Project 5
Analysis of Proton Transport Through LHC

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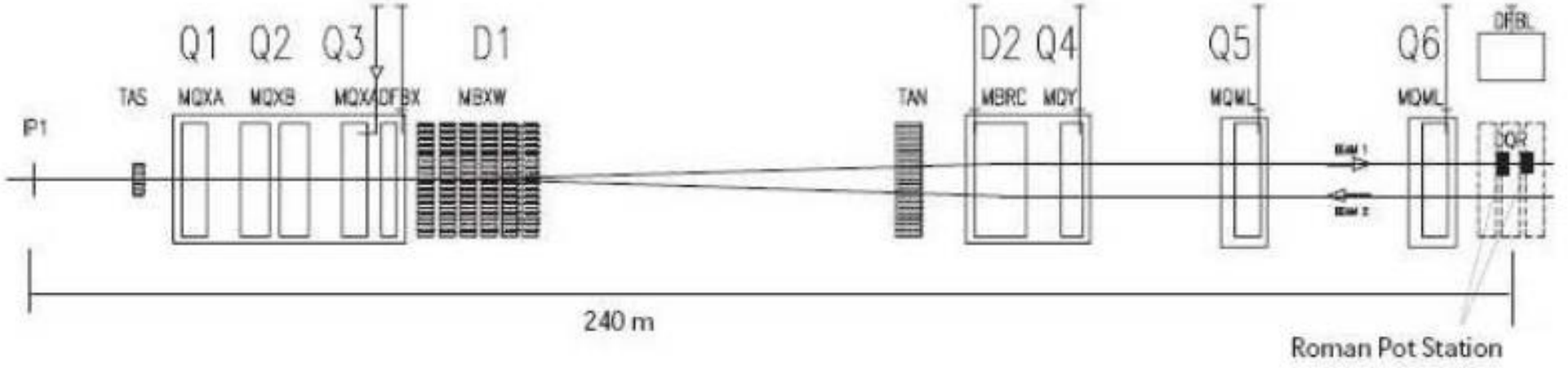
Introduction

- Intact protons are scattered at very small angles, typically into LHC beampipe.
- They are measured in special detectors called **Roman pots** (RP), which are installed about 200 meters from collision point (IP).
- Region between IP and RP is not empty – it contains **several LHC magnets** that are shown in the picture below.
- **Magnetic fields** have impact on proton trajectories.
- **Our goal was to check what is the impact of changing the default values (position and strength) of each element on the proton position in RP.**
- Tools:
  - C++ transport code - simulates the pass of the protons generated by Pythia from IP to ATLAS Forward Proton (AFP) detector which is installed at 205 meters from IP.
  - optics files - contain default description of each LHC element between IP and AFP detector.



