Cambridge LHCb Group

Mind Map 2023

PHYSICS RECONSTRUCTION HARDWARE


PHYSICS
RECONSTRUCTION
HARDWARE
Rare Decays
CP violation


PHYSICS
RECONSTRUCTION
HARDWARE
Rare Decays
CP violation
LS3 Enhancements
LS4 Upgrade II


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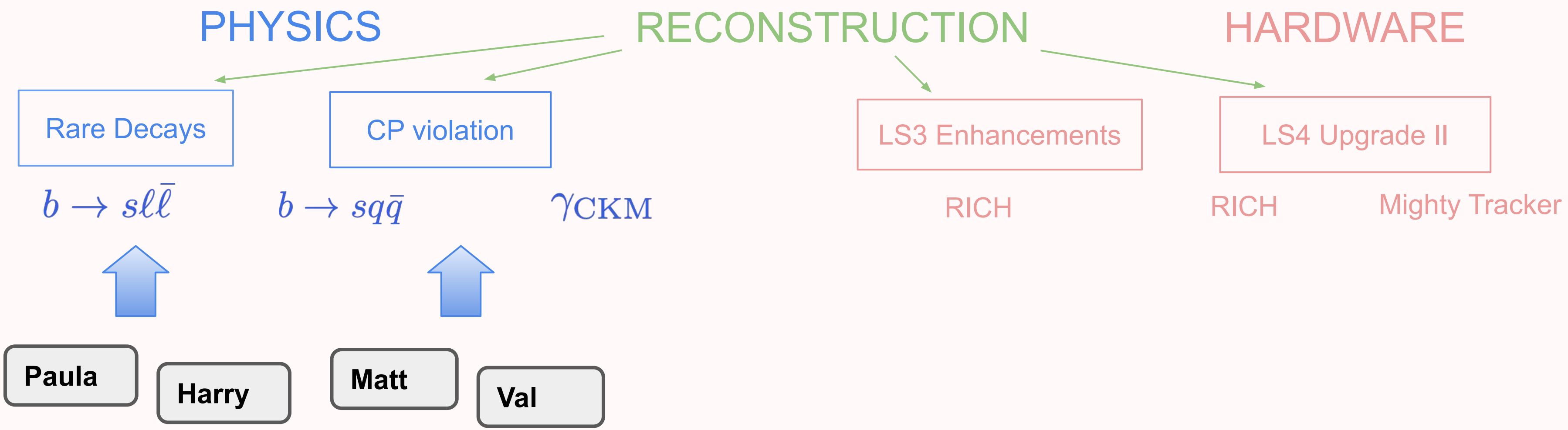
RICH

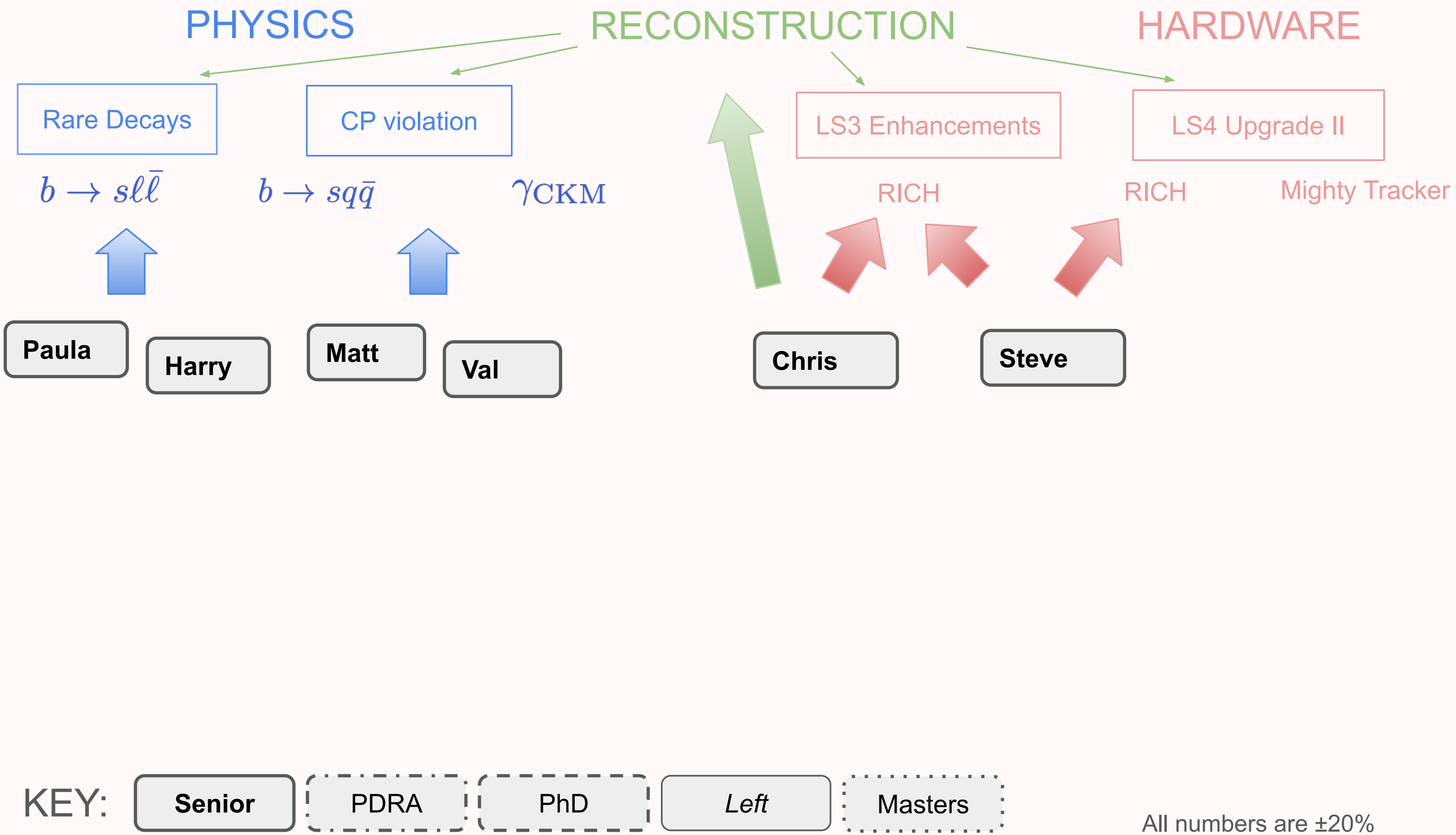
RICH

Mighty Tracker



KEY: **Senior** PDRA PhD *Left* Masters

All numbers are ±20%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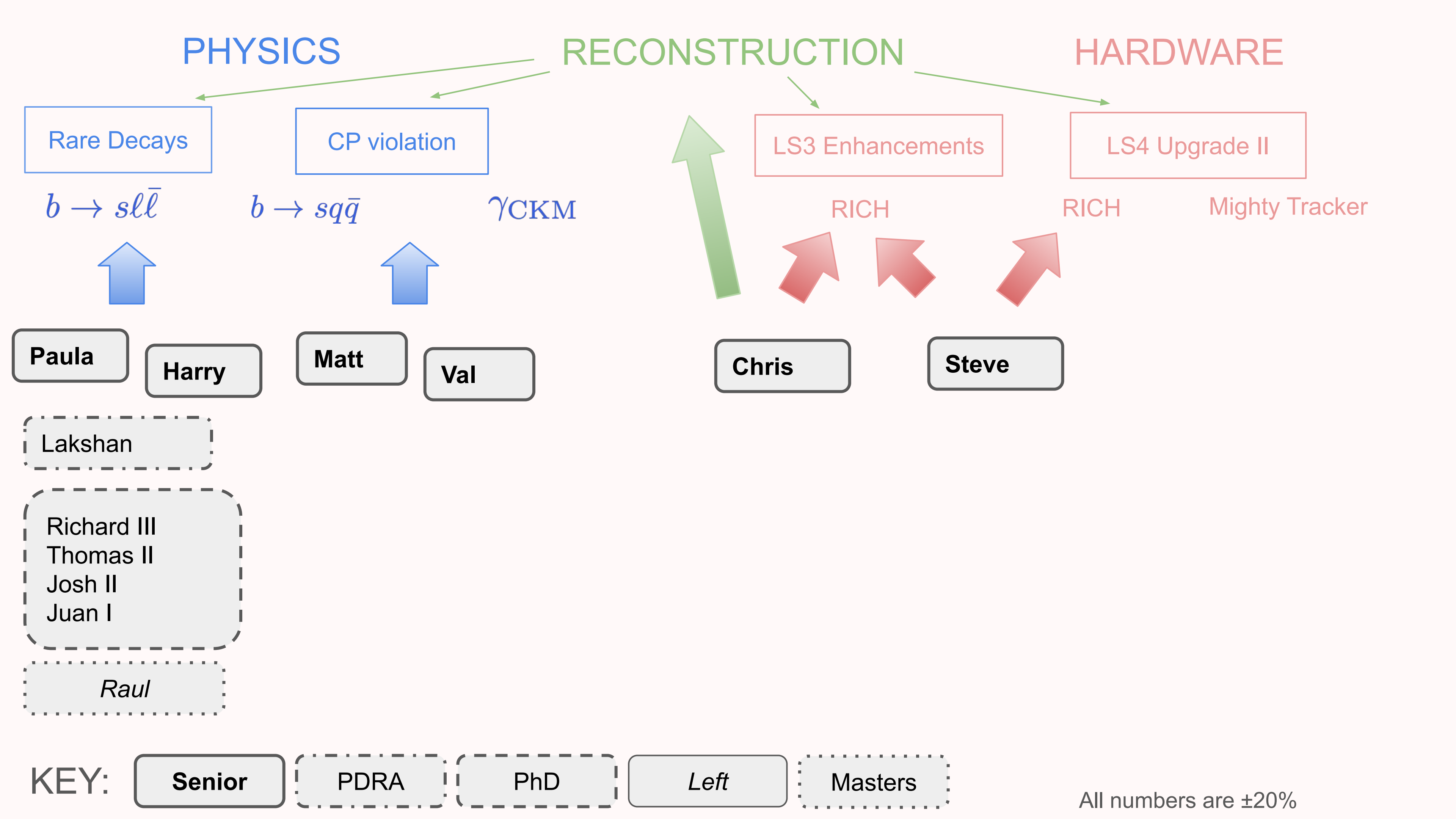
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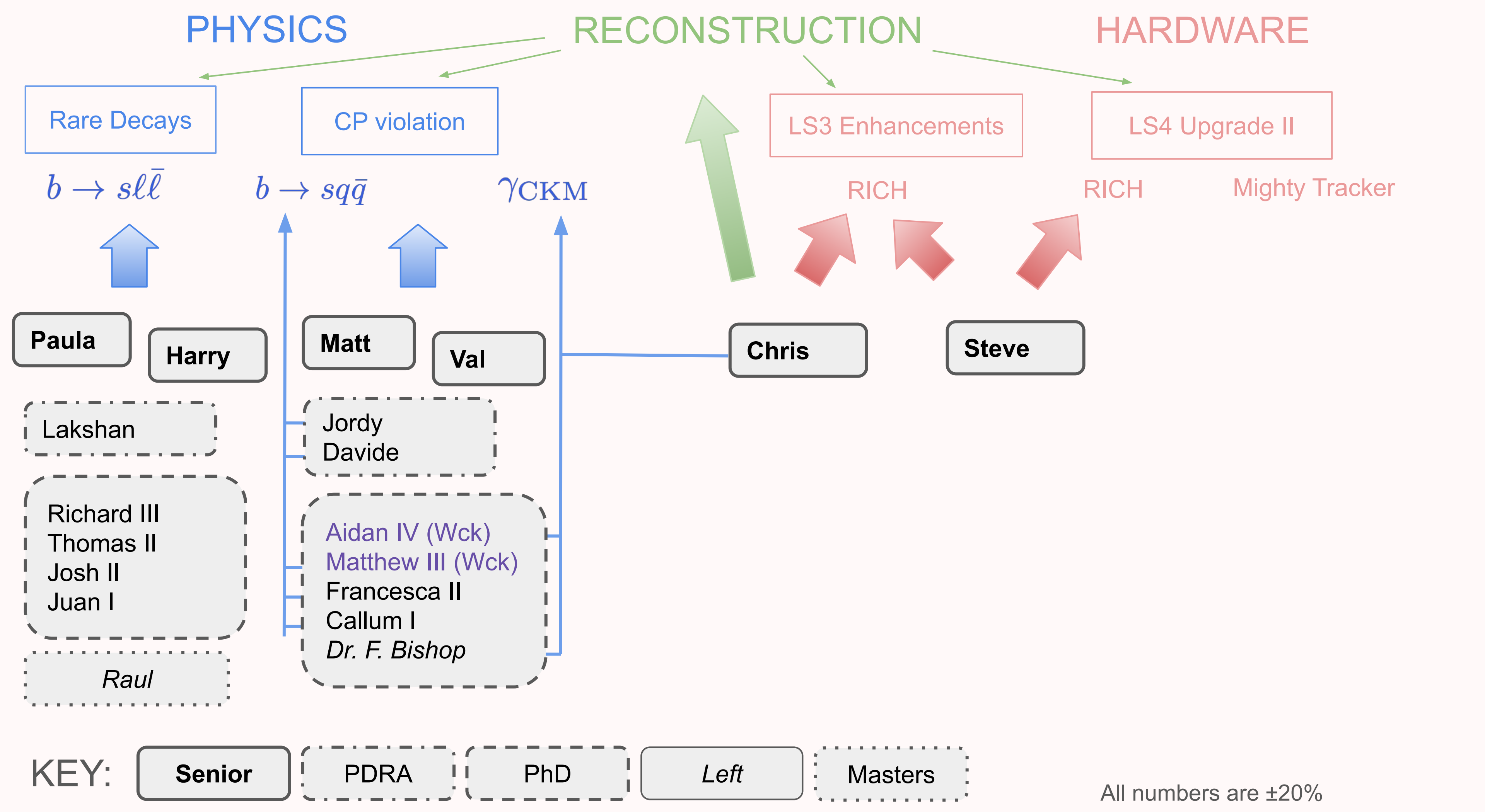

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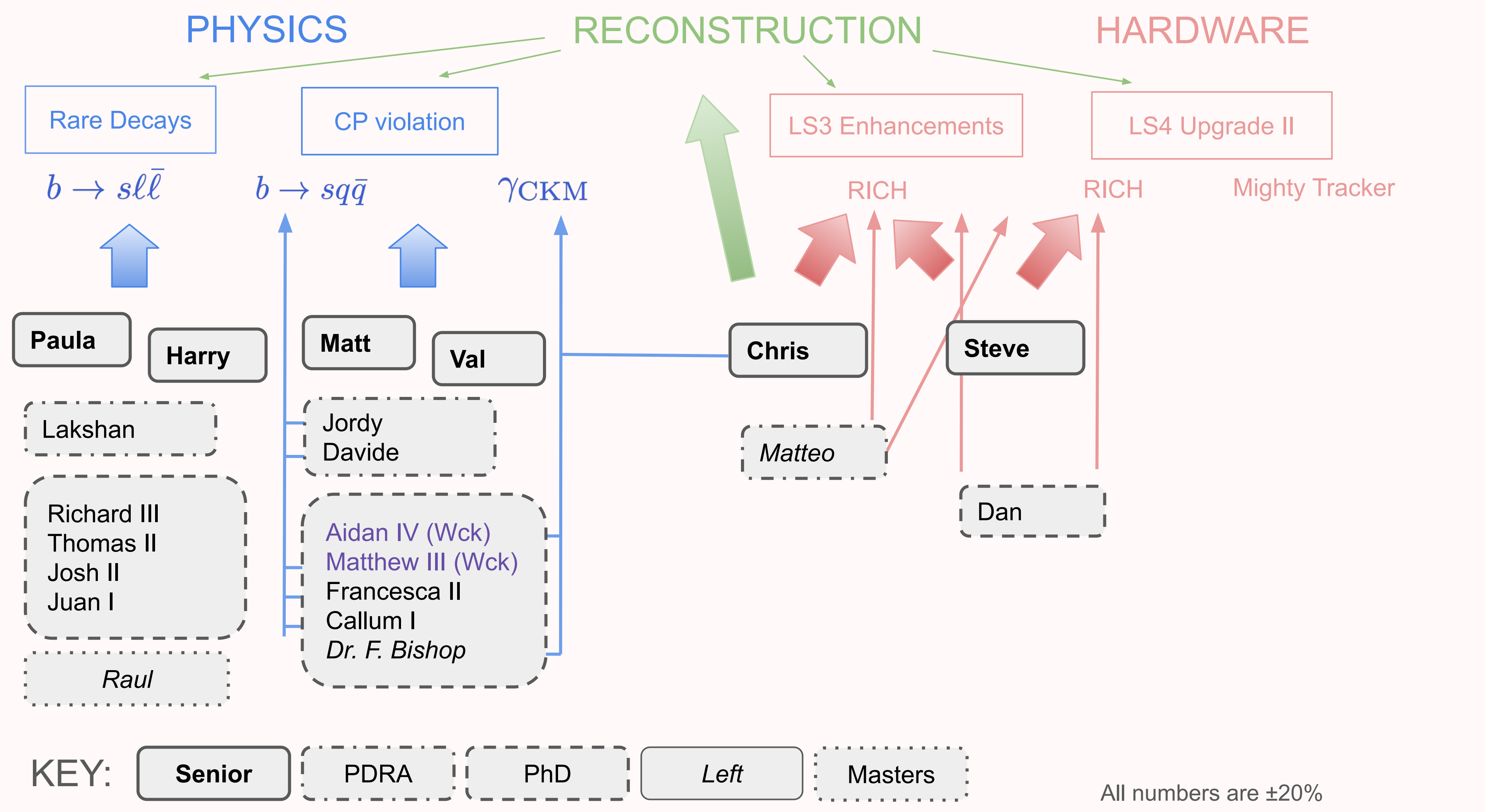
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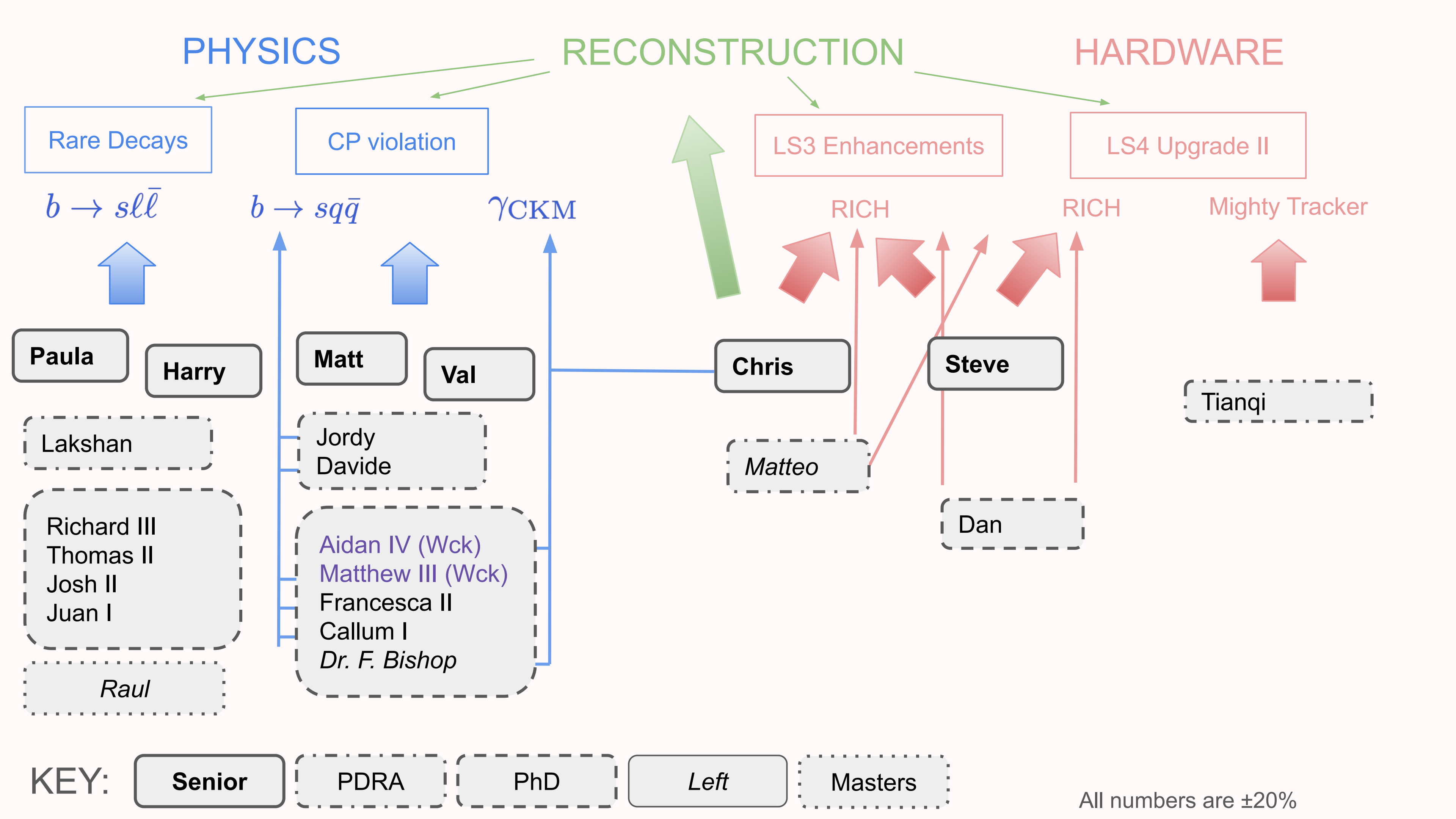

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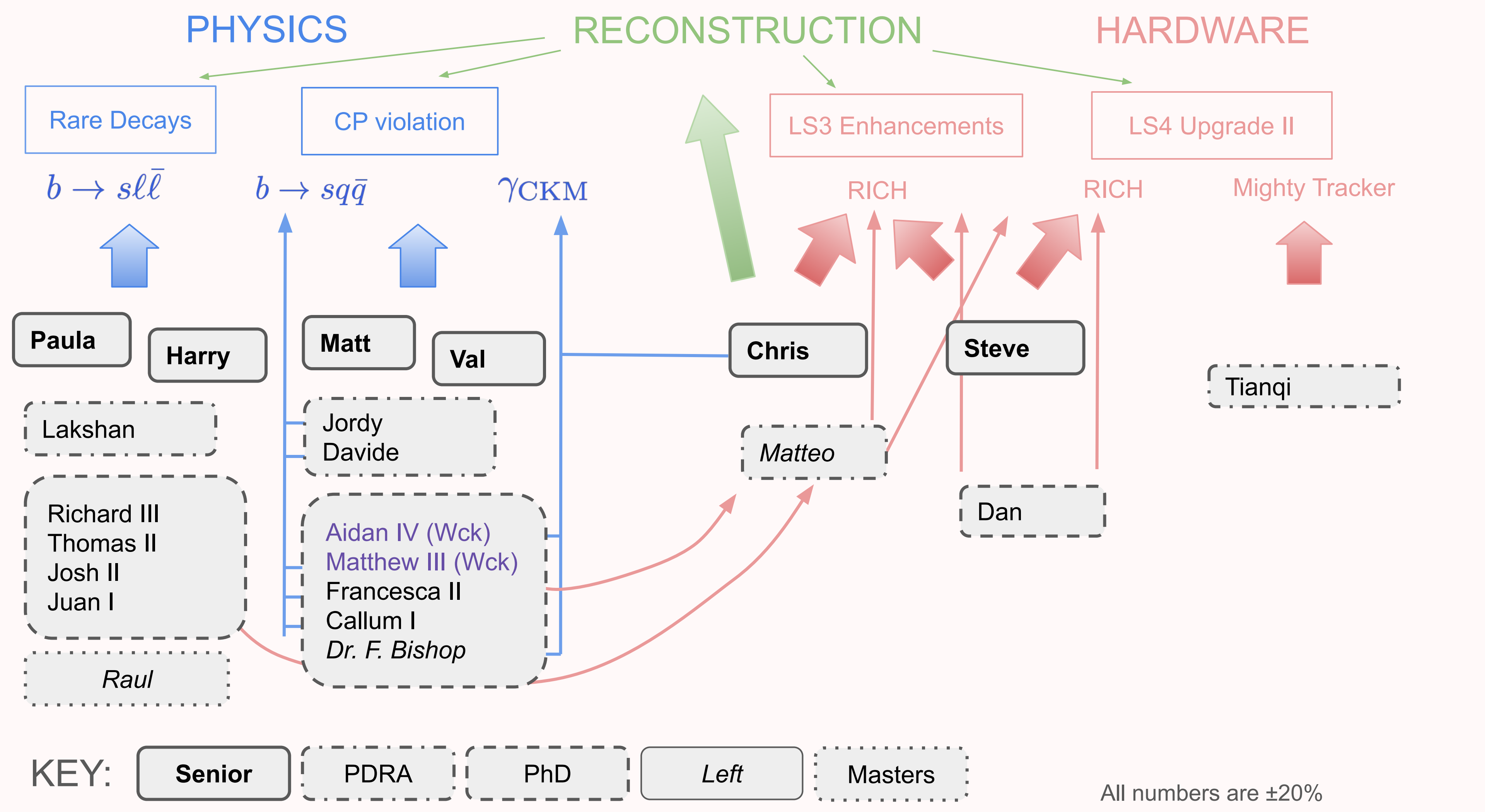

