

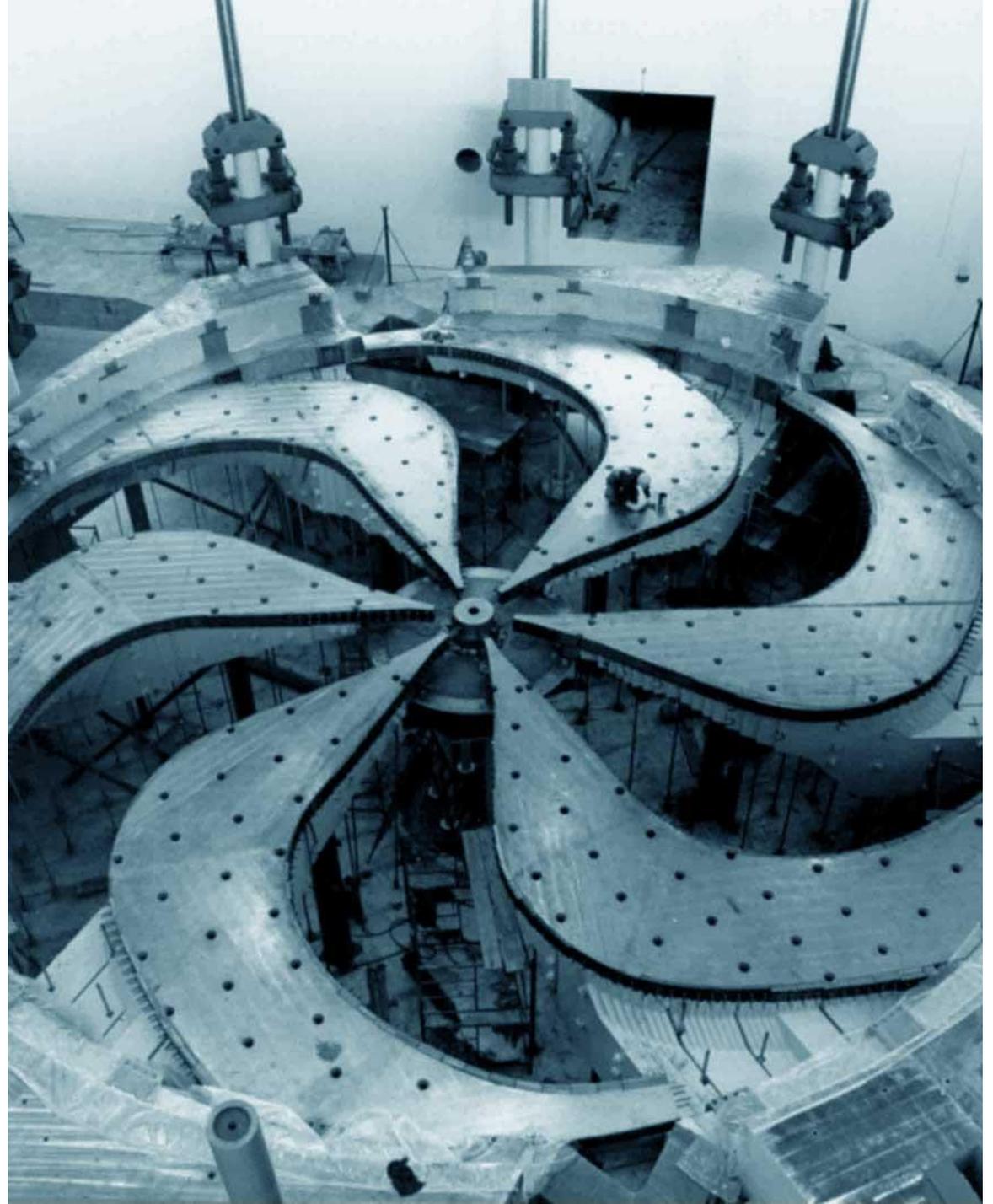
Experience with Field Emission at TRIUMF (ISAC-II)

