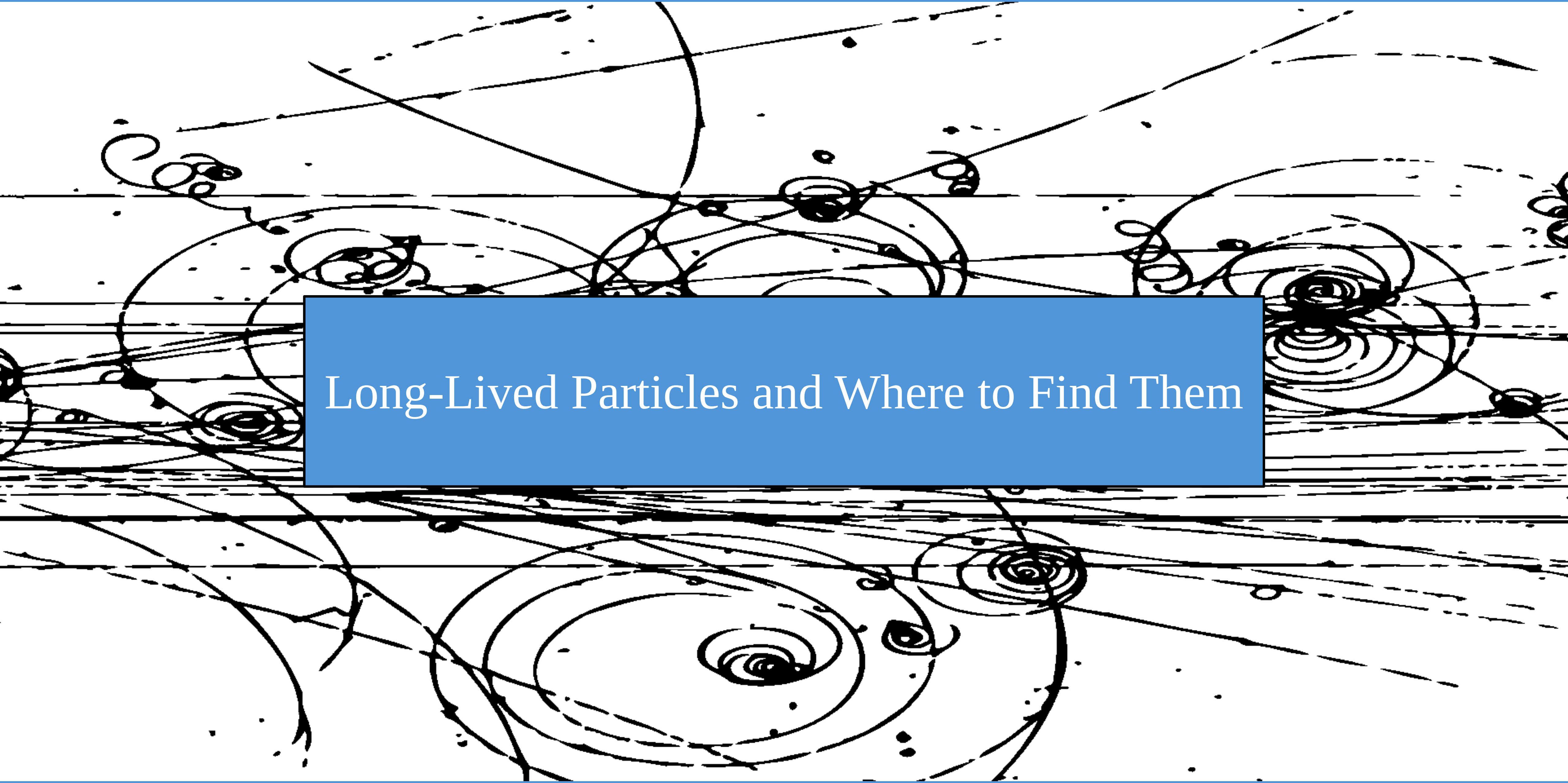
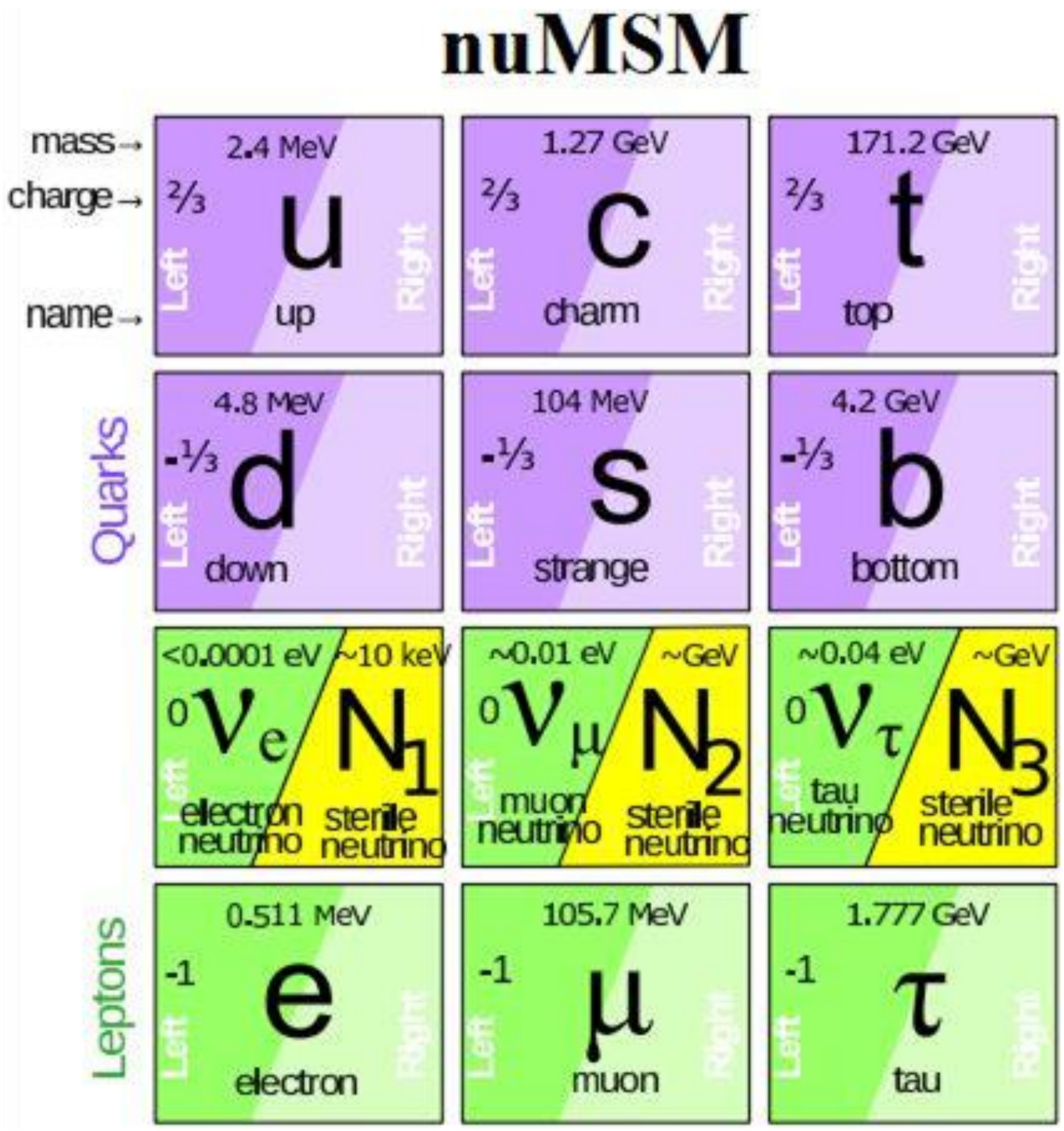
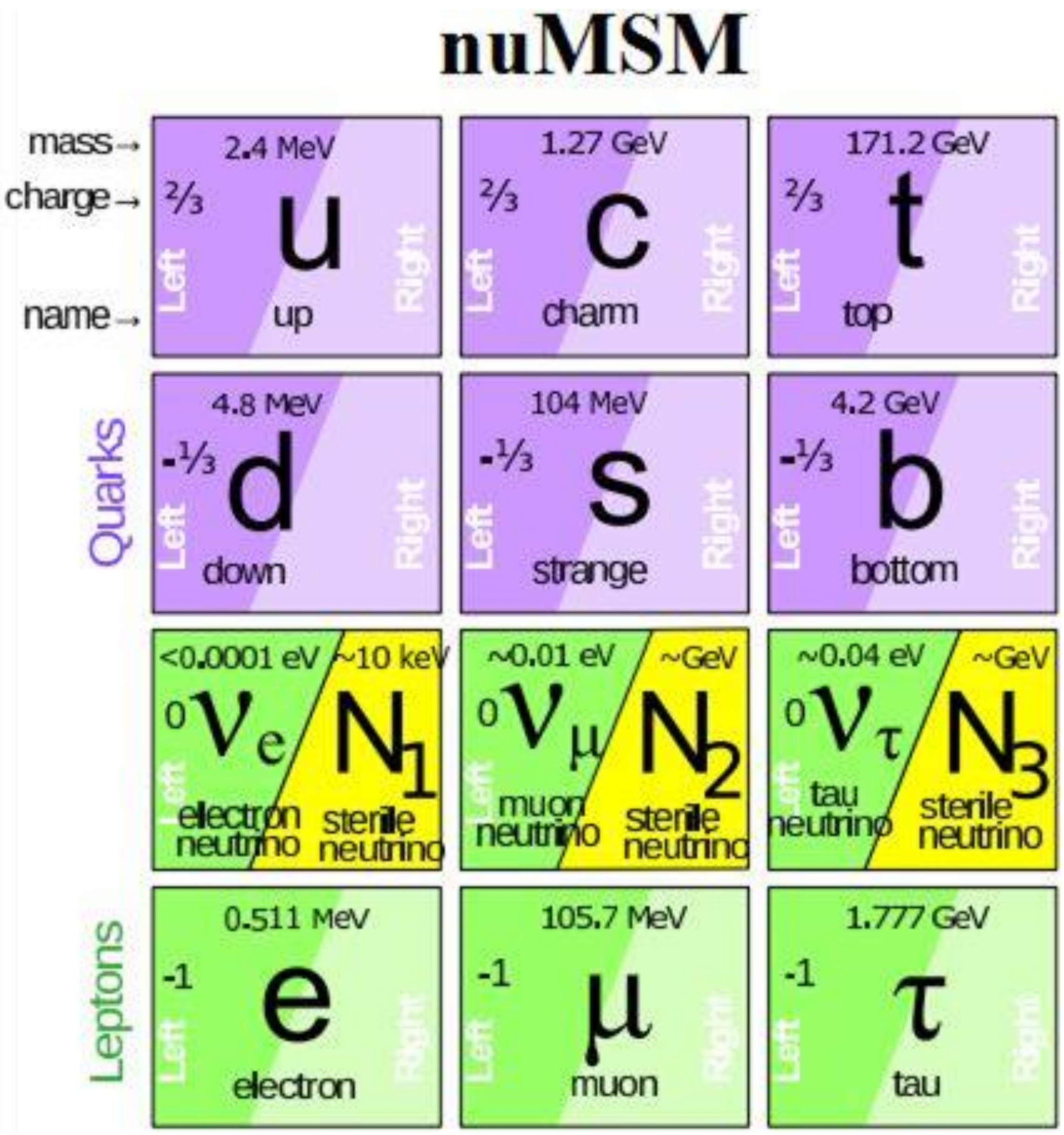


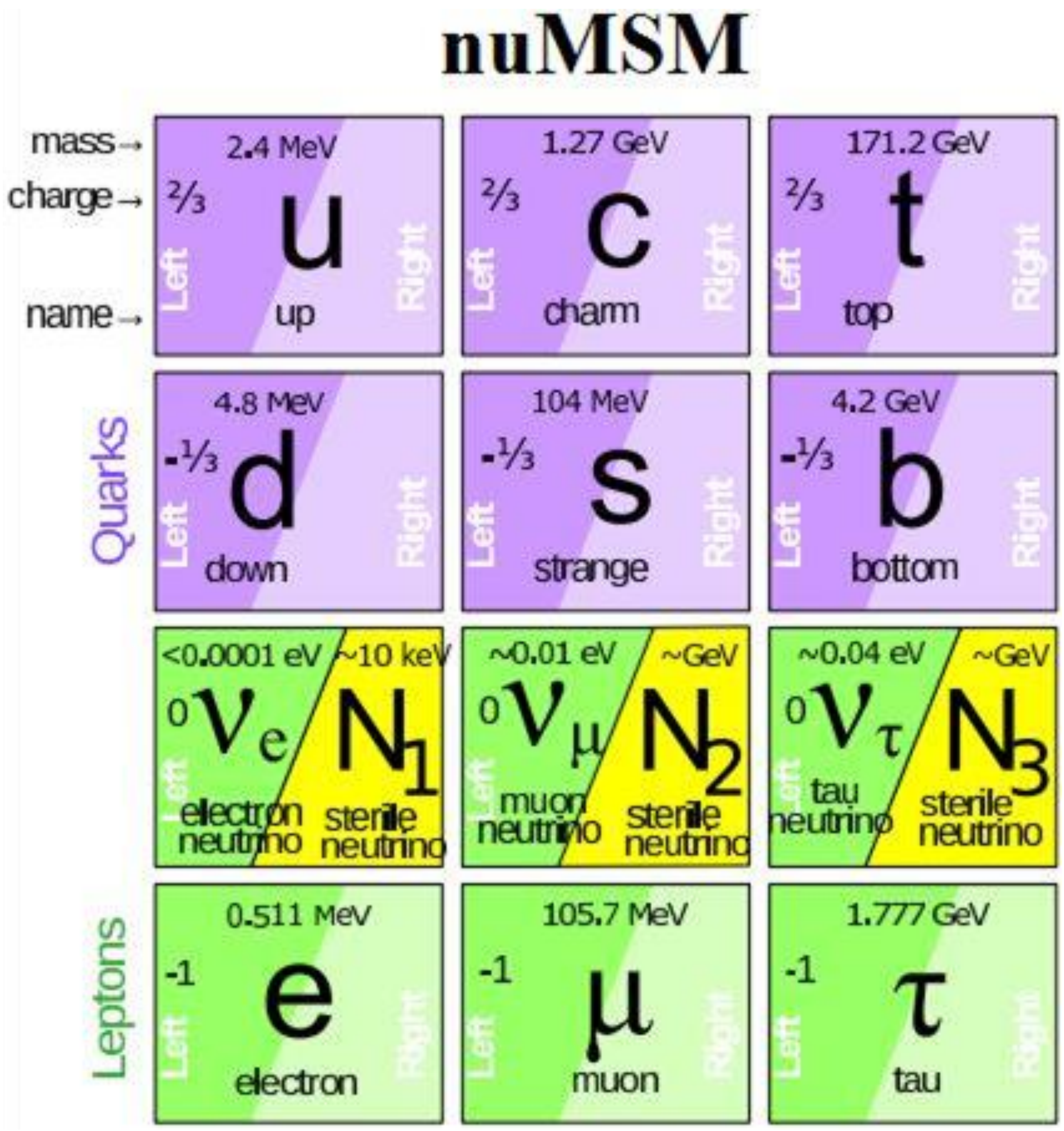
Long-Lived Particles and Where to Find Them



- Extend SM with three heavy neutral leptons (HNLs): $N1$, $N2$, $N3$

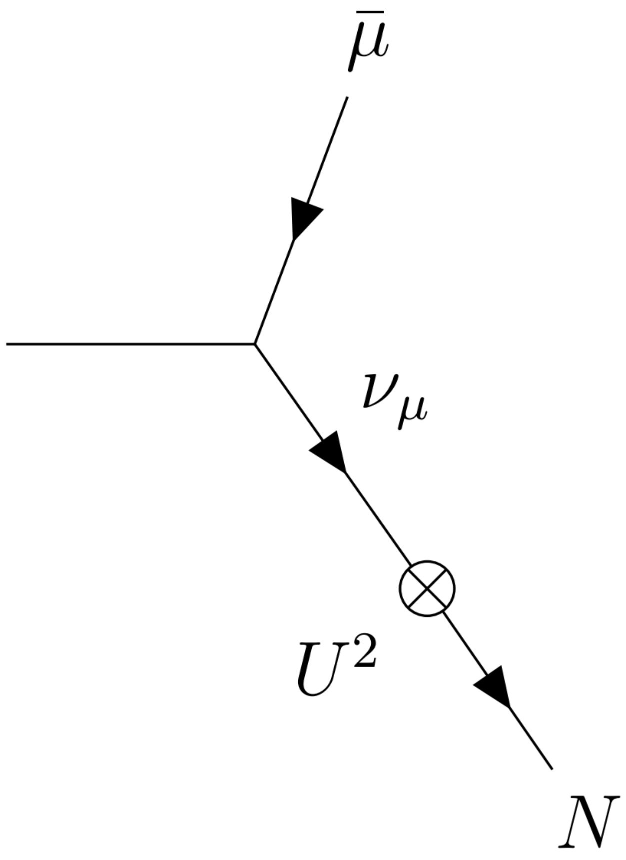


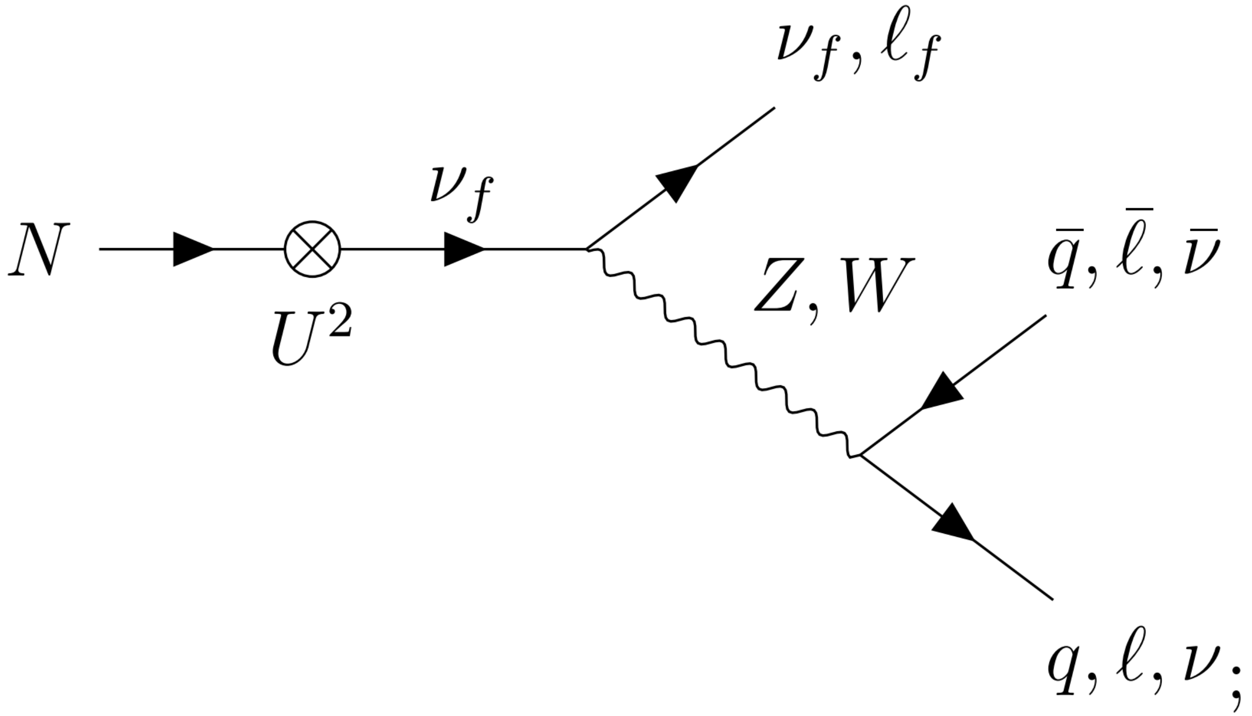
- Extend SM with three heavy neutral leptons (HNLs): $N1$, $N2$, $N3$
- $N2$ and $N3$ have masses in $\mathcal{O}(1)\ GeV$ range and generate masses of active neutrinos via seesaw mechanism



