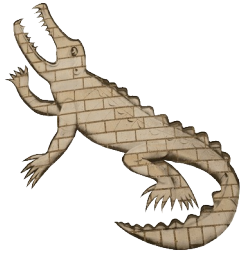
UNIVERSITY OF CAMBRIDGE

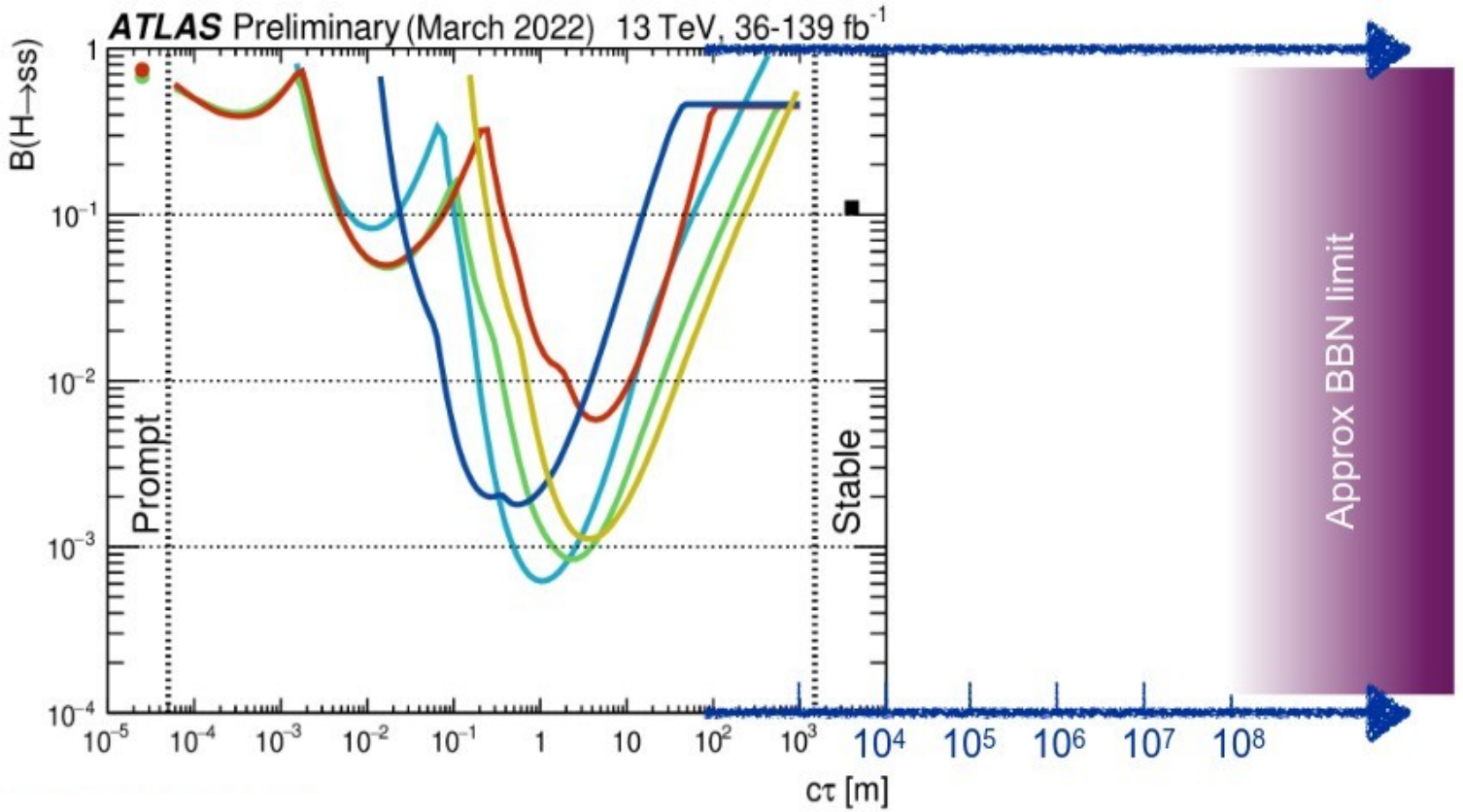


ANUBIS: An Underground Belayed In Shaft Experiment
Initial commissioning results from proANUBIS
LLP2024

Michael Revering, On Behalf of the ANUBIS Collaboration

Motivation

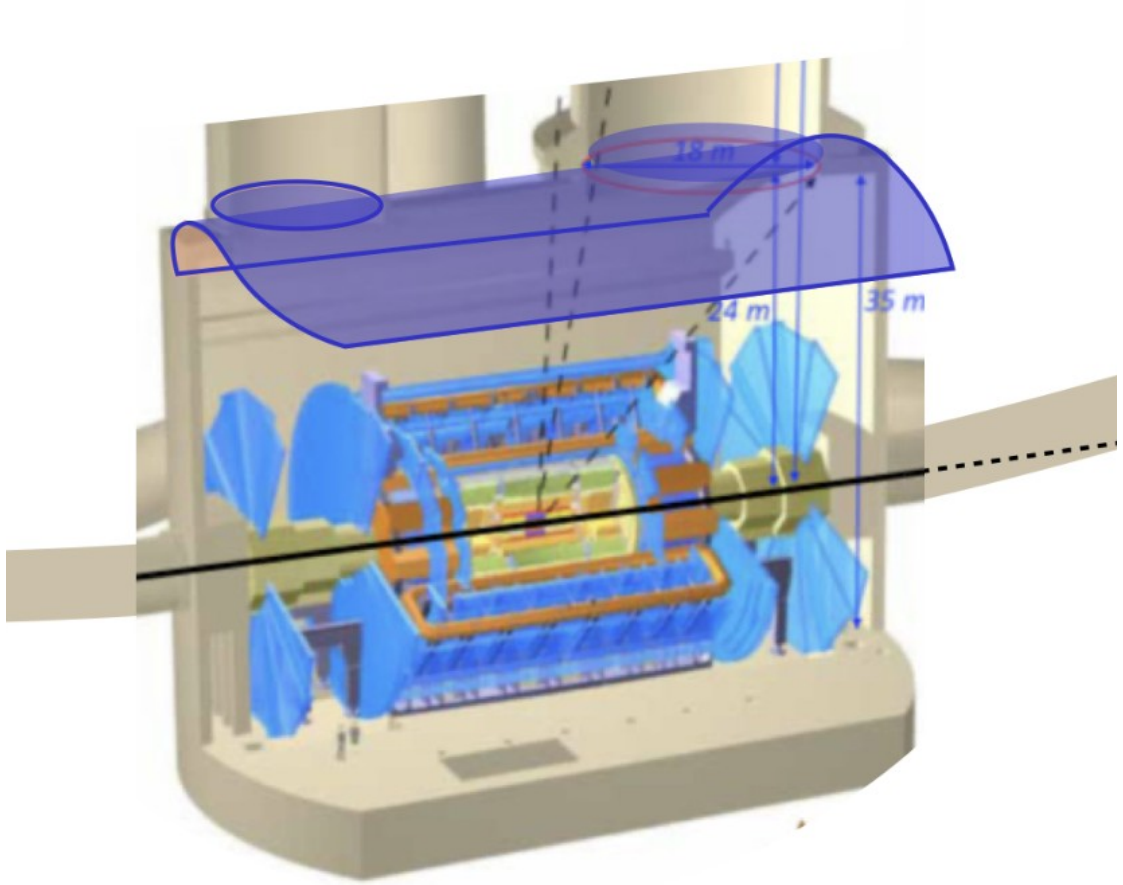
- Many BSM theories predict long-lived particles, arising through some combination of small couplings, heavy decay mediators, or small mass differences.



