Triggering on Muon Showers

in the BMT of the CMS experiment for the HL-LHC upgrades

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Key points

- The **HL-LHC** program will offer unprecedented opportunities for **HEP,** demanding **new workflows and data processing techniques** to achieve **high-precision** Standard Model (**SM**) measurements and expand the search for **BSM physics.** [1]
- Implementing muon **shower identification** for **Phase-2 L1 trigger** and DAQ **upgrades**, will enhance the efficiency of reconstructing **high-momentum** muons and improve the sensitivity to, for example, **long-lived particles** (LLPs). [2]

In the context of the **CMS Muon Level-1 Trigger** (L1T)

- A **muon shower identification algorithm based on** Drift Tube (DT) **hit multiplicity** has been developed for **the BMTL1 boards** [4]. Its performance is **planned to be evaluated** using 2025 collision data in the **DT Slice Test**.
- With the inclusion of **shower Trigger Primitives** (SP), new strategies are also being studied for implementation at the **Barrel Filter** (BF) level **of the CMS Muon L1T system**.

Context

Muon reconstruction is based on cross-matching trigger primitives (TP) from different subdetectors. **In Phase-2**, the **Analytical Method** (AM) **algorithm**, using DT local cells information, **will produce** straight-line muon **TPs** within a 25 ns window **with up to 99% efficiency** [3]. **However**, for high-momentum muons, **electromagnetic showers** can activate multiple cells in a small area of DT chambers, leading to a **combinatorial explosion of TPs**, spurious data, processing delays, and a significant **impact on muon reconstruction algorithms** and **L1T efficiency** (10%)(see fig 1). [2]

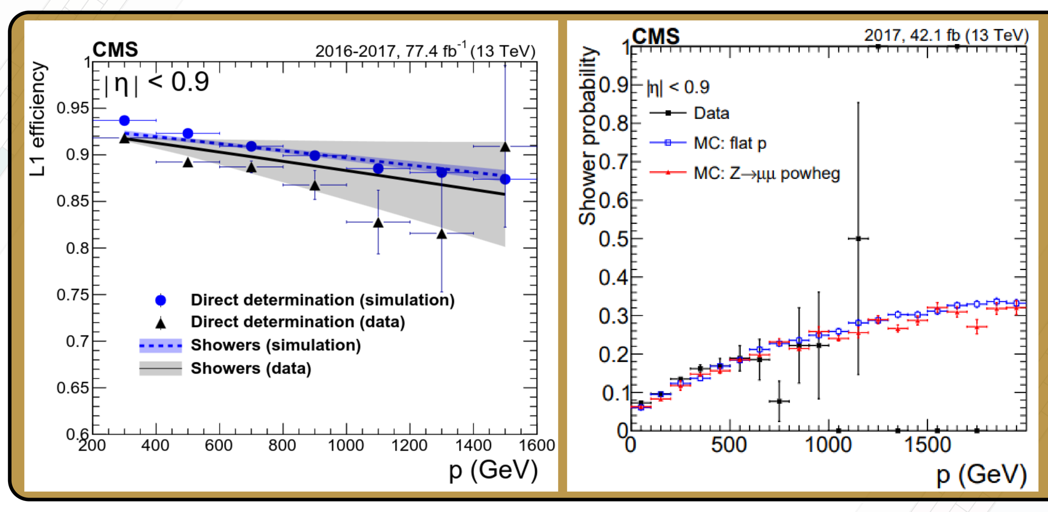


Figure 1. (left) shows how efficiency decreases with increasing muon momentum, this is directly connected with the increase of the number of muon showers, as their production probability (right) grows with momentum. [2]

Barrel filter

Defining: $\vec{L}_1(u) = \vec{a} + u\,(\vec{a} - \vec{b})$ and $\vec{L}_2(t) = \vec{p} + t\,\vec{d}$

