Shape Optimization of a Compact DC Photo-Electron Gun using IGA

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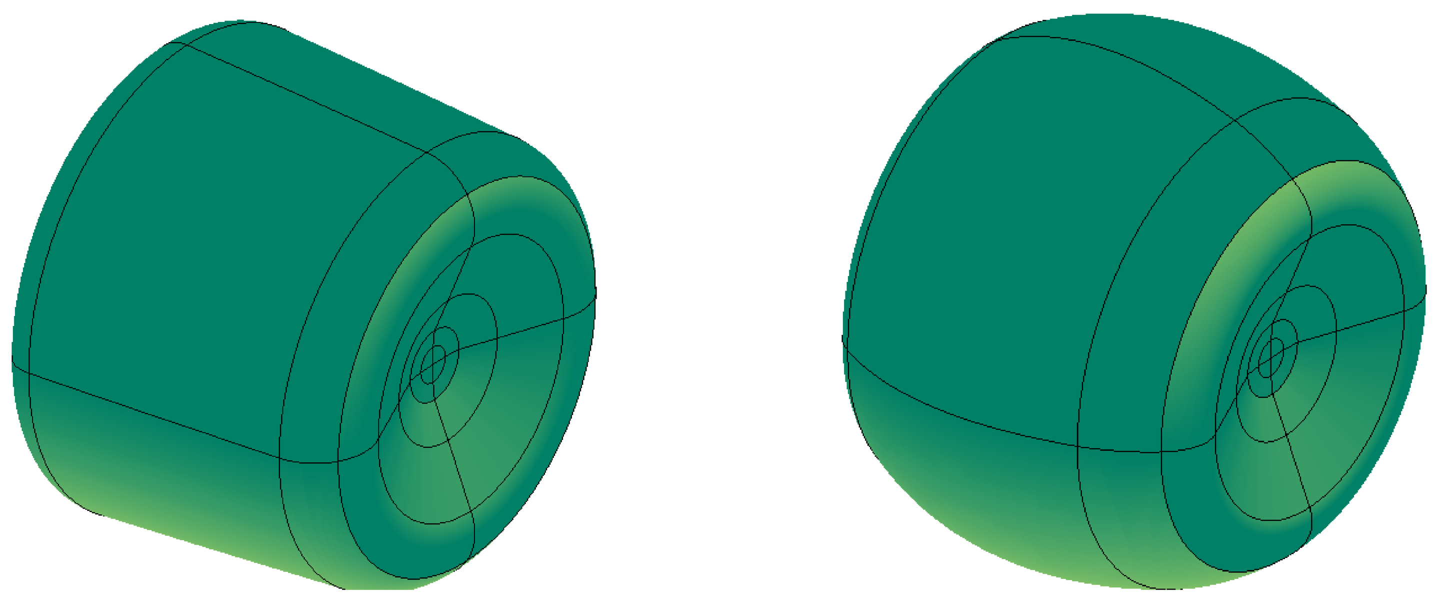
Motivation

Compact DC photo-electron guns meet the demands of high-current applications such as energy recovery linacs. A main design parameter is the electric field strength, which is limited by the field emission threshold of the electrode material. Optimizing the electrode geometry allows for higher gradients and thus increased gun perfomance.



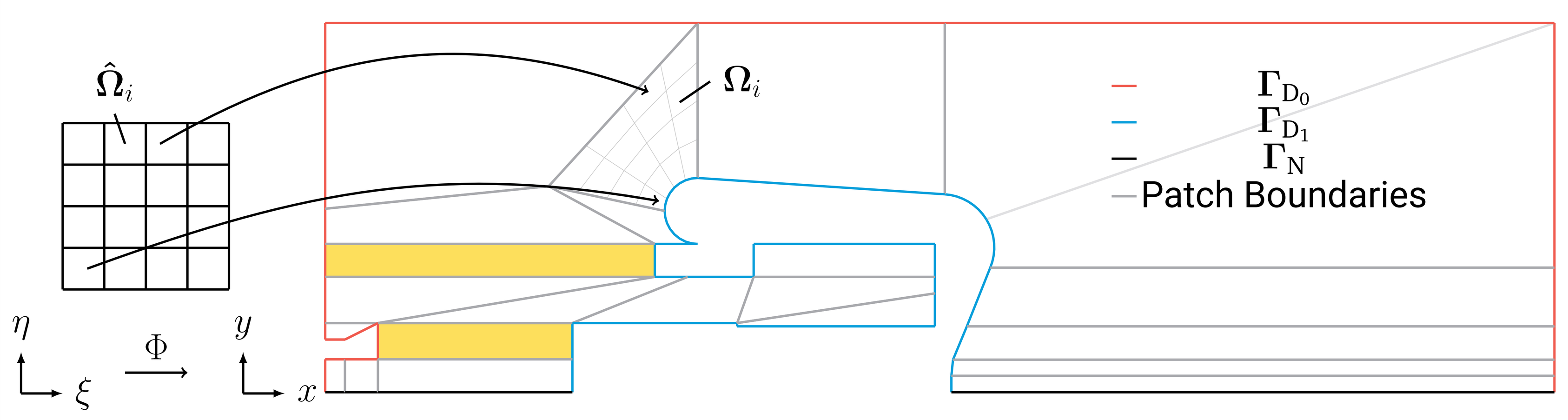
The problem is described by Maxwell's equations and the PDE for the electrostatic potential reads

