Exploring the lifetime frontier with MATHUSLA

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Why MATHUSLA?

• ATLAS, CMS, LHCb have a wide program to search for LLPs
• However these searches are limited by a number of factors:
  • triggers
  • backgrounds from collisions (including pileup)
  • backgrounds from the beam
  • cosmics
  • the size of the detector

• A detector working in a clean **background-free** environment would increase the sensitivity
• **MATHUSLA is designed to be such detector**
**MATHUSLA concept**

- **MATHUSLA:** **M**asive **T**iming **H**odoscope for **U**ltra **S**table neutral **p**articles
- Dedicated detector placed on the surface, close to the IP of CMS (or ATLAS)
- Planned to start working for the HL-LHC

- **HL-LHC → order of** \( N_h = 1.5 \times 10^8 \) **Higgs boson produced**
- **Observed decays:**
  \[
  N_{\text{obs}} \sim N_h \cdot \text{Br}(h \to \text{ULLP} \to \text{SM}) \cdot \varepsilon_{\text{geometric}} \cdot \frac{L}{bct}
  \]
  \( \varepsilon = \text{geometrical acceptance along ULLP} \)
  \( L = \text{size of the detector along ULLP direction} \)

- **To collect a few ULLP decays with** \( c\tau \sim 10^7 \text{ m} \)**
  require a 20 m detector along direction of travel of ULLP and about 10 % geometrical acceptance

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*slide from Cristiano Alpigiani*
MATHUSLA description

- **MATHUSLA: MA**sive **T**iming **H**odoscope for **U**ltra **S**table neutra**L** p**A**rticles
- Dedicated detector placed on the surface, close to the IP of CMS (or ATLAS)
- Large volume filled with air as decay volume with several detector layers for tracking
- Designed to accomplish excellent background rejection and robust tracking
**MATHUSLA description**

- **MATHUSLA**: MAsive Timing Hodoscope for Ultra Stable neutraL pArticles
- Dedicated detector placed on the surface, close to the IP of CMS (or ATLAS)
- Large volume filled with air as decay volume with several detector layers for tracking
- Designed to accomplish excellent background rejection and robust tracking
- Original design gives sensitivity to neutral LLPs with lifetime up to the Big Bang Nucleosynthesis (BBN) limit ($10^7 - 10^8$ m):
  - 5 layers for robust tracking (originally RPCs, currently scintillators are being considered)
  - 1 layer on the floor to veto on particles coming from the IP
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  - In terms of size, three benchmarks were studied for the LoI:
    - 20 m high
    - surface of 200x200 m$^2$, 100x100 m$^2$, 50x50 m$^2$
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    - 20 m high
    - surface of 200x200 m$^2$, 100x100 m$^2$, 50x50 m$^2$
    - with decreasing sensitivity

![Graph](image-url)
Modular concept

- Need to cover a wide surface with detector material
- Current design considers a modular configuration
  - Easy to adapt to available land
  - Allows for staged integration with incremental ramp-up
- 100 towers with 10x10 m$^2$ surface
- 5 tracking layers on top
- 1 veto layer on the bottom
- 20 m air decay volume
Geometry configuration

- Several configurations under study pursuing the highest sensitivity within the available land surrounding the CMS IP.
Current configuration

- The current MATHUSLA detector concept is 100x100 m\(^2\) located at the surface of CMS.
- Currently working with CERN civil engineers to:
  - determine the feasibility of excavating to install MATHUSLA slightly below surface.
  - and feasibility of building a structure (building) with crane coverage to house MATHUSLA.

- 100m x 100m experimental area.
- 30m x 100m assembly area.
- ~7.5m offset to center of beam.
- ~68m to IP.
Current configuration

- The current MATHUSLA detector concept is 100x100 m$^2$ located at the surface of CMS
- Currently working with CERN civil engineers to:
  - determine the feasibility of excavating to install MATHUSLA slightly below surface
  - and feasibility of building a structure (building) with crane coverage to house MATHUSLA
- **100x100 m$^2$ buried a few meters deep** has several advantages:
  - getting closer to the IP, increases solid angle wrt surface option
  - sensitivity is comparable to the original 200x200 m$^2$, used as benchmark in the LoI
  - respects landscape
Detector material

- We are investigating using extruded scintillator bars with wavelength shifting fibers embedded in the bars that are readout by Si photomultipliers.
- Considering to have scintillators for the 5 tracking layers
  - good resolution, no need to use high voltages or gas
- Time difference between the two ends gives information on one coordinate; width of the bar gives information on the other coordinate. Overall good resolution
- Some effort to be started soon to determine the sensitivity using scintillators instead of RPCs for tracking

Fig. 8 Photo detection efficiency (PDE) in NUV-SiPMs as a function of wavelength (crosstalk and afterpulse not included).

- AdvanSiD NUV3S-P (SHiP test):
  - [http://advansid.com/attachment/get/up_53_1432731710.pdf](http://advansid.com/attachment/get/up_53_1432731710.pdf)
Summary

• Good progress on the MATHUSLA detector design since the last LHC LLP workshop
• Letter of Intent was submitted in Nov 2018
• Main updates since then are in the geometry and details of installation:
  • 100x100 m$^2$ configuration
  • a few meters underground
  • moving closer to the IP
  • increase solid angle to get sensitivity comparable to the largest benchmark considered in the LoI (200x200 m$^2$)
• Studies to determine the optimal detector material ongoing
  • scintillator bars with wavelength shifting fibers embedded in the bars that are readout by Si photomultipliers
  • considering the option of having all detector layers made of scintillators