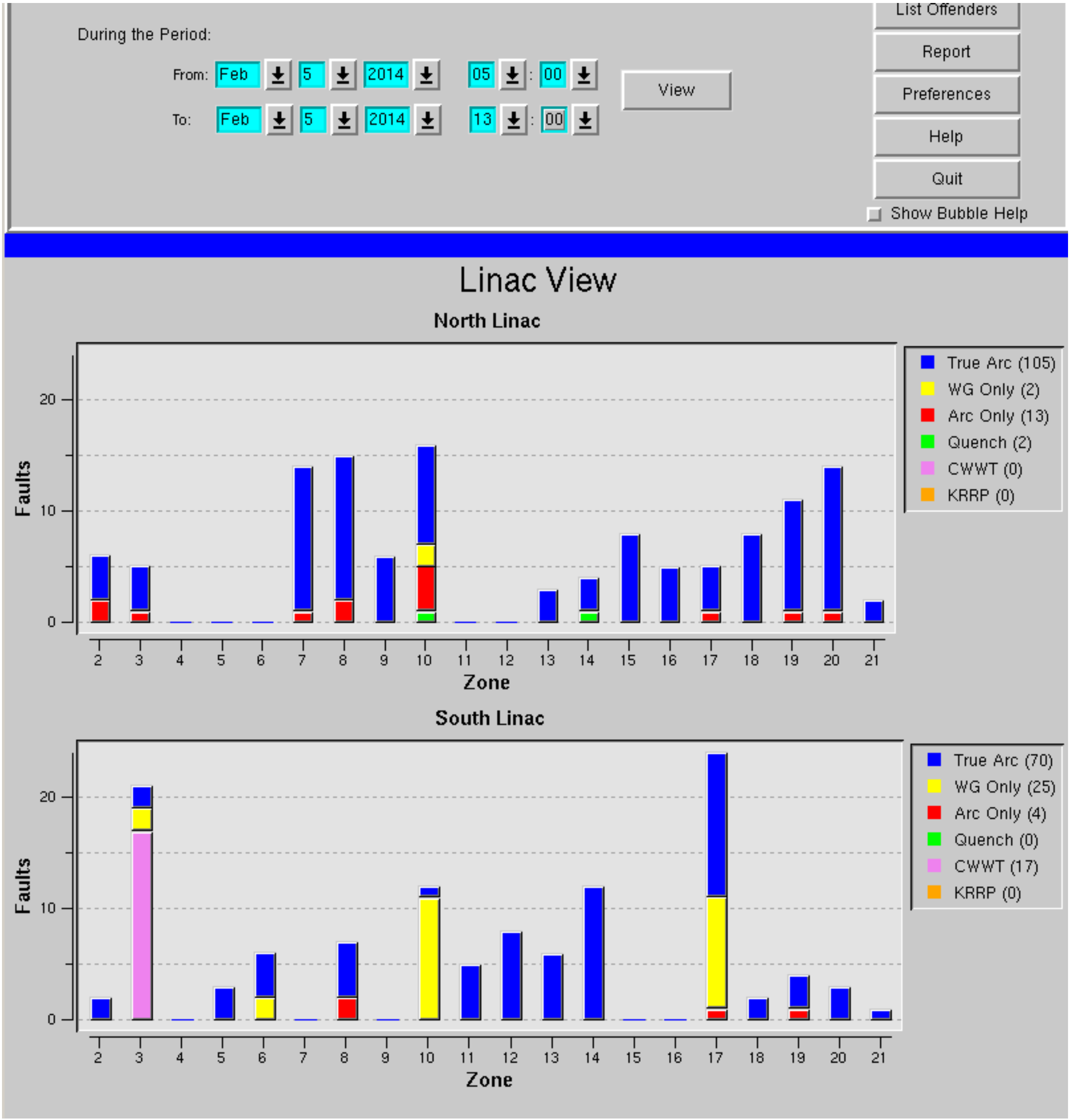
State of CEBAF's SRF

Jay Benesch

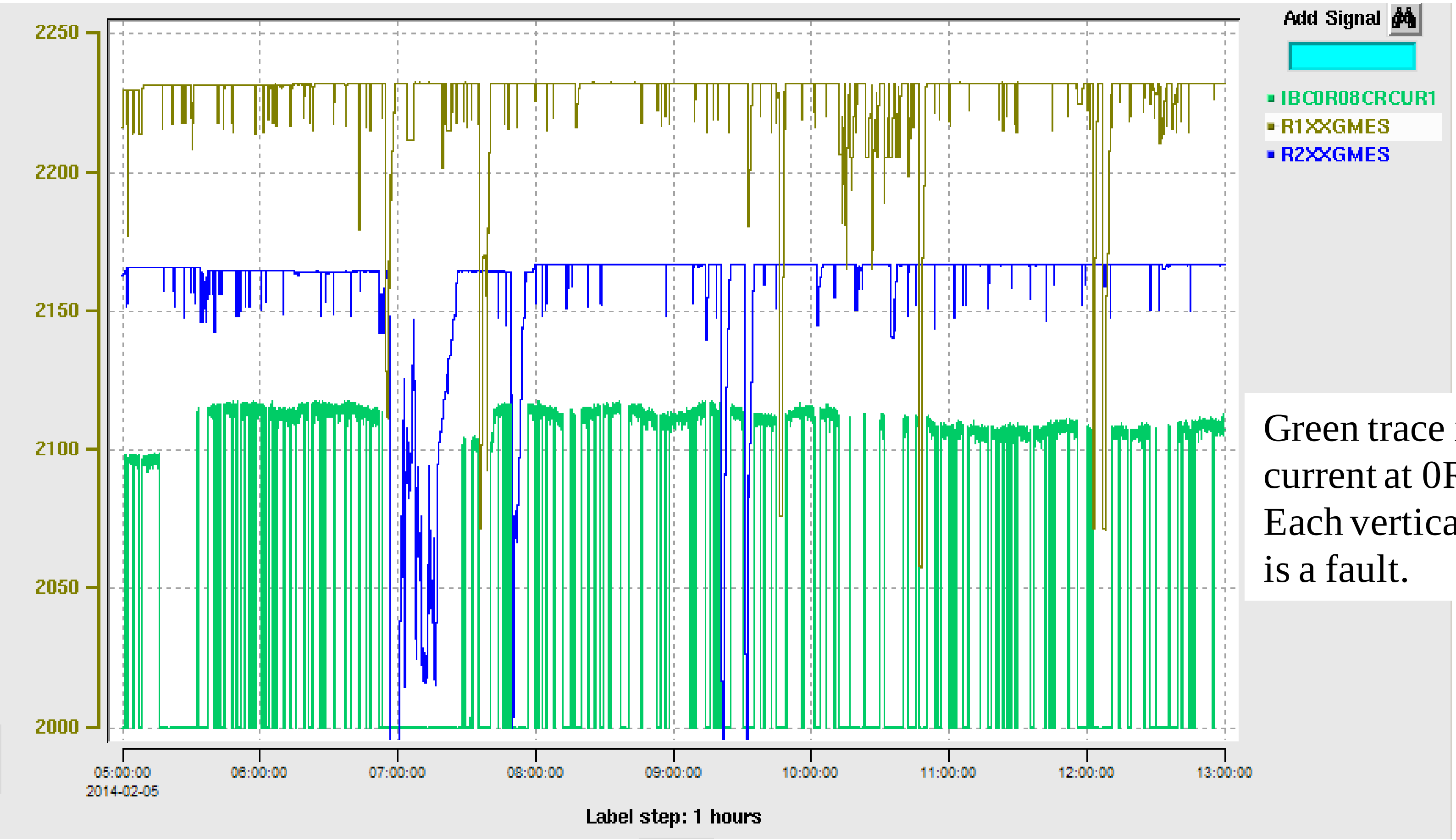
April 3, 2014

Old RF Faults Feb. 5 1090 MeV/linac run



175 True arc faults, 22/hour, in 240 cavities. 200 MeV/pass reduction to reach 5/hour. 4/hour of other types would likely remain the same. CWWT in one cavity, negligible loss when it's reduced.

