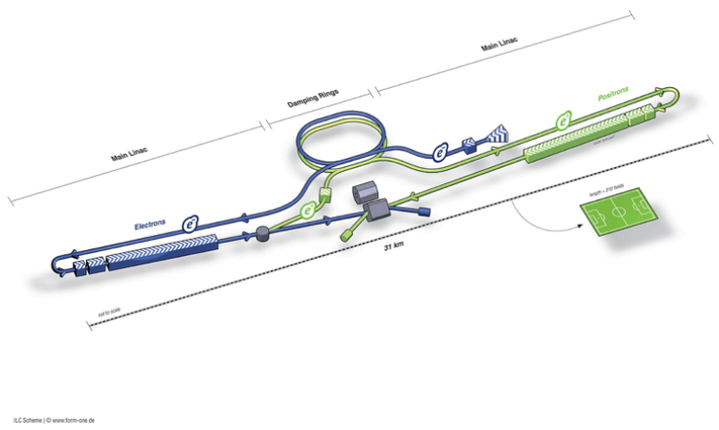
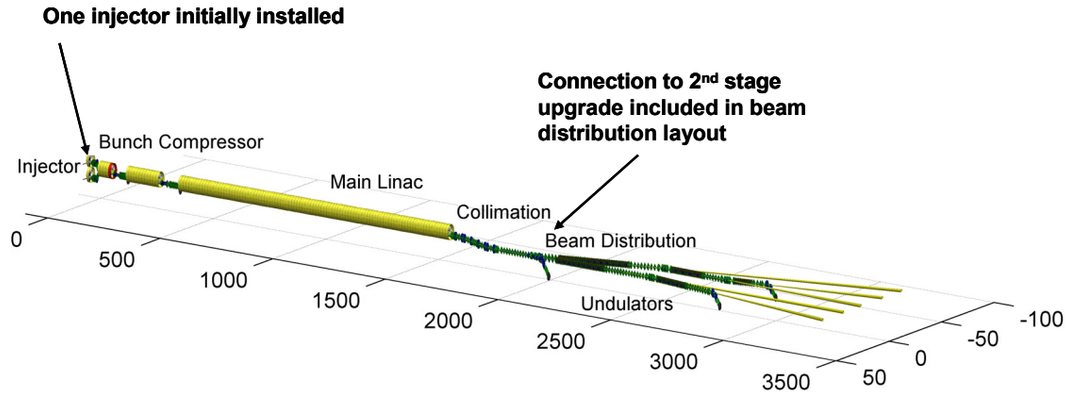
Performance results from elliptical cavities

E.Elsen

ILC



European XFEL



FCC Week 2015, Washington, March 22-27, 2015

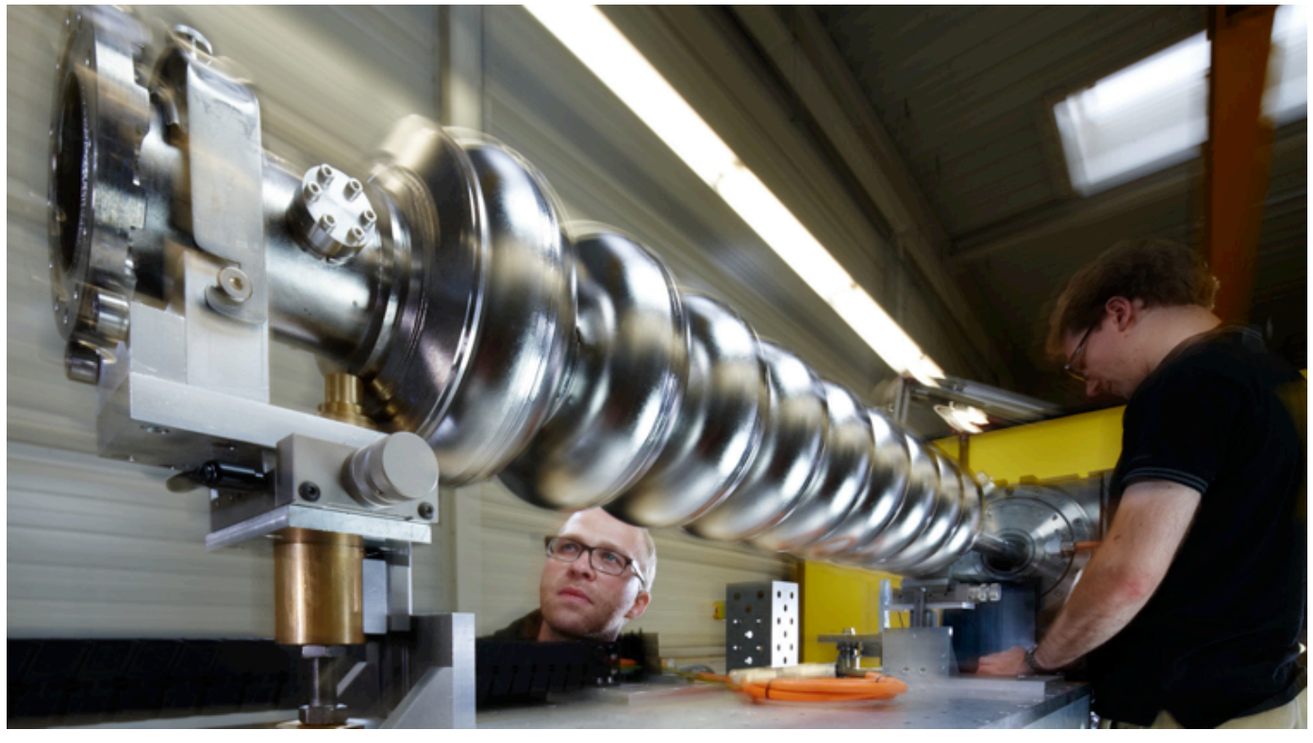
Superconducting RF cavities

- Over the past two decades **development** on superconducting cavities has focussed on β=1 cavities at 1.3 GHz.

  - tremendous improvements in accelerating field E_{acc} and quality Q_0

  - cost improvements

  - Results today from industrial production for the **European XFEL**



European XFEL

- x-ray Free-electron laser under construction in Hamburg
- will use a 17.5 GeV superconducting RF linac
- 800 cavities in 100 cryomodules
- $\langle E_{acc} \rangle$ = 23.4 MeV/m
- $Q_0 > 1 \times 10^{10}$

