Highlights from LHCb

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CNRS/LPNHE

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LHCb – a forward detector @ LHC

JINST 19 (2024) P05065
See G. Cavallero @ T12
See M. Ruiz Diaz @ T12
See W. Krupa @ T11
See F. Borgato @ T11

Key detector physics drivers (for upgraded detector)

Vertex resolution

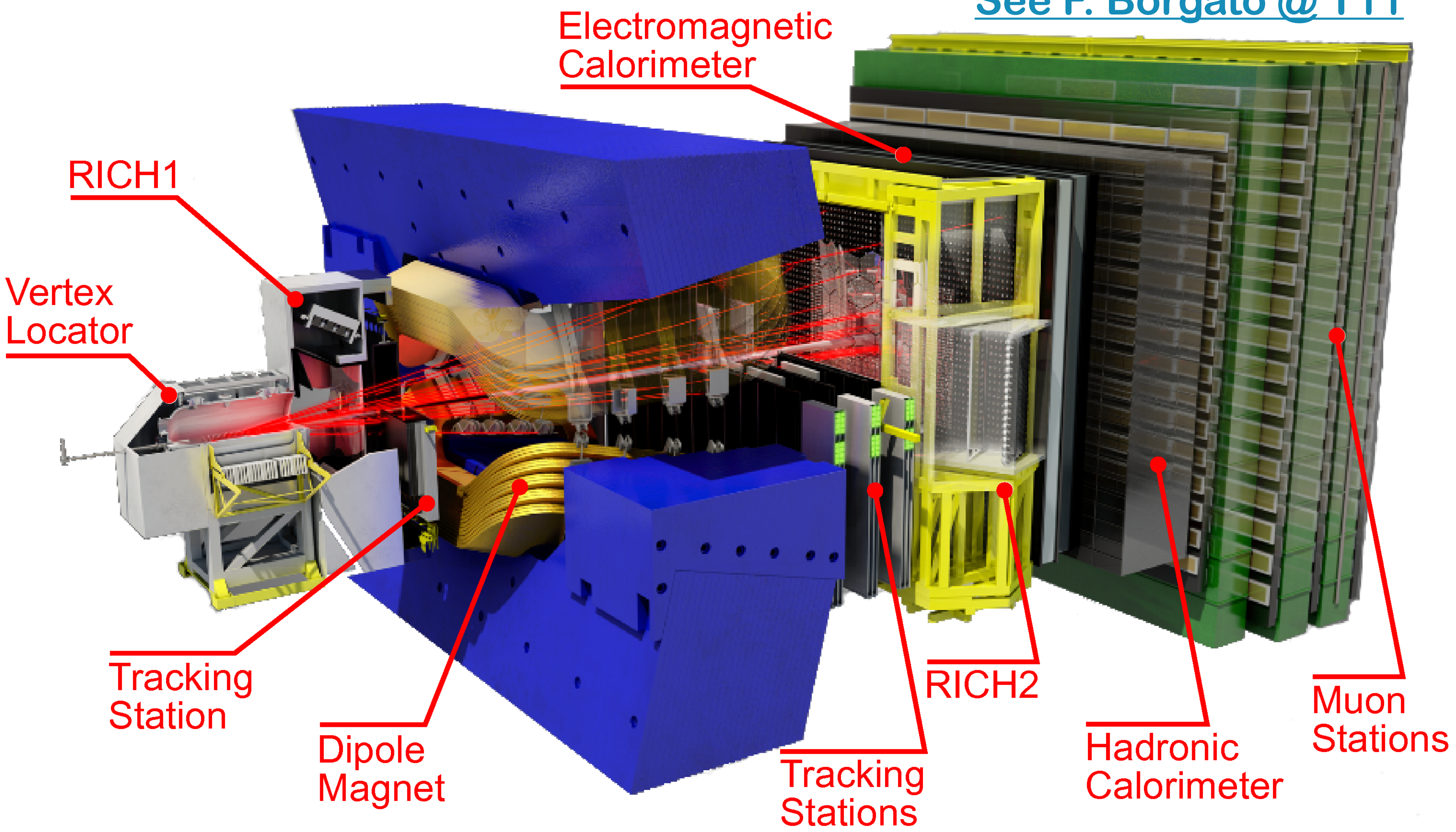
$\sigma_{IP} \sim 19\ \mu m$ @ $p_T = 2$ GeV

Particle ID

$\varepsilon(K\rightarrow K) \sim 95\%$ @ 4% misID

Momentum resolution

σ_p/p 0.45% – 1.1% @ p = 2 – 200 GeV



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LHCb – past, present, and future

Run 1				LS1		Run 2				LS2			Run 3					LS3			Run 4				LS4		Run 5					
2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
3 fb^{-1}						9 fb^{-1}							23 fb^{-1}								50 fb^{-1}						>300 fb^{-1}					

31113111111113333131333313331313131311131331113133133133333131333313133313131311133133333313333313331111311311133133313333113113313133133113111333

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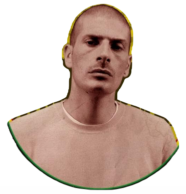

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2009 2010 2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022 2023 2024 2025 2026	2027 2028 2029	2030 2031 2032 2033	2034 2035	2036 2037 2038 2039 2040 2041
3 fb^{-1}		9 fb^{-1}		23 fb^{-1}		50 fb^{-1}		>300 fb^{-1}

The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

LHCb – past, present, and future

Align and calibrate detector in quasi-real time, full detector reconstruction and pileup suppression in trigger

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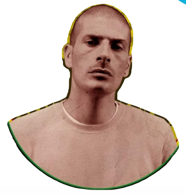

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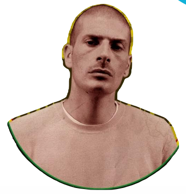
Greatly improved tracker & PID granularity, 30 MHz detector readout & GPU trigger performing a near-full detector reconstruction

LHCb – past, present, and future

Align and calibrate detector in quasi-real time, full detector reconstruction and pileup suppression in trigger

Enhance PID with precise timing and improved granularity, explore enhanced readout boards with fast tracking



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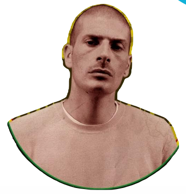



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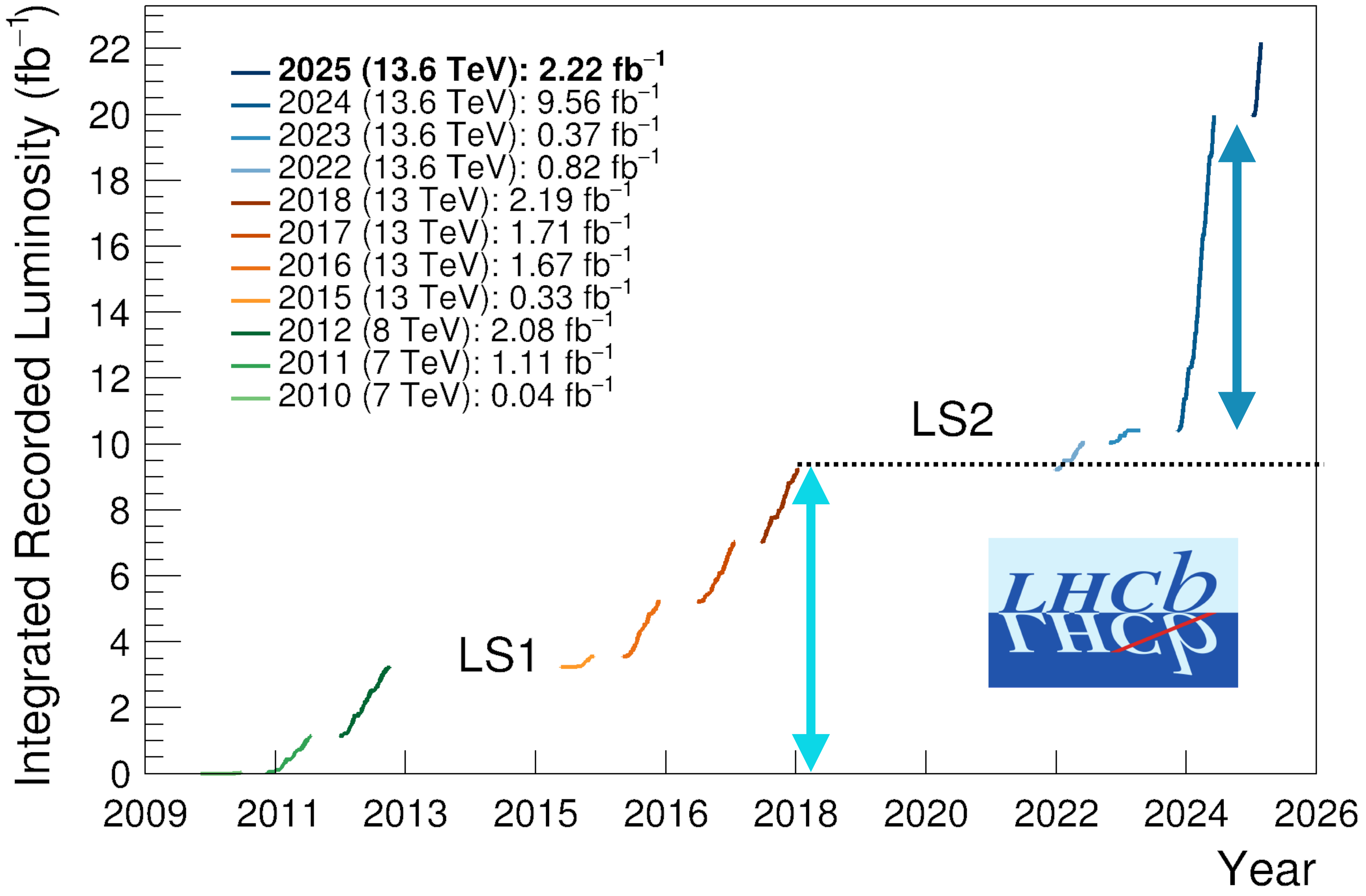
The forward flavour detector concept works! Many world-best measurements. Pioneering use of quantised and unbiasing ML algorithms in real time and offline.

Greatly improved tracker & PID granularity, 30 MHz detector readout & GPU trigger performing a near-full detector reconstruction

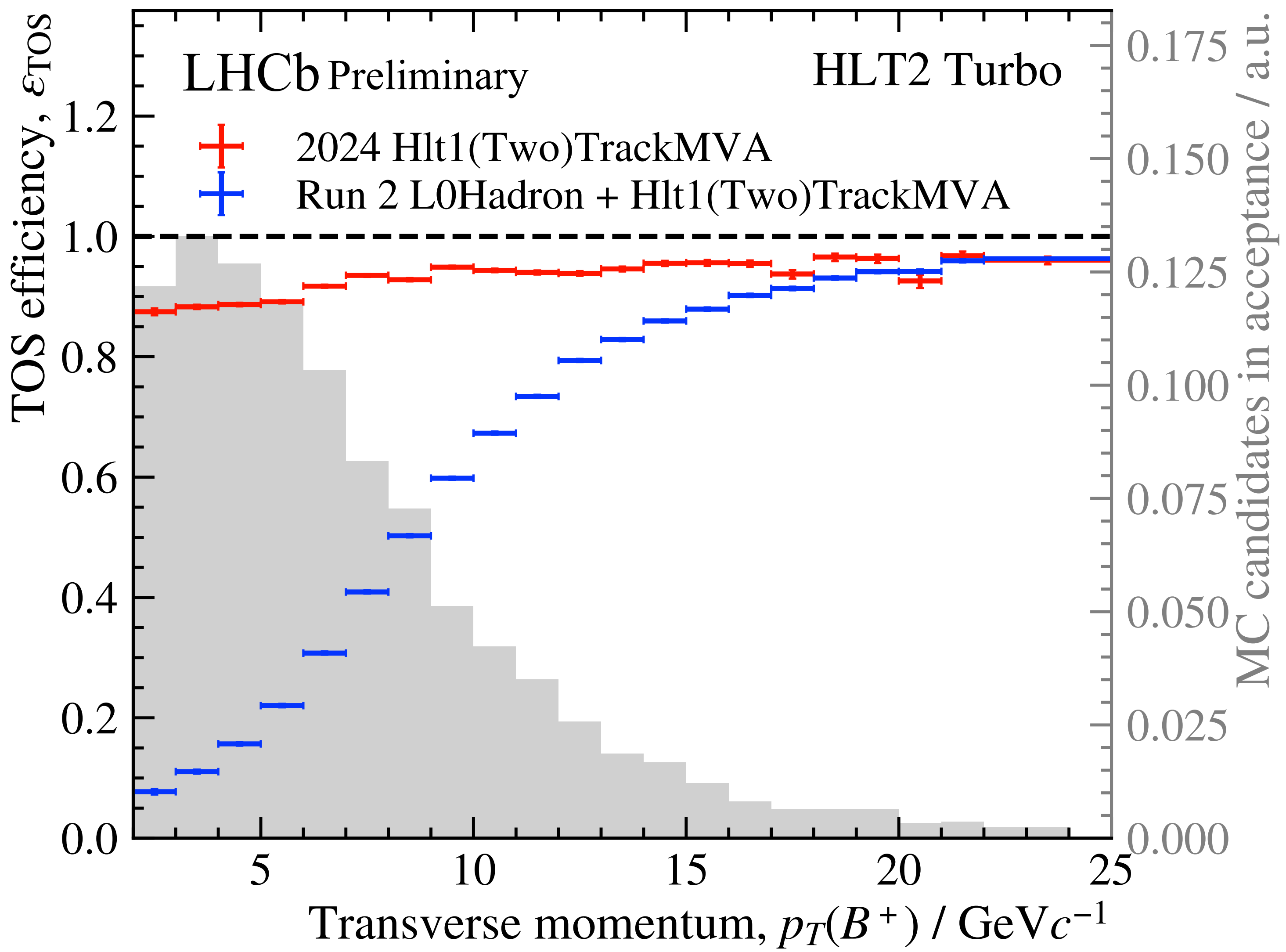
Deploy 4D tracking, PID, and calorimetry + a highly granular pixel tracker to be processed by a heterogenous trigger

LHCb in Run 3: twice doubled data

See D. vom Bruch @ T12



LHCb-FIGURE-2024-030



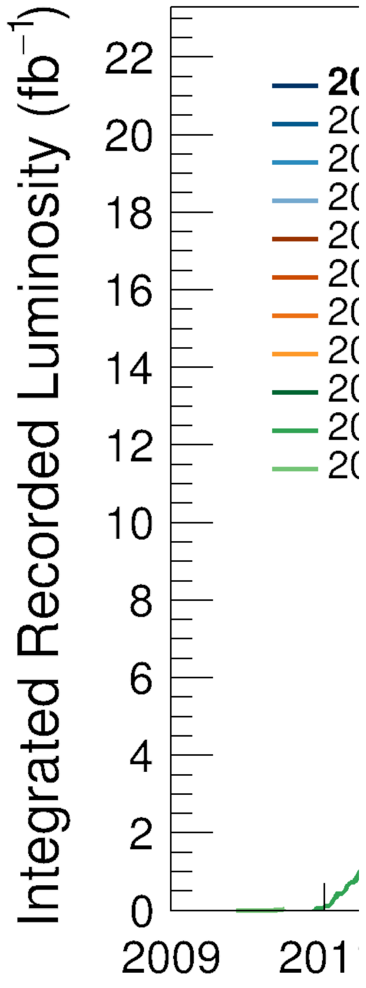
Doubled the recorded integrated luminosity thanks to excellent detector&LHC performance

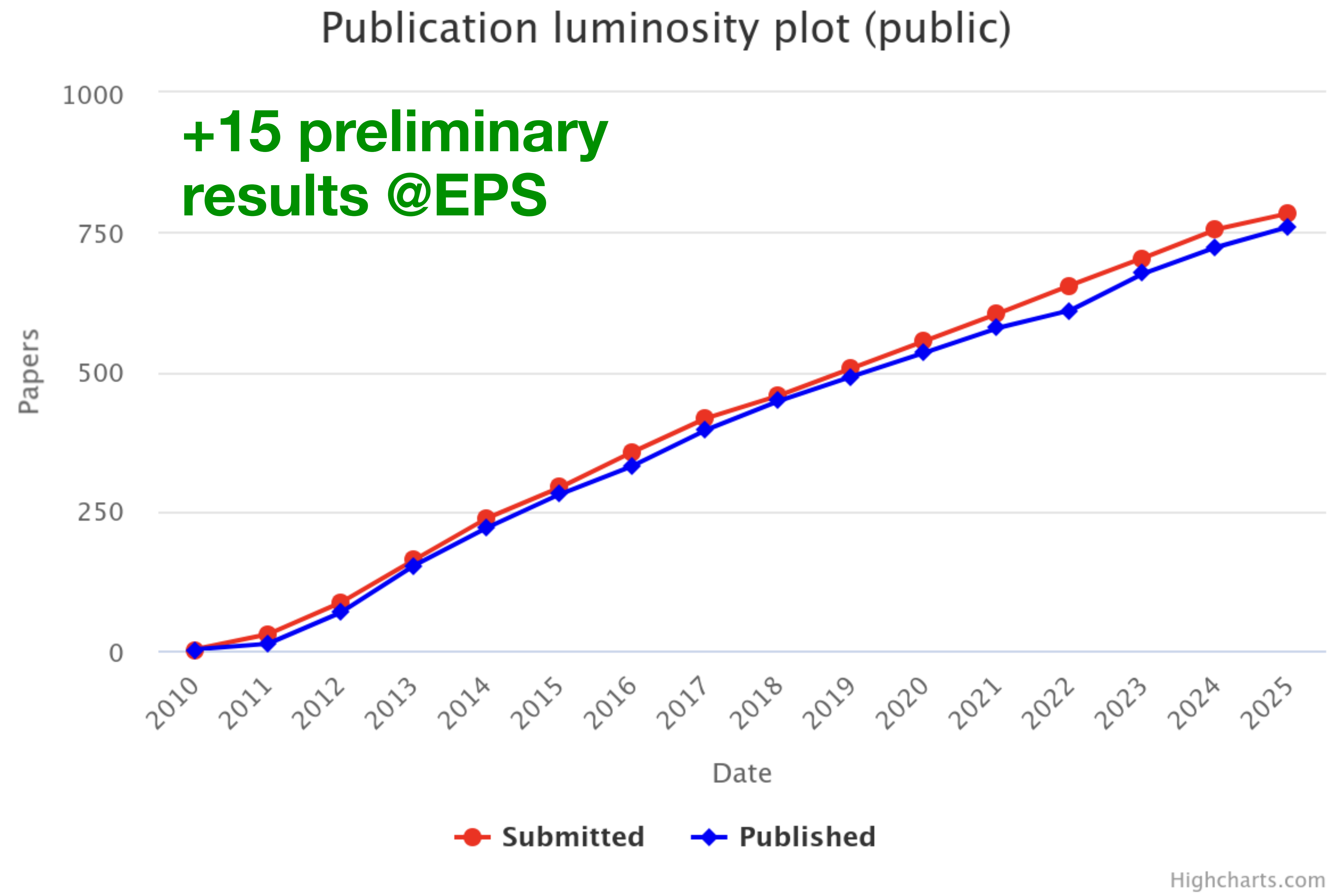
More than doubled the efficiency for hadronic signals thanks to 30 MHz GPU tracking trigger

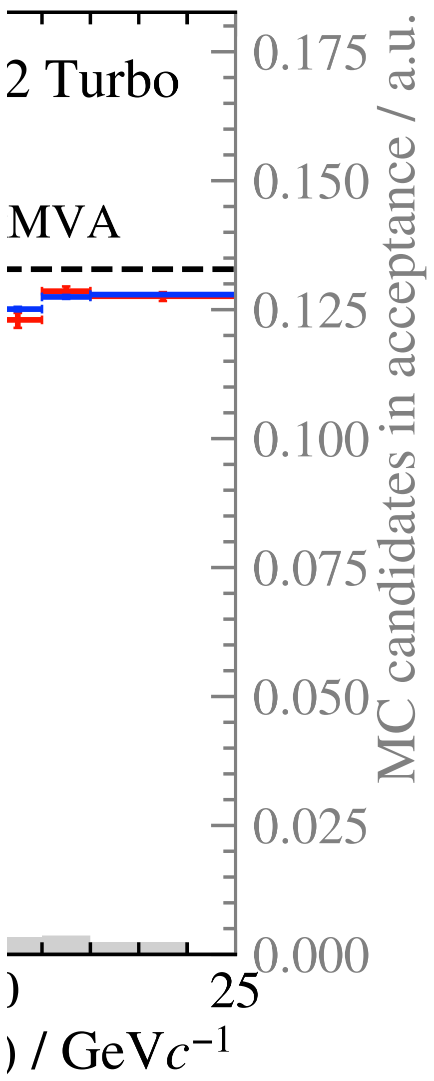
After some tough years a fast start to 2025 datataking with excellent detector efficiency

LHCb in Run 3: twice doubled data

. vom Bruch @ T12





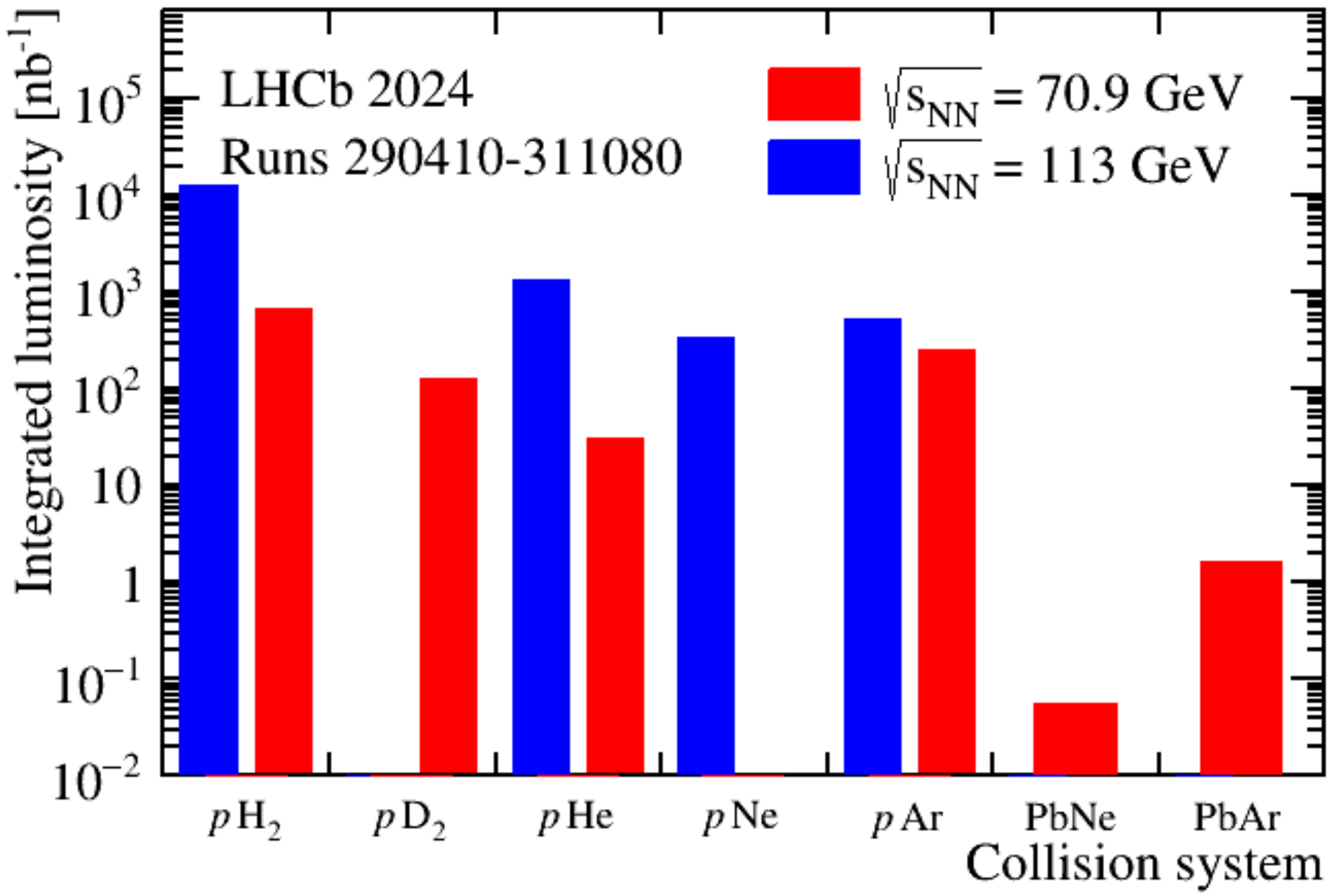


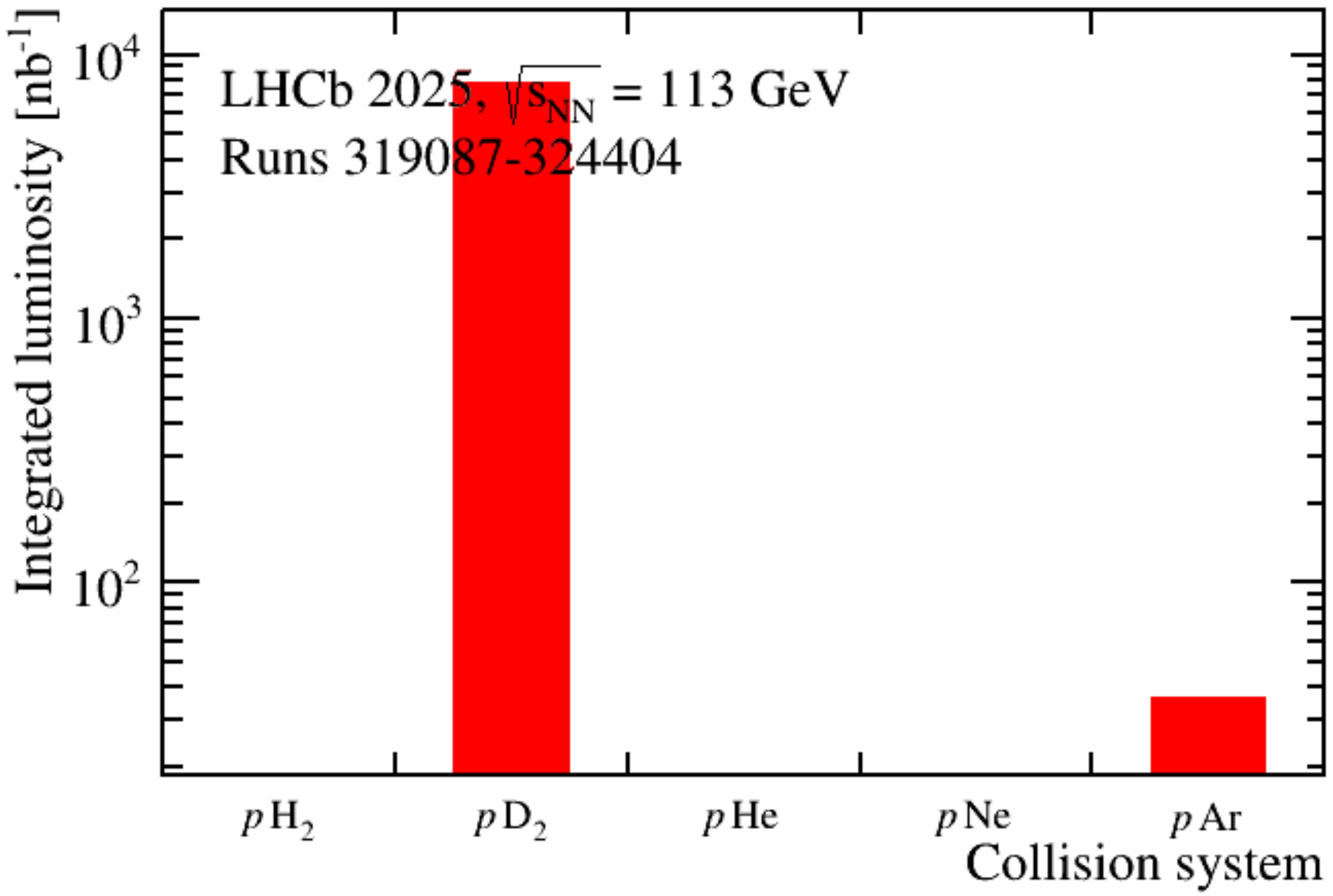
Doubled the ... erformance

More than do ... cking trigger

After some to ... fficiency

LHCb in Run 3: collider and fixed target!





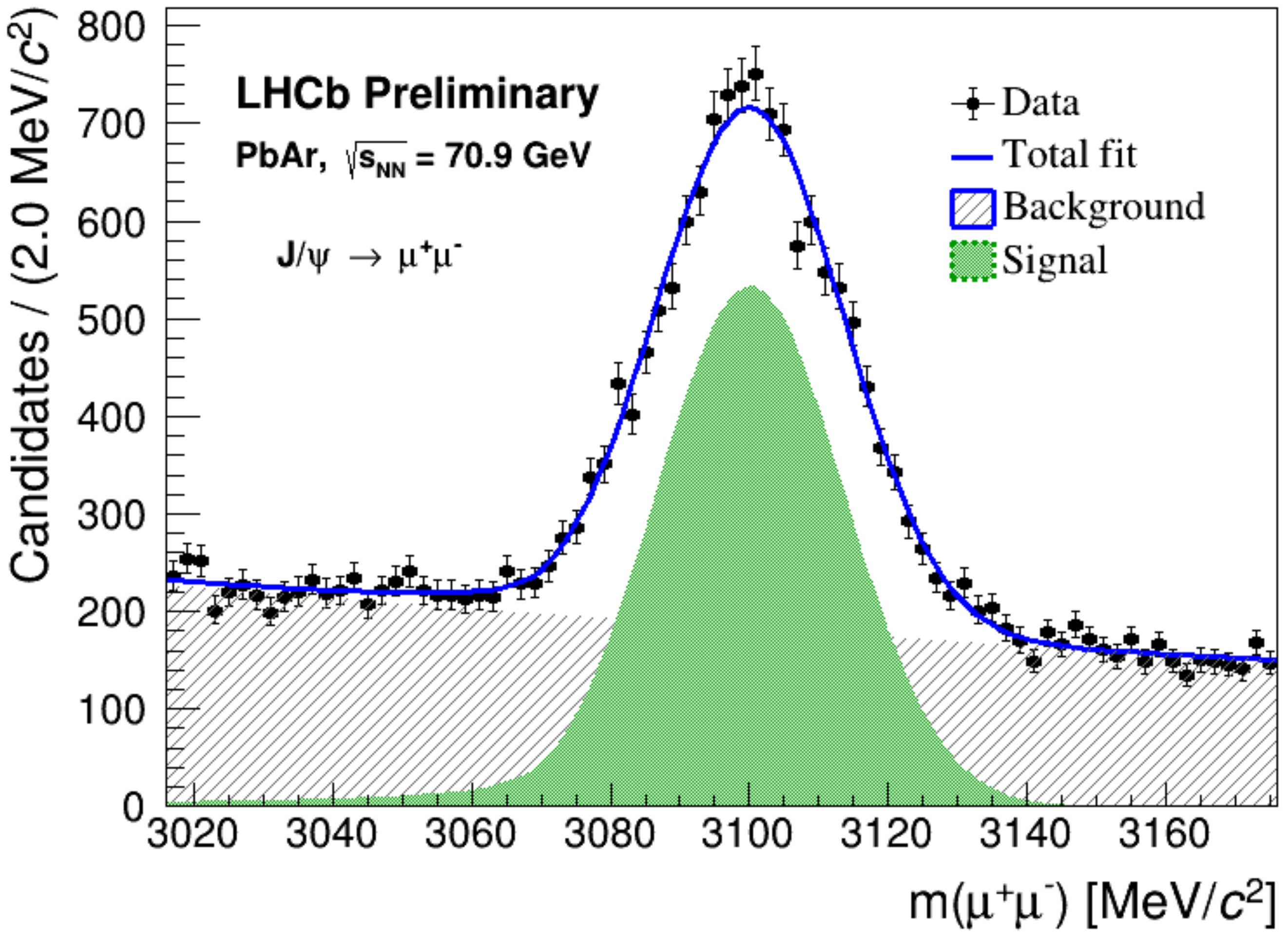
LHCb is both a collider-mode and a fixed target experiment!

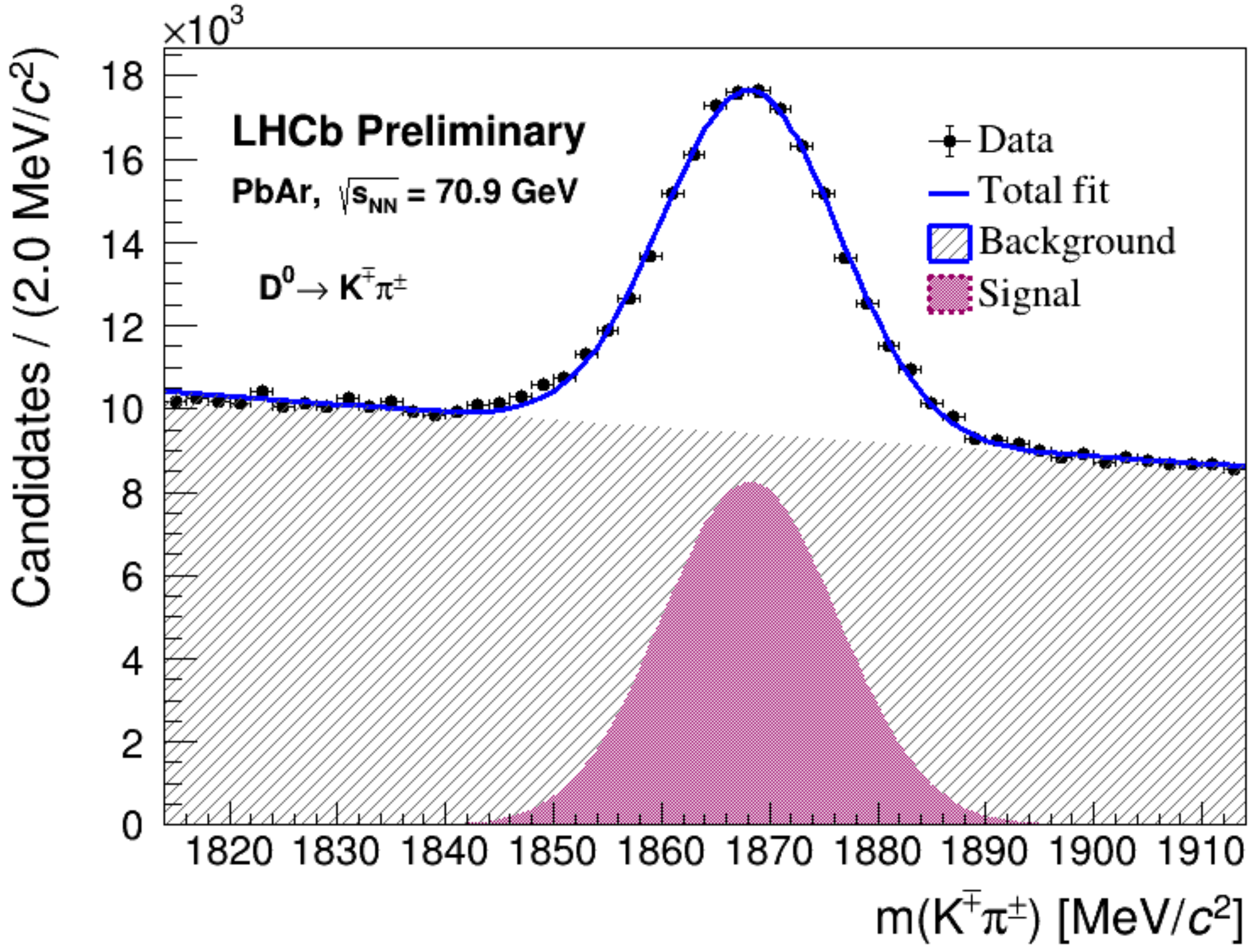
The success of the SMOG2 cell and the operational flexibility of the full software trigger enable LHCb to conduct a tremendously broad program of fixed-target physics

Lead fixed-target signals in Run 3 data

NEW!

