

Sources Subgroup

Kaoru Yokoya (KEK)

2021.3.16, LCWS2021, Accelerator Plenary

Sources Subgroup

Covers the Electron source and Positron source

Clarke, Jim	ASTeC
Doebert, Steffen	CERN
Grames, Joe	JLAB
Hayano, Hitoshi	KEK
Kuriki, Masao	Hiroshima U.
List, Benno	DESY
List Jenny	DESY
Moortgat-Pick, Gudrid	Hamburg U.
Riemann, Sabine	DESY
Sievers, Peter	CERN
Yokoya, Kaoru (chair)	KEK

Pre-Lab Schedule on Technical Preparation

Focus on SRF and positron

1st year:

- Extend SRF cavity cost-reduction R&D
- Start a pre-series SRF cavities production in cooperation with industry
- Continue e+ source survey and internal review.

2nd year:

- Complete SRF cost-reduction R&D with success yield statistics and extend the preparation to assemble the cavities with cryomodule (CM)
- Review e+ source scheme

3rd year:

- Demonstrate “Cryomodule Global transfer, with HPGS (high pressure gas safety) legal-process, shipment, and SRF QA test after transport
- Establish e+ source scheme down-select, and prototyping of critical items (such as e+ target)

4th year:

- Evaluate CM performance after CM shipment and demonstrate the QA, and establish SRF Hub Lab. functioning
- Progress prototyping of critical items (such as e+ target)

What Should be Done within 2020

Slide when IDT started

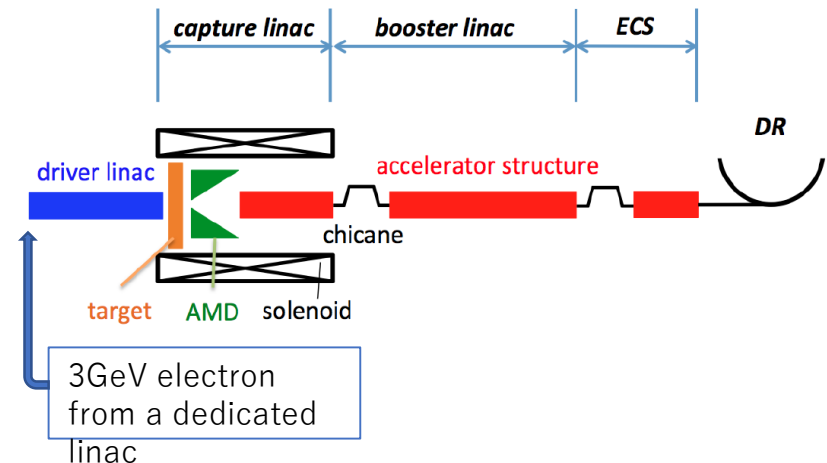
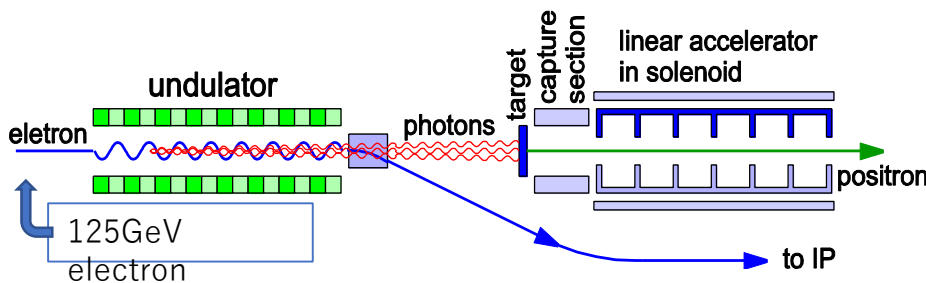
- List up the technical preparations to be done in the Pre-Lab
 - Issues pointed out by SCJ and MEXT
 - Technical items necessary for writing EDR
 - Possible partners
 - Existing expertise
 - Need not guarantee now research cooperation and budget
 - Rough evaluation of the necessary cost
-
- 2021 Feb.: First draft of budget request (each region/lab.)
 - To establish Pre-Lab we need KEK-to-Lab bilateral MoU

Technical Issues Pointed out by SCJ and MEXT on the Sources

- ILC Advisory Panel (MEXT)
 - Target cooling
 - Replacement of activated target
- SCJ
 - Prototype rotating target
 - Magnetic focusing system right after target
- These refers to the Undulator Scheme

