Space charge limit for BGI in LHC and SPS – strategy for the future

Marcin Patecki, Mariusz Sapiński
CERN

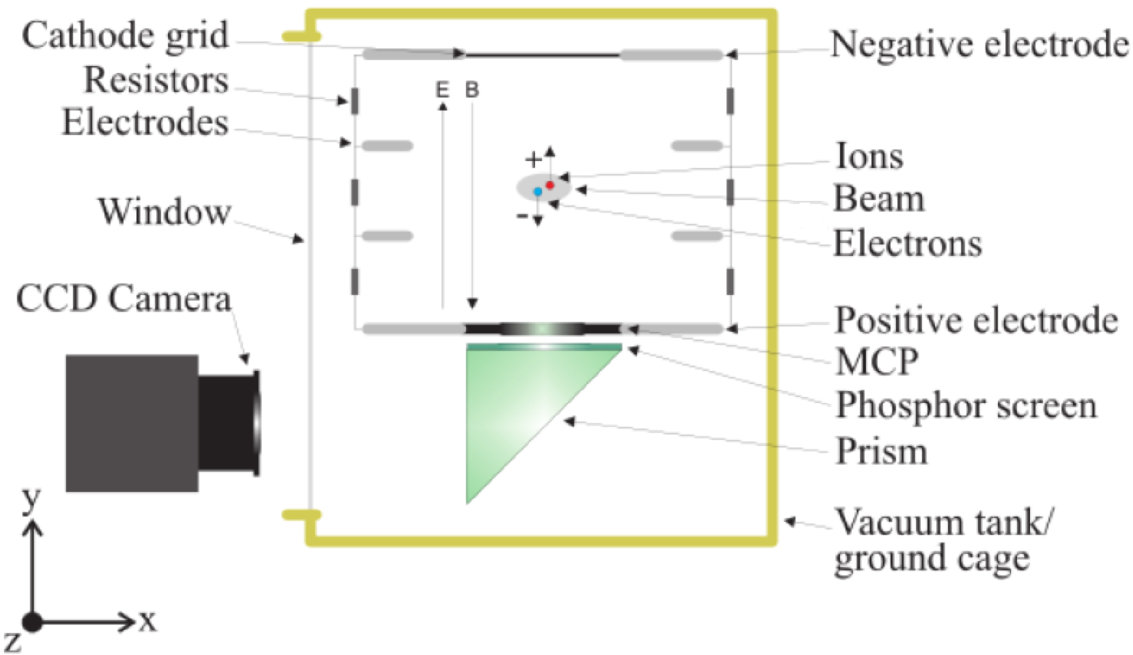
Outline

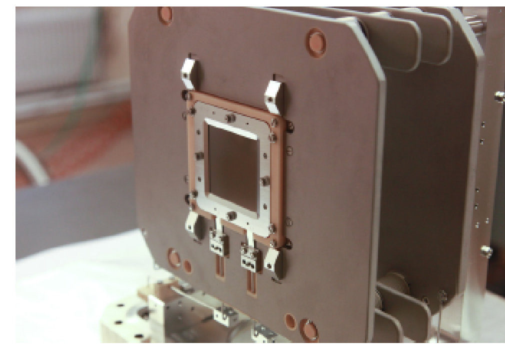
- Motivation
- BGI description
- PyECloud simulation description
- Geant4 simulation of the electron initial momentum
- PyECloud simulation results
- Conclusions

Motivation

- We tried to calibrate the BGI in order to ensure the proper measurements, but we failed.
- We were looking for possible reasons.
- We realized that the electrons liberated in the ionization process strongly interact with the beam charges.
- Those interactions affect electron trajectories and the overall beam profile;
- We run the simulations to check the BGI limits.

BGI operation principle





- High Voltage: -2kV applied for cathode and +2kV for anode
- Magnetic field of 0.22 T
- Filled with Argon gas of low pressure ≈ 10^{-8} mbar

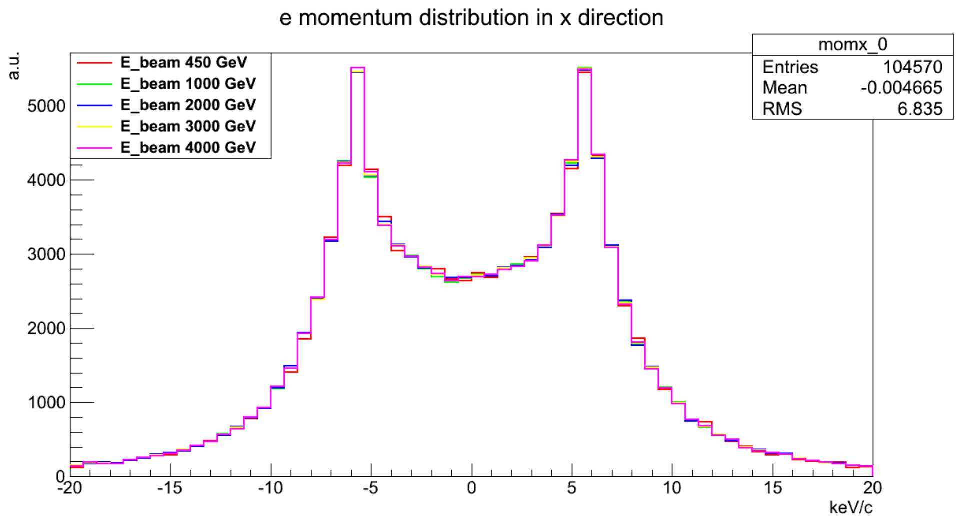
What is PyEClOUD:

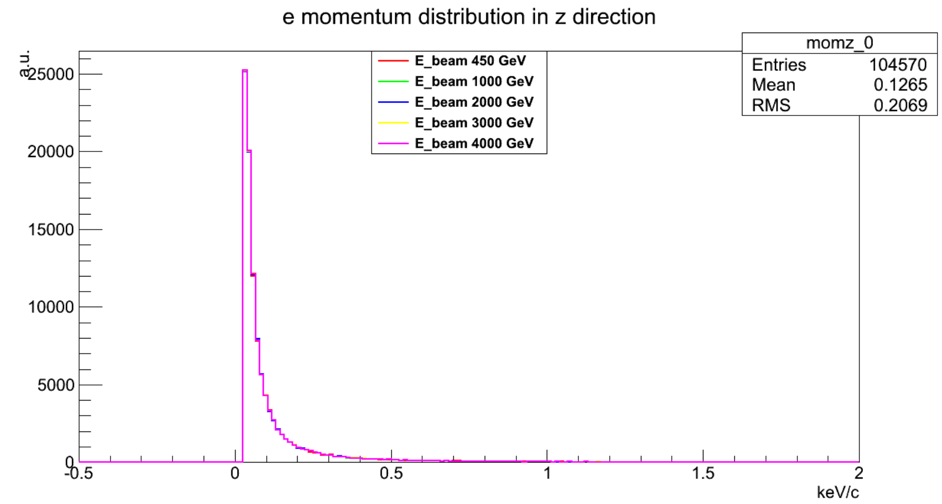
- Written by G. Iadarola, G. Rumolo at CERN;
- Newly developed code for the simulation of the electron cloud build-up in particle accelerators;
- Adapted for BGI, it performs the 2D tracking of the electrons in the presence of the beam charges and external electric and magnetic fields
- More details:
  http://ecloud12.web.cern.ch/ecloud12/Proceedings/Edited/Iadarola-edited.pdf

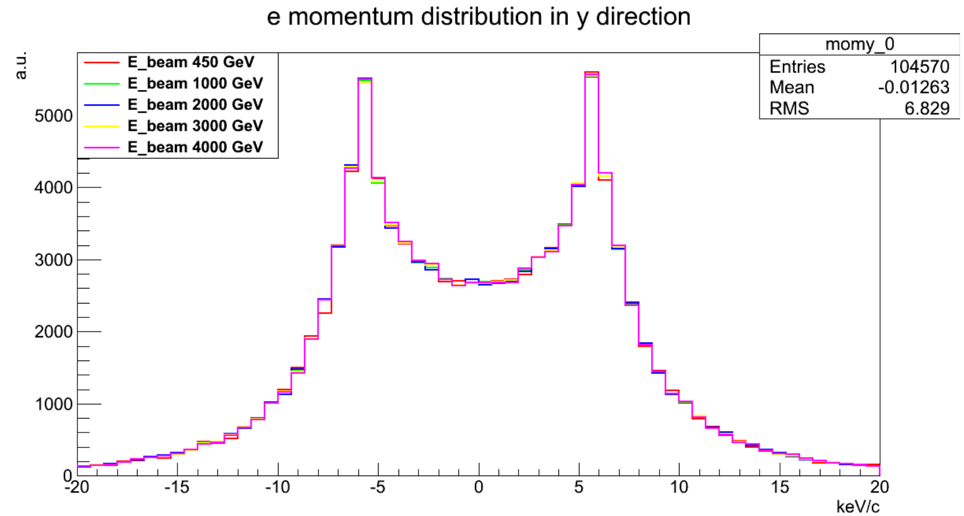
Electrons initial momentum

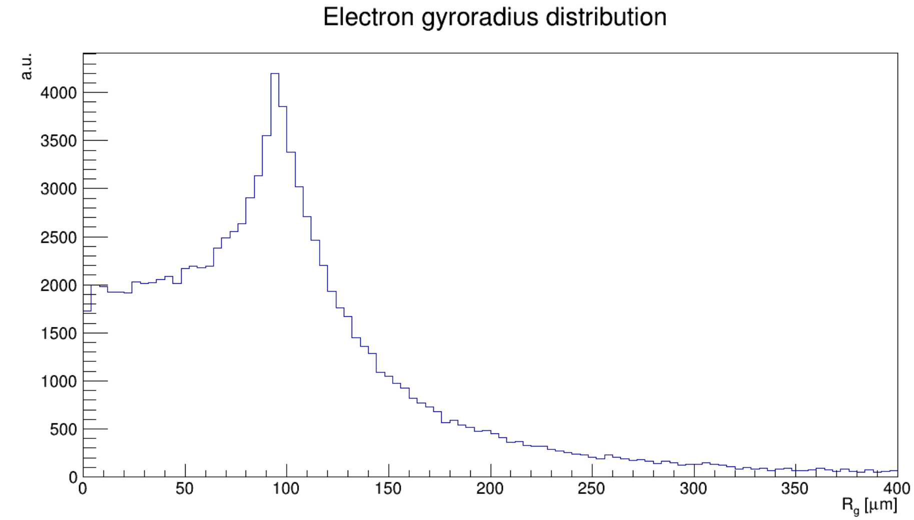
- The electrons created in the ionization process have the initial momentum and it is important to take it into account;
- We obtained the initial momentum of electrons from Geant4 simulation;
- We used the special settings for low energy electromagnetic physics.

