Status of 5.0 MeV MESA Kicker

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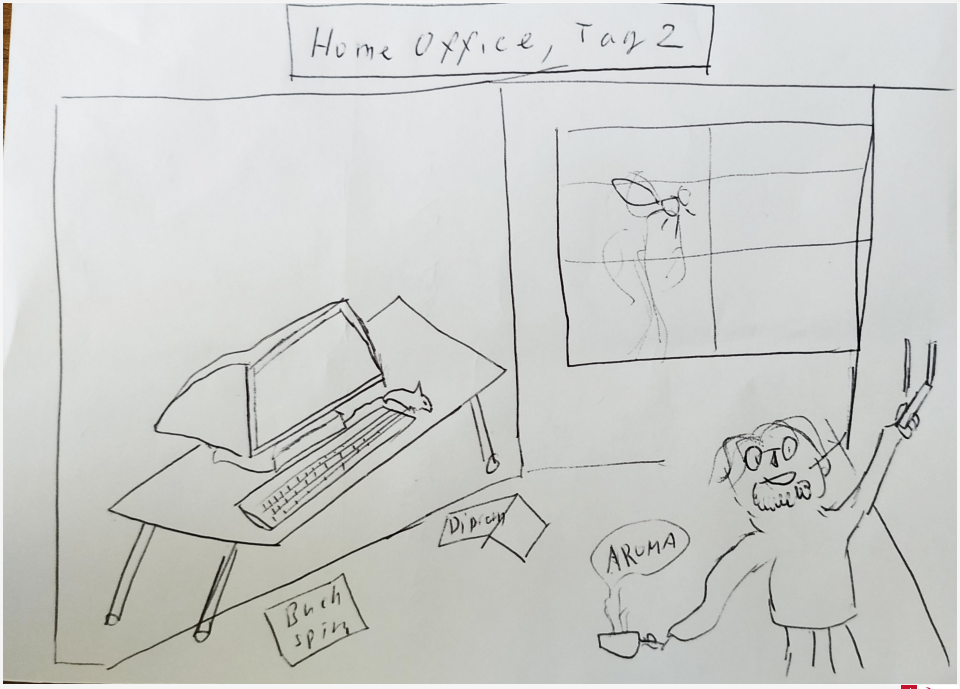
Workshop on Polarized Sources, Targets and Polarimetry 2022
PSTP22

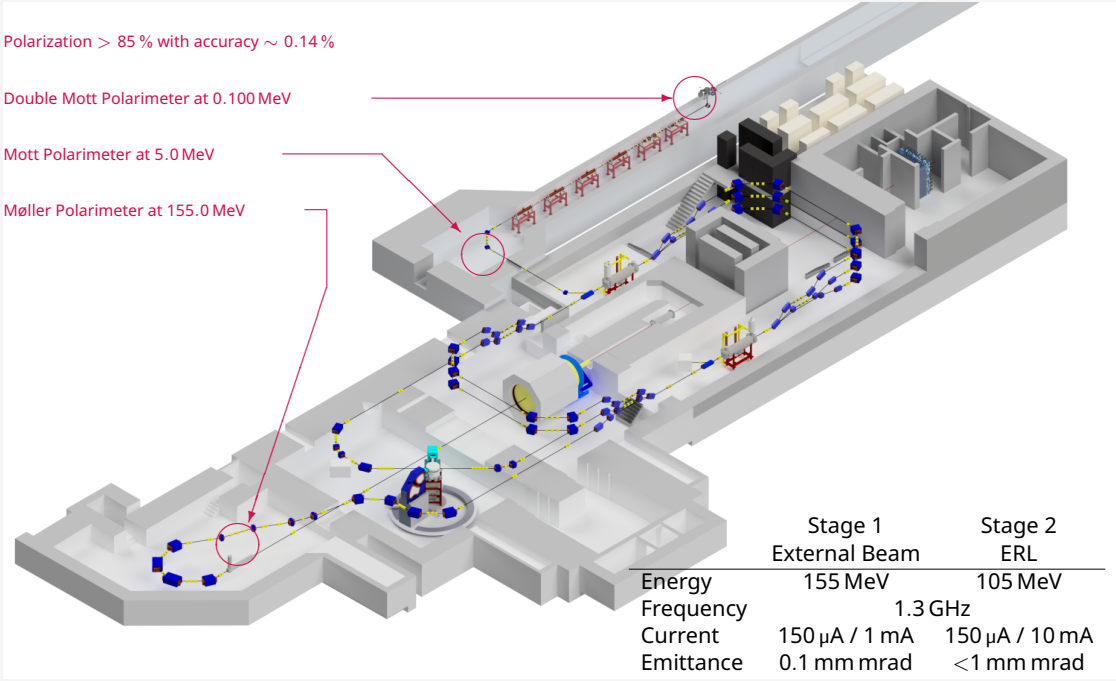
Outline

Outline



"The second day of lockdown"", Mainz, Spring 2020

MESA accelerator



	Stage 1 External Beam	Stage 2 ERL
Energy	155 MeV	105 MeV
Frequency	1.3 GHz	
Current	150 µA / 1 mA	150 µA / 10 mA
Emittance	0.1 mm mrad	<1 mm mrad

