

LHCb and CODEX-b: flavor and dark sector efforts in Hungary

Biplab Dey



R-ECFA visit, Budapest
23rd September 2022

OVERVIEW: ELTE/HUNGARY ENTERING LHCb

- **New faculty** (Biplab Dey) joined ELTE in **January 2021** to establish a new flavor/dark sector group in Hungary.
- Negotiations with the LHCb CB went smoothly. ELTE CMS colleagues and department head participated in meetings with CB.
- ELTE accepted by LHCb as an **Associated** Member in **February 2021**. Associated to CERN.
- ELTE signed **MOU** with CERN in **April 2022** for LHCb M&O.
- Strong push from LHCb management to contribute to LHCb **Upgrade II**.

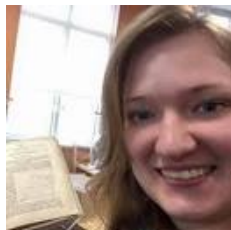
GROUP RESEARCH THRUSTS: THE THREE LEGS

- **Flavor anomalies** in $b \rightarrow s$ penguins and exotic hadrons
 - NP searches via **LFUV** in $b \rightarrow s\ell^+\ell^-$ and **radiative** $b \rightarrow s\gamma$ decays.
 - Exotic **spectroscopy**: pentaquark and tetraquark discoveries.
- LHCb **ECal Upgrade** for Run4 and Phase-II (\geq Run5).
 - Closely tied to electron/photon reconstruction needs for anomalies.
 - Thrust on **timing** for pileup. Simulation and ECal lab at ELTE.
- **CODEX-b**: new LLP (long-lived particle) detector in LHCb
 - **High transversity** (complementary to FASER). Invisible Higgs (+other heavy objects) decays.
 - ELTE: founding member and key roles in efforts on **CODEX- β** for **Run3**.
 - **ERC COG'21** w/ ELTE: **grade B**. Positive but asked to get approval.

MANPOWER



Biplab Dey (PI)



Amy Schertz (PD)

- Postdoc hired in **May 2022**. Focusing in LFUV searches in $\Lambda_b \rightarrow pK^- \ell^+ \ell^-$ w/ full Run1+Run2, and ECal R&D.
- Obviously not enough for such a large project! No PhD students yet and no other FTE for CODEX-b.

LEADERSHIP AND VISIBILITY OF ELTE GROUP

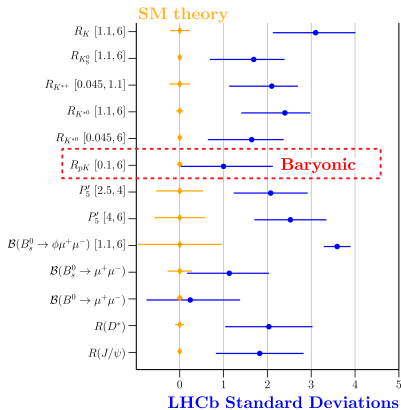
- PI: member of **LHCb Editorial Board** and core Physics Planning Group (**PPG**).
- PI: **convener** of Radiative Rare Decays WG and Amplitude Analysis WG in LHCb.
- PI: organised large **workshop** on Hadron Spectroscopy at MITP in March'22. Organizing joint LHCb-Belle II Radiative Workshop at CERN in 2023.
- PI: **convener** of CODEX-b Simulation WG.
- **PD**: invited to give **summary talk** on LHCb Anomalies at MITP in Oct'22.

FUNDING PERSPECTIVES

- *Significant risk to project if funding not found.* Even M&O's for 2 FTE's not guaranteed beyond 2025.
- Inside Hungary, have applied to two starting (OTKA) grants and two advanced grants (Momentum/Forefront). No success as yet.
- Some observations from the review comments:
 - Asks why other Hungarians not in project. Despite repeated explanations that this is a completely new project and CMS people can't be in LHCb.
 - Asks to name the people to be hired, presumably assuming a group already exists. However, *the application is to form the group in the first place* and PD ads can only be open calls.
- Absence of long-term PP/HEP support from funding agency (like NSF/DOE grants in the US).

