Kicker Manget for the MESA 5.0 MeV Mott Polarimeter

V. Tyukin[1]

[1]Inst. of Nuclear Physics
JGU Mainz
Germany

Workshop on Polarized Sources, Targets, and Polarimetry
Jefferson Lab, in Newport News, VA, USA
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Outline

Outline

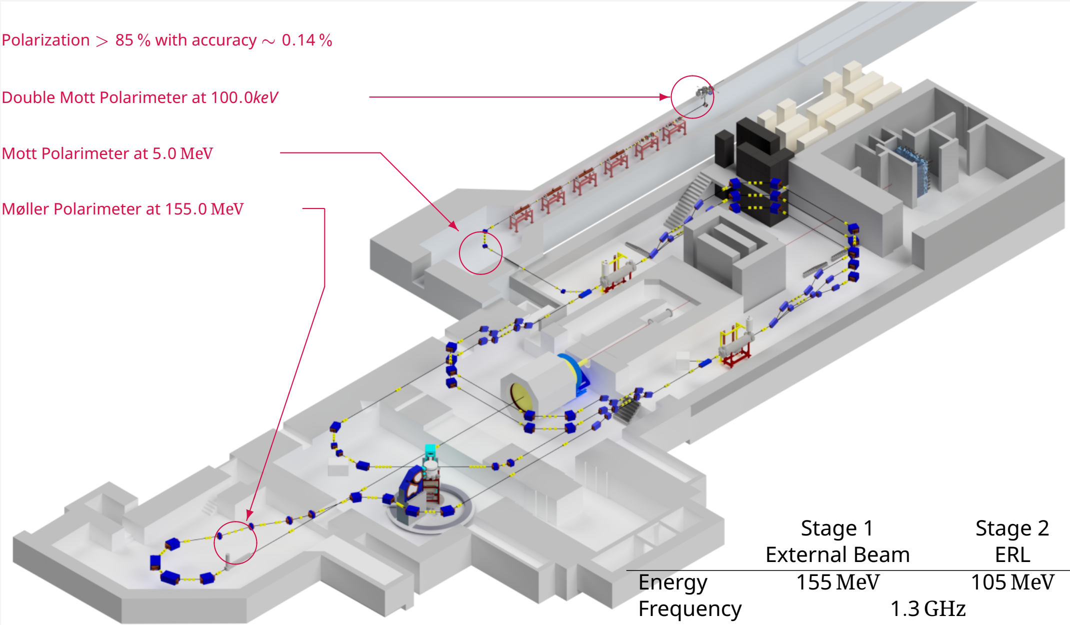
MESA accelerator

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 mm mrad	$<$ 1.0 mm mrad

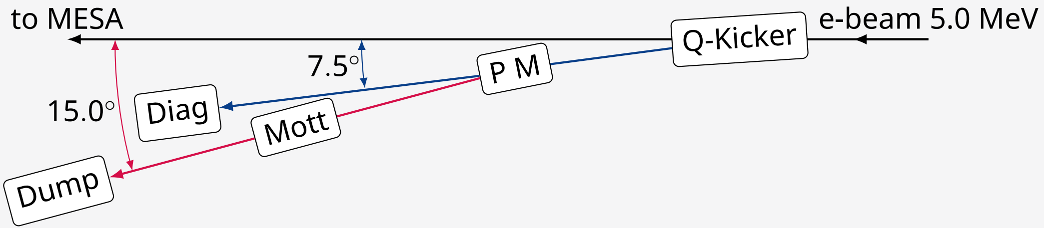
Beam polarimetry for the P2 Experiment @ MESA