$$\begin{aligned} \nabla\cdot(\varepsilon\nabla\varphi) &= 0 && \text{in } \Omega,\\ \varphi &= 0 && \text{on } \Gamma_{\mathrm{D}_0},\\ \varphi &= -200\ \mathrm{kV} && \text{on } \Gamma_{\mathrm{D}_1},\\ \partial_n\varphi &= 0 && \text{on } \Gamma_{\mathrm{N}}, \end{aligned}$$

where φ is the electrostatic potential, ε the electric permittivity, Ω the problem domain and the Γ's are the boundaries.

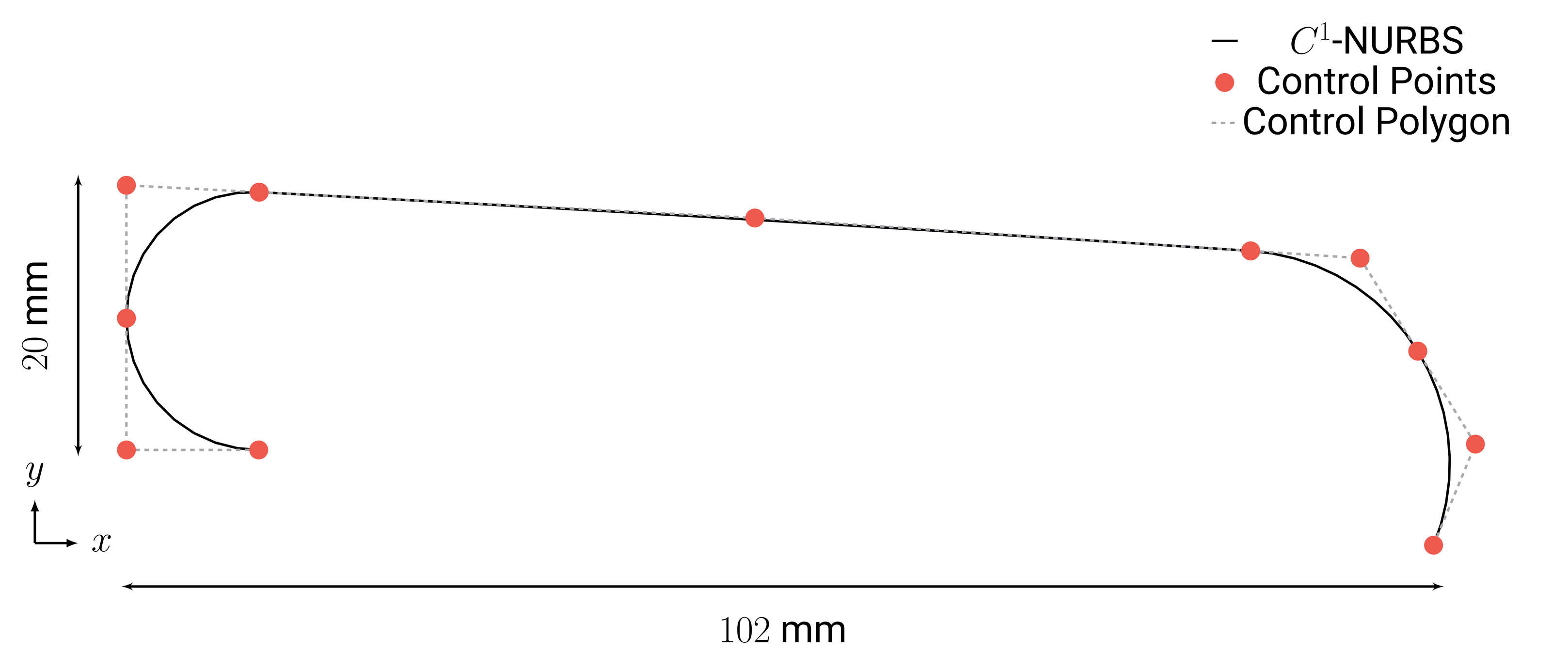
Isogeometric Analysis

Isogeometric Analysis employs NURBS basis functions for both the geometry description and as the solution space of the numerical method. This allows to exactly represent curved geometries and at the same time leads to smooth and accurate field solutions.



Due to the axisymmetry of the geometry it suffices to consider half of the longitudinal cross-section of the gun. The elements of any patch i share a single parameter space $\hat{\Omega}_i$ and are mapped to the physical space Ω_i via a NURBS mapping

$$\begin{aligned} \Phi\colon \hat{\Omega}_i &\to \Omega_i\\ (\eta,\xi) &\mapsto (x,y). \end{aligned}$$



