LHCb at Nikhef

SAC Visit, 13 April 2023

N.Tuning for the Bfys group

Nikhef

Outline

- Group
  - People power
  - Funding
  - Timeline
- Technology
  - VELO
  - SciFi
  - RTA
  - Upgrade II
- Physics
  - CP violation
  - Rare decays

Group

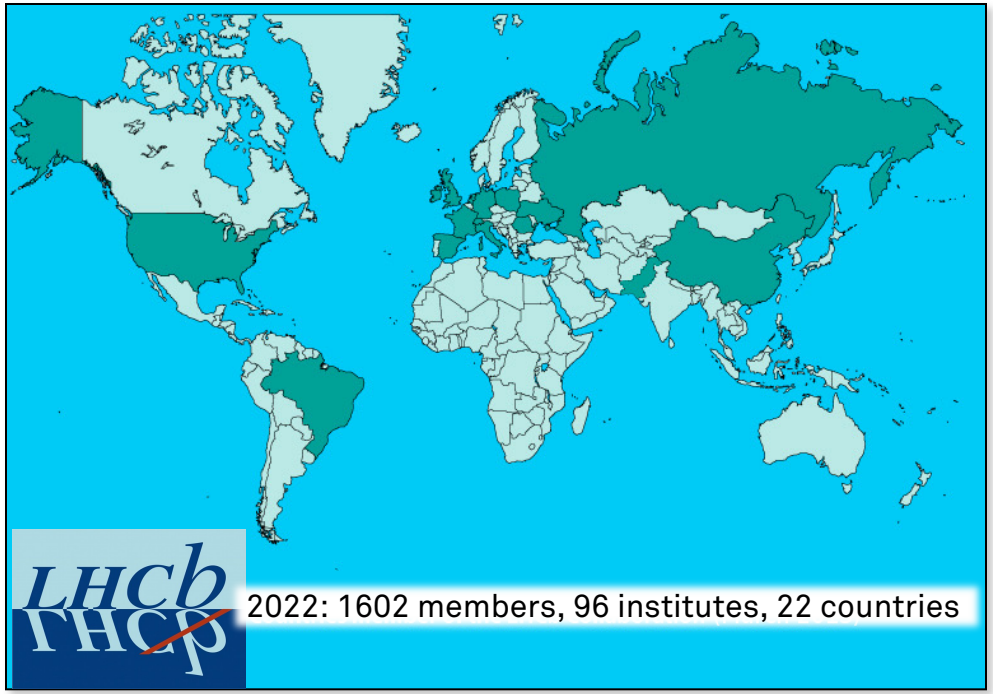
- Program leader: Marcel Merk + Mara Senghi Soares

People	
Staff	11
Postdocs	5
PhD	12

Output	
Papers	665
Theses	43
MSc	50

Funding	MoU
LHCb	4.95M€
LHCb Upgrade I	3.2 M€
LHCb Upgrade II	~6 M€?

Partners	(staff)
VU Amsterdam	(2)
RuG Groningen	(1.5+1)
UM Maastricht	(3)
Nikhef Amsterdam	(4.5)



https://greybook.cern.ch/experiment/detail?id=LHCB

Group: people

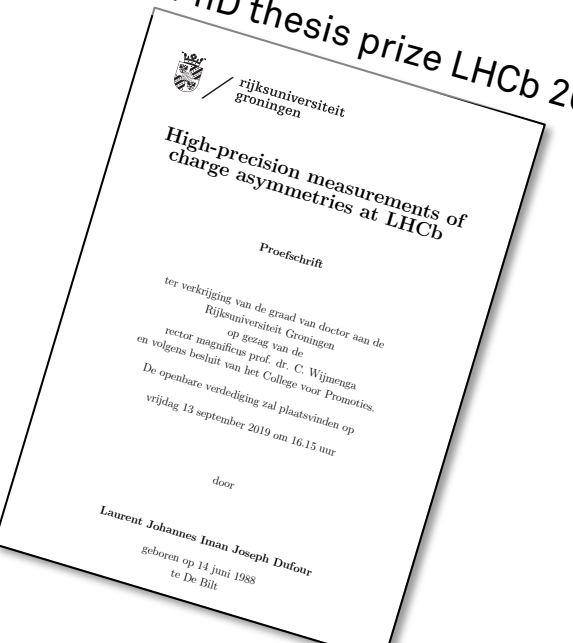
- Groningen: being reinforced
- Maastricht: new Faculty of Science and Engineering

Partners	
VU	Amsterdam
RuG	Groningen
UM	Maastricht
Nikhef	Amsterdam

Group: output

LHCb Early Career Prize 2022

PhD thesis prize LHCb 2020



rijksuniversiteit groningen

High-precision measurements of charge asymmetries at LHCb

Proefschrift

ter verkrijging van de graad van doctor aan de Rijksuniversiteit Groningen op gezag van de rector magnificus prof. dr. C. Wijmenga en volgens besluit van het College voor Promoties.

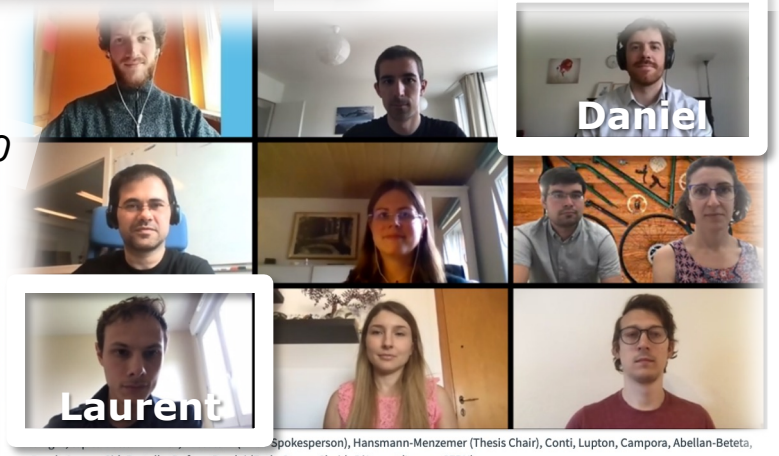
De openbare verdediging zal plaatsvinden op vrijdag 13 september 2019 om 16.15 uur

door

Laurent Johannes Iman Joseph Dufour

geboren op 14 juni 1988 te De Bilt

LHCb Early Career Prize 2020



Spokesperson), Hansmann-Menzemer (Thesis Chair), Conti, Lupton, Campora, Abellan-Beteta, Bruch, Lemos Cid, Bertella, Dufour, Dordei (Early Career Chair), D'Argent (Image: CERN)

On 11 June, LHCb announced the winners of the 2020 PhD Thesis and Early Career Scientist Awards.

The LHCb Thesis Awards recognize excellent PhD theses and additional work that have made an exceptional contribution to LHCb. In parallel, the Early Career Scientist prizes are awarded to recognize outstanding achievements of early career scientists to the benefit of LHCb.

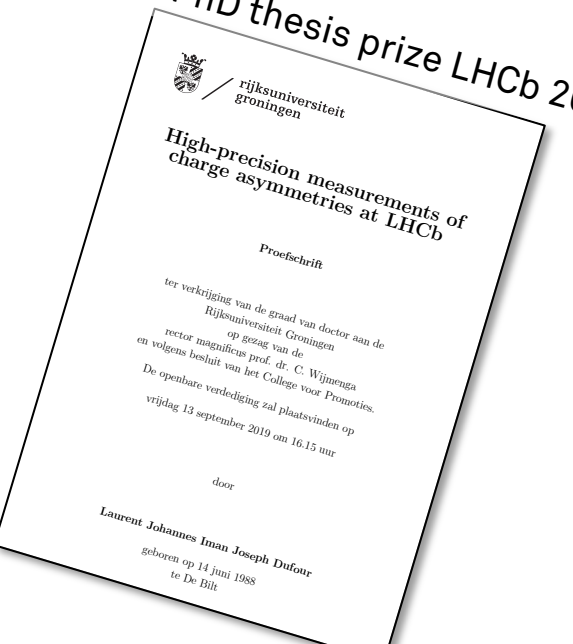
This year's winners of the Thesis prize are Philippe D'Argent (Heidelberg University) and Laurent Dufour Nikhef/Groningen University. Carlos Abellan Beteta (Zurich), Claudia Bertella (CERN), Daniel Campora (Nikhef), Vladim Conti (INFN, Milan), Edgar Lemos Cid (Santiago de Compostela), Olli Lupton (Warwick), Mark Smith

Group: output

LHCb Early Career Prize 2022

2022 responsibilities
Deputy project leader VELO, SCIFI, RTA
Physics subWG conv TD-B2OC
Physics coordinator
Physics performance convener
Membership comittee chair
Speakersbureau deputy chair
2023 responsibilities
Data Quality coordinator
Deputy project leader VELO
Run coordinator
Speakersbureau deputy chair
RTA WP convener

PhD thesis prize LHCb 2020



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Group: funding

End of funding:

- NWO program
- Vici (2x)
- Projectruimte
- Postdoc on Swiss grant

Funding	MoU	
LHCb	4.95M€	9%
LHCb Upgrade I	3.2 M€	7%
LHCb Upgrade II	~6 M€?	~5% ?

➢ Worries about long term funding

- ***All sources above ending***
  - from now on depend on *possible future* structural Nikhef funding
  - NWO "ENW groot" requests
    - Physics proposal turned down
    - Technology proposal "Faster" successful (2 PhD, 1 postdoc)
- Stimulate grant requests (risk for strategic choices)
  - Veni & Marie Curie, Vidi, Vici limited…

Decreasing impact on LHCb

Group: funding opportunities

- Worries about long term funding
  - *All sources above ending*
    - from now on depend on *possible future* structural Nikhef funding
    - NWO "ENW groot" requests
      - Physics proposal turned down
      - Technology proposal "Faster" successful (2 PhD, 1 postdoc)
  - Stimulate grant requests
    - Veni & Marie Curie, Vidi, Vici limited…

Opportunities :

- **National Roadmap** (2024) LHC detector investment
- **Summit** (2024) LHC long term personnel
- **ENW-XL** (2024) LHCb topical + partners
- **Individual grants**

Timeline

You are here

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035+
	Run III				Run IV									Run V
LS2						**LS3**						**LS4**		
LHCb 40 MHz **UPGRADE I**		$L = 2 \times 10^{33}$			**LHCb** **Consolidate**			$L = 2 \times 10^{33}$ $50\ fb^{-1}$				**LHCb** **UPGRADE II**		$L=1\text{-}2\times10^{34}$ $300\ fb^{-1}$
ATLAS **Phase I Upgr**		$L = 2 \times 10^{34}$			**ATLAS** **Phase II UPGRADE**			**HL-LHC** $L = 5 \times 10^{34}$						**HL-LHC** $L = 5\times10^{34}$
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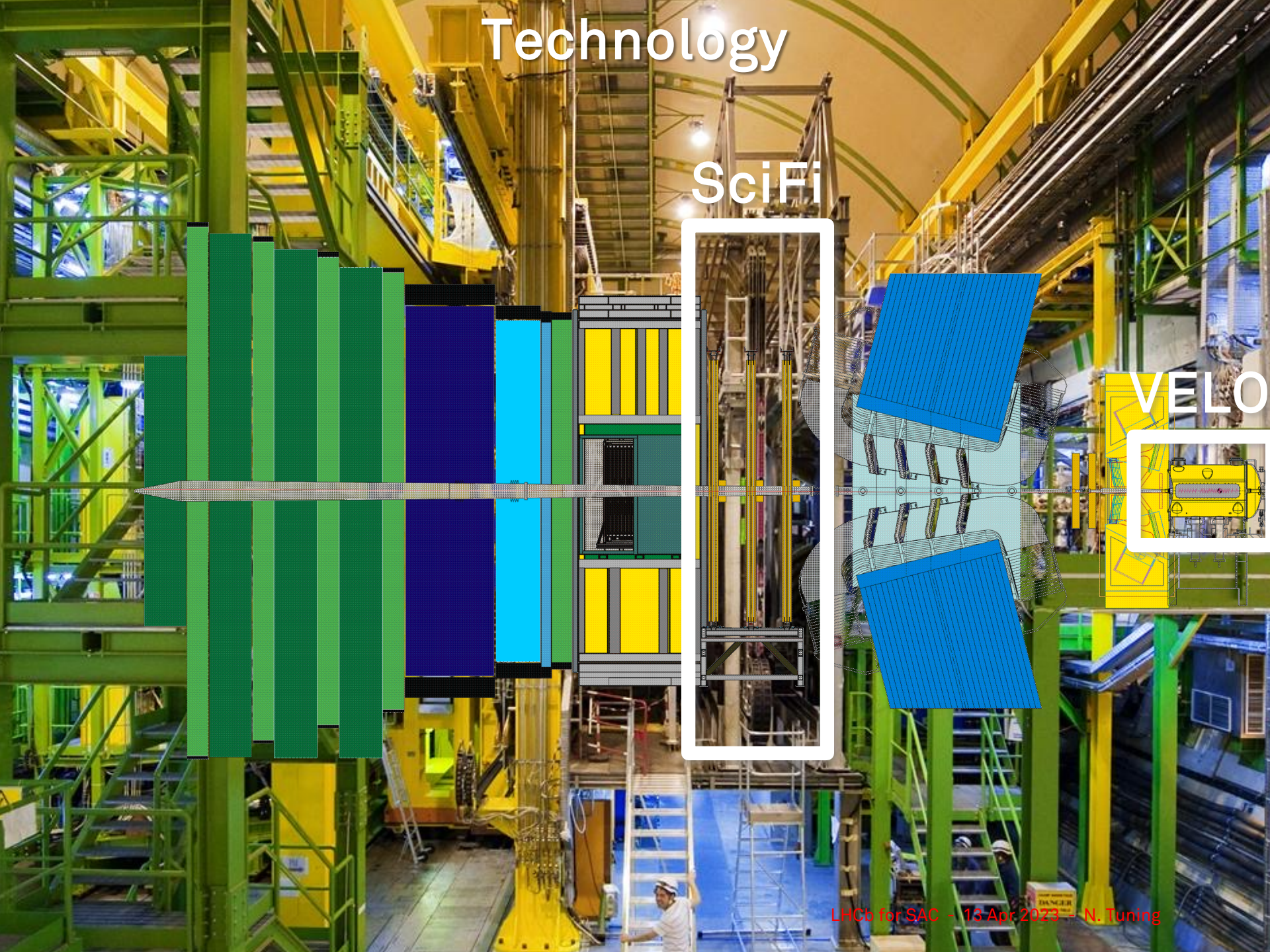
Belle II		$L = 3 \times 10^{35}$				$7\ ab^{-1}$					$L = 6 \times 10^{35}$		$50\ ab^{-1}$	

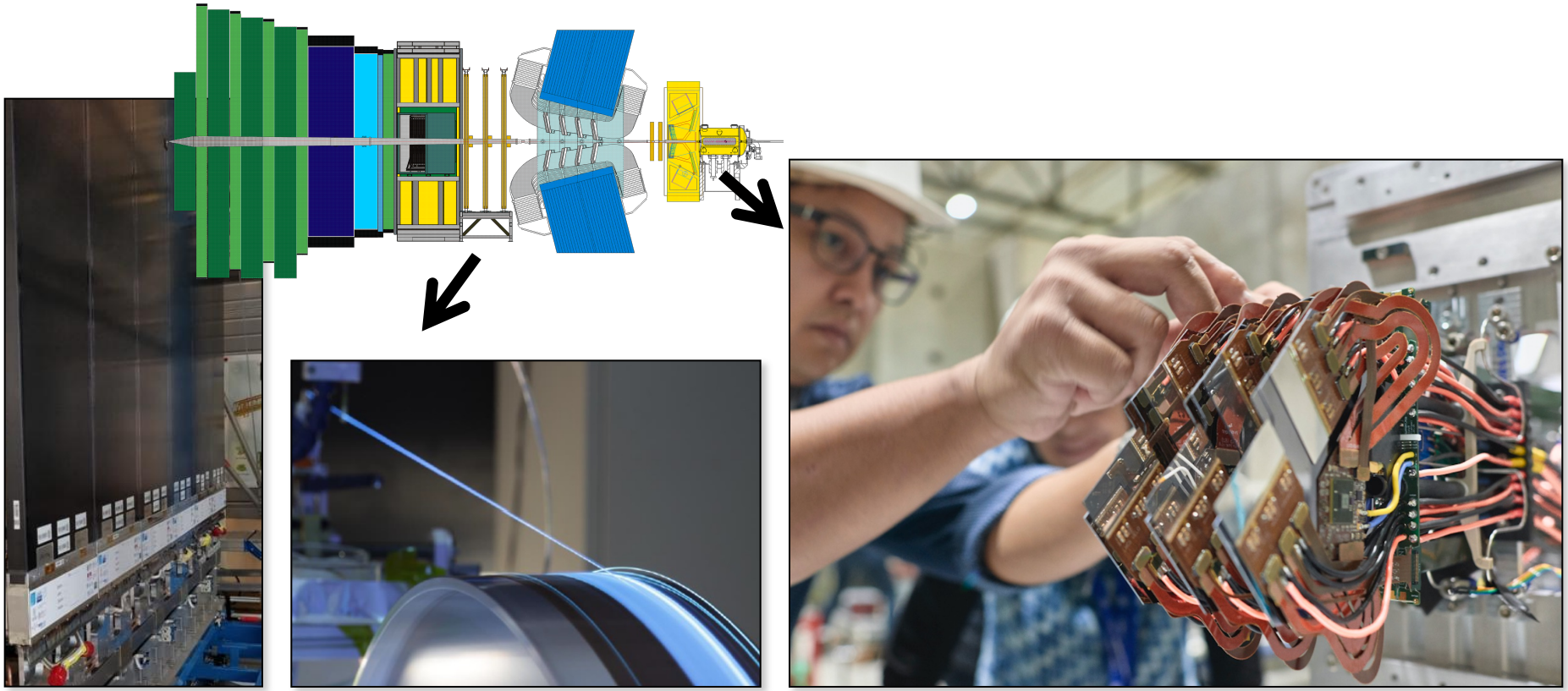
LHC schedule:

https://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

Technology



Technology



Scintillating Fibers

- New technology
- Si strip resolution for lower price

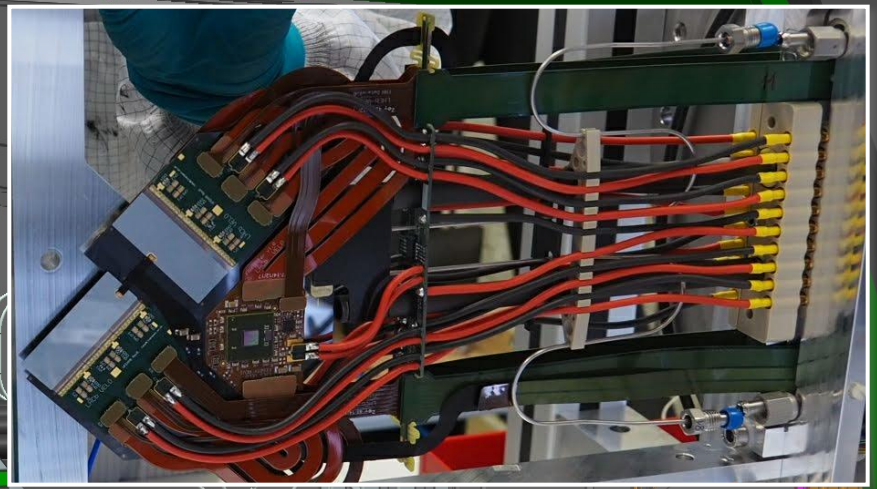
RTA (reconstruction)

- 40 MHz, 400 tracks
- 2-10 GB/s to storage

VELO pixels

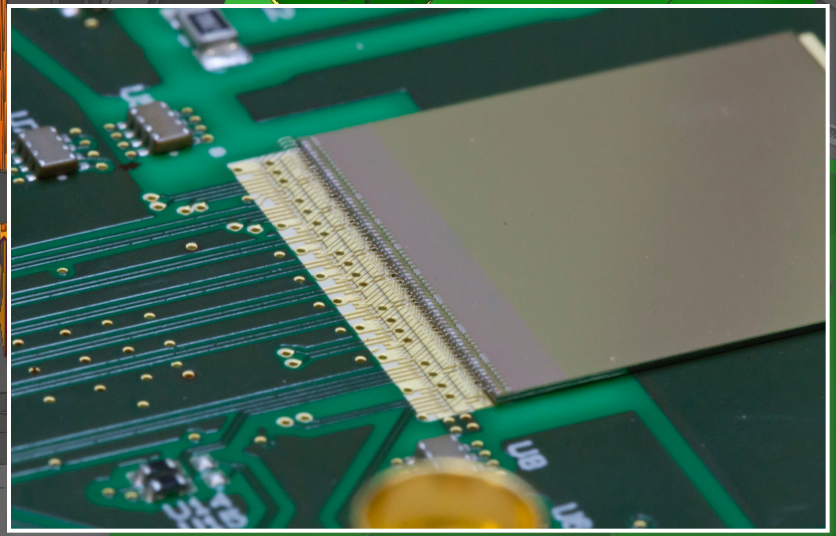
- Synergy with Medipix
- Fast track reconstruction

