A Plague of Field Emission

17.3 years of CEBAF experience

Jay Benesch

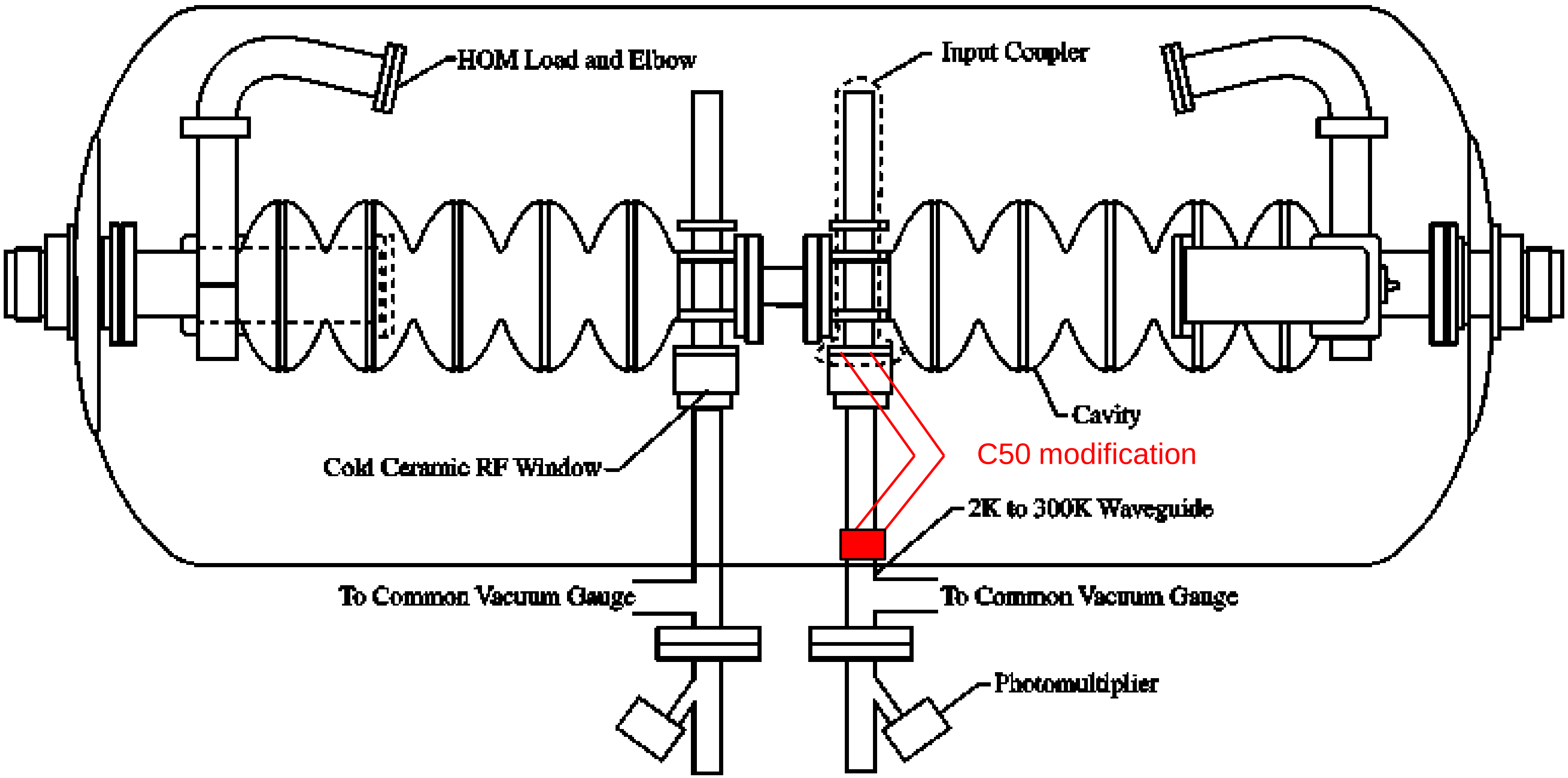
Outline

- Why should JLab care?
- Cavity pair
- Statistical analysis of "true arc" faults
- current status
- Effects of new emitters, Isabel and controlled warm-ups
- Helium processing history, including recent success of helium processing on C100-4
- Energy reach

Why JLab should care

- 6 GeV machine is foundation for 12 GeV machine
- During 6 GeV run Nov-Dec 2009, 50 days, there were 7037 true arc faults recorded, 141/day or ~6/hour.
- Ops beam restoration time is ~20 seconds but NP experimentalists cut perhaps twice that from data.
- If performance of installed base hadn't since deteriorated, this would represent ~1.6 hours/day of physics lost to true arc faults. Other faults also cost time; I can't model them.
- Two more C50s since 12/09 suggest 8% fewer, 1.45 hrs/d
- Since the installed base has deteriorated since 2009 and the 300K cycle will cut another 5% off gradient at fixed fault rate, you should care.

Old style cavity pair

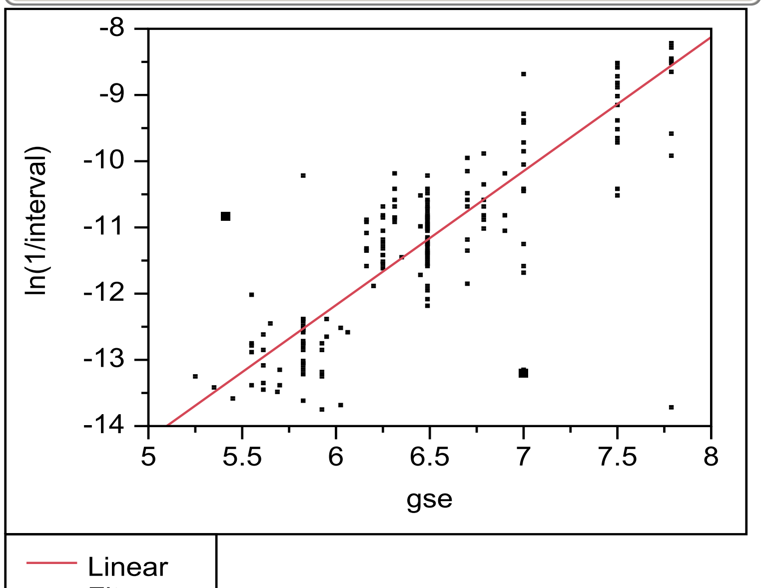


Hypothesis used in modeling

- Assume cold ceramic window is a perfect capacitor.
- Q=I*t=C*V (constant current)
- Capacitor arcs over surface or through ceramic at constant voltage, thus Q constant. (Verified at 10% level in vertical test.)
- 1/t = I/Q, t is interval between faults – a charge-discharge sawtooth
- Assume I=a*exp(b*GSET) as it is solvable in closed form while Fowler-Nordheim form, with correct physics, isn't.
(http://rspa.royalsocietypublishing.org/content/119/781/173.full.pdf)
- ln(I)=A+b*GSET
- ln(1/interval)=intercept+slope*gset
- Empirically, hypothesis works well over time intervals from 100s to 12 days (~10^6s)

Exponential vs Fowler-Nordheim

Bivariate Fit of ln(1/interval) By gset



Linear Fit

ln(1/interval) = -24.31679 +

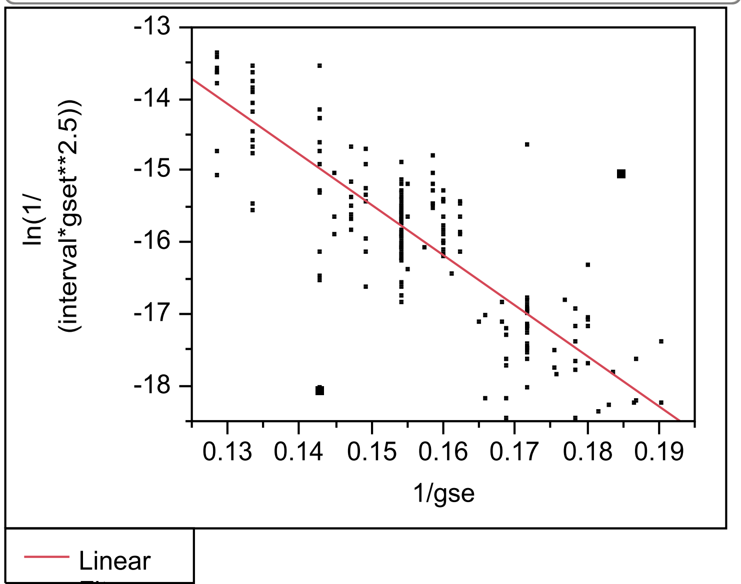
Summary of Fit

RSquare	0.812792
RSquare Adj	0.811729
Root Mean Square Error	0.558301
Mean of Response	-11.2182
Observations (or Sum Wgts)	178

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-24.31679	0.475693	-51.12	<.0001 *
gset	2.0238762	0.073215	27.64	<.0001 *

Bivariate Fit of ln(1/(interval*gset**2.5)) By 1/gset



Linear Fit

ln(1/(interval*gset**2.5)) = -4.92471 -

Summary of Fit

RSquare	0.750138
RSquare Adj	0.748718
Root Mean Square Error	0.547898
Mean of Response	-15.8774
Observations (or Sum Wgts)	178

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.92471	0.478245	-10.30	<.0001 *
1/gset	-70.34991	3.060464	-22.99	<.0001 *

RF Fault database

- “true arc” fault: simultaneous light and vacuum signals
- old fault logger data in my possession begins 1/30/95. 130447 true arc faults ending 12/20/2002.
- new fault logger data begins 1/1/2003. ~400K cavity faults since of which 294420 are “true arcs”, ~3/4.
- 424867 true arc faults available for analysis.
- Two analysis tools: JMP, www.jmp.com , a commercial exploratory data analysis package from SAS, and
- R www.r-project.org a comprehensive free open source environment for doing statistics.

