SPACE CHARGE EFFECTS AND FOCUSING METHODS FOR LASER ACCELERATED ION BEAMS

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LIGHT

Laser Ion Generation, Handling and Transport

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- Simulation setup, major tasks and objectives

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- Combination of space charge criteria and focusing
- Inductive coupling and ohmic losses

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LIGHT-Project

LIGHT – **L**aser **I**on **G**eneration, **H**andling and **T**ransport
(see e.g. A. Almomani et al: *LIGHT Project Report*)

Experimental sequence:
•GSI *PHELIX* Laser hits a thin metal foil target
•Proton plasma is accelerated by TNSA mechanism (e.g.)
•Proton beam is focused and carried to re-buncher cavity

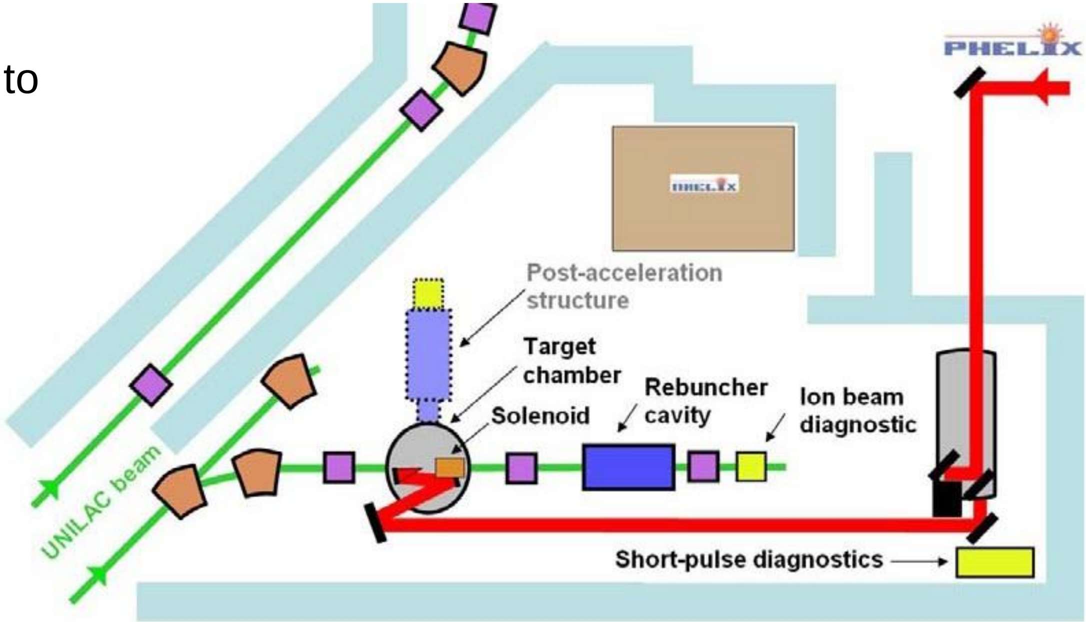

Fig from: A. Almomani, S. Busold et. al. : *LIGHT Project report*

LIGHT-Project

Z6 target chamber

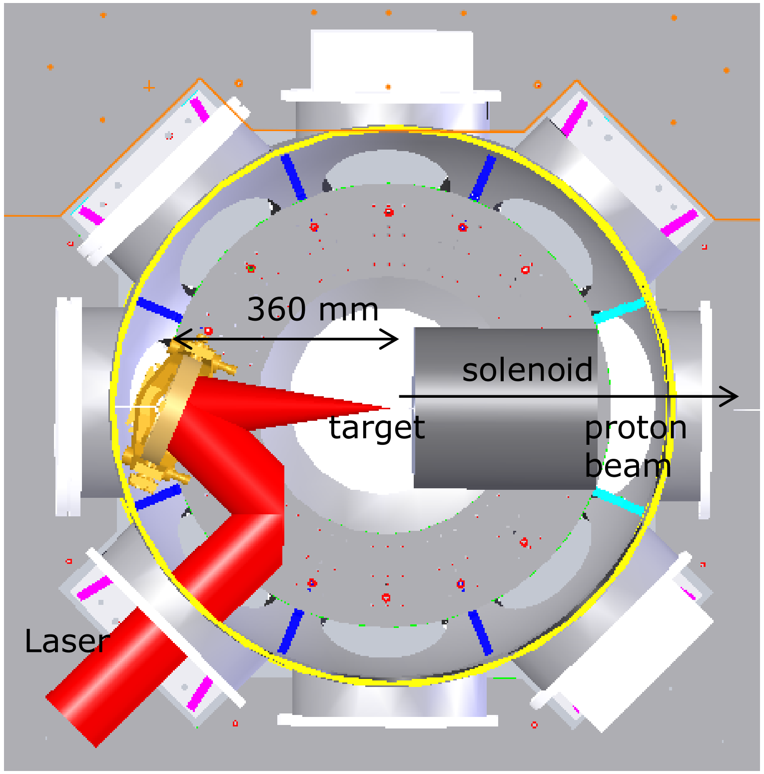

Fig from: S. Busold et. al. : *DPG 2012 Stuttgart talk*

LIGHT-Project

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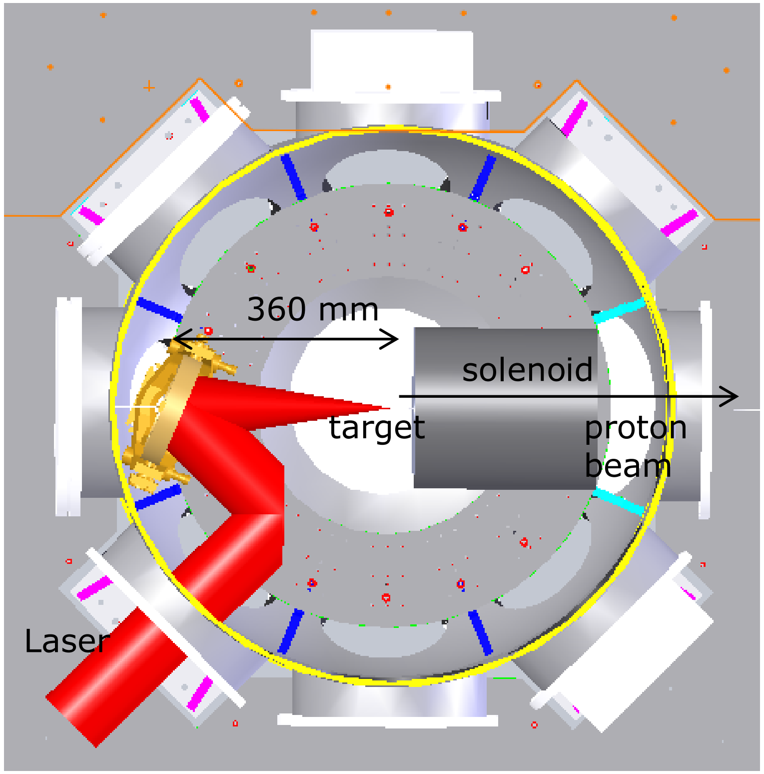