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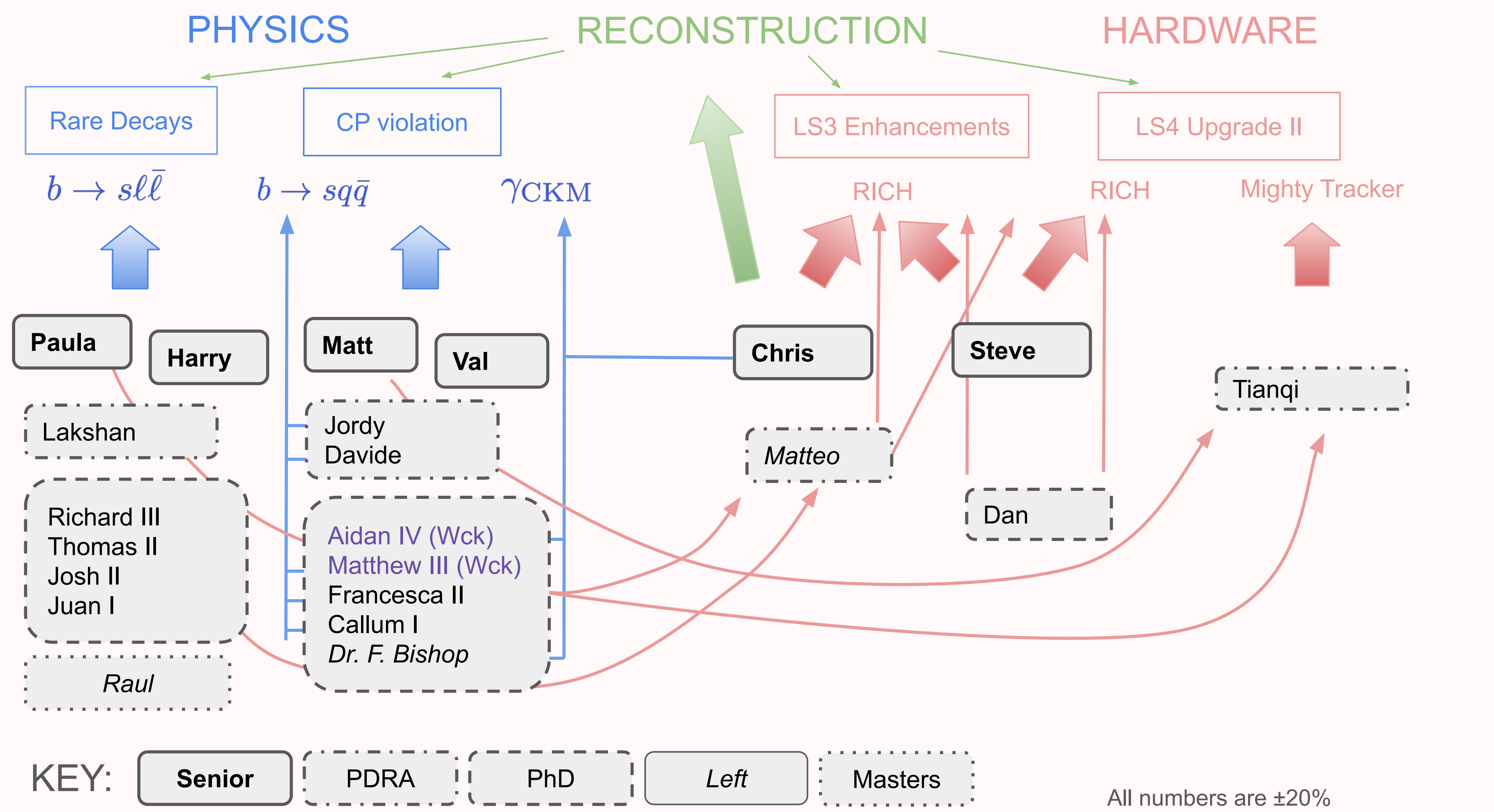
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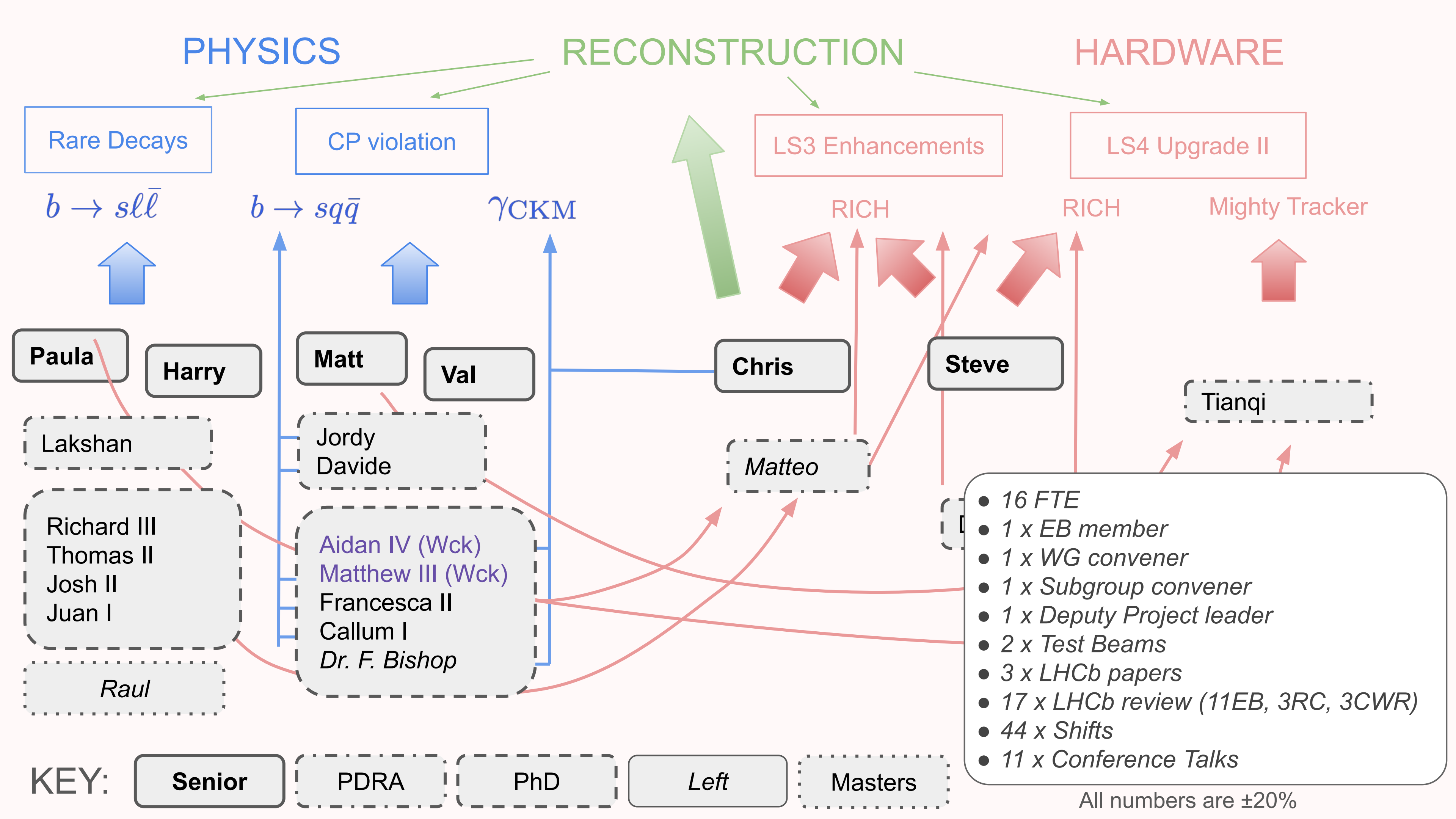
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16 FTE
1 x EB member
1 x WG convener
1 x Subgroup convener
1 x Deputy Project leader
2 x Test Beams
3 x LHCb papers
17 x LHCb review (11EB, 3RC, 3CWR)
44 x Shifts
11 x Conference Talks
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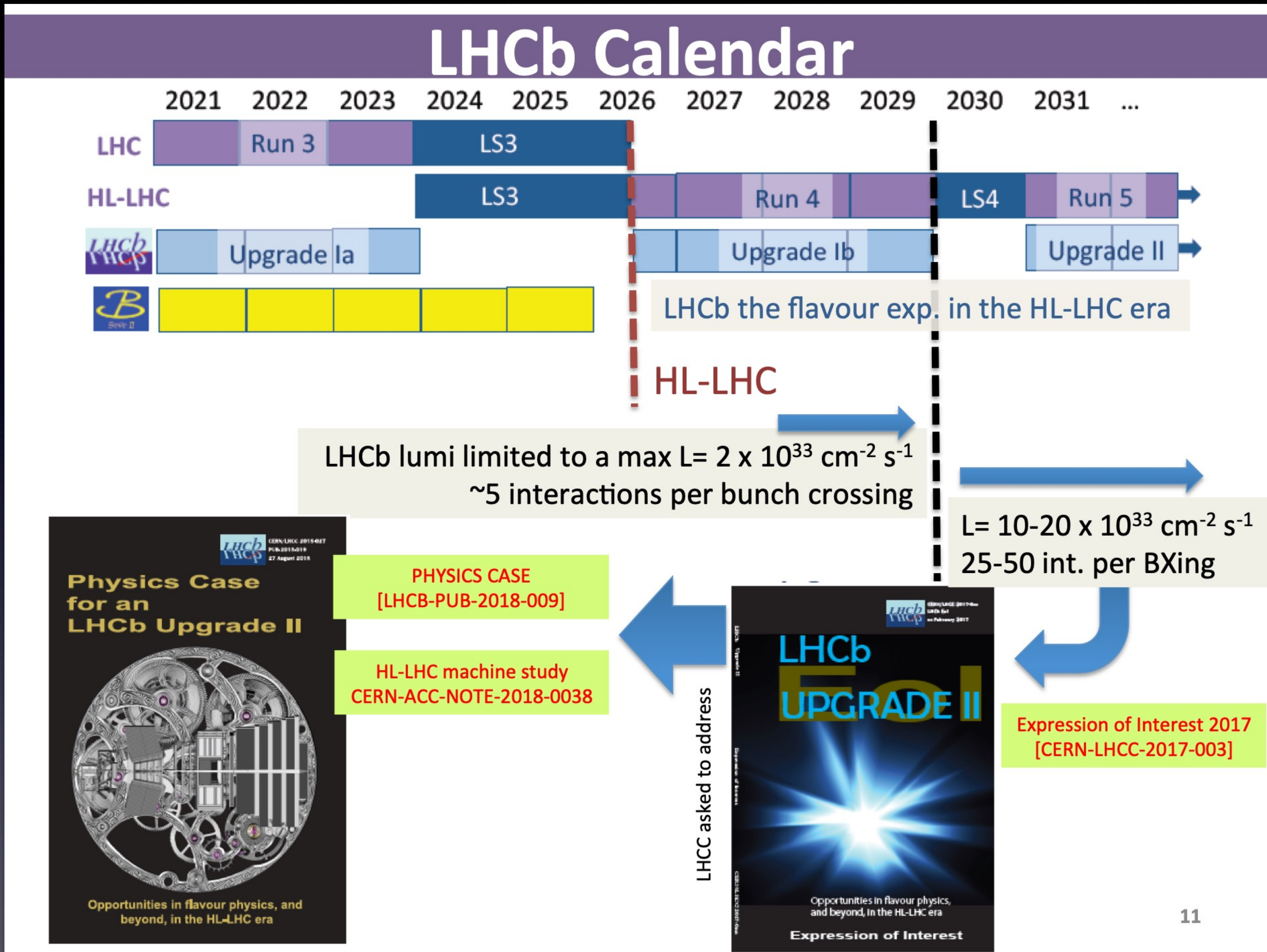
LHCb Run3

LHCb Upgrade

- **run 1 has been a great success for the LHC, LHCb, ... and the Standard Model**
  - but current measurement precision in the flavour sector still allows significant contributions from New Physics
- **precision of most LHCb results will still be limited by statistics after run 2**
  - leading systematic uncertainties will often decrease with available statistics
- **after run 2 would need > 10 years with current LHCb to double precision again**

LHCb upgrade after run 2
increase annual event yields by
- increasing instantaneous luminosity
- increasing trigger efficiencies

2010	run 1	0.037 fb^{-1} @ 7 TeV
2011		1 fb^{-1} @ 7 TeV
2012		2 fb^{-1} @ 8 TeV
2013	LS 1	minor maintenance work
2014		
2015	run 2	5 fb^{-1} @ 13 TeV
2016		
2017		
2018	LS 2	LHCb upgrade
2019		
2020	run 3	15 fb^{-1} @ 14 TeV
2021		
2022		
2023	LS 3	?
2024		
2025		
2026++	run 4	5 fb^{-1} / year @ 14 TeV


LHCb Calendar
2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 ...
LHC
Run 3
LS3
HL-LHC
LS3
Run 4
LS4
Run 5
Upgrade Ia
Upgrade Ib
Upgrade II
LHCb the flavour exp. in the HL-LHC era
HL-LHC
LHCb lumi limited to a max L= 2 x 10^33 cm^-2 s^-1
~5 interactions per bunch crossing
L= 10-20 x 10^33 cm^-2 s^-1
25-50 int. per BXing
Physics Case for an LHCb Upgrade II
Opportunities in flavour physics, and beyond, in the HL-LHC era
PHYSICS CASE
[LHCB-PUB-2018-009]
HL-LHC machine study
CERN-ACC-NOTE-2018-0038
LHCC asked to address
LHCb
UPGRADE II
Opportunities in flavour physics, and beyond, in the HL-LHC era
Expression of Interest
Expression of Interest 2017
[CERN-LHCC-2017-003]
11

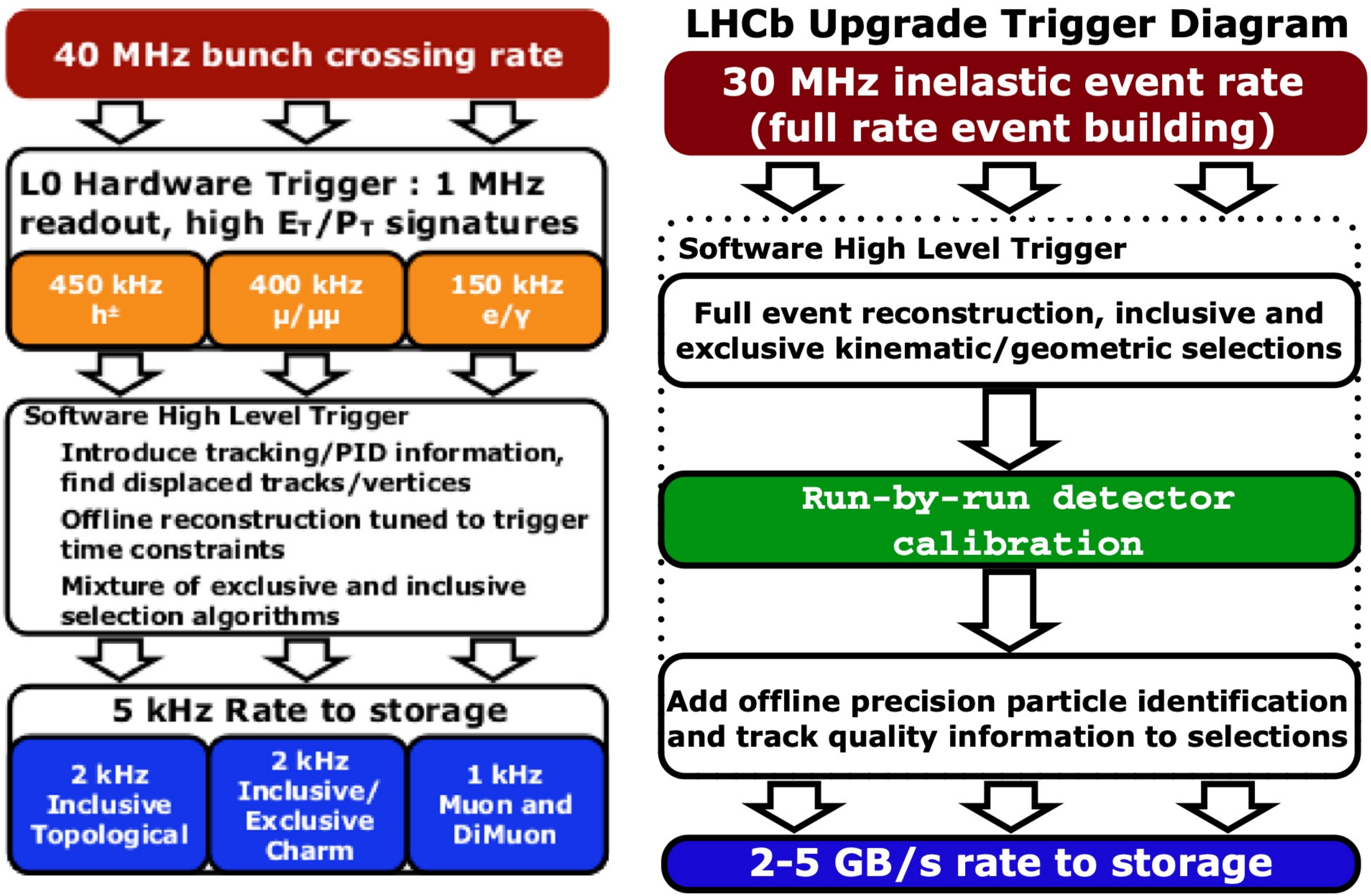
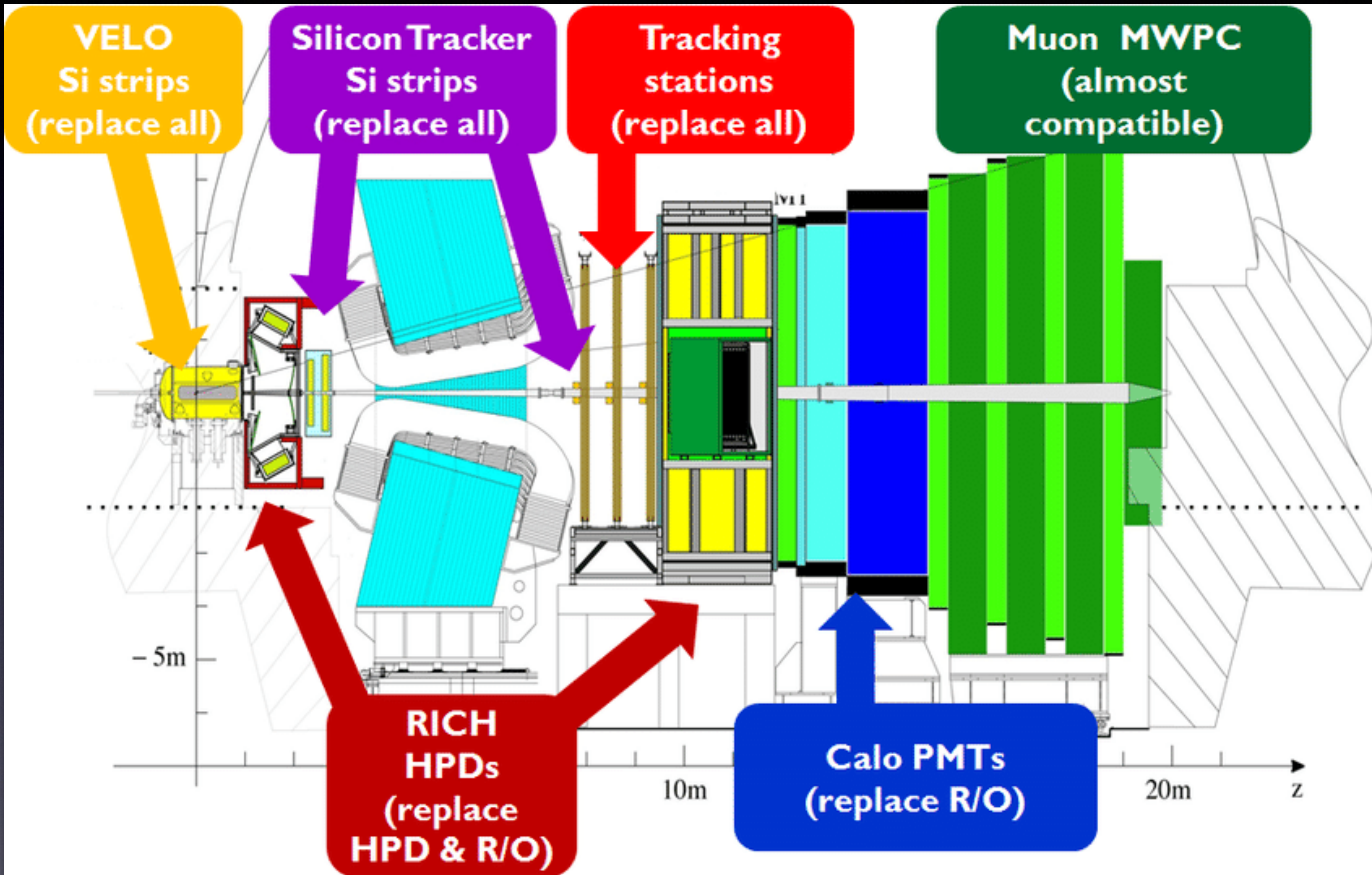
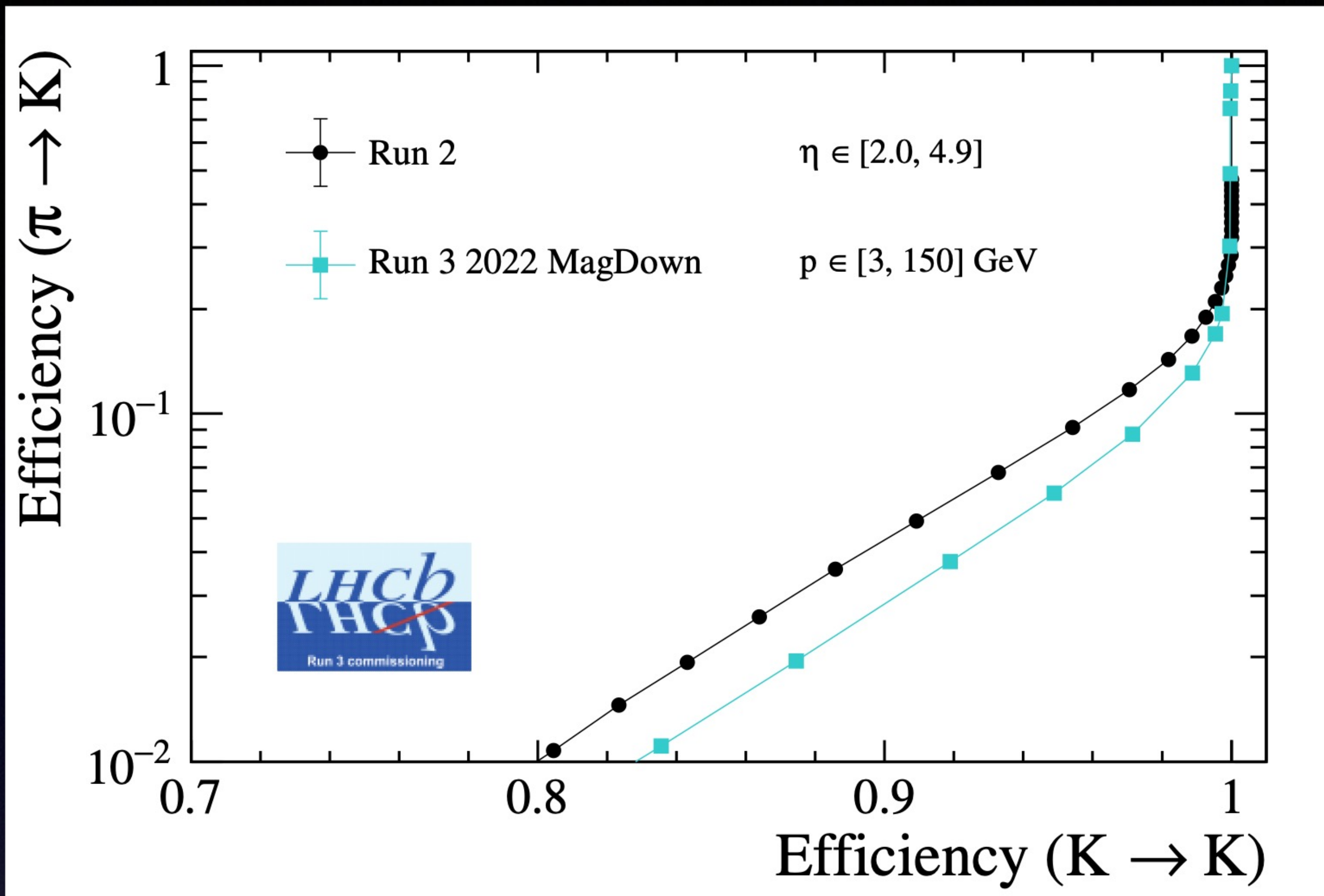


Fig. 1. The LHCb trigger schemes for Run I (left) and Upgrade (right).