Zhongyuan Yao

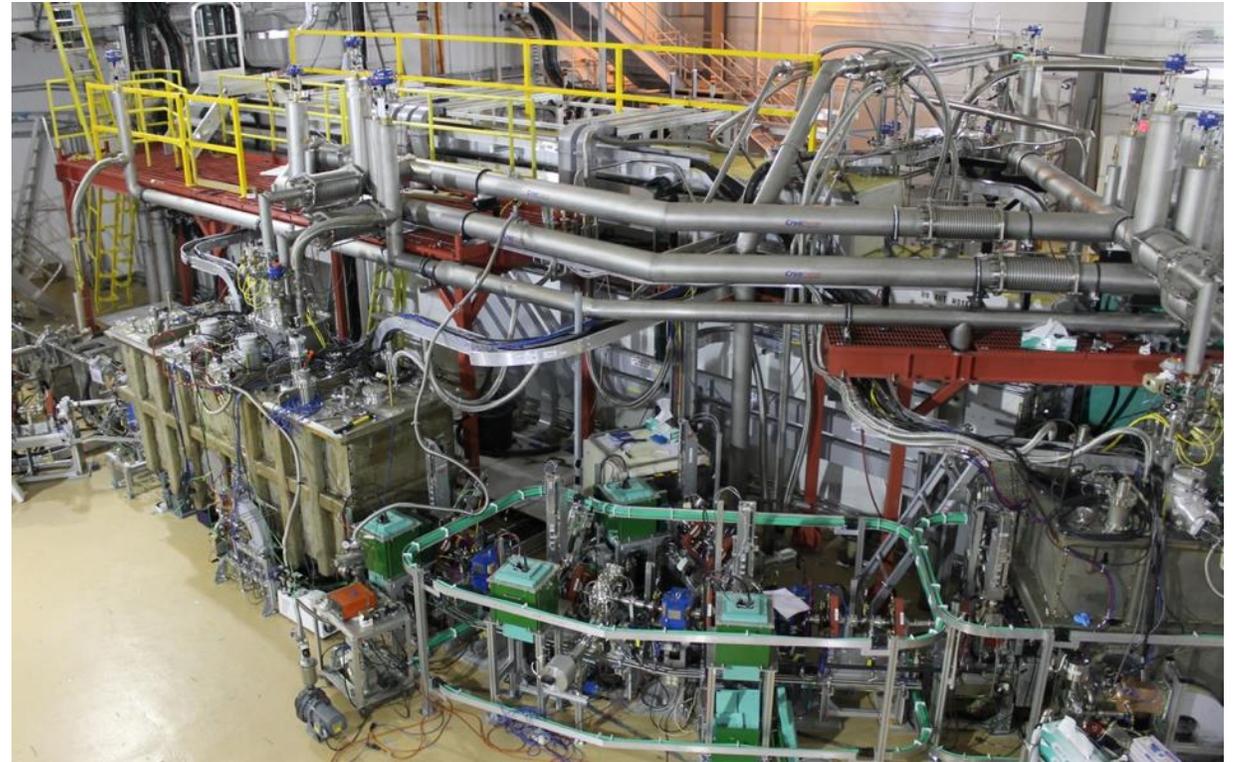
WG2: Field Emission and Its Root Causes

Apr. 10, 2025

TTC, Daejeon, Apr. 8-11, 2025



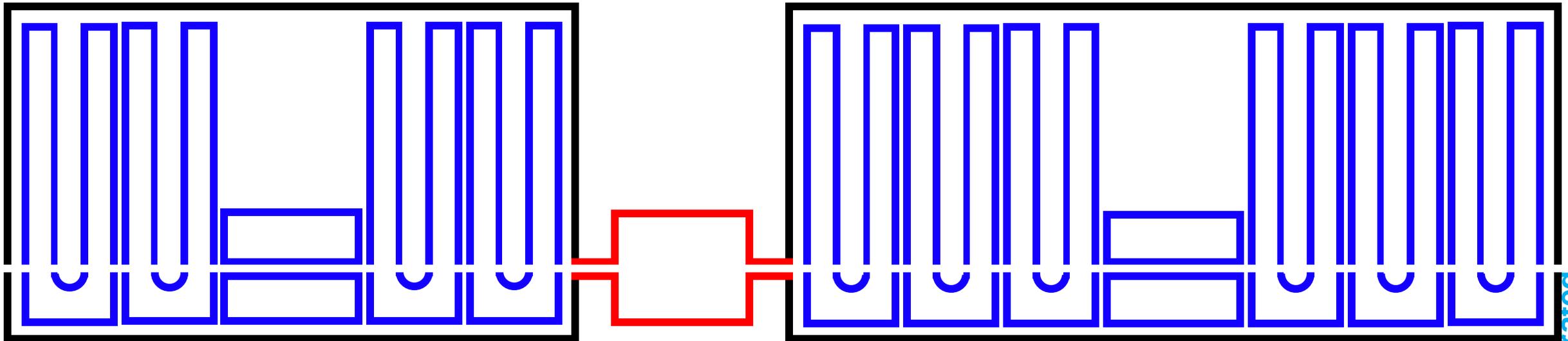
- ISAC-II heavy ion linac (left)
- ARIEL e-Linac (right)

