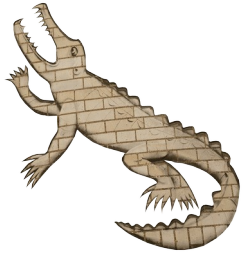
UNIVERSITY OF CAMBRIDGE



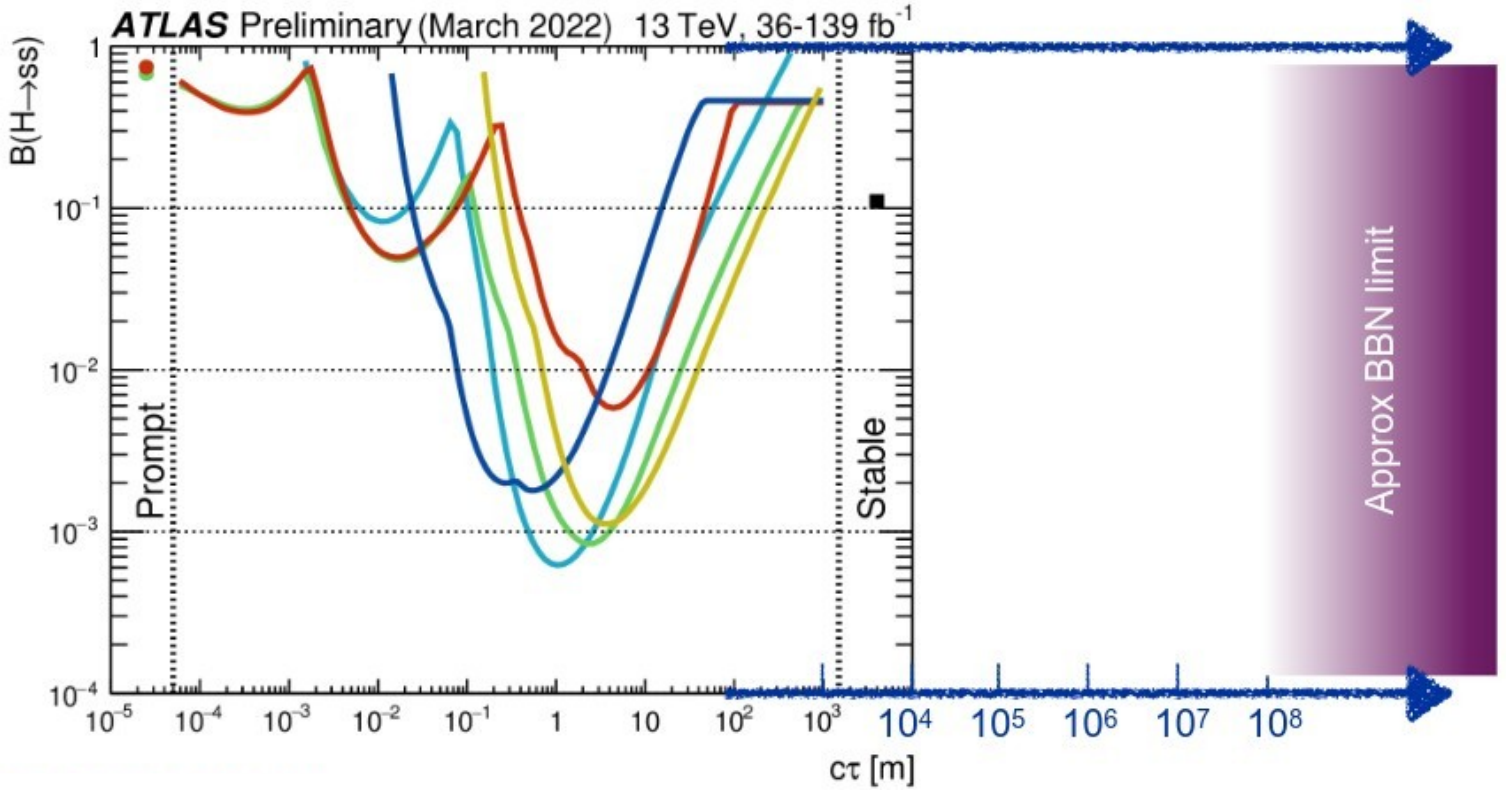
ANUBIS: Status and Next Steps

Physics Beyond Colliders Annual Workshop

Michael Revering, On Behalf of the ANUBIS Collaboration

Motivation

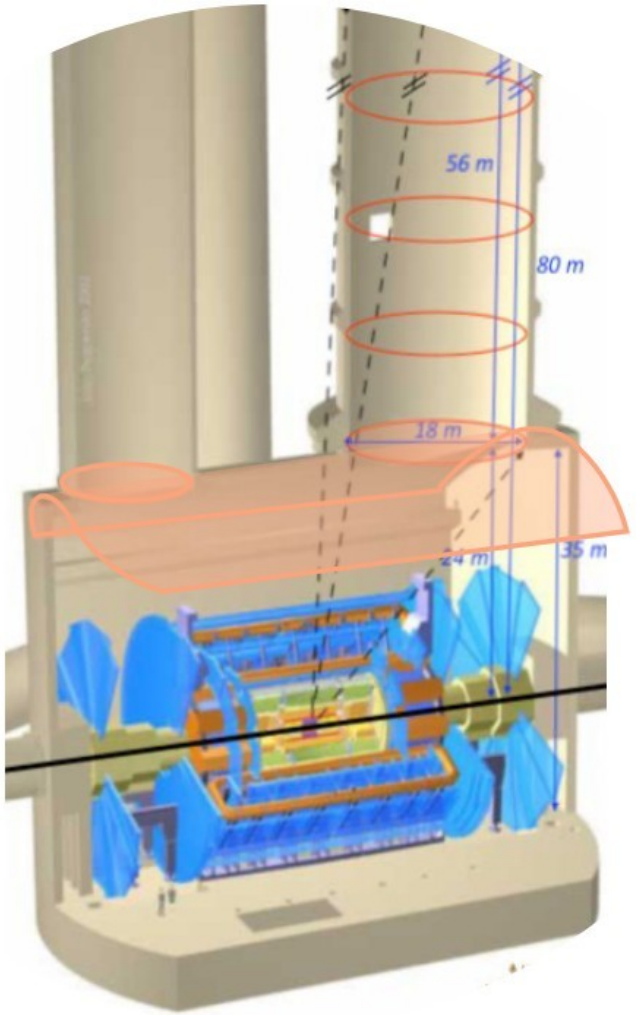
- Many BSM theories predict long-lived particles, arising through some combination of small couplings, heavy decay mediators, or small mass differences.



