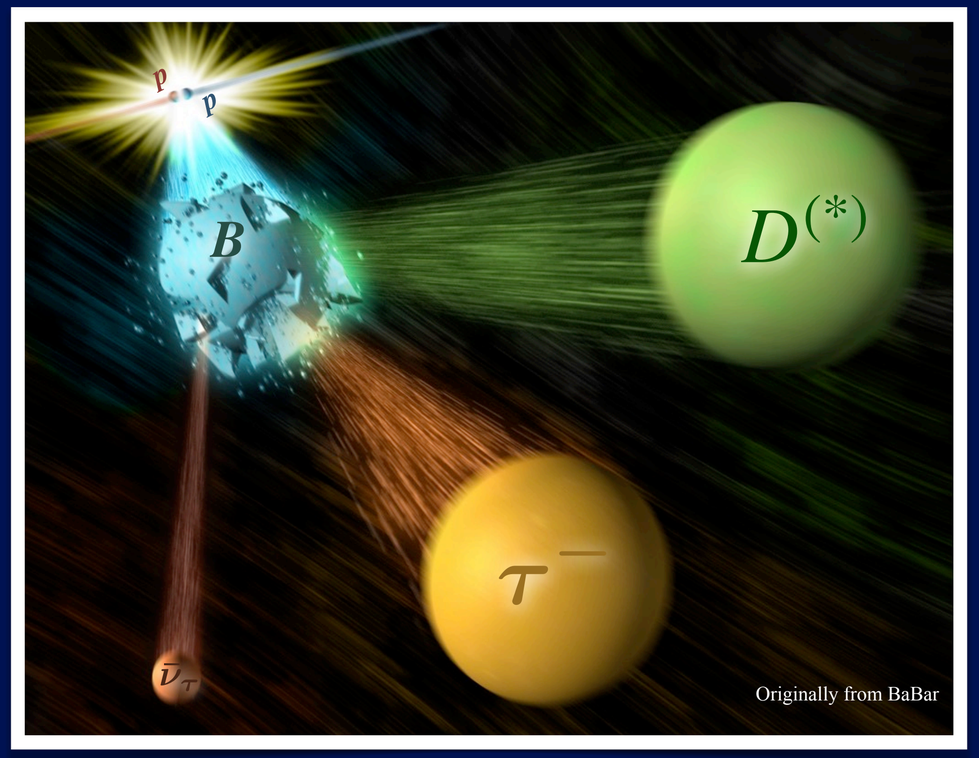
New physics in heavy quark decays? Challenges to Lepton Flavor Universality and prospects with an upgraded LHCb detector

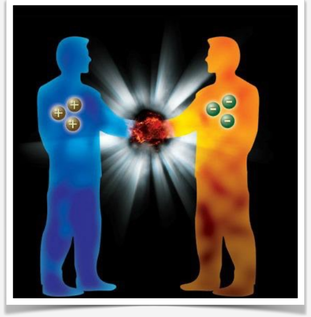


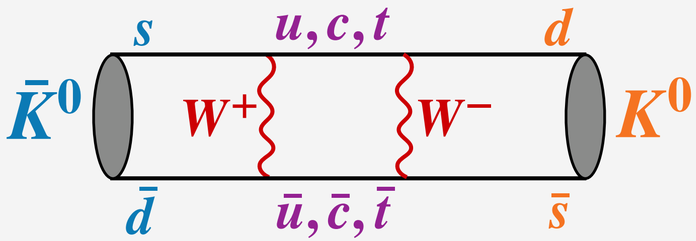
Manuel Franco Sevilla
University of Maryland

30th September 2025
UMD physics department colloquium

Outline

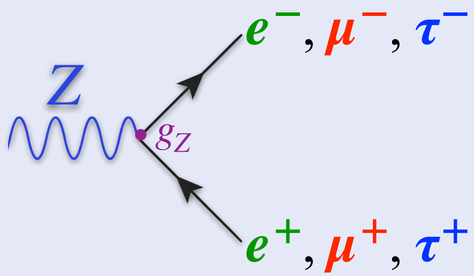
1. Searching for “New Physics”

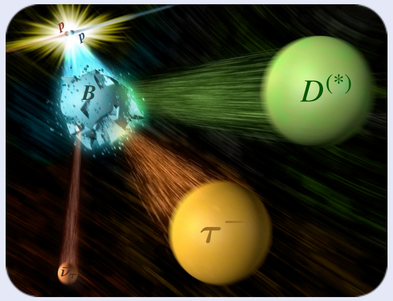




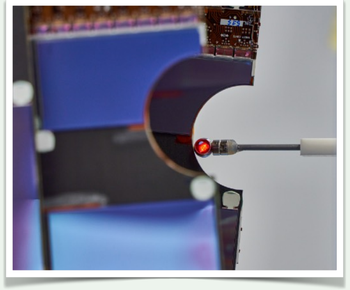
2. The machines

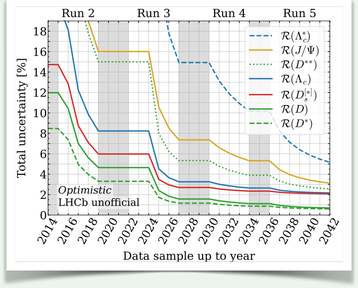
3. Lepton Flavor Universality violation?





4.Building the UT and future prospects with upgraded LHCb

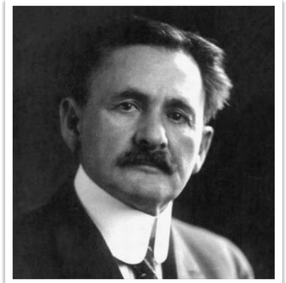




Quick history of classical physics

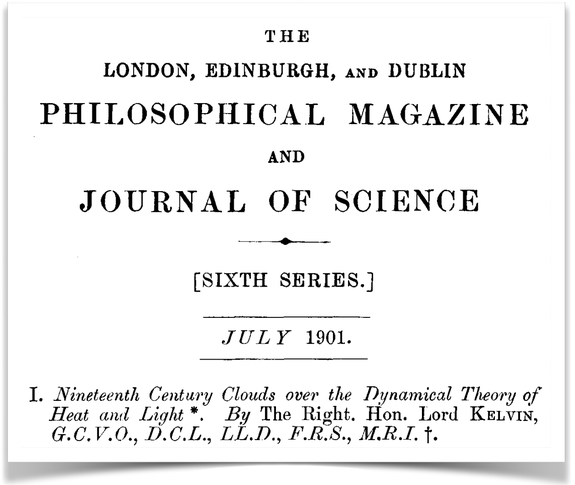
Newton's laws — *Kinetic theory of heat* — *Conservation of energy* — *Coulomb's law* — *Light interference, diffraction* — *2nd law thermo* — *Maxwell equations* — *Statistical mechanics*

XVII century	XVIII century	XIX century
Classical Physics		



Michelson in 1894

*"It seems probable that most of the **grand underlying principles have been firmly established**...*
*An eminent physicist remarked that the future truths of physical science are to be looked for in the **6th place of decimals**"*



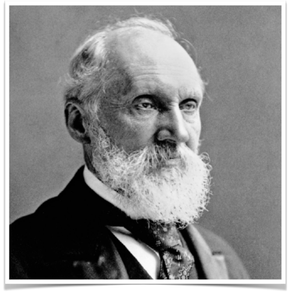
THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE

[SIXTH SERIES.]

JULY 1901.

I. *Nineteenth Century Clouds over the Dynamical Theory of Heat and Light* *. *By* The Right. Hon. Lord KELVIN, *G.C.V.O., D.C.L., LL.D., F.R.S., M.R.I.* †.

Ultraviolet catastrophe — *Michelson-Morley experiment*



Lord Kelvin in 1901

*"The **beauty** and **clearness** of the **dynamical theory**, which asserts heat and light to be modes of motion, is at present **obscured by two clouds**"*

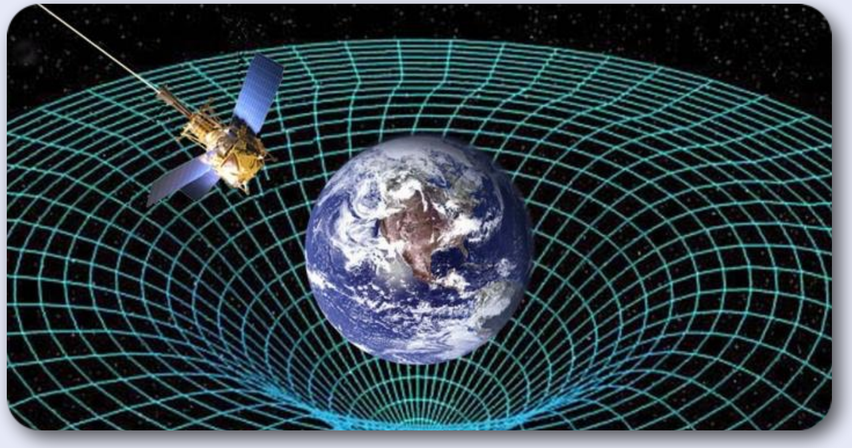
Quick history of modern fundamental physics

Ultraviolet catastrophe — *Michelson-Morley experiment* — *$E = h\nu \rightarrow$ Quantum physics* — *Special Relativity* — **General Relativity** — *Schrödinger equation* — *Positron discovery* — *QED* — *Particle zoo* — *Higgs mechanism* — **Standard Model of particle physics** — *QCD* — *W/Z bosons* — *Top quark* — *Higgs discovery* — *Gravitational waves*

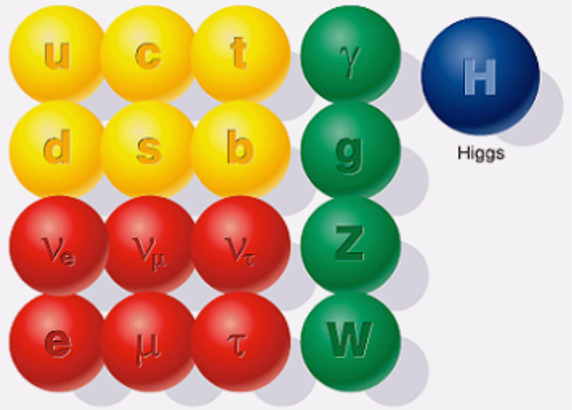
XIX century	XX century	XXI century
Classical Physics	Modern Physics	

General Relativity

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

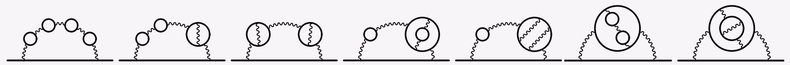


Quantum Field Theory + $SU(3) \times SU(2)_L \times U(1)$ symmetry +



Standard Model of particle physics

Most precise and comprehensive theory in the history of mankind



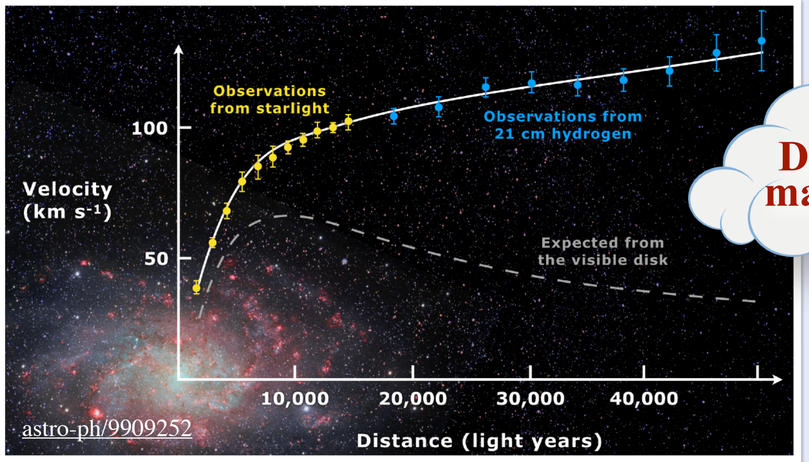
$$\left.\frac{g_e - 2}{2}\right|_{\text{SM}} = 0.001\ 159\ 652\ 181\ 606\ (230)$$

Atoms 7, 28 (2019)

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

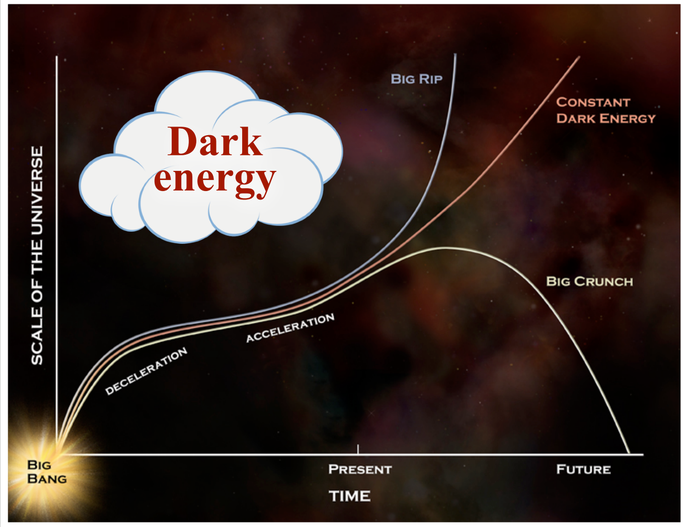
Phys. Rev. Lett. 100, 120801 (2008)

Some *clouds* today

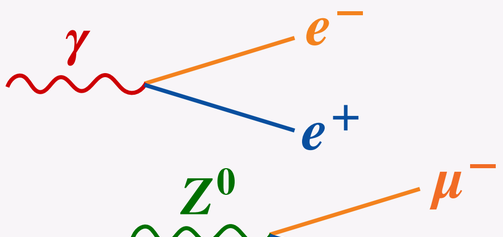


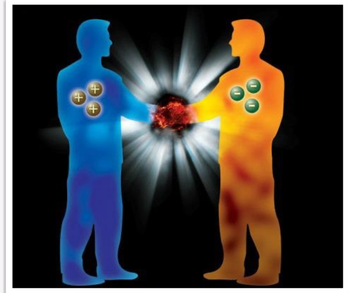
Dark matter

NASA CXC M. Weiss



Dark energy





Matter ≫ Antimatter

GR-SM unification

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

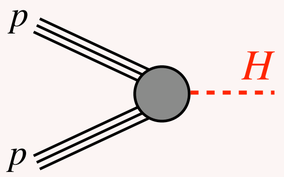
$$SU(3) \times SU(2)_L \times U(1)$$

Searching for new physics

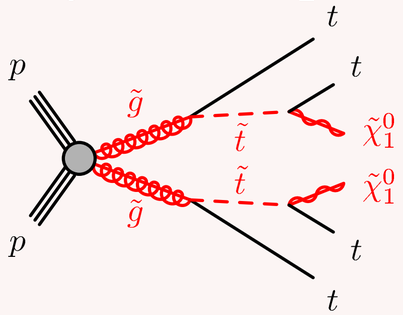
Direct searches

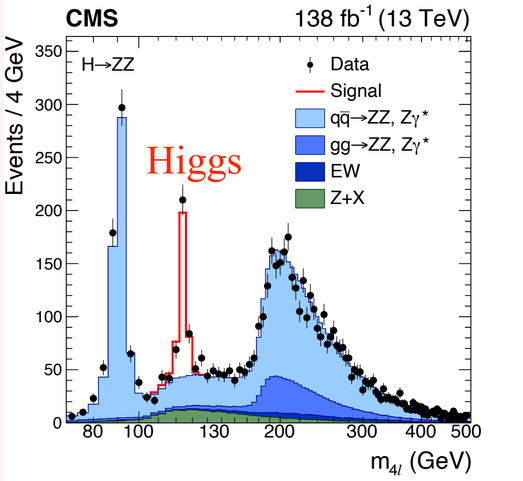
Produce and *detect* new physics

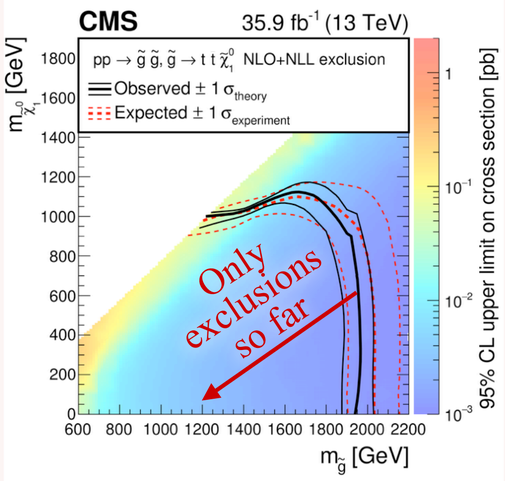
Colliding protons *hard enough*, we **produced Higgs bosons** at the LHC



Also **hoped** to see **supersymmetric particles**

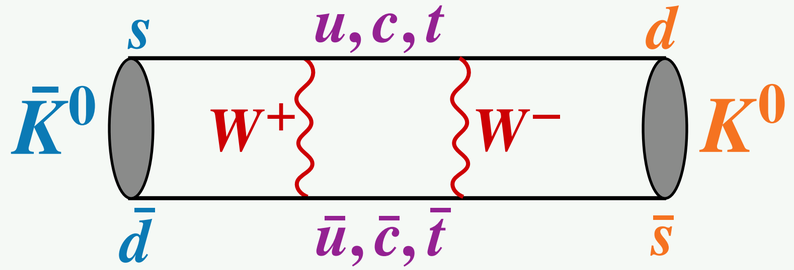






Indirect searches

Compare *precision SM measurements* to predictions looking for new *virtual contributions*

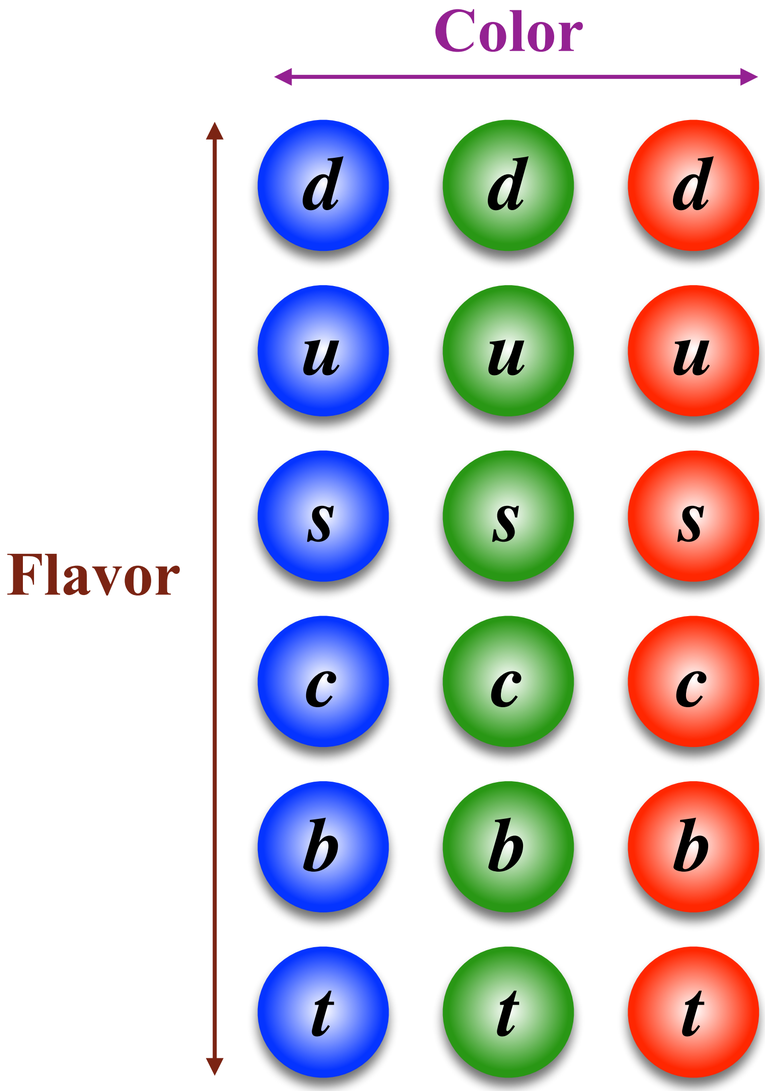


For instance, the study of the **decays of neutral kaon mesons (~ 0.5 GeV) predicted**

- The **charm quark** and that its mass was ~ 1.5 GeV
- The **bottom** (4.2 GeV) and **top** (173 GeV) **quarks**

At LHCb, we focus on **measurements** that give us **access to mass scales beyond the reach** of **current particle accelerators**

Focus on *Flavor physics*

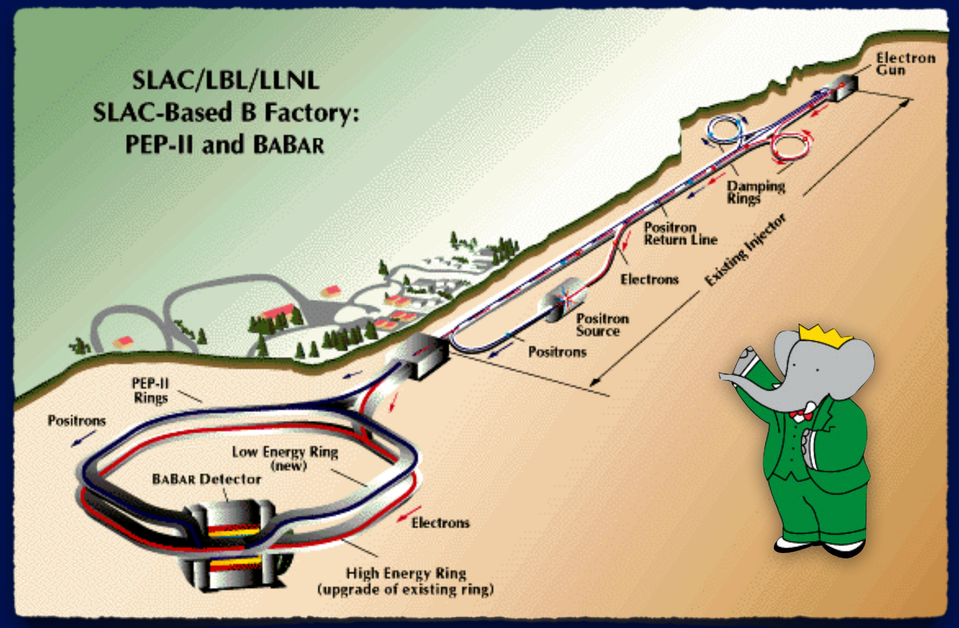


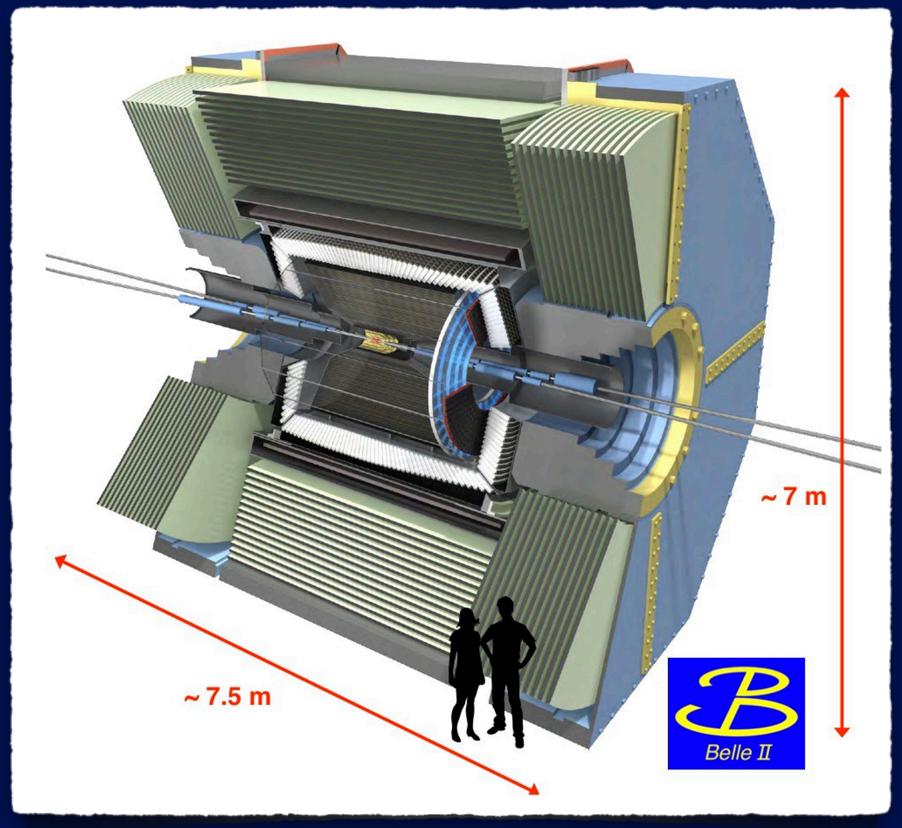
"The term flavor was first used in particle physics in the context of the quark model of hadrons. It was coined in 1971 by Murray ***Gell-Mann*** *and* ***his student*** *at the time,* ***Harald Fritzsch****, at a* ***Baskin-Robbins ice-cream*** *store in* ***Pasadena****.*

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

RMP 81, 1887 (2009)

2. The machines





B factories

	Accelerator	Lab	Country	From	To
BaBar	PEP-II	SLAC	USA	1999	2008
Belle	KEKB	KEK	Japan	1999	2010
Belle II	KEKB	KEK	Japan	2018	~2035