C100 faults during run



Green trace is current at 0R08. Each vertical line is a fault.

I count 12 large reductions in GMES corresponding to C100 full or half-zone faults. The two in SL (R2) ~0930 lasted 5 minutes each.

Fault Rates

- No mechanism exists for useful accumulation of C 50 and C100 fault rate and duration information. My guess: a 5% hit on availability. I look forward to Rama's talk.
- C50 zones have frequently been bypassed because Ops has gradient headroom running at 800 MeV/linac given C100s. The zone-common hardware is taxed. Steve's talk.
- January 24 – March 22 FaultLogger accumulated
  - 1202 waveguide vacuum faults (601 pairs)
  - 557 arc-only faults (mostly NL 7,8 SL 4,6,8,10,13,17)
  - 875 CWWT faults
  - 4576 "true arc" faults = arc + waveguide vacuum

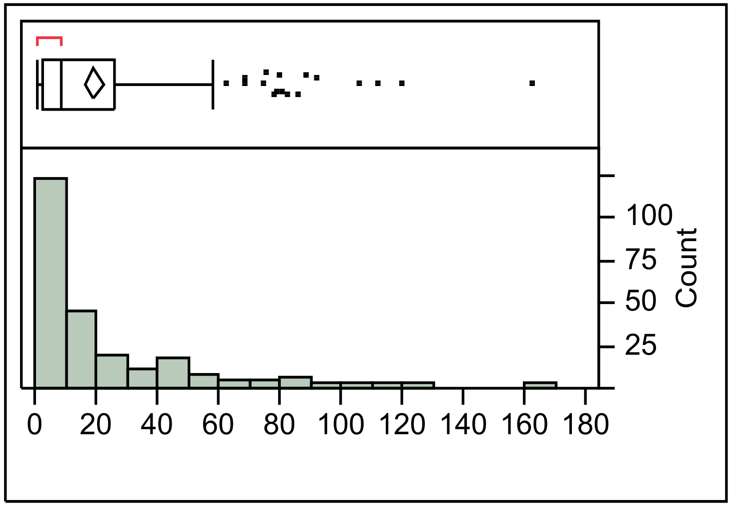
CWWT faults

2L106	202
2L058	159
2L083	105
2L064	84
1L177	64
2L132	59
2L055	28
2L188	28
1L137	26
2L062	22
1L108	19
2L034	17
2L138	8
1L105	7
2L048	7

835/875 of CWWT faults in these 15 cavities. 19 other cavities have 5 or fewer. CED limits are now appropriate.

True arc faults

- The only faults I've been able to model statistically.
- Initial lem models used old average slope and Drury's (EmaxOp – 0.5) for intercept-equivalent, gradient at which a fault occurs every eight hours. log(1/interval) = A + B*GSET
- 4576 faults cited above allow 75 models of modest reliability (2+ σ) with nine or more fault intervals

