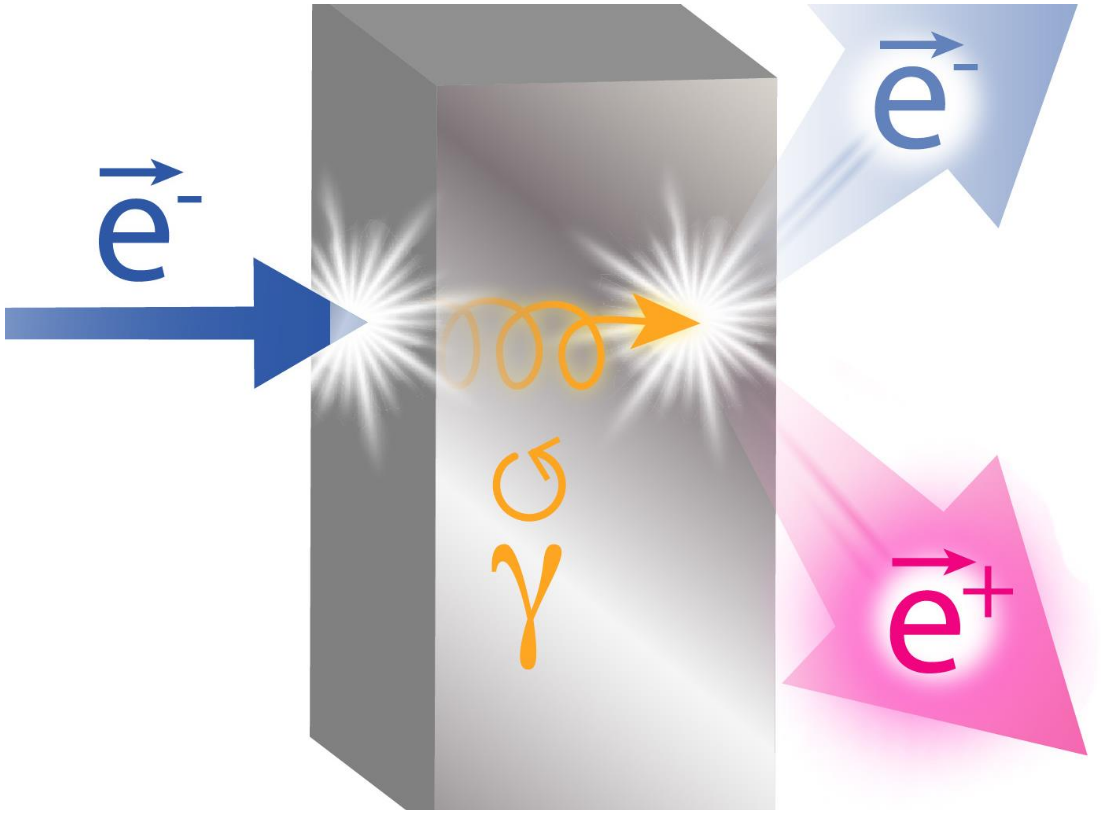
JLAB Positron Target

- Positron target design with CFD
- Target concepts for JLab's e+ source
- Prototype target status
- Summary



Silviu Covrig Dusa (for the Ce+BAF Collaboration)

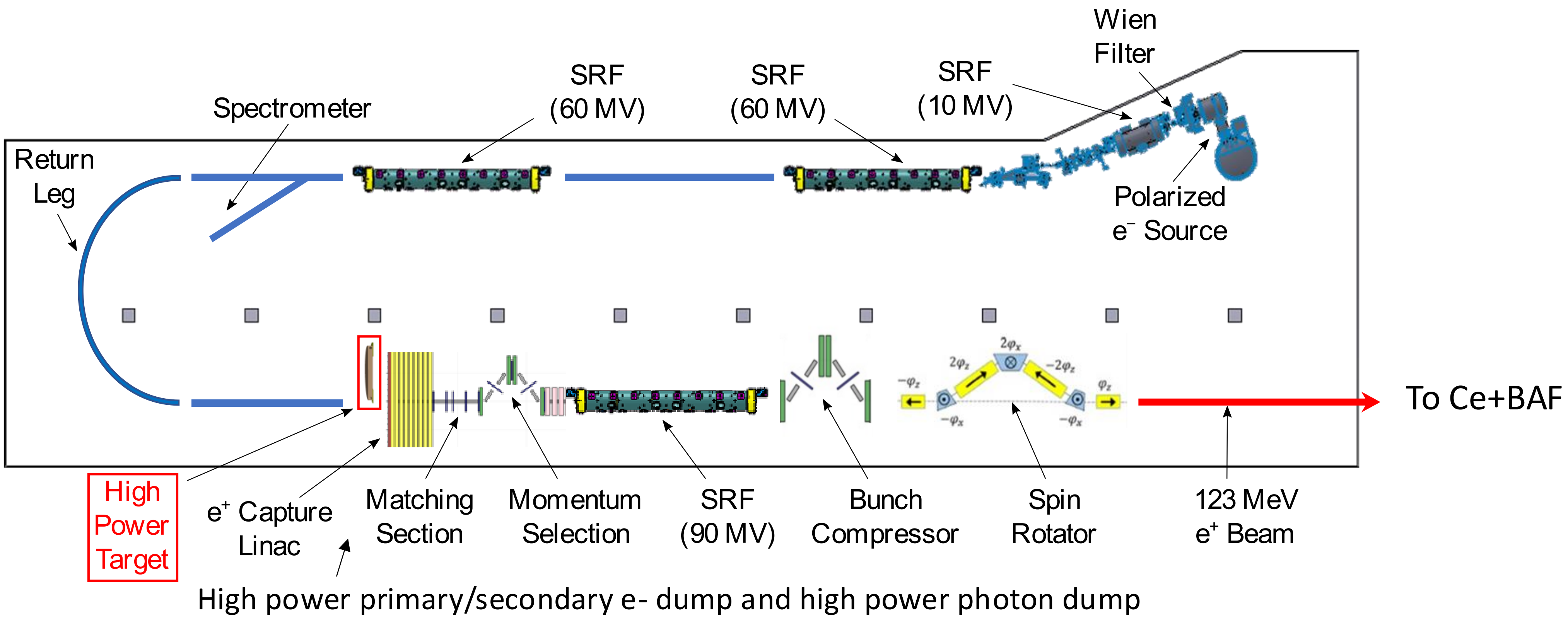
Jefferson Lab

PWG annual workshop

24-26 Mar 2025

LERF Polarized Positron Source Concept

- LDRD during the pandemic envisioned the use of LERF infrastructure (300 MeV SRF, e- ERL)
- Design two injectors (e- and e+)
- Develop a scheme to inject into CEBAF, make it into Ce(+/-)BAF
- Provide either e- or e+ on demand



Ce+BAF positron target status

- We are in the process of evaluating several target concepts before settling on a production target for the e+ source@jlab:
  - Xelera Research LLC (Ithaca,NY) in collaboration with Jlab is pursuing a liquid metal jet target that could produce e+
  - SLAC group has a liquid xenon recirculating target concept we are assessing
  - SKEKB group has developed a high power rotating solid target for the ILC that we are assessing
  - Jlab is prototyping a rotating solid target design
- JLAB-Xelera are collaborating under the DOE SBIR program (Phase II underway)
- JLAB-SLAC-SKEKB are collaborating under a DOE-SC-HEP funding opportunity that supports the development of advanced accelerator technologies
- Two ODU grad students are working on the prototype positron target
- Our goal is to settle on a production target design within ~3 years

Ce+BAF positron general target parameters

- Design goal: the target should be able to take a 1 mA CW e- beam current and have a lifetime of 6 months to 1 year (or longer)
- Tungsten is preferable as a target material: high Z (high e+ yield) and high melting temperature (thermal resilience to high power beam deposition), but we are also considering W-Cu alloys (90-10 or 85-15)
- Optimal W target thickness for e+ production from an incoming 120 MeV, 1 mA e- beam, would be 4 mm, current target wheel diameter 38 cm
- Fluka estimates for heating power deposition in such a target are in the range of 17 kW. The highest power target used at jlab was the Qweak target at 2.1 kW beam power. The upcoming MOLLER LH2 target would be rated for 4.5 kW.
- Water seems to be the best option for cooling such a target
- CFD simulations indicate that the W target will have to be rotated with a mild frequency (less than 10 Hz) to extend its lifetime (the W disk radius depends somewhat on the rotation frequency)
- Target design power is 20 kW, target maximum temperature < 900 K

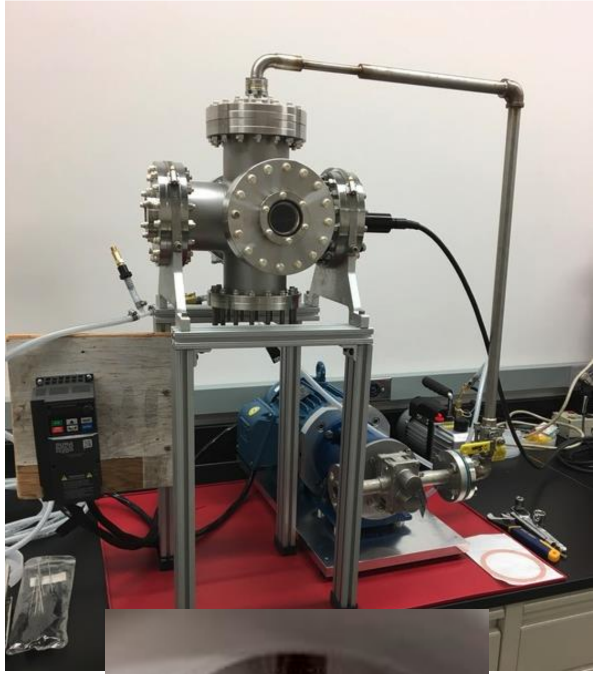
Xelera target design

- DOE-SBIR phase I completed, phase II underway

- SBIR phase I: successfully constructed and tested a 3 mm x 10 mm GaInSn metal jet target prototype (shown in upper right picture, lower right picture shows the nozzle and liquid jet)

- SBIR phase II (2024-2026) aims to test a recirculating liquid metal target at LERF with 10 MeV and 1-10 mA beam (the e+ production liquid metal would be PbBi)
  - Assess (with CFD) and study the thermal properties of the target
  - Vacuum compatibility with SRF
  - If possible, characterize the e+ distribution
  - Assess the risks/issues associated with operating such a target

