Results of performance test and error estimation in AMTF

† This work was done by many advices from W.-D. Möller and D. Reschke

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♦ The seminar is done in 20/Jan/2015

♥ The slides are updated in 5/Feb/2015

Abstract

Performance tests for cavities and modules are on-going in AMTF for XFEL. In this seminar, the recent results are presented including the error estimation. Moreover, some topics, Q_{ext} shifting in V.T., performance degradation in module test, and so on, are discussed.

Outline

- Introduction
- Measurement system/method in V.T.
- Q_{ext} shift in V.T.
- Error estimation in V.T.
- Error estimation in module test
- Performance degradation
- Summary

Introduction

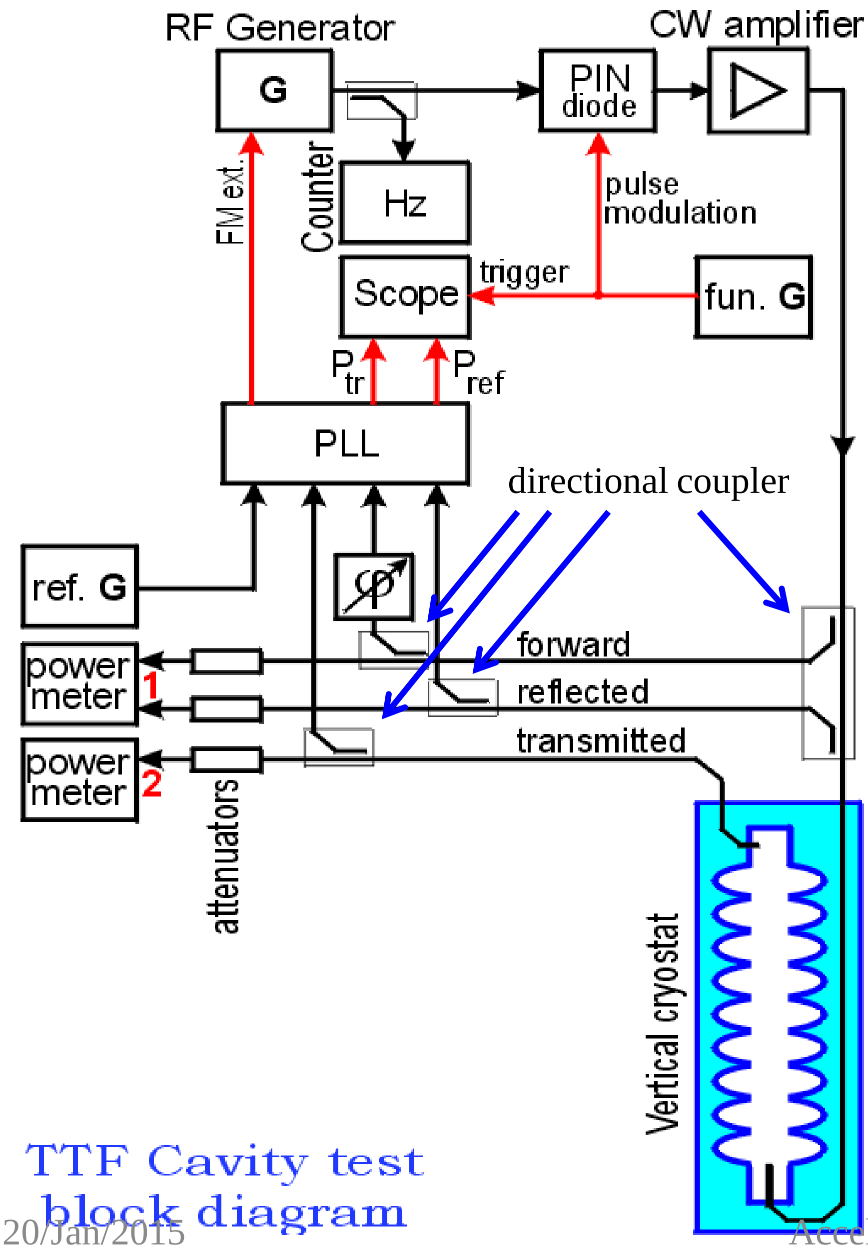
How much is systematic error in performance tests at AMTF?

How about validity in performance tests?

How many cavities had the degradation in CM test?

They are also hot issues for the ILC!

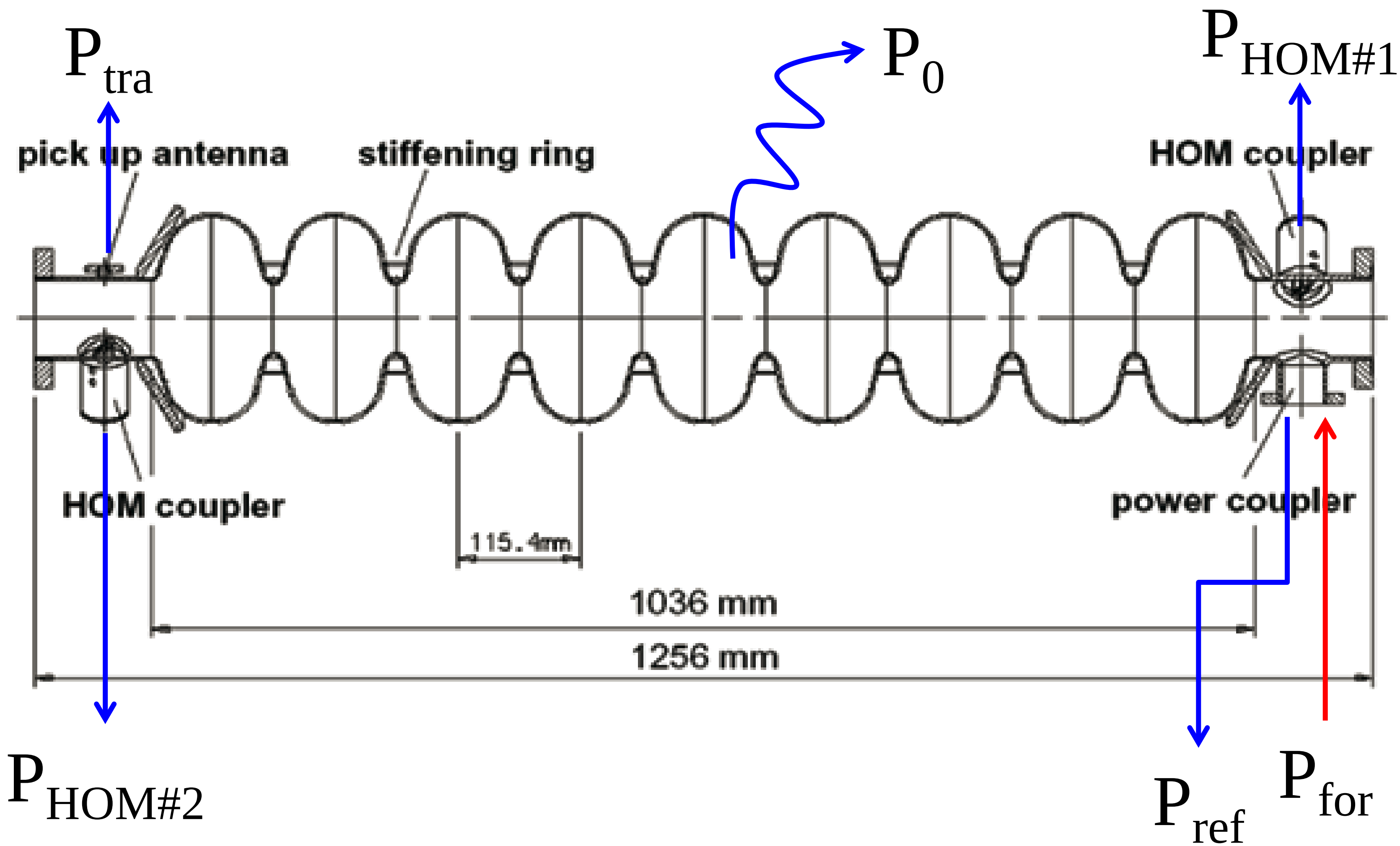
Measurement system in V.T.



TTF Cavity test block diagram

- ✓ Fixed coupler is used (typically, over-coupled)
- ✓ Four cavities per stand
- ✓ Complicated switching circuit is used
- ✓ Radiation measurement at the both ends

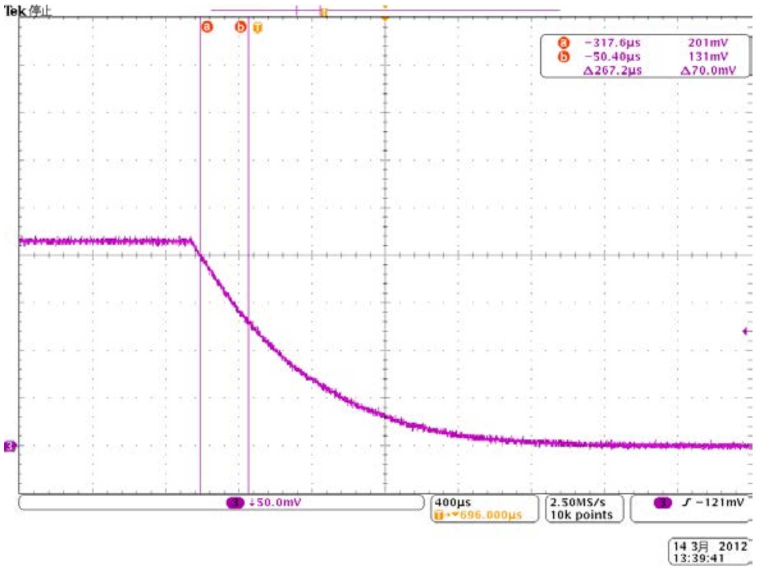
Power conservation law in steady state



$$\boxed{P_{for} = P_0 + P_{ref} + P_{tra} + P_{HOM\#1} + P_{HOM\#2}}$$

Measurement method in V.T.

- First measurement (calibration) point (at lowest gradient)
  - P_0 is estimated from power balance in steady state (always)
  - τ (decay time) is measured from RF switch off
  - Then, every parameter is derived



- After second measurement points
  - Q_{tra} should be constant for every measurement point (assumption)
  - Then, every parameter is derived (τ is not necessary)

Formulas for cavity testing

$$P_{for} = P_0 + P_{tra} + P_{ref} + P_{HOM\#1} + P_{HOM\#2}$$

$$\frac{P_{ref}}{P_{for}} \equiv \Gamma^2$$

$$\beta = \frac{1 \pm |\Gamma|}{1 \mp |\Gamma|}, \beta_{tra} = \frac{Q_0}{Q_{tra}} = \frac{P_{tra}}{P_0}, \beta_{HOM\#1,2} = \frac{Q_0}{Q_{HOM\#1,2}} = \frac{P_{HOM\#1,2}}{P_0}$$

$$Q_L = \omega\tau$$

$$Q_0 = (1+\beta)(1+\beta_{tra}+\beta_{HOM\#1}+\beta_{HOM\#2})Q_L$$

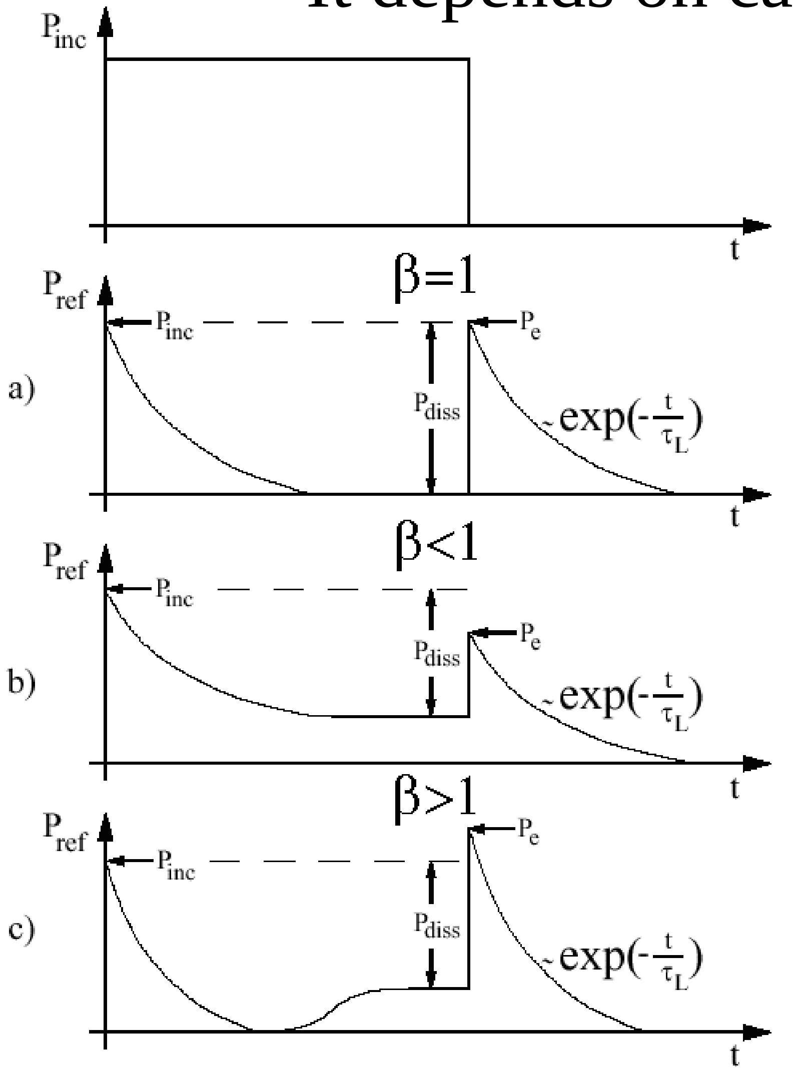
$$Q = \frac{\omega U}{P} \Rightarrow PQ = const.$$

$$Q_{tra} = \frac{P_0 Q_0}{P_{tra}}, Q_{HOM\#1,2} = \frac{P_0 Q_0}{P_{HOM\#1,2}}$$

Validity check by Q_{ext} measurement

P_{ext} is derived from RF switch off

It depends on cavity and coupler geometry

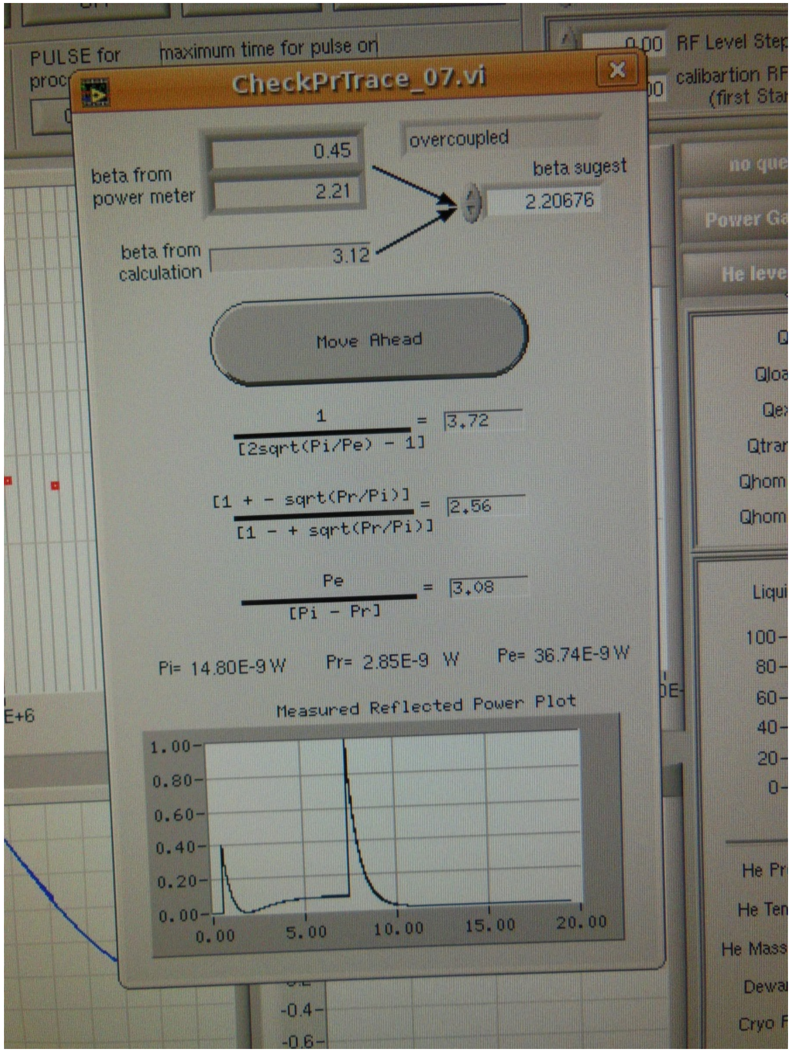


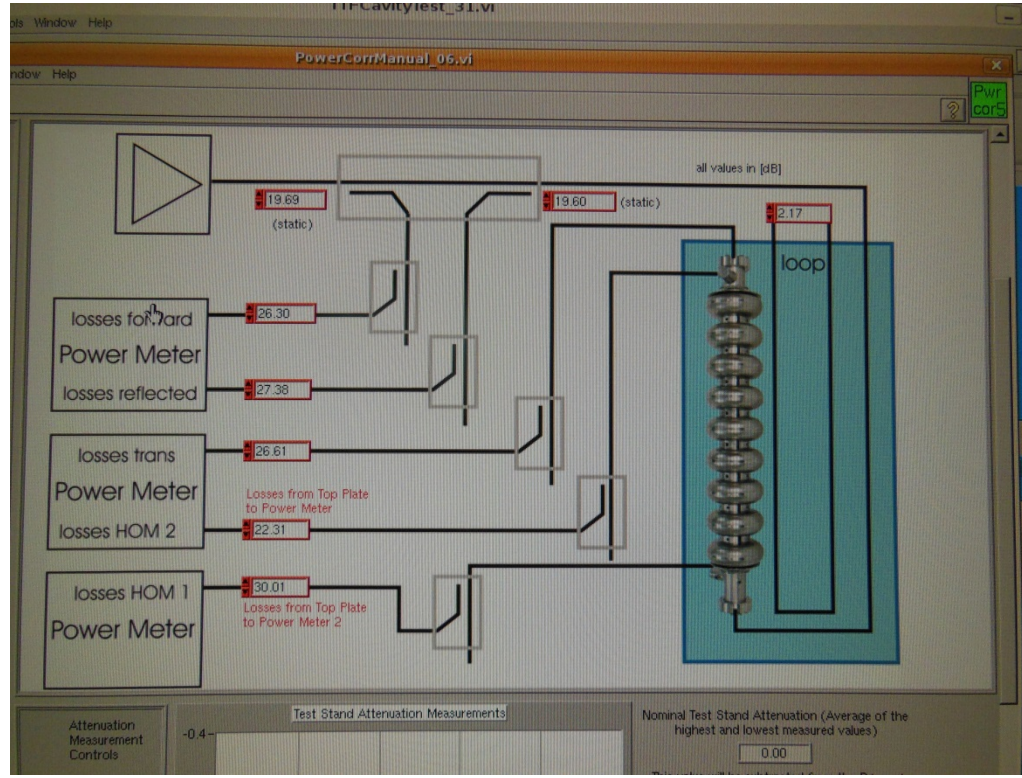
$$P_{ext} = 4P_{for}\left(\frac{\beta}{1+\beta}\right)^2$$

$$Q_{ext} = \frac{P_0 Q_0}{P_{ext}} = \frac{P_{tra} Q_{tra}}{P_{ext}}$$

This is effective only for V.T.
Because, β is not so high.

LabVIEW program in V.T.





