CRYOGENIC RF TEST

# JLab US-DQW-002+1HOM
# 14-15 May 2018

Test data and pictures courtesy of H. Park, T. Powers (JLab)

First of all,

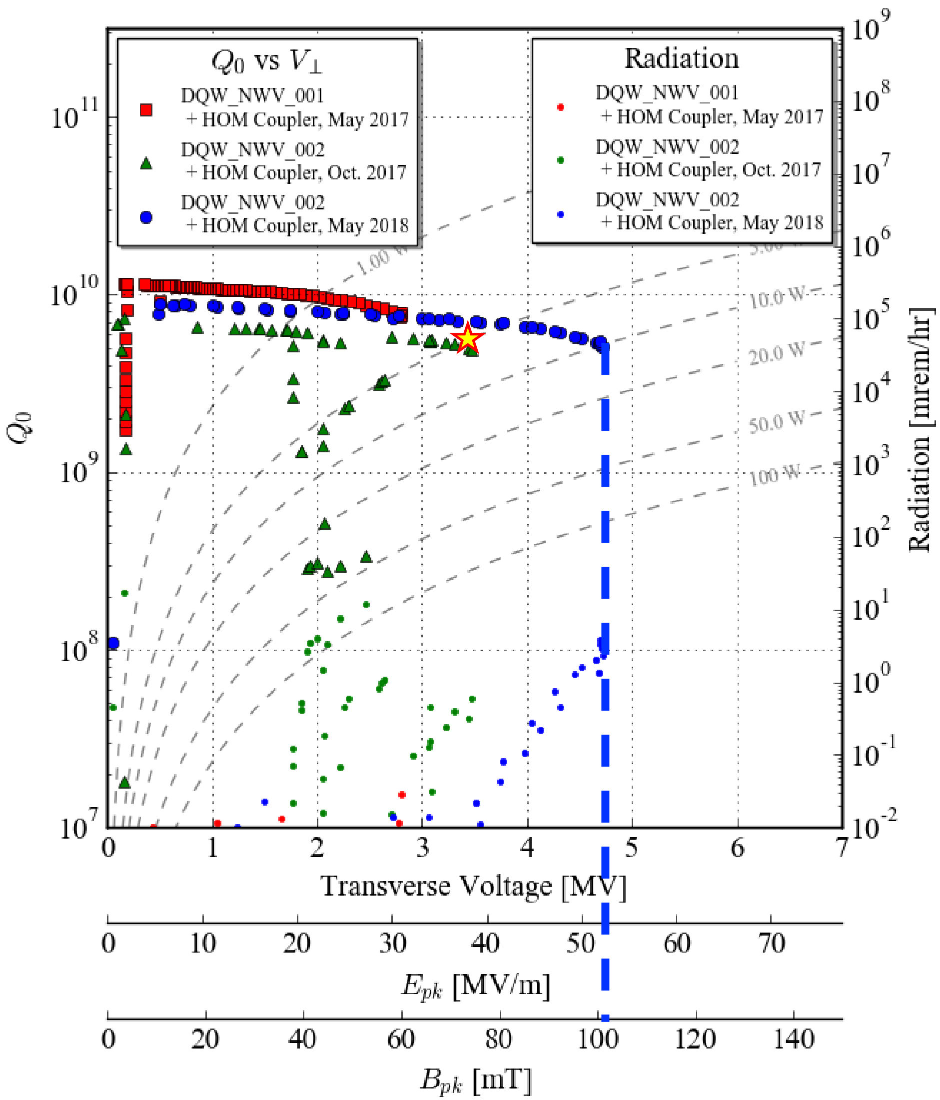
*Congratulations for the crabbed bunches in SPS!*

First time that proton bunches are crabbed!

23 May 2018

# Comparison with other tests

Plots courtesy of J. A. Mitchell (Lancaster U., Cockcroft, CERN)




***Great results:* high Vt *and* high Q at max Vt**

- Cavity performance complies with Funct. Spec. (~40% field margin, < 5 W at nominal Vt)
- At quench field (4.7 MV), maximum fields of:
  - 106 mT and 52 MV/m (cavity)
  - 63 mT and 34 MV/m (filter)
- Quench limits CW operation – magnetic quench
- No evident temperature increase prior to quench
- Only OST#2 (see later) responded to quench
- Hard multipacting band below 0.5 MV
- Field emission onset at 3.2 MV

***US-DQW* vs other crabs**

- RFD team reported 4.8 MV with no quench of RFD + HOM tested in JLab early this month.
- CERN DQW reached 3.4 MV prior to quench with 3 filters.

# Comparison with other tests

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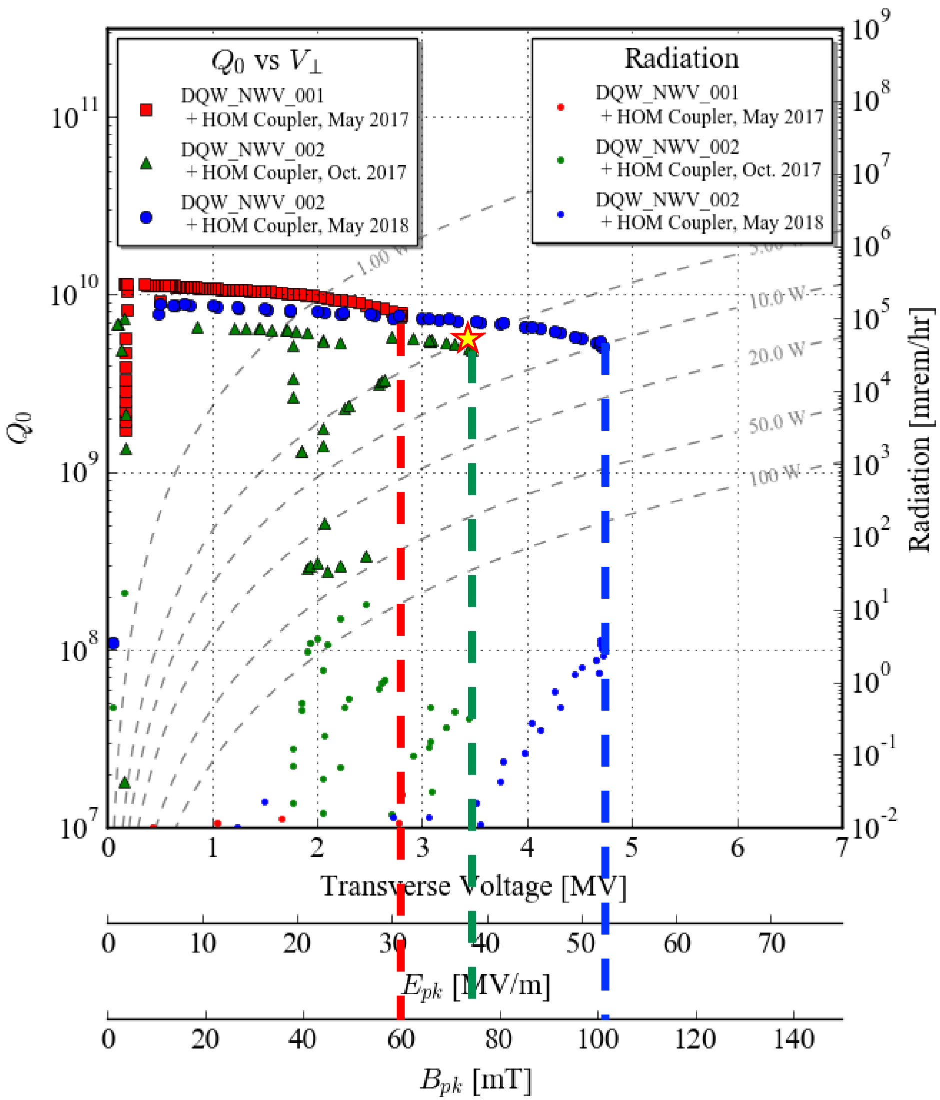



| Assembly | Test | Max Vt (MV) | FE (MV) | CX |
|---|---|---|---|---|
| DQW-001+HOM<br>Filter: *rinse*<br>*Flange set #b* | May'17 | 2.8 | n/a | #B-5<br>#D-7<br>#E-8 |
| DQW-002+HOM<br>Cavity: *light BCP, HPR*<br>*Flange set #a* | Oct'17 | 3.6 | n/a | #F-4<br>#D-7<br>#E-8 |
| DQW-002+HOM<br>Filter: *100 um BCP, 600C, light BCP, rinse*<br>*Flange set #a* | Jan'18 | 3.1 | 2.6 | check |
| DQW-002+HOM<br>Cavity: *HPR*<br>Filter: *rinse*<br>Cavity+filter: *120C*<br>*Flange set #a* | May'18 | 4.7 | 3.2 | none |