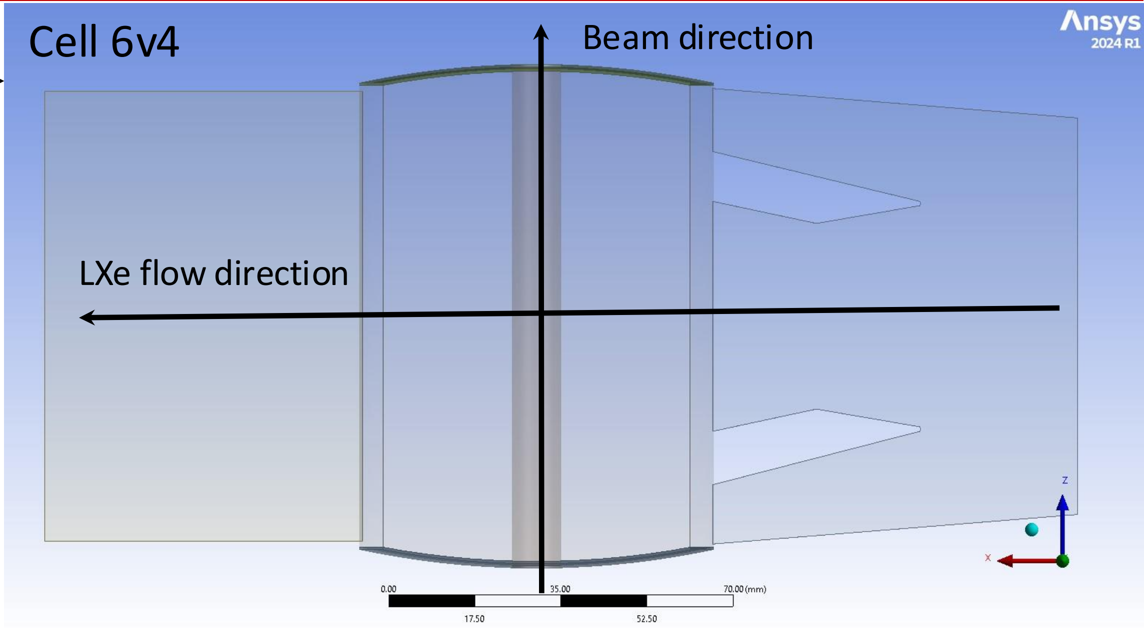
- See Val Kostroun’s talk for details

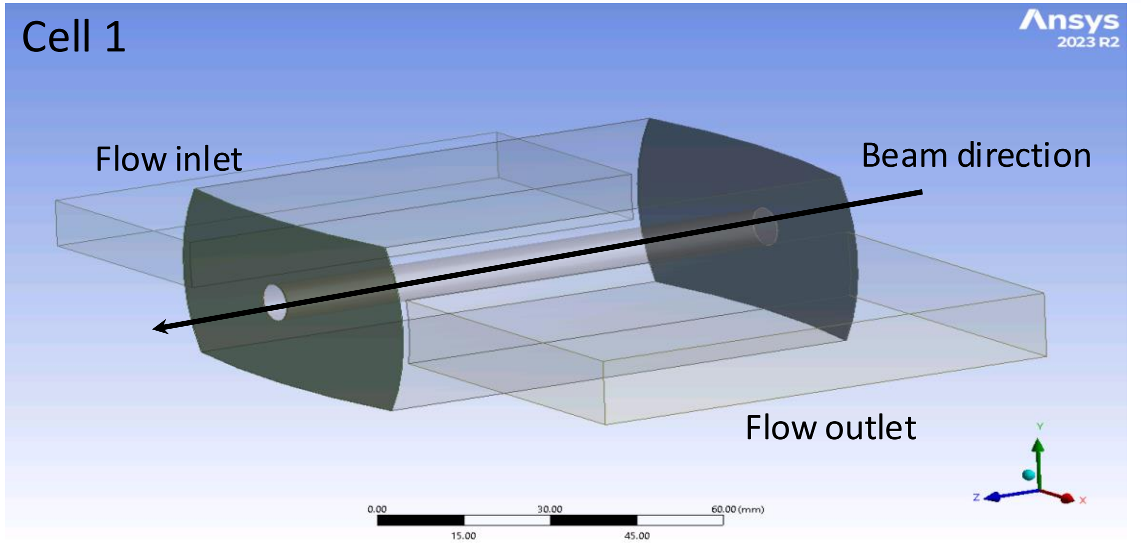


Pictures are courtesy of K. Smolenski and V. Kostroun

Liquid Xenon (LXe) Target Update

- Developed 6 cell geometries and simulated with CFD, cell-1 to cell-6v4 (most promising geometry with 0.5 mm Al/Be wall thickness in beam)
- Cell length in beam is 10 cm
- CFD simulation parameters:
  - 2-phase flow considered, LXe at cell inlet at 170 K, 35 psia, 2.5 m/s (saturates at 181.8 K and freezes at 160.4 K), properties corrected for T-dependence
  - Time-dependent simulations: beam is ON for 1 ms then OFF for 199 ms, and so on, beam frequency 5 Hz (cell-1 through cell-3)
  - Beam pulse sampled with 4 time steps (time resolution 0.25 ms)
  - Implemented the ILC beam structure for cell-5 and cell-6
- For cell 6 will implement the beam power deposition from the SLAC group





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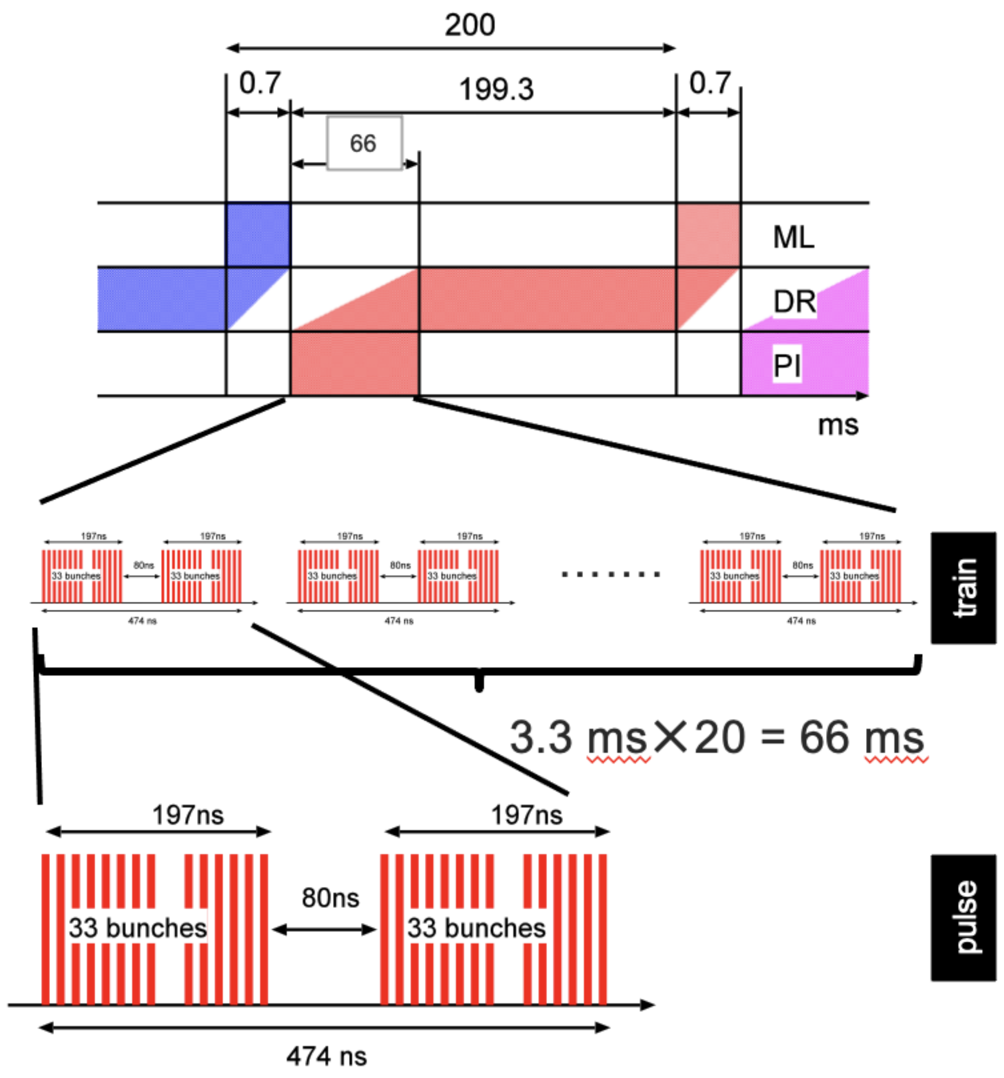
ILC Beam Beam Structure

- ILC beam structure has a repetition period of 200 ms
- ILC beam time structure: 20 pulses for 66 ms, no beam for 134 ms, repeat
- The beam is actually ON for 0.474 μs of the 3.3 ms "pulse"
- CFD time resolution is 50 μs for these simulations

- The same beam time structure was implemented for both LXe target (cells 5,6) and the SKEKB target

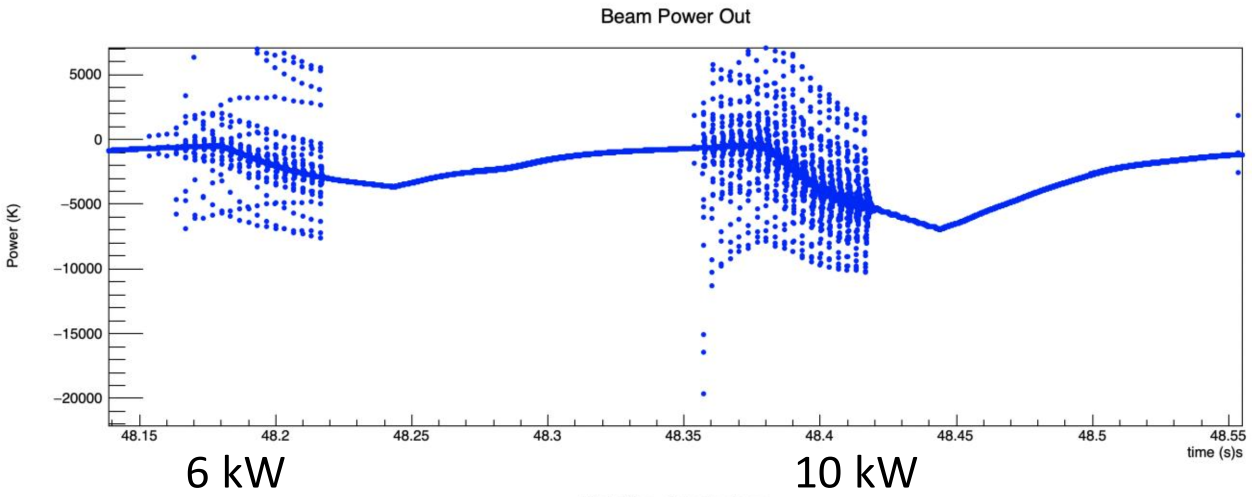
- The spatial beam power distribution was provided by each group for their respective target designs

