

Triggering on muon showers

Javier Prado Pico
on behalf of the CMS collaboration

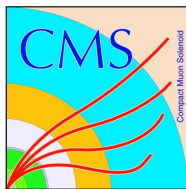
TWEPP 2024



Funded by
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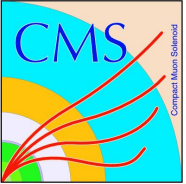
European Research Council
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ICTEA
Instituto Universitario de Ciencias
y Tecnologías Espaciales de Asturias



Introduction



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What are muon showers?

How are they produced?

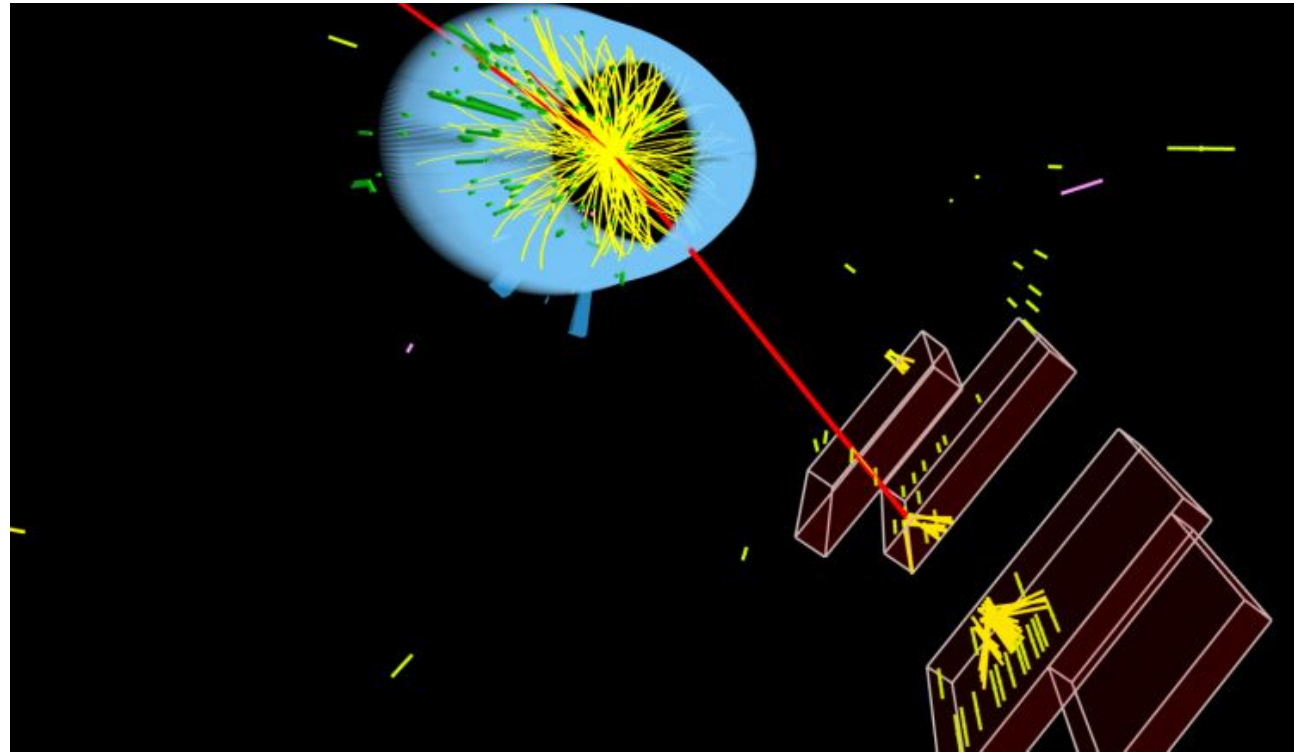
Why are they important?

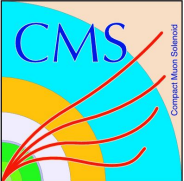
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What are muon showers?