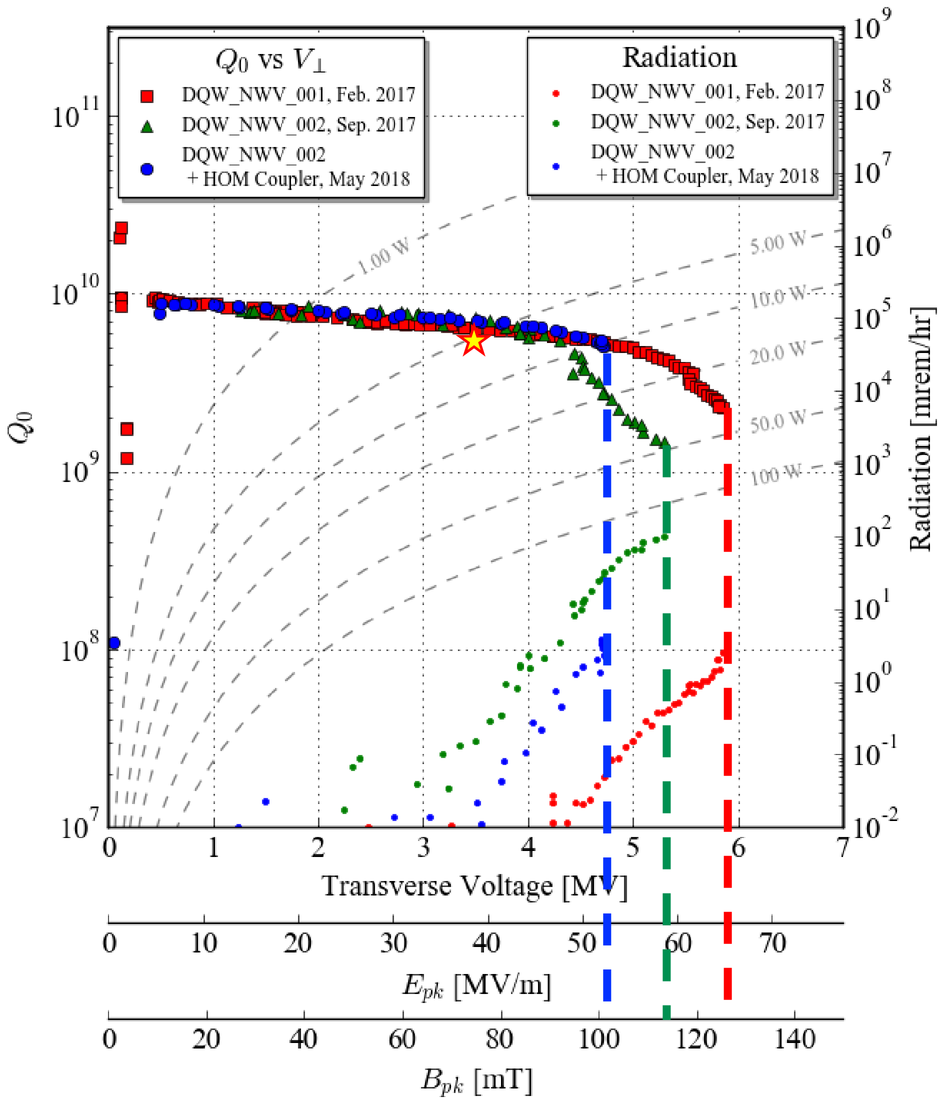
# Comparison with other tests

Plots courtesy of J. A. Mitchell (Lancaster U., Cockcroft, CERN)

*"Bare" vs "cavity with filter"*

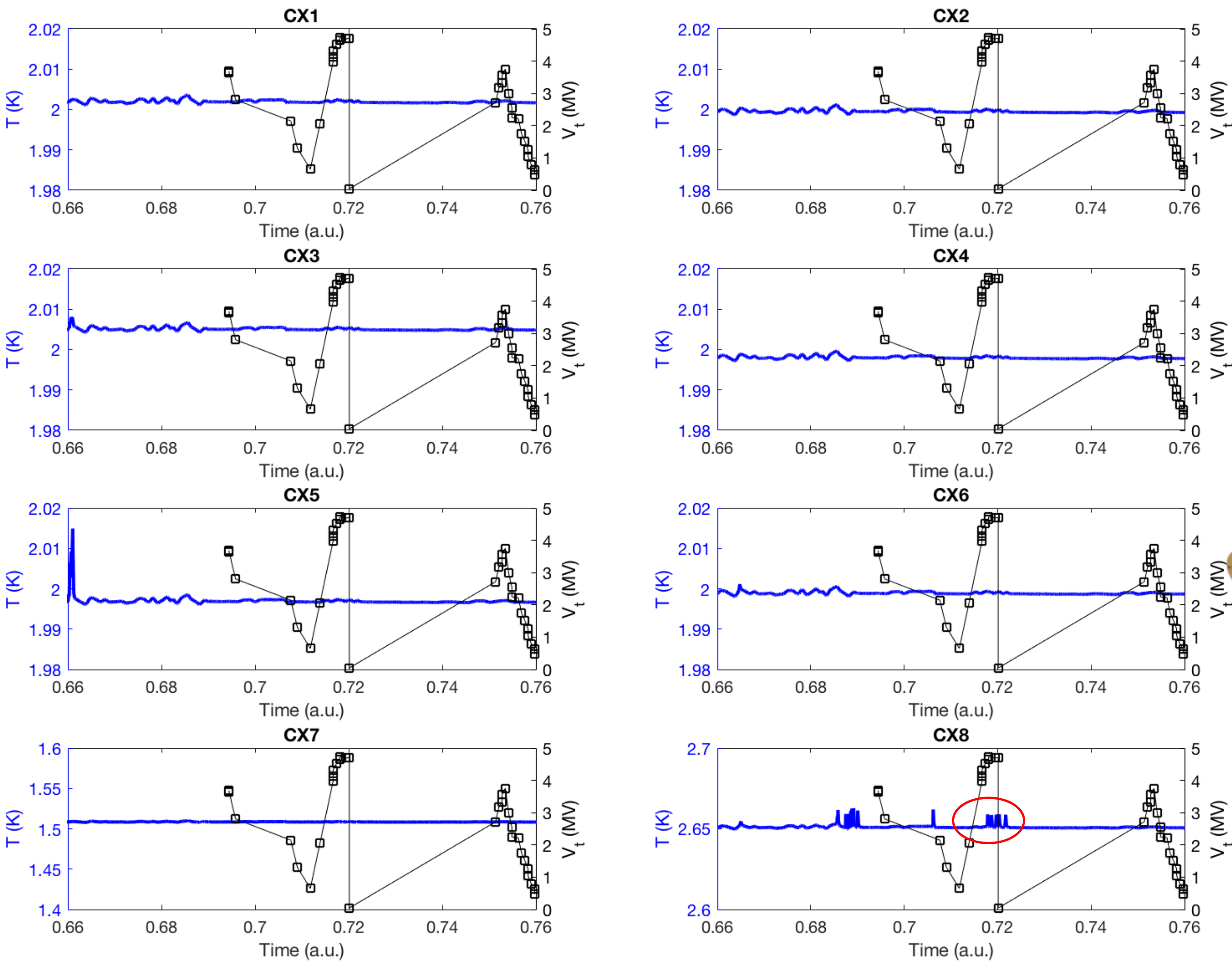
- Last test reached the highest quench field of any DQW cavity with filter (incl. CERN ones).
- No evidence of High-Field Q-slope (HFQS).
- Improved FE onset (3.2 MV) w.r.t. bare NWV-DQW-002 (2.8 MV) -- with great impact on Q, but lower onset than for bare NWV-DQW-001 (4.1 MV).

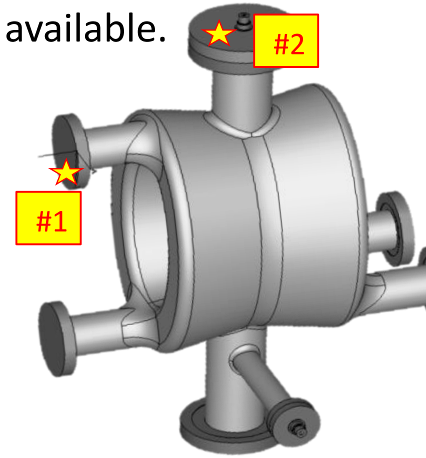
  *-- standard surface treatment required --*
- Maximum field is still lower than for best performing bare DQW cavities.

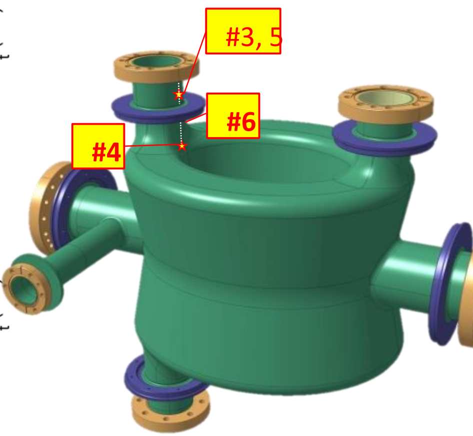


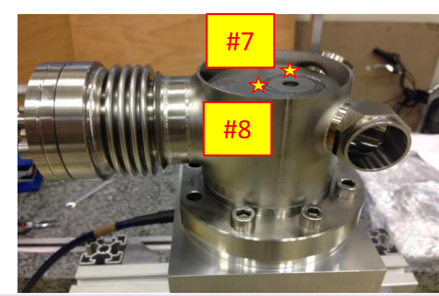
# Signal from CERNOX – a quiet run

- CERNOX data does cover testing time on May 15. Only CERNOX data for May 14 available.
- No significant temperature increase from CERNOX – note small T range.