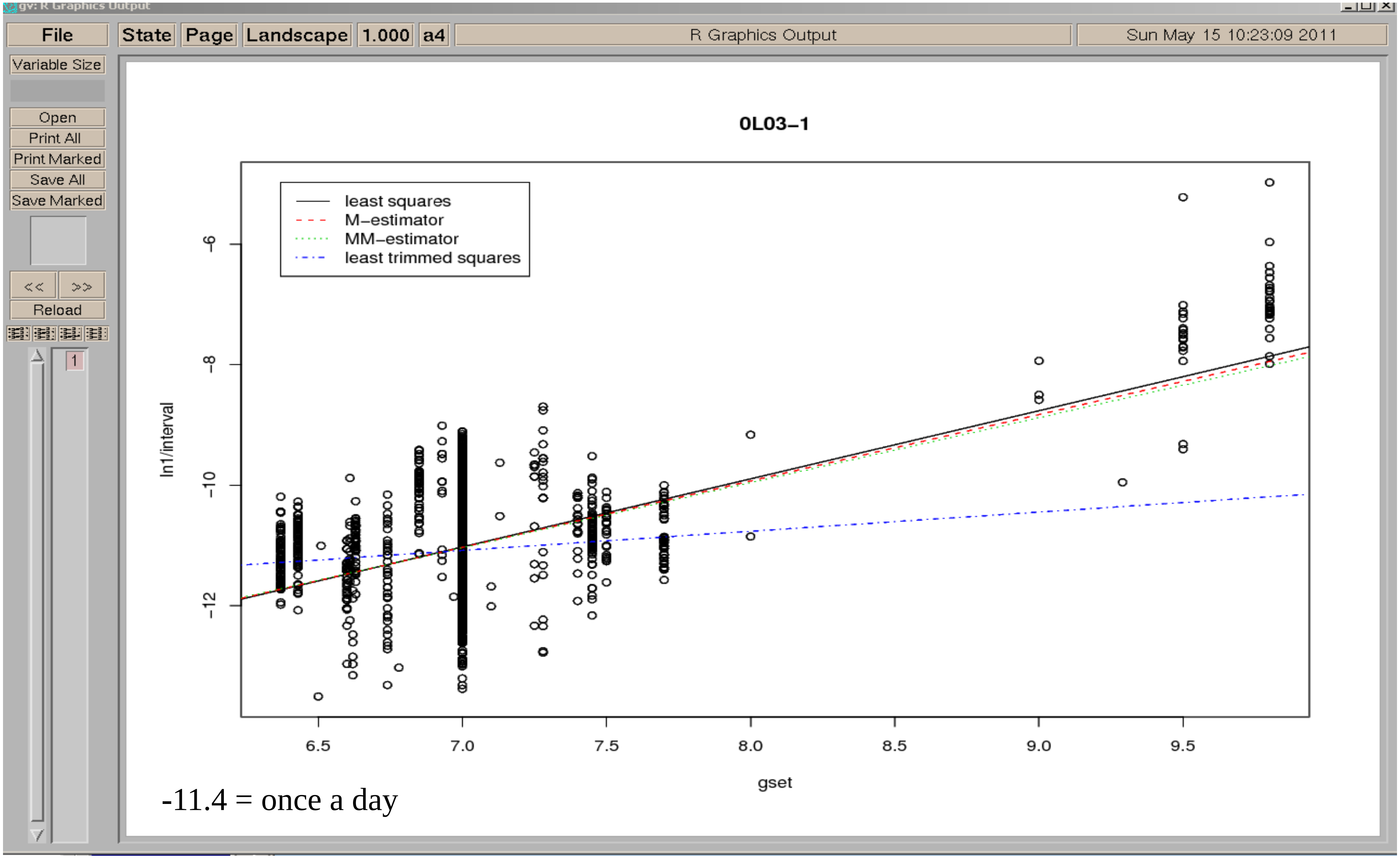
for detailed discussions

- TN 95-059
- TN 98-045
- TN 01-020
- TN 05-057
- TN 10-008

- **https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-11306**

statistical analysis example

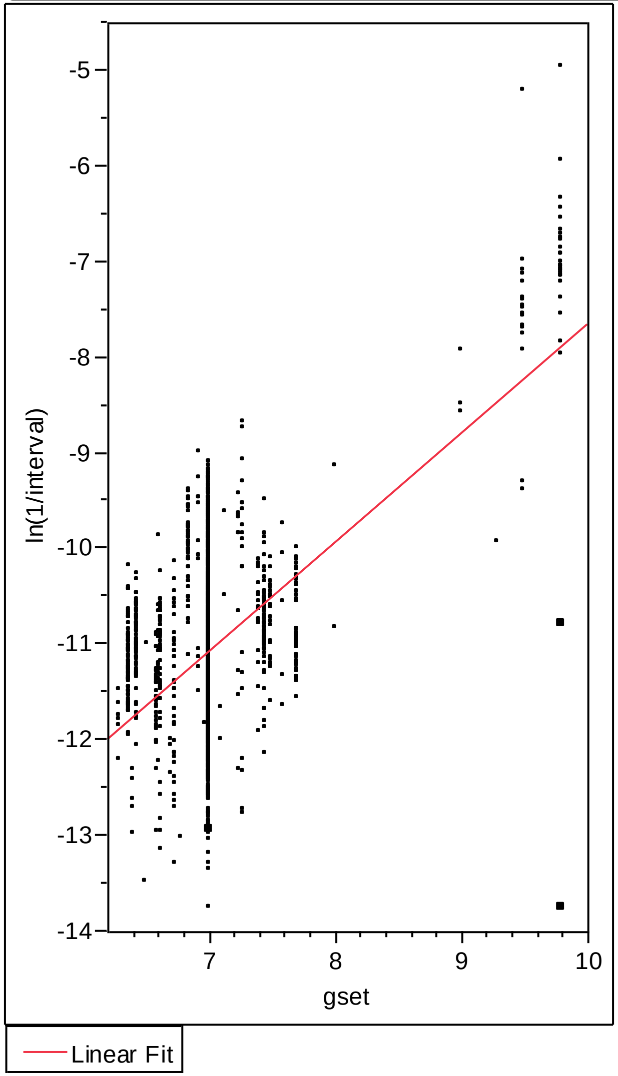
R tool output: 0L03-1



-11.4 = once a day

Cavity 0L03-1 2003-2012

Bivariate Fit of ln(1/interval) By gset



Linear Fit

ln(1/interv al) = -19.03937 + 1.1404755*gset

Summary of Fit

RSquare	0.308641
RSquare Adj	0.30831
Root Mean Square Error	0.802138
Mean of Response	-11.0144
Observ ations (or Sum Wgts)	2092

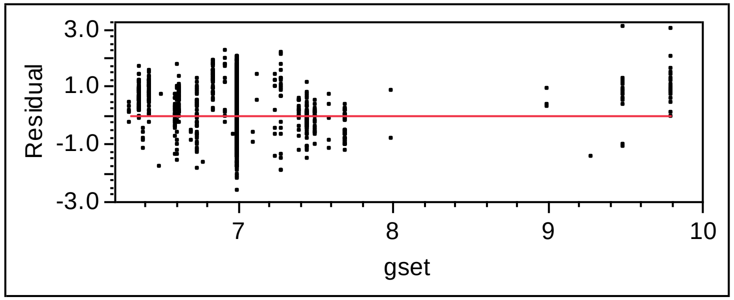
73% of points at gset=7

Analysis of Variance

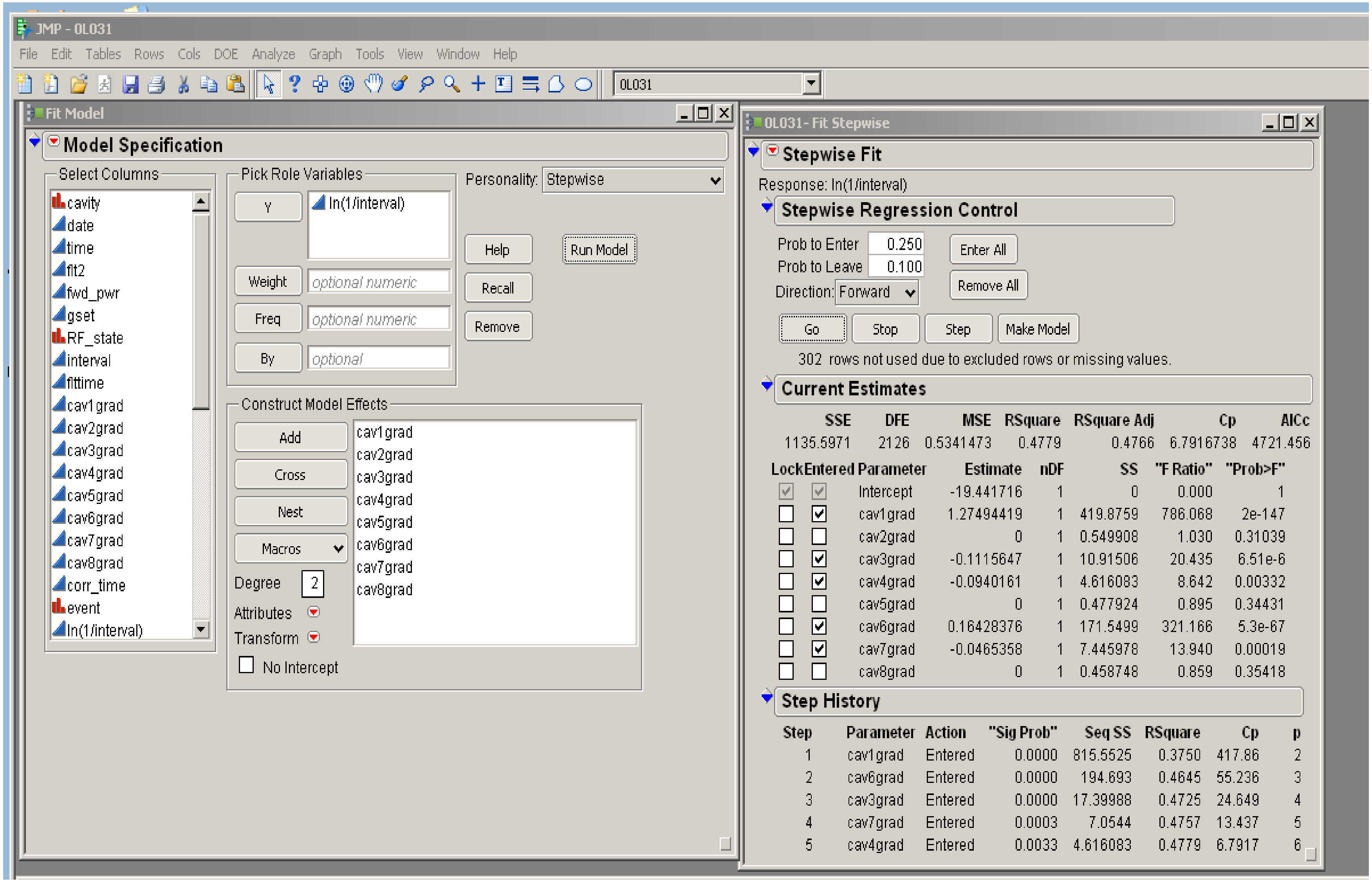
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	600.3353	600.335	933.0293
Error	2090	1344.7603	0.643	**Prob > F**
C. Total	2091	1945.0956		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-19.03937	0.263305	-72.31	0.0000*
gset	1.1404755	0.037337	30.55	<.0001*

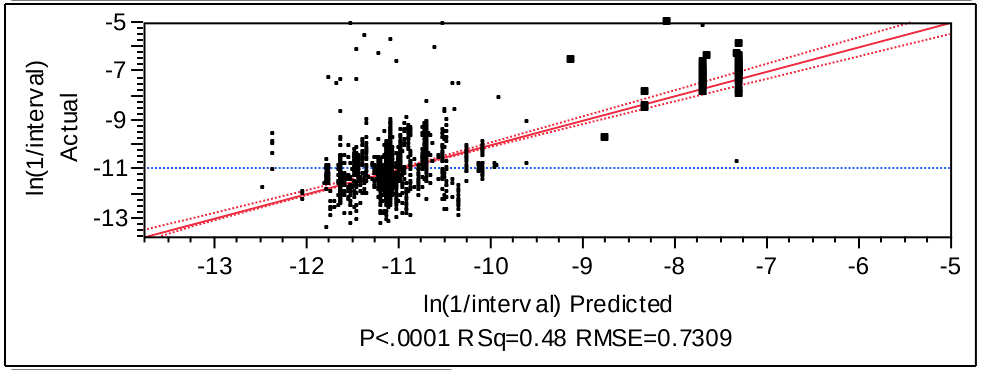


Stepwise regression 0L03-1 (1)



Stepwise regression 0L03-1 (2)

Actual by Predicted Plot



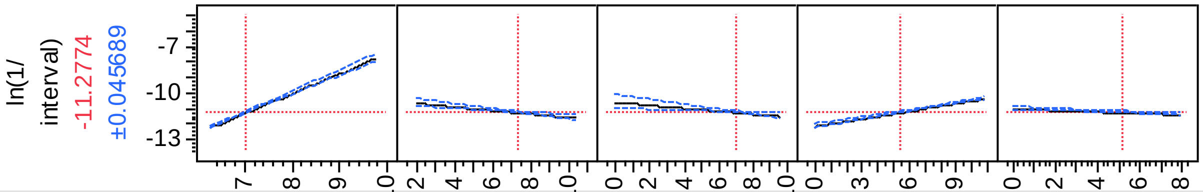
Summary of Fit

RSquare	0.477865
RSquare Adj	0.476638
Root Mean Square Error	0.730854
Mean of Response	-10.971
Observations (or Sum Wgts)	2132

