End-cell Analysis
DESY/TTF vertical test data

C.M. Ginsburg (Fermilab)

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Data sample

- http://tesla-new.desy.de/content/cavitydatabank/index_eng.html
- “Best” tests of all 117 cavities from Production Batches 1, 2, 3, and 4
- Data extracted July 24, 2006.
- 105 out of 117 cavity records included Q vs. Eacc tests
- The test data record contains:
  - Gradient limit for all cells together, from π-mode measurement
  - Maximum gradient seen by cells 1&9, 2&8, 3&7, 4&6, and 5, from other fundamental passband mode measurements
    - Calculation shown on p.4
  - Each measurement’s limiting factor, e.g., breakdown (quench), field emission, or power limit
  - NB: The limiting factor is inserted into the database by hand at the end of the test, and may show experimenter’s bias
  - Many other things not used here

Analysis Technique

- For each mode, the gradient measured by the pick-up probe is that seen by the end-cell
- Gradient seen by pairs of cells (or cell 5) determined by scaling measured gradient in the end-cell by the relevant E_{cell} factor
  - E_{cell} calculation shown on p.4
- Maximum gradient seen by pairs of cells (or cell 5), determined in this manner, in any mode measurement, is recorded in the database.
- Assume the lowest maximum gradient in a pair of cells (or cell 5) indicates that the cause of the limitation is physically located in that pair of cells (or cell 5)
- Completeness of this analysis depends on the assumption of field flatness in all cells
- In many cases, the lowest maximum gradient was evident in more than one pair of cells (or cell 5).

Analysis Technique (cont.)

Cell(s) responsible for cavity breakdown may be isolated using the measurement of gradient limits for the non-π-mode passbands

Relative gradient for a given cell and mode:

$$E_{rel} = \frac{\sin\left[\left(cell - \frac{1}{2}\right) * \frac{mode}{number\ of\ cells} * \pi\right]}{\sin\left(\frac{mode}{2 * number\ of\ cells} * \pi\right)}$$

mode ≈[1:9]
cell ≈[1:9]
number of cells = 9
mode=9 for π-mode etc.

E_{cell} factors

cell/mode	π	8π/9	7π/9	6π/9	5π/9	4π/9	3π/9	2π/9	π/9
1 (or 9)	1	1	1	1	1	1	1	1	1
2 (or 8)	1	0.88	0.53	0	0.65	1.35	2	2.53	2.88
3 (or 7)	1	0.65	0.18	1	1.23	0.53	1	2.88	4.41
4 (or 6)	1	0.35	0.82	1	0.23	1.53	1	1.88	5.41
5	1	0.00	1.06	0	1.31	0	2	0	5.76

After verifying that this was the technique used in the database, I used the database numbers

Question 1

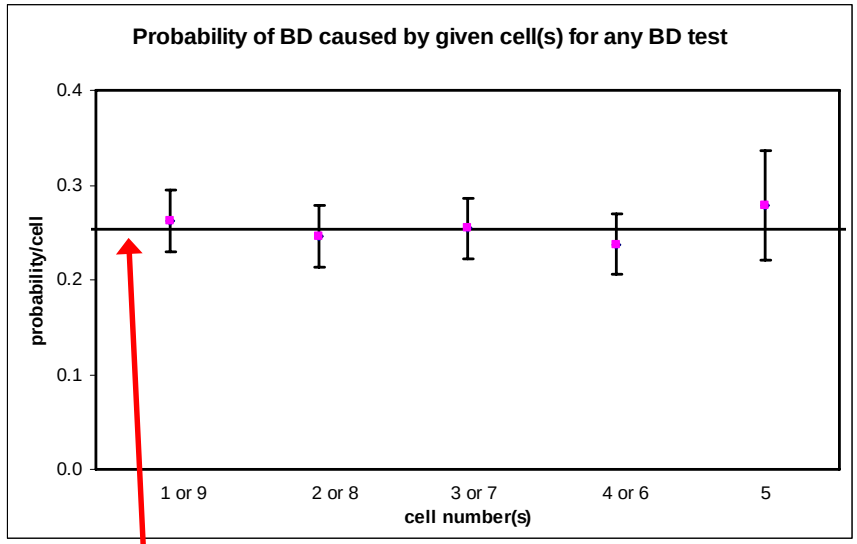
- **Question:** Are the end-cells most likely to limit cavity gradient?

- **Answer:** No!