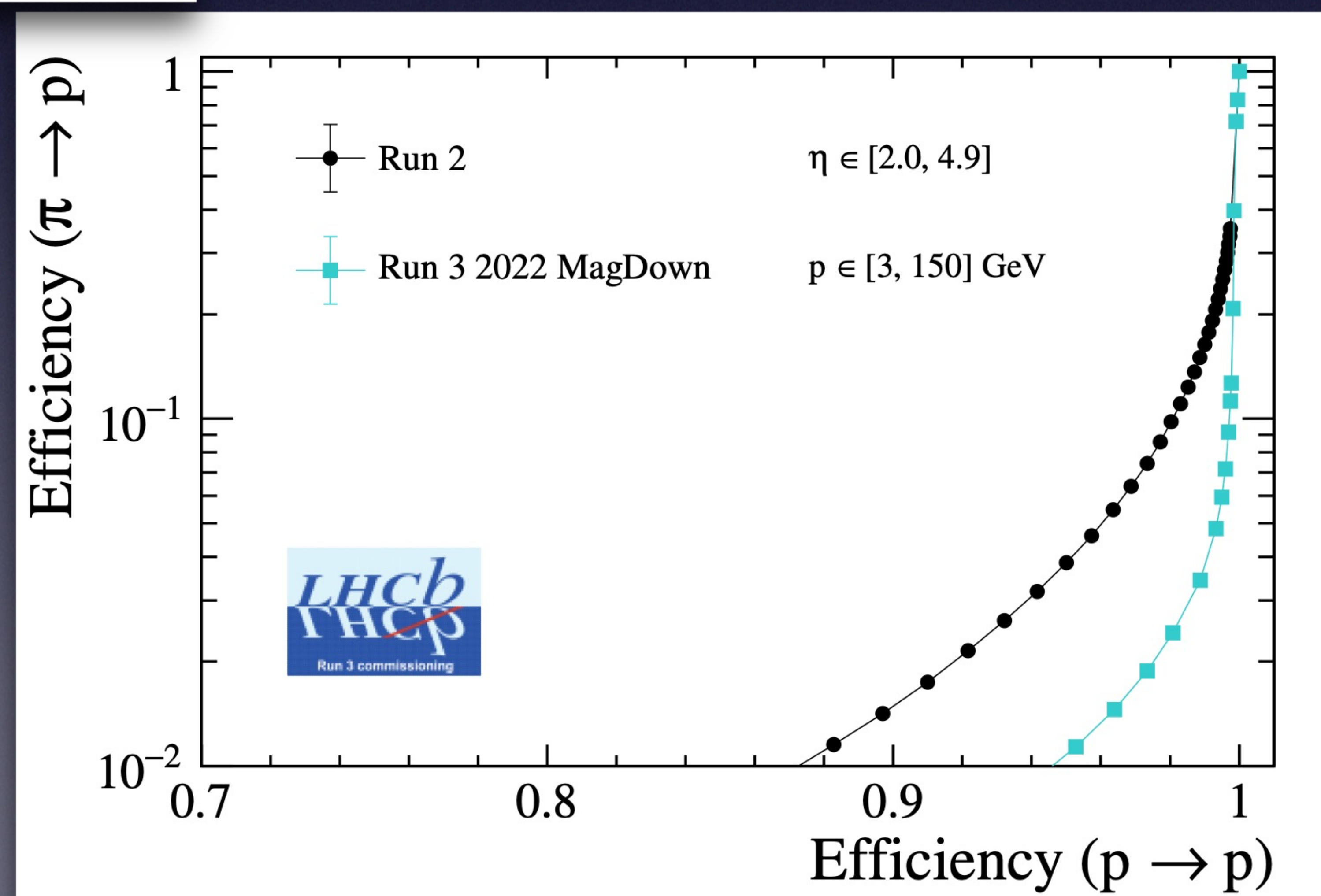
Upgrade 1 (Current)



2022 Data RICH Performance

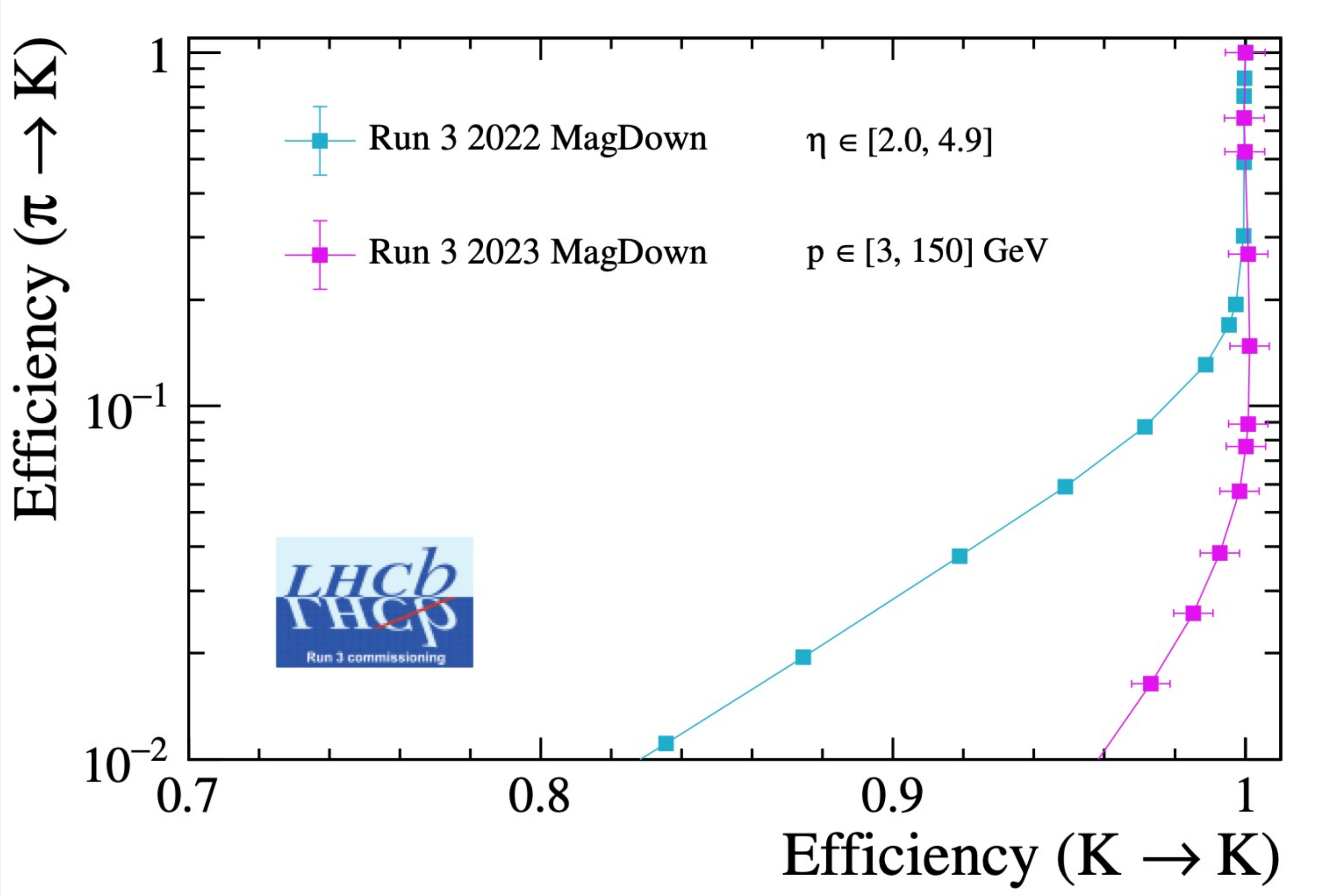


https://lbfence.cern.ch/alcm/public/figure/details/620



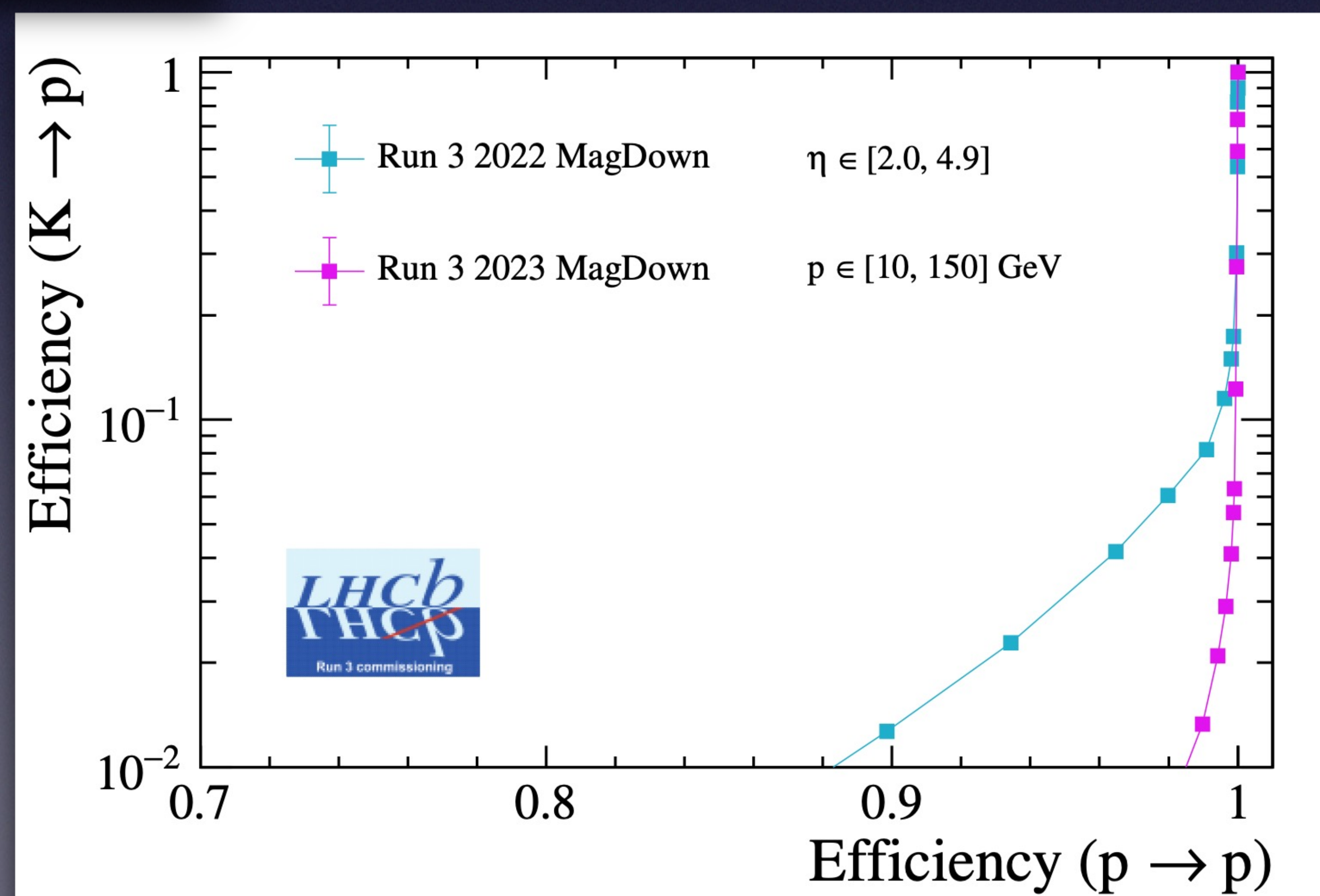
- Better performance in Run3, even though occupancies are higher
  - Run2 <#PVs> ~= 1.8
  - Run3 <#PVs> ~= 3.0

2023 Data
RICH Performance



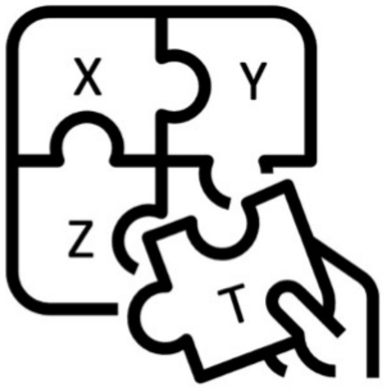
https://lbfence.cern.ch/alcm/public/figure/details/620

- Better performance in 2023
  - In part due to data taking conditions. Open Vertex Locator, slightly lower luminosity.
  - But also improved detector calibration and alignment.



So What Next ? Upgrade II …

Novel feature of the LHCb detector: fast timing

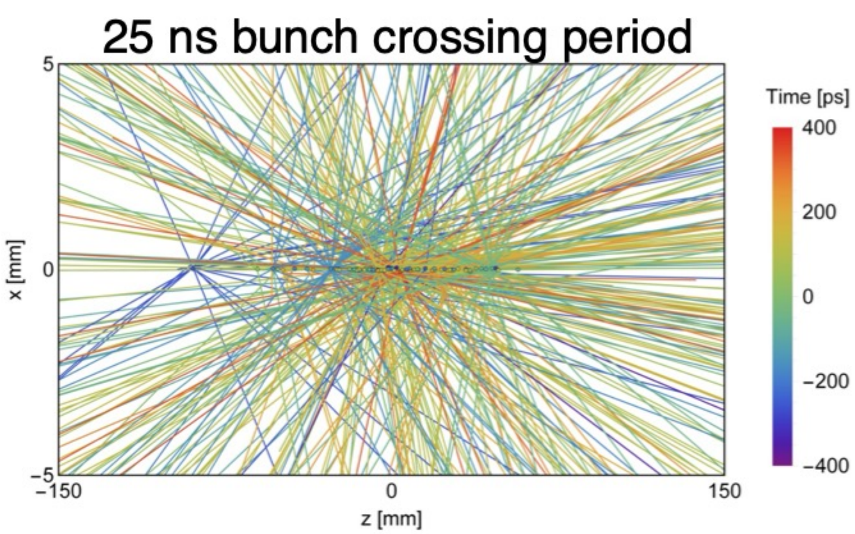


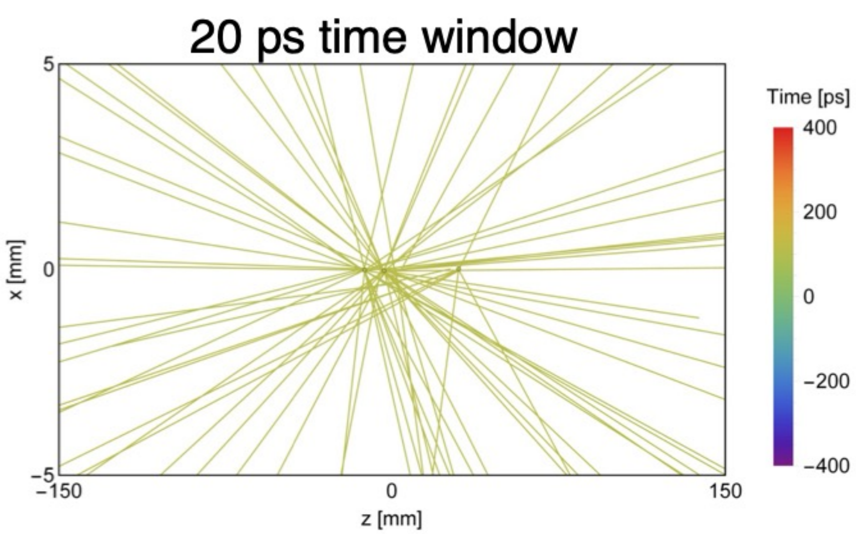
A new dimension will be added to the LHCb experiment.

Timing information with a **few tens of ps resolution** per particle will allow charged tracks and photons to be associated to the correct interaction vertex.

VELO, RICH, ECAL and TORCH will be fast timing detectors.

- Adds a new dimension to the **information exchange** between sub-detectors.
- Could all contribute to the same estimate of the **track time as it passes the detector**.
- Opens up **new avenues for data suppression** in front-end hardware and in software trigger.
- Sets challenging R&D requirements particularly for sensor technologies and front-end ASICs.





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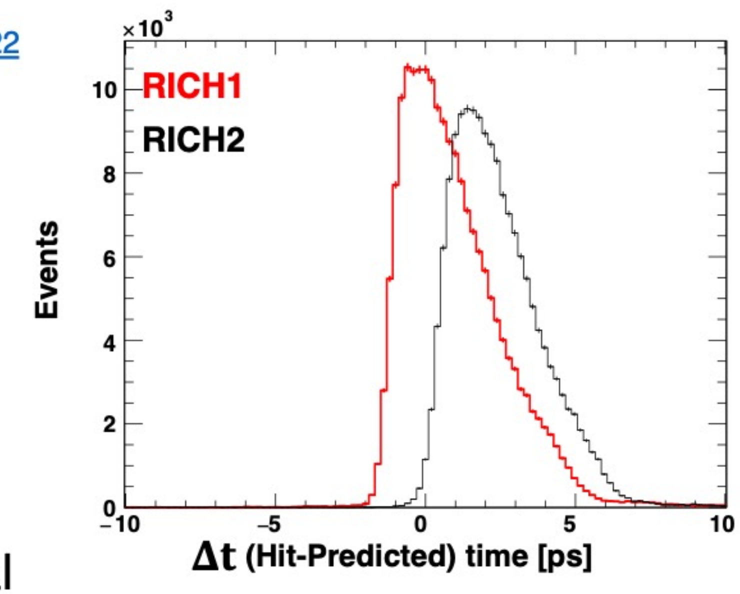
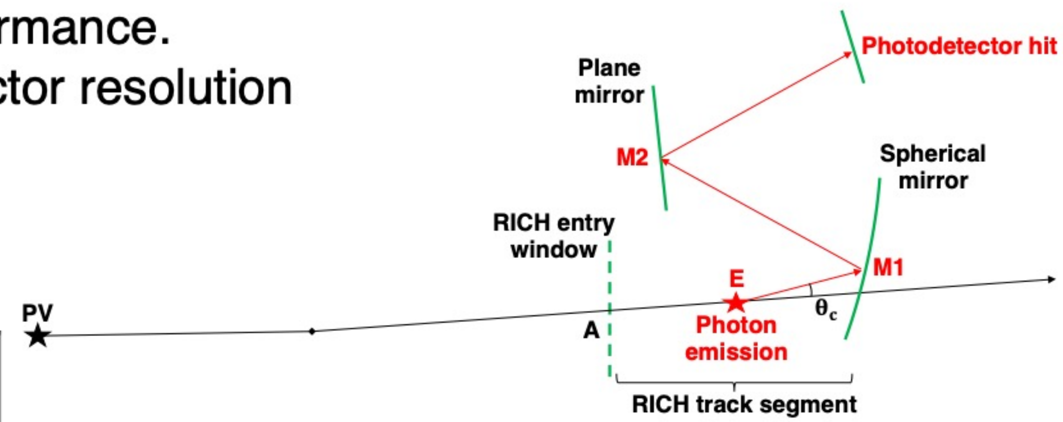
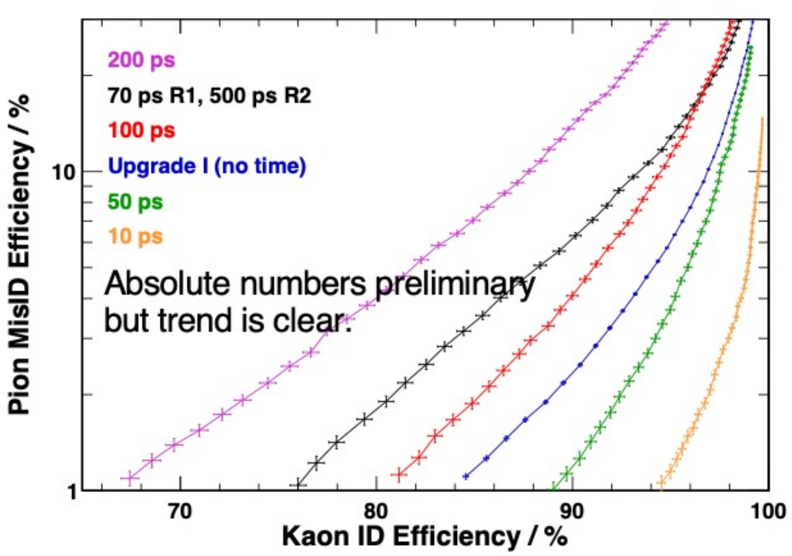
Fast timing in the RICH detectors

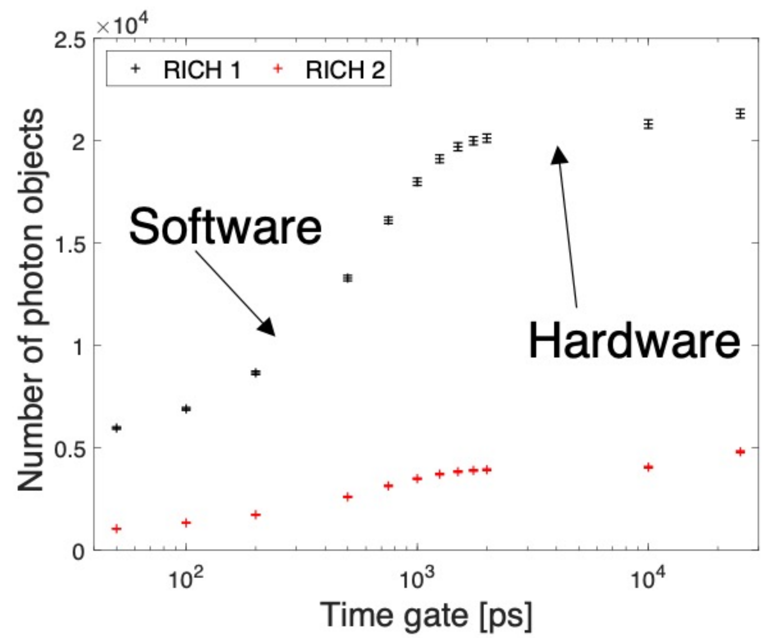


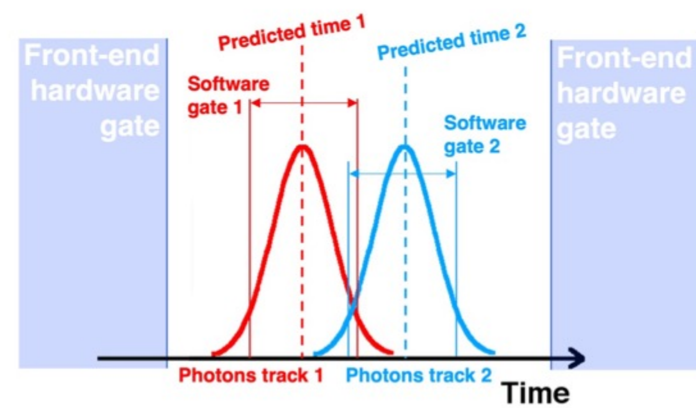
Owing to the prompt Cherenkov radiation and focusing mirror geometry, all photons from a given track arrive at approximately the same time at the photon detector plane.

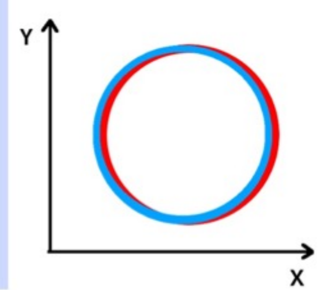
- Using **reconstructed parameters** in the RICH algorithms and the PV t-zero, can predict the detector hit times to within 10 ps.
- **Time gate around the predicted time** significantly reduces combinatorial background and helps to recover the Run 3 particle ID performance.
- **Faster detectors are better**, as in practice the photon detector resolution will dominate the width of the time gate. Aiming for a resolution better than 100 ps.











A RICH Christmas Carol!

Dan Foulds-Holt

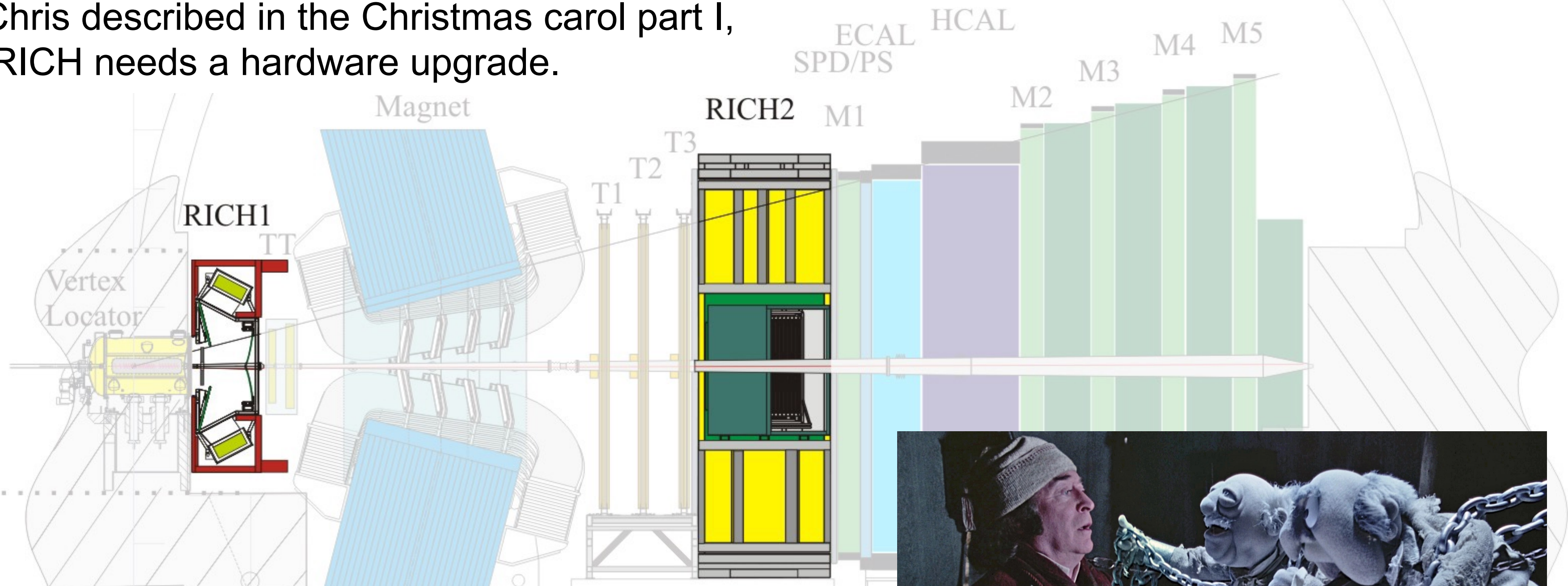
A RICH Christmas Carol!

THE SEQUEL!

Dan Foulds-Holt

RICH throughout the years

As Chris described in the Christmas carol part I, the RICH needs a hardware upgrade.



Just like another story of self-improvement, let's look through time!

The RICH of Christmas past

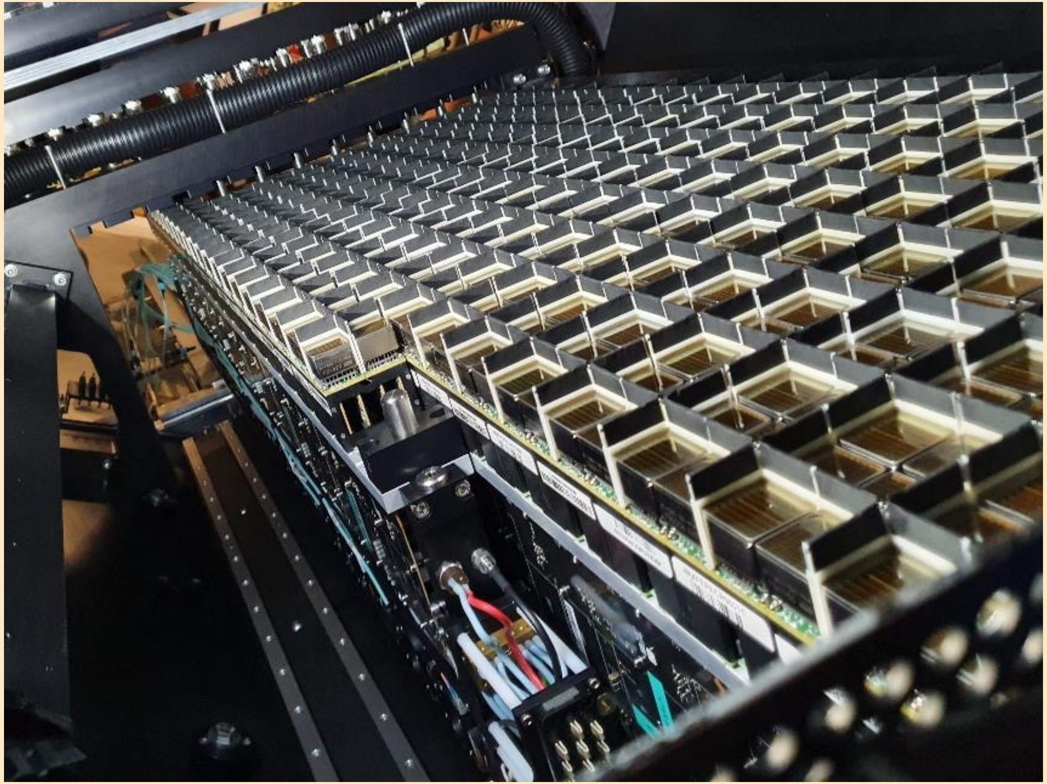
The RICH used Hybrid Photon Detectors and individual readout boards bonded to each detector.

This did not grant any timing information.

The RICH of Christmas present

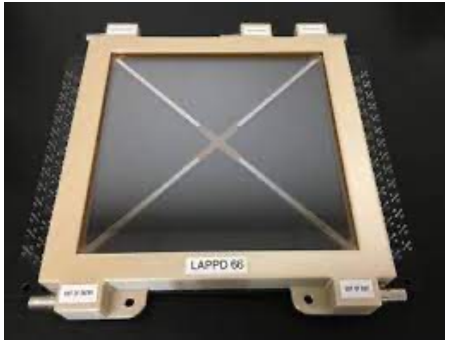
The current RICH has shifted to using MaPMTs. Readout is through a CLARO chip and an FPGA.

This applies a 6.23 ns front end timing gate, but no additional time information...