- ✓ β is calculated in four ways
  - ✓ β from power meter is stored
- ✓ Then, Q_{ext} is calculated

Used Data for this analysis

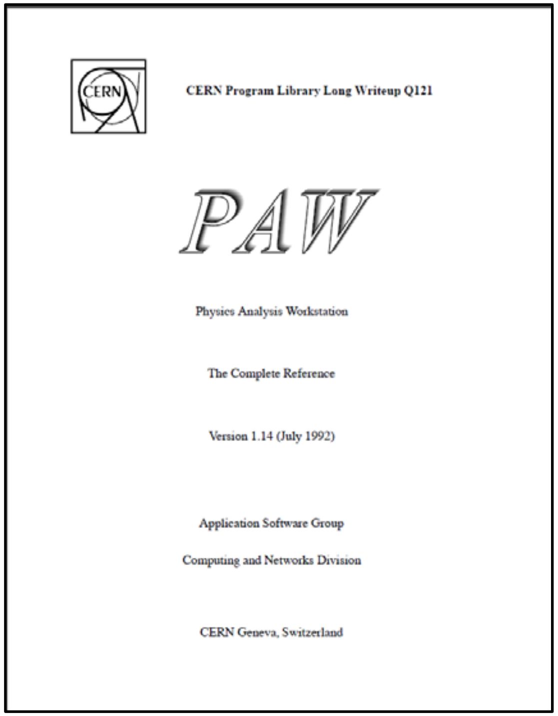
- ttfvert1.desy.de (server)
- /home/ttf/ttfcavity.db/cavity.CAV00*/test.*/
  - /data/[date]qe*.txt (raw data)
  - expCAV00*+01lg.txt (experiment log file)
  - Files.txt (brief report, limiting cause, radiation, etc.)
  - pwr_corr.cfg (cable calibration)
  - RF_state.txt (time stamp for RF switch ON/Off)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Cavity	Time	Eacc	Q0	Q load	Q ext	Q trans	Q homtop	Q hombot	P trans	P ref	P inc	P diss	P homtop	P hombot	beta	Rep Rate	Duty cyc.	f0	Temp	Tau	CP Volt	X-Ray
2	CAV00177	06/10/14;	2.41E+06	2.62E+10	6.16E+09	8.36E+09	2.39E+11	9.87E+12	2.54E+12	2.53E-02	7.42E-02	3.33E-01	2.31E-01	6.12E-04	2.38E-03	2.787012	1.00E+00	50	1.30E+09	1.99E+00	7.54E-01	0.00E+00	0
3	CAV00177	06/10/14;	4.38E+06	2.81E+10	6.25E+09	8.36E+09	2.39E+11	1.02E+13	2.54E+12	8.35E-02	2.63E-01	1.06E+00	7.09E-01	1.96E-03	7.85E-03	2.97358	1.00E+00	50	1.30E+09	1.99E+00	7.33E-01	0.00E+00	0
4	CAV00177	06/10/14;	7.77E+06	2.79E+10	6.25E+09	8.37E+09	2.39E+11	1.03E+13	2.54E+12	2.63E-01	8.19E-01	3.37E+00	2.25E+00	6.12E-03	2.47E-02	2.948525	1.00E+00	50	1.30E+09	1.99E+00	7.71E-01	0.00E+00	0
5	CAV00177	06/10/14;	1.08E+07	2.59E+10	6.15E+09	8.38E+09	2.39E+11	1.03E+13	2.54E+12	5.05E-01	1.46E+00	6.67E+00	4.64E+00	1.17E-02	4.73E-02	2.760792	1.00E+00	50	1.30E+09	1.99E+00	7.75E-01	0.00E+00	0
6	CAV00177	06/10/14;	1.33E+07	2.40E+10	6.02E+09	8.36E+09	2.39E+11	1.03E+13	2.54E+12	7.67E-01	2.05E+00	1.05E+01	7.63E+00	1.78E-02	7.20E-02	2.577763	1.00E+00	50	1.30E+09	1.99E+00	7.46E-01	0.00E+00	0
7	CAV00177	06/10/14;	1.62E+07	2.18E+10	5.87E+09	8.35E+09	2.39E+11	1.03E+13	2.54E+12	1.15E+00	2.75E+00	1.66E+01	1.25E+01	2.67E-02	1.08E-01	2.372858	1.00E+00	50	1.30E+09	1.99E+00	7.06E-01	0.00E+00	0
8	CAV00177	06/10/14;	1.93E+07	2.00E+10	5.69E+09	8.26E+09	2.39E+11	1.04E+13	2.54E+12	1.62E+00	3.53E+00	2.47E+01	1.94E+01	3.72E-02	1.53E-01	2.214597	1.00E+00	50	1.30E+09	1.99E+00	6.75E-01	0.00E+00	0
9	CAV00177	06/10/14;	2.25E+07	1.90E+10	5.53E+09	8.09E+09	2.39E+11	1.04E+13	2.54E+12	2.21E+00	4.69E+00	3.49E+01	2.77E+01	5.05E-02	2.08E-01	2.158184	1.00E+00	50	1.30E+09	1.99E+00	6.56E-01	0.00E+00	0
10	CAV00177	06/10/14;	2.51E+07	1.81E+10	5.37E+09	7.91E+09	2.39E+11	1.04E+13	2.54E+12	2.75E+00	5.74E+00	4.50E+01	3.62E+01	6.31E-02	2.58E-01	2.110832	1.00E+00	50	1.30E+09	1.99E+00	6.46E-01	0.00E+00	0
11	CAV00177	06/10/14;	2.81E+07	1.73E+10	5.18E+09	7.67E+09	2.39E+11	1.03E+13	2.53E+12	3.43E+00	7.21E+00	5.85E+01	4.74E+01	7.93E-02	3.24E-01	2.082749	1.00E+00	50	1.30E+09	1.99E+00	6.42E-01	0.00E+00	0
12	CAV00177	06/10/14;	3.11E+07	1.63E+10	5.00E+09	7.46E+09	2.39E+11	1.03E+13	2.52E+12	4.21E+00	8.66E+00	7.50E+01	6.16E+01	9.78E-02	3.98E-01	2.029428	1.00E+00	50	1.30E+09	1.99E+00	6.49E-01	0.00E+00	0
13	CAV00177	06/10/14;	3.43E+07	1.52E+10	4.64E+09	6.89E+09	2.39E+11	1.02E+13	2.50E+12	5.12E+00	1.17E+01	9.78E+01	8.04E+01	1.20E-01	4.88E-01	2.058202	1.00E+00	50	1.30E+09	1.99E+00	6.44E-01	0.00E+00	0
14	CAV00177	06/10/14;	3.76E+07	1.40E+10	4.37E+09	6.55E+09	2.39E+11	1.02E+13	2.51E+12	6.16E+00	1.42E+01	1.26E+02	1.05E+02	1.44E-01	5.87E-01	2.012908	1.00E+00	50	1.30E+09	1.99E+00	6.37E-01	0.00E+00	0
15	CAV00177	06/10/14;	4.09E+07	1.27E+10	4.09E+09	6.21E+09	2.39E+11	1.02E+13	2.50E+12	7.29E+00	1.62E+01	1.62E+02	1.37E+02	1.70E-01	6.97E-01	1.925663	1.00E+00	50	1.30E+09	1.99E+00	6.32E-01	0.00E+00	0
16	CAV00177	06/10/14;	4.40E+07	1.13E+10	3.77E+09	5.83E+09	2.39E+11	1.03E+13	2.51E+12	8.46E+00	1.79E+01	2.07E+02	1.79E+02	1.96E-01	8.05E-01	1.832825	1.00E+00	50	1.30E+09	1.99E+00	6.18E-01	0.00E+00	0.001

Analysis tools for this work

- PAW (CERN library)
  - very useful tool for complicated analysis

- Shell (Linux)
  - Text data production used in PAW
    (original files should be modified)



CERN Program Library Long Writeup Q121

PAW

Physics Analysis Workstation

The Complete Reference

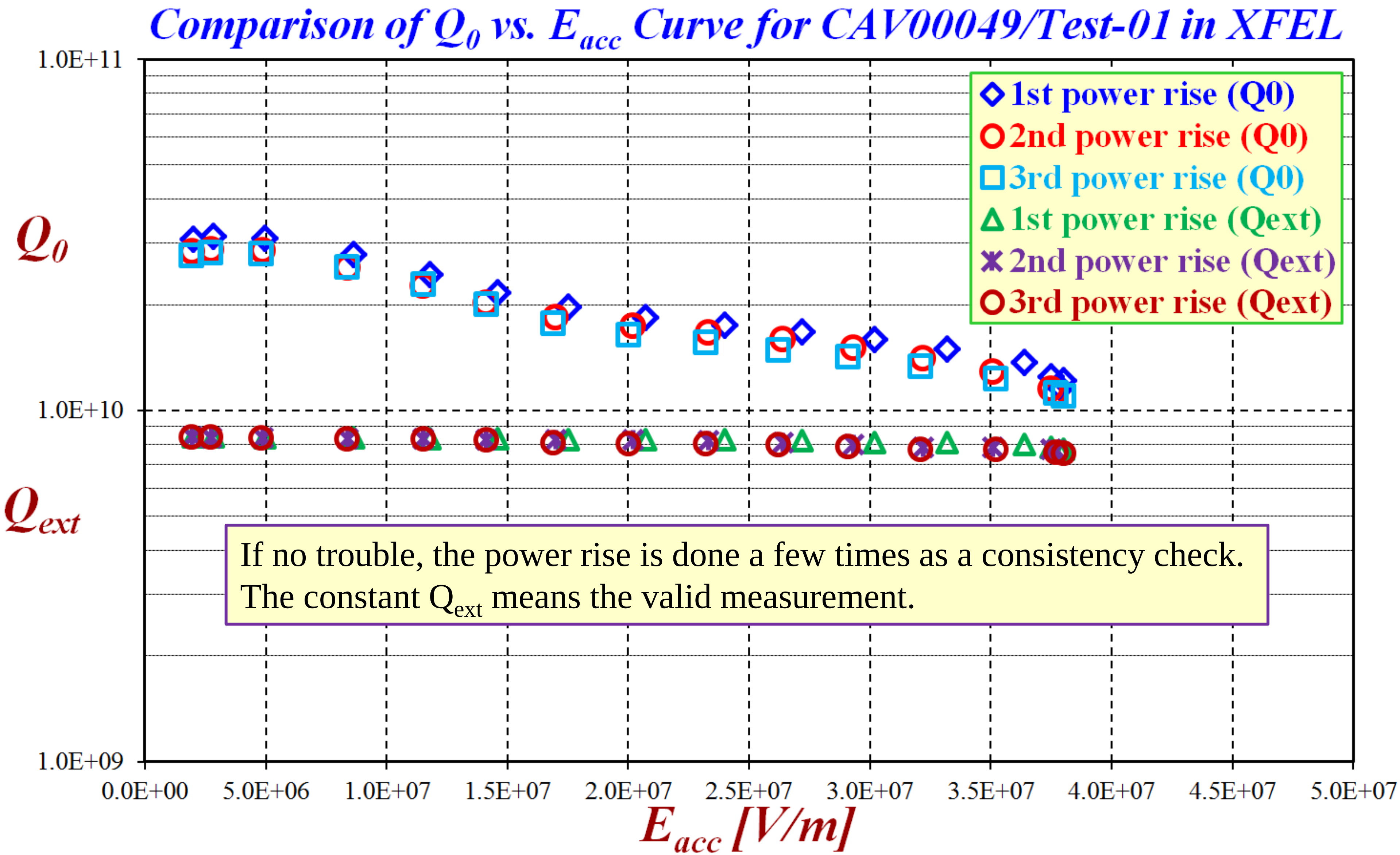
Version 1.14 (July 1992)

Application Software Group

Computing and Networks Division

CERN Geneva, Switzerland

Typical example in V.T. result



If no trouble, the power rise is done a few times as a consistency check.
The constant Q_{ext} means the valid measurement.

Items for error estimation

- Cable calibration parameters
  - The distribution should be estimated
- Q_{ext} distribution for each V.T.
  - Typically, when a cavity is in the transient state or β approaches one, something happens

Error estimation in cable calibration

Error estimation in cable calibration

Content of “pwr_corr.cfg”

pwr_corr.cfg

```
[global]
S21_for=-42.06
S21_ref=-43.47
S21_trans=-46.27
S21_hom1=-36.22
S21_hom2=-36.43
```

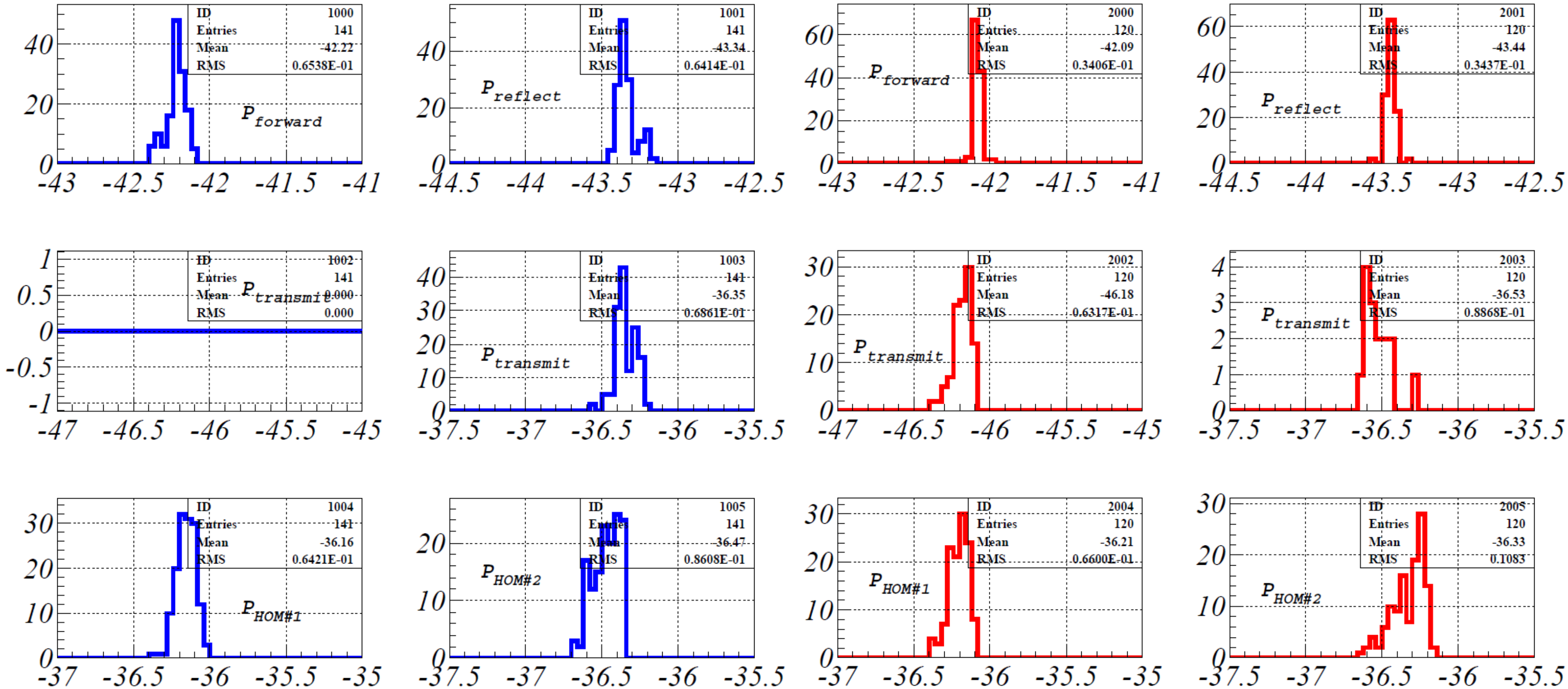
XATC1

They are separated into XATC1 or XATC2, due to the different cables.

XATC2

After that, every data is accumulated as histogram.
XATC1 has 141 events, and XATC2 has 120 events.

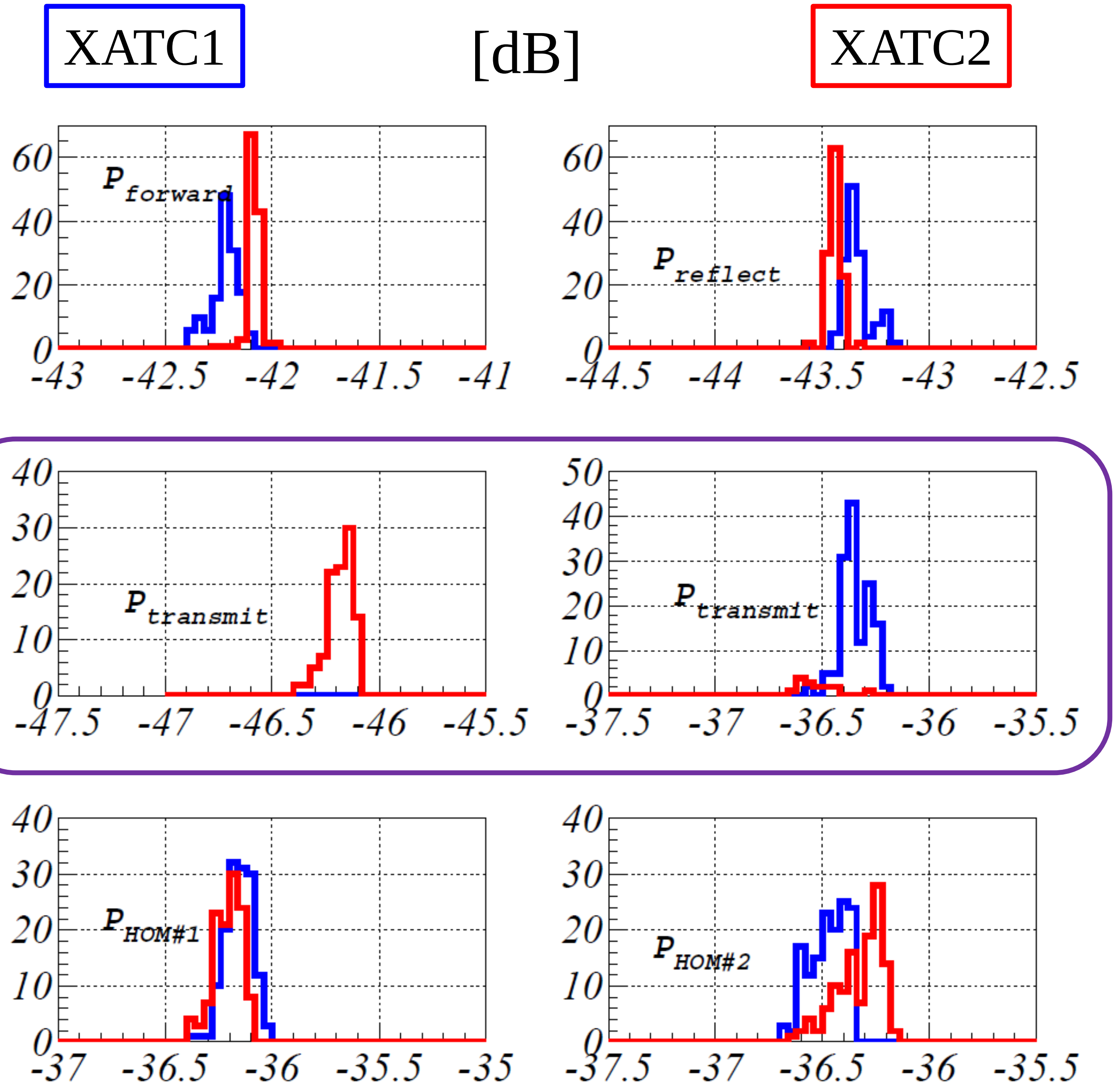
XATC1 [dB] XATC2



$P_{forward}$: 0.07 dB, $P_{reflect}$: 0.06 dB
$P_{transmit1}$: 0.0 dB, $P_{transmit2}$: 0.07 dB
P_{HOM1}: 0.06 dB, P_{HOM2}: 0.09 dB

$P_{forward}$: 0.03 dB, $P_{reflect}$: 0.03 dB
$P_{transmit1}$: 0.06 dB, $P_{transmit2}$: 0.09 dB
P_{HOM1}: 0.07 dB, **P_{HOM2}: 0.11 dB**

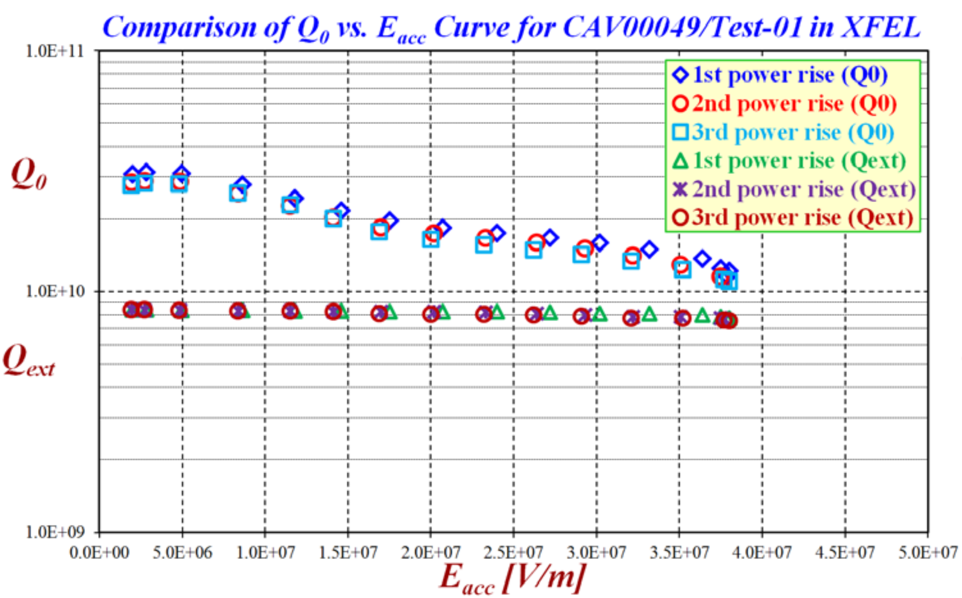
The max. RMS is 0.1 dB, this means systematic error of **±2.5%** in power measurement.


