Exercise: magnetic & electric fields

Apply fields to a simple beamline

The problem

- We will use the beamline constructed in the geometry exercise
- The first objective is to use the dipole to deflect the incoming beam (previously impacting on the beam dump) exactly onto the z-axis and through the quadrupoles
- Then, we will change the beam characteristics and use the quadrupoles to focus it at a desired location
- As an extra problem, we will accelerate the protons with an electric field

The input file

- You can start from the provided input or from your own solution to the geometry exercise, if complete
- All the magnets are in place and the initial beam is defined

Apply magnetic field to the dipole and run

1. Define a dipole field (**`MGNCREAT`**) and apply it to the dipole replica (**`MGNFIELD`**)
    - What is the correct magnetic field strength *B* to deflect the incoming beam by an angle θ=20° and deflect it onto the z-axis? The strength is given by:

$$B[T] = \frac{p\left[\frac{eV}{c}\right]}{c\left[\frac{m}{s}\right] \cdot R[m]}$$

    where *p* is the momentum, *c* is the speed of light and *R* is the required bending radius, already **`#define`**’d in the input (as *Rbend*)

2. Run the input (just a few particles are enough) and plot the proton fluence scoring on the x-z plane (i.e. top view of the beamline)
    - Is the beam brought onto the z-axis? If not, check your input.

Apply magnetic fields to the quadrupoles

- The three quadrupoles will be in an FDF configuration (Focusing-Defocusing-Focusing)
  - By convention, “focusing” means “focusing on the horizontal plane for positively charged particles”)

3. Define a focusing and a defocusing quadrupole field (**`MGNCREAT`**) and apply the focusing field to Q1 and Q3, and the defocusing one to Q2 (**`MGNFIELD`**)
   - What is the difference between the two? Just a 90° azimuthal rotation!
   - Apply the following gradients (careful with the unit):
     - g_{Q1} = 25.268 T/m
     - g_{Q2} = 28.683 T/m
     - g_{Q3} = 46.449 T/m

4. Plot the fields in the quadrupoles on the transverse plane (x-y) and check that the quadrupole configuration you have defined is indeed correct

Adjust beam parameters and run

- If you run now (with the pencil beam) nothing will happen, since the beam will still be encountering zero field on the z-axis inside the quadrupoles

5. Change the beam parameters so that the effect of the quadrupoles can become apparent
    - Define a ±3% uniform momentum spread
    - Define a Gaussian divergence with σ=5 mrad
    - Define a Gaussian beam profile with σ=2.5 mm

6. Run 5 cycles of 50000 primaries each; since the beam should not be hitting anything, this will be quite fast.

7. Plot the proton fluence scoring on the x-z plane (i.e. top view of the beamline) and on the y-z plane (side view). Observe the action of the quadrupoles and the focusing of the beam on both planes at around z=3 m.

Extra problem: electric field

- Let’s give a small push to the protons after they exit the beamline

- Define a vacuum region within an RCC placed around z=300cm, with a radius of 5 cm and a length of 20 cm
- Apply an electric field to this region so that the protons receive an additional 50 MeV of energy
  - What should be the magnitude of the electric field component along the z-axis (in kV/cm) to achieve this?

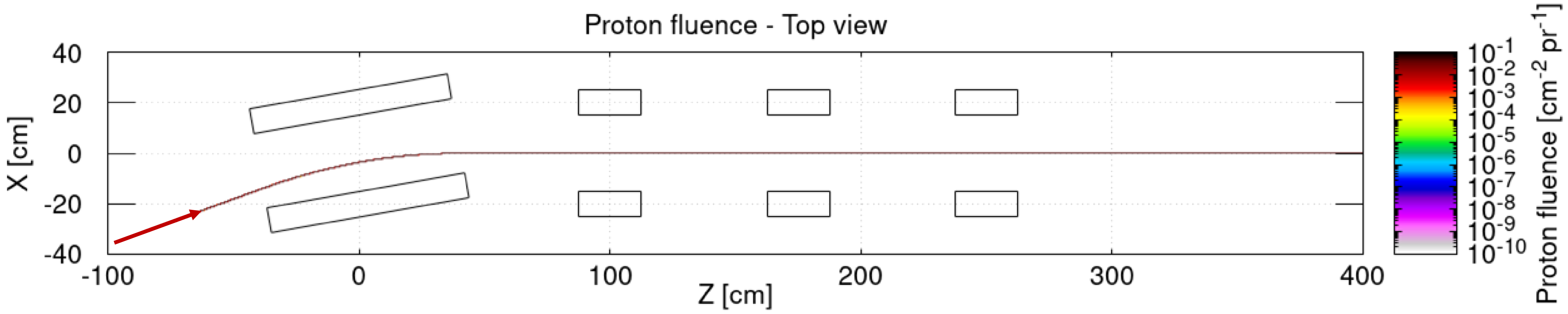
- Add two USRBDX scorings to score the energy spectrum of the incoming and outgoing protons in this region