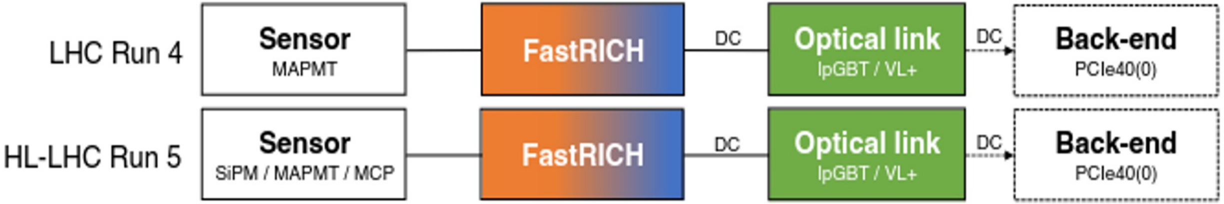
The RICH of Christmas future

The future RICH will likely need **new photodetectors** along with the **FastRICH** chip giving an improved readout board with time resolution.

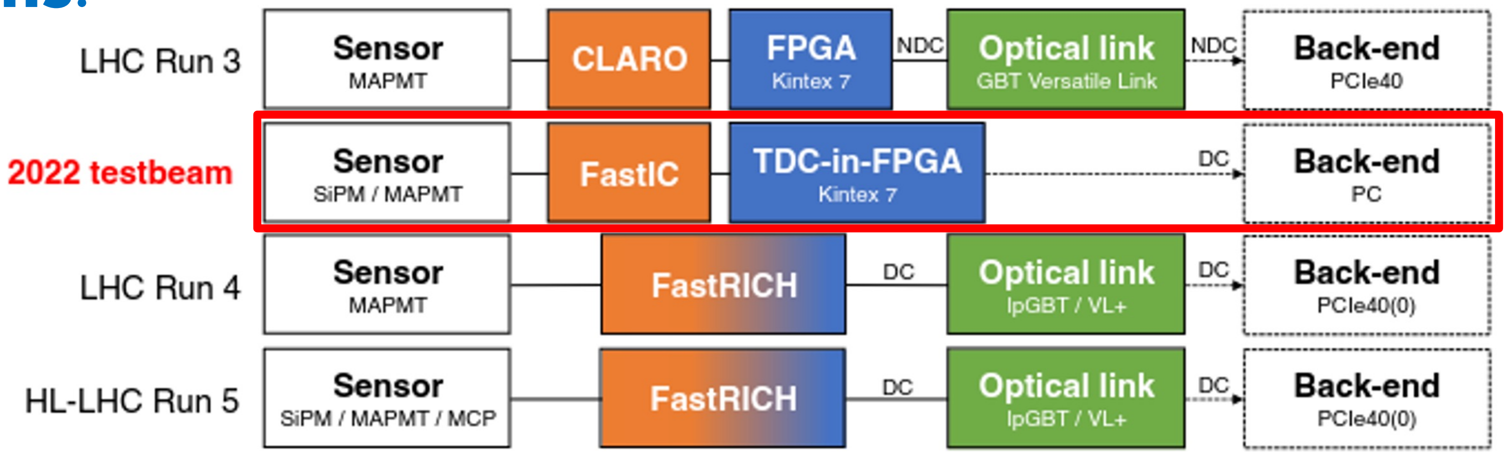


LAPPD / MCP

SiPM



Testbeams!

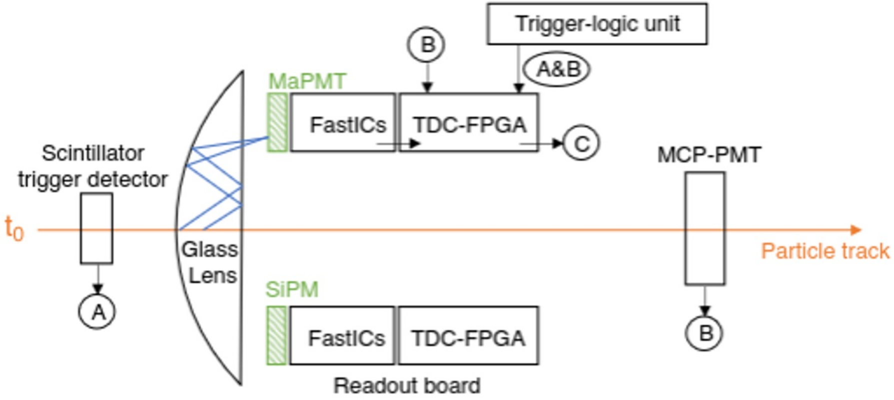


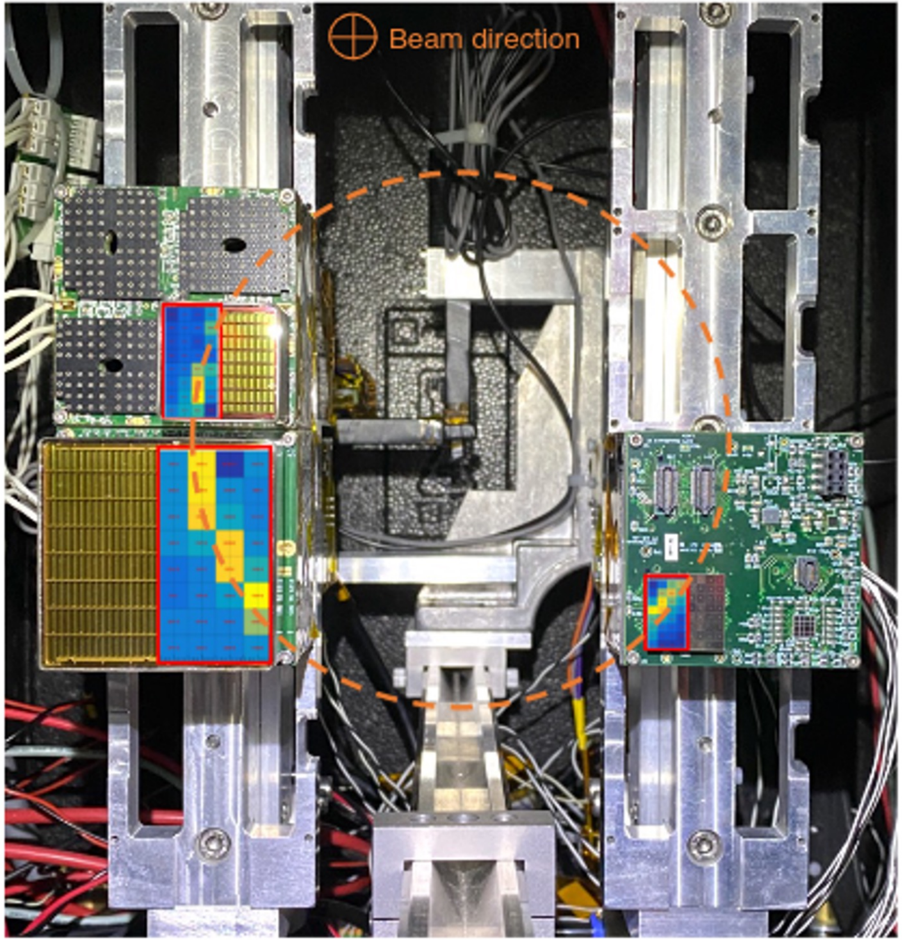
Testbeam campaigns are needed to rigorously test the detectors and readout electronics!

In 2022, testbeams were carried out using the FastIC chip and a TDC with 150ps resolution.

The 2022 Testbeam

The testbeam was able to take lots of Cherenkov data while testing the photodetectors and readout electronics.





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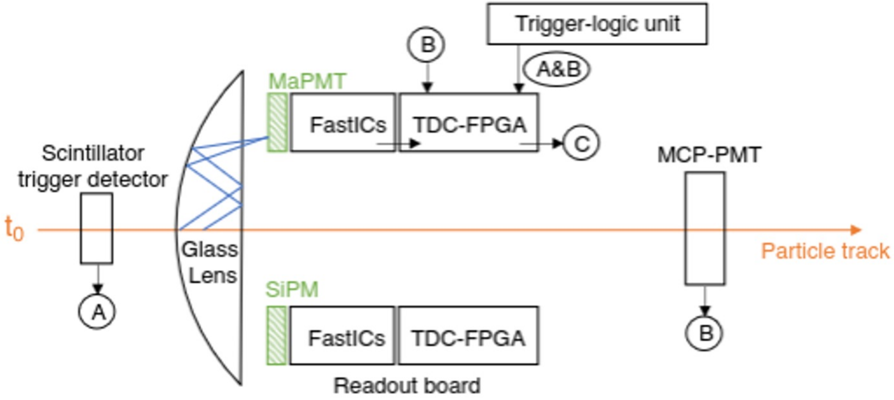
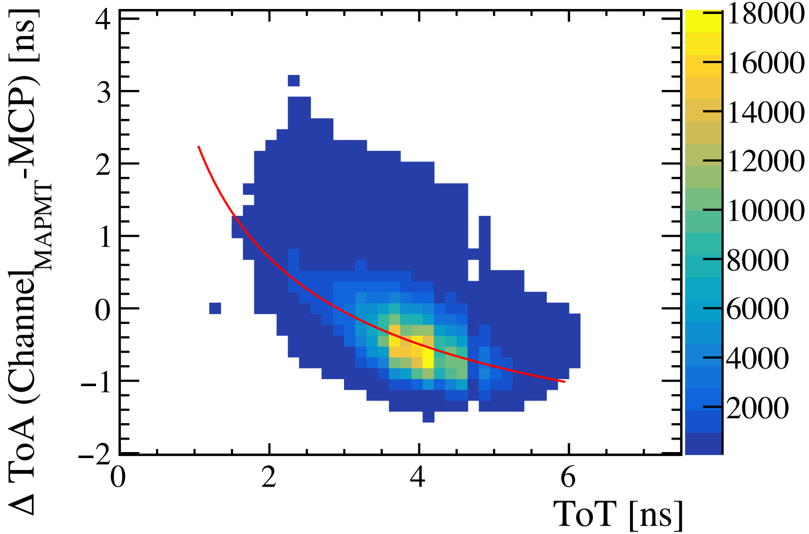
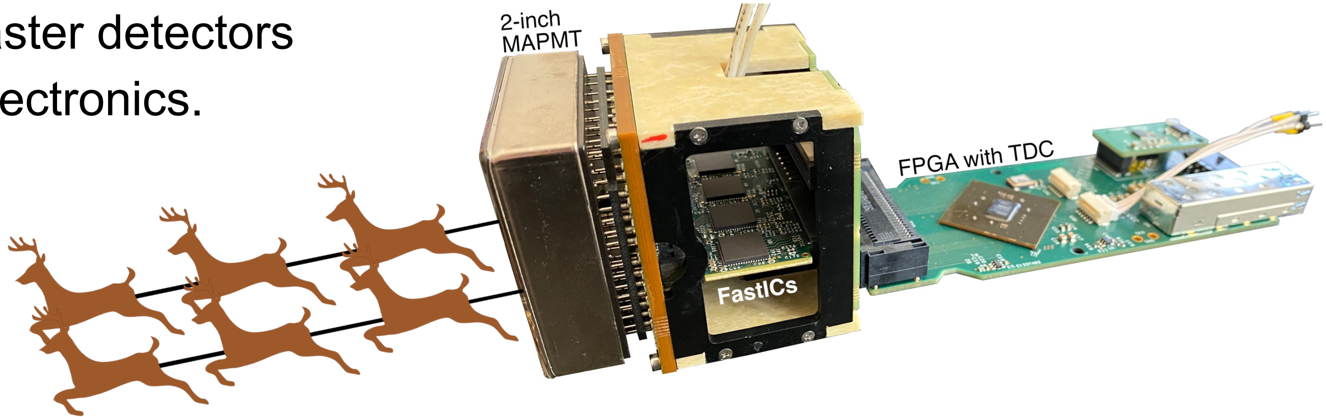


The 2022 Testbeam

Best performance from the testbeam returns a time resolution of **176ps**. This is approaching the MaPMT detector resolution!

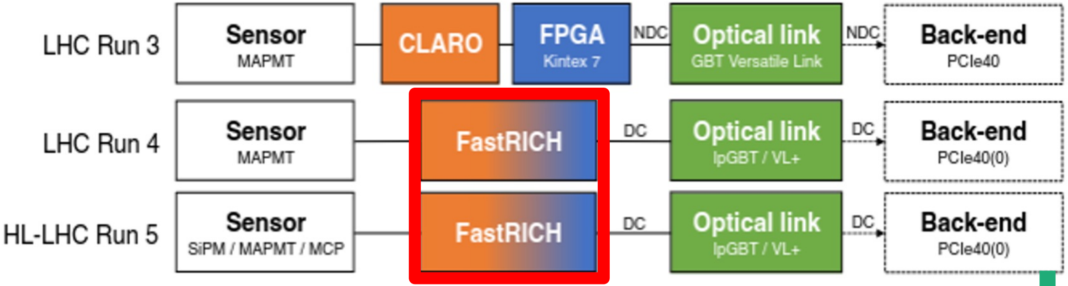
We have successfully reached the timing limit of what the MaPMT can achieve but for the faster detectors we need improved electronics.

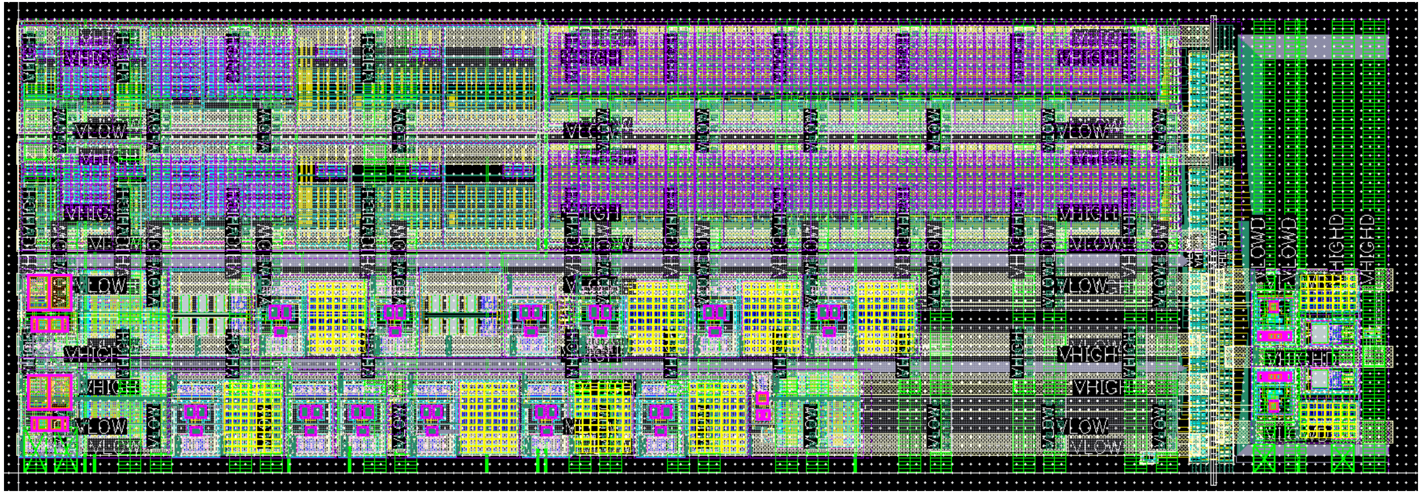




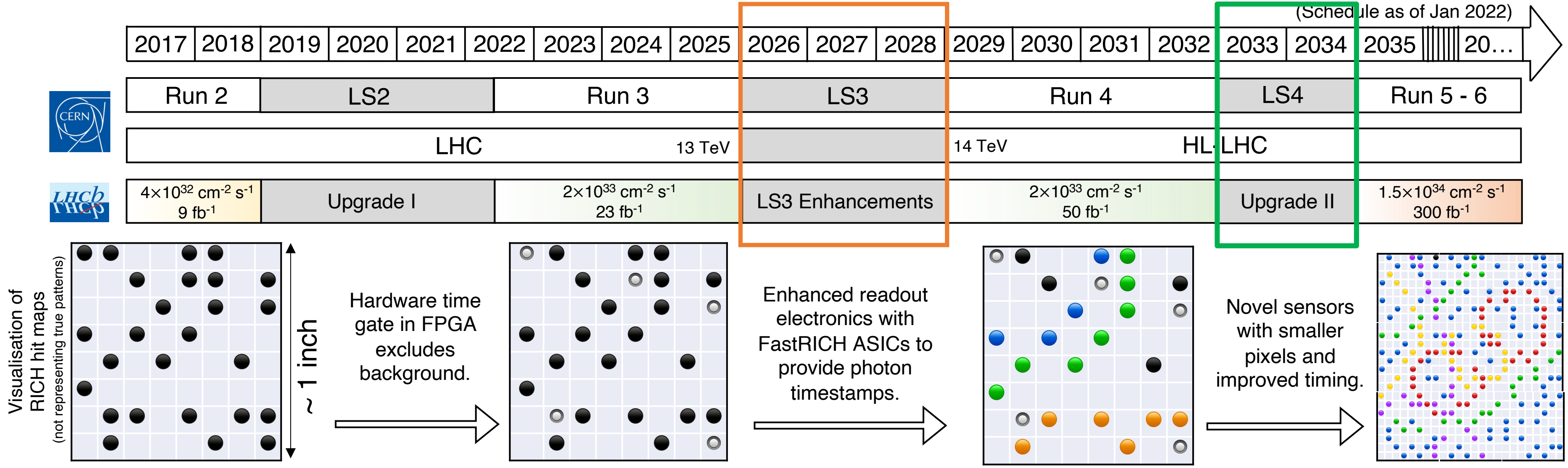
FastRICH

The FastRICH simplifies the readout chain and provides timing measurement with ~25 ps bins.

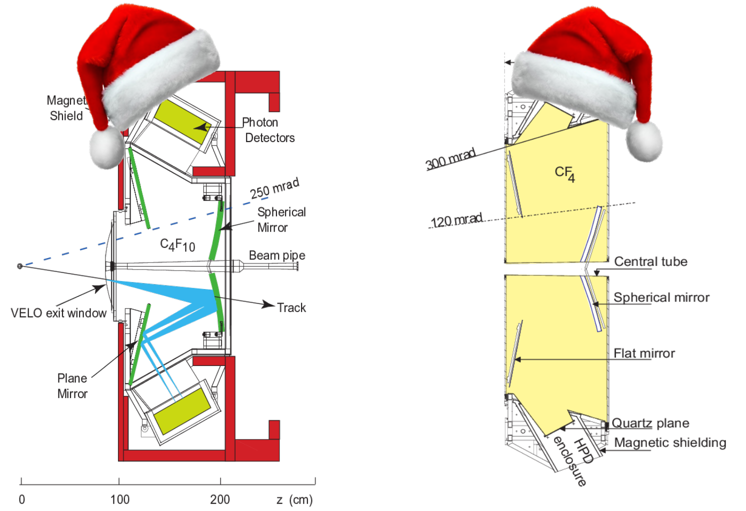




RICH schedule



Extensive work is being done to prepare for the upcoming upgrades in both **readout electronics** and **photodetectors**. Ensuring the RICH will continue to provide PID after the jump in luminosity and beyond.

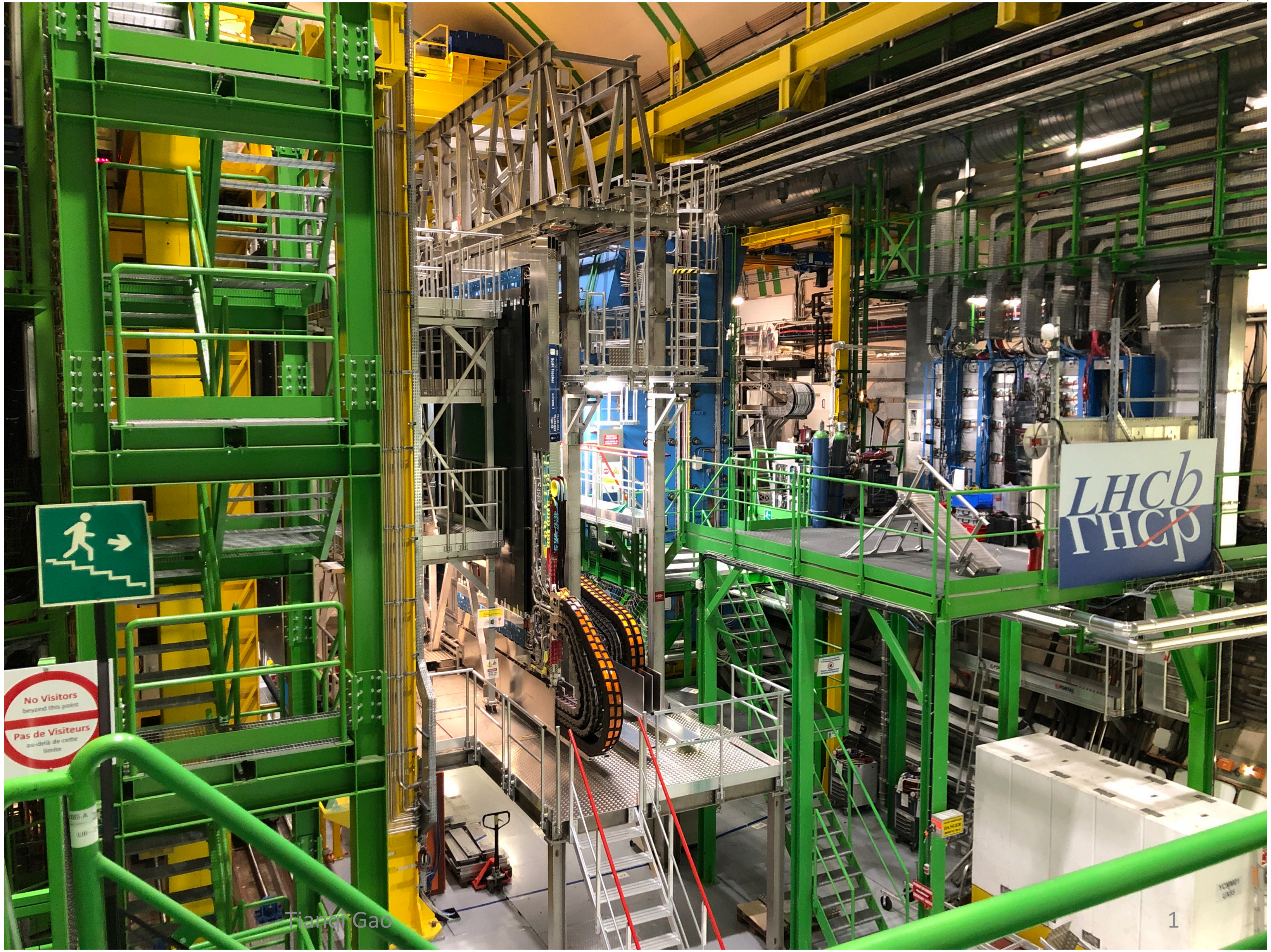


Join LHCb RICH for the physics, stay for the BBQs!