XATC1
[dB]
XATC2
P forward
P reflect
P transmit
P transmit
P HOM#1
P HOM#2
-43 -42.5 -42 -41.5 -41
-44.5 -44 -43.5 -43 -42.5
-47.5 -47 -46.5 -46 -45.5
-37.5 -37 -36.5 -36 -35.5
-37 -36.5 -36 -35.5 -35
-37.5 -37 -36.5 -36 -35.5

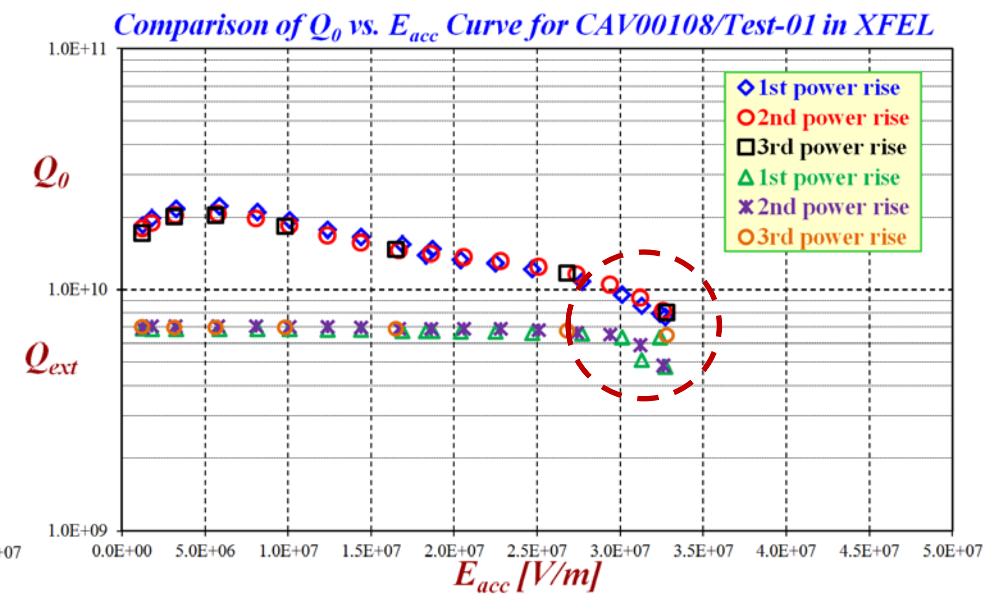
Error estimation in Q_{ext} distribution

Examples of Good / No Good Q_{ext}

Good example (CAV00049, Test-01)



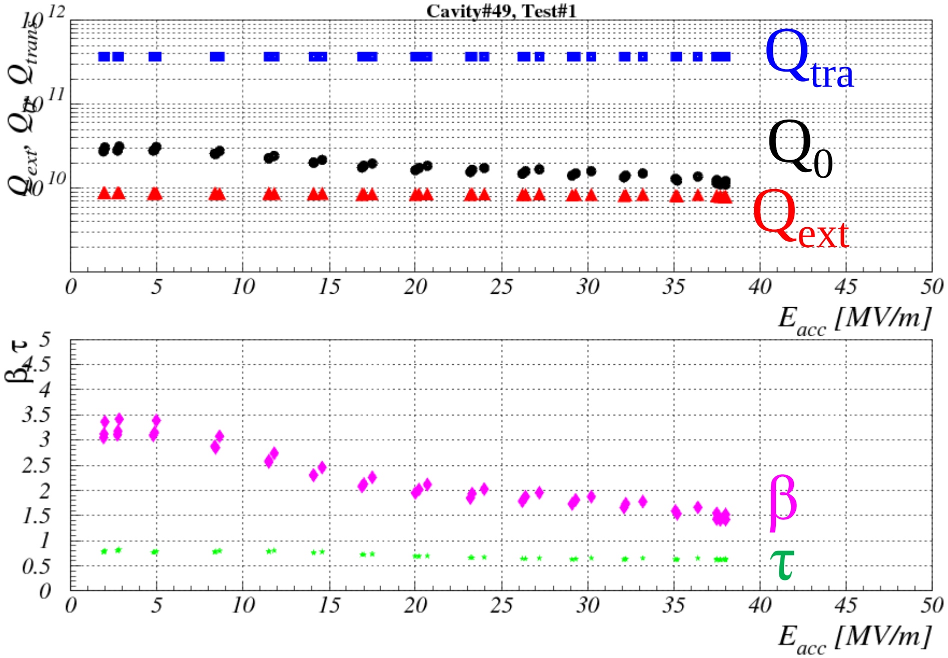
No good example (CAV00108, Test-01)



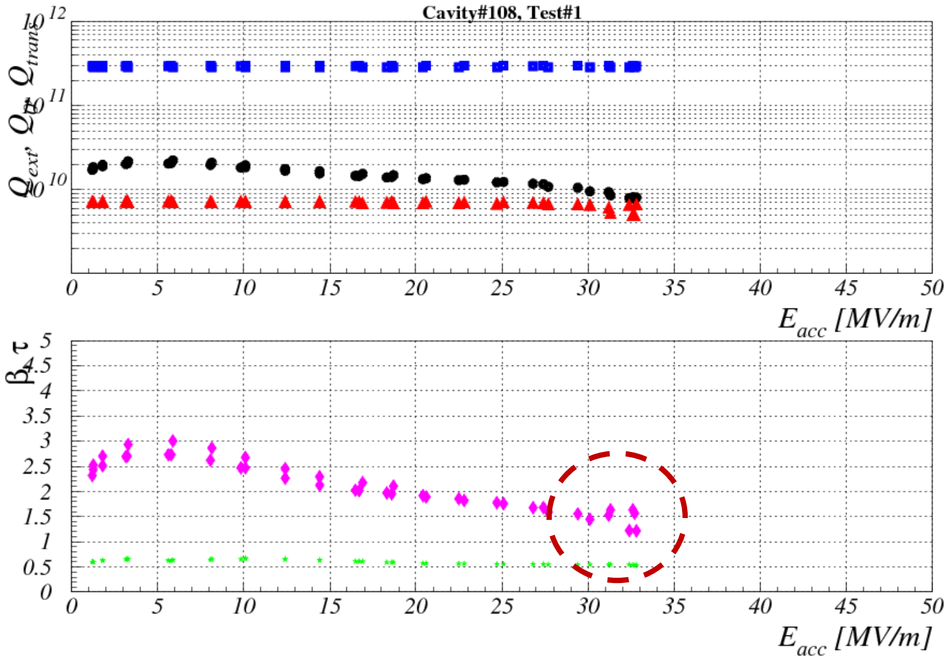
Almost all V.T.s have constant Q_{ext}.
But, sometimes, it has No good measurement.
Then, we can evaluate the validity for Q_{ext}.

Examples of Good / No Good Q_{ext}

Good example (CAV00049, Test-01)



No good example (CAV00108, Test-01)

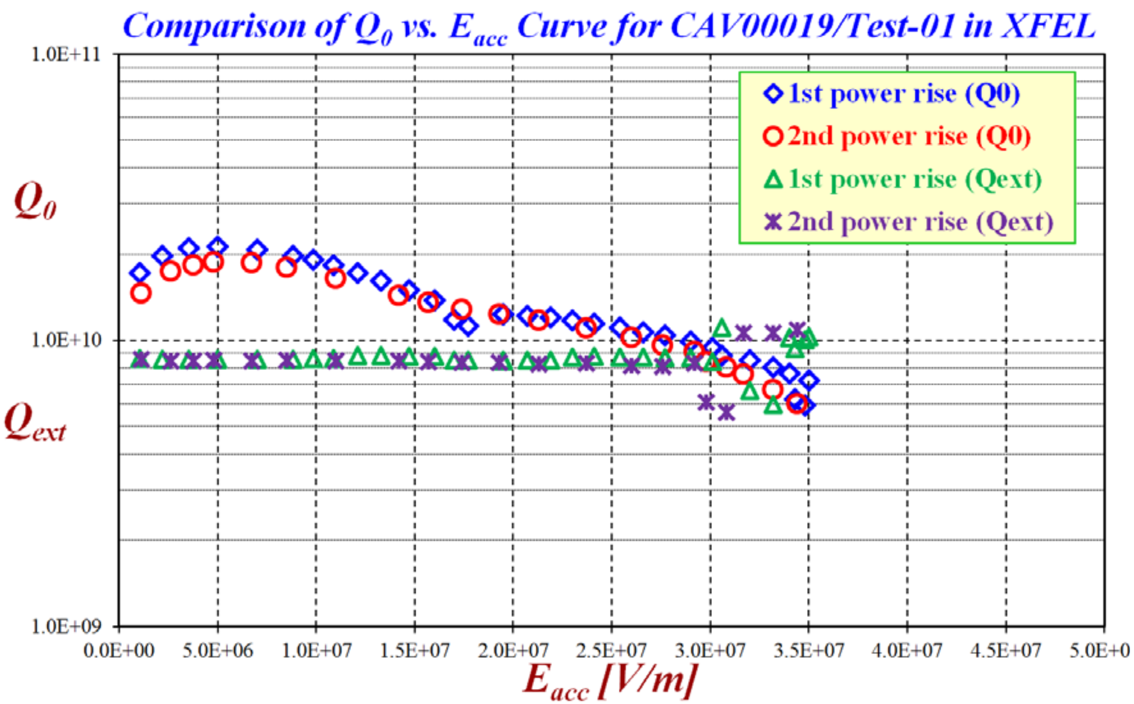


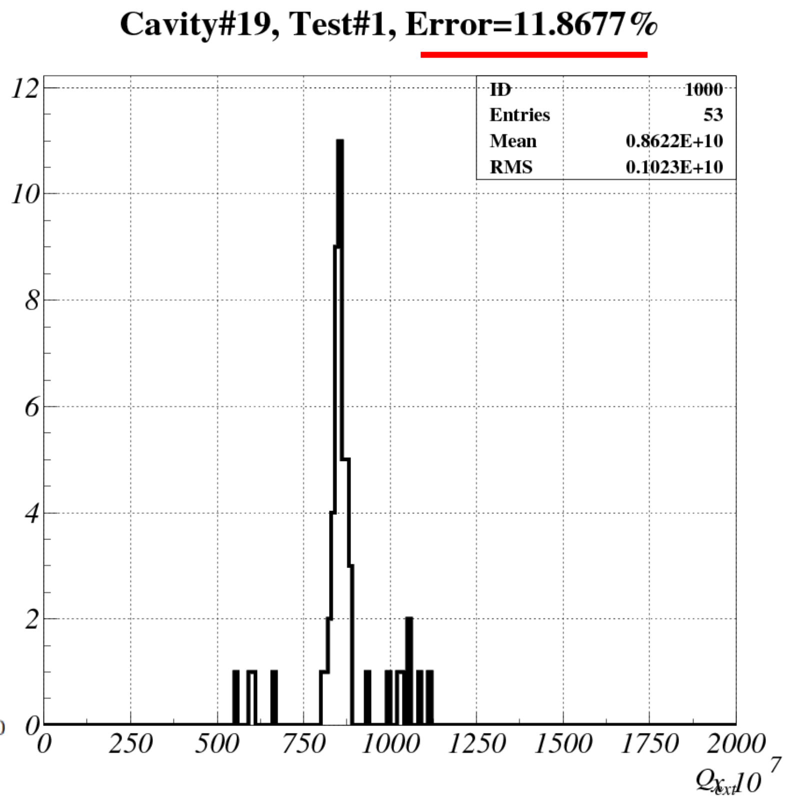
About No Good Q_{ext}

- Q_{ext} shift at β~1 (Q_{ext}~Q_0) → Pattern 1
- Q_{ext} shift by sudden β jump → Pattern 2

Q_{ext} distribution in CAV00019/Test01

Pattern 1

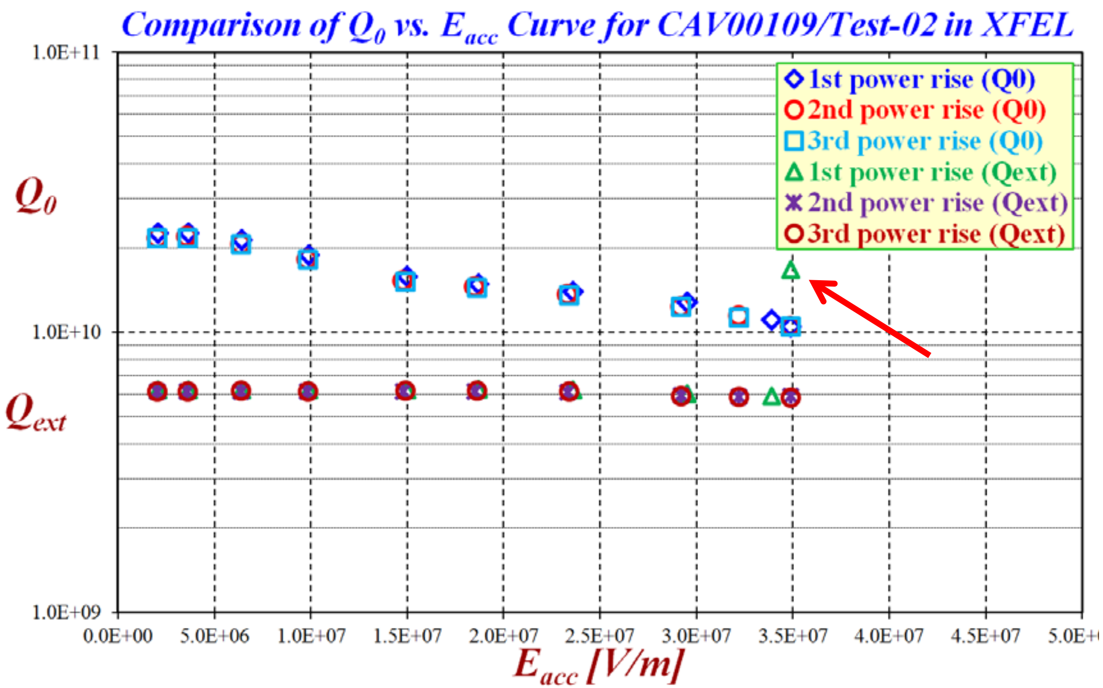


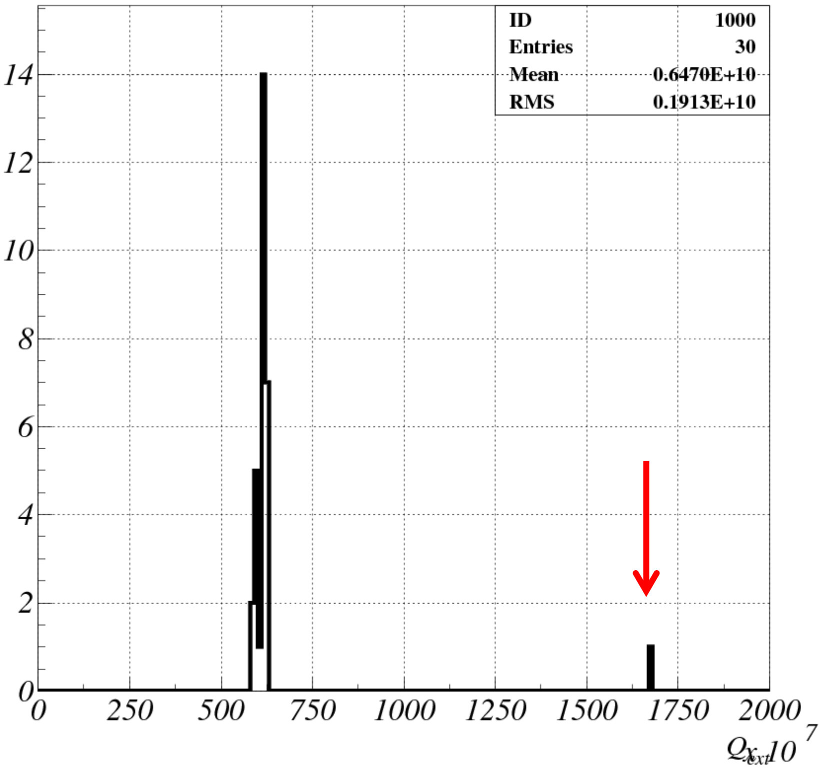


Error = RMS / Mean * 100 = %

Q_{ext} distribution in CAV00109/Test02

Pattern 2



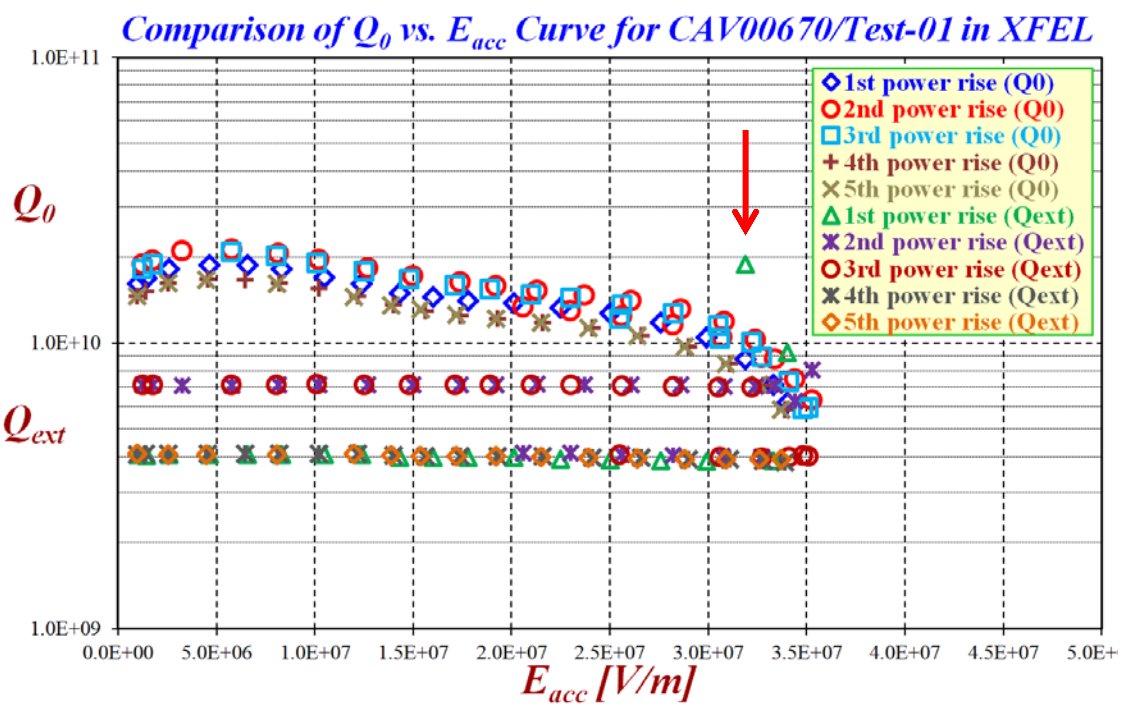


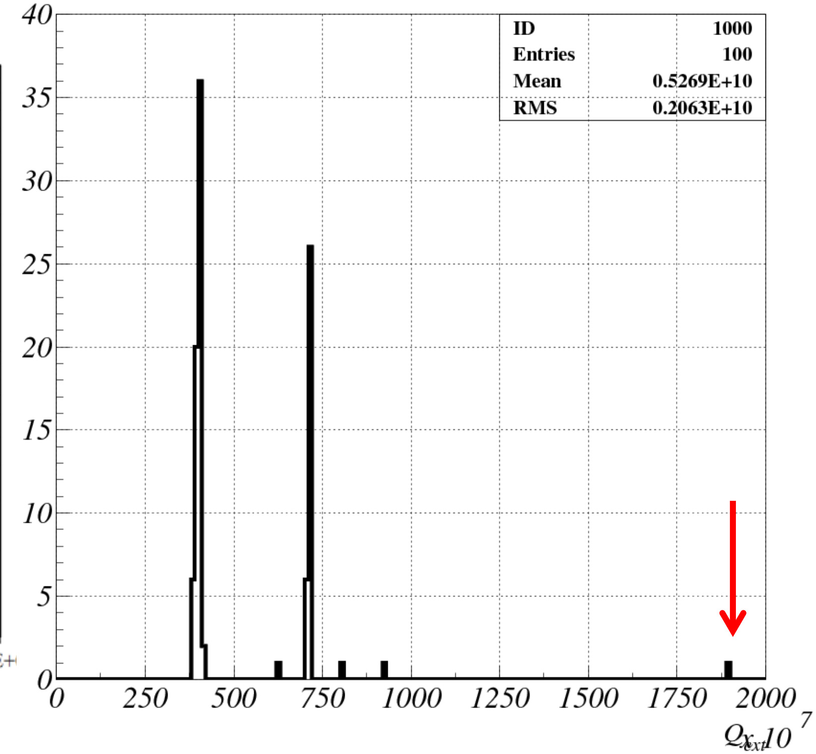
No reason is written down in the experiment log.

Why did Q_{ext} jump at only last point in the first power rise?

Q_{ext} distribution in CAV00670/Test01

Pattern 2

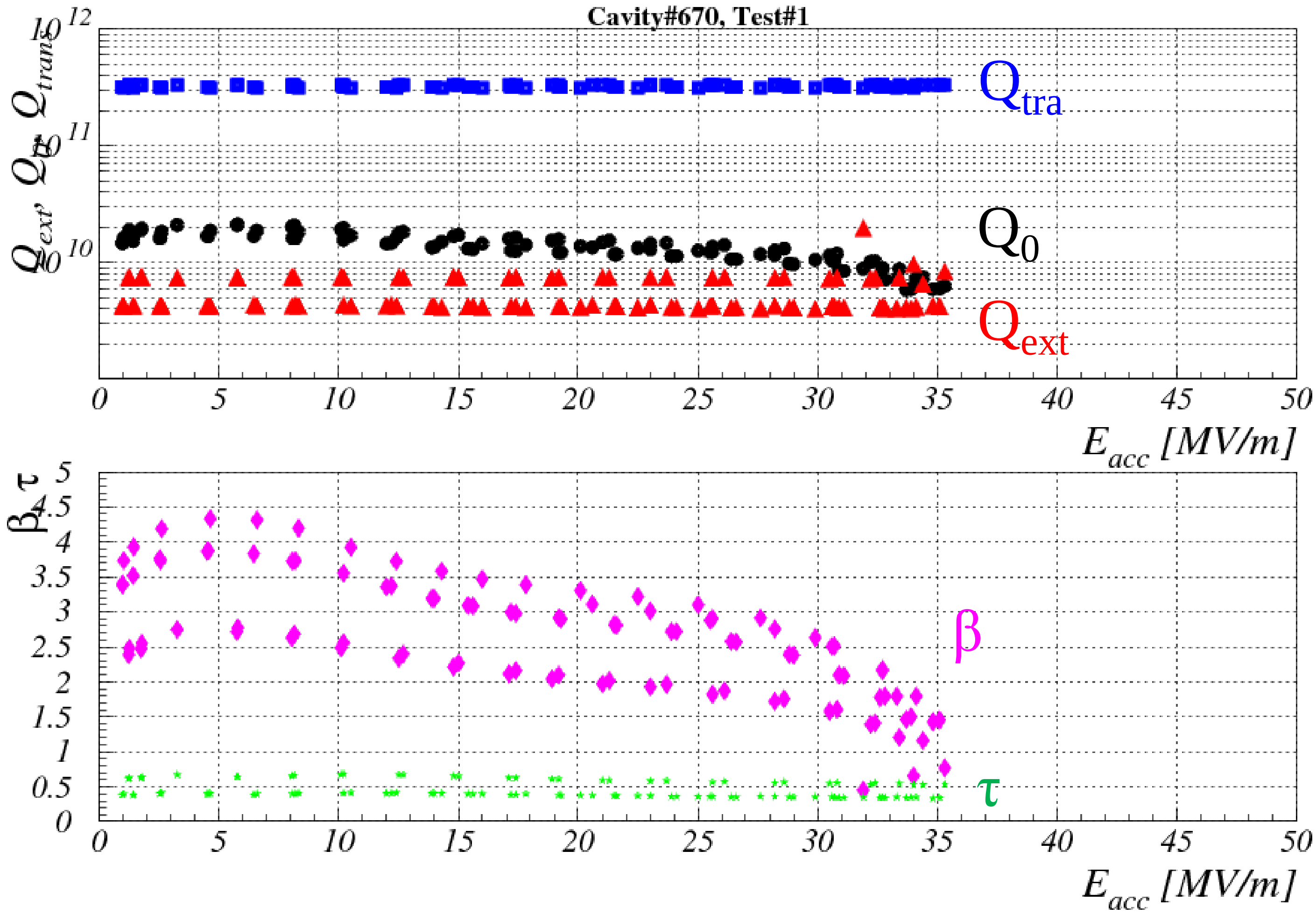




There is no reason for this phenomenon in the experiment log!

