LINEAR COLLIDER COLLABORATION

Designing the world's next great particle accelerator

POSIPOL 2015

International Positron Source Workshop

2-4 September 2015

Cockroft Institute, UK

Sabine Riemann (DESY)

POSIPOL 2015

Topics

- Project Overviews and Physics
- Undulator Sources
- Conventional Sources
- Compton Sources
- Target and Material Studies

https://eventbooking.stfc.ac.uk/news-events/posipol-281?agenda=1

~20 participants + remote participants (and talks)

POSIPOL 2015 topics (1)

Project Overviews and Physics Considerations

- ILC Update, K. Yokoya
- CLIC Update, S. Doebert
- Updates to LC Physics Case for Polarized Beams G. Moortgat-Pick
- ILC BDS Footprint, T. Okugi

Target and Material Studies

- Update on Target Simulations of the Undulator Based e+ Source, A. Ushakov
- Status Radiation-cooled Target for the Undulator Based e+ Source, S. Riemann
- Heat Load of the Radiation Cooled Ti Target of the Undulator-based e+ Source, F. Dietrich

POSIPOL 2015 topics (2)

Conventional Sources

- Beam Dynamics Studies of the CLIC Positron Source, C. Bayar
- Investigations on a Reliable Positron Source for ILC and CLIC with the Hybrid Target, I. Chaikovska
- Overview and Change Request by K. Yokoya
- Simulation of 300 Hz e+ Linac, M. Kuriki
- Energy Deposition in Source, T. Takahashi
- Klystron and Modulator for 300 Hz Linac, S Fukuda
- ILC 300 Hz Source Target Stress, J. Song
- Slow Rotation Target. T. Omori
- Flux Concentrator, P. Martyshkin
- Super KEKB e+ Source, T. Kamitani

- Review of Undulator and Conventional Driven Target Parameters, P. Sievers

POSIPOL 2015 topics (3)

Undulator Sources

- Calculation of Acoustic Waves in ILC Baseline Target, O. Adeyemi
- ANL ILC Baseline Target Wheel Update, W. Gai
- Optimisation of the Undulator Source of Polarized Positrons, E. Bulyak
- Effects of Non-ideal Undulator Spectra on Positron Production, M. Jenkins
- Realistic unduators for intense gamma-ray beams at future colliders, A. Alrashdi

Compton Sources

- Compton e+ Source, T. Takahashi
- ICS Source Developed by RadiaBeam and Brookhaven, F O'Shea

Outline (of this talk)

- Undulator based source
- Conventional source scheme for the ILC
- CLIC
- Discussion

Undulator-based e+ source

- Undulator studies
- Target cooling design
  - **Ti Target, Ø1m, 2000rpm (100m/s) in vacuum,**
  - **TDR: water-cooling of target**
  - **LLNL prototyping → water-cooling is difficult, alternatives are highly desired**
  - **2 solutions are under consideration**
    - Cooling by thermal radiation (DESY/Uni HH)
    - Cooling with sliding pads (ANL/Tsinghua)

e+ target cooling by thermal radiation

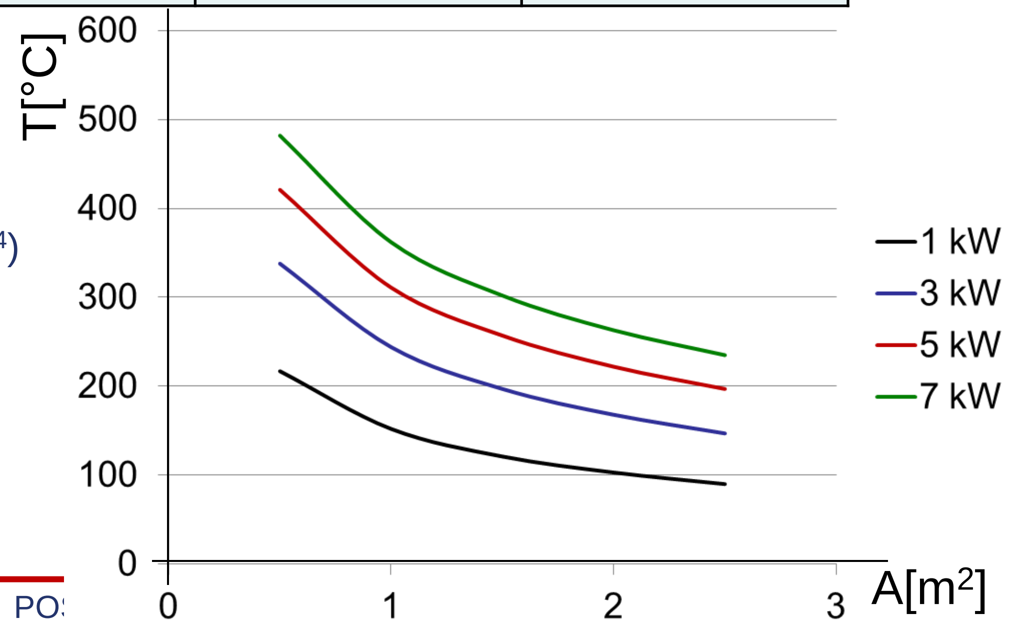
DESY/U Hamburg/P. Sievers

E_{cm} and luminosity determine energy deposited in target (P_{e+} ≤30%)

E_{beam} [GeV]	E_{dep} [kW]	ΔT_{max}/pulse [K]	E_{dep} [kW]	ΔT_{max}/pulse [K]
	Nominal luminosity		High luminosity	
120	5.0	66	-	-
175 **(ILC EDMS)**	3.9	125	-	-
250 **(ILC EDMS)**	2.0	130	4.1	195
250	2.3	85	4.6	165

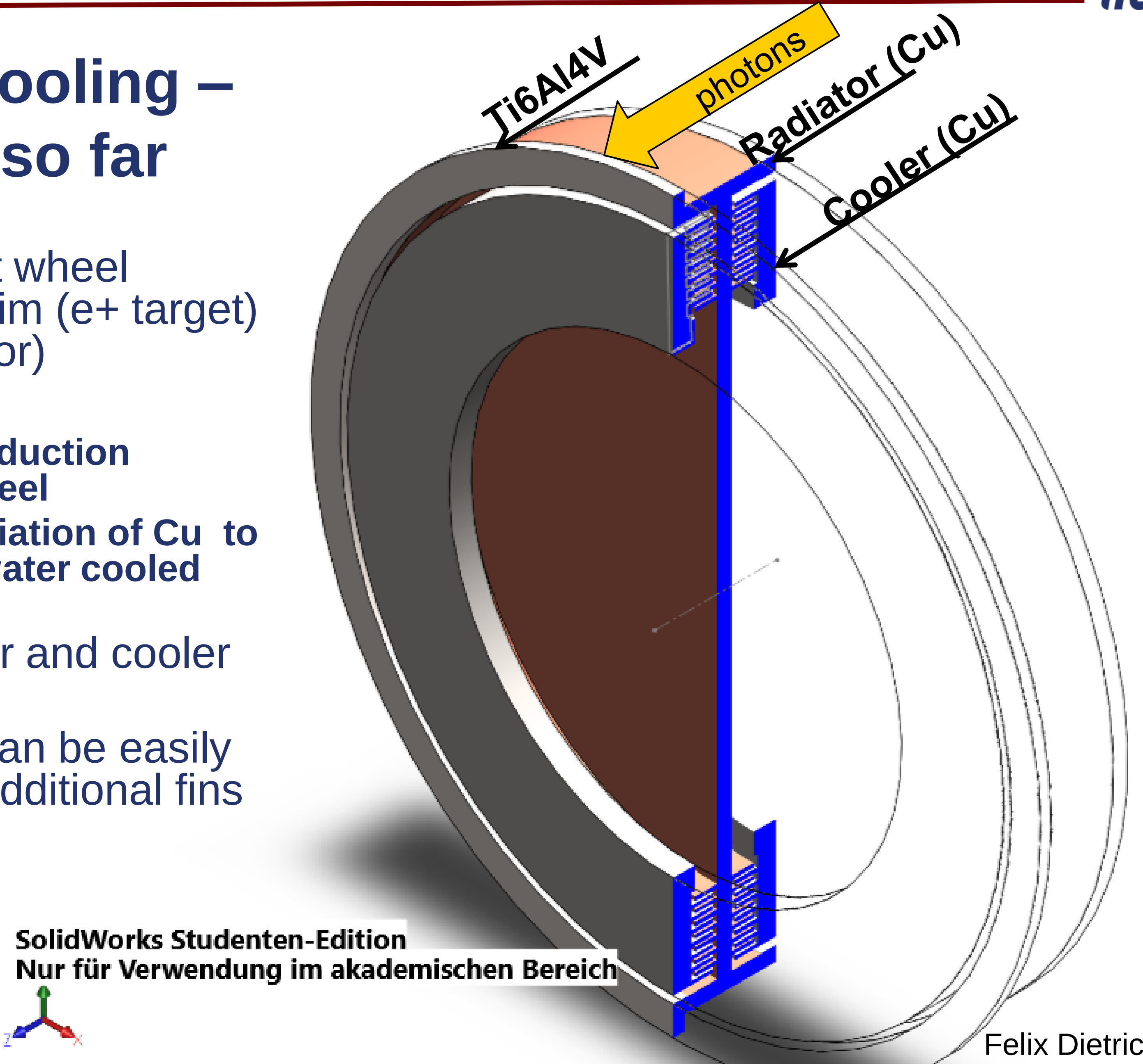
$$P \sim \sigma \varepsilon A \left(T^4_{radiator} - T^4_{cool} \right)$$

σ = St.-Boltzmann const = 5.67 × 10^{-8} W/(m^2K^4)
ε = emissivity = 0.7
A = Area of thermal radiation



Radiative cooling – considered so far

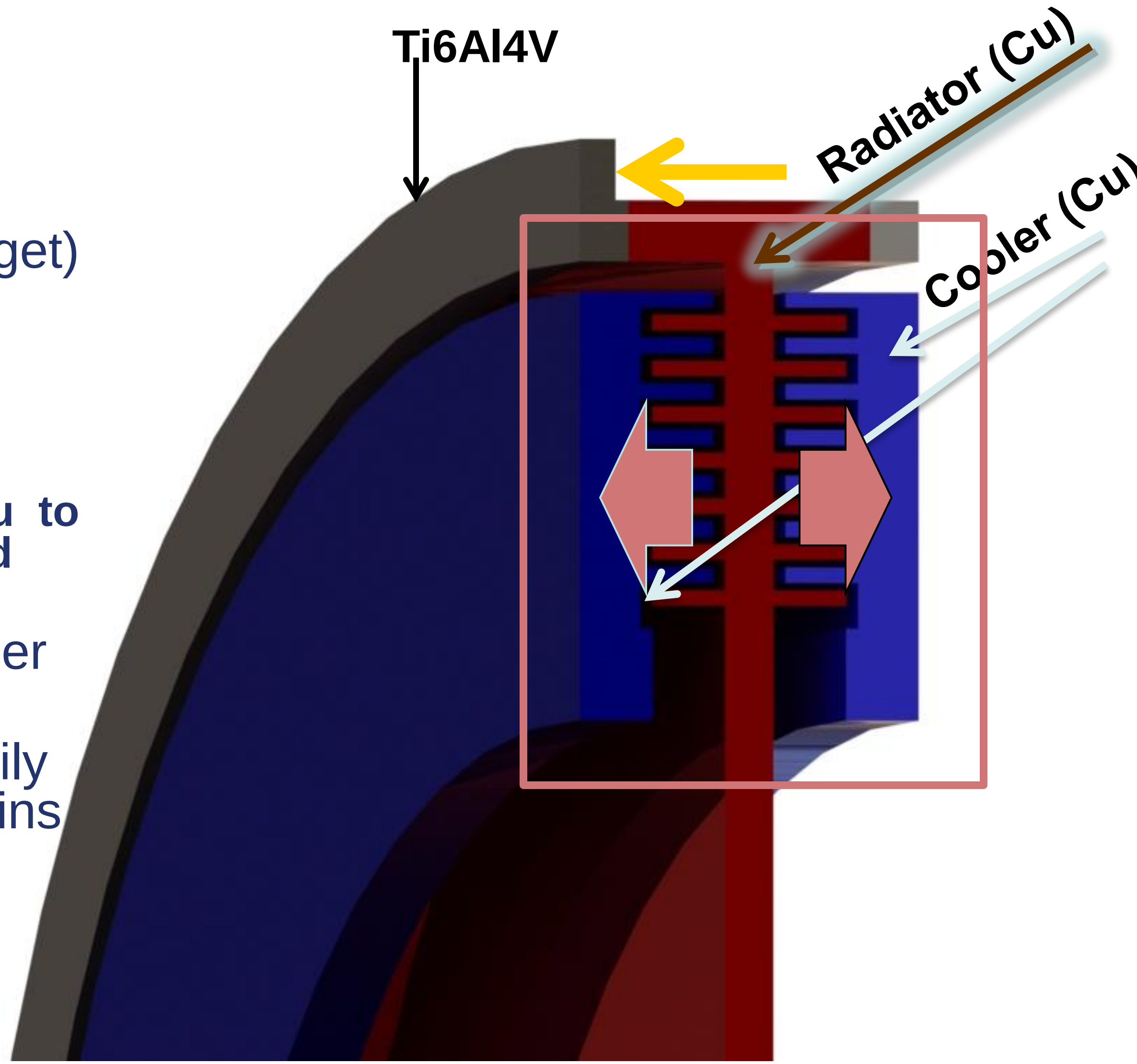
- Rotating target wheel consists of Ti rim (e+ target) and Cu (radiator)
- Heat path:
  - **thermal conduction Ti → Cu wheel**
  - **Thermal radiation of Cu to stationary water cooled coolers**
- Target, radiator and cooler are in vacuum
- Cooling area can be easily increased by additional fins