P2 Experiment @ MESA

- MESA accelerator is being built in Mainz
- CW spin polarized electron beam, polarization $\sim 85\,\%$
- Beam current $\sim 150\,\mu\mathrm{A}$, beam energy $\sim 155\,\mathrm{MeV}$
- Double Mott polarimeter at $100.0\,\mathrm{keV}$ with gold foil targets
- Mott polarimeter at $5.0\,\mathrm{MeV}$ with gold foil targets
- Møller polarimeter at $55.0 - 155.0\,\mathrm{MeV}$ with polarized atomic hydrogen target.
- The goals at MESA $P_{\text{Mott, double}} = P_{\text{Mott, 5.0 MeV}} = P_{\text{Møller ,H}}$
- Accuracy $\Delta P < 0.5\%$
- Møller polarimeter measurements in online mode
- Both Mott polarimeters measurements only in offline mode

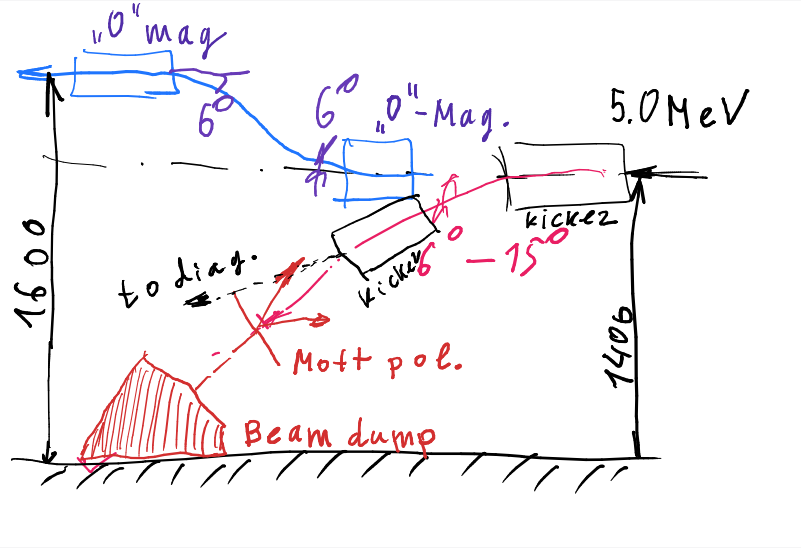
Why kicker is needed

- Beam current $\sim 150\,\mu\mathrm{A}$, beam energy $\sim 0.10, 5.0, 155.0\,\mathrm{MeV}$
- The problem is that during a run it is undesirable to switch off or change operation condition because a significant thermal drift of the production laser and/or cathode is possible
- An acceptable duty cycle $d.c. \sim 0.01$ with a switch period $t \sim 1.0\,\mathrm{s}$
- $t_{On/Off} \sim 0.001\,\mathrm{s}$, $t_{Mott} \sim 0.010\,\mathrm{s}$ and $t_{beam} \sim 0.988\,\mathrm{s}$
- $t_{On/Off} \sim 0.001\,\mathrm{s}$ requires quick iron free kicker

Basic definitions

- Magnetic or electrostatic quick kicker with bend angle $\sim 6.0 - 15.0\,^{\circ}$
- $T_{beam} = 5.0\,\mathrm{MeV}$
- m, c, q in SI units
- rigidity: $\rho B = \beta\gamma \frac{m c}{q} = 0.018\,\mathrm{T\,m}$
- magnetic kicker with $\rho = 2.0\,\mathrm{m}$ requires $B = 0.009\,\mathrm{T}$
- magnetic kicker with $\rho = 1.5\,\mathrm{m}$ requires $B = 0.012\,\mathrm{T}$
- electrostatic kicker with $\rho = 2.0\,\mathrm{m}$ requires $E = 2.7\,\frac{\mathrm{MeV}}{\mathrm{m}}$

Beam line - Stairway to heaven



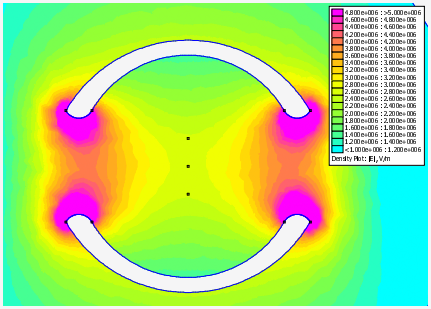
Blue: beam shift line, Black: kicker
Red: Mott polarimeter 5.0 MeV, beam diagnostics, beam dump

