Cryomodule Performance including Degradation: Comparison of Cavity Performance in XFEL Cryomodules

Nick Walker
DESY
TTC 2015 - SLAC - 01/12/15

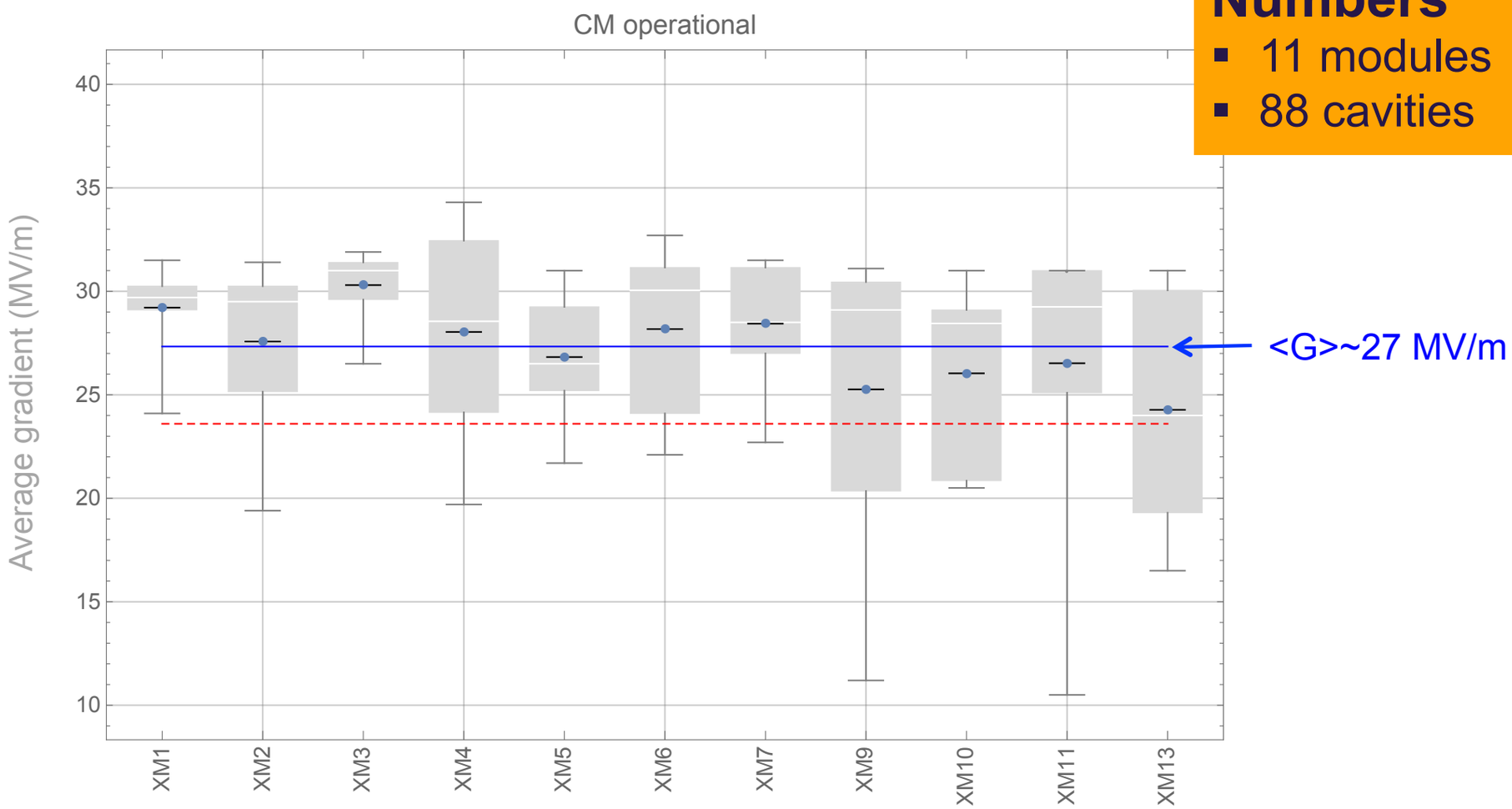
One year ago

E-XFEL Cavity Vertical vs. Module Test Statistics

Bottom Line: average module operational gradient

TTC 14 @ KEK

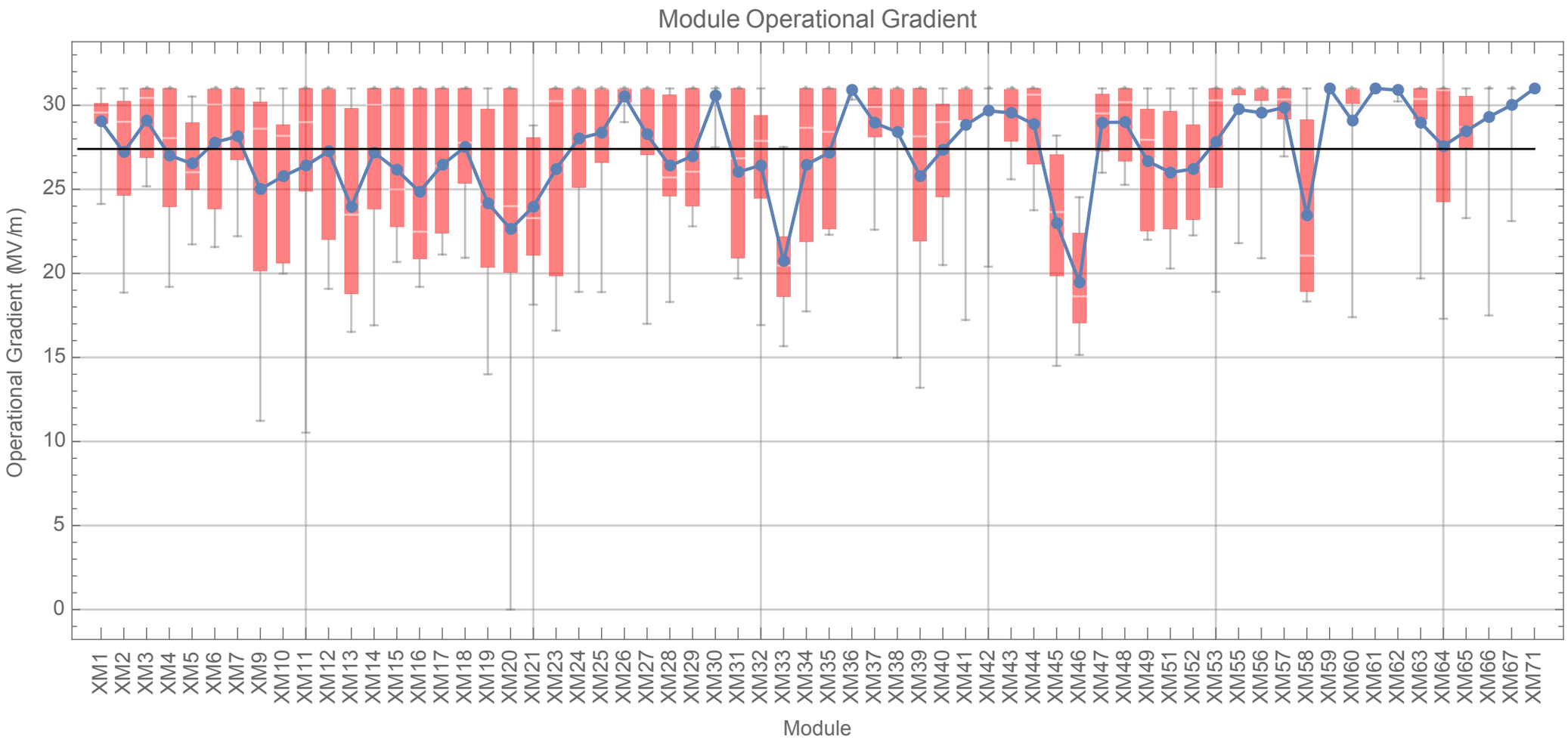
Numbers
- 11 modules
- 88 cavities



02.12.2014, TTC meeting - KEK, Tsukuba, Japan
Nick Walker (DESY) for the cavity analysis team

Today 64 modules (512 cavities)*

* in XFEL DB



$\langle G_{op} \rangle = 27.5$

NB: 31 MV/m administrative limit for module tests
(no administrative limit for VT)

Nicholas Walker ● DESY ● nicholas.walker@desy.de

Irfu

About Gradient Comparison

iXFEL X-Ray Free-Electron Laser

- Accelerating gradients are the most scrutinized module performance parameters, although heat loads, alignment and PED certification are entering the acceptance criteria.
- The absolute gradient is the result of the whole production chain, from the Nb sheet to the RF module test (MT). It is mostly determined by **cavity manufacturing** and **module assembly**.
- The quality of module assembly shows in the gradient difference between cavity acceptance (VT) and module acceptance (MT).
- The VT vs. MT comparison of both the 'maximum' and the 'operational' gradients is impaired by a **systematic error:**
  - Maximum gradients depend on 1) RF duty cycle, 2) cooling conditions and, 3) magnetic environment, which are completely different from VT to MT → *mostly cavity-independent error*
  - Oprational gradients depends, **in addition,** on X-Ray measurement devices which are completely different from VT to MT (although cross-calibrated) → *mostly cavity-independent error*
  - Finally, Q_0 is not measured in MT: therefore the MT usable gradient could correspond to **lower** or **higher** Q_0 values → *cavity-dependent error*