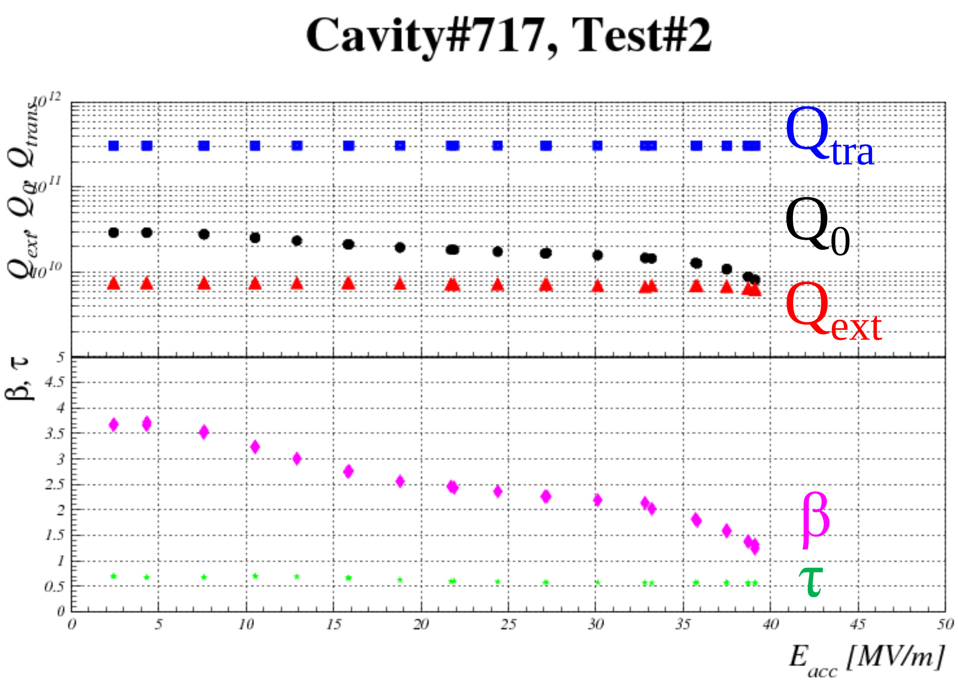
Examples of Good / No Good Q_{ext}

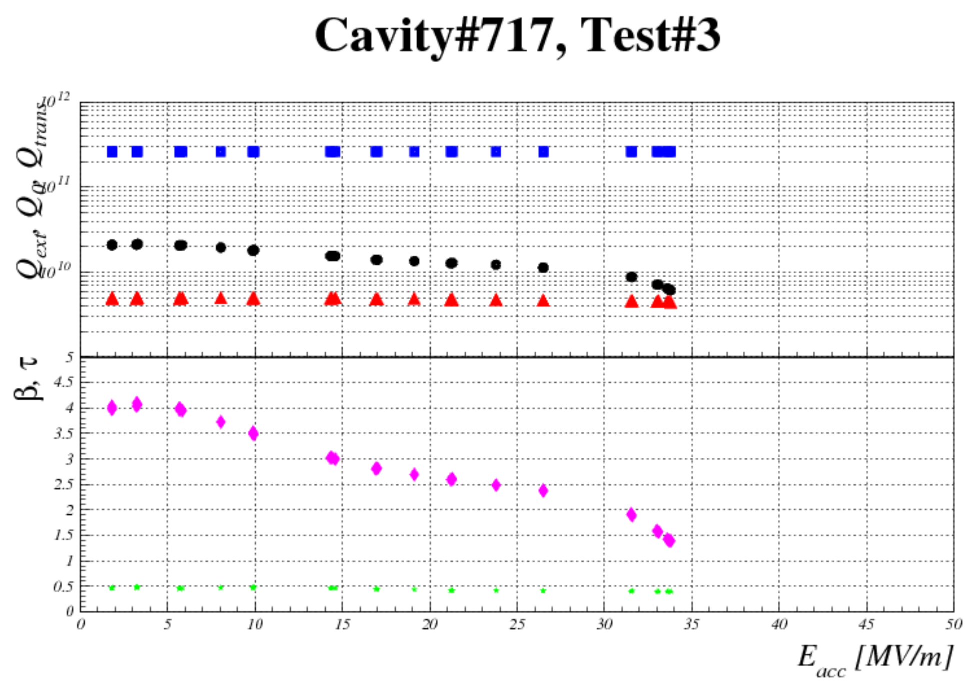
No Good example (CAV00670, Test-01)



Examples of Good / No Good Q_{ext}

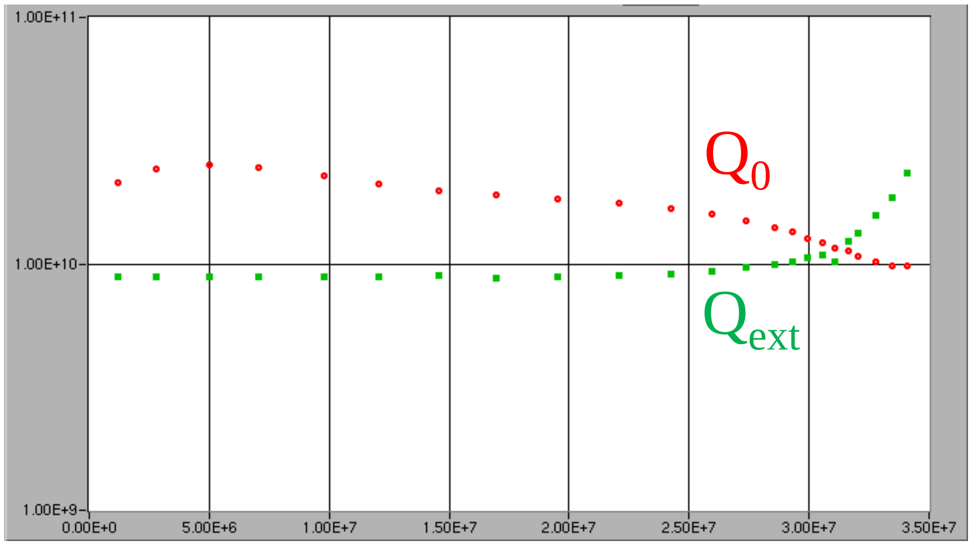
No Good example (CAV00717, Test-02/-03)

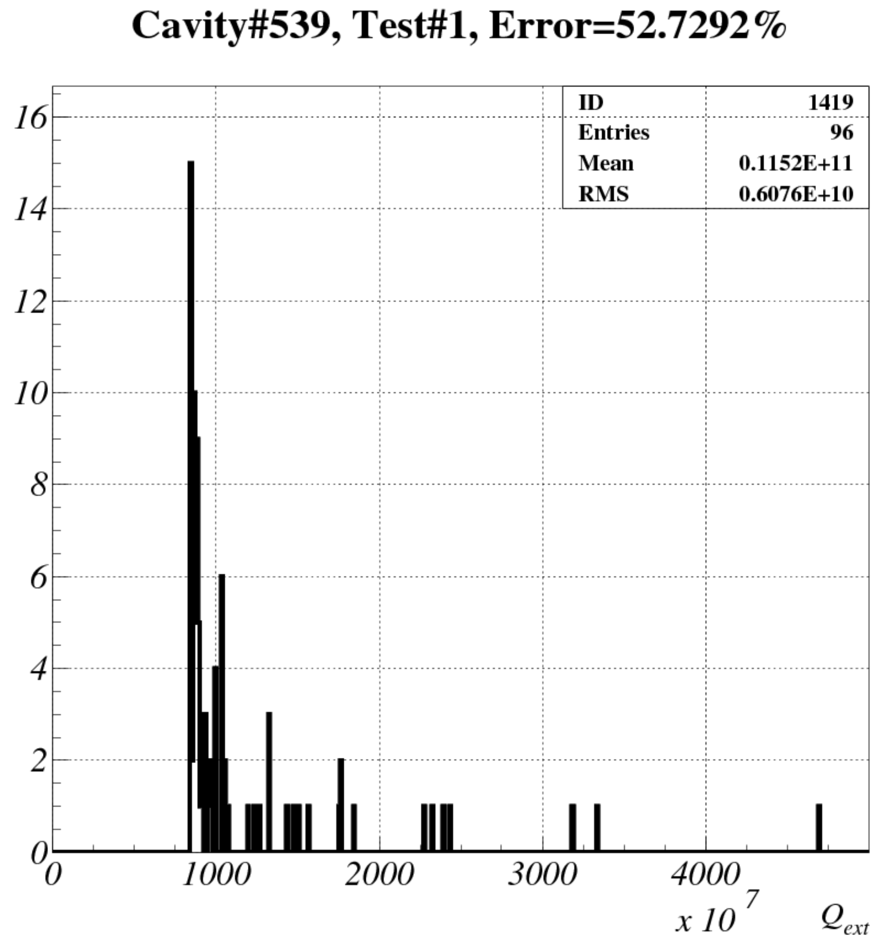




Q_{ext} distribution in CAV00539/Test01

worst case

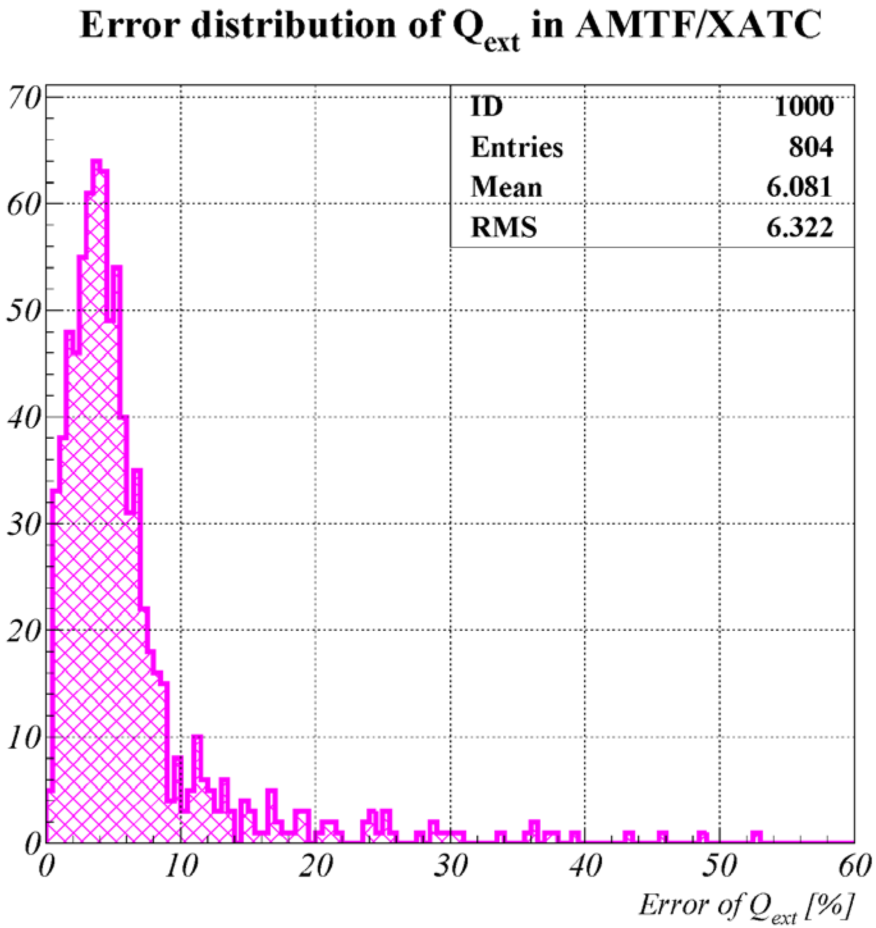




The Q_{ext} gradually shifts around higher gradient.

→ Pattern 1

Error distribution of Q_{ext}



total # of tests; 804
(till 16/Jan/2015)

Mean of error; **6.1%**

Error of Q_{ext}	# of test
0~10%	705
10~20%	65
20~30%	21
30~40%	9
40~50%	3
50~60%	1

>95%

Calculation of error estimation for Power, E_{acc} measurement

Error estimation in V.T.

- $\sigma_{\text{cable calibration}}$; $\pm 2.5\%$
- σ_{Qext}; $+6.1\%$

$$\left.\begin{array}{l} \sigma_{\text{cable calibration}};\quad \pm 2.5\% \\ \\ \sigma_{\text{Qext}};\quad +6.1\% \end{array}\right\} \sigma_{\text{total}}$$

Error propagation formula

$$\sigma_{total} = \sqrt{\sigma_{cable}^{2} + \sigma_{Qext}^{2}}$$

= 6.6% (in power measurement)

Translation into error for E_{acc}

$$E_{acc} = 31.0\sqrt{P_{tra}Q_{tra}}$$

$$\mathbf{(1 \pm x)^{1/2} \sim 1 \pm x/2 \; (x << 1)}$$

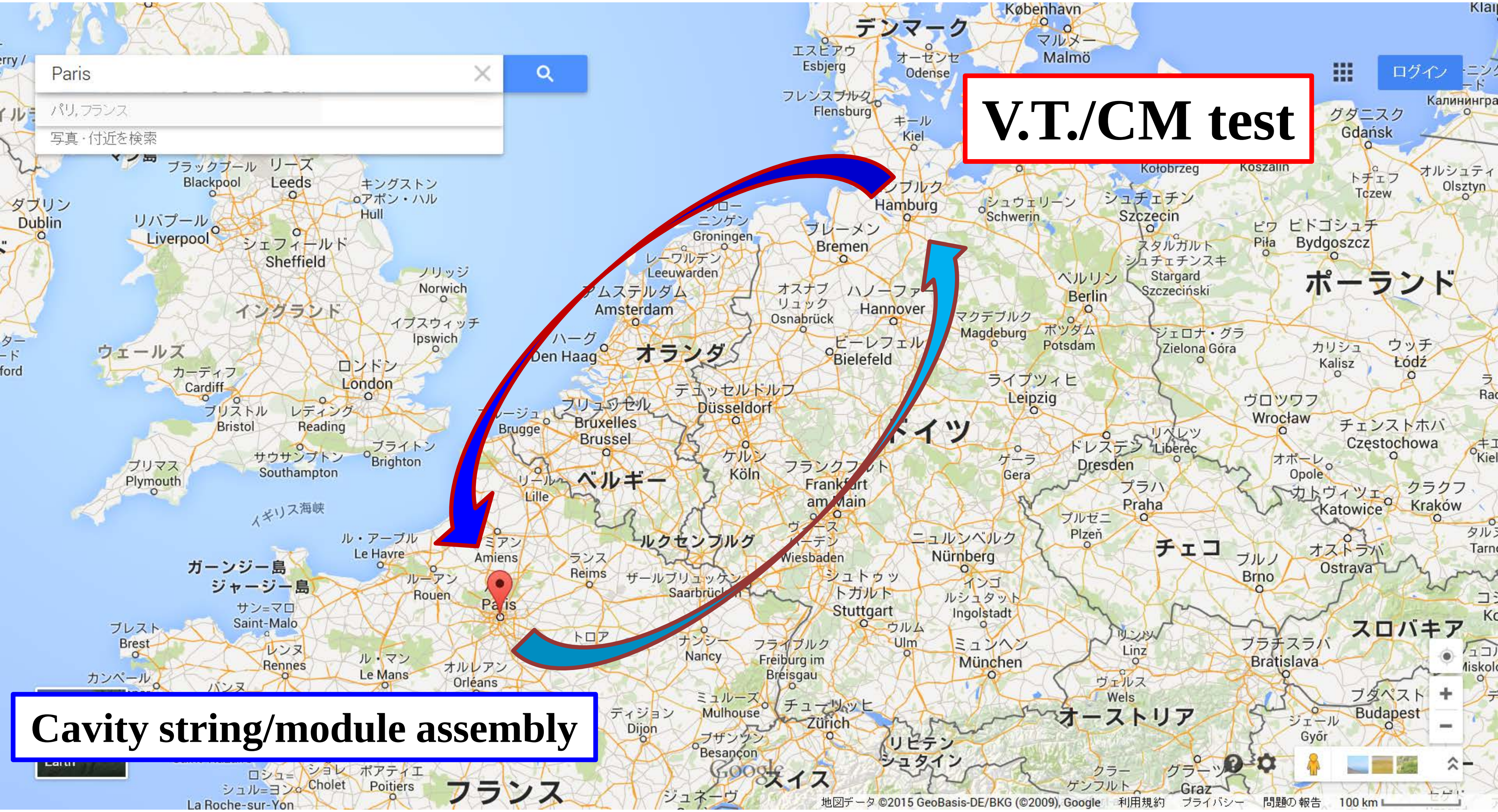
0.066

$\boxed{\sigma_{Eacc} = 3.3\% \text{ (in field measurement)}}$

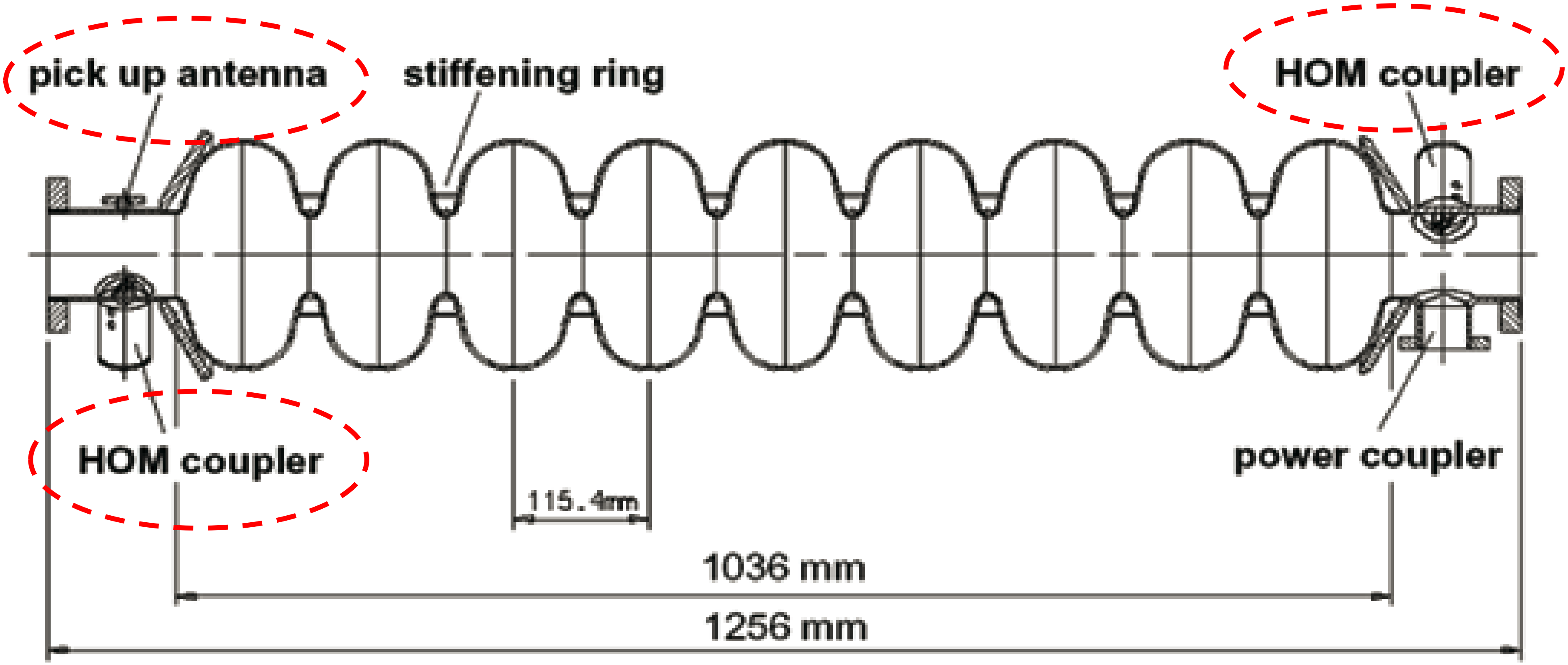
Short Summary

- ✓Error in power measurement for V.T.; 6.6%
- ✓Error in field measurement for V.T.; 3.3%
- ✓Largest error in Q_{ext}; 53%
  - ✓95% of every test is within error of 20%

V.T. to CM test


Paris
パリ, フランス
写真・付近を検索
V.T./CM test
Cavity string/module assembly

Not exchanged ports after last V.T.