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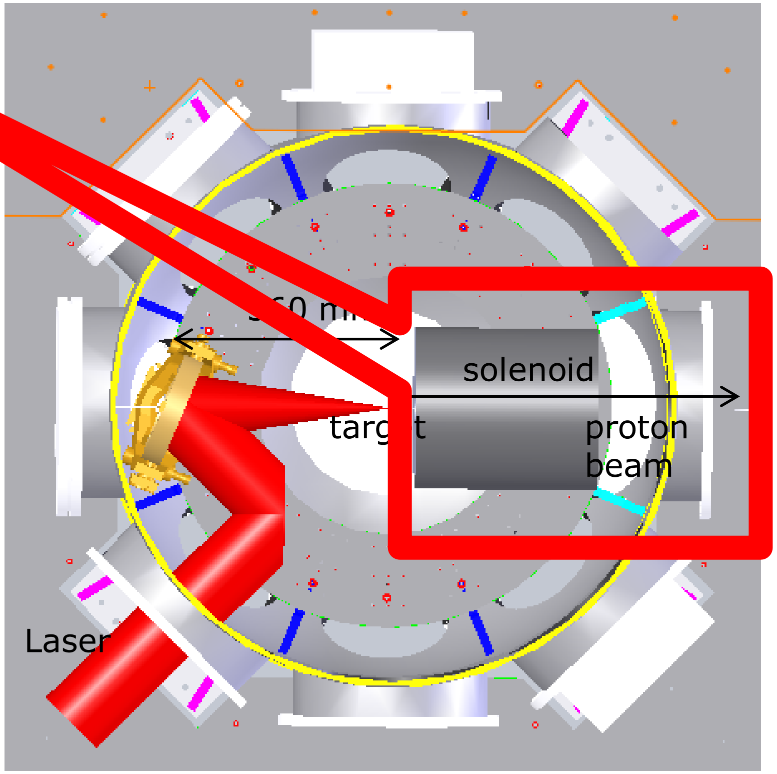
From TNSA mechanism we know:
•High intense proton beam
•Beam shows high energy spread
•After acceleration beam can be treated as quasi neutral: Protons and co-moving electrons
•Beam shows high initial divergence

LIGHT-Project

Considered area:
•Beam properties and models after acceleration
•Beam focusing and collimation methods
•Optical and technical properties of the focusing elements

Z6 target chamber



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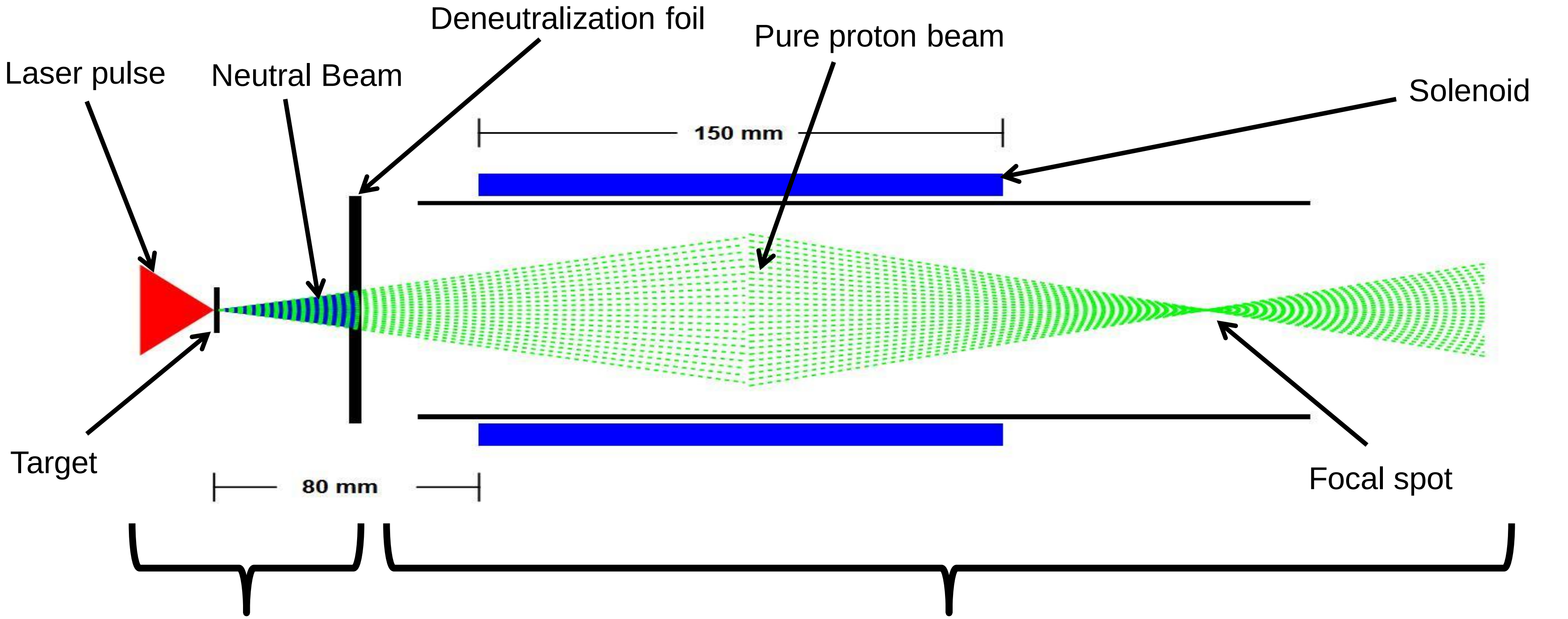
Scetch of simulation setup



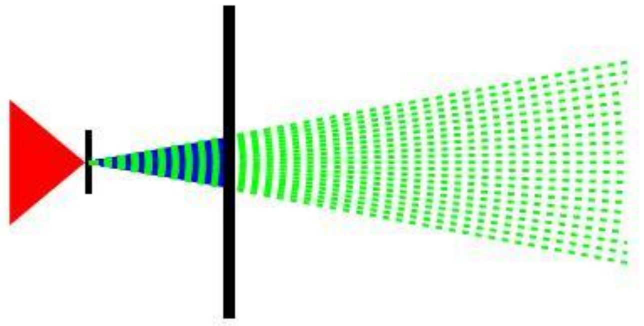
Region 1: SC free drift: VORPAL 5.2©

Region 2: Focusing with solenoid: SC negligible, VORPAL 5.2©, CST Particle Studio©, CST EM Studio©

Major Objectives, Tasks and Tools

Region 1:

- Neutral beam of protons and co-moving electrons drifts into space
- A thin metal foil removes all electrons of the beam



Tasks: Where to place the foil, so that after the foil space charge can be neglected?

