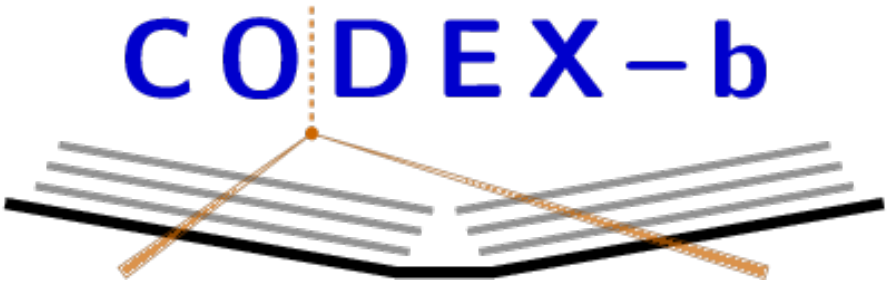
RPC Commissioning at CODEX-β

Michael Peters

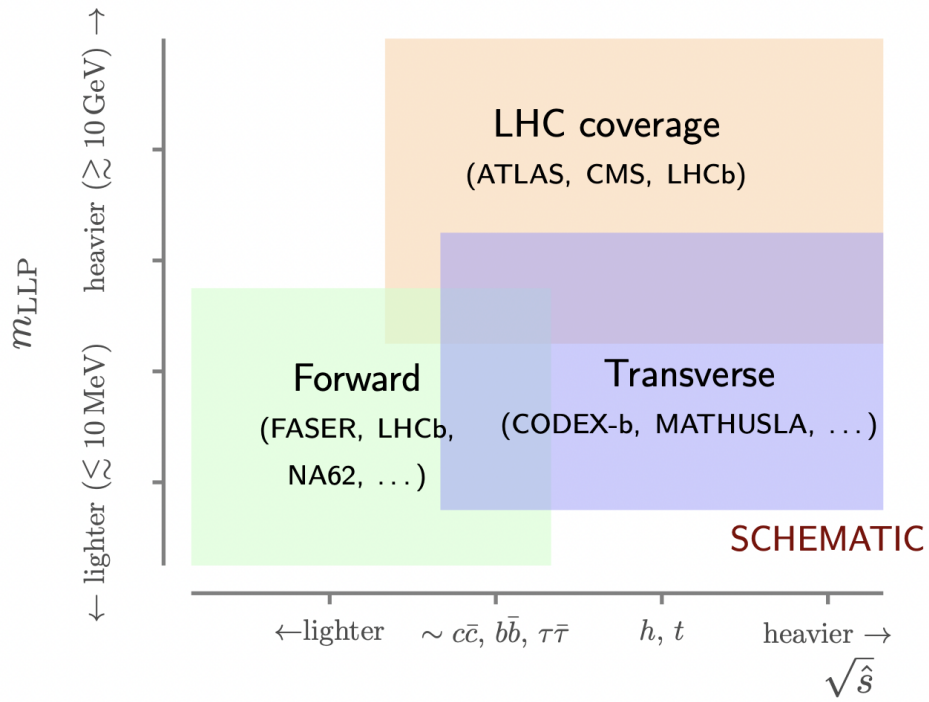
on behalf of the CODEX-b collaboration

10 September 2024



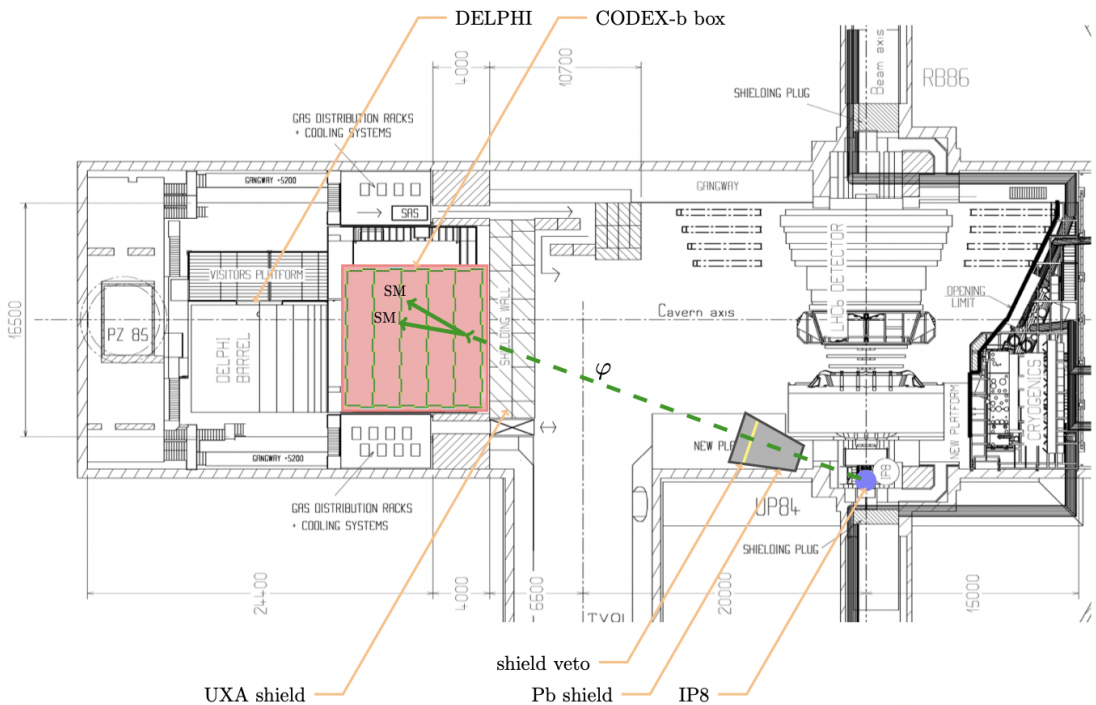
Overview

- We want to search for displaced decays-in-flight of exotic long-lived particles (LLPs).
- These LLPs emerge from many BSM scenarios (hidden or dark sectors).
- To do this, we want to look in an important region of phase space (Higgs to light LLPs) to complement the reach of existing LHC experiments.



