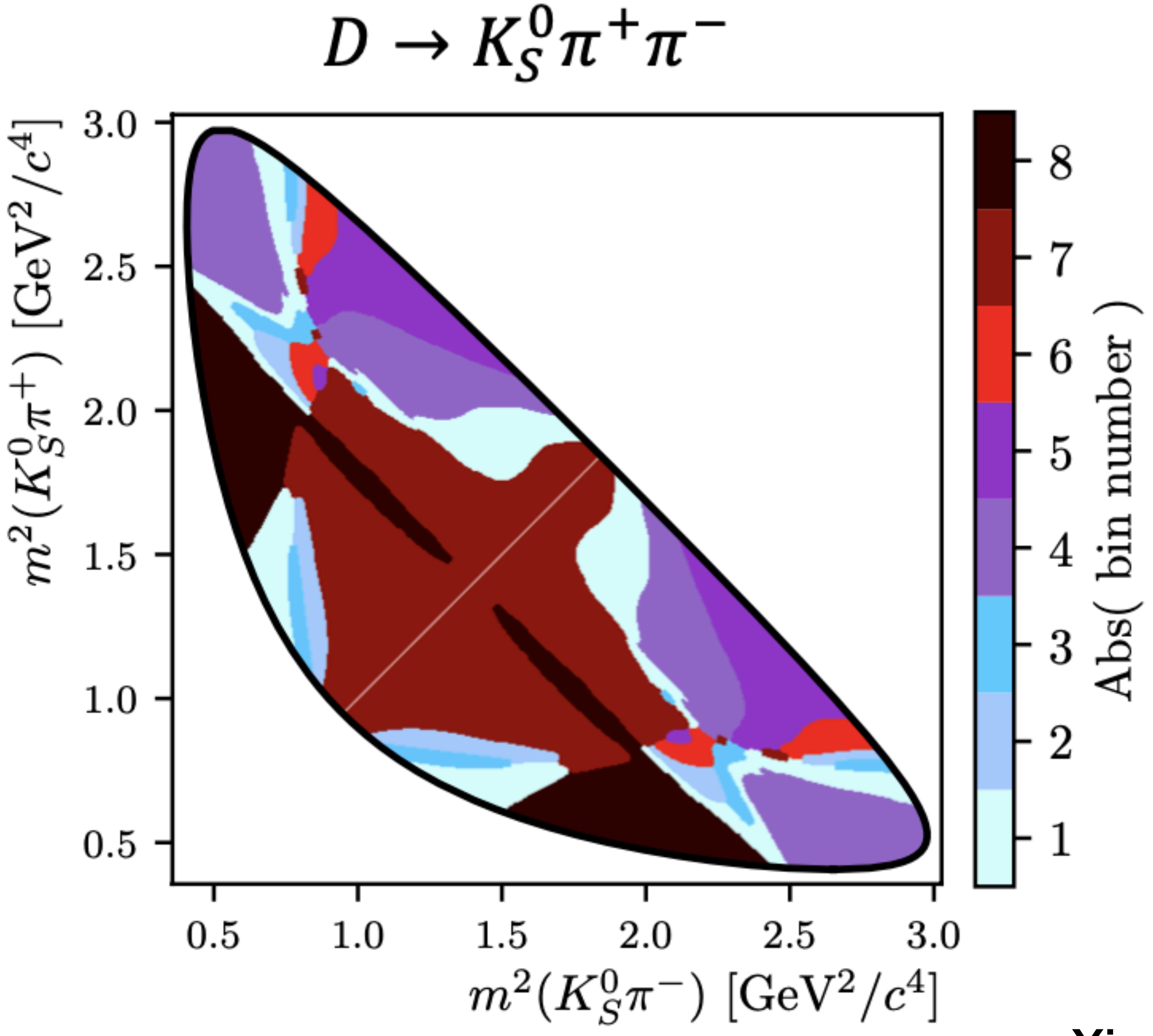
$\overline{B^0}$

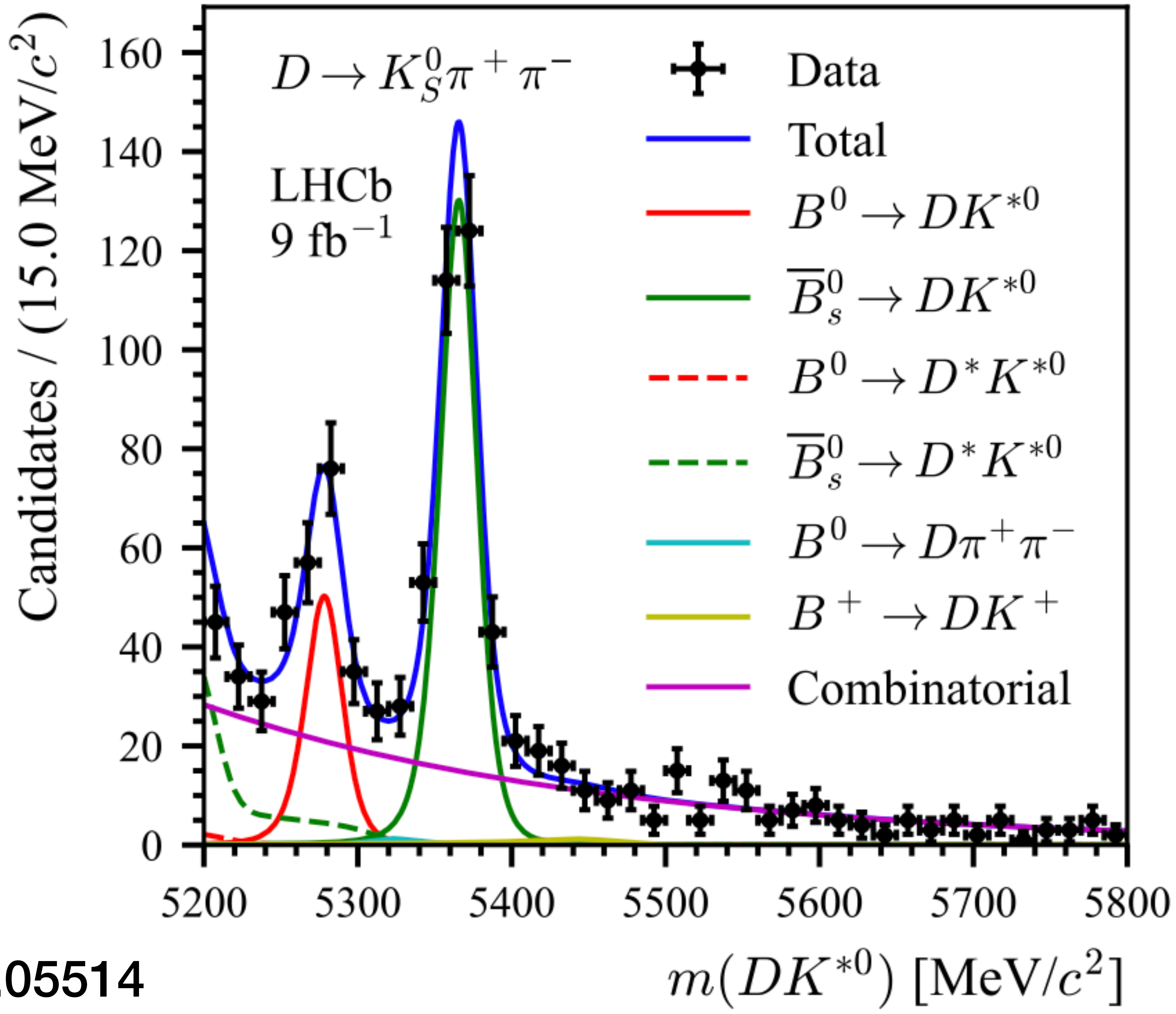


B^0

Seophine's talk

The $K_s hh$ family

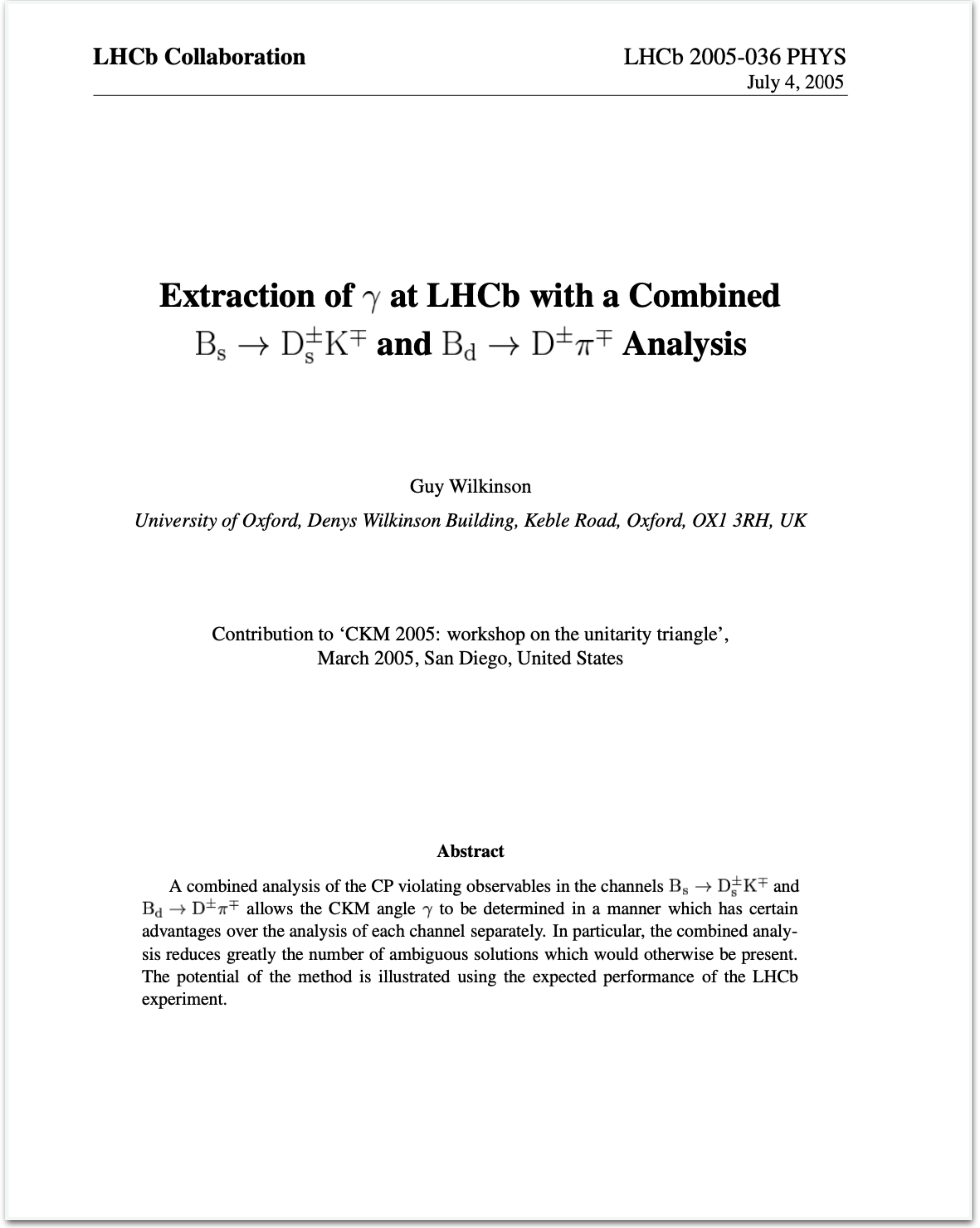




arXiv.2309.05514
LHCb-PAPER-2023-012, in preparation
LHCb-PAPER-023-029, in preparation

Innes' talk

Once upon a time…. Today



LHCb Collaboration LHCb 2005-036 PHYS
July 4, 2005

Extraction of γ at LHCb with a Combined $B_s \to D_s^{\pm} K^{\mp}$ and $B_d \to D^{\pm}\pi^{\mp}$ Analysis

Guy Wilkinson

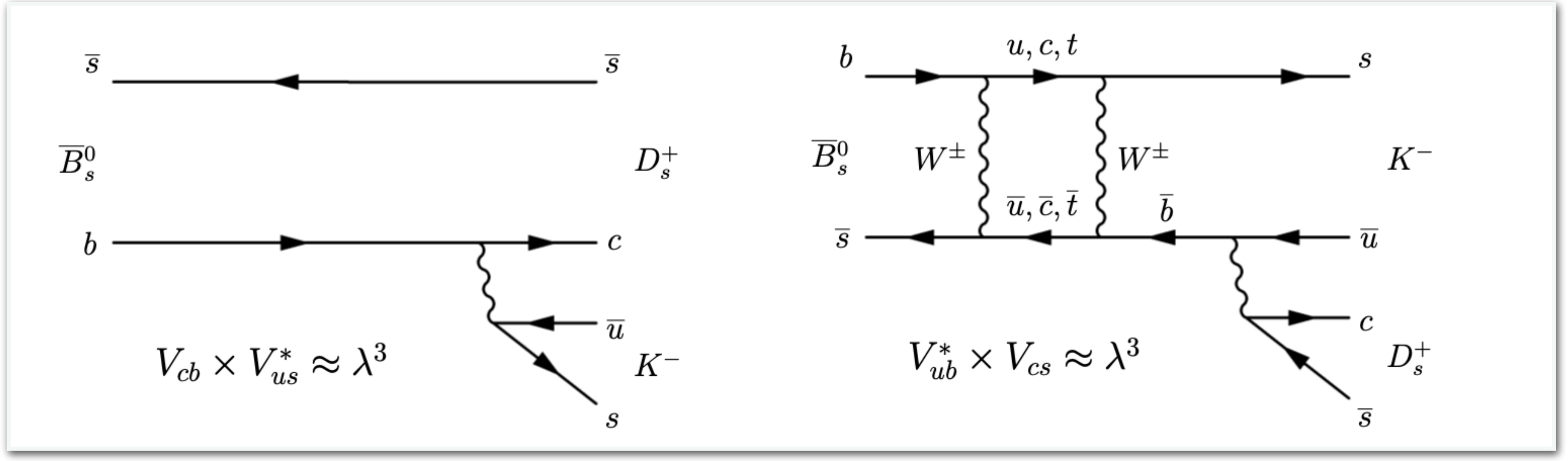
University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH, UK

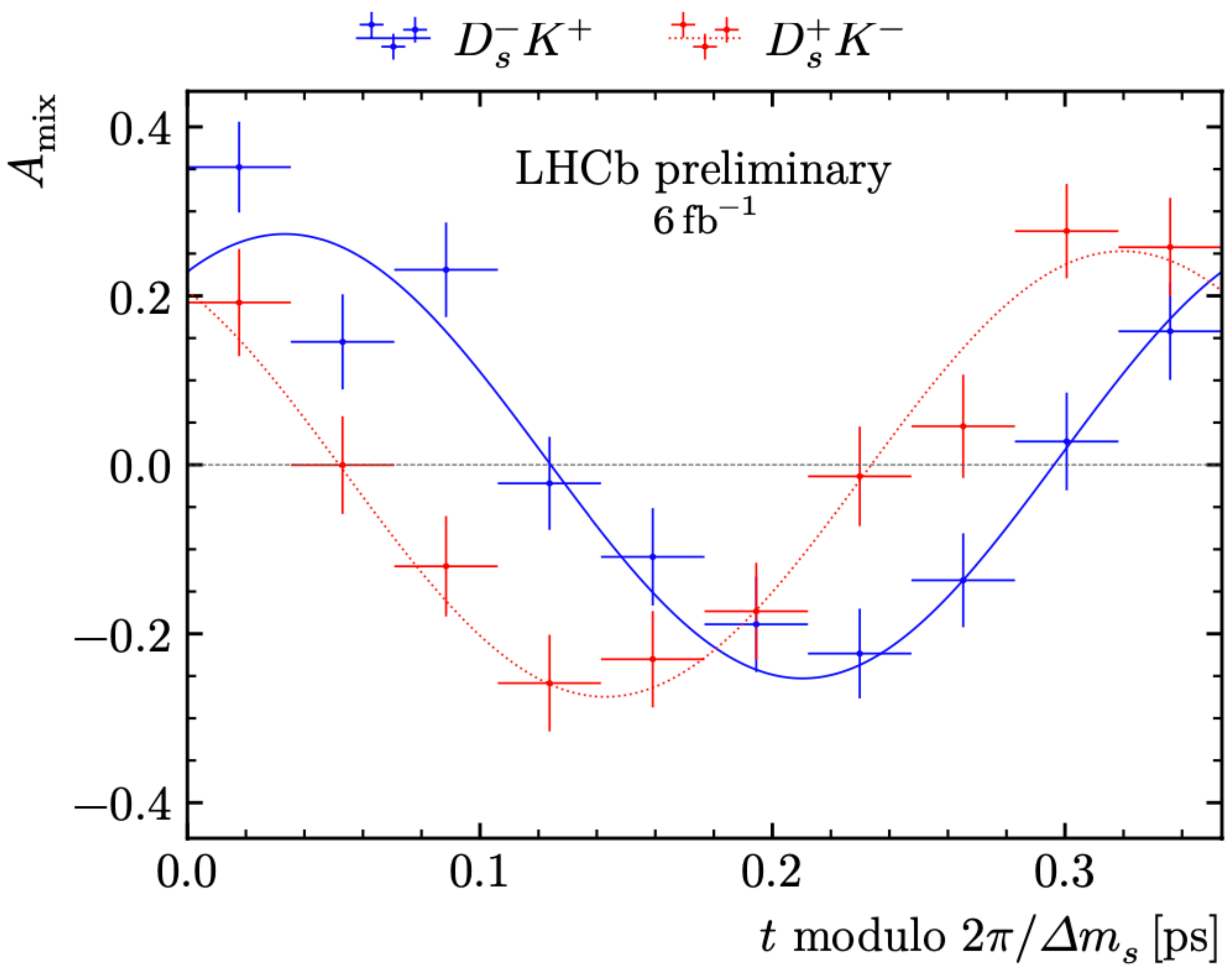
Contribution to 'CKM 2005: workshop on the unitarity triangle',
March 2005, San Diego, United States

Abstract

A combined analysis of the CP violating observables in the channels $B_s \to D_s^{\pm} K^{\mp}$ and $B_d \to D^{\pm}\pi^{\mp}$ allows the CKM angle γ to be determined in a manner which has certain advantages over the analysis of each channel separately. In particular, the combined analysis reduces greatly the number of ambiguous solutions which would otherwise be present. The potential of the method is illustrated using the expected performance of the LHCb experiment.