cea

Irfu

About Gradient Comparison

i XFEL X-Ray Free-Electron Laser

- Accelerating gradients are the most scrutinized module performance parameters, although heat loads, alignment and PED certification are entering the acceptance criteria.
- The absolute gradient is the result of the whole production chain, from the Nb sheet to the RF module test (MT). It is mostly determined by **cavity manufacturing** and **module assembly**.
- The quality of module assembly shows in the gradient difference between cavity acceptance (VT) and module acceptance (MT).
- The VT vs. MT comparison of both the 'maximum' and the 'operational' gradients is impaired by a **systematic error:**
  - Maximum gradients depend on 1) RF duty cycle, 2) cooling conditions and, 3) magnetic environment, which are completely different from VT to MT → *mostly cavity-independent error*
  - Oprational gradients depends, **in addition,** on X-Ray measurement devices which are completely different from VT to MT (although cross-calibrated) → *mostly cavity-independent error*
  - Finally, Q_0 is not measured in MT: therefore the MT usable gradient could correspond to **lower** or **higher** Q_0 values → *cavity-dependent error*

cea

O. Napoly
On the Comparing of VT and Module Gradients

Irfu

About Gradient Comparison

XFEL X-Ray Free-Electron Laser

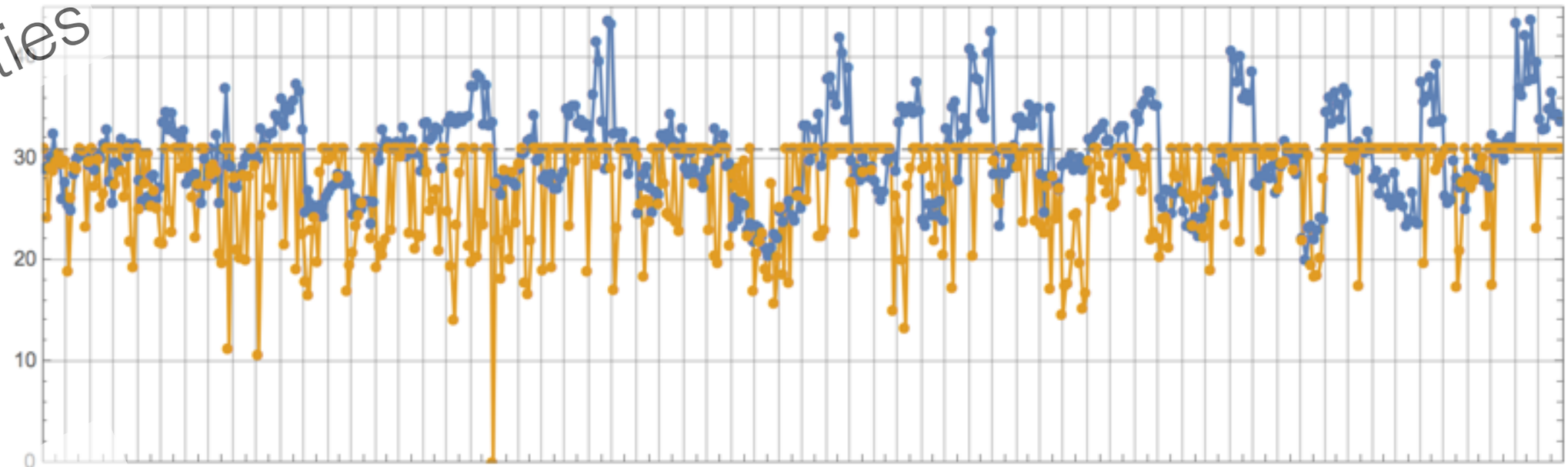
- Accelerating gradients are the most scrutinized module performance parameters, although heat loads, alignment and PED certification are entering the acceptance criteria.
- The absolute gradient is the result of the whole production chain, from the Nb sheet to the RF module test (MT). It is mostly determined by **cavity manufacturing** and **module assembly**.
- The quality of module assembly shows in the gradient difference between cavity acceptance (VT) and module acceptance (MT).
- The VT vs. MT comparison of both the 'maximum' and the 'operational' gradients is impaired by a **systematic error:**
  - Maximum gradients depend on 1) RF duty cycle, 2) cooling conditions and, 3) magnetic environment, which are completely different from VT to MT → *mostly cavity-independent error*
  - Oprational gradients depends, **in addition,** on X-Ray measurement devices which are completely different from VT to MT (although cross-calibrated) → *mostly cavity-independent error*
  - Finally, Q_0 is not measured in MT: therefore the MT usable gradient could correspond to **lower** or **higher** Q_0 values → *cavity-dependent error*

cea

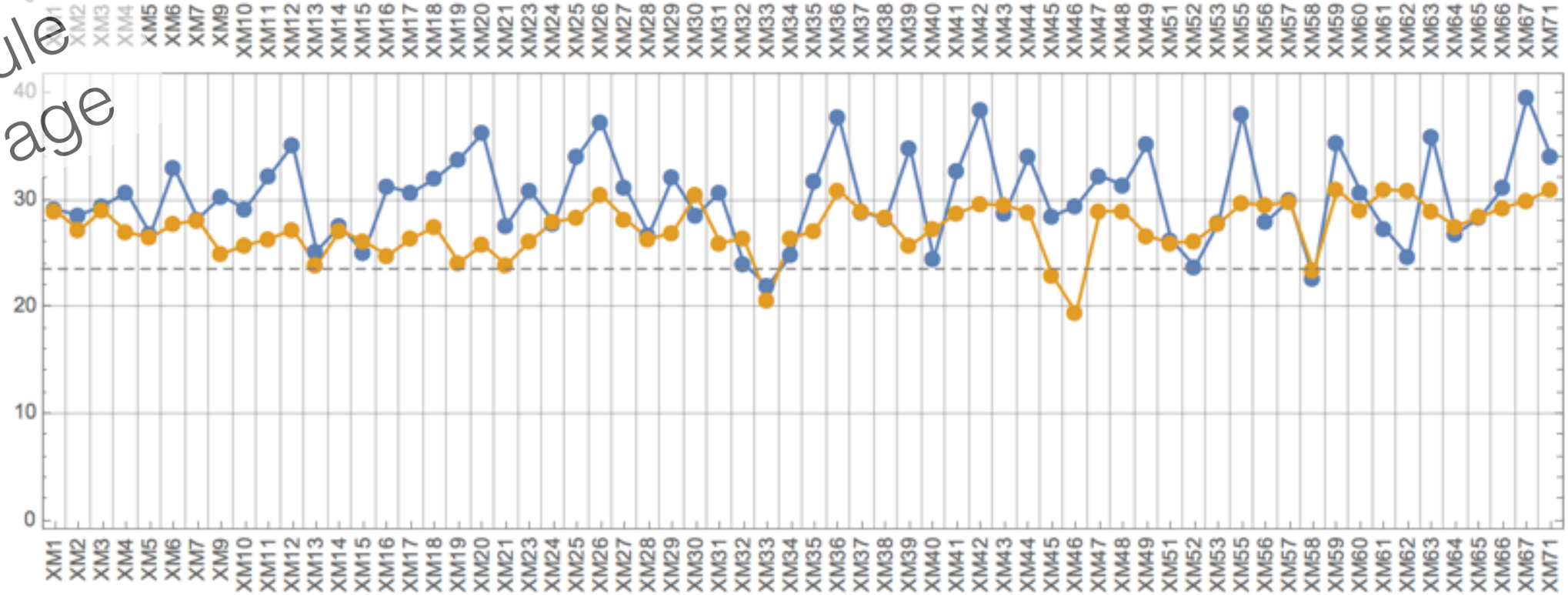
All true

XFEL module results: Usable Gradient

cavities



Module average

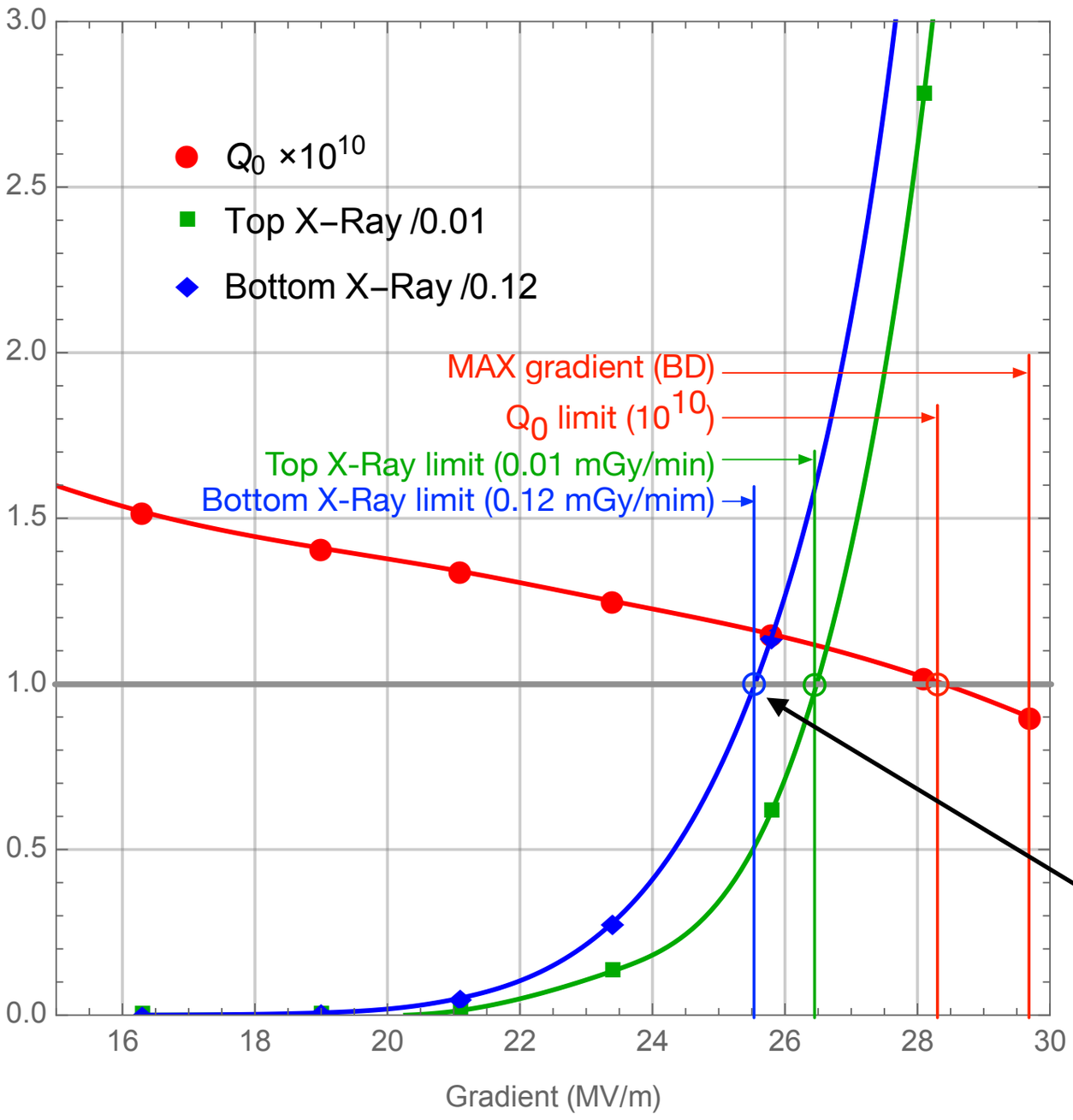


64 modules, 512 cavities

Nicholas Walker ● DESY ● nicholas.walker@desy.de

Usable Gradient: Definition

VT Power Rise (example)

