Thermionic Bunched Electron Sources for High-Energy Electron Cooling

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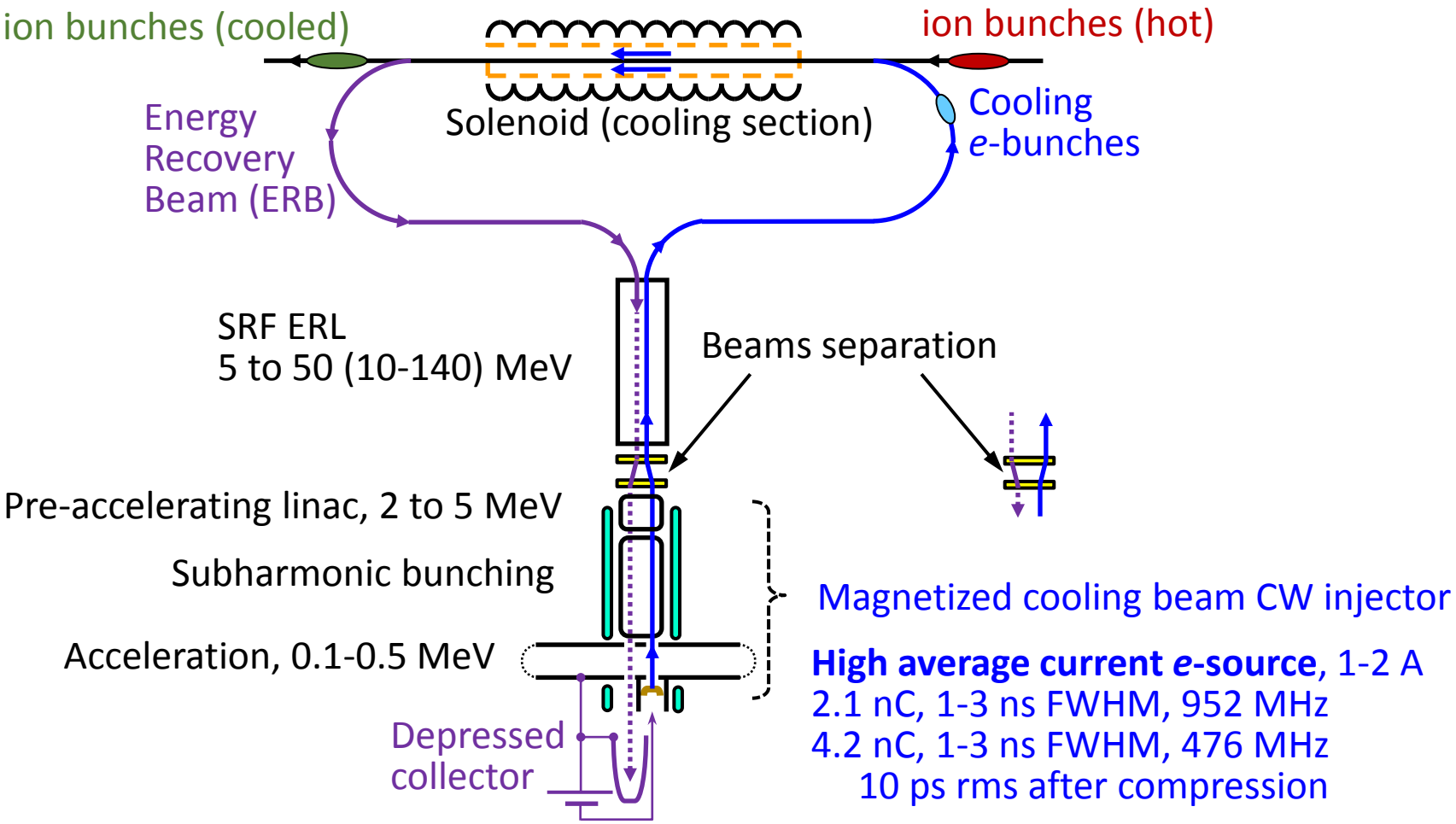
Outline

- HEEC schemes (e-sources, beam-beam kicker integration)
- Beam-beam kicker
- Required electron sources
- Emission gating and acceleration schemes
- Obtaining broad range of bunch repetition rates
- Summary

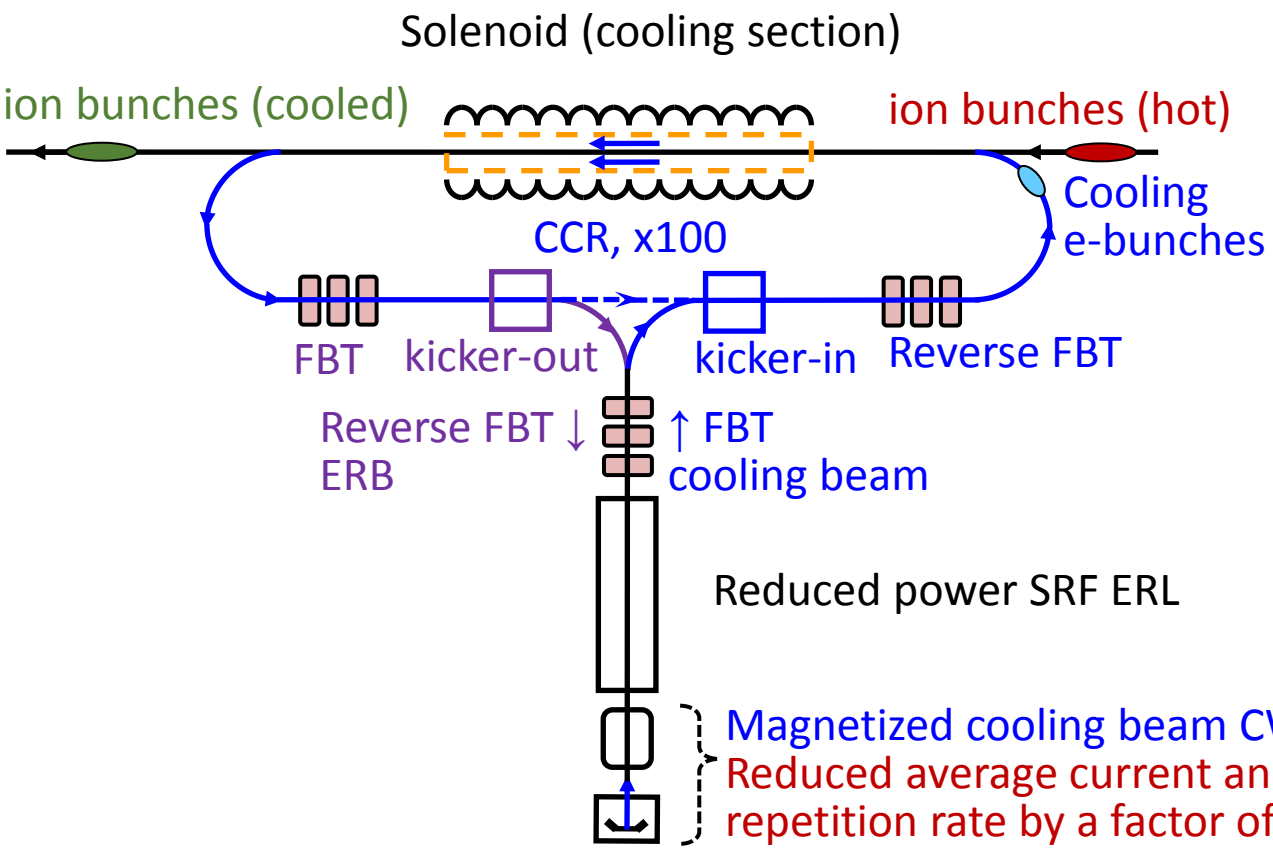
Single Current HEEC with Counter ERL



Y. Derbenev "Cooling with Magnetized Electron Beam" *MEIC Spring 2015*

Y. Derbenev "Head-on ERL for HEEC" *JLEIC R&D Meeting*, CASA, March 17, 2016

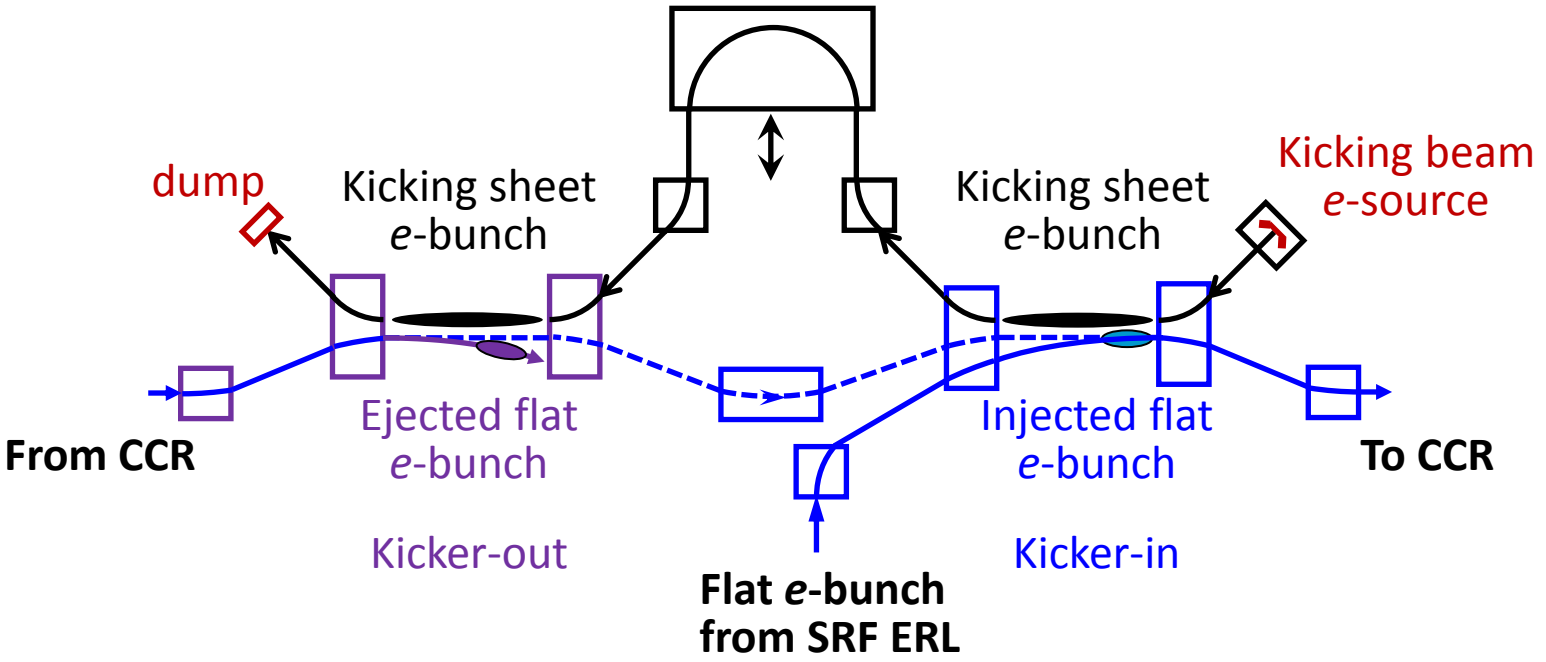
Circulating Current HEEC with Counter ERL



e-source, 0.02-1 A average current
1 nC, 1-3 ns FWHM, 9.52-952 MHz
2 nC, 1-3 ns FWHM, 4.56-456 MHz
10 ps rms after compression