- Run once more and plot the energy spectrum of protons entering and exiting the electric field region. Can you observe the acceleration?

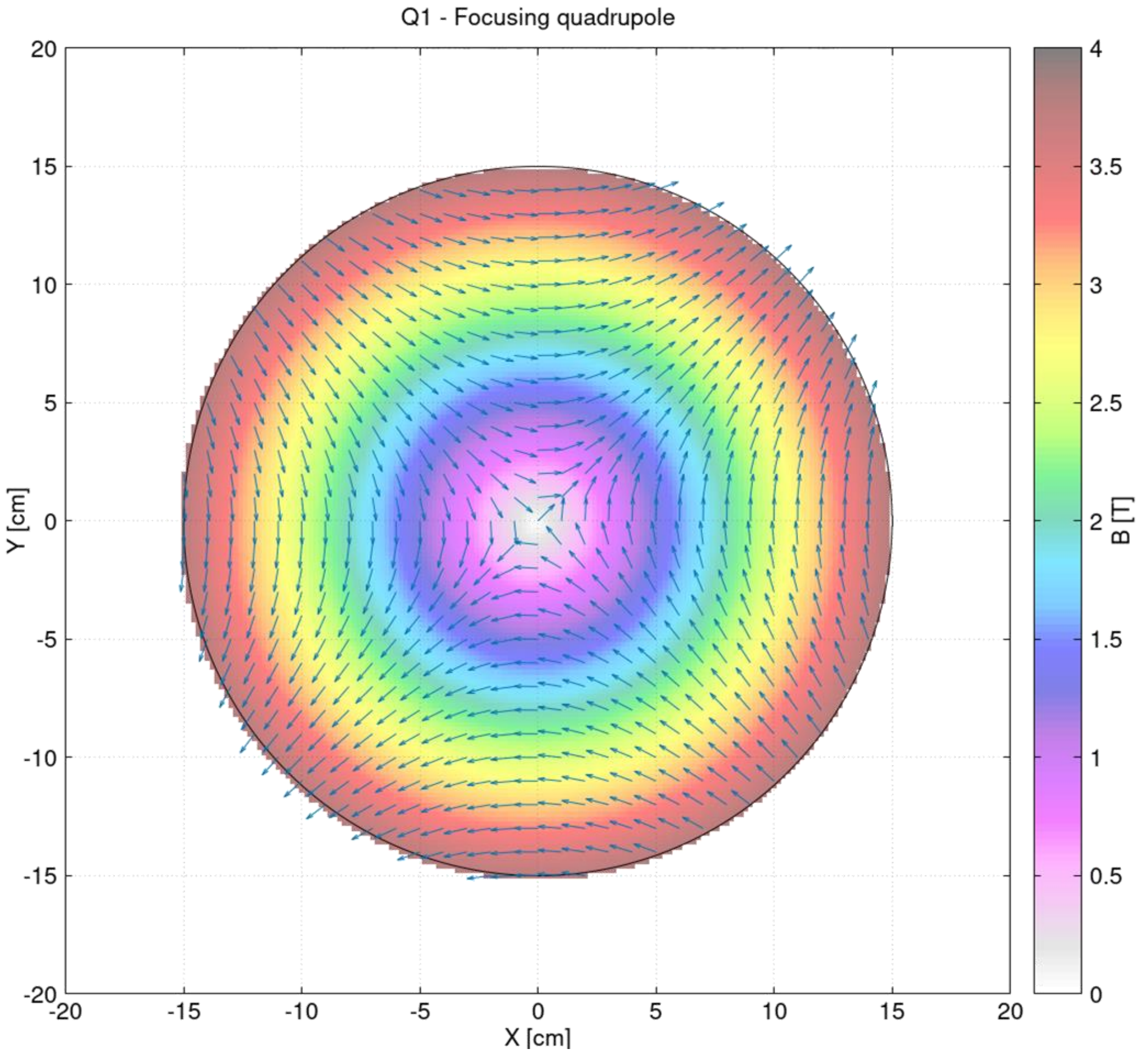