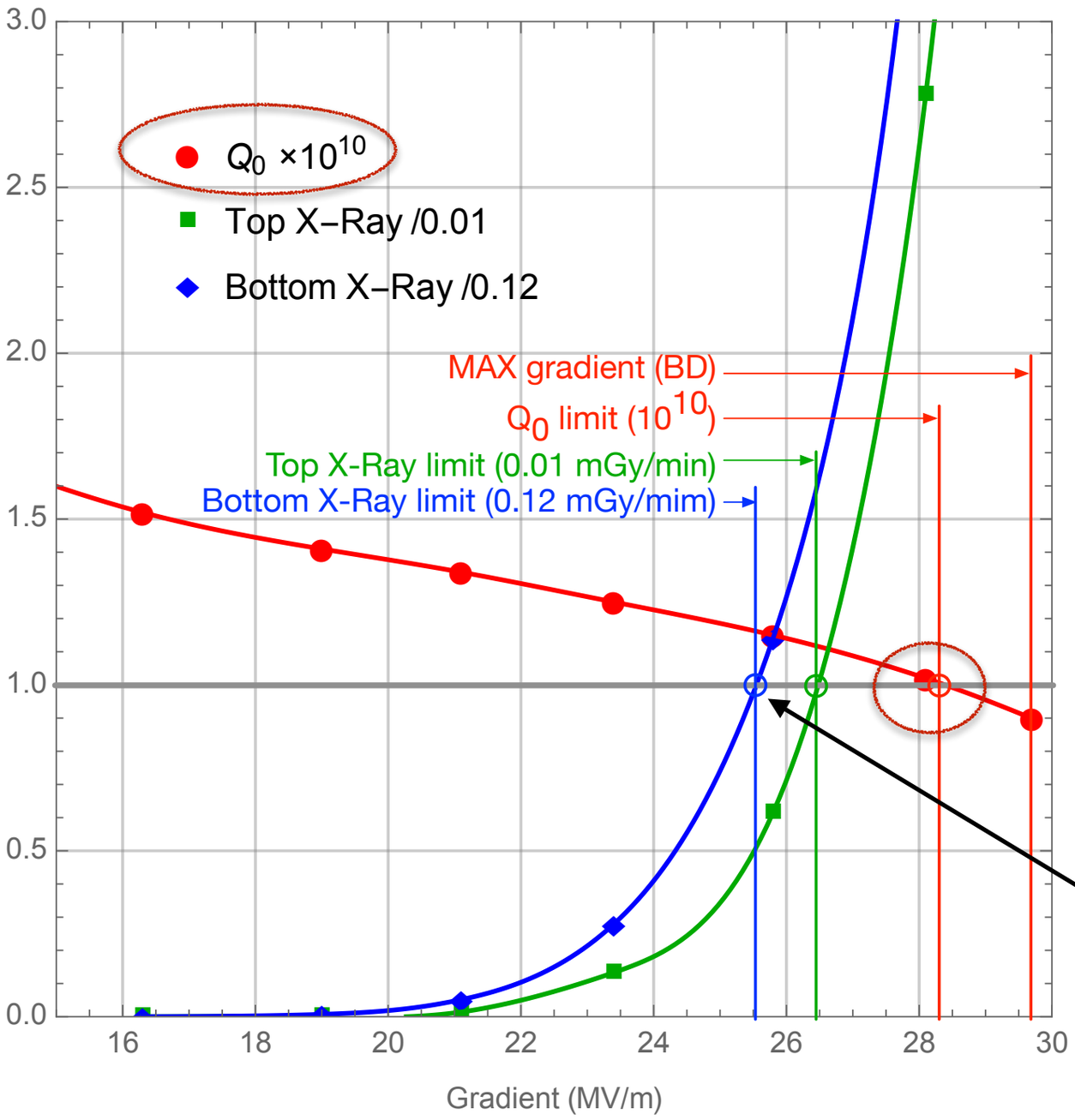


Max. usable gradient
= 25.5 MV/m

Nicholas Walker ● DESY ● nicholas.walker@desy.de

Usable Gradient: Definition

VT Power Rise (example)



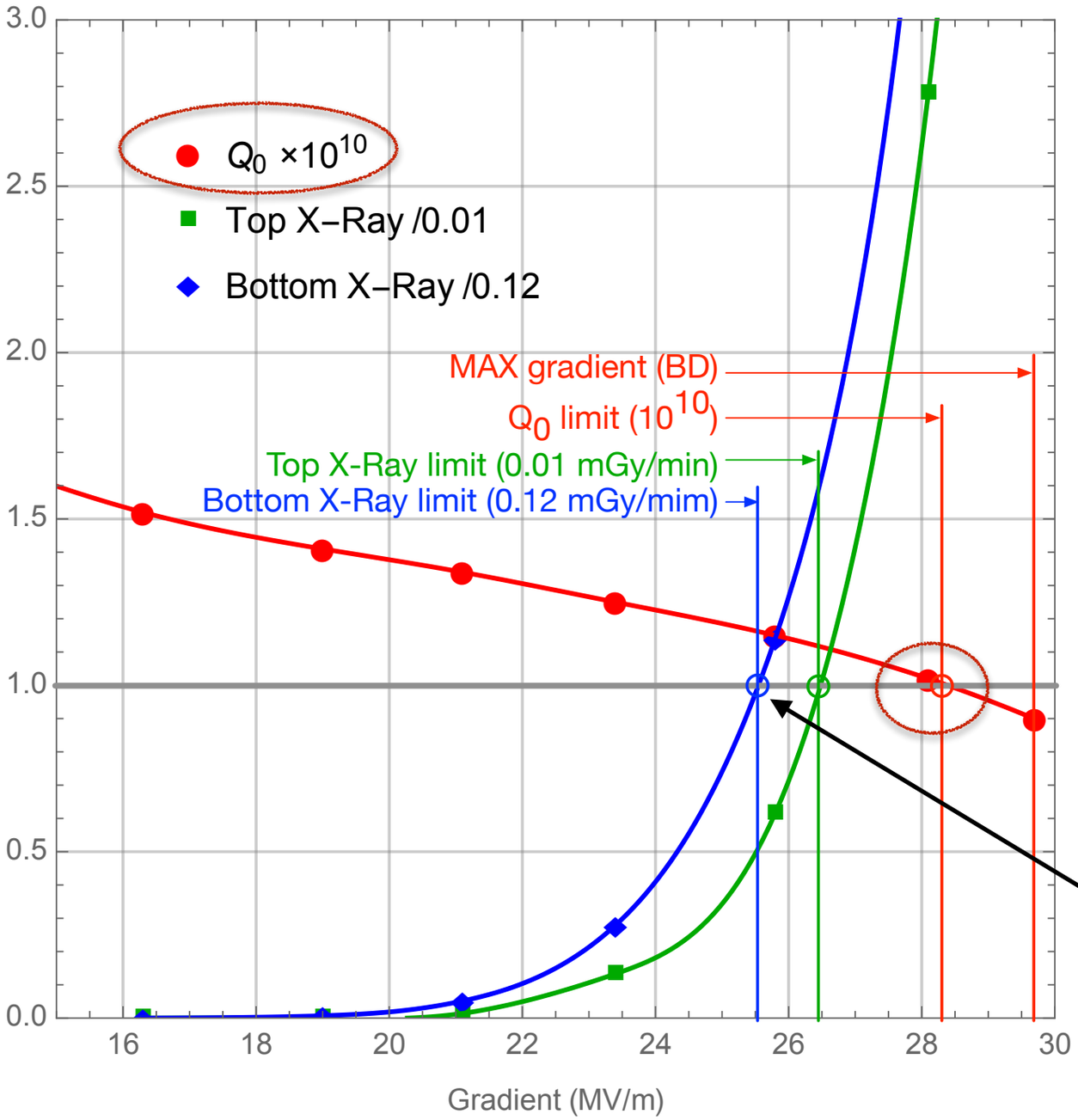
Not included in Module Test
(Can't measure individual cavity Q_0)

Max. usable gradient
= 25.5 MV/m

Nicholas Walker ● DESY ● nicholas.walker@desy.de

Usable Gradient: Definition

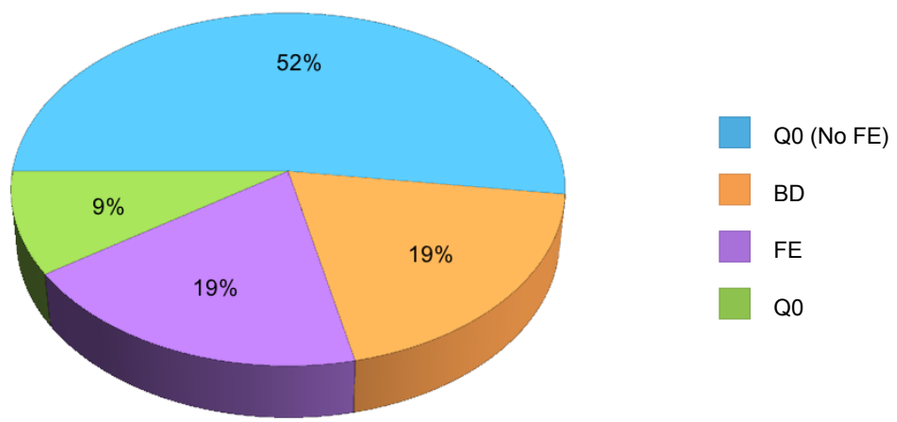
VT Power Rise (example)