ATL-PHYS-PUB-2022-007

- ATLAS detector sensitivity to long lifetimes (cτ>~10m) limited by physical size.
- Forward detectors such as FASER can probe these lifetimes, but are limited to light LLPs (<1GeV).

The ANUBIS Experiment Proposal

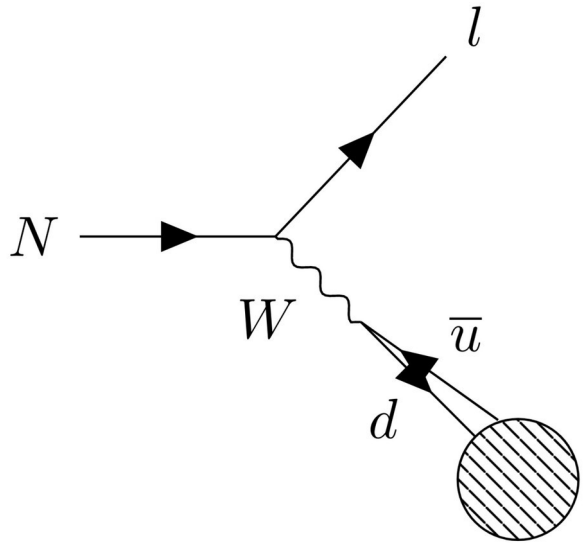


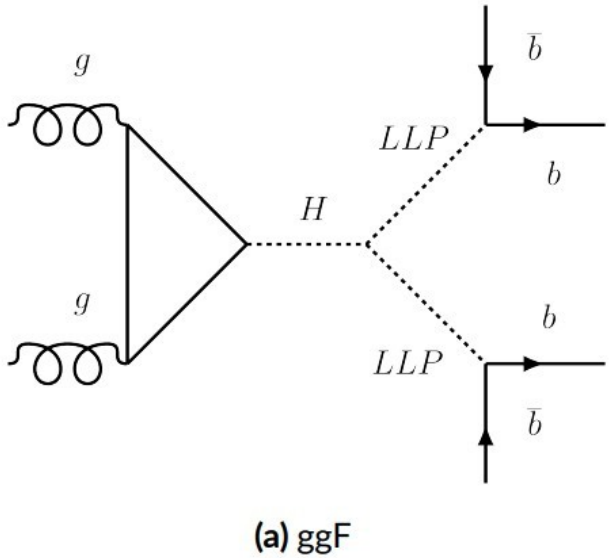
Ceiling configuration preferred over original in-shaft arrangement due to larger solid angle coverage.

- Large, nearly empty volume of the ATLAS experimental provides ideal decay volume.
- ATLAS detector information can actively veto collision backgrounds.
- Transverse position provides sensitivity to higher-mass LLP models (>1 GeV) and electroweak-scale+ mediators.
  - -Strong complementarity with forward-physics facilities (FASER, SHIP).
- RPC detector technology allows for a large instrumented area at relatively low cost *O(*10 M£).
- Incorporated as an official ATLAS sub-project.