- CW spin polarized electron beam, polarization $\sim 85\,\%$, current $\sim 150\,\mu\mathrm{A}$, energy $\sim 155\,\mathrm{MeV}$
- Double Mott polarimeter at $100.0\,\mathrm{keV}$ with gold foil targets
  - originally developed by Prof. J. Keßler Mott polarimeter
  - measurements only in offline mode
  - currently in storage
- Mott polarimeter at $5.0\,\mathrm{MeV}$ with gold foil targets
  - originally developed at JLAB (currently R. Thapa)
  - measurements in quasi-online mode
- Møller polarimeter at $55.0 - 155.0\,\mathrm{MeV}$ with hydrogen or iron target.
  - with polarized atomic hydrogen target, online mode
  - with polarized iron target, offline mode
  - the same target solenoid and the same detector system (currently M. Kravchenko)
- The goals at MESA: $P_{\text{Mott, double}} = P_{\text{Mott, 5.0 MeV}} = P_{\text{Møller},\mathrm{H}} = P_{\text{Møller},\mathrm{Fe}}$
- Accuracy $\Delta P < 0.5\%$

Why kicker is needed at 5.0 MeV beam line ?

- The problem is that during a run it is undesirable to switch off or change the 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

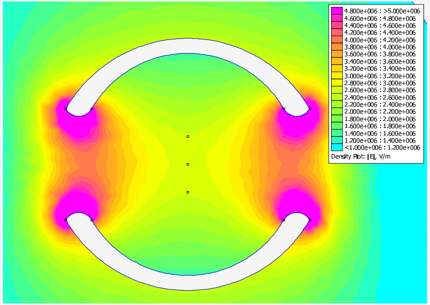
Arrangement of 5.0 MeV beam distribution unit.



- Q-Kicker: the extraction from the main beam-line with first stage 7.5 ° is provided by the kicker iron free magnet.
- Q-Kicker: duty factor 0.01, rise time 0.1 ms.
- Q-Kicker: rigidity: $\rho B = \beta \gamma \frac{m c}{q} = 0.018\,\mathrm{T\,m}$ is required for $\rho = 2.0\,\mathrm{m}$ magnetic field $B = 0.009\,\mathrm{T}$ or electrostatic field $E = 2.7\,\frac{\mathrm{MeV}}{\mathrm{m}}$
- 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)
- Beam line diameter (inside) $\sim 35.0\,\mathrm{mm}$

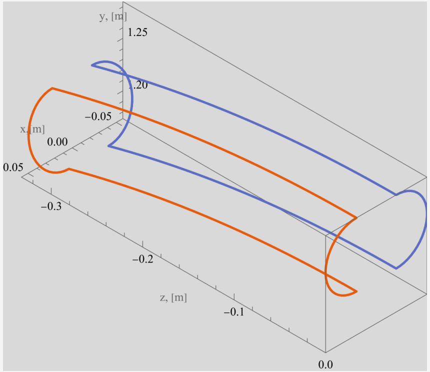
Outline

Electrostatic field and magnetic field kickers



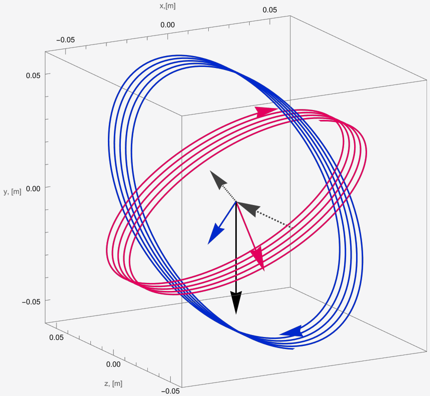
Electrostatic kicker

- 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)

