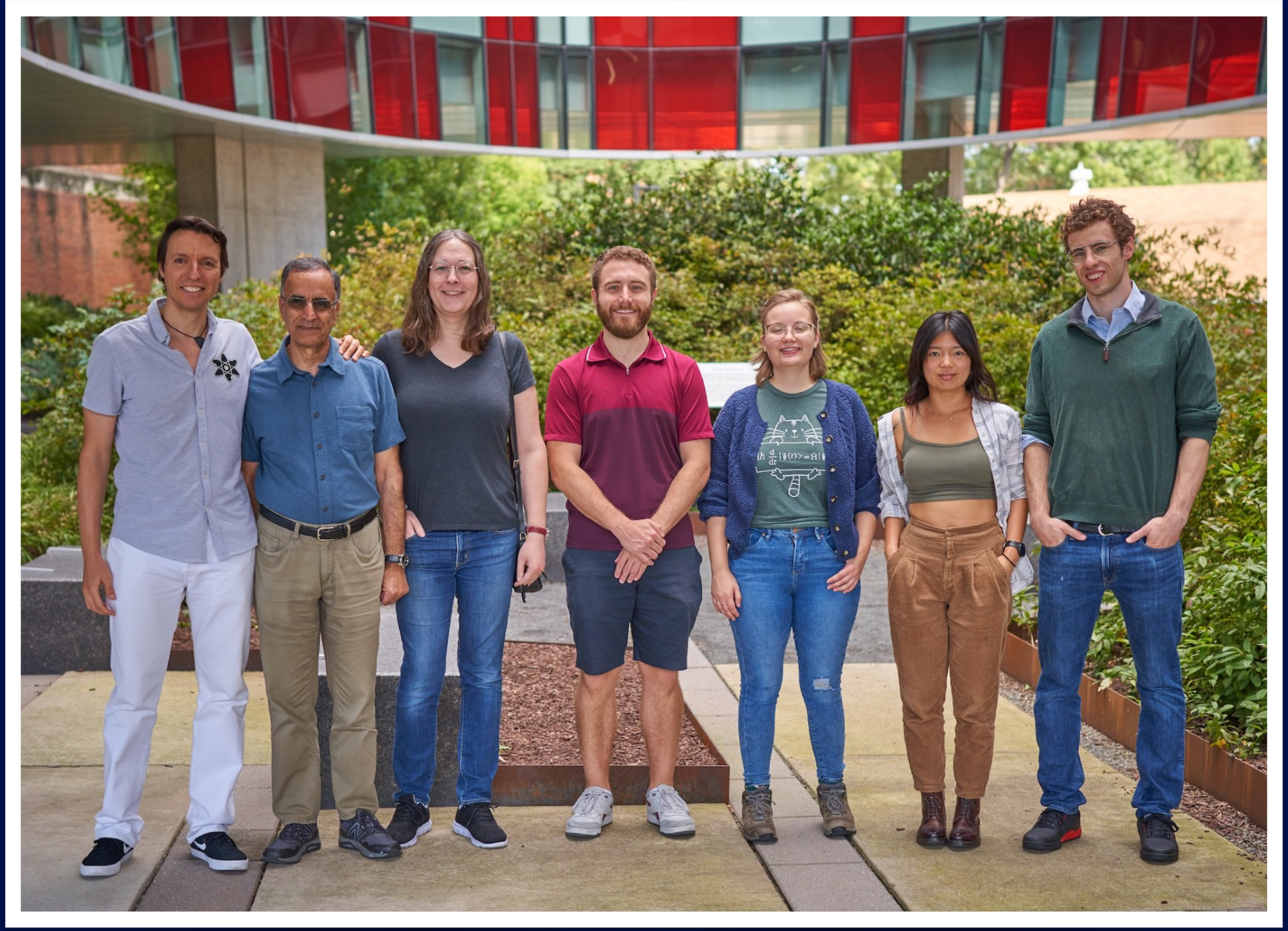
The LHCb experiment @ UMD



Manuel Franco Sevilla
University of Maryland

19th April 2025
Quarknet @ UMD
kickoff event

Quick bio

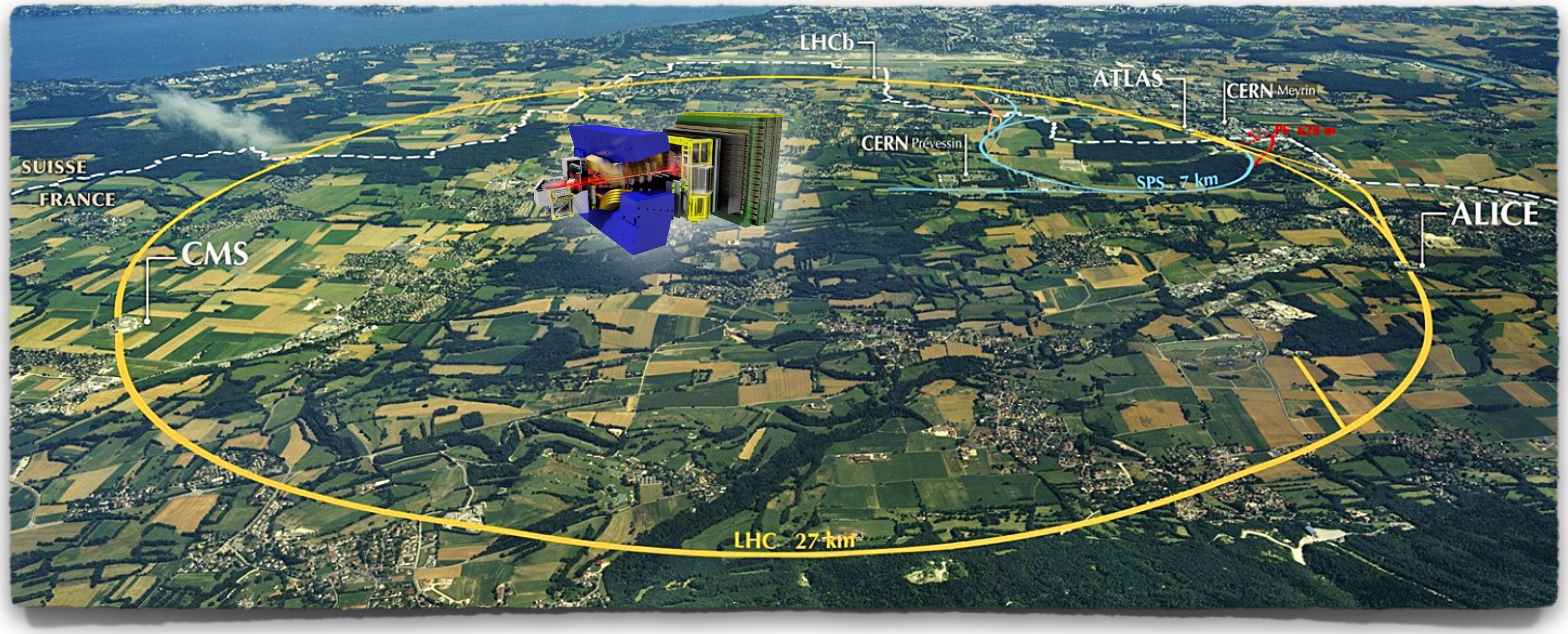
Physics PhD at Stanford on **BaBar** experiment (**SLAC**)

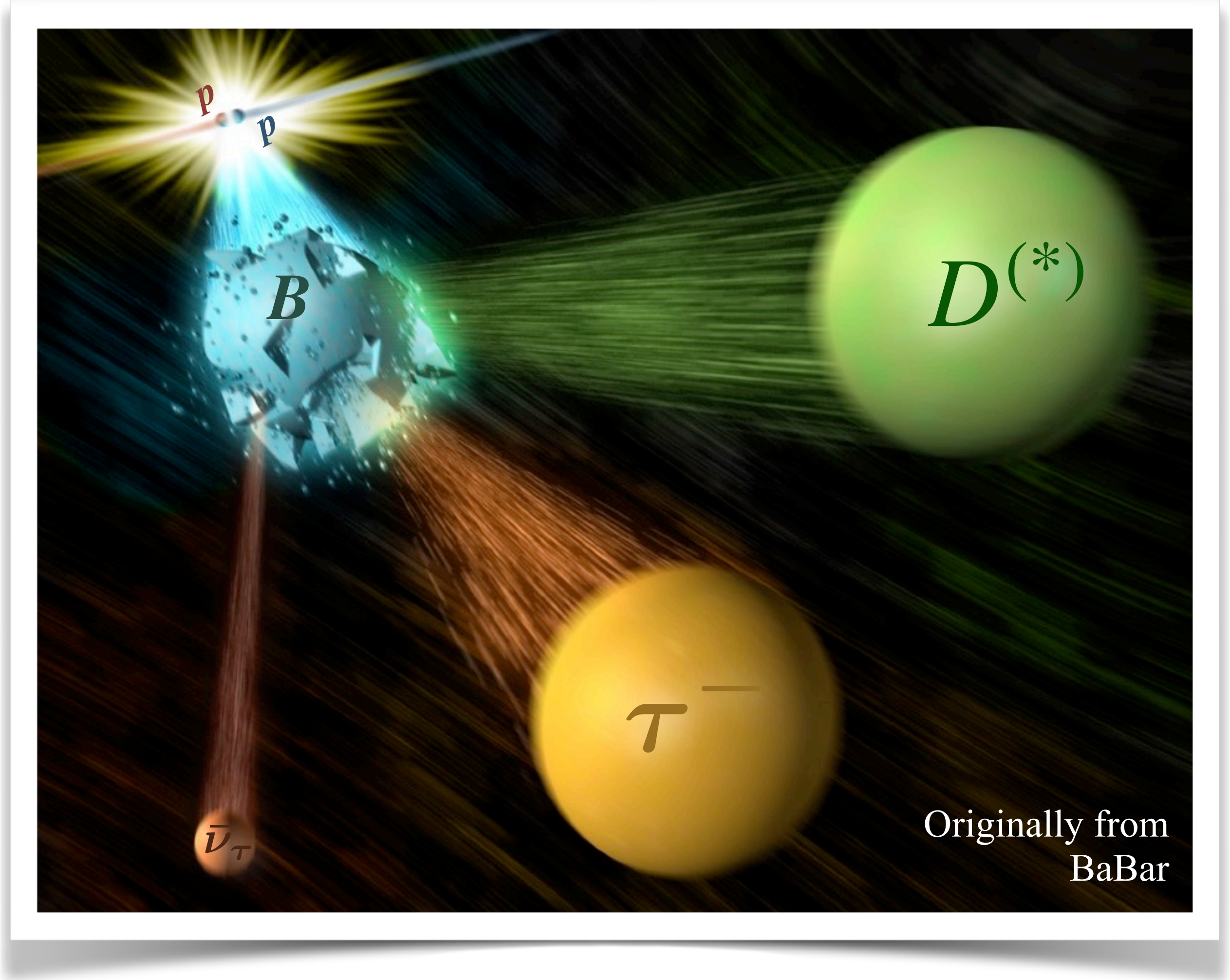
First evidence for **Lepton Flavor Universality violation (LFUv) in $B \to D^{(*)}\tau^-\nu_\tau$ decays**

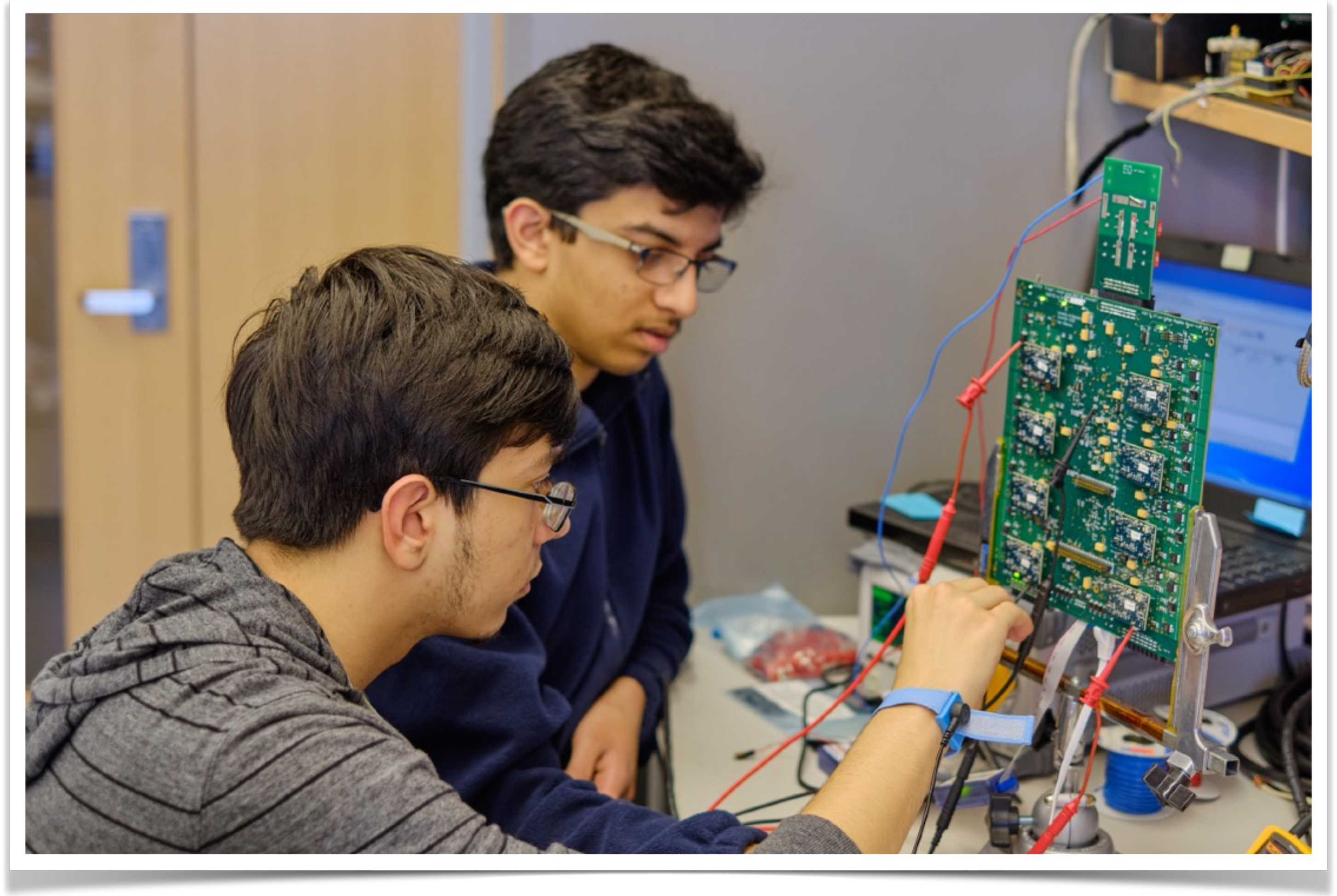
Search for **Supersymmetry** at **CMS**

Search for **LFUv** at **LHCb**

Grew up and studied electromechanical engineering in **Spain**







- The **LHC** and the **LHCb** **experiment**
- **LHCb physics @ UMD**
  - **CP violation**
  - **Search** for **Lepton Flavor Universality violation**
- **LHCb detector development @ UMD**
  - **Construction** and **installation** of the **Upstream Tracker**

Please, interrupt me as much as you like!

Quick history of Fundamental Physics

Ultraviolet catastrophe	$\boxed{E = h\nu \rightarrow \text{Quantum physics}}$	*General Relativity*	*Positron discovery*		*Particle zoo*	**Standard Model of particle physics** (boxed)				*LHC* →		
Maxwell equations	*Michelson-Morley experiment*	*Special Relativity*	*Schrödinger equation*	*QED*	*Higgs mechanism*	*QCD*	*Neutrino masses*	*Higgs discovery*				

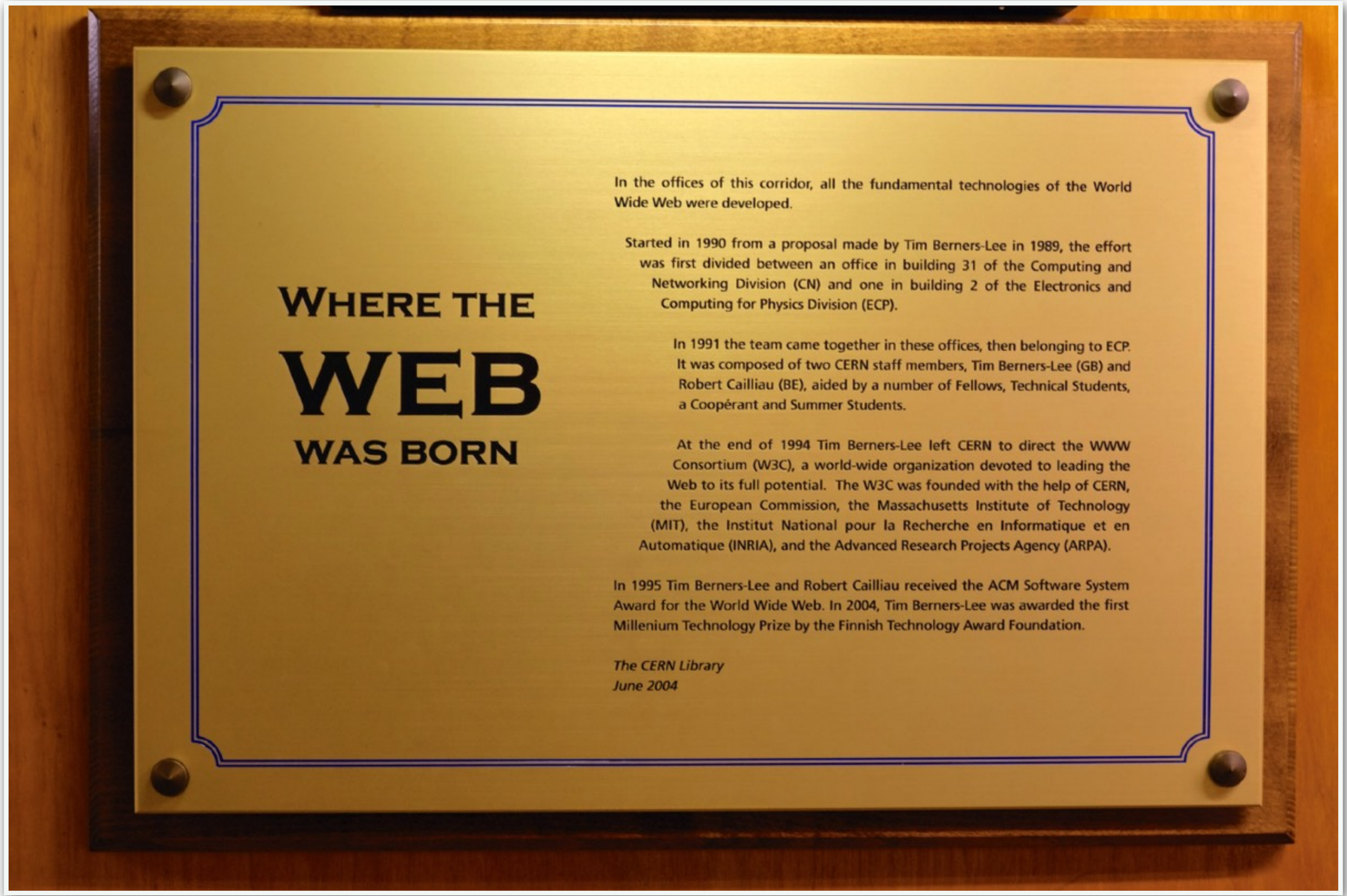
XIX century	XX century	XXI century
Classical Physics	Modern Physics	

Explosive growth **culminating** in the **SM of particle physics** (and GR)

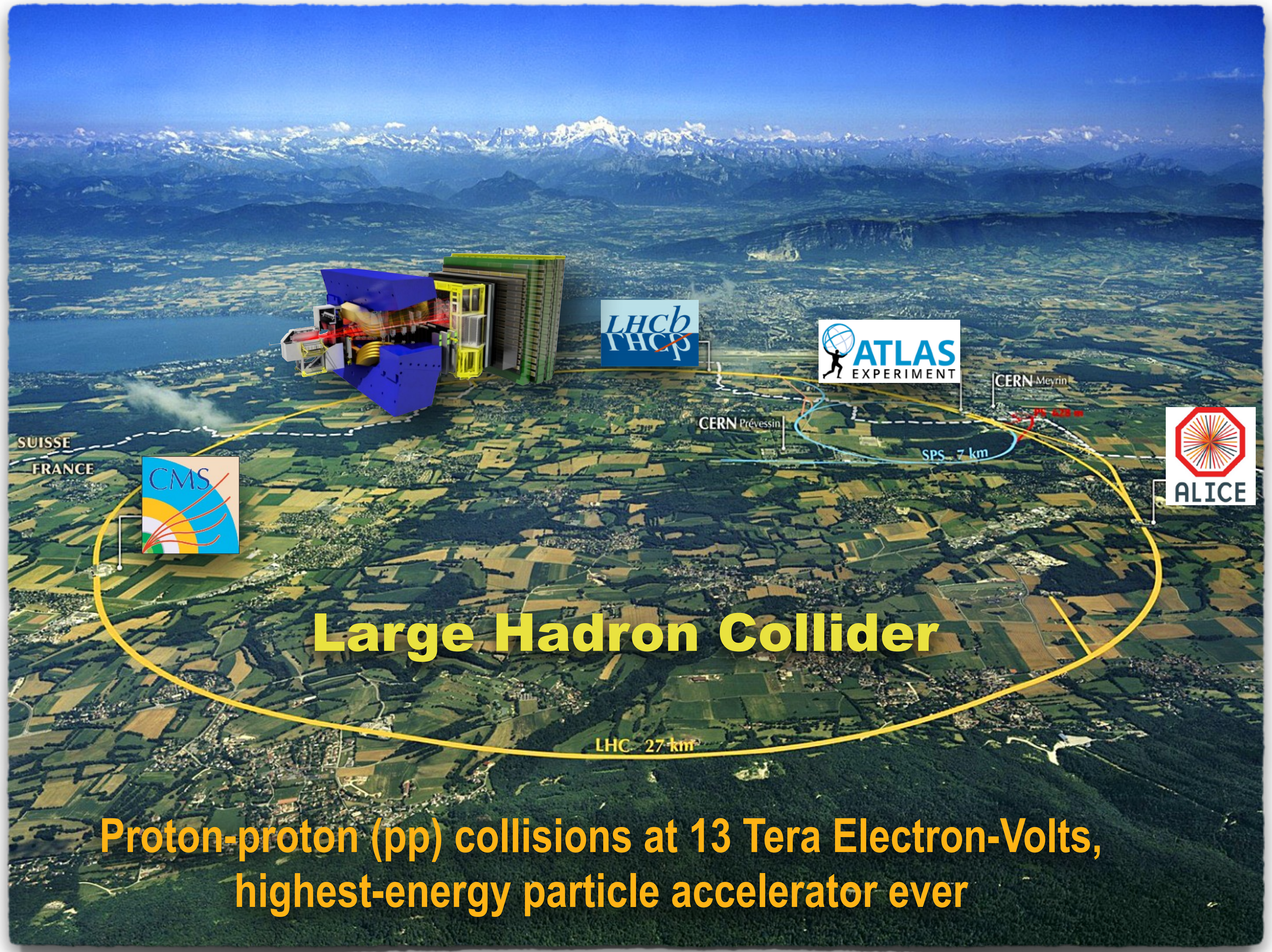
With the **LHC** we aim to **go beyond**

Proposal for the WWW

For the LHC at CERN, 1989

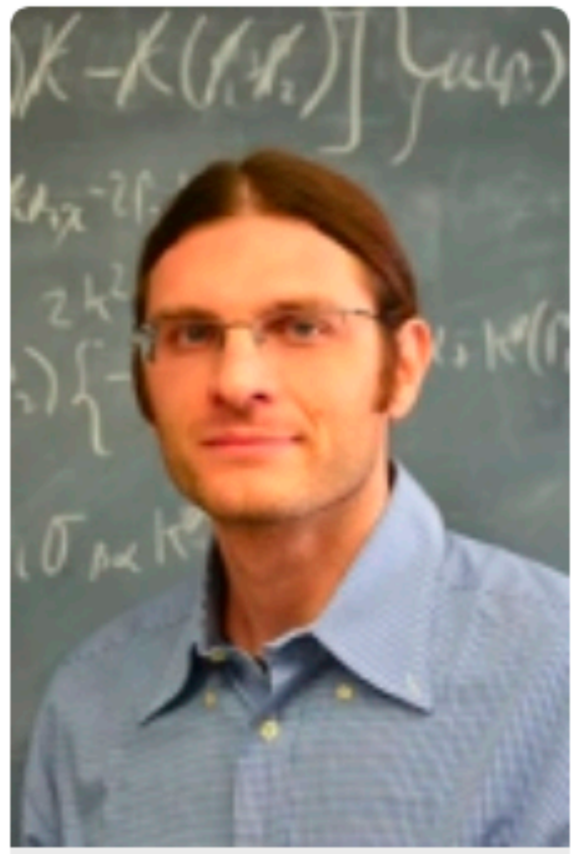


The Large Hadron Collider



- **27 km** rings **colliding protons**
  - CERN laboratory in Geneva, Switzerland
- ATLAS and CMS
  - Discovered **Higgs boson** in 2012
  - **Direct searches** for **new physics**
- LHCb
  - **Precision flavor measurements**
  - **Indirect searches** for **new physics**
- Alice
  - **Heavy ion** measurements
  - Focus on **quark-gluon plasma**