Optimized for **clean** $e^+e^- \to B\bar{B}$ production

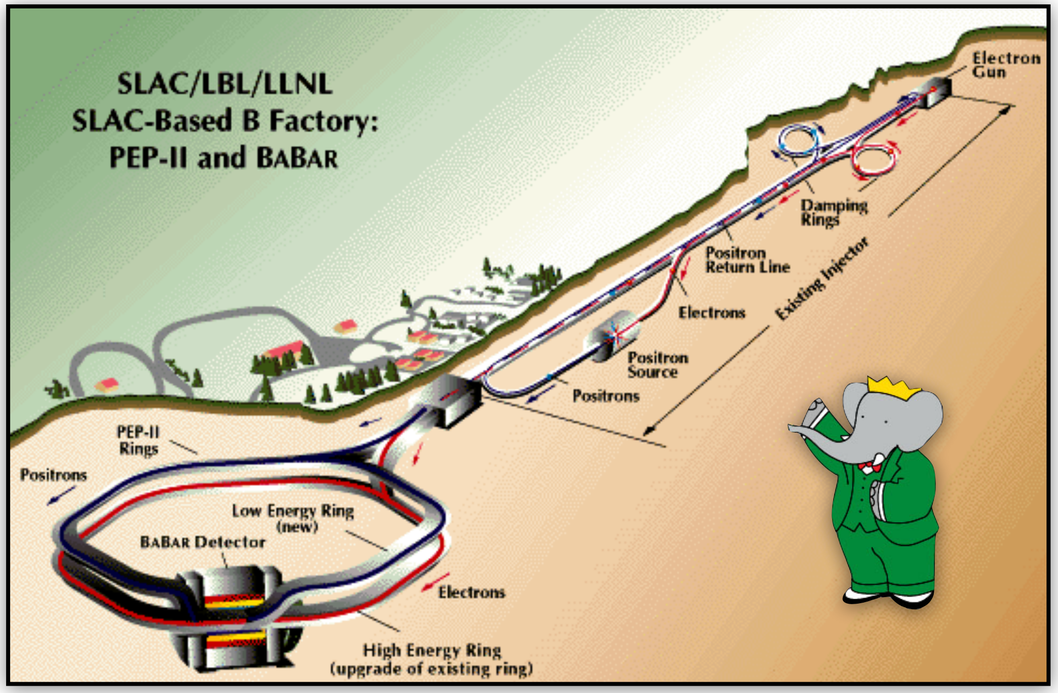
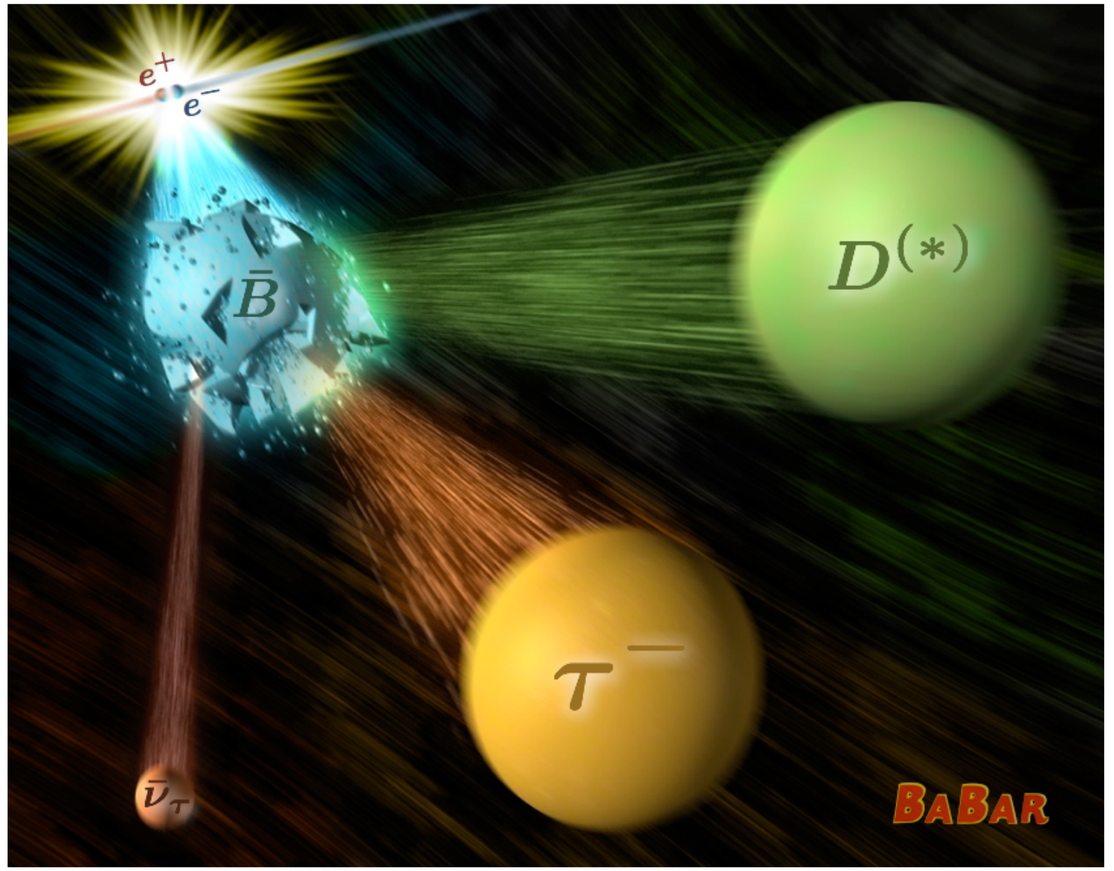


Photo of a $B \to D^{(*)}\tau\nu_\tau$ **event!**



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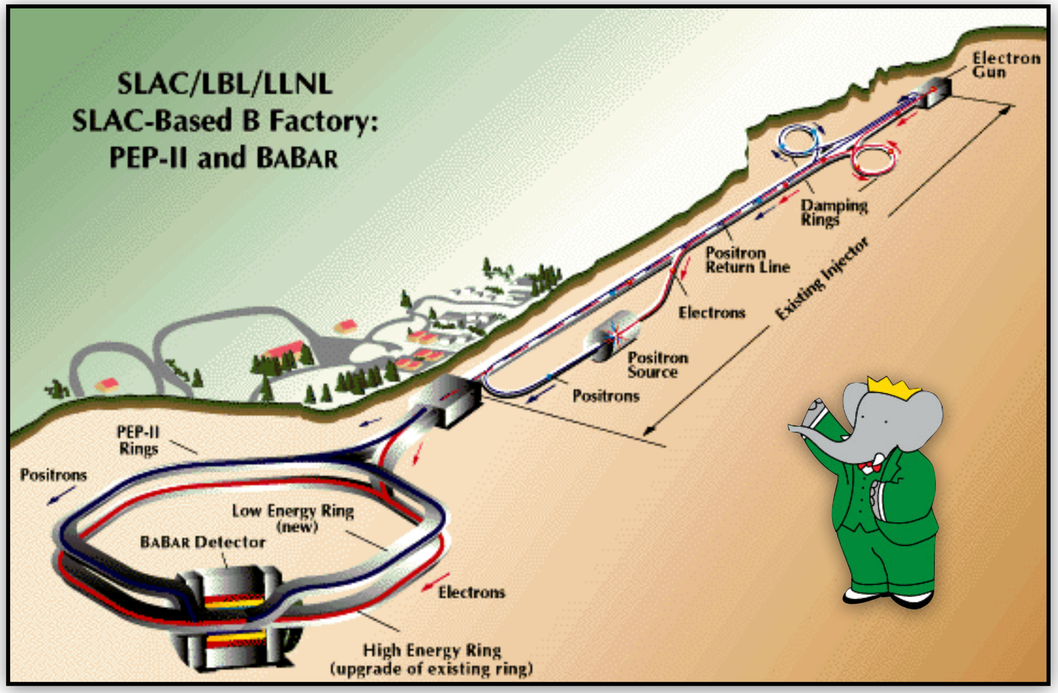
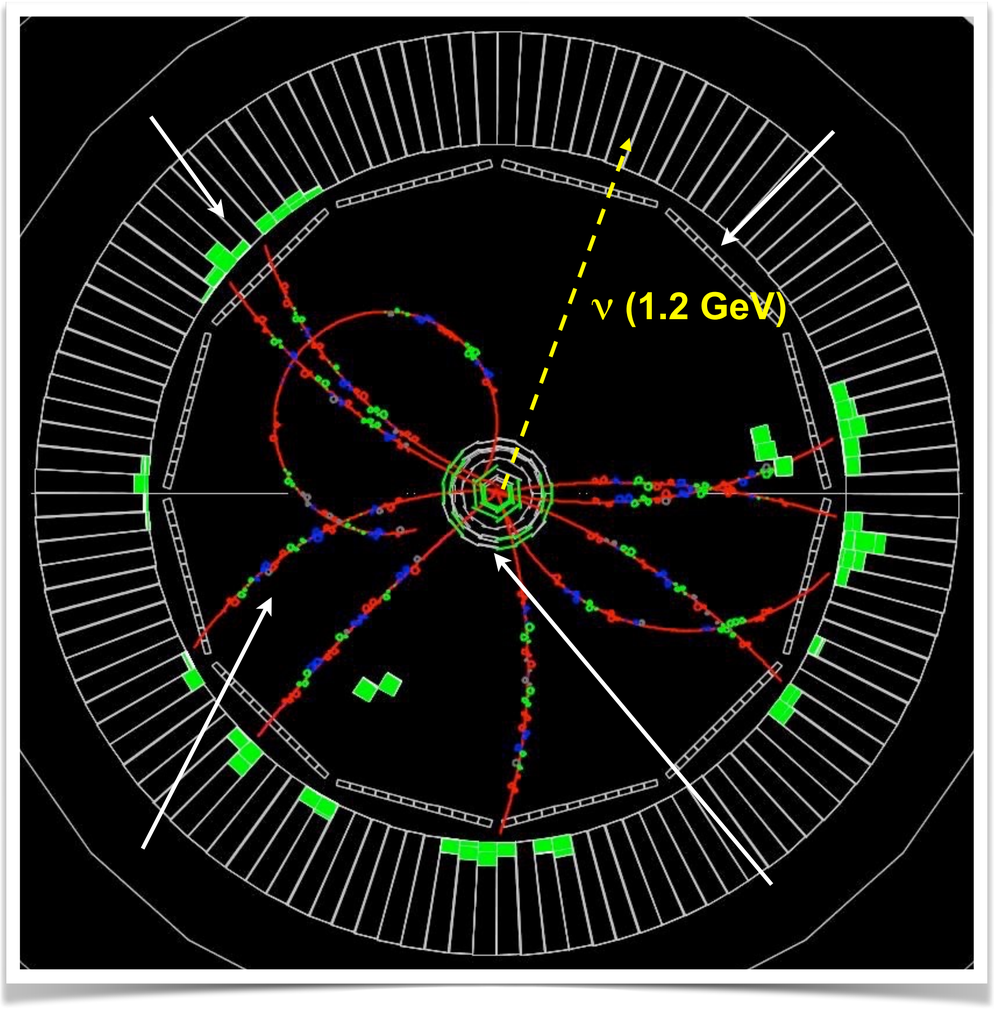
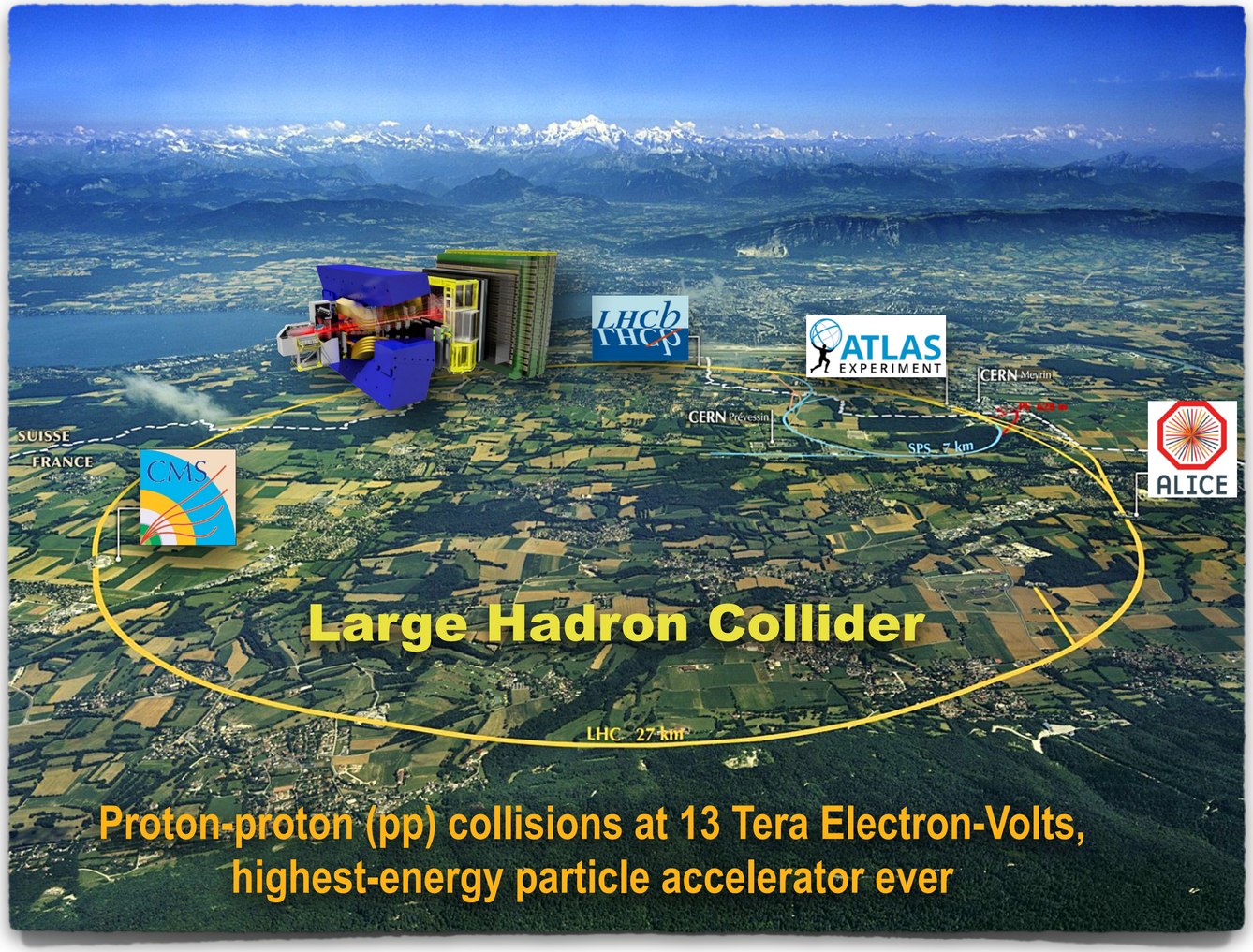
Optimized for **clean** $e^+e^- \to B\bar{B}$ production



Since **100%** of e^+e^- **collision energy** goes **to** $B\bar{B}$, can **reconstruct ν 4-momentum**

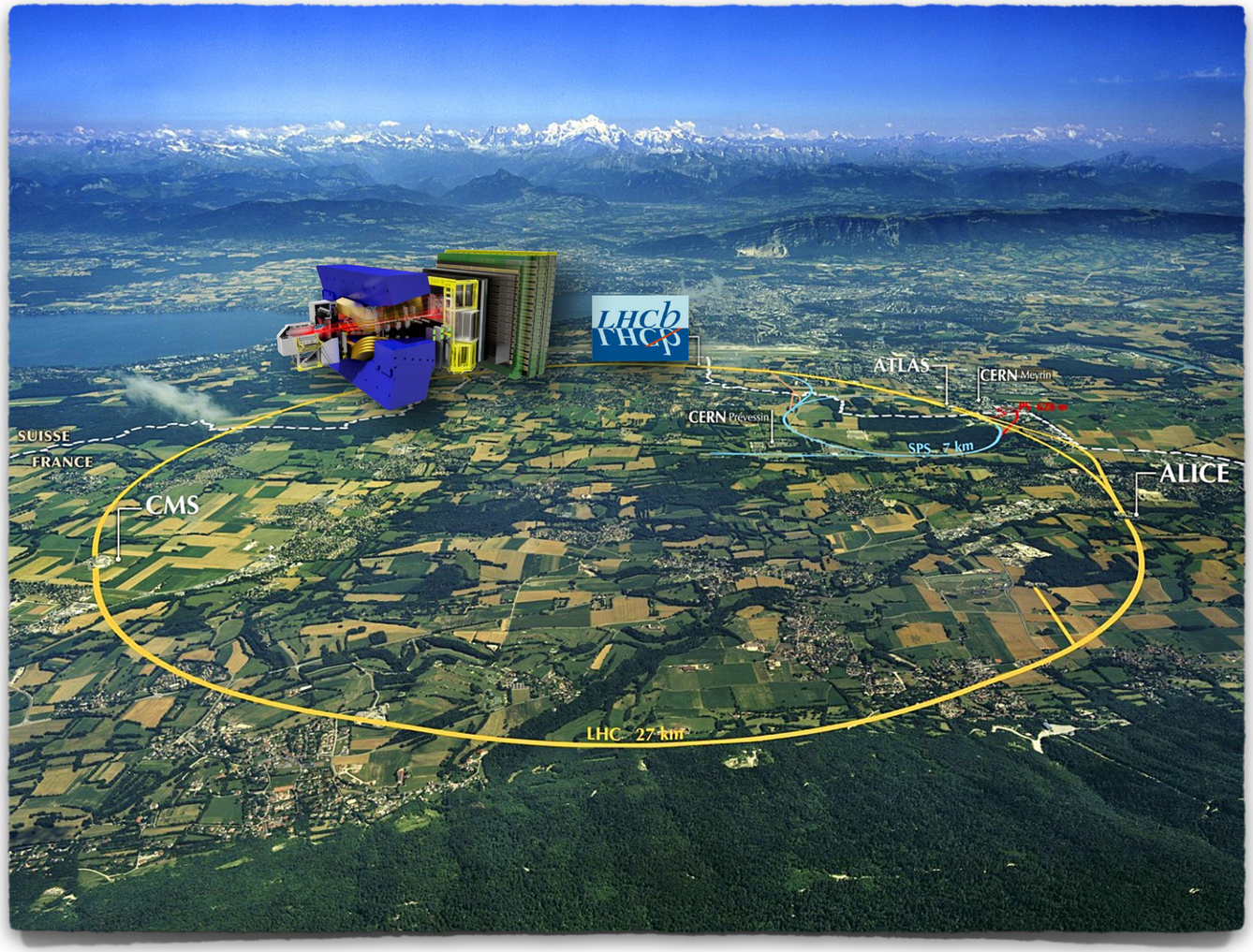


The Large Hadron Collider

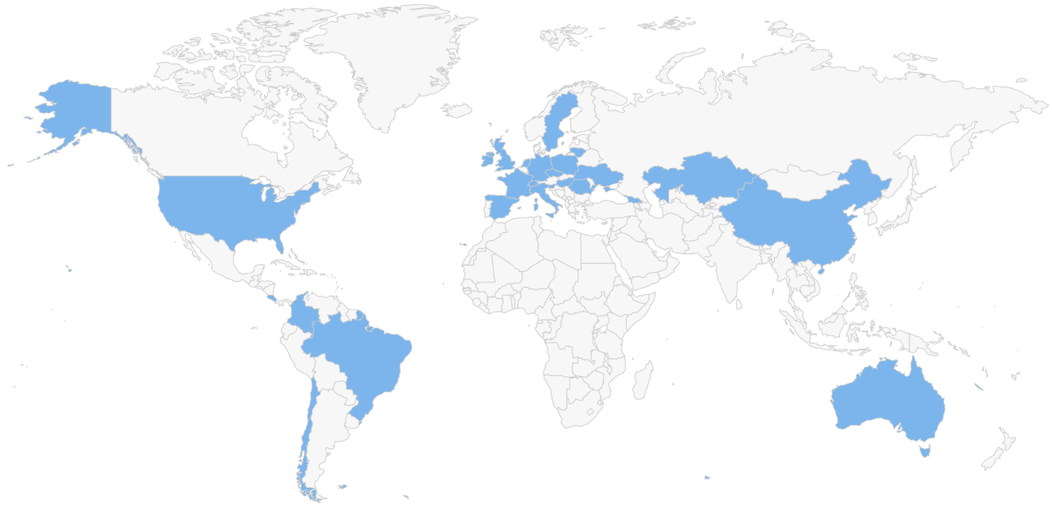


- **27 km** rings **colliding protons**
  - ➡ CERN laboratory in Geneva, Switzerland
- ATLAS and CMS
  - ➡ Discovered **Higgs boson** in 2012
  - ➡ **Direct searches** for **new physics**
- LHCb
  - ➡ **Precision flavor measurements**
  - ➡ **Indirect searches** for **new physics**
- Alice
  - ➡ **Heavy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

LHCb collaboration



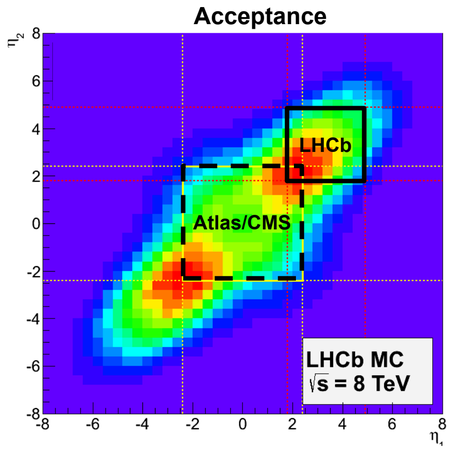
- A **large collaboration**
  - 25 countries, 105 institutes, **1808 members**

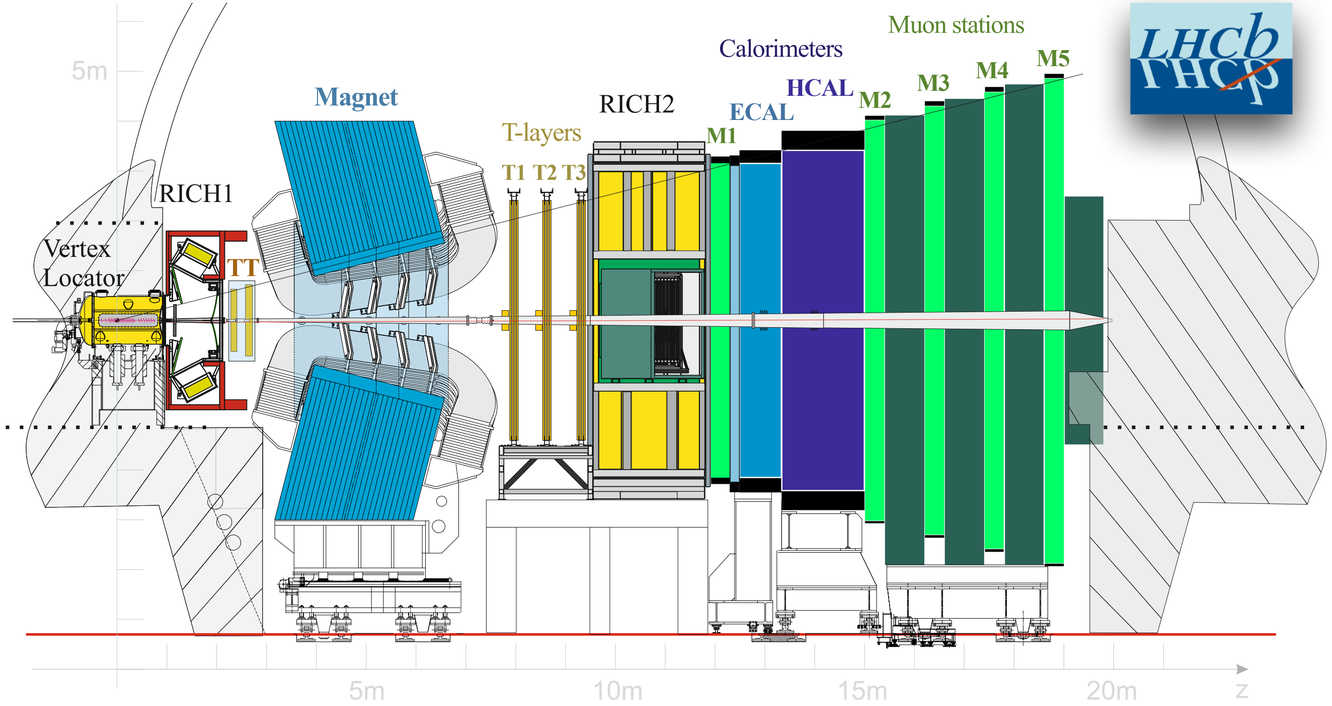


- **US** participation
  - Currently 8 institutes, 82 members
    - **Significant growth in the last years**