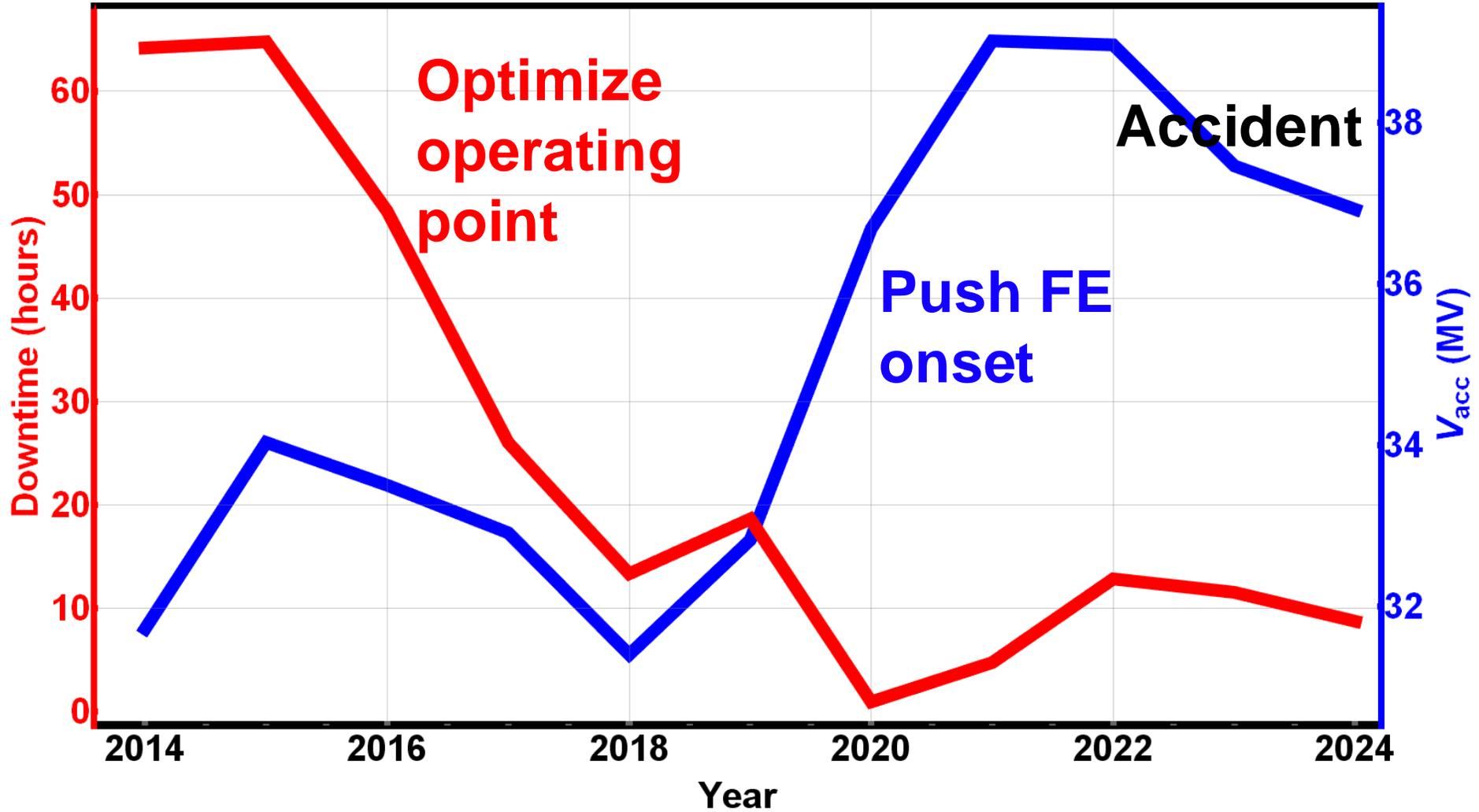


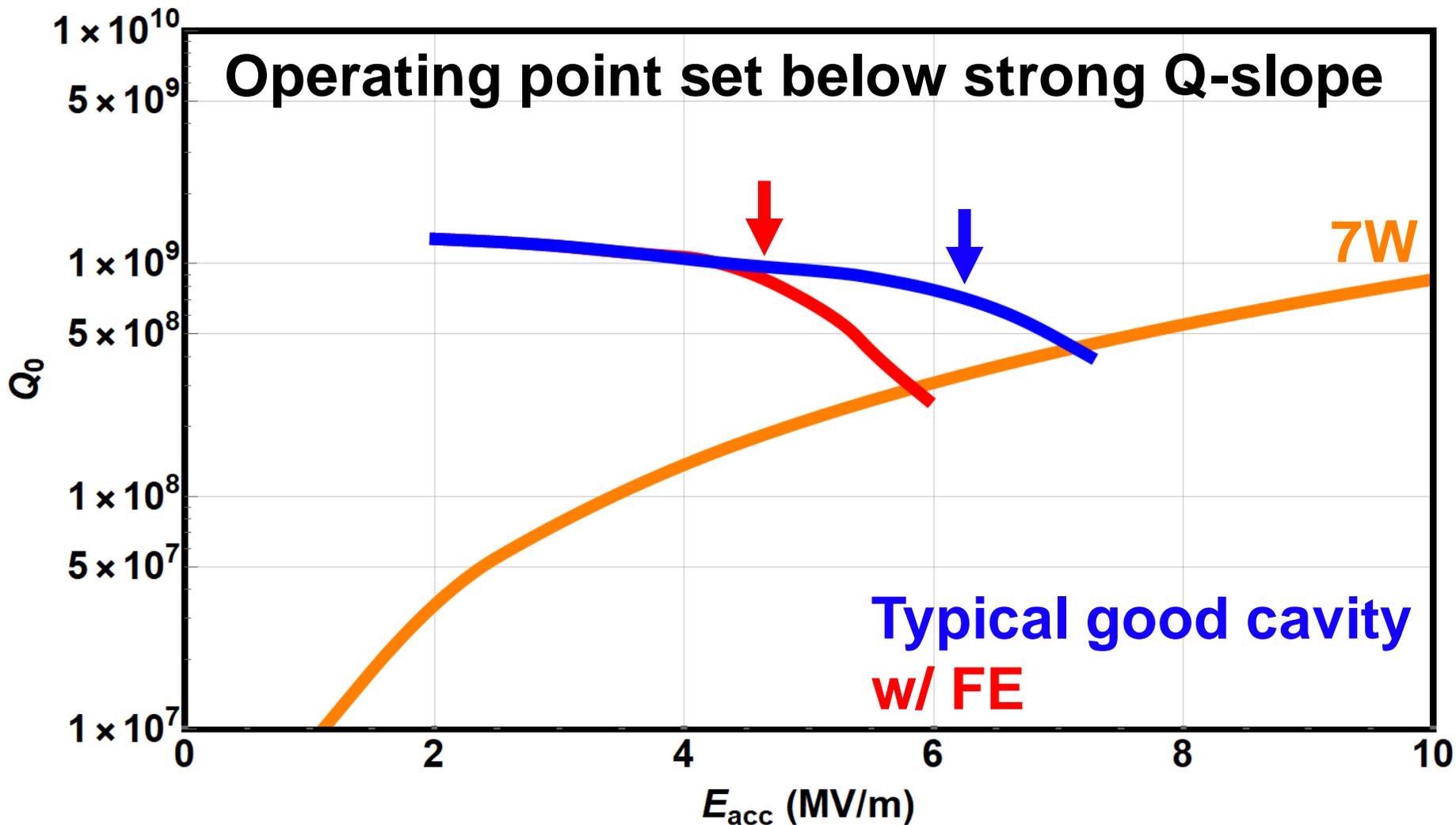
- 8 CMs with 40 Nb QWRs (4/6/8 cavities per CM)
- Operating temperature 4K
- Operating E_{acc} 6MV/m (V_{acc} 1MV per cavity)
- Drive RF power <200W (bandwidth <20Hz)
- Warm diagnostic box between CMs
- Warm up to room temperature in winter

