Exploring the lifetime frontier with MATHUSLA

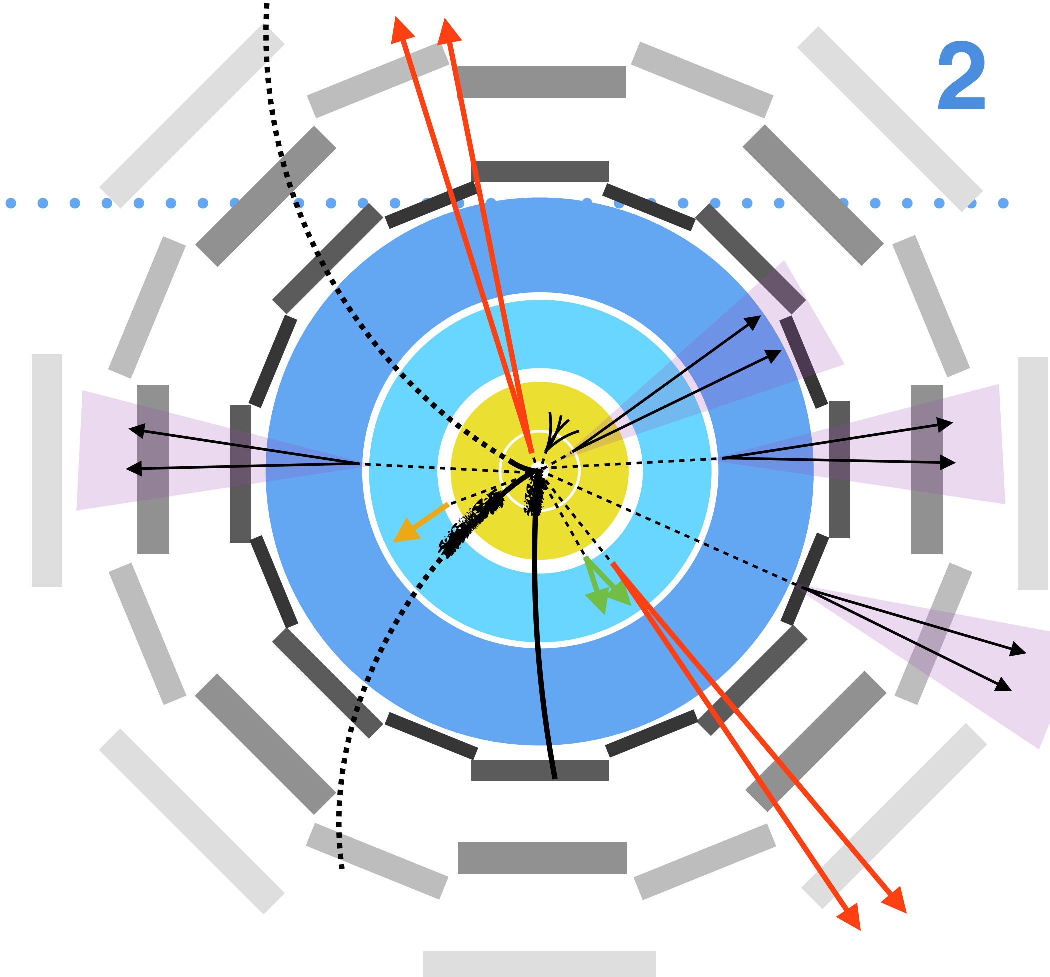
Emma Torró, for the MATHUSLA Collaboration

