Experience with Field Emission at TRIUMF

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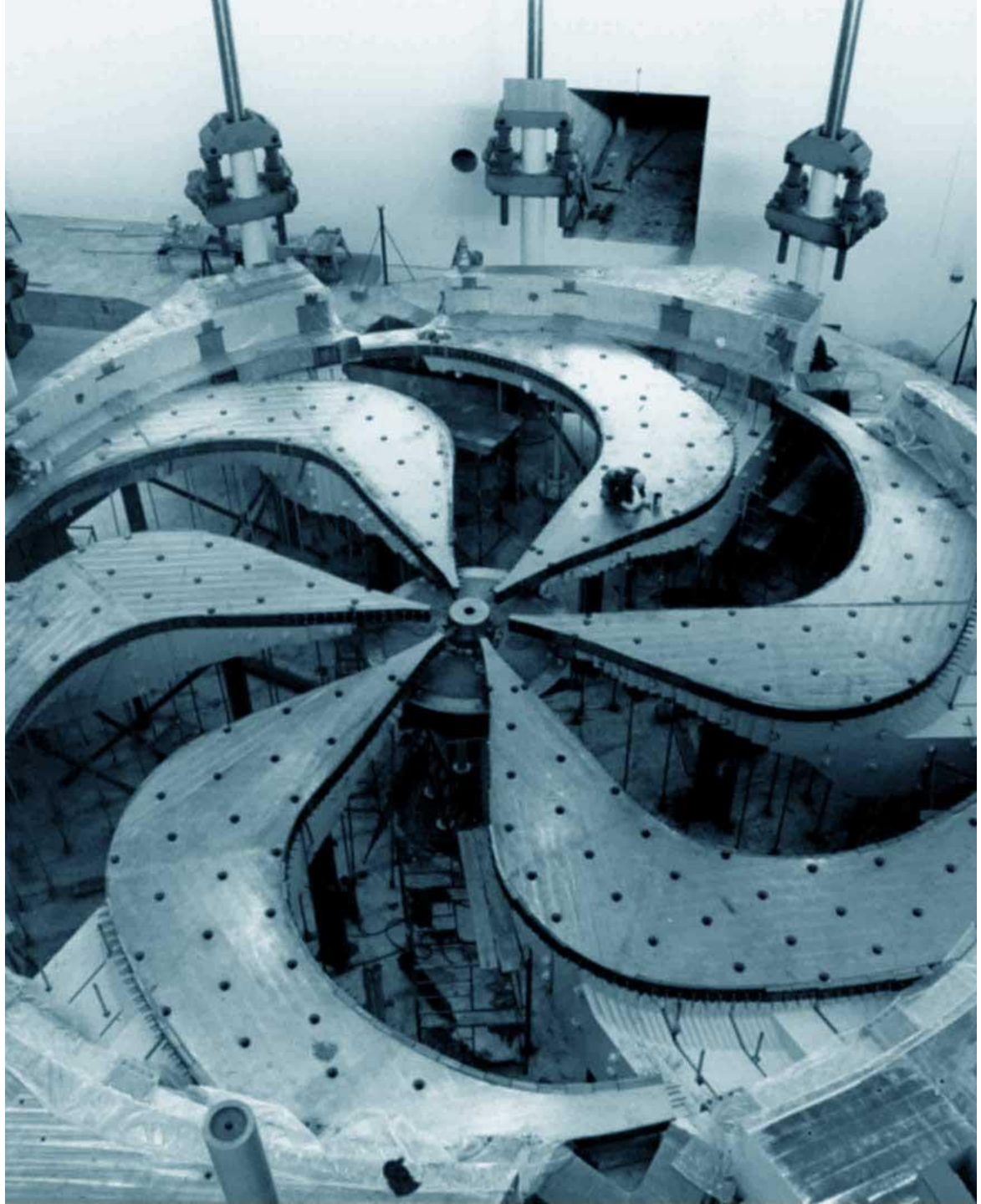
RF/SRF, Accelerator, TRIUMF