Circulating Current HEEC

Beam-Beam Kicker with Magnet Dipoles



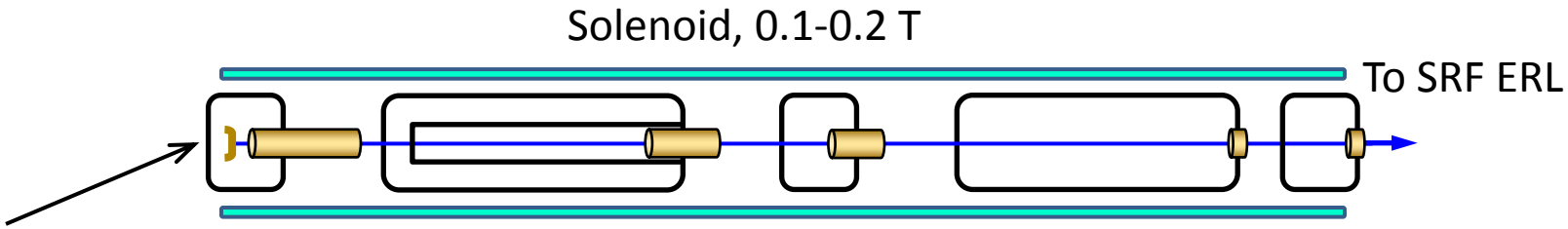
Kicking beam *e*-source

Bunched sheet beam, ~10x150 mm

>2 nC, <1ns FWHM, 4.56-456 MHz

>1 A average current, 0.1-0.5 MeV

Bunch Compression and Pre-acceleration



Bunched ***e*-source**
36^{th} subharmonic
36 MHz
1-3 ns FWHM
0.1-0.5 MeV

Ballistic Buncher 1
12^{th} subharmonic
108 MHz
150 ps FWHM

Ballistic Buncher 2
3^{rd} subharmonic
433 MHz
50 ps FWHM

Linac
5 MeV

Tapered phase velocity buncher
Linac frequency, 9-cells
1296 MHz
10-20 ps FWHM, 2 MeV

The scheme and example values adopted from

1. Yeremian *et al. "*Boeing 120 MeV RF linac injector design and accelerator performance comparison with PARMELA" *Proc. PAC'89* IEEE (1989)
2. C. H. Kim "Electron Injector Studies at LBL" *LBNL Paper* LBL-29227 (2010)
3. N. S. Sereno "Booster Subharmonic RF Capture Design" *APS ANL,* LS-297 (2002)

Required Electron Source

Emission Gating and Acceleration

Gating

Pulsed [1] Limited repetition rate to low subharmonics

Limitations
- Jitter errors (gap voltage, current, bunch charge, timing)
- Poor to no control HOM
- Limited grid voltage, 200 V (small gap, dense grid, higher emittance)
- Limited DC floating, 100 kV

$$I_{gap} \sim \frac{C_{gap}+C_{circuit}}{\tau_{rise}} \left(\frac{j_{peak} d_{gap}^2}{2.33 \cdot 10^{-6}} \right)^{2/3}$$

d_{gap} =0.25 mm, j_{peak} =11A/cm^2 $\rightarrow$ U_{gap} = 200 V

C_{gap} + $C_{circuit}$= 30 pF, t_{rise}= 0.3 ns $\rightarrow$ I_{gap} = 20 A

$C_{circuit}$ co-sources jitter. j_{peak} and d_{gap} limit I_{gap}

1. M. J. Browne *et al.* "A multi-channel pulser for the SLC thermionic electron source" *PAC'85* SLAC-PUB-3546.

RF harmonics Repetition rate from the linac frequency to its low subharmonics

Advantages
- No jitter sources
- DC floating, 500 kV
- For two and more harmonics, higher grid voltage, >200 V attainable (larger gap, less dense grid, lower emittance)

Required Electron Source

Emission Gating and Acceleration

Acceleration

DC

10 MV/m (up to 30 MV/m with Mo) possible, CW (advantage)
Applicable to long bunches, no RF curvature (advantage)
HV DC insulation, Floating cathode (limitation)
Limited to 0.5 MeV (limitation)

RF TM_{010}, $\lambda/4$

no HV DC insulation (advantage)
Higher energies > 0.5 MeV in Linacs attainable (advantage)
Limited accelerating gradient, <7 MV/m CW (limitation)
Due to larger TM_{010} cavity, bunch duration to be <0.3 ns FWHM (limit.)
$\lambda/4$ structures can work with longer bunches, <100 ns FWHM (advan.)

Cooling beam CW *e*-source

Bunched magnetized beam, ~3 mm radius
0.02-2 A average current
2.1 nC, 1-3 ns FWHM, 9.52-952 MHz
4.2 nC, 1-3 ns FWHM, 4.56-456 MHz
10 ps rms after compression

Kicking beam CW *e*-source

Bunched sheet beam, ~10x150 mm
>1 A average current, 0.1-0.5 MeV
>2 nC, <1ns FWHM, 4.56-456 MHz

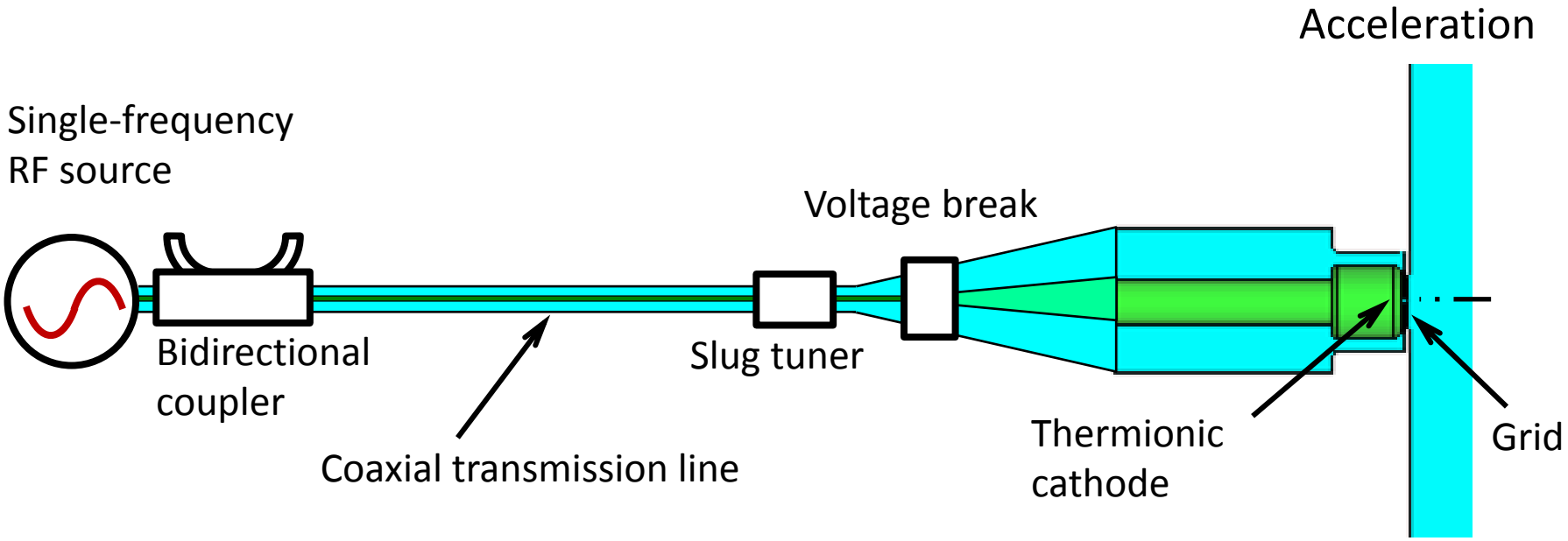
Bunched electron sources. Gating and acceleration

Single frequency gating of thermionic emission

Gridded Cathode

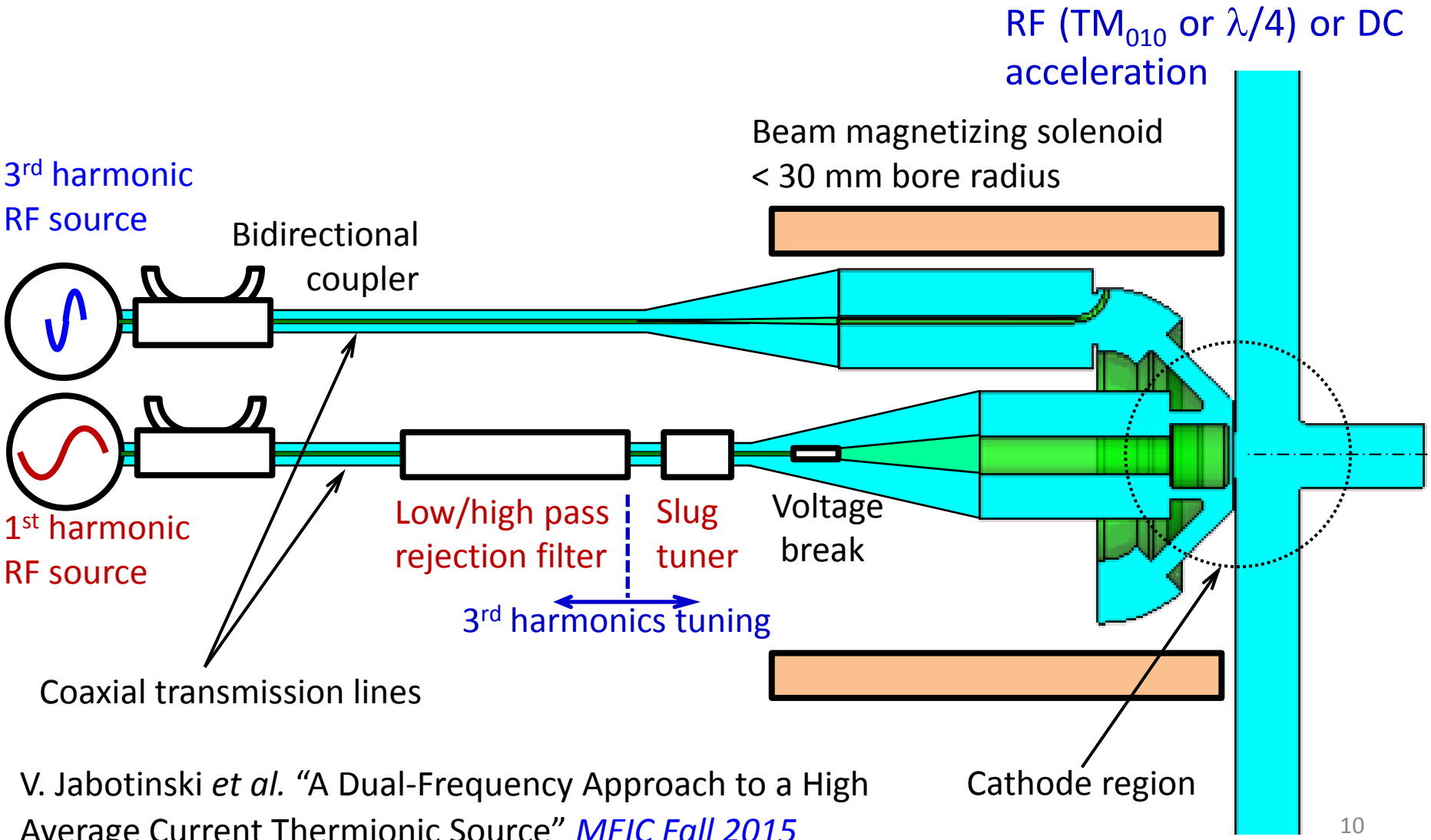
DC (IOTs, TRIUMF) or RF (TM_{010} or $\lambda/4$) Acceleration