Results

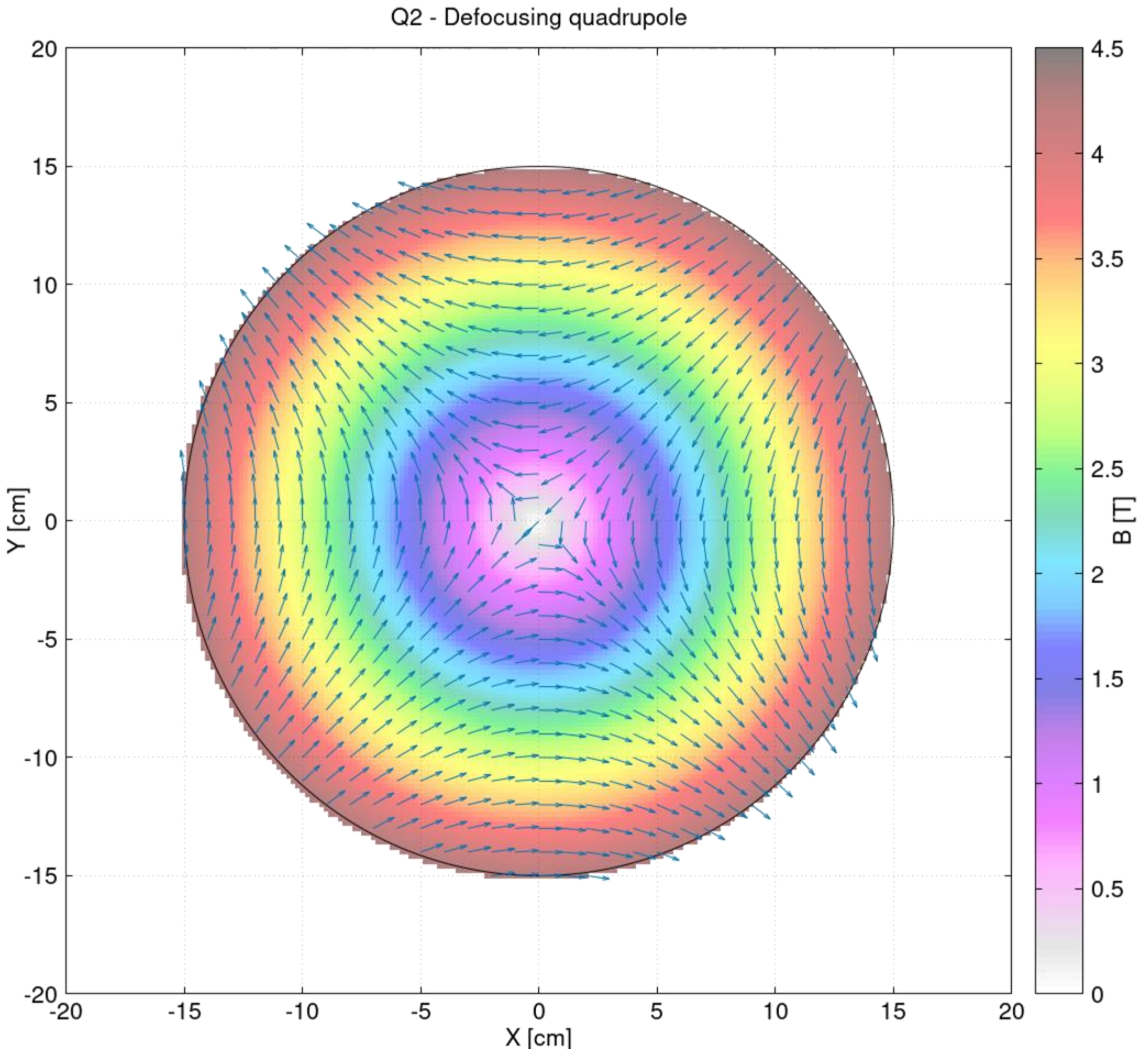
Proton fluence with pencil beam

- The dipole deflects the incoming beam onto the z-axis

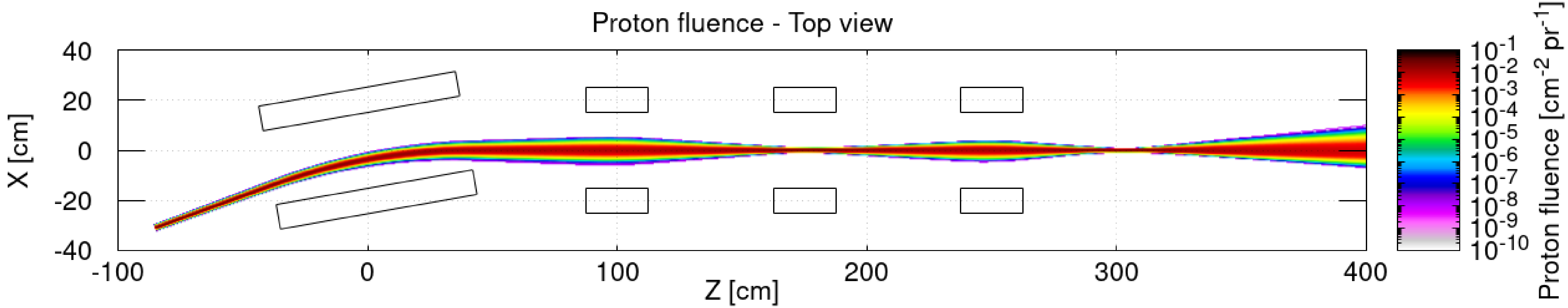