Courtesy: J. Groth

- Beam height above floor should be moved up by 0.2 m
- Bending angle of $6.0 - 15.0\,^\circ$ in one or two stages possible
- E.g. first stage $7.5\,^\circ$ with a kicker, second stage $7.5\,^\circ$ with a normal dipole magnet

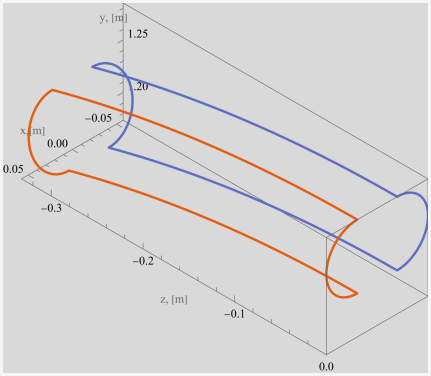
Outline

Electrostatic and magnetic field kickers



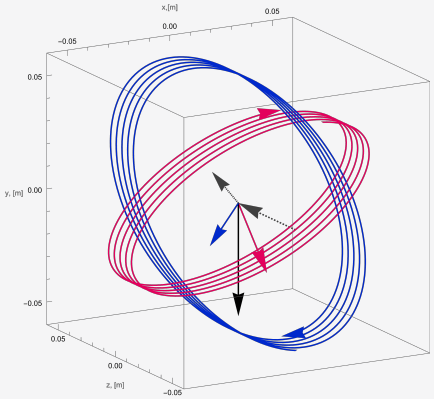
Electrostatic kicker

- electrostatic kicker requires $E = c\,B = 2.7\ \frac{\mathrm{MV}}{\mathrm{m}}$
- with gap $= 0.04\,\mathrm{m}$
- operation voltage $U_{plate} \sim \pm 54.0\,\mathrm{kV}$ would be too high



Bent saddle coil (BSC)

- $R_{coil} = 1.25\,\mathrm{m}$
- $B_{coil} = 0.0146\,\mathrm{T}$
- $\theta_{coil} = 15.0\,^\circ$
- $CS_{coil} = 0.030 \times 0.015\,\mathrm{m}$
- $I_{coil} \sim 622.0\,\mathrm{A} \times \mathrm{turn}$ would be very high



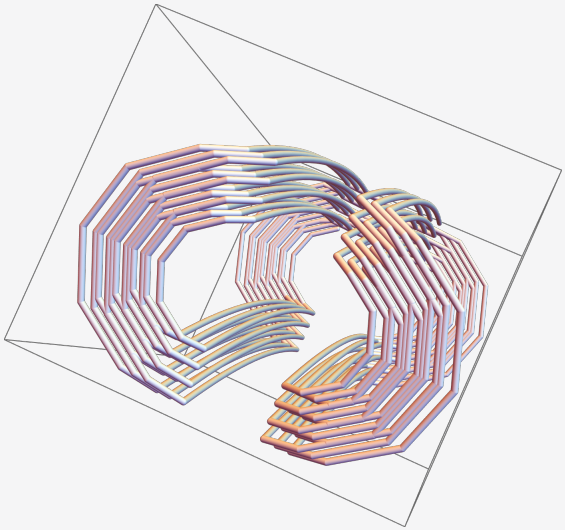
Canted Cosine Theta (CCT)

- proposed in 1970
- two loops induce B field red and blue lines, black line points to summarized B, dashed lines to moving electron

Source: D. Meyer, R. Flasck, *Nuclear Instruments and Methods* **1970**, *80*, 339–341

Outline

Mathematica Wolfram I



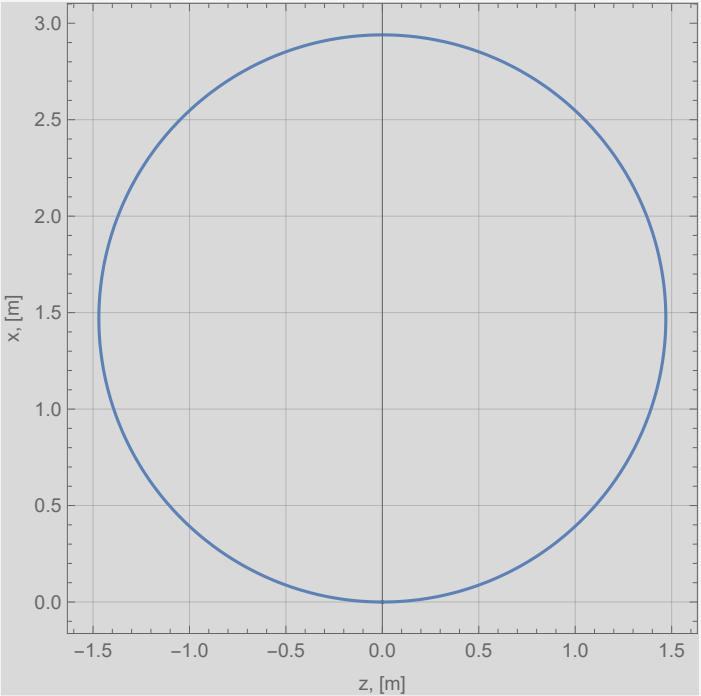
Example: draft view of BSC-Kicker

- Grid of short current segments: CoilNode[[n]]
- Grid of segment position: CoilVector[[n]]
- Directly using of Biot–Savart law for each segment
- Embarrassingly parallel problem
- Solution of BMT equation of spin movement
- Solution of moving equations