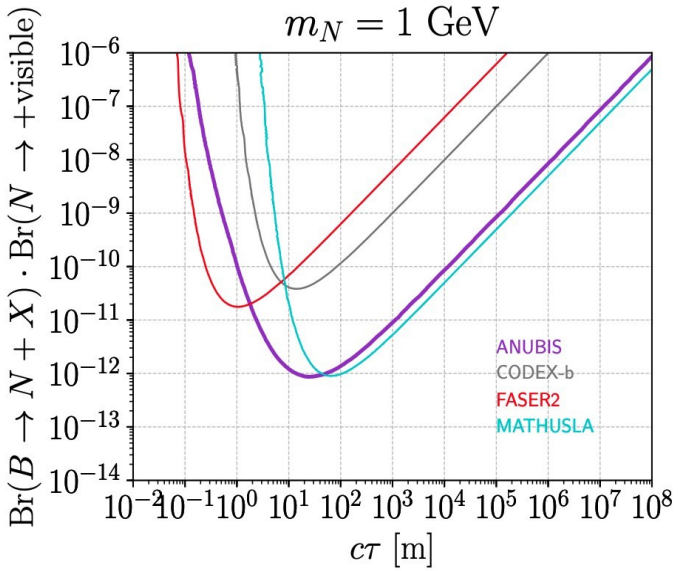
ANUBIS Sensitivity

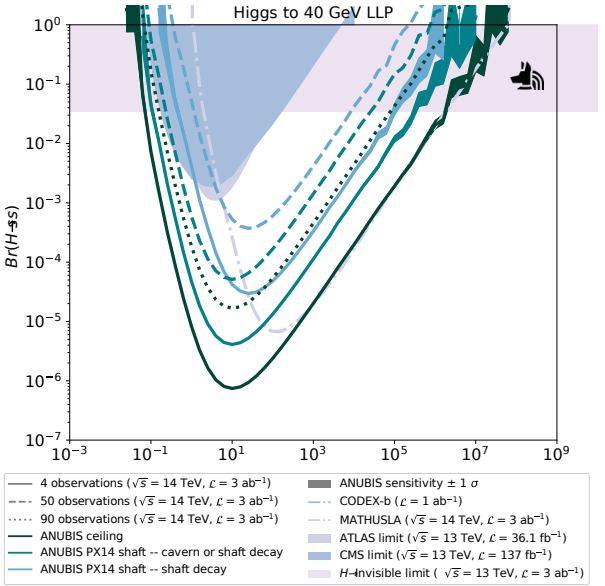
- Several existing studies involving ANUBIS sensitivity currently published.
  - Heavy Neutral Leptons [1-3]
  - R-parity violating SUSY (neutralinos) [4]
  - Scalar-Higgs portal [5]