LHCb-FIGURE-2025-014
See J. Authier @ T04





Efficient reconstruction of PbAr signals at √s=70.9 GeV

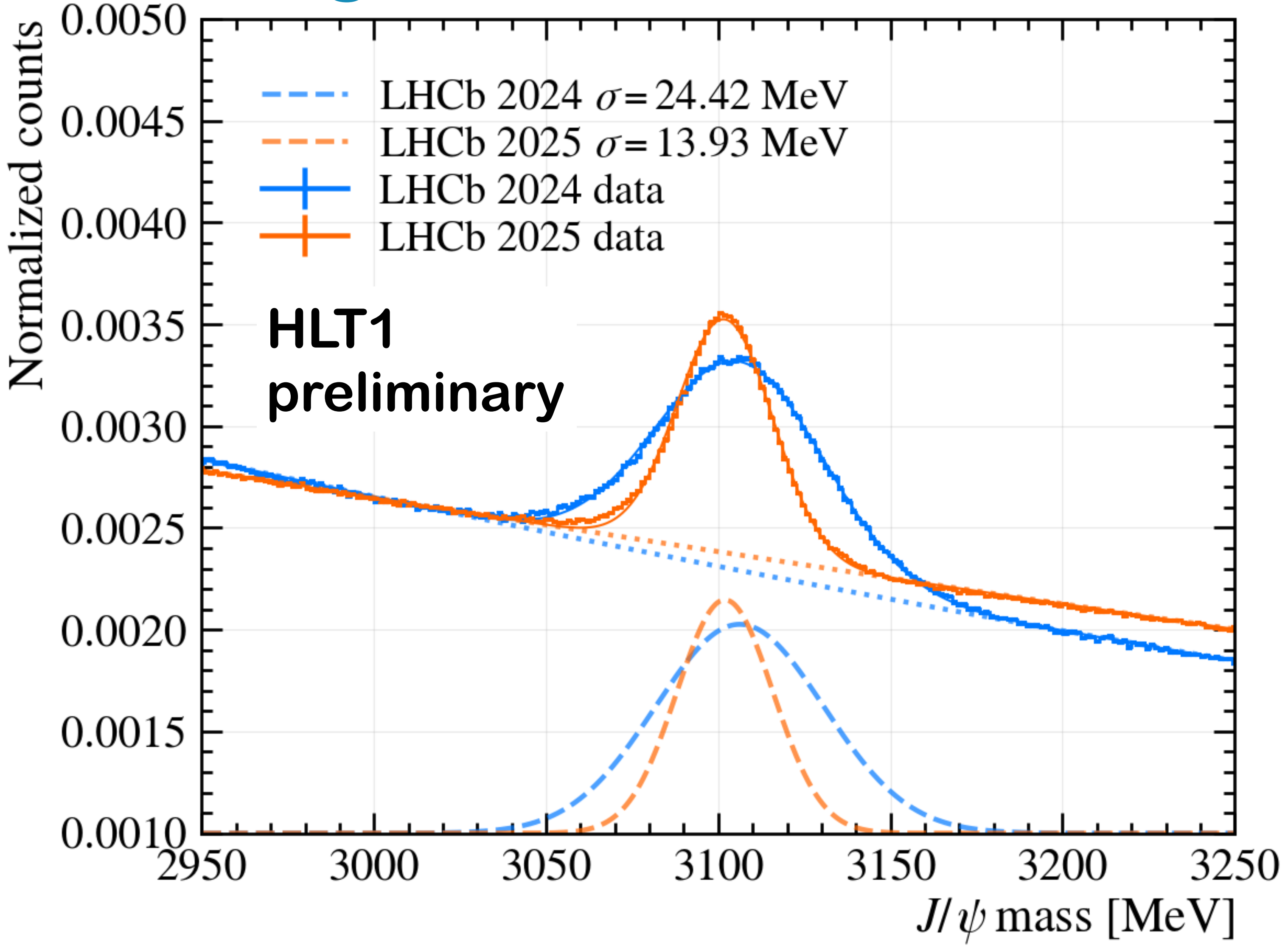
Cross-section measurements with this and other configurations are on their way

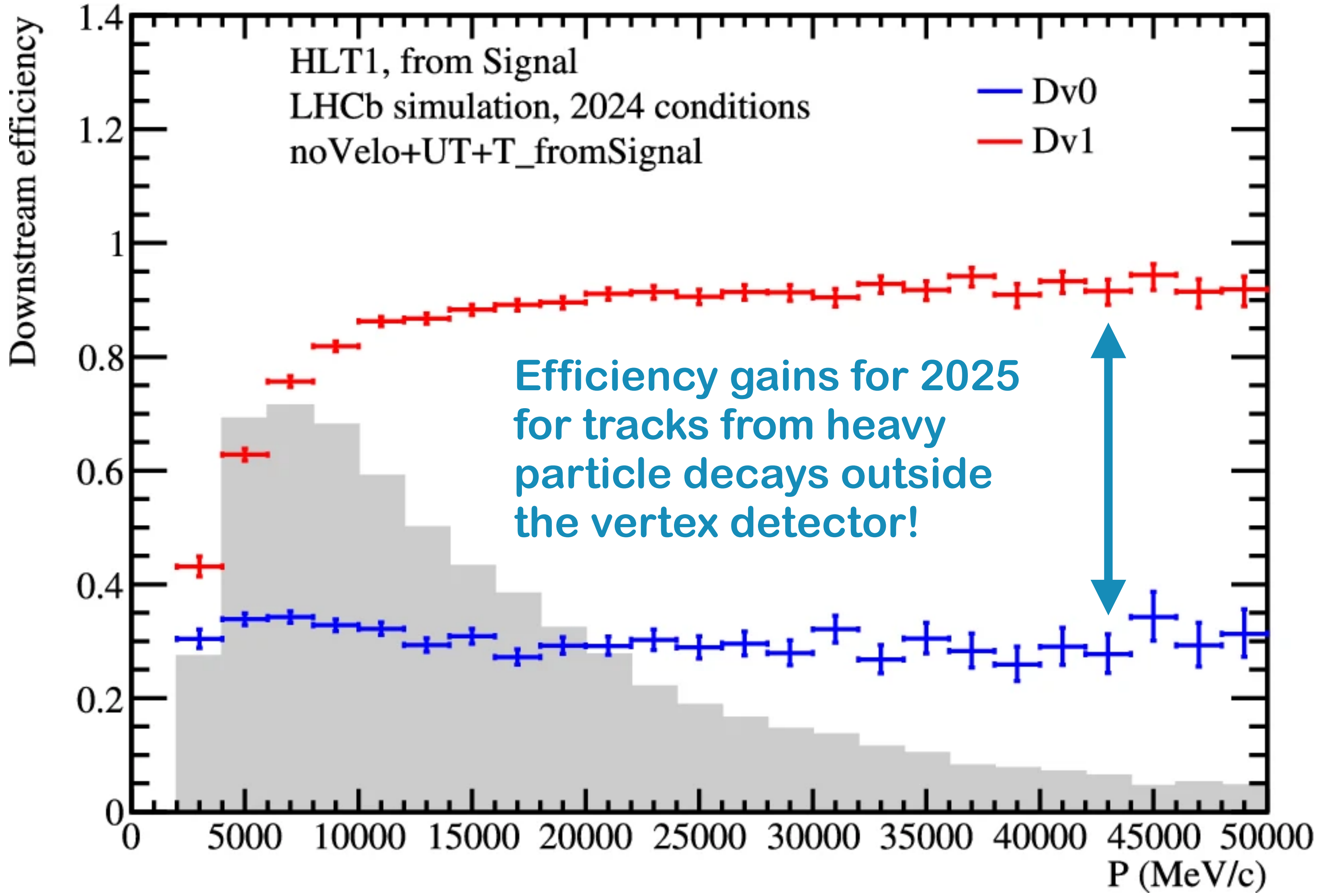
Towards a full 30 MHz reconstruction

See D. vom Bruch @ T12
See J. Zhuo @ T09
See S. Libralon @ T09

NEW!

Kholoimov et al. CSBS Volume 9, article number 10, (2025)





We now reconstruct tracks originating anywhere in the detector and Kalman fit them at 30 MHz

Together with CALO and Muon ID goes far beyond TDR design! Cost neutral because of GPUs.

Achieved by delivering a production-grade heterogeneous framework from scratch in 4 years.

Towards a full 30 MHz reconstruction

See D. vom Bruch @ T12
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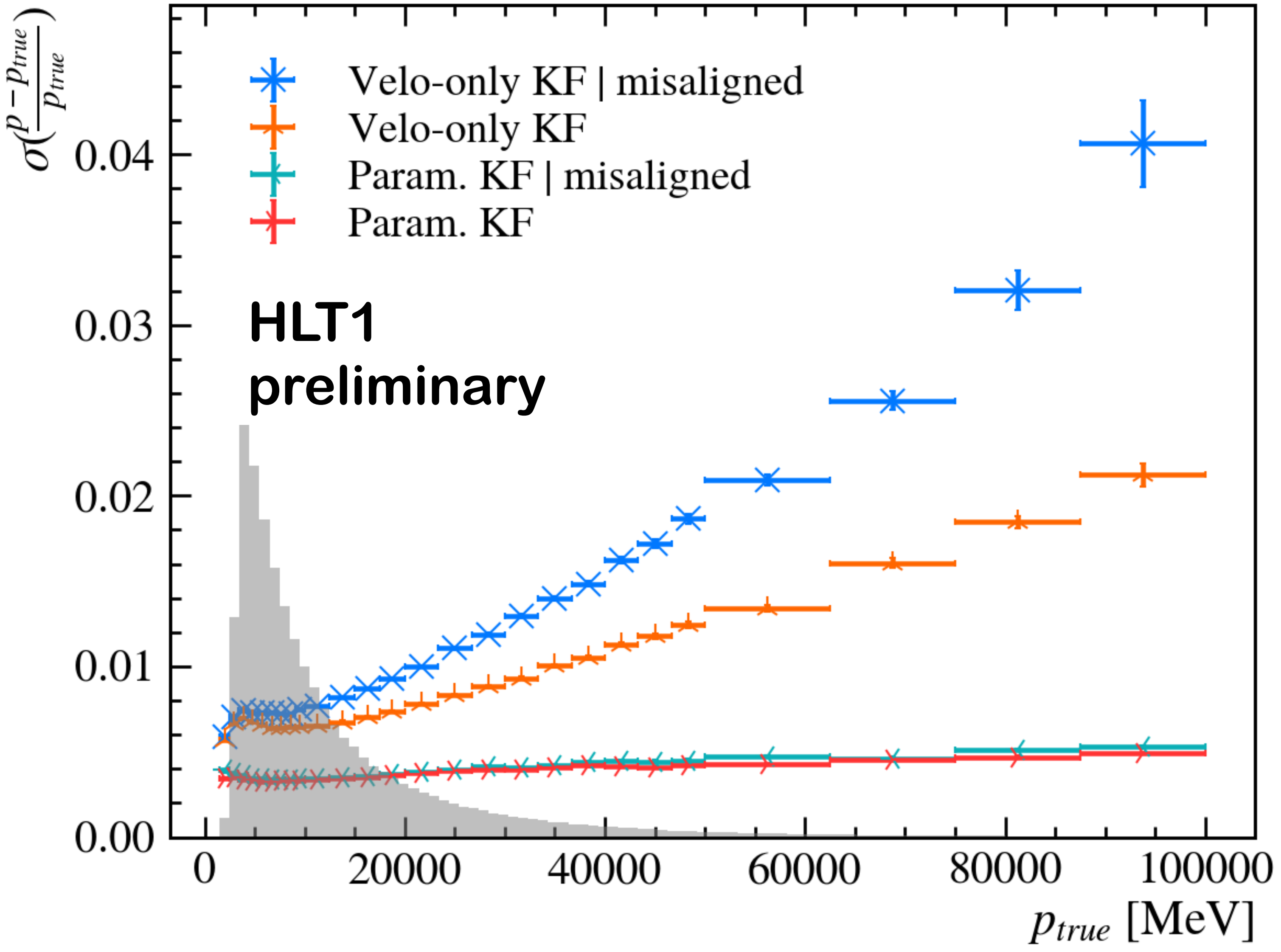
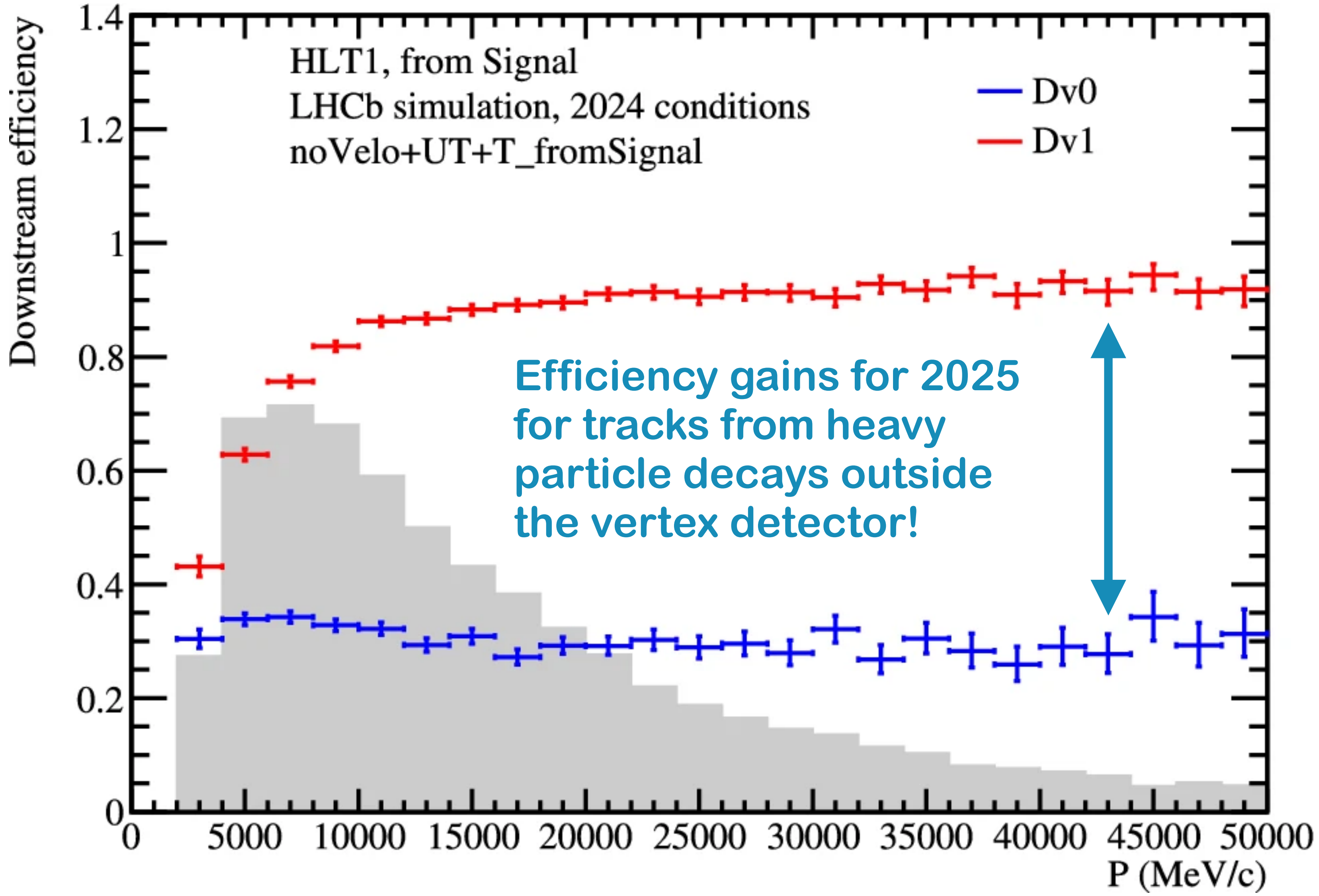




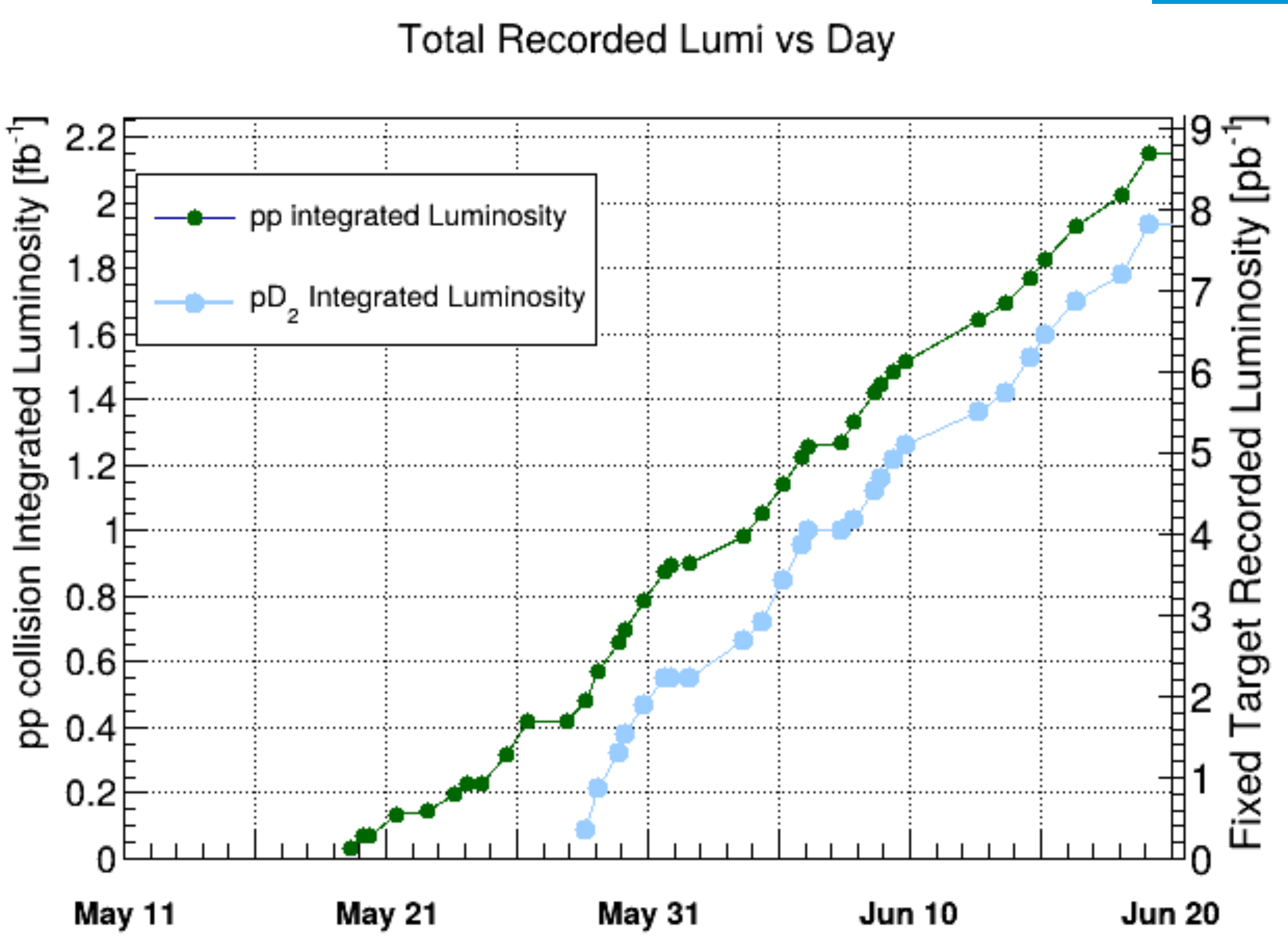
The parametrised Kalman filter also makes HLT1 more robust against detector misalignments

In continuity with a focus on robustness against changing detector conditions which has been a hallmark of LHCb's reconstruction and real-time processing since Run 1

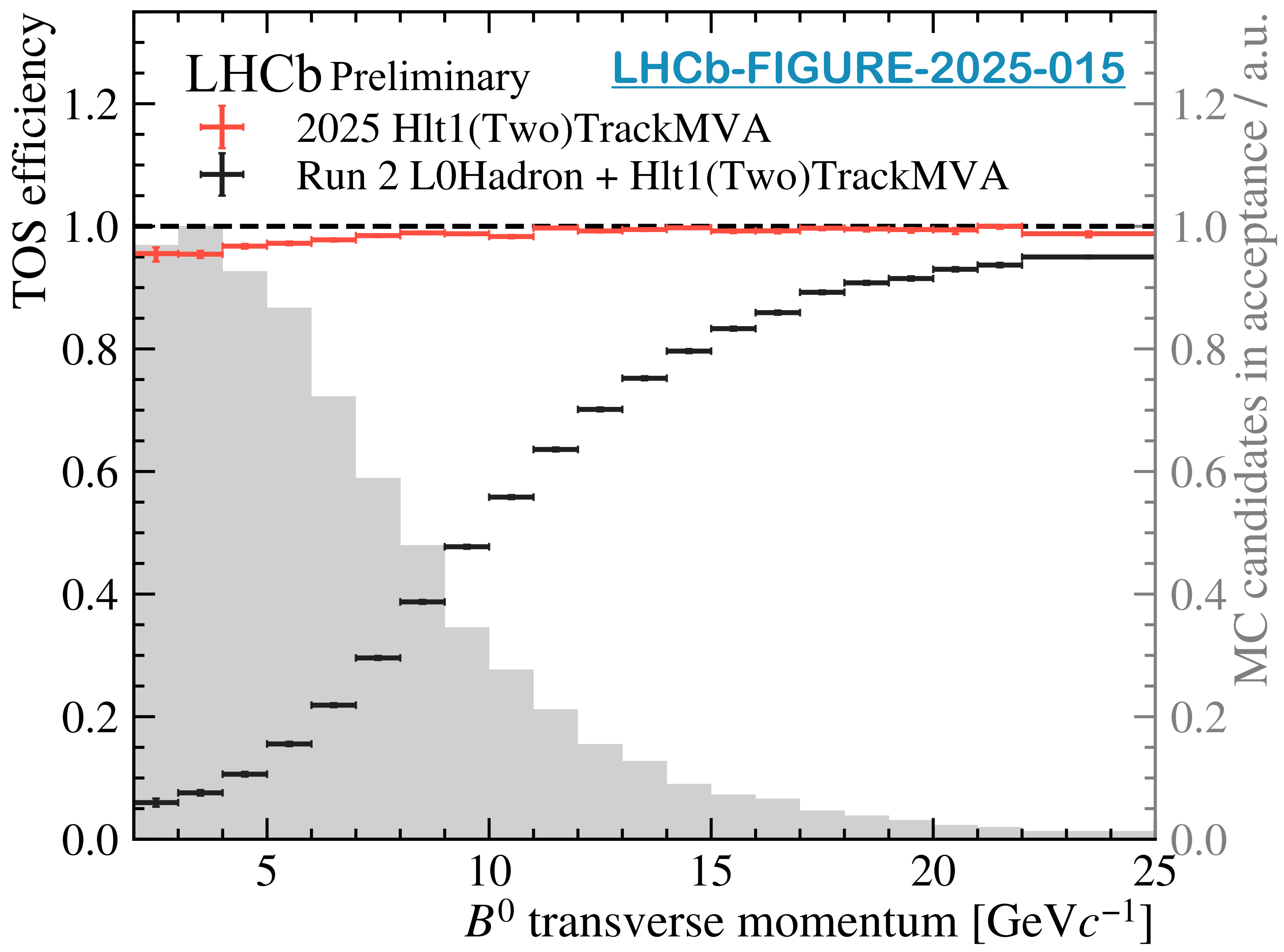
LHCb operations in 2025

NEW!

See D. vom Bruch @ T12

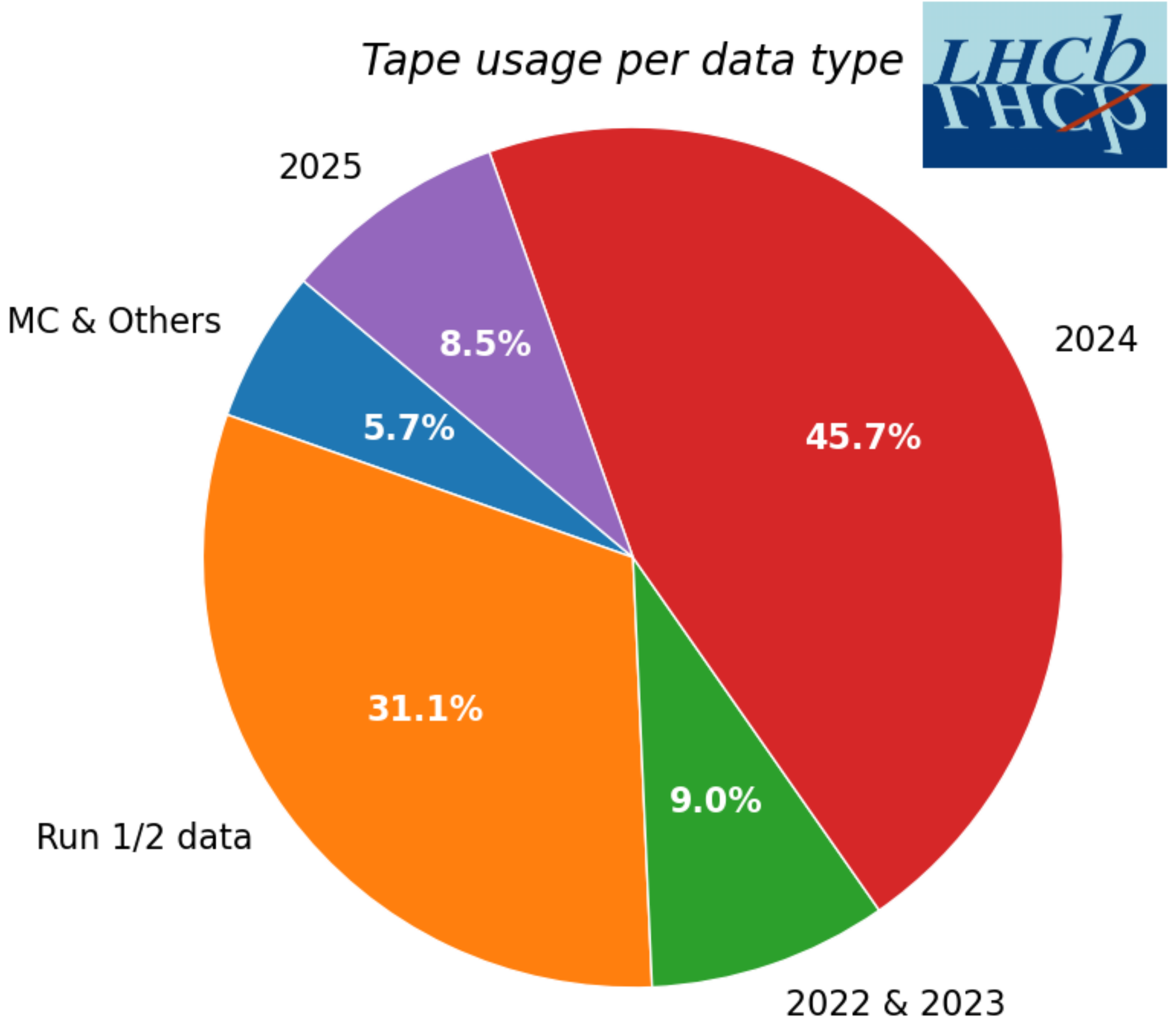


Efficiencies maintained above nominal luminosity in 2025!

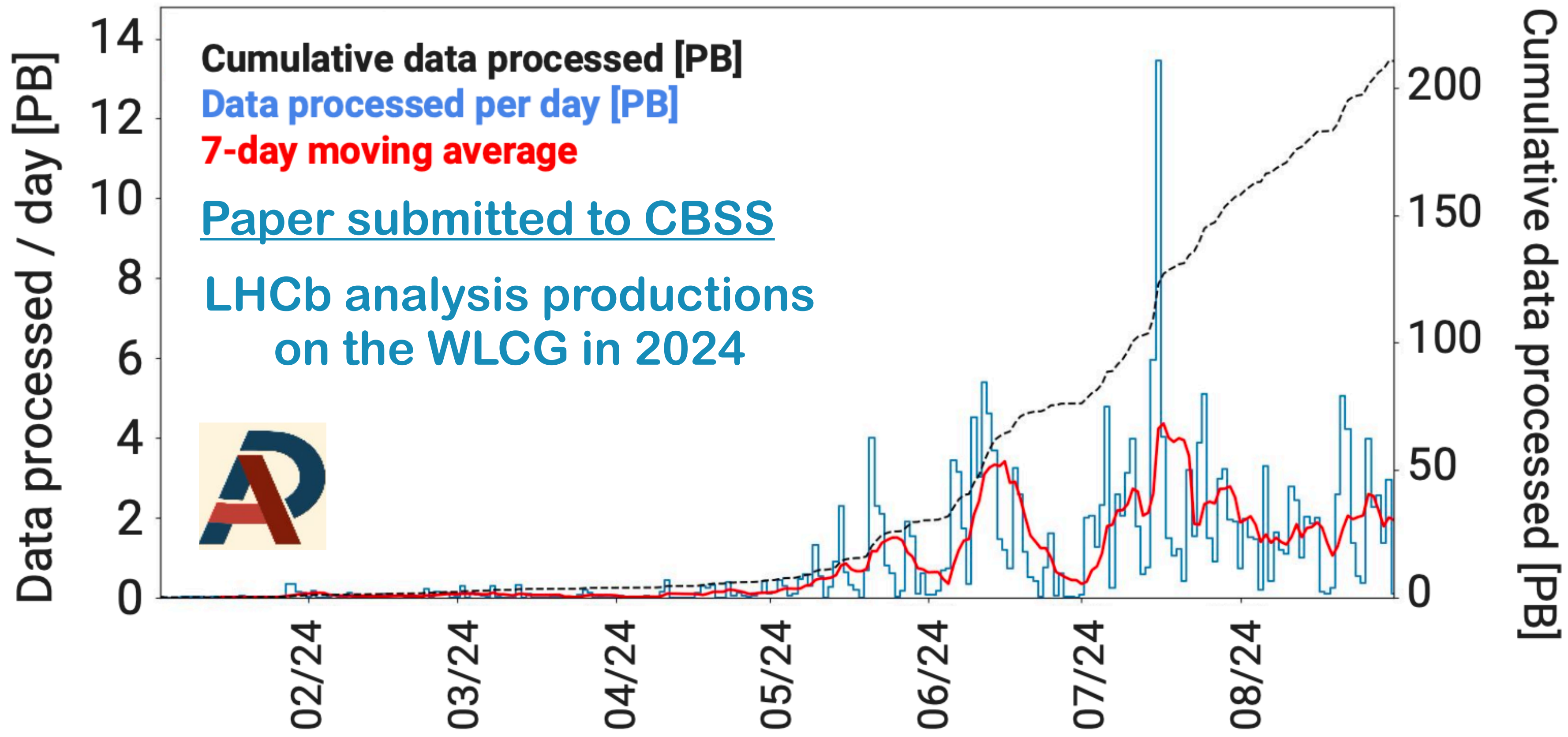


Routine datataking above design pp luminosity and with fixed-target collisions in parallel

LHCb computing in Run 3

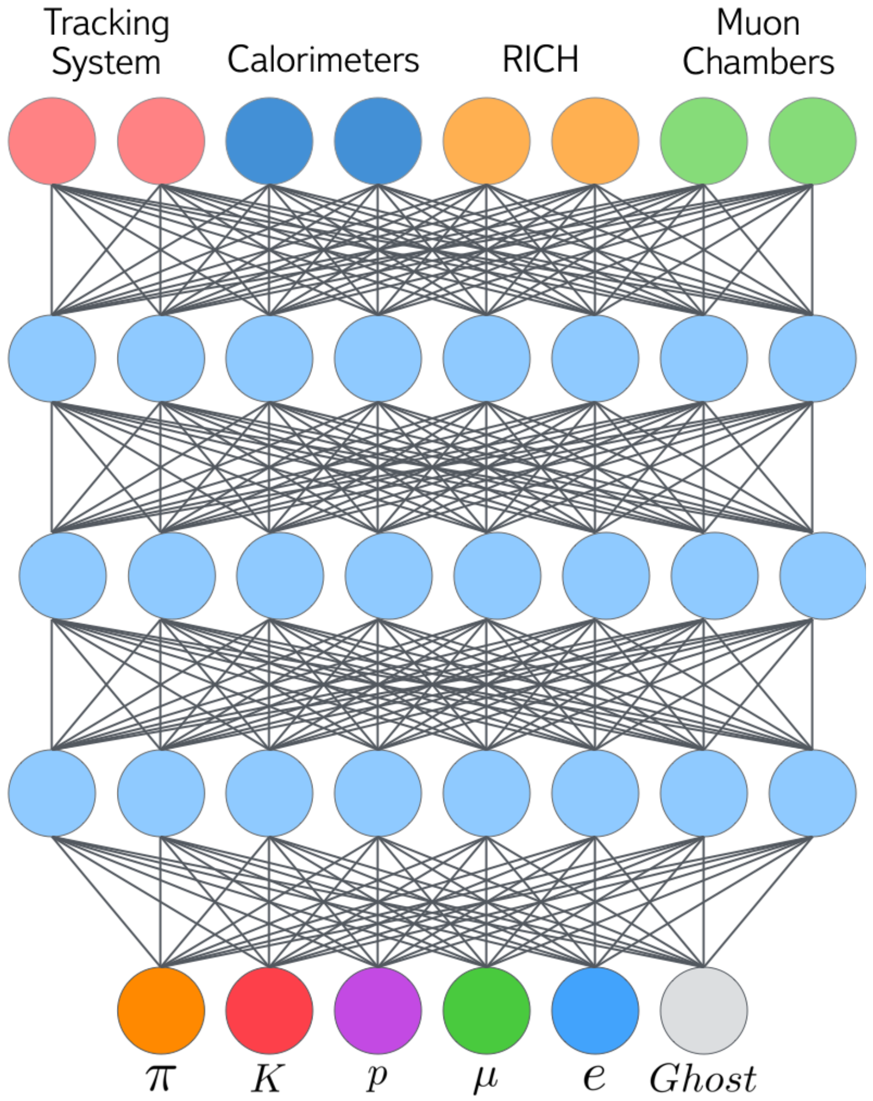


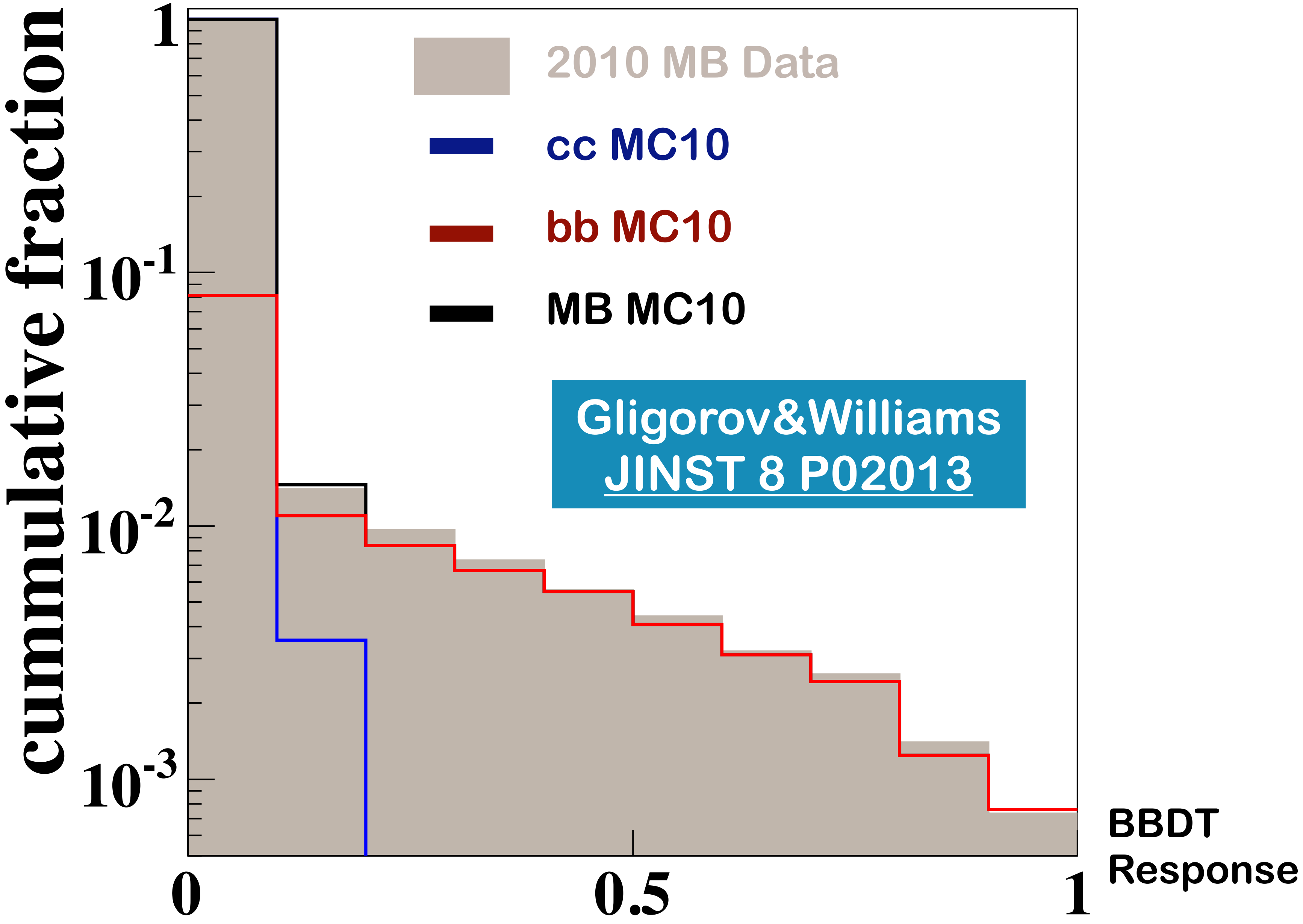
Highly automated analysis productions deliver physics-analysis-ready data across the full physics programme with very low latency



LHCb at the edge of ML/AI since Run 1

See A. Poluektov @ T16





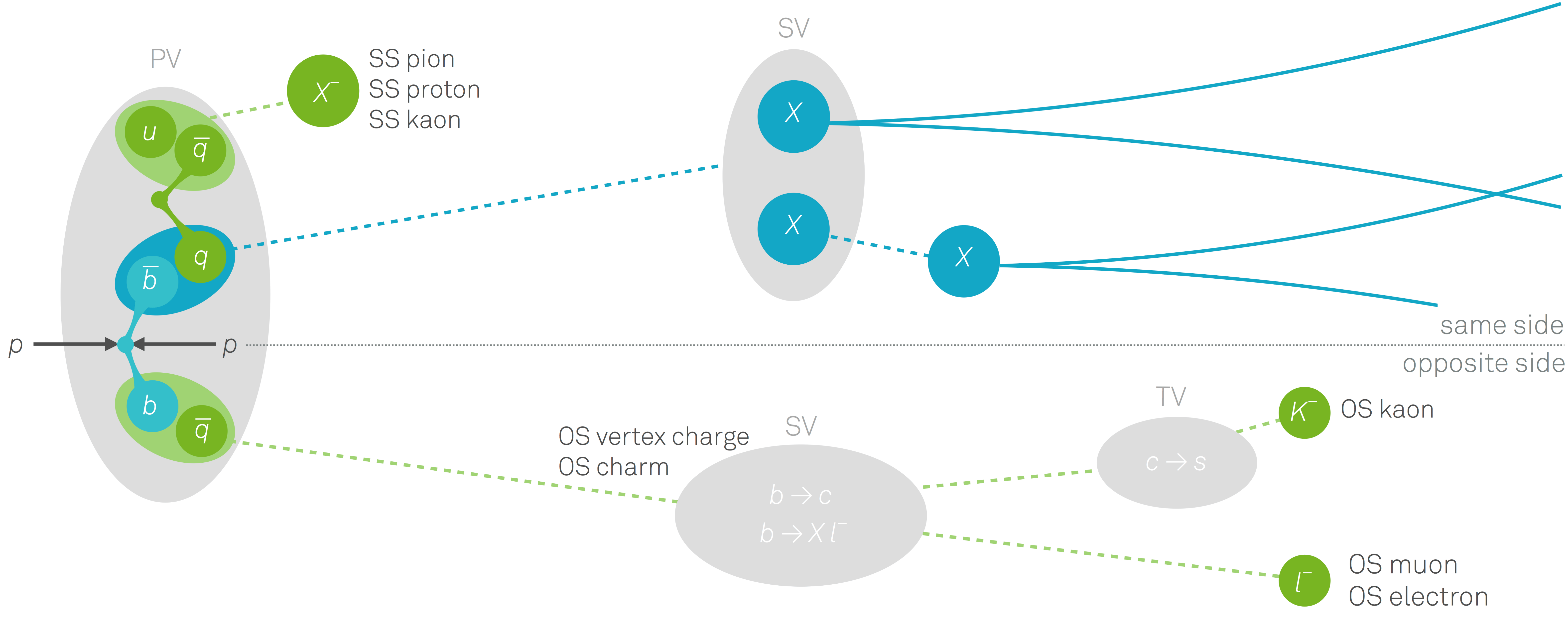
Quantised machine learning used for the main heavy flavour triggers since 2011

Over time a gradual expansion of the use of neural networks for fake rejection, particle identification, and clustering throughout the reconstruction chain

A global AI flavour classifier @ LHCb

See J. Wendel @ T16

NEW!