Mathematica Wolfram II

```
E0[{x_, y_, z_}] = {0, 0, 0};                                   (* magnitic and electric fields *)

B0[{x1_, y1_, z1_}] = μ0 I_coil / (4 π) Sum[ CoilVector[[n]] × ({x1, y1, z1} - CoilKnode[[n]]) / Norm[({x1, y1, z1} - CoilKnode[[n]])]^3, {n, 1, nsum}];

r[t_] = {x[t], y[t], z[t]};          (* radius vector *)        sp[t_] = {spx[t], spy[t], spz[t]};   (* spin vector *)



solution = NDSolve[ Join[
                    löse Diff···  verknüpfe

   Thread[ ∂t,t r[t] == -q/(γ m c) (1/c E0[r[t]] + ∂t r[t] × B0[r[t]]) ],
   fädle auf

   Thread[ ∂t sp[t] == -q/(γ m c) sp[t] × ((1 + a γ) B0[r[t]] - a γ^2/(γ + 1) (∂t r[t] × B0[r[t]]) ∂t r[t] - γ (a + 1/(γ + 1)) r[t] × E0[r[t]]) ],
   fädle auf

   Thread[ r[0] == {0.0, sr, Lfree} ],                          (* {x[0]==0.`,y[0]==1.25`,z[0]==1.`} *)
   fädle auf
   Thread[ Evaluate[∂t r[t] /. t → 0] == {0.0, 0.0, -β} ],      (* {x'[0]==0.`,y'[0]==0.`,z'[0]== -β} *)
   fädle auf  werte aus
   Thread[ sp[0] == {0, 0, 1}] ],                               (* {spx[0]==0, spy[0]==0, spz[0]==1} *)
   fädle auf

  {x, y, z, spx, spy, spz}, {t, itime} ];                       (* simultaniosly solution of moving and BMT equations *)
```

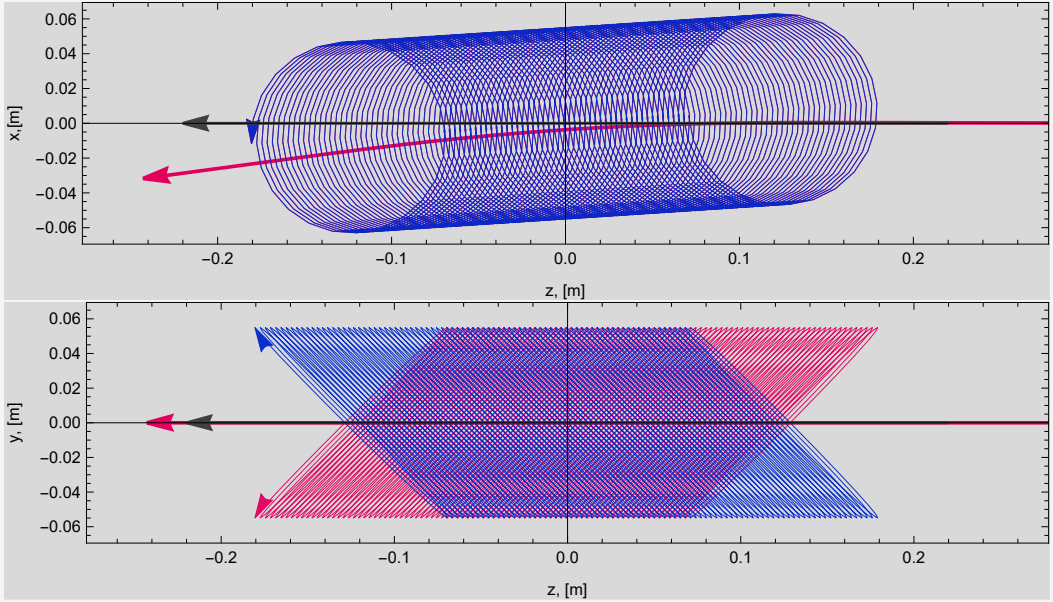
Mathematica Wolfram. Check on magic energy



