Plasma devices: plasma dechirper and plasma lens

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on behalf of SPARC_LAB collaboration
• **Active plasma lens**
  o focusing with the current magnetic filed
  o experimental setups
  o emittance preservation in APL

• **Plasma based dechirper**
  o self-induced dechirping wakefield
  o capillary and gas jet setups
  o experimental results & standing questions

• **Conclusions**
Active plasma lens
Discharge-current inside gas-filled capillary

✓ The gas is used as a conductor, to create a current
✓ An azimuthal field, created by the current, radially grows inside of the current and decreases outside of it
✓ Capillary keeps the gas and thus the current confined

Advantages

✓ Cylindrical symmetry in focusing (~ solenoids)
✓ Favorable focusing strength $K \sim 1/\gamma$ (~ quadrupoles)
✓ Large focusing gradient $\sim kT/m$
✓ Tunability by adjusting the current amplitude

Experimental setup

SPARC APL setup

EOS
PMQ1
Capillary
PMQ2
THz

Transverse diagnostics
Longitudinal diagnostics

Inner view of the interaction chamber


CLEAR APL setup

**Plasma lens experimental setup**

**BELLA APL setup**


**MaMi APL setup**

First APL experiments results

SPARC APL results

Active plasma lens

Discharge current

Passive plasma lens

SPARC APL results

BELLA APL results

The lens proved to be capable to focus the beam, however emittance deterioration was observed (e.g. at SPARC 1.0 to 3.6 mm•mrad)

Beam quality dependencies:

✓ current distribution → non-linear focusing (aberrations at the edges)
✓ passive plasma lens effects
✓ size of the beam at the injection into the lens


Passive plasma lens effects

Passive plasma lens regimes

Interaction with plasma:

✓ there are two regimes for the passive plasma lens
✓ passive plasma lens is significantly weaker than the APL (during the experiments at SPARC ~250 T/m for APL while for passive lens only 30 T/m)
✓ most of the emittance deterioration happens under condition $k_p \sigma_z \sim 1$

Current distribution inside the capillary

Non uniform distribution of the current leads to a non linear gradient of the magnetic field

\[ J(r) = \sigma E \propto T_e^{3/2} \]
\[ B_\varphi(r) = \mu_0 r^{-1} \int_0^r J(r') r' \, dr' \]


The peak current was increased from ~90 A to ~220 A, which extended a linear gradient area of the capillary.

- Better ionization of the H2 led to a better distribution of the current
- Increased linear part of the magnetic field gradient
- The emittance was preserved (0.8 → 0.9 mm•mrad)
- Improved minimum spot size (21 → 17 µm)

Use of the heavier atoms improved the distribution of the current density.

Mapping of the magnetic field was done.

Emittance preservation inside the APL

- There was observed the dependence of the emittance on the size of the beam at the entrance to the capillary.
- For smaller sizes (higher density) of the incoming beam the interaction with the plasma starts to affect the incoming beam quality.

**Two conflicting requirements**

- Smaller beam size is needed to avoid aberration effects from non-linear mag. field gradient.
- Larger incoming beam size is preferable to avoid any interaction with the plasma.

Active plasma lens: summary

✓ it works!, it was demonstrated the APL can preserve the quality of the beam.

✓ it highly flexible, the change of the lens strength can be easily changed from 10s to 1000s T/m

To keep in mind about APL:

✓ emittance deterioration mostly caused by non-uniformity of the current density

✓ active plasma lens favors higher peak current, due to the better linearity of the resulting magnetic field/ proper choice of the gas for the plasma

✓ interaction with the plasma can cause some issues, even as severe as current profile

✓ low bunch densities ($n_b << n_p$) are preferable for preventing passive plasma lens effects
Plasma based “dechirper”
**Plasma dechirper, basic idea**

- **Longitudinal phase-space manipulation with the wakefield induced in plasma by the beam itself.**
  - The large gradient that plasma can sustain (~ GV/m) allows to imprint or remove large energy correlation (chirp) from the beam by means of relatively short structures (~ cm).

- **Large flexibility of the method, by varying parameters of the system:**
  - Plasma density (large density → large wake amplitude)
  - Beam density (large density → large wake amplitude)
  - Length of the plasma channel (cumulative effect)

- **Applications:**
  - Energy-chirp removal (“dechirper”) for PWFA, LWFA
  - Bunch compressors (dogleg/chicane beamlines)

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**Self-wakefield created by the chirped beam**

*Graph showing the energy and wakefield versus z (um).*

Plasma dechirper, experimental setup

SPARC plasma dechirper setup

- Capillary based setup with a discharge

Capillary setup with entrance screen
Plasma dechirper, experimental setup

Plasma dechirper, experimental results

Energy spread (plasma density)

Beam LPS at the injection

Beam parameters:
- $E=100$ MeV
- $Q=200$ pC
- $\sigma_{x,y} \approx 20(32) \mu$m
- $\sigma_z = 75 \mu$m (250 fs)
- $\varepsilon_{x,y} \approx 1.1(1.4) \mu$m

Initial energy spread $\sim 0.6 \%$

Dechirper

Final energy spread $\sim 0.1 \%$
Plasma dechirper, experimental results

Beam parameters:

- $E = 46\,\text{MeV}$
- $Q = 40\,\text{pC}$
- $\sigma_{x,y} = 40\,\mu\text{m}$
- $\tau = 300\,\text{fs (FWHM)}$
- $\varepsilon_{x,y} = 1.5\,\mu\text{m}$

Conclusions on Plasma Dechirper:

- it was demonstrated that Plasma dechirper can be used to manipulate the beam LPS
- the correlated energy spread was completely removed, leaving only uncorrelated part

To keep in mind about Plasma Dechirper:

- it can decrease the energy of the tail
- parameters of the Plasma Dechirper are interconnected and should be changed accordingly

\[
6 \times \sigma_z \leq \lambda_p/4 \quad \sigma_x = \sqrt{\frac{2}{\gamma}} \sqrt{\frac{\epsilon_n}{k_p}}
\]

- was not fully characterized yet (beam quality after the PD).
Thank You