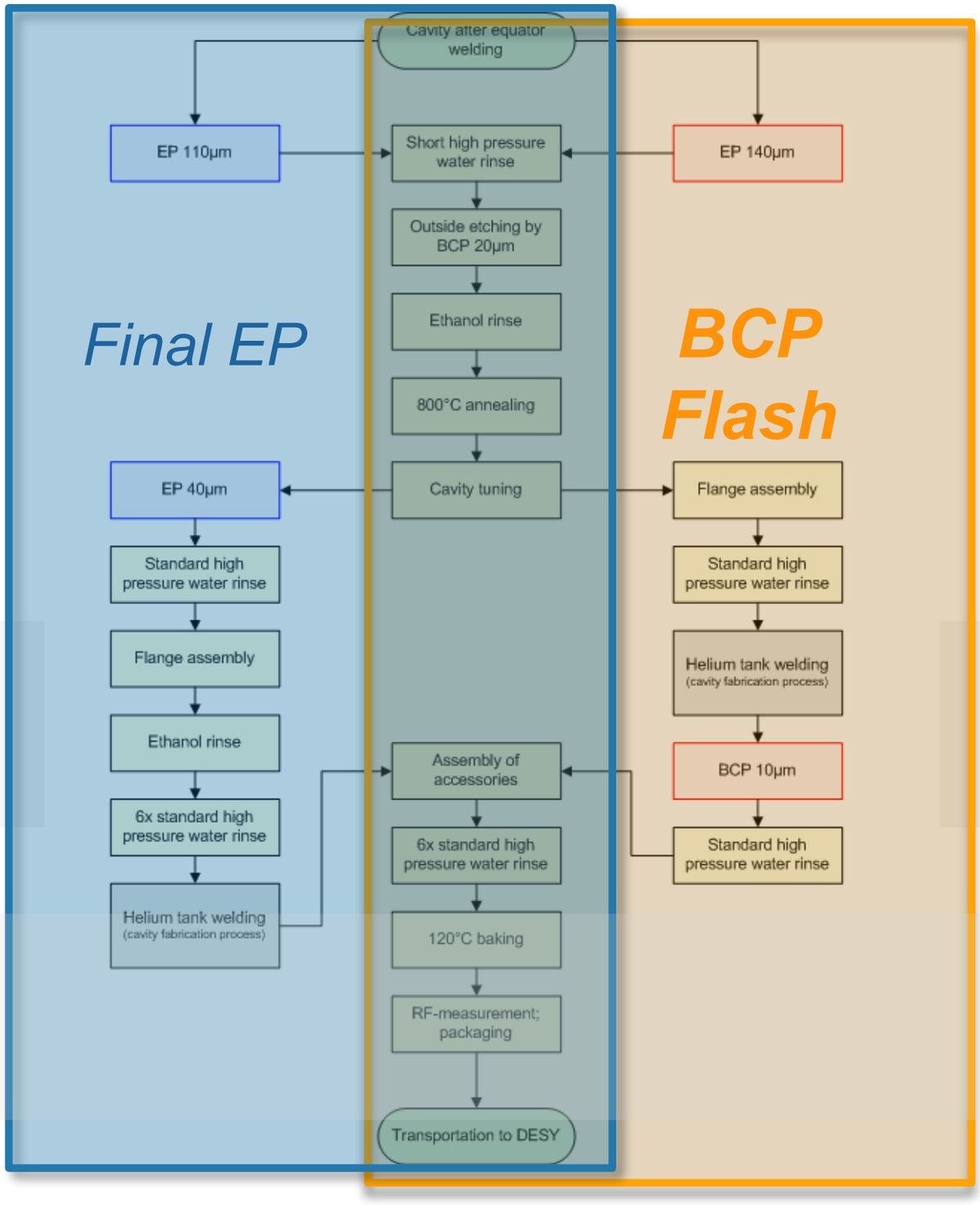
Disclaimer

- All results shown here were obtained in collaboration with the European XFEL cold linac team in particular
  - Cavity manufacturers
    - E. Zanon
    - Research Instruments (RI)
  - CEA Saclay / Alsyom
  - INFN Milano
  - IFJ-PAN
  - DESY
- and specifically for the results of this talk
  - D Resche, D Kostin, L Monaco, J Schaffran, L Steder, N Walker, M Wiencek, Y Yamamoto

Thanks for providing the results!

Cavity preparation along two routes

Research Institutions
– 40 µm Final EP



Zanon
– 10 µm Flash BCP

Cavity preparation closely supervised by DESY…

…and INFN Milano

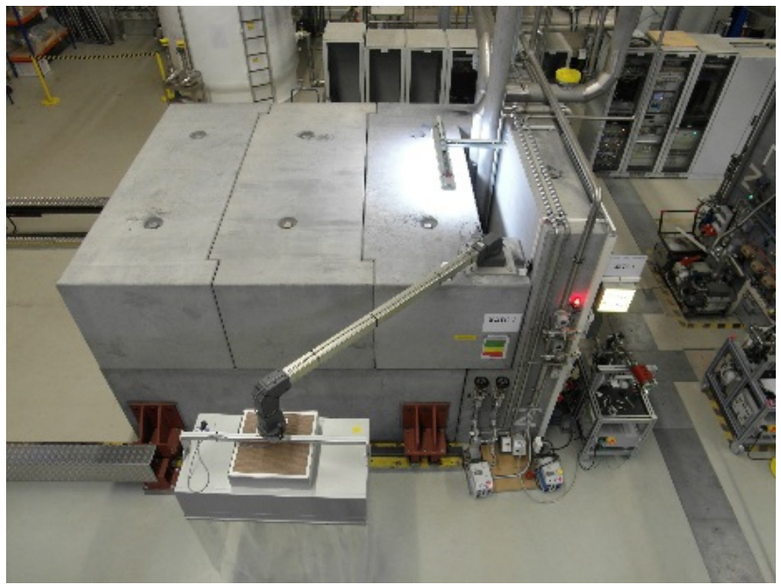
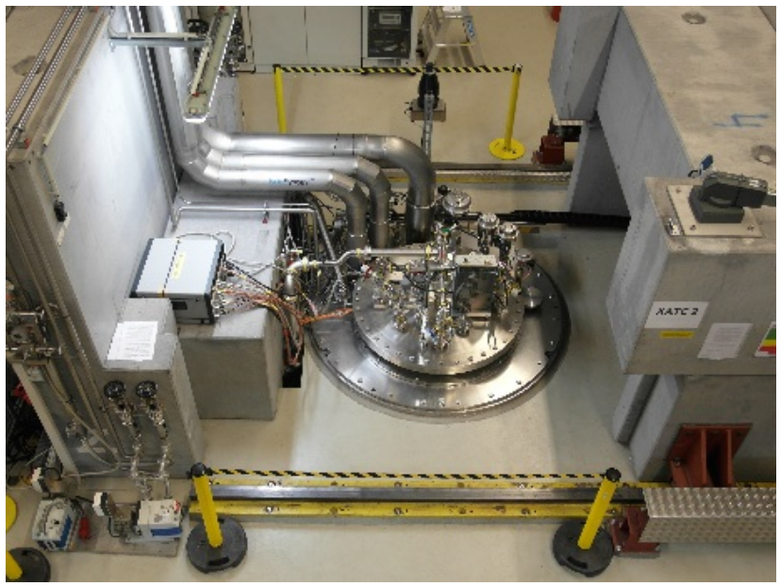
Cavities built to spec…

…no performance guarantee

Vertical acceptance test at DESY

- First cold acceptance test of cavities (built to order)
  - Results presented here based on 522 cavities delivered (including 20/24 ILC-HiGrade cavities)
- Cavities equipped with He-tank and fixed high-Q antenna (ILC-HiGrade cavities w/o tank)
  - hence over-coupled at low and medium fields
- Q(E) at 2K in fundamental mode (π-mode) only
  - long-pulse; few secs only, to protect HOM feed-thrus

Tests at AMTF



Acceptance criteria for vertical test

- Usable gradient
  - > 26 MV/m (10% above required average design operating gradient)
  - > 20 MV/m since May 2014 (to optimise number of re-treatments and re-tests)

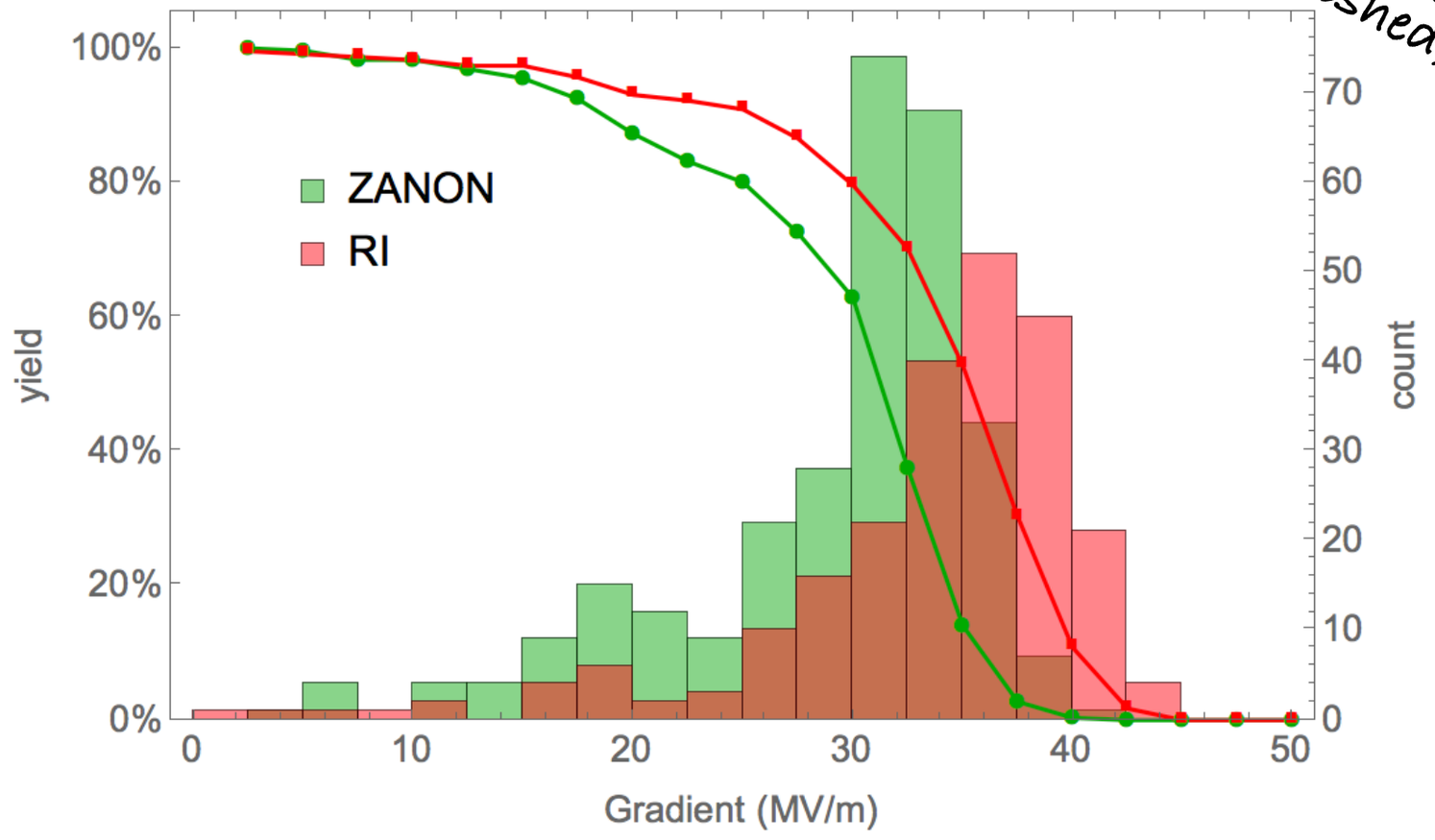
- Definition of usable gradient by
  - Quench or
  - $Q_0 < 1x10^{10}$ or
  - Gradient at X-ray level:
    upper detector > $1x10^{-2}$ mGy/min; lower detector > 0.12 mGy/min