Individual curves can easily be manipulated by moving their control points and multiple curves may be glued together to attain higher continuity across their interfaces. Using the above C^1-continuous curve for the optimization guarantees an optimized geometry that fulfills manufacturing requirements.

Shape Optimization

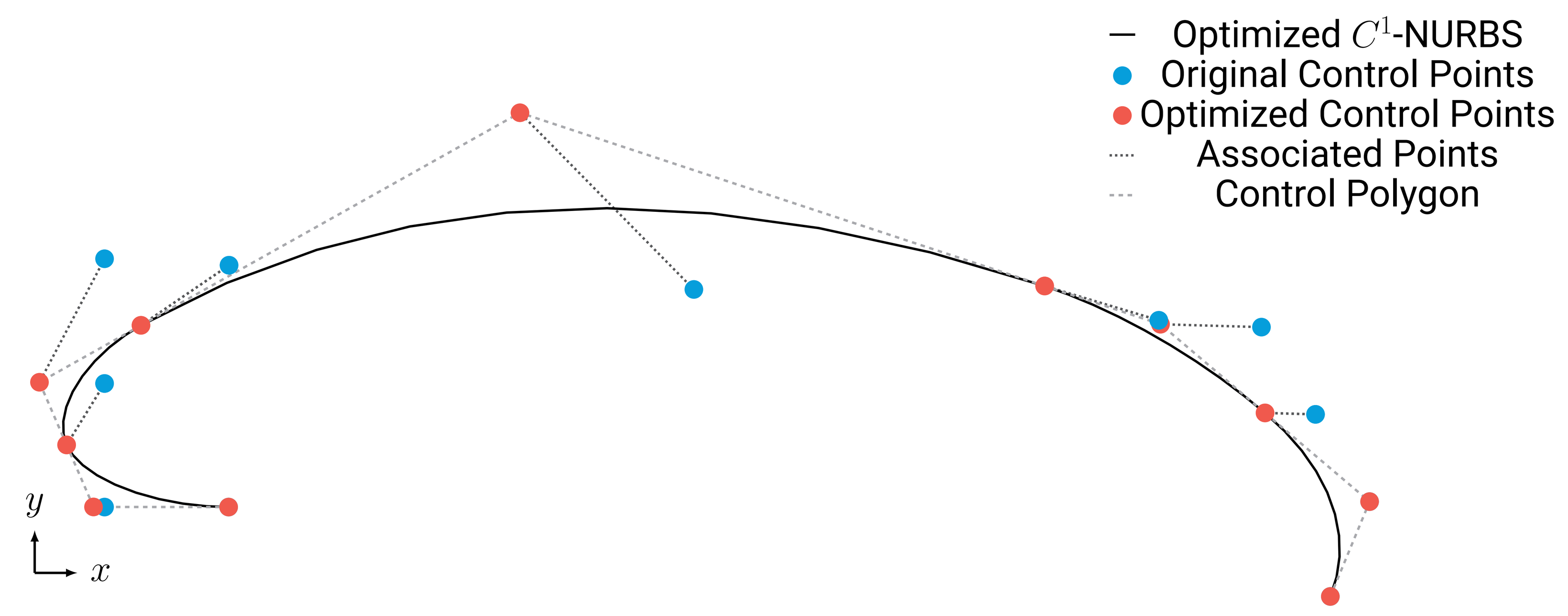
The aim of the optimization is to minimize the maximal electric field strength in the vicinity of the electrode. This is accomplished by finding an optimal configuration of the control points under additional geometric constraints. The cost function is given by

$$f(\mathbf{p}) = \frac{1}{|I|}\sum_{i\in I}\max_{\mathbf{x}\in\Omega_i}\|\mathbf{E}(\mathbf{x})\|_2,$$

where $\mathbf{p}$ is a vector containing the control point coordinates, I is an index set and $\mathbf{E}$ is the electric field. The maxima are averaged to ensure that the field strength is simultaneously minimized across all patches. The full optimization problem then reads