Sorted Parameter Estimates

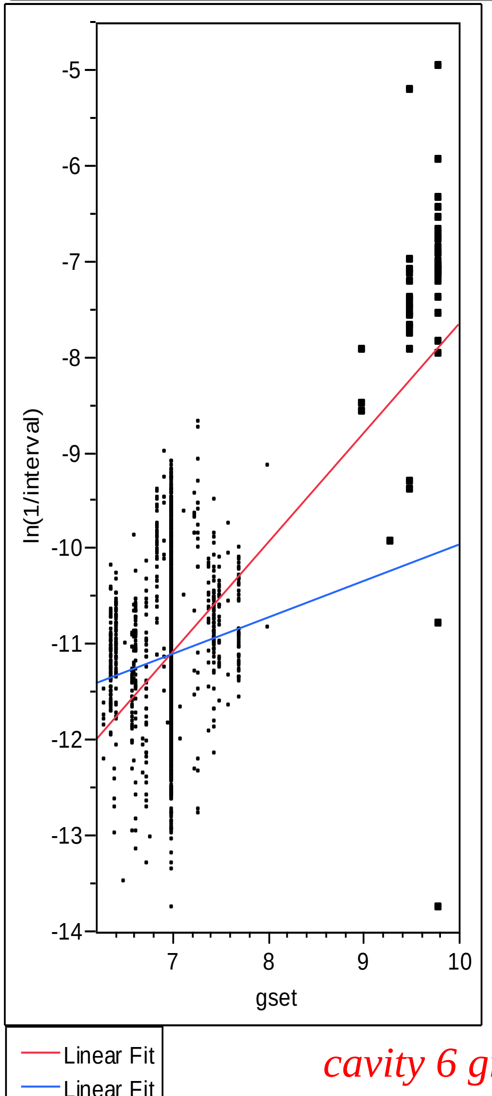
Term	Estimate	Std Error	t Ratio	Prob>|t|
cav1grad	1.2749442	0.045474	28.04	<.0001*
cav6grad	0.1642838	0.009167	17.92	<.0001*
cav3grad	-0.111565	0.02468	-4.52	<.0001*
cav7grad	-0.046536	0.012464	-3.73	0.0002*
cav4grad	-0.094016	0.031981	-2.94	0.0033*

Prediction Profiler



Cavity 0L03-1 less high gradient

Bivariate Fit of ln(1/interval) By gset



Linear Fit

ln(1/interval) = -19.03937 + 1.1404755*gset

Summary of Fit

RSquare	0.308641
RSquare Adj	0.30831
Root Mean Square Error	0.802138
Mean of Response	-11.0144
Observations (or Sum Wgts)	2092

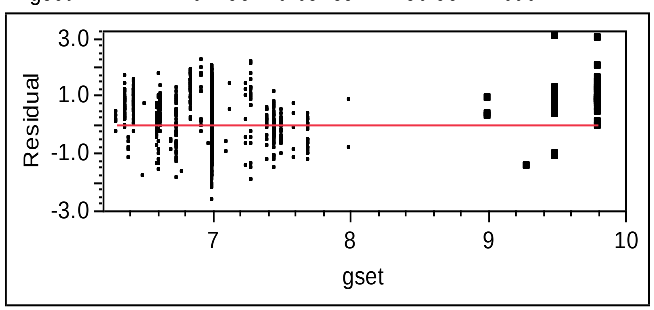
adding cavity 6 gradient to eqn yields R^2=0.464

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	600.3353	600.335	933.0293
Error	2090	1344.7603	0.643	**Prob > F**
C. Total	2091	1945.0956		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-19.03937	0.263305	-72.31	0.0000*
gset	1.1404755	0.037337	30.55	<.0001*



Linear Fit

ln(1/interval) = -13.73613 + 0.3776977*gset

Summary of Fit

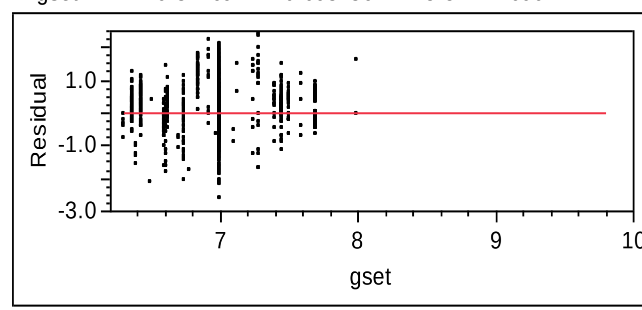
RSquare	0.014804
RSquare Adj	0.014321
Root Mean Square Error	0.771251
Mean of Response	-11.1015
Observations (or Sum Wgts)	2044

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	18.2513	18.2513	30.6833
Error	2042	1214.6403	0.5948	**Prob > F**
C. Total	2043	1232.8916		<.0001*

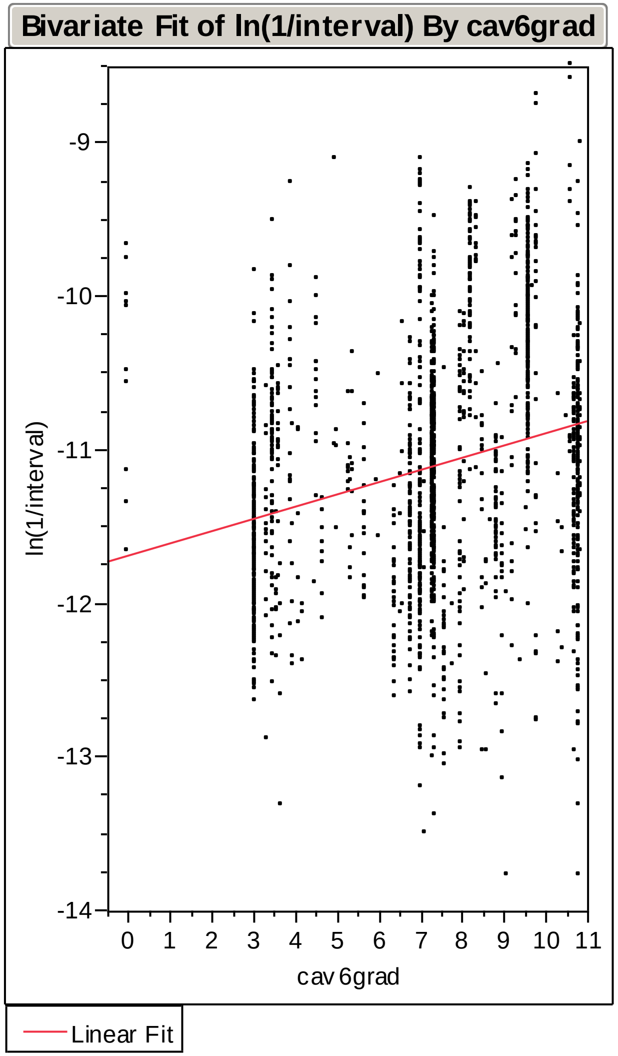
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-13.73613	0.475936	-28.86	<.0001*
gset	0.3776977	0.068186	5.54	<.0001*



cavity 6 gradient has R^2 of 0.065 for low gradient only points, four times cavity 1.

0L031 fit by cav 6 grad



Linear Fit

ln(1/interval) = -11.67989 + 0.0791936*cav6grad

Summary of Fit

RSquare	0.064978
RSquare Adj	0.064519
Root Mean Square Error	0.752339
Mean of Response	-11.102
Observations (or Sum Wgts)	2038

quoted on previous slide

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	80.0848	80.0848	141.4892
Error	2036	1152.4030	0.5660	**Prob > F**
C. Total	2037	1232.4878		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-11.67989	0.051365	-227.4	0.0000*
cav6grad	0.0791936	0.006658	11.89	<.0001*

Linear fit suggests setting cavity 6 to 3.5 MV/m to keep fault rate on cavity 1 to once/day but we can’t afford that, so I’d start with 9 MV/m (16h) and see what happens.

This work

- Re-examined all 425K true arc faults
- Looked at discontinuities for each: what I call new field emitters within a beam run, model changes across an obvious down (even a long weekend), changes across Isabel, changes across controlled 300K cycles, changes due to ceramic warm window installation, etc.
- After analysis similar to that shown, divided the data into 2253 time blocks for 328 cavities, or about seven each in 17.3 years.
- I didn't look for changes across maintenance days, 4-8 hour periods.   Some of the new emitters might have so occurred, but I did not check each in the elog.

How I quote results

- Models of form ln(1/interval)=intercept+slope*gset
- Set interval to 2 days, 172800 seconds, and solve for gset.
- Use this predicted gradient for 2 day fault interval for other calculations.
- Why 2 days? 30 old style zones, 240 cavities, in CEBAF. 2d fault interval is 120 faults/day or 5/hour.
- Since these true arc faults are ~3/4 the total RF faults when my models are up to date, this provides margin for the ten total faults per hour that Ops guarantees Physics.

Current status

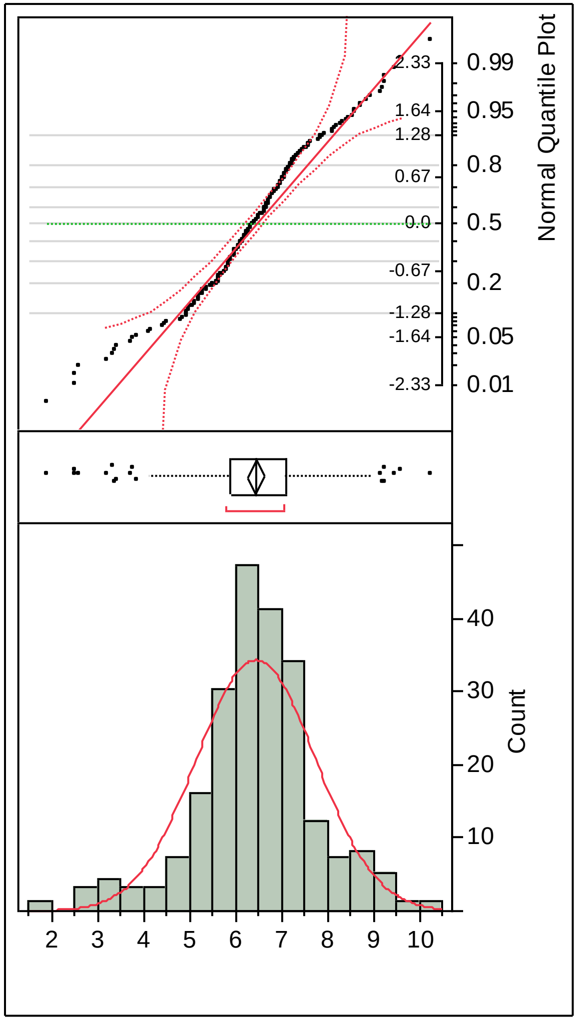
lem: linac energy manager

- Original version written by Larry Doolittle.
- Documented in "Operational optimization of large scale SRF accelerators", J.R. Delayen, L.R. Doolittle, C.E. Reece, PAC 1999.
- Minimized both RF fault rate and cryo load. Worked but often found minima which changed dramatically when one cavity was turned off so linac quads and optics changed.
- C. Slominski removed cryo load from objective function at my direction when he rewrote the code. Much more stable. Cryo load will likely be re-introduced for 12 GeV Ops.
- My statistical models of the cavities are the principal input for the calculation. Cavities without models get set to GSET.DRVH or OPSDRVH, e.g. C50 and C100.
- Fratricidal cavities get set via OPSDRVH

summary of May 2012 models

Distributions

2 days



Normal(6.45354,1.29524)