Fifth LHC LLP workshop
29 May 2019
CERN

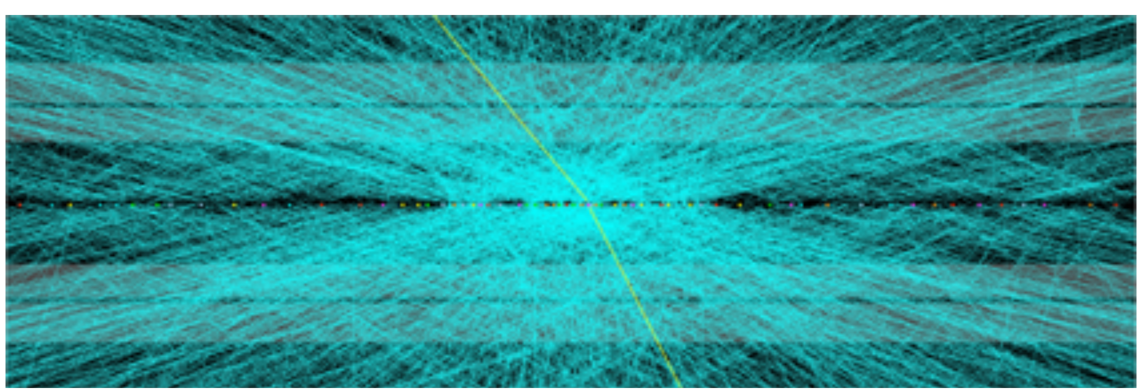
UNIVERSITY of WASHINGTON

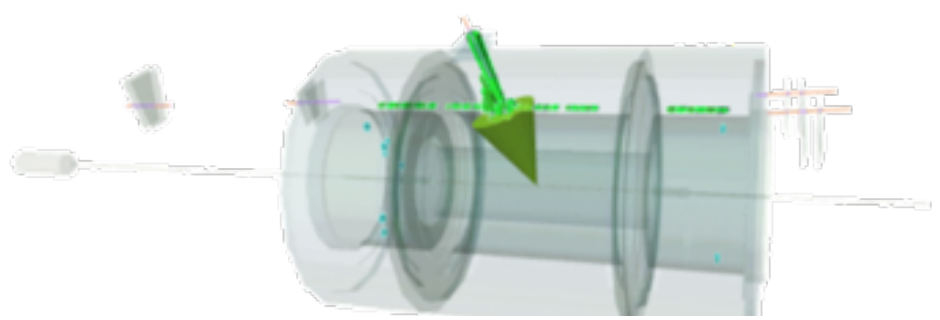
MATHUSLA

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

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

- **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)
- Planned to start working for the HL-LHC

➢ HL-LHC → order of N_h = 1.5 x 10^8 Higgs boson produced

➢ Observed decays:

$$N_{\mathrm{obs}} \sim N_h \cdot \mathrm{Br}(h \to \mathrm{ULLP} \to \mathrm{SM}) \cdot \epsilon_{\mathrm{geometric}} \cdot \frac{L}{bc\tau}$$

ϵ = geometrical acceptance along ULLP

L = size of the detector along ULLP direction

$b \sim m_h /(n \cdot m_X) \leq 3$ for Higgs boson decaying to n = 2, $m_X \geq 20$ GeV

❖ To collect a few ULLP decays with $c\tau \sim 10^7$ m require a 20 m detector along direction of travel of ULLP and about 10 % geometrical acceptance

$$L \sim (20\,\mathrm{m}) \left(\frac{b}{3}\right) \left(\frac{0.1}{\epsilon_{\mathrm{geometric}}}\right) \frac{0.3}{\mathrm{Br}(h \to \mathrm{ULLP})}$$

slide from Cristiano Alpigiani

MATHUSLA description

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- 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
- Letter of Intent submitted in November 2018: [MATHUSLA LoI: arXiv 1811.00927](https://arxiv.org/abs/1811.00927)

arXiv:1811.00927v1 [physics.ins-det] 2 Nov 2018

A Letter of Intent for MATHUSLA: a dedicated displaced vertex detector above ATLAS or CMS

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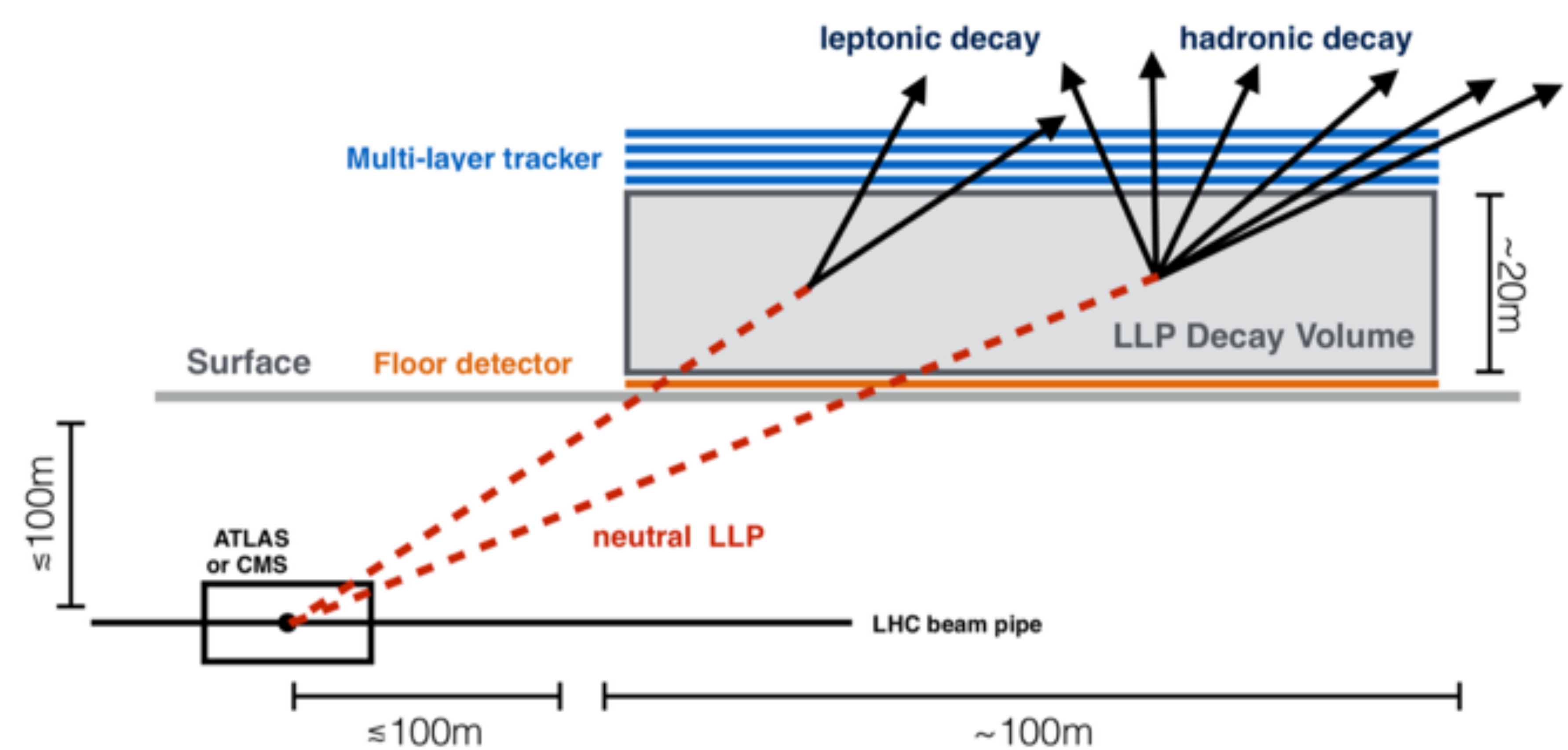
- Original design gives sensitivity to neutral LLPs with lifetime up to the Big Bang Nucleosynthesis (BBN) limit (10^7 - 10^8 m):
  - 5 layers for robust tracking (originally RPCs, currently scintillators are being considered)
  - 1 layer on the floor to veto on particles coming from the IP



