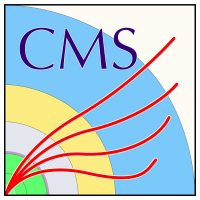


SAPIENZA
UNIVERSITÀ DI ROMA

A time-based search for new physics at the CMS Experiment

XXXV ISFR, Monopoli (BA)

Participant Student Talk

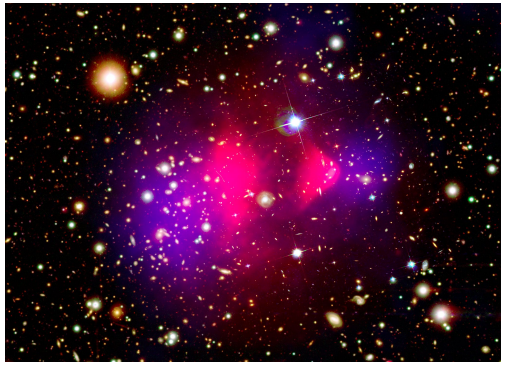
4th October 2025

Tiziano Pauletto

Introduction

There are several reasons to search for **Beyond the Standard Model** (BSM) physics.

- Dark Matter
- Baryon Asymmetry
- Hierarchy problem
- …



X-ray: NASA/CXC/M.Markevitch et al.
Optical: NASA/STScI;
Magellan/U.Arizona/D.Clowe et al.
Lensing Map: NASA/STScI; ESO WFI;
Magellan/U.Arizona/D.Clowe et al.

In this presentation:

- A search for BSM physics focusing on **Heavy Stable Charged Particles** exploiting **timing information** at the **CMS experiment**
- An overview of the **MIP Timing Detector** that will be installed in CMS in the next years & its **impact on searches**

The physics landscape: Heavy Stable Charged Particles

Namely Beyond Standard Model particles which are:

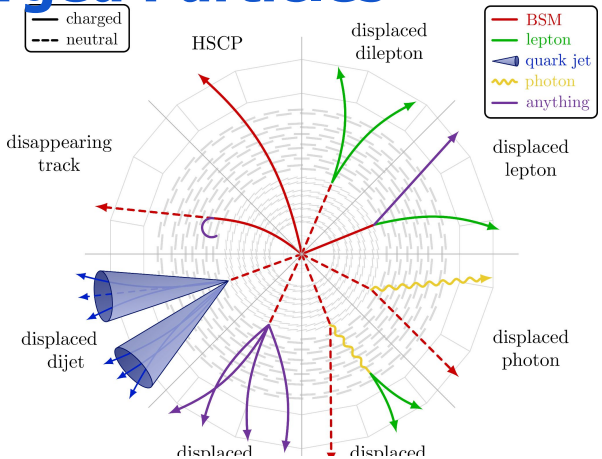
- **Massive** (m ≳ 200 GeV)
- **Long lived** (can travel through whole detector)
- **|Q| > 0,** also fractionally charged or multiply charged

Can be:

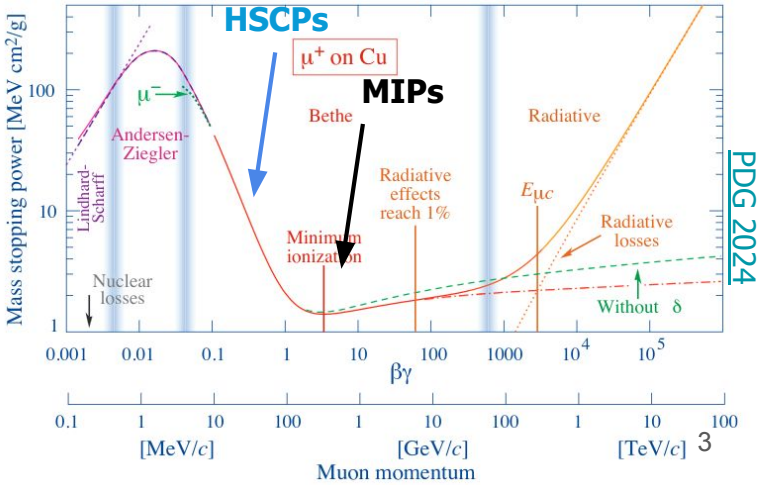
- **Lepton-like:** only EM interaction
- **Hadron-like:** EM and strong interaction