Not included in Module Test
(Can't measure individual cavity Q_0)

VT UG limiting criterion

(~50% cavities have G>30 MV/m)

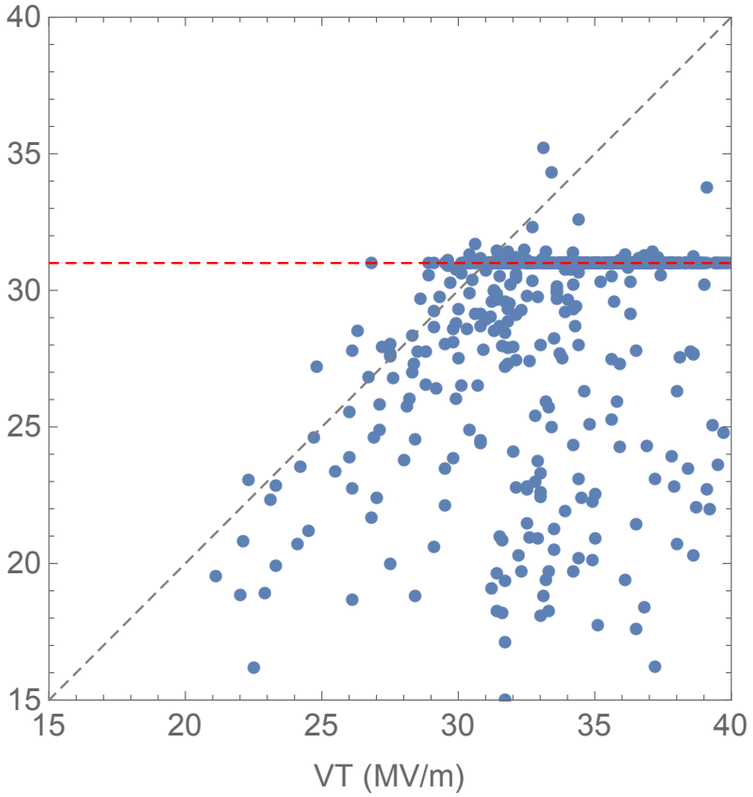


Max. usable gradient
= 25.5 MV/m

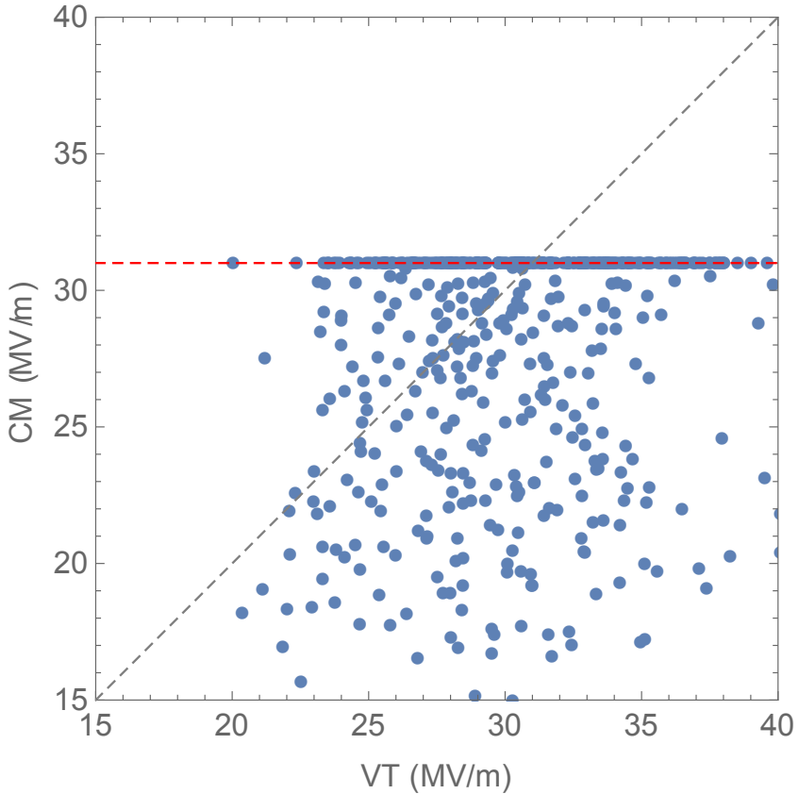
Nicholas Walker ● DESY ● nicholas.walker@desy.de

Module v VT (individual cavities)

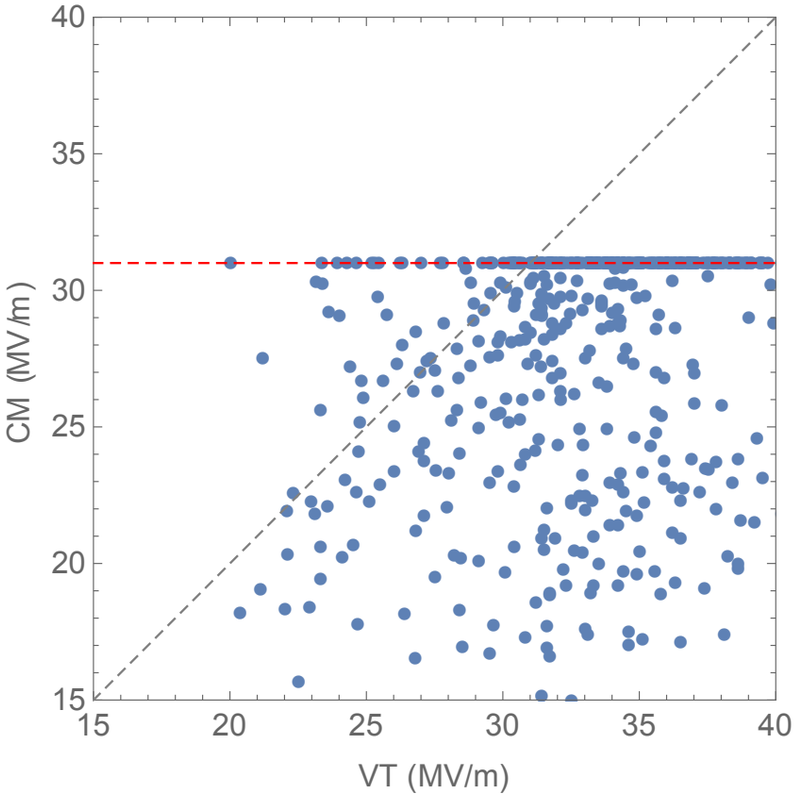
Maximum



Usable



Usable (VT No Q_0)



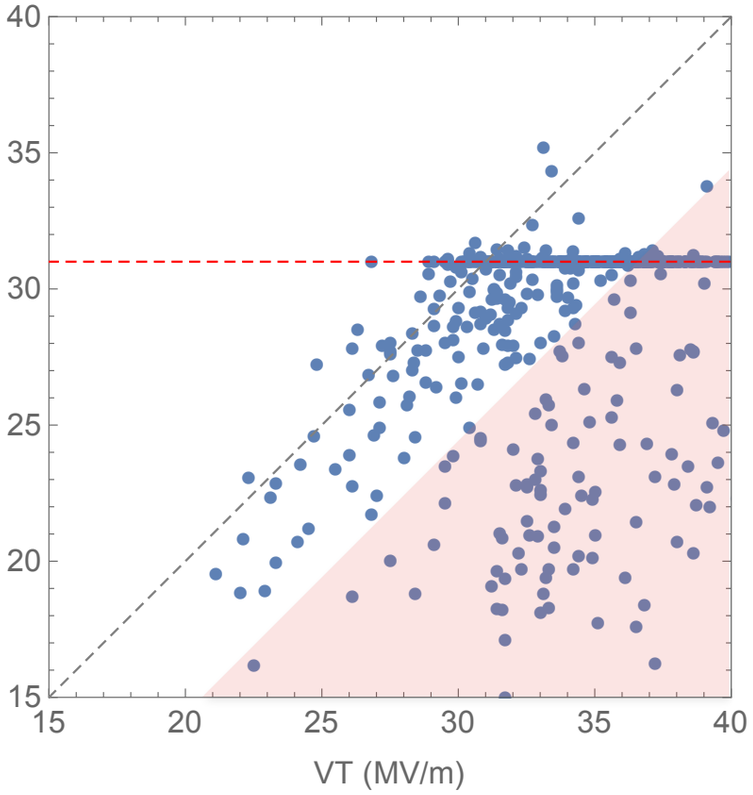
VT estimated error ±1.3 MV/m
Module estimated error ±2.5 MV/m