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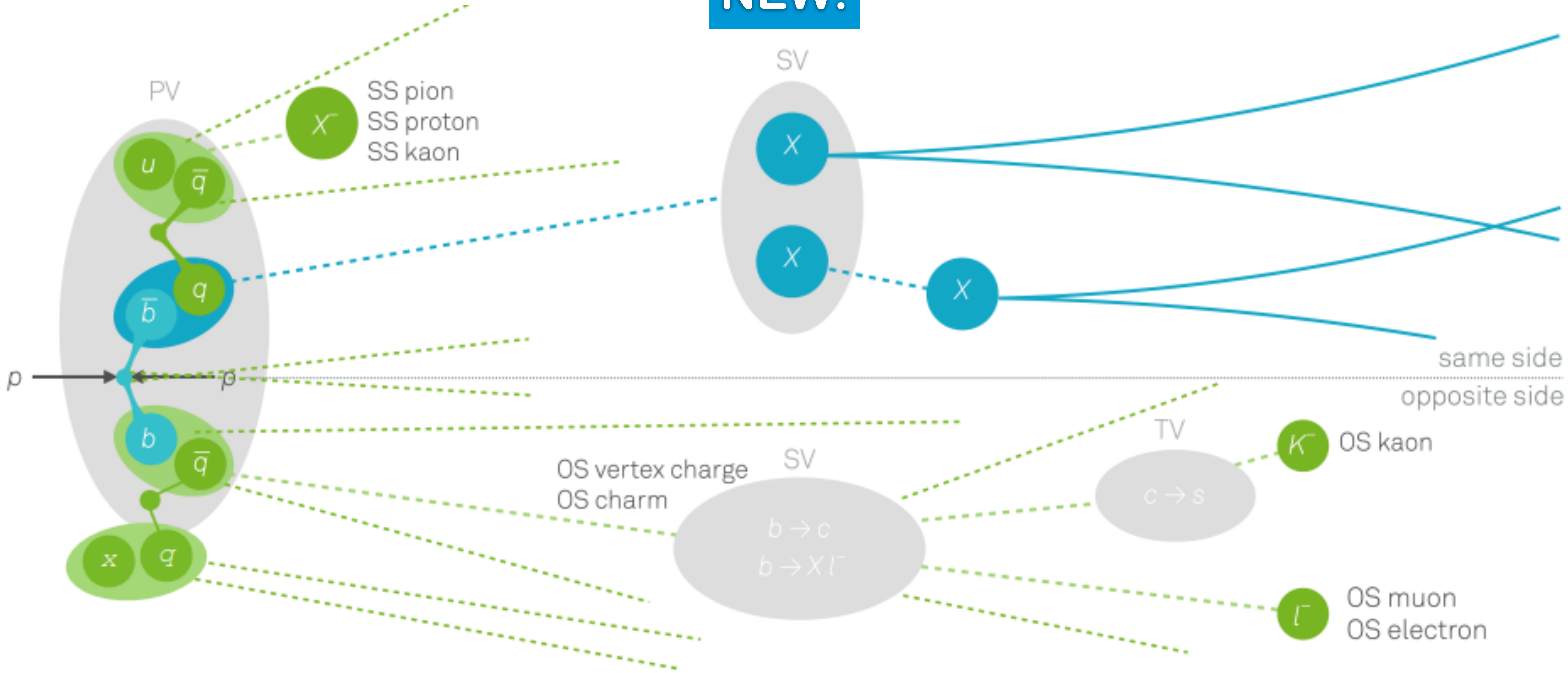


A global AI flavour classifier @ LHCb

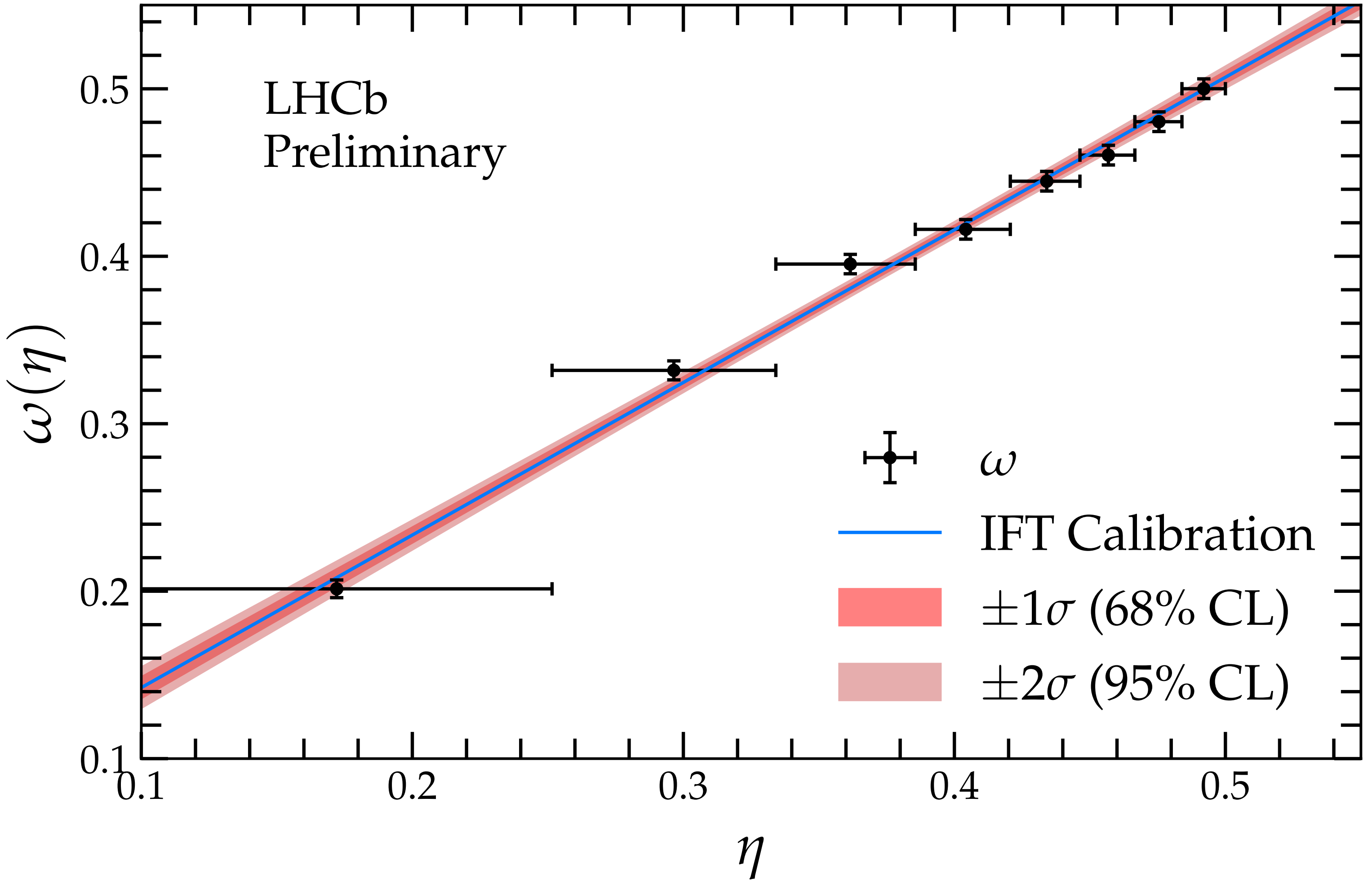
LHCb-PAPER-2025-024

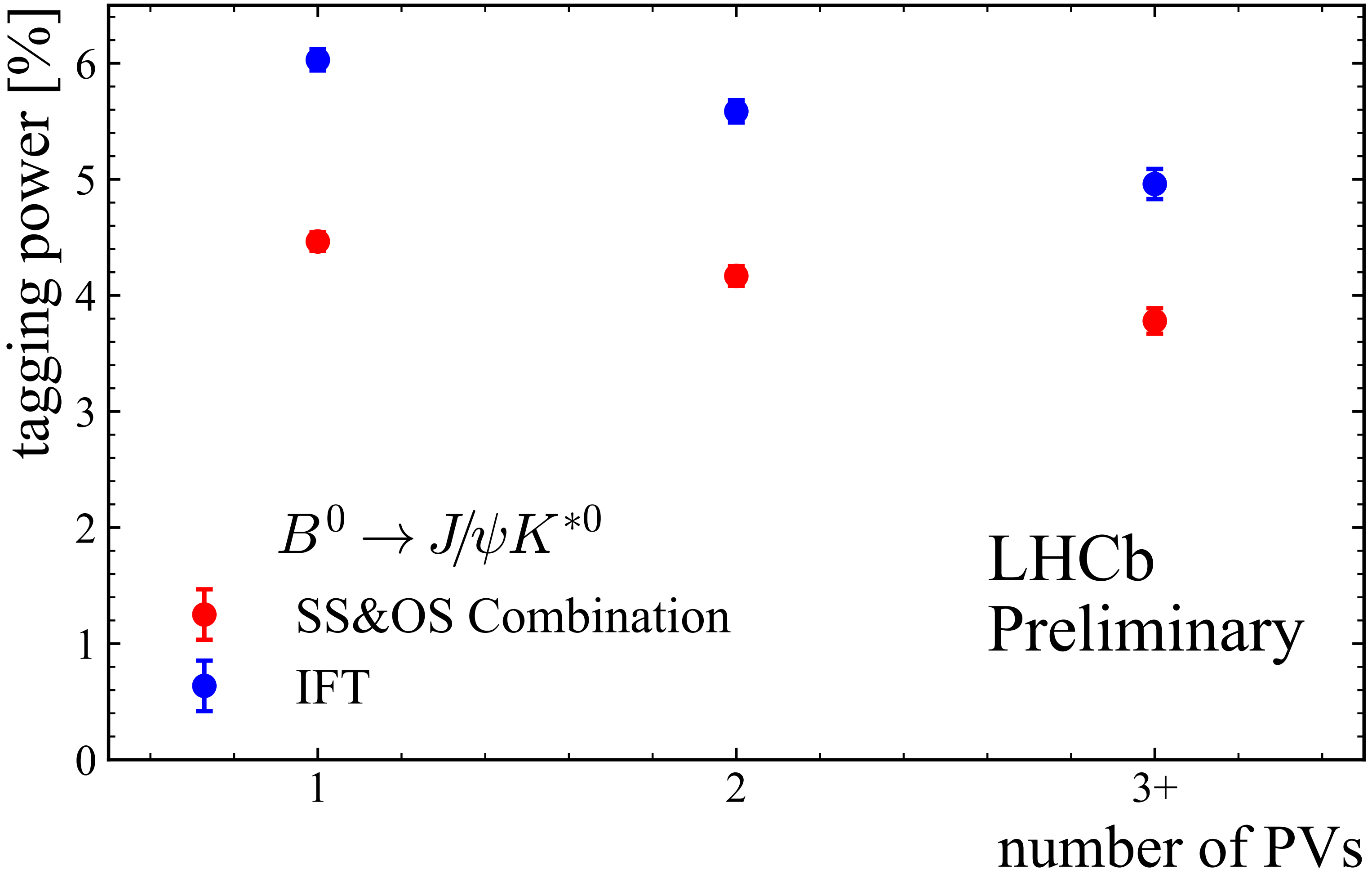
See J. Wendel @ T16

NEW!

Gains stable with pileup and p_T

Pathfinder for future upgrades!





The global classifier can be calibrated and ported between decay modes

Gain of 20-35% of tagging power compared to classical algorithms!

Re-analysis of core legacy LHCb measurements with this new tagger is on the way

First LHCb Run 3 results!

NEW!

Measurements of charmed meson and antimeson production asymmetries at $\sqrt{s}$ =13.6 TeV

LHCb collaboration†

Abstract

This article presents doubly differential measurements of the asymmetries in production rates between mesons containing a charm quark and those containing an anticharm quark in proton-proton collisions at a centre-of-mass energy of $\sqrt{s} = 13.6$ TeV using data recorded by the LHCb experiment. The asymmetries of D^0, D^+ and D_s^+ mesons are measured for two-dimensional intervals in transverse momentum and pseudorapidity, within the range $2.5 < p_{\mathrm{T}} < 25.0\,\mathrm{GeV}/c$ and $2.0 < \eta < 4.5$. No significant production asymmetries are observed. Comparisons to the PYTHIA 8 and Herwig 7 event generators are also presented, and their agreement with the data is evaluated. These measurements constitute the first measurements of production asymmetries at this centre-of-mass energy of colliding beams, and the first measurements with the LHCb Run 3 detector.

Measurement of *CP* asymmetry in $D^0 \to K^0_{\mathrm{S}} K^0_{\mathrm{S}}$ decays with the upgraded LHCb detector

LHCb collaboration†

Abstract

A measurement of *CP* asymmetry in $D^0 \to K^0_{\mathrm{S}} K^0_{\mathrm{S}}$ decays is reported, based on a data sample of proton-proton collisions collected by the upgraded LHCb experiment in 2024 at a center-of-mass energy of 13.6 TeV, corresponding to an integrated luminosity of about $6.2\,\mathrm{fb}^{-1}$. The $D^0 \to K^0_{\mathrm{S}} \pi^+\pi^-$ decay is used as a calibration channel. The time-integrated *CP* asymmetry for the $D^0 \to K^0_{\mathrm{S}} K^0_{\mathrm{S}}$ mode is measured to be

$$\mathcal{A}^{CP}(D^0 \to K^0_{\mathrm{S}} K^0_{\mathrm{S}}) = (1.86 \pm 1.04 \pm 0.41)\%,$$

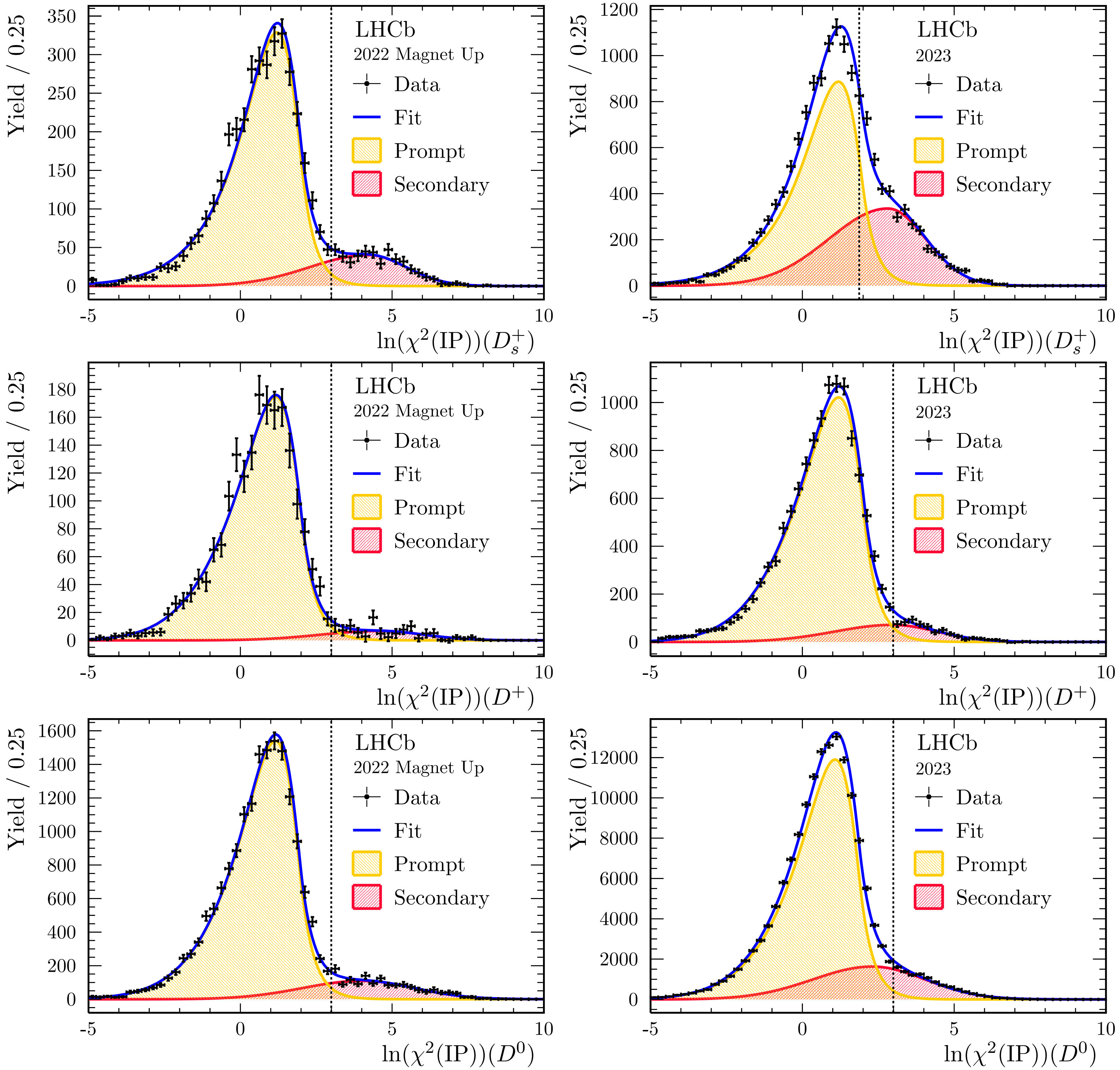
where the first uncertainty is statistical, and the second is systematic. This is the most precise determination of this quantity to date.

Charm production asymmetries

Measured through fits to (anti)-particle yields, separating the prompt and secondary charm production.

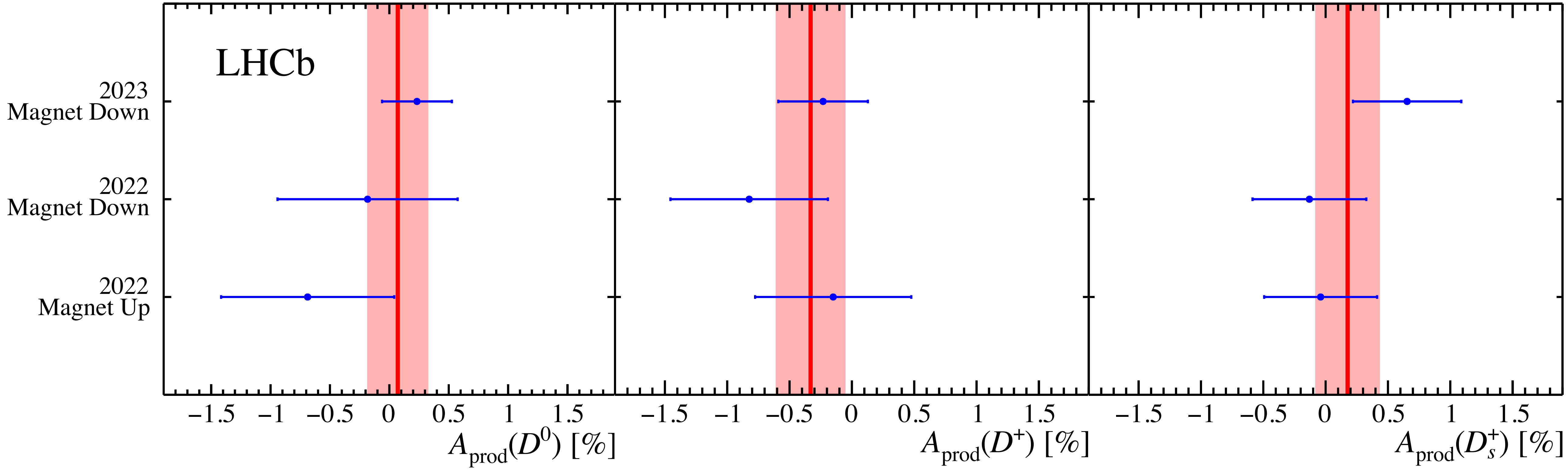
Detector asymmetries cancelled in a data-driven manner using kinematic matching and appropriate choices of control channels.

The chosen cancellation methodology holds to $O(10^{-4})$ corrections, one order of magnitude below the current measurement sensitivity.



See L. Dufour @ T05

Charm production asymmetries



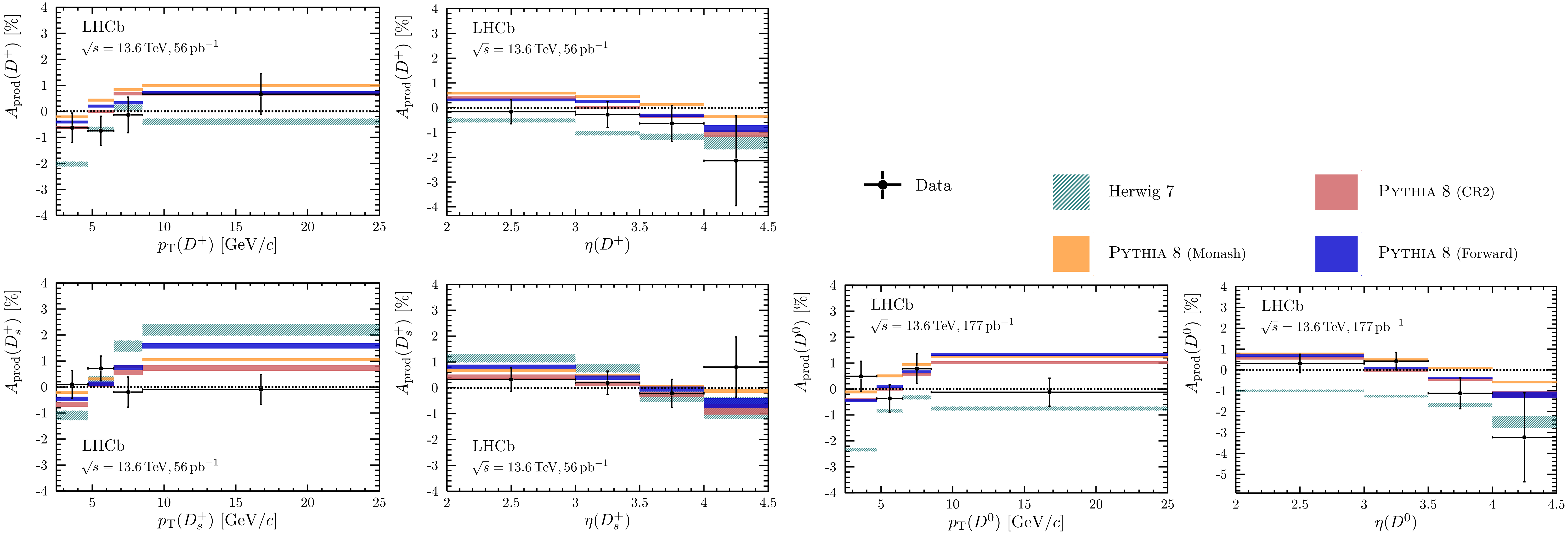
$$A_{\mathrm{prod}}(D^0) = (0.07 \pm 0.26\,(\mathrm{stat}) \pm 0.10\,(\mathrm{syst}))\%,$$
$$A_{\mathrm{prod}}(D^+) = (-0.33 \pm 0.29\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst}))\%,$$
$$A_{\mathrm{prod}}(D_s^+) = (0.18 \pm 0.26\,(\mathrm{stat}) \pm 0.08\,(\mathrm{syst}))\%.$$

Statistically limited measurement

Main systematics from modelling of secondary charm and fits to extract the raw asymmetries.

See L. Dufour @ T05

Charm production asymmetries



Measurement in agreement with theory expectations within uncertainties

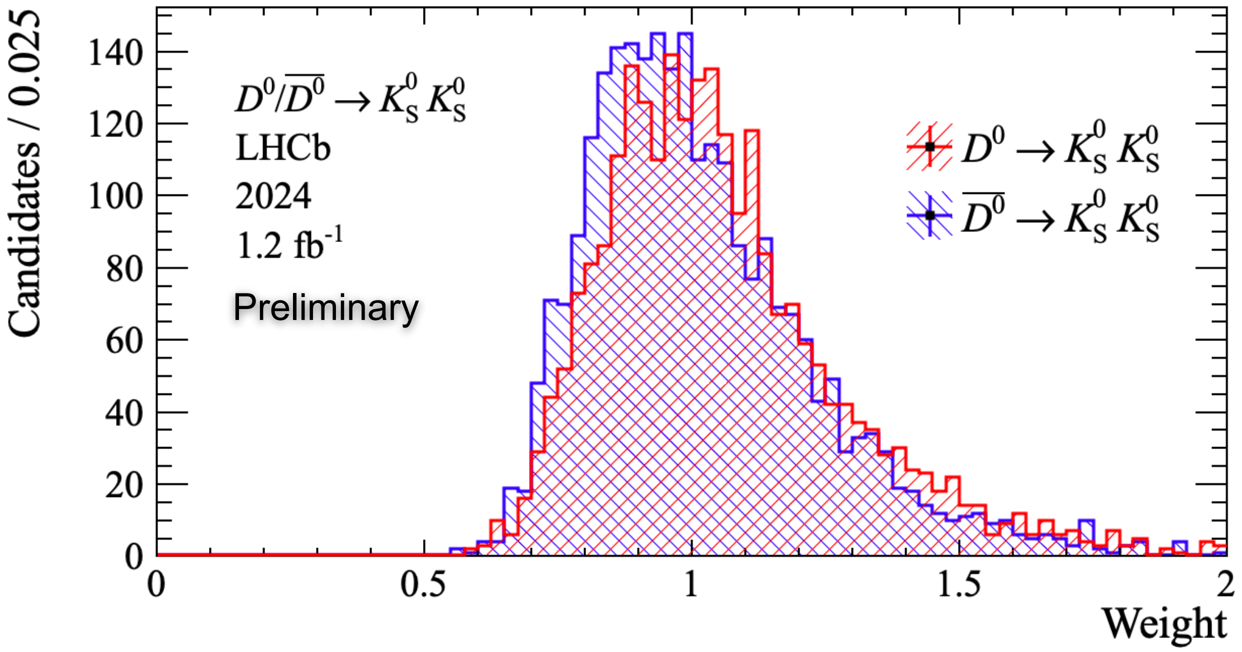
See L. Dufour @ T05

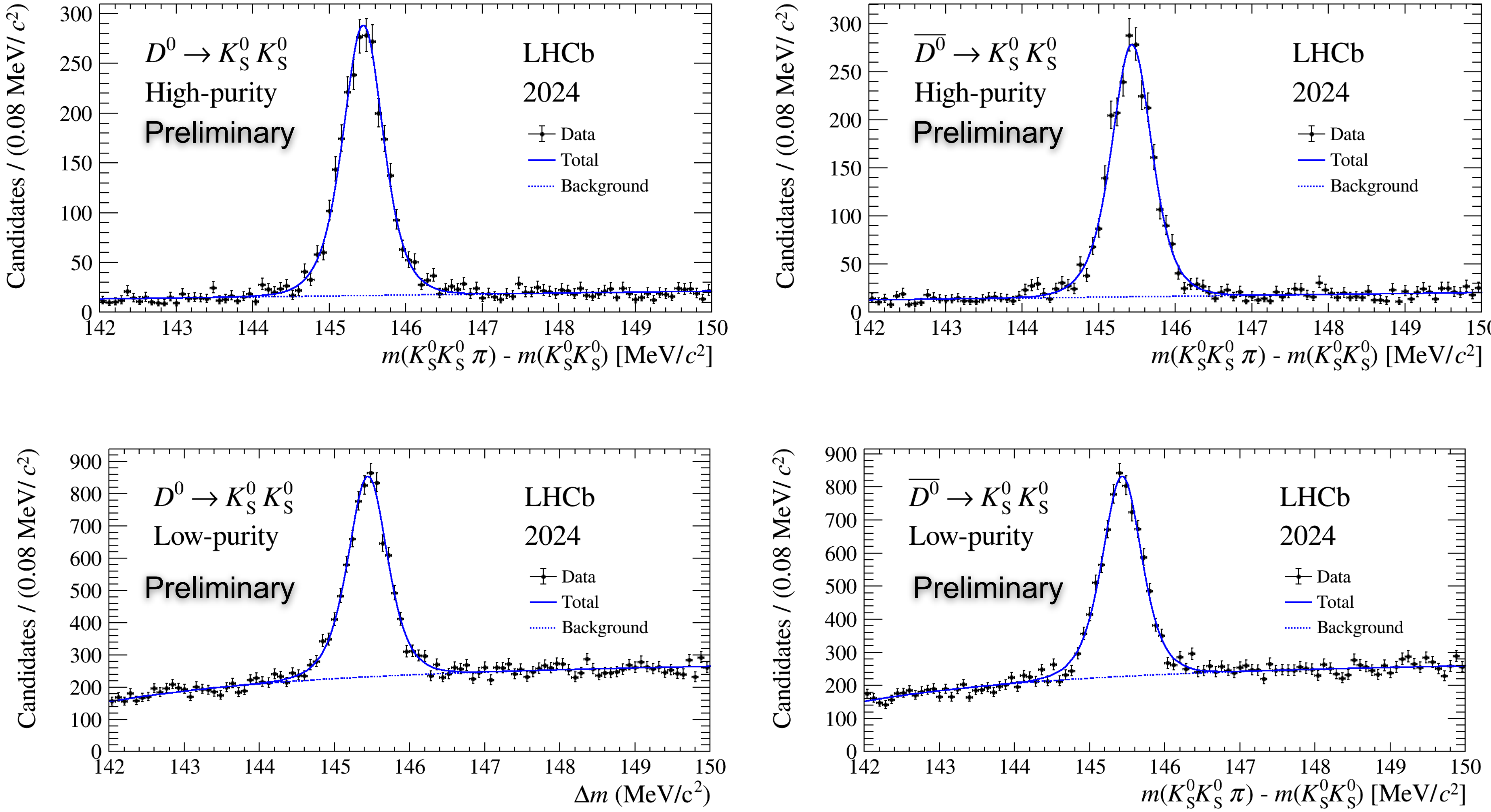
CP violation in $D^0 \to K^0_S K^0_S$ decays

NEW!

Measured using $D^{*0} \to D^0 \pi$ decays

Raw CPV from fits to (anti)-particle yields is corrected for detector asymmetries in a data-driven manner using kinematic matching with the $D^0 \to K^0_S \pi\pi$ control channel



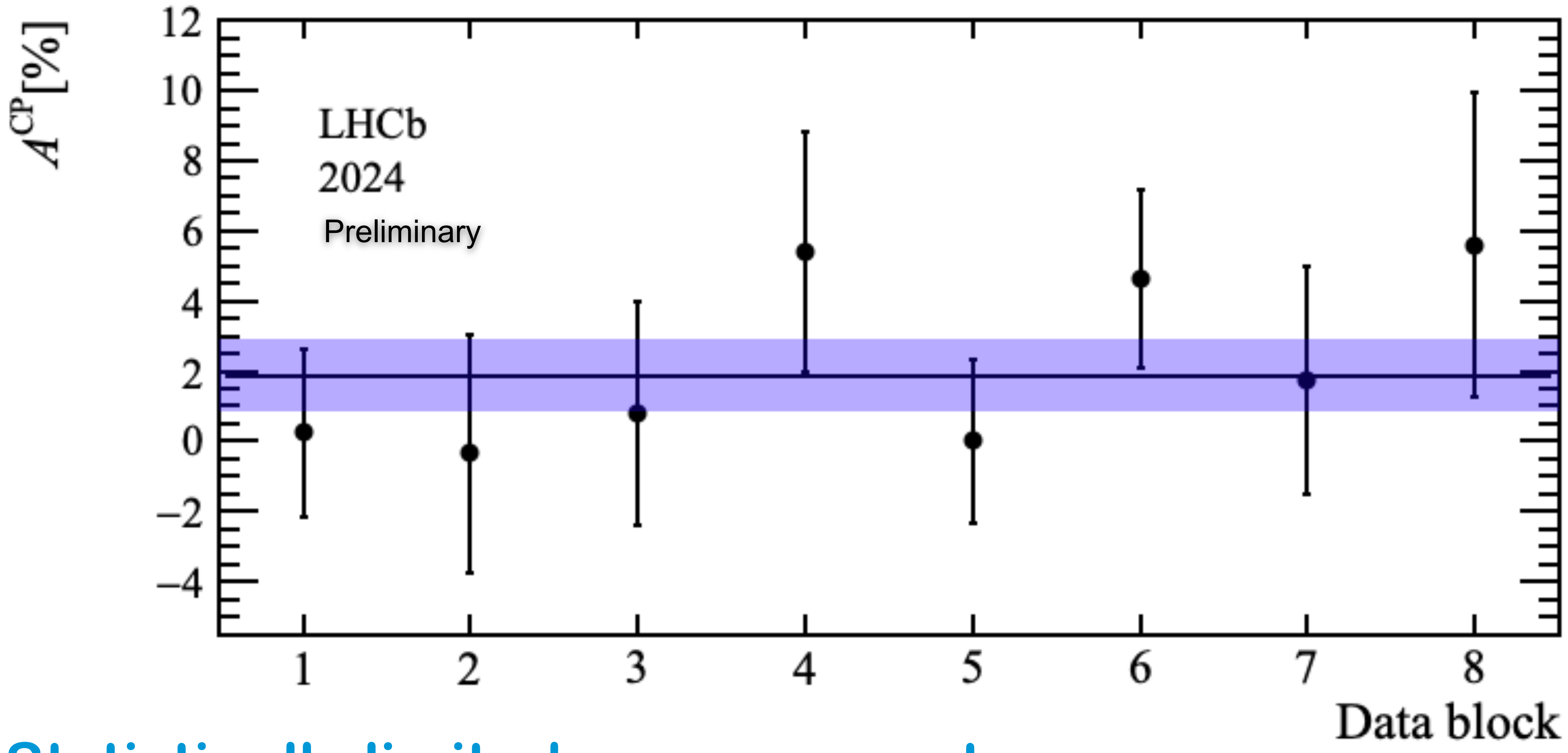


See G. Punzi @ T07

CP violation in $D^0 \to K^0_S K^0_S$ decays

NEW!