Quantiles

100.0%	maximum	10.27
99.5%		10.1944
97.5%		9.272
90.0%		8.072
75.0%	quartile	7.12
50.0%	median	6.46
25.0%	quartile	5.87
10.0%		5.01
2.5%		3.33
0.5%		2.022
0.0%	minimum	1.95

Moments

Mean	6.4535426
Std Dev	1.2952441
Std Err Mean	0.086736
Upper 95% Mean	6.6244738
Lower 95% Mean	6.2826114
N	223

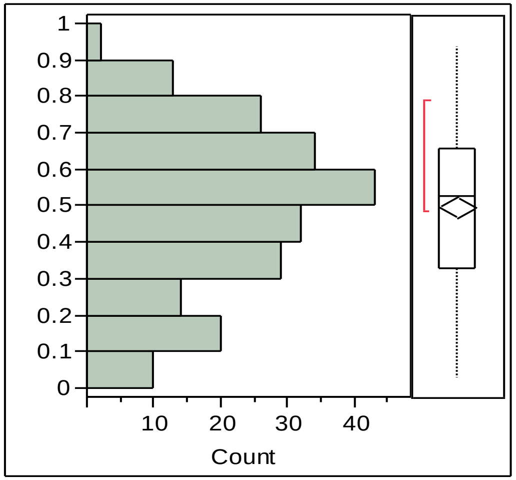
Horizontal axis in histogram is gradient (MV/m) at which the fault interval is two days. I have models for 223/248 C25 cavities in the machine. 240 C25 cavities will be in the linacs. 240*6.45*0.5=774 MeV best case with 120 faults/day or 5 faults/hour. With a more typical 8 cavities down, 750 MeV, before 300K cycle changes. And more faults.

Ten C50 modules averaged 40 MeV each May 2012 Qweak run, 400 MeV total.

Model quality

Distributions

R_squared



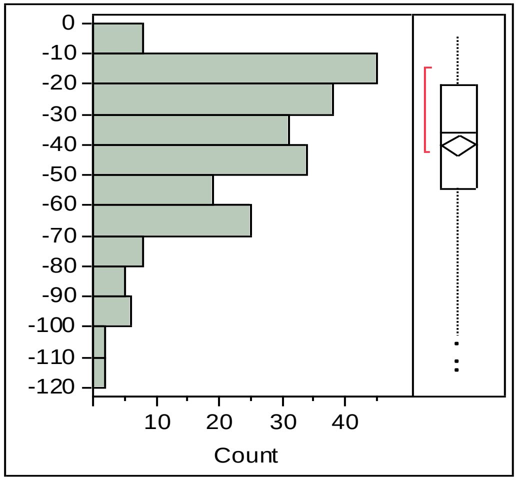
Quantiles

100.0%	maximum	0.9349
99.5%		0.93104
97.5%		0.8698
90.0%		0.77764
75.0%	quartile	0.6568
50.0%	median	0.5252
25.0%	quartile	0.3265
10.0%		0.15846
2.5%		0.08201
0.5%		0.02875
0.0%	minimum	0.02824

Moments

Mean	0.49631
Std Dev	0.2183167
Std Err Mean	0.0146196
Upper 95% Mean	0.5251208
Lower 95% Mean	0.4674991
N	223

t_intercept



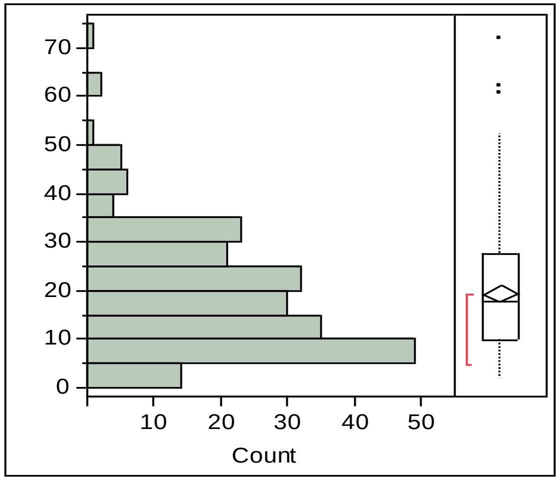
Quantiles

100.0%	maximum	-4.909
99.5%		-5.0291
97.5%		-9.166
90.0%		-13.8
75.0%	quartile	-20.55
50.0%	median	-35.89
25.0%	quartile	-54.75
10.0%		-71.18
2.5%		-97.864
0.5%		-115.15
0.0%	minimum	-115.5

Moments

Mean	-40.09263
Std Dev	23.571135
Std Err Mean	1.5784399
Upper 95% Mean	-36.98198
Lower 95% Mean	-43.20327
N	223

t_slope



Quantiles

100.0%	maximum	71.5
99.5%		70.2952
97.5%		48.8062
90.0%		34.322
75.0%	quartile	27.36
50.0%	median	17.64
25.0%	quartile	9.6356
10.0%		5.7858
2.5%		3.38
0.5%		2.0524
0.0%	minimum	1.93

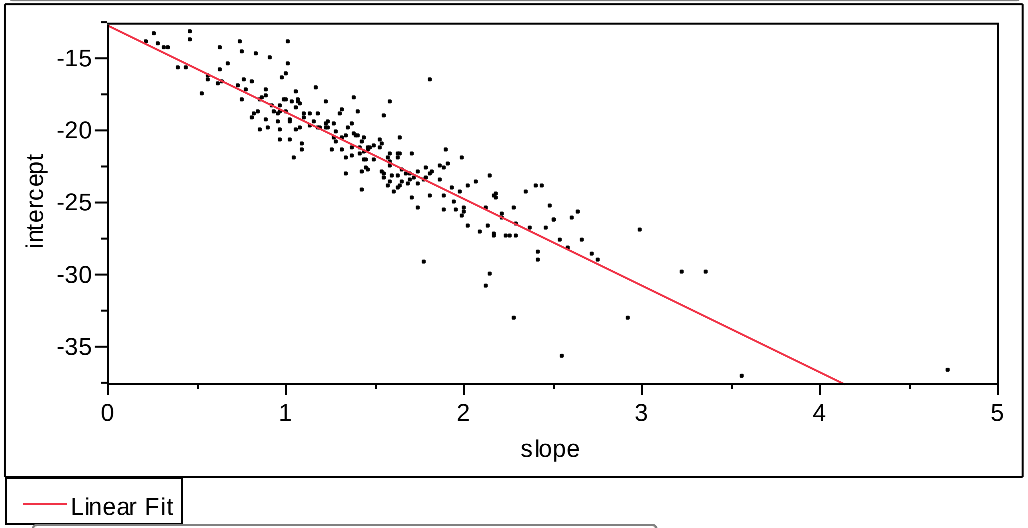
two with t<3

Moments

Mean	19.217532
Std Dev	12.260651
Std Err Mean	0.8210339
Upper 95% Mean	20.835549
Lower 95% Mean	17.599514
N	223

Puzzle

Bivariate Fit of intercept By slope



Linear Fit

intercept = -12.70419 - 5.9768921*slope

Summary of Fit

RSquare	0.827809
RSquare Adj	0.82703
Root Mean Square Error	1.78723
Mean of Response	-21.8667
Observations (or Sum Wgts)	223

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-12.70419	0.305517	-41.58	<.0001*
slope	-5.976892	0.183366	-32.60	<.0001*

I have no idea why the slope and intercept of the fits are so correlated.

I can use this when t_{slope} is less than 3.

