Triggering on muon showers

Javier Prado Pico
on behalf of the CMS collaboration

TWEPP 2024

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Universidad de Oviedo
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Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias

Introduction

What are muon showers?

How are they produced?

Why are they important?

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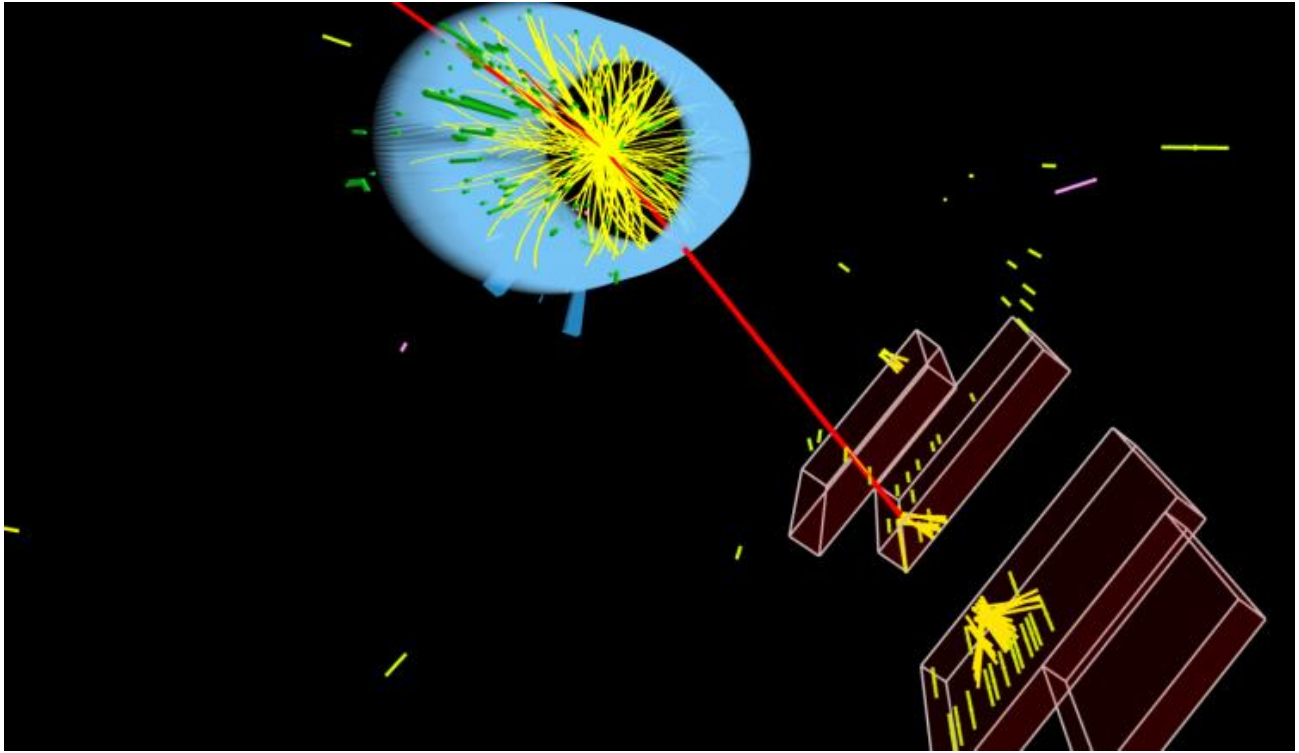
What are muon showers?

Characterized by a high amount of secondary particles



Muon producing a shower in the second and third station

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Bremsstrahlung

Atomic number

Thickness

Probability of radiating

$$P \propto Z^2 \frac{T}{X_0}$$

Radiation length of the material

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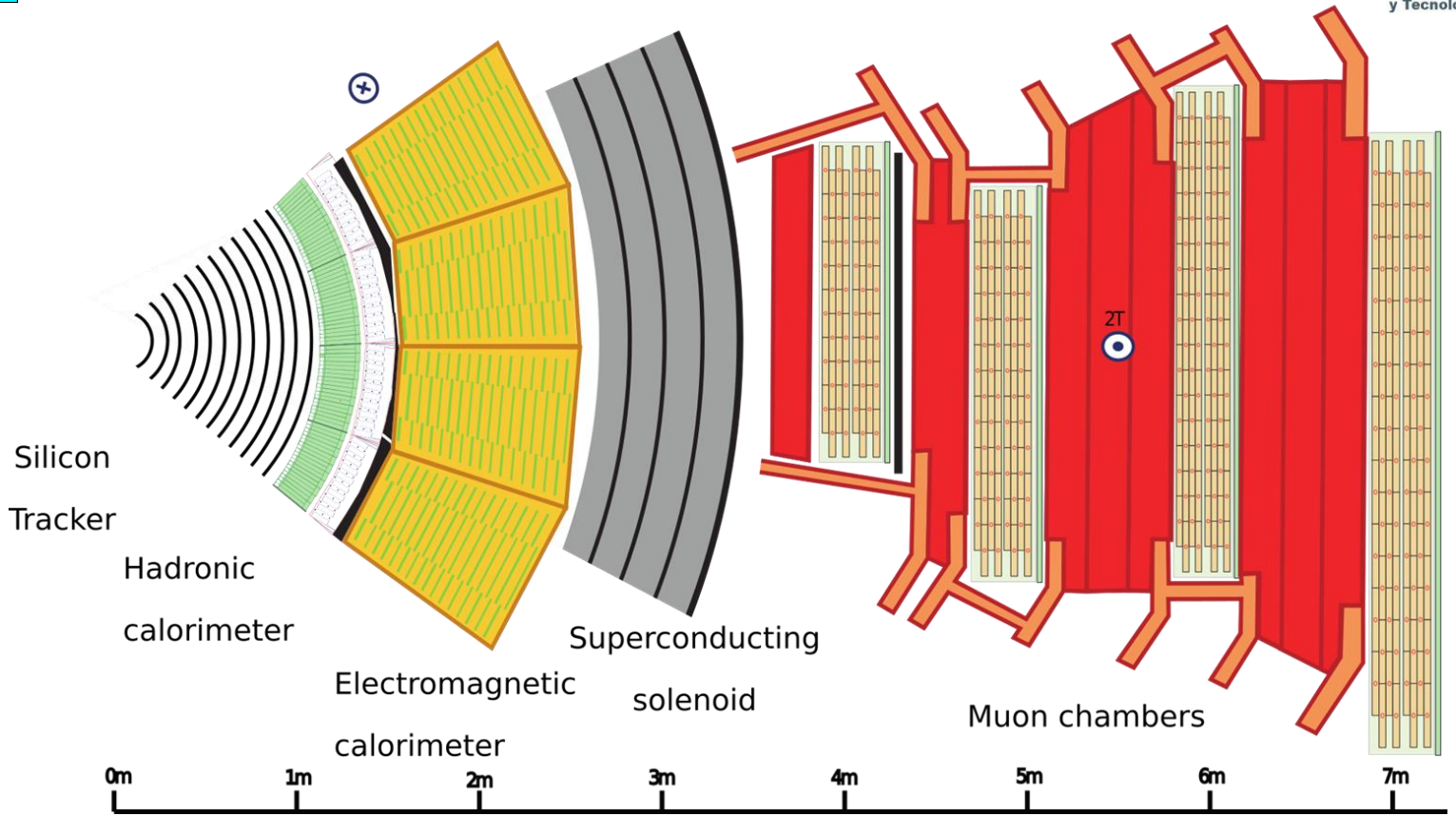
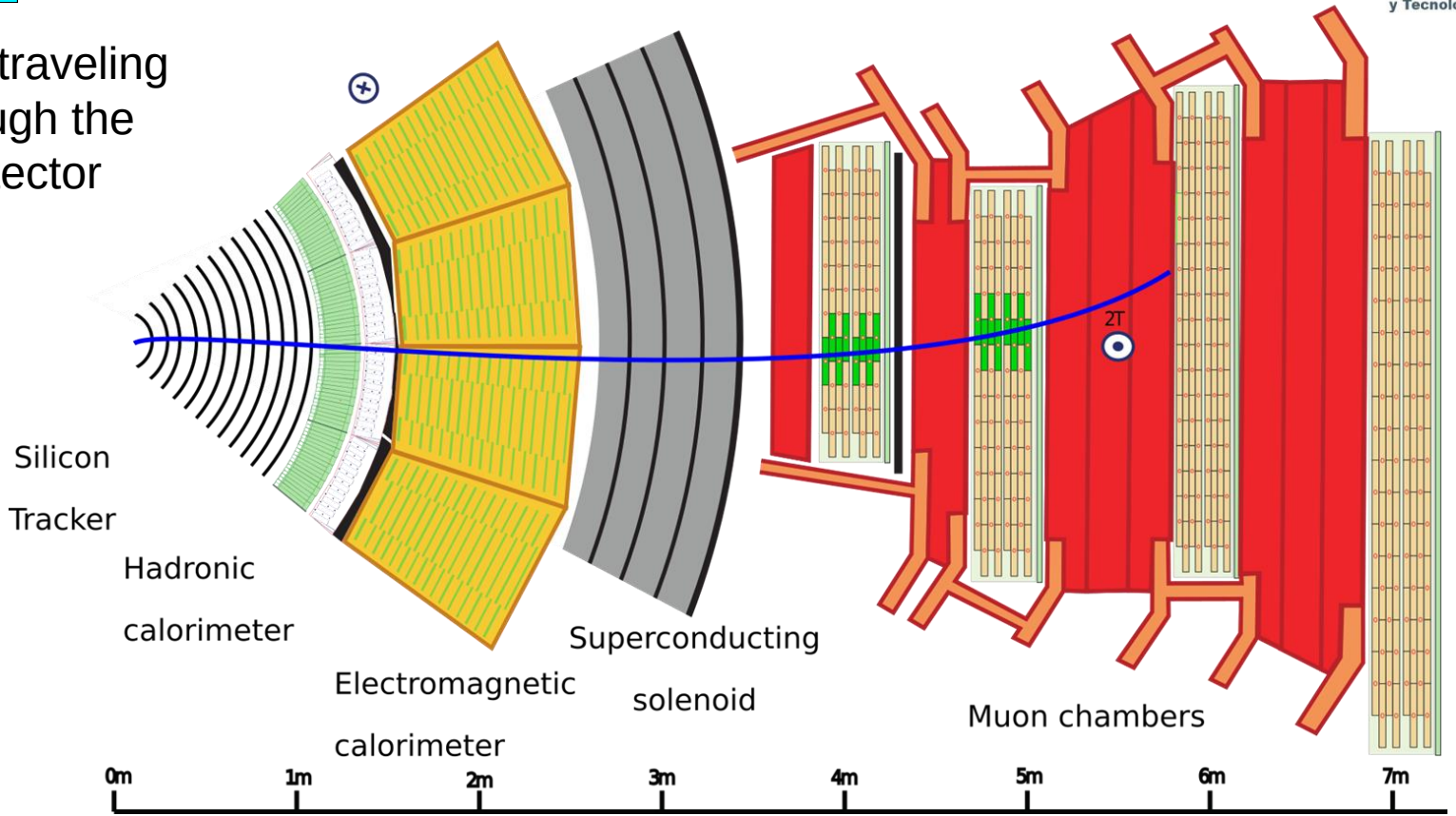
Bremsstrahlung