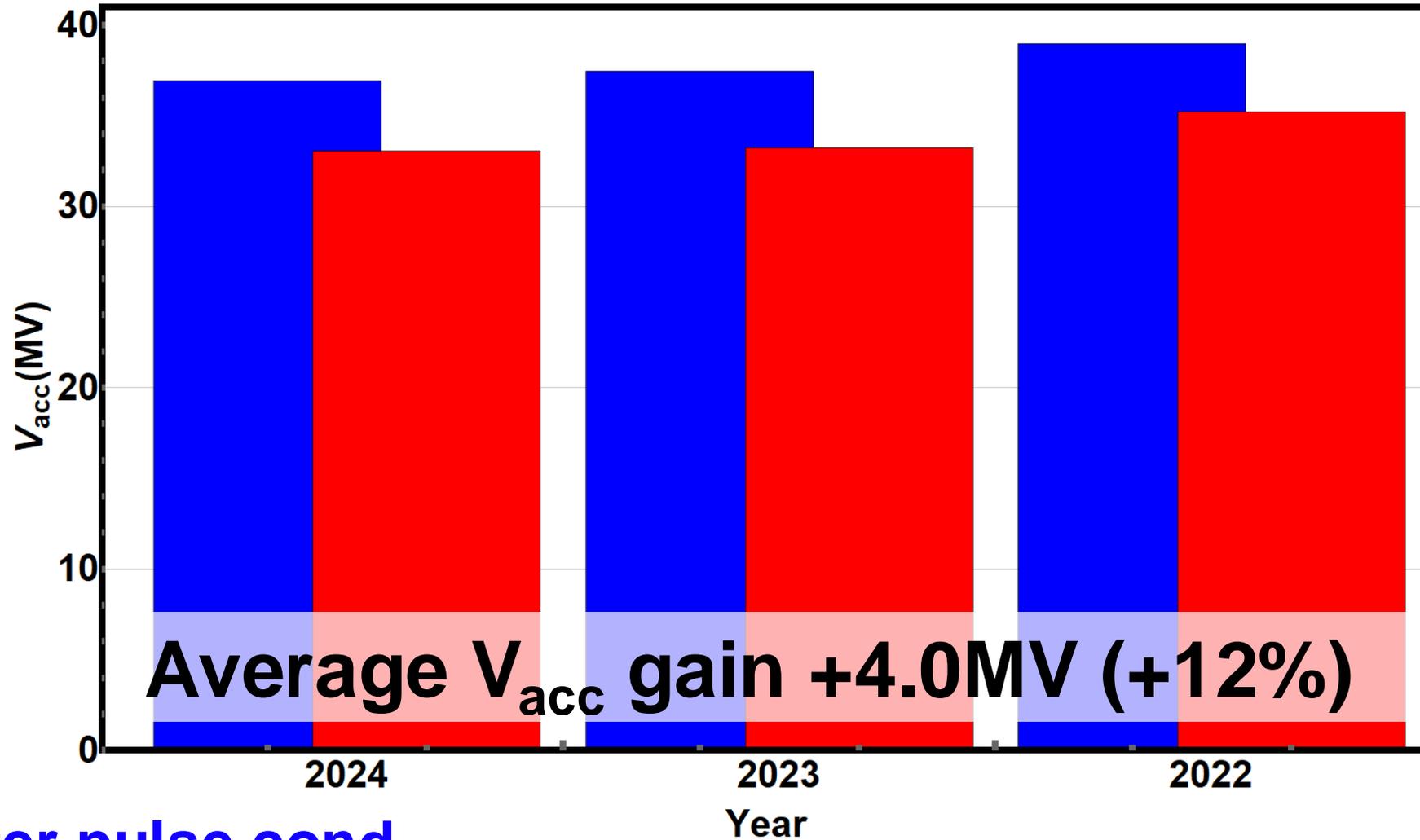


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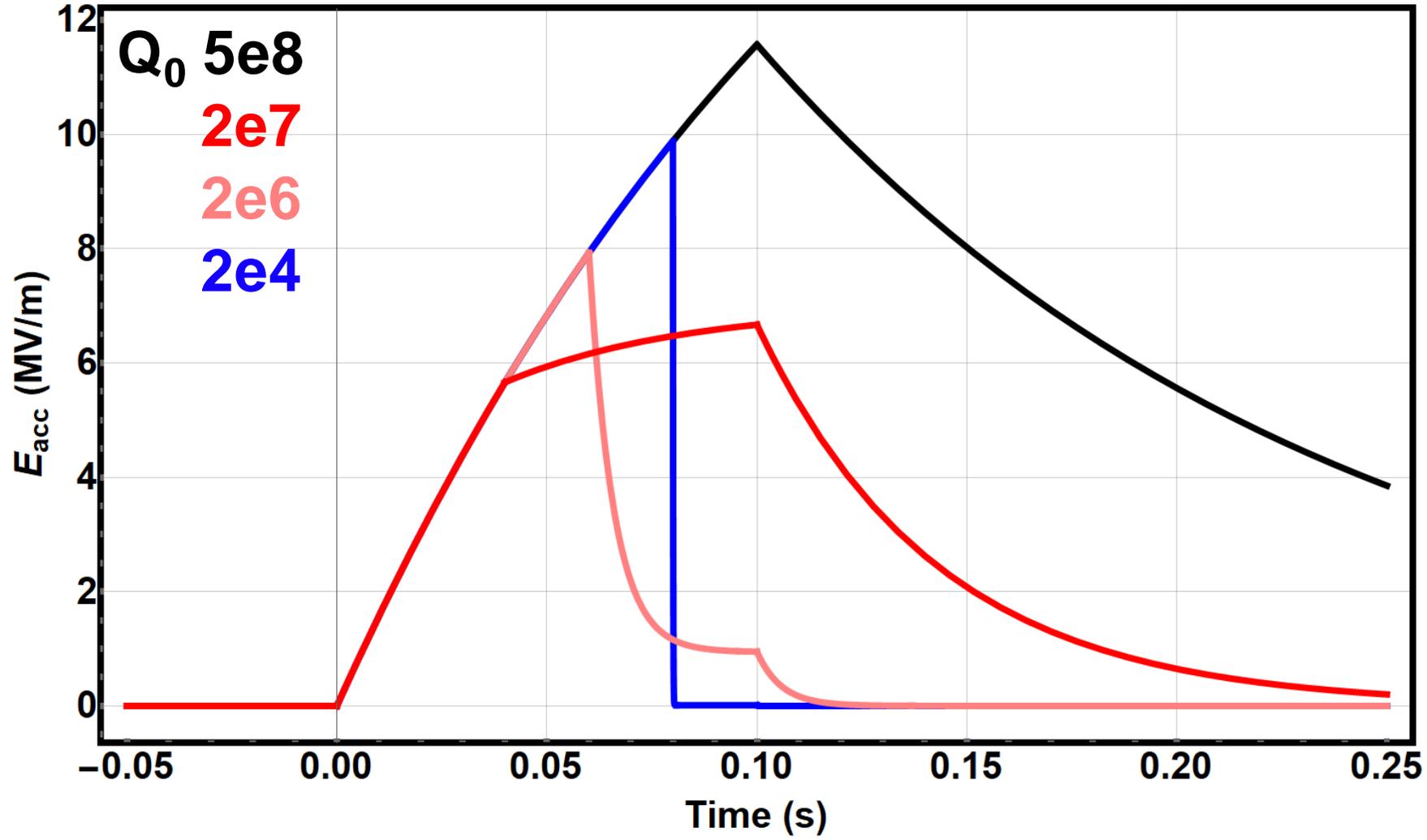
After pulse cond.
Before pulse cond.