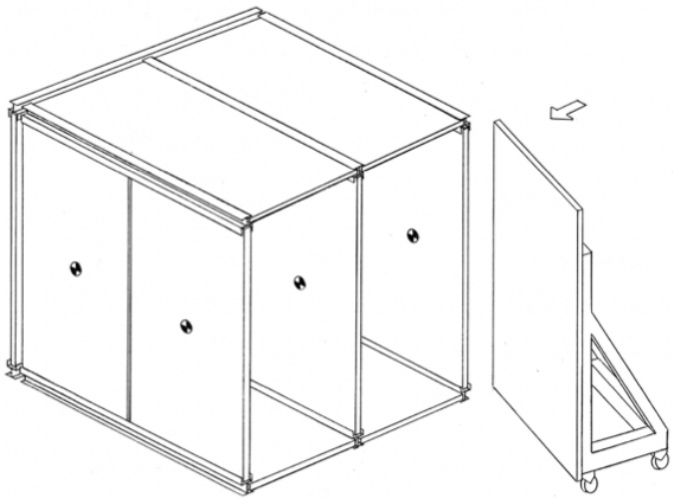
CODEX-b

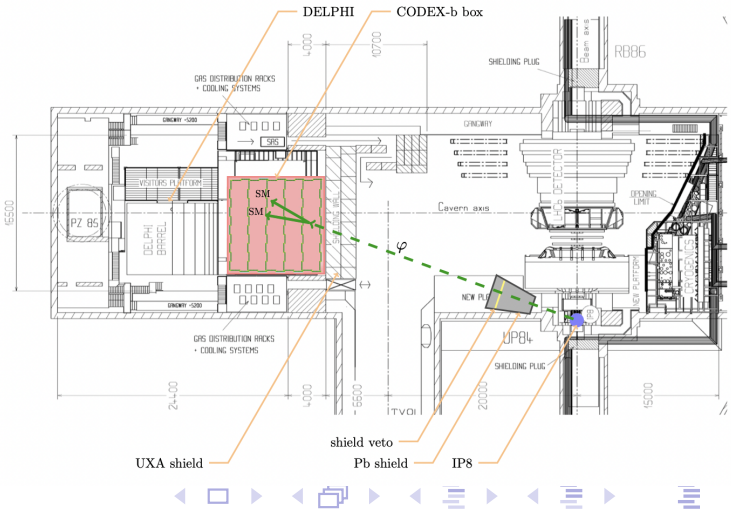
- The COmpact Detector for EXotics at LHCb (CODEX-b) is a proposed transverse detector.
- 10m cube of five-hundred 2m x 1m triplet RPC panels arranged into six external faces and four internal faces along the x-axis.
- Near-zero background by lead shield, shield veto, and concrete wall
- More details: arxiv:2203.07316, arxiv:2406.12880



CODEX-β

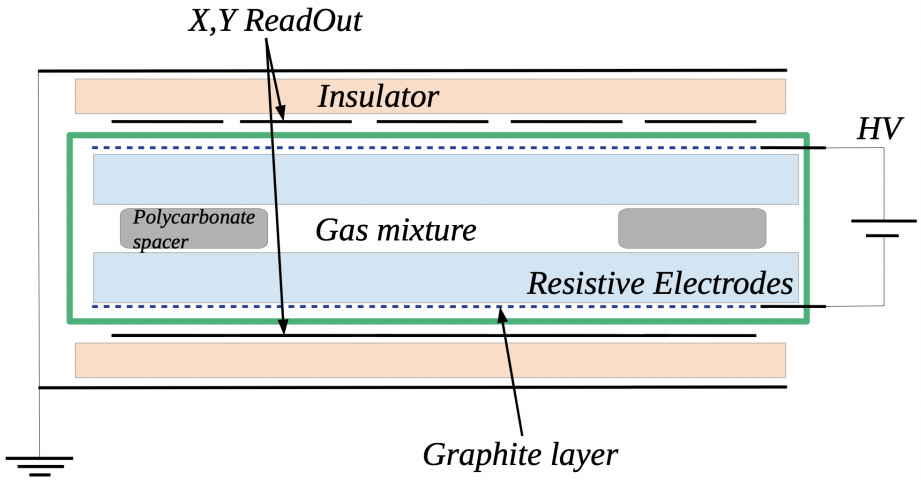
- Codex-β is a small-scale demonstrator of Codex-b: a 2m cube of fourteen 2m x 1m triplet RPCs to be placed in the currently empty LHCb server room.
- Goals:
  - Validate background estimates. Same location as full detector.
  - Establish proof of principle. We are using these RPCs for tracking.
  - Integrate with LHCb software trigger. We want to use CODEX-b trigger save events in LHCb.
- We will use the pp collisions from the collision point of the LHCb experiment.





RPC design

- Based on BIS7 RPC design from ATLAS Phase-2 upgrade.
  - Usual benefits: fast, cheap, compact, and modular
- **Triplet:** three RPC "singlets" stacked together. Requiring hit coincidence reduces trigger noise.
- Orthogonal strip panels provide 2D hit positions.

