RPCs to Search for LLPs with the ANUBIS Detector

RPC **2022**

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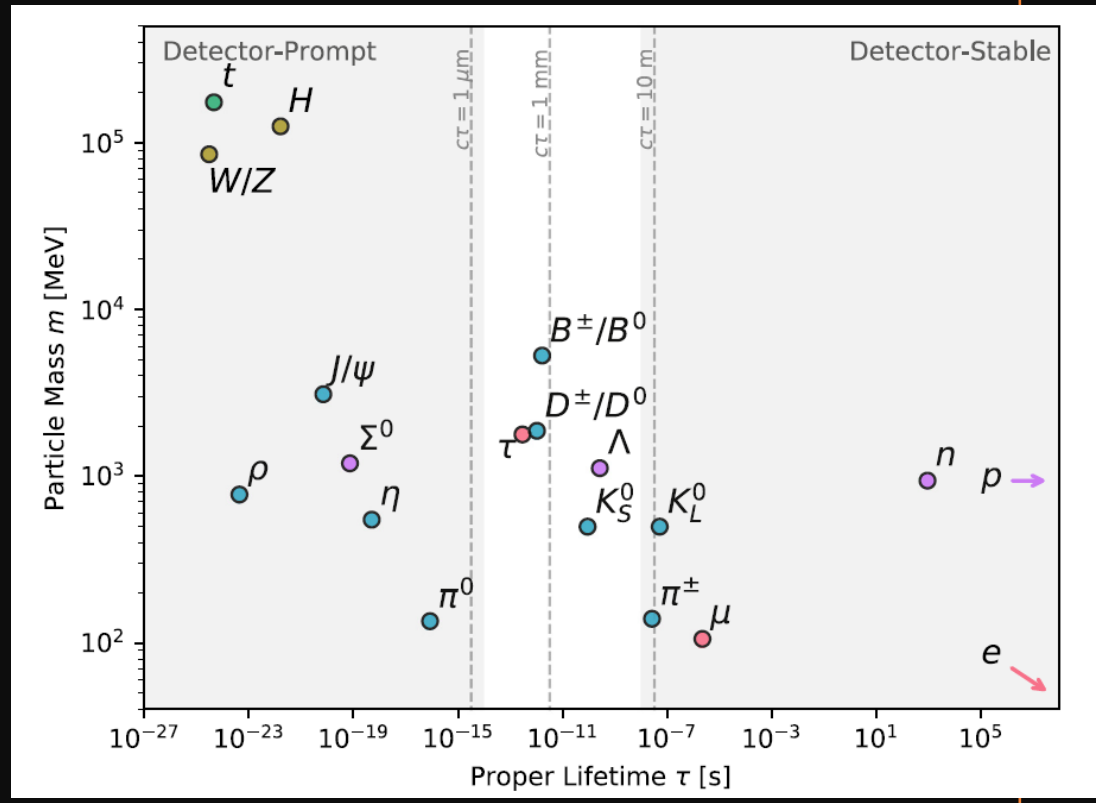
UNIVERSITY OF CAMBRIDGE

Introduction to LLPs

Why Long-Lived Particles?

- Three main routes to long lifetimes
  - Small mass splittings (e.g. approximate symmetry)
  - Small couplings
  - Very massive mediators
- Common in many BSM theories (and in the SM)
- Often appear alongside Dark Matter
- Approximate upper limit on lifetime from Big Bang Nucleosynthesis $\tau \approx 0.1\text{s}$ ($c\tau \approx 3 \times 10^7\text{m}$)

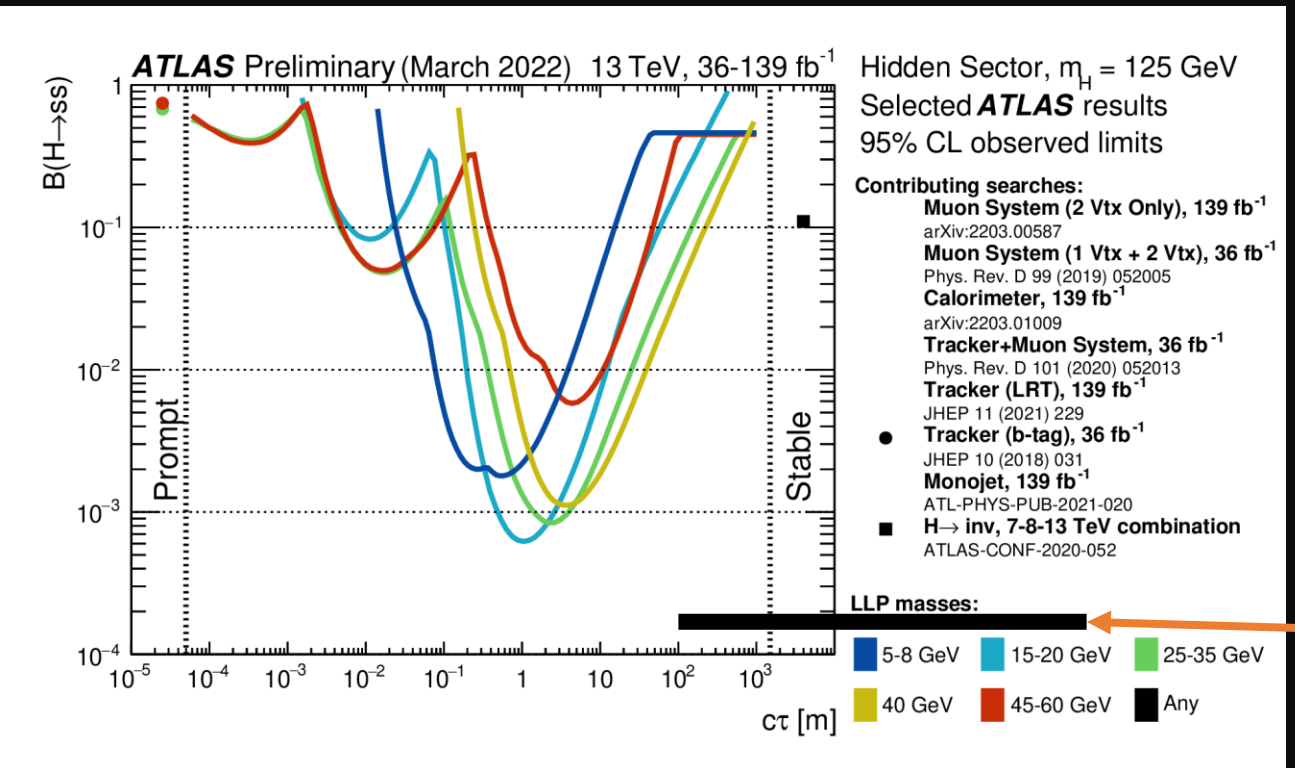
$$\tau^{-1} = \frac{1}{2m_X}\int d\Pi_f |\mathcal{M}|^2$$