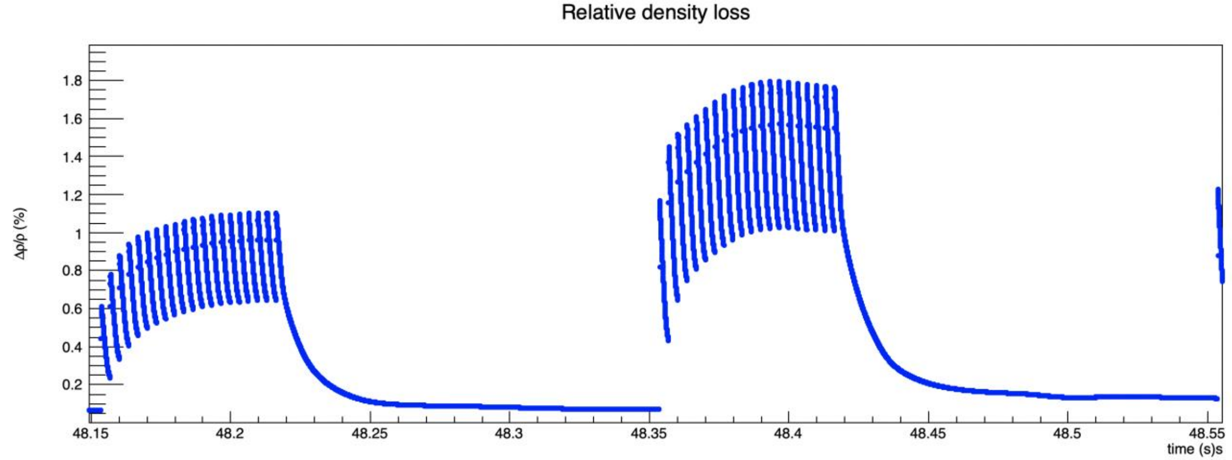


LXe cell-5 with ILC beam

- These are preliminary results
- Beam powers implemented: 200 W, 500 W, 6 kW and 10 kW
- Al windows are 0.2 mm thick
- Pressure spikes when the beam turns ON, this should be investigated with a finer time resolution to check for possible shock waves

Power	200 W	500 W	6 kW	10 kW
$(\Delta\rho/\rho)_{max}$	0.2%	1%	4%	10-14%
$(\Delta\rho/\rho)_{core}$	0.1%	0.2%	1%	1.8%
T_{maxin}	172	176	186	204
T_{maxout}	172	176	192	218

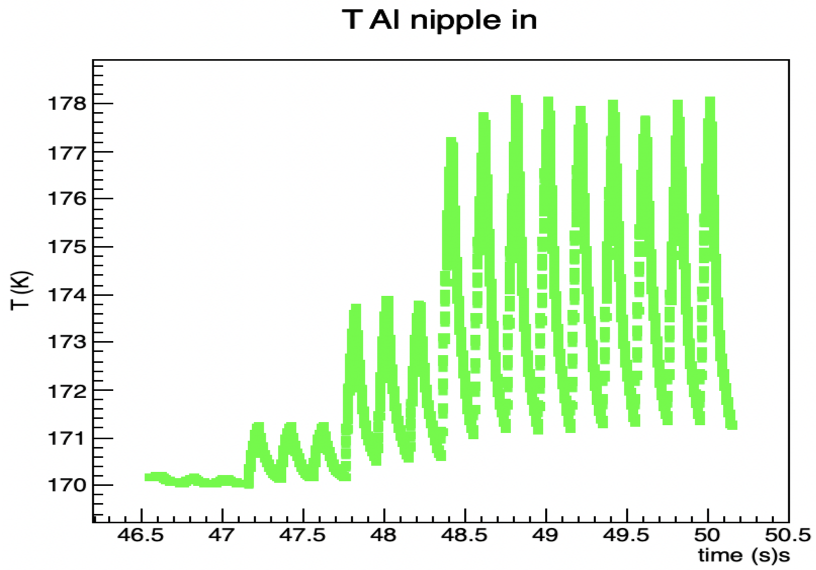


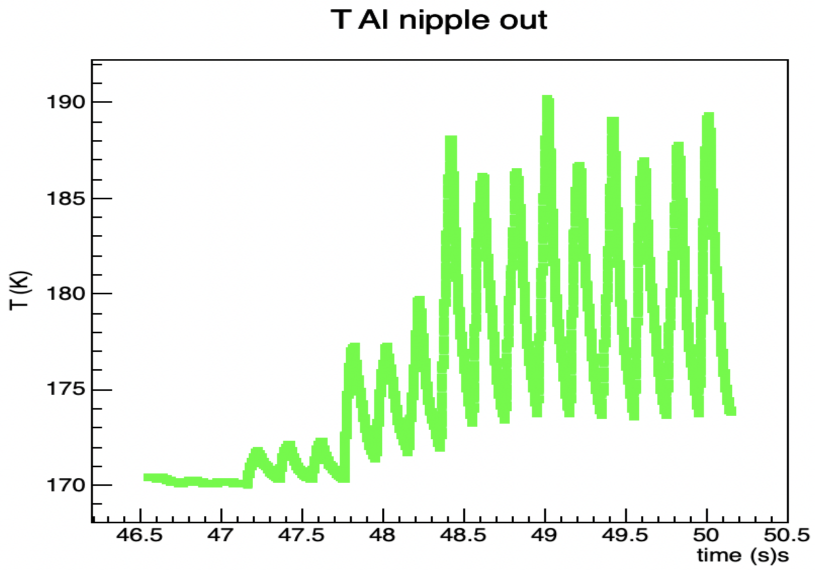


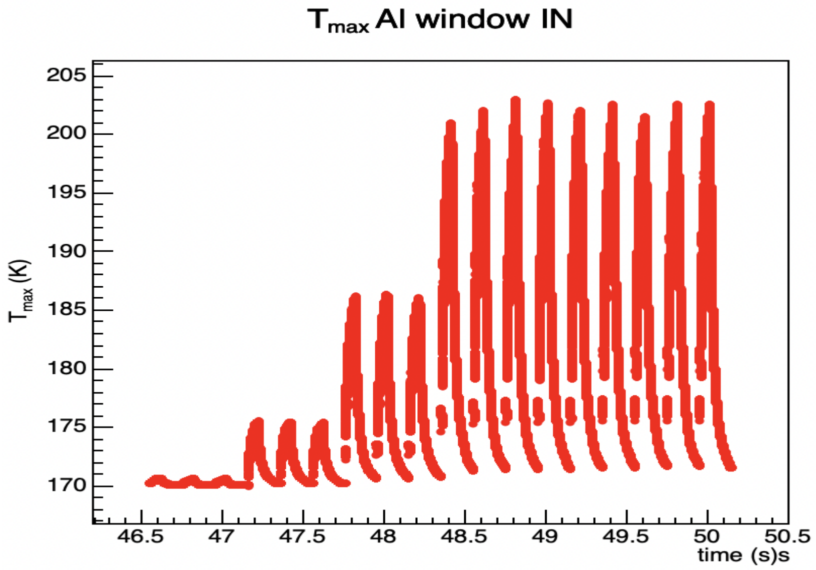
LXe Cell-5 Windows Temperature

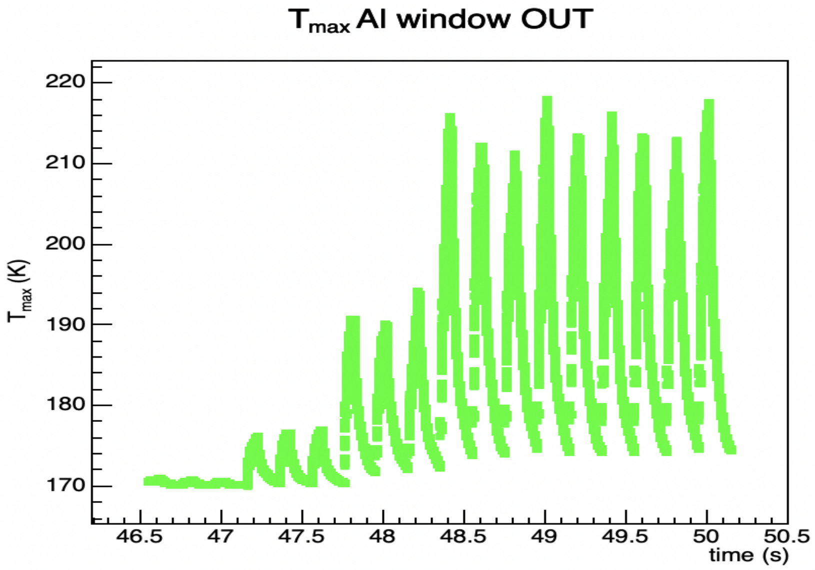
Four beam powers considered: 200 W, 500 W, 6 kW and 10 kW

