Designing a plasma lens for the ILC

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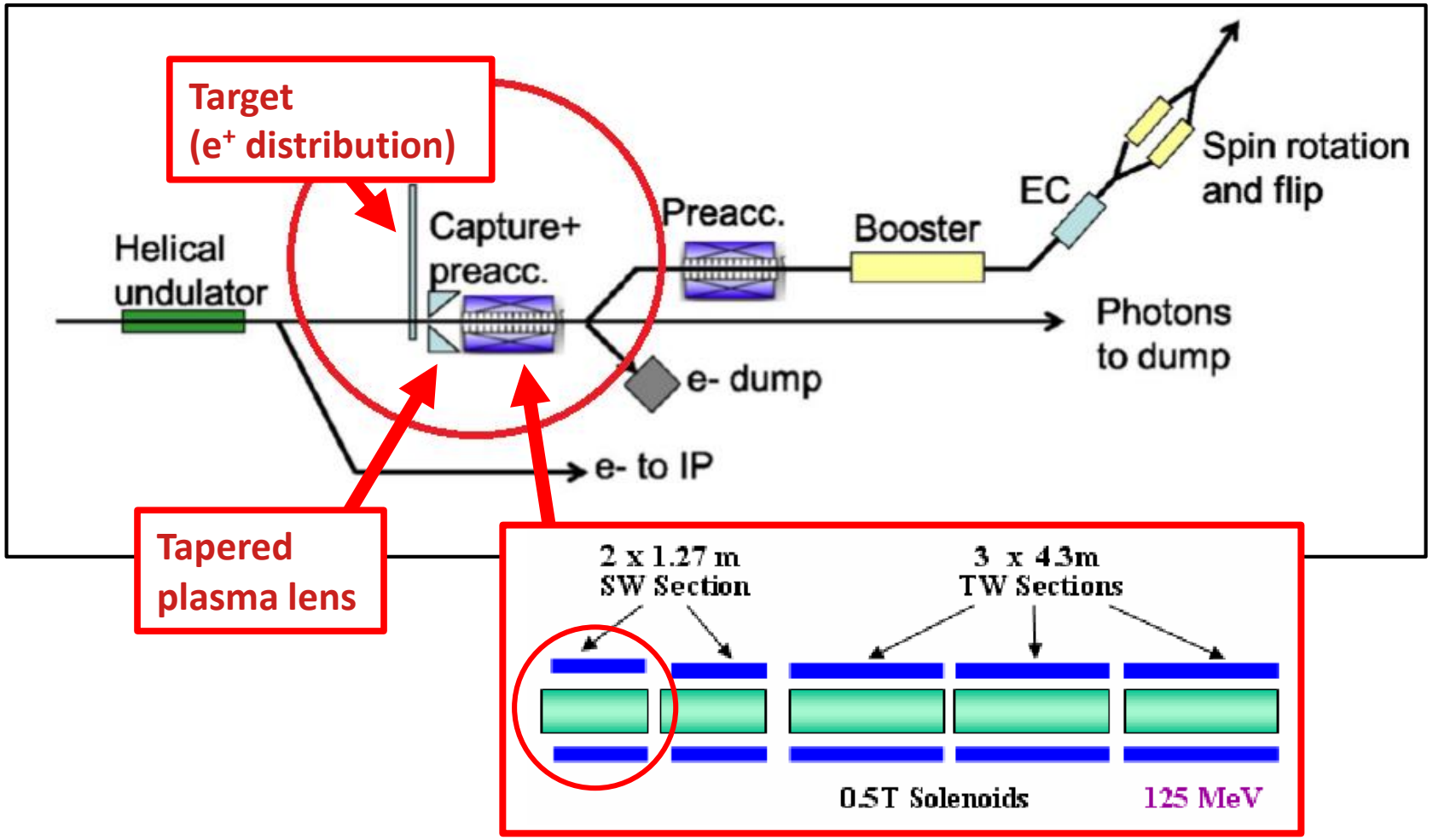
Overview

- Optical matching device

→ Our case: Match positrons behind undulator source

- Using common positron distribution for ILC e^+ source (priv. comm. M. Fukuda)
- All simulations based on ASTRA code (K. Flöttmann)
- Space Charge neglected!
- Goal: Alternative to quarter wave transformer

Components



Sources: 1) J.W. Wang. POSITRON INJECTOR ACCELERATOR AND RF SYSTEM FOR THE ILC*. 2007.
2) F Dietrich. Status of the undulator-based ILC positron source. 2019.

