The beam extraction system for the 5 MeV Mott at MESA

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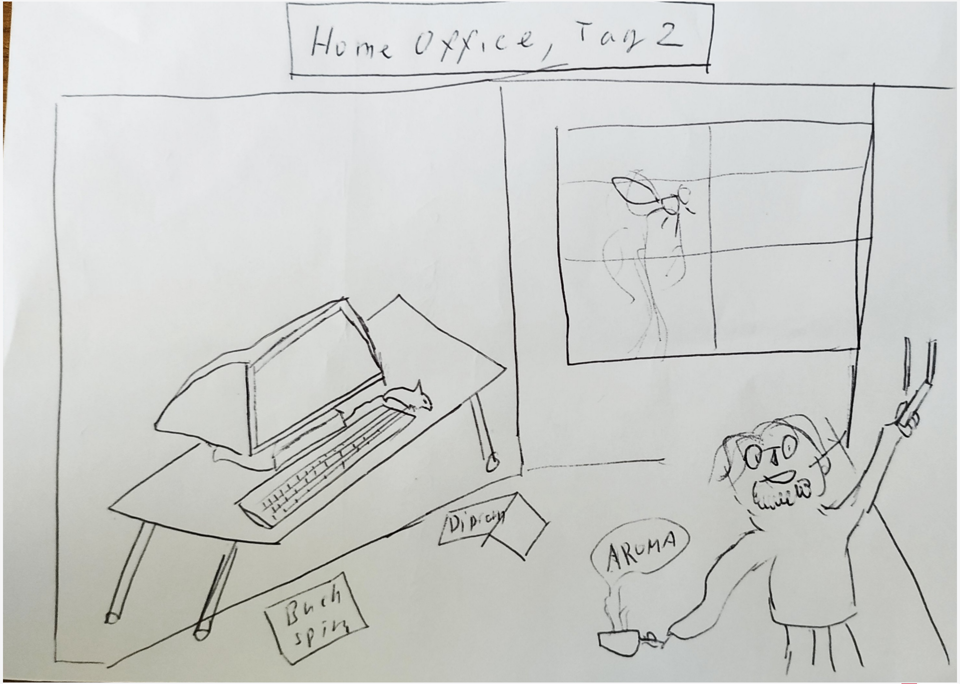
Outline

Outline



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

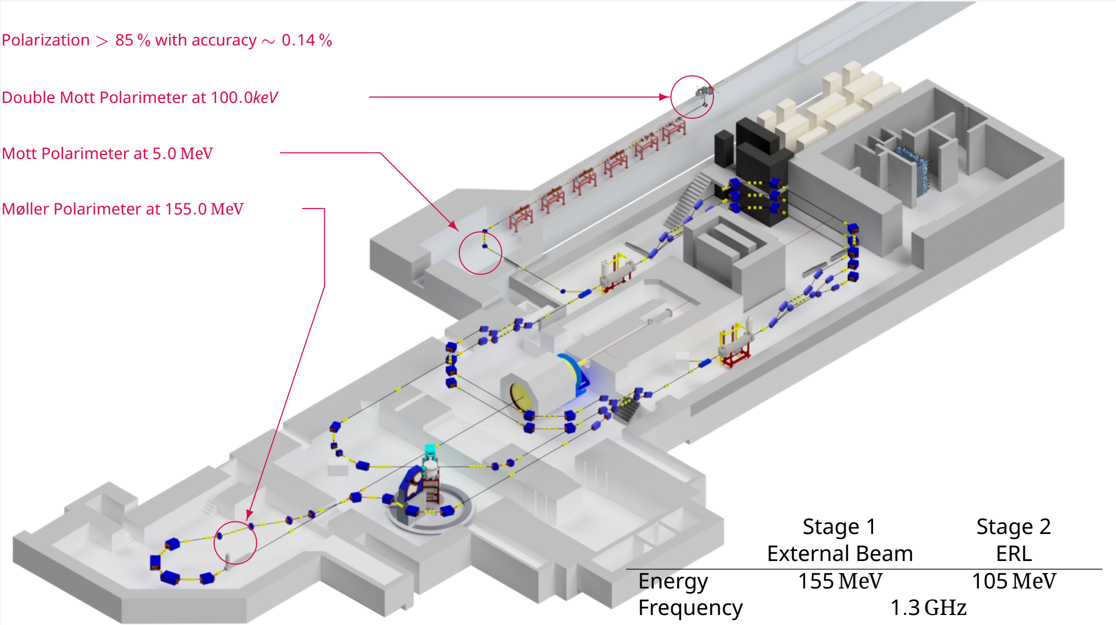
MESA accelerator

Polarization $>$ 85 % with accuracy $\sim$ 0.14 %

Double Mott Polarimeter at 100.0*keV*

Mott Polarimeter at 5.0 MeV

Møller Polarimeter at 155.0 MeV



	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 mmmrad	$<$ 1.0 mmmrad

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 $P_{\text{Mott, double}} = P_{\text{Mott, 5.0 MeV}} = P_{\text{Møller},\mathrm{H}}$
- Accuracy $\Delta P < 0.5\%$
- Møller polarimeter measurements in online mode
- Both Mott polarimeters measurements only in offline mode