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

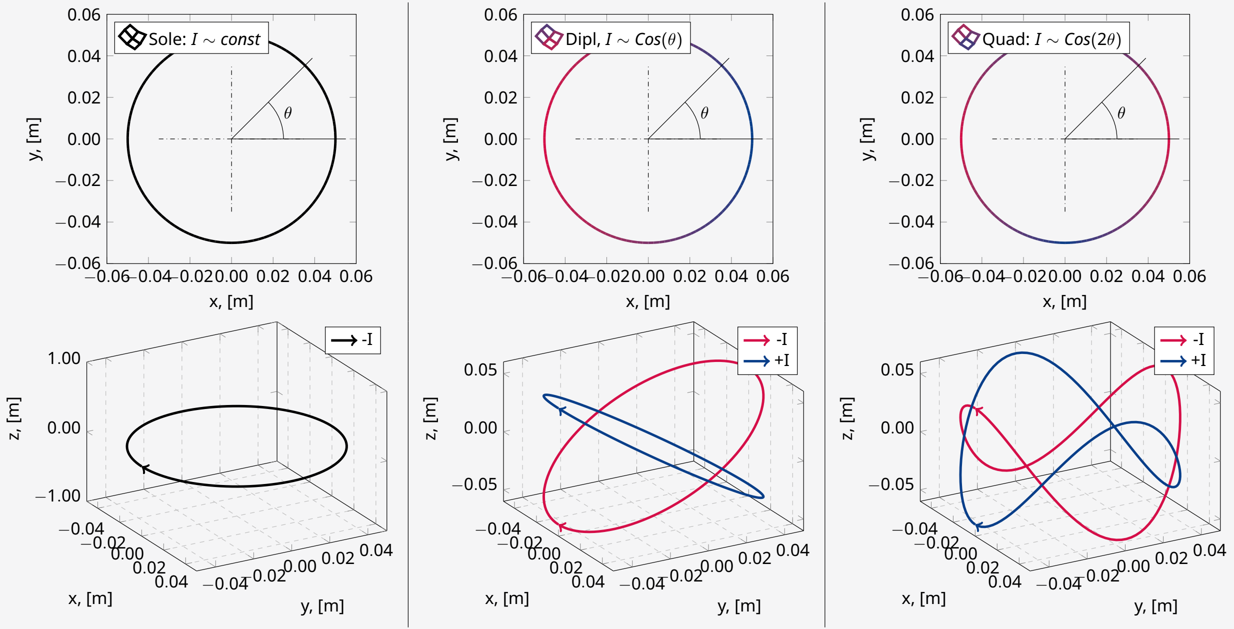


Canted Cosine Theta (CCT)

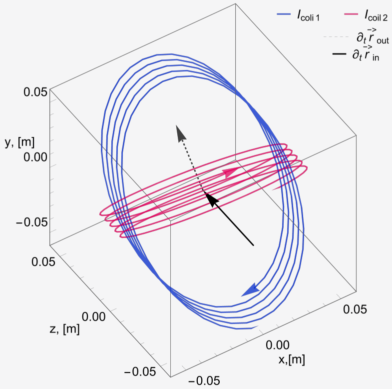
- proposed in 1970
- two loops induce B field red and blue lines, black line points to summarized B, dashed lines to moving electron

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

CCT as solenoid, dipole and quadrupole fields



Switch to another configuration



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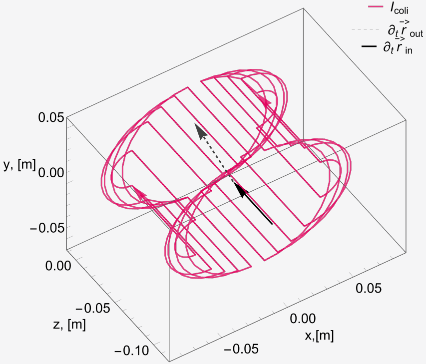
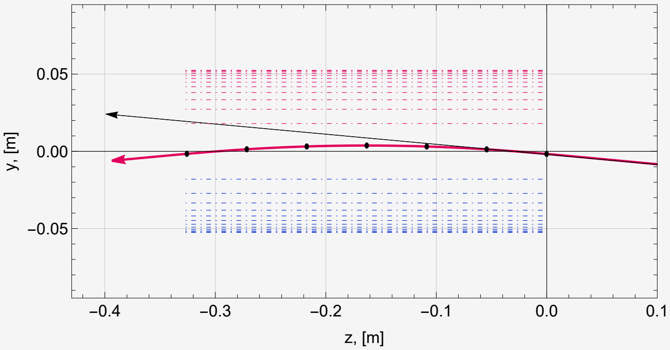