Two Positron Source Schemes

- Positron issue is a bit different from other areas
- R&D of two different types of positron source is on-going
- Undulator Scheme
 - Baseline (TDR vol.3-I Sec.4.3.2-10 and vol.3-II, Chap.5)
 - Electron beam ($>100\text{GeV}$) goes through helical undulator \rightarrow photons ($>$ several MeV) \rightarrow target \rightarrow positron
 - New scheme
 - Polarized positron ($\sim 30\%$, can be raised to $\sim 60\%$ by photon collimator)
- Electron-Driven Scheme
 - Backup (only a very brief description in TDR vol.3-I Sec.4.3.11.1)
 - A few GeV electron linac \rightarrow target \rightarrow positron
 - Long experience
 - Unpolarized positron



Positron Group Report

- Positron Group Report, May 23, 2018,
 - <http://edmsdirect.desy.de/item/D00000001165115>
 - Describes the status of both schemes
 - Compared the status to some extent
- Already more than 2.5 years since then. There are many progresses since then.
- But at present both of the two schemes still have remaining technical issues
- Need demonstration of 100% technical feasibility as early as possible

Critical Issues for the Feasibility

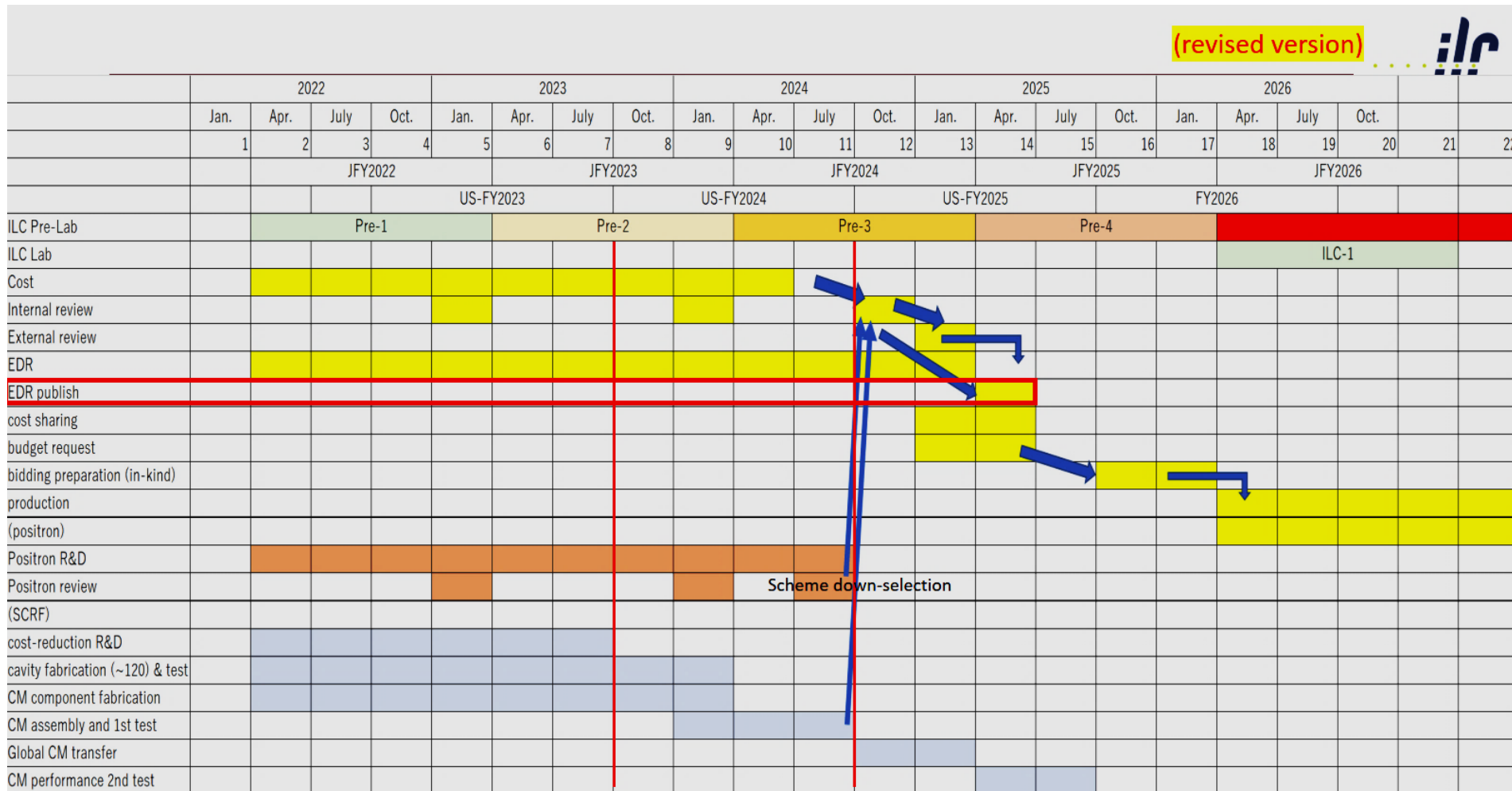
- There are remaining issues that are critical for the feasibility
 - Feasibility must be demonstrated during Pre-Lab period
 - I mention here about them very briefly. Detail will be presented in the individual talks
- Undulator Scheme
 - ✓ Focusing system right after the target (WP-7)
 - TDR adopted Flux Concentrator (peak field ~ 3.2 Tesla) but it turned out not to work.
 - Expected positron yield using a substitute device (peak field ~ 1 Tesla) is low. The Positron Group Report quoted a number 1.3 but later turned out to be lower than 1.
 - ✓ Rotating target : only a design exists (WP-6)
- Electron-driven Scheme
 - ✓ Rotating target: prototype under test (WP-8)
 - ✓ Capture cavity right after the target (WP-10)
 - Beam current is a few Ampere
 - Transient beam-loading compensation is not trivial