Baden, Andrew



Belloni, Alberto

Eno, Sarah

Palmer, Christopher

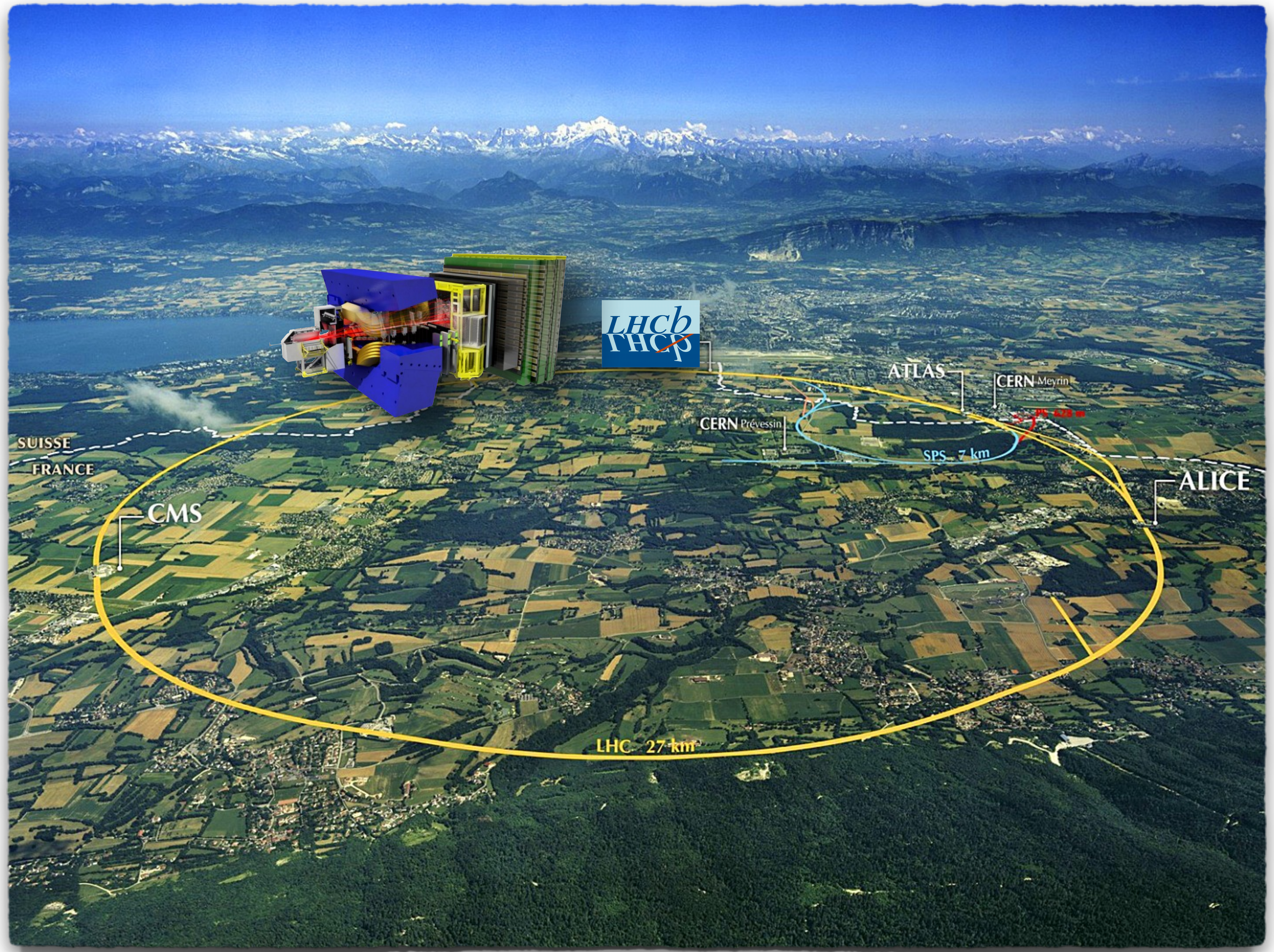
Skuja, Andris

Franco Sevilla, Manuel

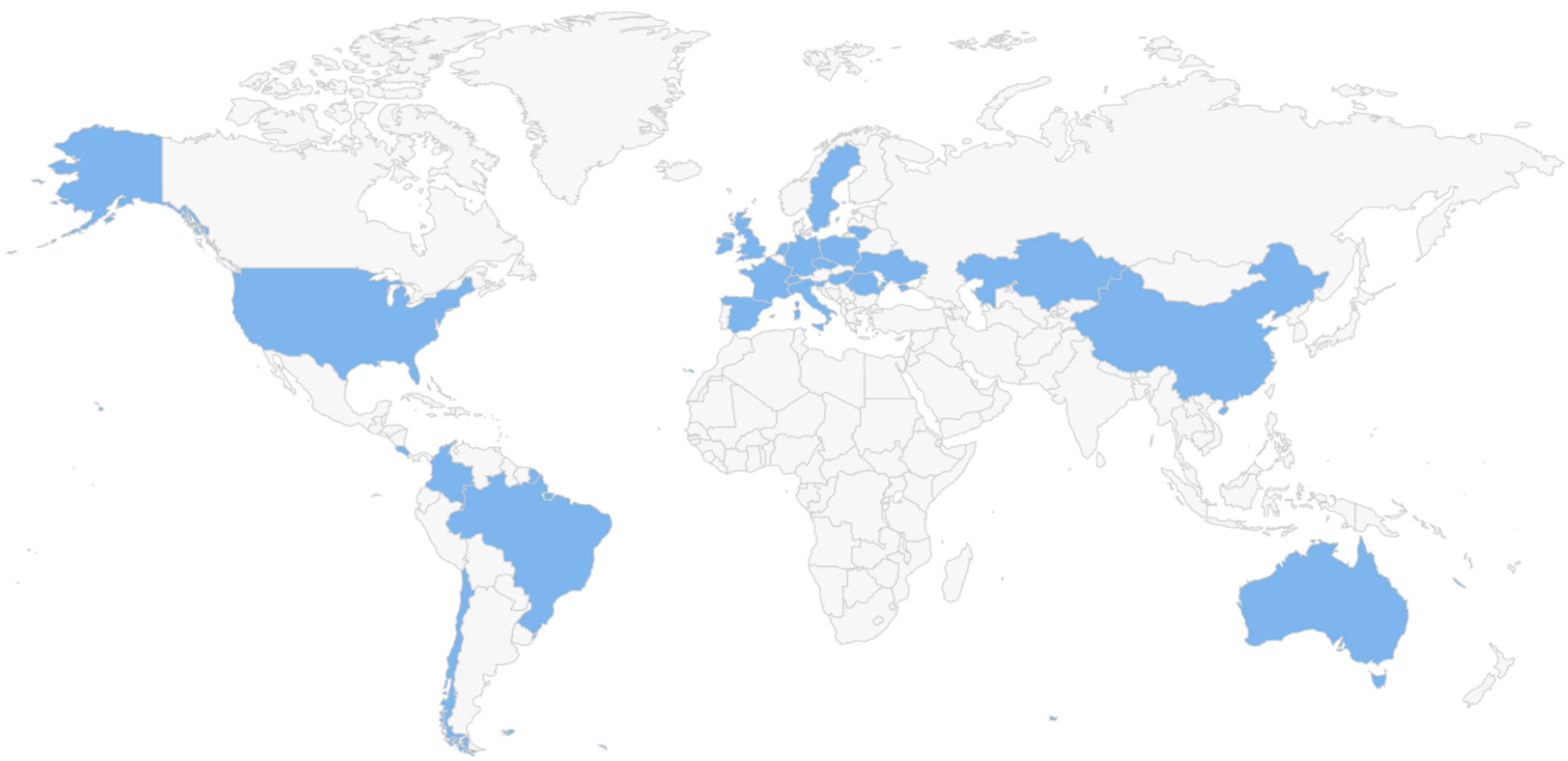
Jawahery, Abolhassan

Hamilton, Phoebe

LHCb collaboration

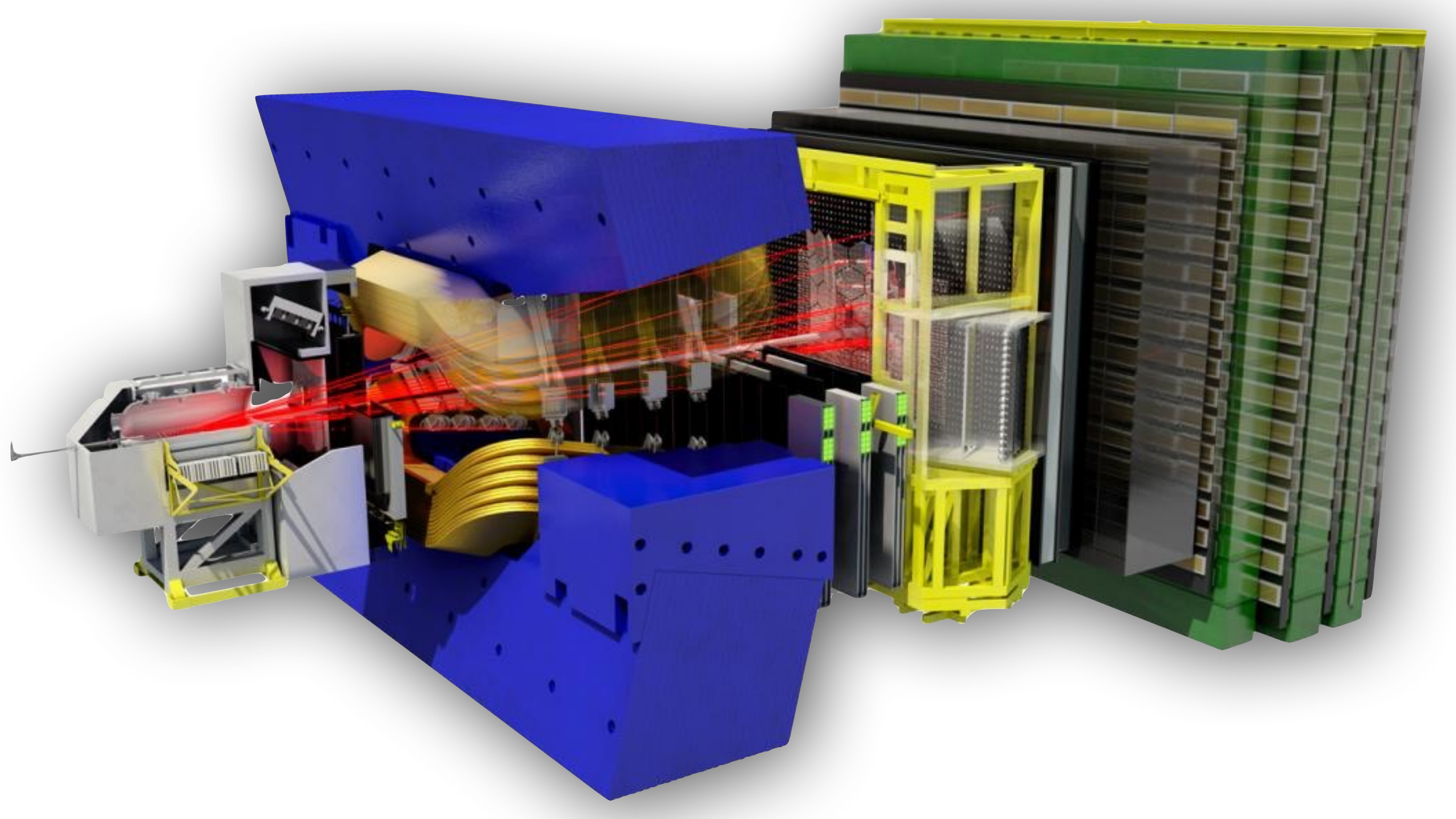


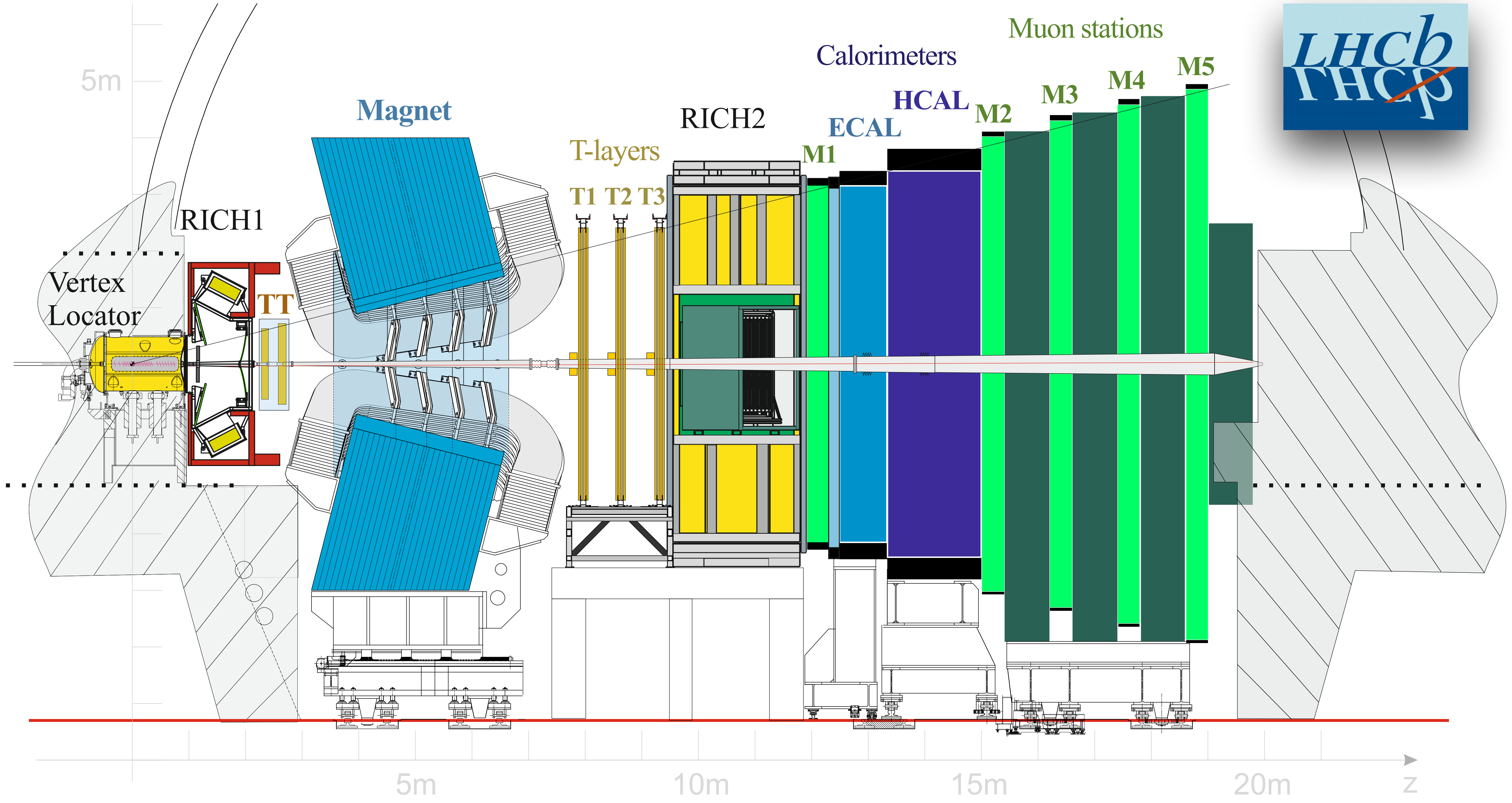
- **A large collaboration**
  - 24 countries, 101 institutes, 1782 members



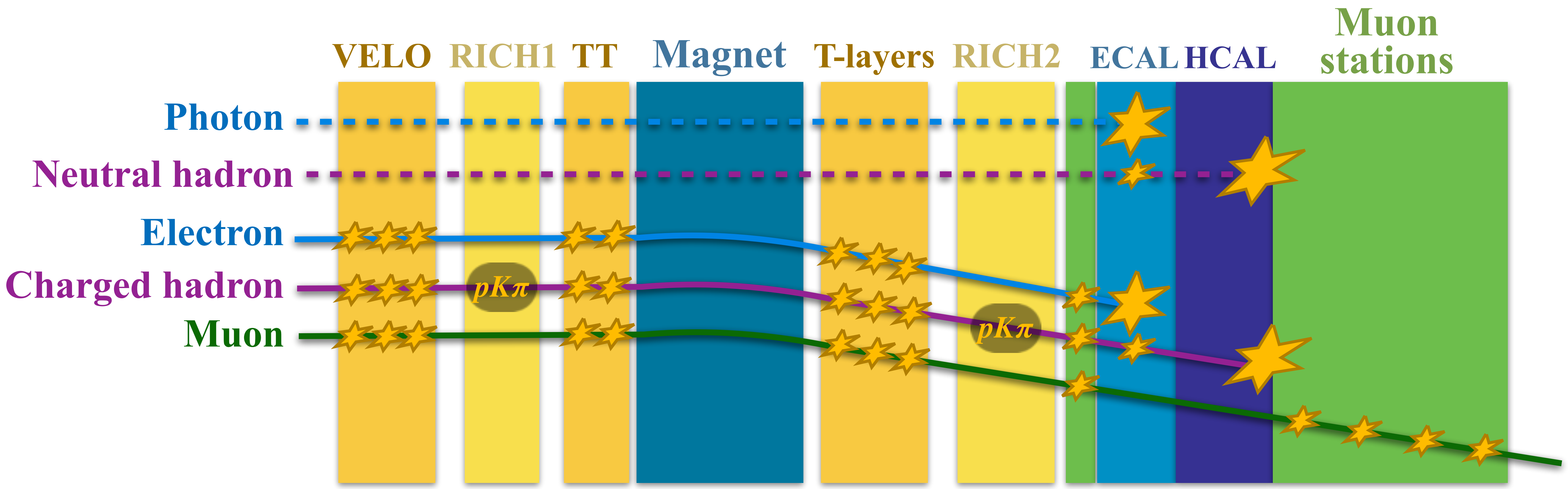
- **US participation**
  - Currently 8 institutes, 86 members
    - **NSF**: Cincinnati, Maryland, MIT, Syracuse
    - **DOE/NSF nuclear**: Los Alamos, Kent state, Michigan, Ohio State

The LHCb detector

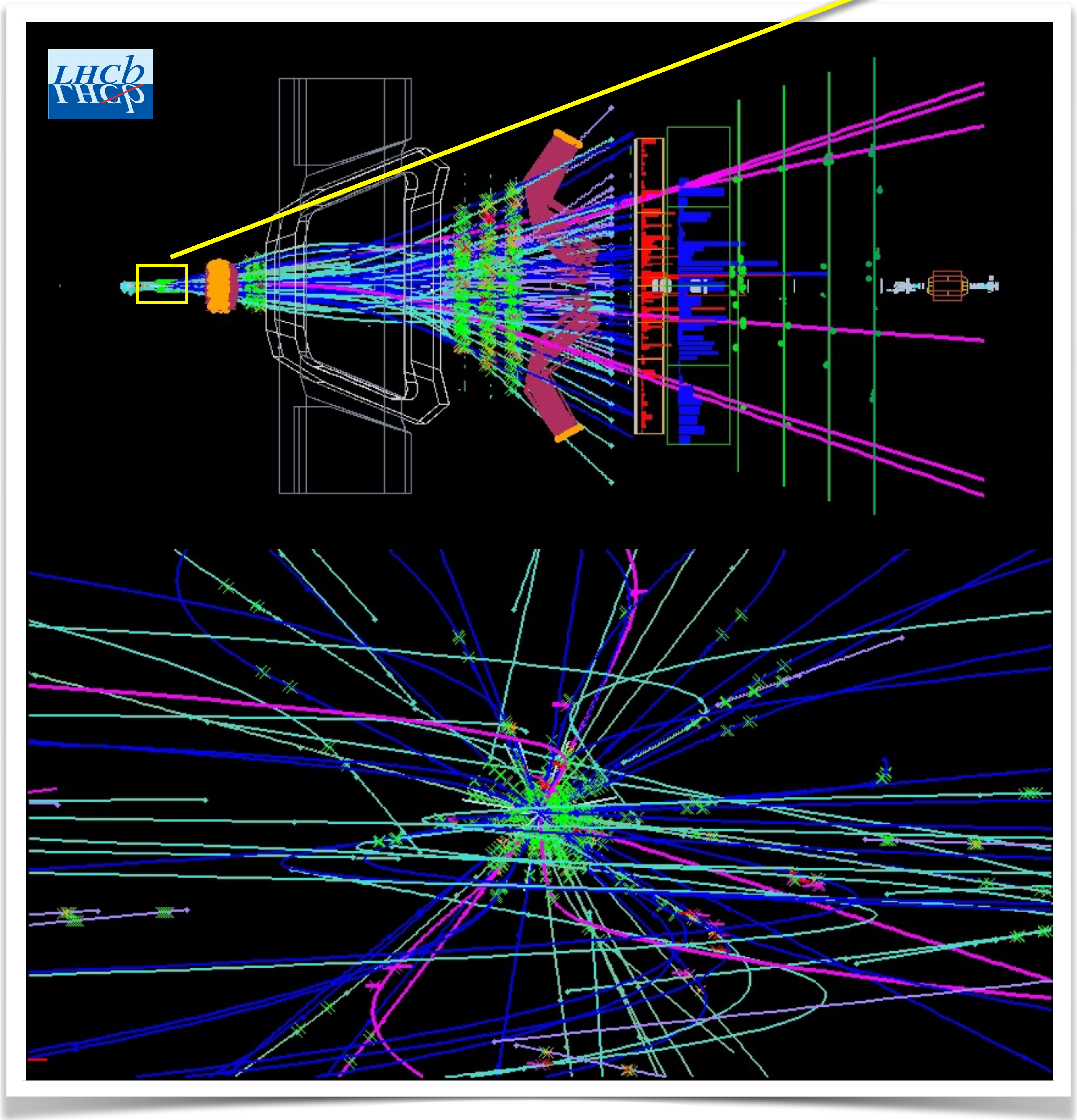


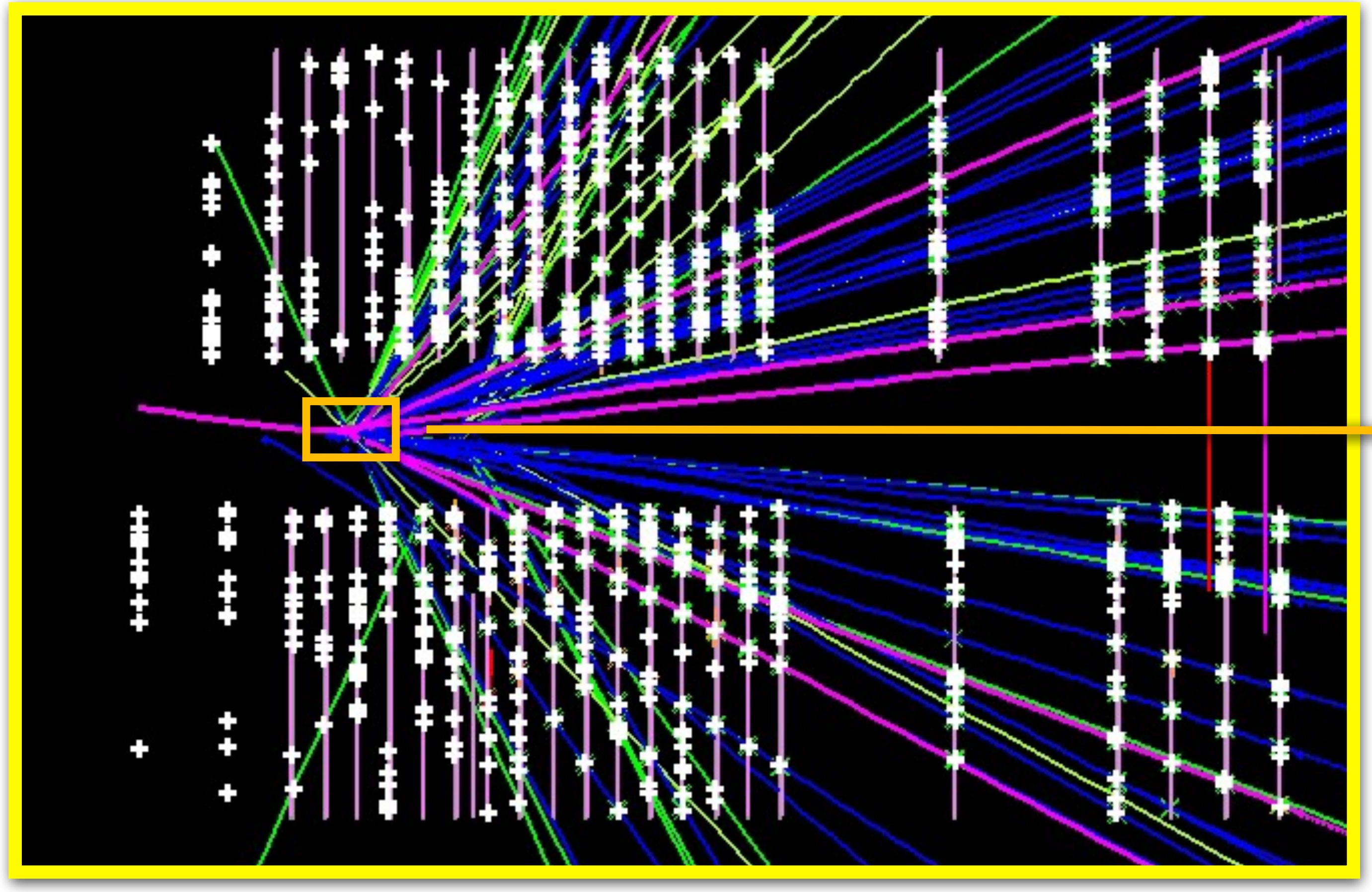


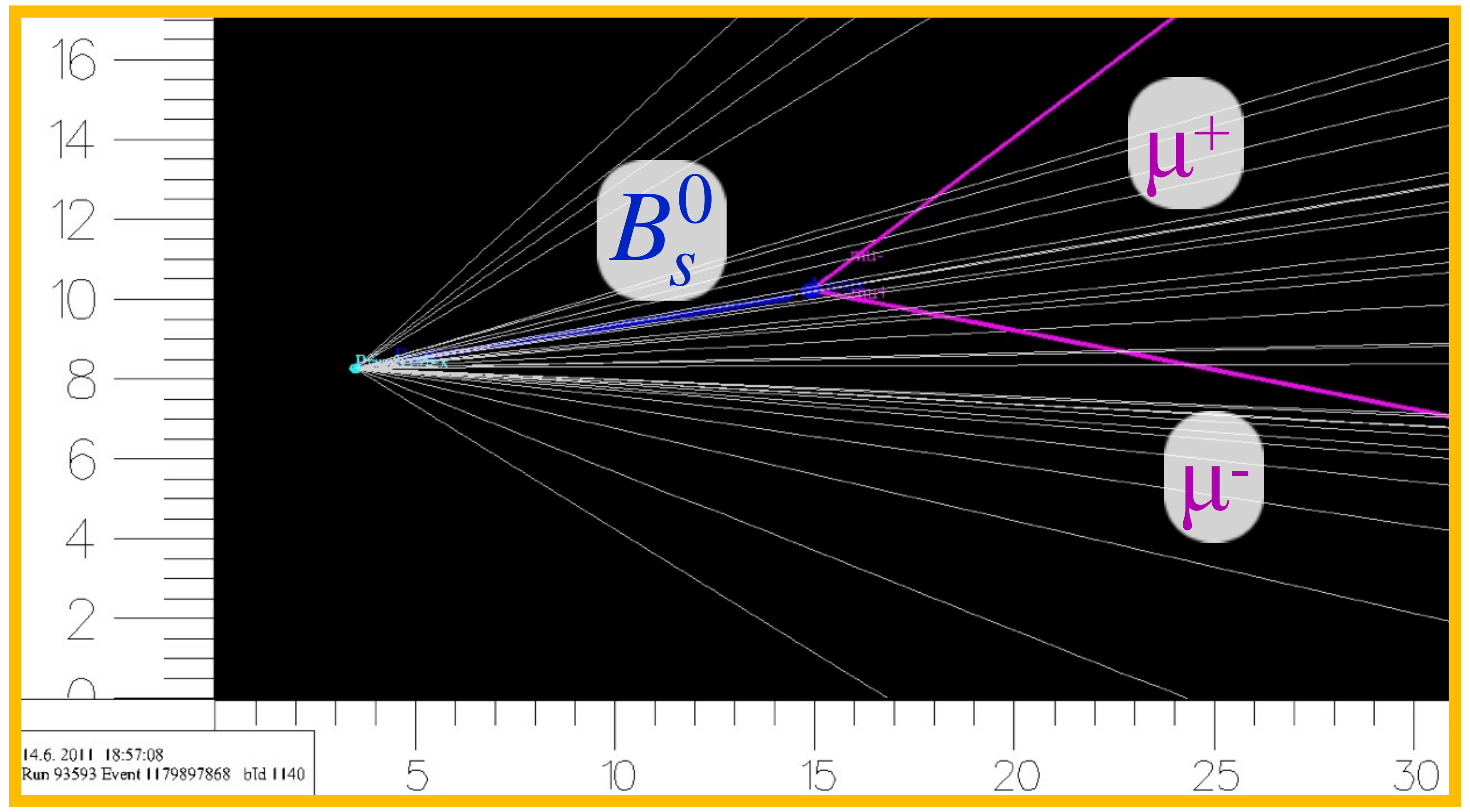
- **Many layers** to **detect different particles**
  - **Neutral particles** only seen in **calorimeters**
  - **Charged** particles leave **charge deposits** in **trackers**
    - **Momentum** from **magnet bending**
  - **Muon station** are trackers **shielded by steel**