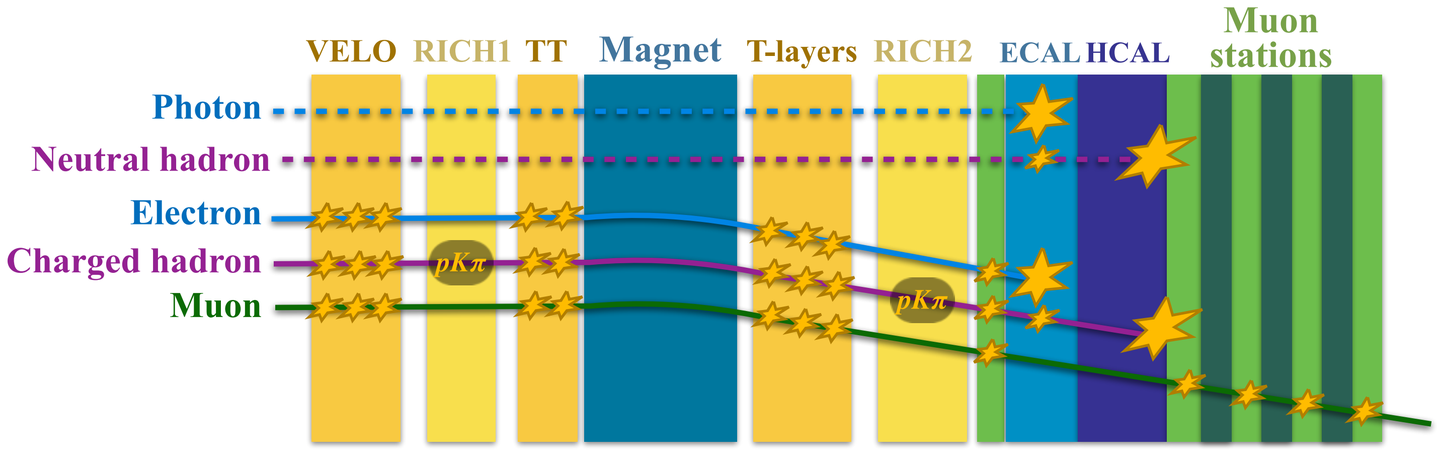
The LHCb detector

- ~ 100k b-hadrons per second
  - 25% of $b\bar{b}$ with 4% of solid angle



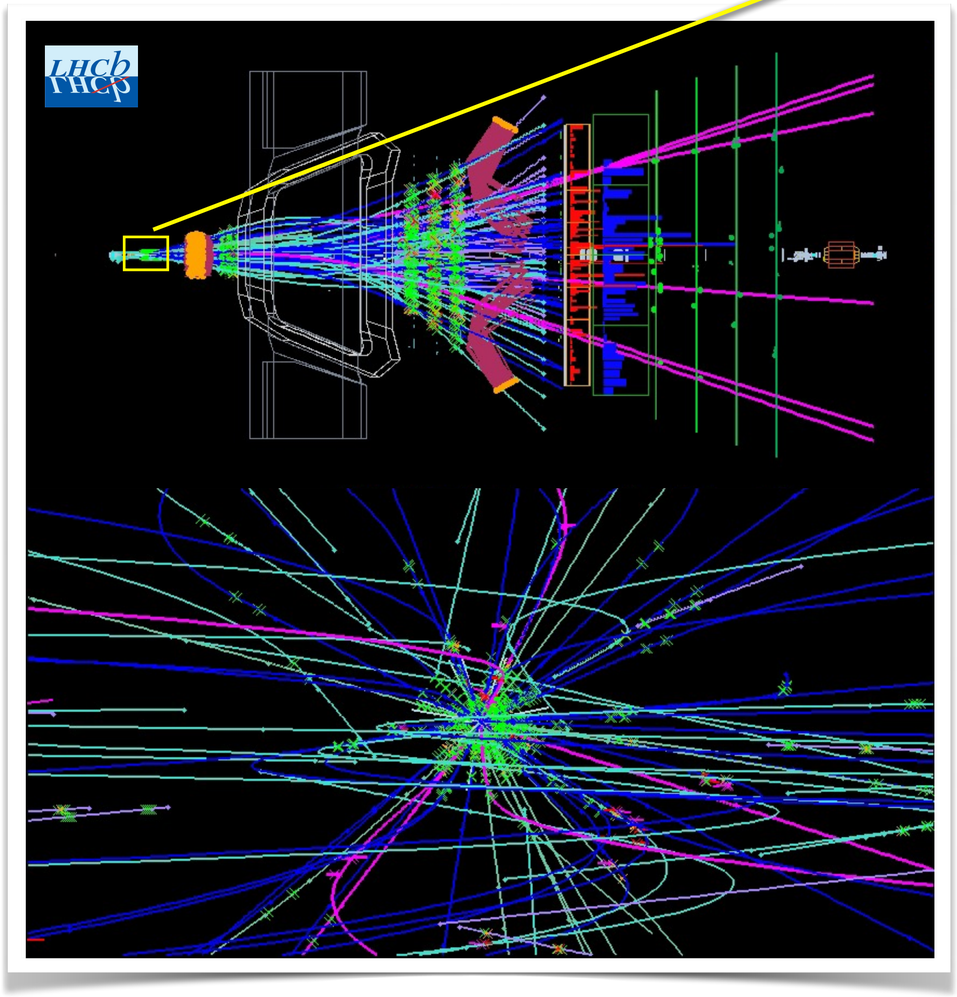


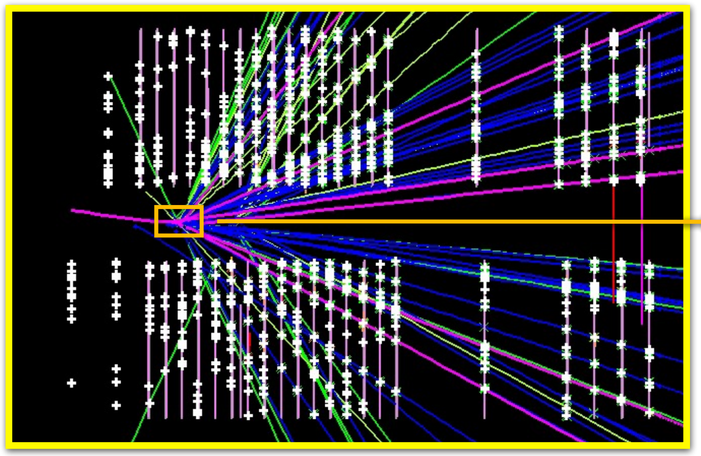
- **Neutral particles** only seen in **calorimeters**
- **Charged** particles leave **charge deposits** in **trackers**
  - **Momentum** from **magnet bending**
- **Muon station** are trackers **shielded by steel**

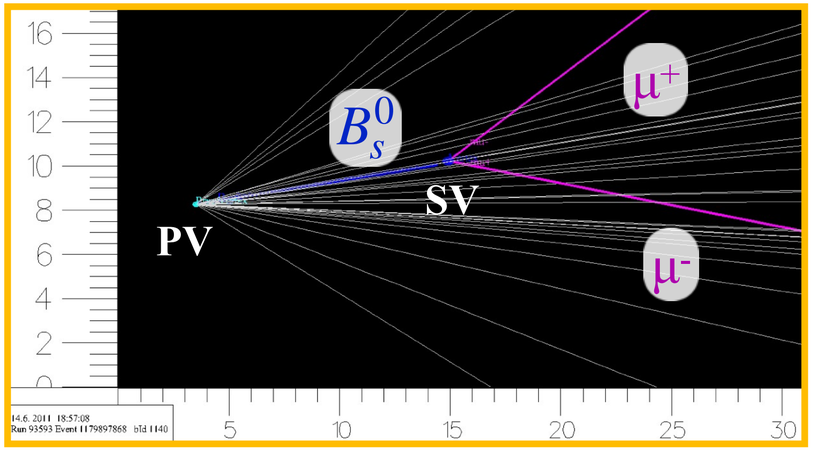


Vertexing is key to LHCb

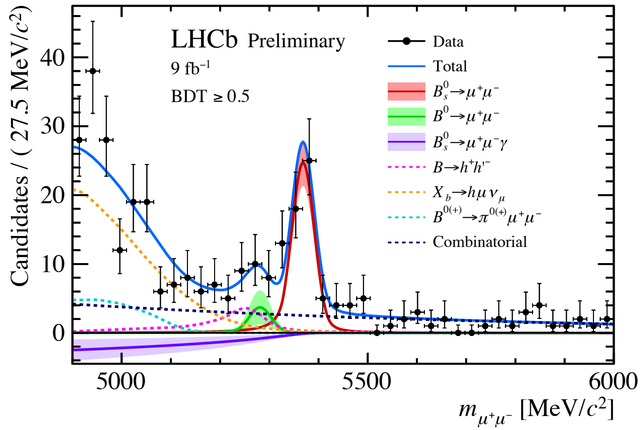
How do we make sense of this mess?







- **B mesons lifetime** $\sim 10^{-12}$ s
  - Most other particles have $\sim 10^{-21}$ 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

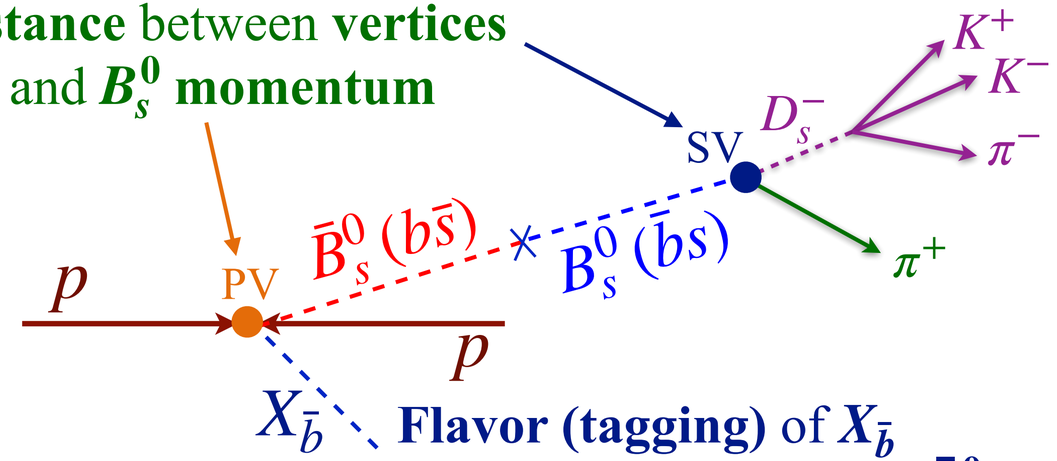


$pp \to X_b B_s^0 X$

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

B_s^0 oscillations: the most beautiful plot

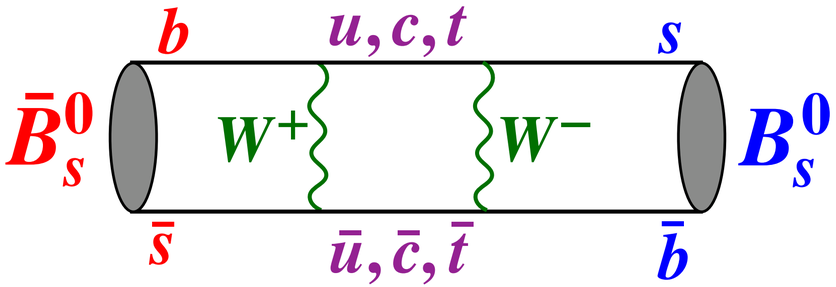
Find **decay time** with **distance** between **vertices** and B_s^0 **momentum**

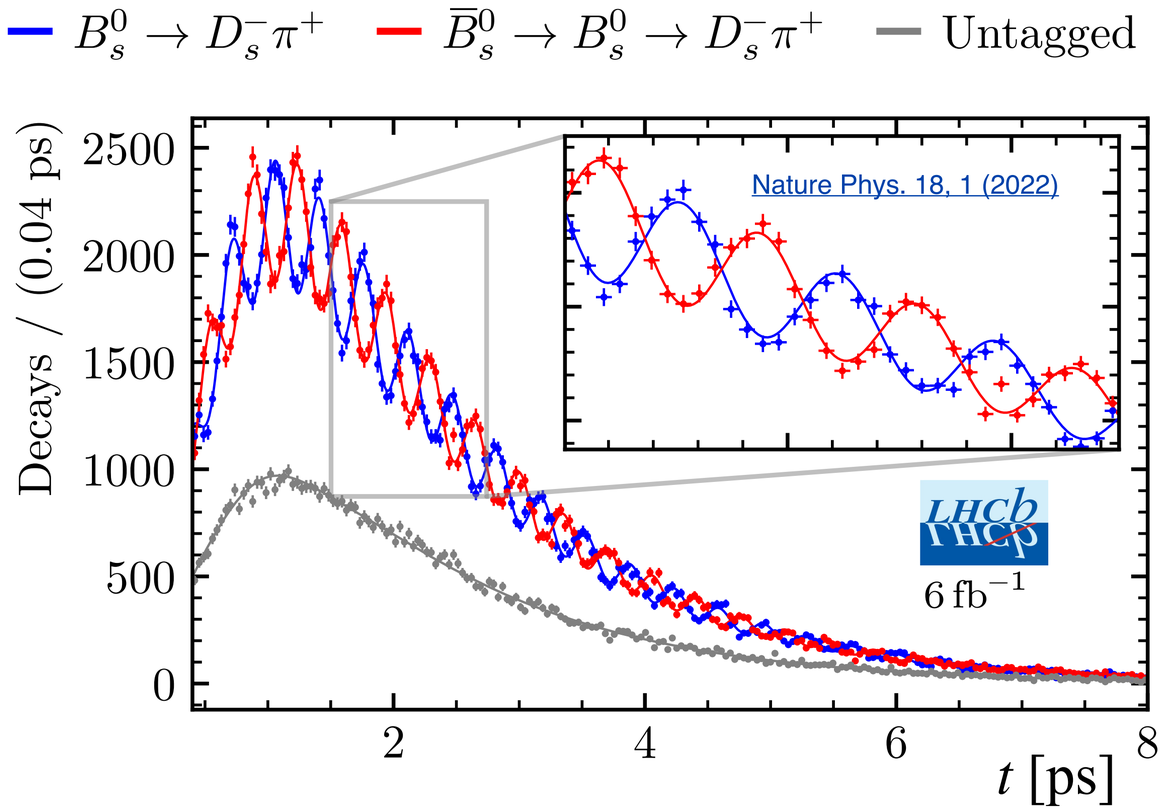


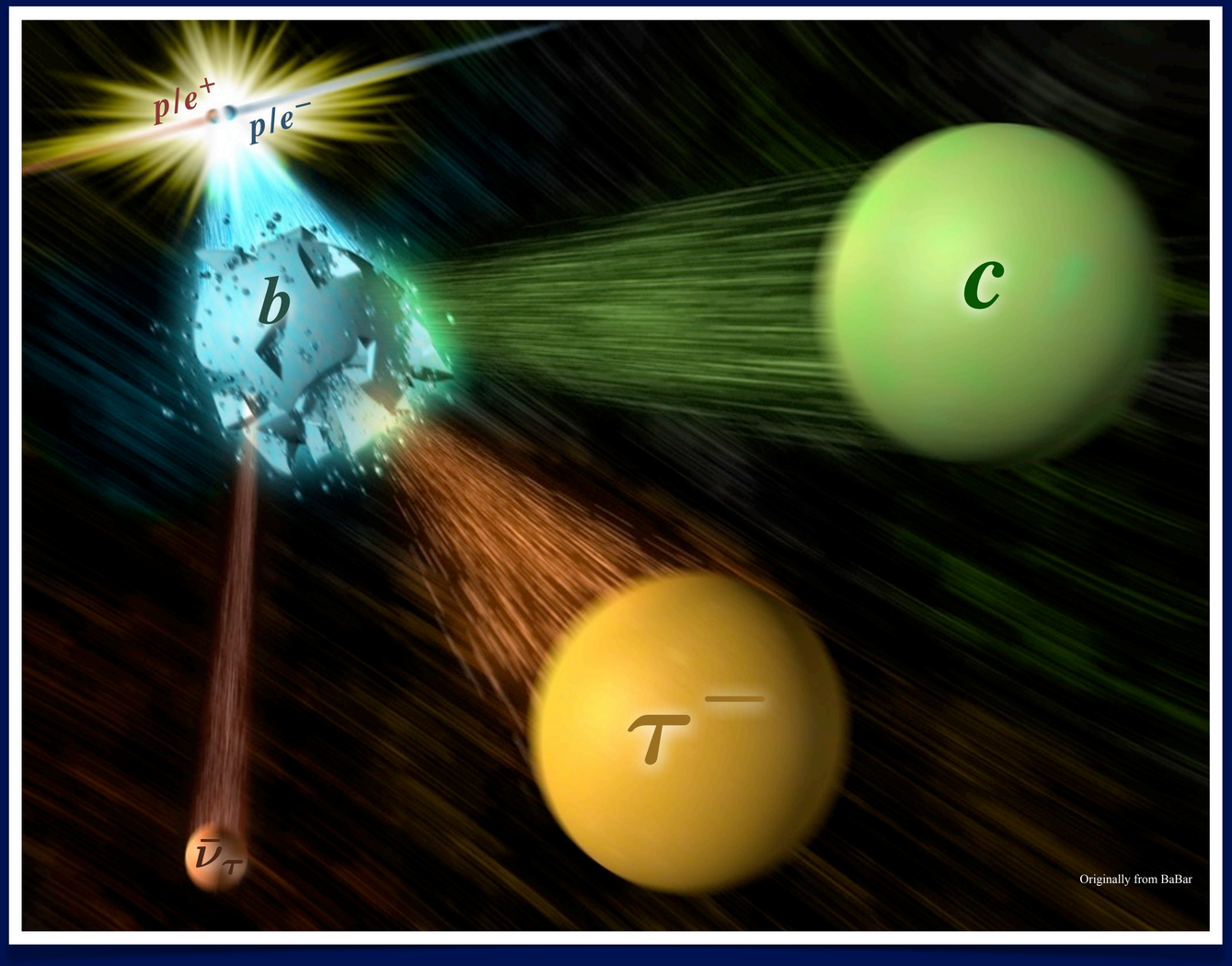
Flavor (tagging) of $X_{\bar{b}}$ gives **original flavor** of $\bar{B}_s^0$

With **2nd order perturbation theory** and $\bar{B}_s^0 - B_s^0$ **mixing**, easy to show that $B_s^0 \to D_s^- \pi^+$ **decay-time distribution** is given by

$$P(t) \sim e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) \pm \cos(\Delta m_s t)\right]$$

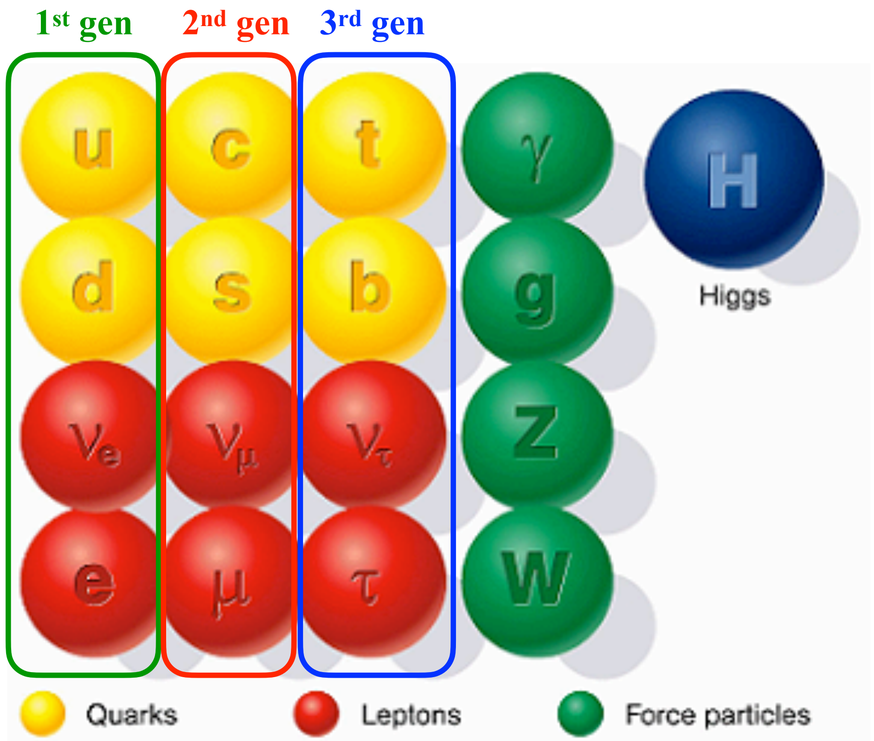






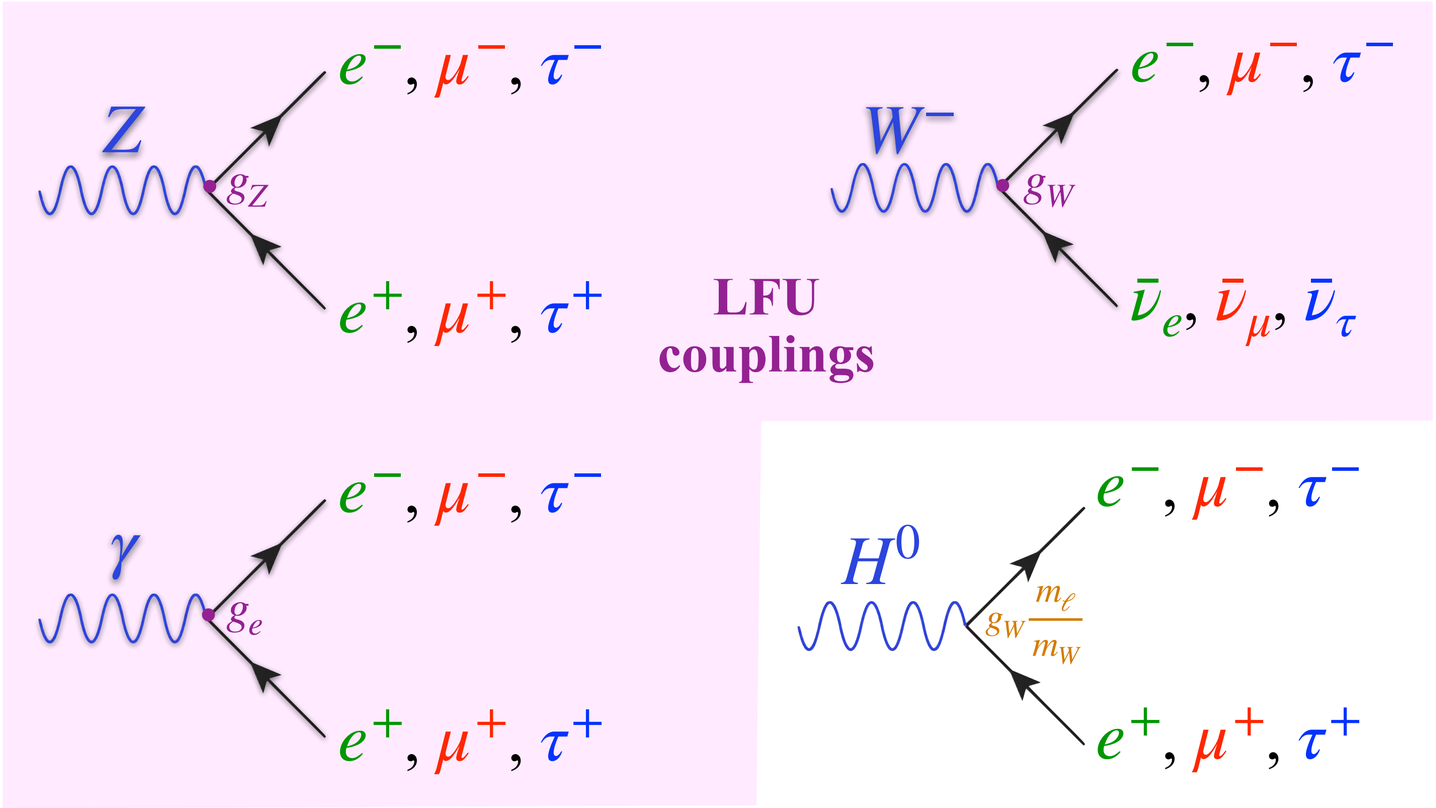
3. LFU violation in $b \to c\tau\nu$ transitions?

