The MATHUSLA Detector

MAssive Timing Hodoscope for Ultra Stable

To search for ultra long-lived neutral particles (ULLPs)

Decay very far from the interaction point ($c\tau \sim 10^7$ m)

Do not interact with SM particles

Why Search for Long Lived Particles?

Dark Matter
Dark Energy
Hierarchy Problem
Matter/Anti-Matter Asymmetry

Motivated searches for new physics

Many extensions to the SM contain LLP
• Hidden Valley
• StealthSUSY
• Baryogenesis Models
• 2 Higgs Doublet Models
• Hidden Sector Models

What we know...

Hidden Sector

What we want to probe...

(Idea for Schematic taken from Strassler)
Current Searches

Specialized triggers and analysis methods re-purpose ATLAS to select the decays and reject background.

LLP decays in the ATLAS Calorimeters

LLP is produced

Backgrounds typically QCD, cosmics, cavern background, etc. depending on the analysis.

→ Rarely background free!
LHC Experiments have been busy!
**ATLAS Long-lived Particle Searches** - 95% CL Exclusion

**Status:** July 2015

### Model Description

<table>
<thead>
<tr>
<th>Model</th>
<th>Signature</th>
<th>$\mathcal{L} dt$ [fb$^{-1}$]</th>
<th>Lifetime limit</th>
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<td>SUSY</td>
<td>RPV $\chi_l^i \rightarrow e\nu\nu$</td>
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<td>OGM $\chi_l^i \rightarrow Z\nu$</td>
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<td>AMSB $p\bar{p} \rightarrow \chi_l^i\chi_l^i$</td>
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<td>GMSB non-pointing or delayed $\chi_l$</td>
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<td>Stealth SUSY</td>
<td>2 ID/MS vertices</td>
<td>19.5</td>
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<td>Hidden Valley $H \rightarrow x_l x_l$</td>
<td>2 low-EMF trackless jets</td>
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<td>FRVZ $H \rightarrow 2\gamma + X$</td>
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*Only a selection of the available lifetime limits on new states is shown.*
Much Longer Lifetimes Are Possible

Big Bang Nucleosynthesis

- Defines the upper limit on the lifetime
- Approximately 0.1 seconds ($10^7$ or $10^8$ m)
- Limit comes from the n/p ratio
- Robust against most variations and is considered conservative

Conclusions: to access these long lifetimes we need a detector really far away, with no background

\[ c\tau = 0.5 \text{ m} \]
\[ c\tau = 1 \text{ m} \]
\[ c\tau = 2 \text{ m} \]

arXiv: 1706.01920
MATHUSLA Overview

Surface Detector size is determined by acceptance!
Overall Design

\[ N_{\text{obs}} \sim N_h \cdot Br(h \rightarrow ULLP \rightarrow SM) \cdot \epsilon_{\text{geometric}} \cdot \frac{L}{bc\tau} \]

\( c\tau \) – Lifetime of U LLP
\( b \) – kinematic constant: \( \frac{m_h}{m_h - n \cdot m_X} \)

(less than 3 for 2 body decay with \( m_X \sim 20 \text{ GeV} \))

\( N_h \) - 1.5 \times 10^8 during HL-LHC

\[ \epsilon_{\text{geometric}} \text{ Fraction of } 4\pi \text{ covered by MATHUSLA} \]

If
• \( c\tau \sim 10^7 \text{ m} \)
• Need a to collect a few

Then
• \( L = 20 \text{ m} \)
• \( \epsilon_{\text{geometric}} = 10\% \)
What Is The Sensitivity?

Some sensitivity at the BBN limit
That is big?

200 m \times 200 \text{ m} \quad (\epsilon_{\text{geometric}} \sim 10\%)

Perhaps easier at CMS as they have unused land already owned by CERN
Detector Design

Internal design motivated by the differences between signal and background!

Goal is very high efficiency and almost zero background

\[ \phi \rightarrow XX \]

Two jets of charged (and neutral) particles
Point back along direction of \( \phi \)
Point back to LHC interaction Point

No Interaction

Backgrounds:
- Cosmics from above
- \( \mu \) from LHC
- Atmospheric \( \nu \) from below (or above)
- \( \nu \) from LHC
Detector Design

$L = 20\text{ m}$

5 layers of RPC chambers

Top/Bottom layer of Scintillator

Decay Volume

Scintillator

Precise timing.
~ 80ns to cross top to bottom

Resistive Plate Chambers

“Cheap” tracking chambers
Decent timing

Differentiate between upward and downward going
Assure decay happened inside decay volume.

Pointing back to origin of particle
Cosmic Muon Background

10 MHz rate (over $200^2 \, m^2$)

- Downward traveling
- No vertex
- Hits bottom scintillator

Multiple ways to reject this background
Main worry: combinatorics with another background
LHC Muons

Rate from HL-LHC is ~ 10 Hz

- Muons must have $p \sim 70$ GeV to penetrate rock
- Some lack vertex
- Vertex-track multiplicity

Bottom scintillator-plane efficiency crucial
Upward Going Cosmic Neutrinos

- For muons above 300 MeV
- Does not point back to detector
- For some forms of signal this may be irreducible
- Combinatorics with cosmic ray

~ 100 per year

Will have to be carefully measured when LHC is turned off
LHC Neutrinos

- Does point back to detector
- Vertex-track multiplicity
- Combinatorics with cosmic ray

This will need further study, but is a very small background

~ few per run
Anchoring The Background Estimates

We are developing a GEANT-4 simulation to better understand these backgrounds.

And a fast simulation to aid in detector design.

We need some way to anchor these simulations in reality, however.

Test Stand
The MATHUSLA Test Stand

Repurpose DØ forward muon scintillator paddles (thanks, DØ!)

Repurpose RPC’s from the Argo cosmic ray experiment

Place test stand in ATLAS assembly building (P1)
Test Stand Status

Status
• Scintillator is being tested & characterized at CERN
• RPC’s will arrive any week now
• Support structures completing design/safety
• Aim to run in the fall of 2017 until winter shutdown

Goals
• Develop background rejection algorithms
• Understand algorithm performance in relation to full MATHLUSA design simulation
• Trigger: proposed to have only upward and downward going scintillator pair
  • The goal is not to hunt for signal with such a small $\epsilon_{\text{geom}}$
• Create an LOI with a well understood background estimation
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Conclusion

- A novel idea to cover the complete phase space for neutral decaying ultra long lived particles
  - Takes advantage of field’s investment in the LHC
- Large Surface Detector – close to 200 x 200 m
- Composed of
  - Top and bottom scintillator planes to record direction and if particles are thru-and-thru
  - 5 layers of RPC’s to reconstruct secondary vertex
- Low background requirements will make detector design and quality control important
- Other interesting physics – like cosmic ray bundles – being explored
- Always looking for new people