VELO

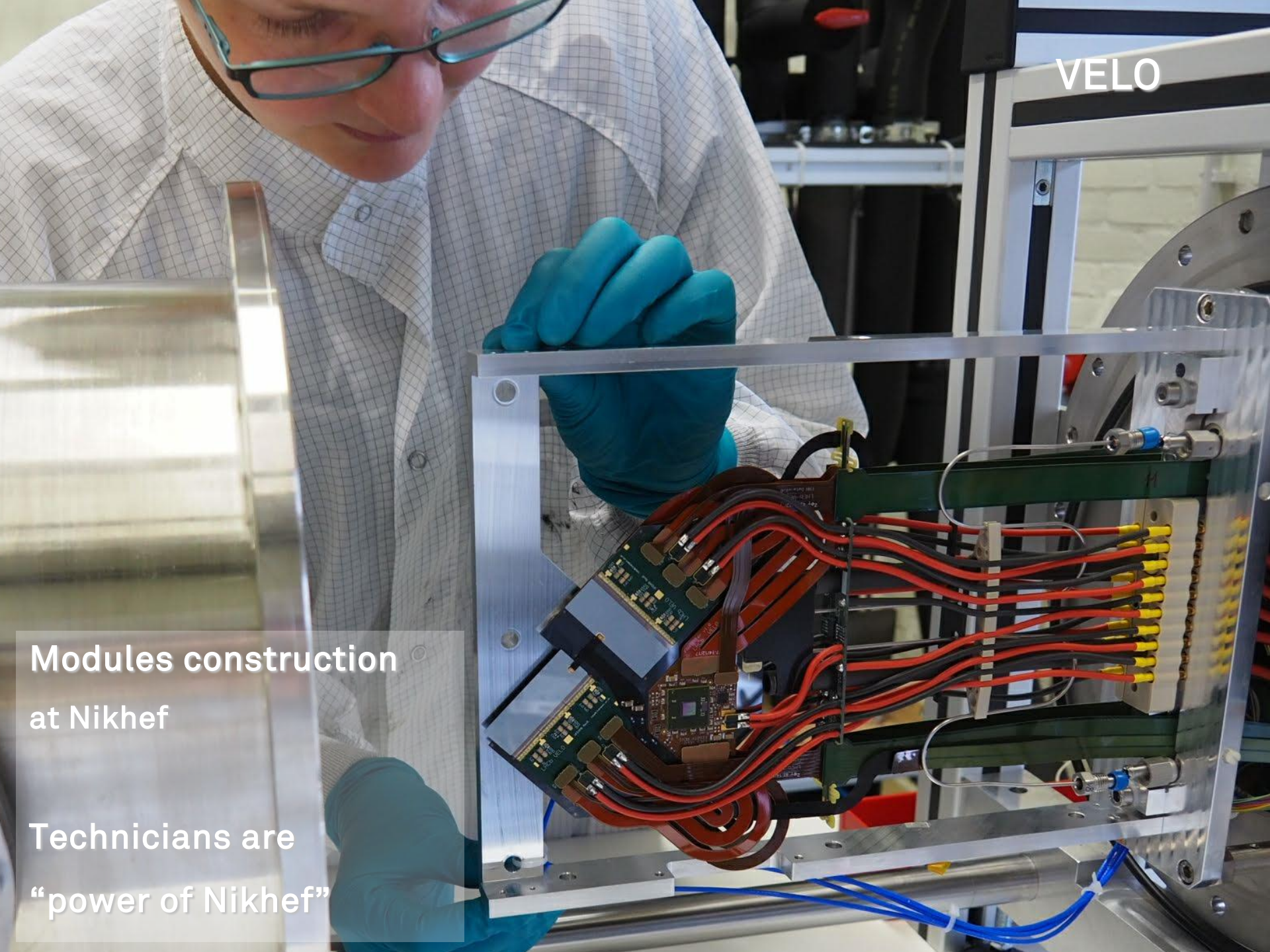


1) Module design & production

2) Electronics “VeloPix” chip



3) Vacuum envelope “RF-Box”



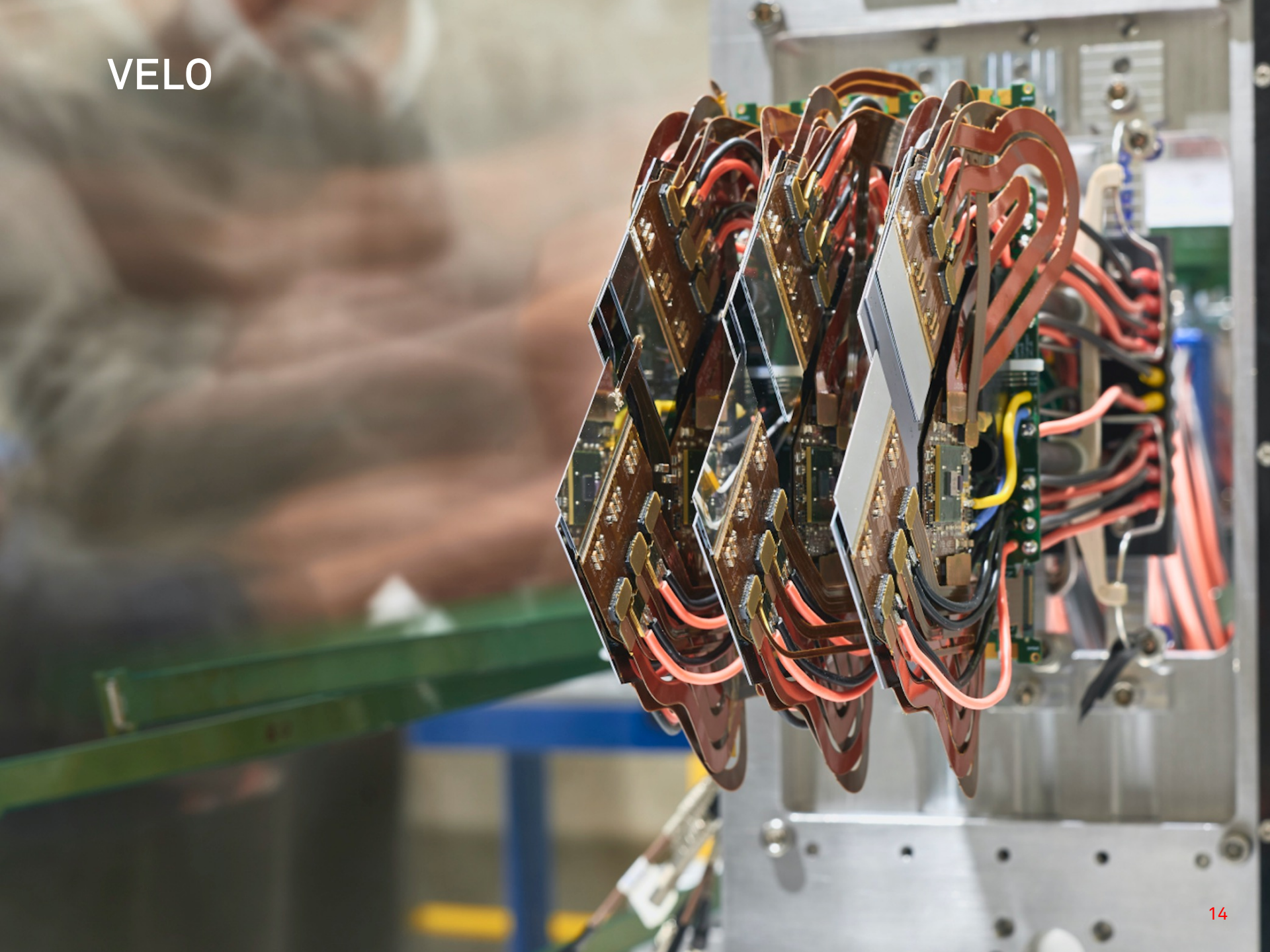
Modules construction

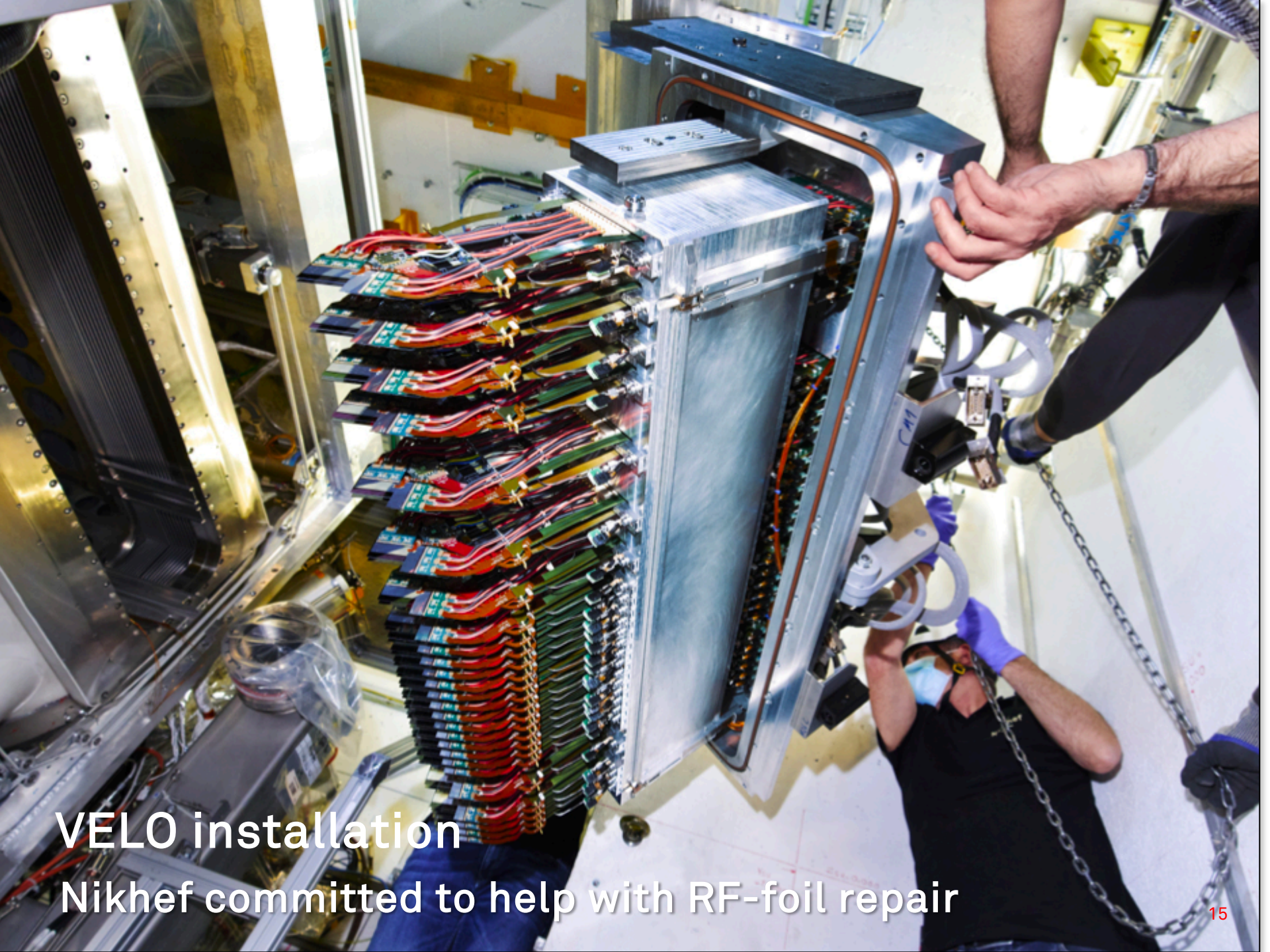
at Nikhef

Technicians are

“power of Nikhef”

VELO

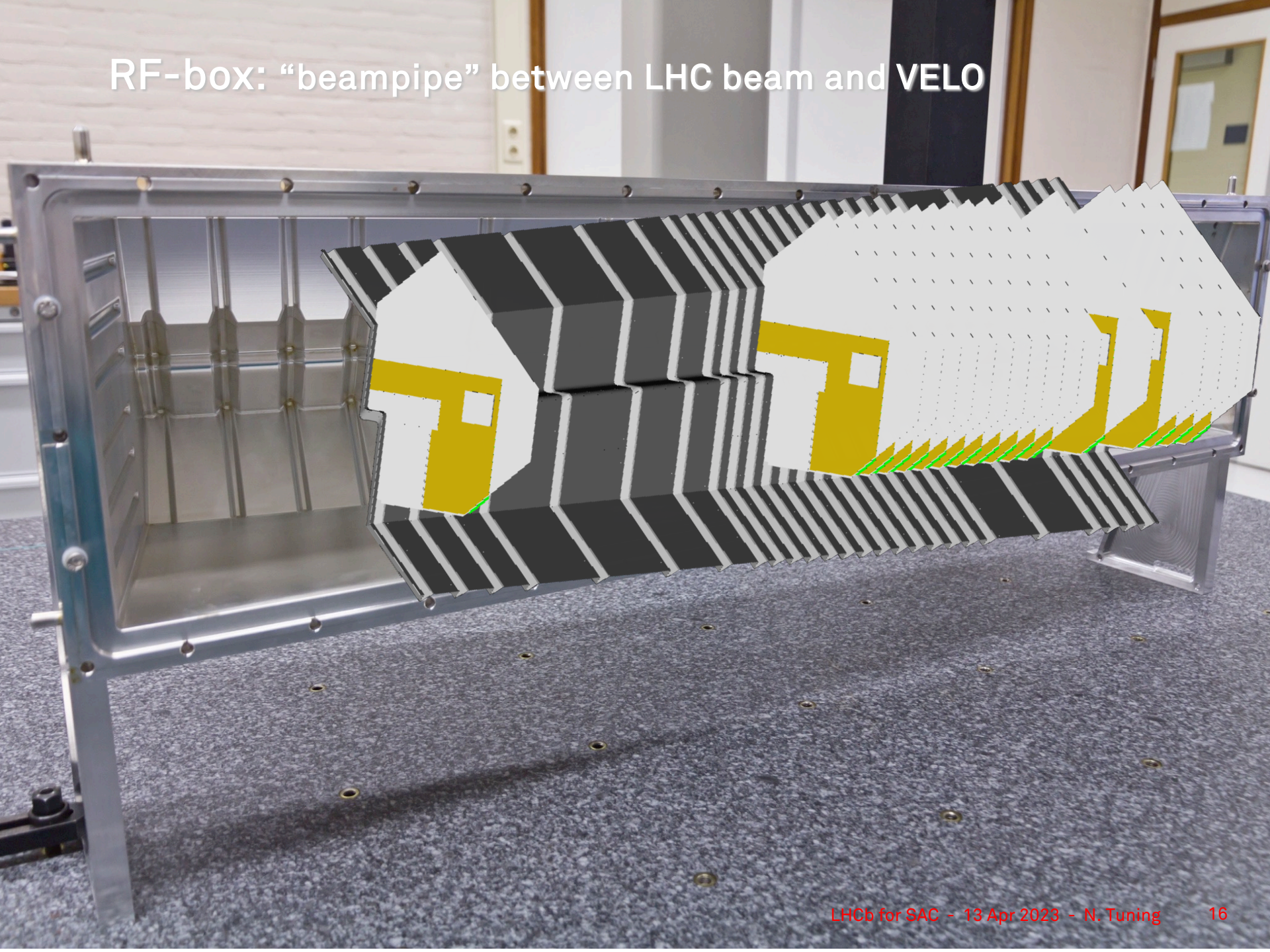




VELO installation

Nikhef committed to help with RF-foil repair

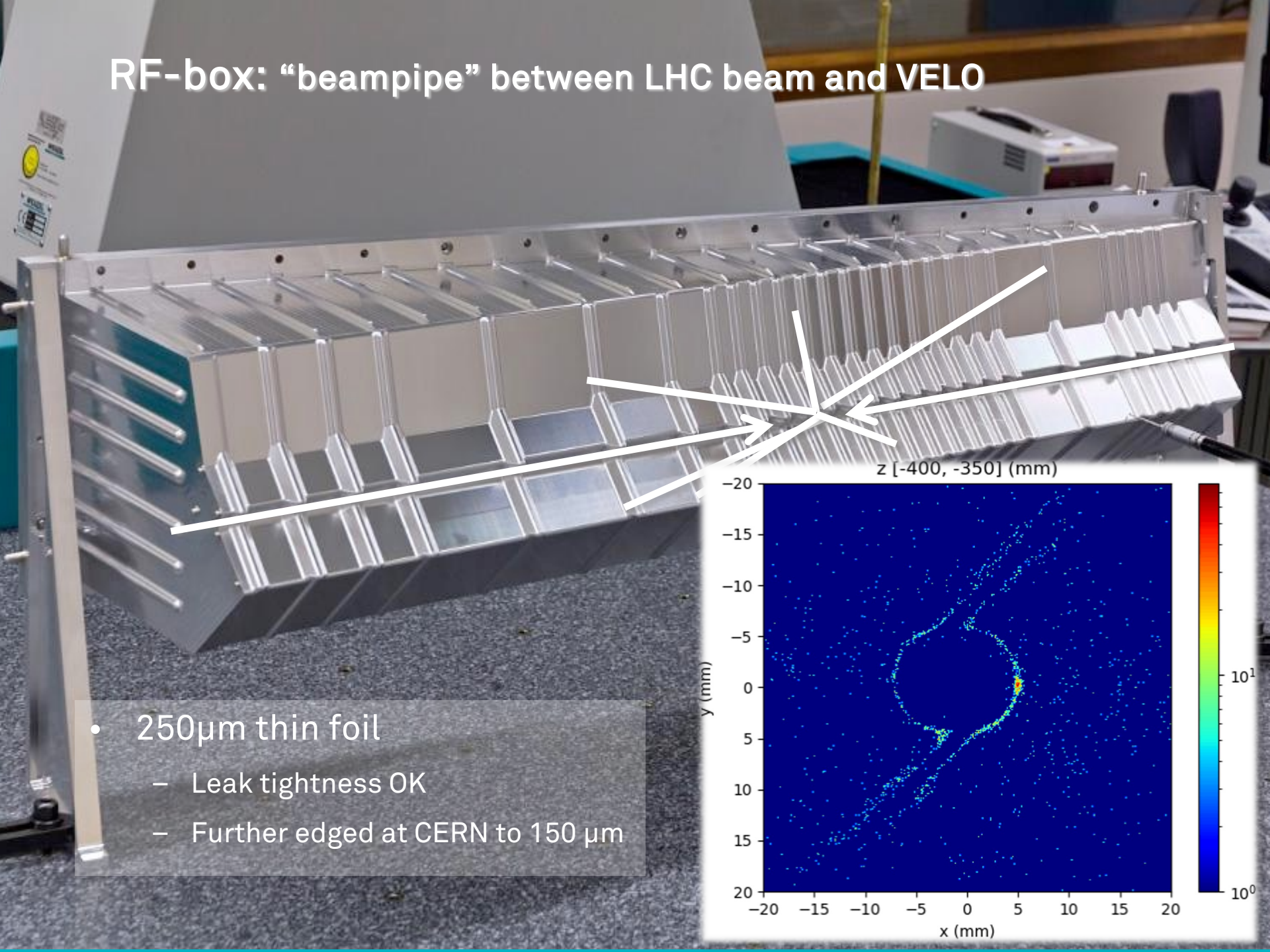
RF-box: “beampipe” between LHC beam and VELO