Characterized by a high amount of secondary particles

Muon producing a shower in the second and third station





Bremsstrahlung



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Atomic number

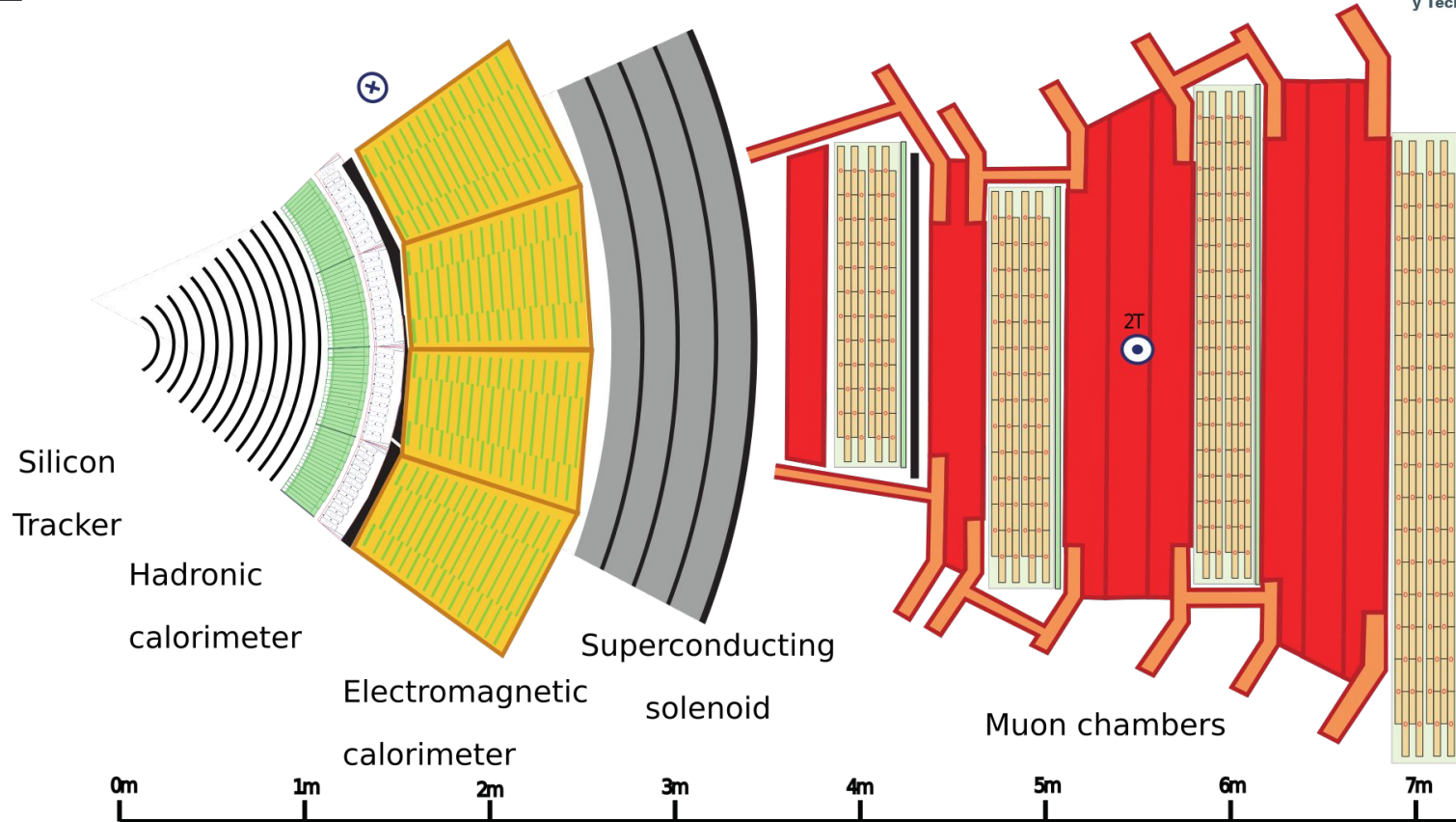
Thickness

Probability of radiating

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

Radiation length of the material

Bremsstrahlung





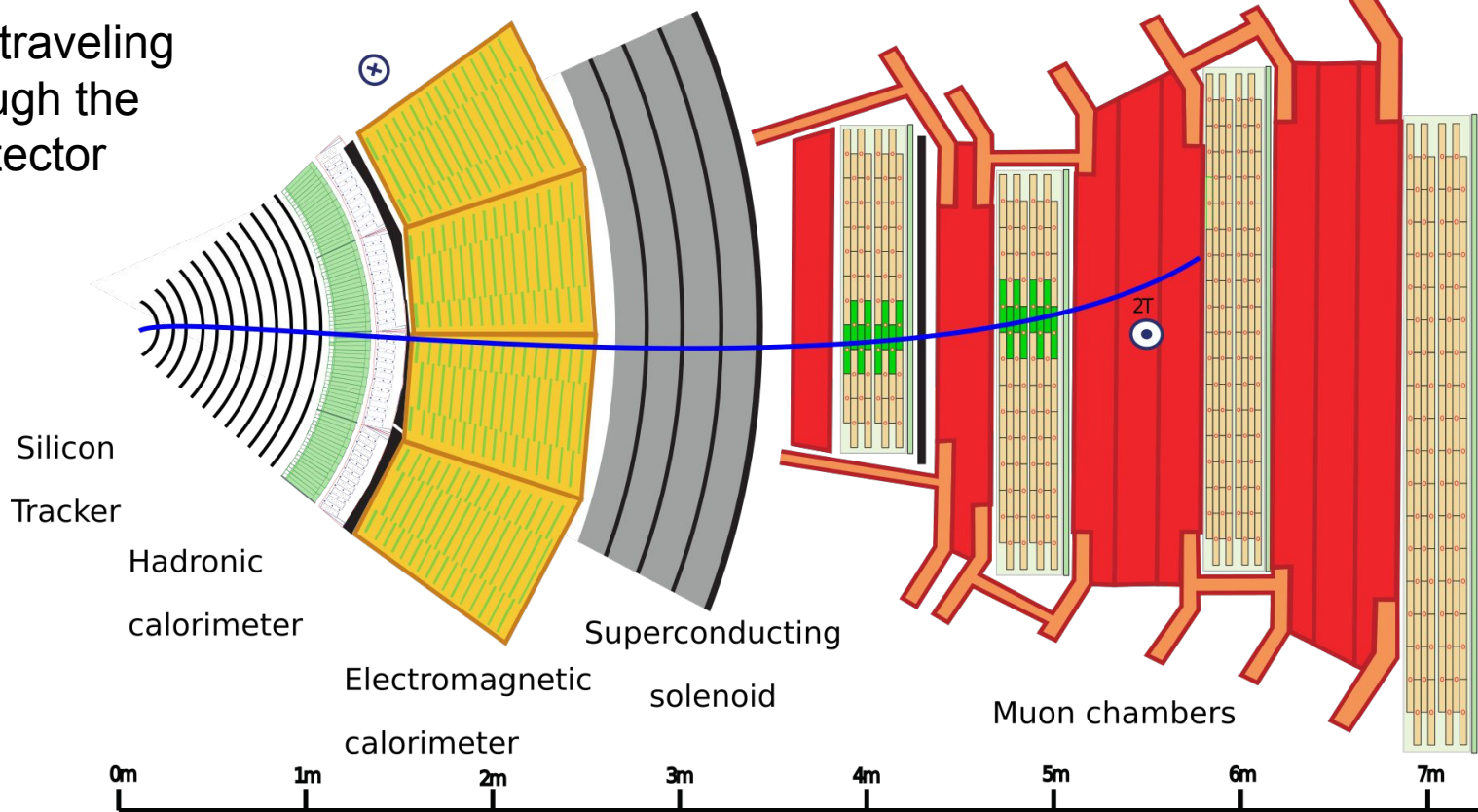
Bremsstrahlung

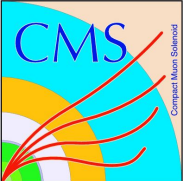


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Muon traveling through the detector





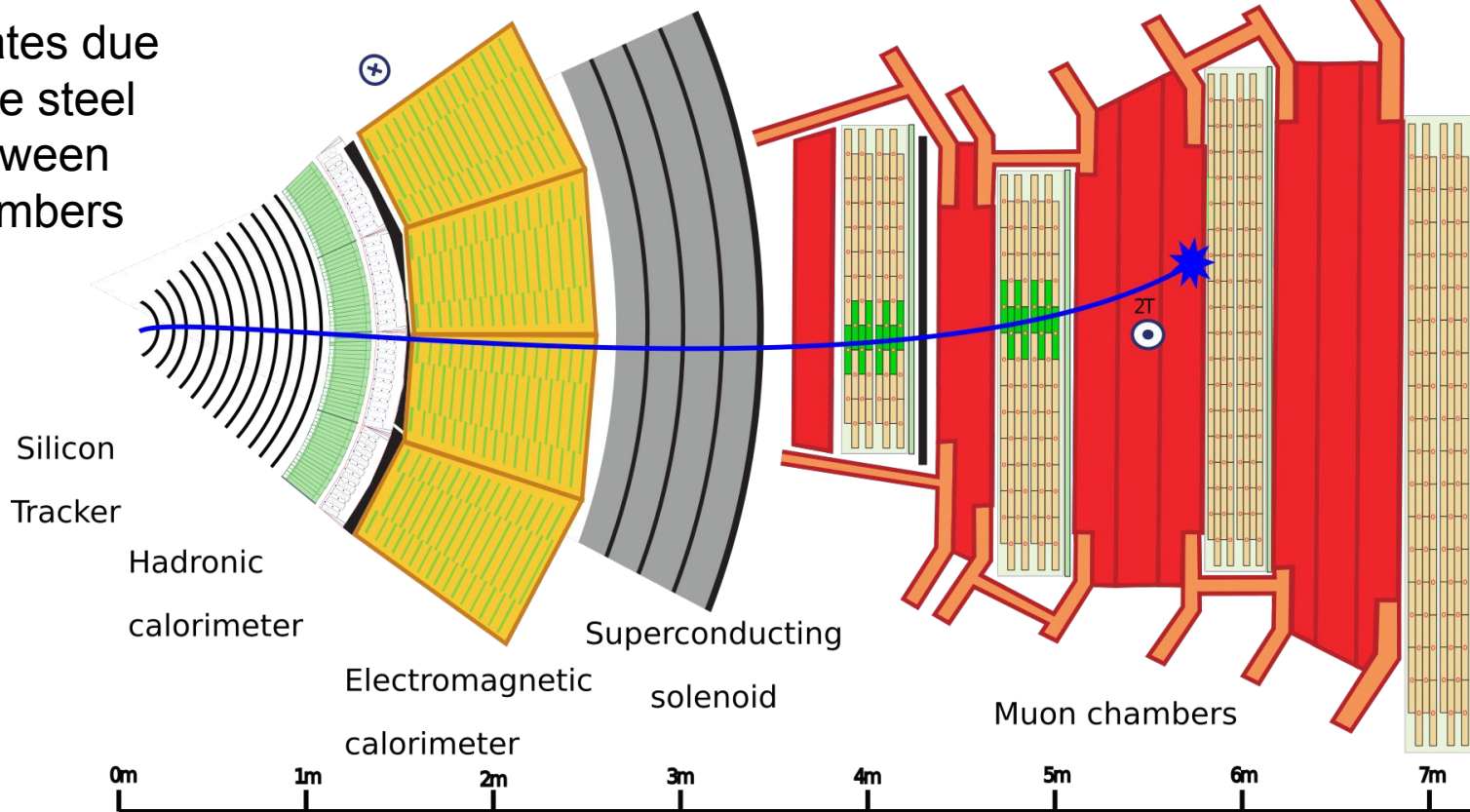
Bremsstrahlung

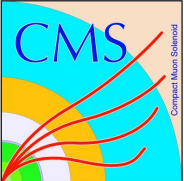


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Radiates due to the steel between chambers





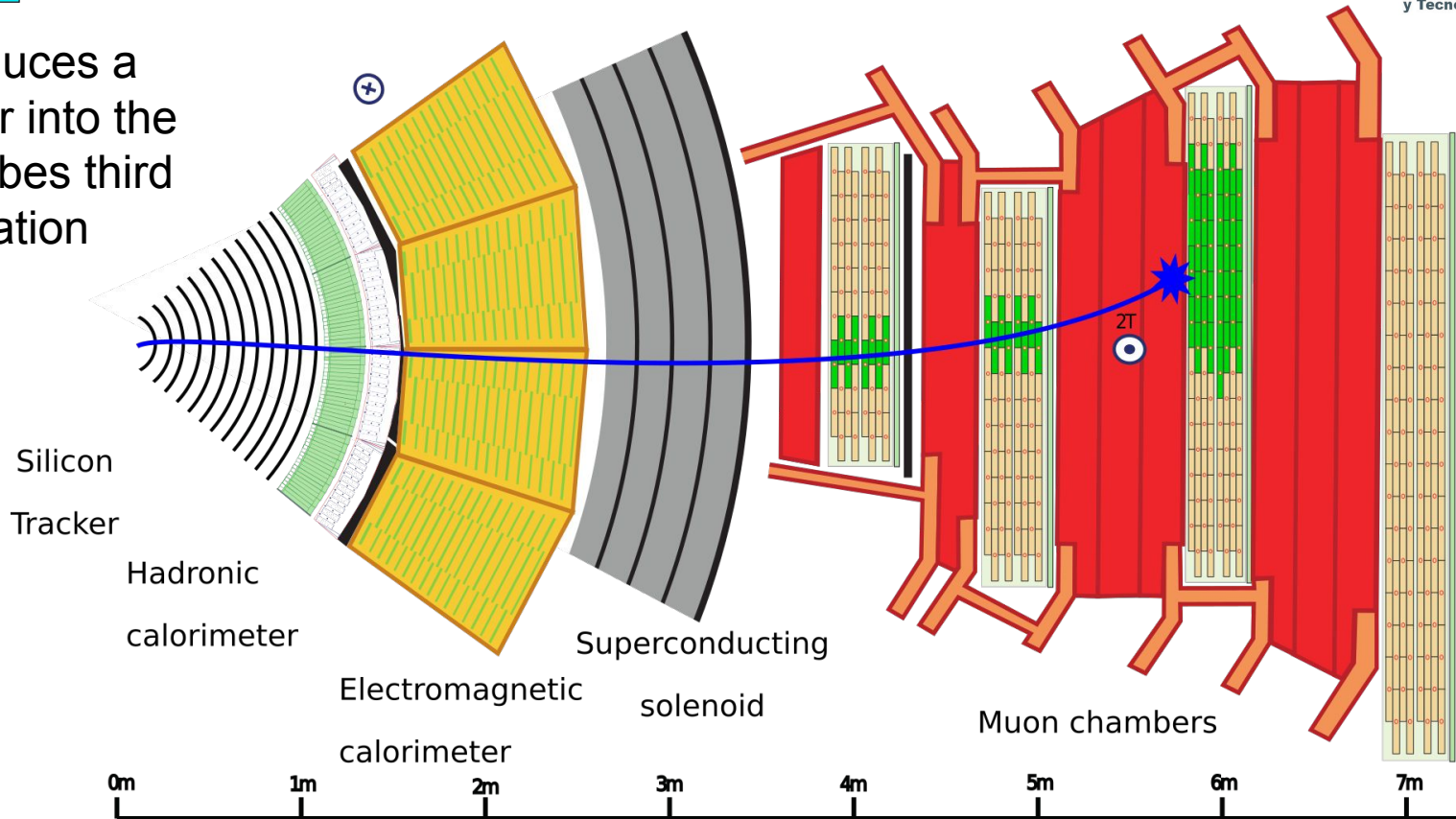
Bremsstrahlung

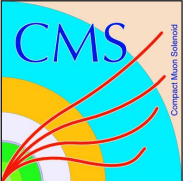


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Produces a shower into the drift tubes third station





