Precursor Experiment at COSY

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Contents

Proof of principle experiment using COSY
(“Precursor experiment”)

Highest sensitivity will be achieved with a new type of machine:

- An **electrostatic circular storage** ring, where
  - centripetal force produced primarily by electric fields.
  - E field couples to EDM and provides required sensitivity ($< 10^{-28}\,\mathrm{e\,cm}$).
  - In this environment, magnetic fields mean evil (since μ is large).

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- In magnetic machine, particle spins (deuterons, protons) precess about stable spin axis ($\simeq$ direction of magnetic fields in dipole magnets).
- Use RF device operating on some harmonic of the spin-precession frequency:
  - $\Rightarrow$ *Phase lock* between spin precession and device RF.
  - $\Rightarrow$ Allows one to accumulate EDM effect as function of time in cycle (~ 1000 s).

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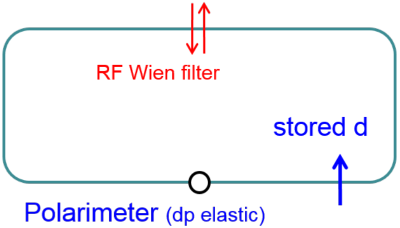
Goal of proof-of-principle experiment:

Show that storage ring (COSY) can be used for a first direct EDM measurement.

RF Wien filter

A couple more aspects about the technique:

- RF Wien filter ($\vec{E} \times \vec{B}$) avoids coherent betatron oscillations in the beam:
  - Lorentz force $\vec{F}_L = q(\vec{E} + \vec{v} \times \vec{B}) \simeq 0$.
  - EDM measurement mode: $\vec{B} = (0, B_y, 0)$ and $\vec{E} = (E_x, 0, 0)$.



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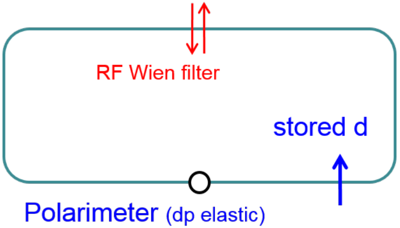

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- If $d \neq 0 \Rightarrow$ *accumulation* of vertical polarization P_y, during spin coherence time $\tau_{SCT} \sim 1000\,\mathrm{s}$.

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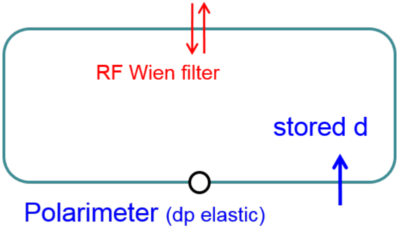

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Statistical sensitivity:

- in the range 10^{-23} to 10^{-24} e cm for $d(deuteron)$ possible.
- Systematic effects: Alignment of magnetic elements, magnet imperfections, imperfections of RF-Wien filter, etc.

Buildup of $P_y(t)$ using RF Wien filter for deuterons

Model calculation at beam momentum $p_d = 970\,\text{MeV/c}$:

- $G = -0.143$, $\gamma = 1.126$, $f_s = |f_{\text{rev}}(\gamma G + K_{(=0)})| = 120.765\,\text{kHz}$
- Length of device: $L_{\text{WF}} = 1.55\,\text{m}$ [1].
- Assumed deuteron EDM: $d = 10^{-20}\,\text{e cm}$.
- Electric RF field: $1000 \times E_{\text{WF}} = 2.145 \times 10^6\,\text{MV/m}$ [1].