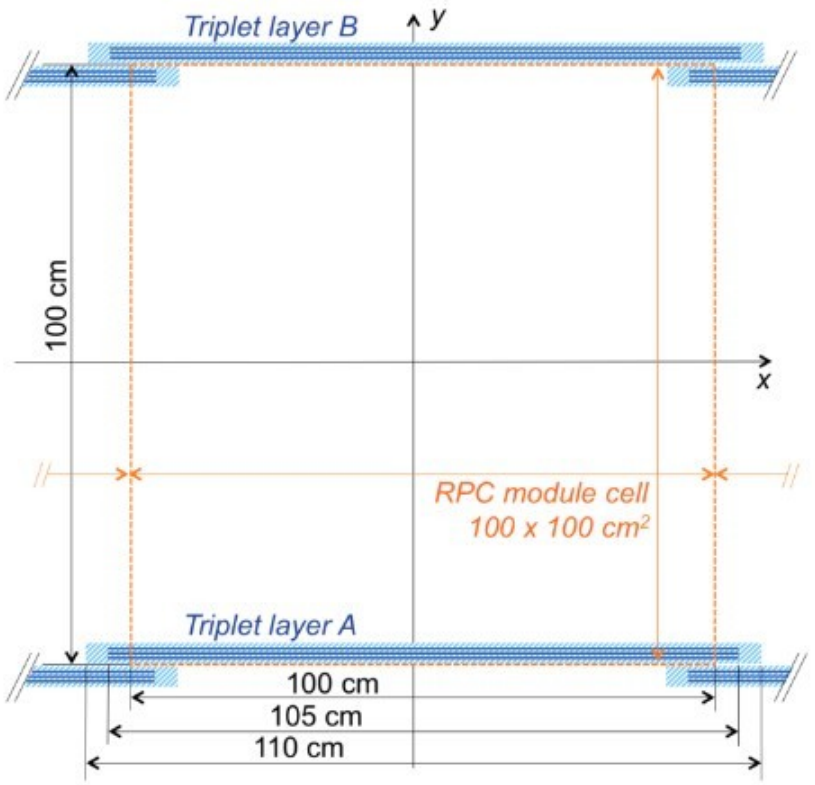
(a) ggF





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

ANUBIS Detector Technology

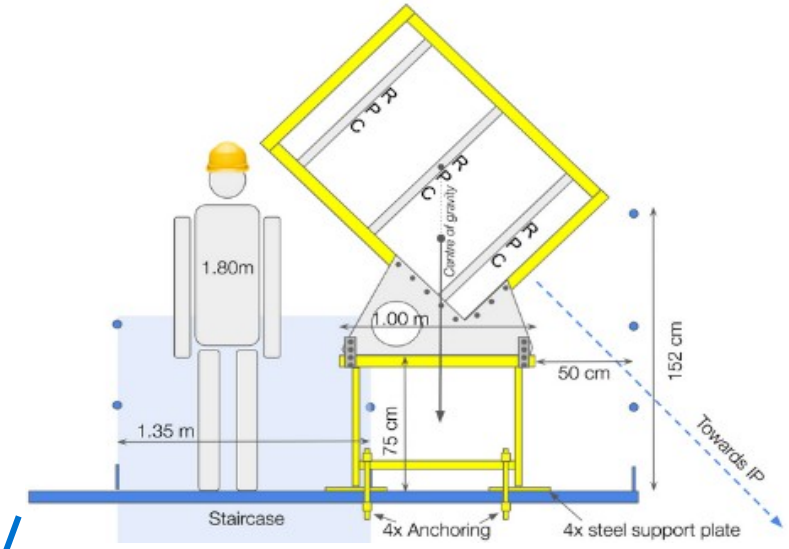


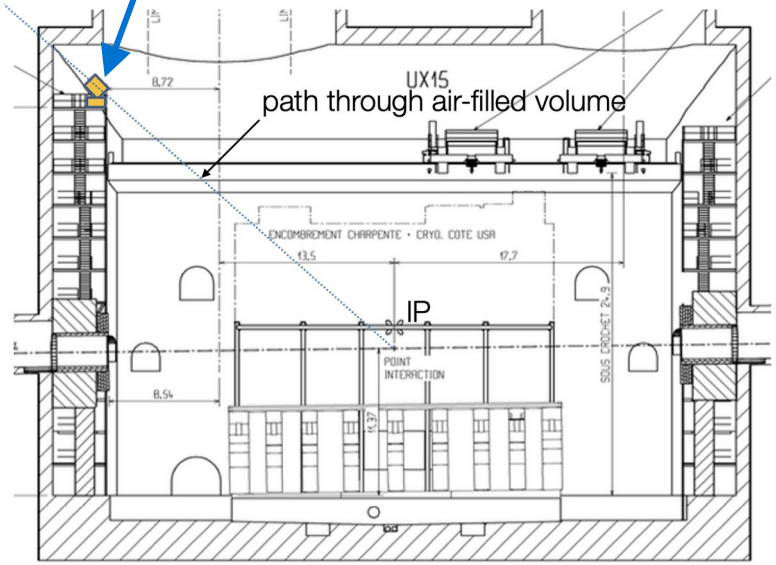
Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

- Plan to use triplet RPC layers separated by an air gap in ANUBIS.
- Use BIS-7 RPC technology developed for ATLAS muon system.
  - Reduced R&D due to existing ATLAS RPC production significantly reduces cost.
- Prototype detector (“proANUBIS”) created to test RPCs and validate background models.

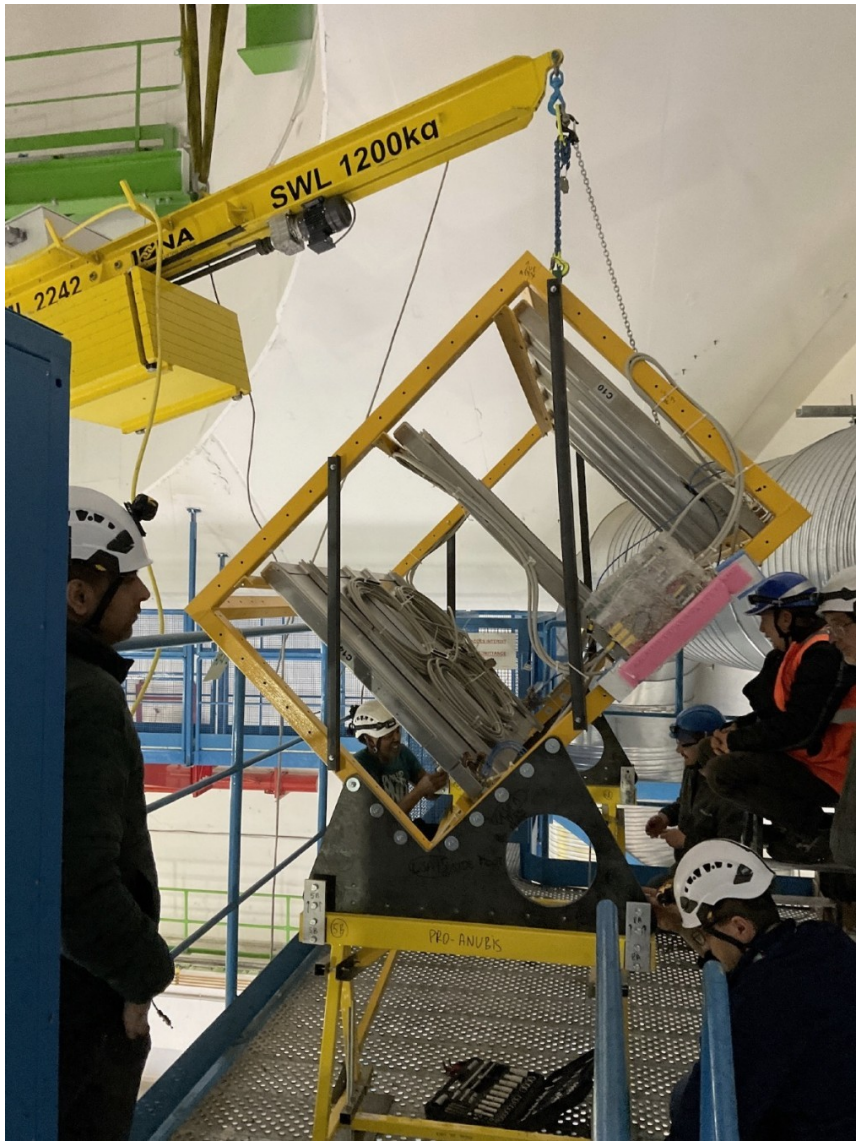
The proANUBIS Detector

- Constructed in 2022, installed in ATLAS cavern March 2023.
- Main goals:
  - Measure hit/track efficiency
  - Measure cosmics
  - Identify muons from ATLAS triggers
  - Measure punch-through rates
  - Validate background model





Status Before Re-commissioning



- Learned many significant details from 2023 prototype running:
  - Unexpected format of RPC signal output to hardware trigger prevented operation in triggered mode.
  - Time constraints didn't allow for full checks of cable mapping and channel quality within the cavern.
- For 2024 running, performed comprehensive testing of upgraded trigger system remotely.

Re-commissioning Report

- Performed “Re-commissioning” in February 2024 with this knowledge
  - Upgraded trigger boards and RPC connectors to fix signal polarity and improve termination.
  - Gas/Ambient “weather station” repaired
  - Verified channel mapping, replaced bad cables, studied noise hits, identified dead channels.
- Significant software effort to develop successful triggered TDC operation.