Lepton Flavor Universality (LFU)



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, PRL 131, 051803 (2023)

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

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

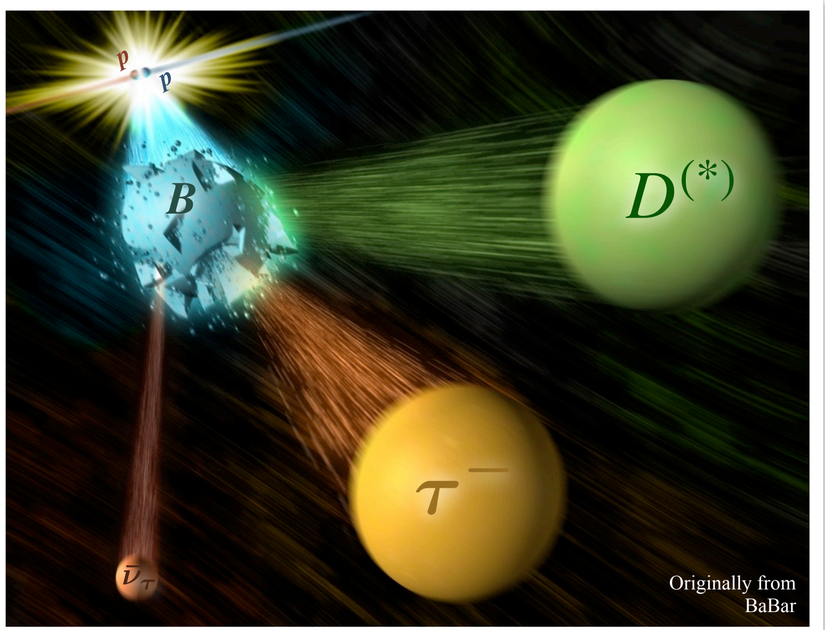
HFLAV, Eur. Phys. J. C77 (2017) 895

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

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

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 $\mathcal{B}$

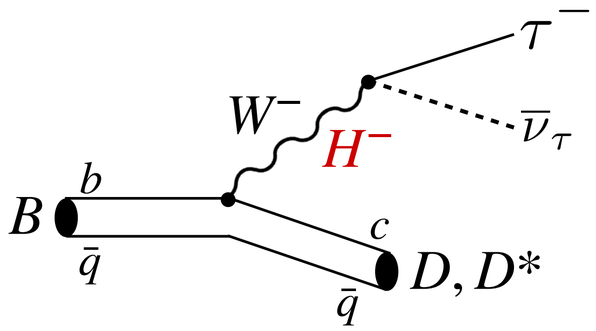
HFLAV

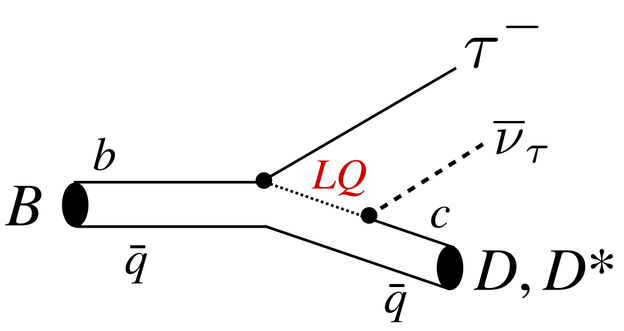
$$\mathcal{R}(D)^{SM} = 0.296 \pm 0.004$$

$$\mathcal{R}\left(D^*\right)^{SM} = 0.254 \pm 0.005$$

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

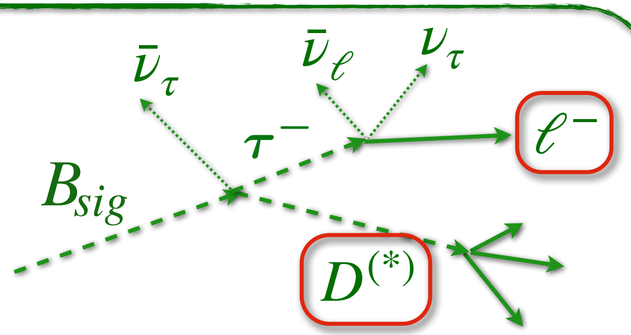
Any established **deviations** would be clear indications of **New Physics beyond the SM**





Signal vs Normalization

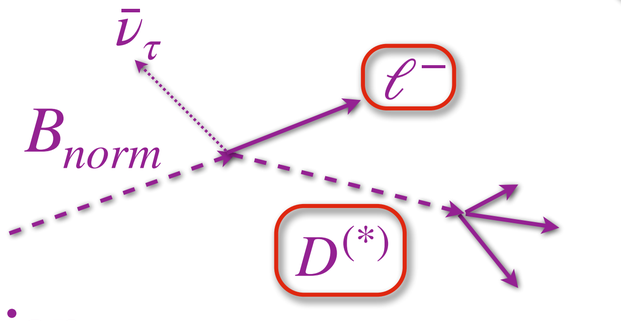
Three undetectable neutrinos ν



Signal

$B \to D^{(*)}\tau\left(\to \ell\nu\bar{\nu}\right)\bar{\nu}$

One undetectable neutrino ν



Normalization

$B \to D^{(*)}\ell\nu$

~ The τ **lepton** in **signal** decays can be **reconstructed** as $\tau^- \to \ell^-\nu_\tau\bar{\nu}_\ell$

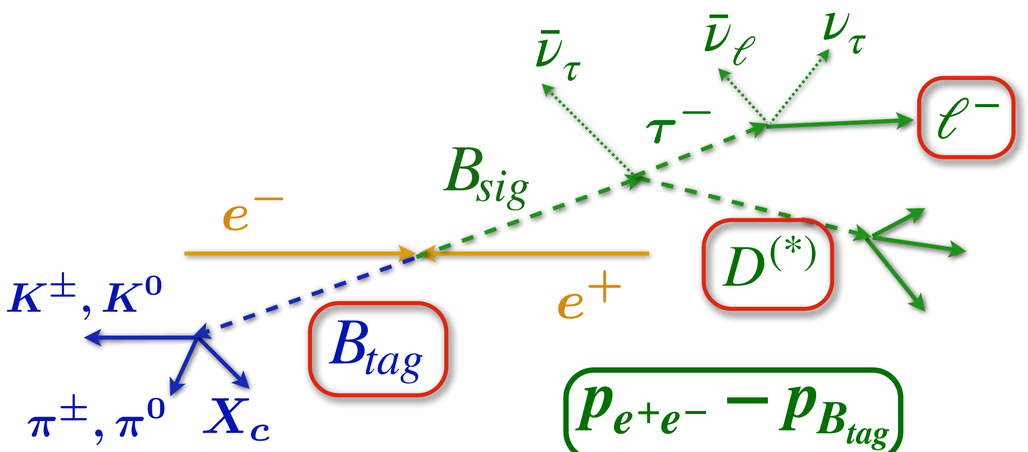
$$\mathcal{R}\left(D^{(*)}\right) = \frac{\mathcal{B}\left(\bar{B} \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(\bar{B} \to D^{(*)}\ell\nu_\ell\right)}$$

~ **Signal** has **same visible particles** as **normalization decays**

Many **experimental uncertainties cancel** on $\mathcal{R}\left(D^{(*)}\right)$ **ratios**

Neutrinos are **undetectable**, so **how** do we **tell signal** and **normalization apart?**

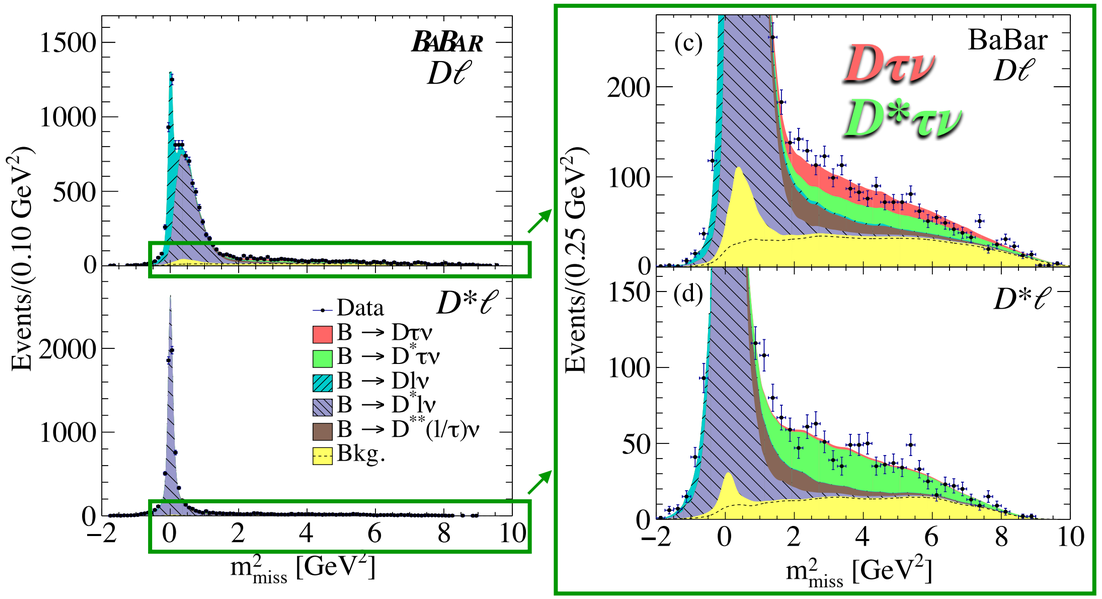
Missing mass at the B factories



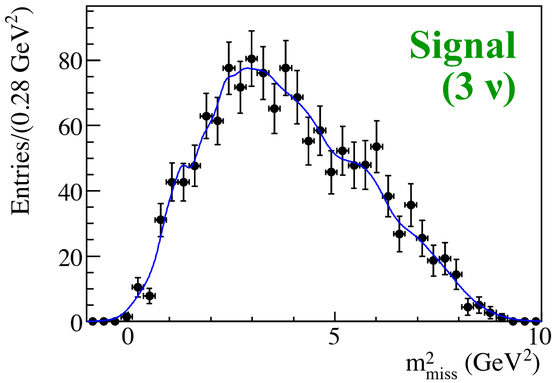
$$m^2_{miss} = \left(p_{B_{sig}} - p_{D^{(*)}} - p_\ell\right)^2$$

$$p_{e^+e^-} - p_{B_{tag}}$$

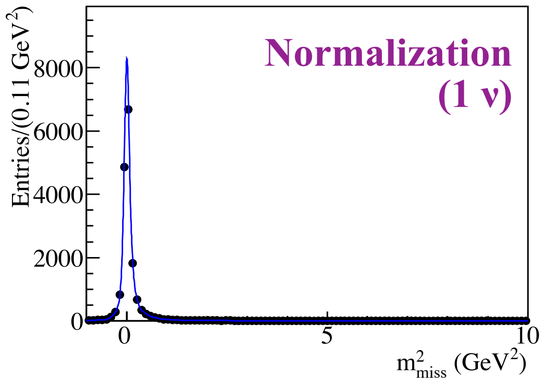
Phys. Rev. Lett. **109**, 101802 (2012)

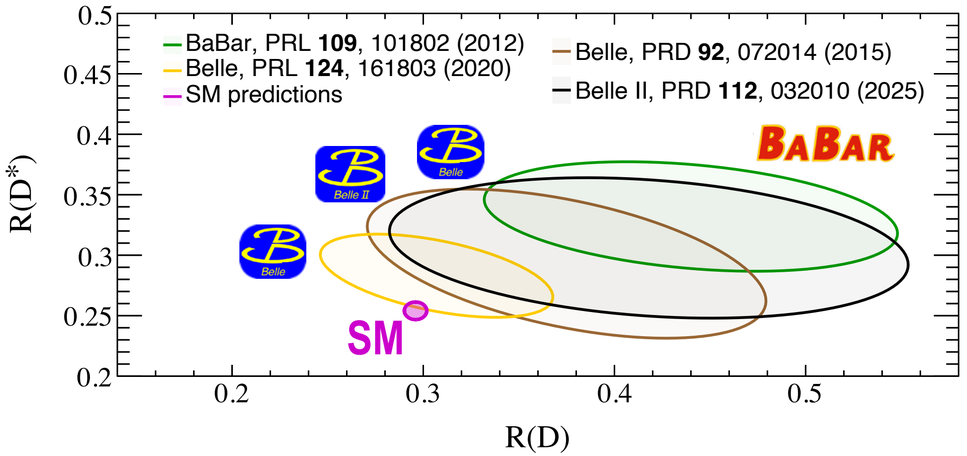


$$B \to D^*\tau\left(\to \ell\nu\bar{\nu}\right)\bar{\nu}$$

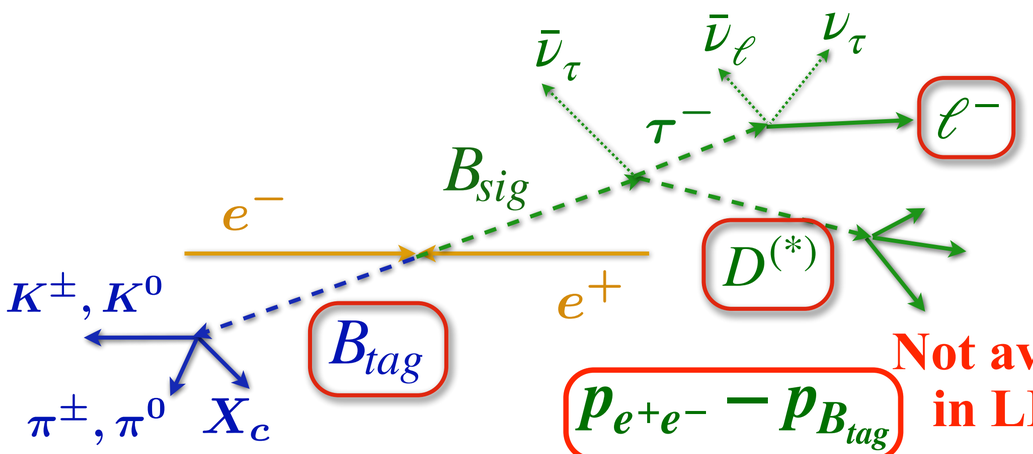


$$B \to D^*\ell\nu$$





$\mathcal{R}\left(D^{(*)}\right)$ in LHCb

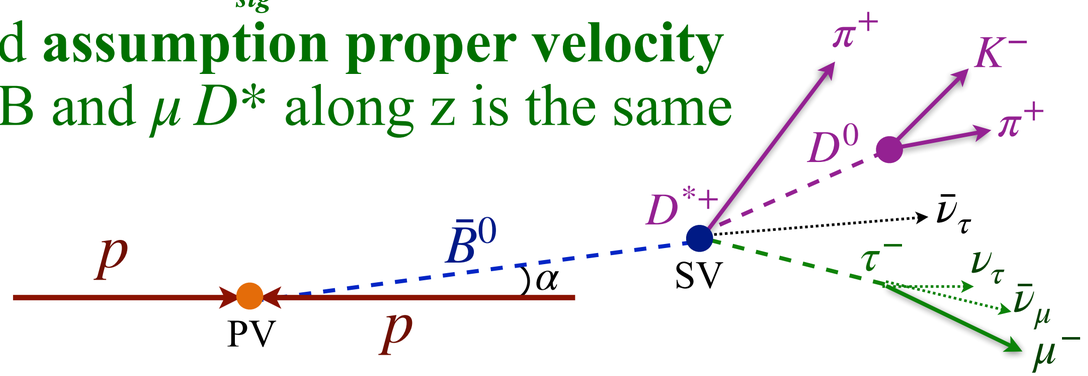


Not available in LHCb!

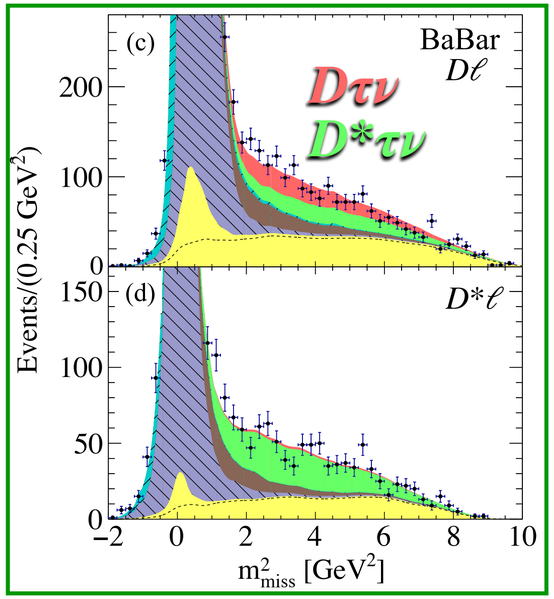
$$m^2_{miss} = \left(p_{B_{sig}} - p_{D^{(*)}} - p_\ell\right)^2$$

$p_{e^+e^-} - p_{B_{tag}}$

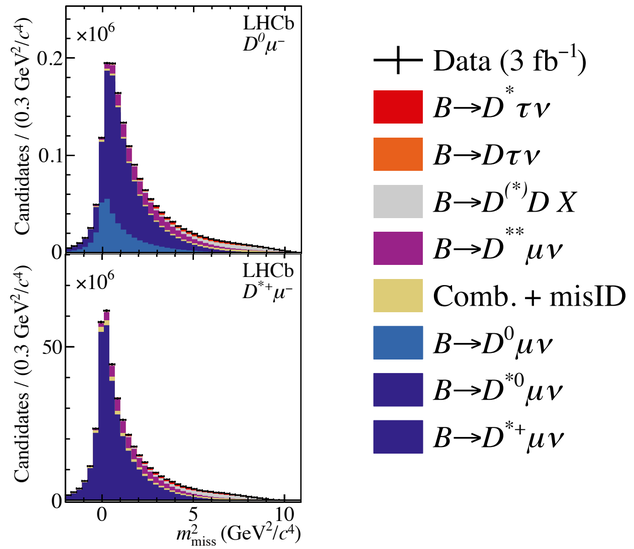
Estimate $p_{B_{sig}}$ based on ***B* vertex**
and **assumption proper velocity**
of B and μ D^* along z is the same

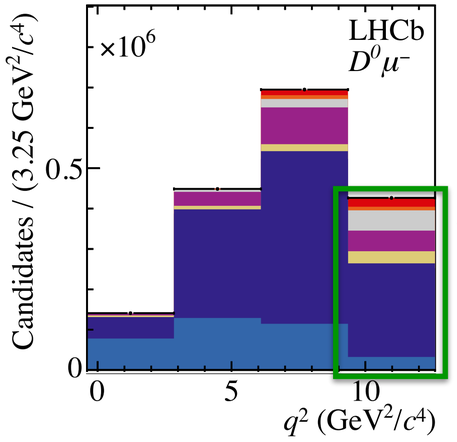


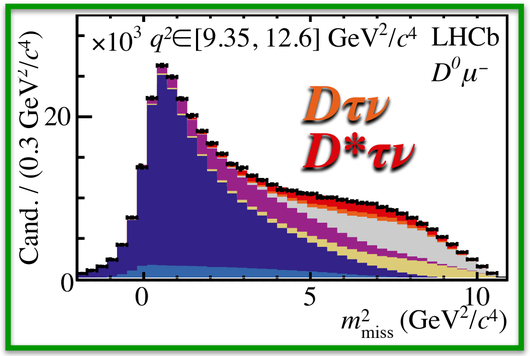
Phys. Rev. Lett. **109**, 101802 (2012)



Phys. Rev. Lett. **131**, 111802 (2023)



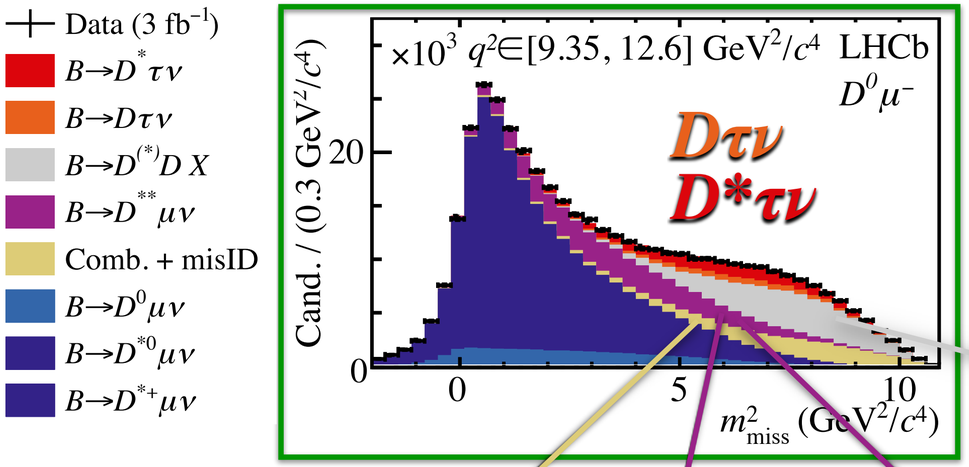




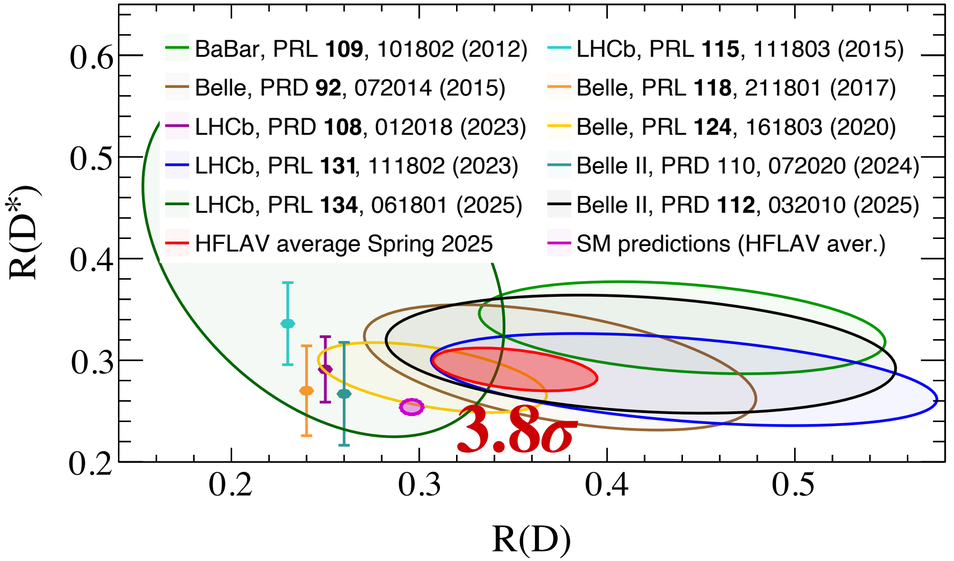
Had to **add q^2 to fit**, and even in **cleanest bin, lots of background**

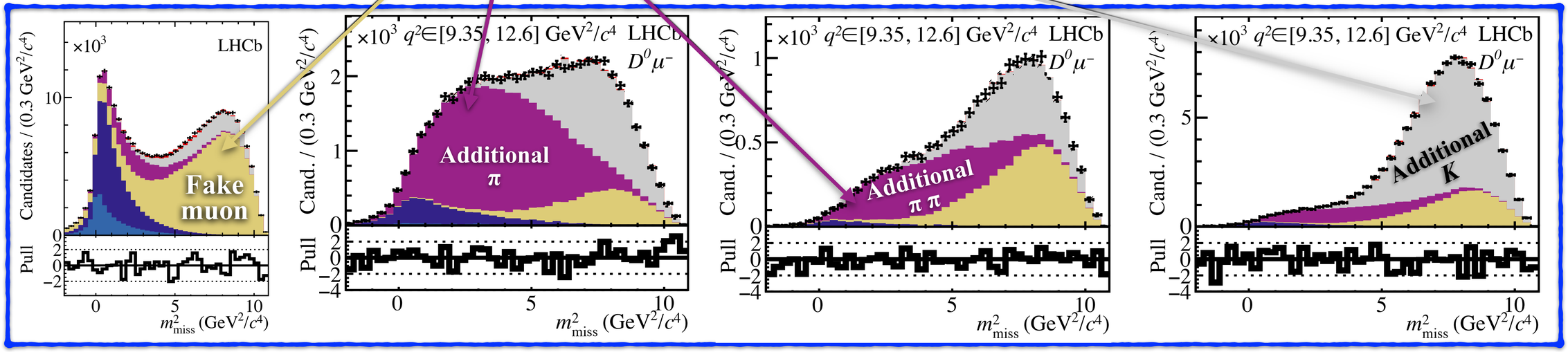
Measuring challenging bkgs in LHCb

Phys. Rev. Lett. **131**, 111802 (2023)



Extremely challenging analysis, with **proof-of-concept measurement** of $\mathcal{R}(D^*)$ **in 2015,** and $\mathcal{R}(D) - \mathcal{R}(D^*)$ **in 2023**

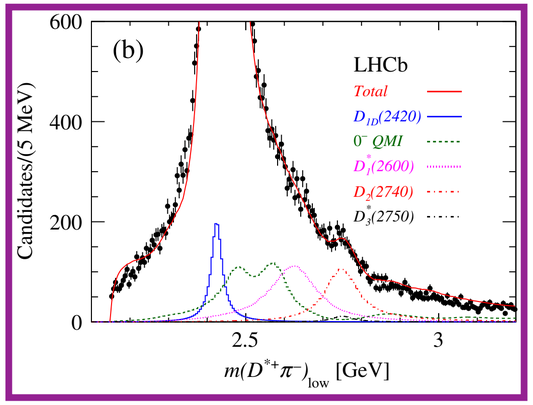




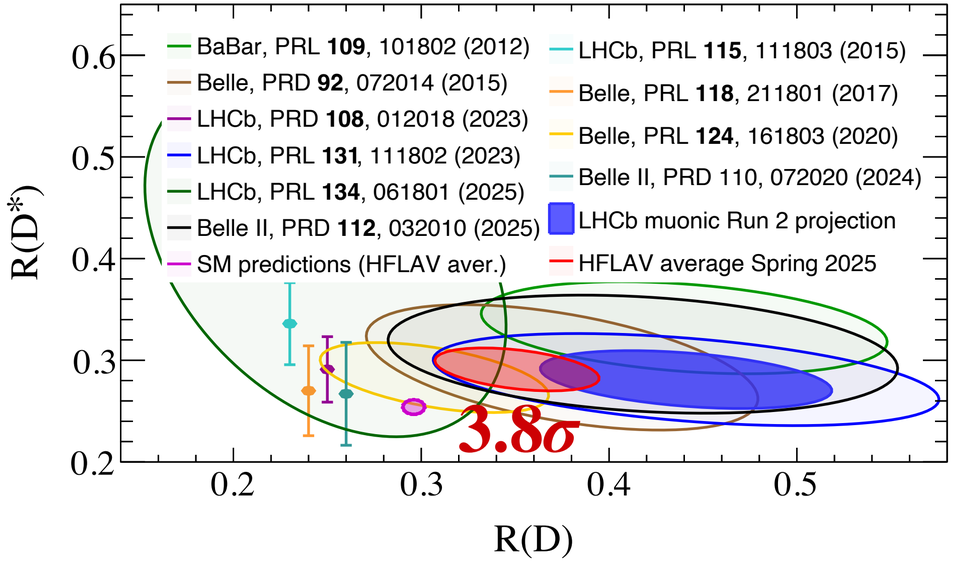
Dedicated data control samples to **measure bkgs**

New result coming soon

- Currently working on **update** based on **LHCb's Run 2 data**
  - **2 times more luminosity**
  - **2 times higher $b\bar{b}$ cross section**
  - **50-100% higher efficiency**
    - Better trigger, selection



- Update will have **5-10 times more B mesons than Run 1 result!**
  - Working on **refining background model** to take advantage of high statistics
- **Potential** to become **best measurement in the world**
  - Depending on final systematic uncertainties

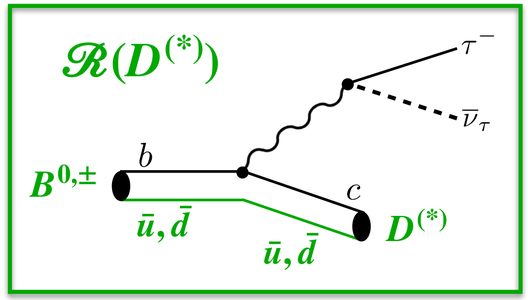


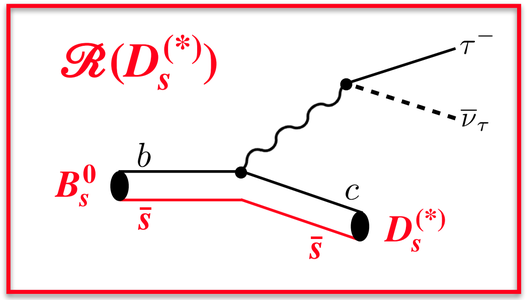
Extraordinary claims** require **extraordinary evidence

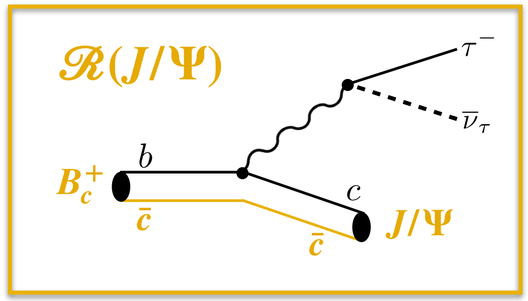
Even if we reach 5σ in the challenging $\mathcal{R}\left(D^{(*)}\right)$ measurements, we will probably need a correlated pattern of anomalies **beyond $\mathcal{R}\left(D^{(*)}\right)$** to **believe the *New Physics***