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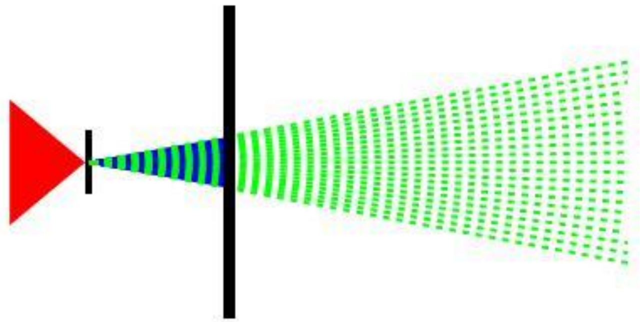


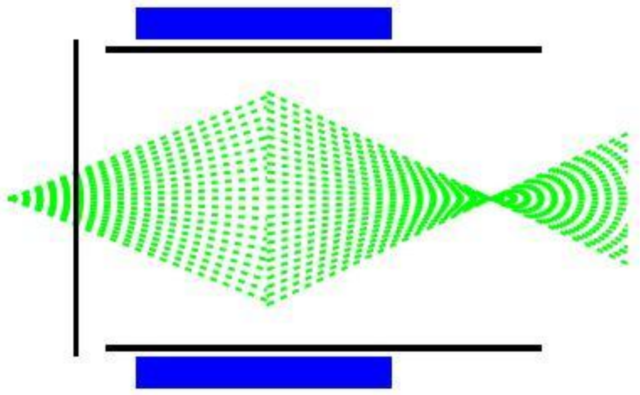
Region 2:

- Pure proton beam focused by a pulsed power solenoid
- Space charge negligible

Tasks:

- Verifiy the Space charge criterion
- Get optical and technical properties of the solenoid

Tools: VORPAL 5.2©, CST Studio©



Space charge and beam model

Simple bunched beam model:

- Homogeneous cylindrical bunch
- Has Inital divergence
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r_0	0,1 mm
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E_{kin}	10 MeV
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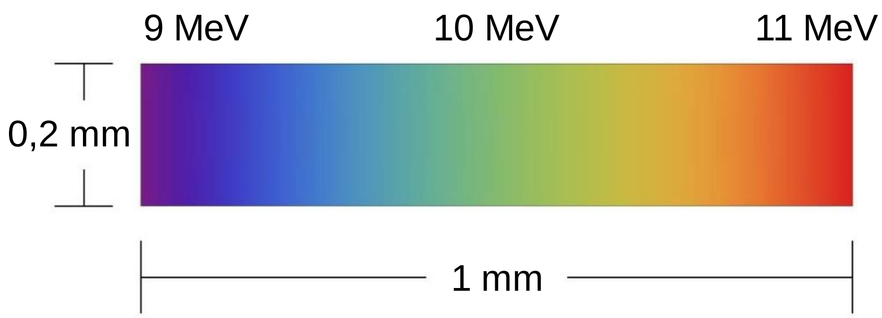

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Approximations:
•Longitudinal expansion only due to velocity spread:
•Edge effects neglected ↔ infinite long beam

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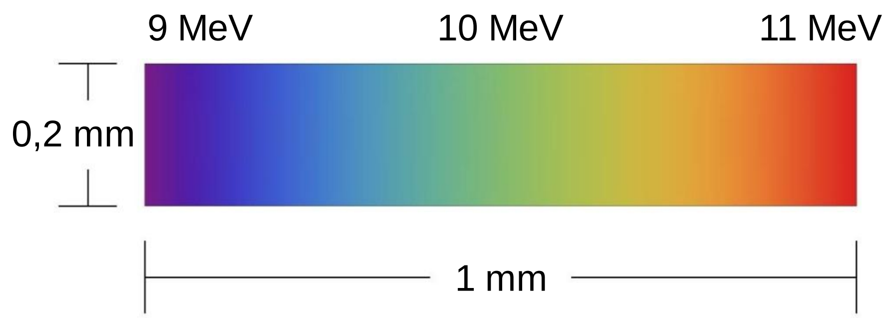

Transversal envelope equation

One finds the **transversal envelope equation** for the expansion of the beam radius r:

$$\frac{d^2\sigma}{dz^2} = \frac{K(z)}{\sigma}, \quad \sigma = \frac{r}{r_0}$$

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With the **perveance:**

$$K(z) = \frac{Z^2 \rho(z)(1-\kappa)}{\beta_\parallel^2 c^2 \gamma^3 m_p} \frac{e^2}{2\varepsilon_0}, \quad \kappa = \frac{N_e}{N_p}$$

With: Z charge number of the ions (e.g. Z=1 for protons), ρ particle density, m_p particle mass, r_0 initial radius, e elemental charge, c lightspeed, γ Lorentzian factor and κ the ratio of protons and electrons (neutralization factor)

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Perveance is a measure for space charge effects and depends on beam parameters! It is the leading quantity in rating the importance of space charge !

Verification by VORPAL© simulation

Worst case: Bunch only consists of protons, $\vartheta_0 = 0°$.
$K_0 = 1{,}32 \cdot 10^6\ m^{-2}$

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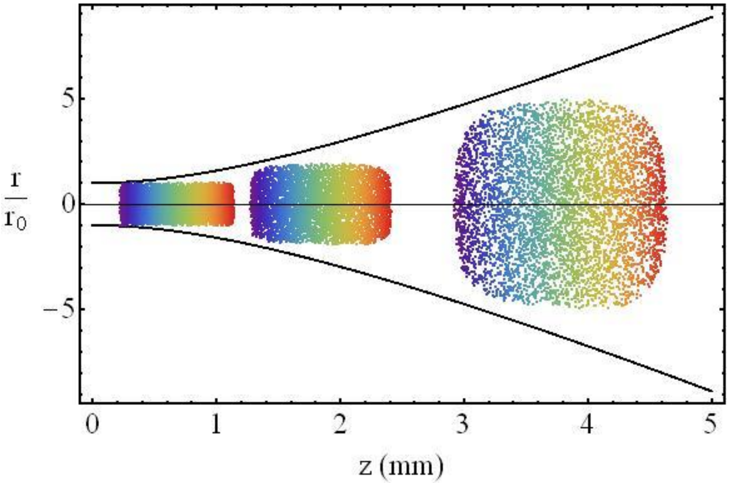