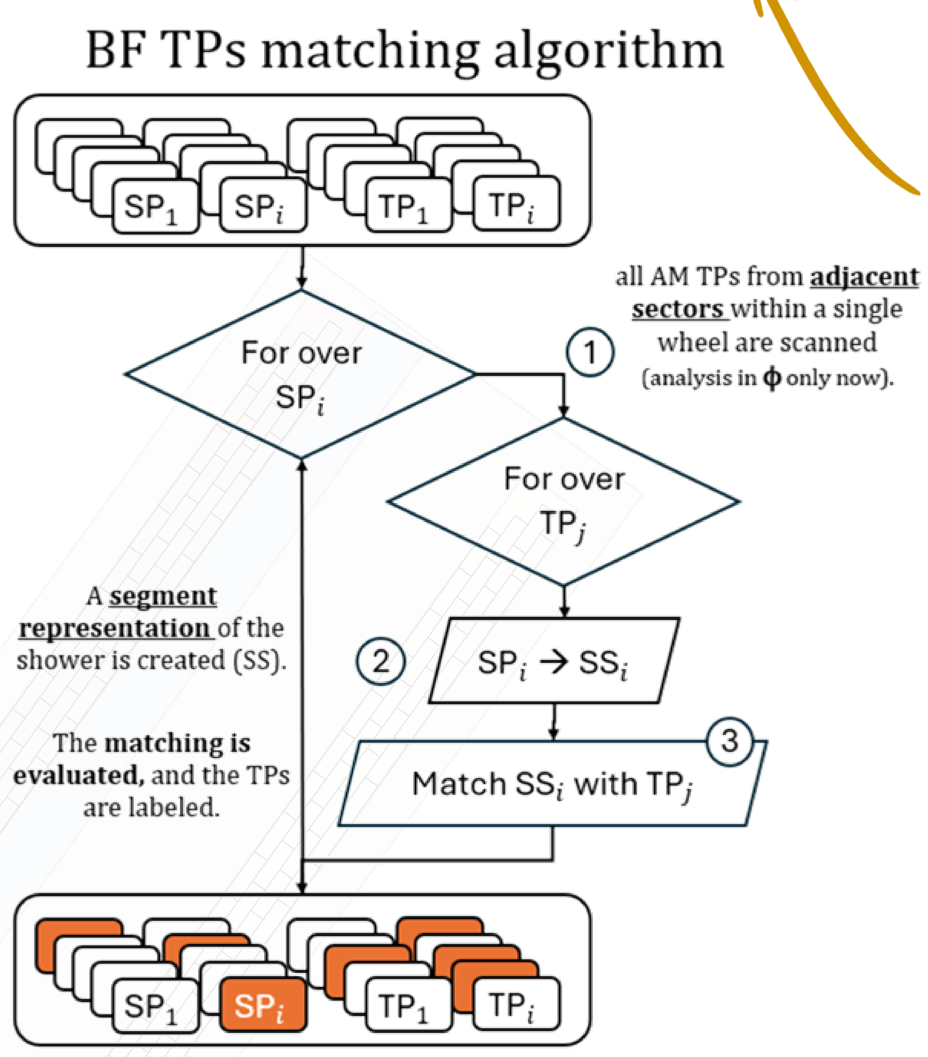
∴ There is a **match If** $\left\{(t,u) \mid \vec{L}_1(u) = \vec{L}_2(t) \wedge 0 < u < 1\right\} \neq \emptyset$