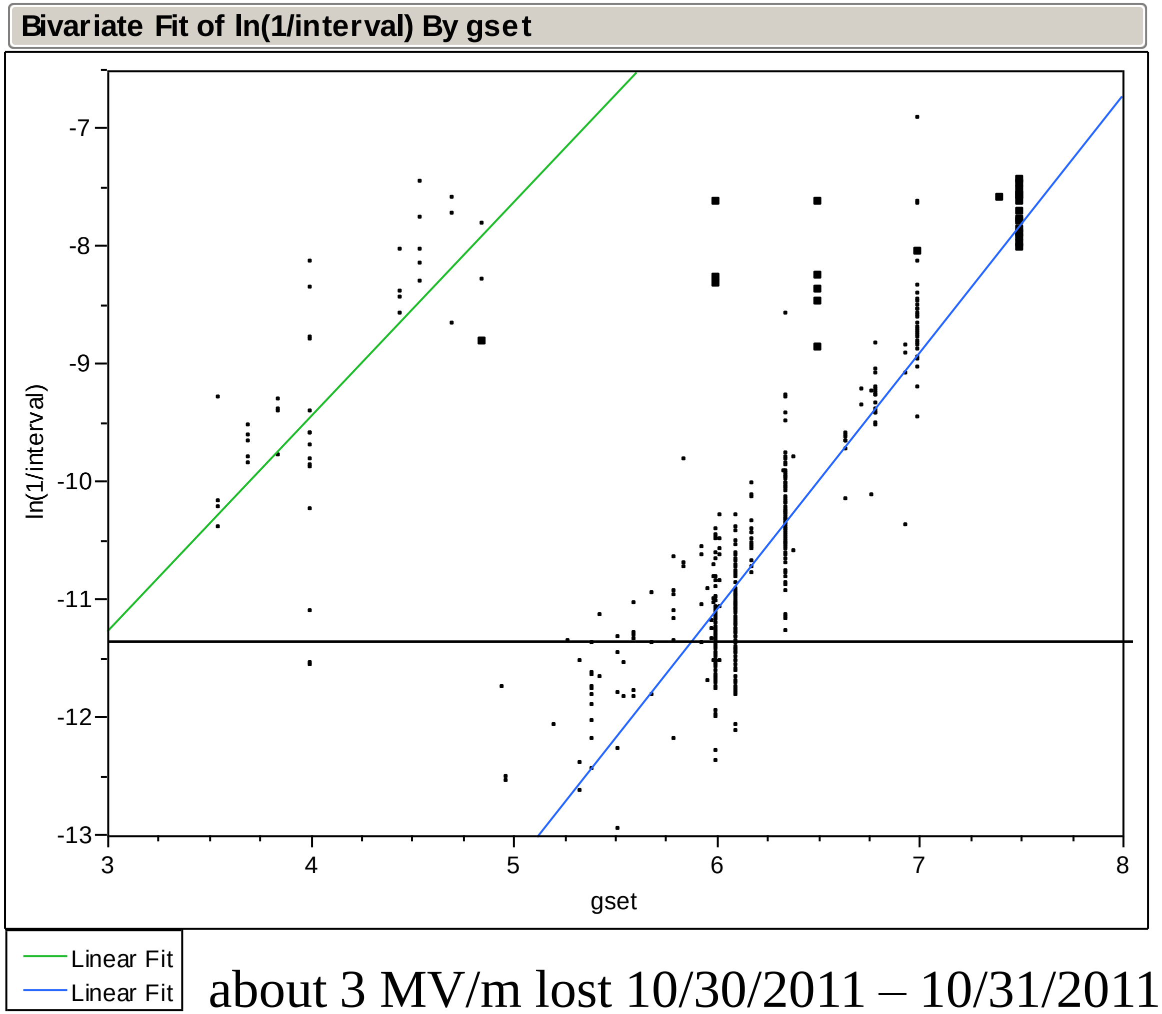
Changes over 17 years

2012 analysis

New field emitters: 8.4/year

1L15-4

-11.4 = once a day

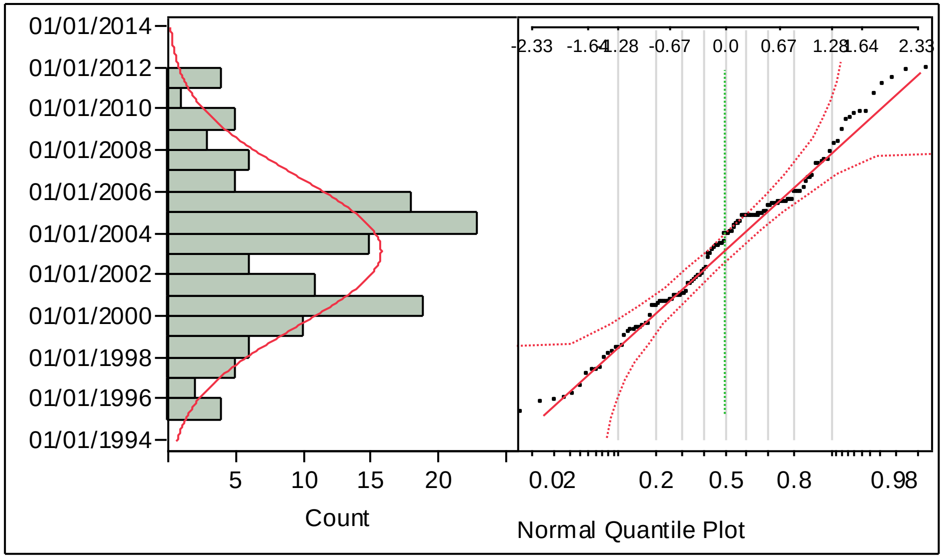


about 3 MV/m lost 10/30/2011 – 10/31/2011

New emitter start dates

Distributions

start_date



Normal(3.13e+9,1.14e+8)

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	3.1304e+9	3.1115e+9	3.1493e+9
Dispersion	s	114254782	102371073	129284530

-2log(Likelihood) = 5711.24367274153

Goodness-of-Fit Test

Shapiro-Wilk W Test

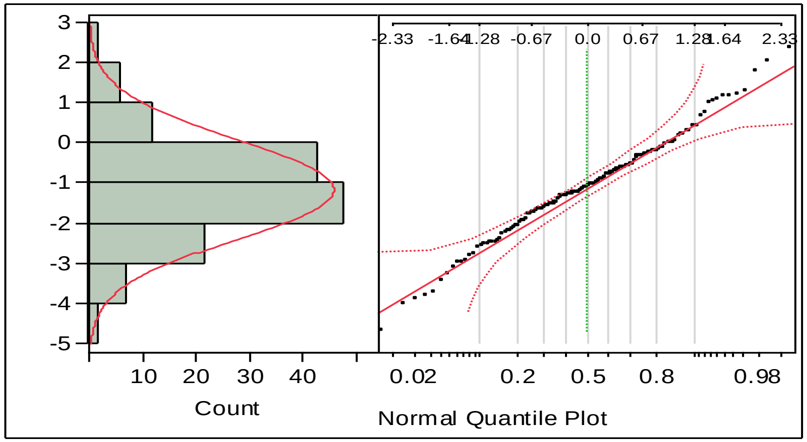
W	Prob<W
0.985098	0.1246

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

I haven't a clue as to why the distribution is consistent with normal.

New emitters: MV/m and fractional losses

delta



Normal(-1.136,1.23495)

Moments

Mean	-1.135986
Std Dev	1.234948
Std Err Mean	0.1036345
Upper 95% Mean	-0.931108
Lower 95% Mean	-1.340864
N	142

-1.14 MV/m loss each or ~ 5 MeV/yr

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-1.135986	-1.340864	-0.931108
Dispersion	s	1.234948	1.1060942	1.3980502

-2log(Likelihood) = 461.910738561348

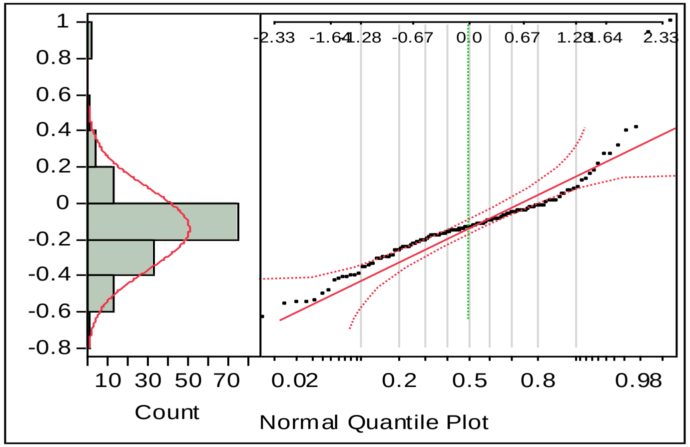
Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.992196	0.6270

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

delta/previous



Normal(-0.14,0.22241)

Moments

Mean	-0.140001
Std Dev	0.2224084
Std Err Mean	0.0186641
Upper 95% Mean	-0.103103
Lower 95% Mean	-0.176898
N	142

fractional loss 14%

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.140001	-0.176898	-0.103103
Dispersion	s	0.2224084	0.1992024	0.2517823

-2log(Likelihood) = -24.9416609599498

Goodness-of-Fit Test

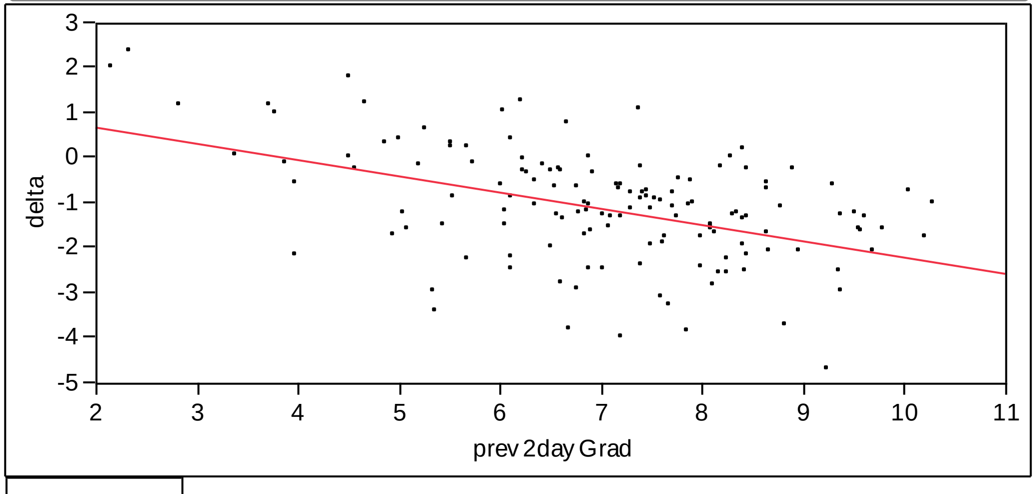
Shapiro-Wilk W Test

W	Prob<W
0.872106	<.0001*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

New emitters: gradient dependence

Bivariate Fit of delta By prev2dayGrad



Linear Fit

delta = 1.4082074 - 0.3613694*prev2dayGrad

Summary of Fit

RSquare	0.226716
RSquare Adj	0.221193
Root Mean Square Error	1.089842
Mean of Response	-1.13599
Observations (or Sum Wgts)	142

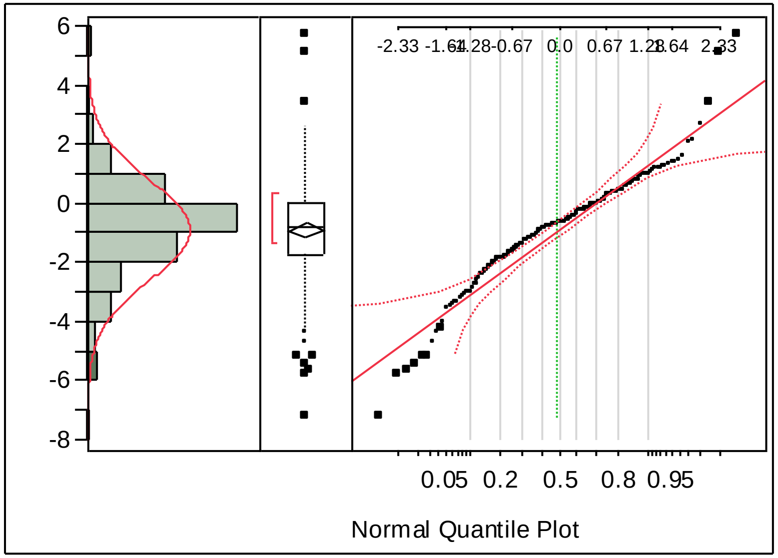
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1.4082074	0.407509	3.46	0.0007*
prev2dayGrad	-0.361369	0.056405	-6.41	<.0001*

gradient loss to new emitter vs previous gradient for 2 day fault interval

Isabel

delta



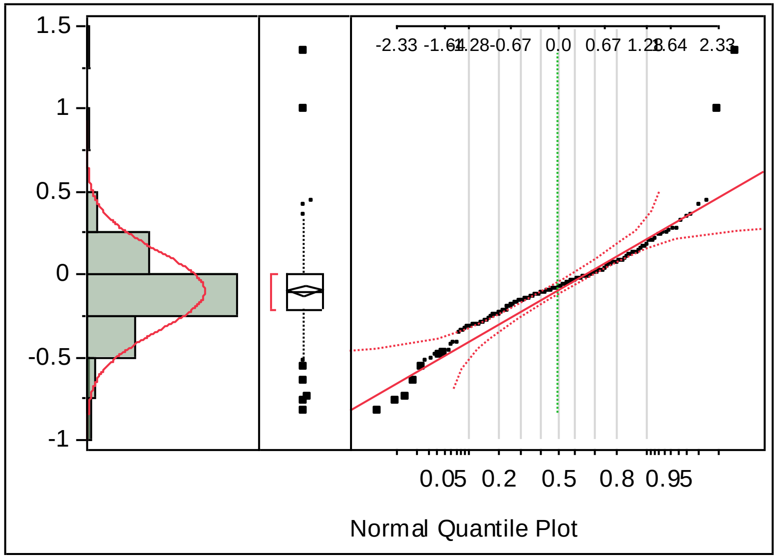
Normal(-0.8674,1.69588)

Moments

Mean	-0.867389
Std Dev	1.6958842
Std Err Mean	0.1190277
Upper 95% Mean	-0.632693
Lower 95% Mean	-1.102085
N	203

-0.9 MV/m

delta/previous



Normal(-0.0993,0.24085)

Moments

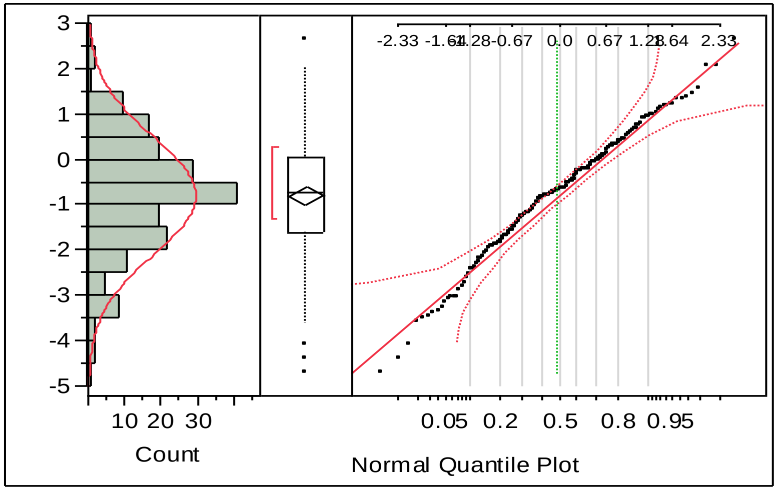
Mean	-0.099322
Std Dev	0.2408478
Std Err Mean	0.016946
Upper 95% Mean	-0.065907
Lower 95% Mean	-0.132737
N	202