ATL-PHYS-PUB-2022-007

- ATLAS detector sensitivity to long lifetimes (c >~10m) limited by physical size, backgrounds from material interactions.
- Forward detectors can probe these lifetimes but have limited sensitivity to heavy LLPs (>1 GeV) and mediators.

The Anubis Experiment Proposal

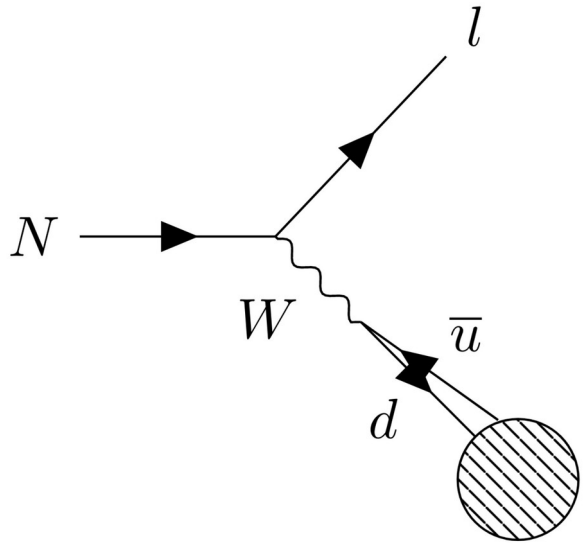


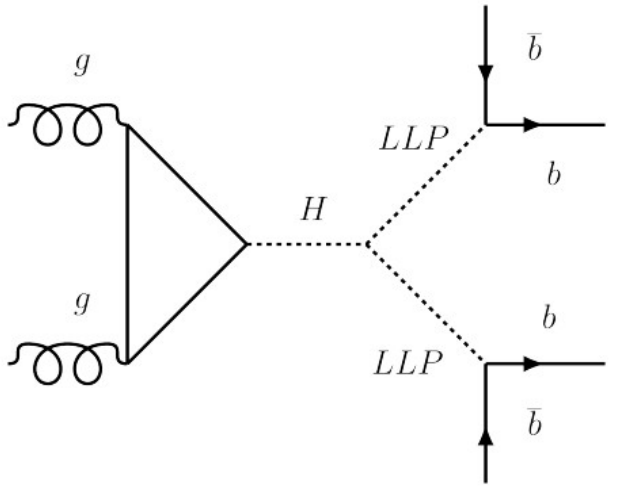
ANUBIS proposes to cover the shaded region (blue) with RPC detectors

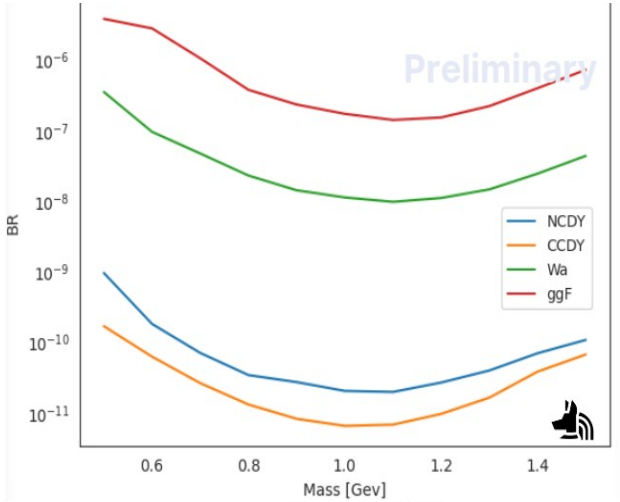
- Large, nearly empty ATLAS experimental cavern provides ideal decay volume.
  - Can cover significant solid angle with minimal SM backgrounds.
  - ATLAS detector information can actively veto collision products.
- Transverse position provides sensitivity to higher-mass LLP models (>1 GeV) and electoweak-scale+ mediators.
  - Strong complementarity with forward physics facilities.
- RPC detector technology allows for a large instrumented area at relatively low cost *O(*10 M£).

