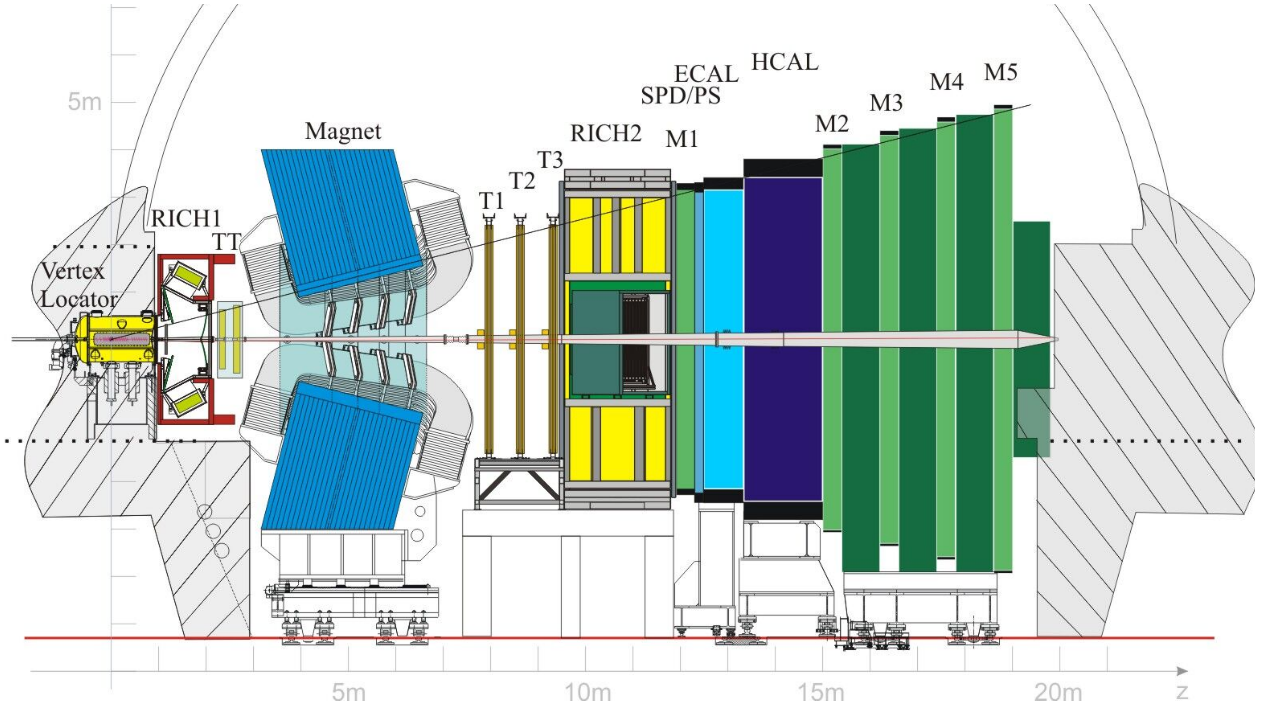
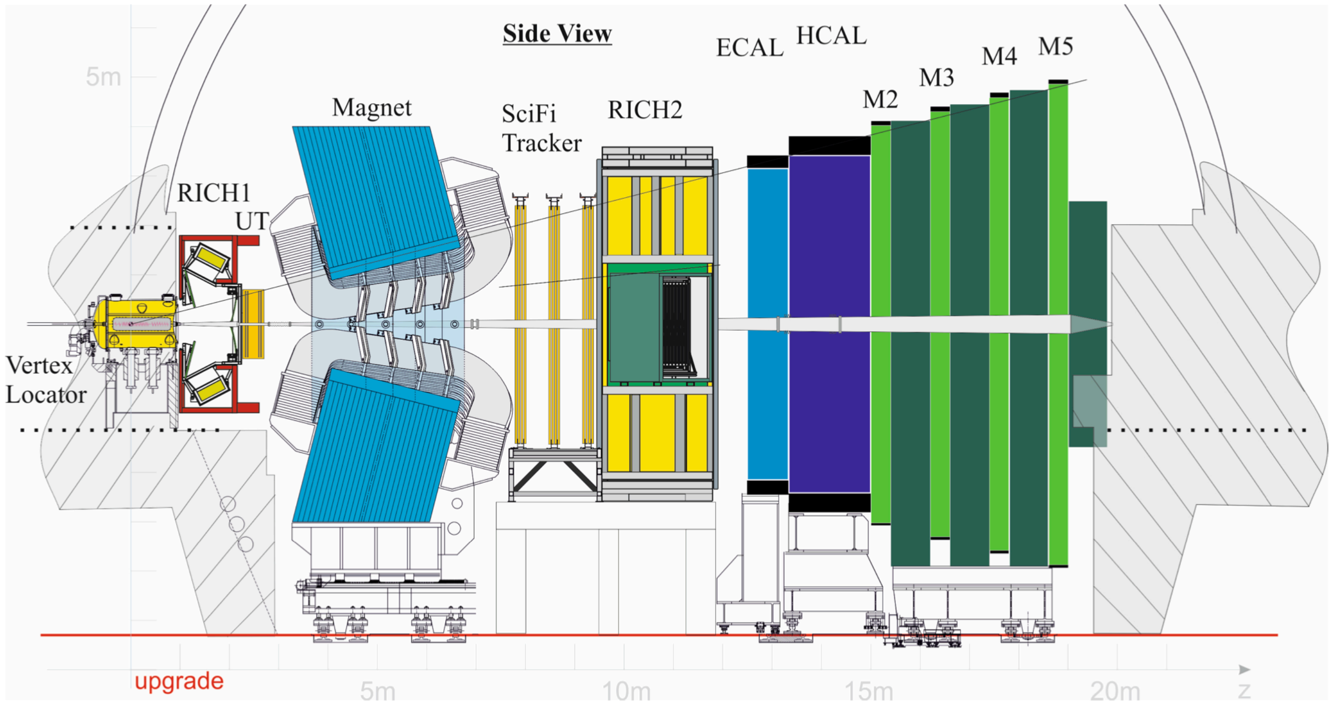
Eluned Smith (MIT) on behalf of the LHCb-US community

LUA meeting, December 2023

This Talk

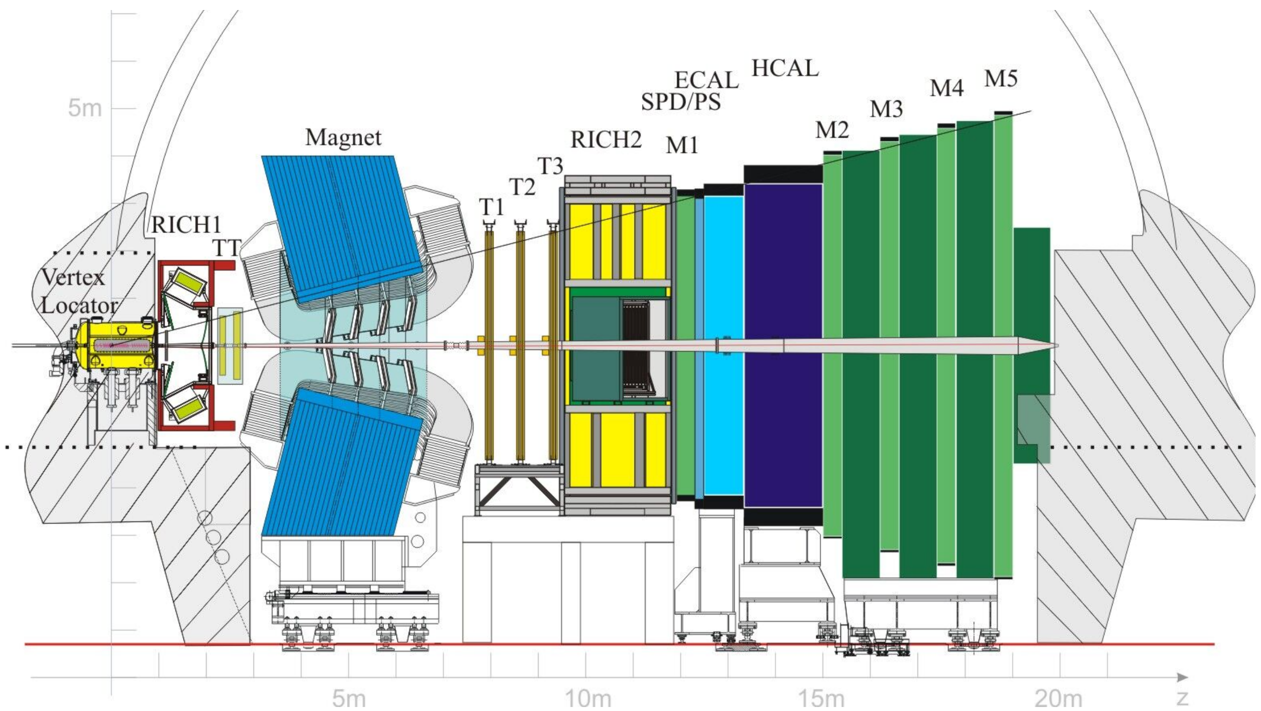


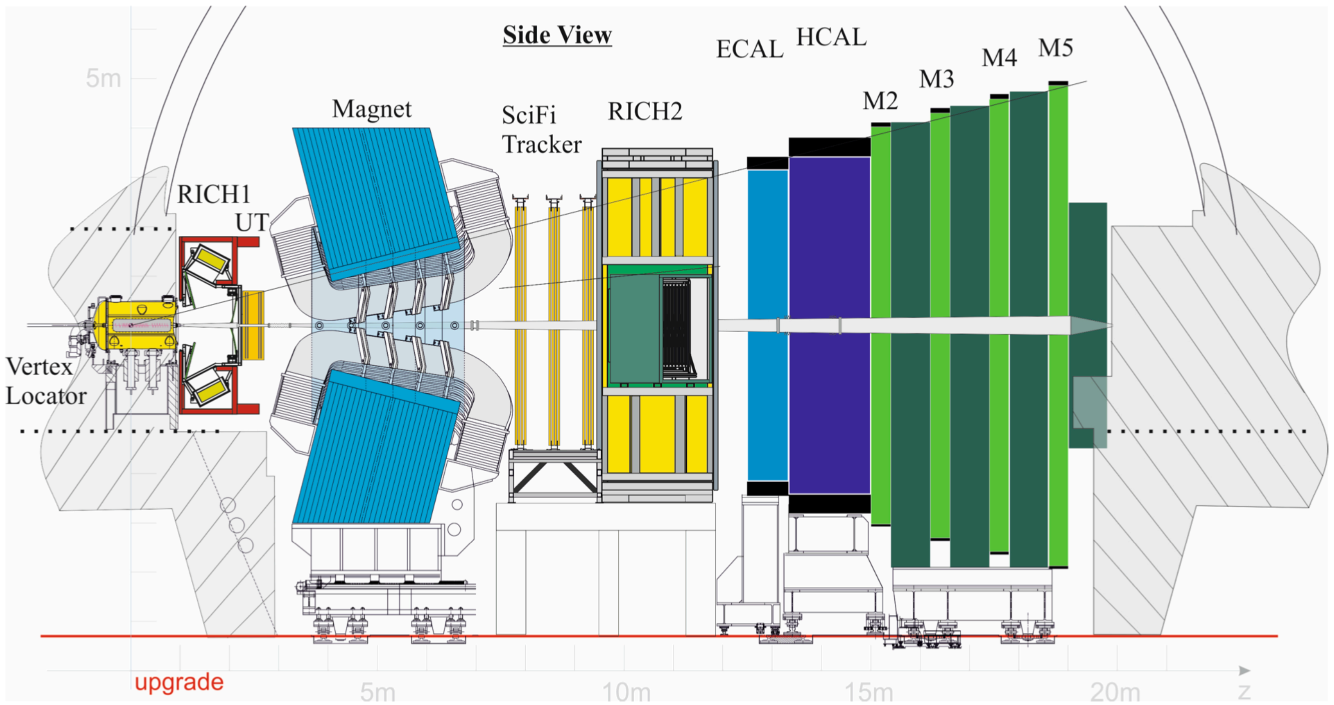


LHCb (2011-2018)

LHCb Upgrade I (2022-2032)

This Talk

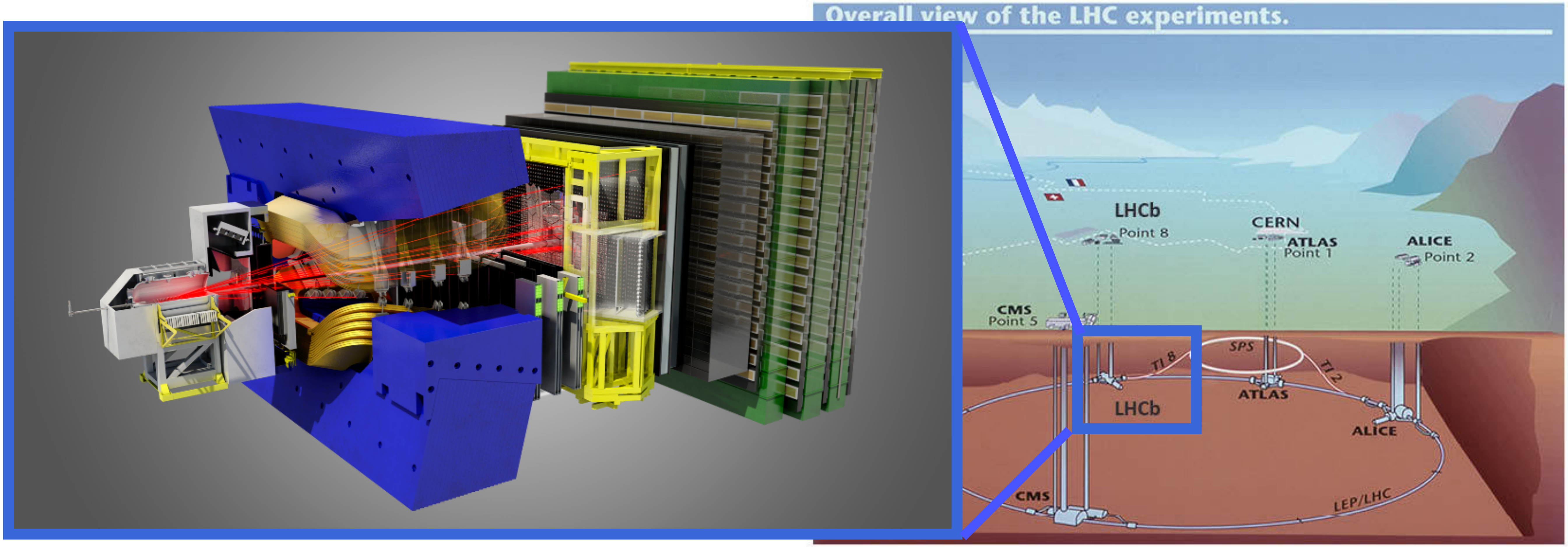




LHCb (2011-2018) → LHCb Upgrade I (2022-2032)

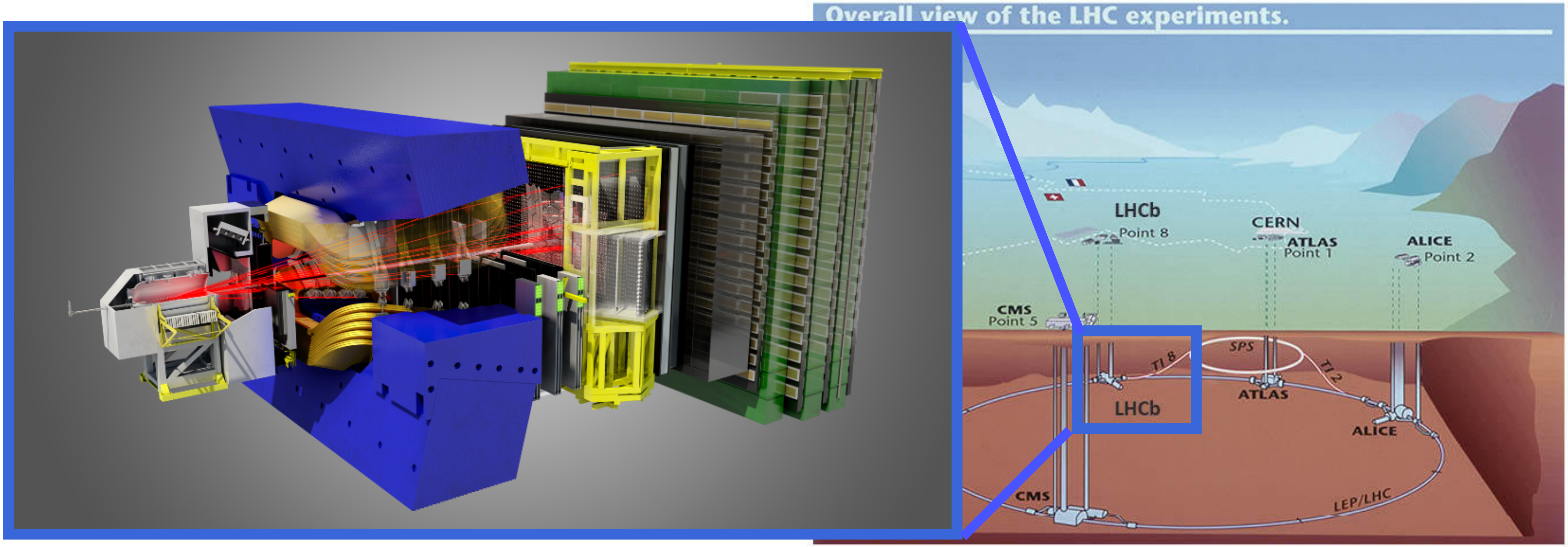
- Overview of LHCb detector Upgrade I and commissioning status
- Examples of US-led flagship measurements

The LHCb detector

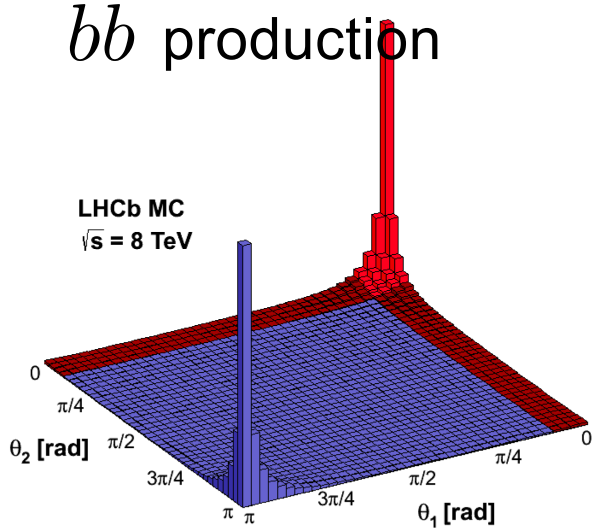


- LHC**b** is a general purpose detector in the forward region

The LHCb detector

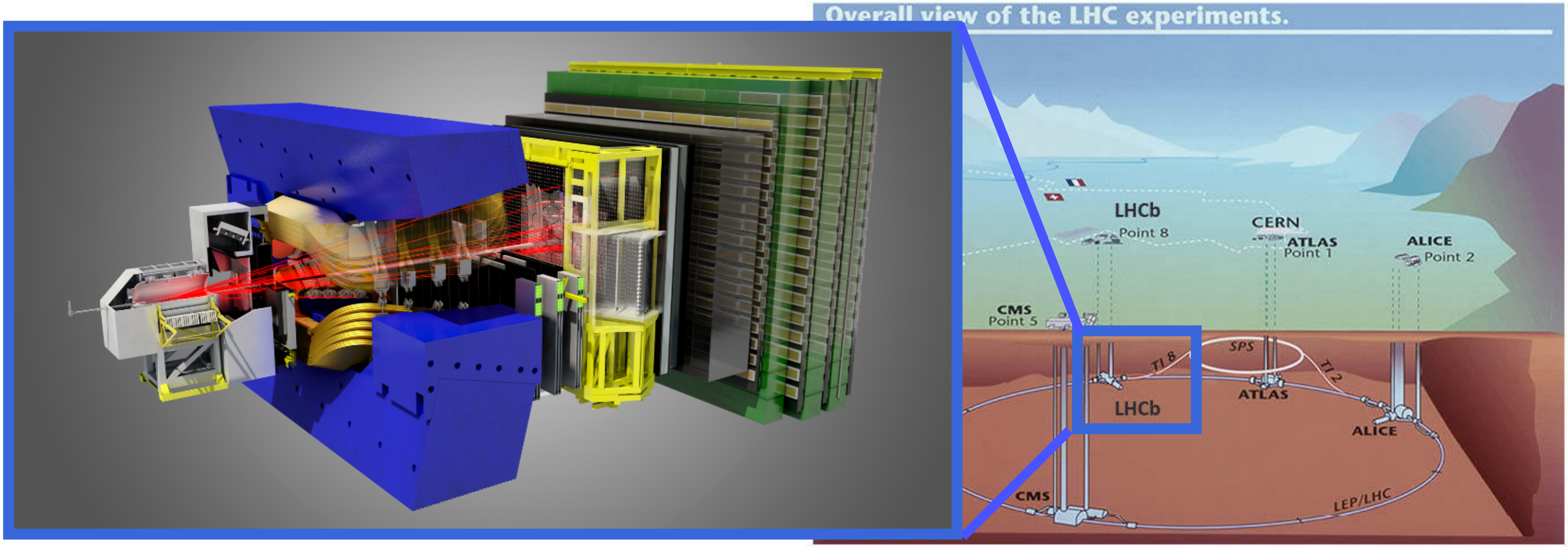


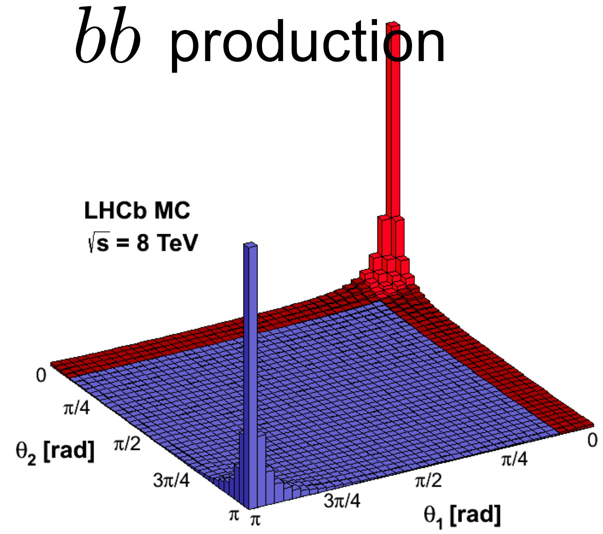
$b\bar{b}$ production



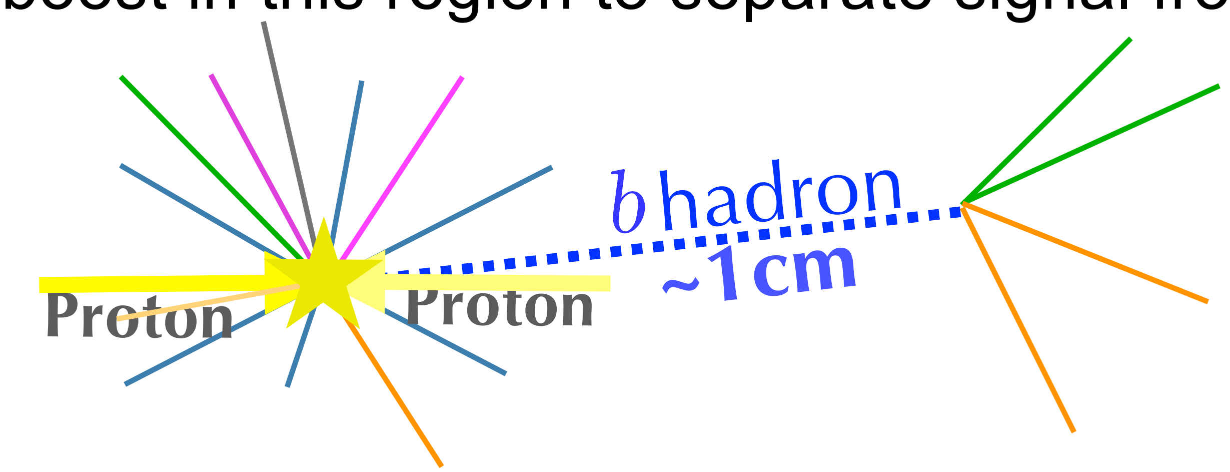
- LHC**b** is a general purpose detector in the forward region
- $b\bar{b}$ produced mostly in forward-background regions - **only instrument forward region**

The LHCb detector





- LHC**b** is a general purpose detector in the forward region
- $b\bar{b}$ produced mostly in forward-background regions - **only instrument forward region**
- Exploit boost in this region to separate signal from bkg