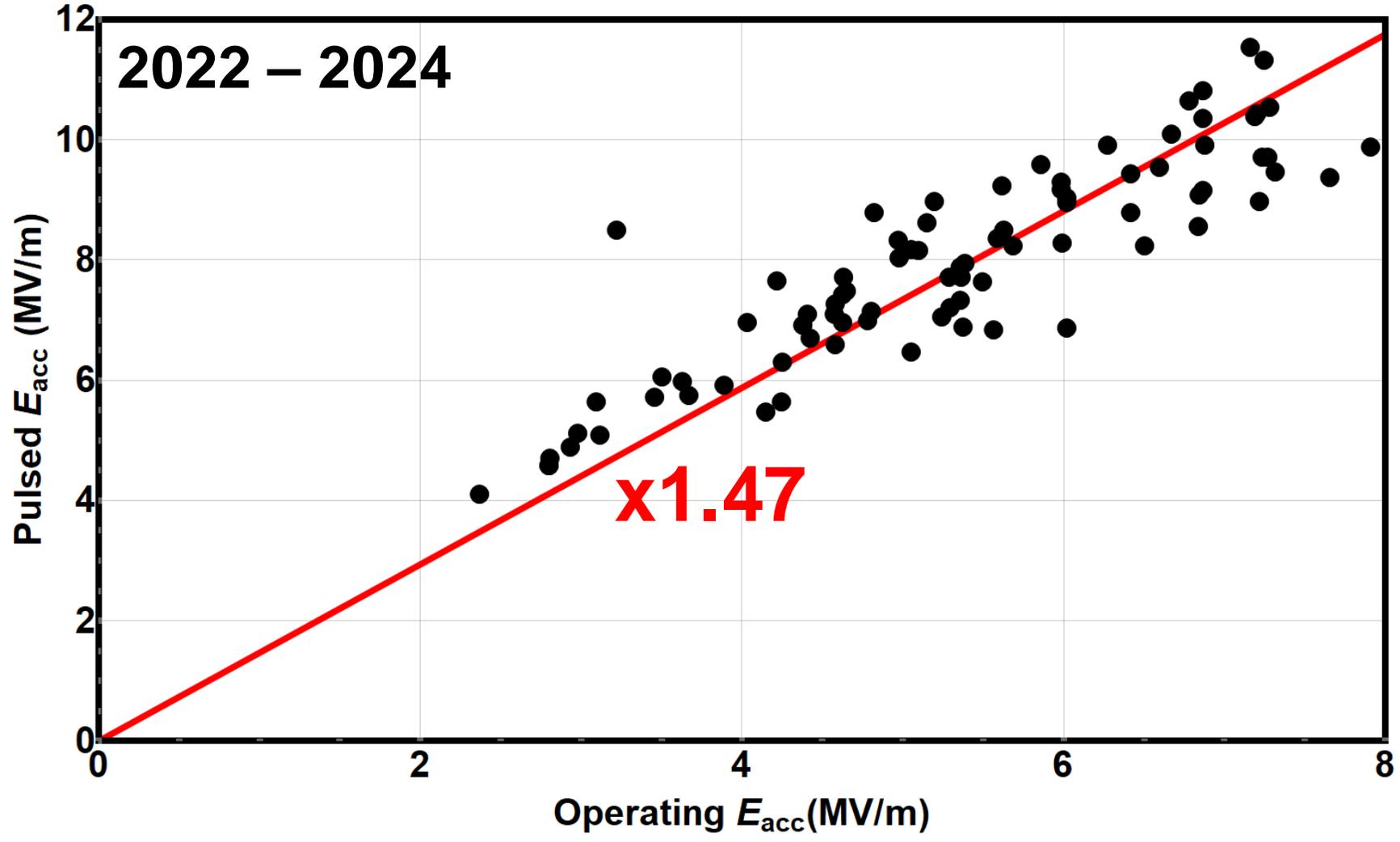
■ Configuration

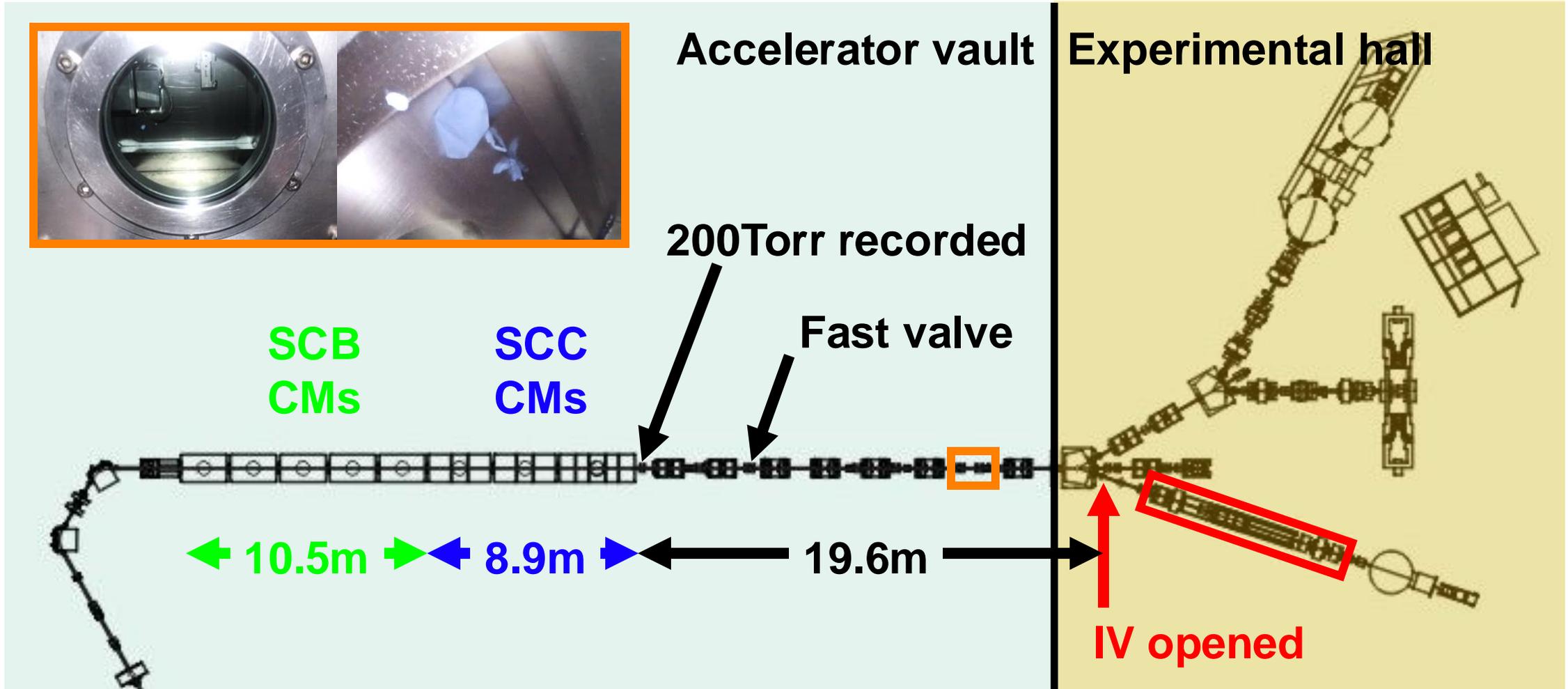
- 40~100ms pulse length, 1Hz repetition rate, up to 200W P_{FWD}
- Variable coupler, slightly over coupling $\beta \sim 10$, normal cavity decay $\sim 200\text{ms}$
- Pulse to 50% higher field than the operating field
- Pursue 'electronic' quench to break through FE barriers