Not using the quite the same techniques





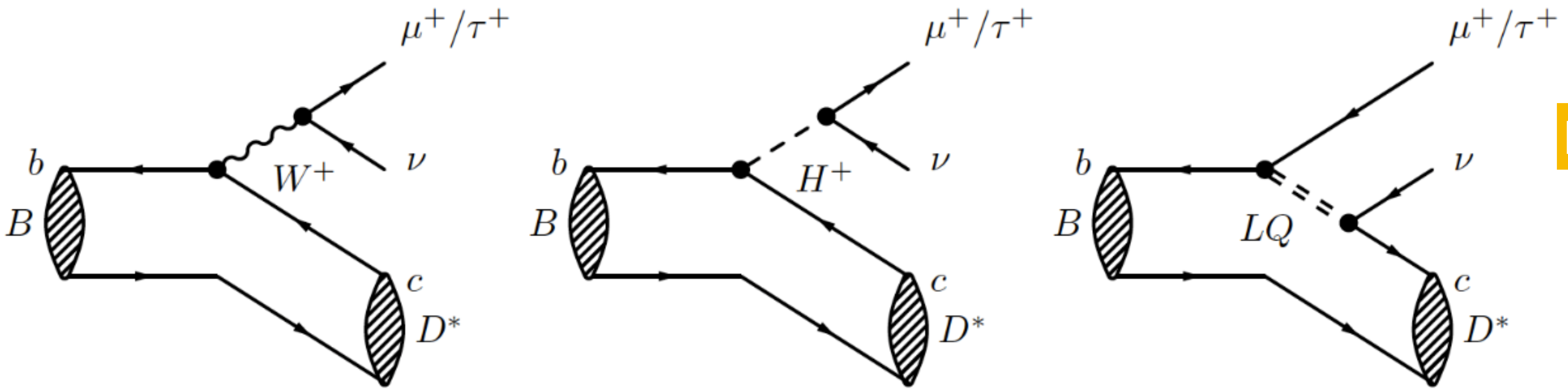
CONF-2023-003 in preparation

Quentin's talk

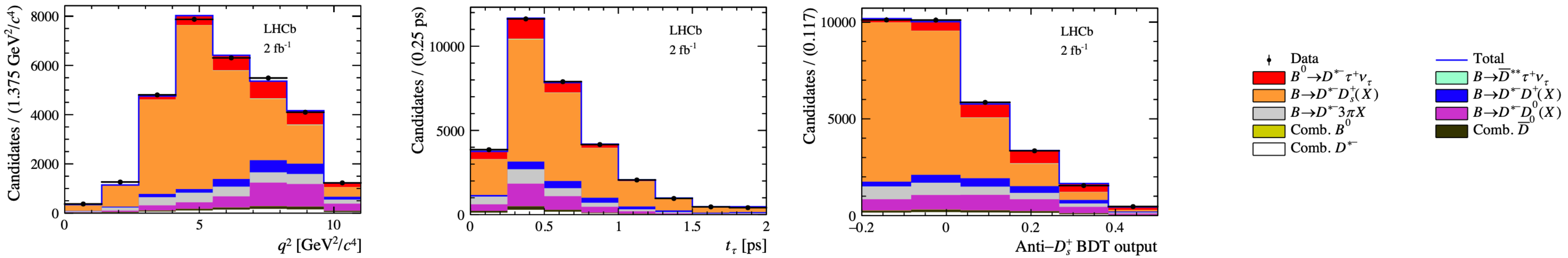

b→sl⁺l⁻
b→clν

Marta and Marcello’s talks

Proving TeV NP



Hadronic τ decays

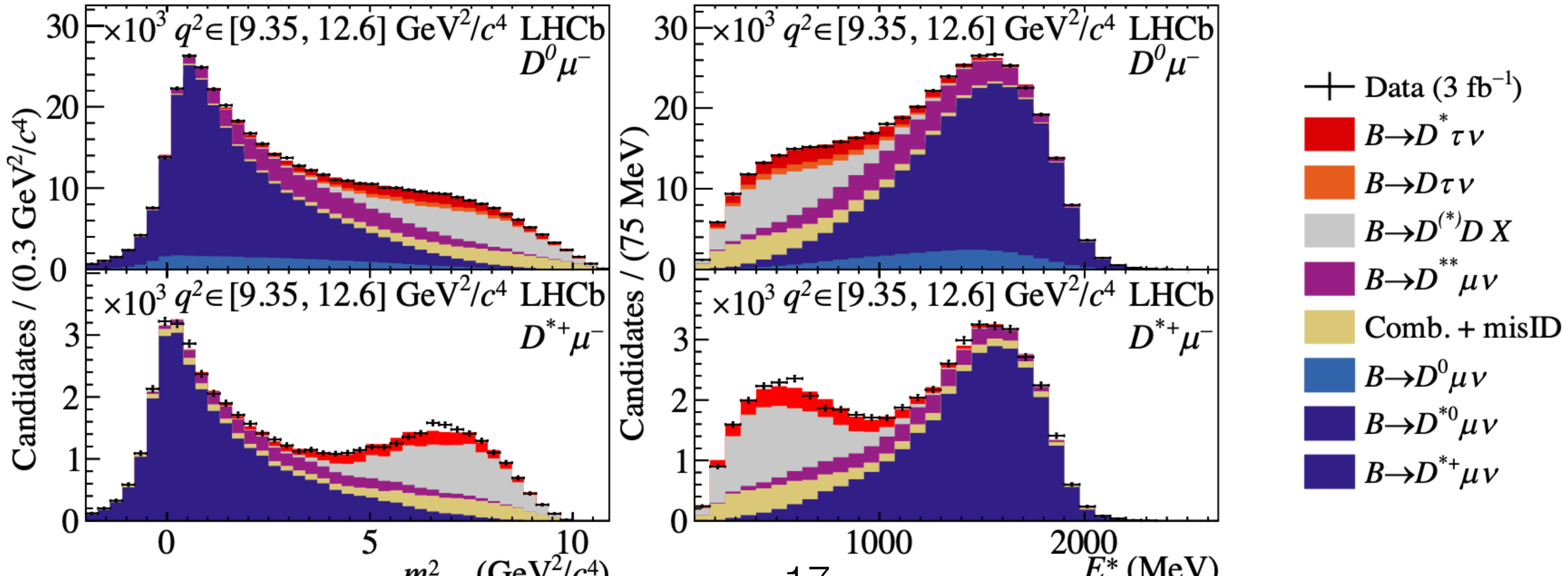


$D^0\mu^-$

n

Muonic τ decays

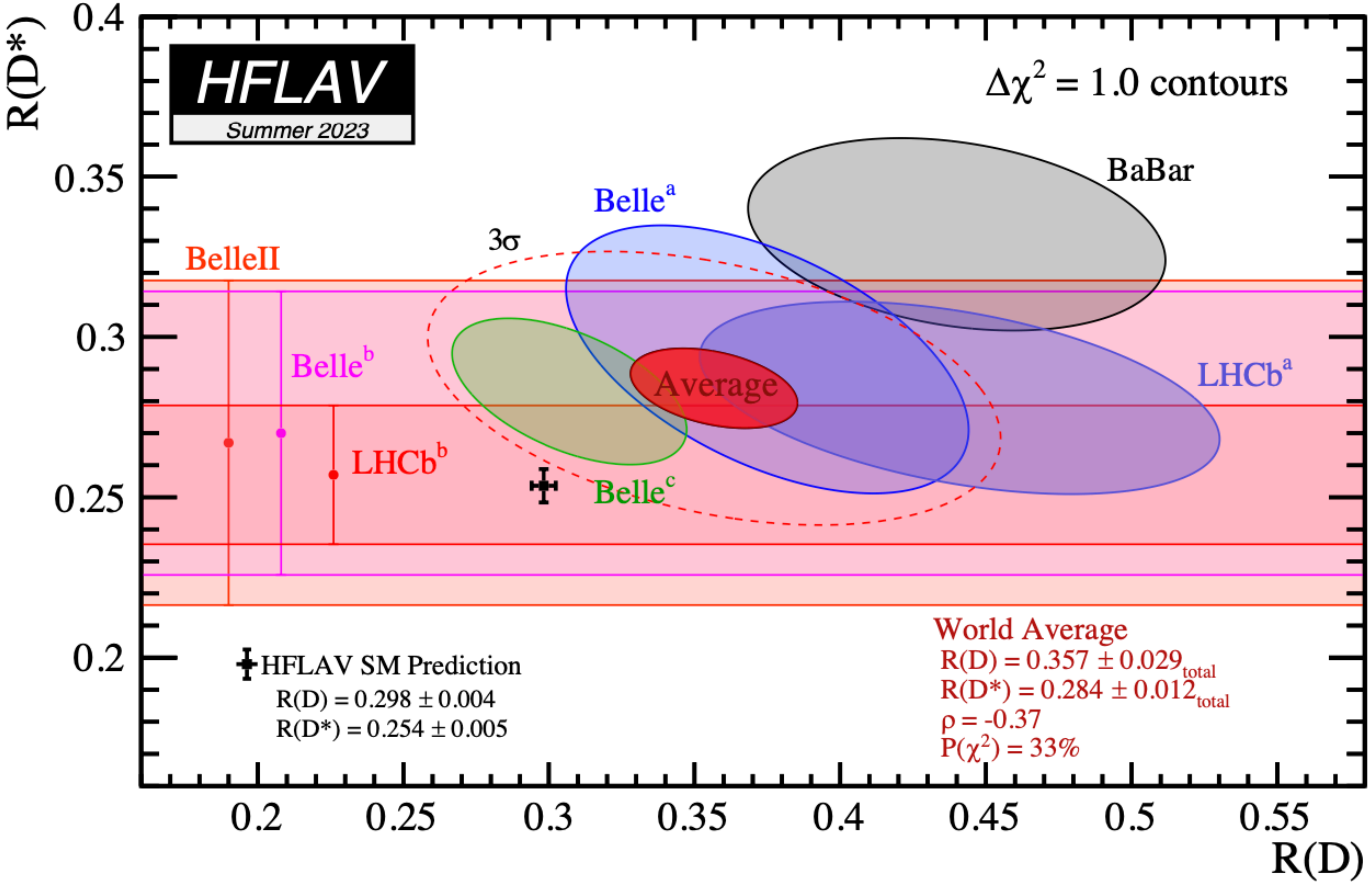
$D^{*+}\mu^-$



Direct determination CKM elements

Blase’s talks

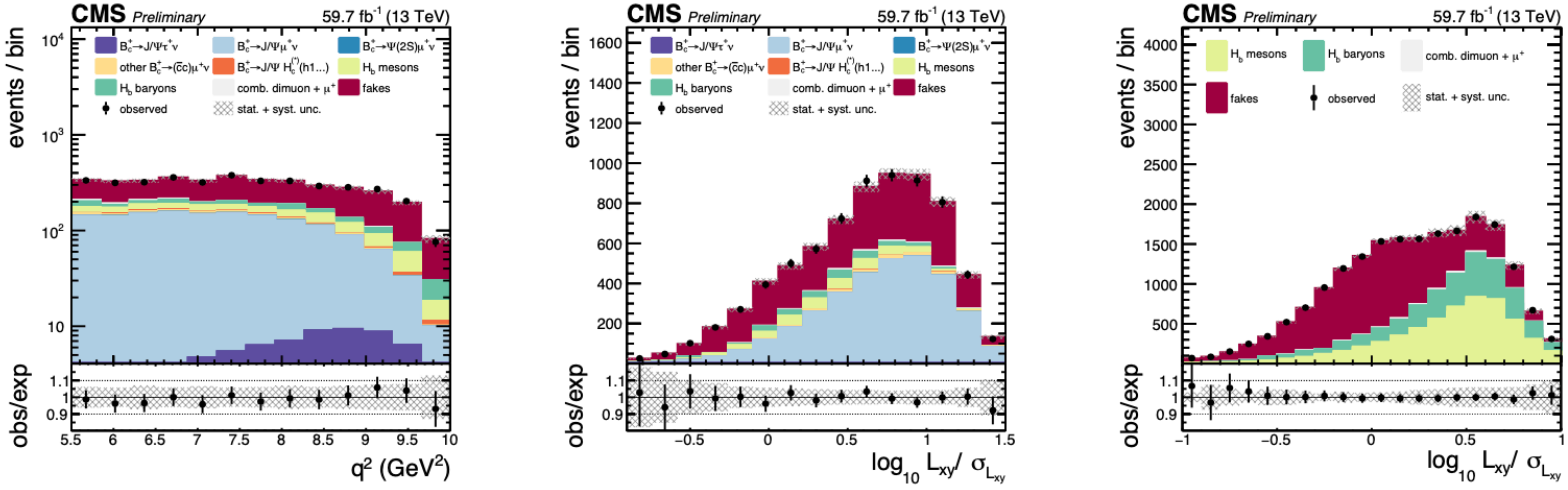
Marta and Marcello's talks



The question to model builders & EFT folks, is there still room for NP here?

Switching families

$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi\, \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi\, \mu^+ \nu_\mu)}$$

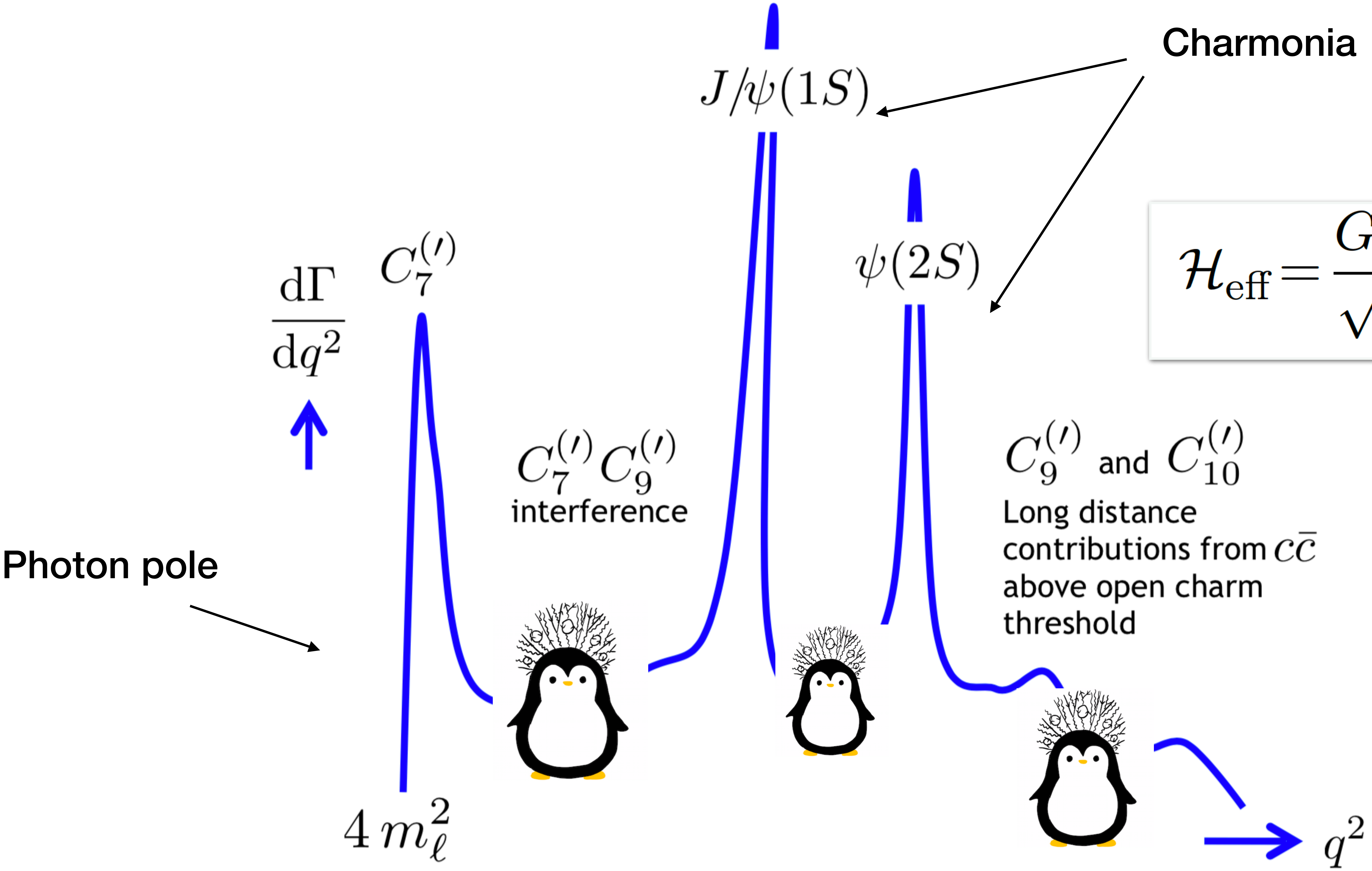


$$R(J/\psi) = \frac{\mathcal{B}(B_c^+ \to J/\psi\, \tau^+ \nu_\tau)}{\mathcal{B}(B_c^+ \to J/\psi\, \mu^+ \nu_\mu)} = 0.17^{+0.18}_{-0.17}\,(\text{stat.})^{+0.21}_{-0.22}\,(\text{syst.})^{+0.19}_{-0.18}\,(\text{theo.}) = 0.17 \pm 0.33,$$

Riccardo's talk

CKM-BPH-22-012

Switching poles

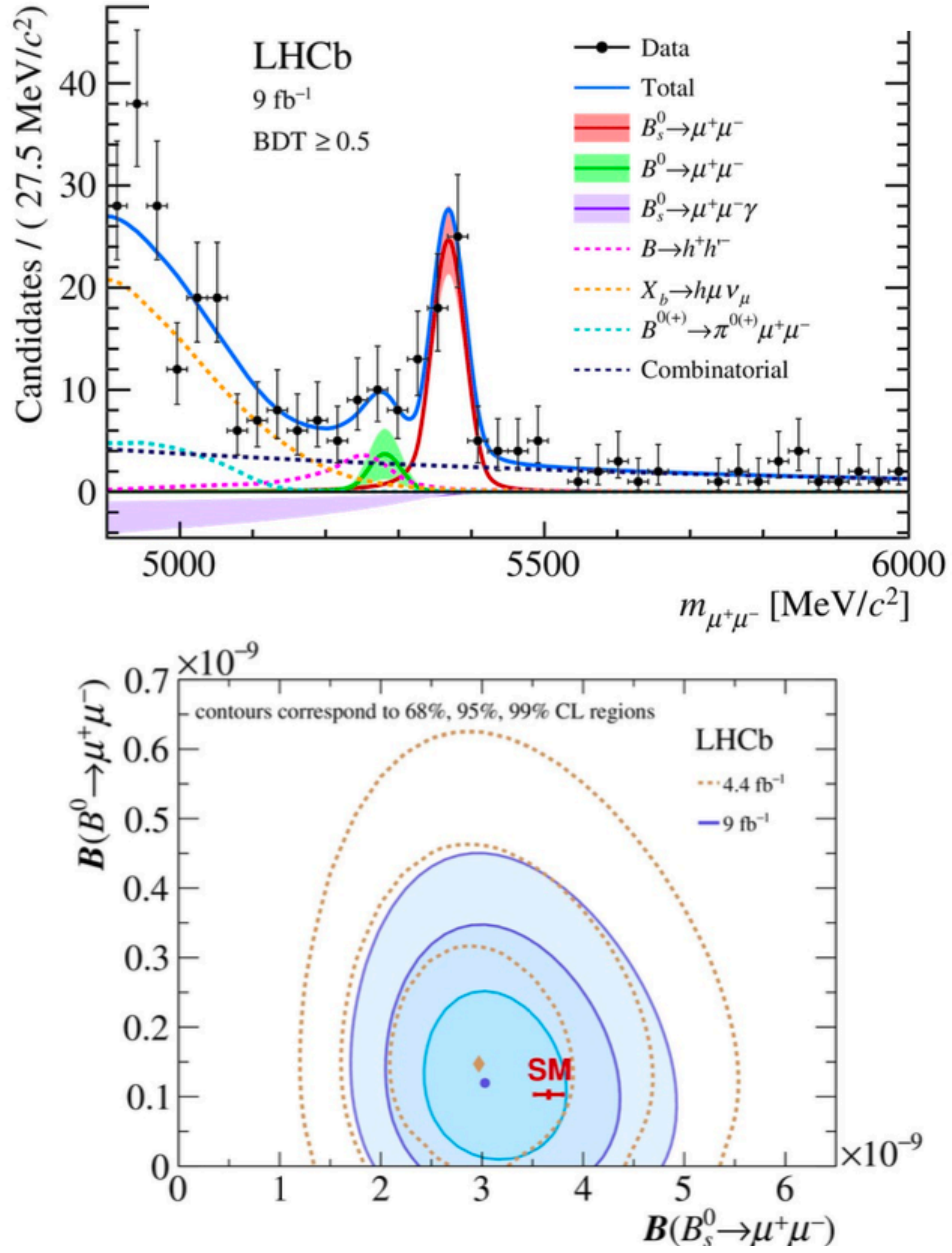


Our favorite WET

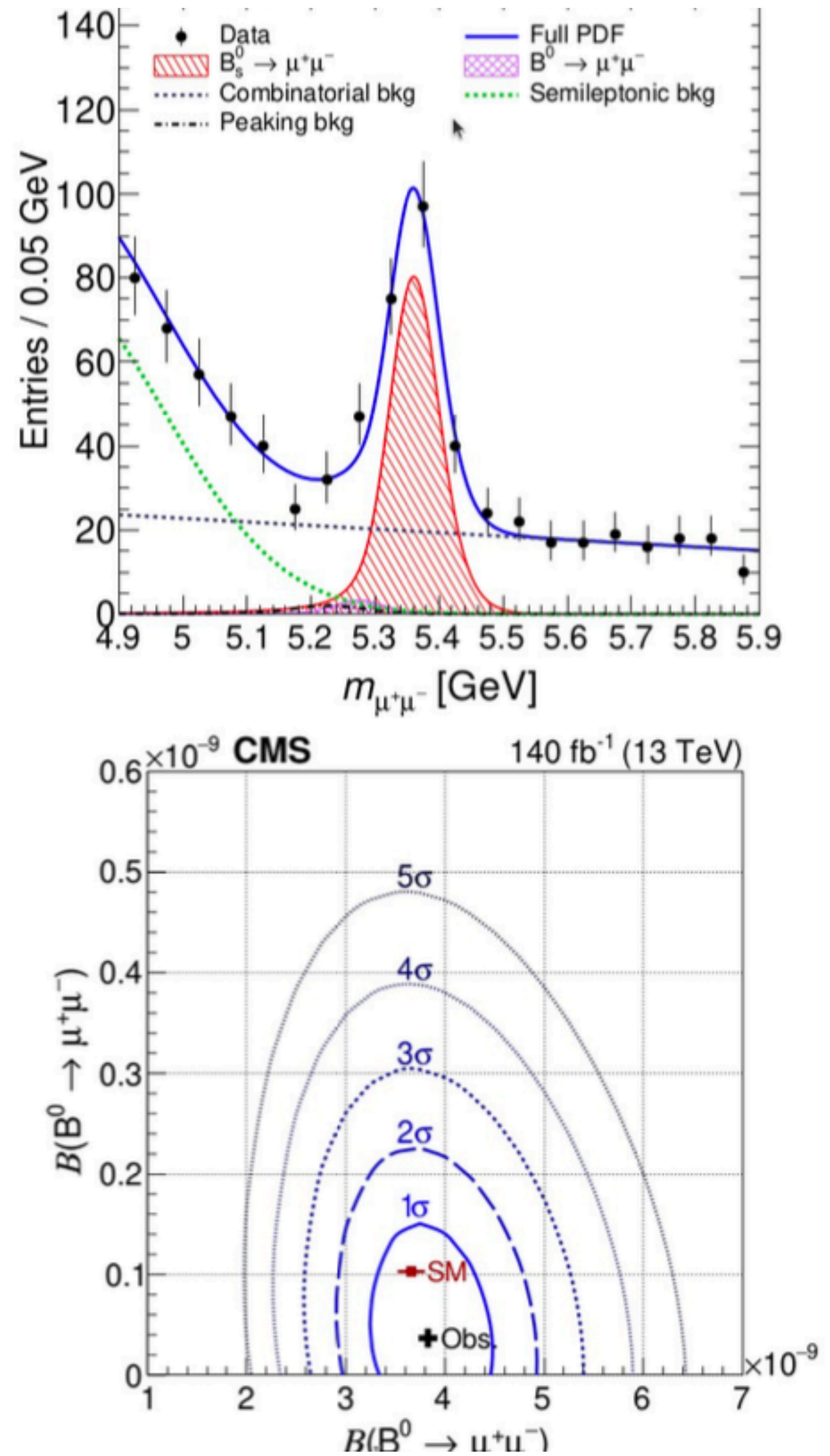
$$\mathcal{H}_{\text{eff}} = \frac{G_F}{\sqrt{2}} \lambda^{\text{CKM}} \sum_i C_i \mathcal{O}_i + h.c,$$

Marzia's talk

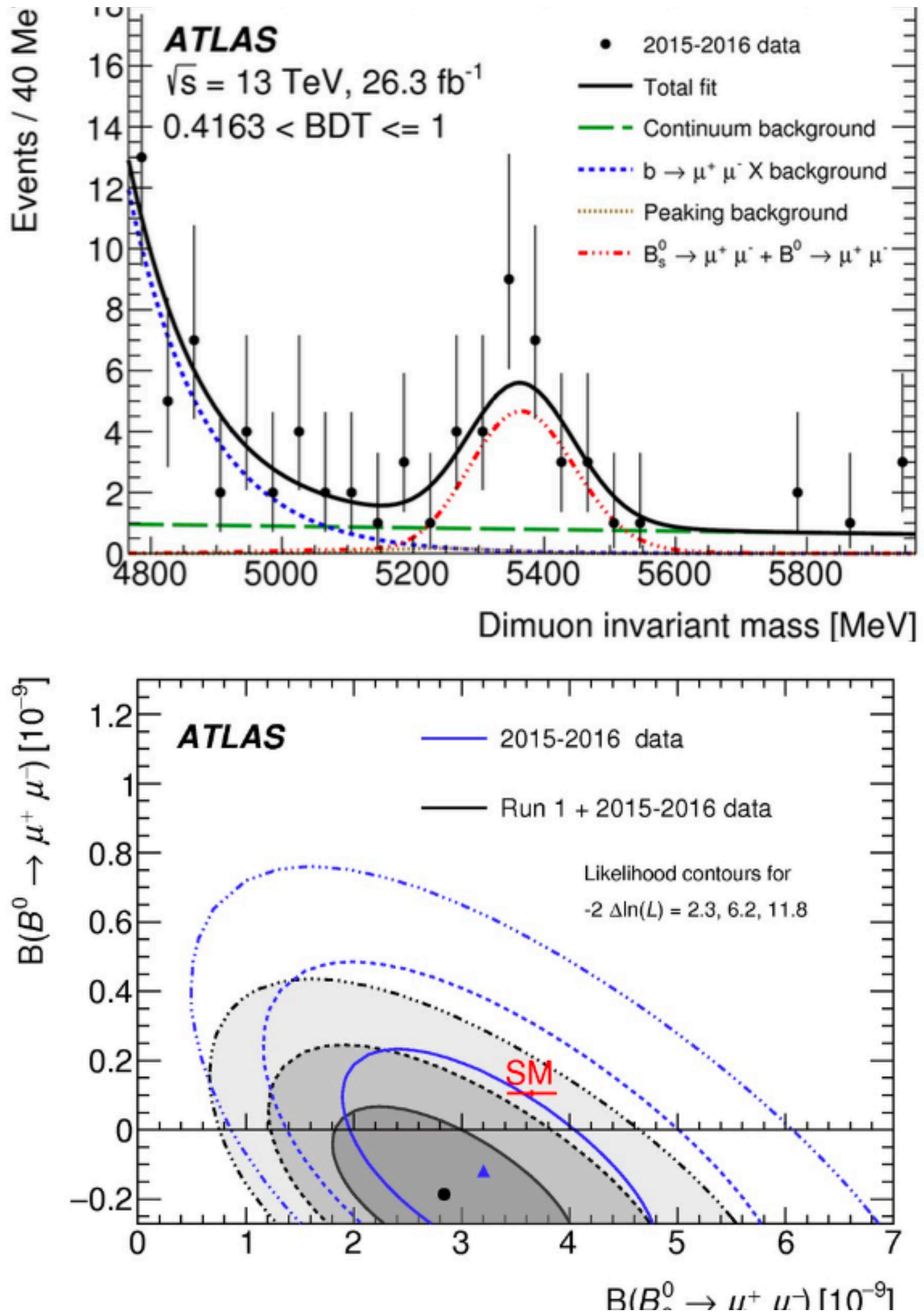
How rare is a *B*-rare mode?