Felix Dietrich

Radiative cooling – considered so far

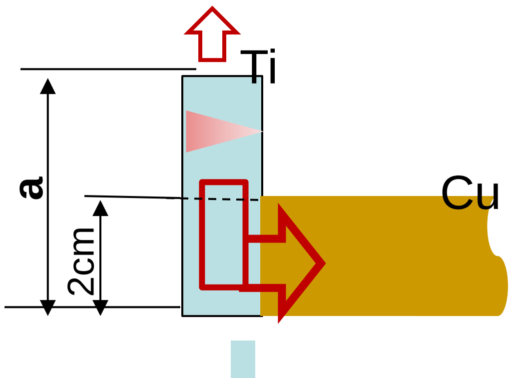
- Rotating target wheel consists of Ti rim (e+ target) and Cu (radiator)
- Heat path:
  - **thermal conduction Ti → Cu wheel**
  - **Thermal radiation of Cu to stationary water cooled coolers**
- Target, radiator and cooler are in vacuum
- Cooling area can be easily increased by additional fins



Equilibrium temperature distribution in target

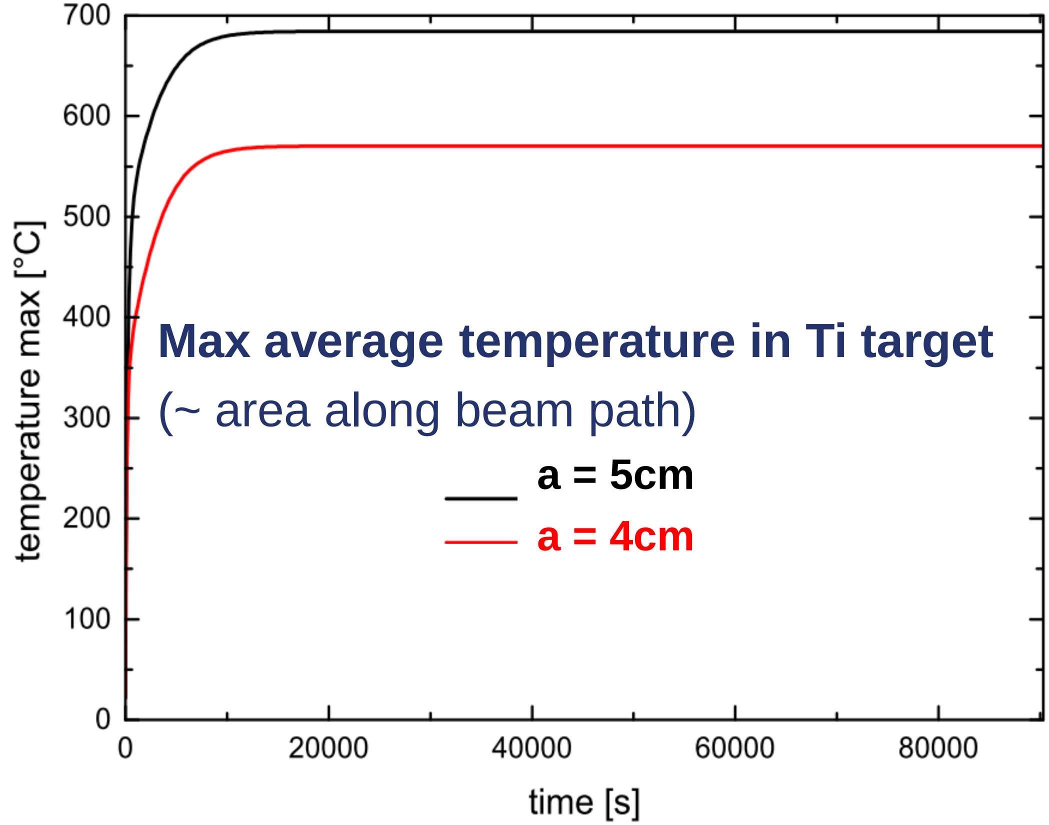
Temperature evolution over time, ANSYS

- E_{cm} = 500GeV; E_{dep} = 2.3 kW, A ~2.8 m^2



- After ~3 hours equilibrium temperature distribution reached
- $T_{max} \approx 570°C$ (a = 4cm)
- Distance beam path to Ti-Cu contact is important

Felix Dietrich

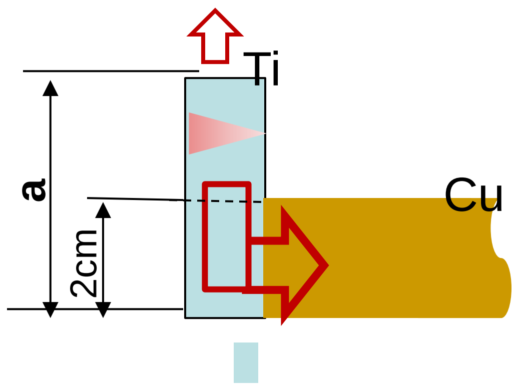


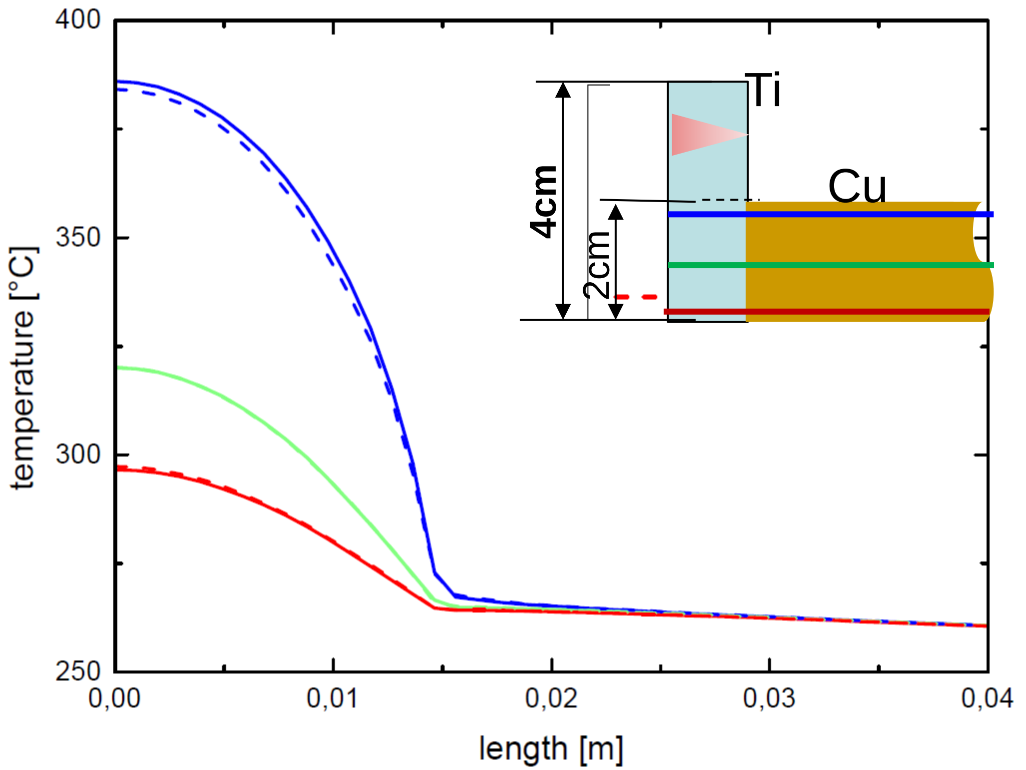
Equilibrium temperature distribution in target

Temperature evolution over time, ANSYS (Ti has low thermal conduct.)

- E_{cm} = 500GeV; E_{dep} = 2.3 kW; A ~2.8 m^2

Felix Dietrich





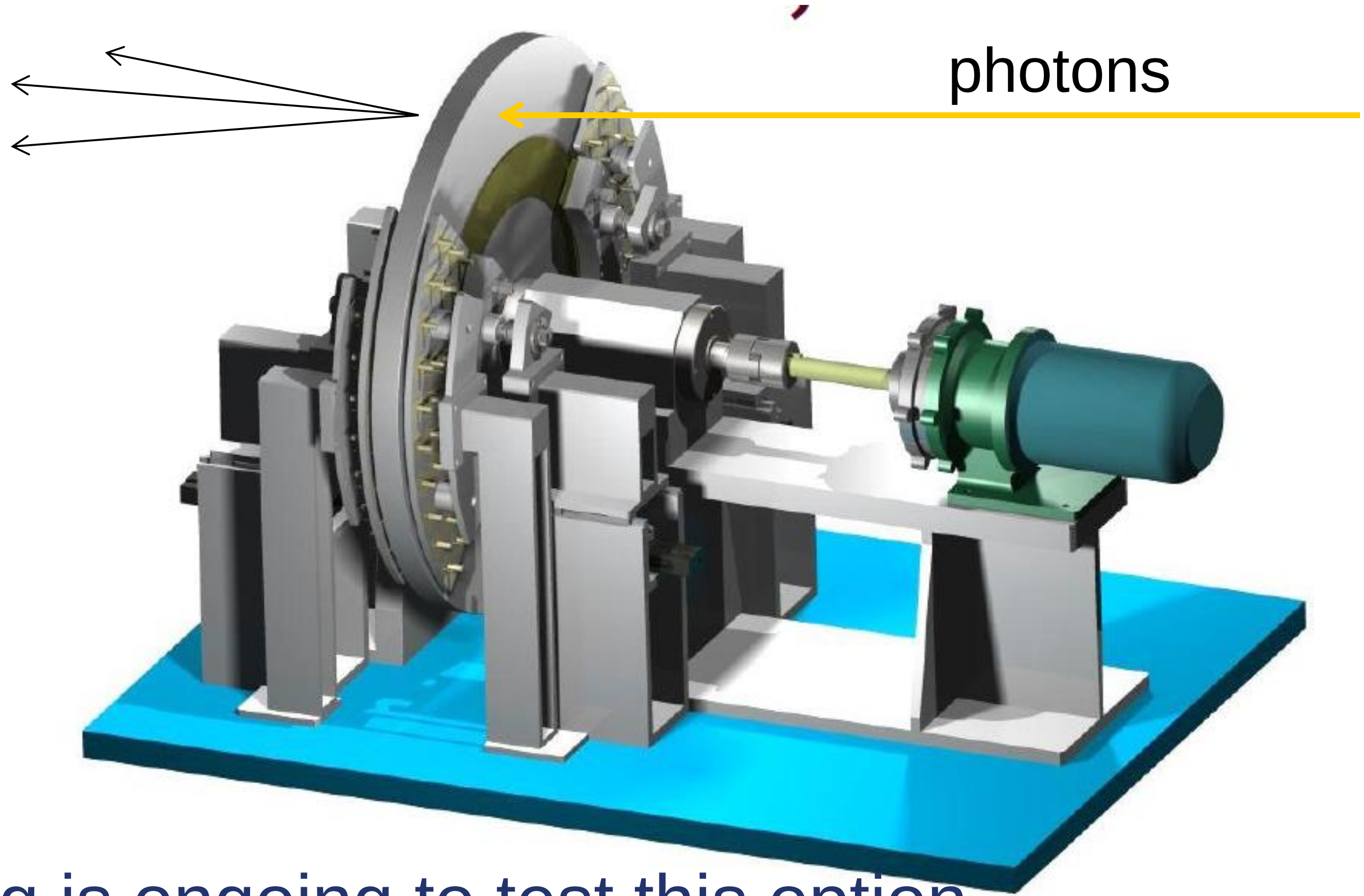
- After ~3 hours equilibrium temperature distribution reached
- $T_{max} \approx 570°C$ (a = 4cm)
- Distance beam path to Ti-Cu contact is important

→ Optimize target and radiator size for lower T_{max} in Ti

→ Heat transfer is also an issue for sliding contact cooling

Active sliding contact cooling

- W. Gai, ANL/Tsinghua



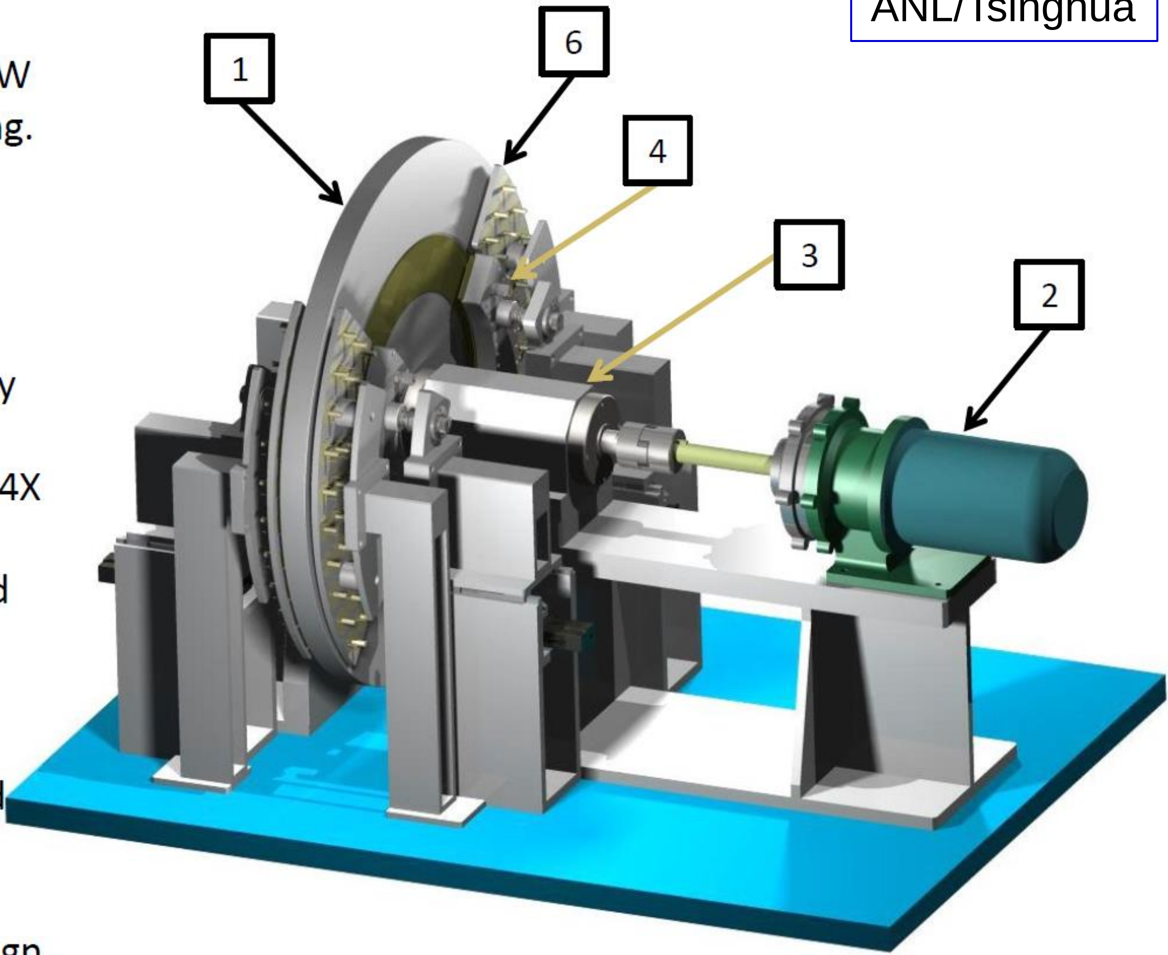
Prototyping is ongoing to test this option