■ Outcome

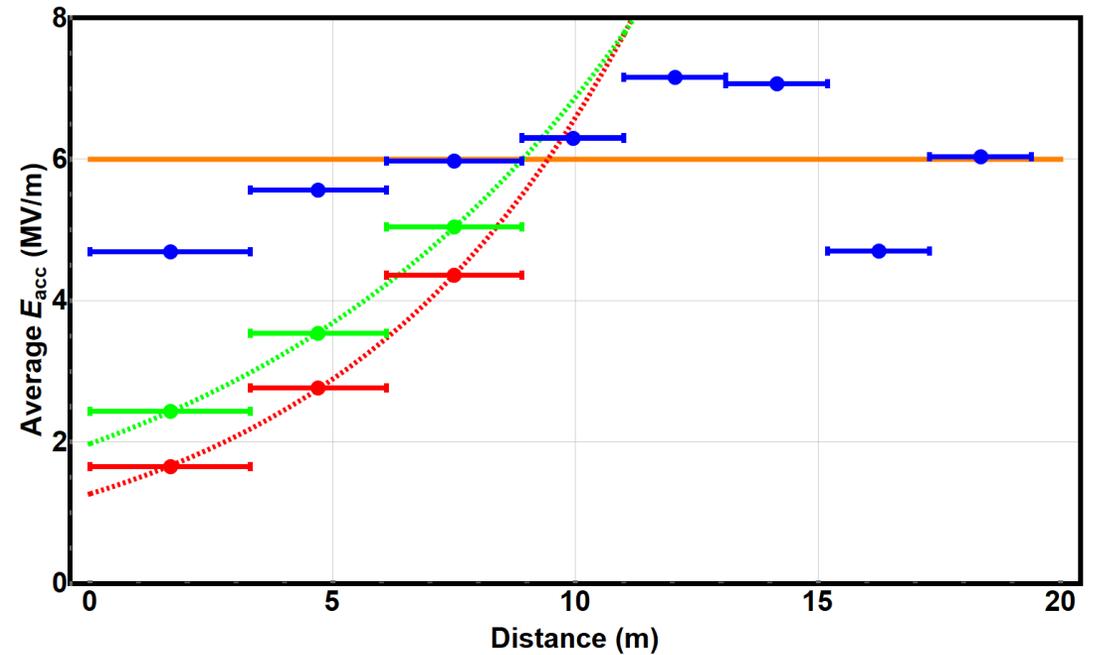
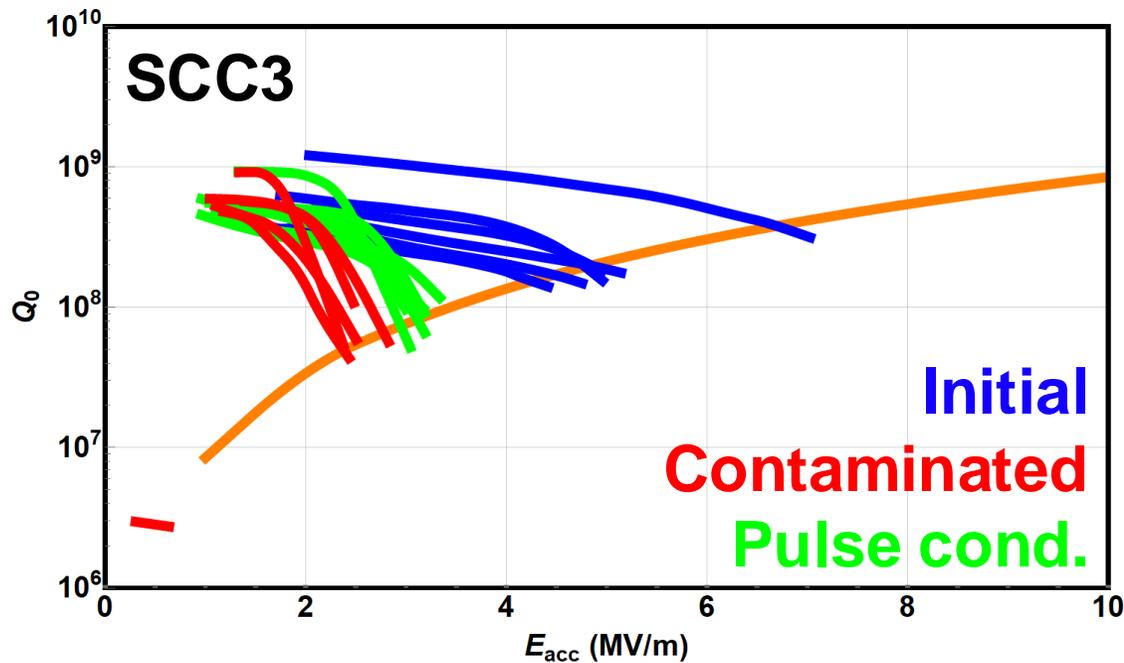
- Improvement in minutes w/ 'electronic' quench, while requires hours to days w/ 'thermal' quench or even no changes
- Effective to restore ISAC-II cavity performance