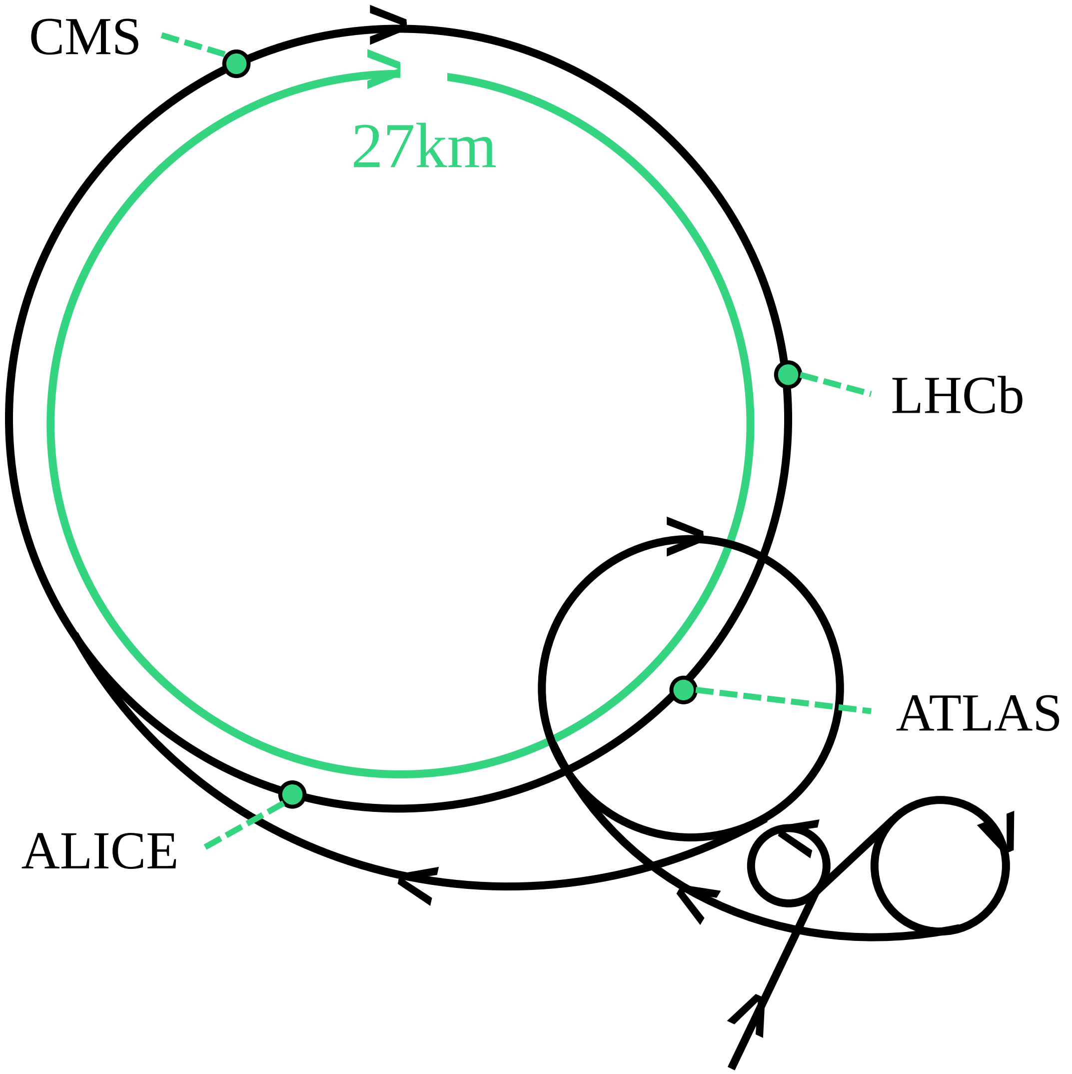
- Extend SM with three heavy neutral leptons (HNLs): $N1$, $N2$, $N3$
- $N2$ and $N3$ have masses in $\mathcal{O}(1)\ GeV$ range and generate masses of active neutrinos via seesaw mechanism
- $N1$ has in $\mathcal{O}(10)\ keV$ range and life-time greater than the age of the Universe. Viable dark matter candidate

These NHLs could be produced in heavy flavor decays and decay back to visible final states

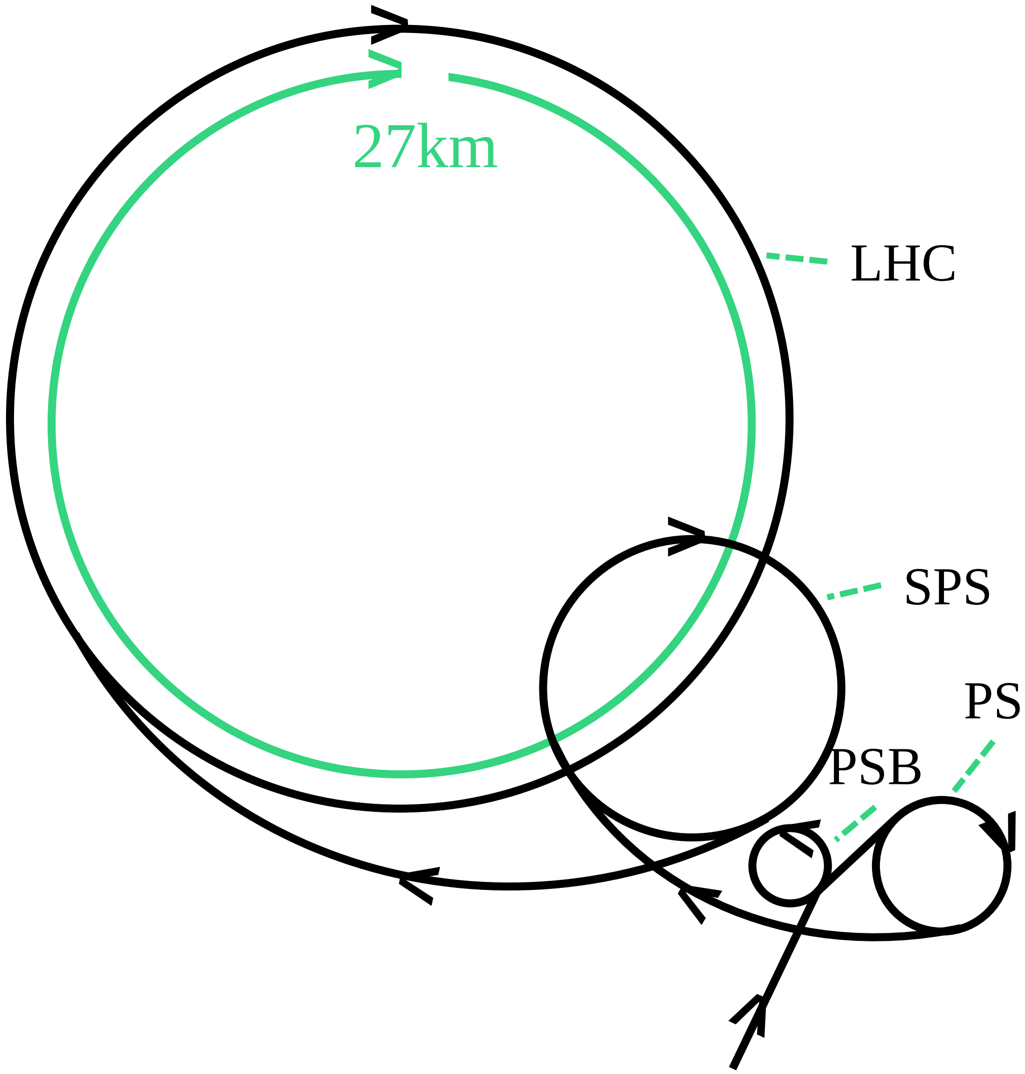


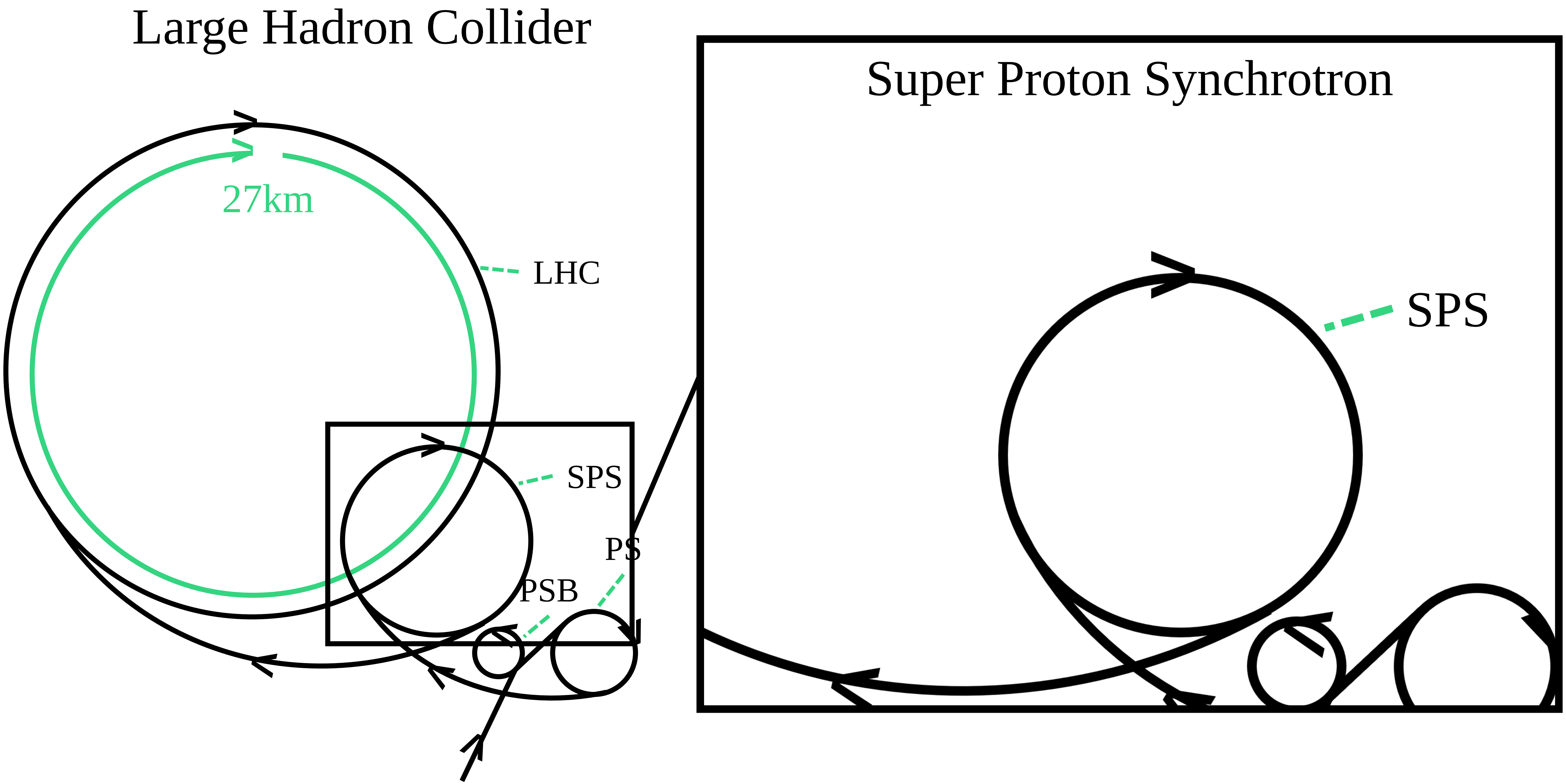


Large Hadron Collider



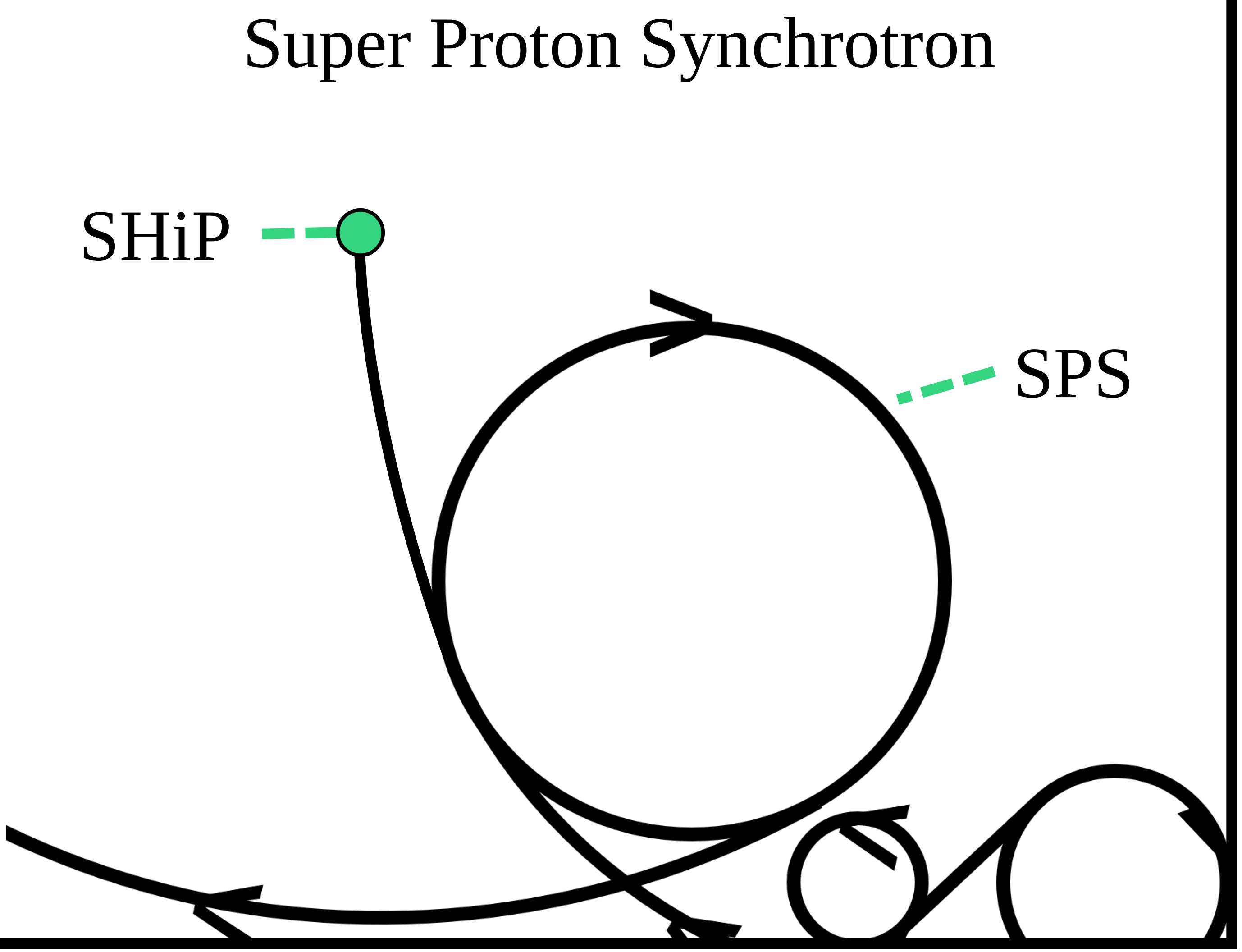
Large Hadron Collider

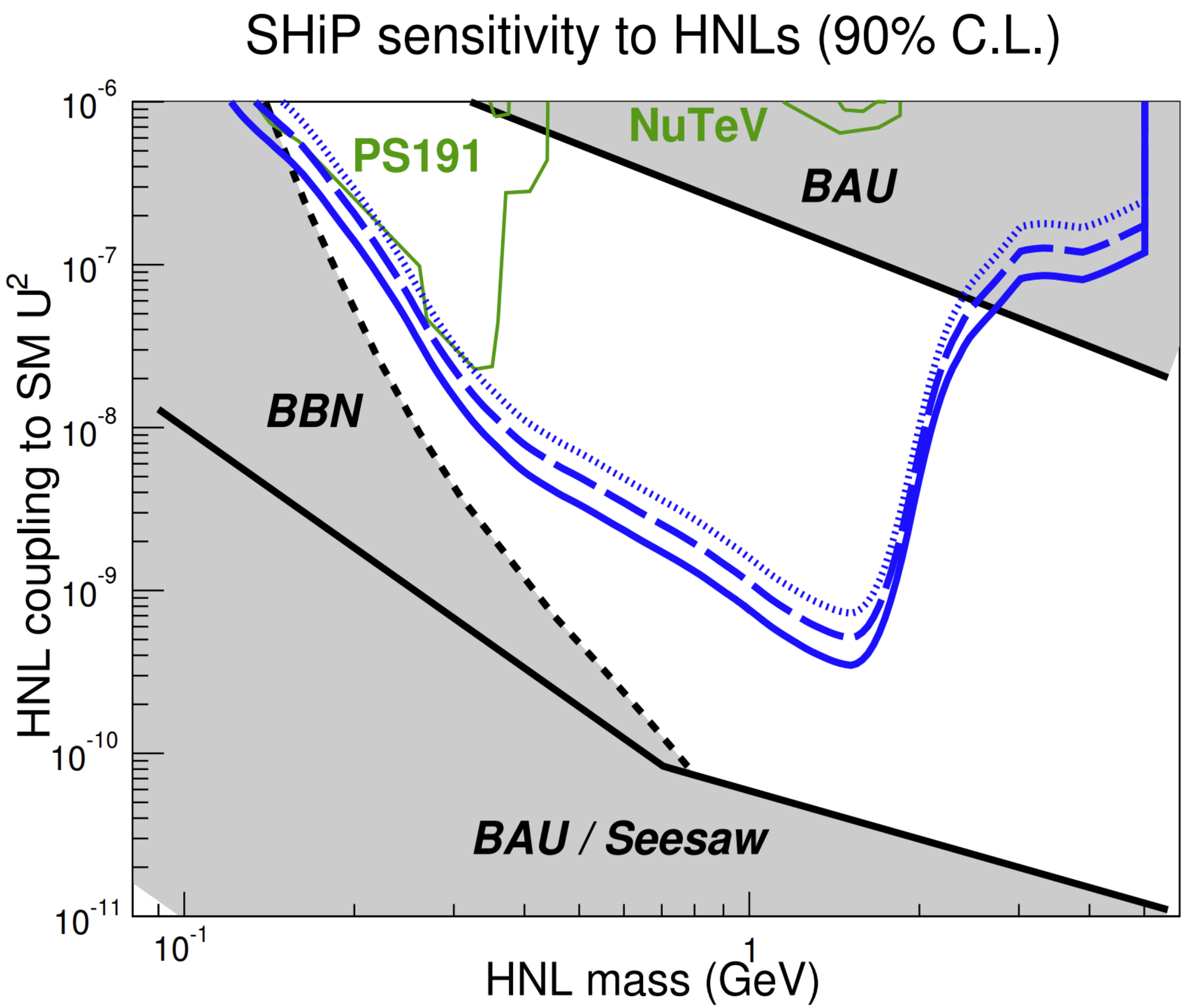



Large Hadron Collider
27km
LHC
SPS
PS
PSB
Super Proton Synchrotron
SPS

Large Hadron Collider

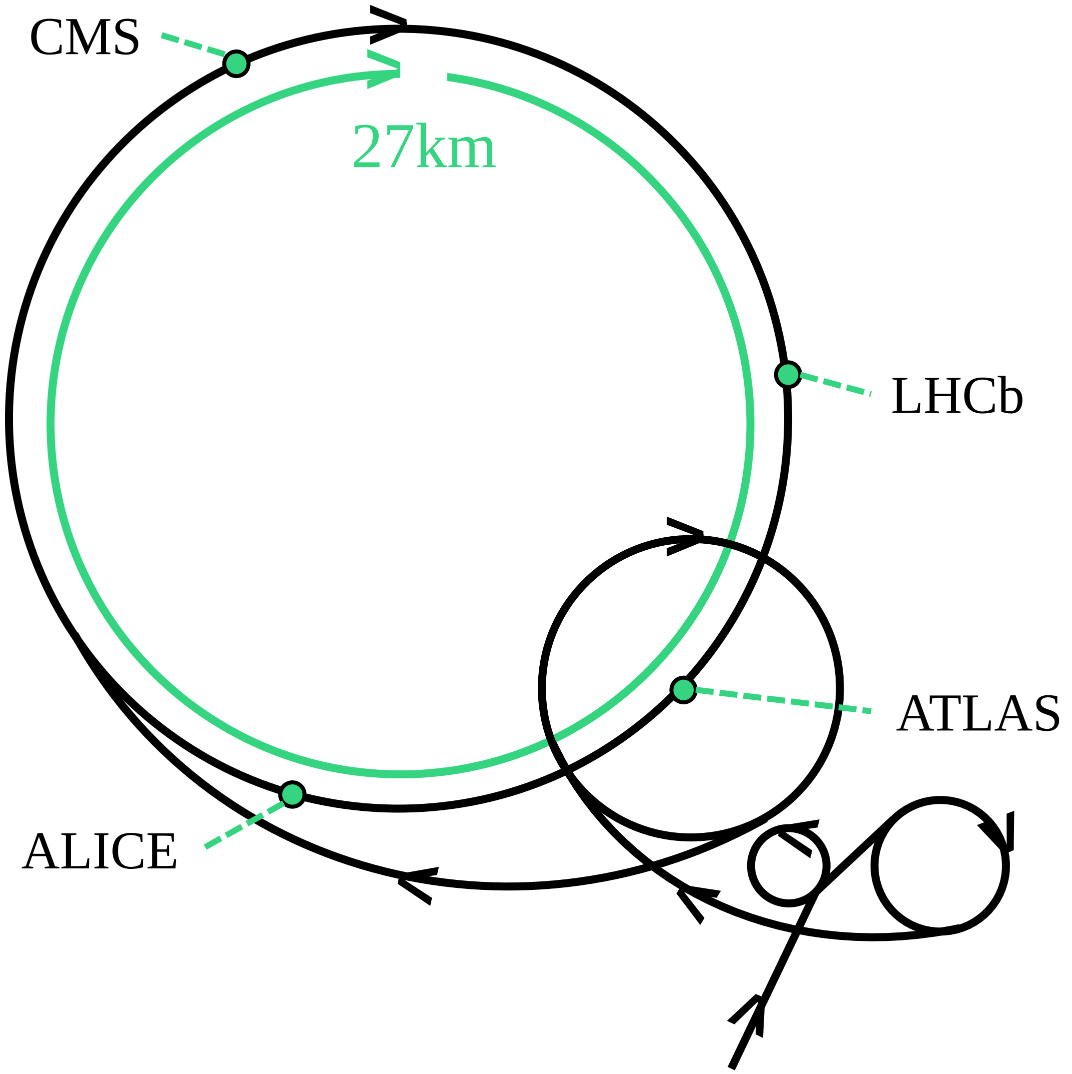
- SHiP searches for light LLPs with masses below $\mathcal{O}(10)\ GeV$
- Dedicated 400 GeV proton beam branched off SPS extraction line and delivered to SHiP
- Beam is aimed at target with magnetized hadron absorber and active muon shield, followed by long evacuated decay volume with detectors for particle tracking and ID