Electron momentum distribution





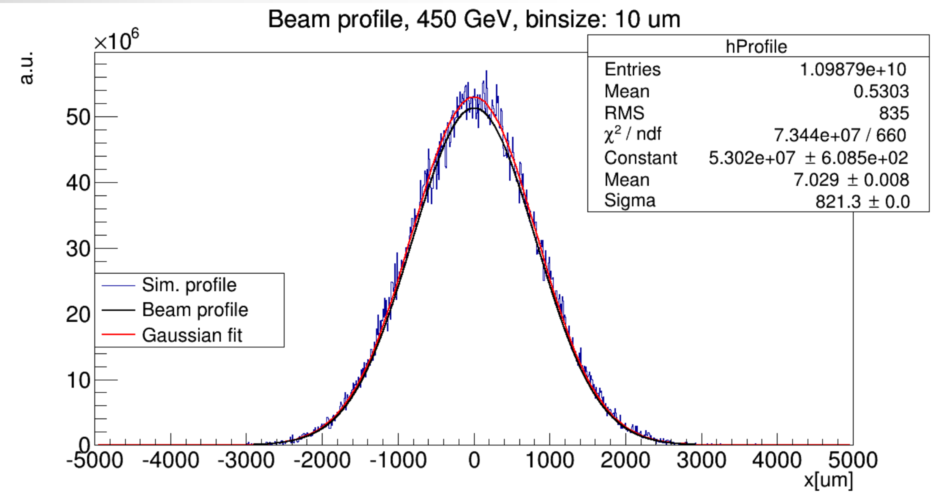


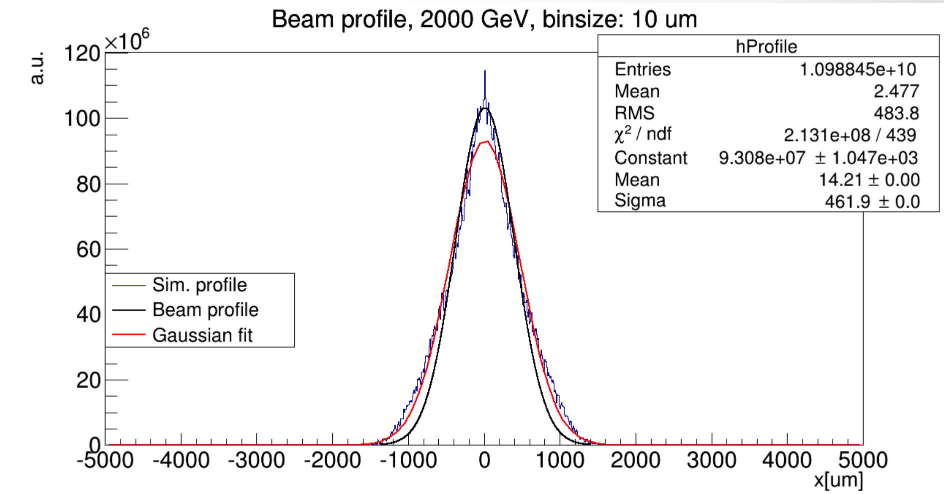


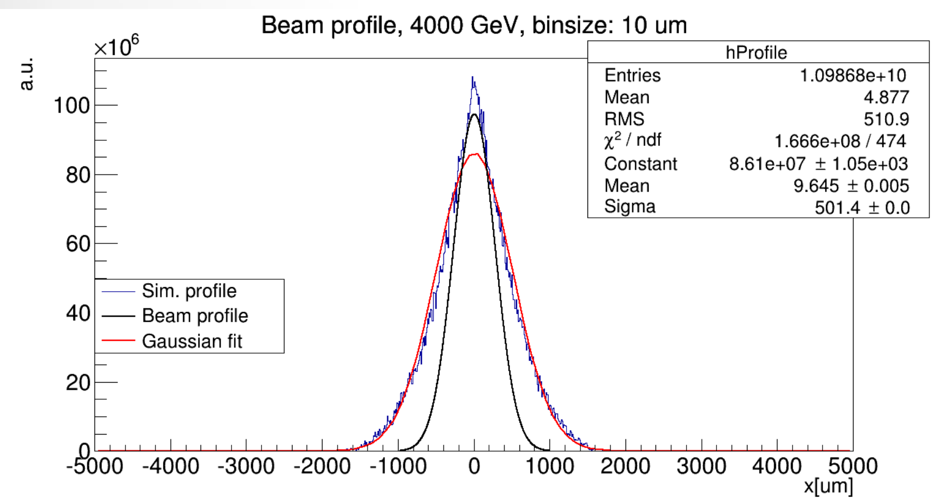
Simulation input

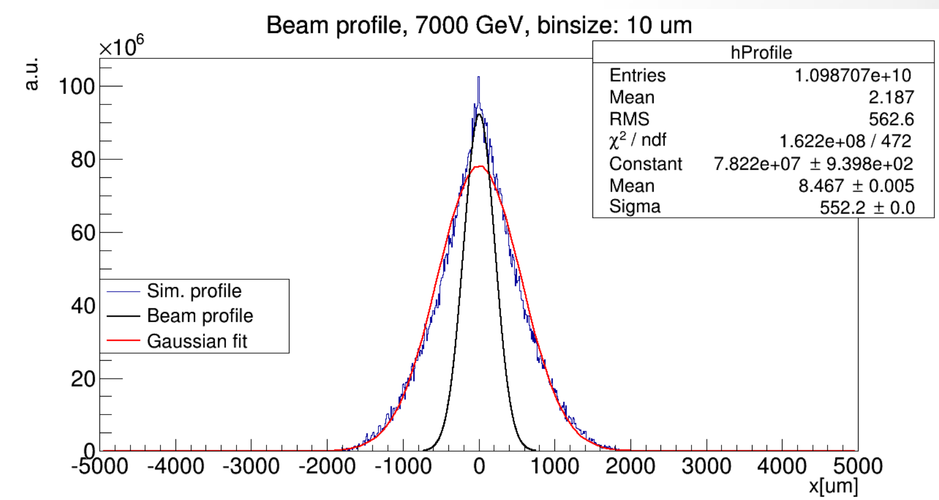
- $E_{beam} = 26 - 7000\ GeV;$
- $E = \frac{4000\ V}{8.5\ cm}$ - electric field of the chamber (y direction);
- $B = 0.2 - 1.5\ T;$
- $I = 1.1 - 1.65 \cdot 10^{11}\ \frac{protons}{bunch}$ - proton beam intensity;
- $I = 1.0 - 2.0 \cdot 10^{10}\ \frac{charges}{bunch}$ - ion beam intensity
- $\varepsilon_x = 0.5 - 3.5\ \mu m$ – horizontal beam emittance;
- $\varepsilon_y = 0.5 - 3.5\ \mu m$– vertical beam emittance;
- $\beta_x = 80, 213\ m$ – horizontal beta function;
- $\beta_y = 80, 213\ m$ – vertical beta function;
- $\sigma_z = 1.0 - 1.5\ ns$ – length of the bunch (4 sigma in time);