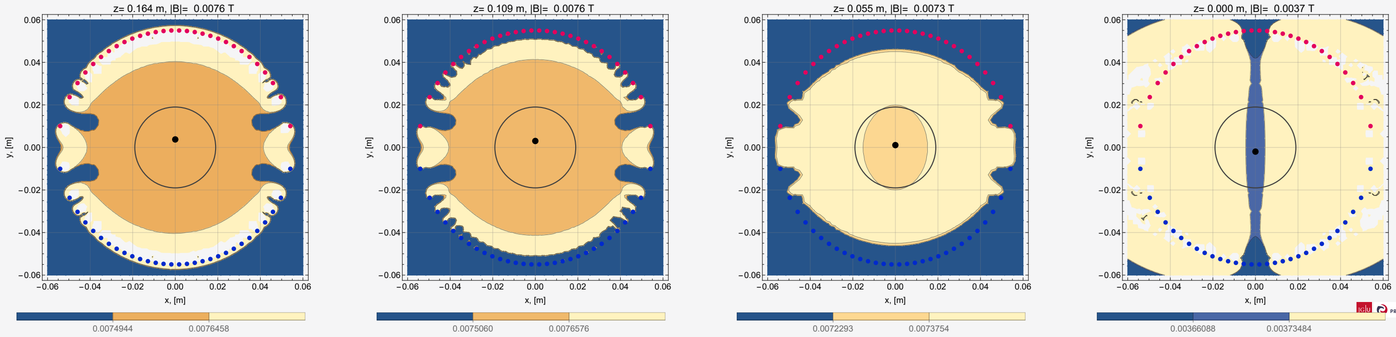
- ✗
- two power supplies necessary
- difficulties in production
- split in two parts not possible

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

Good field region

- 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 ±1% are marked as points in the upper right picture.
- The black circle shows the vacuum tube.
- Mathematica Wolfram, version 13.2