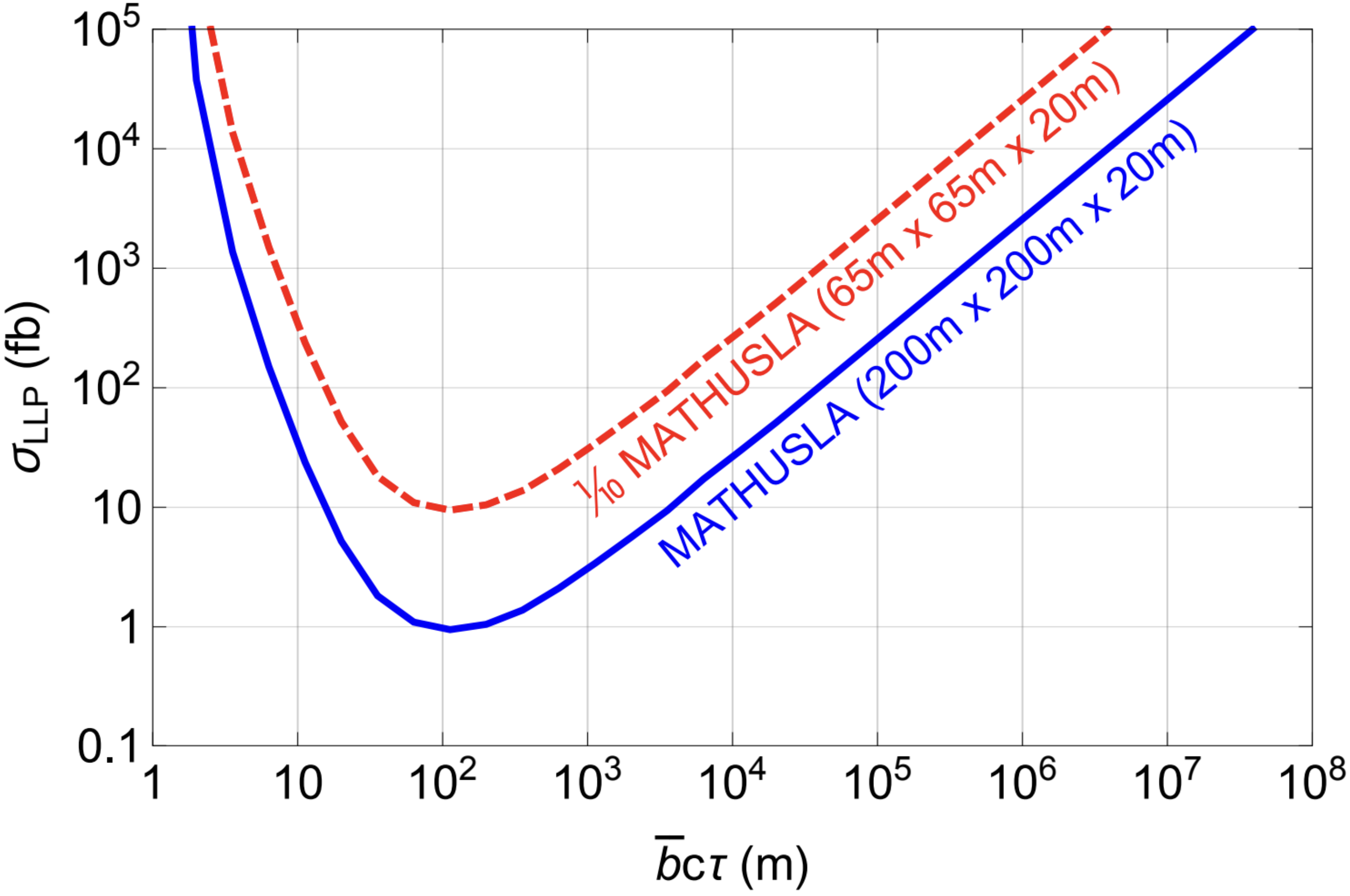


Although SHiP is a general-purpose LLP detector, it is well suited for a νMSM search due to its sensitivity to HNLs

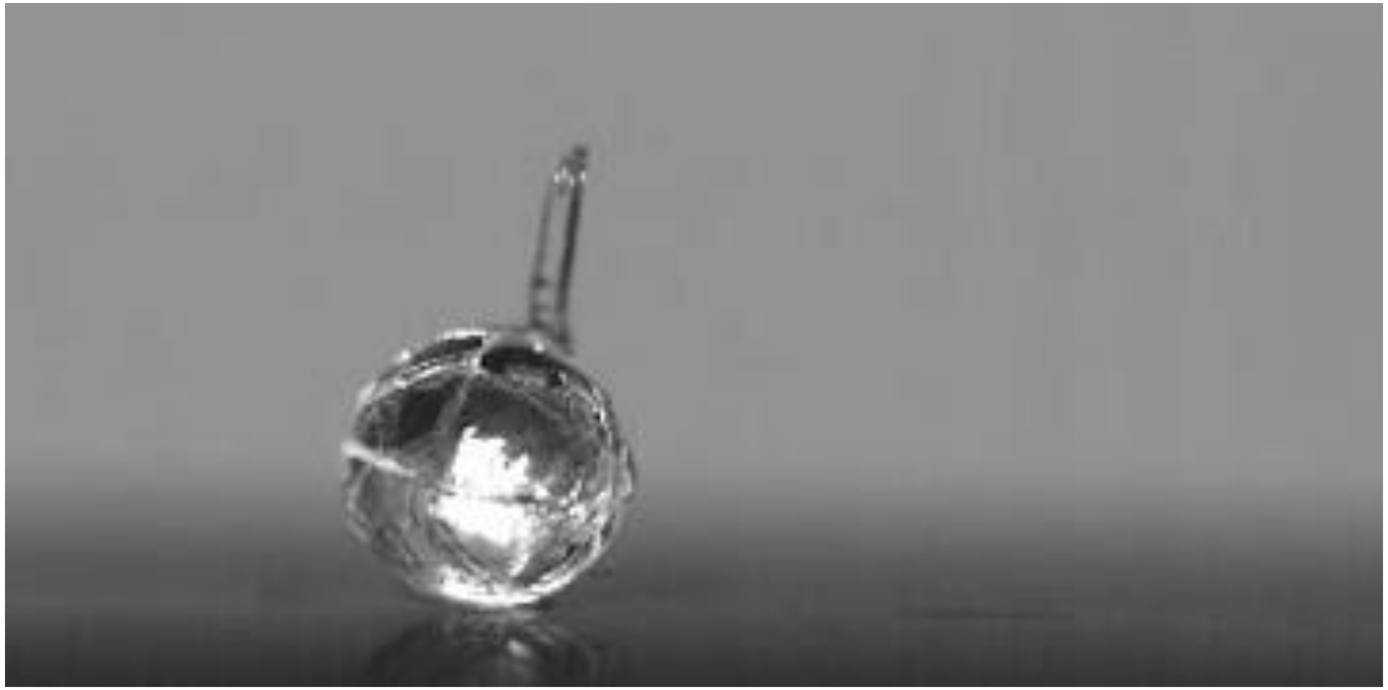
Large Hadron Collider



MATHUSLA “Model independent” limits

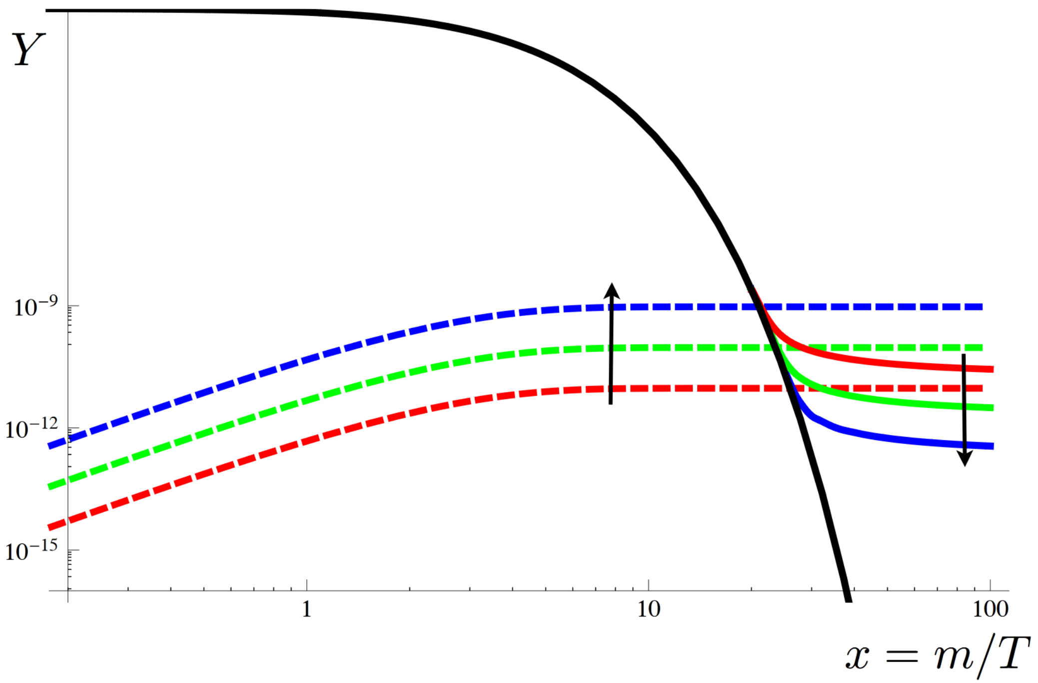


Dark Matter Freeze In!



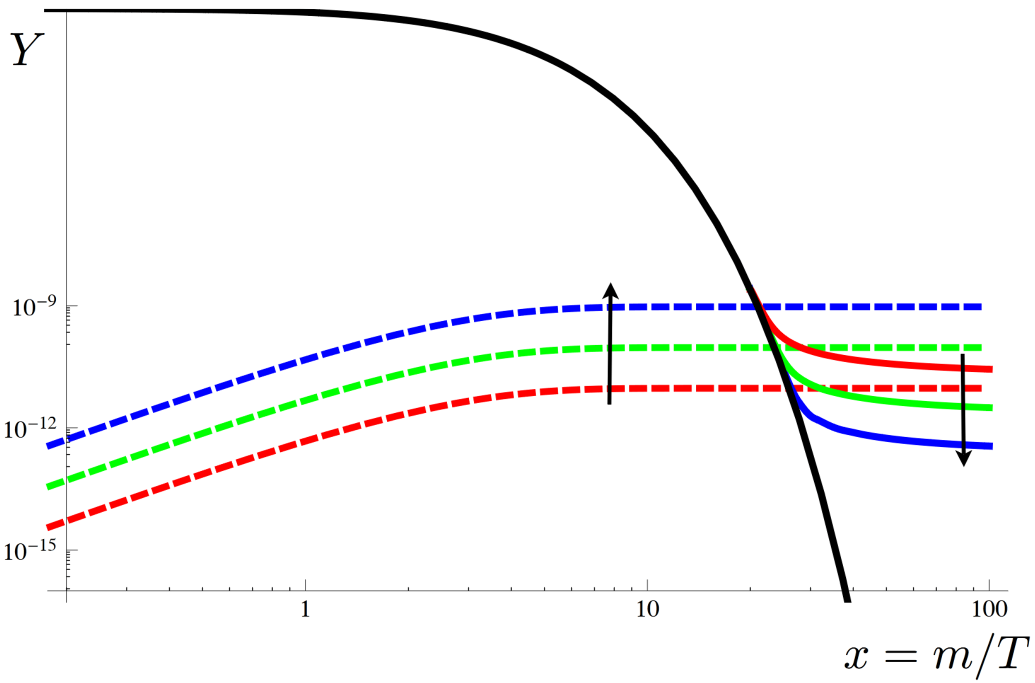
$$A \rightarrow \chi + SM$$

Dark Matter Freeze In!



$$A \to \chi + SM$$

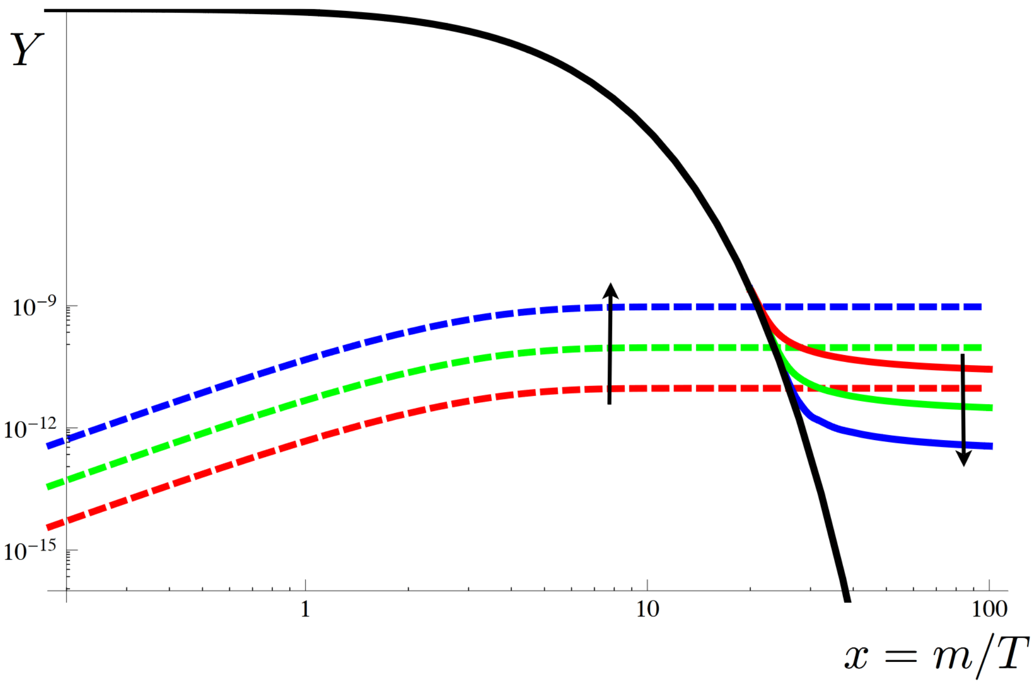
Dark Matter Freeze In!



$$A \to \chi + SM$$

LLP

Dark Matter Freeze In!

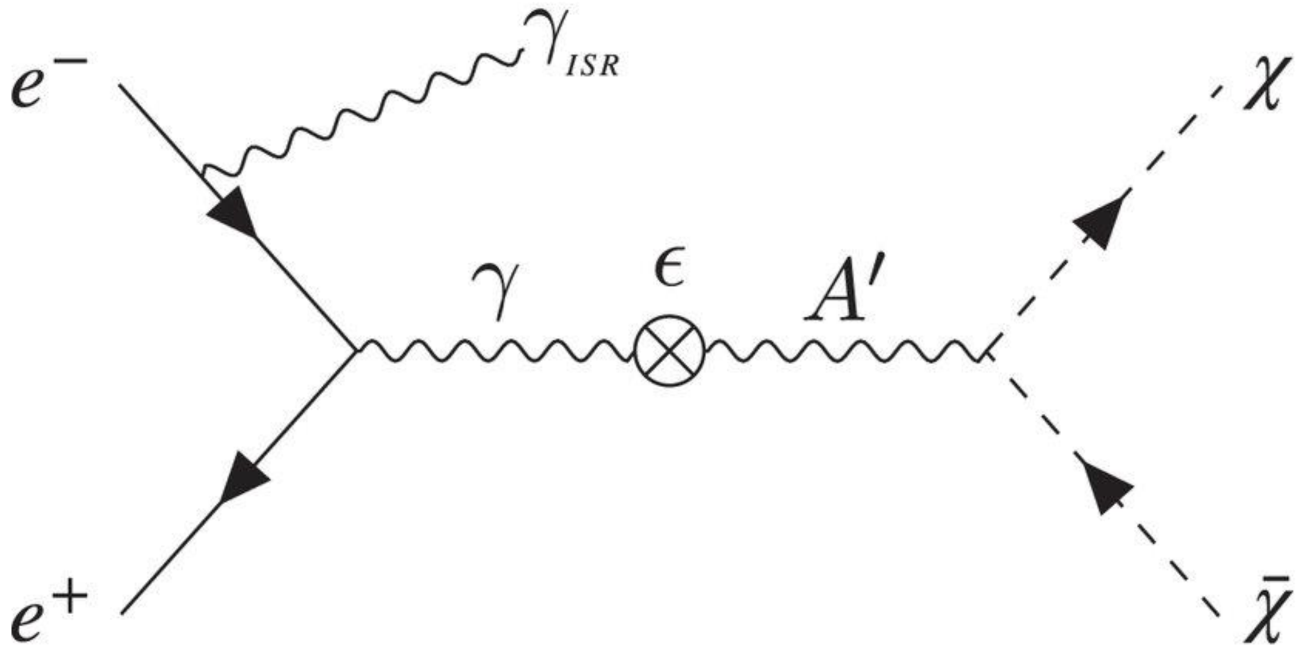


$$A \to \chi + SM$$

LLP

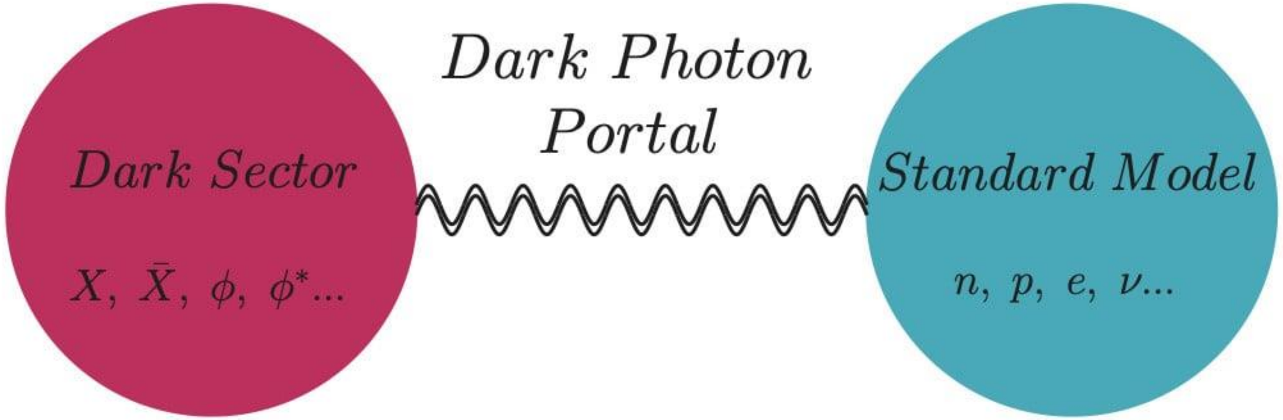
Detect This

- Dark photons are introduced to explain dark matter
- Just as the ordinary photon mediates the electromagnetic force, the dark photon is hypothesized to mediate a new force within the dark sector.
- The dark photon can have a small mass, depending on the specific theoretical model.
- One of the main ways dark photons could interact with ordinary matter is through kinetic mixing with the ordinary photon.