Drawback: long bunch duration (slide 12)



Dual-Frequency Gating of Thermionic Emission

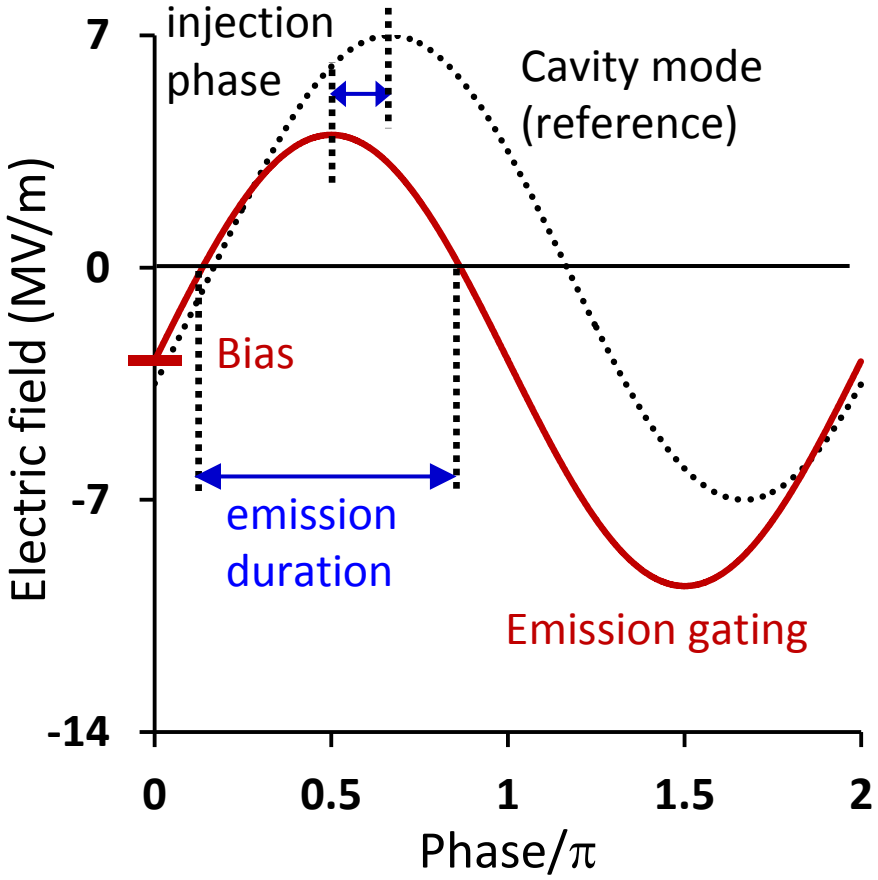
1st and $(2n+1)\lambda/4$-modes 3rd-harmonic

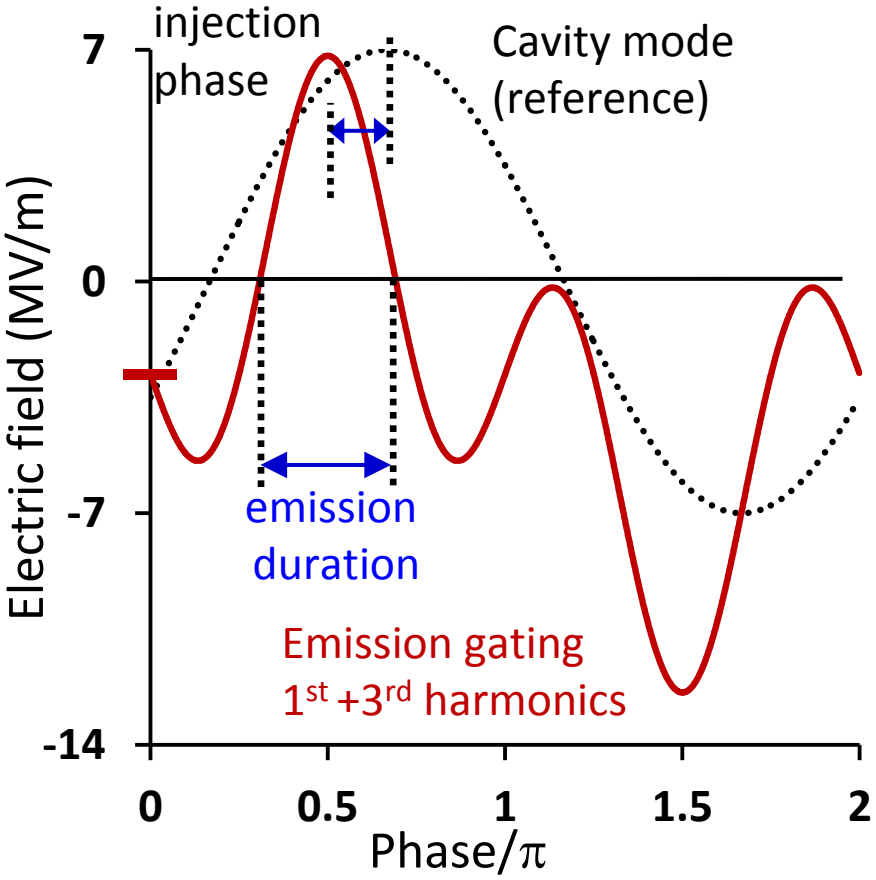


V. Jabotinski *et al.* "A Dual-Frequency Approach to a High Average Current Thermionic Source" *MEIC Fall 2015*

Dual-Frequency Gating of Thermionic Emission

Shortening Bunch Duration



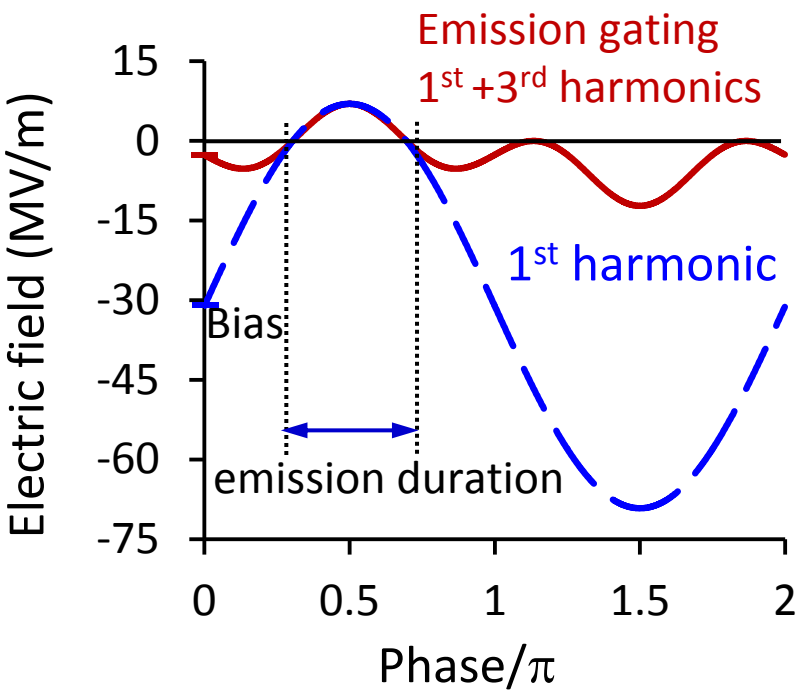


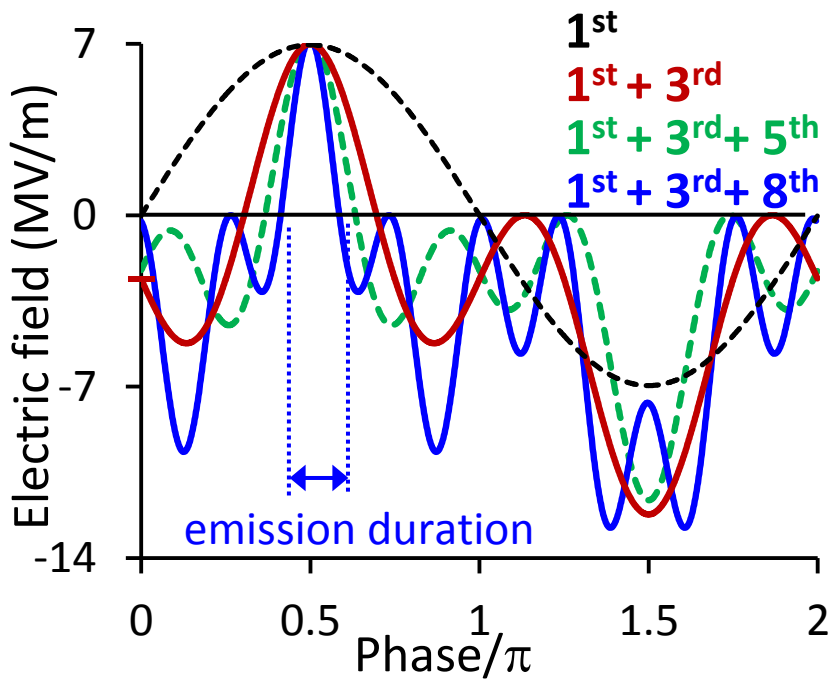
Gating the emission with the 1st harmonic (IOT, TRIUMF)

Gating the emission with the 1st and 3rd harmonics.