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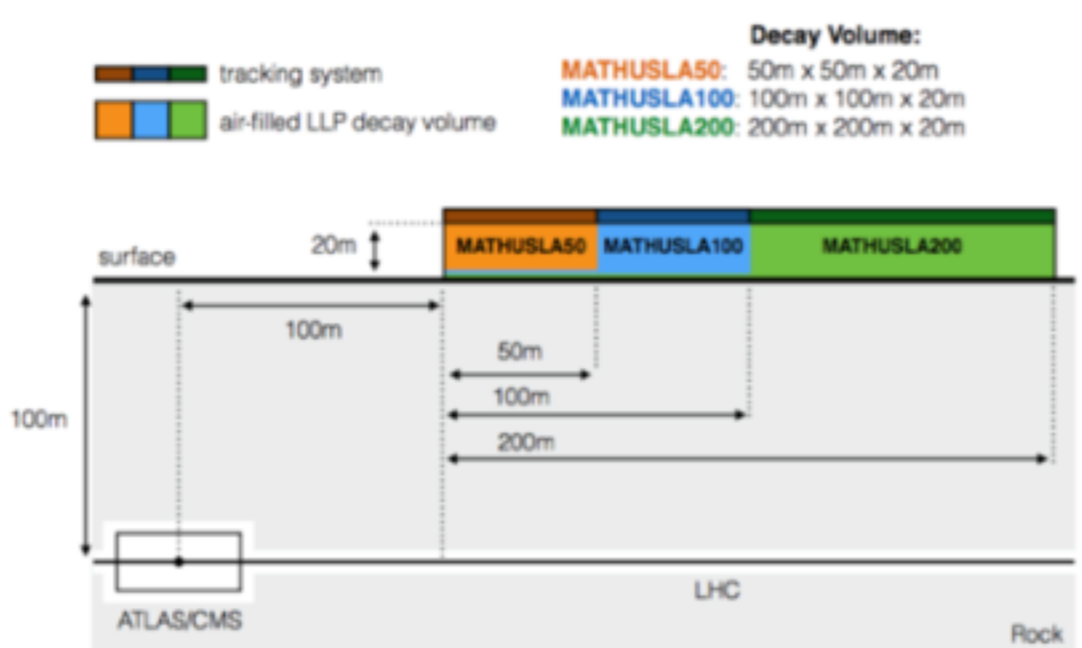
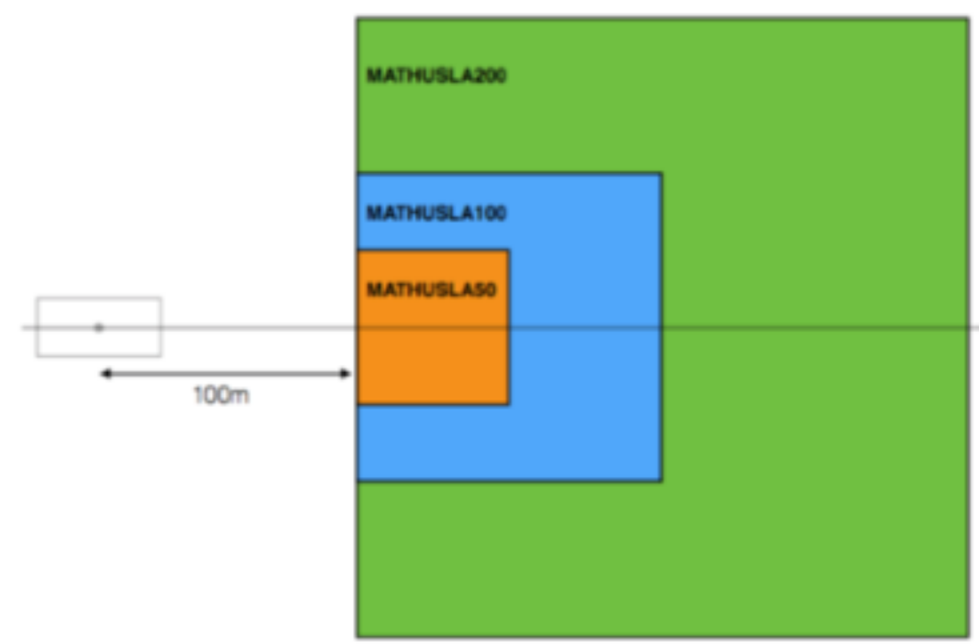
  - In terms of size, three benchmarks were studied for the LoI:
  - 20 m high
  - surface of 200x200 m^2, 100x100 m^2, 50x50 m^2