That could be **reduced to evaluate:**

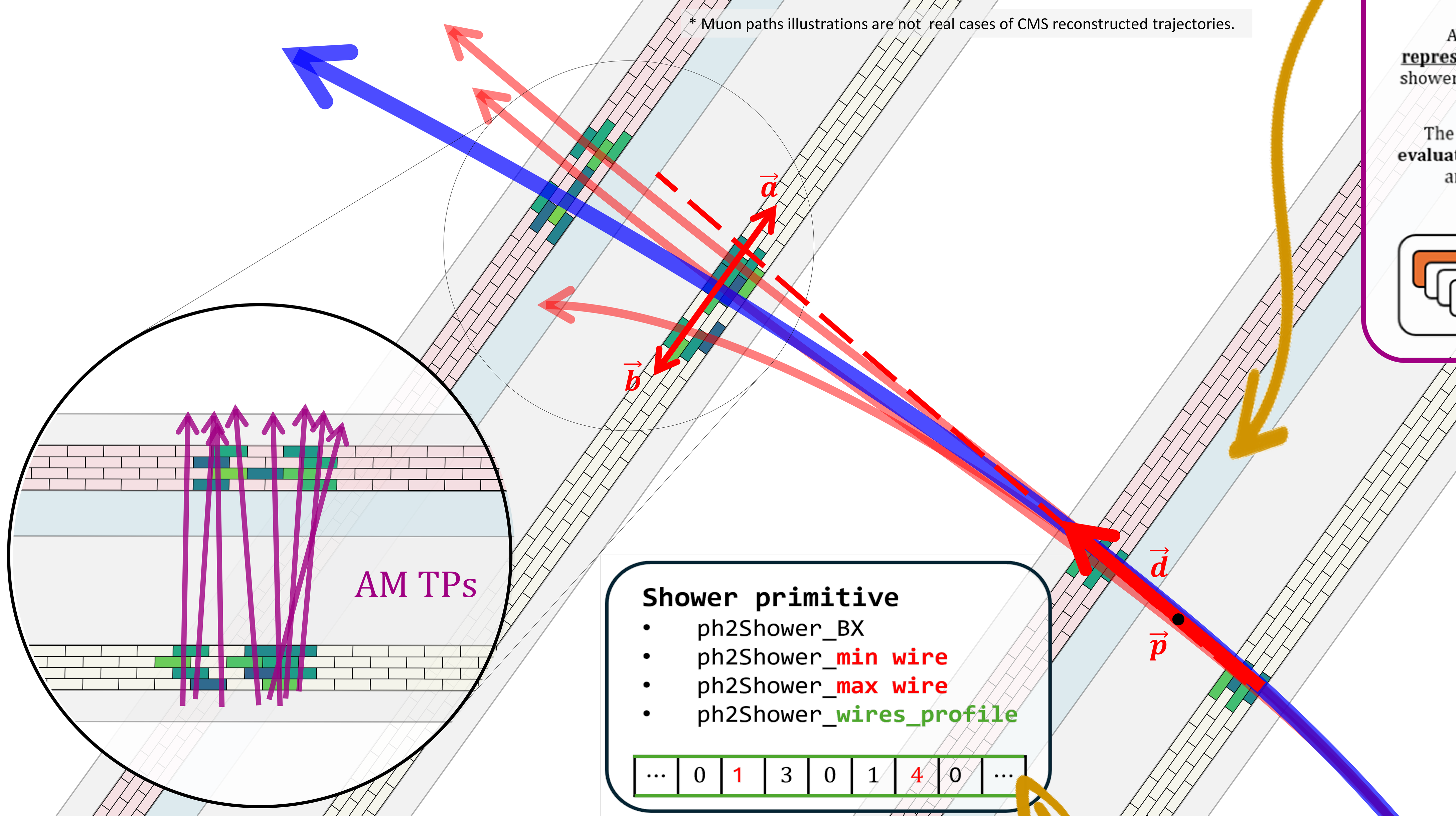
$$u = \frac{\det|\vec{V_2}\ \ -\vec{d}|}{\det|\vec{V_1}\ \ -\vec{d}|} \quad \text{and} \quad t = \frac{\det|\vec{V_1}\ \ \vec{V_2}|}{\det|\vec{V_1}\ \ -\vec{d}|}$$

With $\vec{V_1} = \vec{a} - \vec{b}, \vec{V_2} = \vec{p_1} - \vec{a}$, and $|\vec{V_1}\ \ -\vec{d}| \neq 0$

How are we making the primitives match?