0.2 mm thick Al windows in beam





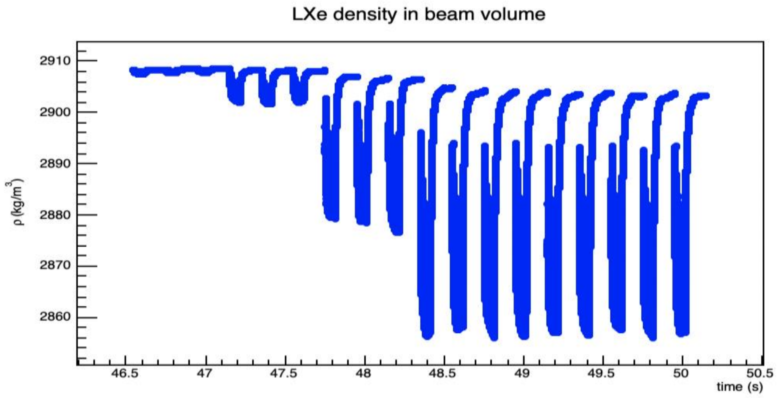


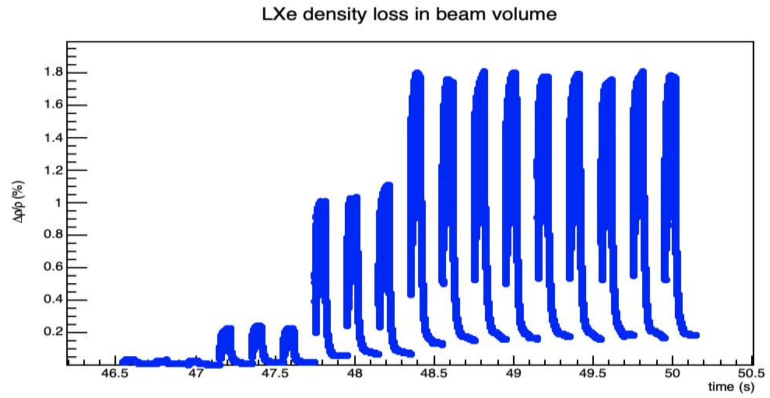


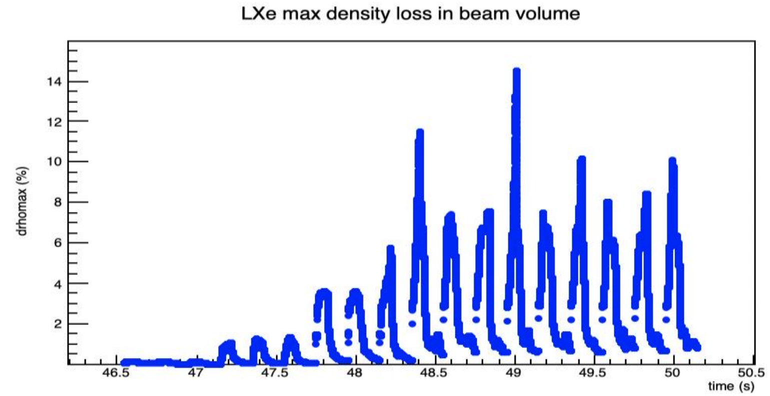
LXe Cell-5 Summary Plots

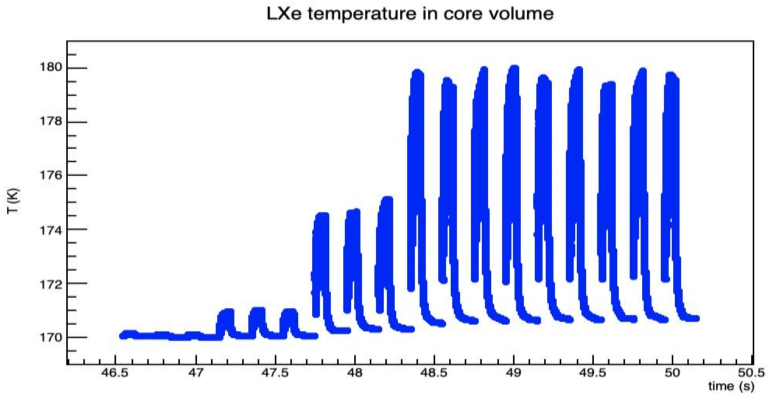
- Core volume (cylinder centered on the beam axis with 5 mm radius) values:
  - LXe density
  - Relative density loss
  - Max relative density loss
  - Temperature
  - Flow velocity magnitude
  - Max temperature

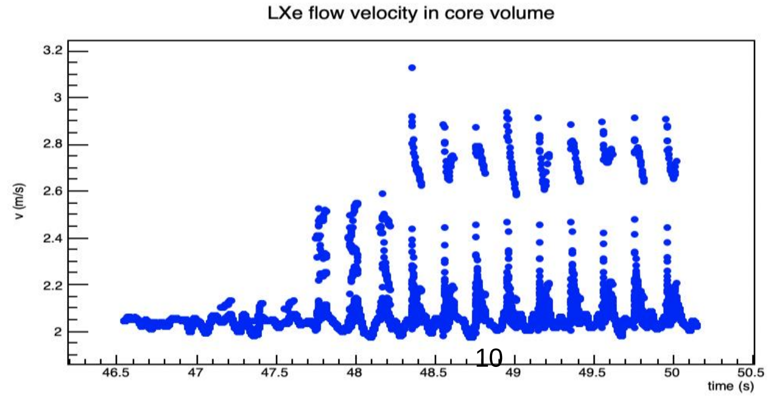
  At the 4 beam power values

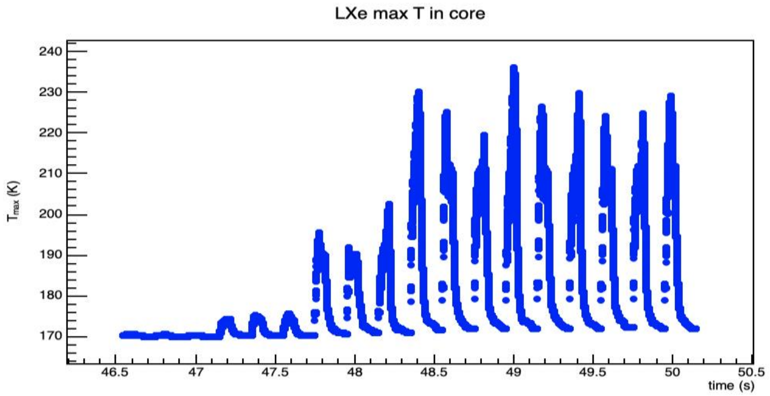












LXe Cell-6v4 Flow Distribution

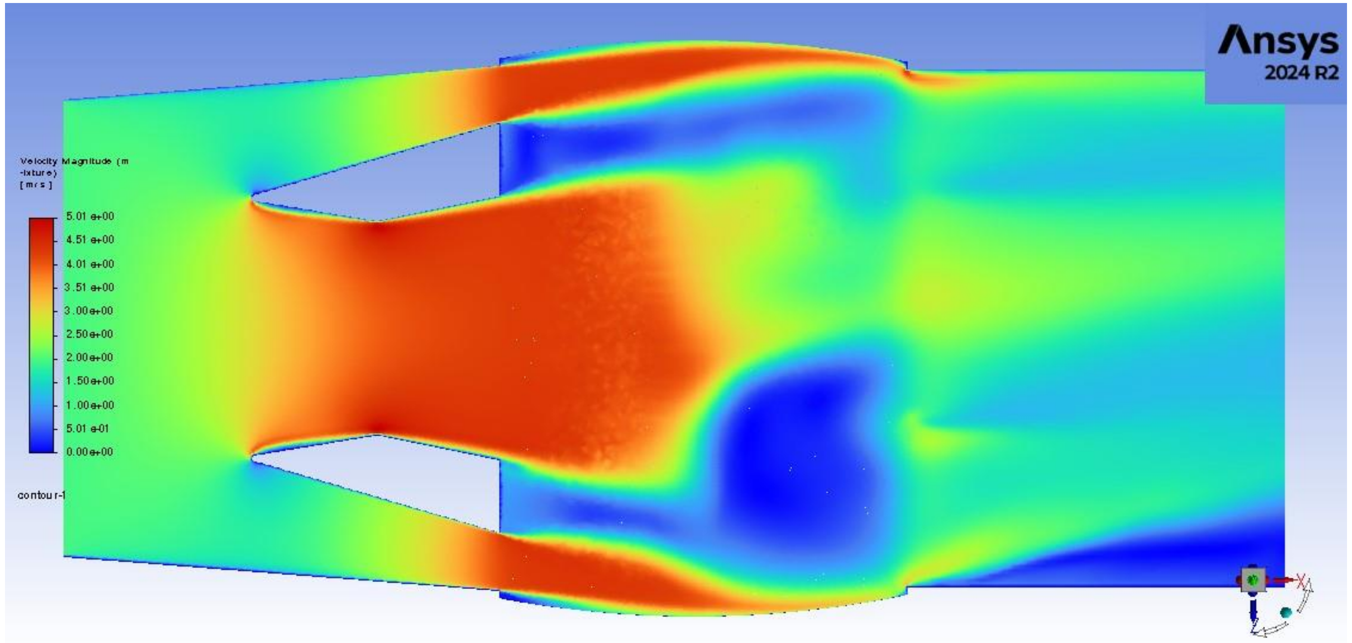
- Better liquid flow through the beam axis with good jetting at the beam nipples

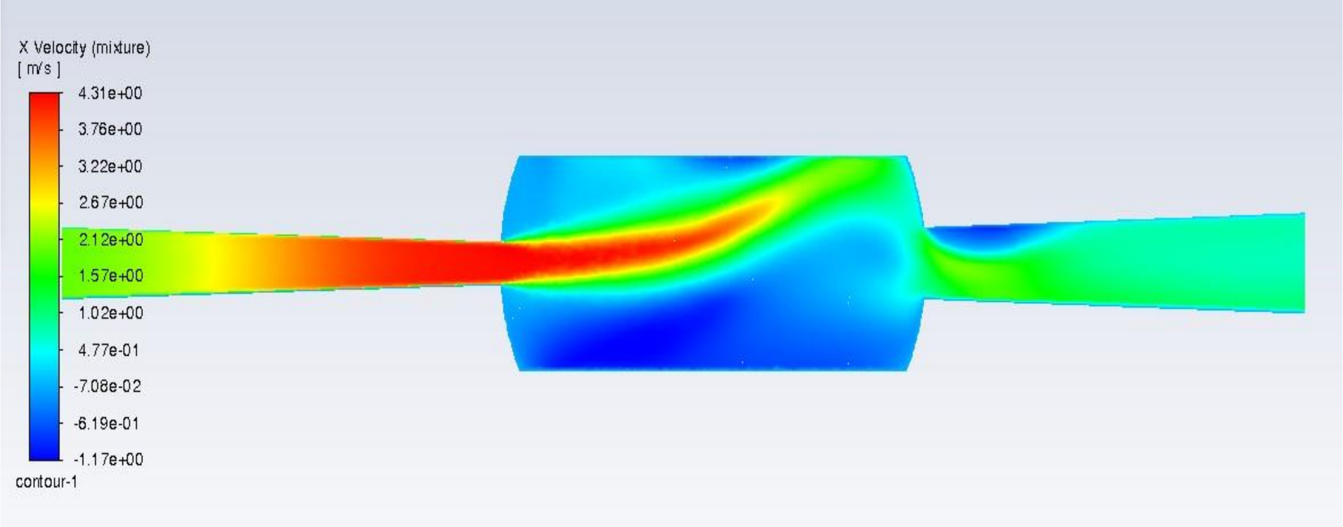
- v flow at inlet is 2 m/s, jets at the windows are about 4 m/s, average flow through the beam volume 1.8-2.5 m/s (oscillates in time), much better than previous geometries

- The cell needs some design to optimize the flow in the beam volume

- In principle the current geometry is ready for beam ON simulations

- This model has Al/Be windows 0.5 mm thick, one number considered in the SLAC beam power loss simulations (the other one is 2 mm)