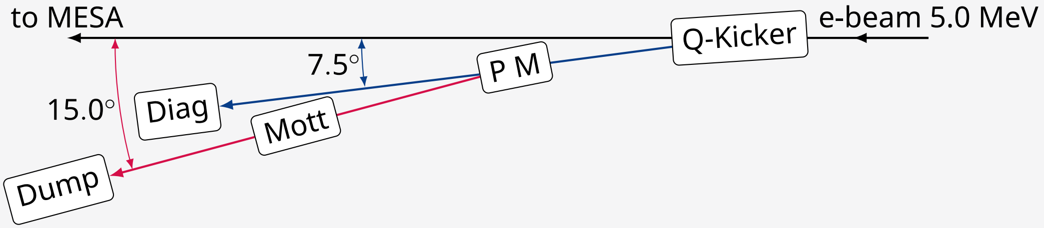
Why kicker is needed

- Beam current $\sim 150\,\mu$A, beam energy $\sim 0.10, 5.0, 155.0\,$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 $t \sim 1.0\,$s
- $t_{On/Off} \sim 0.001\,$s, $t_{Mott} \sim 0.010\,$s and $t_{beam} \sim 0.988\,$s
- $t_{On/Off} \sim 0.001\,$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 $E = 2.7\,\frac{\mathrm{MeV}}{\mathrm{m}}$

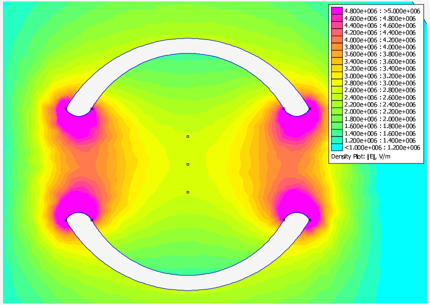
Possible arrangement of 5.0 MeV beam distribution unit.



- Q-Kicker: the extraction from the main beam-line with first stage 7.5° is provided by the kicker magnet.
- Q-Kicker: duty factor 0.01, rise time 0.1 ms.
- PM electromagnet: ”on-state” second stage 7.5° with a normal dipole magnet to Mott polarimeter,
- PM electromagnet: ”off-state” beam diagnostic.
- Diag: beam diagnostic system (e.g. longitudinal phase space diagnostics)

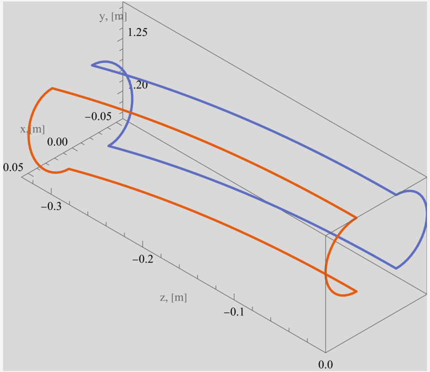
Outline

Electrostatic and magnetic field kickers



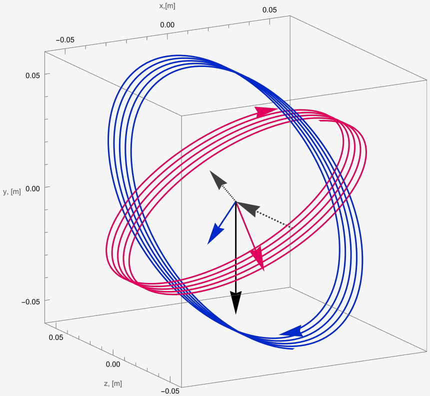
Electrostatic kicker

- 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)