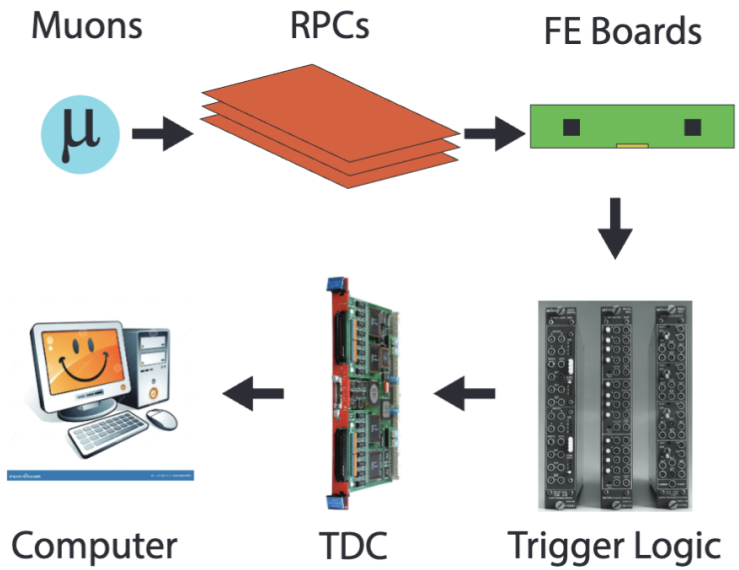


Gas mixture

- For testing our RPCs, we use the "standard" gas mixture: 94.7% R-134a (1,1,1,2 tetrafluoroethane), 5% isobutane, and 0.3% SF6 (sulfur hexafluoride).
- For Codex-β, we plan to use a modified gas mixture: 30% CO2, 64% R-134a (1,1,1,2 tetrafluoroethane), 5% isobutane, and 1% SF6 (sulfur hexafluoride).
- We want to use and test an eco-gas mixture after full commissioning with the standard gas mixture. The current thought is: HFO + variable % of CO2.

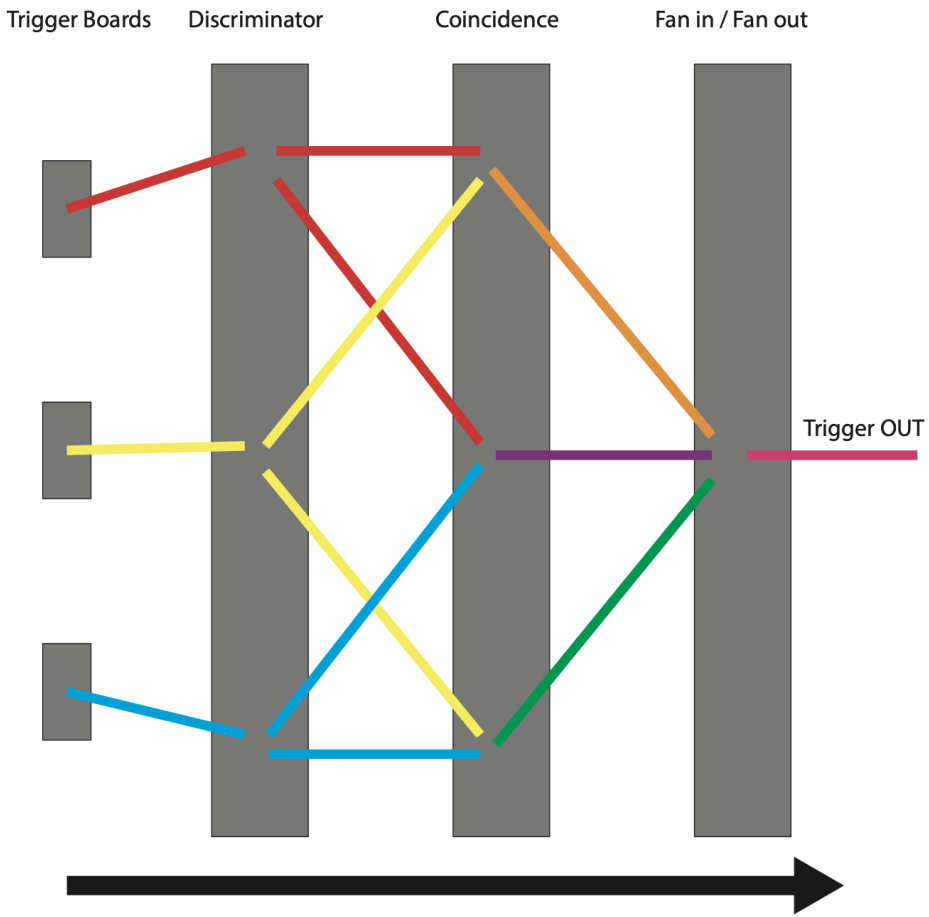
Commissioning data flow

- We use cosmic muons for testing.
- Cosmic muons create an electron avalanche in gas gap.
- Current in strip panels converted to low voltage differential signal by front end electronics (want good timing resolution).
- Signals sent through trigger logic to produce a signal only for valid hits.
- Hits and trigger sent to time-to-digital converter (TDC).
- TDC interfaces with a computer for further data analysis.



Trigger logic

- One trigger board per triplet layer (top, mid, bot).
- Coincidence unit for each permutation of layer pairs.
- Trigger on coincidence of at least two layers.
- FI/FO collects the coincidences and outputs a single trigger signal.
- Trigger signal is then sent to the TDC, which is combined with the digitized hit data.