RF-box: “beampipe” between LHC beam and VELO

- 250µm thin foil
  - Leak tightness OK
  - Further edged at CERN to 150 µm

RF-box: “beampipe” between LHC beam and VELO



- 250µm thin foil
  - Leak tightness OK
  - Further edged at CERN to 150 µm

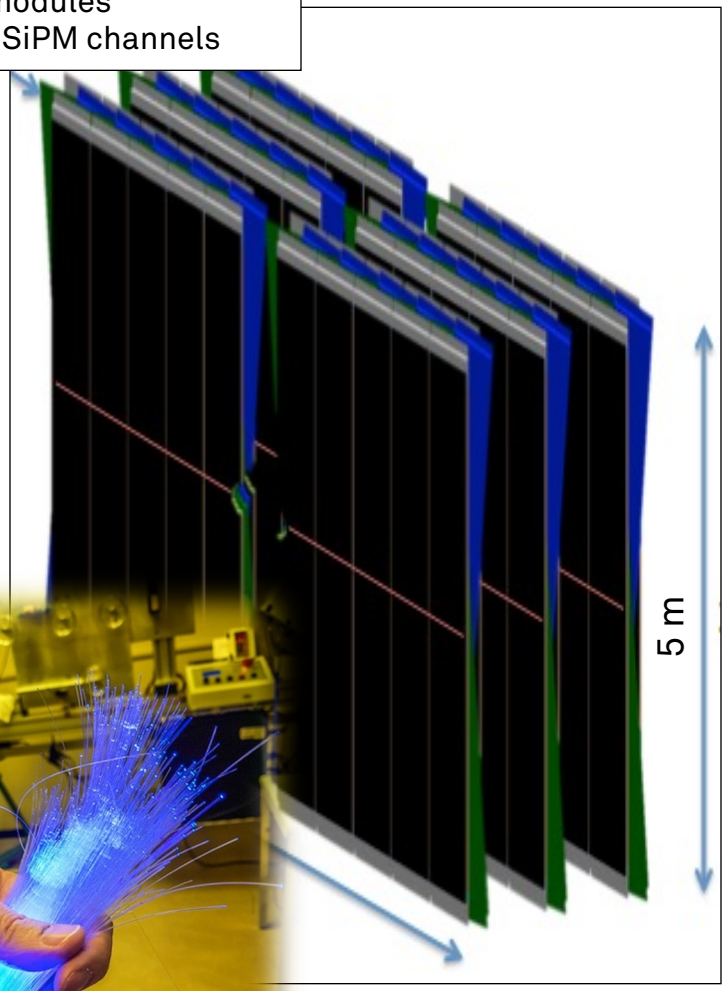
SciFi Tracker

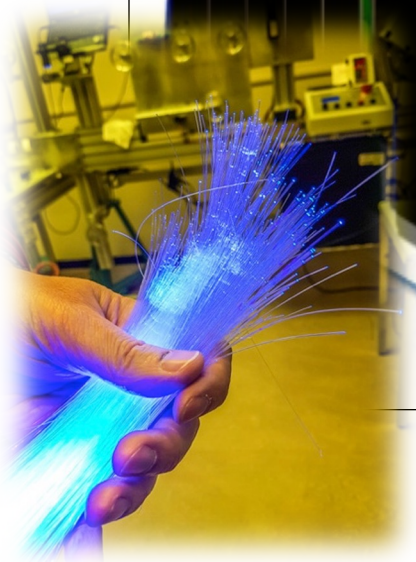
Nikhef responsibilities

Modules: production at Nikhef
Coldbox: production and design
Electronics: Digital part, firmware and controls