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

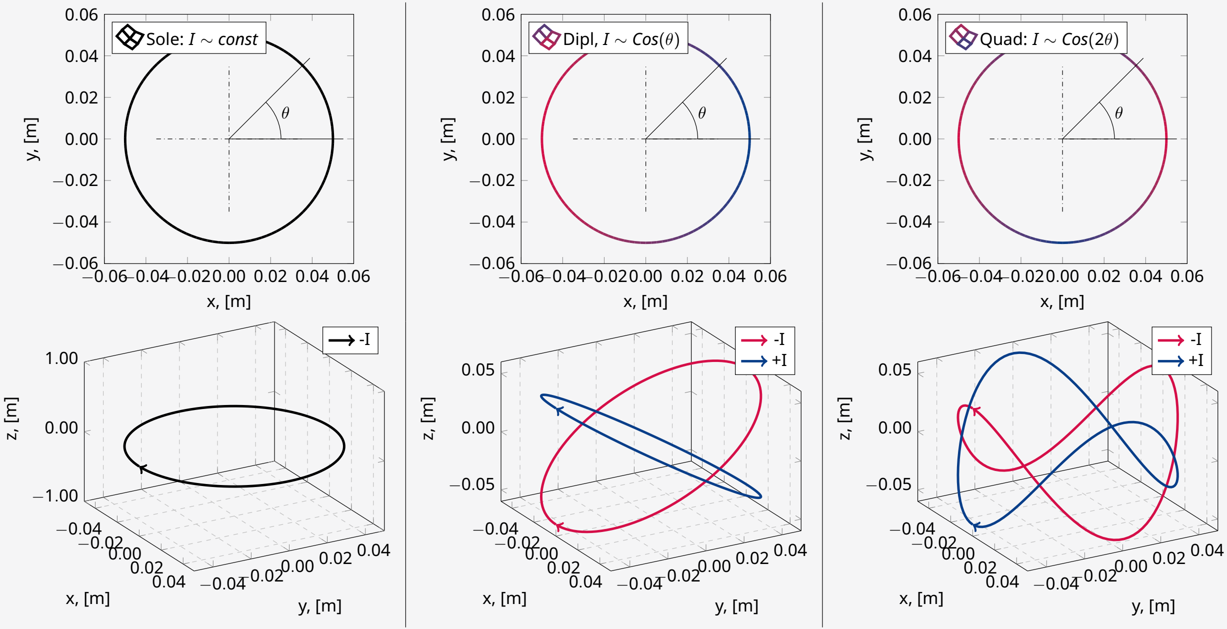


Canted Cosine Theta (CCT)

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

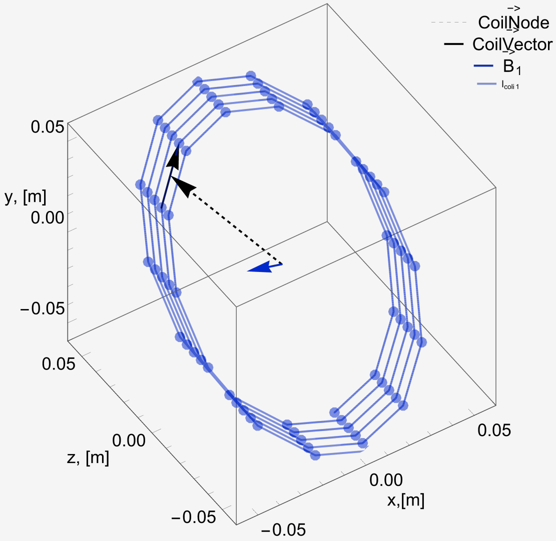
Source: D. Meyer, R. Flasck, *Nuclear Instruments and Methods* **1970**, *80*, 339–341