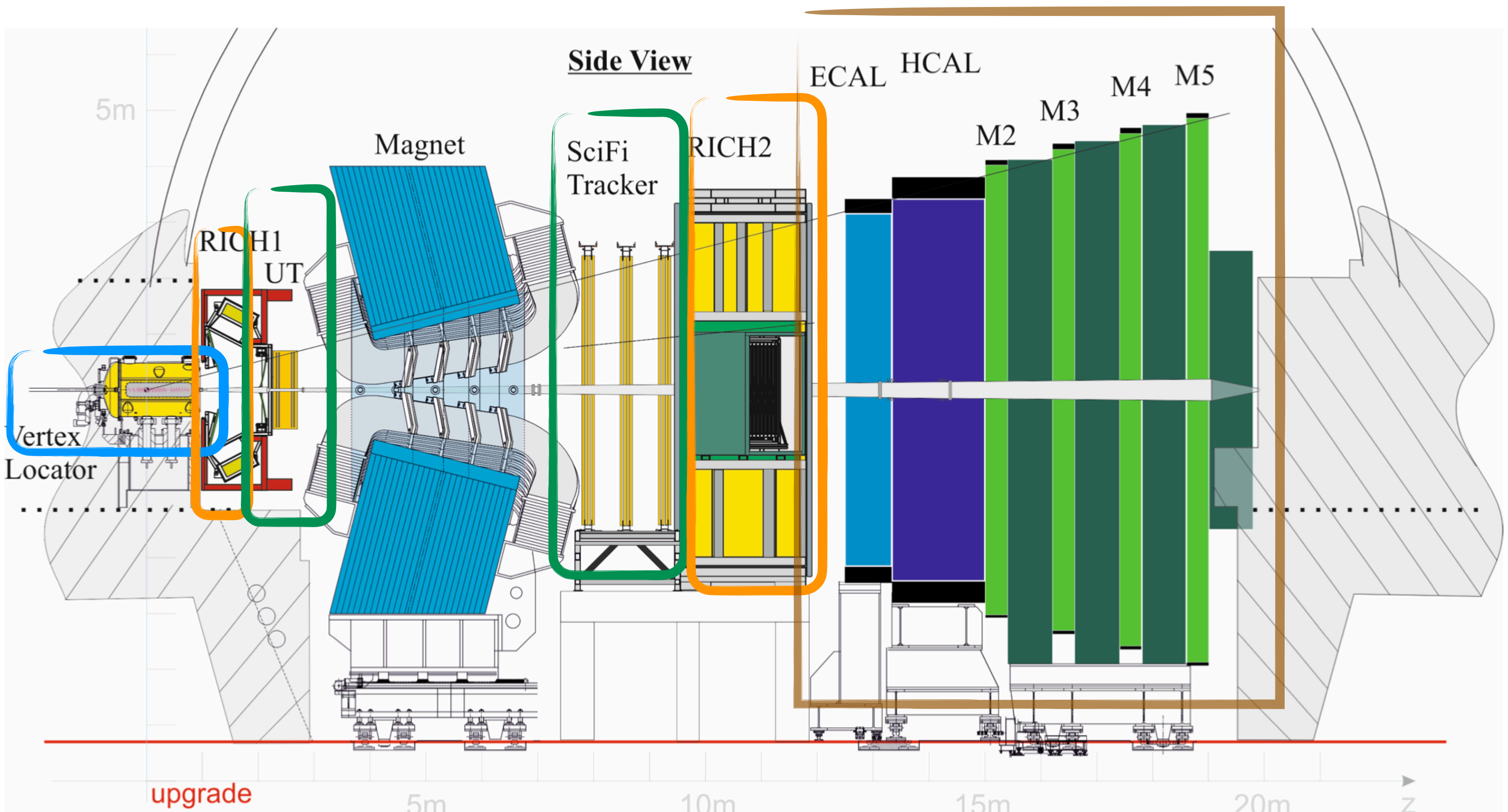


The LHCb detector : upgrade I

➤ Increased inst. lumi (pile-up now ~ 6) + removed hardware trigger

New Vertex detector

- Si-microstrip →Si-pixel
- Closer to beam
- Improved IP resolution



New PID detector

- new photon detectors + readout

New tracking system

- Si-strip + straw-tubes → Scintillating fibres
- Si-strip UT → > granularity

New read out

+ new GPU trigger/data centre

The LHCb detector : upgrade I

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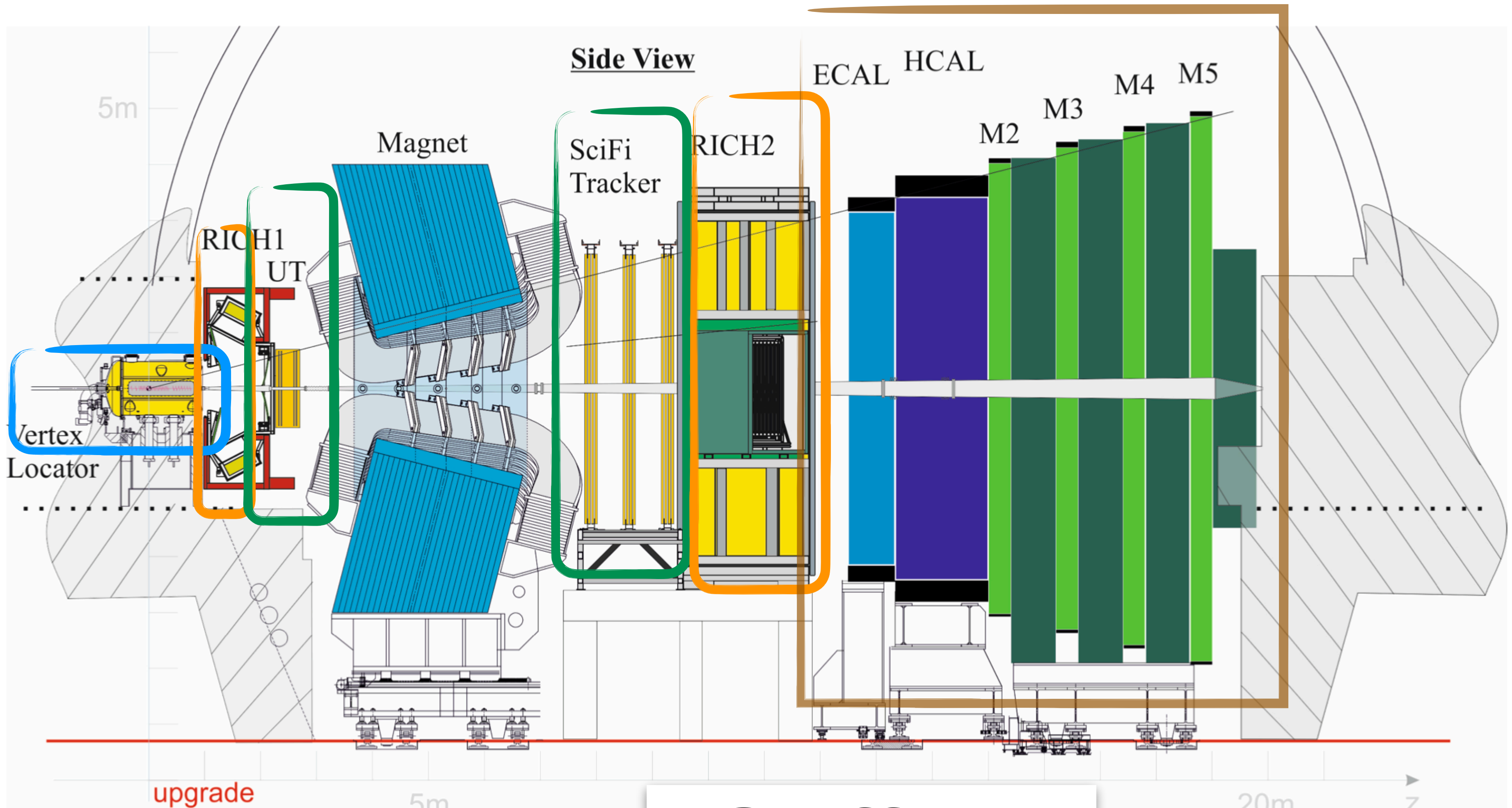

US efforts

New PID detector

- new photon detectors + readout

New tracking system

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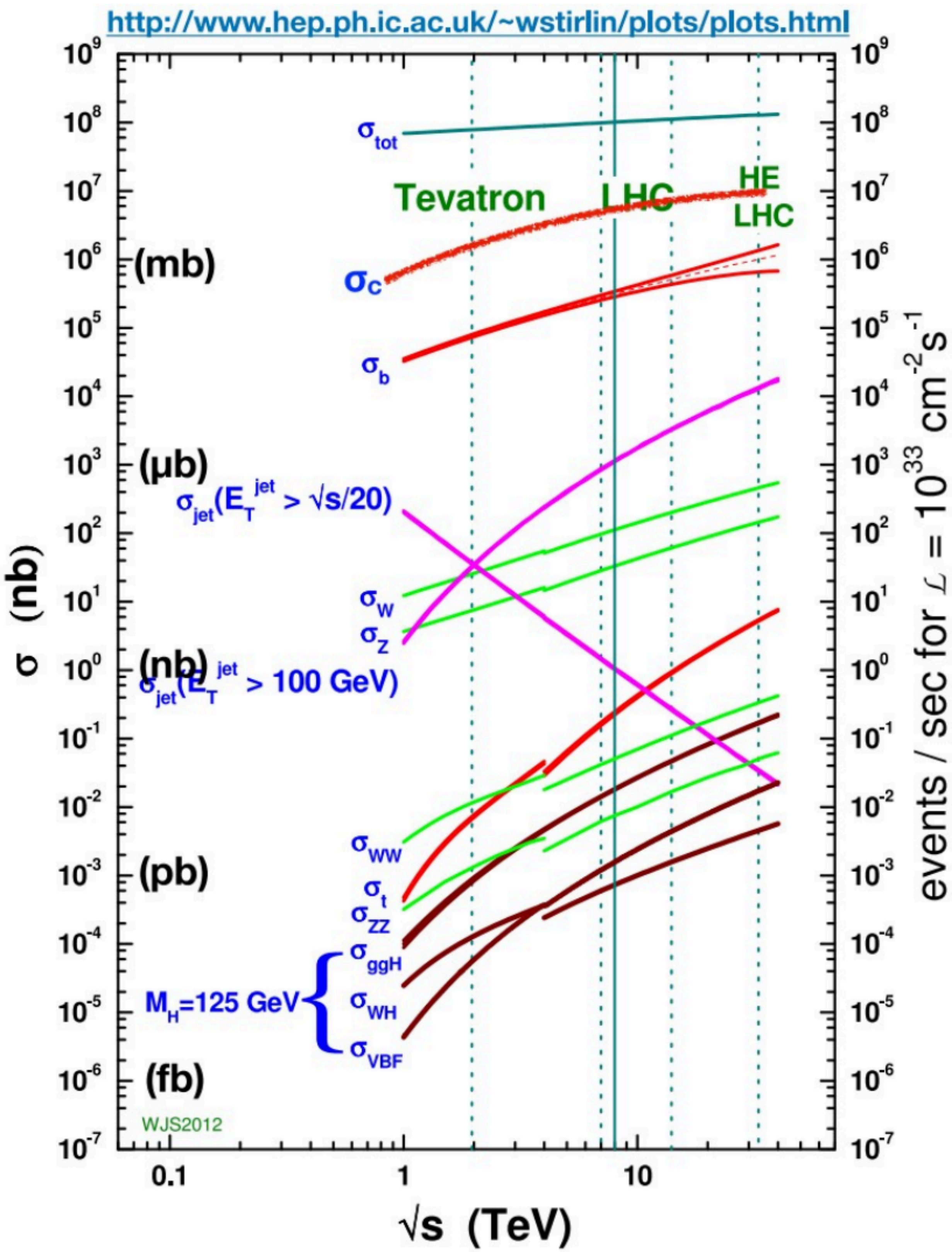
New read out

new GPU trigger/data centre

GPU-based trigger:Allen

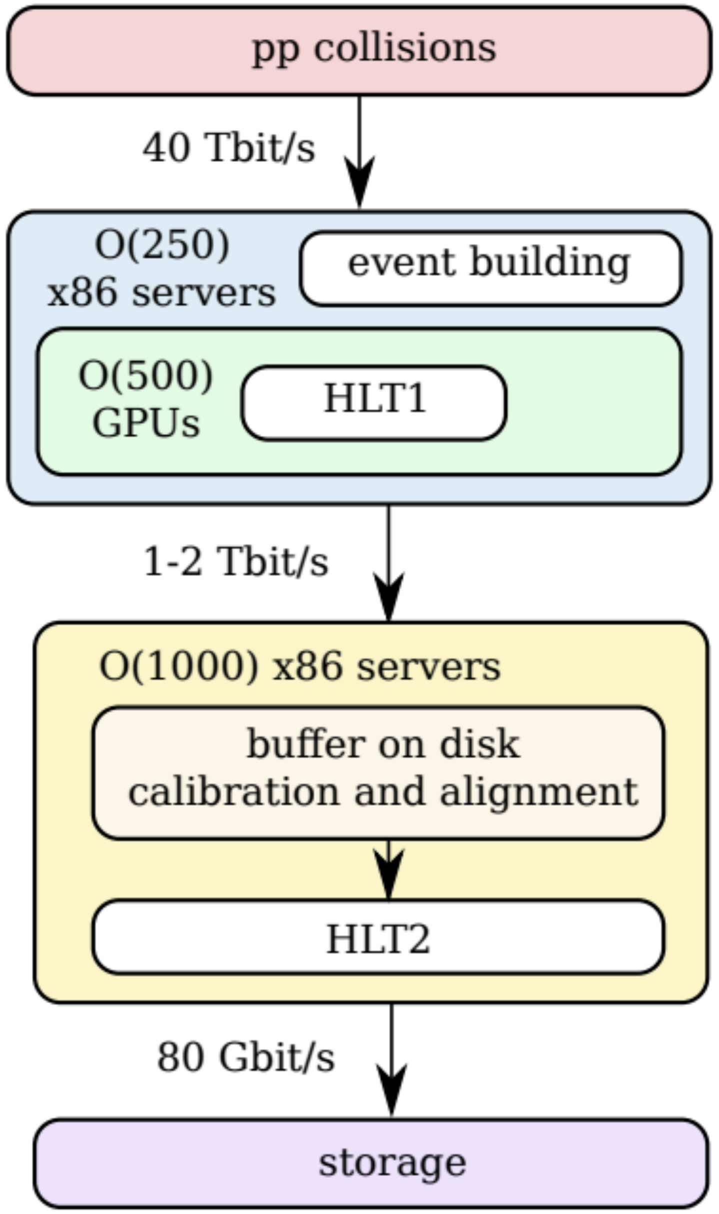


All signal is low p_T and high rate, need to trigger on tracks

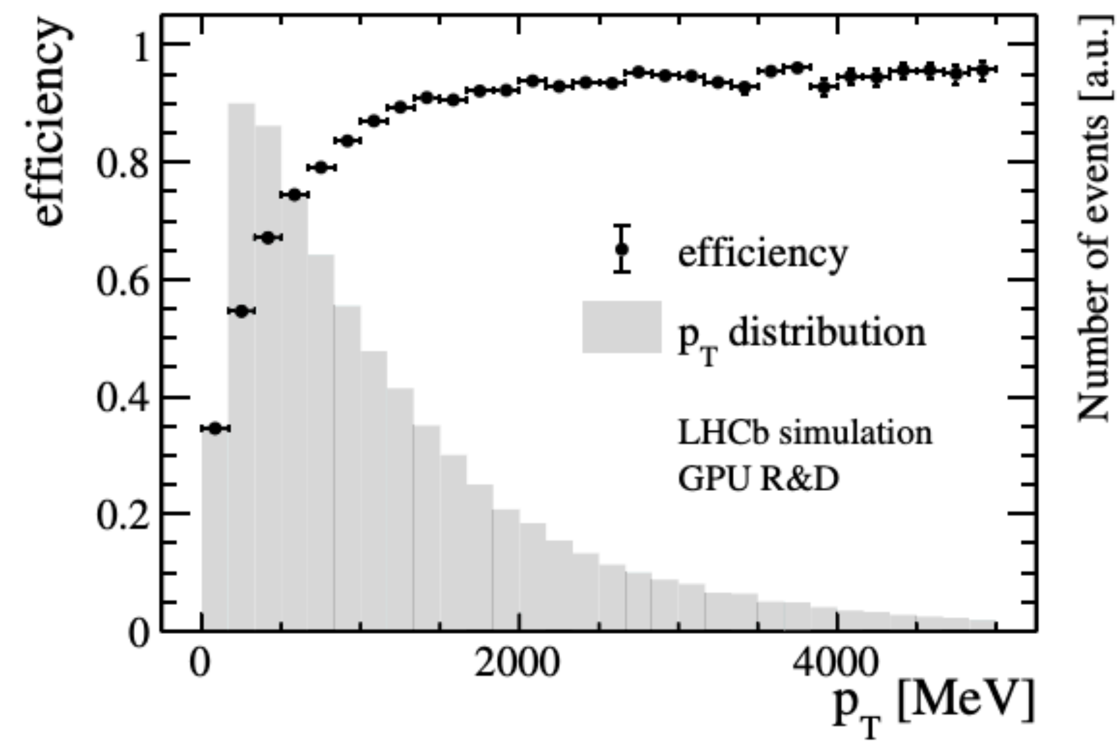
Low rate, efficiently triggered by local p_T signals

GPU-based trigger:Allen

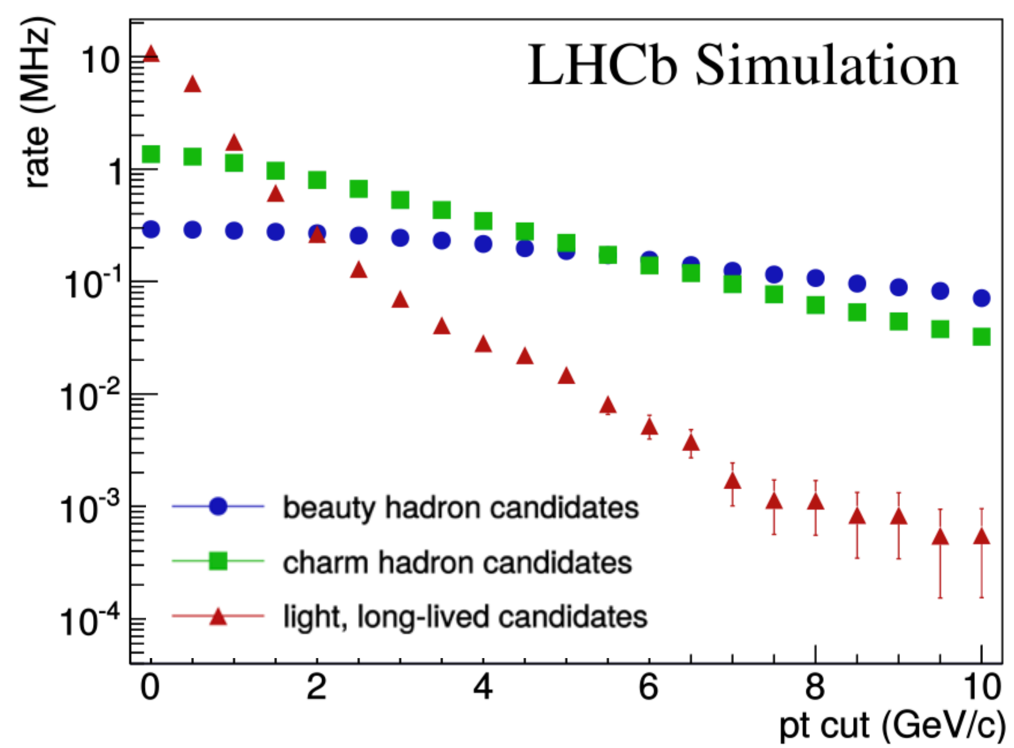
Use GPUs to process 40Tb/s of data



https://link.springer.com/article/10.1007/s41781-020-00039-7



https://cds.cern.ch/record/1670985/files/LHCb-PUB-2014-027.pdf



The LHCb physics program

Rare Decays — $b \to s(d)\ell^+\ell^-$ and $b \to s\gamma$ $(R_K, P_5', ...)$

Heavy Ions — Proton-lead, lead-lead and also fixed target (SMOG)

Semi-leptonic — $b \to c(u)\ell\nu$ ($R(D^*), V_{ub}, ...$)

QCD,EW, exotica — W mass measurement, vector boson production, dark photons,..

Spectroscopy — Pentaquarks, tetra quarks, quarkonia…

CP violation — Time-dependent, time independent

Charm — $D^0 - \bar{D}^0$ mixing, first observation of CPV in charm, …

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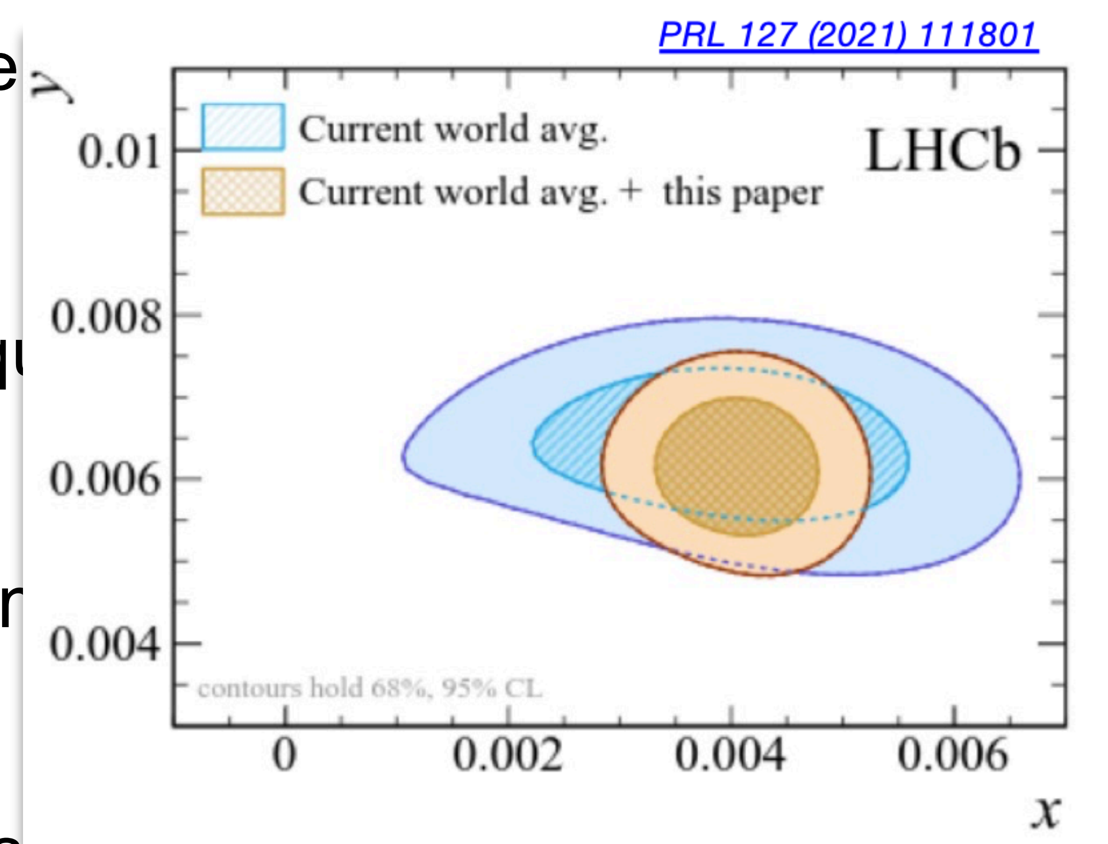

The LHCb physics program

US-Focus

Rare Decays	$b \to s(d)\ell^+\ell^-$ and $b \to s\gamma$ $(R_K, P_5', \dots)$
Heavy Ions	Proton-lead, lead-lead and also fixed target (SMOG)
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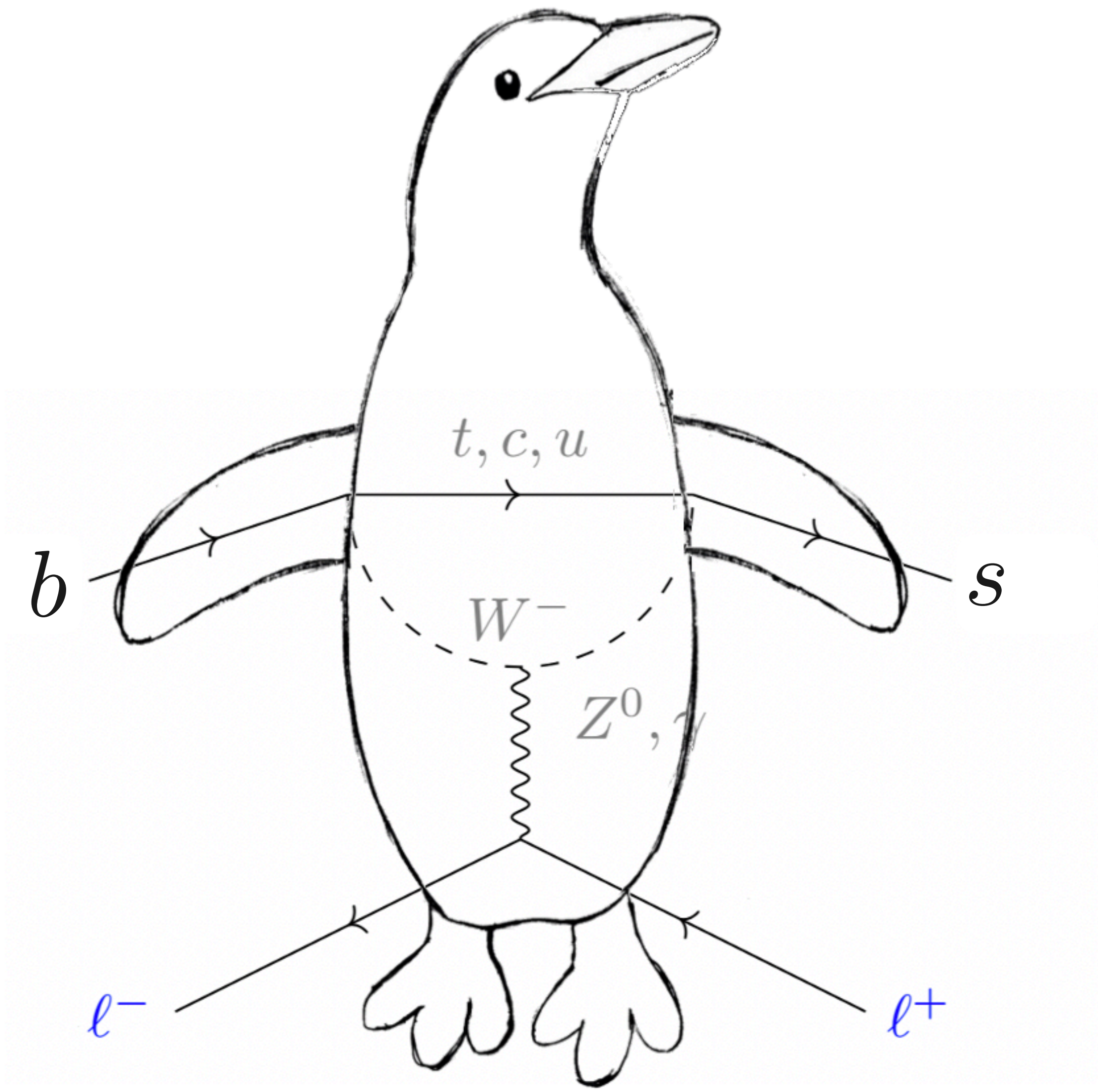
Electroweak Penguins

