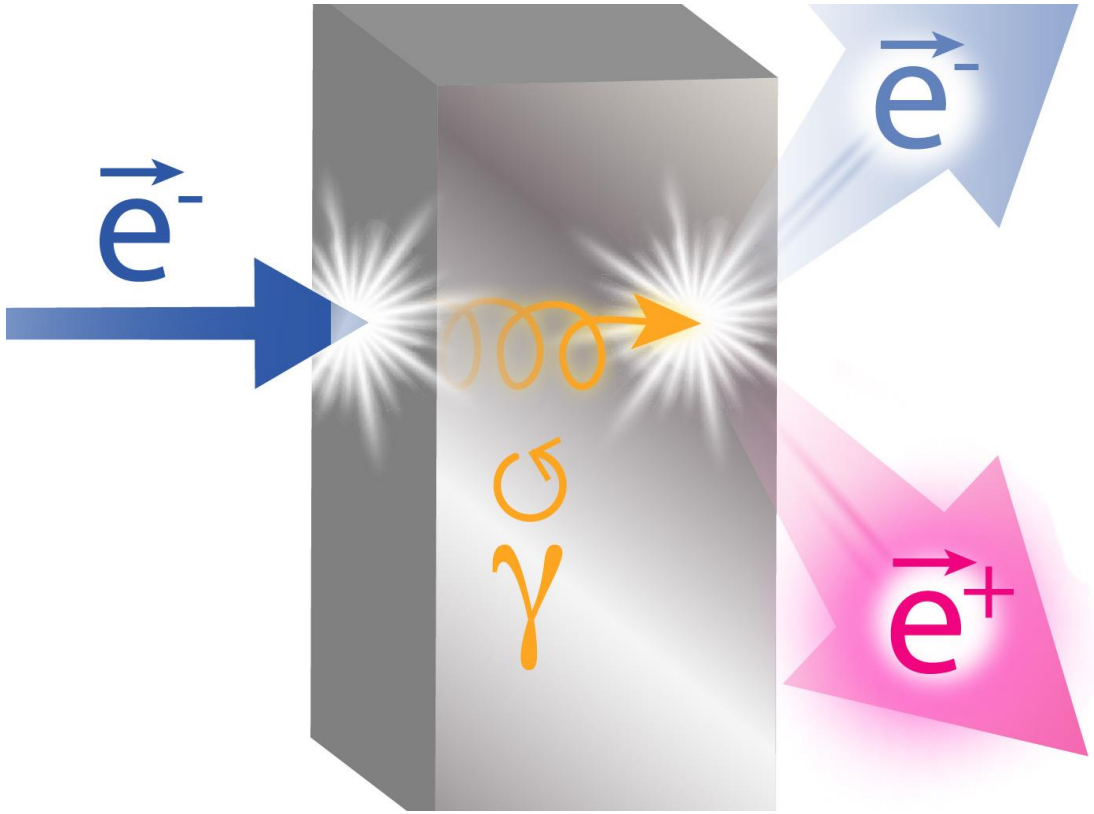
JLAB Positron Target

- Positron source concept at LERF
- Target concepts for JLab's e+ source
- Summary



Silviu Covrig Dusa (for the Ce+BAF Collaboration)

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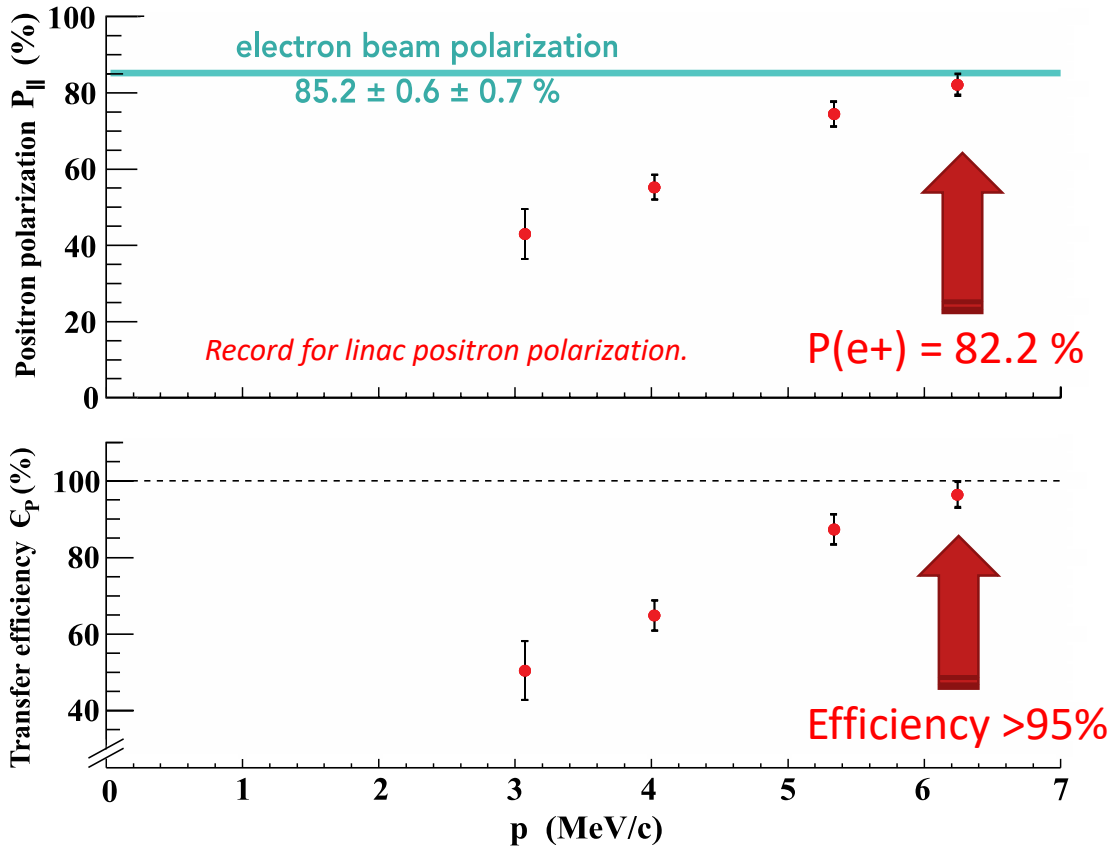
Positron program timeline at Jlab

- It started with PEPPo – 2012
  - Electrons 8 MeV, 1 μA, 85% polarization
  - Positron polarization 82%, no current measured
  - Target was 1 mm thick tungsten
- Continuous development over the past decade
- Positron program White Paper published EPJ A, vol. 58, special issue, Apr 2022 (proposed e+ program estimated to take 1121 days)
- Jul 2023: PAC-51 awarded 357 (PAC) days for e+ proposals
- Positron Working Group (PWG) formed (users and Jlab staff) has monthly meetings
- Ce+BAF group, successor to PEPPo group, made mostly on Jlab staff, has weekly meetings