RF Gating of the Emission

Effect of higher harmonics





1st vs. 1st + 3rd

Amplitude x7.9 (RF power x62.4)

Bias x11.9

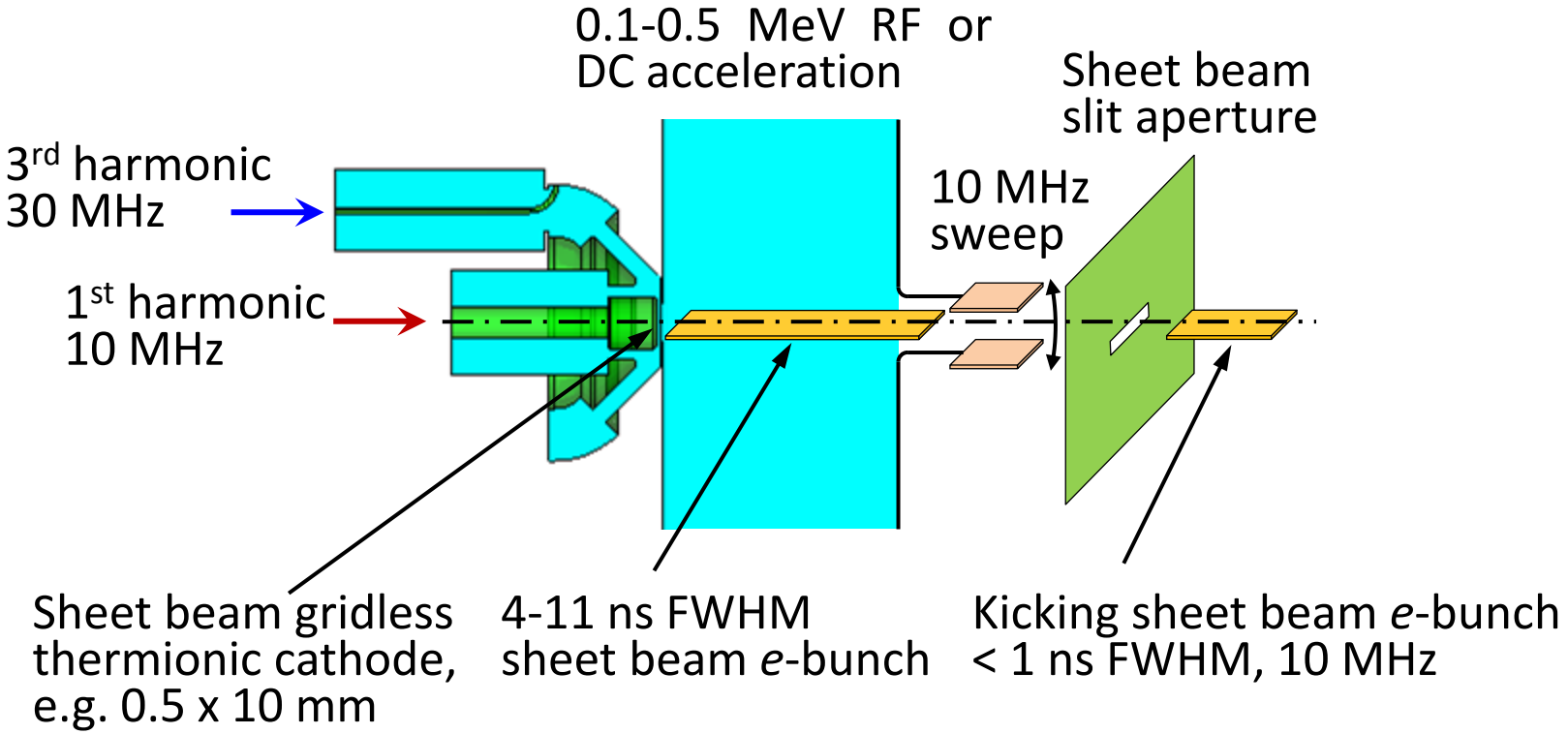
Harmonics	Emission duration (deg.)
1st	180
1st + 3rd	70.6
1st + 3rd+ 5th	48.1
1st + 3rd+ 8th	31.3

$$\tau > 4\sin^{-1}\frac{\sqrt[3]{j_{peak}\sqrt{d_{gap}}/2.33\cdot10^{-6}}}{\sqrt{2E_{peak}}}\ (\text{rad})$$

τ>92.6° at 20 A/cm^2, 0.5 mm, 5 MV/m

Kicking Sheet Beam E-source

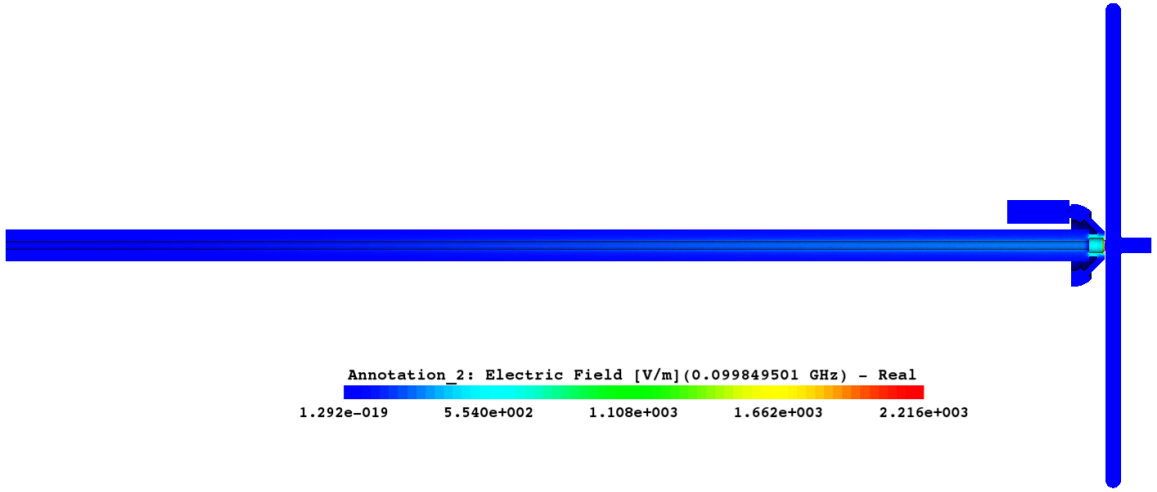
Low subharmonic repetition rate

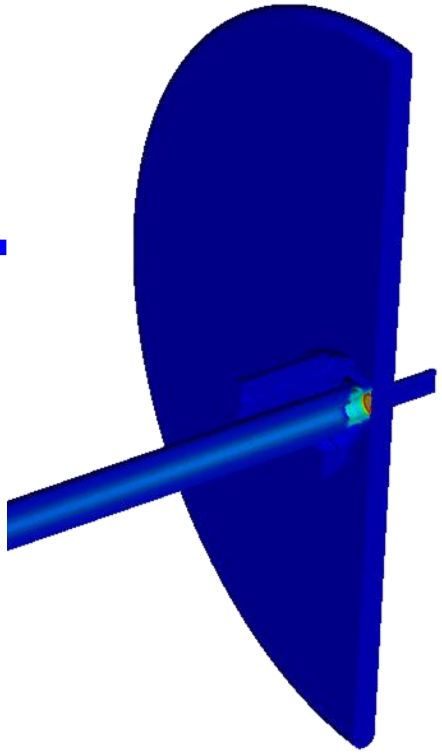


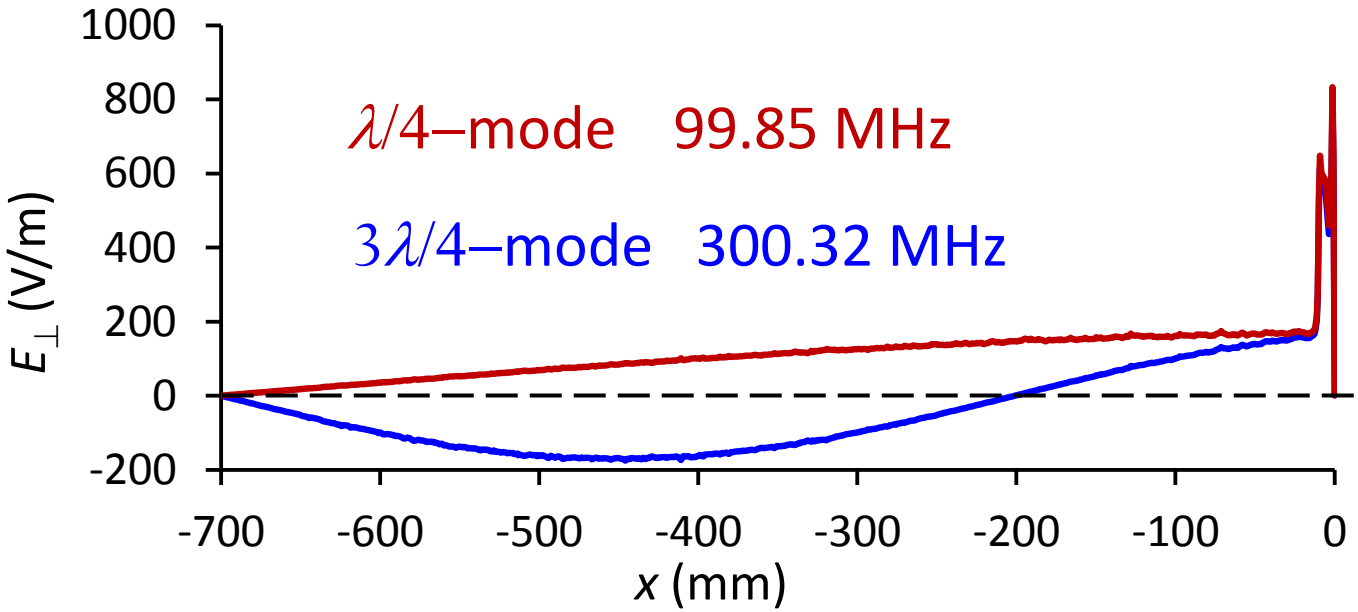
Sweeping is not needed for >40 MHz repetition rates or can be avoided with 3-harmonics gating for the lower frequencies, 10 MHz.