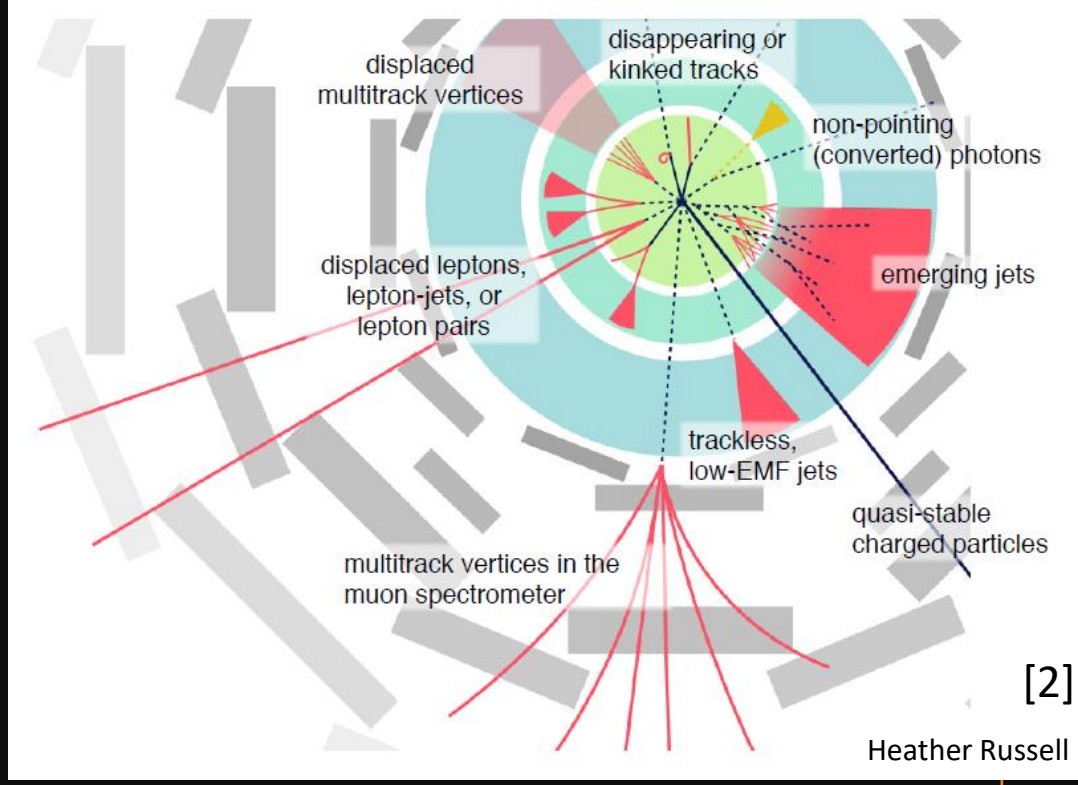


[1]

LLPs in ‘Prompt’ Experiments

- There are many different experimental signatures depending on the charge, decay modes and lifetime of the LLP





[2]

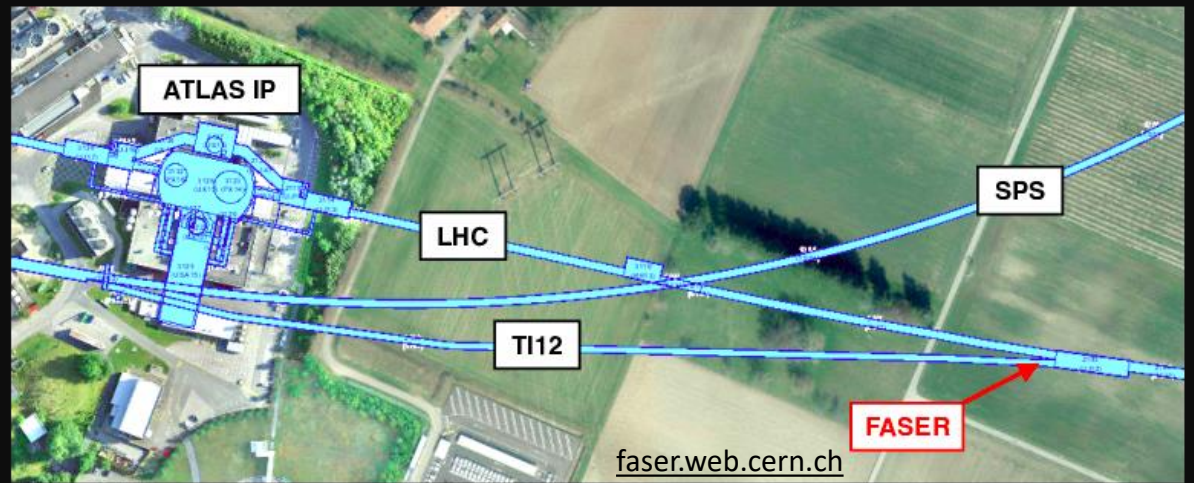
Heather Russell

- Most are limited by the physical size of the detector
- Very long-lived ‘detector stable’ particles are constrained by searches for invisible particles
  - E.g. $h \rightarrow$ invisible

Uncovered range!

Dedicated LLP Detectors

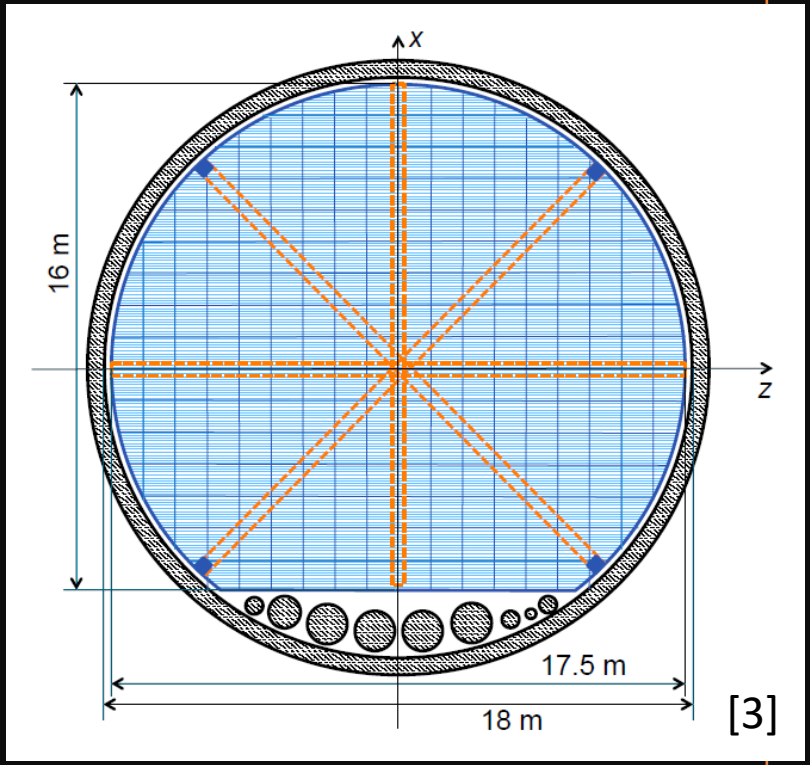
- Motivates constructing dedicated detectors further away from the interaction points
- Two main types:
  - On-axis have increased sensitivity to lighter LLPs
  - Off-axis have increased sensitivity to heavier LLPs
- Two on-axis detectors constructed at the LHC: FASER and MAPP
  - Most significant costs usually civil engineering, use existing LHC tunnels
- What about off-axis?