Yield of cavities **as received**

Preliminary (unpublished)

- Average yield well-above 23.4 MV/m

- Final EP affects high field performance (RI reaches higher E_{acc}).



Cavities	522	(88%)
Tests	522	(63%)

	Tests	Average	RMS	Yield@20	Yield@26	Yield@28
ZANON	291	29.3	6.8	87%	78%	71%
RI	231	33.6	7.	93%	90%	86%
All	522	31.2	7.2	90%	83%	77%

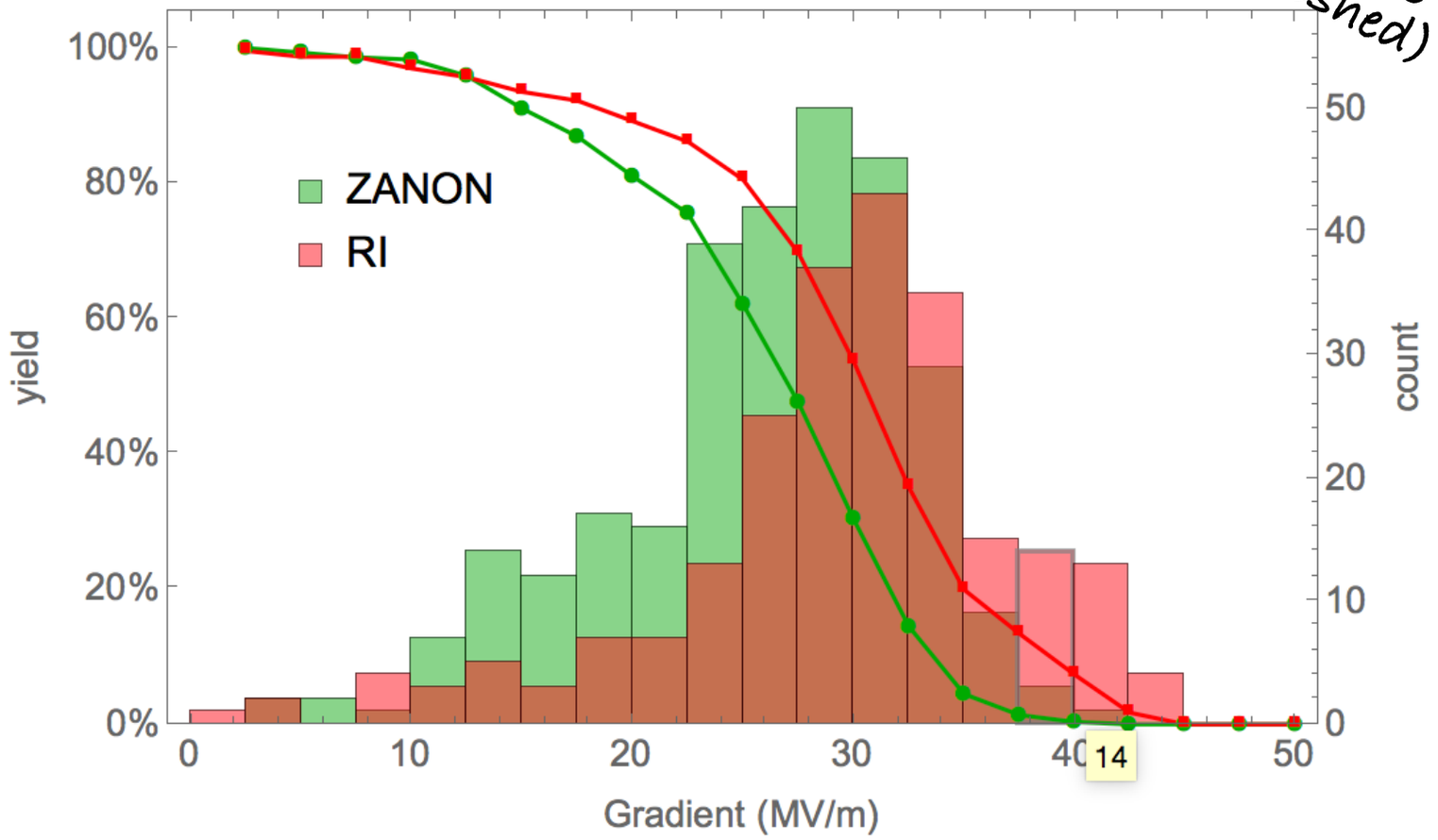
Yield of cavities at **usable field**

Preliminary (unpublished)

- Useable field imposes operational requirements

- E typically lowered by 4 MV/m

- cause largely understood →retreatment



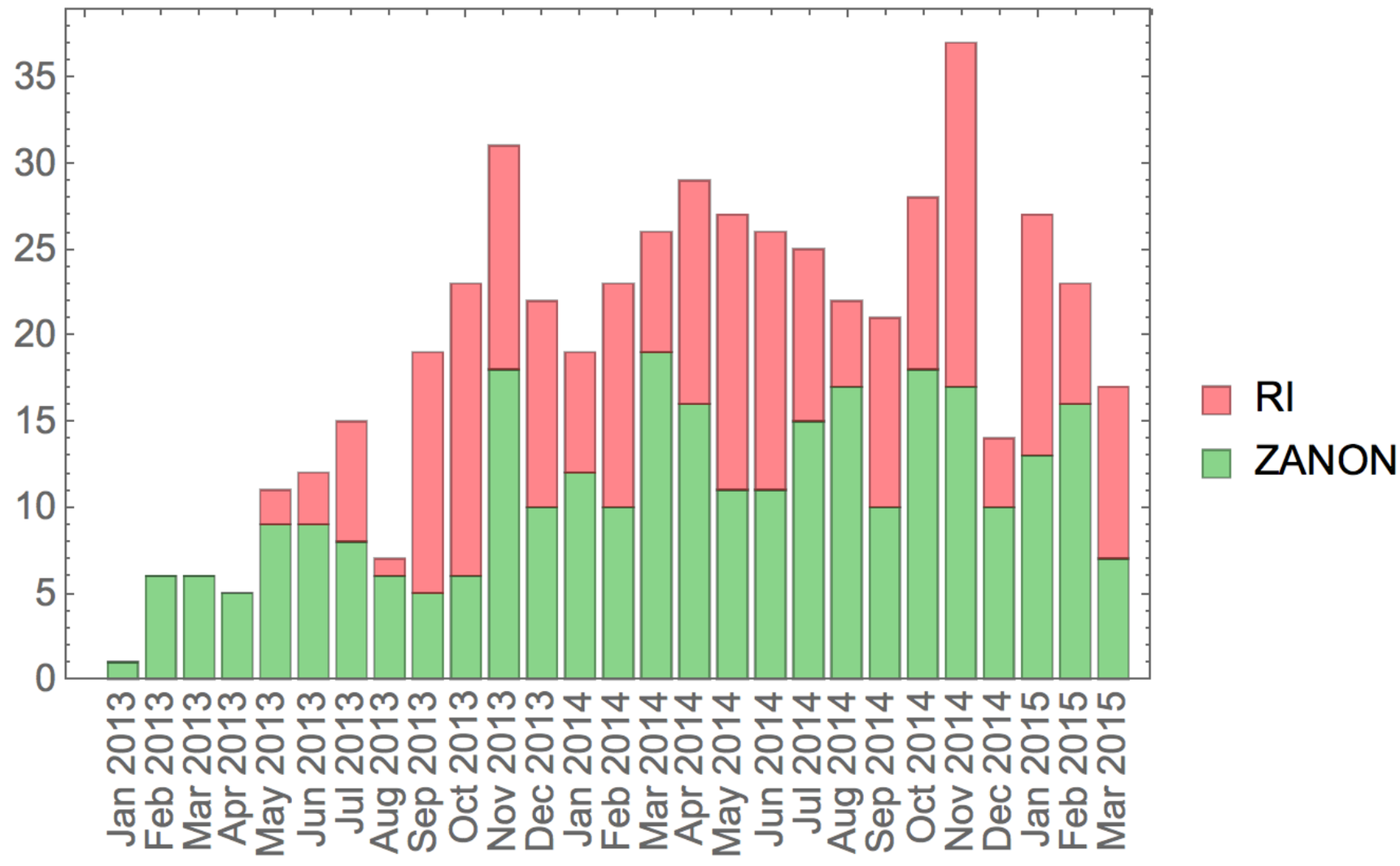
Cavities	521	(88%)
Tests	521	(63%)