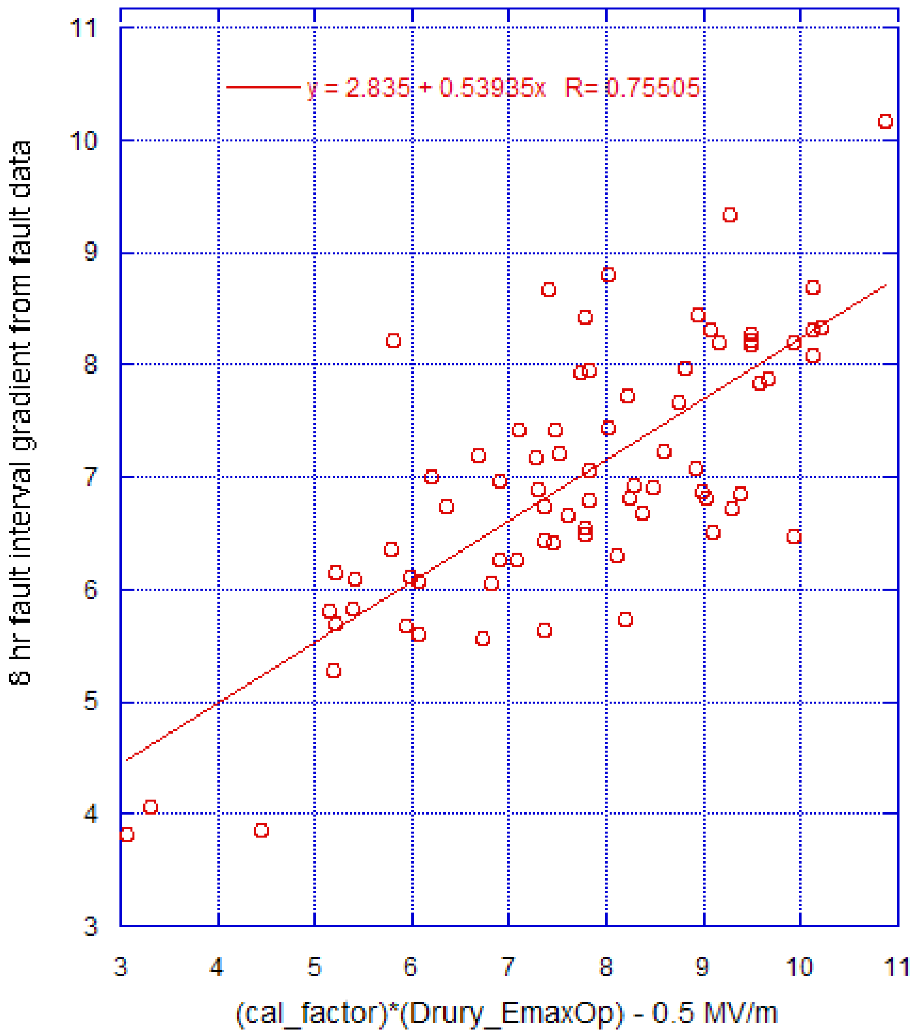


Quantiles

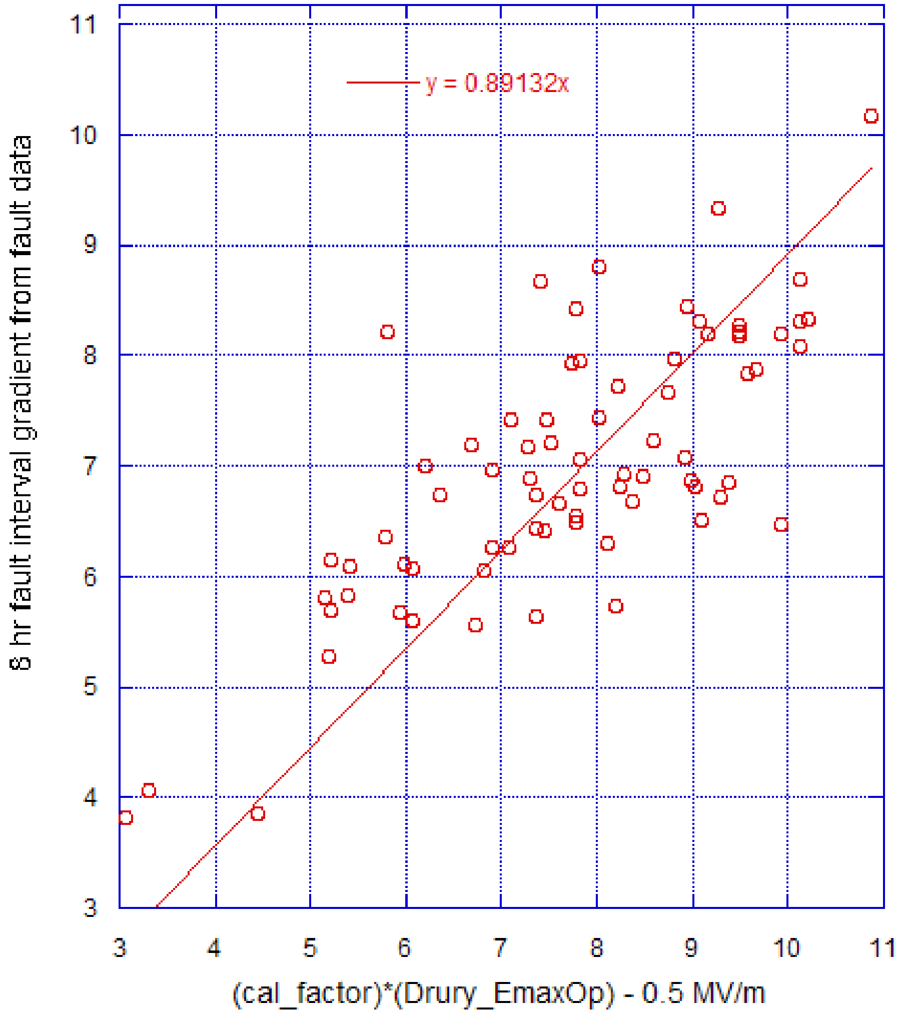
100.0%	maximum	163
99.5%		155.475
97.5%		89.375
90.0%		50.5
75.0%	quartile	26
50.0%	median	9
25.0%	quartile	3
10.0%		1.5
2.5%		1
0.5%		1
0.0%	minimum	1

Faults per cavity. Cavities with 10 or more faults examined, model yield ~2/3

True arc faults II



True arc faults III

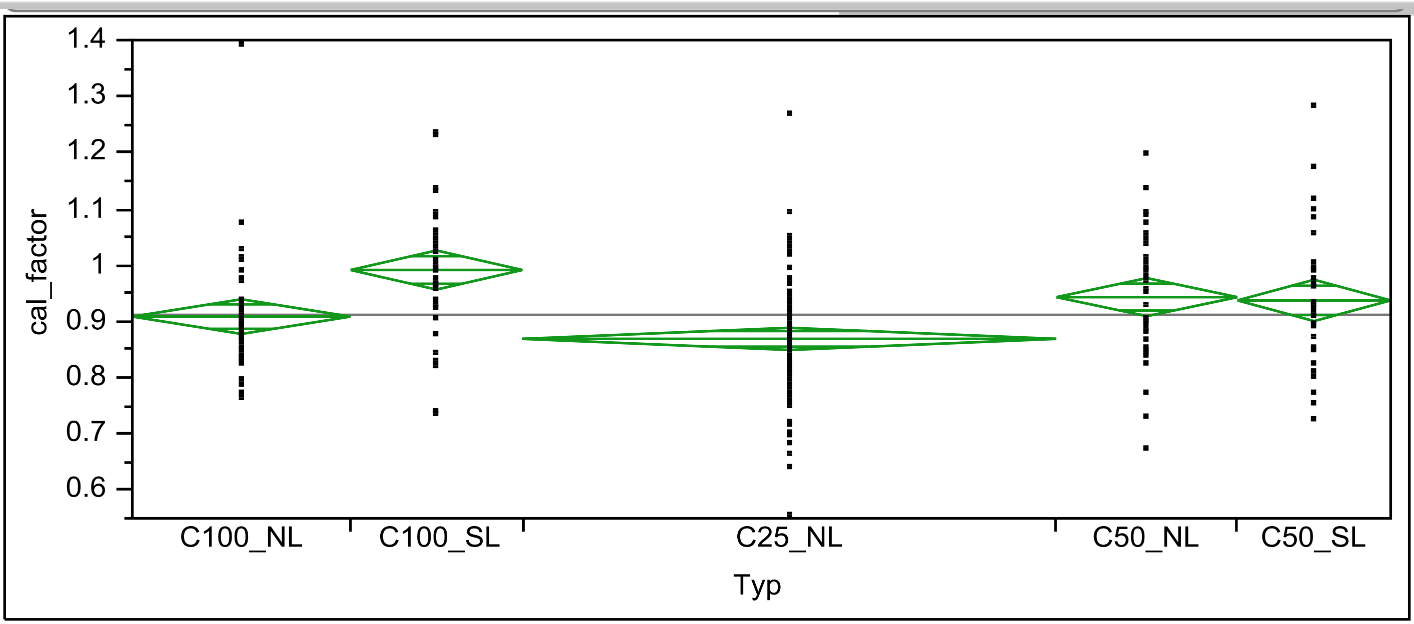


I plan to remove the 0.5 MV/m offset to increase the number of trips in 165 cavities without models.

Beam based calibration

- Required as SRF recommissioning chose to over-write existing beam-based calibration and Ops system didn't retain 2012 download values.
- Obtained dP(BEM, BdL) vs ESET for one reference cavity in each linac, 1L26-6 and 2L26-1.
- Balanced each other cavity in NL, each high momentum cavity in SL against the reference, making a null measurement at constant arc energy and optics.
- R100 measurements in 0L06 spectrometer found a coding confusion which complicated the application of the data to the machine.
- NL cumulative error is now understood and is a few ppt.
- SL error assessment will have to wait until remainder of linac is done.
- SL C25 and C50 modules had 0.92 multiplier applied Jan. 24. SL C100s had half of required factor applied Feb. 7.
- SL lem fudge factor 1.013.
- Values which follow include compensation for FCC code confusion, not yet fully applied to machine. Apply April 7-10?