Data block	Yield	$\mathcal{A}^{CP}$ [%]
1	2915 ± 85	0.3 ± 2.4
2	1385 ± 55	-0.3 ± 3.4
3	1639 ± 56	0.8 ± 3.2
4	1534 ± 75	5.5 ± 3.4
5	3149 ± 94	0.0 ± 2.4
6	2544 ± 77	4.6 ± 2.6
7	1599 ± 67	1.7 ± 3.3
8	911 ± 54	5.6 ± 4.3



Systematic source	σ_{syst}
Calibration sample size	0.24%
k choice	0.20%
Fit model	0.27%

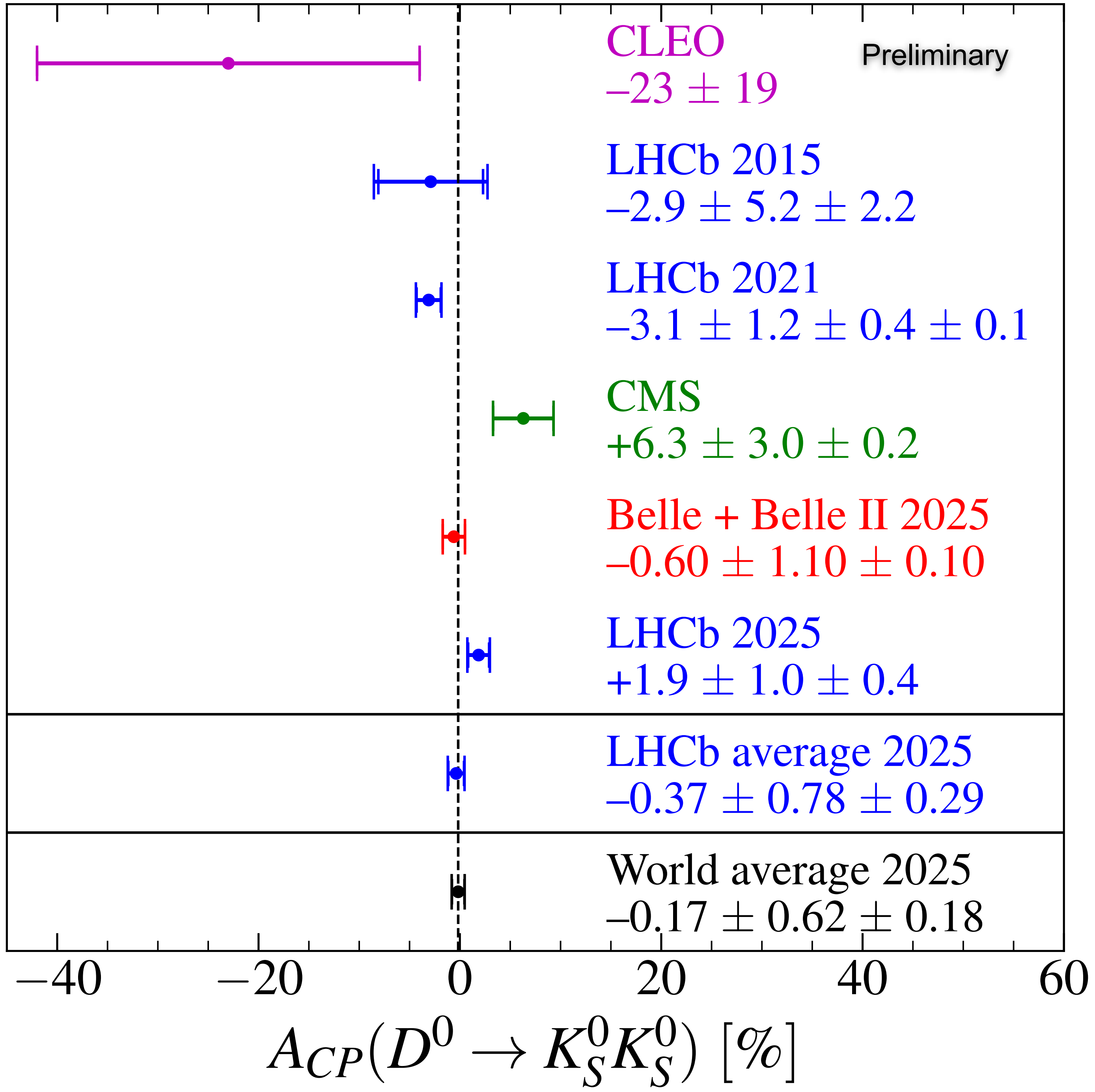
Statistically limited measurement

Results show excellent stability throughout 2024 datataking despite changing detector efficiencies and pileup conditions. Many kinematic and geometric stability checks performed with no issues found.

See G. Punzi @ T07

CP violation in $D^0 \to K^0_S K^0_S$ decays

NEW!



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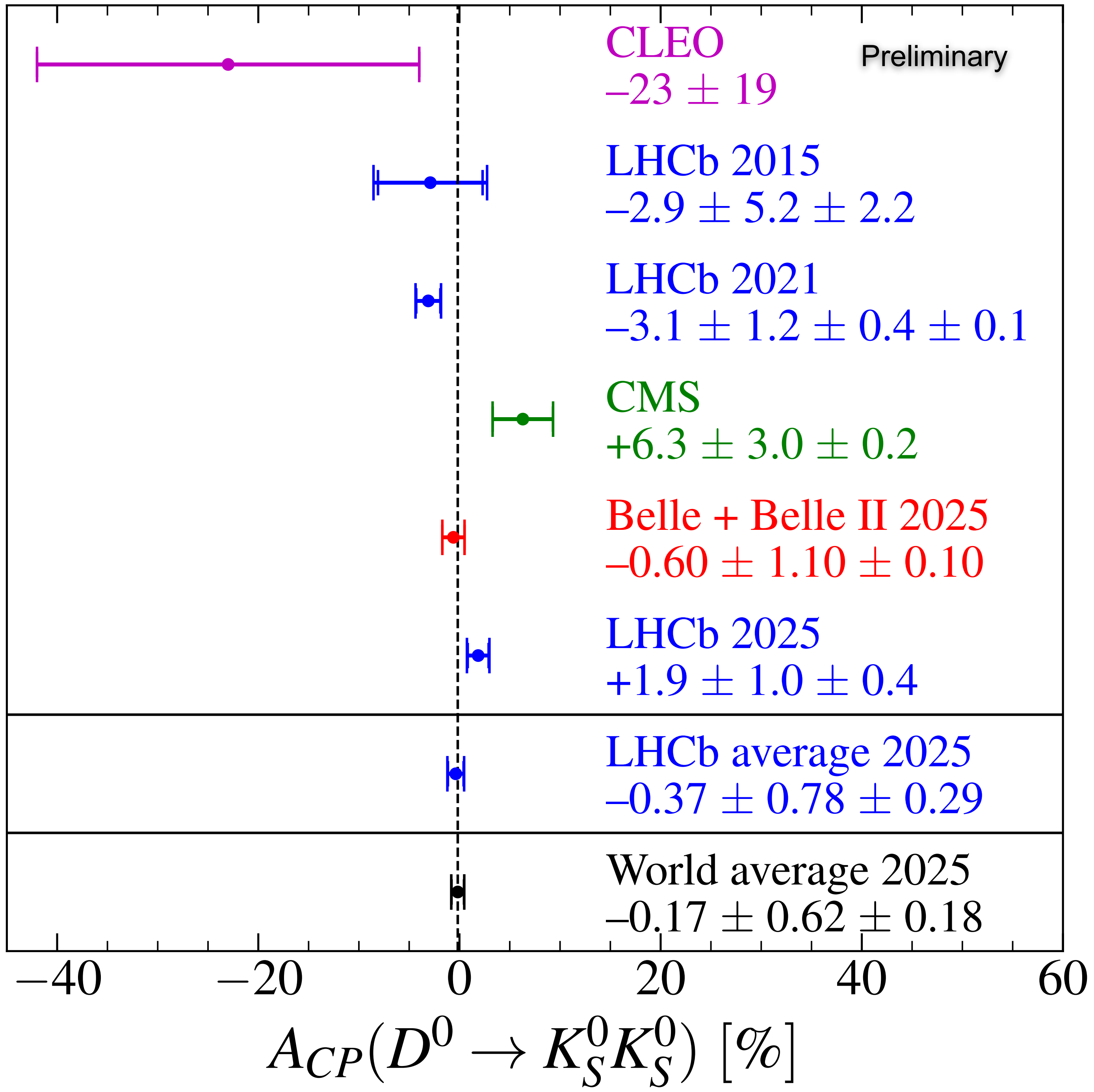


NEW!

World average and LHCb internal average compatible with zero and statistically limited.

The LHCb average is fully coherent with the Belle/Belle II and CMS results.

The LHCb 2024 and Run 1+2 results are in ~3σ tension with each other

We have performed an extensive set of additional checks to the Run 2 LHCb result inspired by optimisations developed during the Run 3 analysis, but found no issues.

A lot of room for improvement with 2025 and 2026 data, including K^0_S particles decaying outside the vertex detector. Stay tuned for the Run 3 legacy analysis!

See G. Punzi @ T07

Continuing the Run 1+2 harvest

NEW!

Search for $H \to b\bar{b}$ and $H \to c\bar{c}$ in $\sqrt{s} = 13$ TeV pp collisions at LHCb using machine learning techniques

LHCb collaboration†

Abstract

In this paper, two machine learning techniques for jet physics at LHCb are presented: a regression-based method for jet energy calibration and a deep neural network algorithm for jet flavour tagging, distinguishing between b-quark, c-quark, and light parton jets. These techniques are applied in a search for inclusive $H \to b\bar{b}$ and $H \to c\bar{c}$ decays using LHCb data corresponding to an integrated luminosity of $1.6\,\mathrm{fb}^{-1}$. The analysis sets 95% confidence level limits on these decays, demonstrating LHCb's unique sensitivity in the forward region.

Measurement of the $W \to \mu\nu$ cross-sections as a function of the muon transverse momentum in pp collisions at 5.02 TeV

LHCb collaboration†

Abstract

The $pp \to W \to \mu\nu$ cross-sections are measured at a proton-proton centre-of-mass energy $\sqrt{s} = 5.02$ TeV using a dataset corresponding to an integrated luminosity of $100\,\mathrm{pb}^{-1}$, recorded by the LHCb experiment. Using muons in the pseudorapidity range $2.2 < \eta < 4.4$, the cross-sections are measured differentially in twelve intervals of muon transverse momentum in the range $28 < p_\mathrm{T} < 52$ GeV. Integrated over p_T, the measured cross-sections are

$$\sigma_{W^+\to\mu^+\nu_\mu} = 300.9 \pm 2.4 \pm 3.8 \pm 6.0\,\mathrm{pb},$$
$$\sigma_{W^-\to\mu^-\bar{\nu}_\mu} = 236.9 \pm 2.1 \pm 2.8 \pm 4.7\,\mathrm{pb},$$

where the first uncertainties are statistical, the second are systematic and the third are associated with the luminosity calibration. These integrated results are consistent with theoretical predictions.

This analysis introduces a new method to determine the W boson mass using the measured differential cross-sections corrected for detector effects. The measurement is performed on a small dataset as a proof of principle. This method yields

$$m_W = 80371 \pm 130 \pm 32\,\mathrm{MeV},$$

where the first uncertainty is experimental and the second is theoretical.

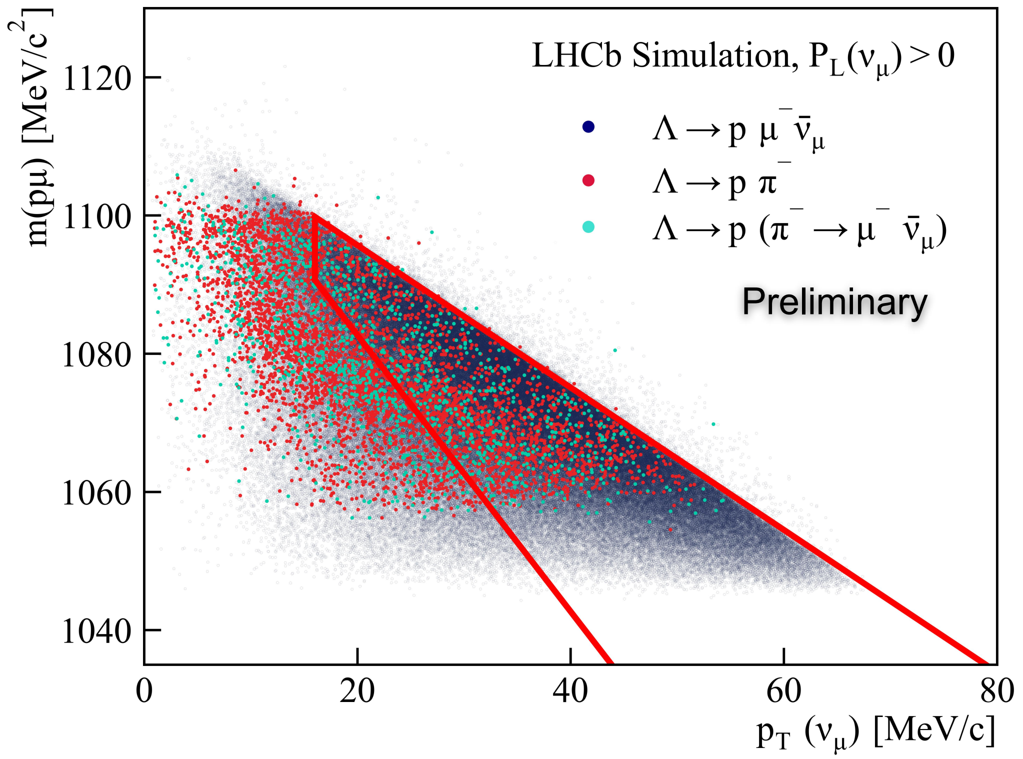
Branching fraction measurement of the $\Lambda \to p\mu^-\bar{\nu}_\mu$ decay

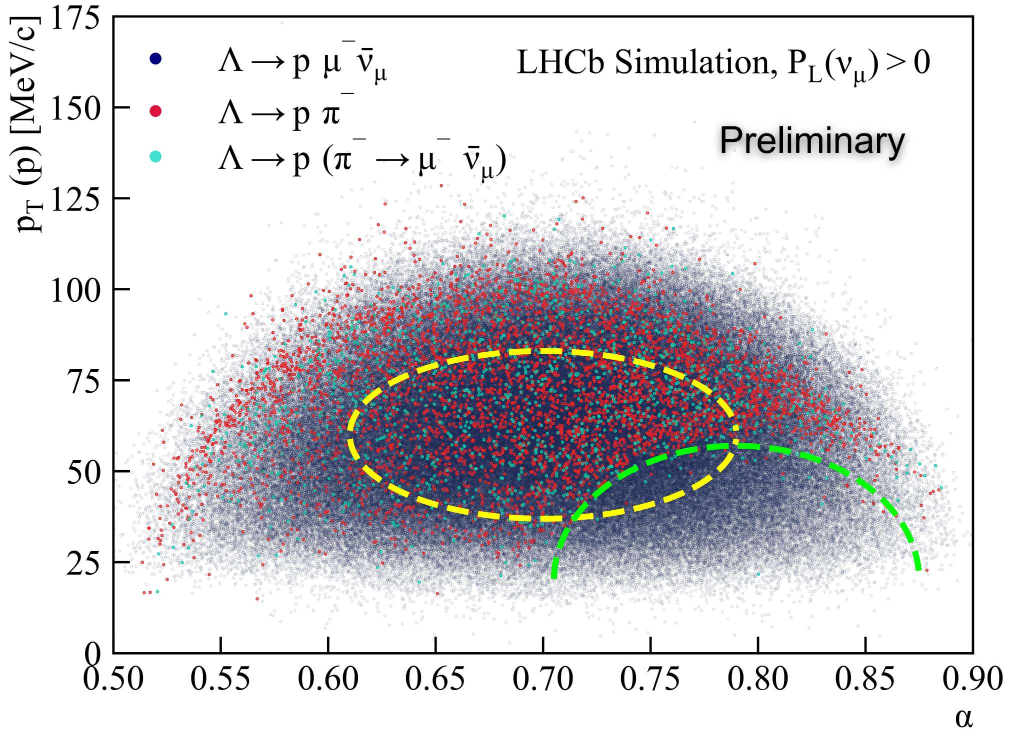
LHCb collaboration†

Abstract

A measurement of the branching fraction for the decay $\Lambda \to p\mu^-\bar{\nu}_\mu$ is reported using proton-proton collision data collected by the LHCb experiment at a centre-of-mass energy of 13 TeV. The analysis is based on data recorded during 2016–2018, corresponding to an integrated luminosity of $5.4\,\mathrm{fb}^{-1}$. The measured branching fraction is $\mathcal{B}(\Lambda \to p\mu^-\bar{\nu}_\mu) = (1.462 \pm 0.016 \pm 0.100 \pm 0.011) \times 10^{-4}$, where the uncertainties are statistical, systematic and due to the knowledge of the normalisation mode branching fractions, respectively. This result improves by a factor of two the precision of the branching fraction measurement compared to the previous best measurement and sets a tighter bound on lepton flavour universality in $s \to u$ quark transitions. The result is extracted via a two-dimensional template fit, based on simulated distributions, and using $\Lambda \to p\pi^-$ decays as a normalisation channel. The result is in good agreement with previous measurements and the extracted lepton flavour universality test observable $R^{\mu e} = \frac{\Gamma(\Lambda\to p\mu^-\bar{\nu}_\mu)}{\Gamma(\Lambda\to pe^-\bar{\nu}_e)} = 0.175 \pm 0.012$ is compatible with the Standard Model prediction at the level of 1.5 standard deviations.

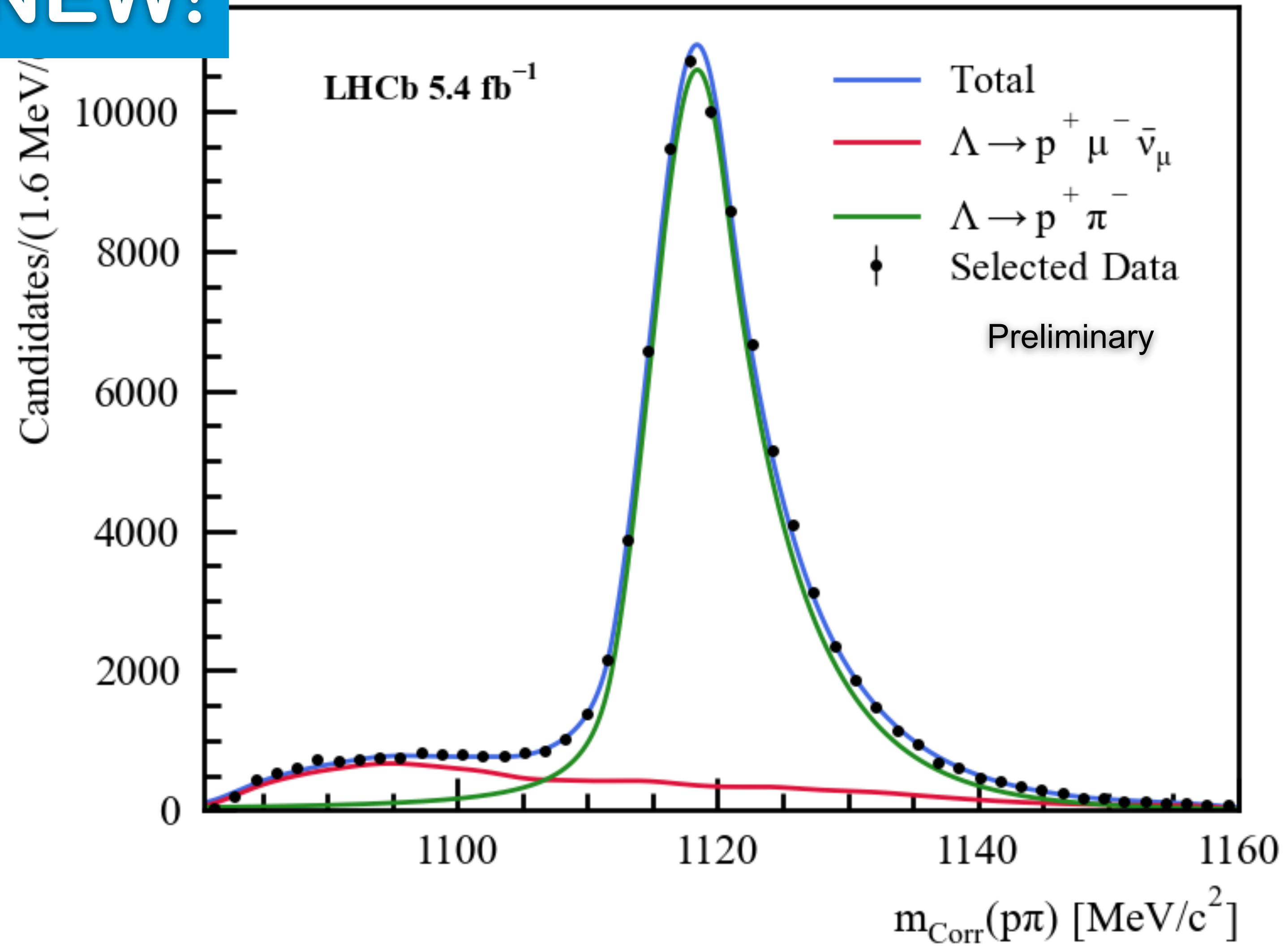
Measurement of $\Lambda \to p\mu\nu$





NEW!

See A. Brea @ T07



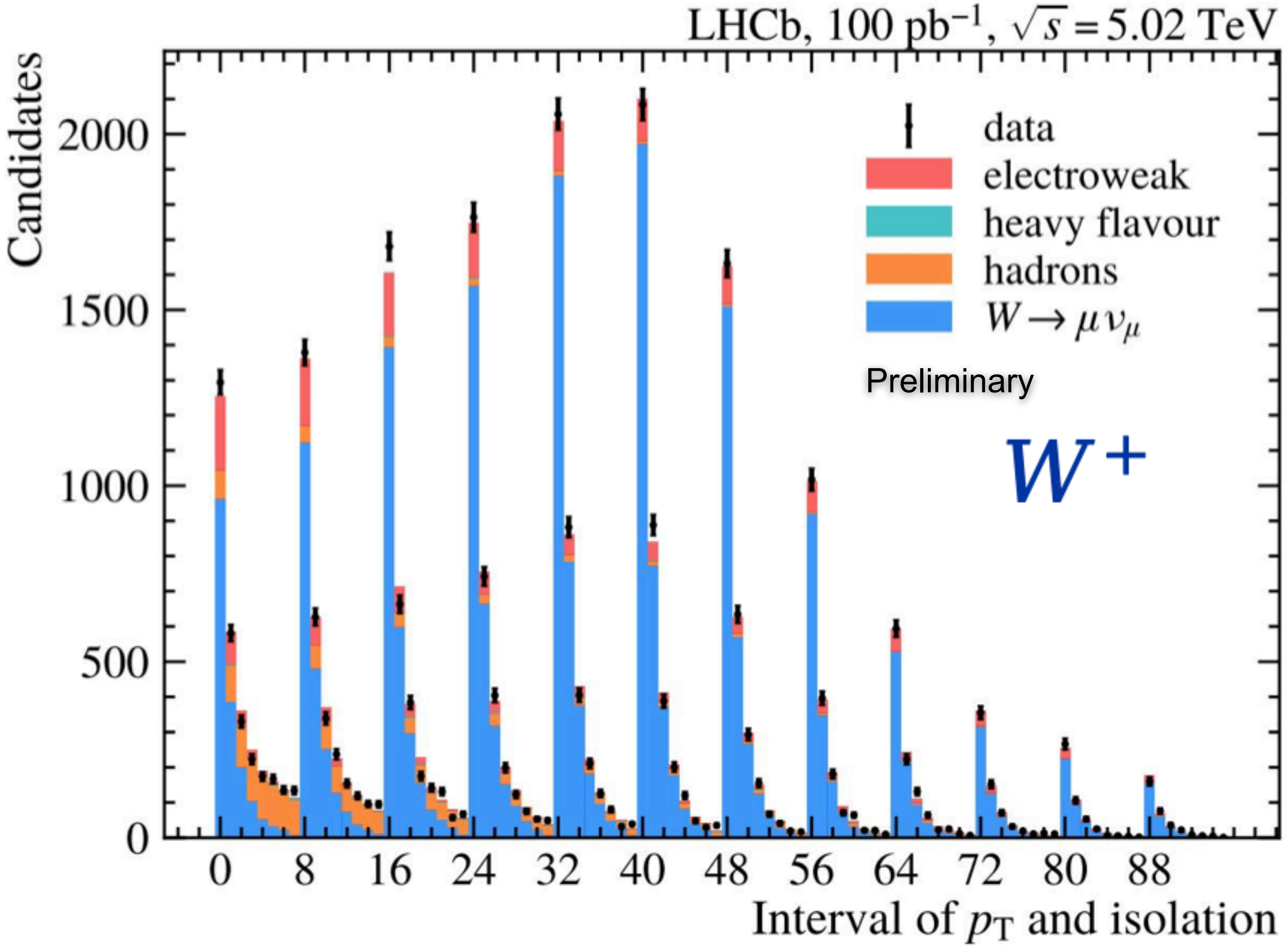
When interpreted as a lepton universality test agrees with SM predictions at 1.5σ

Feasible due to the exquisite precision of LHCb's vertex detector and tracker

W→$\mu\nu$ cross-sections @ 5.02 TeV

NEW!

See M. Xu @ T06



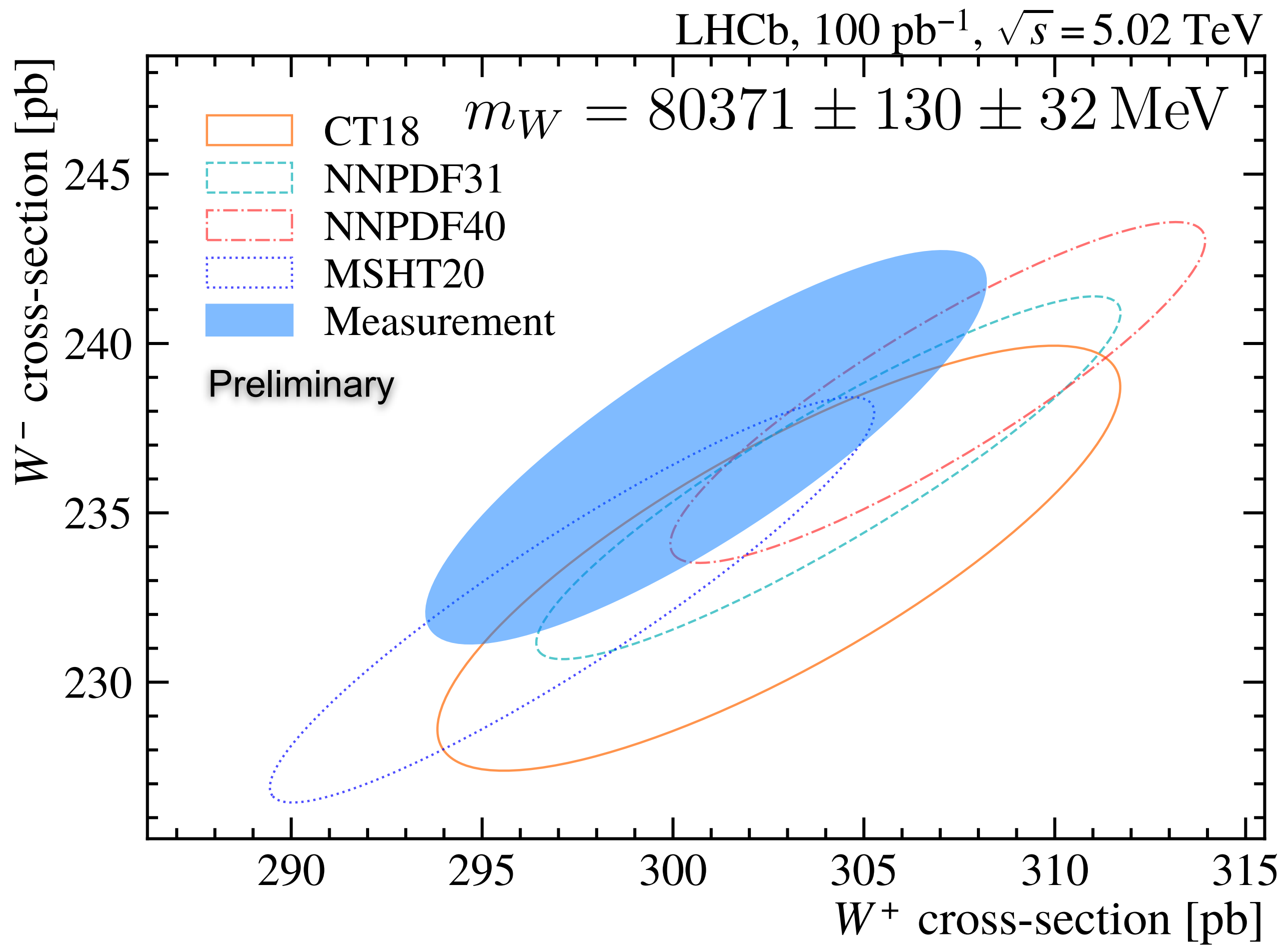


Figure 11: Integrated cross-sections compared to $\mathcal{O}(\alpha_s^2)$ predictions.

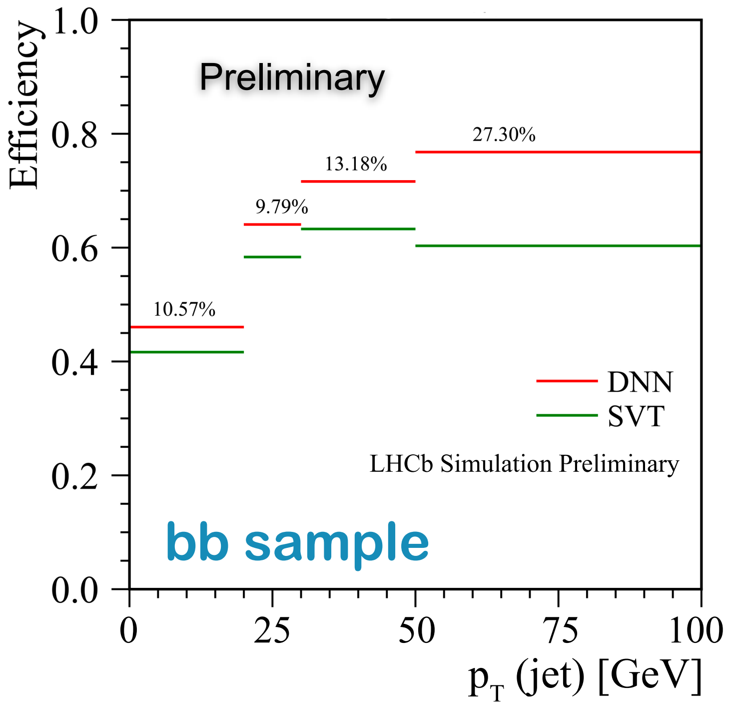
Model-independent differential measurement of the W→$\mu\nu$ cross-section

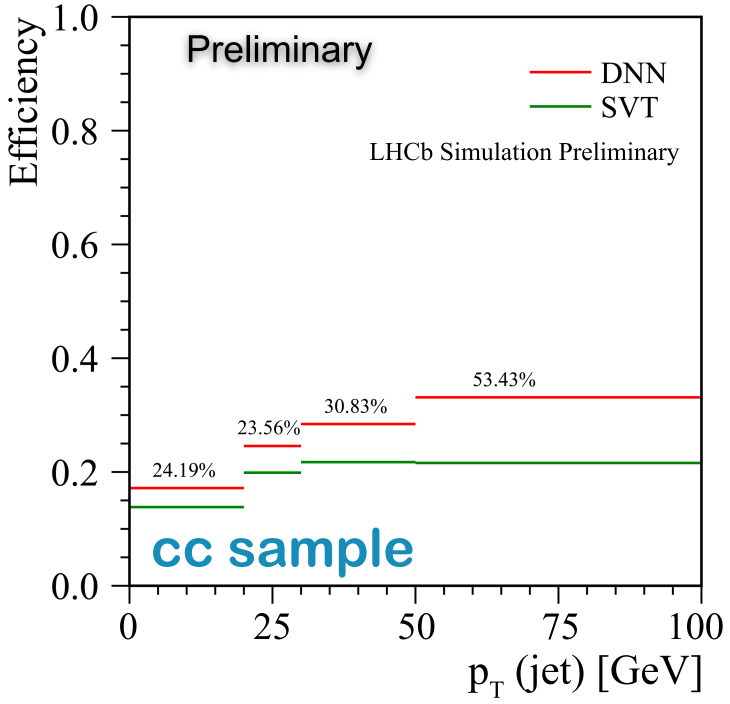
This measurement can then be recast into a measurement of the W mass

Projected full Run 1+2 sensitivity to the W mass with this technique is 12 MeV

ML/AI for Higgs measurements @ LHCb

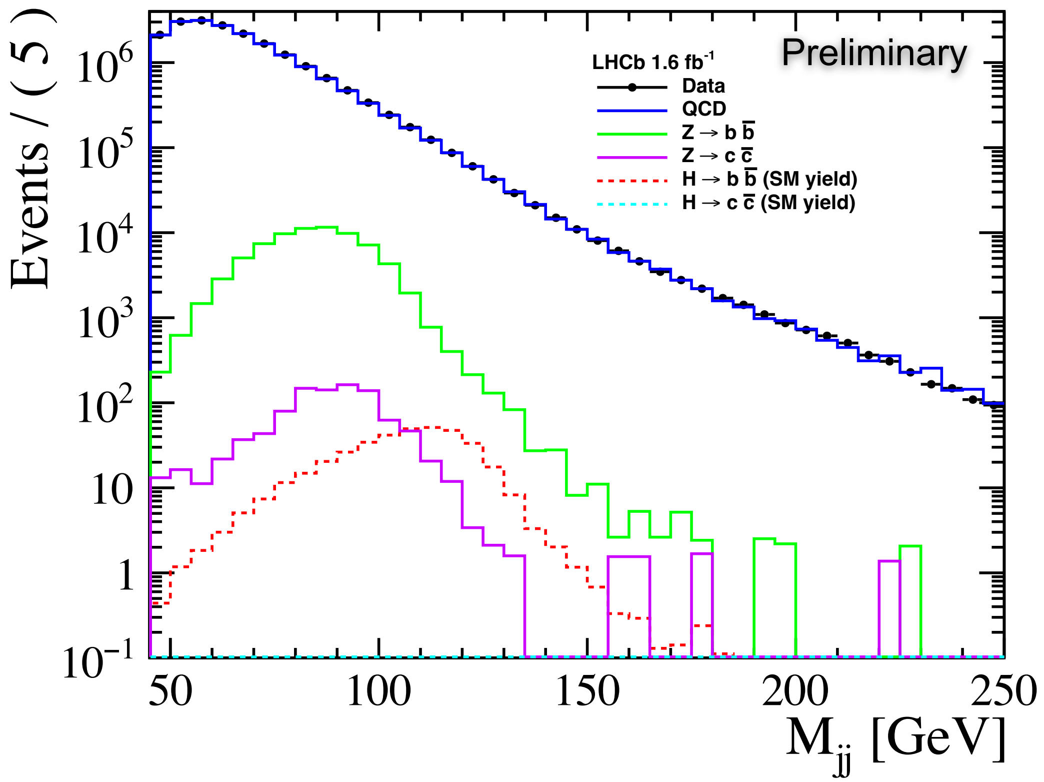
See M. Xu @ T08



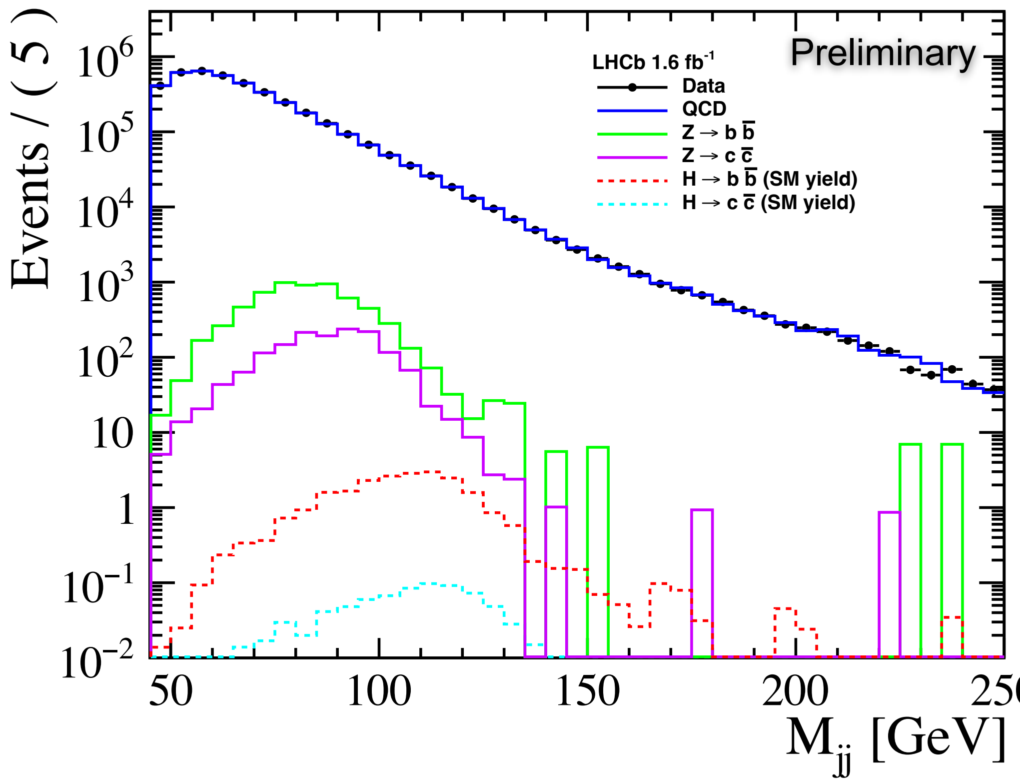


NEW!