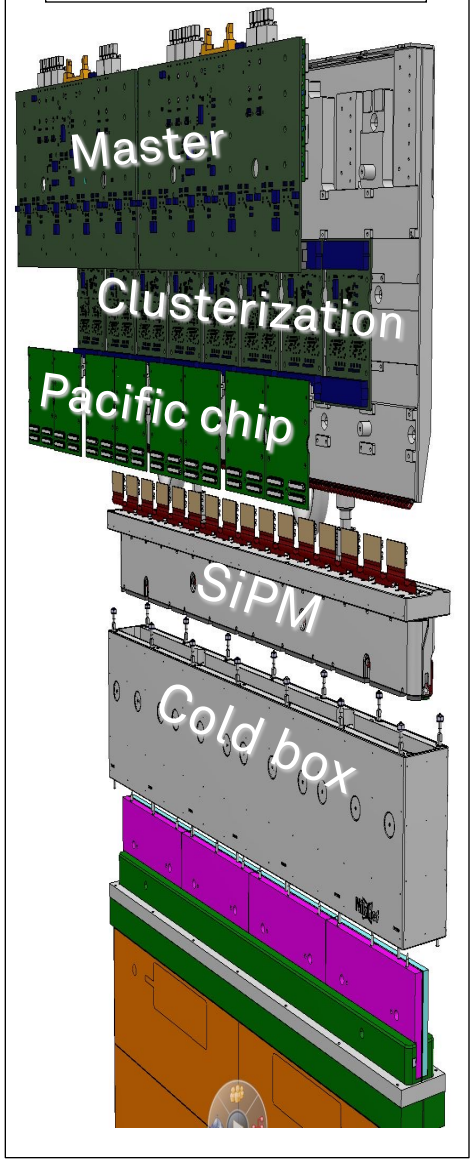
SciFi Tracker

1 Detector:
= 11.000 km fibres
= 128 modules
= 600k SiPM channels

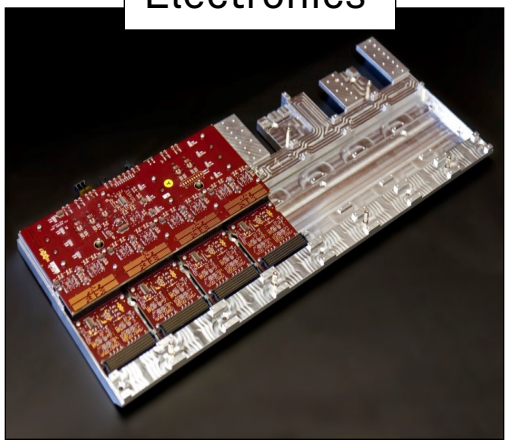




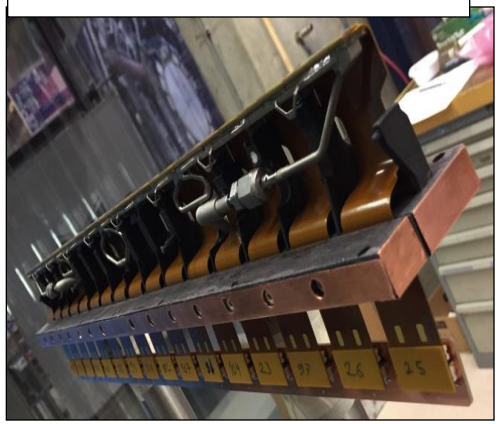
Module endpiece



Electronics



Flex cables and SiPM



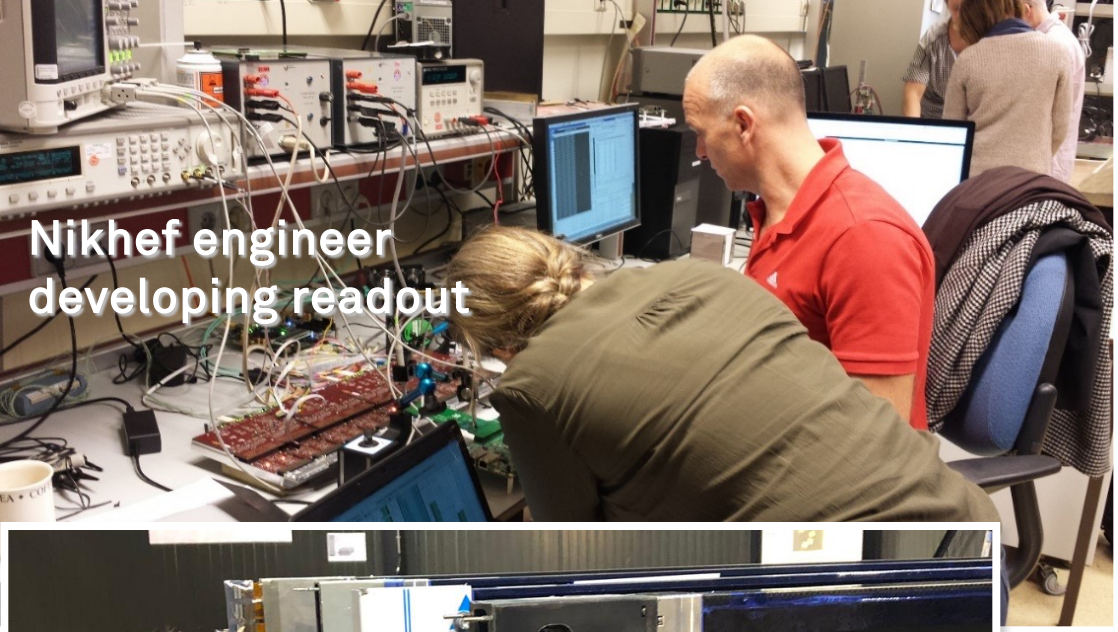
SciFi Tracker

Nikhef engineers designed and mount cabling

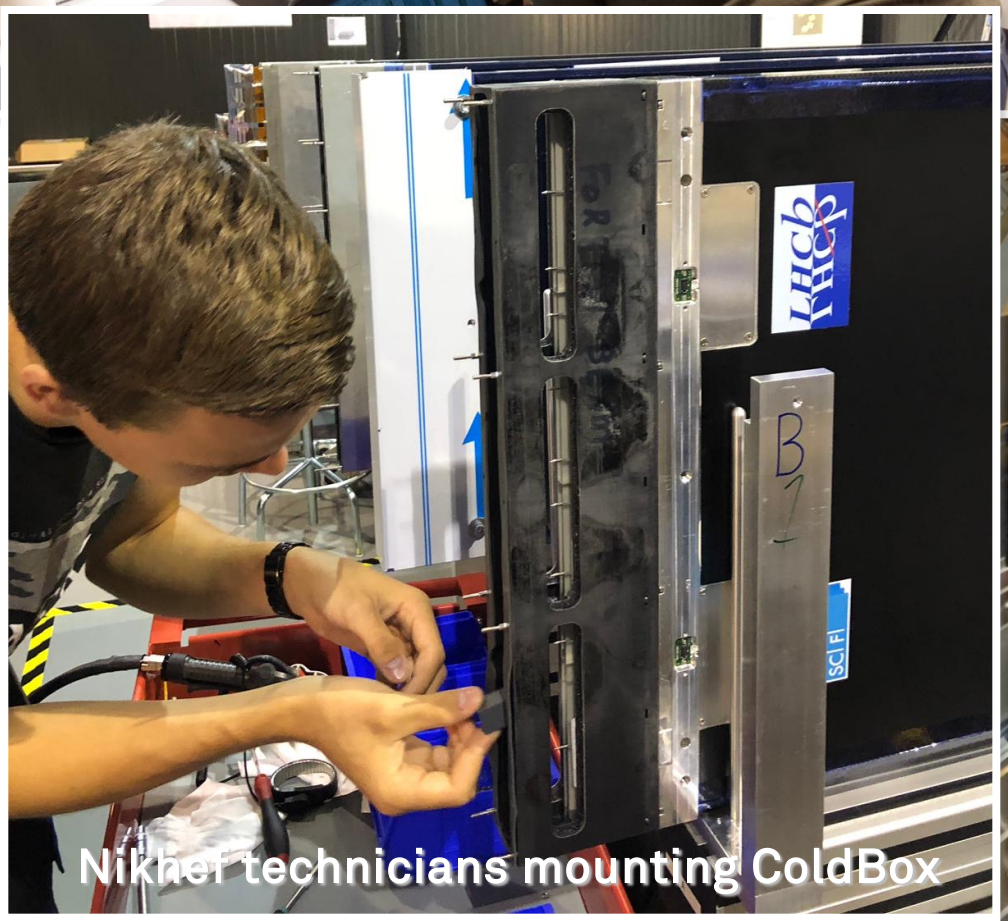
Nikhef technicians prepared frames

Nikhef engineers designed digital electronics

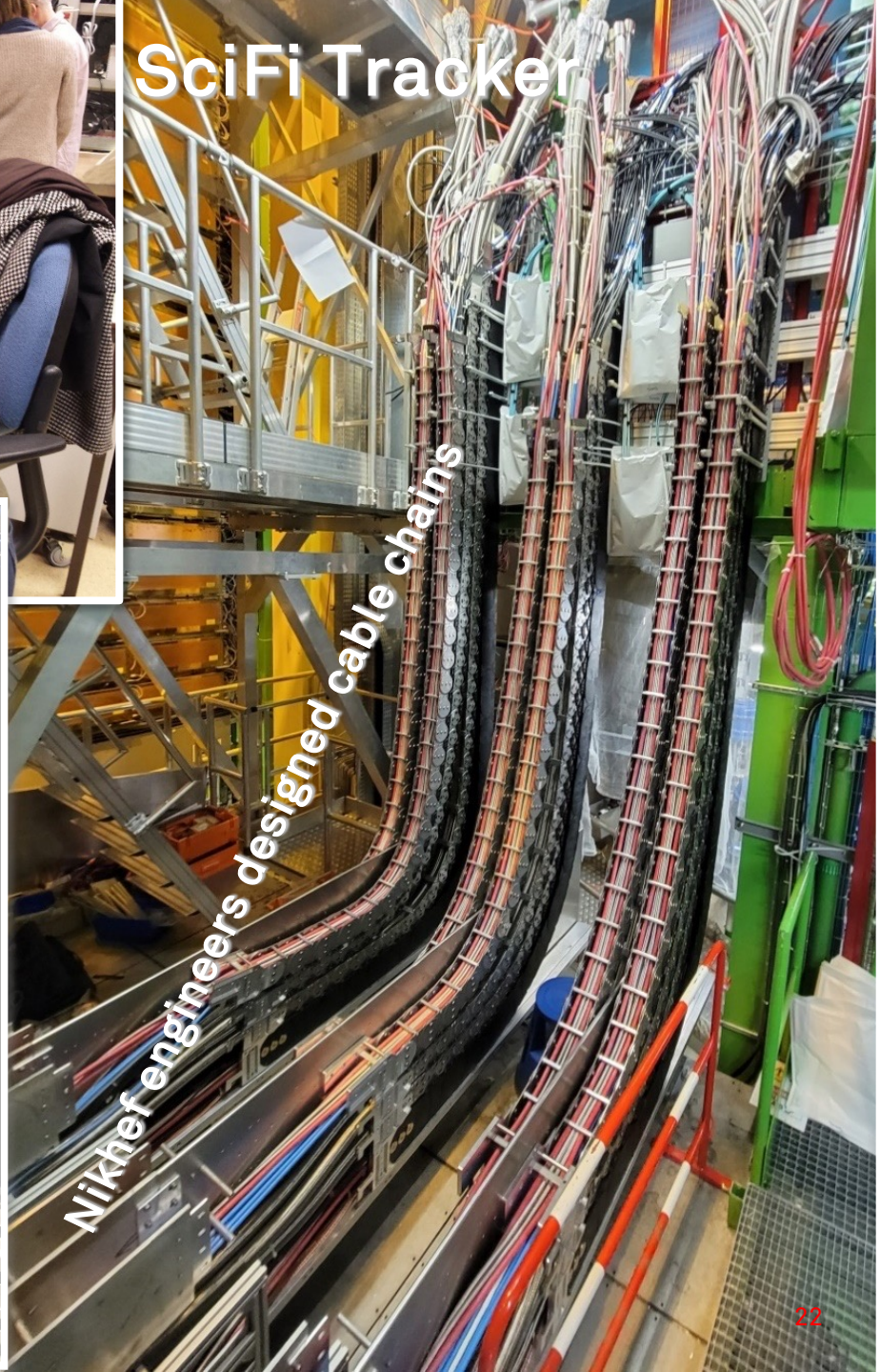
SciFi Tracker



Nikhef engineer developing readout

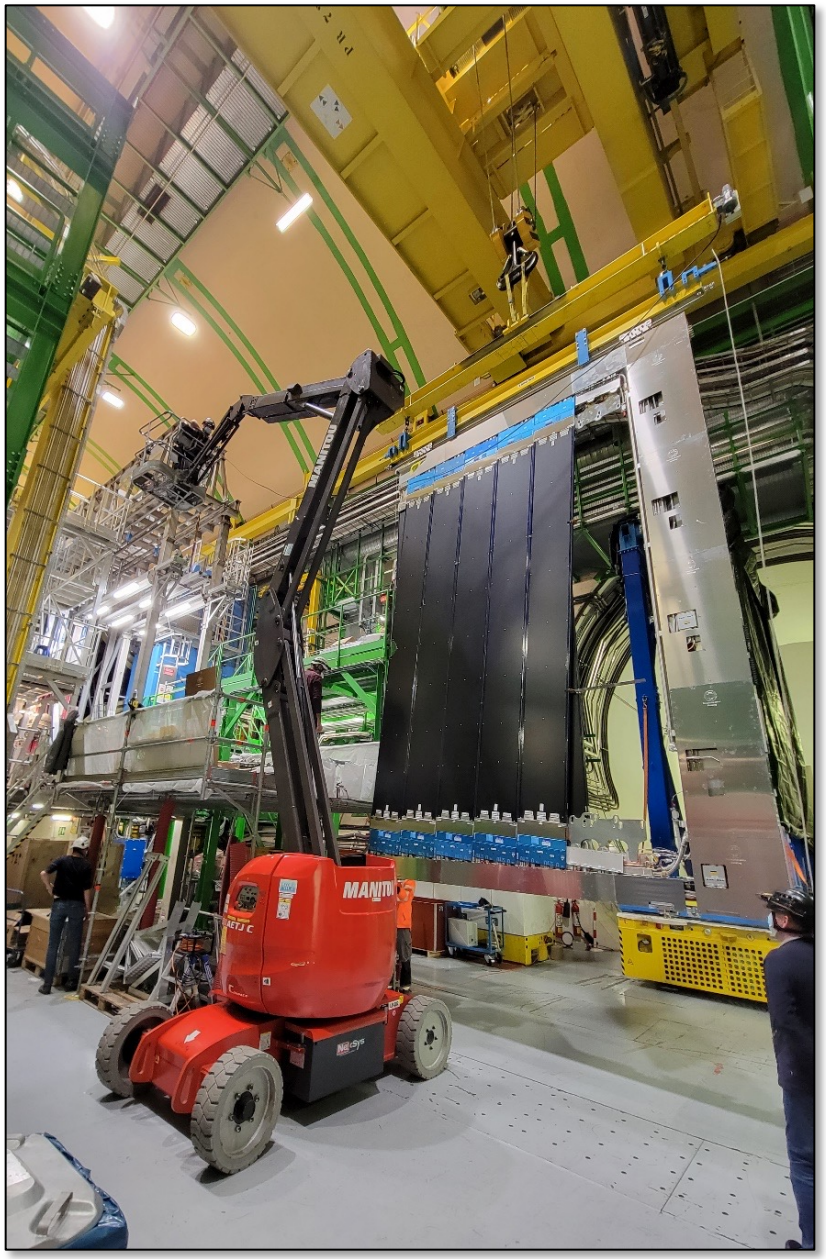


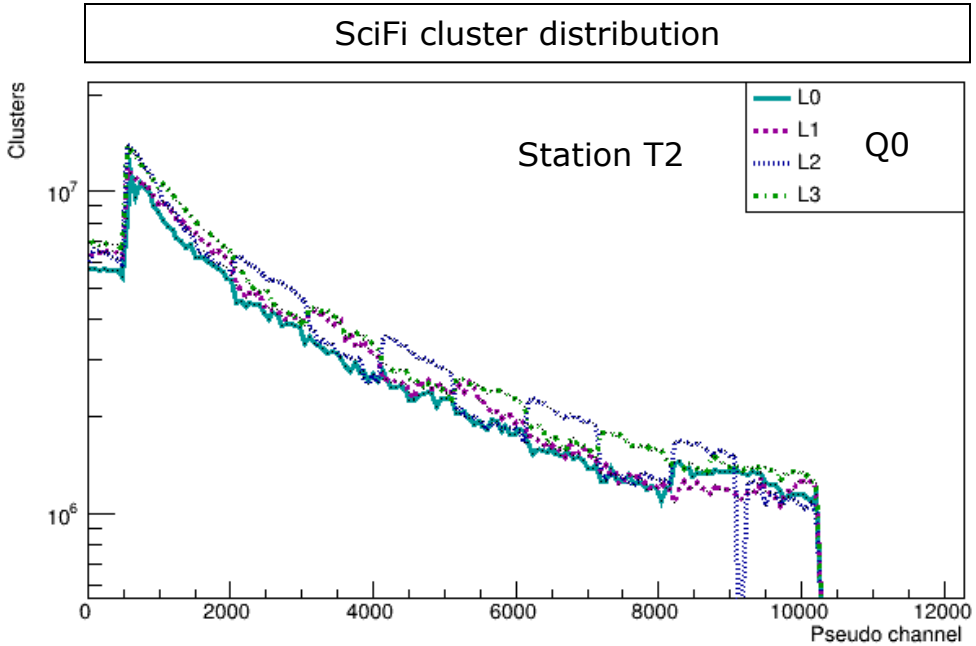
Nikhef technicians mounting ColdBox



Nikhef engineers designed cable chains

SciFi Tracker

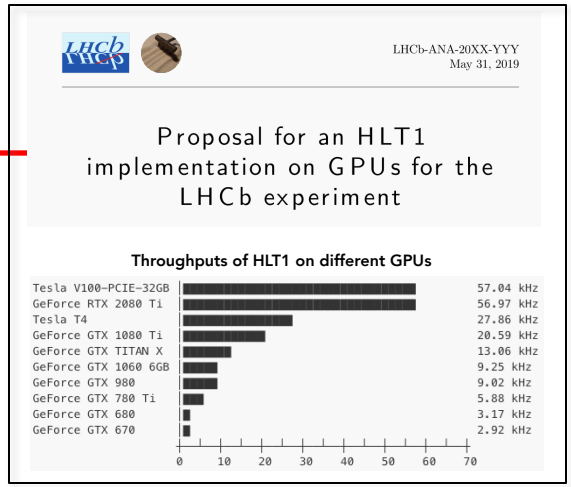


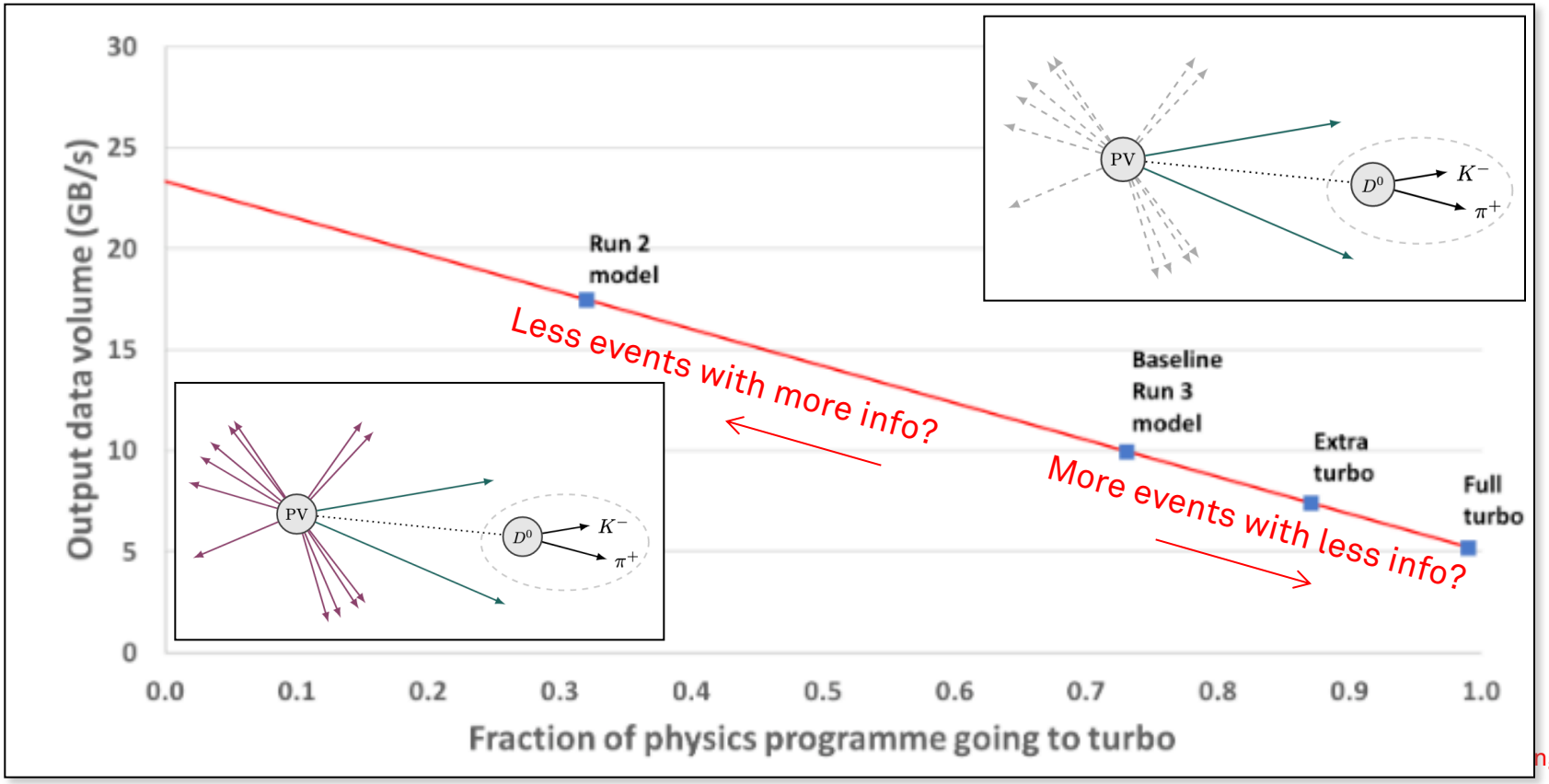


RTA (real time analysis)

(aka: reconstruction, trigger, alignment)

- New project, with large Nikhef involvement
- Many open questions (choices)
- Challenging and inviting computing aspects





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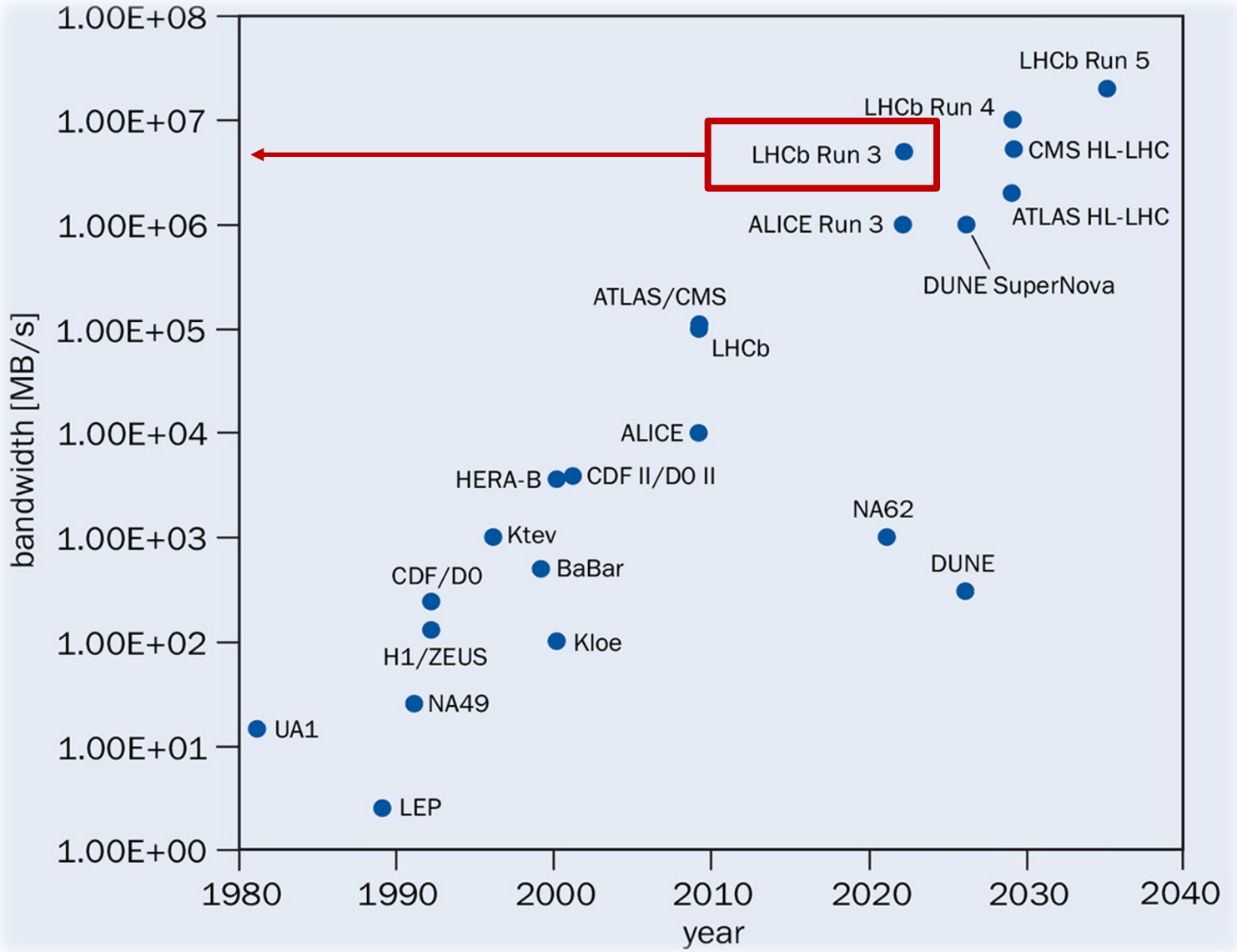
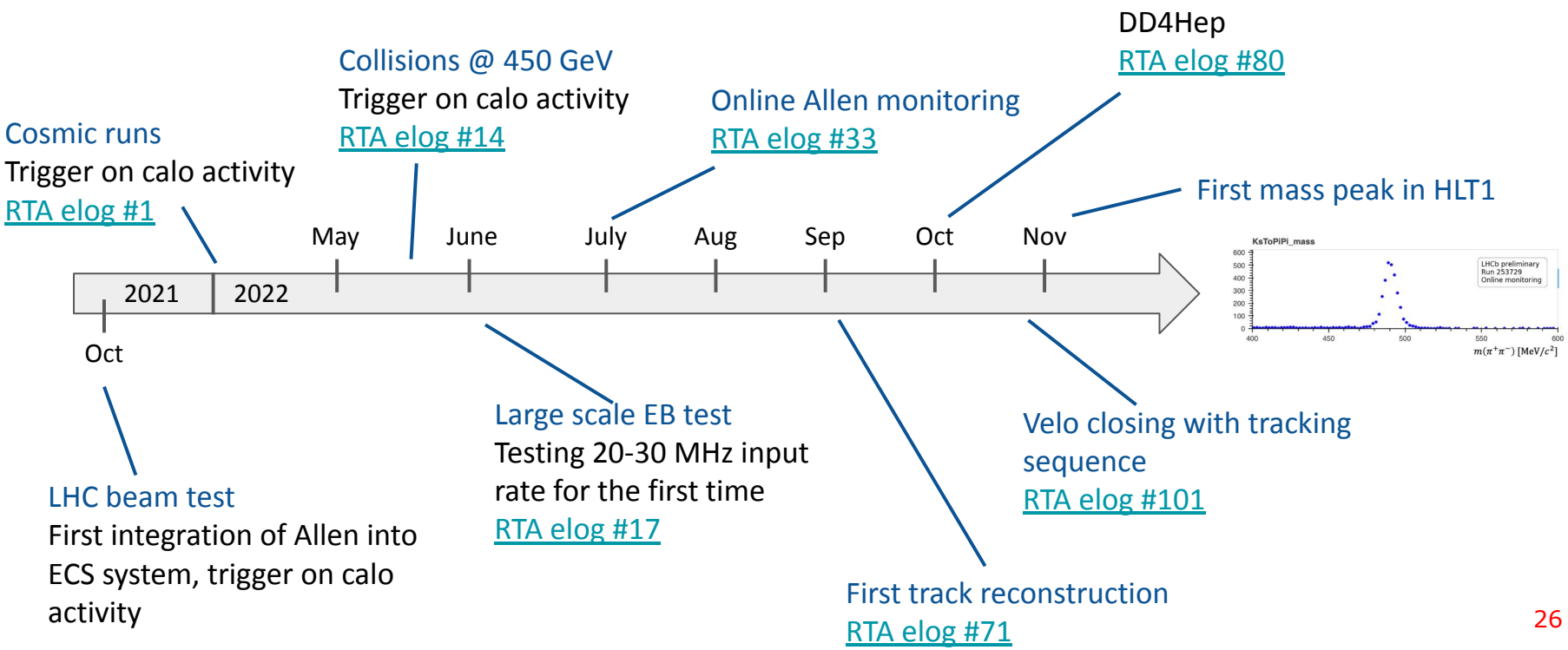


https://cerncourier.com/a/lhcb-looks-forward-to-the-2030s/

RTA (real time analysis)

(aka: reconstruction, trigger, alignment)

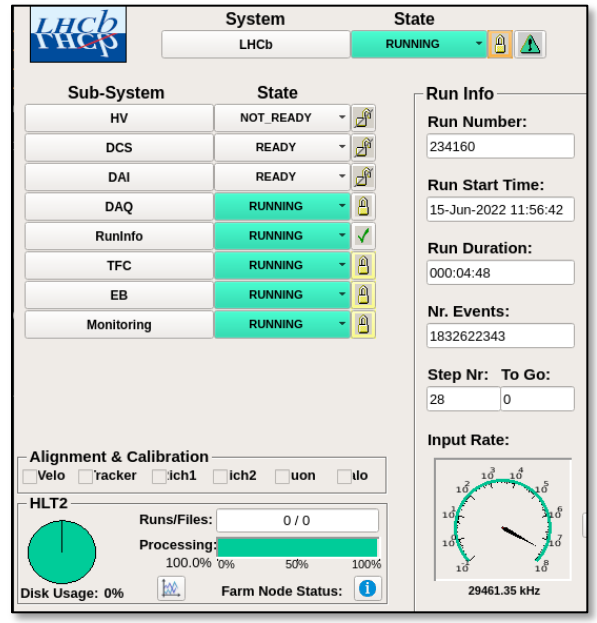
- Strong involvement
  - Nikhef+VU founding member + management roles
  - HLT1 (framework, algorithms, GPU operations)
  - HLT2 framework (made multi-threaded, selections, persistence)
- Progress in 2022 :

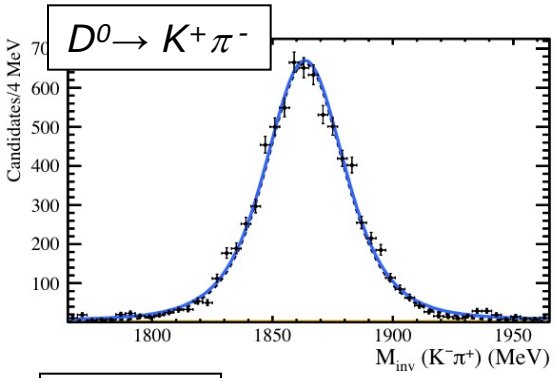


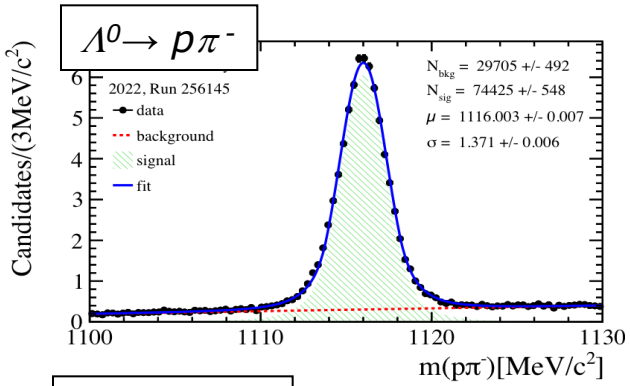
RTA (real time analysis)

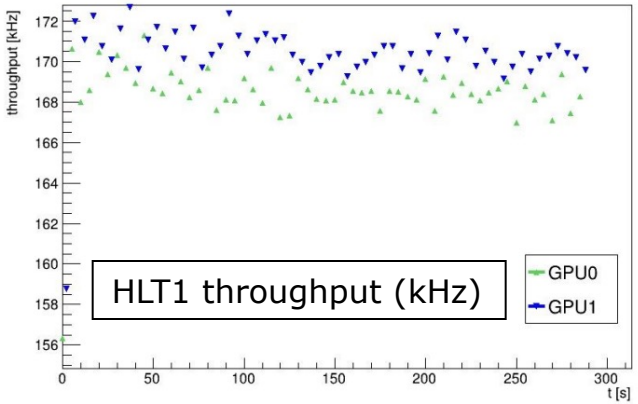
(aka: reconstruction, trigger, alignment)

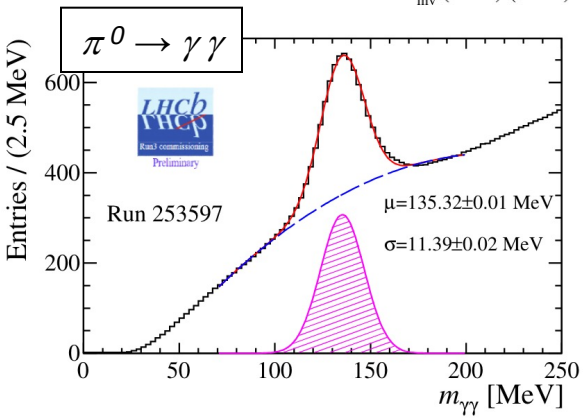
- Achievements:
  - HLT1: rate tests to 25-30 MHz (record throughput)
  - HLT2: ~1500 selection lines implemented…
  - Alignment: using new software framework

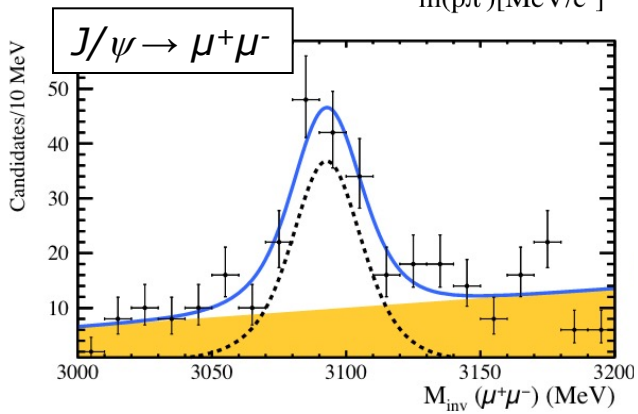












Upgrade II

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035+
	Run III				Run IV									Run V
LS2						**LS3**						**LS4**		
LHCb 40 MHz **UPGRADE I**		$L = 2 \times 10^{33}$			**LHCb** **Consolidate**			$L = 2 \times 10^{33}$ $50\ fb^{-1}$				**LHCb** **UPGRADE II**		$L=1\text{-}2\times10^{34}$ $300\ fb^{-1}$
ATLAS **Phase I Upgr**		$L = 2 \times 10^{34}$			**ATLAS** **Phase II UPGRADE**			**HL-LHC** $L = 5 \times 10^{34}$						**HL-LHC** $L = 5\times10^{34}$
CMS **Phase I Upgr**		$300\ fb^{-1}$			**CMS** **Phase II UPGRADE**									$3000\ fb^{-1}$
Belle II		$L = 3 \times 10^{35}$				$7\ ab^{-1}$					$L = 6 \times 10^{35}$		$50\ ab^{-1}$	

LHC schedule:

https://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm

Upgrade II

Precision → highest mass scales

Update of the European Strategy for Particle Physics

1. Major developments from the 2013 Strategy

...

The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. ***The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.***

Detector Plans: LHCb-TDR-023

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2021-012
LHCb TDR 23
24 February 2022

Framework TDR for the LHCb Upgrade II

Opportunities in flavour physics, and beyond, in the HL-LHC era

The LHCb collaboration

Abstract

This document is the Framework Technical Design Report for the Upgrade II of the LHCb experiment, which is proposed for the long shutdown 4 of the LHC. The upgraded detector will operate at a maximum luminosity of $1.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, with the aim of integrating $\sim 300\,\mathrm{fb}^{-1}$ through the lifetime of the high-luminosity LHC (HL-LHC). The collected data will allow to fully exploit the flavour-physics opportunities of the HL-LHC, probing a wide range of physics observables with unprecedented accuracy. In particular, the new physics mass scale probed, for fixed couplings, will almost double as compared with the pre-HL-LHC era.

The accomplishment of this ambitious programme will require that the current detector performance is maintained at the maximum expected pile-up of ∼40, and even improved in certain specific domains. To meet this challenge, it is foreseen to replace all of the existing spectrometer components to increase the granularity, reduce the amount of material in the detector and to exploit the use of new technologies including precision timing of the order of a few tens of picoseconds. The design options for each sub-detector are discussed, and the ongoing efforts to face the associated technology challenges. For the first time, elements of the environmental impact of the project are considered. Finally, details are given about the project schedule, the cost envelope and the participating institutes.