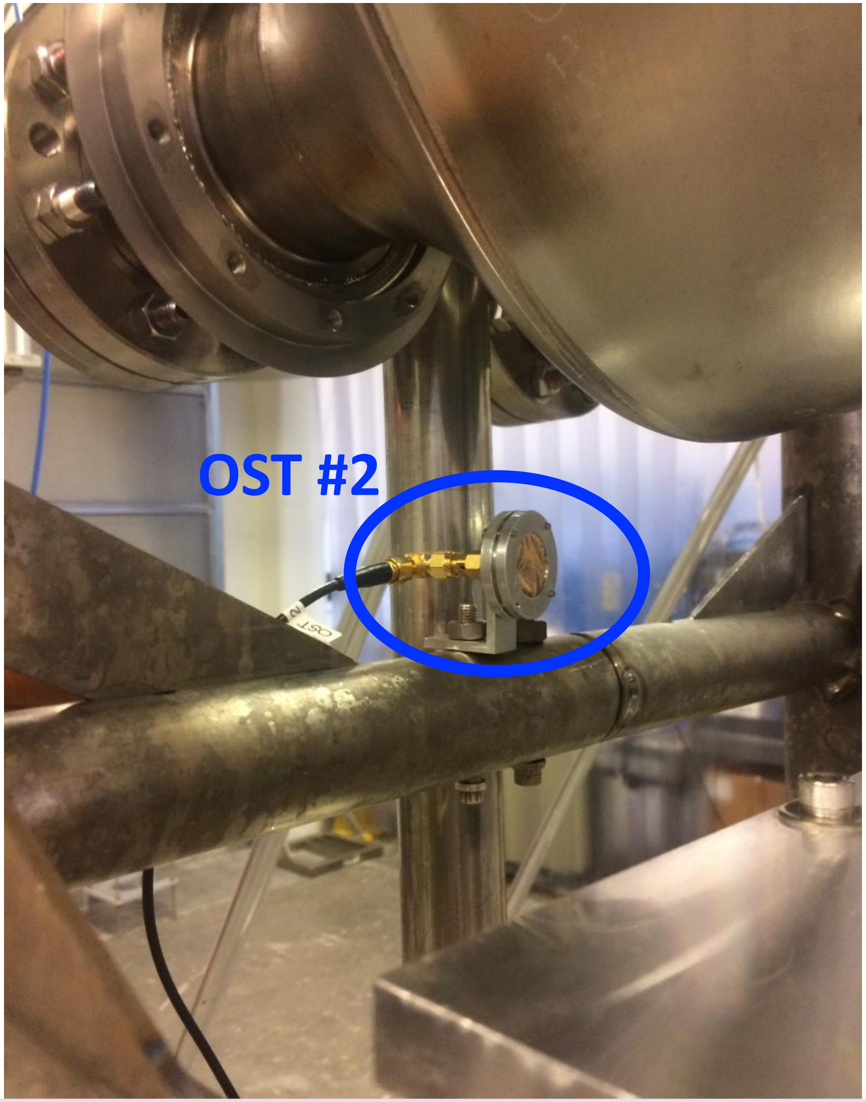



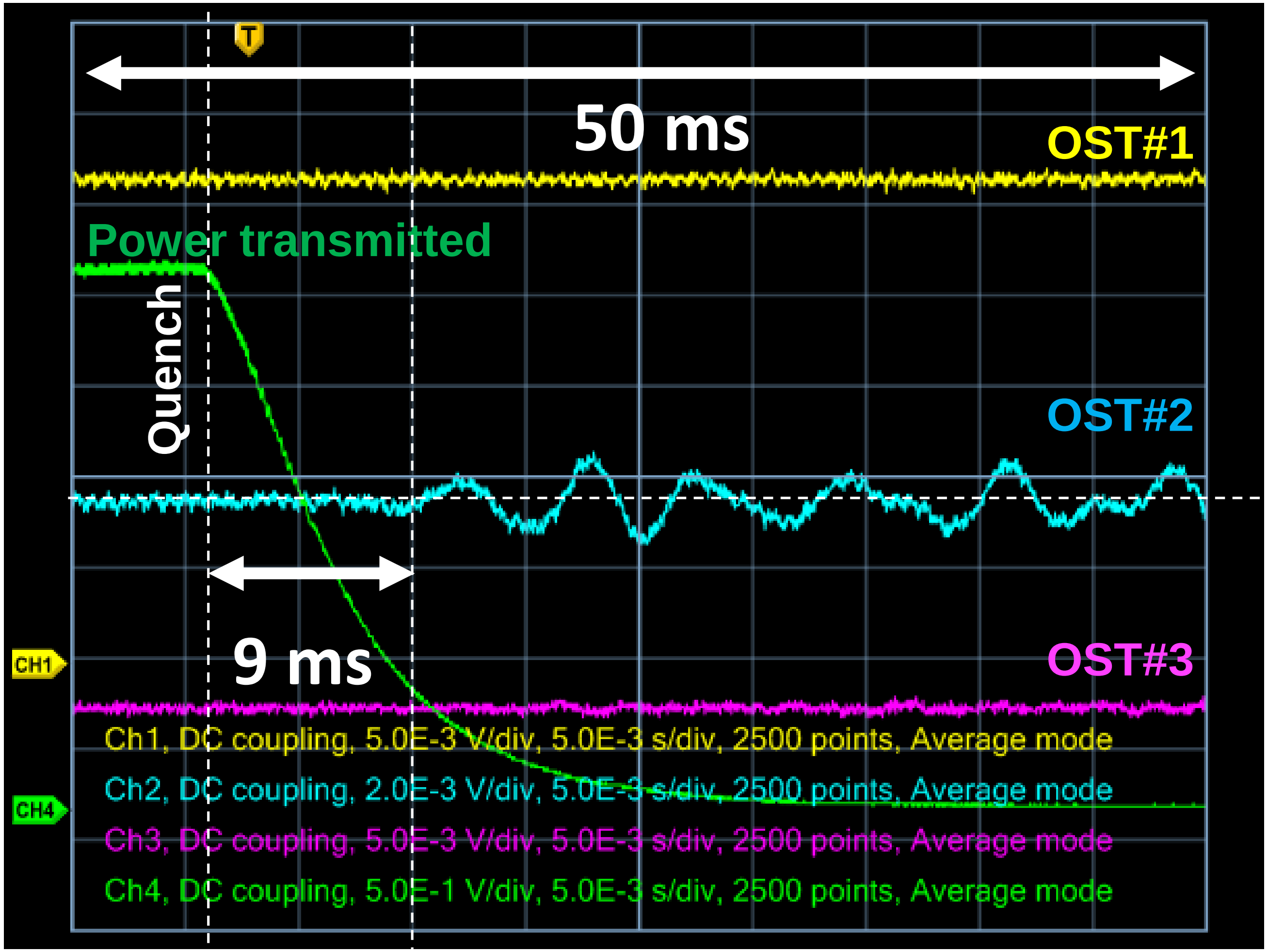
# Location of Oscillating Superleak Transducers (OST)

Five (5) OSTs on the bottom around HOM filter and one (1)OST on the top looking at HOM.



# Signal from OSTs – event 1

With quench, signal only detected from OST#2.
OST signal appears 9 ms after quench → distance is about 0.14 m (v =15.6 m/s at 1.98




TDS 2024B - 12:29:06 PM 5/15/2018

# Second sound in helium II – temperature dependence

**The two-fluid theory and second sound in liquid helium**

Russell J. Donnelly

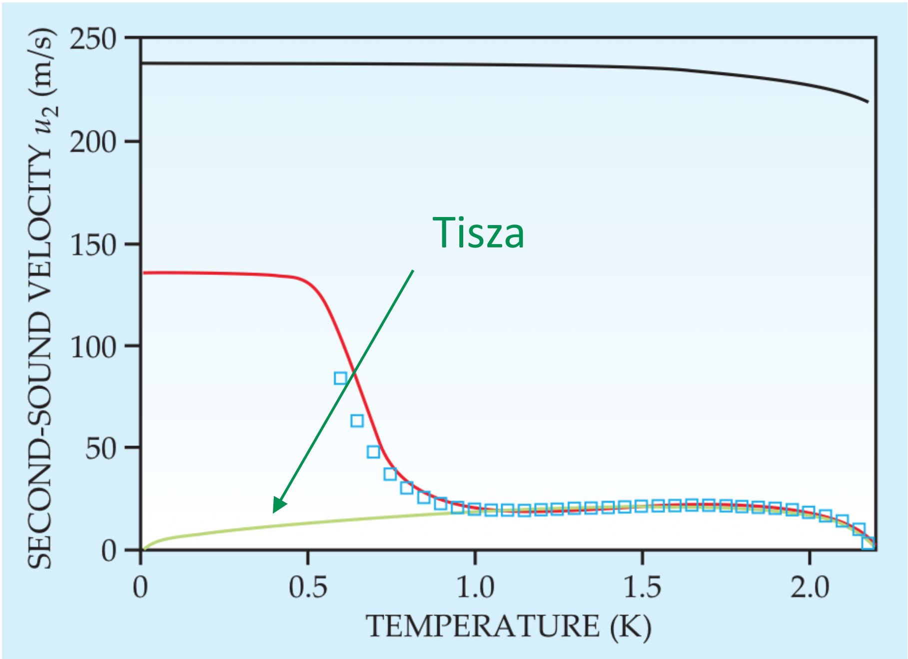
https://physicstoday.scitation.org/doi/pdf/10.1063/1.3248499

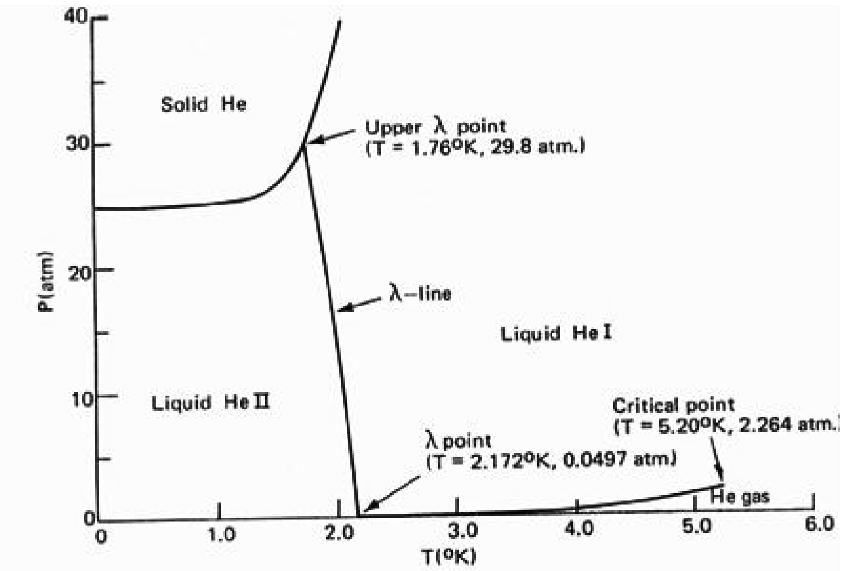
Citation: Physics Today **62**, 10, 34 (2009); doi: 10.1063/1.3248499

Tisza's analysis led to the expression[1]

$$u_2 = 26\sqrt{\frac{T}{T_\lambda}\left[1-\left(\frac{T}{T_\lambda}\right)^{5.5}\right]}\ \text{m/s},$$