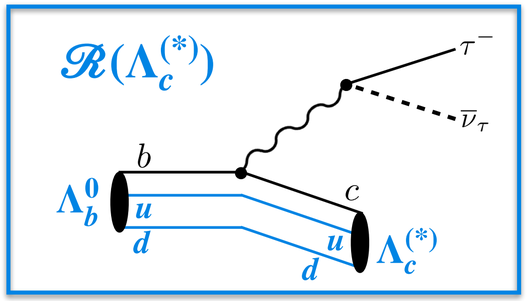
Other $b \to c\tau\nu$ transitions

- **If NP** in $b \to c\tau\nu$, we **should see anomalies** in **related decays**
  - **LHCb** has **access** to **b-hadrons** with **different spectator quarks**



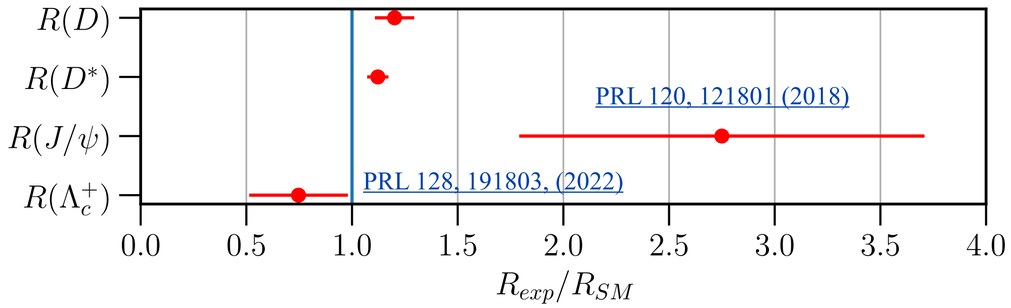






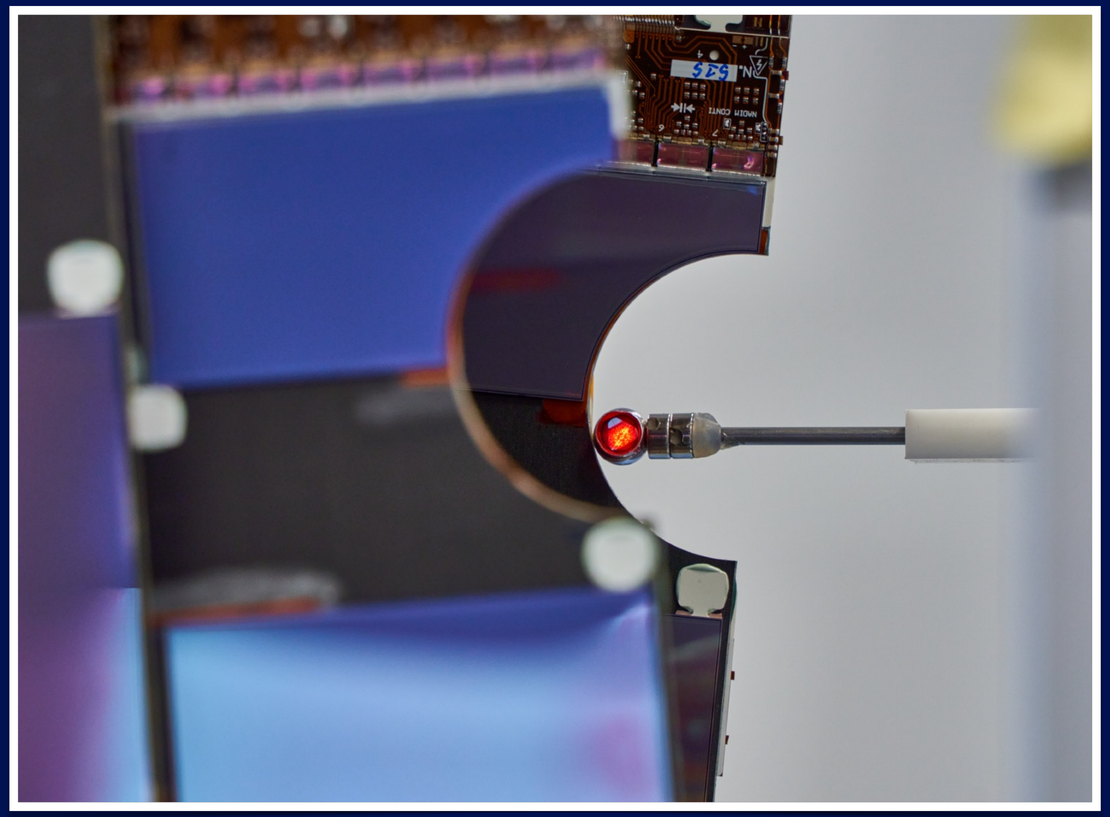
$$\mathscr{R}\left(X_c\right) = \frac{\mathscr{B}\left(X_b \to X_c \tau \nu_\tau\right)}{\mathscr{B}\left(X_b \to X_c \ell \nu_\ell\right)}$$

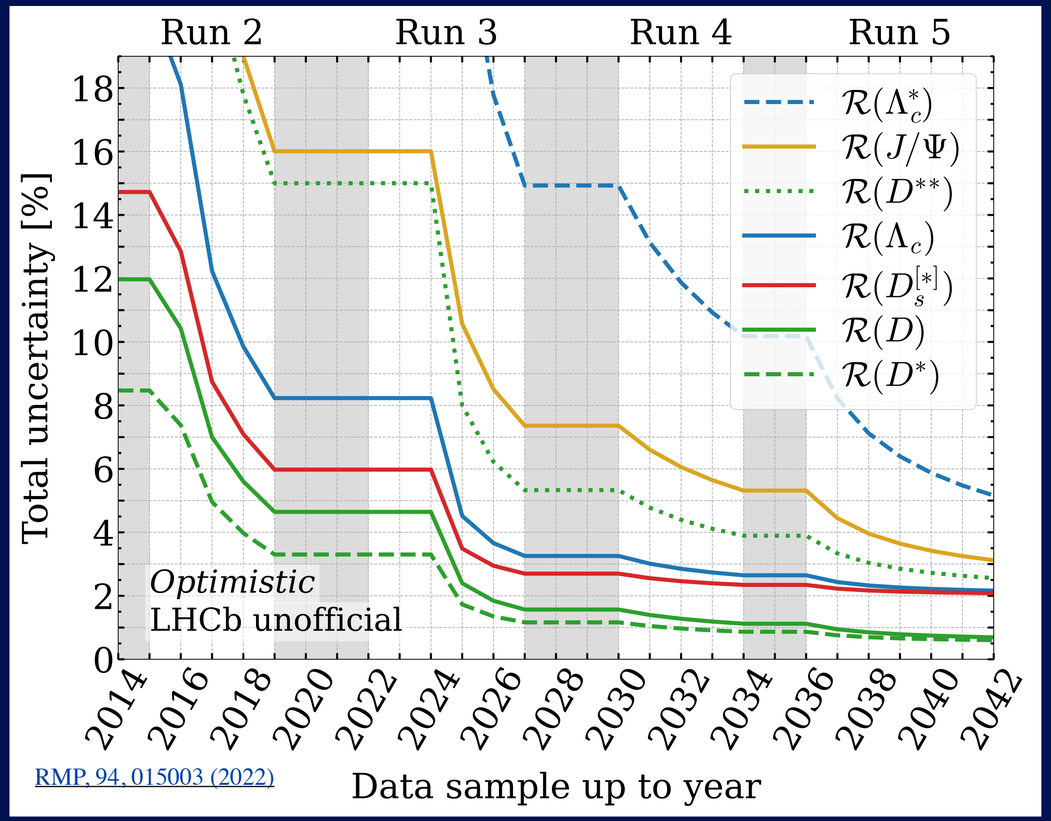
$\mathscr{R}(J/\Psi)$, $\mathscr{R}(D_s^{(*)})$, and $\mathscr{R}(\Lambda_c^{(*)})$ have many uncertainties uncorrelated with $\mathscr{R}(D^{(*)})$



Proof-of-concept measurements of $\mathscr{R}(J/\Psi)$ and $\mathscr{R}(\Lambda_c^{(*)})$ already published

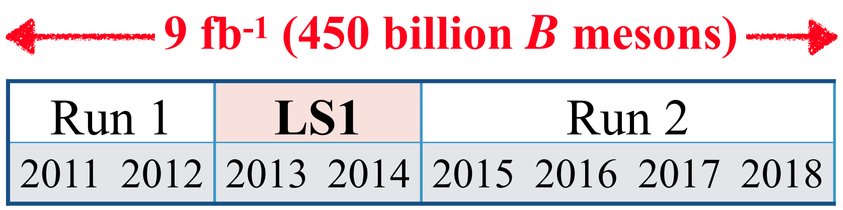
We will **need much larger data samples** to **access all LFU ratios** as well as **kinematic distributions**



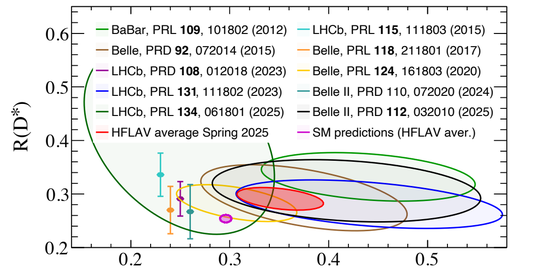


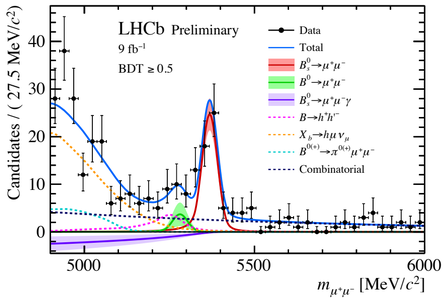
4. Building the UT and future prospects with upgraded LHCb

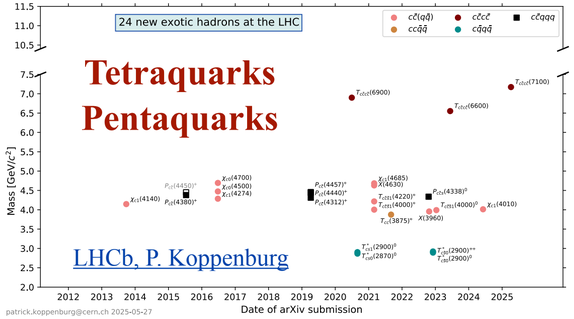
Limitations of LHCb until 2018

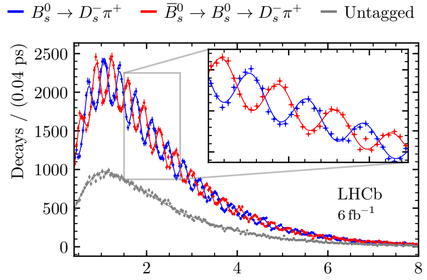


Beautiful results with **Runs 1** and **2**



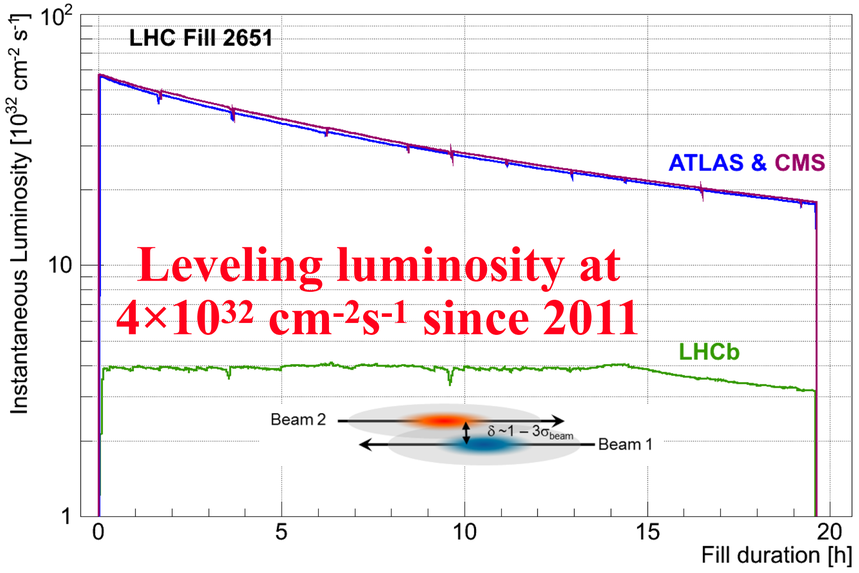




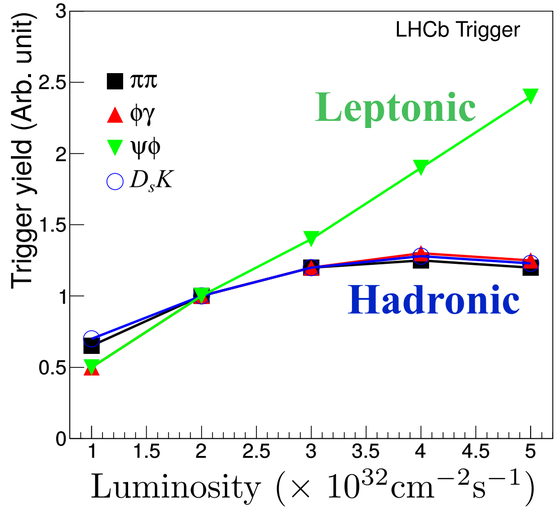


Runs 1 and 2

40 MHz pp collisions → **L0** Hardware → 1 MHz Detector readout → **HLT** Software → 12.5 kHz (0.6 GB/s) Events on disk



- Have been **luminosity leveling since 2011**
  - ➡ Data sample limited to **1-2 fb^{-1}/year**
- **2011-2018 detector cannot cope** with **higher lumi**
  - ➡ **Low efficiency** for **hadronic** decays **due to hardware trigger**



Upgrade I

9 fb^{-1} (450 billion *B* mesons) → **Upgrade I** ← **Goal: 50 fb^{-1} (2,500 billion *B* mesons)**

Run 1		LS1		Run 2				LS2			Run 3					LS3			Run 4			
2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033

Runs 1 and 2

40 MHz pp collisions → **L0** Hardware → 1 MHz Detector readout → **HLT** Software → 12.5 kHz (0.6 GB/s) Events on disk

Upgrade I

CERN-LHCC-2012-007

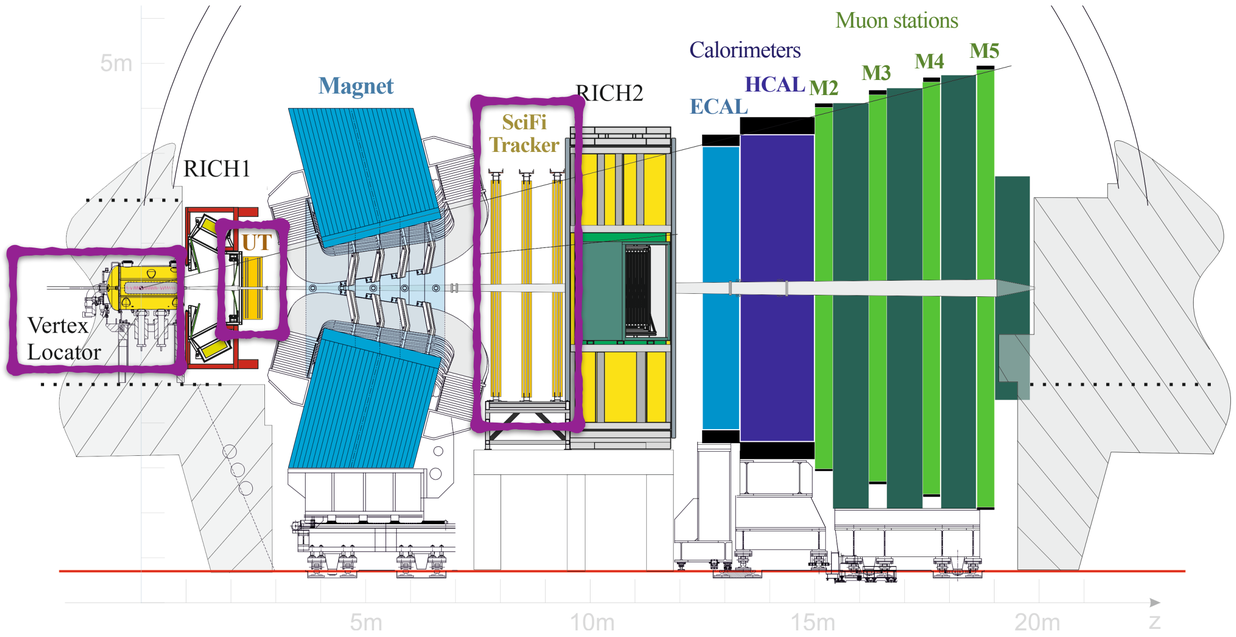
40 MHz pp collisions → Detector readout → **HLT** Software → $\mathcal{O}$(100 kHz) [$\mathcal{O}$(10 GB/s)] Events on disk

1st hadron collider detector with **no HW trigger!**

All electronics upgraded to send every hit to **flexible software trigger (GPUs + CPUs)**

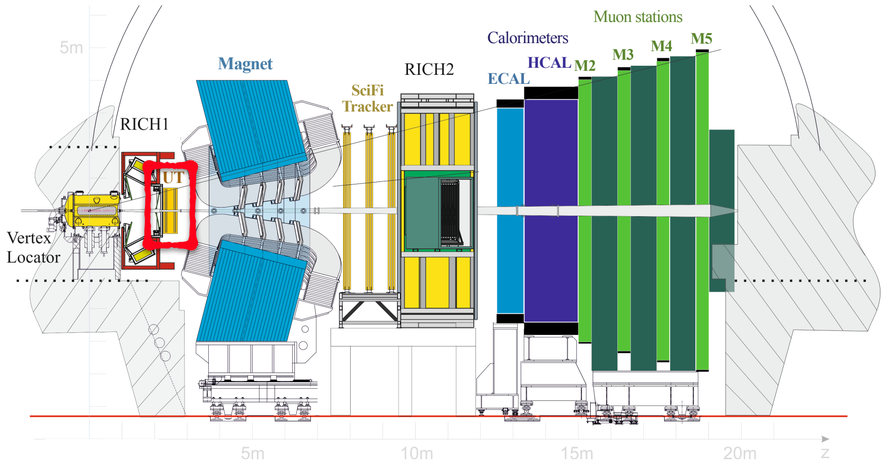
3 new trackers: Pixel VELO, UT, SciFi

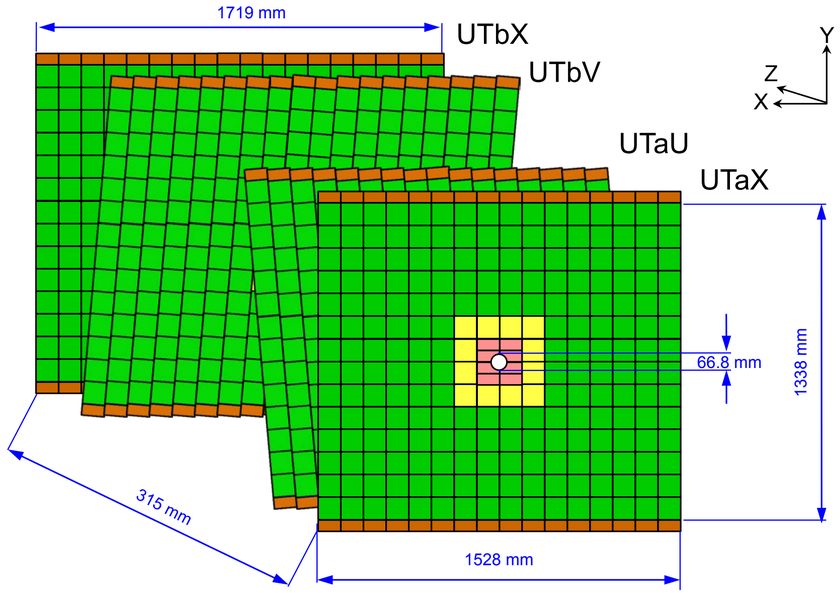
Upstream Tracker (UT) with US leadership



CERN-LHCC-2012-007

The Upstream Tracker (UT)

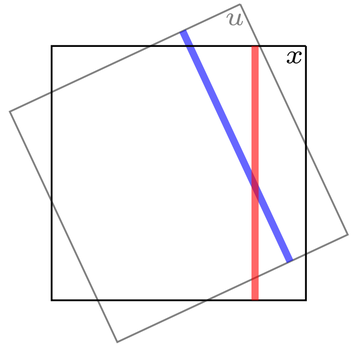


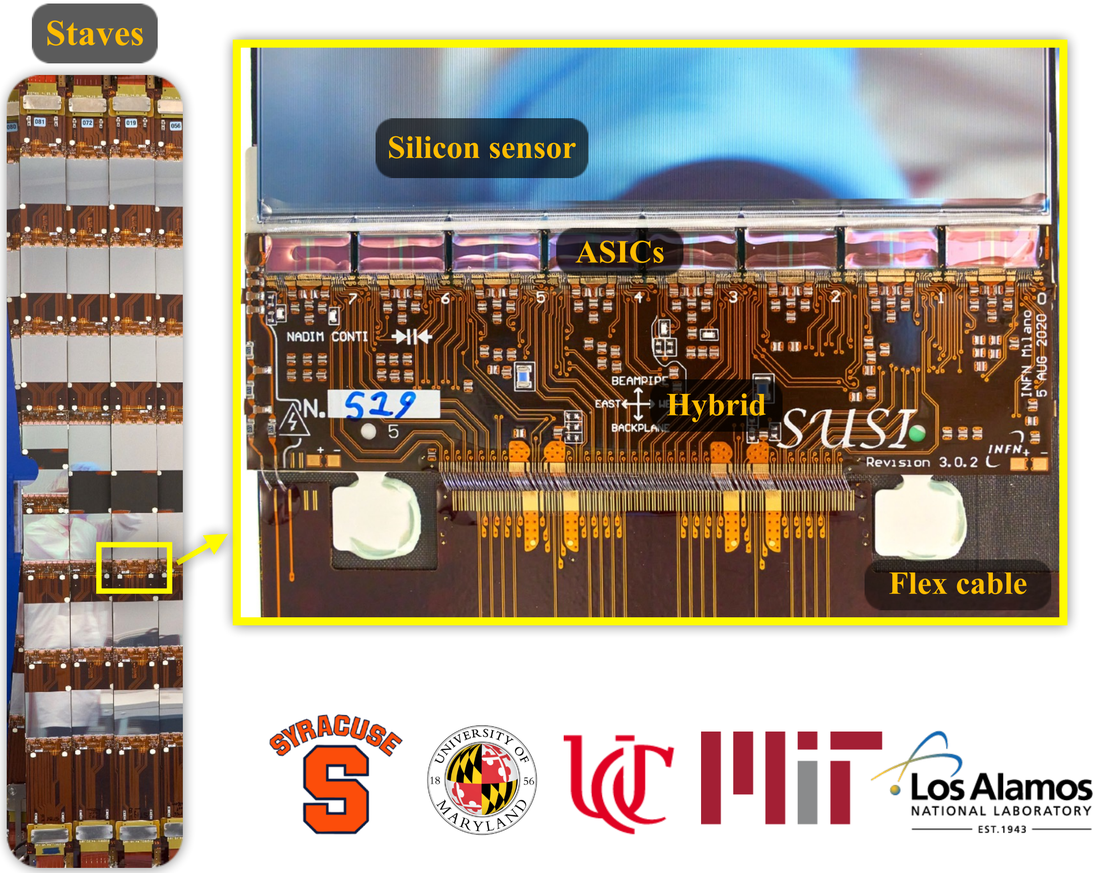


~ **4 layers** of **silicon strips** with **40 Mhz readout**

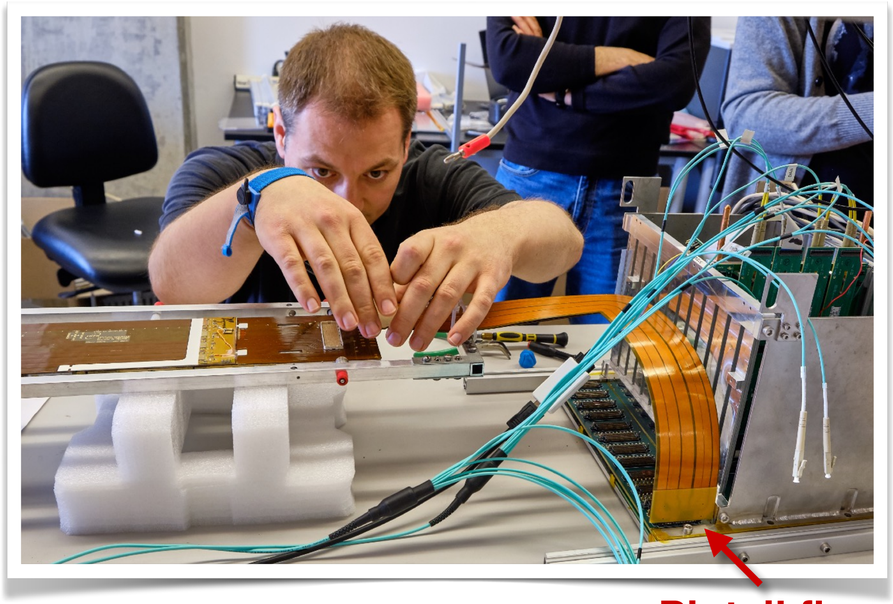
➡ **Crucial** for **triggering** and **long-lived particle** reconstruction

➡ **Vertical (x)/stereo (u) layers** give x-y





UT readout electronics



- **Readout chain**
  - ➡ Stave → Pigtail → **Backplane** → **DCB** → Fibers → LHCb DAQ
- **Precise voltages/currents** provided by **LVRs**
  - ➡ Remote sensing accounts for Volt. drops on cables

UMD's in-kind contributions

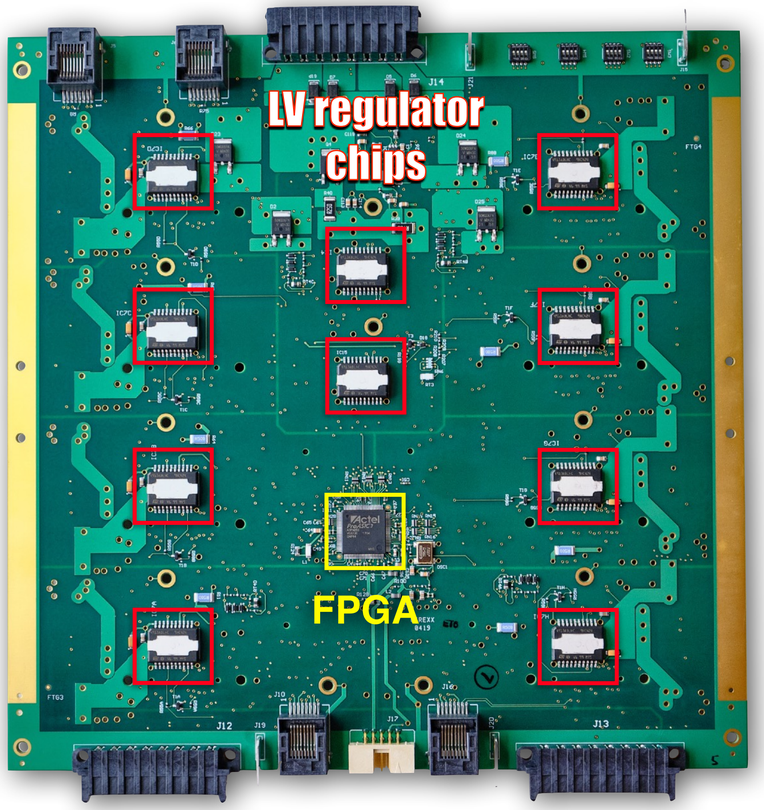
270 DCBs

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

Plus 3,000+
ancillary boards!

