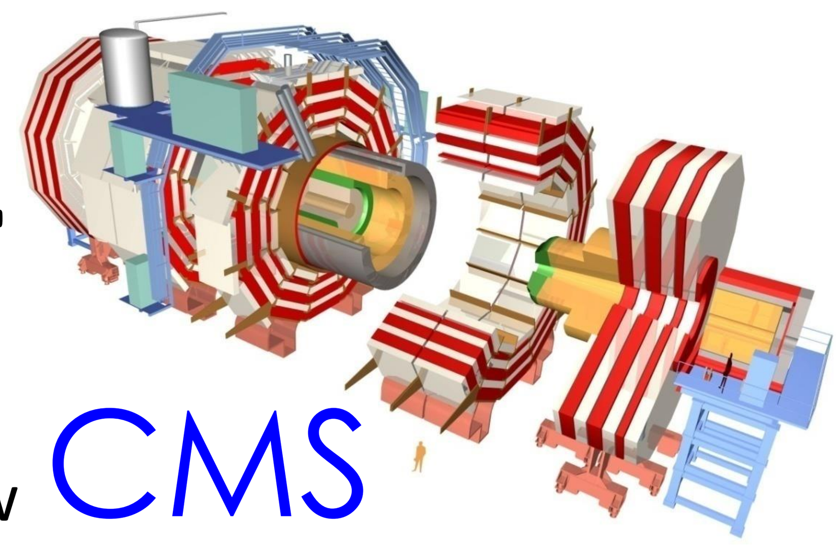
The algorithm of the CMS Level-1 Overlap Muon Track Finder trigger



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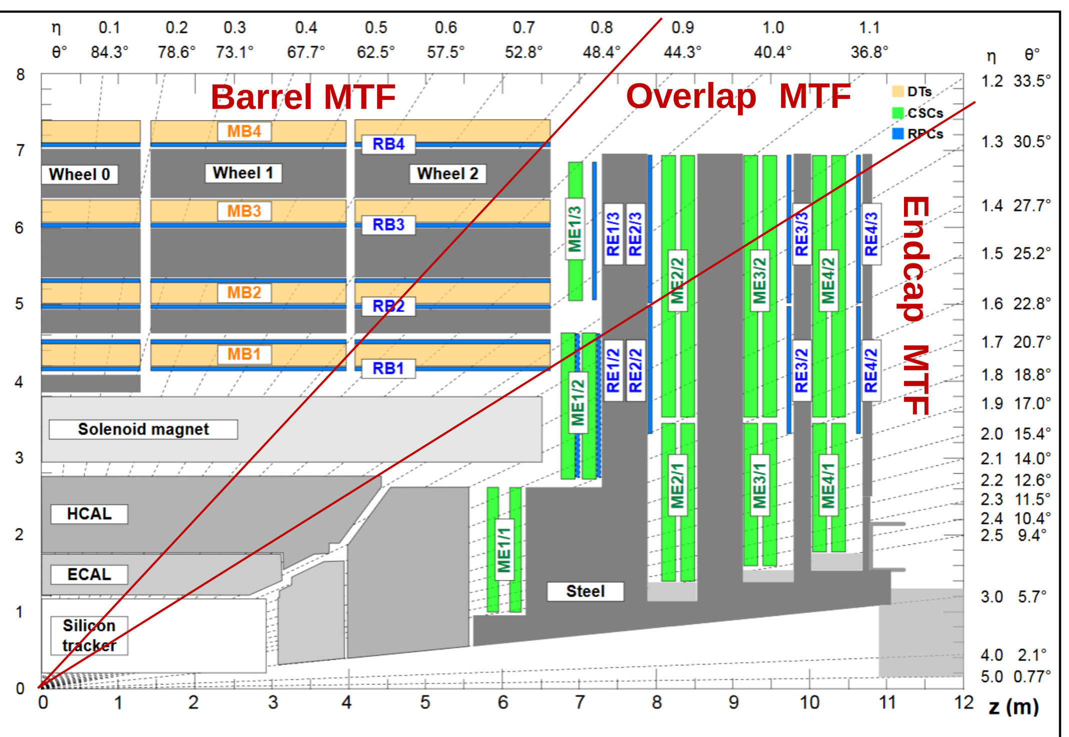
CMS Level-1 Trigger – the system based on a custom electronics built around the FPGA devices – was upgraded in 2016. The new Muon Trigger was divided into three parts, processing data from the barrel, overlap and endcap regions of the detector, respectively.



Why did you need a new muon trigger? The previous CMS muon trigger was working pretty well.