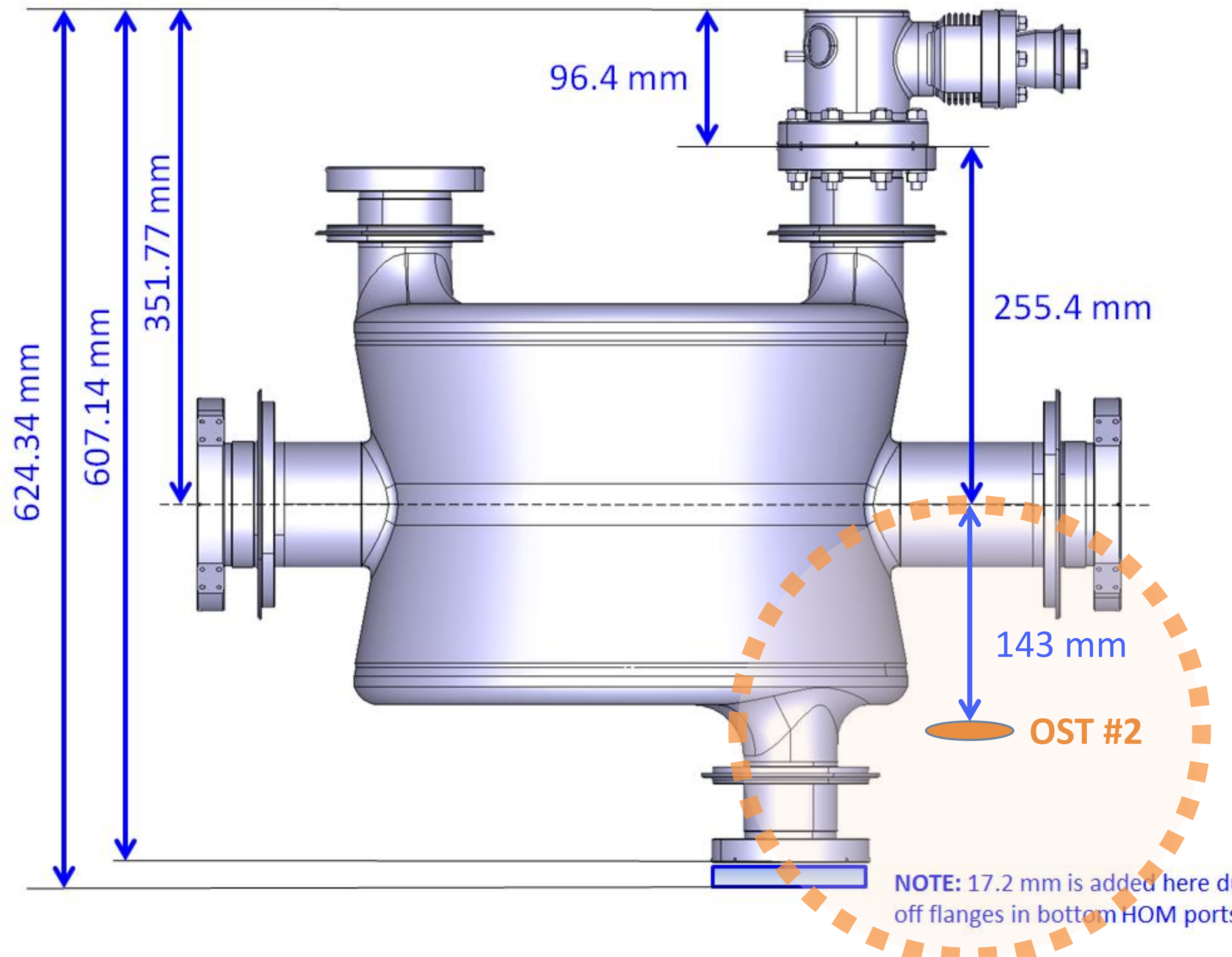
Lambda point ($T_\lambda$) of helium is 2.17 K at 1 atm.




The phase diagram of He[4].

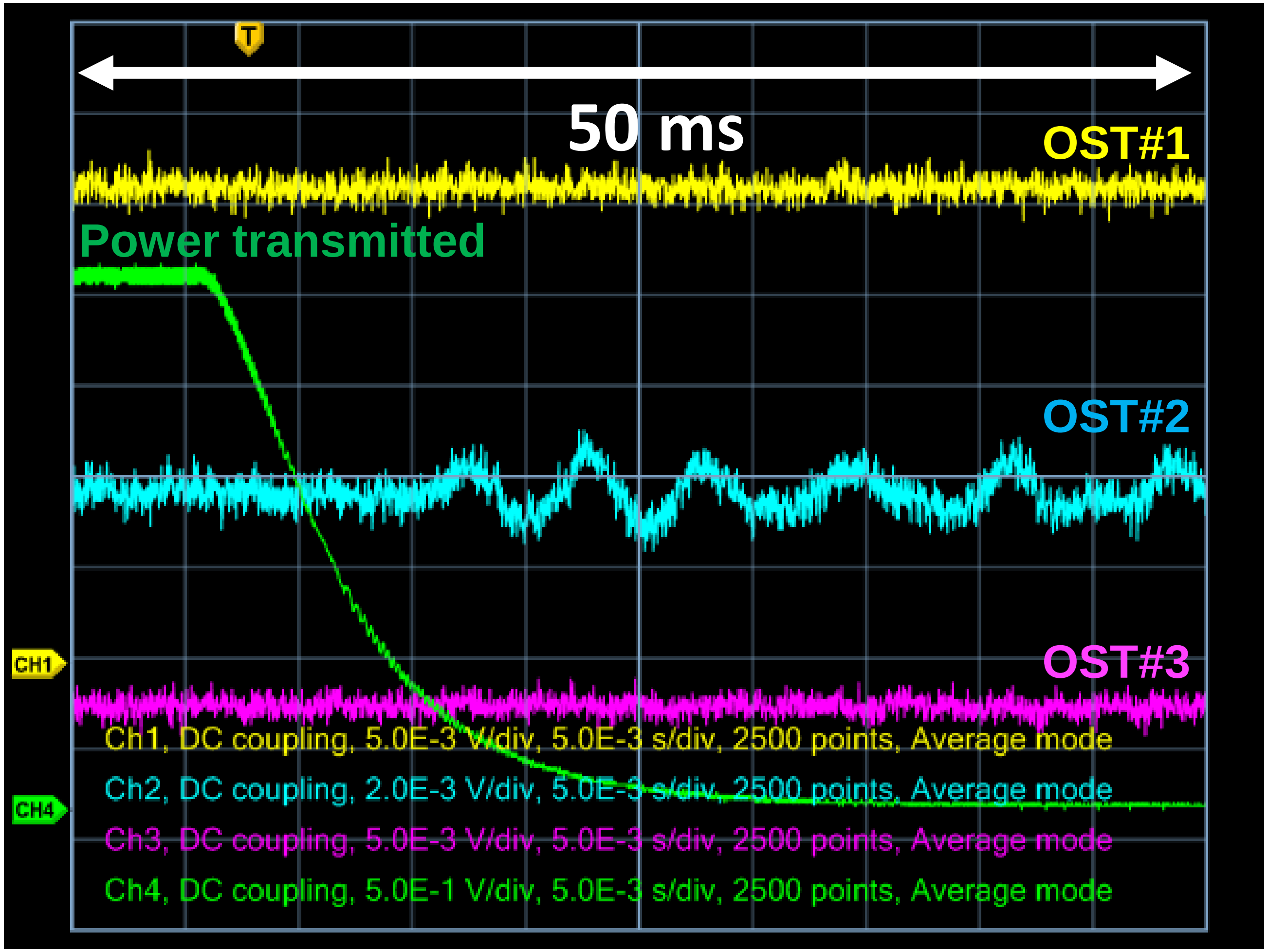
# Dressed cavity dimensions and OST #2 location




**NOTE:** 17.2 mm is added here due to blank off flanges in bottom HOM ports

# Signal from OSTs – event 2

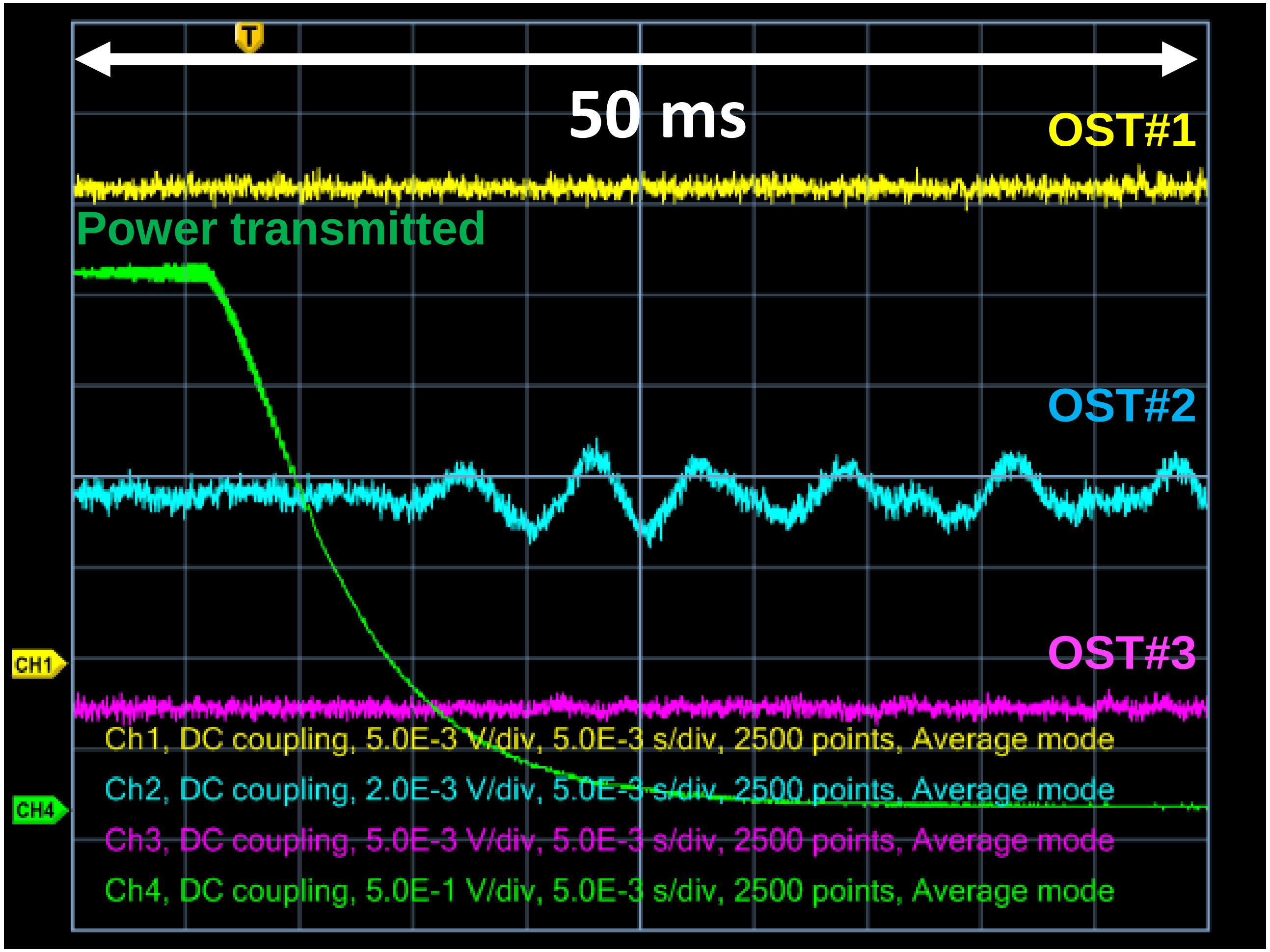
With quench, signal only detected from OST#2.
OST signal appears 9 ms after quench → distance is about 0.14 m (v =15.6 m/s at 1.98