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Long-lived particles

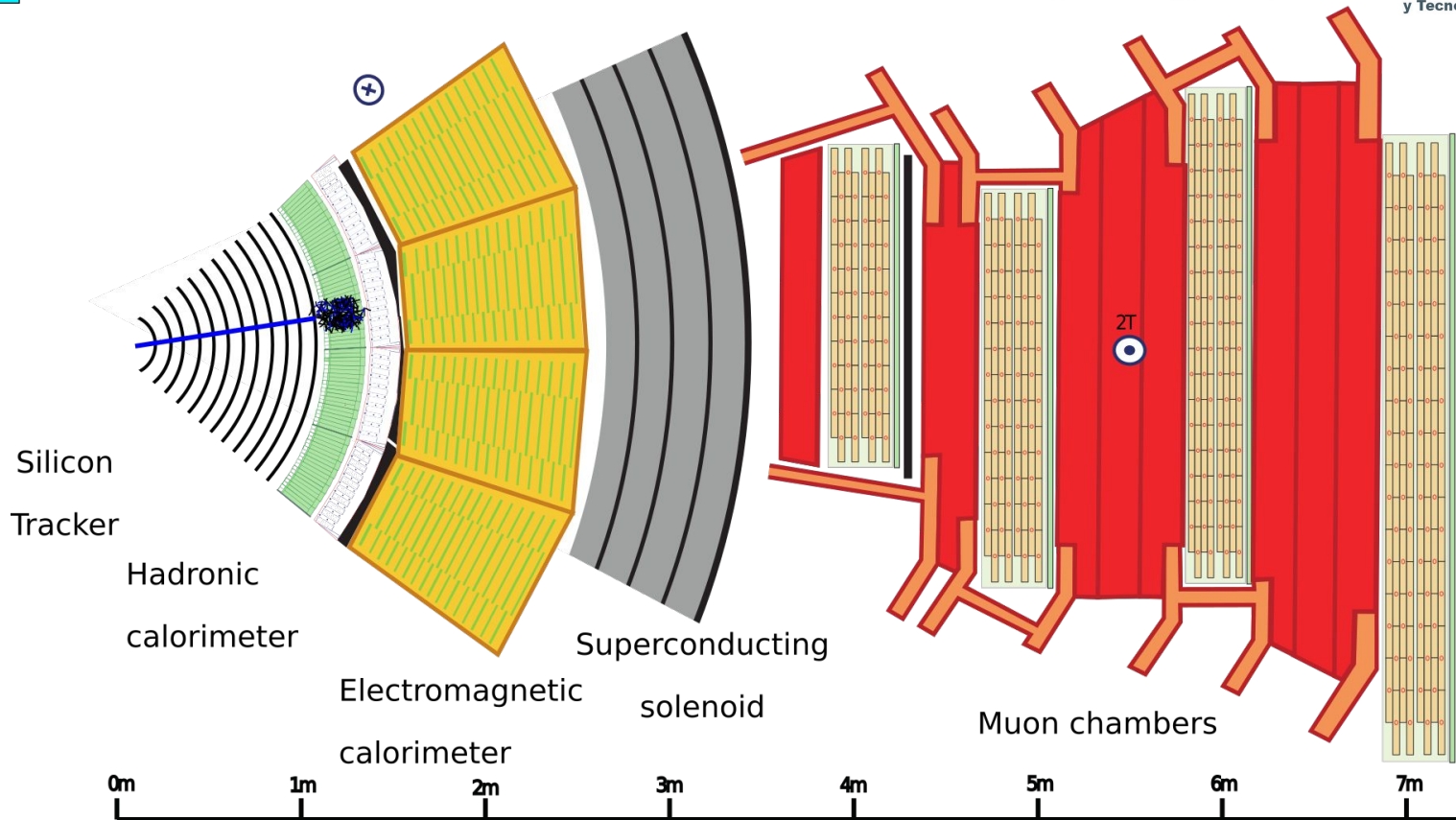
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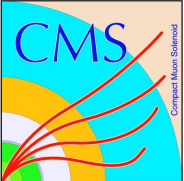


Long-lived particles



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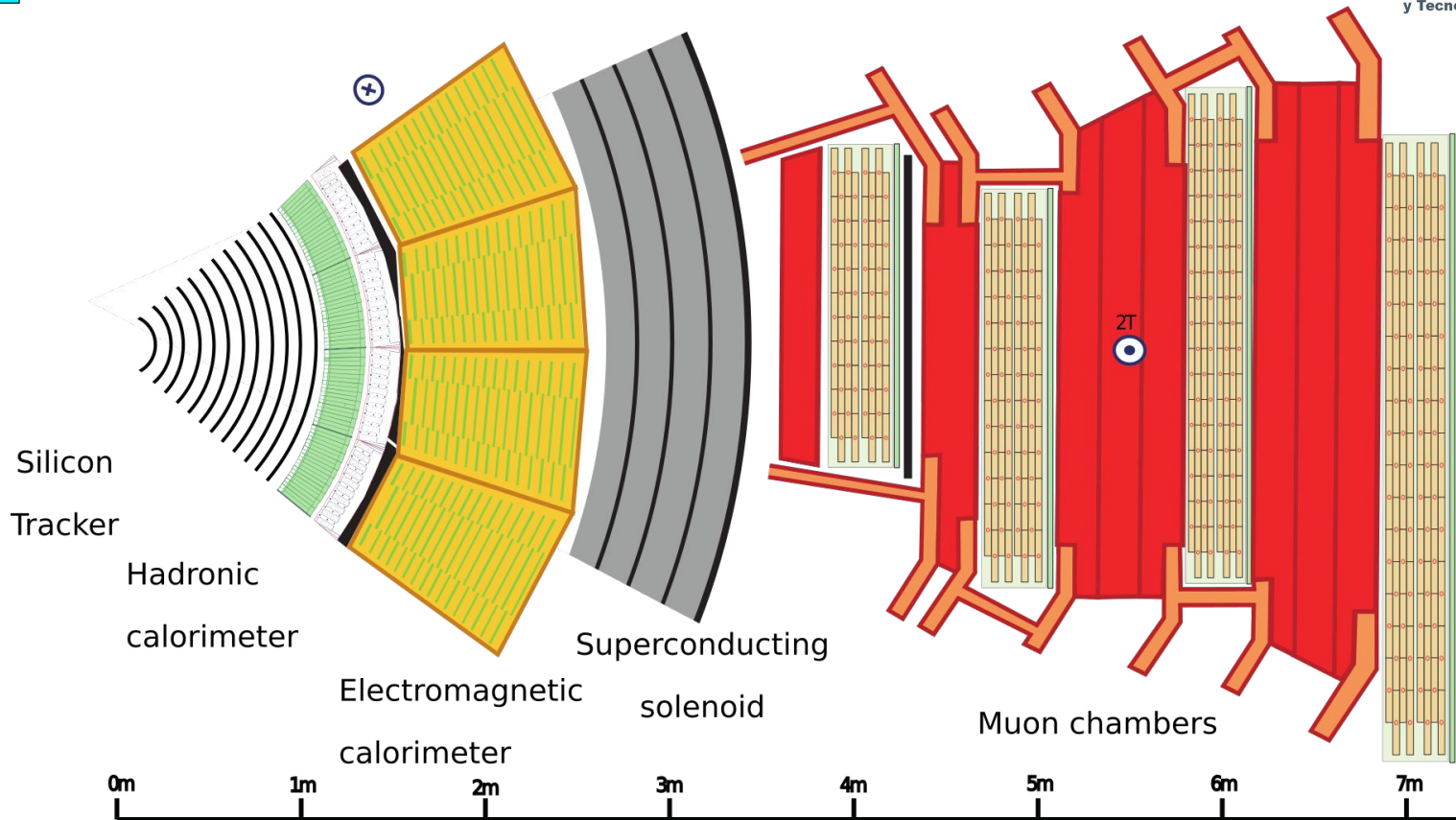


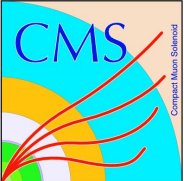


Long-lived particles



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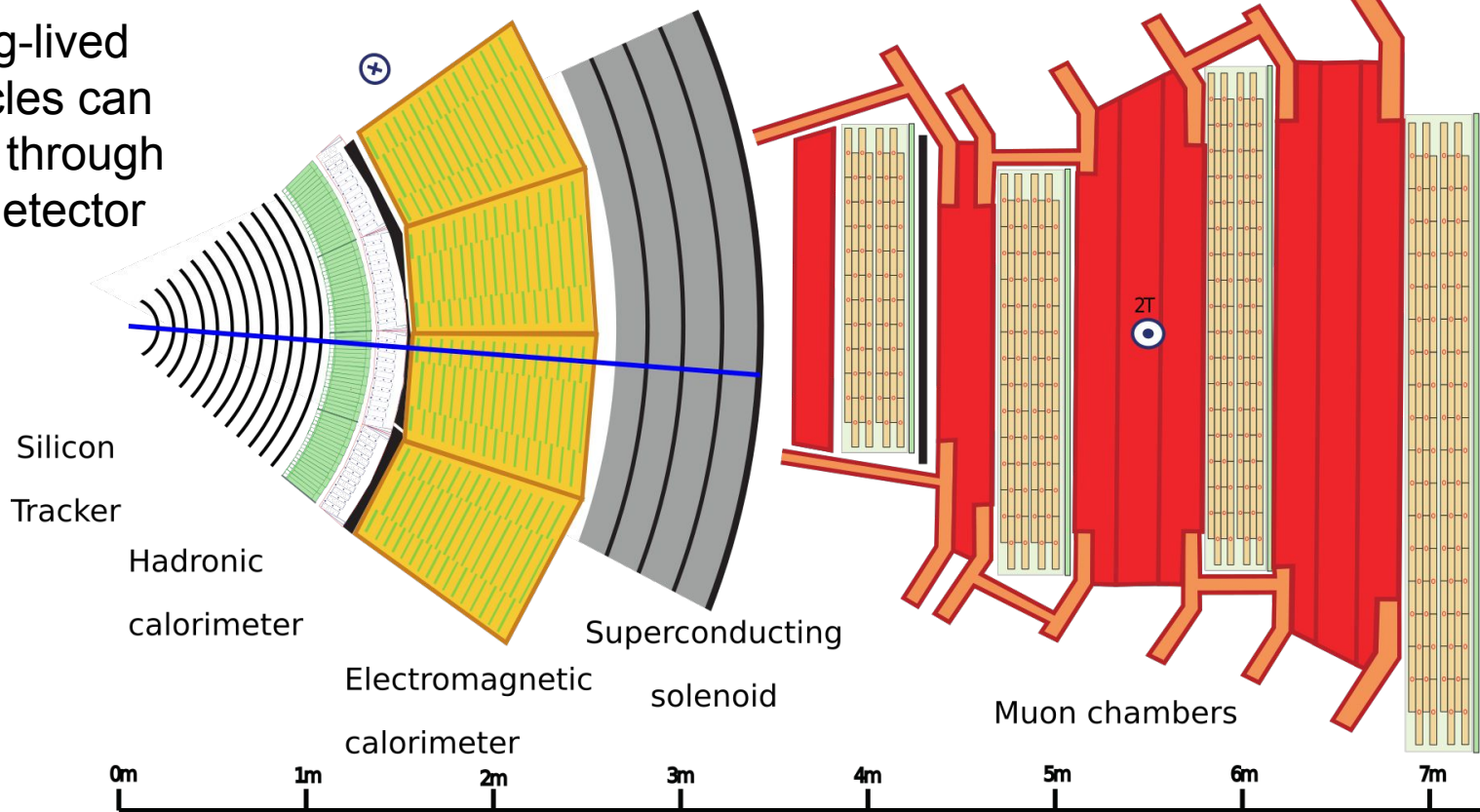
Long-lived particles