Experimental signature:

➔ High p_T track
➔ Travelling at $\beta \lesssim 0.9$
  - Lower Bethe-Bloch region, higher dE/dX
  - High Time-of-Flight → delayed time signature in muon detectors
➔ (In hadron-like case): interaction with calorimeters



J. Antonelli



PDG 2024

Physics models

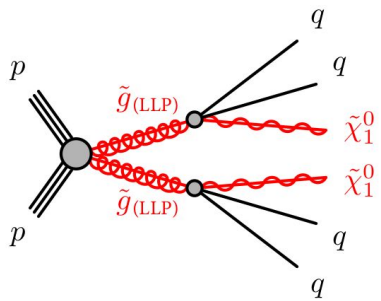
Search is mainly **signature-driven**. But with various theory motivations:

Can be:

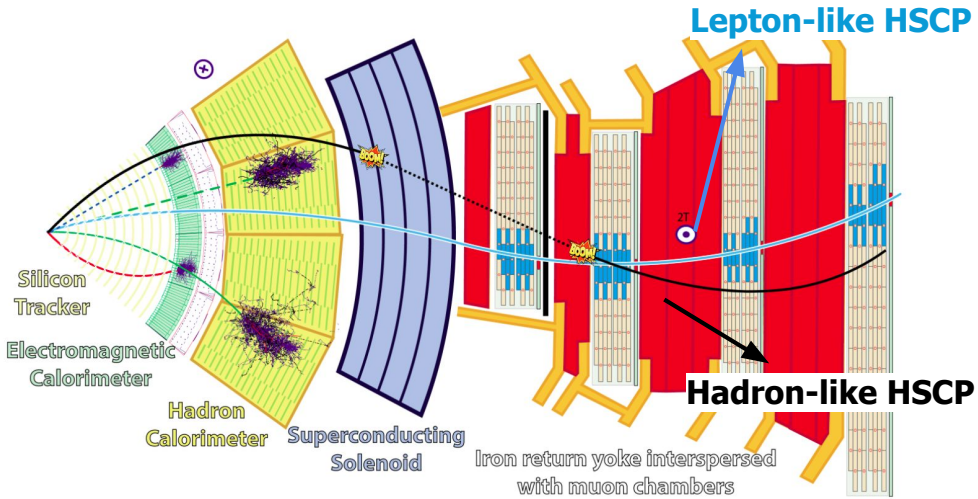
- **Lepton-like:** stau pair production from GMSB models, or tau-prime models with |Q|=1,2e, or fractionally charged in superstring models.
- **Hadron-like:** gluino or stop pair production in some SUSY scenarios.

These kind of particles could elude other searches, due to reco algorithms usually assuming |Q|=1 and $\beta \sim 1$.

Moreover, hadron-like HSCPs can interact w. SM particles in the detector and change their properties.



arXiv:2205.06013v2

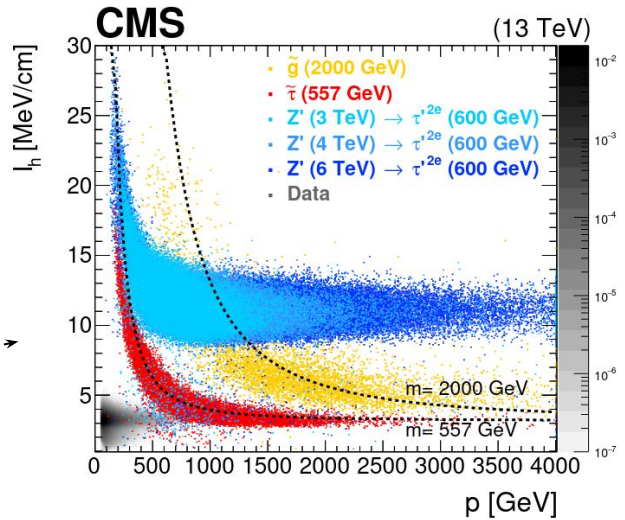


Key variables in the HSCP search

$$I_h = K\frac{m^2}{p^2} + C$$

Searches for HSCPs can exploit information from different subdetectors:

- **Tracker**: dE/dX info
  - Pixel & strip detectors can give information on deposited charge (I_h value)
  - Relate I_h to mass of particle → use to discriminate signal



arXiv:2410.09164

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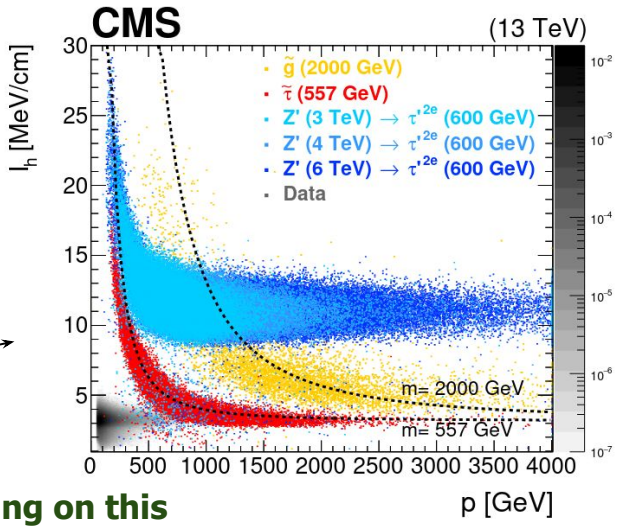
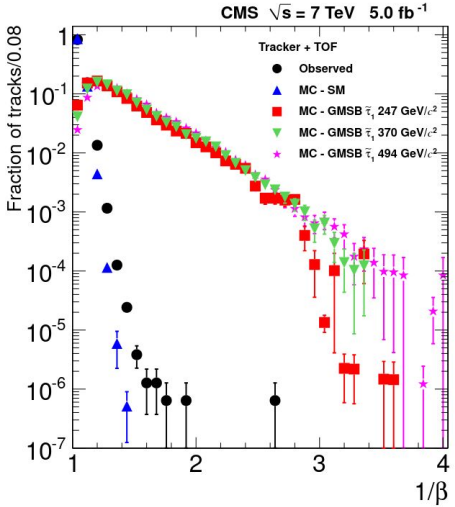


arXiv:2410.09164

Focusing on this

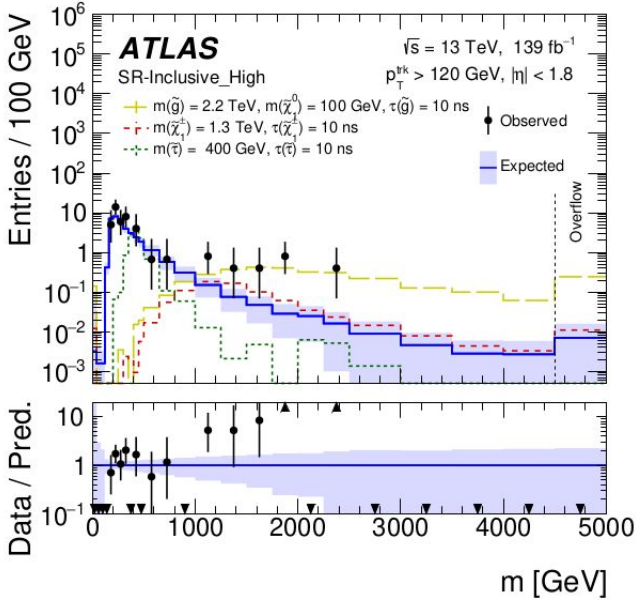
- **Time-of-Flight (ToF):** time info given by DTs and CSCs
  - Time resolution ~ 1.5 ns
  - Two variables are available:
    - **time @ IP (t_{IP})** computed assuming β = c
    - β assuming in-time production of particle
  - Time & β are measured by computing δt between signal and signal of muon produced at IP in-time w. collision
  - Use β as discriminating variable in combination w. dE/dX
  - Used in two Run 1 analyses [1,2]