Active Sliding Contact Cooling

Overview

ANL/Tsinghua

1. Rotating 1M dia Target Wheel at 2k rpm (100 m/s) while extracting ~10kW by using active sliding contact cooling.
2. Target wheel is driven by a magnetically coupled drive motor which separates the motor from the vacuum.
3. Stability of wheel controlled by heavy duty machine spindle.
4. Temperature of wheel controlled by 4X Active Sliding Contact Cooling Pads.
5. Cooling Pad's temperature controlled by water/coolant.
6. Heat applied to wheel using UHV radiant filament heaters.
7. Diagnostic feedback: RPM, Temp and Pressure of Cooling Pads, Temp of Target Wheel, Vibration, etc.
8. All material UHV compatible. All design parameters verified by our MathCad program.



Full Size Target Wheel Ready for Operations in Vacuum

Active Sliding Contact Cooling - Phase 1

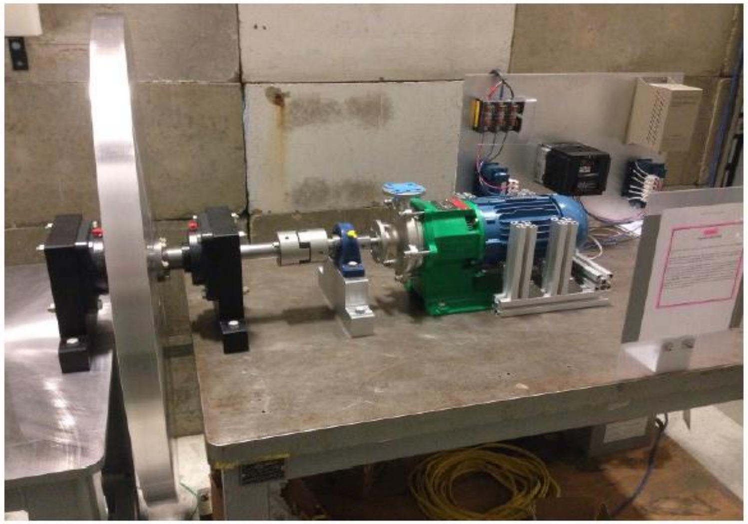
Accomplishments for Phase 1 - Drive System Test - Completed By Mid-August

• Vacuum Compatible Drive System • Test: Motor and Controls • Purchase Test Target Wheel
COMPLETED

– **No problem to run with 2000rpm**

Assembly with a test wheel

– **Safety regulations ⇔ no test until bunker / engineering safety enclosure has been setup and approved**



Plan

ANL/Tsinghua

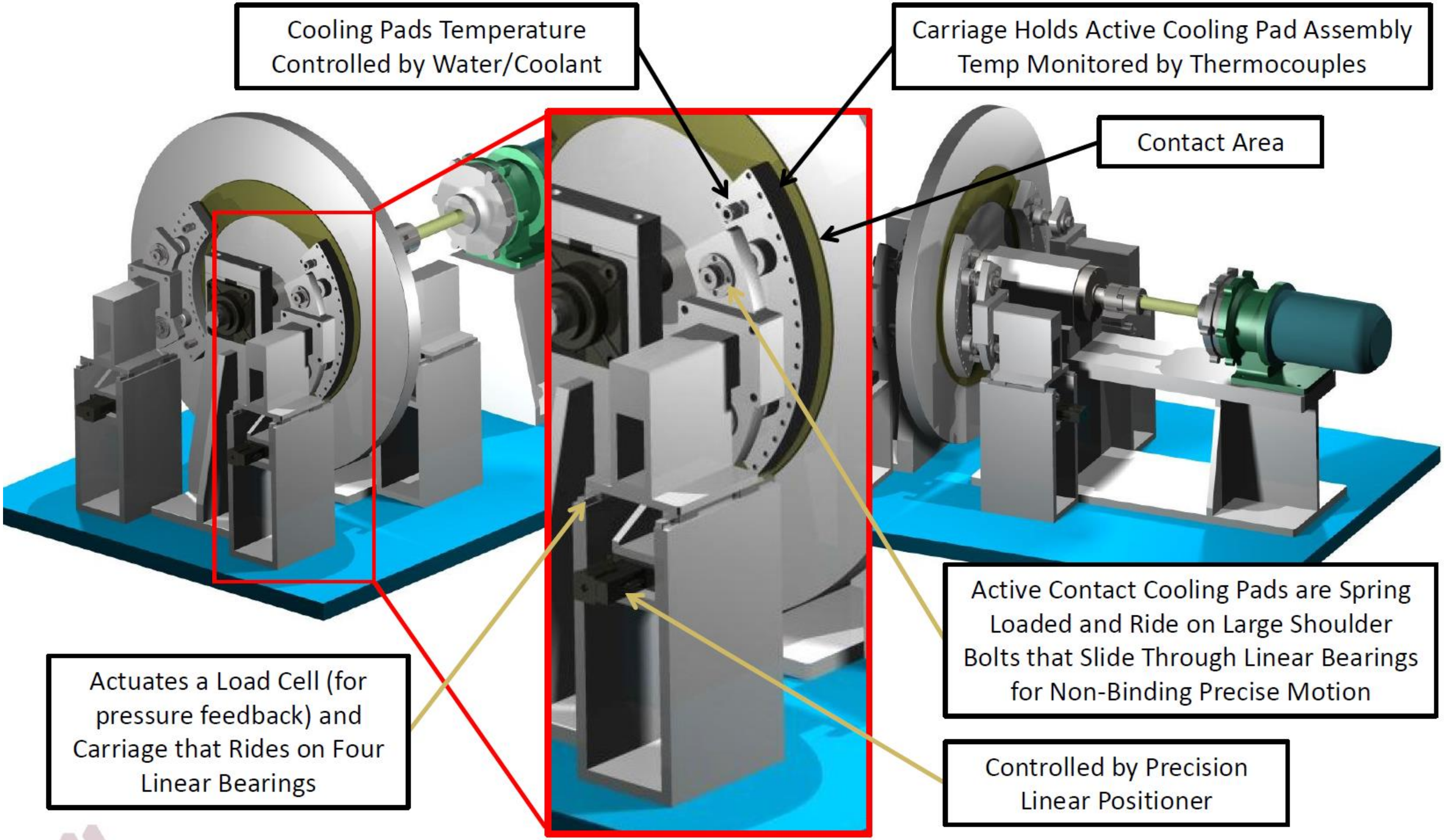
- Tribology study of the candidate contacting materials
  - **Sliding tests using vacuum-compatible dry solid lubricant → friction, wear data**
  - **SiC rings lapped to sub-wavelength flatness for counterfaces, with MoS2 for lubrication**
- The 1m diameter test wheel has been assembled.
- Phase 2: test the cooling system
- Phase 3: Vacuum test

Remark: mechanical/engineering issues (bearing, vacuum seals, …) are similar for thermal radiation and sliding contact cooling

Active Sliding Contact Cooling

ANL/Tsinghua

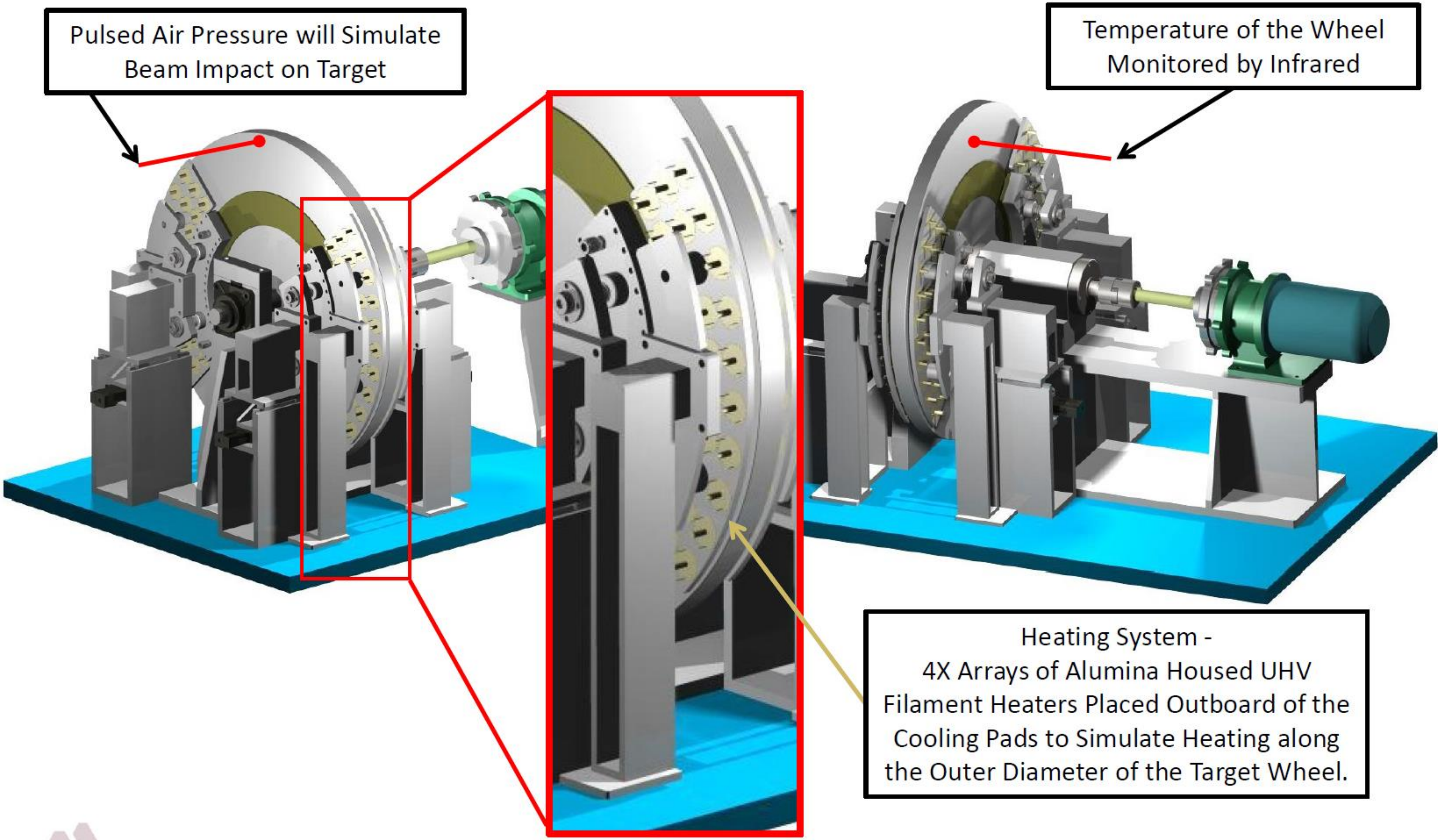
Deliverables - Phase Two - Cooling System Details



Active Sliding Contact Cooling

ANL/Tsinghua

Deliverables - Phase Two - Heating System Details



Undulator studies

UK group (I. Bailey, M. Jenkins, A. Alreshdi)