DAQ

DAQ software then handles data acquisition and manipulation in four phases:

1. **Acquisition** - TDC operation and raw data collected.
2. **Conversion** - Raw data converted to global channel number and time measurement.
3. **Analysis** - Testing variables calculated.
4. **Plotting**

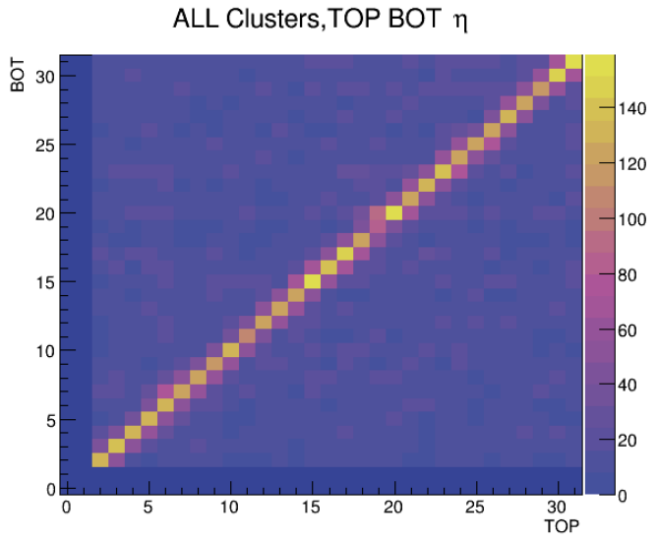
Commissioning tests

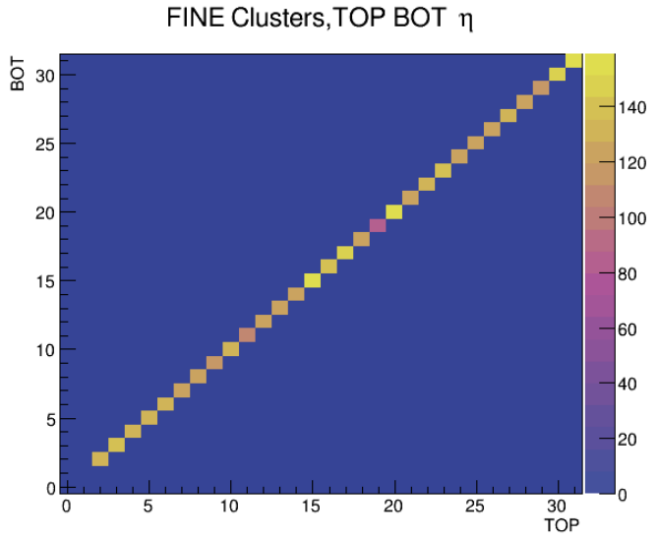
- We test for the overall performance of our detectors. Data collection lasts for one minute per test.
- We also test for gas leaks (3 mbar, failure if $\Delta p = .1$ in 3 mins) and "voltampermetric" data.

HV	Trigger	Test Name
Off	OFF	Electronic Noise
Off	ON	Correlated Electronic Noise
4000V	OFF	Electronic Noise due to HV
1-Ly On @WP / 2-Ly Off	ON	Independence Test
2-Ly On @WP / 1-Ly Off	ON	Fake Muon Check (correlated noise due to chamber)
All-Ly On @WP	OFF	Chamber Noise
All-Ly On @WP	ON	Cable Check
2-Ly On / 1-Ly HV scan	ON	Efficiency Scan, Overall checks & performance

Commissioning tests

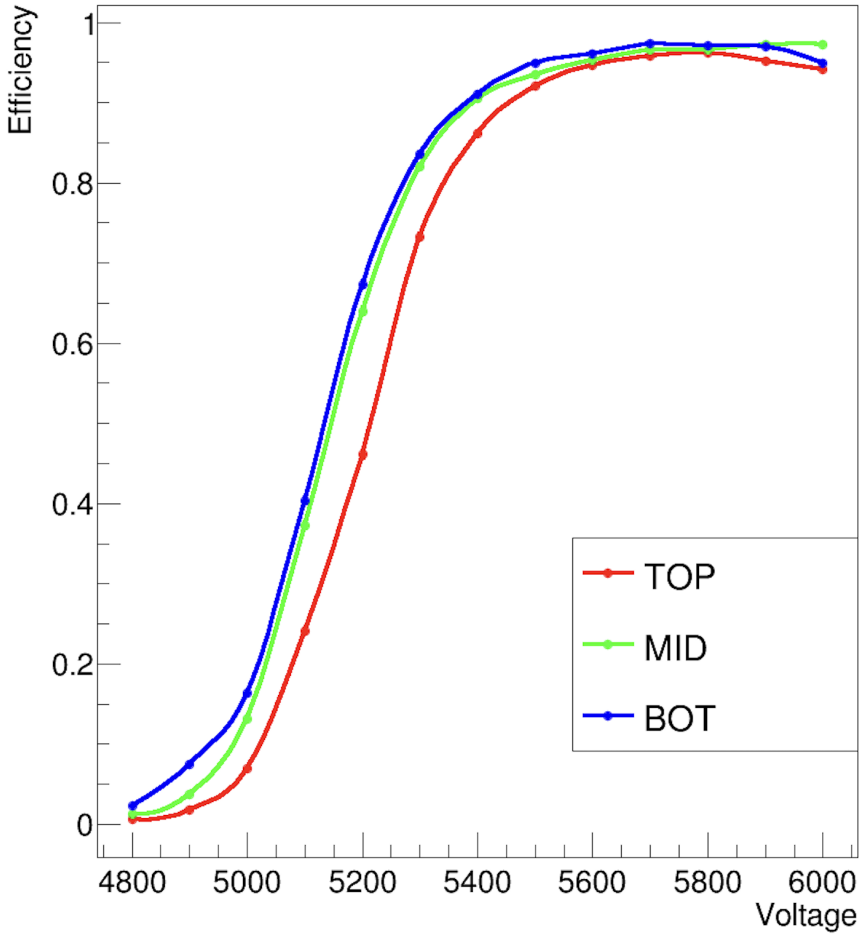
We expect to see hits at the same channel number in the same time window between two singlets (this would be a trigger).

