Undulator-Based Source at 250 GeV CM Energy with Different Optical Matching Devices (Pulsed FC and QWT)

Andriy Ushakov (University of Hamburg)

International Workshop on Future Linear Colliders (LCWS2017)

Strasbourg, France

26 October 2017

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

LINEAR COLLIDER COLLABORATION

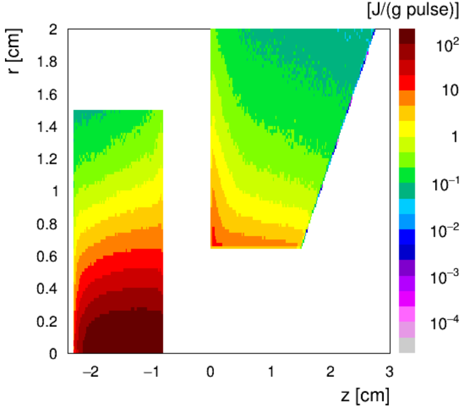
Outline

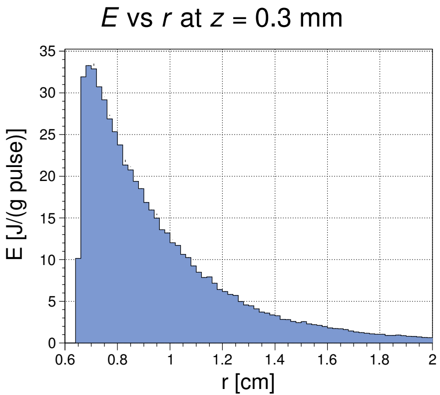
- Issue of high PEDD in pulsed Flux Concentrator (FC)
- What can be done to reduce PEDD in FC
- Model of Quarter Wave Transformer (QWT)
- Positron source parameters used in simulations
- Estimations of positron yield
- Peak energy deposition in QWT
- Radiation damage of QWT
- Summary

Issue of High PEDD in FC (AWLC2017 Talk)

125 GeV e^-, 1312 bunches/pulse, 231 m undulator, $K = 0.85$, TDR dogleg, $0.4X_0$ target

Energy Deposition in 3.2 T pulsed FC with 6.5 mm aperture radius





Note: Target rotation is not taken into account

PEDD = 43.7 J/(g pulse) in rotated with 100 m/s target

PEDD_{FC} = 33.3 J/(g pulse)

ΔT_{inst} = 86.4 K/pulse

PEDD(Cu) < 7 ÷ 12 J/g [TESLA-FEL-2006-05 Report]

What Can be Done to Reduce PEDD in FC?

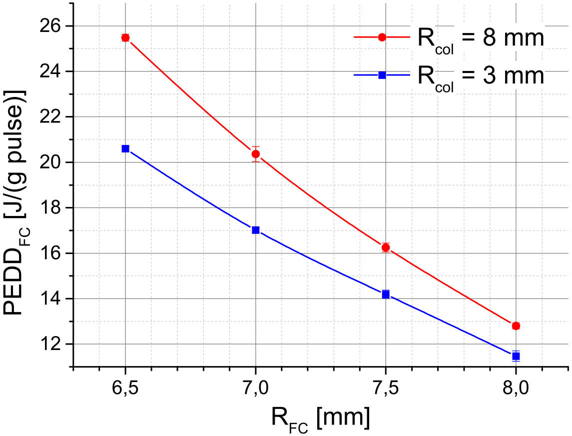
AWLC2017 talk

- Using compact e^- dogleg instead of TDR dogleg reduces the distance between undulator and target on 168.8 m, that results in reduction of PEDD in FC from 33.3 J/(g pulse) to 29.3 J/(g pulse) for 231 m helical undulator with K = 0.85 at 250 GeV CM energy.
- Reduction of target thickness to 7 mm results in $\approx$ 8% lower PEDD in FC.
- Increase of e^- beam energy at beginning of undulator to 128 GeV (energy losses in undulator are 3 GeV) and reduction of target thickness to 7 mm result in PEDD of 25.5 J/(g pulse).
- Applying of photon collimator upstream the target can reduce PEDD down to 18.5 J/(g pulse).
- To get PEDD $\approx$**12 J/(g pulse)** aperture of 3.2 T FC has to be increased from 6.5 mm to $\approx$**8 mm**.