$\Delta G \sim \pm 2.8$ MV/m ⇒ define degradation as >5.6 MV/m

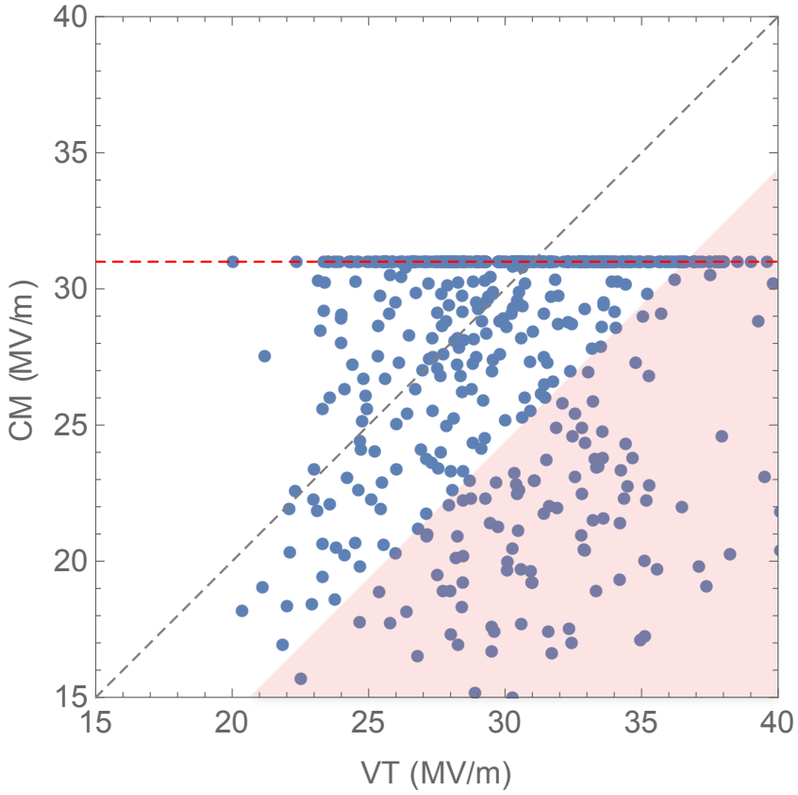
Nicholas Walker ● DESY ● nicholas.walker@desy.de

Module v VT (individual cavities)

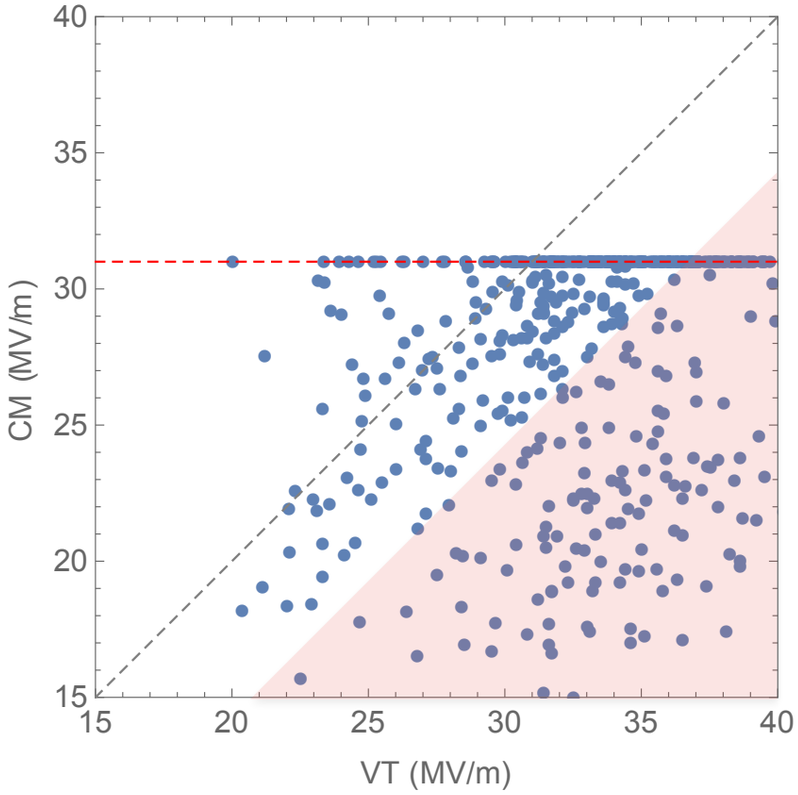
Maximum



Usable



Usable (VT No Q_0)



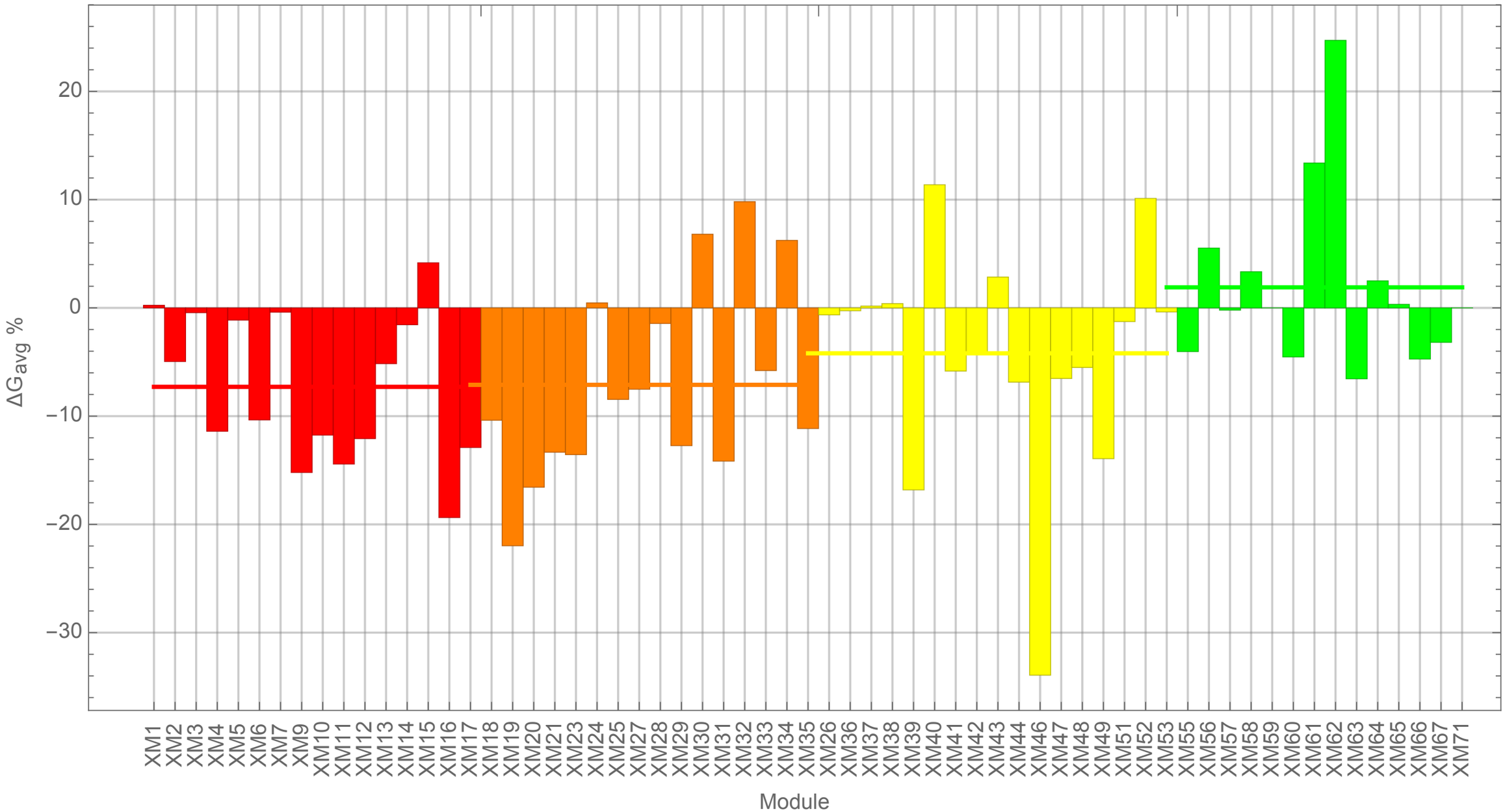
VT estimated error ±1.3 MV/m
Module estimated error ±2.5 MV/m

$\Delta G \sim \pm 2.8$ MV/m ⇒ define degradation as >5.6 MV/m

Nicholas Walker ● DESY ● nicholas.walker@desy.de

VT v Module: Average Usable Gradient

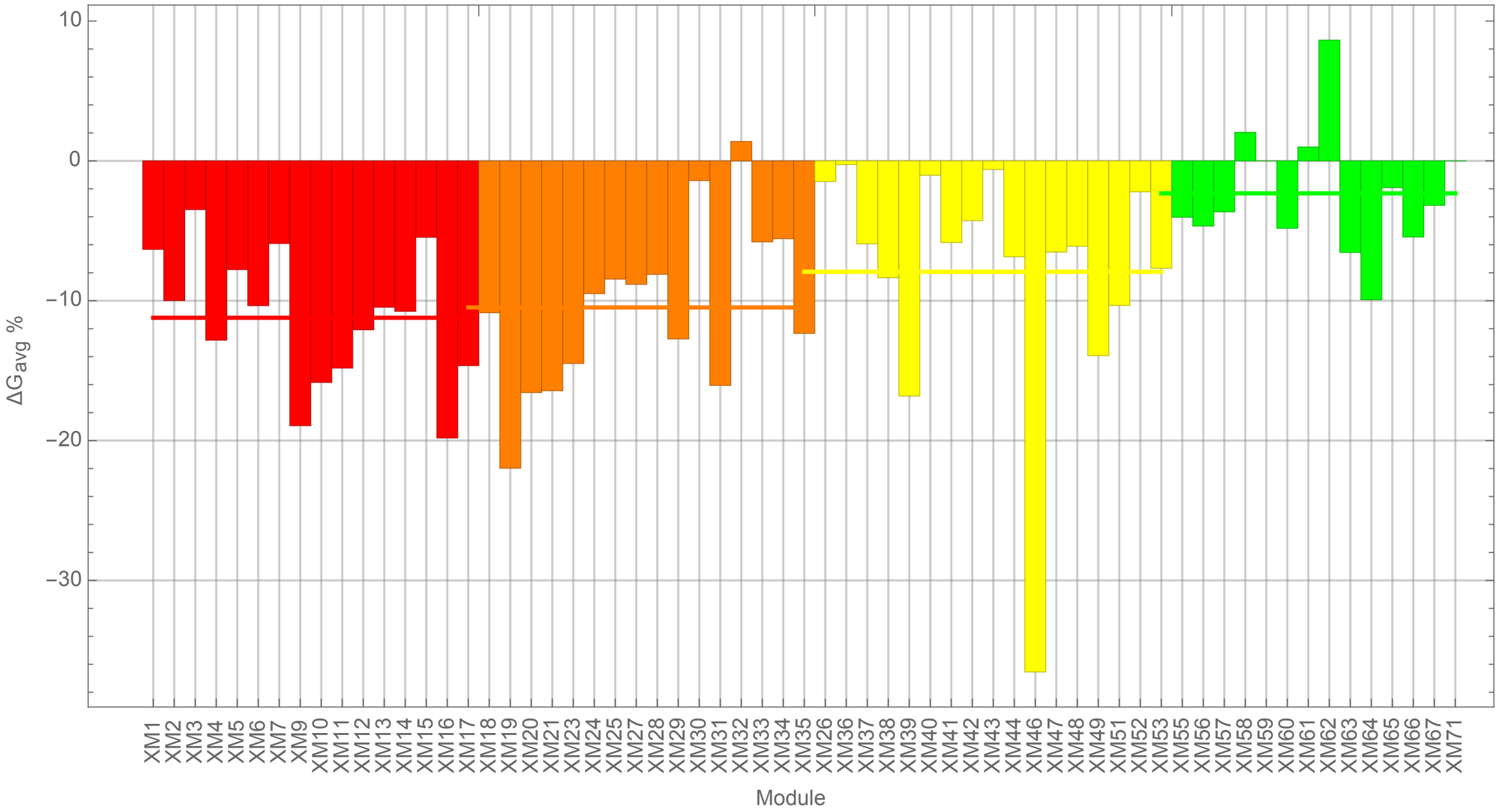
Standard definition of VT usable gradient
VT gradient clipped to 31 MV/m