bb search



cc search

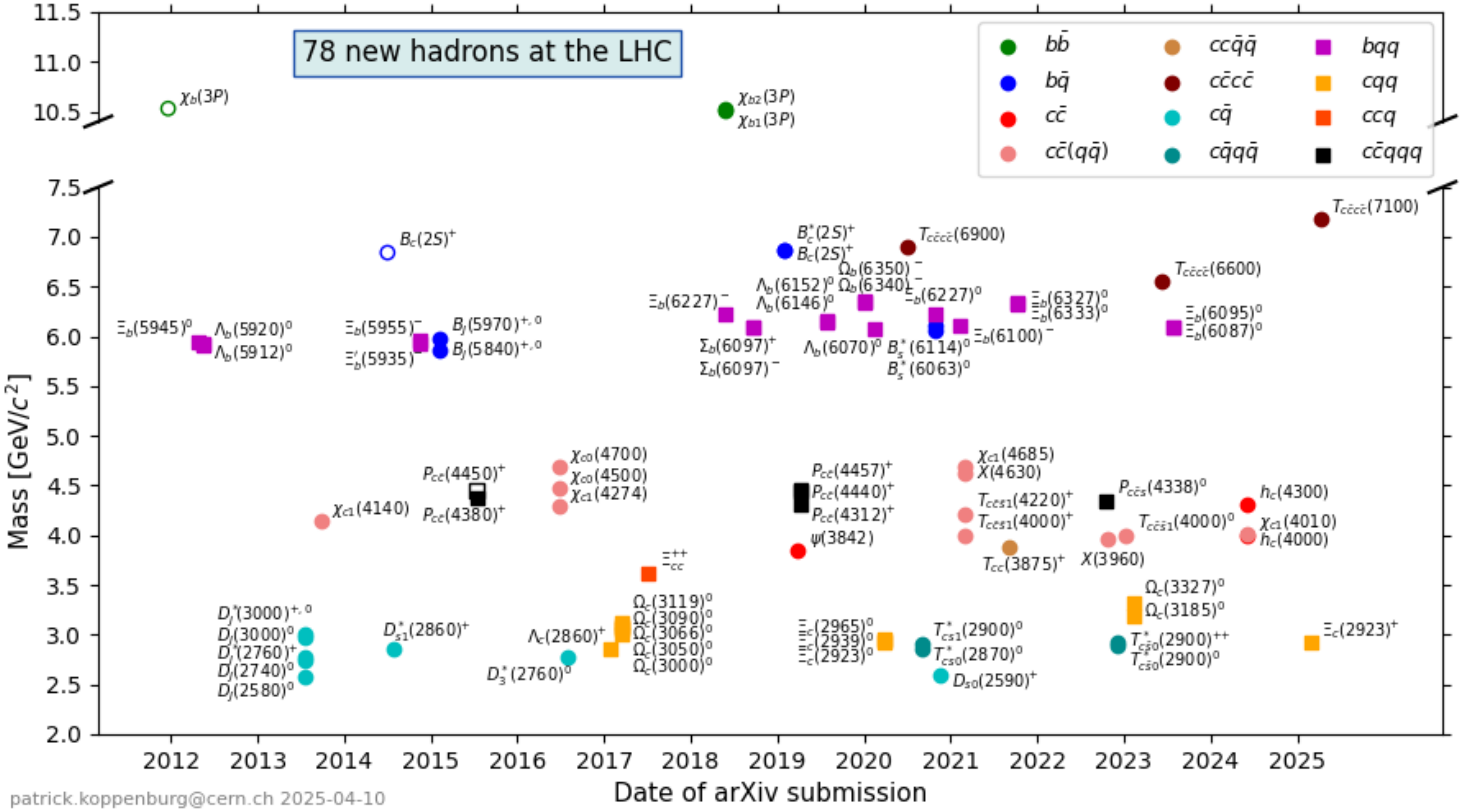


	σ_{UP}/σ_{SM} 2016	σ_{UP}/σ_{SM} Run 2	σ_{UP}/σ_{SM} Run 4	σ_{UP}/σ_{SM} U2
$H \to b\bar{b}$	11.1	6.0	1.1	0.38
$H \to c\bar{c}$	1834	990	141	45

Showcases power of new deep NN jet identification and regression-based jet energy calibration algorithms

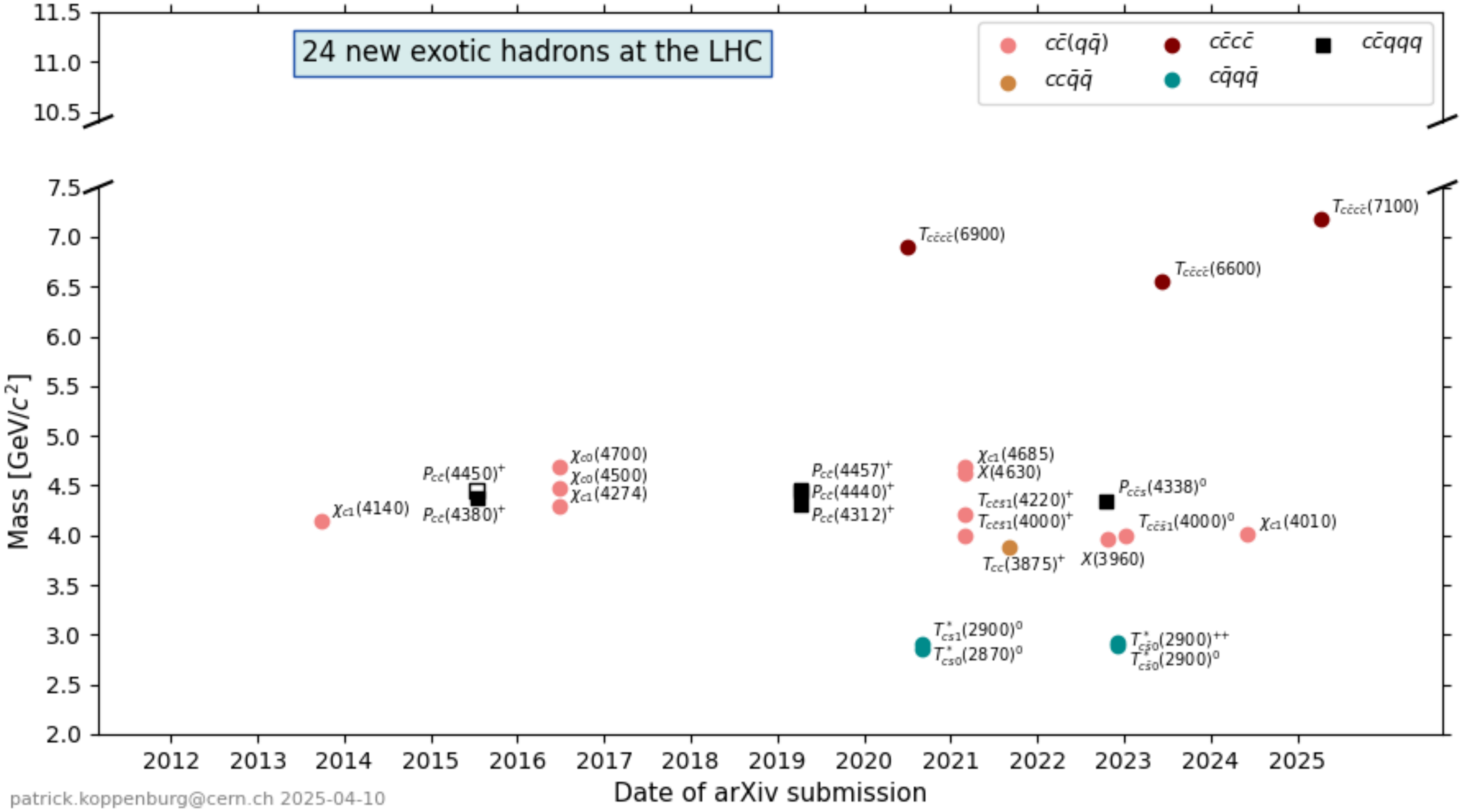
An observation of H→bb with LHCb might be possible in Run 4!

An exotic hadron factory



Credit to Patrick Koppenburg for the picture

An exotic hadron factory

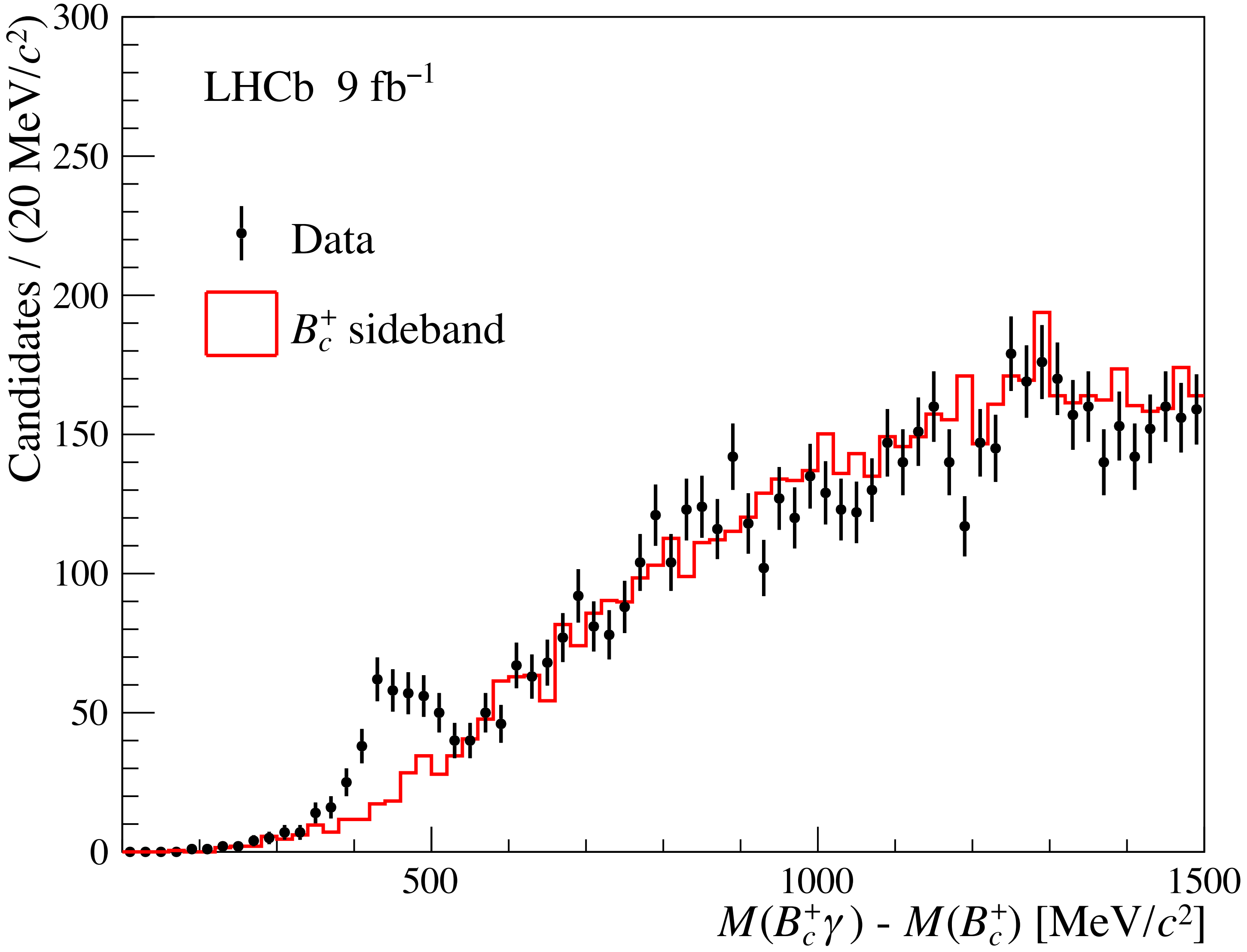


Credit to Patrick Koppenburg for the picture

Spectroscopy highlight: $B_c\gamma$

LHCb-PAPER-2015-014
LHCb-PAPER-2015-015
See Y. Wang @ T05

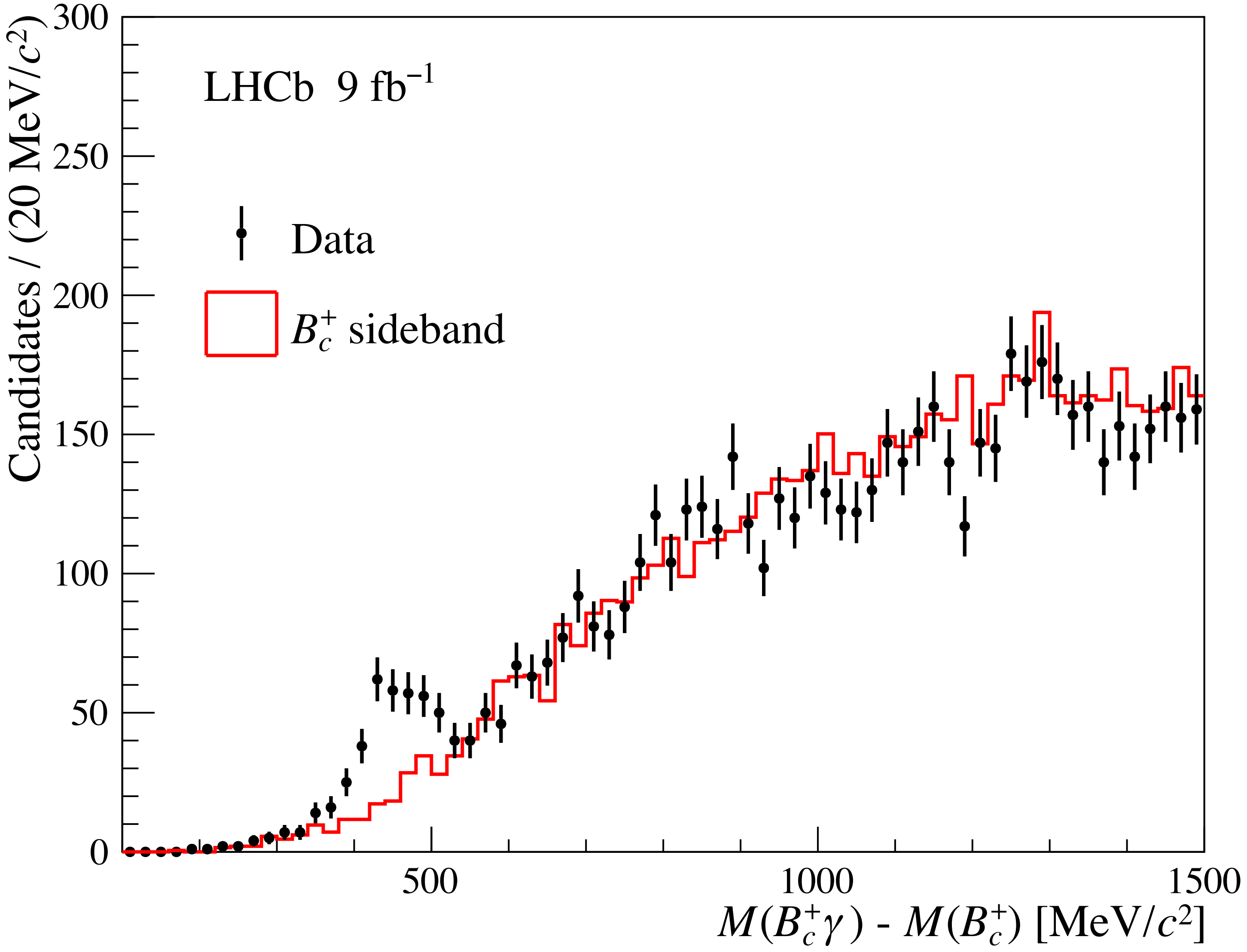
NEW!

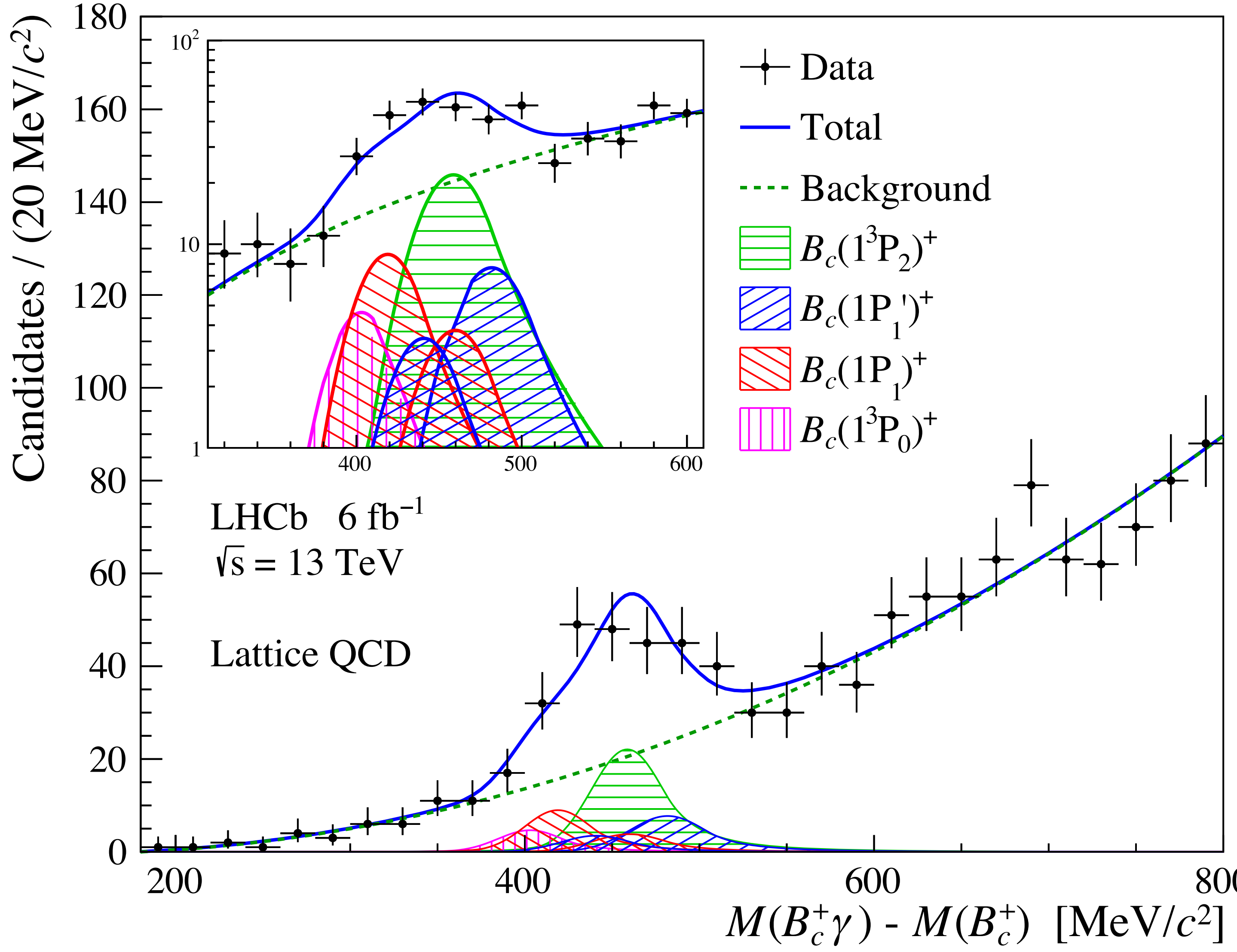


Spectroscopy highlight: $B_c\gamma$

LHCb-PAPER-2015-014
LHCb-PAPER-2015-015
See Y. Wang @ T05

NEW!

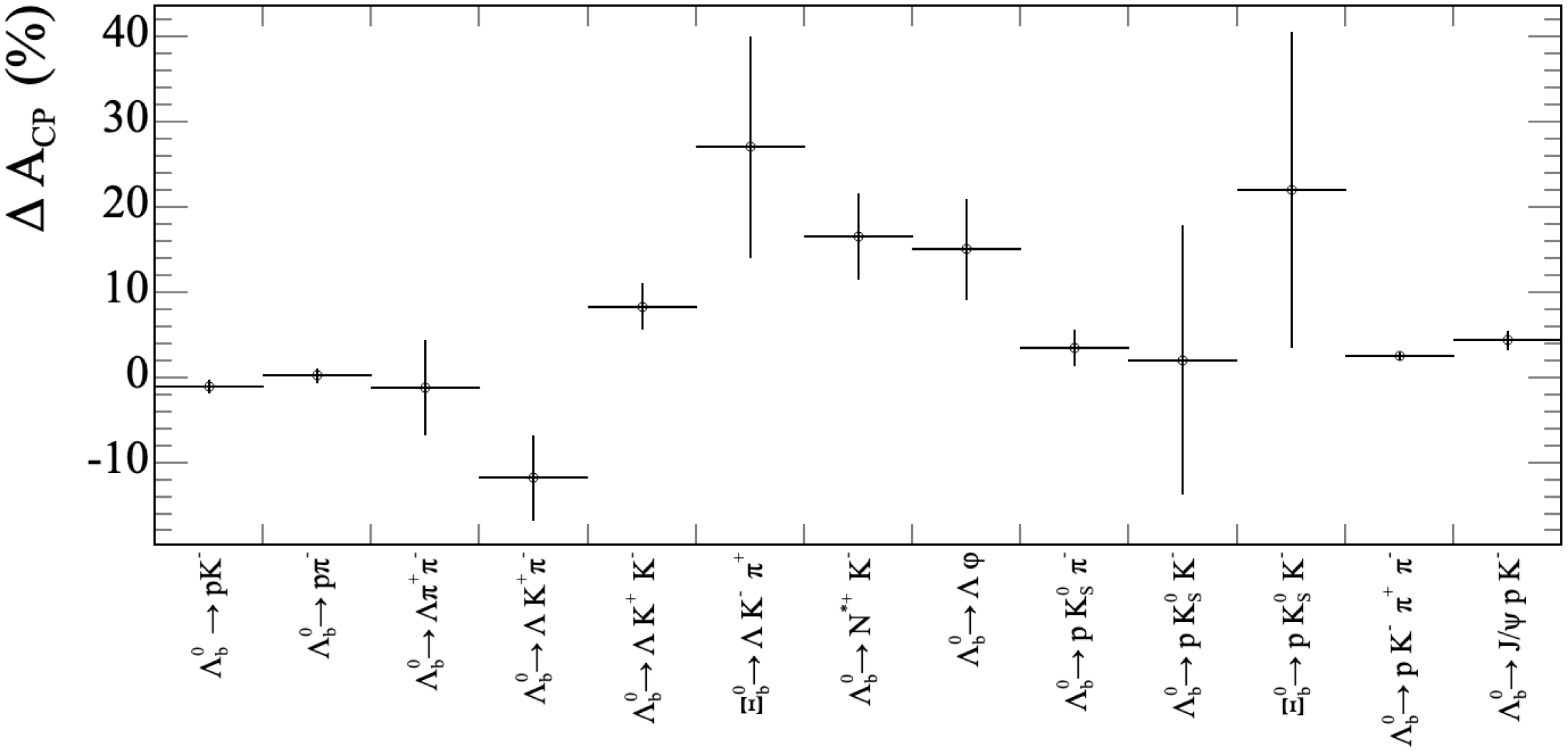




$$R = \frac{N(B_c(1P)^+ \to B_c^+\gamma)}{N(B_c^+)} \cdot \frac{\varepsilon(B_c^+)}{\varepsilon(B_c(1P)^+ \to B_c^+\gamma)} = 0.20 \pm 0.03 \pm 0.03$$

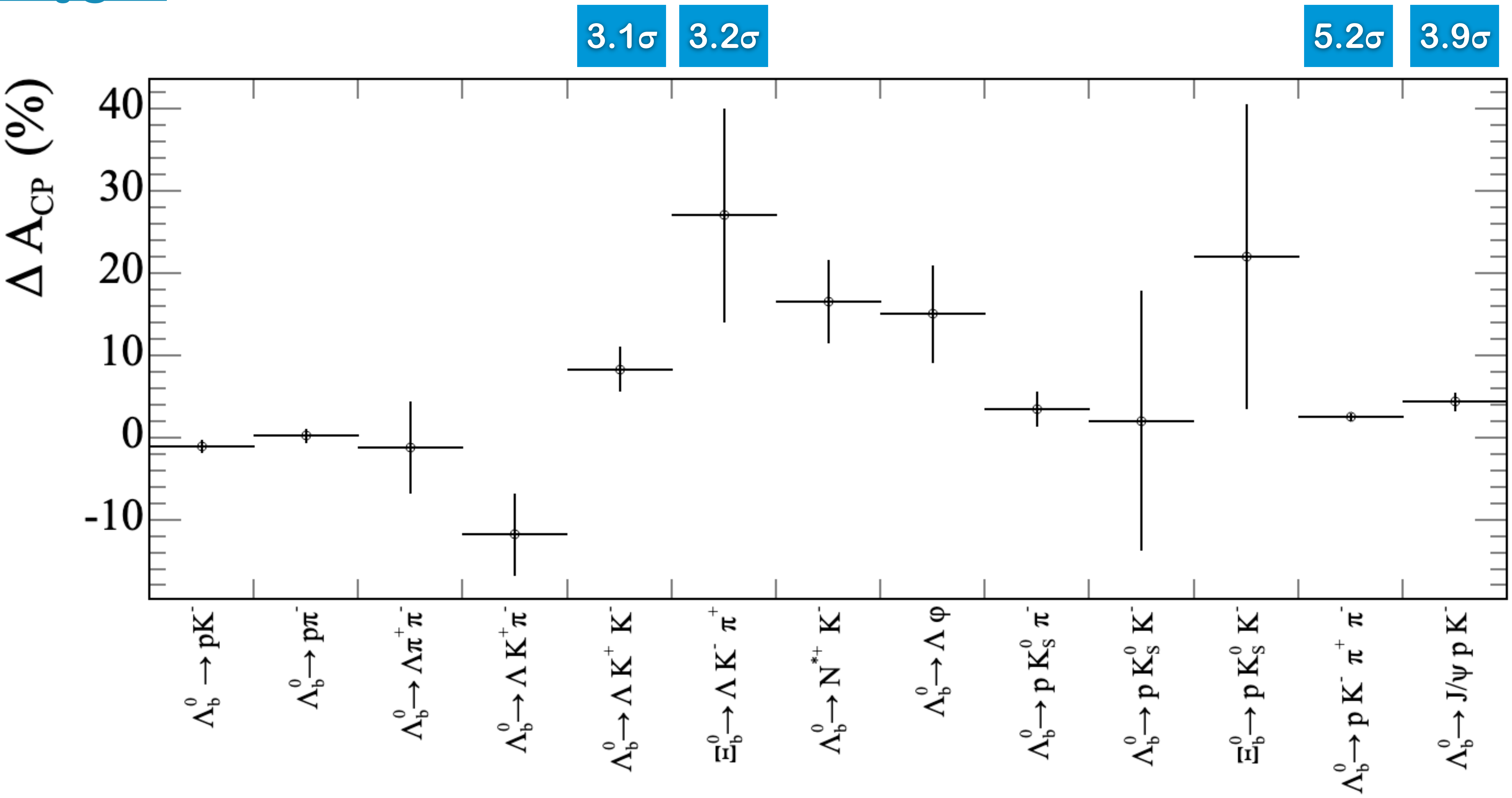
CPV highlight: baryons!

See X. Yang @ T07



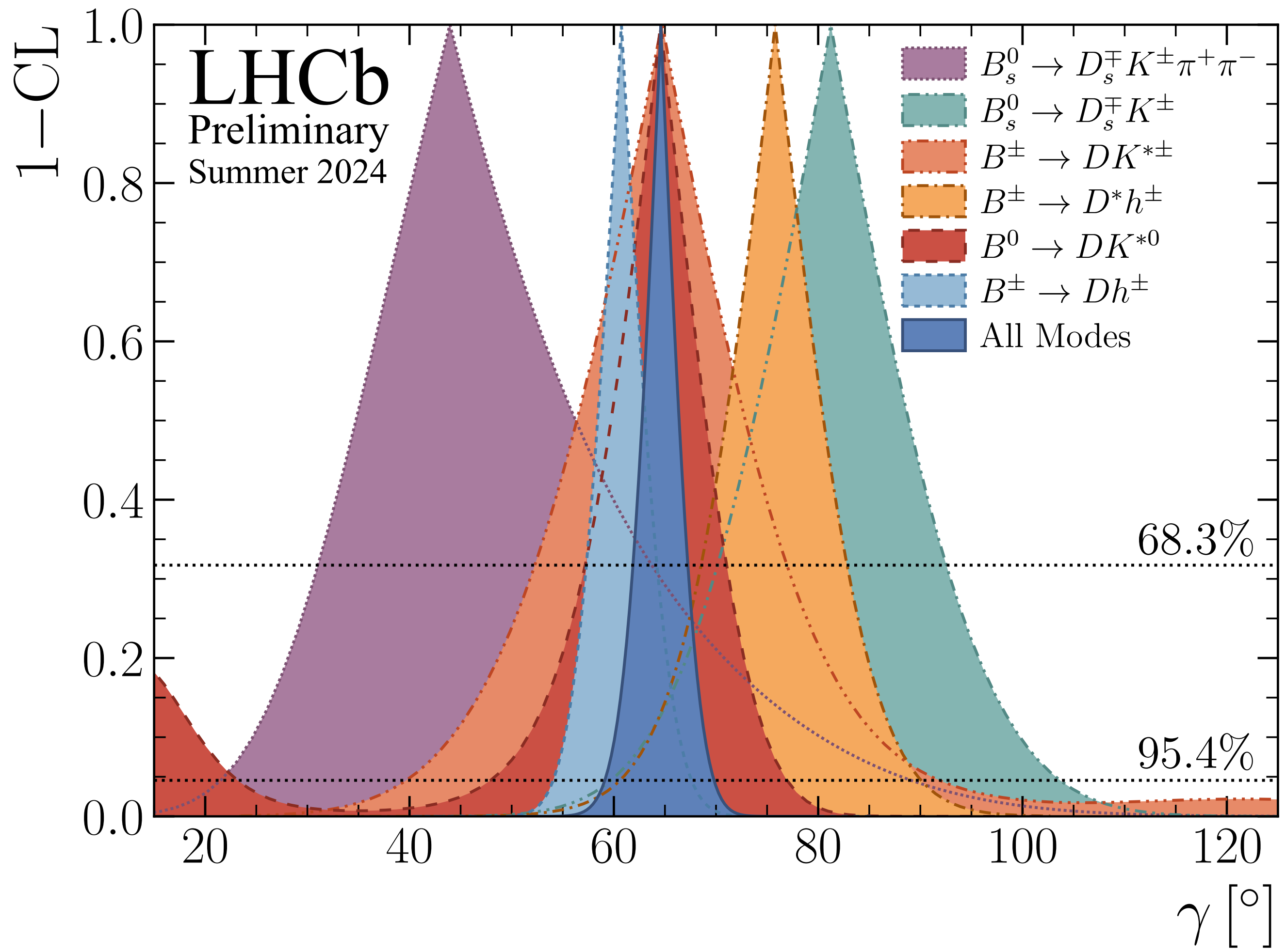
CPV highlight: baryons!

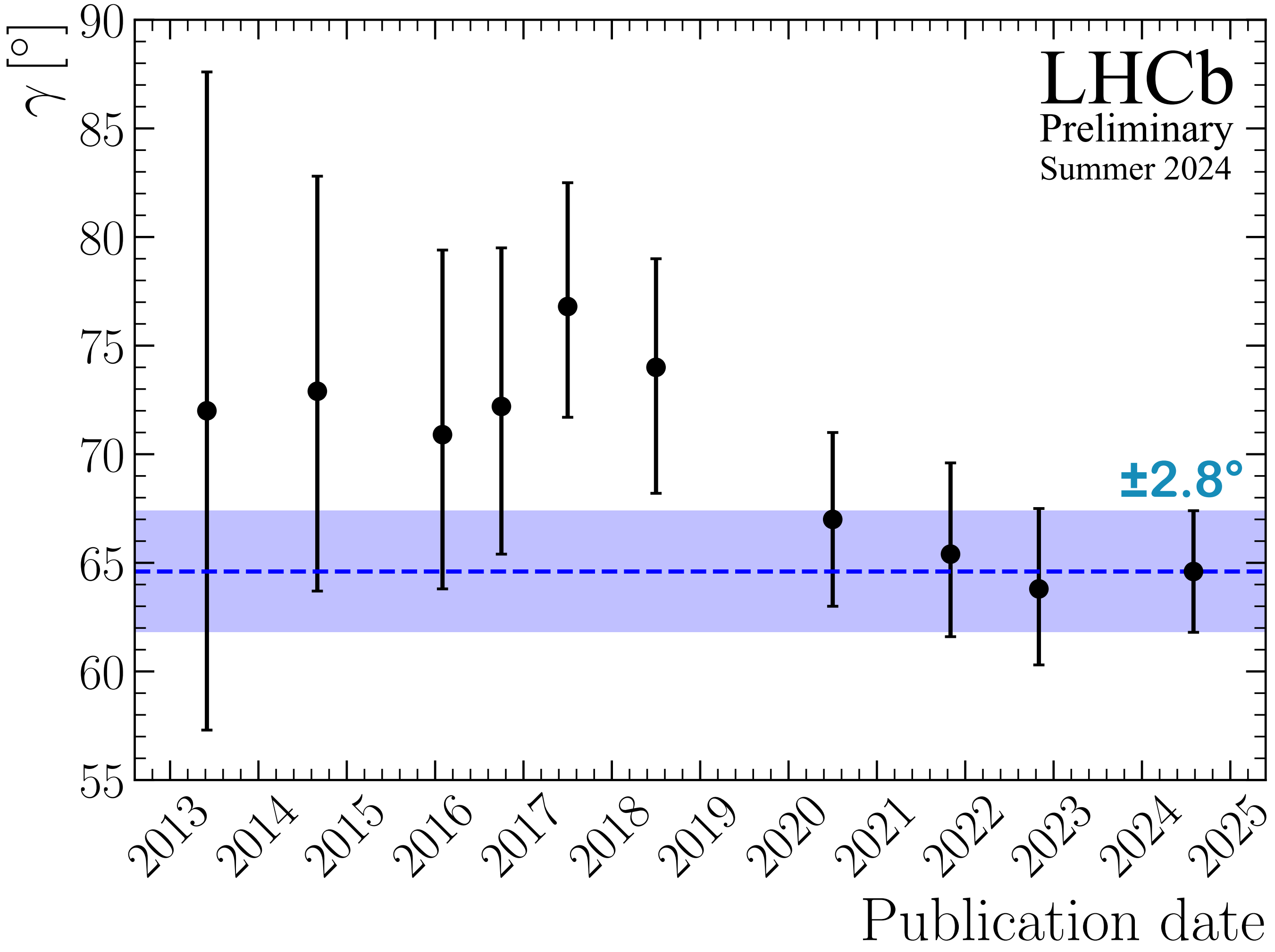
See X. Yang @ T07



CKM state of the art with LHCb in 2025

LHCb conference note 2024-004



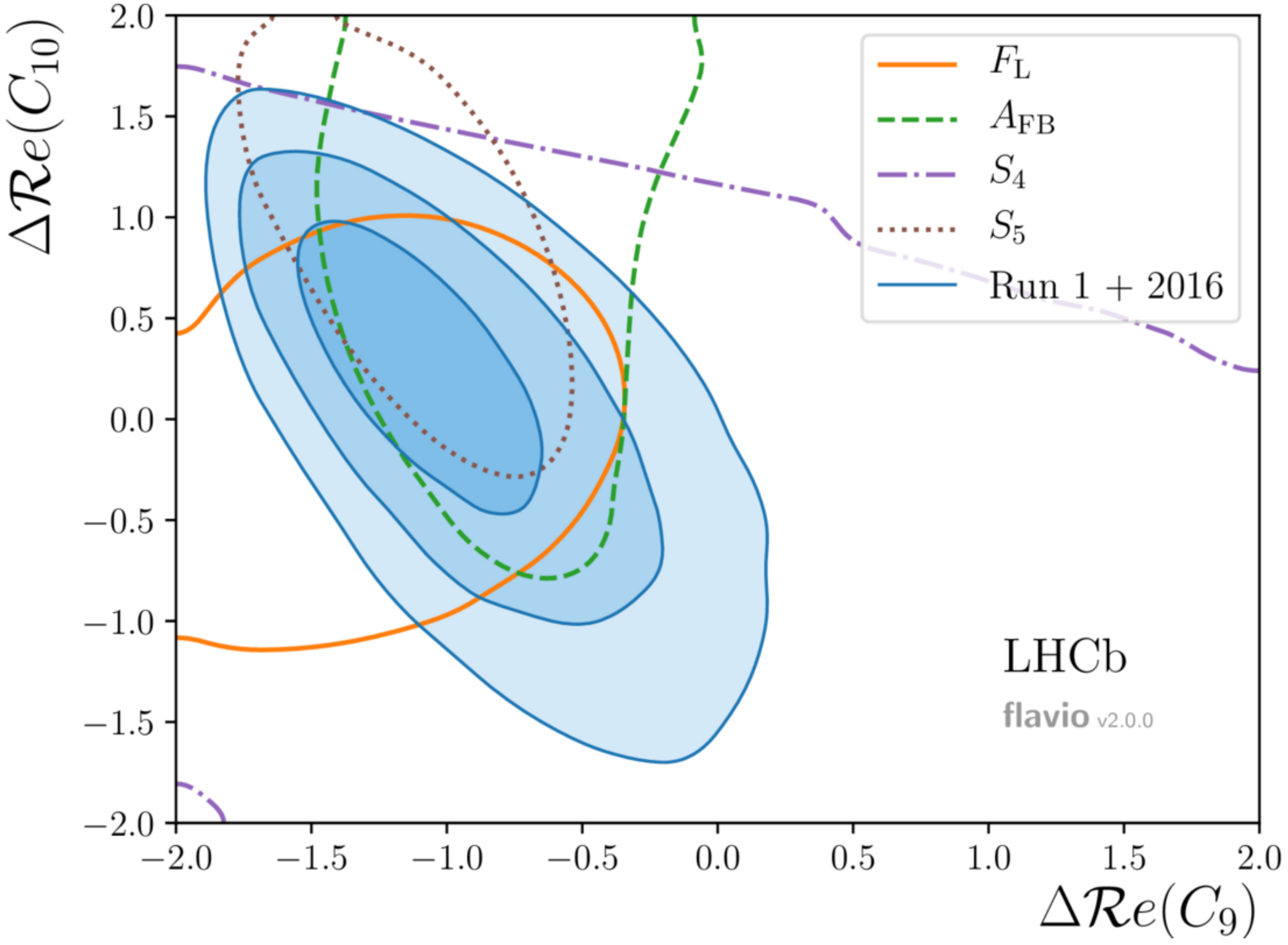


LHCb 2009 measurements roadmap, statistical uncertainty only!
Achieved precision in remarkable agreement with predictions.