Backup

LEPTON FLAVOR UNIVERSALITY VIOLATION



- $R_X \equiv \frac{\mathcal{B}(b \rightarrow s \mu^+ \mu^-)}{\mathcal{B}(b \rightarrow s e^+ e^-)} \sim 1$ in the SM.
- Global EFT fits on BF's, angular analyses, LFUV $\Rightarrow 4\sigma$ -ish tension.
- Spin-1/2 Λ_b^0 : richer set of angular observables than spin-0 B 's.
- PI published 1st observation of $\Lambda_b^0 \rightarrow p K^- \mu^+ \mu^-$ w/ Run1.
- Full Run1+Run2 LFUV angular analysis ongoing.

Towards a complete angular analysis of the electroweak penguin decay $\Lambda_b^0 \rightarrow p h^- \ell^- \ell^+$

LFUV pheno paper
in preparation

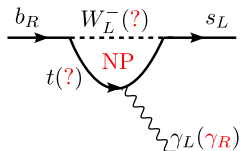
Biplab Dey¹ and Amy M. Schertz¹

¹ELTE Eötvös Loránd University, Budapest, Hungary

(Dated: September 21, 2022)

We investigate the rare electroweak penguin transition $b \rightarrow s \ell^+ \ell^-$ through angular analyses in

RH CURRENT SEARCHES IN $b \rightarrow s\gamma$

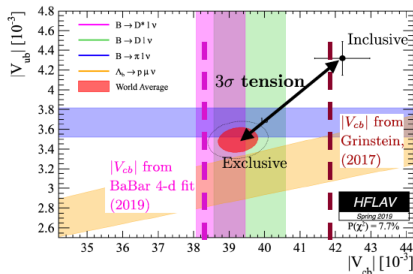


- SM: outgoing photon is is **purely LH**.
- No TDCPV in $B^0 \rightarrow f_{CP}\gamma$, since b and \bar{b} go to different final states and don't mix.
- Excellent null tests for SM. Complementary to high- p_T searches of W_R^\pm .
- C.f. **Belle (II)**: LHCb has higher statistics, but lower flavor tagging power. Overall, we're very **competitive**.
- PI's main thrust: TDCPV of $B^0 \rightarrow K_S^0\pi^+\pi^-\gamma$ and first observation of $B_s \rightarrow K_S^0K^+\pi^-\gamma$.
- Major improvements: including neutral cone **isolations** against peaking $\pi^0/\eta \rightarrow \gamma(\gamma)$ backgrounds and **neutral PID** calibration.
- PI is current **convener** of Radiative WG.

TENSIONS IN THE SEMI-LEPTONIC SECTOR: *BABAR*

- PI's 2019 *BABAR* paper “revived” tension in $|V_{cb}|$. Puzzle continues with new lattice data.

$|V_{ub}|$ - $|V_{cb}|$: TENSIONS IN TWO CRITICAL PARAMETERS



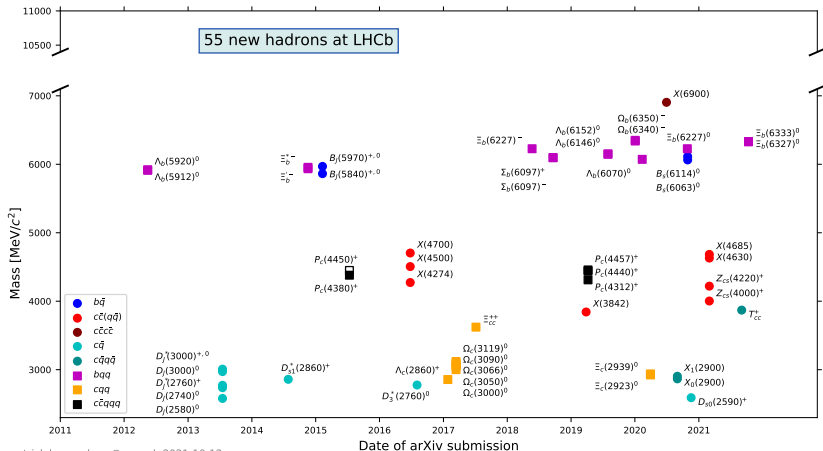
- Circa 2017, **Grinstein/ Gambino**: $|V_{cb}|$ “resolved” by zero-recoil extrapolation issue?
- 2019: back to the drawing board.
- 2021/22: lattice $w > 1$ FF’s.