Nicholas Walker ● DESY ● nicholas.walker@desy.de

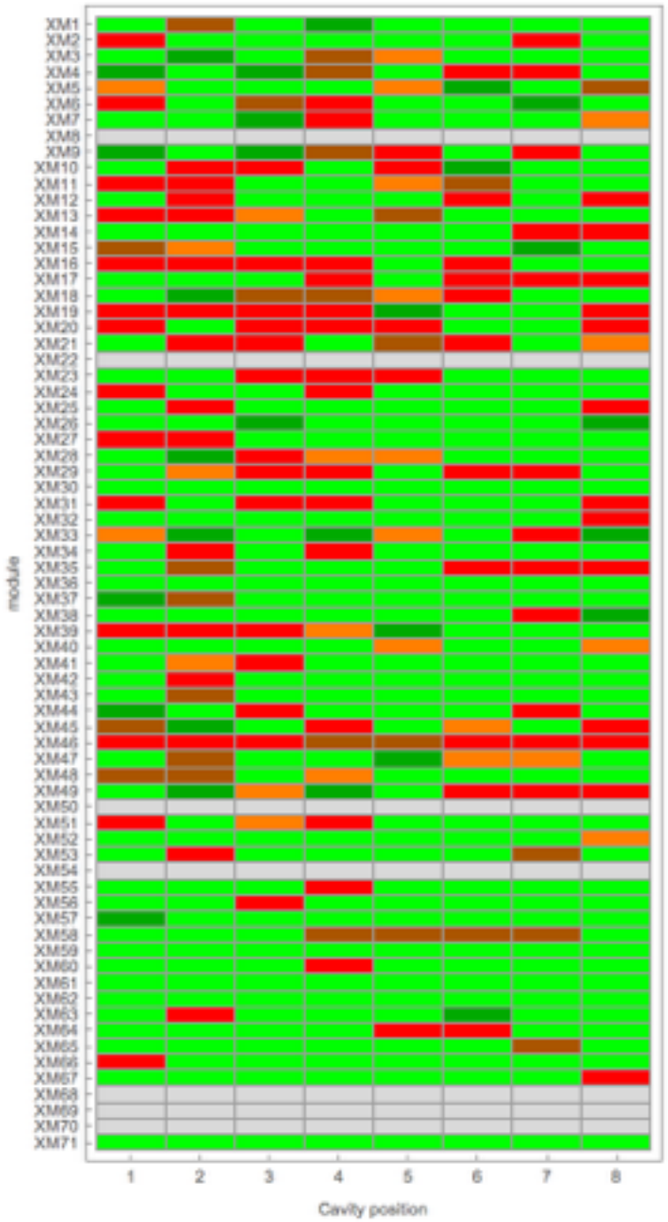
VT v Module: Average Usable Gradient

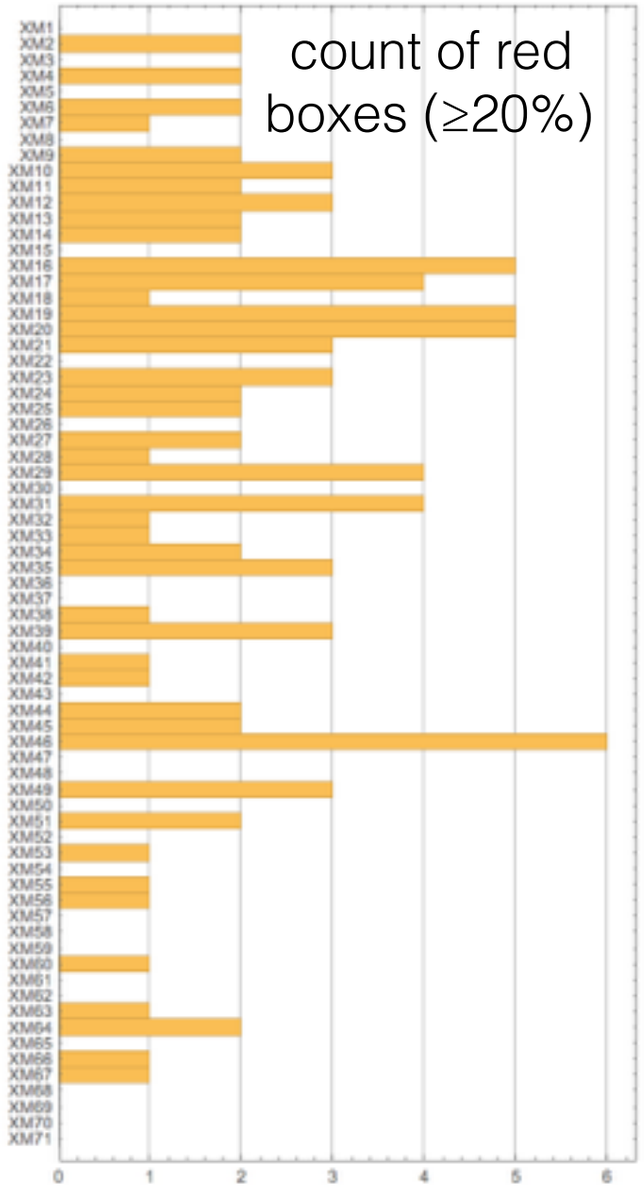
definition of VT usable gradient **ignoring Q_0**
VT gradient clipped to 31 MV/m

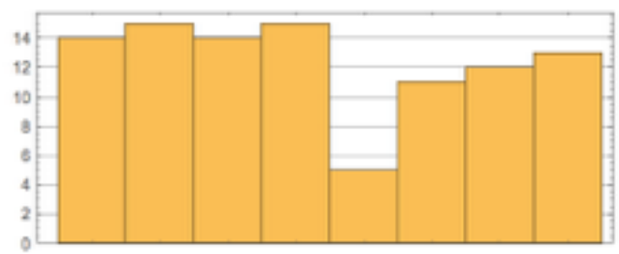


Nicholas Walker ● DESY ● nicholas.walker@desy.de

VT v Module: Degraded cavities







standard definition of VT usable gradient (VT clipped to 31 MV/m)