CCT as solenoid, dipole and quadrupole fields



Outline

Mathematica Wolfram I

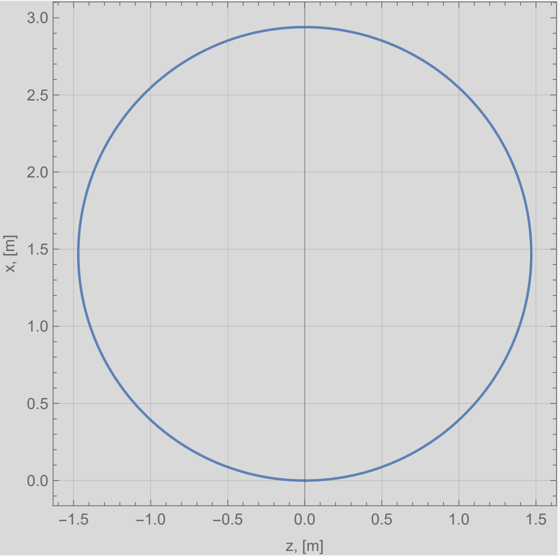


Example: draft view of coil segment

- 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 equation

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

B0[{x1_, y1_, z1_}] = μ0 Icoil/(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 *)
```

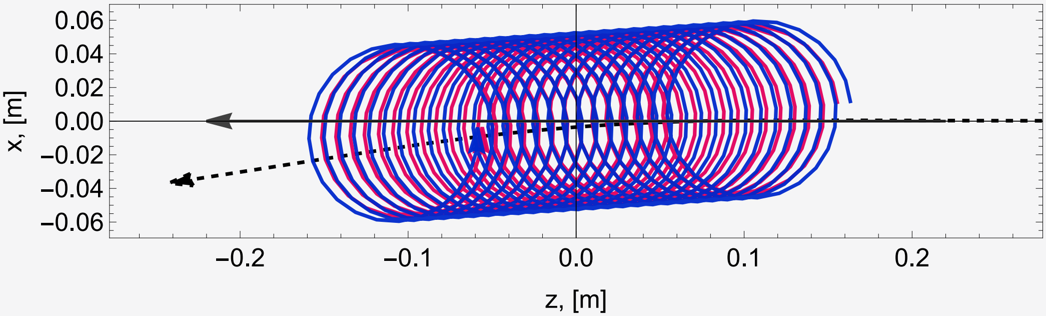
Mathematica Wolfram. Check on magic energy

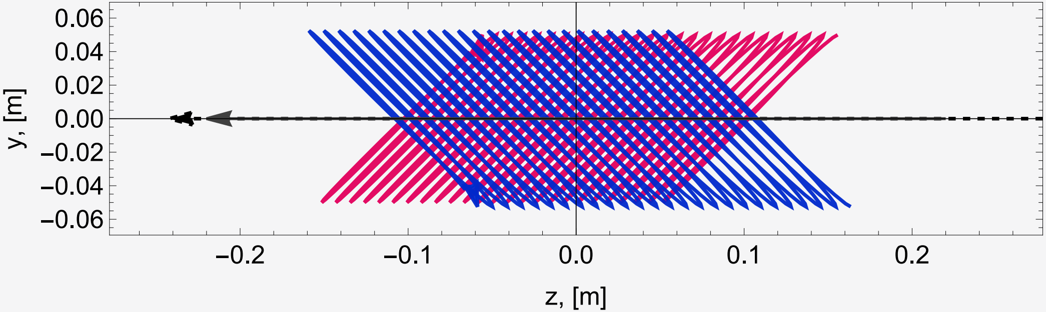


- $g_e = 2.00231930436322$
- $a = \frac{g_e - 2}{2}$,
- $\gamma = \frac{N_{spinrotations} - 1}{a}$
- $T_{beam} = (\gamma - 1) m_e$
- $T_{magic} = 440.1, 880.8, 1321.4, 1762.1$ MeV
- started and finished at point $r(0) = r(t_f) = \{0, 0, 0\}$
- started and finished with spin vector $sp(0) = sp(t_f)\{0,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