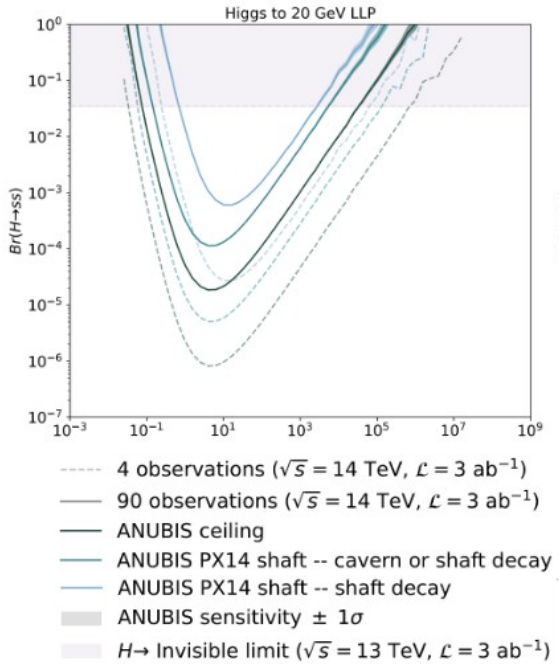
ANUBIS Sensitivity

- Several existing studies involving ANUBIS sensitivity currently published.
  - Heavy Neutral Leptons [1-3]
  - R-parity violating SUSY (neutralinos) [4]
  - Scalar-Higgs portal [5]
- New sensitivity studies underway using specialized framework, detailed talk on Wednesday



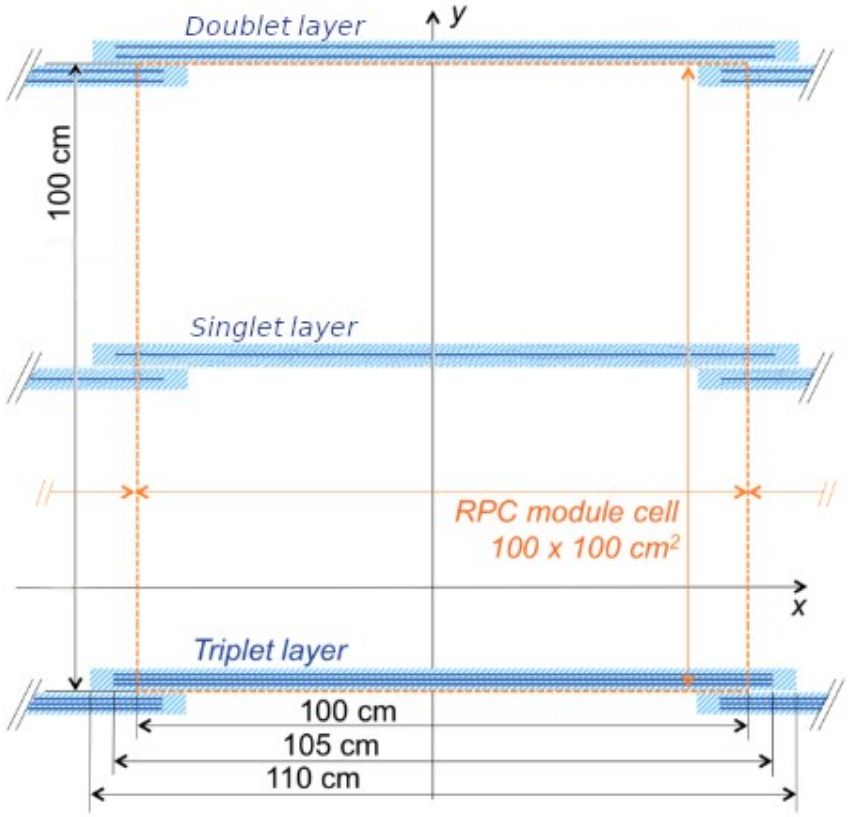






[1] 2001.04750 [2] 2105.13851 [3] 2010.07305 [4] 2008.07539 [5] 1909.1302

ANUBIS Detector Technology

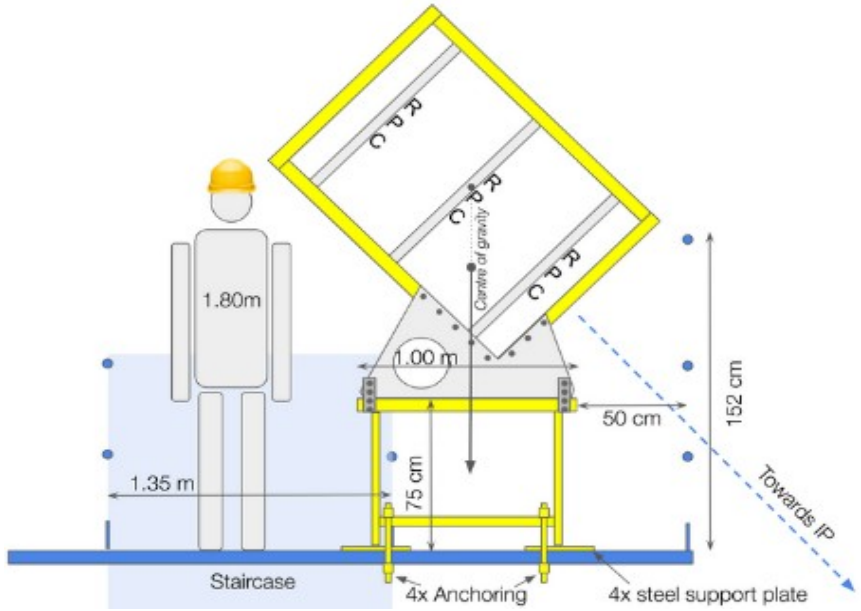


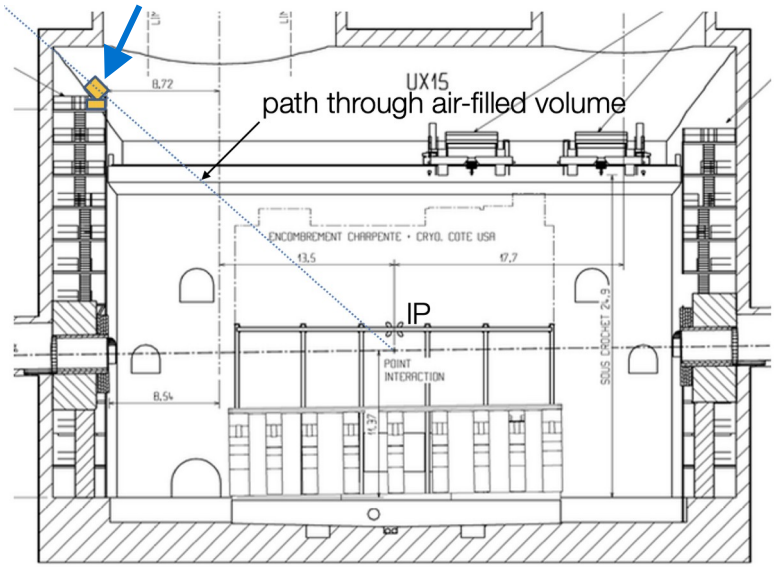
Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