ANUBIS Overview

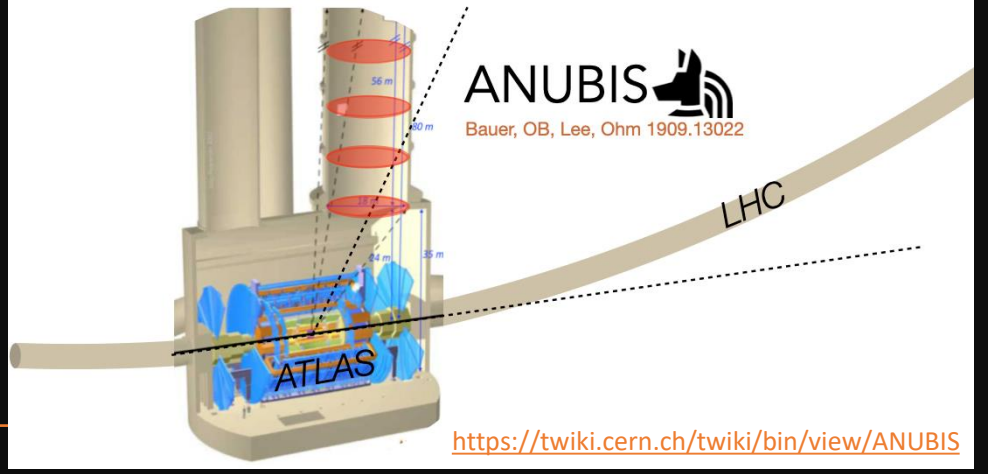
The ANUBIS Proposal

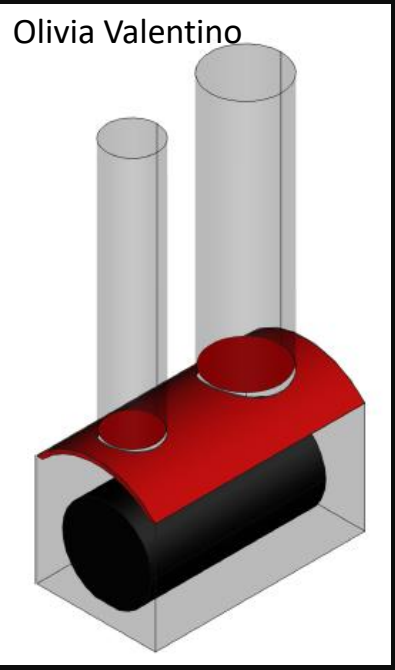
- Instrument the ATLAS cavern
- Detectors ~20m away from the IP
  - Currently ATLAS can efficiently reconstruct displaced vertices to ~7m
- Close enough to ATLAS to participate in L1 trigger decision
  - ATLAS data can be used to analyse ANUBIS events
  - Extra background rejection based on ATLAS selections
- Data taking for all of the HL-LHC. Projected integrated luminosity $\mathcal{L}_{\mathrm{int}} \approx 3\mathrm{ab}^{-1}$
- Each tracking station is made of two layers of triplets separated by 1m



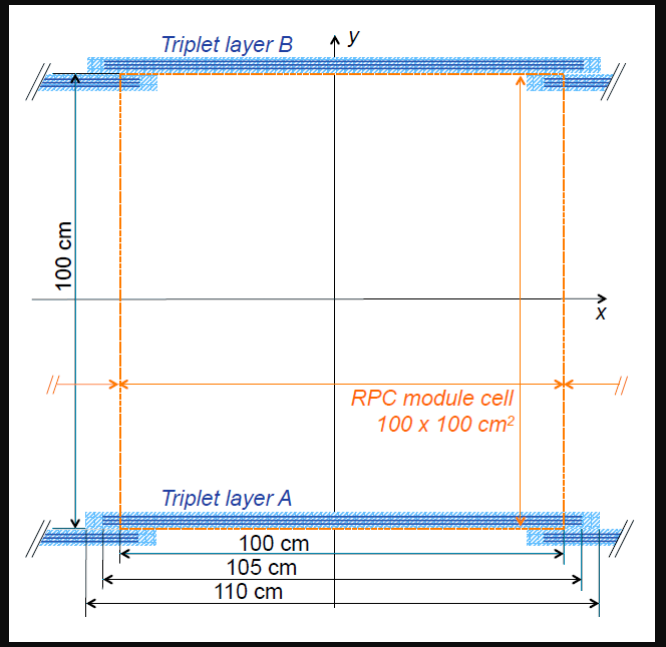
[3]