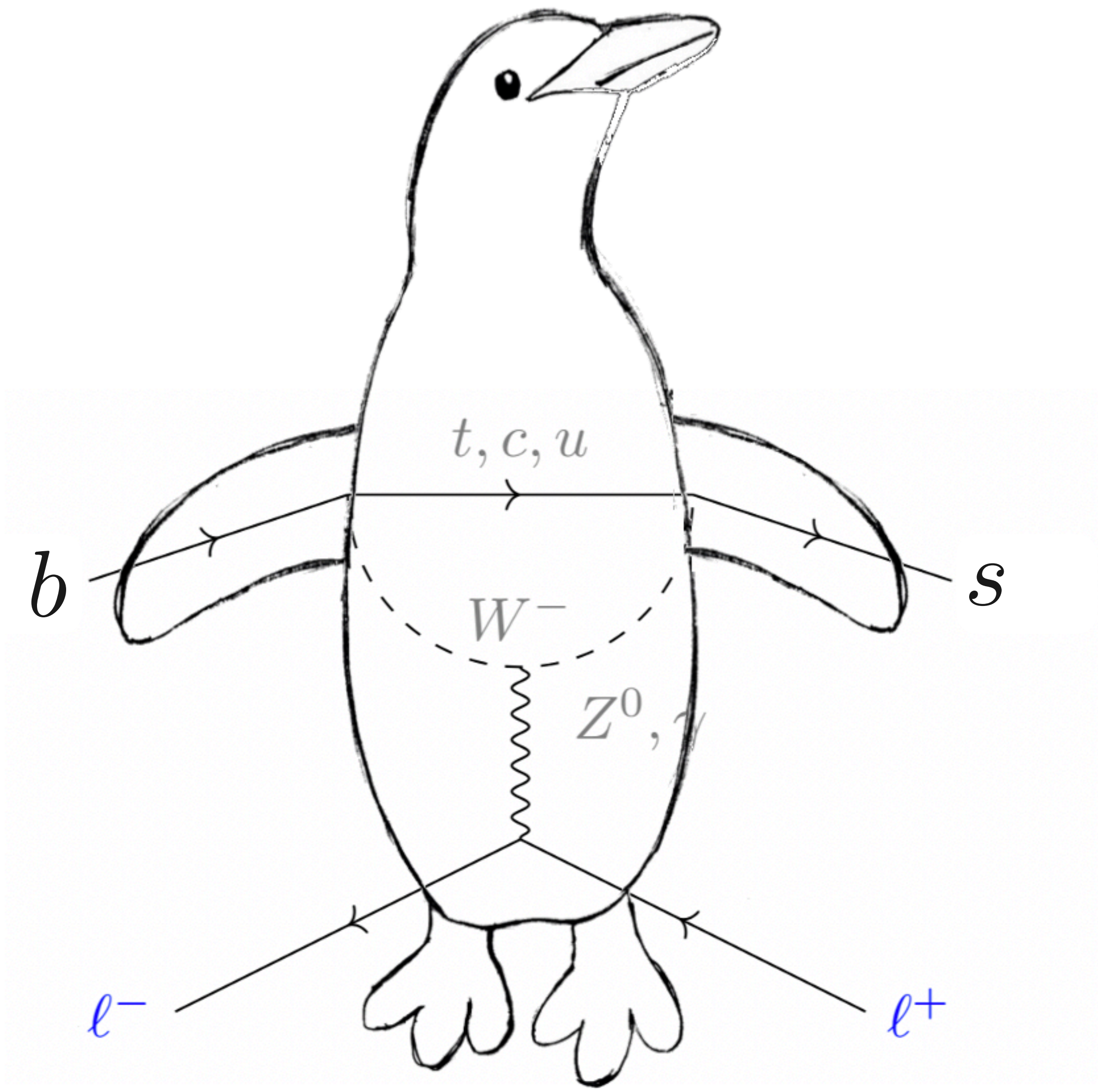


$$b \to s\ell^+\ell^-$$

Standard Model

Suppressed in the SM as mediated via loop diagrams

Electroweak Penguins



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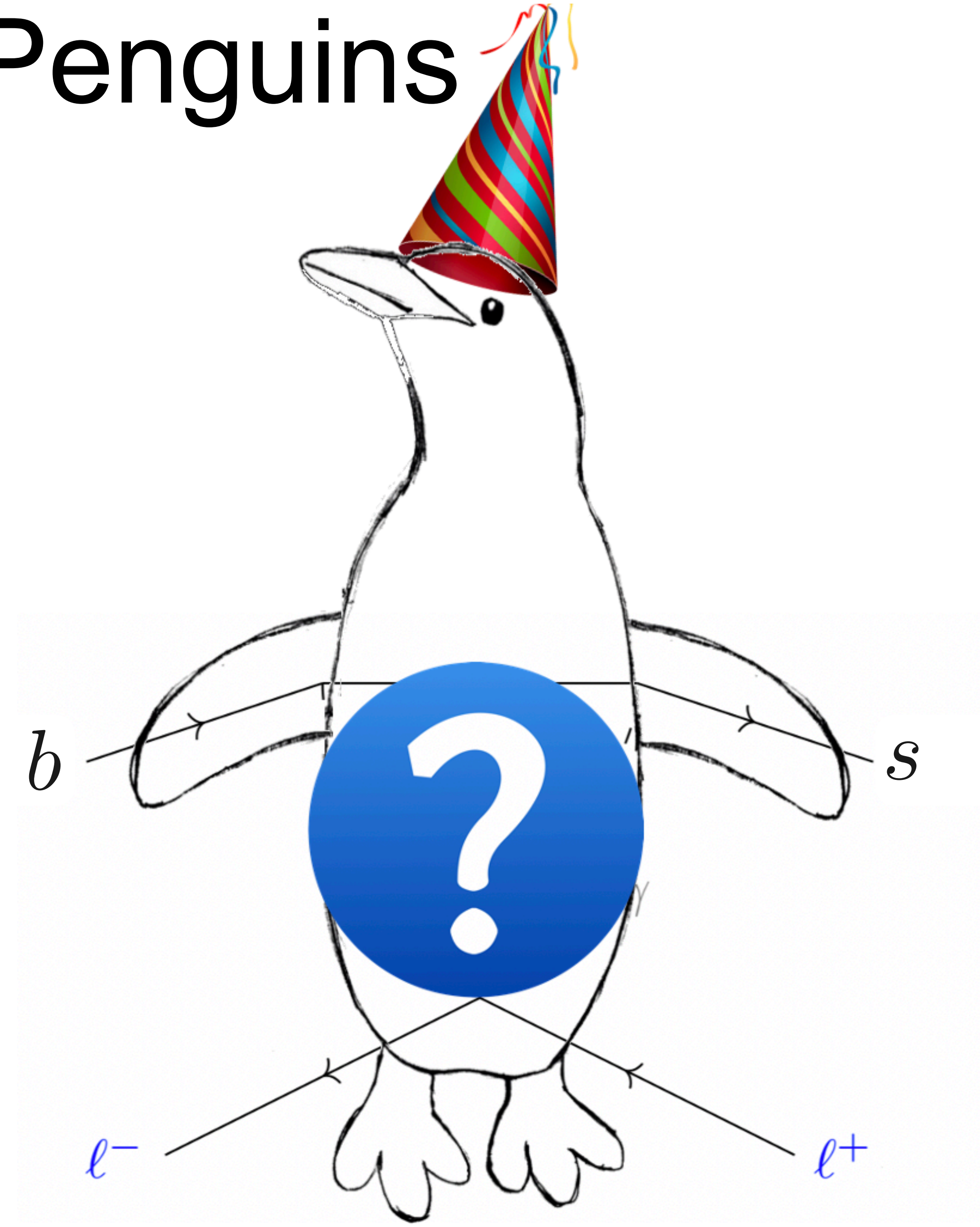
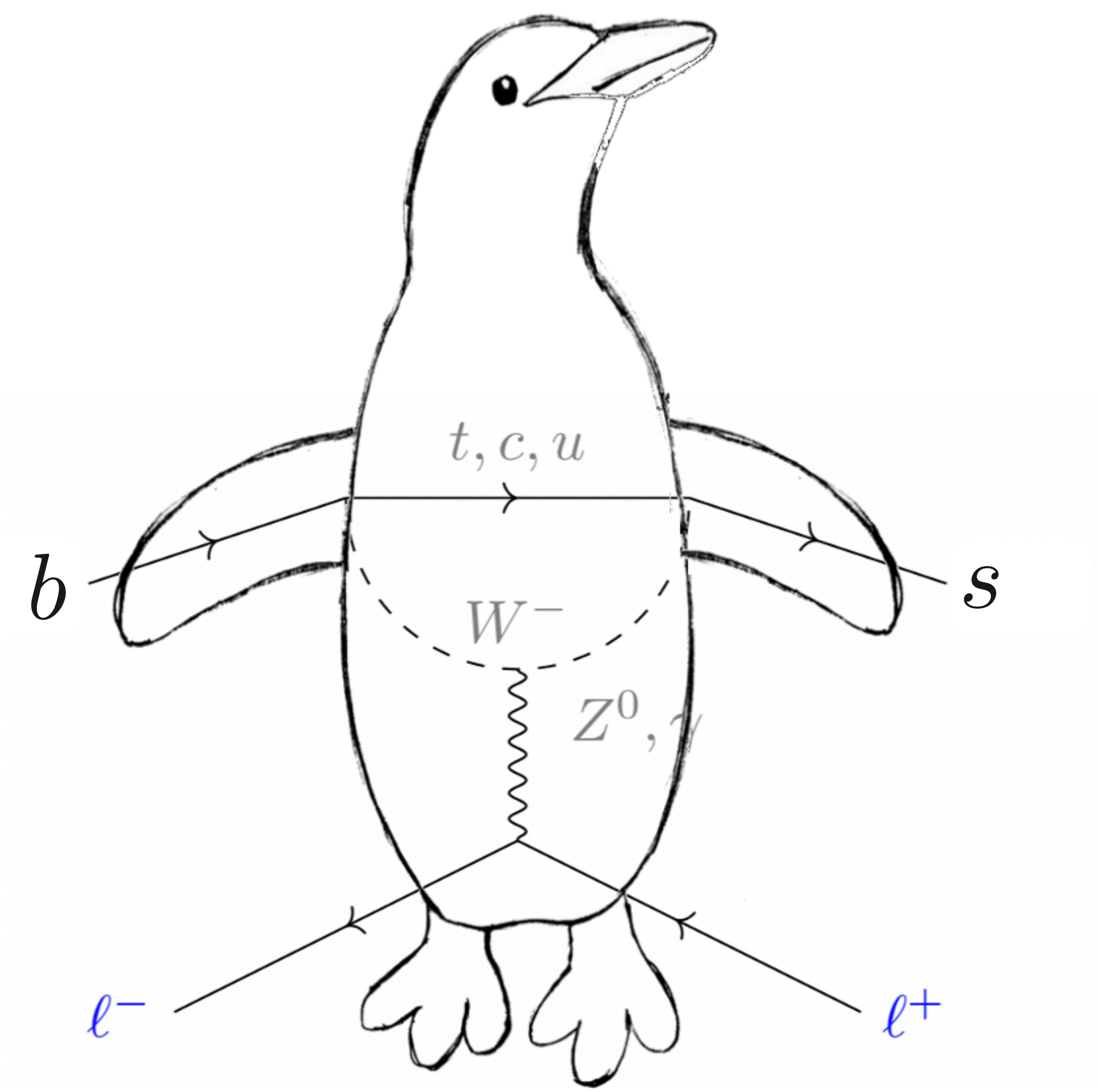


New Physics

Suppressed in the SM as mediated via loop diagrams

Suppression = very sensitive to New Physics diagrams

Electroweak Penguins



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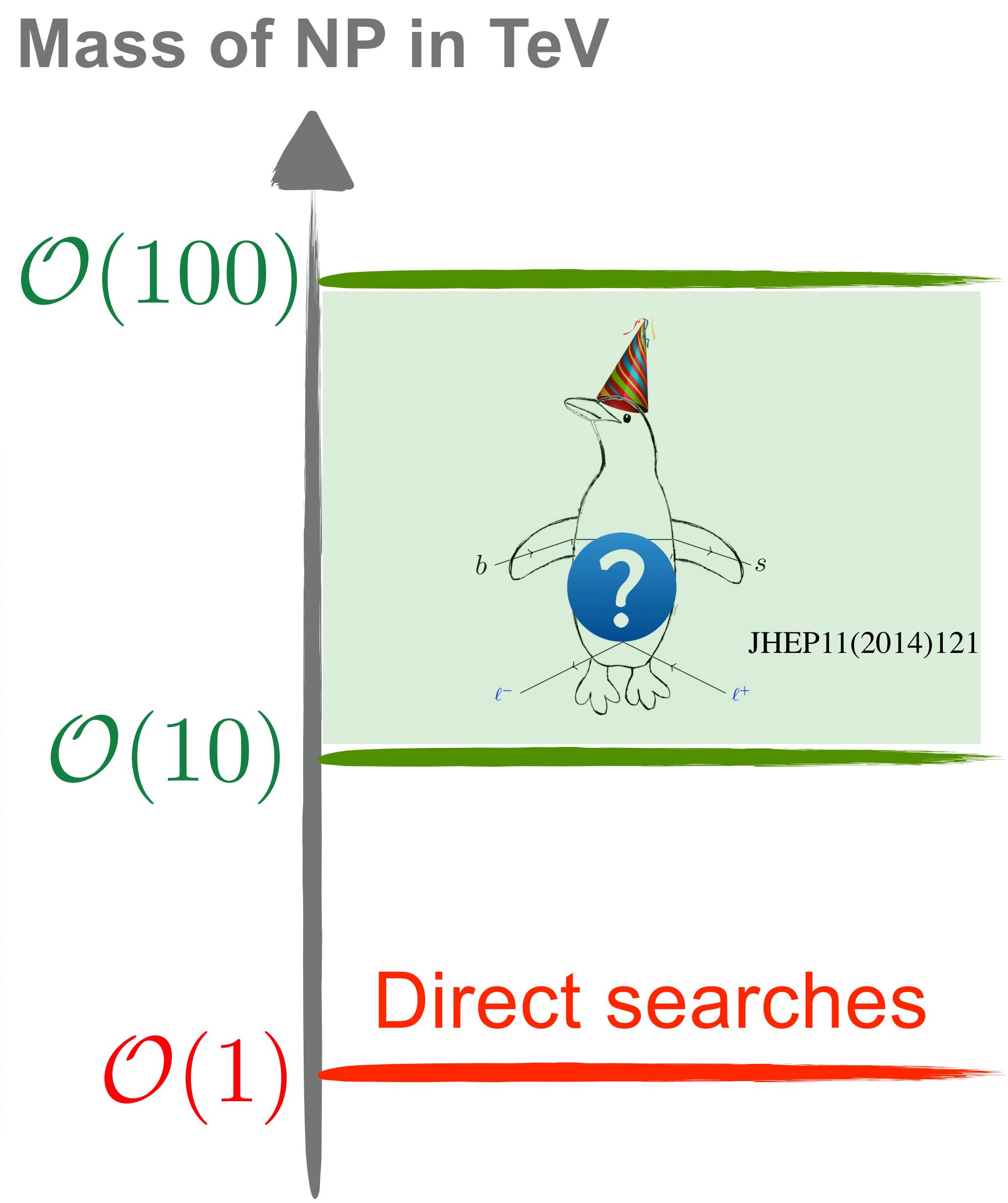
Standard Model

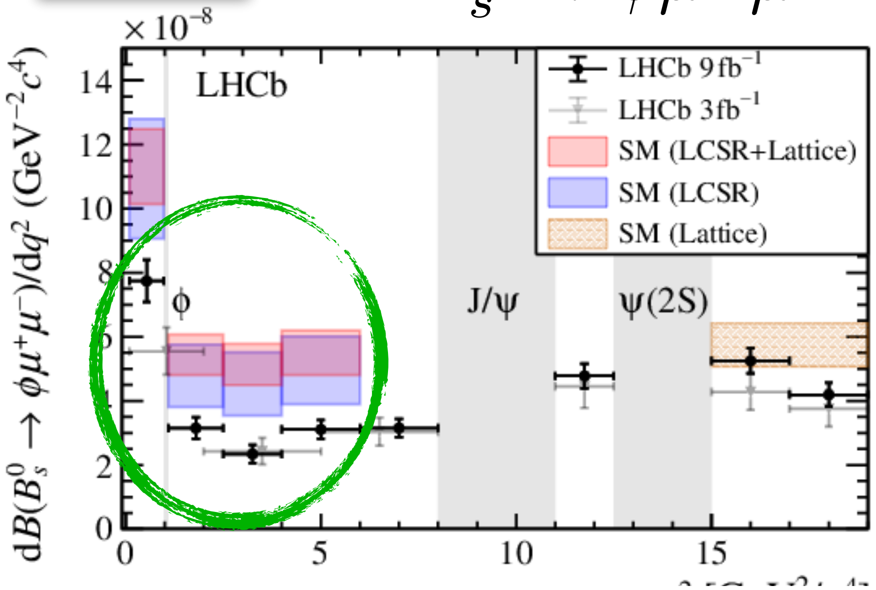


New Physics beyond the TeV

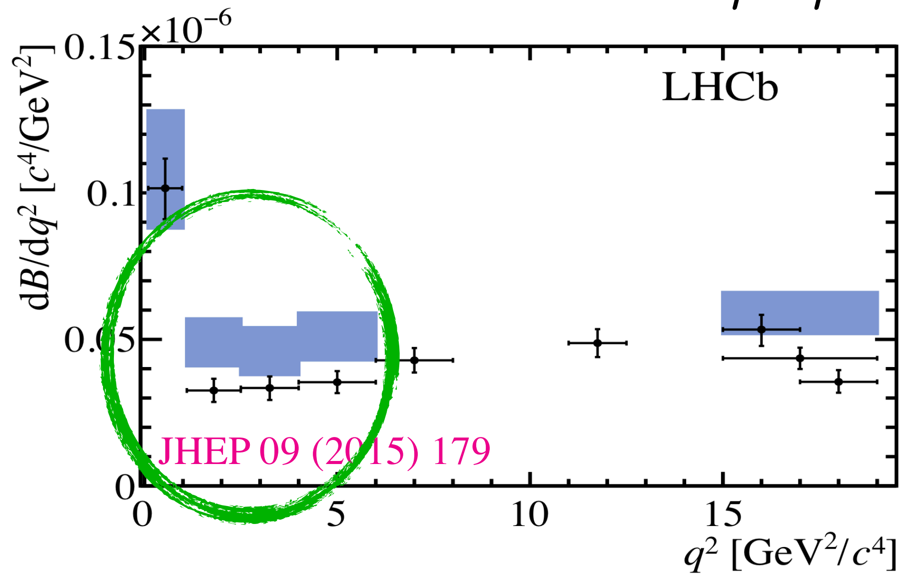
Suppression = very sensitive to New Physics diagrams

