3rd semester report

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Ph.D. Thesis title:

Challenging the Standard Model and searching for new physics at the LHC with the CMS experiment

Introduction: Luminosity measurement at LHC

The CMS Collaboration expects all of its collaborators to take an experimental physics responsibility, a central task that is beneficial for the whole collaboration, in order to become a full member, a signing author of the collaboration. I chose to participate in the luminosity calibration as the precise knowledge of the luminosity is essential for almost all measurements at the Large Hadron Collider (LHC) and it is the dominant source of systematic uncertainty for various Standard Model cross-section measurements of W, Z and top quark production. Its typical uncertainty at present is about 2.5% per year and we aim to provide an improved measurement targeting a final value well below 2%.

A total of six systems are used to measure luminosity at CMS. Each luminometer reads out a rate of the specific quantities observed in the detector (hits, tracks, clusters, etc.). This rate, R, should be proportional to the instantaneous luminosity, L_{inst}, with the constant of proportionality given by the visible cross section, σ_{vis}:

$$R = L_{inst}\,\sigma_{vis}\,.$$

In practice, the luminometers usually exhibit some nonlinear dependence on the instantaneous luminosity or on external factors such as the LHC filling scheme; these nonlinearities need to be corrected to obtain an accurate measurement.

The calibration constant σ_{vis} is determined using Van der Meer (vdM) beam separation scans that measure the beam overlap width that appear in the single bunch instantaneous luminosity formula

$$L_{inst}=\frac{N_{1i}N_{2i}f}{2\pi\,\Sigma_x\Sigma_y}\,,$$

where N_{1i} and N_{2i} are the number of protons in the two individual beams for the colliding bunch i, f is the orbit frequency and Σ_x , Σ_y are the beam overlap widths in x and y direction.

There are several systematic effects which affect the beam overlap width measurement, and hence the σ_{vis} extracted from the vdM scan procedure. One of the main effects is the **length scale calibration** (LSC) which corrects the possible differences between the actual and nominal LHC beam separations during the scans. It is determined by exploiting the high precision of the CMS inner tracker using the reconstructed vertex positions during a special beam separation scan for LSC. There are two different kinds of LSC scans, the constant separation scan and the variable separation scan. Another important effect comes from **orbit drifts** i.e. the potential movement of LHC orbit during the vdM scan. The correction for orbit positions is determined using two separate beam position monitor (BPM) systems, the *DOROS BPM* system situated close to the experiment and the *BPM*s in the LHC arcs.

Description of research work carried out in current semester

During this semester, I **finished the analysis of the constant separation scan** in the 2018 proton-proton vdM scan data taken at $\sqrt{s}$ = 13 TeV, and with this **I fulfilled the CMS authorship requirements becoming a signing member of the collaboration in December 2019**.

In the constant separation scan, the beams are separated by about 1.4 σ_{beam} and moved together first in the x direction forward and backward and then the same procedure is repeated in the y direction. The CMS tracker is used to reconstruct the position of the luminous region and the resulting position is plotted against the nominal beam position; a linear fit is then applied to extract the slope which gives the LSC correction factor and its uncertainty. During the measurement, we select all vertices belonging to a scan step after the beam positions are stabilized, either using the LHC *Timestamps* or by selecting a full luminosity section (*LS*), a 23 s period of data taking where the beams are kept stable. The luminous region position is determined either from the *average* vertex position or for a Gaussian *fit* to the distribution. To study the effect of the pixel detector alignment, we analysed the data using the *Prompt* reconstruction and also an improved tracker calibration (*ReReco)*.

The previous preliminary analysis performed by the DESY group showed several problems leading to an inflated uncertainty (Table 1 shows some of these problematic results):
1- The LS analysis failed for ReReco data and (some of) Prompt data.
2- Inconsistent results between per-step average and per-step fit methods.
3- The orbit drift correction increased the forward/backward discrepancy.

I debugged the old code and wrote a new one to fix all these problems. Table 2 shows the improved results from my work. I not only corrected the technical and procedural problems but also implemented a new orbit drift correction using both the *DOROS BPM* system and the *arc BPM* measurements. The results show that the orbit drift correction – as was expected – indeed decreases the forward/backward discrepancy and decreases significantly the systematic uncertainty.

Next semester, I will implement the new orbit drift correction to the variable separation method and I will perform LSC also for the 2017 proton-proton vdM scan data. The 2017-18 results will be published together in the final CMS run 2 luminosity calibration paper, expected to appear in late 2020.

The improvement on the length scale calibration systematics was included in the **CMS Conceptual Design Report for the HL-LHC upgrade** [1].

I presented the CMS 2018 preliminary luminosity calibration results on the **Zimányi School Winter Workshop** in December 2019.