The LHCb Mighty Tracker project

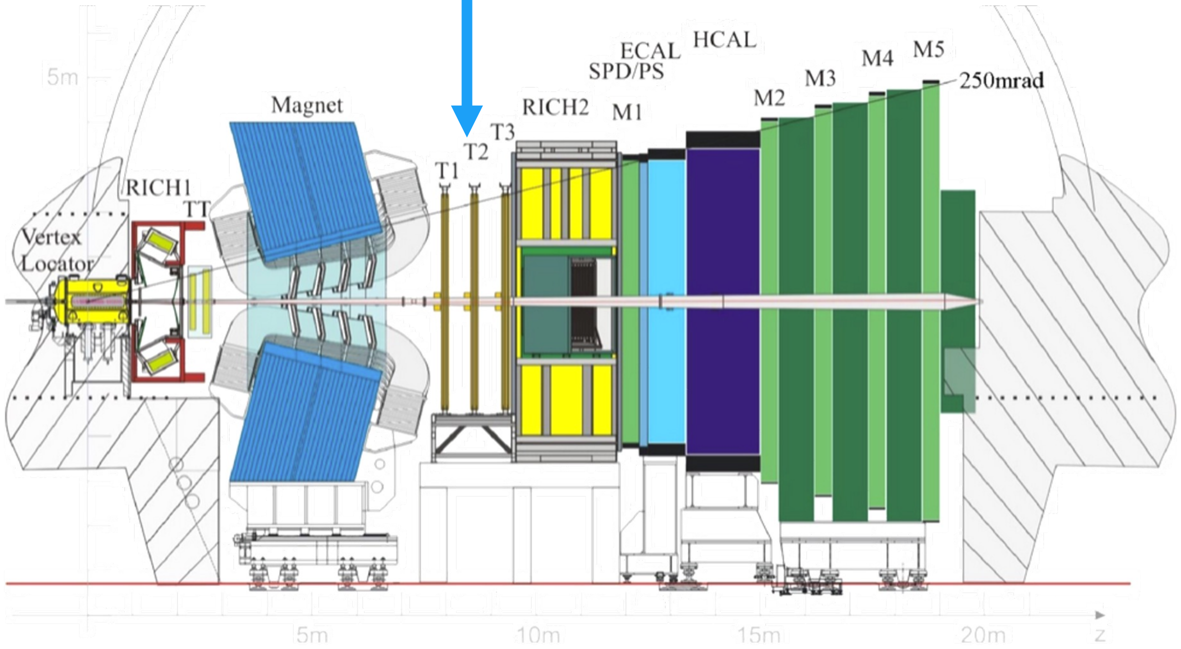
Christmas meeting
Tianqi Gao

From my 2023
underground tour

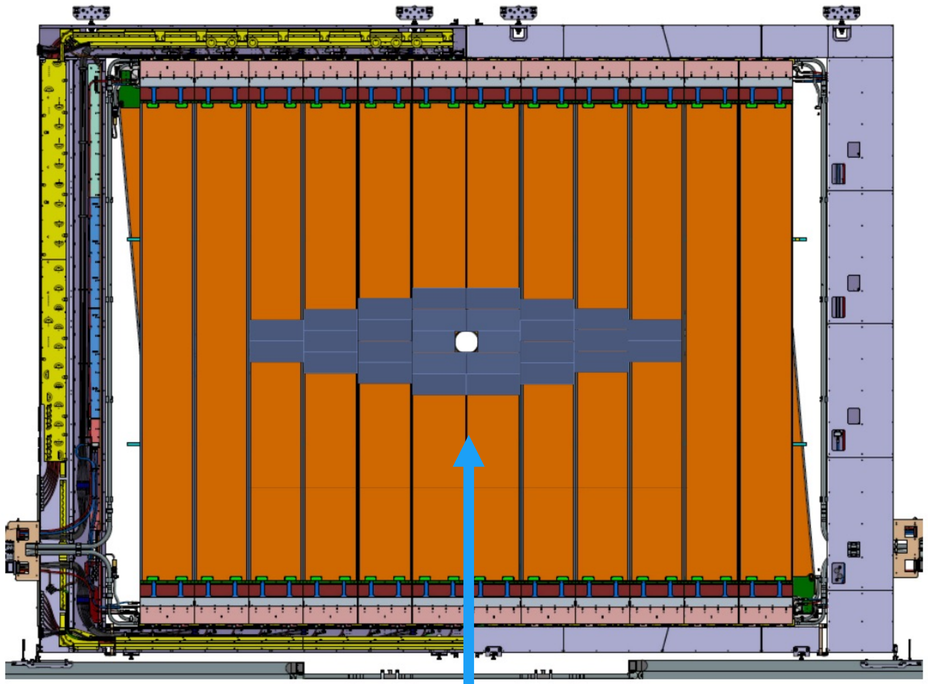


The LHCb Mighty Tracker project

SciFi trackers



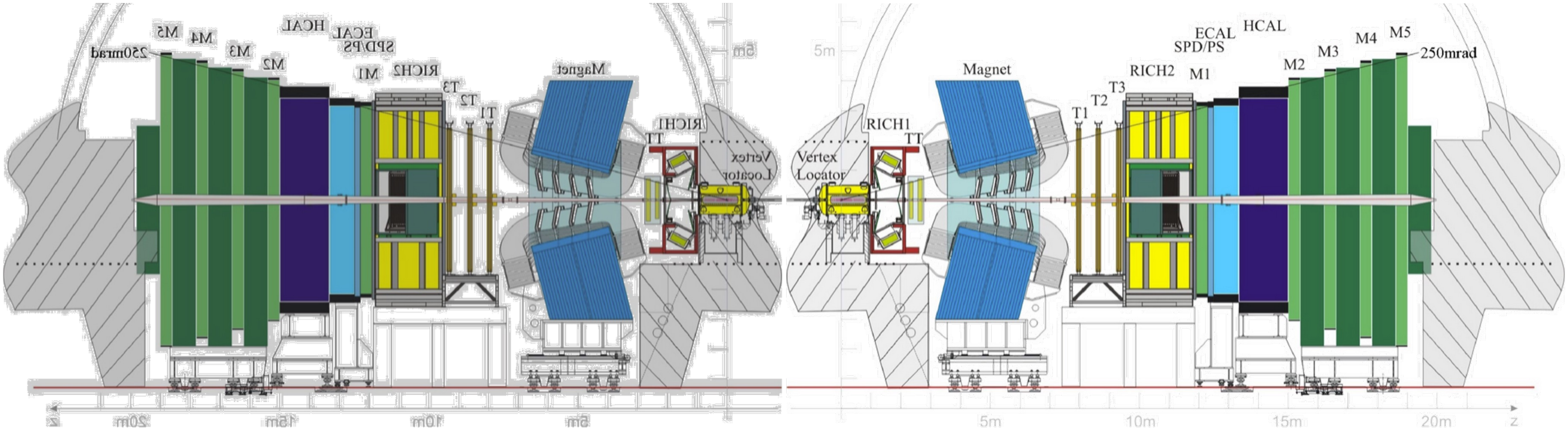
Turn 90º around the vertical axis



Mighty trackers

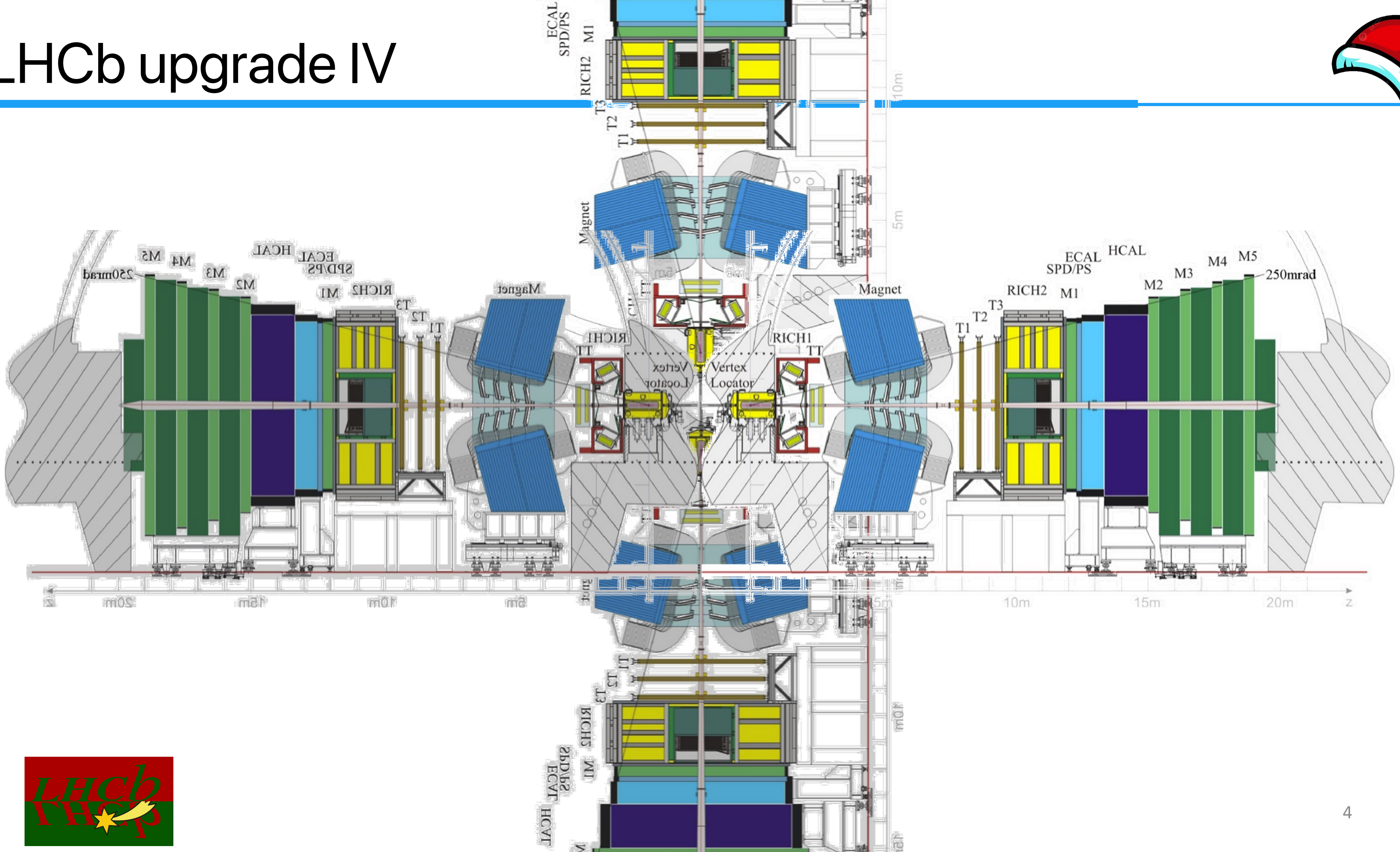
- 20m long LHCb detector
- Mighty-tracker is placed inside of the SciFi-tracker
- SciFi doesn’t have vertical information, MT adds it

The LHCb Mighty Tracker project

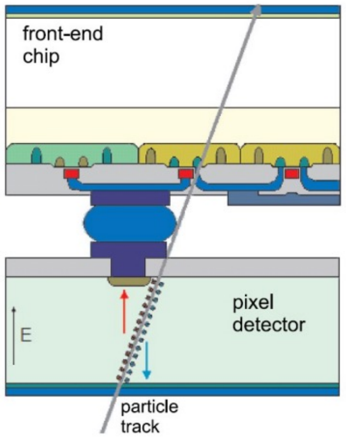


- There, the full LHCb detector
- η is from 2 to 5 and from –2 to -5

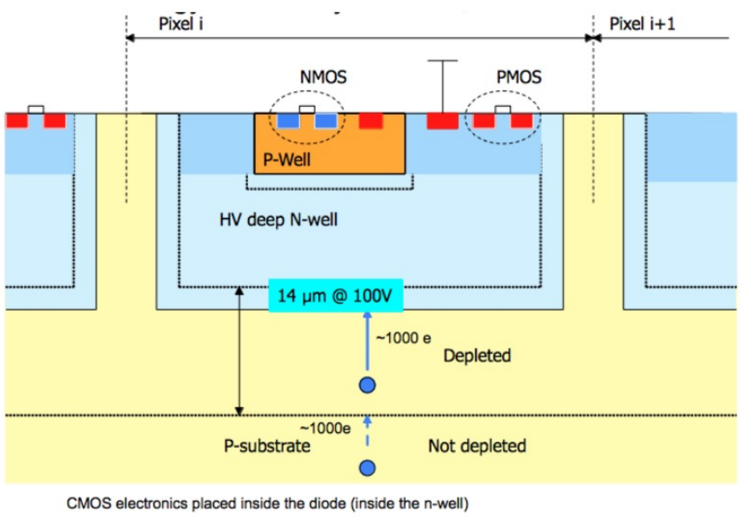
LHCb upgrade IV



Monolithic Active Pixel Sensor (MAPS)/HV-CMOS



Hybrid



HV-CMOS

Steve Worm 2015

MightyPix1

Version:

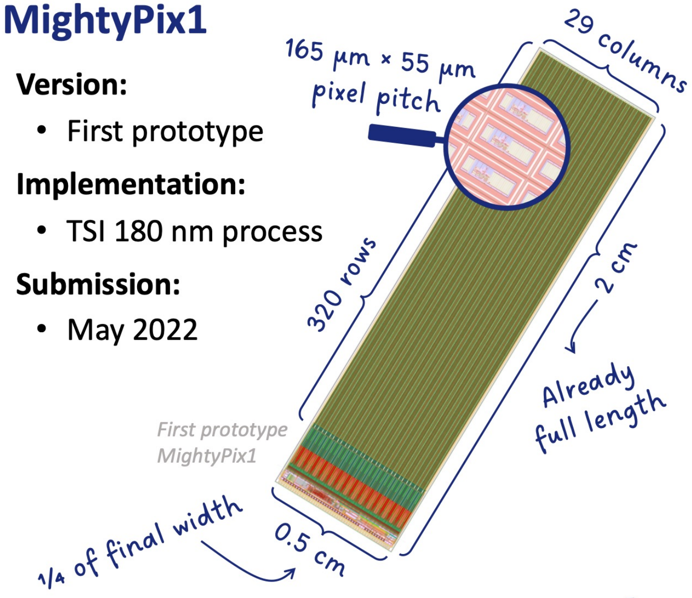
- First prototype

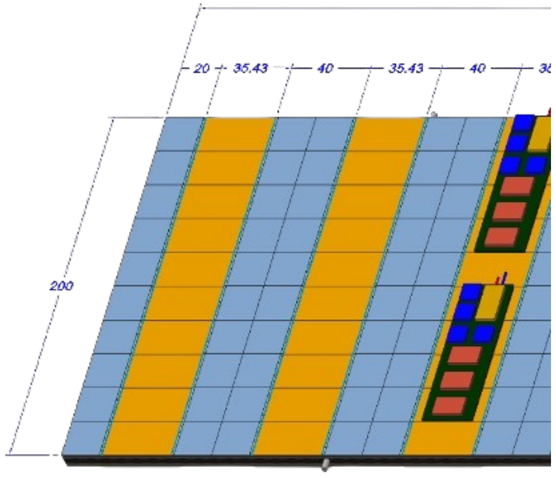
Implementation:

- TSI 180 nm process

Submission:

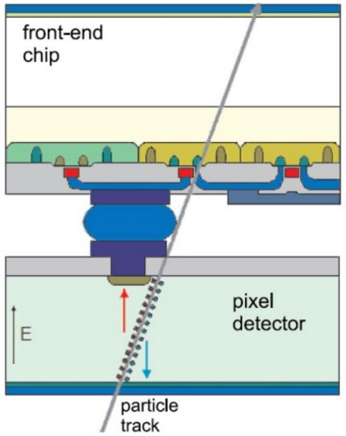
- May 2022





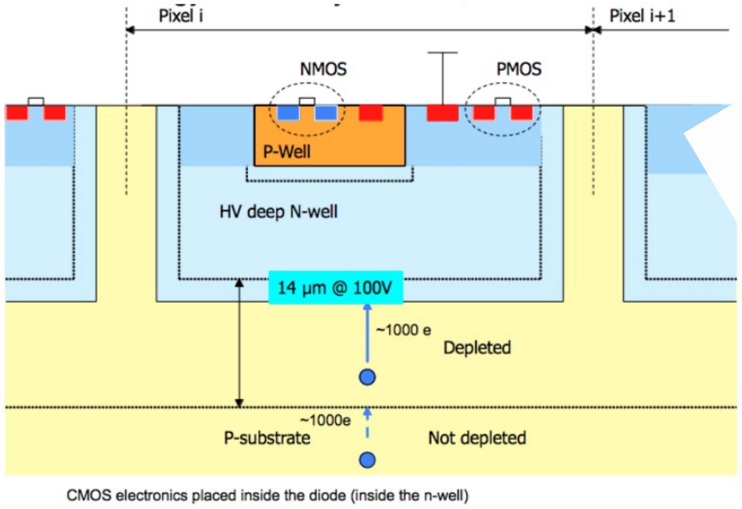
- Industry-standard CMOS processes -> mass fabricate -> cheaper
- We ask them to make a CPU using an old 180 nm process, then stop them right after photolithography but before they thin out the "useless" p-substrate
- Each pixel is placed vertically along the sensor, each sensor is placed horizontally on a module
- 37k pixels per sensor, 140 sensors per module

Monolithic Active Pixel Sensor (MAPS) – HV-CMOS

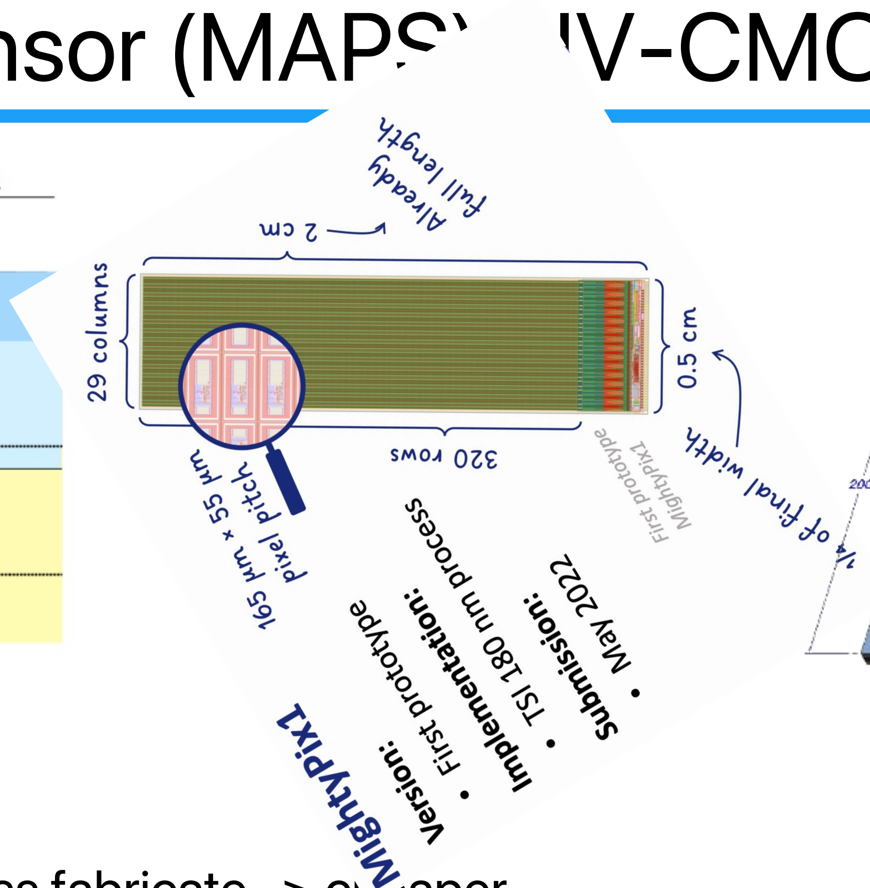


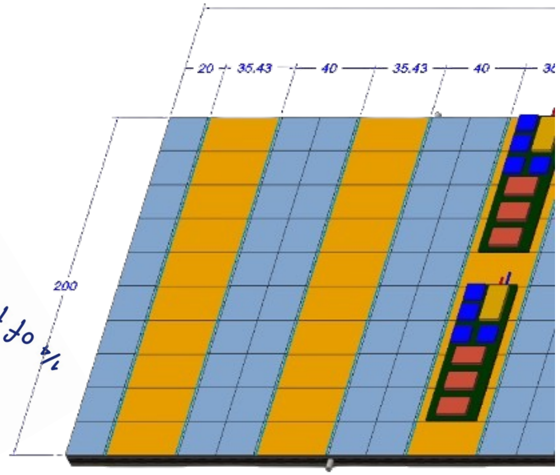
Hybrid

Steve Worm 2015



HV-CMOS





- Industry-standard CMOS processes -> mass fabricate -> cheaper
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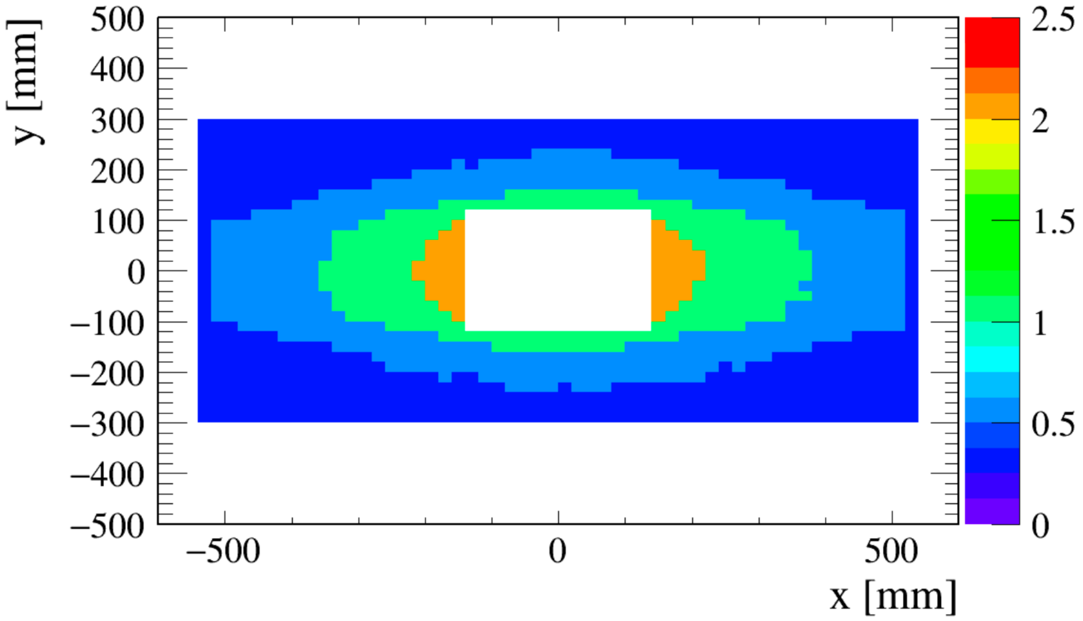
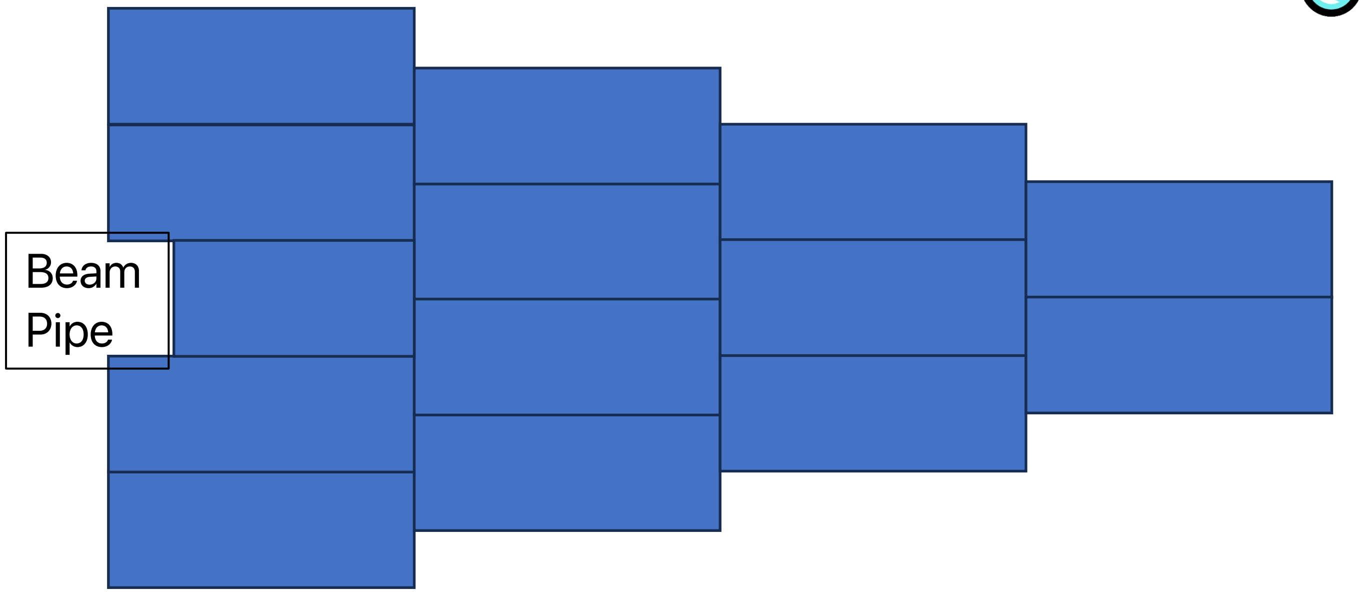
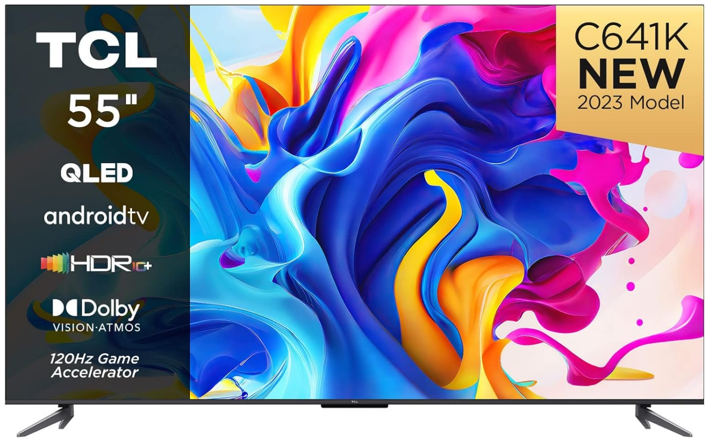
Monolithic Active Pixel Sensor (MAPS)/HV-CMOS

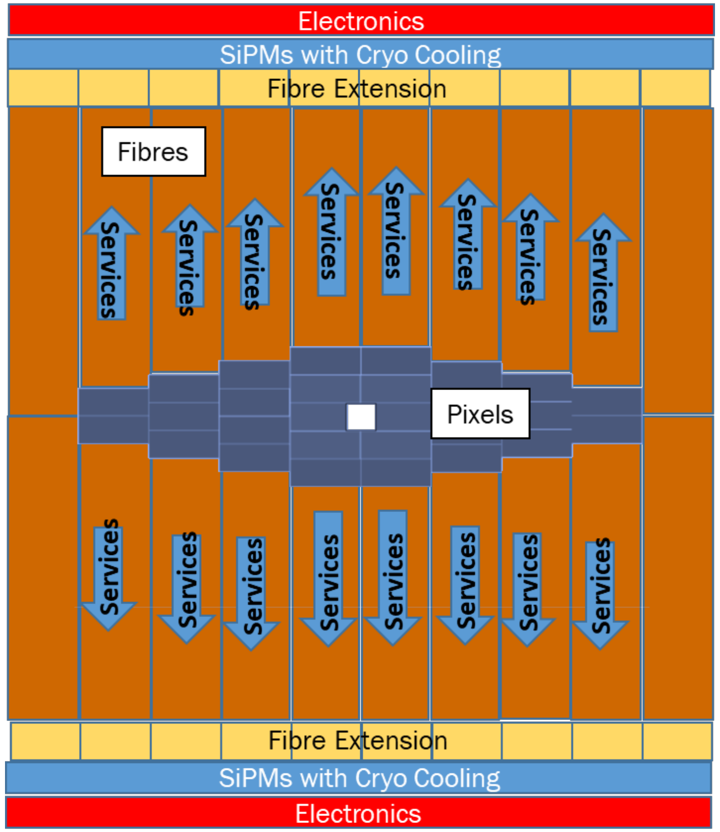


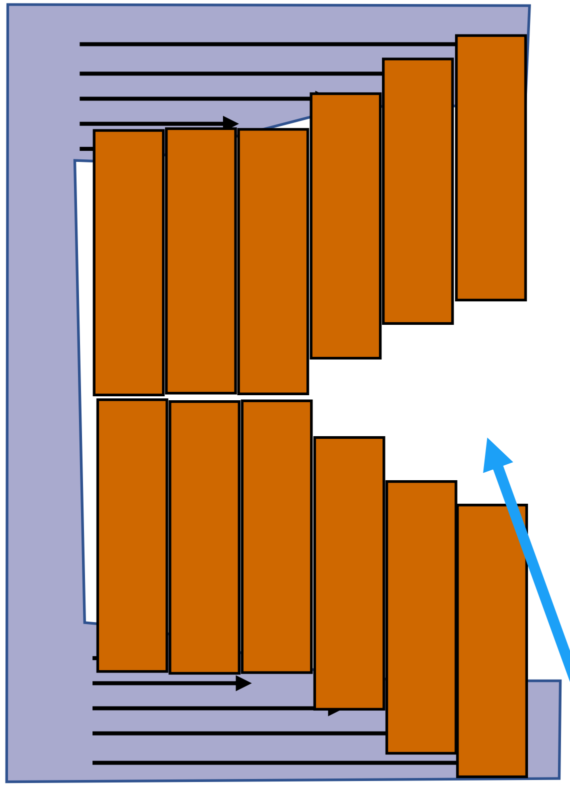


- The mighty tracker is ~4.4 x 1 m^2, each module is ~20 x 52.8 cm^2
- 37k pixels per sensor, 140 sensors per module
- 14 modules per layer, 6 layers
- totalling 11760 sensors or 435 million pixels, a 4k TV has 8.3 million pixels