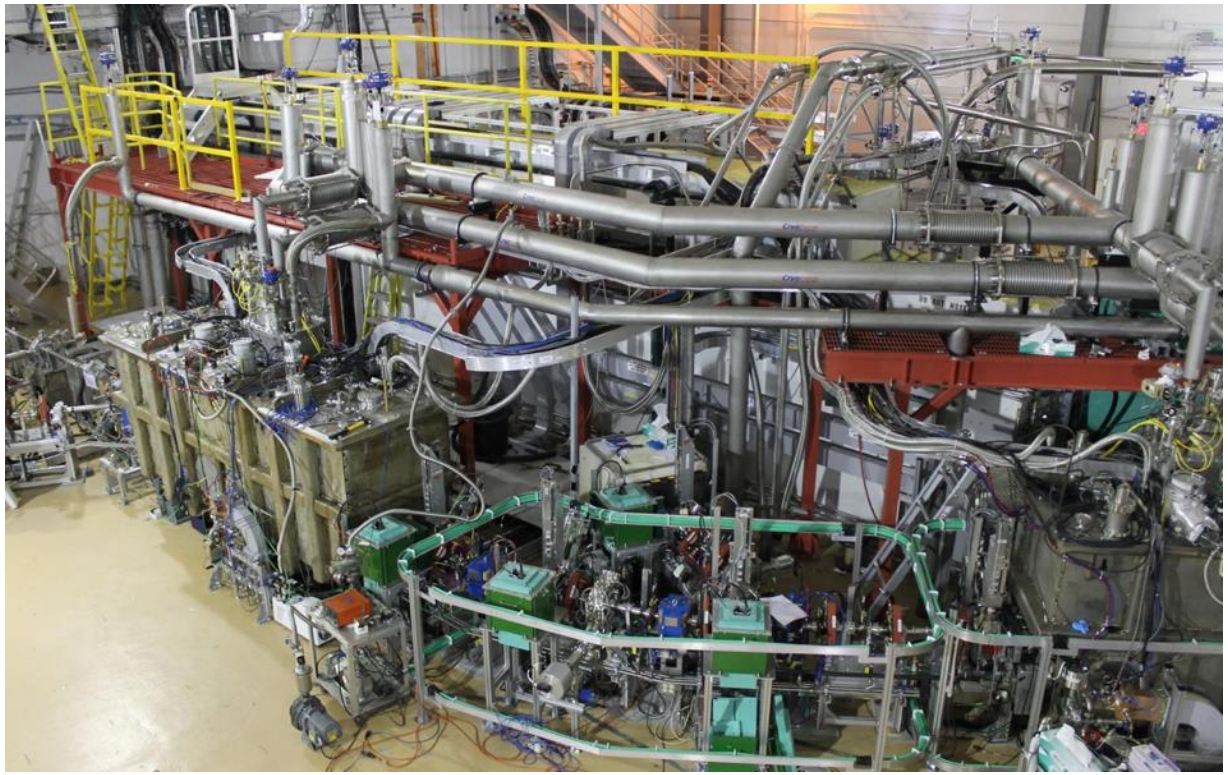
Jan. 28, 2025



CM01 Field Emission Workshop, Jan. 28-29, 2025

SRF Linac at TRIUMF

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

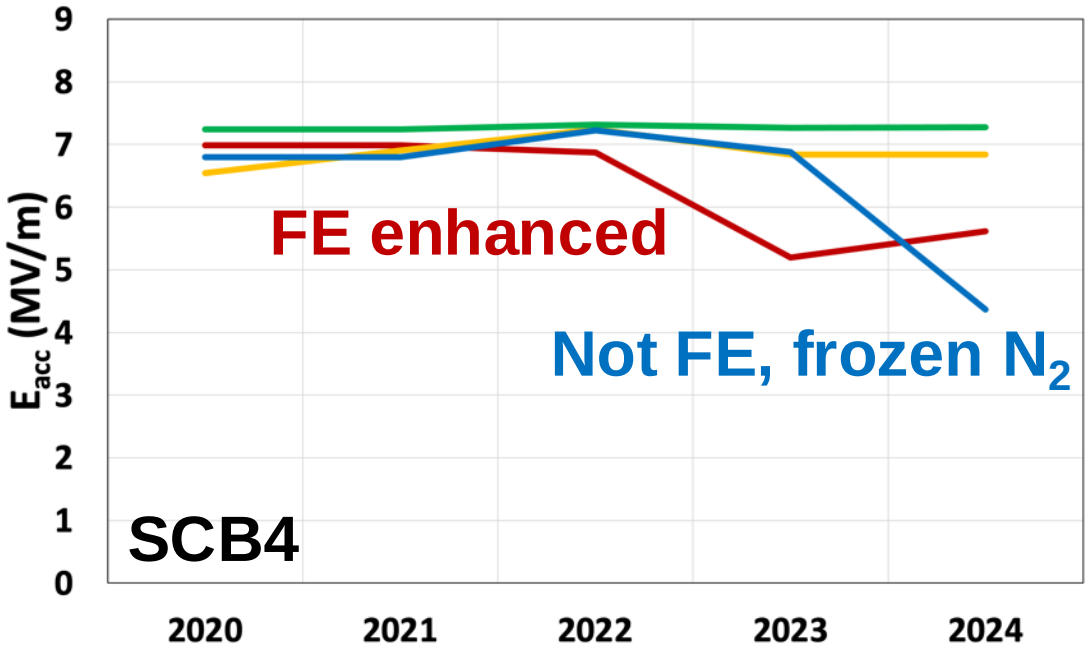


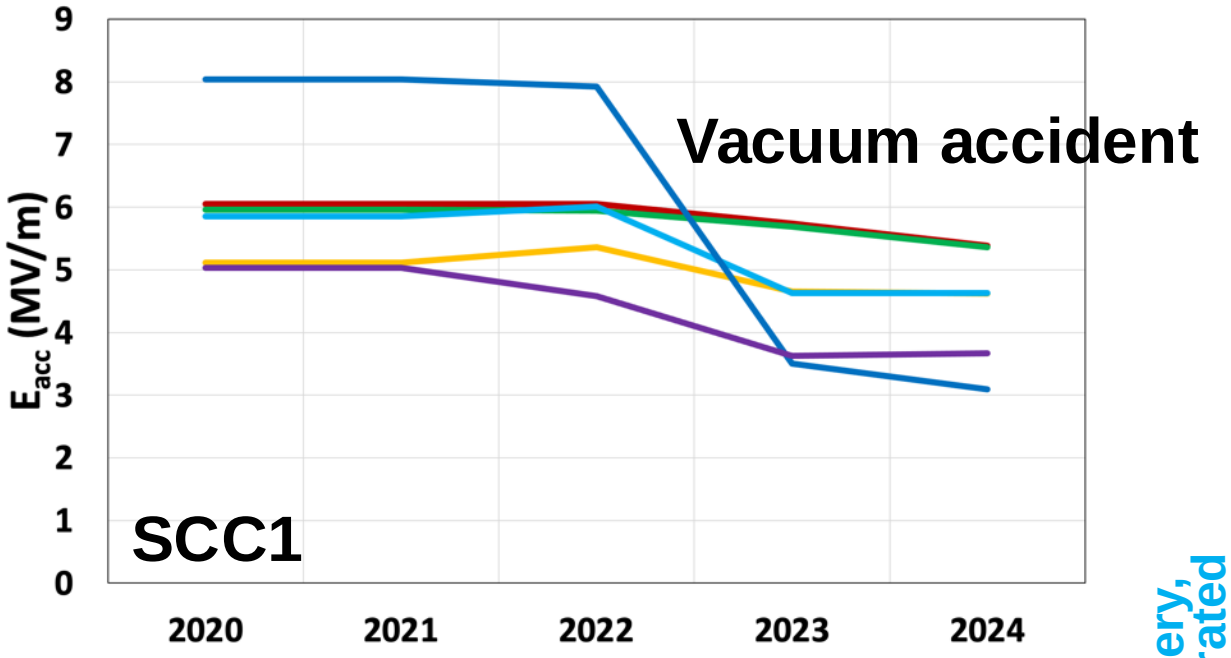
ISAC-II Heavy Ion Linac

- 8 CMs with 40 QWRs
- 4/6/8 cavities per CM
- Operate at 4K
- Operating E_{acc} 6MV/m
- Warm sections between CMs
- In operation
  - Phase-I SCB 2006
  - Phase-II SCC 2010
- Warm up Jan.-Mar. every year

ISAC-II Performance History

- Operating E_{acc} is generally stable over years unless known issues
- Small differences due to inconsistent pulse conditioning