Summary of $b \to s\mu^+\mu^-$ branching fractions

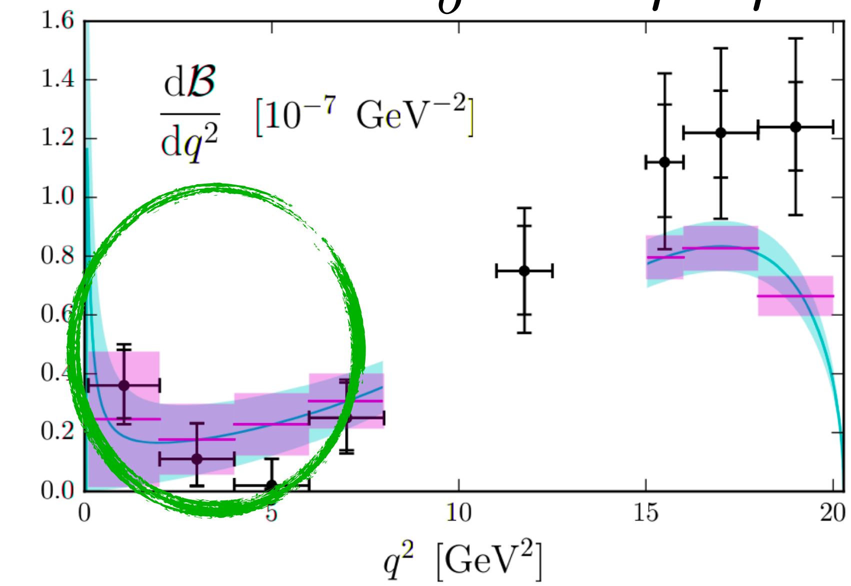
$B_s^0 \to \phi\mu^+\mu^-$

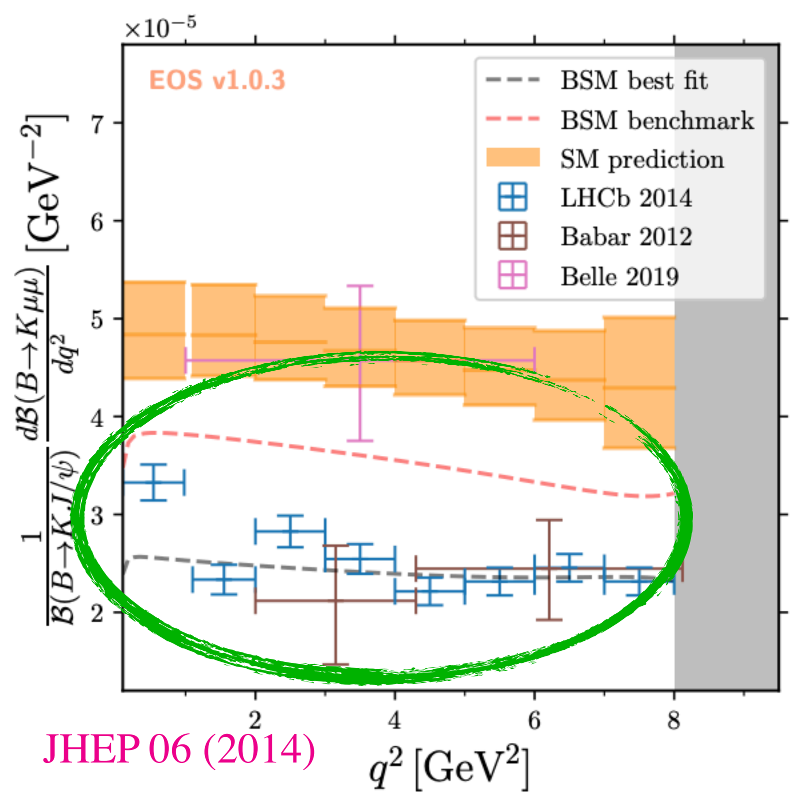


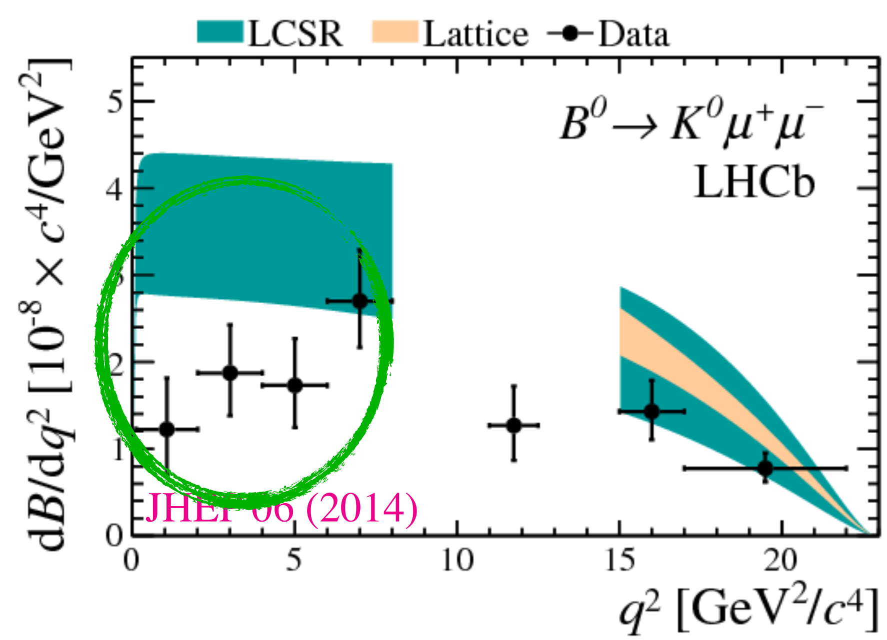
$B^0 \to K^{*0}\mu^+\mu^-$

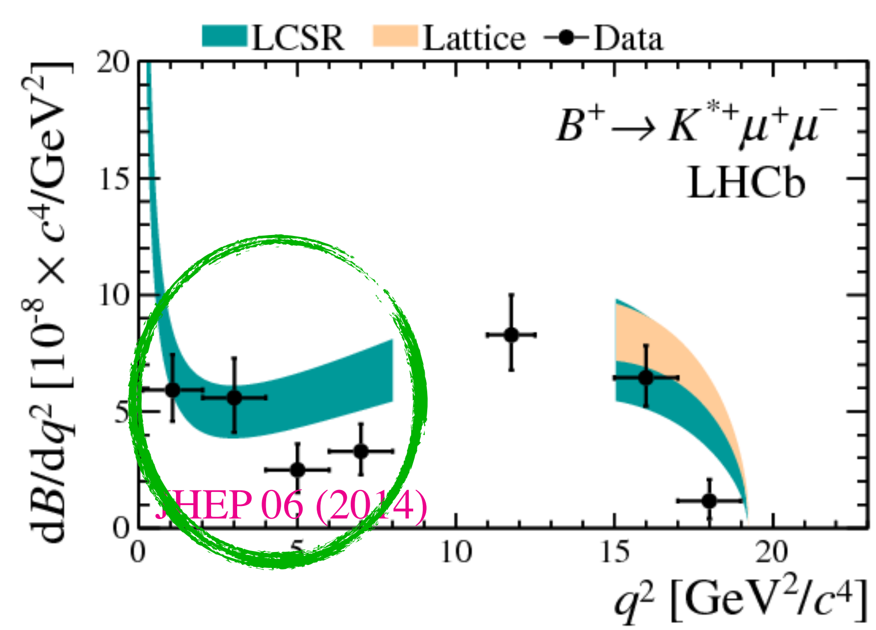


$\Lambda_b^0 \to \Lambda\mu^+\mu^-$









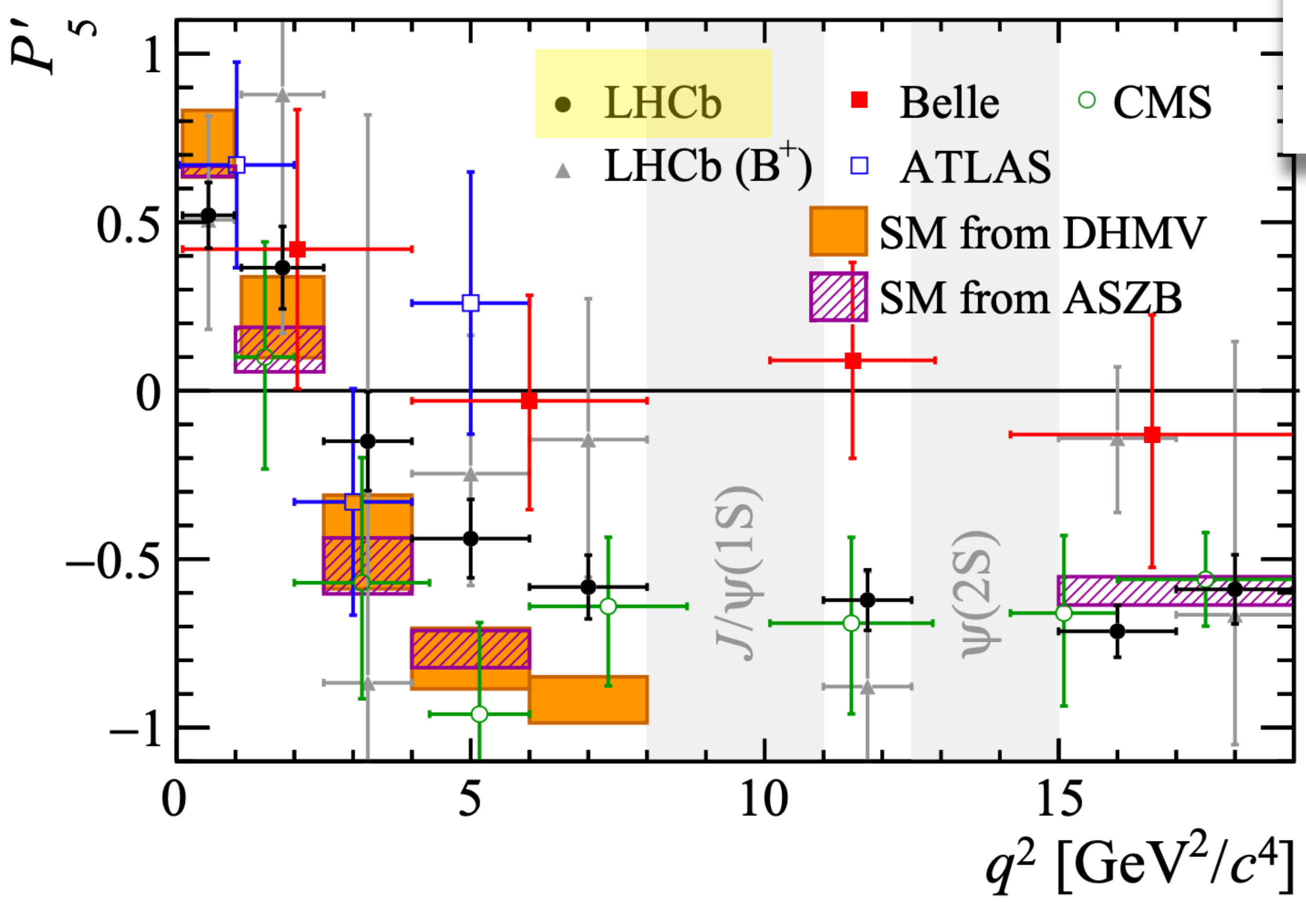
Same pattern, decay rate too low!!

$$q^2 = m^2(\mu^+\mu^-)$$

Angular analysis of $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$

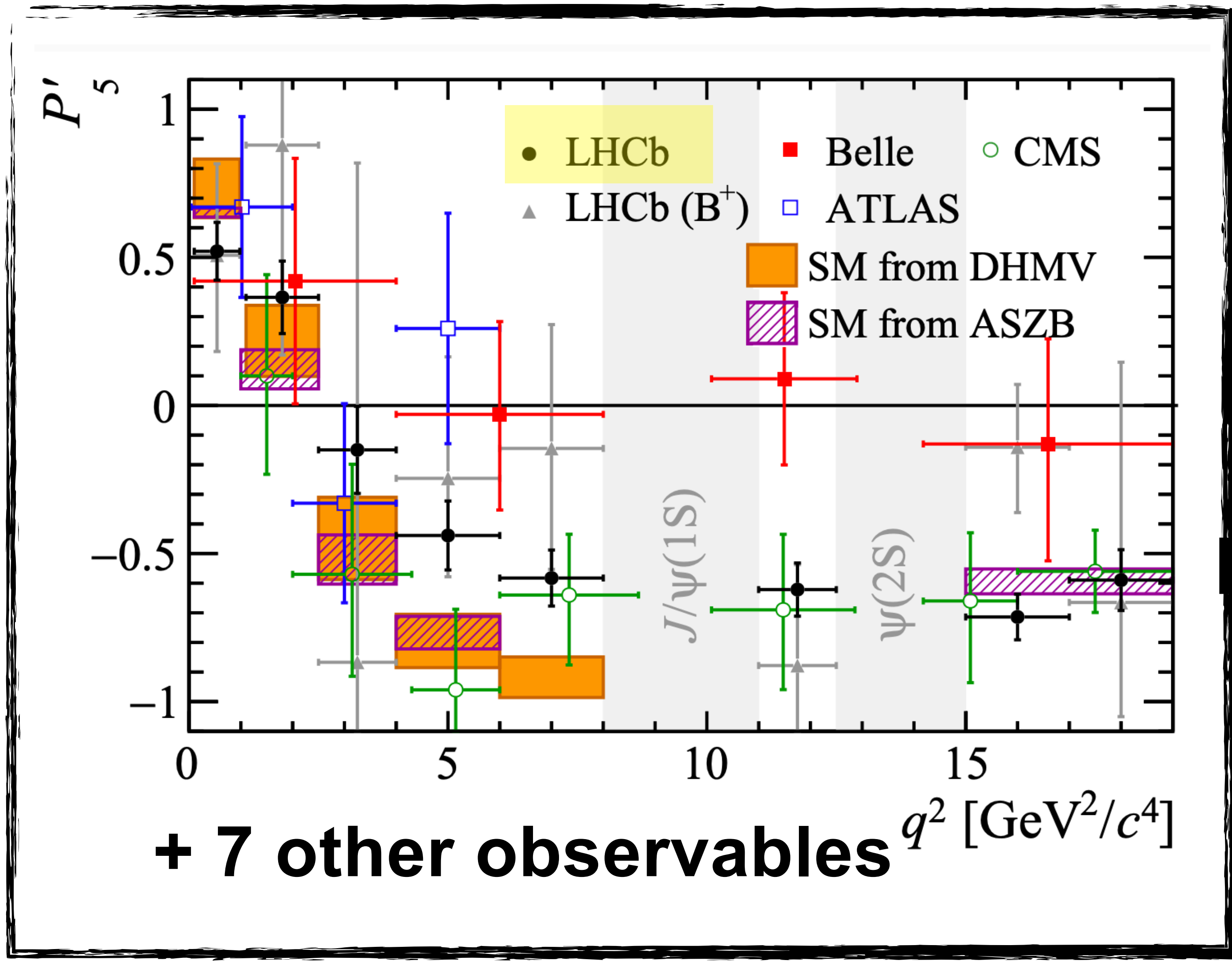
LHCb B0 PRL 125, 011802 (2020) . LHCb B+ PRL 161802 (2021) ATLAS: JHEP 10 (2018) 047

Belle: PRL 118 (2017), CMS:PLB 781 (2018) 517541

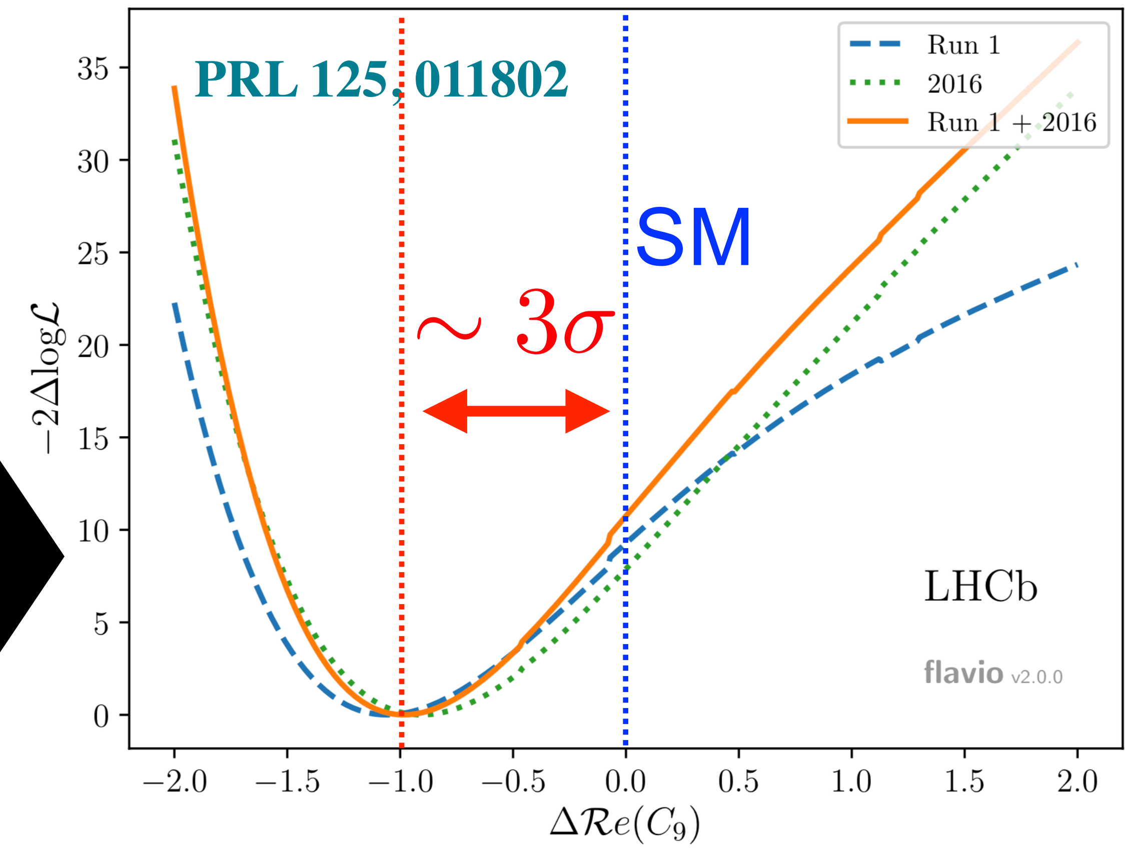


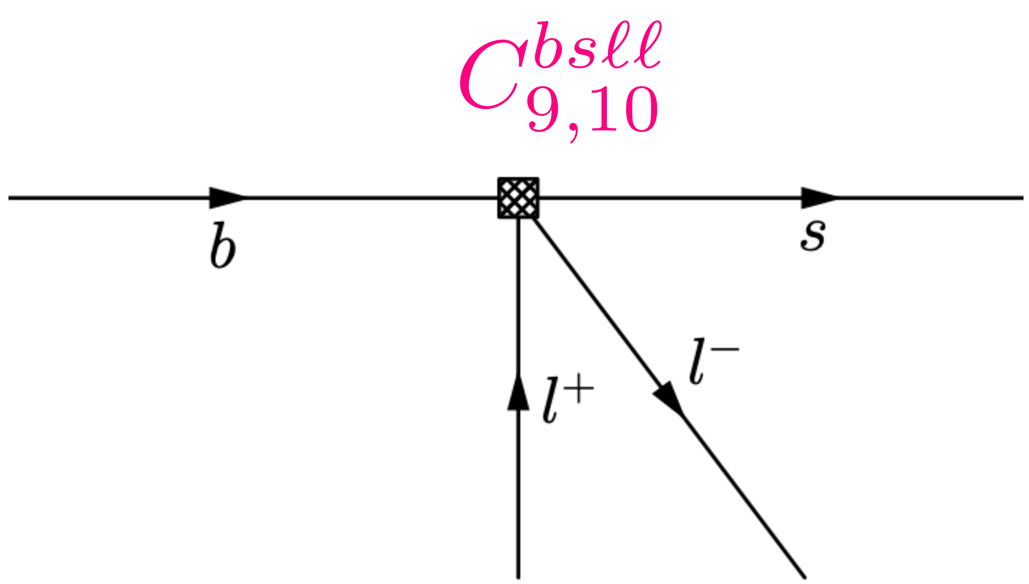
Massachusetts Institute of Technology

Angular analysis of $B^0 \to K^{*0}(\to K^+\pi^-)\mu^+\mu^-$



+ 7 other observables



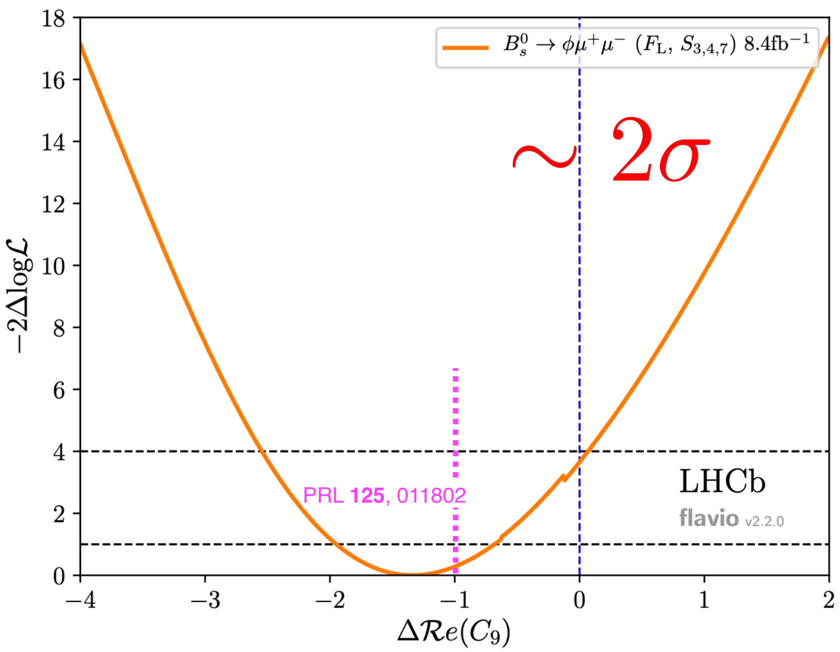


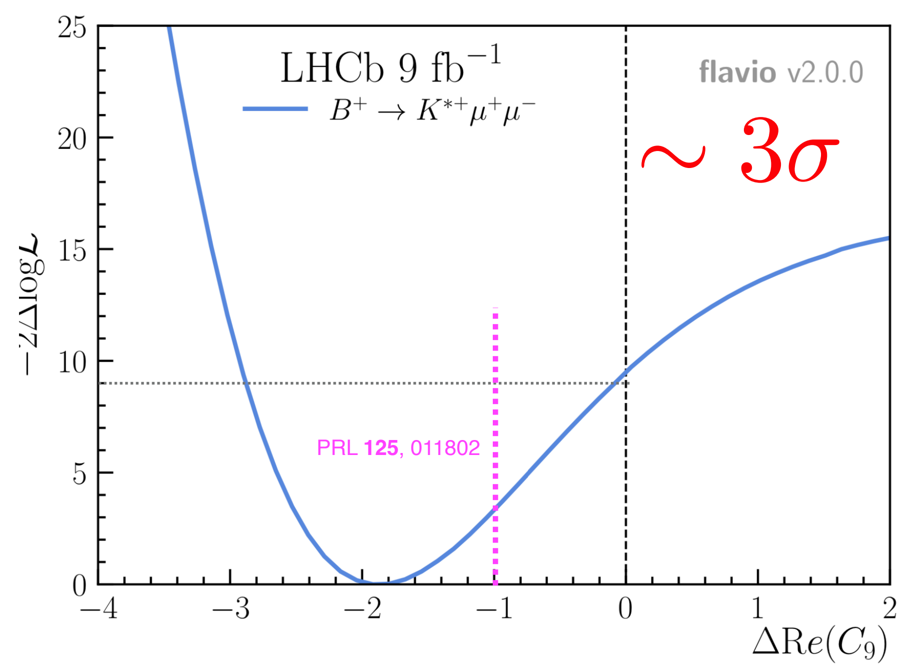
Express "global" agreement of all 8 observables with SM in terms of underlying effective couplings

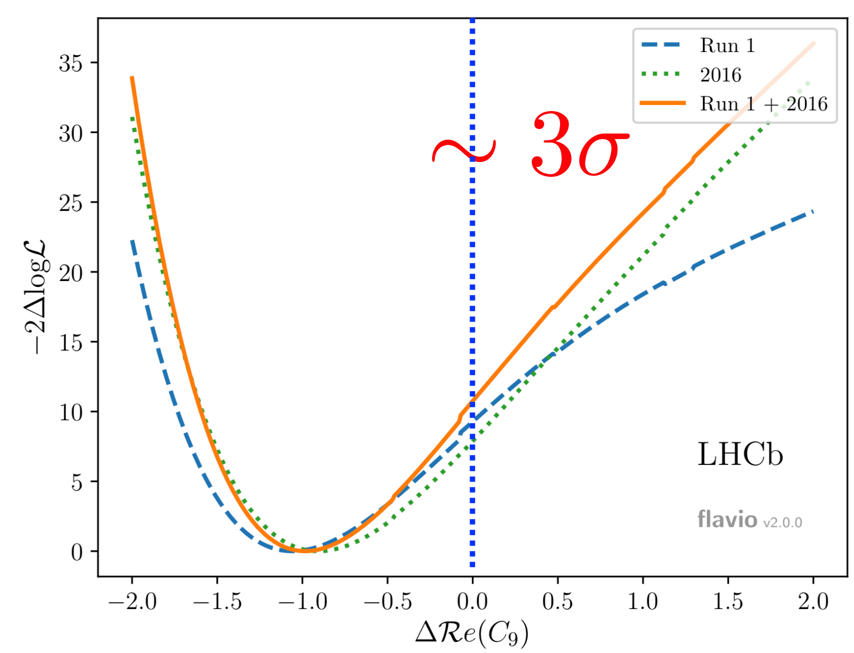
p-value ~0.001

Summary of angular analysis

$B_s^0 \to \phi\mu^+\mu^-$	$B^+ \to K^{*+}\mu^+\mu^-$	$B^0 \to K^{*0}\mu^+\mu^-$
$\Delta\mathcal{R}e(\mathcal{C}_9) = -1.3\,^{+0.7}_{-0.6}$	$\Delta\mathcal{R}e(\mathcal{C}_9) = -1.9$	$\Delta\mathcal{R}e(\mathcal{C}_9) = -0.99^{+0.25}_{-0.21}$
JHEP 11 (2021) 043	Phys. Rev. Lett. **126**, 161802	Phys. Rev. Lett. **125**, 011802

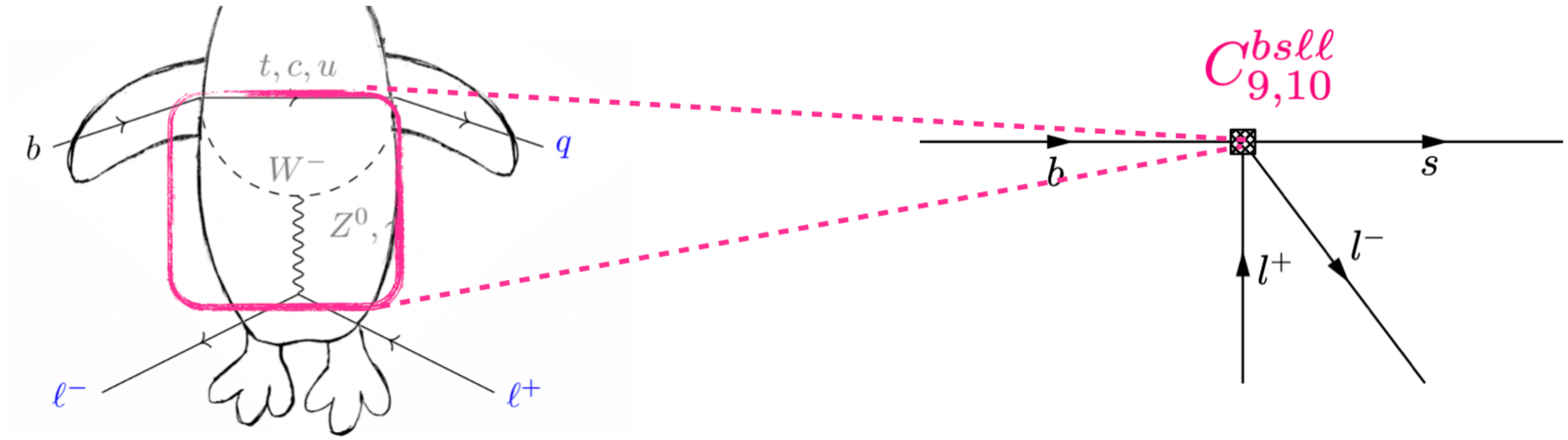


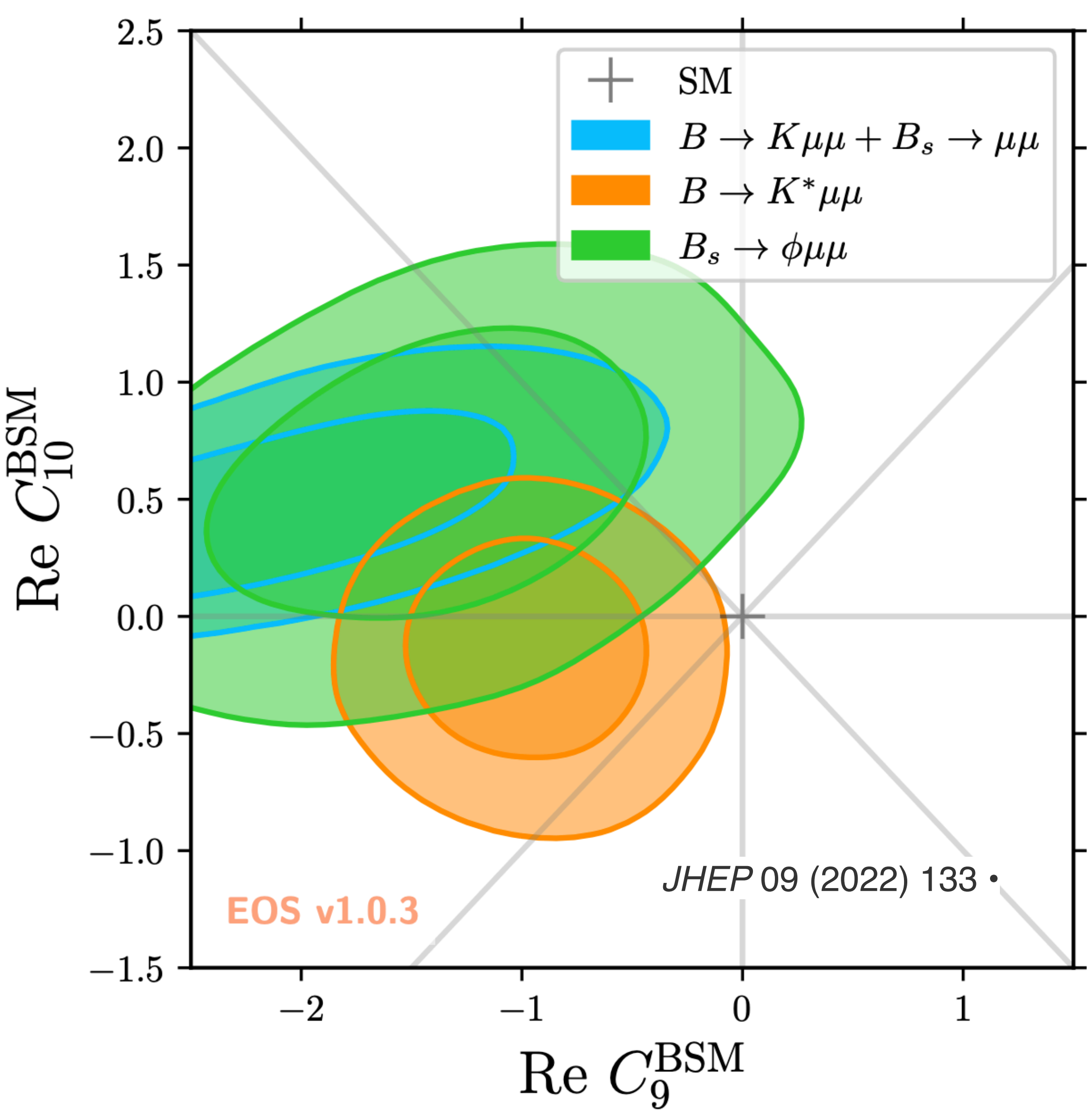




Same pattern, negative definitions in effective coupling

Global fit to underlying effective couplings





- Results across angular observables and branching fractions consistent

- Overall deviation from SM at the 4-5 σ level

- Brand-new result (LHCb-PAPER-2023-032) favours C_9 shift in $B^0 \to K^{*0}\mu^+\mu^-$ also accounting for non-local QCD