Geometry



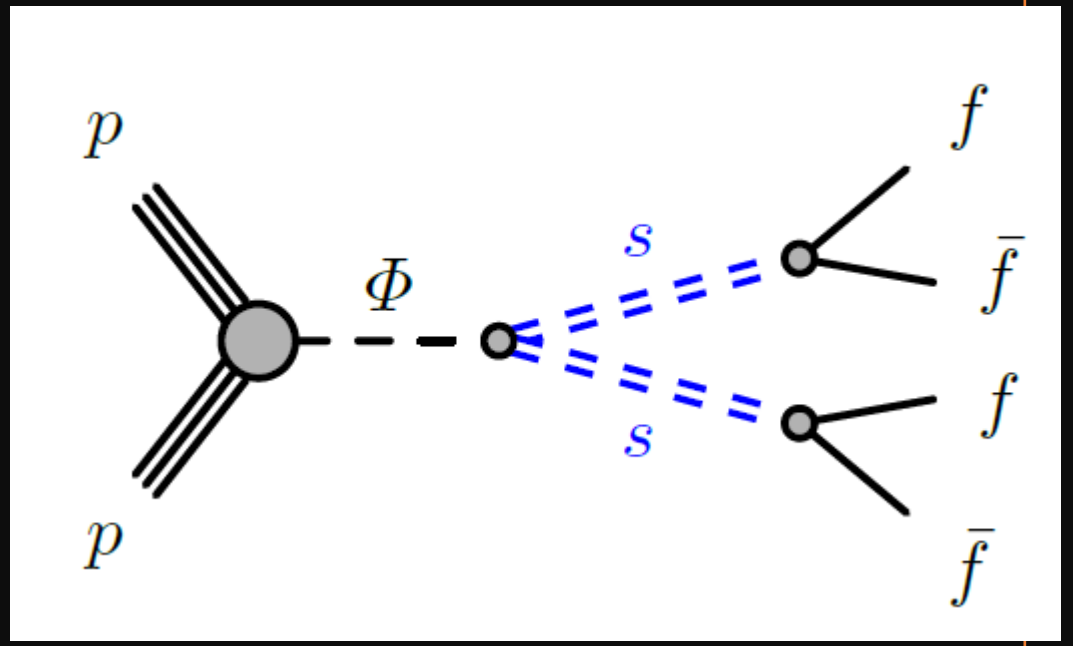


- Proposal: instrument the ceiling of the ATLAS cavern
  - Include stations in the two service shafts
- Previous idea was to instrument *just* the PX14 service shaft
- Larger active volume ($4.3 \times 10^4 \mathrm{m}^3$ vs $1.3 \times 10^4 \mathrm{m}^3$) but larger detector area
- Expected total detector area is O($10^3 \mathrm{m}^2$)



[3]

Benchmark Signal Model



- Standard model Higgs decaying to two LLPs which then decay $s \rightarrow b\bar{b}$
- Consider a range of LLP lifetimes and masses
- s is electrically neutral and does not interact strongly
  - Passes through ATLAS without interacting
- Physics signature is a vertex which appears between two tracking layers
- SM backgrounds: neutral, long-lived
  - Neutron – air interactions
  - K_L^0 - decays and air interactions
- Have to pass through the calorimeter ($\sim 10\lambda$) without interacting

Detector Requirements

- Low cost => Very large detector areas to cover
- Good time resolution
  - Measure β or y (assuming $\beta = 1$, $\delta t \approx 0.5\text{ns} \Rightarrow \delta y \approx 15\text{cm}$)
- Angular resolution limits ability to measure collimated decays
  - $\delta\alpha < 0.01\text{rad} \Rightarrow m_{\text{LLP}} > 0.5\text{GeV}$
  - Also improves ability to localise the vertex
  - Connected to the spatial resolution
- Desired high per-triplet hit efficiency avoids missing events and improves discrimination between signal and background
- Motivates use of RPCs

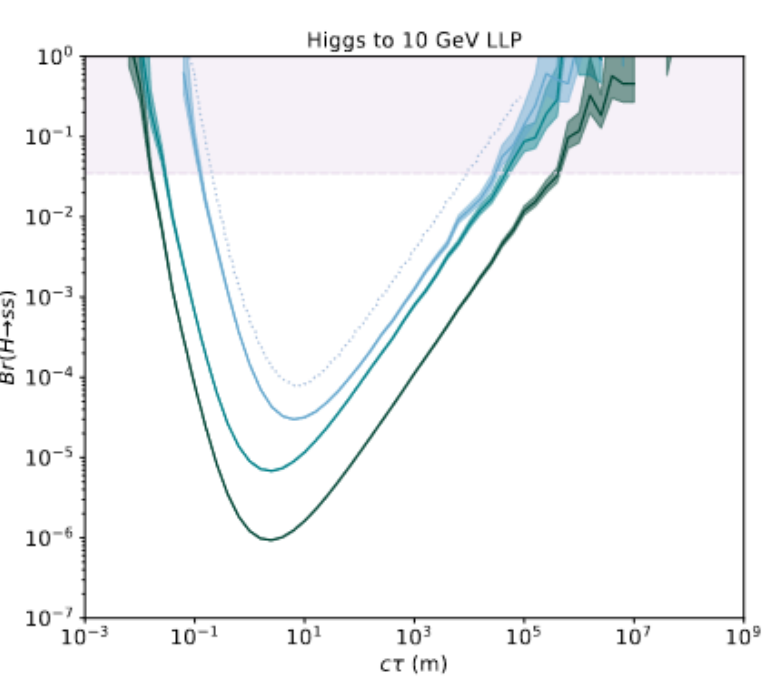
TABLE I. Required performance specifications for ANUBIS.

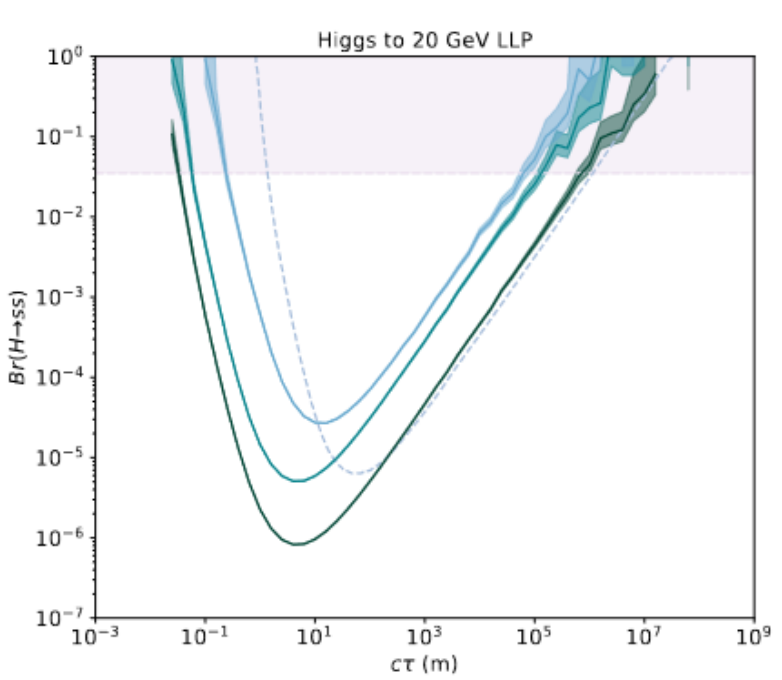
Parameter	Specification
Time resolution	$\delta t \lesssim 0.5$ ns
Angular resolution	$\delta\alpha \lesssim 0.01$ rad
Spatial resolution	$\delta x, \delta z \lesssim 0.5$ cm
Per-layer hit efficiency	$\varepsilon \gtrsim 98\%$