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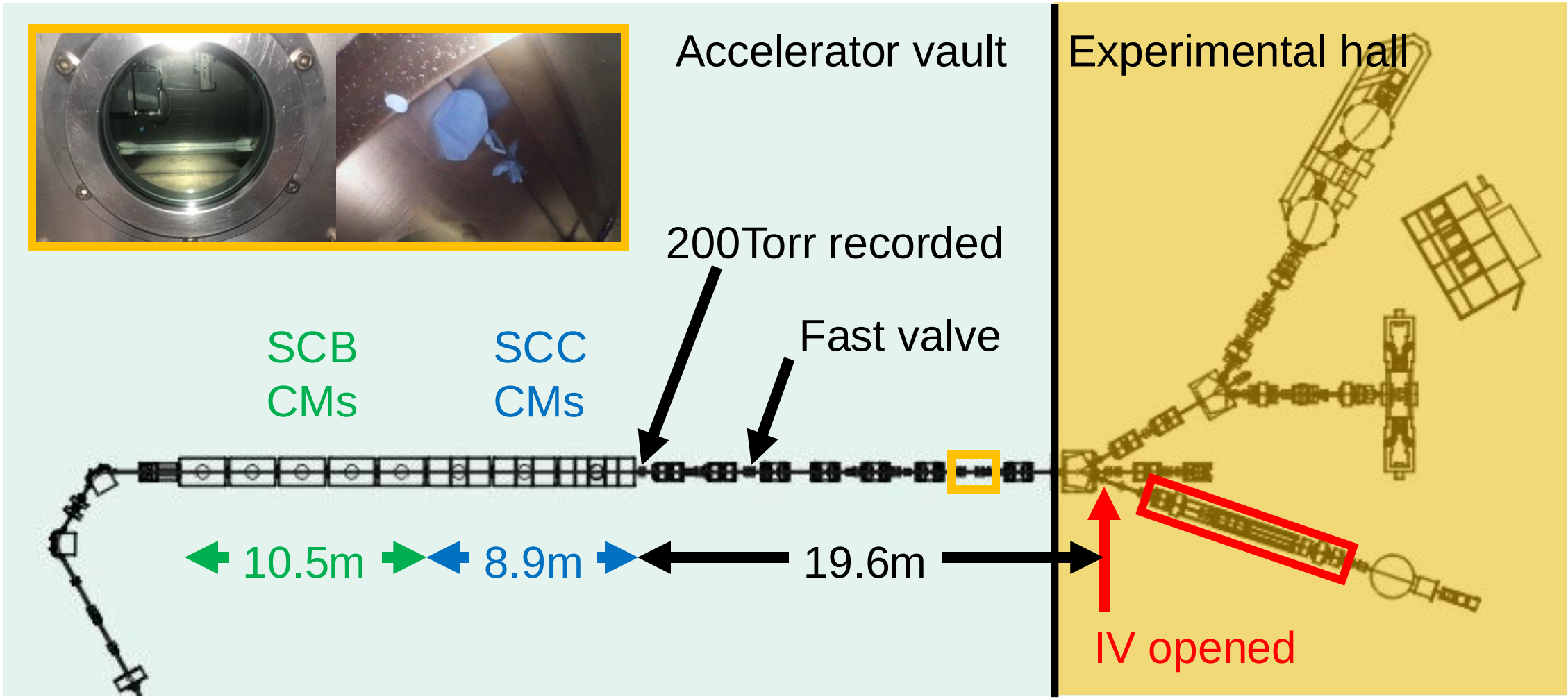
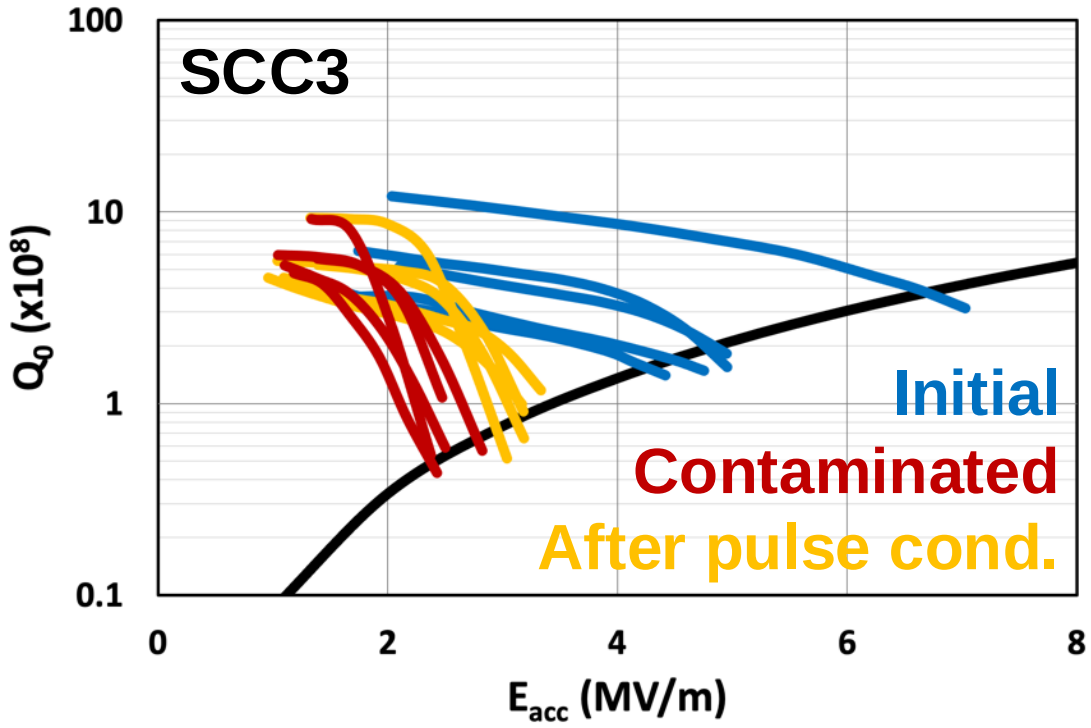
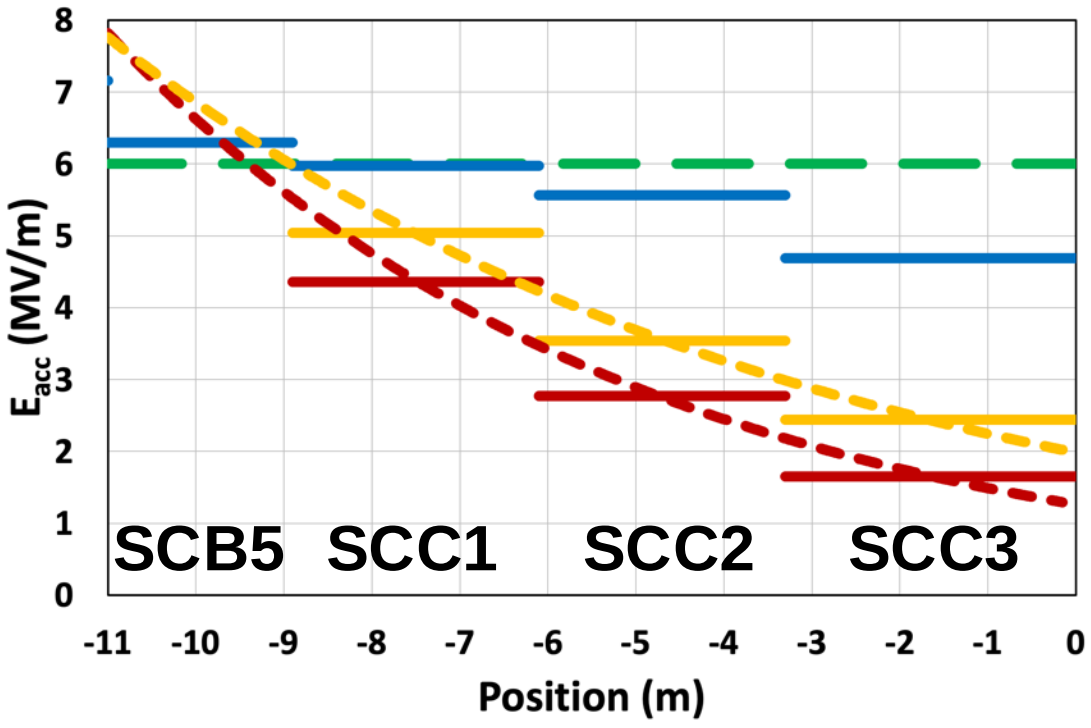
ISAC-II Vacuum Accident (2022)