Selection of the Scheme

- The positron scheme for the project start must be decided
- Deadline of the decision
 - Sufficient time for the remaining R&D should be guaranteed
 - Design must be fixed as early as possible for the process “internal design review → external review → budget request”
- As a compromise, we are planning the “selection” in the **middle of the third year of the Pre-Lab** (~ Sept. 2024)
 - Recently we shifted the time of decision
 - The deadline was the end of the first year (Mar. 2022) in the previous schedule
 - So, more time for R&D
- Some work packages contain critical issues that must come to results by this deadline

Pre-Lab Timeline

(revised version)



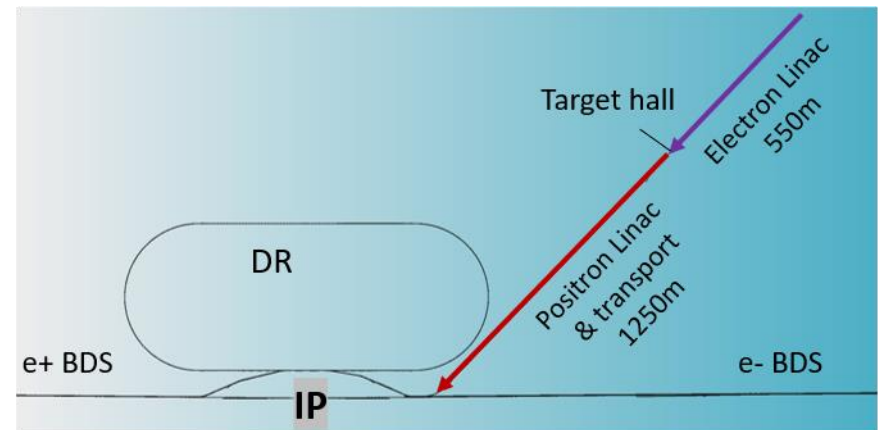
IDT-WG2-Sources meeting (Jan.11,2021)

7

Tunnel Configuration

- Two schemes require different tunnel configuration
- Currently the CFS team is considering the tunnel layout shown below

- If the e-driven scheme is selected, it is installed in a separate tunnel (read line below)
- Main tunnel will be the same as in TDR, i.e., the space for the undulator scheme will be reserved for future upgrade to polarized positron
- Thus, the undulator system can be installed later without large CFS work



- Keep in mind, however, minimum CFS design for the undulator system is needed from the beginning (e.g., the location of the target hall, width of the BDS tunnel, etc.)
- If the undulator scheme is selected, the extra tunnel for the e-driven system will not be constructed
 - For the CFS design it is enough to eliminate the extra tunnel

Work Packages for Sources

➤ Electron Source

- ✓ WP4 Laser, HV gun, cathode

➤ Undulator Scheme

- ✓ WP5 Undulator
- ✓ WP6 Target
- ✓ WP7 Focusing system

- Photon dump is included in the DR/BDS/DUMP subgroup (WP-18)

➤ e-Driven Scheme

- ✓ WP8 Target
- ✓ WP9 Flux Concentrator
- ✓ WP10 Capture Cavity

- The injection kicker to the DR is included in WP14 of DR/BDS/DUMP subgroup

➤ Common Issue

- ✓ WP11 Target Maintenance

- Target shield must be designed.
- The expected life of the target is not long (less than a few years).
- It must be replaced together with its surroundings) by remote handling.
- This is more or less common to the two schemes.