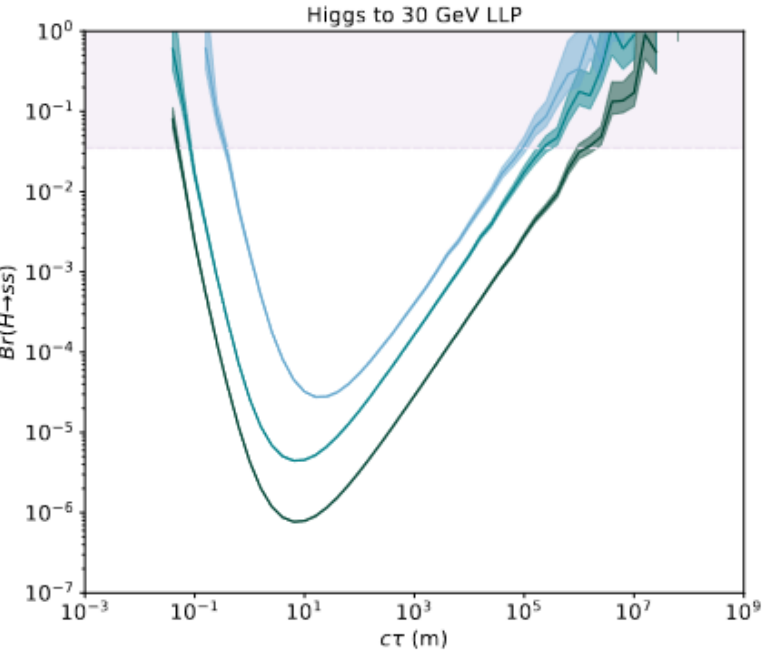
[3]

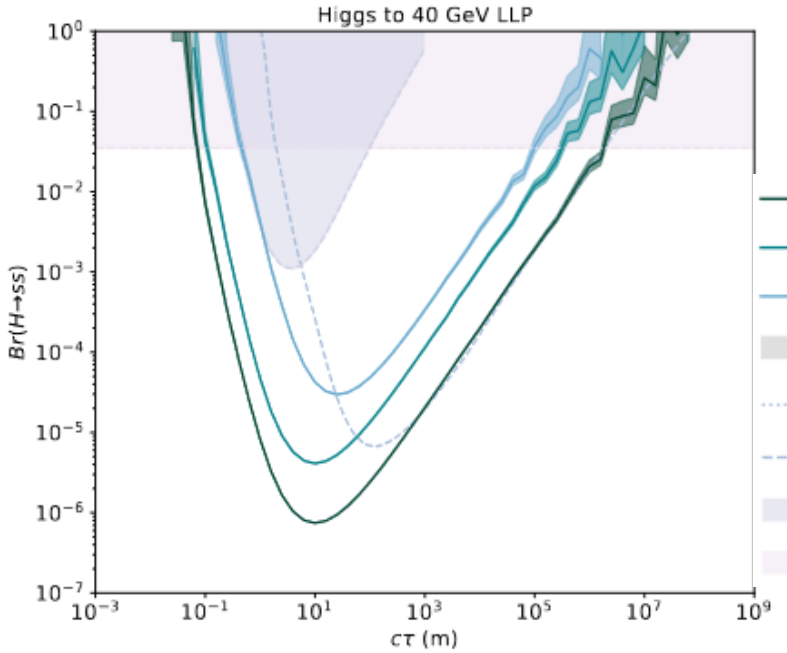
Projected Sensitivity

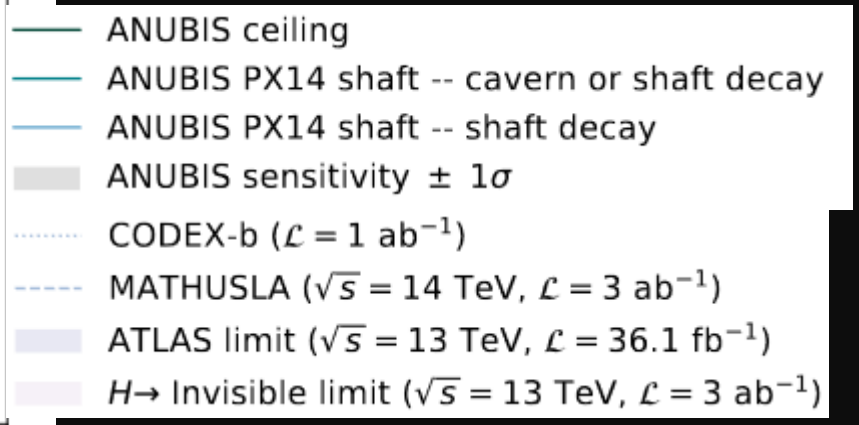
- Estimates from simple (non-G4) simulation
- Sensitivity assumed from 50 (90) observed events for the shaft (ceiling) geometry