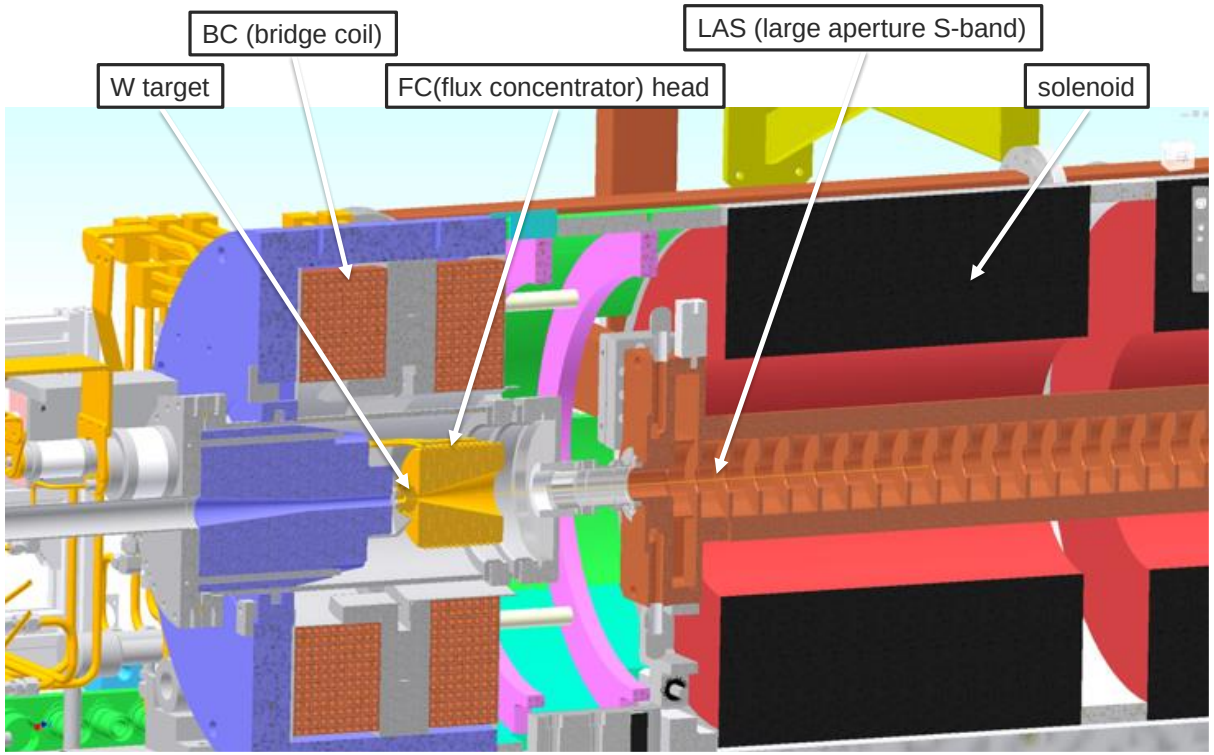
D. Abbott et al., Phys. Rev. Lett. ***116*** *(2016) 214801*

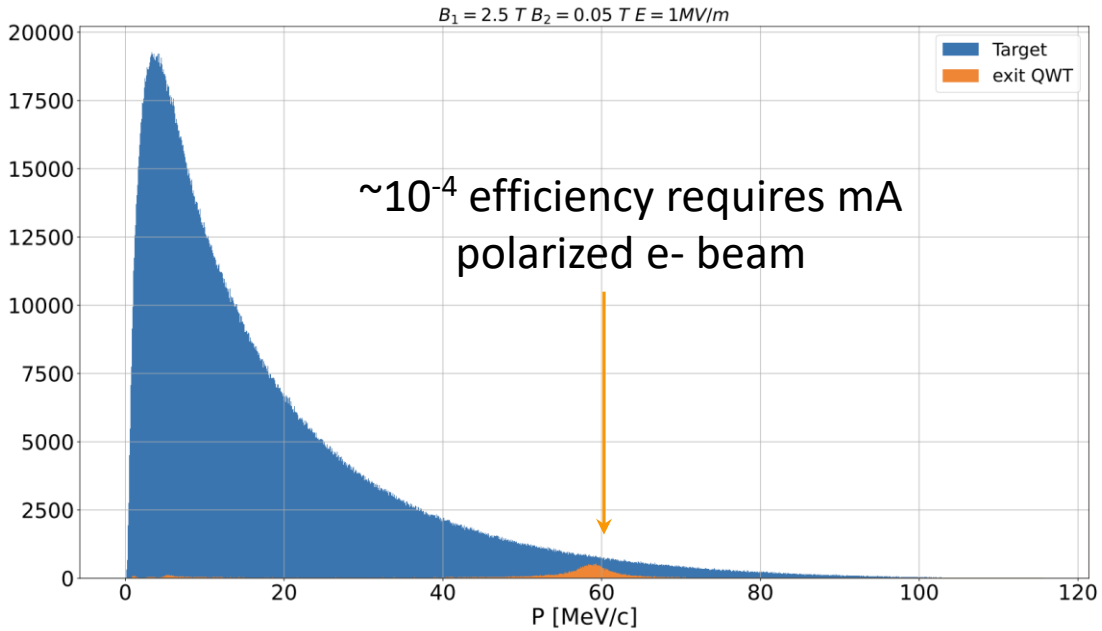
Positron source

Source
- High power target
- High field solenoid
- RF capture

Jlab's CW polarized e+ will be unique compared with previous e+ sources

S-KEKB pulsed-positron source concept (5 Hz, 3 GeV e-)





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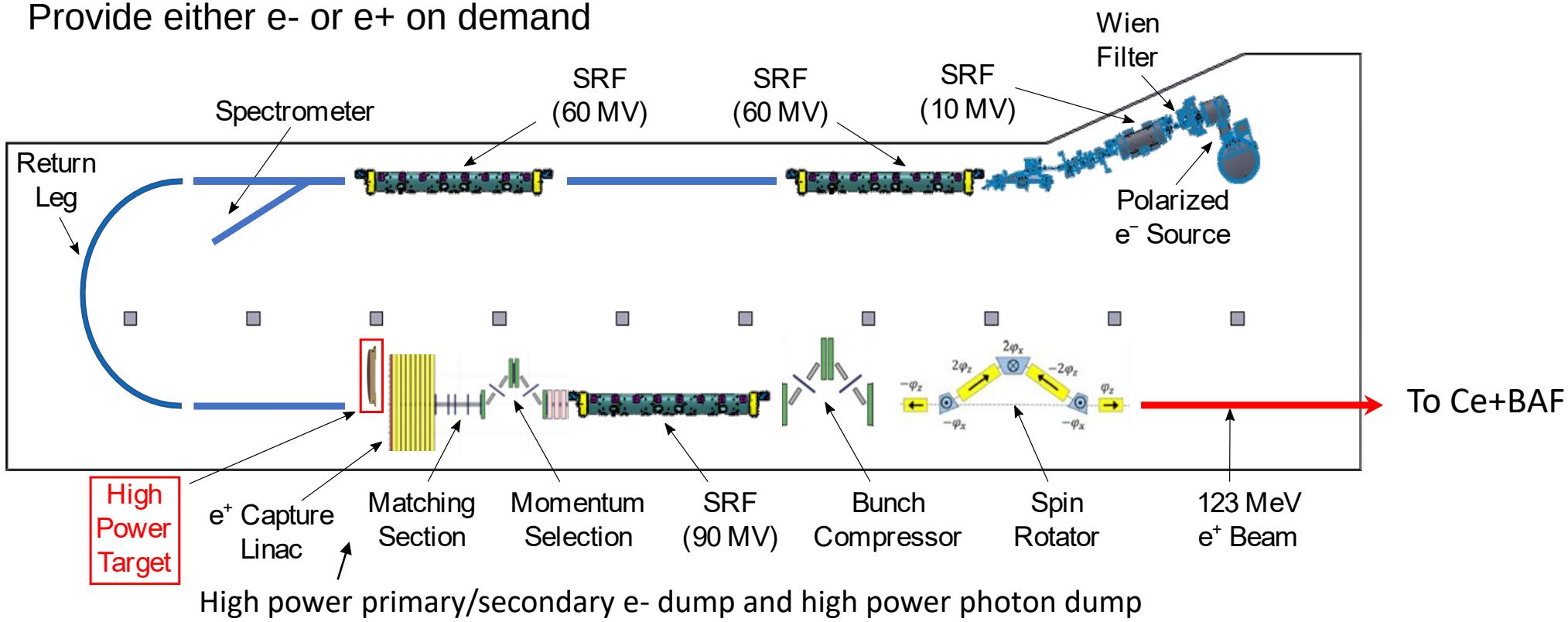
LERF Polarized Positron Source Concept