LCWS Parallel Sessions on Sources

PDT	CET	JST		
15(Mon)22:00	16(Tue)06:00	16(Tue)14:00	Polarized Electron Source R&D for the EIC	E. Wang
22:20			Development of a 500 kV Polarized Electron Source	C. Hernandez-Garcia
22:40			Development of the Polarized Electron Source at MESA	K. Aulenbacher
23:00			Record-level quantum efficiency from a high polarization strained GaAs/GaAsP superlattice...	W. Liu
23:20			Discussion of future R&D	J. Grames
23:40			Status of the FCC-ee positron source	I. Chaikovska
16(Tue)22:00	17(Wed)06:00	17(Wed)14:00	Status of KEKB positron source	Y. Enomoto
22:15			Simulation studies for ILC and SKEKB E-Driven positron source	M. Fukuda
22:30			Overview of R&D status of ILC E-Driven positron source	T. Omori
23:00			Compensation of the transient beamloading effect in the capture linac of E-Driven positron source	M. Kuriki
23:15			Transient property analysis of the APS cavity in E-Driven capture linac	S. Konno
23:30			Update on the flux concentrator activities	H. Bajas
23:45			Simulations to optimize the CLIC and FCC source	Y. Zhao
17(Wed)22:00	18(Thu)06:00	18(Thu)14:00	Undulators @ XFEL	W. Decking
22:15			Superconducting undulator technology at ANL	Y. Ivanyushenkov
22:30			Realistic undulator field	K. Alharbi
22:45			OMD Pulsed Solenoid	P. Sievers
23:00			OMD QWT	N. Hamann
23:15			OMD Plasma Lense	M. Formela
23:30			Undulator Target Test at MAMI	S. Riemann
23:45			A first look at the ILC positron source for nuclear and particle physics	I. Bailey

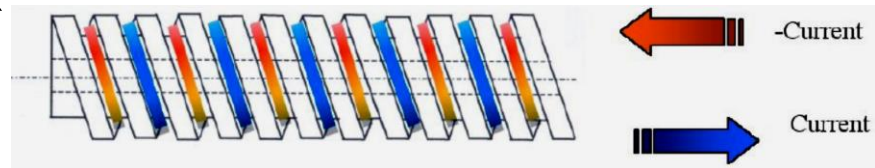
WP-4 Electron Source

- 3 major components
 - DC HV Photon gun
 - Laser
 - Photo cathode
- No foreseeable technological “show-stoppers” in TDR design
- But many progresses since TDR time
- Design should be improved in Pre-Lab
- A new problem
 - commercial supplier of High-P GaAs photocathodes disappeared
- New possibilities to be studied in Pre-Lab
 - fiber technologies
 - Higher voltage ~350kV ?
 - Commercialize strained superlattice GaAs / GaAsP photocathodes with $P > 90\%$ and $QE > 1\%$

Parameter		TDR
Number Electrons per microbunch	N_e	3×10^{10}
Number of microbunches	n_b	1312
Width of microbunch	t_b	1 ns
Time between microbunches	Δt_b	556 ns
Microbunch rep rate	f_b	1.8 MHz
Width of macropulse	T_B	729 μ s
Macropulse repetition rate	F_B	5 (10) Hz
Charge per micropulse	C_b	4.8 nC
Charge per macropulse	C_B	6300 nC
Average current from gun ($C_B \times F_B$)	I_{ave}	31.5 (63) μA
Average current macropulse (C_B / T_B)	I_B	19.8 mA
Duty Factor in macropulse (1 ns / 556 ns)	DF	0.18 %
Peak current of micropulse (I_B / DF)	I_{peak}	11 A