Pictured (left to right): Aashaq Shah, Oleg Brandt, Michael Revering, Paul Swallow, and Julian Wack. Also instrumental: Giulio Aeilli (top right) and Luca Pizzimento (not pictured)

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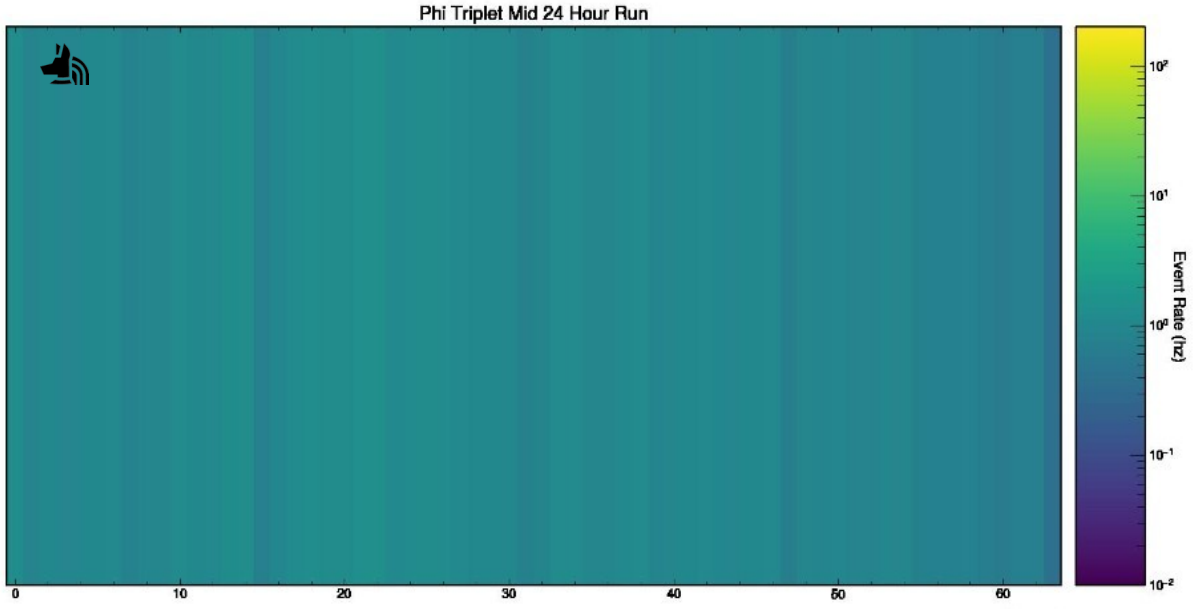
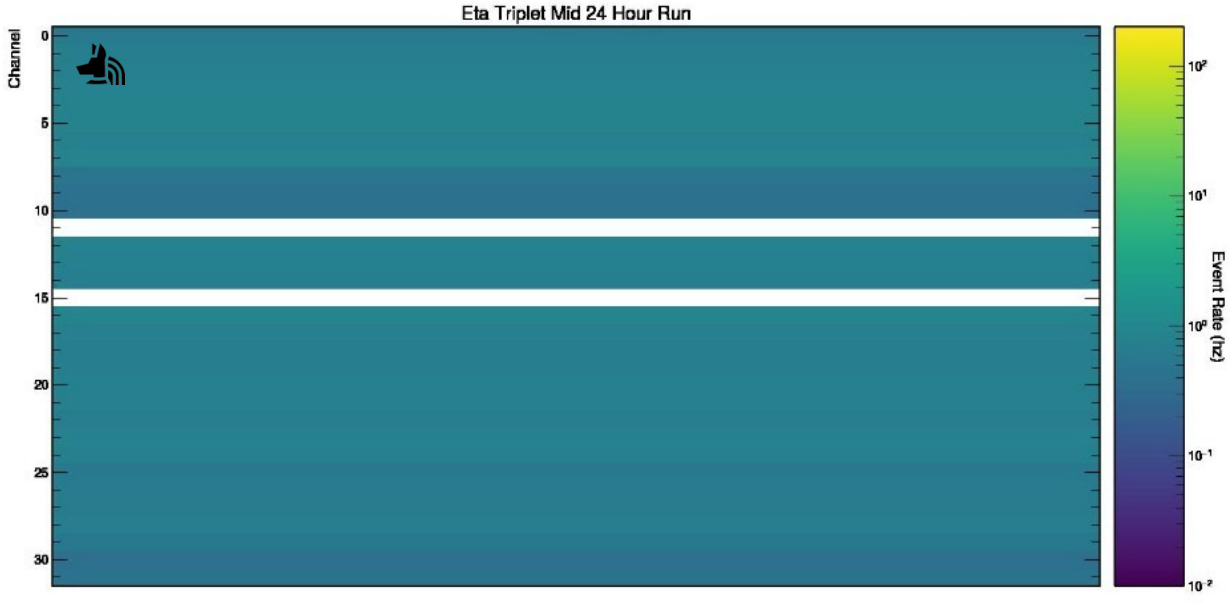
Ready For 2024 Physics Running!