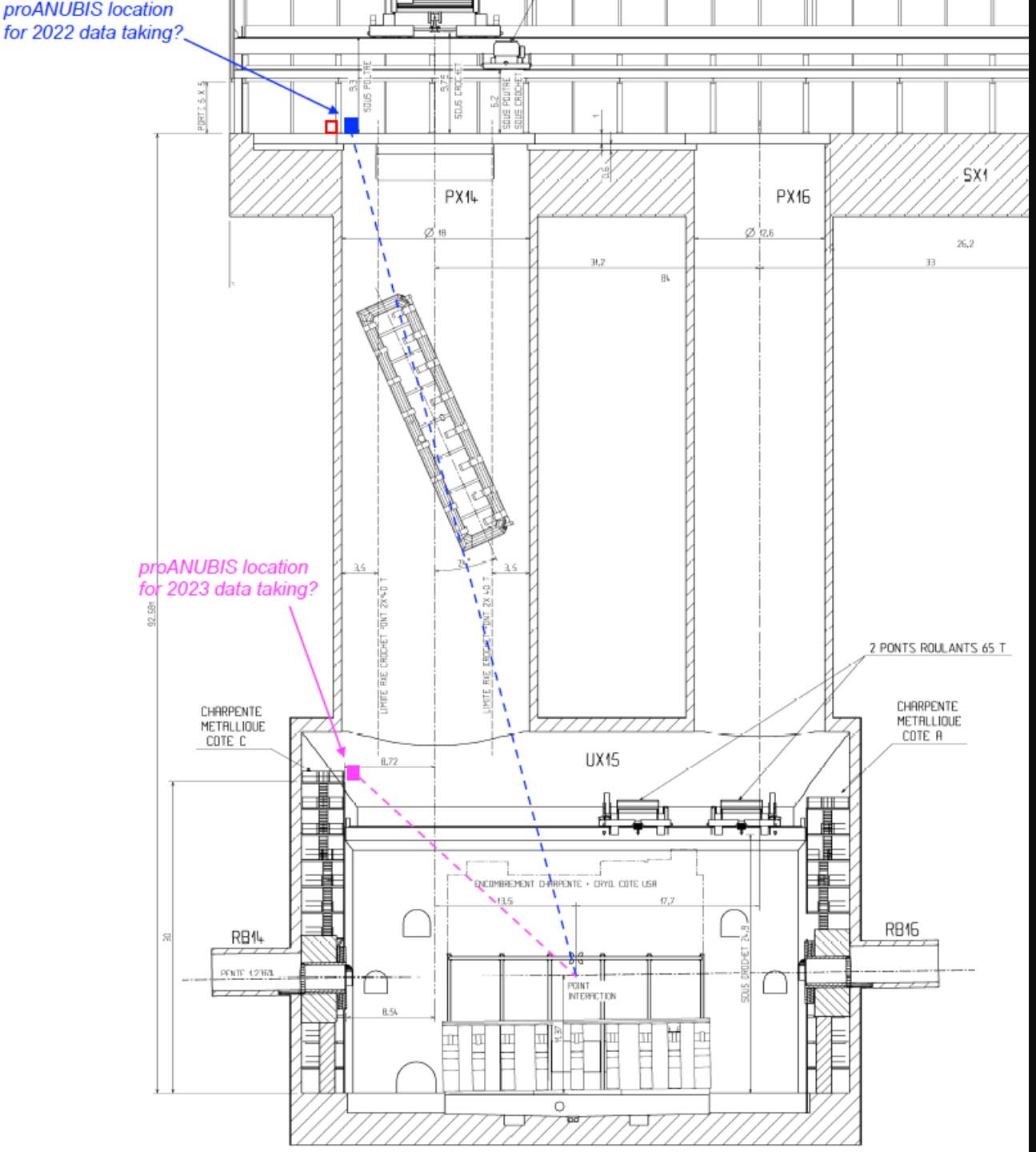








ProANUBIS Plan and Construction

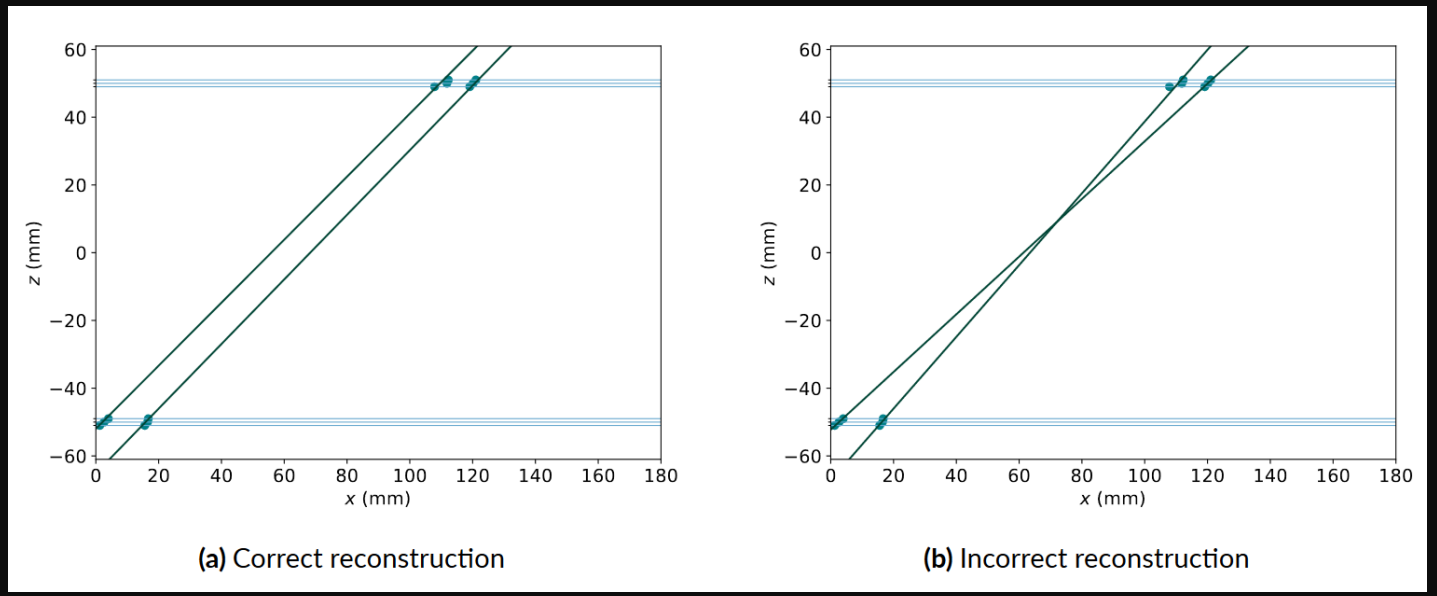


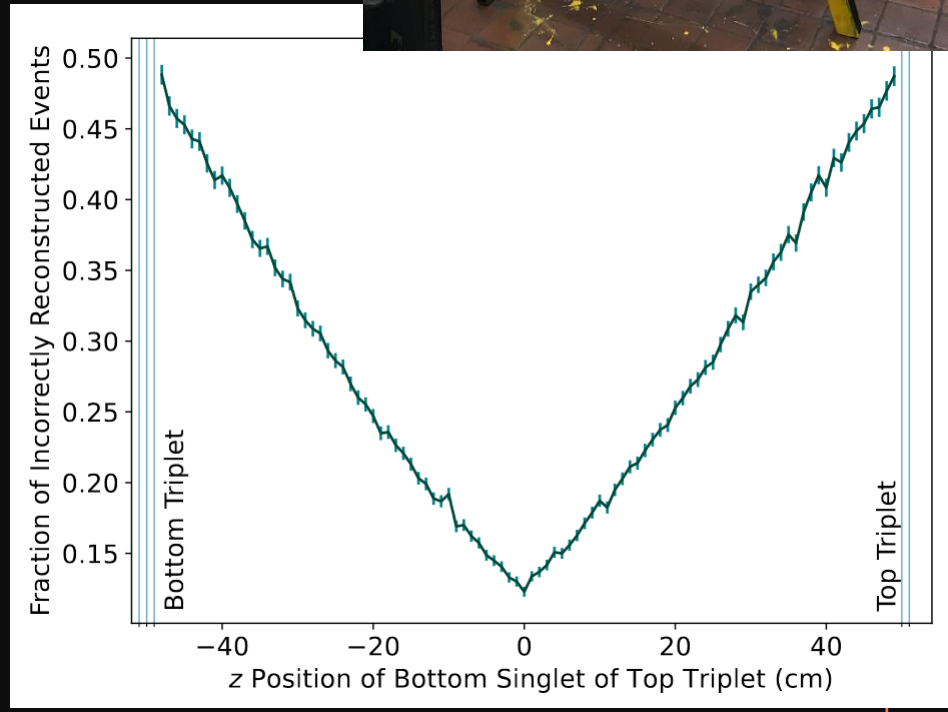
ProANUBIS

- Demonstrator module to be installed during Run 3
- Formed of 6 BIS7 RPC units
- Performance goals
  - Commissioning, hit + track efficiency
  - Test track extrapolation from ATLAS: identify muons selected by triggers and synchronise the detectors
- Physics goals
  - Validate Geant4 simulations
  - Measure rates of secondaries from hadrons interacting with concrete lid (2022)
  - Measure rates of hadrons from punch-through jets (2023)