Examples of profiles

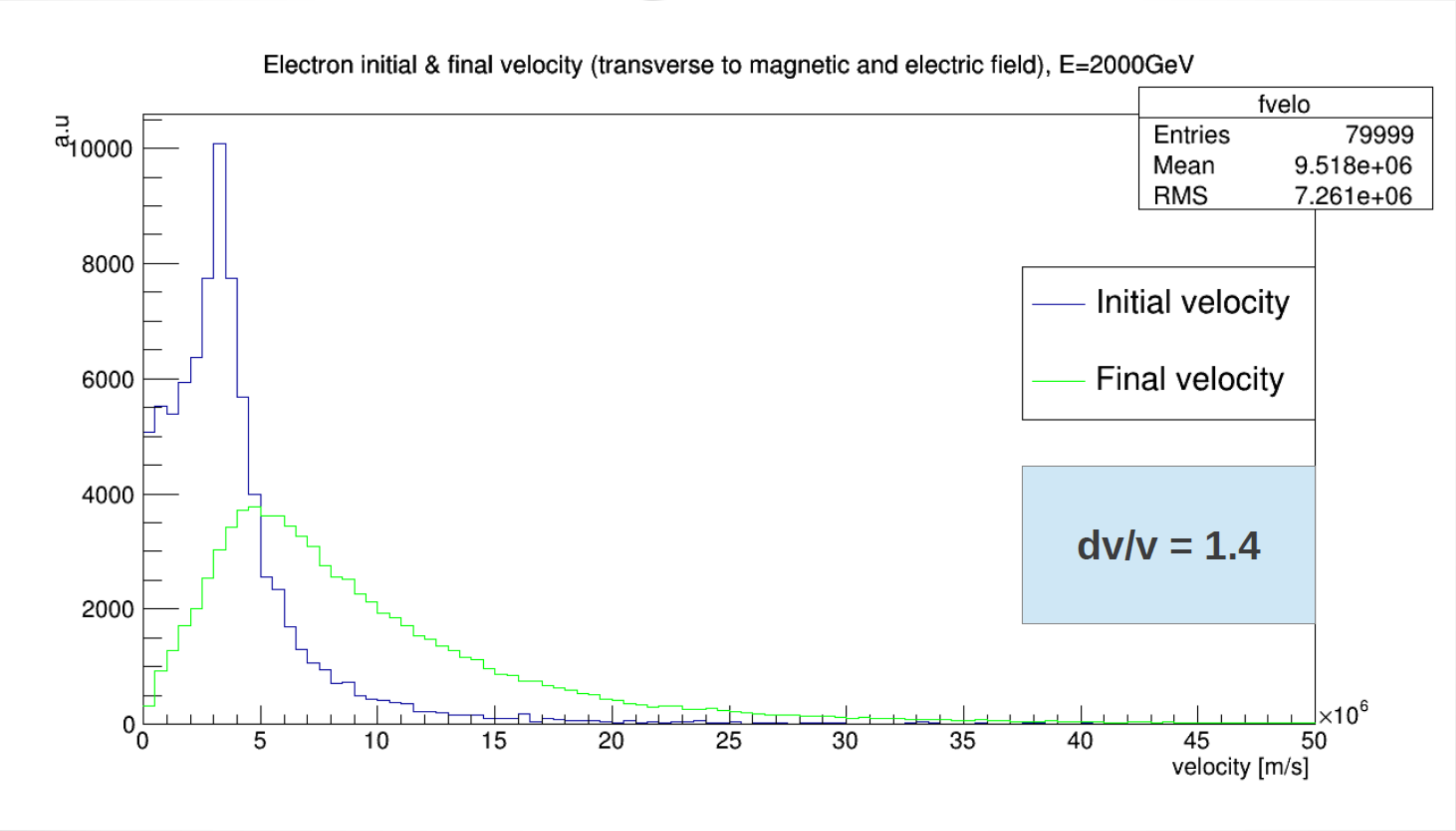




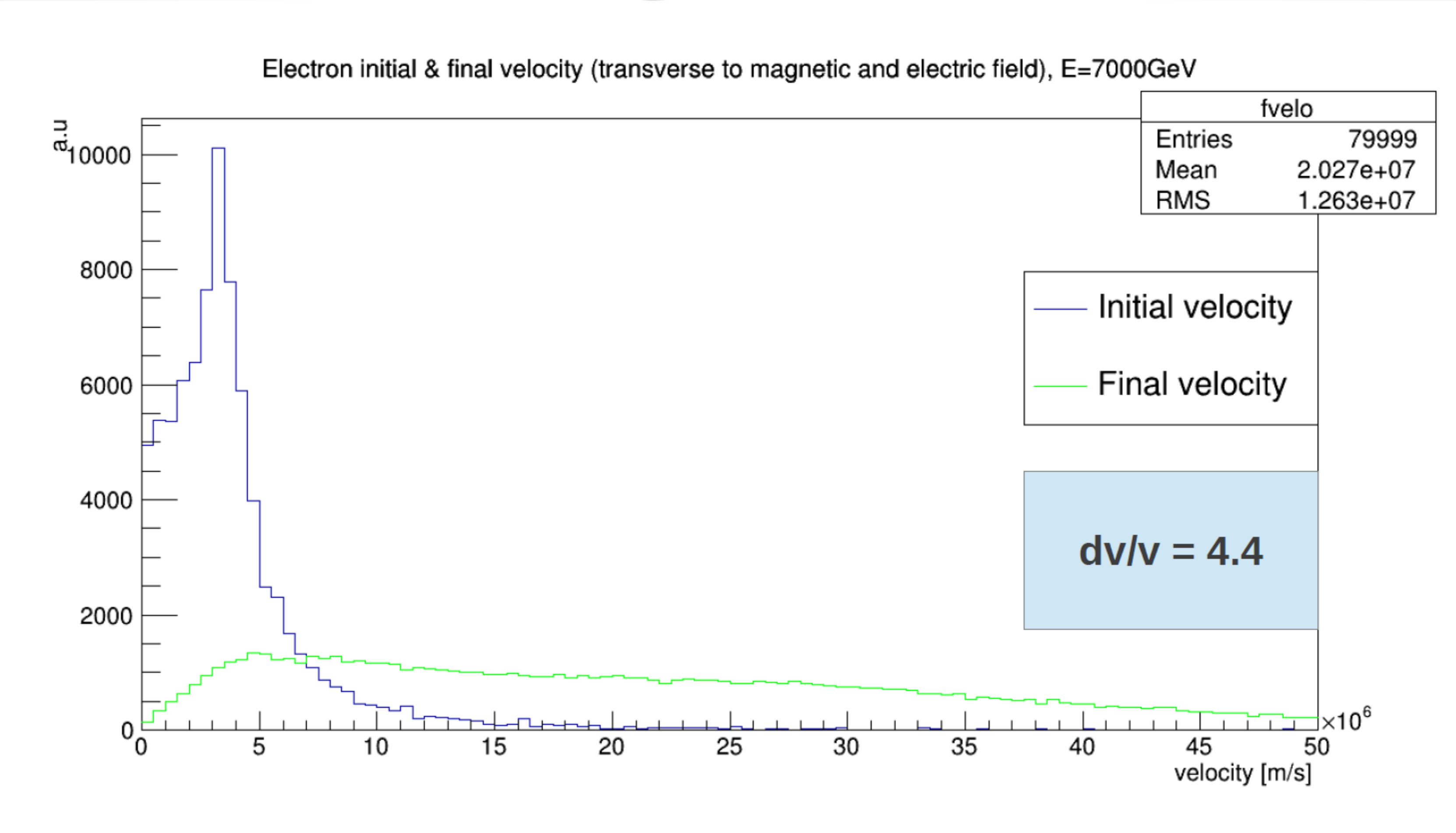




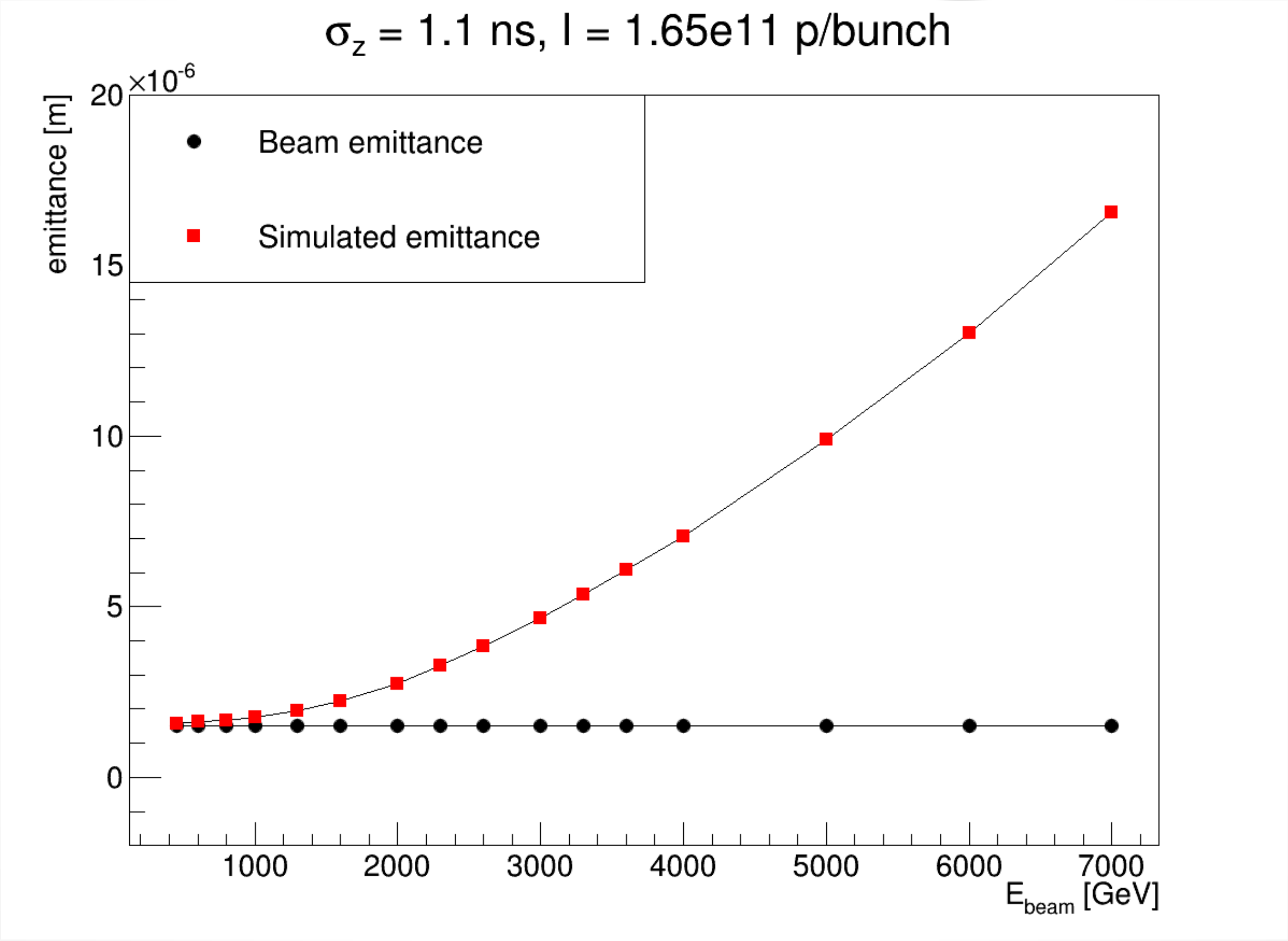
Velocity increase



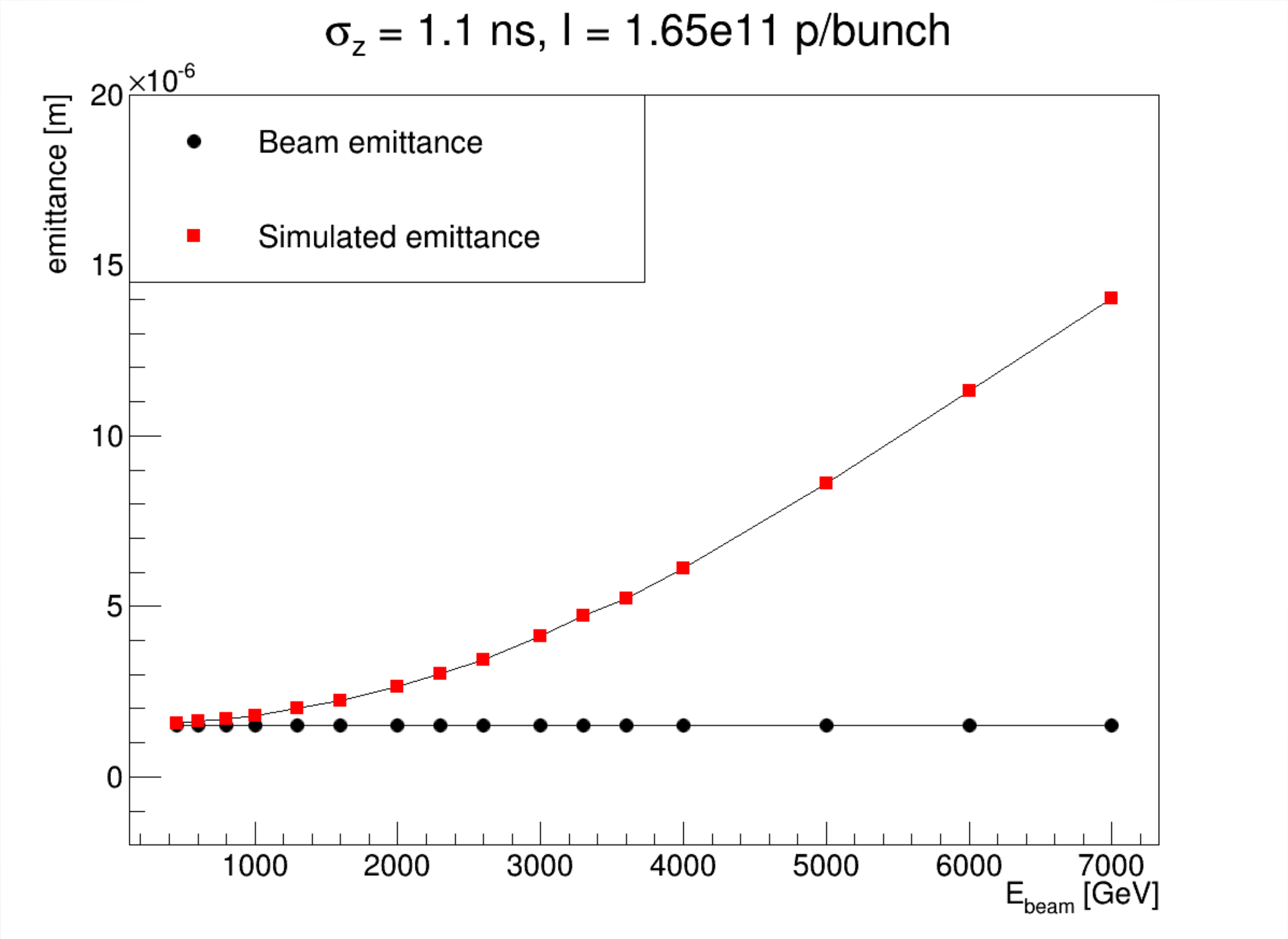
Velocity increase



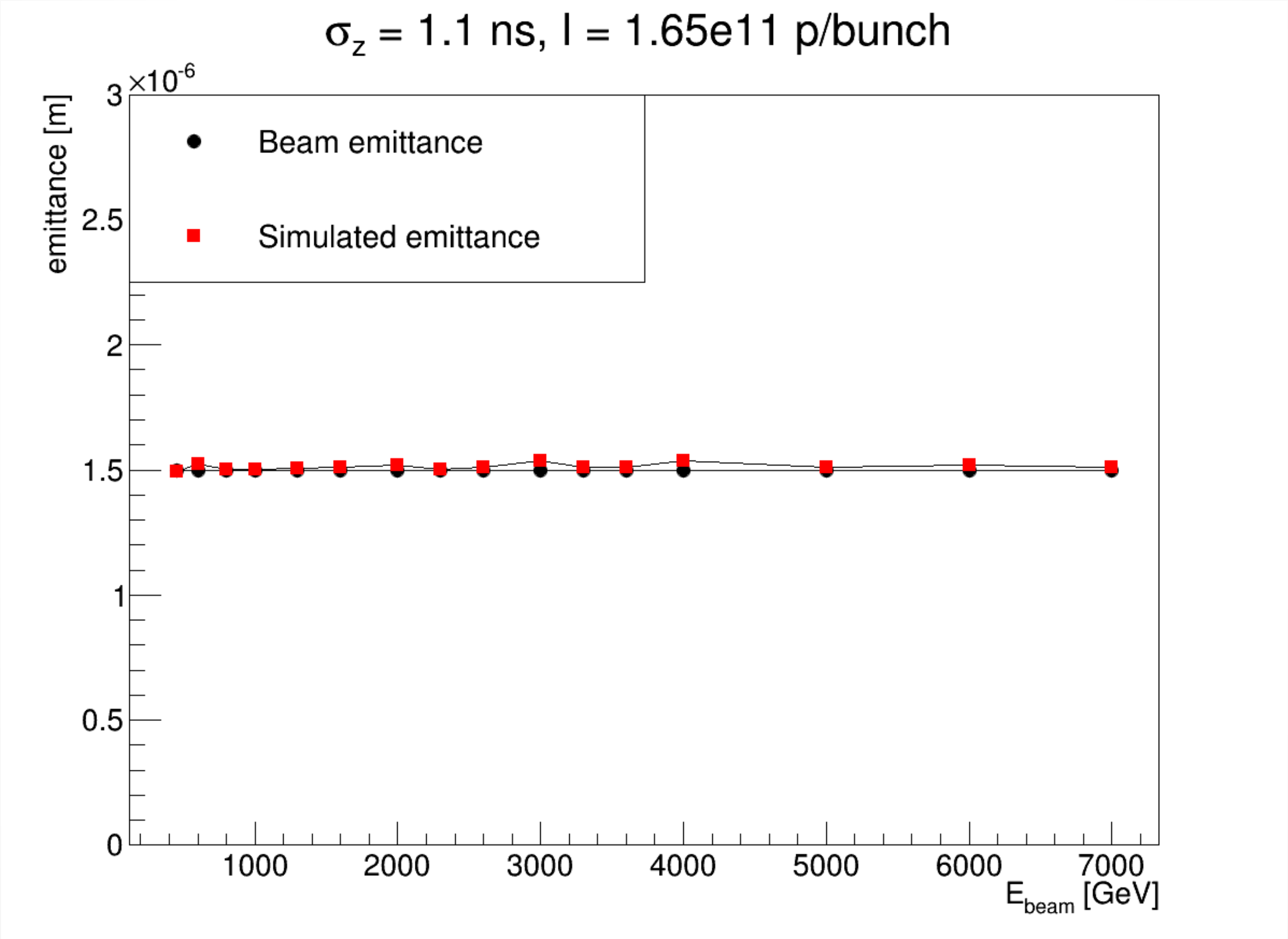
Results – profile broadening



Higher electric field $E = \frac{10000\ V}{8.5\ cm}$



Higher magnetic field B = 1T



Magnetic field threshold

- We cooperate with **Giuliano Franchetti (GSI)** who tries to calculate analytically the magnetic field threshold for dumping the space charge effects on electrons.
- Threshold magnetic field necessary to keep the relative increase of velocity smaller than D (10%):

$$B_t = \sqrt{\frac{1}{2(2\pi)^{3/2}\epsilon_0} m\gamma \frac{1}{D} \frac{R_b}{\rho_0} \frac{N}{\sigma_z {\sigma_r}^2}}$$

- We used the PyECloud code for simulations in order to check if the formula:

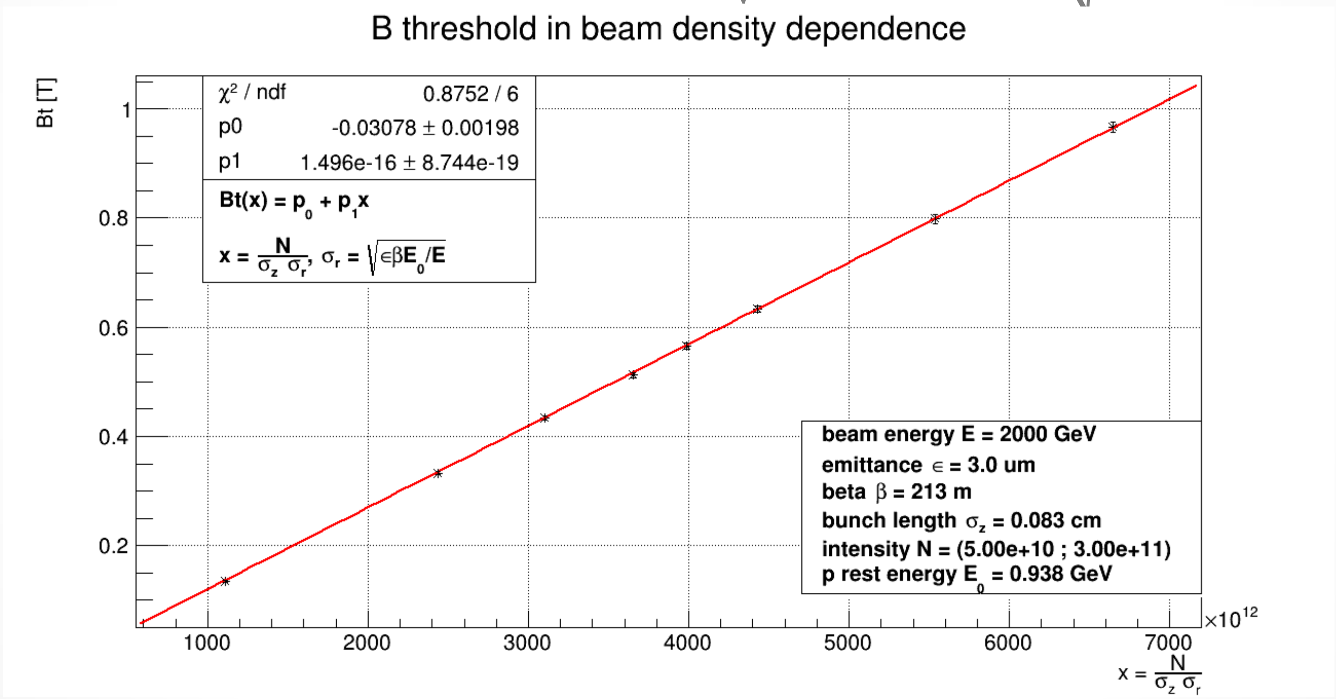
$$B_t = A\sqrt{\frac{N}{\sigma_z {\sigma_r}^2}}, \text{ A = const}, \sigma_r = \sqrt{\frac{\varepsilon\beta}{\gamma}}.$$

is correct.

Magnetic field threshold

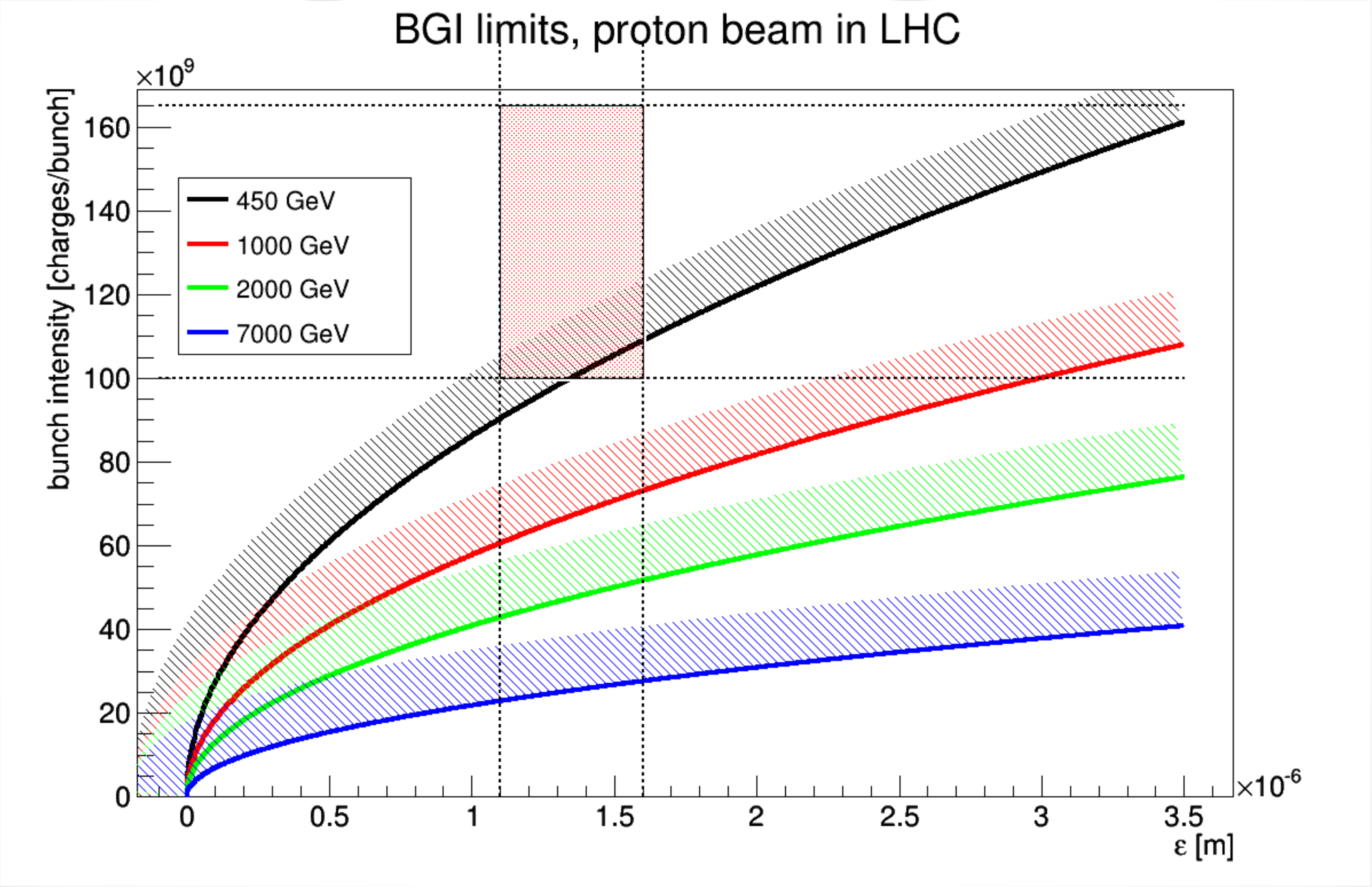
- We have found the formula which allows to approximate the theshold magnetic field

$$B_t(E, N, \sigma_z, \varepsilon) \propto \frac{N}{\sigma_z \sigma_r} = \frac{N\sqrt{\gamma}}{\sigma_z\sqrt{\varepsilon\beta}}, \qquad \sigma_r = \sqrt{\frac{\varepsilon\beta}{\gamma}}$$