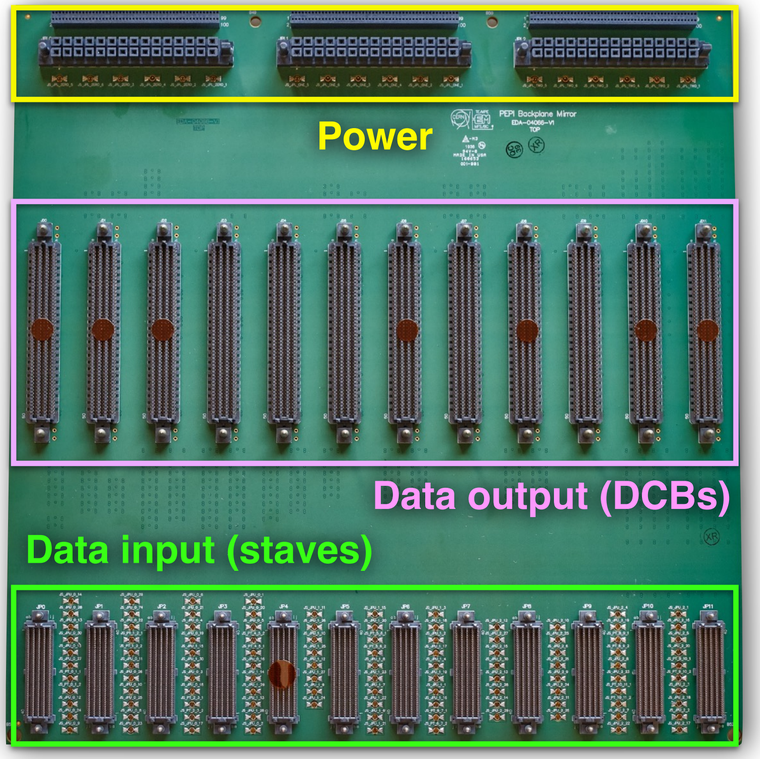
295 LVRs

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



30 Backplanes

Distribution of signals to
balance the data load



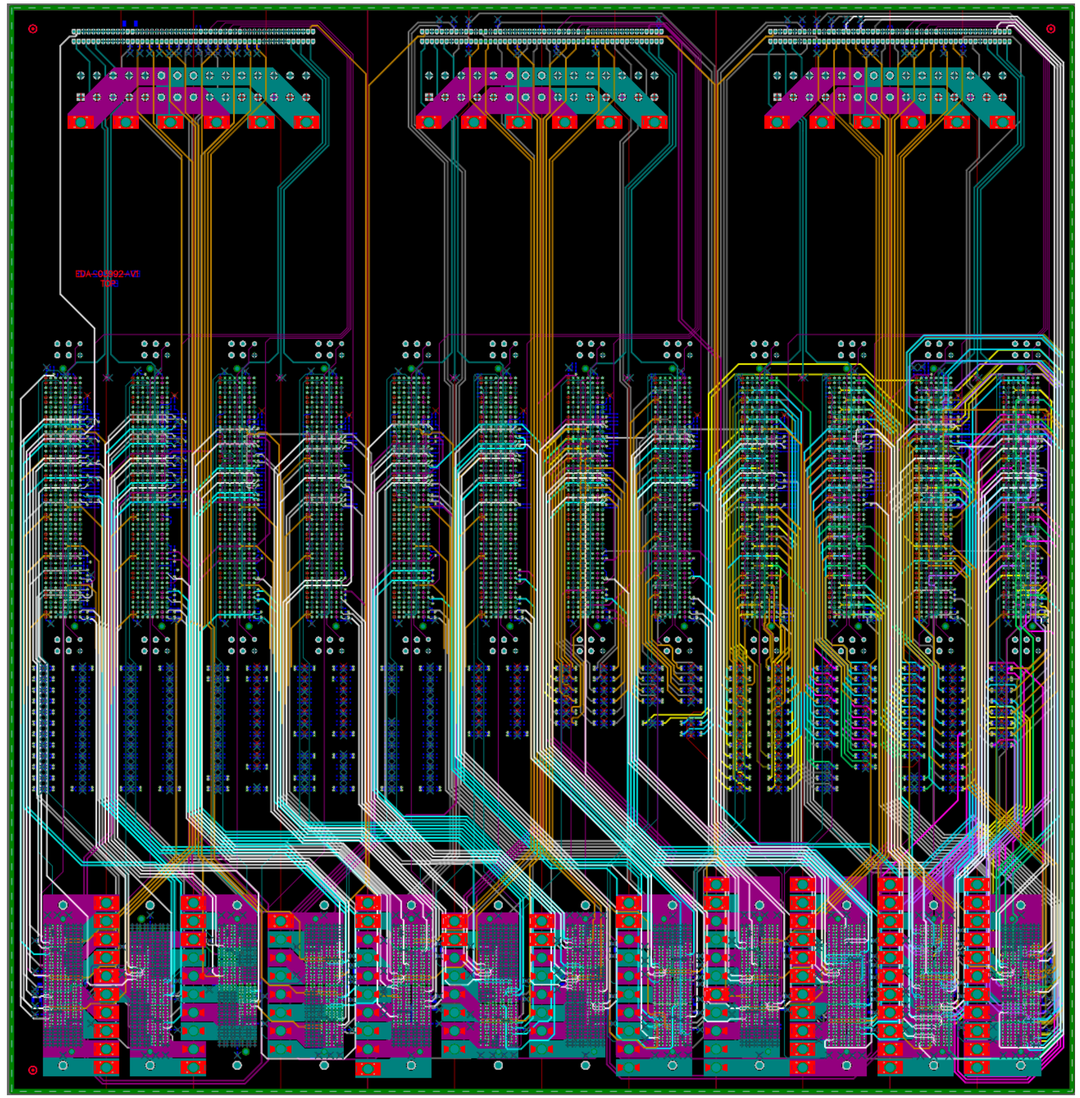
Which of these boards was the most challenging?

The backplane!

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

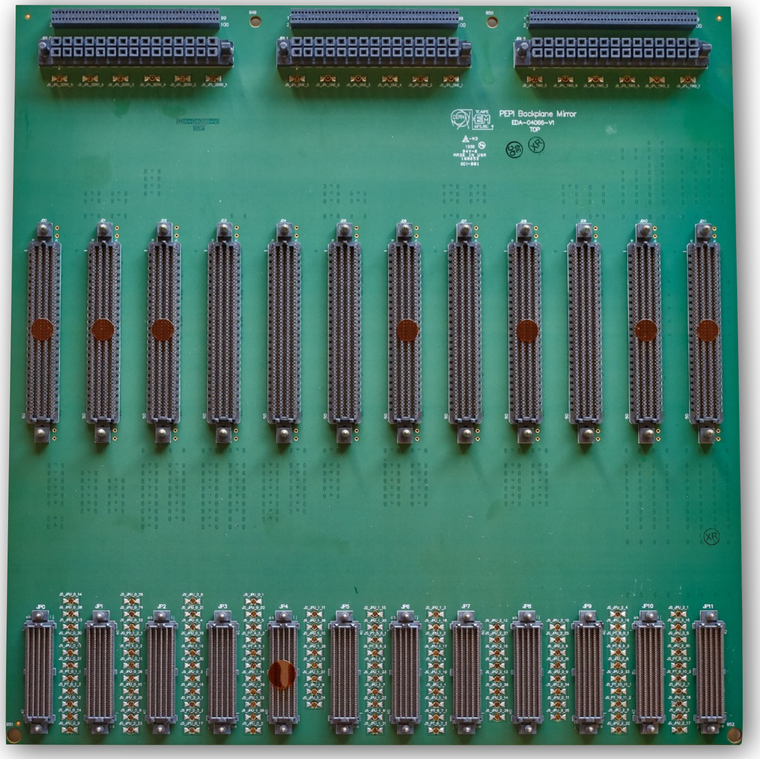
Bottom connectors have 500 pins with 800 μm pitch led to **150 μm vias**

Board/via = **2.8 mm/150 μm → 18.7 ratio, not manufacturable!**



30 Backplanes

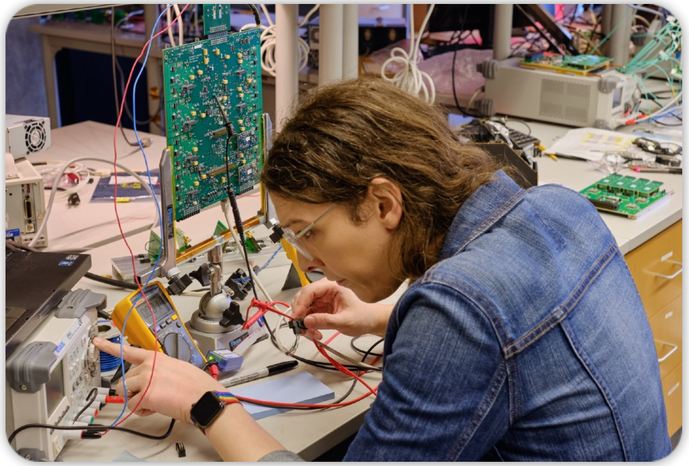
Distribution of signals to **balance the data load**

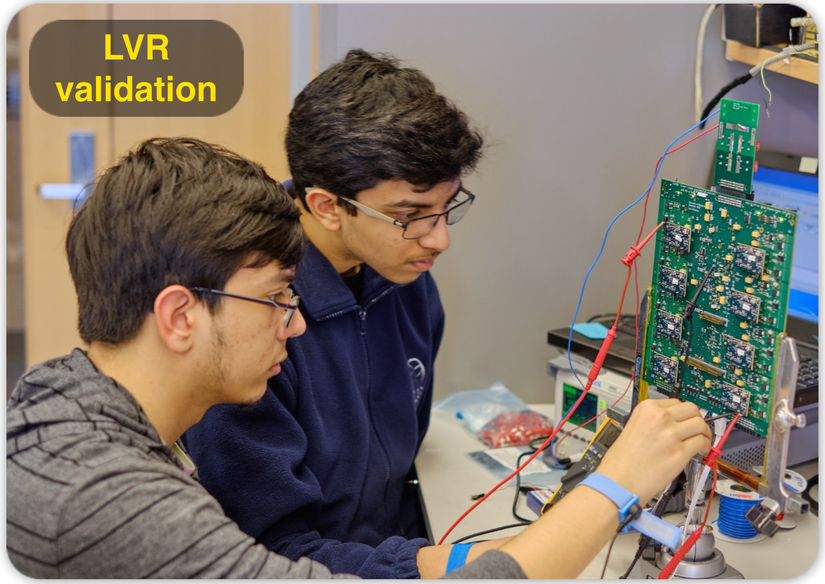


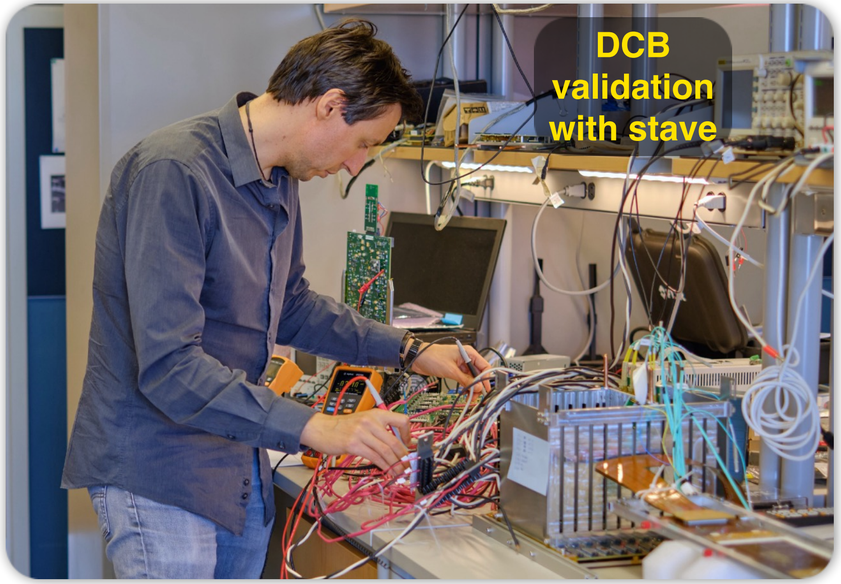
2014-2019: design and validation

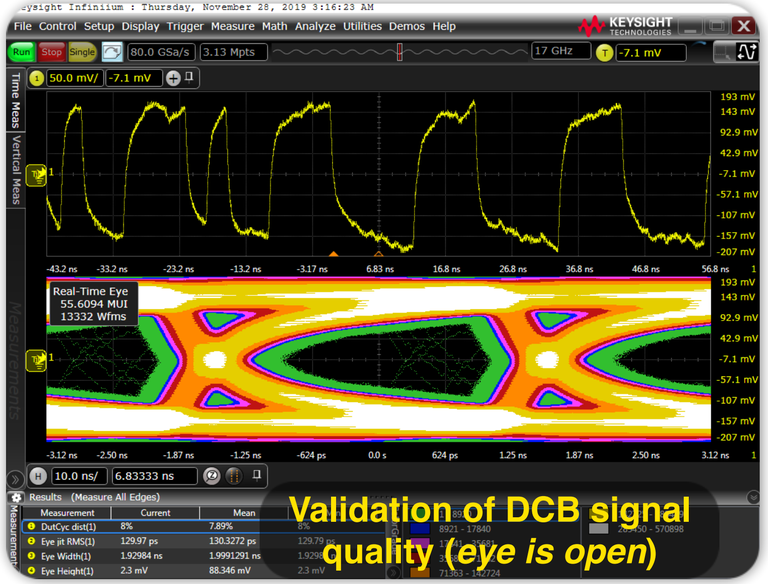
- Several **design iterations** during **2014-2019**
- **Full functionality** validated in **2019**

Engineers: **O'bannon, Lutz, Hamilton**



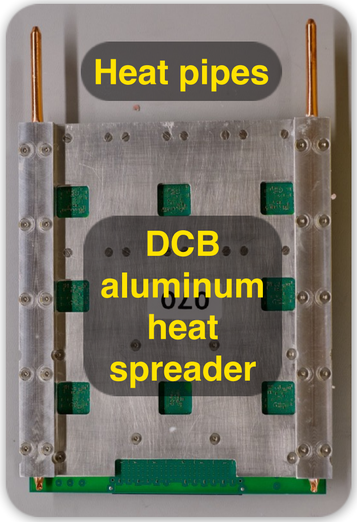


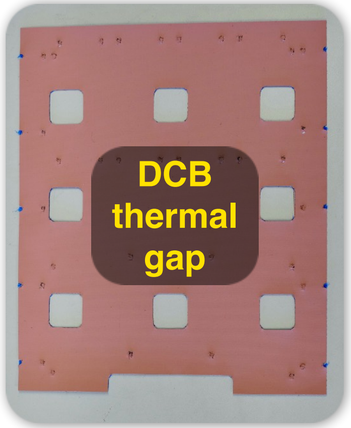


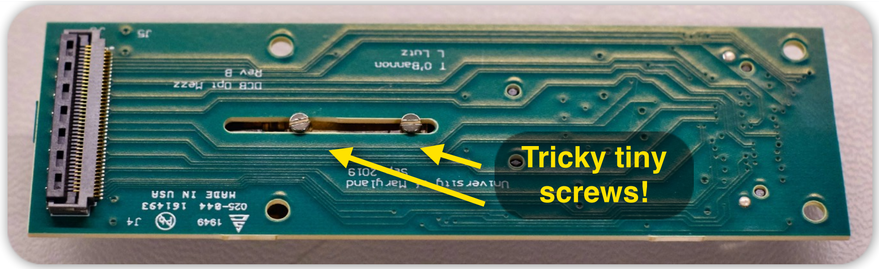


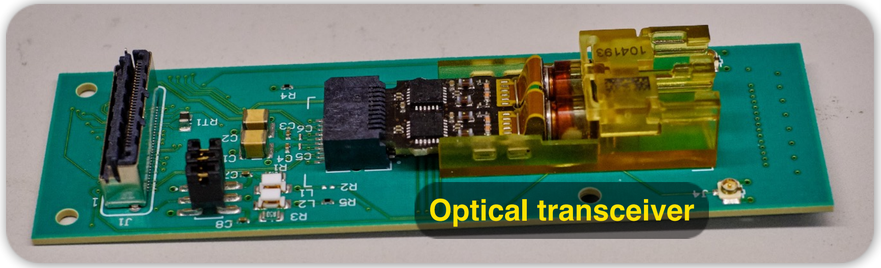
Validation of DCB signal quality (*eye is open*)

DCB and LVR assembly

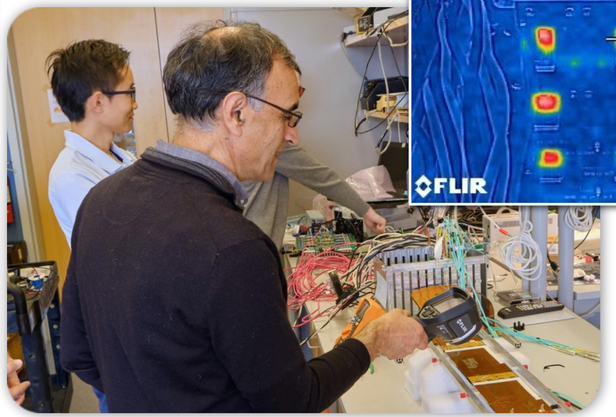




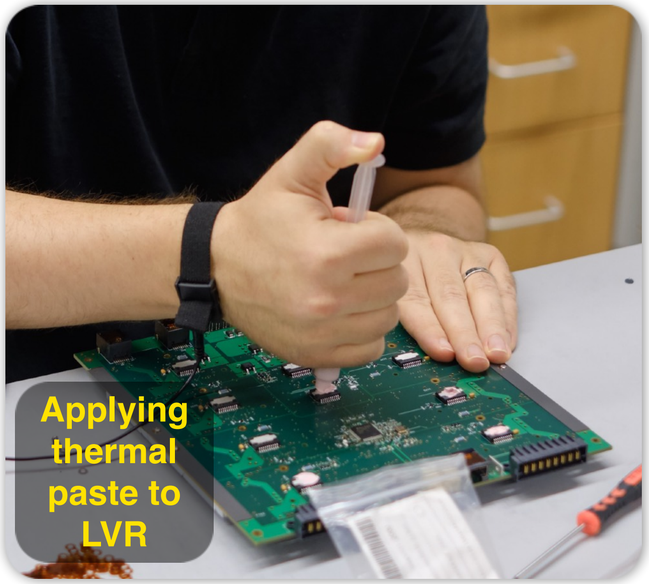


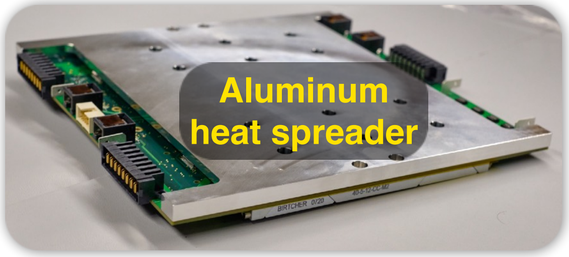


Measuring temperature with FLIR

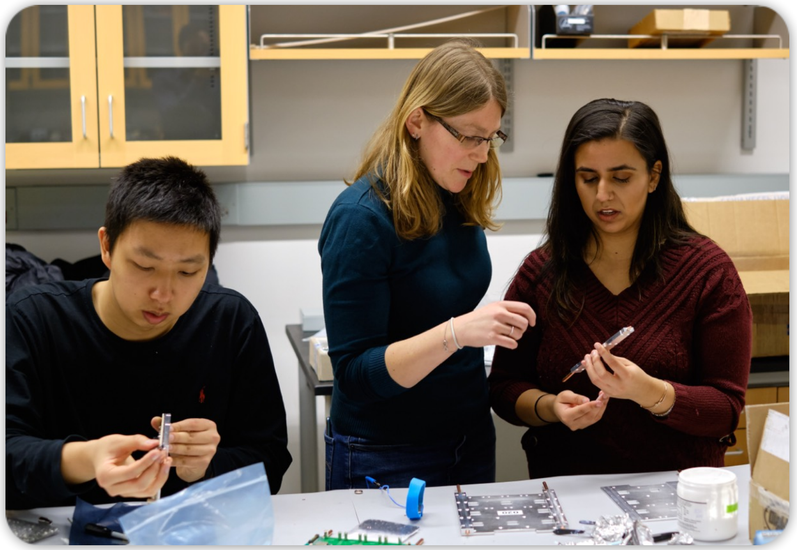


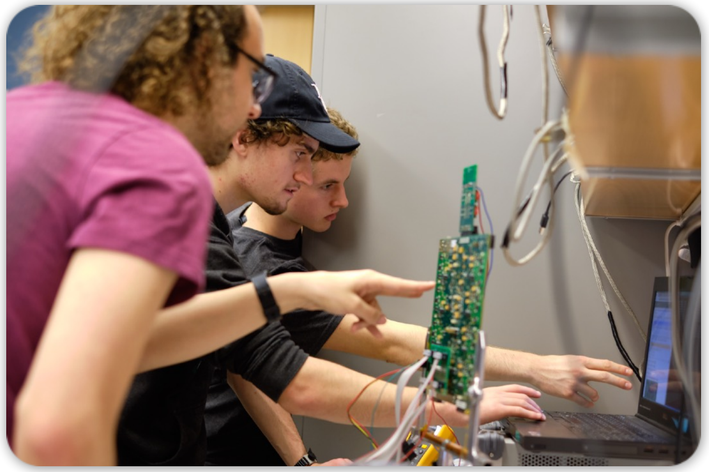
Good thermals

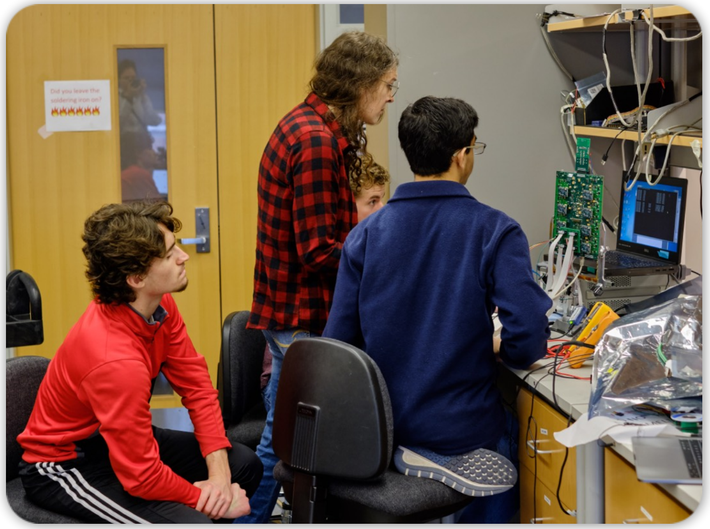




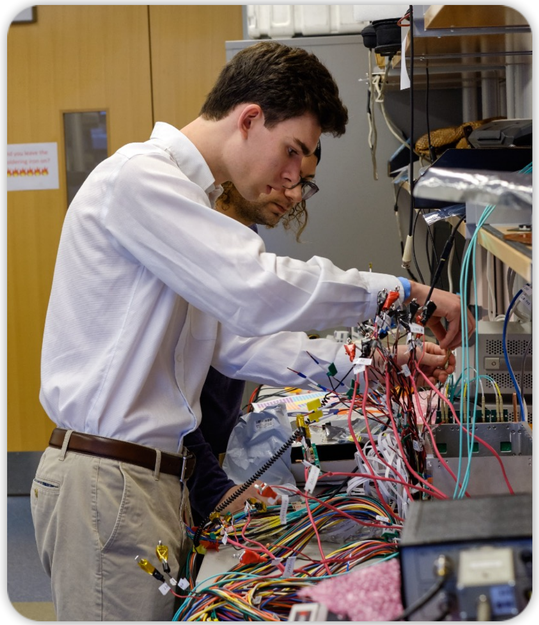
2020: trained 10 undergrads



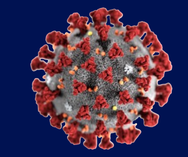




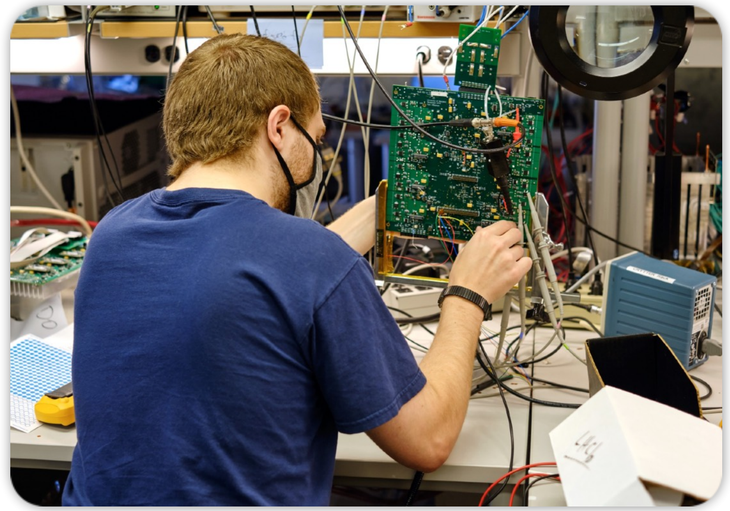
In preparation for **immense effort** of **assembly + burn in + QA**



but then... COVID-19



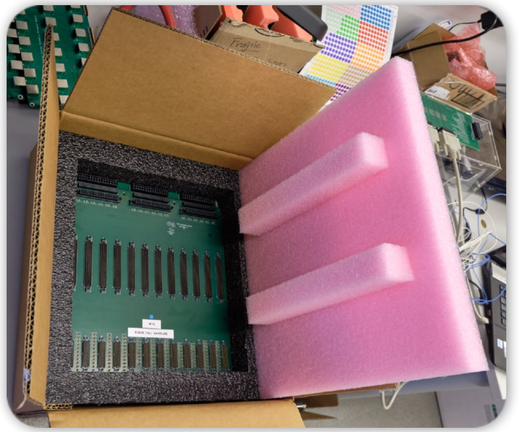
- **Lab closed March-June**
  - ➡ Lost all undergrads 😭
- For several months, could only work on **documentation**, **software, LVR firmware**

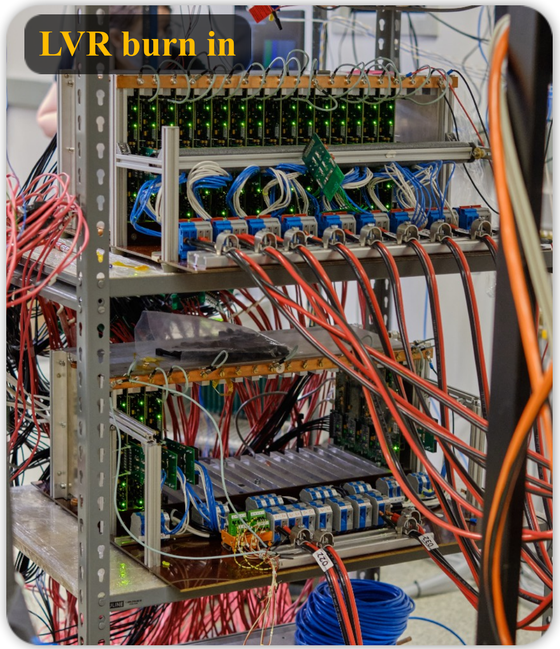


- Summer **shifts** by **grad students, postdocs, faculty**
  - ➡ In September **4 undergrads returned**

2021: burn in and shipping to CERN!