Pictured (left to right): Aashaq Shah, Oleg Brandt, Michael Revering, Paul Swallow, and Julian Wack. Also instrumental: Giulio Aeilli (top right) and Luca Pizzimento (not pictured)

proANUBIS Status

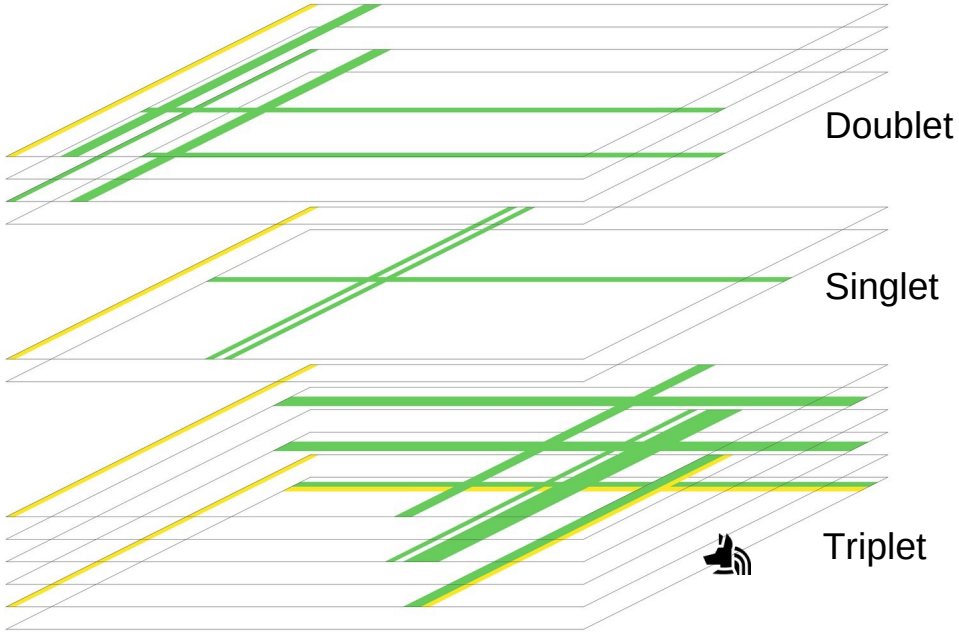
- Triggered data taking operational, detector performs very well.
  - 571/576 RPC strips active (>99% efficient!).
- Stable triggered running over hour+ timescales.
  - Event rate of ~8 Hz with LHC beam off using coincidence requirement of three RPC panels.



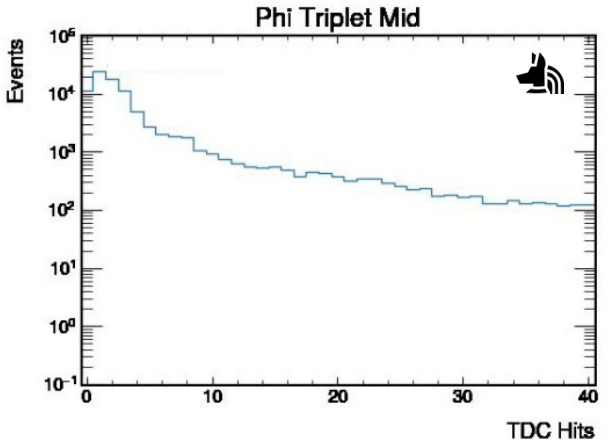


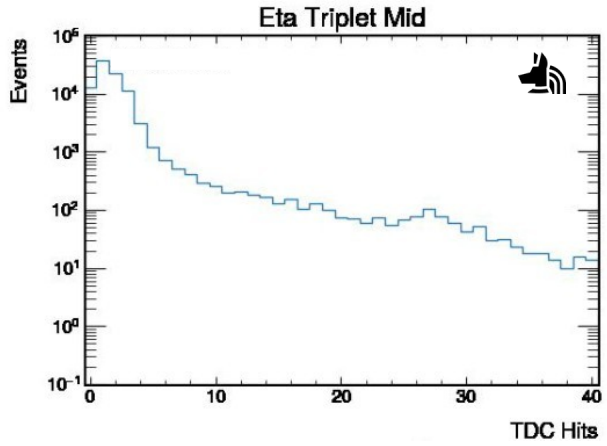
proANUBIS Status

- Analysis of proANUBIS data just beginning.
  - Several students working on RPC strip clustering and track reconstruction (T. Adolphus, P. Collins, and Y. Wan).
  - Can then project tracks to measure RPC strip efficiency.
  - Studying hit timing information to see muon time-of-flight, signal propagation offsets, and time resolution.