RF Gated Thermionic Electron Source

Low subharmonic repetition rates

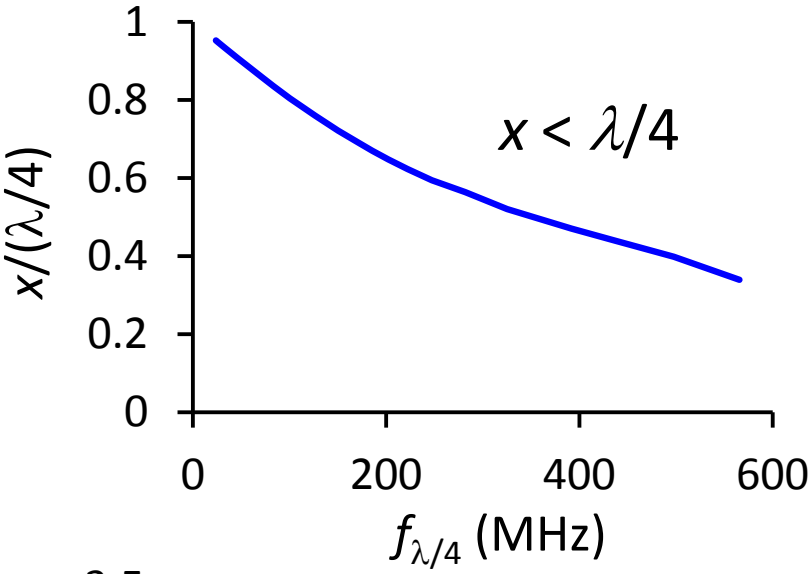


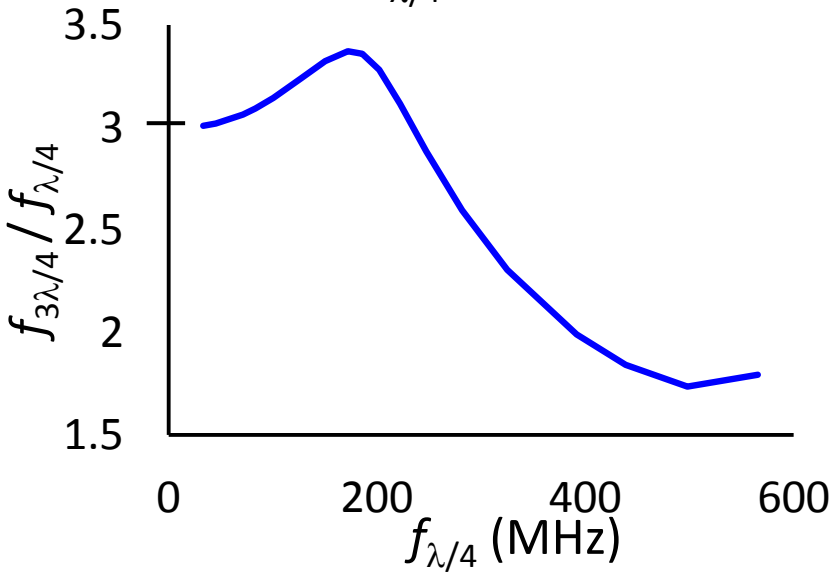




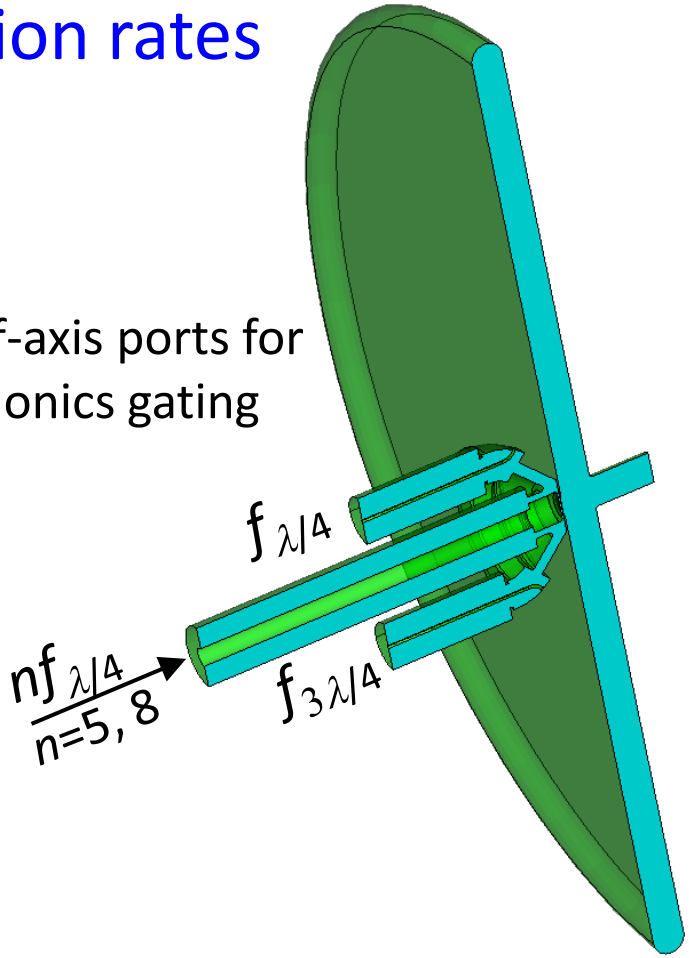
RF Gated Thermionic Electron Source

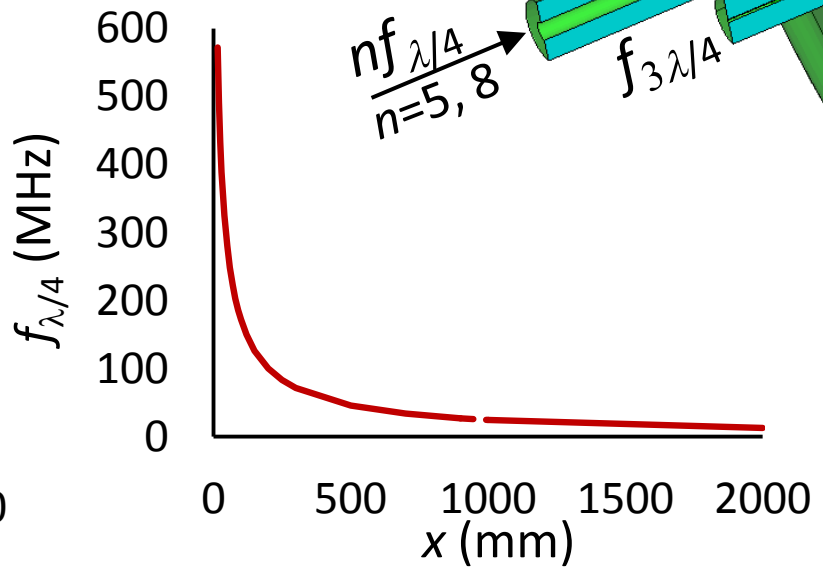
Low subharmonic repetition rates





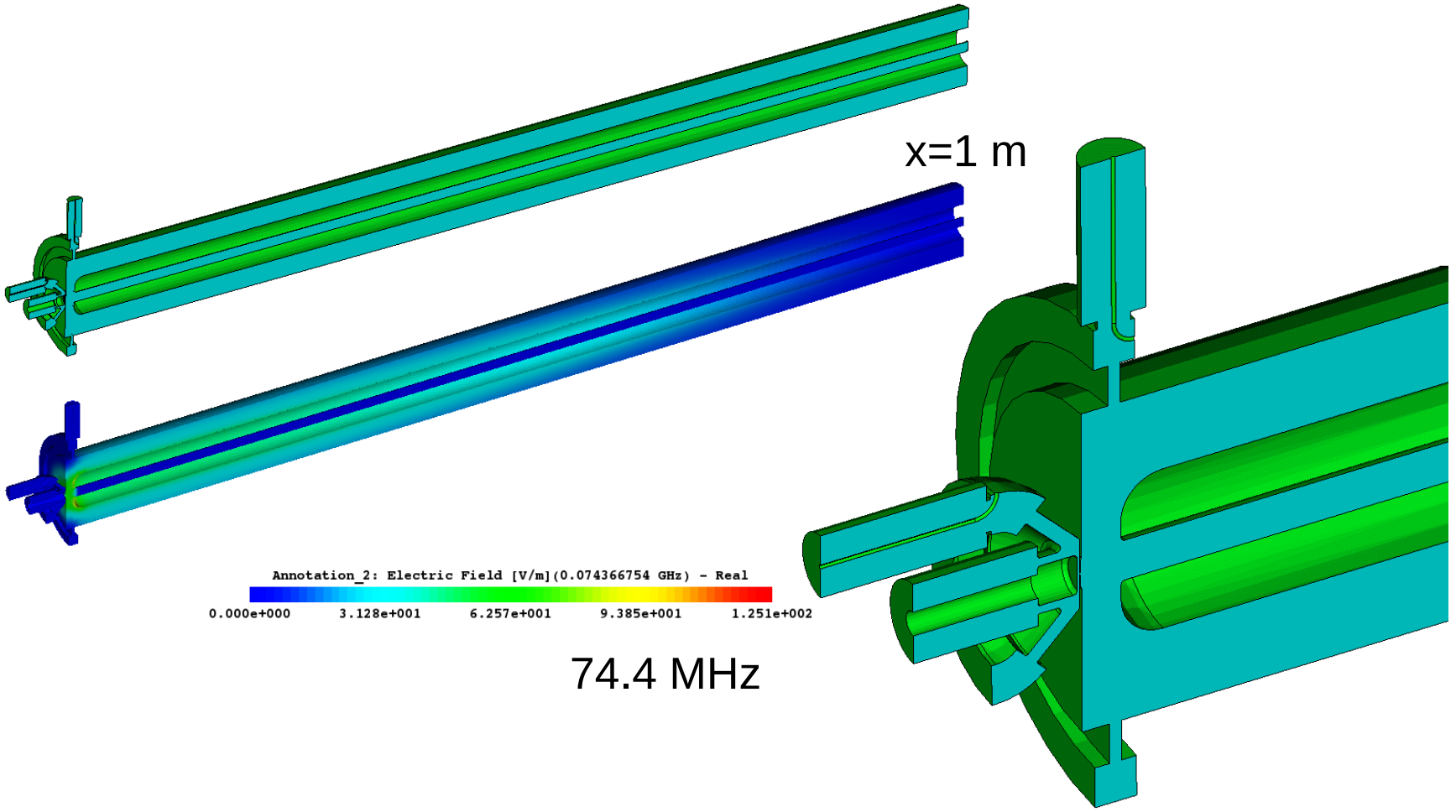
Two off-axis ports for
3-harmonics gating