Feynman diagram for a dark photon produced by kinematic mixing in a radiative process and decaying invisibly.
Credit:Dark Sector first results at Belle II ,DOI:10.1088/1402-4896/abfef2

Dark Photon



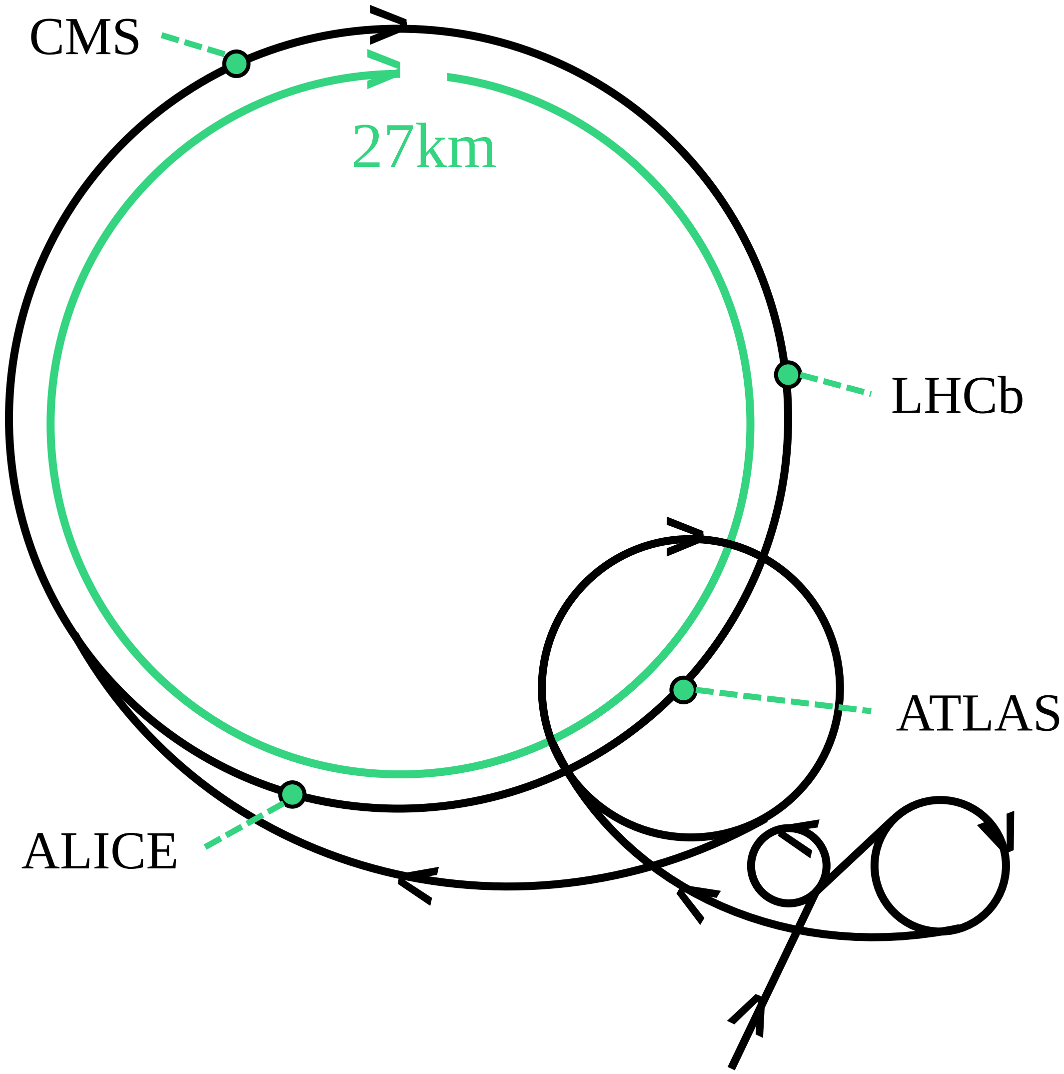
Credit: https://n3as.berkeley.edu/

- The kinetic mixing term in the Lagrangian can be written as:

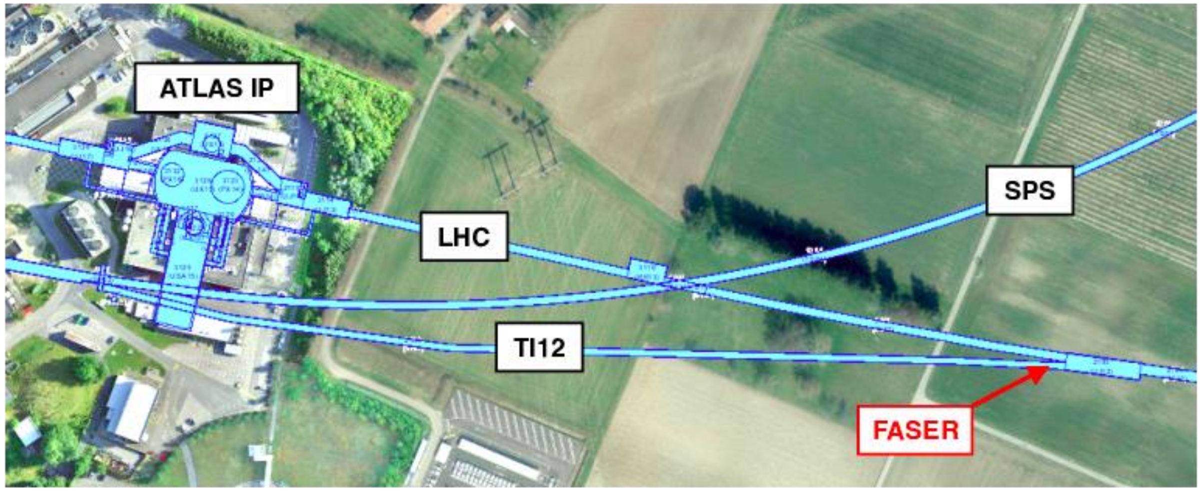
$$\mathcal{L} \supset -\frac{\epsilon}{2} F_{\mu\nu} F'^{\mu\nu}$$

- This means that dark photons can couple to the electromagnetic field with a small mixing parameter, ϵ, allowing them to interact weakly with charged particles.
- Experiments are conducted to directly search for dark photons through their potential decays or interactions with ordinary matter. These include collider experiments, fixed-target experiments, and beam dump experiments.

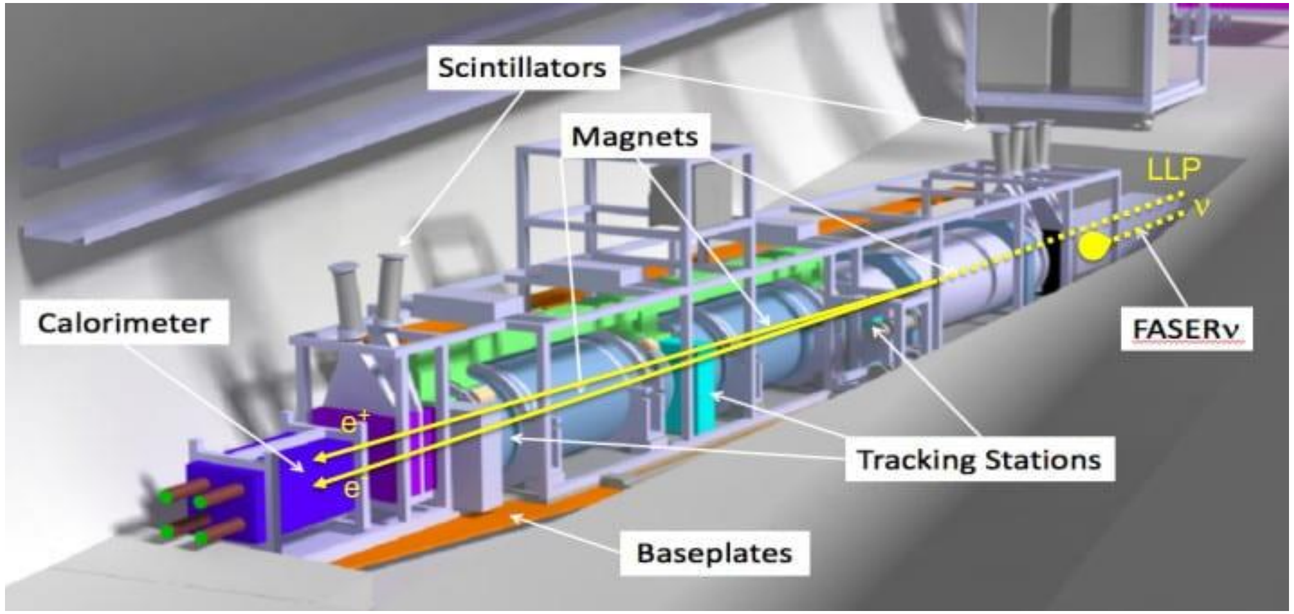
Large Hadron Collider



- FASER is one of eight particle physics experiments at the Large Hadron Collider (LHC) at CERN.
- It is designed to both search for new light and weakly coupled elementary particles, and to study the interactions of high-energy neutrinos.
- The FASER experiment was approved in 2019 and took its first data in March 2021.
- FASER is now taking data in in LHC's Run 3 from 2021.

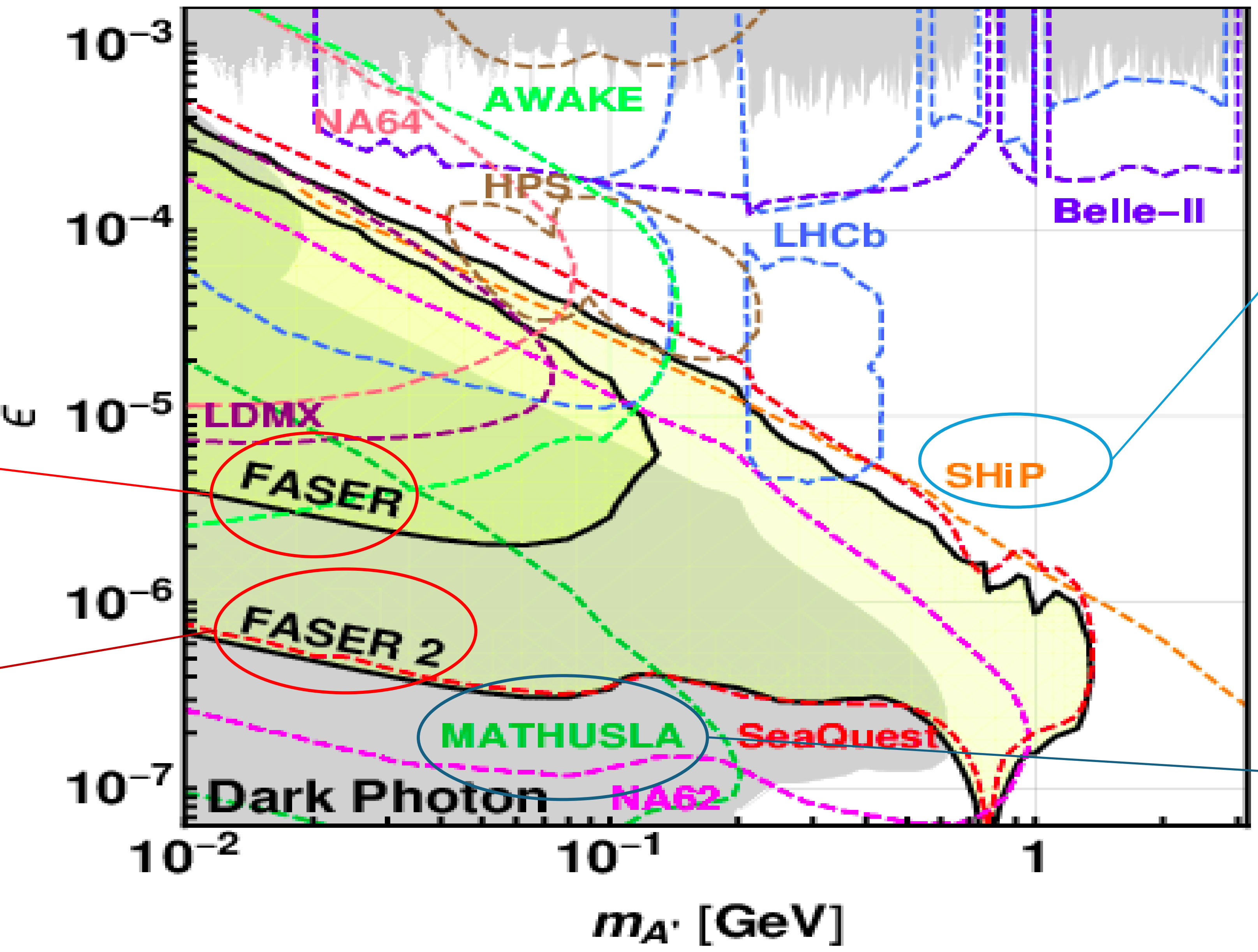


Map showing the location of FASER in the TI12 tunnel. FASER's location is 480 m away from the ATLAS interaction point



Running as extension of ATLAS beam

Future upgrade

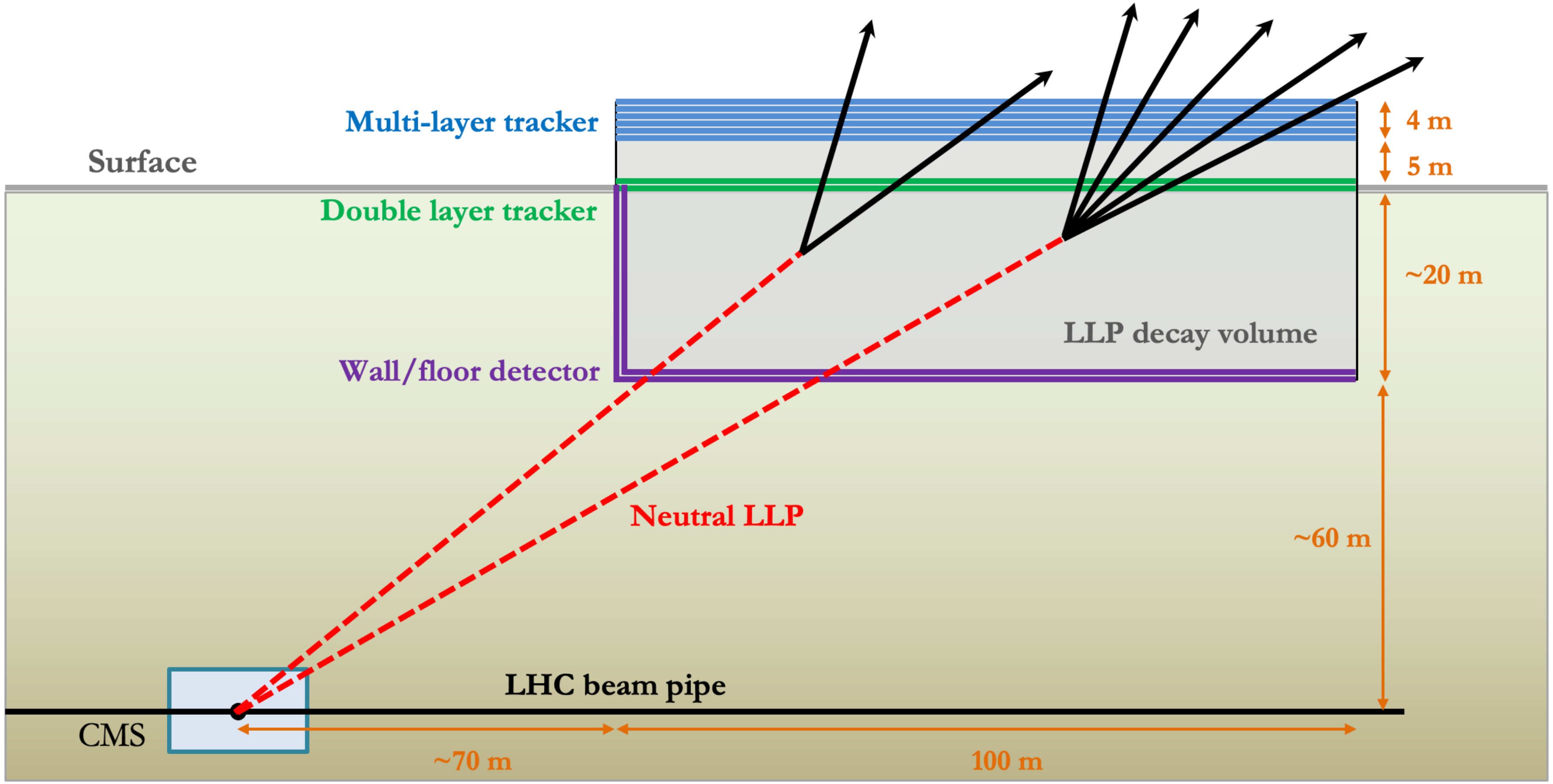


Beam dump extension of SPC

FASER projected sensitivity to dark photons, compared to other experiments, such as MATHUSLA.(Credit: FASER Collaboration, https://faser.web.cern.ch/)

Proposed above CMS

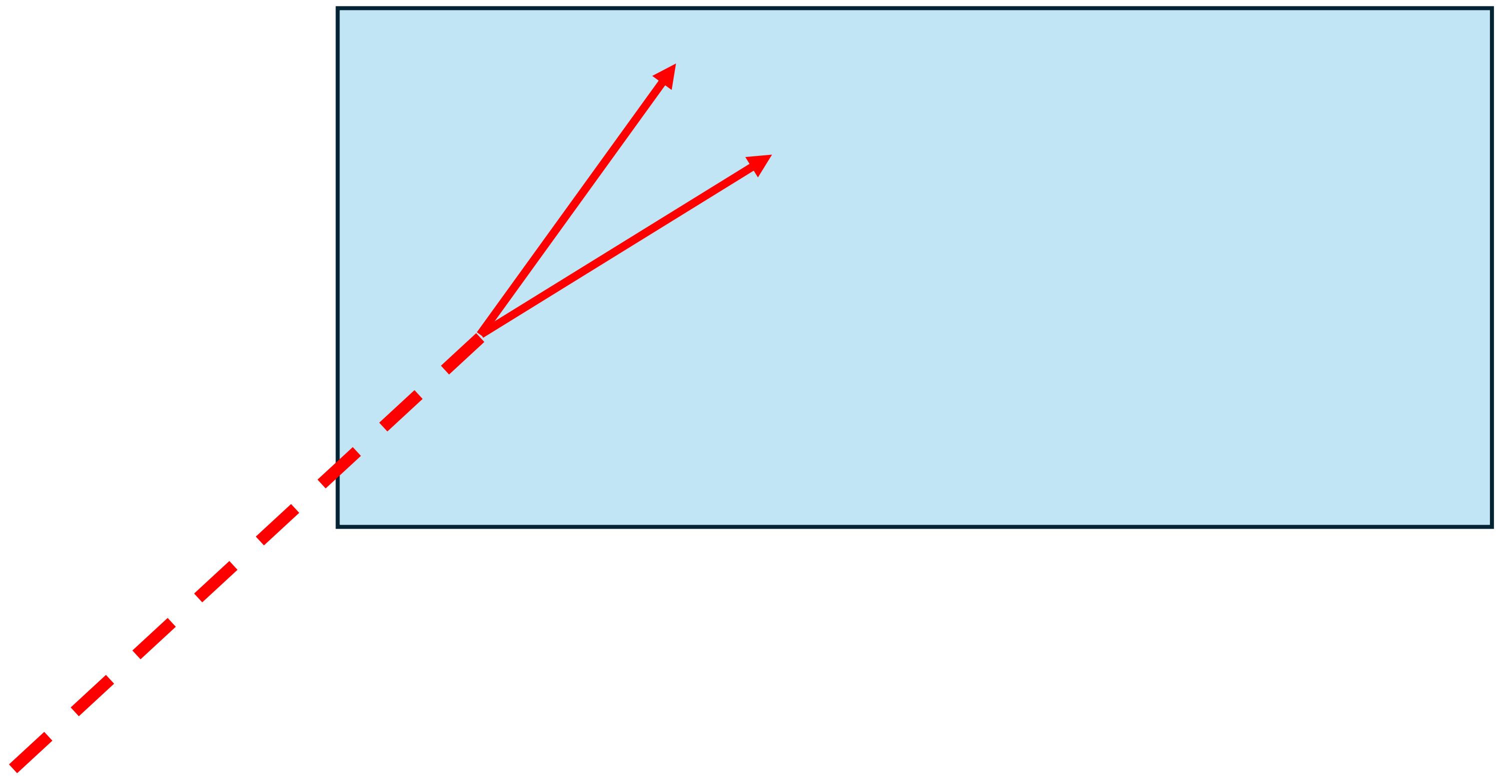
1. Detector is a **particle spectrometer** (separate by mass, momentum, ID)
2. Particles **created within** (or nearby) the **spectrometer**