- Before the pandemic the e+ injector was conceived somewhere in CEBAF
- 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



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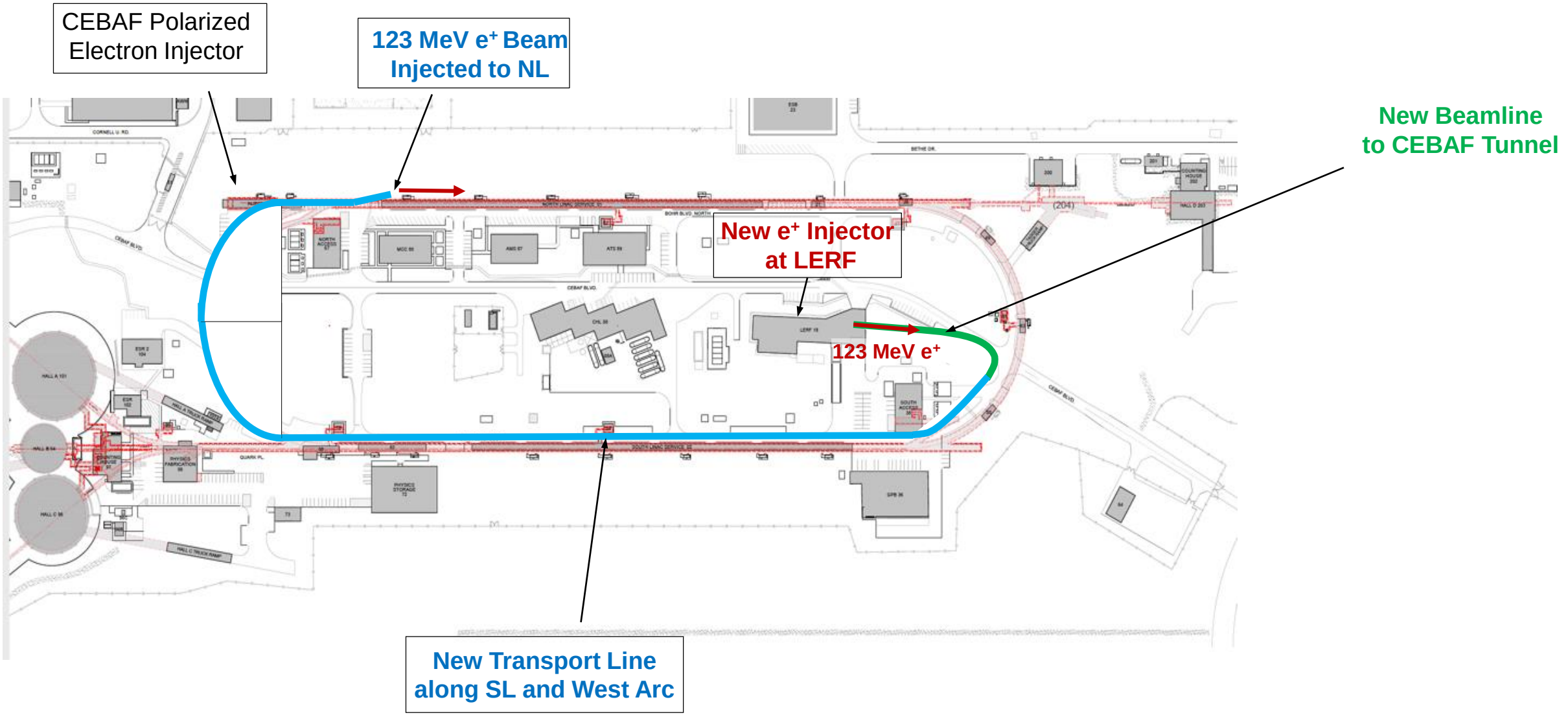
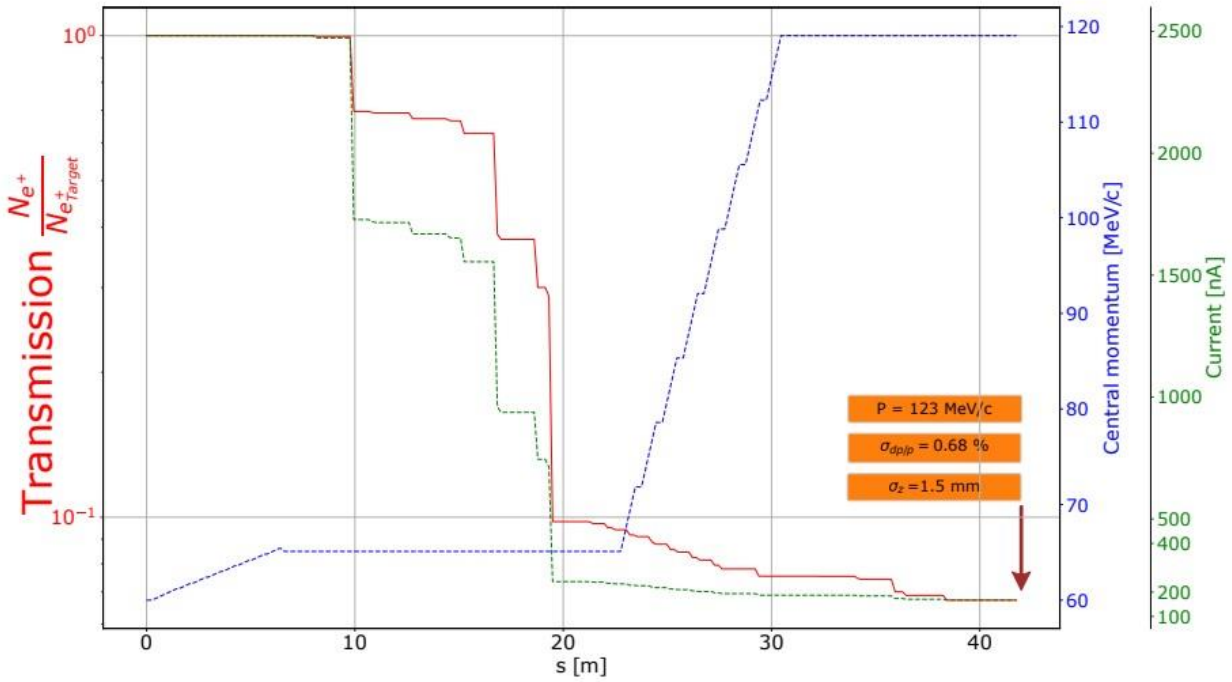
Positrons: from source to Halls