Beam based calibration II



Missing Rows 106

Excluded 39

Oneway Anova

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
C100_NL	47	0.908596	0.01565	0.87778	0.9394
C100_SL	37	0.991385	0.01764	0.95665	1.0261
C25_NL	115	0.869000	0.01001	0.84930	0.8887
C50_NL	39	0.943179	0.01718	0.90935	0.9770
C50_SL	33	0.937364	0.01868	0.90059	0.9741

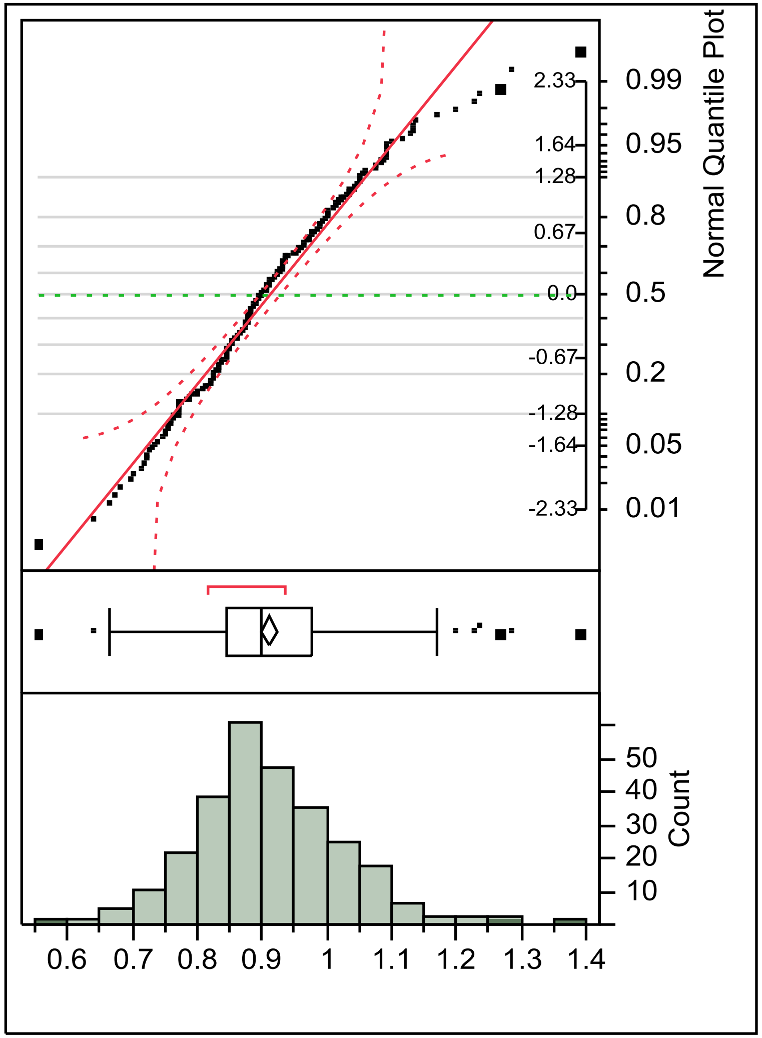
Std Error uses a pooled estimate of error

NL values are confirmed by incremental changes in lem fudge factors since all cavities have been measured.

SL values have no independent confirmation.

Three distributions are normal as shown. C100_NL requires top outlier removal and C25_NL top and bottom outliers removal for normality.

Beam based calibration III



Quantiles

100.0%	maximum	1.392
99.5%		1.35276
97.5%		1.1762
90.0%		1.0529
75.0%	quartile	0.977
50.0%	median	0.9
25.0%	quartile	0.846
10.0%		0.7712
2.5%		0.6992
0.5%		0.5866
0.0%	minimum	0.556

Moments

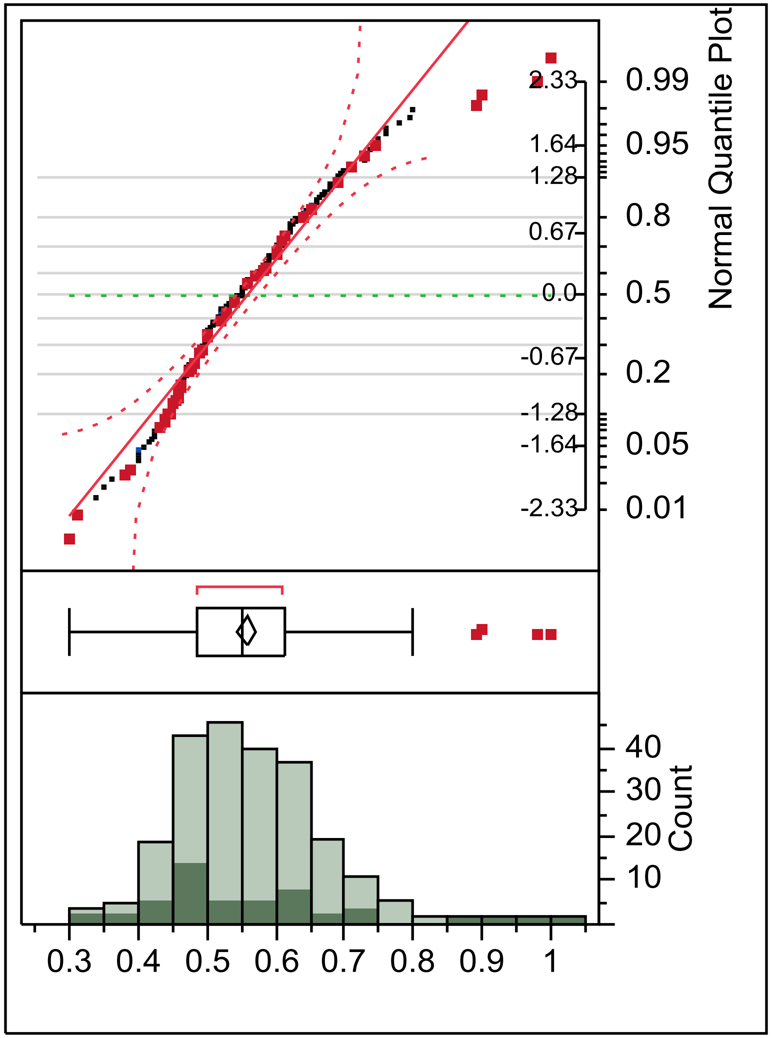
Mean	0.9115765
Std Dev	0.1149531
Std Err Mean	0.0069829
Upper 95% Mean	0.9253244
Lower 95% Mean	0.8978287
N	271

Beam based calibration IV

- 150 functional cavities remain to be calibrated or checked, most in South Linac. Two to three shifts, depending on arc 2 momentum.
- C50 cavities can be measured at 800 MeV/linac with acceptable errors. C25 cavities don't have enough (GSET-3) for adequate change in 1690 MeV arc.
- Shunt system (in)stability limits minimum beam energy.
- After calibration, fault data for lem statistical models may be obtained parasitically over ~45 weeks of operation as after Isabel or in a concentrated 10 day period (no beam)

Commissioning Field Emission Onset

FE/Emax



Quantiles

100.0%	maximum	1
99.5%		0.9973
97.5%		0.7955
90.0%		0.69069
75.0%	quartile	0.615
50.0%	median	0.55
25.0%	quartile	0.48601
10.0%		0.4443
2.5%		0.37446
0.5%		0.30135
0.0%	minimum	0.3