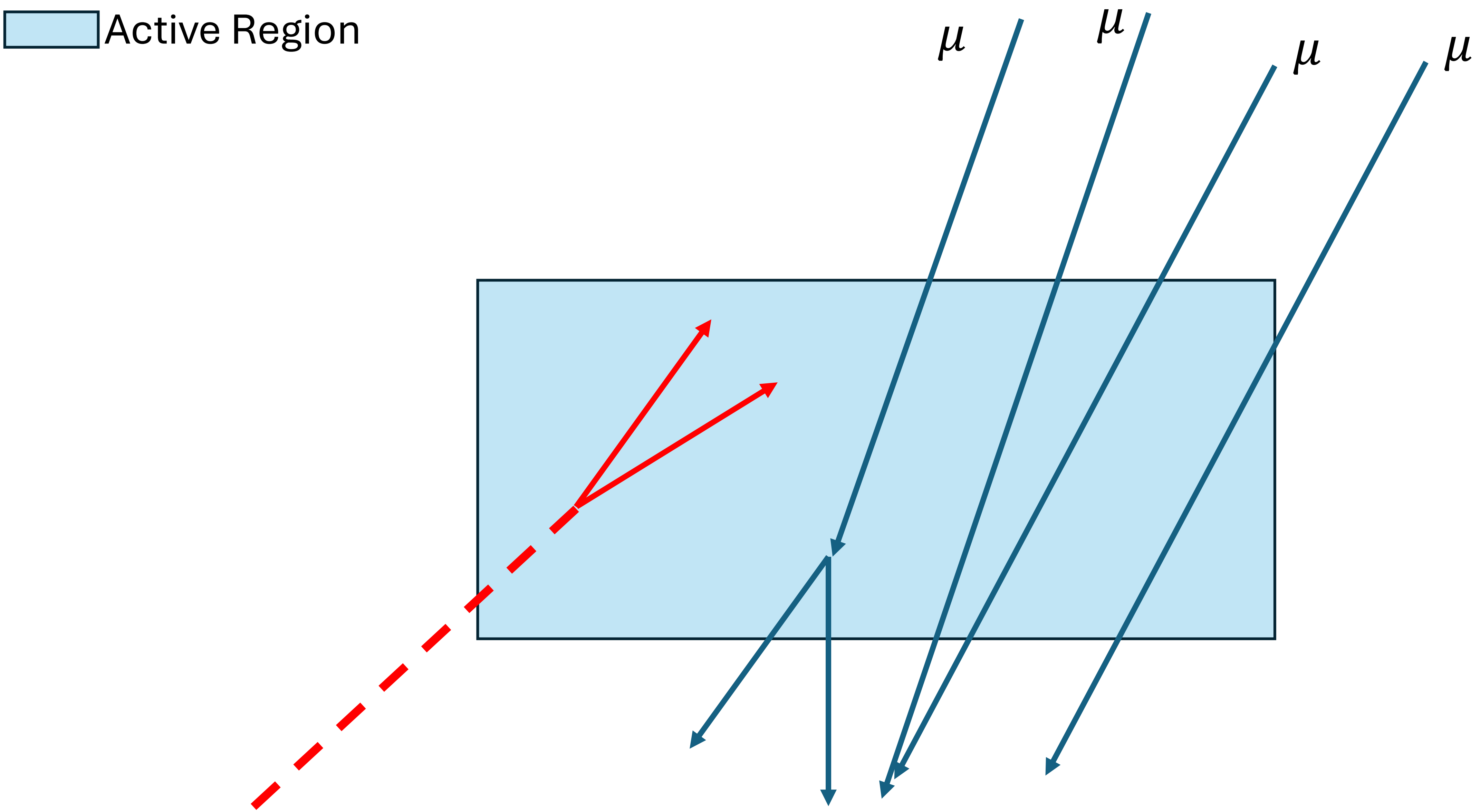


MATHUSLA, https://mathusla-experiment.web.cern.ch/

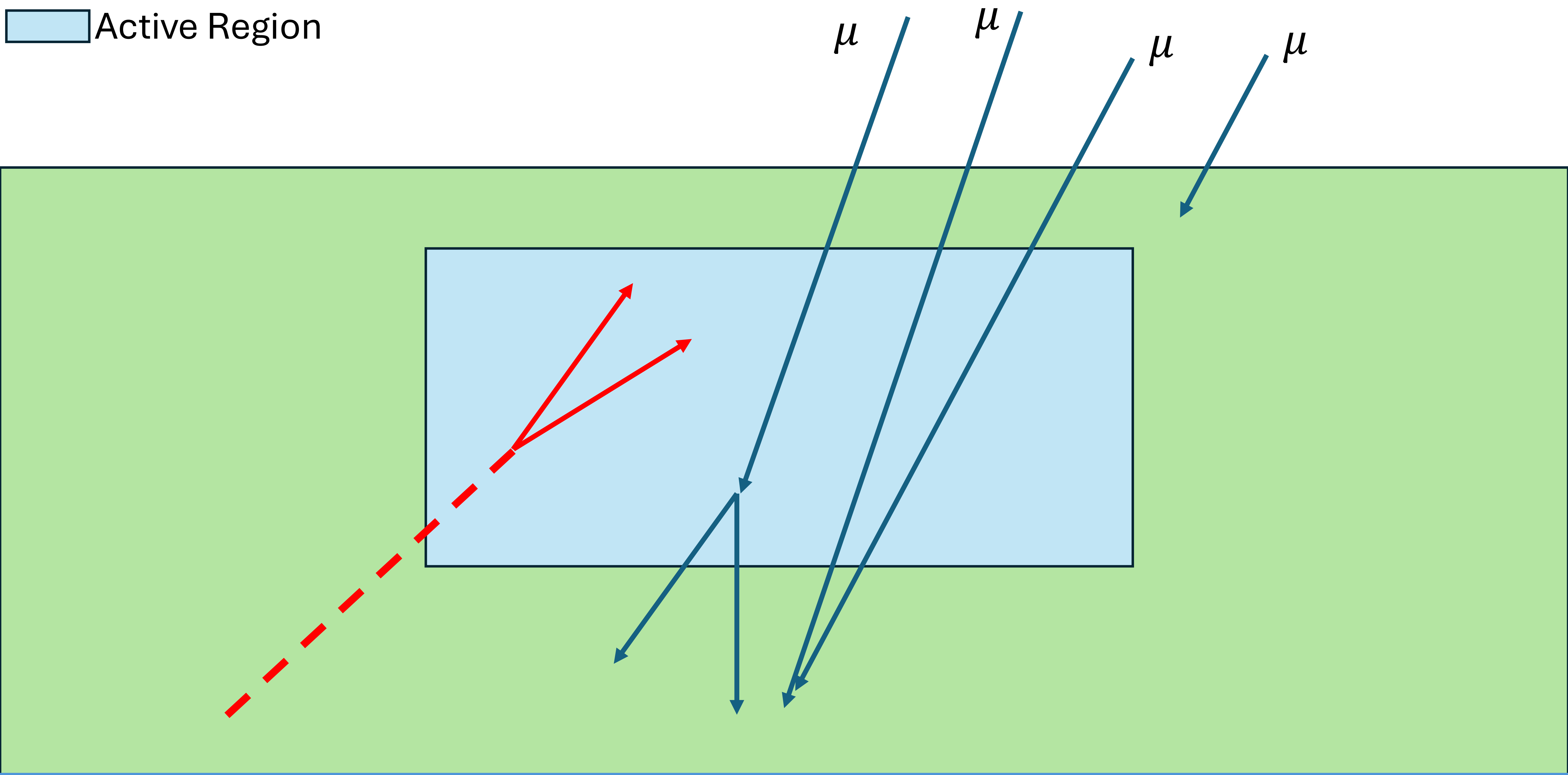
Background

Active Region



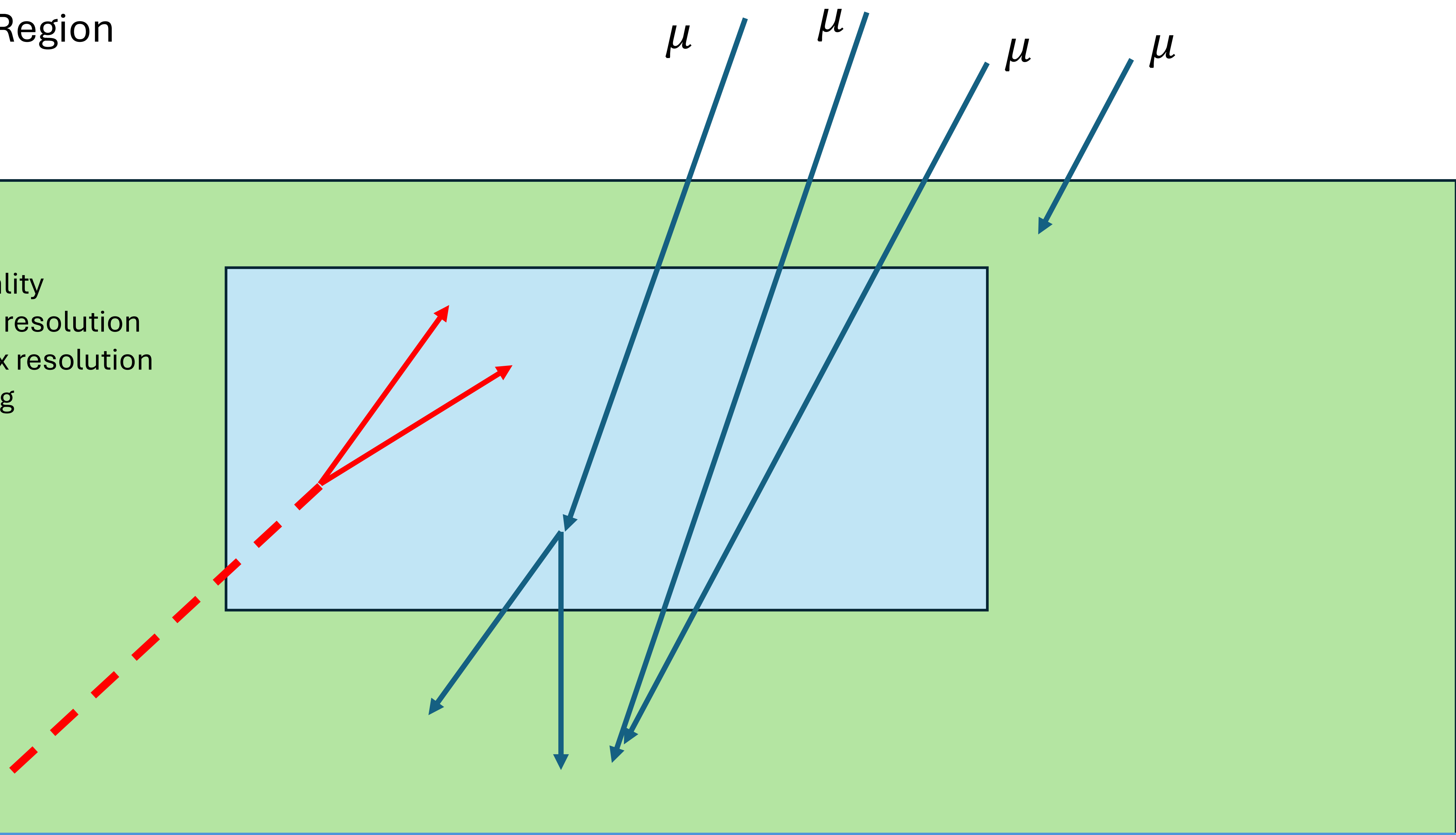

Active Region
μ
μ
μ
μ

Background



Background

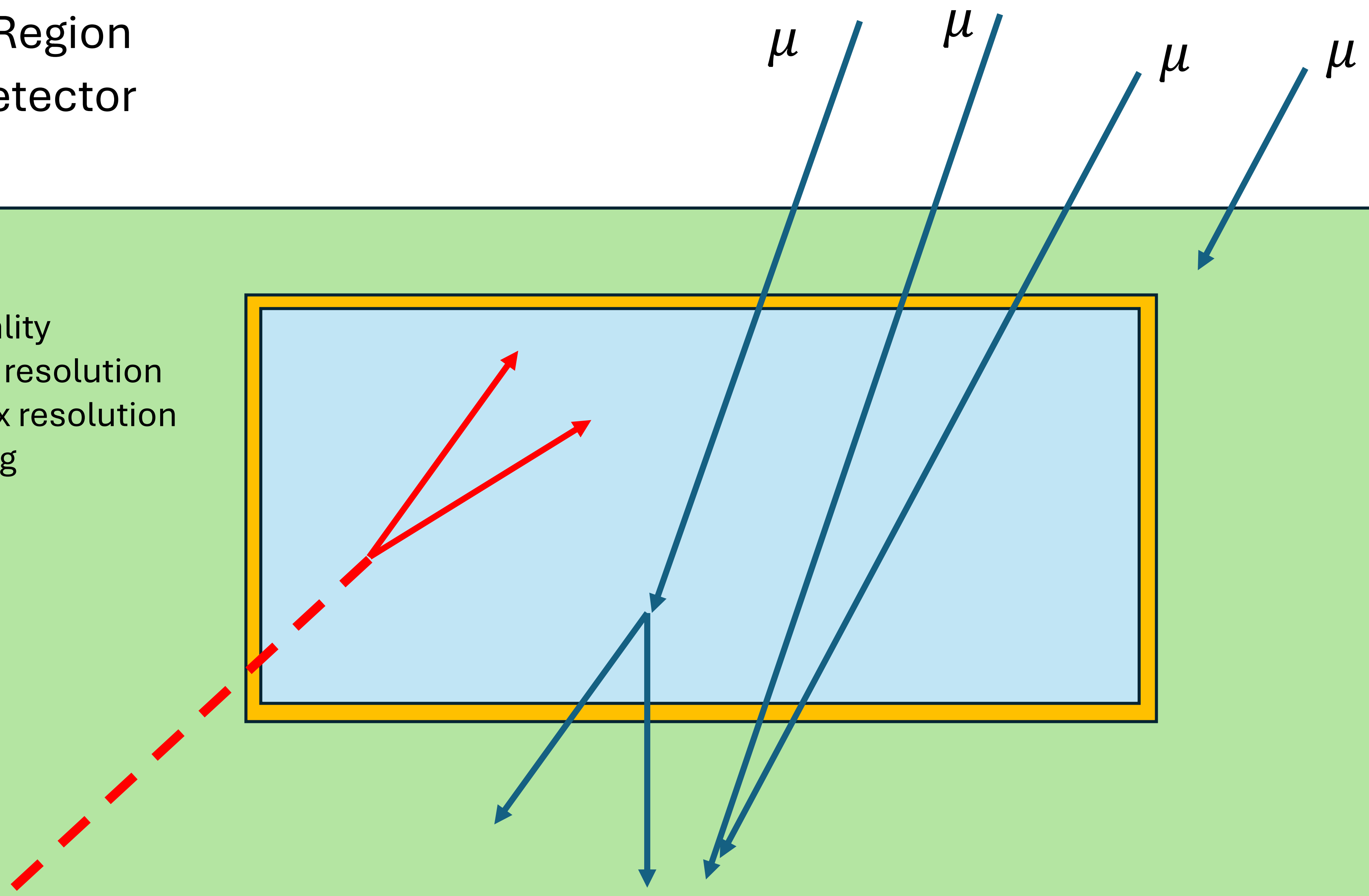
Active Region



Solution:
- Directionality
  - Track resolution
  - Vertex resolution
  - Timing

Active Region
Veto Detector

Solution:
- Directionality
    - Track resolution
    - Vertex resolution
    - Timing
- Veto



Active Region
Veto Detector

Solution:
- Directionality
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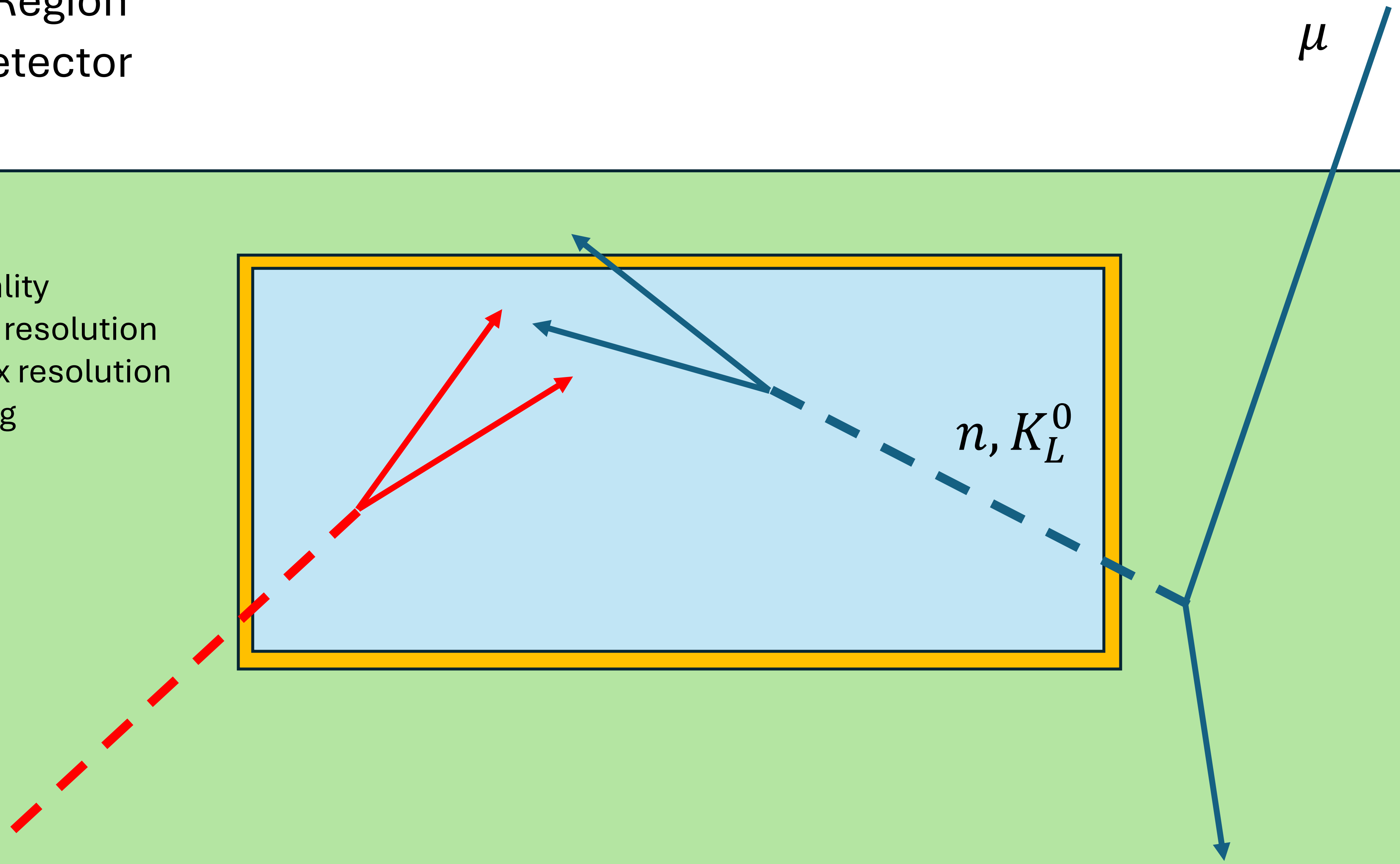
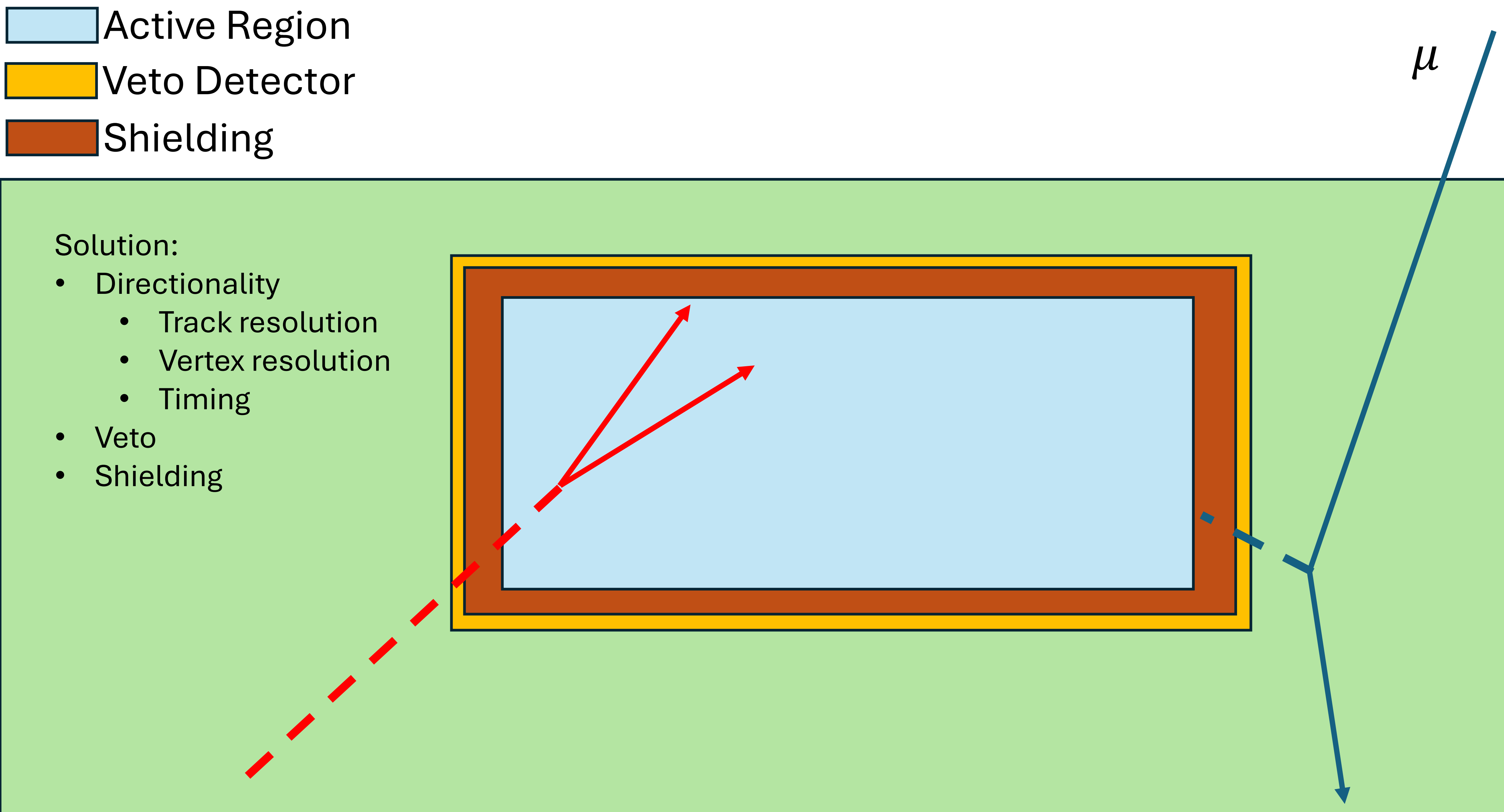
  - Timing
- Veto