TDS 2024B - 1:30:34 PM 5/15/2018

# Signal from OSTs – event 3

With quench, signal only detected from OST#2.
OST signal appears 9 ms after quench → distance is about 0.14 m (v =15.6 m/s at 1.98

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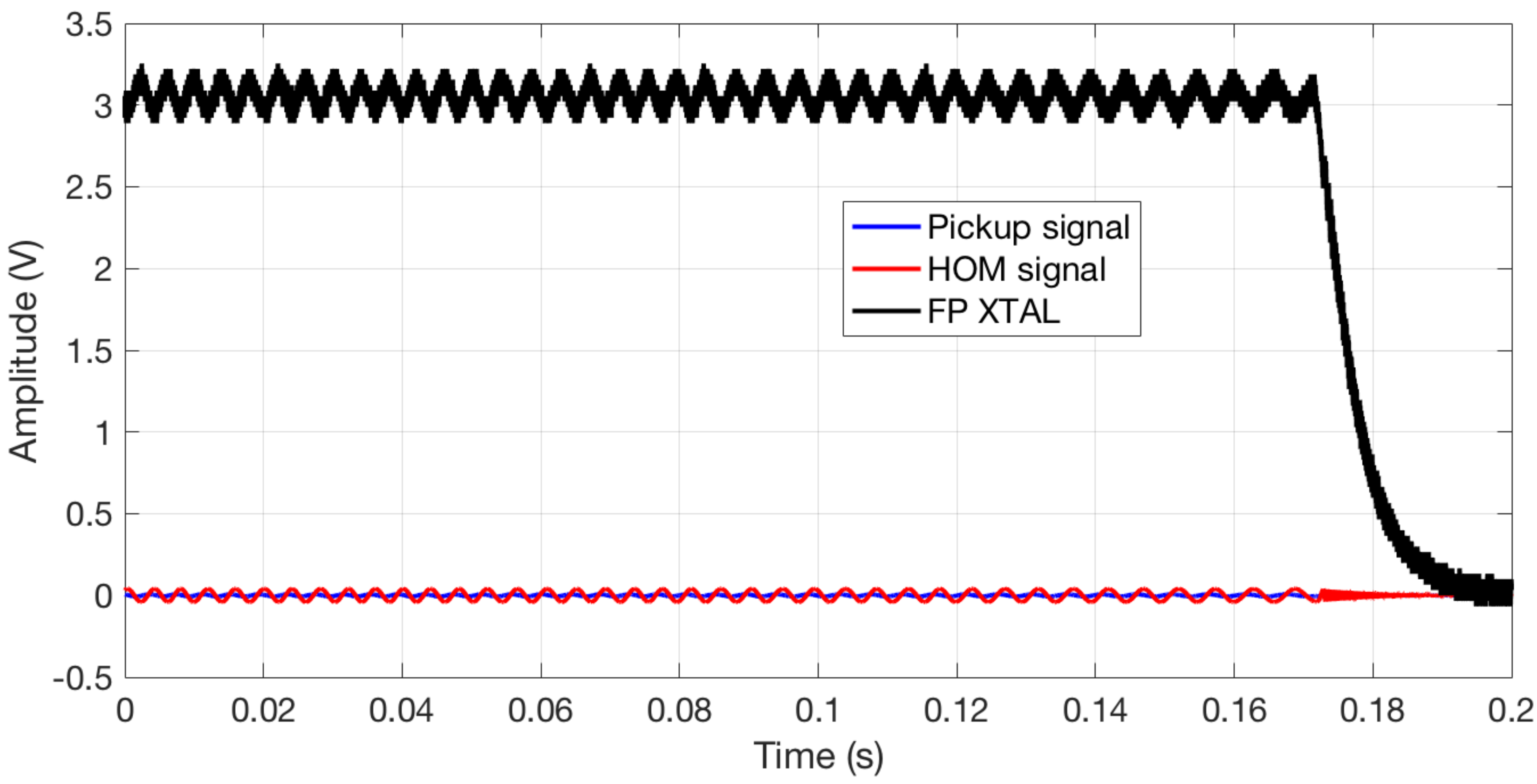
# Time domain input and HOM signals

Analysis on-going.



# Comparison with other tests – coupling

| Assembly | Test | *External Q for input probe,* $Q_{ext,IC}$ (aka $Q_1$) | *External Q for pickup probe,* $Q_{ext,PC}$ (aka $Q_2$) |
|---|---|---|---|
| Design | CST | 2e9 | 8e11 |
| NWV-DQW-001 | Warm | 1.92e9 | 1.77e12 |
| | Cold Feb'17 | 2.07e9 | 1.60e12 |
| NWV-DQW-002 | Warm | 1.83e9 | 1.19e12 |
| | Cold Jun'17 | 2.05e9 | 1.78e12 |
| | Cold Sep'17 | 1.83e9 | 1.20e12 |
| NWV-DQW-001 + 1HOM | Cold May'17 | 2.10e9 | 1.47e12 |
| NWV-DQW-002 + 1HOM | Cold Oct'17 | 1.93e9 | 1.21e12 |
| | Cold Jan'18 | n/a | n/a |
| | Cold May'18 | 2.12e9 | 1.21e12 |

When was the cavity disassembled?

| *Multipacting predicted* | | | *Found during tests w/o filter* | |
|---|---|---|---|---|
| MP band [MV] | Region | Code | MP voltage [MV] | Comments |
| (0.26) | Cavity waist | CST | 0.17, 0.2 | Hard. Conditioned 1.5h at 10-20 W input power before first breach through. Every quench will cause cavity to drop into this zone for about 30 minutes. Found for every test. |
| (0.1 – 0.5) | Cavity waist | ACE3P | | |
| (1.06) | Cavity-small port | CST | 1.1 | Soft |
| (1.0 – 2.5) | Waist | CST | 1.9, 2.3 | Soft |
| (0.8 – 3.5) | Lunette | CST | 1.9, 2.3, 3.0 | Soft |
| (1.6 – 3.0) | Cavity-beam port<br>Cavity-small port | ACE3P | 1.9, 2.3, 3.0 | Soft |
| (4.0 – 4.5) | Lunette | ACE3P | 4.5 | Soft. Quenched into this MP band for a few minutes. |

| *Predicted* | | | *Found during tests with or w/o filter* | |
|---|---|---|---|---|
| MP band [MV] | Region | Code | MP voltage [MV] | Comments |
| (0.26) | Cavity waist | CST | 0.17, 0.2 | Hard. |
| (0.1 – 0.5) | Cavity waist | ACE3P | | |
| (2.12) | HOM stub | CST | (1.8 - 2.3) | Soft (May'17 and Oct'17) |
| | | | (2 - 3) | Soft (only May'17) |

# Lessons learned and next test

## LESSONS LEARNED

- At this point, **surface treatment is key** to reach high fields in the cavity with filters.
- Jamie's **improved HOM filter** – based on the design under test – provides better transmission of critical HOMs and simplifies manufacturability.
  - → Any considerations about cleaning?
- In the last test, there is **barely any Q degradation as field increases**. As we envision the complete cavity setup with 3 filters instead of only 1:
  - → Can we assume the same Q degradation with 1 and 3 filters?
  - → Adding filters just multiplies risk of early quench.

## NEXT TESTS

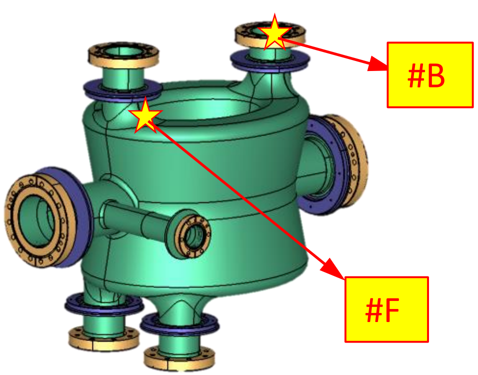
- SPS MDs: is **low-energy multipacting** band posing any issue for cavity operation?
- Perform HPR on cavity and rinse of filter before every assembly for a test followed by 120C bake.
- Revisit OST location.

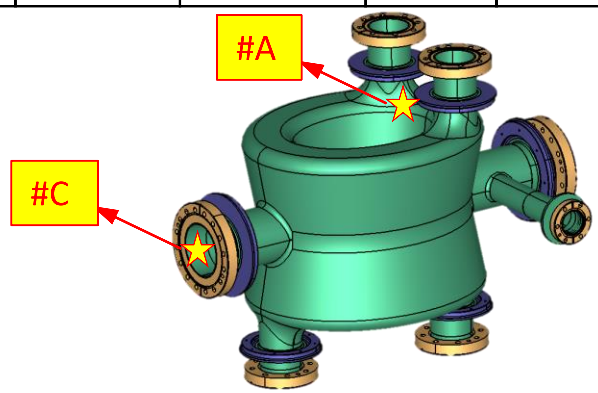
1) Discriminate if quench in **cavity or filter**…
   → use spacer to lower Hpk in filter and check if cavity+HOM reach higher field level.