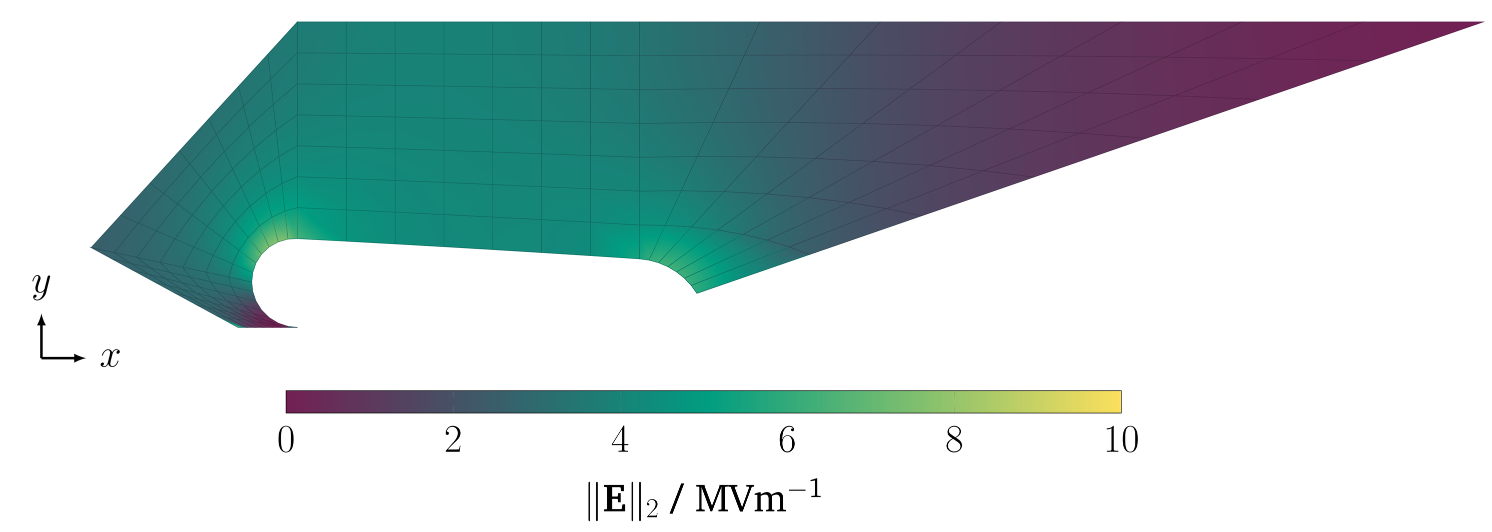
$$\begin{aligned} \min_{\mathbf{p}} \quad & f(\mathbf{p}),\\ \text{subject to} \quad & \mathbf{h}(\mathbf{p}) \leq \mathbf{0}, \end{aligned}$$