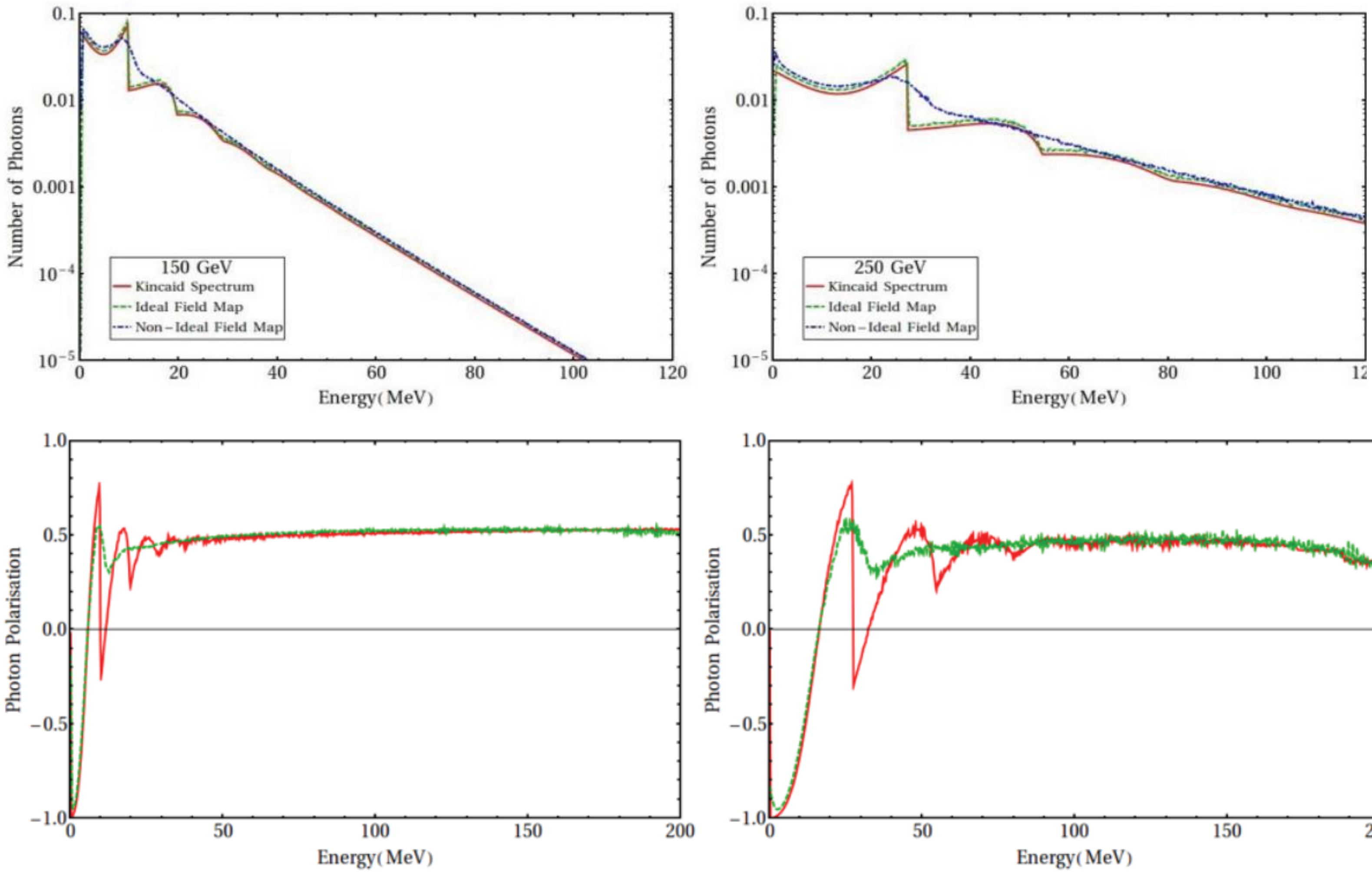
M. Jenkins: Effect of non-ideal undulators on e+ production

- **Yield and polarization**
- **HUSR/GSR code**
  - developed at Cockcroft Institute by David Newton; is still in development
  - simulates a photon spectrum from an arbitrary magnetic field map
  - Using different arbitrary maps is possible in HUSR e.g. include errors in the magnet, tapering, etc
- **Simulation for ILC TDR parameters**
- **Perfect alignment of undulator modules was assumed**
- **Only errors are errors in field within undulator module**

Non-ideal undulator spectra

M. Jenkins

E_{beam} = 150 GeV 250GeV



Positron yield and polarization

M. Jenkins

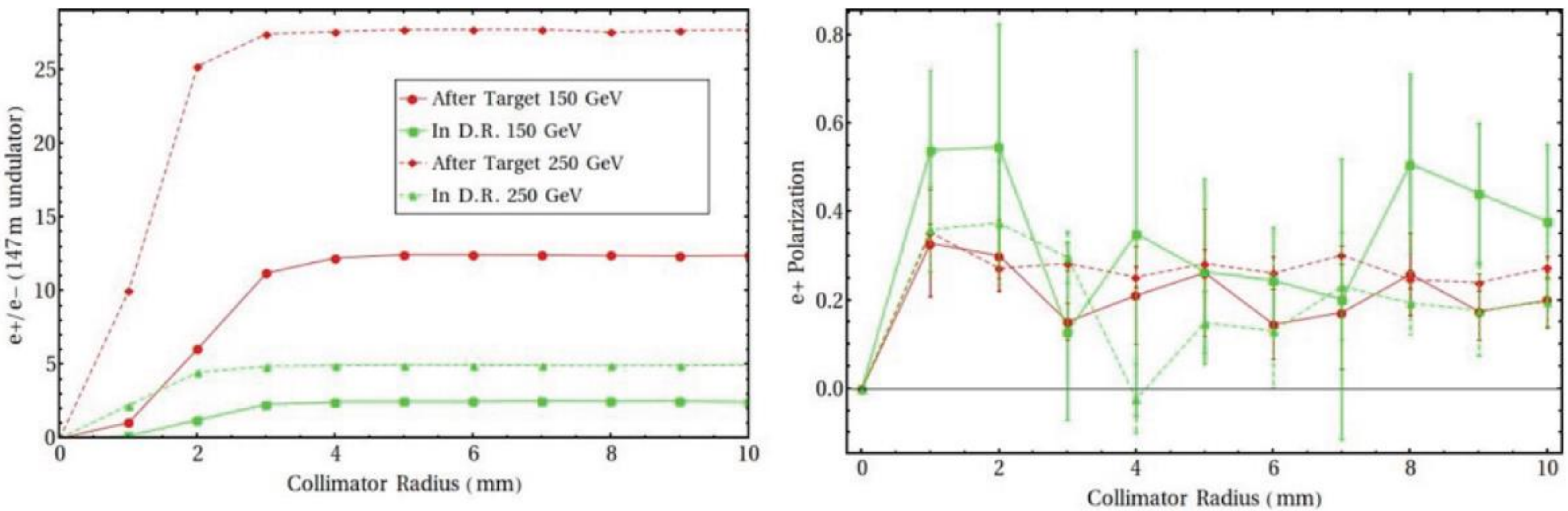
- ILC undulator, 147m long

	Ideal @150GeV	Non-ideal @150GeV	Ideal @250GeV	Non-ideal@250GeV
e+ yield [e+/e-]	2.5	2.7	4.6	4.7
P(e+) [%]	21.9	37.8	16.9	19.7

M. Jenkins

e+ polarization and yield with photon collimation

- Yield is not effected
- Polarization upgrade seems difficult for non-ideal undulator spectra



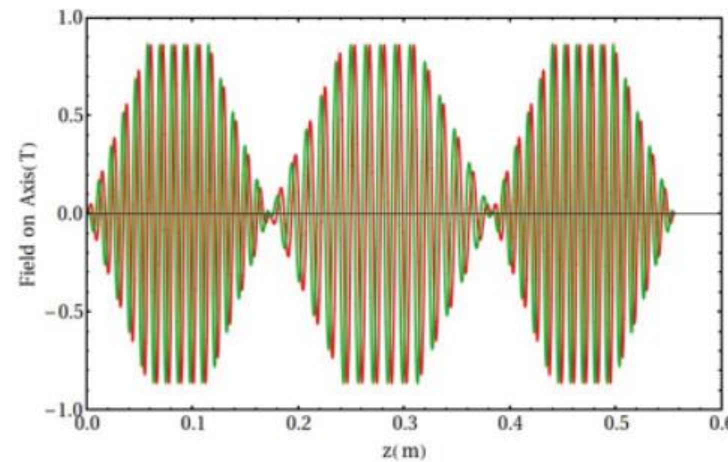
Results have to be checked and verified, further studies are needed

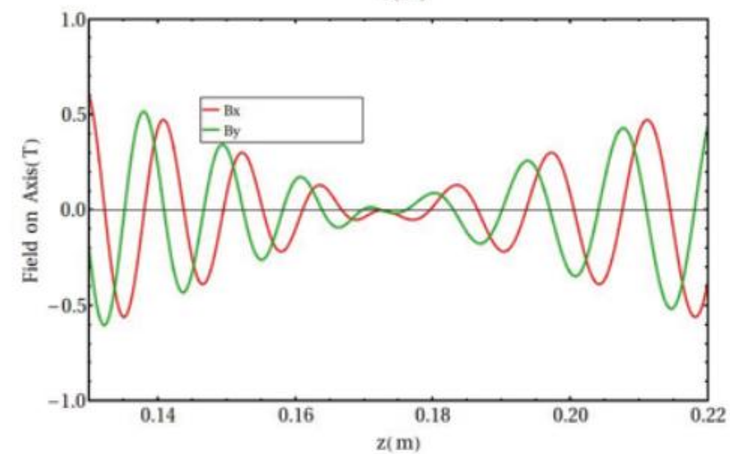
Optimizing the undulator

M. Jenkins

- Optimization to increase yield and/or polarization
- Interesting option: **multi-K undulator**

- Made up of several short undulators all in one module
- This example has three short undulators in one module each 15 periods long
- The first and third undulators have K= 0.92, the middle undulator has K= 1.12





M. Jenkins

Multi-K undulator

- e+ yield comparable, polarization increased
- More work needed

	Ideal @150GeV	Non-ideal @150GeV	Ideal @250GeV	Non-ideal @250GeV	Multi-K	
					150GeV	250GeV
e+ yield [e+/e-]	2.5	2.7	4.6	4.7	2.5	5.1
P(e+) [%]	21.9	37.8	16.9	19.7	41.9	23.9

Electron driven positron production

- Positron section & change request
- Status e- driven e+ generation
  - **Positron yield optimization**
  - **Positron conversion target**
  - **Radiation tolerance of magnetic fluid for vacuum seal**
  - **Target cooling**
  - **Flux concentrator**
  - **Plan**

Positron section (K. Yokoya)

- In the TDR, polarized positrons are produced by converting photons produced in a long undulator by the electron beam.
- The cooling for the converter tartet still needs substantial R&D.
- In addition, for very low-energy operation, the positron flux may not be sufficient.
- A backup scheme for positron production is under study using a conventional source, from which positrons will not be polarised. This must be compatible with the TDR accelerator tunnel layout so that both options could be installed in the same tunnel.

Change Request

K. Yokoya

- At this moment
  - It is obviously premature to change the baseline
  - But it is necessary to make the backup design ready
  - CFS design is the most urgent
- Possible contents of the change request
  - Make the CFS design compatible with both undulator source and e-driven source
  - For the tunnel design a system design of the e-driven source to somewhat detail is necessary
- Deadline
  - There is no rigorous deadline
  - But hopefully before November workshop
  - Tentatively, deadline for detailed design should be the end of September

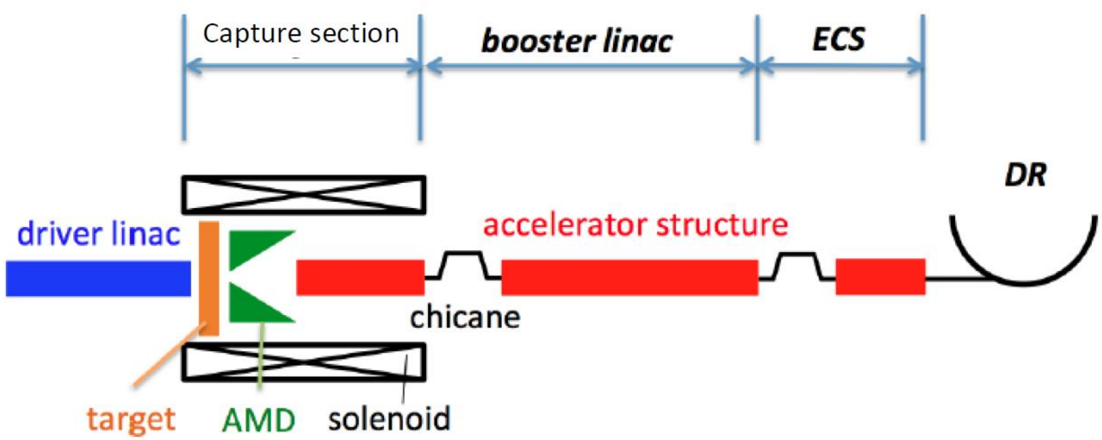
Preparing a Detailed Report on e-Driven Source

K. Yokoya

- System design of e-driven source
  - Simulation
  - Electron driver linac (S-band NC)
  - Target
  - Flux concentrator
  - Capture section (L-band)
  - Booster linac (L-band + S-band)
  - Energy compressor
  - Tunnel, Radiation safety (coupled with general BDS tunnel design)
  - Cost
- Least advanced is the booster linac
  - Drives the design of the tunnel
- Timeline: end of September (well before the November workshop at Whistler)
- Possible change request in ~October
  - Compatible tunnel design for undulator plus e-driven sources
- This work is also needed for the response to Nomura survey

Status e- driven positron generation

- See Andriy’s talk today
- Layout
  - **6GeV e- linac**
  - **Capture section (target, flux concentrator, L-band 300Hz NC linac) → 250MeV e+, chicane to separate e+ from e- and photons**
  - **Booster linac up to 5GeV L band and S–band NC**
  - **Energy compression to fit to DR phase space**