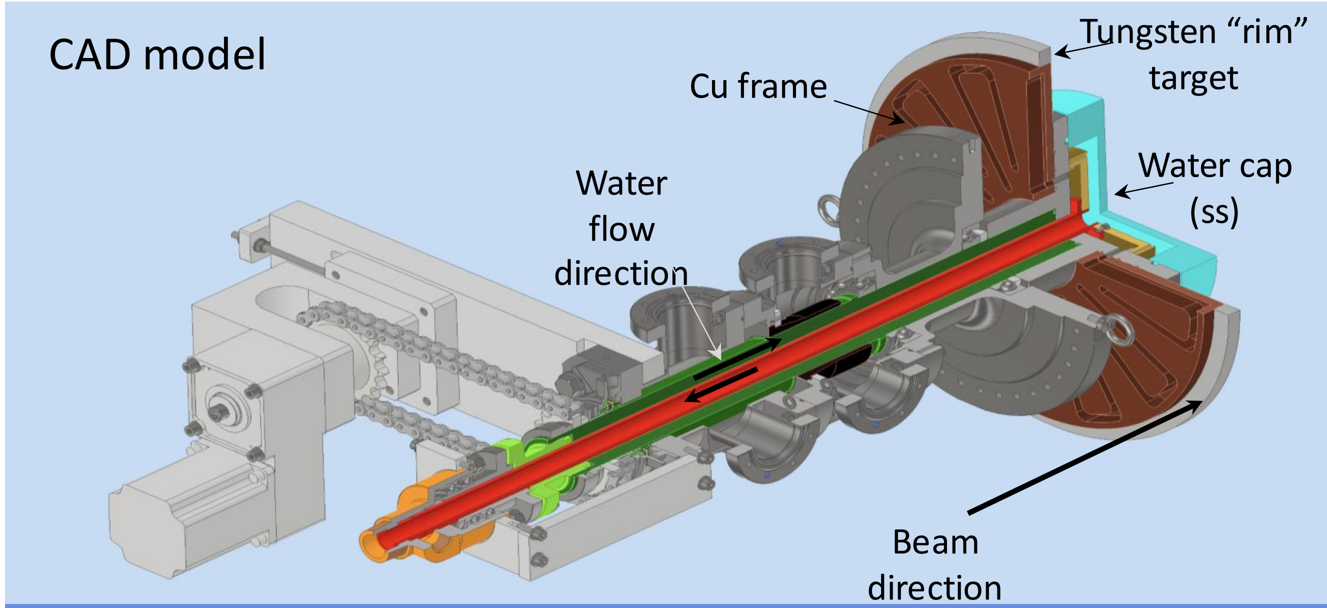
SKEKB Rotating Target prototype for ILC

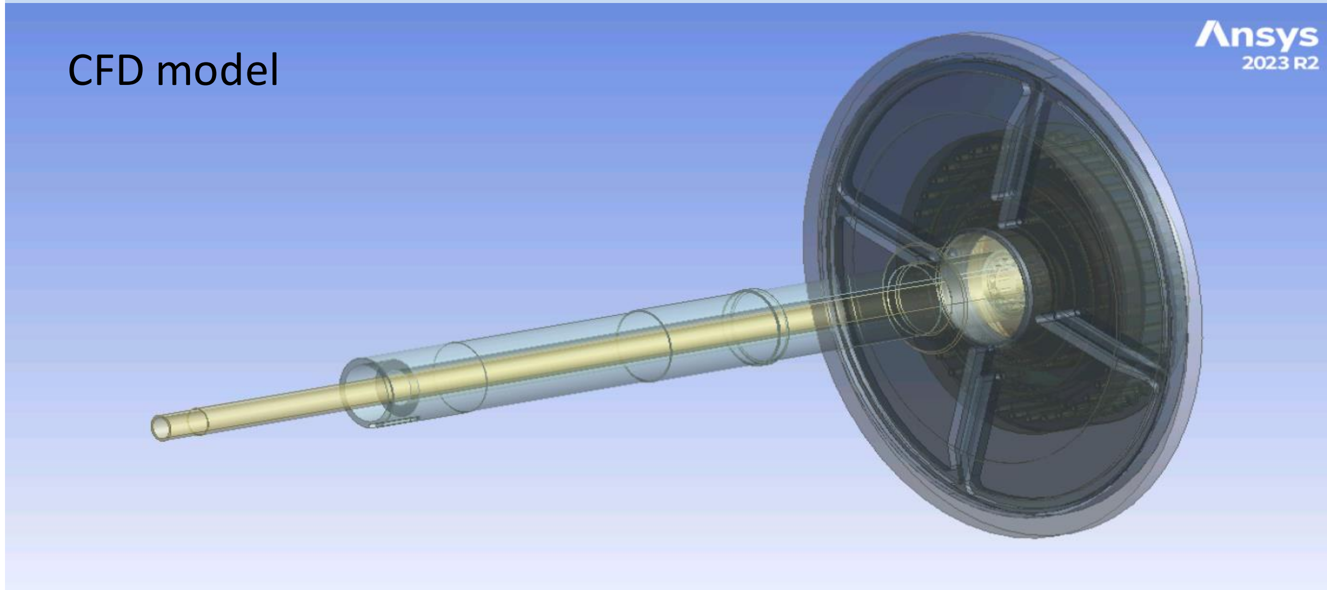
- Implemented the SKEKB target geometry in CFD – 2023
- ILC beam time structure: 20 pulses for 66 ms, nothing for 134 ms, repeat

- CFD standard parameters:
  - target material W 16 mm thick, 25 cm radius, W ”welded” to Cu frame, rotates at 3.75 Hz
  - Simulated CW beam 20 kW power, σ = 2.2 mm, beam spot diameter 6 mm
  - Water coolant in at 290 K, 1.167 kg/s, 5 atm

- Cases studied over the past 2 years
  - ILC beam structure with standard CFD parameters
  - Water pressure loss vs. inlet mass rate
  - Max temperature in target vs. rotation frequency
  - Max temperature dependence on thermal contact Cu-W

- Contact W-Cu: considered 2 cases
  - Ideal, no thermal resistance in contact
  - Thin insulating layer of WO3, 0.25 mm thick with thermal conductivity 0.5 W/m*K



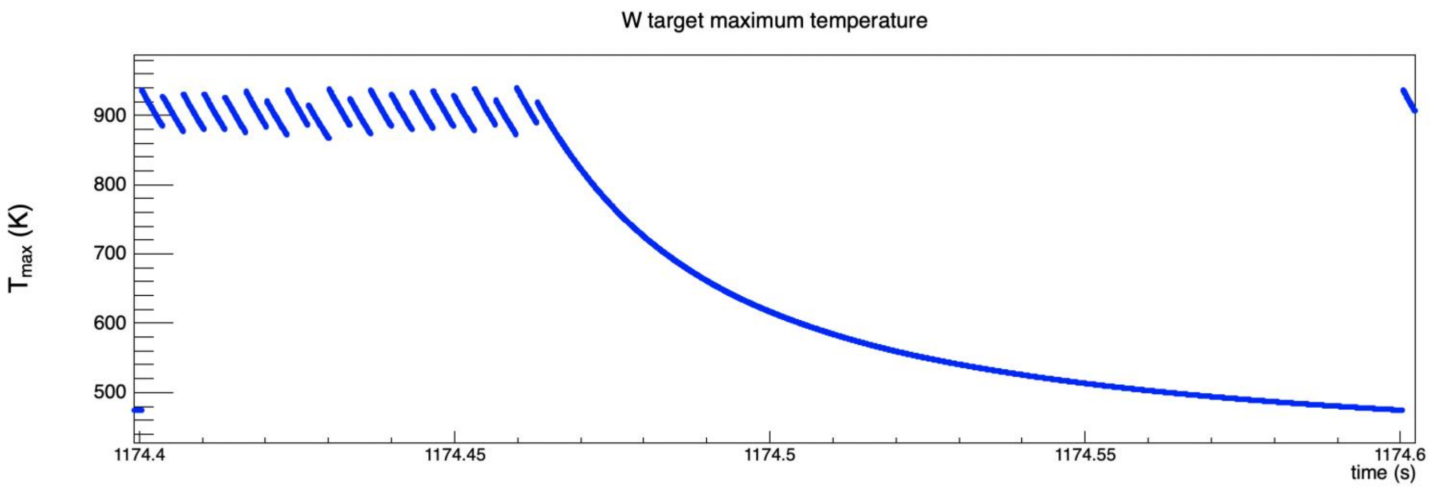


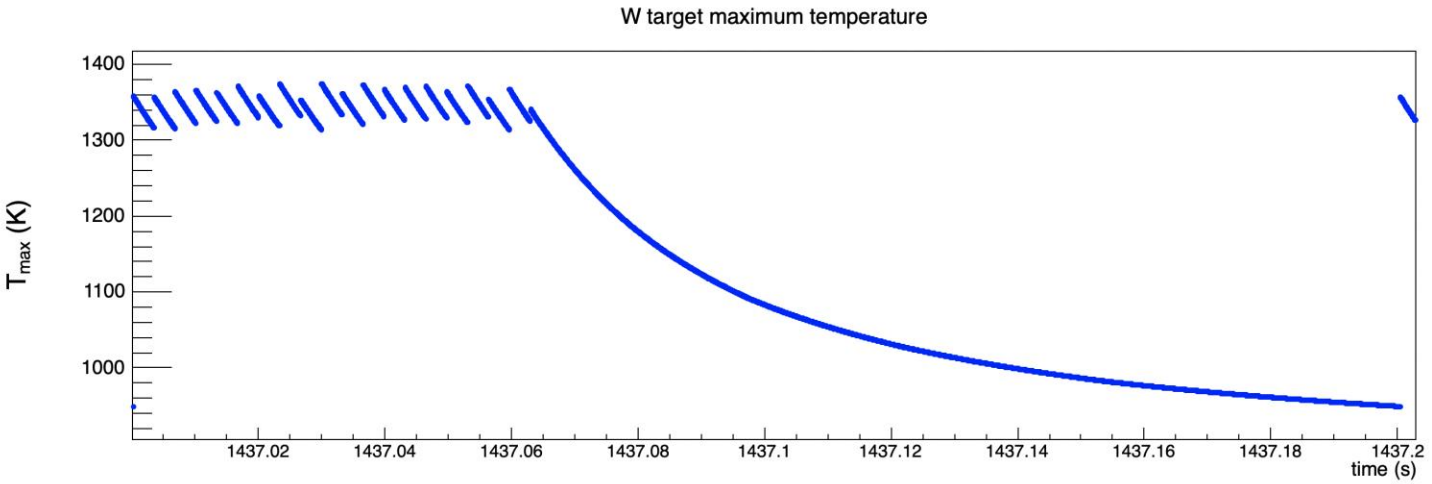
SKEKB Rotating Target – thermal contact influence on max T

- Max temperature for ideal contact W-Cu for 20.4 kW of beam power varies peak-to-peak between 870 K – 940 K, ΔT_{max} = 650 K
- Max temperature in the W target decreases to 474 K with beam OFF, over 134 ms