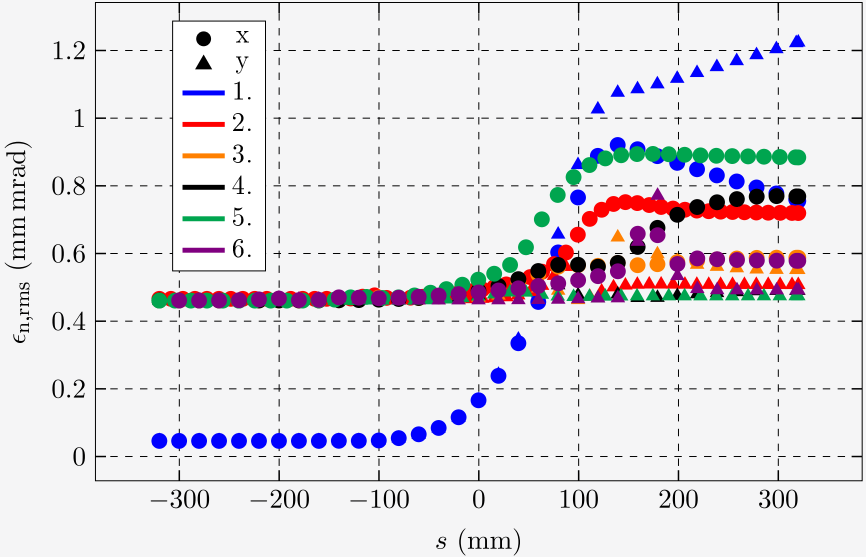
Transfer matrix BSC and CCT cases

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

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

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

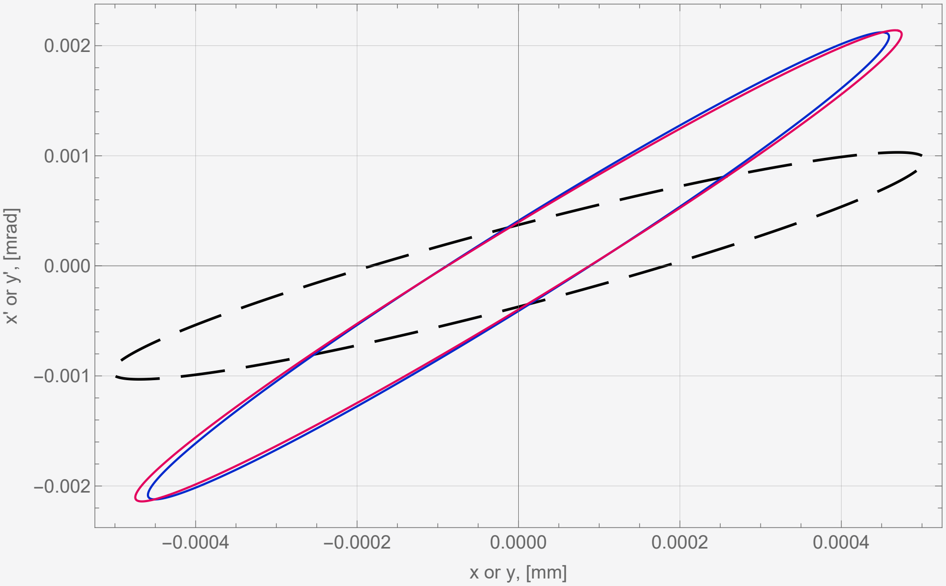
Beam tracking and emittance



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

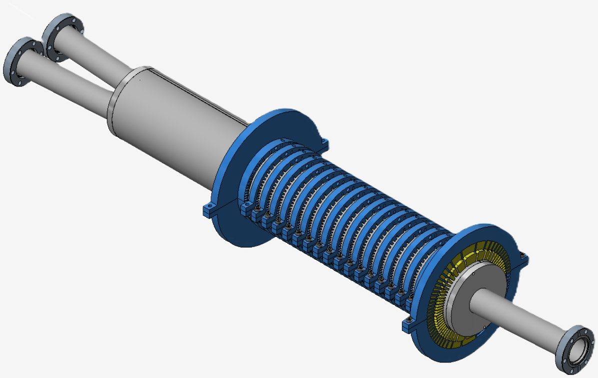
Beam tracking and emittance

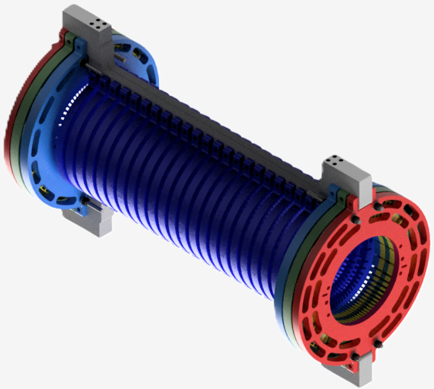


- Beam tracking inside of the kicker
- Black dashed line input emittance
- Red and blue lines emittances after kicker