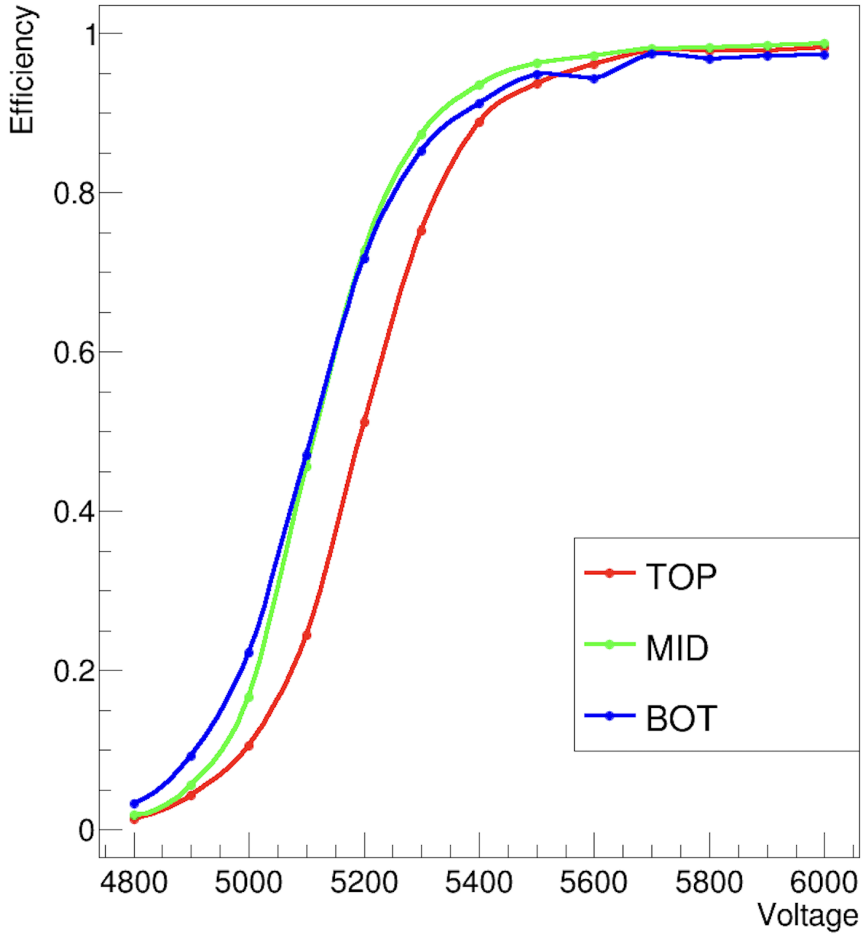




Efficiency scan

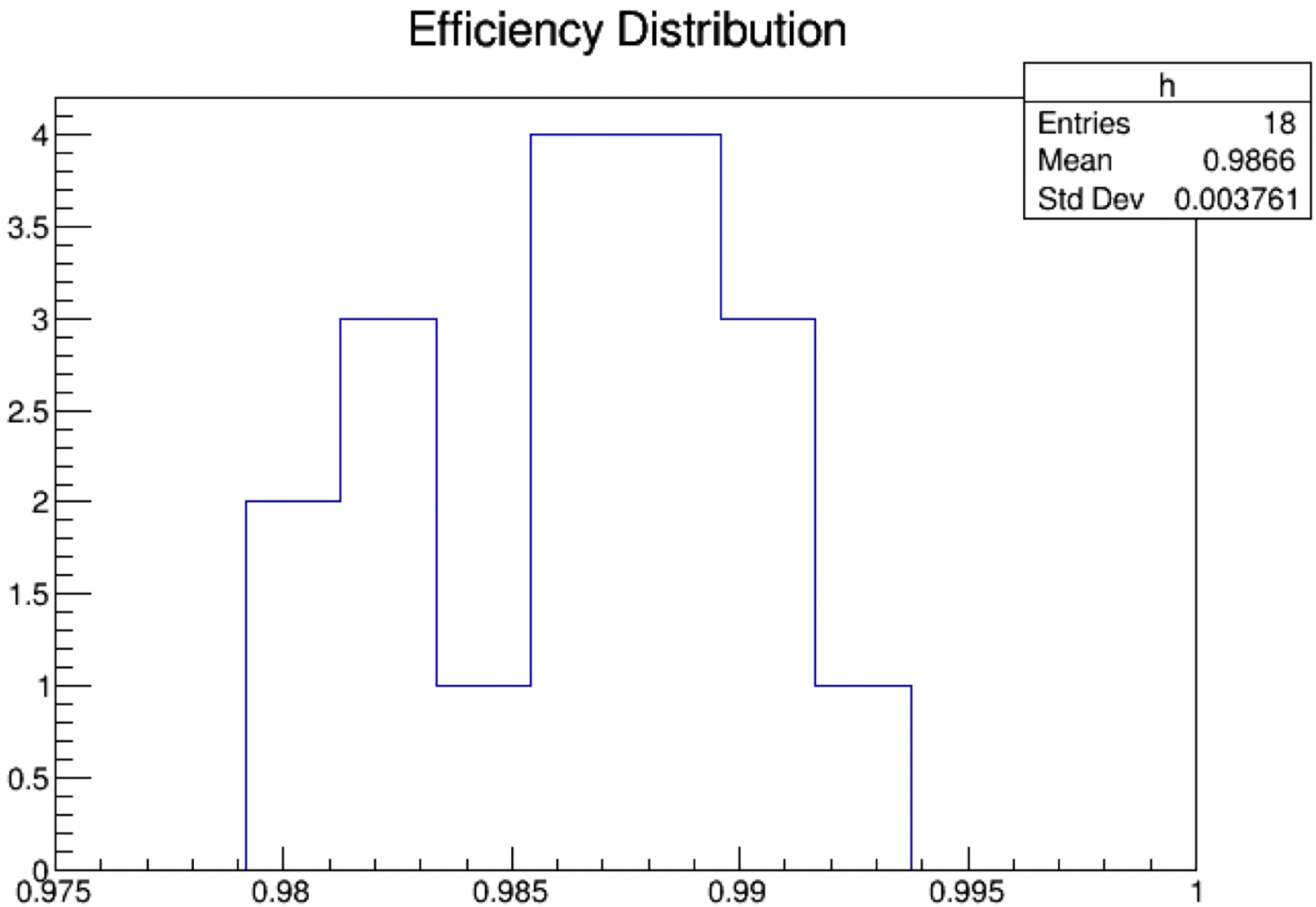
Efficiency of a given layer is calculated as the ratio of hits in the other two layers at working point to hits in all three layers, in the same channel. Want efficiency $\geq$98% when all channels are at working point (5800 V).