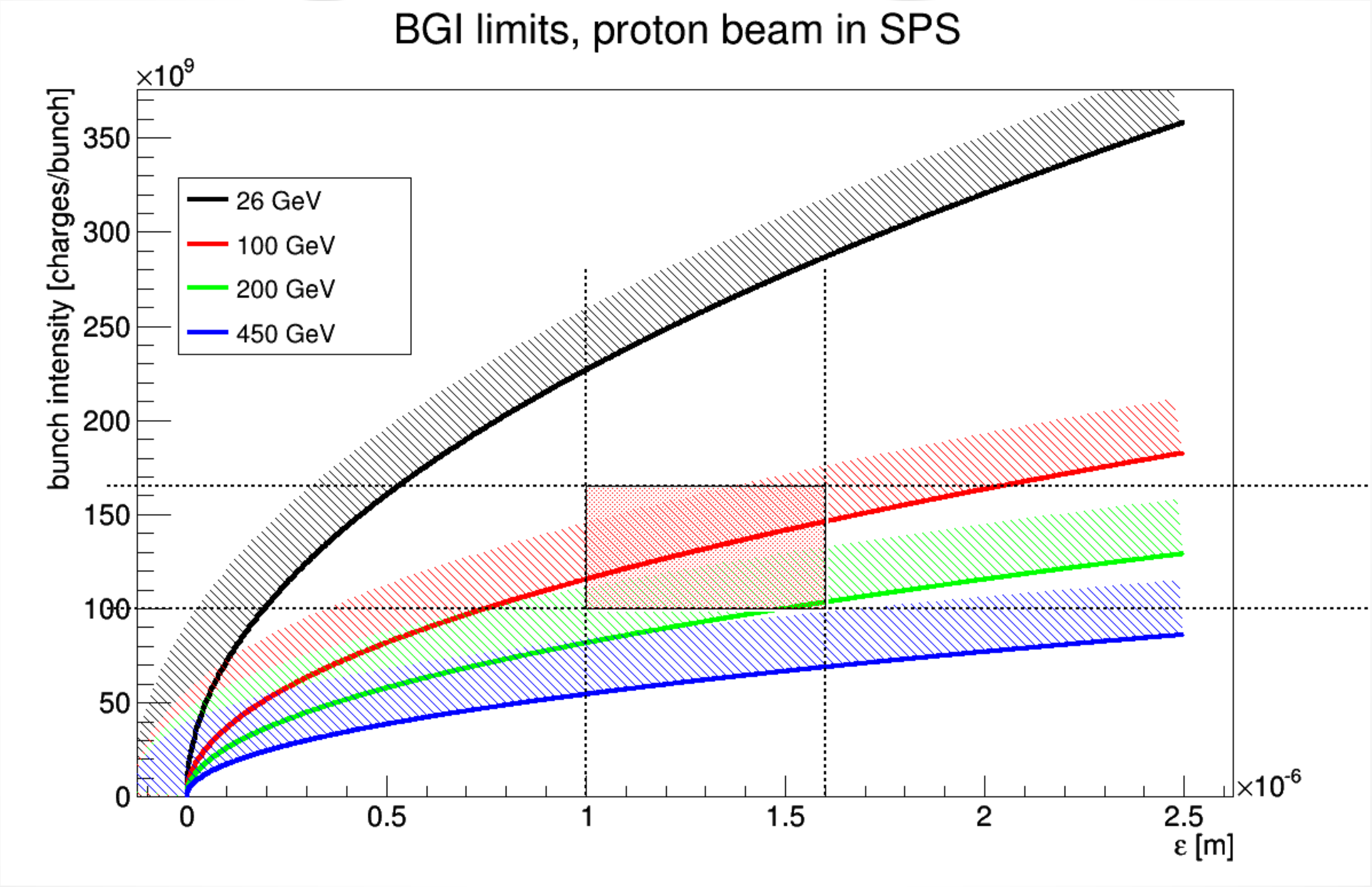


$$B_t(E, N, \sigma_z, \varepsilon) \approx 1.5 \cdot 10^{-16} \frac{N}{\sigma_z \sigma_r} = 1.5 \cdot 10^{-16} \frac{N\sqrt{\gamma}}{\sigma_z\sqrt{\varepsilon\beta}} [T]$$