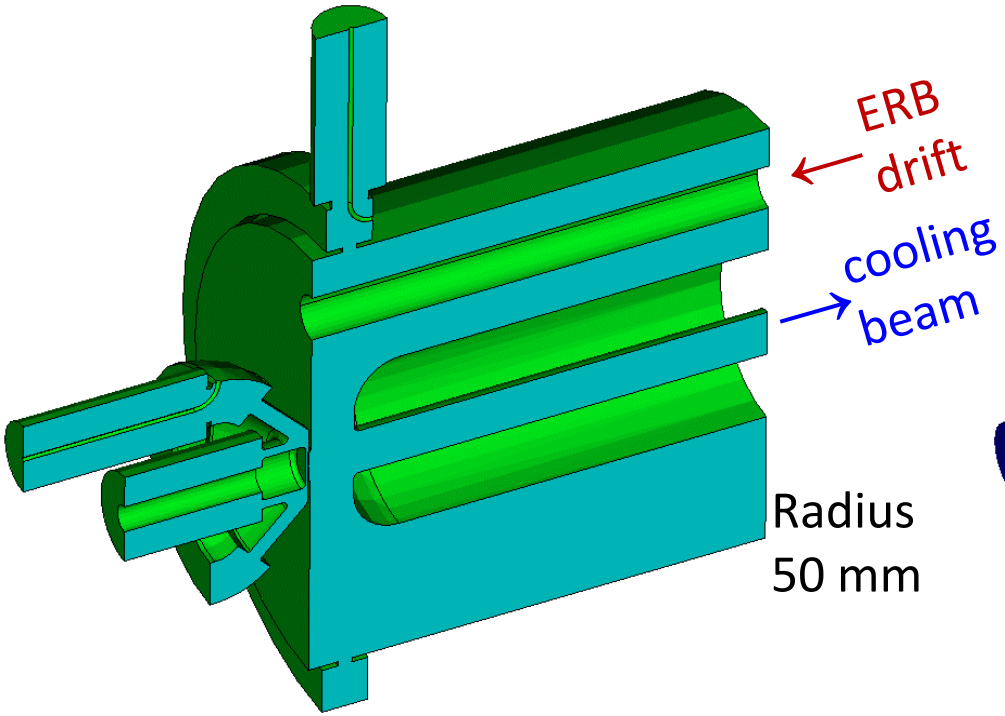
RF Gated Thermionic Electron Source

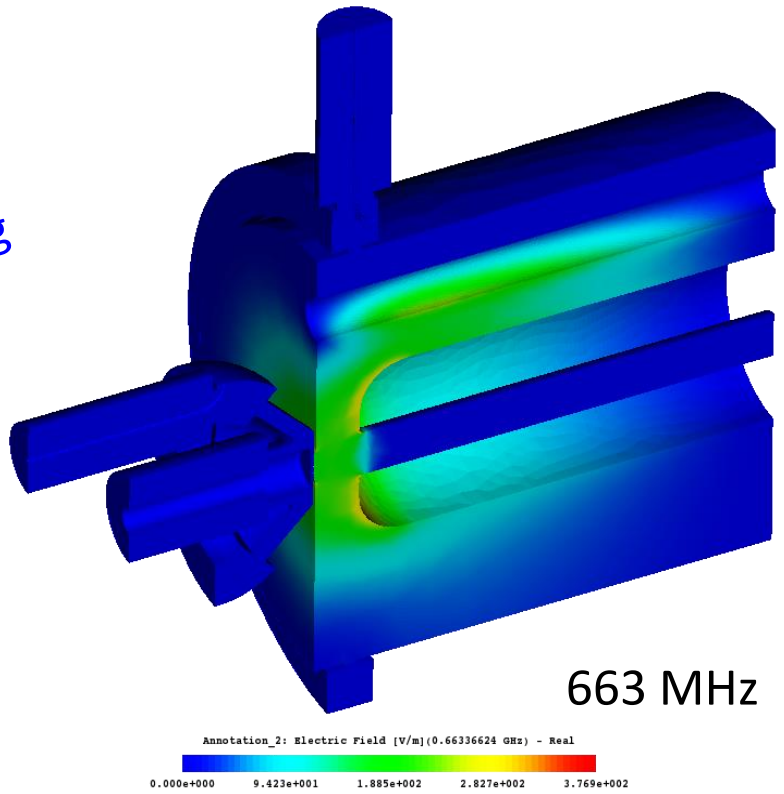
Quarter-wave bunching structure



RF Gated Thermionic Electron Source

Quarter-wave bunching structure with ERB drift tube



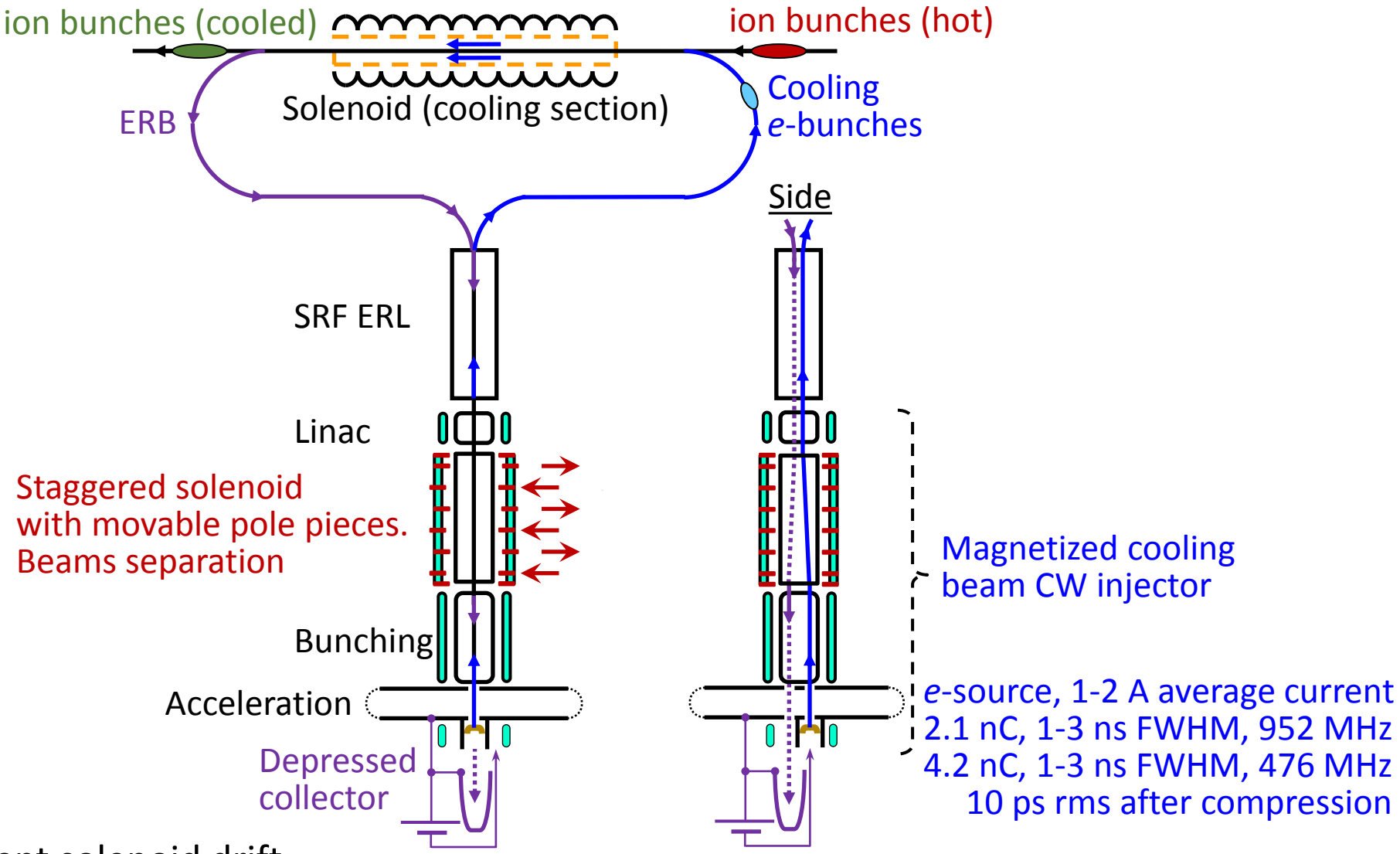


Summary

- We have considered HEEC schemes, identified critical components, their integration, and requirements including the needed electron sources and beam-beam kicker.
- Beam-beam kicker scheme using magnet dipoles is proposed
- Thermionic emission is inherently suitable for attaining high average current electron beams that are imperative for HEEC
- Methods for the emission gating and acceleration have been preliminary explored and e-sources for the cooling and the kicking beams are presented.
- Techniques aimed at low subharmonic repetition rates along with the linac frequency from the thermionic e-sources are discussed.
- Preliminary studies outlined the most critical approaches important to developing highly efficient HEEC and the electron sources.

Back up slides

Counter ERL. In-Solenoid Beams Separation

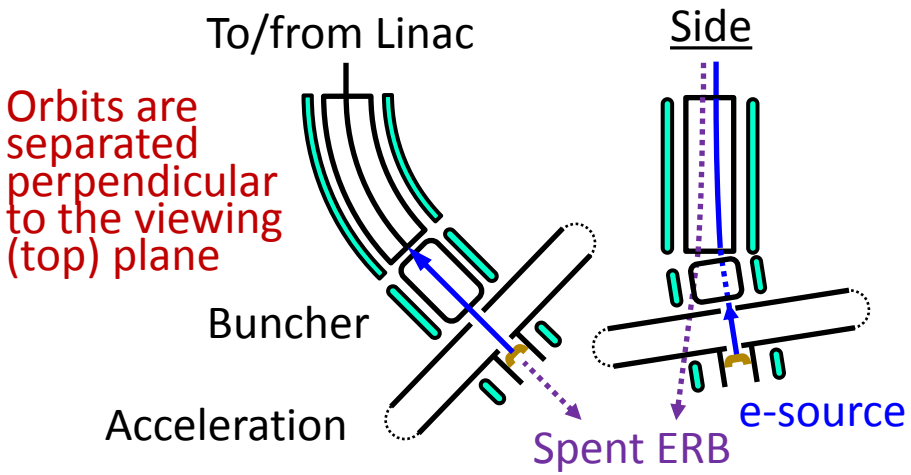


Bent solenoid drift:

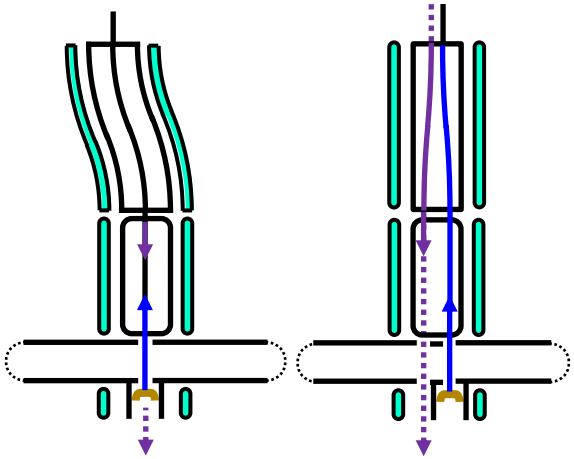
Y. Derbenev "Head-on ERL for HEEC" *JLEIC R&D Meeting*, CASA, March 17, 2016

Beams Separation using Bent Solenoid Drift

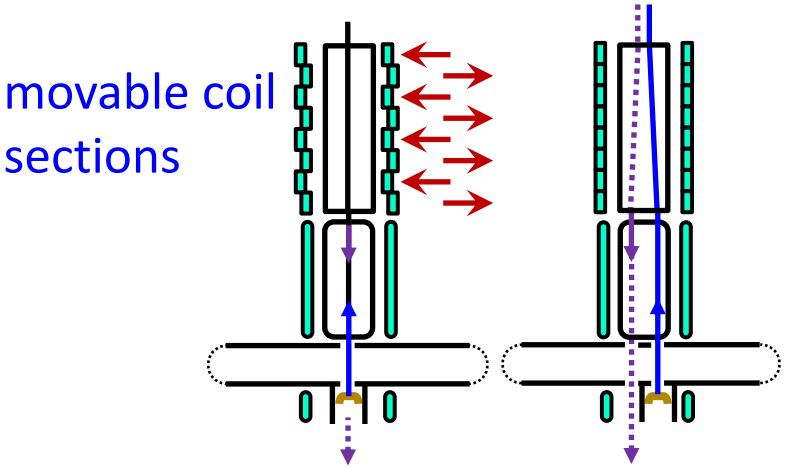
Bent Solenoid [1]