Contamination

- Affected range is about 9m, includes downstream 3 CMs
- HPR required, 2 completed and performance restored





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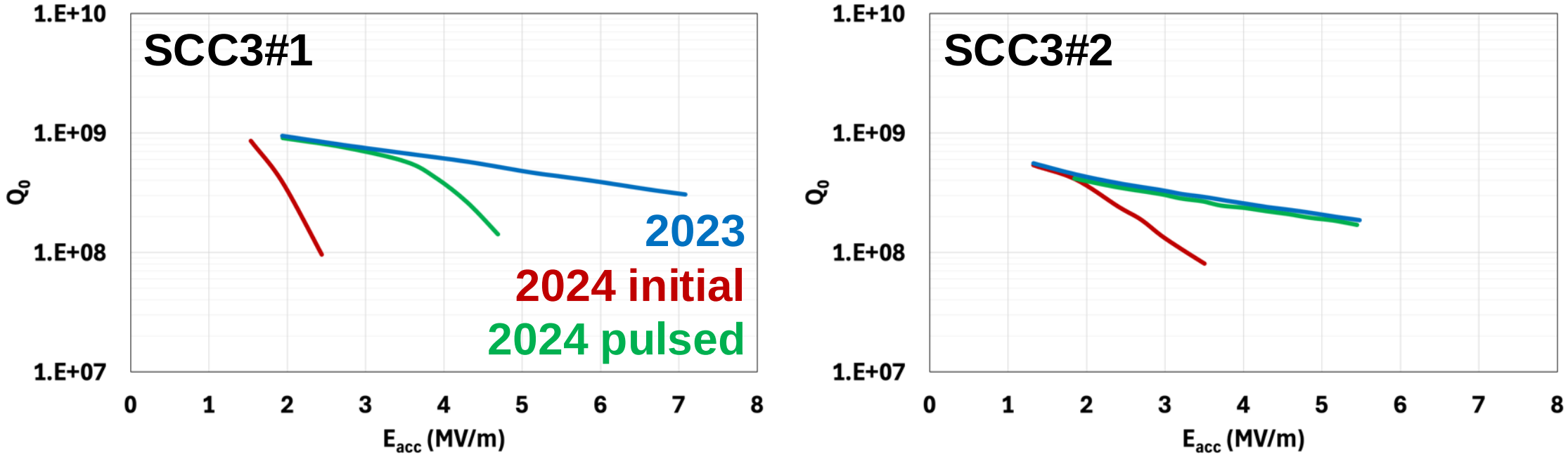
Emitter Reappeared

- SCC3#1&#8 degraded after thermal cycle in shutdown
- Neighbors #2&#7 restored after pulse conditioning
- May related to actuation of isolation valves



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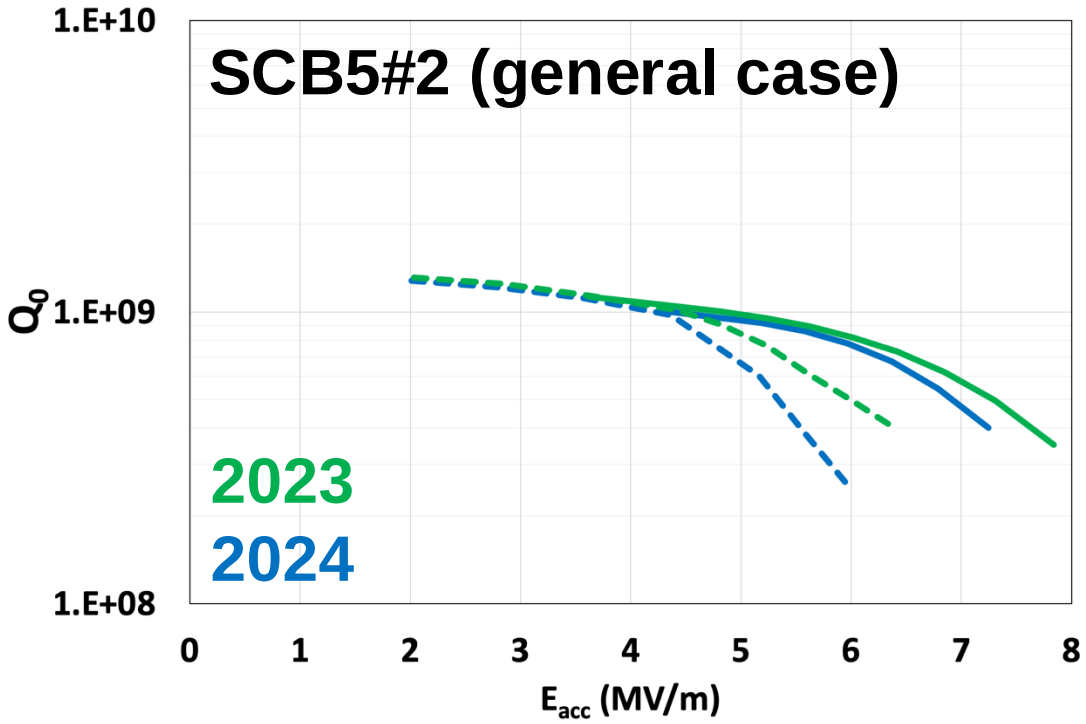
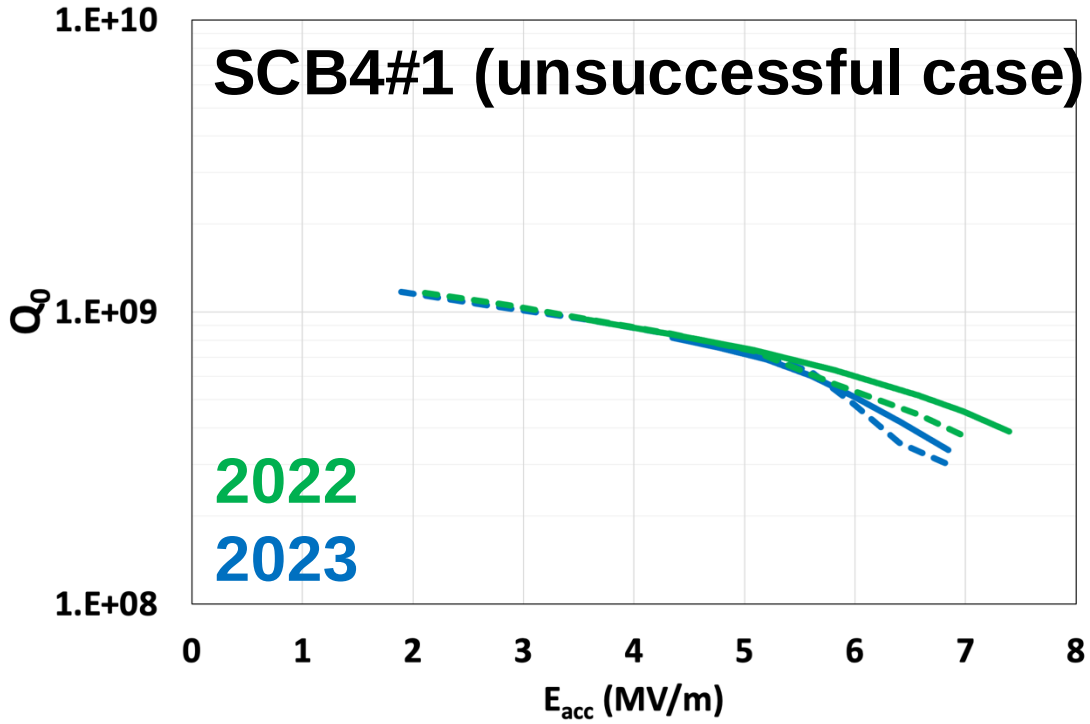
Thermal Cycle in Shutdown