PEDD in FC vs Aperture Radius of FC

128 GeV e^-, 1312 bunches/pulse, $K = 0.85$, compact dogleg, 7 mm target

Peak field of FC is **3.2 T**

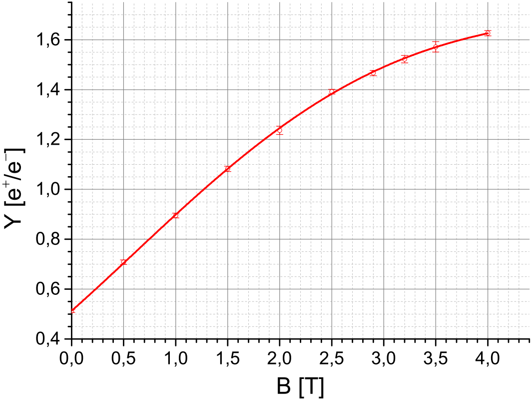


FC aperture radius has to be increased from 6.5 mm to ≈8 mm, to reduce PEDD down to ≈12 J/g

e^+ Yield vs Peak Field of FC

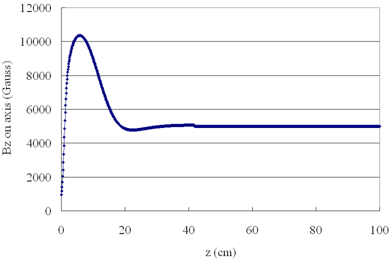
231 m undulator, $K = 0.85$

Aperture radius of FC is **6.5 mm**

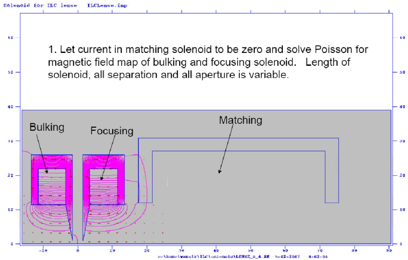


What if every capturing magnet technology fails, a safe solution: ¼ wave solenoid

- Low field, 1 Tesla on axis, tapers down to ¼ T.
- Capture efficiency is only 25% less than flux concentrator
- Low field at the target reduces eddy currents
- This is probably easier to engineer than flux concentrator
- SC, NC or pulsed NC?



ANL ¼ wave solenoid simulations



W. Liu

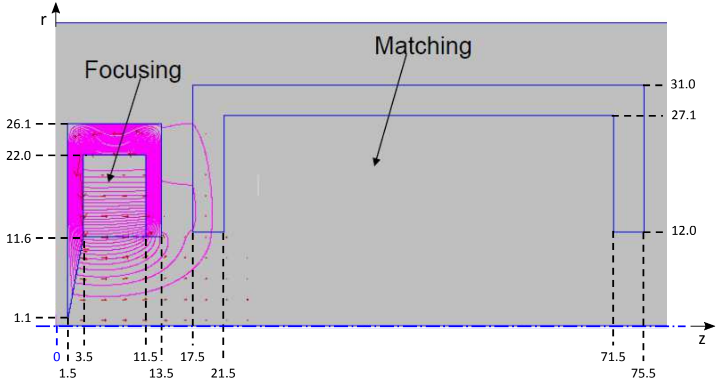
The target will be rotating in a B field of about 0.2T

Wanming Liu, Wei Gai, LCWS 2010

41

Model of QWT Used in Simulations

Geometry of QWT was taken from Wei Gai and Wanming Liu (ANL) LCWS2010 talk.
Dimensions were taken from M. Fukuda (KEK) AWLC2017 talk.