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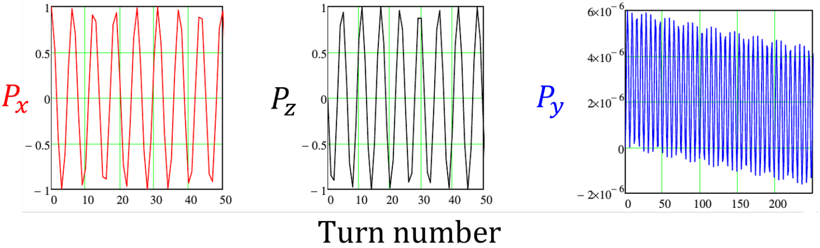

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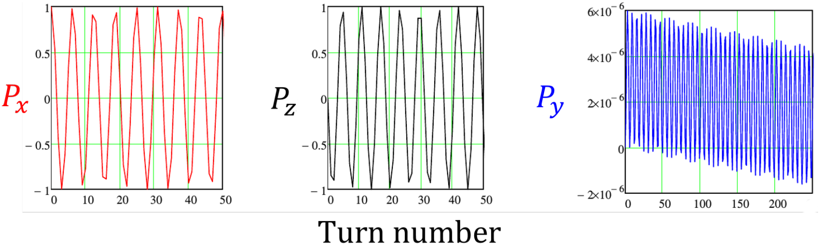

EDM effect accumulates in $P_y \propto d$ [2, 3].

Waveguide RF Wien filter

Device developed at IKP in cooperation between:

- **RWTH Aachen, Institute of High Frequency Technology:** Dirk Heberling, Dominik Hölscher, and PhD Student Jamal Slim
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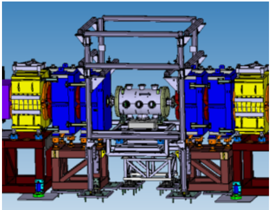

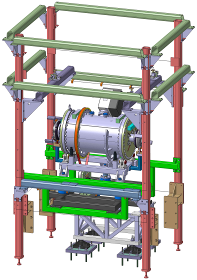

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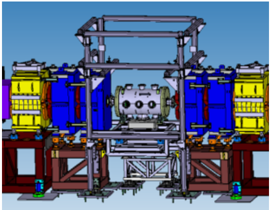
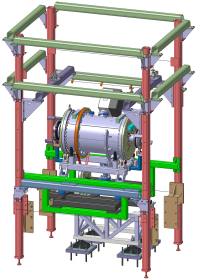
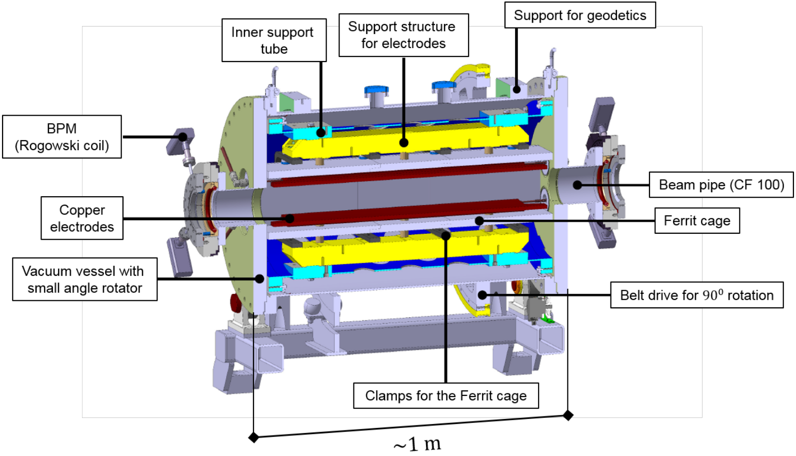




Device will be installed in PAX low-β section at COSY.

$\Rightarrow$ Allows for systematic studies with respect to divergence of beam.