- ~50% cavities need pulse conditioning after thermal cycles, most cavities' performance can be restored





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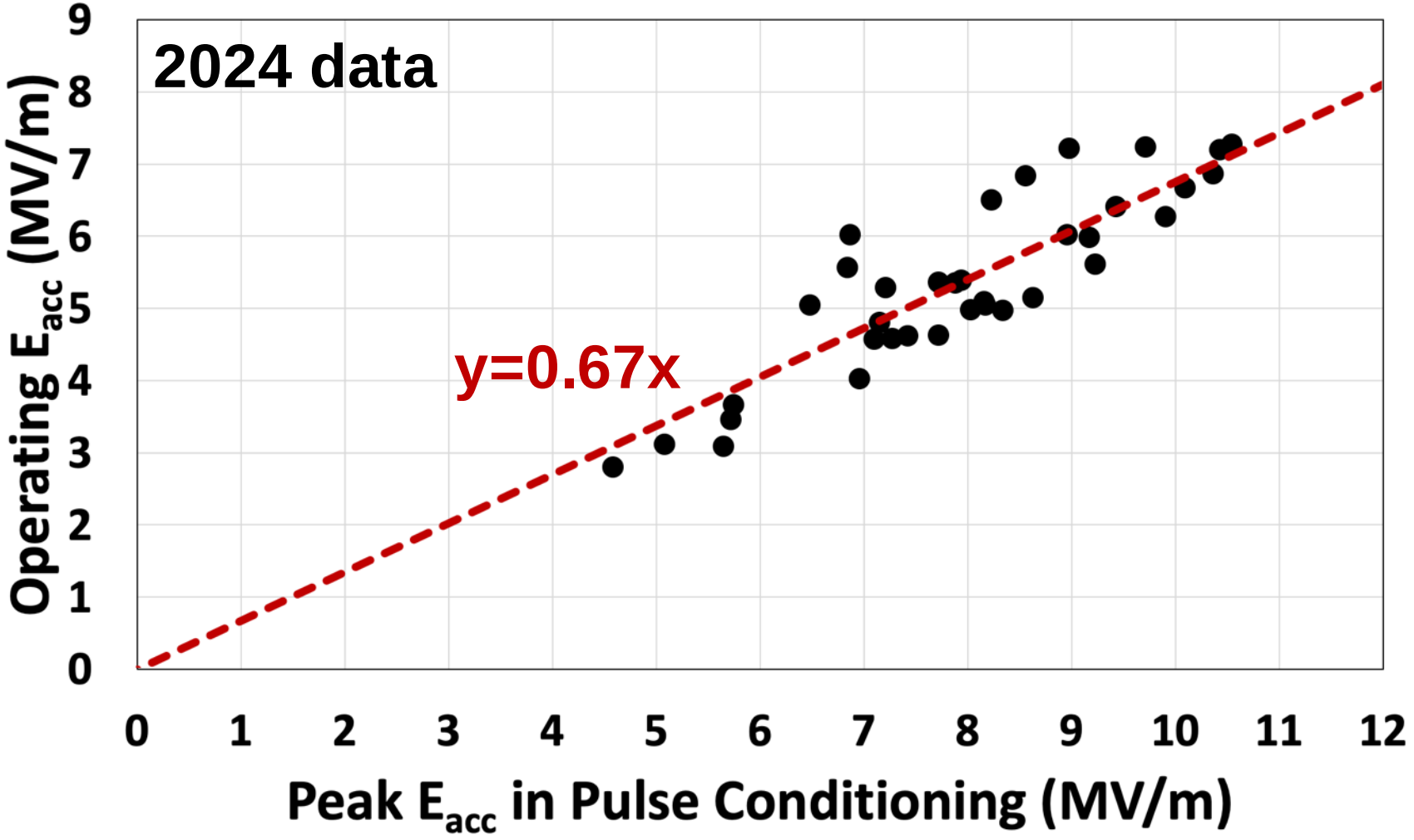
ISAC-II Pulse Conditioning

- Configuration
  - 40~100ms pulse length, 1Hz repetition rate, up to 200W P_{FWD}
  - Variable coupler, slightly over coupling β~10, normal cavity decay ~200ms
  - Pulse conditioning to 50% higher 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