- Plan to use three RPC Chambers separated by air gaps.
- Use BIS78 RPC technology developed for ATLAS muon system.
  - Reduced R&D from existing ATLAS RPC production significantly reduces cost.
- Understanding of backgrounds and detector performance critical for experiment design – created prototype detector ("proANUBIS") to help achieve this.

The proANUBIS Detector

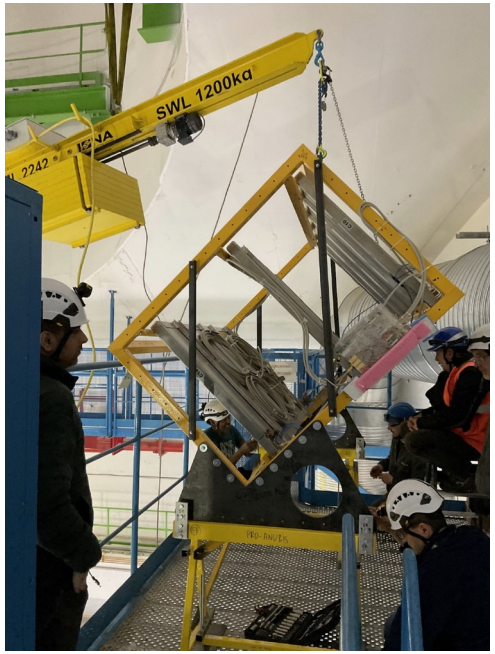
- A single ANUBIS module with the expected three-chamber configuration.
- Constructed in 2022, installed in ATLAS cavern March 2023.
- Goals:
  - Validate detector technology and performance.
  - Synchronize timing with ATLAS
  - Combined particle reconstruction in proANUBIS and ATLAS.
  - Measure punch-through rates.
  - **Measure hadronic interactions in air.**



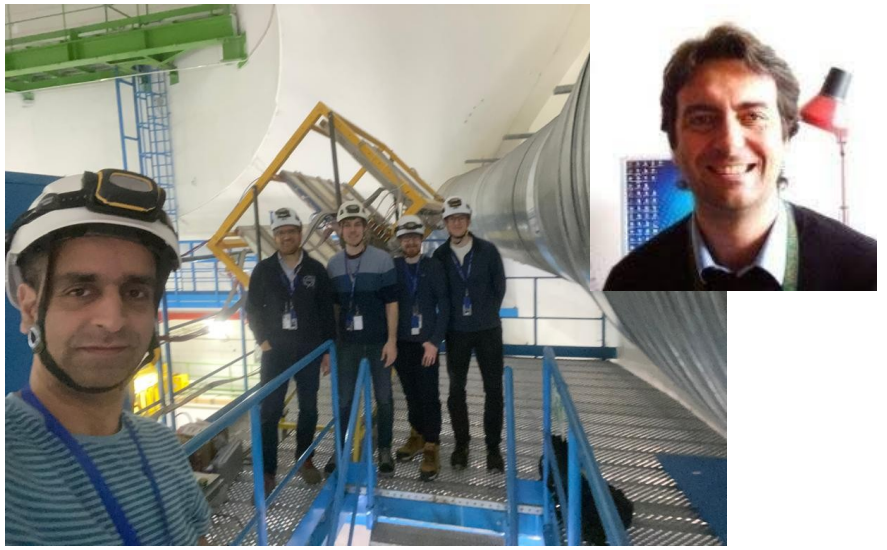


Prototype Re-commissioning

- Prototype “re-commissioning” in February 2024 to upgrade trigger system.
  - Unexpected signal polarity previously prevented triggered operation.
  - Verified channel mapping, replaced bad cables, studied noise hits, identified dead channels.
- Significant software effort to solve problems in triggered TDC operation.