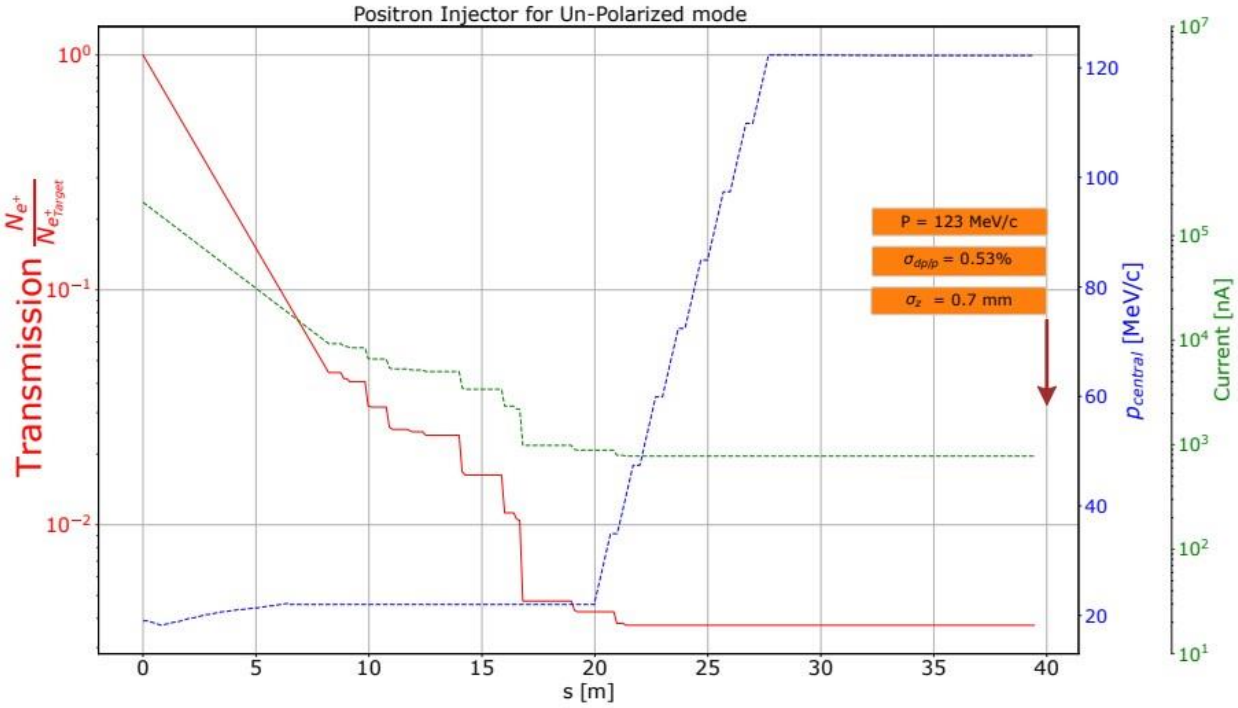


Modeling the CW positron source (S. Habet and A. Ushakov)



Polarized positron source
estimated positron current 170 nA,
goal is >50 nA

Unpolarized positron source,
estimated positron current 700 nA,
goal is > 1000 nA



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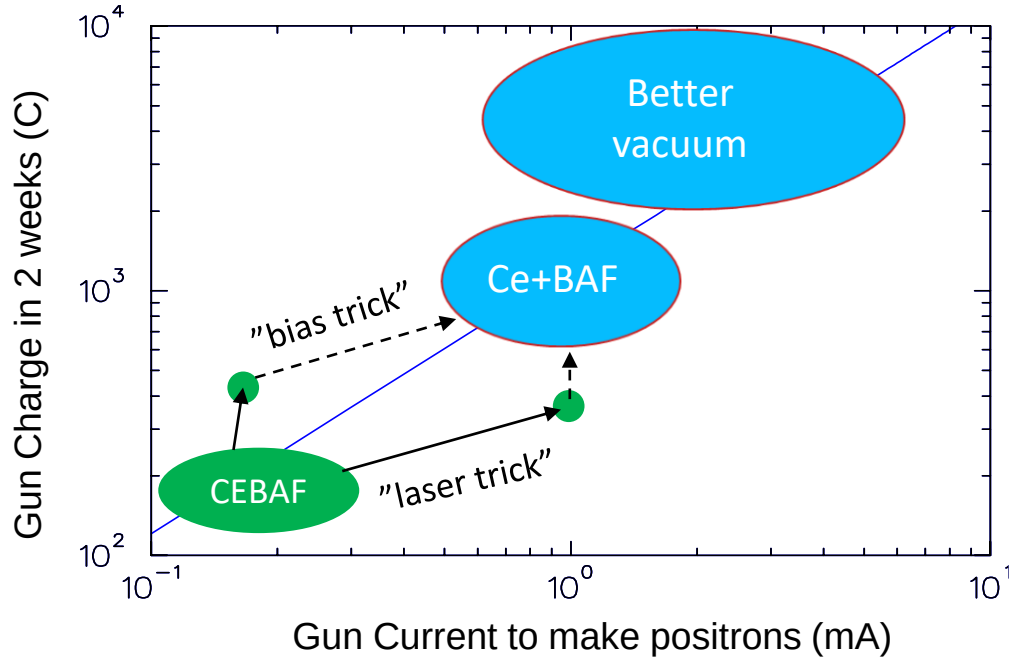
Ce+BAF parameters

- Ce+BAF = C(electron or positron)BAF
- e+ beam will have larger phase-space than e- CEBAF beam, hence “degraded” e- source that mimics the e+ phase-space could be used to understand the transport limitations of current CEBAF machine

Machine Parameter	CEBAF e-	Ce+BAF		
		e+	Degraded e-	e-
Multiplicity	4	1 or 2		
Max. Energy (ABC/D)	11/12 GeV	11/12 GeV		
Beam Repetition	250/499 MHz	250/499 MHz		
Duty Factor	100% cw	100% cw		
Unpolarized Intensity	170 μA**	> 1 μA	>> 1 uA	170 μA**
Polarized Intensity	170 μA**	> 50 nA	>> 1uA	170 μA**
Beam Polarization	> 85%	> 60%	>85% ?	>85%

Polarized e- source (PES) @ 1 mA (J. Grames, M. Poelker)

- Current CEBAF PES charge lifetime is 200 C (at 0.2 mA), this would last 2 days in e+ delivery mode
- Avenues for improvement:
  - Anode bias (+1 kV) could extend lifetime a factor of 2x (400 C), would last ~ 1 week in e+ delivery mode
  - Increase laser spot size (current < 1 mm^2 to several mm^2) could extend lifetime to 500+C (however will need to build a new gun to test it out)
  - Improve vacuum in the photogun chamber (use materials with 1000x less outgassing than currently used materials and baking the gun before use)
- The PES goal for the e+ era is to deliver >1mA e- for weeks on end



Positron beam proposals to PAC-51 (Jul 2023)

NUMBER	TITLE	CONTACT PERSON	HALL	DAYS REQUESTED	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION
PR12+23-002	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	Eric Voutier	B	100	100	**A-**	C1
PR12+23-003	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of Coulomb Corrections in DIS	Dave Gaskell	C	9.3	9.3	**A-**	C1
PR12+23-005	A Dark Photon Search with a JLab positron beam	Bogdan Wojtsekhowski	B	60			Deferred
PR12+23-006	Deeply Virtual Compton Scattering using a positron beam in Hall C	Carlos Munoz Camacho	C	137	137	**A-**	C1
PR12+23-008	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	Axel Schmidt	B	55	55	A	C1
PR12+23-012	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	Michael Nycz	C	56	56	**A-**	C1
Total number of days				**417.3**	**357.3**		

C1 = Conditionally Approved

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 (originally for isotope production) 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 a pulsed source that we are assessing
  - We are also assessing a rotating target design different from the SKEKB design
- JLAB-Xelera are collaborating under the DOE SBIR program
- JLAB-SLAC-SKEKB are collaborating under a DOE-SC-HEP grant funding opportunity that supports the development of advanced accelerator technologies (1 year funding in progress, submitted in Dec 2023 for a 3 year grant 2024-2027)
- Kathleen Mahler (ODU) wants to do a PhD thesis about the positron target: develop a prototype high power target and thermally assess it with a high power laser within 2 years
- Our goal is to settle on a production target design within 3 years