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Transversal expansion:
Analytical calculation from envelope equation (black line) and VORPAL© simulation (stroboscopic pictures)

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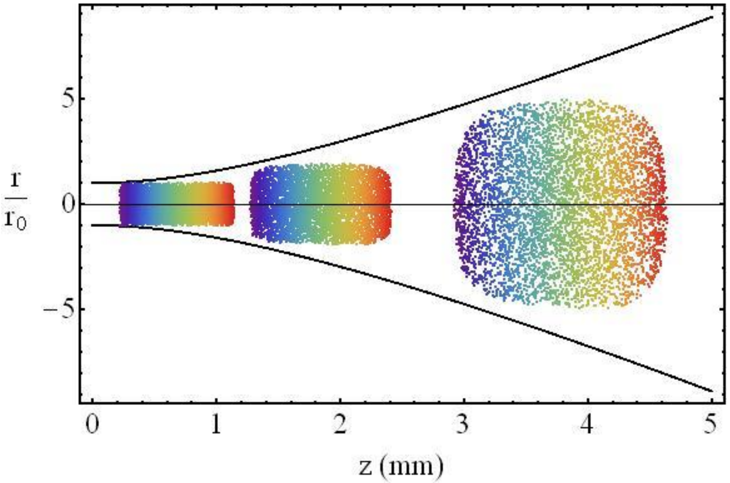

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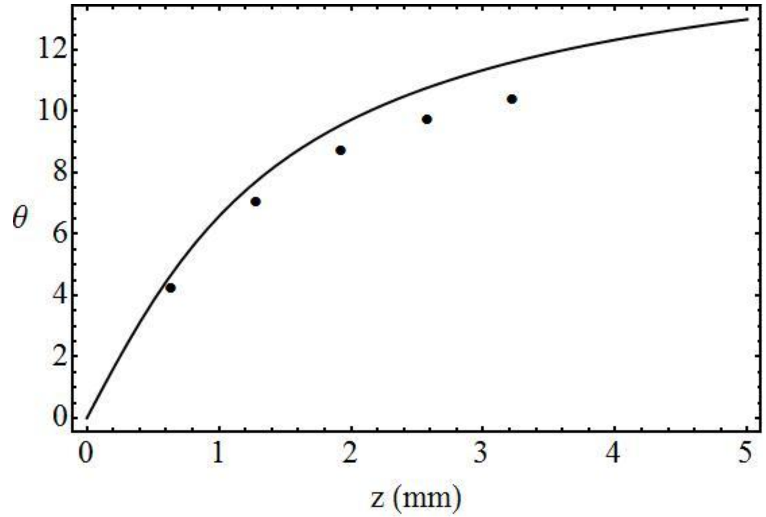

Bunch divergence angle:
Comparison of analytical calculation from envelope equation (black line) and VORPAL© simulation (dots).

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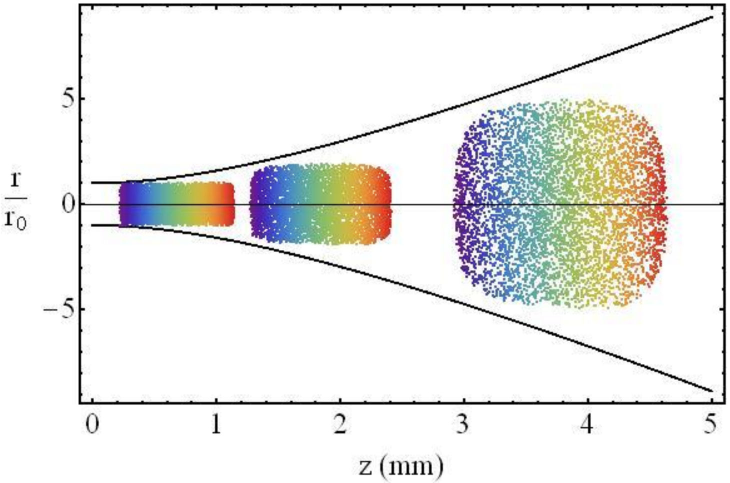

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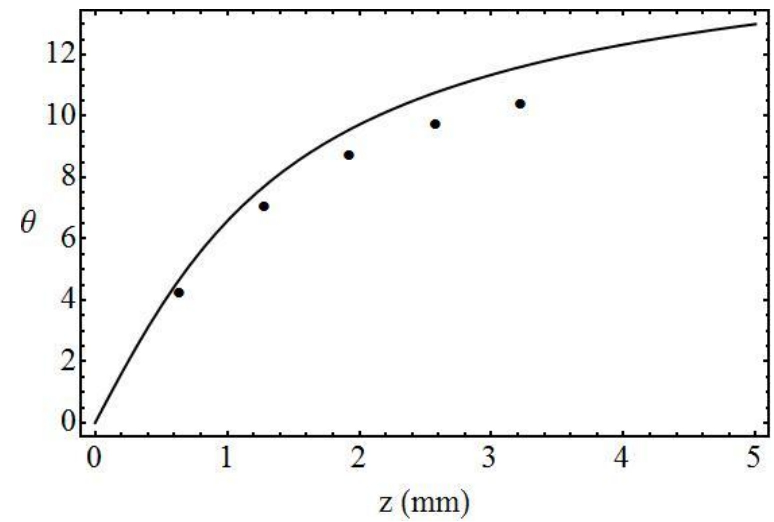
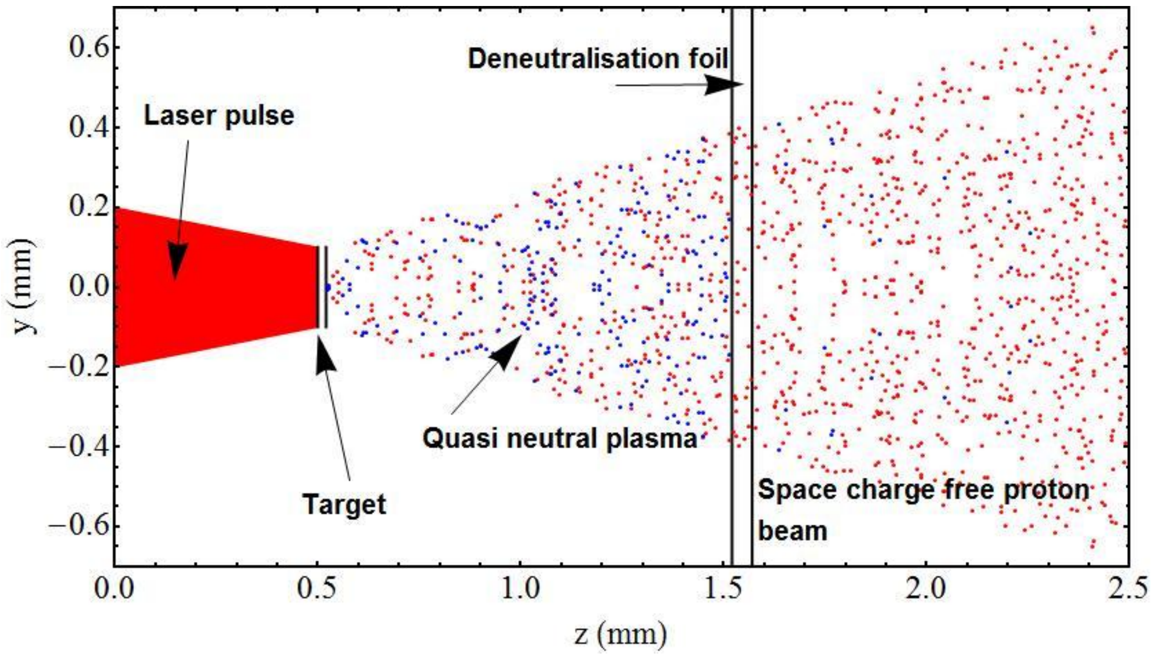