	Tests	Average	RMS	Yield@20	Yield@26	Yield@28
ZANON	290	25.9	6.8	81%	56%	42%
RI	231	29.5	7.7	89%	76%	68%
All	521	27.5	7.4	85%	65%	54%

Cavities received and tested

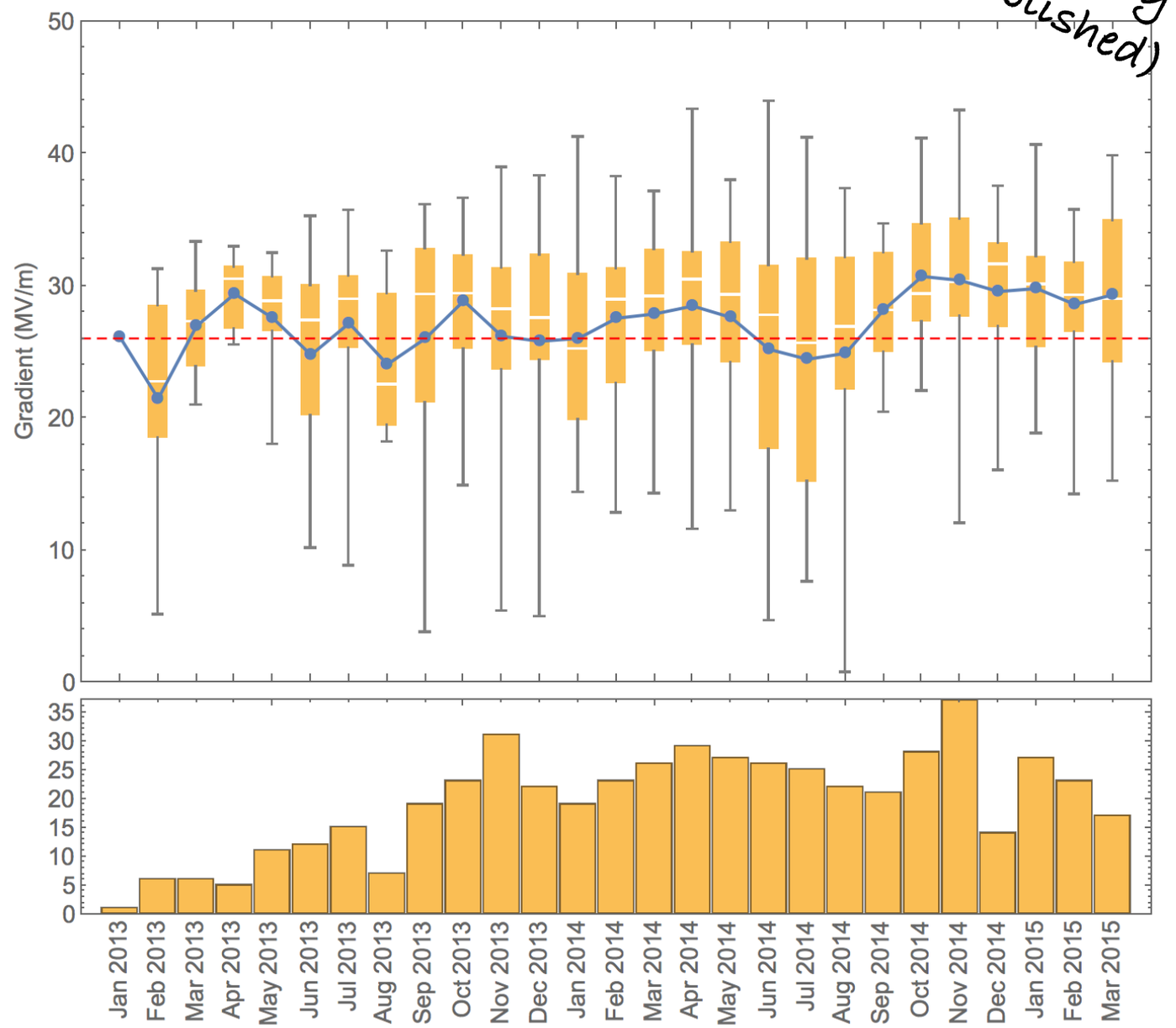
Preliminary (unpublished)

- 522 cavities so far
  - typically 10 cavities per month per vendor



Gradient performance by month

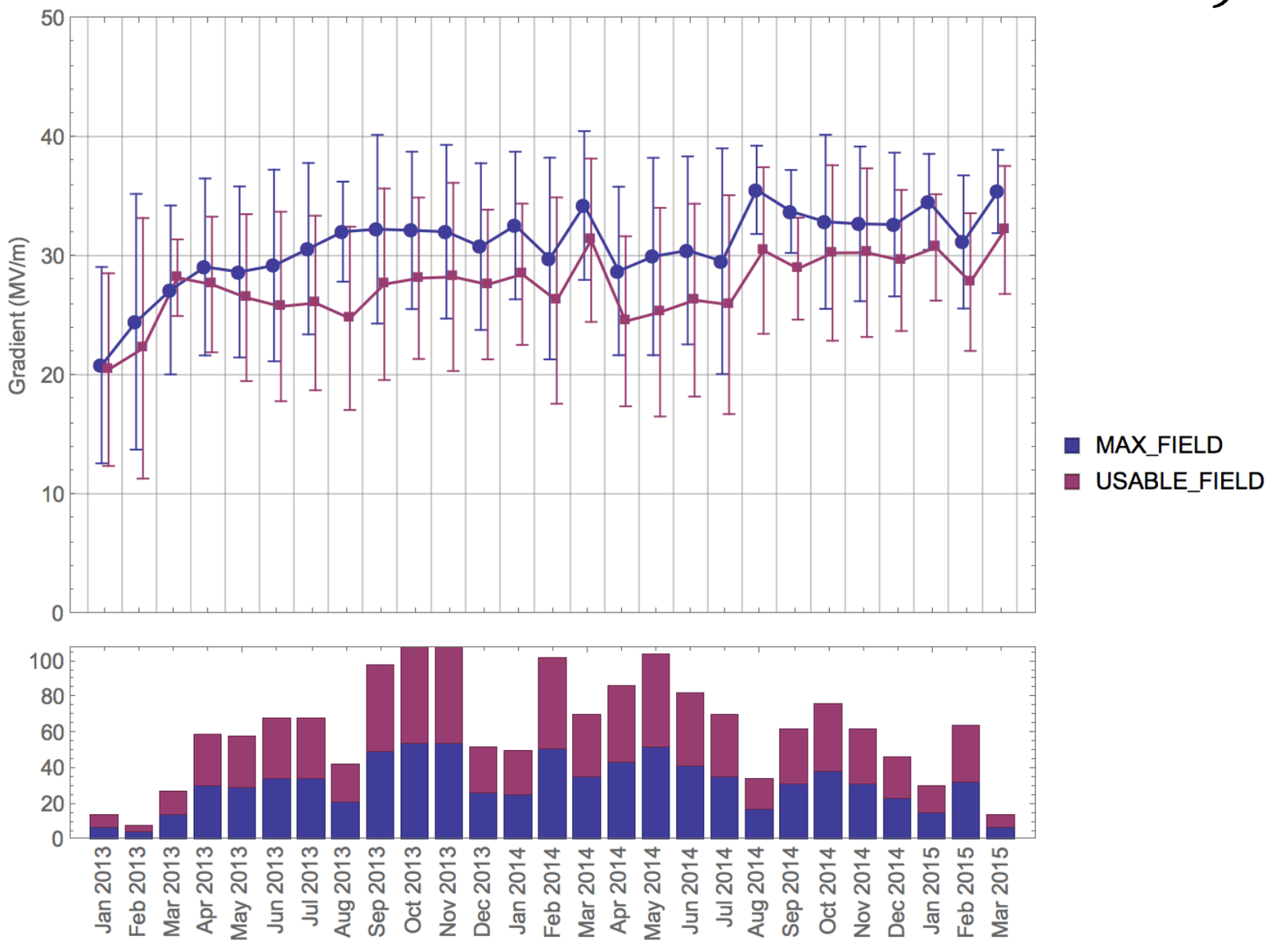
- Average gradient higher than required (23.4 MV/m)
- fairly steady results
- recently slight increase in gradient and reduction in spread