The LHCb physics program

Rare Decays	$b \to s(d)\ell^+\ell^-$ and $b \to s\gamma$ $(R_K, P_5', ...)$
Heavy Ions	Proton-lead, lead-lead and also fixed target (SMOG)
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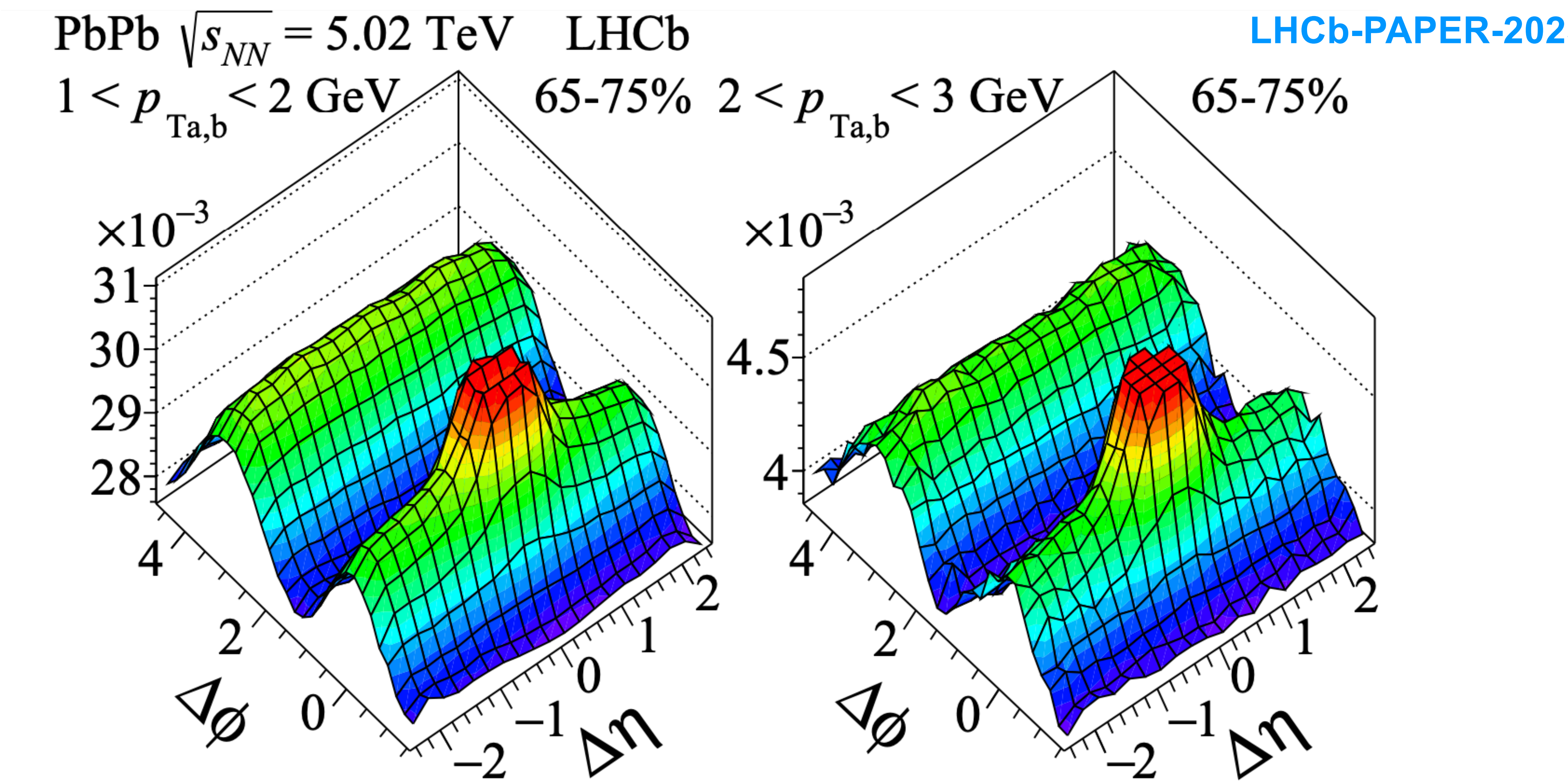
Heavy ion runs at LHCb: Quark Gluon Plasma

➤ Harmonic coefficients → hydrodynamic of quark-gluon plasma

➤ First LHCb results of the second- and the third-order flow harmonic coefficients of charged hadrons as a function of transverse momentum in the forward region

LHCb-PAPER-2023-031

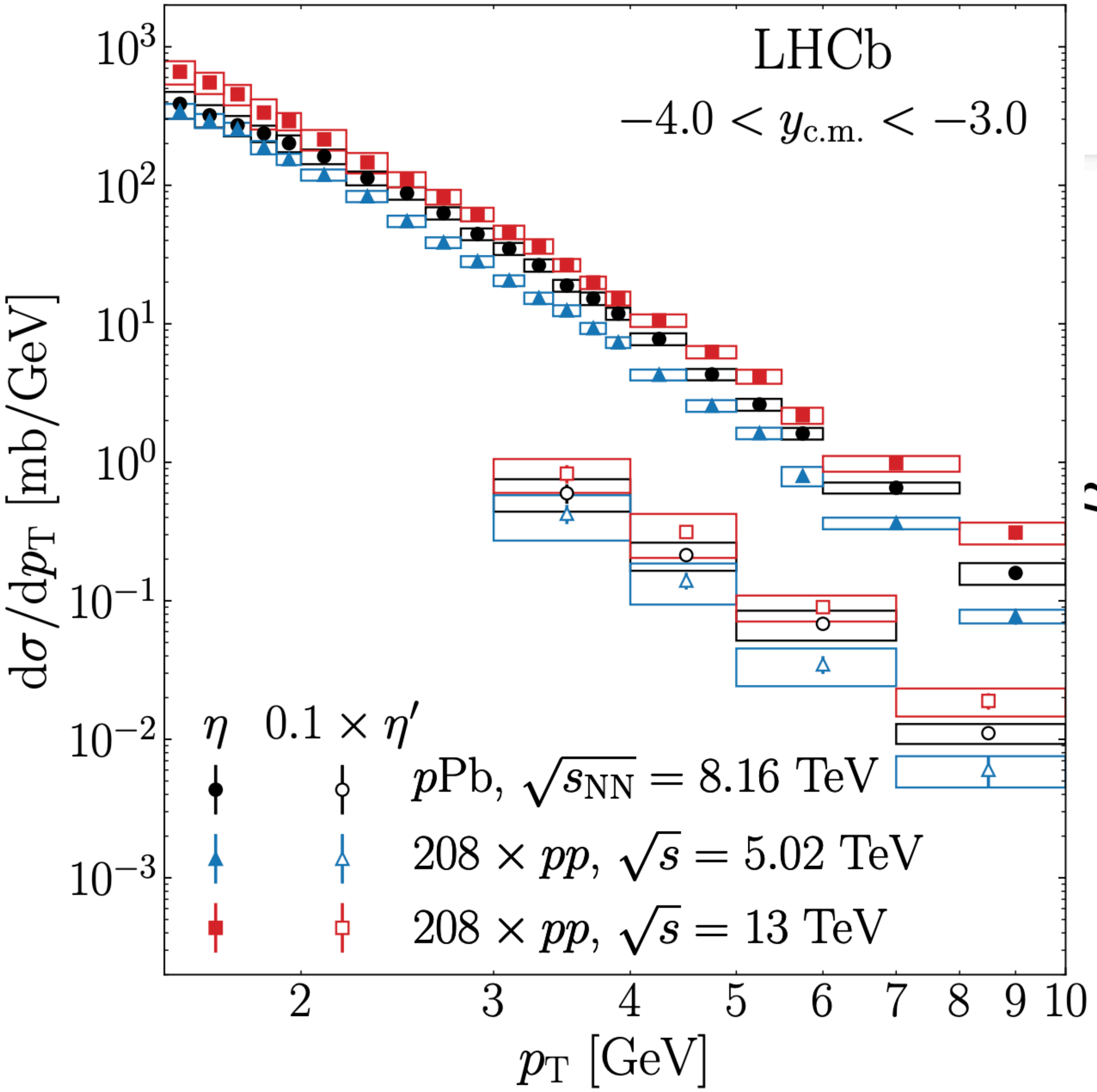


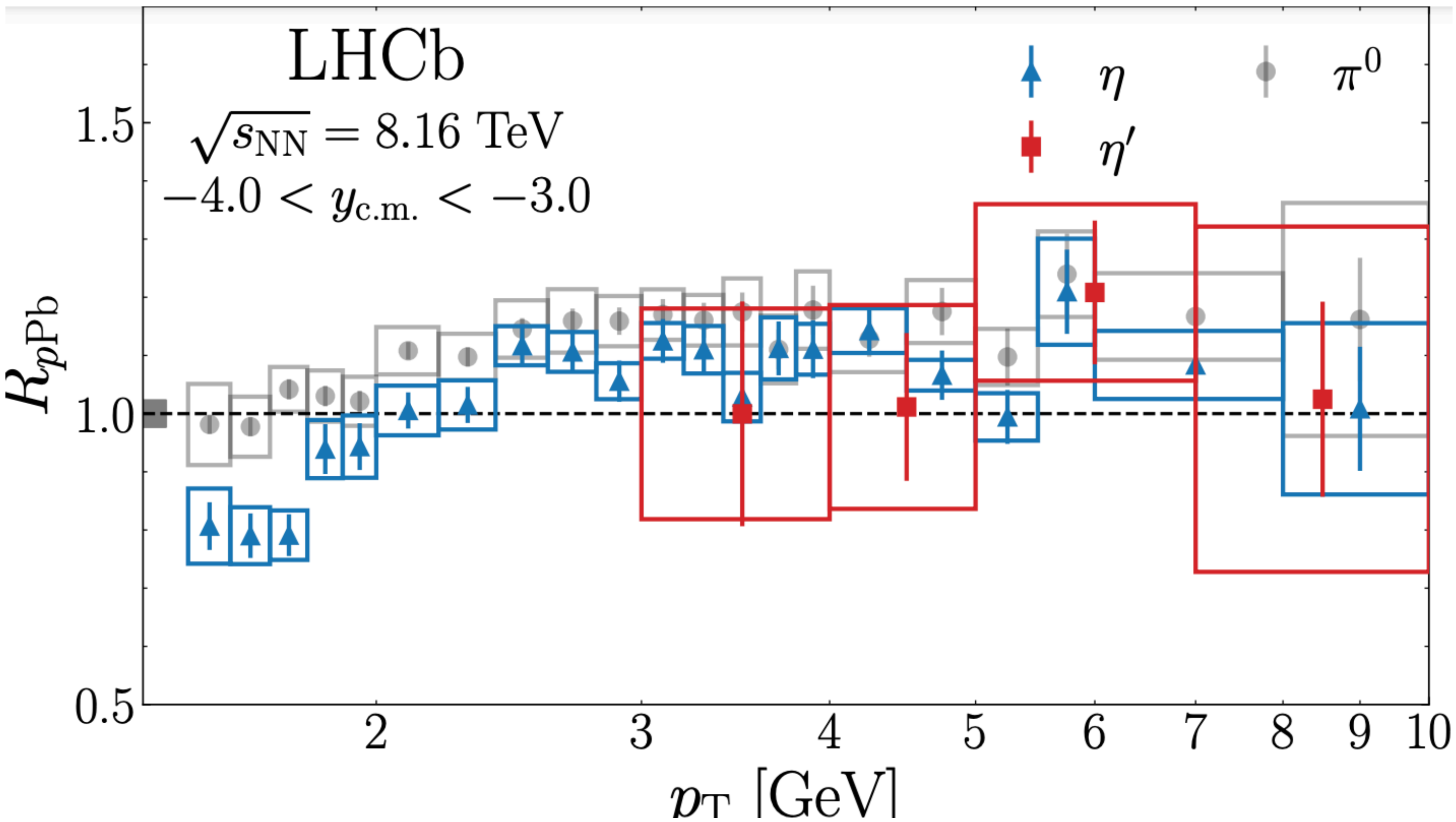
PbPb collisions in 2018 at a center-of-mass energy of 5.02 TeV

Heavy ion runs at LHCb: $\eta^{(\prime)}$ production

Differential cross section of $\eta^{(\prime)}$ in pp (5TeV and 13TeV) and pPb collisions (8 TeV)

Used to calculate nuclear modification factors





LHCB-PAPER-2023-030

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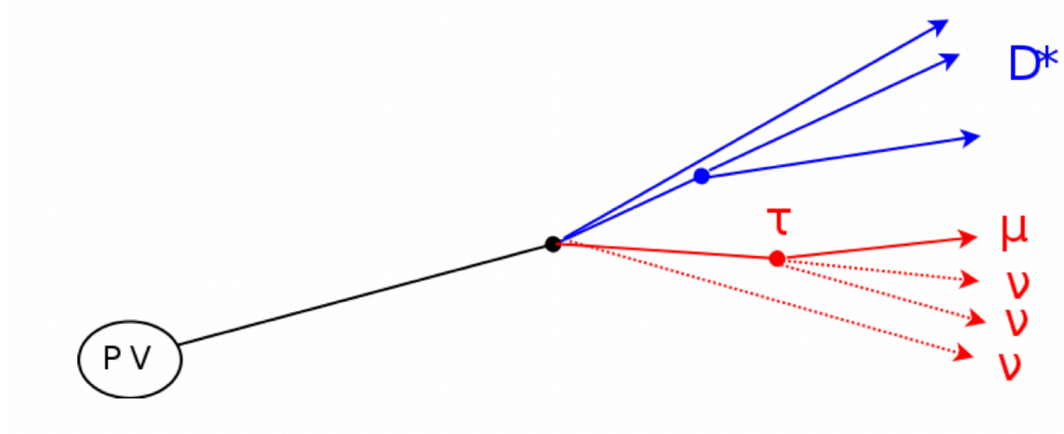
Joint measurement of $R(D^*)$ and $R(D^0)$ at LHCb

- Simultaneously measure $R(D^*)$, $R(D^0)$ via $\tau \to \mu\nu\nu$
- Challenge: neutrinos, missing energy
- We know flight direction of B: use missing transverse momentum, as well as energy of muon, to separate signal/background

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}\ell^- \bar{\nu}_\ell)}$$



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PHYS. REV. LETT. 131 (2023) 111802

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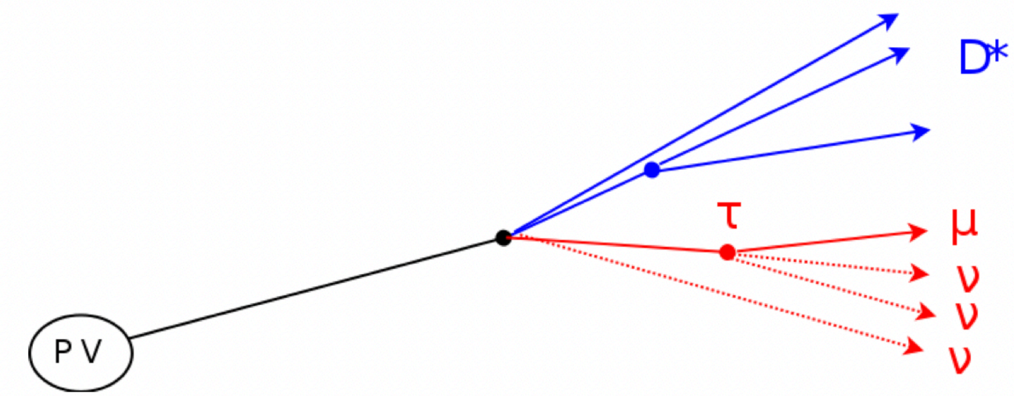
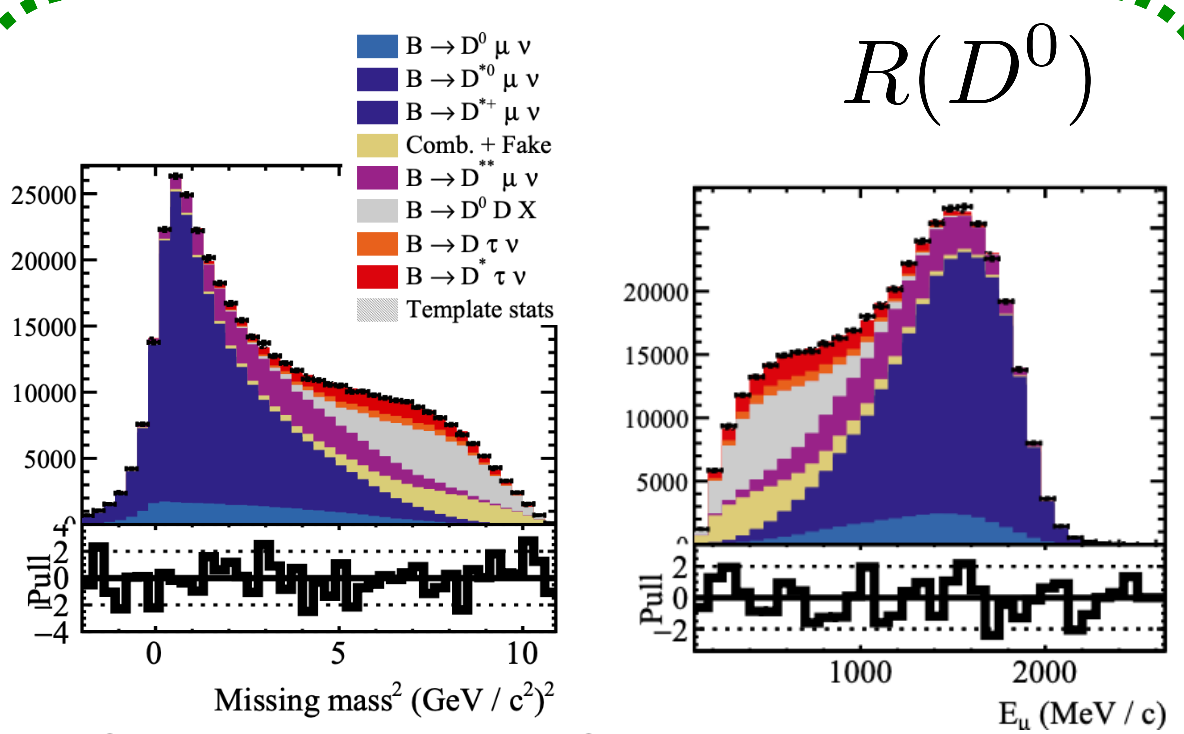
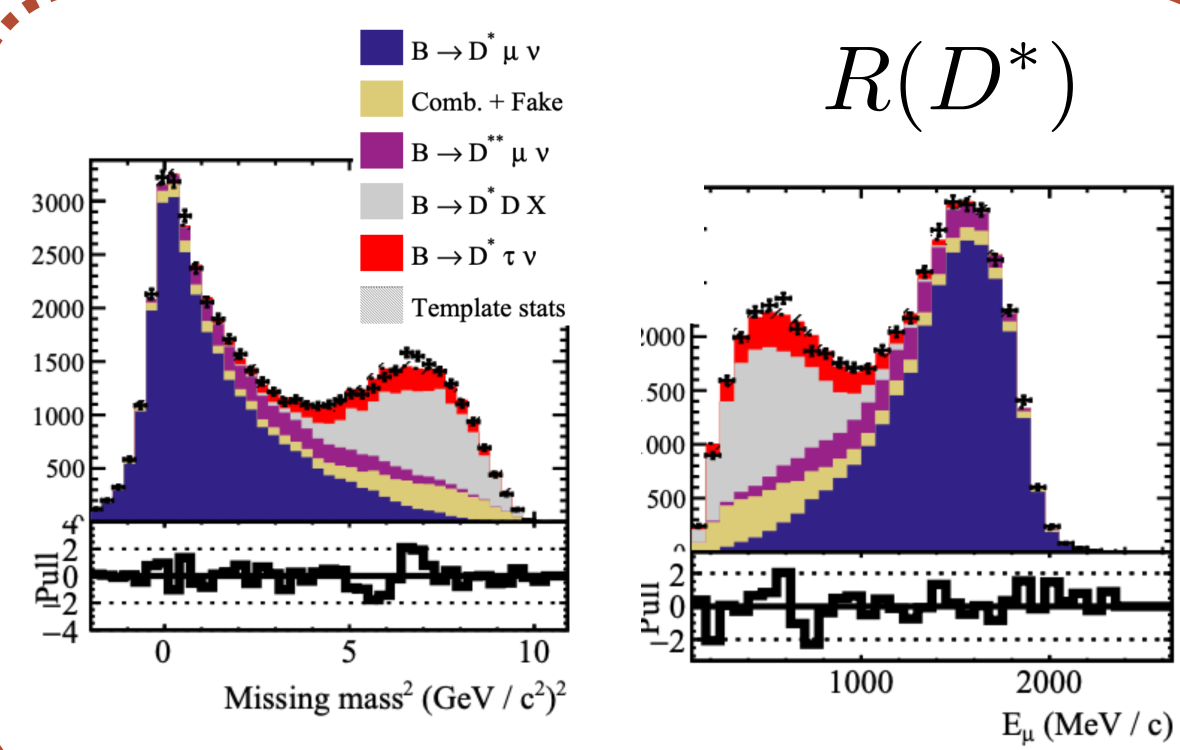