Due to finite bunch length, simulation results are below analytical → analytical calculations are upper limit!

Deneutralization with a foil

Deneutralization with thin metal foil:

- Bunch is initially quasi neutral and drifts into space
- At some position z_{foil} place a thin foil to absorb electrons
- Determine z_{foil} such that space charge can be neglected behind foil
- Place focusing elements behind the foil



Sample calculation

Initial conditions:

- Bunch is neutral with $\vartheta_0 = 0°$ and $K_0 = 1{,}32 \cdot 10^6\ m^{-2}$

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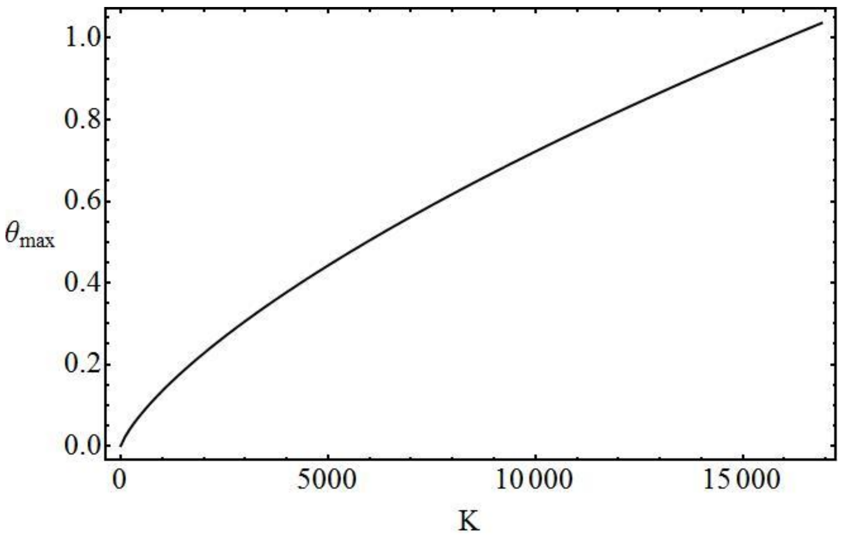
- Bunch is neutral with $\vartheta_0 = 0°$ and $K_0 = 1{,}32 \cdot 10^6\ m^{-2}$
- Tolerable max. angle after deneutralization: $\vartheta_{max} \leq 1° \rightarrow K \leq 15.000 m^{-2}$ after foil!



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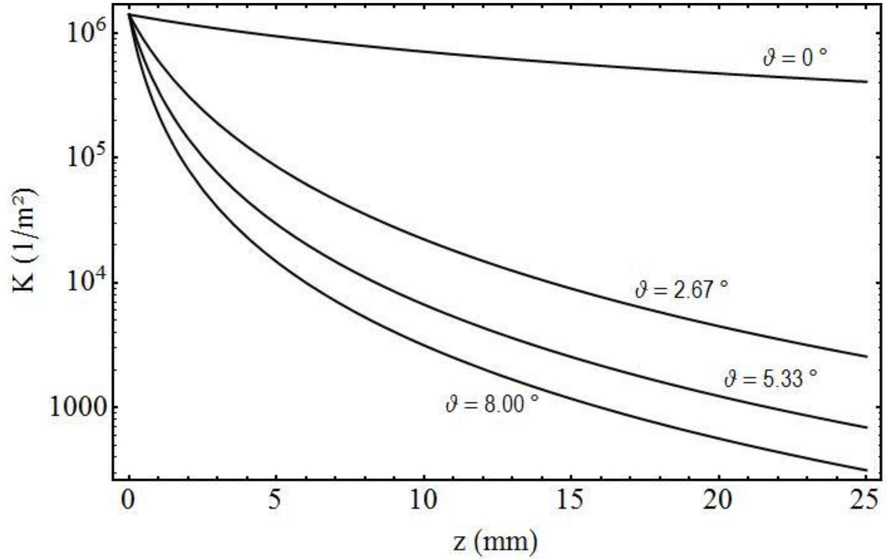

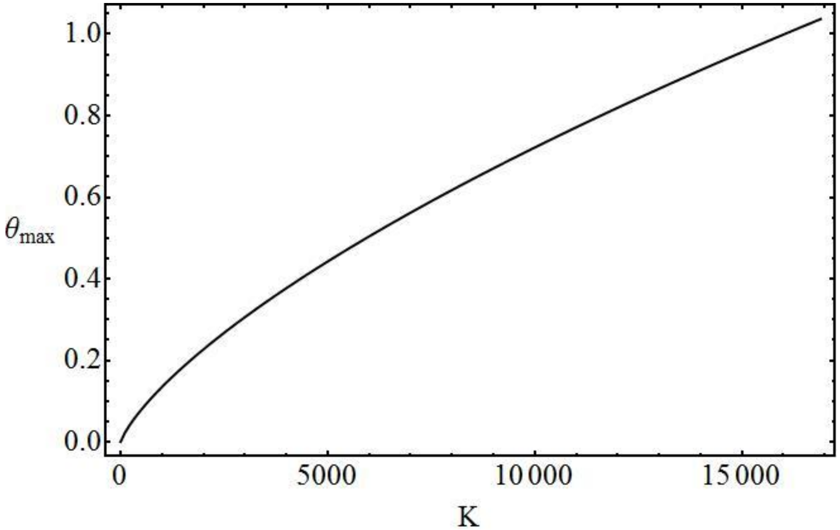

Foil position from Space charge criterion:

$z_{foil} \approx$ 1 m behind the target!