Undulator Scheme

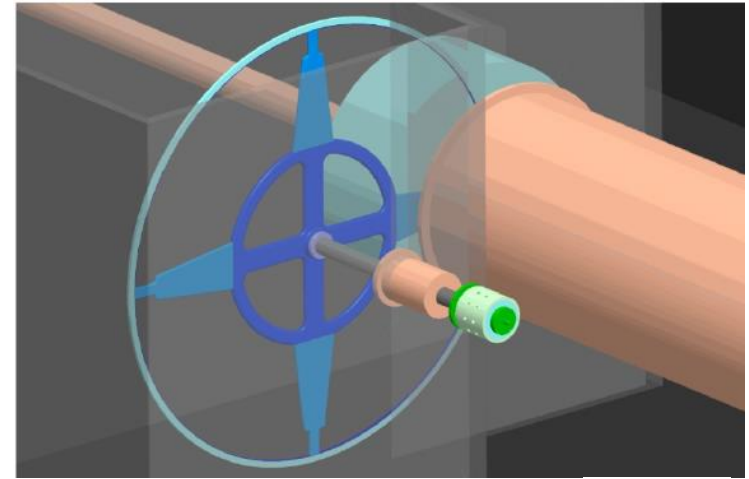
- Use the 125GeV electron beam
- It goes through helical undulators and emit photons (circularly polarized)
 - Undulator : pitch 11.5mm, inner aperture diameter 5.85mm, $K \leq 0.92$, total field length 231m
 - Super-conducting, 4K



- Average photon energy at the target 9MeV
- Electron loses $\sim 3\text{GeV}$. After emission the electrons go to the IP (Interaction point).
- Photons hit the target at $\sim 160\text{m}$ downstream of the undulator
- The first process in the target is $\gamma \rightarrow e^+e^-$
 - Hence, the target can be thin (Ti alloy, 7mm = $0.2X_0$ thick)
 - Energy deposit on the target $\sim 2\text{kW}$

Undulator Scheme (continued)

- The target is a ring (diameter 1qm), made of Ti alloy, rotating at 2000 rpm (100m/s)
 - Avoid heat concentration in 1ms pulse
 - Water cooled (TDR)
- Produced positrons are focused by flux concentrator (TDR) or QWT (latest) or pulsed solenoid
- Then, accelerated to 400MeV by normal-conducting cavities (1.3GHz, long pulse up to 1ms)



TDR

- Then, accelerated to 5GeV by super-conducting cavities (same as those in the main linac), and injected to the Damping Ring.
- Most photons go to the photon dump at ~2km downstream (~50kW)

WP-5 Undulator

➤ Undulator has been developed since long ago

- Short pitch, high field
- 2006 at RAL and Cornell
- Two 1,75 undulators in one cryostat
- Reached sufficient magnetic field $>30\%$
- → relatively in good shape

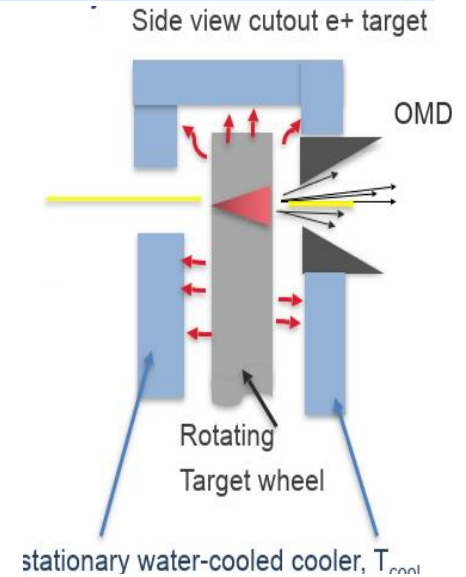
➤ Further study items

- Errors
- Alignments
- Possibility of other parameters (shorter pitch, higher/lower field)

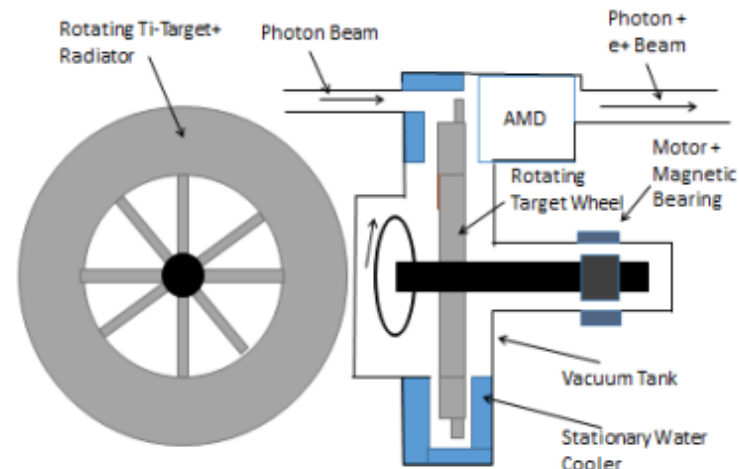


WP-6 Rotating Target for Undulator Scheme

- R&D of water-cooled target failed
 - Vacuum leak through magnetic fluid
 - Now developing Radiation-cooled target
 - Target material: Ti alloy.
Property confirmed in experiments at MAMI (Mainz)
 - Heat deposit 2kW
 - Target geometry optimization being done
 - Rotation in vacuum by bearings
-
- Fabricate (non-rotating) a sector with heating device for confirming thermal property by the “selection”
 - Full wheel prototype later