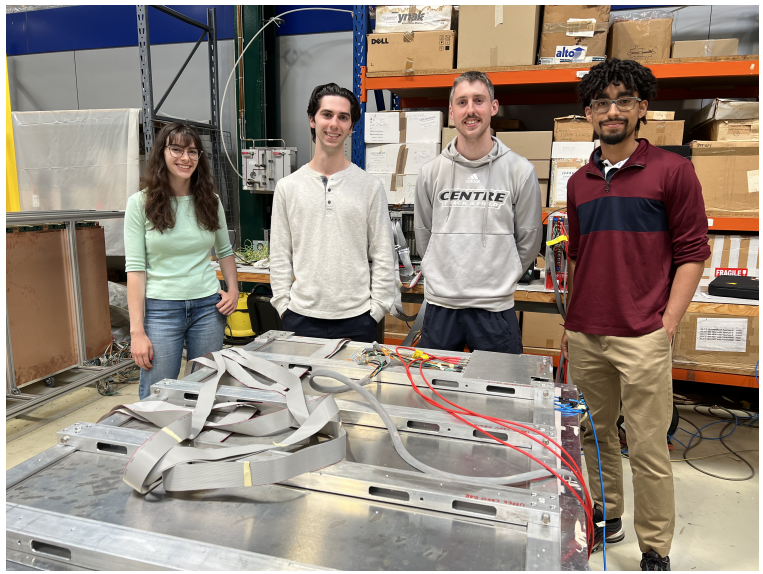
Efficiency scan

"Want efficiency $\geq$98% at 5800 V"...which we get!



Conclusion

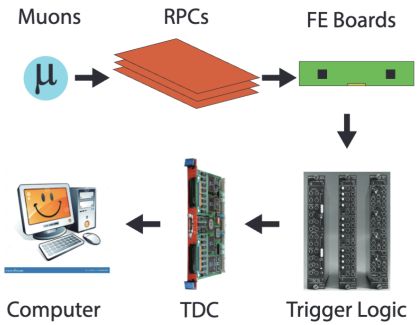
- CODEX-b is a proposed RPC tracking detector to search for LLPs in an unexplored transverse region.
- Codex-β is the prototype under construction to validate background models, use of RPCs for tracking, integration with LHCb, and use of eco-gas mixture.
- RPC commissioning is proceeding successfully for Codex-β.
- 41/42 singlets built, 10/14 triplets pass commissioning tests, remaining 4 not yet commissioned.
- We're soon moving underground to begin installing Codex-β.
    - Target: Winter 2024 - Spring 2025 and data taking 2025.
- Call for collaborators!