After last V.T., pick-up and two HOM ports are never exchanged

↓

This means the Q values for these ports are still conserved in CM!

Translation from Q_{tra} into K_t

In STF, we usually evaluate the change of **Q_{tra}** between V.T. and C.T.
But, in DESY, you use K_t for the evaluation.

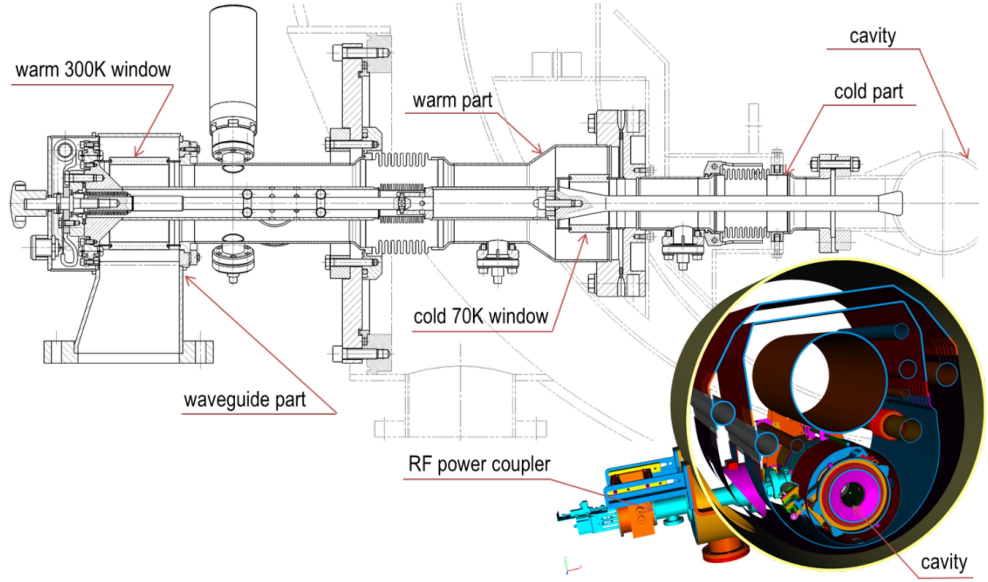
TESLA Cavity Formula

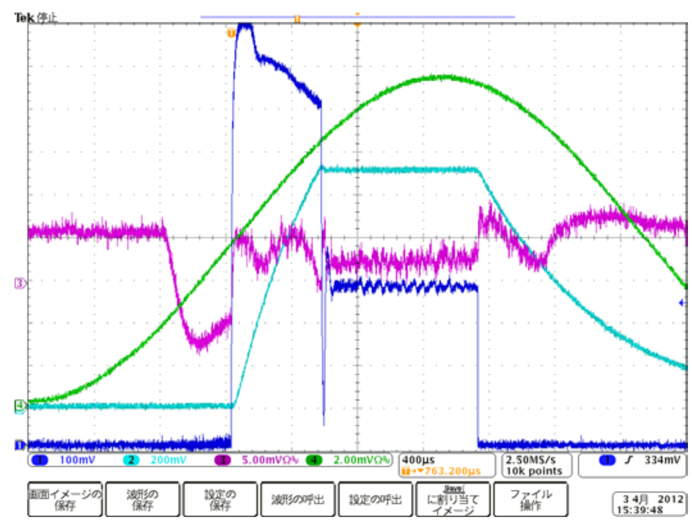
$$E_{acc} = \frac{1}{L_{eff}} \sqrt{(R/Q) P_{tra} Q_{tra}} = 31.0 \sqrt{P_{tra} Q_{tra}} = K_t \sqrt{P_{tra}}$$

$$(L_{eff} = 1.035m, R/Q = 1030\Omega)$$

$$\because K_t \equiv 31.0 \sqrt{Q_{tra}}$$

Measurement system in CM test

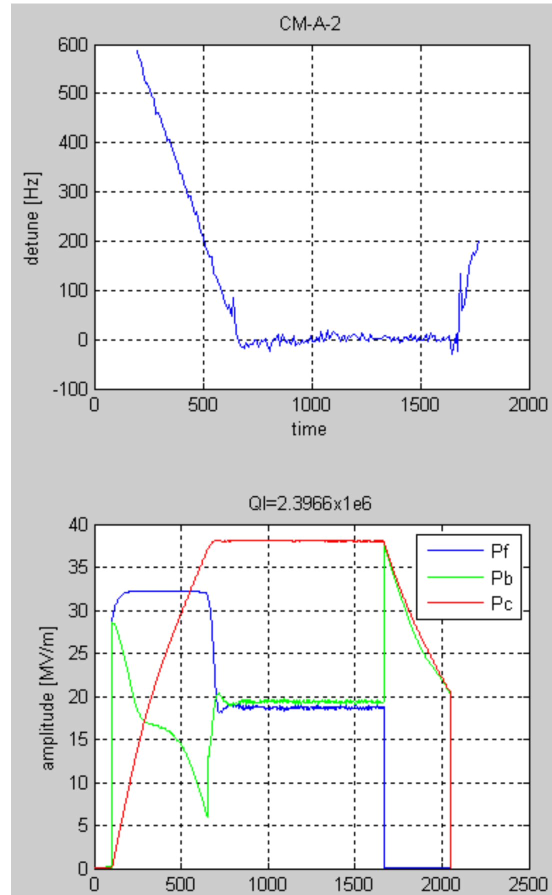




- ✓ Input coupler changed (port also)
  - ✓ β~1 → β~5000
- ✓ Input power increased
  - ✓ P_{for}~200W → P_{for}~300kW
- ✓ measurement method
  - ✓ long pulse (10sec) → short pulse (1.4msec)
- ✓ Q_{ext} measurement is difficult, but change of K_t (Q_{tra}) is used instead

Measurement method in CM test

- Cable calibration
  - Every cable loss is measured by Network Analyzer or TDR
- Low power test using Network Analyzer ($4P_{for}Q_L=P_{tra}Q_{tra}$)
  - Every Q value (Q_L, Q_{tra}, $Q_{HOM\#1}$, $Q_{HOM\#2}$) is evaluated
- High power test using Klystron
  - Q_L is evaluated again at the pulse end



Formulas for module testing

$$Q_L = \omega\tau = 2\pi f\tau$$

$$E_{acc} = \frac{1}{L_{eff}}\sqrt{(R/Q)\cdot 4P_{for}Q_L}\left(1-e^{-\frac{t}{2\tau}}\right)$$

$$(L_{eff} = 1.035m, R/Q = 1030\Omega, t = 1.3m\sec)$$

$$K_t = \frac{E_{acc}}{\sqrt{P_{tra}}}, Q_{tra} = \left(\frac{K_t}{31.0}\right)^2$$

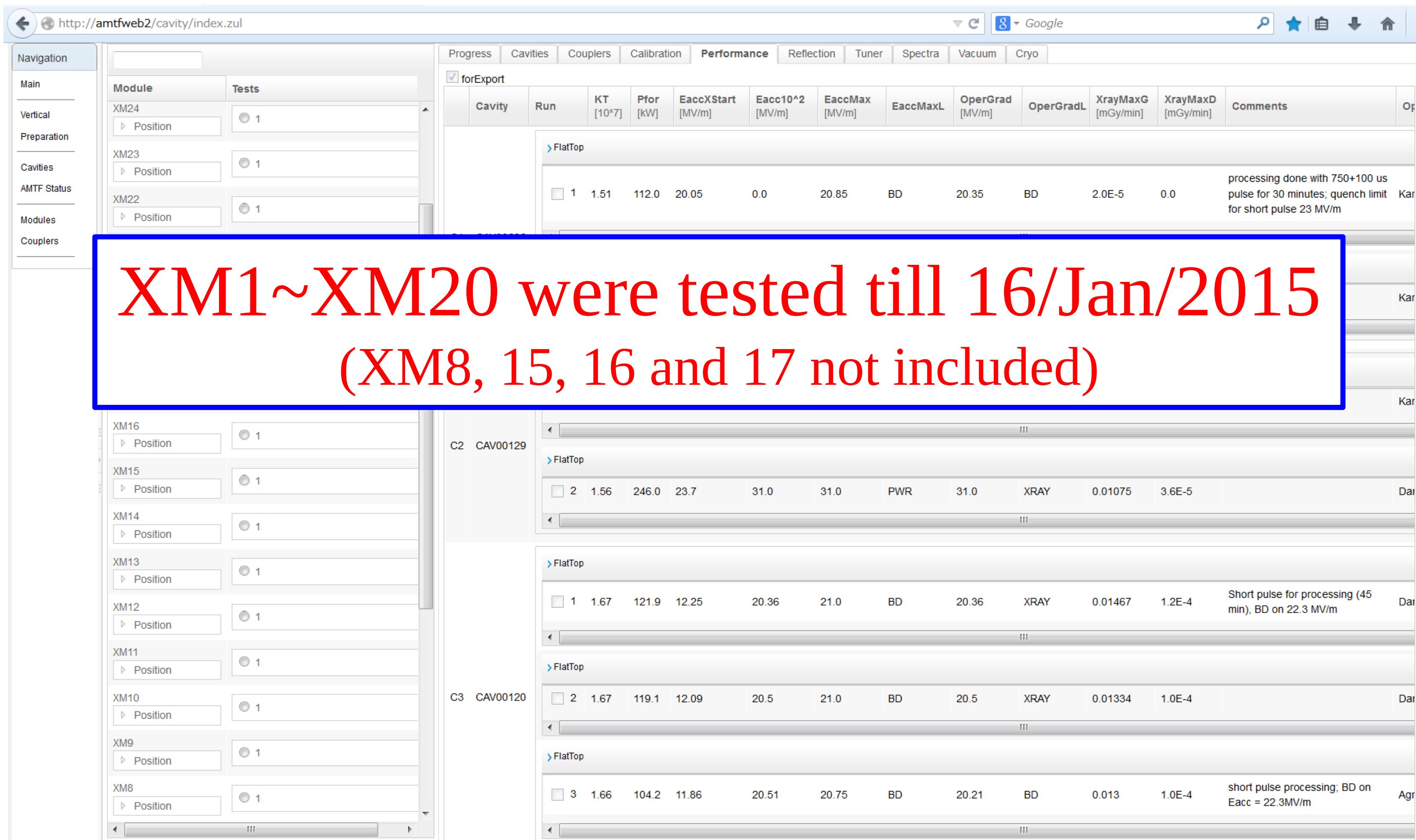
$$P_{tra}Q_{tra} = P_{HOM\#1,2}Q_{HOM\#1,2}$$

Calibration data at AMTF

- ✓τ is measured around 5MV/m
- ✓E_{acc} is calculated using Q_L ($t \rightarrow \infty$)
- ✓K_t is estimated using E_{acc}
- ✓Every Q value is derived

Used Data for this analysis

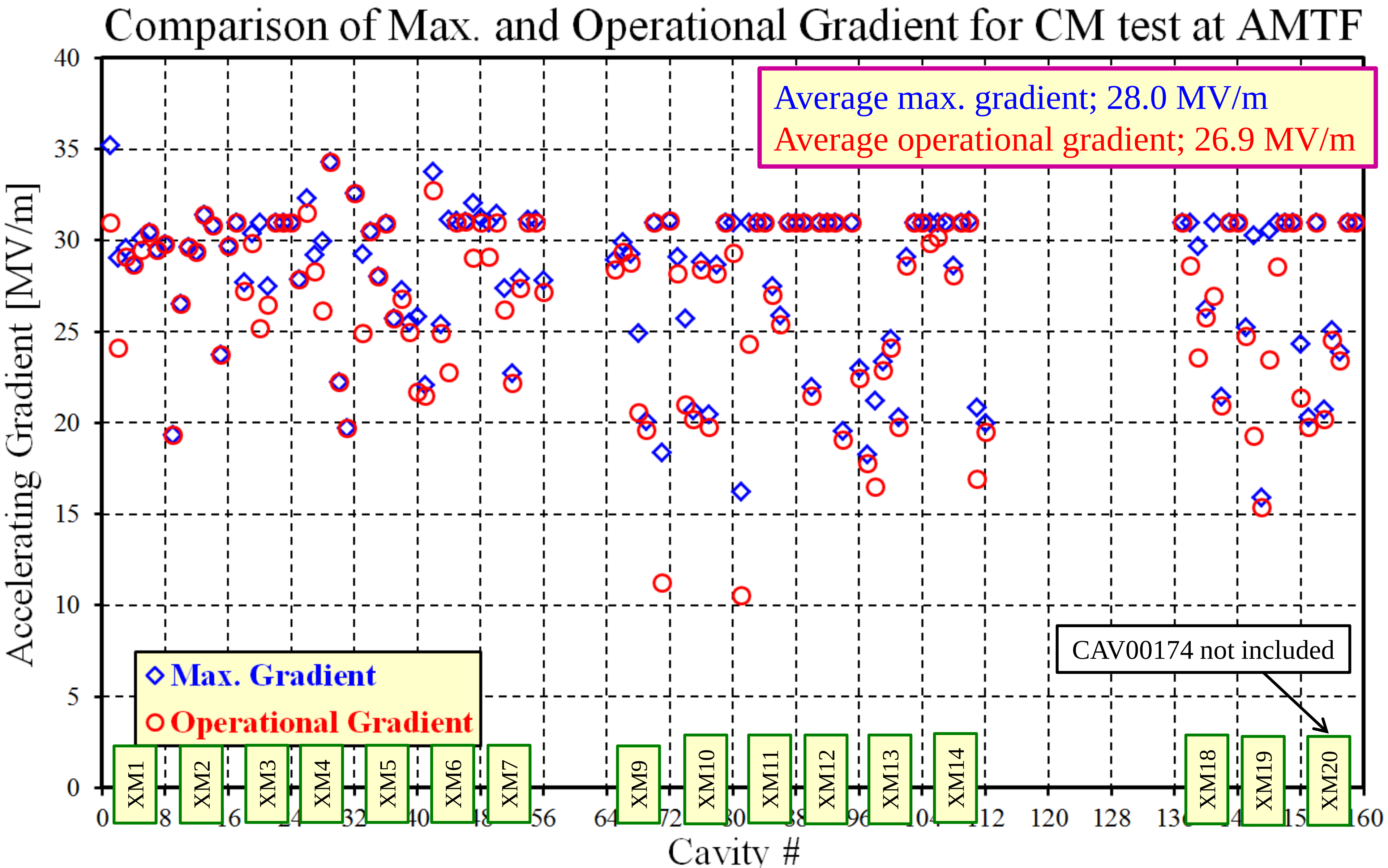
- http://amtfweb2/cavity/index.zul
  - Special web site by Polish colleague (W. Mateusz)



XM1~XM20 were tested till 16/Jan/2015

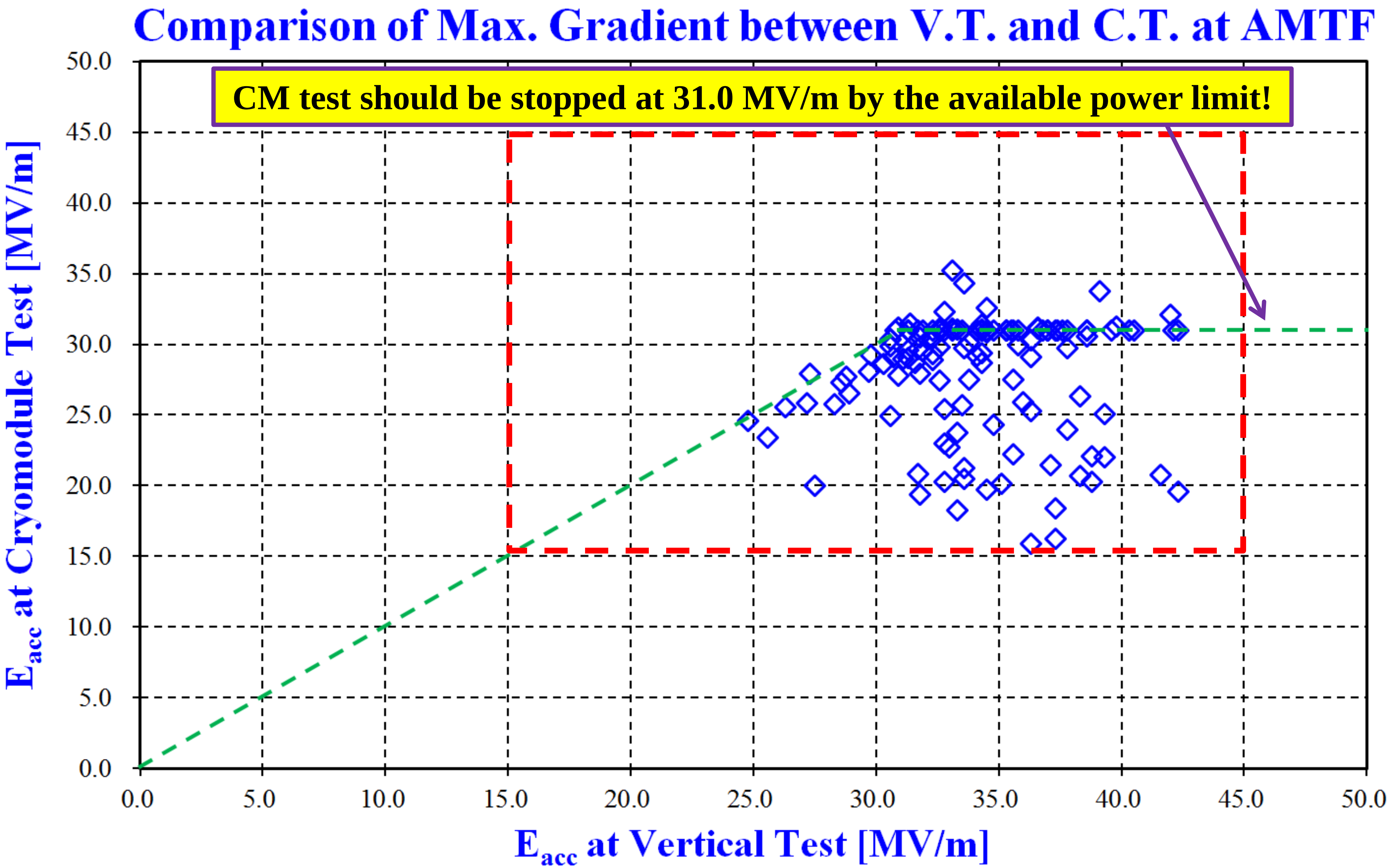
(XM8, 15, 16 and 17 not included)

Comparison of Max./Operational E_{acc} for CM

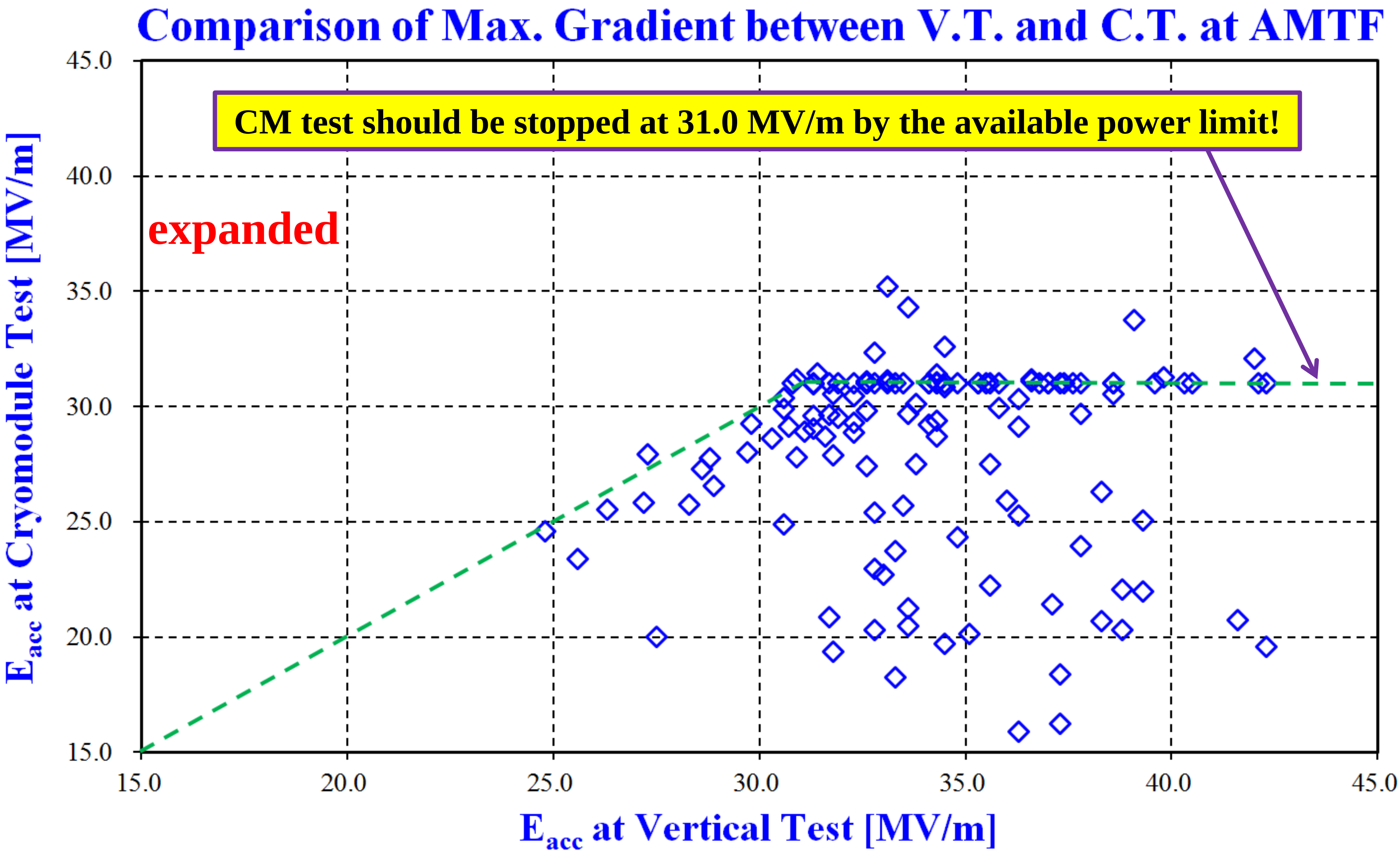


CM test should be stopped at 31.0 MV/m by the available power limit!