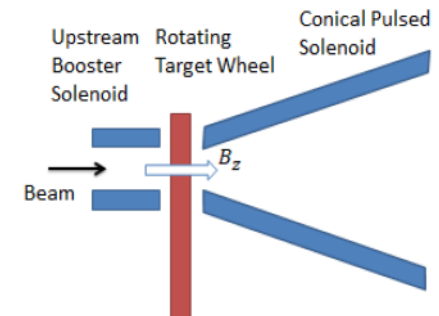
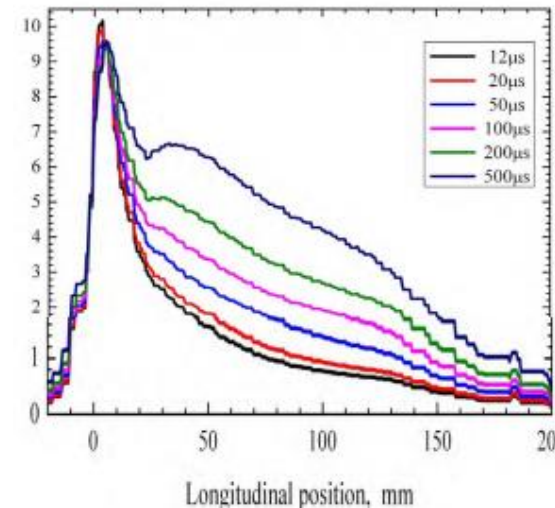


$$P \sim \sigma \epsilon A (T_{radiator}^4 - T_{cool}^4)$$



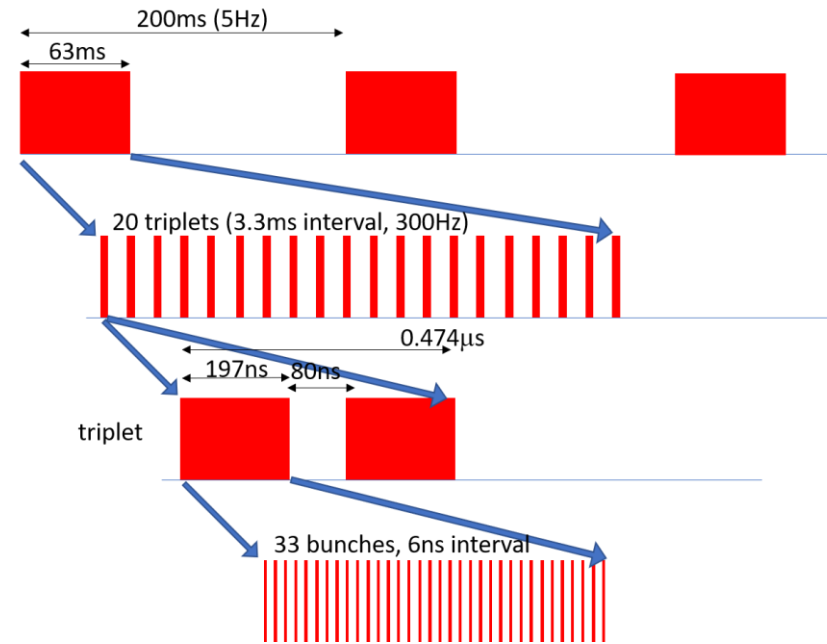
WP-7 Optical Matching Device

- Flux concentrator in TDR failed
 - Time dependence of the field within the long pulse (1ms) due to the skin depth effects
- QWT (Quarter Wave Transformer) with peak field ~ 1 Tesla gives low yield (< 1)
- Possible OMD
 - Pulsed solenoid (main candidate)
 - Improved QWT (higher field/sharper field rise)
 - Flux concentrator (less serious time dependence)
 - Plasma lens
- Pulsed solenoid
 - ✓ Design in progress
 - ✓ Various issues
 - Time dependence of the field
 - Magnetic field on the target
 - Mechanical strength against magnetic field
 - ✓ What can be done by the time of “selection”