arXiv:1205.0272

State of the art & perspectives

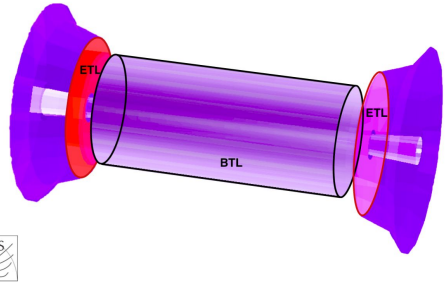
- CMS Run 1 analyses **Tracker-only** [1,2]
- CMS Run 1 analysis using **Tracker+ToF** [1,2]-
- ATLAS Run 1 analysis **Tracker-only**
- ATLAS Run 2, **Tracker(+ToF)**, 3.3 σ **excess observed in dE/dX** but **not ToF signature**
- CMS Run 2 analysis, using Tracker-only signature, **no excess seen** w/ model addressing ATLAS analysis
- Now investigating Run 3 with a ToF-based approach

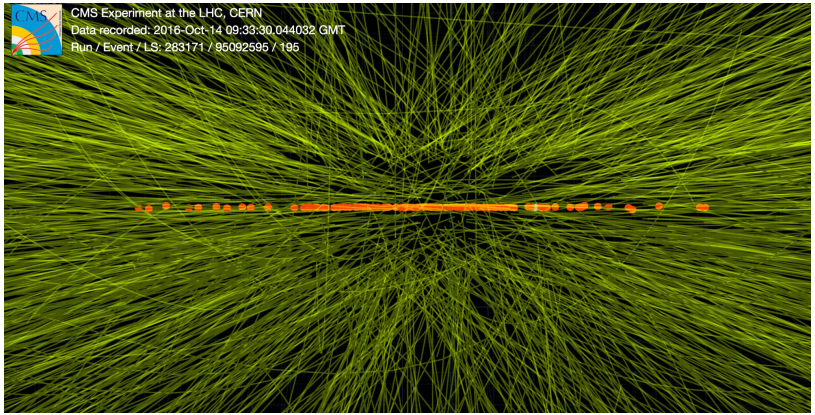


arXiv:2205.06013v2

Brief introduction to MTD

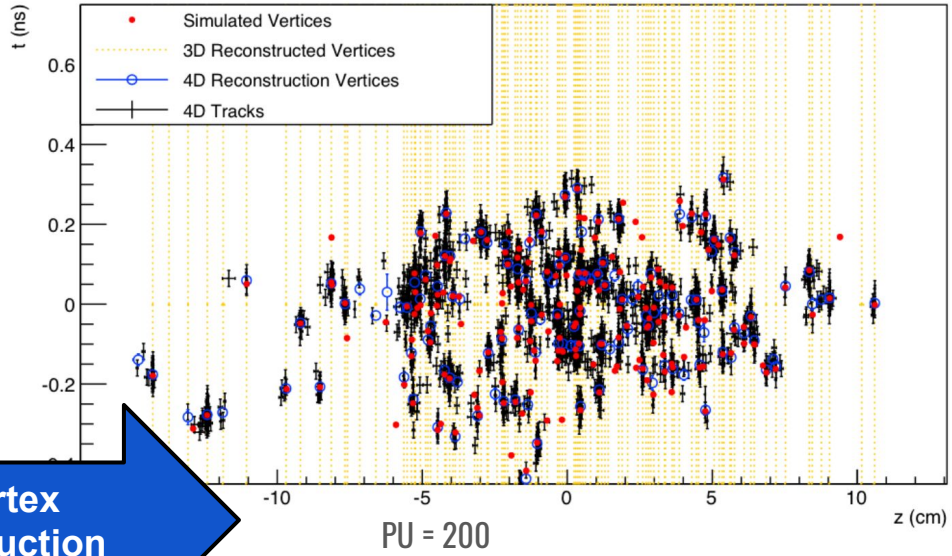
During **High-Luminosity LHC** (HL-LHC): **increase** of number of **mean collisions per bunch crossing** (pileup, PU), from <PU> ~ **60** → <PU> ~ **140-200**. Overlapping in **~10 cm,** up to **~2 vtx/mm** density. Degradation of reconstruction performance.
The **MIP Timing Detector** (MTD) will be introduced in CMS for HL-LHC & will assign **charged track times** with a resolution of ~ **30-60** ps