Outline

The vacuum chamber and coil as 3D Model

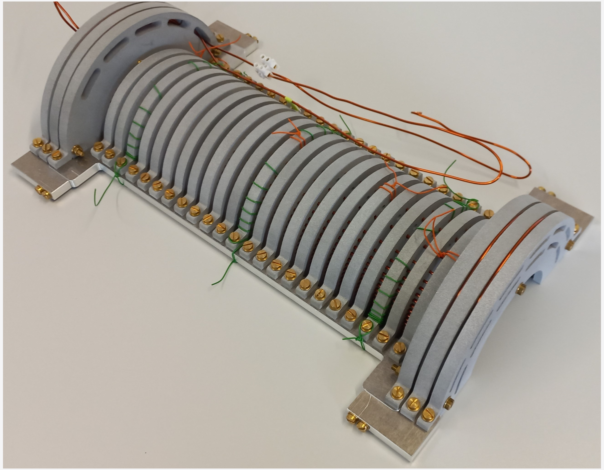


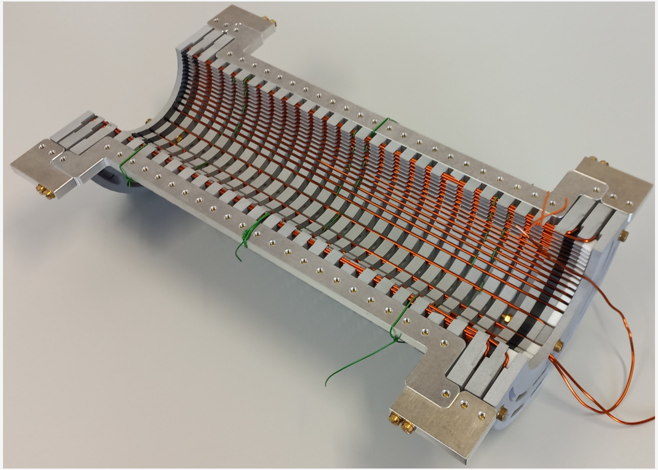


- Vacuum chamber and coil
- The total length $\sim 1000\,\mathrm{mm}$

- Coil in details
- The total length $\sim 500\,\mathrm{mm}$

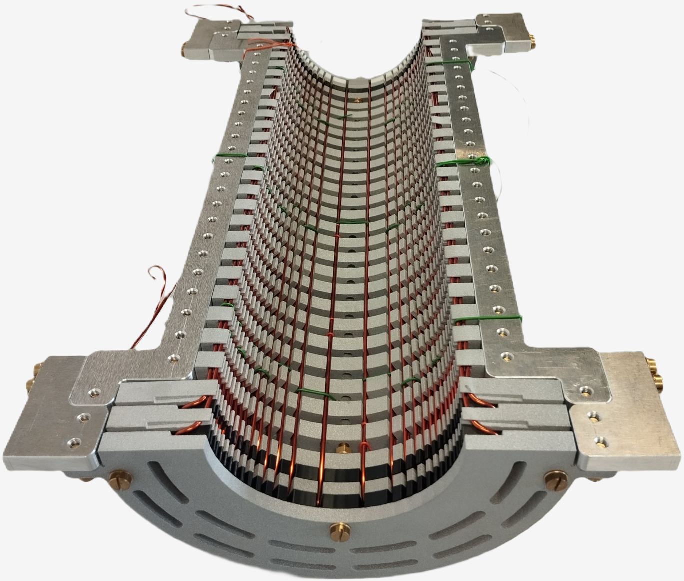
The coil: 3D-Print





- 3D Print from Alumid of holders. View outside
- View inside

The coil: parameters



- Detail site view of half coil
- Dimensions LxBxH $\sim 500x250x125\,\mathrm{mm}$
- Working current $\sim 22.5\,\mathrm{A}$
- Power consumption $\sim 120.0\,\mathrm{W}$
- Bending angle $7.50\,^\circ$
- Spin is bent to $7.59\,^\circ$
- Inductance $L_{coil} \sim 400.0\,\mu\mathrm{H}$
- Second half of coil in production
- General test expected 2024

Outline

Summary and outlook

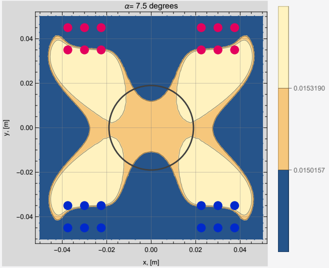
- Online with duty circle 0.01 measurement of beam polarization at MESA seems to be possible
- CCT 5.0 MeV kicker's coils and chamber in fabrication
- 5.0 MeV bending unit and polarimeter on production
- For references see Talk PSTP-2022 V. Tyukin, K. Aulenbacher, C. Matejcek, *PoS* **2023**, *PSTP2022*, 026

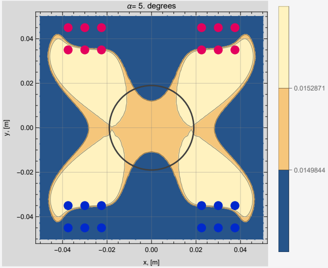
Thank for support

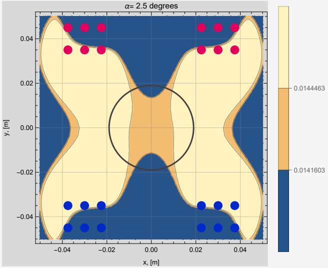
Thank you for your attention!