Bremsstrahlung

Muon traveling through the detector



Bremsstrahlung

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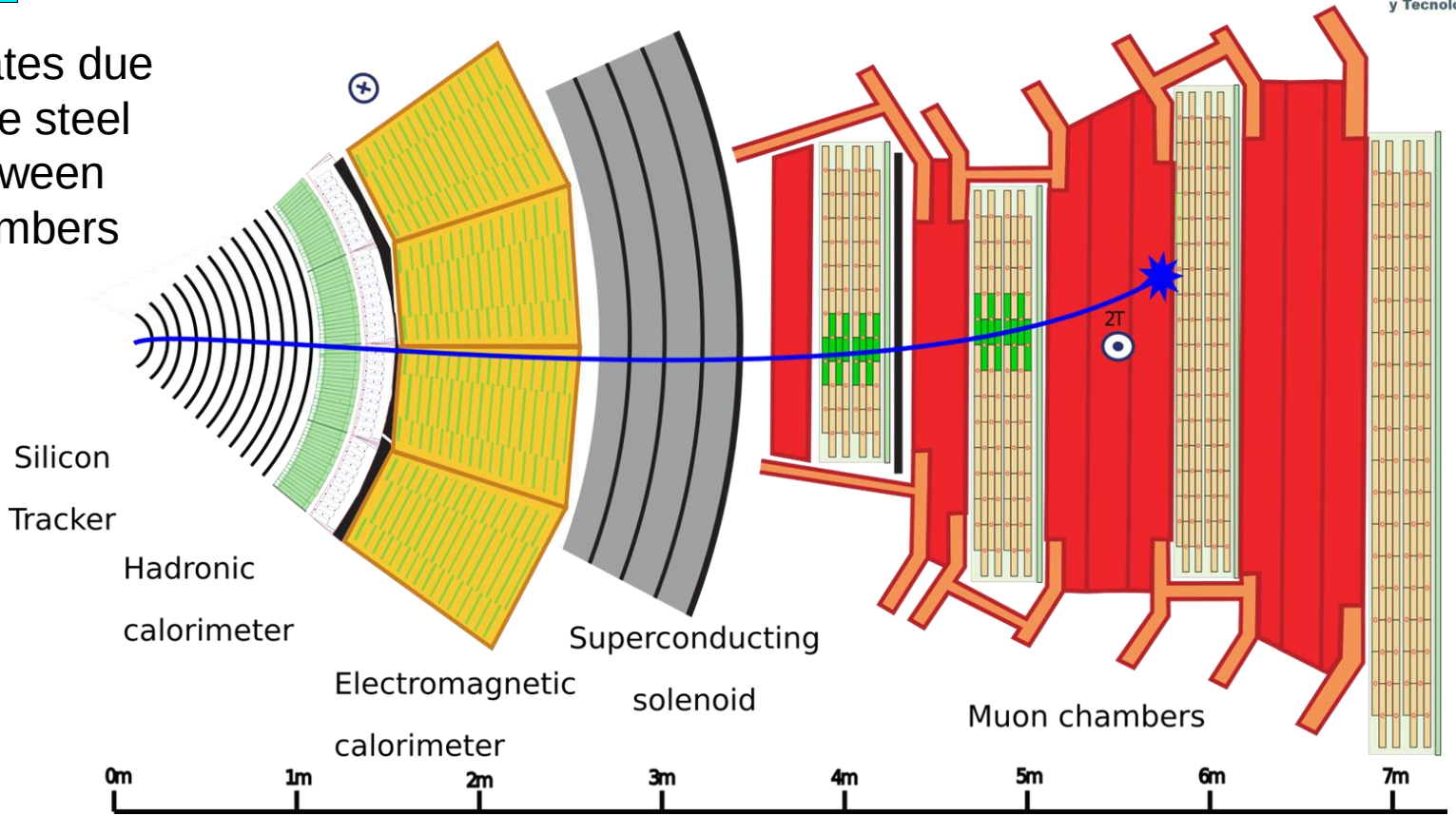
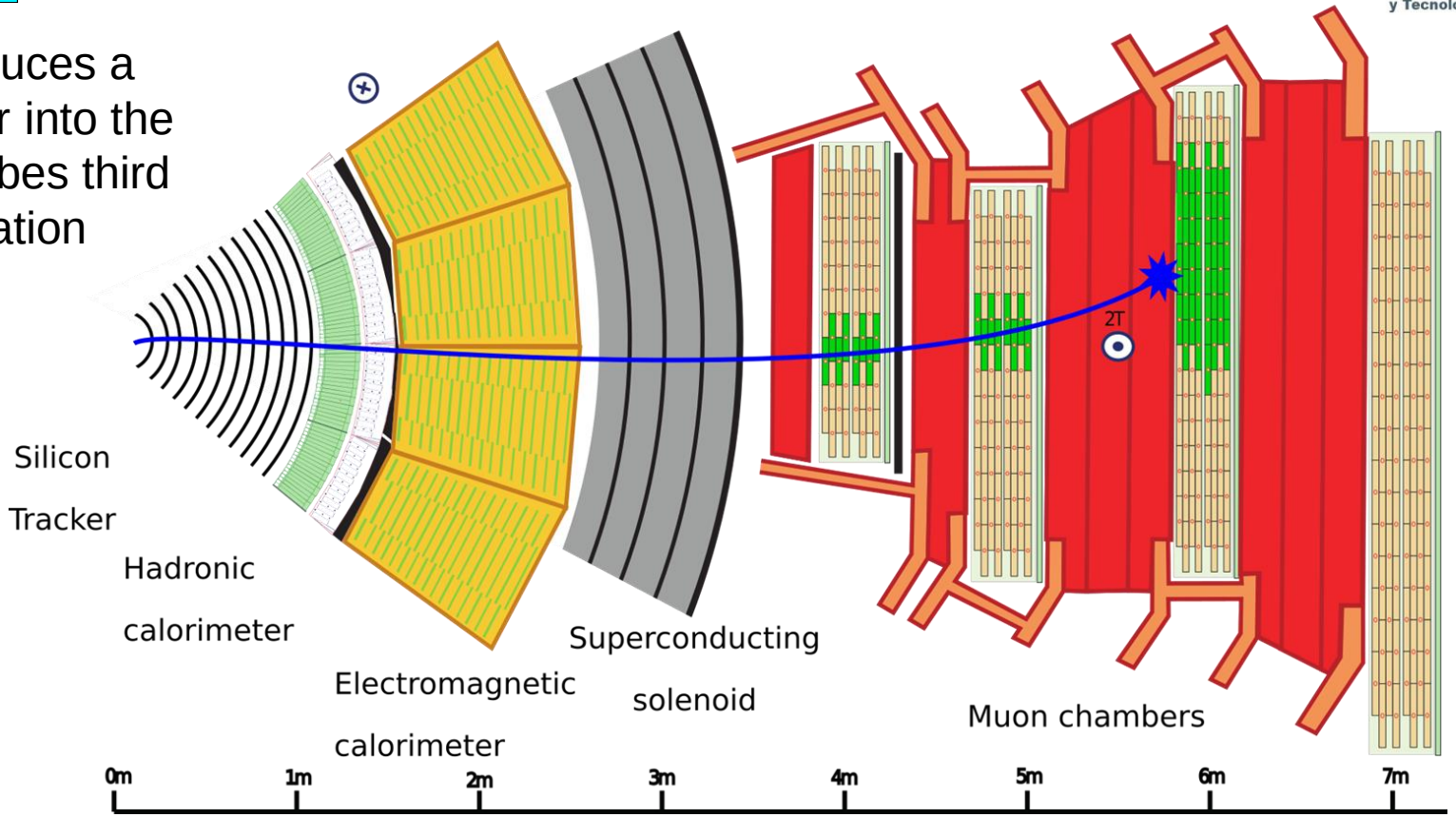
Radiates due to the steel between chambers