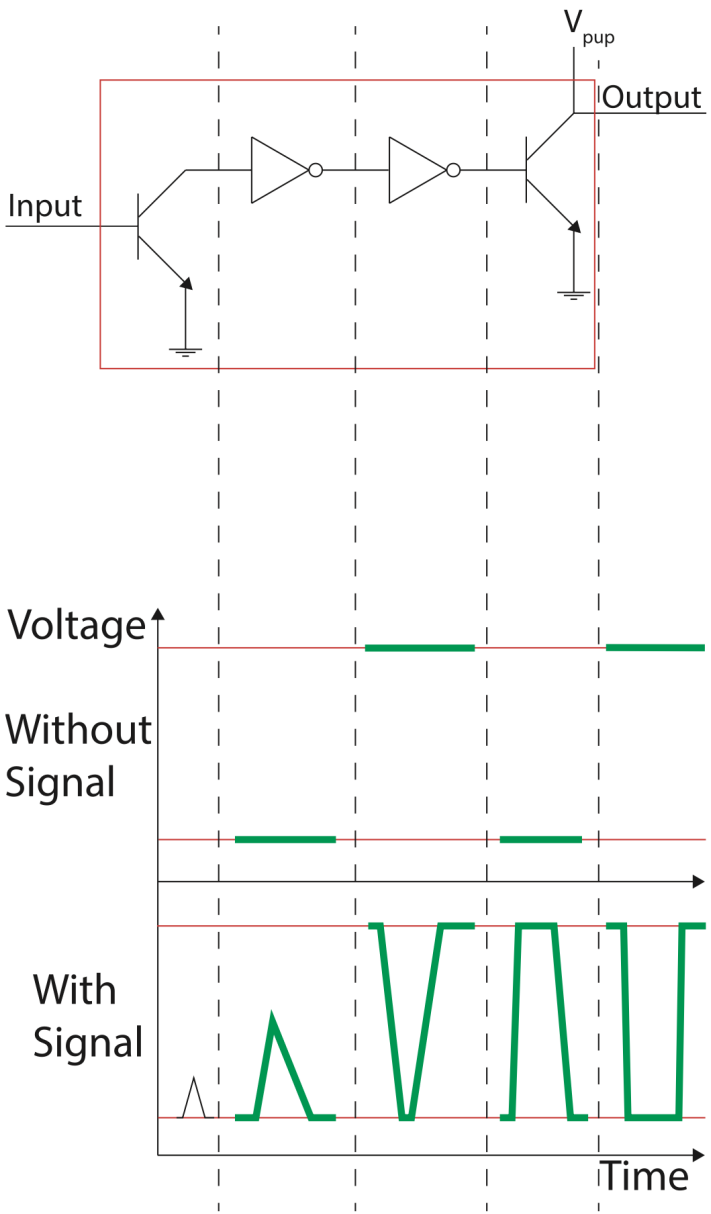


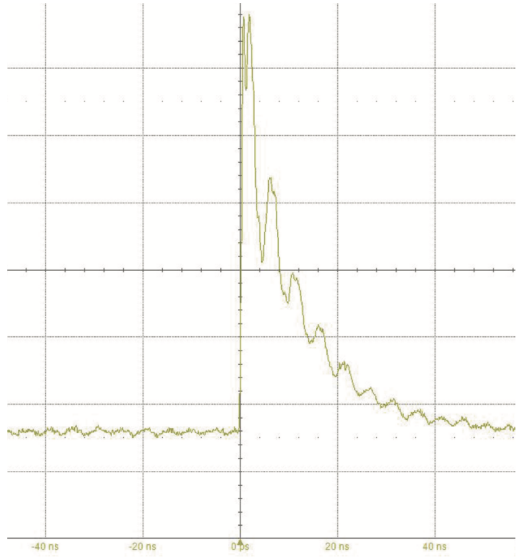
References

Proposal: arXiv:1708.09395
Expression of interest: arXiv:1911.00481
Snowmass whitepaper: arXiv:2203.07316
Technical design report: arXiv:2406.12880

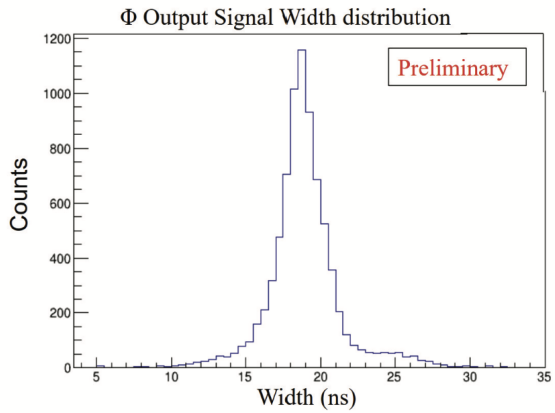
Front end boards







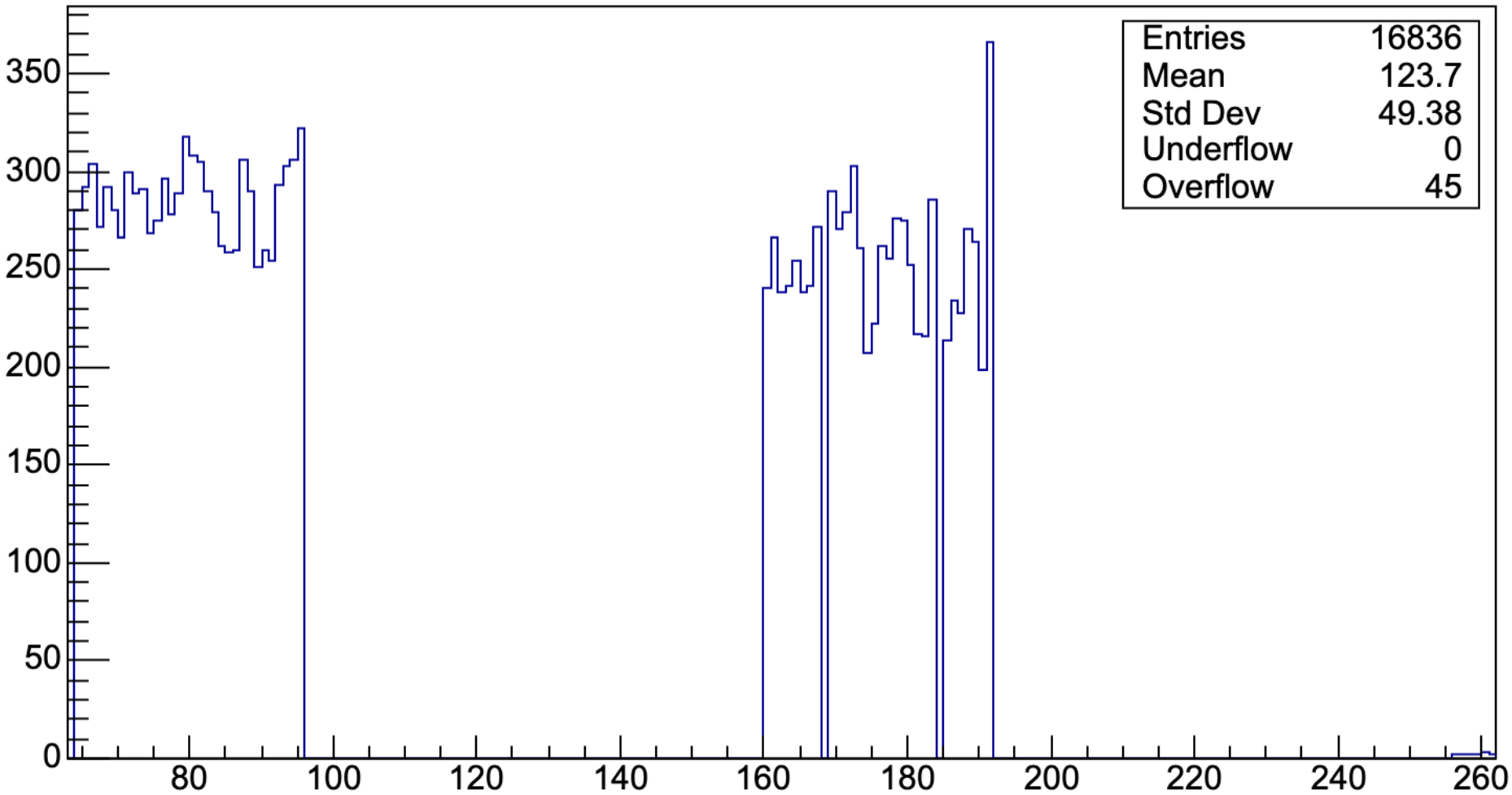
Front end electronics amplify the signal from the gas gap, output hits as a falling-edge LVDS pulse.