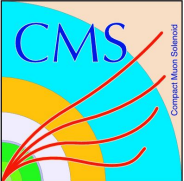


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Long-lived particles can travel through the detector





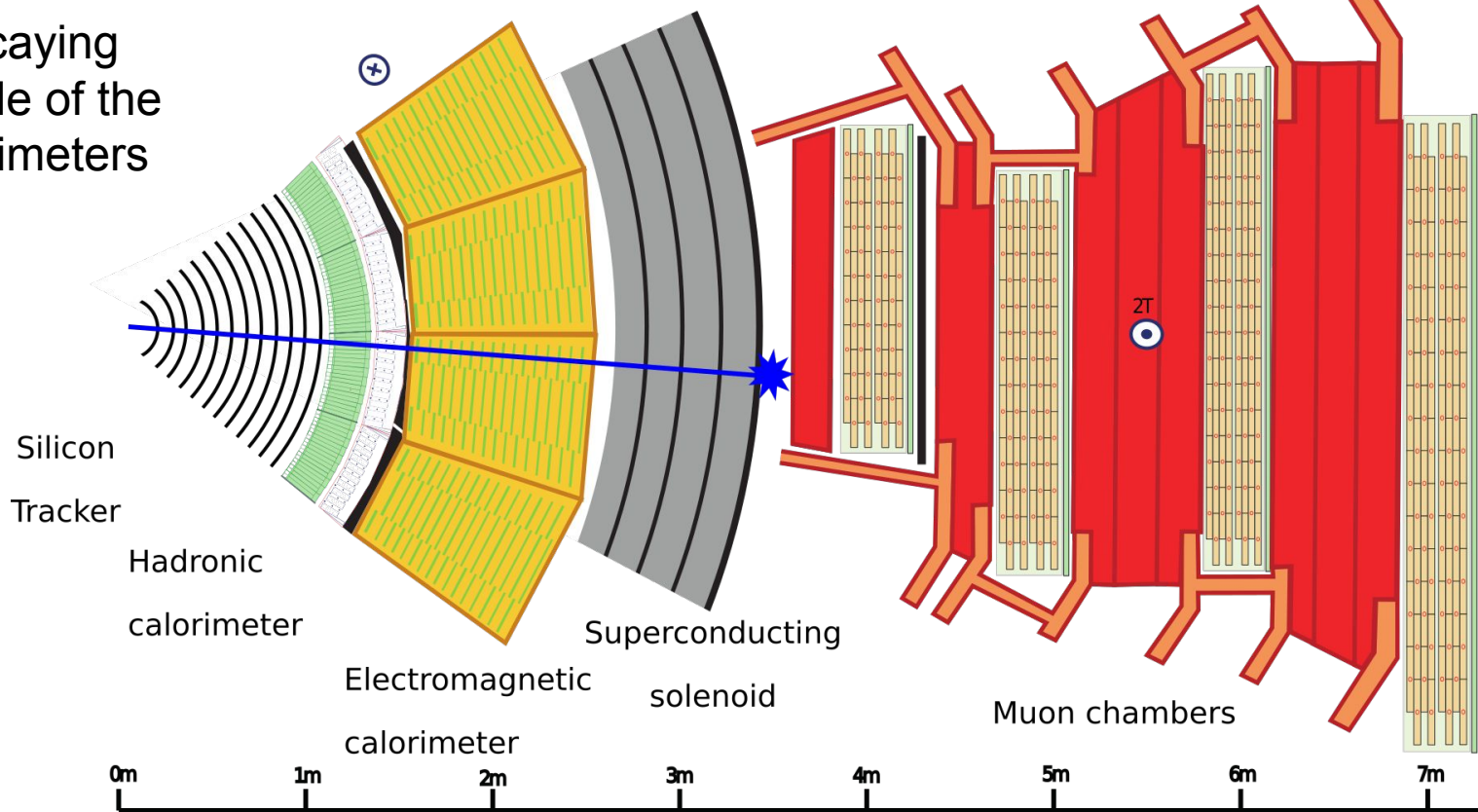
Long-lived particles

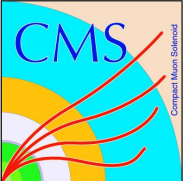


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Decaying
outside of the
calorimeters





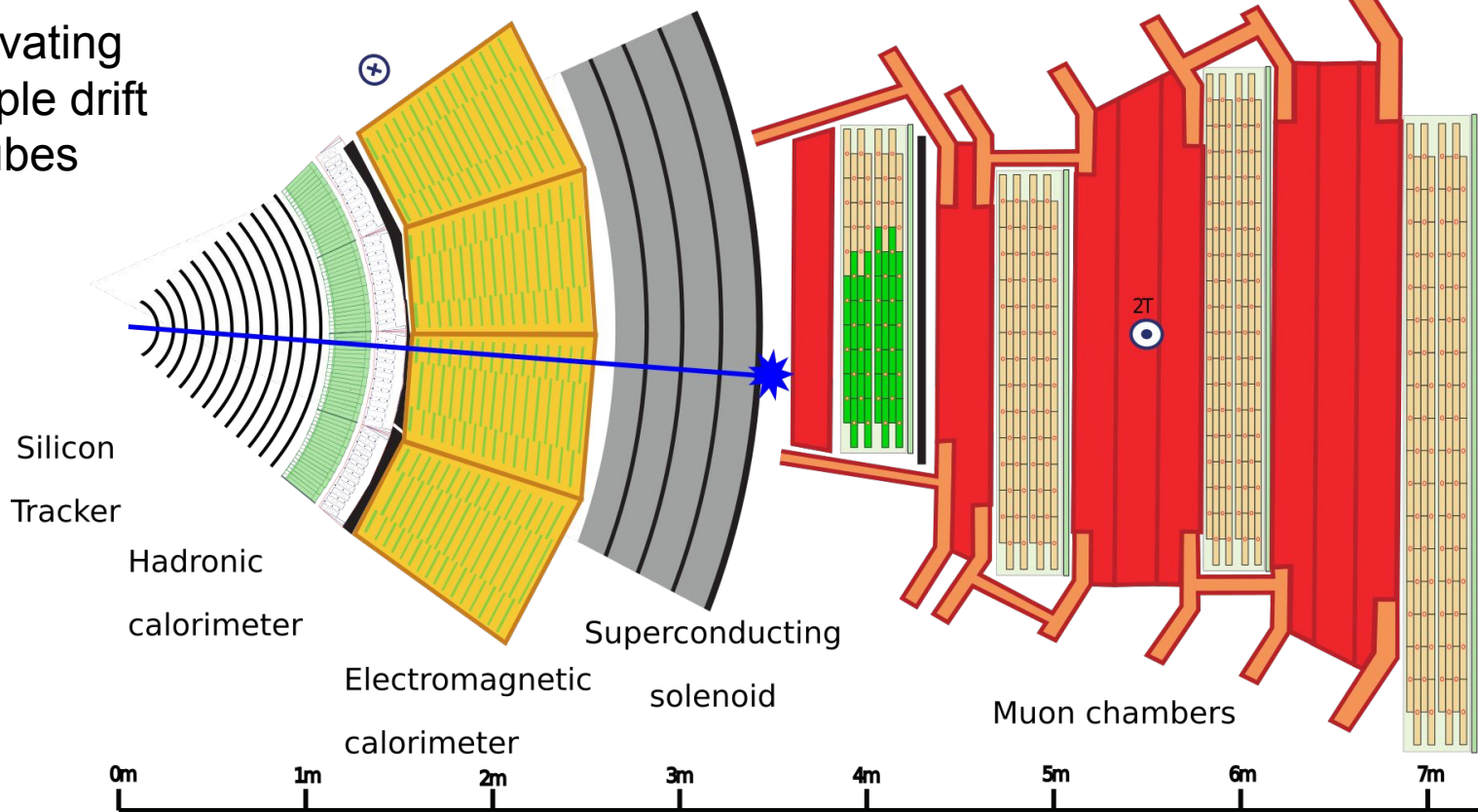
Long-lived particles

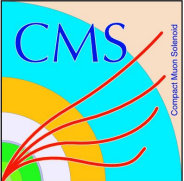


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Activating
multiple drift
tubes