Ce+BAF positron target parameters

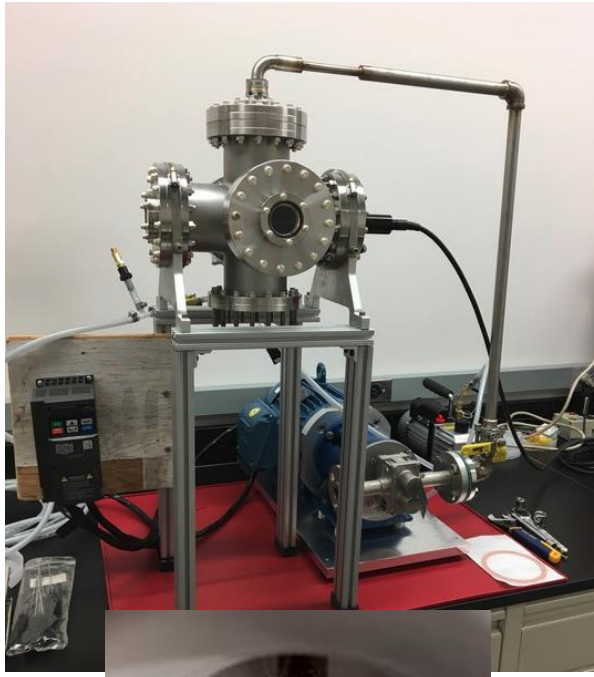
- Design goal: the target should be able to take a 1 mA CW e- beam current and have a lifetime of 6 months to 1 year
- Tungsten is preferable as a target material: high Z (high e+ yield) and high melting temperature (thermal resilience to high power beam deposition)
- Optimal W target thickness for e+ production from an incoming 120 MeV, 1 mA e- beam, would be 4 mm
- Fluka estimates for heating power deposition in such a target are in the range of 17 kW (the highest power target we used in a Hall at jlab was the Qweak target at 2.1 kW beam power)
- Water seems to be the best option for cooling such a target
- Preliminary CFD simulations seem to 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)

Xelera target design

- DOE-SBIR phase I completed, submitted for a phase II in Nov 2023

- 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)

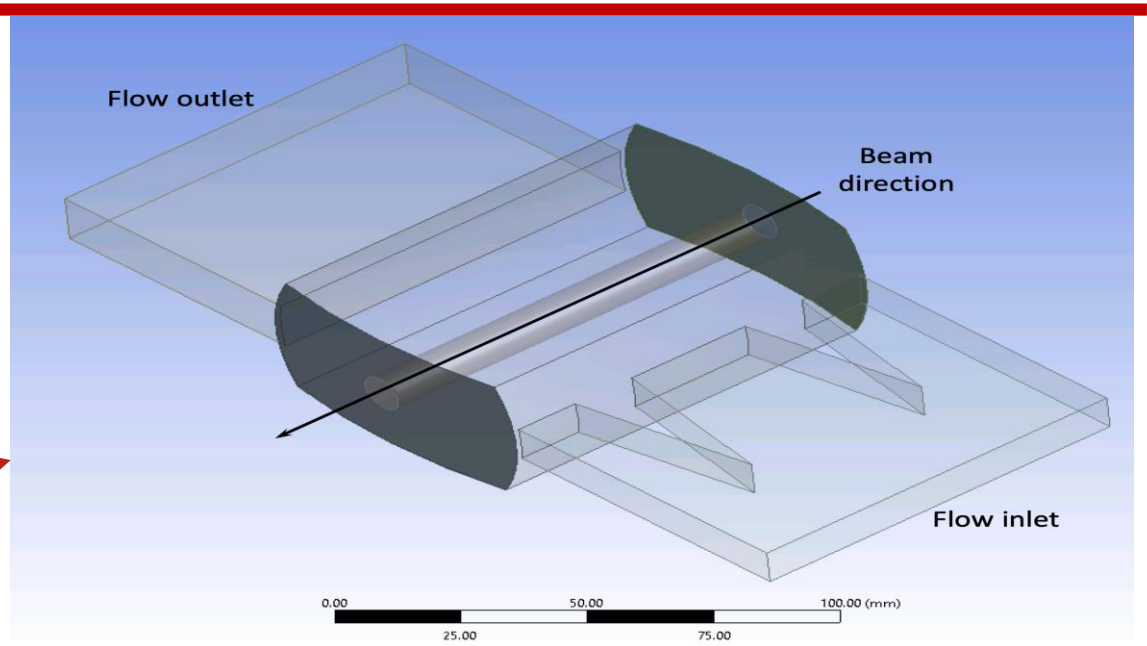
- SBIR phase II (2024-2026), if approved, aims to test a recirculating liquid metal target at LERF with 10 MeV and 1 mA beam (the e+ production liquid metal would be PbBi)
  - Assess (with CFD) and study the thermal properties of the target
  - Vacuum compatibility with SRF
  - If possible, characterize the e+ distribution
  - Assess the risks/issues associated with operating such a target
    - Integration with the jlab source
    - Radiation (shielding, contamination etc.)
    - Lifetime/decommissioning/changing the target, target parts, servicing
    - Industrial hygiene/hazardous materials
    - ?

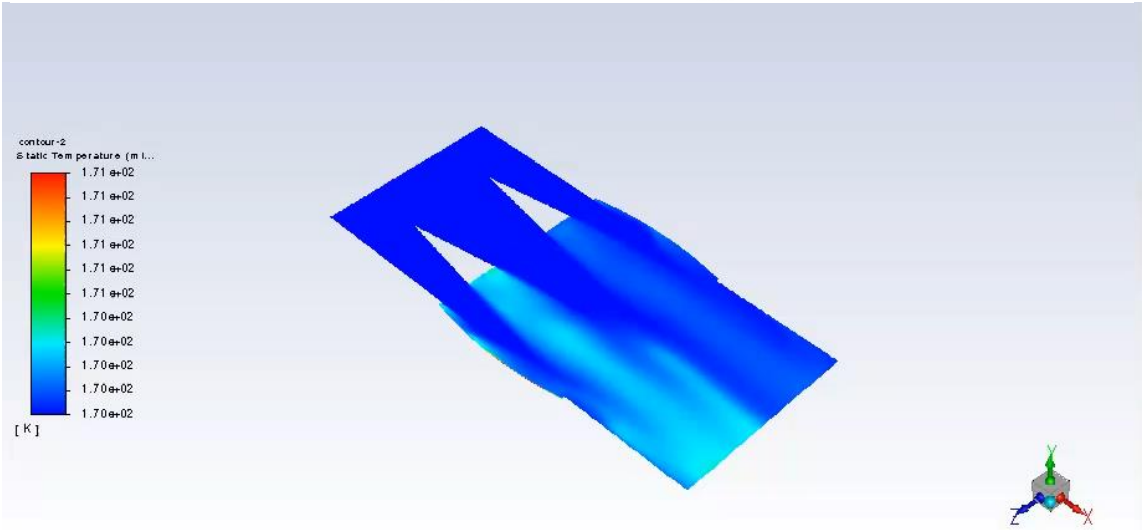


Pictures are courtesy of K. Smolenski and V. Kostroun

Liquid Xenon target concept

- SLAC-RIKEN group: LXe positron target concept for future Linear Colliders
  - 10 cm long for 3, 6 and 10 GeV e- beams
- As part of our 3-party collaboration (jlab-slac-skekb), funded under a DOE-HEP grant:
  - developed a cell geometry at jlab and simulated it with CFD
  - After 3 geometry iterations found a model that might satisfy the ILC requirements
- 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
  - Beam power considered 5 kW equivalent, Fluka fit for energy deposition
  - Time-dependent simulations: beam is ON for 1 ms then OFF for 199 ms, and so on, beam frequency 5 Hz
  - Beam pulse sampled with 4 time steps (time resolution 0.25 ms)