Commissioning tests

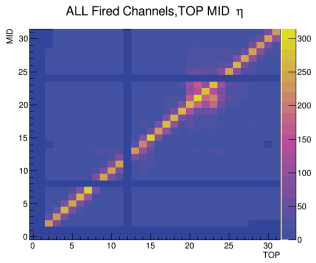
Comissioning Tests				
Name	Trigger Mode	High Voltage (V)	Number of Runs	Notes
Electronic Noise	Off	0	1	Tests for hits generated by the low voltage supplied to the front end boards. Ideally no hits are seen.
High Voltage Noise	Off	4000	1	Tests for hits generated by the high voltage supplied to the modules. Ideally no hits are seen.
Chamber Noise	Off	5800	1	Tests for the rate of noise relative to the rate of muon hits.
Correlated Electronic Noise	On	0	1	Tests to make sure the electronic noise hits are eliminated by the trigger.
Independence	On	1 @ 5800, 2 @ 0	3	Test to make sure there are no hits being recorded in the test layer, because the high voltage is turned off for the other two so they won't be able to trigger on muons.
Fake Muon	On	2 @ 5800, 1 @ 0	3	Test to make sure there are no FINE hits being recorded in the test layer, because the high voltage is turned off for the test layer so no muons should be detected.
Trigger Check	On	5800	1	Tests the module how it will be when actively taking data underground.
Efficiency Scan	On	1 @ 4800-6000, 2 @ 5800	39	Keep two layers at working point, test the other layer in 100 volt increments from 4800V to 6000V. The efficiency of the test layer should increase from ~0 to (ideally) 100%.

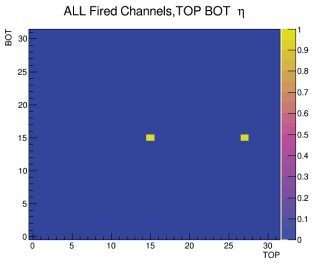
Results (fake muon)

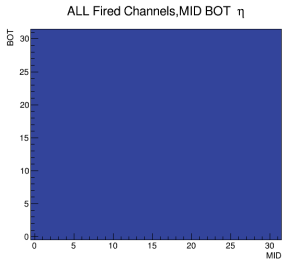


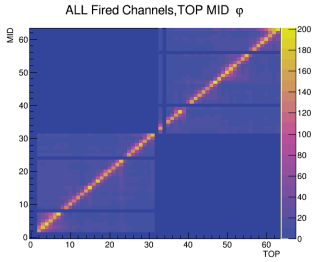
Results (fake muon)

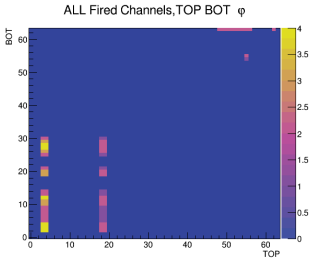
Top-Mid

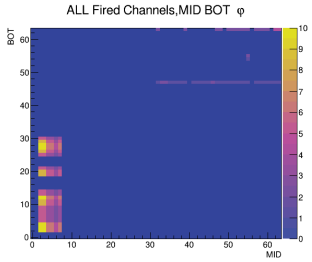




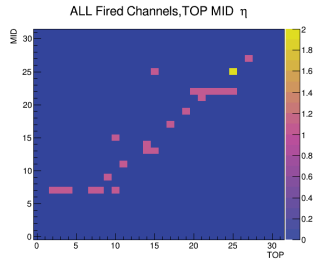


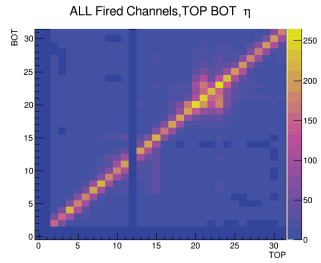


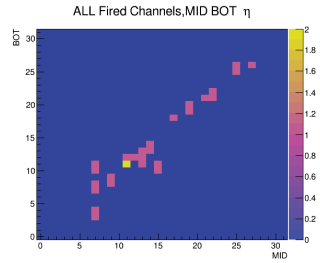


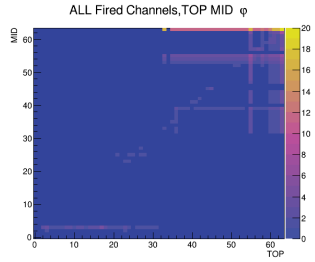


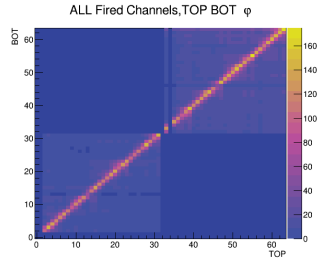
Top-Bot

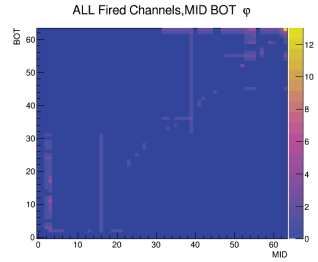












Mid-Bot