Impact of operational constraints

Preliminary (unpublished)

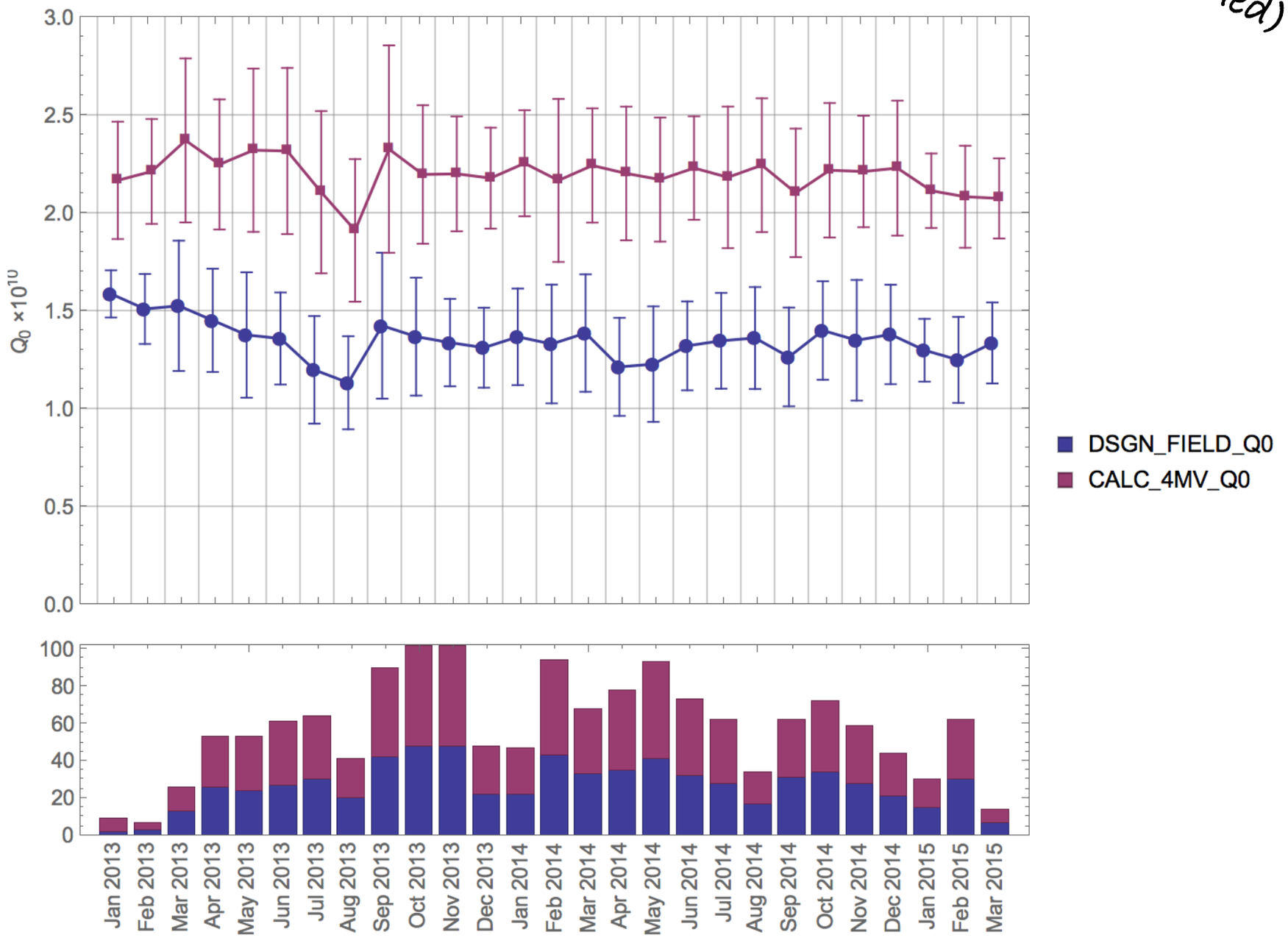
- typically maximum field and usable field differ by 4 MV/m
- Q_0
- Field emission



Q_0 over time

Preliminary (unpublished)

- Q_0 at 23.4 MV/m
- Q_0 at 4 MV/m



Retreatment of cavities failing first acceptance test

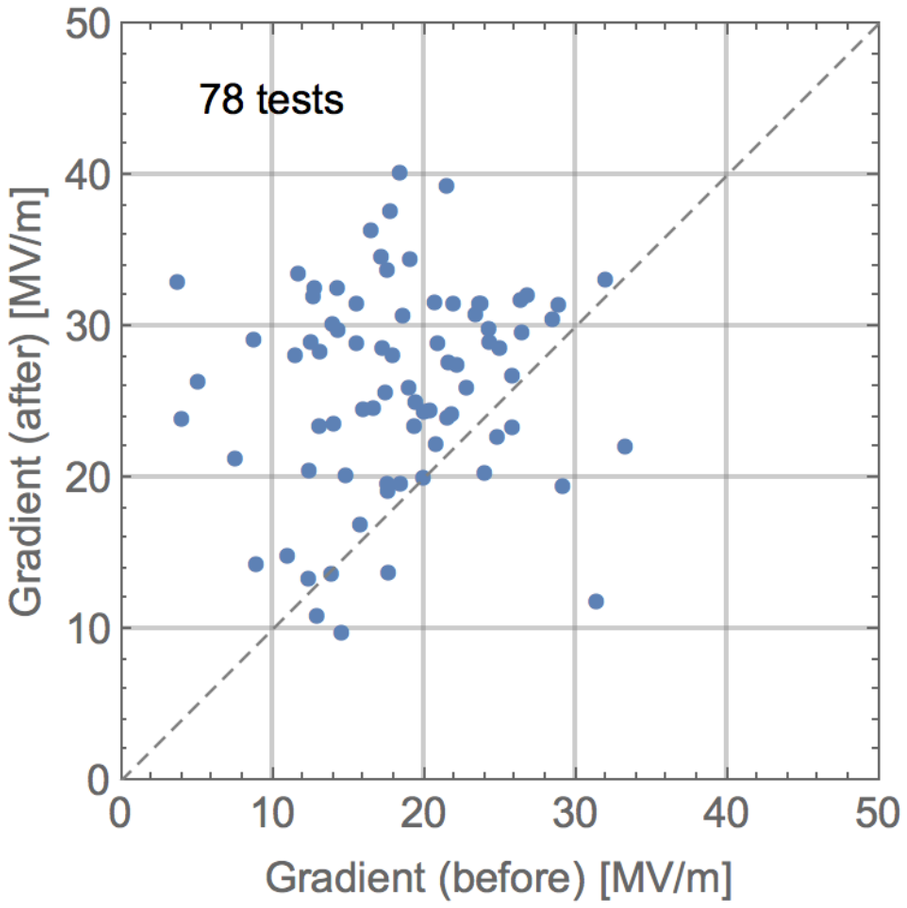
- Reasons for re-treatment:
  - field emission (59 cavities)
  - quench at “low” gradient (6 cavities)
  - low Q-value at low gradient (4 cavities)
  - leak (2 cavities)
  - other (7 cavities)