Nicholas Walker ● DESY ● nicholas.walker@desy.de

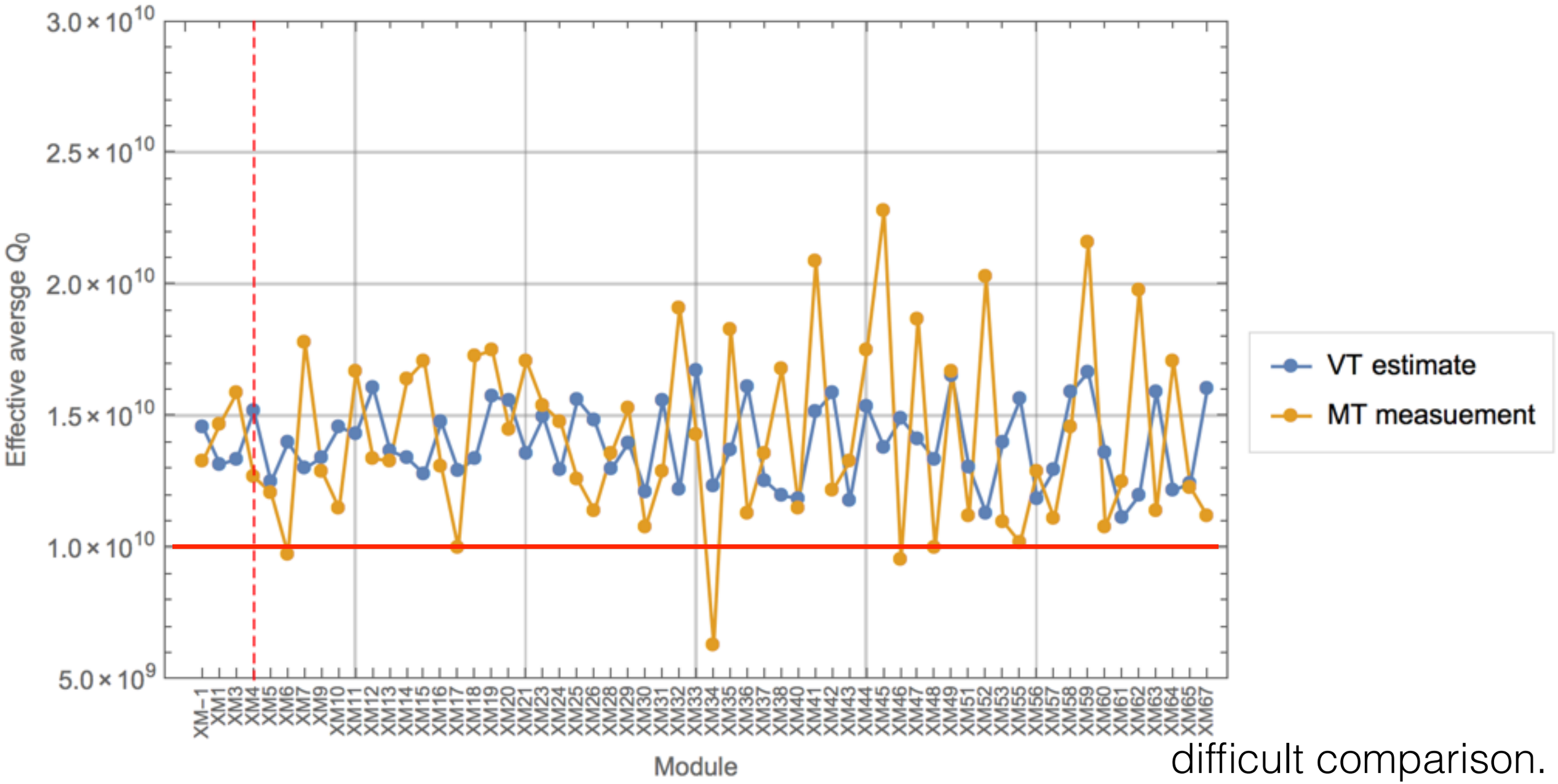
Summary stats

	All Modules			Last 14 Modules		
	Maximum gradient			Maximum gradient		
	VT	MT	relative	VT	MT	relative
	33.8 ±4.0	28.5 ±4.2	-15% ±13%	34.4 ±4.2	29.9 ±2.8	-12% ±10%
VT clipped	30.5 ±1.6	28.5 ±4.2	-6% ±13%	30.5 ±1.6	29.2 ±2.8	-2% ±6%
	Usable gradient			Usable gradient		
	VT	MT	relative	VT	MT	relative
	30.5 ±4.3	27.4 ±4.8	-8% ±19%	30.9 ±5.1	29.3 ±3.7	-3% ±18%
VT clipped	28.9 ±2.6	27.4 ±4.8	-5% ±18%	28.9 ±2.7	29.3 ±3.7	+2% ±15%
	Usable gradient no Q0			Usable gradient no Q0		
	VT	MT	relative	VT	MT	relative
	32.8 ±4.3	27.4 ±4.8	-15% ±17%	33.4 ±4.8	29.3 ±3.7	-11% ±15%
VT clipped	30.0 ±2.2	27.4 ±4.8	-8% ±16%	30.0 ±2.4	29.3 ±3.7	-2% ±13%

Nicholas Walker ● DESY ● nicholas.walker@desy.de

A quick look at Q_0

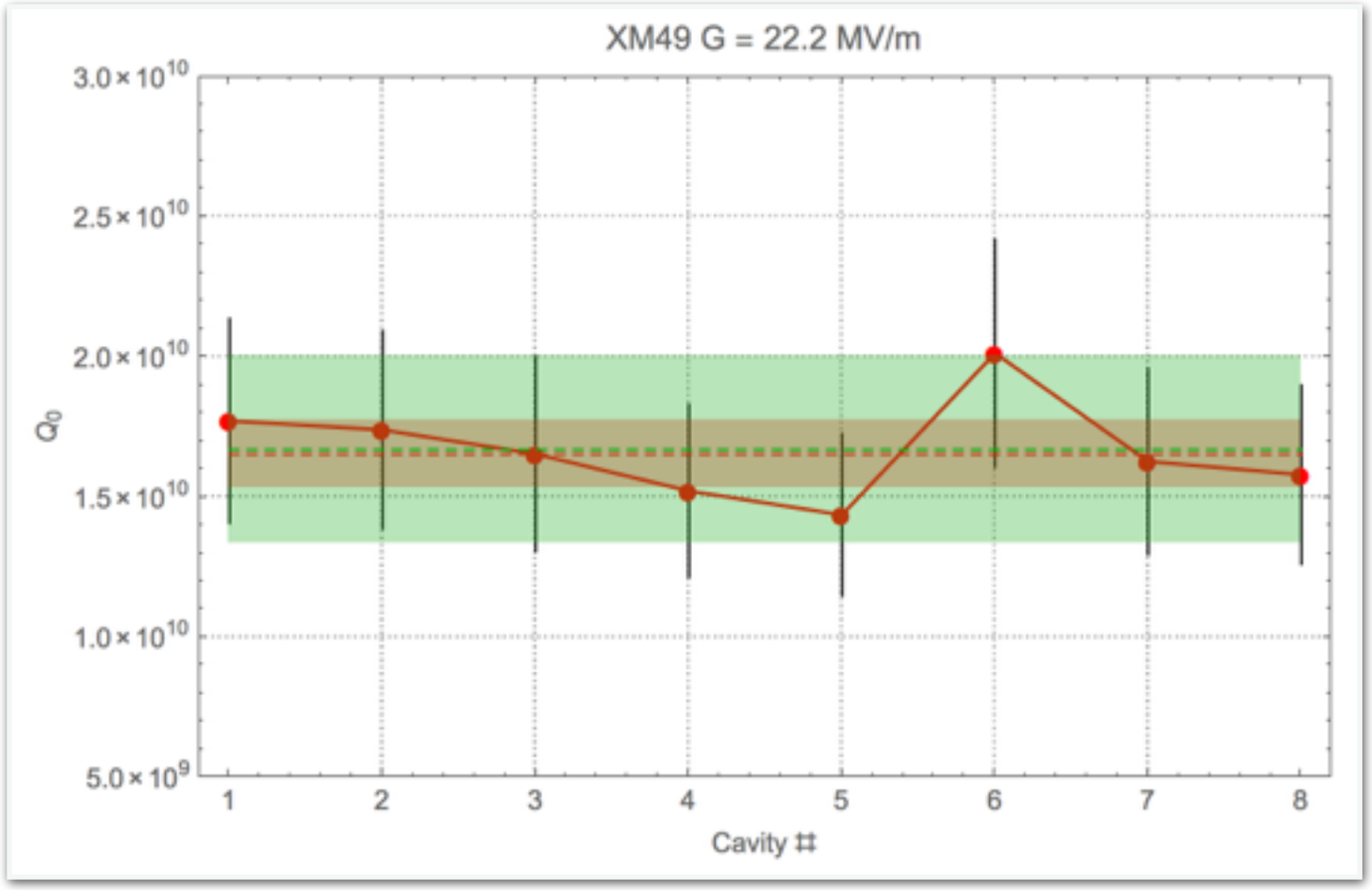
You thought it was hard to compare gradients…



difficult comparison.
Large errors (~20%)

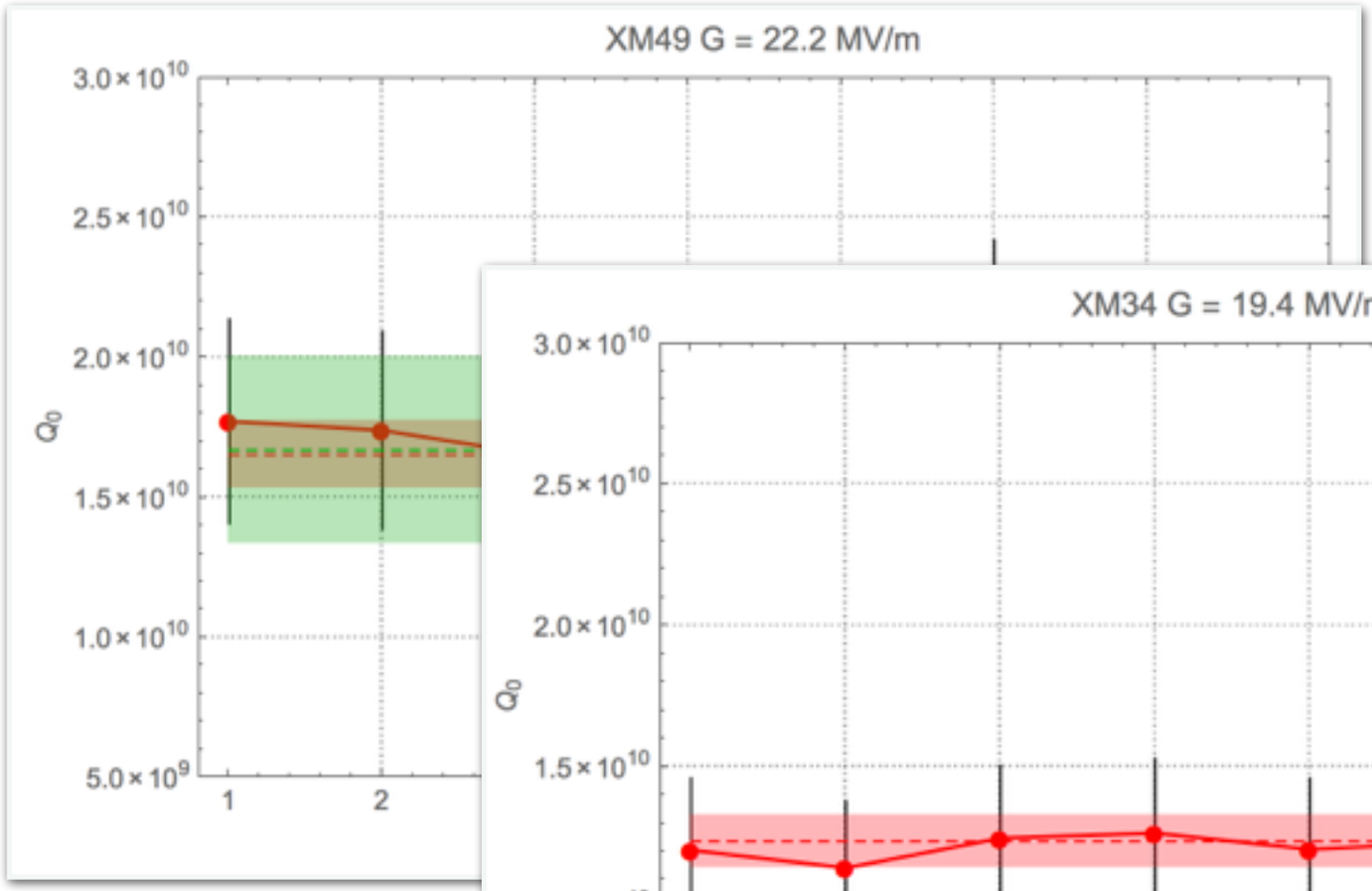
Nicholas Walker ● DESY ● nicholas.walker@desy.de