Mechanics and integration





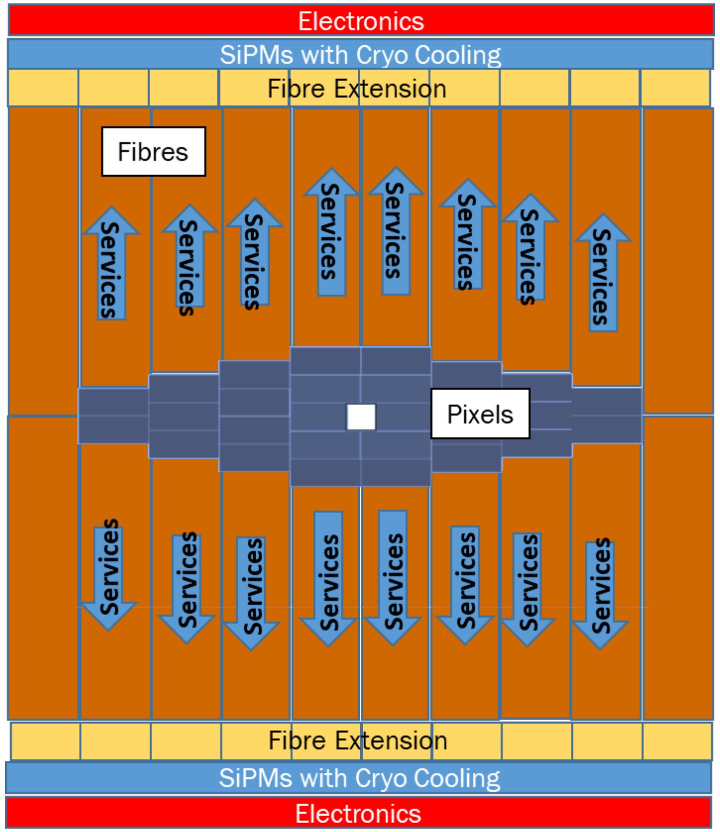
- Support structure for Mightypix
  - Wingardium Leviosa
- Coolant type
  - Felix Felicis
- Cooling method
  - Glacius

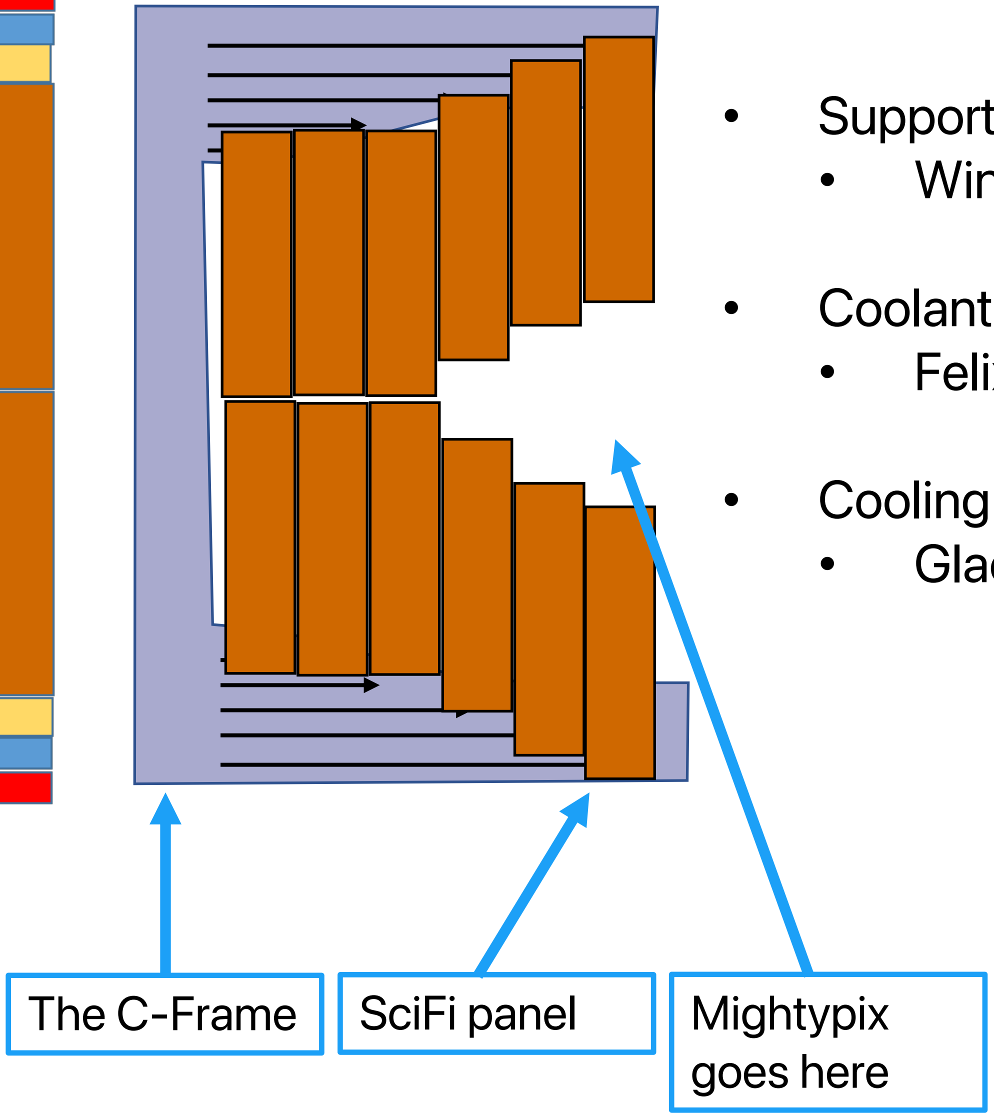
The C-Frame

SciFi panel

Mightypix goes here

Mechanics and integration





- Support structure for Mightypix
  - Wingardium Leviosa

- Coolant type
  - Felix Felicis
- Cooling method
  - Glacius

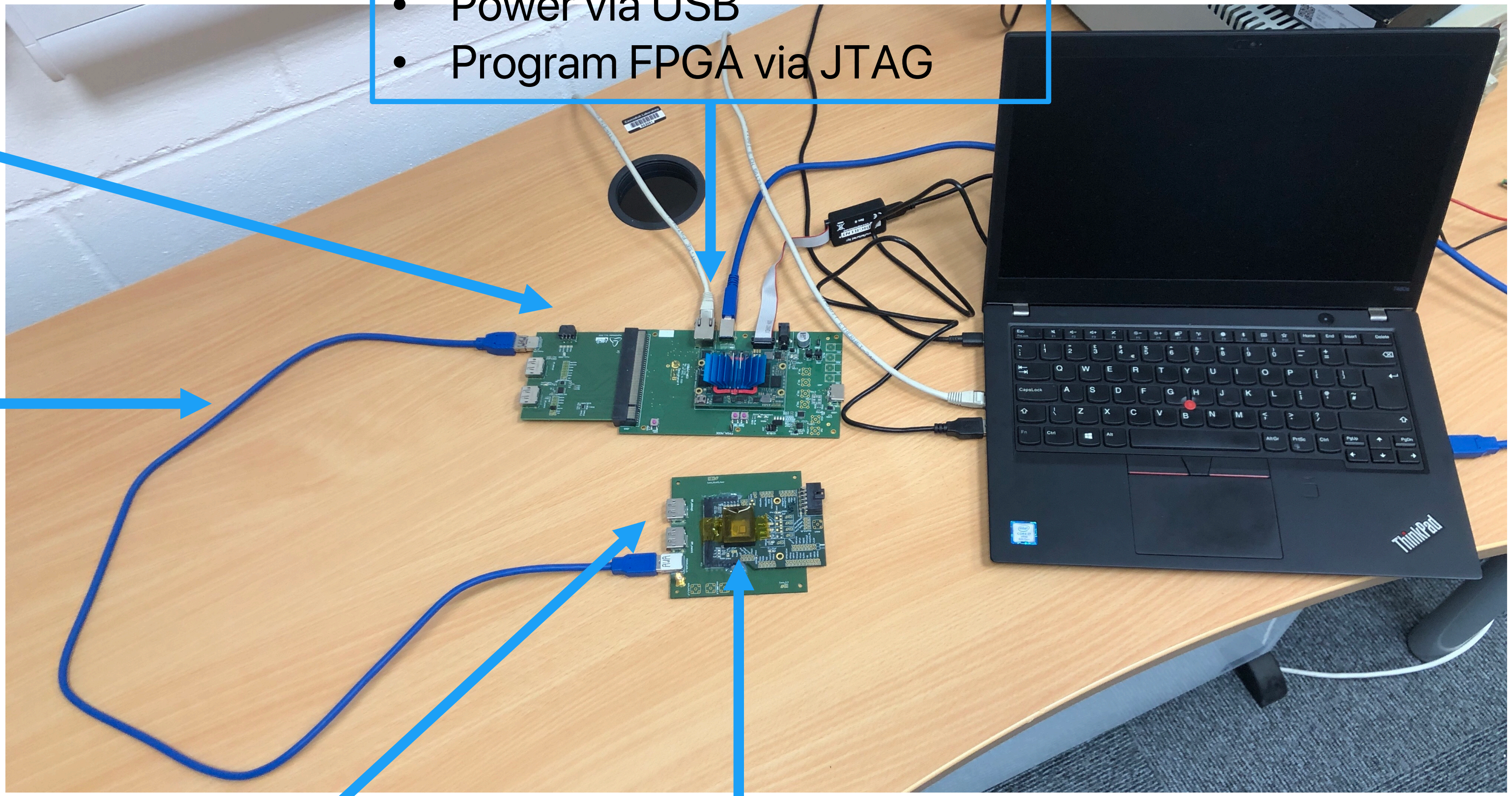
Cambridge’s involvement

From left to right:

- Ethernet for control/data out
- Power via USB
- Program FPGA via JTAG

DC power for sensor

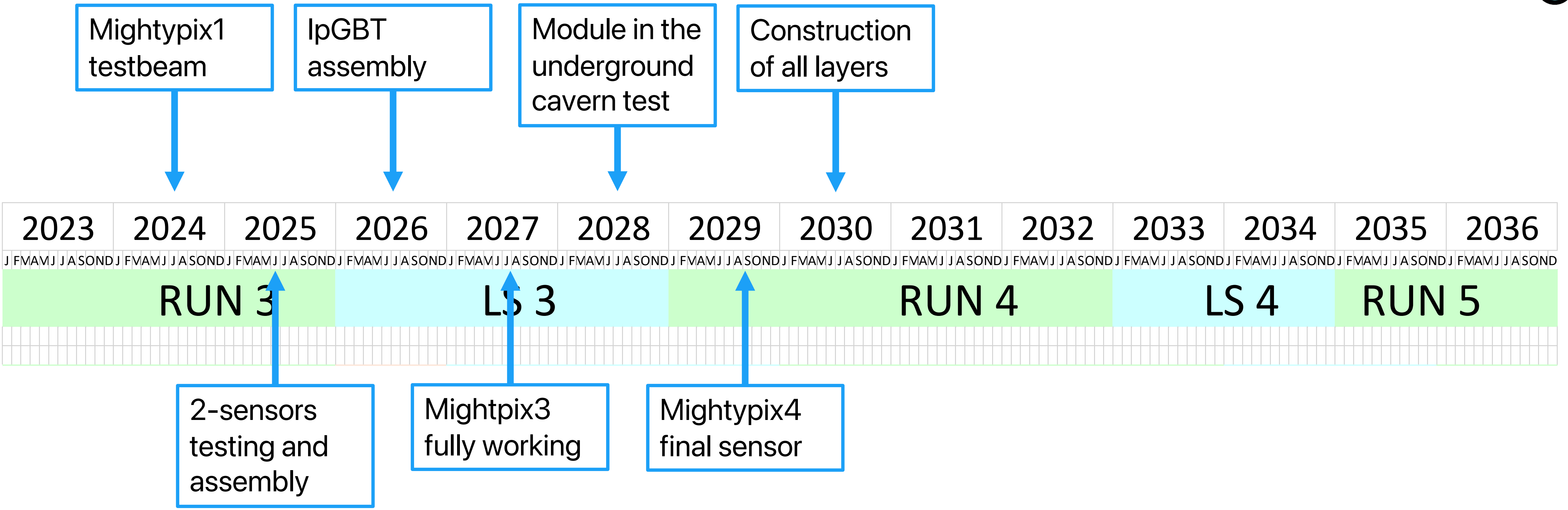
Power to Run2020 via USB



Special displayport cables, for control/data and debugging

Run2020 sensor

Timeline



Mightypix1 testbeam
lpGBT assembly
Module in the underground cavern test
Construction of all layers
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
RUN 3
LS 3
RUN 4
LS 4
RUN 5
2-sensors testing and assembly
Mightpix3 fully working
Mightypix4 final sensor

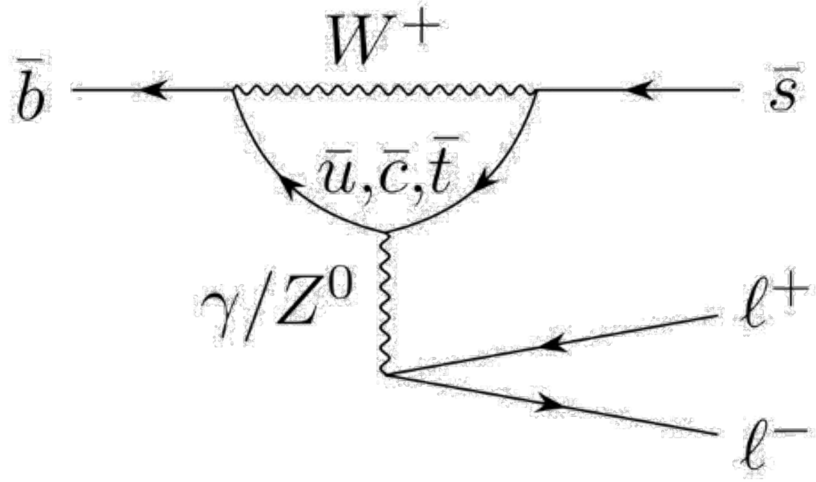
Rare Decays at LHCb

LHCb

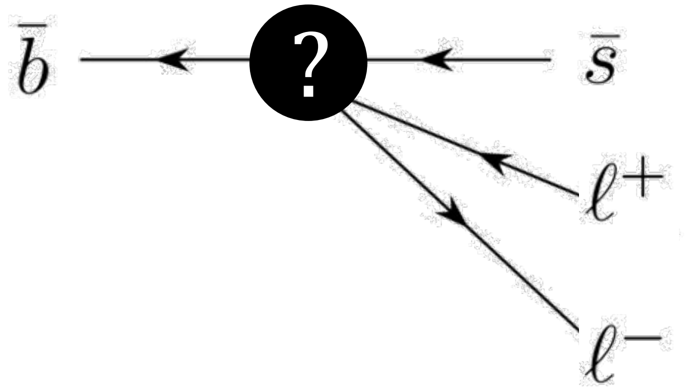
UNIVERSITY OF CAMBRIDGE

Why Rare Beauty Decays?

Standard Model



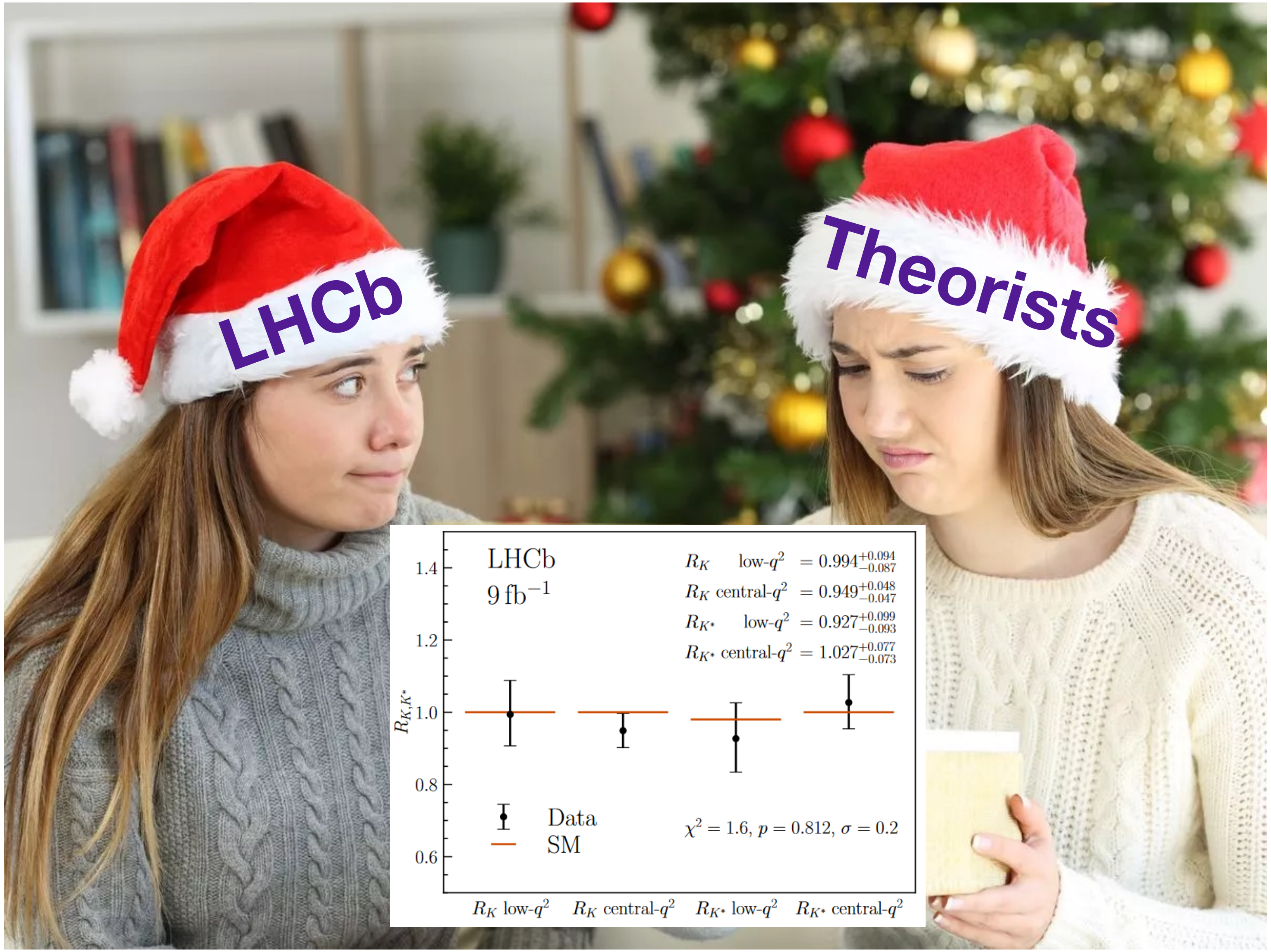
New Physics



- $b \to s\ell^+\ell^-$ and $b\bar{s} \to \ell^+\ell^-$ transitions, are **flavour-changing neutral current** (FCNC) processes → forbidden at tree level in the Standard Model (SM)
- supressed in SM (branching fractions $\mathcal{O}(10^{-10})$–$\mathcal{O}(10^{-6})$) and sensitive to **New Physics** (NP)
- particles associated with NP quantum fields can have masses above reach of direct searches at LHC

Last Christmas

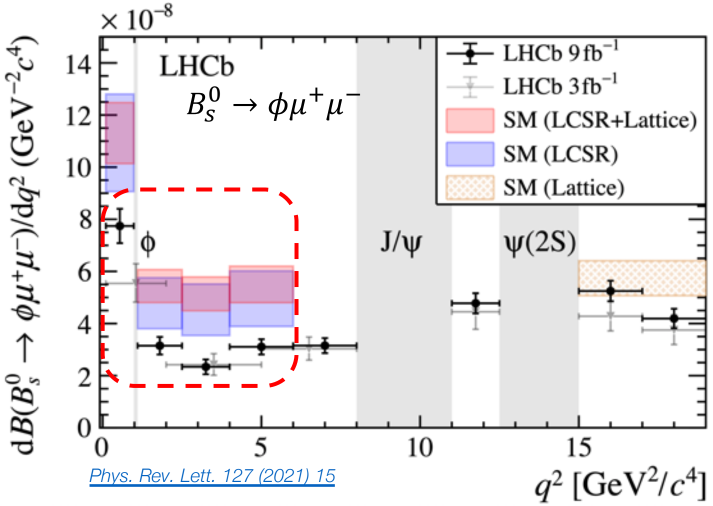
Last Christmas



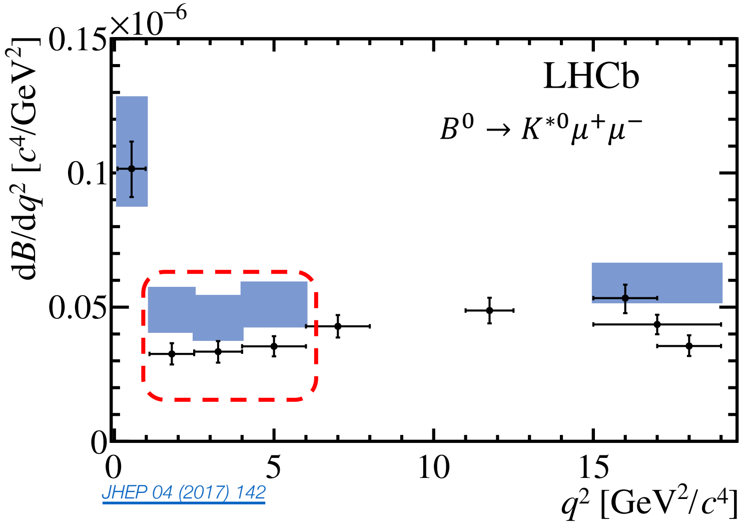
Last Christmas

Last Christmas

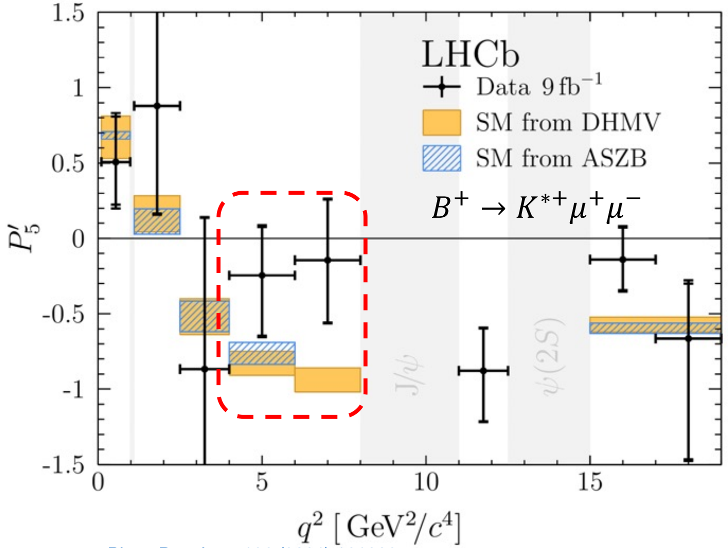
Anomalies



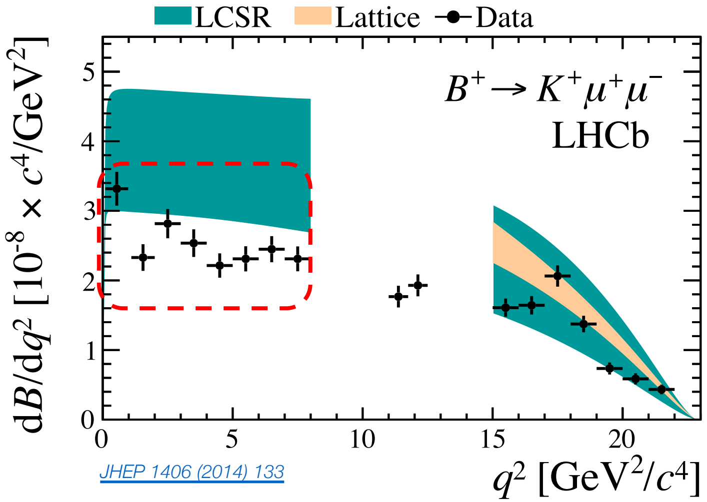
Phys. Rev. Lett. 127 (2021) 15



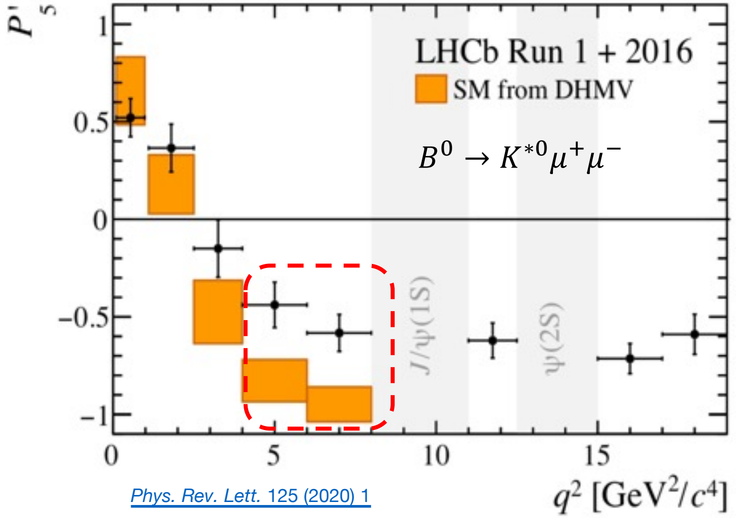
JHEP 04 (2017) 142



Phys. Rev. Lett. 126 (2021) 161802



JHEP 1406 (2014) 133



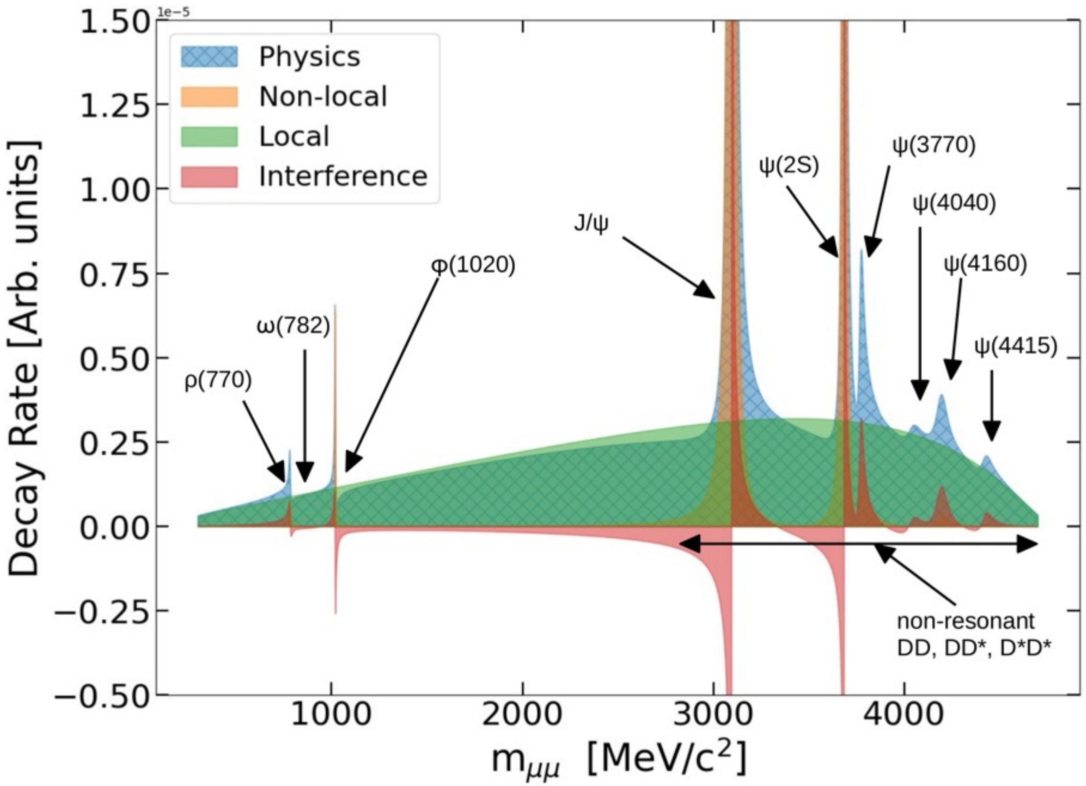
Phys. Rev. Lett. 125 (2020) 1

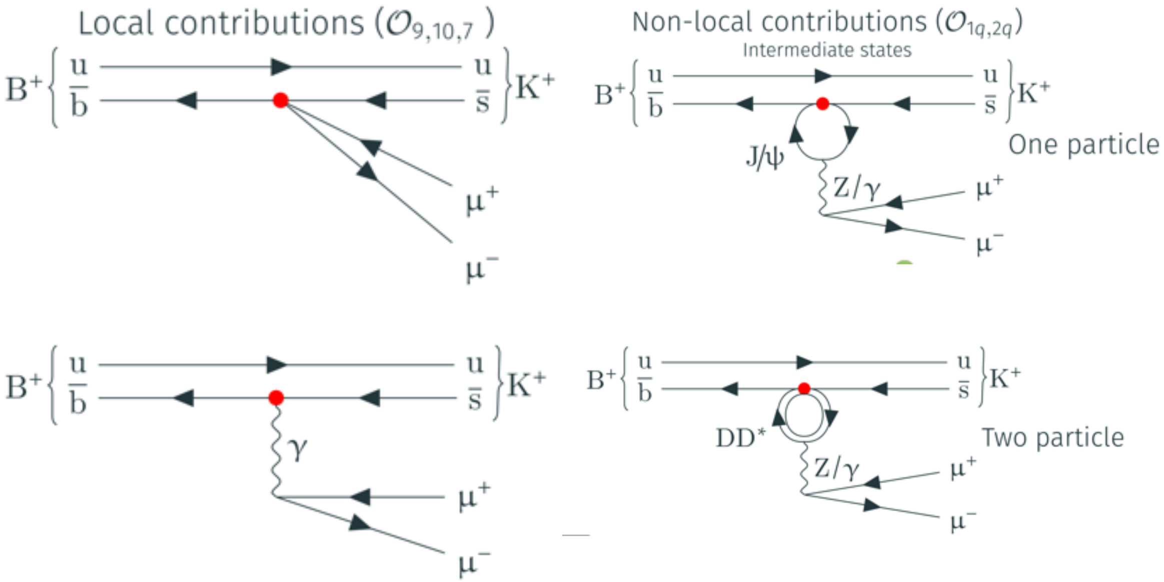

Lakshan Mahdan
LHCb

Analysis of $B^+ \to K^+\mu^+\mu^-$

- The dimuon spectrum of b->sll transition contain both local and non-local (hadronic) contributions
- Underestimated hadronic effect could potentially explain the anomalies seen
- Analysis aims to measure the local SM and NP while accounting for the hadronic effects directly using data in the full dimuon spectrum.
- Sensitive to NP enhanced tau-loop effects to dimuon spectrum