LHCb-preliminary



$m^2_{\text{miss}} = (p^\mu_B - p^\mu_D - p^\mu_\mu)^2$

LHCb-preliminary



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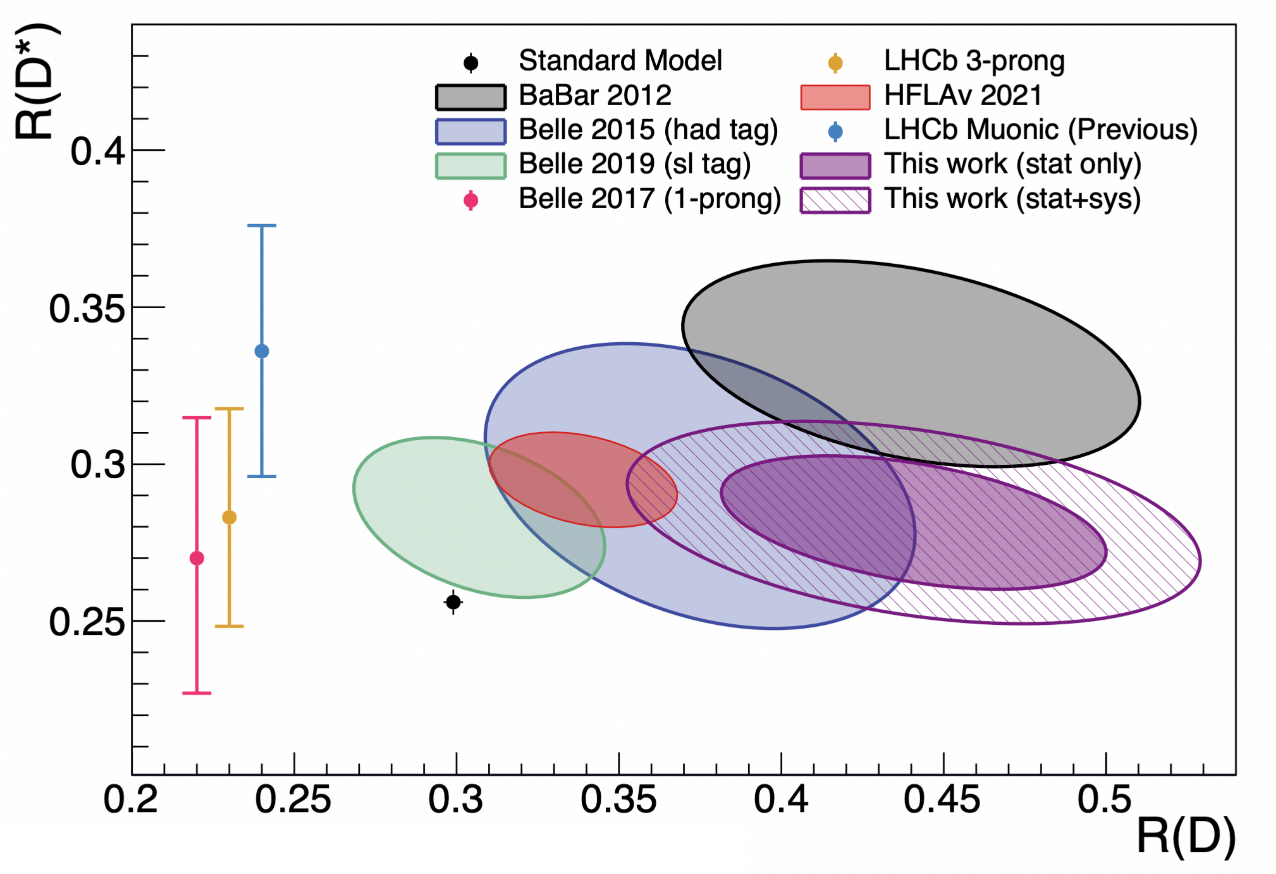

$$R(D^*) = 0.281 \pm 0.018 \pm 0.024$$

$$R(D) = 0.441 \pm 0.060 \pm 0.066$$

Correlation coeff: $\rho = -0.43$

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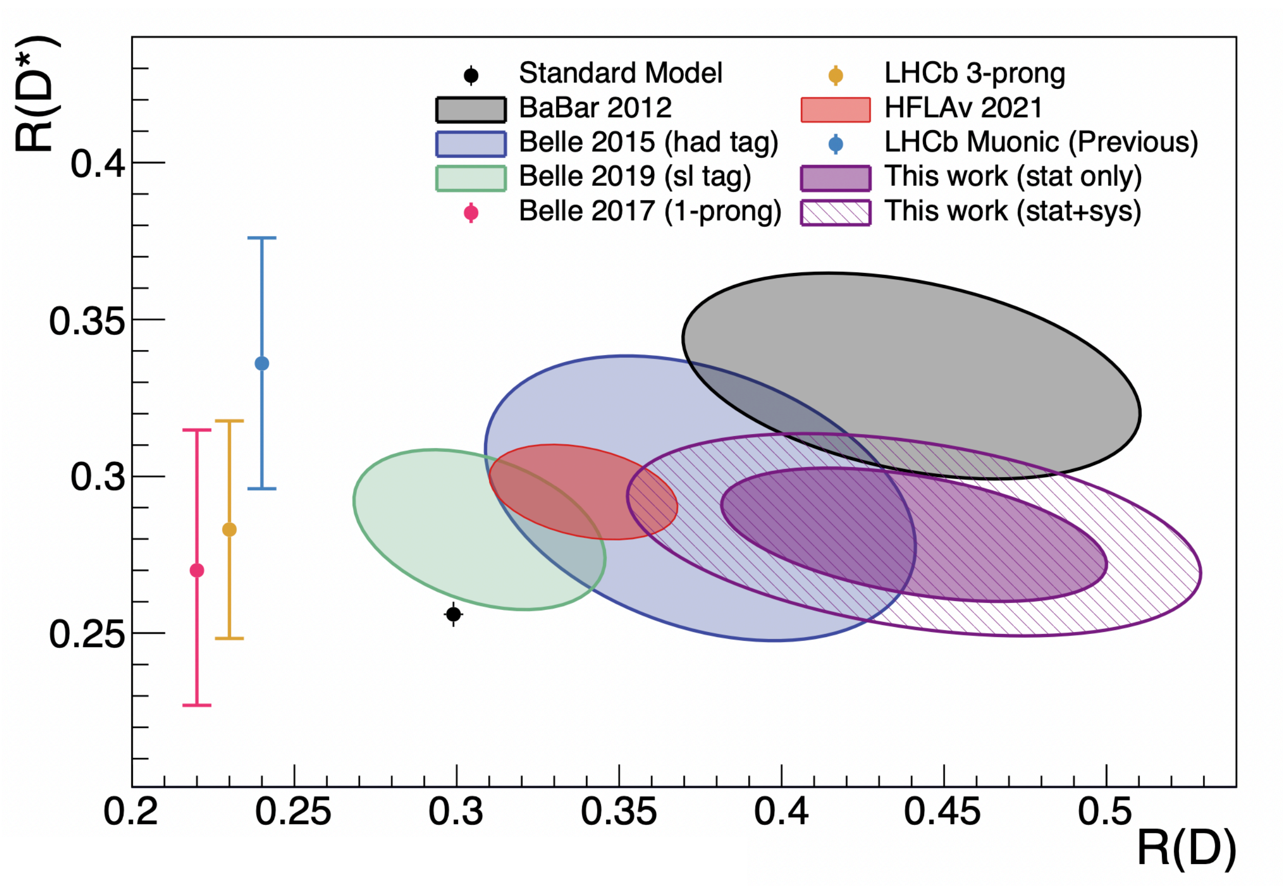

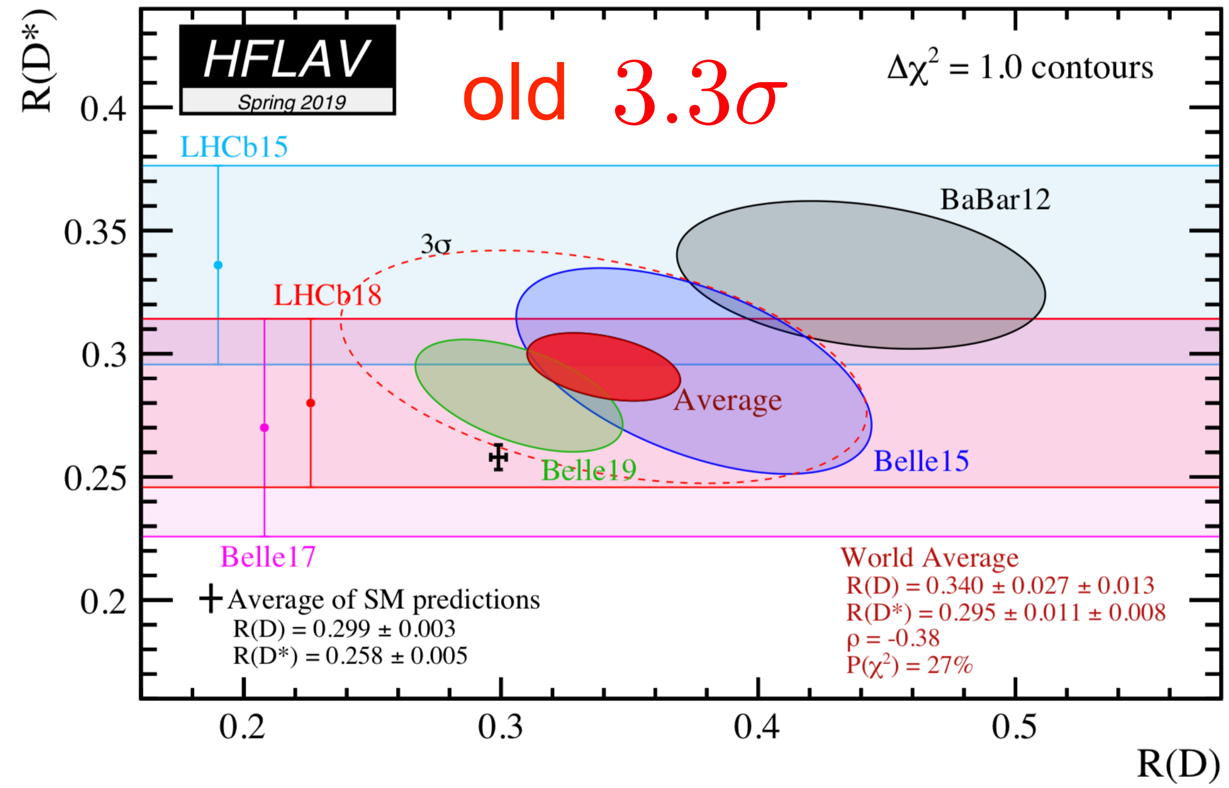

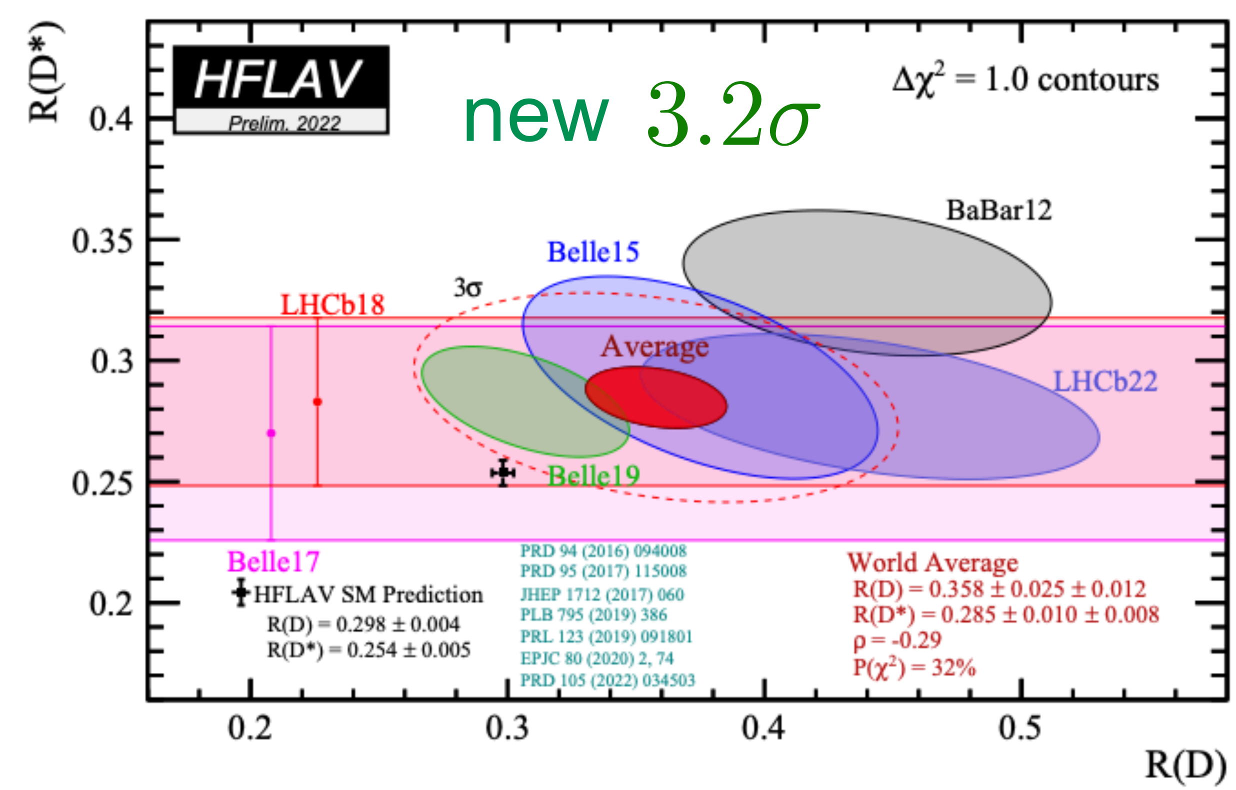

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Spectroscopy	Pentaquarks, tetra quarks, quarkonia…
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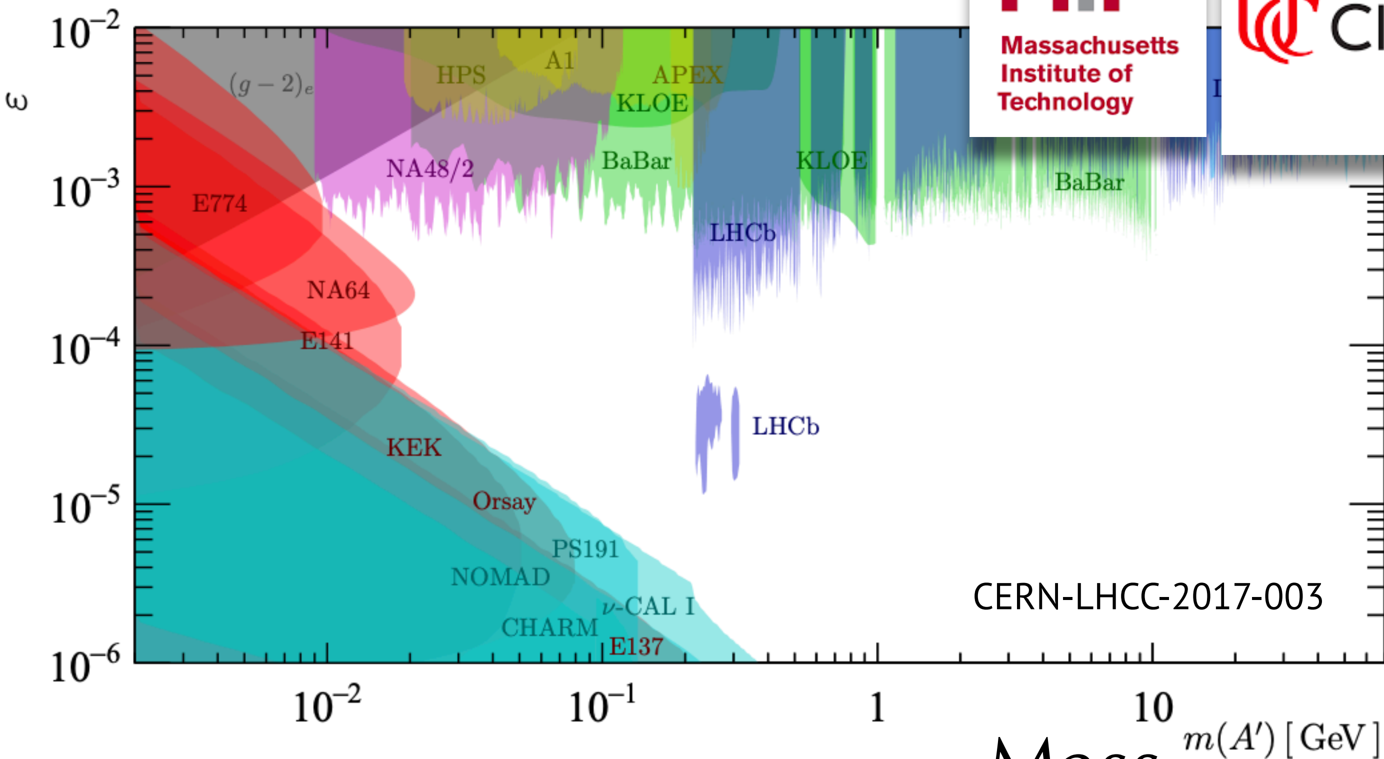
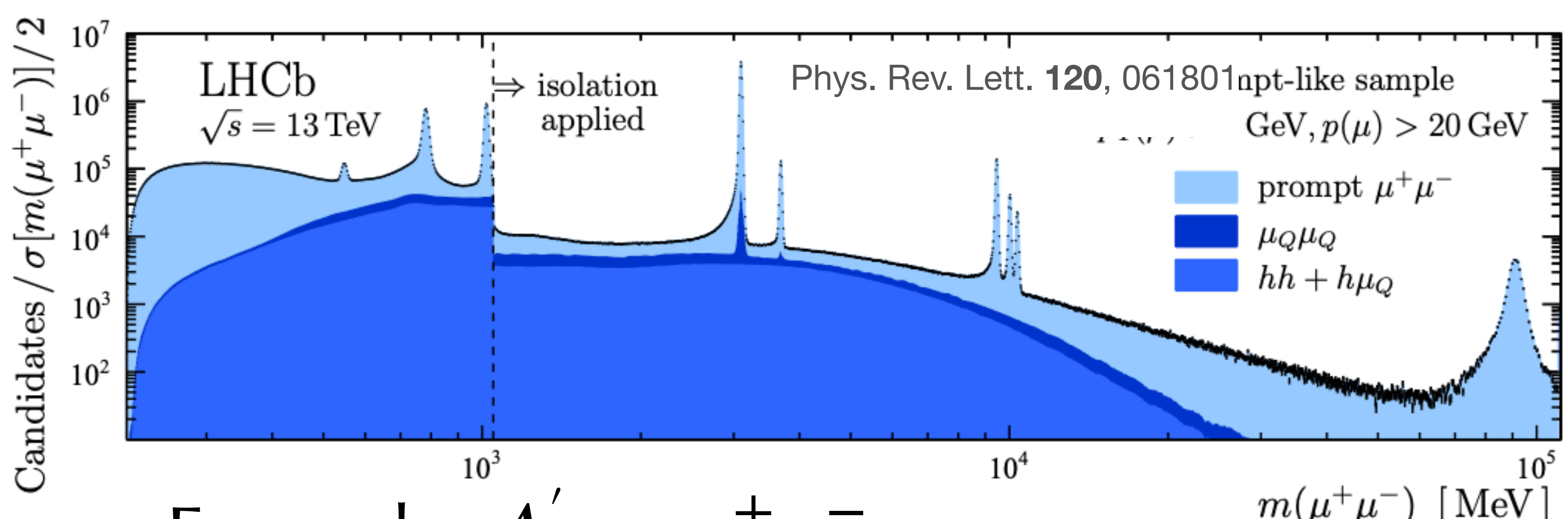
CP violation	Time-dependent, time independent

Searches for dark photons: $A^{'}$

Coupling w.r.t SM photon

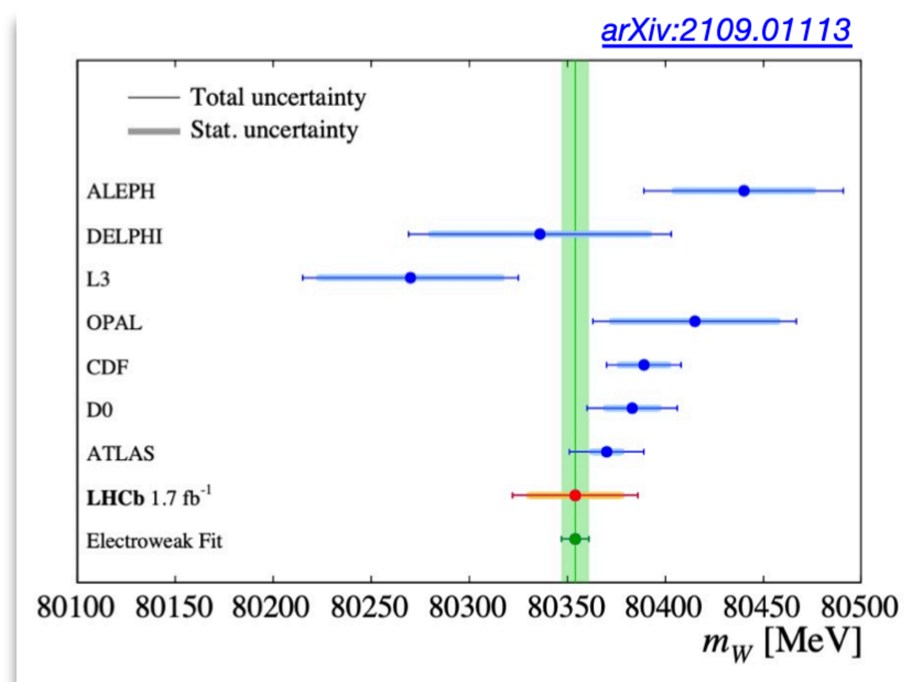


Mass



Example: $A^{'} \to \mu^+\mu^-$

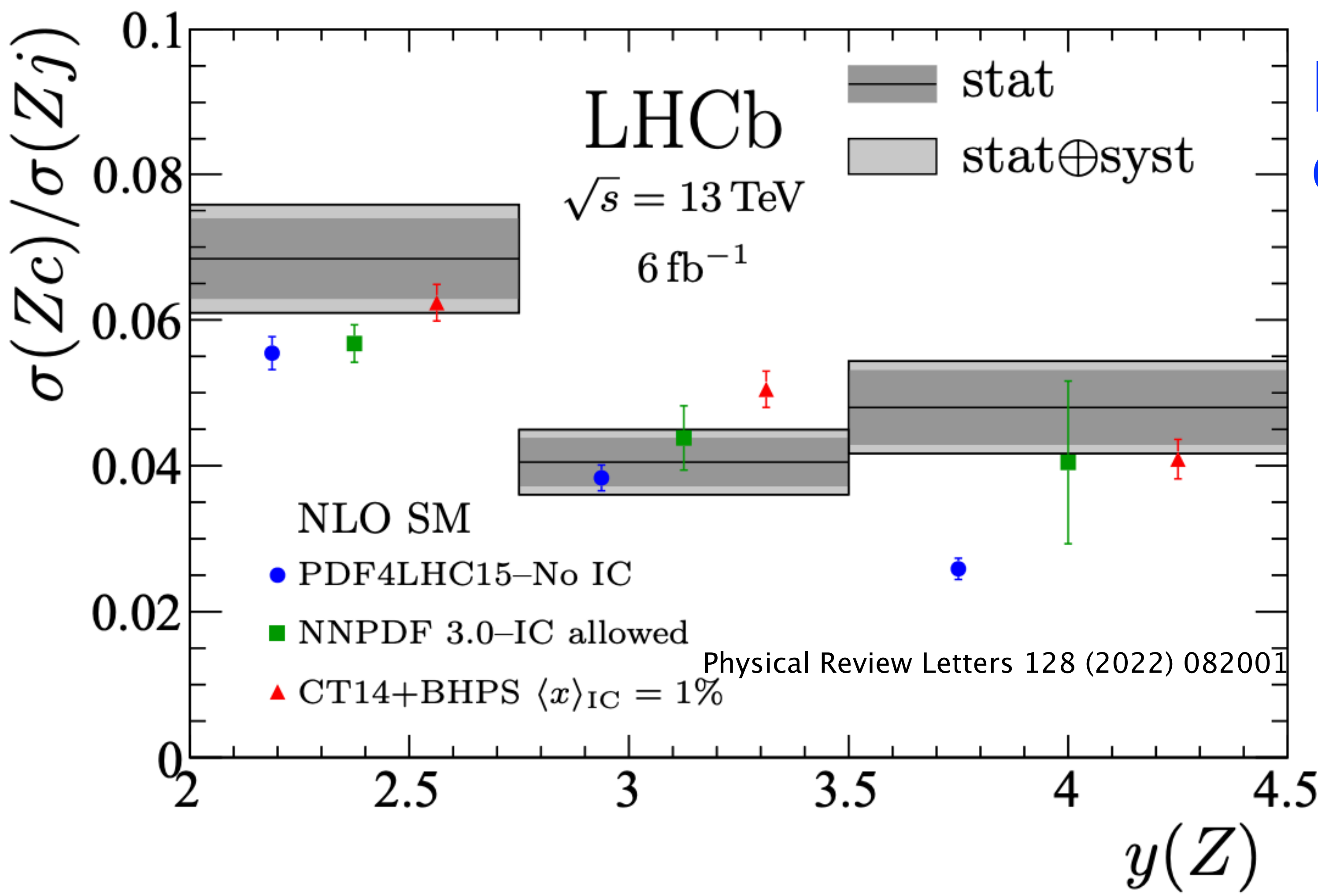
W mass



First measurements of Zc jets in forward region

$$\mathcal{R}_j^c \equiv \sigma(Zc)/\sigma(Zj),$$

Massachusetts Institute of Technology



Prediction with no intrinsic charm

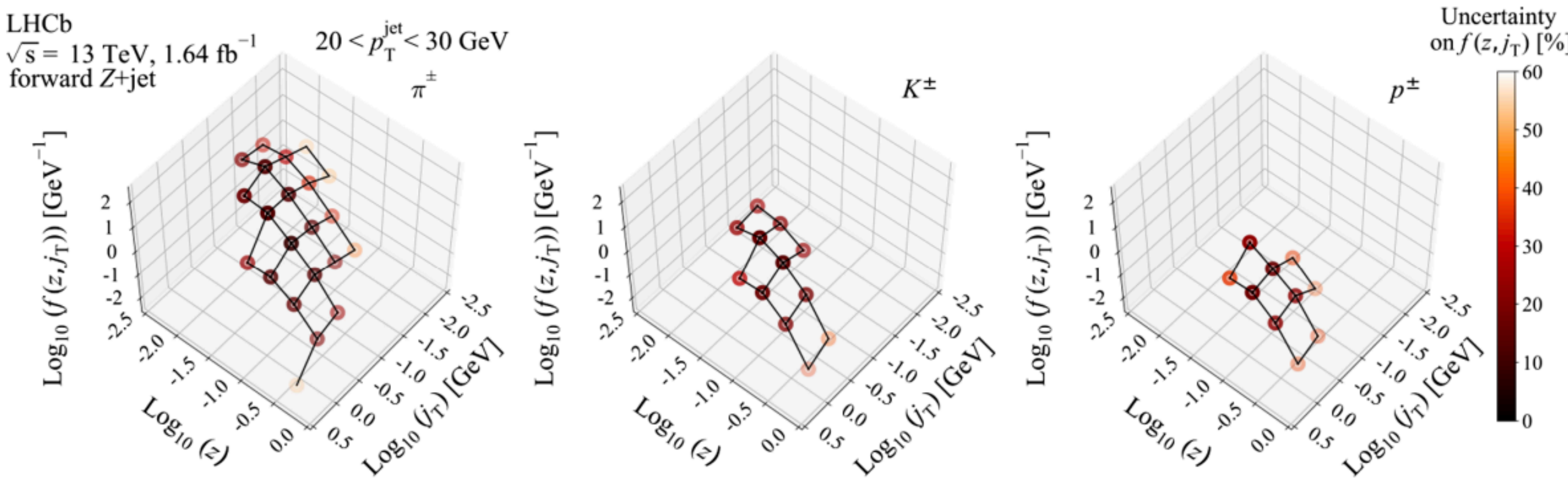
Prediction with intrinsic charm

Prediction with intrinsic charm, mean momentum fraction 1%

Z-rapidity

Z-tagged jet fragmentation functions

$$z = \frac{\mathbf{p}_{\mathrm{had}} \cdot \mathbf{p}_{\mathrm{jet}}}{|\mathbf{p}_{\mathrm{jet}}|^2}, \qquad j_{\mathrm{T}} = \frac{|\mathbf{p}_{\mathrm{had}} \times \mathbf{p}_{\mathrm{jet}}|}{|\mathbf{p}_{\mathrm{jet}}|} \qquad f(z, j_{\mathrm{T}}) = \frac{1}{N_{Z+\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{had}}(z, j_{\mathrm{T}})}{\mathrm{d}z\,\mathrm{d}j_{\mathrm{T}}}$$



PRD108, L031103 (2023)

➤ First measurement of jet fragmentation fractions for charged pions, kaons, and protons within jets recoiling against a Z boson.