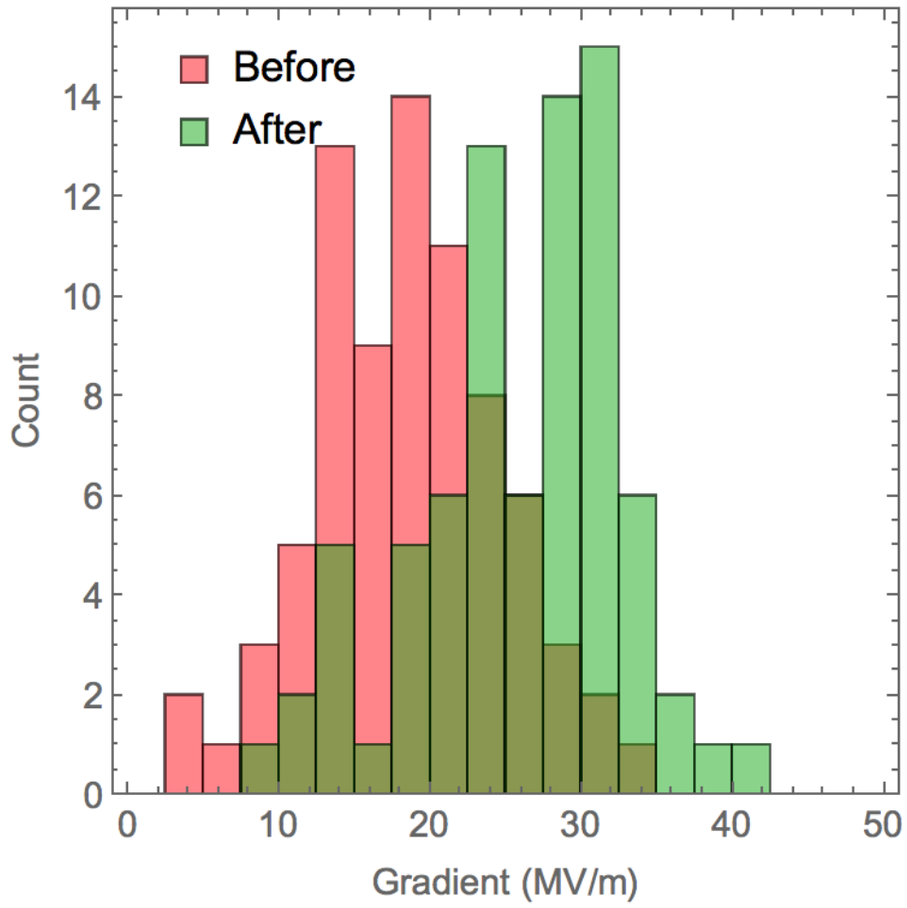
Assessment of procedure for retreatment

- Optical inspection often informed subsequent step
    - in most cases an additional High-Pressure-Rinse (HPR) removed the emitter
    - sometimes manufacturer mechanically removed surface irregularities

Effect of retreatment: Gradient

Preliminary (unpublished)



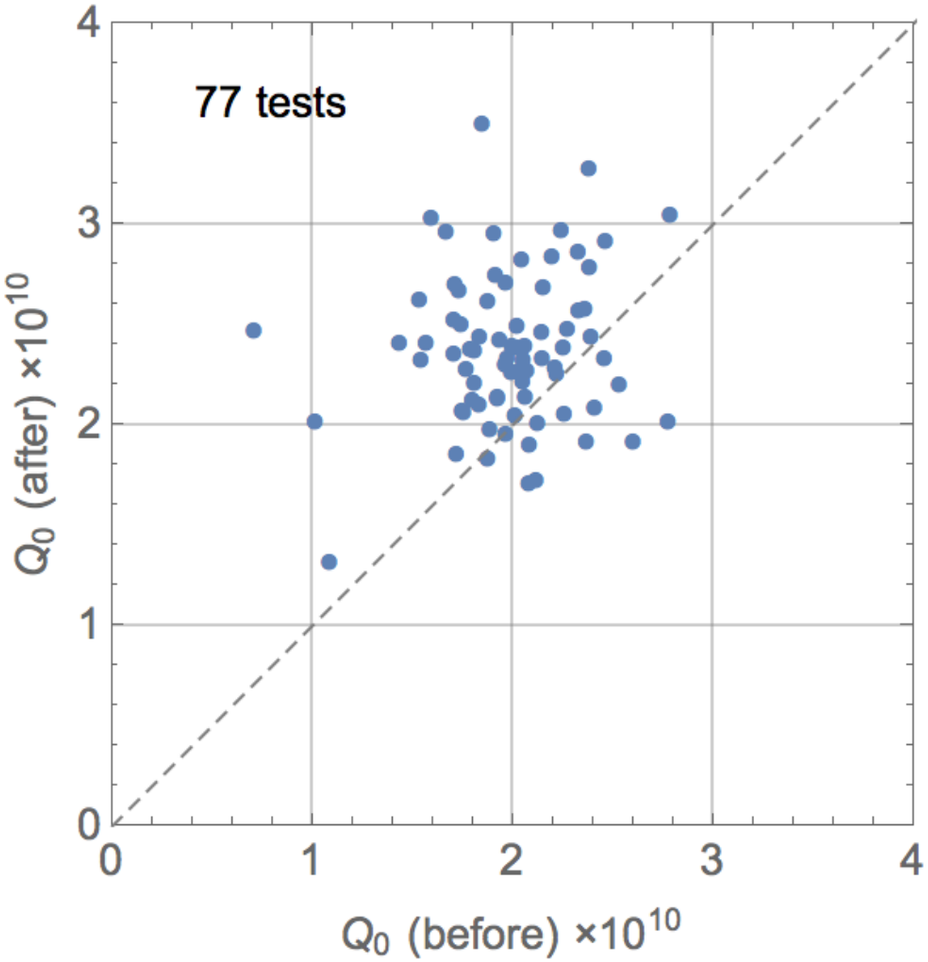


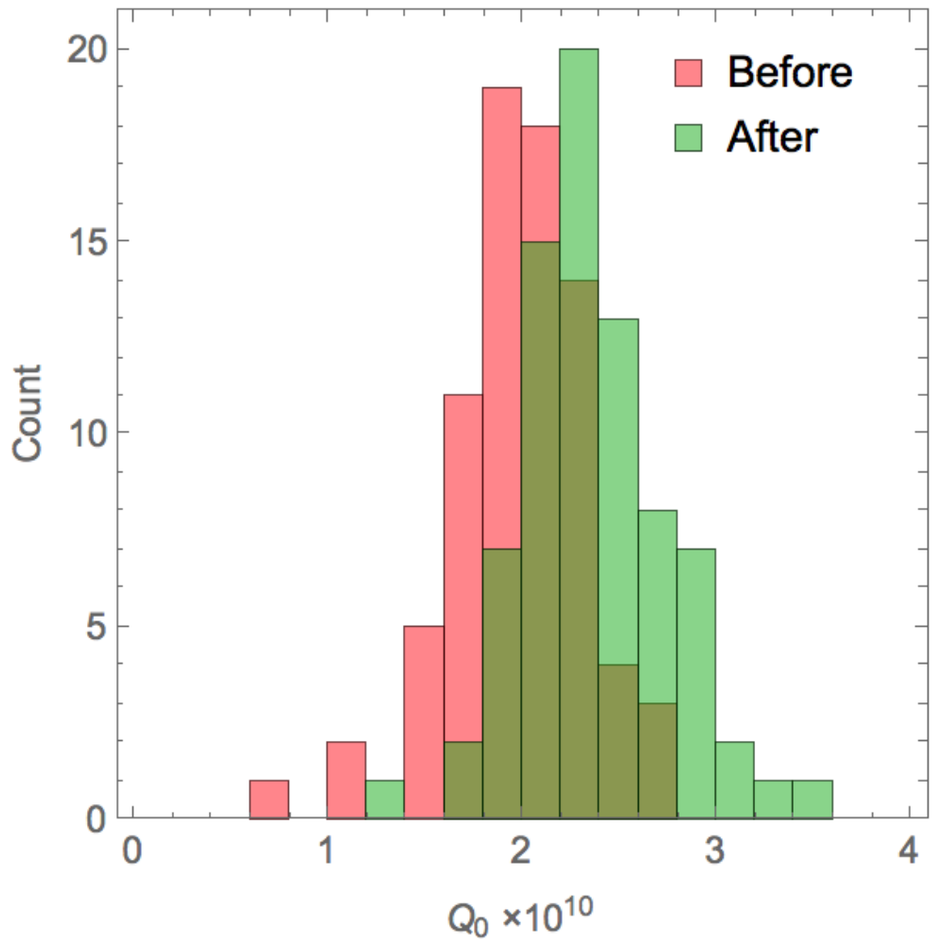
retreatment, low Q	4
retreatment, quench	6
retreatment, FE	59
retreatment, other	7
retreatment, leak	2