LHC increased the luminosity, so we had to improve the muon trigger to reduce the output rate. In practice this denotes **more accurate measurement of the muon transverse momentum**. In the barrel-endcap overlap region we have up to 18 layers of the muon detectors (DT, CSC and RPC) that potentially assure precise and robust tracking. But the previous track finding algorithms were not able to use so many detector hits for the momentum measurement.

OK, so what is your idea of the track finding algorithm?

We based it on the classic machine learning algorithm: **naïve Bayes classifier**. We divided the muon's momentum spectrum into 52 bins – we call them "**golden patterns**", and we assumed that the likelihood that a muon has a given p_T is just a product of the likelihoods of the muon hit phi positions (in each layer):

$$P(p_T|\varphi_1,\dots,\varphi_i) = \frac{P(\varphi_1,\dots,\varphi_n|p_T)P(p_T)}{P(\varphi_1,\dots,\varphi_n)} = \frac{\boldsymbol{P(\varphi_1|p_T)\times\dots\times P(\varphi_n|p_T)P(p_T)}}{P(\varphi_1,\dots,\varphi_n)}$$

And we assign to the muon the p_T of the „golden pattern" with the highest likelihood.

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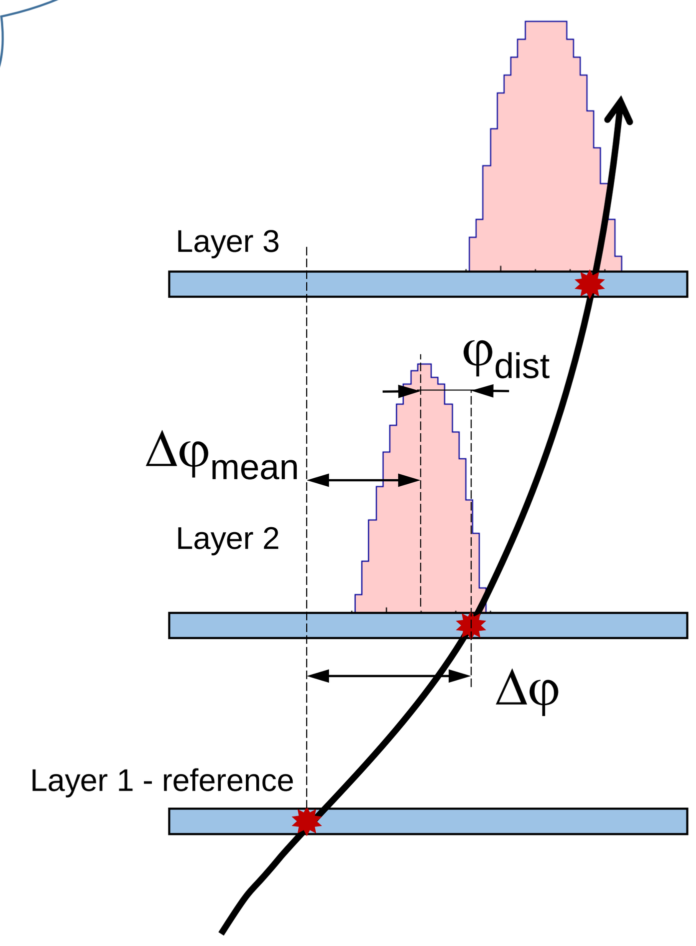
Wait, but you can do like that only if the hits are not correlated, while the muon hit positions are highly correlated!

True, that's why we actually are not using the absolute hit position, but the distance (φ_{dist}) between each hit and one chosen hit that we call **reference hit** (minus average bending $\Delta\varphi_{mean}$). Then the correlation is much weaker.



Hms, not stupid. But the muon chambers do have some inefficiency. If there are no hits in some layers, then what? The likelihood is 0.

Right. For that reason we include the likelihoods only from the detector layers which have a hit. We **select the "golden patterns" with the highest number of fired layers**, and only out of those we choose the one with the highest total likelihood.