Bremsstrahlung

Produces a shower into the drift tubes third station



Long-lived particles

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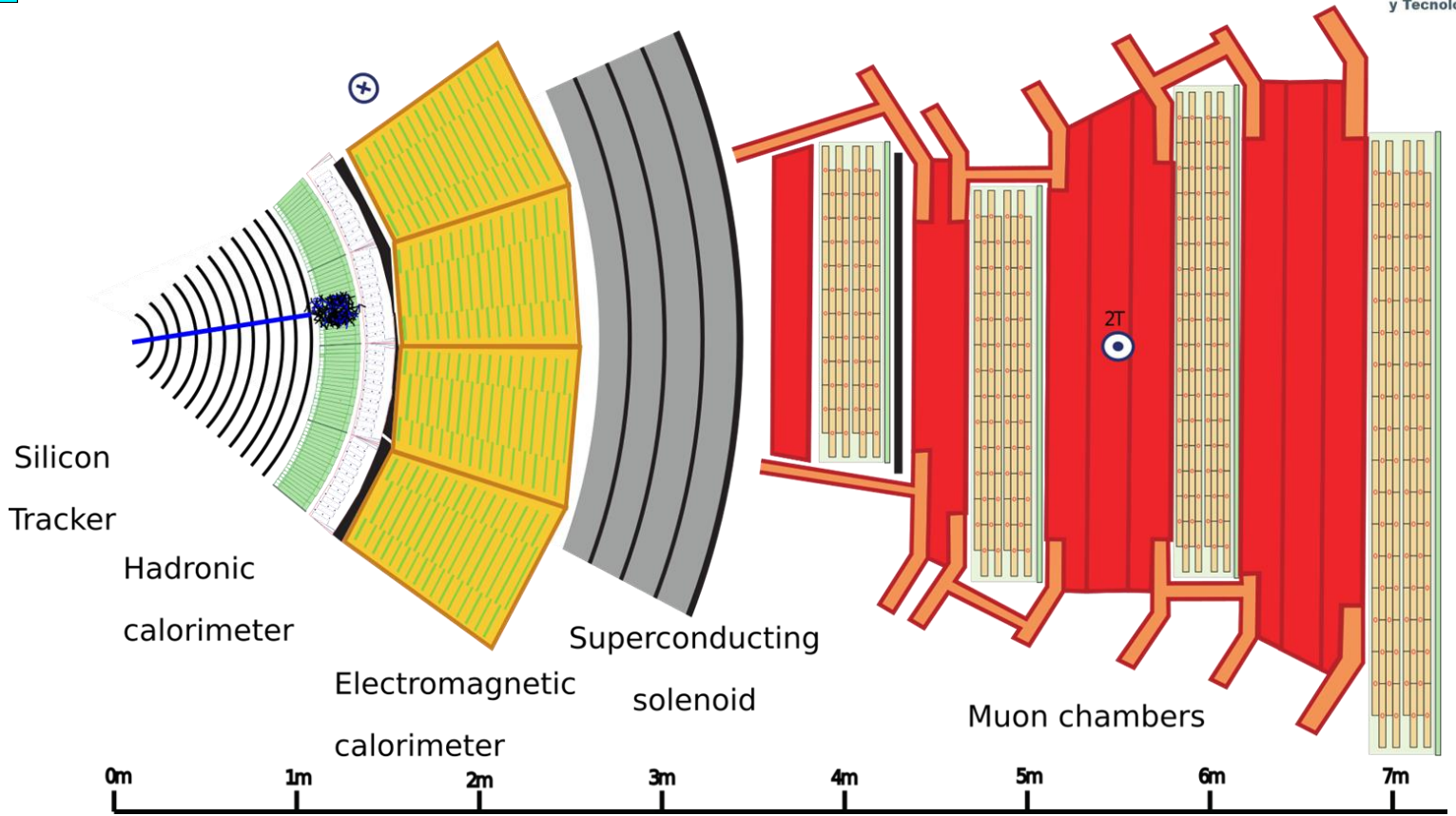
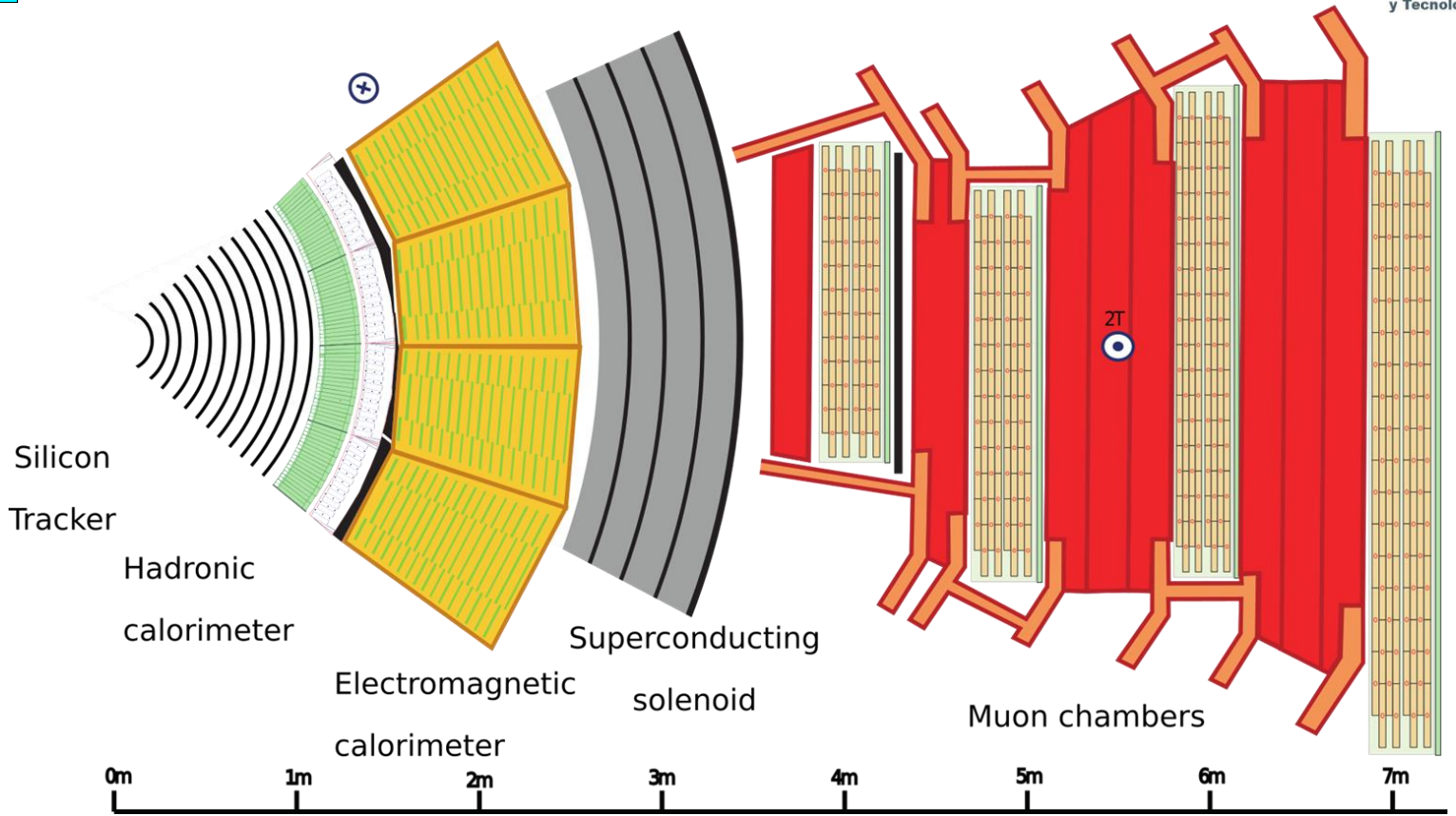
Long-lived particles