- Note: some tension in $|V_{cb}|$ between $B \rightarrow D^*$ and $B \rightarrow D$.
- Stress-testing **HQET** and **flavor-SU(3)** ($B \rightarrow D^{(*)}$ vs $B_s \rightarrow D_s^{(*)}$).
- Implications of the form-factors on SL LFUV.

PI's ICHEP'22 slides

EXOTIC TETRAQUARKS AND PENTAQUARKS

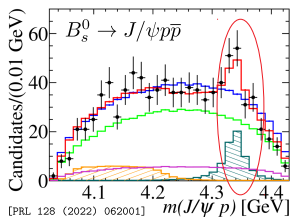
- Long sought after. LHCb: at least **one heavy quark** needed.



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NEW EXOTICS: ONGOING ELTE ANALYSES

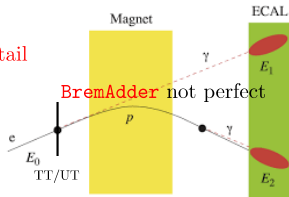
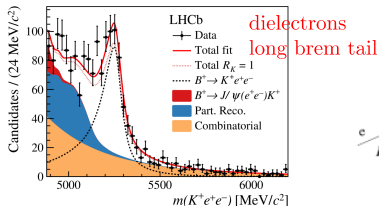
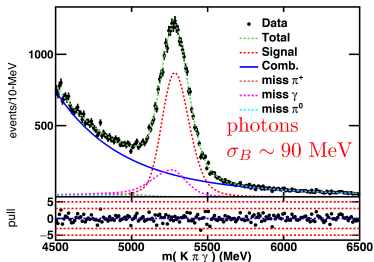
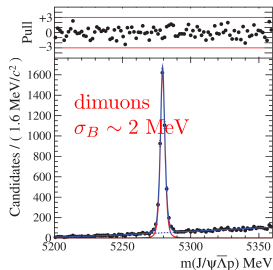
- First LHCb Pentaquark (2015): $\Lambda_b^0 \rightarrow J/\psi p K^-$. New searches in $\Lambda_b^0 \rightarrow J/\psi p K_s^0 \pi^-$.



- Pentaquarks in B -meson decays: PI led 1st observation of $B_{(s)}^0 \rightarrow J/\psi p \bar{p}$.
- Full Run1+Run2: “evidence” for pentaquark. PI: improved BDT almost 30% increase in stats. Thrust to move this to “observation”.
- New tetraquarks in $B \rightarrow J/\psi K \pi \pi$: 7-dimensional phase-space. Exotics seen but very challenging analysis!
- PI is currently the **convener** of Amplitude Analysis WG

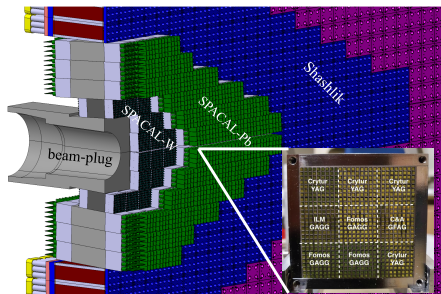
ELECTRONS AND PHOTONS AT LHCb

- Calo objects (e/γ) hard at LHCb: ECal resolutions and brem.

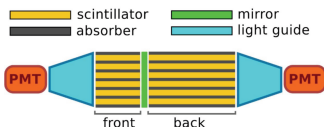


ECAL UPGRADE PHASE-II (U2)

- Unchanged ECal in LS2. Consolidation in LS3 (rad. damage) and full replacement in LS4 with **10-20 ps timing** to kill pileup.