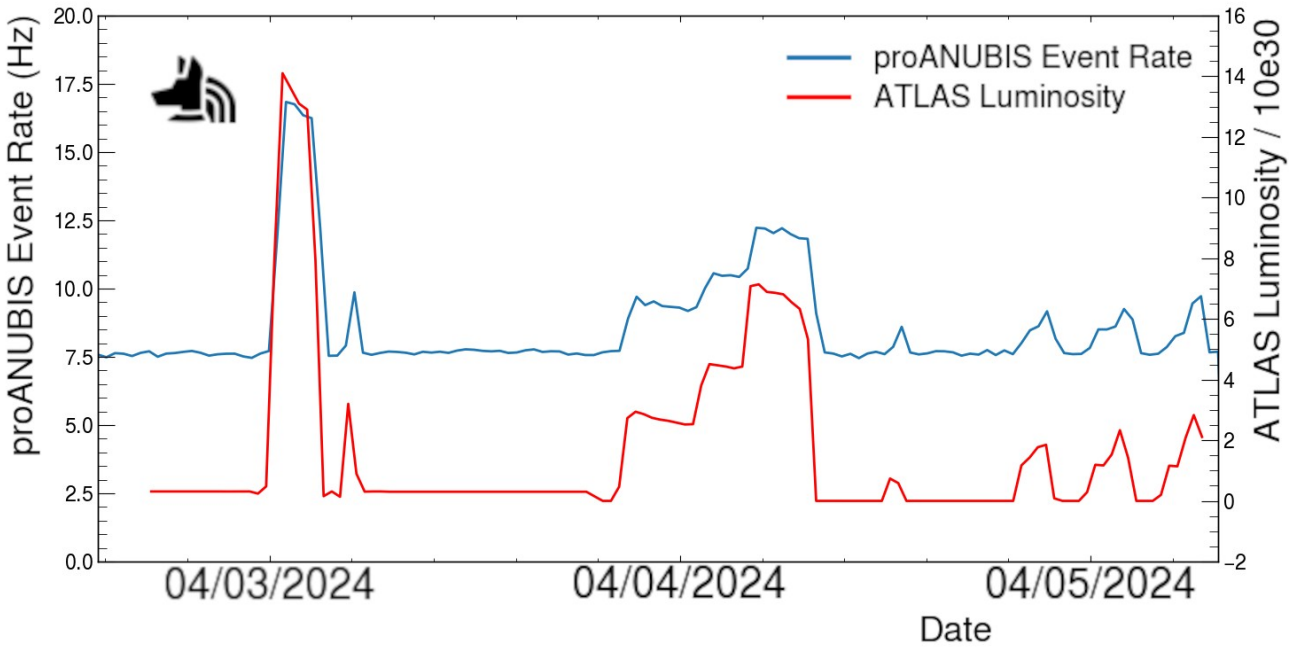


Ambient conditions monitoring in proANUBIS



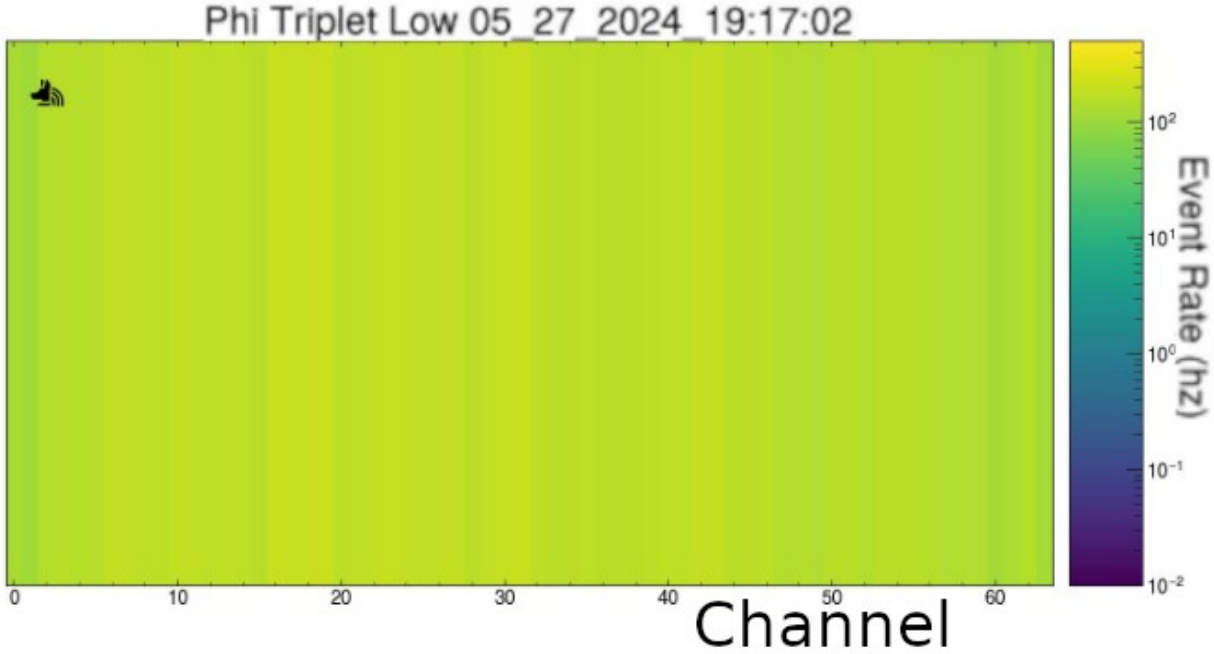
proANUBIS Baseline Status

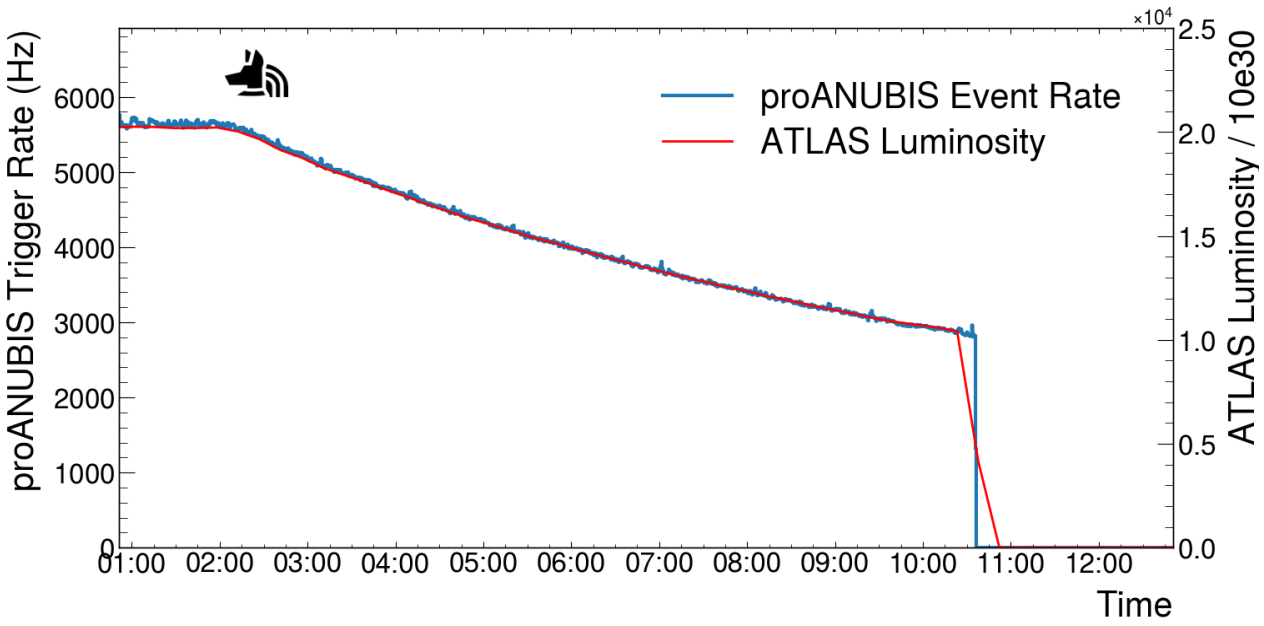
- Triggered data taking operational, detector performing well.
  - 571/576 RPC strips active (>99% efficient!).
- Early data runs show clear correlation between proANUBIS event rate and ATLAS luminosity.