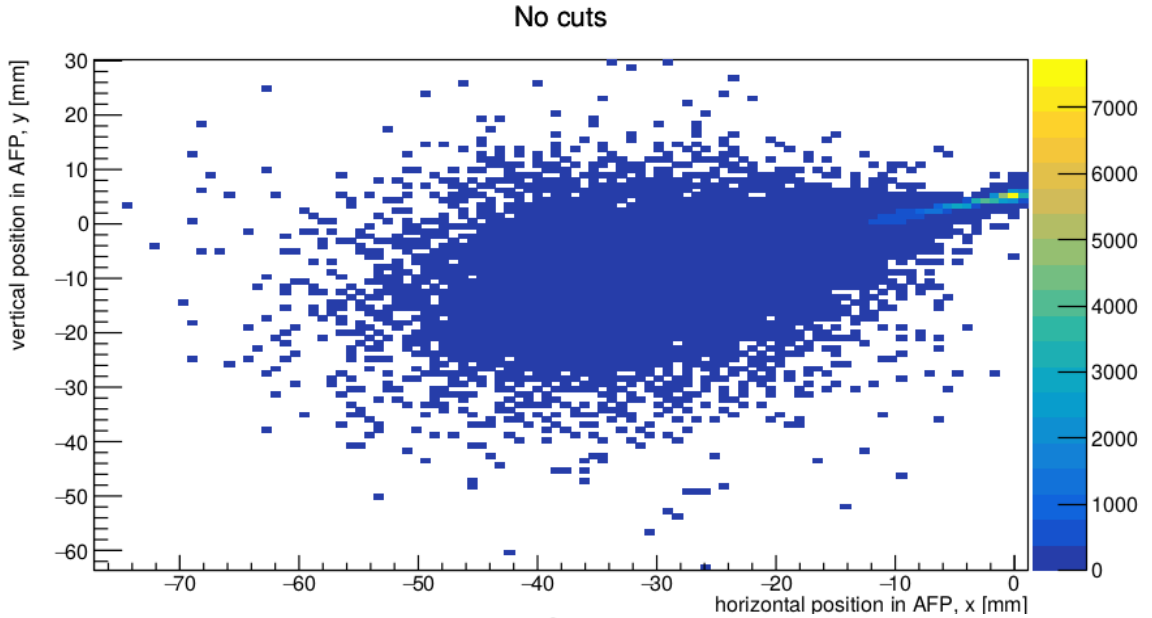
Main Aims

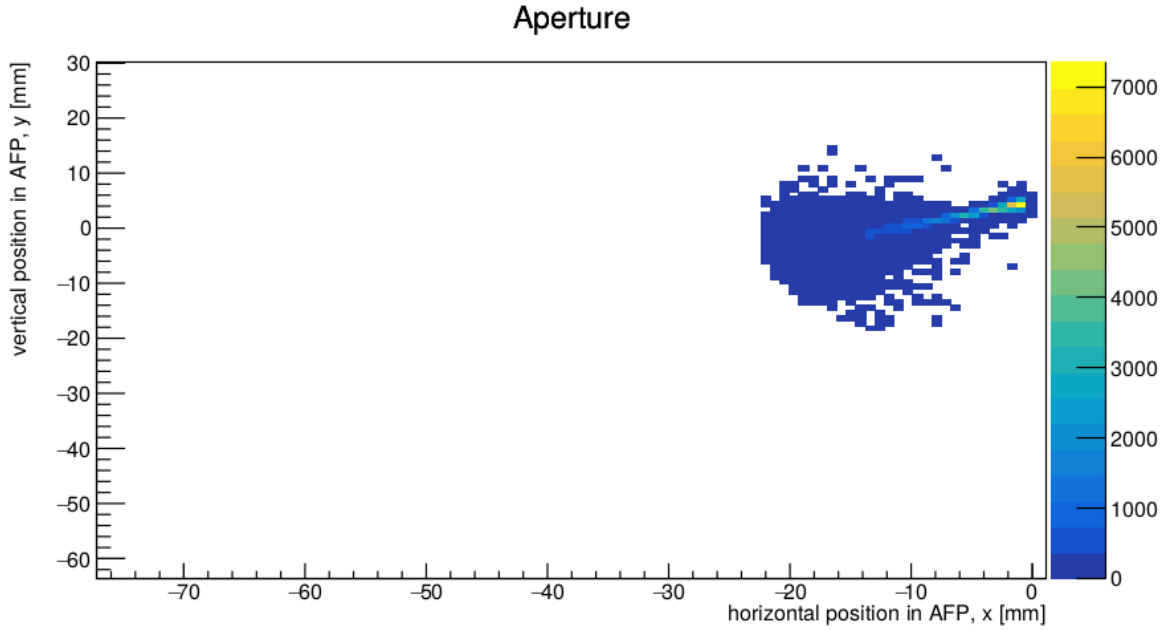
- Implementation of **shift** (x, y, z axes) of the magnets and their **strength** changes.
- Implementation of the aperture of the magnet:
  - **aperture** - the shape of LHC beampipe/elements.
- Implementation of the collimators:
  - **collimator** - filtering protons (machine protection).
- To understand the impact of those changes to the proton's positions inside the AFP detector.
- To check the differences between the optics with shifted magnets and the default ones.