Moments

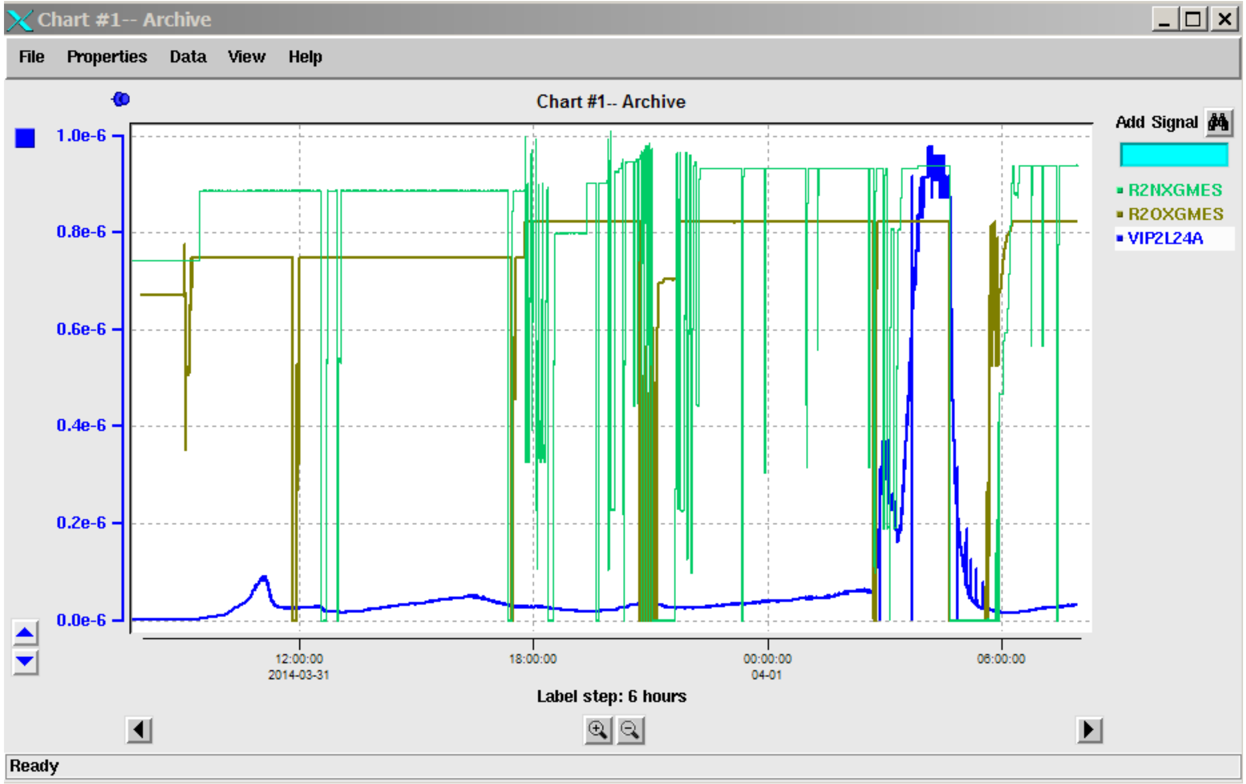
Mean	0.55809
Std Dev	0.1073588
Std Err Mean	0.0071414
Upper 95% Mean	0.5721626
Lower 95% Mean	0.5440174
N	226

Data taken from M. Drury's commissioning summary spreadsheet downloaded 7 Feb. 2014. Emax is the highest gradient achieved in the testing. FE is field emission onset. There are many zones for which the latter was not in the spreadsheet. Red points in upper graph and darker green in histogram are C100 cavities.

Girder pressure rises due to field emission

- https://logbooks.jlab.org/entry/3274314
- The following zones had their slow trip point level adjusted to 5e-8:
  North LINAC
  VIP1L07A&B
  VIP1L15A&B
- South LINAC
  VIP2L05A
  VIP2L08A&B
  VIP2L15A&B
  VIP2L16A&B
  VIP2L17A&B
  VIP2L18A
- C100 gradients were turned down for 800 MeV/linac run in lieu of changing vacuum set points and again Tuesday night for 6.1 GeV run to hall A.
- Cavities in zones by ion pumps listed were also lowered en masse
- **We now know from Peter's work and the FEL that even catastrophic vacuum events produce at worst 30% degradation. Ron's 1E-8 set point has been proved to be far too conservative. We shouldn't be closing the gate valves.**

SL23/SL24 incident Tuesday owl

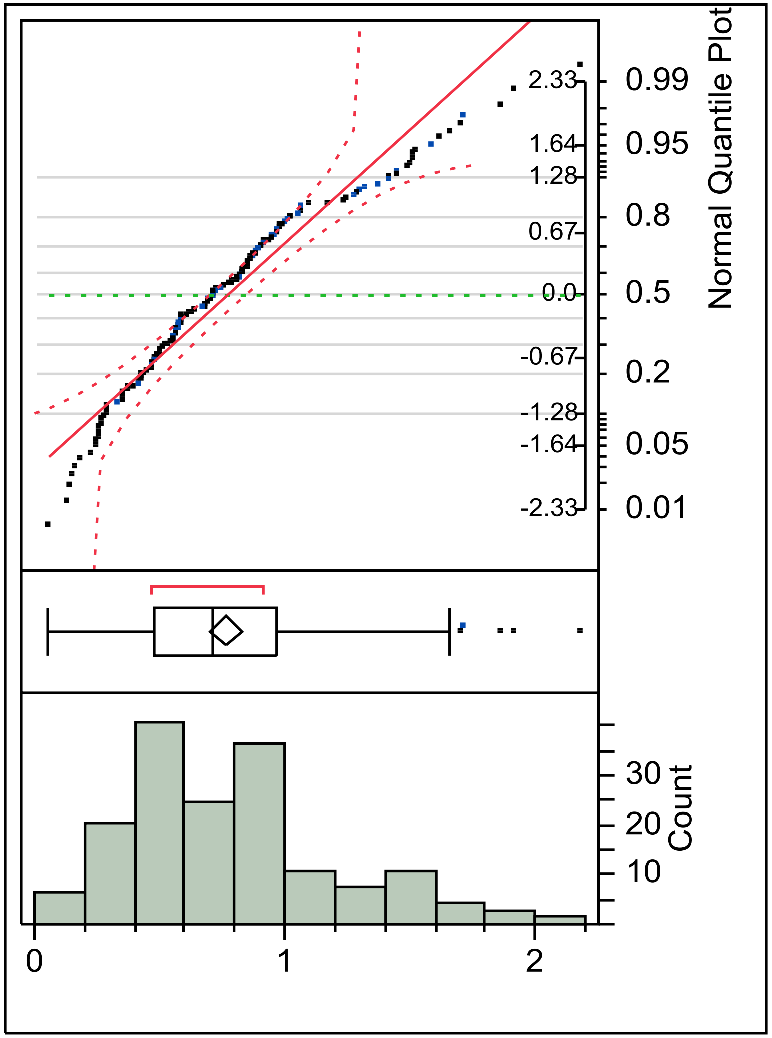


Many trips in SL23 (green) through the last 24 hours; fewer in SL24. Valve between them closed when vacuum (blue) rose abruptly and didn't open until both had been off for a couple of hours. GMES scale max 150 MV/m Ops lost another hour Tuesday swing to 2L26 vacuum interlock.