ISAC-II Pulse Conditioning



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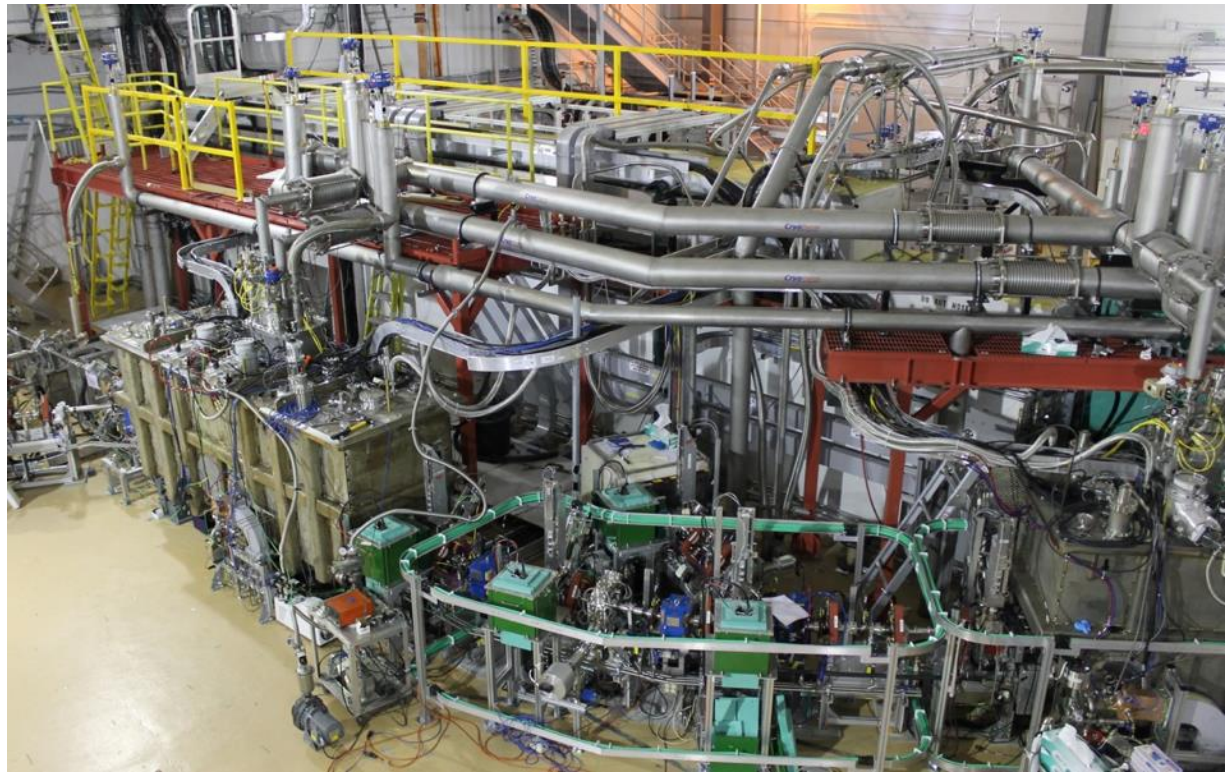
ARIEL e-Linac

- 1.3GHz 9-cell cavities
- 1 in injector CM (EINJ), 2 in accelerator CM (EACA)
- Operate at 2K
- Operating E_{acc} 10MV/m
- Warm sections between CMs
- In commissioning stage since 2014



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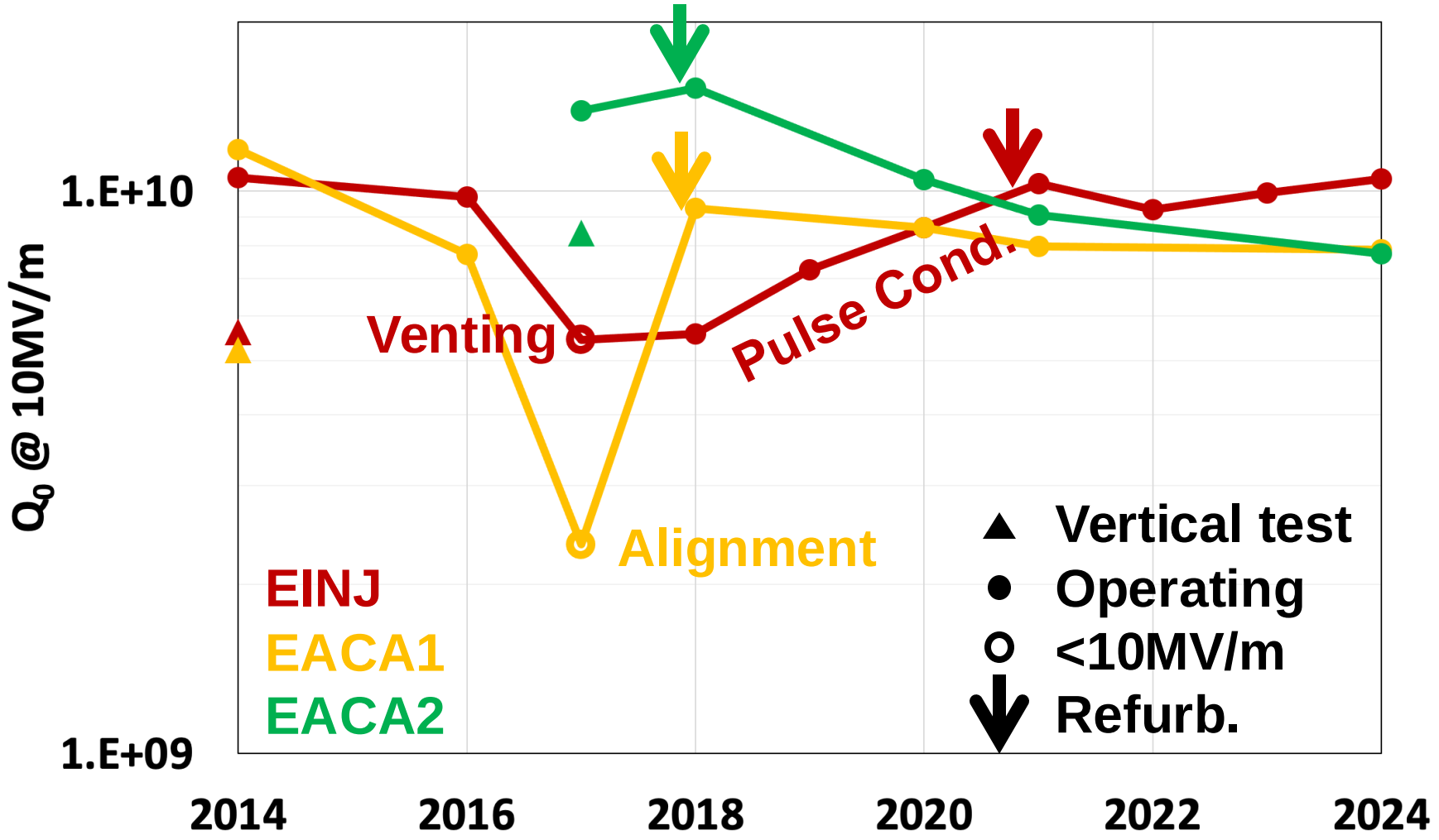
e-Linac Performance History