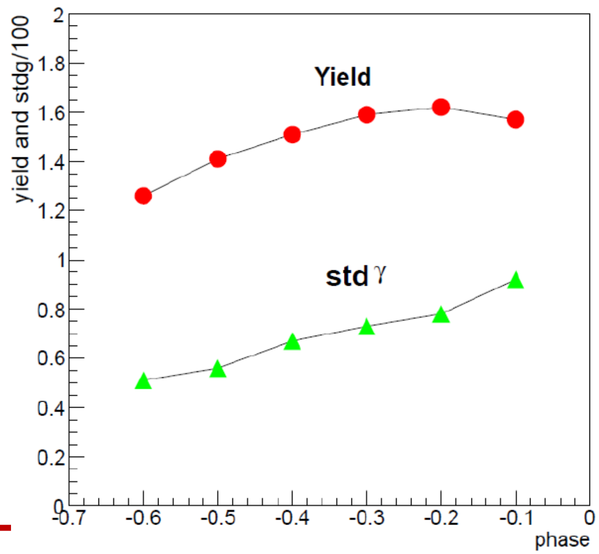
Positron yield optimization

M. Kuriki

See M. Kuriki; re-evaluated capture efficiency assuming realistic and conservative RF configuration including beam loading effect

- Rms spot size on target: 4mm (peak energy deposition density <30J/g)
- L-band SW structure based on structure designed by J. Wang for the undulator capture section; but structure has large aperture (2a=60mm), optimized for the e+ source ⇔ higher yield
- Field gradient is 25MV/m at zero current, 10MV/m at 2A beam loading
- Transverse motion in booster and ECS is considered but tracking simulation is desired to estimate the exact yield

Parameter	Value	Unit
Drive Beam Energy	6.0	GeV
Target material	W-Re	
Target thicknesss	14	mm
Beam Size (rms)	4.0	mm
AMD peak field	5.0	T
R_{AMD} (smallest aperture of AMD, 2a)	16.0	mm
Average gradient (MV/m)	8.4 – 22	MV/m
Accelerator Aperture (2a)	60	mm
Solenoid	0.5	T
Booster	Hybrid (L-band + S-band)	



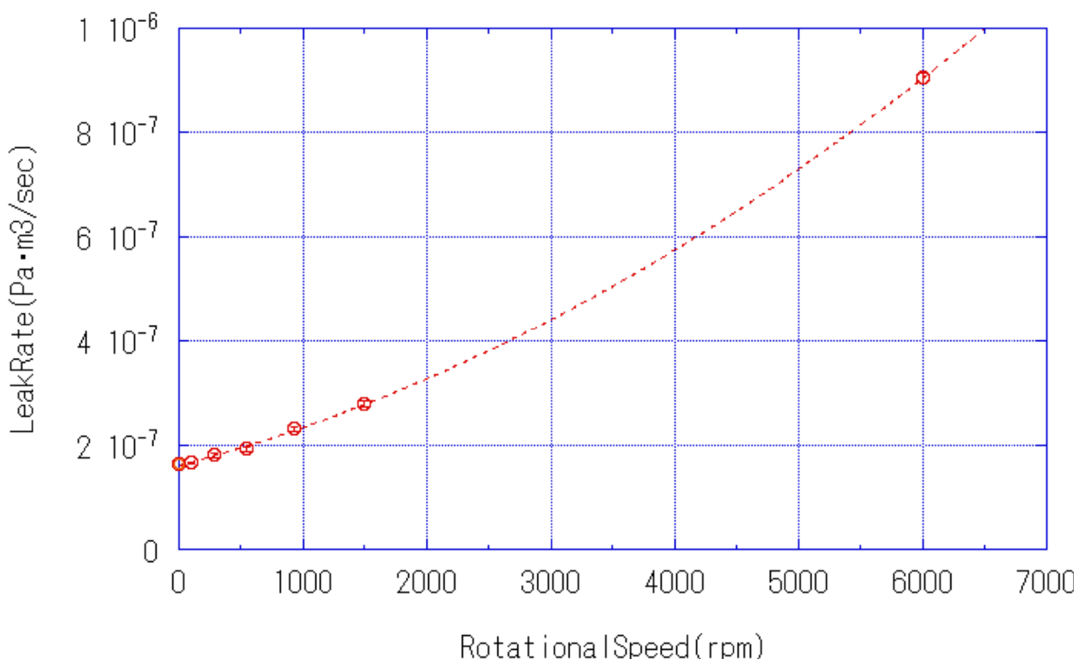
T.Omori

The e+ conversion target

W-Re disk in vacuum, d=1.4cm, Ø = 0.5m; rotation: ~5m/s at the rim

- Issues:
  - **Vacuum seal**
    - Use magnetic fluid
    - Leak rate <10^{-7} Pa can be achieved → ok (both CN-oil and F-oil)

FY2014

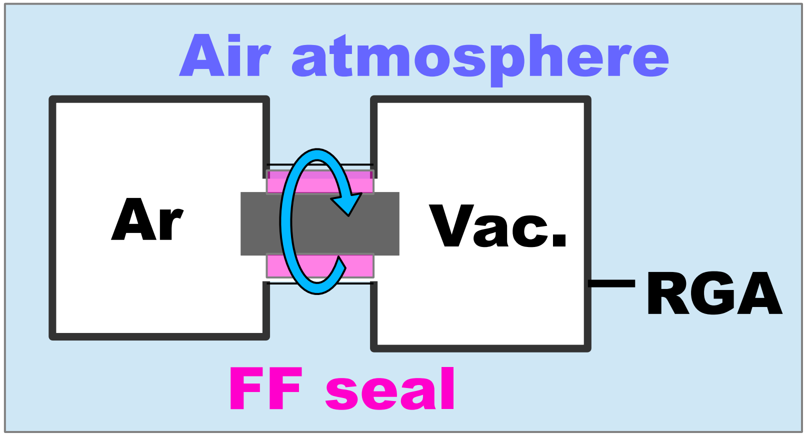


  - **Degradation under radiation ⇔ tests**
- Prototype (same size and weight as real) to be fabricated and tested in FY 2015-16

T.Omori

Radiation tolerance of magnetic fluid

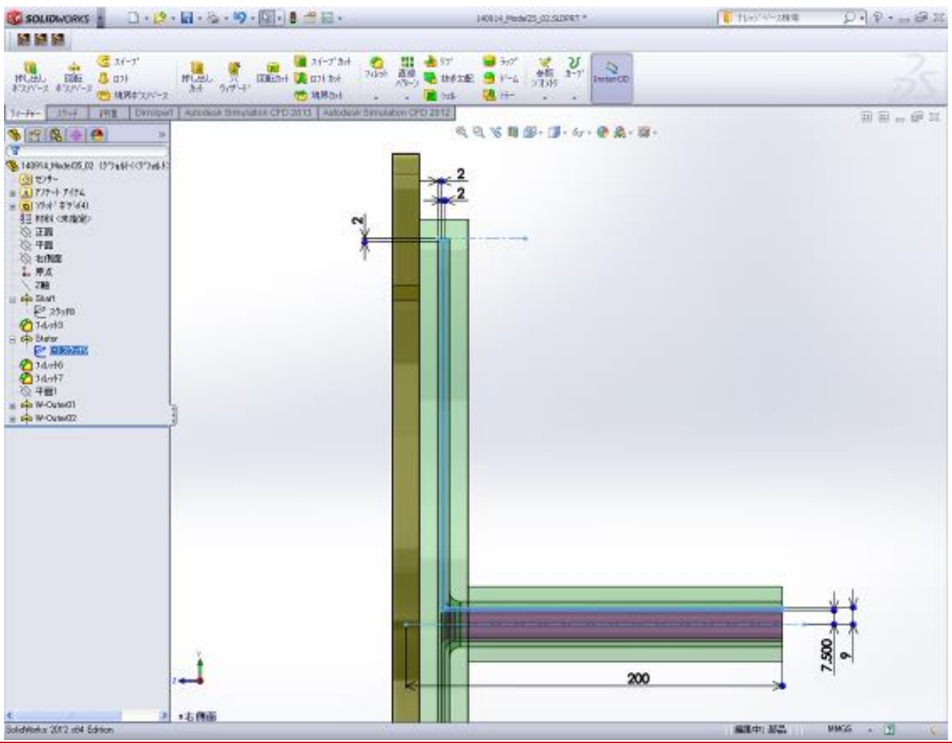
- Simulation of the target region: 1.5MGy/year (2630 bunches /pulse, 1year = 10^7s)
- Test with γ-ray source, Co-60, at the Takasaki Advanced Radiation Research Institute, JAEA
  - **F-oil – dissociation already at low dose (0.27MGy)**
  - **CN-oil: increased viscosity, but NO dissociation**
  - **test continued, used irradiated fluid in vacuum seal:**
    - The seal with fluid dosed with 4.7 MGy (3 ILC years) is examined with Ar purged chamber.
    - Rotation : 0 - 600 rpm.
    - No leak was found.

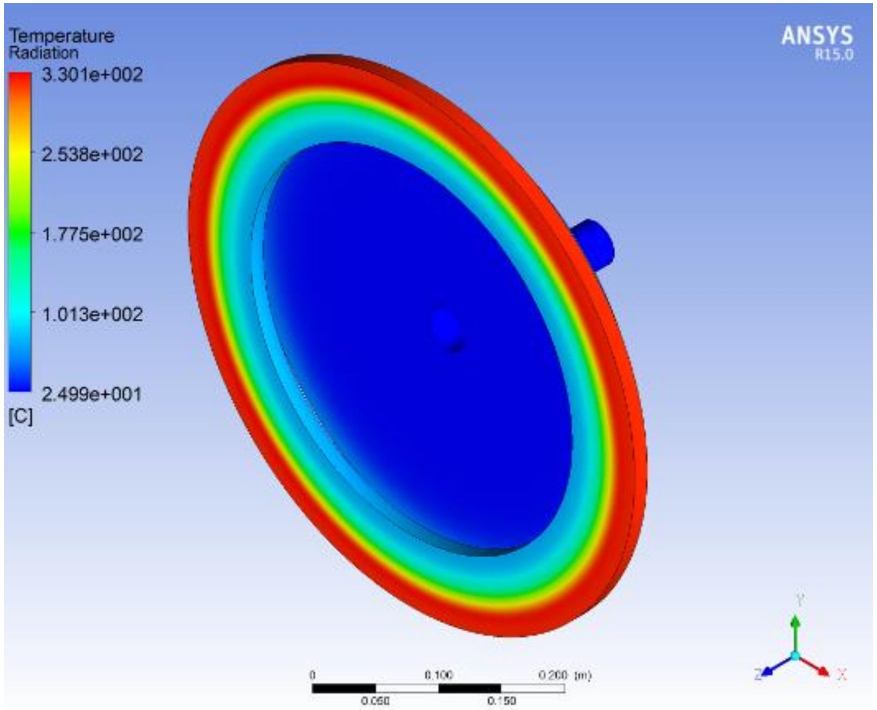


T.Omori

Cooling of the target wheel

- About 35kW are deposited in the target
- Indirect cooling (water circulating in Cu, no direct contact to W) is found to be much better
  - **600rpm, max Temp is 330°C**

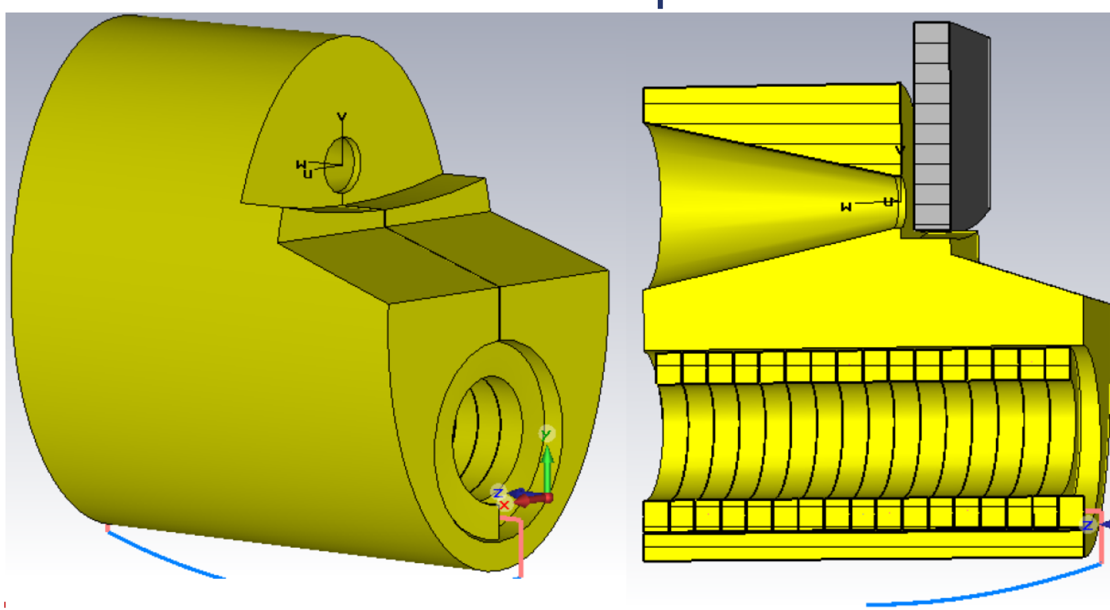


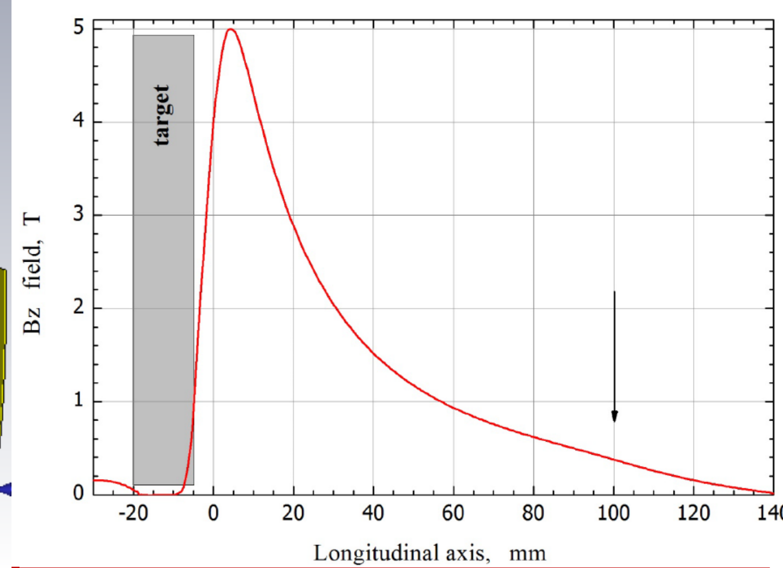


P. Martyshkin

Flux concentrator (FC)