- $g_e = 2.00231930436322$
- $a = \frac{g_e - 2}{2}$,
- $\gamma = \frac{N_{spinrotations} - 1}{a}$
- $T_{beam} = (\gamma - 1)m_e$
- $T_{magic} = 440.1, 880.8, 1321.4, 1762.1\,\mathrm{MeV}$
- started at point $r(0) = \{0, 0, 0\}$ with $sp(0) = \{0, 0, 1\}$
- finished $r(t_f) = \{0, 0, 0\}$ with $sp(0) = \{0, 0, 1\}$

Outline

Coils and beam



- $I_{coil} = 22.5\,\mathrm{A}$
- $N_{turns} = 84$
- bending 7.50°
- spin is bent to 7.59°
- $L_{coil} \sim 0.002\,\mathrm{H}$

red and blue - coils, black arrow - without B-field, red arrow - bent beam

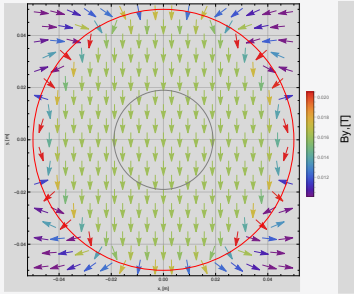
Transfer matrix BSC and CCT cases

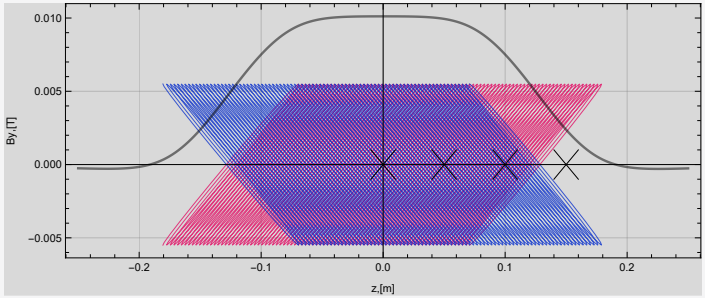
$$TM_{BSC} = \begin{pmatrix} 1.031 & 2.368 & 0. & 0. \\ +0.027 & 1.033 & 0. & 0. \\ \epsilon & \epsilon & 0.785 & 2.043 \\ \epsilon & \epsilon & -0.213 & 0.717 \end{pmatrix}$$

$$TM_{CCT} = \begin{pmatrix} 0.940 & 2.24 & \epsilon & \epsilon \\ -0.055 & 0.927 & \epsilon & \epsilon \\ 0. & 0. & 0.892 & 2.22 \\ 0. & 0. & -0.082 & 0.918 \end{pmatrix}$$

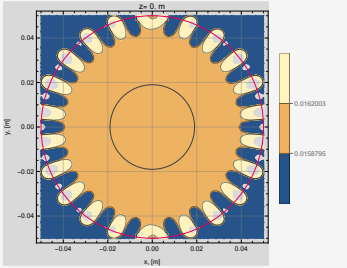
Total 4x4 transfer matrices, with $\epsilon \leq 1.0 \times 10^{-6}$ uncoupled motion of electron.

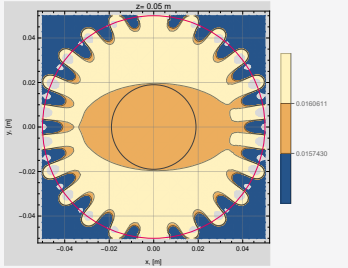
Good field regions

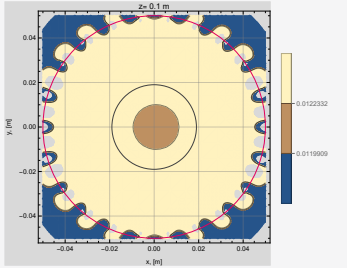


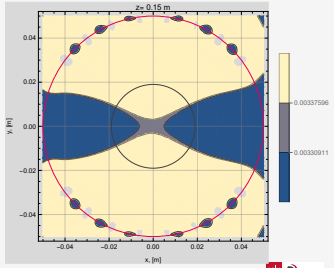


- left: vector map of magnetic field at the center of kicker
- middle: magnetic field profile along z-axis with both coils in background
- lower row: good field region $\pm 1\%$ at marked points