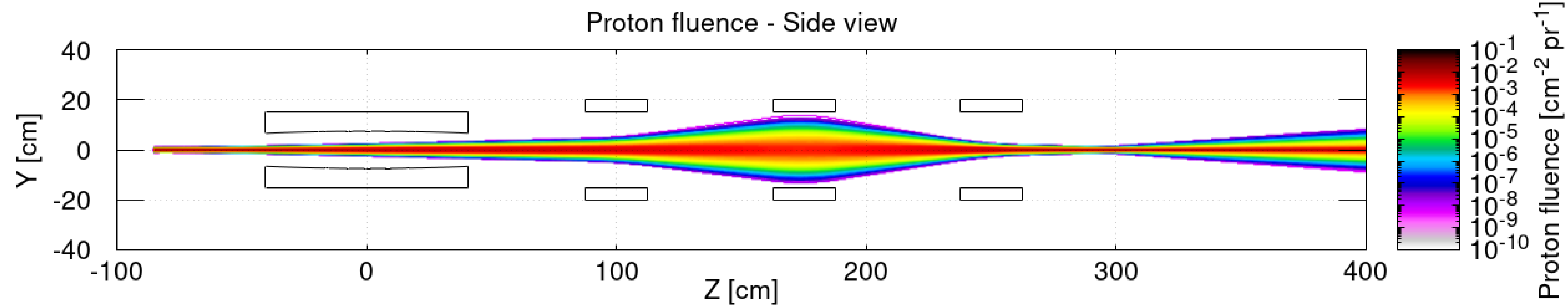
Quadrupole fields


Q1 - Focusing quadrupole

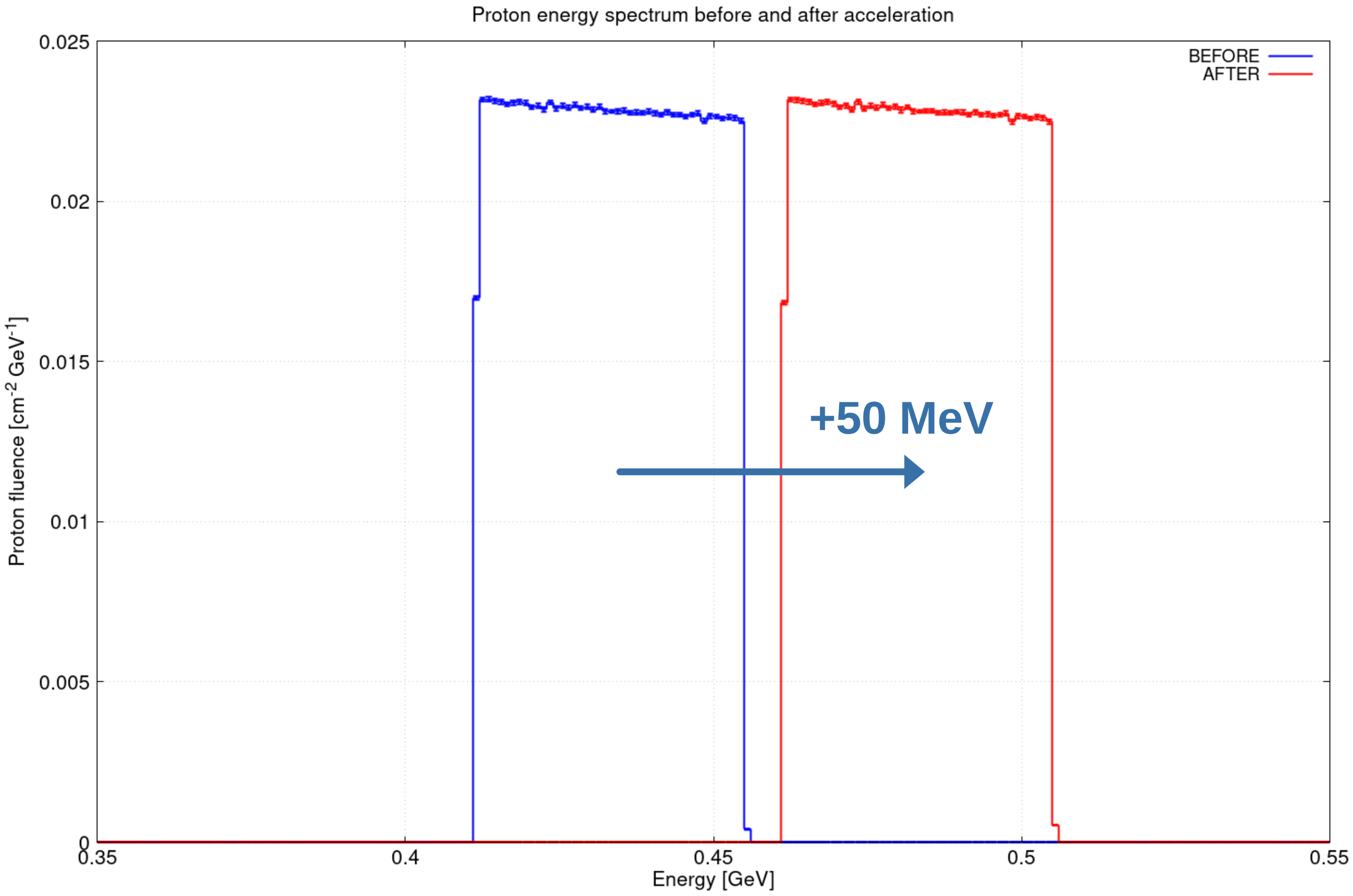

Q2 - Defocusing quadrupole

Proton fluence with dp/p=3%, Δφ=5 mrad(σ), Δx/y=2.5 mm(σ)


Proton fluence - Top view


Proton fluence - Side view

Acceleration with electric field



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