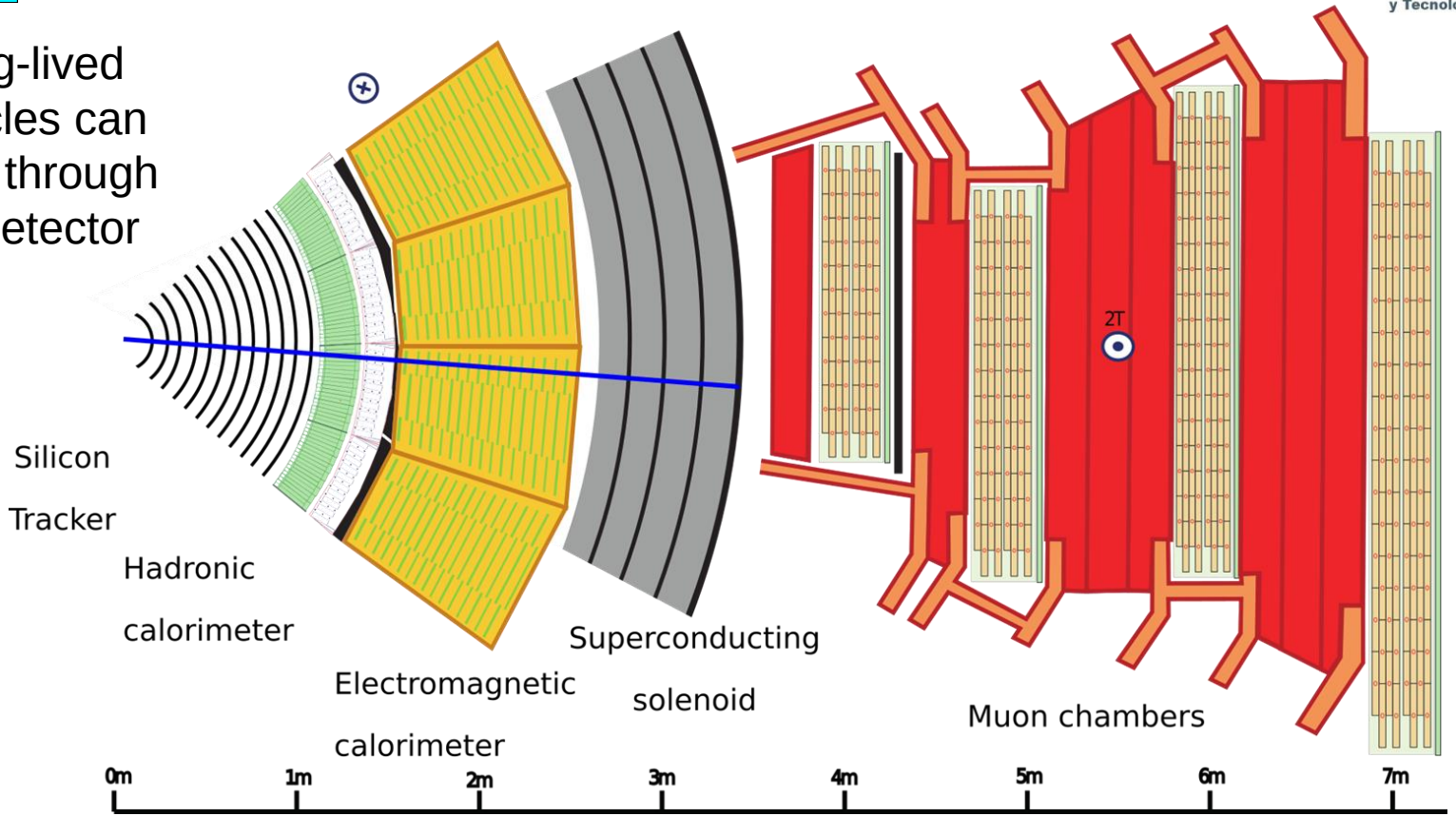


Long-lived particles



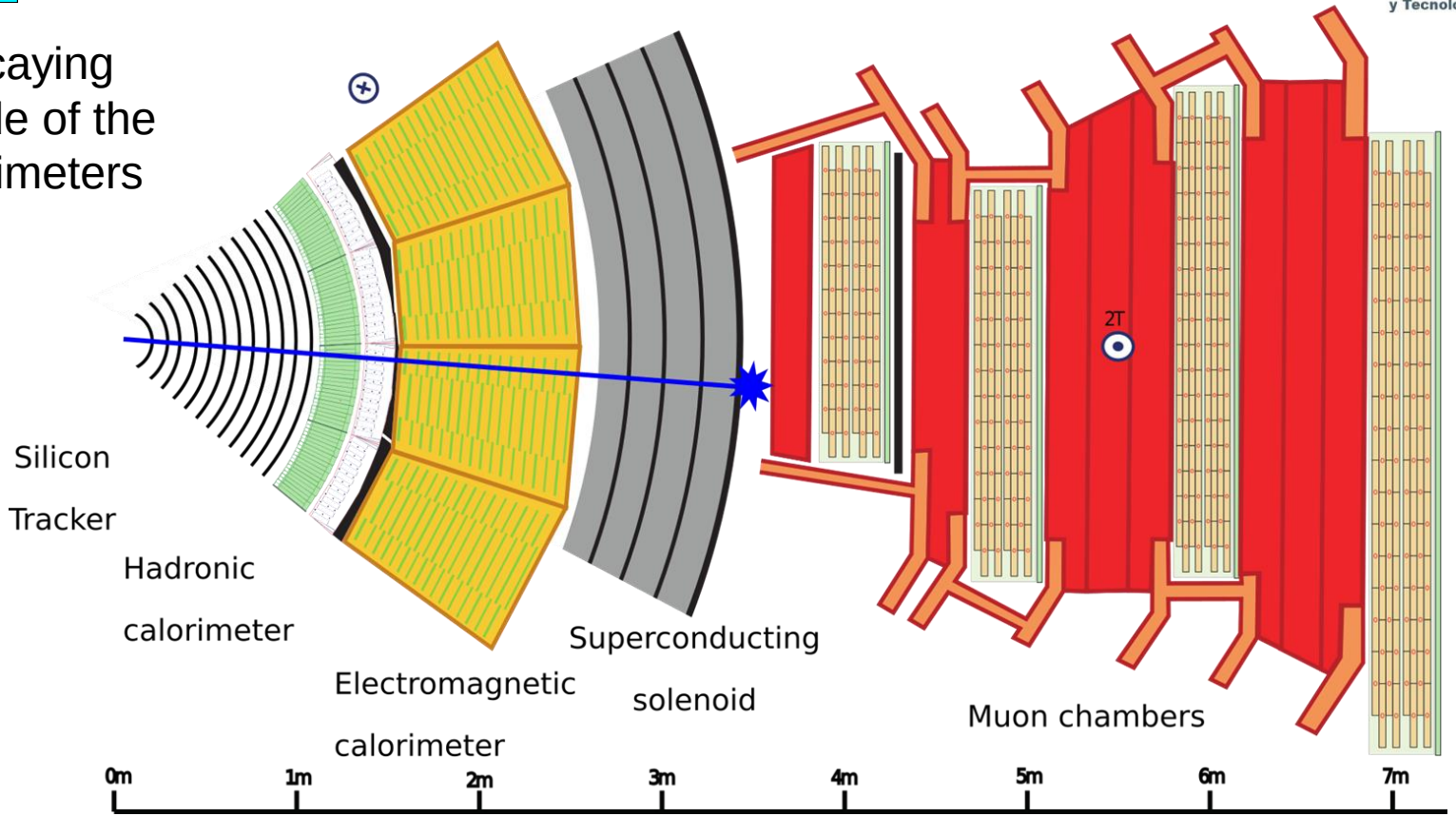
Long-lived particles

Long-lived particles can travel through the detector



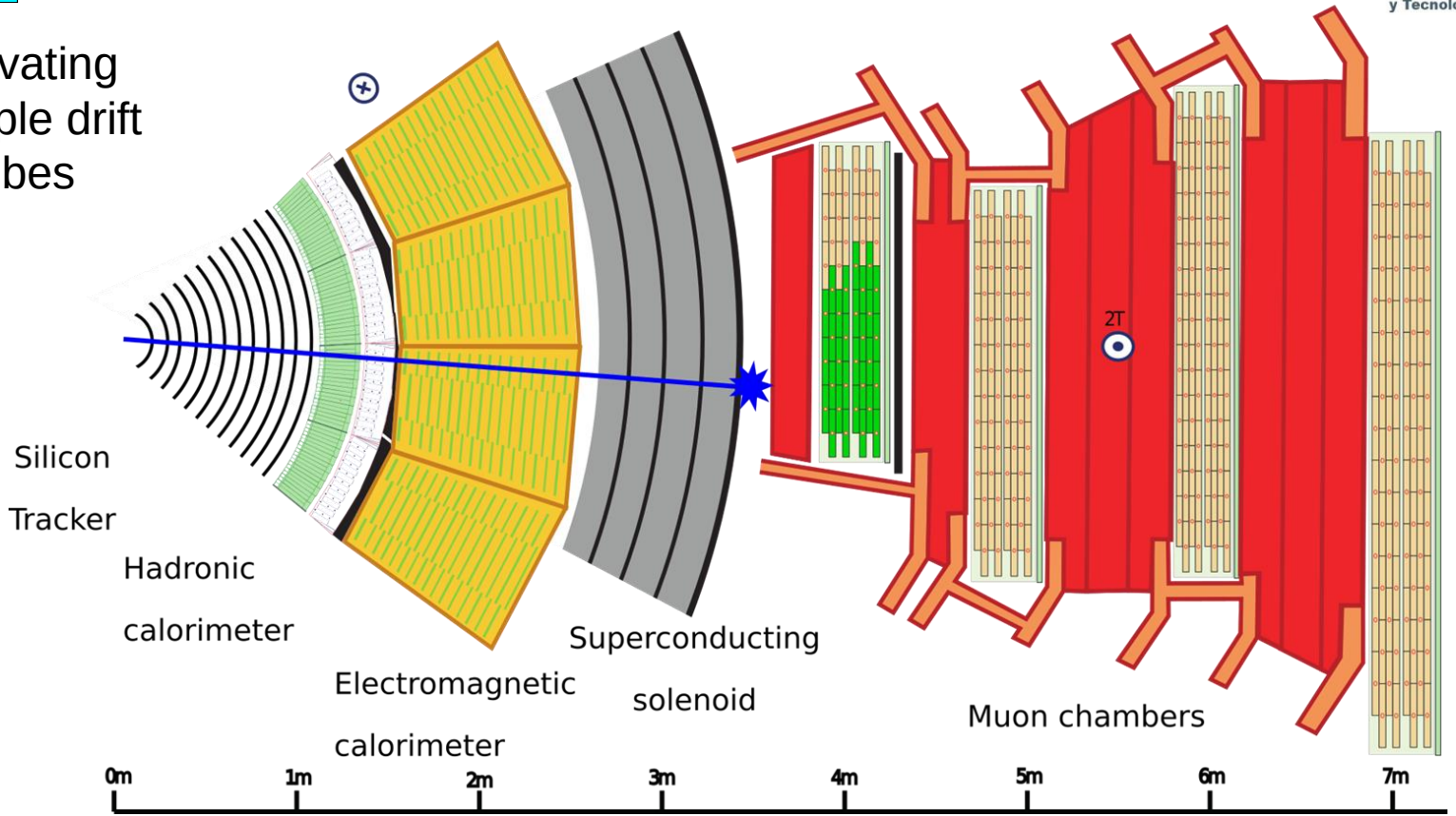
Long-lived particles

Decaying outside of the calorimeters



Long-lived particles

Activating multiple drift tubes



Physics Motivations

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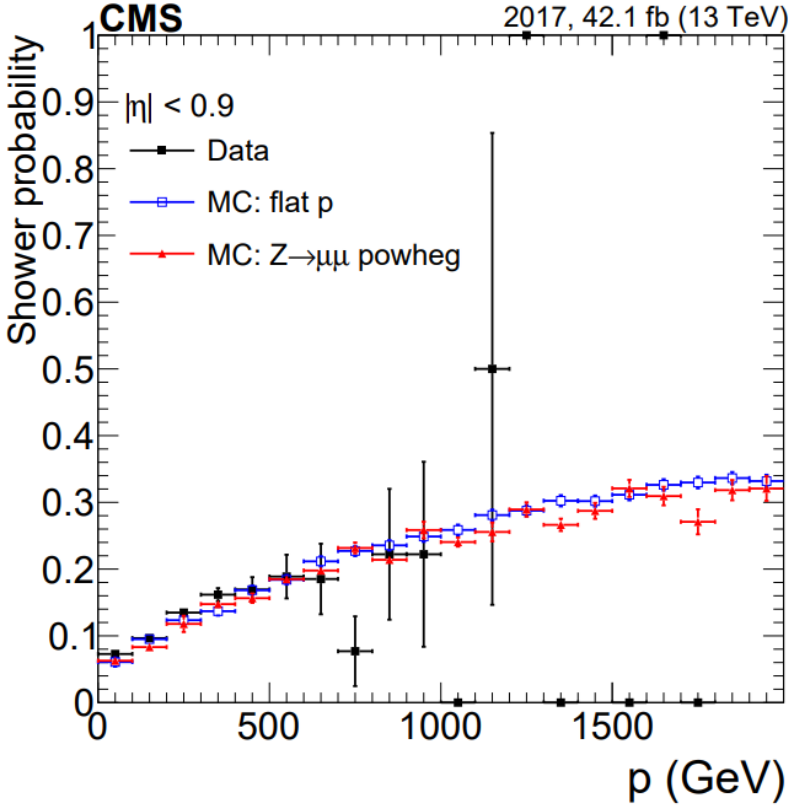
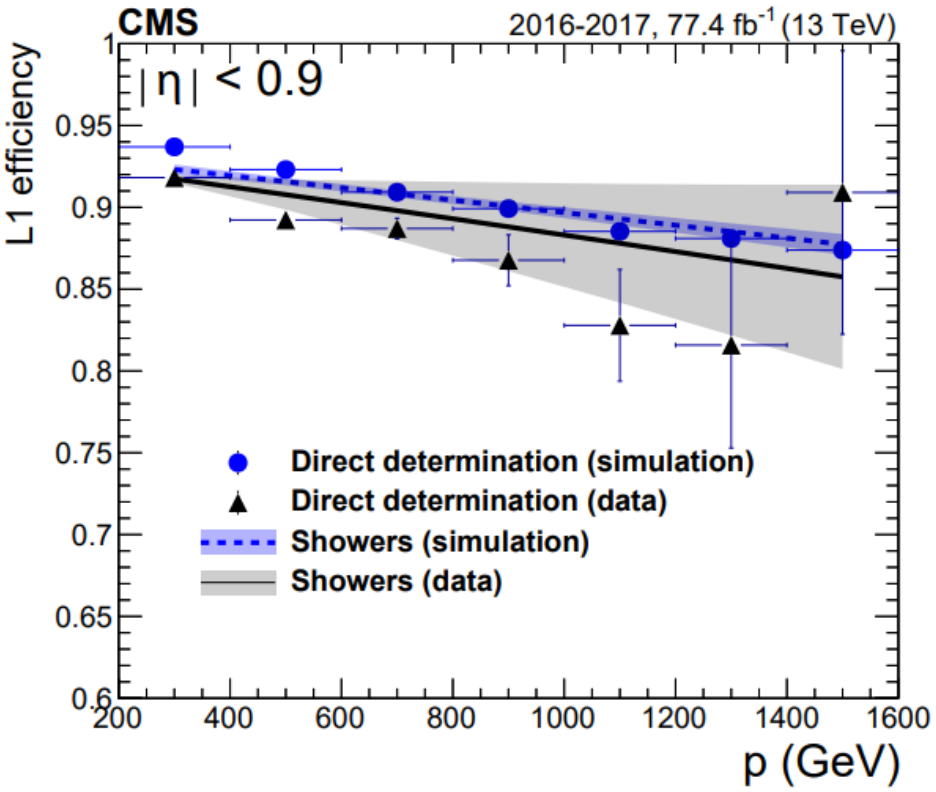
Physics Motivations