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Physics Motivations

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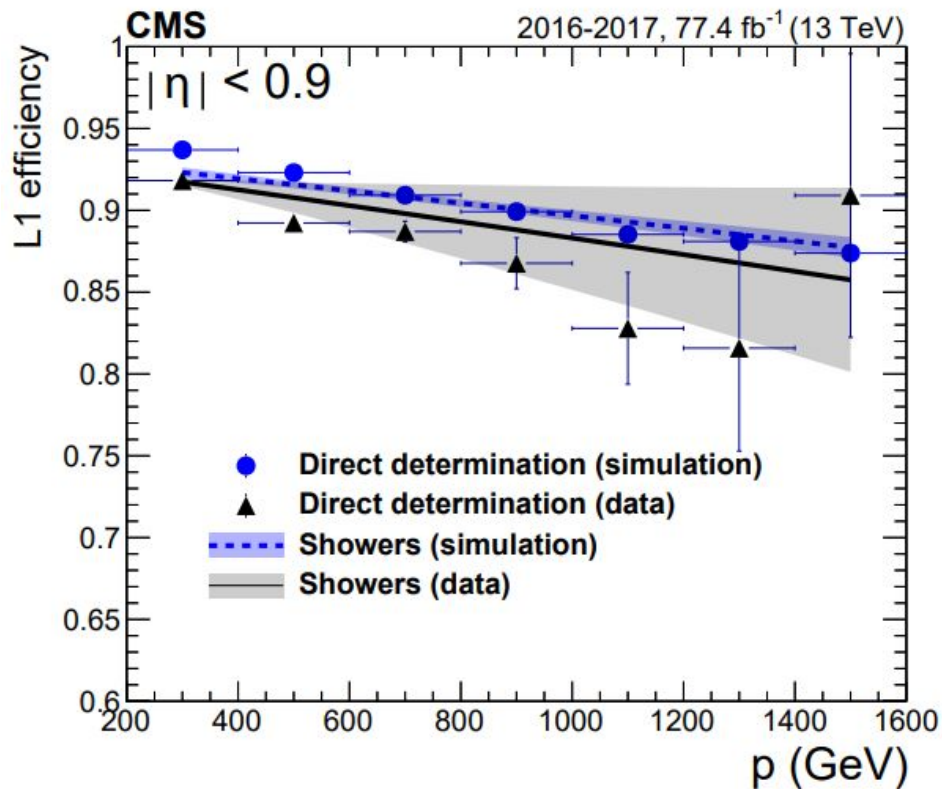
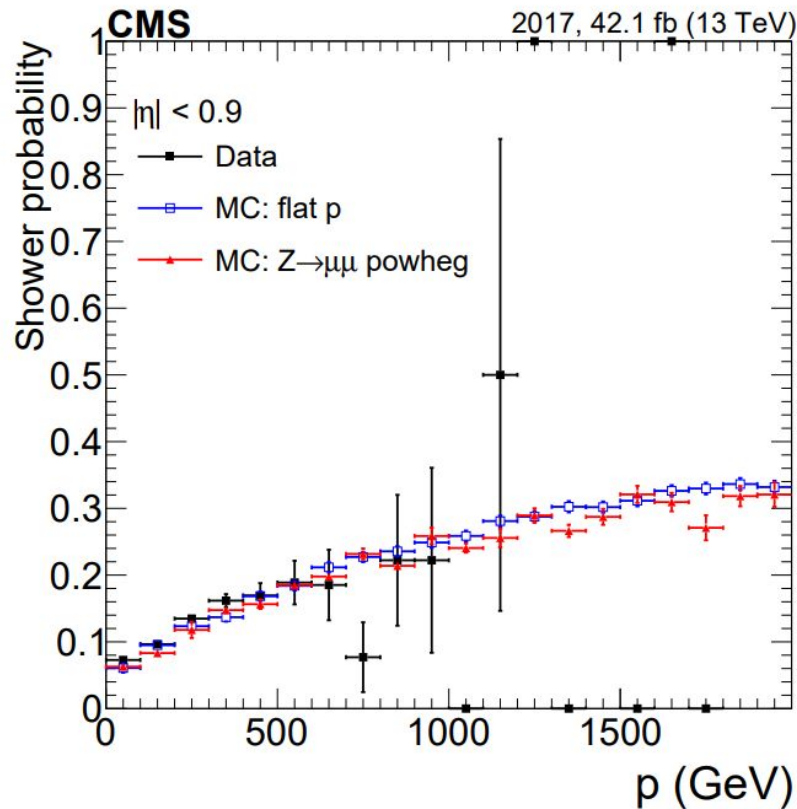


Physics Motivations

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Physics motivation

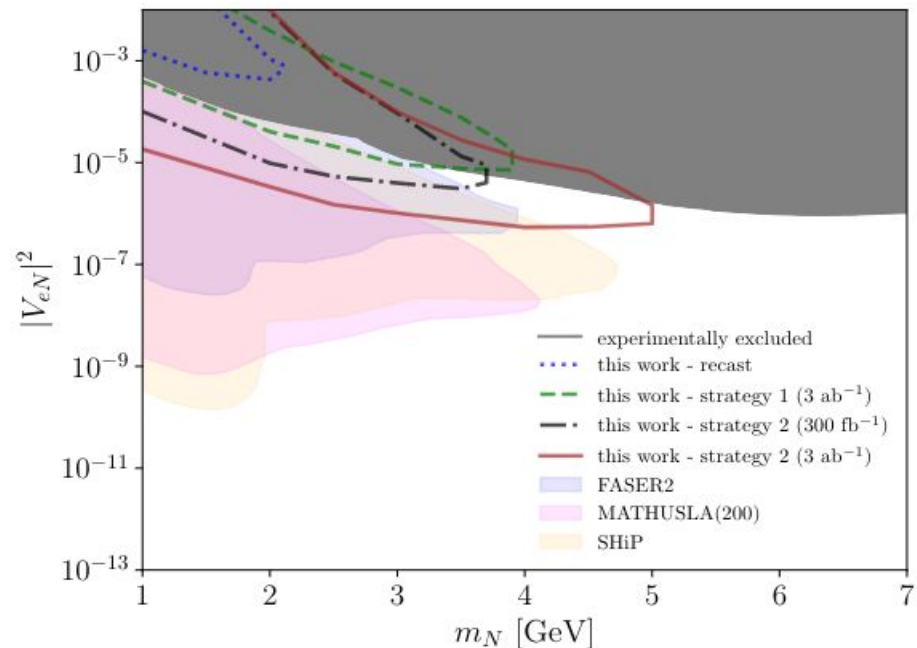
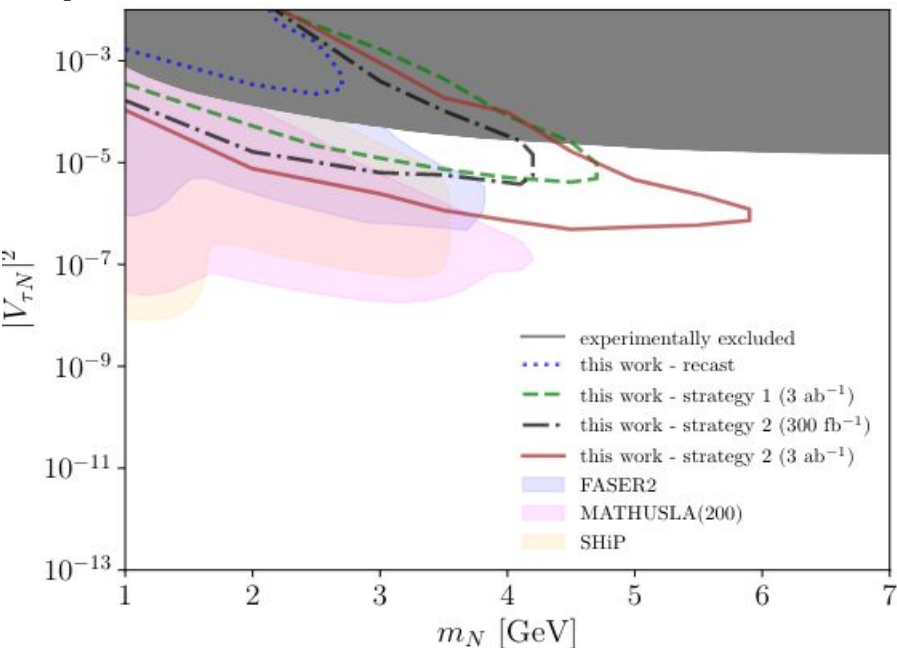


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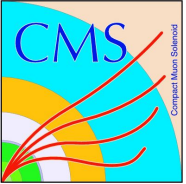


Increase sensitivity by several orders of magnitude to search for heavy neutral leptons

arXiv:2210.17446



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



Introduction



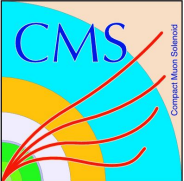
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How do we get this information from the detector?

Any solution to the previous problems?

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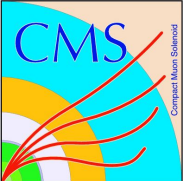