- Talk by P. Martyshkyn (BINP)
- Nose FC type with front aperture of 16 mm looks mostly acceptable as ILC matching device.
- 5T peak field, pulse duration 25μs
- e+ yield computation with real field is required
  - adiabatic decreasing of longitudinal profile
  - transverse component field value on axis





T.Omori

FC leakage field on target

- B-field on rotating target → eddy currents → heating
  - **1 kW (3.2 kW in 63 msec). This is 1/30 of the heat deposited by the beam**

  → no problem
- Braking power, attractive/repulsive forces are small → no problem

T.Omori

Plan

- Design study was made with company (RIGAKU)
- Full-size prototype will be built (FY2015-2016)
  - **Diameter of wheel is 500 mm**
  - **Weight and moment same as those of the real**
  - **locations of the vacuum seal and bearing as in real target**
  - **no water channels, water circulation is within the past experience of the company**
- irradiated ferromagnetic fluid will be used in the prototype
- continuous running test (~1 year?) → prove that vacuum is always at good level

CLIC Project status

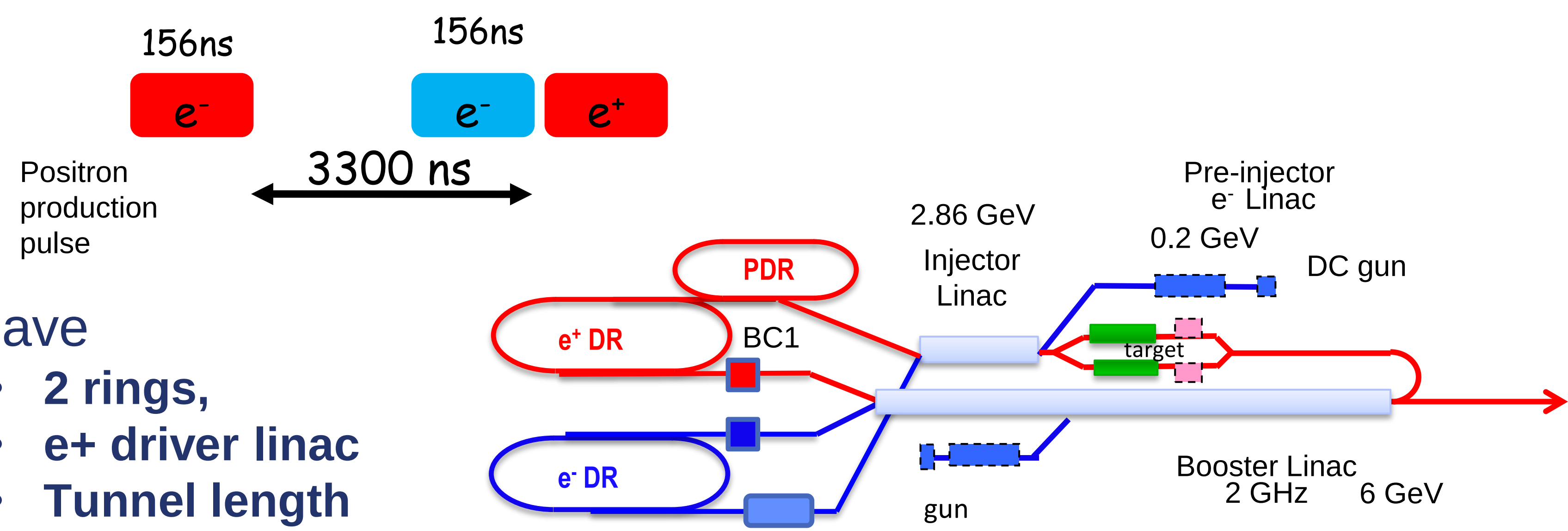
- Talks:
  - S. Doebert: Overview CLIC Status and plans
  - Beam Dynamics Studies of the CLIC Positron Source (C. Bayar, Ankara Uni/CERN)
  - Investigations on a reliable Positron Source for ILC and CLIC with the Hybrid Target (I. Chaikovska, LAL/IN2P3-CNRS)
- 2013-18: Development Phase
  - **Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors**
- 2018-19: Decisions
  - **On the basis of LHC data and Project Plans (for CLIC and other potential projects as FCC), take decisions about next project(s) at the Energy Frontier.**

→ CLIC program maintained essentially until 2018;
well defined program to consolidate technical work and documentation for the project implementation plan but severe lack of resources (mainly manpower)

S. Doebert

Status of the CLIC Injectors

- Unfortunately not much work done lately since not a priority
- New baseline studies focus on cost savings, just got the potential new parameters
- Some work started on the e+ source
  - **Alternative CLIC baseline layout: without driver linac and e- PDR, 2GHz bunch spacing everywhere**

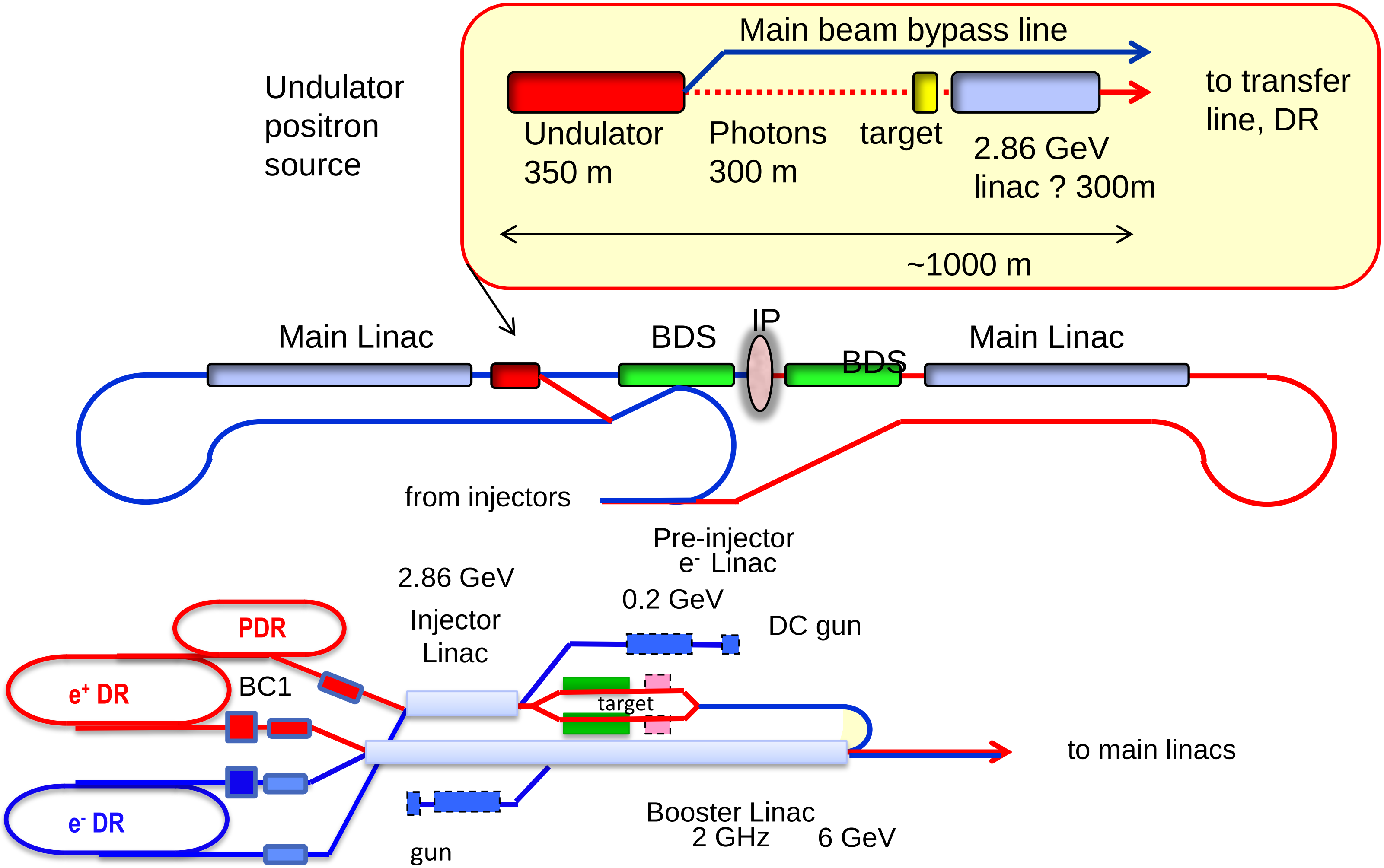


→ Save
- **2 rings,**
- **e+ driver linac**
- **Tunnel length**

potential: 200MCHF

S. Doebert

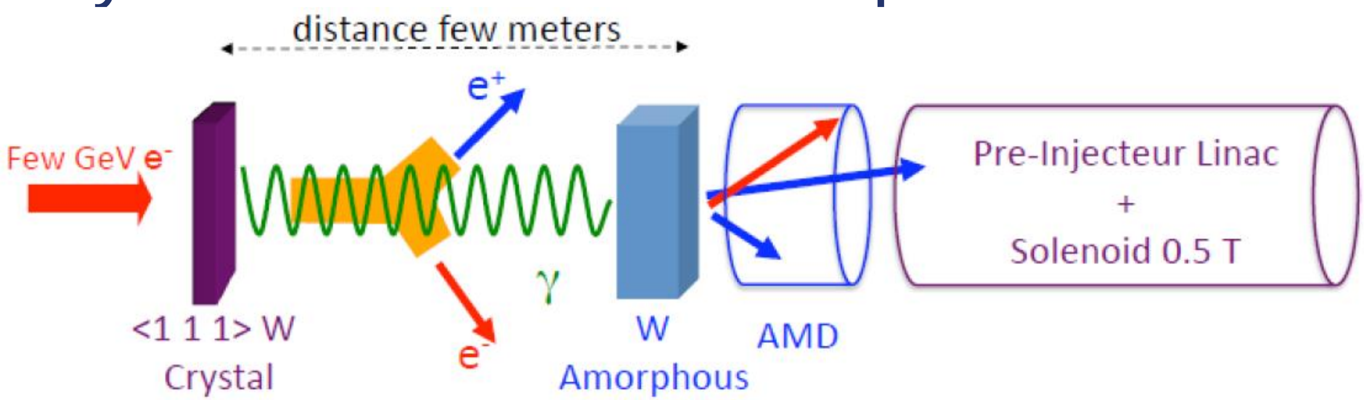
CLIC layout with undulator based e+ source



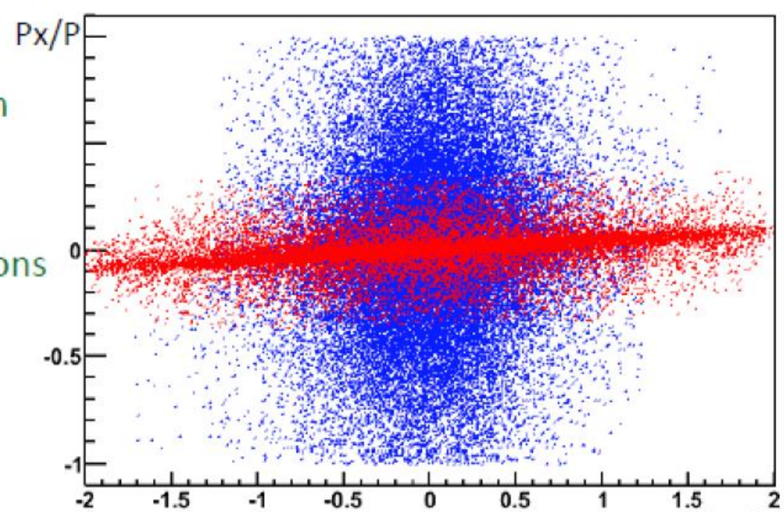
C. Bayar

Hybrid target to generate e+ at CLIC

Study of AMD effect on the positron beam (Cafar Bayar)



- $B(z)=B_{min}/(1+\alpha z)$
  - B_{max} = 6 T, B_{min} =0.5 T, L=0.2 m
- After the AMD
  - Small angles & large dimensions easier to transport
- e^+ yield (Ne^+/Ne^-) : 1 to 4
- $\langle E_{e+} \rangle$: 50 to 110 MeV



Blue:
after target
Red:
after AMD

Solenoidal field of 1T instead of 0.5T ? Studies are ongoing as well as optimizing the whole system

T. Okugi: *Consideration to arrange the beam sources to ILC BDS tunnel (Confirmation of the present ILC optics deck)*

The ILC BDS and CFS group must have communications with source group to design the BDS tunnel layout.

1st Step ; We want to make a baseline ILC BDS tunnel design of tunnel cross section and conventional facilities by LCWS2015.

The questions in this presentation is important to design the baseline ILC BDS tunnel.