- Max temperature for thin insulating layer W-WO3-Cu, with 0.25 mm WO3, for 20.4 kW beam power, varies between 1310 K – 1370 K, ΔT_{max} = 1080 K
- Max temperature decreases to 948 K with beam OFF, over 134 ms

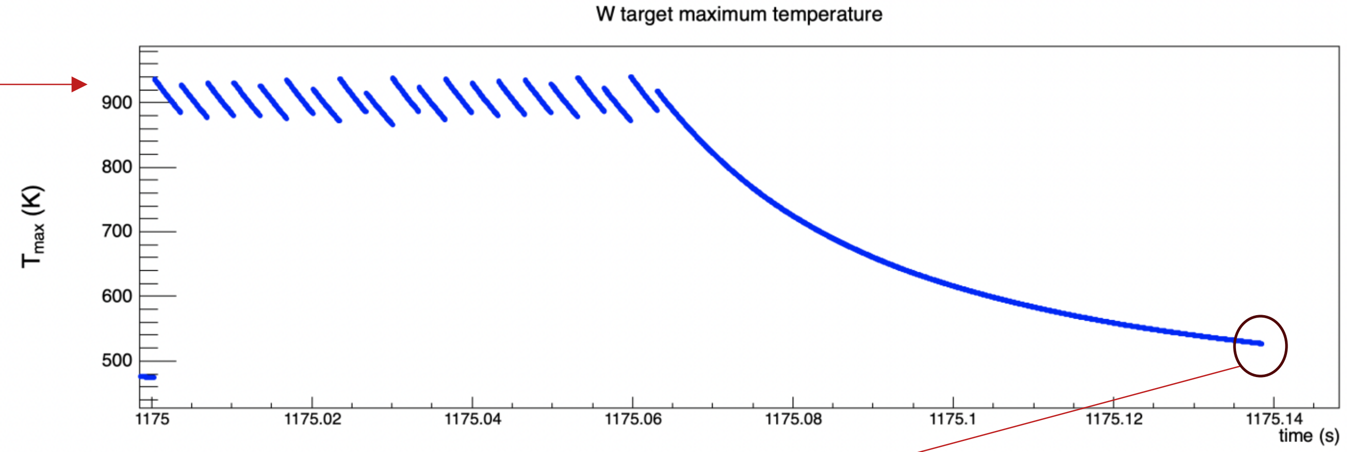
- Even a thin (0.25 mm) insulating layer between W and Cu increases max T by 430 K or a 66% increase



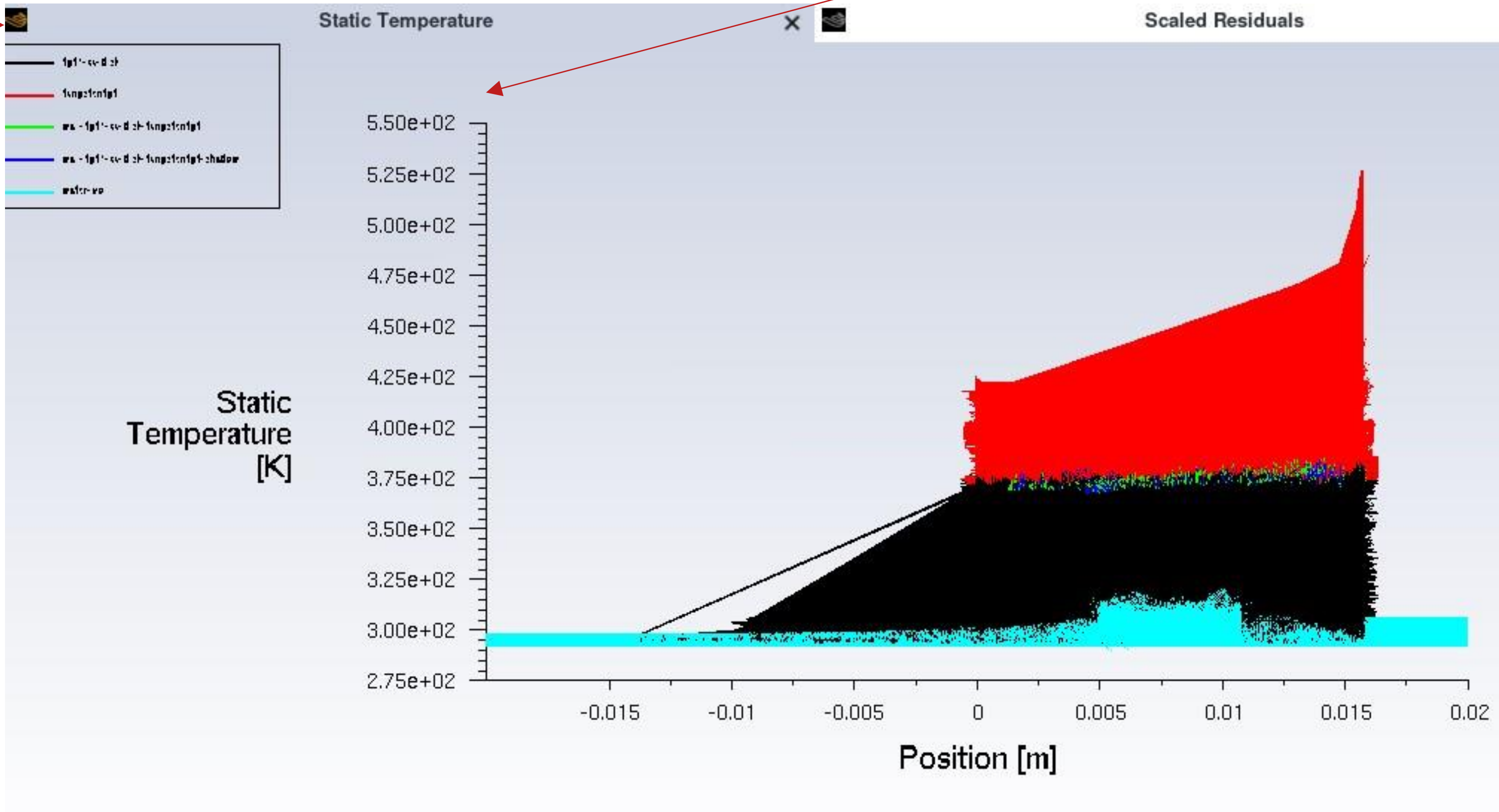


SKEKB Temperature Distribution in Target

- Max T in W for ideal thermal contact between W-Cu, 20.4 kW beam power in target



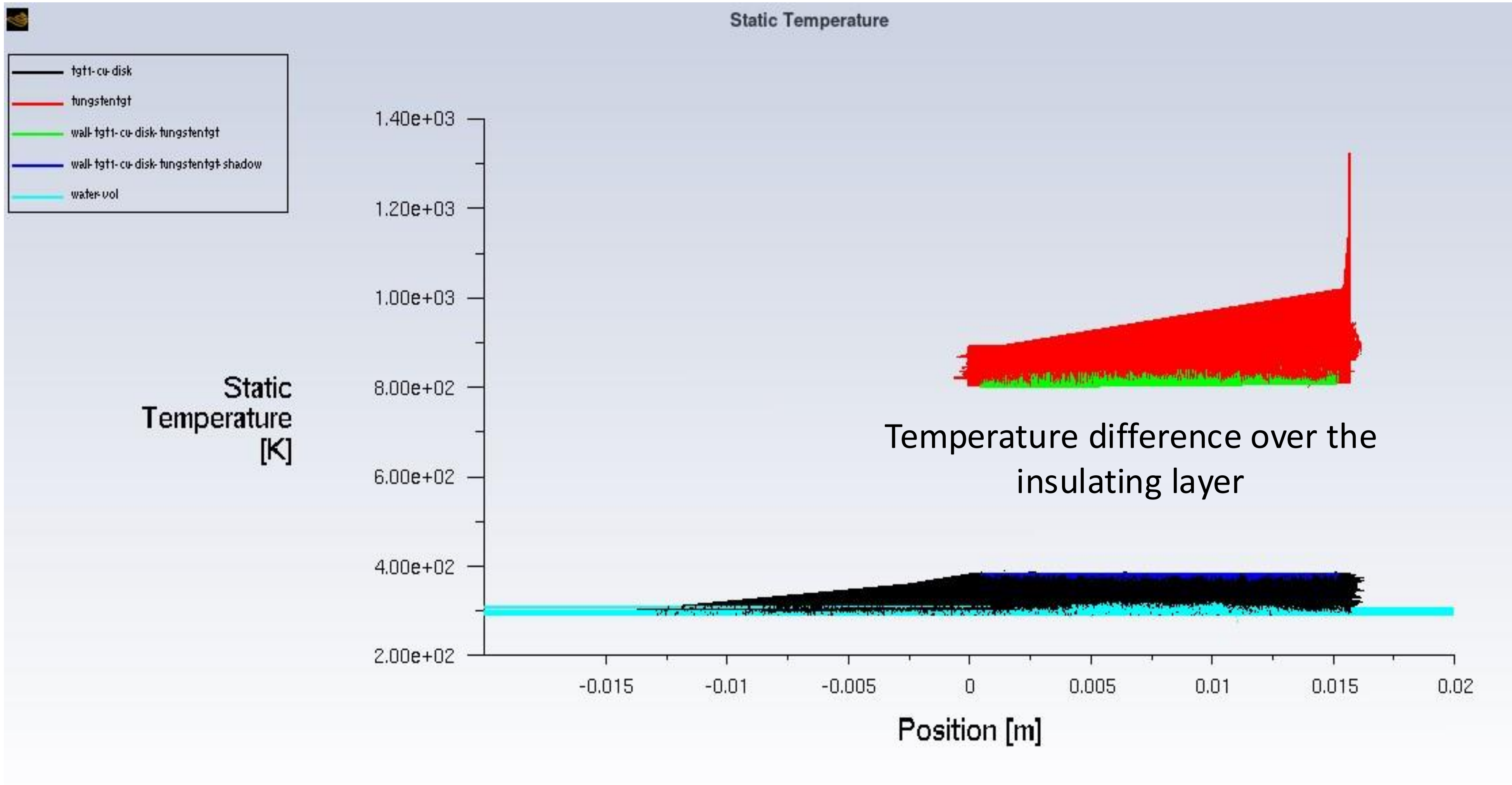
- Snapshot of temperature distribution in the target at an instant in time during beam OFF, when the max temperature in the W is 540 K, along the beam axis



- Red is Tungsten
- Green and Blue are the two faces of the contact W-Cu frame
- Black is Cu frame
- Turquoise is water