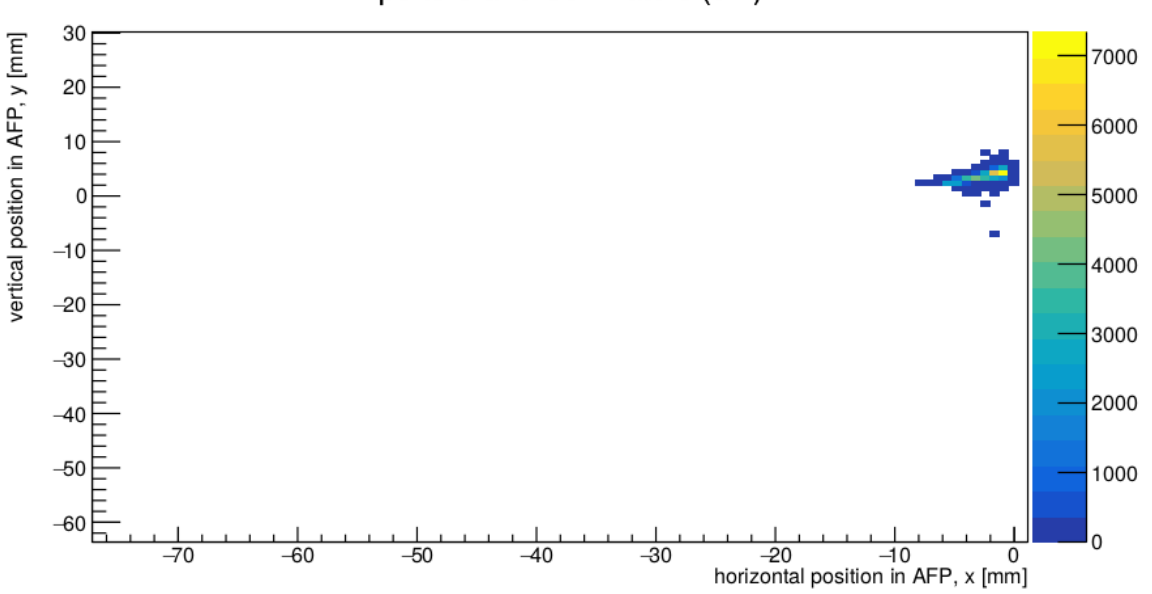
```
void ProtonTransport::DoShift(const Magnet& m, const string& op) {
  if (magnet_to_shift.find(m) != magnet_to_shift.end()) {
    if (magnet_to_shift.at(m).GetXShift() != 0)
      x = ApplyOperation(x, magnet_to_shift.at(m).GetXShift(), op);
    if (magnet_to_shift.at(m).GetYShift() != 0)
      y = ApplyOperation(y, magnet_to_shift.at(m).GetYShift(), op);
    if (magnet_to_shift.at(m).GetZShift() != 0) {
      z = ApplyOperation(z, magnet_to_shift.at(m).GetZShift(), op);
      x = ApplyOperation(x,
                         ApplyOperation(sx,
                                        magnet_to_shift.at(m).GetZShift(),
                                        "*"),
                         "+");
      y = ApplyOperation(y,
                         ApplyOperation(sy,
                                        magnet_to_shift.at(m).GetZShift(),
                                        "*"),
                         "+");
    }
  }
}
```

Implementation of Aperture and Collimators

- Aperture – description of the shape of LHC beampipe/elements.
- Information provided in optics files.
- Effect of aperture – compare top right to bottom left plot.
- Collimators – filtering protons with too high momentum, used for machine protection.
- Two collimators before AFP.
- Example – bottom right – collimators closed to 5σ, where σ is the width of the beam.