LHCb PRL 128 (2022) 041801

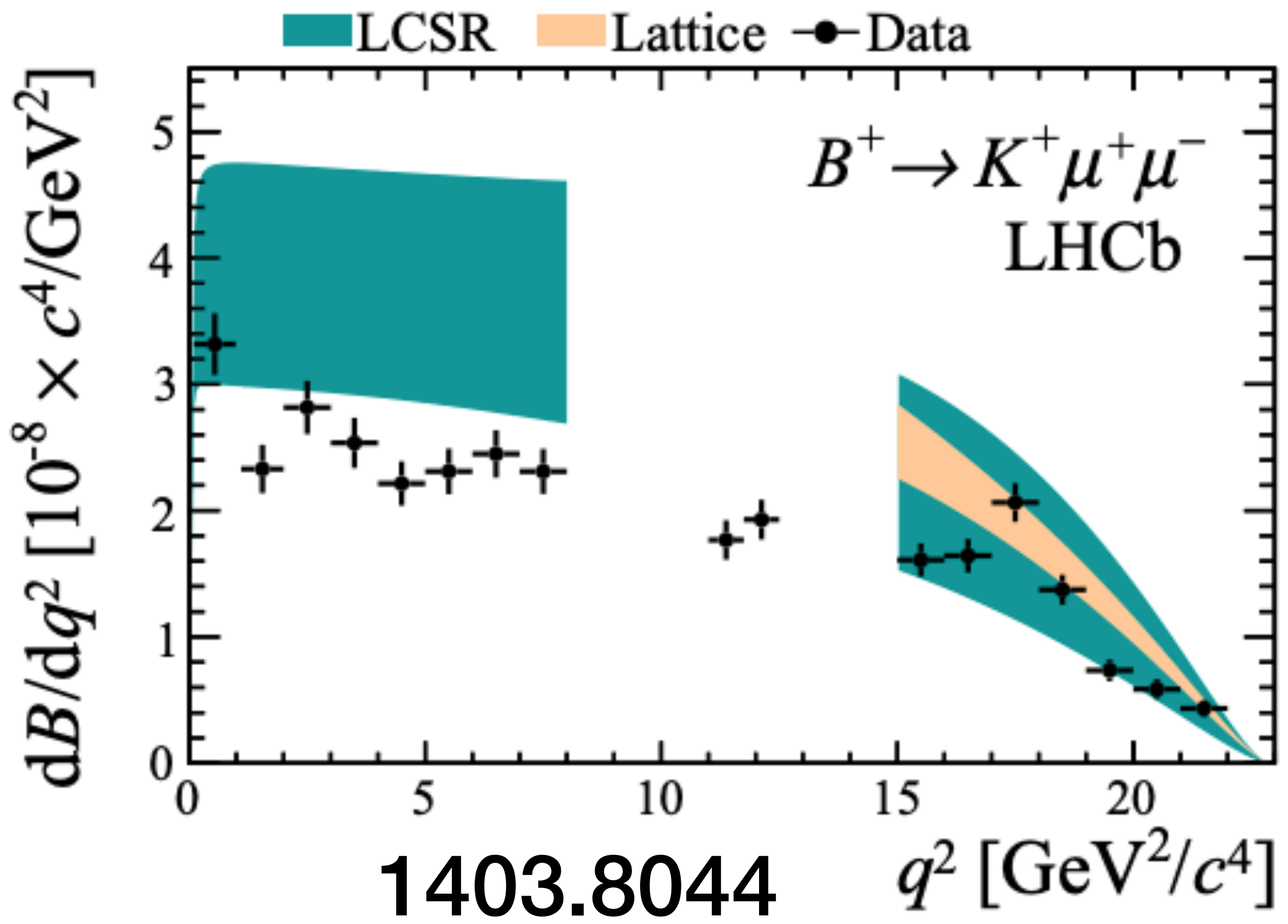


CMS PL B842 (2023) 137955

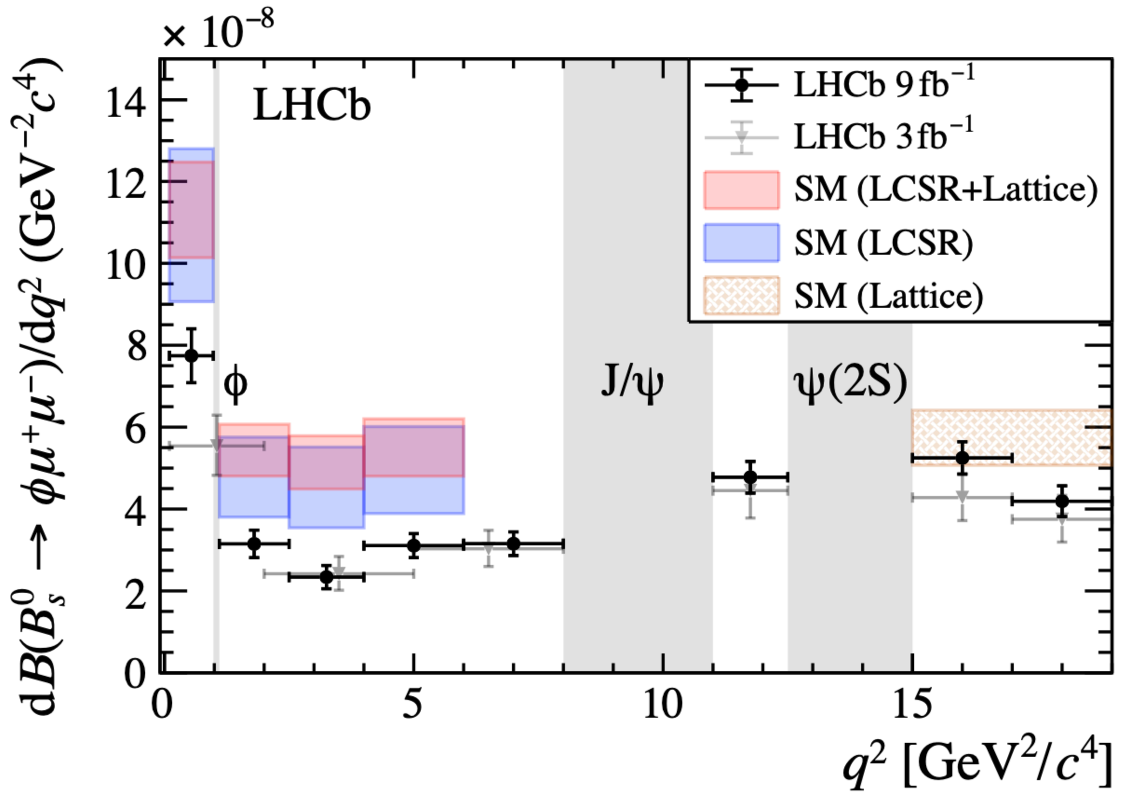


ATLAS JHEP 04 (2019) 098

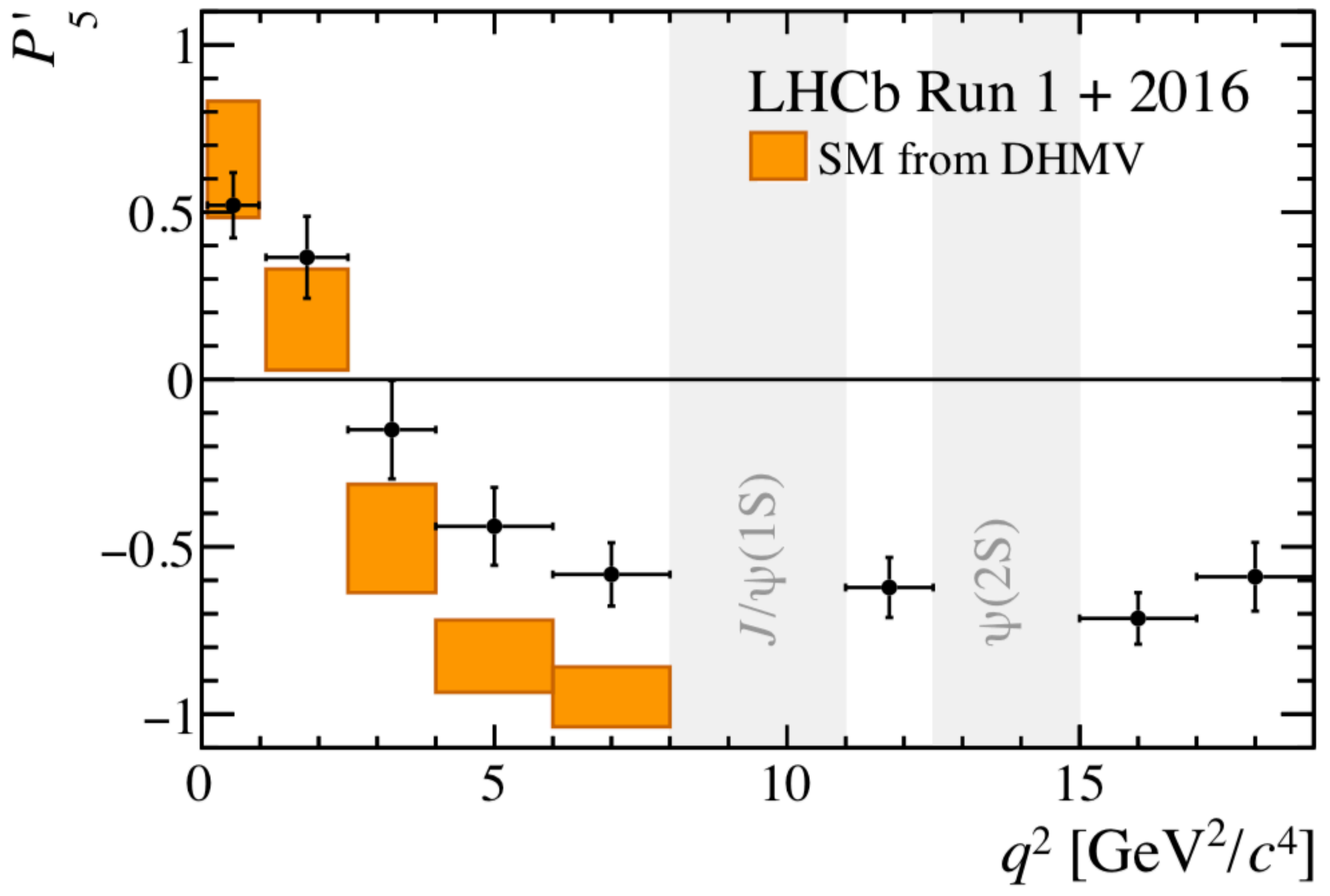
A collection of tensions



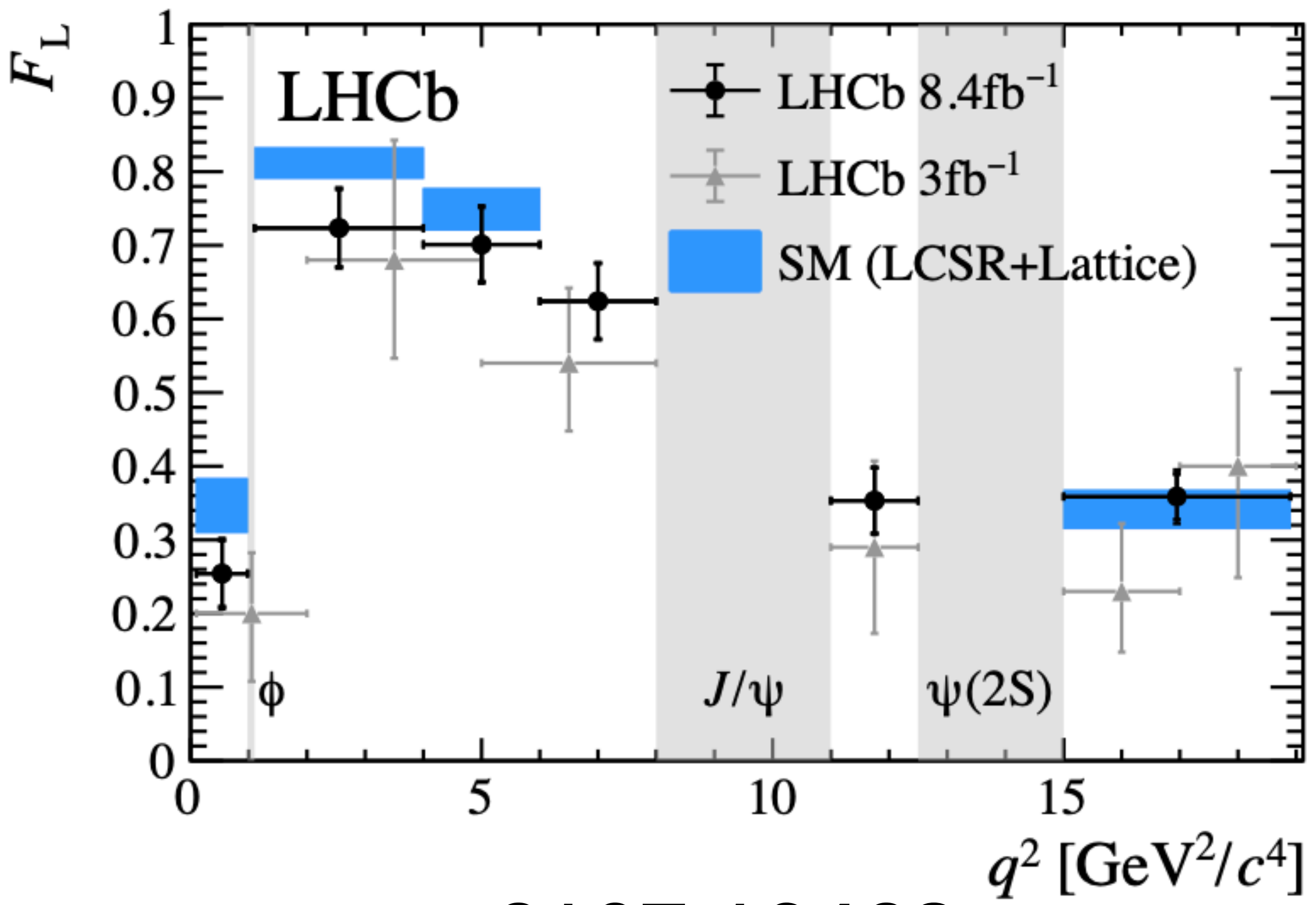
1403.8044



2105.14007.



2003.04831

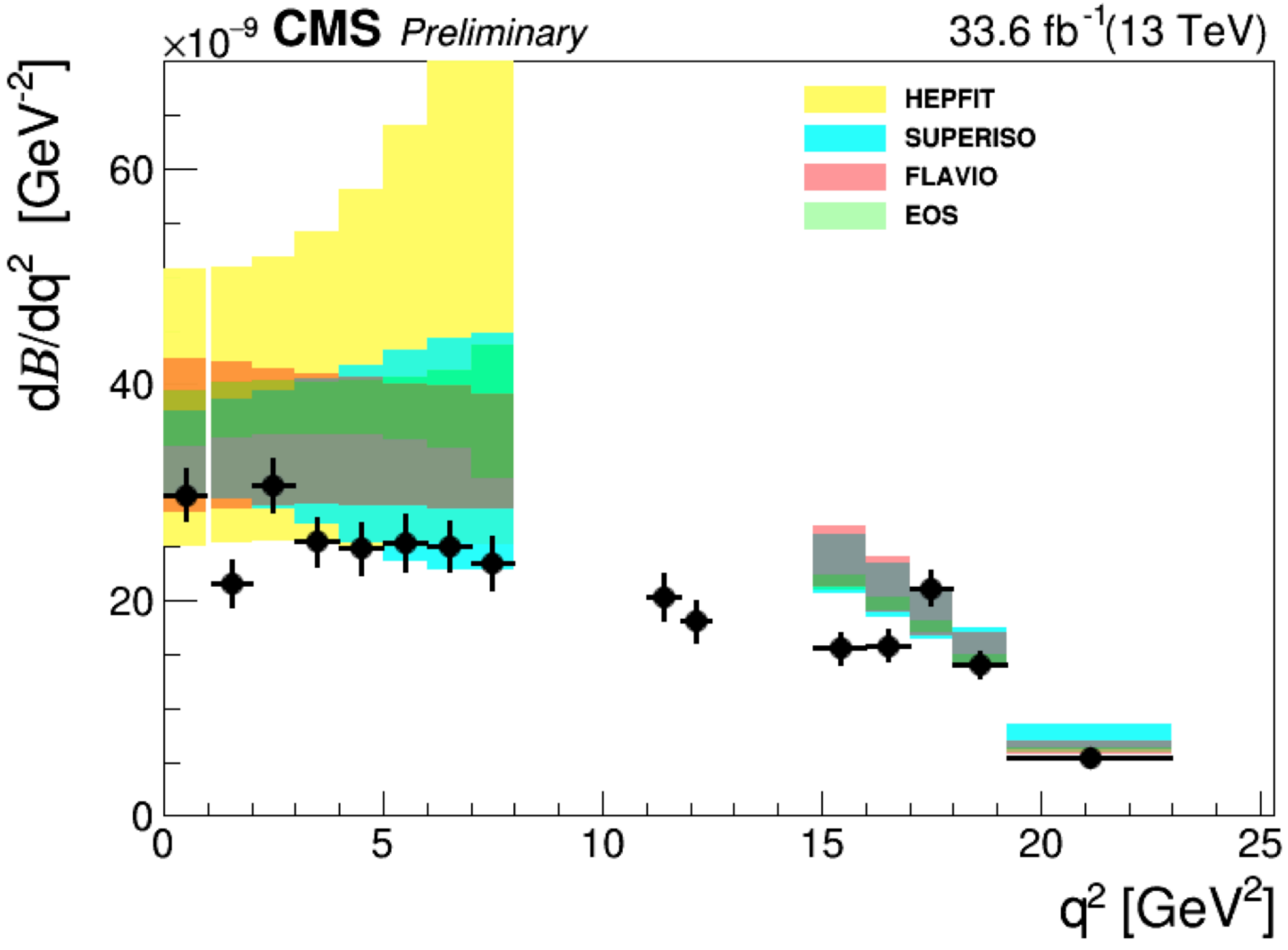


2107.13428

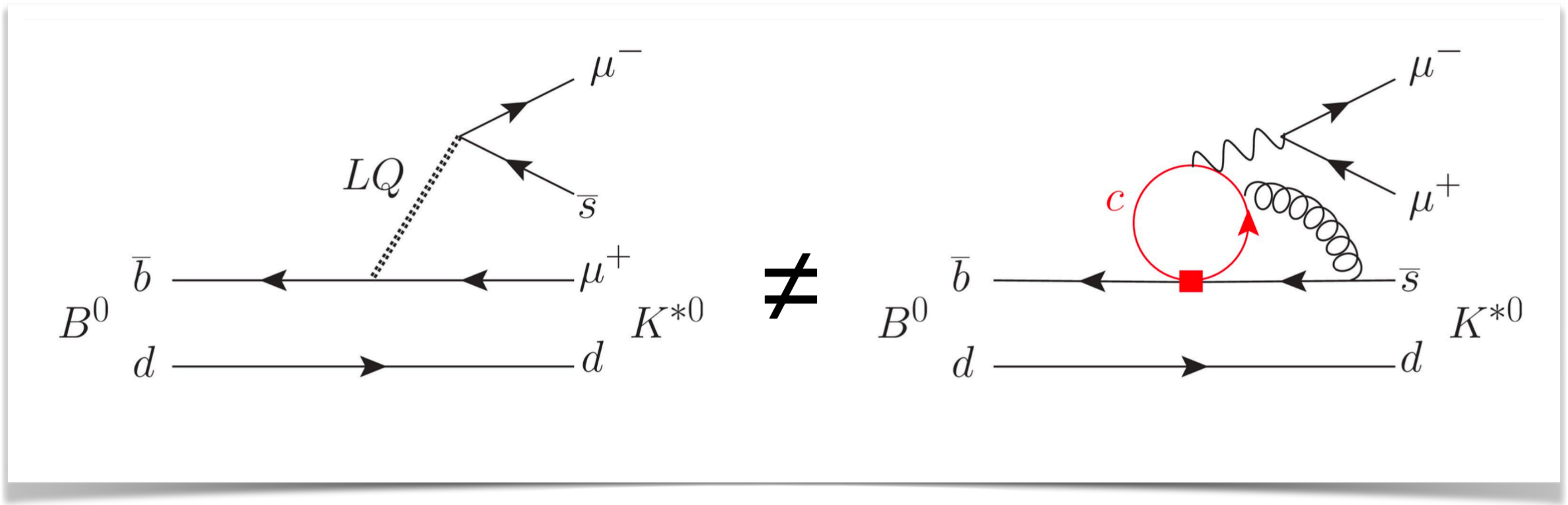
Also new results with *b*-baryons !