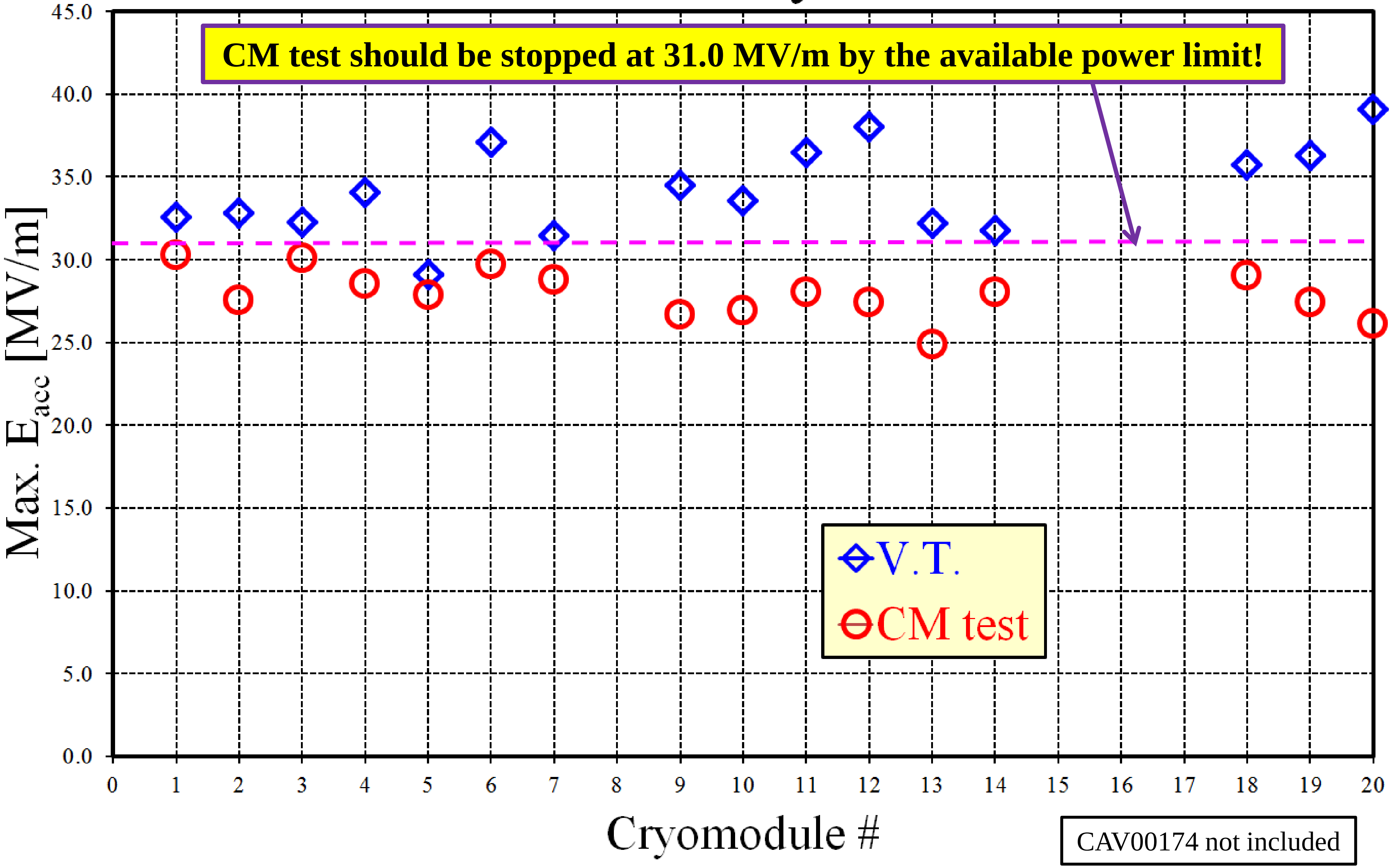
Comparison of Max. E_{acc} between V.T. and C.T.



Comparison of Max. E_{acc} between V.T. and C.T.

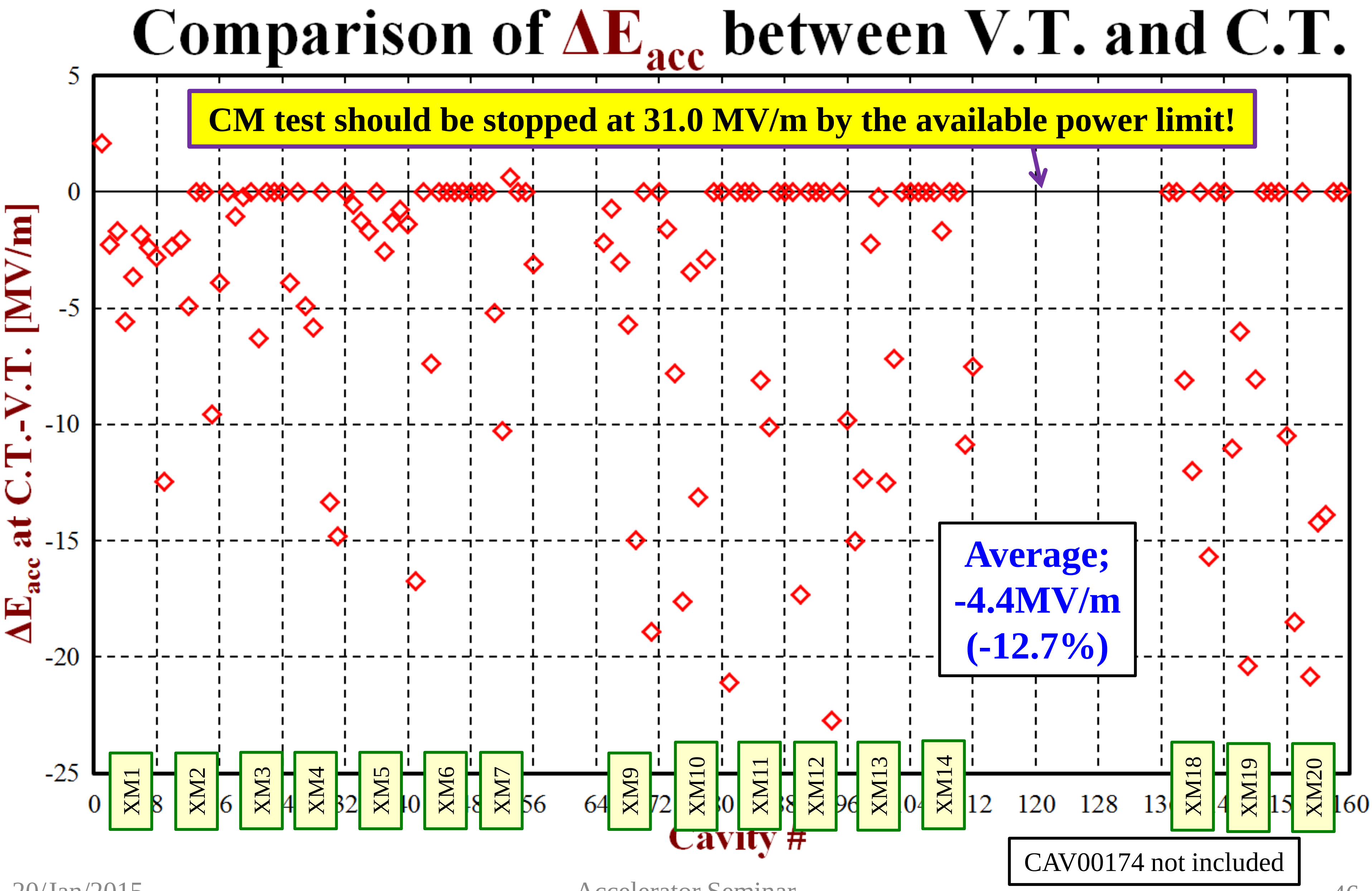


Performance of each Cryomodule in AMTF

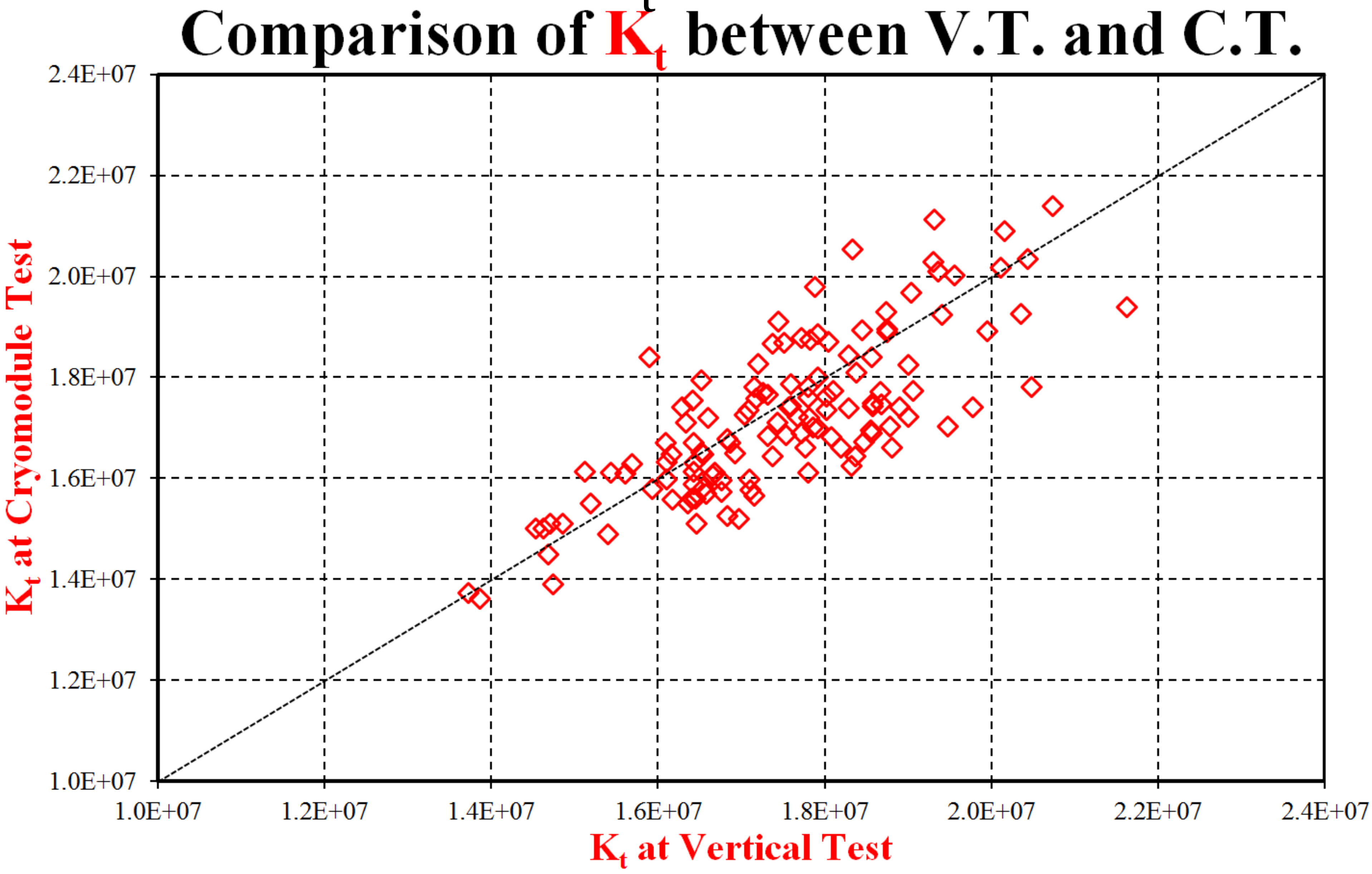


CAV00174 not included

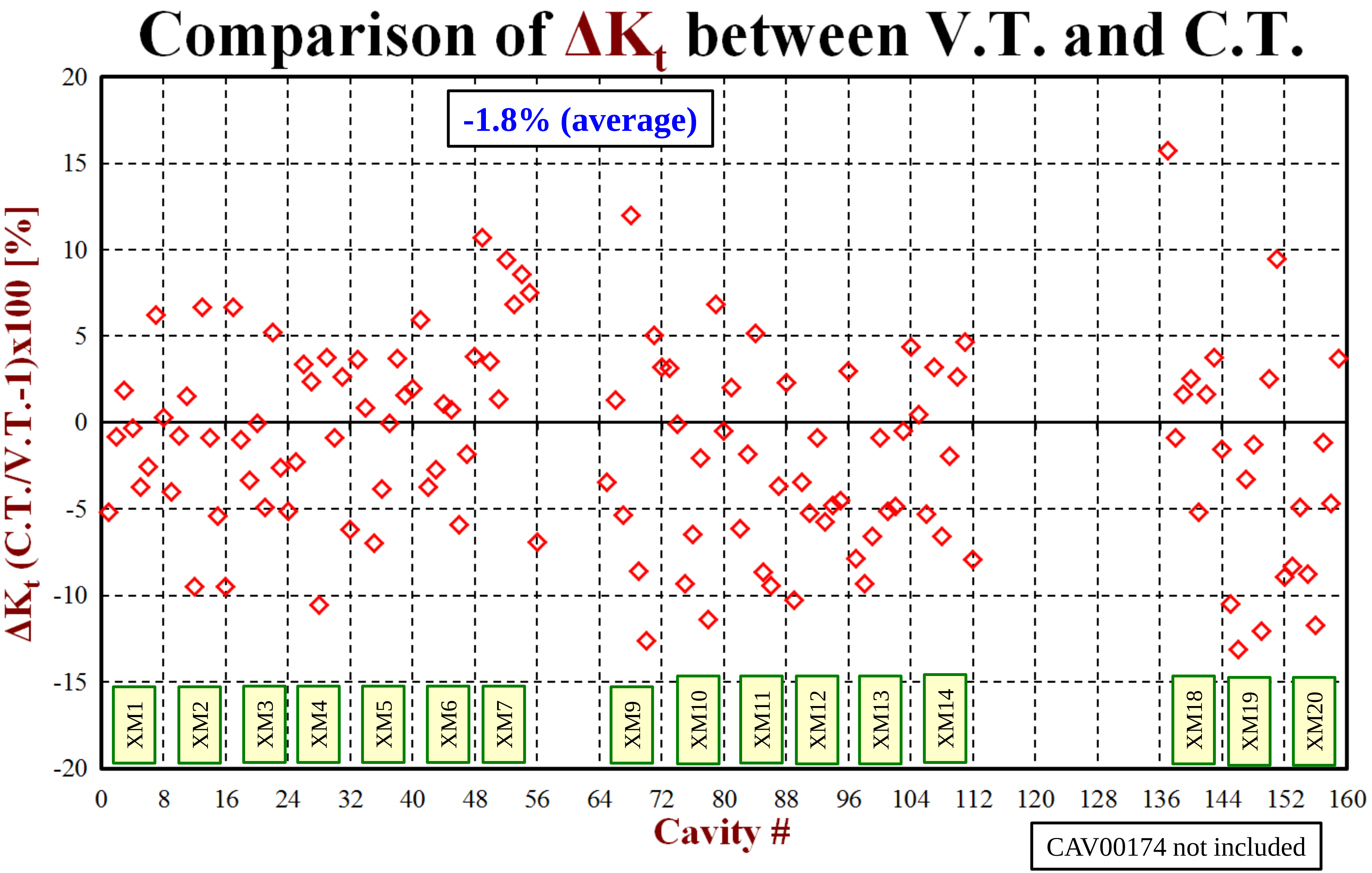
Change of Max. Field (ΔE_{acc}) from V.T. to C.T.



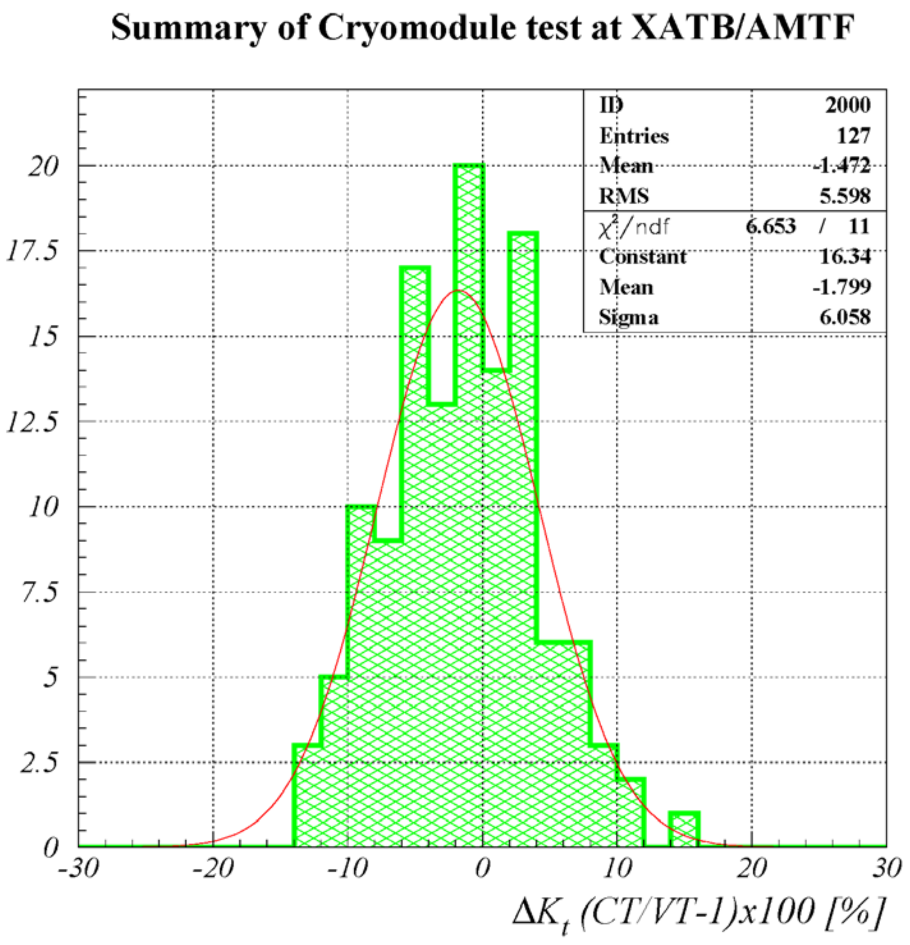
Correlation of K_t both V.T. and C.T.



Comparison of ΔK_t between V.T. and C.T.