Analysis in Review within LHCb



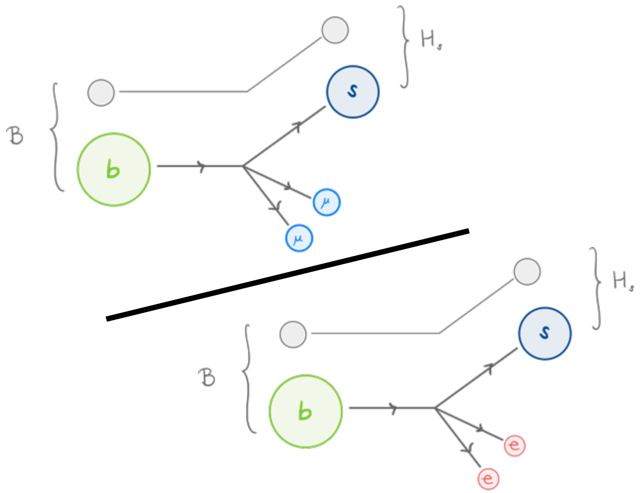



Davide Lancierini

LFU measurements at LHCb: R_K

- $R_{H_s \equiv K}$ measurements compare the branching ratios of $B^+ \to K^+\ell\ell$ decay to e and μ final states

$1 \overset{\text{SM}}{=}$



$$\overset{\text{exp}}{=} \frac{N(B \to K^+\mu\mu)}{N(B \to K^+ee)} \frac{\varepsilon(B \to K^+ee)}{\varepsilon(B \to K^+\mu\mu)}$$

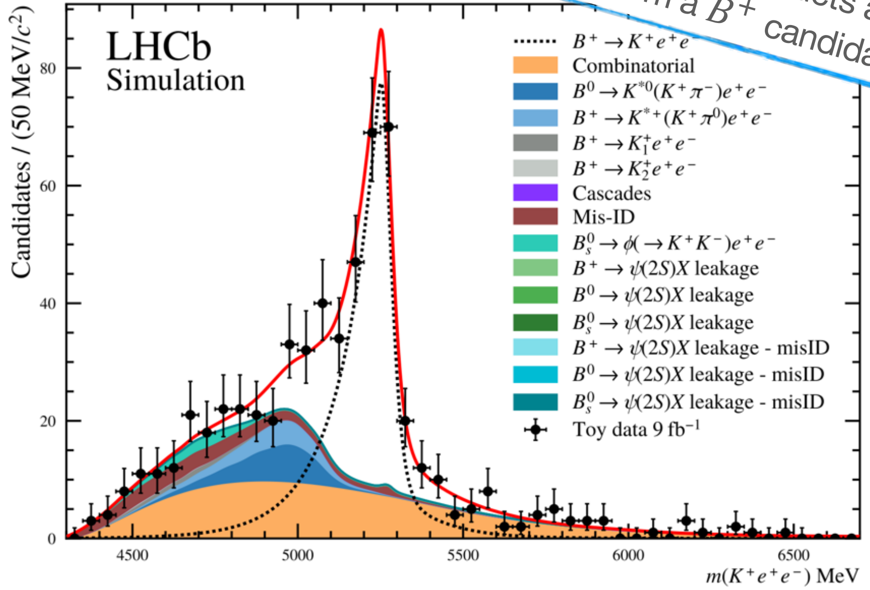
- Challenging as it requires precise knowledge of the signal yield (N) and the selection efficiency (ε) of decays that exploit different sub-detection systems at LHCb
  - Different reconstruction efficiencies, resolution, backgrounds btw e and μ

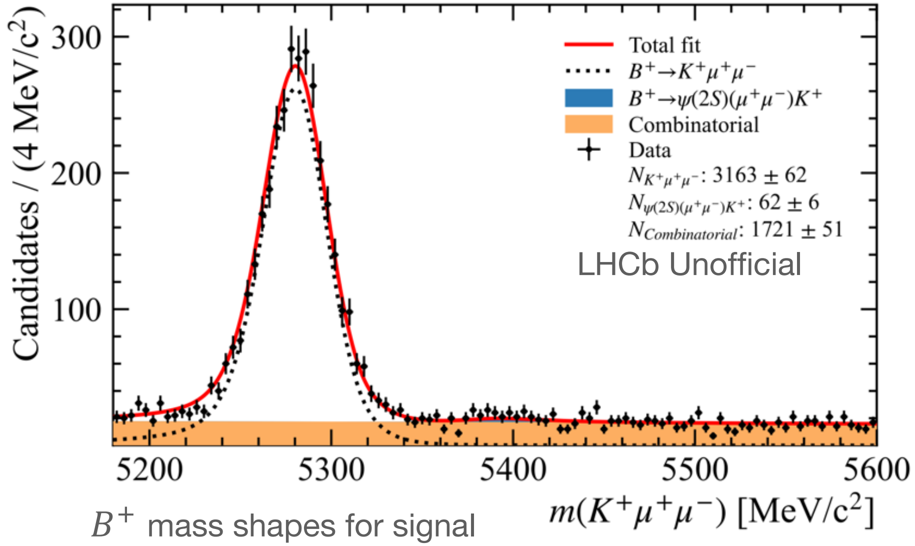
- We're involved in the measurement of R_K in kinematic region where the dilepton pair carries away most of the B^+ momentum, where existing measurements have big uncertainties ($\sim 18\%$)

R_K at high dilepton invariant mass q^2

Combinatorial background: events polluting the signal region where tracks from different decay products are combined to form a B^+ candidate

- We extract the signal yield (N) via unbinned maximum likelihood fits to the B^+ mass shape.
- In this kinematic region, lower efficiency and resolution in the electron mode induce a warping of the combinatorial background shape (strong contrast with muons).
- For combinatorial background events, the B^+ mass cannot be arbitrary low and q^2 arbitrary high → B^+ mass shape warping due to phase-space.
- We developed a "physically" inspired model to describe this phase-space cut at low B^+ mass:
    - Allows to minimise the number of parameters needed to describe the combinatorial shape and maximise the sensitivity to R_K at high q^2 (est. ~ 8% tot uncert.)

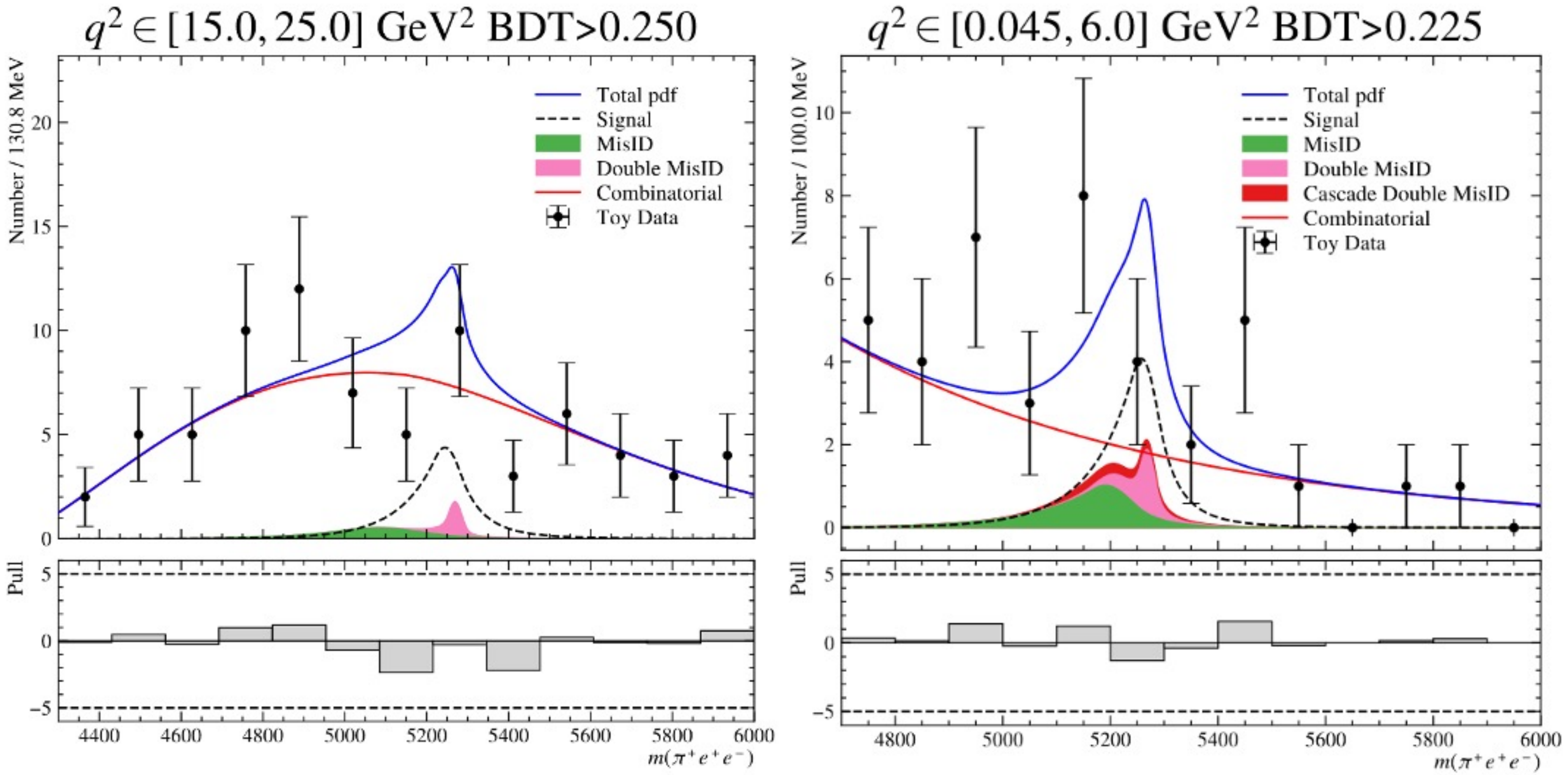




B^+ mass shapes for signal electrons (top) and muons (bottom)


Richard Williams

Search for $B^+ \to \pi^+ e^+ e^-$



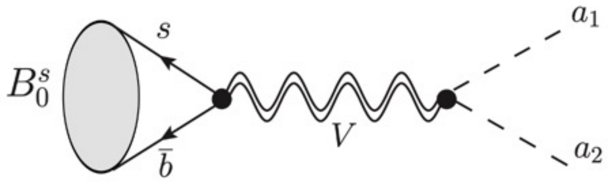
Close to final selection in our search for the as yet unobserved decay, splitting our signal region to help model backgrounds, with 2.2σ expected sensitivity.


Thomas Long

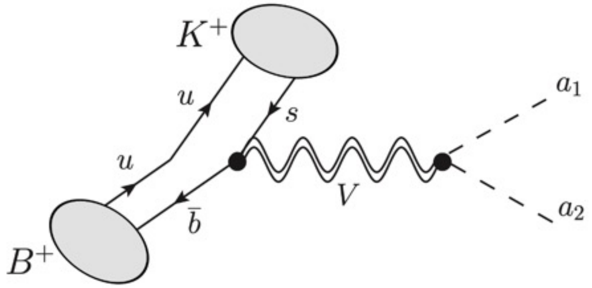
B Decays to Multiple Muons

Motivation

- Enhanced B decays to multiple muons arise naturally in non-minimal composite Higgs models, with flavour-violating heavy vectors (V) and light resonances (a) [arXiv:1902.10156, arXiv:2206.01759].



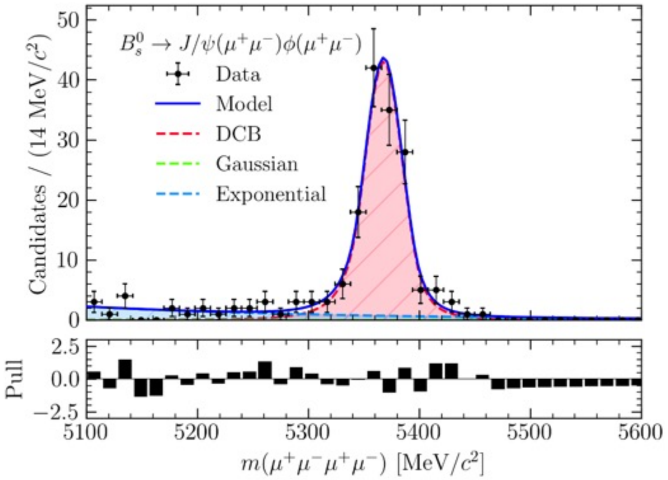
- Depending on the invariant mass of these light resonances, decays of the form $B_s \to a_1 a_2$ and $B^+ \to K^+ a_1 a_2$ could give rise to 4μ or 6μ.



- Small coupling of a to V raises possibility of relatively long-lived intermediates.
- Aim: Measure (or set limits on) BFs for $B_s \to 4\mu/6\mu$ and $B^+ \to K^+4\mu/K^+6\mu$ (both prompt and long-lived a) relative to $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)$ as the normalization mode using Run 2 data.

Progress

- Simulation corrections mainly complete.
- Signal selection and efficiency calculation framework established - complete selection yet to be finalised.
- Yield of normalisation mode $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(\mu^+\mu^-)$ determined from fit to the invariant mass distribution.
- Systematic uncertainties and potential exclusive background sources in signal window to be studied.
- Prepare fitting strategy for signal modes and calculate expected upper limits.



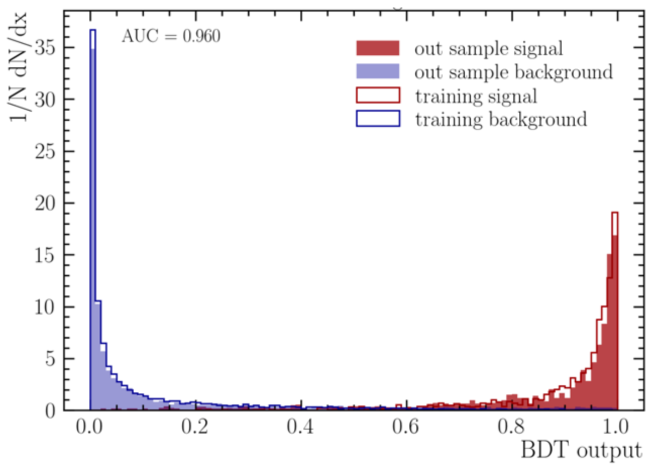
Search for Lepton Flavour Violation with $\Lambda_b \to pK\tau\mu$

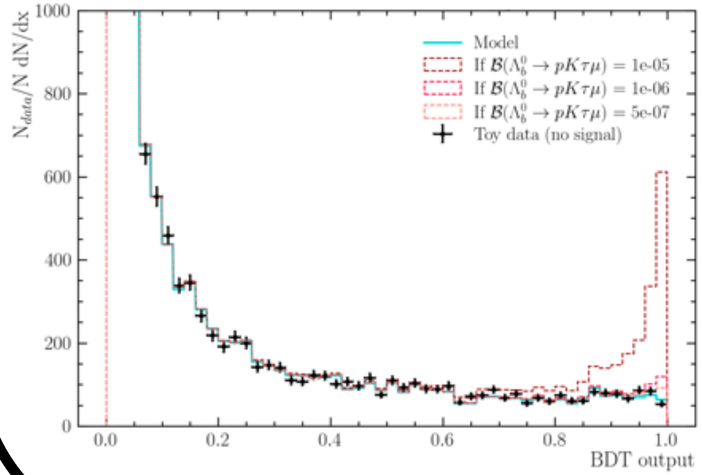
Motivation

- Lepton-flavour violating decays may arise in BSM physics introducing mechanisms breaking LFV, such as leptoquarks [arXiv:1511.01900, 10.1007/JHEP10(2018)148].
- An observation of $\Lambda_b \to pK\tau\mu$ where $\tau \to \mu\nu_\tau\bar{\nu}_\mu$, would constitute a clear sign of NP.
- Large deviations predicted for τ, and current experimental constraints on LFV decays with $\mu\ \tau$ or $e\ \tau$ in the final state are worse than on decays with $e\ \mu$ [10.1007/JHEP06(2023)143, arXiv:2207.04005].
- Aim: Set upper limit on (or measure) $\Lambda_b \to pK\tau\mu$ BF relative to normalisation mode $\Lambda_b^0 \to pK(J/\psi \to \mu^+\mu^-)$ using Run 2 data.
- Energy loss due to unreconstructed neutrinos which means $m(\Lambda_b^0)$ is not suitable for obtaining signal yield.

Progress

- Preliminary studies of physical backgrounds has been completed.
- BDT for discriminating signal from combinatorial background.
- Preliminary fit to normalisation mode.

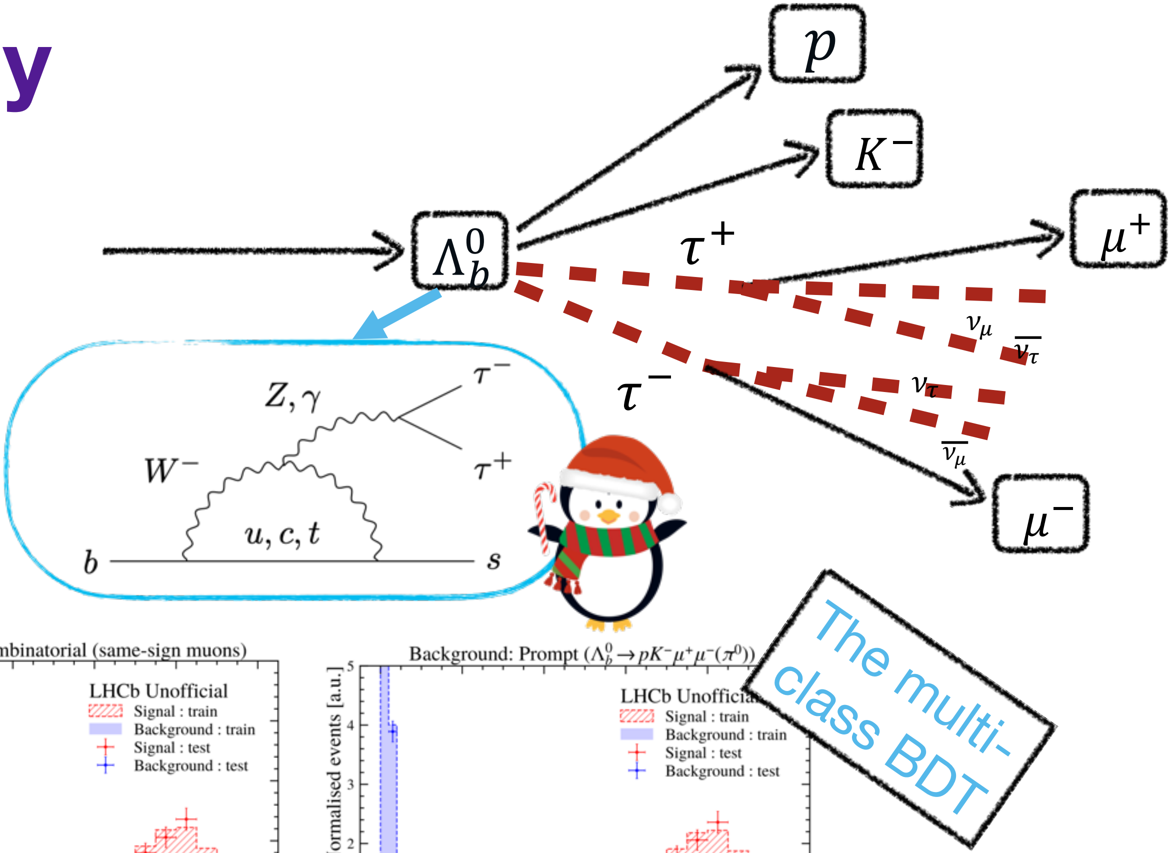




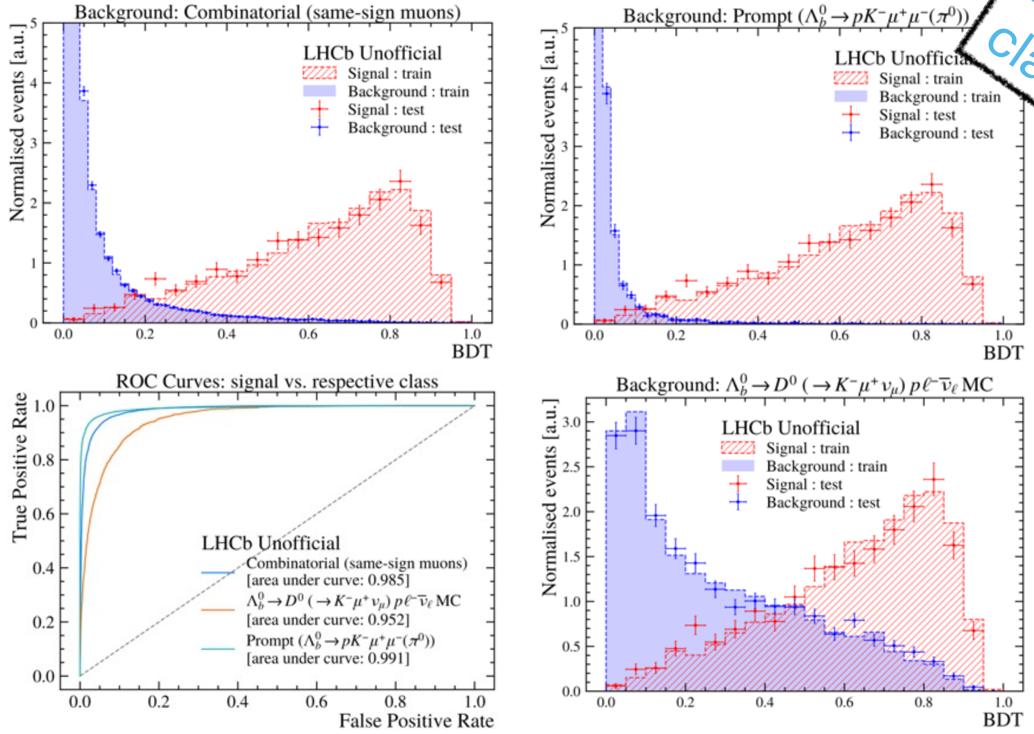
- Investigating template fit to BDT output (toy sample), using the known shapes of the signal and background used for the training.


Josh Bex
Rab

A search for the rare decay $\Lambda_b^0 \to pK^-\tau^+\tau^-$ at LHCb



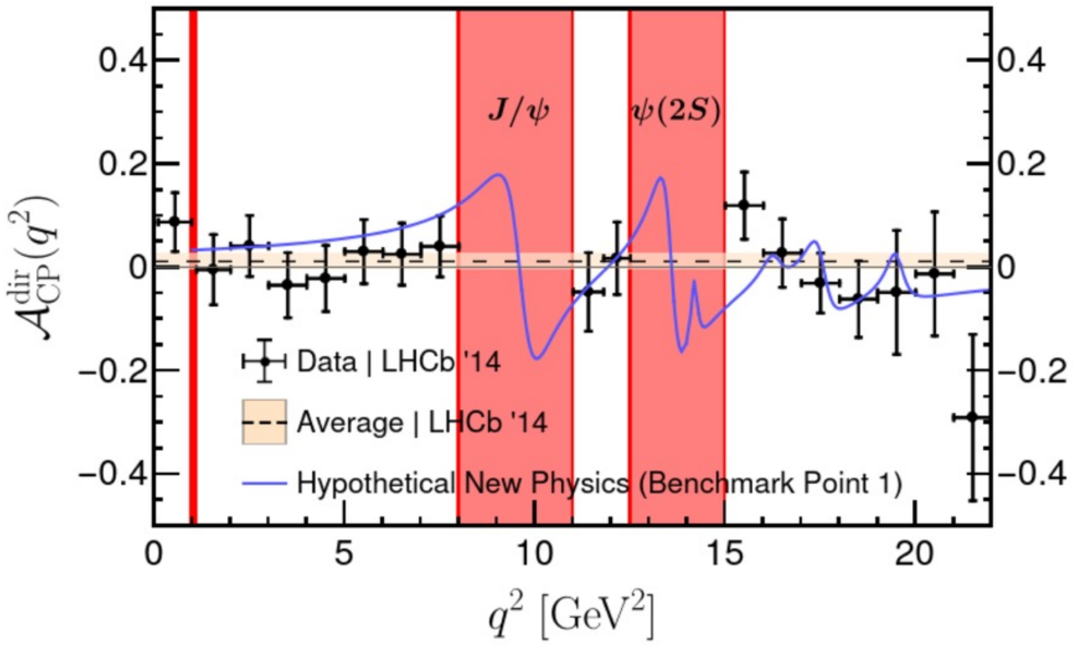
- Motivation?
  - Rare loop level process, sensitive to new physics entering at tree level.
  - Models explaining $R(D) - R(D^*)$ anomalies predict enhanced $b \to s\tau\tau$ branching fractions (expected even for LFU in light lepton generations). [1]
- Progress highlight?
  - Work on selection, for which central feature is BDT to discriminate against combinatorial, prompt, and semi-leptonic background classes.
  - Lack of tau vertex requires many backgrounds to be considered. Most important backgrounds are semi-leptonic, e.g. the background in the bottom right-hand plot: $\Lambda_b^0 \to D^0 p\ell^-\overline{\nu_\ell}, D^0 \to K^-\mu^+\nu_\mu$.