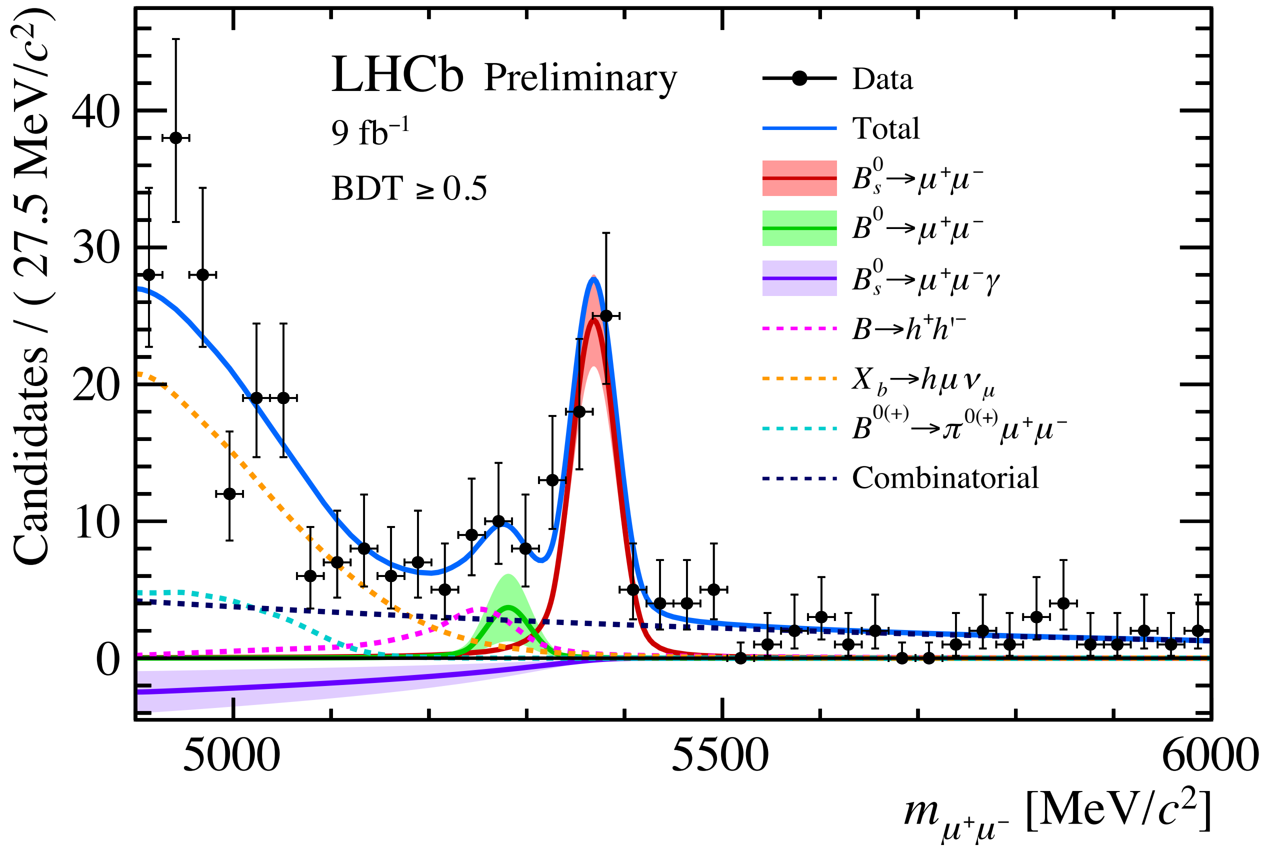
Vertexing is key to LHCb





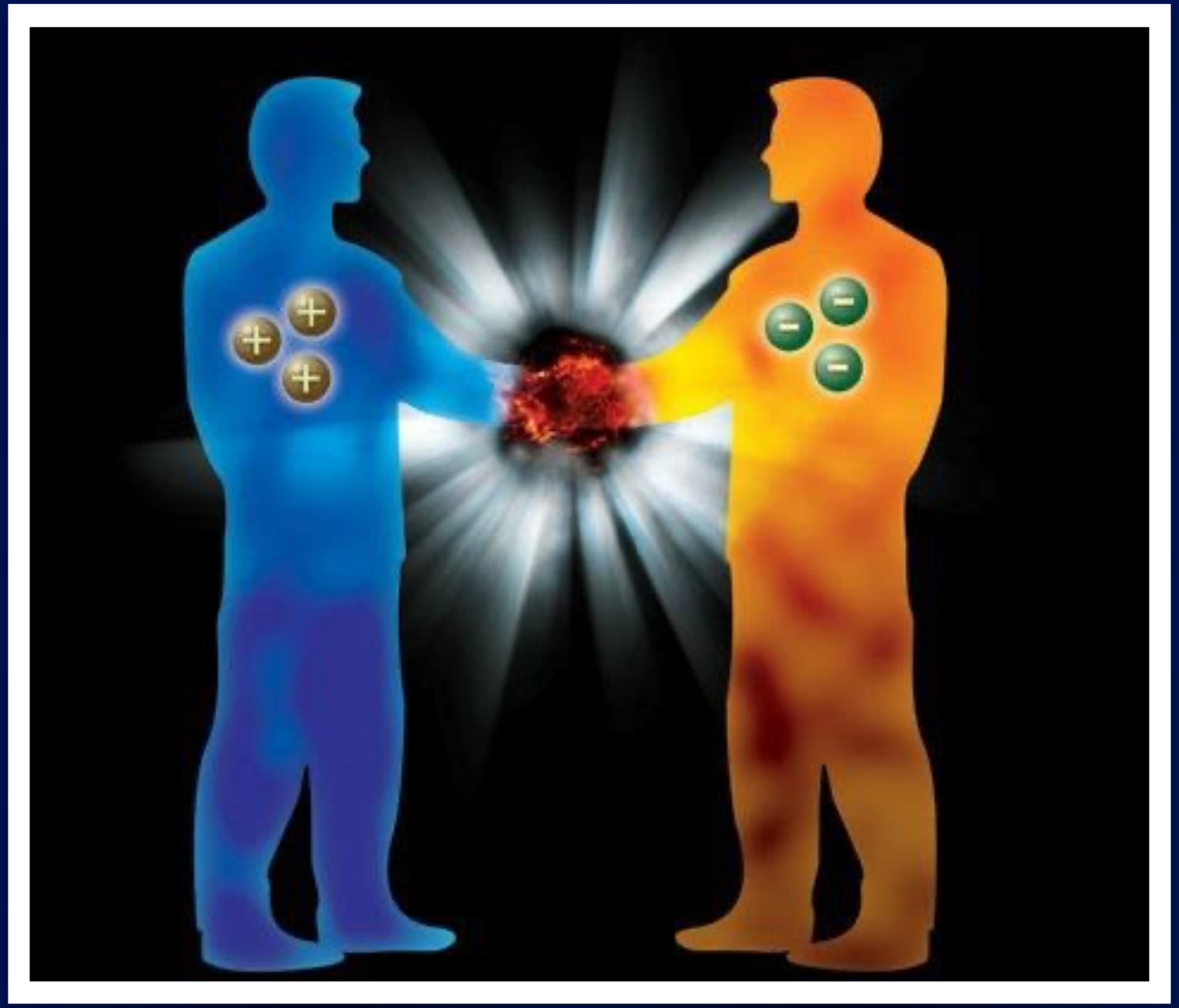


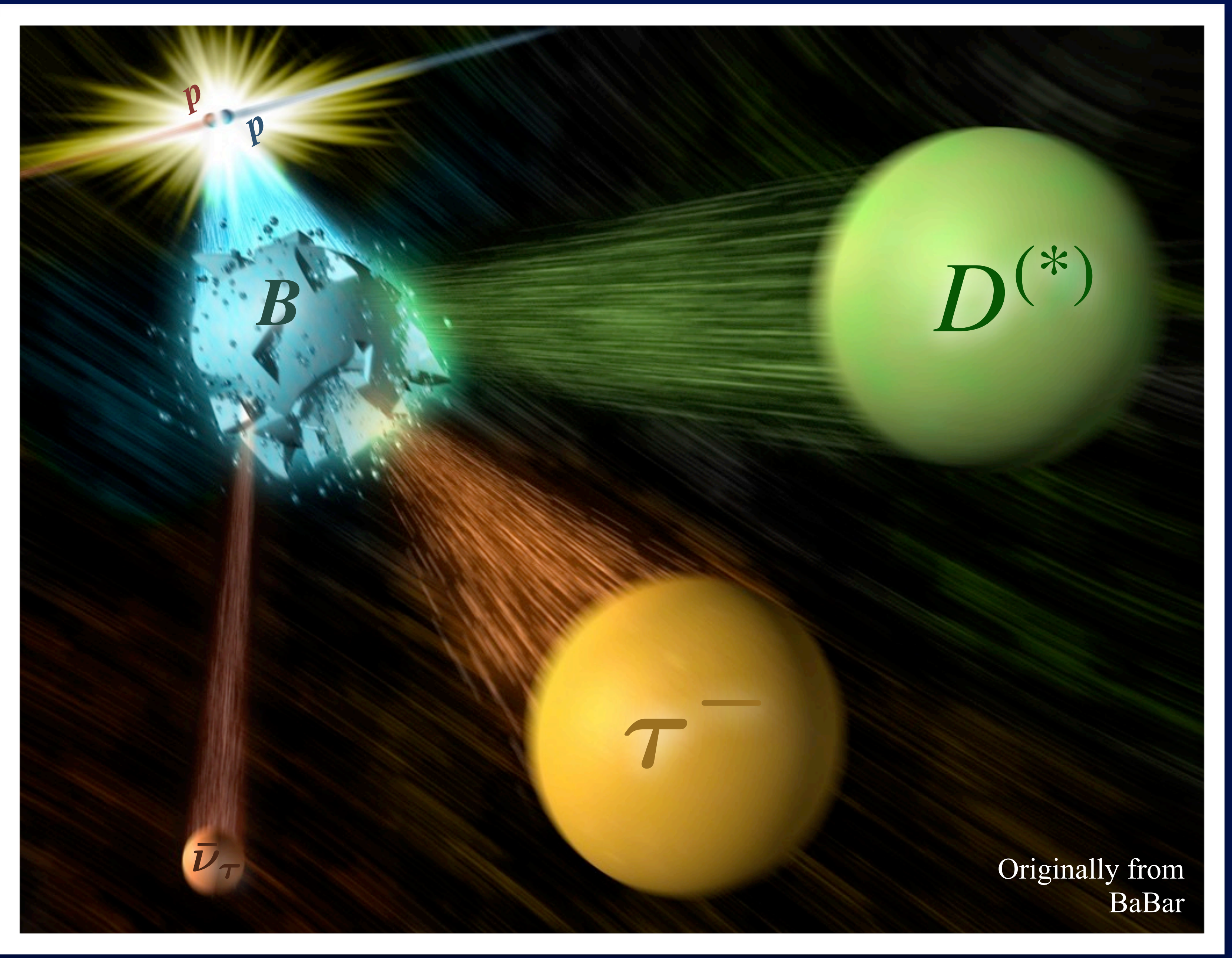
- **B mesons lifetime** is ~10^{-12} s
  - ➡ Most other particles have ~10^{-21} s
- They **can fly cms** before decaying thanks to **large speed** and **time dilation**
- **Superb vertexing** by VELO
  - ➡ Can reconstruct decay vertices with 13 μm resolution in transverse plane



$$pp \to X_b B_s^0 X$$
$$B_s^0 \to \mu^+\mu^-$$

Analysis of LHCb data @ UMD



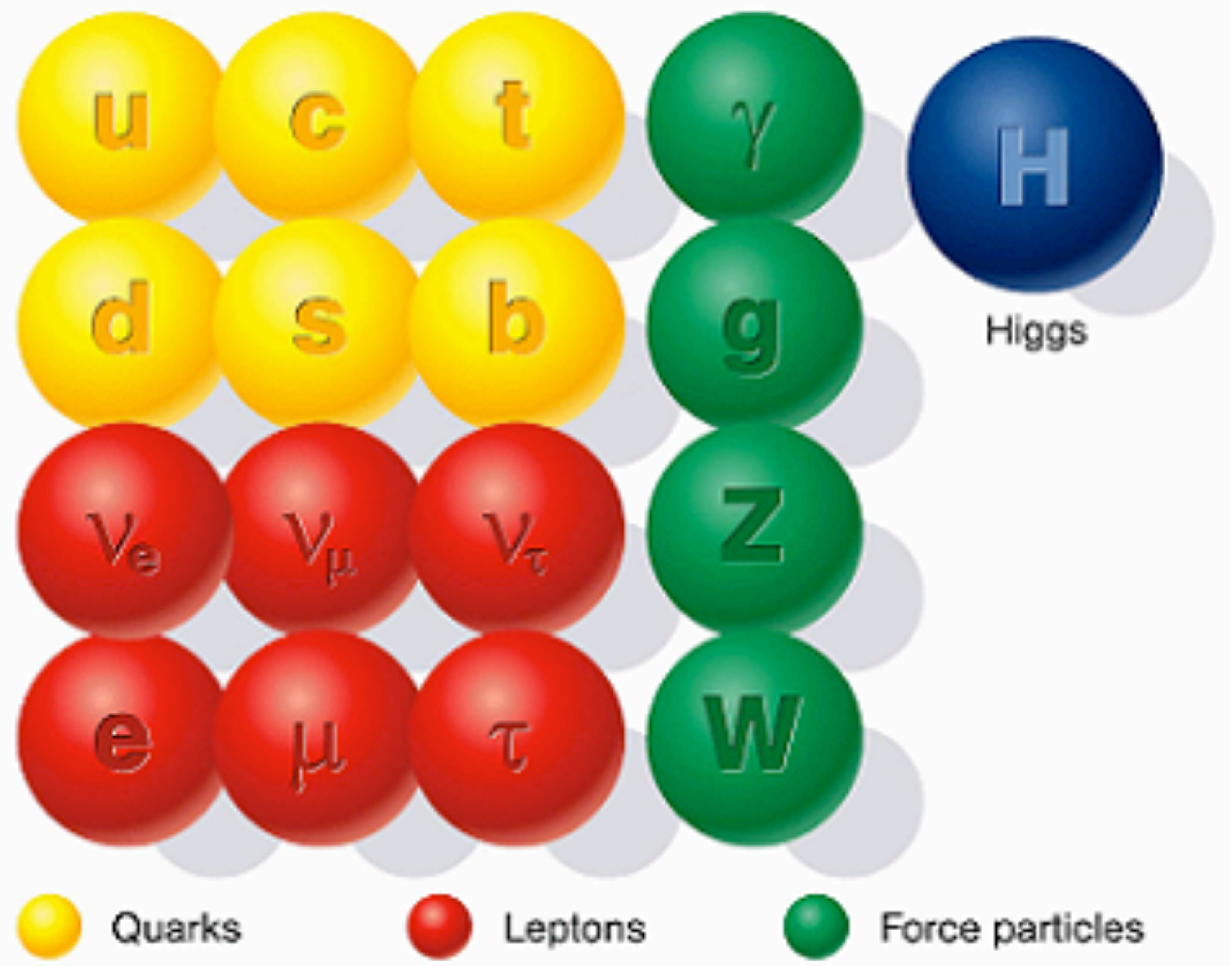


The Standard Model: great but not enough

$$SU(3) \times SU(2)_L \times U(1)$$

symmetry

+



cokada / Getty Images/iStockphoto

Duke

englandlogistics

VMU

Most precise and **comprehensive theory** in the **history of mankind**

$$\left.\frac{g_e - 2}{2}\right|_{\mathrm{SM}} = 0.001\ 159\ 652\ 181\ 606\,(230)$$

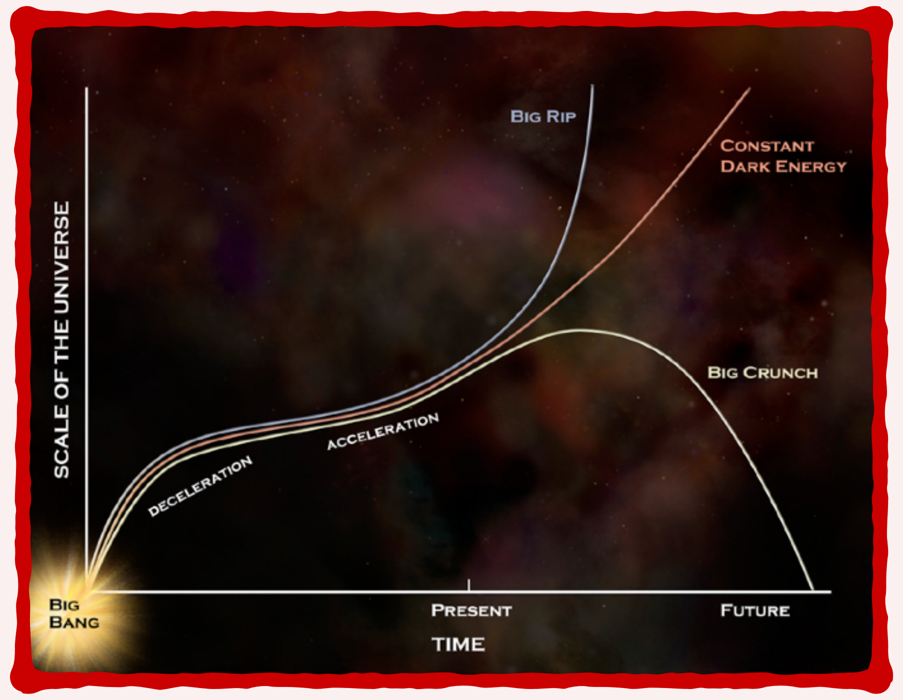
Atoms 7, 28 (2019)

$$\left.\frac{g_e - 2}{2}\right|_{\mathrm{exp}} = 0.001\ 159\ 652\ 180\ 73\,(28)$$

Phys. Rev. Lett. 100, 120801 (2008)

NASA/STScI; ESO WFI; Magellan/U.Arizona/ D.Clowe et al.