Damping Ring acceptances

- Energy acceptances
  → Longitudinal cut: ± 7 mm
  taken from M. Fukuda
- Other additional Cuts e.g. emittance cut
  → Future research

Positron Energy	5 GeV
Dynamic Aperture	<0.07 mrad
Energy Acceptance	0.75 %
Longitudinal Acceptances	3.4 x 37.5 cm-MeV
Longitudinal Emittance	0.75 x 33 % x mm

Source: M; Barish B; Buesser K Adolphsen, c; Barone. Technical Design Report | Volume 3.i: Accelerator RD. 2013.

Simulations

- Optimize e^+ yield after longitudinal cut
  - Scan parameters independently
  - → iterative process
- Practically limited electric current I_0
- → 3000 A and 5000 A

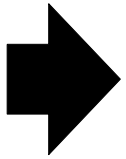
	symbol
Plasma lens length	z_{max}
Opening radius	R_0
Tapering order	n
Tapering strength	g
Plasma lens-standing wave tube distance	d
Electric current	I_0
SWT starting phase	φ_0

$$R(z) = R_0(1+gz)^n$$

Plasma lens radius along beam line

Optimization Results

	symbol	value	unit
Plasma lens length	z_{max}	6	cm
Opening radius	R_0	3.8	mm
Tapering order	n	1	1
Tapering strength	g	136	m^{-1}
PL-SWT distance	d	1	cm
Electric current	I_0	3000	A
SWT starting phase	φ_0	220	deg



After longitudinal cut (14 mm):
41.7 % of 42917 e^+

Optimum Stability

- Simulation with a deviation of ± 10 % of each ideal parameter:

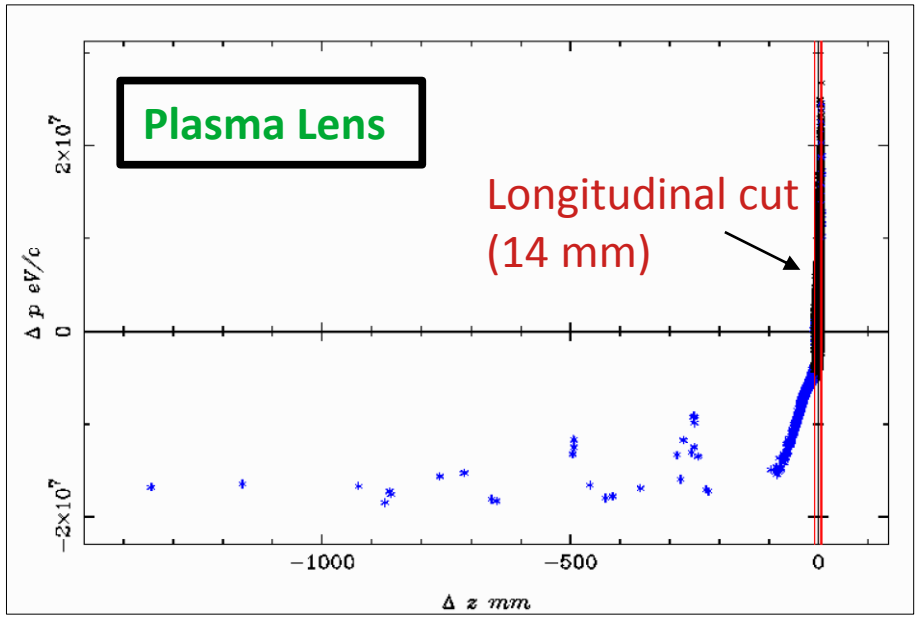
Stability	−10 % deviation	+10 % deviation
Distance PL-SWT	+0.2 % yield	−0.2 % yield
Plasma lens length	−0.3 % yield	−0.2 % yield
Phase	−0.5 % yield	−0.4 % yield
Tapering strength	−0.2 % yield	−0.3 % yield
Opening radius	−0.1 % yield	−1.1 % yield
Current strength	−1.5 % yield	+1.2 % yield