proANUBIS Data Rates

- Data-taking ongoing for all of 2024 LHC operation.
  - Using trigger coincidence requirement of four η panels, see event rates ~1 hz with beam off and *O(*~few kHz) during collisions.
- proANUBIS has ~90% uptime during 2024 LHC runs.
  - >1 TB of data collected, corresponding to ~10^9 events and >23 fb^{-1} of ATLAS luminosity.

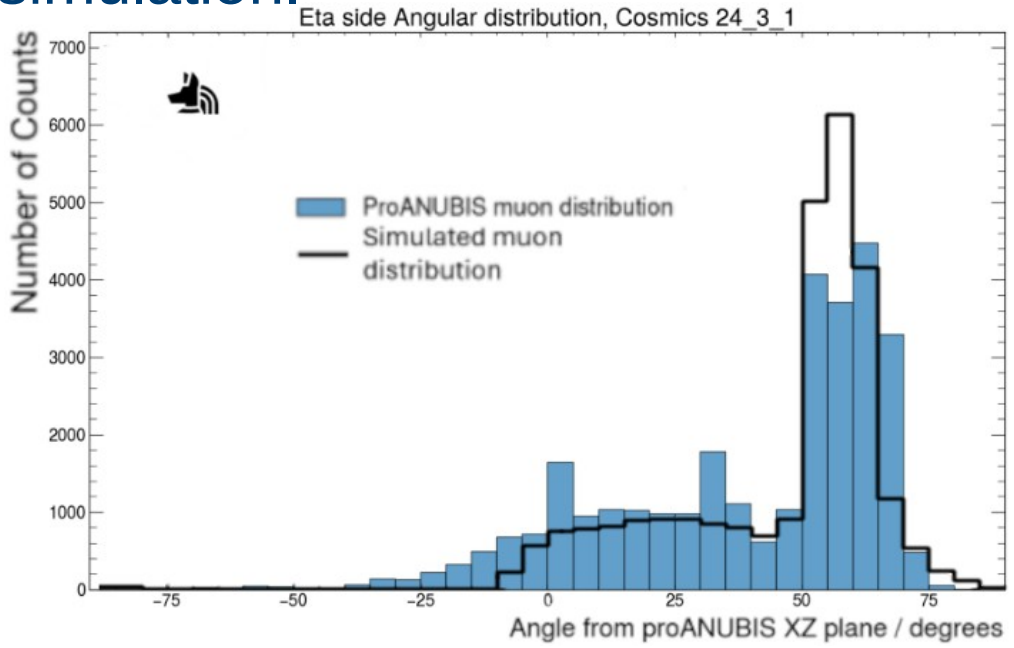


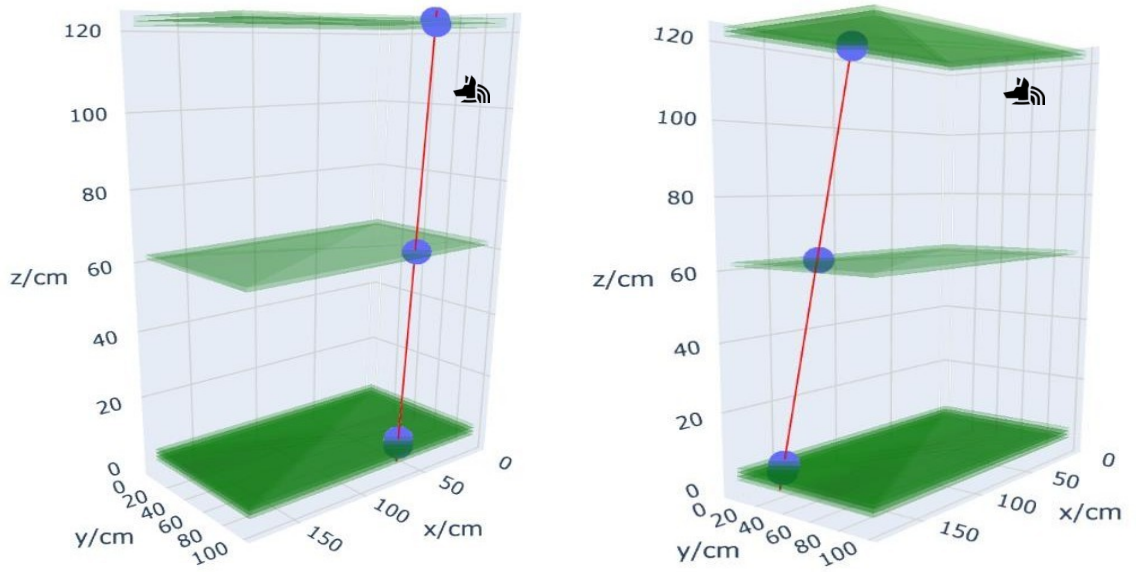


proANUBIS Data Analysis

- Analysis of proANUBIS data underway.
  - RPC strip clustering and track reconstruction performed by several students (T. Adolphus, P. Collins, and Y. Wan)
  - Reconstructed muon angles from cosmic runs show good agreement with simulation.