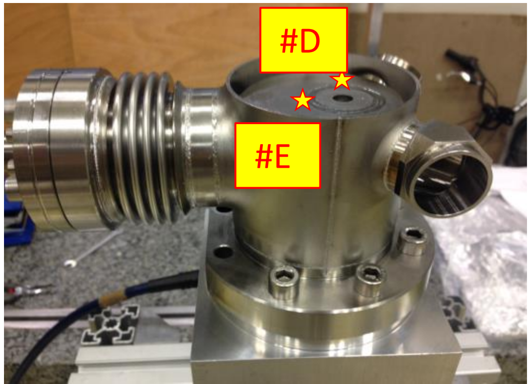
2) Test with 2$^{nd}$ filter on cavity 001 and test of cavity with 2 filters (one top, one bottom)

# Comparison with other tests

| | <u>Assembly</u> | <u>Test</u> | <u>Max Vt (MV)</u> | <u>FE (MV)</u> | <u>CX</u> |
|---|---|---|---|---|---|
| I | DQW-001+HOM<br>Filter: *rinsing*<br>*Flange set #b* | May'17 | 2.8 | n/a | #B-5 (FPC port flange)<br>#D-7 (HOM filter)<br>#E-8 (HOM filter) |
| II | DQW-002+HOM<br>Cavity: *light BCP, HPR*<br>*Flange set #a* | Oct'17 | 3.6 | n/a | #F-4 (HOM port base)<br>#D-7 (HOM filter)<br>#E-8 (HOM filter) |
| III | DQW-002+HOM<br>Filter: *100 um BCP, 600C, light BCP, rinsing*<br>*Flange set #a* | Jan'18 | 3.1 | 2.6 | [FE limited]<br>Check |
| IV | DQW-002+HOM<br>Cavity: *HPR*<br>Filter: *rinsing*<br>Cavity+filter: *120C bake*<br>*Flange set #a* | May'18 | 4.7 | 3.2 | None |