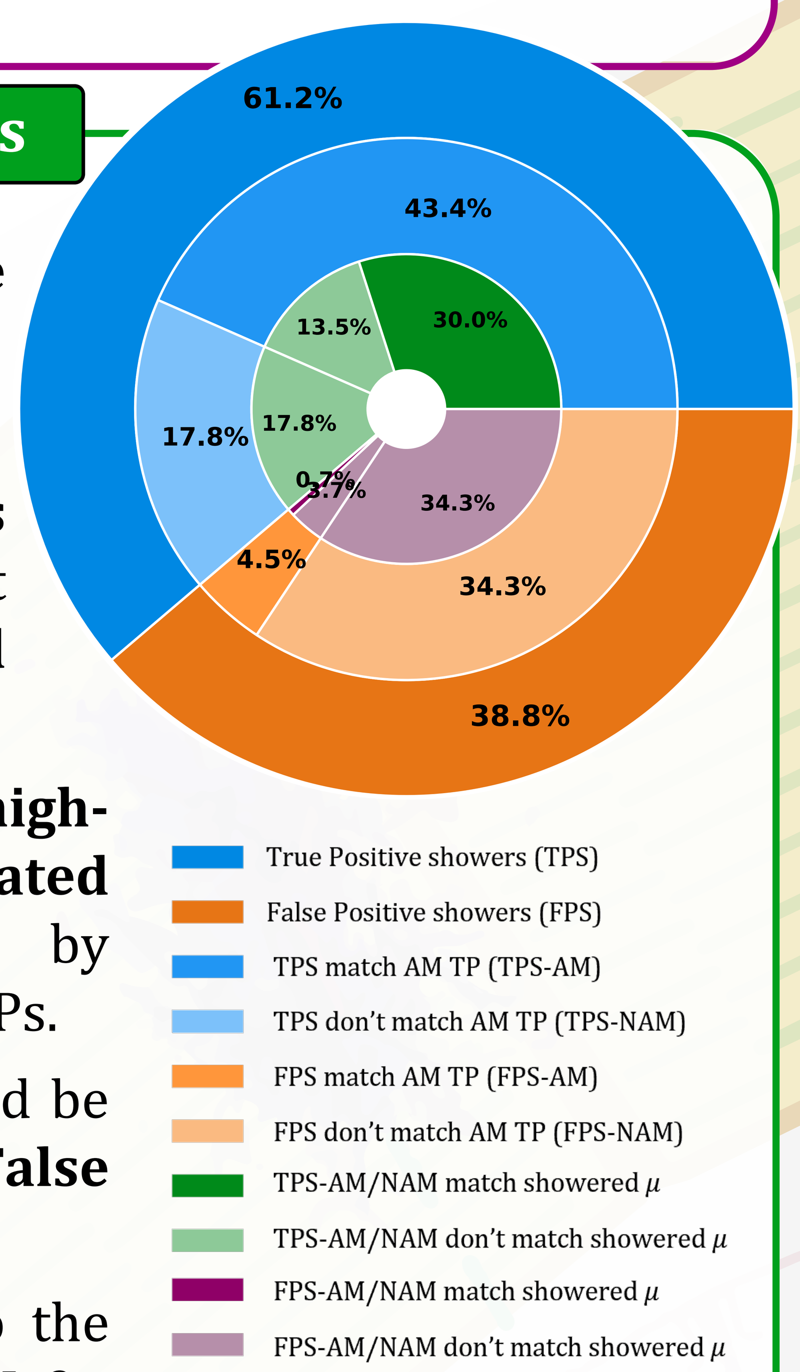


We are implementing **shower–AM TPs matching** at the **L1T BF** stage to correlate both primitives and provide **additional input to the Track Finders** (TF), aiming to improve high-momentum muon reconstruction in the presence of electromagnetic showers.



Results and next steps

Initial simulations have shown that:



- **unmatched showers** are certainly not related to **showered high-p_T muons.**
- between **40-60%** of **high-p_T muons that radiated can be identified** by matching SPs and AM TPs.
- **Matching criteria** could be good to **filter False Positive** showers.

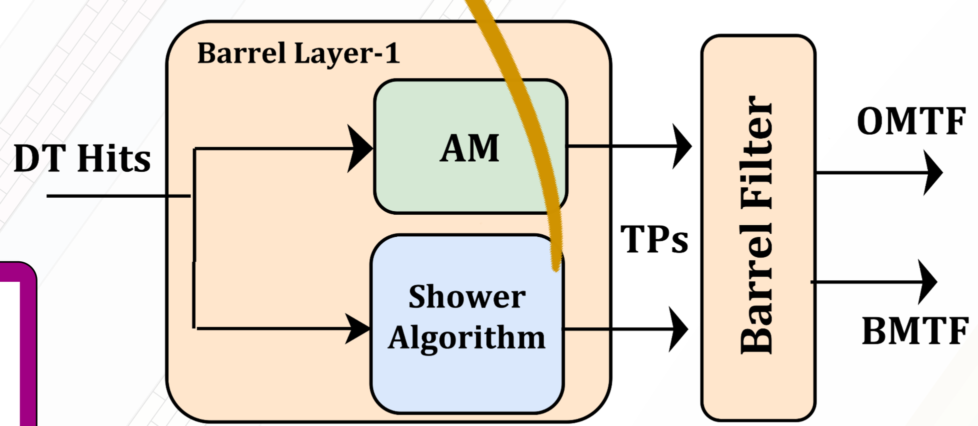
○ Expand the analysis to the **z-r plane** and utilize **AM-θ. TPs** could improve identification efficiencies.