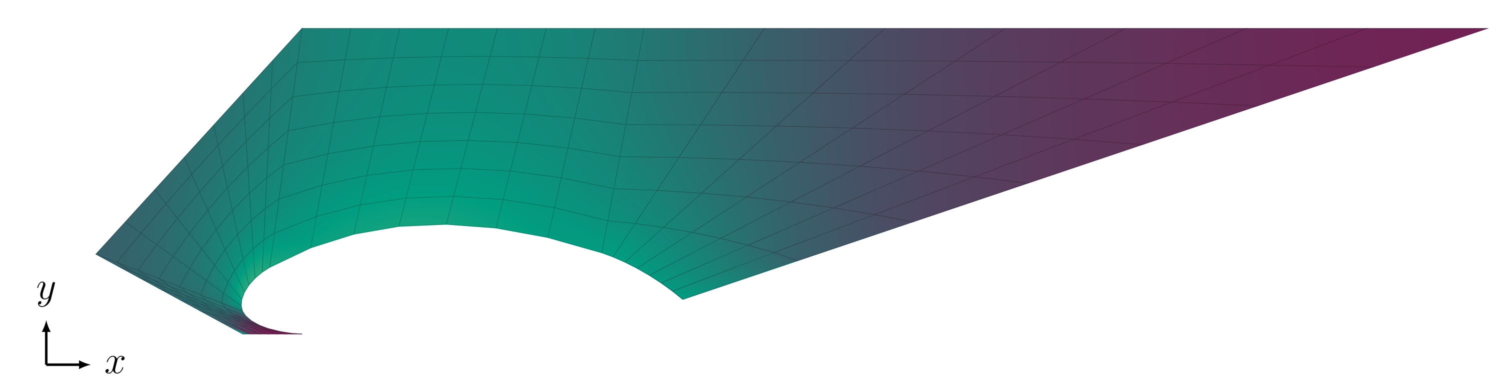
where $\mathbf{h}$ is made up of constraints on the volume of the electrode and the relative position of the control points.



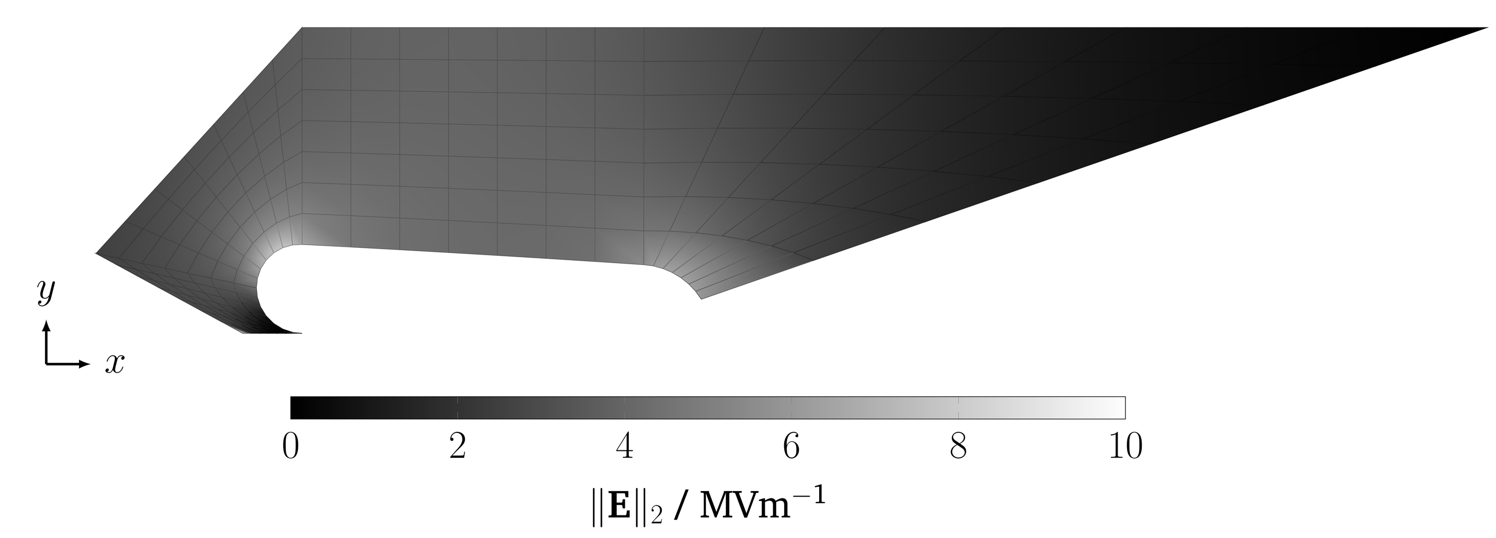
Results

The results show the magnitude of the eletric field in the region of interest. A significant improvement in terms of the maximal value is visible. Originally we had $\max_{\mathbf{x}\in\Omega_i}\|\mathbf{E}(\mathbf{x})\|_2 = 7.62\ \mathrm{MVm}^{-1}$ and after optimization we obtained $\max_{\mathbf{x}\in\Omega_i}\|\mathbf{E}(\mathbf{x})\|_2 = 5.837\ \mathrm{MVm}^{-1}$.





The results were further validified using CST EM Studio, which resulted in $\max_{\mathbf{x}\in\Omega_i}\|\mathbf{E}(\mathbf{x})\|_2 =$.



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