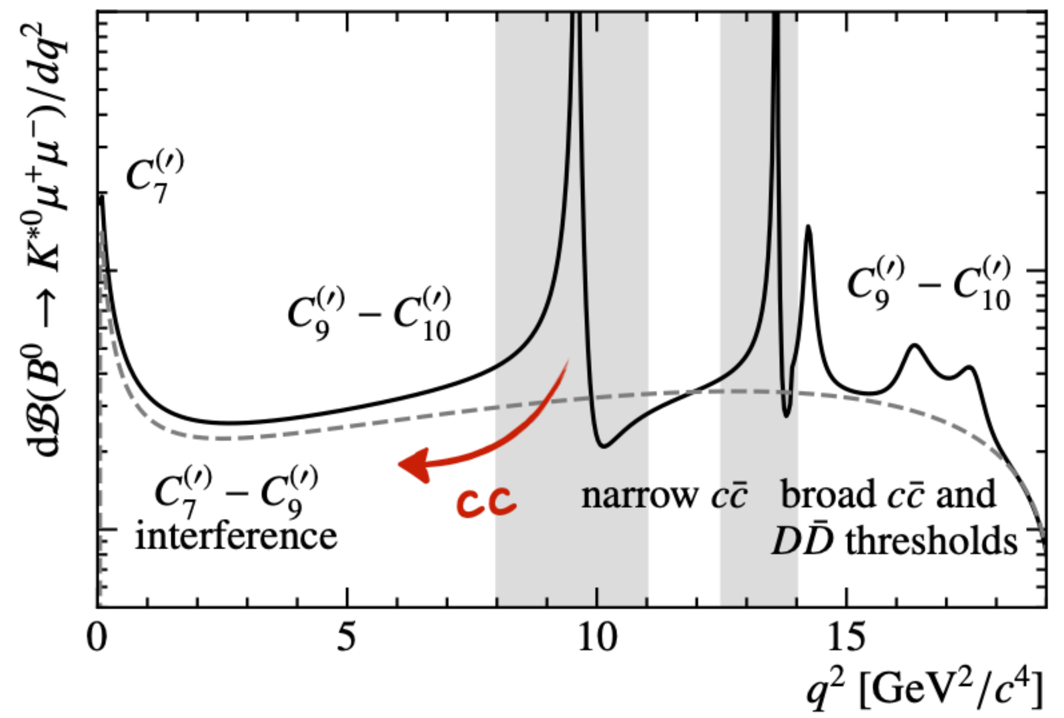
Ulrik's talk

NP or QCD?



Riccardo's talk





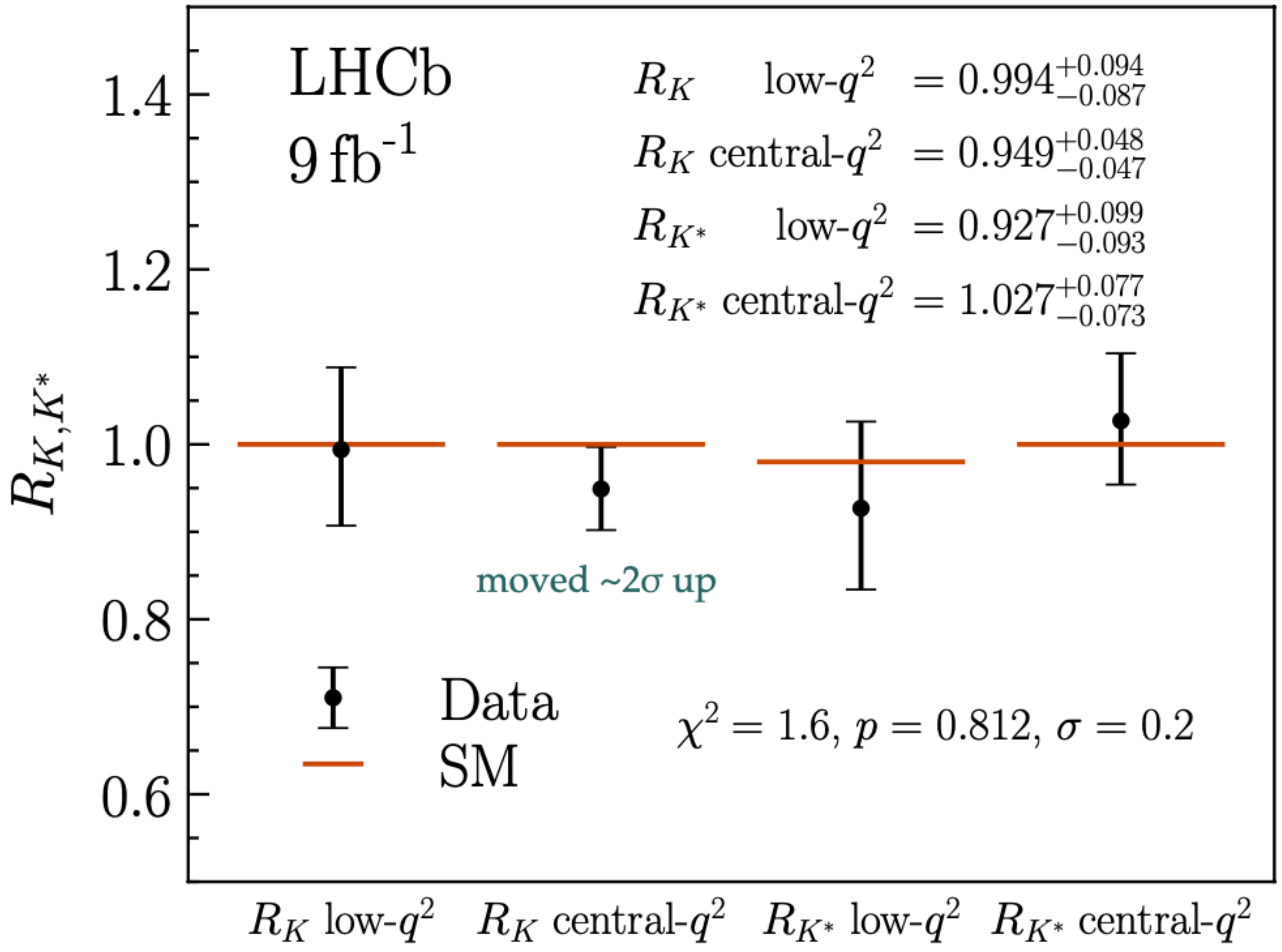
Never ever forget about the charm loops !

New result for CKM

Andrea's talk

No further comments your honour

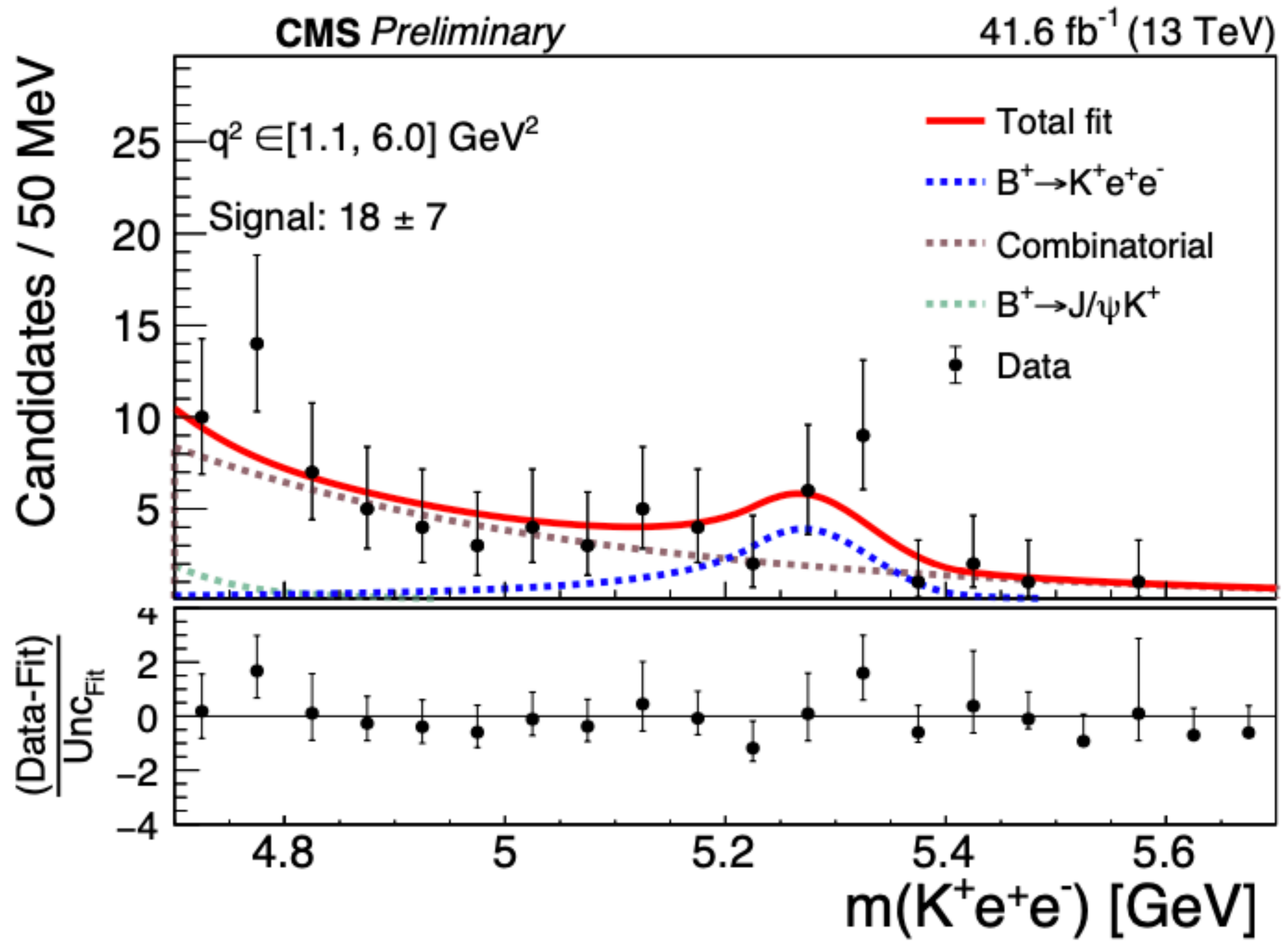
$$R_H \equiv \frac{\int \frac{d\Gamma(B\to H\mu^+\mu^-)}{dq^2}\,dq^2}{\int \frac{d\Gamma(B\to He^+e^-)}{dq^2}\,dq^2},$$



LHCb-PAPER-2022-045/046

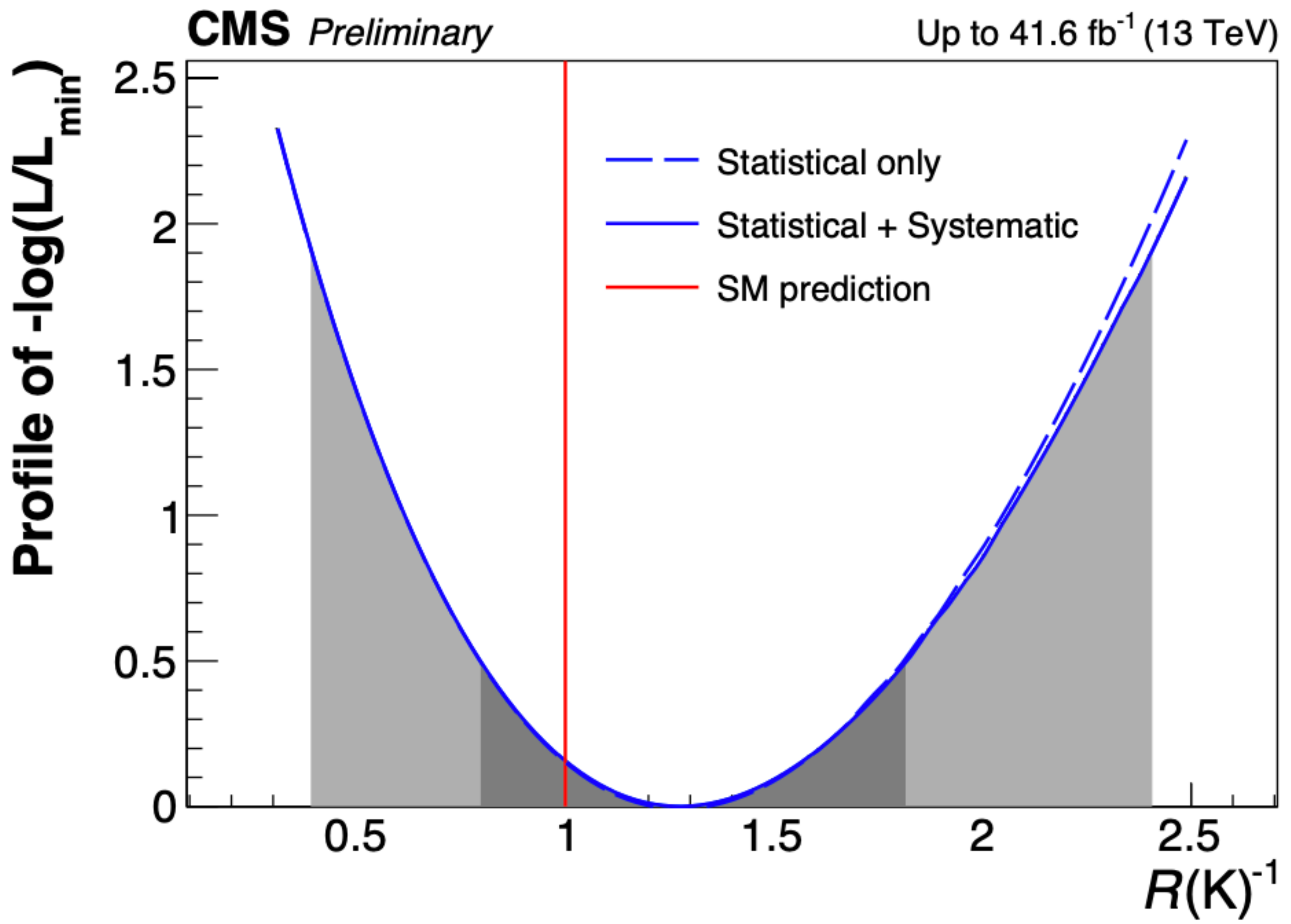
Martino’s talk

Across the ring



CMS-BPH-22-005

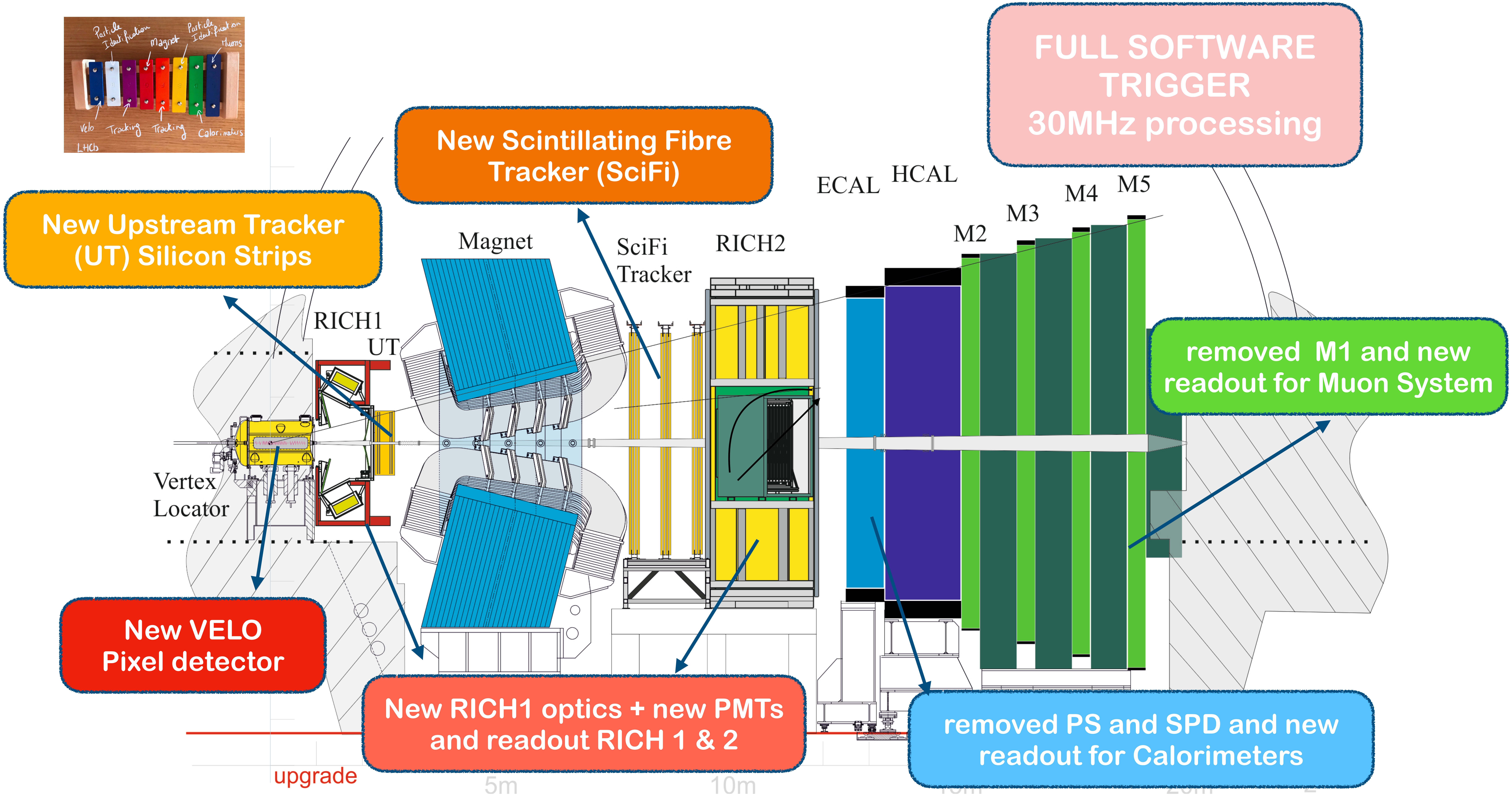
Riccardo's talk



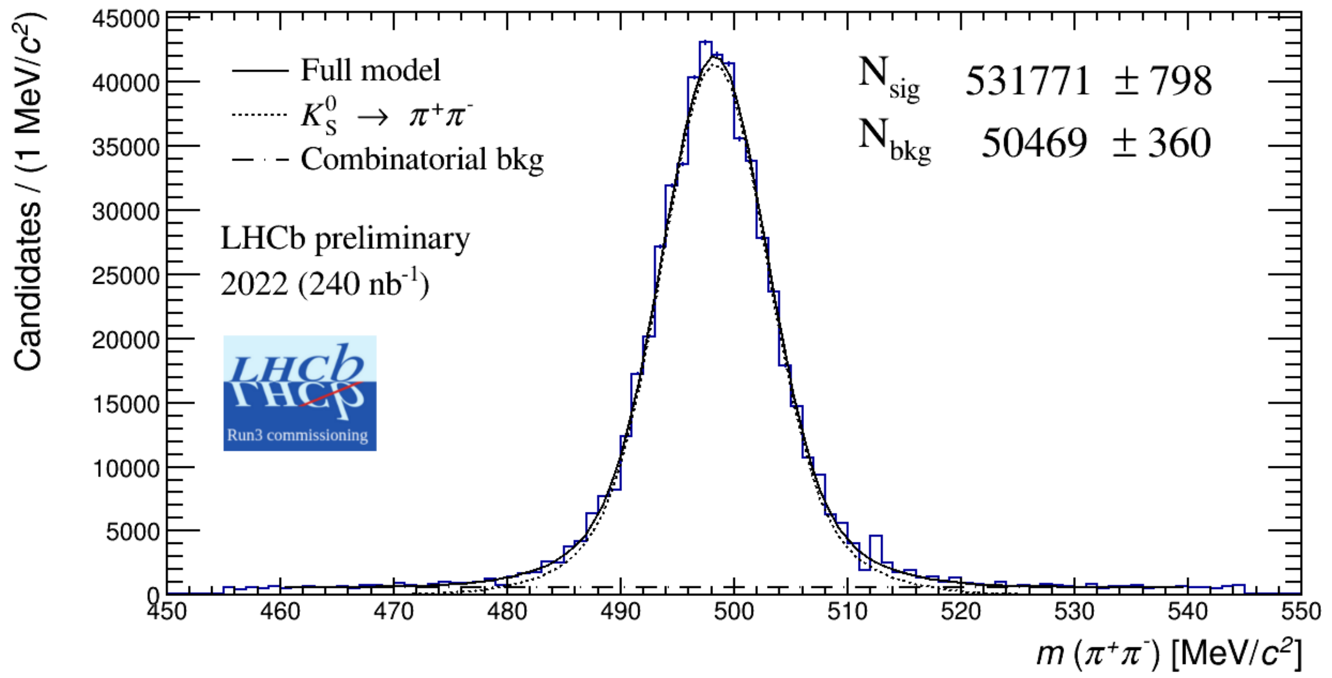
From the B-parked data

Upgrade(s)