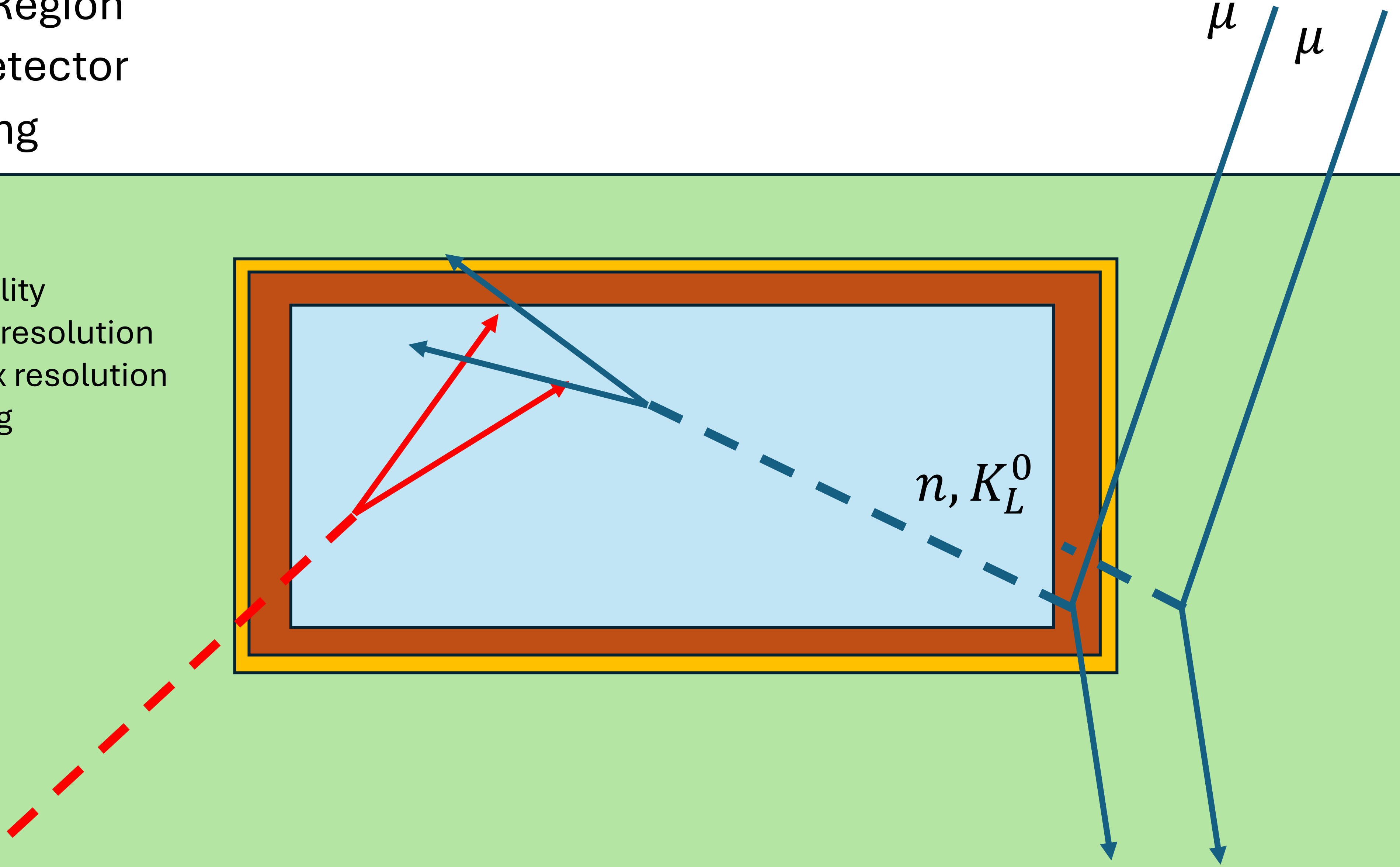




Solution:
- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding

Active Region
Veto Detector
Shielding

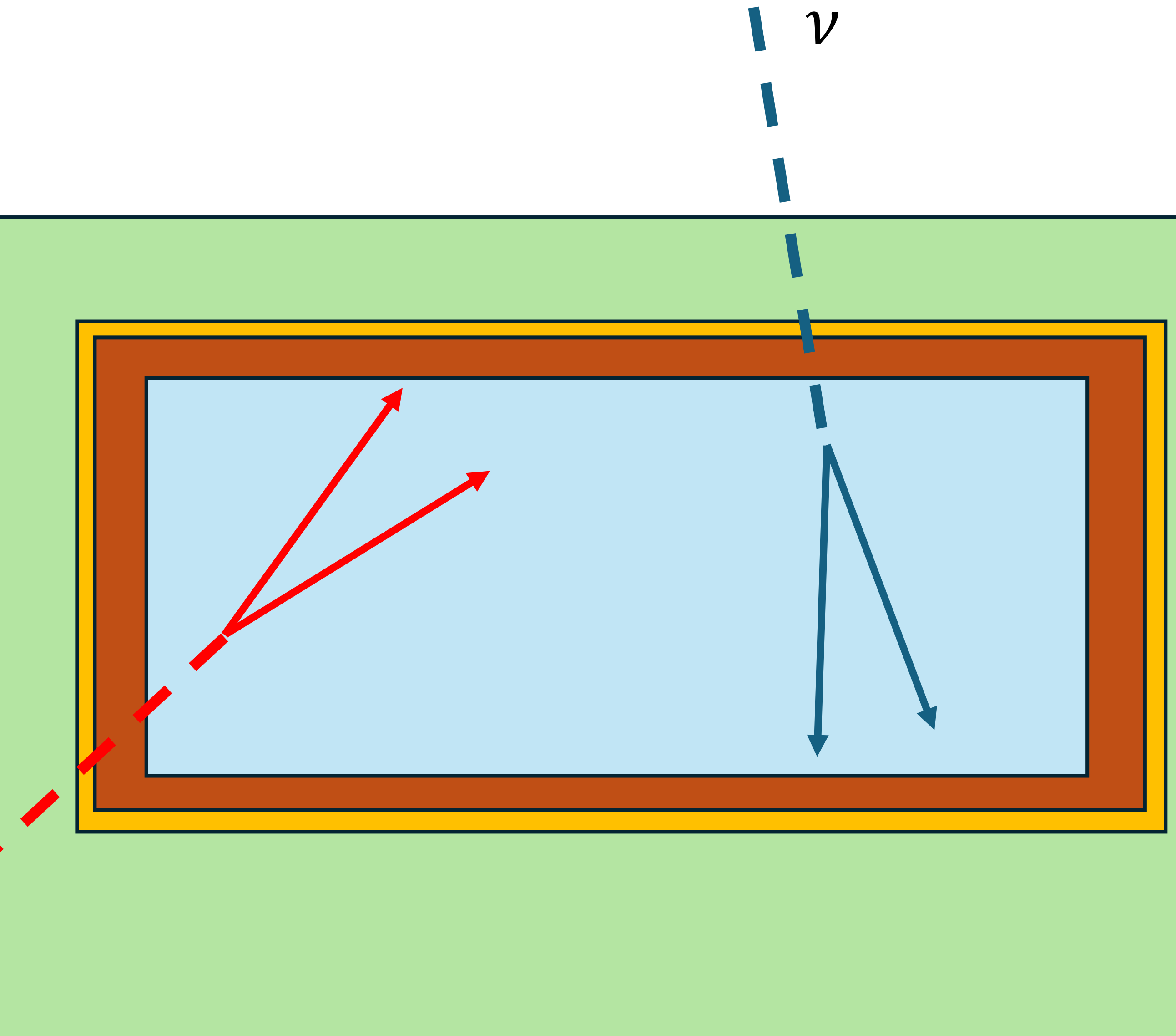
Solution:
- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding



Active Region
Veto Detector
Shielding

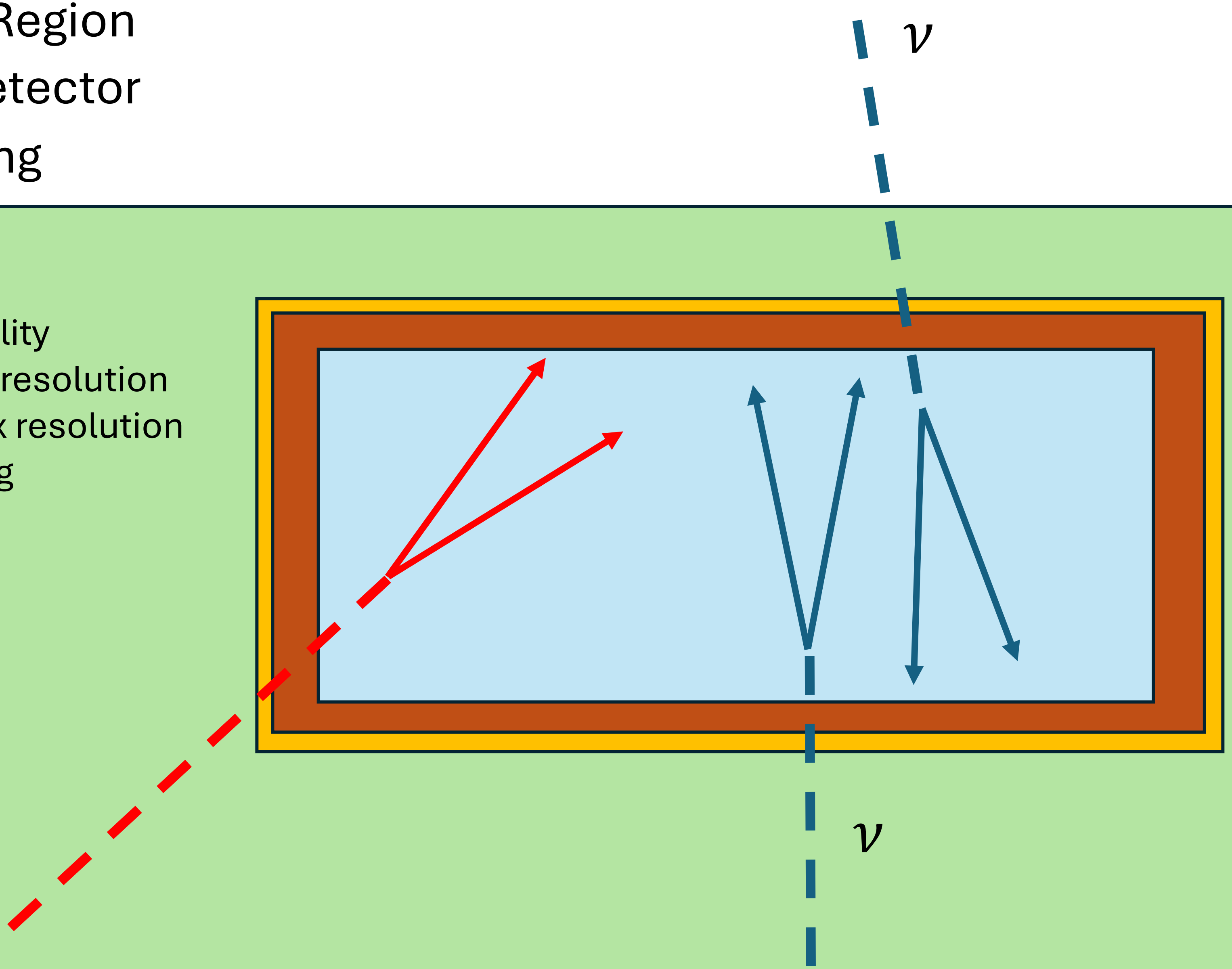
Solution:

- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding



Active Region
Veto Detector
Shielding

Solution:
- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding



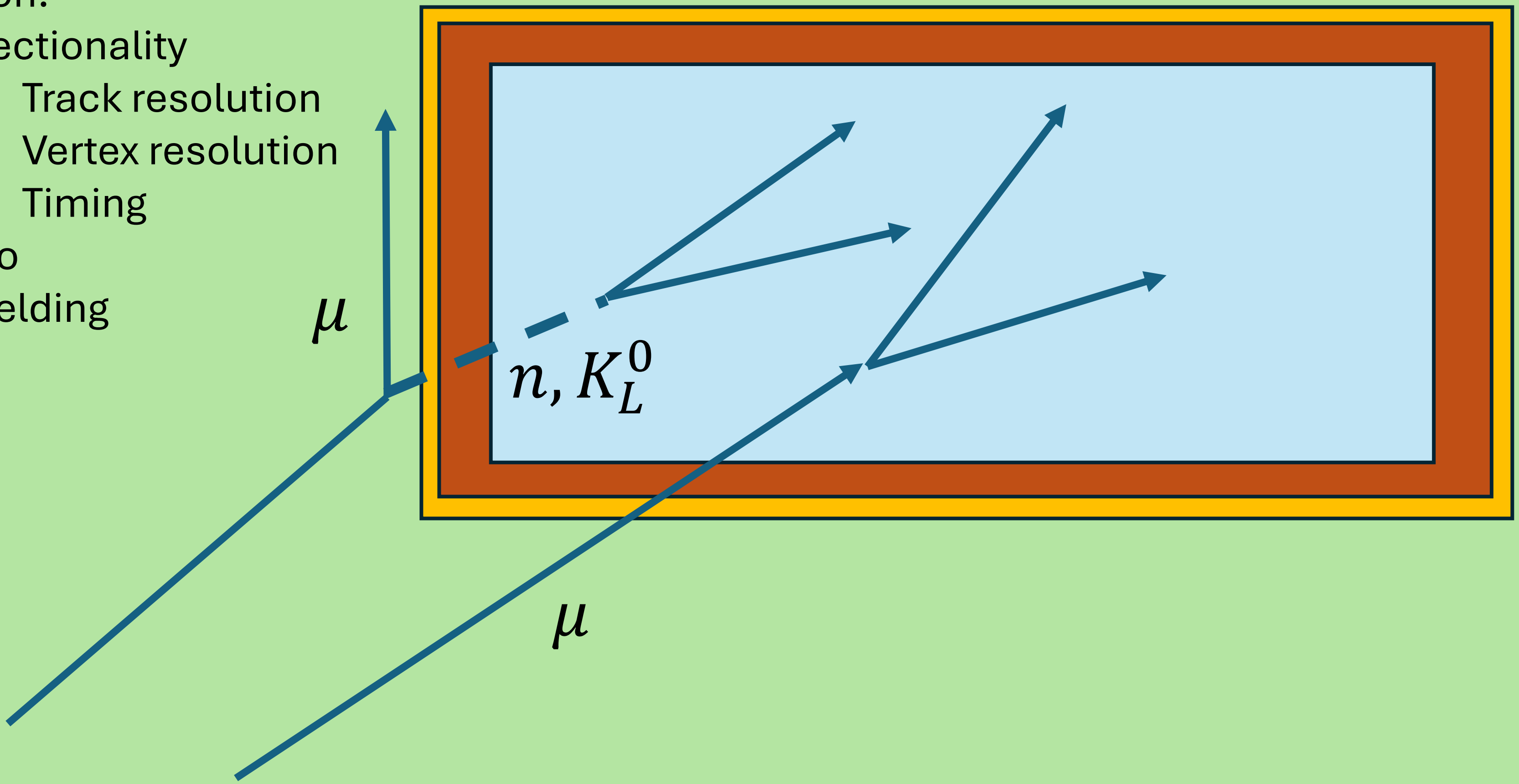
Active Region

Veto Detector

Shielding

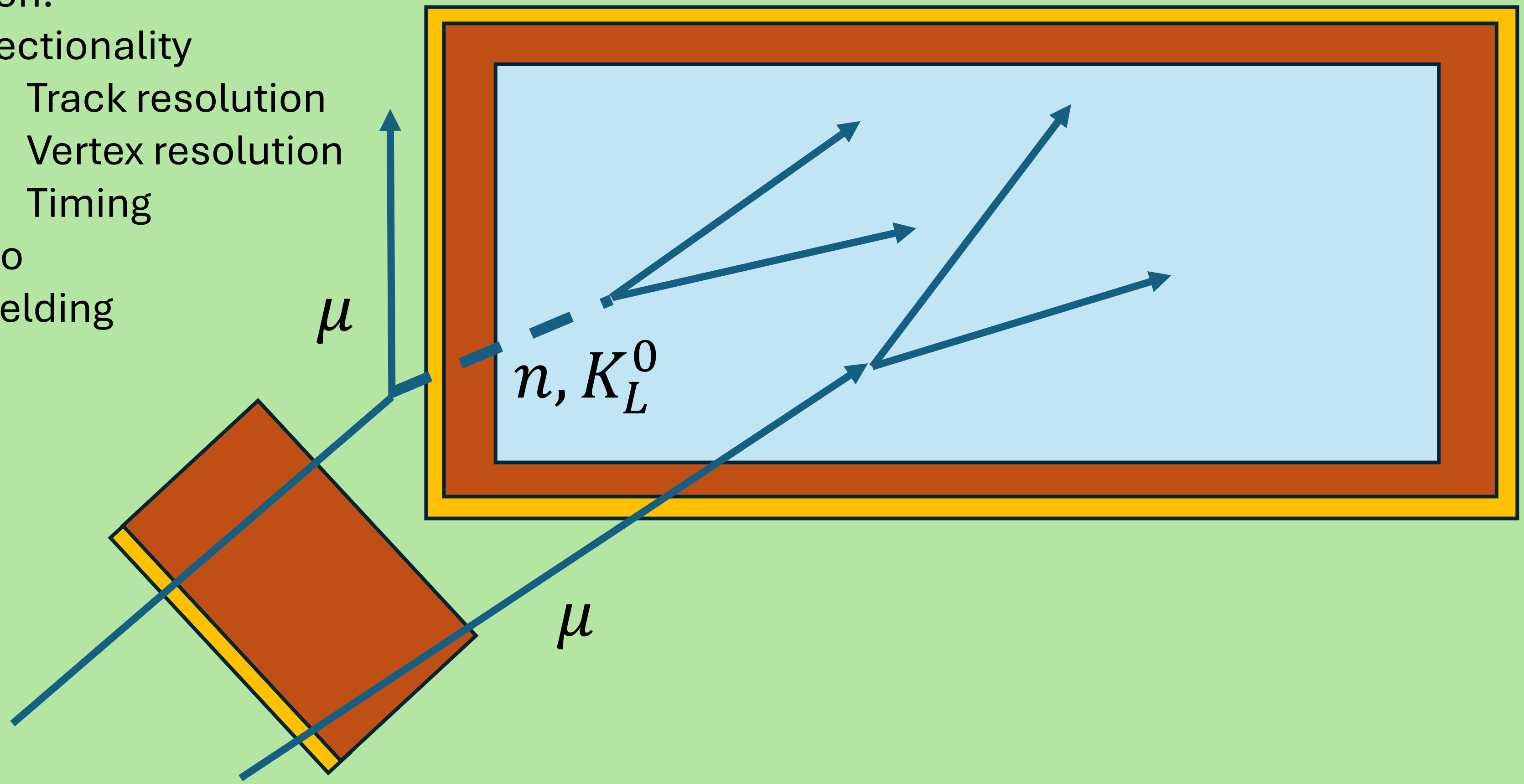
Solution:

- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding



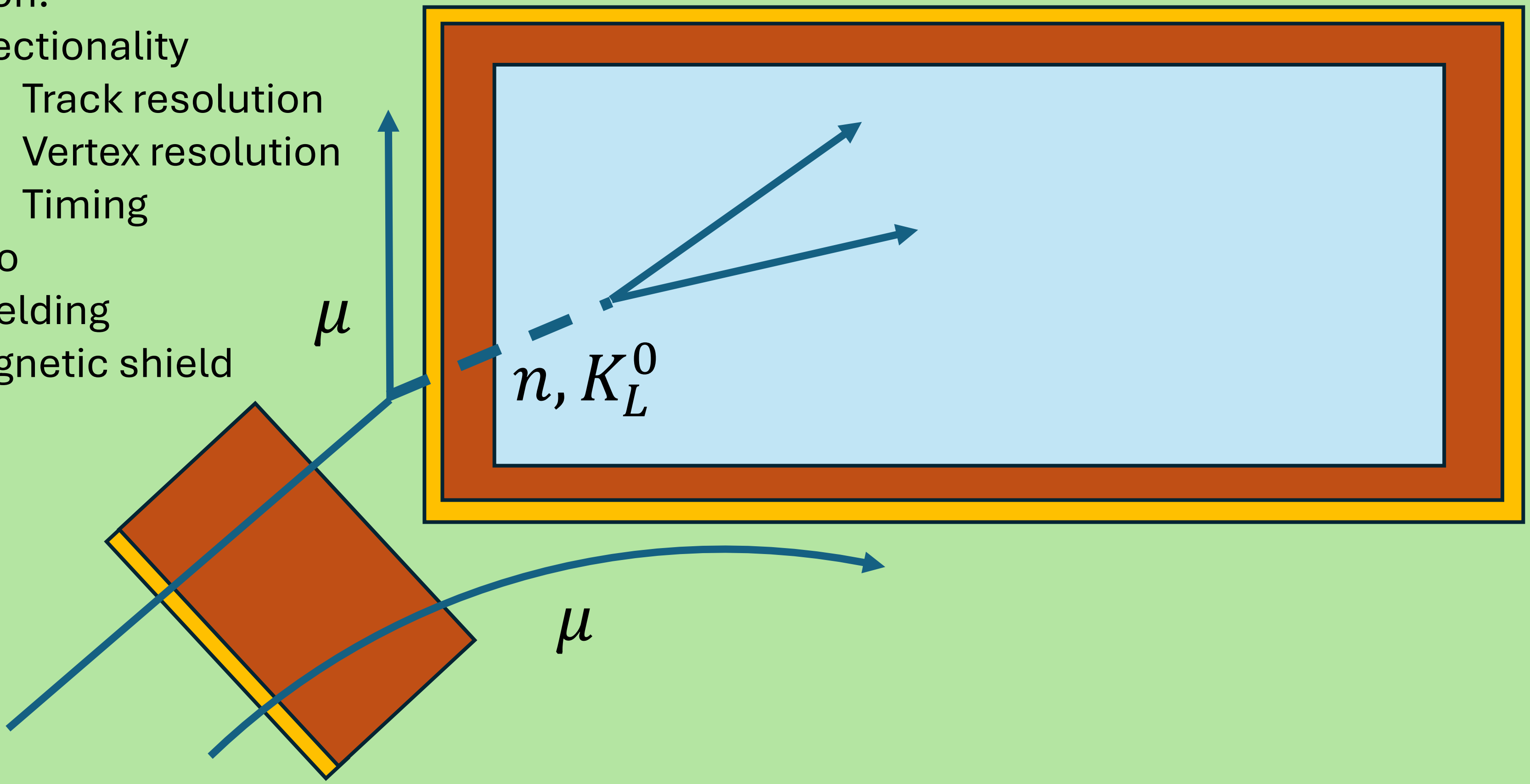
Active Region
Veto Detector
Shielding

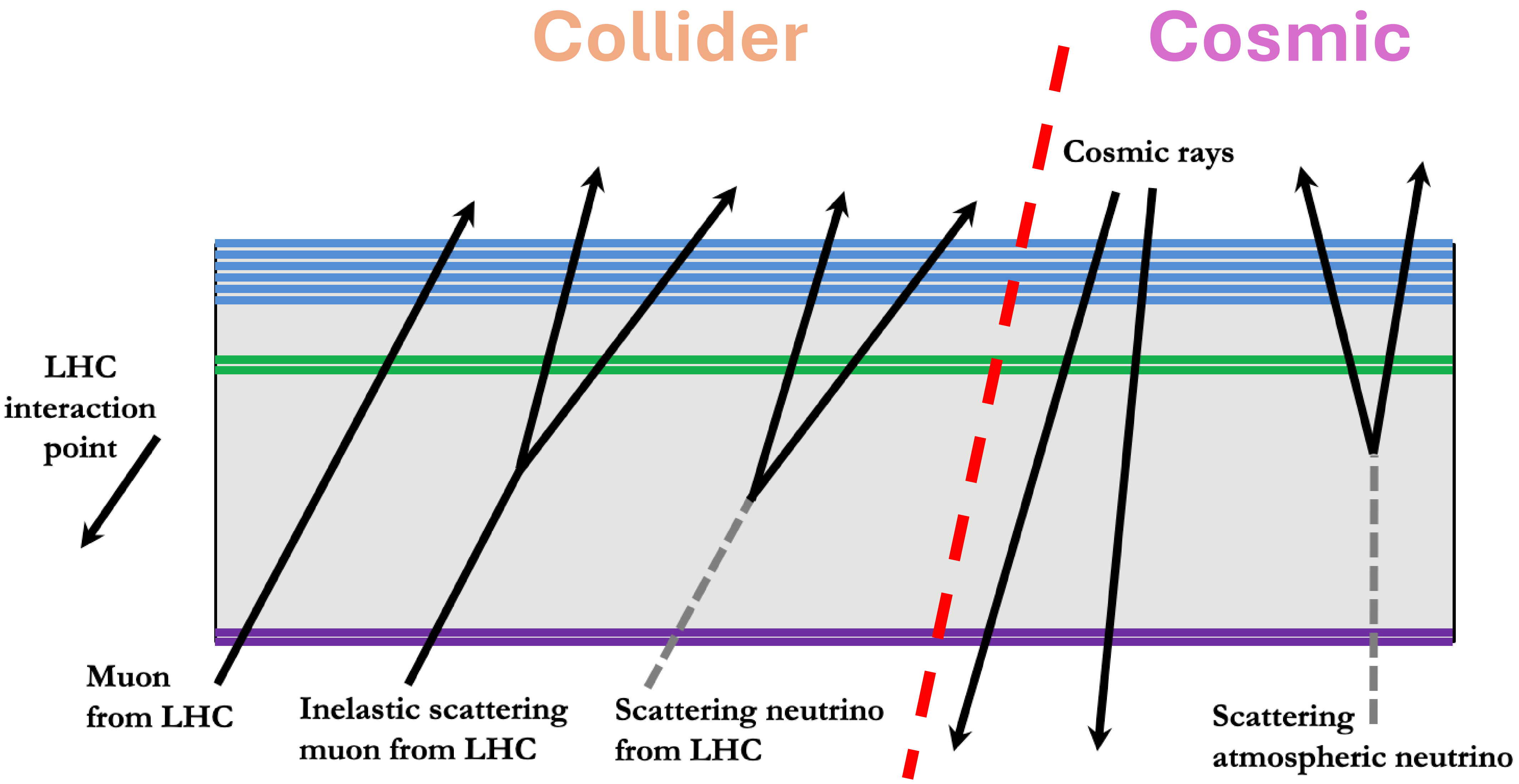
Solution:
- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding

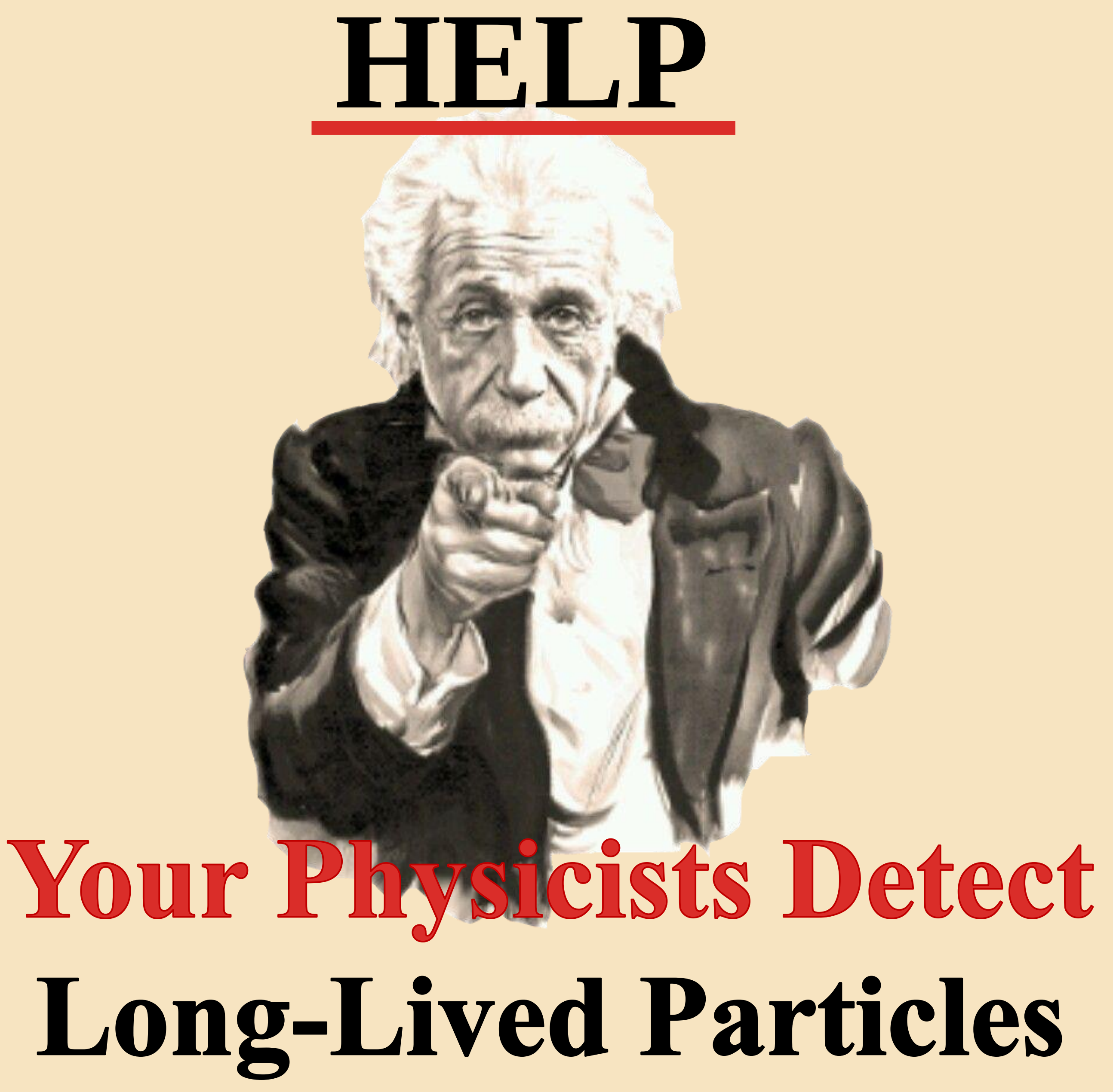


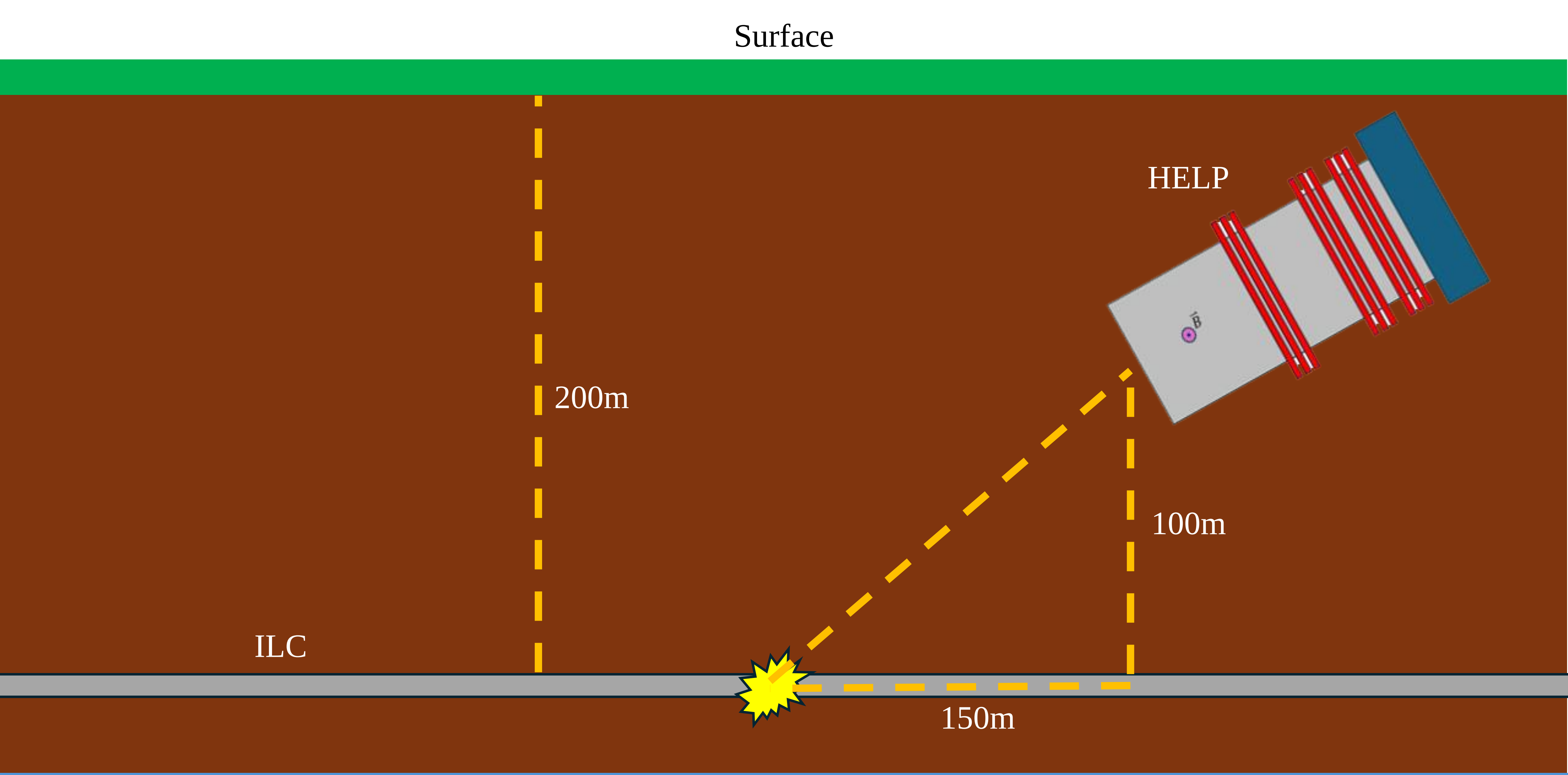
Solution:

- Directionality
  - Track resolution
  - Vertex resolution
  - Timing
- Veto
- Shielding
- Magnetic shield

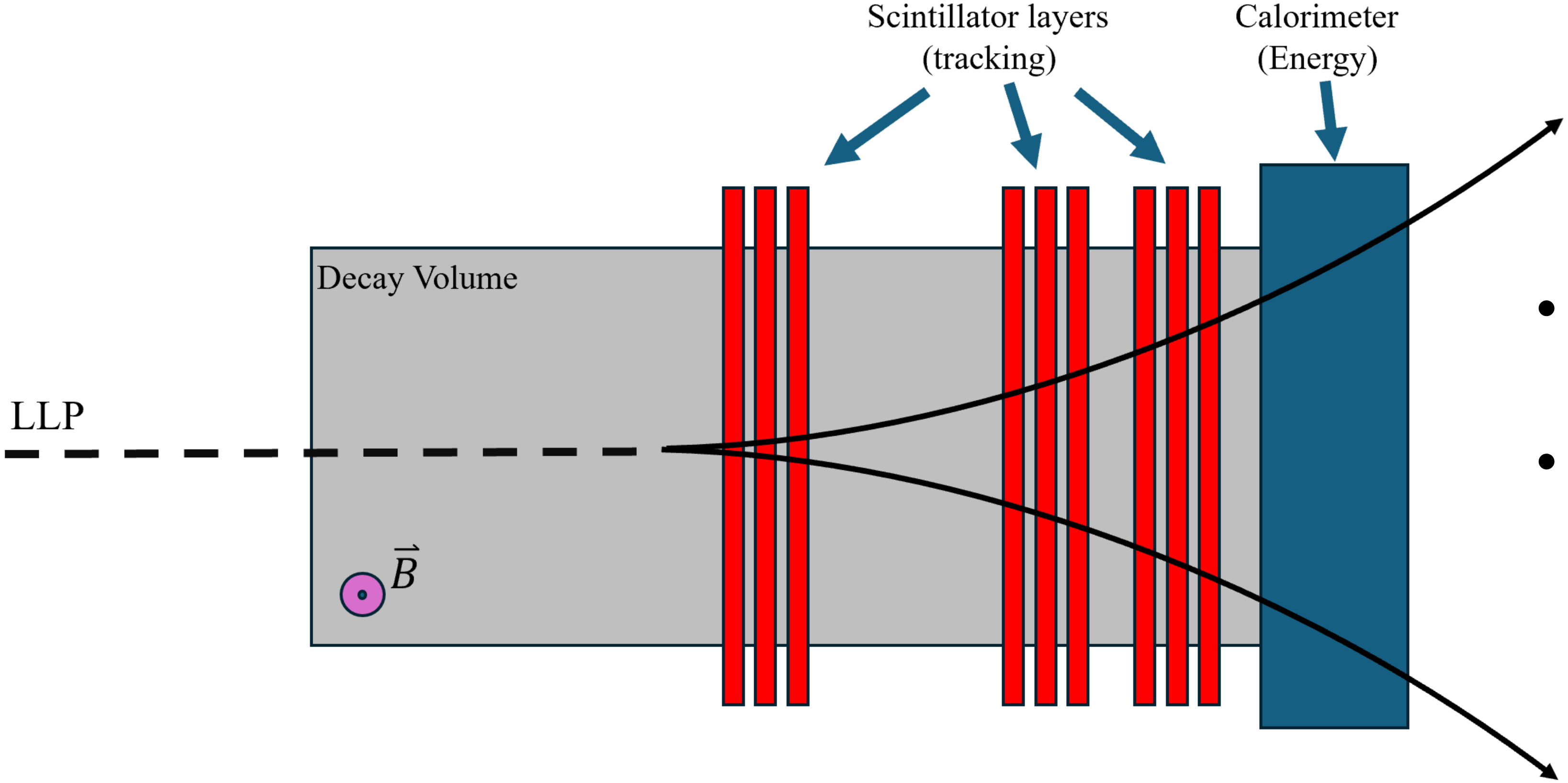



Collider
Cosmic
Cosmic rays
LHC interaction point
Muon from LHC
Inelastic scattering muon from LHC
Scattering neutrino from LHC
Scattering atmospheric neutrino

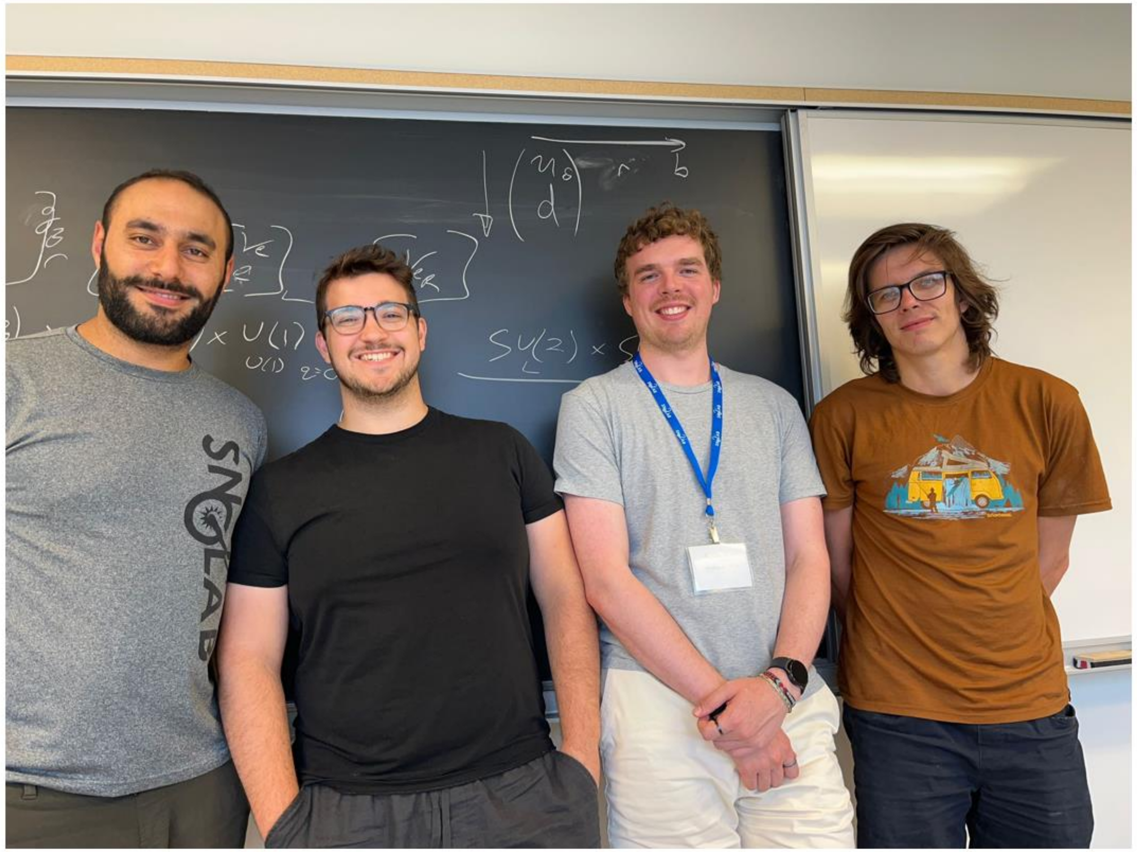

HELP
Your Physicists Detect
Long-Lived Particles


Surface
HELP
200m
100m
ILC
150m

Minimal Viable Product



- Searching for LLPs with masses below $\mathcal{O}(1000) GeV$
- Minimal upkeep needed



Our last collaboration meeting!