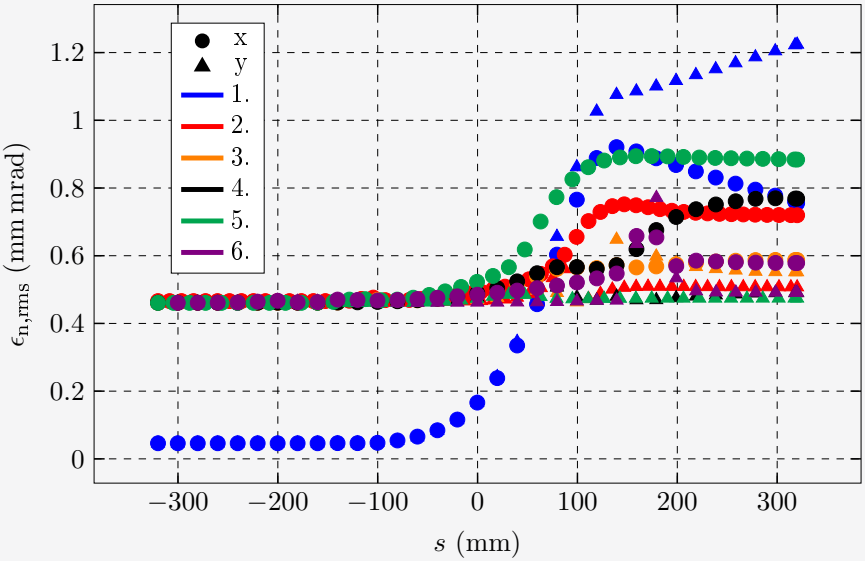








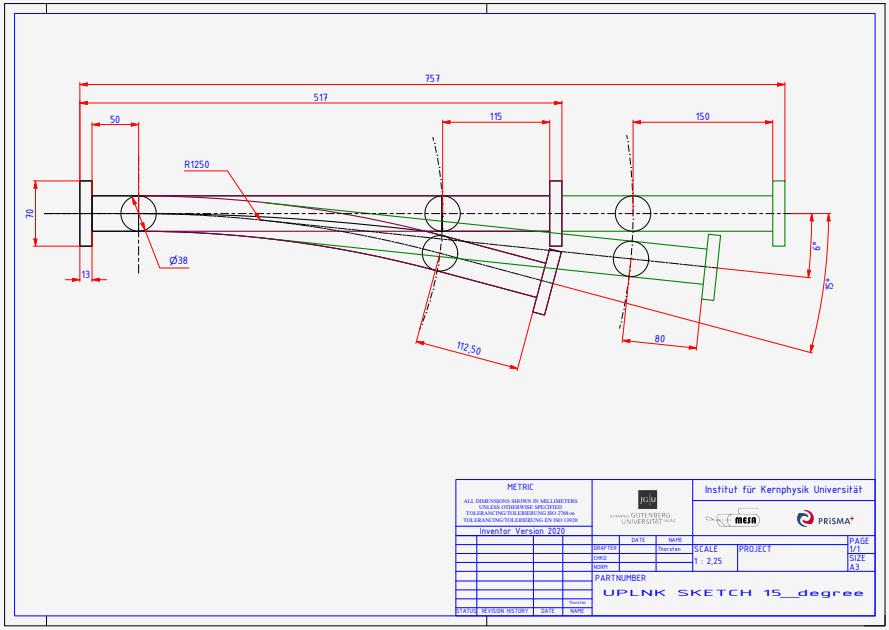
Emittance tracking



Emittance growth in x and y planes is investigated. Lines from 1 to 5 BSC kickers, line 1 scaled by factor 10, line 6 CCT

Courtesy Dr. Christoph Matejcek, private communications, 2022

Possible mechanical design

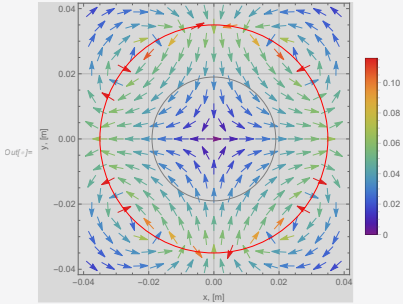


Draft of bending chamber for bending angle from 6° (green) to 15 ° (black)

Courtesy Th. Feldmann

Possible applications at MAMI and MESA

- as corrector magnet at low energy $T_{beam} = 100.0\,\mathrm{keV}$ with $d_{coil} = 0.045\,\mathrm{m}$, $current_{coil} = 1.0\,\mathrm{A}$ and just 20 turns



- due to very good field as quadrupole for electron separation at atomic hydrogen target

- something else

Outline

Summary and outlook

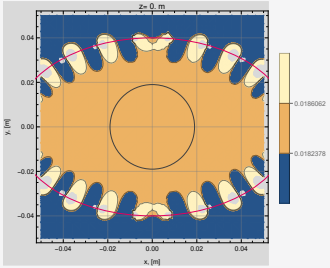
- CCT kicker is preferred
- Hardware in fabrication

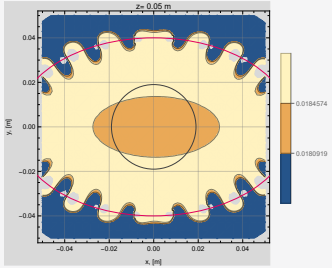
Thank for support

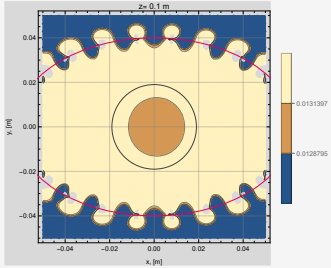
Thank you for your attention!