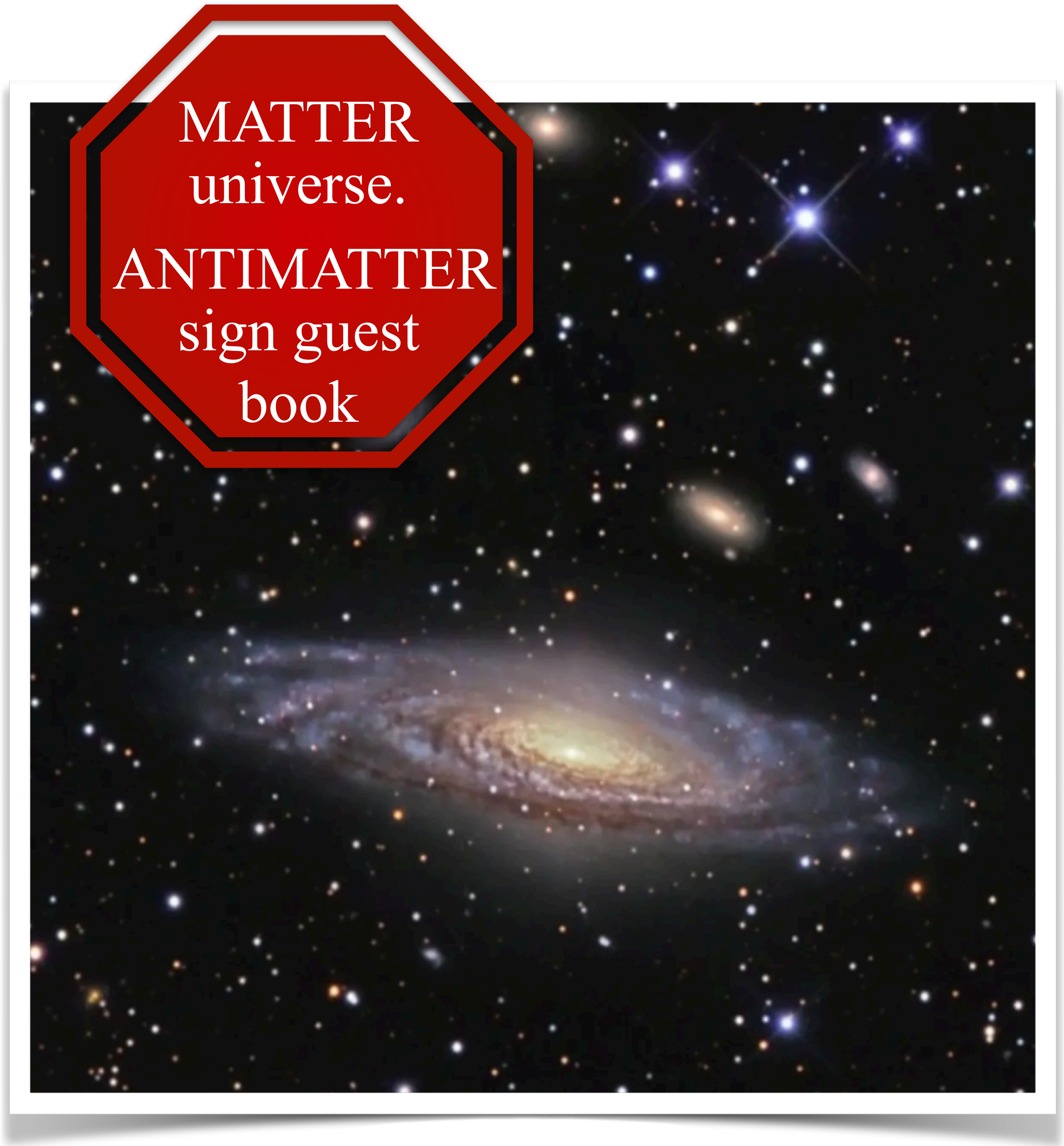
NASA/CXC/M. Weiss



... but Dark matter/energy, matter/antimatter, nature of generations, etc

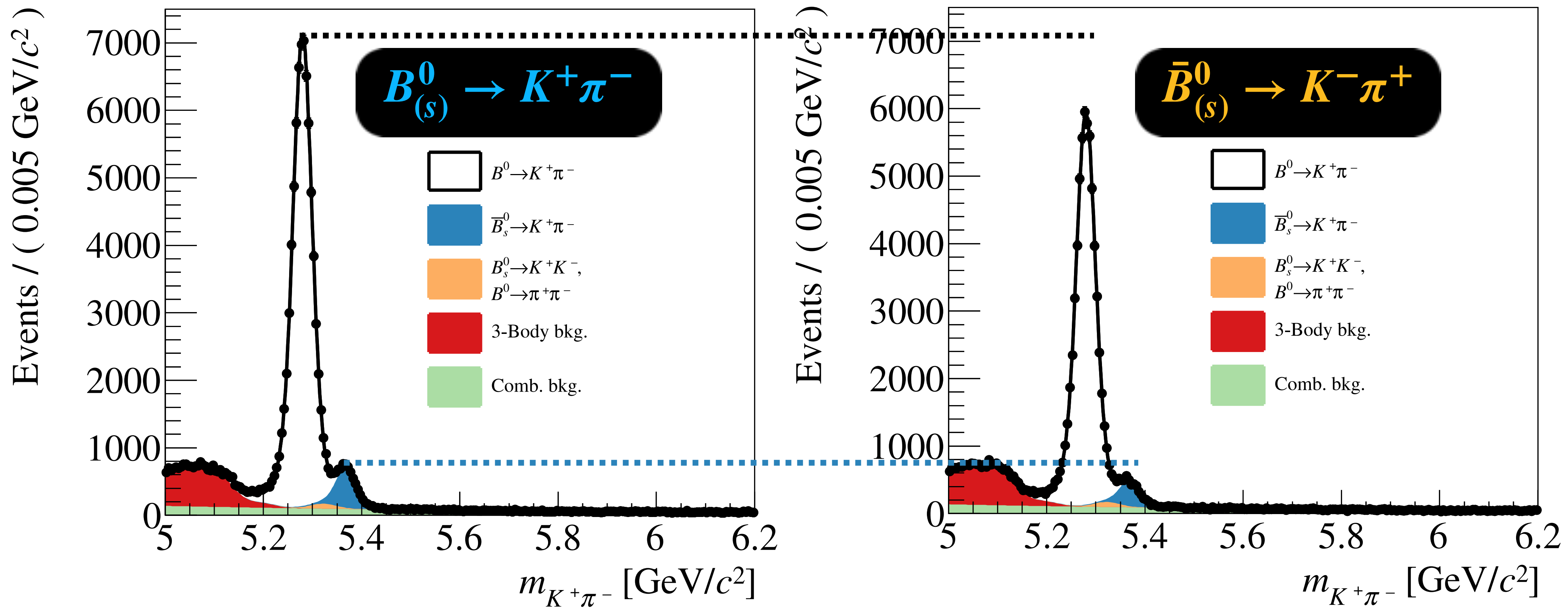
CP violation: $B \to K\pi$ puzzle

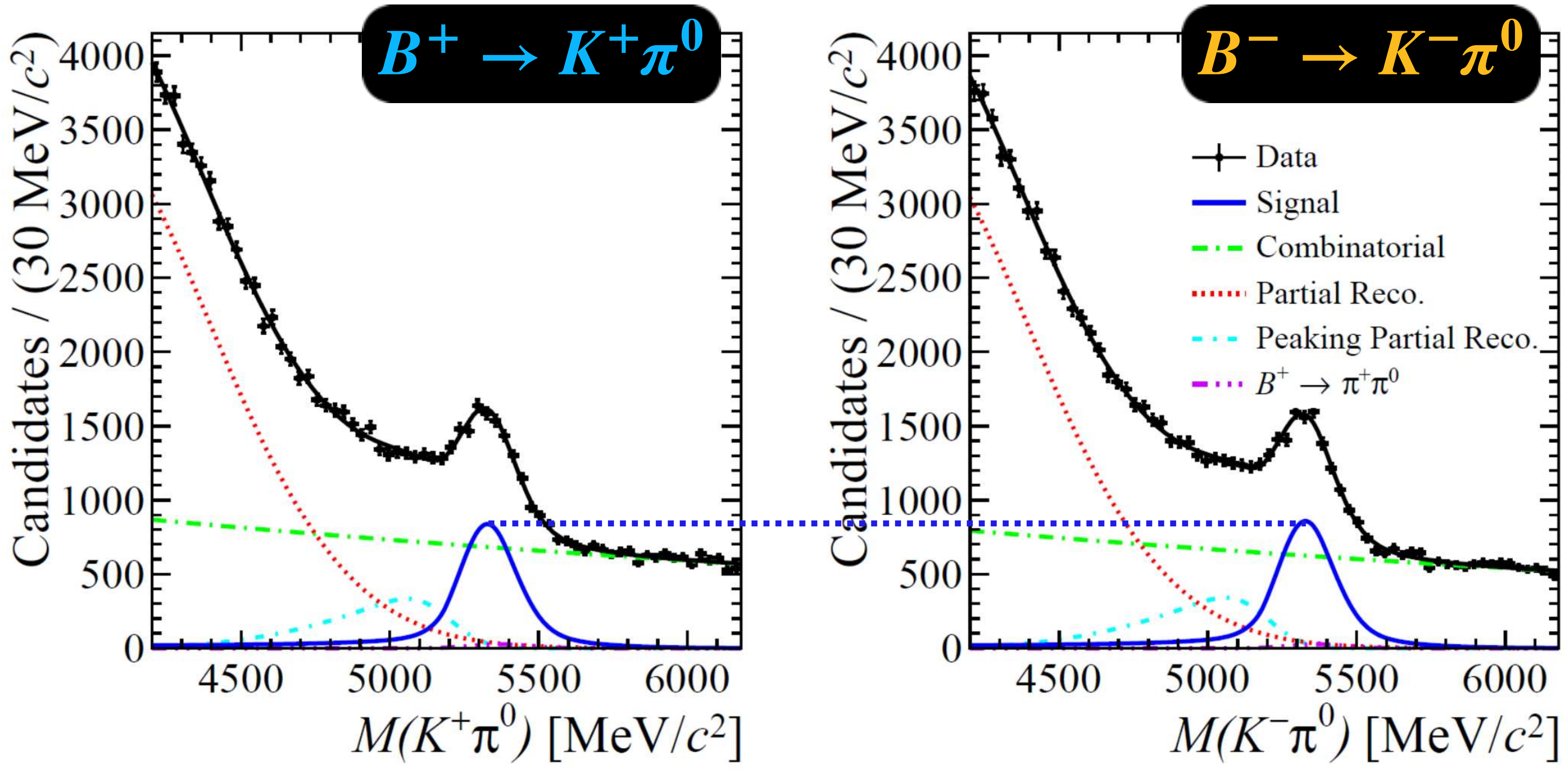
- **Broad effort** aiming to **shed light** on so-called $B \to K\pi$ ***puzzle***
  - **Compares behavior** of B **mesons**, and their ***evil twins*** the **anti-B mesons** ($\bar{B}$)



Our **measurement on $B^+ \to K^+\pi^0$**

[PRL 126, 091802 (2021)]





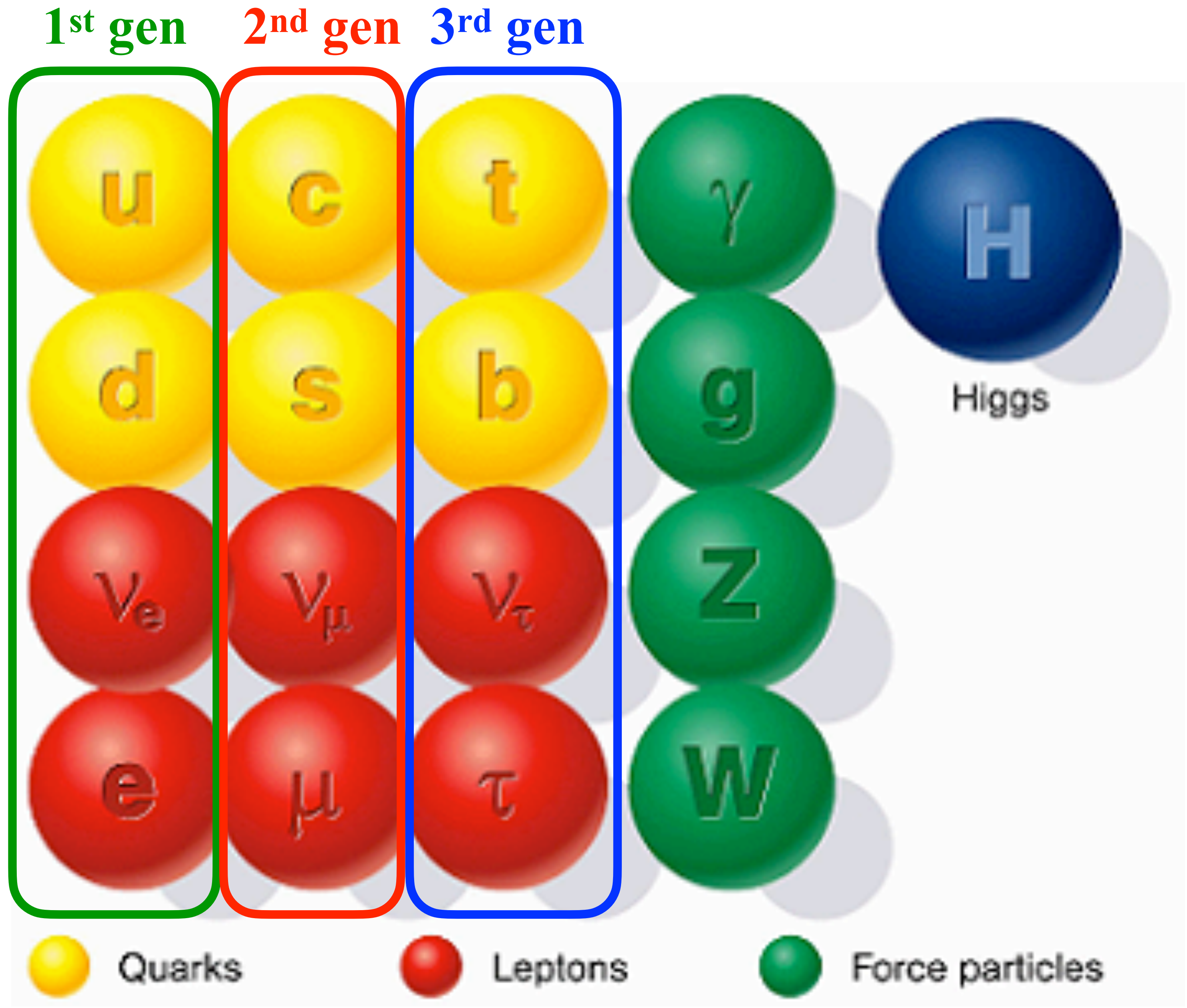
Difference between **CP asymmetry** of $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ now at **8.2σ**!

Flavors of the Standard Model

$$SU(3) \times SU(2)_L \times U(1)$$

symmetry

+



"The term flavor was first used in particle physics in the context of the quark model of hadrons. It was coined in 1971 by Murray Gell-Mann and his student at the time, Harald Fritzsch, at a Baskin-Robbins ice-cream store in Pasadena.

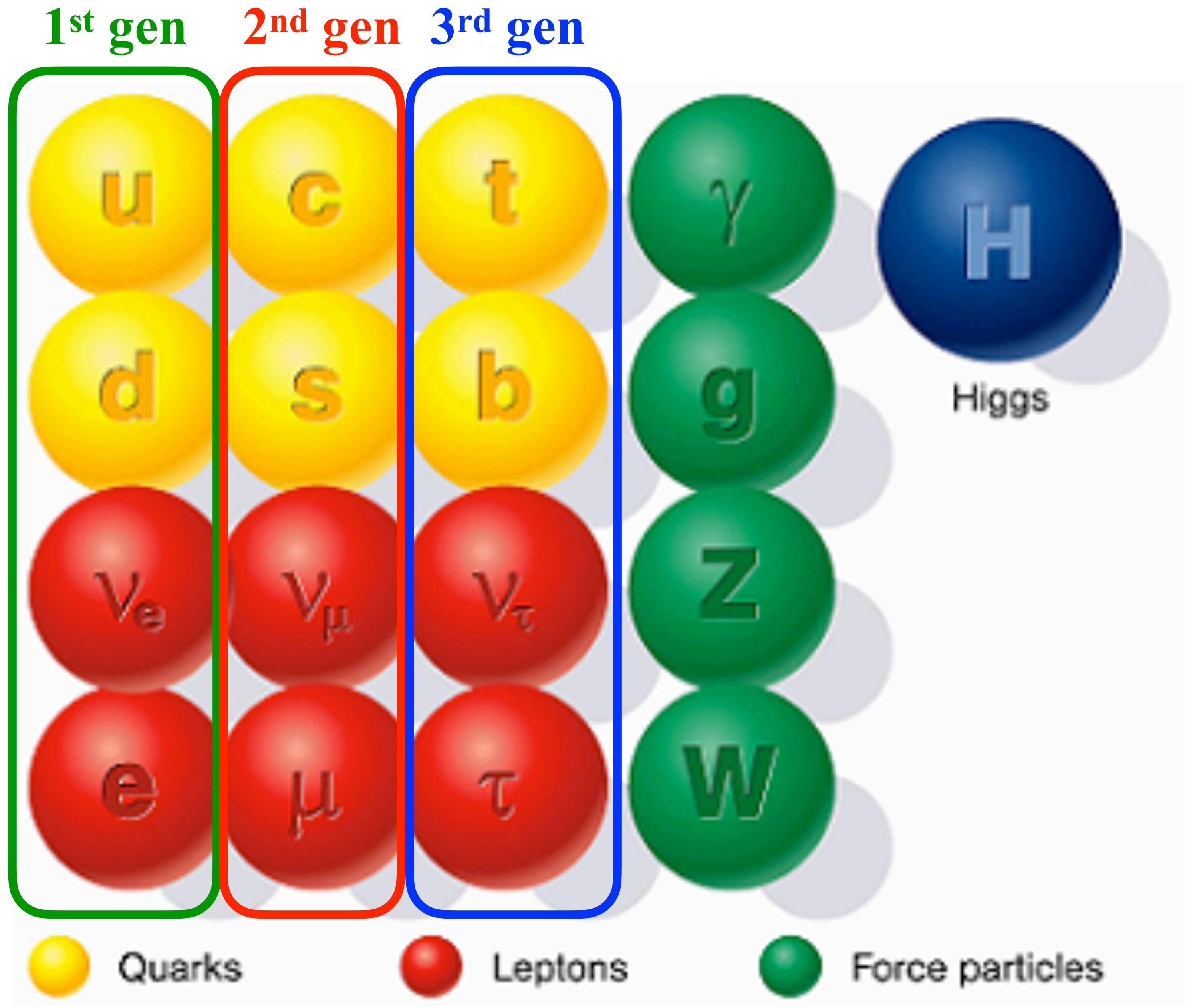
Just as ice cream has both color and flavor so do quarks."

RMP 81, 1887 (2009)

Lepton Flavor Universality (LFU)

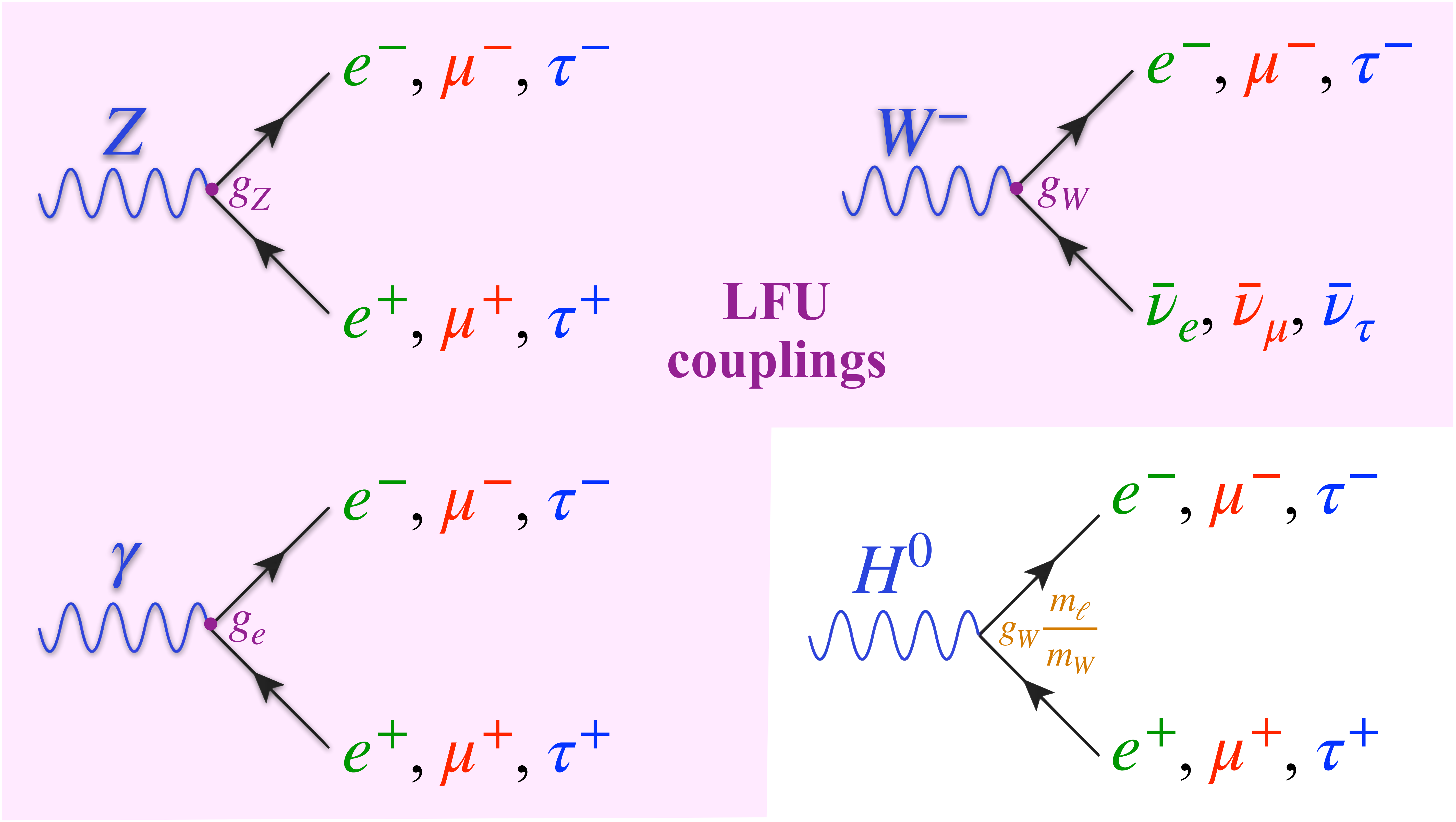
$SU(3) \times SU(2)_L \times U(1)$
symmetry

+



SM assumption

Electroweak gauge **couplings** to **three fermion generations** are **identical**



Can **test SM by testing LFU**

LFU tested to great precision*

LFU tests with e/μ (1st/2nd gen.)

To **0.28%** in Z decays

$$\frac{\Gamma_{Z\to\mu\mu}}{\Gamma_{Z\to ee}} = 1.0009 \pm 0.0028$$

LEP, Phys. Rept. 427 (2006) 257

To **0.8%** in W decays

$$\frac{\mathcal{B}(W\to e\nu)}{\mathcal{B}(W\to \mu\nu)} = 1.004 \pm 0.008$$

CDF + LHC, JPG: NPP, 46, 2 (2019)

$$\frac{\Gamma_{J/\psi\to\mu\mu}}{\Gamma_{J/\psi\to ee}} = 1.0016 \pm 0.0031$$

PDG (BESIII), RPP, Chin. Phys. C40 (2016) 100001

To **0.2%** in meson decays

$$\frac{\Gamma_{\pi\to e\nu}}{\Gamma_{\pi\to\mu\nu}} = (1.234 \pm 0.003)\times 10^{-4}$$

PiENu, Phys. Rev. Lett. 115, 071801 (2015)

3.1σ tension

$$\frac{\Gamma^{1.1-6}_{B\to K^+\mu\mu}}{\Gamma^{1.1-6}_{B\to K^+ee}} = R_K = 0.846^{+0.043}_{-0.040}$$

LHCb, Nature Phys. 18, 3 (2022)

To **0.14%** in $\tau\to\ell\nu\nu$

$$g_\mu/g_e = 1.0018 \pm 0.0014$$

PDG, A. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

LFU tests with τ (3rd gen.)

To **0.32%** in Z decays

$$\frac{\Gamma_{Z\to\tau\tau}}{\Gamma_{Z\to ee}} = 1.0019 \pm 0.0032$$

LEP, Phys. Rept. 427 (2006) 257

2.6σ tension in W decays

$$\frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 1.070 \pm 0.026$$

LEP, Phys. Rept. 532, 119 (2013)

To **6.1%** in D_s decays

$$\frac{\Gamma_{D_s\to\tau\nu}}{\Gamma_{D_s\to\mu\nu}} = 9.95 \pm 0.61$$

HFLAV, Eur. Phys. J. C77 (2017) 895

To **0.15%** in $\tau\to\ell\nu\nu$ (with τ_τ)

$$g_\tau/g_\mu = 1.0030 \pm 0.0015$$

PDG, S. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

LFU tested to great precision

LFU tests with e/μ (1st/2nd gen.)

To **0.28%** in Z decays

$$\frac{\Gamma_{Z\to\mu\mu}}{\Gamma_{Z\to ee}} = 1.0009 \pm 0.0028$$

LEP, Phys. Rept. 427 (2006) 257

To **0.8%** in W decays

$$\frac{\mathcal{B}(W\to e\nu)}{\mathcal{B}(W\to \mu\nu)} = 1.004 \pm 0.008$$

CDF + LHC, JPG: NPP, 46, 2 (2019)

$$\frac{\Gamma_{J/\psi\to\mu\mu}}{\Gamma_{J/\psi\to ee}} = 1.0016 \pm 0.0031$$

PDG (BESIII), RPP, Chin. Phys. C40 (2016) 100001

To **0.2%** in meson decays

$$\frac{\Gamma_{\pi\to e\nu}}{\Gamma_{\pi\to\mu\nu}} = (1.234 \pm 0.003)\times 10^{-4}$$

PiENu, Phys. Rev. Lett. 115, 071801 (2015)

$$\frac{\Gamma^{1.1-6}_{B\to K^+\mu\mu}}{\Gamma^{1.1-6}_{B\to K^+ee}} = R_K = 0.95 \pm 0.05$$

LHCb, 2212.09152

To **0.14%** in $\tau\to\ell\nu\nu$

$$g_\mu/g_e = 1.0018 \pm 0.0014$$

LFU tests with τ (3rd gen.)

To **0.32%** in Z decays

$$\frac{\Gamma_{Z\to\tau\tau}}{\Gamma_{Z\to ee}} = 1.0019 \pm 0.0032$$

LEP, Phys. Rept. 427 (2006) 257

To **1.3%** in W decays

$$\frac{\Gamma_{W\to\tau\nu}}{\Gamma_{W\to\mu\nu}} = 0.992 \pm 0.013$$

ATLAS, Nature 17, 813 (2021)

To **6.1%** in D_s decays

$$\frac{\Gamma_{D_s\to\tau\nu}}{\Gamma_{D_s\to\mu\nu}} = 9.95 \pm 0.61$$

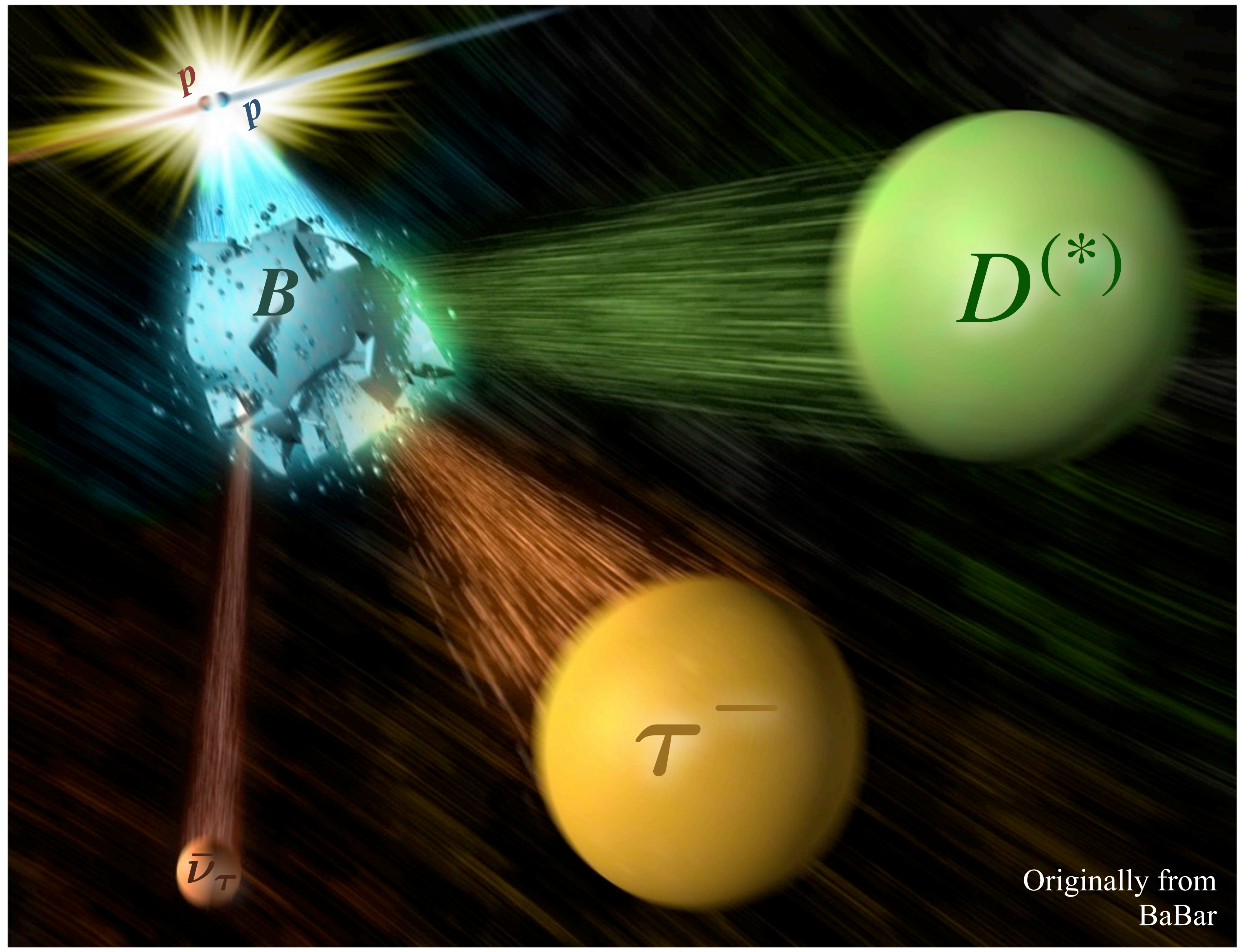
HFLAV, Eur. Phys. J. C77 (2017) 895

To **0.15%** in $\tau\to\ell\nu\nu$ (with τ_τ)

$$g_\tau/g_\mu = 1.0030 \pm 0.0015$$

PDG, S. Pich, Prog. Part. Nucl. Phys. 75 (2014) 41

Testing LFU



Measure $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ and compare them to SM predictions

$$\boxed{\mathcal{R}\left(D^{(*)}\right) = \frac{\mathcal{B}\left(\bar{B} \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(\bar{B} \to D^{(*)}\ell\nu_\ell\right)}}$$

with $\ell = \mu, e$

$\mathcal{R}\left(D^{(*)}\right) \equiv \mathcal{R}(D)$ or $\mathcal{R}(D^*)$

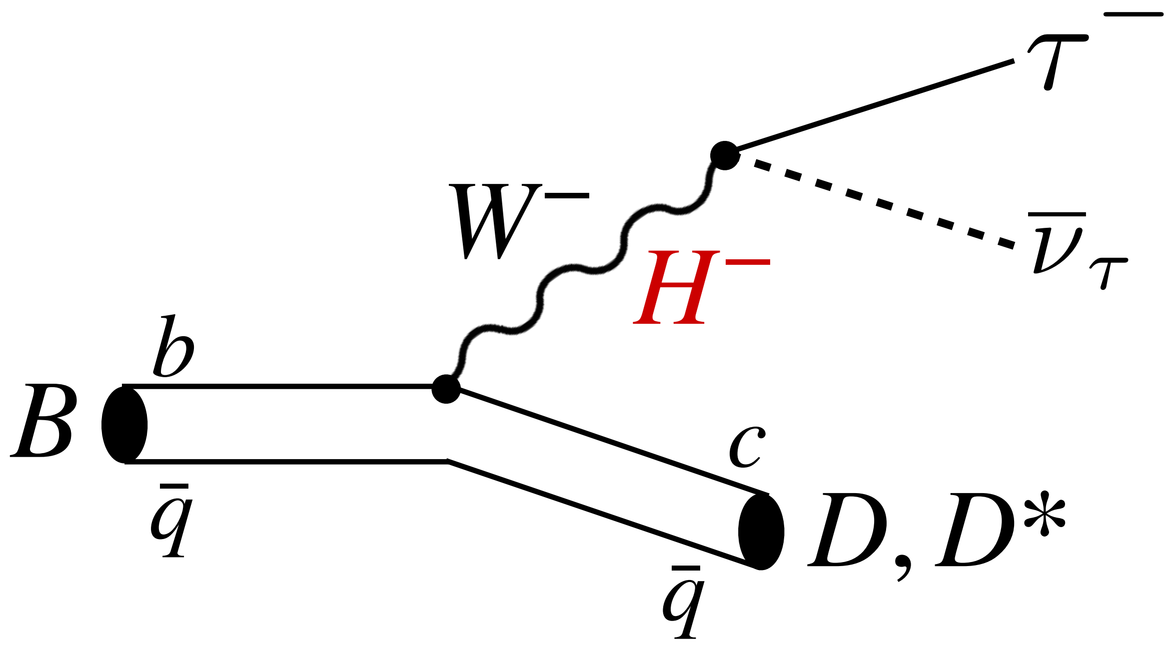
How often a decay occurs is given by $\mathcal{B}$