side view



aerial view

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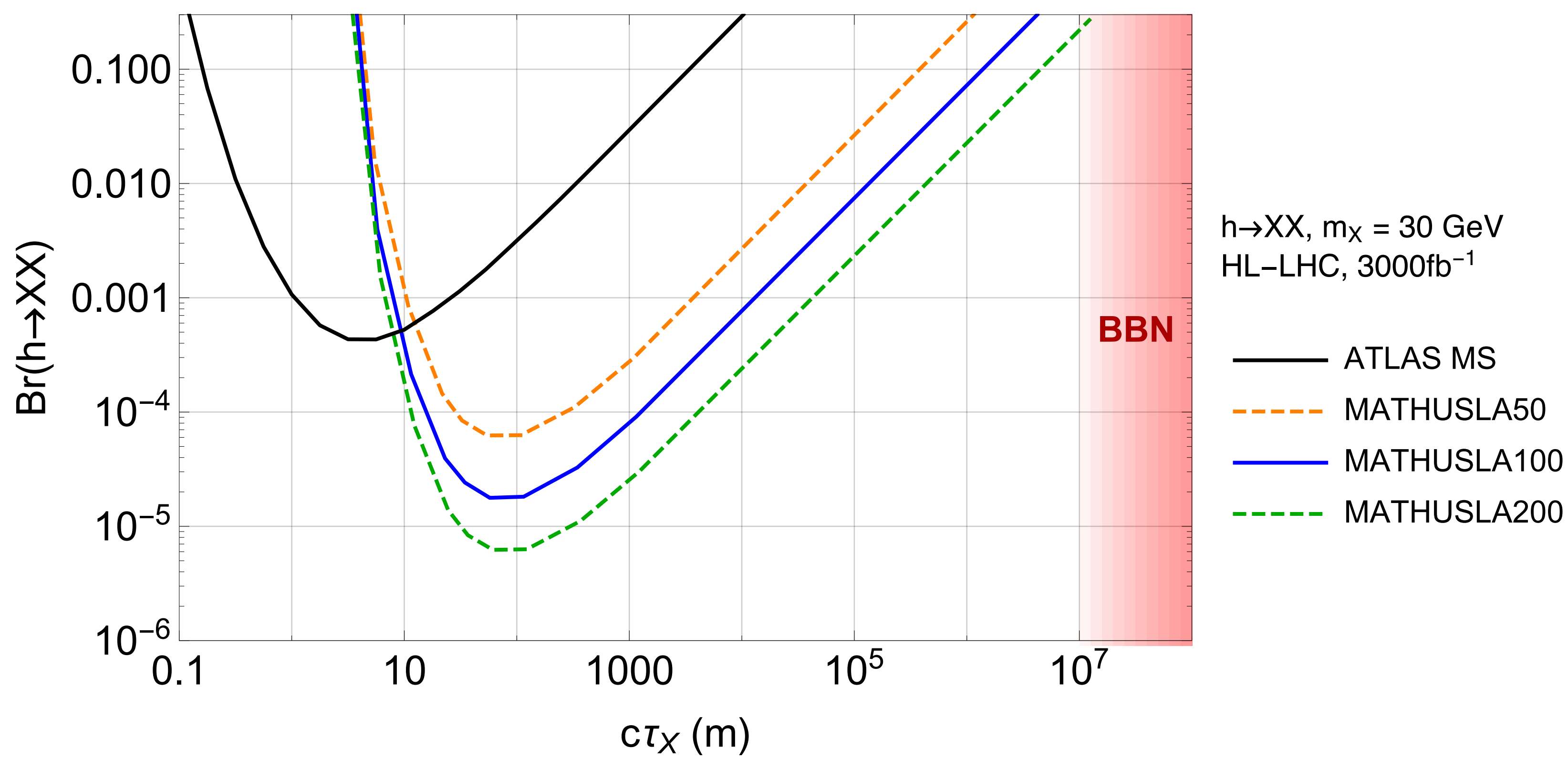
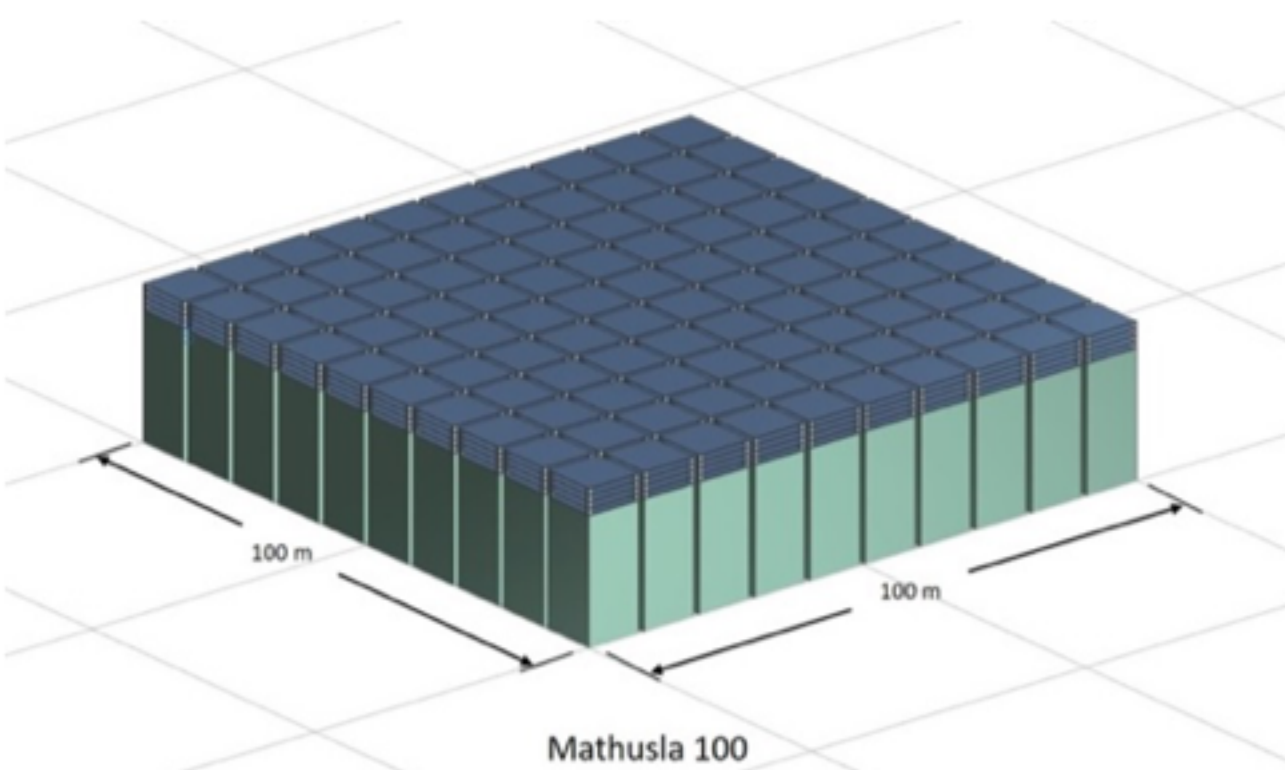