JINST 15 P02027

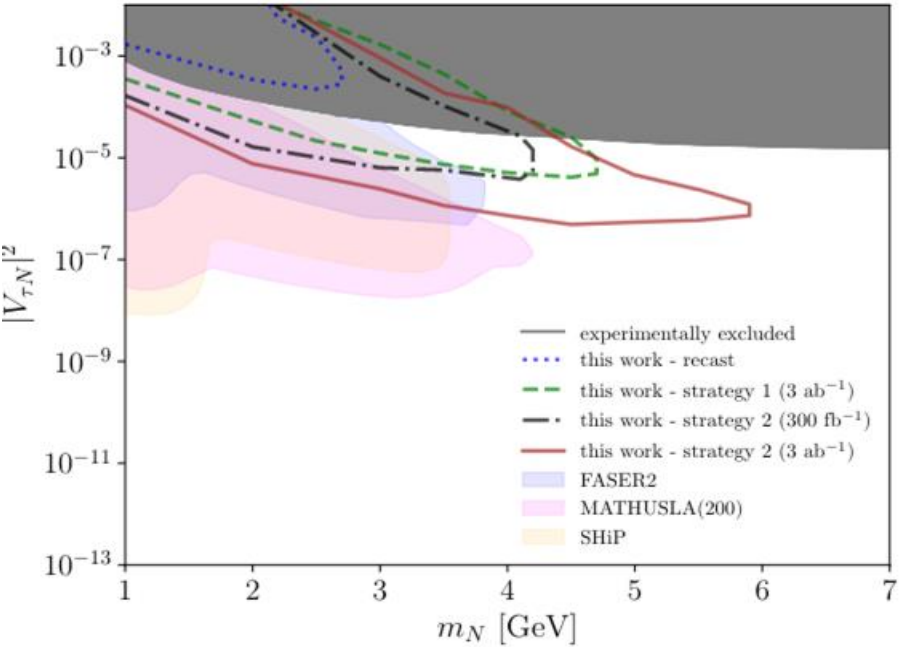


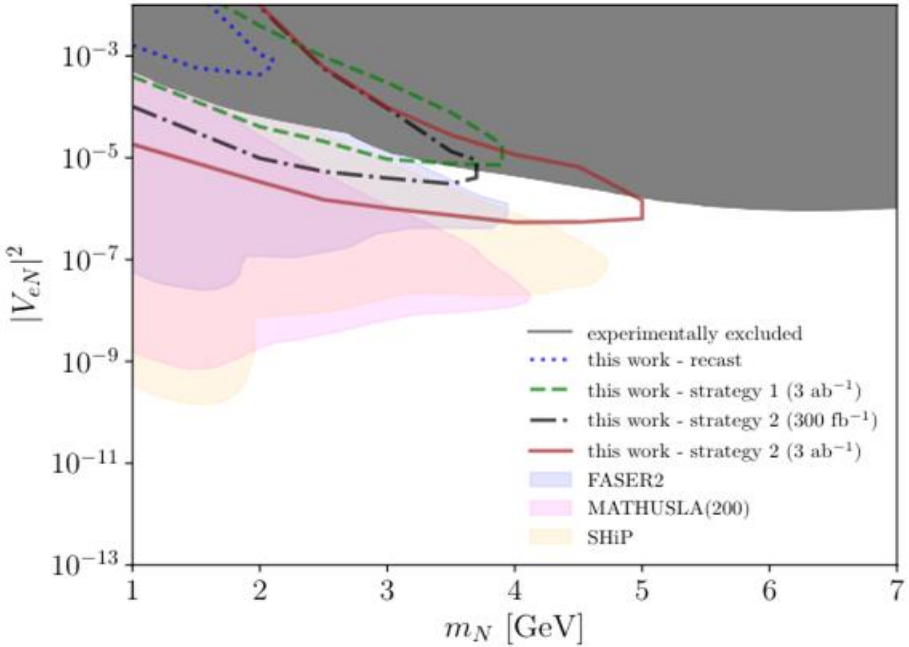


Physics motivation

Increase sensitivity by several orders of magnitude to search for heavy neutral leptons

arXiv:2210.17446





Projected sensitivity of the different proposed search strategies with a displaced shower signature in the CMS muon system

Introduction

How do we get this information from the detector?

Any solution to the previous problems?

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Trigger system

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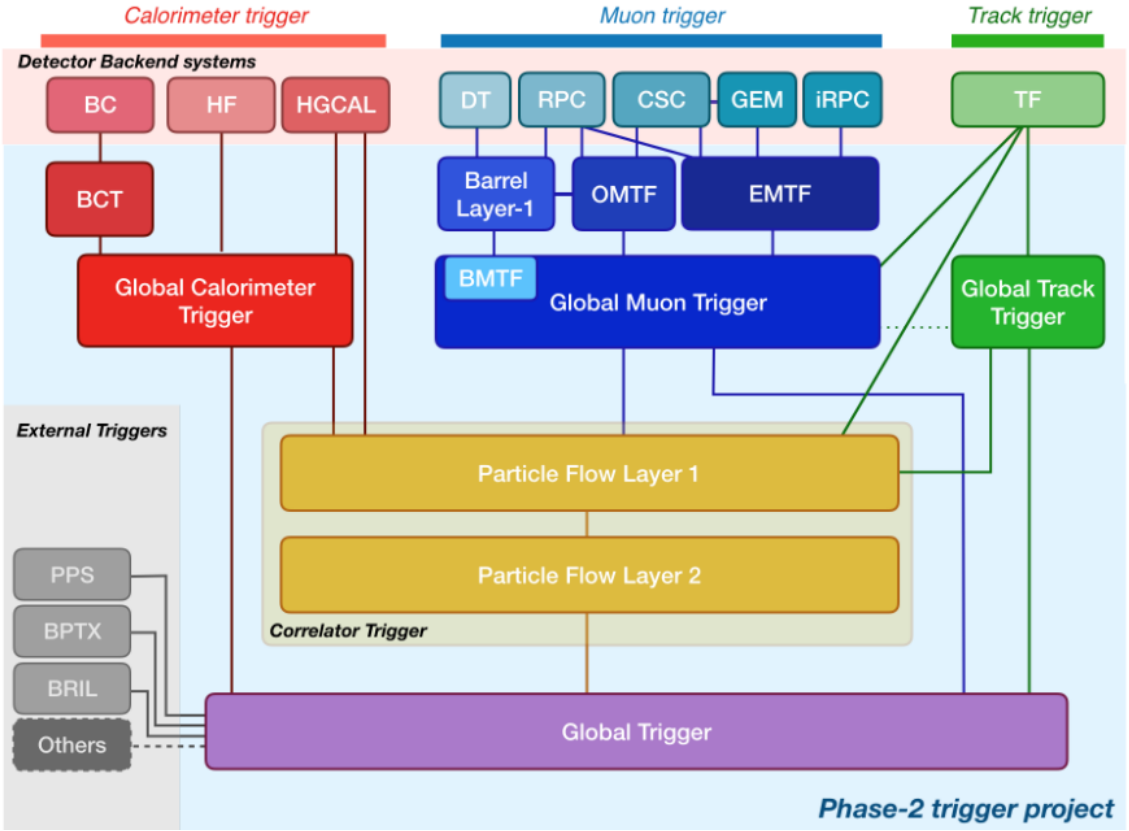
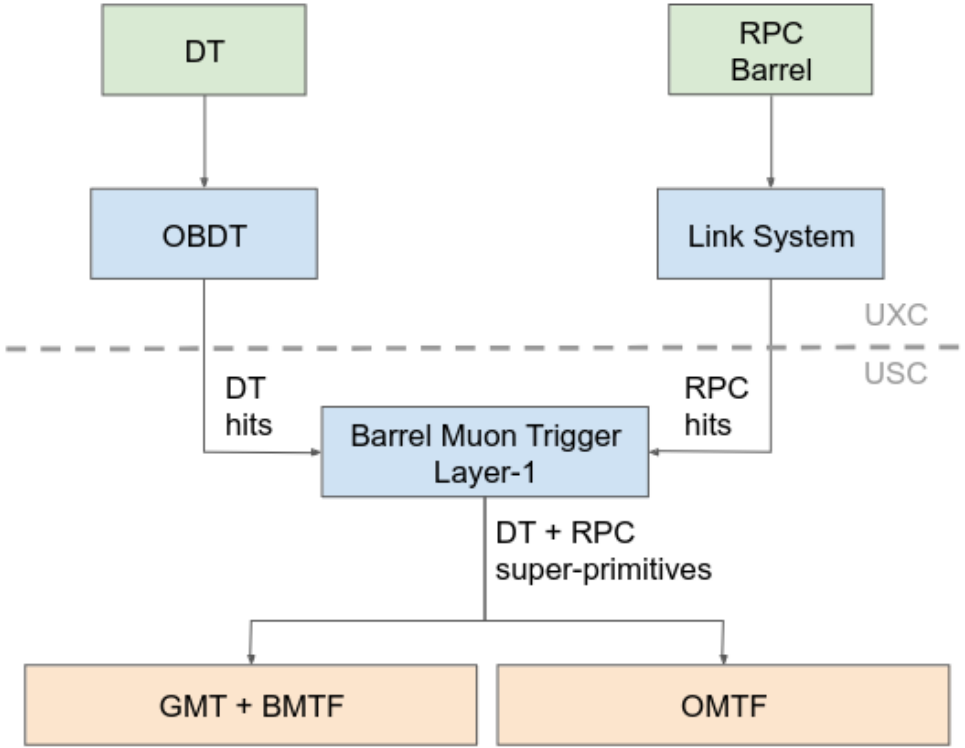
Trigger system