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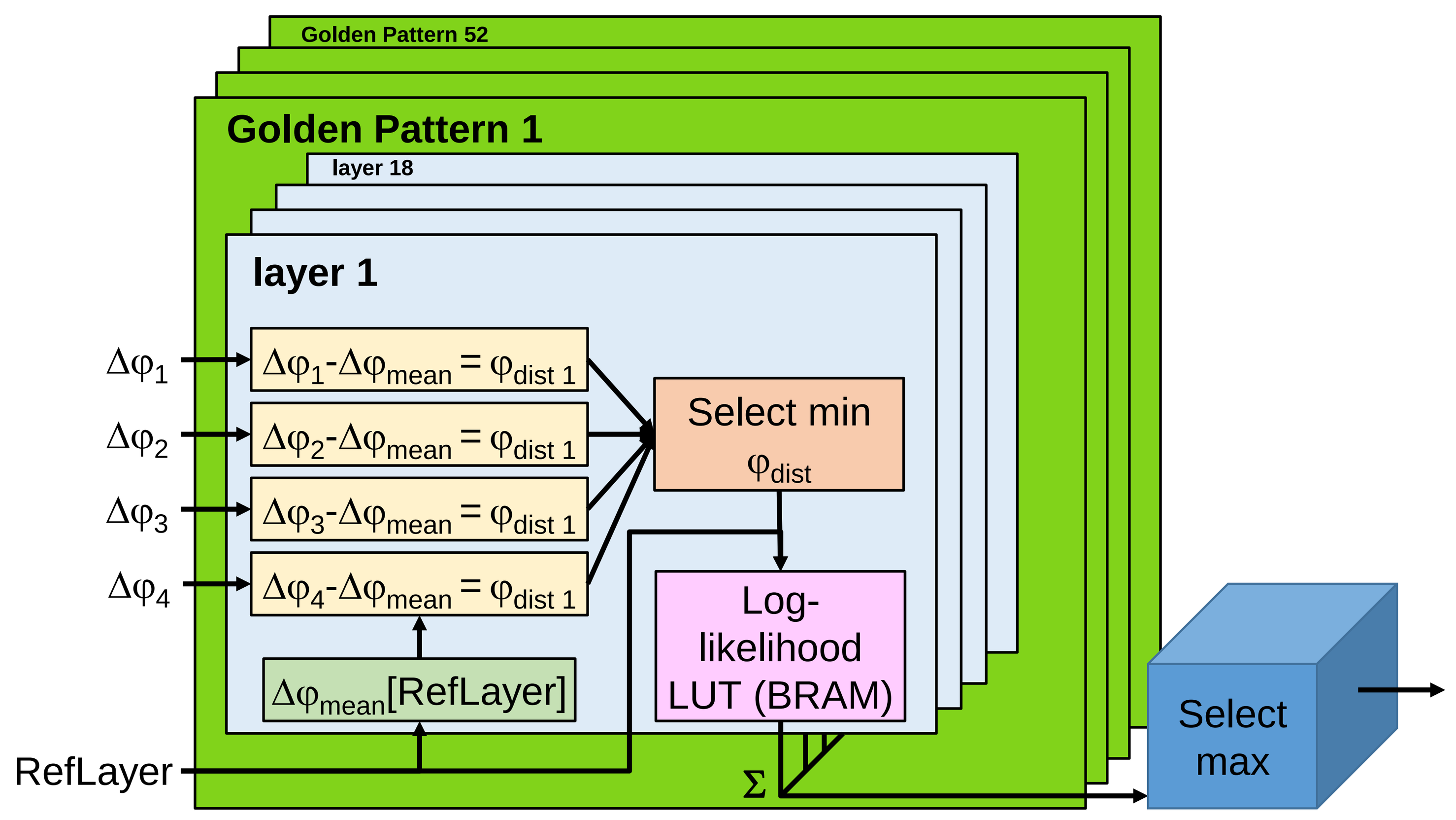

But what if you have more then one hit in a given detector layer?

For each layer of a "golden pattern" we select only one hit that is closest to the middle of the likelihood distribution.

I see one more problem though: the hit you have chosen as a reference can be a fake. Or you can have more than one muon in an event. Then your algorithm fails.

Good point! That's why for each event we **run the algorithm for up to four reference hits**. If this produces duplicated muon candidates, we select only the ones that seem to be unique.