Publications

[1] CMS Collaboration, Phase-2 Upgrade of the CMS Beam Radiation Instrumentation and Luminosity Detectors: Conceptual Design, CMS-TDR-19-003, CMS-NOTE-2019-008 (https://cds.cern.ch/record/002706512?ln=en)

Studies in current semester

I followed 4 lectures this semester:

- Detector Systems in Particle and Nuclear Physics (6 credits)
- Experimental methods of particle physics II (6 credits)
- Quantum chromodynamics (6 credits)
- Week interactions (6 credits)

Participation on conferences, workshops and seminars

- Zimányi School Winter Workshop 2019, 2-6 Dec 2019, Wigner RCP, Eötvös University, Budapest (Hungary). I presented the talk “Precision luminosity measurement with the CMS detector" on behalf of the CMS Collaboration

Attendance on regular seminars, meetings

ELTE Ortvay Colloquia, ELTE Particle Physics Seminars, Hungarian CMS Group Seminars, ELTE CMS group meetings, CMS Luminosity Physics Object Group and CMS BRIL Detector Performance Group meetings

Table 1: Previous (public preliminary) CMS results

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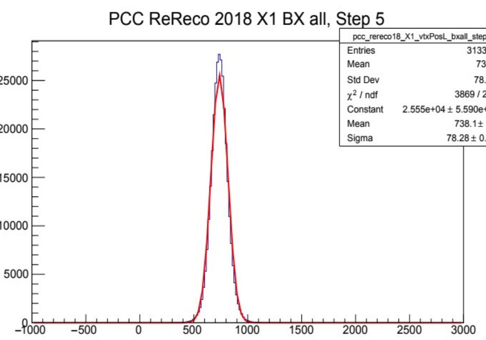
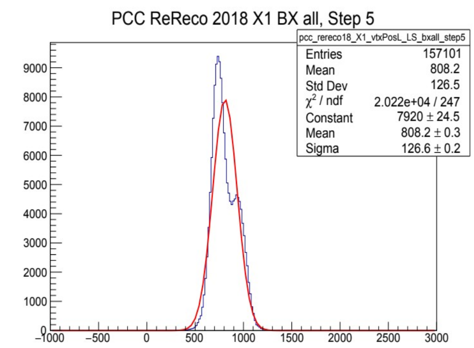
<tr><th></th><th>Timestamp</th><th>Lumi section</th></tr>
<tr><td>X scan step 5
Vertex positions</td><td>
</td><td>
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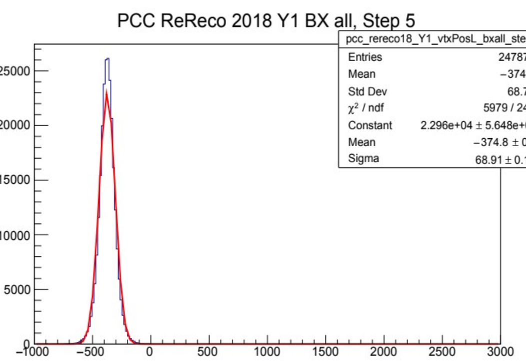
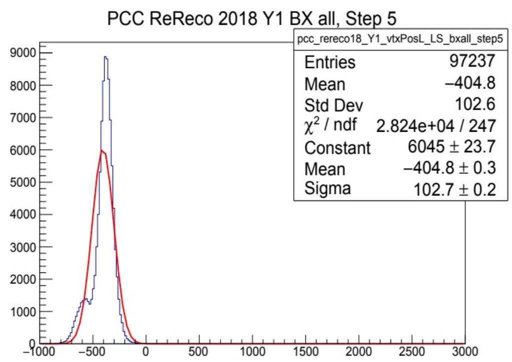
Vertex positions</td><td>
</td><td>
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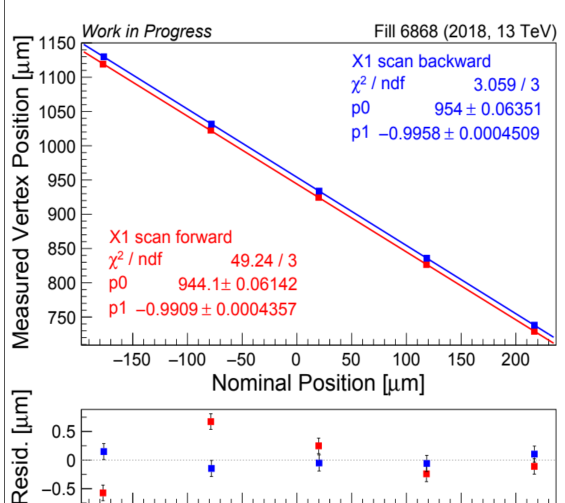
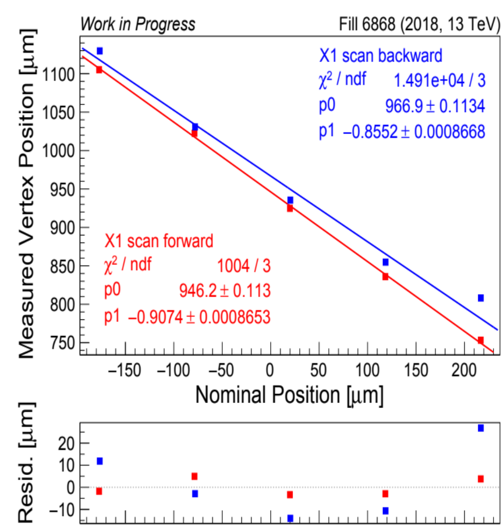
<tr><td>X linear fit</td><td>
</td><td>
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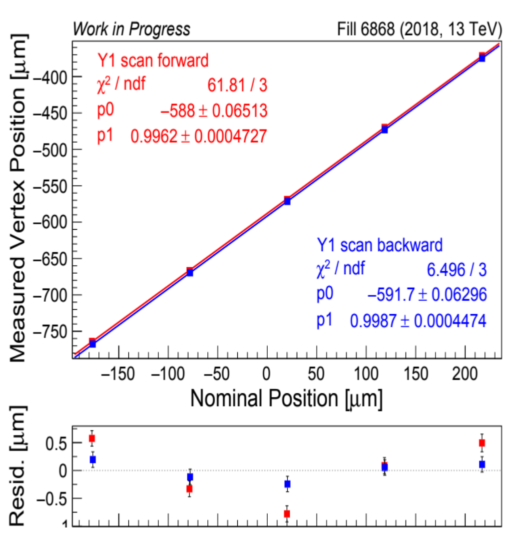
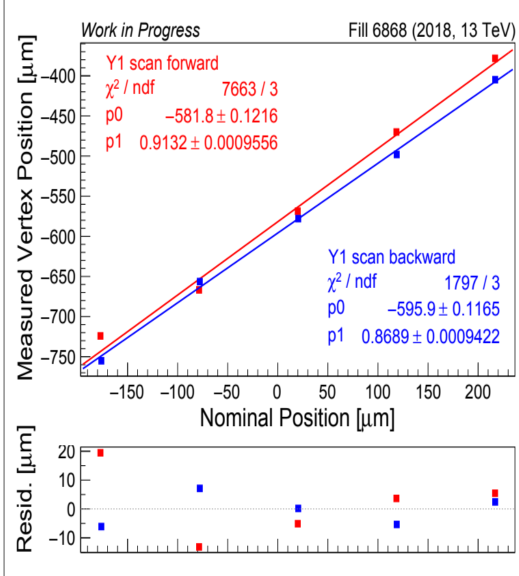
<tr><td>Y linear fit</td><td>
</td><td>
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Table 2: my results