Focusing with pulsed power solenoid

Pulsed power solenoid:

•Model designed in CST EM Studio©
•CST© tracking simulation (space charge free
•VORPAL© simulation (with space charge)
•Comparison of both validates space charge criterion

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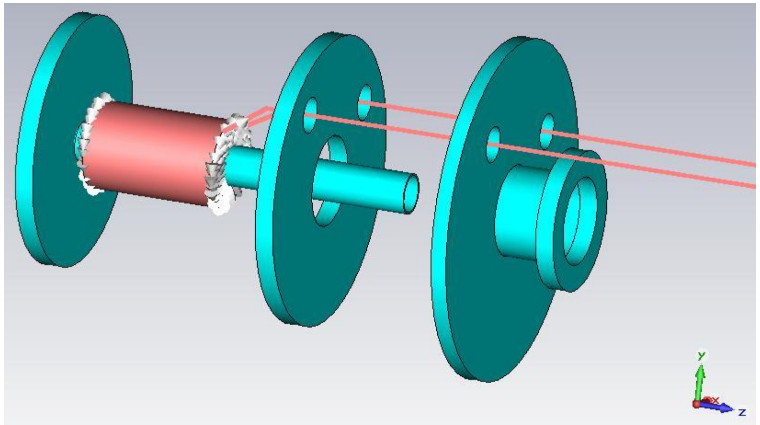

CST© model of the solenoid. Some parts are hidden for better overview

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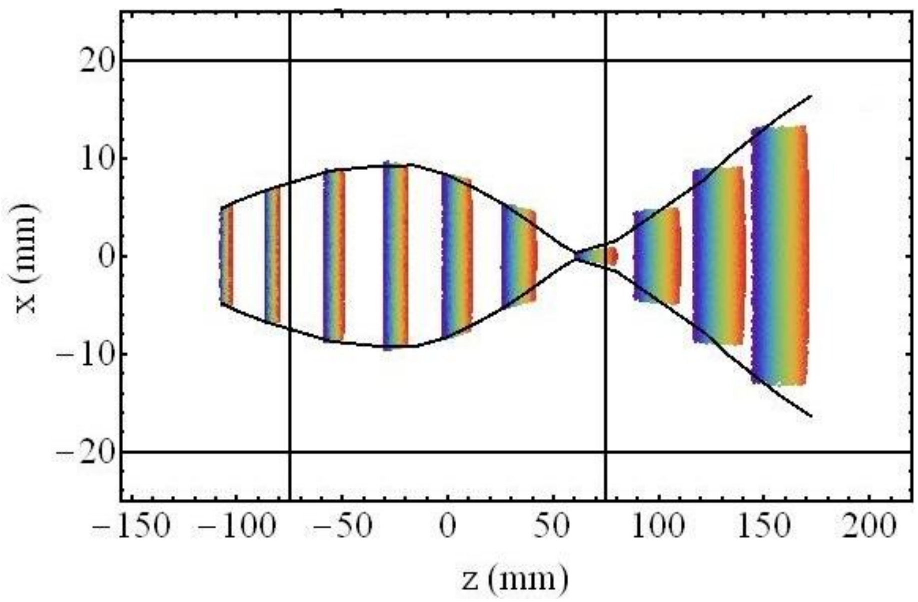

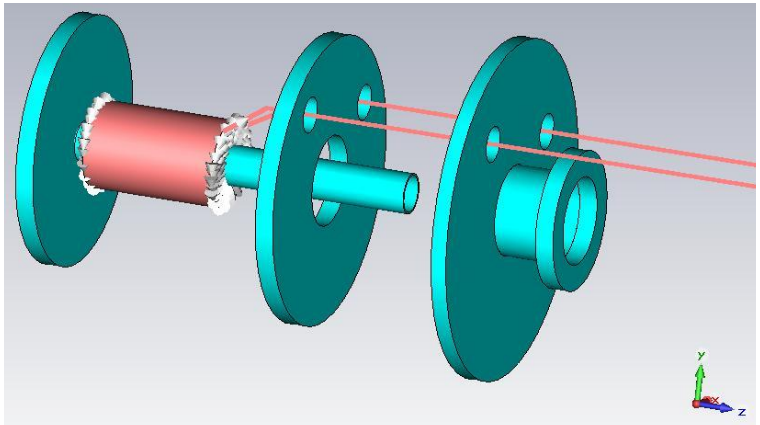

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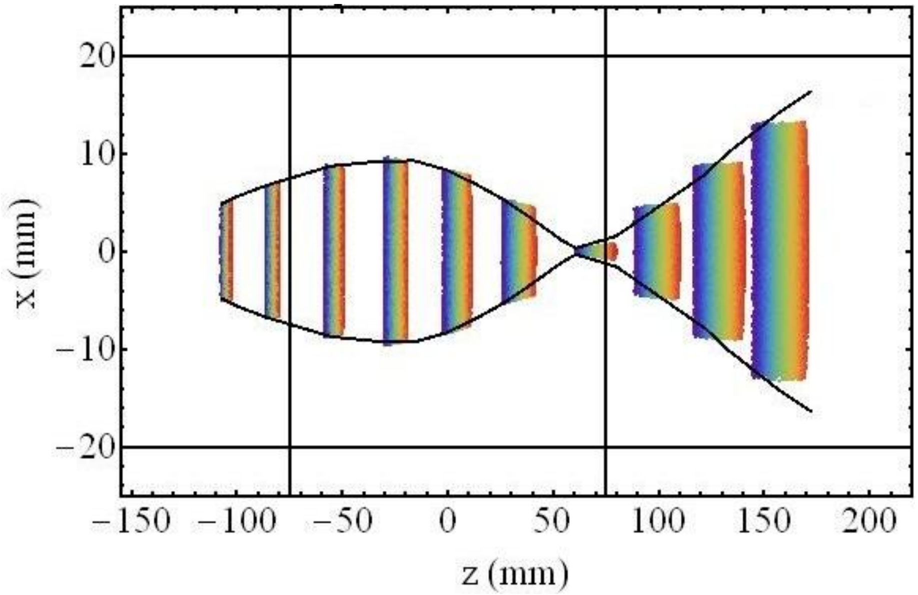