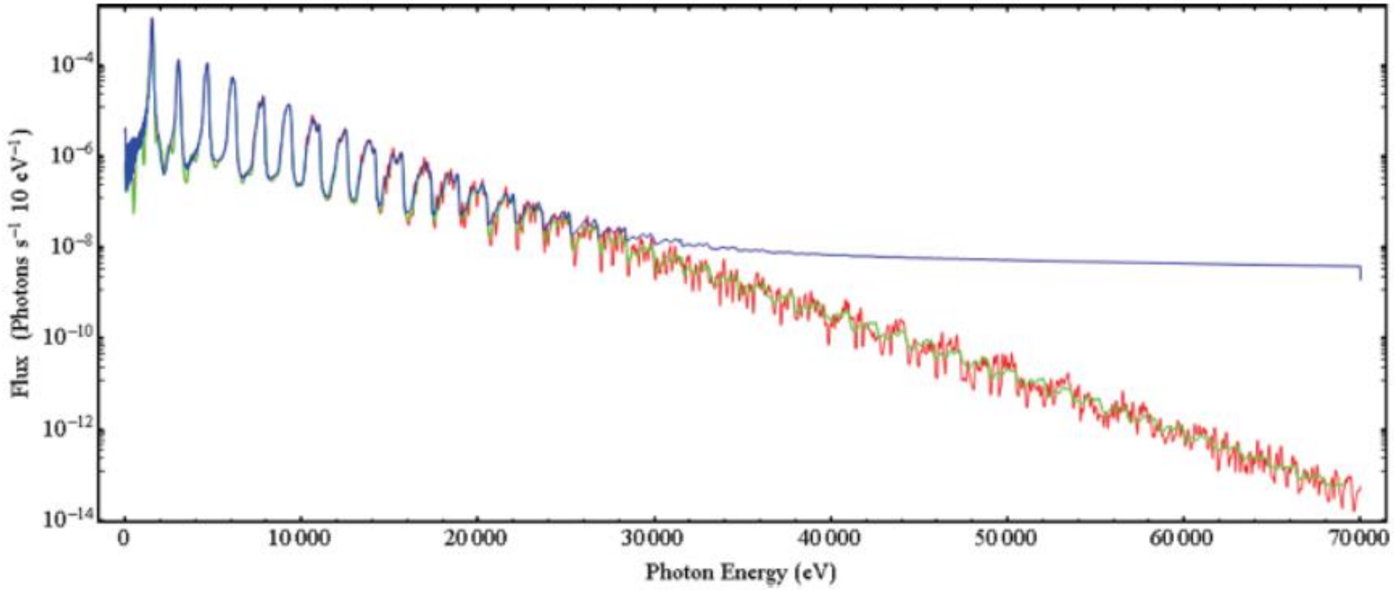
2nd Step ; We want to make a detail ILC BDS tunnel design for special section (capture section etc.) by the end of JFY2015.

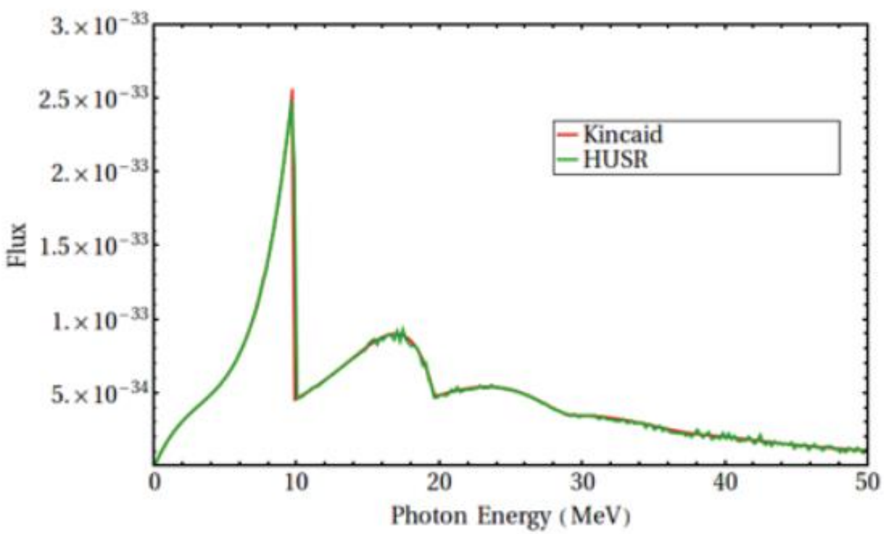
The face-to-face discussion in LCWS2015 is important to design the special section of BDS tunnel.

Thank you!

Backup

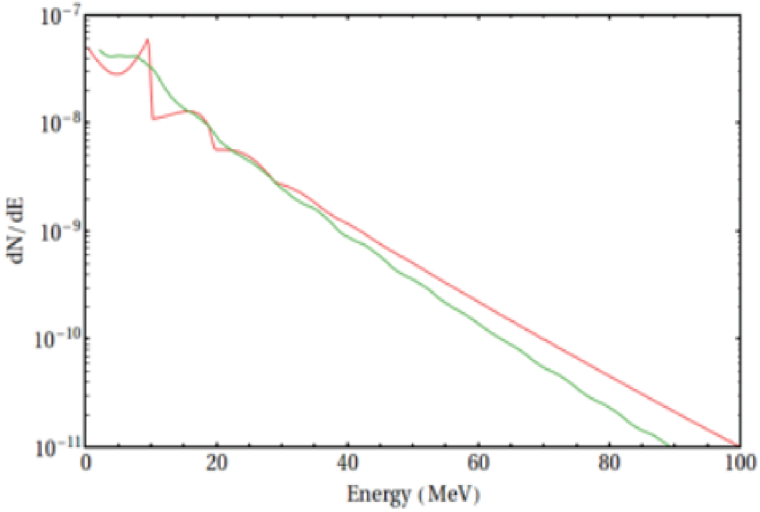
Benchmarking HUSR

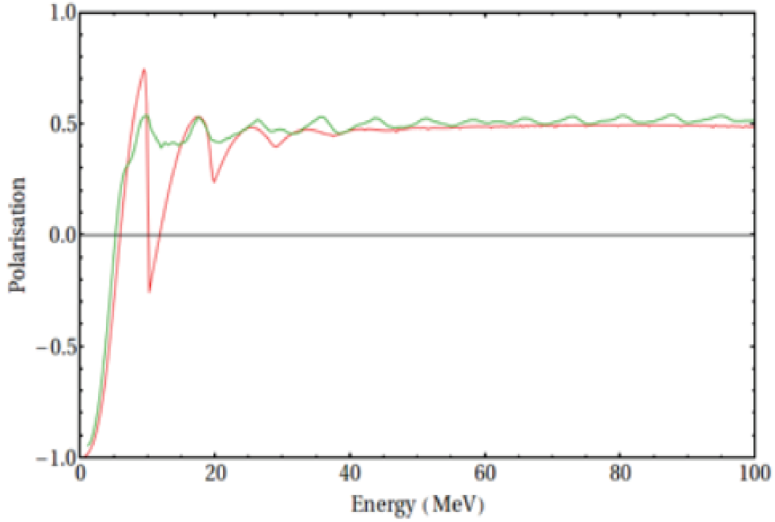




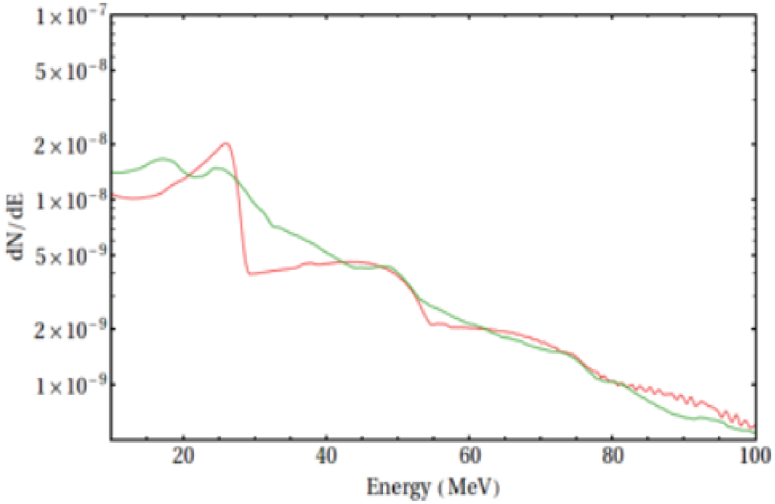
Multi-K Undulator Spectra

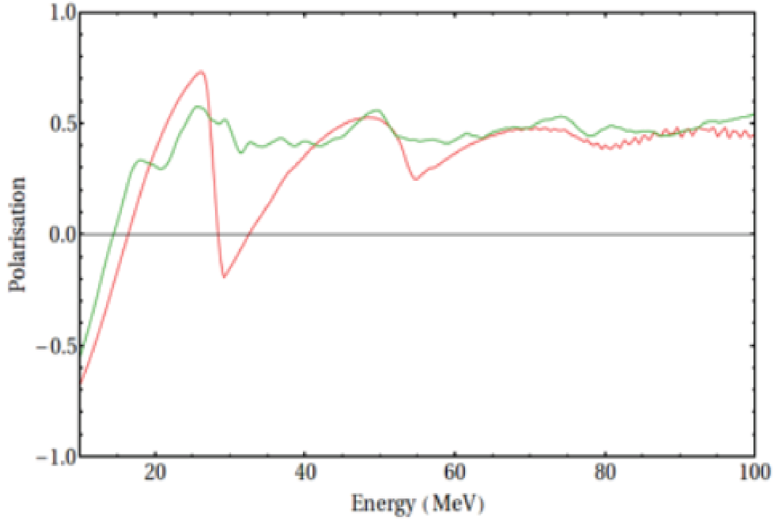
150 GeV





250 GeV

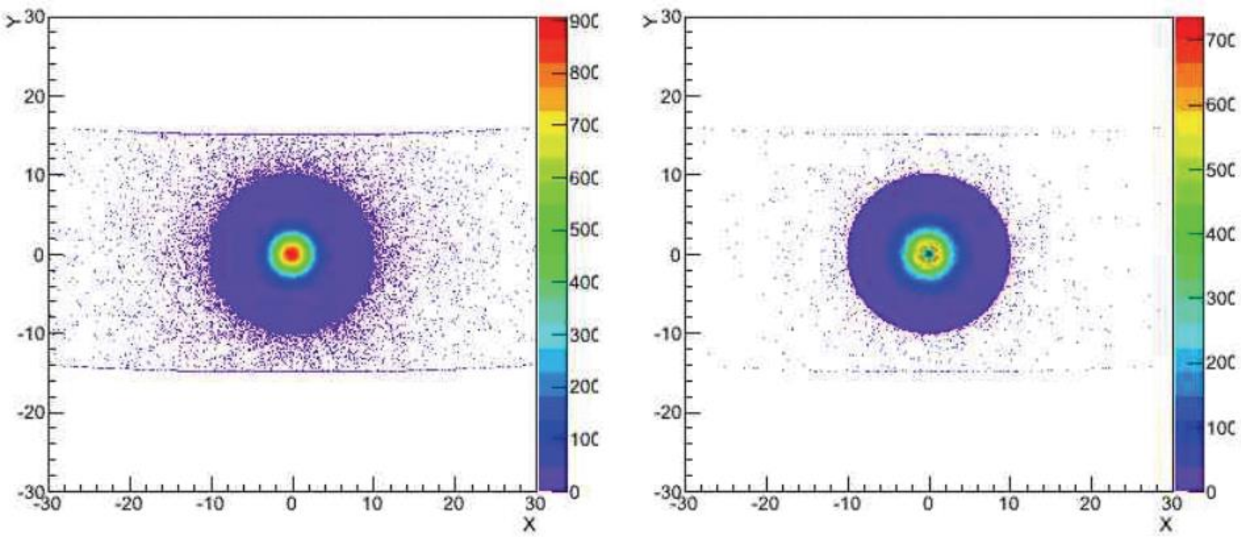




	Ideal @ 150 GeV	Non-Ideal @ 150 GeV	Ideal @ 250 GeV	Non-Ideal @ 250 GeV
Positron Yield (e+/e-)	2.49	2.72	4.56	4.73
Positron Polarisation (%)	21.93	37.80	16.88	19.66
Positron Polarisation Spread (%)	16.65	17.44	2.04	5.56

- Increasing Pe+ by photon collimation

ideal



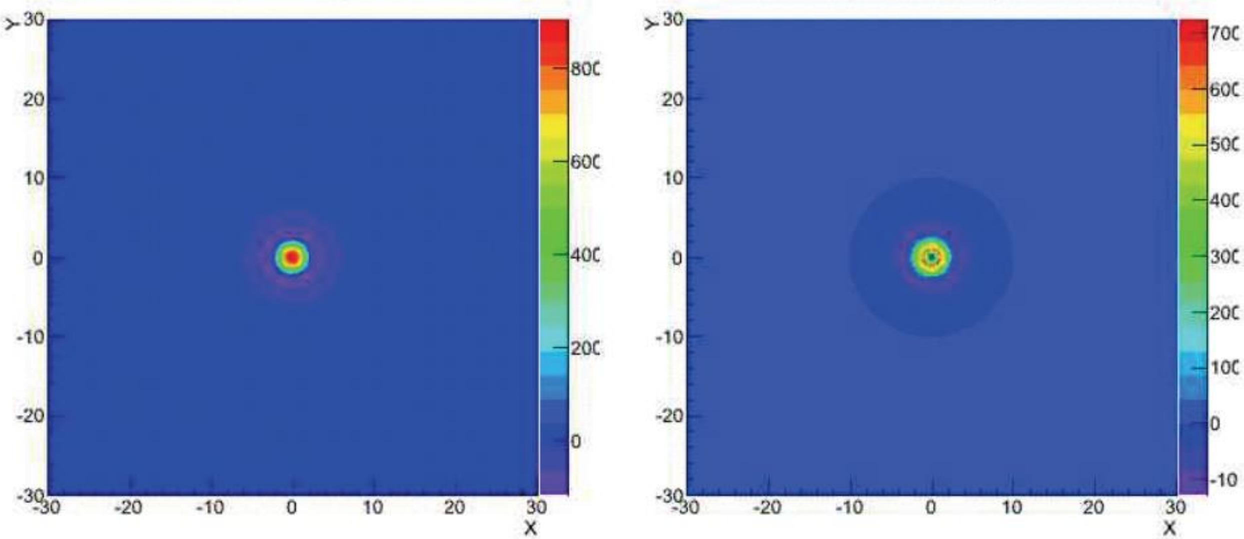
Non-ideal

Photon distribution on the target rim for 150 GeV

	Ideal @ 150 GeV	Non-Ideal @ 150 GeV	Ideal @ 250 GeV	Non-Ideal @ 250 GeV
Positron Yield (e+/e-)	2.49	2.72	4.56	4.73
Positron Polarisation (%)	21.93	37.80	16.88	19.66
Positron Polarisation Spread (%)	16.65	17.44	2.04	5.56