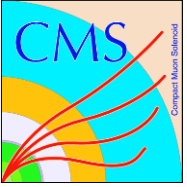


Trigger system

DT+RPC super primitives



Trigger system for HL-LHC



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Triggering in the drift tubes

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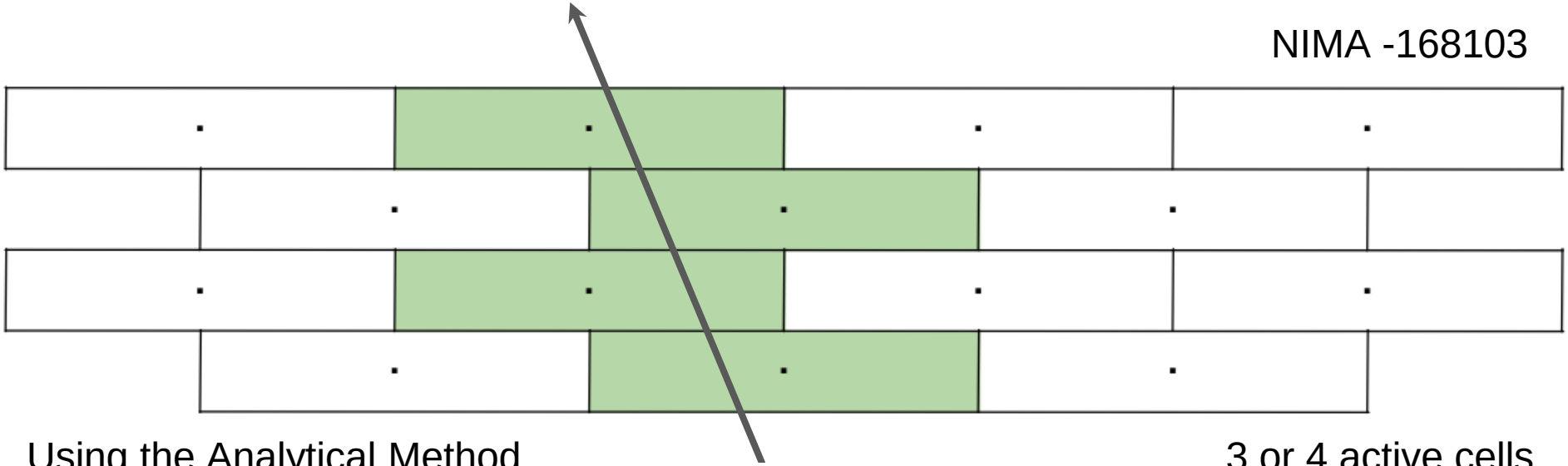
Local DTs reconstruction

NIMA -168103

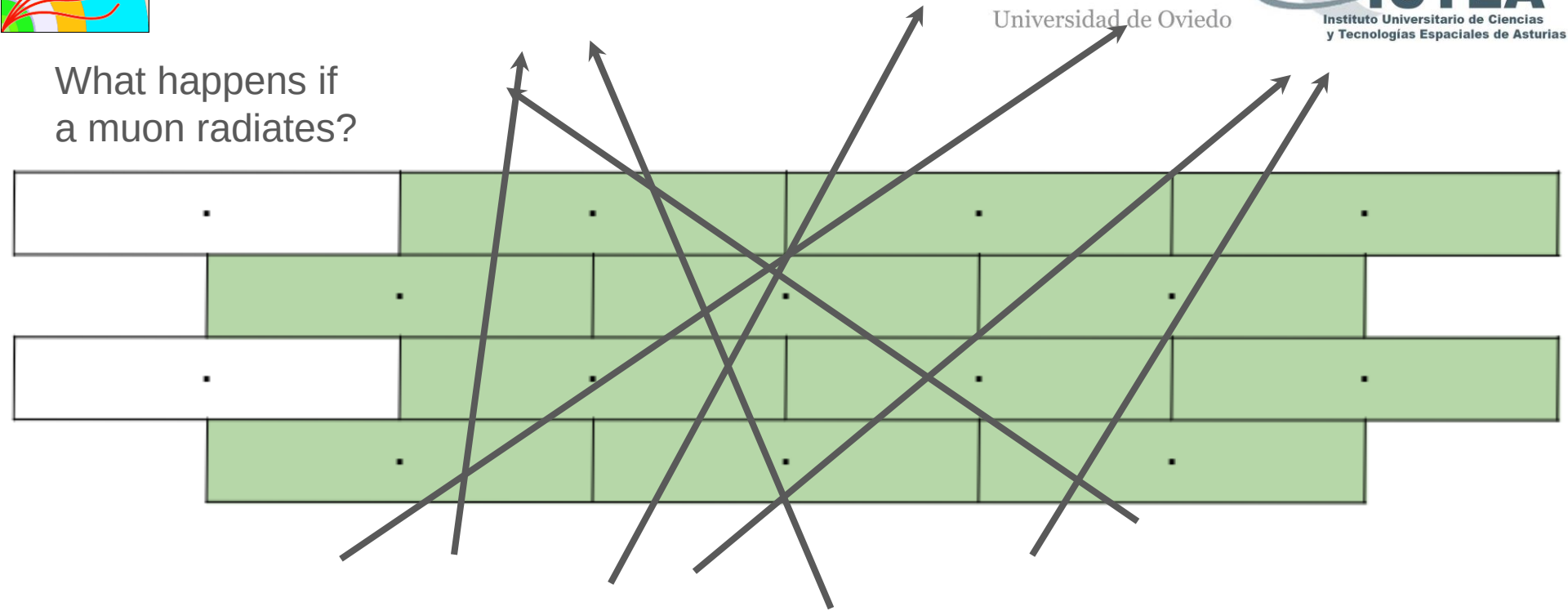


Using the Analytical Method (AM) developed by CIEMAT, UAM and University of Oviedo we can accurately reconstruct tracks

3 or 4 active cells give an unequivocal track of the particle.

Local DTs reconstruction

What happens if
a muon radiates?



Many active cells

Many possible tracks
to calculate!

Waste of time and
spurious data

How can we solve it?

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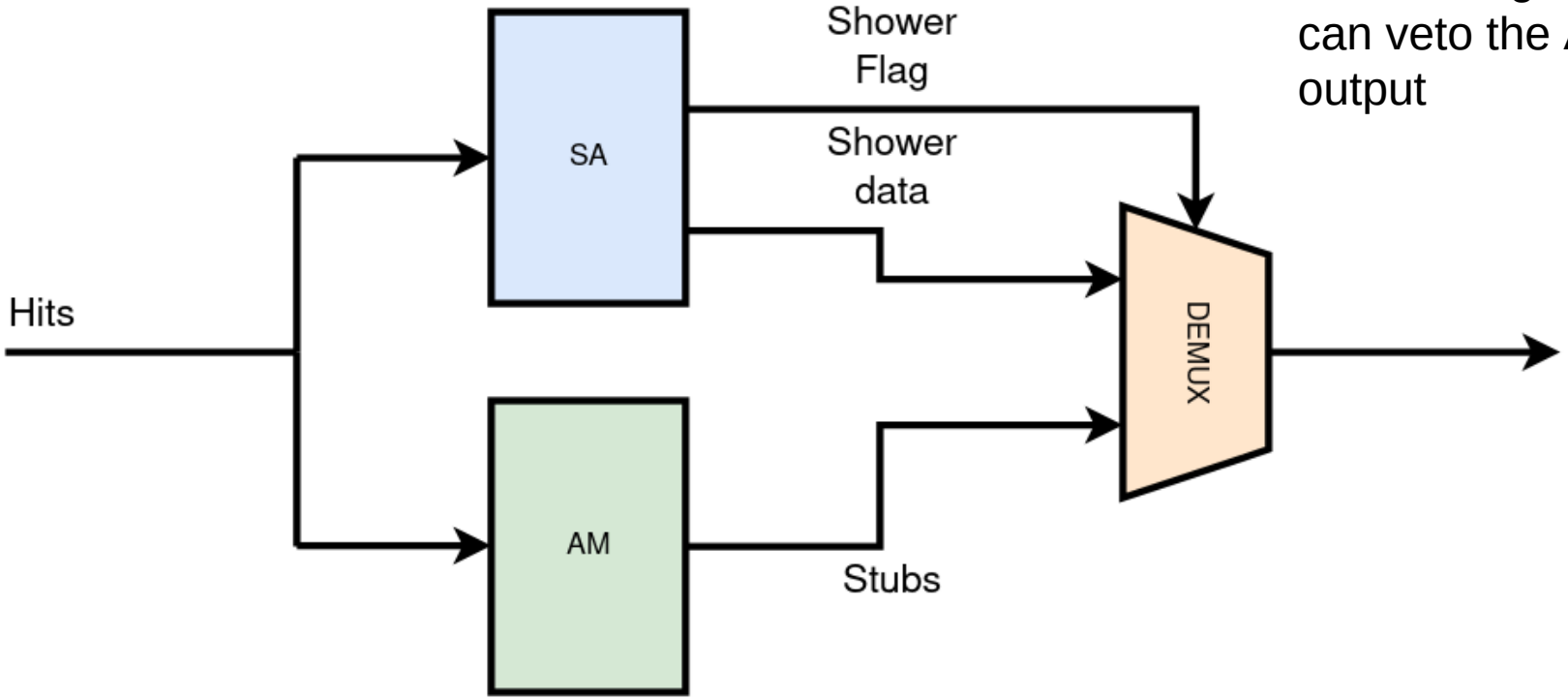
Proposed algorithm