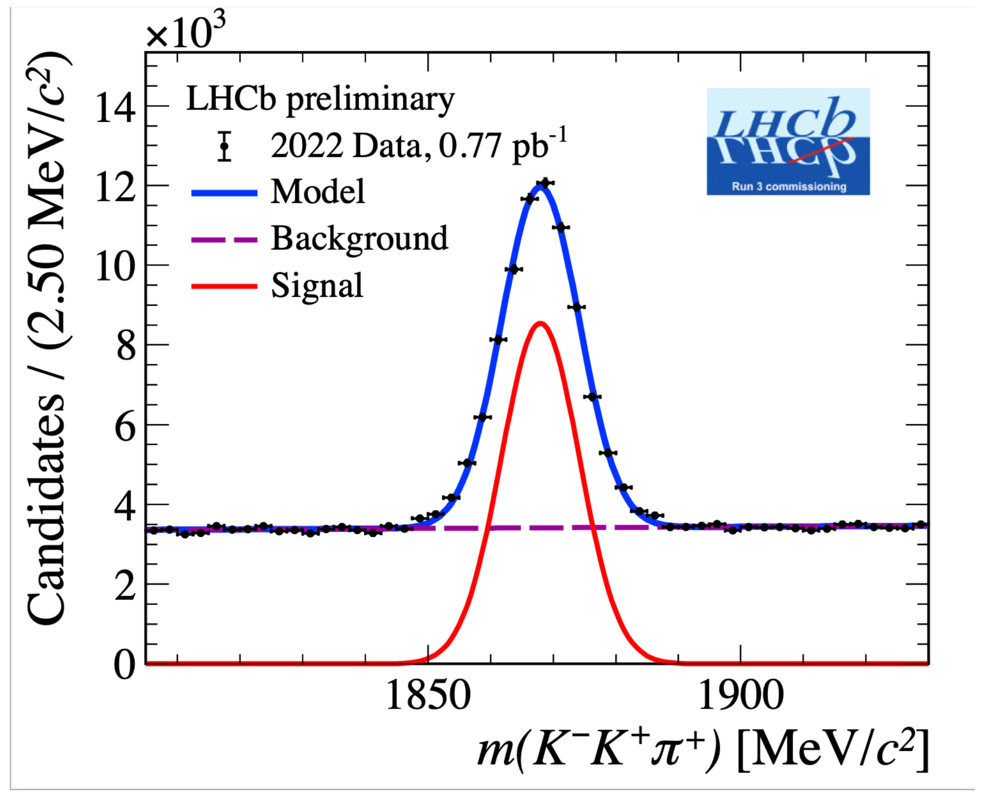
Information for ATLAS & CMS upgrades in the supplementary material


Particle Identification
Magnet
Particle Identification
Muons
Velo
Tracking
Tracking
Calorimeters
LHCb
FULL SOFTWARE TRIGGER
30MHz processing
New Scintillating Fibre Tracker (SciFi)
New Upstream Tracker (UT) Silicon Strips
ECAL
HCAL
M4
M5
M3
M2
Magnet
SciFi Tracker
RICH2
RICH1
UT
removed M1 and new readout for Muon System
Vertex Locator
New VELO Pixel detector
New RICH1 optics + new PMTs and readout RICH 1 & 2
removed PS and SPD and new readout for Calorimeters
upgrade
5m
10m

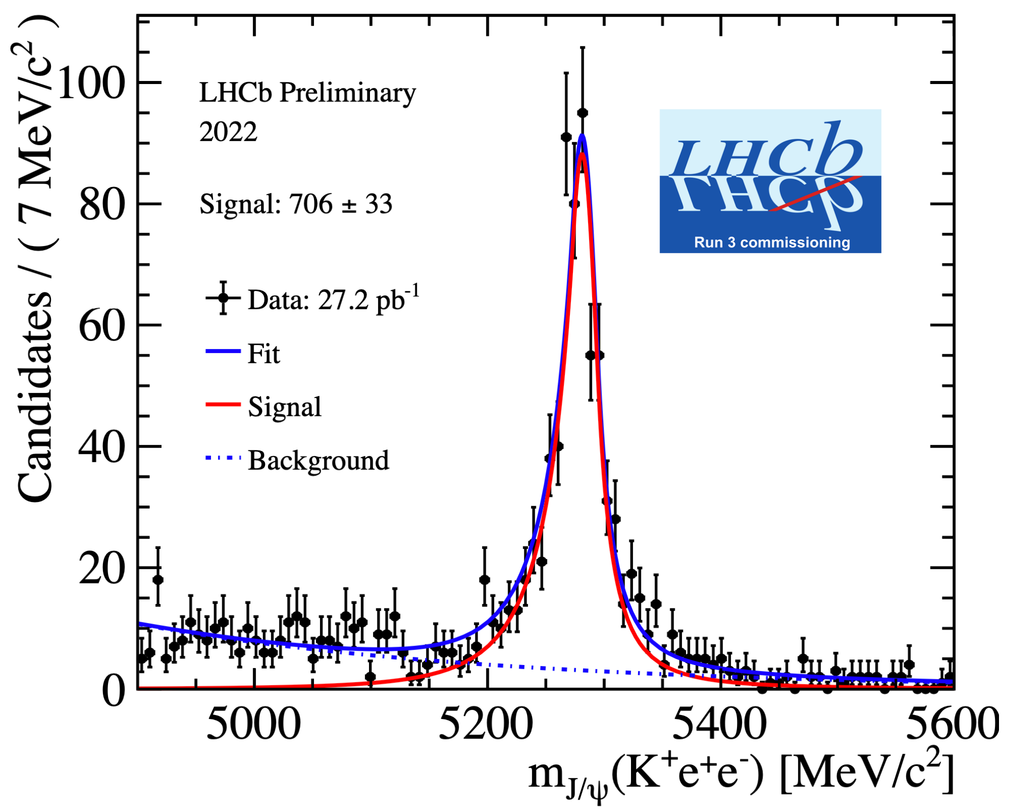
What can we hope for?



LHCb-FIGURE-2023-005



LHCb-FIGURE-2023-009



LHCb-FIGURE-2023-011

[Submitted on 17 May 2023]

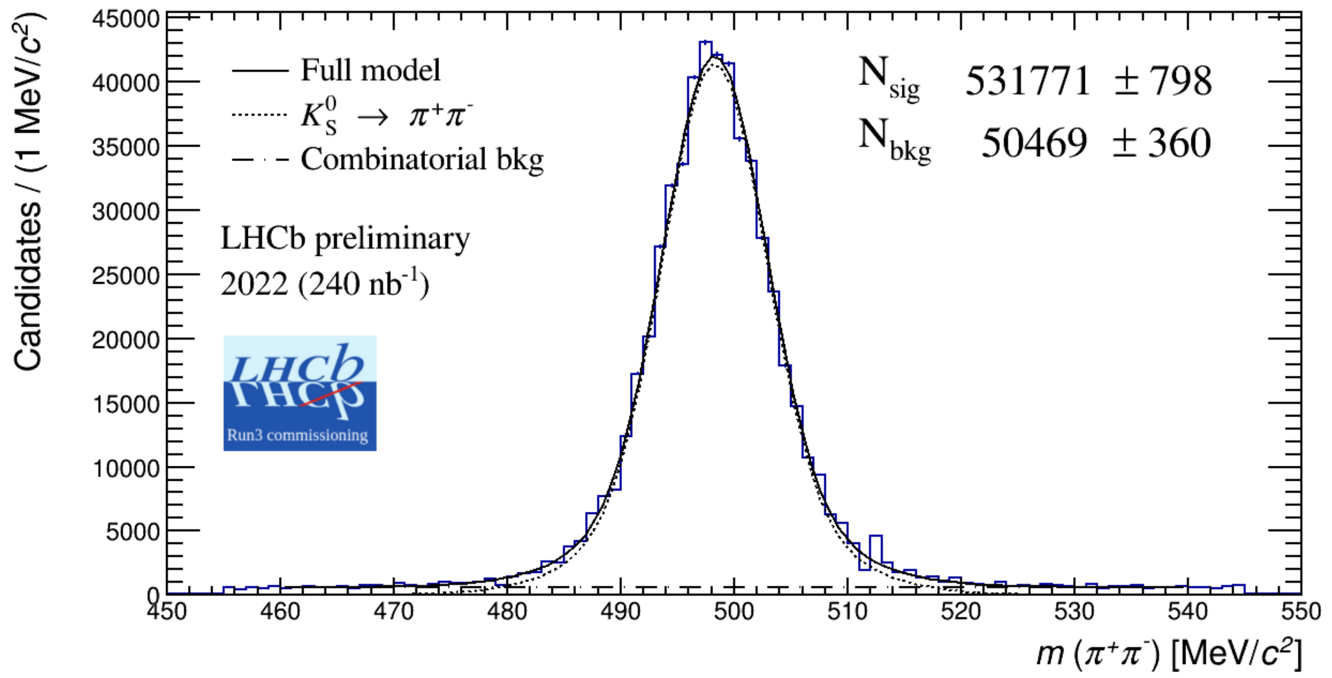
The LHCb upgrade I

LHCb collaboration: R. Aaij, A.S.W. Abdelmotteleb, C. Abellan Beteta, F. Abudinén, C. Achard, T. Ackernley, B. Adeva, M. Adinolfi, P. Adlarson, H. Afsharnia, C. Agapopoulou, C.A. Aidala, Z. Ajaltouni, S. Akar, K. Akiba, P. Albicocco, J. Albrecht, F. Alessio, M. Alexander, A. Alfonso Albero, Z. Aliouche, P. Alvarez Cartelle, R. Amalric, S. Amato, J.L. Amey, Y. Amhis, L. An, L. Anderlini, M. Andersson, A. Andreani, A. Andreianov, M. Andreotti, D. Andreou, J.E. Andrews, M. Anelli, A. Anjam, D. Ao, F. Archilli, K. Arnaud, A. Artamonov, M. Artuso, J. Ashby, E. Aslanides, M. Atzeni, B. Audurier, D. Ayres Rocha, I.B Bachiller Perea, S. Bachmann, M. Bachmayer, J.J. Back, A. Bailly-reyre, P. Baladron Rodriguez, V. Balagura, G. Balbi, W. Baldini, A. Balla, M. Baltazar, H. Band, J. Baptista de Souza Leite, M. Barbetti, P. Barclay, R.J. Barlow, S. Barsuk, W. Barter, M. Bartolini, F. Baryshnikov, J.M. Basels, G. Bassi, M. Baszczyk, J.C. Batista Lopes, B. Batsukh, A. Battig, A. Bay, A. Beck, M. Becker, F. Bedeschi, I.B. Bediaga, C. Beigbeder-Beau, A. Beiter, S. Belin, V. Bellee, K. Belous, I. Belov, I. Belyaev, G. Benane, G. Bencivenni, M. Benettoni, E. Ben-Haim, A. Berezhnoy, F. Bernard, R. Bernet, S. Bernet Andres, D. Berninghoff, H.C. Bernstein, C. Bertella, A. Bertolin, C. Betancourt, F. Betti, Ia. Bezshyiko et al. (1223 additional authors not shown)

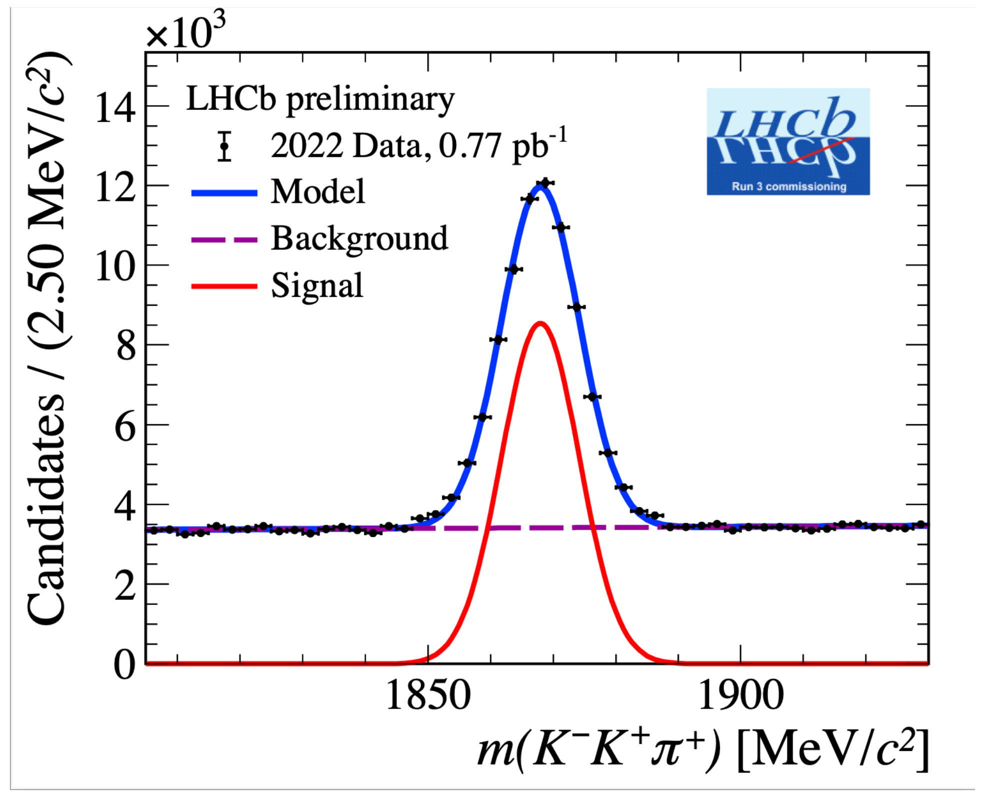
The LHCb upgrade represents a major change of the experiment. The detectors have been almost completely renewed to allow running at an instantaneous luminosity five times larger than that of the previous running periods. Readout of all detectors into an all-software trigger is central to the new design, facilitating the reconstruction of events at the maximum LHC interaction rate, and their selection in real time. The experiment's tracking system has been completely upgraded with a new pixel vertex detector, a silicon tracker upstream of the dipole magnet and three scintillating fibre tracking stations downstream of the magnet. The whole photon detection system of the RICH detectors has been renewed and the readout electronics of the calorimeter and muon systems have been fully overhauled. The first stage of the all-software trigger is implemented on a GPU farm. The output of the trigger provides a combination of totally reconstructed physics objects, such as tracks and vertices, ready for final analysis, and of entire events which need further offline reprocessing. This scheme required a complete revision of the computing model and rewriting of the experiment's software.

2305.10515

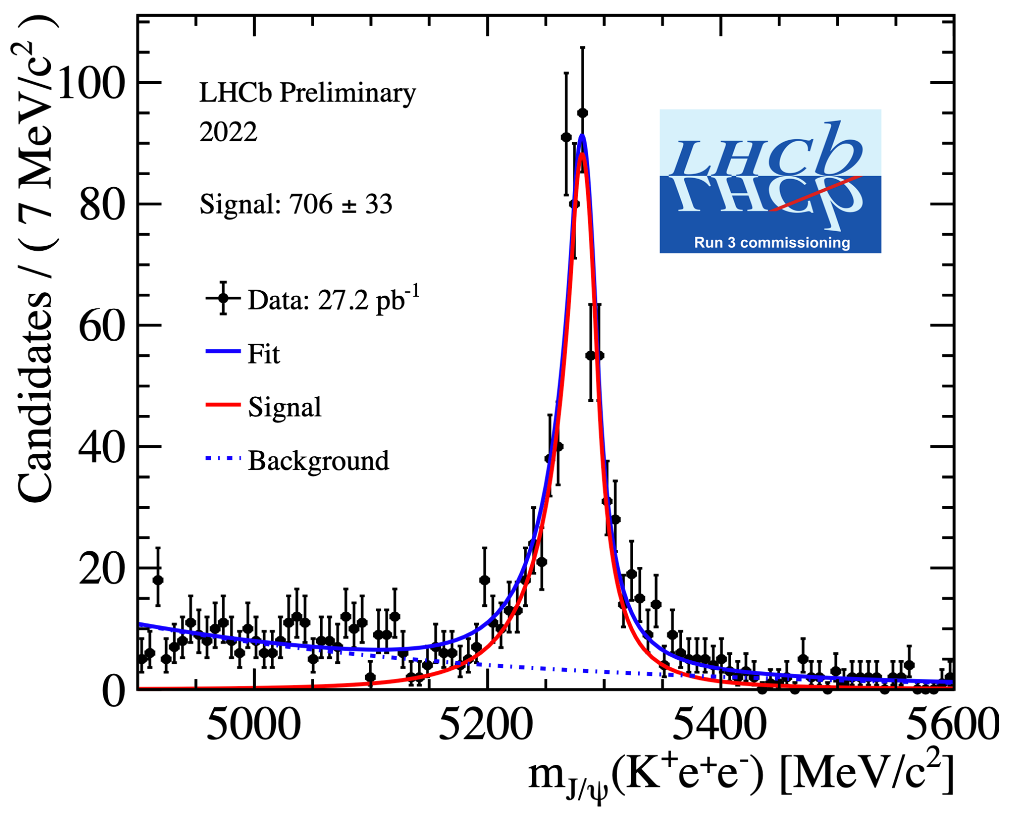
What can we hope for?



LHCb-FIGURE-2023-005



LHCb-FIGURE-2023-009



LHCb-FIGURE-2023-011

[Submitted on 17 May 2023]

The LHCb upgrade I

LHCb collaboration: R. Aaij, A.S.W. Abdelmotteleb, C. Abellan Beteta, F. Abudinén, C. Achard, T. Ackernley, B. Adeva, M. Adinolfi, P. Adlarson, H. Afsharnia, C. Agapopoulou, C.A. Aidala, Z. Ajaltouni, S. Akar, K. Akiba, P. Albicocco, J. Albrecht, F. Alessio, M. Alexander, A. Alfonso Albero, Z. Aliouche, P. Alvarez Cartelle, R. Amalric, S. Amato, J.L. Amey, Y. Amhis, L. An, L. Anderlini, M. Andersson, A. Andreani, A. Andreianov, M. Andreotti, D. Andreou, J.E. Andrews, M. Anelli, A. Anjam, D. Ao, F. Archilli, K. Arnaud, A. Artamonov, M. Artuso, J. Ashby, E. Aslanides, M. Atzeni, B. Audurier, D. Ayres Rocha, I.B Bachiller Perea, S. Bachmann, M. Bachmayer, J.J. Back, A. Bailly-reyre, P. Baladron Rodriguez, V. Balagura, G. Balbi, W. Baldini, A. Balla, M. Baltazar, H. Band, J. Baptista de Souza Leite, M. Barbetti, P. Barclay, R.J. Barlow, S. Barsuk, W. Barter, M. Bartolini, F. Baryshnikov, J.M. Basels, G. Bassi, M. Baszczyk, J.C. Batista Lopes, B. Batsukh, A. Battig, A. Bay, A. Beck, M. Becker, F. Bedeschi, I.B. Bediaga, C. Beigbeder-Beau, A. Beiter, S. Belin, V. Bellee, K. Belous, I. Belov, I. Belyaev, G. Benane, G. Bencivenni, M. Benettoni, E. Ben-Haim, A. Berezhnoy, F. Bernard, R. Bernet, S. Bernet Andres, D. Berninghoff, H.C. Bernstein, C. Bertella, A. Bertolin, C. Betancourt, F. Betti, Ia. Bezshyiko et al. (1223 additional authors not shown)

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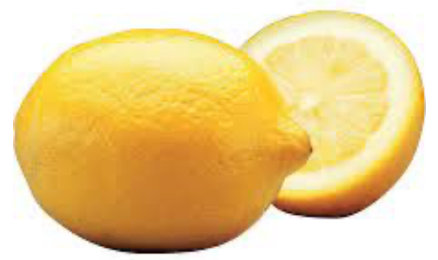
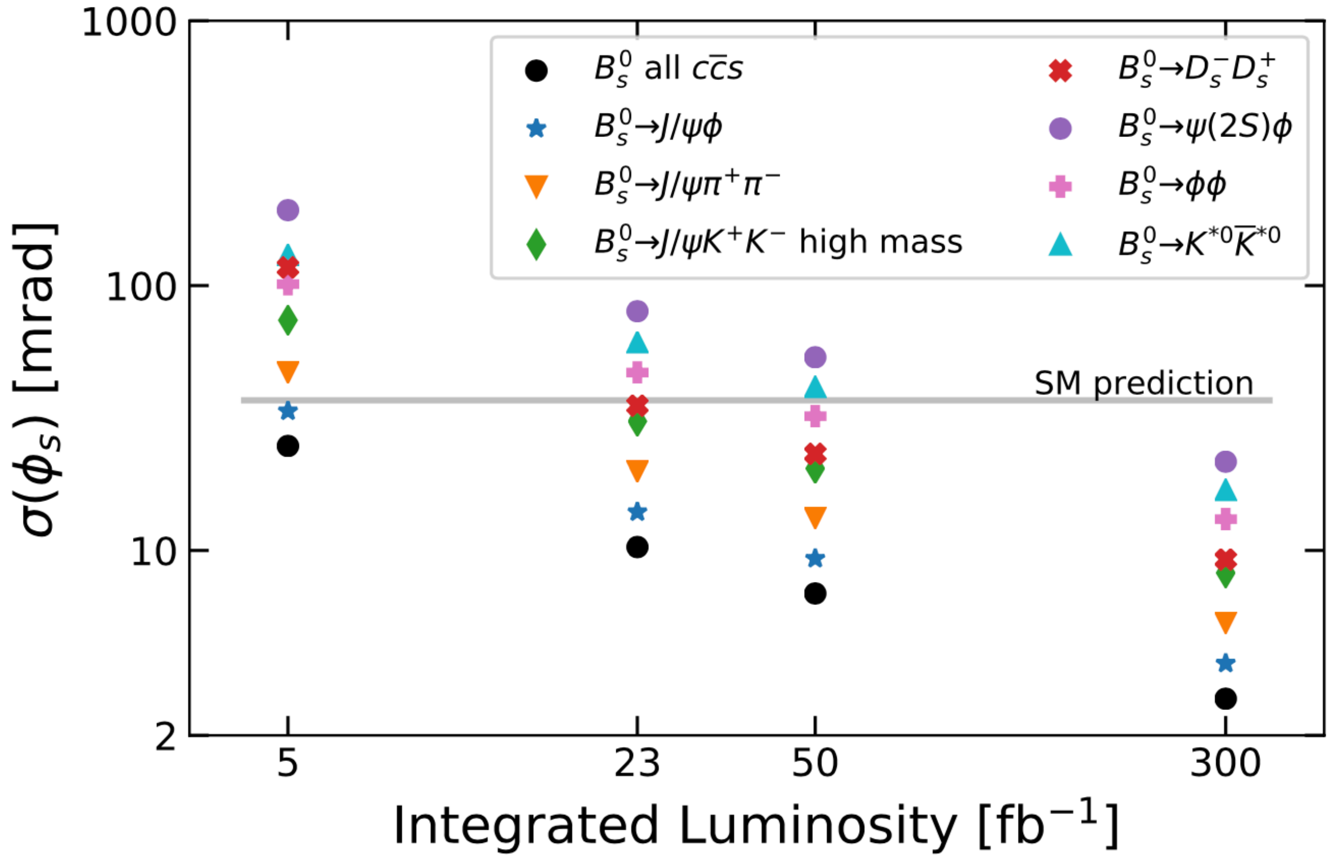
2305.10515