Outline

Coils and beam

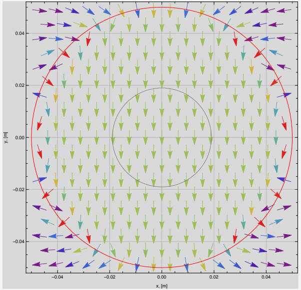


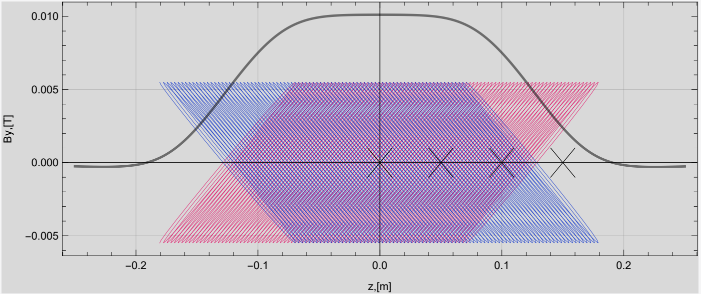


- $I_{coil} = 22.5\,\mathrm{A}$
- $N_{turns} = 84$
- bending 7.50°
- spin is bent to 7.59°
- $L_{coil} \sim 0.002\,\mathrm{H}$

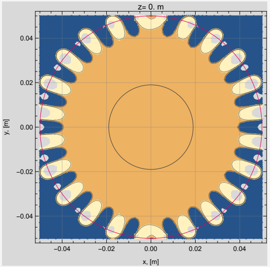
red and blue - coils, black arrow - without B-field, red arrow - bent beam

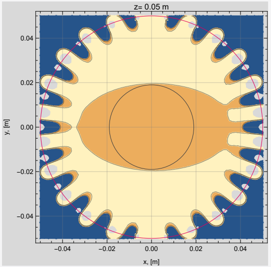
Good field regions I

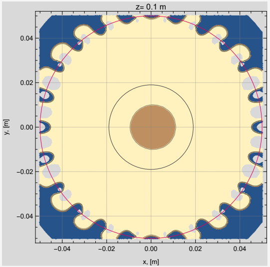


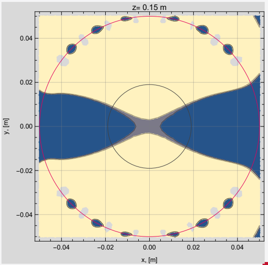


- left: vector map of magnetic field at the center of kicker
- middle: magnetic field profile along z-axis with both coils in background
- lower row: good field region $\pm 1\%$ at marked points

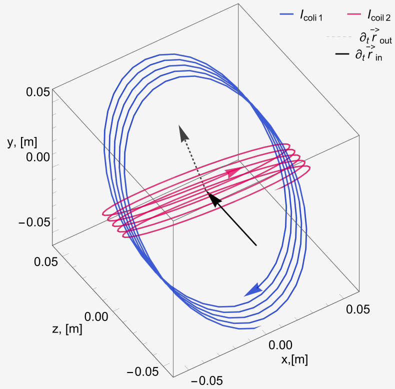








Switch to another configuration



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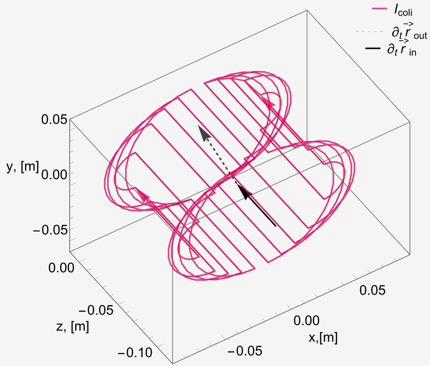