Shower Algorithm can veto the AM output

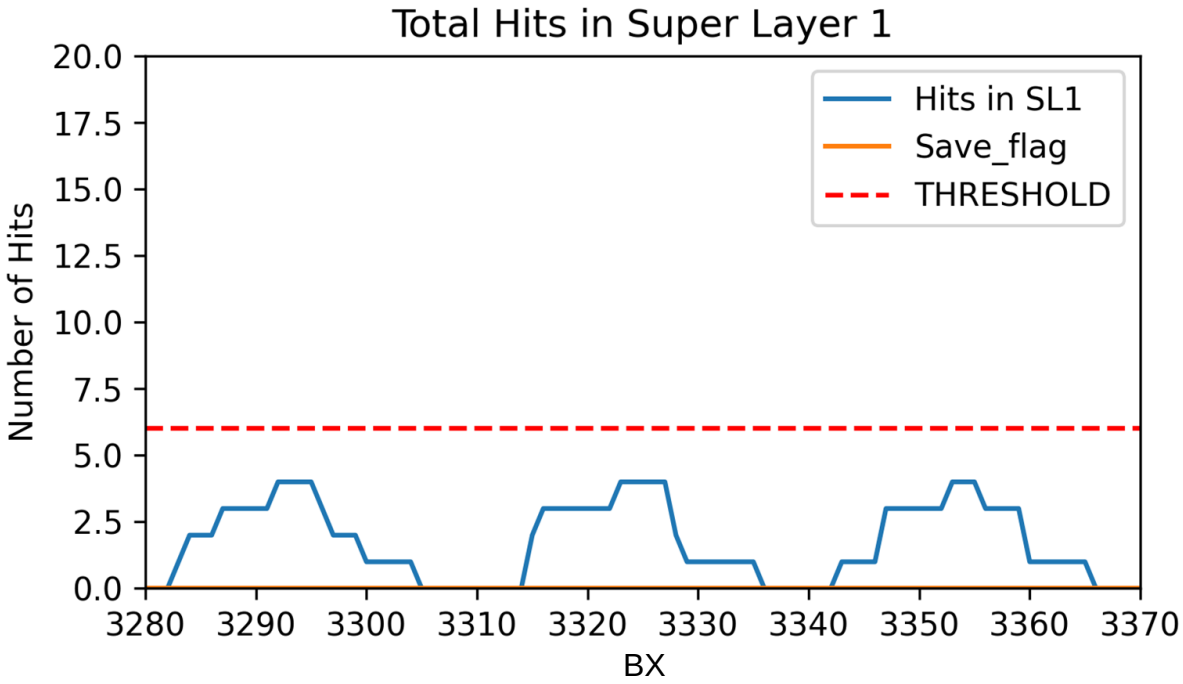


Proposed algorithm

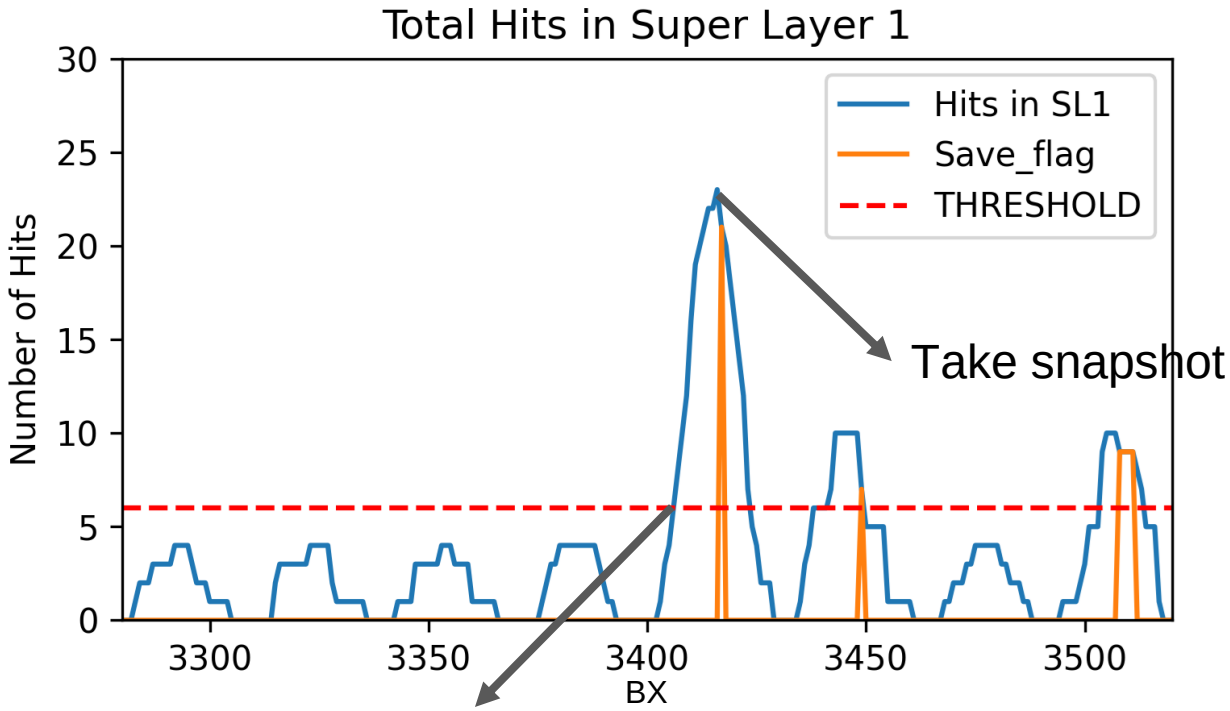
Considerations:

- Each hit is stored for 16BXs (400ns) to account for their drift times
- Hits are received serially

We can represent the total amount of hits in a given superlayer over time



Proposed algorithm



How well does it work?

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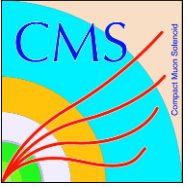

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How do we define a shower?

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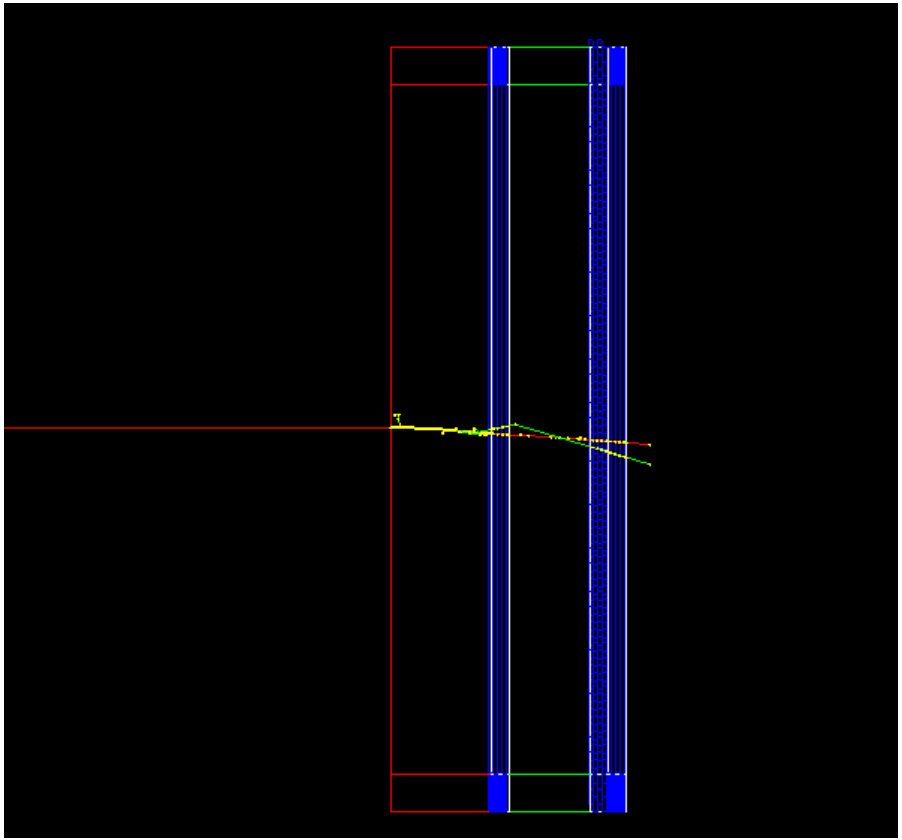
Defining a truth for the definition

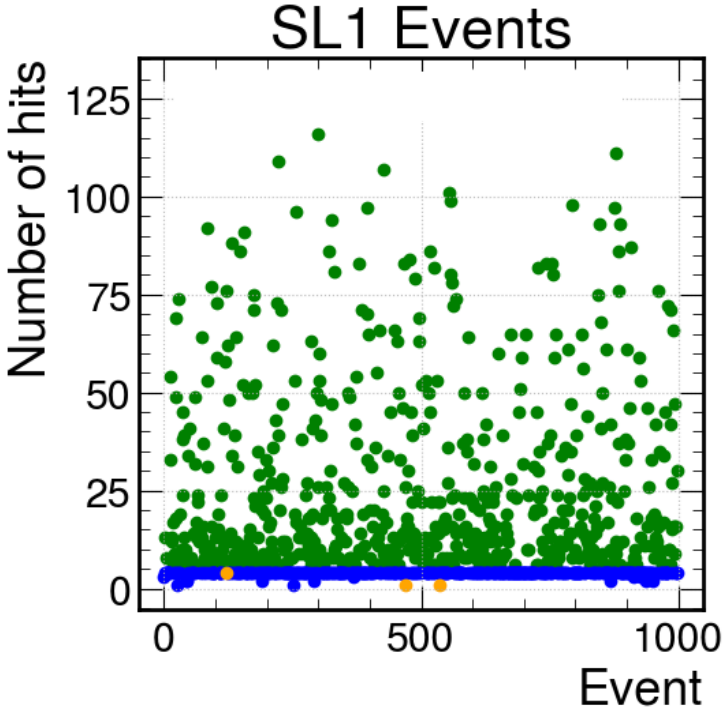
Hard to define a shower without bias.