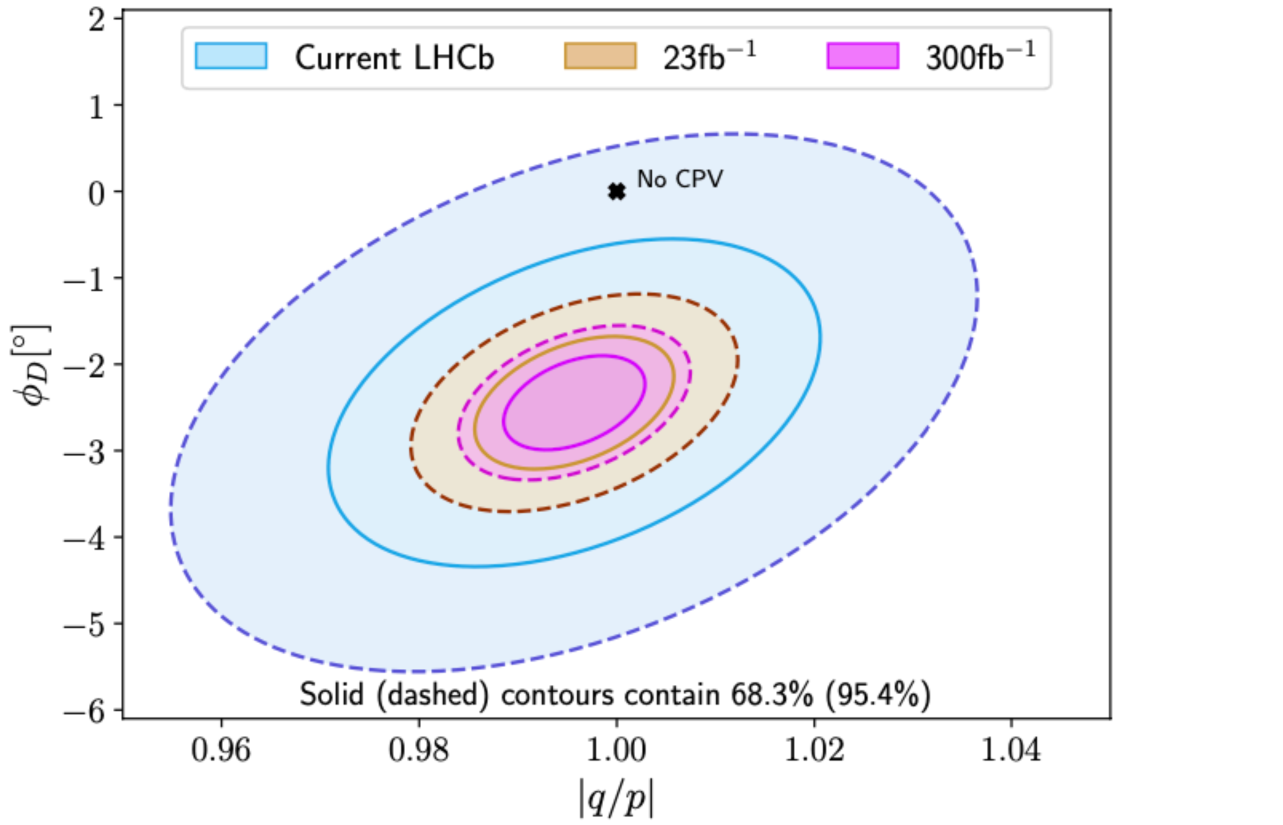
2023 has been a difficult year

VELO Vacuum incident January
LHC incident(s) in the summer

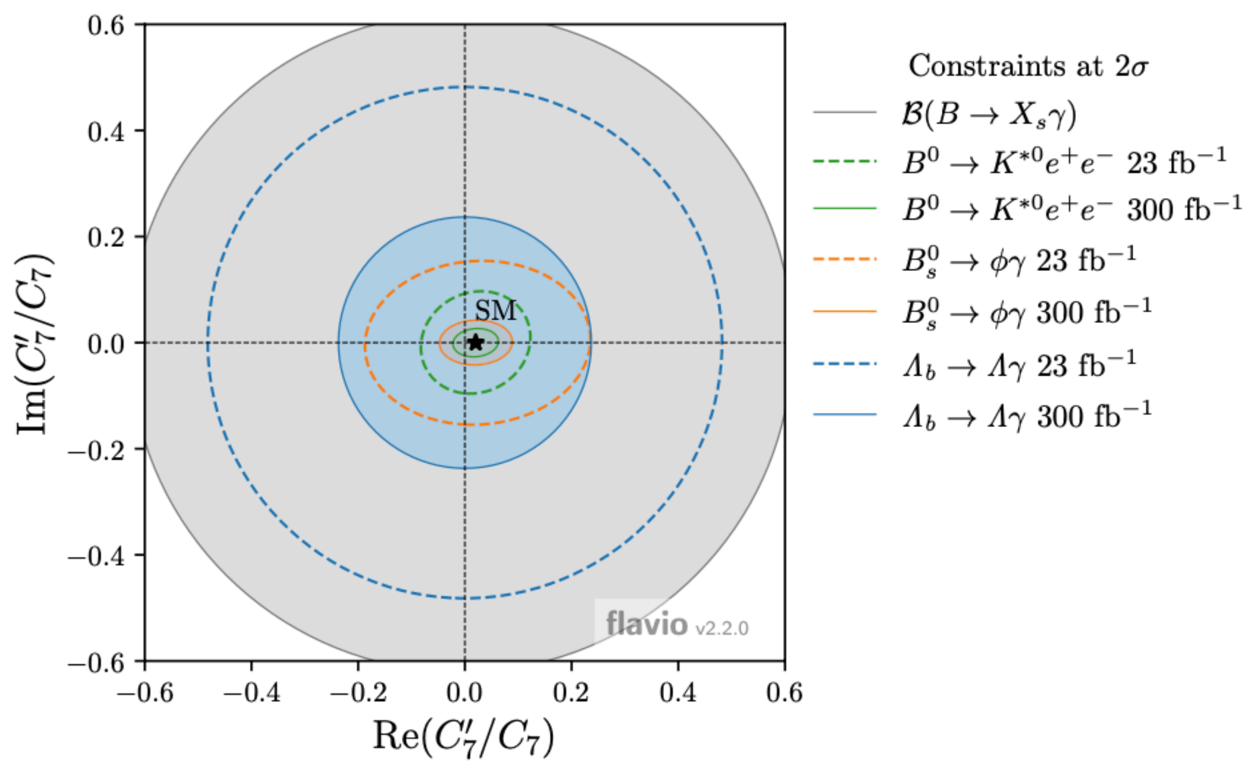


Let's see what the future holds 🤞



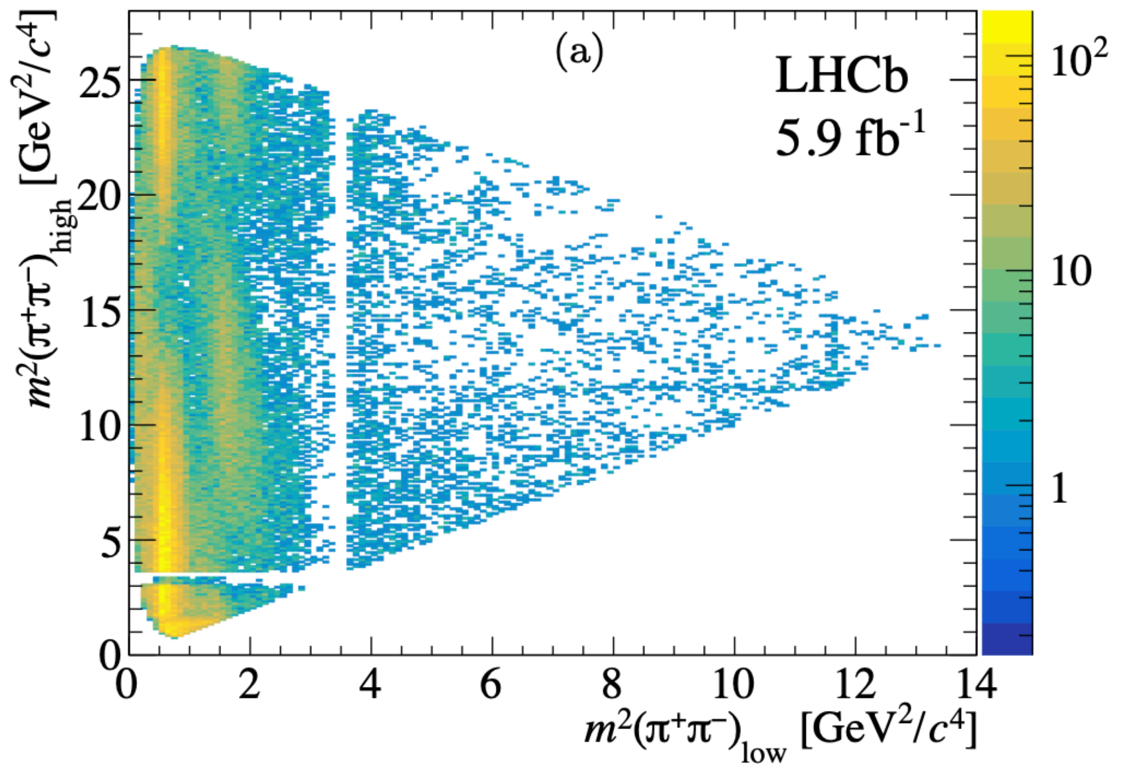


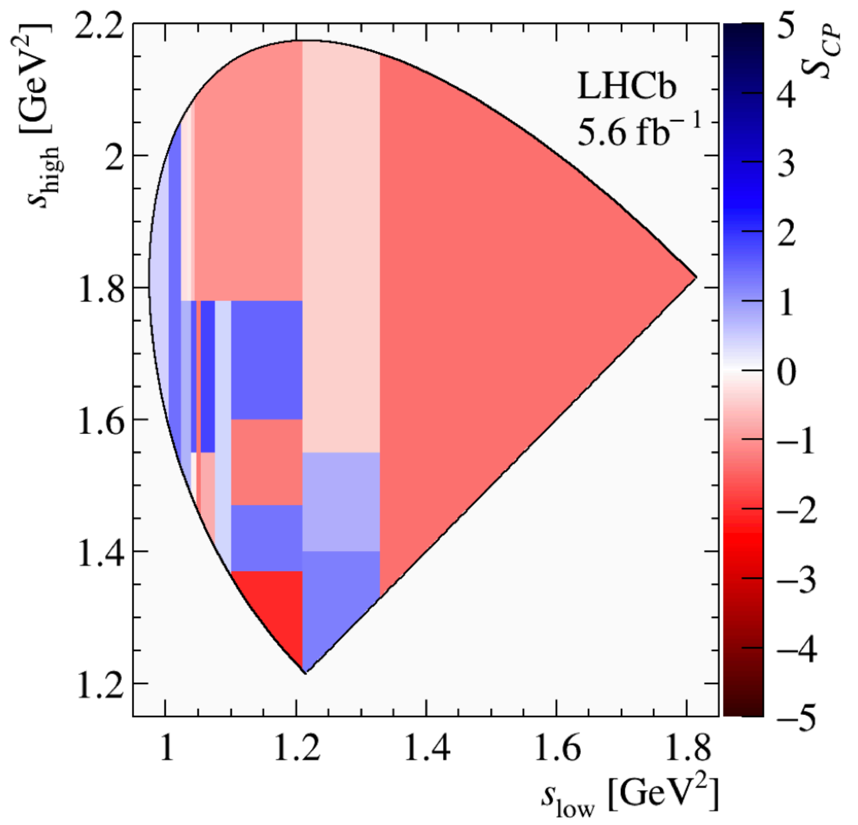
Observable	Current LHCb (up to 9 fb^{-1})		Upgrade I (23 fb^{-1})	(50 fb^{-1})	Upgrade II (300 fb^{-1})
CKM tests					
γ ($B\to DK$, *etc.*)	4°	[9, 10]	1.5°	1°	0.35°
ϕ_s ($B_s^0\to J/\psi\phi$)	32 mrad	[8]	14 mrad	10 mrad	4 mrad
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$ ($\Lambda_b^0\to p\mu^-\overline{\nu}_\mu$, *etc.*)	6%	[29, 30]	3%	2%	1%
$a_{\rm sl}^d$ ($B^0\to D^-\mu^+\nu_\mu$)	36×10^{-4}	[34]	8×10^{-4}	5×10^{-4}	2×10^{-4}
$a_{\rm sl}^s$ ($B_s^0\to D_s^-\mu^+\nu_\mu$)	33×10^{-4}	[35]	10×10^{-4}	7×10^{-4}	3×10^{-4}
Charm					
ΔA_{CP} ($D^0\to K^+K^-,\pi^+\pi^-$)	29×10^{-5}	[5]	13×10^{-5}	8×10^{-5}	3.3×10^{-5}
A_Γ ($D^0\to K^+K^-,\pi^+\pi^-$)	11×10^{-5}	[38]	5×10^{-5}	3.2×10^{-5}	1.2×10^{-5}
Δx ($D^0\to K_S^0\pi^+\pi^-$)	18×10^{-5}	[37]	6.3×10^{-5}	4.1×10^{-5}	1.6×10^{-5}
Rare Decays					
$\mathcal{B}(B^0\to\mu^+\mu^-)/\mathcal{B}(B_s^0\to\mu^+\mu^-)$	69%	[40, 41]	41%	27%	11%
$S_{\mu\mu}$ ($B_s^0\to\mu^+\mu^-$)	—		—	—	0.2
$A_{\rm T}^{(2)}$ ($B^0\to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$A_{\rm T}^{\rm Im}$ ($B^0\to K^{*0}e^+e^-$)	0.10	[52]	0.060	0.043	0.016
$\mathcal{A}_{\phi\gamma}^{\Delta\Gamma}(B_s^0\to\phi\gamma)$	$^{+0.41}_{-0.44}$	[51]	0.124	0.083	0.033
$S_{\phi\gamma}(B_s^0\to\phi\gamma)$	0.32	[51]	0.093	0.062	0.025
$\alpha_\gamma(\Lambda_b^0\to\Lambda\gamma)$	$^{+0.17}_{-0.29}$	[53]	0.148	0.097	0.038
Lepton Universality Tests					
R_K ($B^+\to K^+\ell^+\ell^-$)	0.044	[12]	0.025	0.017	0.007
R_{K^*} ($B^0\to K^{*0}\ell^+\ell^-$)	0.12	[61]	0.034	0.022	0.009
$R(D^*)$ ($B^0\to D^{*-}\ell^+\nu_\ell$)	0.026	[62, 64]	0.007	0.005	0.002