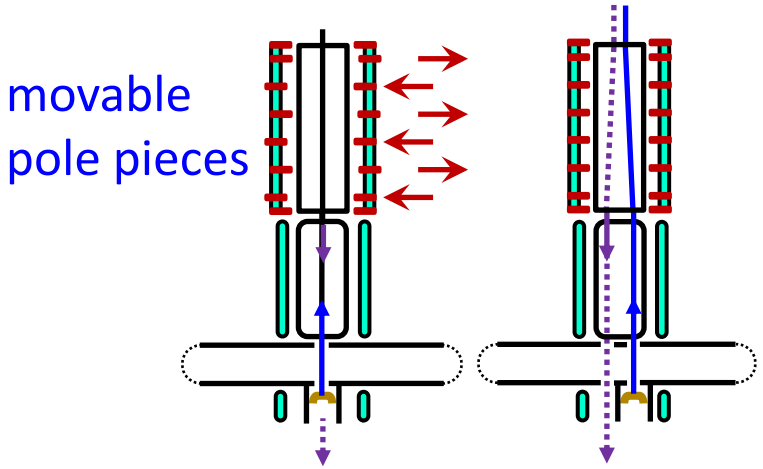
Twisted Solenoid



Staggered solenoid



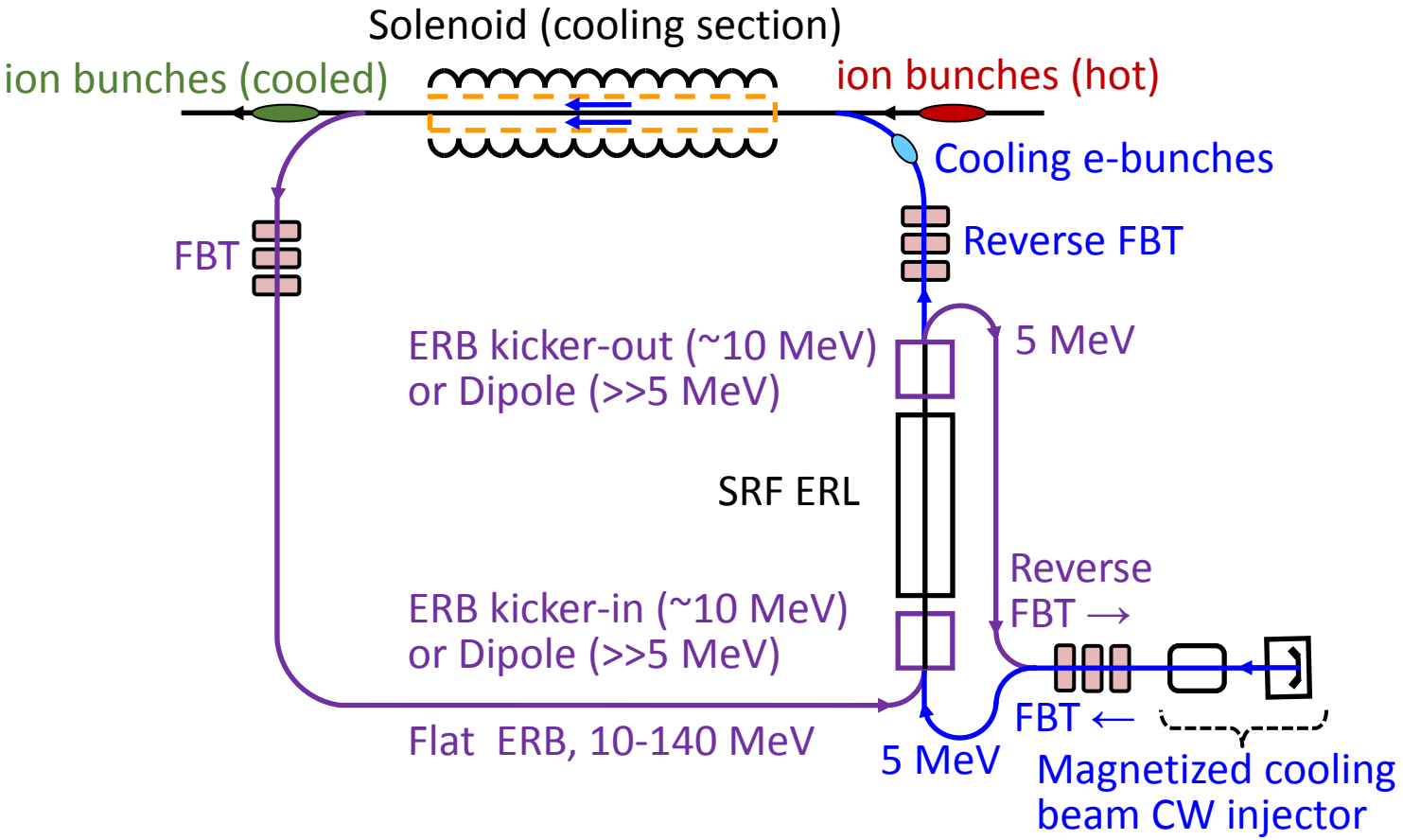
Staggered solenoid



1. Y. Derbenev "Head-on ERL for HEEC" *JLEIC R&D Meeting*, CASA, March 17, 2016

Single Current HEEC

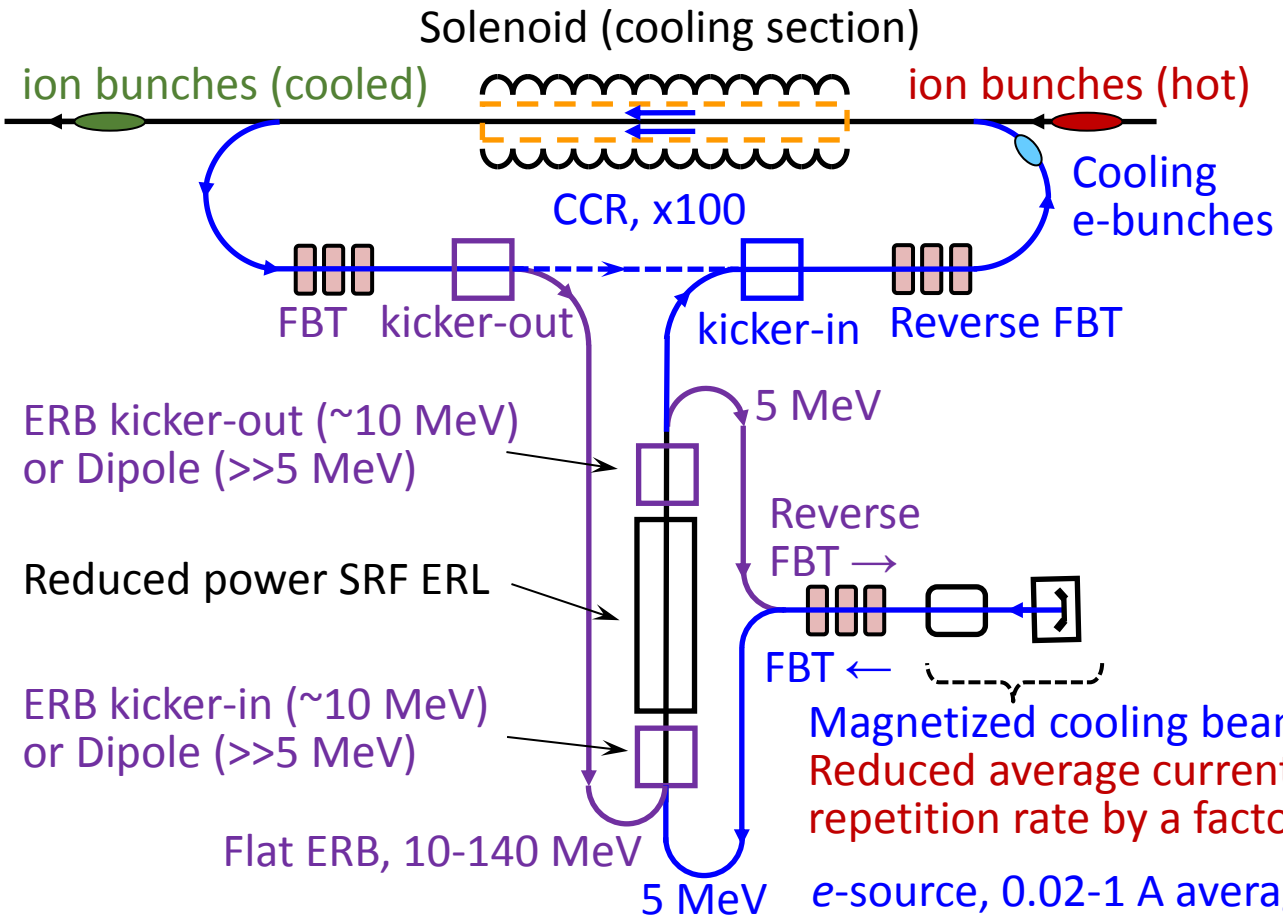
Concurrent SRF ERL. Counter Injector Linac



e-source, 1-2 A average current
2.1 nC, 1-3 ns FWHM, 952 MHz
4.2 nC, 1-3 ns FWHM, 476 MHz
10 ps rms after compression