Features of the waveguide RF Wien filter



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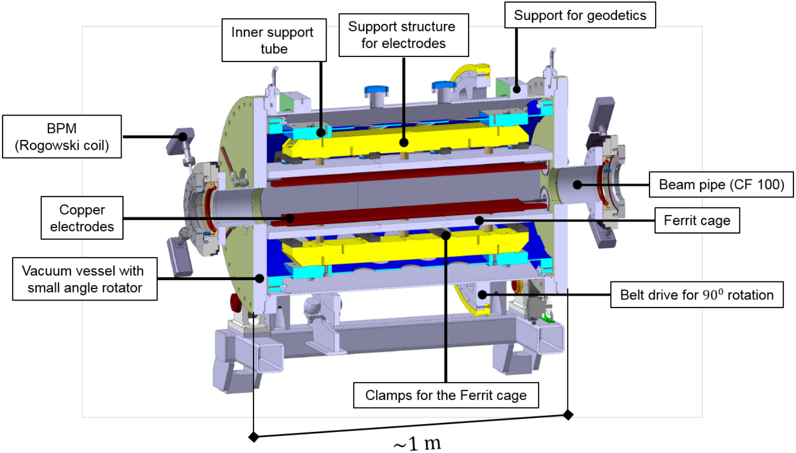
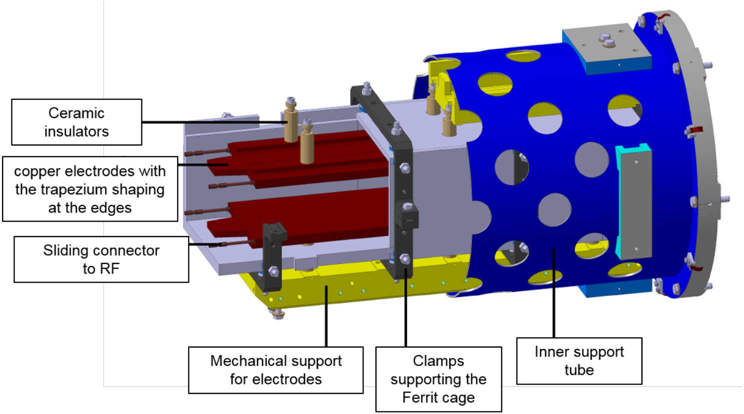


Aim was to build the best possible device, with respect to

- electromagnetic performance [1] and mechanical tolerances [4].
- Excellent cooperation with RWTH Aachen University and ZEA-Jülich

Internal structure



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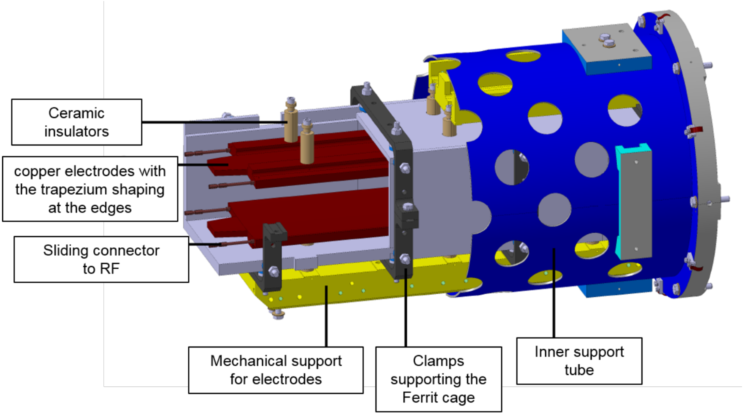


Assembly completed,

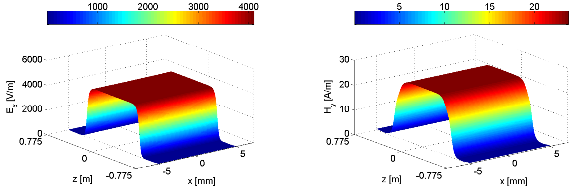
including precision alignment in clean room.

Electromagnetic field simulations [1]

Full-wave simulations

- using CST Microwave Studio[a].

[a] Computer Simulation Technology AG, Darmstadt, Germany, http://www.cst.com



At an input power of 1 kW, magnetic and electric field integrals are ($\ell = 1.550\,\mathrm{m}$):

$$\int_{-\ell/2}^{\ell/2} \vec{B} dz = \begin{pmatrix} 2.73 \times 10^{-9} \\ \mathbf{2.72 \times 10^{-2}} \\ 6.96 \times 10^{-7} \end{pmatrix} \mathrm{T\,mm}\,, \quad \int_{-\ell/2}^{\ell/2} \vec{E} dz = \begin{pmatrix} \mathbf{3324.577} \\ 0.018 \\ 0.006 \end{pmatrix} \mathrm{V} \quad (1)$$