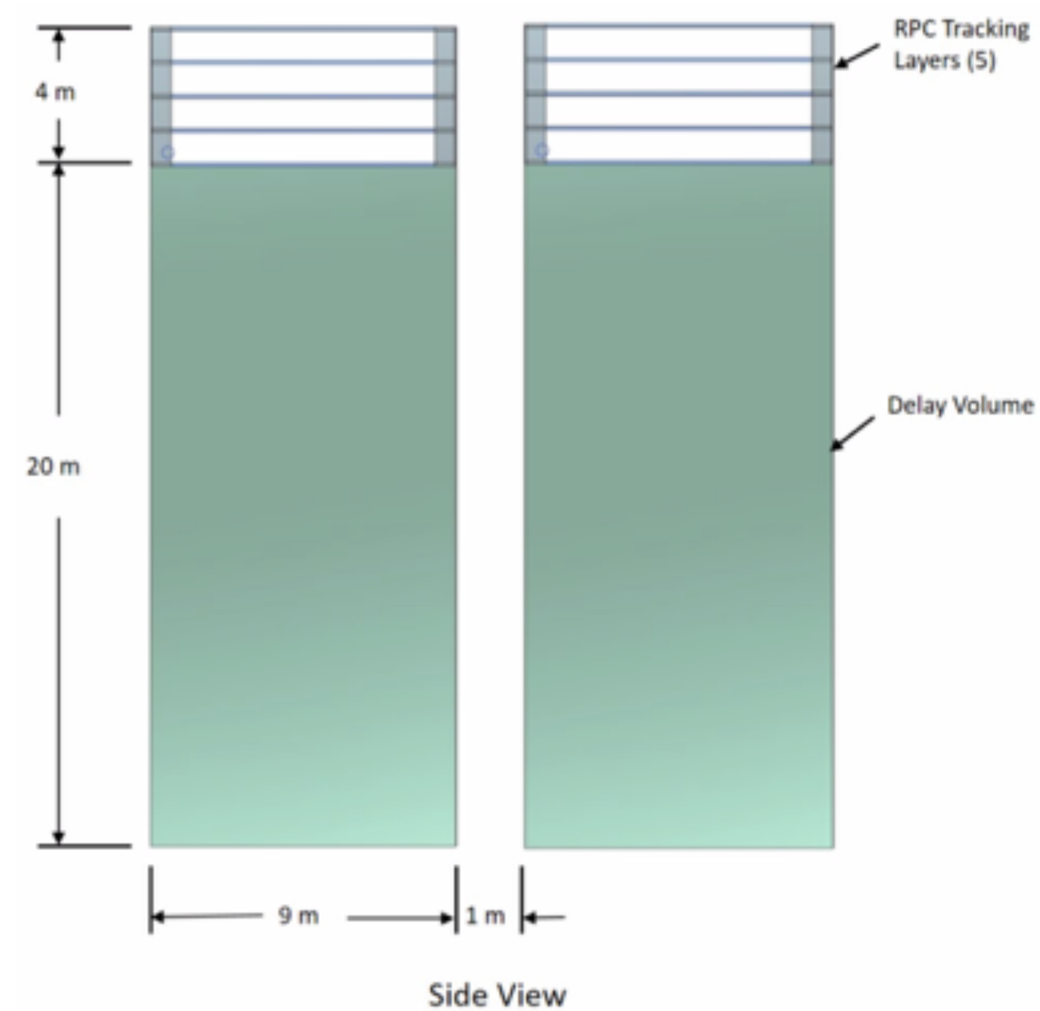
  - 20 m high
  - surface of 200x200 m^2, 100x100 m^2, 50x50 m^2
  - with decreasing sensitivity