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Trigger system

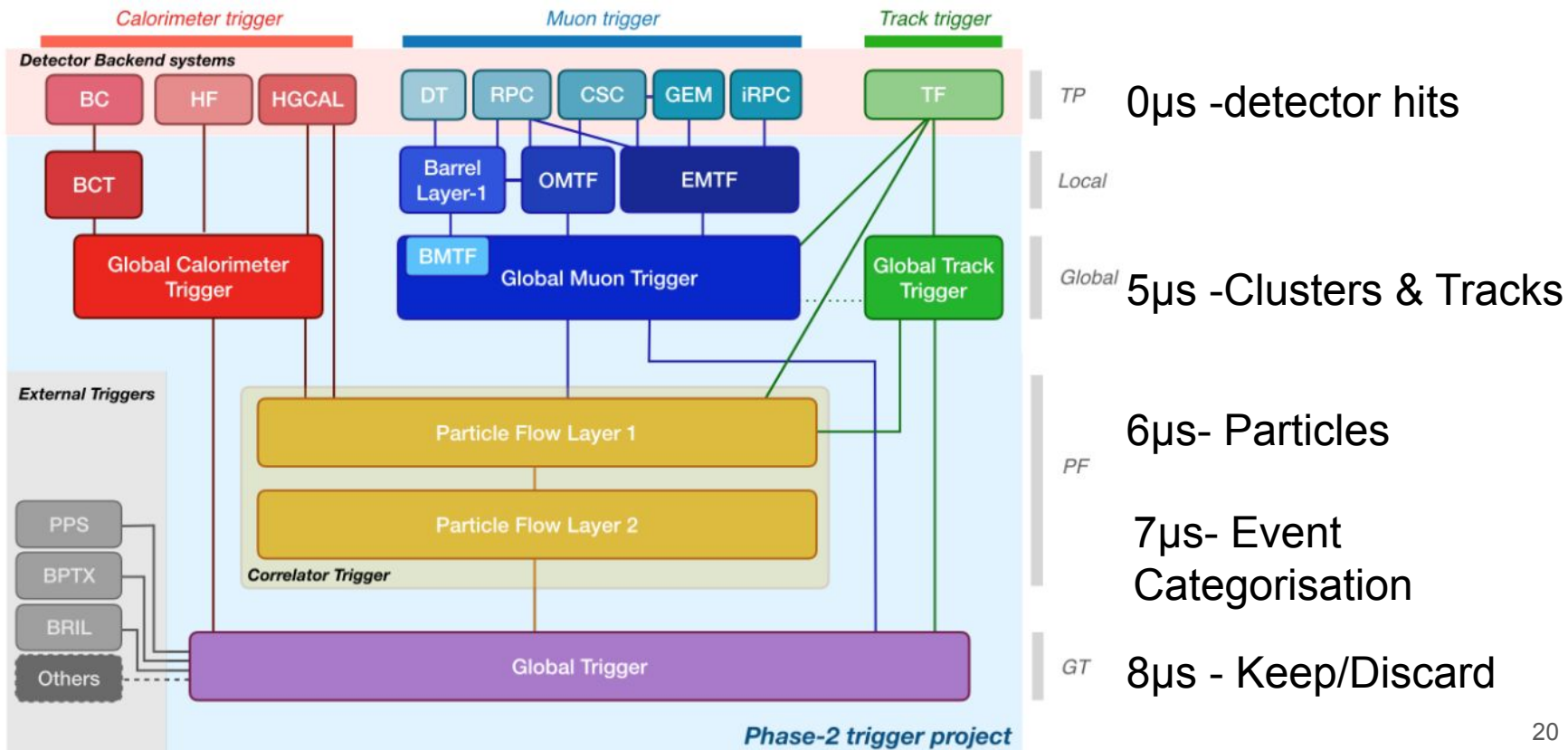
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Trigger system



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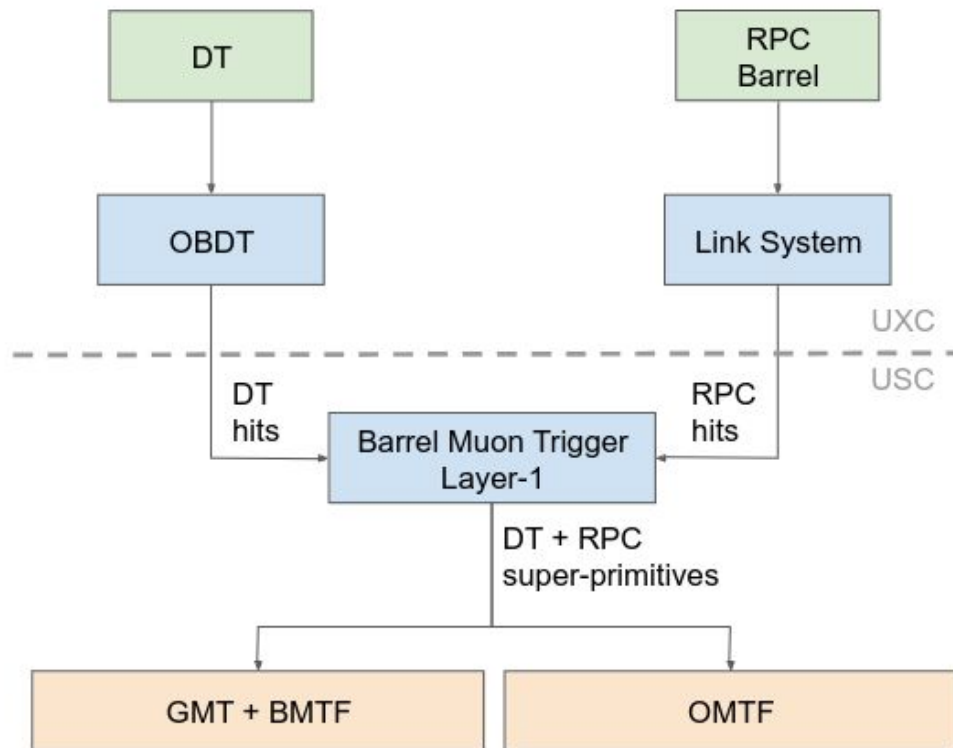
Trigger system



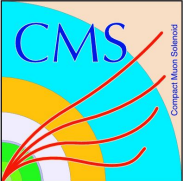
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DT+RPC super primitives



Trigger system for HL-LHC

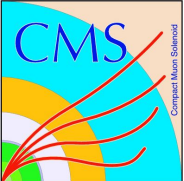


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Triggering in the drift tubes

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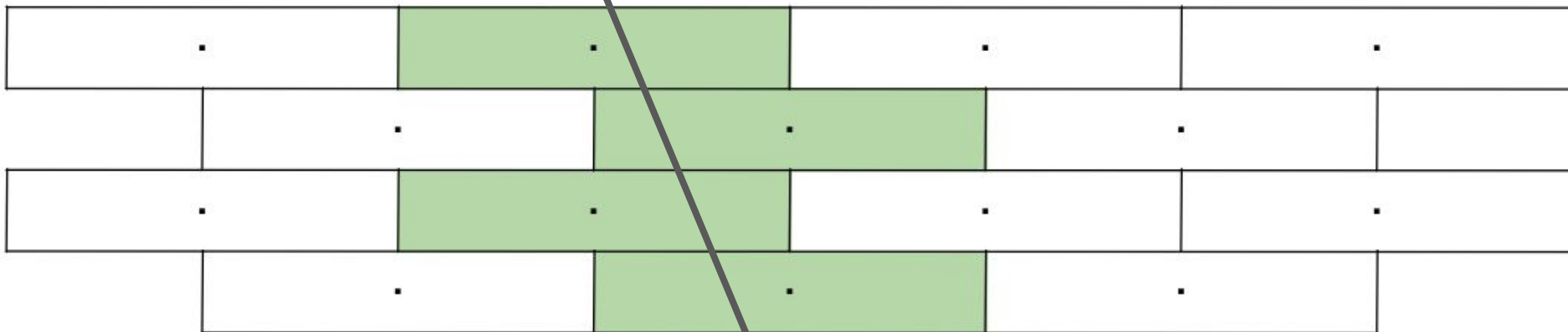
Local DTs reconstruction



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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.



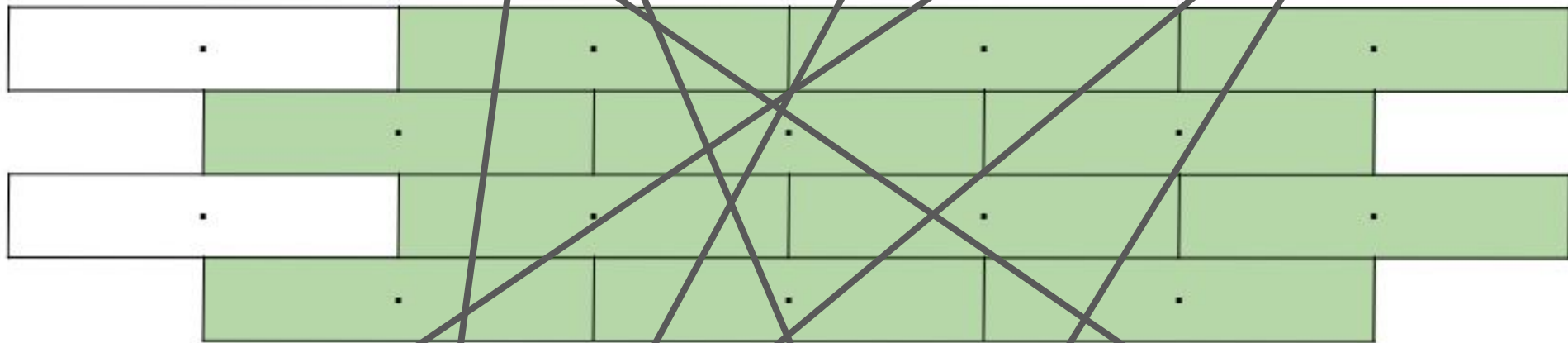
Local DTs reconstruction



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What happens if a muon radiates?



Many active cells

Many possible tracks to calculate!