Required frequencies of RF Wien filter

Resonance condition:

$$f_{\mathrm{WF}} = f_{\mathrm{rev}} \left(\gamma G \pm K \right) , k \in \mathbb{Z}. \tag{2}$$

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Wien filter frequencies f_{WF}

- **Deuterons** at $T_d = 236.0\,\mathrm{MeV}$ ($970.0\,\mathrm{MeV/c}$):

			harmonic K [kHz]				
β	G	γ	**−2**	**−1**	0	**1**	**2**
0.459	−0.143	1.126	**−1621.2**	**−871.0**	−120.8	**629.4**	**1379.6**

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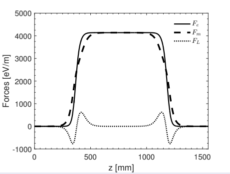
Accomplished design goal of wave guide RF Wien filter and driving circuit [1]:

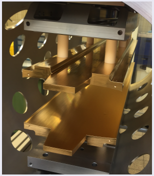
Provide a number of operational frequencies for p and d between 0 to 2 MHz.

Lorentz force compensation [1]

Integral Lorentz force is of order of $-3\,\mathrm{eV/m}$:

- Electric force F_e, magnetic force F_m, and Lorentz force F_L inside RF Wien filter.
- Trapezoid-shaped electrodes determine crossing of electric and magnetic forces.





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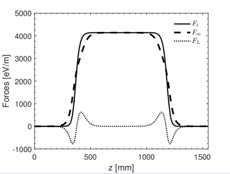
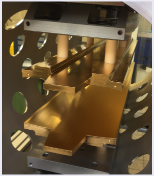




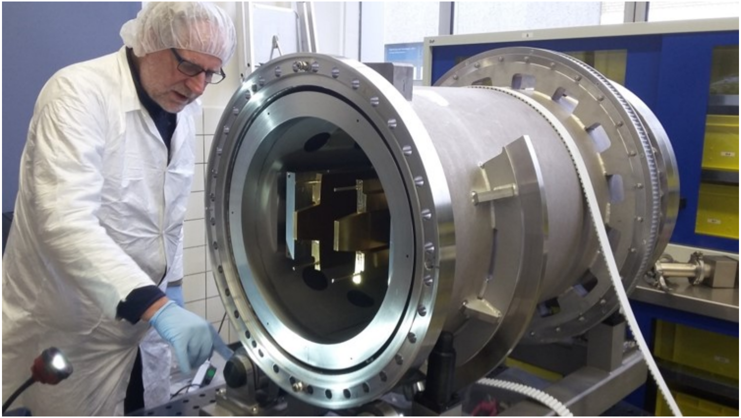
Lorentz force

$$\vec{F}_\mathrm{L} = q\left(\vec{E} + \vec{v} \times \vec{B}\right) , \tag{3}$$

- particle charge q, velocity vector $\vec{v} = c(0, 0, \beta)$, fields $\vec{E} = (E_x, E_y, E_z)$ and $\vec{B} = \mu_0(H_x, H_y, H_z)$, μ_0 vacuum permeability.
- For vanishing Lorentz force $\vec{F}_\mathrm{L} = 0$, field quotient Z_q given by

$$E_x = -c \cdot \beta \cdot \mu_0 \cdot H_y \quad \Rightarrow \quad \boxed{Z_q = -\frac{E_x}{H_y} = c \cdot \beta \cdot \mu_0 \approx 173\ \Omega} . \tag{4}$$

Assembly of RF Wien filter



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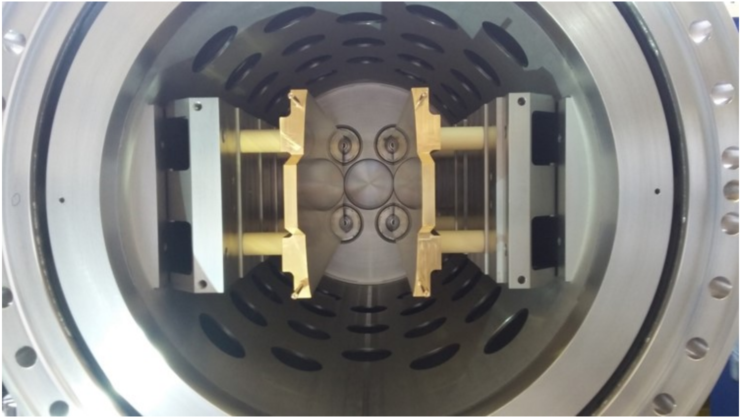