Physics Case: arXiv:1808.08865

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCC-2018-027
LHCB-PUB-2018-009
27 August 2018

arXiv:1808.08865v4 [hep-ex] 5 Apr 2019

Physics case for an LHCb Upgrade II

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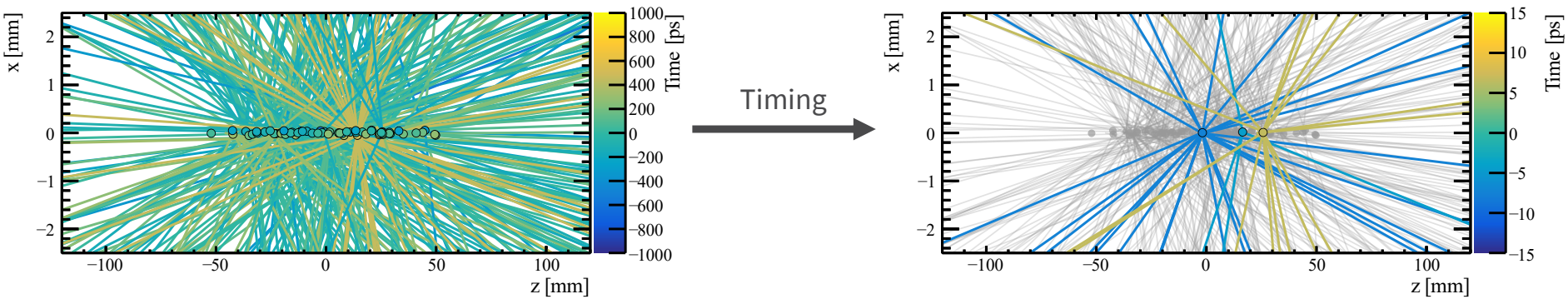
The LHCb collaboration

Abstract

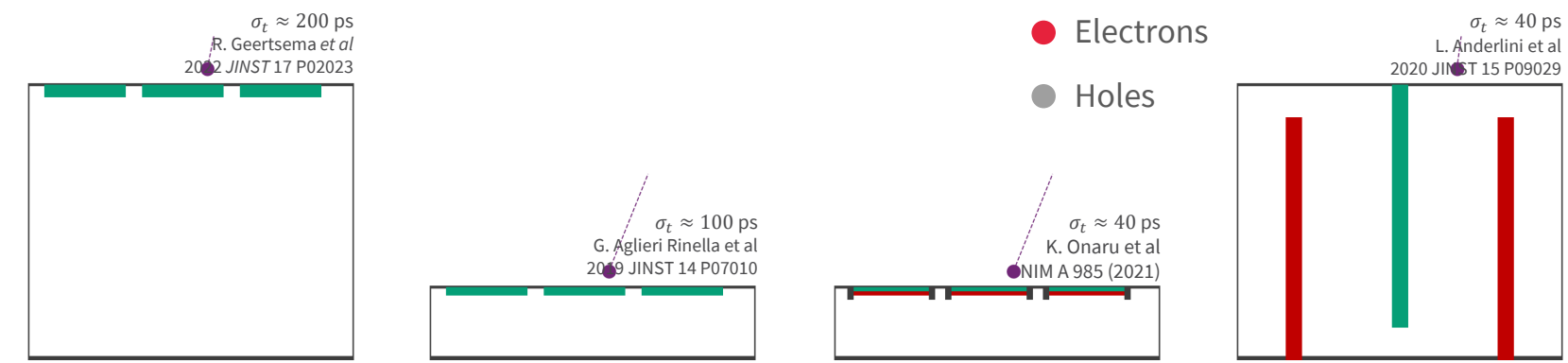
The LHCb Upgrade II will fully exploit the flavour-physics opportunities of the HL-LHC, and study additional physics topics that take advantage of the forward acceptance of the LHCb spectrometer. The LHCb Upgrade I will begin operation in 2020. Consolidation will occur, and modest enhancements of the Upgrade I detector will be installed, in Long Shutdown 3 of the LHC (2025) and these are discussed here. The main Upgrade II detector will be installed in long shutdown 4 of the LHC (2030) and will build on the strengths of the current LHCb experiment and the Upgrade I. It will operate at a luminosity up to $2 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, ten times that of the Upgrade I detector. New detector components will improve the intrinsic performance of the experiment in certain key areas. An Expression Of Interest proposing Upgrade II was submitted in February 2017. The physics case for the Upgrade II is presented here in more depth. *CP*-violating phases will be measured with precisions unattainable at any other envisaged facility. The experiment will probe $b \to s\ell^+\ell^-$ and $b \to d\ell^+\ell^-$ transitions in both muon and electron decays in modes not accessible at Upgrade I. Minimal flavour violation will be tested with a precision measurement of the ratio of $\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$. Probing charm *CP* violation at the 10^{-5} level may result in its long sought discovery. Major advances in hadron spectroscopy will be possible, which will be powerful probes of low energy QCD. Upgrade II potentially will have the highest sensitivity of all the LHC experiments on the Higgs to charm-quark couplings. Generically, the new physics mass scale probed, for fixed couplings, will almost double compared with the pre-HL-LHC era; this extended reach for flavour physics is similar to that which would be achieved by the HE-LHC proposal for the energy frontier.

Upgrade II at Nikhef

- Faster



- Improved time resolutions achieved with variety of designs

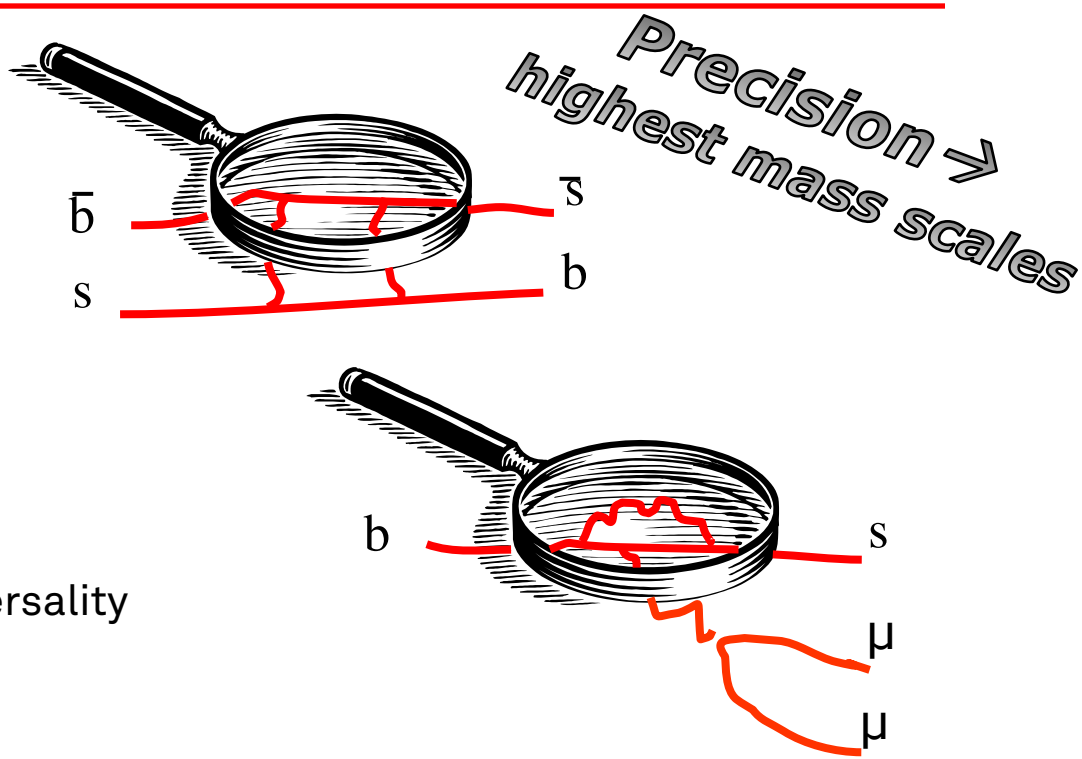


"Thick planar"	"Thin planar"	LGAD	3D
Traditional detector designs	Monolithic/MAPS	Built in gain layer	Vertical pillars
Large signal but slow	Fast but low signal	Fast & large signal Implemented in MAPS? Not as radiation resistant…	Fast & large signal Low fill factor…

From: R.Geertsema LHCP2022

Physics

- At Nikhef
- CP violation
  1) ϕ_s
  2) γ
- Rare decays
  3) Very rare decays
  4) Lepton flavour non-universality
- Long-living particles



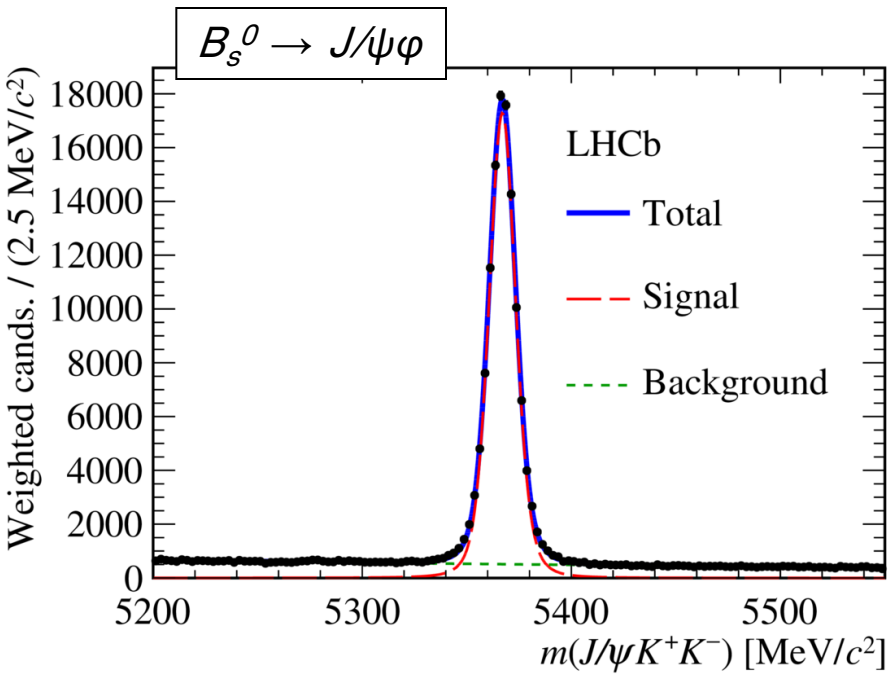
- Other recent LHCb highlights:
  - New 'exotic' hadrons: Tetraquark and pentaquark
  - W-mass
  - D^0 mass difference
  - anti-p production

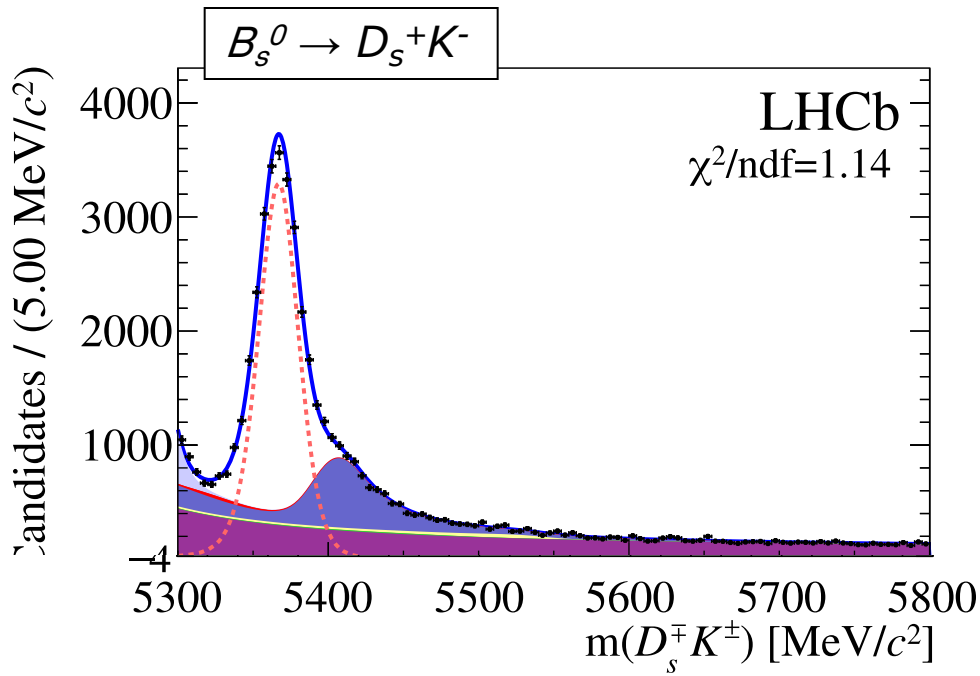
Physics at Nikhef: CP violation

- ϕ_s with $B_s^0 \to J/\psi\varphi$
  - and sin2β

- γ with $B_s^0 \to D_s^+ K^-$
  - and mass difference Δm_s

$$\phi_s^{this} = XXX \pm 0.021(stat.) \pm 0.0068(syst.) \text{ [rad]}$$



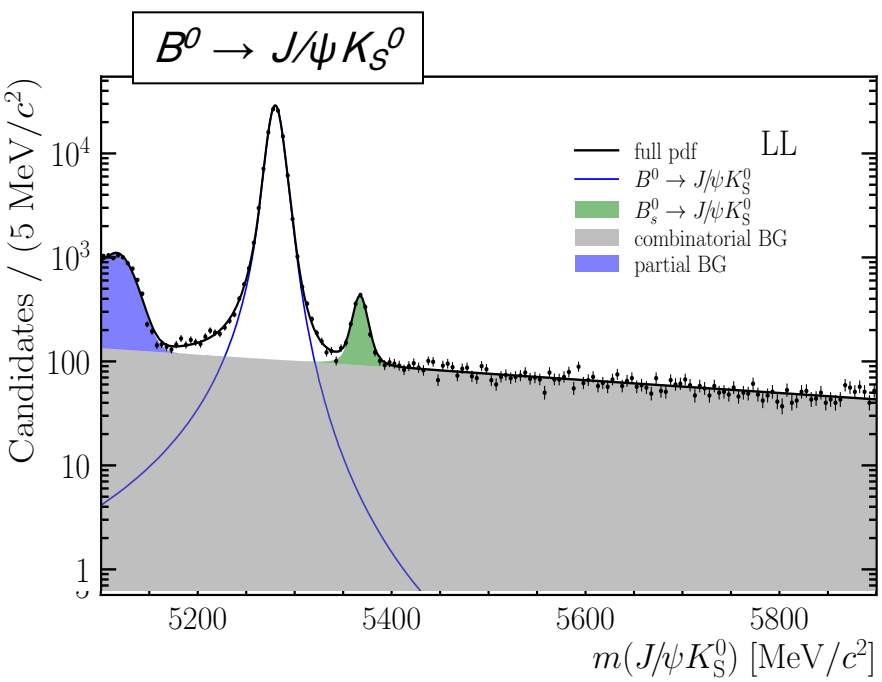


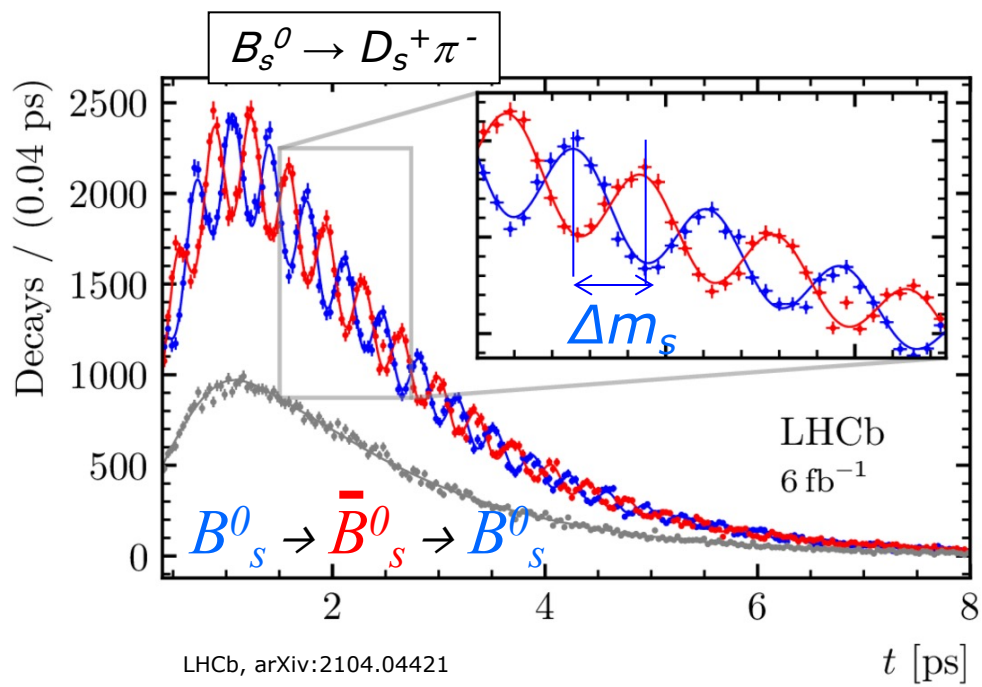
Physics at Nikhef: CP violation

- ϕ_s with $B_s^0 \to J/\psi\varphi$
  - and sin2β

- γ with $B_s^0 \to D_s K$
  - and mass difference Δm_s

$$\Delta m_s = 17.7656 \pm 0.0057\,\mathrm{ps}^{-1}$$

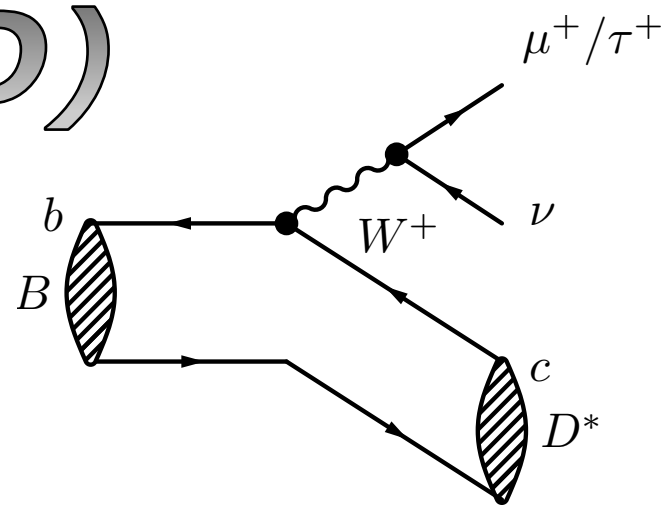




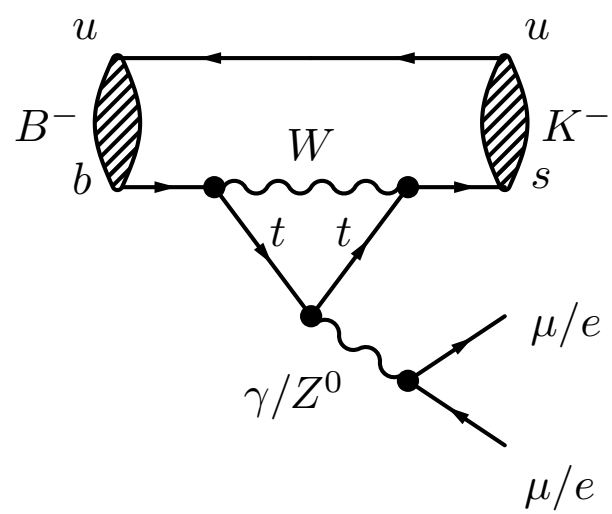
LHCb, arXiv:2104.04421

Hot topic: *Flavour Anomalies*

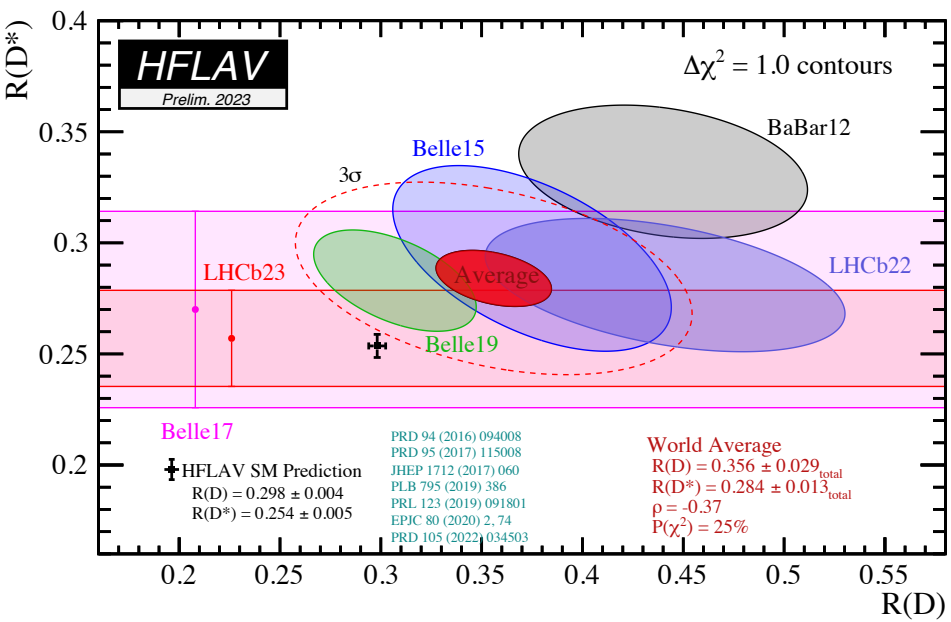
R(D)



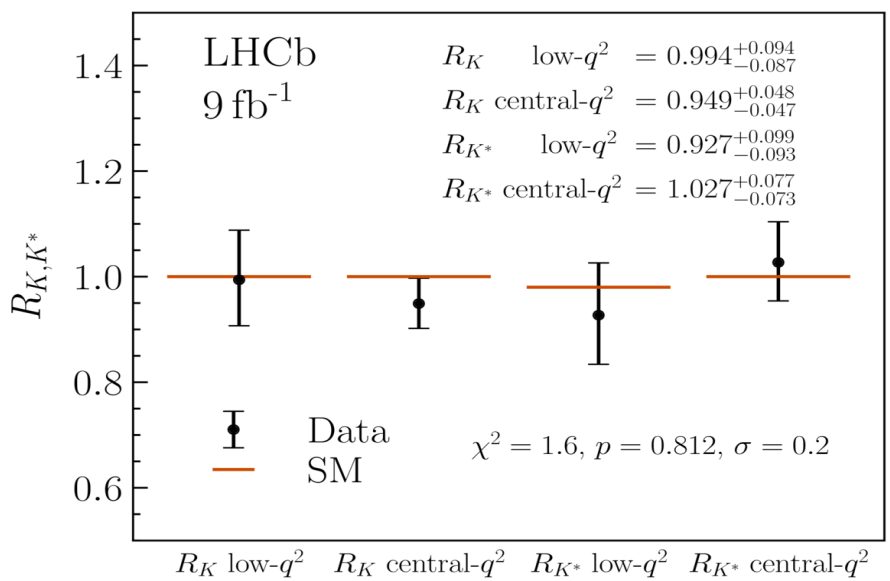
R_K



3.2σ



0.2σ



LHCb, PAPER-2022-052

LHCb, arXiv:2212.09153

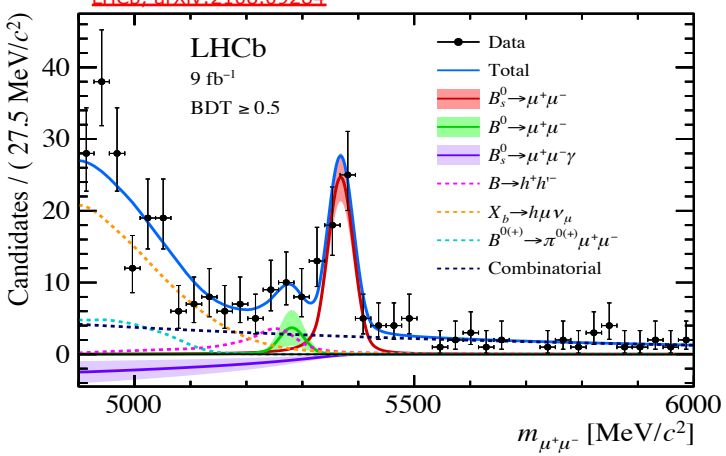
Physics at Nikhef: Rare decays

- **Very rare: $B_s^0 \to \mu^+\mu^-$**
  - LHCb flagship
  - *LFV ?* $\Lambda_b^0 \to \Lambda^0 e^+\mu^-$