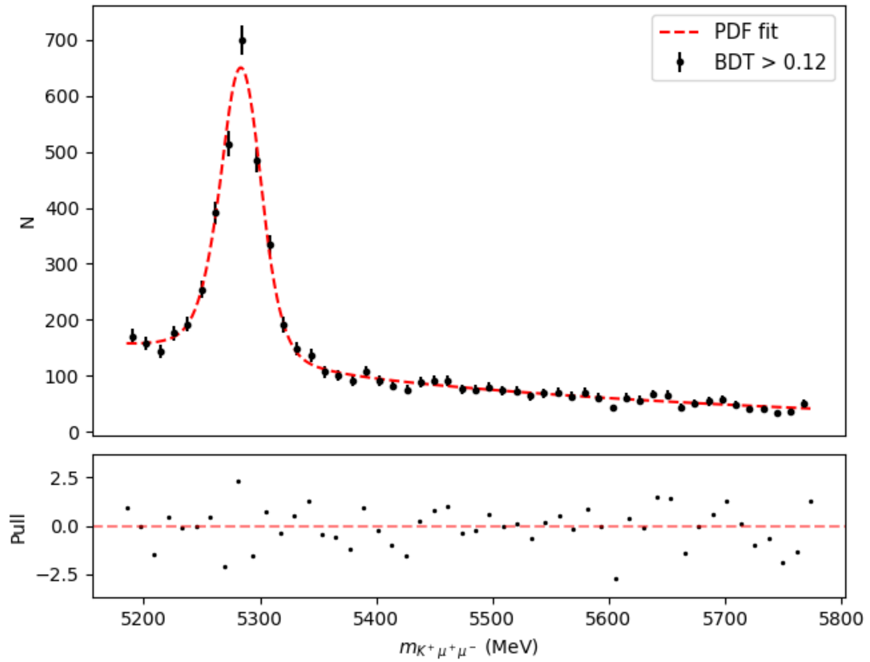


[1] J. Aebischer, G. Isidori, M. Pesut, B. A. Stefanek and F. Wilsch, Eur. Phys. J. C 83 (2023) no.2, 153


Juanjo Castella

A_{CP} in $B^+ \to K^+\mu^+\mu^-$





New physics can induce differences between the CP asymmetries in electronic and muonic decays. Updated measurement of A_{CP} in $B^+ \to K^+\mu^+\mu^-$ decays a first step.

CP violation

No matter how charming

HEP Extravaganza 2023

Jordy Butter
06/12/2023

CPV team (or actually: KstarKstar team)

Overview of activities

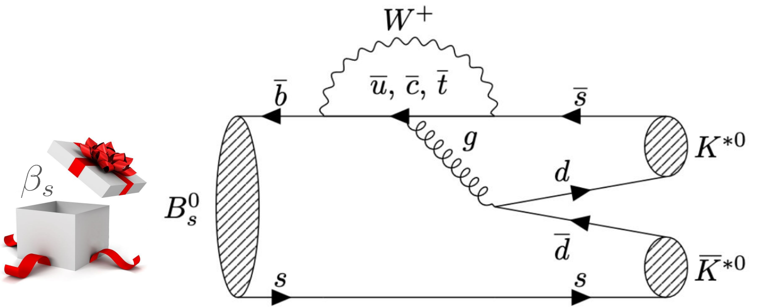
- Charmless B→VV analyses:
  - $B^0_{(s)} \to K^{*0}\overline{K}^{*0}$
  - $B^0 \to \rho^0 K^{*0}$
  - $B^0_{(s)} \to \phi K^{*0}$
  - $B^+ \to \rho^0 K^{*+}$
- Measuring CKM-angle γ :
  - $B^0_s \to D_s^{\mp} K^{\pm}$
  - Gammacombo

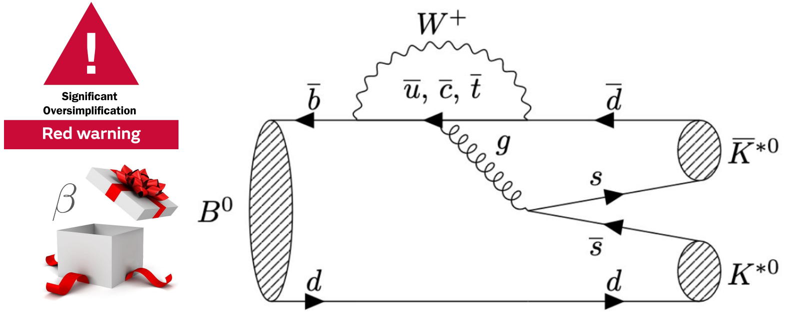
Decay topologies of non-leptonic beauty decays

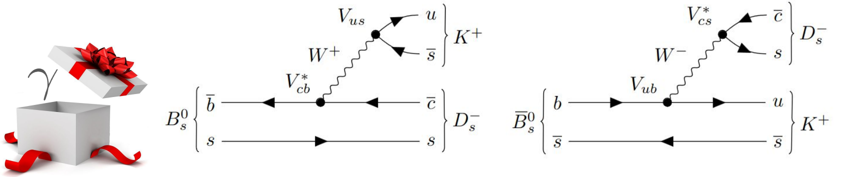
CP violation

$$V_{CKM,\text{Wolfenstein}} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5)$$

- *CP* violation reveals itself in the interference of two decay amplitudes
  - Must be a weak and strong phase difference
- Sometimes, neutral meson mixing necessary: **interference in mixing and decay**
  - Decay-time dependent analysis required
  - Situation for $B^0_{(s)} \to K^{*0}\overline{K^{*0}}$ decays actually a bit more complex due to loop







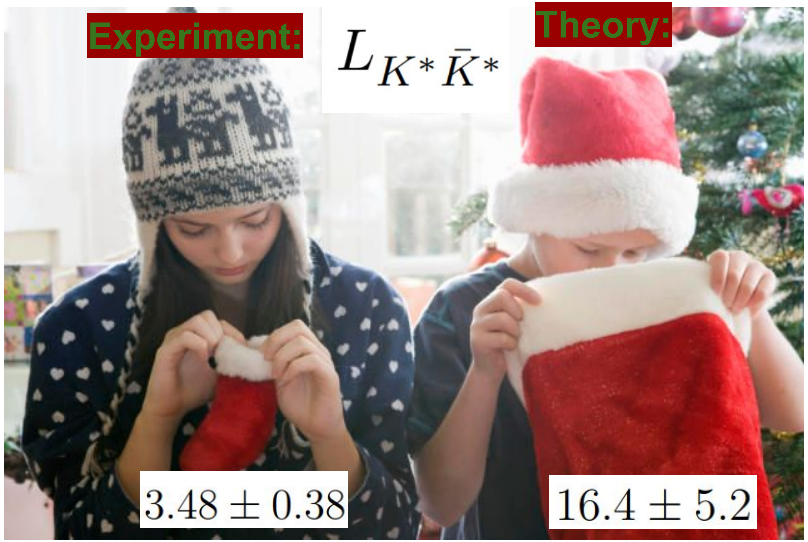
Other parameters of interest

- Time-integrated *CP* violation in $B^0 \to \rho^0 K^{*0}$
- Branching fractions
- Fractions of angular contributions

$$f_{L,\parallel,\perp} = \frac{|A_{0,\parallel,\perp}|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2}$$

  - Tensions between theory and experiment
- Easier to compare the ratio:

$$L_{K^*\bar{K}^*} = G\frac{\mathcal{B}(B_s^0 \to K^{*0}\bar{K}^{*0})}{\mathcal{B}(B^0 \to K^{*0}\bar{K}^{*0})}\frac{f_L^{B_s^0 \to K^{*0}\bar{K}^{*0}}}{f_L^{B^0 \to K^{*0}\bar{K}^{*0}}}$$

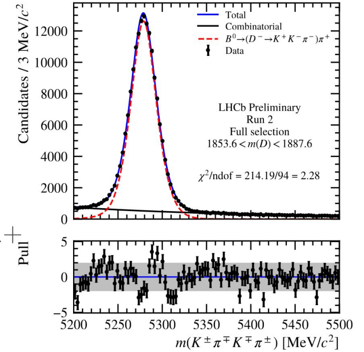


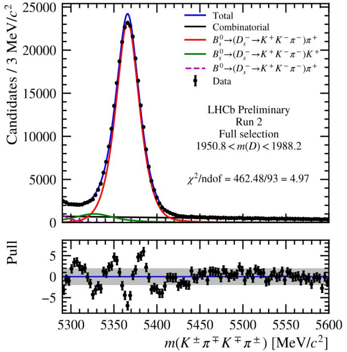
Run 1 and Run 2 data

Branching fraction of $B^0_{(s)} \to K^{*0}\overline{K^{*0}}$ decays

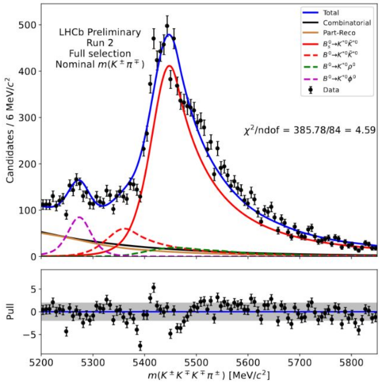
- Almost there for branching fraction measurement
- Simultaneous fit to signal and misID backgrounds
  - *e.g.* m(KPiPi), m(KKKPi), m(KPiPiPi)
- Normalisation channels: $B^0 \to D^-\pi^+$ and $B^0_s \to D^-_s\pi^+$
- Train Combinatorial and PID BDTs
- Amplitude analysis and time-dependent measurement will follow

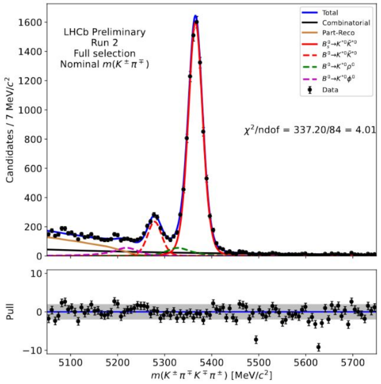
Normalisation channels

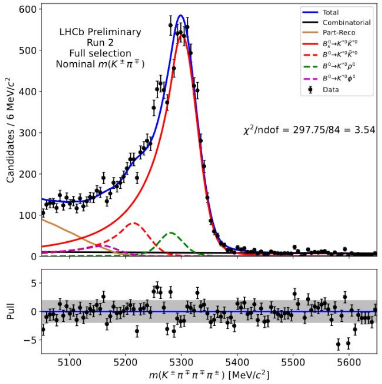




Signal



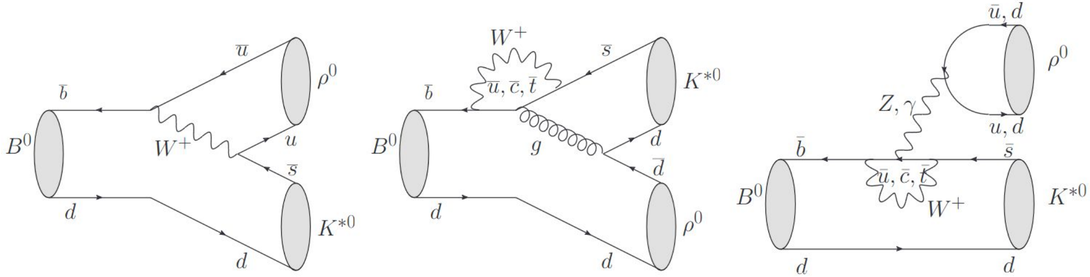




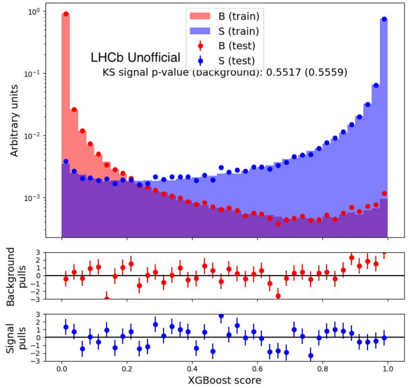
Run 1 and Run 2 data

Study of $B^0 \to \rho^0 K^{*0}$ decays

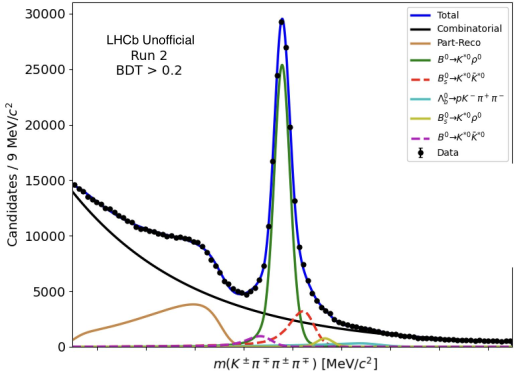
- Also involves amplitude analysis of $B^0 \to (\pi^+\pi^-)(K^+\pi^-)$
  - Including various resonances
- *CP* violation due to penguin-tree interference
  - Similar decay signature as
  - Combinatorial BDT in place
  - Observe $B_s^0 \to \rho^0 K^{*0}$?



Leading Feynman diagrams

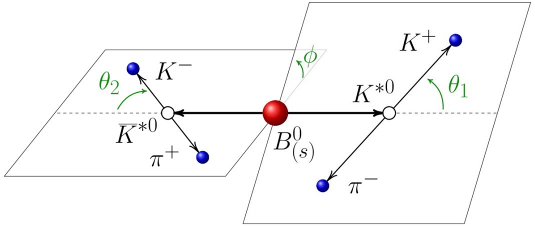


Combinatorial BDT performance

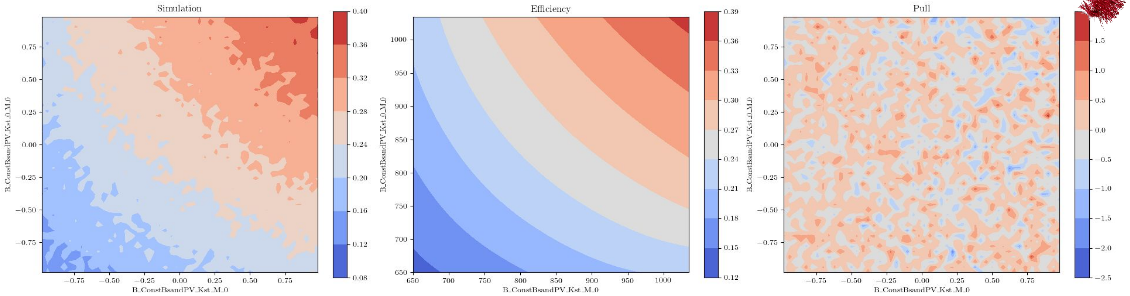


Preliminary mass fit with loose BDT cut

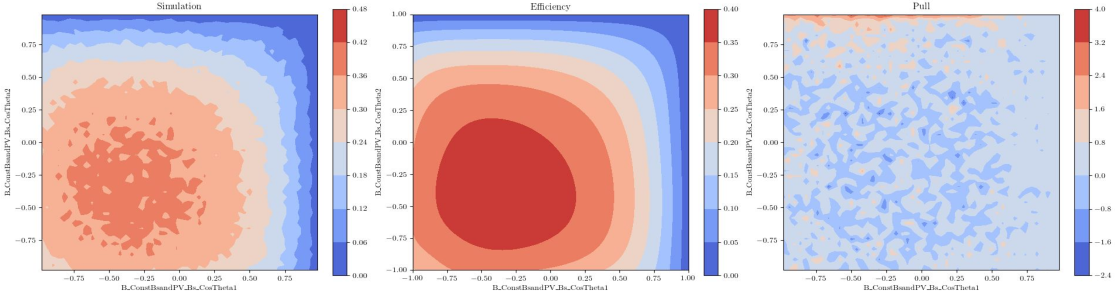
B2VV acceptance studies



- Model the 5D acceptance of $m(K^{*0})$, $m(\overline{K^{*0}})$, $\cos(\theta_1)$, $\cos(\theta_2)$, ϕ
- Model using Legendre Polynomials
- Verified using a BDT method
- Method can be used across B2VV analyses



Results for $m(K^{*0})$ vs $m(\overline{K^{*0}})$



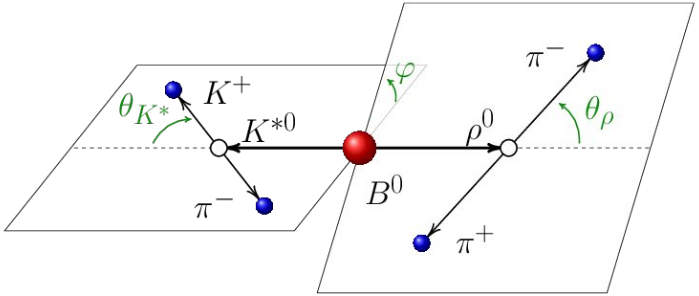
Results for $\cos(\theta_1)$ vs $\cos(\theta_2)$

First Few Legendre Polynomials:

$P(x,0)$	1
$P(x,1)$	x
$P(x,2)$	$\frac{1}{2}(3x^2-1)$
$P(x,3)$	$\frac{1}{2}(5x^3-3x)$
$P(x,4)$	$\frac{1}{8}(35x^4-30x^2+3)$

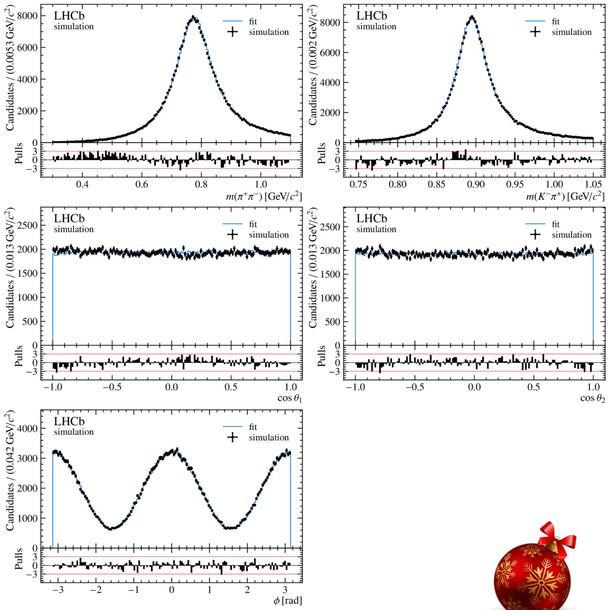
B2VV angular fitter

- Work in progress
- Angular fit to the vars: $m(V_1)$, $m(V_2)$, $\cos(\theta_1)$, $\cos(\theta_2)$, ϕ
- Depending on the decay, many amplitudes and interferences can contribute

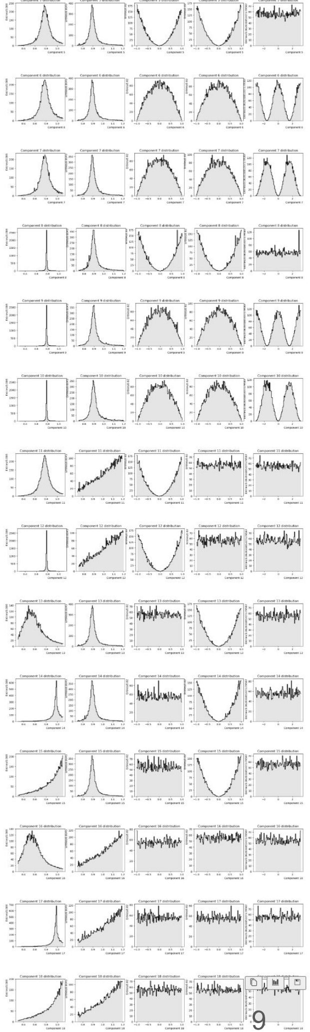


$$
\begin{aligned}
&\mathcal{A}_{VV} + \mathcal{A}_{VS} + \mathcal{A}_{SV} + \mathcal{A}_{SS} \\
&= -\frac{3N}{4\pi}\Bigg[\Big(A_0 \cos\theta_1 \cos\theta_2 + \frac{A_\parallel}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \cos\phi \\
&\quad + i\frac{A_\perp}{\sqrt{2}} \sin\theta_1 \sin\theta_2 \sin\phi\Big)\ \mathcal{M}_1(m_1)\mathcal{M}_1(m_2) \\
&\quad - \frac{A_{VS}}{\sqrt{3}} \cos\theta_1 \mathcal{M}_1(m_1)\mathcal{M}_0(m_2) + \frac{A_{SV}}{\sqrt{3}} \cos\theta_2 \mathcal{M}_0(m_1)\mathcal{M}_1(m_2) \\
&\quad - \frac{A_{SS}}{3}\mathcal{M}_0(m_1)\mathcal{M}_0(m_2)\Bigg],
\end{aligned}
$$

6 amplitudes in $B_s^0 \to K^{*0}\overline{K}^{*0}$



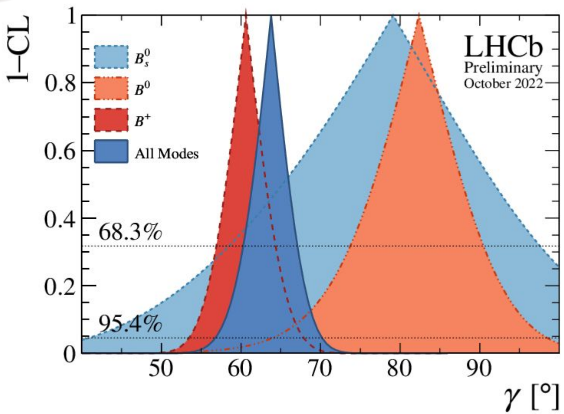
Fit to generator level MC



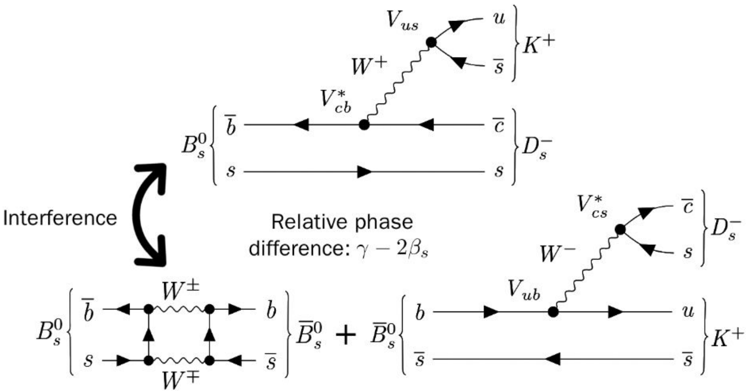
14 amplitudes in $B^0 \to \rho^0 K^{*0}$

Determination of γ

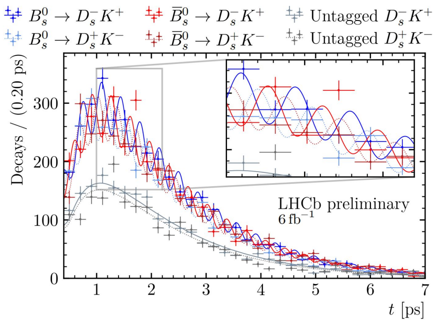
[LHCb-CONF-2022-003]

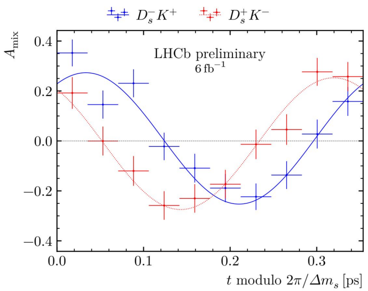


- CKM Fitter:
  $\gamma = (65.5^{+1.1}_{-2.7})^\circ$
- LHCb Combination:
  $\gamma = (63.8^{+3.5}_{-3.7})^\circ$
- **New:** Run 2 measurement $B_s^0 \to D_s^\mp K^\pm$
  $\gamma = (74 \pm 11)^\circ$



[LHCb-CONF-2023-004]





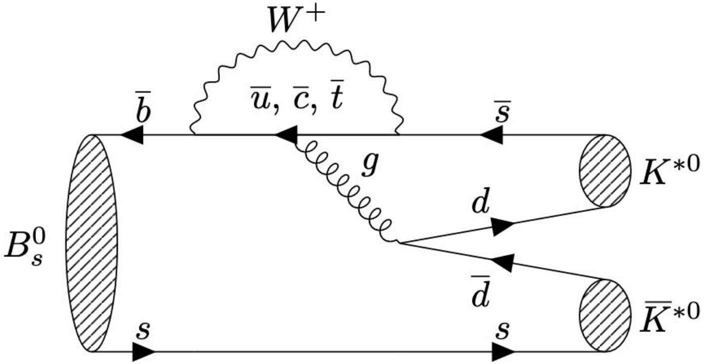
Thanks for your attention!

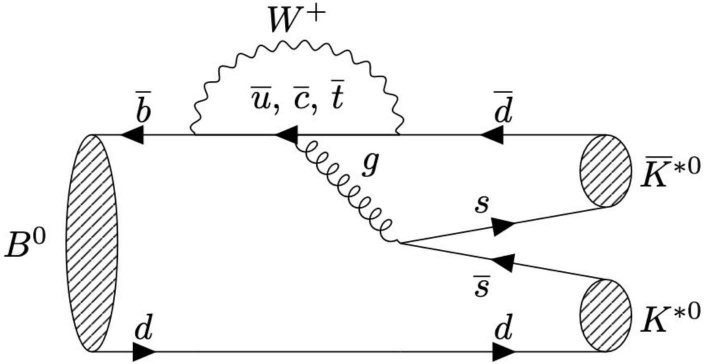
Backup

CP violation, less simplified

Nothing on the analysis yet...

Red warning





$$\mathcal{A} = aP'_{uc} - be^{i\beta_s}P'_{tc}$$

SU(3) symmetry

$$P = P'$$

$$\mathcal{A} = cP_{uc} - dP_{tc}$$

a, *b*, *c* and *d* well known