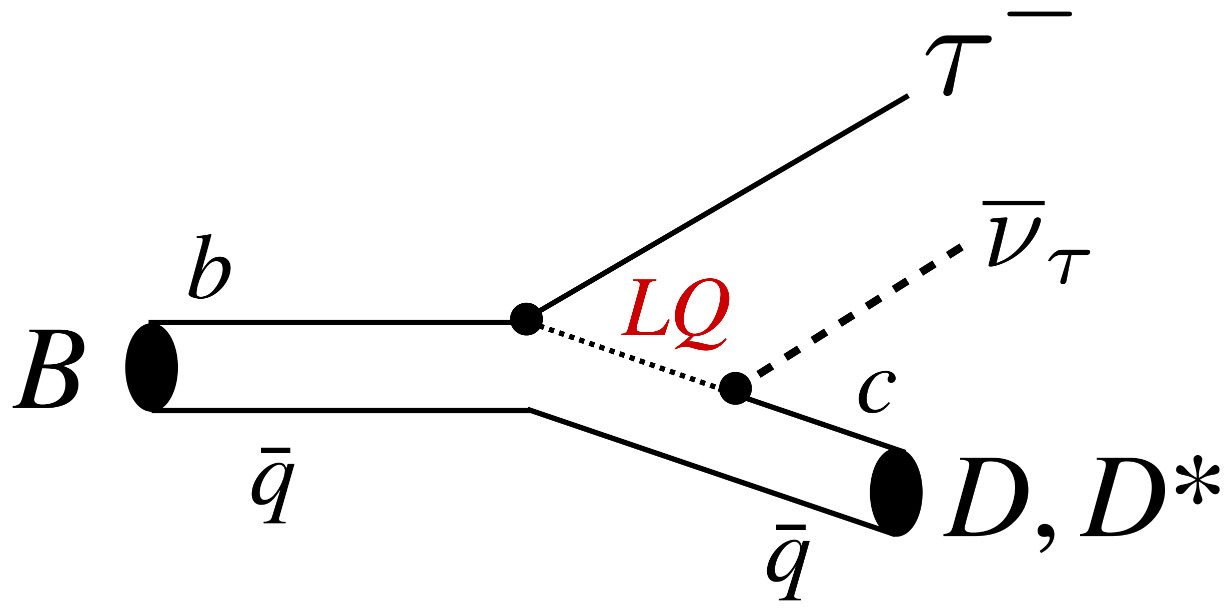
$$\mathcal{R}(D)^{SM} = 0.299 \pm 0.003$$

$$\mathcal{R}\left(D^*\right)^{SM} = 0.258 \pm 0.005$$

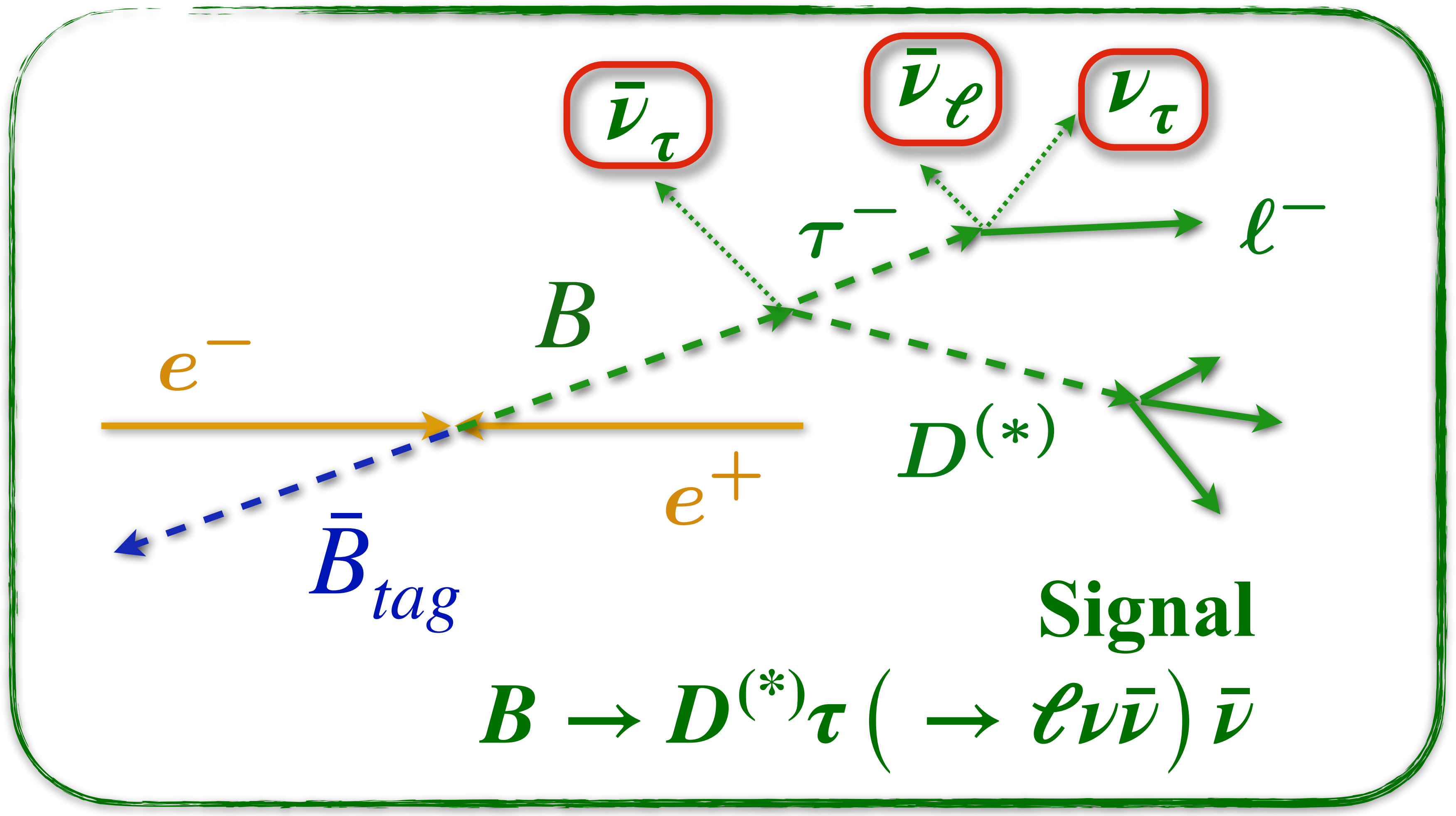
Very solid SM predictions with **just 1-2% uncertainty**

Any established **deviations** would be clear indications of **New Physics beyond the SM**

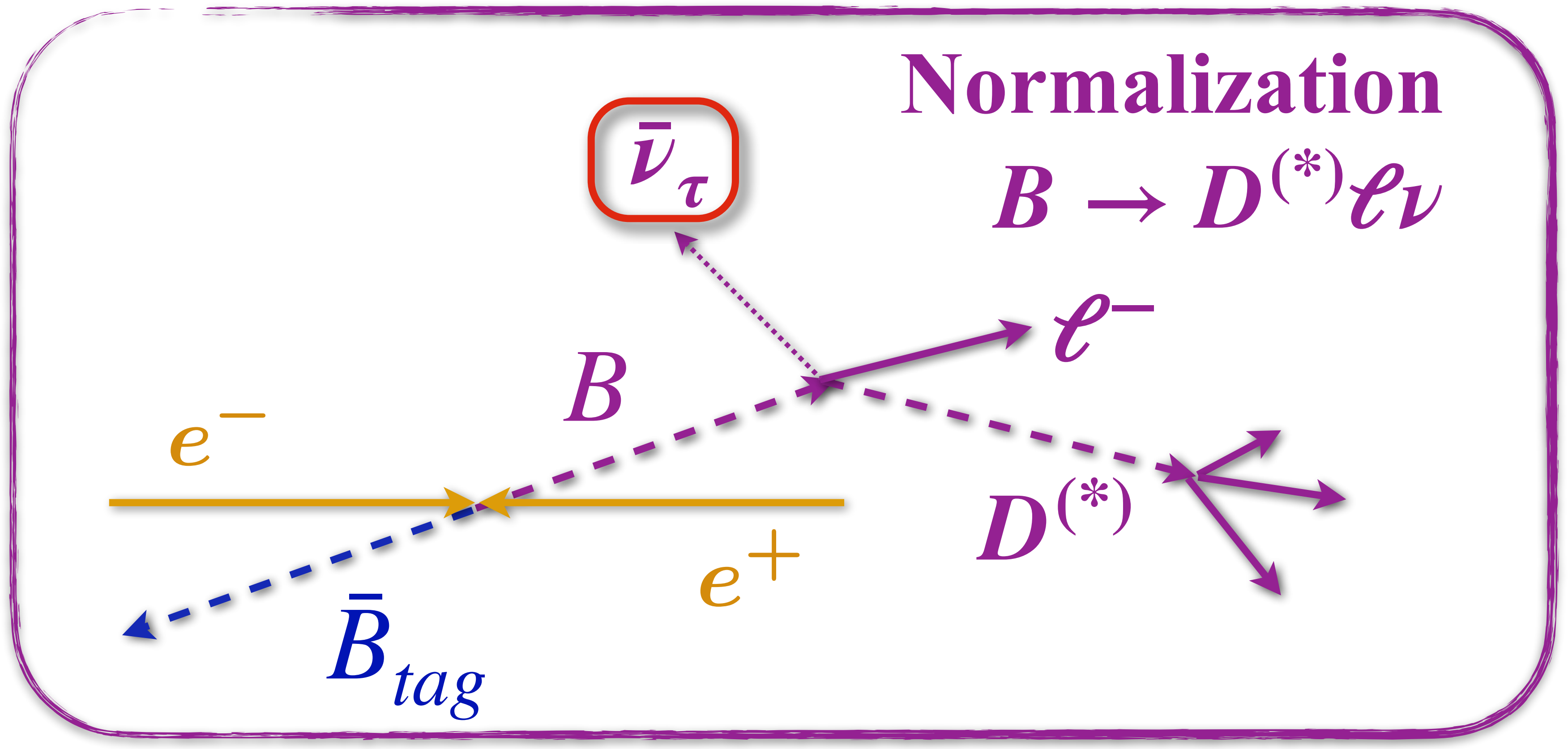




First hints of LFU violation in 2012

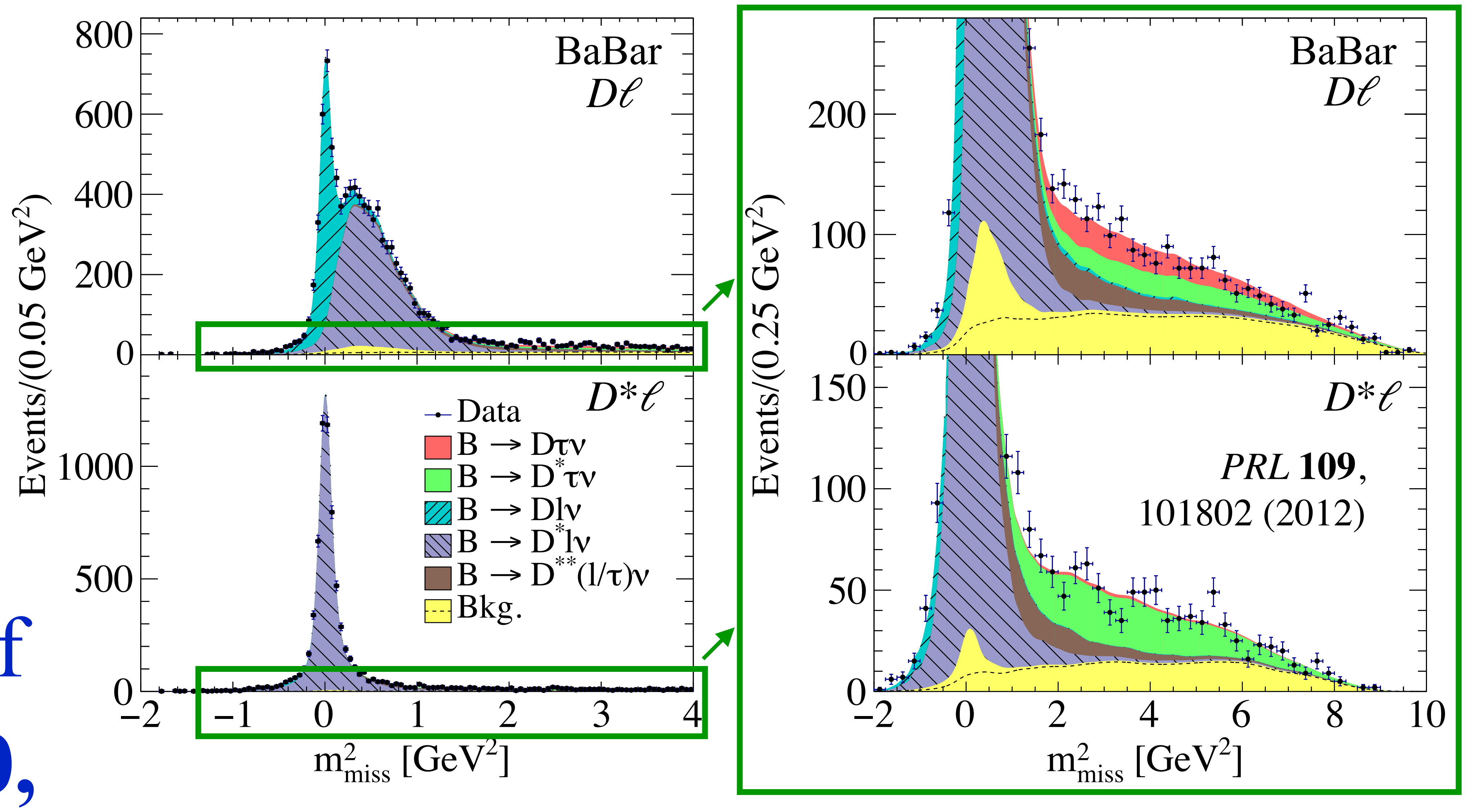


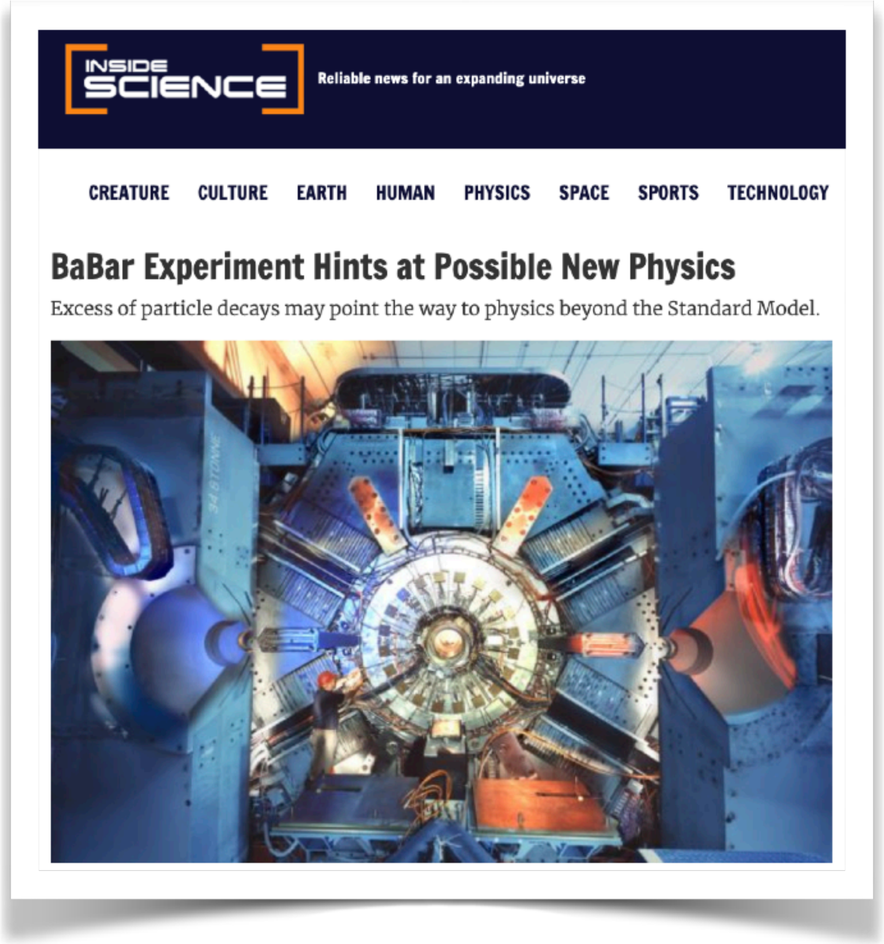
$$\mathscr{R}\left(D^{(*)}\right) = \frac{\boxed{\mathscr{B}\left(\bar{B} \to D^{(*)}\tau\nu_\tau\right)}}{\boxed{\mathscr{B}\left(\bar{B} \to D^{(*)}\ell\nu_\ell\right)}}$$

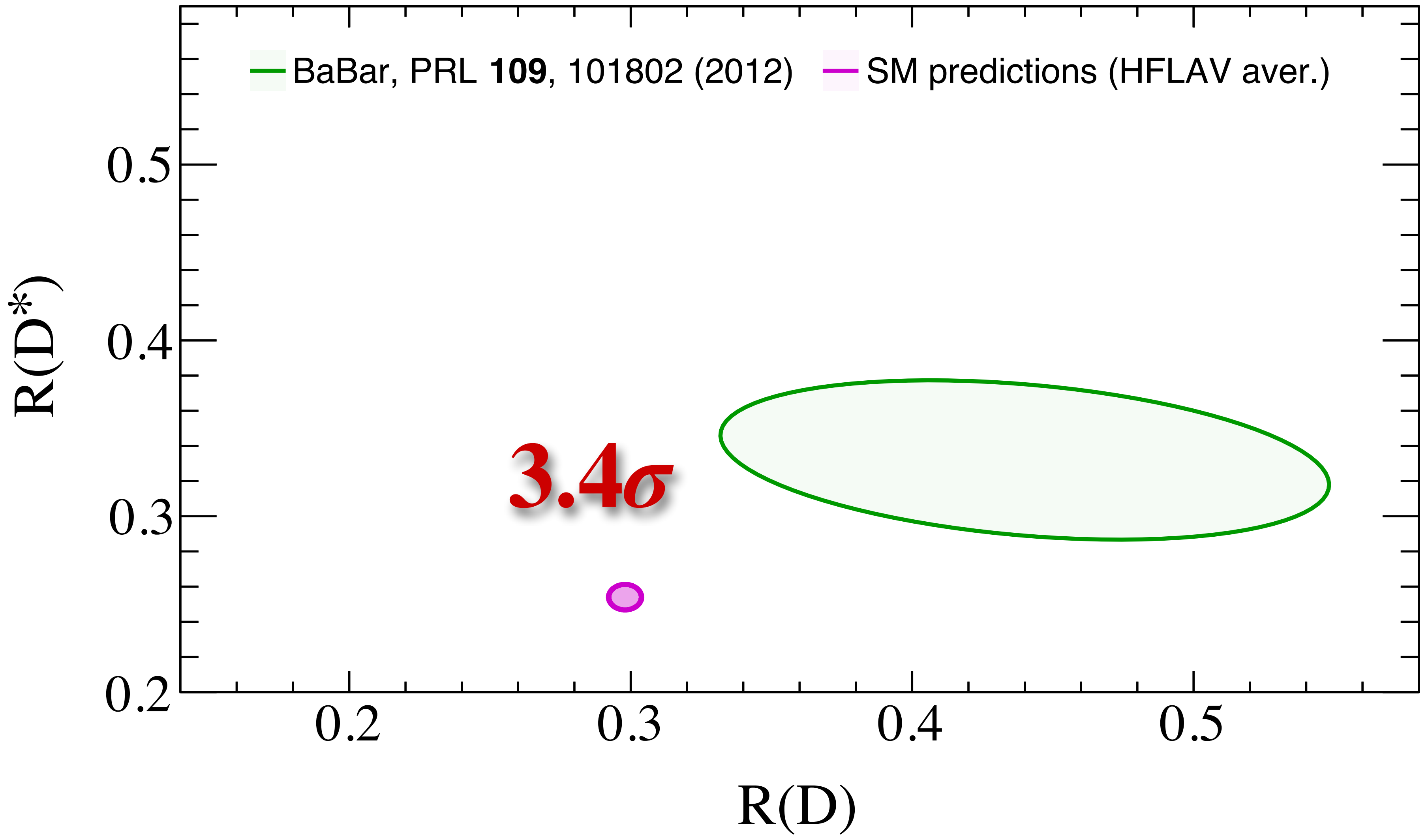


Difficult measurement because **multiple ν in final state**

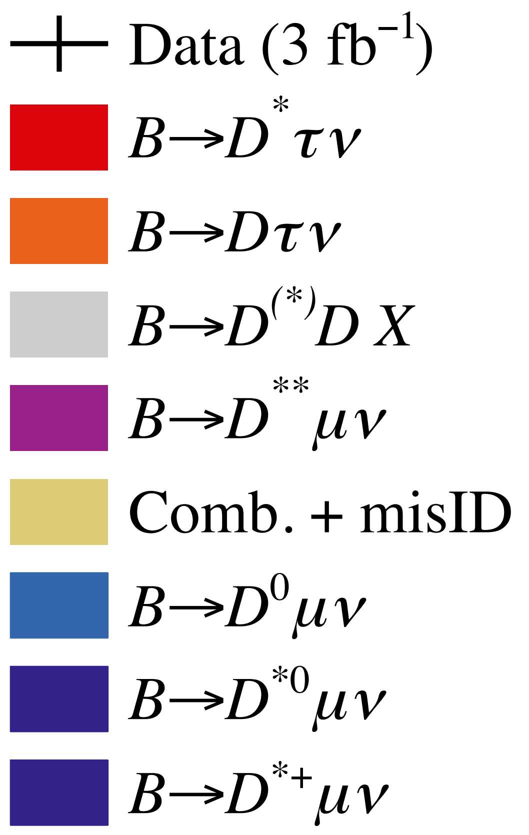
m^2_{miss} distribution of **1 ν** events **peaks at 0,** **3 ν** events are **broad**