Modular concept

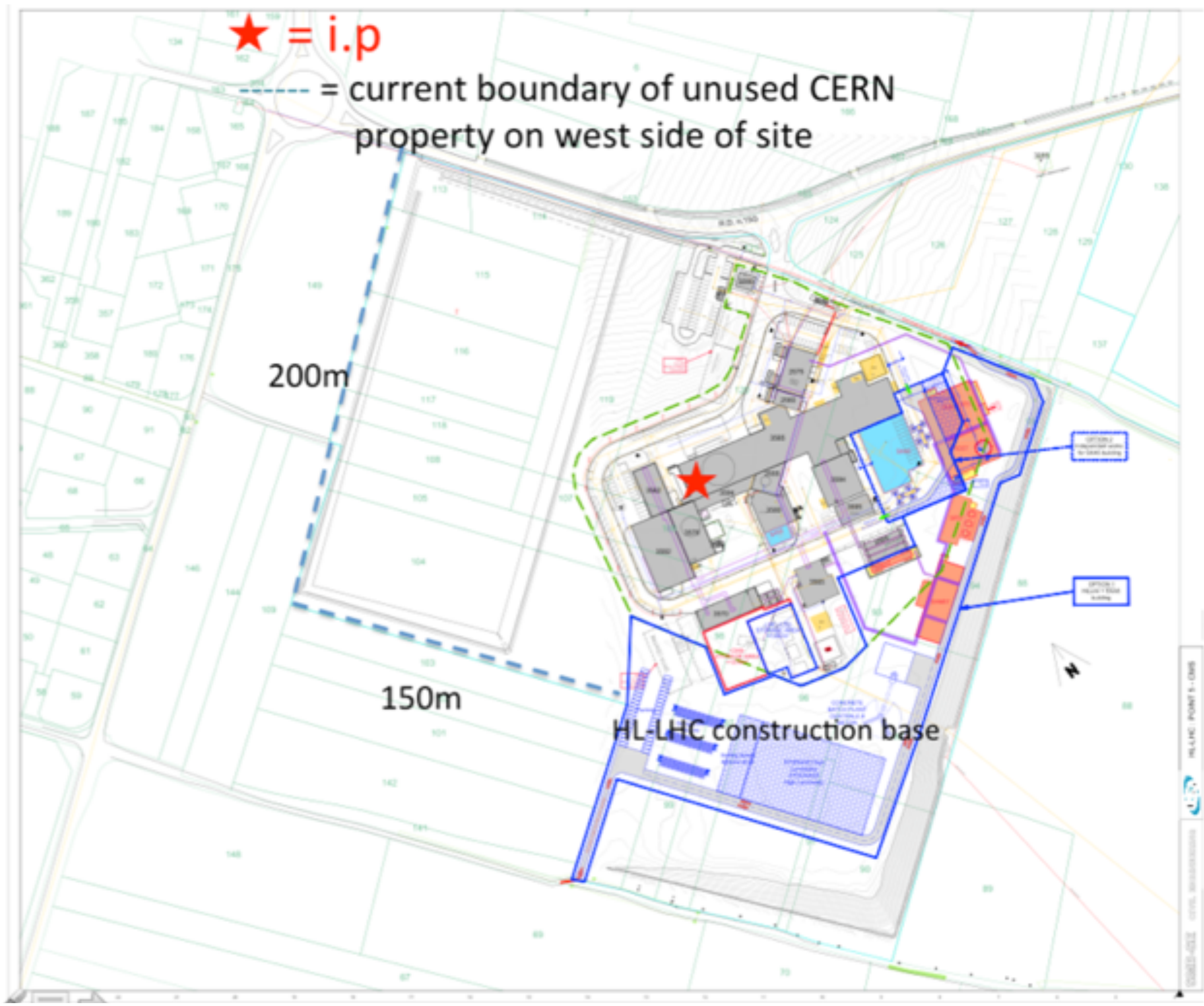
- Need to cover a wide surface with detector material
- Current design considers a modular configuration
  - Easy to adapt to available land
  - Allows for staged integration with incremental ramp-up
  - 100 towers with 10x10 m^2 surface
  - 5 tracking layers on top
  - 1 veto layer on the bottom
  -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