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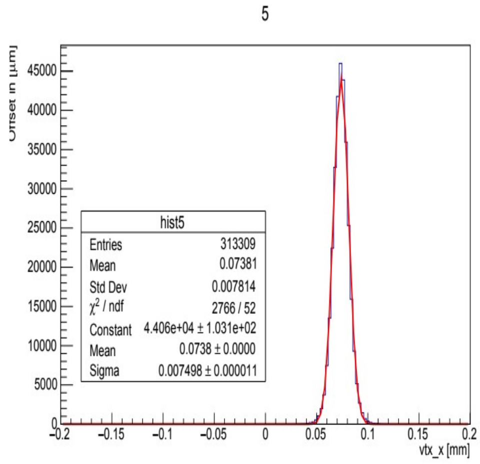
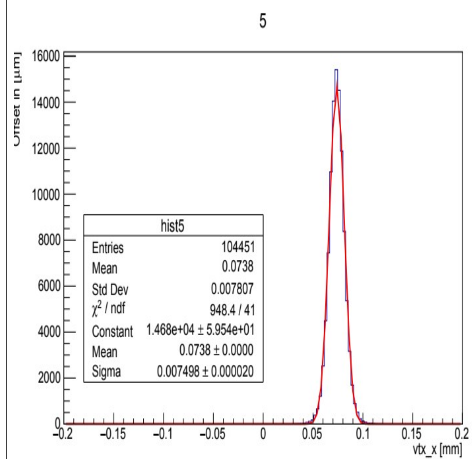
Vertex positions</td><td>
</td><td>
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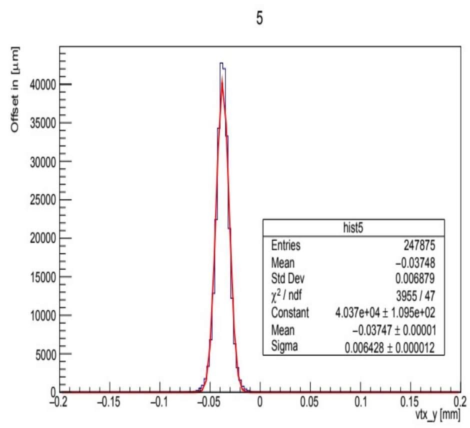
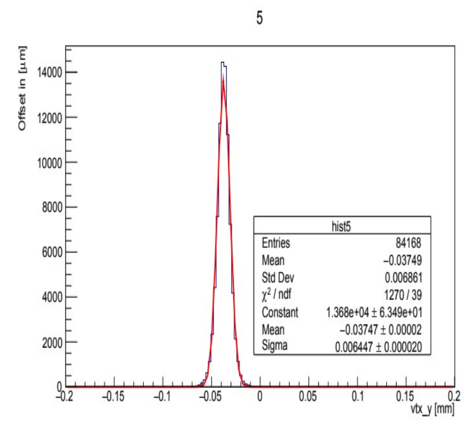
Vertex positions</td><td>
</td><td>
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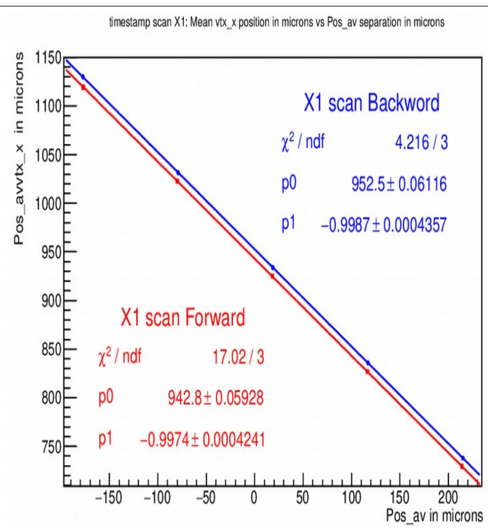
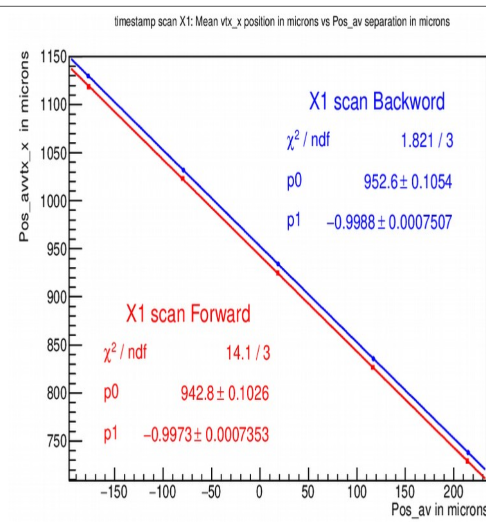
<tr><td>X linear fit (adding the average values of Orbit drift)</td><td>
</td><td>
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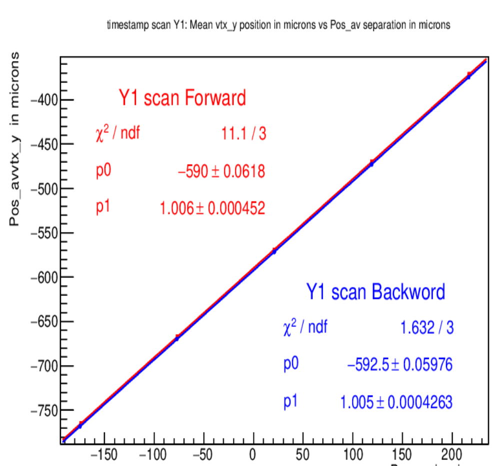
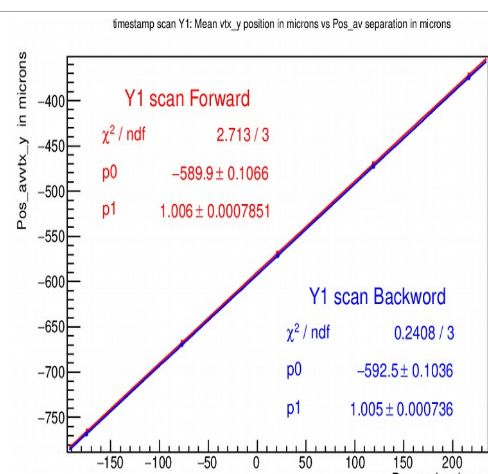
<tr><td>Y linear fit (adding the average values of Orbit drift)</td><td>
</td><td>
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