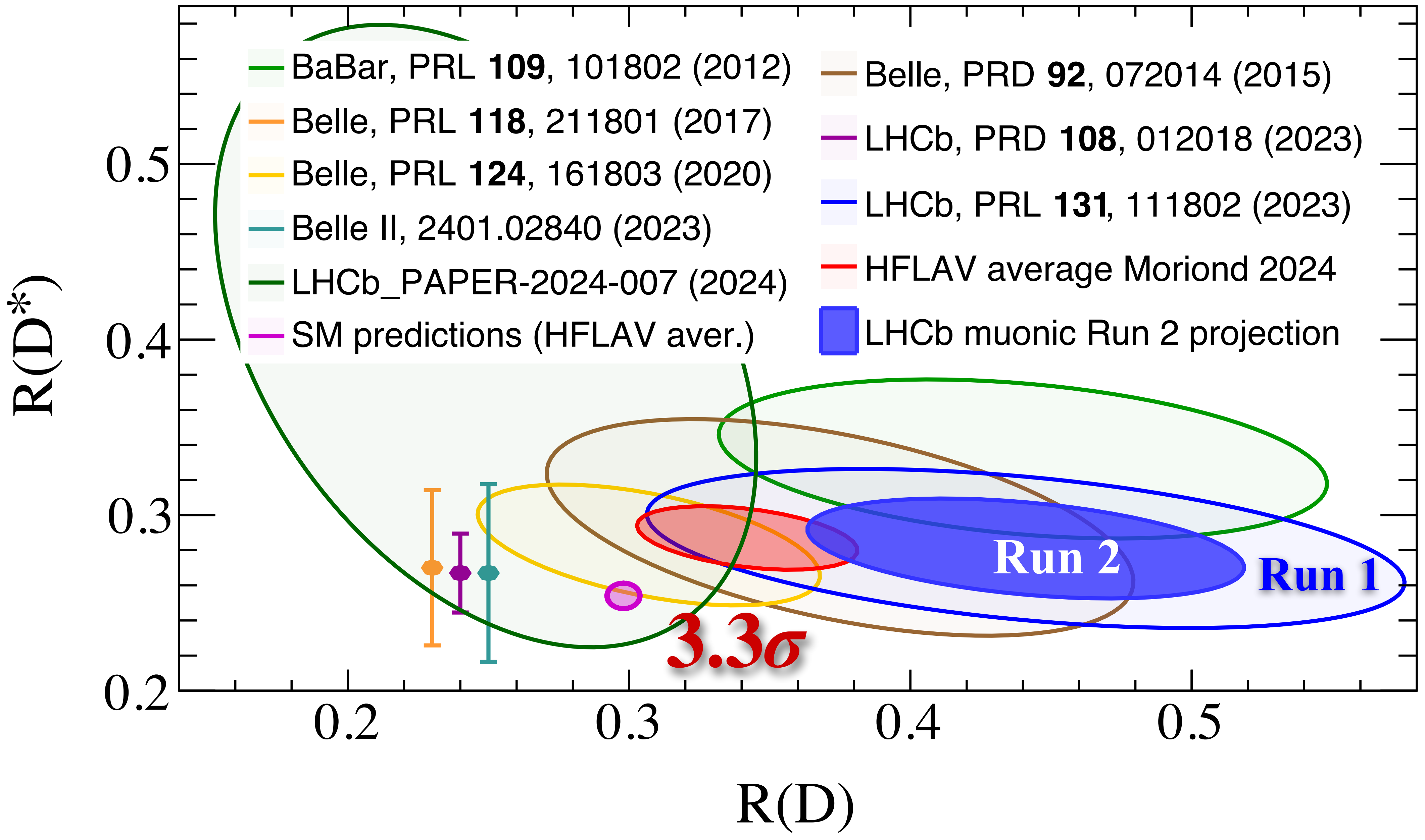


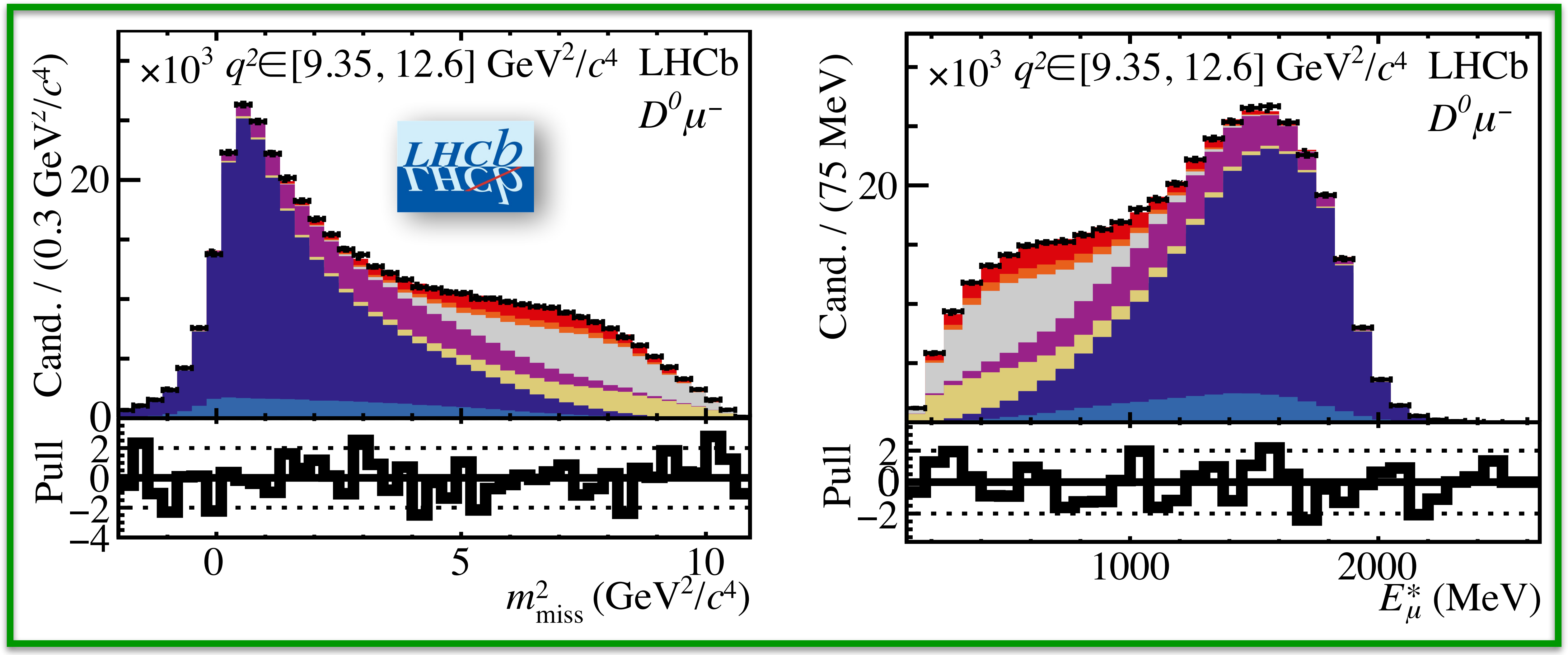


Aiming for world's most precise measurement



Measurements from **BaBar** (e^+e^-, 🇺🇸), **Belle** (e^+e^-, 🇯🇵), and **LHCb** (pp, 🇪🇺) **all** see **hints of LFU violation**





Currently working on a new measurement of $\mathscr{R}(D)$ and $\mathscr{R}(D^*)$ with **6x more data** before → possibility for **best precision in the world**

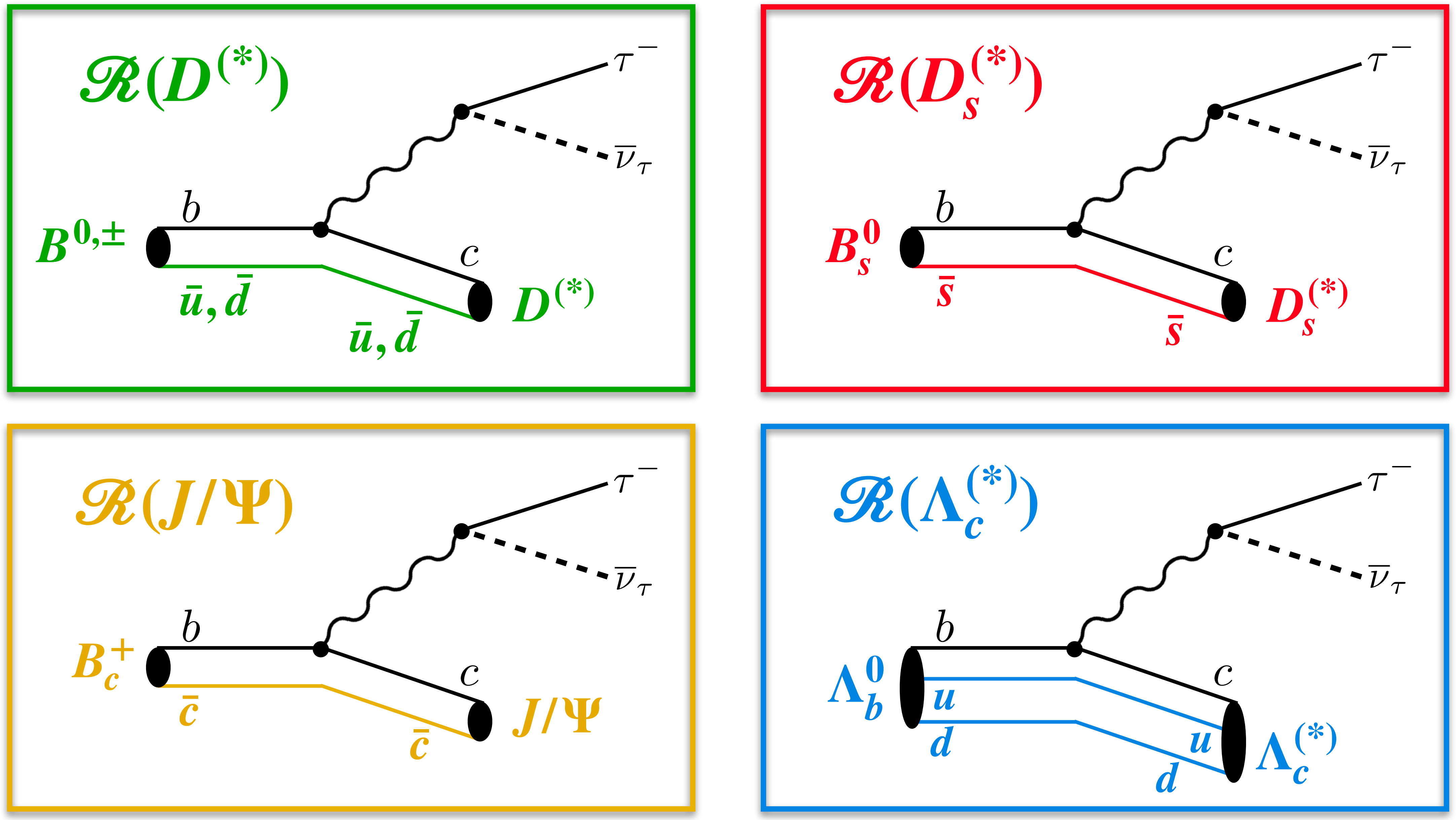
[PRL 131 (2023) 111802](PRL 131 (2023) 111802)

Perhaps **the most interesting *problem*** in **particle physics today!**

We will know in the next few years

Even 5σ on $\mathscr{R}(D)/\mathscr{R}(D^*)$ **would not be sufficient to convince ourselves of NP**

Important to **test other observables,** and **LHCb** has **unique ability to study** $b \to c\tau\nu$ **transitions**

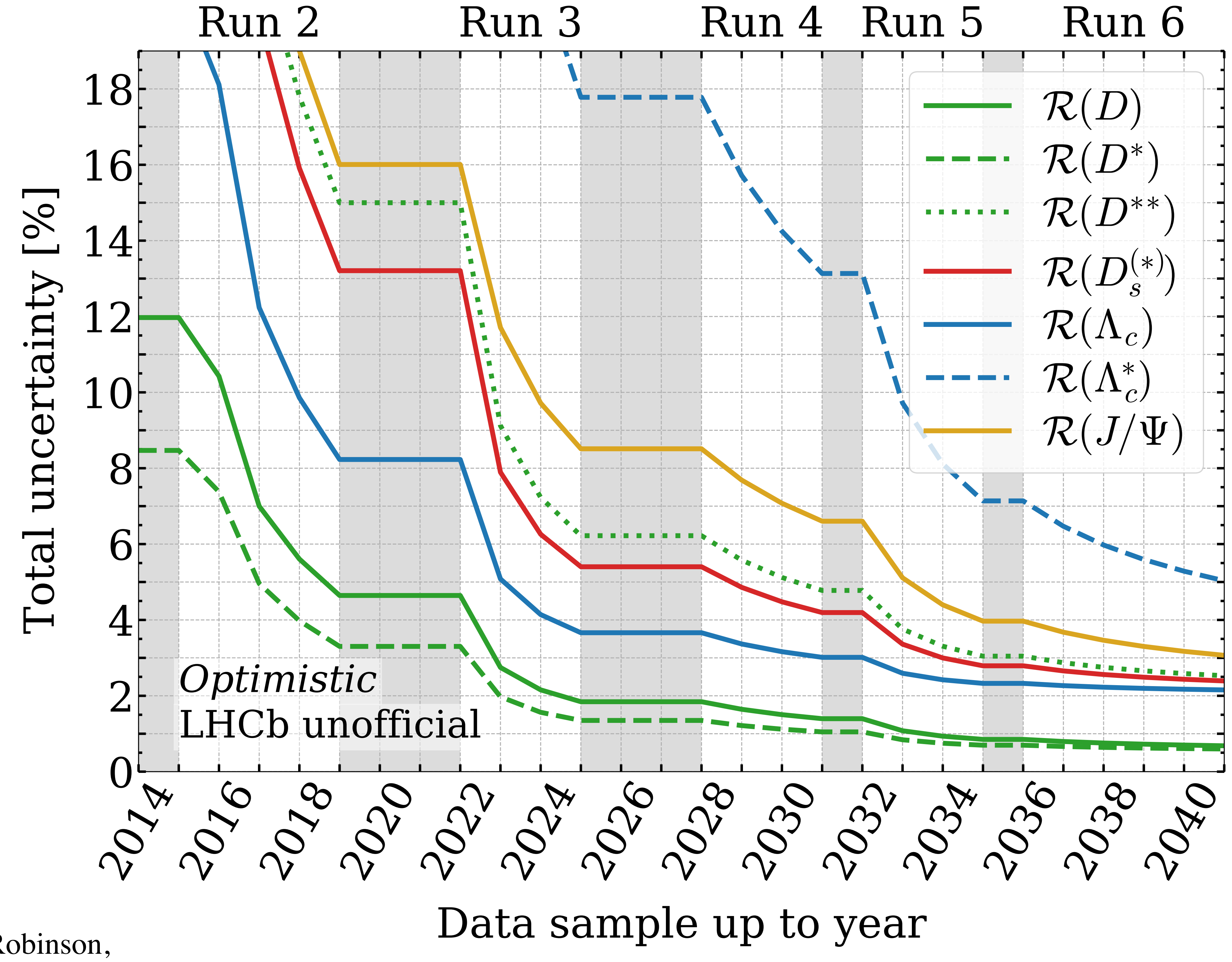


$\mathscr{R}(J/\Psi)$, $\mathscr{R}(D_s^{(*)})$, and $\mathscr{R}(\Lambda_c^{(*)})$ have many uncertainties uncorrelated with $\mathscr{R}(D^{(*)})$

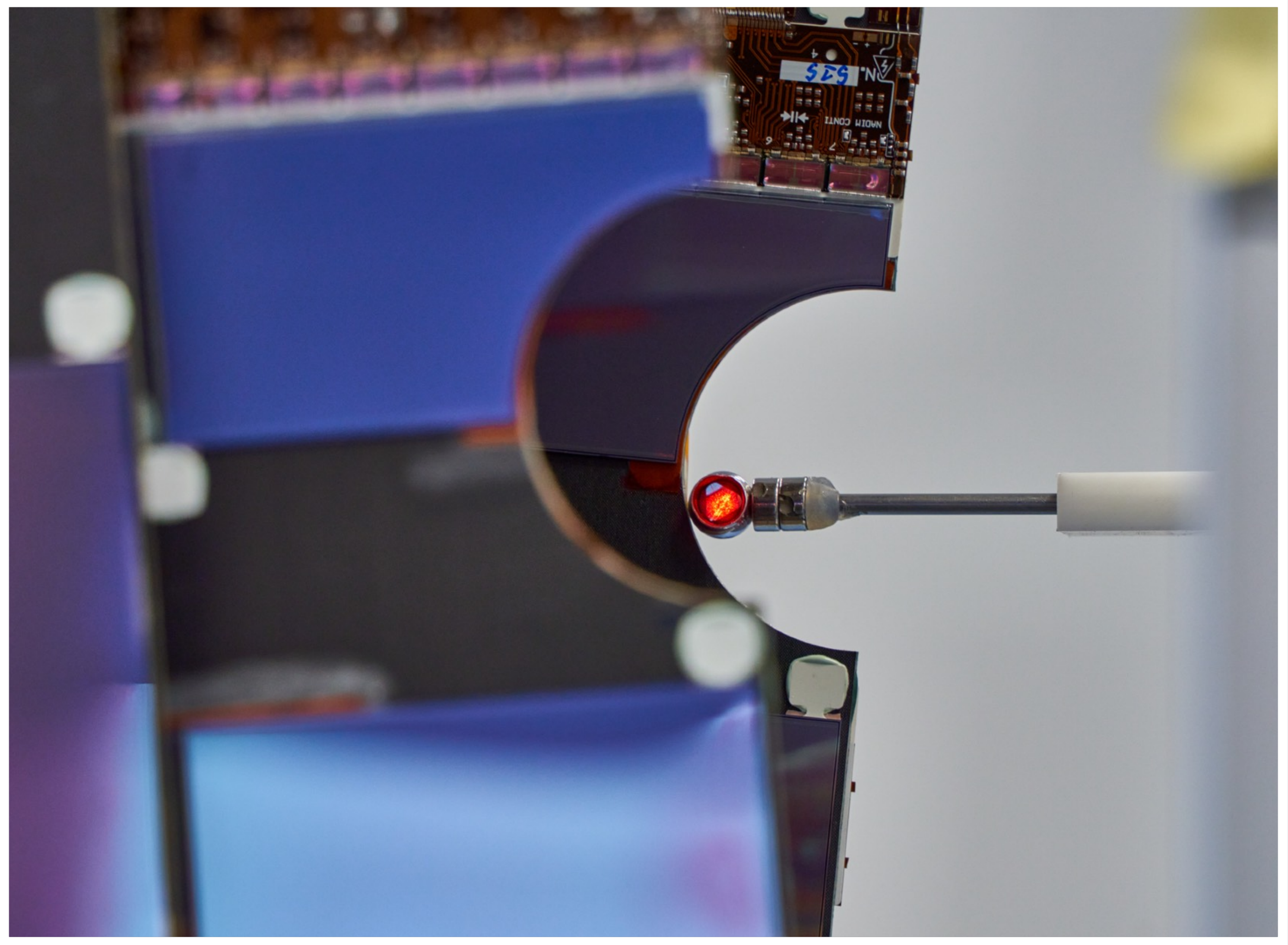
- **LHCb upgrades** will allow us to measure

$$\mathscr{R}\left(X_c\right) = \frac{\mathscr{B}\left(X_b \to X_c \tau \nu_\tau\right)}{\mathscr{B}\left(X_b \to X_c \ell \nu_\ell\right)}$$

to **exquisite precision**



Bernlochner, MFS, Robinson, Wormser, [RMP, 94, 015003 (2022)]



Detector development @ UMD
The Upstream Tracker (UT)

Upgrades of the LHCb detector

450 billion B mesons

Goal: 2,500 billion B mesons

Goal: 15 trillion B's

Upgrade I — Upgrade Ib — Upgrade II

Run 1		LS1		Run 2				LS2				Run 3				LS3			Run 4				LS4		Run 5					
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

Runs 1 and 2

40 MHz pp collisions → **L0** Hardware → 1.1 MHz Detector readout → **HLT** Software → 12.5 kHz (0.6 GB/s) Events on disk

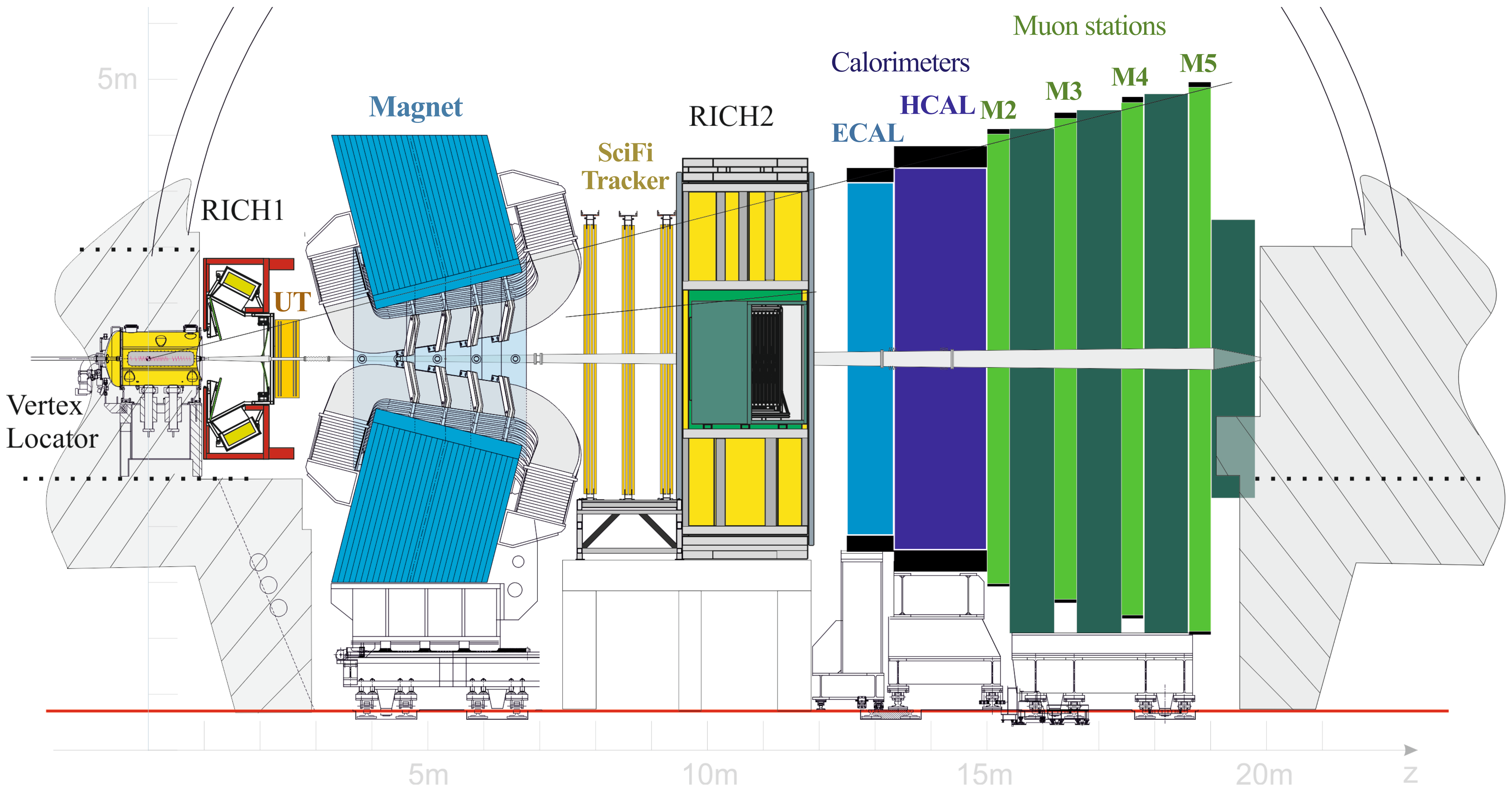
Upgrade I

40 MHz pp collisions Detector readout → **HLT** Software → 100 kHz (2-5 GB/s) Events on disk

Flexible software trigger and 3 new/better trackers

Upgrades Ib and II (described in next talk)