Geometry configutarion

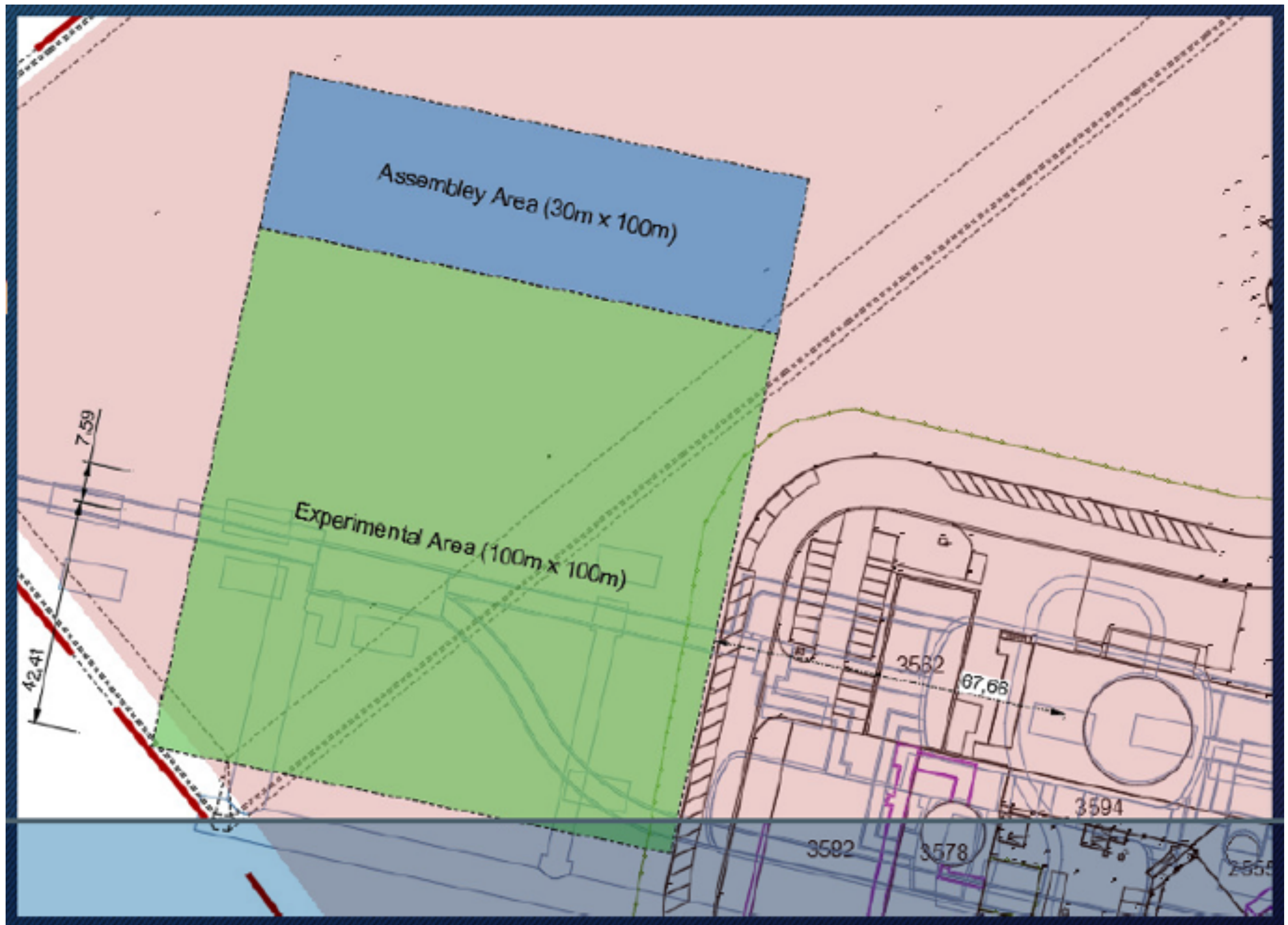
- Several configurations under study pursuing the highest sensitivity within the available land surrounding the CMS IP