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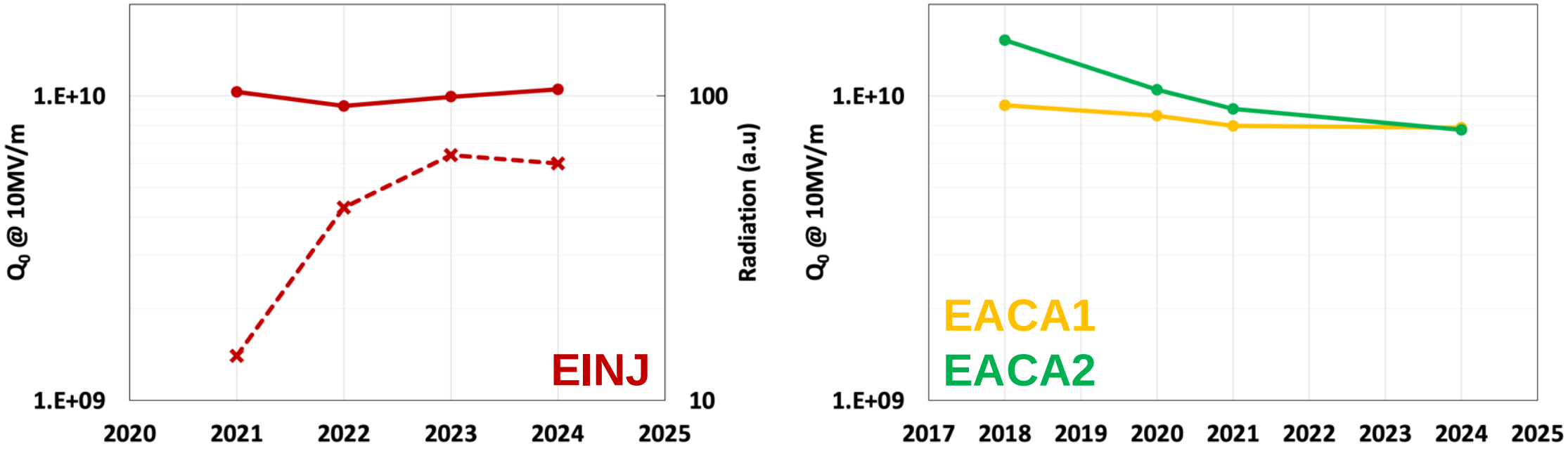
Performance after Refurbishments

- Radiation from EINJ gradually increased
- Heat loads of EACA cavities gradually increased and consistent with radiation



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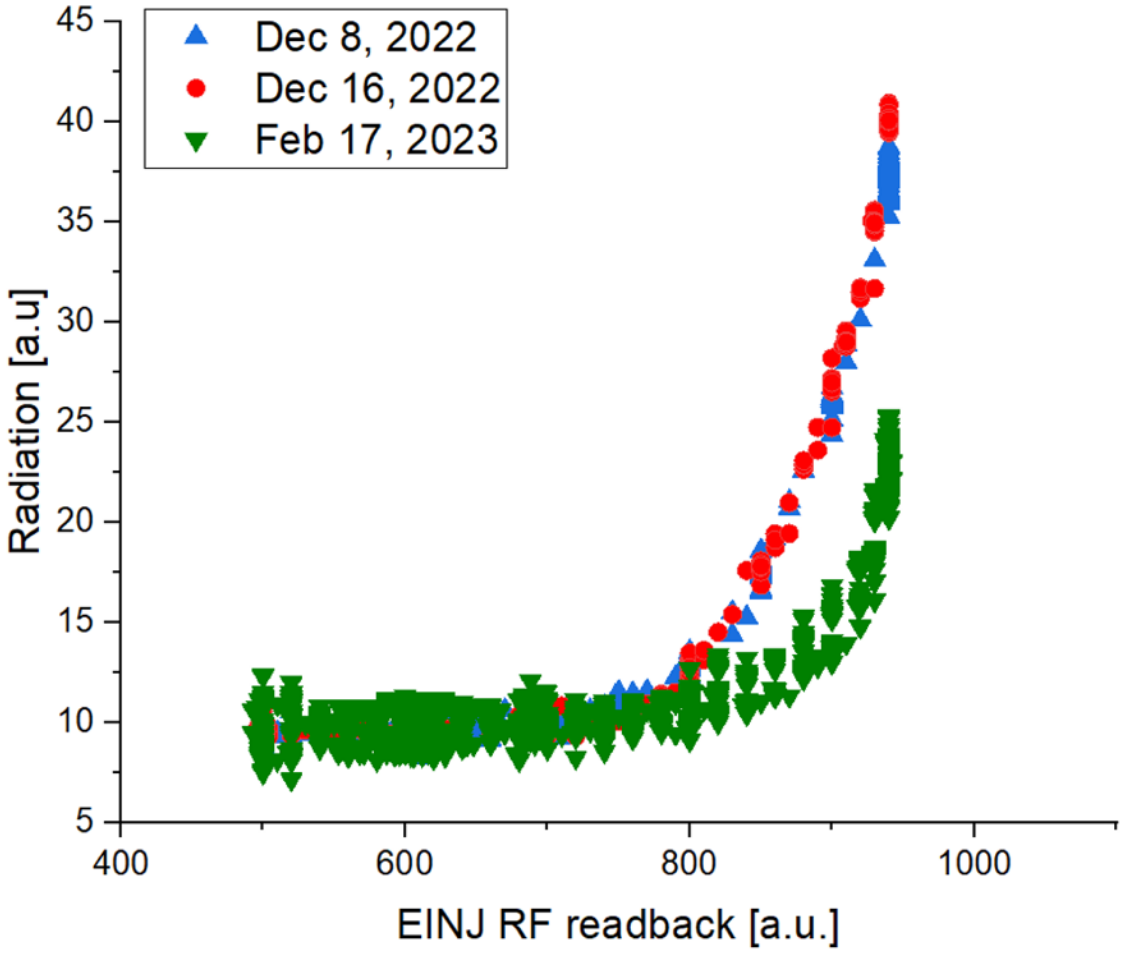
e-Linac Pulse Conditioning

- Configurations
  - Moderate pulse conditioning
    - Drive w/ self-exciting loop (SEL)
    - 15~20ms pulse length, 1~10Hz repetition rate
    - 11~13MV/m E_{acc} w/ a flattop, normal cavity decay <1ms
  - High gradient pulse conditioning
    - Drive w/ signal generator
    - 3ms pulse length, up to 16MV/m E_{acc}
- Outcome
  - Moderate pulse conditioning is more effective on e-Linac
  - High gradient pulse conditioning could make FE worse

e-Linac Helium Conditioning

- Configuration
  - He pressure in 10^{-5}Torr range
  - 10ms pulse length, 5Hz repetition rate, up to 12kW P_{FWD}
  - Pickup voltage slightly below operating E_{acc} w/ a flattop
- Outcome
  - Radiation reduced, but not eliminated
  - <10^{-5}Torr pressure is less effective