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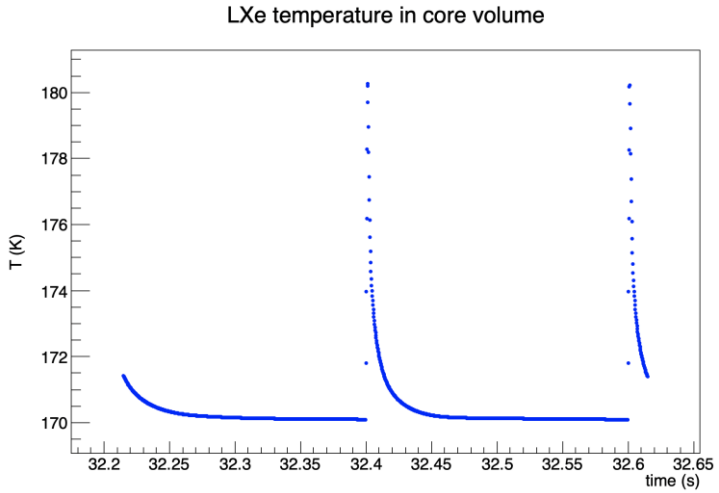
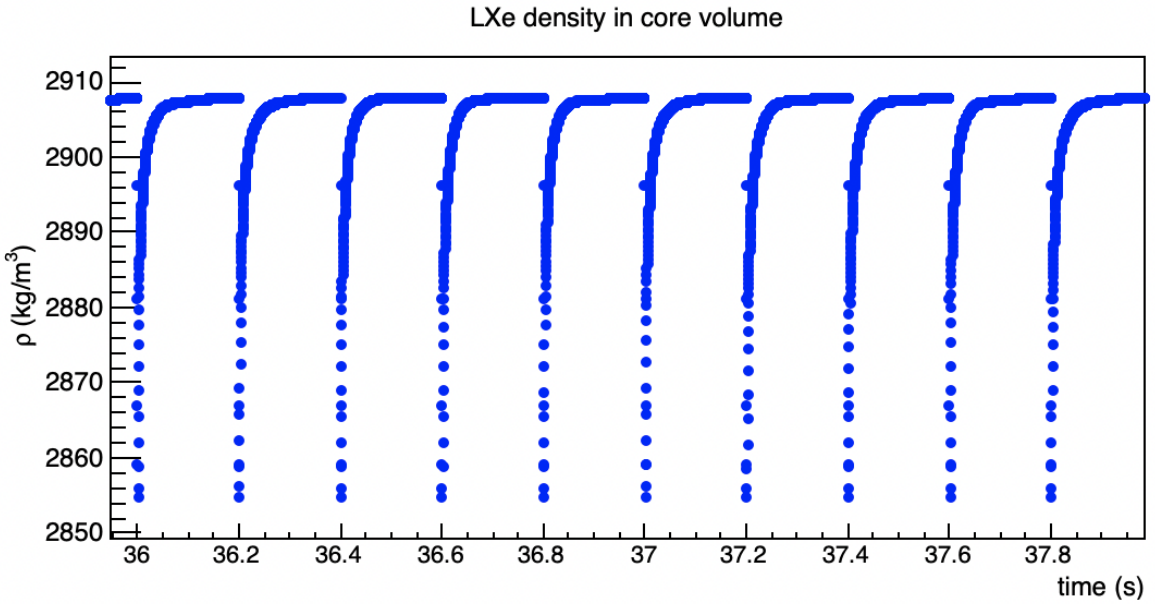
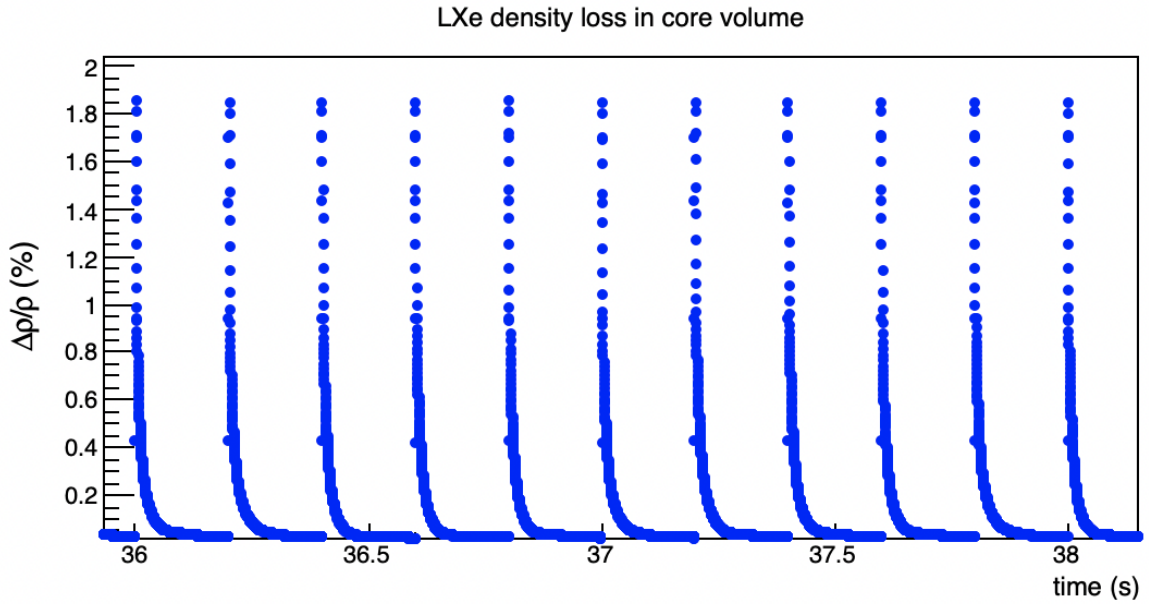
Liquid Xenon target CFD results

- LXe max density loss during the beam pulse 4%, average density loss less than 1% (2% LXe density loss means reaching saturation)
- Max ΔT in cell windows during beam pulse < 7 K
- Pressure spikes when the beam turns ON, this should be investigated with a finer time resolution to check for shock waves
- CFD simulations are on-going