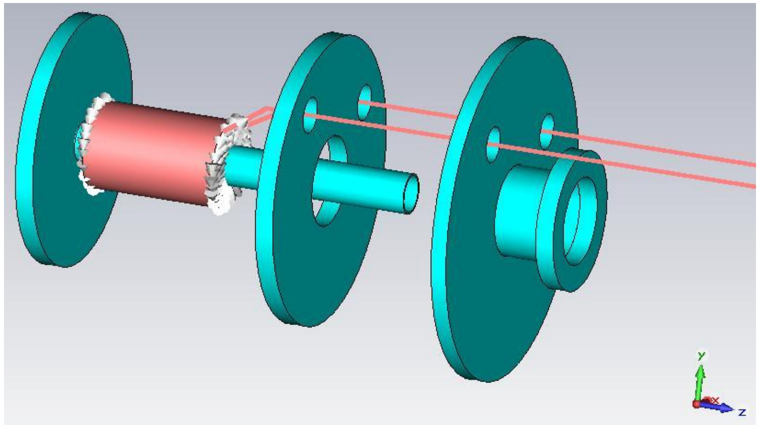

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Results are in good agreement → Space charge criterion yields good results!

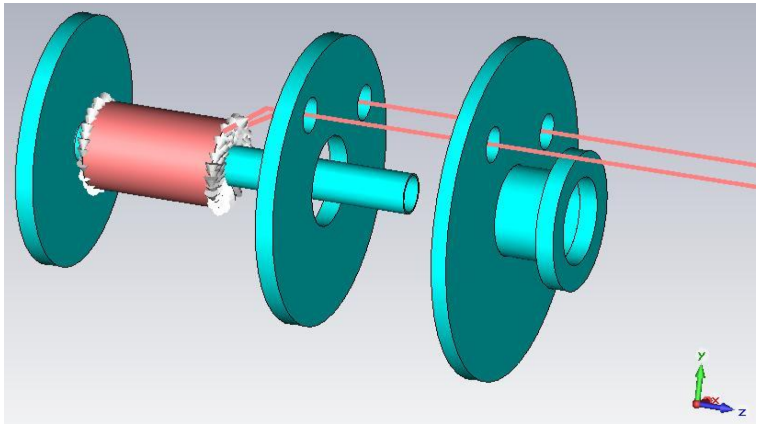
Supply wires field

Supply wires:

•Former solenoid power supply by two wires parallel to the beam pipe

•Dipol field of the wires leed to deflection of the beam

•Results simulated with CST Particle Studio©



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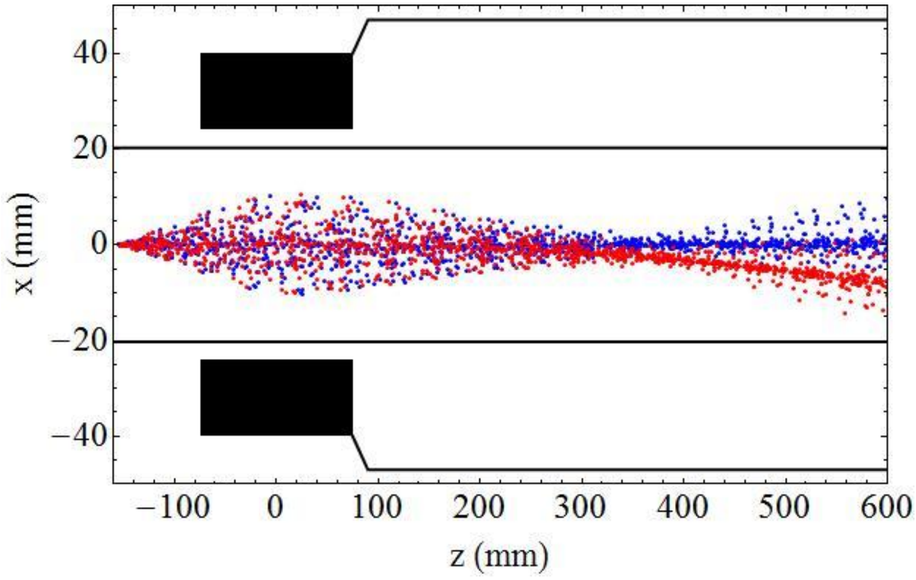

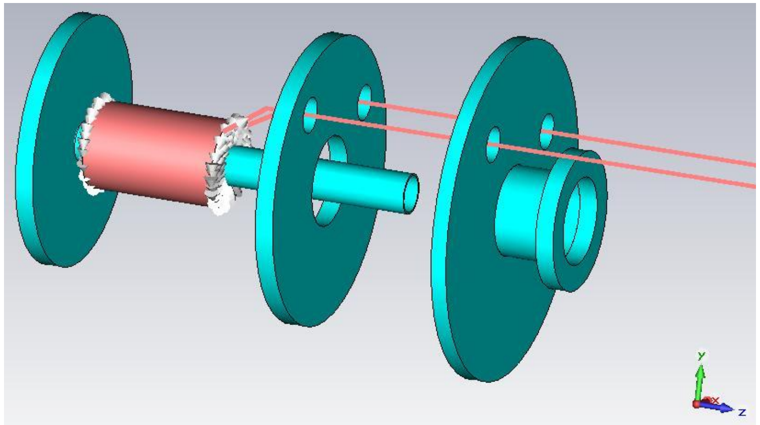

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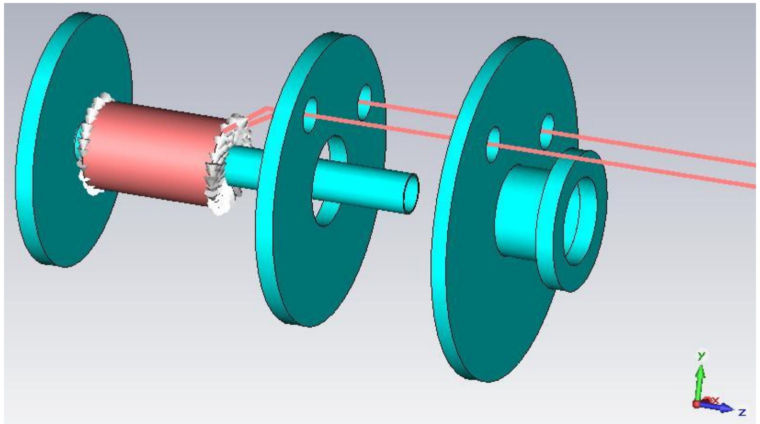