- All boards underwent **rigorous burn-in** procedure
  - Aim to detect cases of **infant mortality**
- **Backplanes** subject to **50 cold/hot cycles** for 23h
- **DCBs** and **LVRs** uninterrupted **running for 2 days**





Final Shipment

Backplane		DCB		LVR	
Ordered	30	Ordered	270	Ordered	295
Received	30	Received	270	Received	295
Burned-in	30	Assembled	270	Set up/QA	293
Initial QA	29	Set up/QA	269	Assembled	293
Assembled	29	Burned-in	269	Burned-in	292
Final QA	29	Final QA	268/269 = 268	Final QA	290
Shipped	25	Shipped	260	Shipped	285

Final PEPI Shipment en route
- All detector boards and CERN spares
- 5/10/10 BP/DCB/LVR spares kept at UMD for testing and debugging
- Expect to arrive in 1-2 weeks

19 Apr. 2021 PEPI and LVR report Slide 2

2020-2021: UT infrastructure

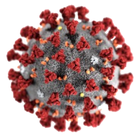
UT construction, infrastructure

UT assembly, installation

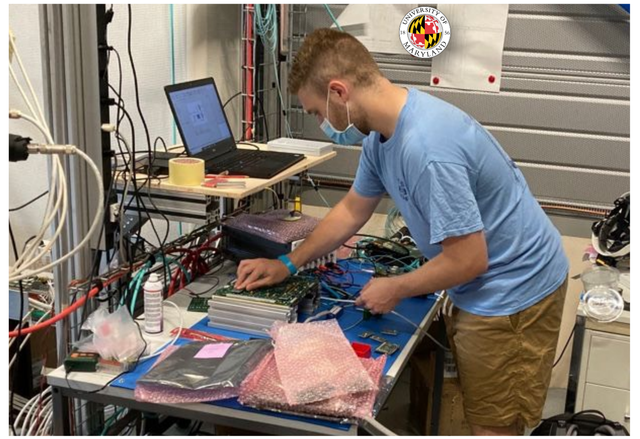
Run 1			LS1			Run 2			LS2		Run 3			LS3		Run 4			
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029

Expected schedule

- **Infrastructure at CERN** was set to **ramp up in 2020**
- **COVID-19 big blow** to UT (primarily non-Europe)
  - Very **difficult to send people to CERN**, **limitations** to work in the lab
  - **Delays** from contractors
  - **No senior leadership** until 2022
  - **UMD's Yipeng Sun stuck in China** Jan-Oct



- **UT infrastructure** in **2020-2021**
  - **Boards received** and **re-qualified**
  - Immense **cable production effort**
  - **Clean room installed** in March 2021



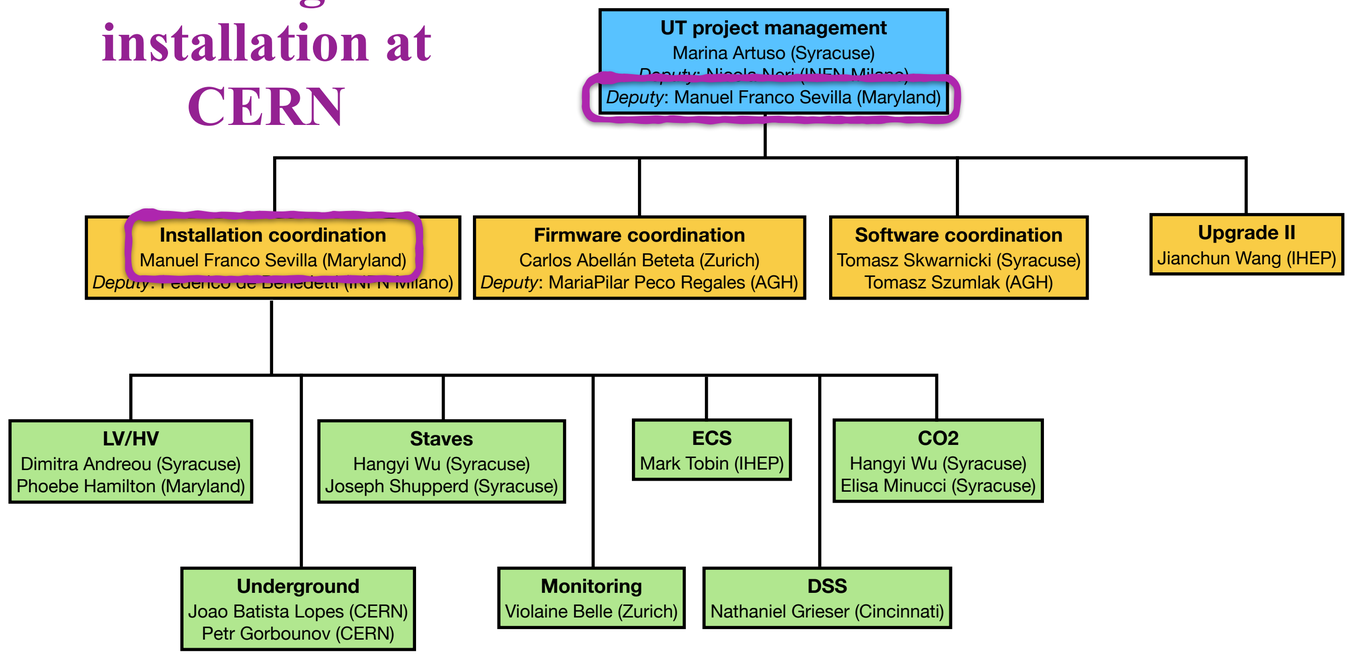
2022: "History has its eyes on us"

- Some **progress** in **1st half of 2022**
  - **Cables**, **fibers**, and **mechanics** for half of UT
  - Installed **7 staves out of 68 total**
- In June, **UT installation coordinator** had to **leave CERN**

- Pressure to **deliver the UT in 2022**
  - *Can LHCb survive without the UT?*
    - Not happily

In charge of installation at CERN

Elevated to deputy project leader



Optimized stave installation sequence I

HV, PT, CO2 prep
15 min - 30 min
2 people

Stave prep
15 min - 1h
2-3 people

Stave convoy
15 min - 30 min
4 people

- **Bottleneck was convoy**
  - ➡ Required 3 people + spotter

Optimized stave installation sequence II

HV, PT, CO2 prep
15 min - 30 min
2 people

Stave prep
15 min - 1h
2-3 people

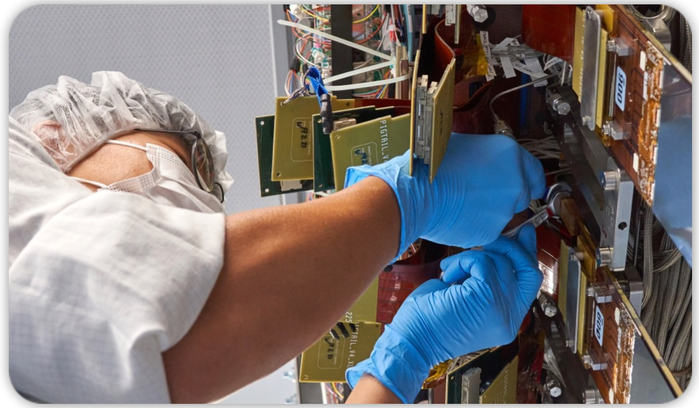
Stave convoy
15 min - 30 min
4 people

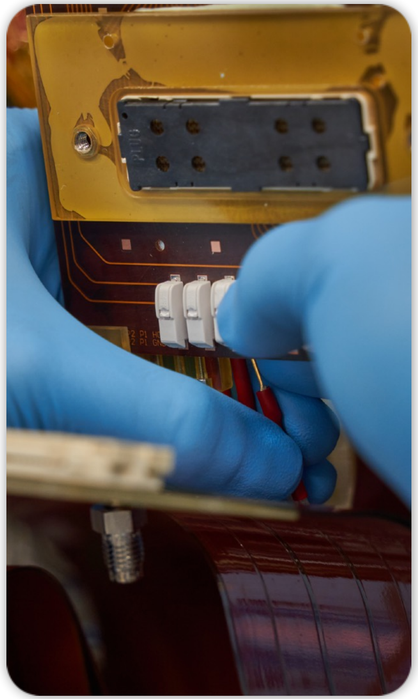
HV plugging + validation
30 min - 1h
2 people

PT plugging
30 min - 2h
2 people

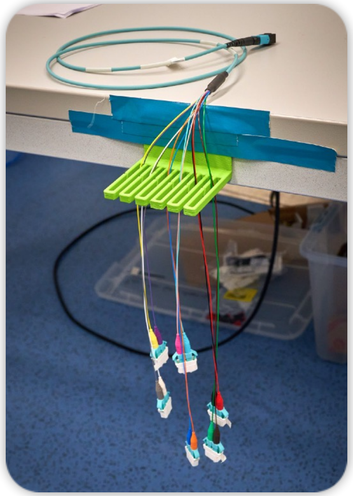
CO2 pipes plugging
30 min - 1h
2 people

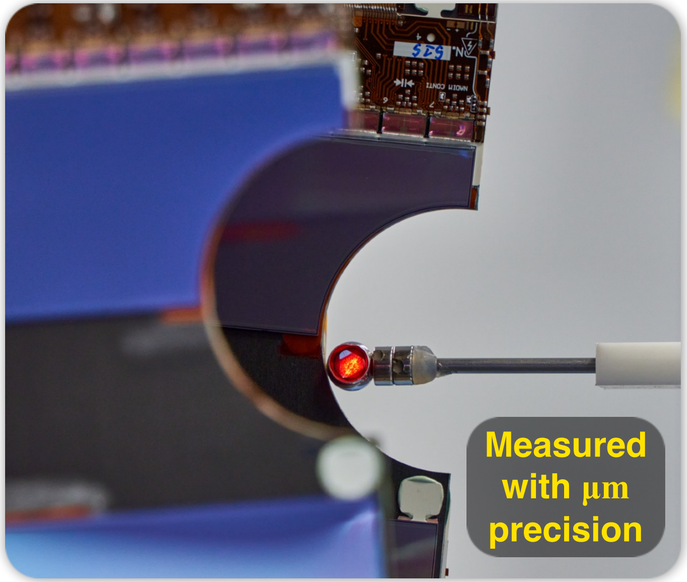
~ In the end, we could do **3 staves/day**



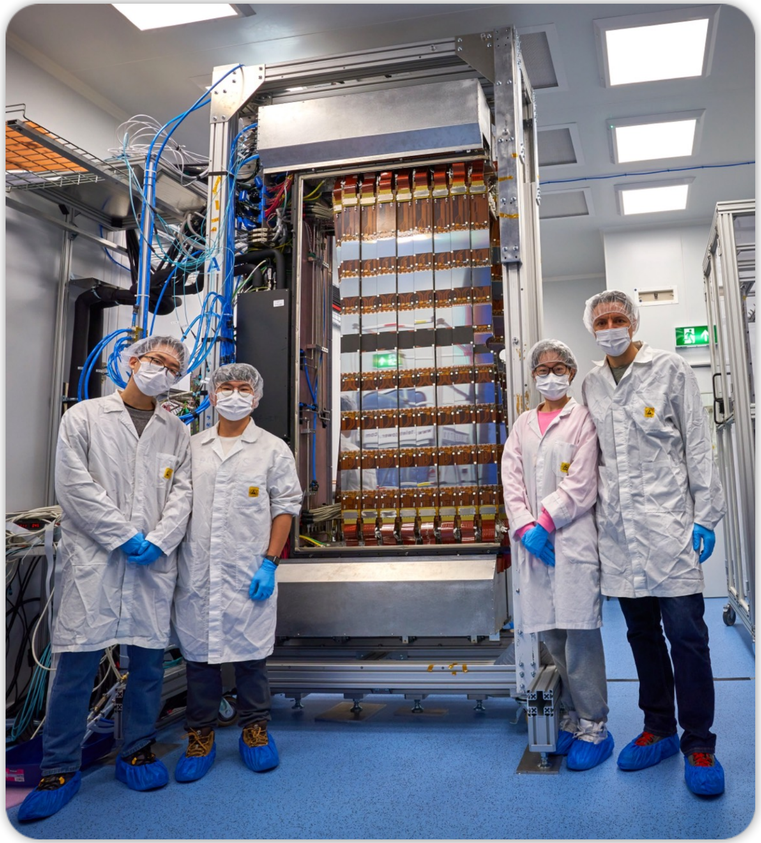


Intense six months



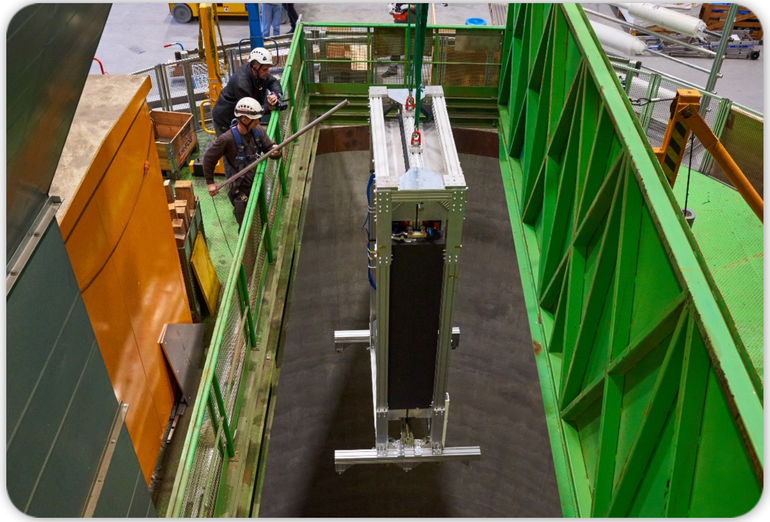


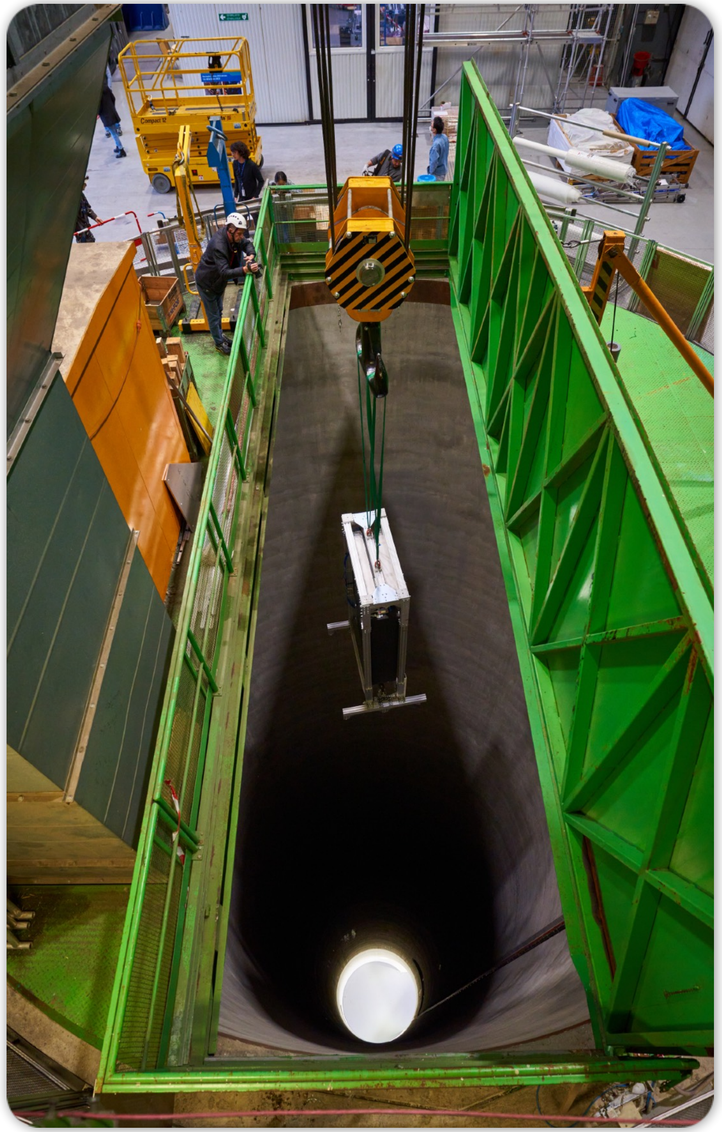
Finished installing **last stave** on **Saturday Dec 10**