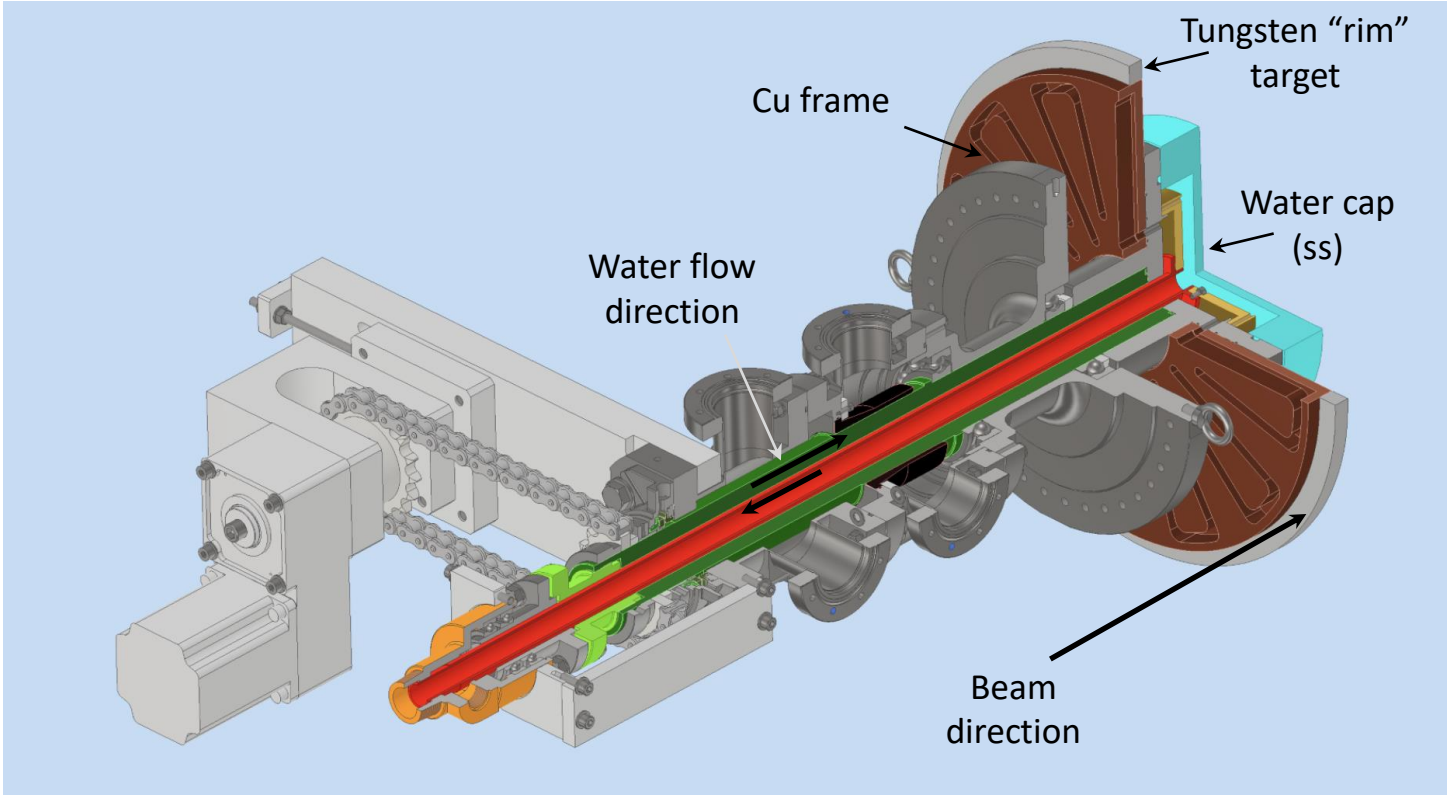




SKEKB rotating target concept

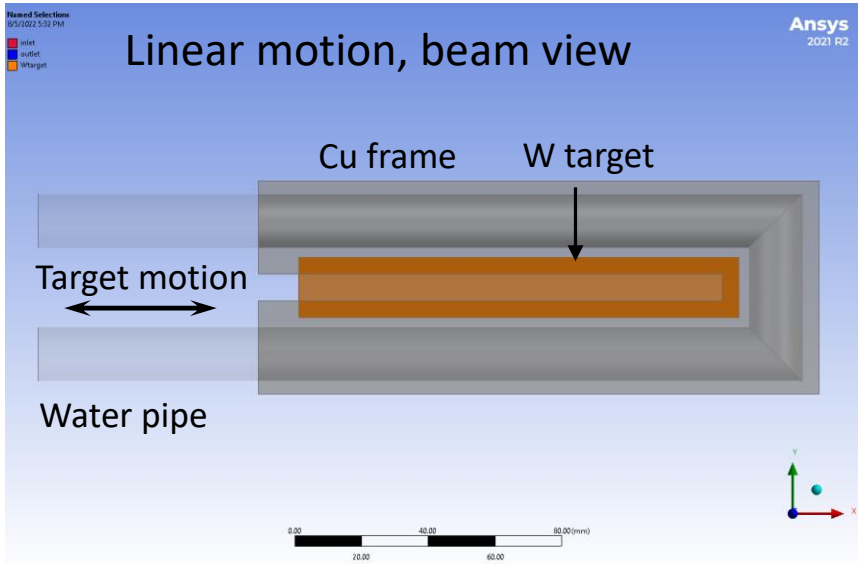
- SKEKB already has a e+ prototype production target, but they are trying to upgrade it for a production target
- As part of the 3-party collaboration (jlab-slac-skekb):
  - Assessing with CFD the skekb rotating target at full beam power with the time structure of the ILC beam and the space structure of the beam power deposition in target from Fluka

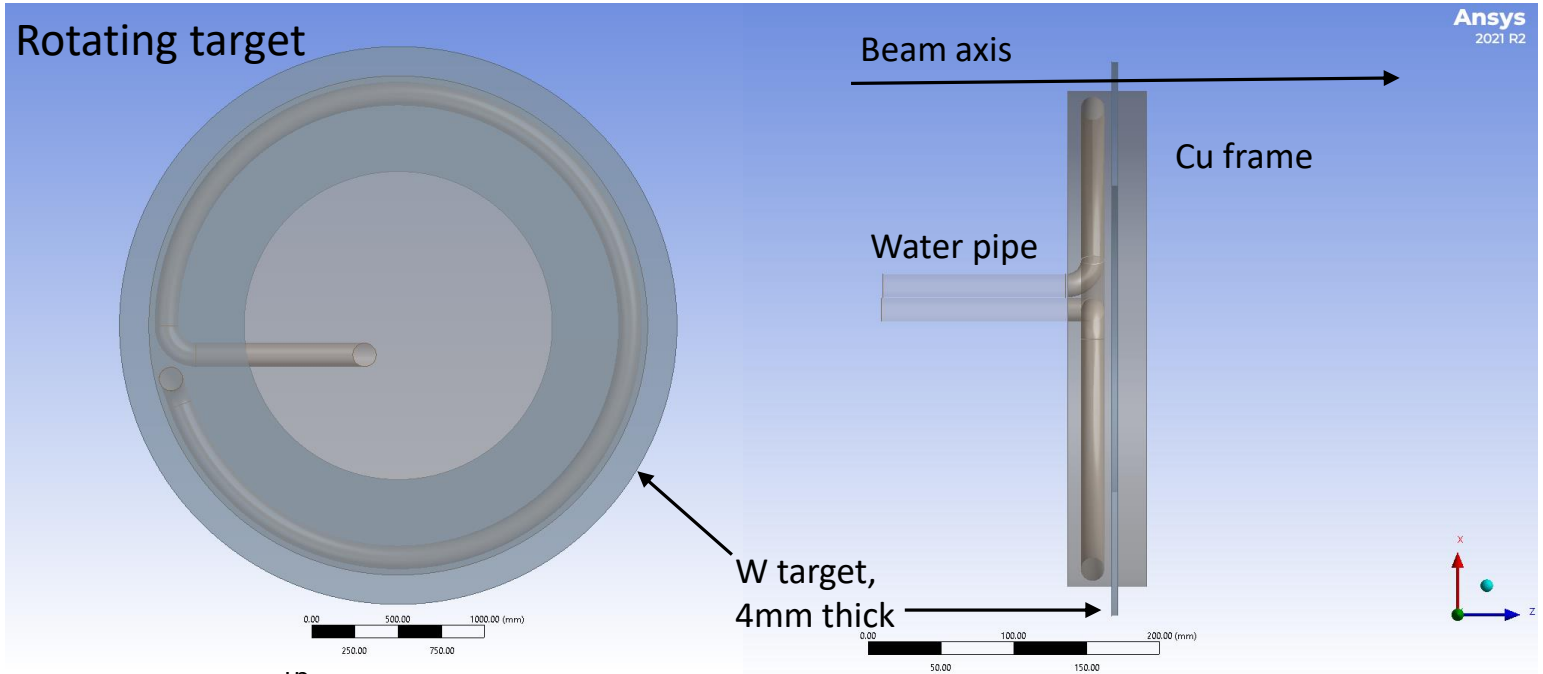
- Implemented the skekb target geometry in CFD
- CFD parameters:
  - target material W 16 mm thick, 25 cm radius, W "welded" to Cu frame, rotates at 3.75 Hz
  - Simulated CW beam 20 kW power, σ = 2.2 mm, beam spot diameter 6 mm
  - Water coolant in at 290 K, 1.167 kg/s, 5 atm
- CFD preliminary results:
  - Max temperatures: 450 K in W, 320 K in water, 380 K in Cu
- CFD simulations are on-going