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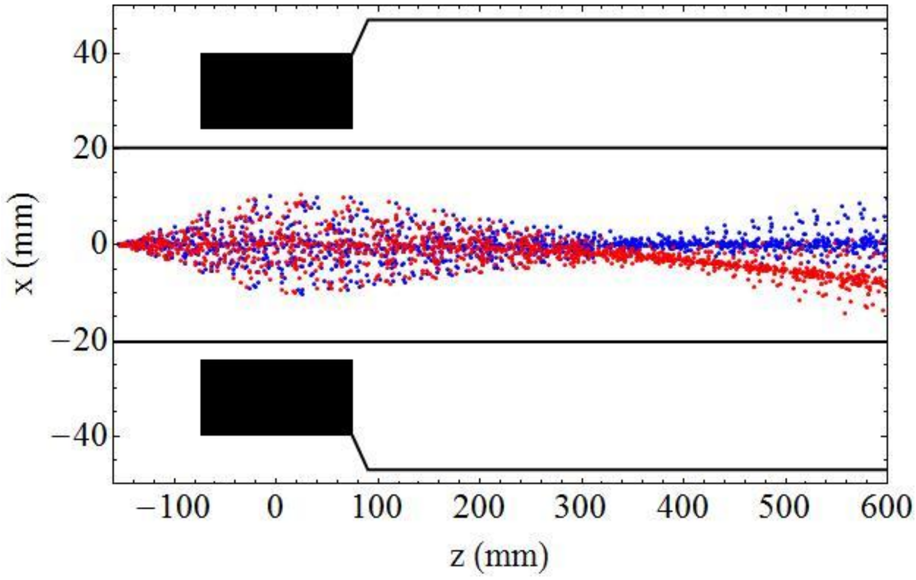

Based on this simulation, the experimental setup was improved!

Ohmic losses and inductive coupling

Ohmic losses and coupling:

•Solenoid operated in pulsed mode

•Shows inductive coupling to surrounding metal parts → time shift between current –and field maximum

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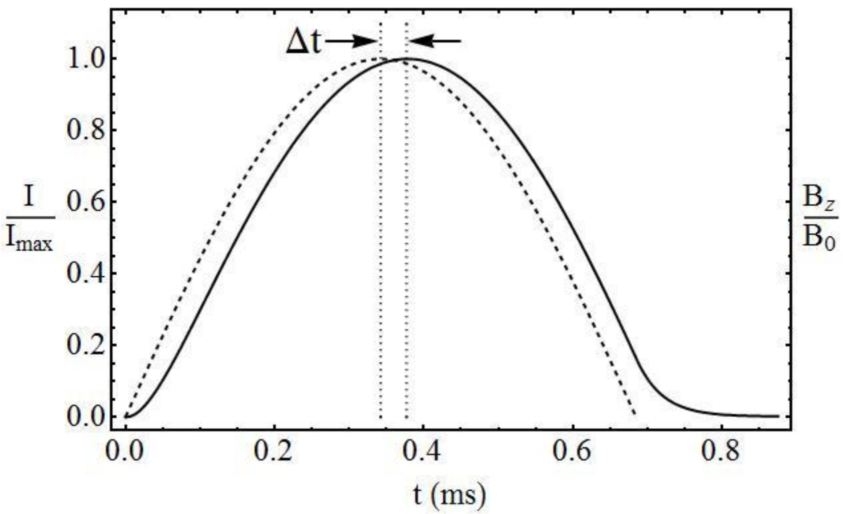

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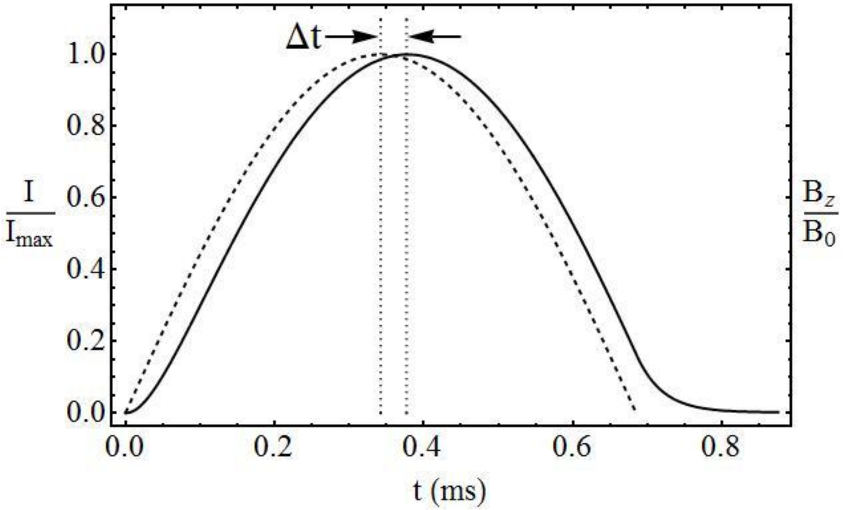

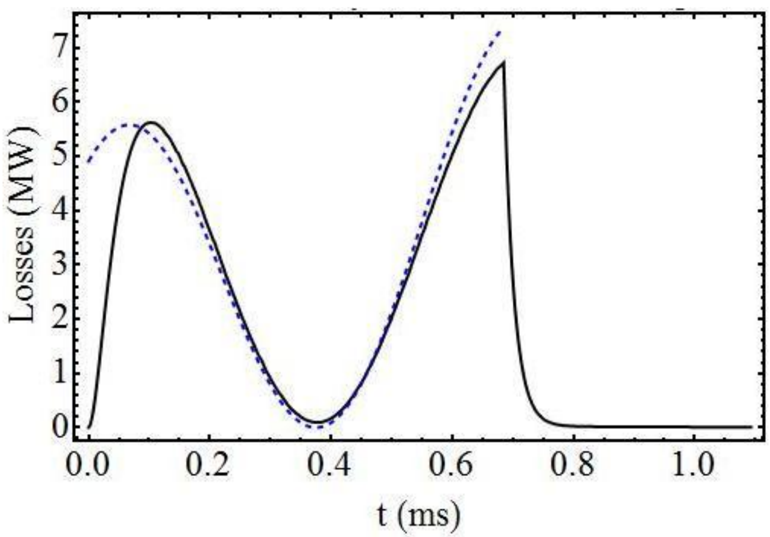

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Conclusions and Outlook

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Outlook:

- Compare different focusing methods, e.g. solenoid and quadrupol tribletts
- Work out a quality criterion for focusing methods
- Answer question: For given task, which method is best?

The End

Thanks for your attention!