Detector Layout

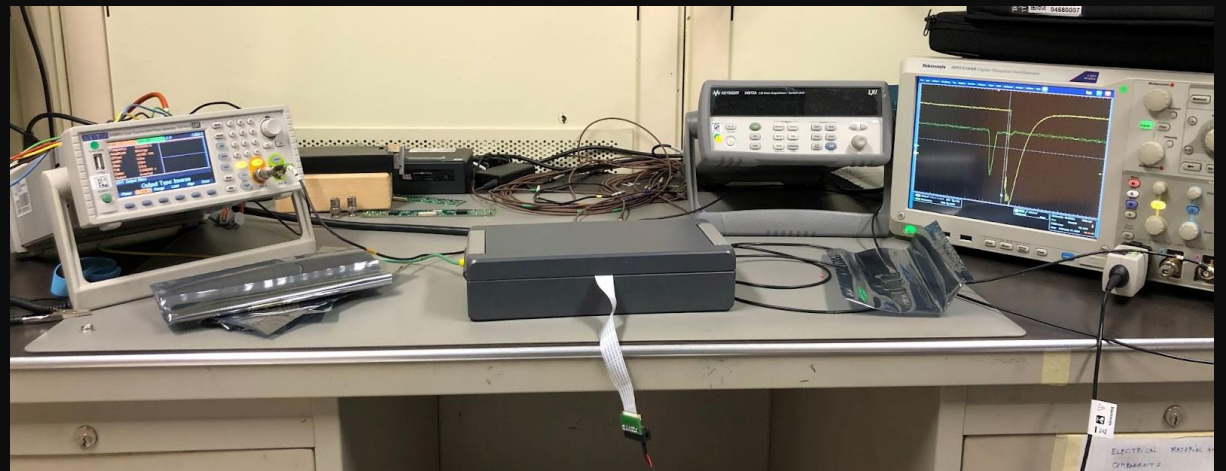
- ProANUBIS layout optimised to avoid misreconstructing close-by tracks
- Ideal layout: a triplet and a doublet 1m apart with a singlet in the middle