- Maintain $\sigma_E/E \sim 10\%/\sqrt{E} \otimes 1\%$ resolution at $\times 50$ higher lumi.
- New radiation-hard, reduced Moliere radius, finer-segmented, fast timing modules (SPACAL)

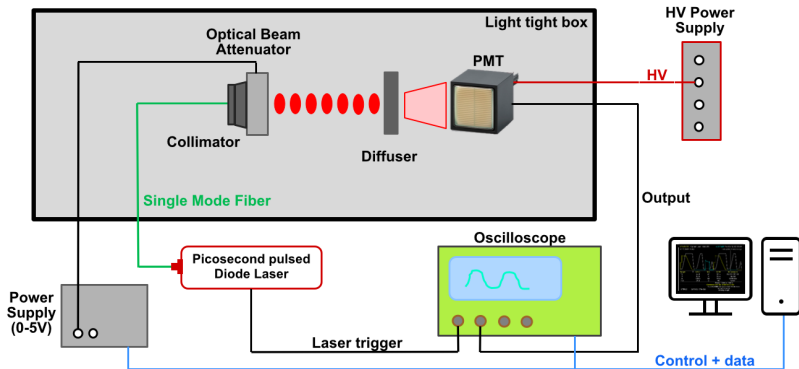


- Two-sided R/O with z -segmentation.
- R&D on Si-W ECal or Si/LAPPD **timing layer** at the shower max.

ELTE NEAR-TERM PLANS FOR U2 ECal

- ELTE part of the ECal group in U2 **Framework TDR**.
- **PD** previously worked on tracking at GlueX/JLab. Developing **brem recovery** algorithms for U2 ECal using $\Lambda_b^0 \rightarrow pK^-e^+e^-$ and $\Lambda_b^0 \rightarrow pK^-\gamma$.
- PI previously: LHCb Silicon (UT/TT) and fiber (SciFi) **trackers**.
- Near-term hardware plans: setting up a small lab for **PMT testing**. Lab space+hardware funding from ELTE.
- Timing performance, wavelength dependence, QE, TTS uniformity, ageing studies. Collaborating with **Barcelona/Paris** groups.

SCHEME FOR PMT TEST-BENCH SETUP



CONFERENCE ORGANISATIONS

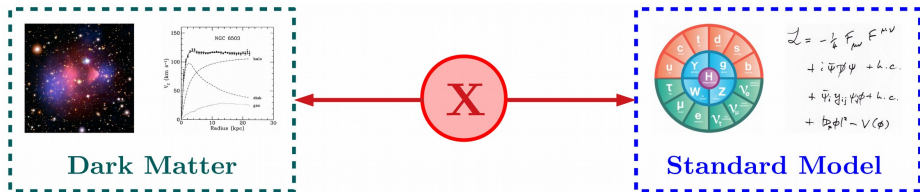
- Very successful **pre-Run3 workshop** at Mainz.

The banner features a central 3D geometric structure with colorful lines radiating from it. On the left, a red triangle contains the text 'MITP VIRTUAL WORKSHOP'. On the right, the text reads 'Hadron Spectroscopy: The Next Big Steps' and '14 - 25 March 2022'. Below this is a globe icon and the URL 'https://indico.mitp.uni-mainz.de/event/246'. At the bottom left are logos for ATLAS, Belle II, BESIII, LHCb, and GlueX. At the bottom right, it says 'PI: lead organizer' and the MITP logo (Mainz Institute for Theoretical Physics).

- Planning joint-LHCb/BelleII **Radiative Penguin Workshop** early next year: Budapest or CERN. Previous editions at Clermont-Ferrand and Lausanne. Includes ECal Upgrade discussions.