	Before	After
Tests	78	78
G_{AVG} (MV/m)	18.5	26.1
G_{RMS} (MV/m)	6.3	6.7
yield @ 20MV/m	40%	82%
yield @ 26MV/m	12%	54%
yield @ 28MV/m	8%	47%

Effect or retreatment: Q_0

Preliminary (unpublished)

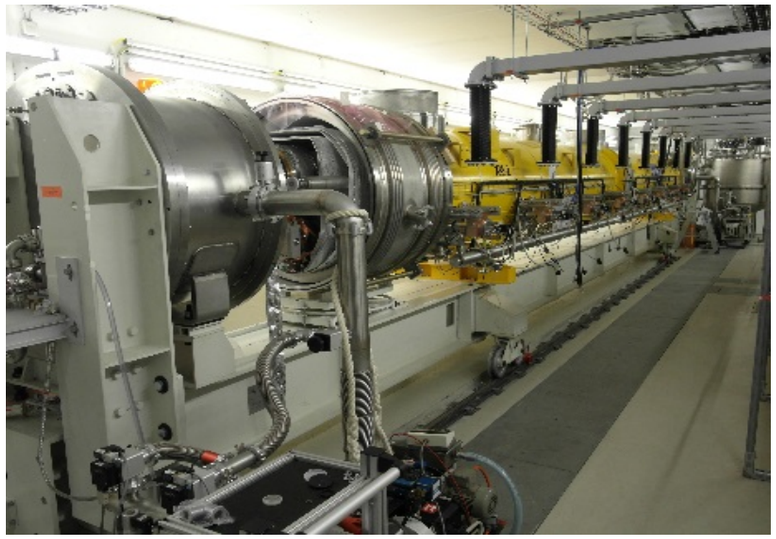




retreatment, low Q	4
retreatment, quench	6
retreatment, FE	58
retreatment, other	7
retreatment, leak	2

	Before	After
Tests	77	77
$\langle Q_0 \rangle$	1.99282×10^{10}	2.36495×10^{10}
σ_{Q_0}	3.54557×10^{9}	3.77659×10^{9}
yield @ 1×10^{10}	99%	100%

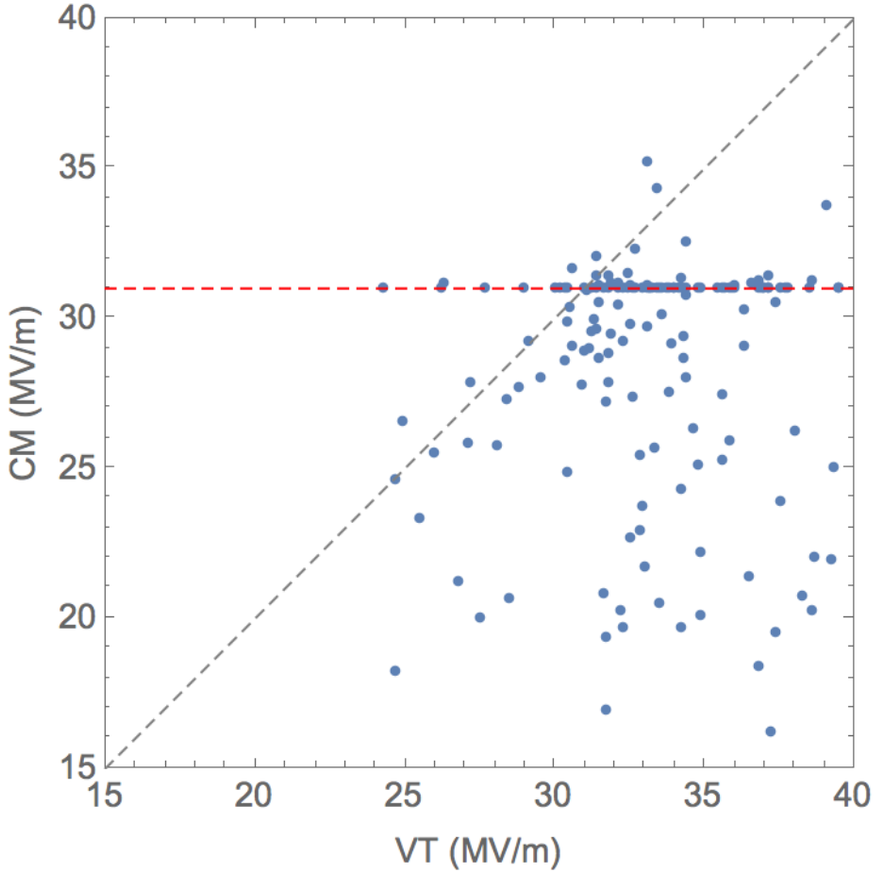
Module tests at AMTF

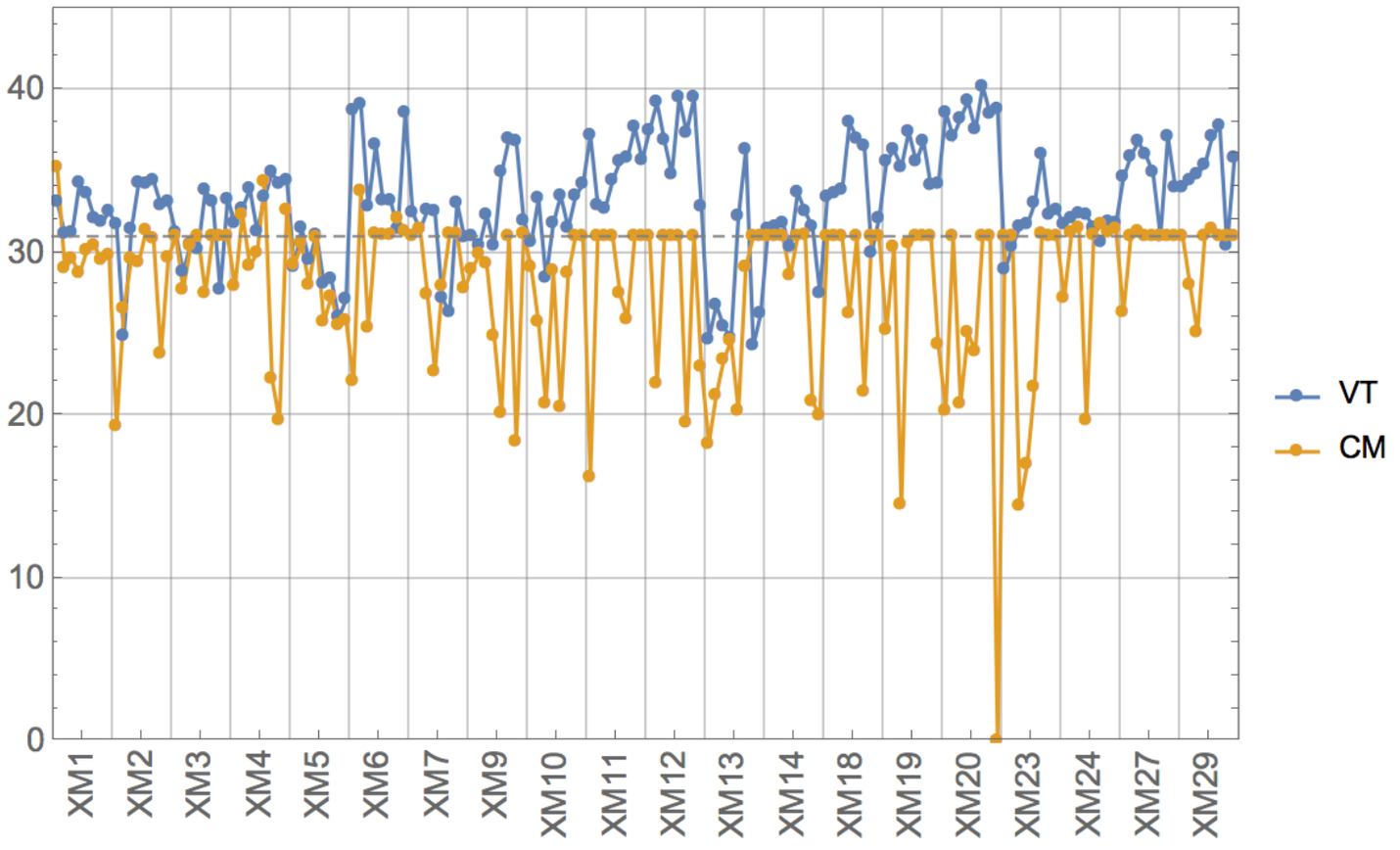


Development of Useable Gradient in Cryomodule

- Groups of 8 cavities mounted in 1 cryomodule
- Operational gradient limitation at 31 MV/m imposed