Q

Cavity Q before and after the SAD

Q0_2014/Q0_2011



Quantiles

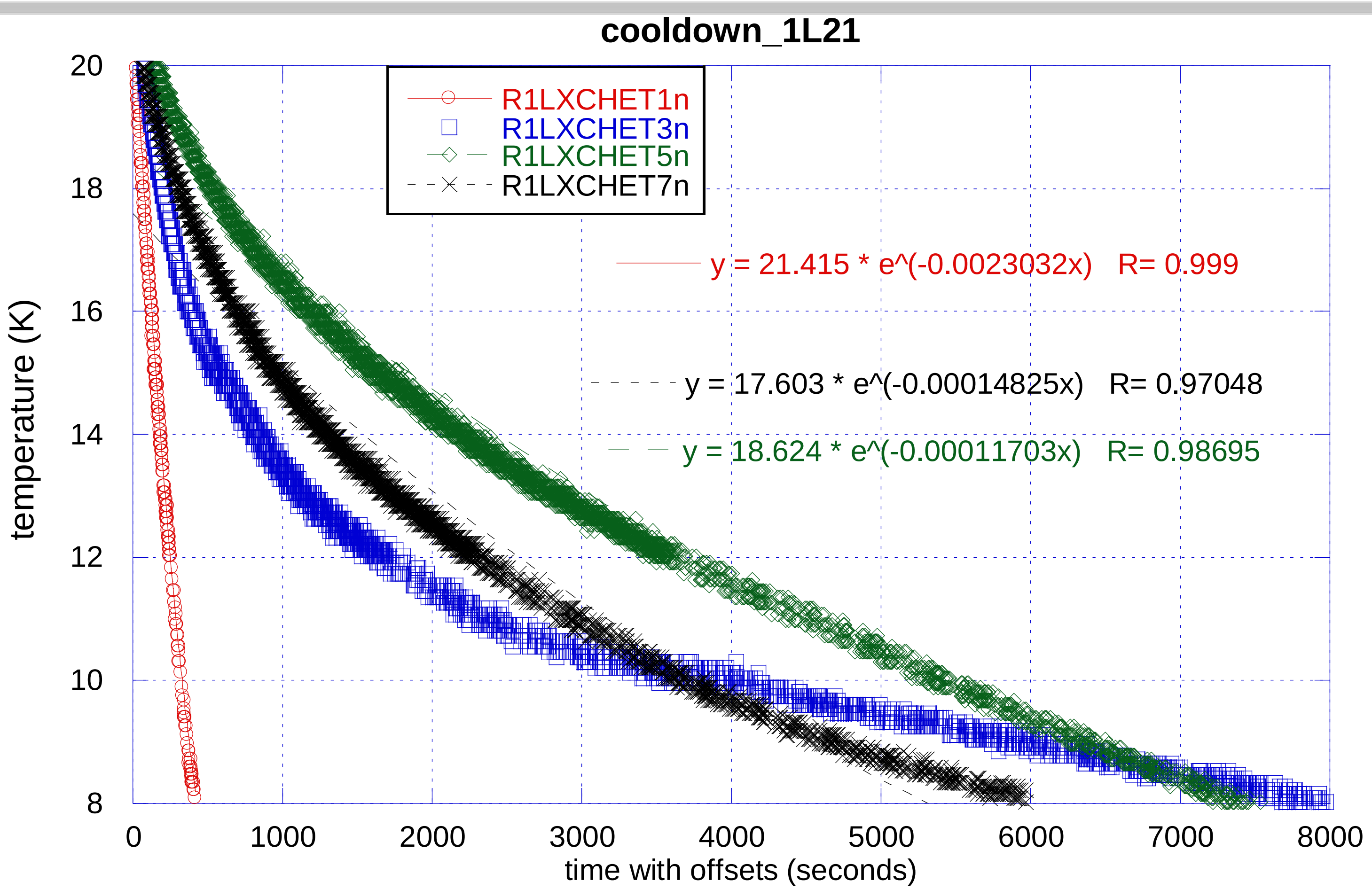
100.0%	maximum	2.18125
99.5%		2.18125
97.5%		1.70629
90.0%		1.41523
75.0%	quartile	0.9629
50.0%	median	0.71105
25.0%	quartile	0.48246
10.0%		0.28516
2.5%		0.1514
0.5%		0.05818
0.0%	minimum	0.05818

Moments

Mean	0.7696152
Std Dev	0.4042184
Std Err Mean	0.0319563
Upper 95% Mean	0.8327287
Lower 95% Mean	0.7065017
N	160

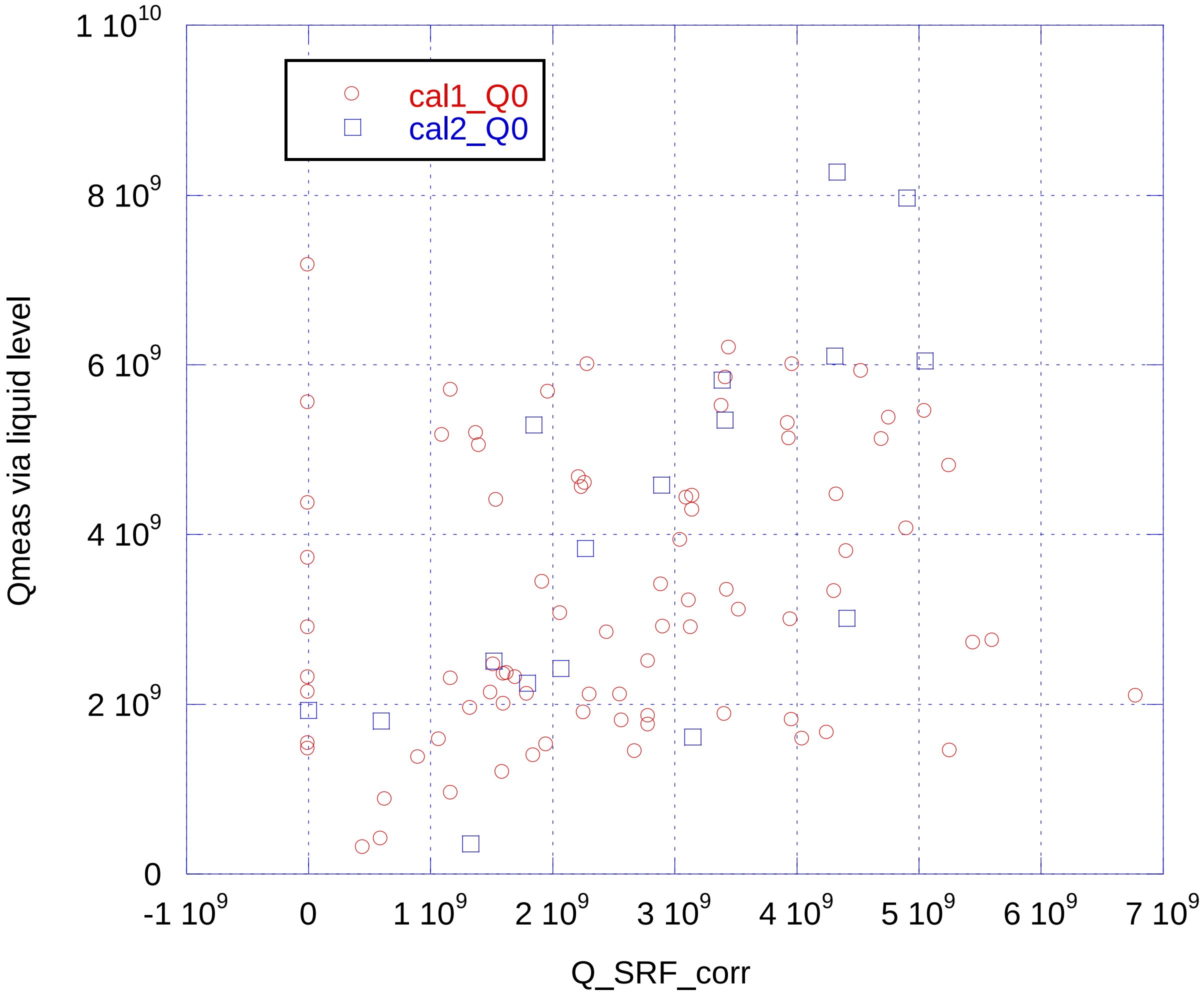
2011 values measured using EPICS and Bickley/Creel/Freyberger/Reece/Turner software. These were likely at lower gradients (less field emission) than the 2014 values measured by SRF commissioning team and scaled by beam-based gradient calibration (F^2) NL-only because SL cavities have not been calibrated with beam.