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General Facts

	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

Measurement Instrumentation

	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

Field Emission in Commissioning

	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

Evolution of Field Emission

	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

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Field Emission Remediation

	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

Acknowledgement

- Thank Y. Ma and P. Kolb for sharing experience and data on ARIEL e-Linac

Thank you
Merci

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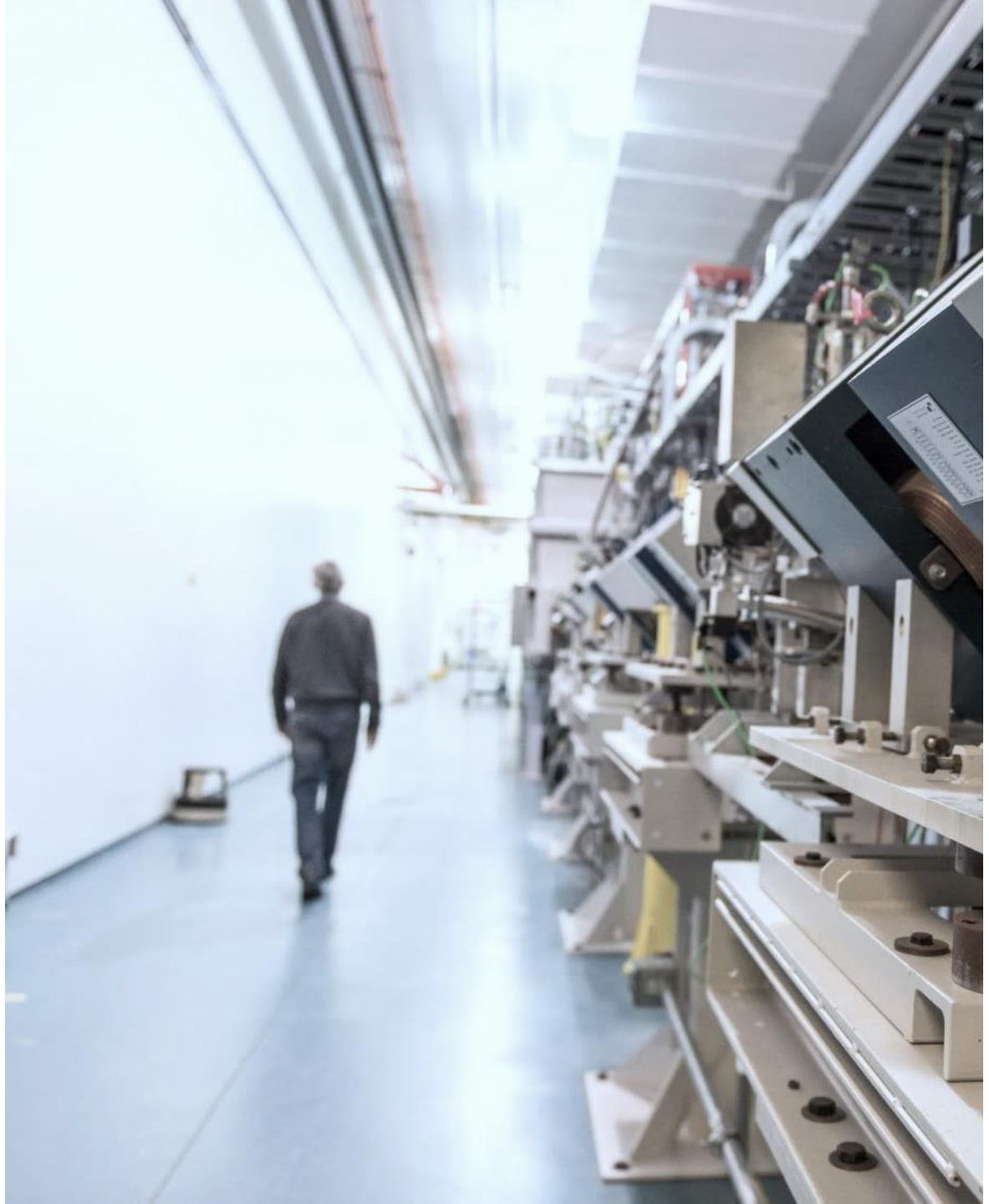
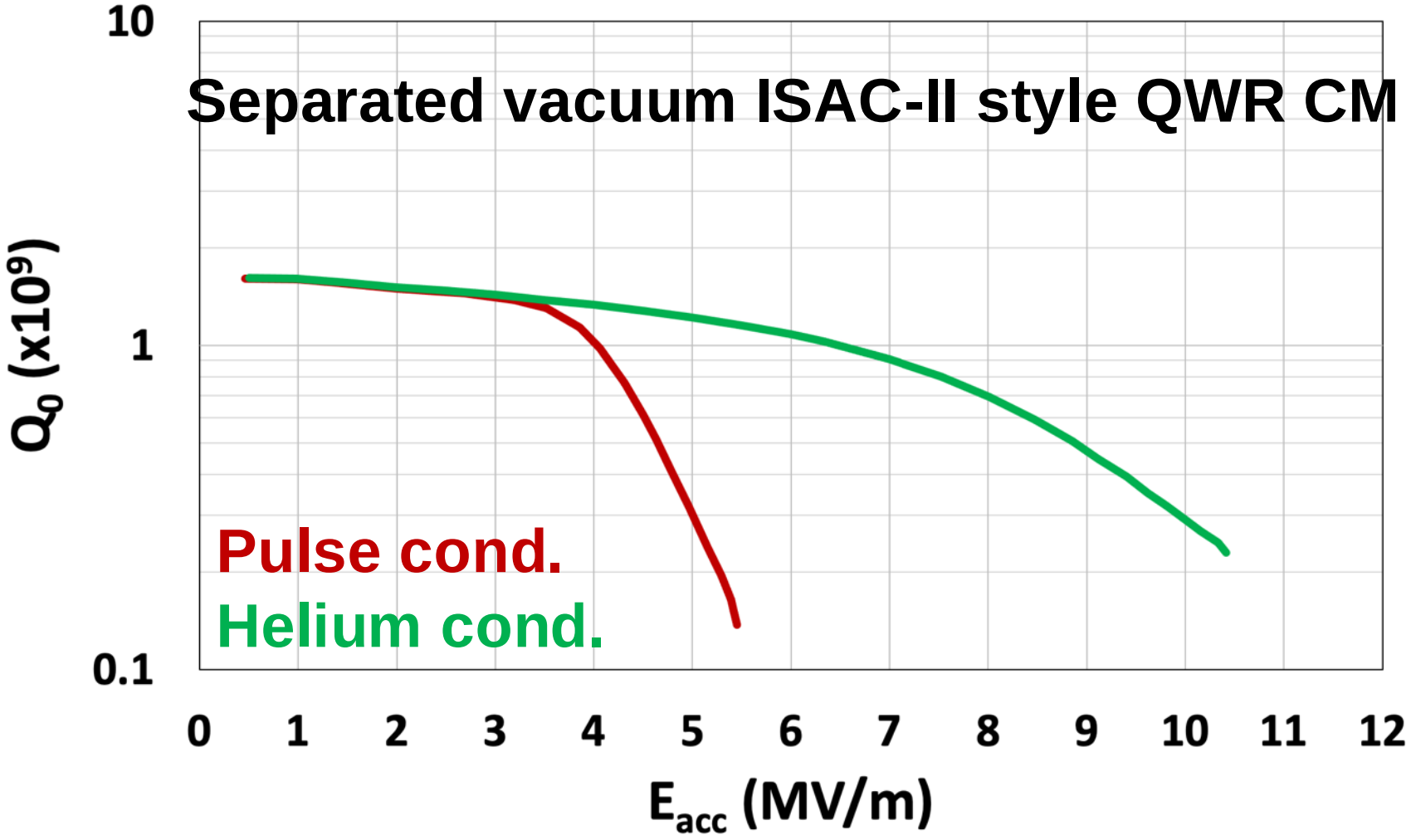


Discovery, accelerated

Helium Conditioning on Other CM



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