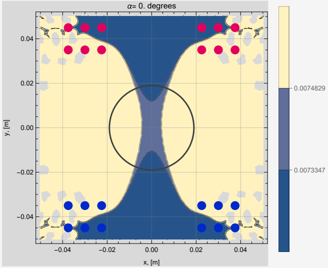
Outline

Good field regions for BSC kicker



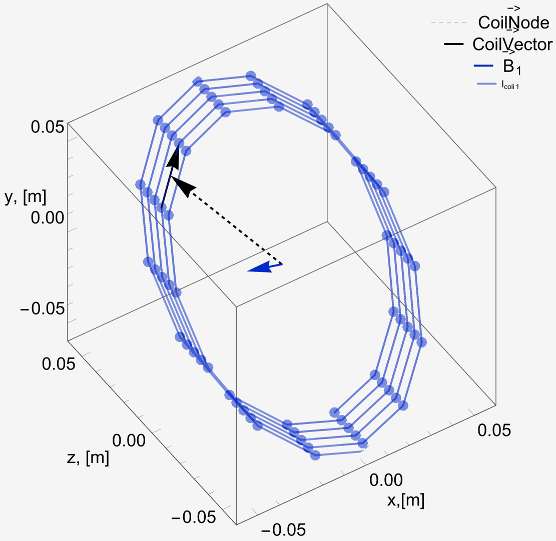






Outline

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 *)
```

$$B0[\{x1\_, y1\_, z1\_\}] = \frac{\mu_0\, I_{coil}}{4\pi} \sum_{n=1}^{nsum} \frac{\overrightarrow{CoilVector}[\![n]\!] \times \left(\{x1, y1, z1\} - \overrightarrow{CoilKnode}[\![n]\!]\right)}{Norm\left[\left(\{x1, y1, z1\} - \overrightarrow{CoilKnode}[\![n]\!]\right)\right]^3};$$

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

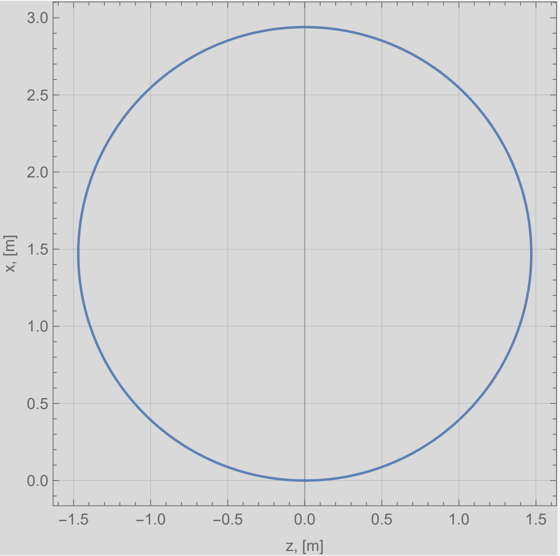
solution = NDSolve[Join[
(löse Diff··· / verknüpfe)

$$\text{Thread}\left[\partial_{t,t}\, r[t] == -\frac{q}{\gamma\, m\, c}\left(\frac{1}{c}\, E0[r[t]] + \partial_t\, r[t] \times B0[r[t]]\right)\right],$$
(fädle auf)

$$\text{Thread}\left[\partial_t\, sp[t] == -\frac{q}{\gamma\, m\, c}\, sp[t] \times \left((1 + a\gamma)\, B0[r[t]] - \frac{a\gamma^2}{\gamma+1}\left(\partial_t\, r[t] \times B0[r[t]]\right)\partial_t\, r[t] - \gamma\left(a + \frac{1}{(\gamma+1)}\right) r[t] \times E0[r[t]]\right)\right],$$
(fädle auf)