SL 21 cooldown rates



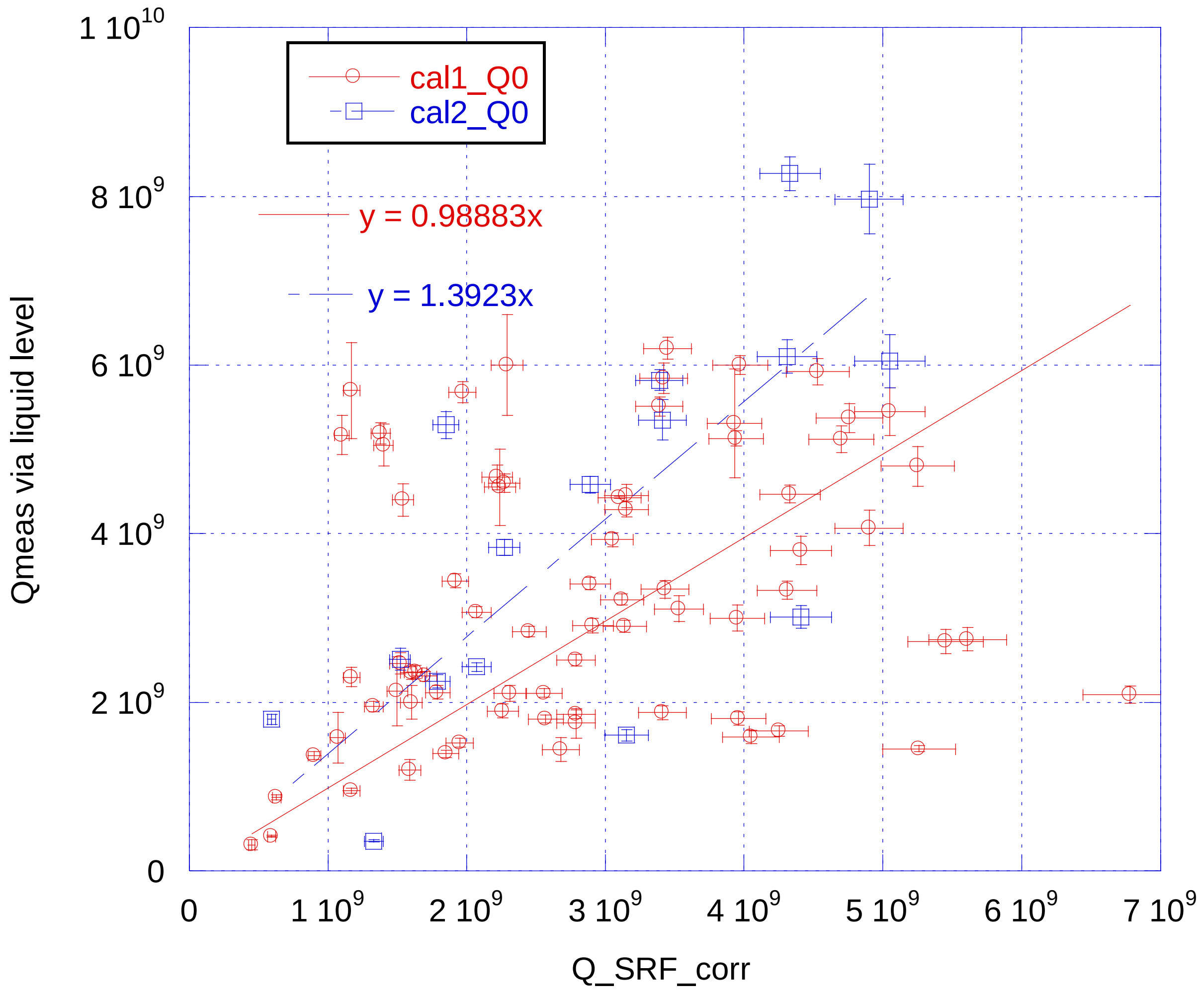
First pair cooldown at half FNAL "fast" rate, third and fourth pair at FNAL slow rate. No statistically significant difference seen in SRF re-commissioning Q as a function of cavity location, so fast cooldown doesn't seem to help our cavities, as Reece predicted. If I had access to low field Q0 values, I could check the correlation again. Or SRF could.

Liquid level based Q measurement vs SRF's



The 9 measurements at x=0 have no Q value in Drury commissioning spreadsheet.

Q comparison II



5% error bars used for SRF measurement (x).

Q measurement program error bars used in y.

Lines provided for author's amusement.

cal1 and cal2 represent successive attempts on a given cavity.

Nine points with x=0 discarded.