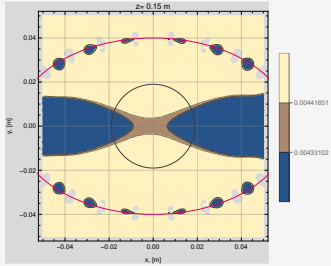
One more thing

Good field regions for elliptical coil

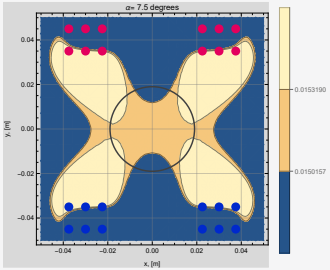


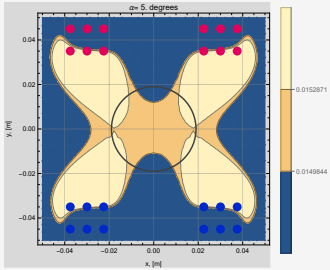


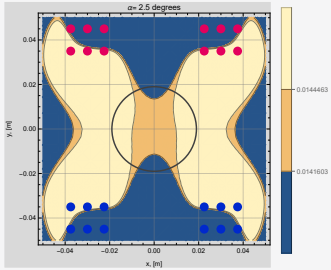


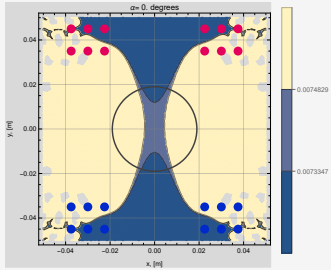


Good field regions for BSC kicker

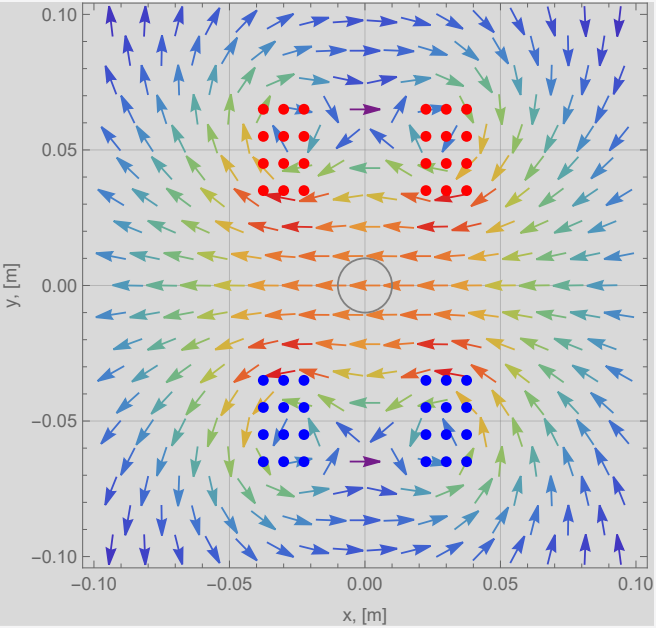




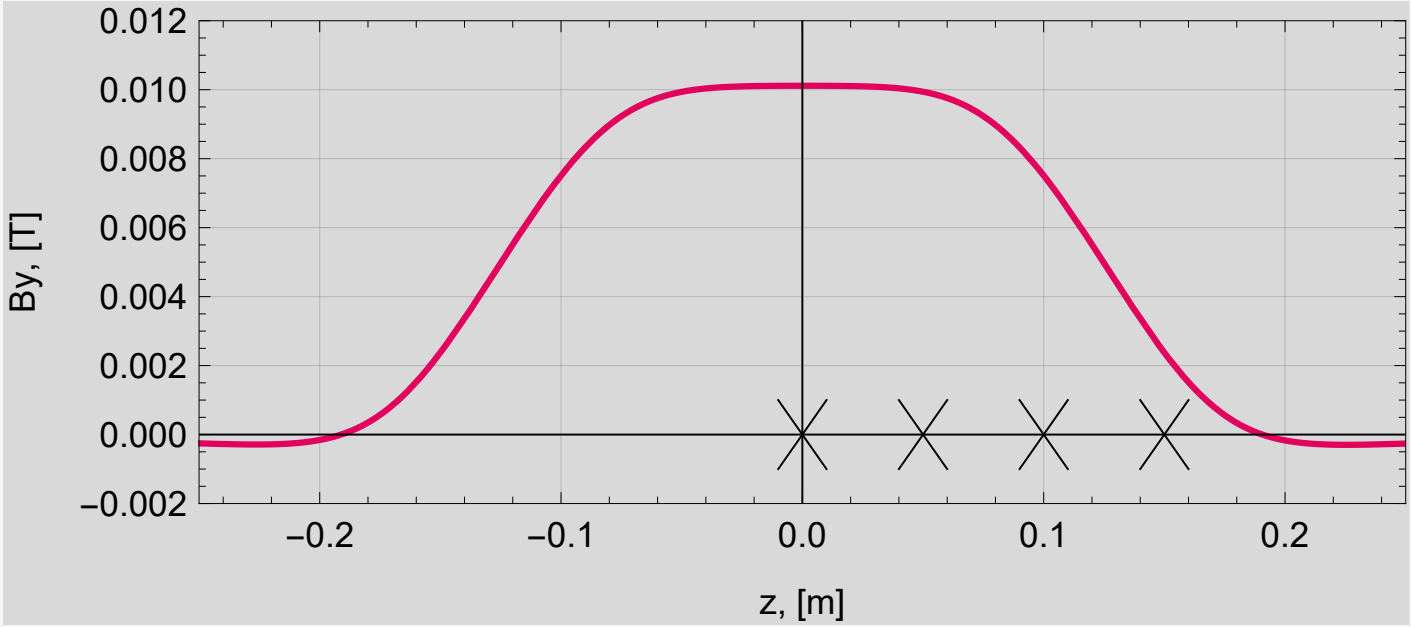




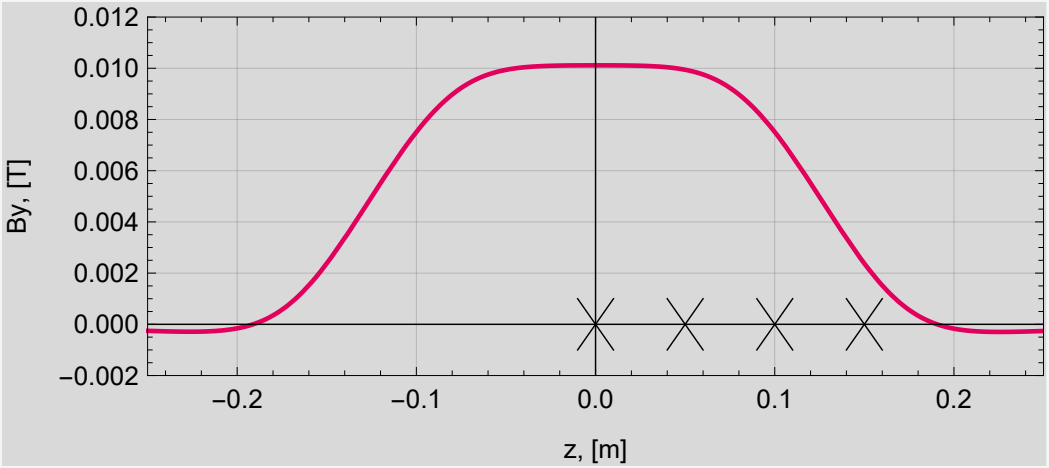
Bx field in center of BSC kicker

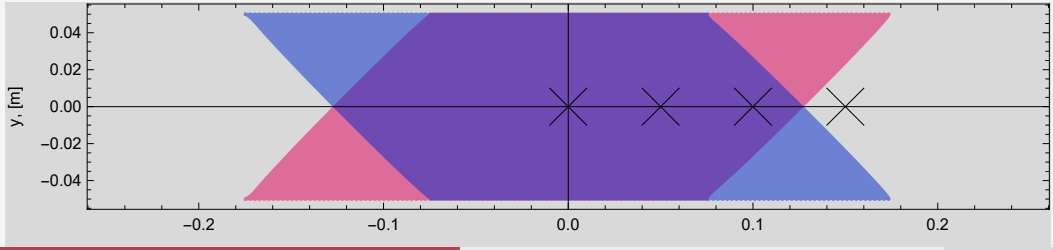


Bx field along beam trajectory I



Bx field along beam trajectory II





Transfer matrix BSC and CCT cases II some results

- $TM_{BSC} = \begin{pmatrix} 1.031 & 2.368 & 0. & 0. \\ +0.027 & 1.033 & 0. & 0. \\ \epsilon & \epsilon & 0.785 & 2.043 \\ \epsilon & \epsilon & -0.213 & 0.717 \end{pmatrix}$
- $TM_{CCT} = \begin{pmatrix} 0.940 & 2.24 & \epsilon & \epsilon \\ -0.055 & 0.927 & \epsilon & \epsilon \\ 0. & 0. & 0.892 & 2.22 \\ 0. & 0. & -0.082 & 0.918 \end{pmatrix}$
- Total 4x4 transfer matrices, with $\epsilon \leq 1.0 \times 10^{-6}$ uncoupled motion of electron.
- in case of parallel start and bending at 7.50° spin is bent to 7.59°
- CCT design of kicker is preferred to BSC one