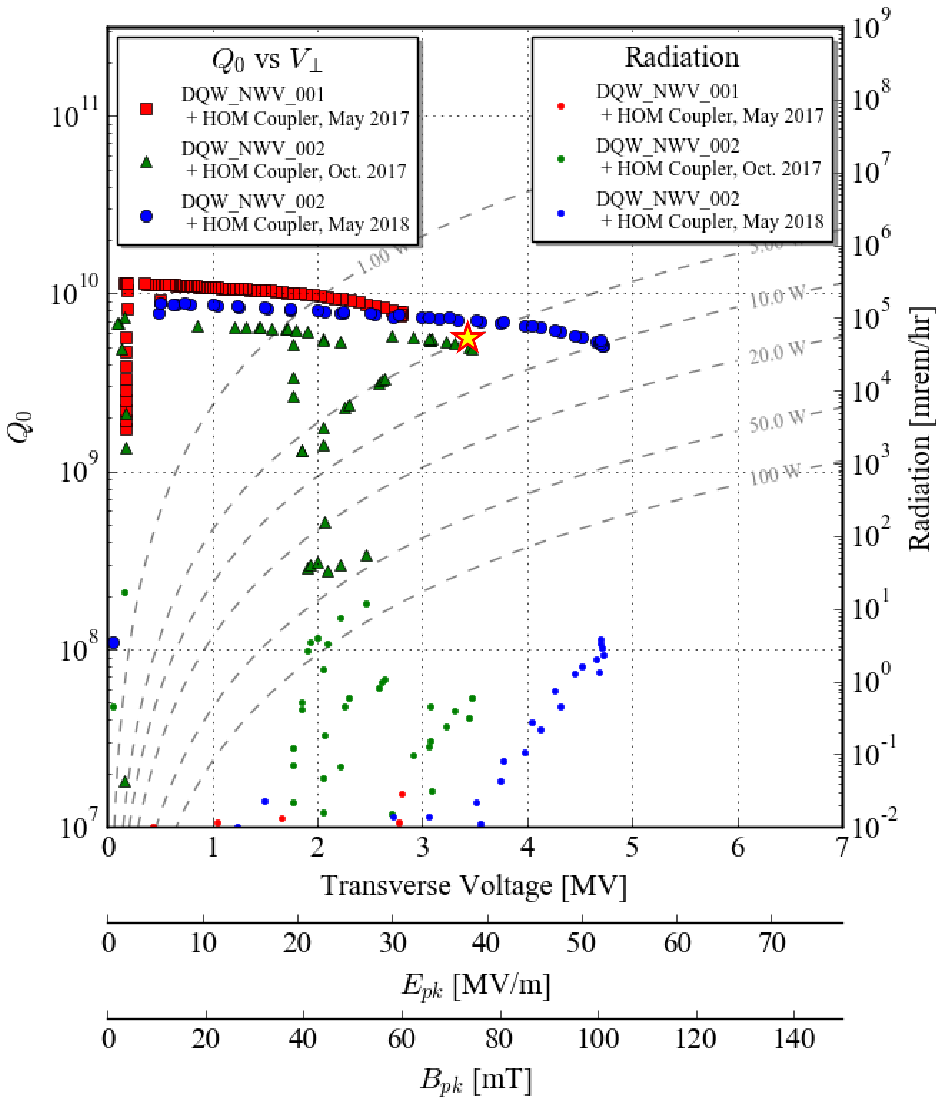


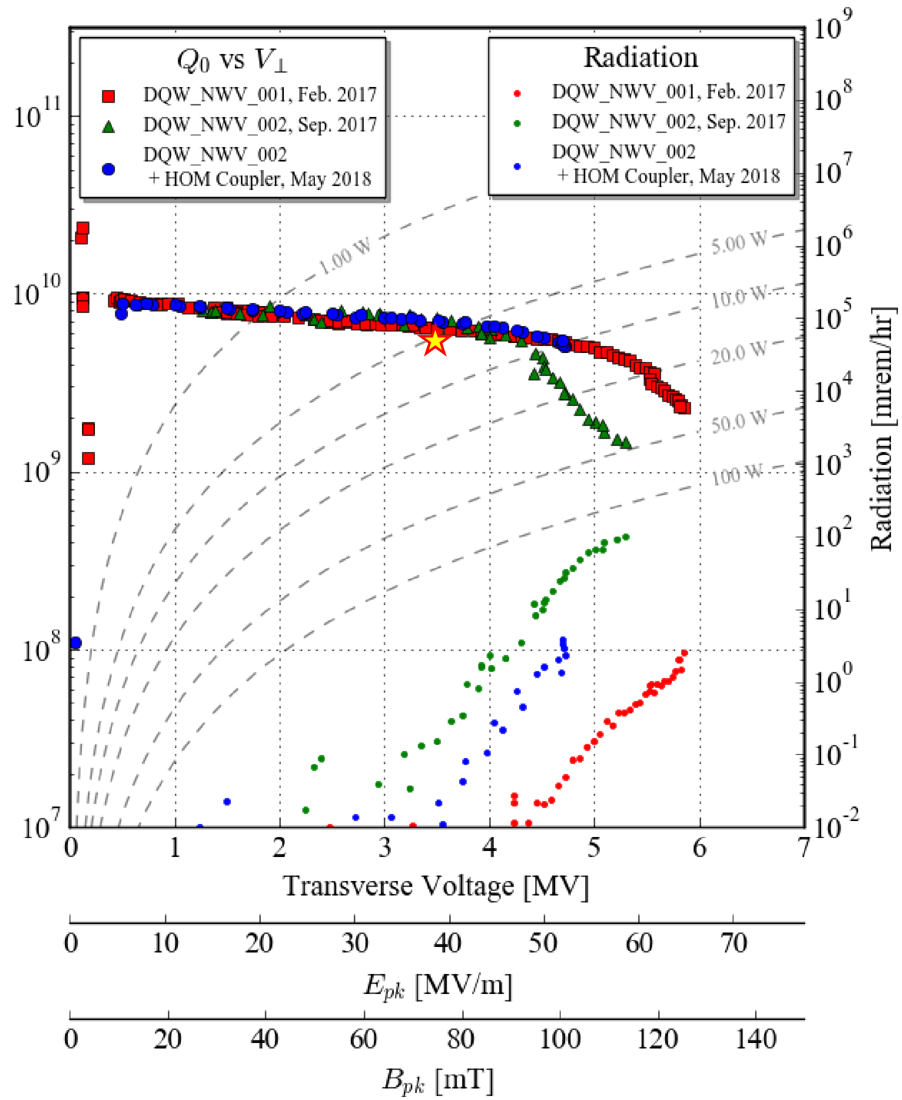



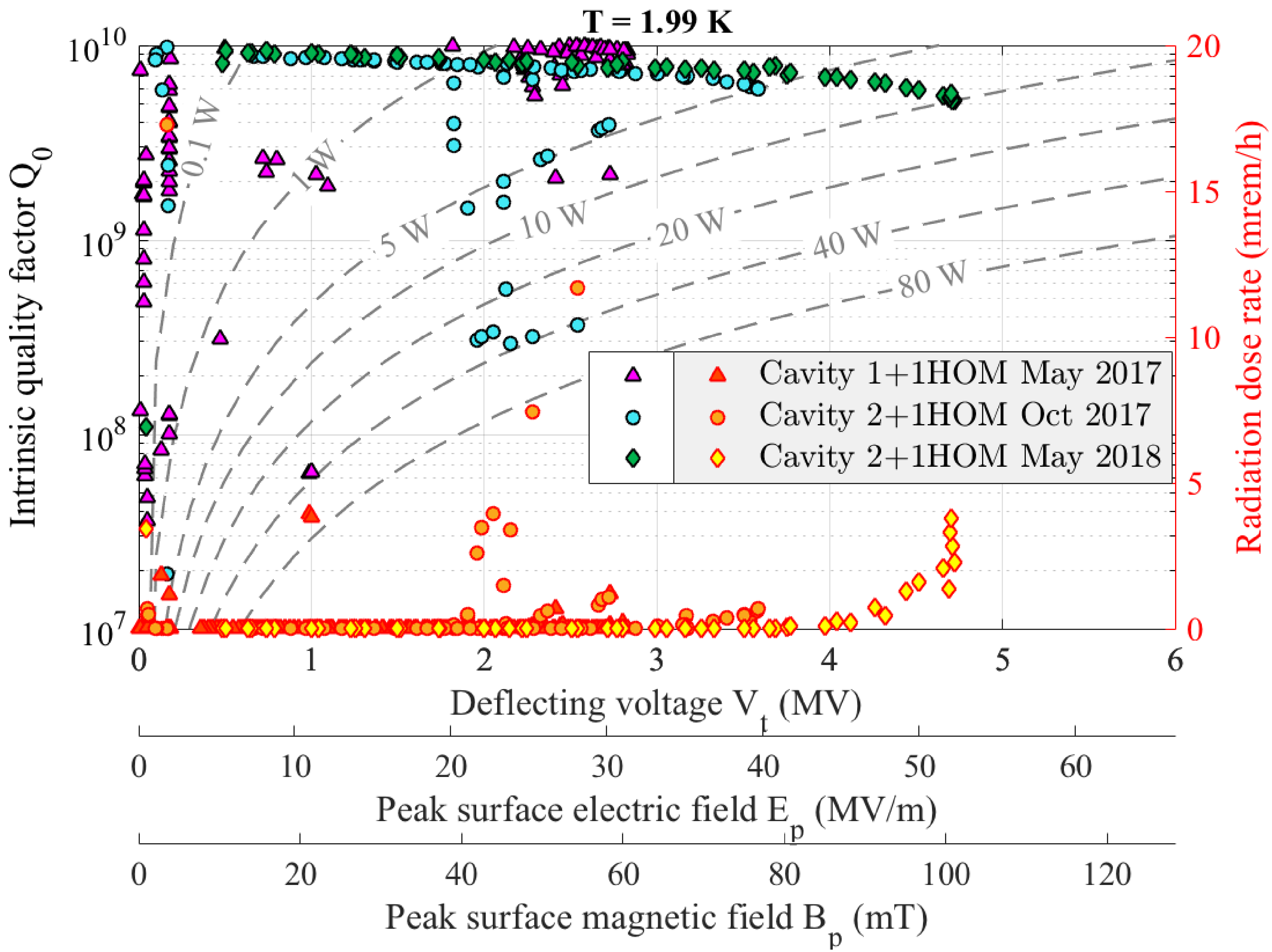



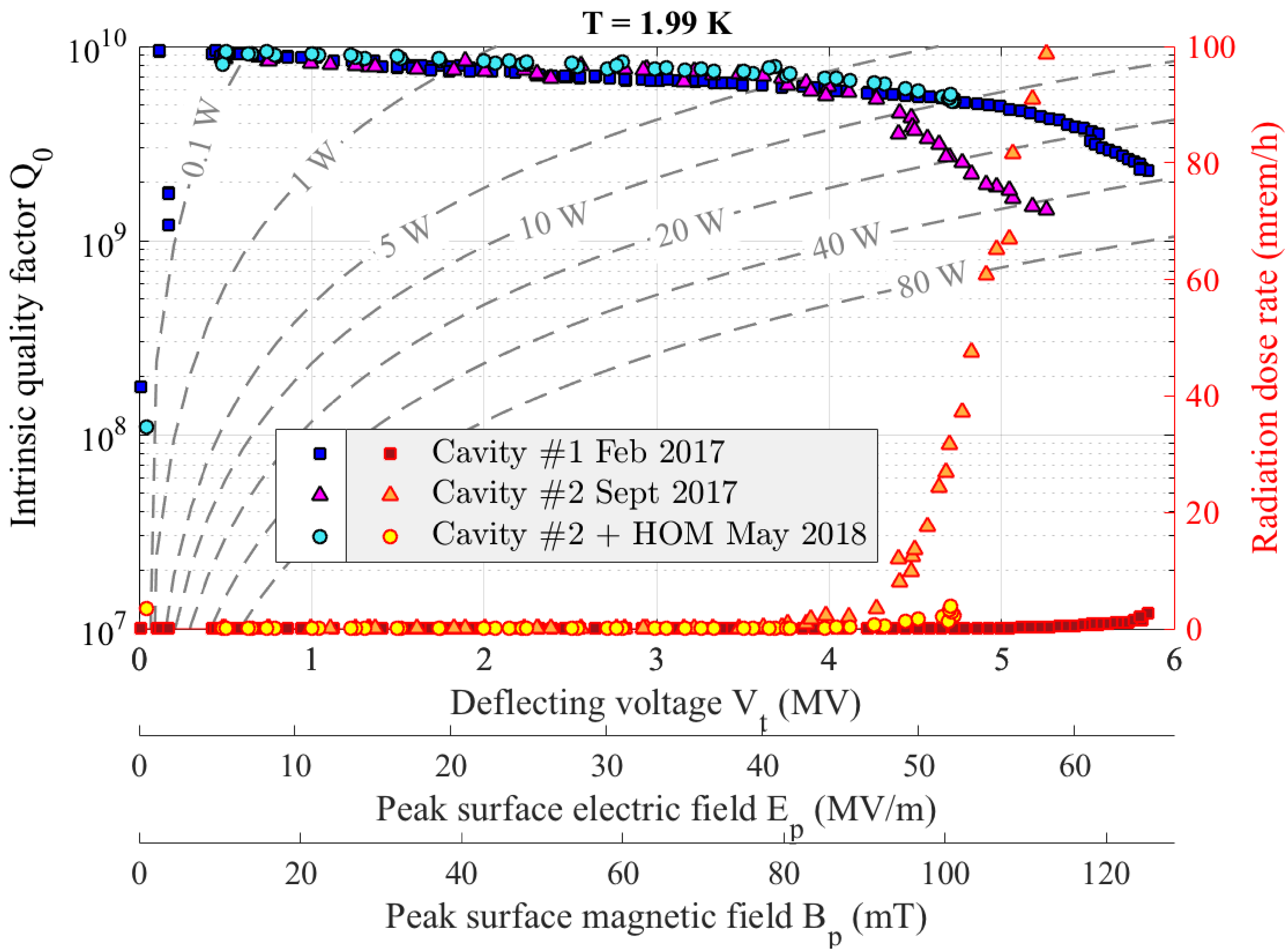
# Comparison with other tests

Plots courtesy of Jamie Mitchell (Lancaster U., Cockcroft, CERN)

