Pulsed quadrupoles for novel accelerators.

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ARES / SINBAD

- Catch highly divergent beams from plasma accelerators & focus SC dominated bunches into plasma (avoid ε-growth)

Current solutions:

- \(\rightarrow\) permanent magnets
  - Fixed gradients / homogeneity issues
  - Radiation-induced demagnetization

- \(\rightarrow\) plasma lenses
  - Transverse homogeneity issues
  - Limited applicability due to plasma wakefields
Pulsed quadrupoles

- Normal conducting air-core coils with \( \cos(2\theta) \)-shape (right figure)
- GSI-development for heavy ion beam final focus (75 T/m in 100mm beamline aperture @400 kA)
- High pulsed currents (>10kA)
- Passive cooling sufficient due to short pulse durations
- High current ramp rates
- Conductors compound of litz wires for homogeneous current distribution
- Target: 200 T/m, 20 mm length (SINBAD PM quadrupole triplet consideration)
Preliminary simulations

→ First 3D model conductor dimensions:

<table>
<thead>
<tr>
<th>Inner diameter</th>
<th>16mm</th>
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<tbody>
<tr>
<td>Thickness</td>
<td>3mm</td>
</tr>
<tr>
<td>Straight section length</td>
<td>20mm</td>
</tr>
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Electrical current scaling with conductor geometry
3D simulation @ 28 kA

- At 28 kA a homogeneous gradient of \( \frac{T}{m} \approx 197 \) is reached in the GFR.

- Conductor aperture 16 mm in diameter - higher gradients by:
  - decreasing aperture
  - increasing current
  - adding magnetic shield (?)

![3D simulation diagram]
3D simulation @ 28 kA

Good field region (GFR) quality requirements met within inner radius of ~4 mm (<$1 \cdot 10^{-2}$ threshold line in red)
Effective length

Calculation of the effective length of the quadrupole in z direction

\[ L_{eff} = \int \frac{G \, dz}{G_{center}} = 33.8 \text{mm} \]
Conductor heating

Heat loss in conductor:

\[ P_V = \frac{\rho}{A} \cdot l \cdot J^2 \cdot A^2 = \rho \cdot l \cdot J \cdot I \]

\[ \text{\( \Rightarrow \) trade-off between \( I \) & \( J \)} \]

Heat transport in conductor:

\[ \dot{Q} = \lambda \cdot A \cdot \frac{T_{\text{hot}} - T_{\text{cold}}}{l} \]

\[ \rho \cdot l \cdot J^2 \approx \lambda \cdot \frac{T_{\text{hot}} - T_{\text{cold}}}{l} \]

\[ \text{\( \Rightarrow \) T only depends on J} \]

(\( \leftrightarrow \) conductor cross section)
For assumed parameters \( R=8\,\text{mm}, d=3\,\text{mm} \) of \( A=27\,\text{mm}^2, \, l=0.16\,\text{m}, \, \rho=1.7\times10^{-2}\,\Omega\,\text{mm}^2/\text{m} \), 28 kA, 10 Hz and \textbf{max. 10 W} loss allows:

\[ T \approx 50\,\mu\text{s} \rightarrow \sim25\,\mu\text{s} \text{ pulse length maximum} \]
Power supply circuit

- Recirculation of energy
- Bipolar capacitor
- $L_{\text{dummy}} \gg L_{\text{quadrupole}}$
  $\rightarrow$ Reduced dummy switch power
- Energy saving $\sim$80%
Conclusion

> Proposal of **pulsed quadrupoles** for highly divergent beams into & out of plasma accelerators (e.g. SINBAD, FLASHForward, LUX)

> Simulations show **feasibility of ~200 T/m** in compact setup

> Full gradient electronics components commercially available

> If **funding & engineering manpower** is commited:

  - Low current **prototype (≤ 1 kA) could be built & tested at PITZ** (test electronics & beamline position available)
  - Learn about mechanical assembly & stability ( & e.g. noise…)
  - Test accuracy of simulations
  - Prove beam stability
Thank you for your attention!
30kA electronics

Needs for 30 kA pulses:

- ~ 5 kV
- ~ 10 µF
- Power switch

PT85QWx45
Thyristor
DYNEX (UK)
4.5 kV
~37 kA
+ Diode

TDI1-50k/16
Pseudospark switch
Pulsed Technology (RU)
25 kV
70 kA