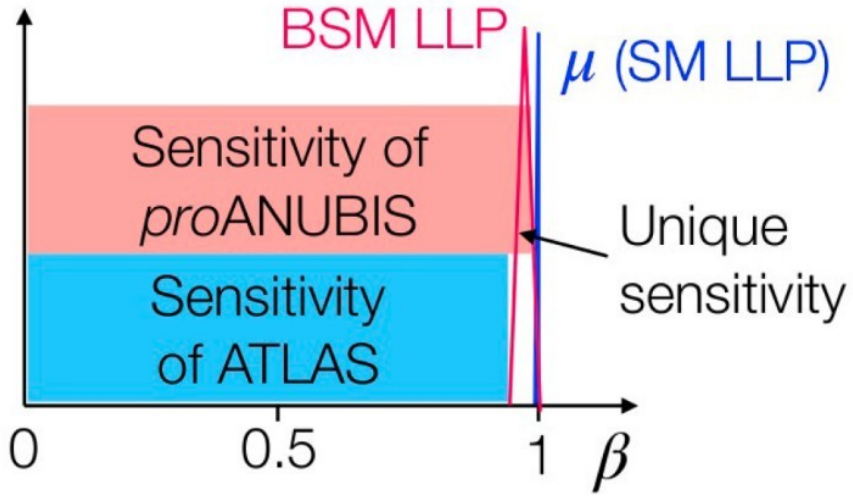
A proANUBIS event





Next Steps in Commissioning and Analysis

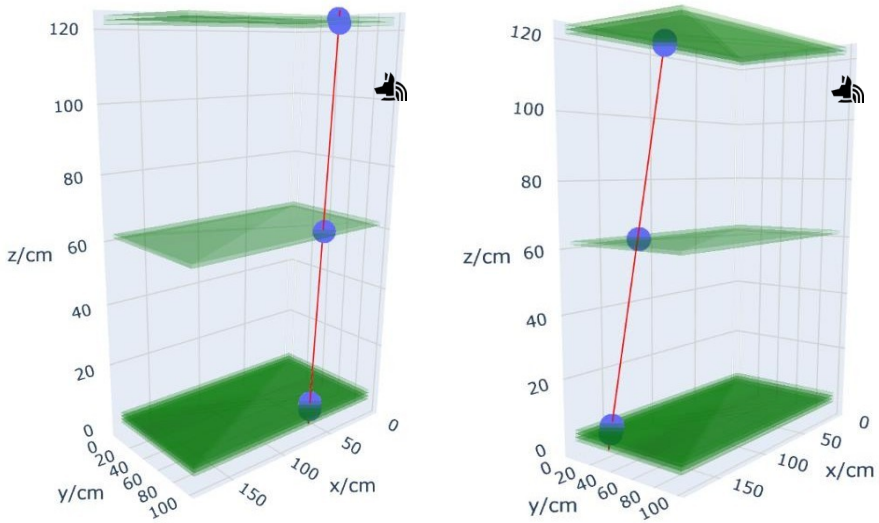
- Implement LHC clock synchronization
  - Have clock and BCR reset, can identify local BX and synchronize w/ LHC via global time.
  - Build full clock synchronization in future using proper time card.
- Run triggered data-taking during LHC collisions.
  - Compare event rate to beam-off running.
  - Look for outgoing particles via time delay between RPC chambers.
  - Try to pair particles observed in ATLAS w/ tracks observed in proANUBIS! (Unique sensitivity to particle β?)



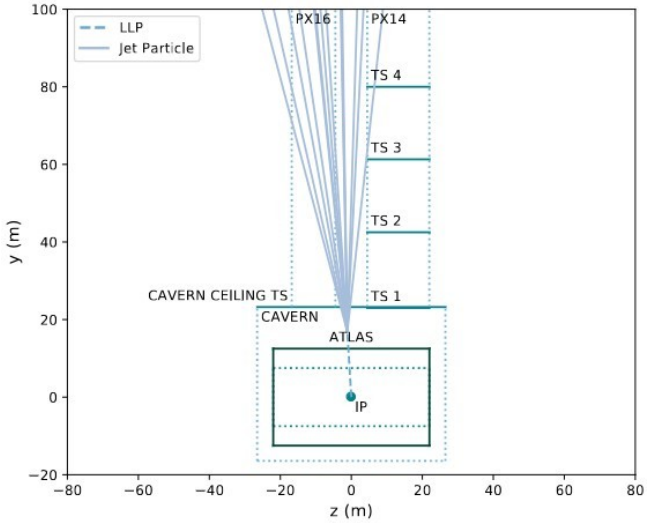
From Juliette Alimena

Next Steps in Analysis

- Implement track reconstruction from RPC hits
  - -Study efficiency using RPC strips along reconstructed tracks.
  - -Study hit/track efficiency with various RPC voltages and thresholds.
- Develop vertexing to identify decay positions within or before pro-ANUBIS.
- Identify background event rate, compare with expectations from Neutron-air interactions and kaon decays and interactions.