Waste of time and spurious data



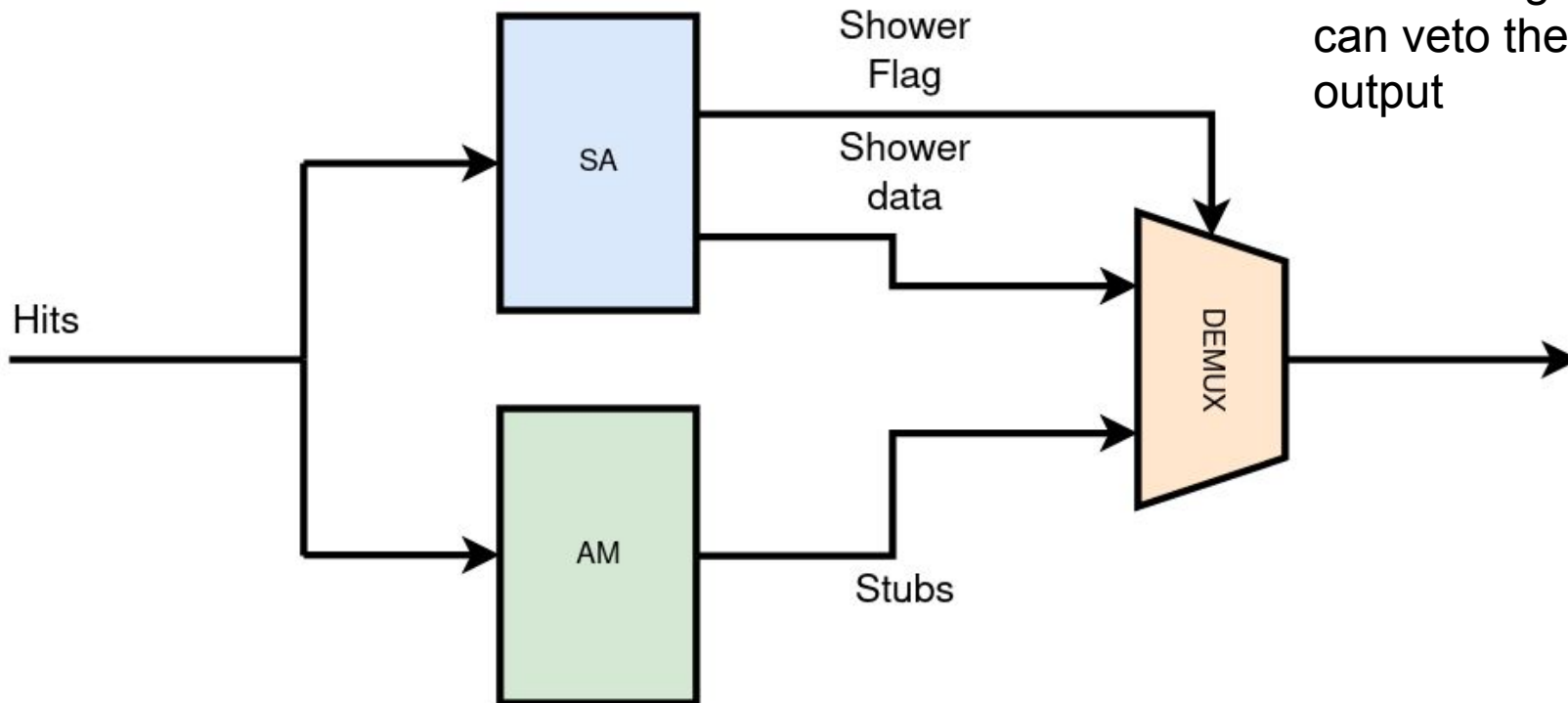
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How can we solve it?

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Proposed algorithm

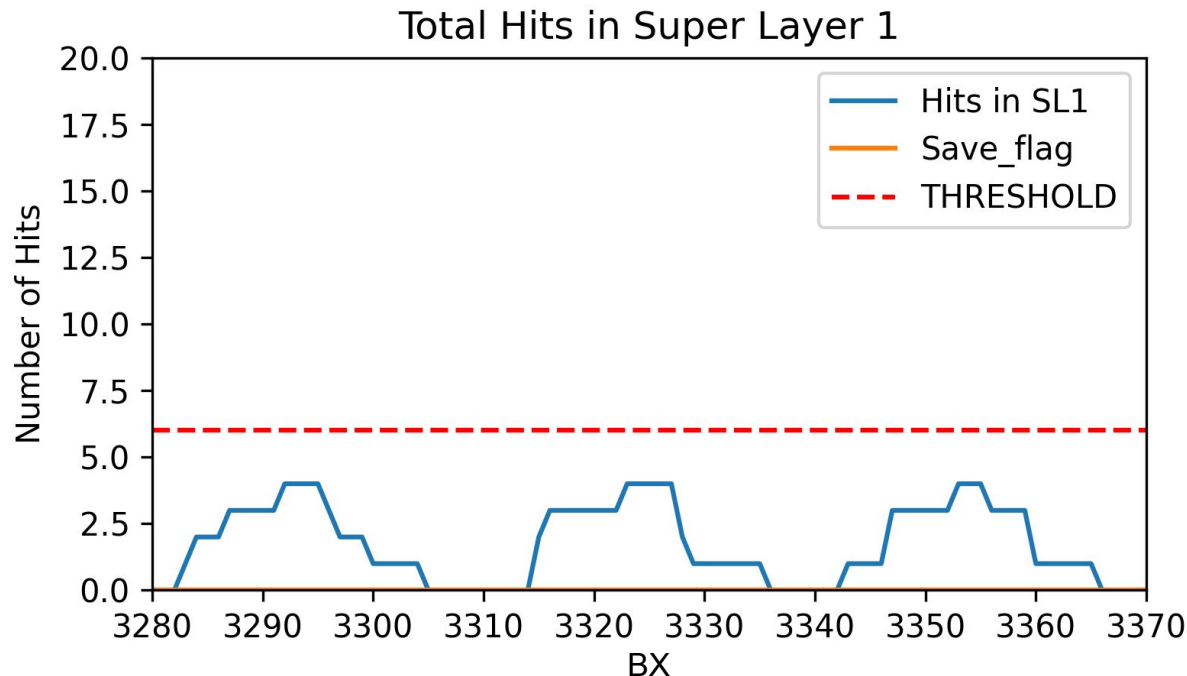


Shower Algorithm
can veto the AM
output

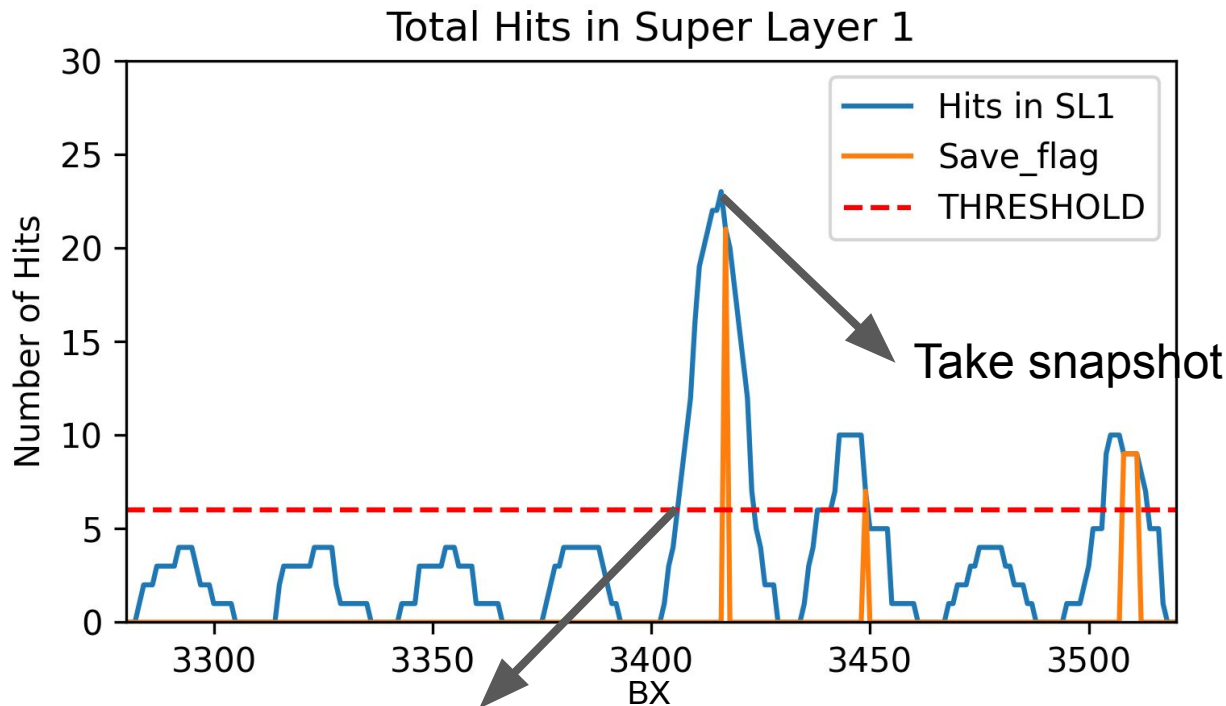
Considerations:

- 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



Signal AM to stop

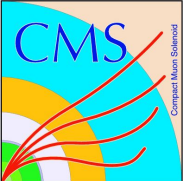


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How well does it work?

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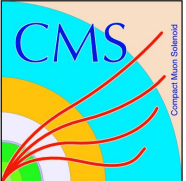


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How do we define a shower?

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Defining a truth for the definition



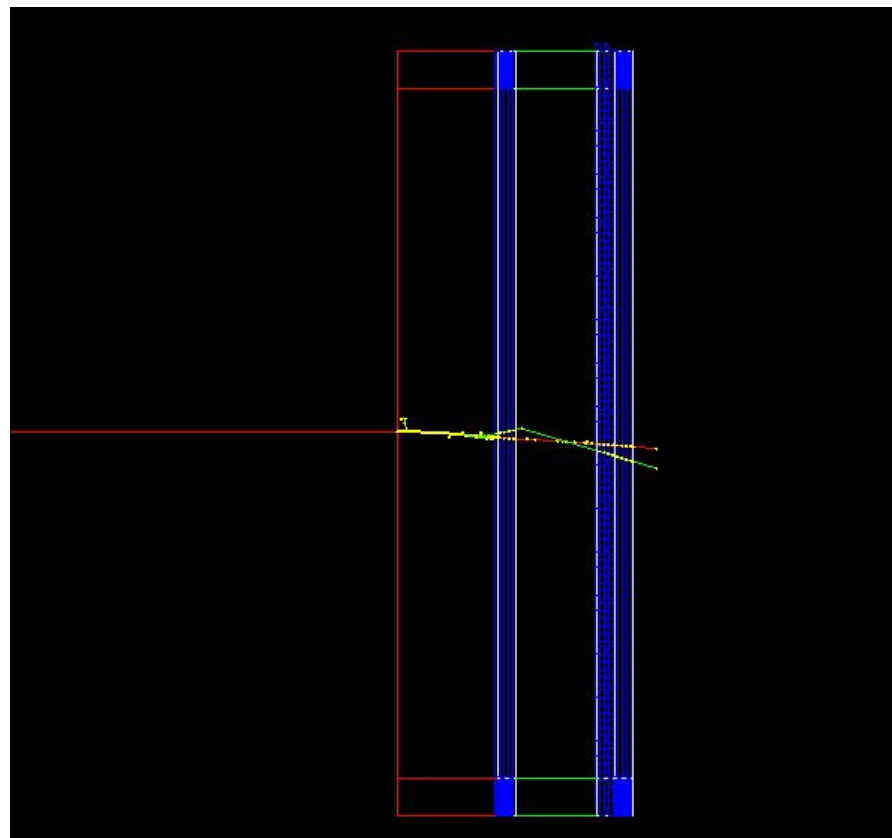
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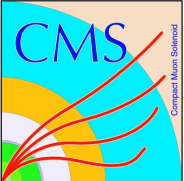


Hard to define a shower without bias.