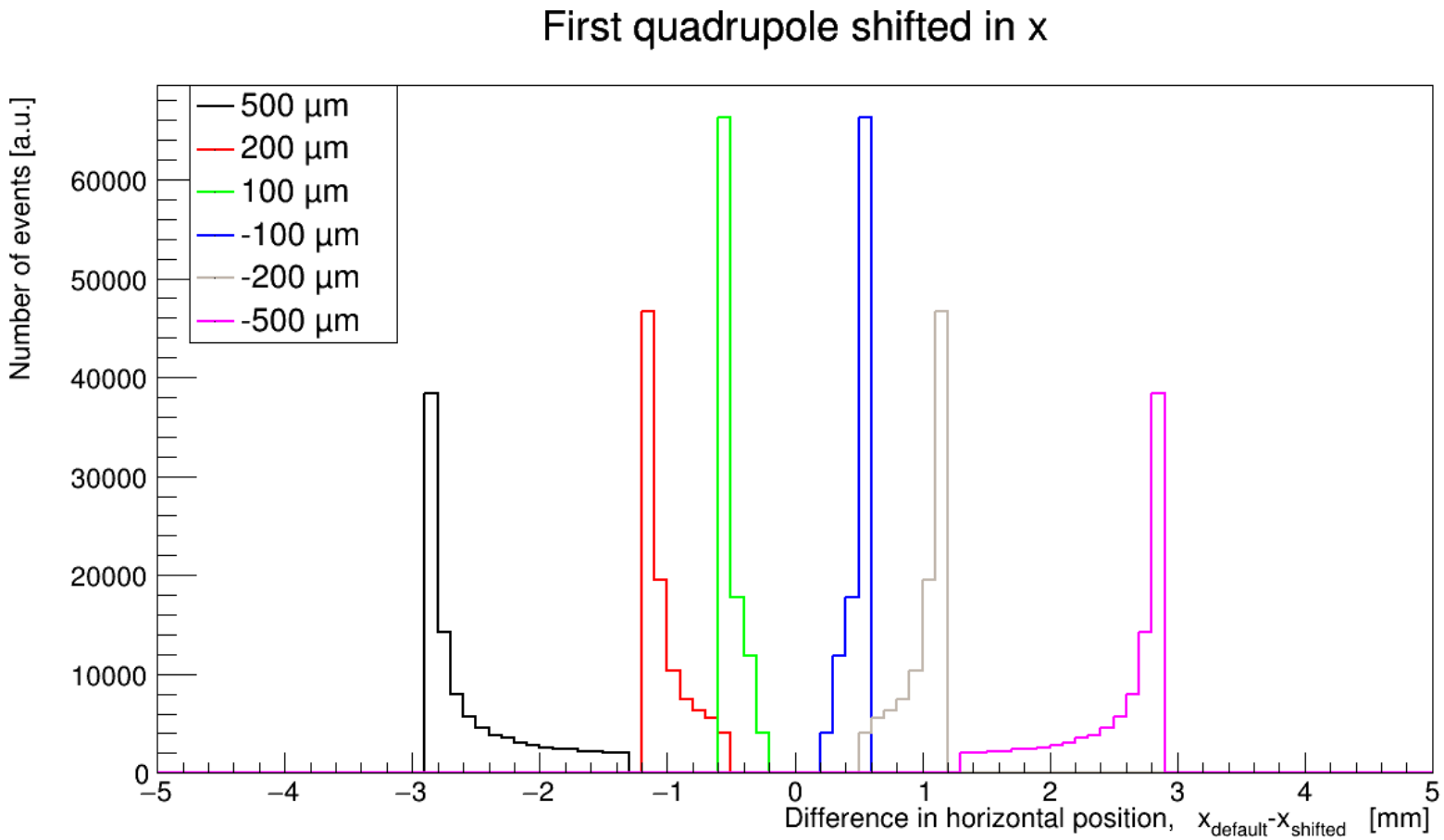






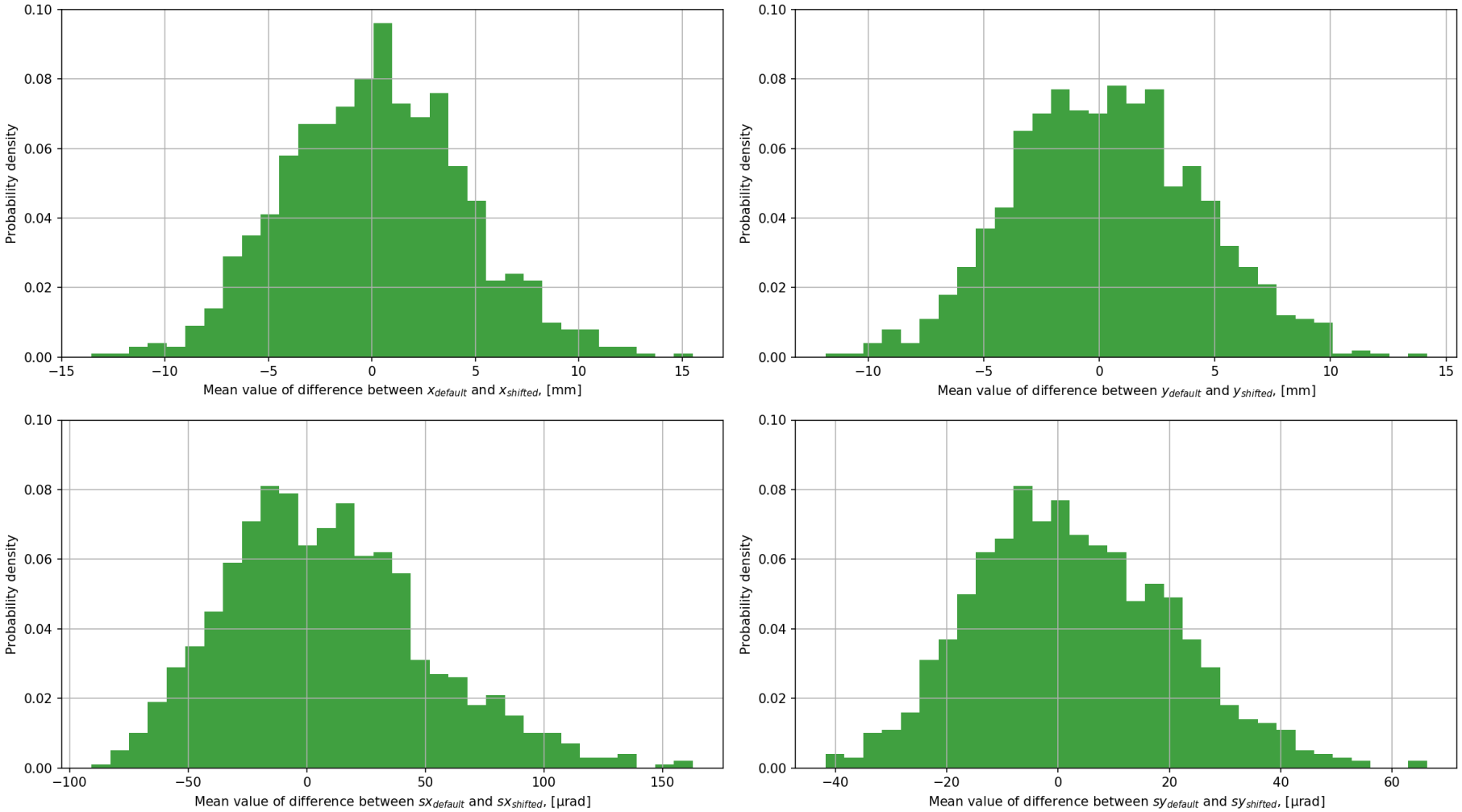
Example: Shift Implementation

- First quadrupole shifted in x.
- Such shift results in a quite **significant** shift of the proton position seen in the AFP detector.
- In order to compare effects of various changes, mean of each difference will be taken.