➤ Charged-hadron distributions studied longitudinally + transversely to the jet direction for jets with transverse momentum 20 < pT < 100 GeV and in the pseudorapidity range 2.5 < η < 4.

UNIVERSITY OF MICHIGAN

The LHCb physics program

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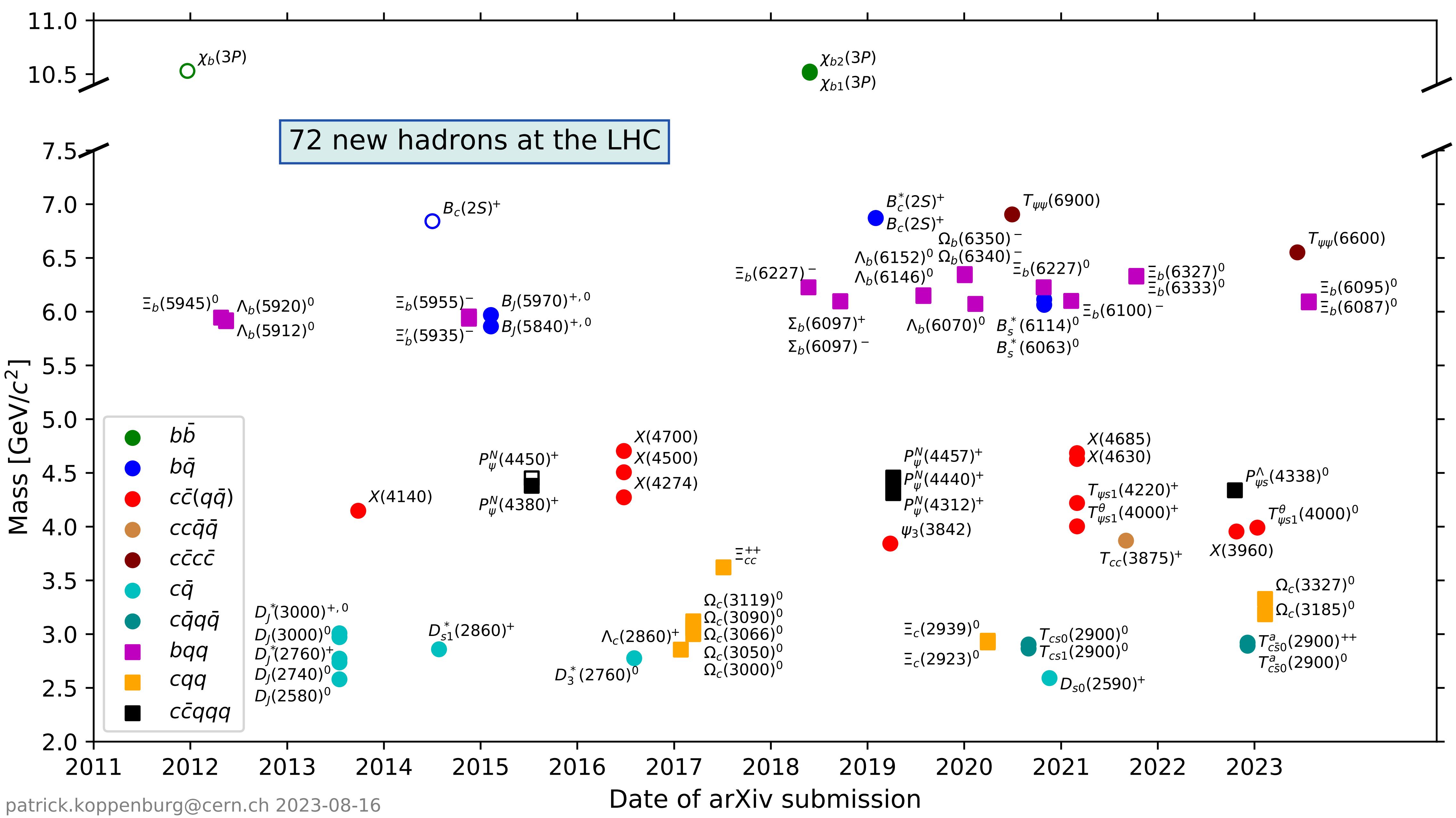
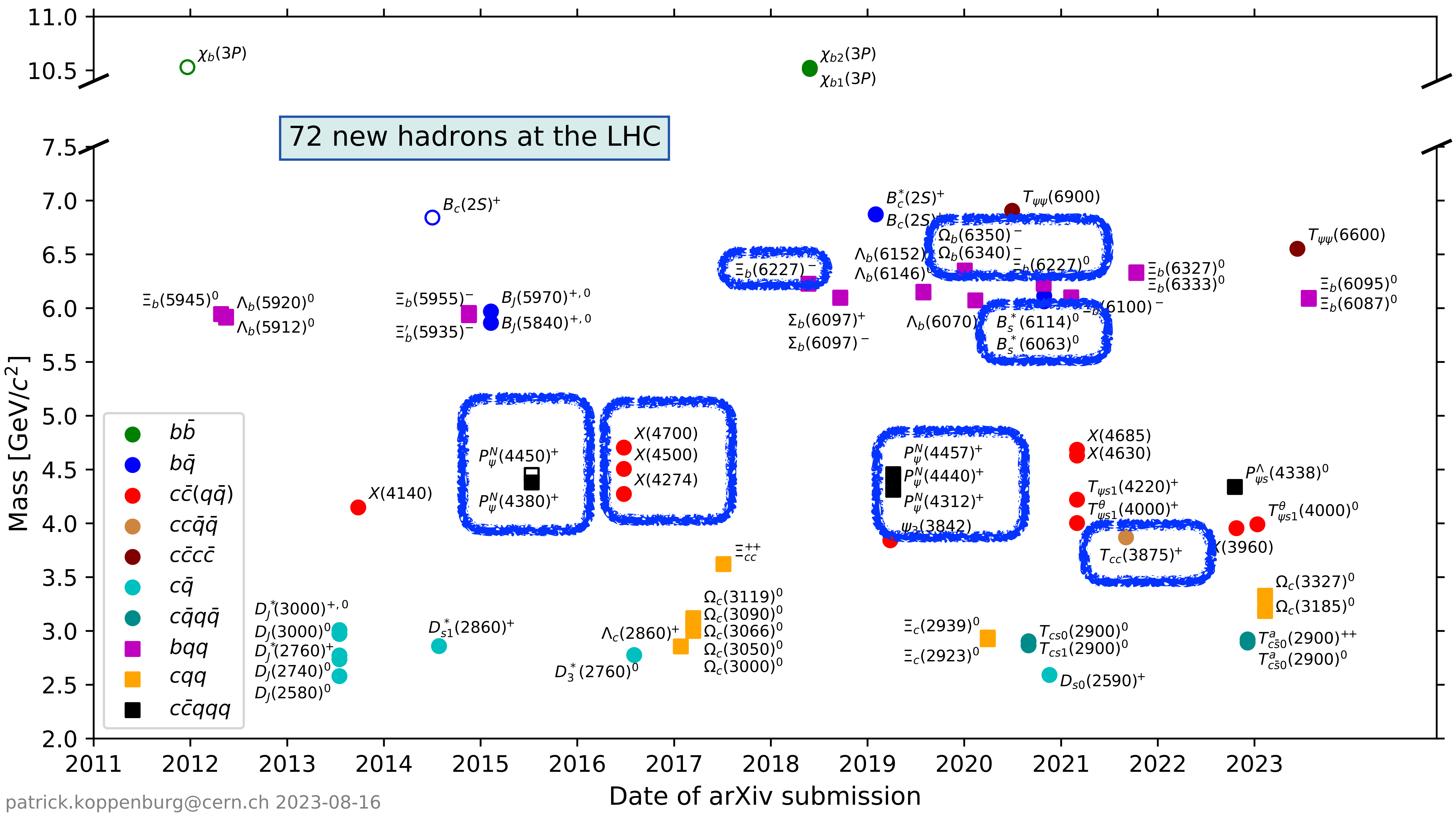
Exotic +conventional hadrons discovered at LHC



64/72 discovered by LHCb, many US-led

Syracuse University

Exotic +conventional hadrons discovered at LHC

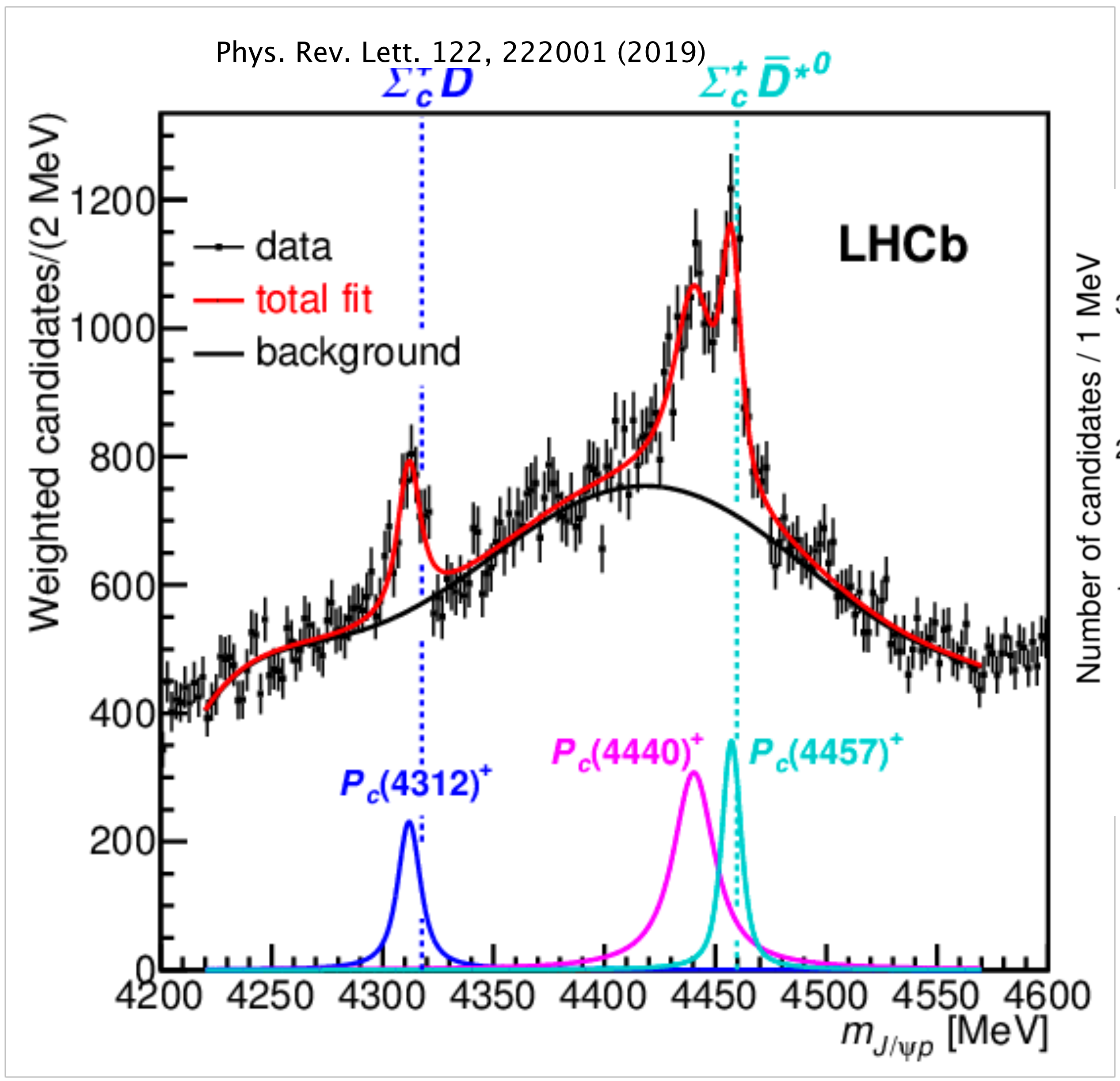


64/72 discovered by LHCb, many US-led

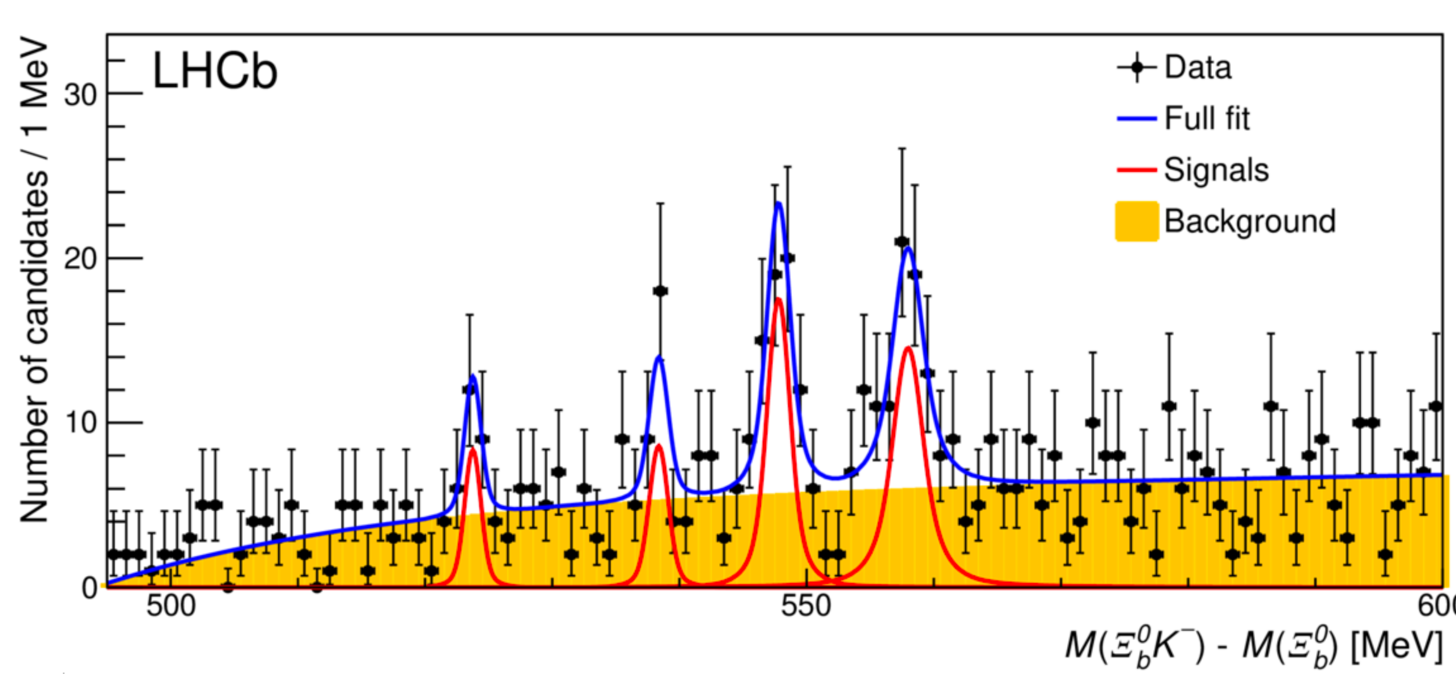
Syracuse University

Exotic +conventional hadrons discovered at LHC

Observation of new pentaquark states



Observations of four new excited Ω_b^- states



PHYS. REV. LETT. 124 (2020) 082002

Syracuse University

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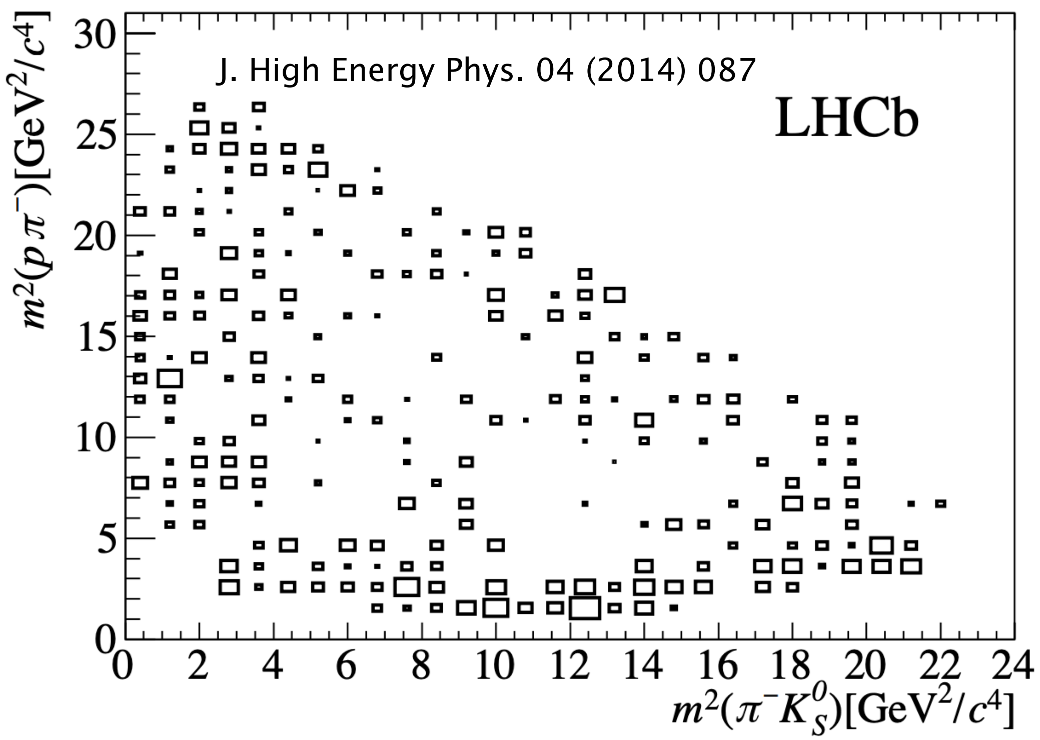
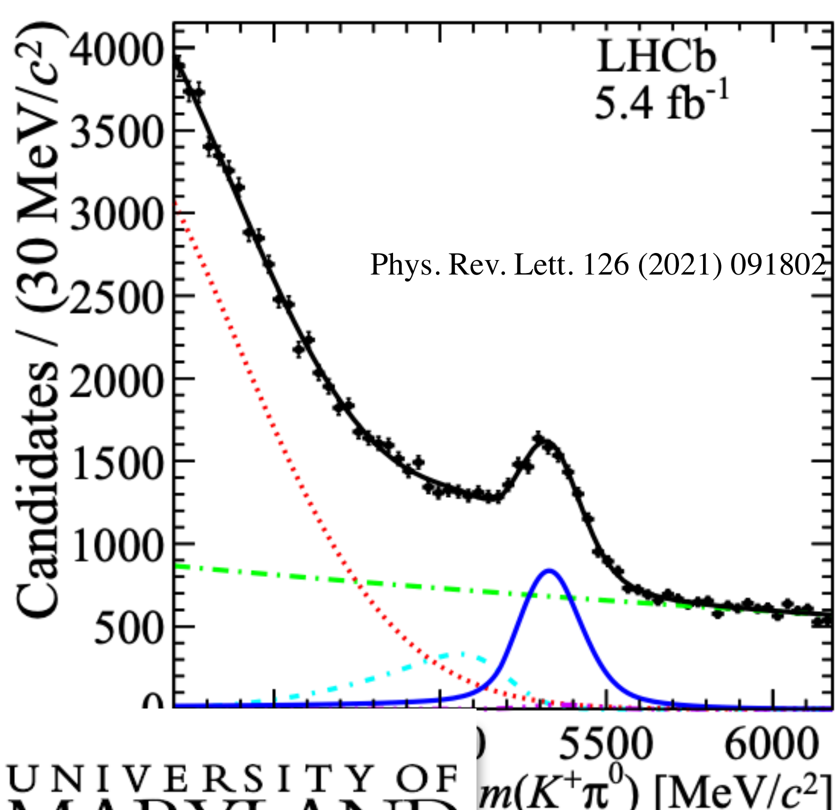
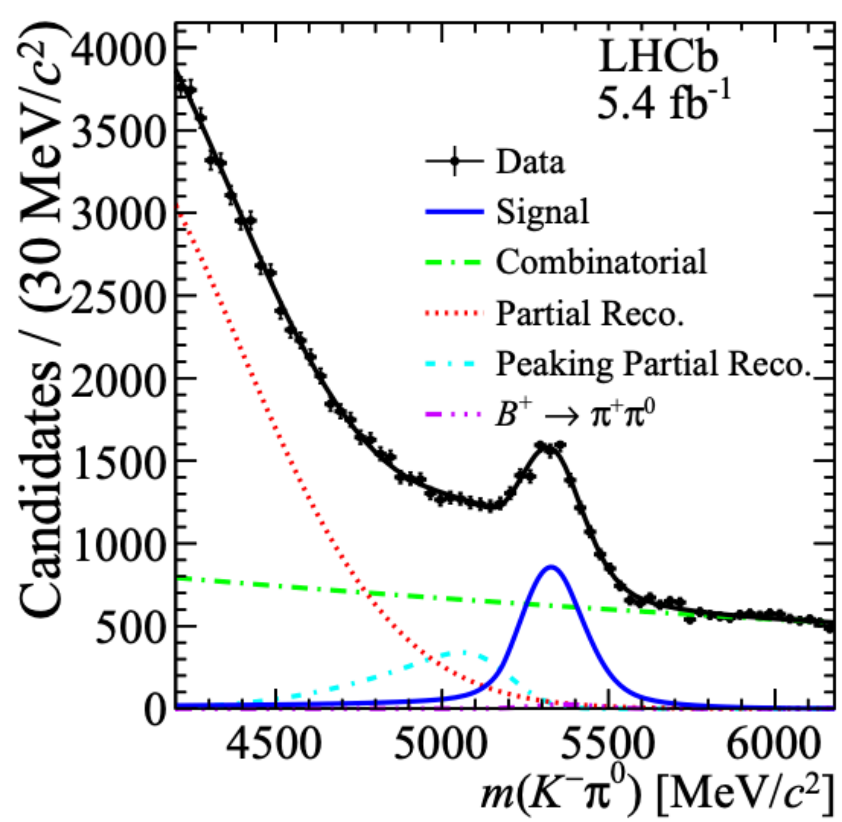
CP violation



Studies of $\Lambda_b^0 \to \bar{K}^0 p \pi^-$ baryons via measurements of integrated $A_{CP} = \dfrac{\Gamma - \bar{\Gamma}}{\Gamma + \bar{\Gamma}}$



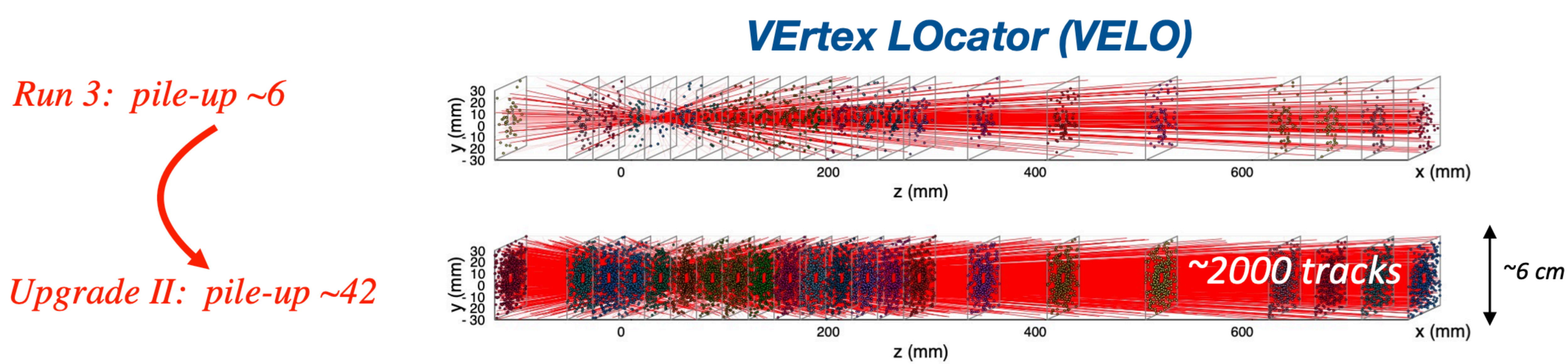


Most precise measurement of direction CP asymmetry in $B^+ \to K^+\pi^0$ →$K\pi$ puzzle