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



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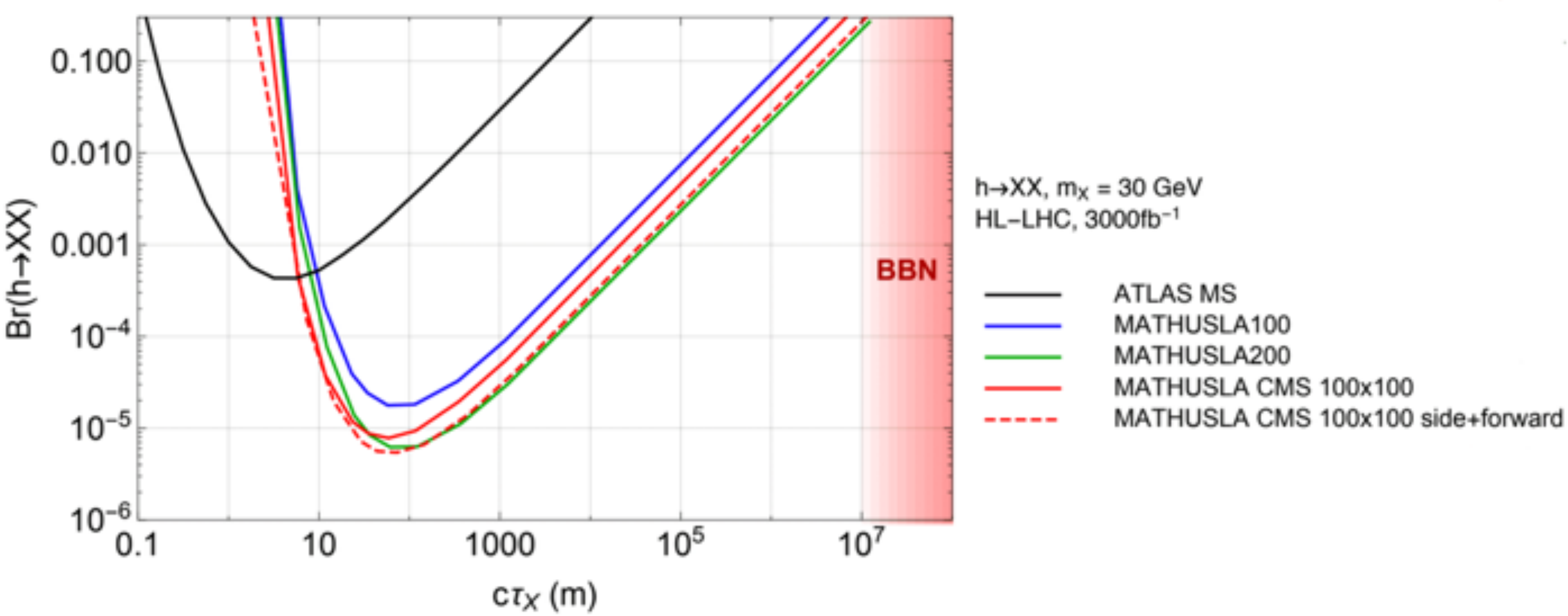
- Currently working with CERN civil engineers to:
  - determine the feasibility of excavating to install MATHUSLA slightly below surface
  - and feasibility of building a structure (building) with crane coverage to house MATHUSLA
- **100x100 m^2 buried a few meters deep** has several advantages:
  - 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
  - repects 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. Overal good resolution
- Some effort to be started soon to determine the sensitivity using scintillators instead of RPCs for tracking

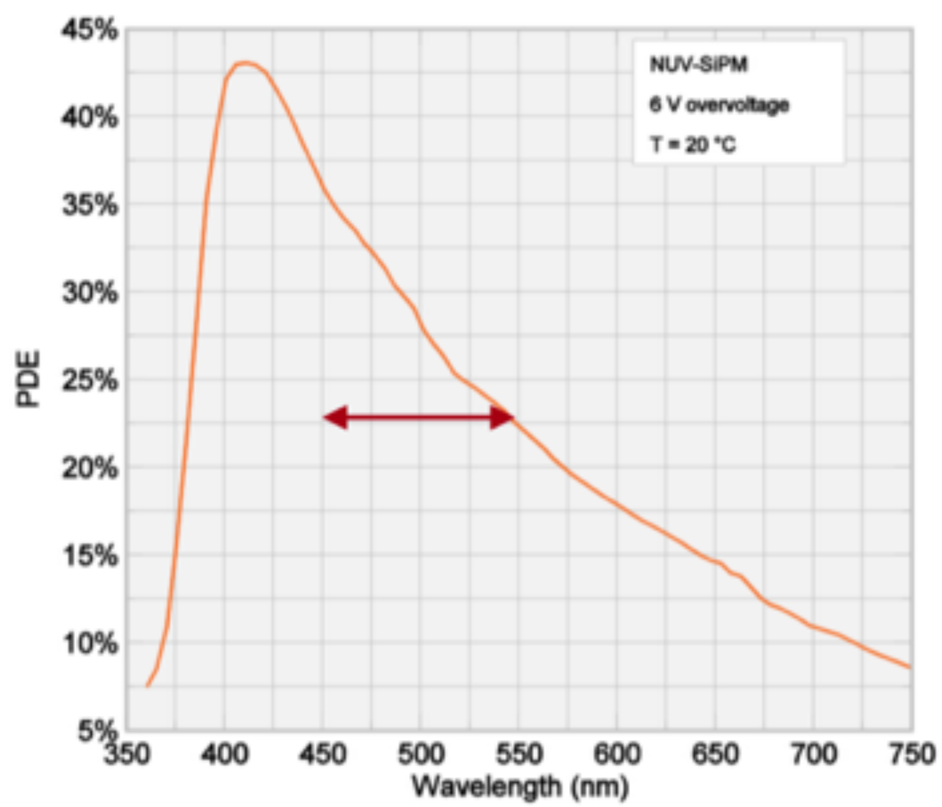


Fig.8 Photo detection efficiency (PDE) in NUV-SiPMs as a function of wavelength (crosstalk and afterpulse not included).

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

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