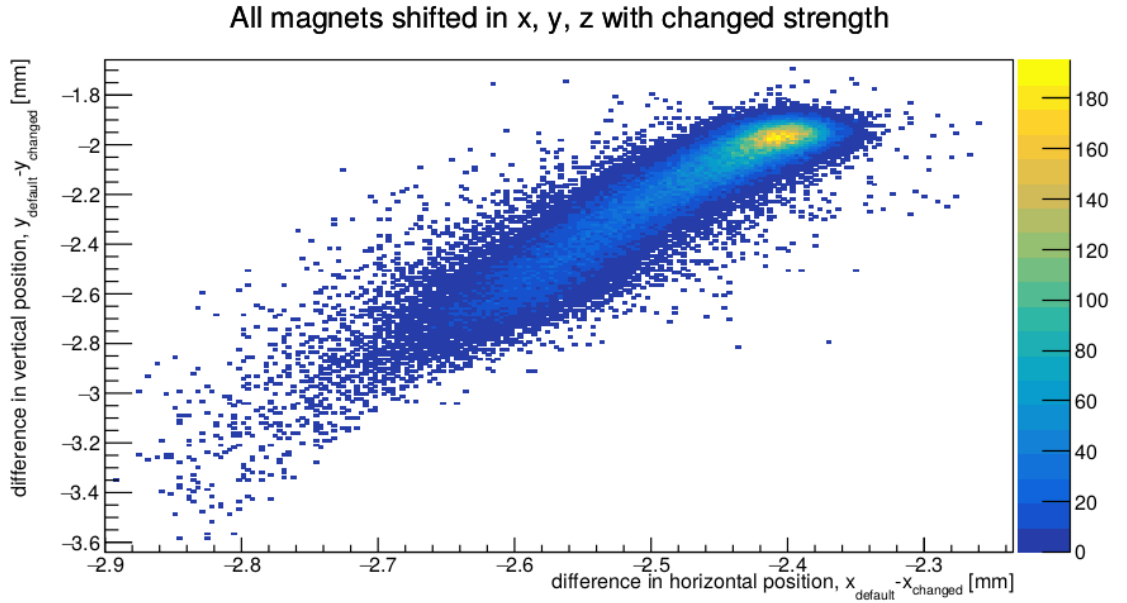
Example: Random Changes of Element's Strength and Position

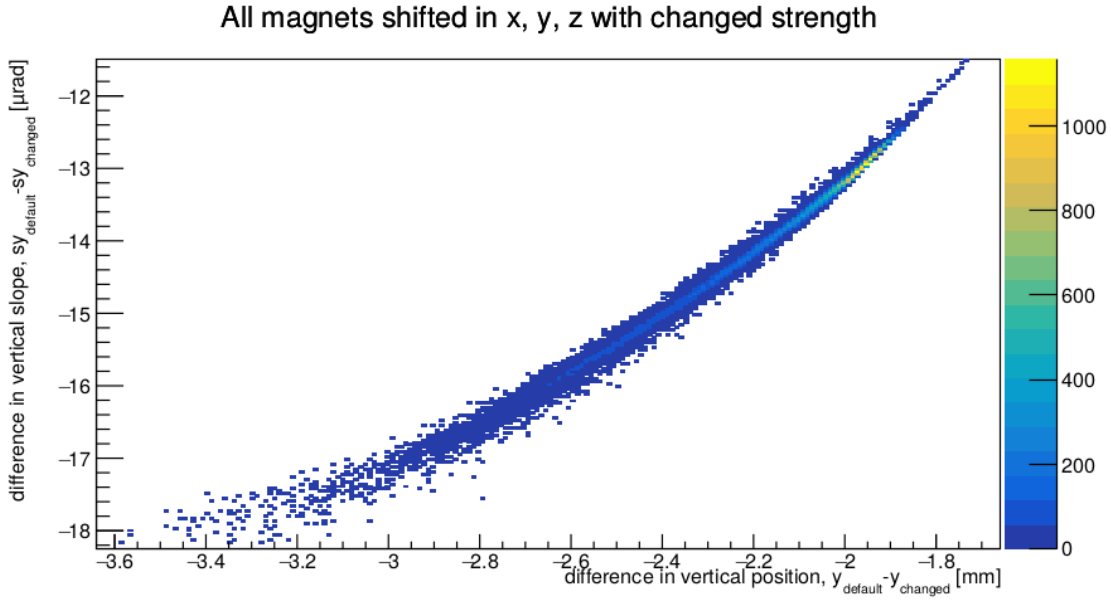
- 1000 sets of random changes.
- Properties of each magnet varied by random value from Gaussian distribution:
  - σ(x) = σ(y) = 250 μm;
  - σ(z) = 1 mm;
  - σ(strength) = 0.5‰.
- Changes in position and strength of magnets have an impact on proton positions and slopes in the AFP detector.
- From the example you can observe:
  - changes in position and strength of magnets have an impact on the positions and slopes of a proton;
  - in case of x difference, value ranges are [–13.55, 15.51] mm;
  - y: [-11.85, 14.17] mm;
  - sx: [–90.81, 162.75] μrad;
  - sy: [–41.73, 66.25] μrad.