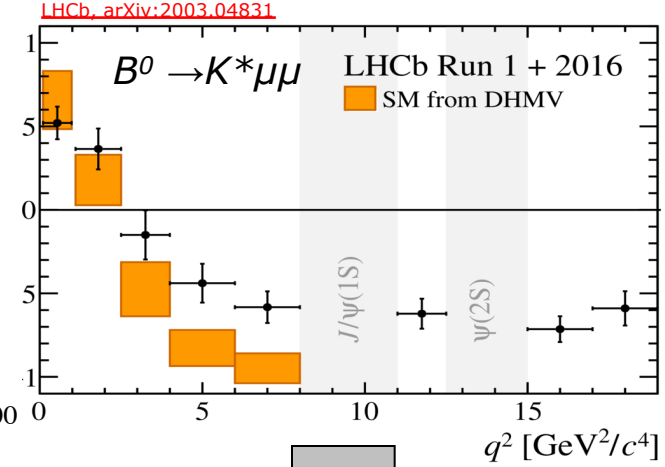
- **Electrons:**
  - Angular: $B^0 \to K^*ee$
  - Validate: $J/\psi \to ee / J/\psi \to \mu\mu$

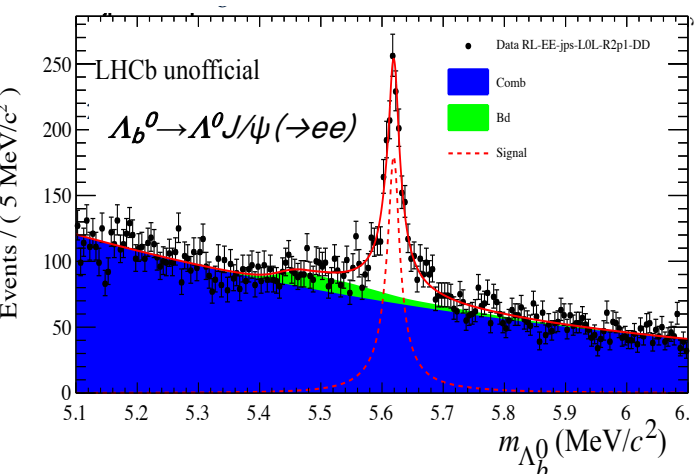
- **Taus:**
  - $B_c^+ \to \tau^+\upsilon$
  - $B_s^0 \to D_s^-\tau^+\upsilon$
  - + Other LLP !

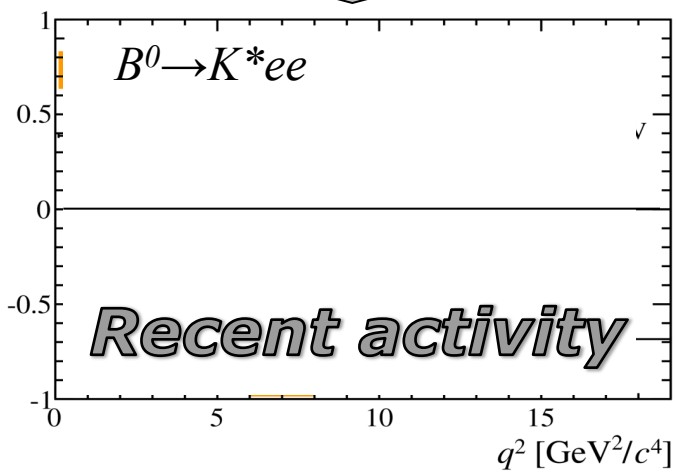
LHCb, arXiv:2108.09284



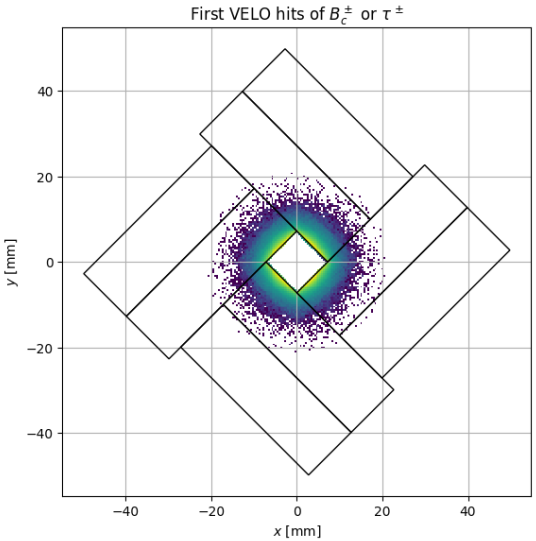
LHCb, arXiv:2003.04831







Recent activity



Physics

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- Rare decays
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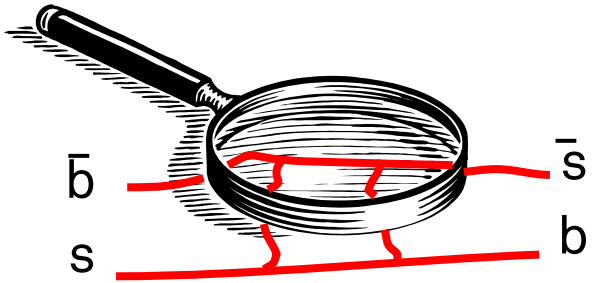
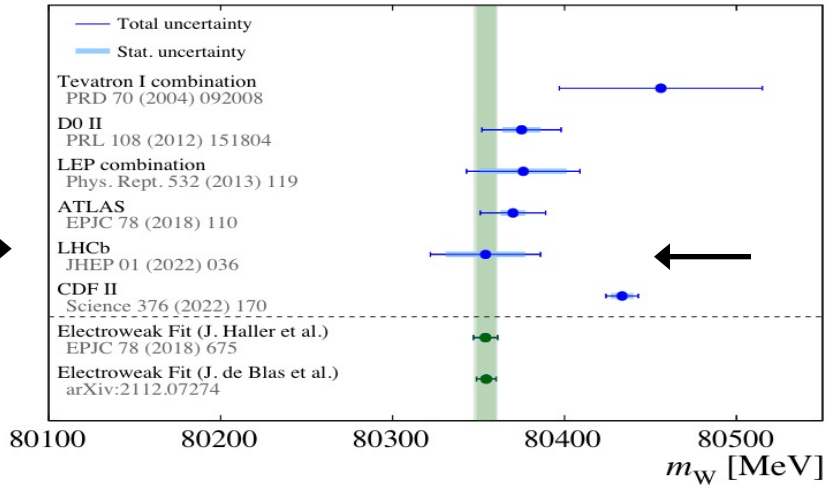
- Long-living particles



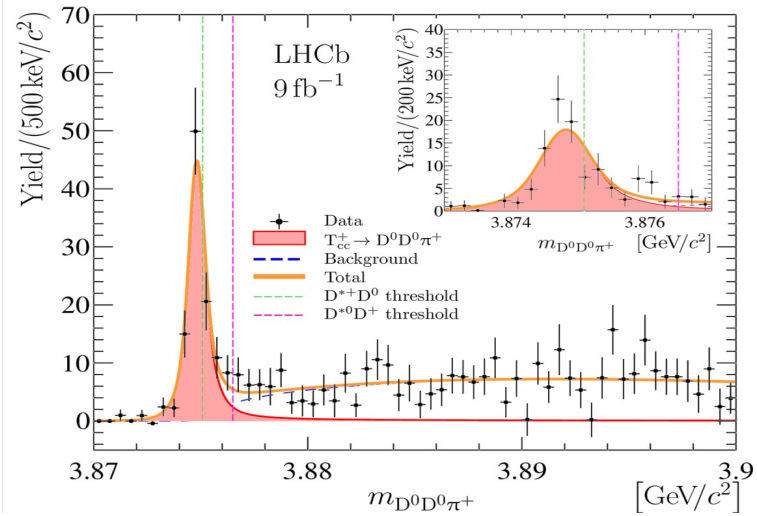
- Other recent LHCb highlights:
  - New 'exotic' hadrons: Tetraquark and pentaquark
  - W-mass
  - D^0 mass difference
  - anti-p production

Other LHCb highlights

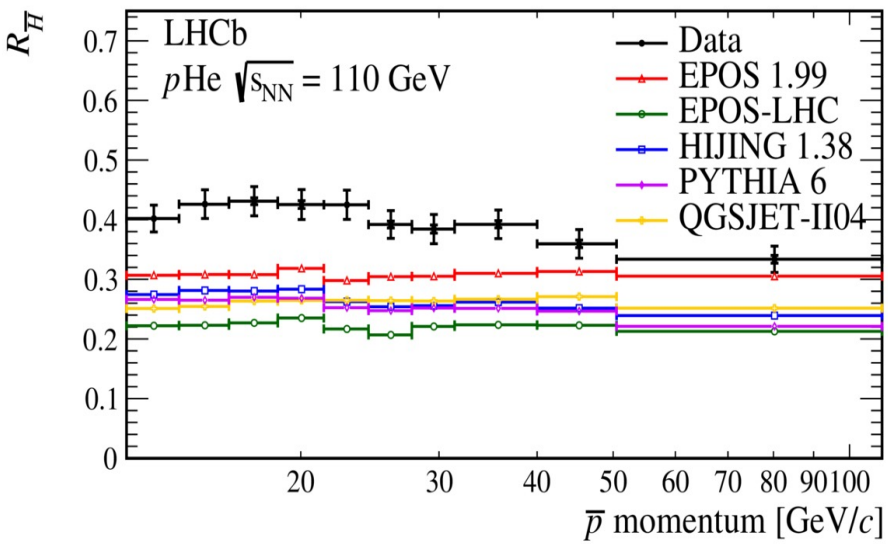
Competitive W-mass measurement



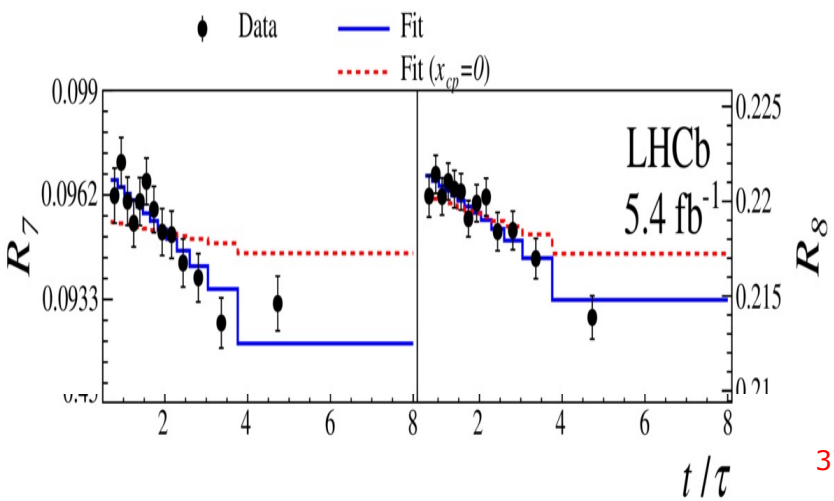
Exotic hadrons: doubly charmed T_{cc} ($cc\bar{u}\bar{d}$)



Anti-p from fixed target: like cosmics!

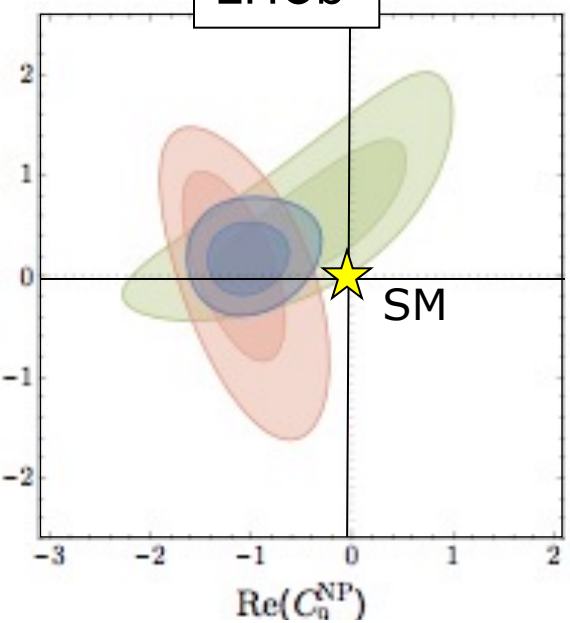


D^0 mass difference (< 10^{-5} eV !)



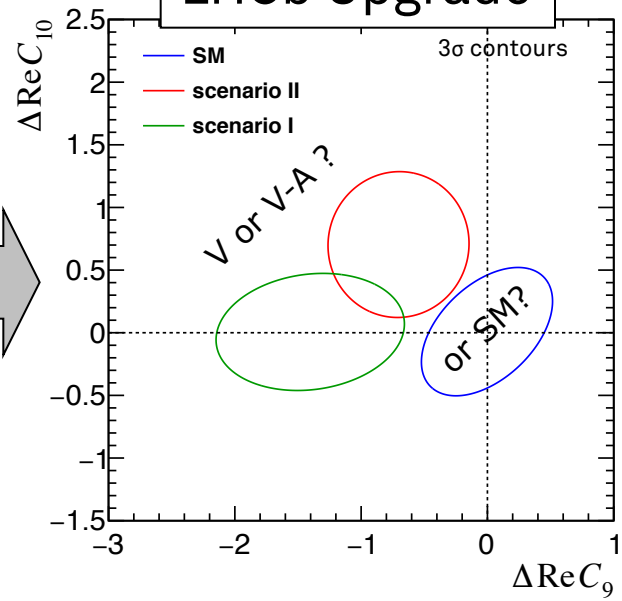
Outlook: Sensitive to highest mass scale!

LHCb

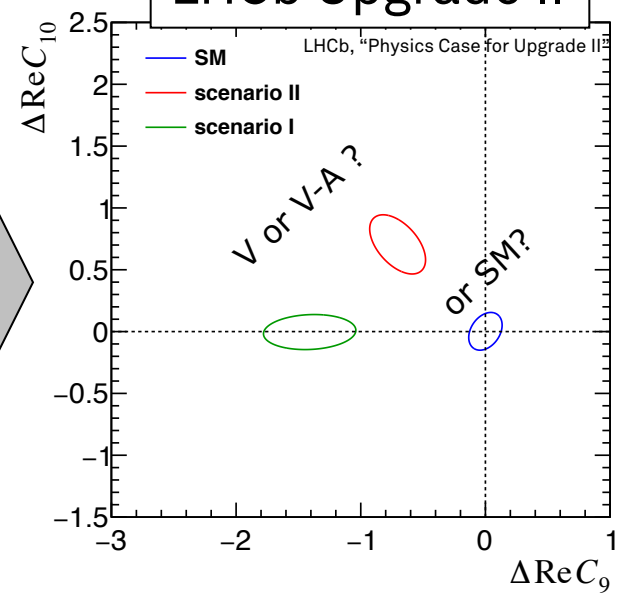


[Charles et al., 1309.2293]

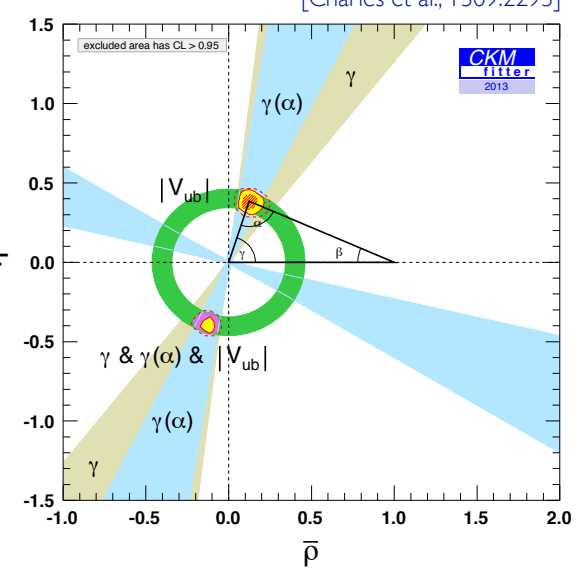
LHCb Upgrade



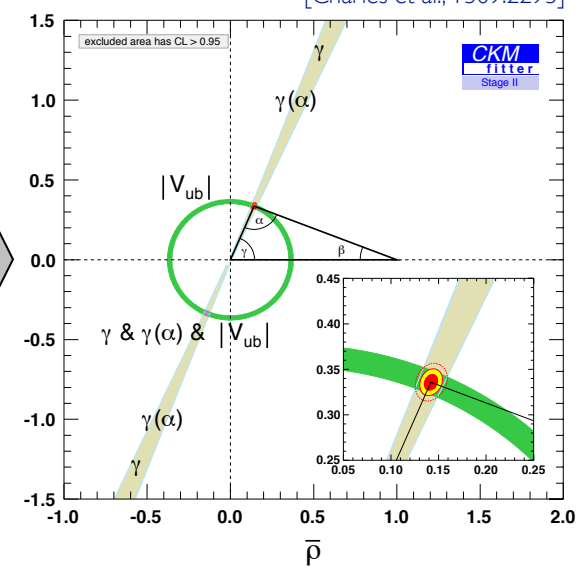
LHCb Upgrade II



[Charles et al., 1309.2293]



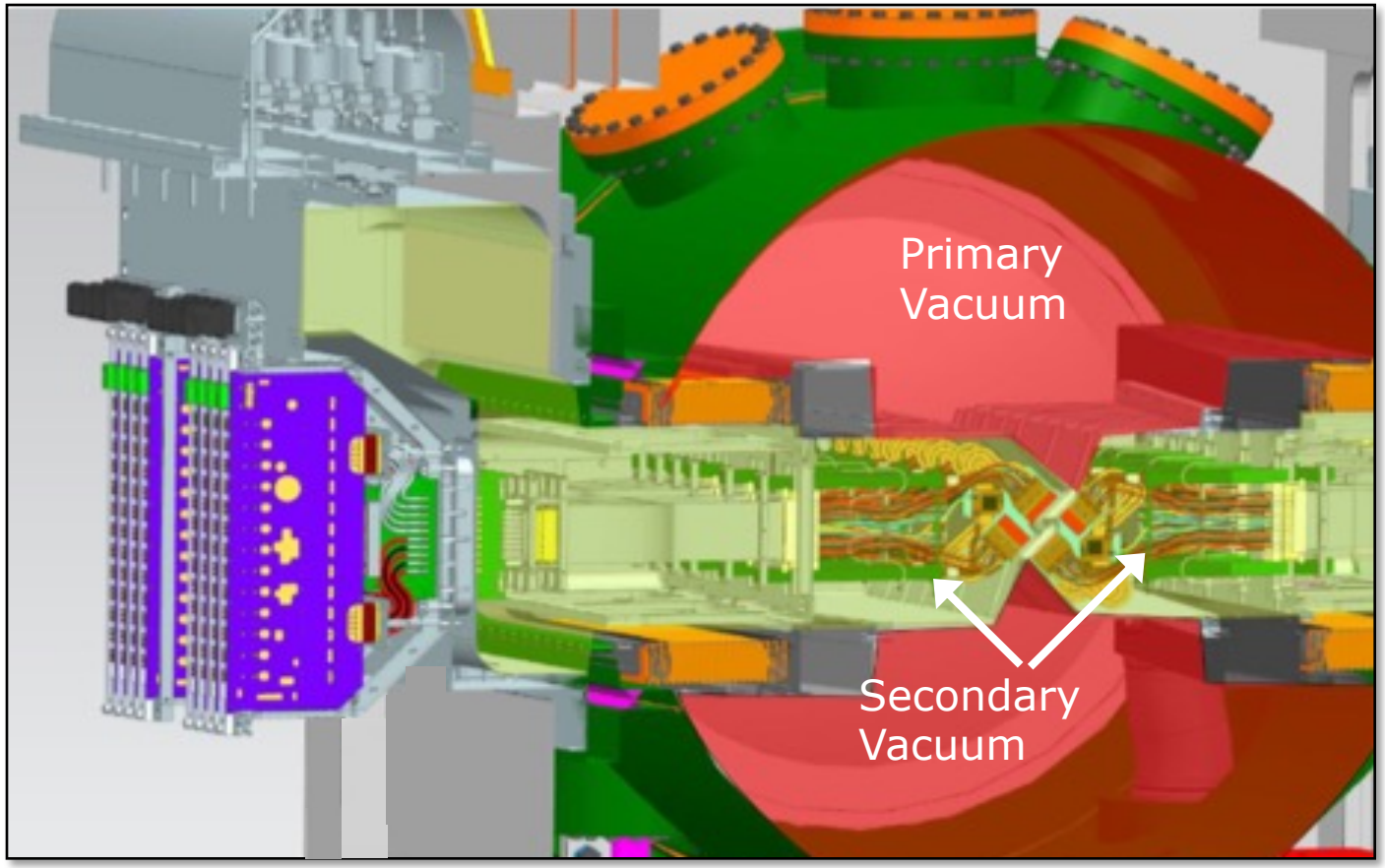
➢ Even after LHCb II (2029) all results statistically limited