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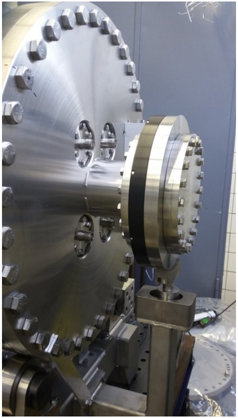

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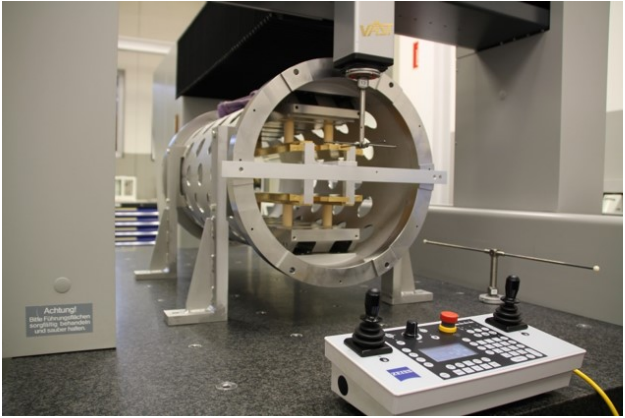

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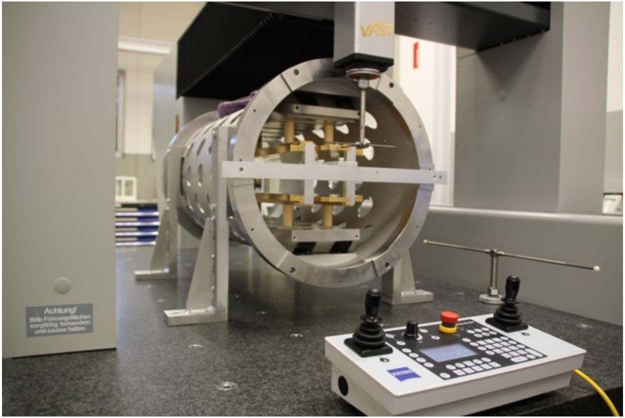
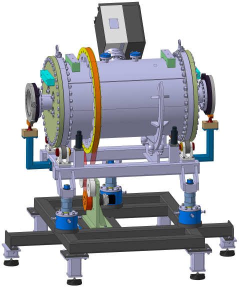


Device moved from ZEA to COSY hall for tests of driving circuit.

Clean room at COSY hall

Commissioning of experimental setup:

- Test of vessel rotation under vacuum.
- RF tests with driving circuit.
- Control system.



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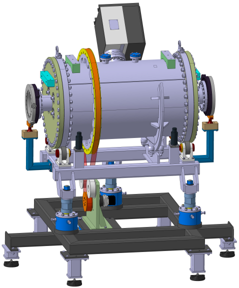
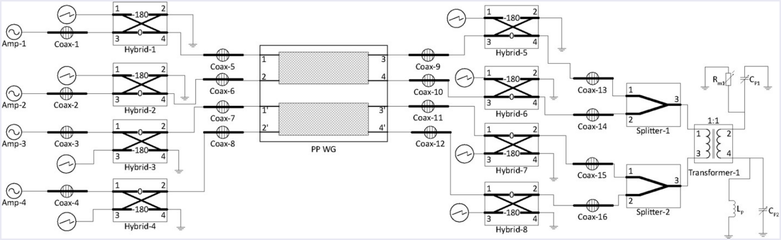


RF Wien filter installation at COSY will take place in April 2017.