Electron-Driven Scheme

- Do not use the electrons going to the IP
 - Hence, the pulse structure can be optimized for the e-driven scheme
 - Expand 0.7ms (1312 bunches) pulse to ~63ms
- Electrons from 3GeV linac (S-band normal-conducting) hit a target
- Target
 - Made of W (or W-Re), 14mm thick
 - Wheel diameter 0.5m, rotating at 225 rpm (5m/s)
 - Water-cooled, vacuum sealed by magnetic fluid
 - The energy deposit on the target is ~20kW



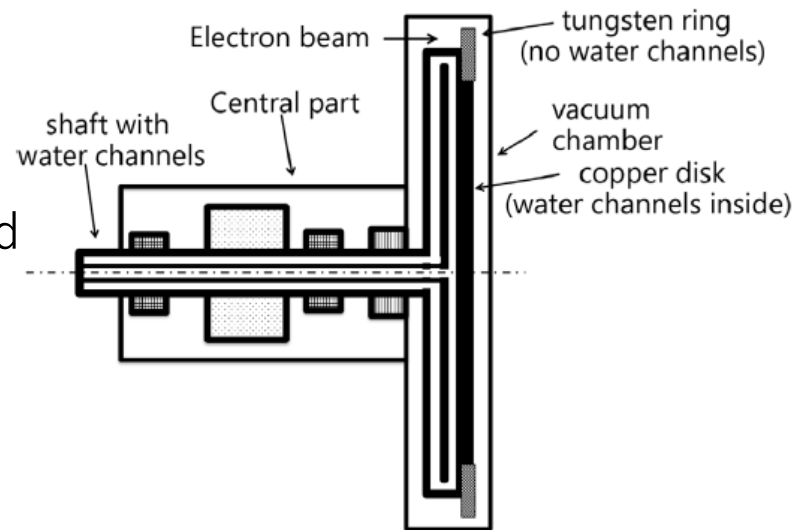
Parameter	Value	Unit
Drive beam energy	3.0	GeV
Bunch charge	4.0	nC
N of bunches in a pulse	66	bunches
Bunch spacing in a pulse	6.15	ns
Average current in a pulse	0.78	A
Pulse repetition	300(100)	Hz

Electron-Driven Scheme (continued)

- Focused by flux concentrator, peak field 5 Tesla, connected smoothly to 0.5 Tesla solenoid
- Accelerated by L-band (1.3GHz) normal-conducting standing-wave linac
- Electrons and photons are separated out at a chicane
- Positrons are then accelerated to 5GeV by travelling-wave L-band linac and later by travelling-wave S-band linac
- The injection to the damping ring requires a special kicker. This will be treated in WP-14.

WP8- Rotating Target for e-Driven Scheme

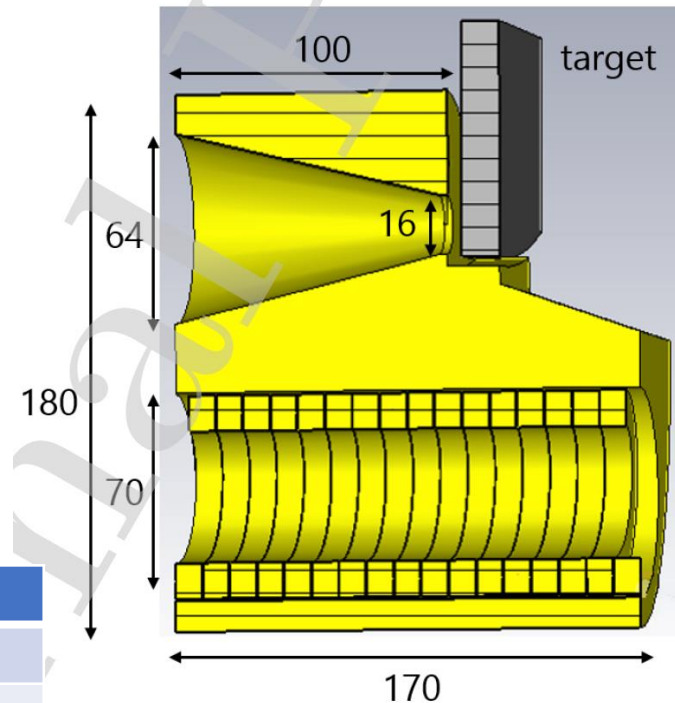
- Water cooling using magnetic fluid seal
 - Same as the TDR design for undulator scheme
- 16 mm W-Re(26) alloy
- Diameter 50cm with 5 m/s tangential speed.
 - Cf. 100m/s for undulator scheme
- Heat deposit $\sim 20\text{kW}$
- PEDD $< 35\text{J/g}$
- Prototype experiments
 - Two stage Ferro-fluid seal
 - Radiation damage of the seal turned out no problem
 - Vacuum leak very small
 - Fatigue to be studied further
 - No heavy wheel yet
 - No cooling/heating yet
- Full prototype to be fabricated and tested in Pre-Lab