LHCB-TDR-023

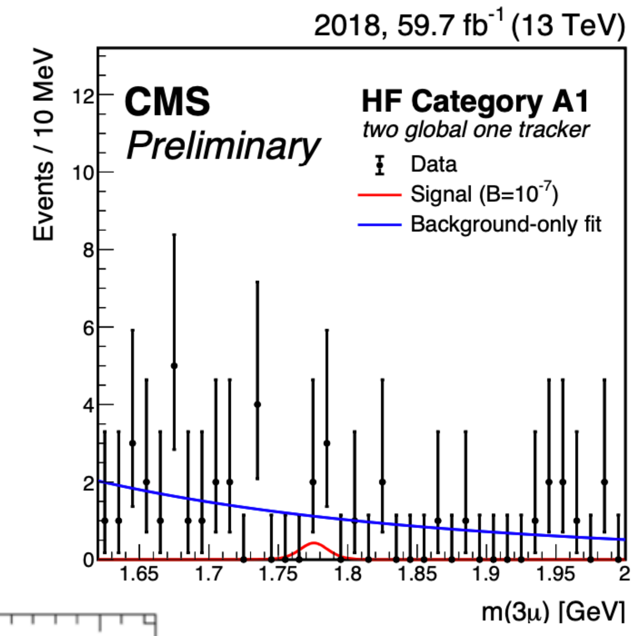
Topics not covered in this talk





CP violation from 3 body & baryons

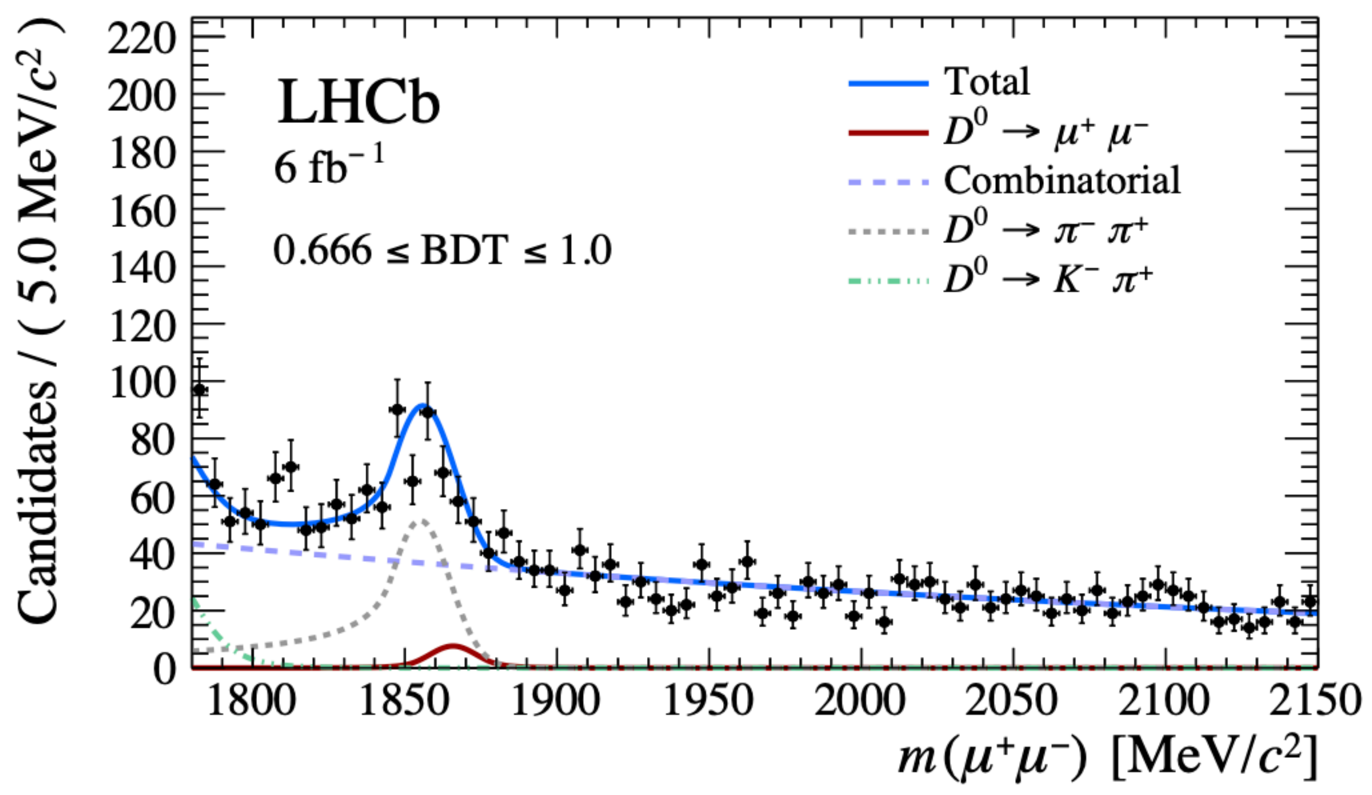
Kaon & Charm Physics

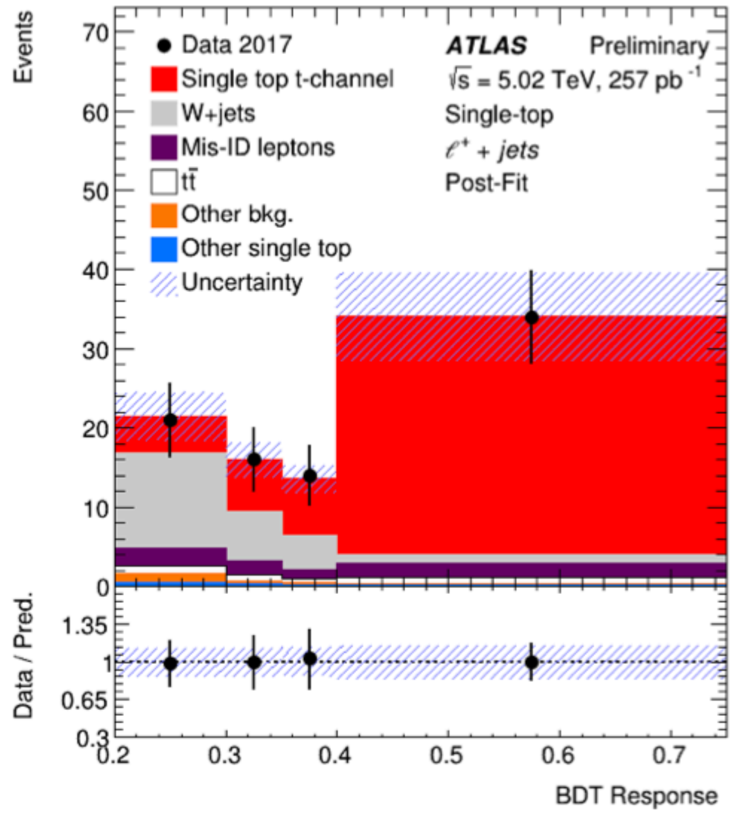


Lepton Flavour Violation & other very rare decays

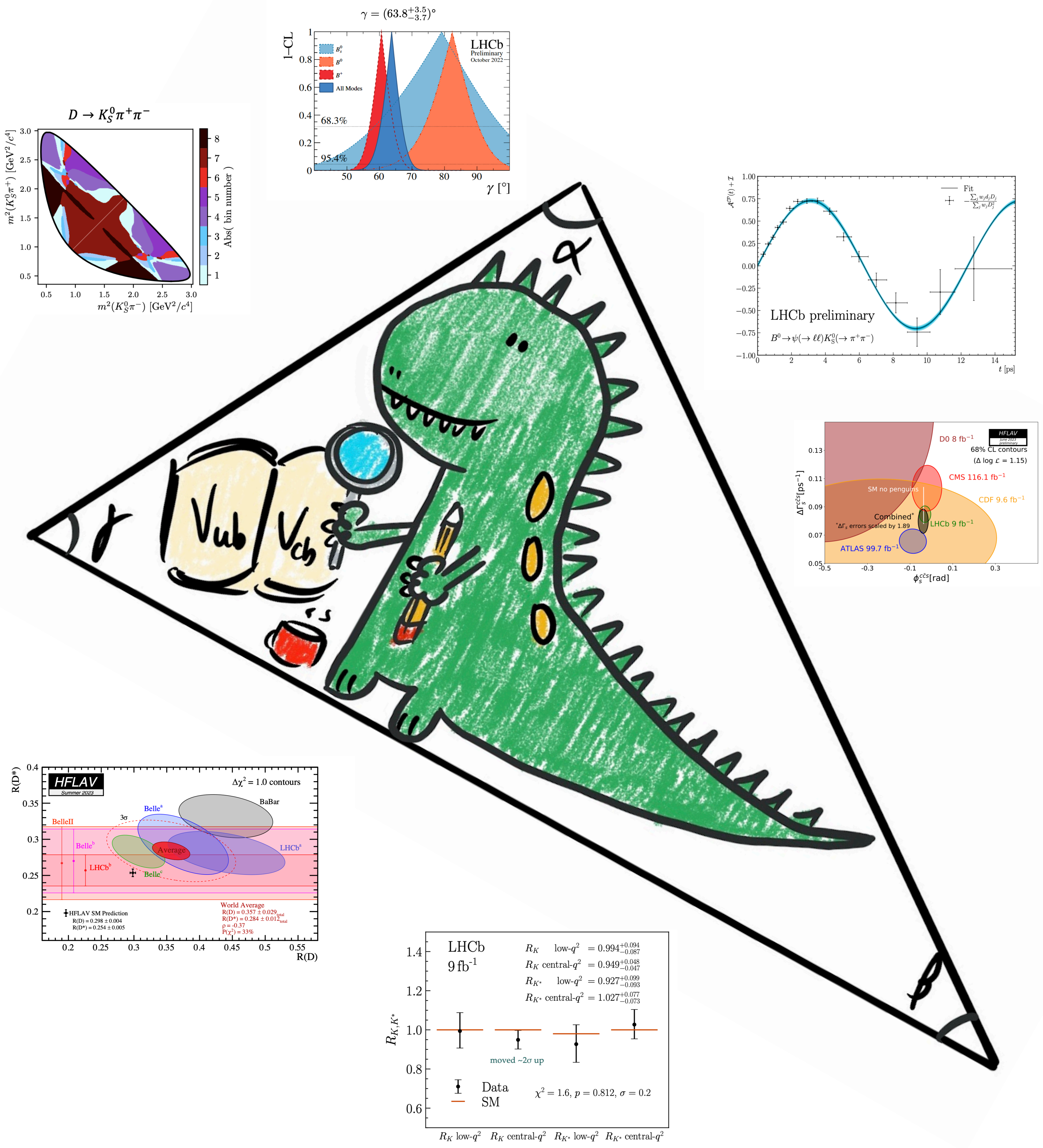
Single top & CPV Higgs measurements

Everything else *et al.*





Conclusion



Dictionary

Definitions from Oxford Languages · Learn more

legacy

/ˈlɛɡəsi/

noun

1. an amount of money or property left to someone in a will.
   "my grandmother died and unexpectedly left me a small legacy"
   Similar: bequest | inheritance | heritage | bequeathal | bestowal | benefaction
2. the long-lasting impact of particular events, actions, etc. that took place in the past, or of a person's life.
   "he left us a rich legacy of buildings that are both innovative architectural creations and genuine works of art"
   Similar: consequence | effect | outcome | upshot | spin-off | repercussion

The second definition sounds like a better option

We are not short of results and material to discuss

Wishing everyone a fruitful workshop !

Thank you to the organisers for the invitation

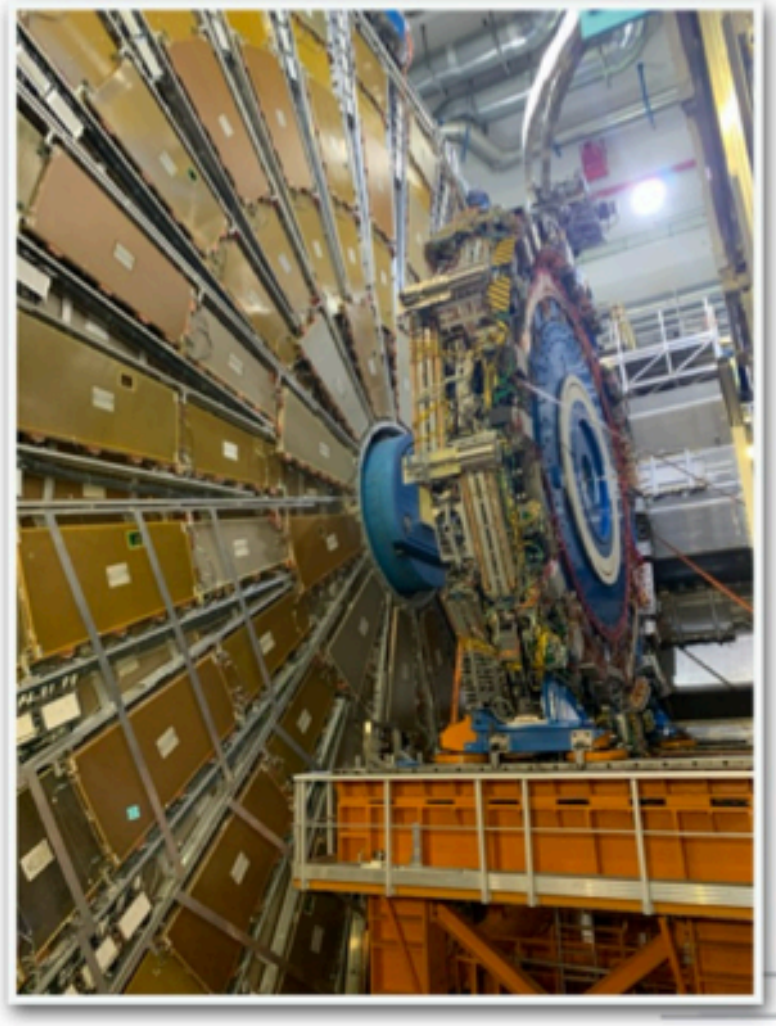
- Overview
- Timetable
- Contribution List
- My Conference
  - My Contributions
- Committees
- Working Groups and Conveners
- Venues
- Accommodation
  - Notice of phishing attempt
- Travel
- Childcare
- Social Program
- Previous Workshops
- Registration
- Conference poster
- Instructions to speakers

And especially for offering childcare options, it can make a big difference. Thank you!

A colouring book for children will soon be available at the CERN Science Gateway

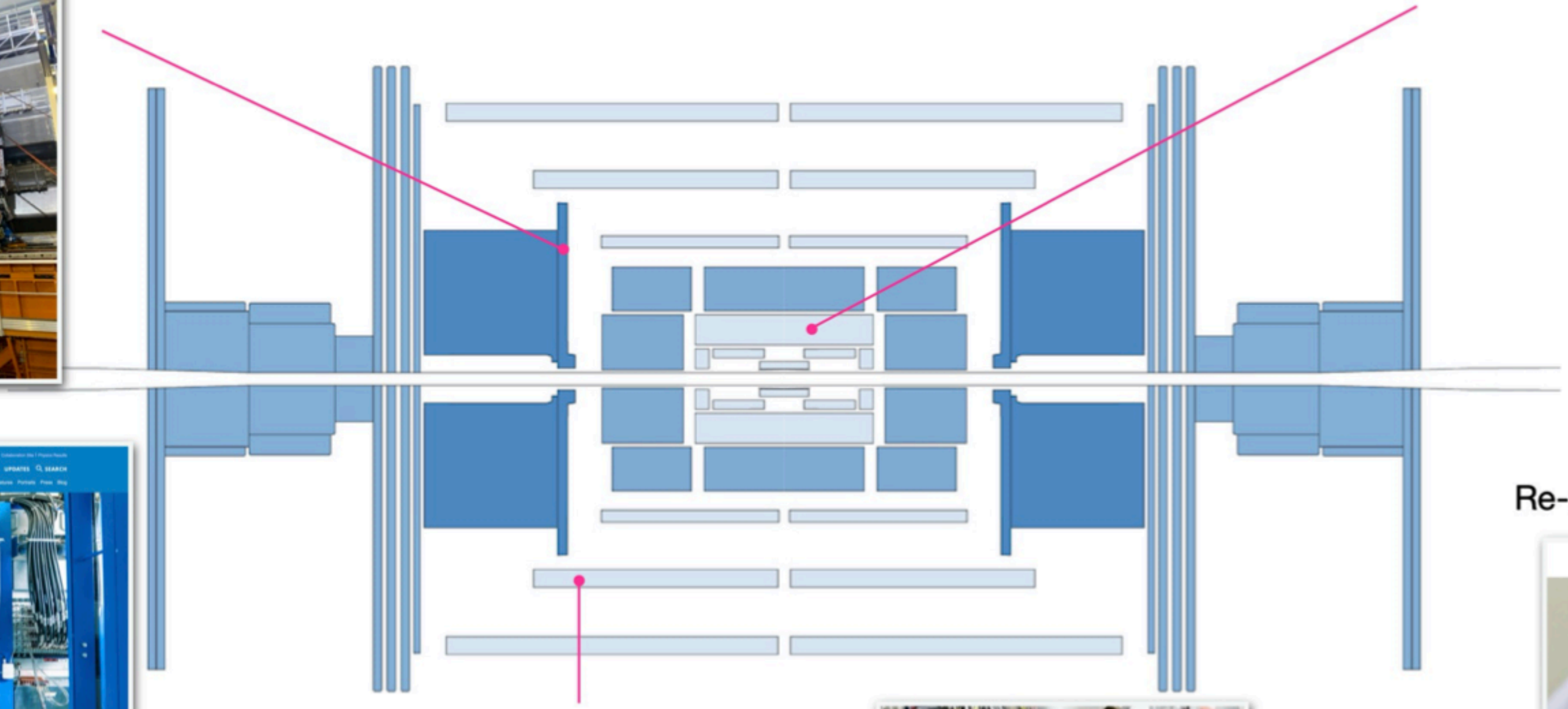
More information yasmineamhis.com

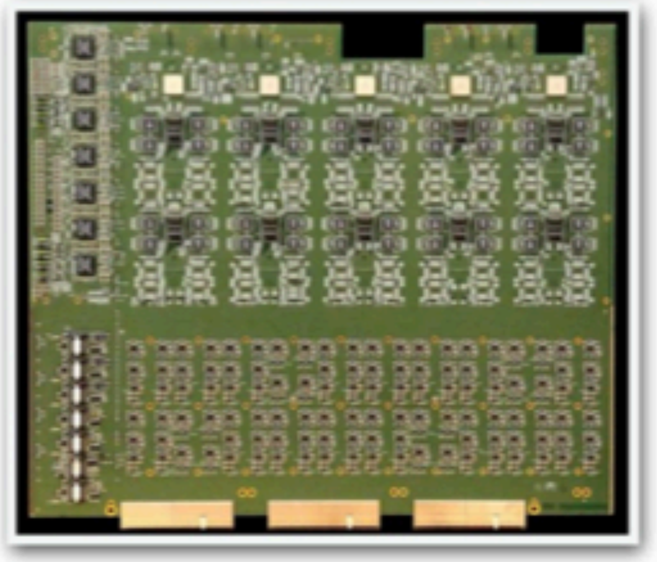
ATLAS Phase-I Upgrades for Run 3



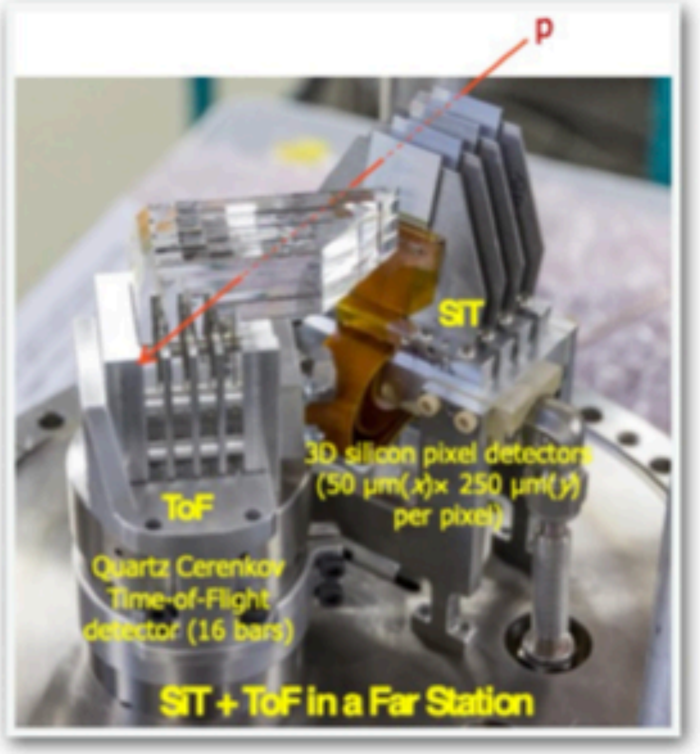
Muon New Small Wheels
Precision tracking, identification and triggering

New LAr Calorimeter digital trigger electronic boards
Improved trigger granularity





AFP
Re-designed TOF detector



Trigger and Data Acquisition
Upgraded hardware, firmware and software for improved trigger and DAQ

[TDAQ Upgrade briefing]

BIS78
New Muon chambers
sMDT and new generation RPC (8 chambers installed)

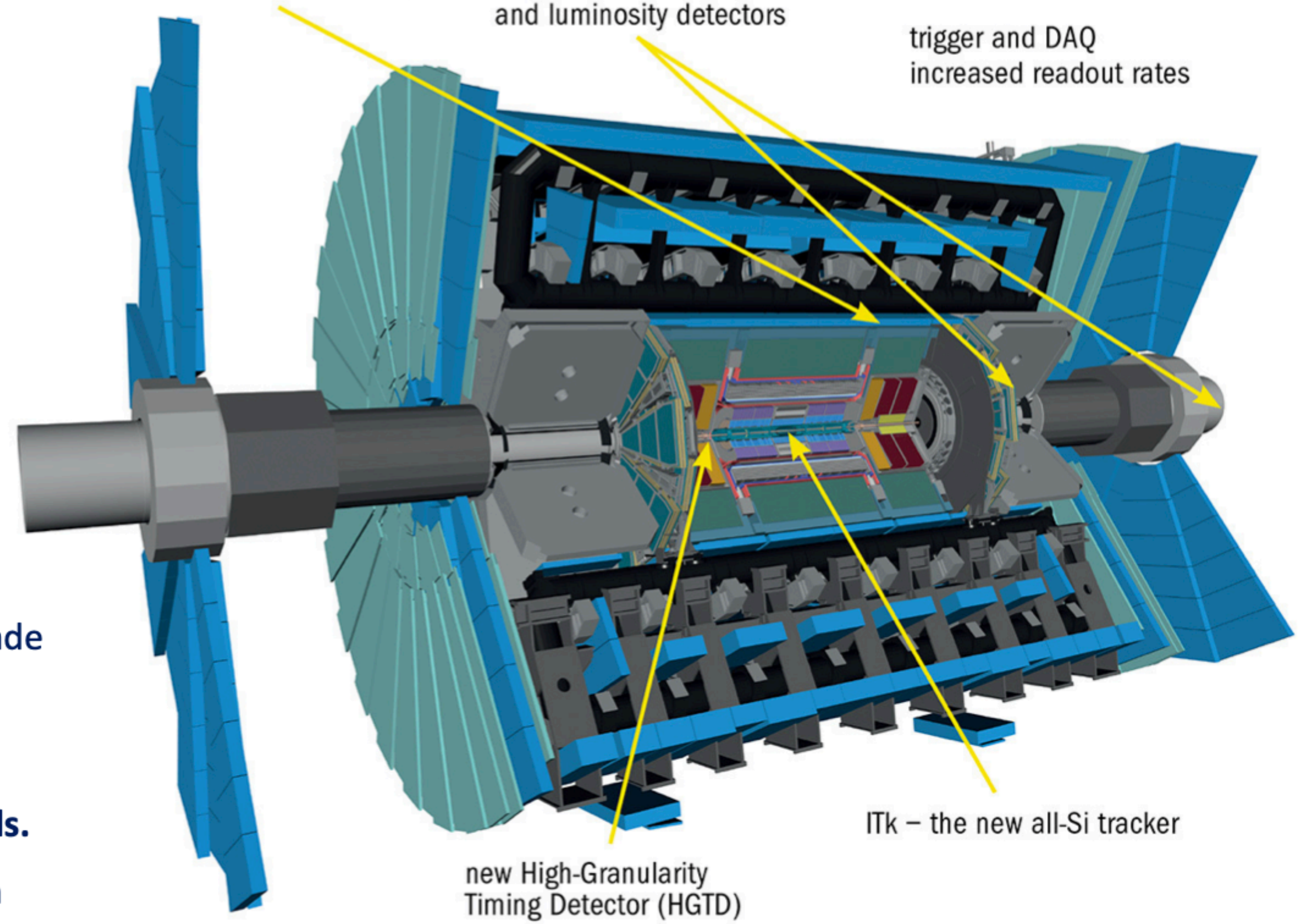
Pamela Ferrari @ EPS 2023

HL-LHC Upgrades

- All silicon tracker up to |η| = 4 with 50x increase in channels
- New inner muon systems for improved trigger acceptance
- New high-granularity timing detector for pile-up rejection
- Trigger: 1 MHz Level-0 rate
  150 kHz full-scan tracking
- LAr/Tile/muons electronics upgrade
- Additional smaller upgrades

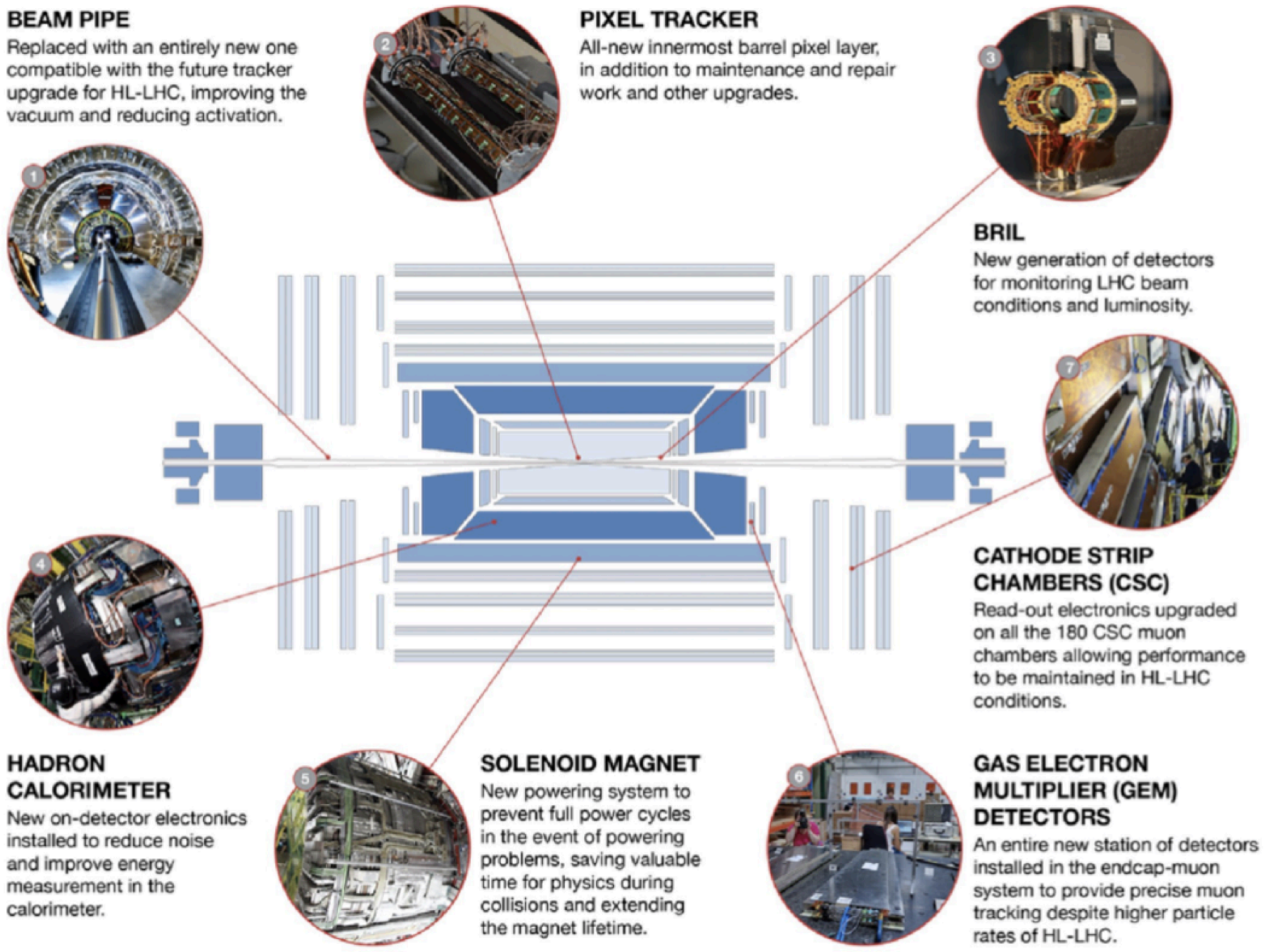
This ambitious upgrade program supports our ambitious physics goals.