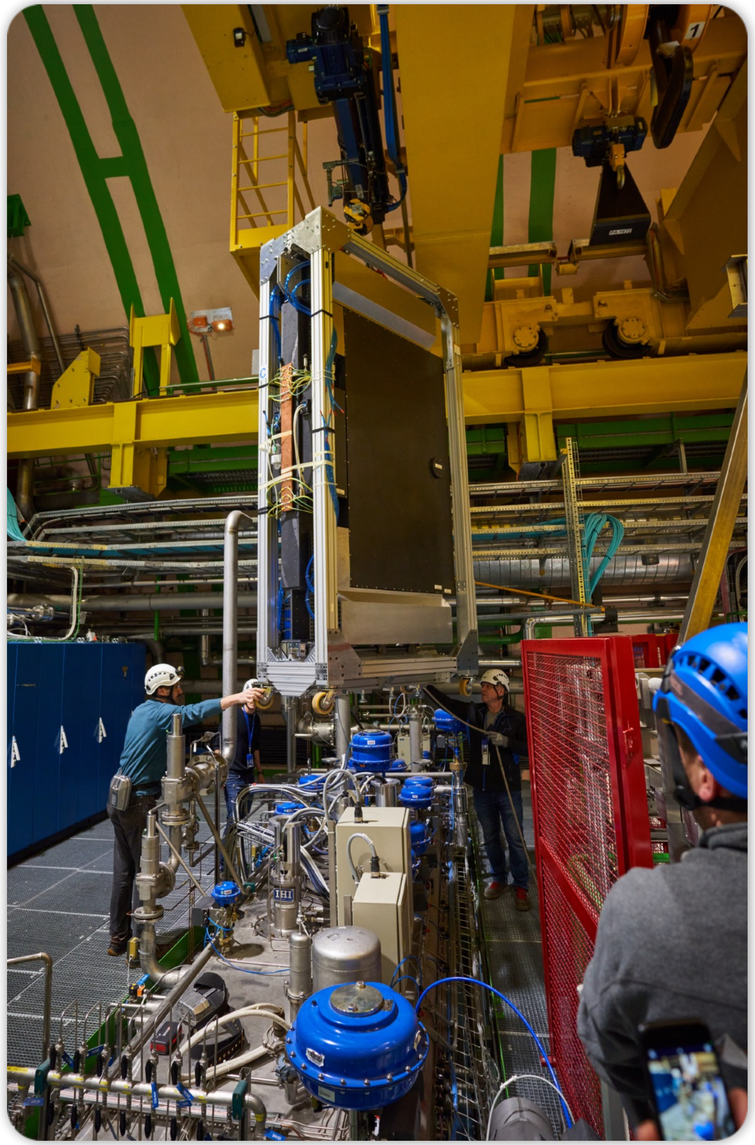
Careful transport

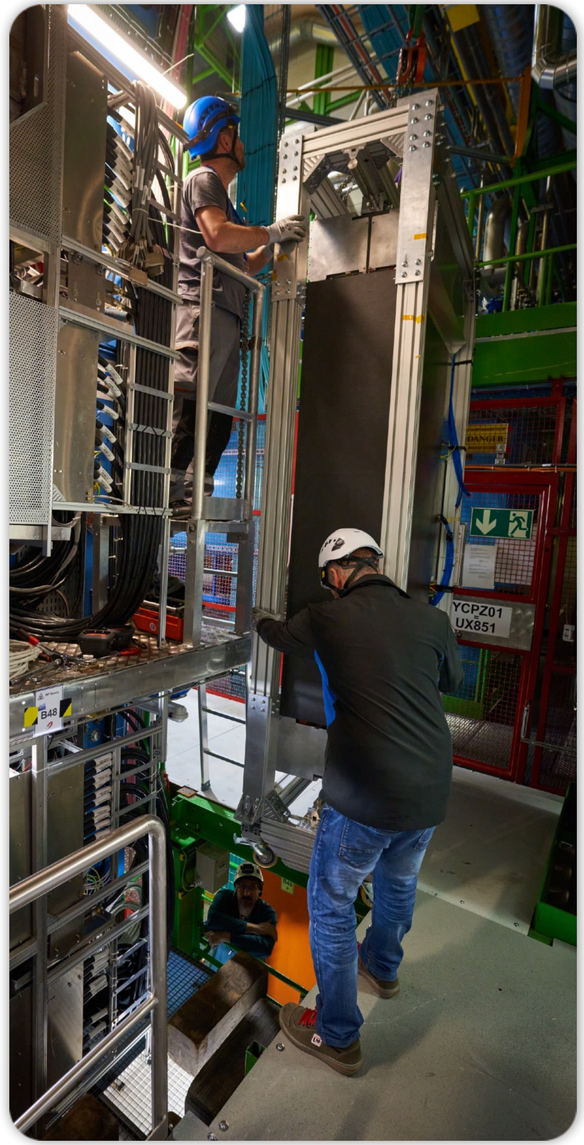
Down the 100 m LHCb shaft



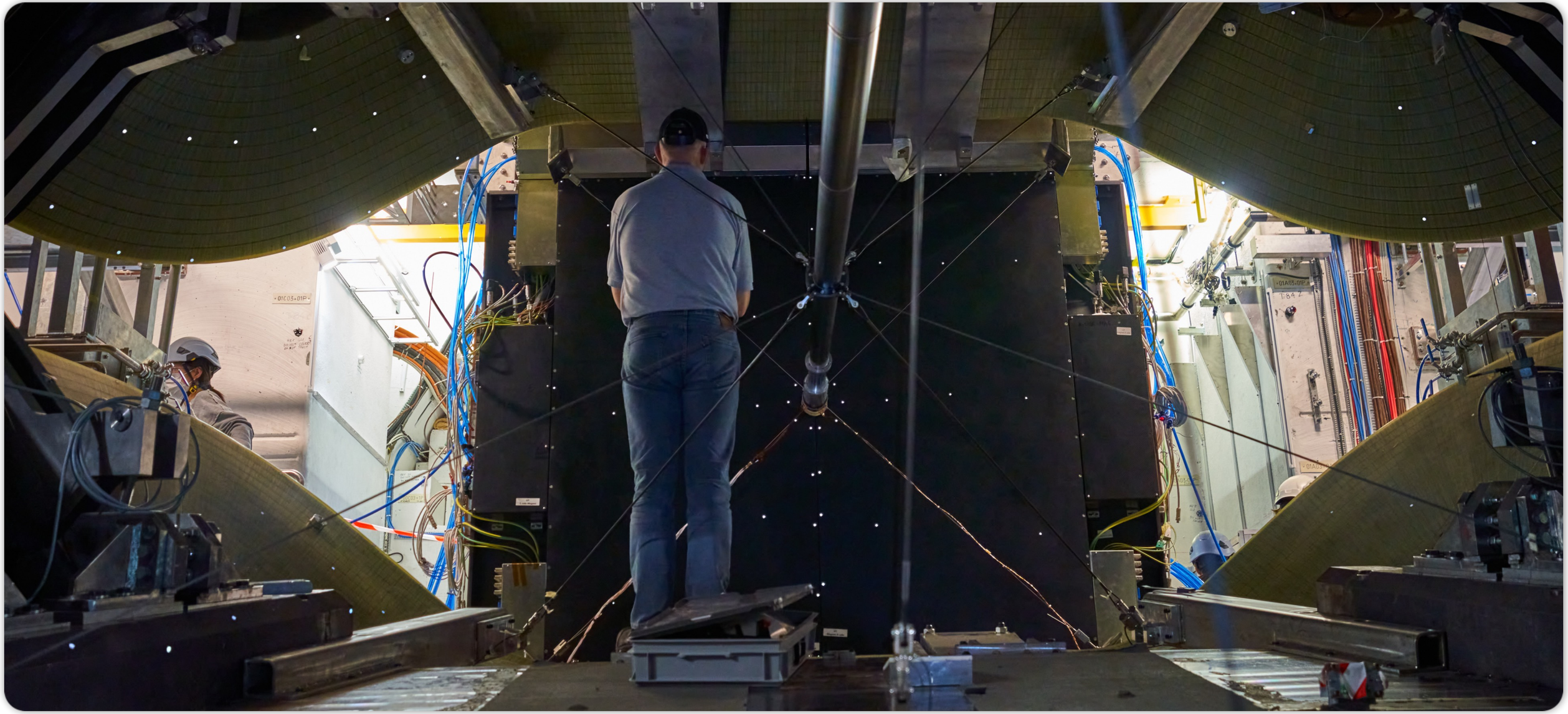


Hoisted over LHCb and installed



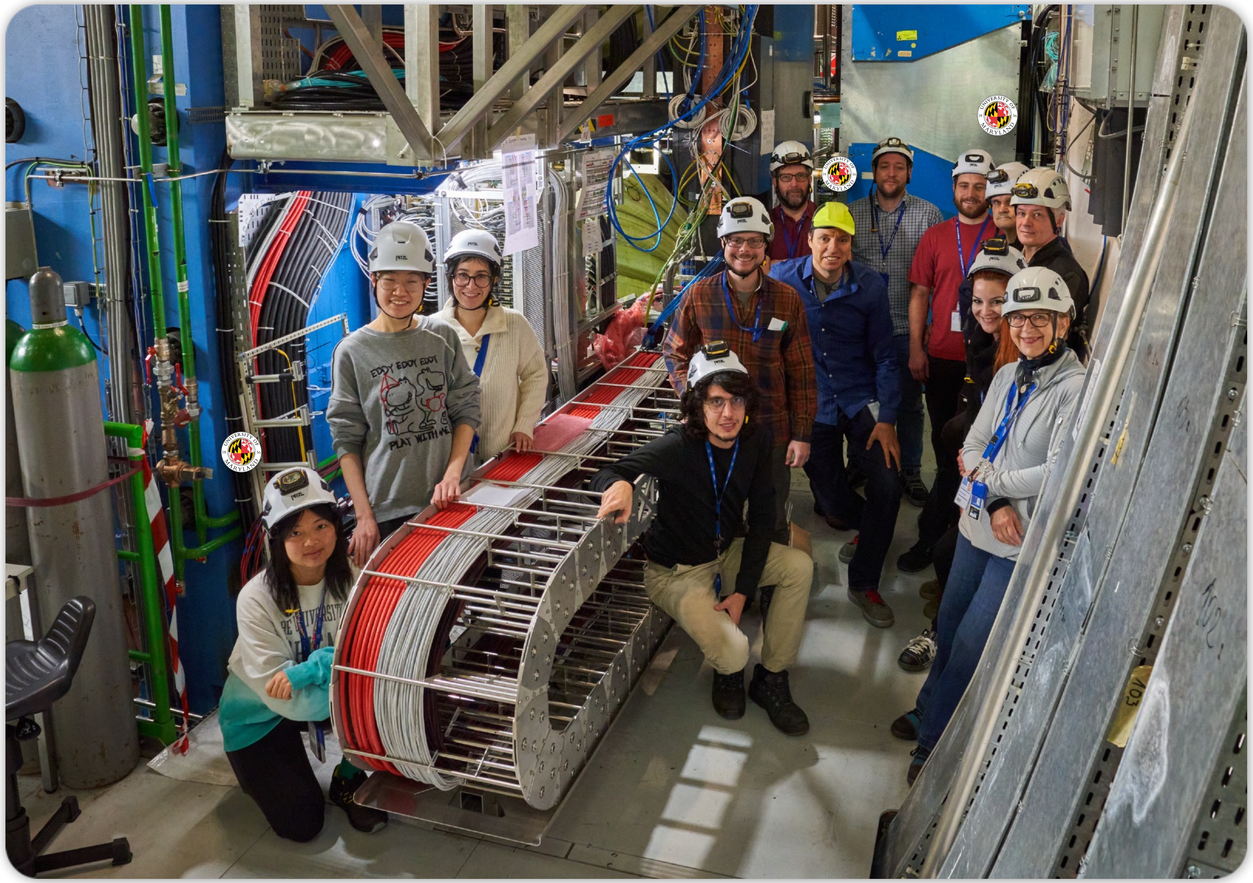


UT in its resting place until 2033



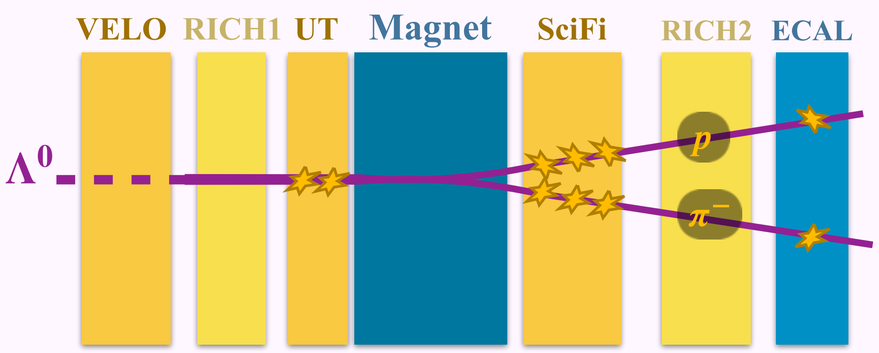
Cabling through Christmas break

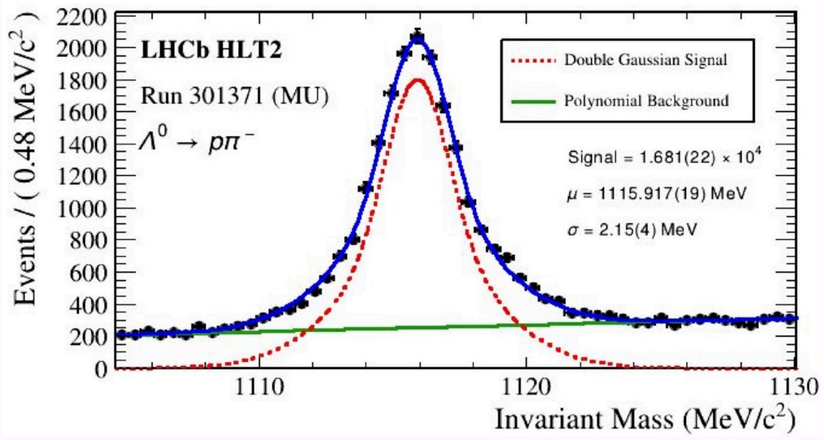
- After installation, **lots of cabling** to be done
  - Committed volunteers **defied European customs** and **worked through break**

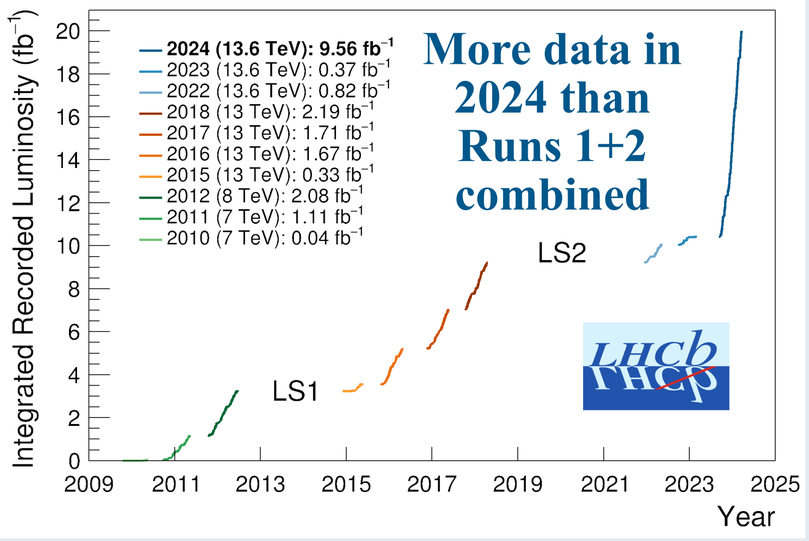


Excellent performance of upgraded detector

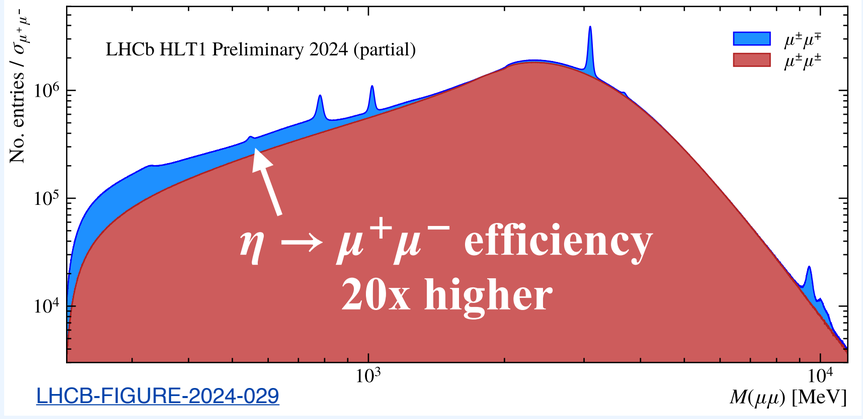
UT working well after joining LHCb data taking in 2024



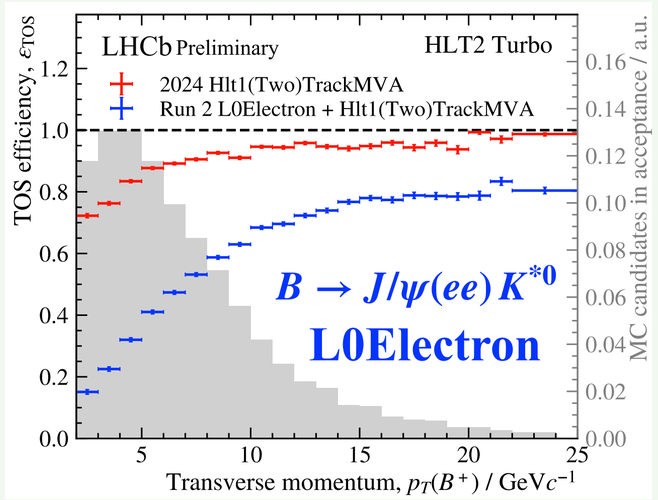




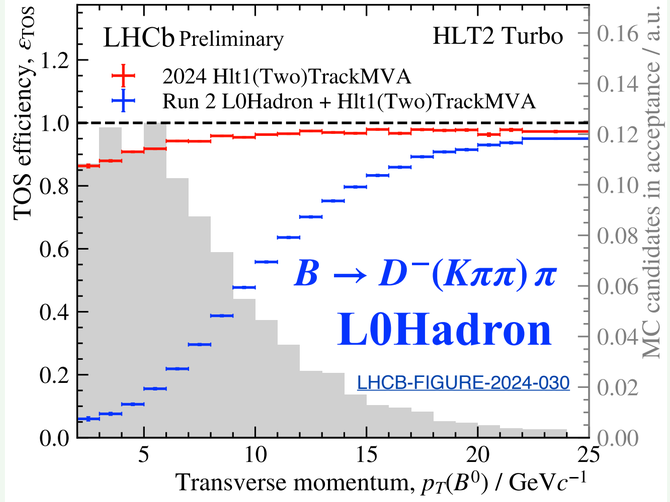
Lipschitz constrained NN in HLT1



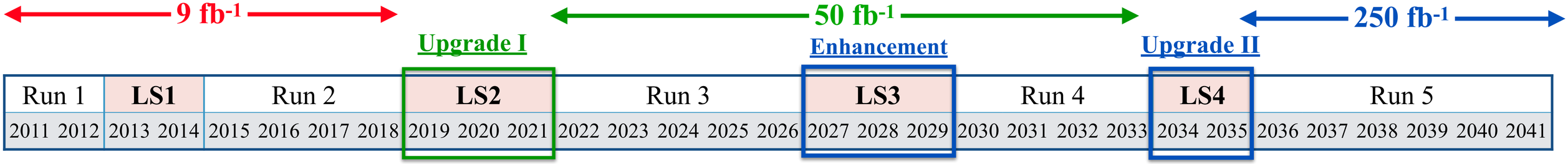
LHCB-FIGURE-2024-029



Larger trigger efficiency

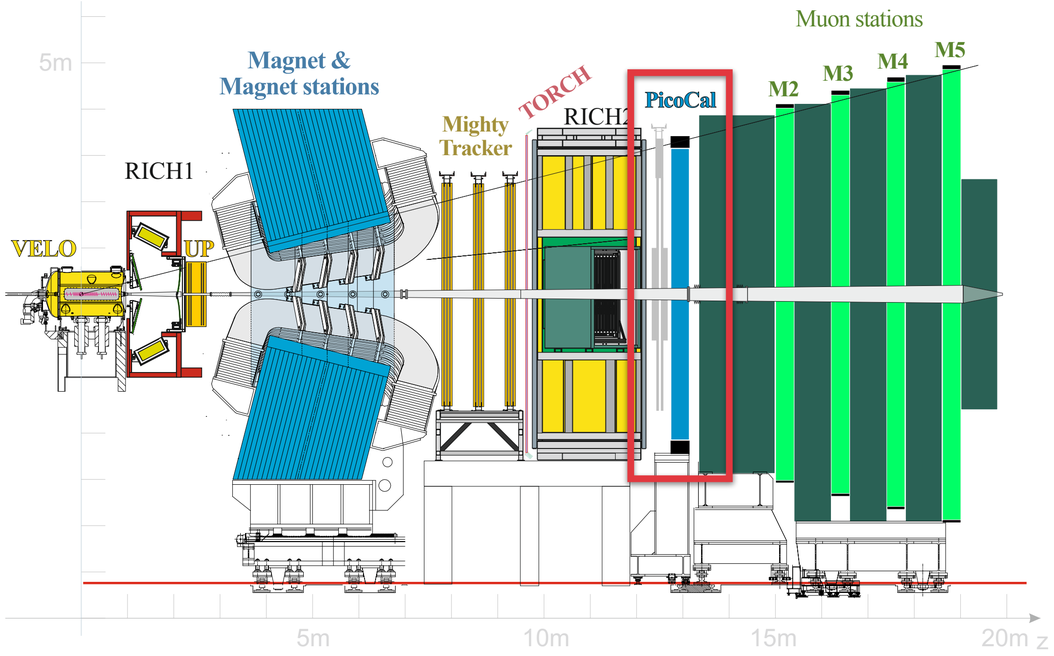


Upgrade II

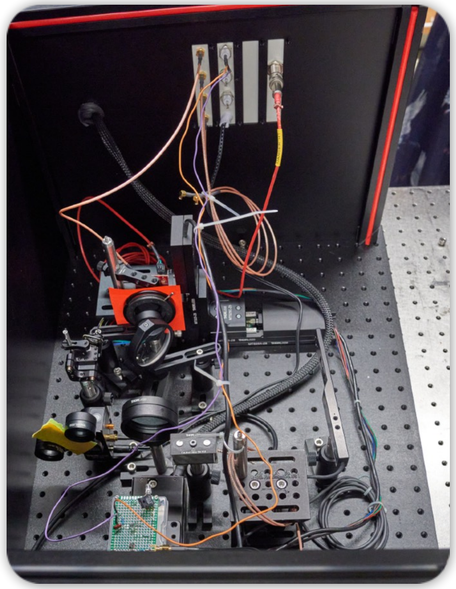


- Given LHCb's performance, **clear case** for **further upgrade** to **fully exploit HL-LHC**

UMD group gearing up to again make c**ritical PicoCal contributions** in **LS3** and **LS4**



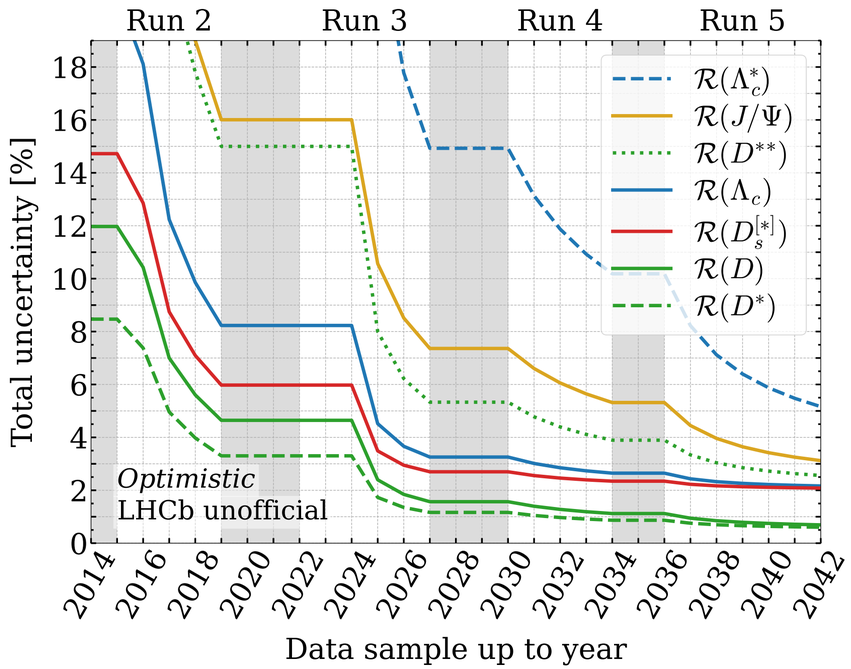
Starting 2026-27 we will be recruiting undergraduates!



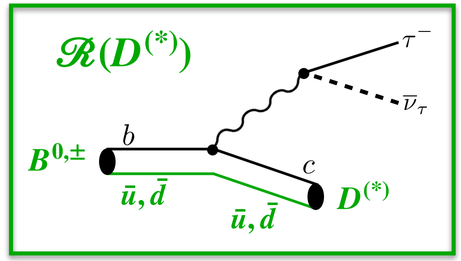
Prospects for LFU

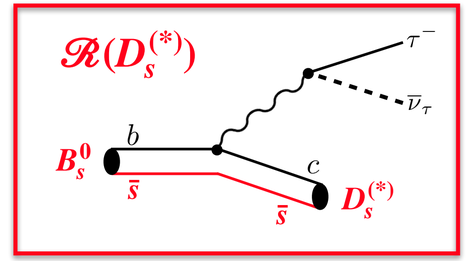
- Upgrades will allow us to **measure $\mathscr{R}(X_c)$** with **1-5% uncertainty**
  - ➡ Sufficient to **establish observation** for **current central values**

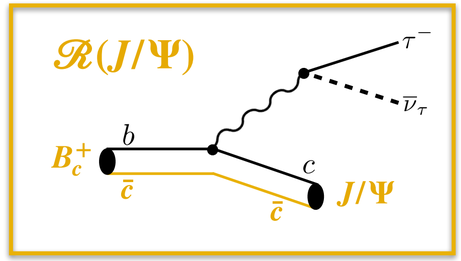
Bernlochner, MFS, Robinson, Wormser, RMP, 94, 015003 (2022)

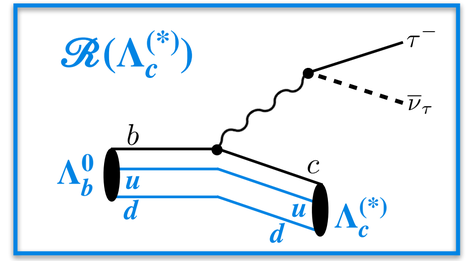


$$\mathscr{R}(X_c) = \frac{\mathscr{B}(X_b \to X_c \tau \nu_\tau)}{\mathscr{B}(X_b \to X_c \ell \nu_\ell)}$$









Also measure **kinematic distributions, sensitive** to **New Physics**

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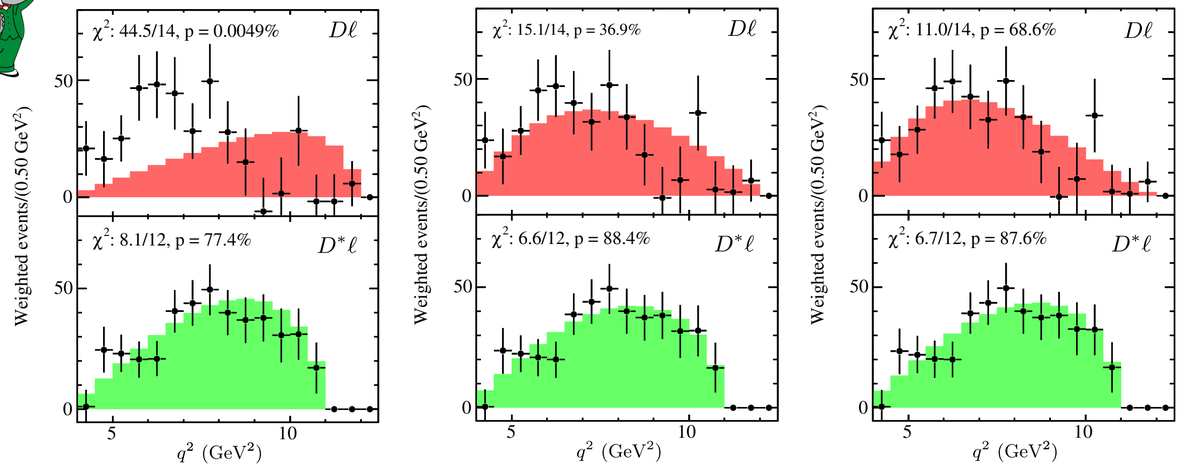
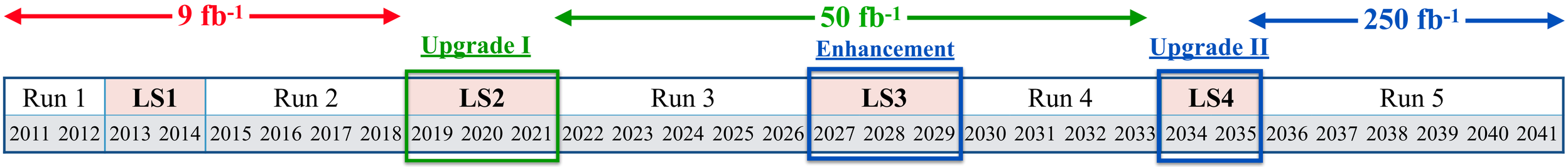
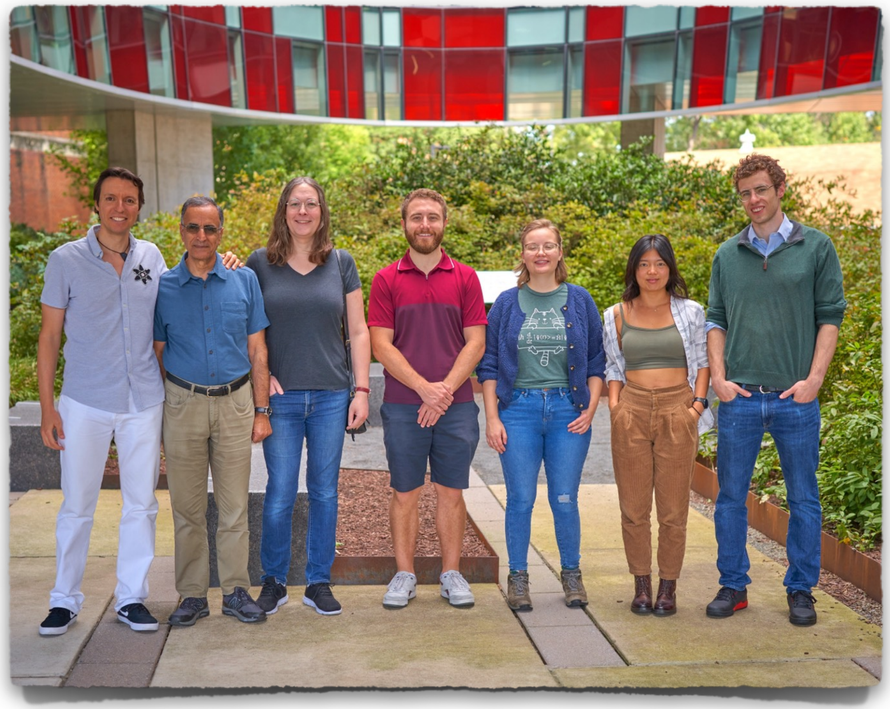


Summary



- **Excellent performance** by **LHCb detector**
- **Persistent anomalies** in $\mathscr{R}(D)$ and $\mathscr{R}(D^*)$
  - LHCb recently published **competitive measurements**
  - **Update** with **5-10x more data coming soon**
- **Exciting prospects** with **upgraded LHCb**
  - **UMD** had **critical contributions to Upgrade I**
    - **Working really well**
  - **Gearing up for Upgrade II**, will be taking in students!



Thank you, and let me know if you have **any questions!**