Discussion: VELO Vacuum incident

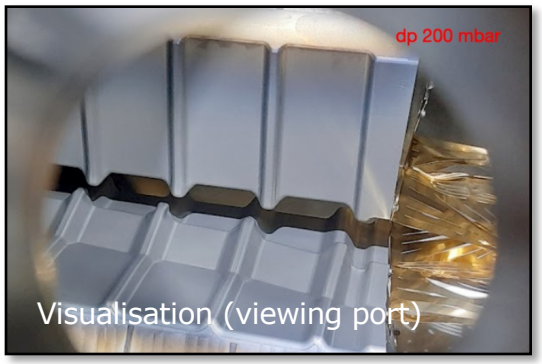
VELO vacuum incident: 10 Jan 2023

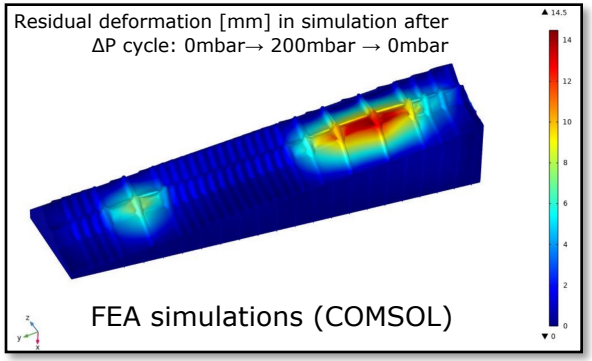
- Loss of control of the protection system during VELO warm up (in Ne)
- Relay failed and damaged a power supply, leading to multiple equipment failures and a pumping action on the primary volume
- Pressure differential of 200 mb built up between the two volumes, whereas the foils are designed to withstand 10 mb only

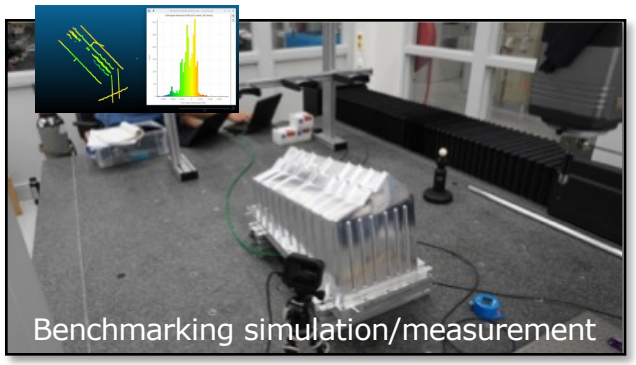


VELO Vacuum Incident: Analysis and Recovery

- As a result of the incident, the RF foils are deformed
- The foils are inside the vacuum tank
  - they can be partially visualised through a viewing port
  - the deformation is simulated, and benchmarked against measurements on a ½ scale box



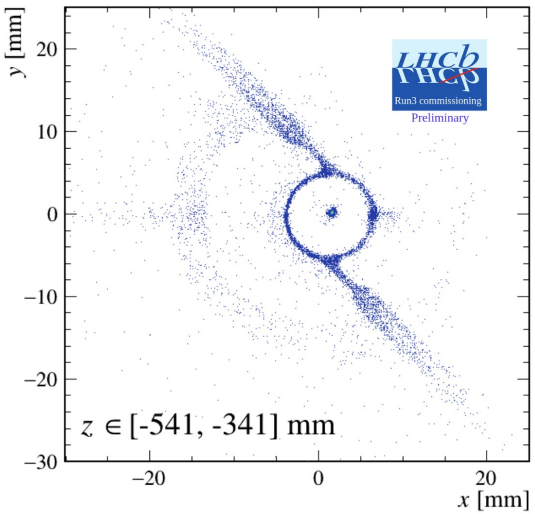




- The analysis shows a plastic deformation of the foils of up to 14 mm
  - ➢ replacing the foils is mandatory
- Priority for LHCb is to preserve VELO undamaged
- This is a significant intervention inside the vacuum tank
  - ➢ planning for next shutdown is currently under study
- Intervention happens in the next YETS: LHCb will run in 2023 with the VELO partially open

VELO Vacuum Incident: Next steps

RF foil tomography 2022



LHCb-FIGURE-2023-001
https://cds.cern.ch/record/2845444

Baseline:

- Operate with damaged foil in '23
  - VELO Closure to 10mm aperture at best
  - Aperture and impedance expected acceptable for machine
  - Replace foil in EYETS '23/'24

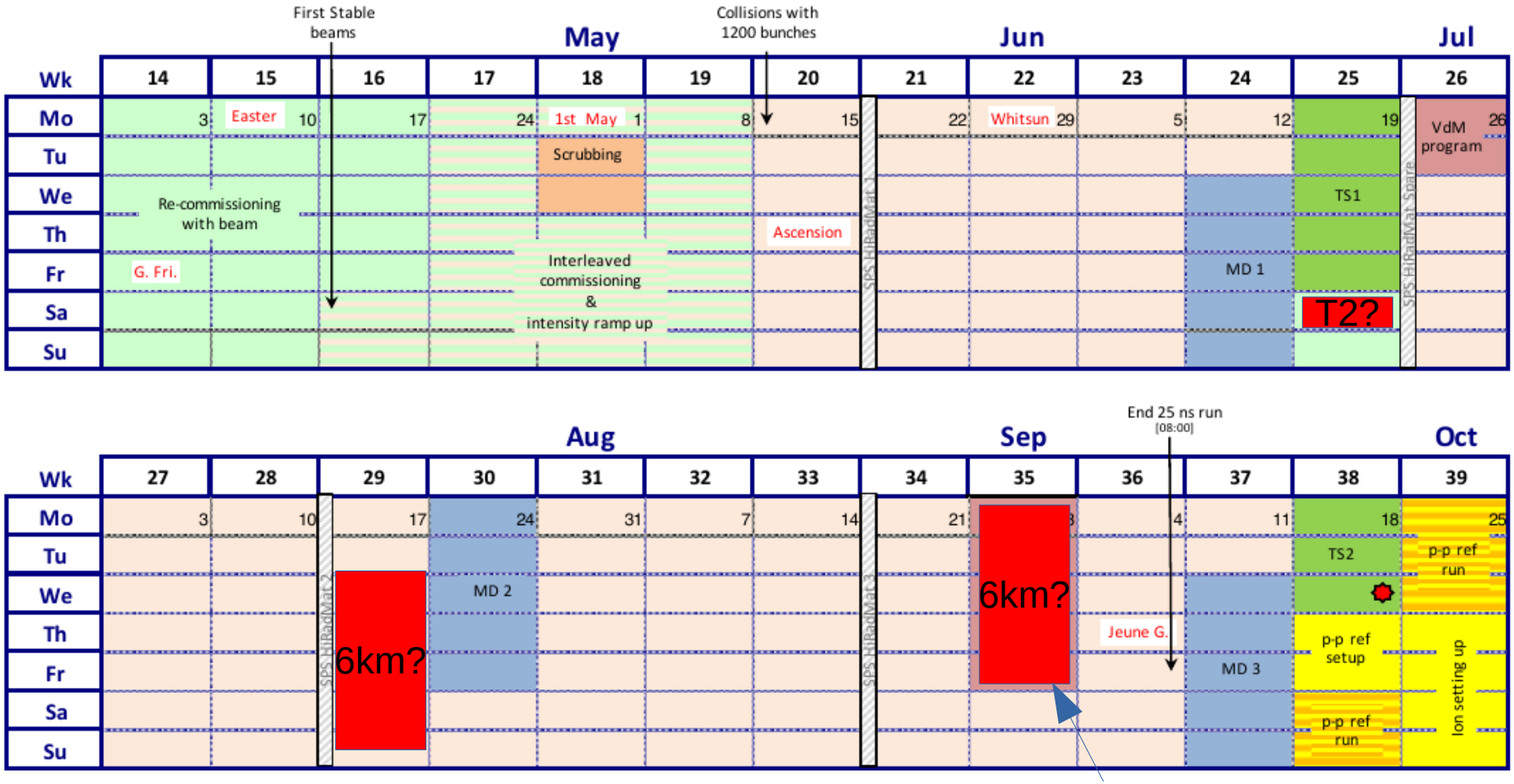
- Physics programme in 2023 will be significantly affected
- Commissioning of Upgrade I systems will proceed as planned

Important checkpoints towards TS1 in June 2023:

1) Tomography (probably with 450 GeV, incl. SMOG1 Ar)
2) Inspect motion system without beam
3) Decide on VELO position
4) Determine maximal radiation dose → luminosity, pile-up

Backup

2023

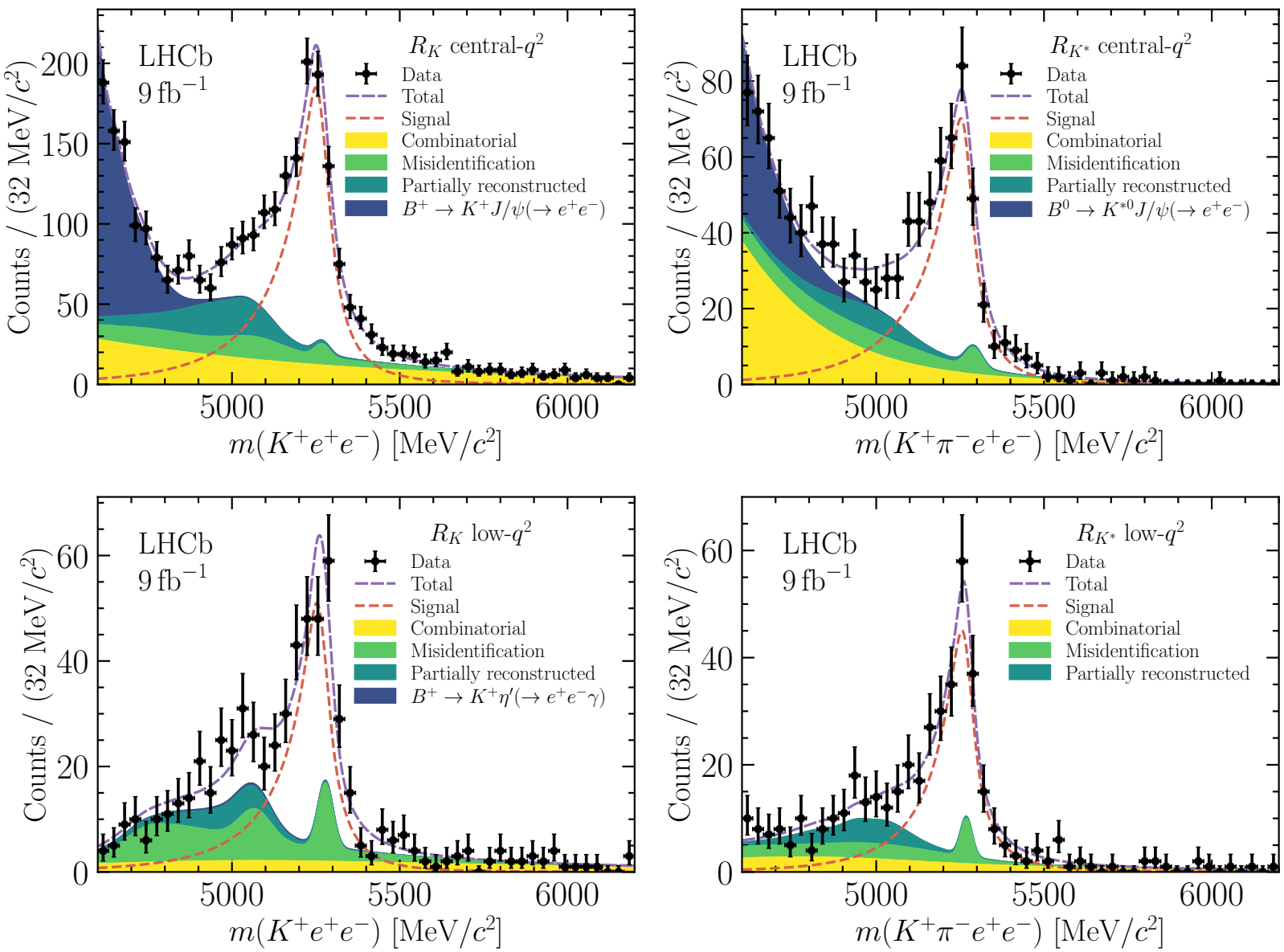


~6 weeks

July + August:

- Shift emphasis towards global commissioning

RX

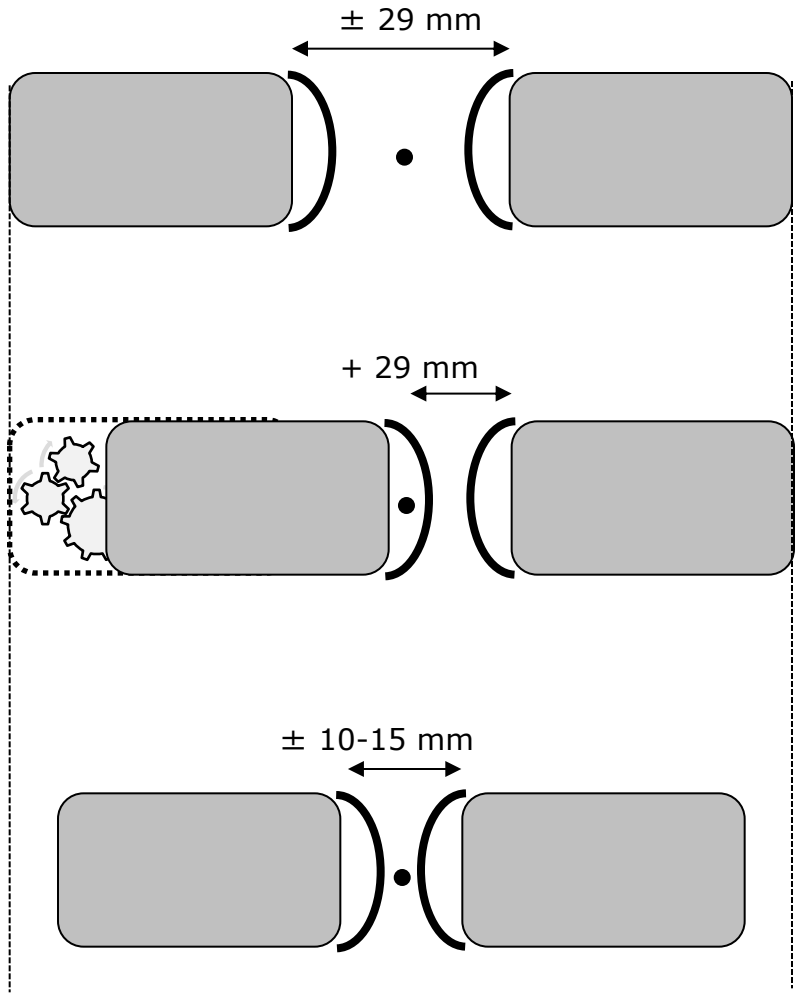

LHCb
9 fb^{-1}
R_K central-q^2
Data
Total
Signal
Combinatorial
Misidentification
Partially reconstructed
$B^+ \to K^+ J/\psi(\to e^+e^-)$
Counts / (32 MeV/c^2)
$m(K^+e^+e^-)$ [MeV/c^2]
LHCb
9 fb^{-1}
R_{K^*} central-q^2
Data
Total
Signal
Combinatorial
Misidentification
Partially reconstructed
$B^0 \to K^{*0} J/\psi(\to e^+e^-)$
Counts / (32 MeV/c^2)
$m(K^+\pi^-e^+e^-)$ [MeV/c^2]
LHCb
9 fb^{-1}
R_K low-q^2
Data
Total
Signal
Combinatorial
Misidentification
Partially reconstructed
$B^+ \to K^+\eta'(\to e^+e^-\gamma)$
Counts / (32 MeV/c^2)
$m(K^+e^+e^-)$ [MeV/c^2]
LHCb
9 fb^{-1}
R_{K^*} low-q^2
Data
Total
Signal
Combinatorial
Misidentification
Partially reconstructed
Counts / (32 MeV/c^2)
$m(K^+\pi^-e^+e^-)$ [MeV/c^2]

Steps to understand mechanics

Fully Open
Tomography at 450 GeV
(if aperture+impedance allows)

One half Open
Inspect Motion System
(if mechanically possible)

Partially Open
Data taking
(if motion system allows)

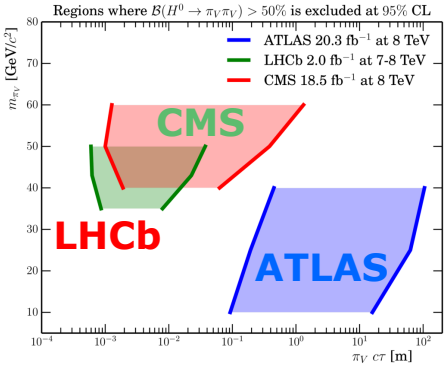


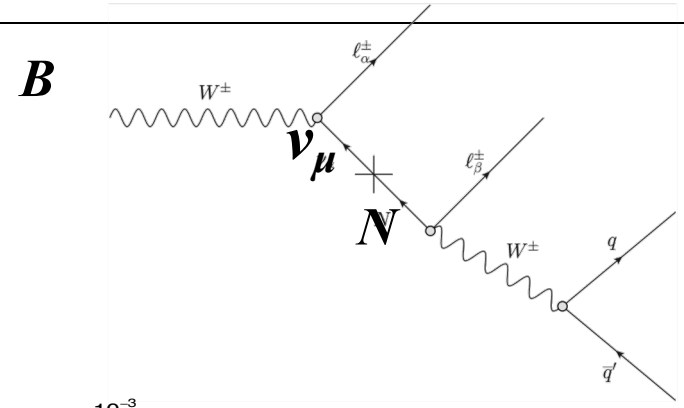
The RF box team at Nikhef

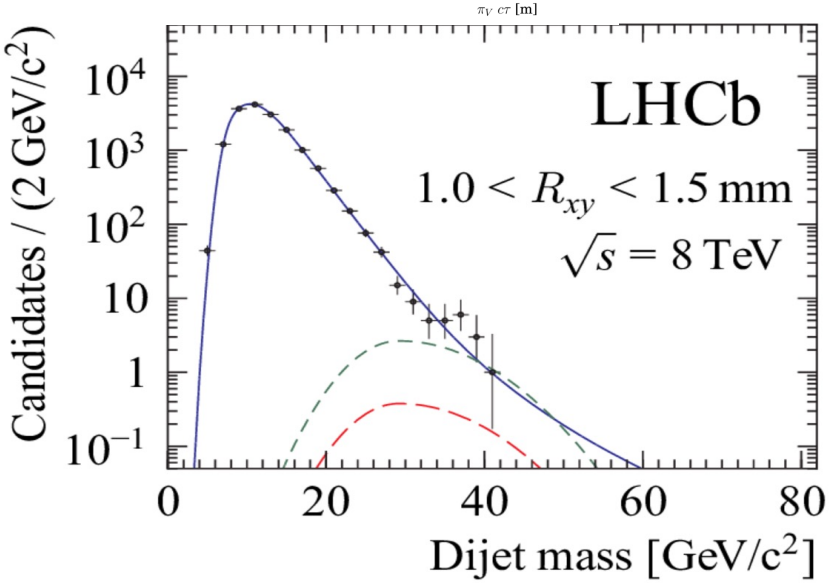
Physics at Nikhef: Long-living particles