Preliminary (unpublished)



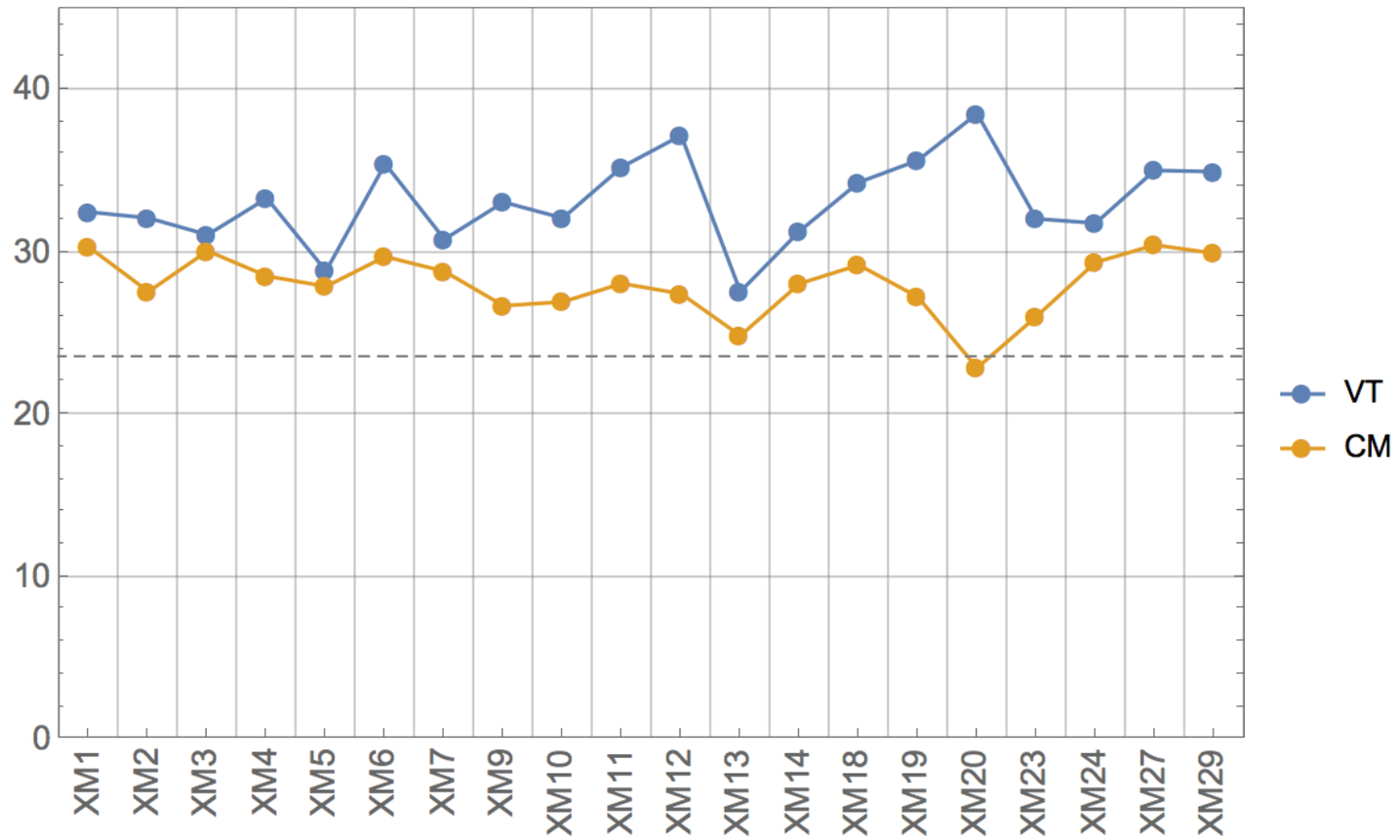


Development of average Useable Gradient in Cryomodule

Preliminary (unpublished)

- Degradation not yet understood
  - Intense manual labour in mounting string of cavities
- Gradient certainly sufficient for European XFEL

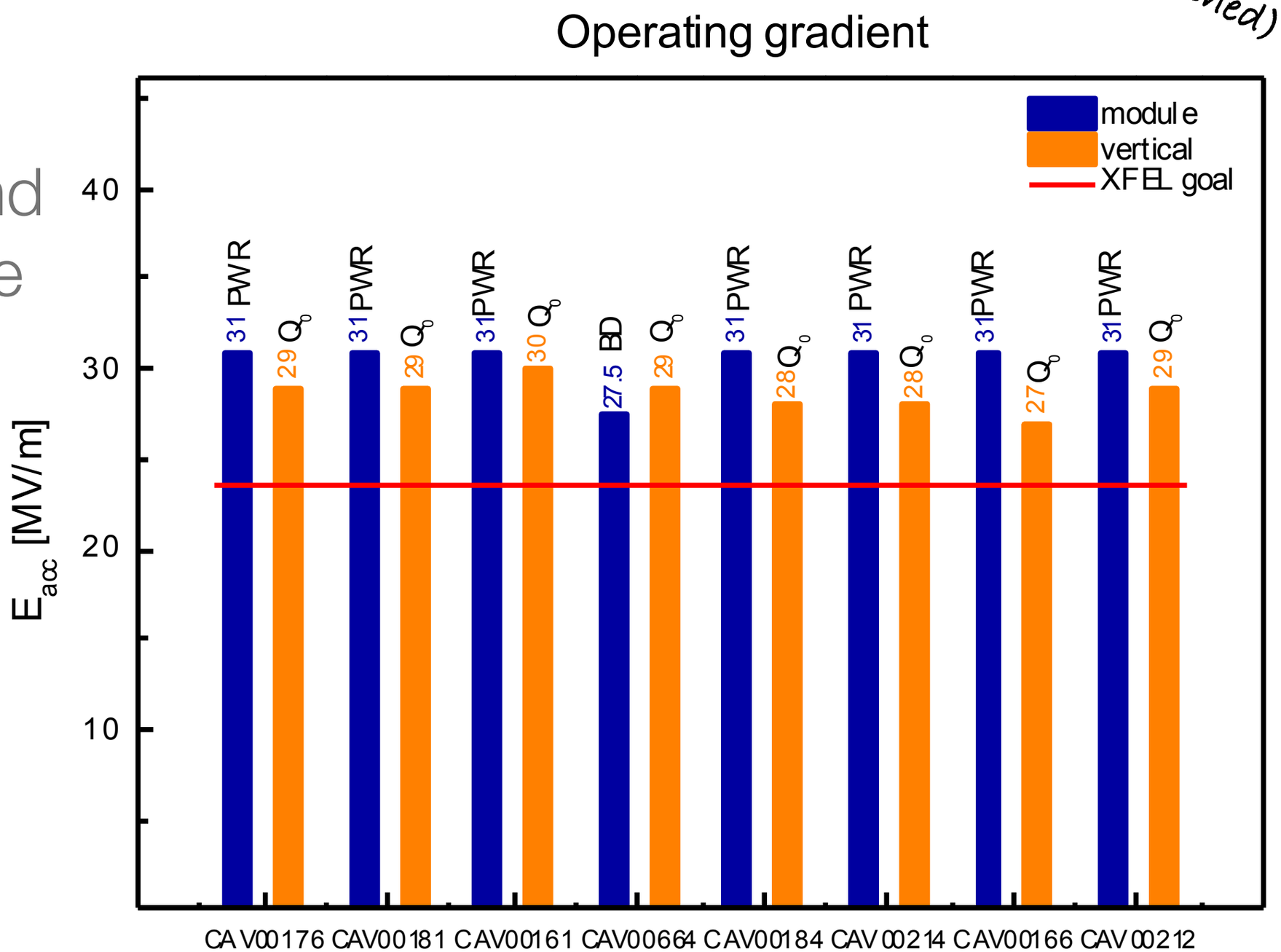
	N_{cavs}	Average	RMS	min	max
VT	159.	33.1	3.4	24.3	40.2
CM	159.	28.2	4.3	14.5	35.2



Cryomodule XM30

Preliminary (unpublished)

- …as a very notable exception and latest module tested



Conclusions

- Industrial production of 1.3 GHz elliptical cavities for the European XFEL is in full swing

  - Gradient and Q_0 exceed requirements for European XFEL

- ILC requirements ($\langle E_{acc} \rangle$ = 31.5 MV/m ± 20%) can be met, particularly when allowing for second treatment step

- Gradient degradation in modules remains a concern for the ILC and a nuisance for European XFEL