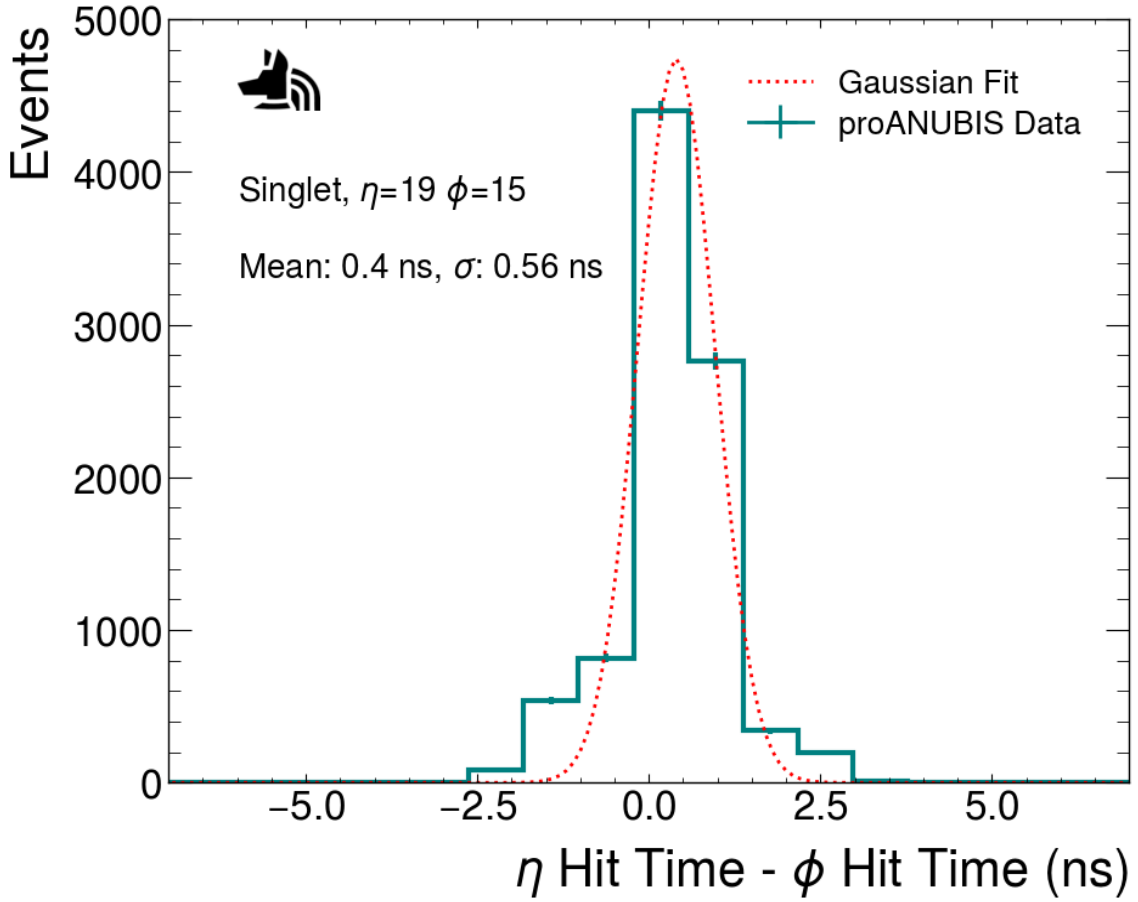
A proANUBIS event





Two reconstructed proANUBIS tracks

proANUBIS Time Resolution

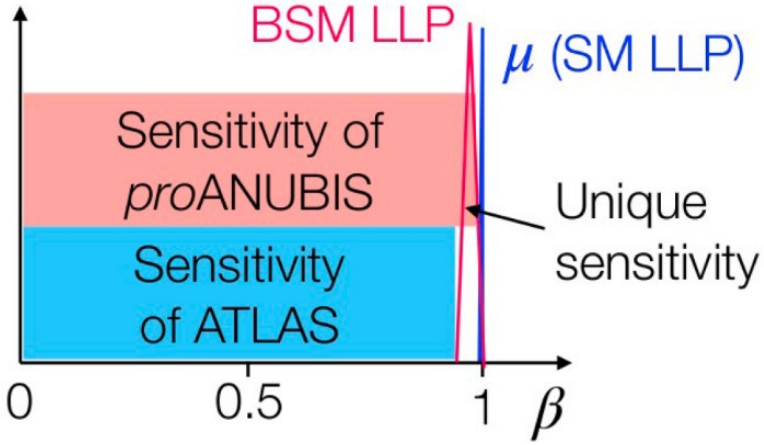


The time difference for two adjacent eta and phi planes at a particular location in the detector, corrected for systematic offsets.

- Studies underway to correct for timing offsets from signal propagation within RPC strips and hardware effects, then precisely measure muon time-of-flight within proANUBIS.
- Investigating RPC efficiency via tag-and-probe method using reconstructed tracks.
  - Large sample size allows for precise, location-dependent efficiency measurements.