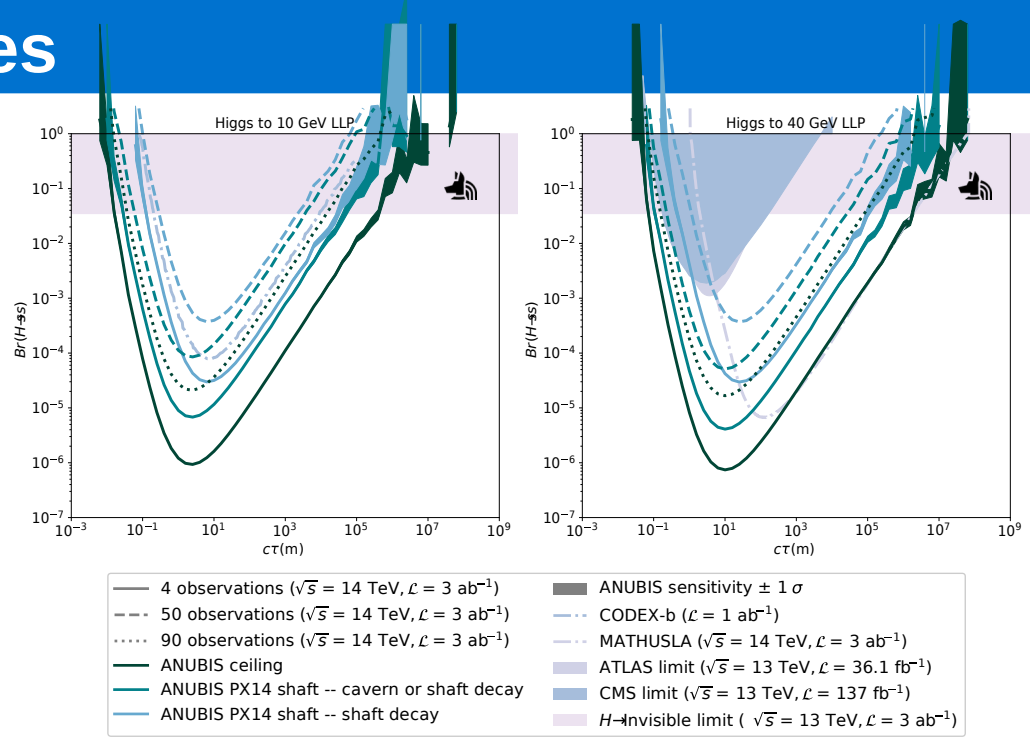
Two proANUBIS events

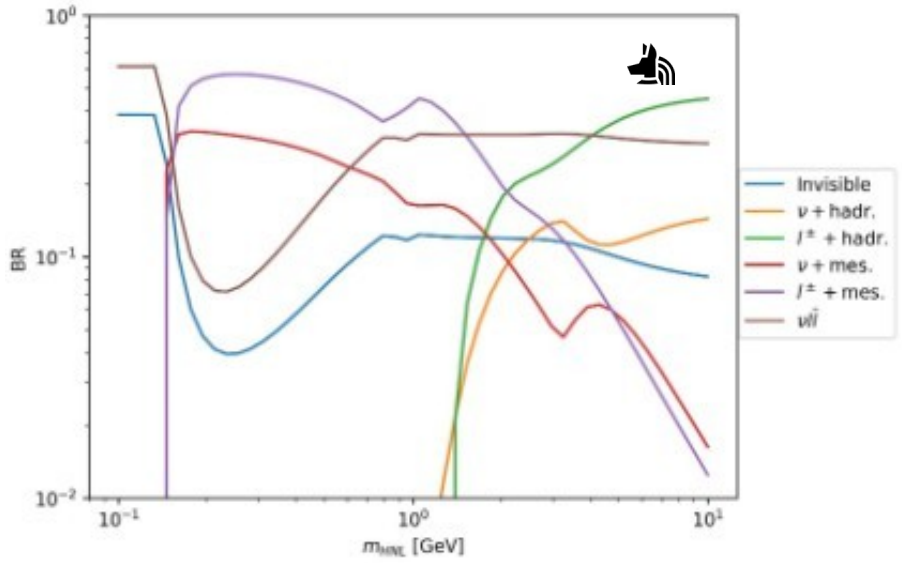


A simulated LLP decay,
CERN-THESIS-2022-169

Sensitivity Studies

- Development is underway on a model-independent framework to perform sensitivity studies in ANUBIS.
  - Breadth of LLP models creates large phase space of possible signals.
  - Framework will:
    - **Generate** LLP events with given cτ
    - Apply **loose selections** based on ANUBIS acceptance and ATLAS active veto.
    - Use number of observed events to **set sensitivity limits** for provided background rates.
- Expect to publish initial HNL sensitivity studies this summer, then extend to other LLP signatures.



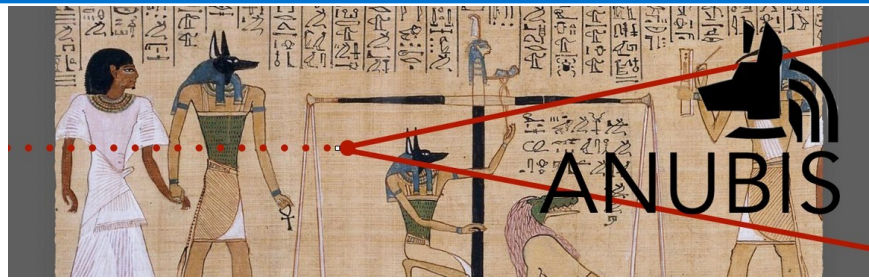


Collaboration

- Only possible due to the support from many institutions, with room for more
- Have prototype data ready to analyze, with many avenues to contribute:
  - LHC Clock synchronization
  - Cosmic measurements.
  - Observe muons from LHC collisions
  - And more!

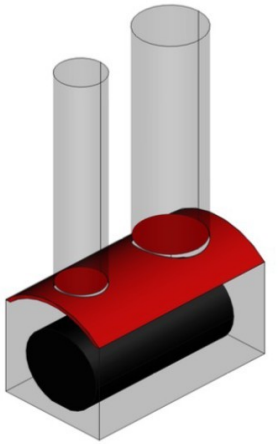
Conclusion

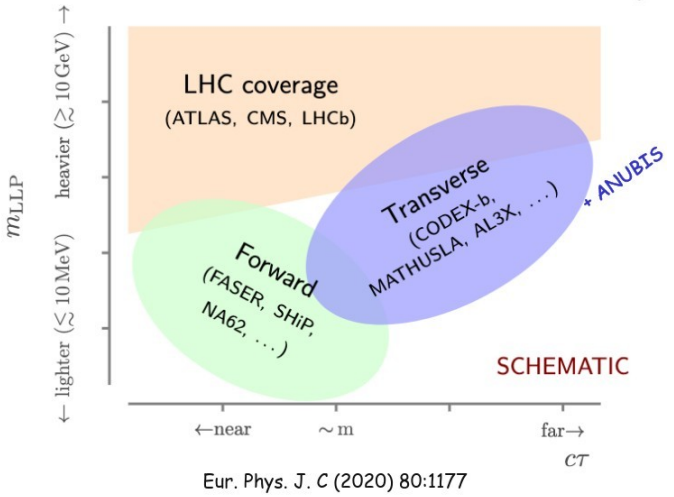
- ANUBIS proposal could help extend the HL-LHC program for LLPs towards the BBN limit.
- ANUBIS ceiling installation sensitive to cτ ~10^6 m, dramatically extending ATLAS reach.
- Re-commissioned prototype detector fully functioning, ready for 2024 pp collision data!
- Several active analysis tasks underway 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
- ANUBIS website
- Initial proposal





Eur. Phys. J. C (2020) 80:1177

Back-Up

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).