Distribution of ΔK_t



Distribution;

mean = -1.5%

r.m.s. = 5.6%

Gaussian;

mean = -1.8%

σ = 6.1%

Mean value is nearly 0. → Good

Gaussian-like distribution → Good

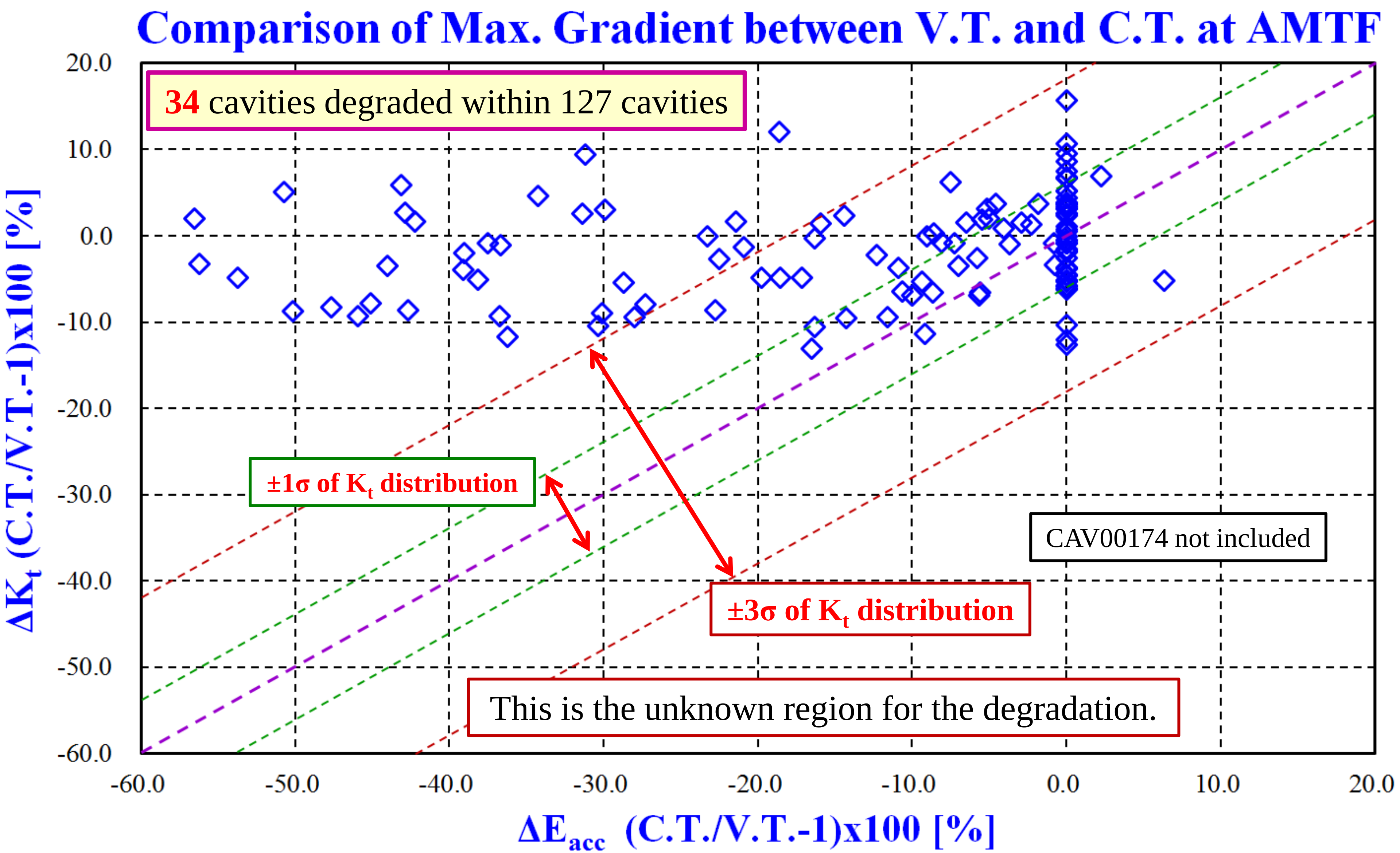
Calibration of Q_t, Q_{HOM1}, Q_{HOM2}

	Cavity	Q_t	Q_t (VT)	error	Q_{HOM1}	Q_{HOM2}
1.	C1/AES-004	6.01×10^{11}	5.9×10^{11}	+ 2%	6.08×10^{11}	2.25×10^{13}
2.	C2/ACC-011	2.48×10^{12}	2.8×10^{12}	-13%	9.45×10^{12}	4.36×10^{12}
3.	C3/Z-108	2.43×10^{11}	1.9×10^{11}	+22%	9.23×10^{11}	2.06×10^{13}
4.	C4/Z-109	3.53×10^{11}	4.0×10^{11}	-13%	4.93×10^{12}	7.22×10^{15}
5.	A1/MHI-05	2.39×10^{11}	2.2×10^{11}	+ 8%	1.90×10^{13}	3.99×10^{13}
6.	A2/MHI-06	2.83×10^{11}	3.4×10^{11}	-20%	1.53×10^{13}	6.42×10^{13}
7.	A3/MHI-07	2.31×10^{11}	2.6×10^{11}	-13%	9.27×10^{12}	6.09×10^{12}
8.	A4/MHI-09	2.50×10^{11}	1.8×10^{11}	+28%	9.96×10^{12}	8.04×10^{13}

error of Q_t = -20 / +28 %

Q_{HOM1} , Q_{HOM2} > 1×10^{12} , OK

Comparison between ΔE_{acc} and ΔK_t



Summary of error estimation

	Power measurement	**Field measurement**
Only V.T.	6.6%	3.3%
V.T. → C.T.	12.6%	6.1%
Summed error	14.2%	6.9%

† These errors show the average number (1σ) for each condition.
1σ includes 68.3%, and 3σ includes 99.7% for normal distribution.

Summary

- Data analysis for V.T./CM test is done with error estimation
- Error in power measurement in AMTF; 14.2%
- Error in field measurement in AMTF; 6.9%
- Largest error of Q_{ext} in V.T. is 53%
- **34** of 127 cavities degraded beyond K_t error

For more detailed analysis

- Cable calibration parameters in CM test
- Q_L check in low / high power tests in CM test

  → should be added in systematic error

  → Error region would be wider

- Δf_{LFD} v.s. E_{acc}^2 as a consistency check

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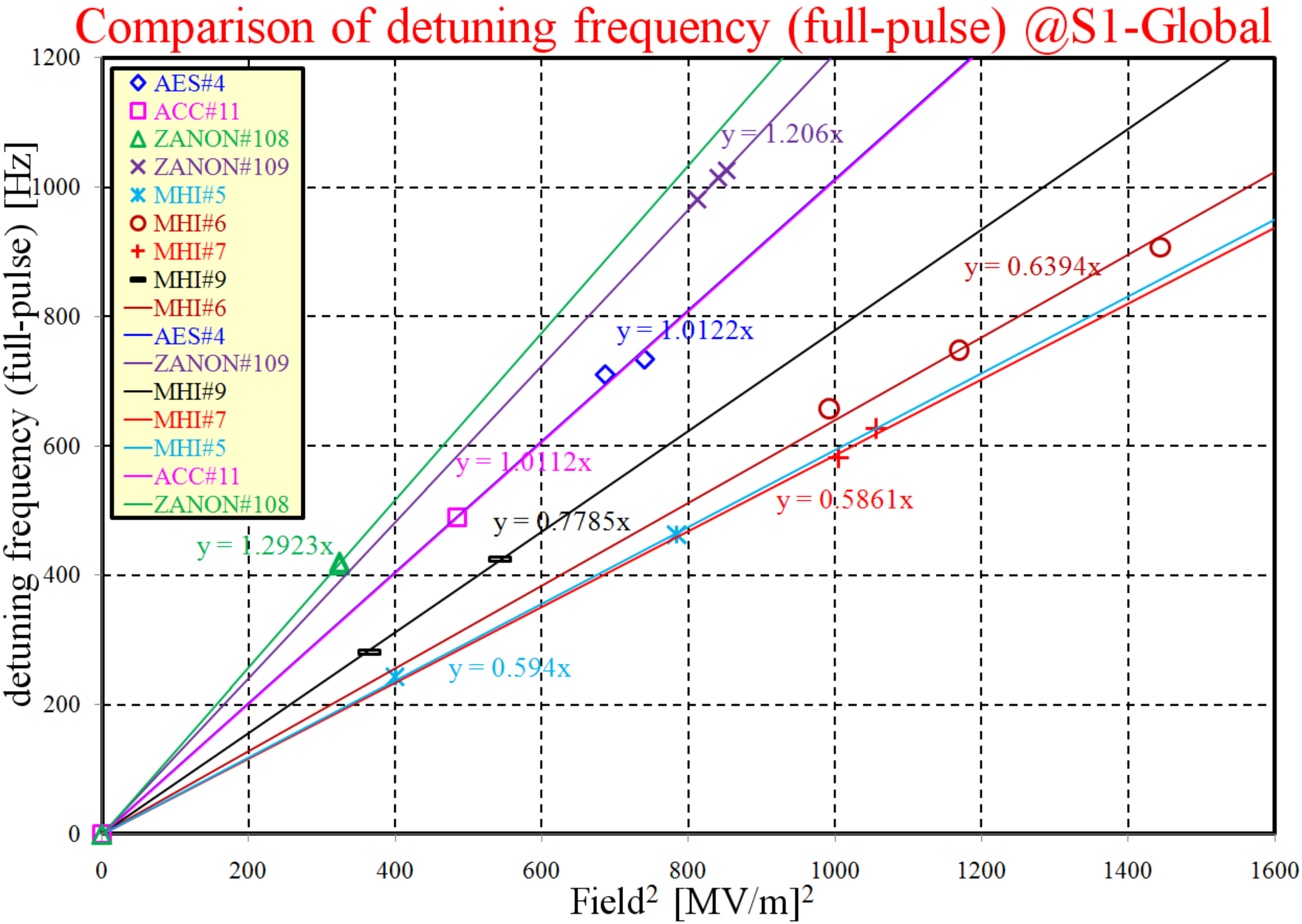
Summary of S1-Global

	A1 MHI#5	A2 MHI#6	A3 MHI#7	A4 MHI#9	C1 AES#4	C2 ACC#11	C3 ZANON #108	C4 ZANON #109
Gradient [MV/m]	28.0	34.2 (31.5)	31.7	23.3	27.2	22.0	18.0	29.2 (28.5)
$\triangle f_{detuned}$ (total) [Hz]	436	710	558	399	708	478	440	1003
$\triangle f_{detuned}$ (rise-up) [Hz]	353	527	427	219	372	248	195	451
$\triangle f_{detuned}$ (only flat-top) [Hz]	83	183	131	180	336	230	245	552
Q_L (High Power) [$x10^6$]	2.55	2.50	2.42	2.31	2.32	2.34	2.37	2.43
Q_L (Low Power) [$x10^6$]	2.41	2.41	2.40	2.41	2.40	2.40	2.41	2.40
Average [pulses]	100	100	100	100	100	100	100	100

Comparison of LFD (full-pulse) in S1-Global





Thank you very much for your attention



Back-up slides

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V.T. results with No GOOD Q_{ext}

Cavity #	Test #	Error of Q_{ext} [%]	Max. E_{acc} [MV/m]	Pattern
ΔQ_{ext} > 50% (1 event)				
CAV00539	Test 01	51.6	34.9	1
ΔQ_{ext} = 30 ~ 50% (12 events)				
CAV00021	Test 01	30.4	34.4	2
CAV00056	Test 02	30.2	38.3	2
CAV00123	Test 03	35.9	37.5	2
CAV00123	Test 04	36.1	34.6	2
CAV00183	Test 01	48.9	29.9	2
CAV00518	Test 02	34.2	23.4	1
CAV00531	Test 01	36.3	31.8	1
CAV00534	Test 01	37.3	30.3	1
CAV00538	Test 01	43.3	3.3	1
CAV00539	Test 02	34.0	33.0	2
CAV00540	Test 01	31.0	34.8	1
CAV00552	Test 01	37.9	25.1	1
CAV00670	Test 01	39.2	35.3	2
CAV00691	Test 01	45.5	30.7	2

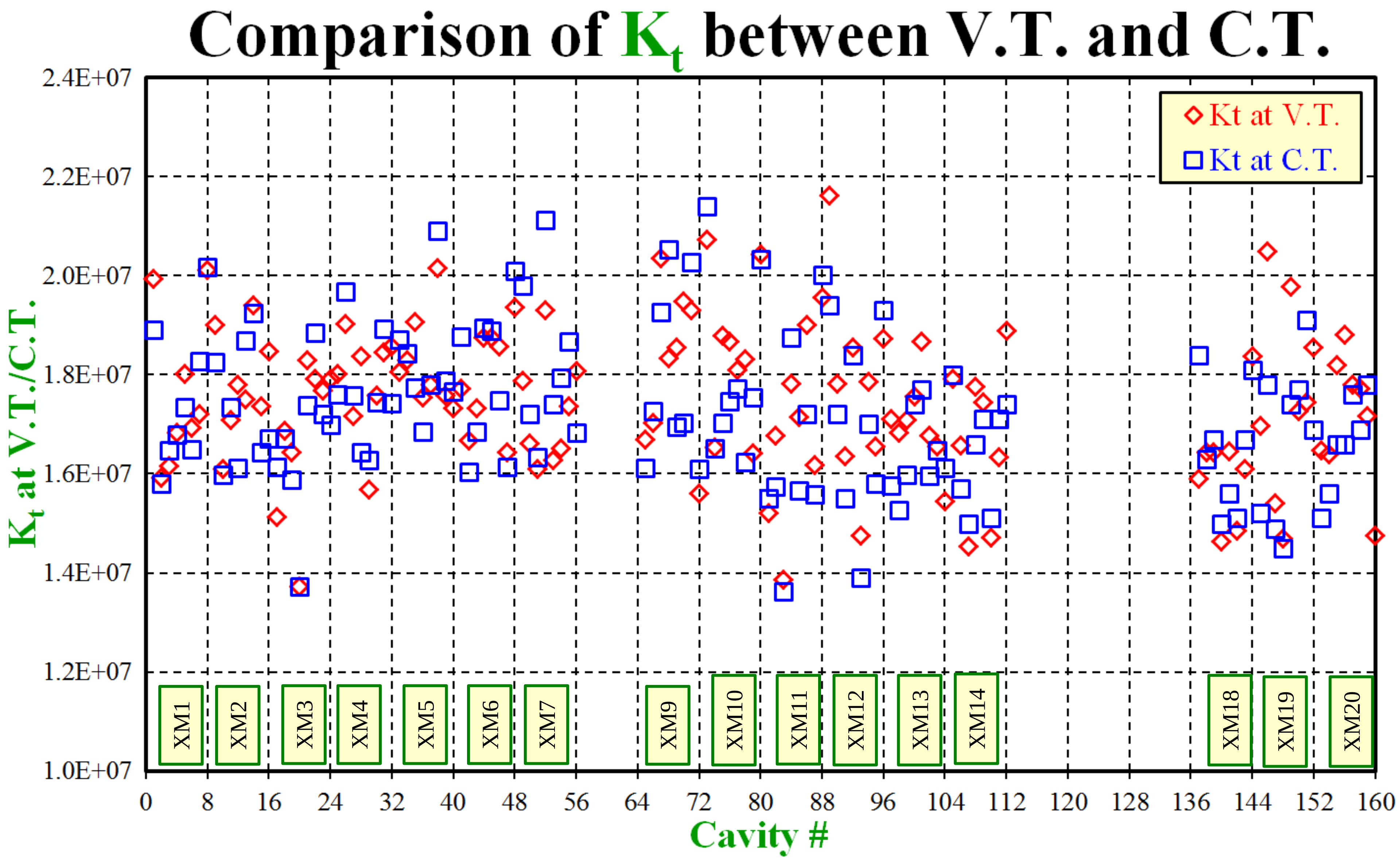
V.T. results with No GOOD Q_{ext}

Cavity #	Test #	Error of Q_{ext} [%]	Max. E_{acc} [MV/m]	Pattern
ΔQ_{ext} = 20 ~ 30% (21 events)				
CAV00048	Test 01	24.5	37.3	1 & 2
CAV00063	Test 01	27.7	37.6	2
CAV00074	Test 01	25.3	36.3	1 & 2
CAV00080	Test 01	23.9	15.1	1 & 2
CAV00108	Test 02	24.3	6.1	1
CAV00109	Test 02	29.6	35.0	2
CAV00121	Test 02	29.4	37.6	1 & 2
CAV00134	Test 01	24.7	8.9	1
CAV00167	Test 01	21.2	29.7	1
CAV00201	Test 01	21.9	1.5	1
CAV00509	Test 02	23.5	8.8	1
CAV00514	Test 01	24.2	33.1	1
CAV00515	Test 02	25.0	27.3	2
CAV00524	Test 01	25.5	29.3	1
CAV00529	Test 01	28.8	32.3	1
CAV00530	Test 01	20.6	32.1	1

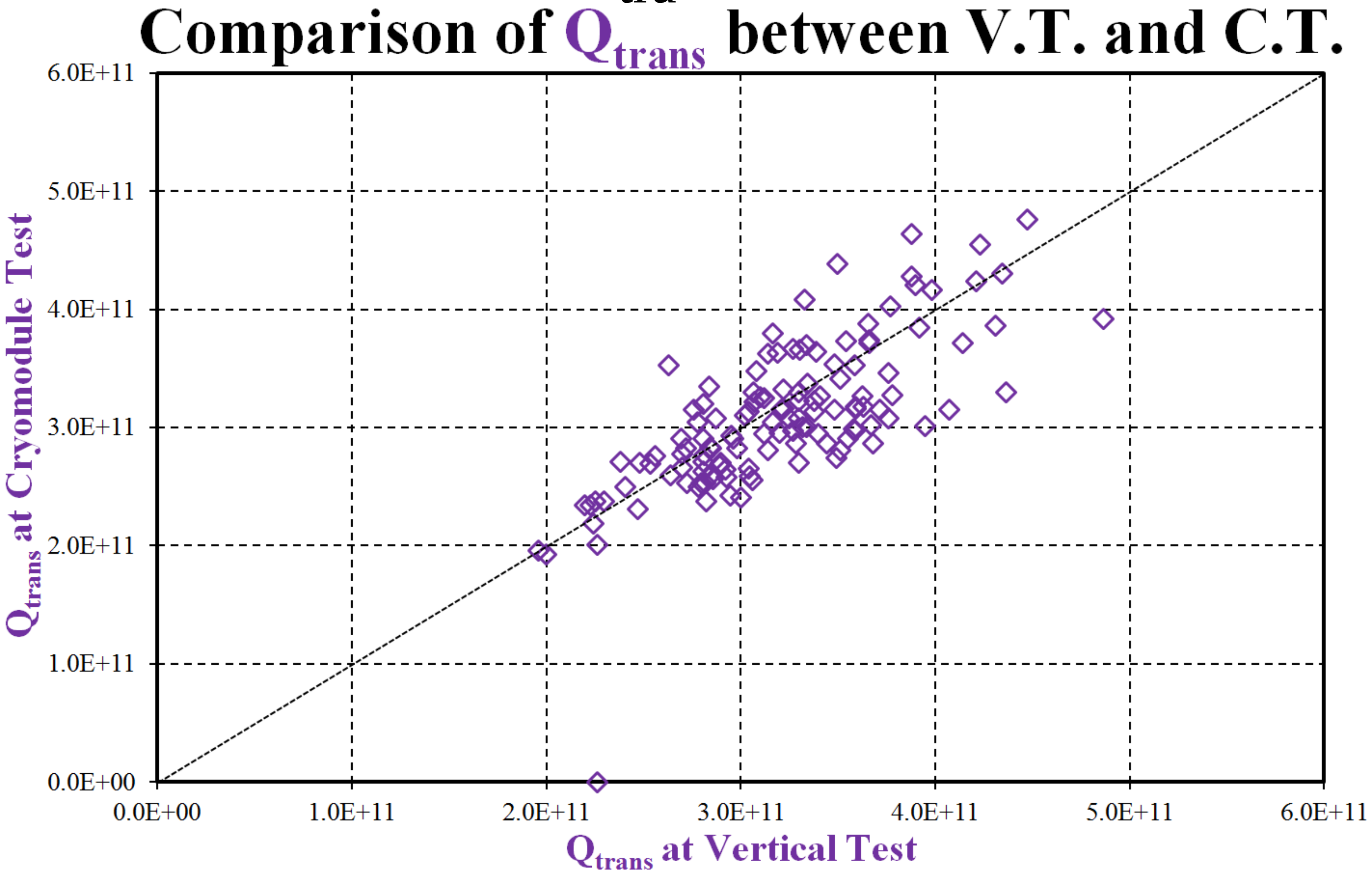
V.T. results with No GOOD Q_{ext}

Cavity #	Test #	Error of Q_{ext} [%]	Max. E_{acc} [MV/m]	Pattern
CAV00533	Test 01	20.6	21.9	1 & 2
CAV00588	Test 01	20.4	19.4	1 & 2
CAV00644	Test 01	28.6	28.4	1
CAV00664	Test 01	25.6	5.6	1
CAV00755	Test 01	21.3	34.6	1 & 2

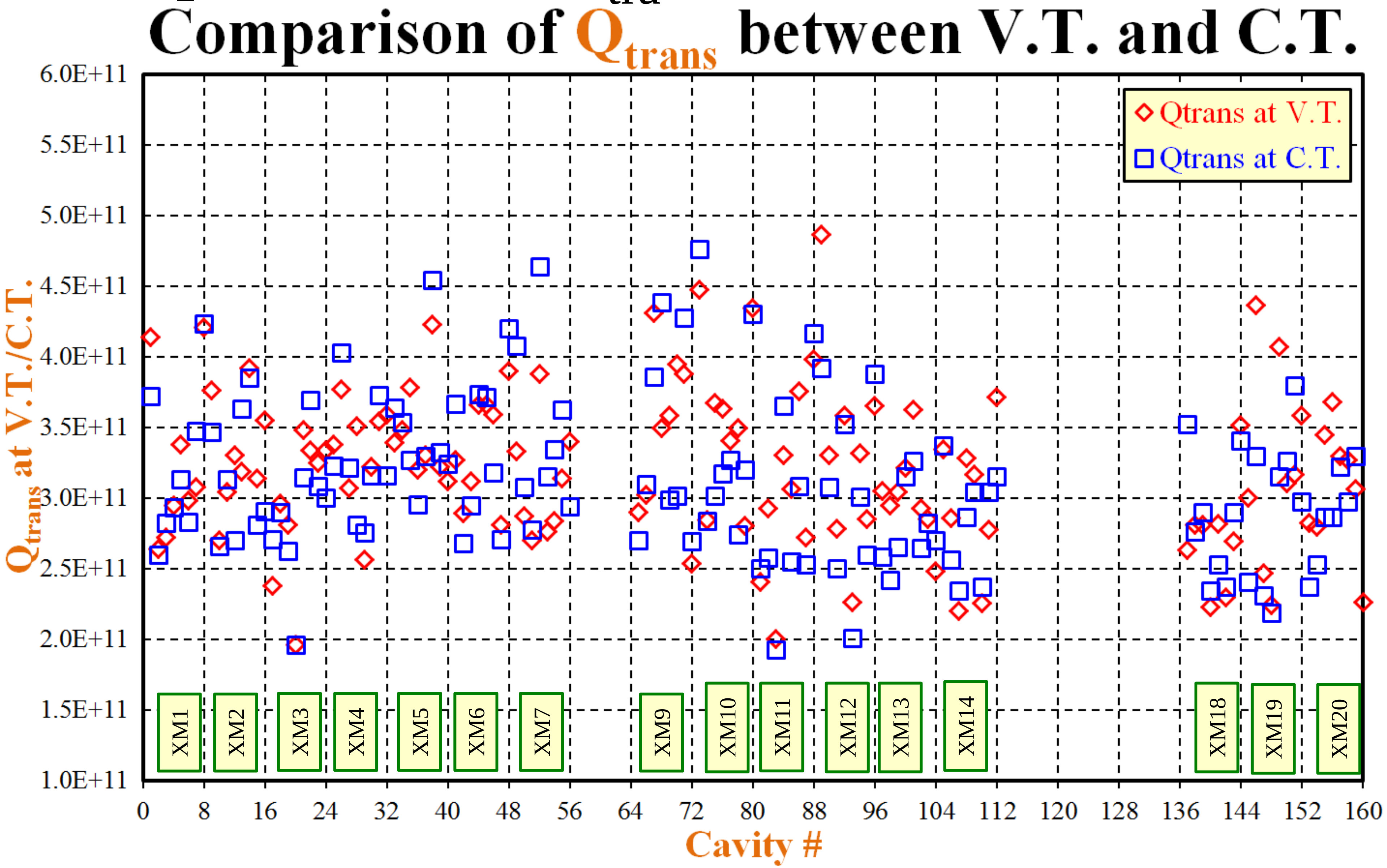
Comparison of K_t between V.T. and C.T.