Even better granularity, improved calorimeter, and fast timing



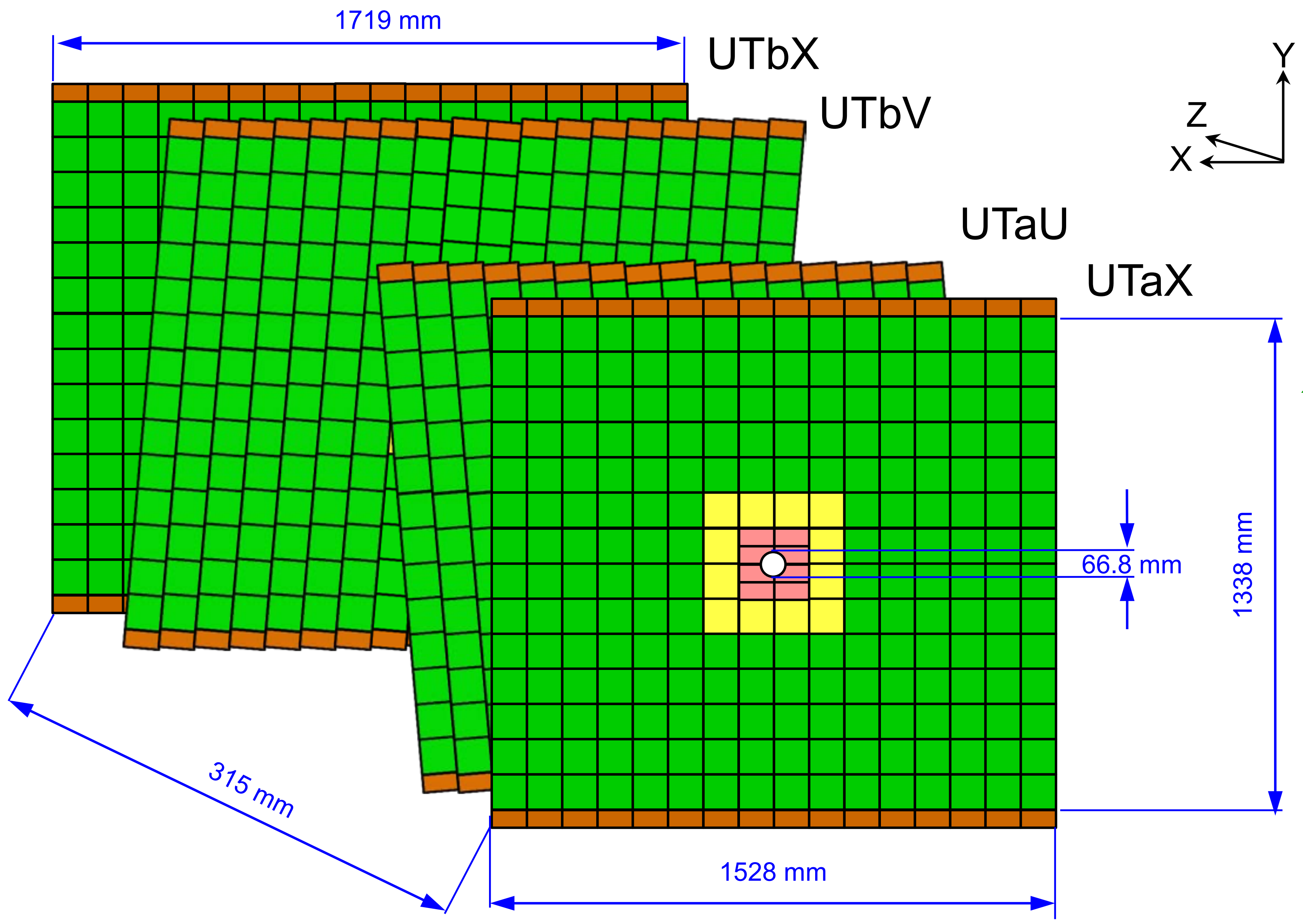
Upstream Tracker

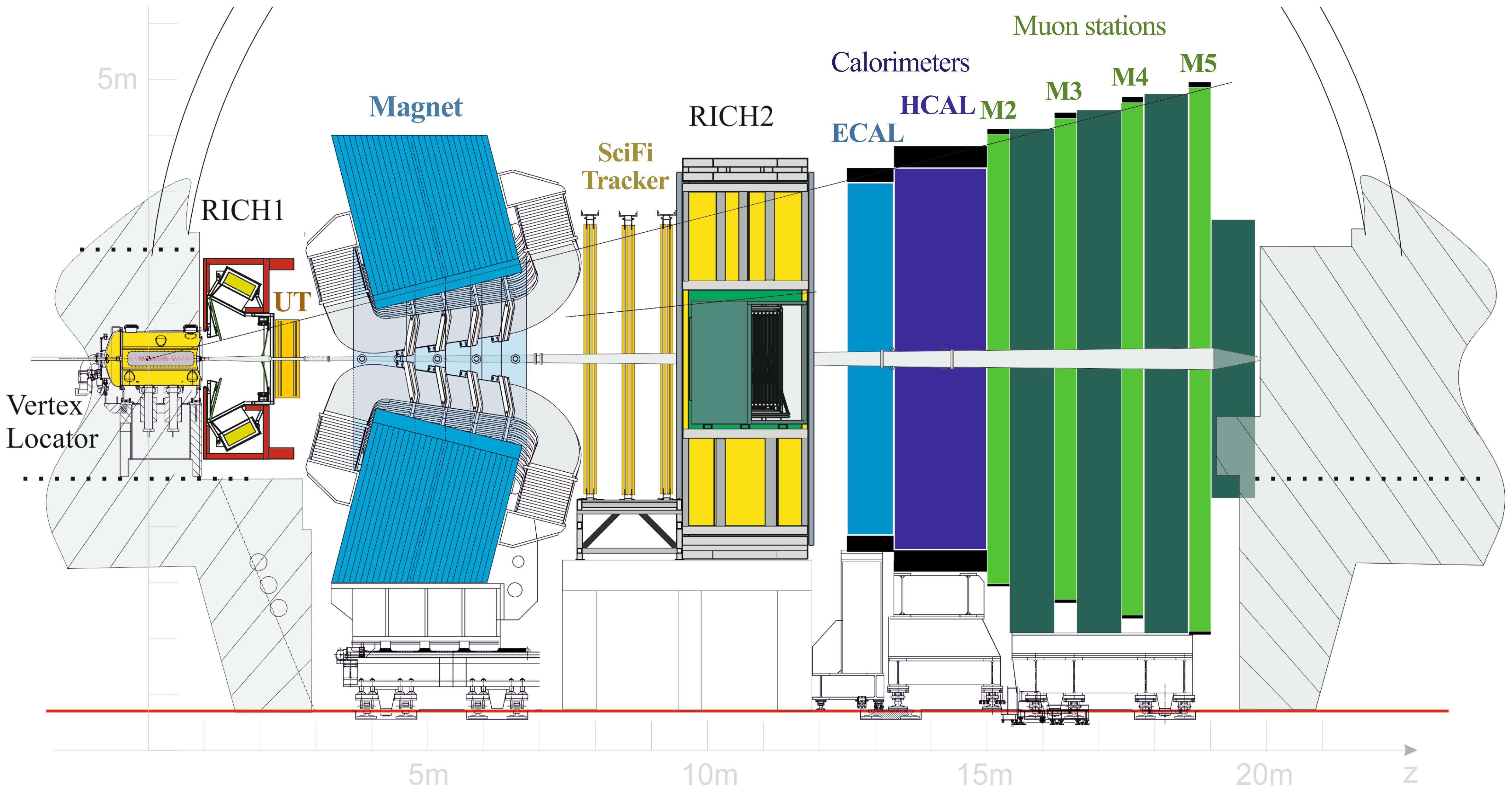
← **450 billion B mesons** →　　← **Goal: 2,500 billion B mesons** →　　← **Goal: 15 trillion B's** →

Upgrade I (LS2)　　**Upgrade Ib** (LS3)　　**Upgrade II** (LS4)

Run 1	LS1	Run 2	LS2		Run 3	LS3	Run 4	LS4	Run 5
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

- New **tracker** with **4 layers of silicon strips**
  - ➡ **Crucial** for high-lumi **triggering**

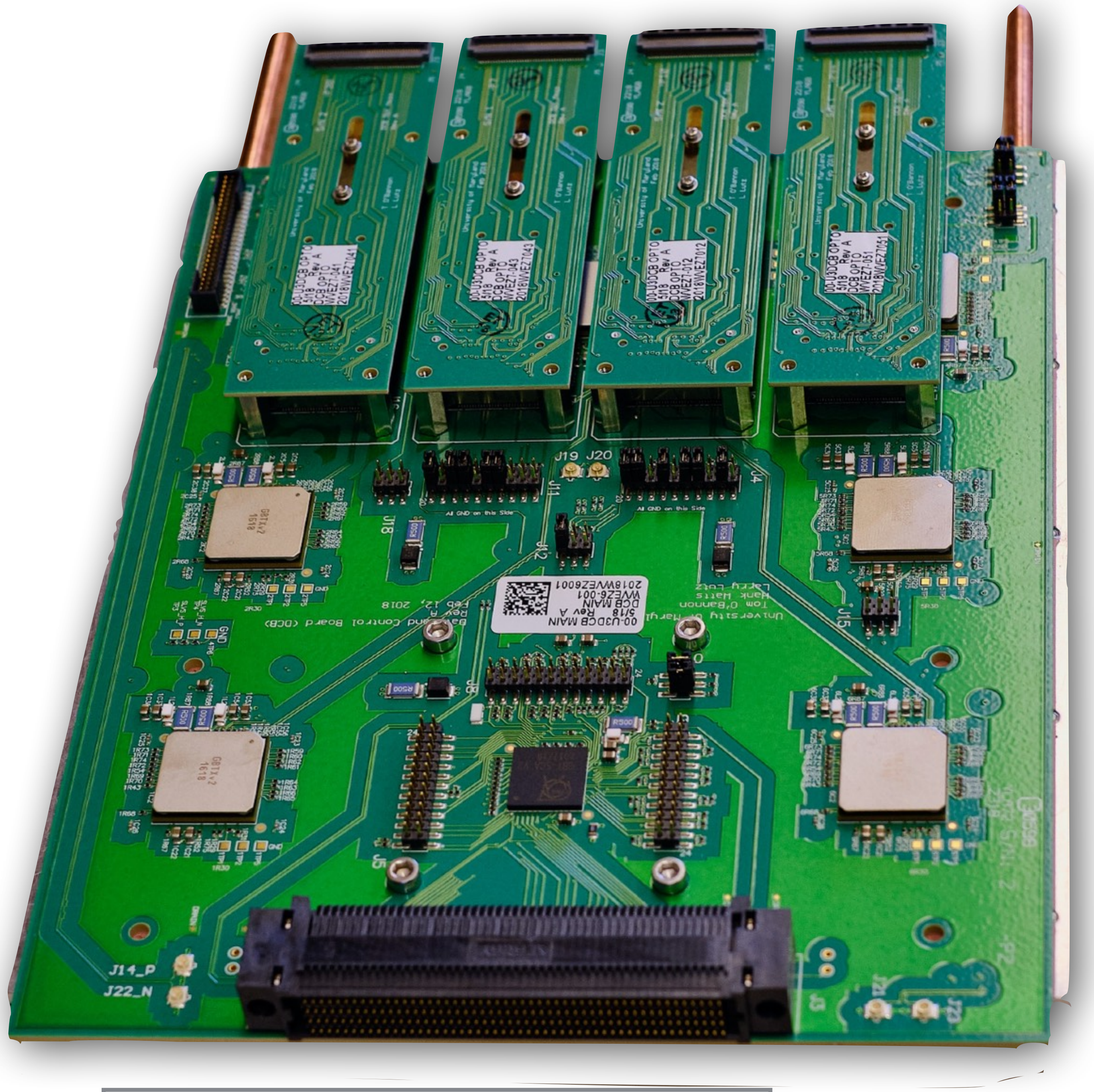




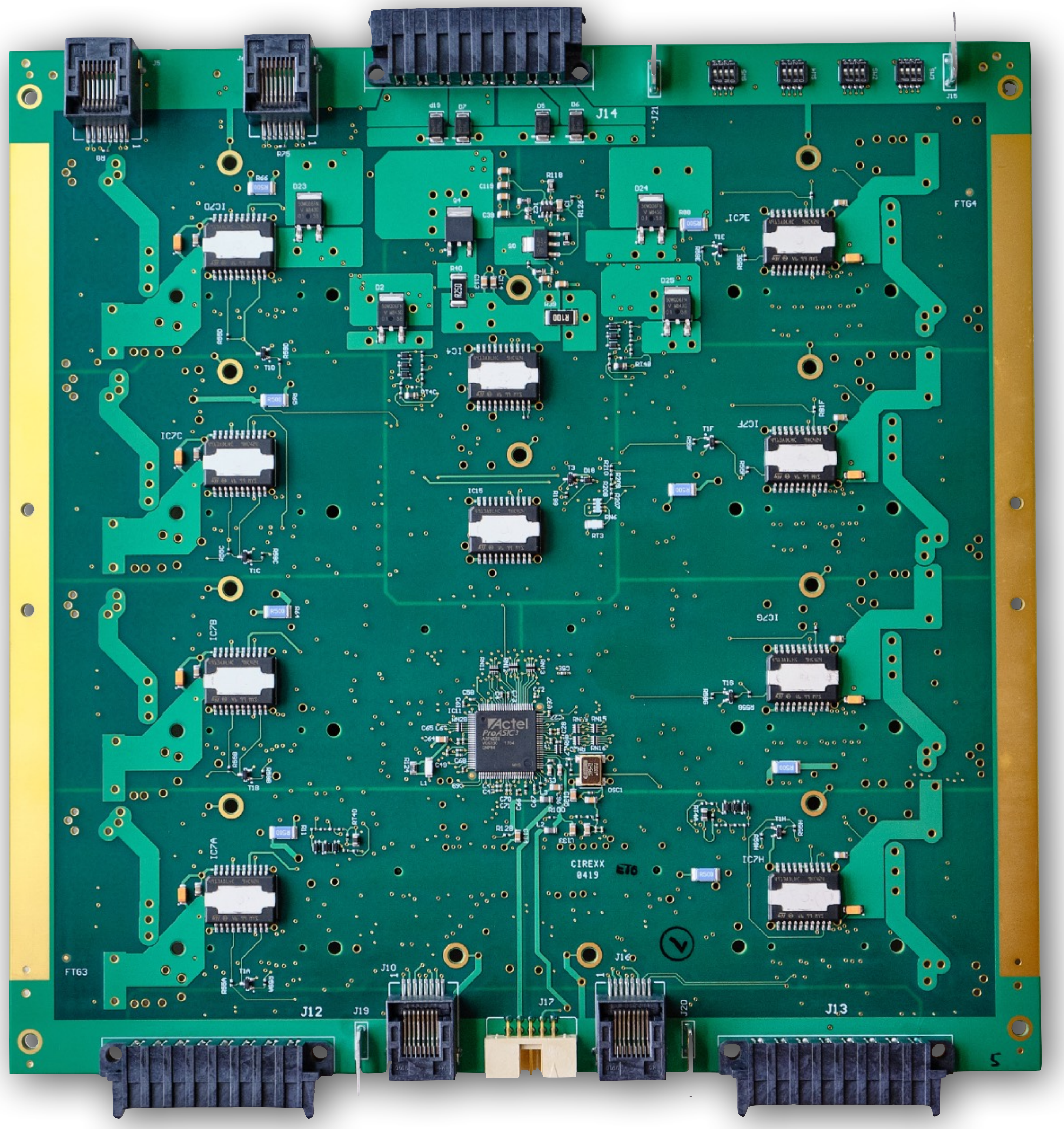
First major contribution from the US 🇺🇸

UMD's in-kind contributions

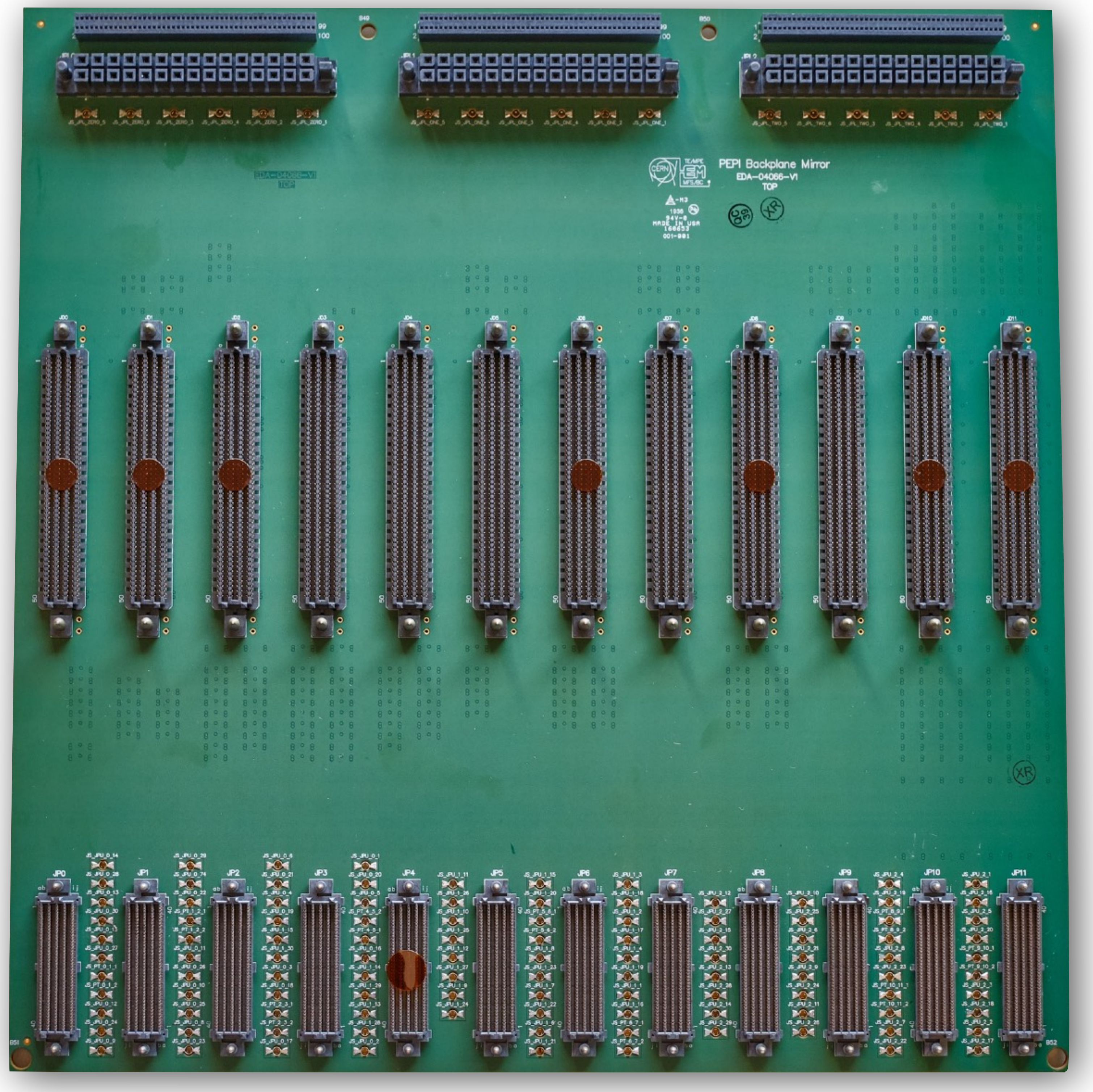
270 DCBs
Rad-hard **slow control** and
6×4.8 Gb/s optical transmission



295 LVRs
Precise DC voltages/currents
with rad-hard LV regulator ASIC



30 Backplanes
Distribution of signals to
balance the data load



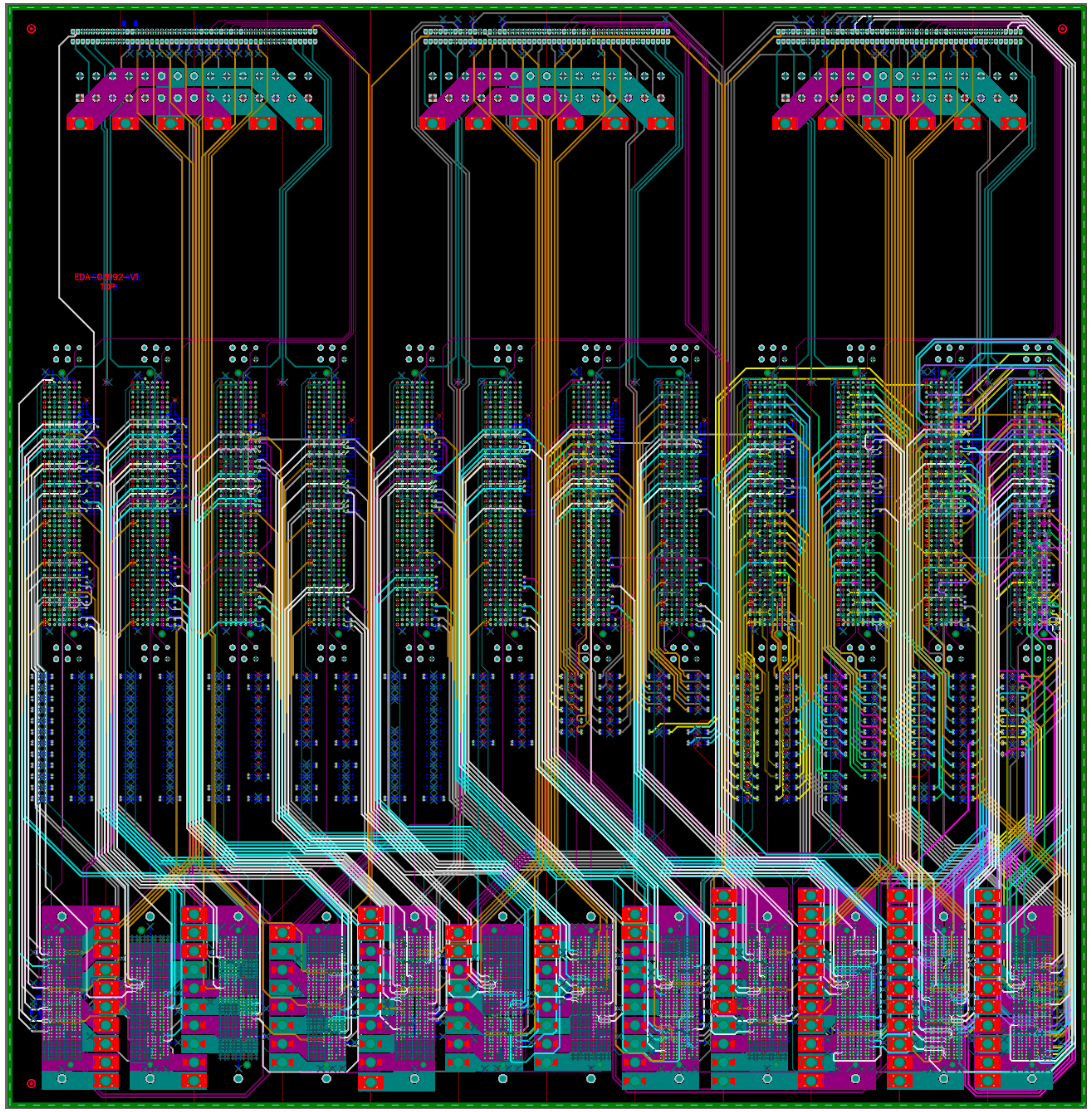
Plus 3,000+
ancillary boards!

Which of these boards was the most challenging?

The backplane!

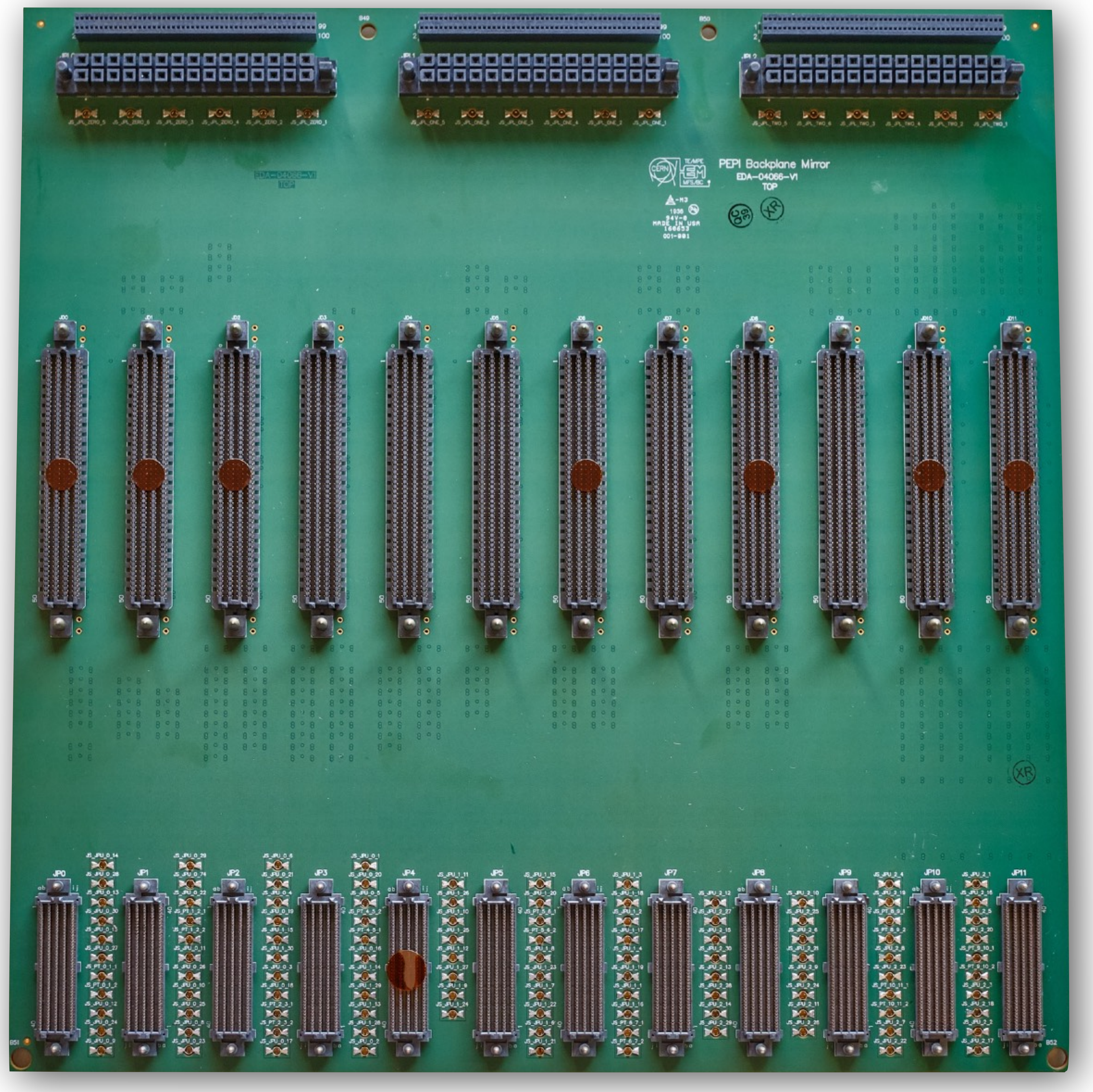
Ultra-high trace **density** necessitated **28 layer PCB**

Bottom connectors have 500 pins with 800 µm pitch led to **150 µm vias** in **2.8 mm thick board → 18.7 ratio!**