EDI Problem Statement

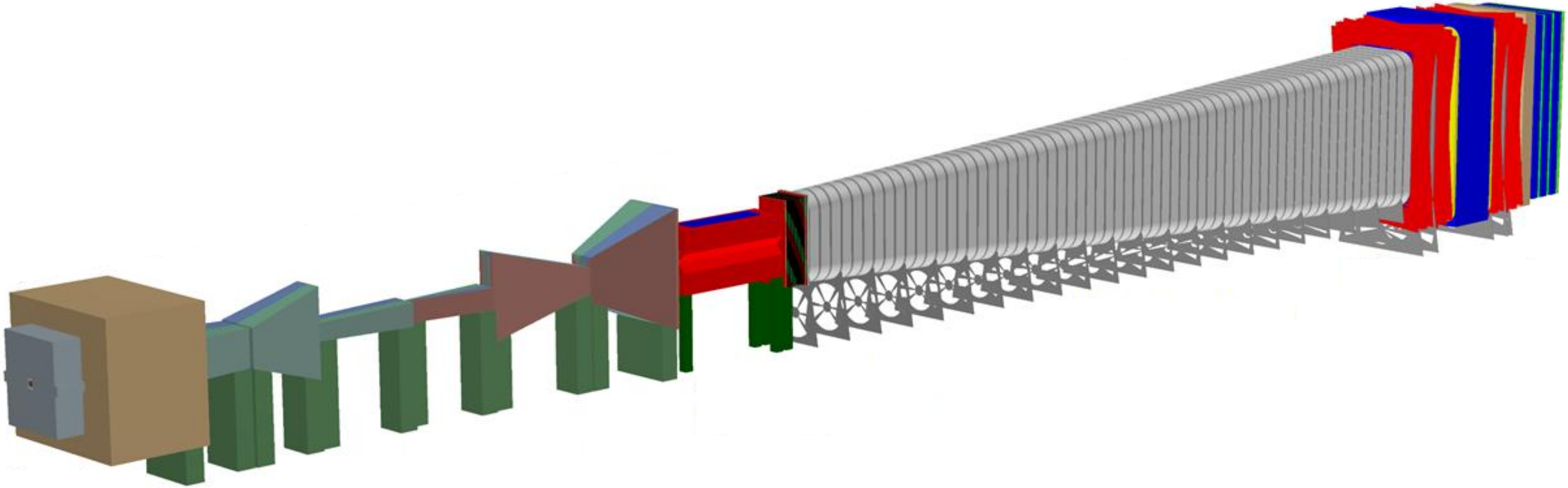
- new collaboration with about 60 people from 5 different counties and 9 different institutions.
- Experiment is currently under construction at a remote site with a very small local group.
- Lack of willingness for other collaborators to be on site to support the construction efforts.
- Funding is limited, which means it is up to the collaboration to ensure the people needed go to site.
- Need rules and policies to ensure that approximately 5 additional collaborators are on site at any given time.

1. Institutional Time Quotas
   - Authorship conditional on fulfilling quotas
   - Clear goals and timeframes for quotas
2. Incentives for Participation
   - Incentives such as possible monetary compensation
3. Support for Remote Assistance
   - Specifically for visa and health requirements
4. Inclusivity requirements
   - Develop and enforce policies that promote a welcoming environment

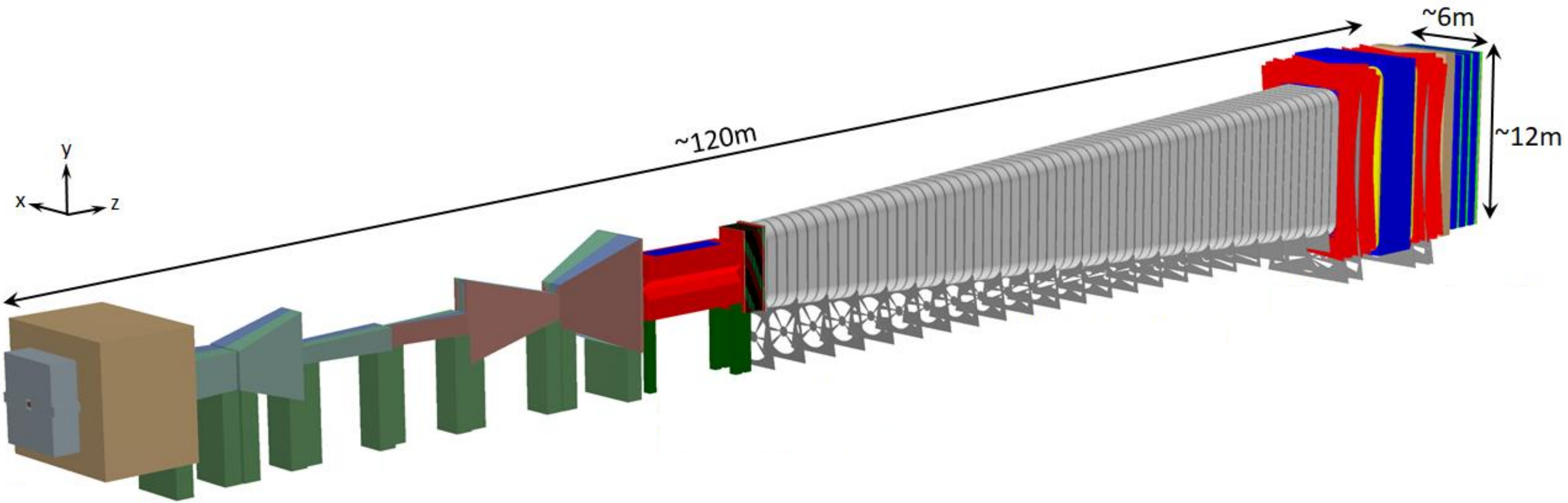
Thanks for listening!

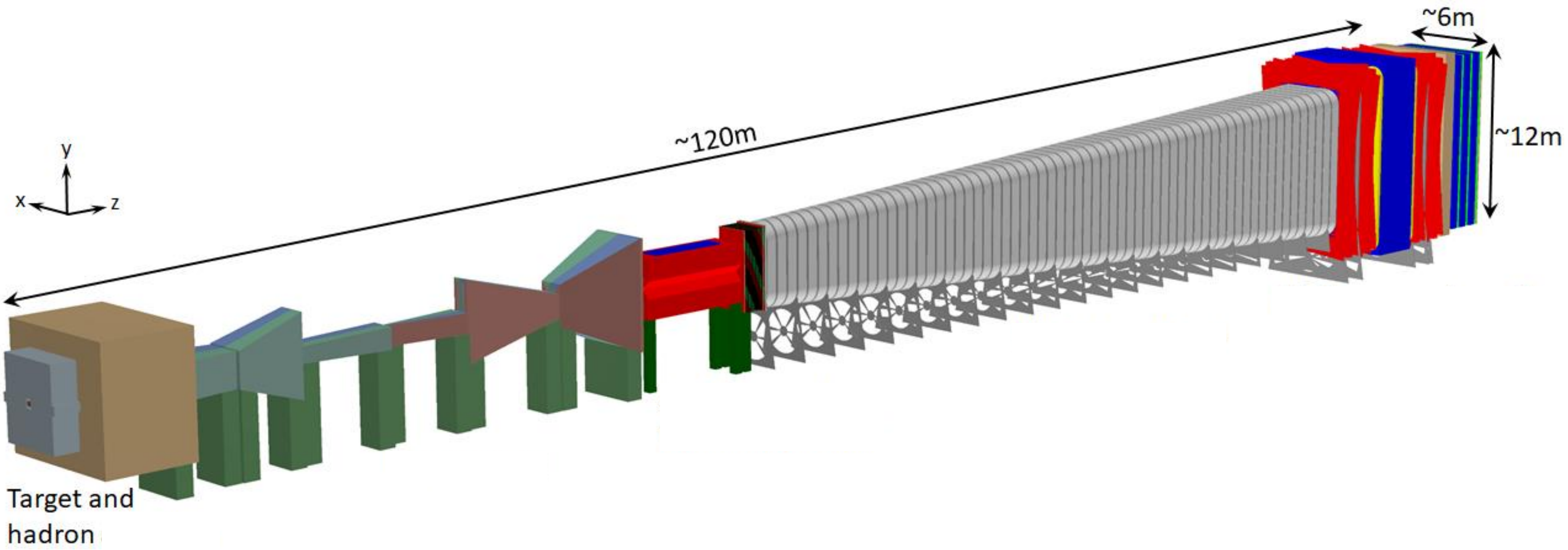
Extra Slides

SHiP: Search for Hidden Particles

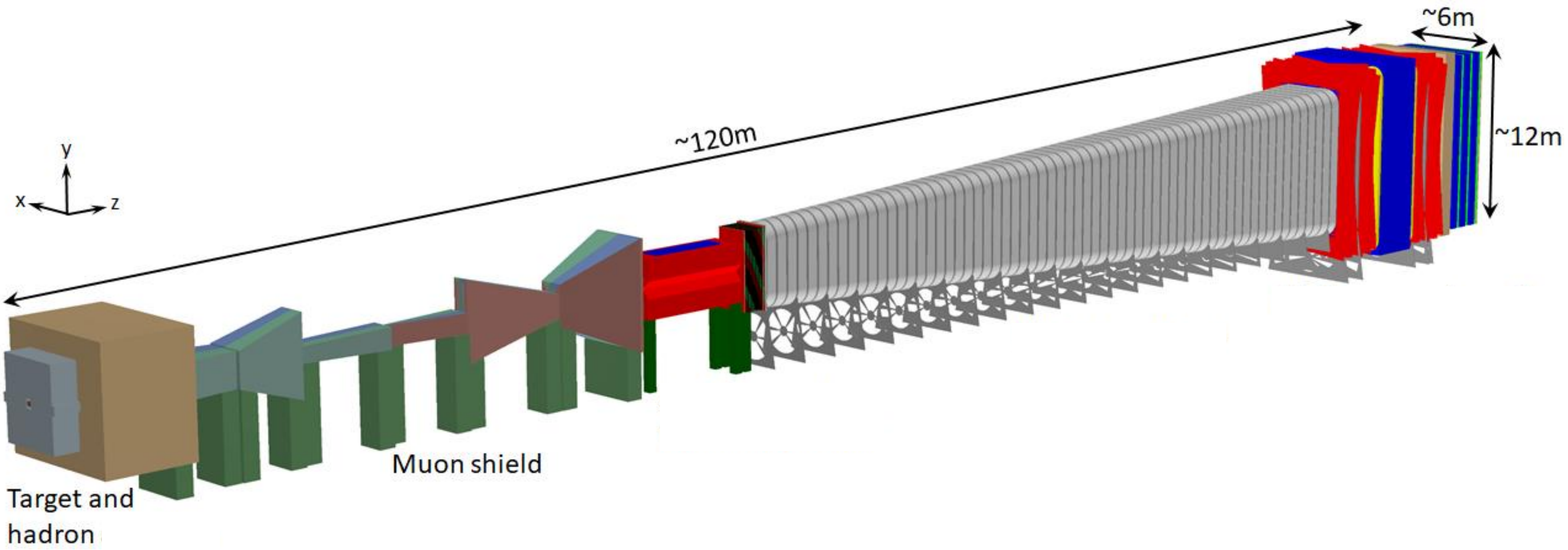


SHiP: Search for Hidden Particles

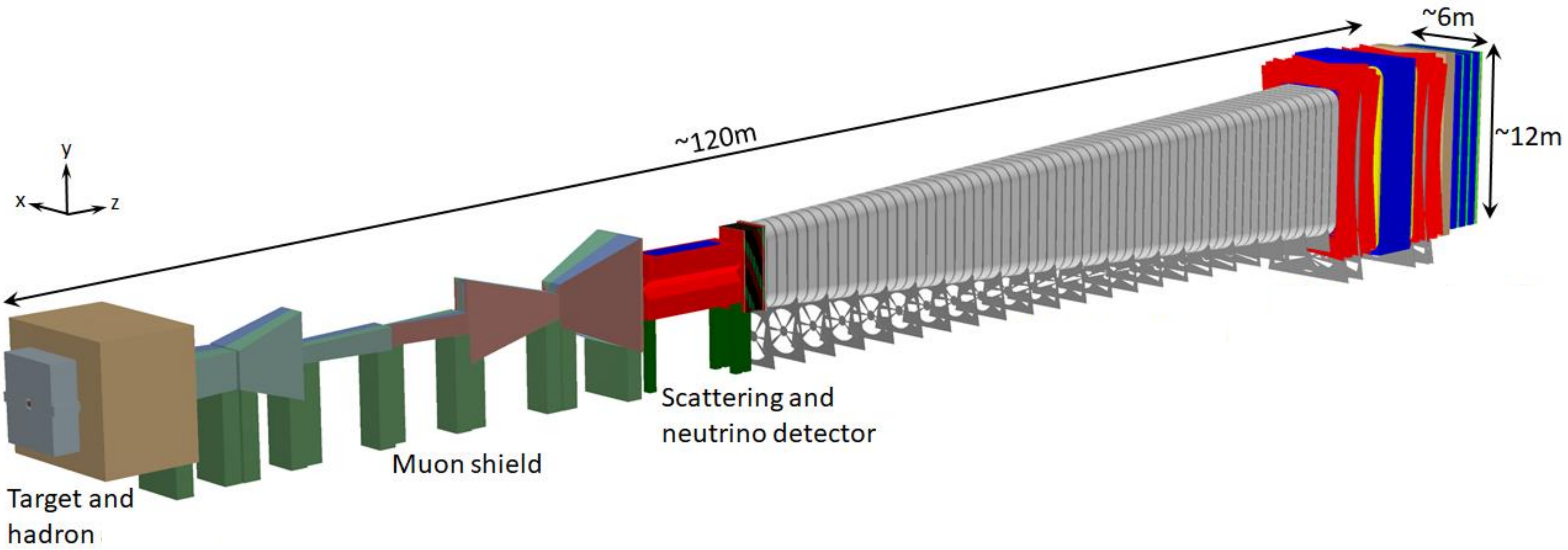




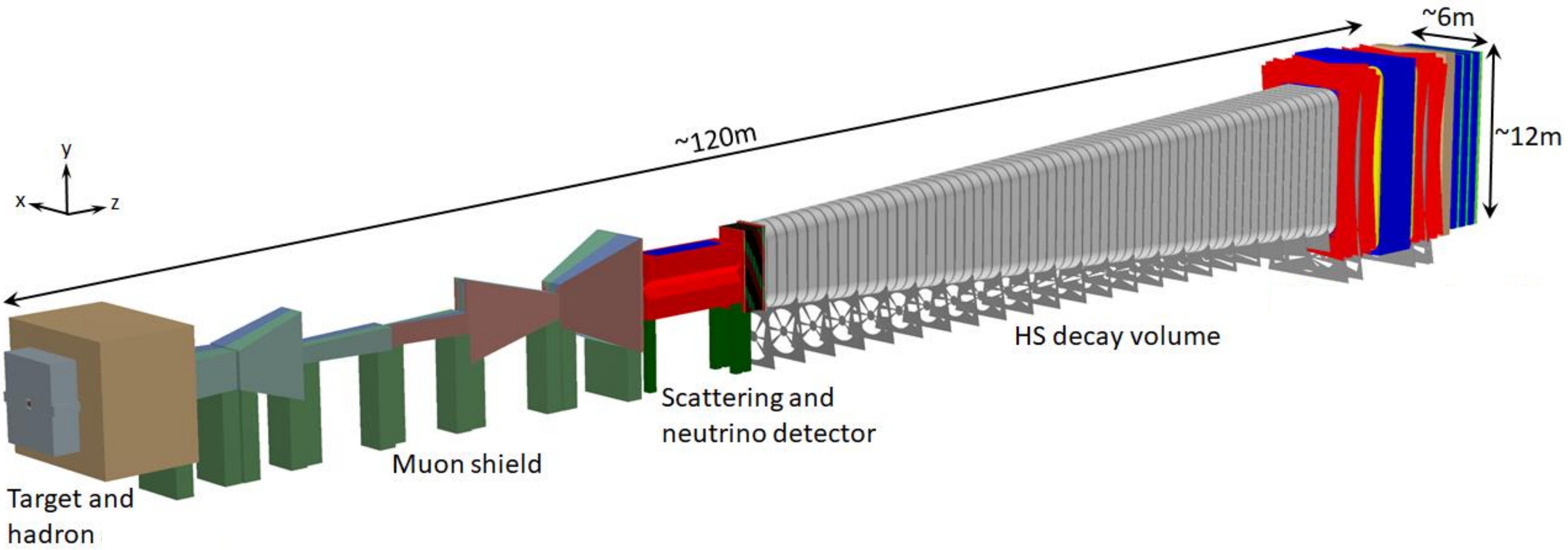
- This is where the proton beam from the SPS collides with a target material, initiating particle production.
- he target is followed by a hadron absorber made of iron, with the aim of stopping the hadronic and electromagnetic products and any residual non-interacting protons



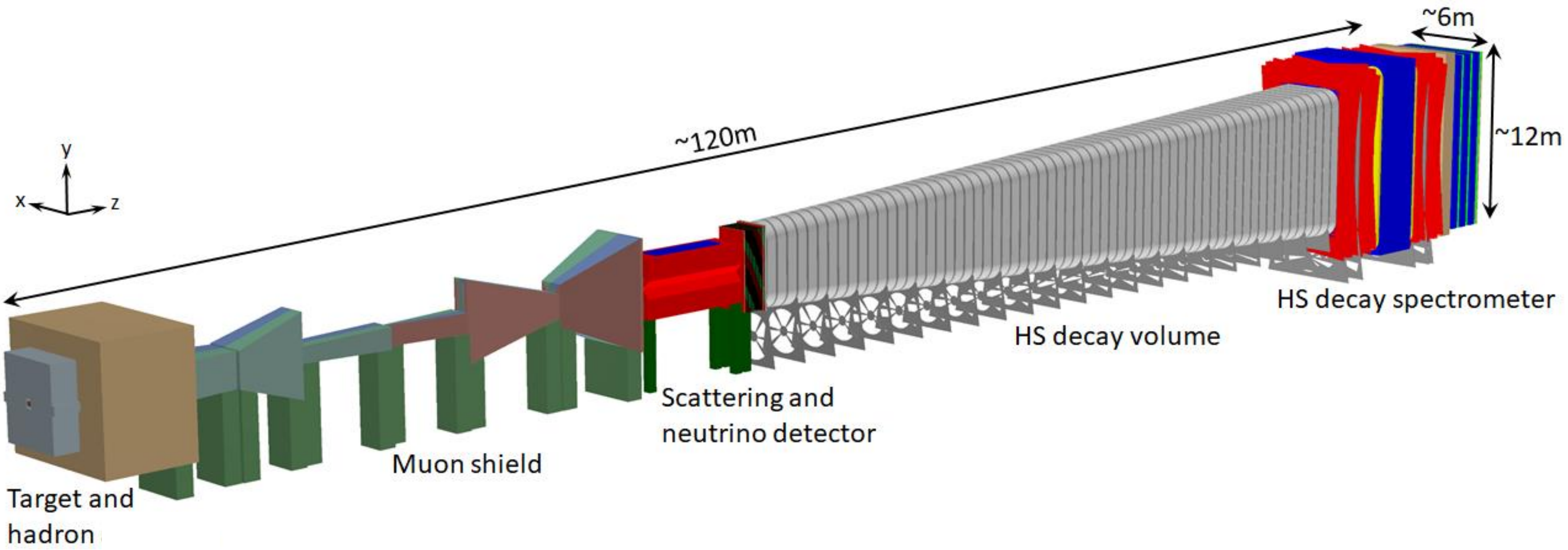
- A very large fraction of the muons emerging from the beam dump will be deflected outside of the SHiP fiducial volume by means of a compact active shielding system based on magnets of alternate polarity, which design was optimised in order to cope with the expected muon spectrum obtained from simulation.



- A dedicated neutrino detector will be placed immediately upstream of the Hidden Sector detector, taking advantage of the muon-cleared area.



- consist of a magnetized target made of bricks of alternated layers of laminated lead and nuclear emulsion foils, similar to those used by the OPERA experiment



- a target tracker and by a muon magnetic spectrometer

Proposed EDI Solutions

1. **Institutional Time Quota**:
   Establish a minimum participation quota for institutions/countries proportional to the number of collaborators to ensure equitable representation and involvement of all groups in the collaboration.
2. **Conditional Authorship**:
   Authorship is conditional to the fulfillment of institution quotas.
3. **Clear Expectations and Advanced Planning**:
   Set clear expectations and plan well in advance for the time required during the construction phase to ensure smooth progress and participation. For instance, schedules can be negotiated among countries when joining the collaboration and precise schedules negotiated among institutions.
4. **Incentives for Participation**:
   Implement possible incentives, such as compensating individuals for their time, to encourage active participation and contribution.
5. **Support for Remote Assistance**:
   Provide support for remote participation, enabling contributors who cannot be physically present to actively engage in the project. For instance, quotas may be satisfied by doing work in organizing and coordinating schedules.
6. **Visa, Health and EDI Requirements**:
   Consider and address visa and health requirements to facilitate the involvement of international collaborators.
7. **Inclusivity requirements**:
   Develop and enforce rules and policies that are inclusive and promote a diverse and welcoming environment for all collaborators present on site.
8. **Case-by-Case Exceptions**:
   Allow for exceptions to be made on a case-by-case basis to accommodate unique circumstances and ensure flexibility.