Q1 Analysis: all BD cells

- Use all potential breakdown cells
- 61 of the “best” cavity tests list the limiting factor of the π-mode test as breakdown, and were included in the following analysis
- 139 such cell(s) breakdowns out of 61 tests
- average 139/61=2.3 cells breakdown for each measurement.
- correlation among cells evident in small point-to-point variation with respect to the error bars

Cell(s) causing BD	# tests w/BD in cell(s)	cell(s) BD prob	BD prob/cell
1 or 9	32	0.5246✂0.0639	0.2623✂0.0320
2 or 8	30	0.4918✂0.0640	0.2459✂0.0320
3 or 7	31	0.5082✂0.0640	0.2541✂0.0320
4 or 6	29	0.4754✂0.0639	0.2377✂0.0320
5	17	0.2787✂0.0574	0.2787✂0.0574



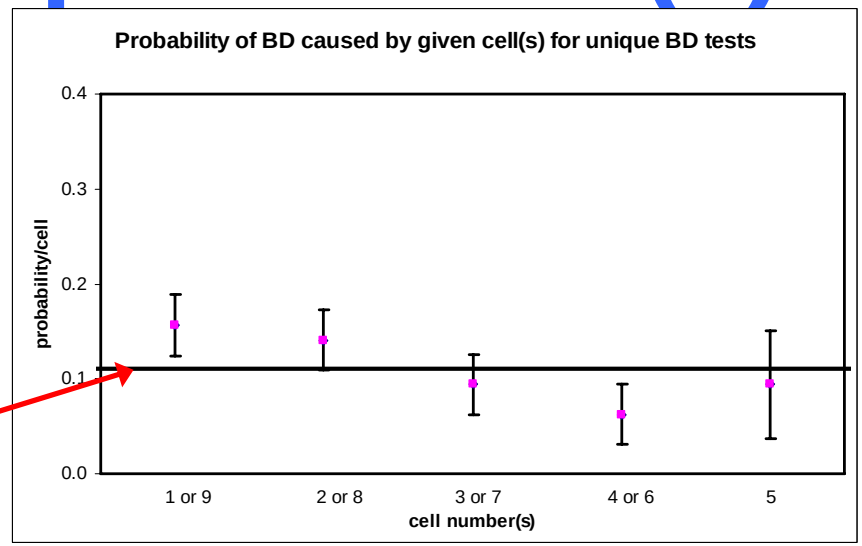
Random BD location probability: (139/61)*(1/9)

Data are consistent with the hypothesis of random BD cell location

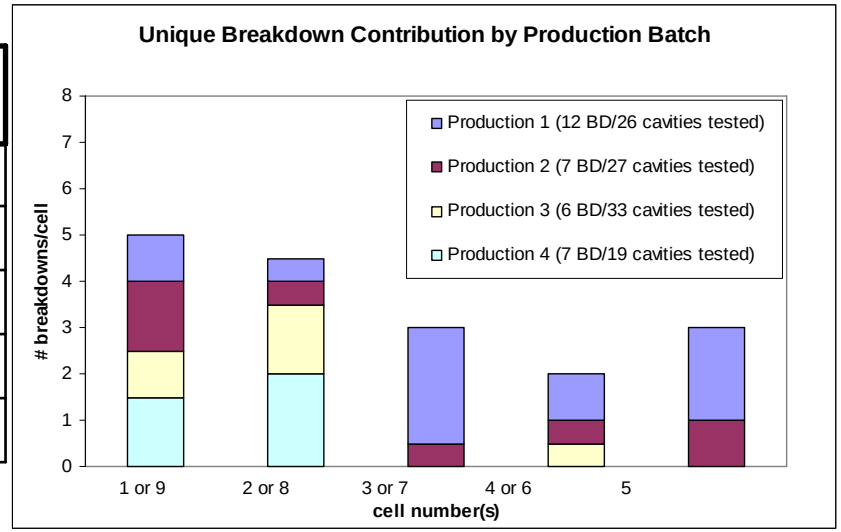
Q1 Analysis: Unique BD cell(s)

- Maybe the cell-to-cell correlation hides the cell dependence!
- Use tests in which a unique pair of cells (or cell 5) demonstrated the limiting gradient
- sample contained 32 tests

Random BD location probability: 1/9



Cell(s) causing BD	# tests w/BD in cell(s)	cell(s) BD prob	BD prob/cell
1 or 9	10	0.3125±0.0819	0.1563±0.0410
2 or 8	9	0.2813±0.0795	0.1406±0.0397
3 or 7	6	0.1875±0.0690	0.0938±0.0345
4 or 6	4	0.1250±0.0585	0.0625±0.0292
5	3	0.0938±0.0515	0.0938±0.0515