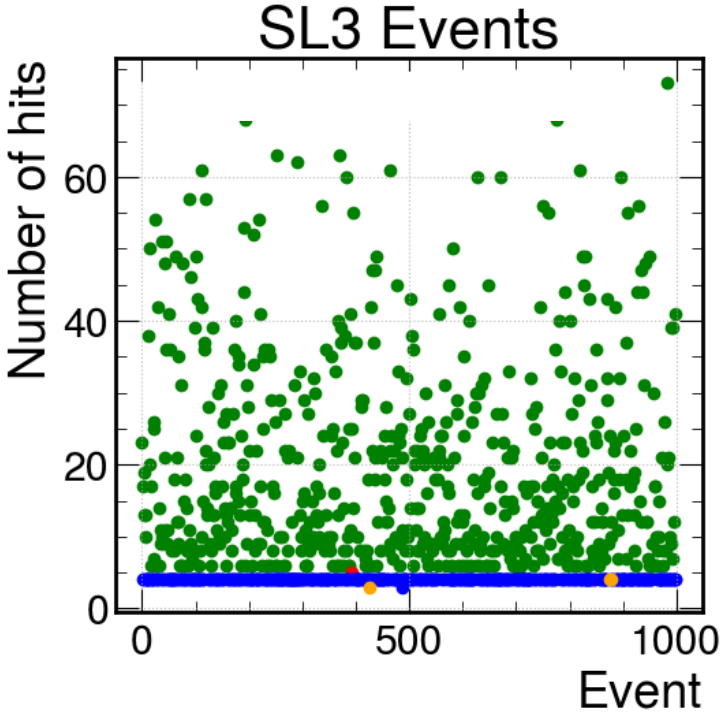
Private simulator in Geant4, reproduces the DT geometry.

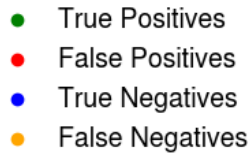
Produce events with muons above 2 TeV.



Algorithm performance



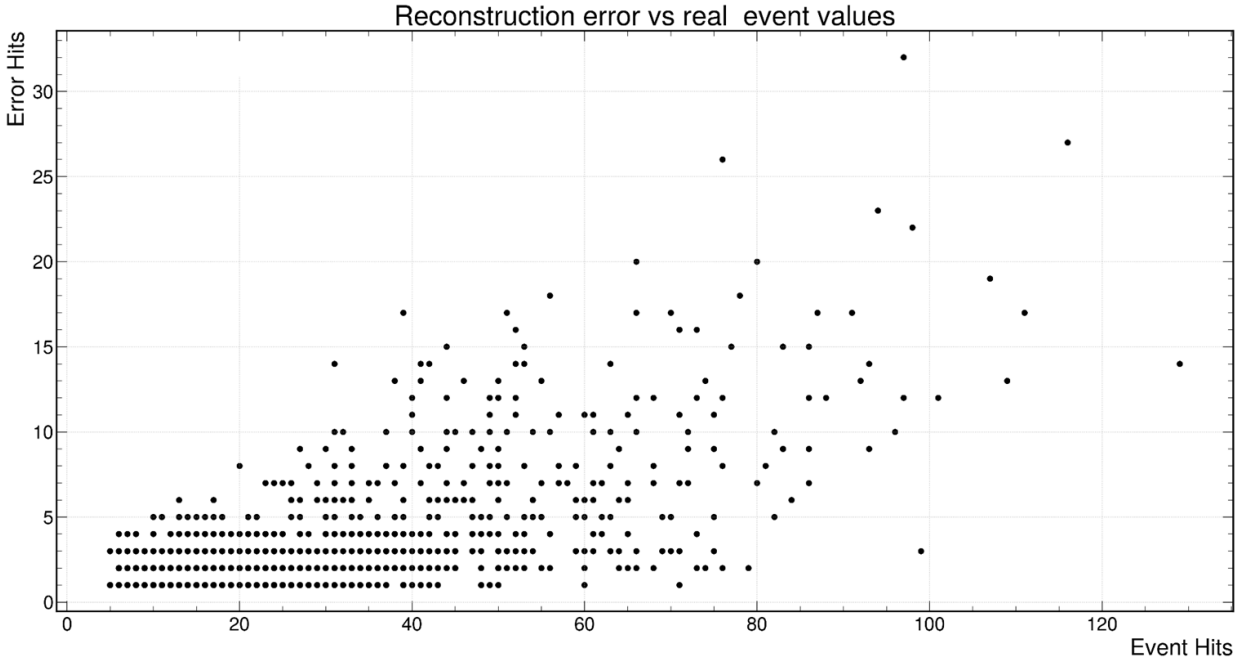




Algorithm performance

	SL1	SL2	SL3
True positives	607	614	621
False positives	0	4	1
True negatives	390	379	375
False negatives	3	3	3
Accuracy(%)	99,7	99,3	99,6
Precision(%)	100	99,4	99,8
Recall(%)	99,5	99,5	99,5
F1(%)	99,7	99,5	99,6

Algorithm performance



Number of hits lost in the reconstruction of the events.

Preliminary results!
Should be easy to improve with a more complex peak detector

Algorithm performance

Reconstruction efficiency by Super Layers			
Metric	**SL1**	**SL2**	**SL3**
Mean Absolute Error (MAE)	03.04	2.46	2.37
Mean Squared Error (MSE)	24.18	13.26	10.84
Root Mean Squared Error (RMSE)	4.92	3.64	3.29

88% of the hits corresponding to a shower event recovered

Preliminary results! Should be easy to improve!

FPGA Performance

Resource consumption with xcvu13p:

Site Type	Used	Available	Util%
CLB LUTs	7038	1728000	0.41
CLB Registers	9995	3456000	0.29
CARRY8	180	216000	0.08
F7 Muxes	72	864000	<0.01

Comparable efficiency with python emulator

Preliminary results!
Should be improved!

Identification and reconstruction close timing @480MHz

Next steps: shower parameter calculation (average position and time) not closing time yet, computationally complex

Conclusions

- Muon showers appear naturally in events with high-momentum muons and result into trigger inefficiencies. They could also appear as a hint of long-lived particles decaying far from the interaction point.
- Current trigger system in the barrel and the foreseen trigger algorithm for phase-2 is not efficient capturing these kind of events
- We present a first algorithm that allows to capture showers in the barrel muon system.
- Further work is needed in the hardware implementation and validation

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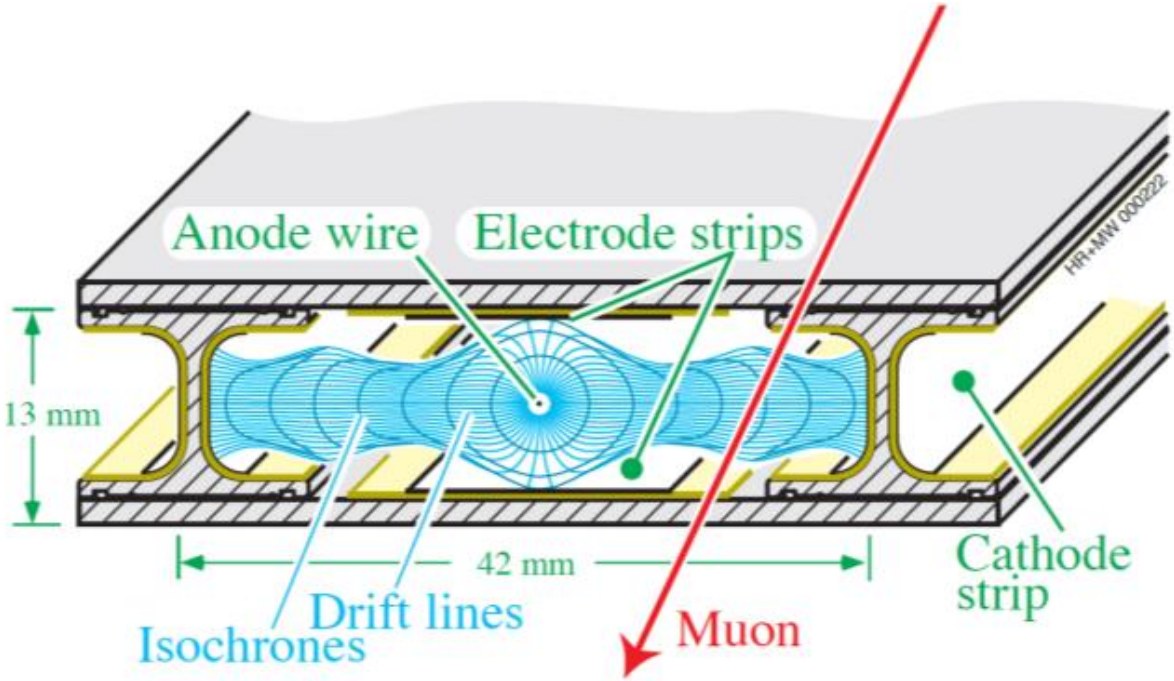
BACKUP


Anode wire
Electrode strips
13 mm
42 mm
Drift lines
Isochrones
Muon
Cathode strip

BACKUP

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14. SLR CLB Logic and Dedicated Block Utilization

Site Type	SLR0	SLR1	SLR2	SLR3	SLR0 %	SLR1 %	SLR2 %	SLR3 %
CLB	1611	0	0	0	2.98	0.00	0.00	0.00
CLBL	907	0	0	0	3.10	0.00	0.00	0.00
CLBM	704	0	0	0	2.85	0.00	0.00	0.00
CLB LUTs	7038	0	0	0	1.63	0.00	0.00	0.00
LUT as Logic	6666	0	0	0	1.54	0.00	0.00	0.00
LUT as Memory	372	0	0	0	0.19	0.00	0.00	0.00
LUT as Distributed RAM	352	0	0	0	0.18	0.00	0.00	0.00
LUT as Shift Register	20	0	0	0	0.01	0.00	0.00	0.00
CLB Registers	9995	0	0	0	1.16	0.00	0.00	0.00
CARRY8	180	0	0	0	0.33	0.00	0.00	0.00
F7 Muxes	72	0	0	0	0.03	0.00	0.00	0.00
F8 Muxes	0	0	0	0	0.00	0.00	0.00	0.00
F9 Muxes	0	0	0	0	0.00	0.00	0.00	0.00
Block RAM Tile	1	0	0	0	0.15	0.00	0.00	0.00
RAMB36/FIFO	0	0	0	0	0.00	0.00	0.00	0.00
RAMB18	2	0	0	0	0.15	0.00	0.00	0.00
URAM	0	0	0	0	0.00	0.00	0.00	0.00
DSPs	2	0	0	0	0.07	0.00	0.00	0.00
Unique Control Sets	575	0	0	0	0.53	0.00	0.00	0.00