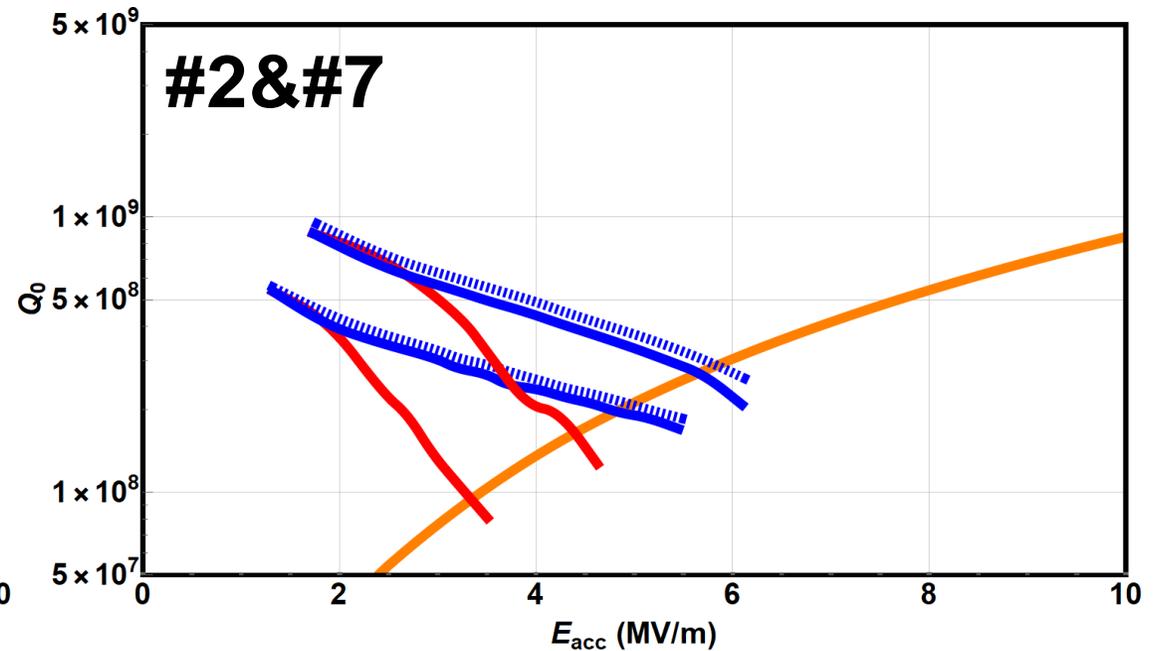
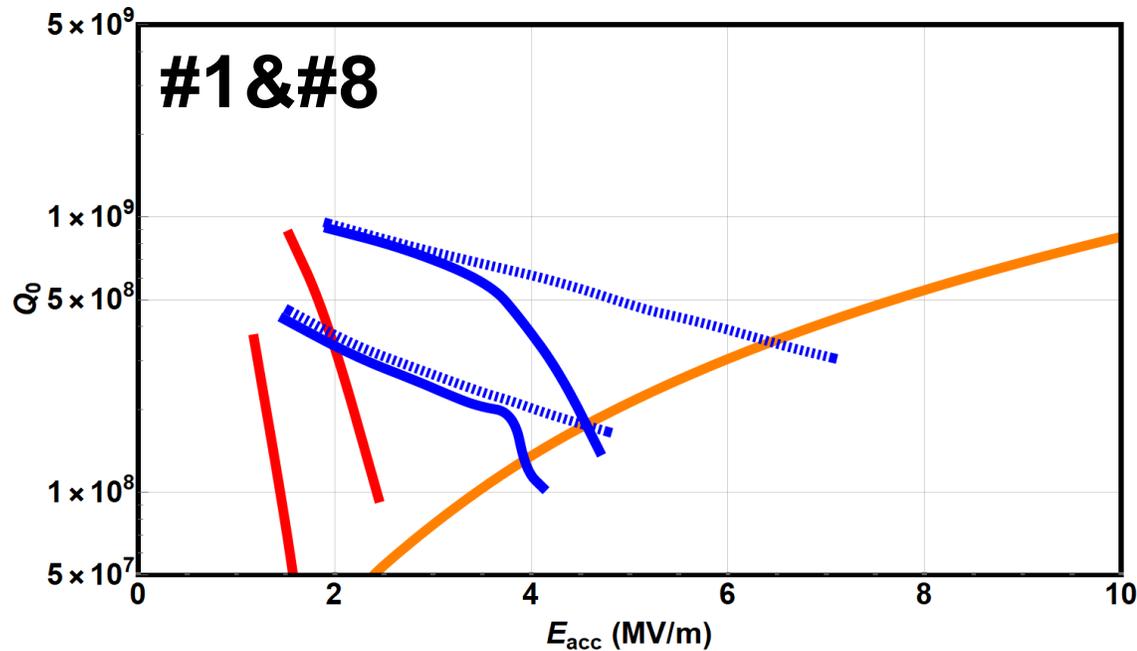




- Affected range is 8.9m, includes downstream 3 CMs
- HPR required, 2 completed and performance restored



- SCC3#1 degraded after thermal cycle in shutdown
- Neighbors #2 restored after pulse conditioning
- May related to actuation of isolation valves