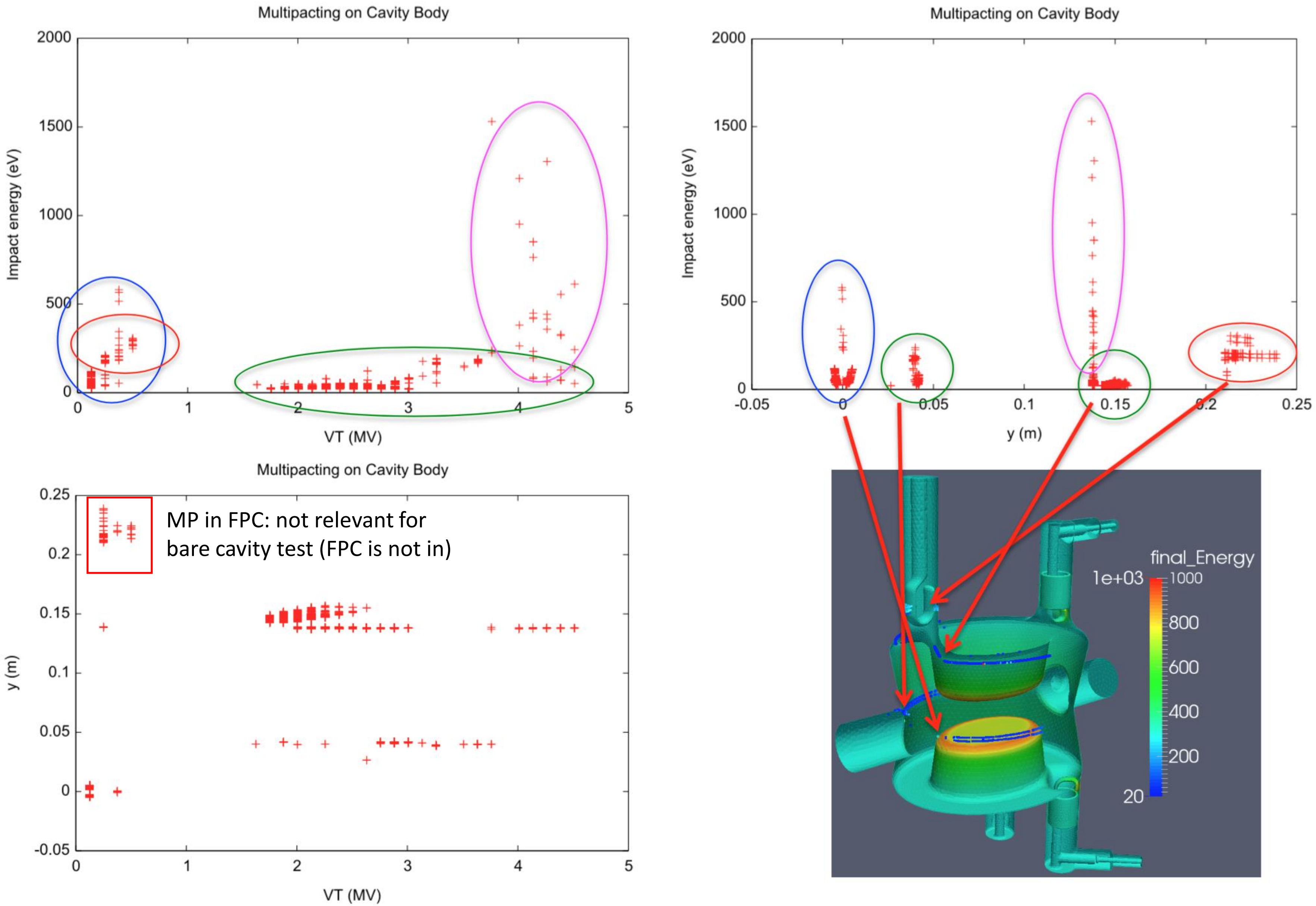


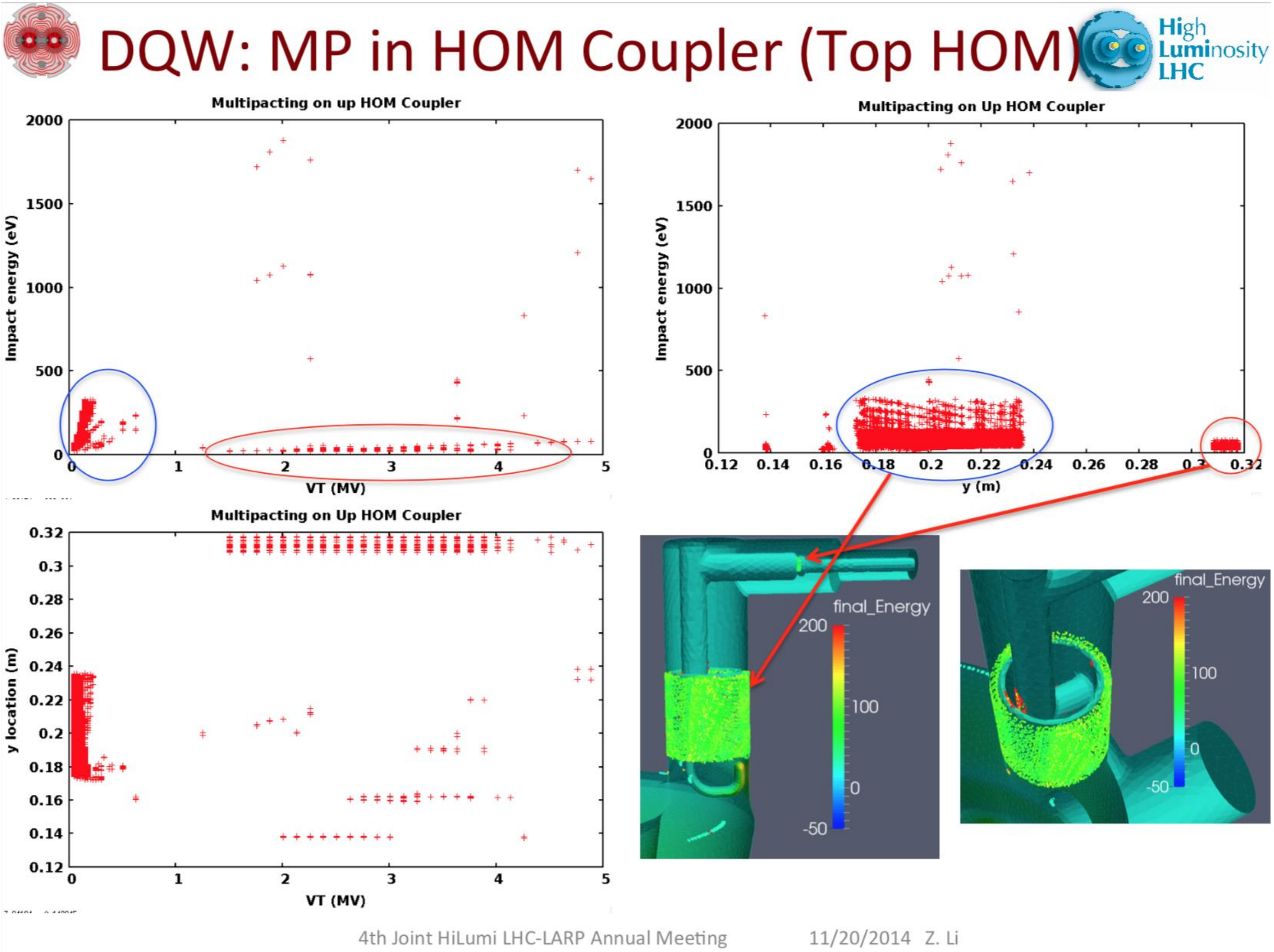

T = 1.99 K
Intrinsic quality factor $Q_0$
Radiation dose rate (mrem/h)
$10^{10}$
$10^{9}$
$10^{8}$
$10^{7}$
20
15
10
5
0
0.1 W
1 W
5 W
10 W
20 W
40 W
80 W
Cavity 1+1HOM May 2017
Cavity 2+1HOM Oct 2017
Cavity 2+1HOM May 2018
0 1 2 3 4 5 6
Deflecting voltage $V_t$ (MV)
0 10 20 30 40 50 60
Peak surface electric field $E_p$ (MV/m)
0 20 40 60 80 100 120
Peak surface magnetic field $B_p$ (mT)


T = 1.99 K
Intrinsic quality factor $Q_0$
Radiation dose rate (mrem/h)
$10^{10}$
$10^{9}$
$10^{8}$
$10^{7}$
100
80
60
40
20
0
0.1 W
1 W
5 W
10 W
20 W
40 W
80 W
Cavity #1 Feb 2017
Cavity #2 Sept 2017
Cavity #2 + HOM May 2018
0 1 2 3 4 5 6
Deflecting voltage $V_t$ (MV)
0 10 20 30 40 50 60
Peak surface electric field $E_p$ (MV/m)
0 20 40 60 80 100 120
Peak surface magnetic field $B_p$ (mT)

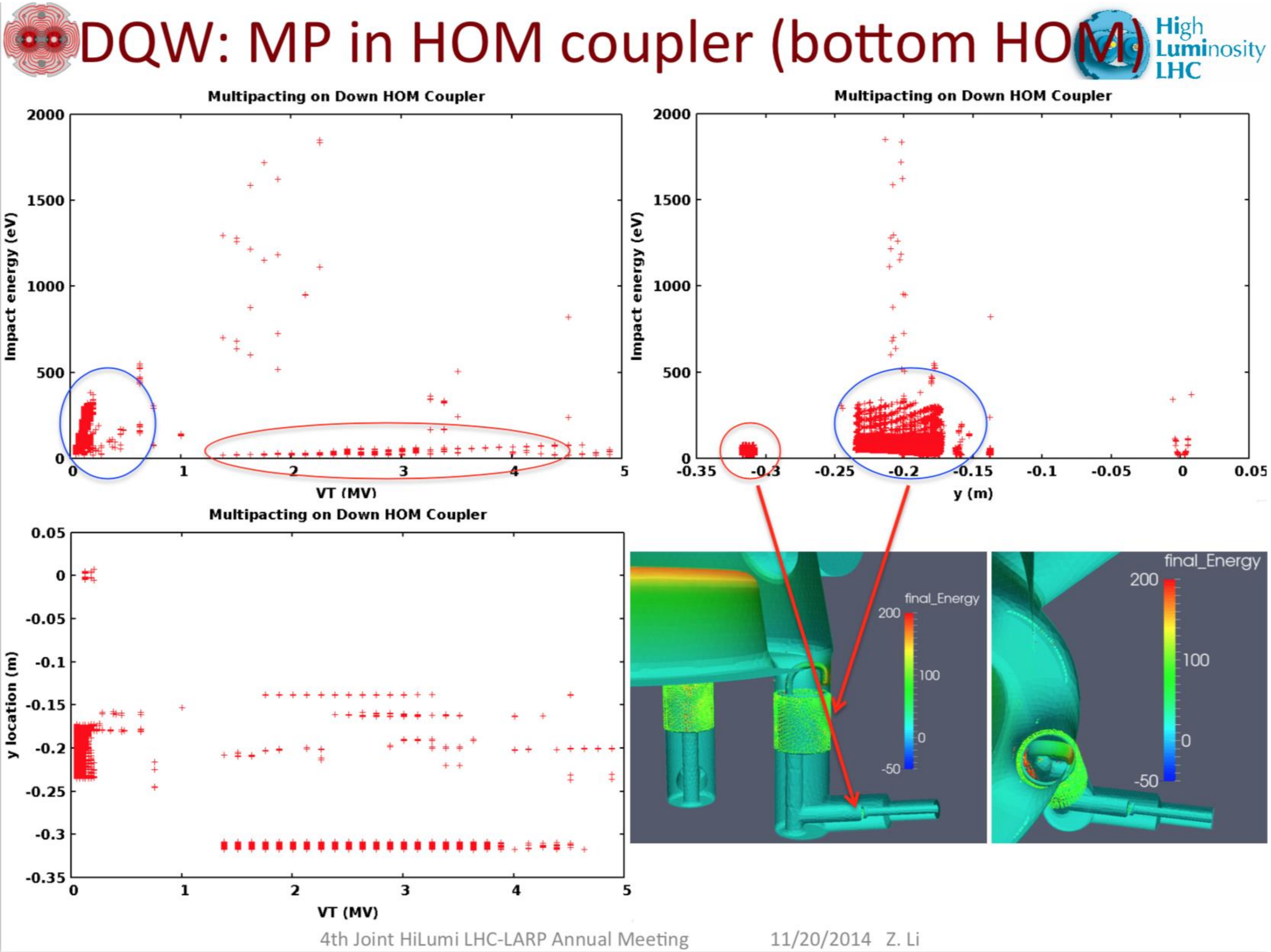
# Multipacting bands [Zenghai Li (SLAC), November 2014]



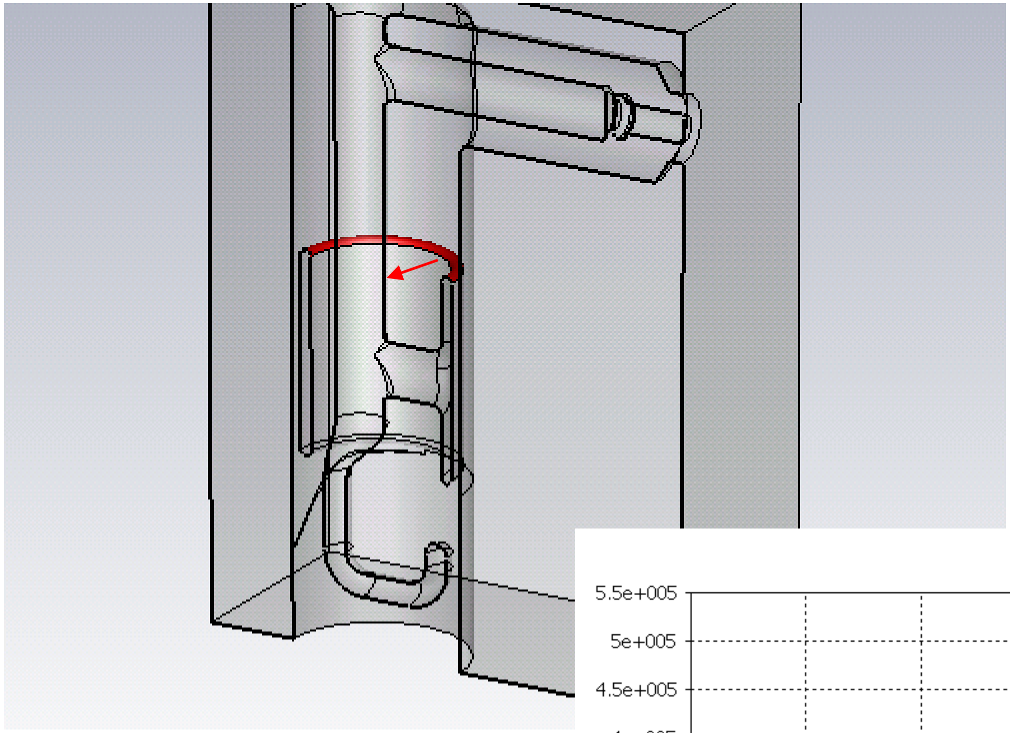
# Multipacting bands



# Multipacting bands



# Multipacting bands



Multipacting might happen between the red circle and the center rod (arrow pointed), with cavity voltage of 1.1 MV. (CST simulation by B. Hall and G. Burt, July 2014)