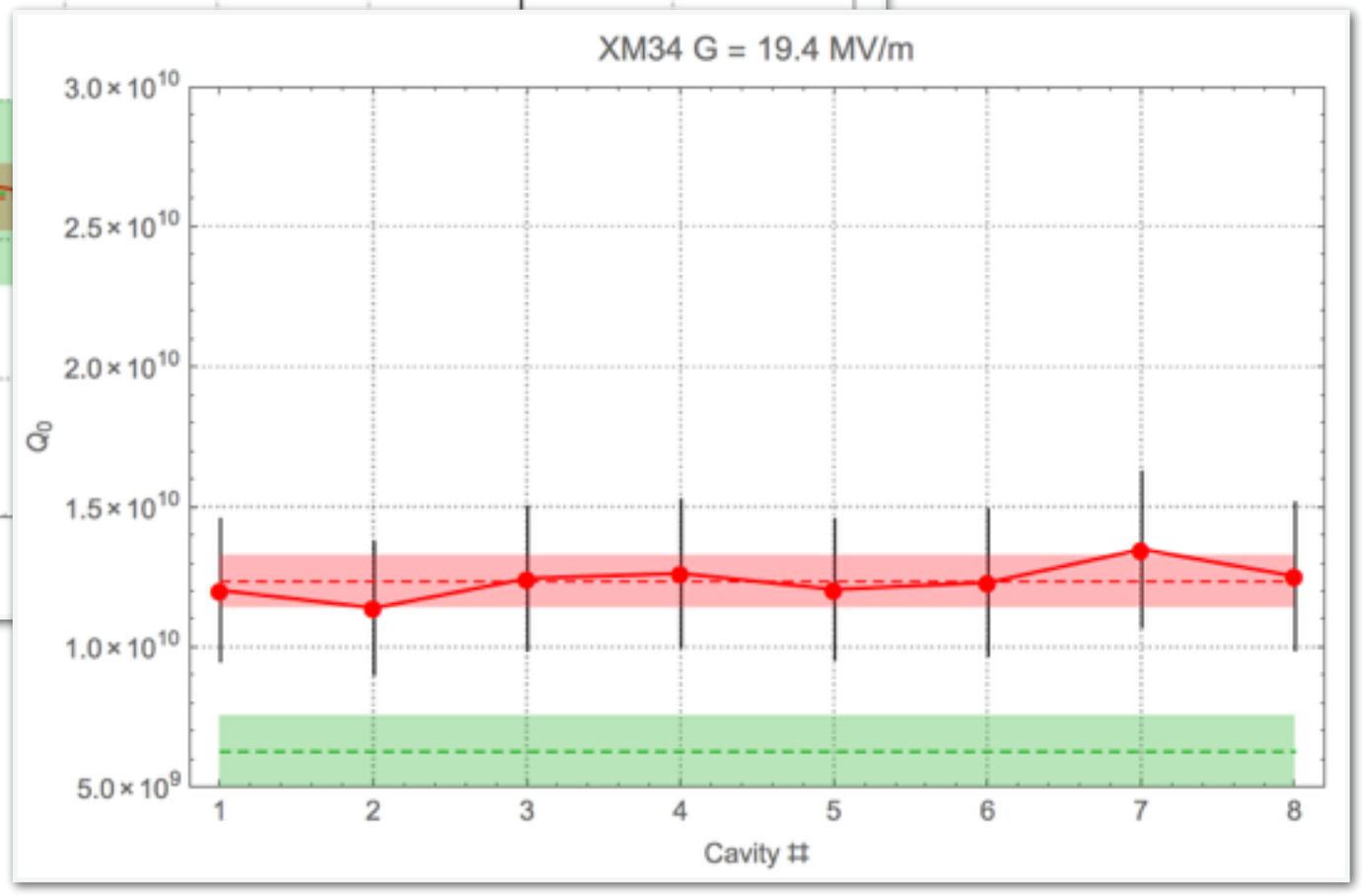
Quick look at Q_0: Examples



Nicholas Walker ● DESY ● nicholas.walker@desy.de

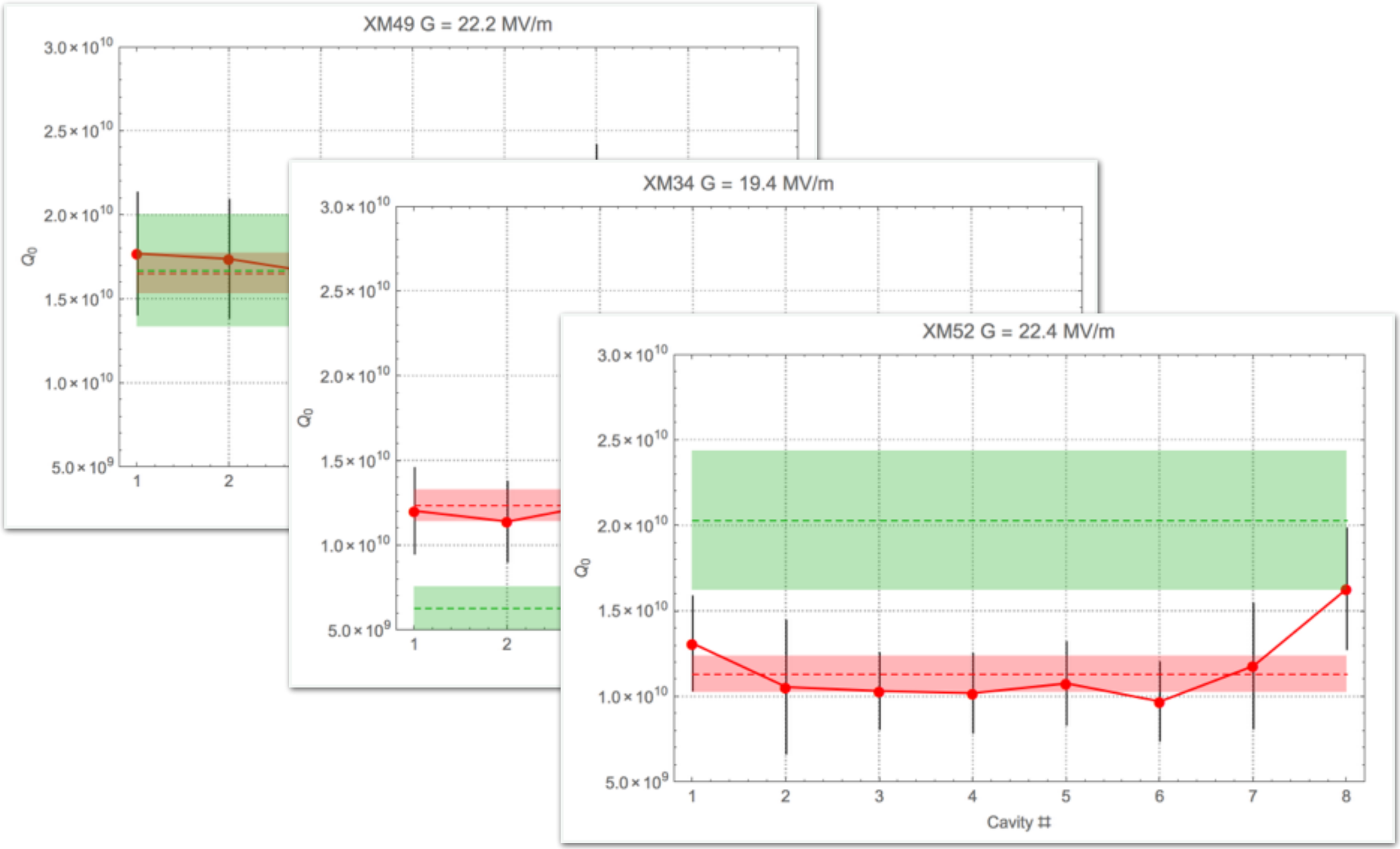
Quick look at Q_0: Examples





Nicholas Walker ● DESY ● nicholas.walker@desy.de

Quick look at Q_0: Examples



Nicholas Walker ● DESY ● nicholas.walker@desy.de

Summary

- XFEL almost there (less than 30 modules to go)
- (Nearly) all modules exceed XFEL requirements
  - G ~27 MV/m (spec. 23.6 MV/m), > Q ≥10^{10}
- Several modules ~30 MV/m
- VT to CM performance (degradation)
  - Difficult to make exact comparison
  - For XFEL production, we can say average degradation is now is essentially zero (+2%)
    - ➡ Spread (±15%) is still an issue for WG distribution and operations
  - Scientifically pedantic degradation: -11% ≤ Δ ≤ -2% (±15%)
- Module Q_0 measurements accuracy poor
  - but still OK for XFEL operations
  - comparisons with predictions from VT difficult

Nicholas Walker ● DESY ● nicholas.walker@desy.de