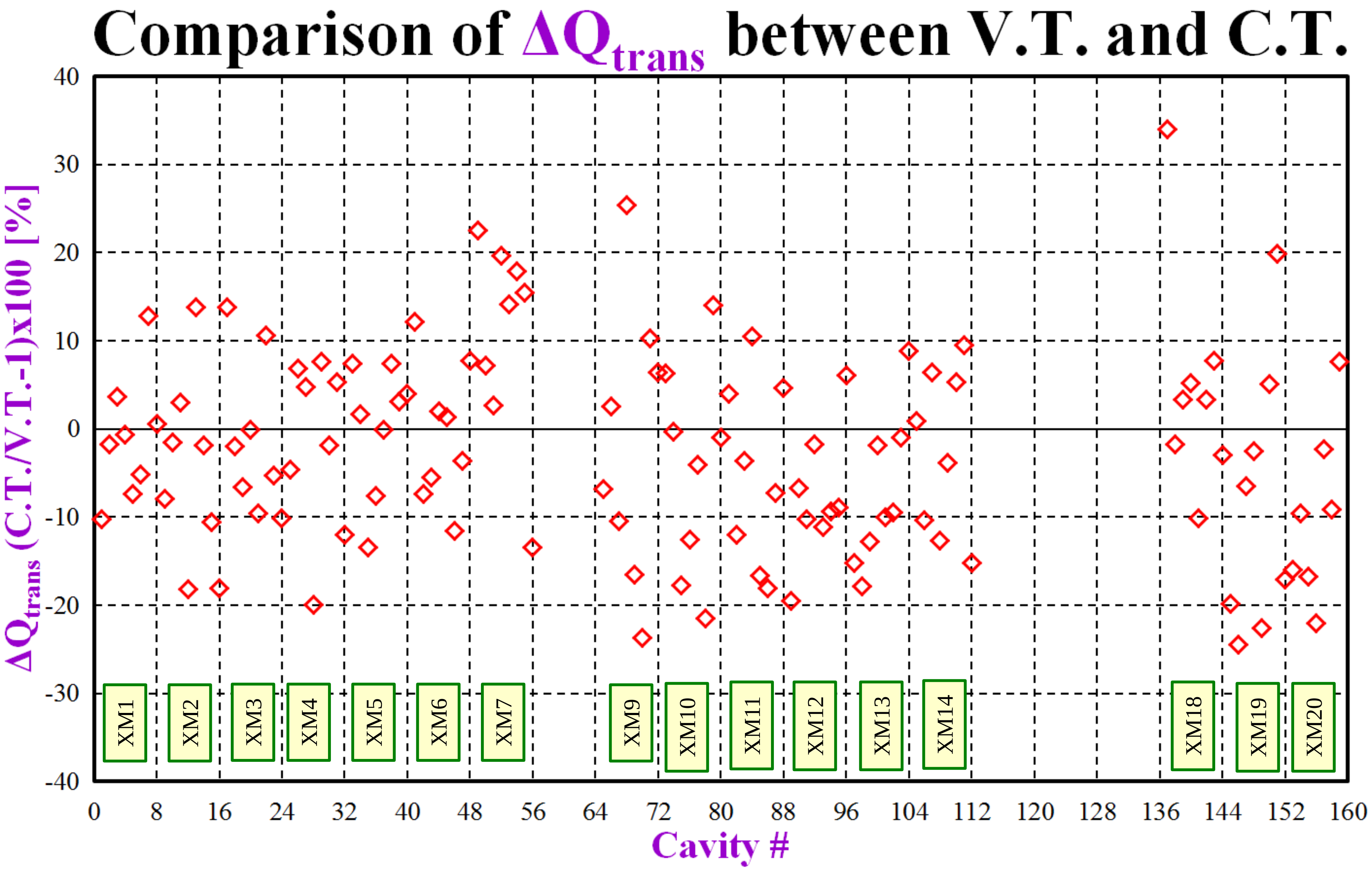
Correlation of Q_{tra} both V.T. and C.T.



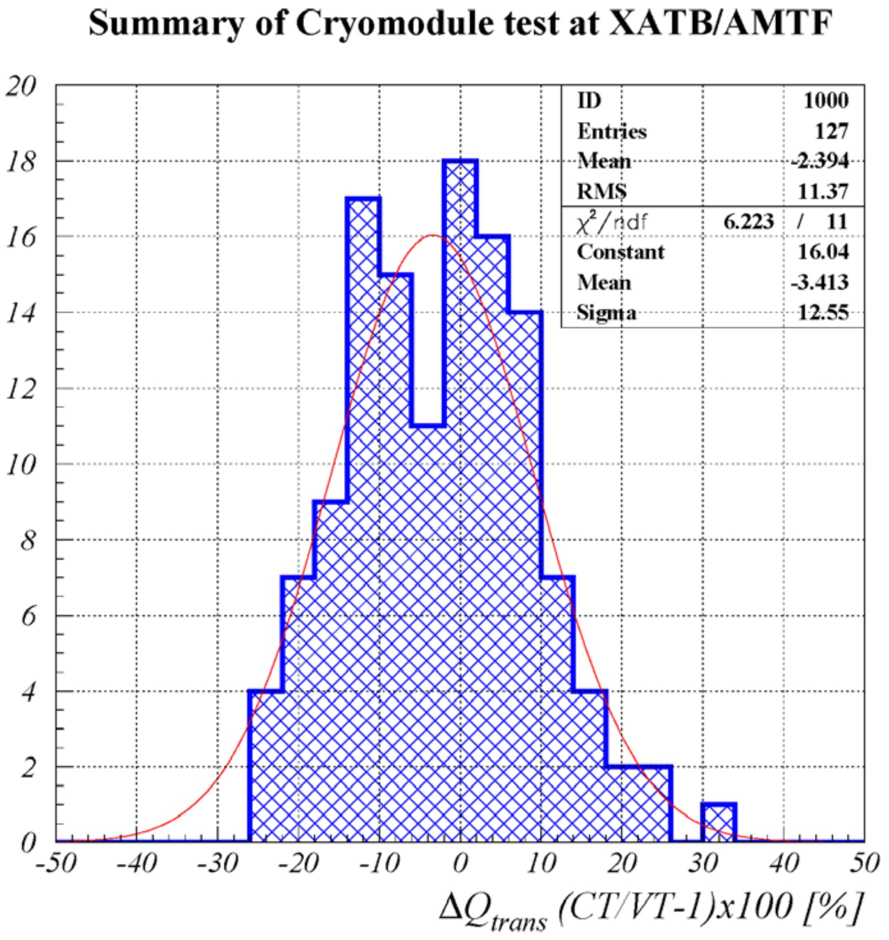
Comparison of ΔQ_{tra} between V.T. and C.T.



Comparison of Q_{tra} between V.T. and C.T.



Distribution of ΔQ_{tra}



Distribution;

mean = -2.4%

r.m.s. = 11.4%

Gaussian;

mean = -3.4%

σ = 12.6%

Mean value is nearly 0. → Good

Gaussian-like distribution → Good

Data analysis for radiation level with geometry check in CM

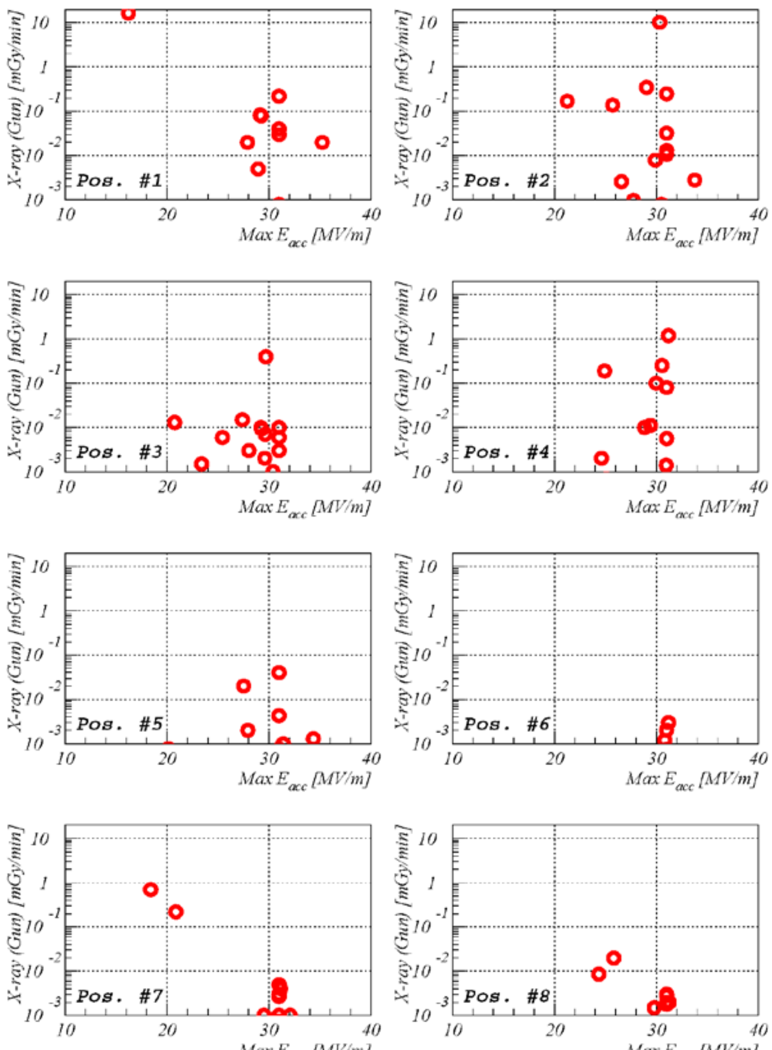
Radiation/Dark-current monitor in XATB

- ✓Radiation monitor
  - ✓Measured at the both ends of CM
  - ✓different distance from each end cavity
    - ✓quadrupole/BPM system, different refrigerator part
- ✓Dark current monitor
  - ✓Not available yet (calibration is necessary?)
  - ✓If available, be able to estimate the max. energy from the energy spectrum, and translate into the max. gradient for each cavity

Radiation level at XATB/AMTF

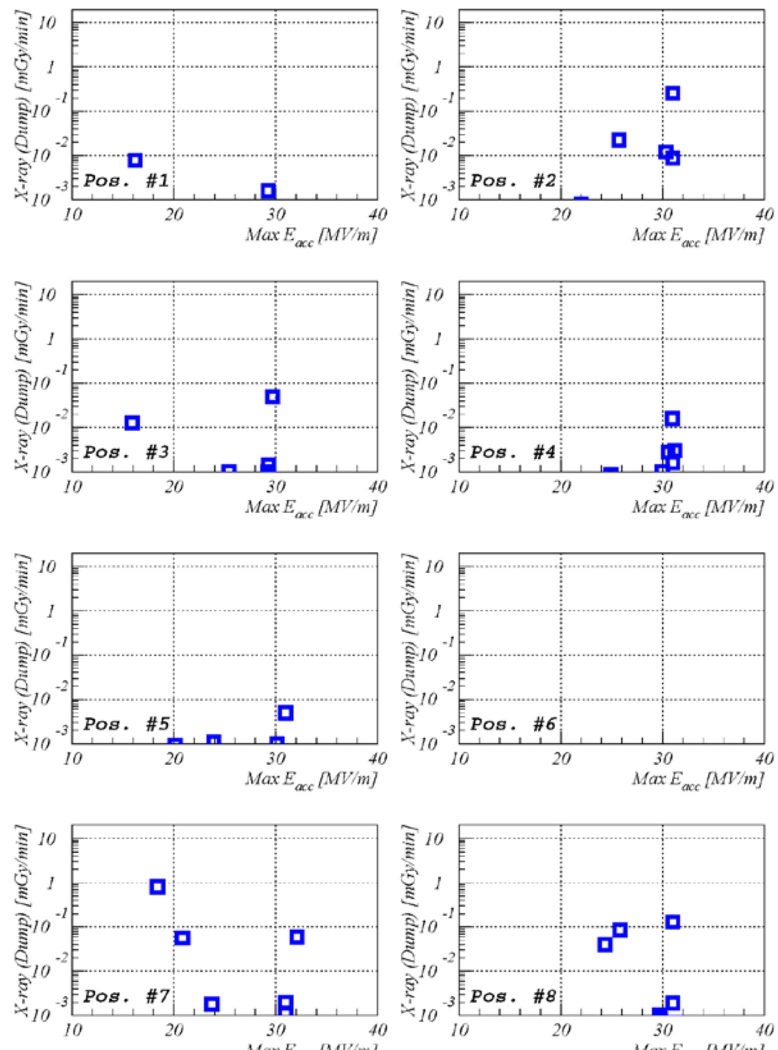
GUN side

Radiation level in Cryomodule test at XATB/AMTF



DUMP side

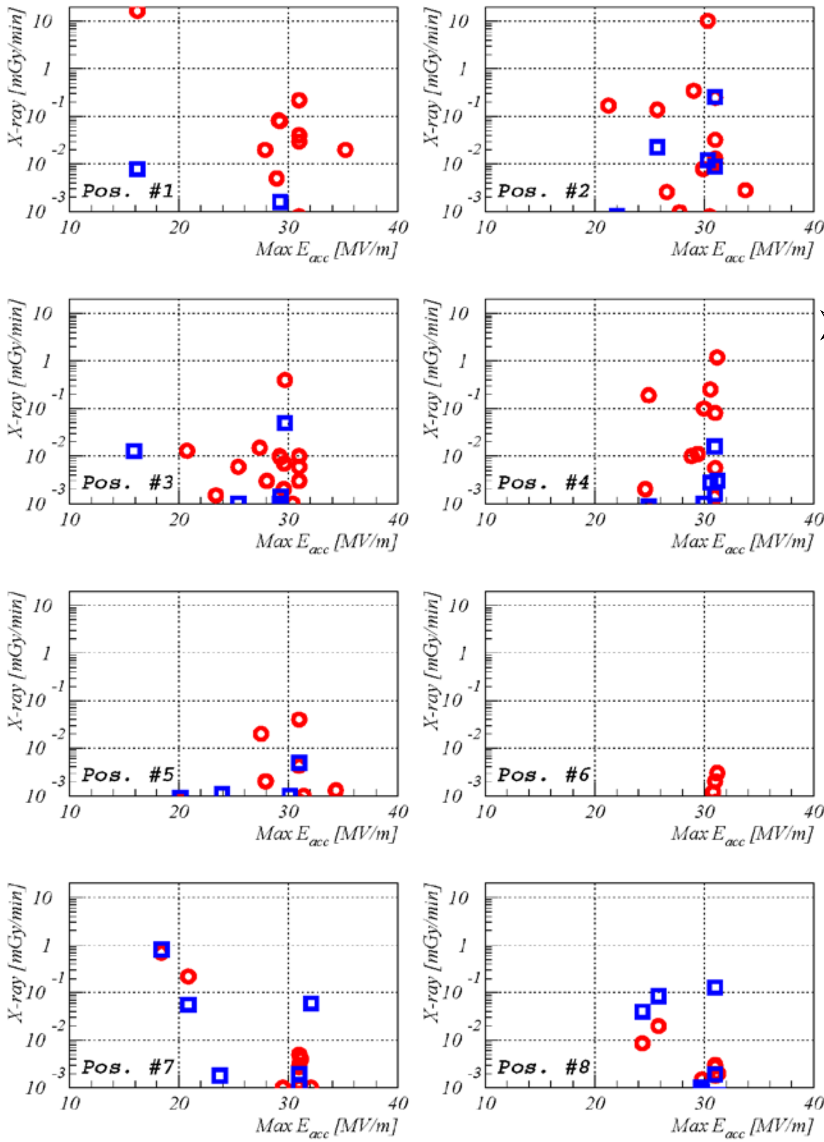
Radiation level in Cryomodule test at XATB/AMTF



Correlation between max. gradient and each radiation level for each cavity position

Radiation level at XATB/AMTF

Radiation level in Cryomodule test at XATB/AMTF



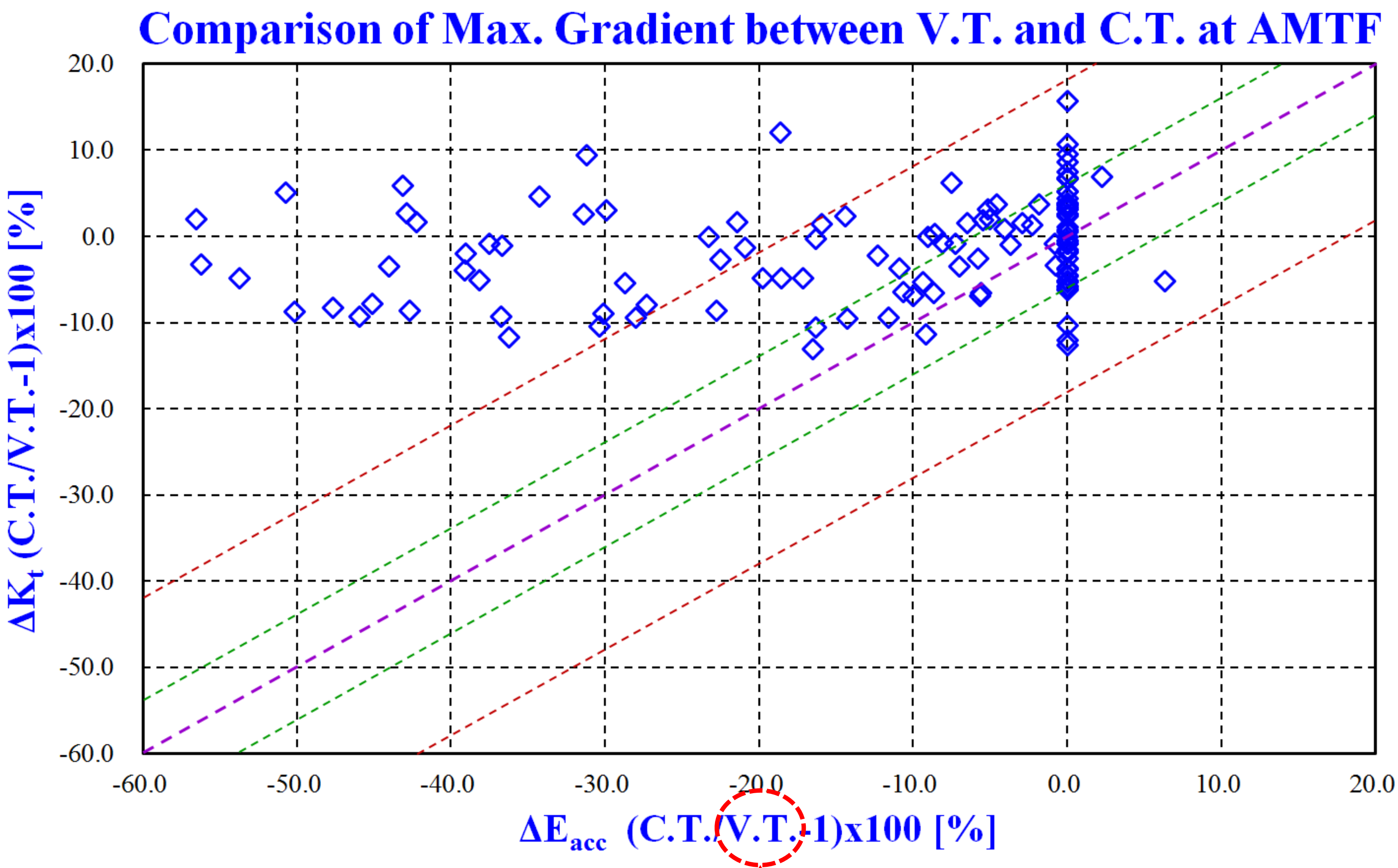
○; GUN side

□; DUMP side

- There is a trend to be observed the higher radiation level for the GUN side
  - Because, the distance is shorter for Cavity position 1
  - Depends on input coupler position (?)

Result with “true” error bar

Comparison between ΔE_{acc} and ΔK_t



Some errors are already included in result for V.T.!

Error estimation formula

V.T. $$\sigma_{total} = \sqrt{\sigma_{K_t}^2 + \sigma_{cable}^2 + \sigma_{Q_{ext}}^2}$$

each cable is different!

CM $$\sigma_{total} = \sqrt{\sigma_{K_t}^2 + \sigma_{cable}^2 + \sigma_{Q_L}^2}$$

common