-10%

changes in modeled 2 day interval gradient across Isabel 300K cycle
left graph shows deltas in MV/m; right graph is delta/previous2day_grad

Isabel with cuts for normality

delta



Normal(-0.7827,1.29897)

Moments

Mean	-0.782694
Std Dev	1.2989719
Std Err Mean	0.093502
Upper 95% Mean	-0.598271
Lower 95% Mean	-0.967117
N	193

-0.78 MV/m

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.782694	-0.967117	-0.598271
Dispersion	s	1.2989719	1.181023	1.4432993

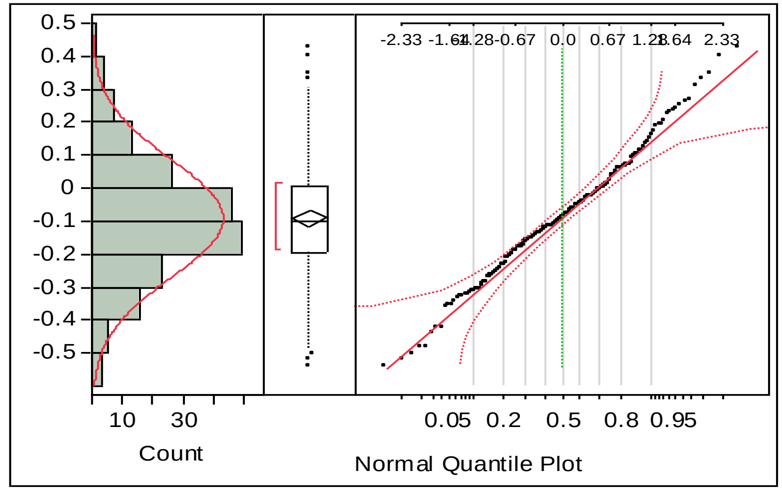
-2log(Likelihood) = 647.677506537668

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.988470	0.1201

delta/previous



Normal(-0.092,0.17829)

Moments

Mean	-0.09198
Std Dev	0.1782932
Std Err Mean	0.0128338
Upper 95% Mean	-0.066666
Lower 95% Mean	-0.117293
N	193

-9.2%

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.09198	-0.117293	-0.066666
Dispersion	s	0.1782932	0.1621039	0.1981032

-2log(Likelihood) = -118.879537832371

Goodness-of-Fit Test

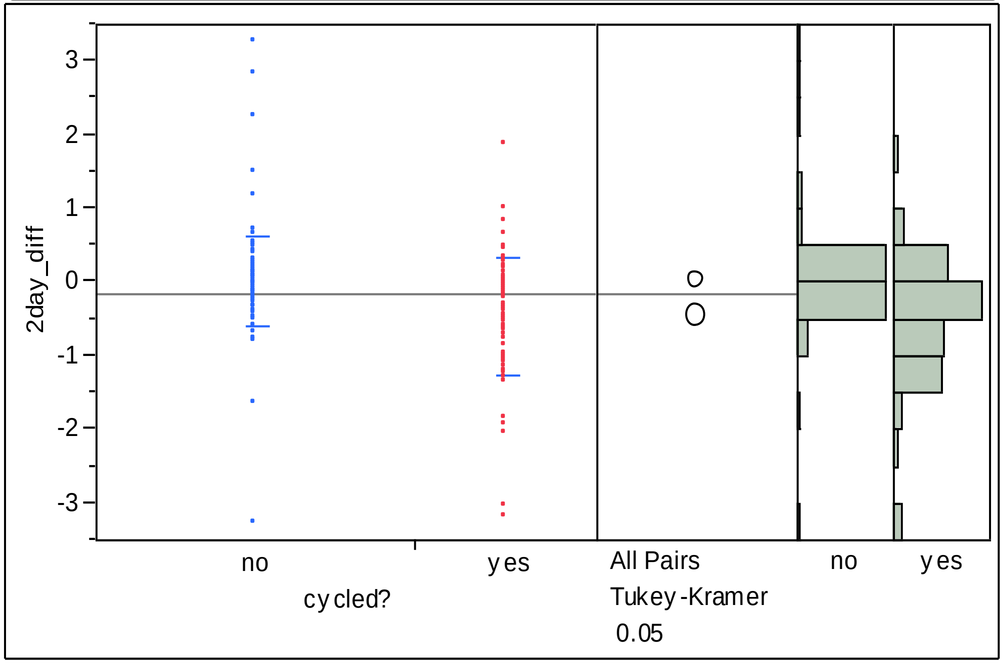
Shapiro-Wilk W Test

W	Prob<W
0.992292	0.4015

2009 CM 300K cycles

- Models were generated in Mar. and Dec. 2009.
- Ten modules went to 300K in April or July 2009
- Average loss of gradient (two day interval) was 7% or 0.5MV/m
- For modules which weren't cycled, average difference was 0.015 MV/m aka zero
- see TN 10-008

Oneway Analysis of 2day_diff By cycled?



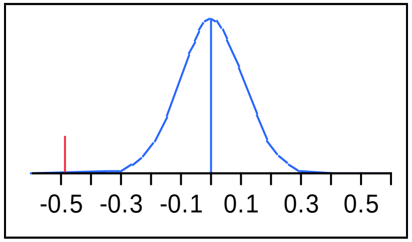
Excluded Rows 111

t Test

yes-no

Assuming unequal variances

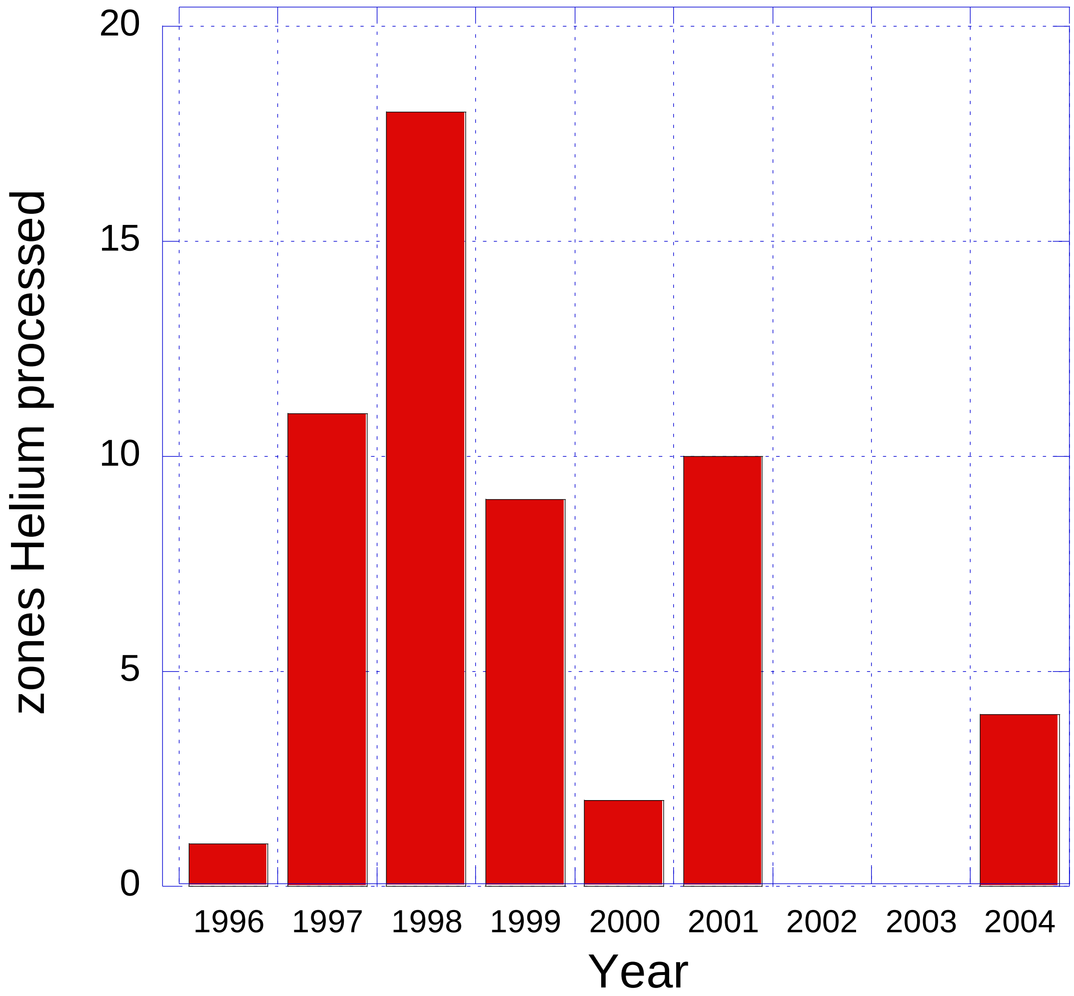
Difference	-0.48527	t Ratio	-4.55586
Std Err Dif	0.10651	DF	124.0112
Upper CL Dif	-0.27444	Prob > |t|	<.0001*
Lower CL Dif	-0.69609	Prob > t	1.0000
Confidence	0.95	Prob < t	<.0001*



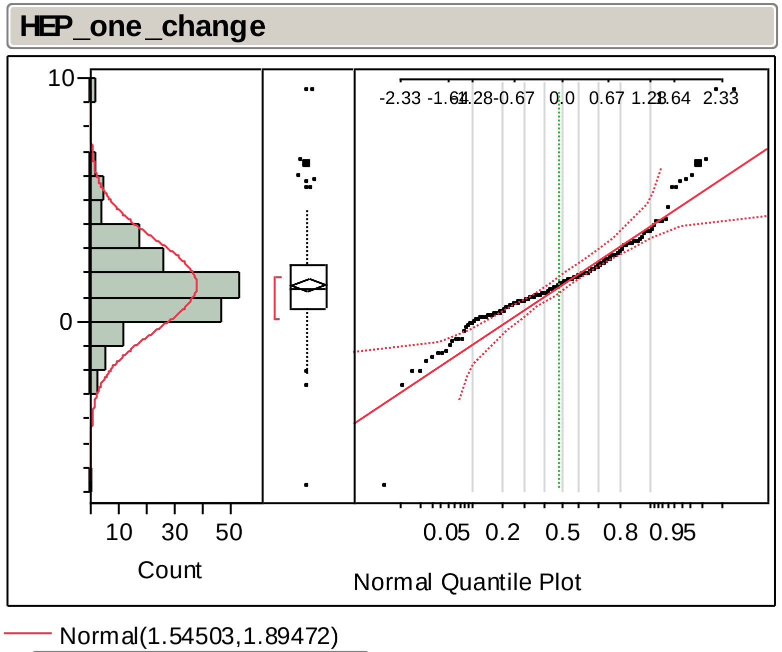
Mitigation

Helium processing

- RF glow discharge "processing" to blunt field emitters by ion back-bombardment.
- Reduces local electric field geometric enhancement and therefore emitted current (~ 1 GV/m is required for field emission)
- Monitored via x-ray production