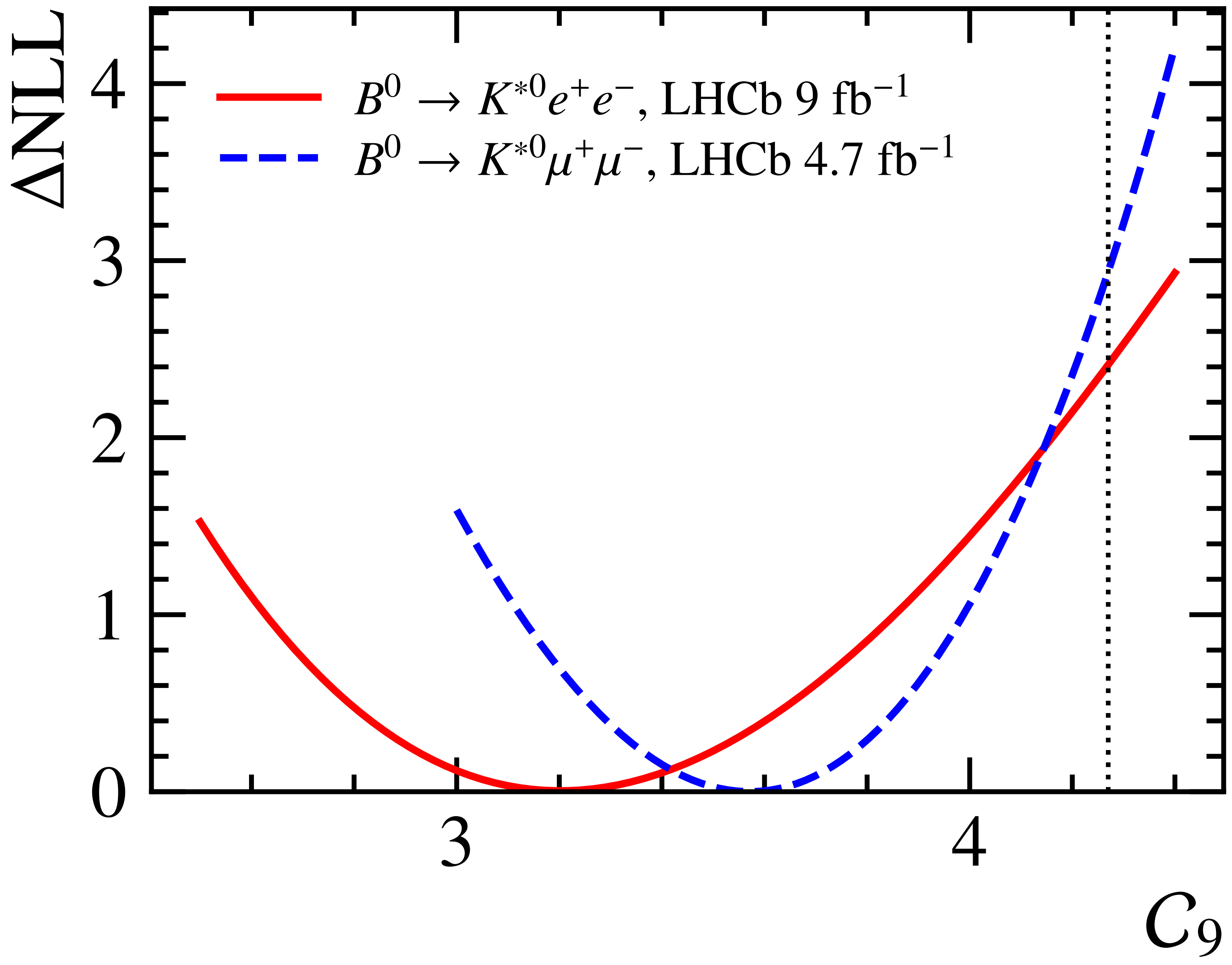
δ_{B^0} (°)	0	45	90	135	180
σ_γ for 0.5 fb^{-1} (°)	8.1	10.1	9.3	9.5	7.8
σ_γ for 2 fb^{-1} (°)	4.1	5.1	4.8	5.1	3.9

b→sll state of the art with LHCb in 2025

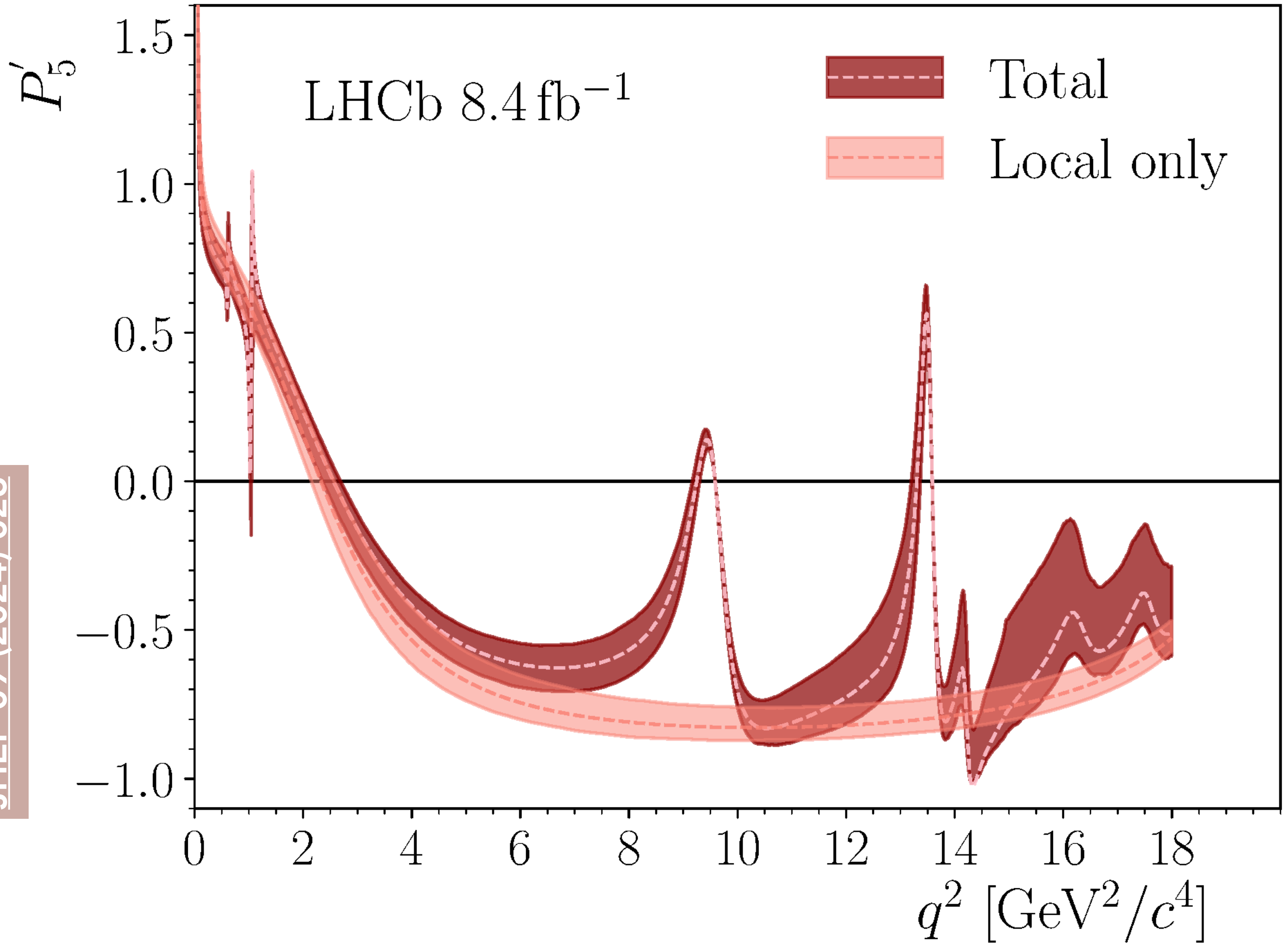
Phys. Rev. Lett. 125 (2020) 011802

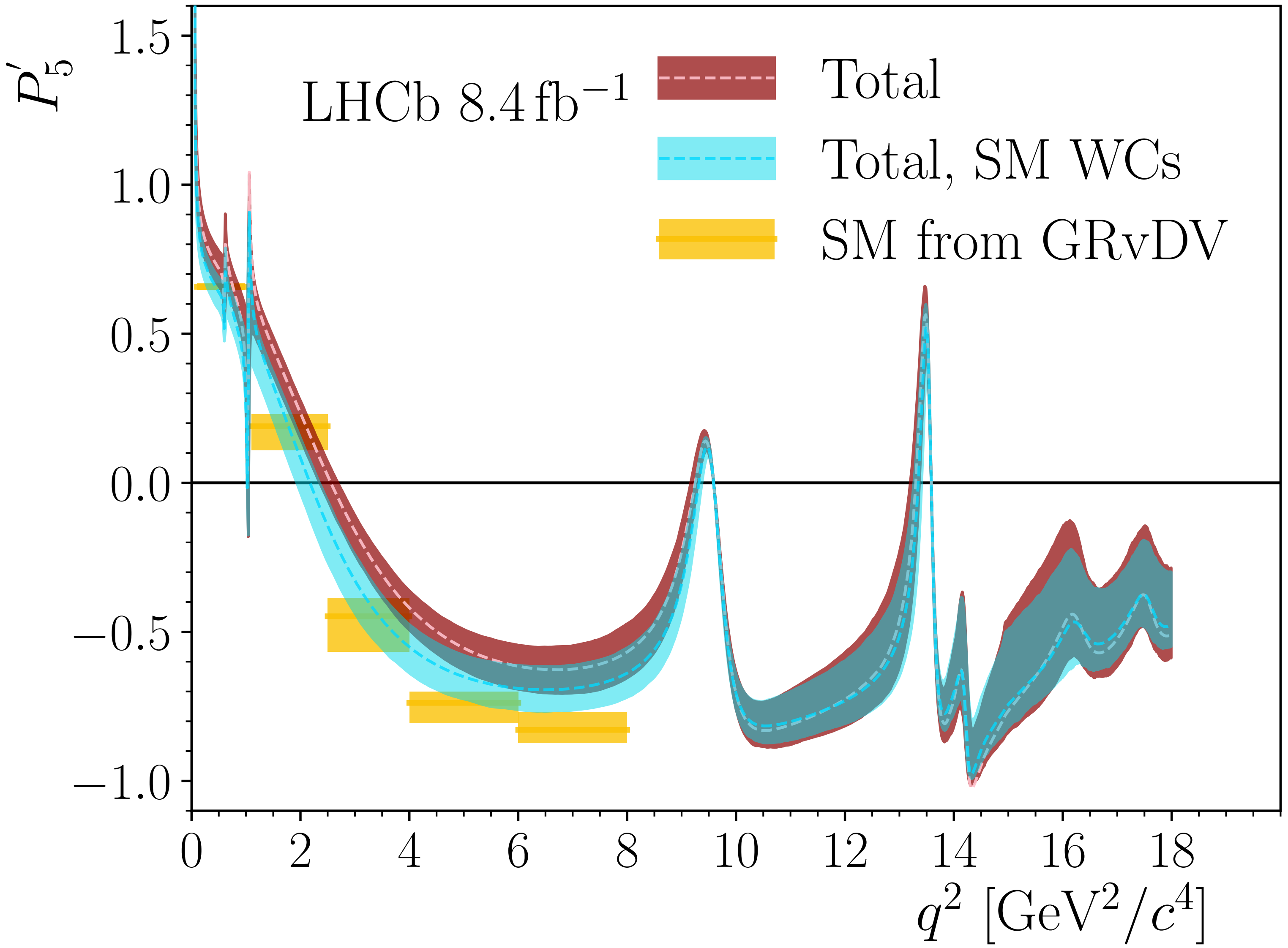


LHCb Paper 2024-022



b→sll state of the art with LHCb in 2025

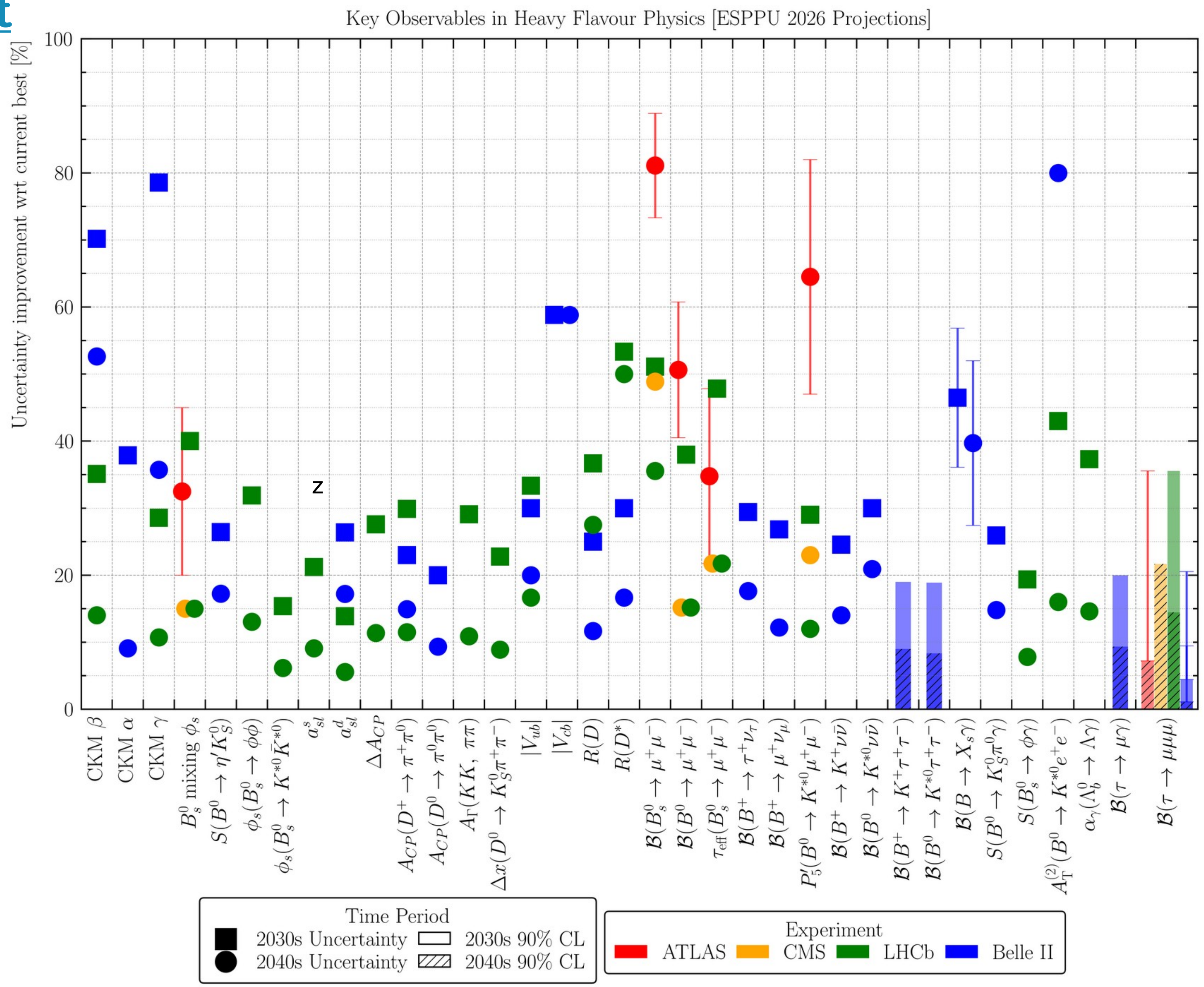




JHEP 09 (2024) 026

So why another LHCb upgrade?

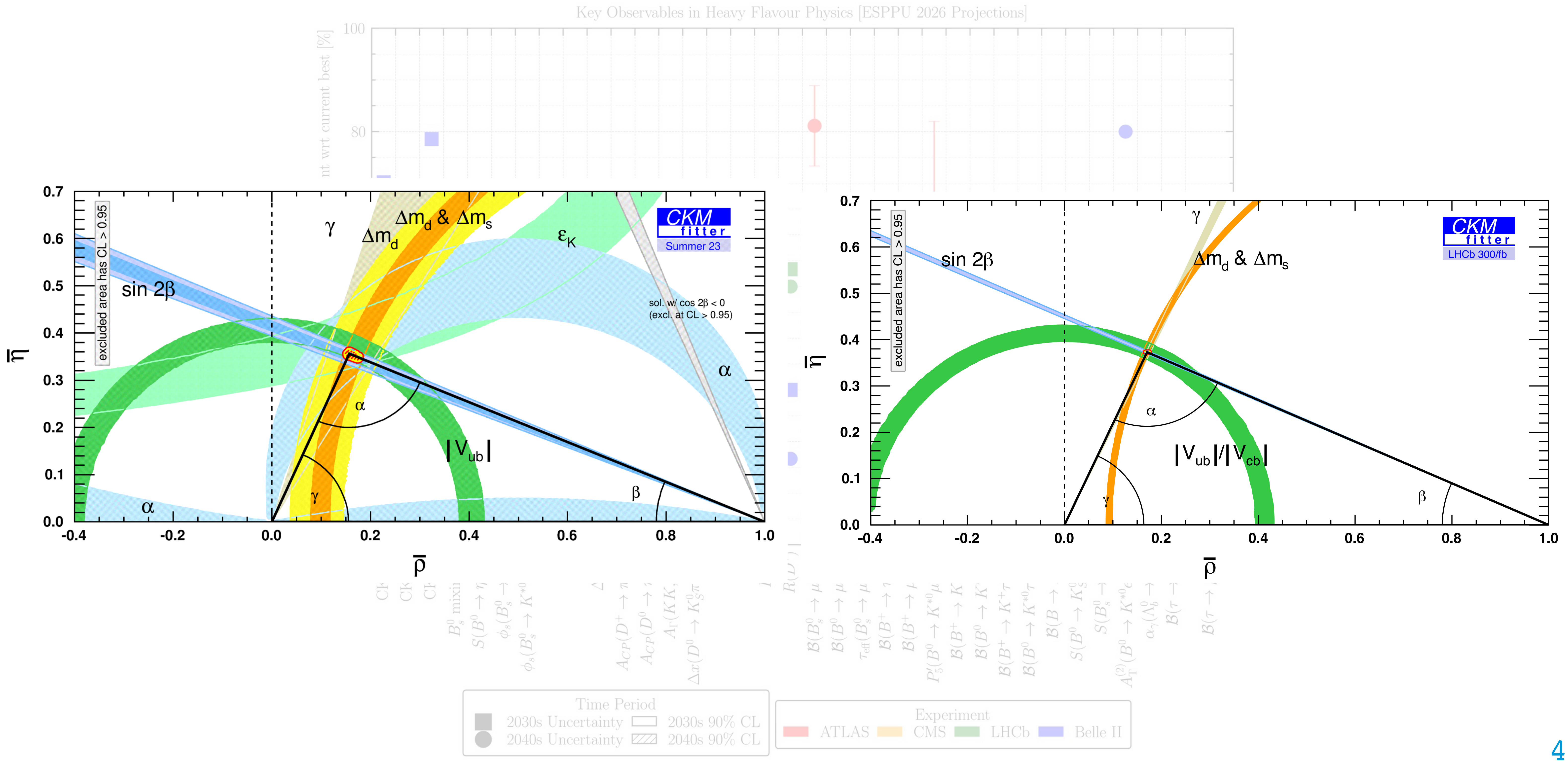
[Joint Flavour ESPPU Input]



Key precision observables remain statistically limited + unique reach for ions, baryons & exotic hadrons

After showing that systematics scale with luminosity in Run 3 – aim to build the best quality U2 detector!

So why another LHCb upgrade?

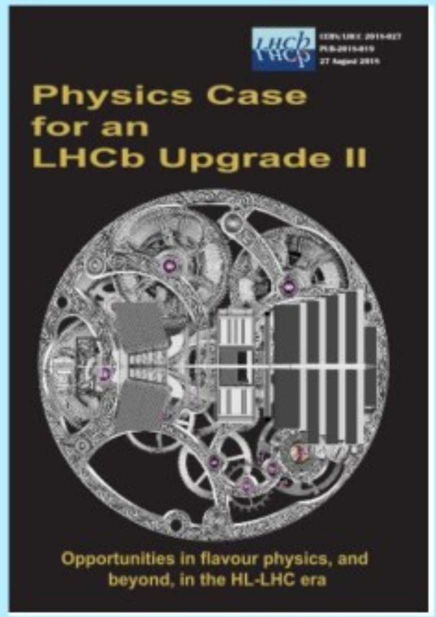


A long journey nears a key checkpoint

EoI

LHCC-2017-003

Physics case



LHCC-2018-027

Accelerator study CERN-ACC-2018-038

CERN Research Board September 2019

"The recommendation to prepare a framework TDR for the LHCb Upgrade-II was endorsed, noting that LHCb is expected to run throughout the HL-LHC era."

European Strategy update 2020

"The full potential of the LHC and the HL-LHC, including the study of flavour physics, should be exploited."

Framework TDR

LHCC-2021-012

Detector design and technology options

R&D program and schedule

Cost for baseline, options for descoping

National interests

Approved by LHCC March 2022

"The **LHCC recommends** that LHCb continue the R&D necessary to complete technical design reports on the proposed schedule, …"

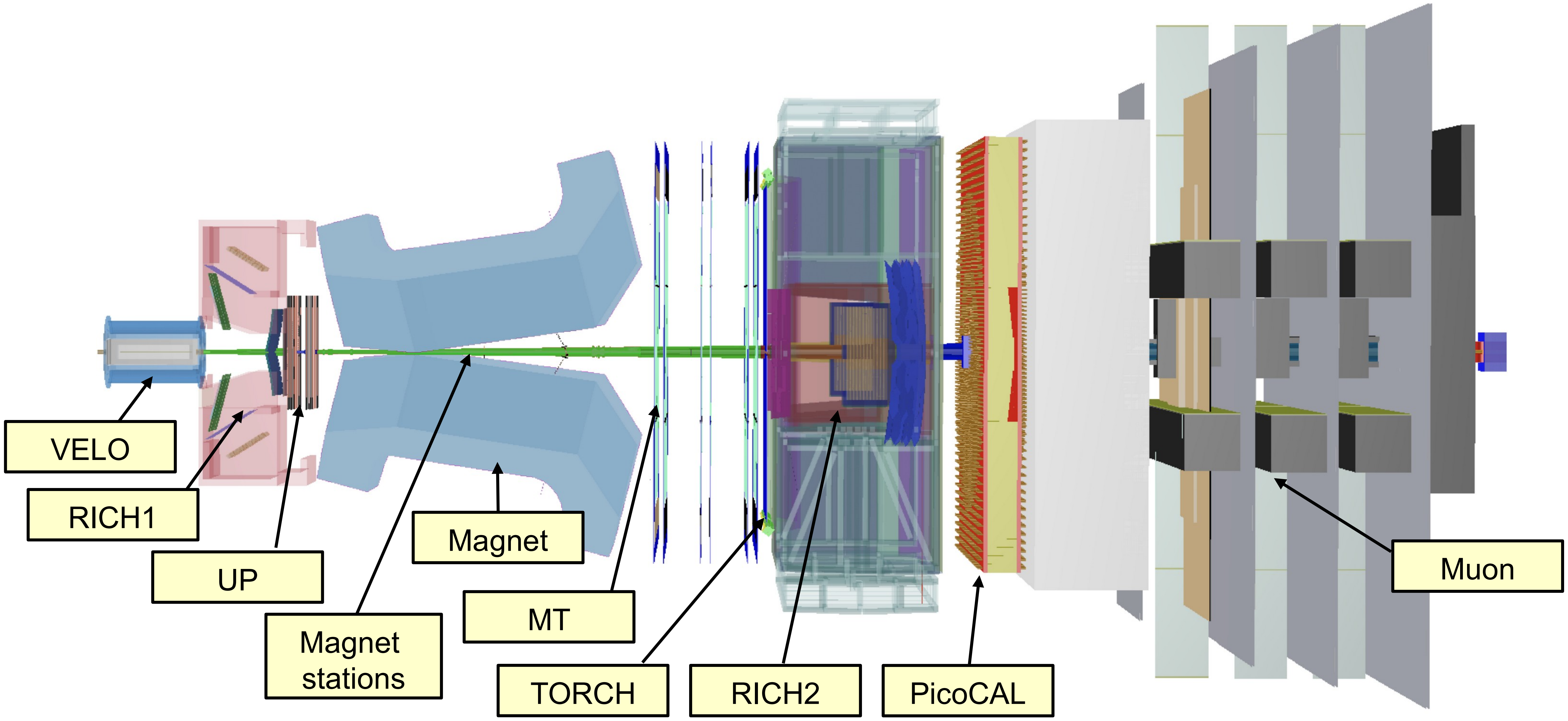
"The **LHCC recommends** the continued investigation of descoping and other cost-saving possibilities. …"

"The **LHCC recommends** that a well-defined process to establish the financial envelope prior to the preparation of TDRs be set up and notes that close coordination with funding agencies will likely be required in this process.

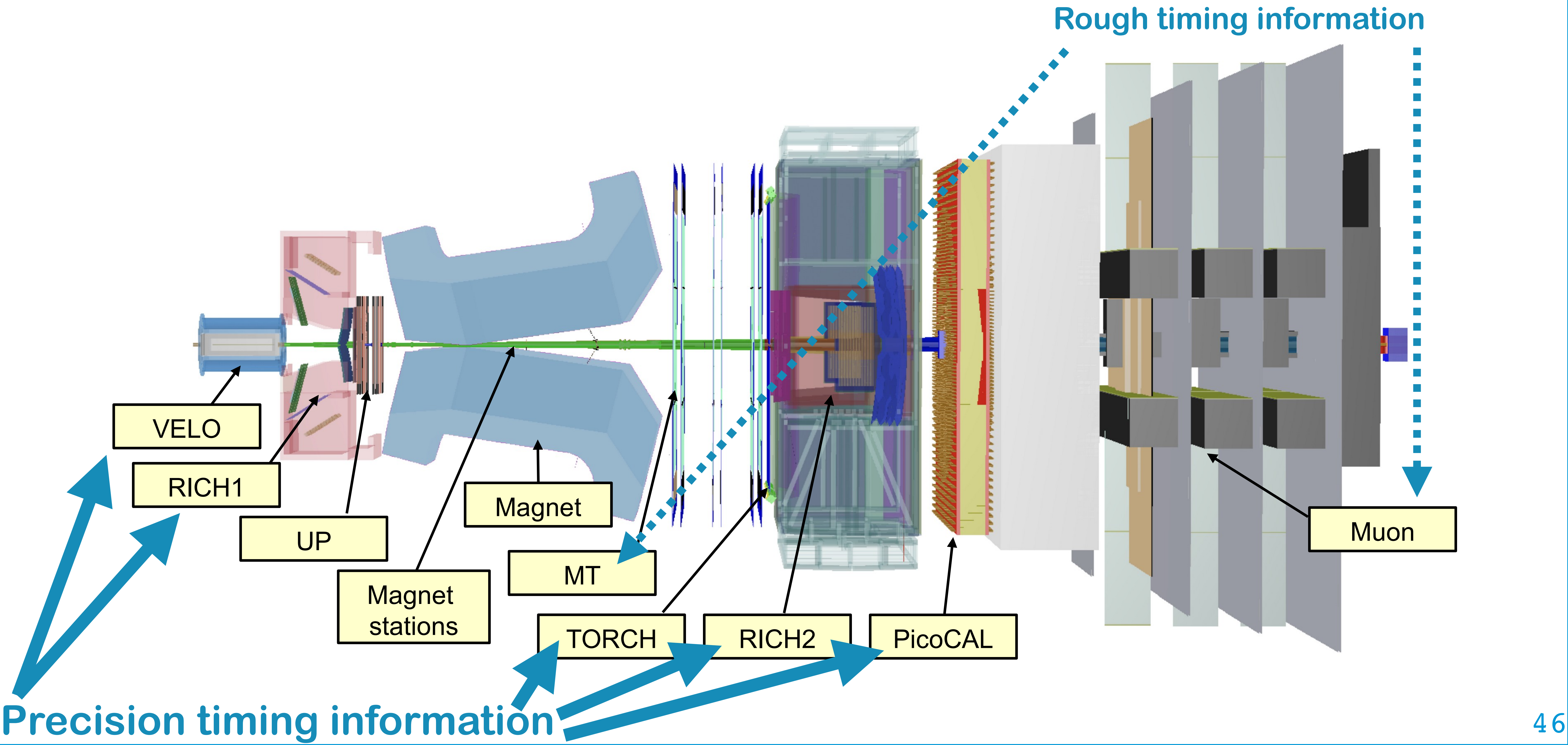
Scoping document

Collaboration is focused on middle scoping scenario as advised by the research board.

LHCb Upgrade 2 detector layout today

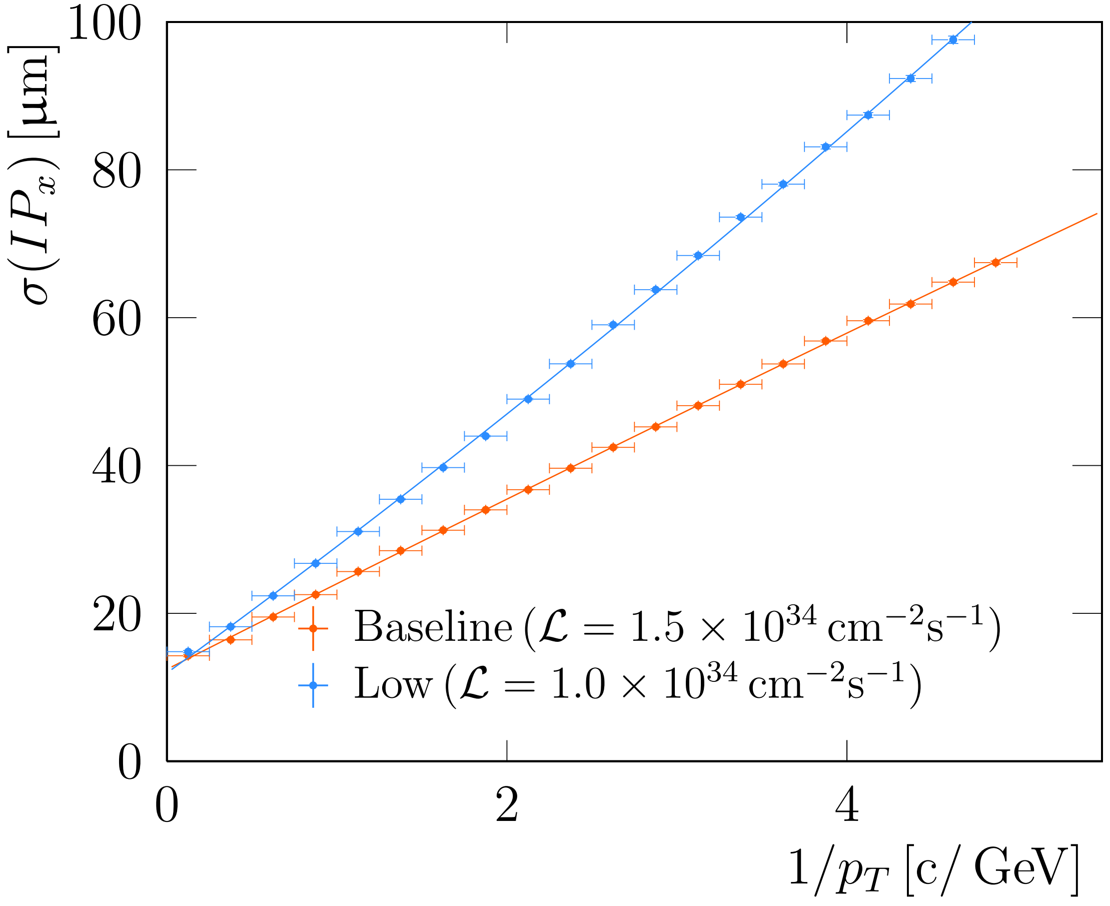


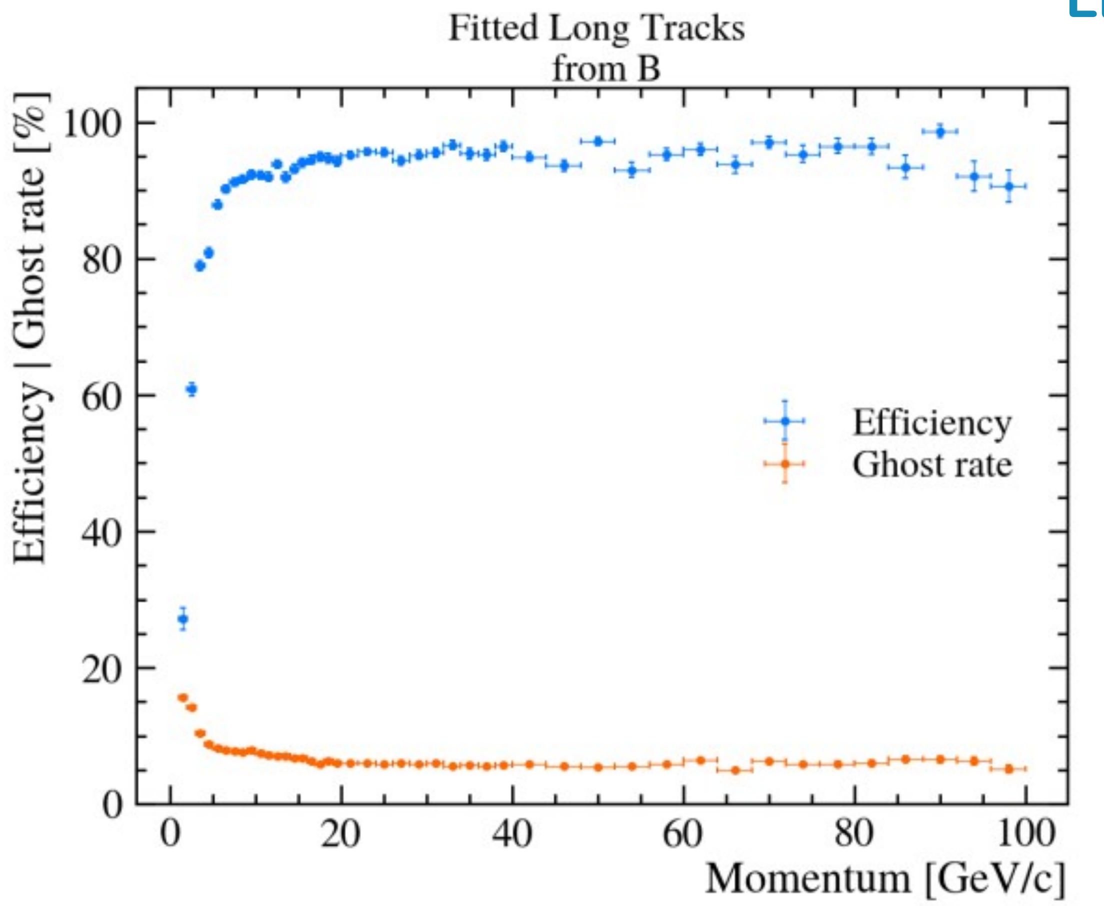
A truly four-dimensional detector

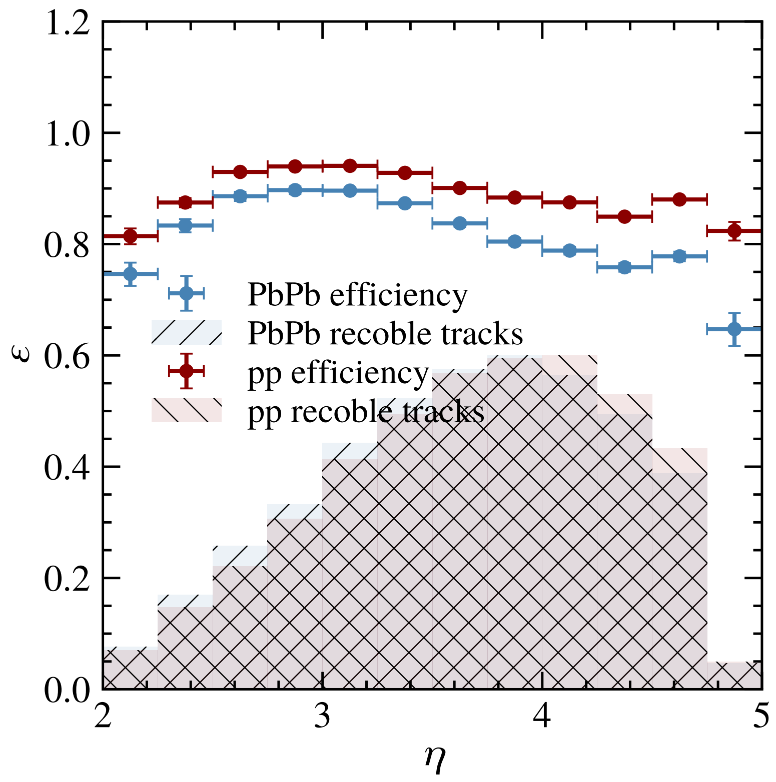


LHCb U2: tracking

LHCb Upgrade 2 Scoping Document







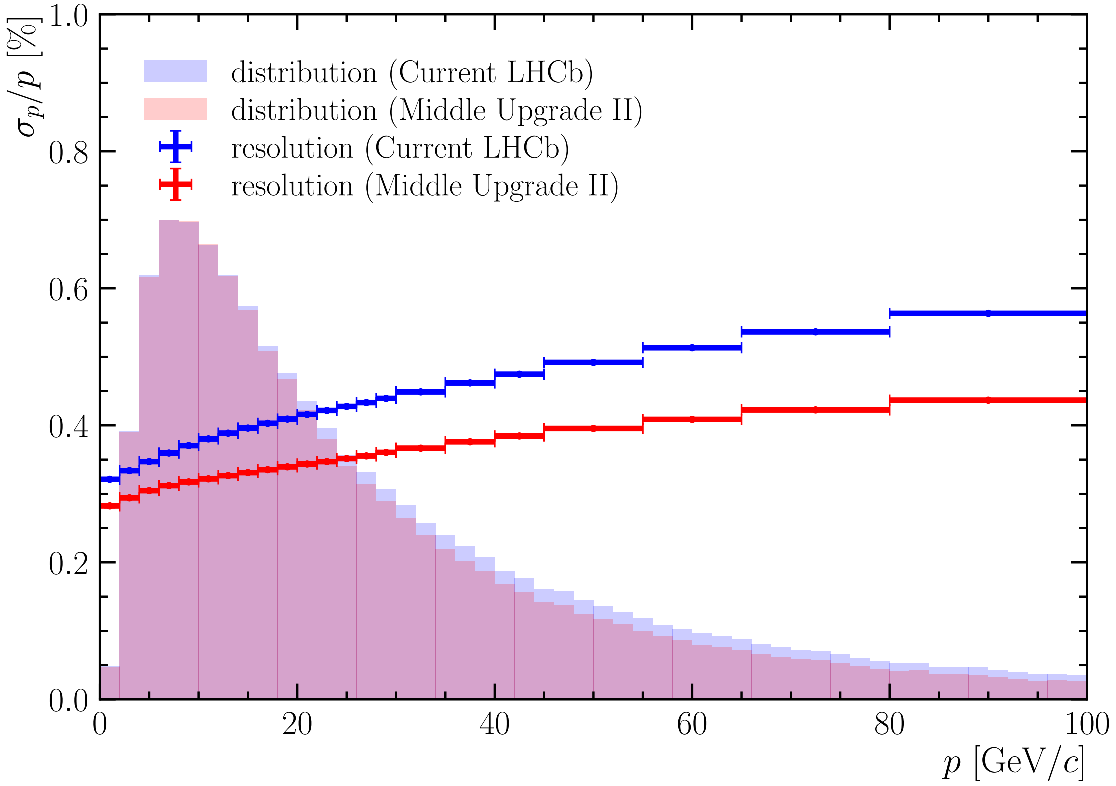
Channel	Relative acceptance %	
	Middle	Low
$B_s^0 \to \mu^+\mu^-$	99.3 ± 0.1	95.3 ± 0.1
$B_s^0 \to \phi(\to K^+K^-)\phi(\to K^+K^-)$	99.4 ± 0.1	90.6 ± 0.2
$D^0 \to K_S^0(\to \pi^+\pi^-)\pi^+\pi^-$	99.7 ± 0.1	84.8 ± 0.8

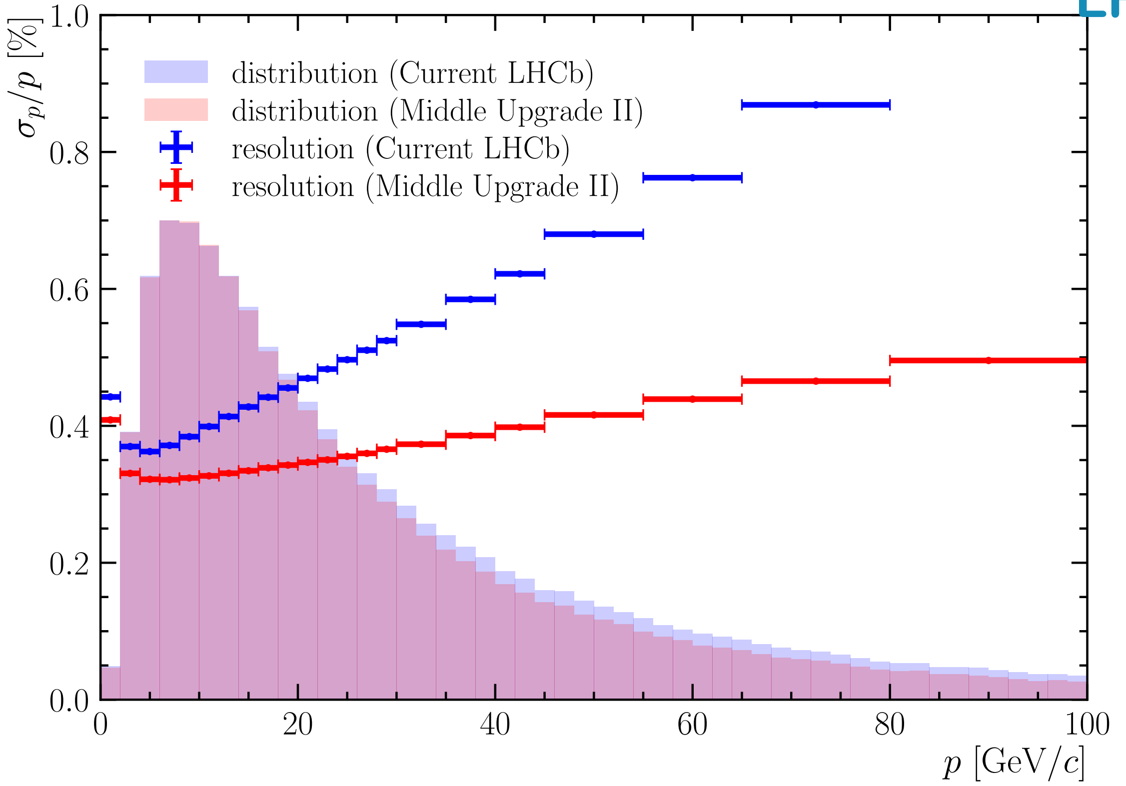
The design ensures high efficiencies with acceptable fake rates!