Private simulator in Geant4, reproduces the DT geometry.

Produce events with muons above 2 TeV.





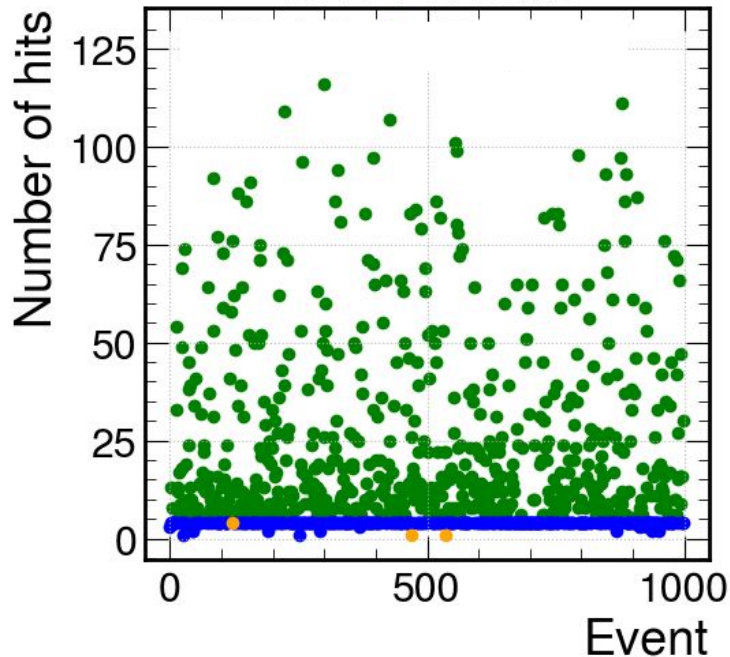
Algorithm performance



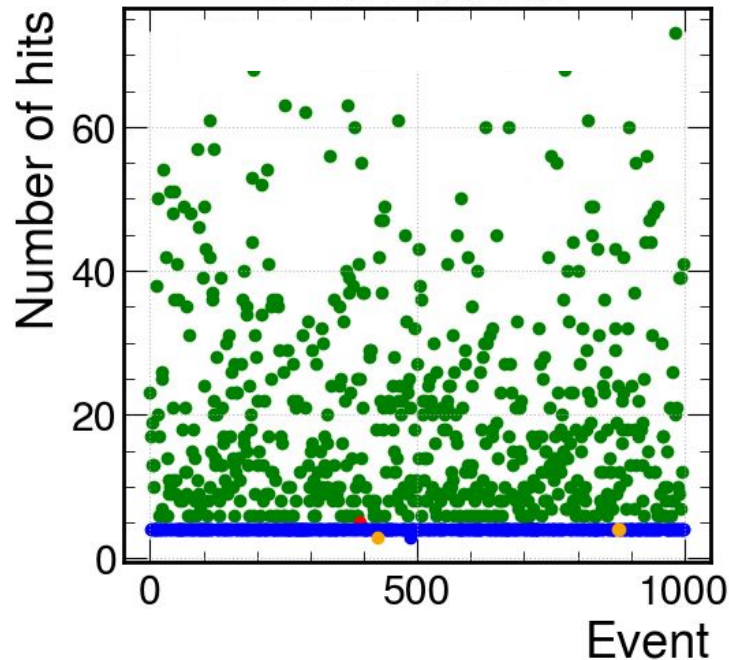
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SL1 Events



SL3 Events

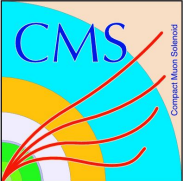


- True Positives
- False Positives
- True Negatives
- False Negatives

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



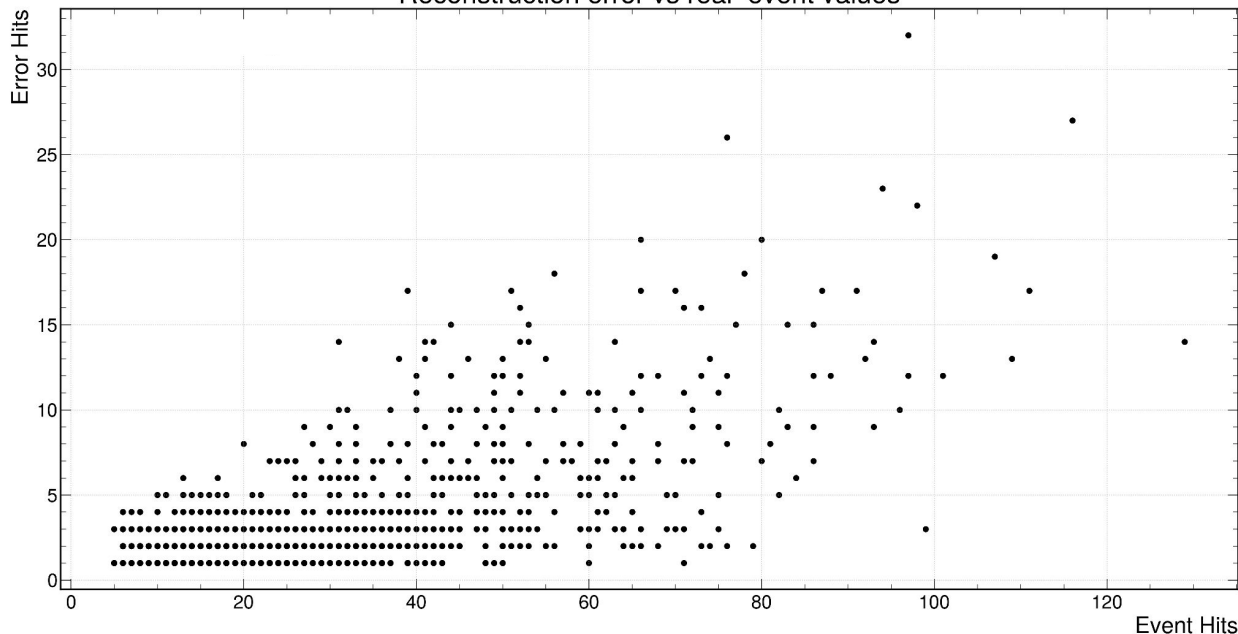
Algorithm performance



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Reconstruction error vs real event values



Number of hits lost in the reconstruction of the events.

Preliminary results!

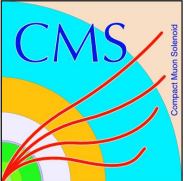
Should be easy to improve with a more complex peak detector

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



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Resource consumption
with xcvu13p:

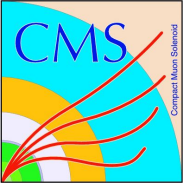
Site Type	Used	Available	Util%
CLB LUTs	7038	1728000	0.41
CLB Registers	9995	3456000	0.29
CARRY8	180	216000	0.08
F7 Muxes	72	864000	<0.01

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



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- 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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Triggering on muon showers

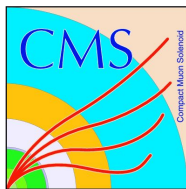
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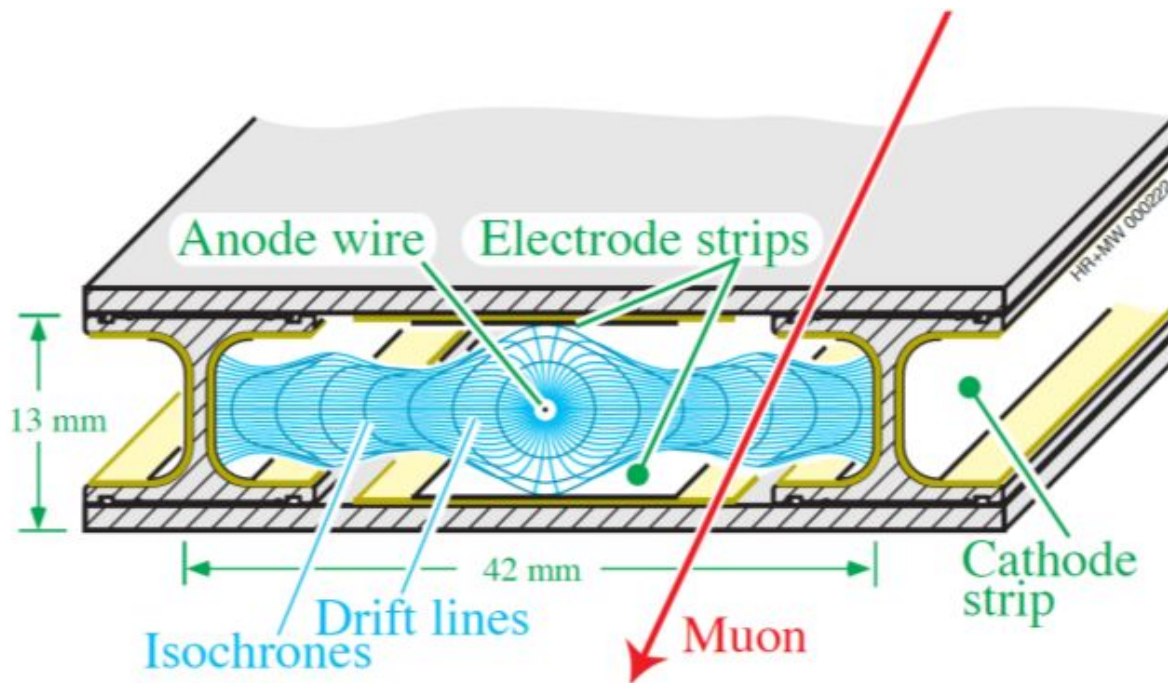
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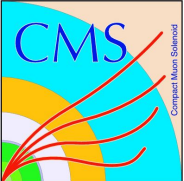


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BACKUP





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