A large fraction of our collaboration is working on these upgrades



Pamela Ferrari @ EPS 2023

CMS detector in Run 3



During Long Shutdown 2 (2018-2022), CMS completed the Phase 1 upgrades and started the Phase 2 upgrades

- **Phase 1**: HCAL barrel readout, new barrel inner pixel (layer 1), PPS fully integrated in CMS (CT-PPS)

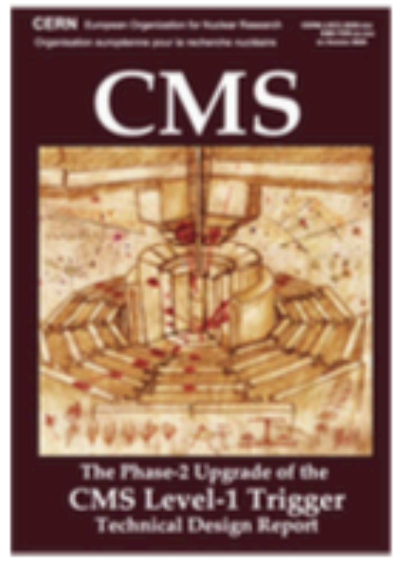
- **Phase 2**: First of GEM chambers installed, upgraded CSC electronics for HL-LHC, new beam pipe.

- **GPU at HLT** and transitioned to a hybrid **CPU + GPU** in trigger software (HLT nodes)

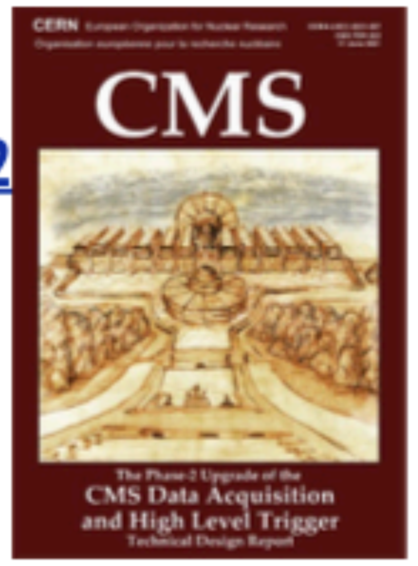
- Installed demonstrators for Phase 2 muon drift tube electronics and Beam Radiation, Instrumentation and Luminosity (BRIL)

The CMS Phase 2 Upgrade

Innovative and extremely challenging new capabilities to fully exploit HL-LHC luminosity

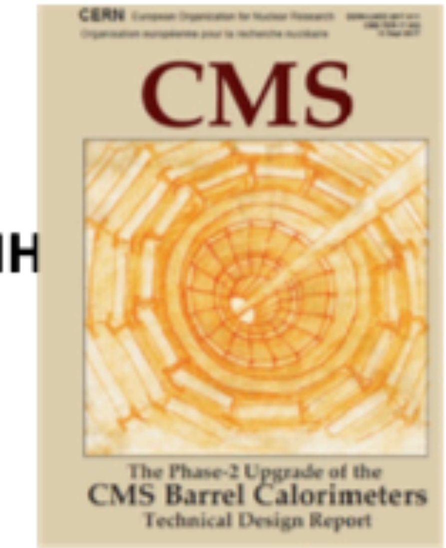


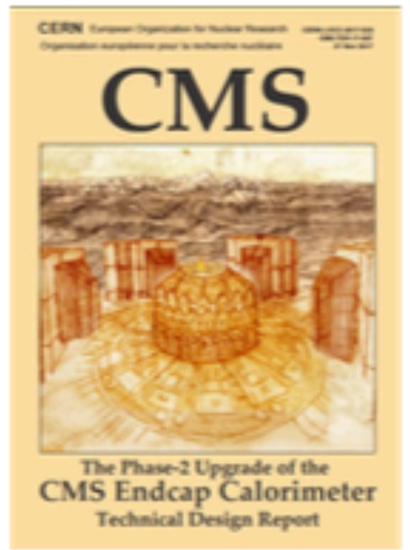
L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting



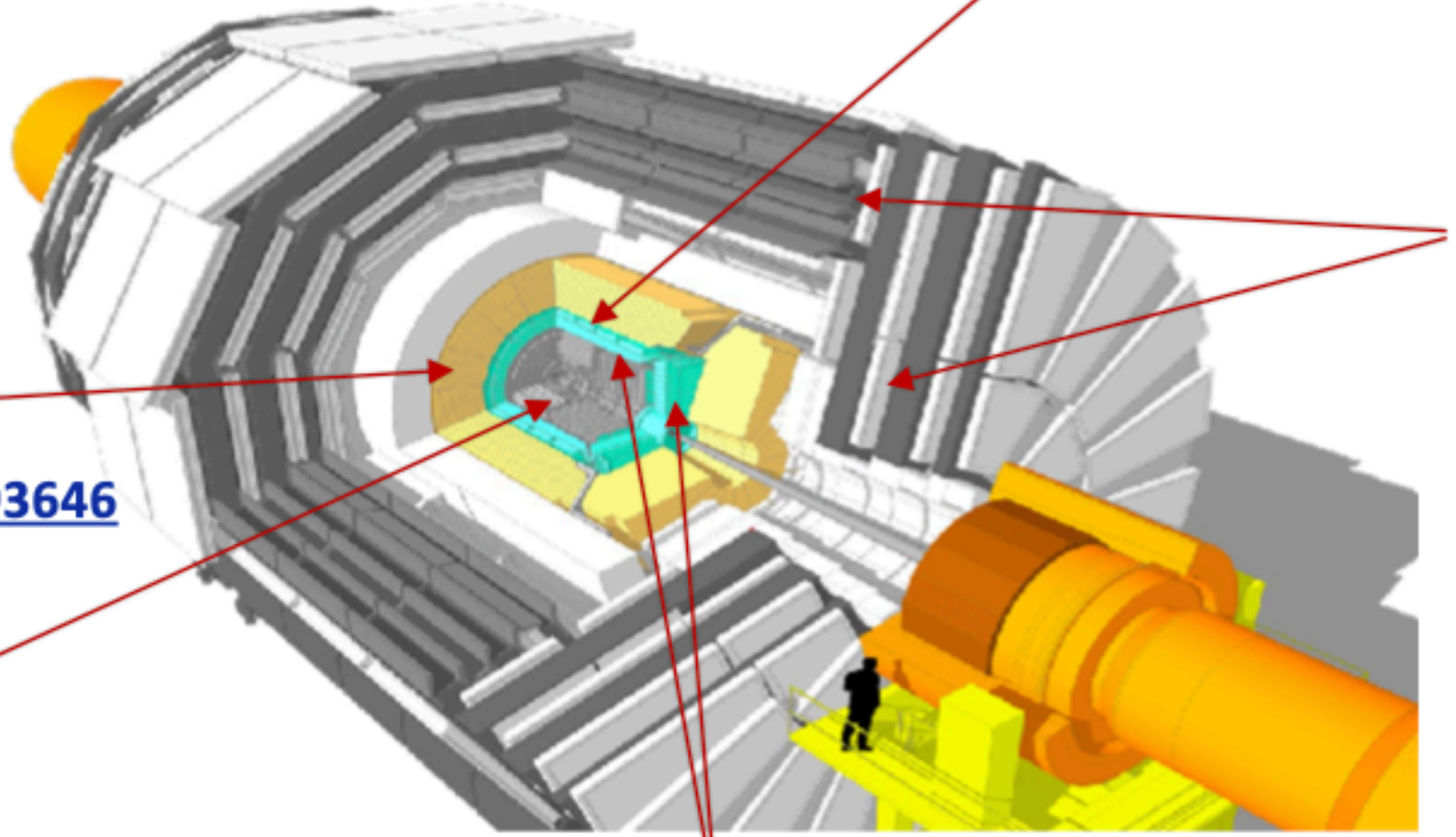
DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output

Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MH with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

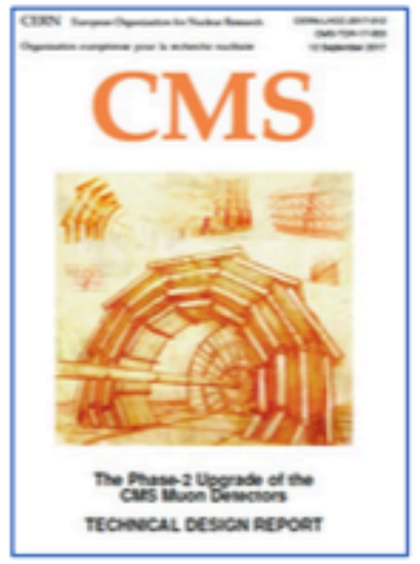


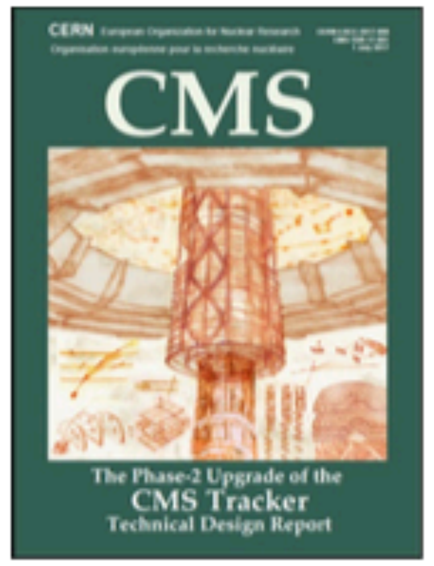


Calorimeter Endcap
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS

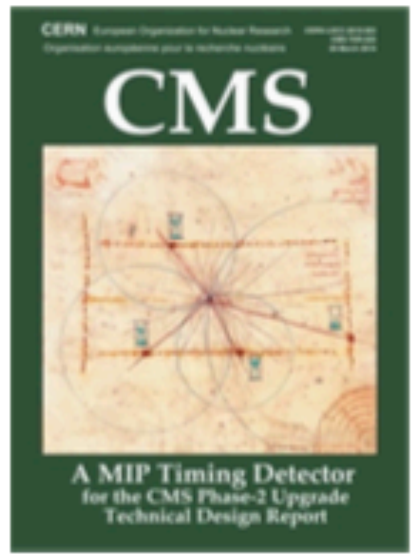


Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$





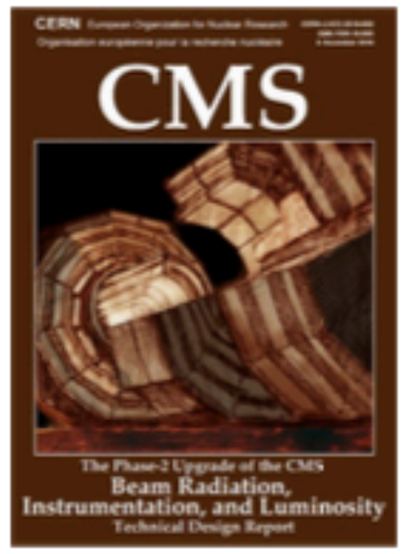
Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

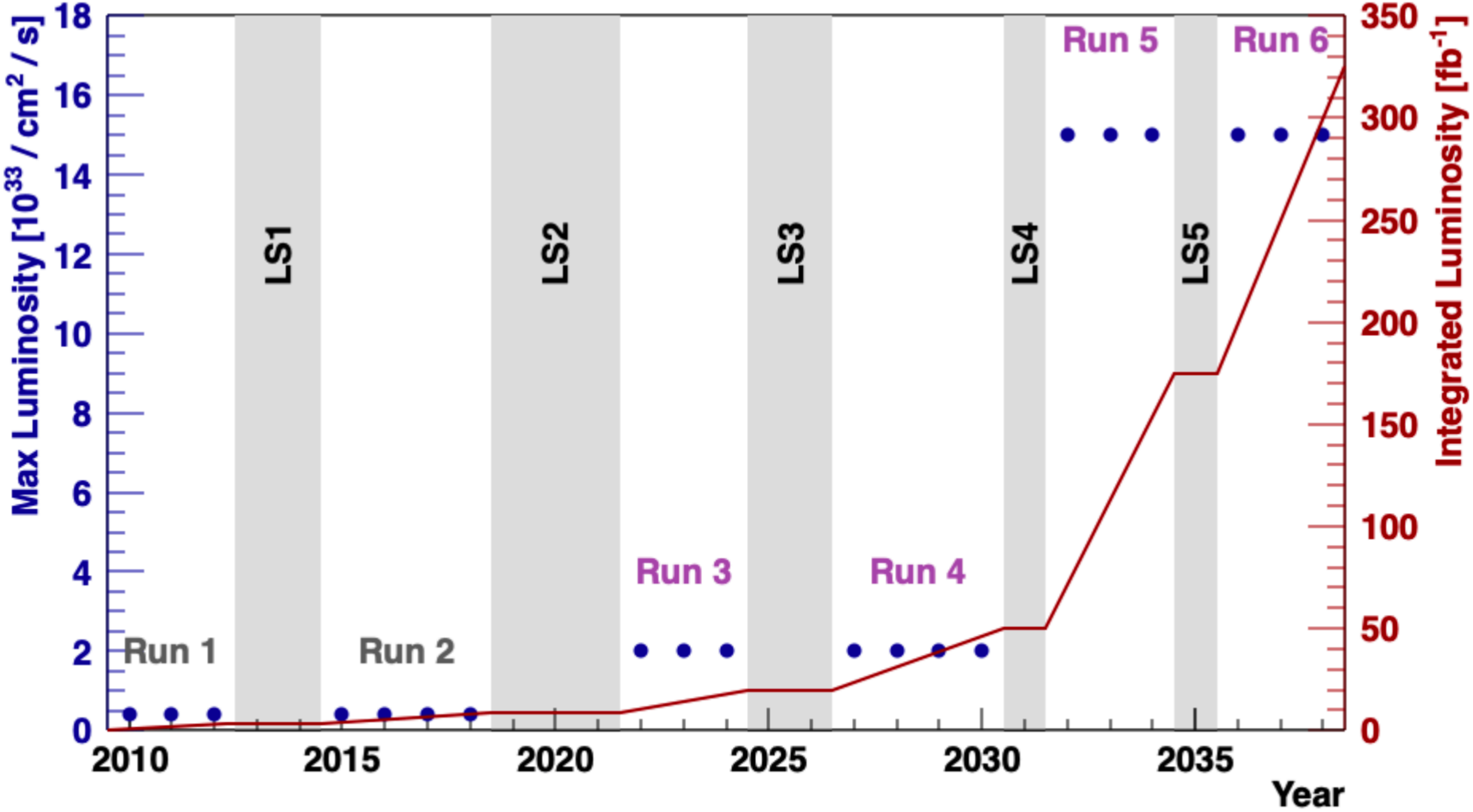


MIP Timing Detector
https://cds.cern.ch/record/2667167

Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch luminosity: 1% offline, 2% online
- Neutron and mixed-field radiation monitors





Max Luminosity [10^33 / cm^2 / s]
18
16
14
12
10
8
6
4
2
0
Run 1
LS1
Run 2
LS2
Run 3
LS3
Run 4
LS4
Run 5
LS5
Run 6
2010
2015
2020
2025
2030
2035
Year
Integrated Luminosity [fb^-1]
350
300
250
200
150
100
50
0

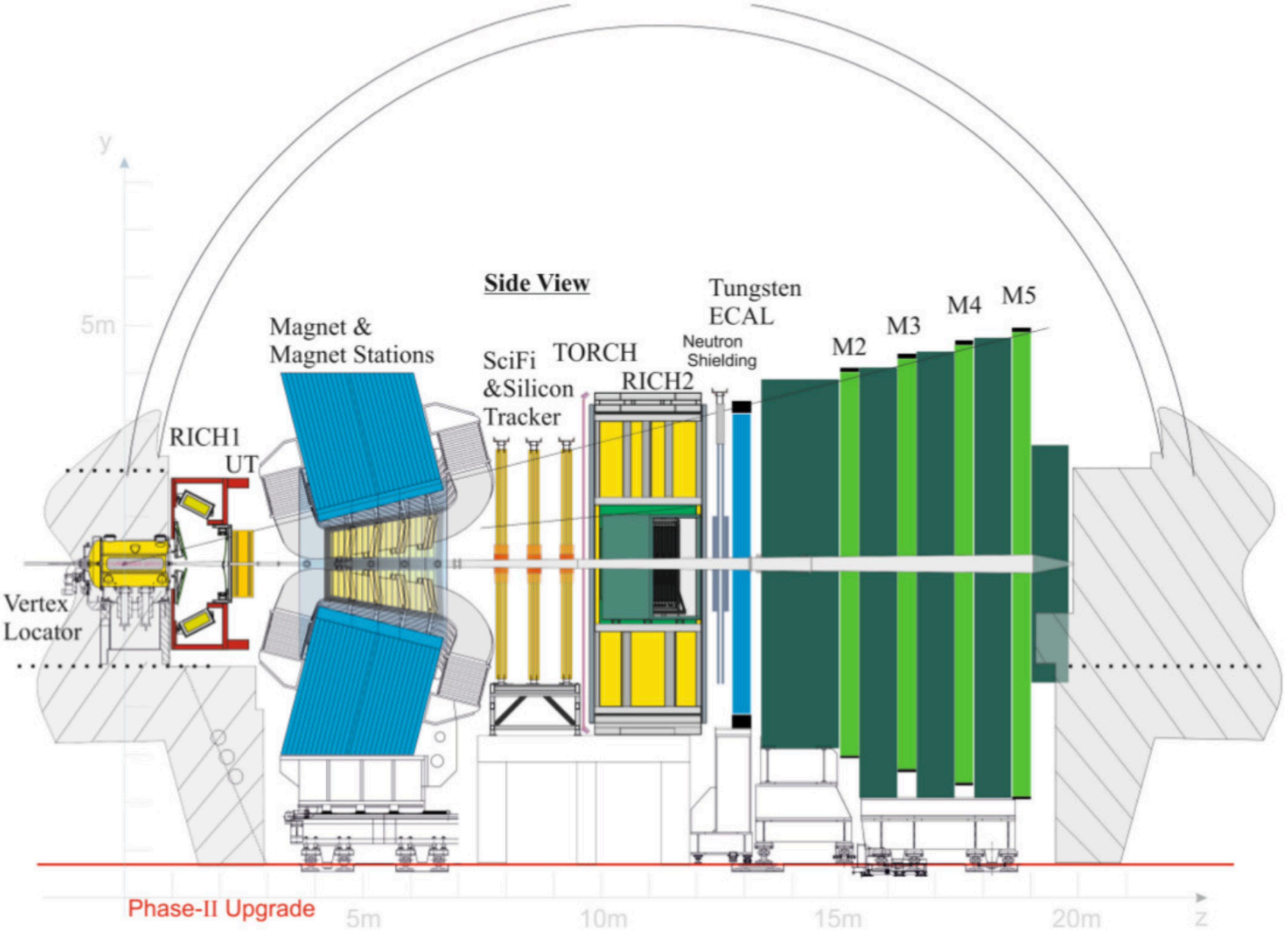
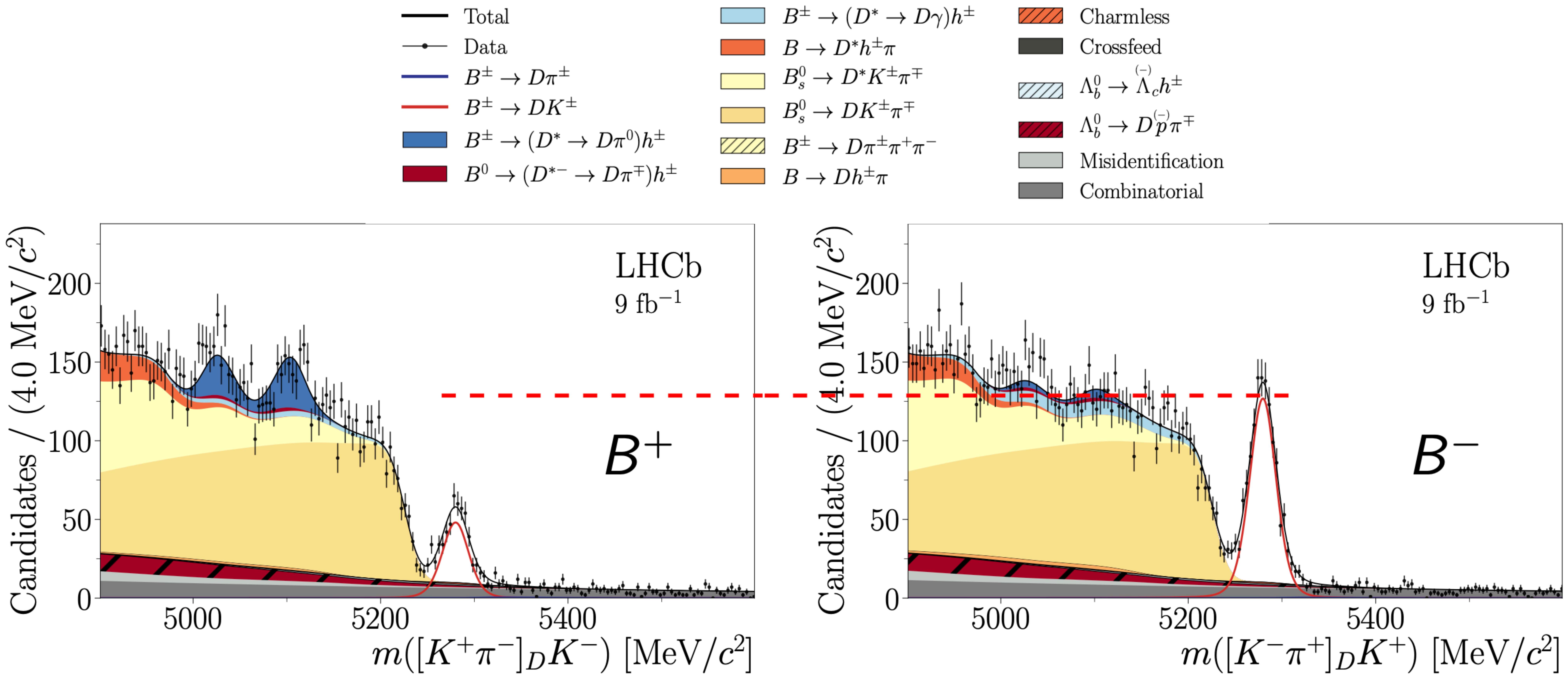


Figure 1.2: Schematic side-view of the Upgrade II detector.

Example of a very spectacular asymmetry



Just drawing a line does not do justice to this work

LHCb, JHEP 04 (2021) 081