WP-9 Flux Concentrator

- Two-conductor flux concentrator.
- Current is applied to the primary coil.
- The eddy current induces the Bz field in the secondary conductor.
- Bz is enhanced by the narrow iris diameter
- Based on FC being used at BINP
- Pre-Lab
 - Cooling system to be studied
 - Full prototype to be constructed with power supply (This can be done later)

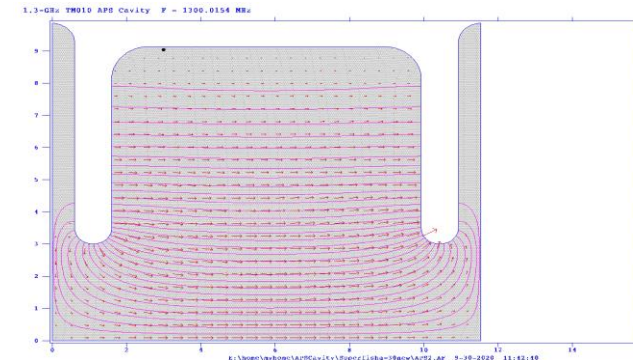
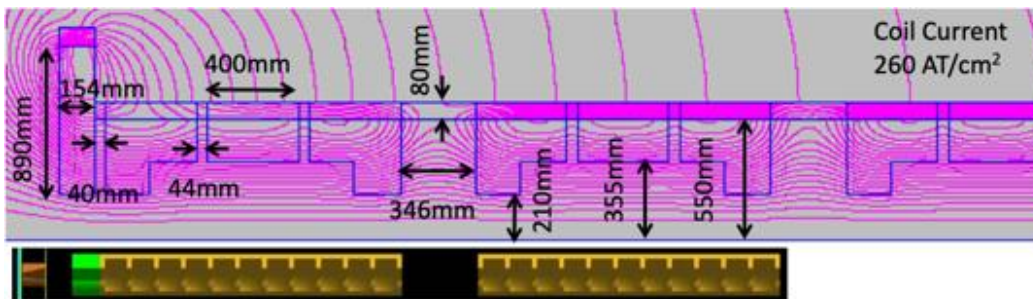
Parameter	Value	Unit
Peak field	5.0	Tesla
FC size	120 x 180	mm ²
Conical cavity length	100	mm
Front aperture diameter	16	mm
Rear aperture diameter	64	mm
Number of windings	16	turns
Ohmic loss	14	kW



Designed by
P. Martyshkin (BINP)

WP-10 Capture Cavity

- Capture linac composed of 41 L-band APS (Alternating Periodic Structure) cavities
 - $R=31.5 \text{ Mohm/m}$, $2a=60\text{mm}$
 - In 0.5 Tesla solenoid
 - heating by hitting particles : $\sim 40\text{kW}$
- Major issue
 - Transient beam-loading
 - Positron current to DR: $0.5\text{A} \times 1.5$ (margin)
 - Net current (with electron) is zero right after target (pair creation) but twice $0.5\text{A} \times 1.5 = 1.5\text{A}$ when e^+ and e^- are captured in the buckets.
 - Even higher if the loss in transport is included
 - By combining two RF sources with phase modulations, Amplitude and Phase modulation is made.
 - Can be compensated for by this method?
 - It is believed this problem can be confirmed by computer simulation



WP-11 Target Maintenance System

- Radiation environment in the target area is severe in both undulator and e-driven system
 - This is a common issue
 - Radiation is higher for e-driven system (about 1 order of magnitude)
 - The area but heavily shielded
- The life of the target is expected to be short in both scheme (at most a few years)
 - Must develop automatic target (with FC, first cavities, solenoid) replacement system

Summary

- Sources Subgroup of IDT/WG2 established
 - Till Dec.2021
 - Work Packages discussed
 - WP4 electron
 - WP5-7 undulator scheme
 - WP8-10 e-driven scheme
 - WP11 target maintenance (common issue)
- Pre-Lab schedule
 - Scheme selection for the project start
 - Expected in middle of the 3rd year of Pre-Lab (~September 2024)
 - Technical feasibility must fully be demonstrated by that time