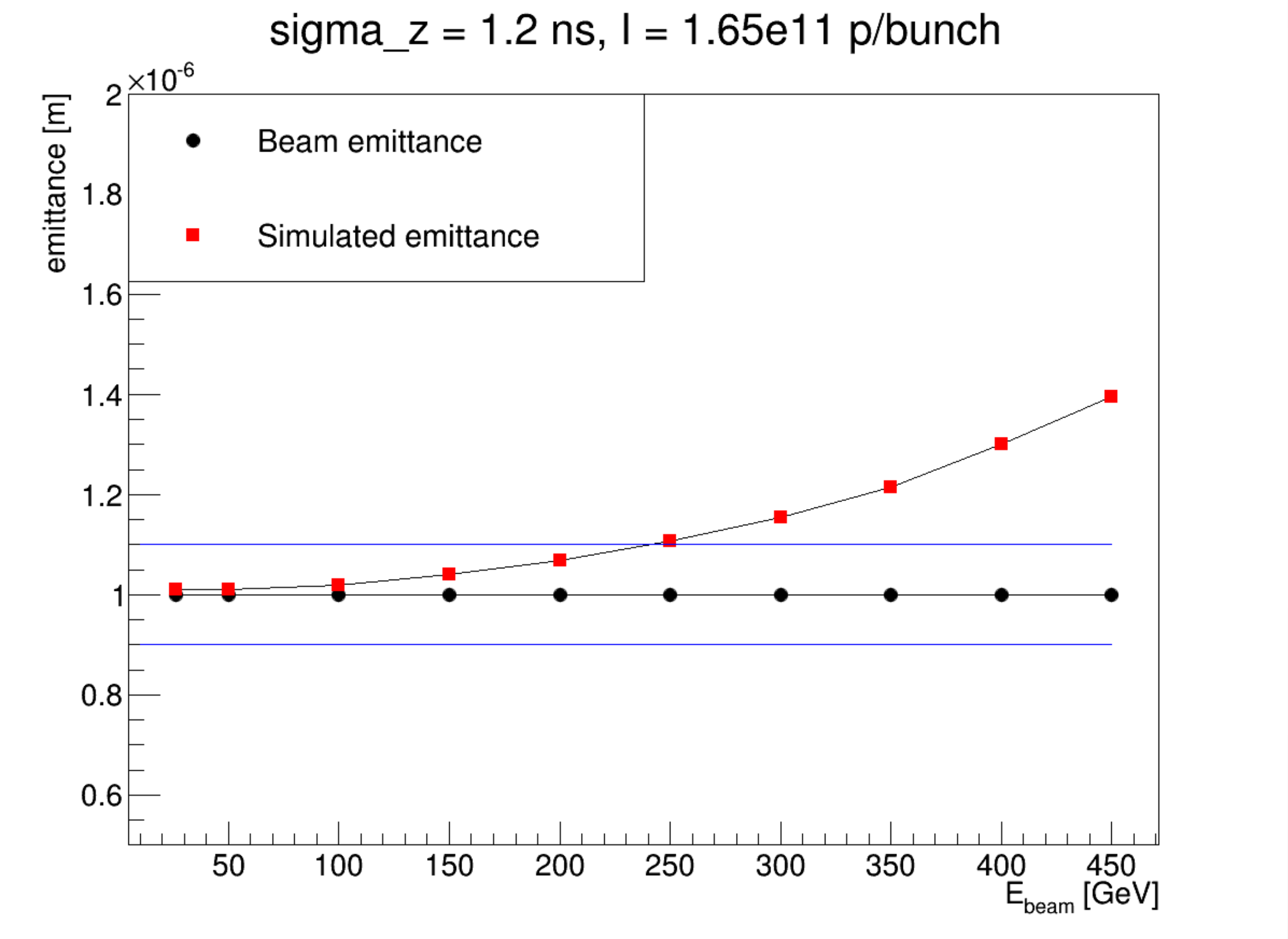
BGI space-charge limits



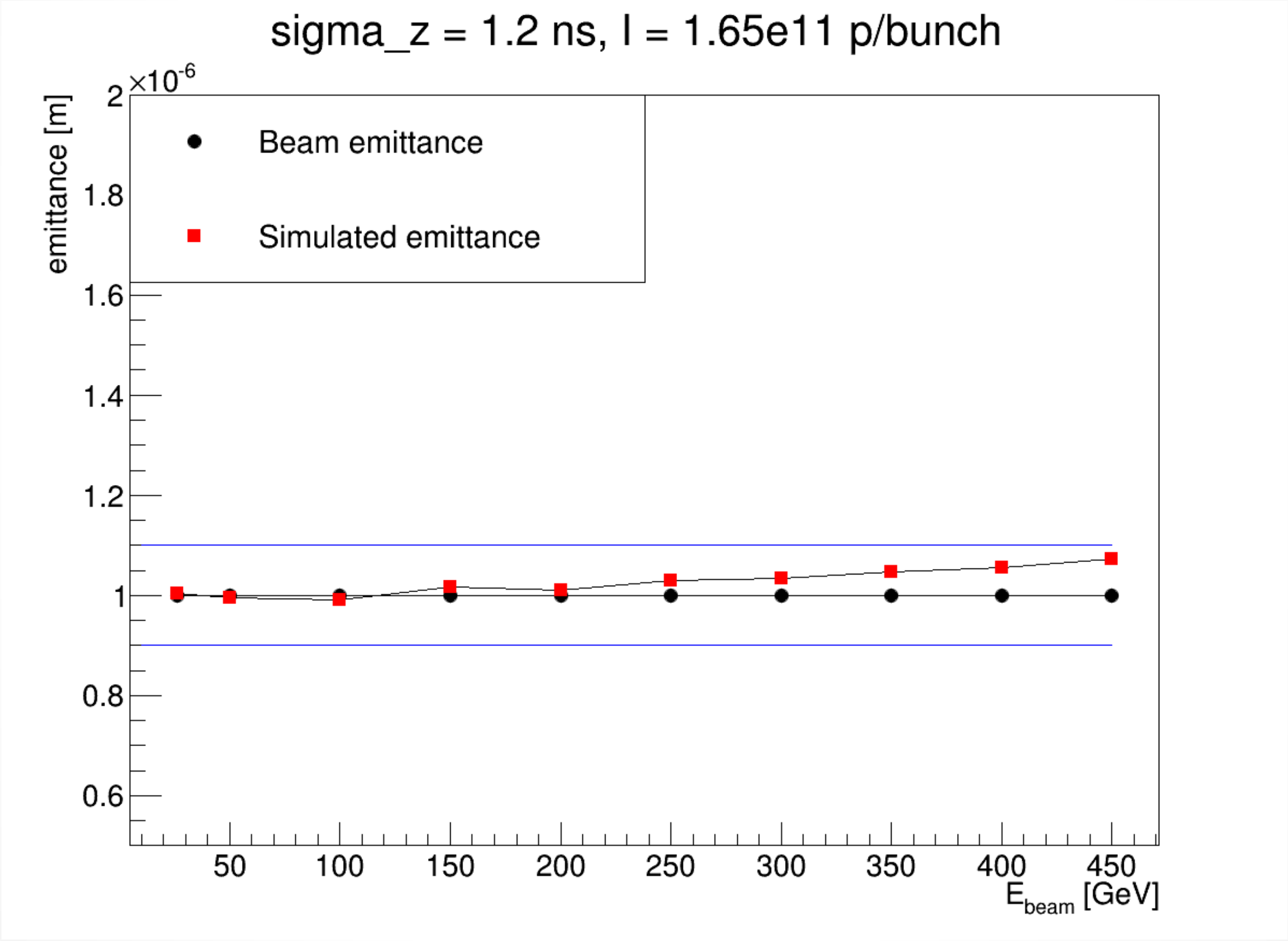
BGI space-charge limits



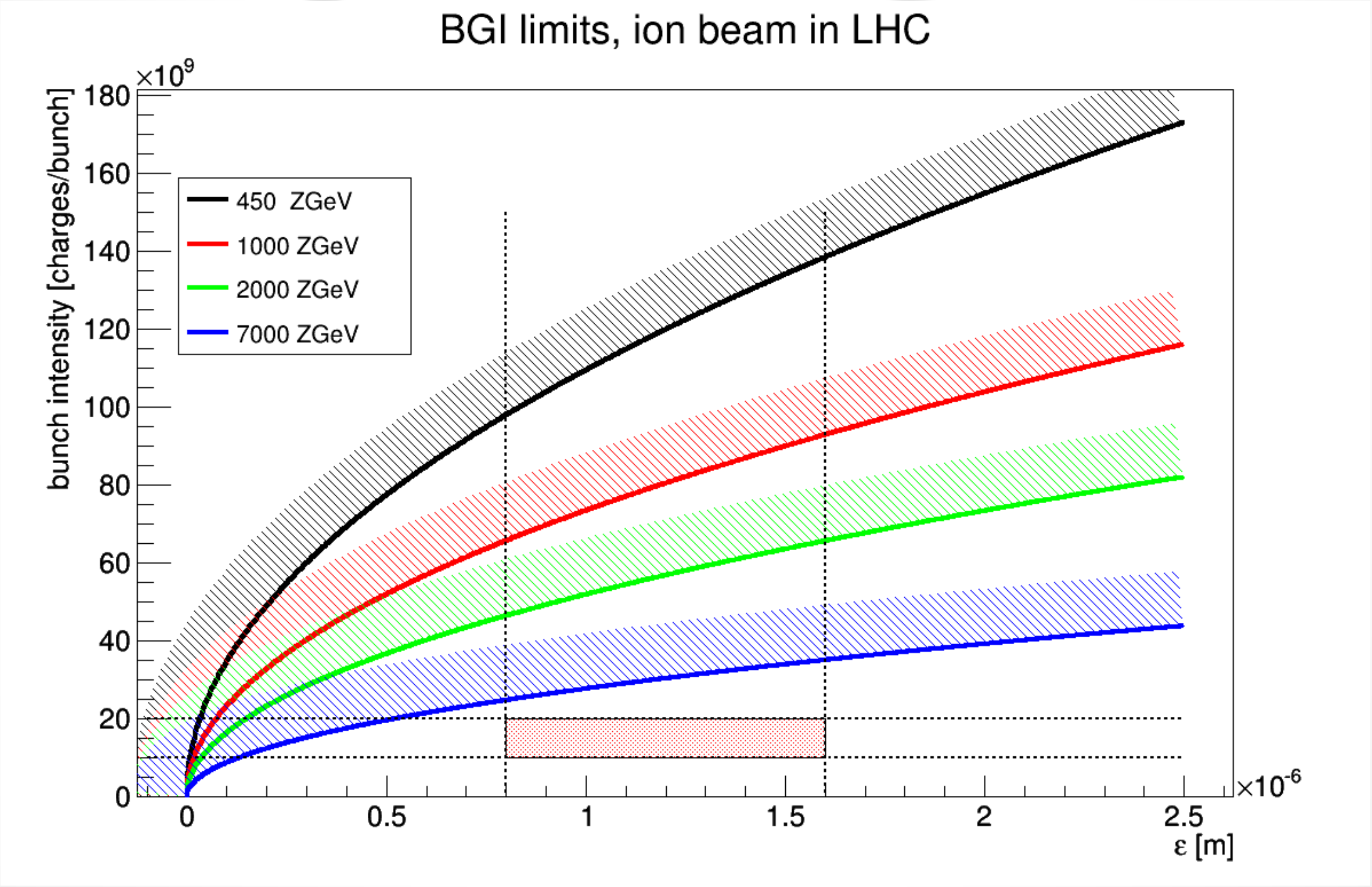
SPS proton beam – emittance for B=0.2 T



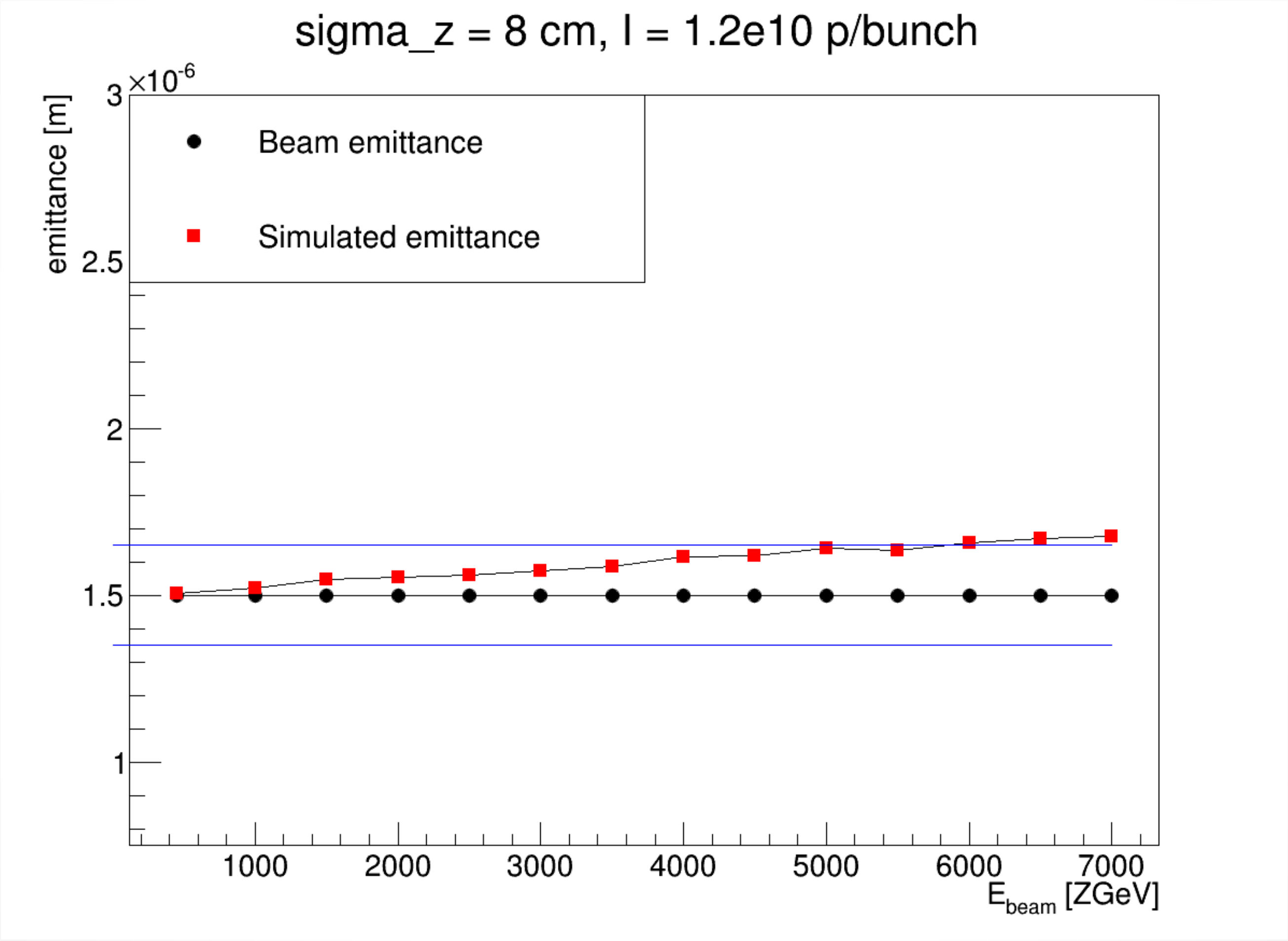
SPS proton beam – emittance for B=0.4 T



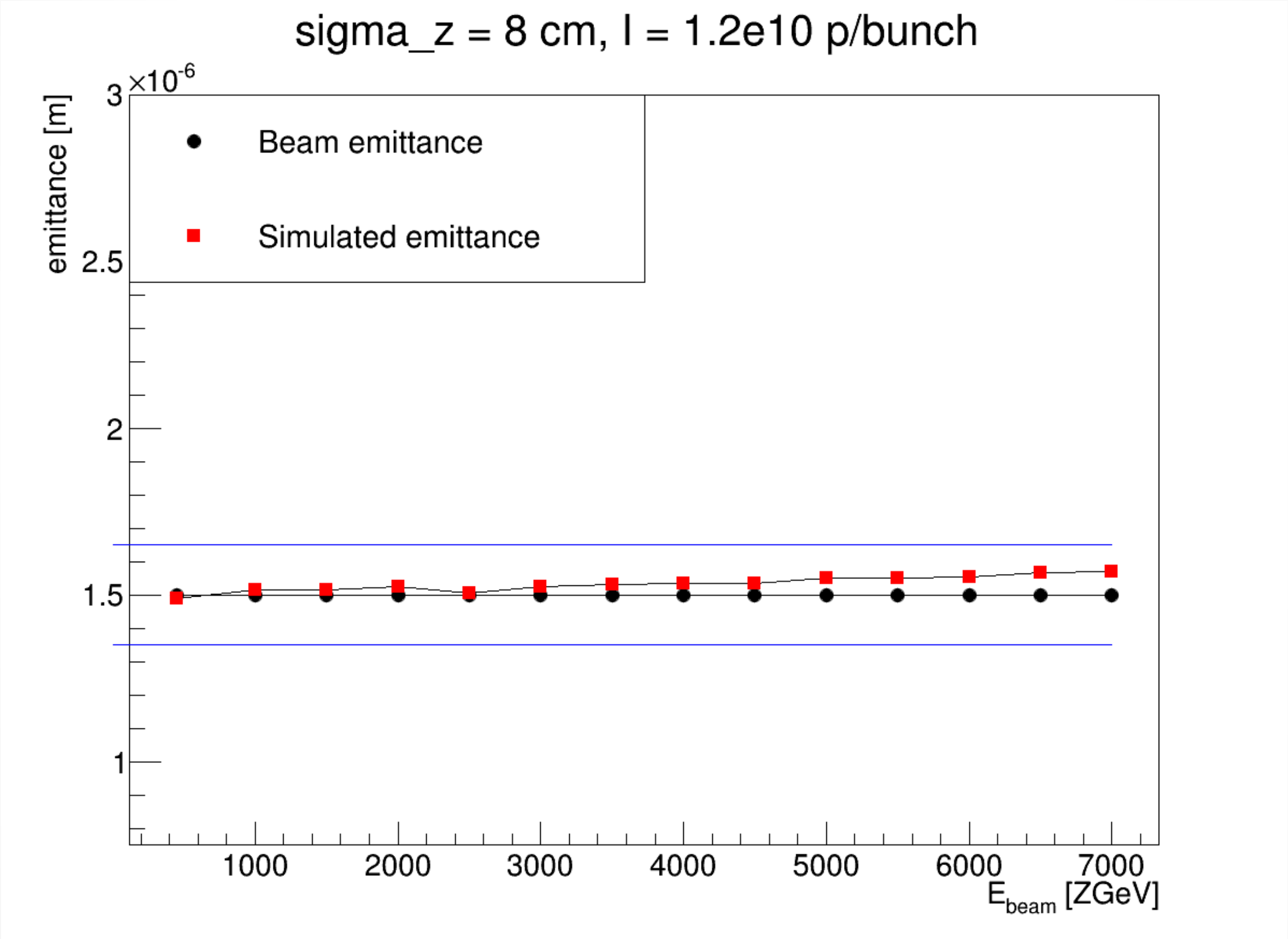
BGI space-charge limits



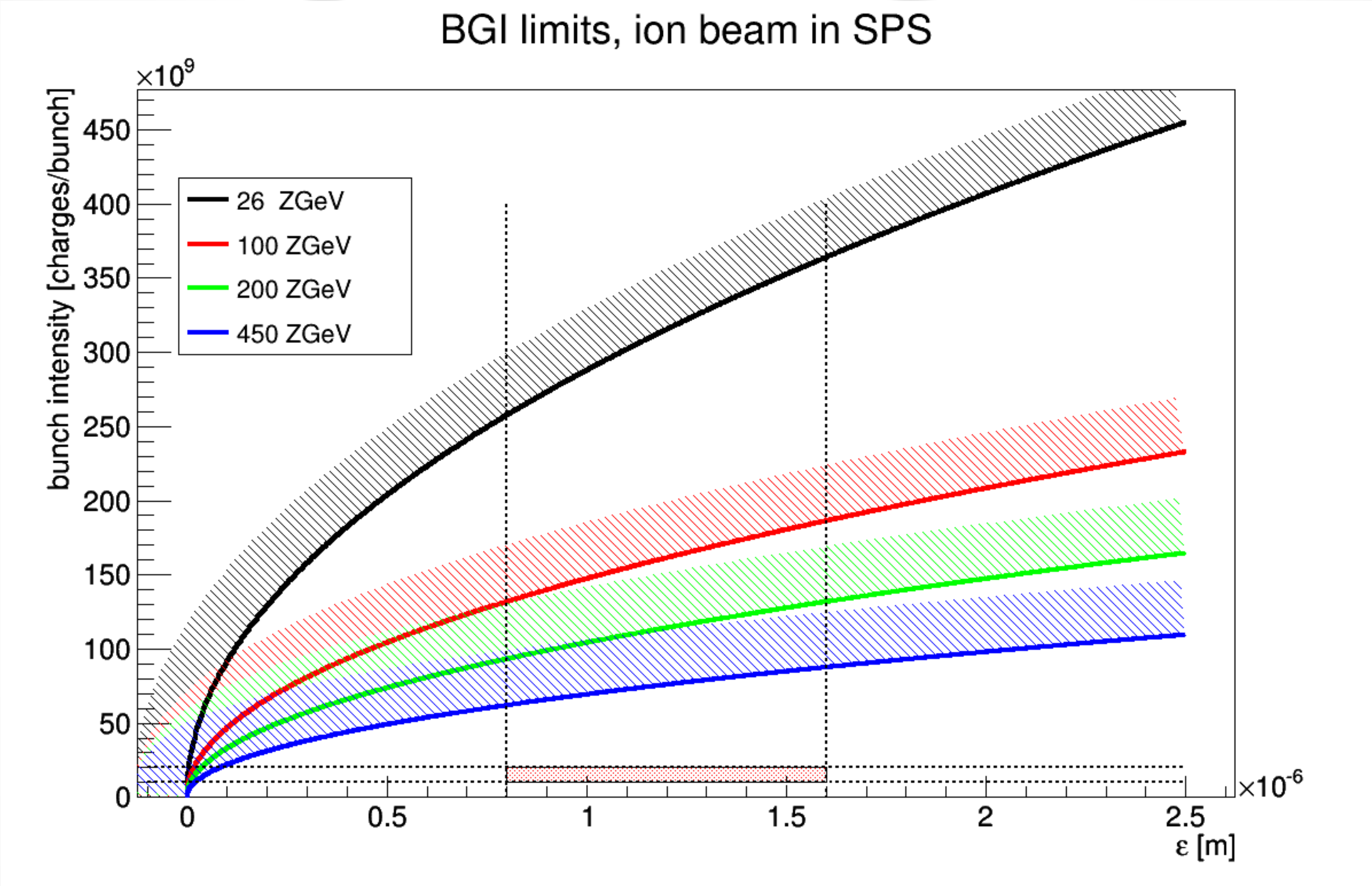
LHC ion beam – emittance for B = 0.2T



LHC ion beam – emittance for B = 0.4T



BGI space-charge limits



Conclusions

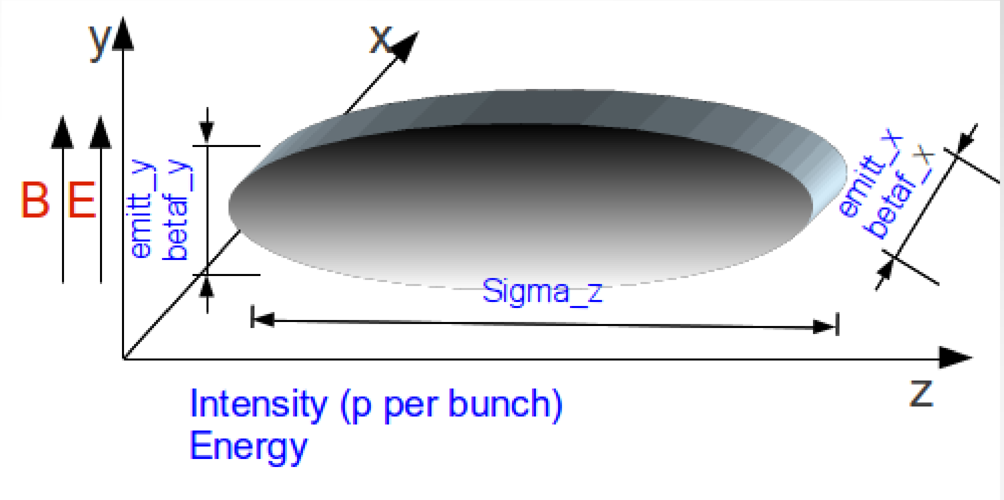
- Effects of **initial electron velocities** and **space charge** deform the observed beam profiles and make BGI impossible to calibrate for some beams on LHC and SPS;
- both effects can be cured by increase of magnetic field;
- with B=0.2 T ion beam in SPS can be measured, ion beam in LHC would need some corrections;
- in order to measure proton beam in LHC we need B=1T, in SPS 0.4 T;
- electric field modification does not help;
- currently we do not have correction for any of the effects but initial electron velocities seem to be easier to correct (effect does not depend on the position inside the bunch)