Example reco event with PU = 100

4D vertex reconstruction

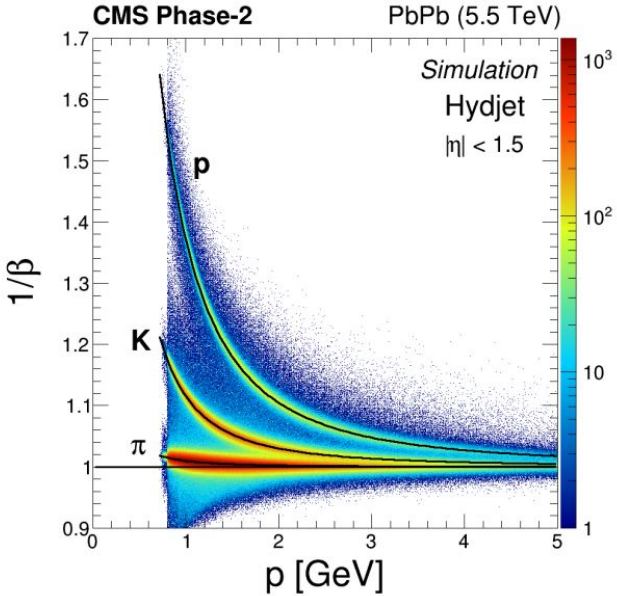


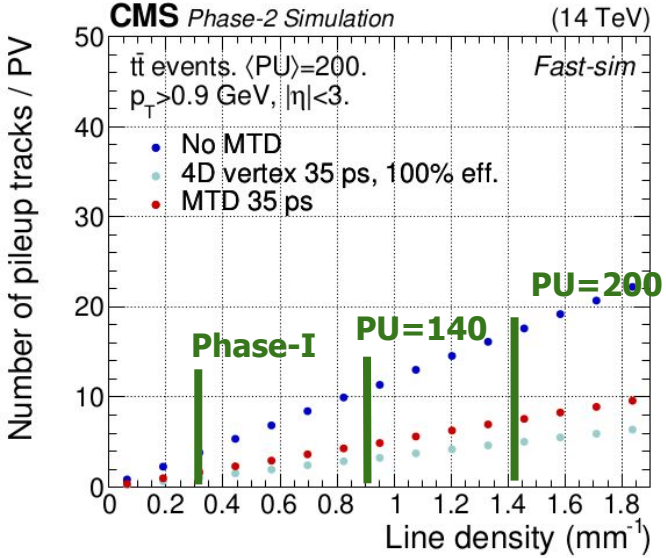
PU = 200

CMS-TDR-014

Improvement in event reconstruction & physics using MTD

- **Effective PU suppression**: making it possible to run with effective PU comparable to now, during all the HL-LHC data-taking
- **Identification of charged hadrons** via time-of flight
- **Improving sensitivity to new physics searches** through non-conventional time signatures
- …



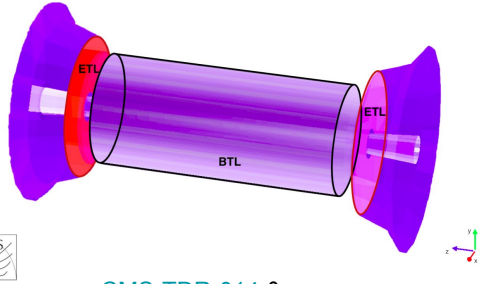


CMS-TDR-014

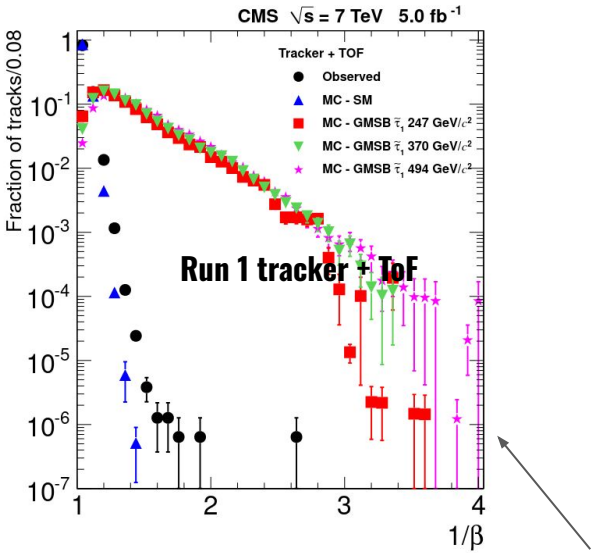
Outlook: analysis exploiting MTD at HL-LHC