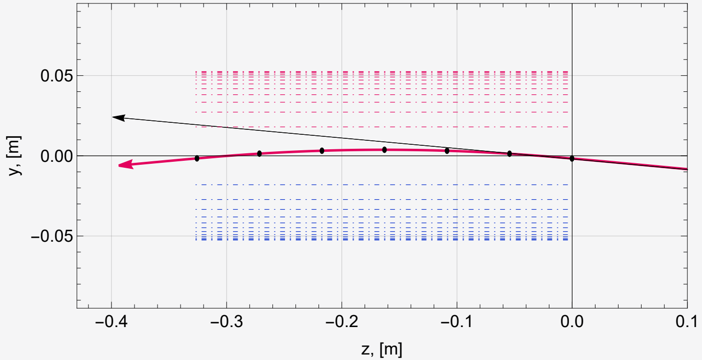


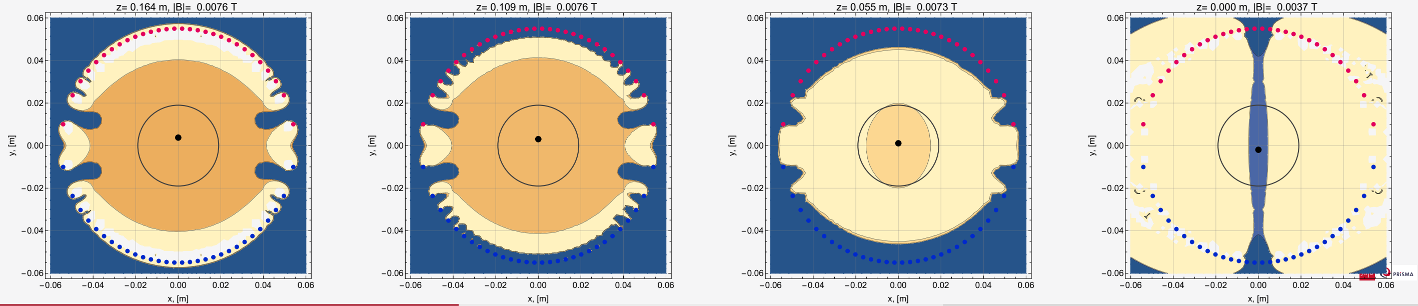
- ✗
- two power supplies is necessary
- difficulties on production
- split on two part not possible

- ✓
- Just one power supply
- look like simple in production
- two separates parts

Good field region II



- Top: view of the CCT kicker with an electron path with (red) and without (black) a magnetic field.
- Bottom: magnetic field profile in x-y planes along z-axis. Good field regions of $\pm 1\%$ are marked as points in the upper right picture.
- The black circle shows the vacuum tube.



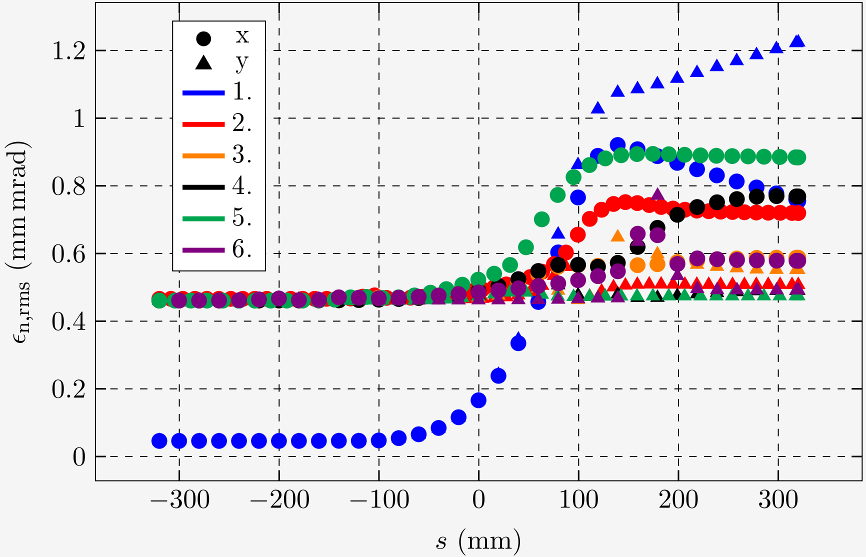
Transfer matrix BSC and CCT cases

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

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

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

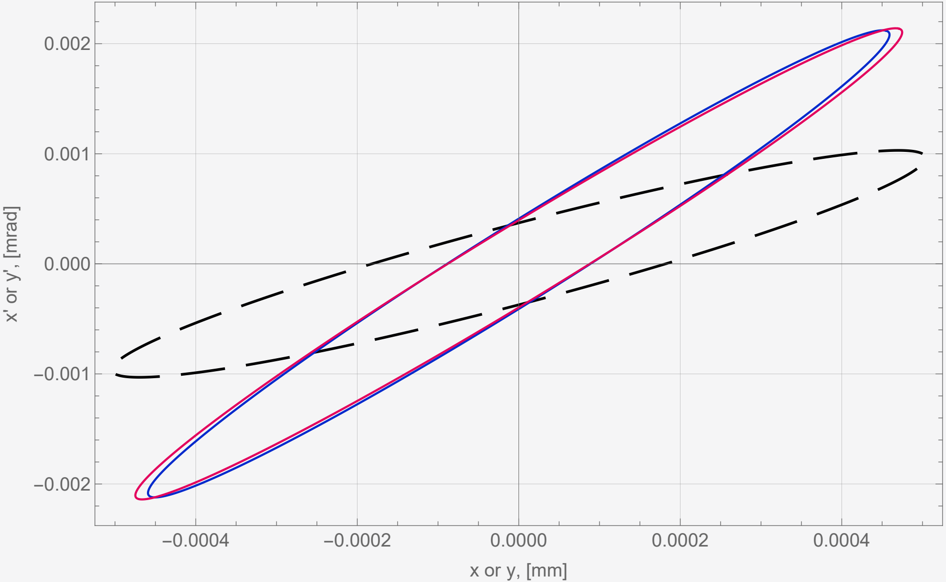