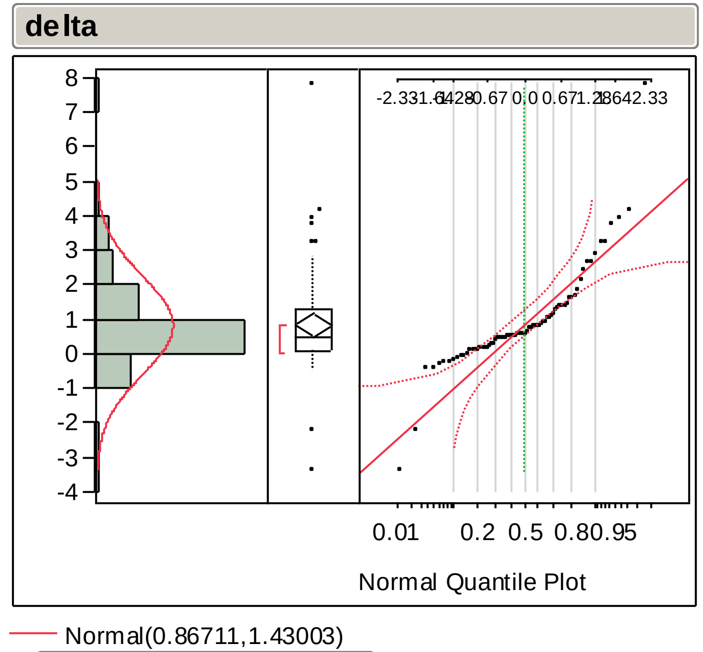


Helium processing



Moments

Mean	1.5450279
Std Dev	1.8947207
Std Err Mean	0.1416181
Upper 95% Mean	1.8244943
Lower 95% Mean	1.2655615
N	179



Moments

Mean	0.8671053
Std Dev	1.4300264
Std Err Mean	0.1640353
Upper 95% Mean	1.1938803
Lower 95% Mean	0.5403302
N	76

First application left graph (41% mean improvement on previous).
Subsequent application right graph (31% improvement on previous)

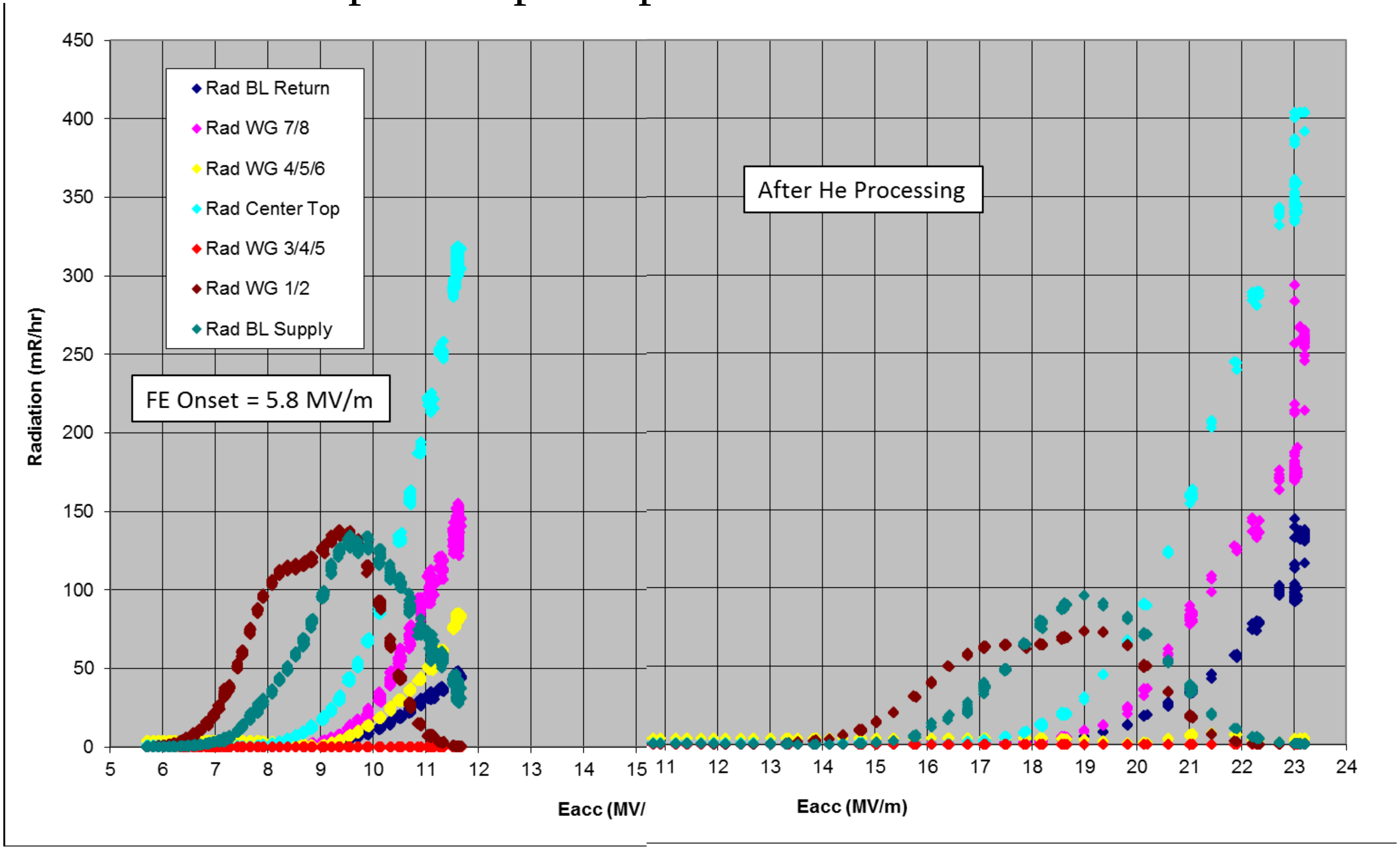
C100-4 helium processing May 2012 (M. Drury)

Cavity	FE onset before	FE onset after	Difference
1	7.3 MV/m	9.4 MV/m	2.1 MV/m
2	5.8	13.0	7.2
3	10.6	12.2	1.6
4	11.1	12.0	0.9
5	6.6	12.8	6.2
6	10.8	14.6	3.8
7	11.1	15.8	4.7
8	10.7	14.8	4.1
MeV w/o FE	51.8 MeV	73.2 MeV	21.4 MeV delta

41% improvement consistent with previous slide

C100-4-2 radiation (M. Drury)

before/after plots superimposed with horizontal offset



Helium processing – possible gains

- 31% of 774 MeV in May 2012 C25 models = **240** MeV
- max allsave gset since 2/2000 less last model = **384** MeV
- smaller of my max 2 day gradient since 3/03 or max allsave gset since 2/2000 less last model = **221** MeV
- August 2000 6 GeV test gset less last model = **216** MeV

- Estimate: 225 MeV may be gained by helium processing the C25 modules.
- Twenty C50 cavity reductions were due to field emission, they might recover ~36 MeV.
- C100 ??

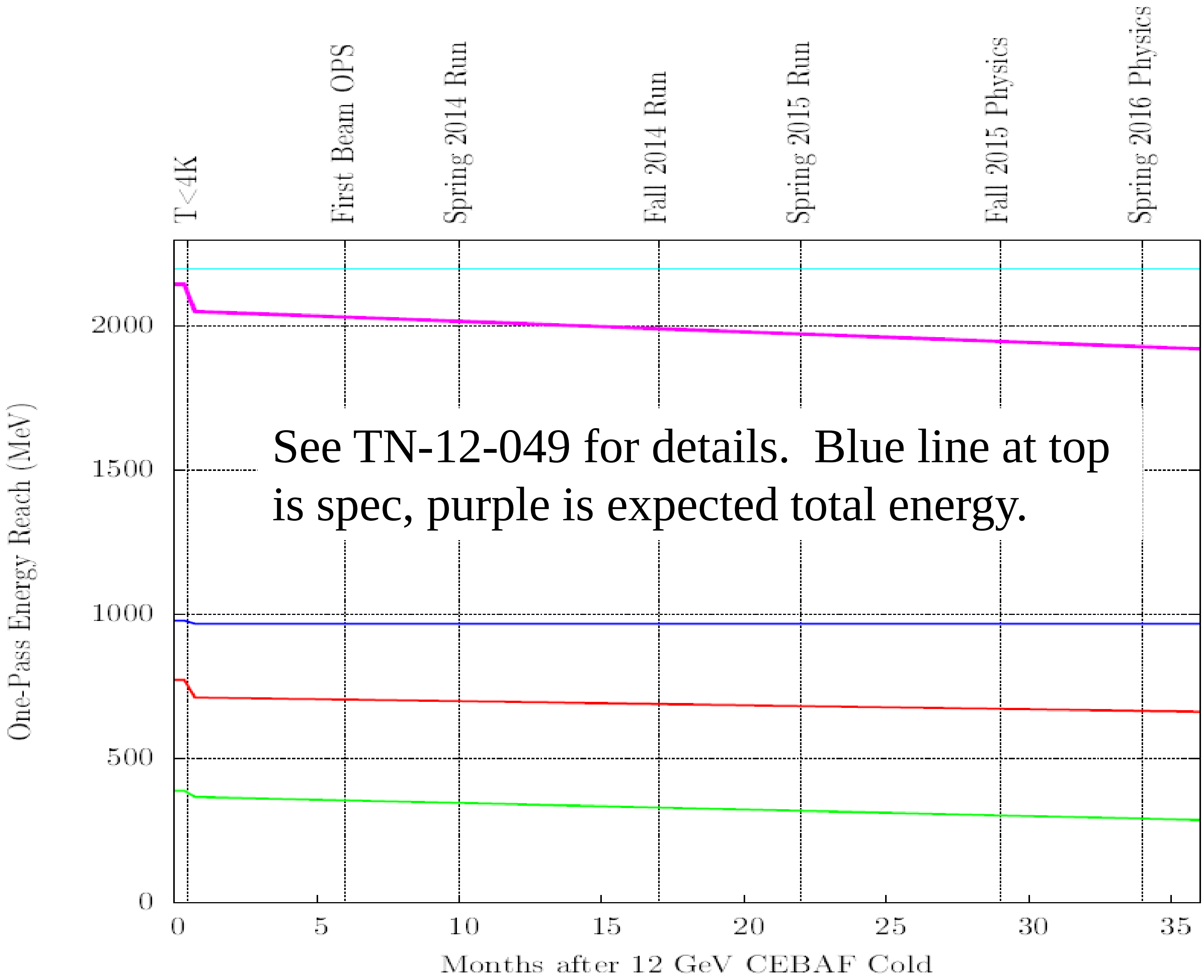
Energy Reach

see also

https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-66429/12-049.pdf

CEBAF Energy Reach and Gradient Maintenance Needs

Jay Benesch and Arne Freyberger



See TN-12-049 for details. Blue line at top is spec, purple is expected total energy.

For more info: July 12, 2012 RF-PIT (Performance Integration Team) material
https://jlabdoc.jlab.org/docushare/dsweb/View/Collection-16674

And for more depressing information:

As Built 12GeV CEBAF Energy and Current Limits

Jay Benesch, Arne Freyberger, Geoff Krafft,

Yves Roblin, Mike Spata, Michael Tiefenback

TN-13-001, February 8, 2013

https://jlabdoc.jlab.org/docushare/dsweb/Get/Document-69781/13-001.pdf

Two recent comments on p values

Two comments on a Jan. 2013 paper on p values I stumbled on via an economics blog which show lots of problems and propose some solutions in dealing with them in observational studies.