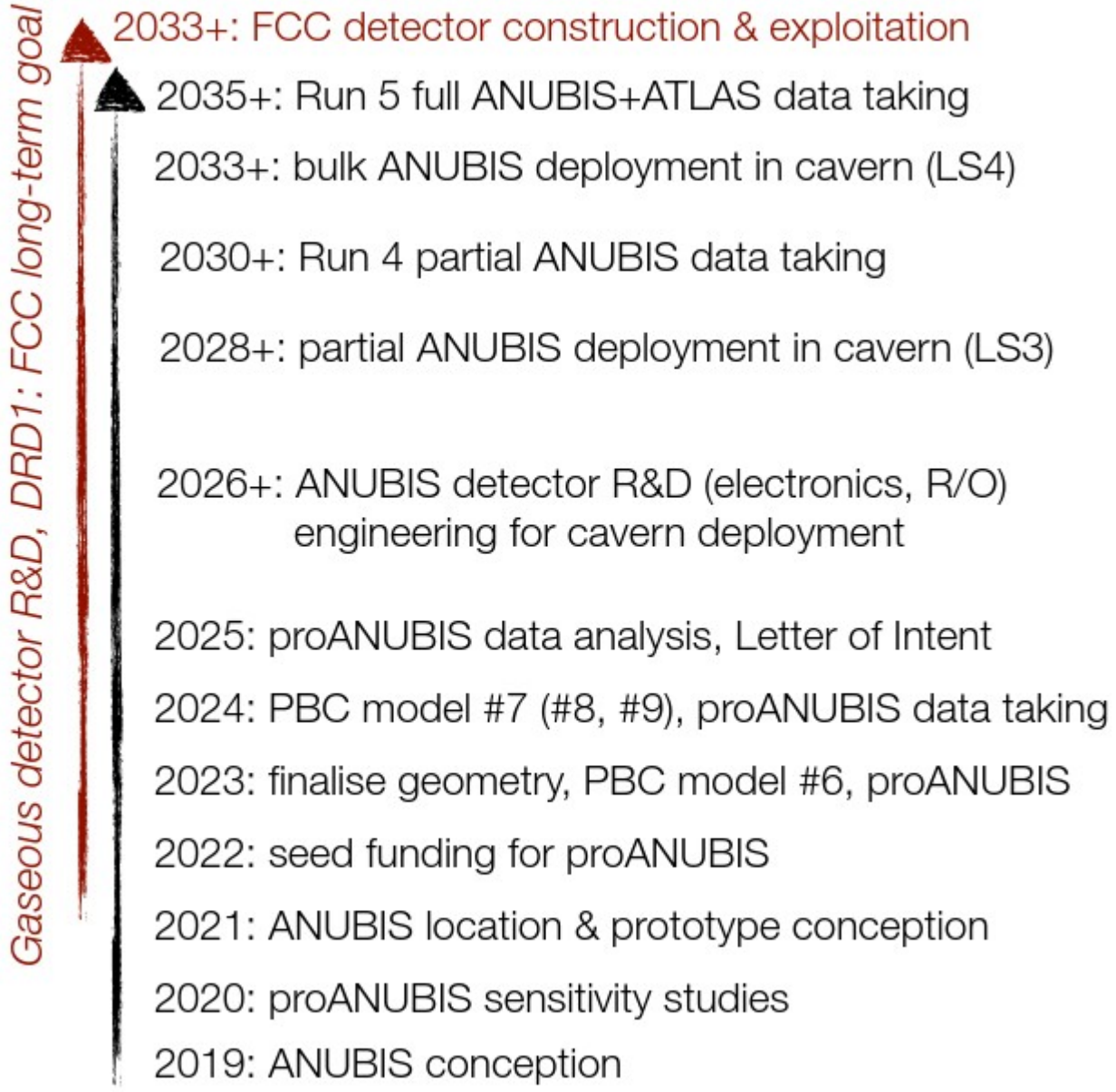
Next Steps in Commissioning and Analysis

- Implement LHC clock synchronization
  - Have clock and BCR reset, can identify local BX and potentially manually synchronize w/ LHC via correlating proANUBIS events and ATLAS muons.
  - Automatized clock synchronization requires additional readout modifications, currently under development.
- With clock synchronization, can study punch-through events and validate background models
  - Have potentially unique sensitivity to muon β (Δβ≈0.5%).



From Juliette Alimena

Future Plans



- Next ~year critical for ANUBIS development.
- Data analysis of proANUBIS needed to validate expected backgrounds and fully motivate expected sensitivity.
- Additional efforts ongoing to develop eco-friendly RPC gas mixes, characterize RPCs, and expand sensitivity projections.

Collaboration

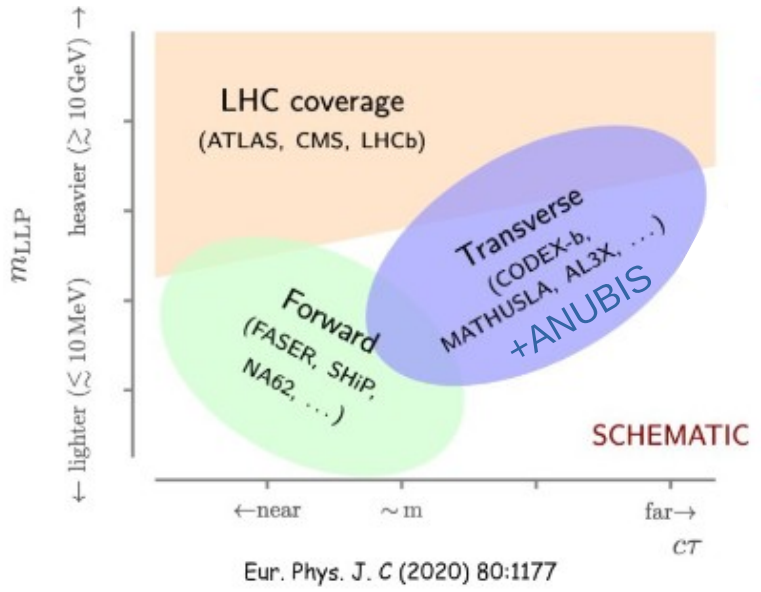
- Only possible due to the support from many institutions, with room for more!
- Significant ongoing effort to analyze and collect data, with many avenues to contribute:
  - LHC Clock synchronization
  - proANUBIS data analysis
  - Track and vertex reconstruction
  - Time alignment
  - Prepare letter of intent
  - And more!

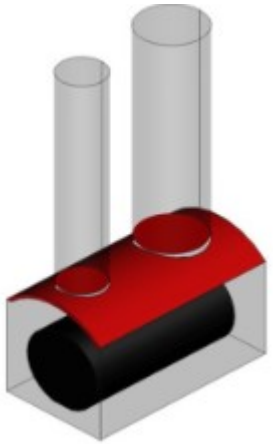
Conclusion

- ANUBIS proposal could help extend the reach of the HL-LHC program to LLPs towards the BBN limit.
- ANUBIS ceiling installation sensitive to cτ ~10^6 m, dramatically extending the ATLAS reach.
- Re-commissioned prototype detector fully functioning, analysis currently underway.
- Several active analysis tasks underway to characterize the RPC strips, develop reconstruction algorithms, and produce physics results.
- Strong complementarity between ANUBIS and forward LLP physics programs.

Additional Resources

- ANUBIS Twiki
- Initial Proposal
- ANUBIS Website





Backup

proANUBIS β Sensitivity

- Timing resolution and path length results in $\delta_\beta \sim 0.1\%$.
  -ATLAS resolution is 2-3%.
- Precision measurement of β could help inform dE/dX search (2205.06013).