Data are consistent with the hypothesis of random BD cell location

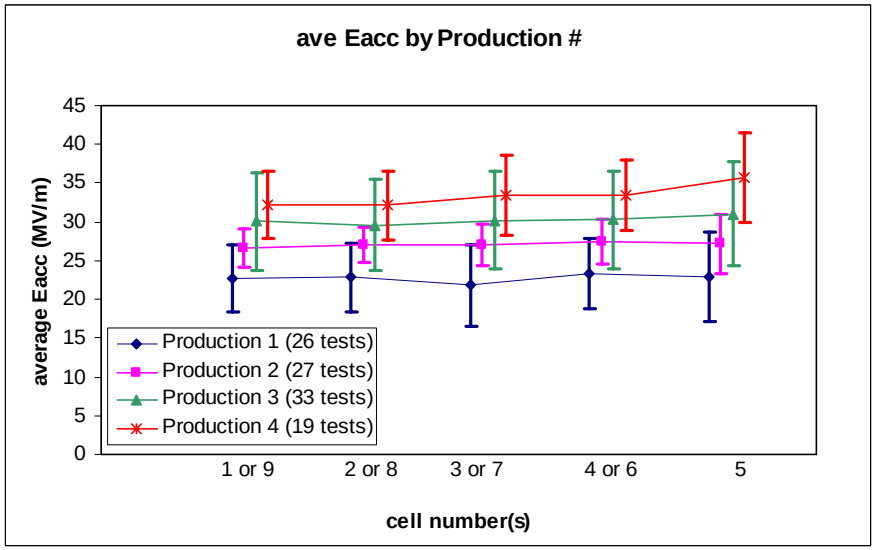
Question 2

- **Question:** Does any cell pair (or cell 5) show a statistically different gradient than others, when separated into individual production numbers? Ignore reason for test limitation.

- **Answer:** no!

Q2 Analysis

- 105 Q vs. E_{acc} cavity tests, independent of test limitation:
  - 26 tests for Production 1
  - 27 tests for Production 2
  - 33 tests for Production 3
  - 19 tests for Production 4
- Clear gradient improvement for all cells with each subsequent production batch



Production	Cell(s)	Average gradient [MV/m]	Standard deviation [MV/m]
1	1 or 9	22.65077	8.274465
1	2 or 8	22.84615	8.259508
1	3 or 7	21.79923	8.817727
1	4 or 6	23.31038	8.482587
1	5	22.89769	9.245171
2	1 or 9	26.66074	2.454498
2	2 or 8	27.11444	2.254157
2	3 or 7	27.08481	2.651137
2	4 or 6	27.44185	2.867716
2	5	27.20111	3.795398
3	1 or 9	30.07364	6.237612
3	2 or 8	29.60727	5.867669
3	3 or 7	30.20848	6.27723
3	4 or 6	30.2903	6.249751
3	5	31.05152	6.790942
4	1 or 9	32.16789	4.323806
4	2 or 8	32.11211	4.459019
4	3 or 7	33.37053	5.190218
4	4 or 6	33.40263	4.514148
4	5	35.73421	5.843486

Data are consistent with the hypothesis of random best/worst cell location

Quantify the Q2 Results

- **Calculate the Kolmogorov-Smirnov (K-S) probability**
  - **K-S probability ♒[0:1]=[most:least] probably deriving from the same parent distribution**
  - **Algorithm from Numerical Recipes in C**
- **Question 2a: Are pairs of (unbinned) gradient distributions from the different *production batches* compatible with representing the same parent distribution**
  - **No. The K-S probabilities are negligible, except, interestingly, for that between production 3 and 4.**

K-S probability	Prod 1	Prod 2	Prod 3	Prod 4
Production 1	1.000000	0.000483	0.000127	0.001883
Production 2	0.000483	1.000000	0.000406	0.026475
Production 3	0.000127	0.000406	1.000000	0.422991
Production 4	0.001883	0.026475	0.422991	1.000000

- **Question 2b: Are pairs of (unbinned) gradient distributions from the different *cell(s)* compatible with representing the same parent distribution**
  - **Yes. Most K-S probabilities indicate it is very likely that these distributions come from the same parent distribution.**

K-S probability	cells 1&9	cells 2&8	cells 3&7	cells 4&6	cell 5
cells 1&9	1.000000	0.968798	0.909878	0.818339	0.373931
cells 2&8	0.968798	1.000000	0.994219	0.373931	0.114970
cells 3&7	0.909878	0.994219	1.000000	0.588237	0.216172
cells 4&6	0.818339	0.373931	0.588237	1.000000	0.818339
cell 5	0.373931	0.114970	0.216172	0.818339	1.000000

Summary/Conclusions

- DESY/TTF vertical CW test data were used to study the cell dependence of cavity test limits.
- No pair of cells, or cell 5, is significantly more likely to breakdown than the others
  - The data support the hypothesis of random breakdown cell location
- No pair of cells, or cell 5, reaches significantly higher (or lower) gradient than the others.
  - The gradient data support the hypothesis of random best/worst cell location
  - Cells are consistent with each other
  - Production batches are different from each other