Emittance tracking I



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

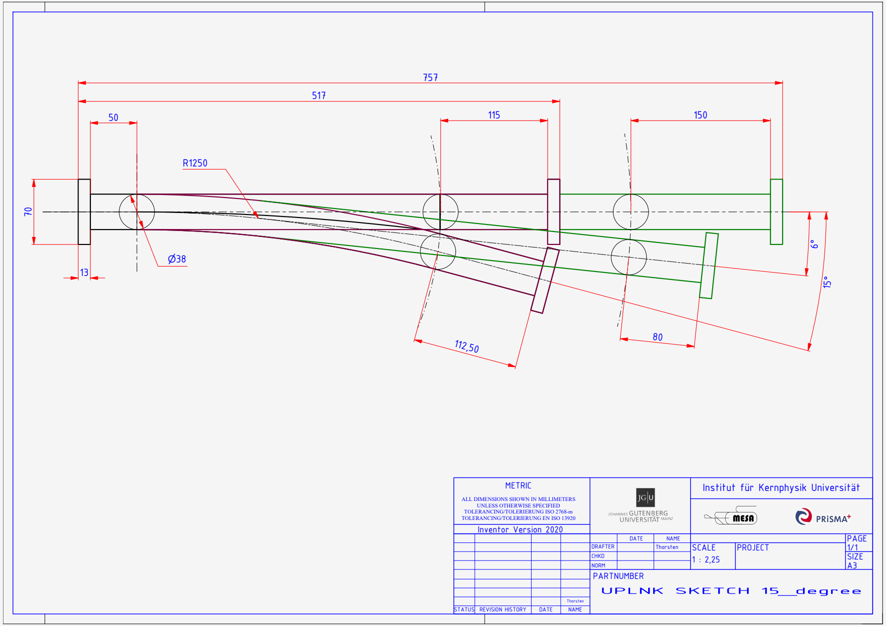
Courtesy Dr. Christoph Matejcek, private communications, 2022

Emittance tracking II



- Beam trecking inside of the kicker
- Black dashed line input
- Red and blue lines after kicker

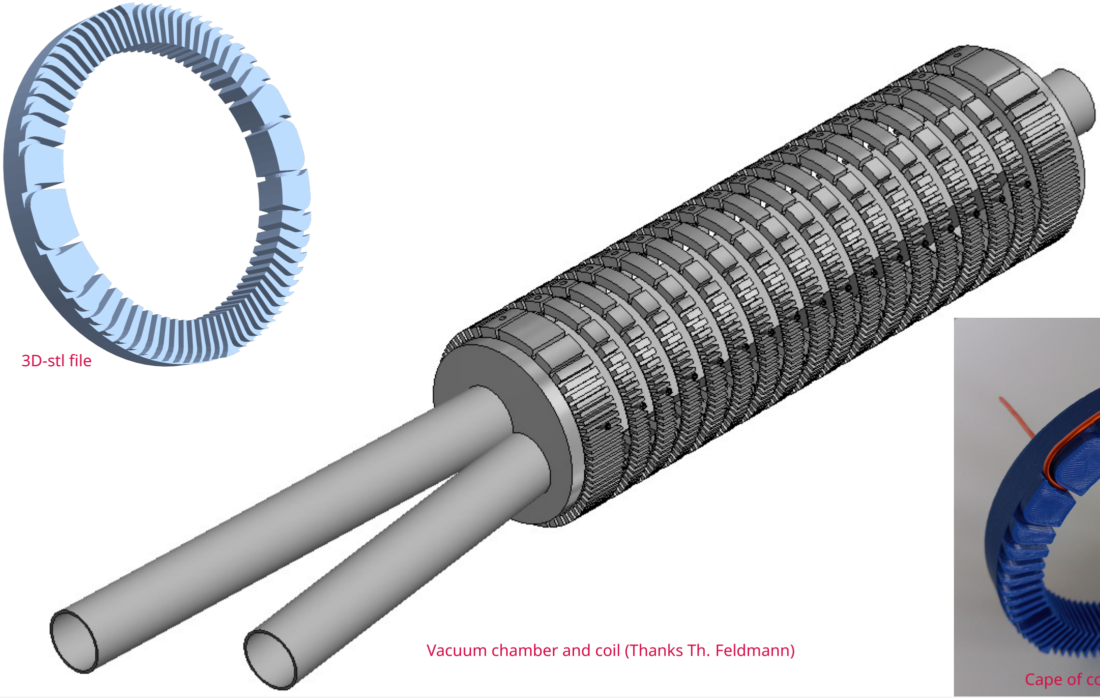
Possible mechanical design



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

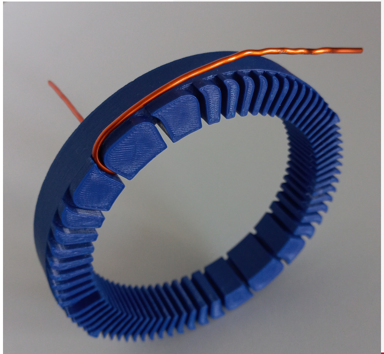
Courtesy Th. Feldmann

Construction design



3D-stl file

Vacuum chamber and coil (Thanks Th. Feldmann)

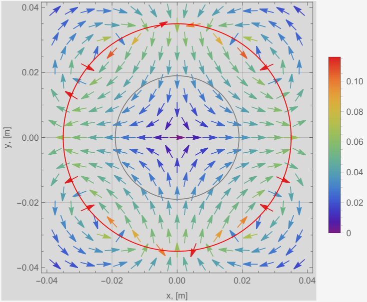


Cape of coil, (Thanks D. Bender)

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

Out[ ]=



- 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
- For further references see Talk PSTP-2022 V. Tyukin, K. Aulenbacher, C. Matejcek, *PoS* **2023**, *PSTP2022*, 026