```
    Thread[ r[0] == {0.0, sr, Lfree} ],                          (* {x[0]==0.`,y[0]==1.25`,z[0]==1.`} *)
    Thread[ Evaluate[∂t r[t] /. t → 0] == {0.0, 0.0, -β} ],      (* {x′[0]==0.`,y′[0]==0.`,z′[0]== -β} *)
    Thread[ sp[0] == {0, 0, 1}] ],                               (* {spx[0]==0, spy[0]==0, spz[0]==1} *)
  {x, y, z, spx, spy, spz}, {t, itime} ];                        (* simultaniosly solution of moving and BMT equations *)
```
(fädle auf; fädle auf / werte aus; fädle auf)

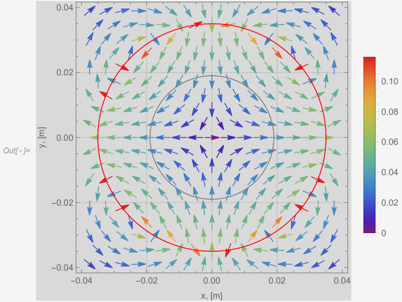
Mathematica Wolfram III. Check on magic energy



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

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



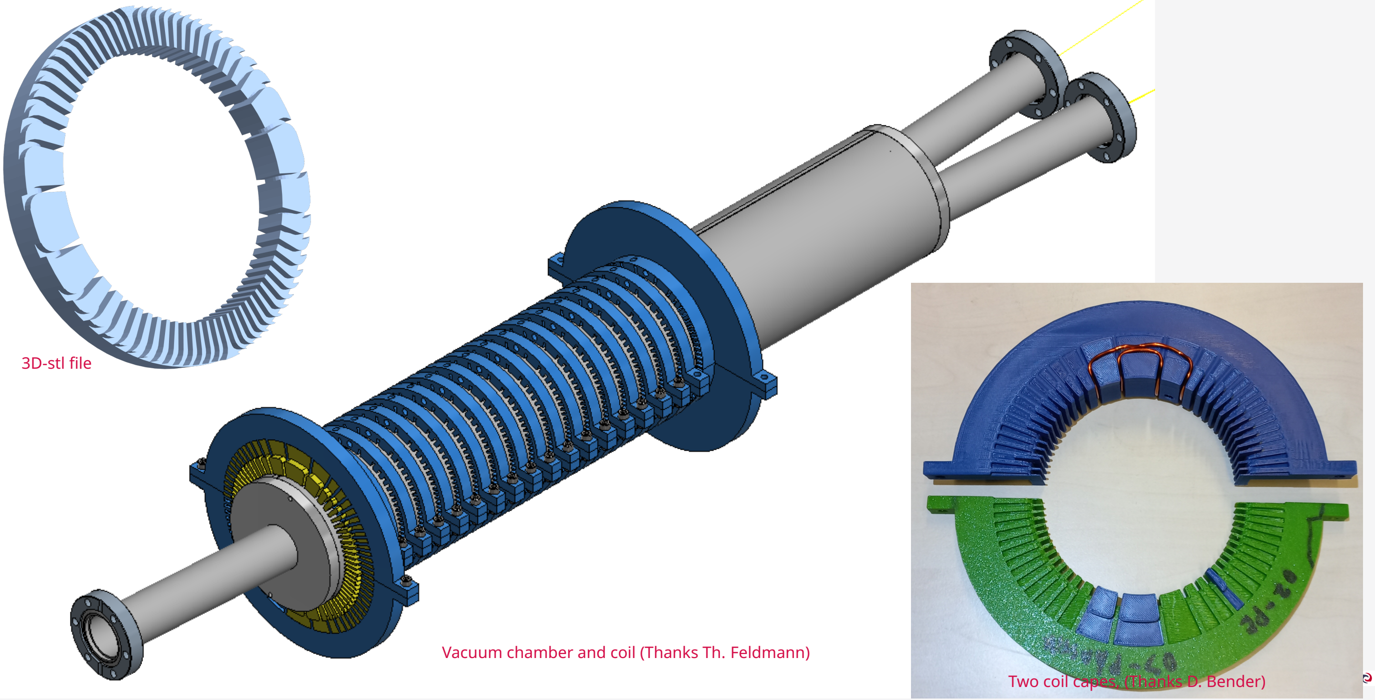
- due to very good field as quadrupole for electron separation at atomic hydrogen target

- something else

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 $B = 0.009\,\mathrm{T}$
- electrostatic kicker with $\rho = 2.0\,\mathrm{m}$ requires $E = 2.7\,\frac{\mathrm{MeV}}{\mathrm{m}}$

The previously design of 5.0 MeV kicker’s chamber and coils



3D-stl file

Vacuum chamber and coil (Thanks Th. Feldmann)

Two coil capes. (Thanks D. Bender)