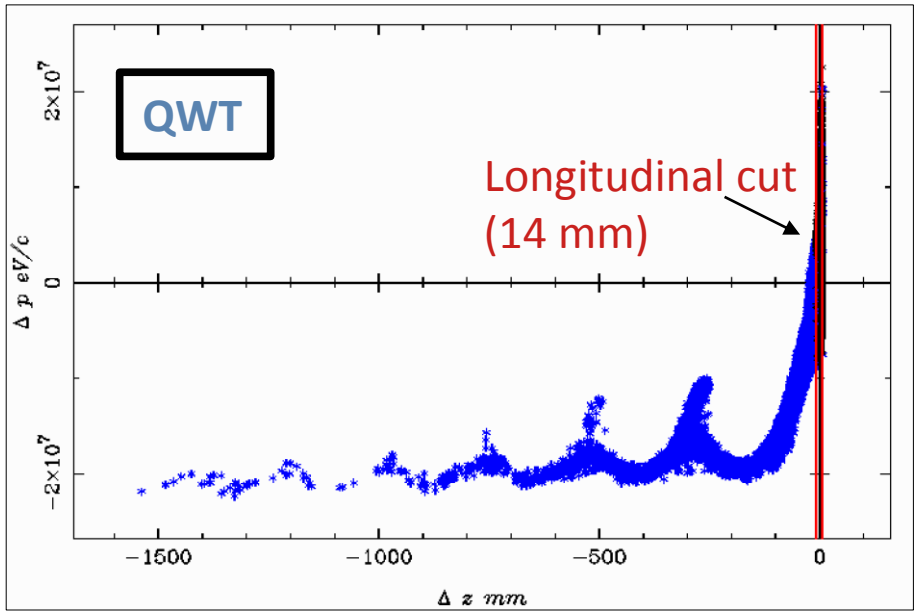
Table 4: Table of absolut positron yield change for a deviation of 10 % for each ideal parameter

Stable maximum!

- Further optimization:
  - PL-SWT distance
  - Current strength (limited in practice)

Comparison with Quarter Wave Transformer





Current ILC OMD design:

- Quarter Wave Transformer
  - Simulations redone in ASTRA:
    - Yield after longitudinal Cut: 17.5 %
      - → factor ~2.4 less yield

Conclusion and future plans

- Plasma lens has high potential
- Positron yield roughly factor 2 better than QWT

- Current ILC plan: 4y prelab phase (starting April 2022)

  -> needed for engineering design and final design choices
- Final selection of positron source (undulator-based versus electron-driven e+ source): foreseen in fall 2024
- Simulation with entire pre-accelerator structure
- Pulsed solenoid (see P. Sievers)
- QWT: Allowed magnetic field at Target
- German grant application submitted for prototyping of plasma lenses for the ILC e+ source
- -> if approved: grant starts mid 2021, results expected 2023/begin 2024
- -> impact on final ILC design

Further information

- Plasma Lenses: Possible alternative OMD at the ILC, 2003.03138.pdf (arxiv.org)
- Upcoming master thesis M. Formela

Thank you for your attention!

Results

```
Specify total bunch length after cut [mm]: 14
Particles taken into account      N =      17886
total charge                      Q =     2.8657E-06 nC
horizontal beam position          x =     0.1159     mm
vertical beam position            y =    -5.1233E-02 mm
longitudinal beam position        z =     1.344      m
horizontal beam size          sig x =     10.04      mm
vertical beam size            sig y =     10.02      mm
longitudinal beam size        sig z =     3.116      mm
average kinetic energy            E =     16.29      MeV
energy spread                    dE =     4328.      keV
average momentum                  P =     16.80      MeV/c
transverse beam emittance     eps x =     9742.      pi mrad mm
correlated divergence         cor x =     3.281      mrad
transverse beam emittance     eps y =     9806.      pi mrad mm
correlated divergence         cor y =     3.161      mrad
longitudinal beam emittance   eps z =    1.1751E+04 pi keV mm
correlated energy spread      cor z =     2123.      keV
emittance ratio eps y/eps x       =     0.9935
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