Thank for support

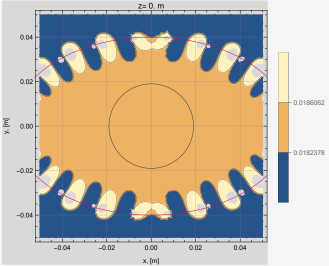
Thank you for your attention!

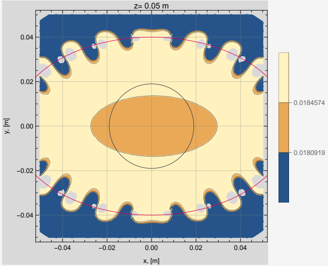
Abstract

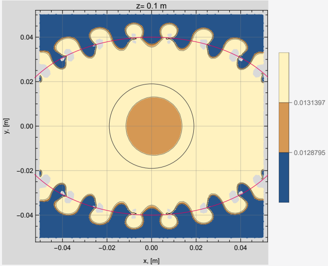
The Mainz Energy recovering Superconducting Accelerator (MESA) requires for carry out of the high-precision measurements exactly measurement the long-term spin properties of the electron beam.

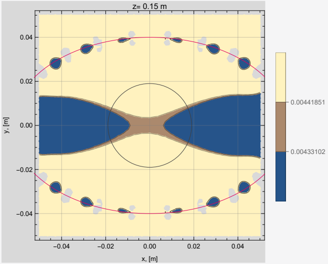
The chain of polarimeters at different beam energy is planed. Previously design of the 5.0 MeV beam section contained a kicker and a Mott polarimeter is presented.

Good field regions for elliptical coil

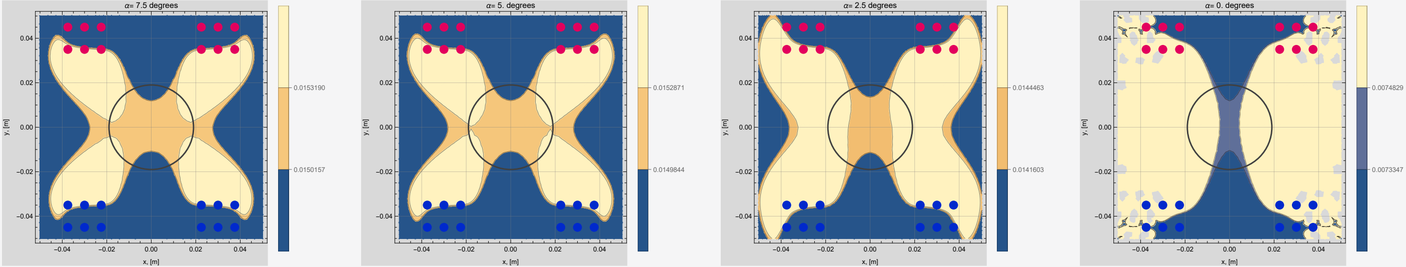




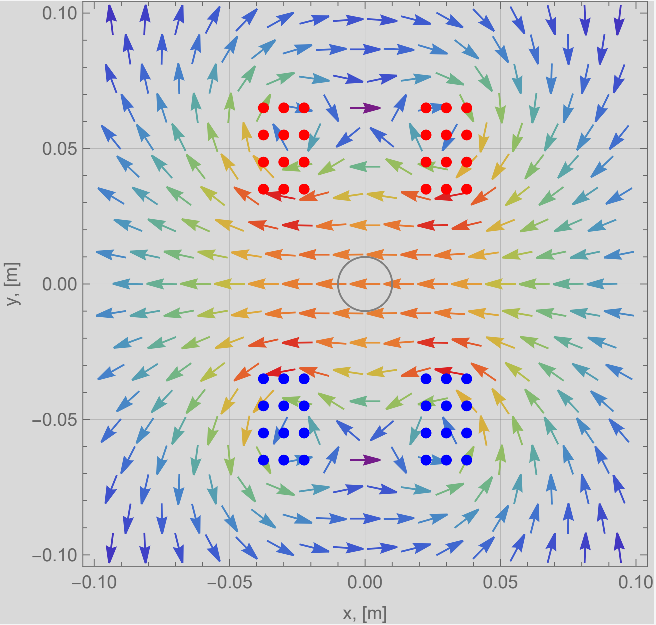




Good field regions for BSC kicker



Bx field in center of BSC kicker



Bx field along beam trajectory II