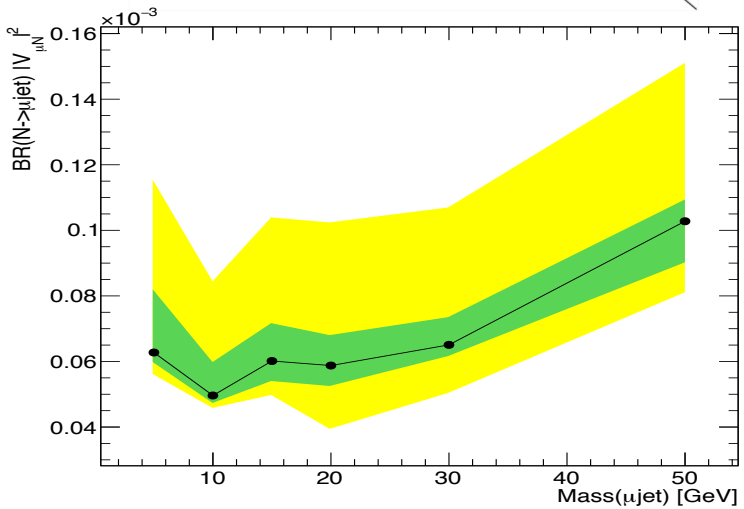
- Search for BSM LLP
  - LHCb unique coverage
  - LLP models accommodate DM candidates

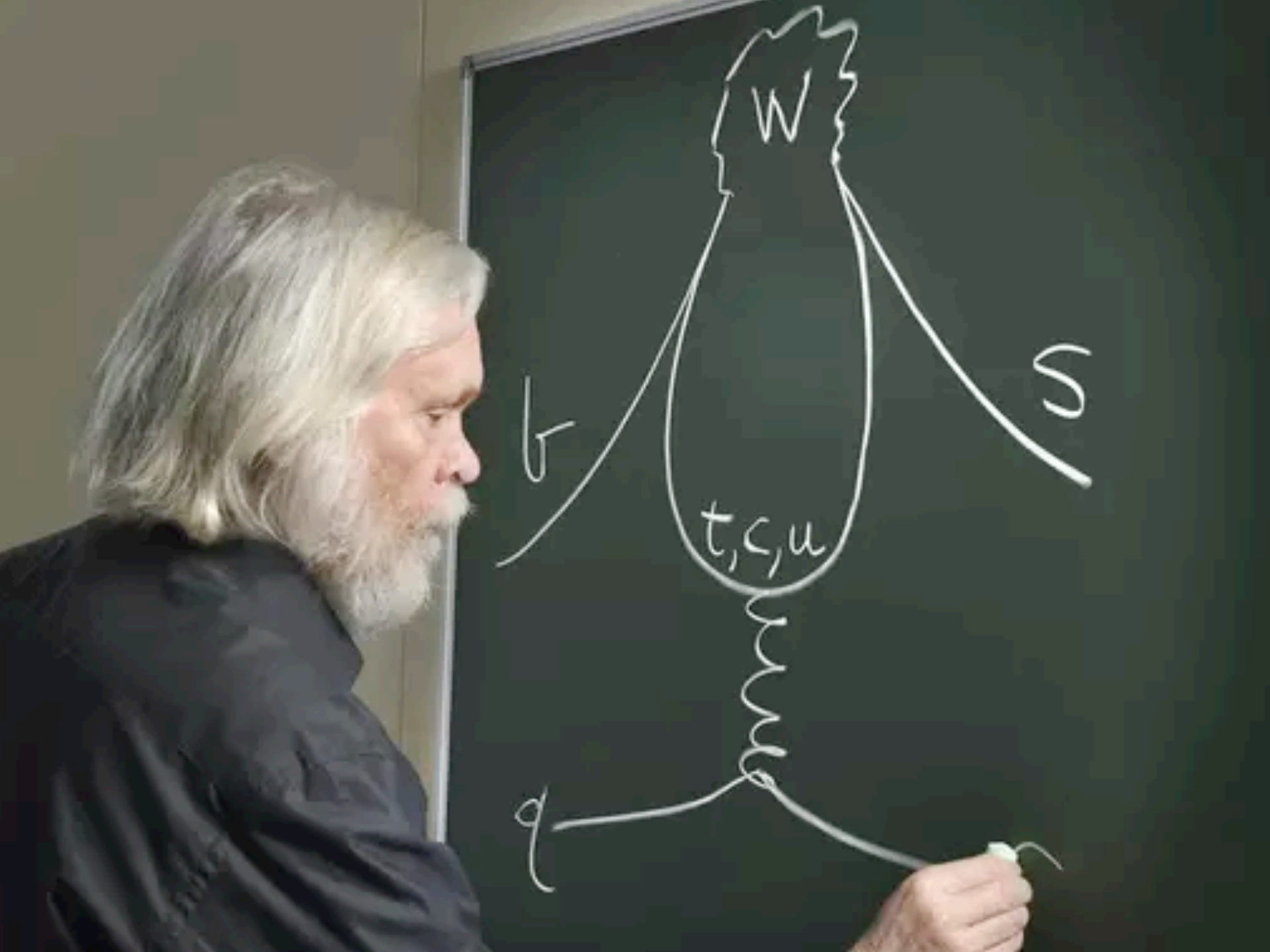
- Majorana ν in W decays
  - from ν-N mixing in B decays
  - competitive with LEP in run-3










W
b
s
t,c,u
q

Intermezzo: Effective couplings

- Effective coupling can be of various "kinds"
  - Vector coupling: C_9
  - Axial coupling: C_{10}
  - Left-handed coupling (V-A): C_9-C_{10}
  - Right-handed (to quarks): C_9', C_{10}', ...
  - ...

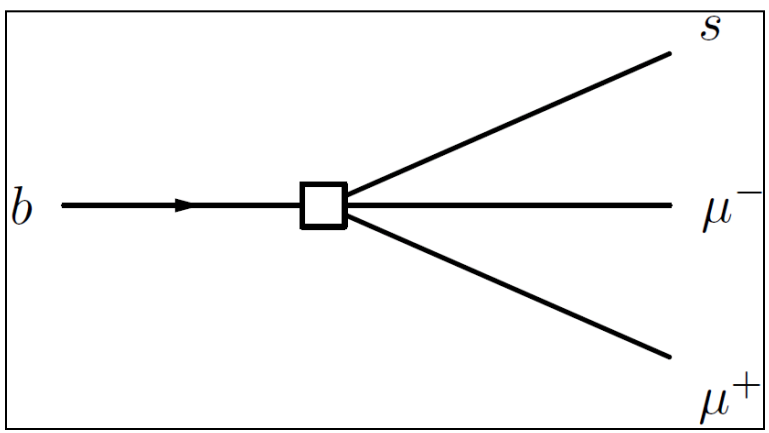
$$\mathcal{H}_{\rm eff} = \frac{G_{\rm F}}{\sqrt{2}} V_{\rm CKM} \sum_i C_i(\mu) Q_i$$

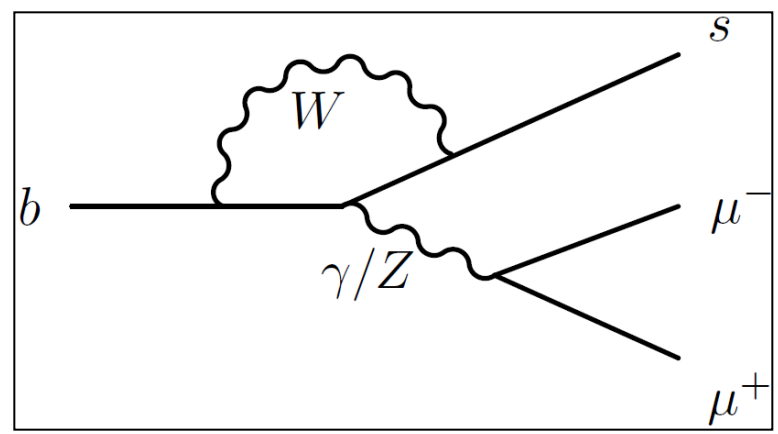
See e.g. Buras & Fleischer, hep-ph/9704376

Semi–Leptonic Operators (fig. 11f):

$Q_{9V} = (\bar{s}b)_{V-A}(\bar{\mu}\mu)_V \qquad Q_{10A} = (\bar{s}b)_{V-A}(\bar{\mu}\mu)_A$

- Analog: *Flavour-changing neutral current*





Intermezzo: Effective couplings

- C_7 (photon), C_9 (vector) and C_{10} (axial) couplings hide everywhere:

$$A_\perp^{L,R} \propto [(C_9^{eff} + C_9^{eff\prime}) \mp (C_{10}^{eff} + C_{10}^{eff\prime})\frac{V(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}(C_7^{eff} + C_7^{eff\prime})T_1(q^2)]$$

$$A_\parallel^{L,R} \propto [(C_9^{eff} - C_9^{eff\prime}) \mp (C_{10}^{eff} - C_{10}^{eff\prime})\frac{A_1(q^2)}{m_B + m_{K^*}} + \frac{2m_b}{q^2}(C_7^{eff} - C_7^{eff\prime})T_2(q^2)]$$

$$A_0^{L,R} \propto [(C_9^{eff} - C_9^{eff\prime}) \mp (C_{10}^{eff} - C_{10}^{eff\prime})] \times [(m_B^2 - m_{K^*}^2 - q^2)(m_B + m_{K^*}A_1(q^2) - \lambda\frac{A_2(q^2)}{m_B + m_{K^*}})] +$$
$$2m_b(C_7^{eff} - C_7^{eff\prime})[(m_B^2 + 3m_{K^*}^2 - q^2)T_2(q^2) - \frac{\lambda}{m_B^2 - m_{K^*}^2 T_3(q^2)}$$

$$F_L = \frac{A_0^2}{A_\parallel^2 + A_\perp^2 + A_0^2}$$

$$S_3 = \frac{A_\perp^{L2} - A_\parallel^{L2}}{A_\perp^{L2} + A_\parallel^{L2} + A_0^{L2}} + L \to R$$

$$S_4 = \frac{\Re(A_0^{L*}A_\parallel^L)}{|A_0^L|^2|A_\parallel^L|^2 + |A_0^L|^2} + L \to R$$

$$S_5 = \frac{\Re(A_0^{L*}A_\perp^L)}{|A_0^L|^2 + A_\perp^L|^2 + |A_0^L|^2} - L \to R$$

$$S_6 = \frac{\Re(A_\perp^{L*}A_\parallel^L)}{|A_\perp^L|^2 + |A_\parallel^L|^2 + |A_0^L|^2} - L \to R = \frac{4}{3}A_{FB}$$

$$S_7 = \frac{\Im(A_0^{L*}A_\parallel^L)}{|A_0^L|^2 + |A_\parallel^L|^2 + |A_0^L|^2} + L \to R$$

$$S_8 = \frac{\Im(A_0^{L*}A_\perp^L)}{|A_0^L|^2 + |A_\parallel^L|^2 + |A_0^L|^2} + L \to R$$

$$S_9 = \frac{\Im(A_\perp^{L*}A_\parallel^L)}{|A_\perp^L|^2 + |A_\parallel^L|^2 + |A_0^L|^2} - L \to R$$

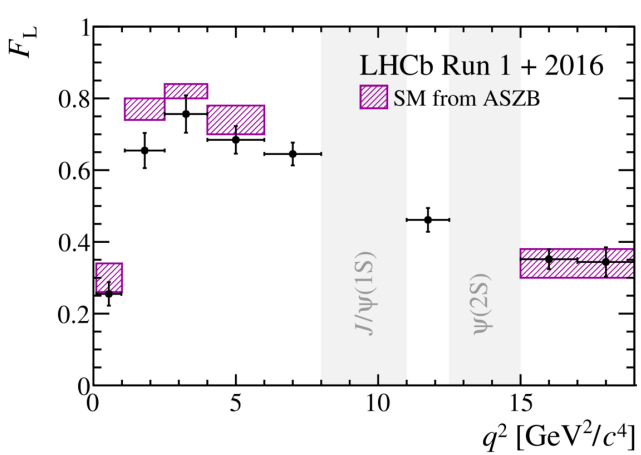
$$\frac{1}{\Gamma}\frac{d^3(\Gamma + \bar{\Gamma})}{d\cos\theta_\ell\, d\cos\theta_K\, d\phi} = \frac{9}{32\pi}\Big[\frac{3}{4}(1 - F_L)\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1}{4}(1 - F_L)\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_L\cos^2\theta_K\cos 2\theta_\ell +$$
$$S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi + S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi +$$
$$S_5\sin 2\theta_K\sin\theta_\ell\cos\phi + S_6^s\sin^2\theta_K\cos\theta_\ell +$$
$$S_7\sin 2\theta_K\sin\theta_\ell\sin\phi +$$
$$S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$

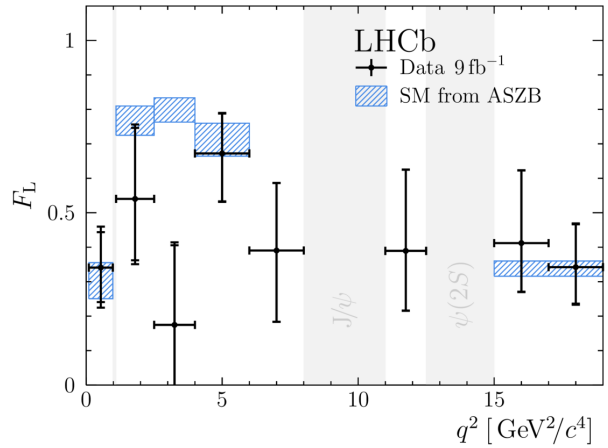
Coherent pattern

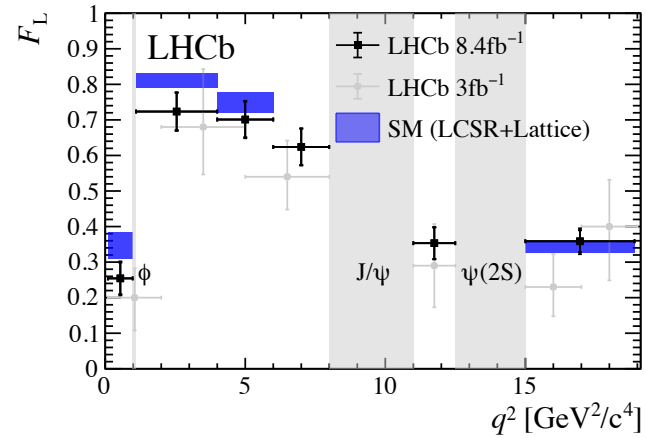
arXiv:2003.04831: $B^0 \to K^{*0}\mu^+\mu^-$

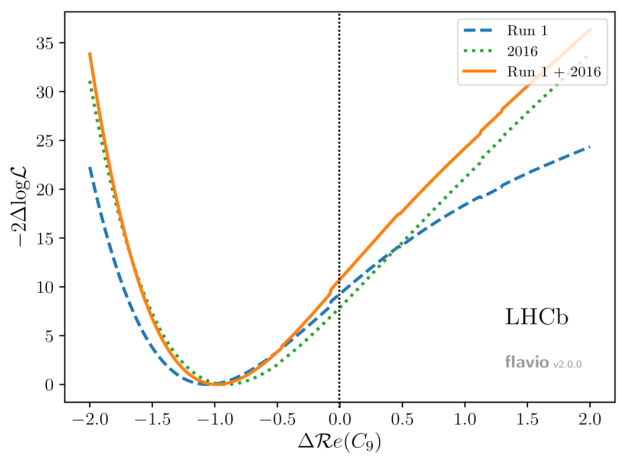
arXiv:2012.13241: $B^+ \to K^{*+}\mu^+\mu^-$

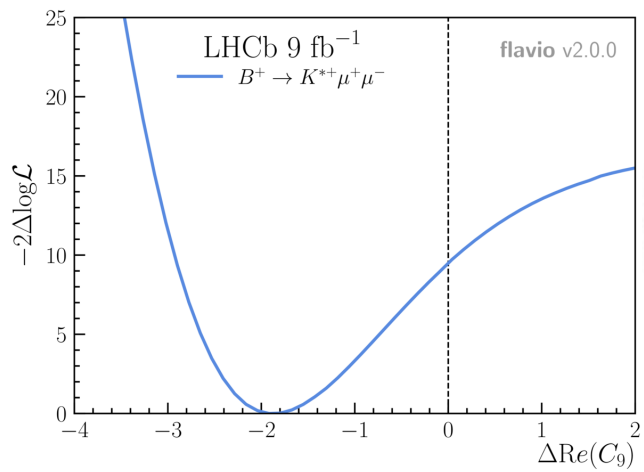
arXiv:2107.13428: $B^0_s \to \phi\mu^+\mu^-$

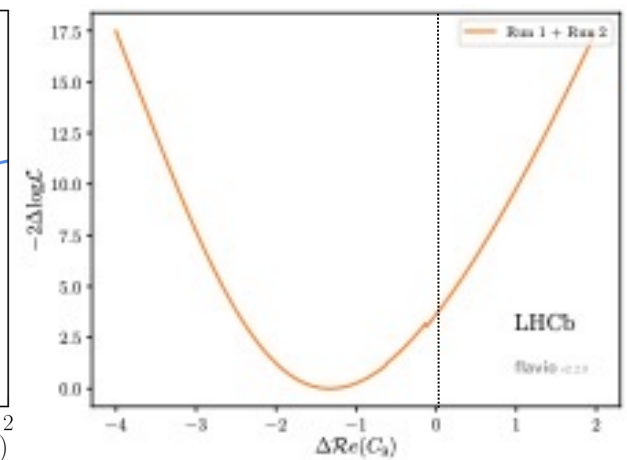


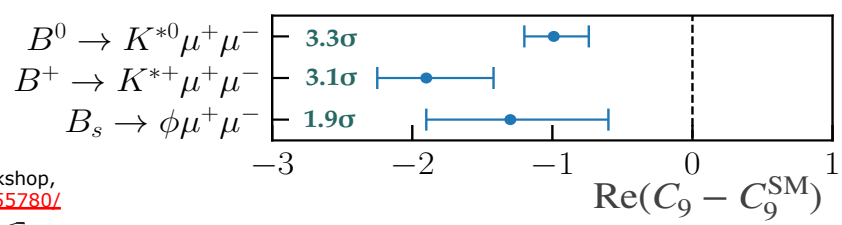








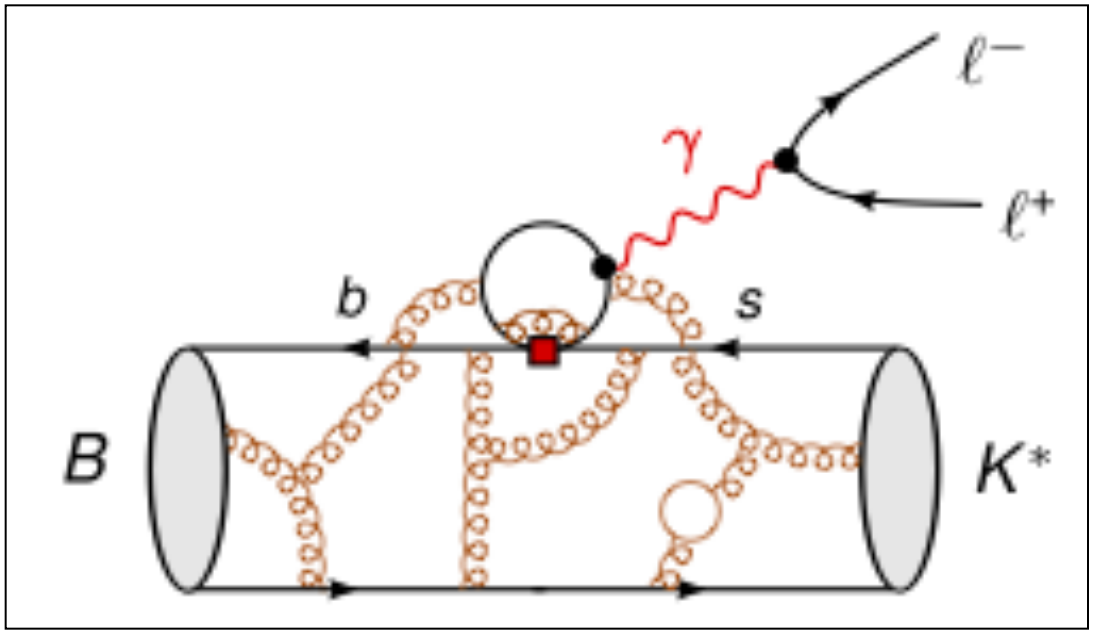


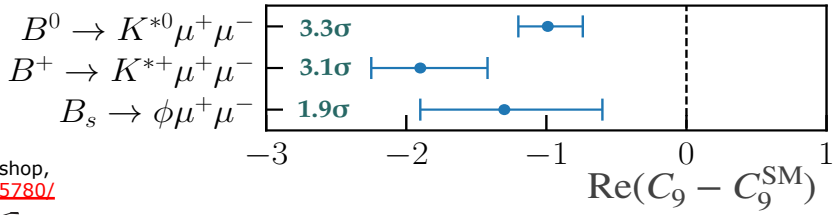


From: Martino Borsato, Flavour Anomaly Workshop, 20 Oct 2021, https://indico.cern.ch/event/1055780/

Coherent pattern

- Charm loop effects could also cause a shift in C_9





From: Martino Borsato, Flavour Anomaly Workshop, 20 Oct 2021, https://indico.cern.ch/event/1055780/

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