- Increasing Pe+ by photon collimation to ~40%

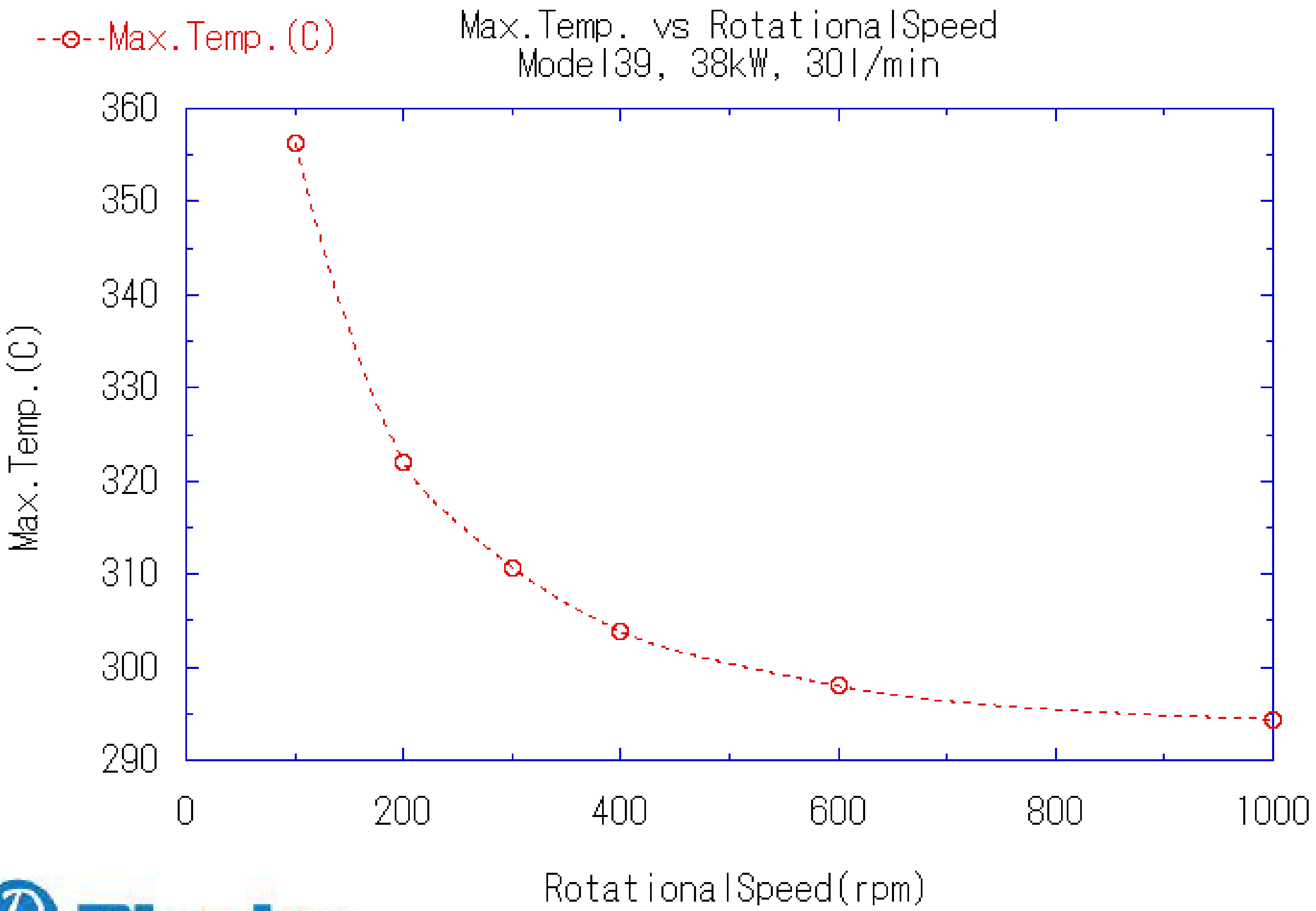
ideal



Non-ideal

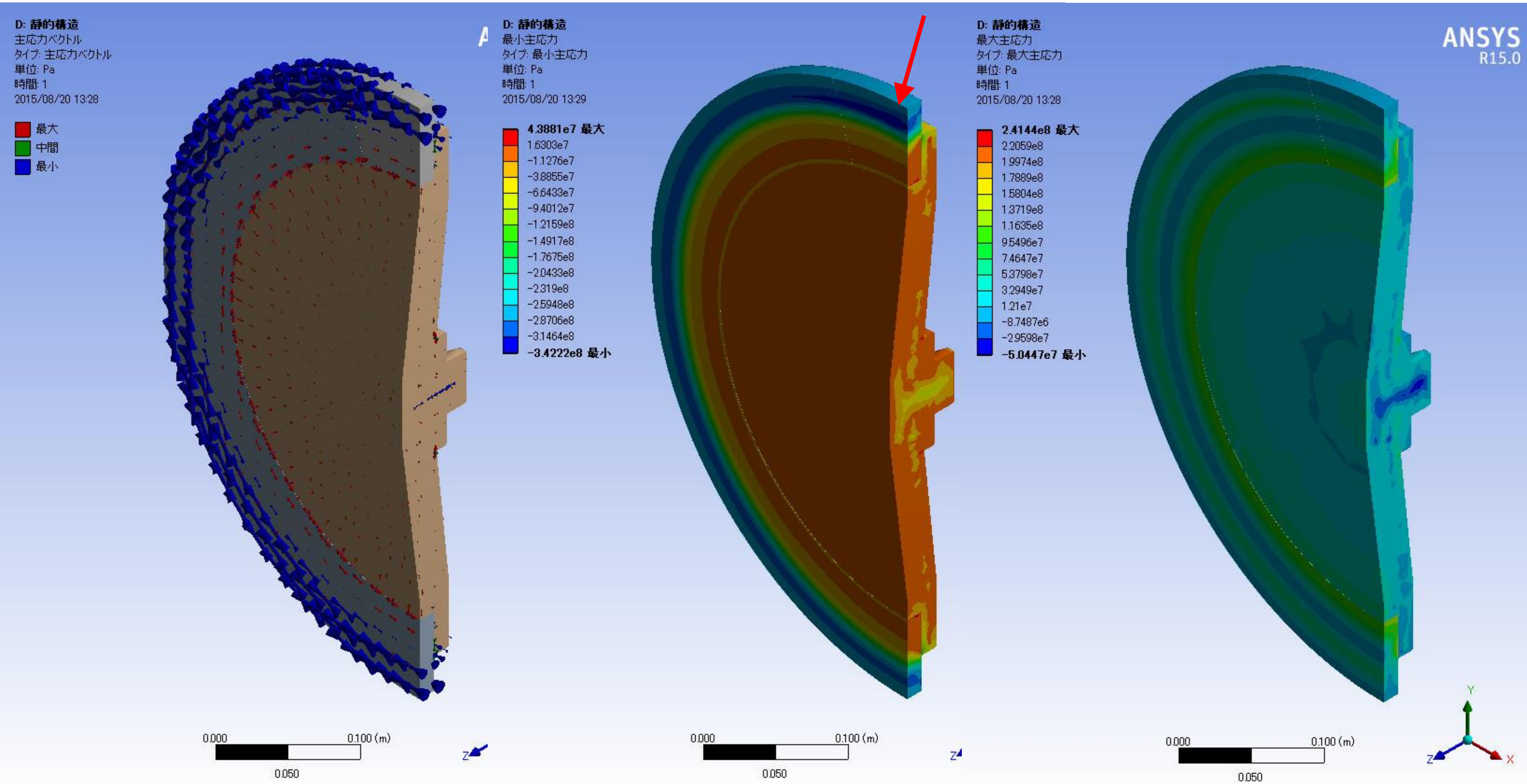
Photon polarisation distribution on the target rim for 150 GeV

Temperature in various rotation speeds: 38kW(CW analysis)



–Nb=2600

Stress: rotation speed 200 rpm, 38kW(CW analysis)



Direction (arrows)

Min Principal Stress (Compression)

→ - 3e+8Pa

Max Principal Stress

(Expansion)

→ 2e+8Pa

Rigaku

~~Nb~~–2600

高温部の応力を正確に得る為に非定常解析が必要

Comparison

P. Sievers

- Conventional e-Beam Driven Target.
- Prototyping:
- Vacuum with a rotating seal.
- Thermal contact between W-target and Cu-cooler: brazing (R+D); clamping.
- Target must tolerate high peak temperatures and thermal shock.
- Bake out of wheel.

- Undulator Driven, Radiation Cooled Target.
- Prototyping:
- Magnetic bearings, rotation and control of the wheel. weight, centrifugal forces and balancing.
- Thermal contact between Ti-target and Cu-cooler: brazing (R+D); clamping.
- No shocks, but target must tolerate high average temperatures .
- Bake out of wheel.

Summary of Questions to Undulator Positron Group

1. *Can I fix the following geometries to consider the tunnel layout ?*

- Length of undulator to 236.016m (319.836m) .
- Drift space from undulator to target as L=412m.

2. *Do you accept the following optics change ?*

- The quadrupole length for undulator cell was increased to 1.0m.
- Gradient of booster linac was set to 27MV/m.
- Length of quadrupoles and cryomodules at booster linac will be changed by discussing with the specialist of SC magnet.
- The backup cryomodules in positron booster linac was arranged as well as electron booster.
- Energy compressor was moved to upstream and changed the parameter to R56=1.4m.
- Path length adjuster was put just after energy compressor.
- Long transport line was gathered after path length adjuster.
- Spin rotator was changed to use normal conducting solenoids.

Could you please tell me the above answers after discussion within group (It is better by the end of this month, at least by LCWS2015) ?

3. *Shall we discuss the layout of the capture section in LCWS2015 (face-to-face meeting) .*
In the meeting, we need the following information.

- geometries from undulator to the end of capture section (up to 125MeV).
- the power loss distribution in capture section.
- size of power supply for flux concentrator and size of apparatus for target.

Summary of Questions to Electron Source Group

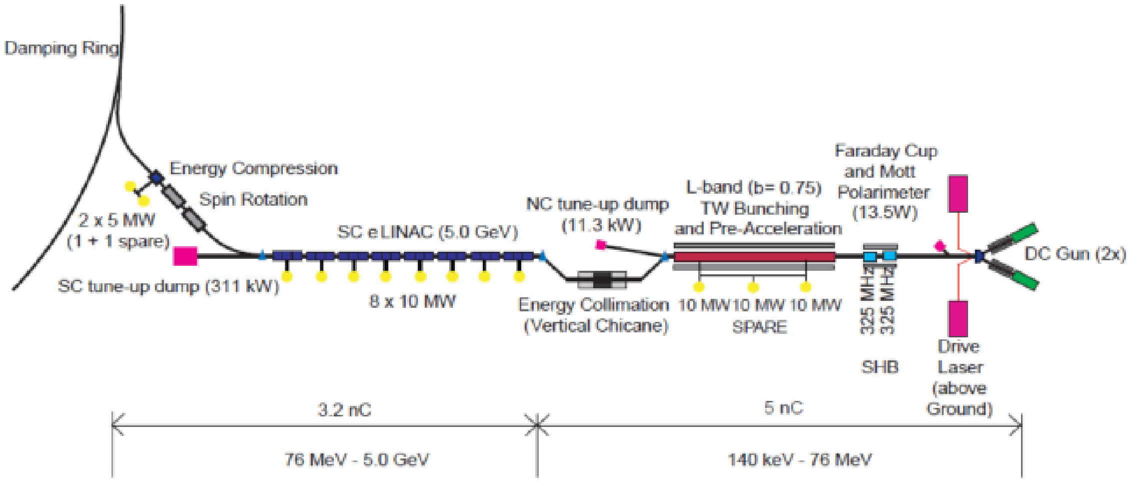
1. Do you accept the following optics change ?

- *Vertical chicane is arranged after 76MeV pre-acceleration, but it is difficult to arrange in beamline (2.80m higher than flour level). Can I change to horizontal chicane ?*
- *Energy compressor was moved to upstream and changed the parameter to R56=1.4m.*
- *Spin rotator was changed to use normal conducting solenoids.*

Could you please tell me the above answers after discussion within group. (It is better by the end of this month, at least by LCWS2015) ?

2. *Shall we discuss the layout of the injector section in LCWS2015 (face-to-face meeting) .*
In the meeting, we need the following information.

- *arrangement of the injector section (GUN to pre-accelerator, no deck in the file storage).*
- *size of power supply for SHB and DC-gun.*
- *size of laser rooms*



Considerations of the electron driven positron source to be integrated to BDS tunnel

Radiation shielding for capture section.

The shielding and the arrangement of capture section is key issue to integrate the beamline to BDS tunnel.

(The radiation dose is 3-4 times larger than SLC, twice more for high luminosity upgrade.)

The electric power and cooling water facilities

The electric power and the capacity of cooling water is roughly 20MW. These are not included in TDR.

Installation procedure and schedule

We must install 28 cryomodules etc. in BDS tunnel for undulator PS.
In parallel, 200 klystron and modulator etc. also must install for electron-driven PS.

Can we install at the same time with same access tunnel ?