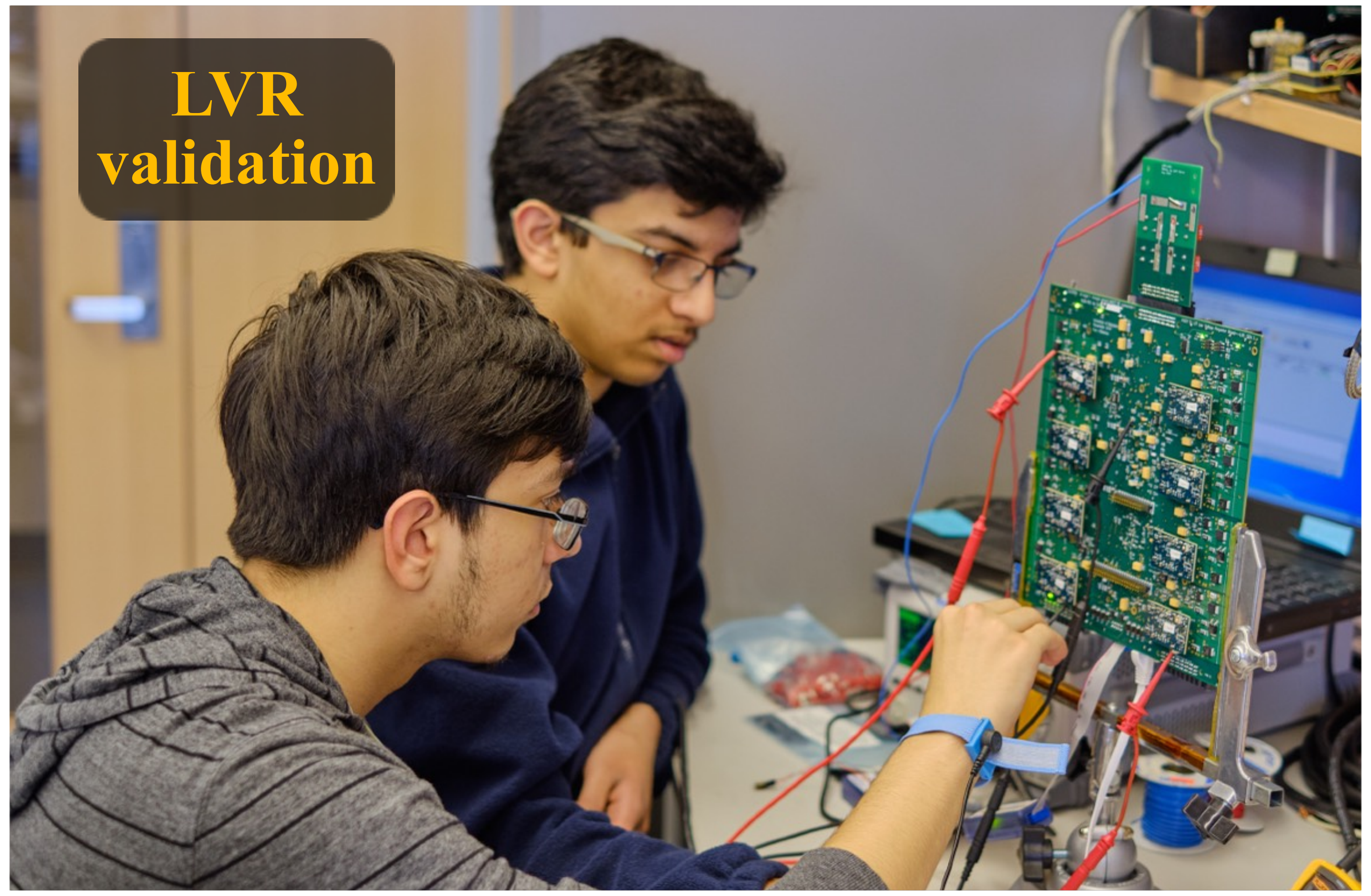


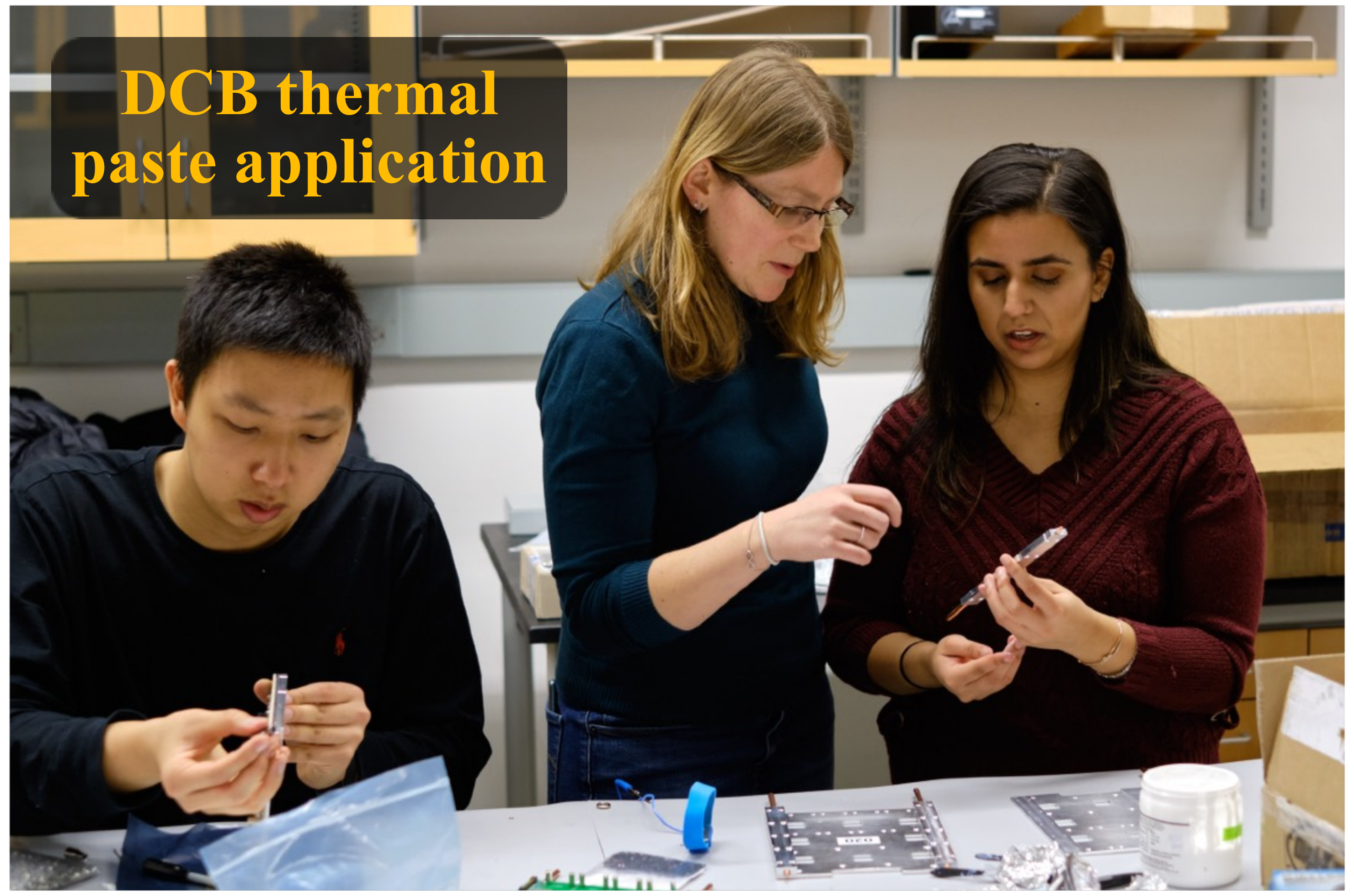
30 Backplanes

Distribution of signals to **balance the data load**



Design/validation/assembly at UMD



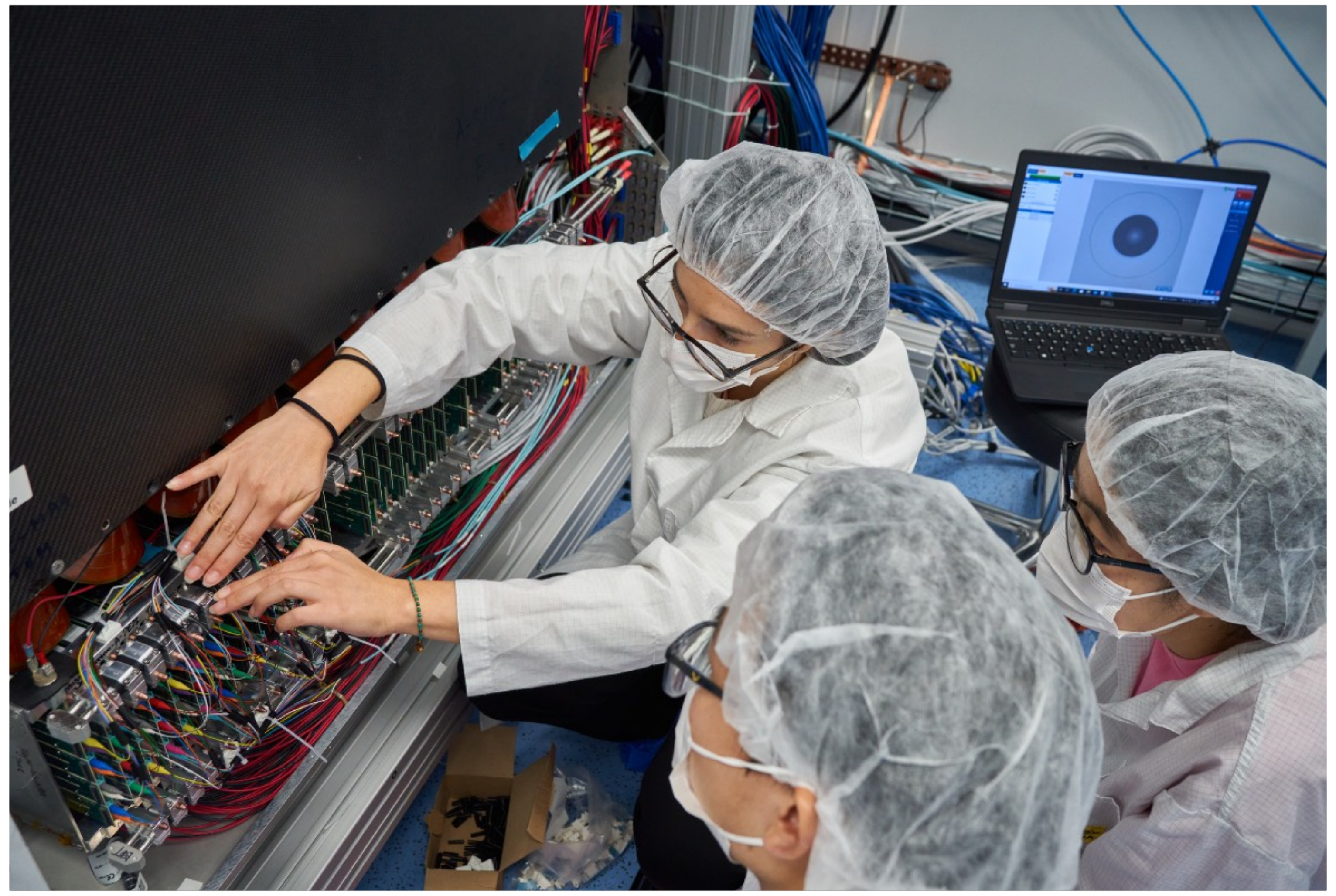


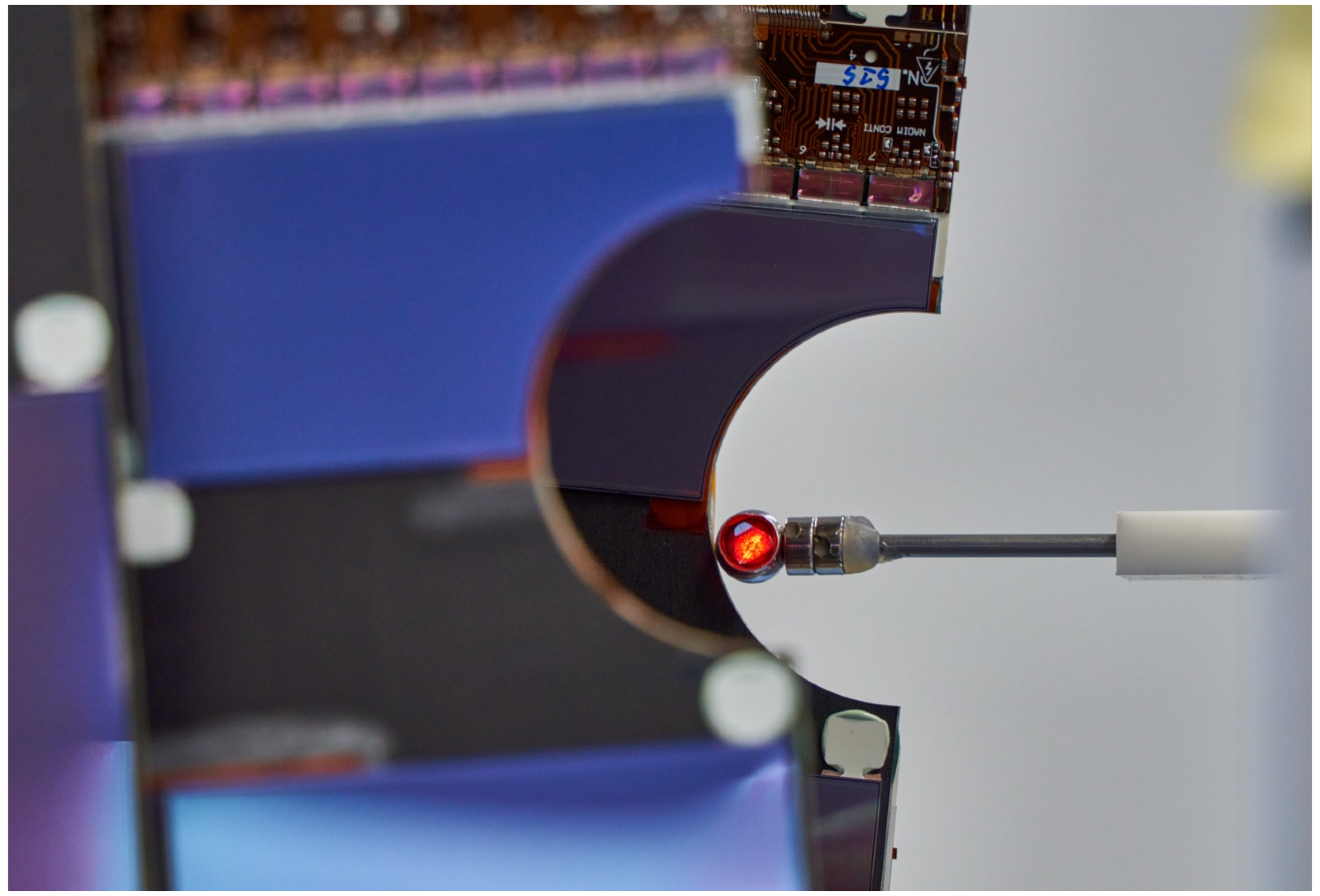
Immense effort from an **electronics engineer**, **3 postdocs**, **4 graduate students**, **12 undergraduate students**, **2 faculty**

Detector assembly at CERN

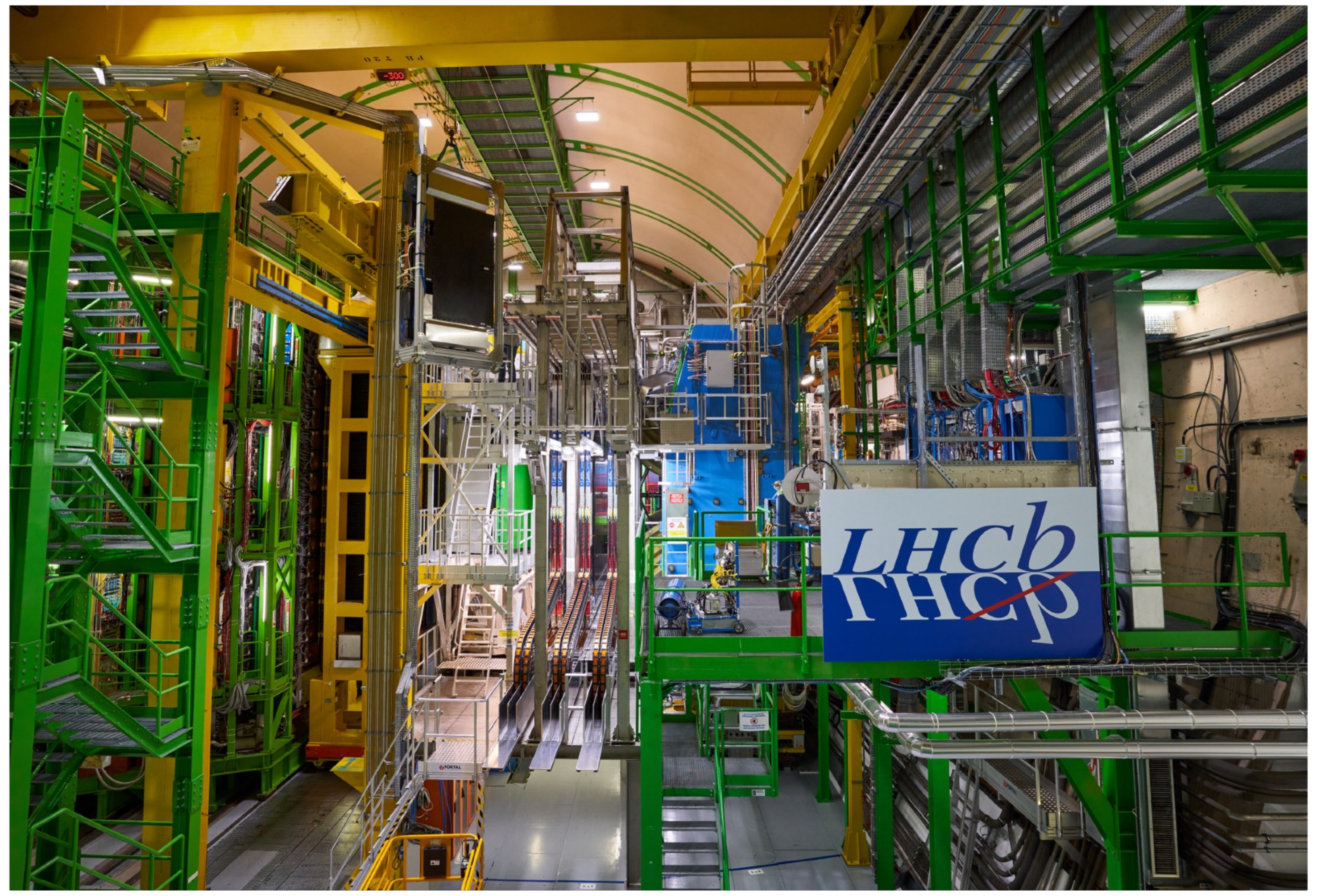
All our postdocs, grad students spent months **at CERN** contributing

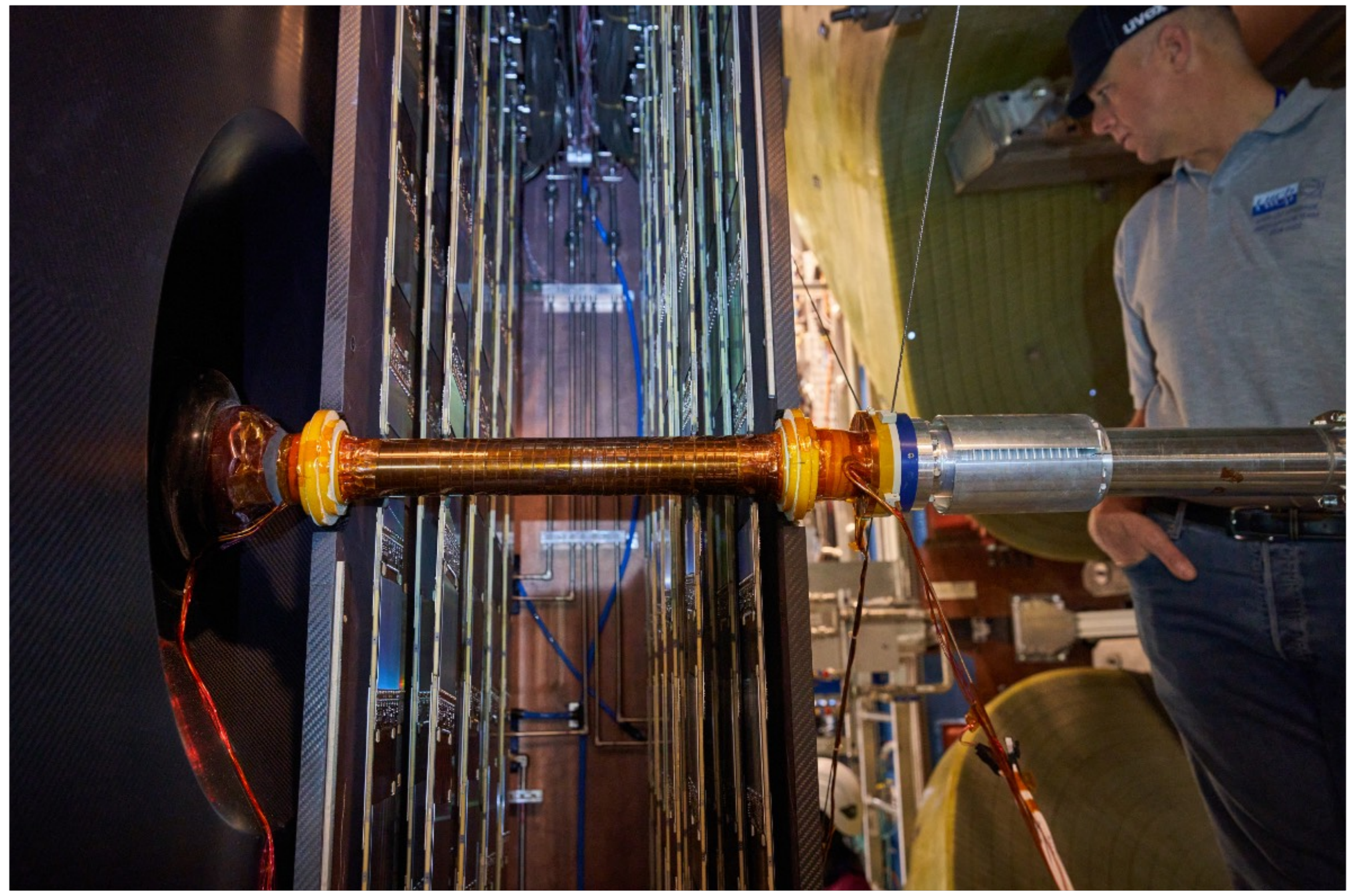
I **led final phase** of **assembly** and **installation**



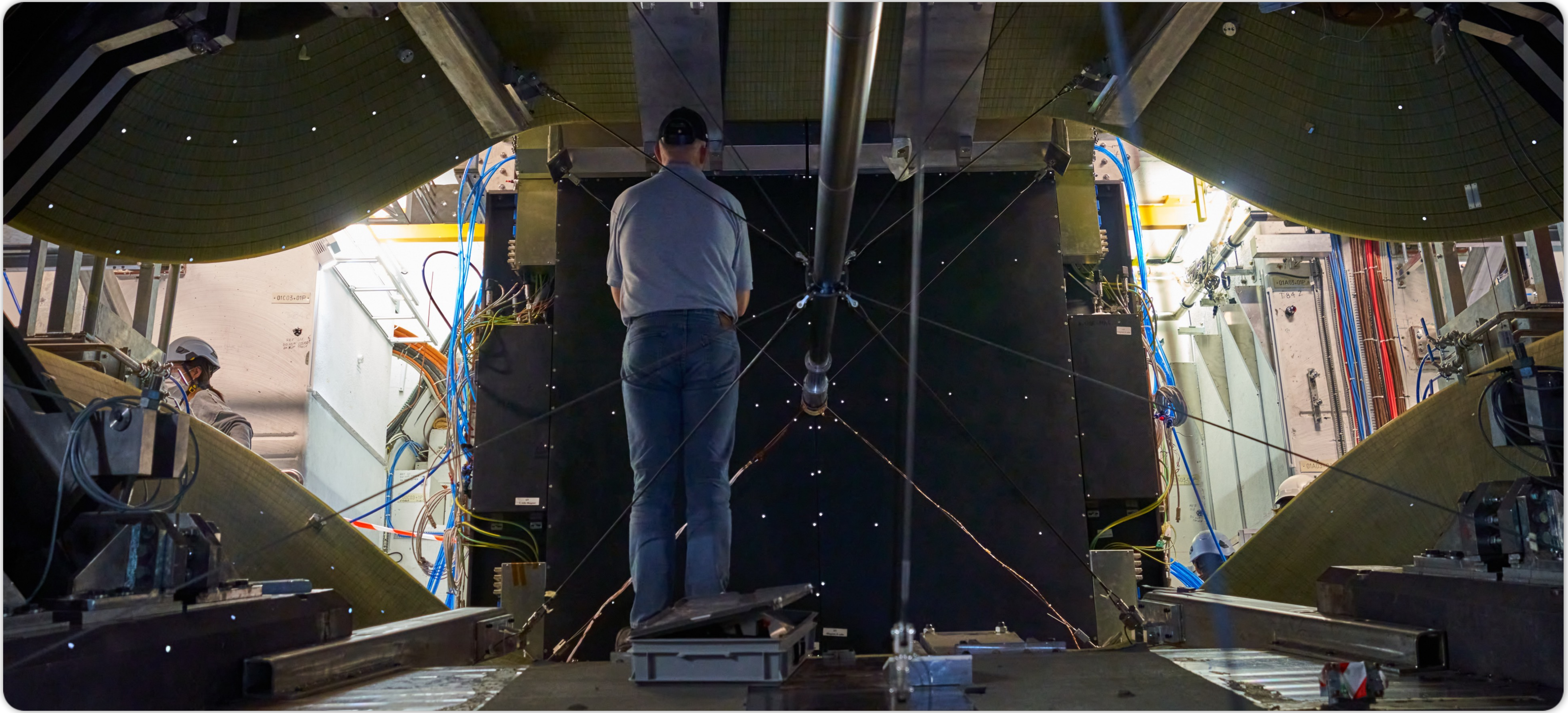


Installation in LHCb cavern





UT's resting place for the next 10 years



Finally, relax

After UT installation, time to go to the **Alps** and **celebrate New Year's <u>together away from home</u>**

Thank you!

Questions?