Field of focusing solenoid is 1.04 T

Field of matching solenoid is 0.5 T

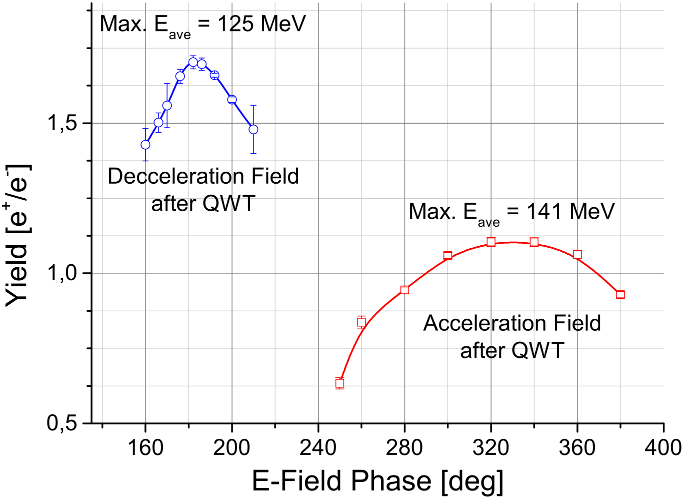
Middle of the target is at $z = 0$

Positron Source Parameters and Simulation Tool

- 128 GeV e^- beam has 3 GeV energy losses in undulator $\Rightarrow$ average energy of 126.5 GeV e^- was used for generation of undulator photons.
- Ideal Kincaid model was used for photon generation in the middle of helical undulator having 231 m active magnet length.
- Distance between the middle of undulator and target was 570 m or 401 m.
- Helical undulator has 11.5 mm period and $K \leqslant 0.92$.
- Ti6Al4V target has 7 mm thickness and space between the target and QWT was $\approx$8 mm.
- Capture accelerator embedded into 0.5 T solenoid has 15.4 m length and average energy gain $\approx$8 MeV/m.
- Positron generation and capture were simulated using Geant4 application (PPS-Sim).
- Positrons were tracked only until the end of capture section (125 MeV).
- DR acceptance was emulated at 125 MeV as following: $\Delta E/E = \pm 2.2\%$ at 125 MeV (energy compressor downstream capture section reduces spread to $\pm 0.75\%$ at DR) $\Leftrightarrow$ $\pm$11 mm long. bunch length cut; $\varepsilon_{nx} + \varepsilon_{ny} < 70$ mm rad.

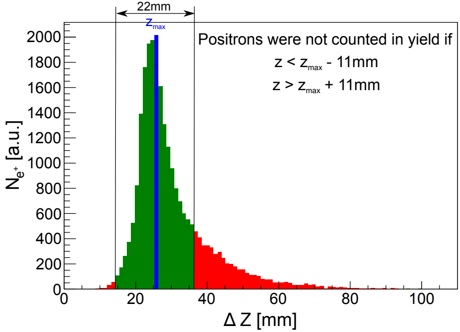
E-Field Phase Scan

231 m undulator, K = 0.92, TDR dogleg, 7 mm thick target, 1.04 T 1st solenoid of QWT

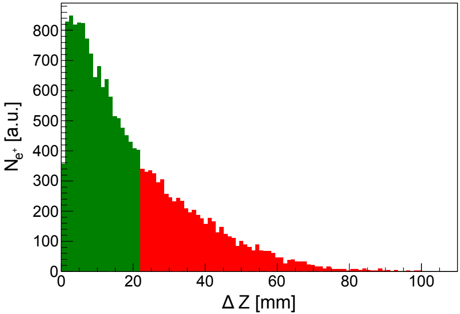


Bunch Length at Different E-Field Phases

Deceleration Positrons after QWT



Acceleration Positrons after QWT



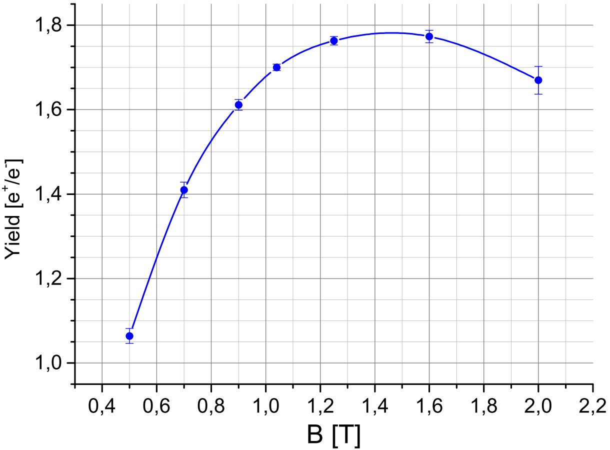
Note:

$\Delta Z = 0$ is position of bunch head (fastest e^+).

“DR” bunch length acceptance is 22 mm.

Positron Yield for Different Peak Values of 1st Solenoid

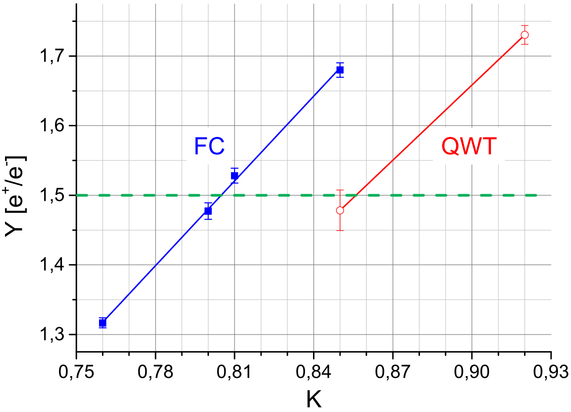
231 m undulator, K = 0.92, 7 mm target thickness



Yield for 1.04 T QWT 1st solenoid with 12 cm length is 4% less than for optimal ≈1.4 T field.