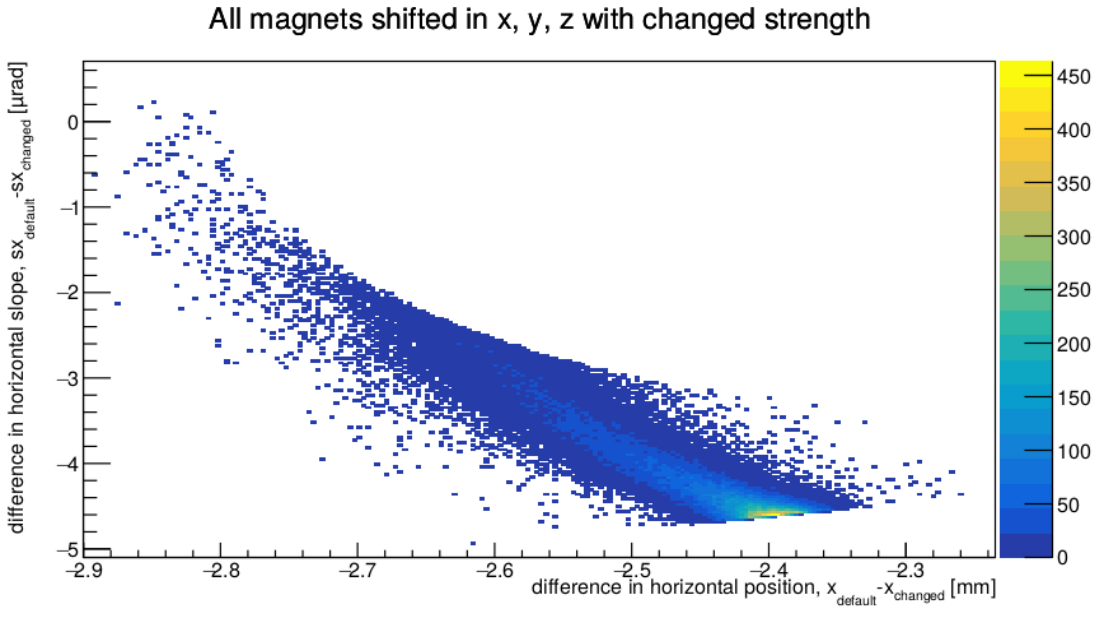


Example: 2D distributions

- Examplary results for all magnets:
  - Shift values:
    - x_shift = 500 μm;
    - y_shift = 500 μm;
    - z_shift = 5 mm.
  - Strengths are multiplied by 1.0005.
- Aperture included.
- Collimators before AFP closed to 15σ and 35σ respectively.
- Such plots allow studies of kinematic dependence.







Summary and Outlook

- We have done some C++ and Python programming during the project:
  - implementation of **shifts** of the magnets in x, y and z axes;
  - implementation of **changes in the strength** of the magnets;
  - implementation of the **aperture** of the LHC elements between IP and AFP detector;
  - implementation of the **two main collimators**.
- The code is available on GitHub.
- We took a look to how certain shifts change the positions and slopes in the AFP detector.
- As for the outlook:
  - introduce constraints (beam positions measured along the LHC);
  - try to find shifts which match with those measurements;
  - try to define "true" optics.

```
int run_id = 1;
TRandom* r = new TRandom();
for (int i = 0; i < 100; i++) {
  std::cout << "Run: " << run_id << std::endl;

  ProtonTransport* p = new ProtonTransport;
  p->SetProcessedFileName(optics_file_name);
  p->PrepareBeamline(false);

  for (const auto& magnet : magnets) {
    p->SetShift(magnet, Shift(r->Gaus(0, 0.00025),
                              r->Gaus(0, 0.00025),
                              r->Gaus(0, 0.001)));

    p->SetStrengthRatio(magnet,r->Gaus(1, 0.0005));
  }

  p->simple_tracking(205.);

  DistributionsDifference* diff =
    new DistributionsDifference(p_default->GetROOTOutputFileName(),
                                p->GetROOTOutputFileName());
  p->WriteChangesInCsv(changes_fn, diff, run_id++);

  std::cout << "done\n\n";
  delete p;
}
```