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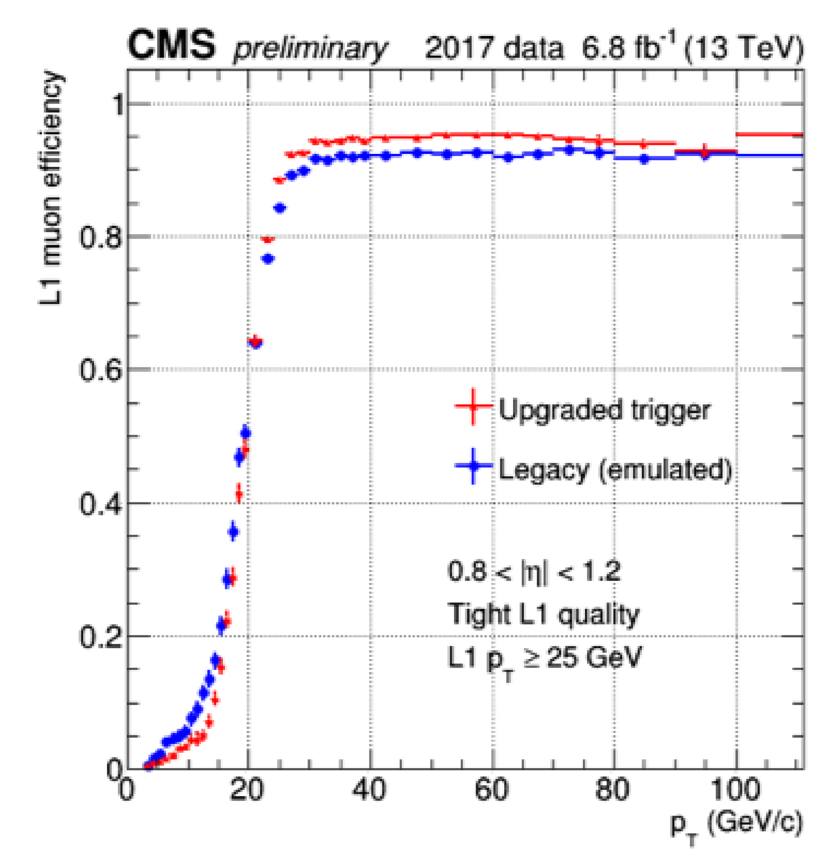
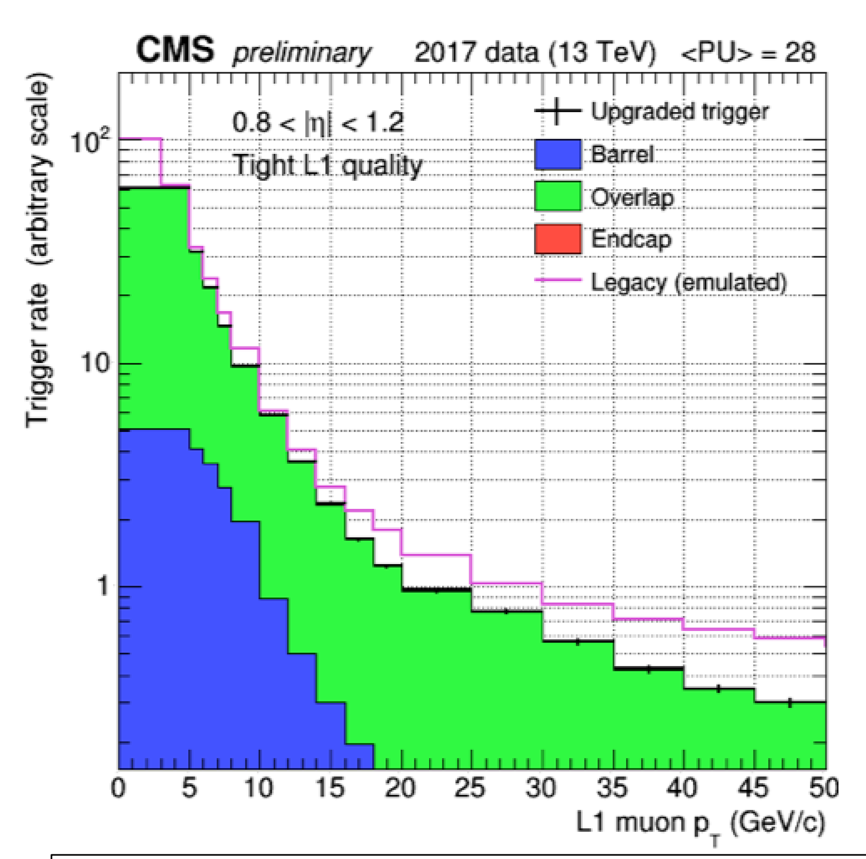
Your algorithm is implemented in the FPGA devices. Calculation of likelihoods requires a lot of floating point multiplications – in FPGA this is slow and consumes a lot of resources.

Yes. Therefore, instead of multiplication of likelihoods we use the **sum of the discretized likelihoods logarithms**.

And what is the performance of your algorithm?

Very good ☺ It gives **25% smaller rate and 2% better efficiency** than the legacy muon trigger in the overlap region.





Artwork: Klara (8y) & Kinga (5y) Buńkowska