Driving circuit

Realization as strip line with load resistor and tunable elements (L's and C's):

- Design layout using four separate 1 kW power amplifiers.



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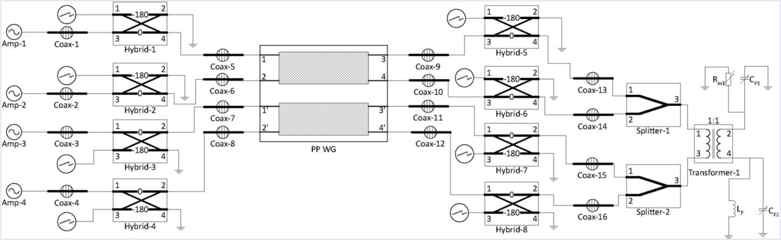

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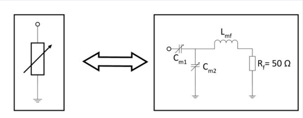

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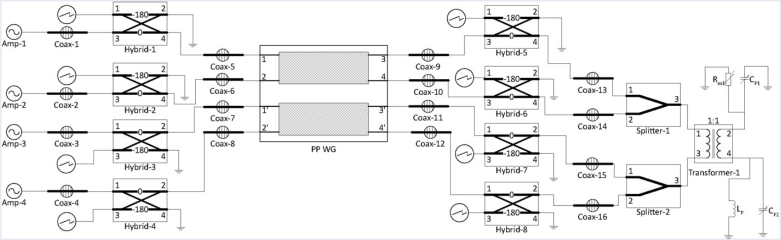

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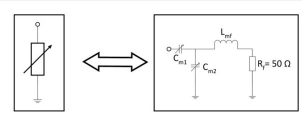

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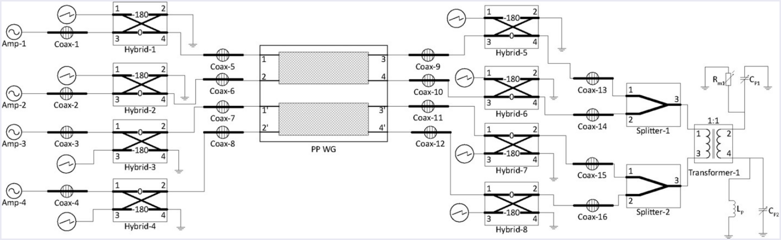

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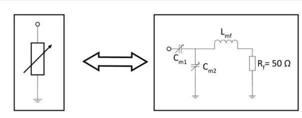

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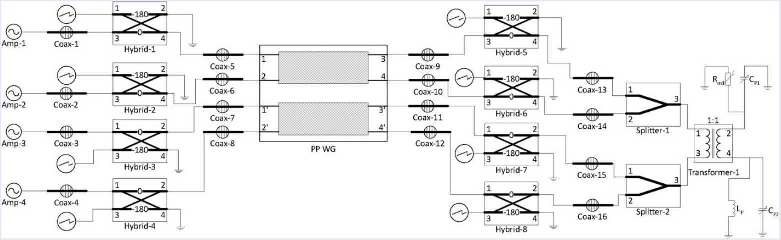

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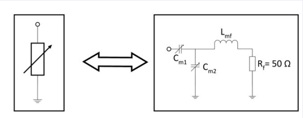

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- Start with input power of $4 \times 1\,\text{kW}$: $\int B_z \text{d}z = 0.109\,\text{T mm}$ [see Eq. (1)].
- Upgrade later to $4 \times 2\,\text{kW}$: $\int B_z \text{d}z = 0.218\,\text{T mm}$.

Toolbox elements for precursor experiment I

Buildup of transverse polarization component due to EDM:

- **Wanted** EDM effect is produced by vertical magnetic field B_y of dipole magnets via $\vec{\beta} \times \vec{B}$ term in T-BMT equation.

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Elements available to study systematics in precursor RF Wien filter experiment:

- Two harmonics $K = \pm 1$, at 630 and 871 kHz available from beginning.

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- Development of orbit-distortion-free helical dipole magnets to map magnetic ring imperfections.

References

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