Circulating Current HEEC

Concurrent SRF ERL. Counter Injector Linac

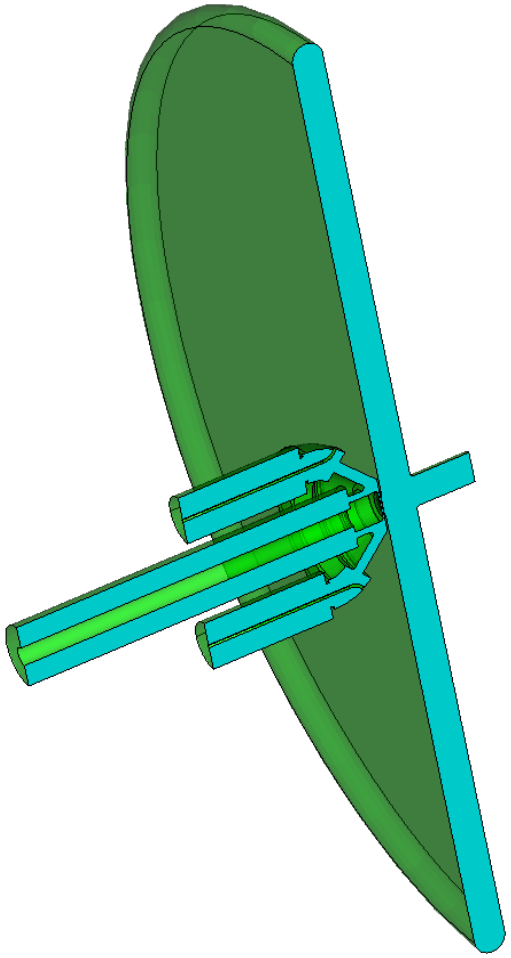


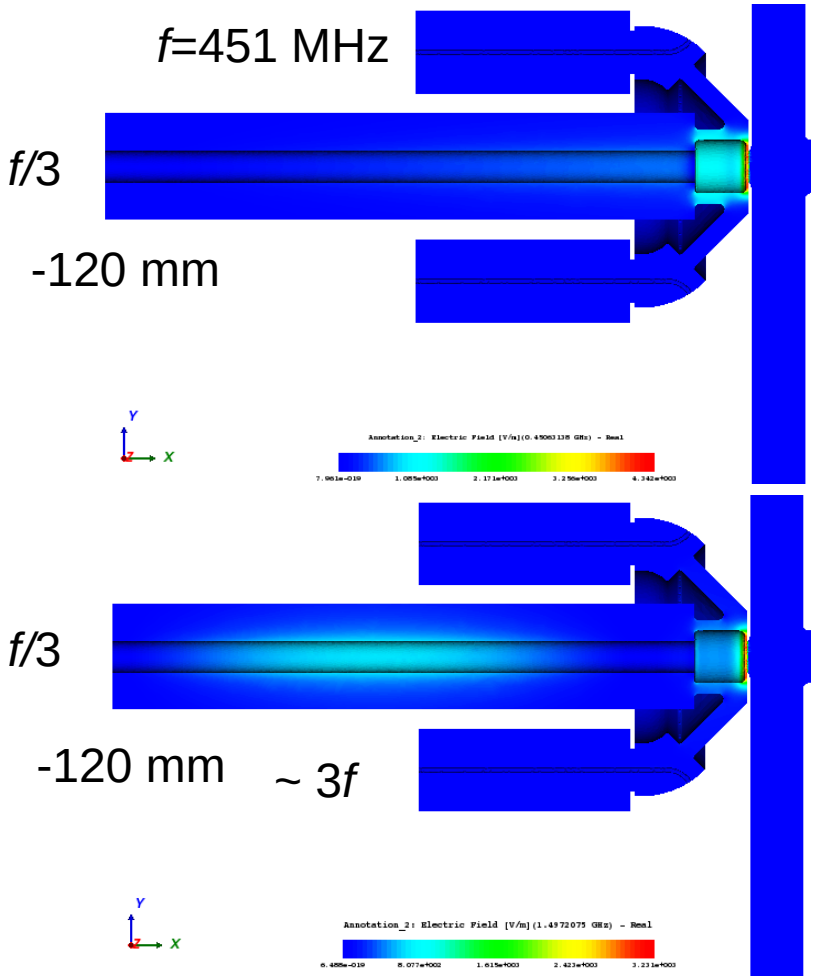
Magnetized cooling beam CW injector
Reduced average current and
repetition rate by a factor of 2-100

e-source, 0.02-1 A average current
1 nC, 1-3 ns FWHM, 9.52-952 MHz
2 nC, 1-3 ns FWHM, 4.56-456 MHz
10 ps rms after compression

RF Gated Thermionic Electron Source

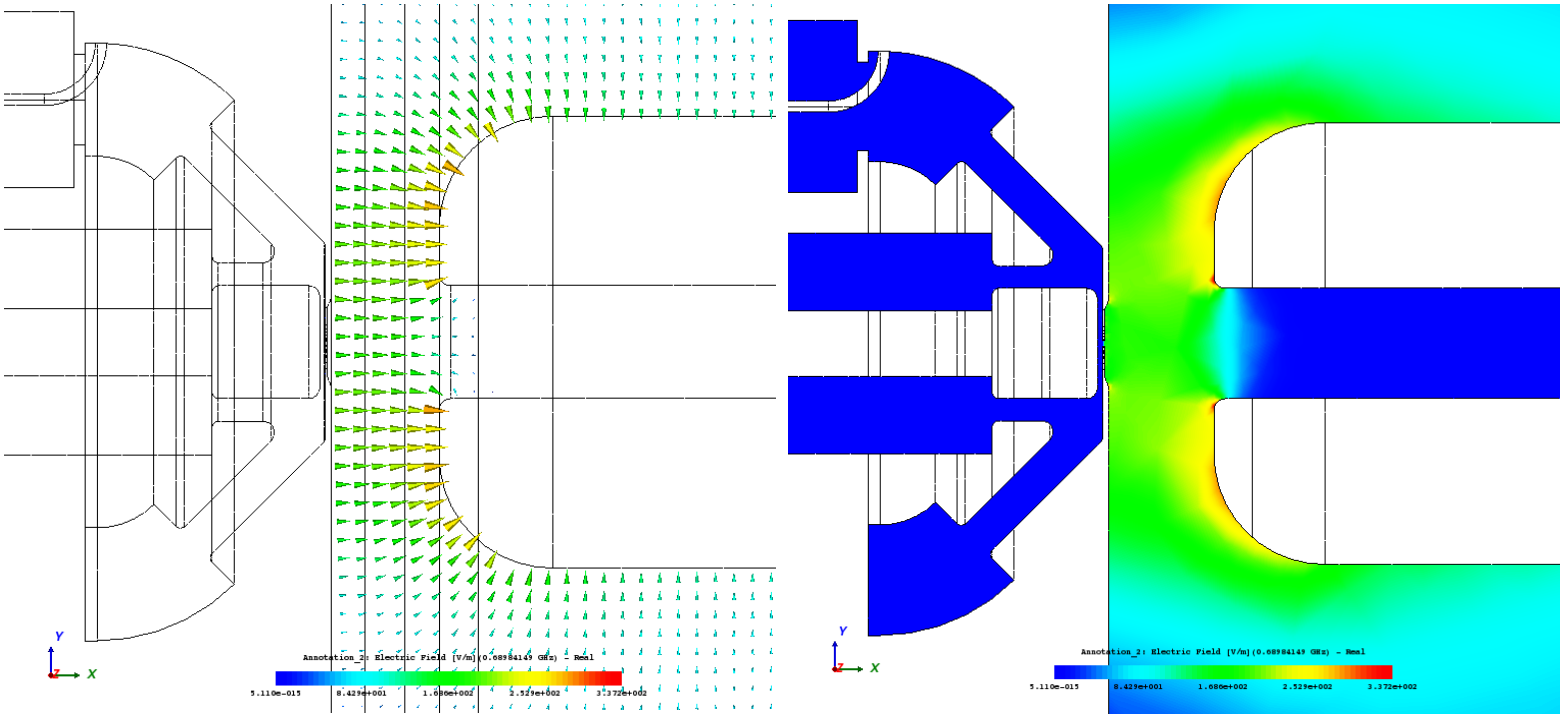
Two off axis ports for three-harmonics gating





RF Gated Thermionic Electron Source

Quarter-wave bunching structure, E-field plots

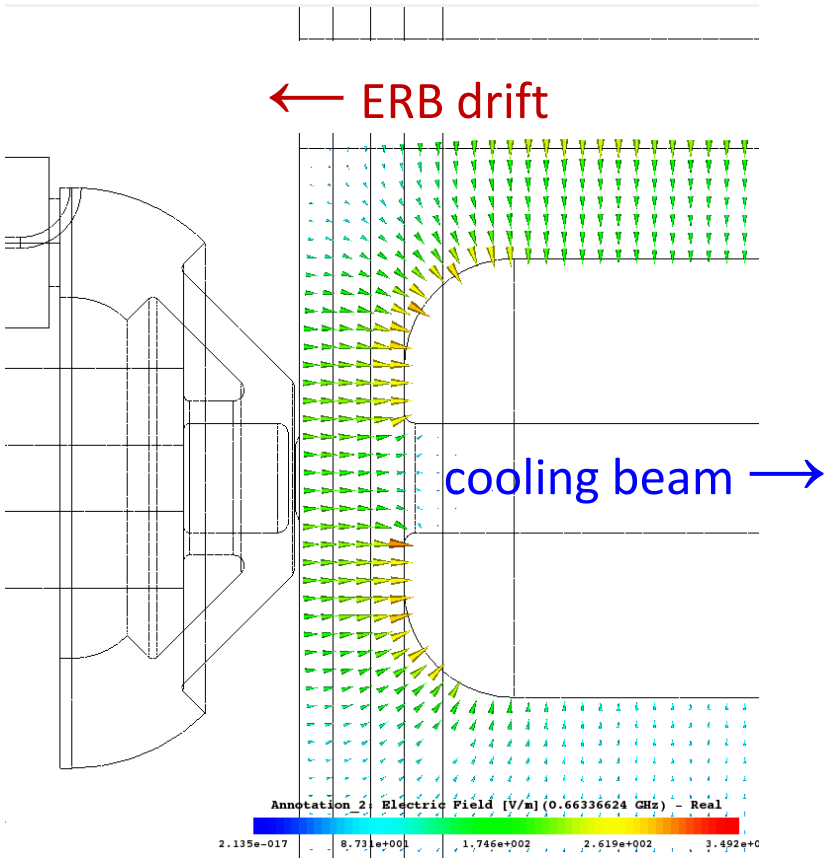


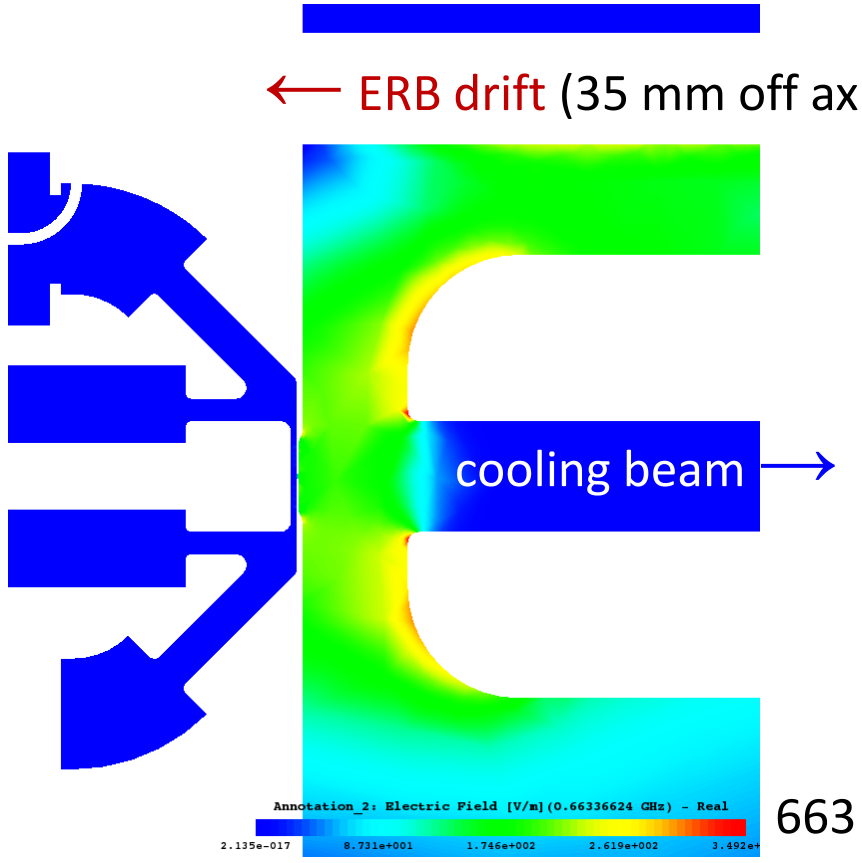
10 mm

74.4 MHz

RF Gated Thermionic Electron Source

Quarter-wave bunching structure with ERB drift channel





Dual-Frequency Thermionic Electron Source

Modeling and Simulations

Dual-frequency emission gating RF structure

Grid region