Similar tracking efficiencies for pp and PbPb will allow reconstruction of the most central collisions.

LHCb U2: tracking (2)

LHCb Upgrade 2 Scoping Document

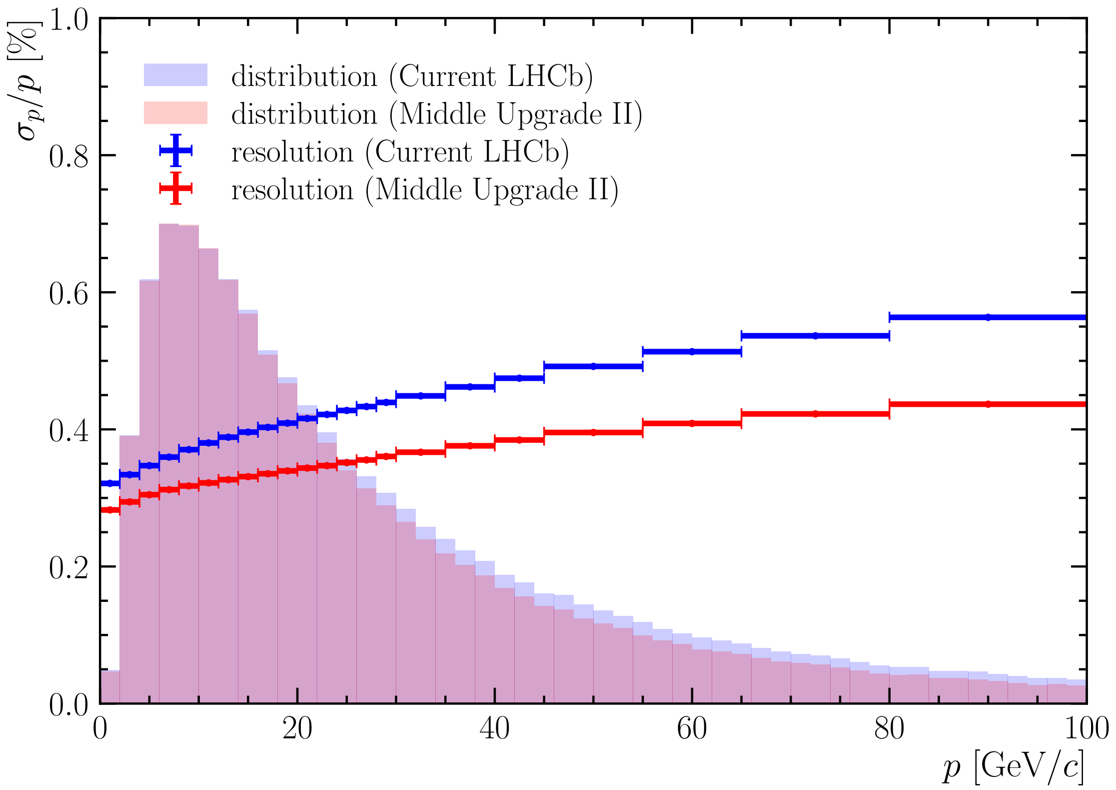


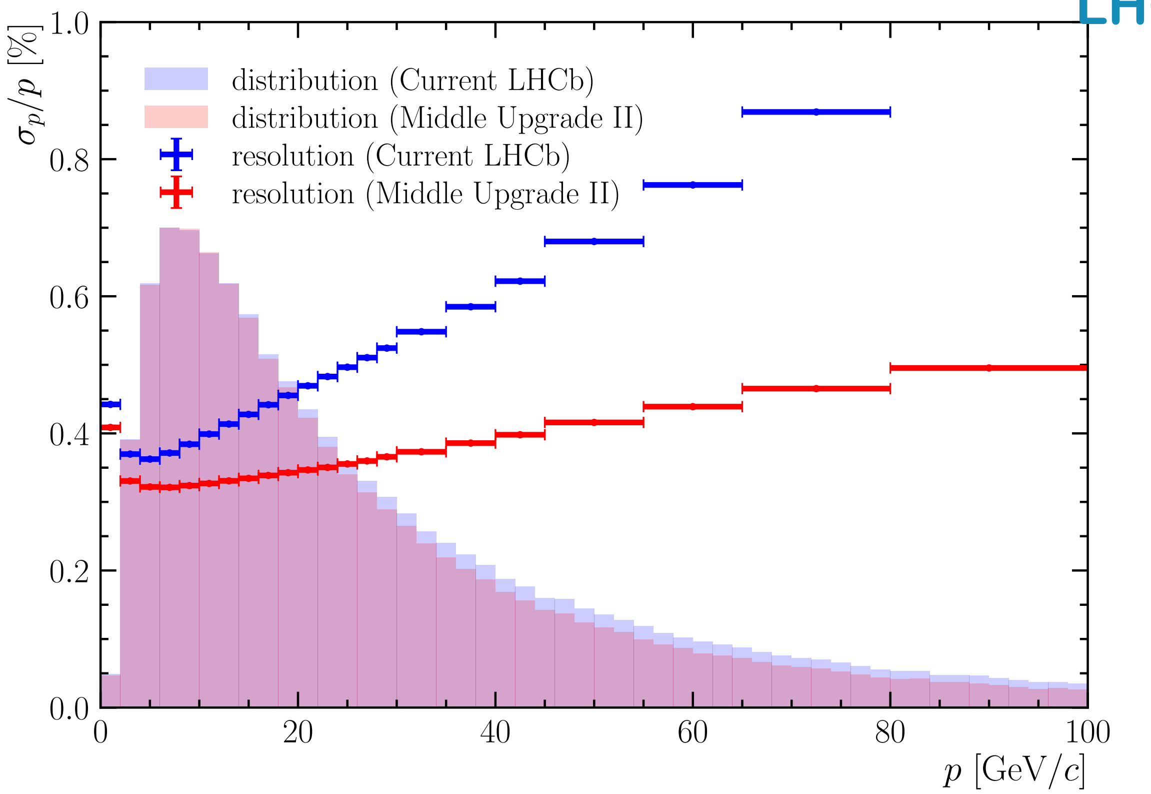


UP + MT (pixels) significantly improves momentum resolution compared to U1 LHCb!

LHCb U2: tracking (3)

LHCb Upgrade 2 Scoping Document





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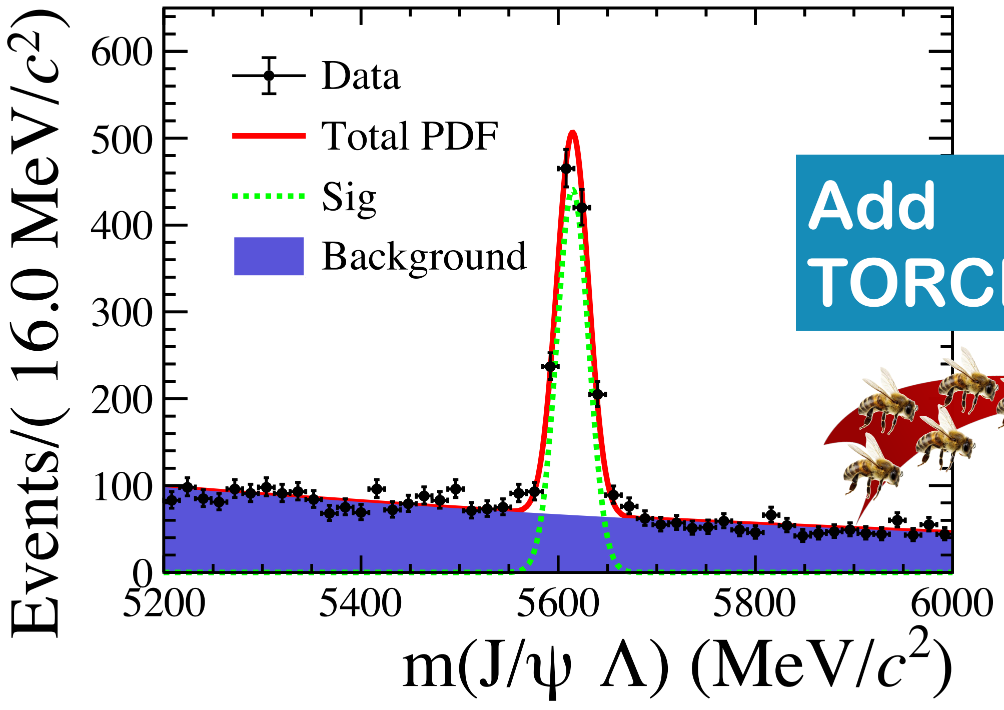
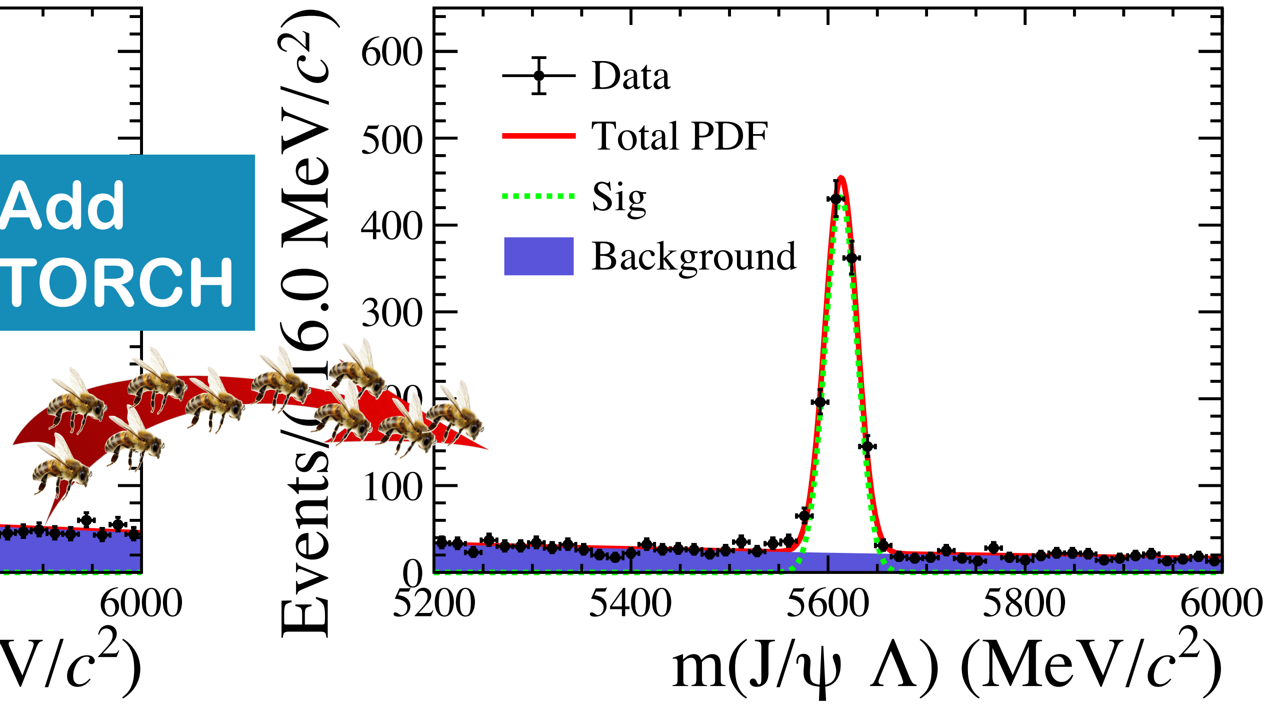


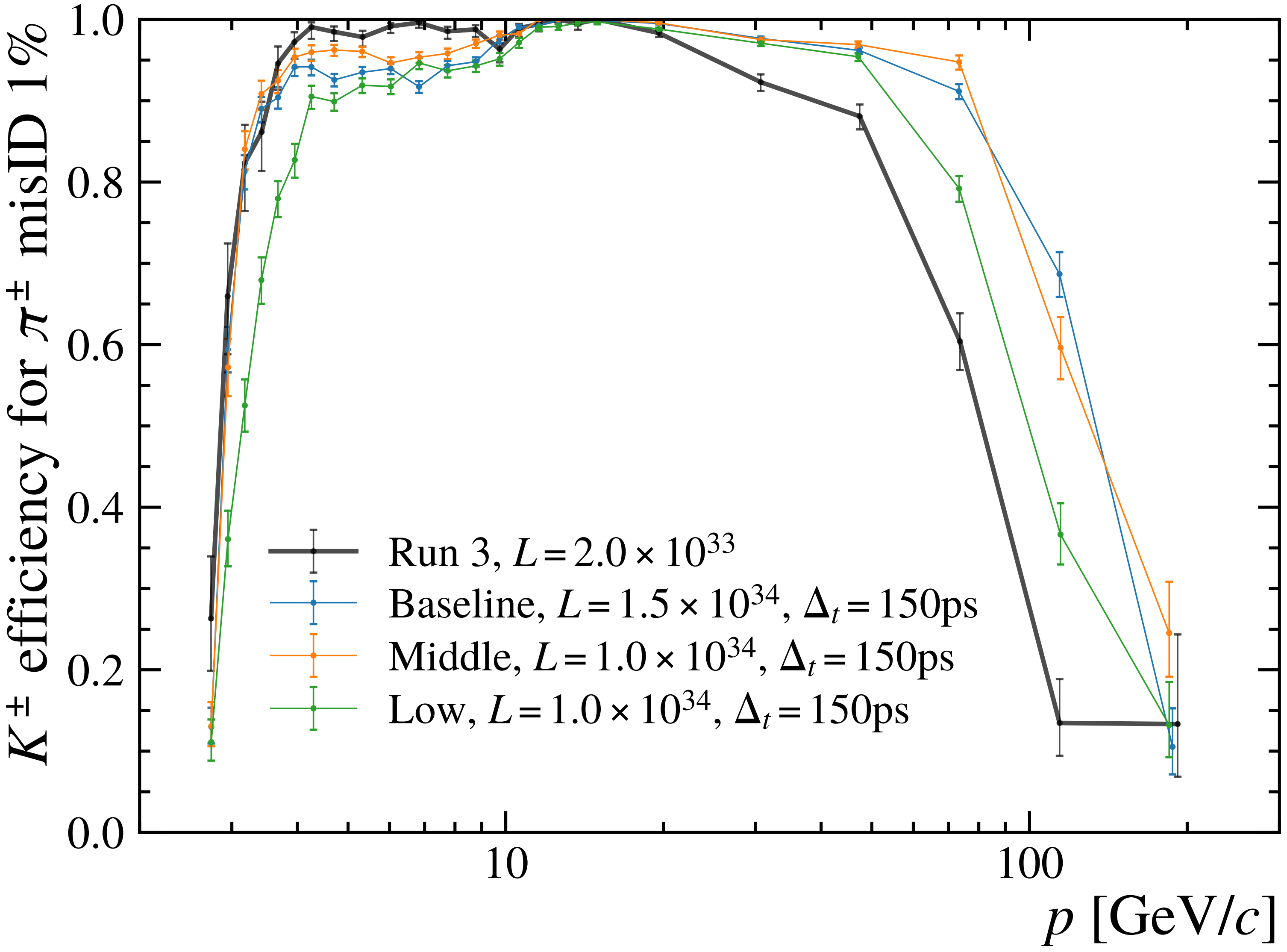
Add TORCH

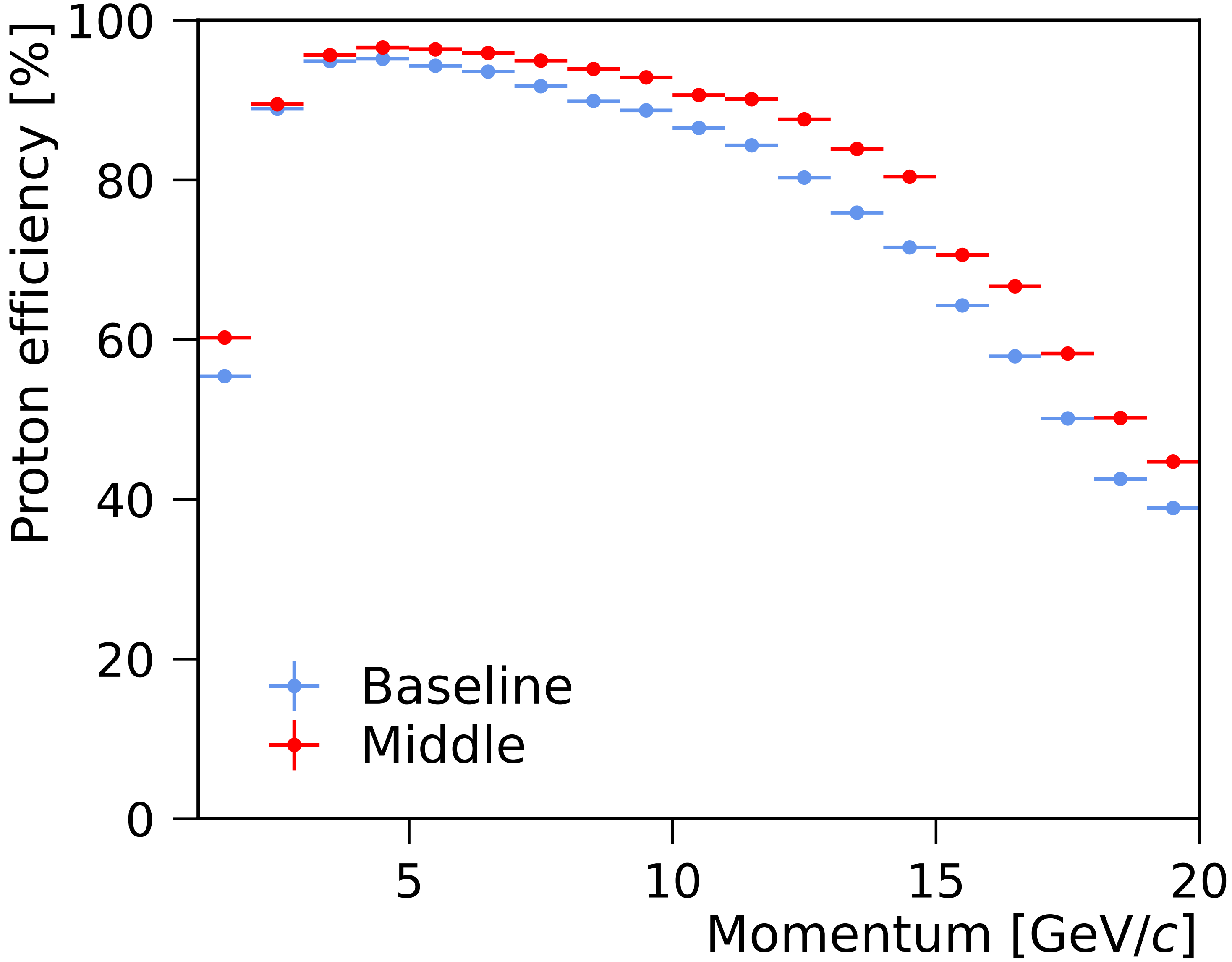


TORCH timing can help suppress backgrounds in tracks without a VELO segment.

LHCb U2: particle identification

LHCb Upgrade 2 Scoping Document



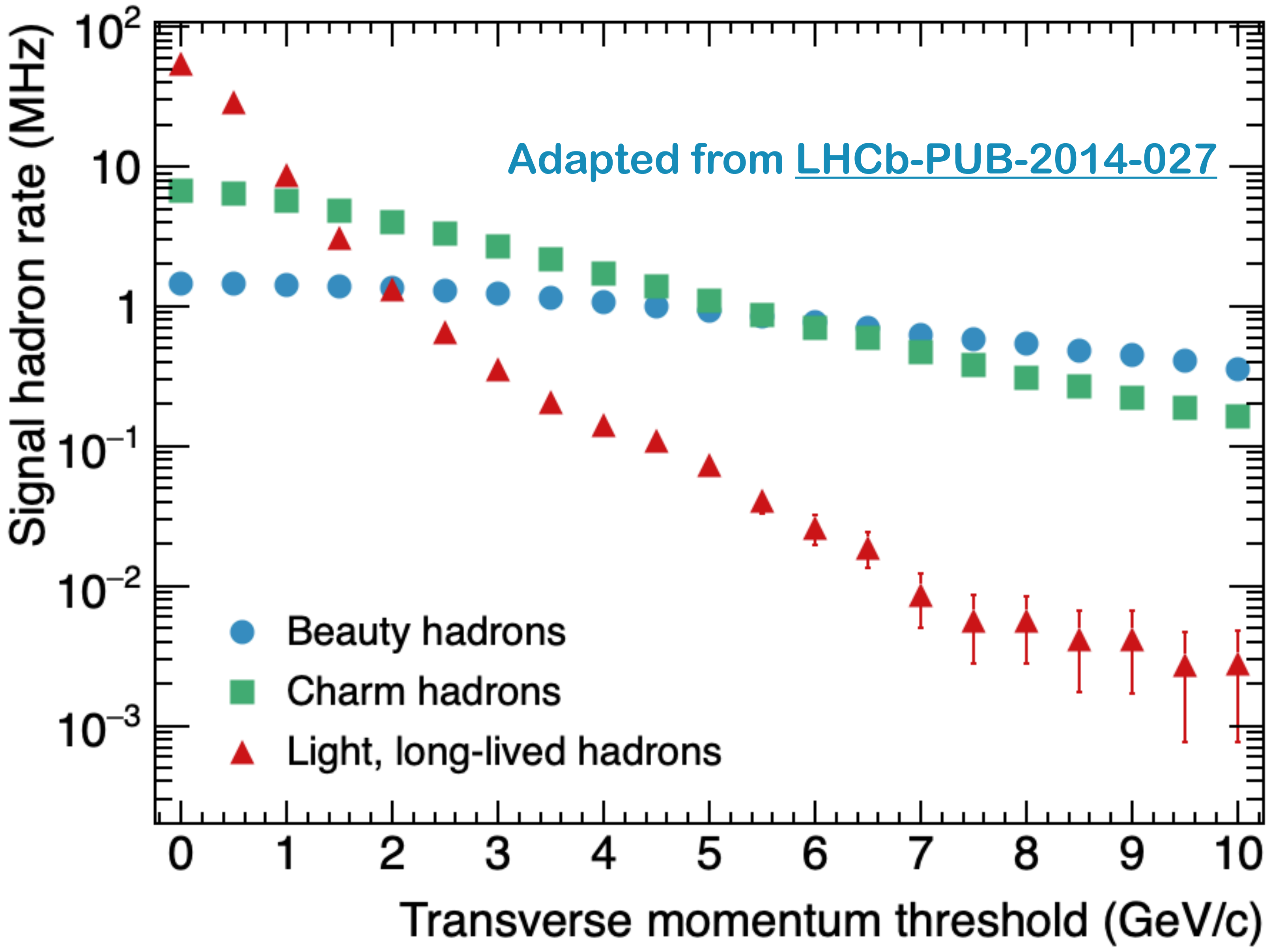


Potential to improve pion-kaon separation at high momenta

TORCH provides additional capabilities at low momenta

LHCb U2: DAQ & real-time analysis

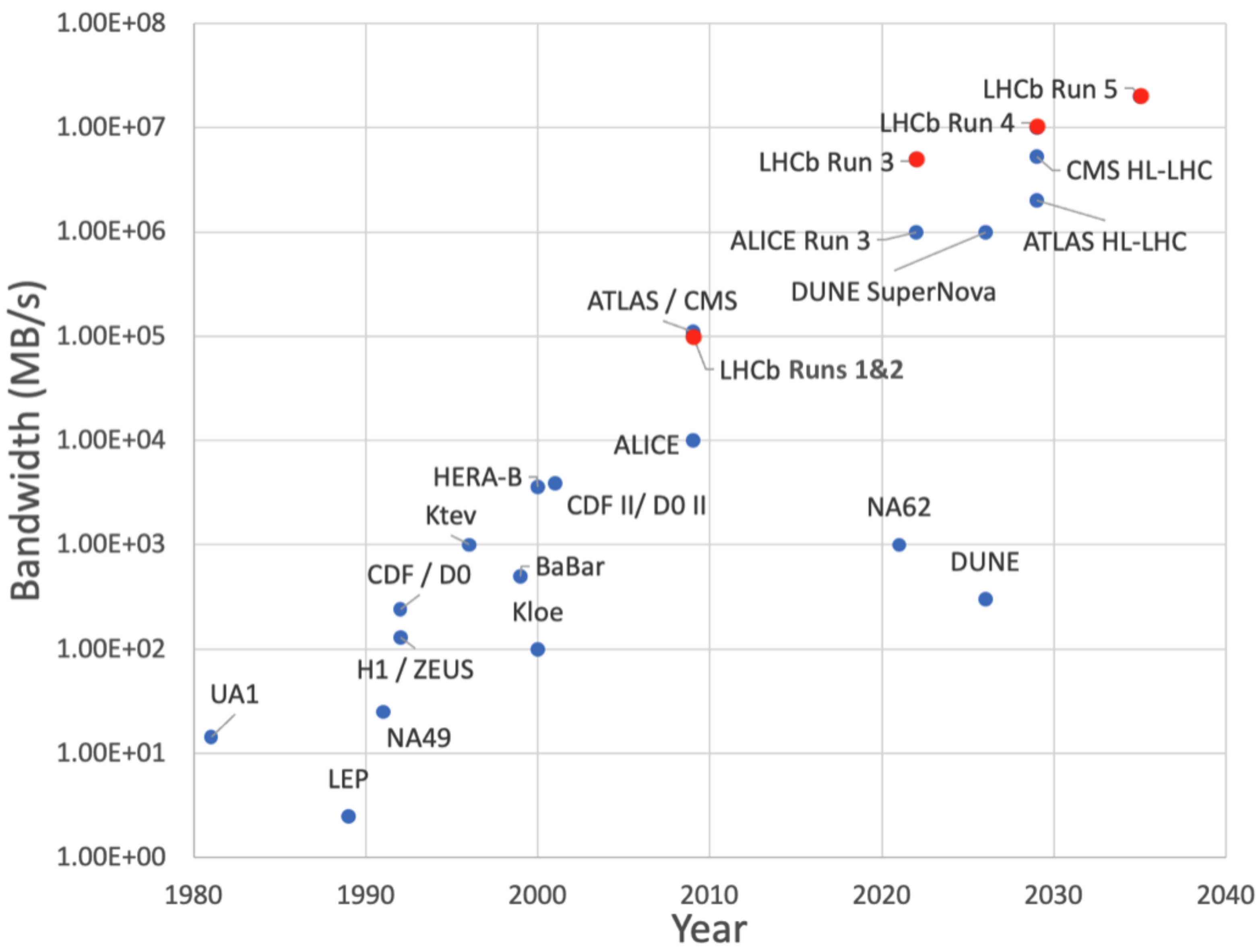
LHCb @ 1e34: partially reconstructed signal rate



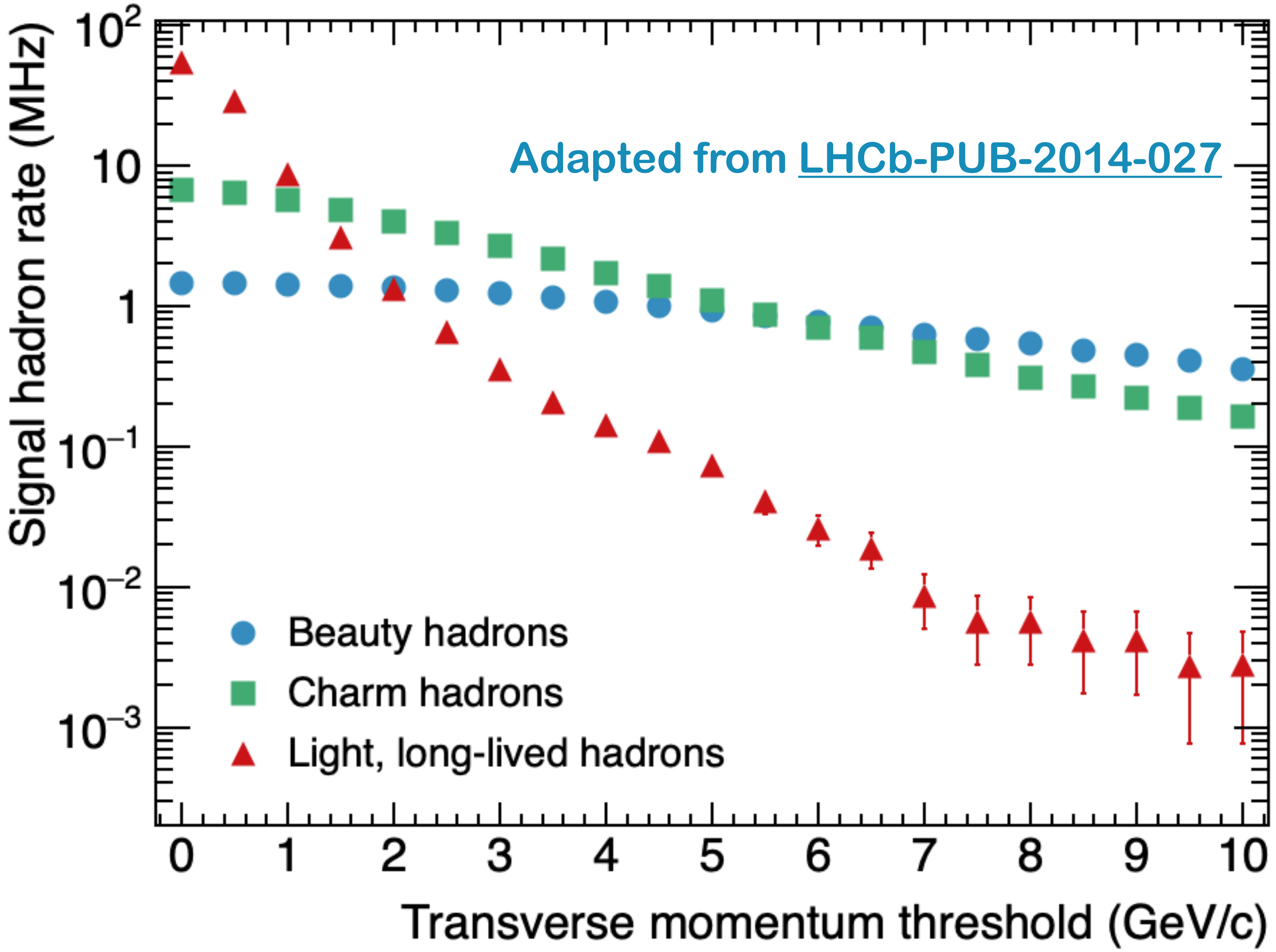
Trigger saturated by signal – must perform real-time analysis!

LHCb U2: DAQ & real-time analysis

A. Cerri, University of Sussex



LHCb @ 1e34: partially reconstructed signal rate



LHCb Upgrade 2 will be the biggest data processing challenge attempted in HEP

The full real-time reconstruction, calibration, and alignment of LHCb U2 is a key technology pathfinder for HEP. If successful will lead to a permanent paradigm shift for high-throughput experiments.

LHCb: far from a conclusion

The LHCb collaboration is only at the start of its journey to understand microscopic reality as precisely as possible

Tipaza

LHCb: far from a conclusion

We would all of course like the next decades to reveal a world of wonders beyond the Standard Model. But what if they don't?

Tipaza

LHCb: far from a conclusion

Knowledge advances through bursts and plateaus: the rapid gains of the 20th century are no guarantee for the 21st

Tipaza

LHCb: far from a conclusion

If we are on a plateau, then we must record the fundamental constituents of nature as precisely as our skill allows.

LHCb: far from a conclusion

When technology allows the next generations to go further, our measurements will be their companions on that journey.

LHCb: far from a conclusion

This is justification & mandate enough to press onwards.

Tipaza

BACKUP

LHCb U2: detector scenarios

LHCb Upgrade 2 Scoping Document

Three detector scenarios considered

Baseline: ultimate acceptance, granularity, and material budget leading to maximal instantaneous luminosity headroom.

Middle: keeps all subsystems but in some cases reduces their acceptance. Lower instantaneous luminosity leads to significant savings in data processing cost.