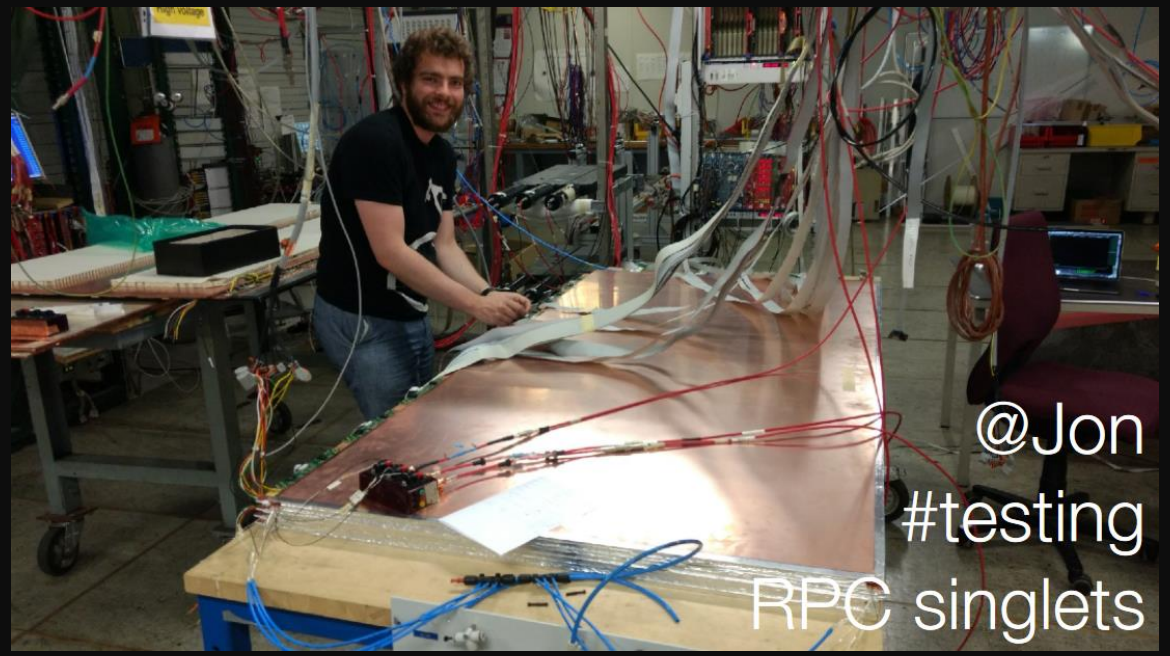


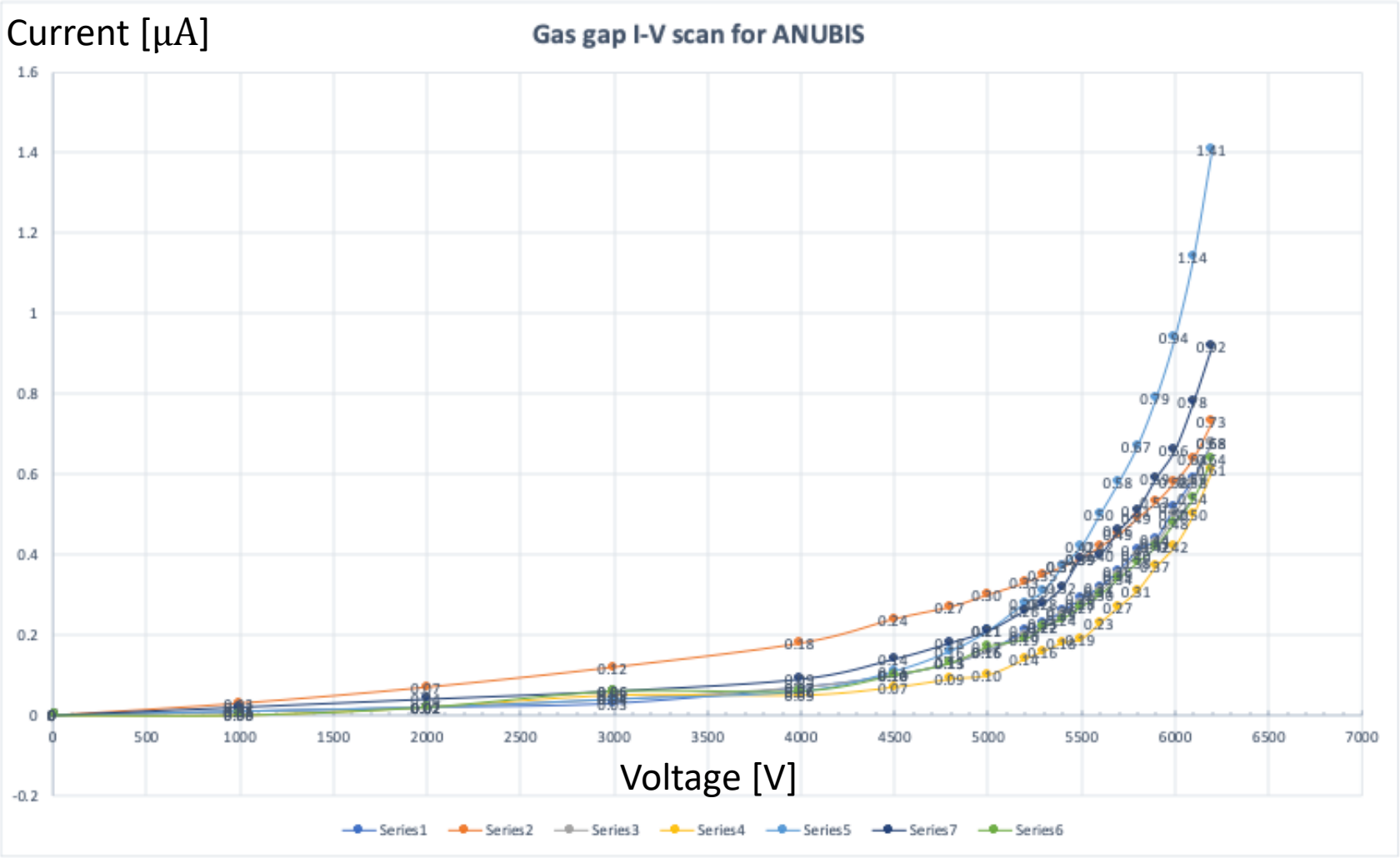


Detector Construction

- Built 7 BIS7 RPC units
  - Oleg, Toby and me with help from Giulio, Luca, Enrico and Luigi
- Full process of construction, starting from the panels
  - Soldered the terminating resistors
  - Attached the FEBs
  - Assembled complete units, including gas gap
  - Begun commissioning and integration
- One full triplet integrated





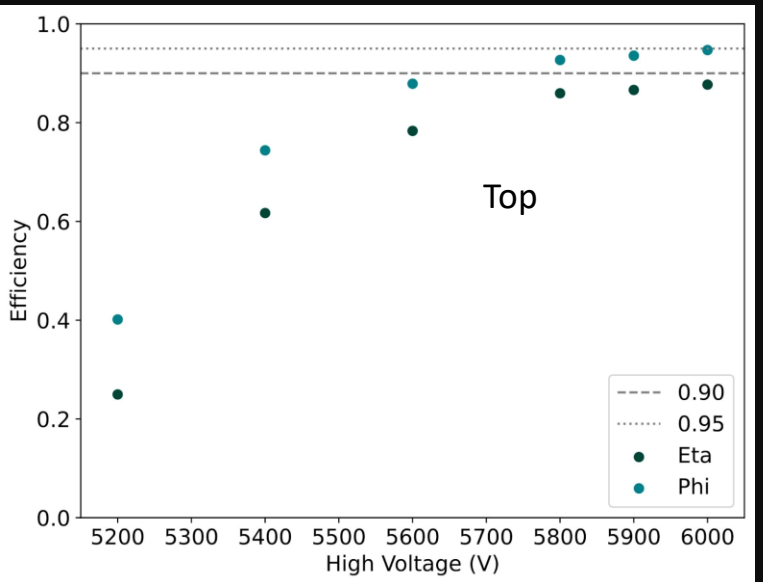


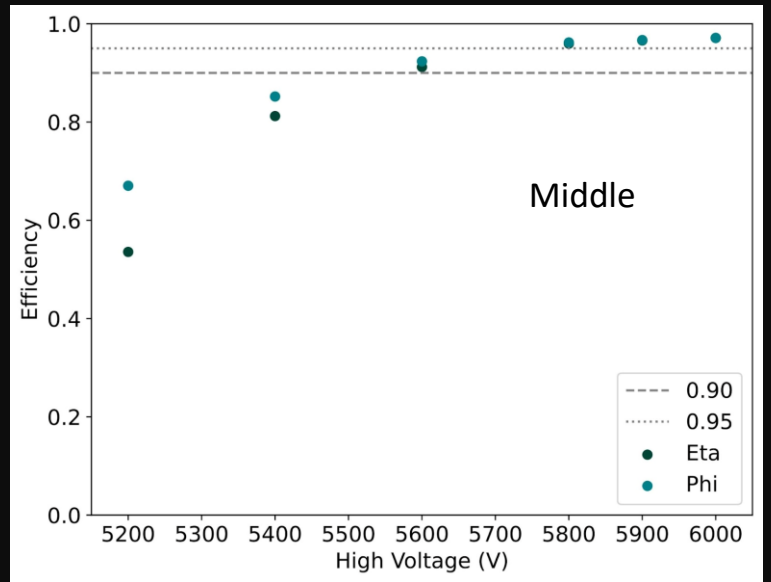
I-V Curves

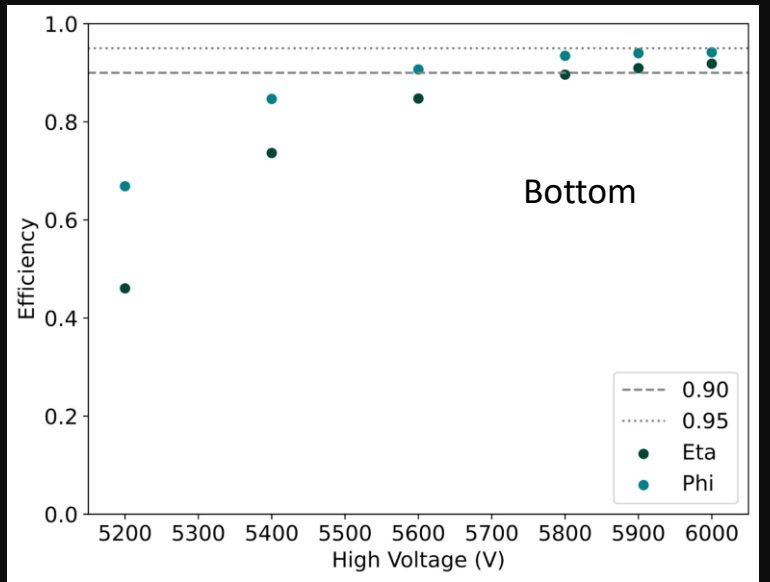
- Curves seem healthy
- Note different bakelite thickness compared to BIS7: 1.3mm vs 1.2mm

Efficiency Curves

- Measured RPC efficiency using a trigger which selected events with a coincidence in two layers
- Look for a matching cluster in the third
- For this test, the cable providing the HV to the middle layer did not have a noise filter
- This layer is noisier: increases its apparent efficiency while reducing the others







Cambridge RPC Development

Cambridge RPC Development

- The grant for ANUBIS also includes funding for dedicated RPC study at Cambridge
- Currently preparing a test setup
  - Characterise performance of the 7th ProANUBIS RPC
  - Test efficiencies with different ecologically friendly gas mixtures

BACKUP

References

[1] Collider searches for long-lived particles beyond the Standard Model

[2] Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

[3] ANUBIS: Proposal to search for long-lived neutral particles in CERN service shafts