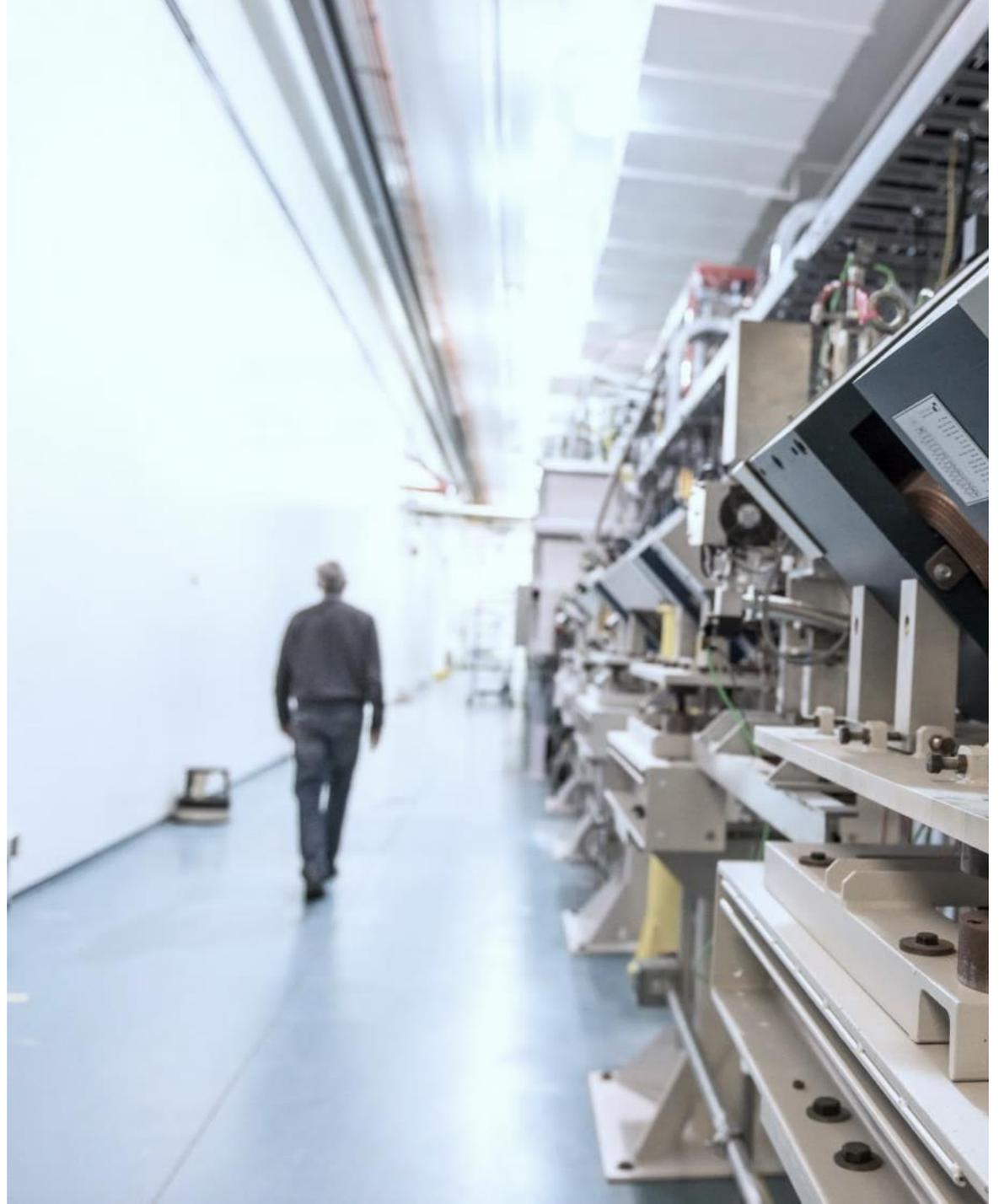


- ISAC-II operating performance, V_{acc} and RF downtime, are strongly dependent on FE
- FE commonly reappears after room temperature thermal cycle in winter shutdown
- Pulse conditioning are effective for mitigating field emission and restoring cavity performance
 - Pulse conditioning is required to reach 50% higher field than the operating field
- Vacuum accident introduced massive field emitters, and affected 3 CMs
 - Refurbishments are time and resource consuming projects

Thank you
Merci
감사합니다

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	ISAC-II	ARIEL e-Linac
Year built/commissioned	SCB 2006 / SCC 2010	2014
Cryomodule string layout	106/141MHz QWRs Single vacuum CM 4/6/8 cavities per CM Warm sections between CMs	1.3GHz 9-cell cavity 1 cavity in injector CM 2 cavities in accelerator CM Warm sections between CM
Particle free installation practices/protocols applied	CM assembly in Class100/1000 Beamline connection in normal environment	String assembly in Class10 Beamline connection in normal environment
Nominal operating gradient	E_{acc} 6MV/m (E_{pk} 30MV/m)	E_{acc} 10MV/m (E_{pk} 20MV/m)
Administrative/operational radiation limits	20uSv/hr outside vault	20uSv/hr outside vault
Accelerated particle species and beam parameters	RIBs, A/q 2~7, 1.5~16MeV/u, ~nA electron current	Electron, 30MeV, 3mA

	ISAC-II	ARIEL e-Linac
Type of sensors	N/A	N/A
Locations and coverage of the machine	N/A	N/A
Continuous monitoring or interval of measurements?	N/A	N/A
Alternative ways to detect field emission?	Q-curve	Beam loss monitor, Q-curve

	ISAC-II	ARIEL e-Linac
Comparison to cavity performance before installation / during acceptance testing	N/A	Lower Q in vertical test due to less effective magnetic shielding, no FE in acceptance tests
Field emission situation as measured during commissioning	N/A	N/A
Any known causes for the field emission (e.g. vacuum/gas sources, particulate sources,...)?	N/A	N/A

	ISAC-II	ARIEL e-Linac
How has field emission in the machine changed over time (location and magnitude)?	Generally stable over years; Emitters reappear and FE determined by RF preparation after each winter shutdown	Gradually increase on all cavities
Are there any spatial patterns observed?	Closer to source in case of known reason	Not clear patterns
Are there known reasons or events this can be correlated with?	Vacuum accident in 2022; Isolation valves of SCC3; No clear reason for emitters reappearance	Vacuum and alignment issues in 2017; No clear reason for long term change, suspect beamline cleanliness
How much performance has been lost due to the increase in field emission?	Flexible performance requirement for post-acceleration	Drop from 30MeV to 28MeV (7%) for beam tuning purpose

	ISAC-II	ARIEL e-Linac
Have there been attempts to decrease field emission in situ?	Pulse conditioning	Pulse conditioning Helium conditioning
If yes, what and to what level of success?	Restore cavity performance unless due to known problem	Mitigate FE, but not remove emitter
If cryomodules have been removed due to field emission, has the issue resurfaced in the replacement?	SCC3, suspect isolation valves cleanliness	Yes, all cavities