Positron Yield vs Undulator K Value

$B_{FC} = 3.2$ T, $B_{QWT\,Sol1} = 1.04$ T, distance from middle of undulator to target is 401 m*



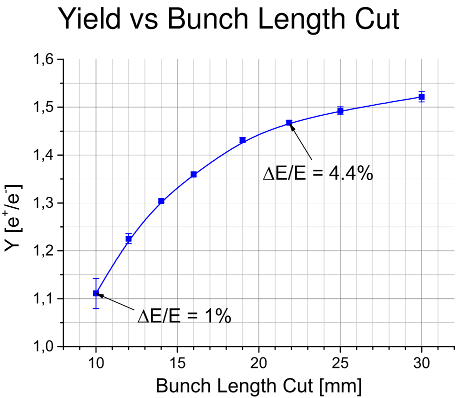
Pulsed Flux Concentrator (FC) has aperture radius of 6.5 mm.

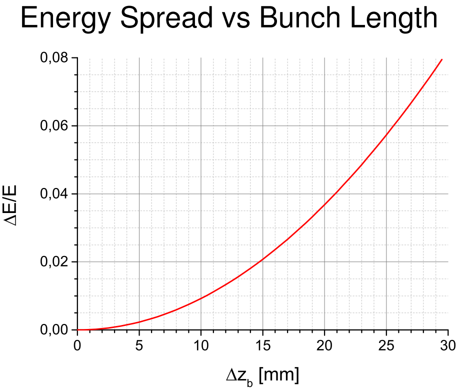
QWT has aperture aperture radius of 11 mm.

*Compact dog-leg for 125 GeV e$^-$ beam designed by Okugi allows reduction up to 168.8 m undulator-to-target distance [https://agenda.linearcollider.org/event/7573/contributions/38619/attachments/31296/47039/PosiPol_okugi_20170316.pdf]

Impact of Bunch Length Cut on e^+ Yield

Undulator K = 0.85, $B_{\text{QWT Sol1}} = 1.04$ T, $\varepsilon_{nx} + \varepsilon_{ny} < 0.07$ m·rad

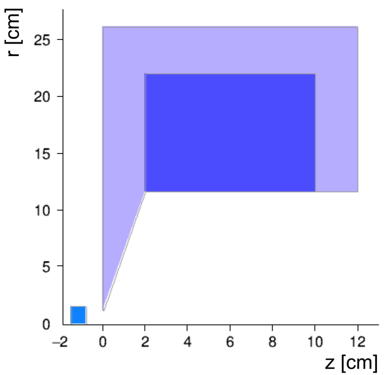




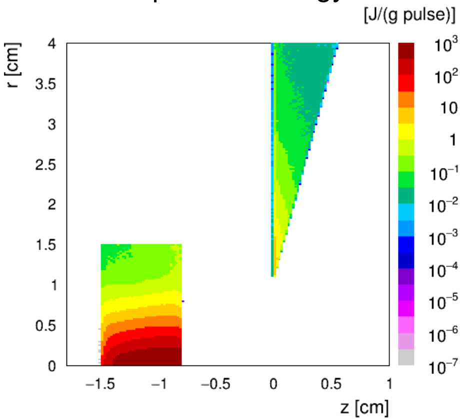
$$\frac{\Delta E}{E} = 1 - \cos\left(\frac{\omega \Delta z_b}{2c}\right)$$

FLUKA Model and Distribution of Deposited Energy

Target and 1st Solenoid of QWT



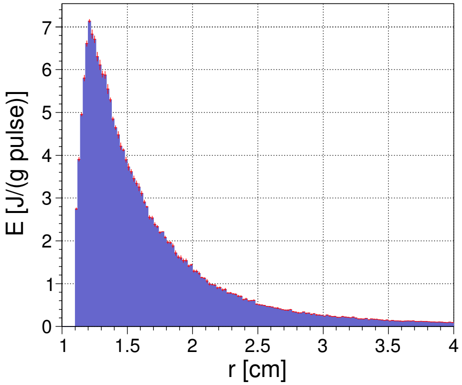
Deposited Energy



Note: target rotation is not taken into account

PEDD and Peak Radiation Damage of QWT

Energy Deposition vs Radius



$\text{PEDD}_{\text{QWT}} \approx$ 7 J/(g pulse) in iron.

PEDD(ARMCO Pure Steel) < 12.5 J/g

Peak damage of QWT after
5000 hours of source operation is
0.12 dpa

Summary

For the undulator-based source at 250 GeV CM energy:

- To reduce PEDD in pulsed FC below 12 J/g, the aperture radius of FC has to be increased from 6.5 mm to $\gtrsim$ 8 mm.
- 1.5 e^+/e^- can be achieved applying QWT suggested ANL group several years ago.
- PEDD in QWT having smallest aperture radius of 11 mm is 7 J/(g pulse). PEDD limit for ARMCO pure steel is 12.5 J/(g pulse).
- Annual peak radiation damage of QWT is at relatively safe level of $\sim$0.1 dpa.