Commentary: P Values and Statistical Practice Gelman, Andrew

http://journals.lww.com/epidem/Fulltext/2013/01000/Commentary___P_Values_and_Statistical_Practice.10.aspx

Rejoinder: Living with Statistics in Observational Research
Greenland, Sander[a,b]; Poole, Charles[c]

http://journals.lww.com/epidem/Fulltext/2013/01000/Rejoinder___Living_with_Statistics_in.11.aspx

C50 reduction reasons

- 20 field emission related (heat load, beam line vacuum)
- 4 warm ceramic window temperature
- 8 warm to cold waveguide vacuum faults
- 34 RF controls, generally called instability
- 6 klystron power instability or absolute limits
- 8 no change since commissioning

- 80 total

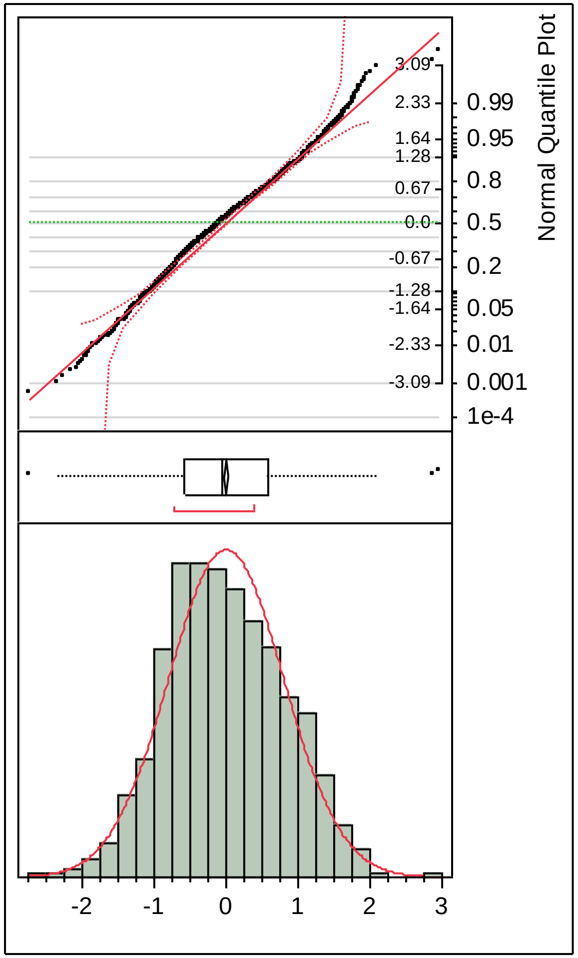
25 un-modeled cavities

1L071 fratricide limits
1L073 Cooper set 8 MV/m limit after 300K cycle, no faults since, once did 9
1L074 Cooper set 8.5 MV/m limit after 300K cycle, no faults since, once did 9.5
1L077 Cooper set 8.6 MV/m CWWT limit
1L078 Cooper set 8.8 MV/m limit after 300K cycle, no faults since, once did 9.6
1L137 fratricide of cavity 8, limited to 10 MV/m which causes one/day in 8
1L138 victim of cavity 7, no gradient dependence on 8
1L161 Cooper set 10 MV/m limit after 300K cycle, no faults since
1L162 Cooper set 10.6 MV/m limit after 300K cycle, no faults since
1L164 GSET.DRVH 10.5 MV/m, no faults there
1L175 quench limit 7.6, no arc faults
1L178 GSET.DRVH 9.1, no arc faults, quench limit 9.4
1L212 GSET.DRVH 11, no arc faults, klystron power limits
1L213 quench limit 8.9 now but has done 10.4 and perhaps 11
2L031 OK at 8.5, Ops keeps turning it down above that when I try to boost it
2L032 a week at 10.6
2L033 long intervals at 10.35
2L054 CWWT limit at 9.15
2L063 hasn't gone above 7 since 6MSD, WG vacuum now limits to 4 (ditto 2L064)
2L108 dead tuner since installation
2L132 fratricide of cavity 1, limited at 9
2L135 fratricide of cavity 6, limited at 7.5
2L175 Cooper and Mounts set arc limit at 7, no recent faults
2L181 BLVF due to field emission from this cavity so bypassed
2L183 fratricide of cavity 4, so limit to 9

test for normality 0L031 residuals

Distributions

Residuals ln(1/interval)



Normal(2.7e-14,0.80195)

Quantiles

100.0%	maximum	2.9845
99.5%		1.86795
97.5%		1.57099
90.0%		1.09443
75.0%	quartile	0.5913
50.0%	median	-0.0502
25.0%	quartile	-0.594
10.0%		-0.9824
2.5%		-1.4739
0.5%		-1.9121
0.0%	minimum	-2.7208

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	2.727e-14	-0.034385	0.0343846
Dispersion	s	0.8019465	0.7783627	0.8270149

-2log(Likelihood) = 5012.3742825258

Goodness-of-Fit Test

KSL Test

D		Prob>D
0.035025	<	0.0100*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

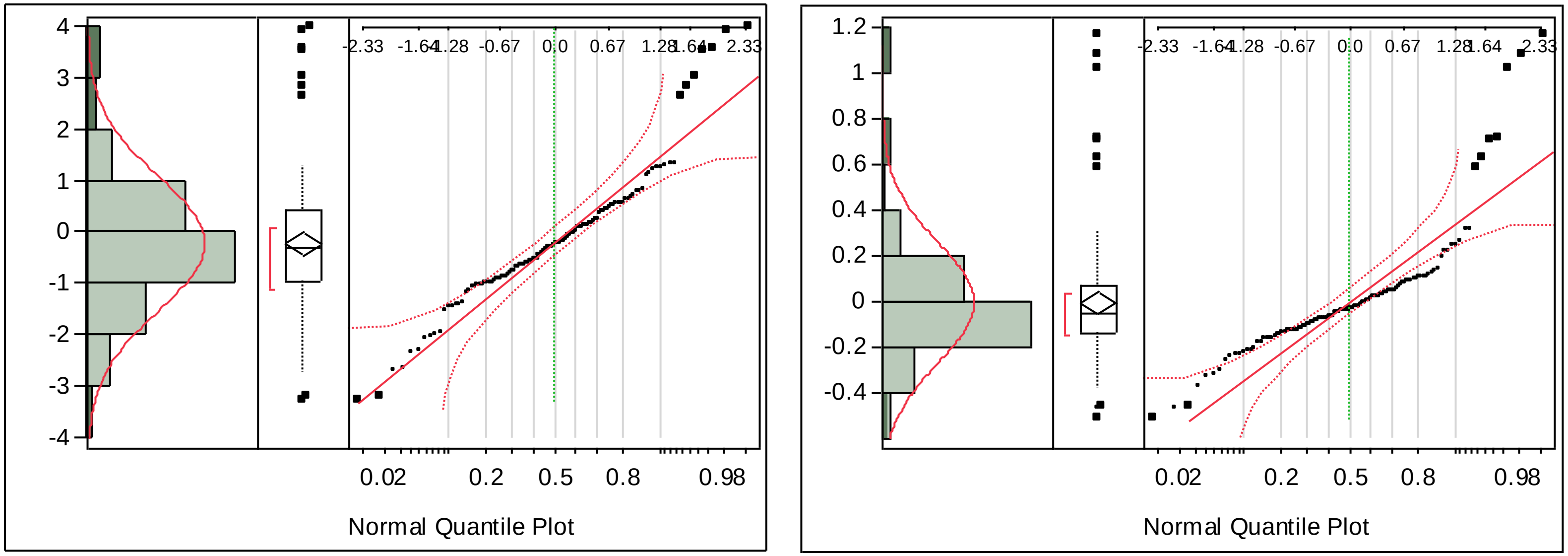
Shapiro-Wilk test used by JMP for less than 2000 samples and KSL test for greater numbers. This distribution is rejected at the P=0.01 level.

KSL: Kolmogorov-Smirnov-Lilliefors (Wikipedia calls it Lillefors test, variation of K-S test)

All controlled 300K cycles

Distributions

delta | **delta/previous**



Normal(-0.2066,1.30393)

Moments

Mean	-0.206581
Std Dev	1.3039298
Std Err Mean	0.1205484
Upper 95% Mean	0.03218
Lower 95% Mean	-0.445342
N	117

Normal(-0.0044,0.2648)

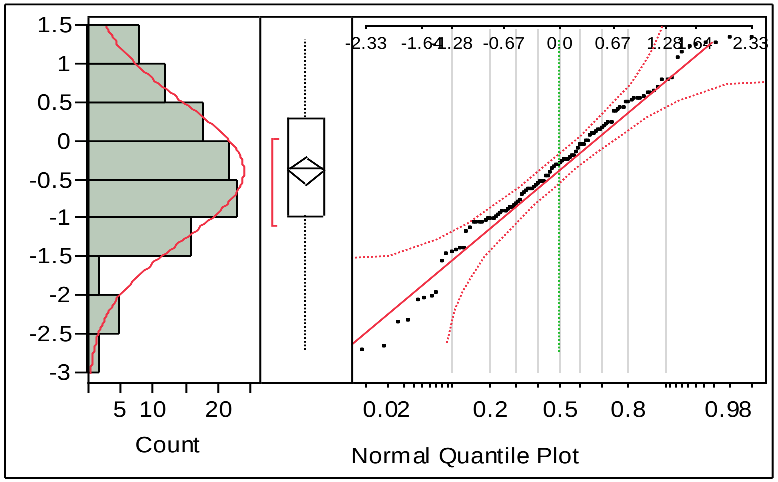
Moments

Mean	-0.004386
Std Dev	0.2648028
Std Err Mean	0.024481
Upper 95% Mean	0.0441019
Lower 95% Mean	-0.052874
N	117

For all controlled 300K cycles for which I have before/after models, effect is smaller: 0.2 MV/m and 0.4%.

Controlled 300K cycles cut for normality

delta



Normal(-0.3787,0.89789)

Moments

Mean	-0.378704
Std Dev	0.8978927
Std Err Mean	0.0863998
Upper 95% Mean	-0.207426
Lower 95% Mean	-0.549981
N	108

-0.4 MV/m after cuts

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.378704	-0.549981	-0.207426
Dispersion	s	0.8978927	0.7920245	1.0366888

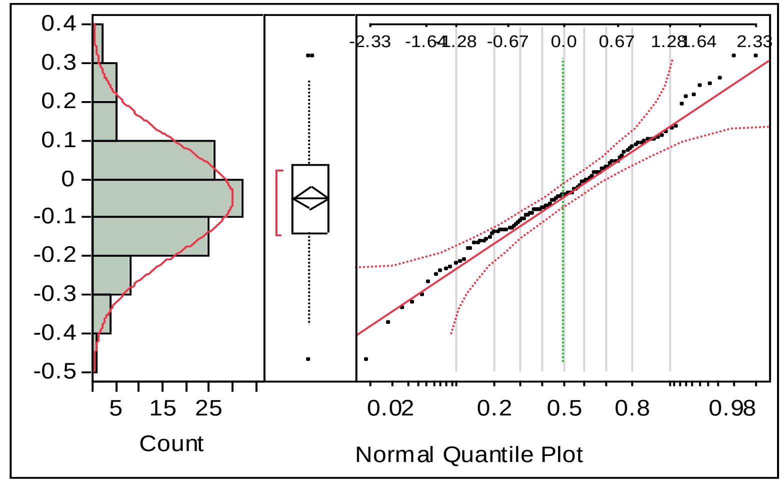
-2log(Likelihood) = 282.226518465222

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.981147	0.1294

delta/previous



Normal(-0.0496,0.14265)

Moments

Mean	-0.049551
Std Dev	0.1426515
Std Err Mean	0.0137267
Upper 95% Mean	-0.02234
Lower 95% Mean	-0.076762
N	108

-5% after cuts. Use this number.

Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-0.049551	-0.076762	-0.02234
Dispersion	s	0.1426515	0.1258319	0.1647026

-2log(Likelihood) = -115.13695965148

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.990824	0.6826

May 18 SL25 test