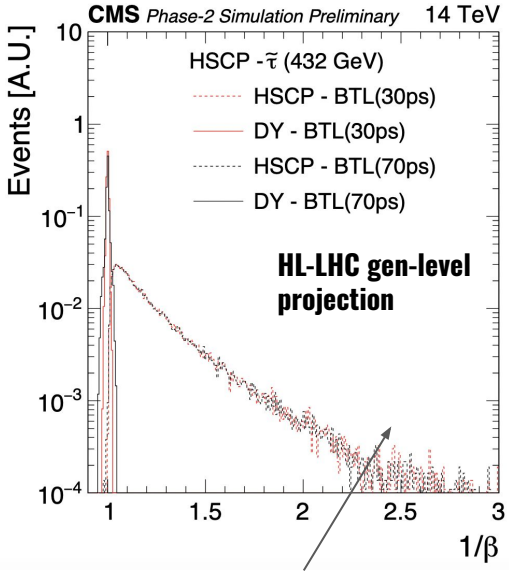
MTD detector will change the landscape of HSCP searches:

- Going from **~1.5 ns** track time resolution **(now)** to → **~30-60 ps (MTD)**
- Assignment of vertex time:
  - ↳ Possibility to **measure Time-of-Flight** → β
  - ↳ In combination with p measurement → **estimate mass of particle**



CMS-TDR-014 &
CMS-DP-2022-25





- In MTD TDR and DPS notes feasibility **studies on HSCP already exist at gen level** (+delphes)

Plan to compare **muon detector-TOF based Run 3** with **MTD-TOF based HL-LHC** performance on a benchmark HSCP scenario **with full simulation** for the very first time.

Next steps

- **Carrying out analysis & setting limits on new physics models** predicting this time signature
- Ambitious upgrade program for CMS during HL-Lumi: **contribution to the software development**
- Carrying out **study of impact of the novel MTD**

Backup

A closer look at time measurement w/ muon system

Muon system is comprised of

- **Drift Tubes** (DTs), **Resistive-Plate-Chambers** (RPCs), **Cathode-Strip-Chambers** (CSCs) and **Gas-Electron-Multipliers** (GEMs).

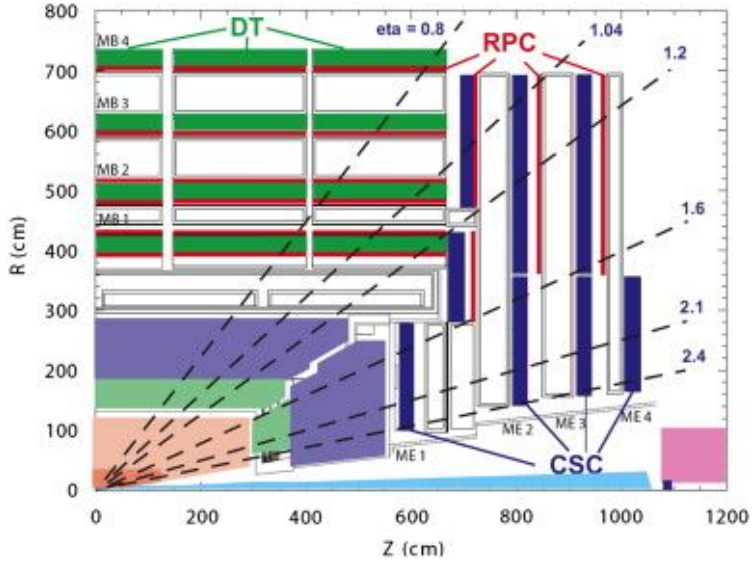
Time measurement available offline given by:

- **DTs** in the barrel ($|\eta| < 1.2$)
- **CSCs** in the endcap ($0.9 < |\eta| < 2.4$)

Exp. time **resolution around ~1.5-2 ns** for both detectors.

Time info can be used to compute:

- **Time computed @ Interaction Point** (t_{IP}) assuming β = c
- **Velocity** assuming muon is produced in-time w/ collision
- Details in the backup



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