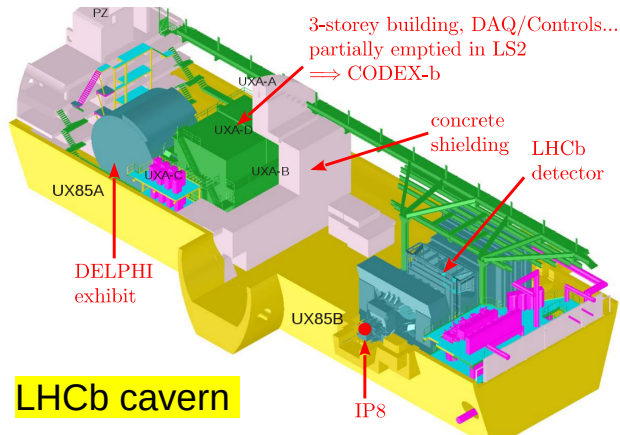
DARK SECTOR SEARCHES AT HL-LHC

- Dark/hidden sector: SM gauge singlets



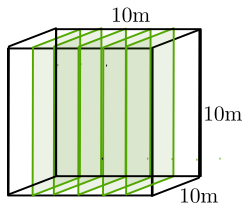
- SM particles can (feebly) interact with DM via mediators/portals
 - Scalar portal \rightarrow Dark Higgs/scalars
 - Neutrino portal \rightarrow Heavy Neutral Leptons
 - Pseudoscalar portal \rightarrow Axion-like particles
 - Vector portal \rightarrow Dark photon
- Feebly interacting \Rightarrow long lived particles (LLP).

CODEX-B: DEDICATED LLP DETECTOR IN LHCb



LHCb cavern

- Instrument with tracking layers



- RPC's from ATLAS upgrade

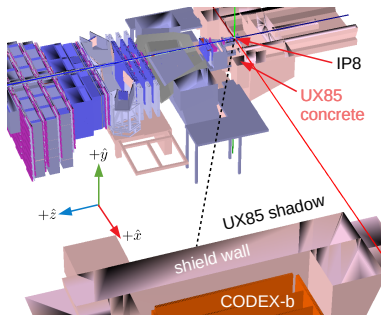
- Shielded, underground, $10 \times 10 \times 10 \text{ m}^3$ vol, $\sim 25 \text{ m}$ from IP8. Novel Joint LHCb-CODEX-b triggers.
- Excellent sensitivity/\$ for all four portals (see [EOI](#)).

LEADERSHIP ROLES

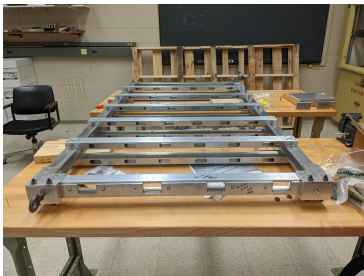
- PI first proposed and coordinated plans to use ATLAS RPCs
- Led **background** measurements inside LHCb cavern in 2018 with CERN summer student.



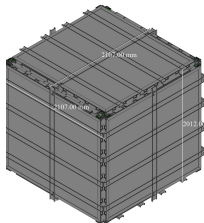
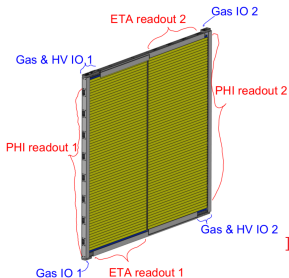
- Simulation **convener**



CODEX- β DEMONSTRATOR



- $2 \times 2 \times 2\text{m}^3$ prototype using 14 RPC chambers from ATLAS upgrade
- Integrable with LHCb online in Run 3
- Construction ongoing and discussions with LHCb management and TB.
- Installation document in preparation.



Engineering drawings

CODEX- β INSTALLATION

CODEX- β Installation Plan

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3 Roock,⁹ Biplob Dey,⁹ Raphael Dumps,⁹ Mohamed Elnehi,¹⁰ Vladimir V. Gligorov,^{4,3}
4 Rebeca Gonzalez Suarez,¹¹ Thomas Gorordo,¹² Connor Henderson,¹⁰ Louis Henry,² Philip
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6 López Soliño,⁸ Titus Mombächer,⁸ Benjamin Nachman,¹² David T. Northacker,¹⁰ Gabriel
7 M. Nowak,¹⁰ Michele Papucci,¹⁶ Gabriella Pásztor,⁹ Luca Pizzimento,¹⁷ Francesco Polci,⁴
8 Desai J. Robinson,^{12,14} Emilio Xosé Rodríguez Fernández,⁸ Heinrich Schindler,² Michael
9 D. Sokoloff,¹⁰ Adityan Suresh,^{12,14} Paul Swallow,¹⁸ Riccardo Vari,¹⁹ Carlos Vázquez Sierra,²
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(Dated: May 2022)

60+ page document
discussions w/ LHCb
management/TB