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

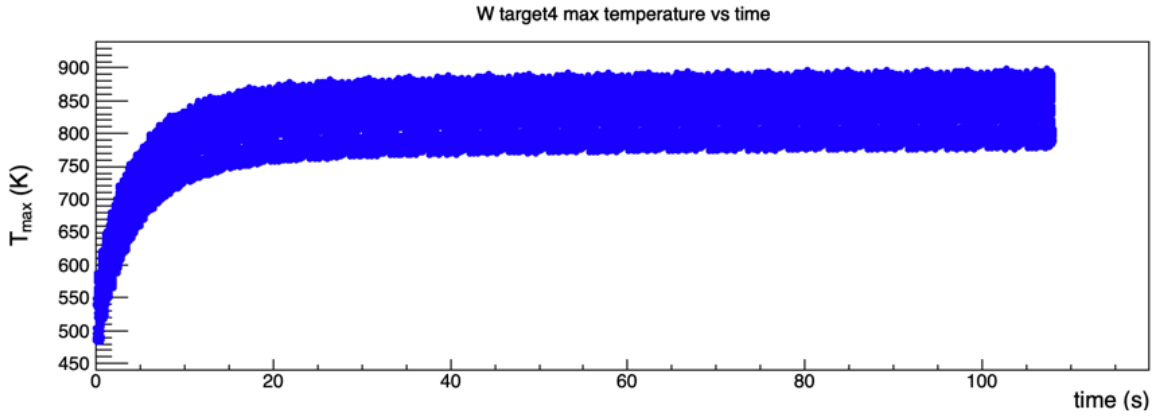


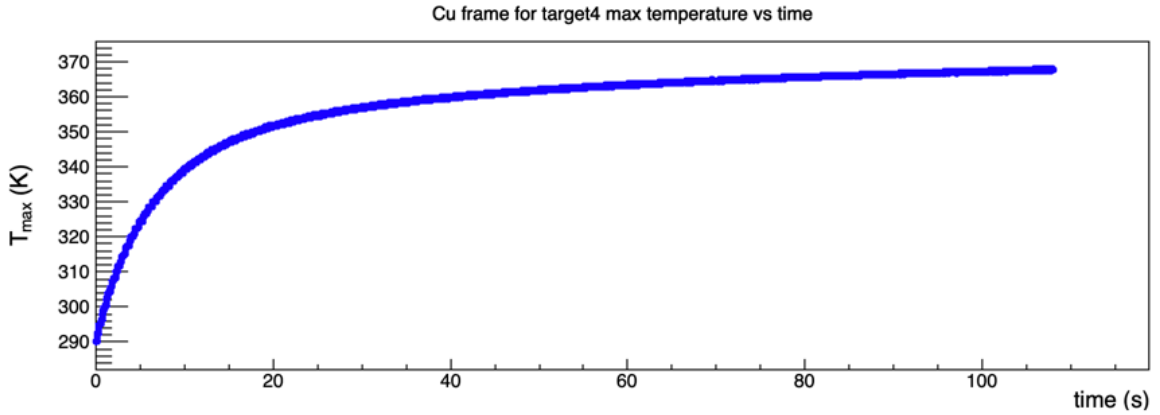


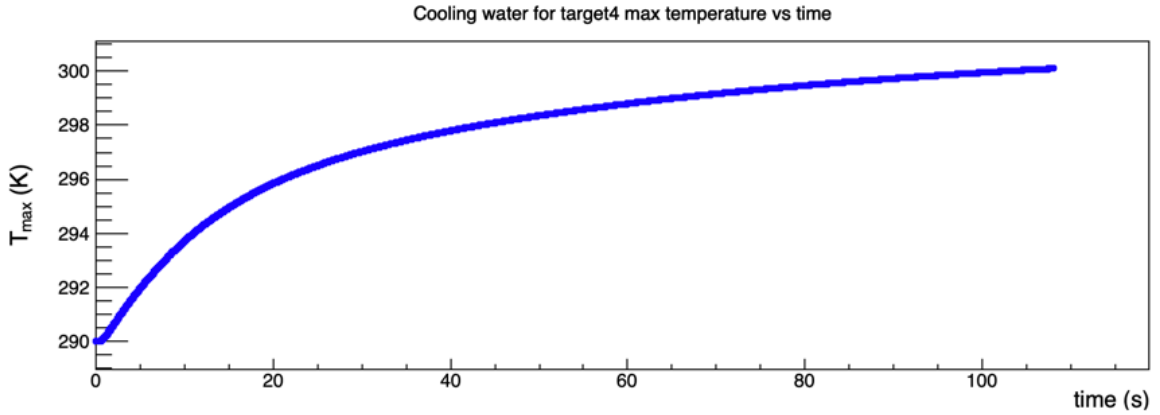
CEBAF rotating W target with CFD

- 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 0.3 kg/s, water pressure loss is 1.5 psi
- Full time-dependent CFD simulations implemented

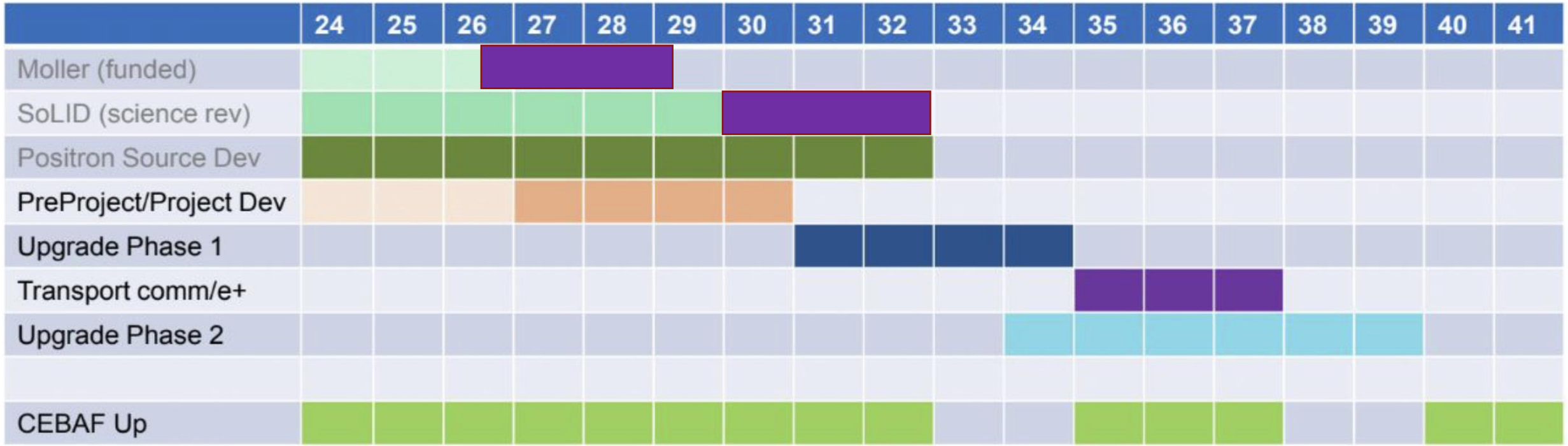
- No studies on target material lifetime
- Started looking at the target engineering, radiological issues, shielding







High level tentative e+ source schedule



Phase 1 includes building a positron source and the tunnel & beamline connecting the source to main machine.

Phase 2 includes the new permanent magnets to allow 22 GeV within current CEBAF footprint.

Summary

- PEPPo delivered proof-of-principle that producing polarized CW e+ would be possible at CEBAF in 2012
- Working on developing a feasible design for the e+ source at LERF within 3-5 years accounting for radiological issues, shielding etc.
- The e+ target:
  - Develop a prototype e+ rotating target within 2 years and test it at LERF (K. Mahler PhD thesis)
  - Down-select a concept for the Ce+BAF production target within the next 2 years
  - Design and engineer the e+ target within the next 5 years
- The Ce+BAF source is supported by lab operations and subjected to budget restrictions going forward