Insulator layer effect of max T

- The influence of a 0.25 mm insulating layer, WO3, between W and Cu



- **Red** is Tungsten
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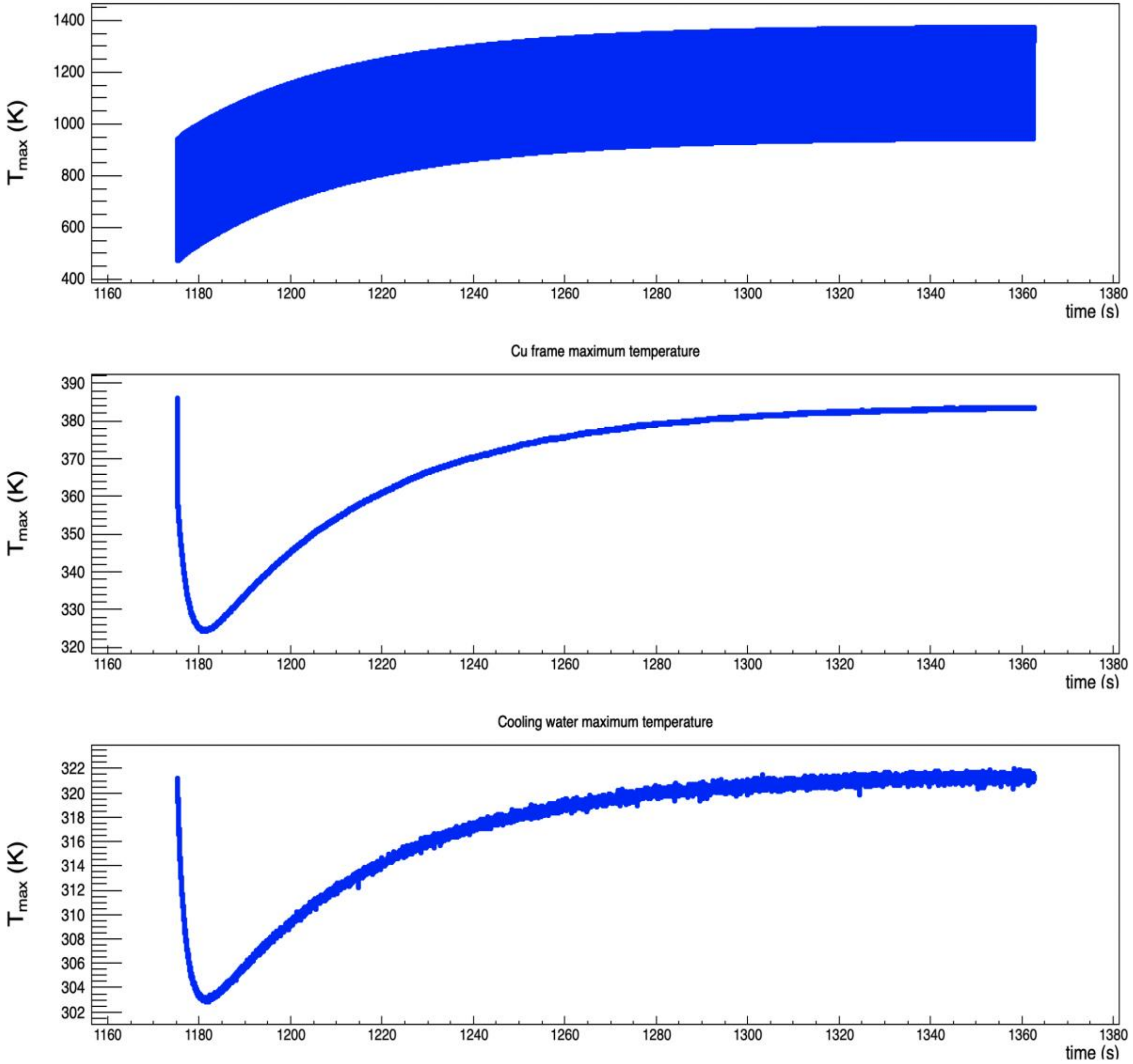
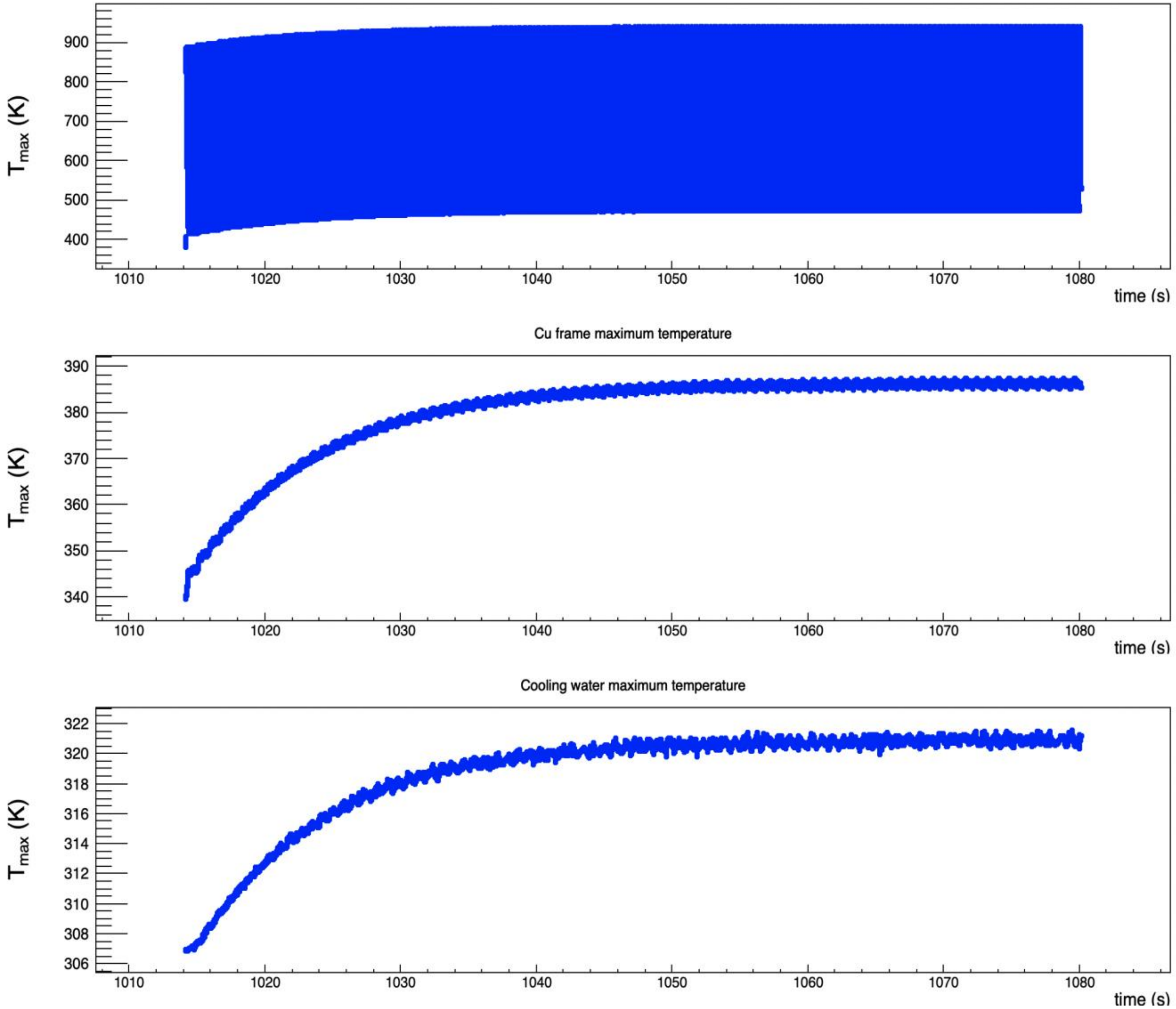
- **Turquoise** is water