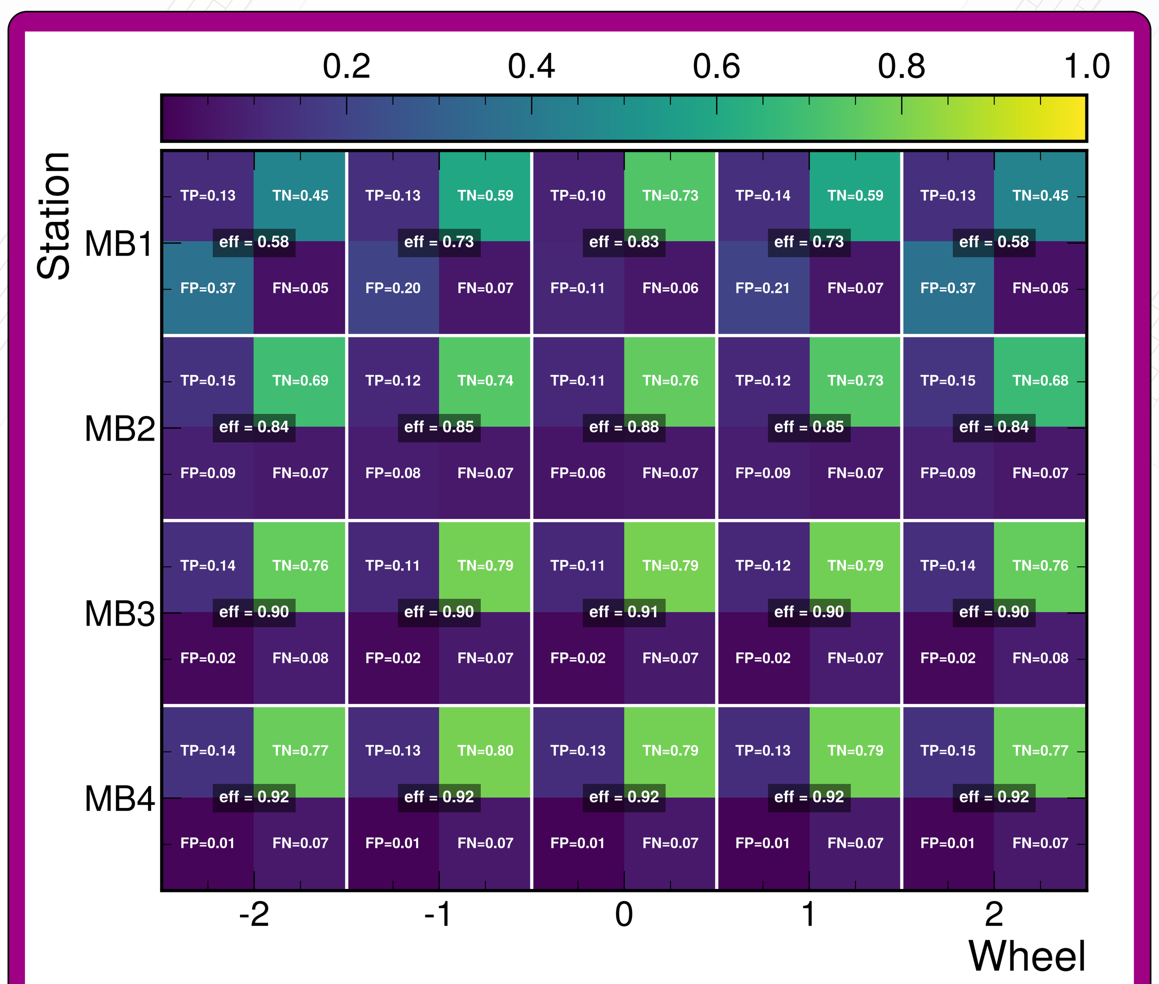
○ Define a meaningful **quality metric** for matching, to be used by the TFs.

○ **Port the algorithm to firmware.**

Our work

The shower algorithm runs in the BMTL1 and **generates trigger primitives** in parallel with those from the AM.





Confusion matrices of shower tagging efficiencies

Studies based on simulated data and emulated SPs have shown **shower tagging efficiencies** in the range of **~60–80%**.

The emulation of the primitives was done through an emulator which **agrees up to 96%** with the **firmware expected primitives**.

References

[1] CMS-TDR-021

[2] JINST 15 P02027

[3] NIMA -168103

[4] JINST 20 C03024

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