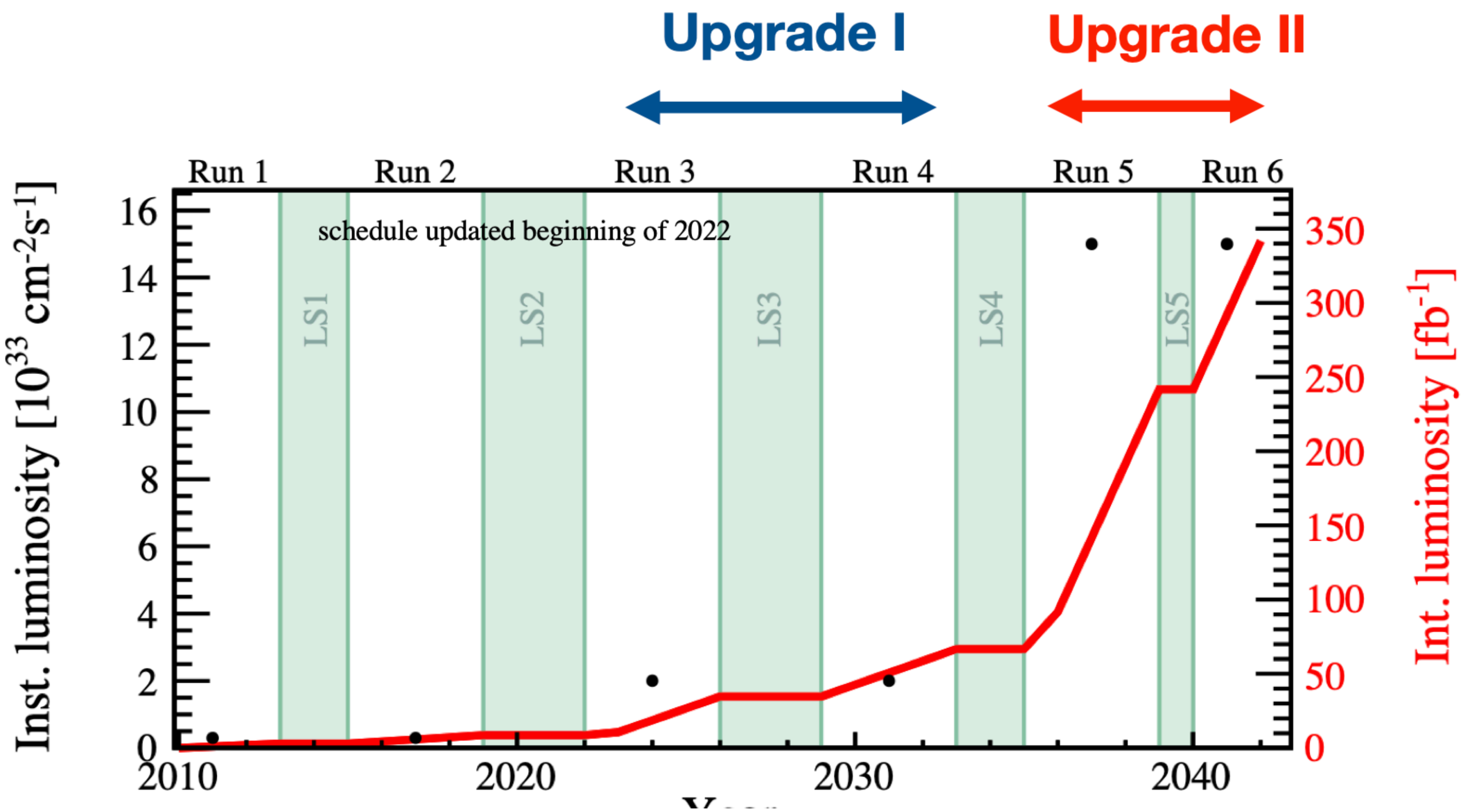
A few words on Upgrade II

Run 1&2	LS2	Run 3	LS3	Run 4	LS4	Run 5	LS5	Run ->
$\mathcal{L} = 4 \times 10^{32}/cm^2s$ $\int \mathcal{L}\,dt = 9$ fb^{-1}	LHCb Upgrade I	$\mathcal{L} = 2 \times 10^{33}/cm^2s$ $\int \mathcal{L}\,dt \approx 23$ fb^{-1}	LHCb Upgrade Ib	$\mathcal{L} = 2 \times 10^{33}/cm^2s$ $\int \mathcal{L}\,dt \approx 50$ fb^{-1}	LHCb Upgrade II	$\mathcal{L} = 2 \times 10^{34}/cm^2s$		$\int \mathcal{L}\,dt \approx 300$ fb^{-1}
2011-2018	2019-2021	2022-2024	2025-2027	2028-2030	2031	2032-2034	2035	2036->

- By end of Upgrade I many observables will still be inaccessible or statistics-limited: **Upgrade II needed to realise full physics potential**
- TDR for Upgrade II released (2021), R&D programmed approved (2022), sub-detector TDRs expected ~ 2026
- Aiming for same performance as Run 3 but with ~40 (as opposed to ~6) pile-up (!)



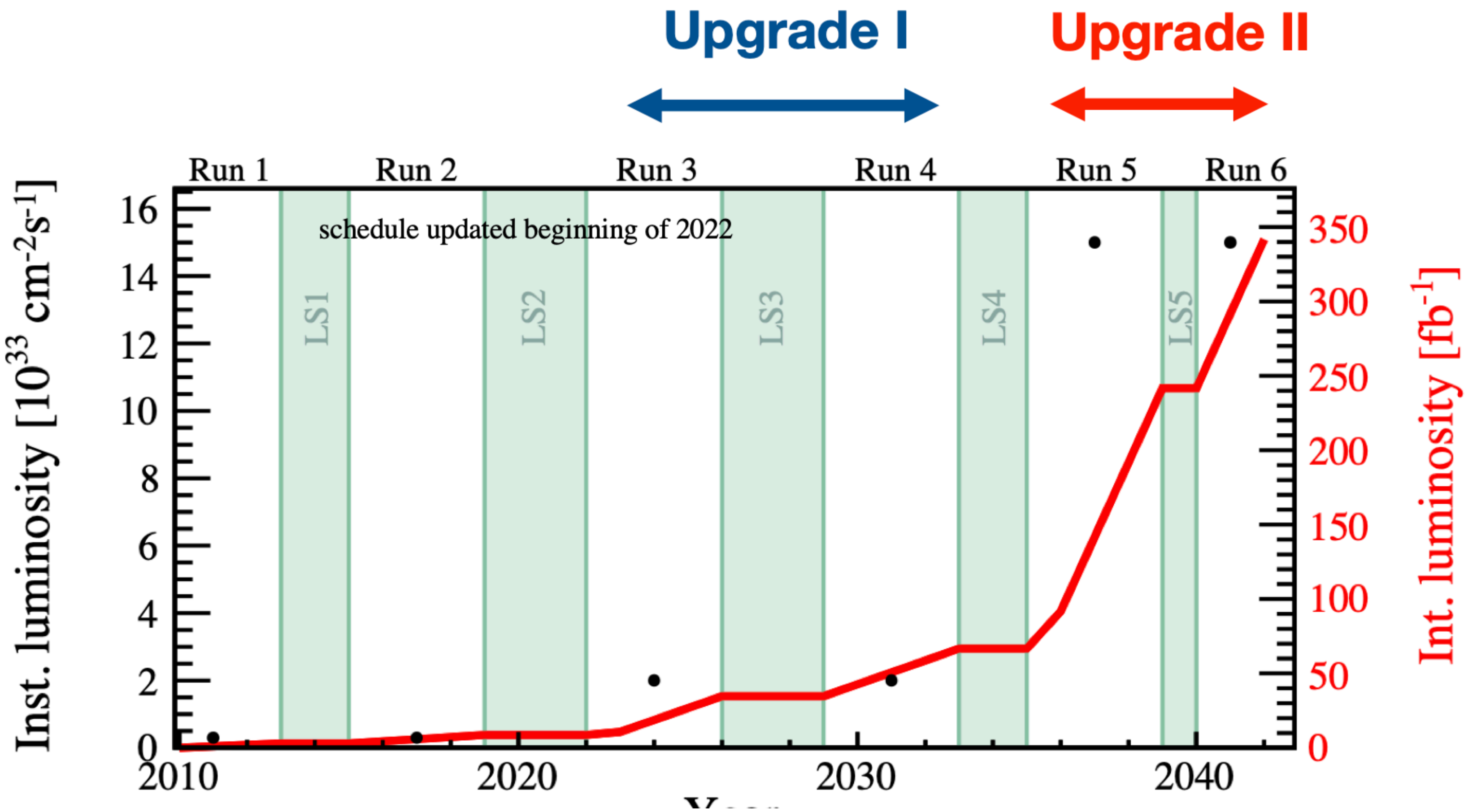
A few words on Upgrade II



Upgrade II requirements:

- Better granularity
- Fast timing (tens of ps)
- Radiation hardness

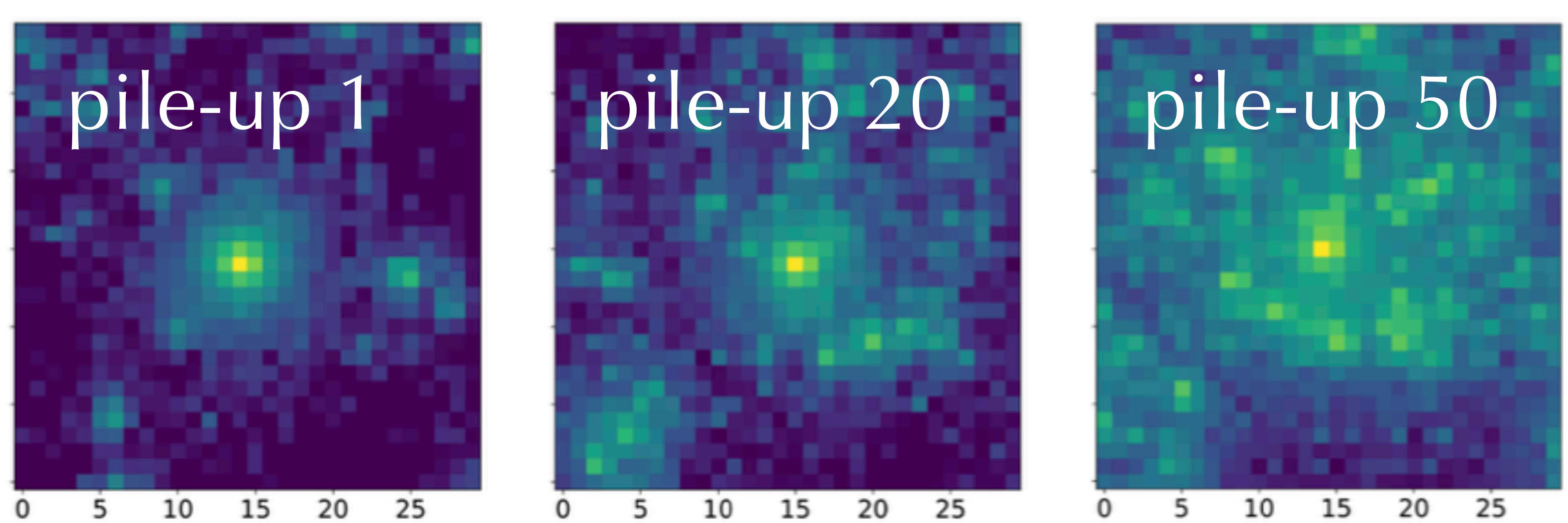
A few words on Upgrade II



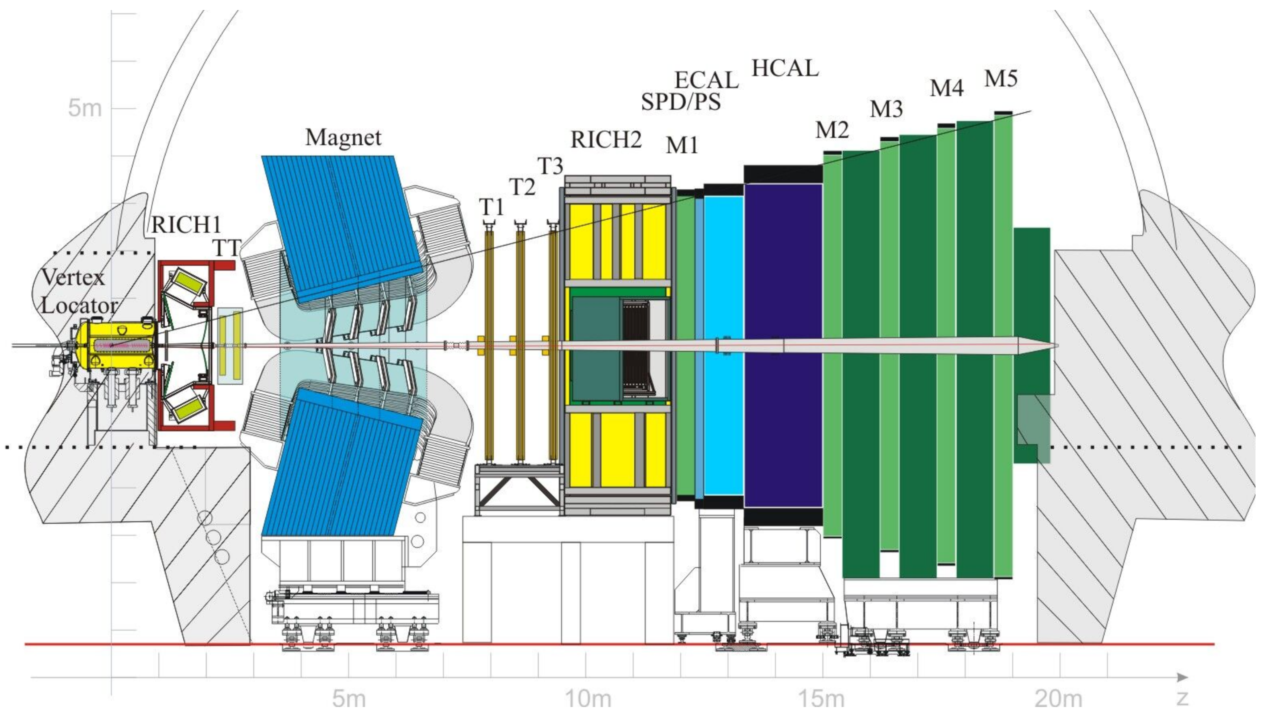
Upgrade II requirements:

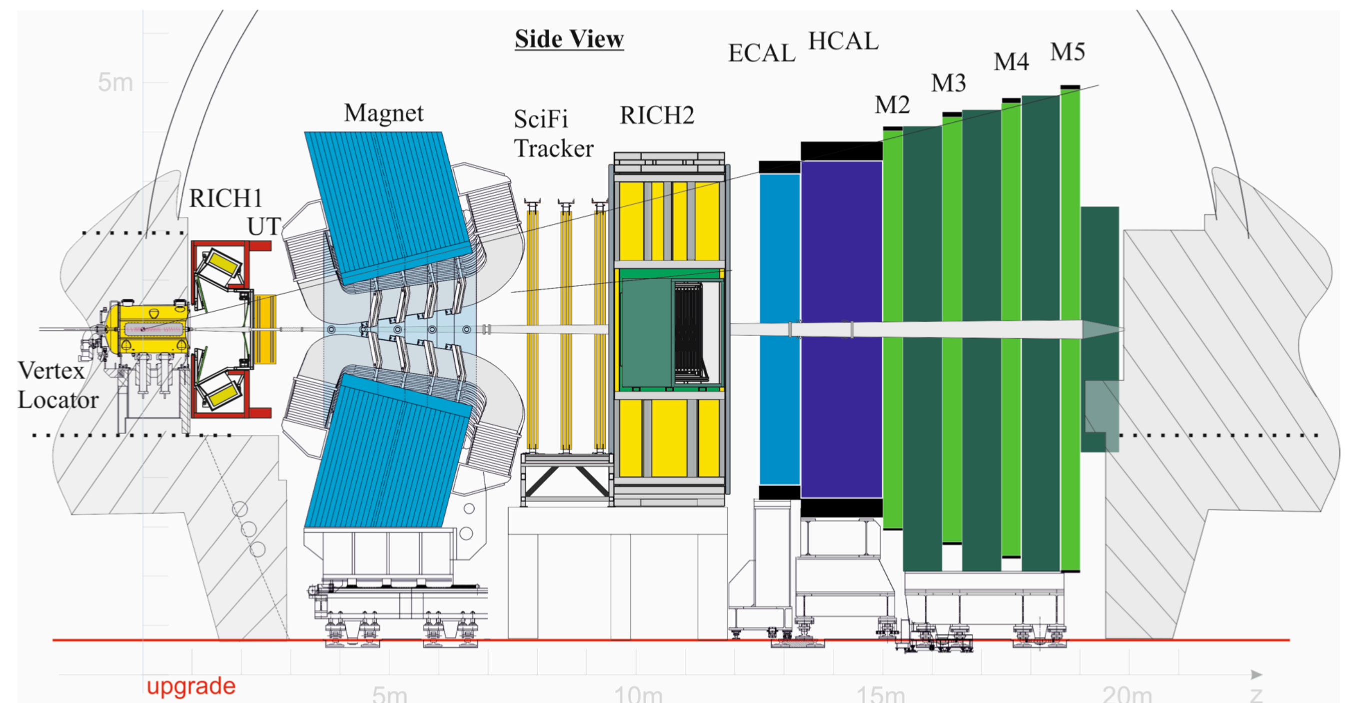
- Better granularity
- Fast timing (tens of ps)
- Radiation hardness

- Likely only general purpose flavour-facility on this time-scale
- US-led effort for R&D into ECAL (Spaghetti Calorimeter with timing)



Conclusions





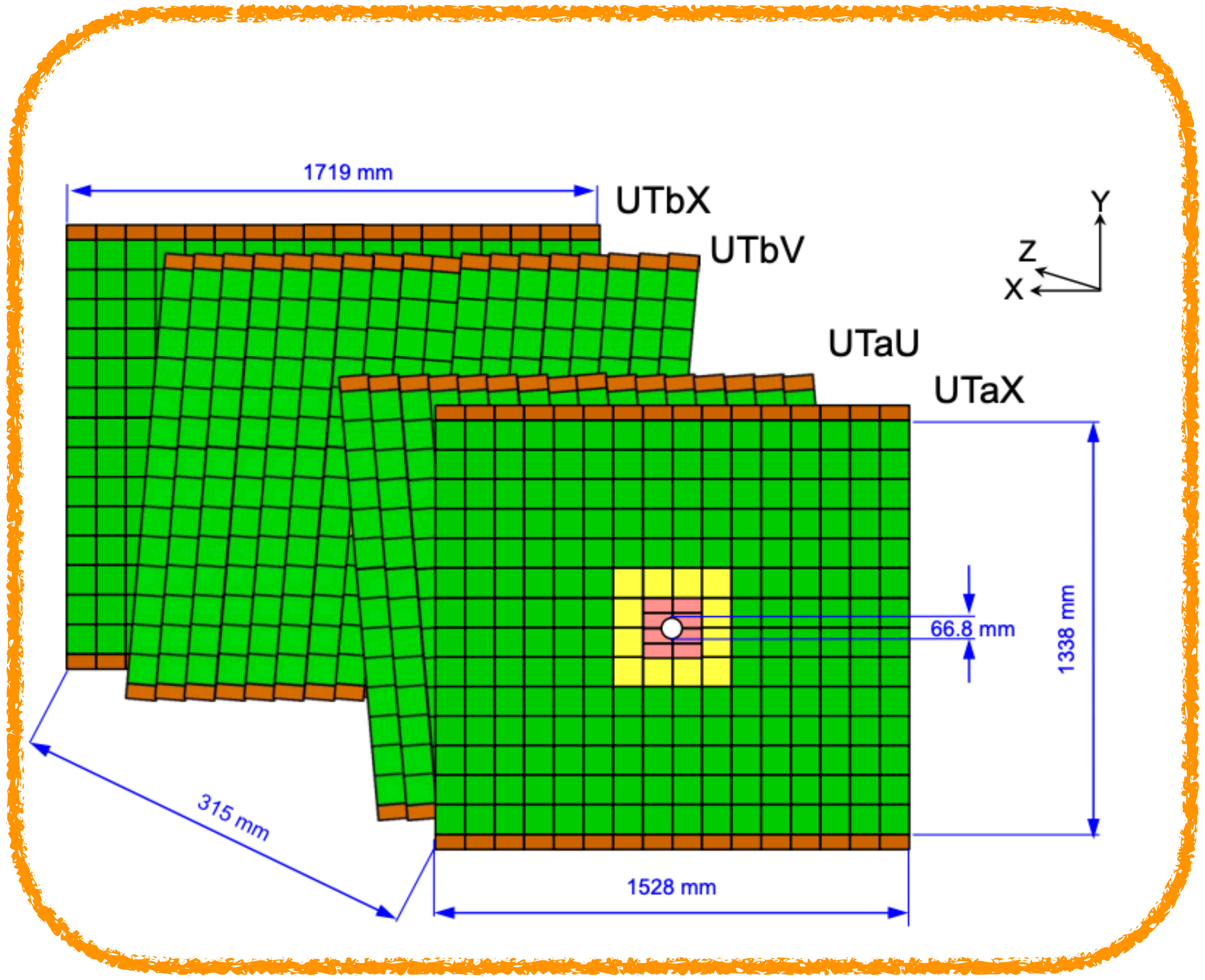
LHCb (2011-2018) → LHCb Upgrade I (2022-2032)

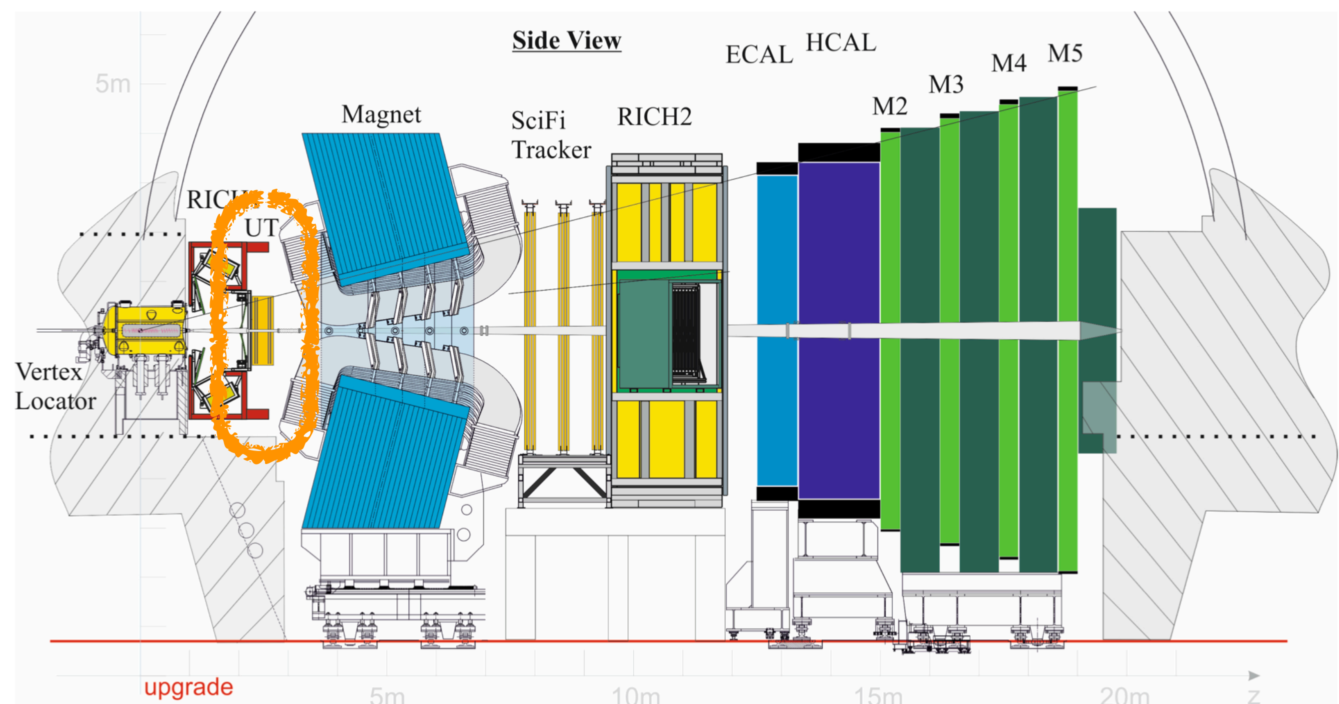
LHCb 'original' has surpassed expectations, producing leading results in wide range of physics programs (*many* not covered today)

Run 3 has started and commissioning is underway!

Expect significant gains from increased lumi + upgraded detector and trigger system

Upstream Tracker





Silicon-strip detector sitting just before magnet

Longer lived particles decay past end of VELO, UT allows for their momentum to be measured + improves the track resolution of particles decaying inside velo

LHCb Upgrade I

- Lumi increase means that ~24% (2%) of events will have a reconstructable $c\bar{c}$ ($b\bar{b}$) pair

- Significant efficiency gains, particularly for low-PT hadrons + electrons

Signal	GEC	TIS -OR- TOS	TOS	GEC $\times$ TOS
$B^0 \to K^{*0}\mu^+\mu^-$	88.9 ± 2.0	90.6 ± 2.0	88.8 ± 2.1	79.0 ± 2.6
$B^0 \to K^{*0}e^+e^-$	84.2 ± 2.7	69.1 ± 3.8	61.7 ± 4.0	52.0 ± 3.8
$B^0_s \to \phi\phi$	83.2 ± 2.6	75.8 ± 3.2	68.5 ± 3.5	57.0 ± 3.4
$D^+_s \to K^+K^-\pi^+$	82.5 ± 3.6	58.5 ± 5.1	42.6 ± 5.1	35.1 ± 4.5
$Z \to \mu^+\mu^-$	77.8 ± 1.2	99.5 ± 0.2	99.5 ± 0.2	77.4 ± 1.2

HLT1 (software trigger) selection efficiency

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