SKEKB T_{max} Summary Plots

W-WO3-Cu contact

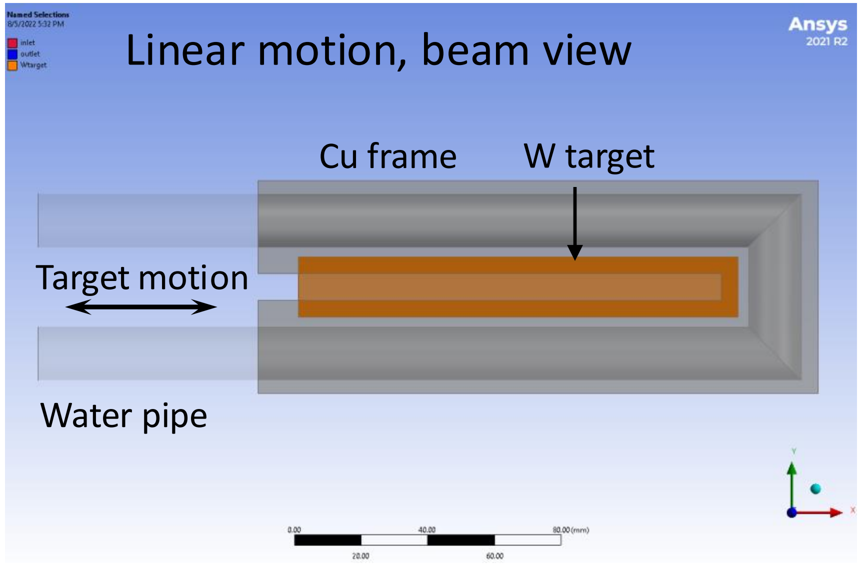


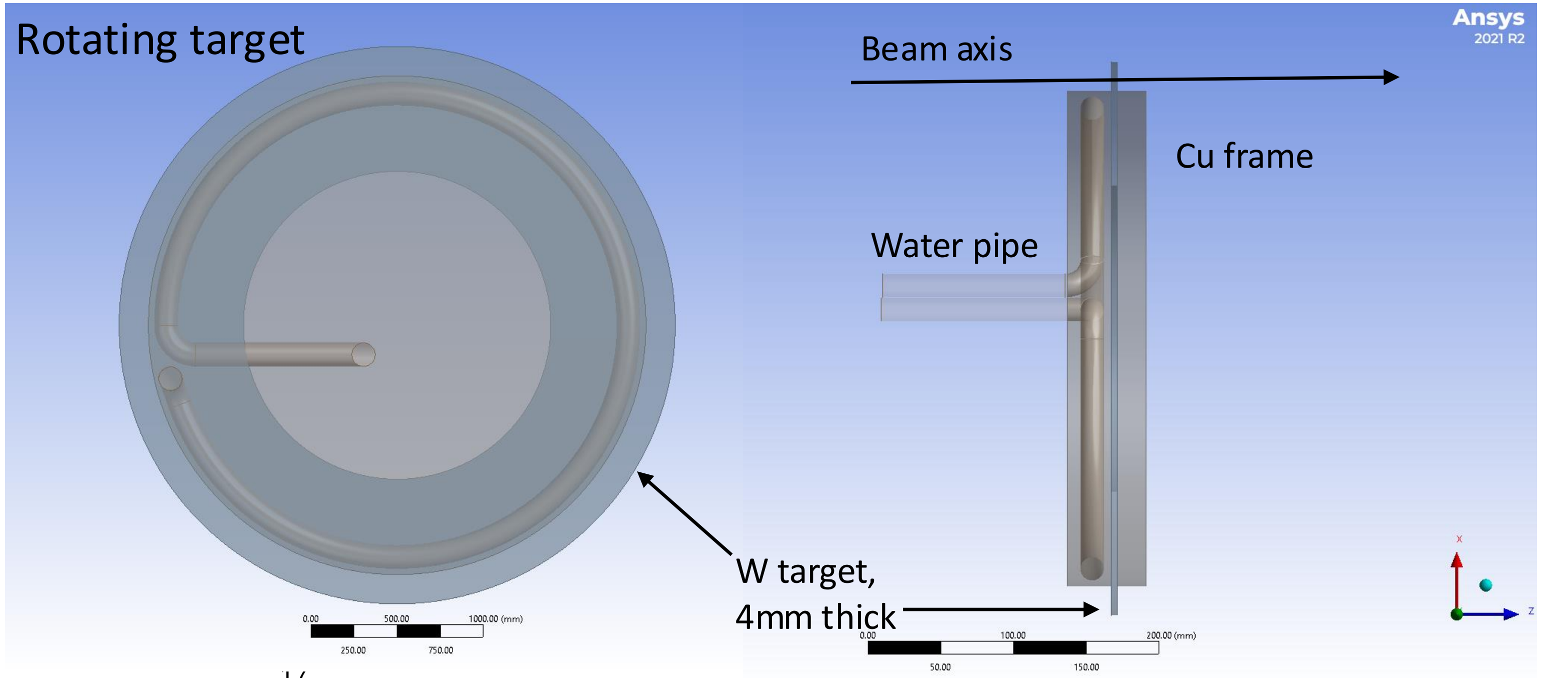
W-Cu ideal contact



JLAB target concept

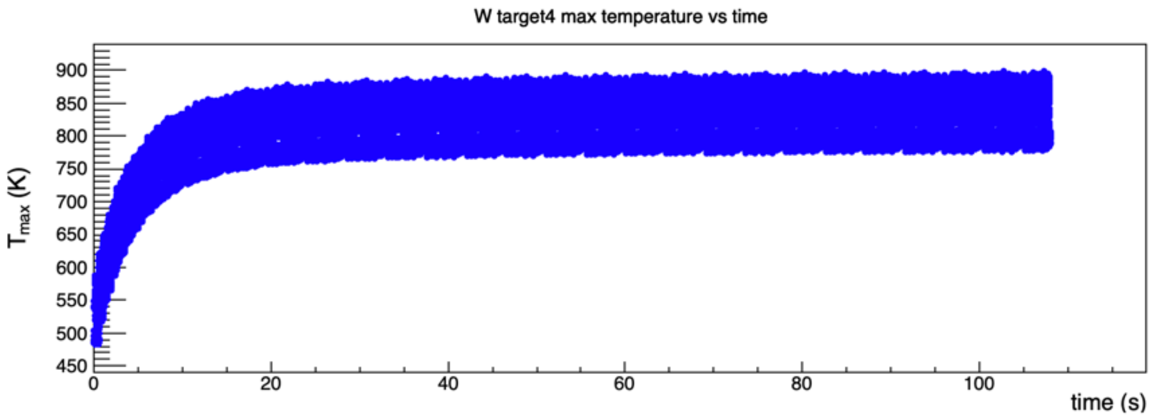
- Focused on assessing with CFD solid high-Z targets, mostly W, for e+ production at CEBAF:
    - A static target could take ~ 1 kW beam power before it melts
    - A linearly moving target could take ~ 4 kW beam power before it melts
    - A rotating target (<10 Hz, >30 cm diameter) could take 20 kW beam power with T_{max} < 1000 K

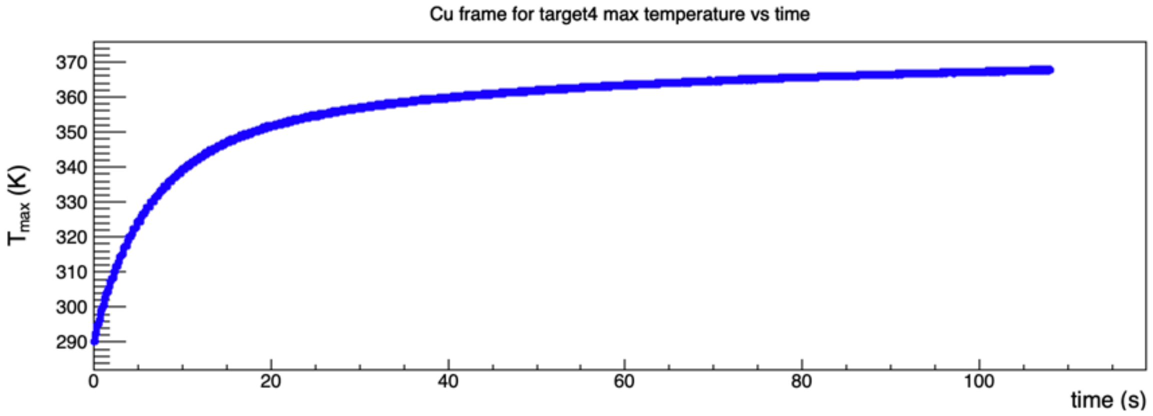


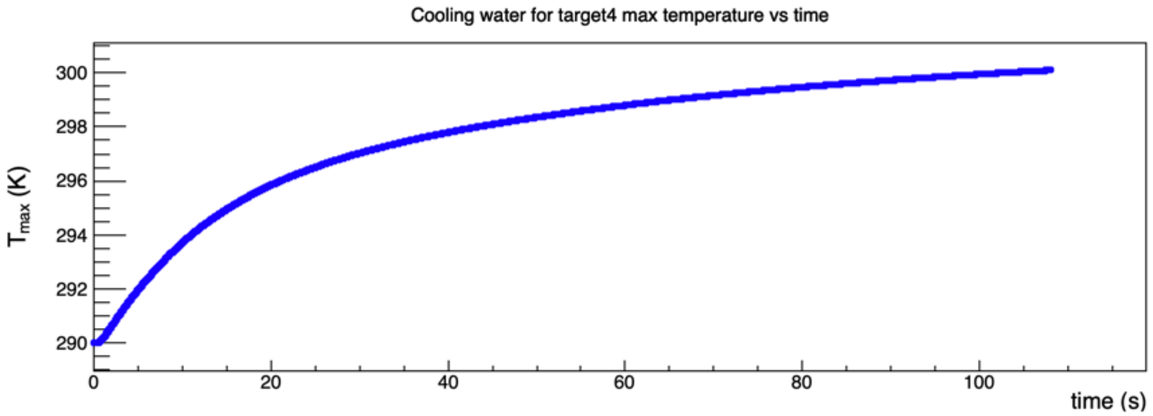


Ce+BAF rotating W target with CFD

- CW-Beam area on W target 4x4 mm^2 or Gaussian profile with σ ~ 1-3 mm
- The beam hits the W target on a circle with radius 18 cm
- The W target rotates at 2 Hz and the water flow is 0.6 kg/s, water pressure loss is 1.5 psi
- Full time-dependent CFD simulations implemented
- No studies on target material lifetime
- We are prototyping this target design







Prototype target project

- DOE-NP issued an FOA for "Research and Development for Next Generation Nuclear Physics Accelerator Facilities" in spring 2024
- Submitted a proposal to design and test a prototype positron target
- The proposal was accepted for funding, starting Nov 2024, actual funding started Jan 2025, for two years
- Proposal goals:
  - CFD benchmarking
  - Vacuum integrity at 1e-6 Pa
  - Target rotation up to 5 Hz
  - Target cooling with water
- We will design, build and test a rotating solid target. The target will rotate in a vacuum chamber, with water cooling provided under a vacuum of 1e-6 Pa
- CFD benchmarking: heat the target with a high-power laser and compare measurements with CFD predictions and improve the CFD modeling of the production target

Prototype target project

- Sandesh Gopinath is the project engineer
- Chandan Ghosh is responsible for materials sourcing for the prototype target, based on radiation loading predictions for the production target materials
- Two ODU graduate students will work on the prototype target:
  - K. Mahler: estimate target lifetime from thermal stress analysis (PhD thesis)
  - Z. Alam: laser heating tests
- High level schedule:
  - CFD calculations to establish a production target design that can take 20 kW beam heating power and have maximum temperature in the target < 900 K (6-9 months)
  - Engineer a prototype target based on the production target design (6-9 months)
  - Procurements: water cooling circuit, target materials, rotation mechanism, instrumentation (12-15 months)
  - Installation of target setup in Lab 6@LERF, spring-summer 2026
  - Testing the prototype target with a high power laser and postprocessing, fall-winter 2026

Acknowledgments

We would like to acknowledge members of the **Ce+BAF Working Group**, the **Jefferson Lab Positron Working Group**, the **DOE industry partner Xelera**, members of the **DOE US-Japan HEP Collaboration,** and collaborators at **Universities and National Labs** which contribute to the positron R&D effort.

T. Abe, J. Benesch, A. Bogacz, L. Cardman, J. Conway, S. Covrig, P. Degtiarenko, Y. Enomoto, S. Gessner, P. Ghoshal, S. Gopinath, J. Grames, J. Gubeli, S. Habet, C. Hernandez-Garcia, D. Higinbotham, A. Hofler, R. Kazimi, M. Kostin, F. Lin, V. Kostroun, V. Lizarraga-Rubio, K. Mahler, Y. Morikawa, S. Nagaitsev, E. Nanni, M. Poelker, N. Raut, B. Rimmer, Y. Roblin, A. Seryi, K. Smolenski, M. Spata, R. Suleiman, A. Sy, D. Turner, C. Valerio-Lizarraga, E. Voutier, M. Yamamoto, S. Zhang

Summary

- Collaborating with SLAC and SKEK-B on state-of-the art CFD simulations for positron target design

- Developing a feasible design for the e+ source at LERF within 3-5 years accounting for radiological issues, shielding etc.

- The JLAB e+ target:
  - Prototype target project funded for 2 years, 2025-2026
  - Develop the prototype rotating target and test it at LERF
  - In collaboration with Xelera, Inc, develop and test a liquid metal target 2024-2026