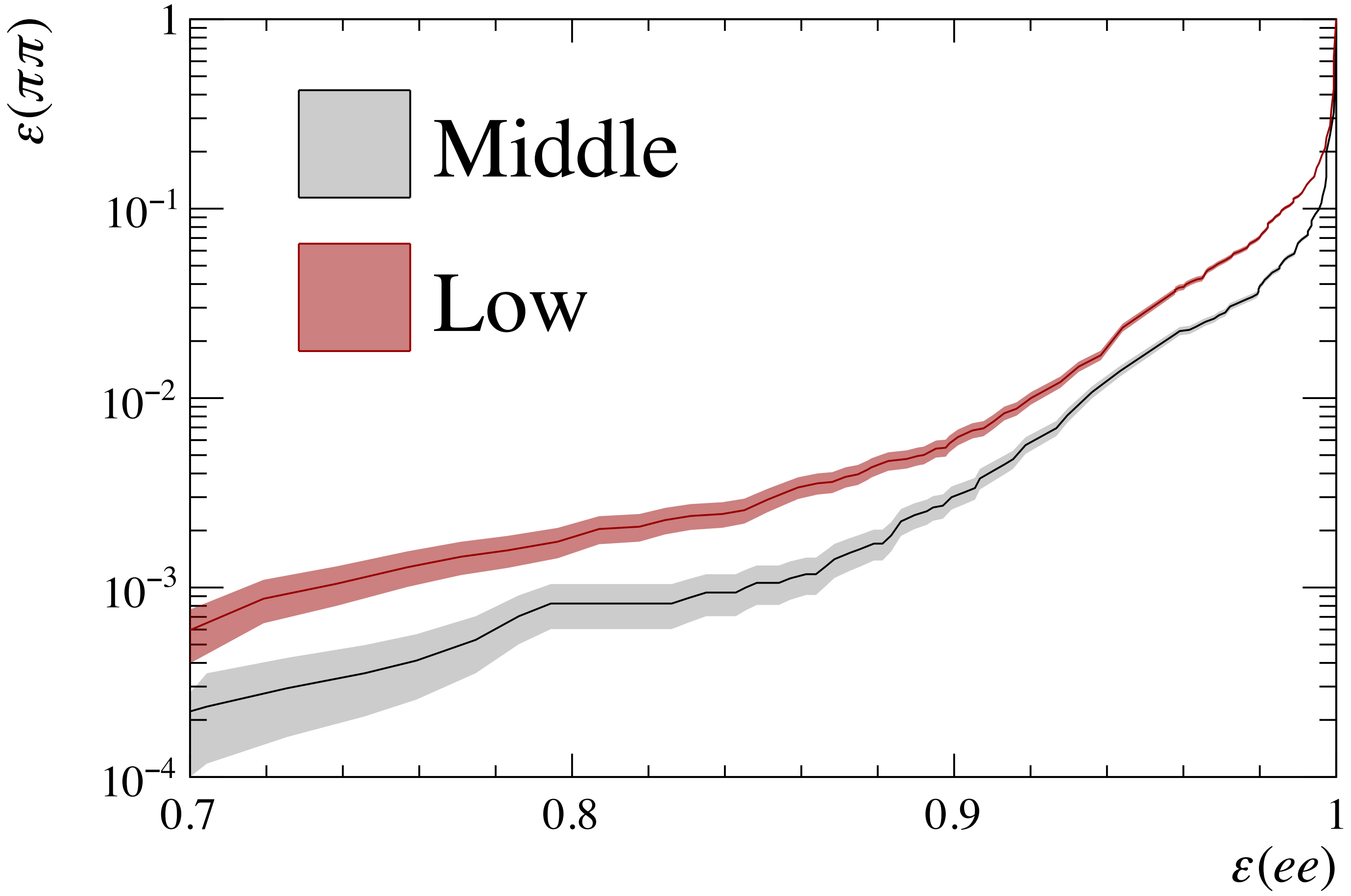
Low: worse acceptance, granularity, and material budget depending on the detector. Two detectors fully removed. Highest risk and least robust option.

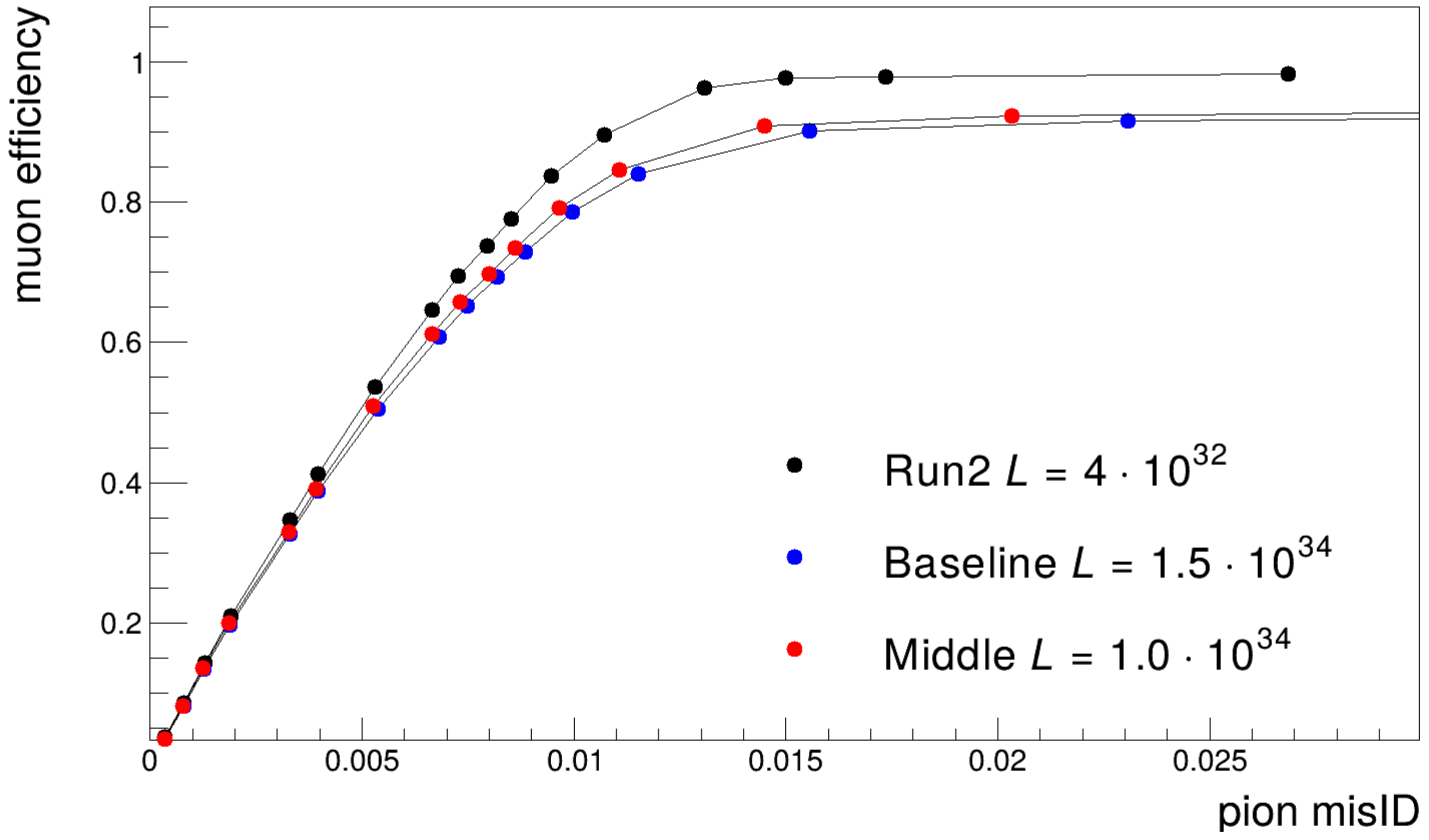
	Baseline	Middle	Low
$\mathcal{L}_{\text{peak}}$ $(10^{34}\,\text{cm}^{-2}\,\text{s}^{-1})$	1.5	1.0	1.0
	(kCHF)	(kCHF)	(kCHF)
VELO	16672	15906	13753
UP	8077	7719	6887
Magnet Stations	2592	2234	0
Mighty-SciFi	21767	21273	17388
Mighty-Pixel	15994	11641	11061
RICH	21450	18415	14794
TORCH	12508	8756	0
PicoCal	27607	27607	21584
Muon	9785	8266	8266
RTA	18800	11700	9500
Online	11800	9467	8993
Infrastructure	14463	13284	12430
Total	181515	156268	124656

All scenarios meet the core physics goals of Upgrade 2, but low has least versatility and robustness

LHCb U2: particle identification (2)

LHCb Upgrade 2 Scoping Document





Electron-pion separation is significantly degraded in the low scenario

The muon ID performance good, but not yet at the excellent levels we are used to. Studies to improve it are ongoing.

U2 schedule, risks, mitigation

LHCb Upgrade 2 Scoping Document

We are making sure lessons from Upgrade 1 are being learned

- **ASIC developments will minimise the number of different chips**
    - **RICH + TORCH | UP + MT(pixel) | MS + MT (SciFi)**
  - **Ensure continuous communication with designers in system test stage**
- **DAQ and firmware will establish the design early & benefit from LS3 enhancements**
  - **Key so that we can start commissioning early with final DAQ system**

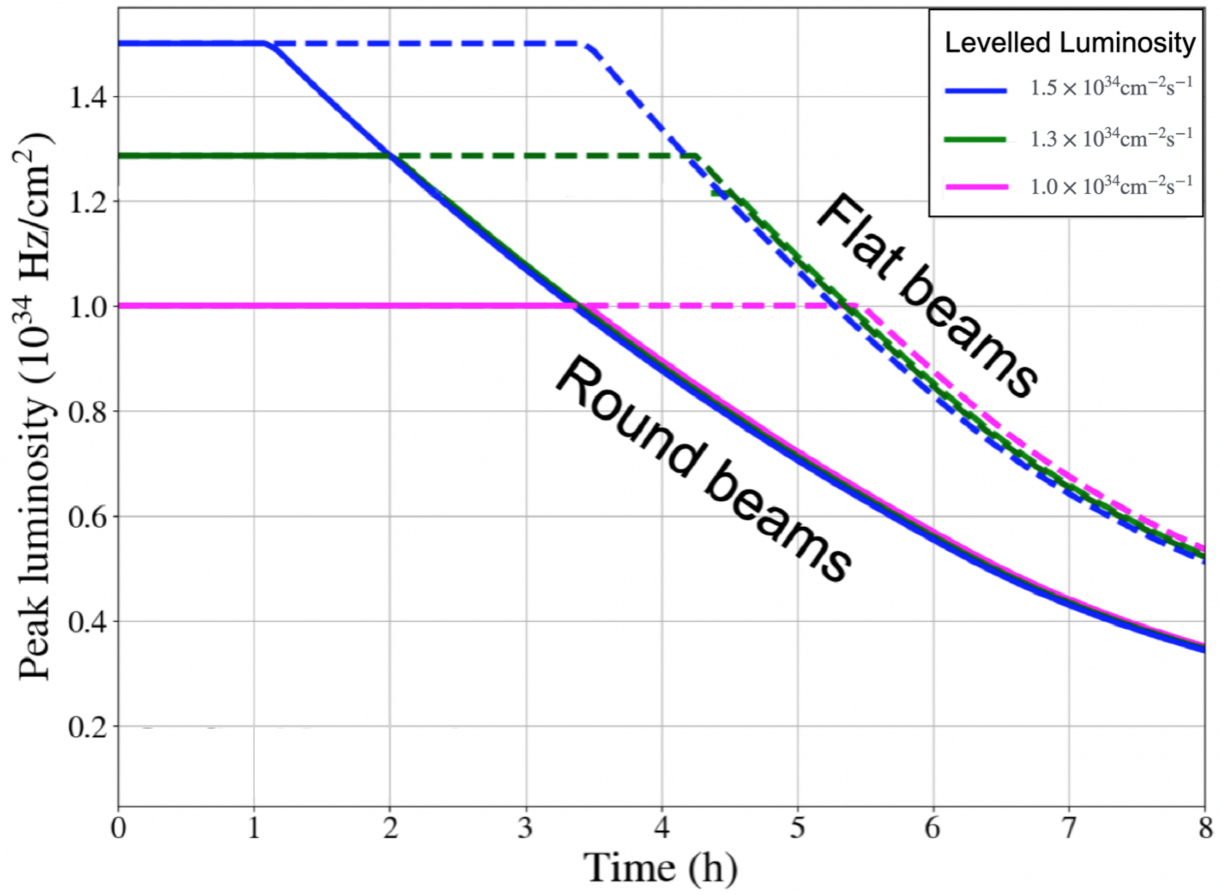
Impact of U2 scenarios on sensitivity

LHCb Upgrade 2 Scoping Document

Baseline	Middle	Low	Impact
	$B^0_{(s)} \to \mu^+\mu^-$		
Improved background rejection from VELO with timing		Worse background rejection	Precise impact under study
Improved mass resolution to separate B^0 and B^0_s peaks			
Loss of muon identification	Loss of muon identification	Loss of muon identification	
Acceptance comparable to current detector		Reduced acceptance	~5% per track
	γ from $B^+ \to DK^+, D \to K^0_S\pi^+\pi^-$		
Improved high momentum kaon/pion separation		Less or no improvement	~10% PID efficiency loss
Background rejection for downstream tracks with RICH2 & TORCH timing	Reduced TORCH acceptance	RICH2 timing only	3x higher background
Acceptance comparable to current detector		Reduced acceptance also for downstream tracks	~10-15% per track
	$D^{*+} \to D\pi^+, D \to K^+K^-$		
Acceptance for long tracks comparable to current detector		Reduced acceptance	Up to 40% total tracking efficiency loss
Improved slow pion acceptance from Magnet Stations		No improvement	
Trigger throughput comparable to current detector		Reduced online farm capacity	Impact on trigger to be evaluated
	ϕ_s from $B^0_s \to J/\psi\phi$		
Loss of muon identification	Loss of muon identification	Loss of muon identification	
Improved high momentum kaon/pion separation		Less or no improvement	
Improved decay time resolution		Worse performance	~10% sensitivity dilution
Improved flavour tagging		No improvement	~5% relative flavour tagging loss

LHCb Upgrade 2 luminosity scenarios

	Round optics			Flat optics		
Levelled $\mathcal{L}_{\text{peak}}$ $(10^{34}\,\text{cm}^{-2}\,\text{s}^{-1})$	1.0	1.3	1.5	1.0	1.3	1.5
β^*_x/β^*_y (m)	1.5/1.5			0.5/1.5		
N_{bunch} total/colliding in LHCb	2760/2574			2760/2574		
Levelled pile-up	28	36	42	28	36	42
Delivered $\mathcal{L}_{\text{int}}$ per year (fb^{-1})	42.16	47.25	49.34	48.73	57.89	63.36
Levelling time t_{lev} (h)	3.42	2.00	1.08	5.42	4.25	3.42
Optimal fill length t_{opt} (h)	7.67	7.58	7.58	7.58	7.50	7.42
$t_{\text{lev}}/t_{\text{opt}}$	0.45	0.26	0.14	0.72	0.57	0.46
RMS luminous region (z) at $t=0$ (mm)	43.30	43.31	43.31	38.41	38.44	38.45
Peak pile-up density at $t=0$ (mm^{-1})	0.29	0.35	0.40	0.41	0.49	0.54



Why enhance LHCb during LS3?

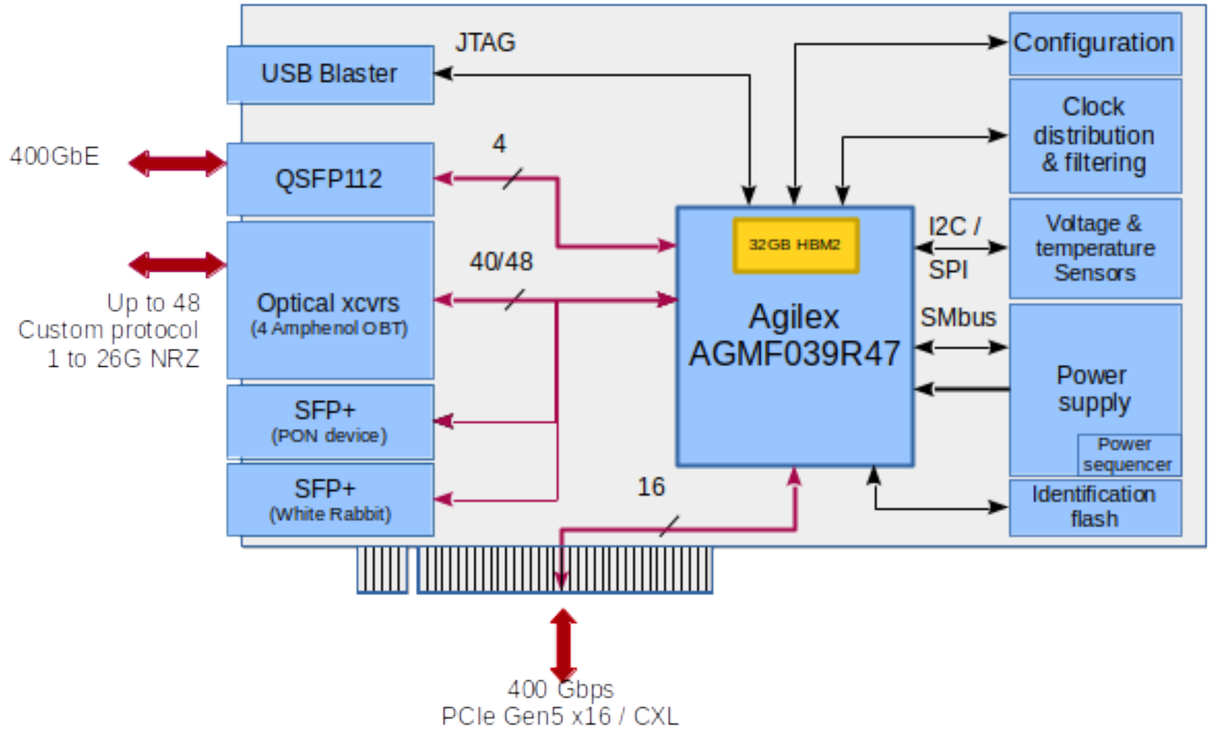
1. Calorimeter radiation damage must be addressed – use this opportunity to improve instead of standing still
2. We know precision timing is mandatory for U2 physics performance: exercise as much of this as possible in LS3 so we can learn any lessons long before Run 5
3. We must nurture and develop a team with the right mixture of skills to master heterogeneous computing architectures of the 2030s. This is best done through concrete incremental work.

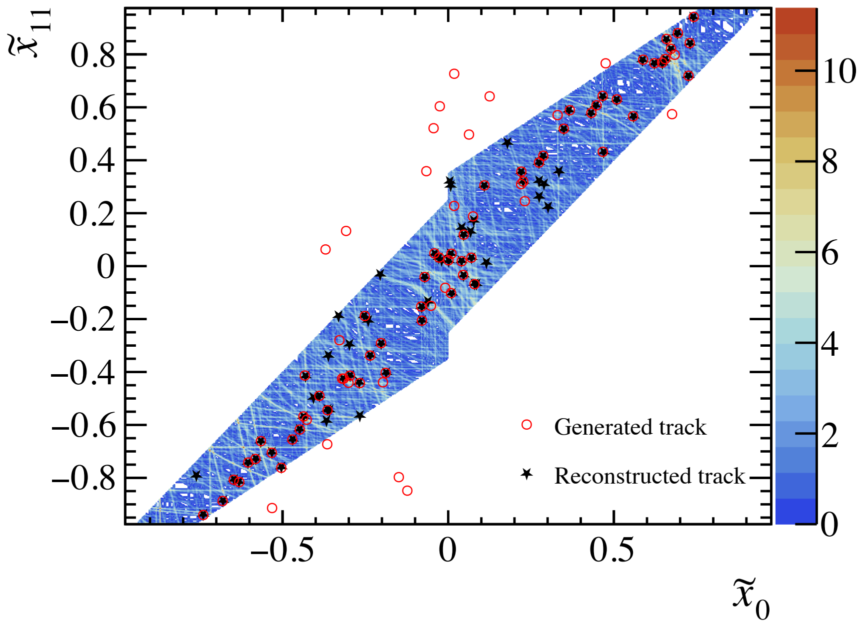
And of course seize any opportunity to improve the physics sensitivity of Run 4!

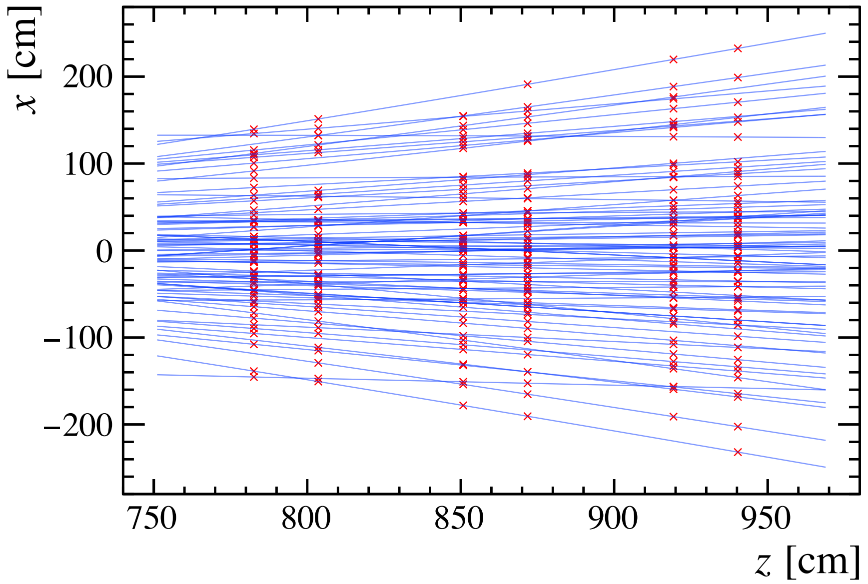
LS3 enhancements: data acquisition

The aim is to exercise the following features ahead of Run 5

1. Clock distribution with jitter and deterministic phase of O(10) ps
2. The usage of lpGBT links
3. The usage of very high speed links running at 100Gbit/s using data-centre protocols like Ethernet 400 or PCIe Gen5
4. Creation and use of reconstruction primitives embedded within the readout, with potential gains for triggering already in Run 4.



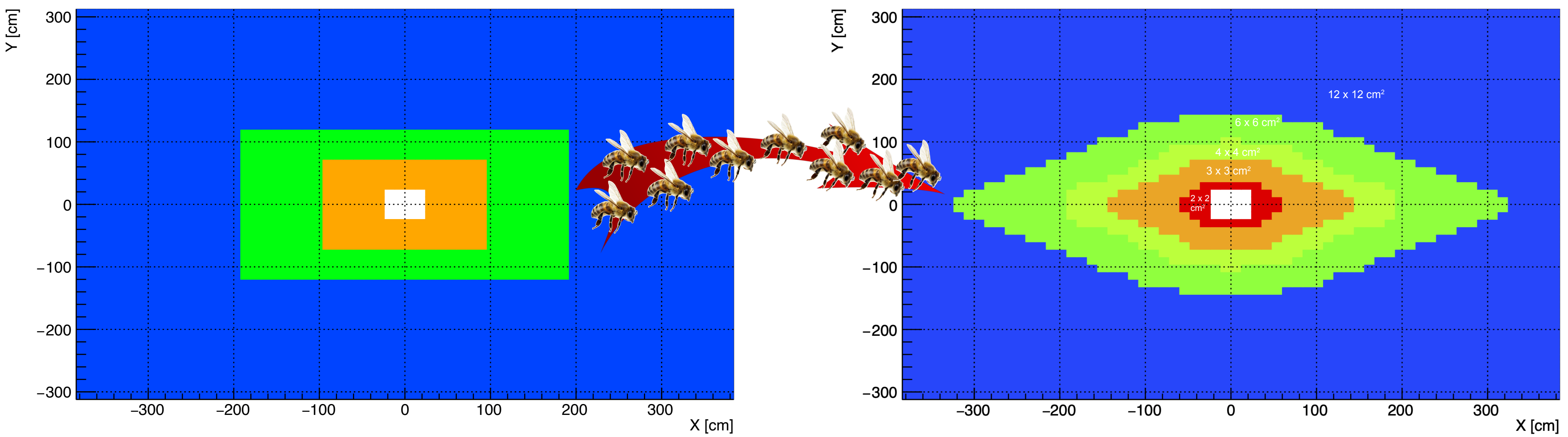


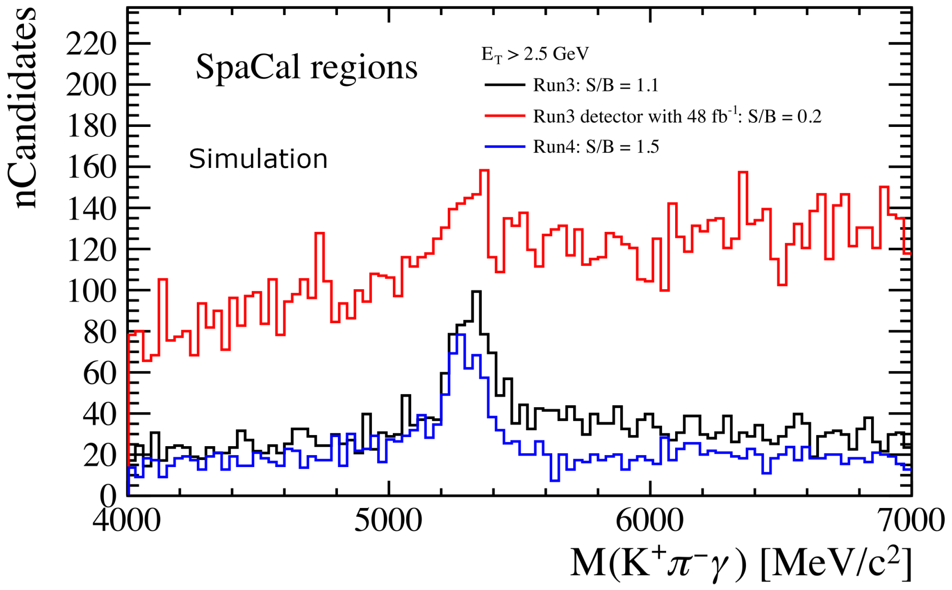


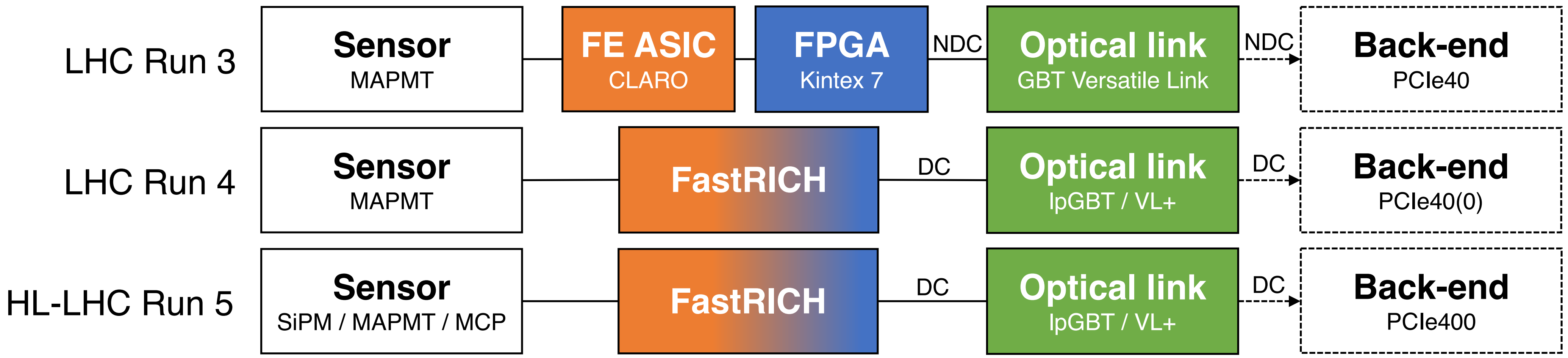
General architecture of online + DAQ system remains unchanged for Run 4

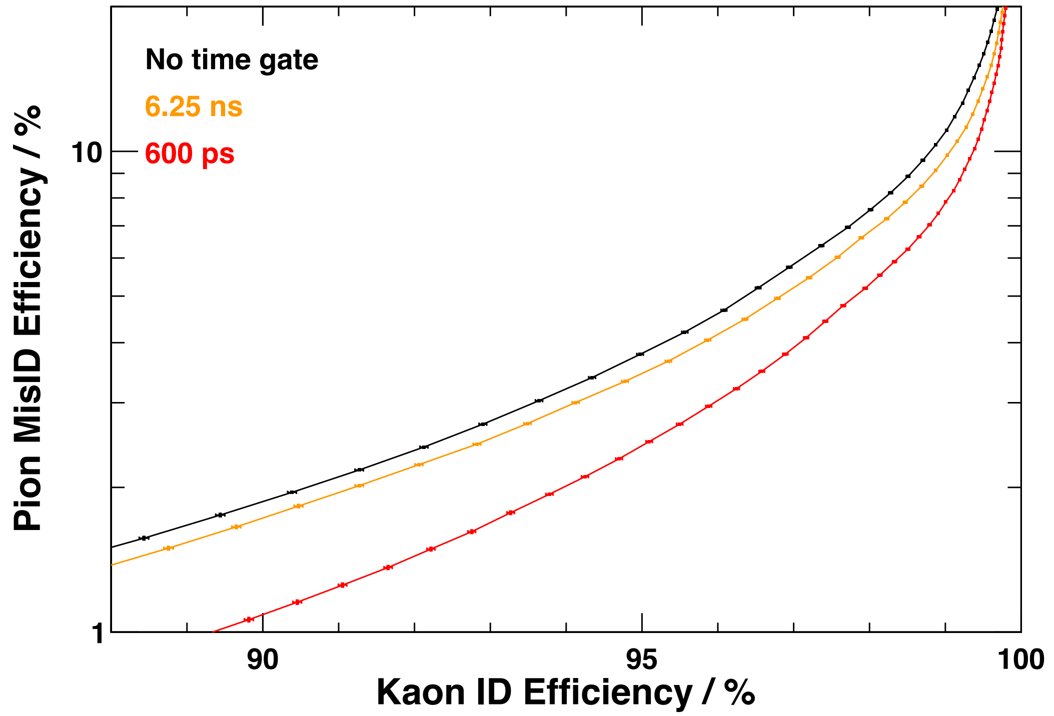
LS3 enhancements: particle ID

[LHCb particle identification enhancements TDR]







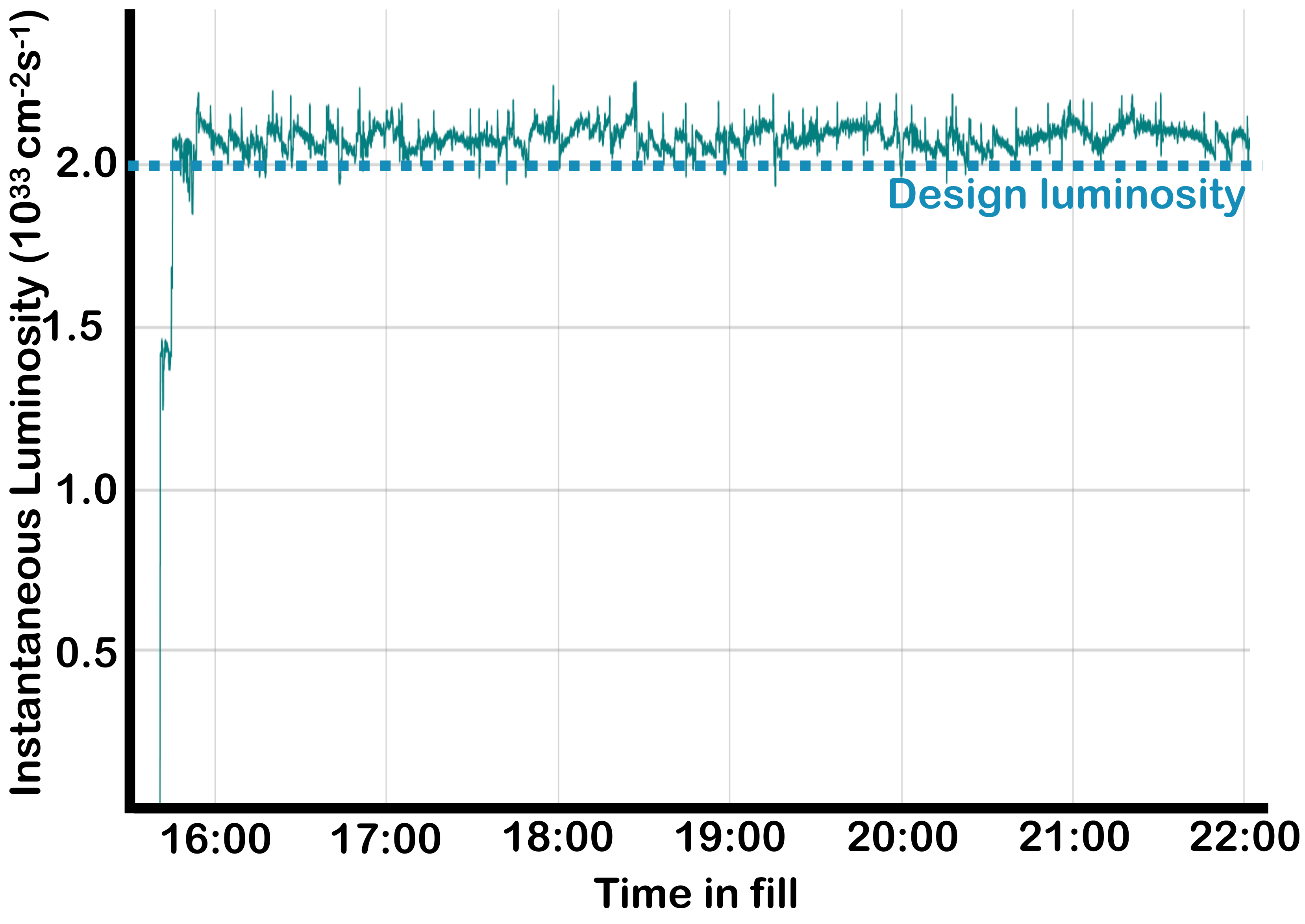


Enhanced calorimeter granularity & SpaCal modules: maintain performance despite radiation damage

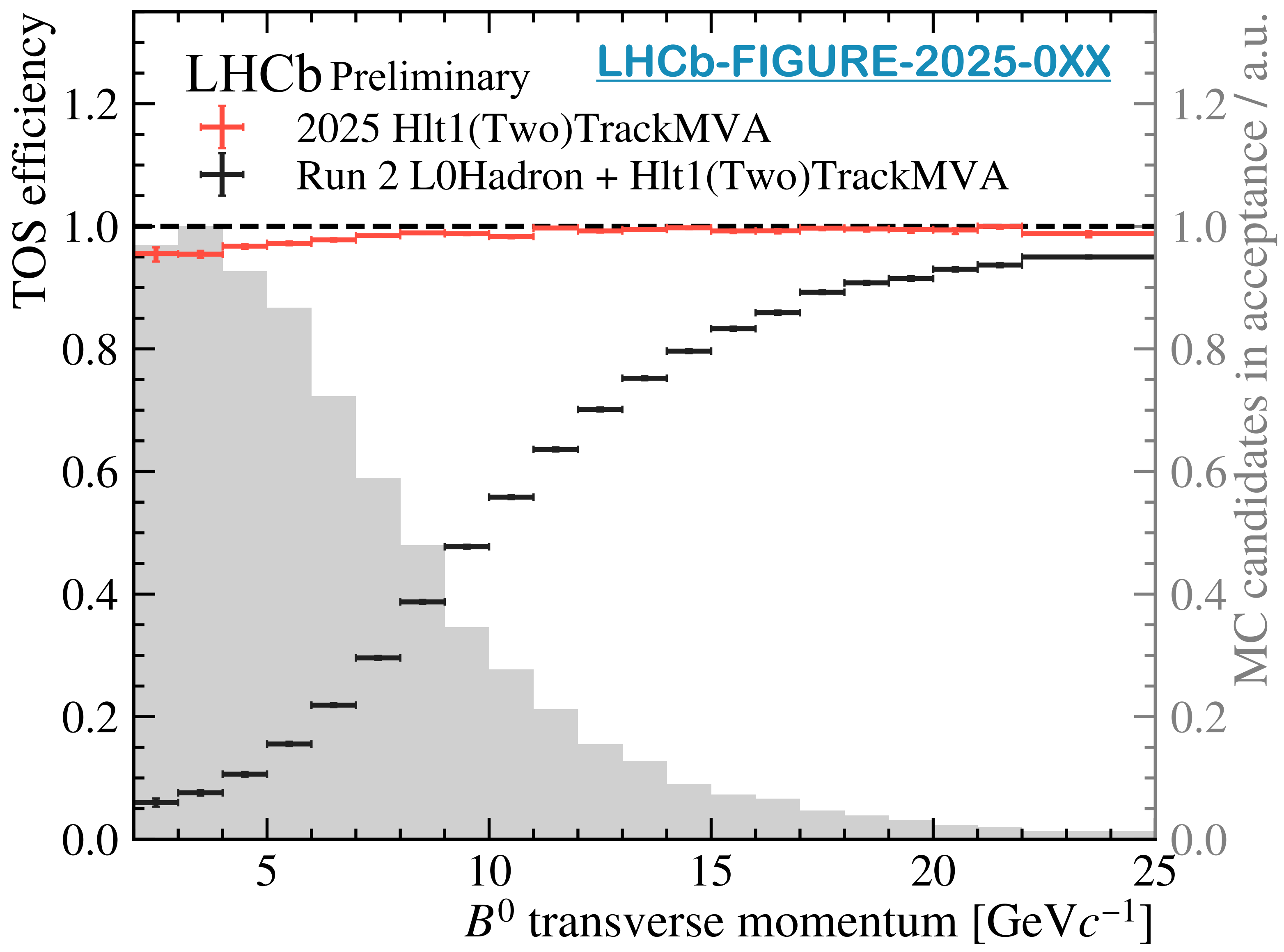
Fast timing information in the RICH: improved hadron identification and gain experience for Run 5

LHCb operations in 2025

NEW!



Efficiencies maintained above nominal luminosity in 2025!



Routine datataking above design luminosity with fixed-target collisions in parallel