Thank you for your attention...

...and possibly see you again!

Extra slides

PyECLOUD simulation describtion



- Protons are placed in bunch according to input parameters (Gaussian distribution);
- Bunch goes through the window of given length;
- In each timestep we consider only protons which are inside the window;
- Electrons are generated inside the widnow in the position of protons...
- ...and they move according to the electric field of protons and to the external electric and magnetic fields;
- In each timestep we consider newly generated electrons and all the electrons from previous steps and the current proton distribution;

Sigma correction

- We assume that $\sigma_{meas}{}^2 = \sigma_{beam}{}^2 + \sigma_{corr}{}^2$
- We obtain $\sigma_{corr}{}^2$ by fitting:

$$\sigma_{meas}{}^2(E) = \frac{A}{E} + \sigma_{corr}{}^2$$ [1], where

$A = \varepsilon\beta E_0$, $\frac{A}{E} = \sigma_{beam}{}^2$ and $\sigma_{corr}{}^2$ is fitting parameter

- We also tried to fit another function:

$$\sigma_{meas}{}^2(E) = \frac{A}{E} + B \cdot E$$ [2], where

$A = \varepsilon\beta E_0$, $\frac{A}{E} = \sigma_{beam}{}^2$ and B is fitting parameter related to the correction.

Sigma correction