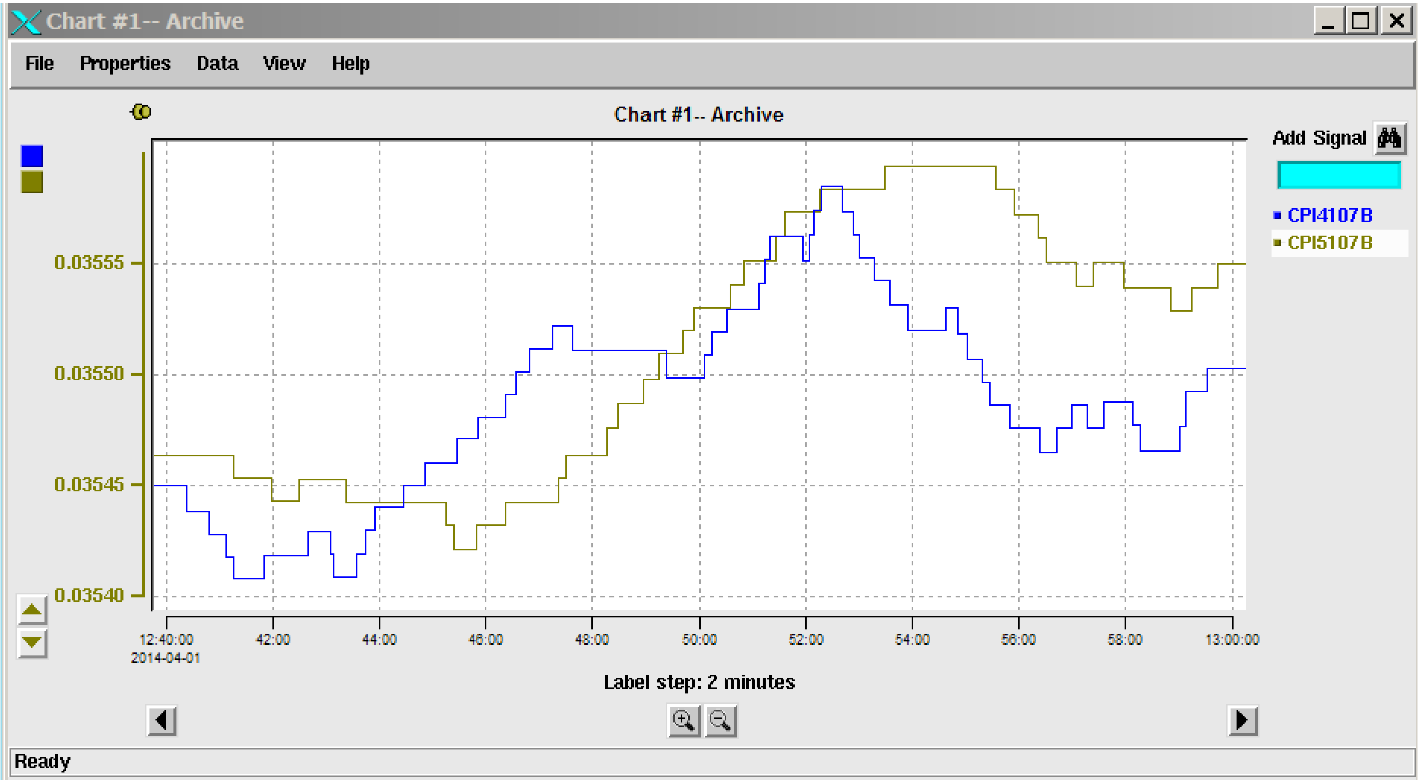
Q measurement III

- Ops Q measurement is severely impacted by thermal shorts in the liquid level (LL) sensors. About half the NL and a fifth of the SL sensors have thermal shorts in the range of interest, 86-94%. The shorts affect Cryo, too.
- Changing the liquid level lower alarm limit in the old cryomodules to the midpoint of the HOM flange would ease parasitic Q measurement. With tune beam we might expose it entirely. A layout showing LL sensor and upper HOM load elbows/flanges is requested from SRF.
- Thermal analysis of this region was requested of Ed Daly.
- Lowering the nominal LL would provide additional ullage for LHe density change from 2K to 4K, making it easier for Cryo to pump down after a trip.

Pressure variation

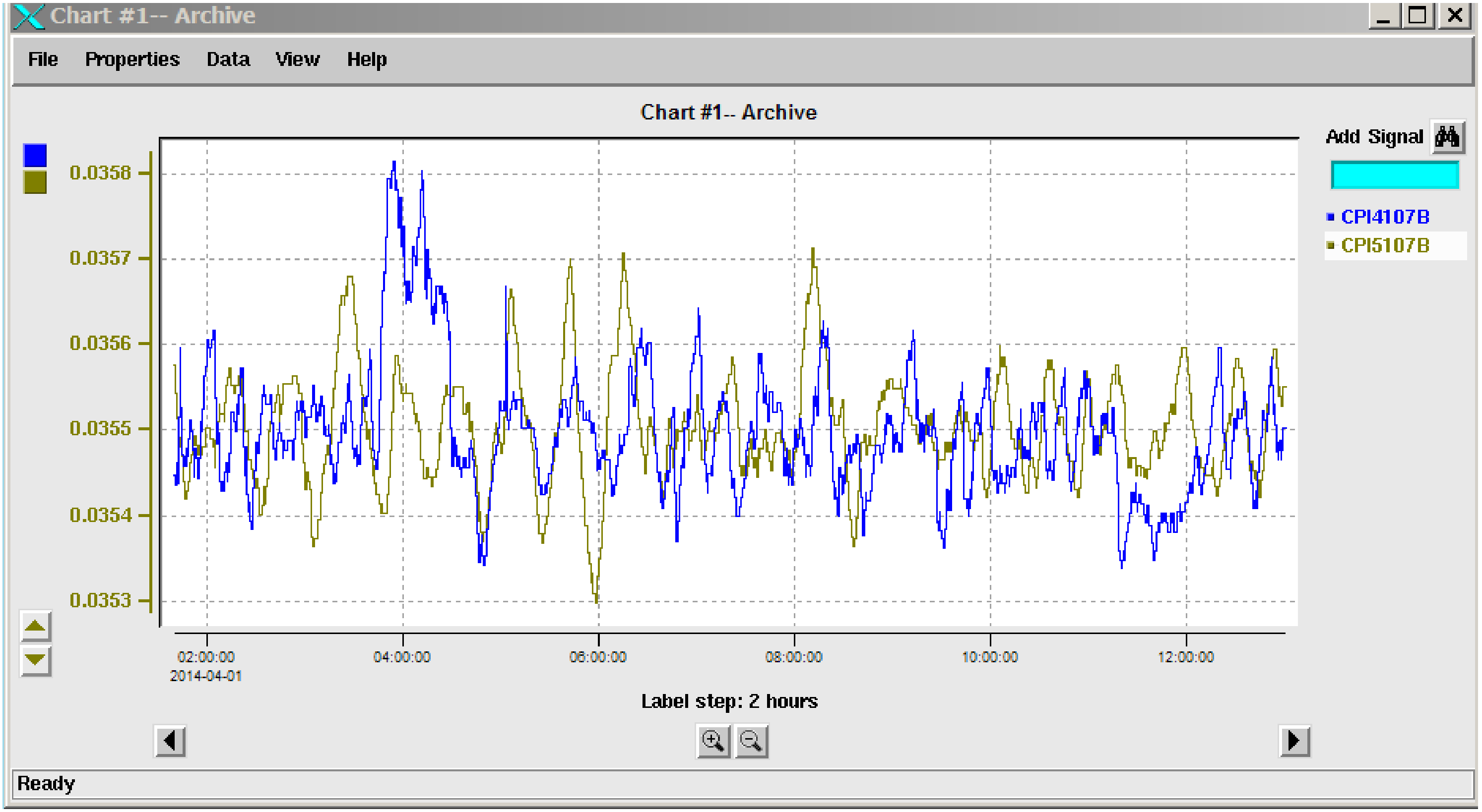
- Old cavities have 2-4 Hz/torr or 1.5-3 Hz/mbar pressure sensitivity. Input bandwidth > 180 Hz
- New cavities have 200-300 Hz/torr or 150-230 Hz/mbar sensitivity. Input bandwidth ~ 40 Hz
- Cryo pressure control is remarkably the same with two CHLs as it was with one, 0.5-0.6 mbar peak to peak.
- C100 pressure sensitivity is poorly matched to cryo pressure control capability.
- See Jonathan's and Mat's talks

CPI4107B NL, CPI5107B SL



200 µbar = 152 mTorr -> 30-45 Hz variation over ten minutes for C100s. Higher frequencies not recorded by EPICS archiver and may be limited by ADC resolution.

12 hour span



Longer term variations in both linacs 0.5 mbar.

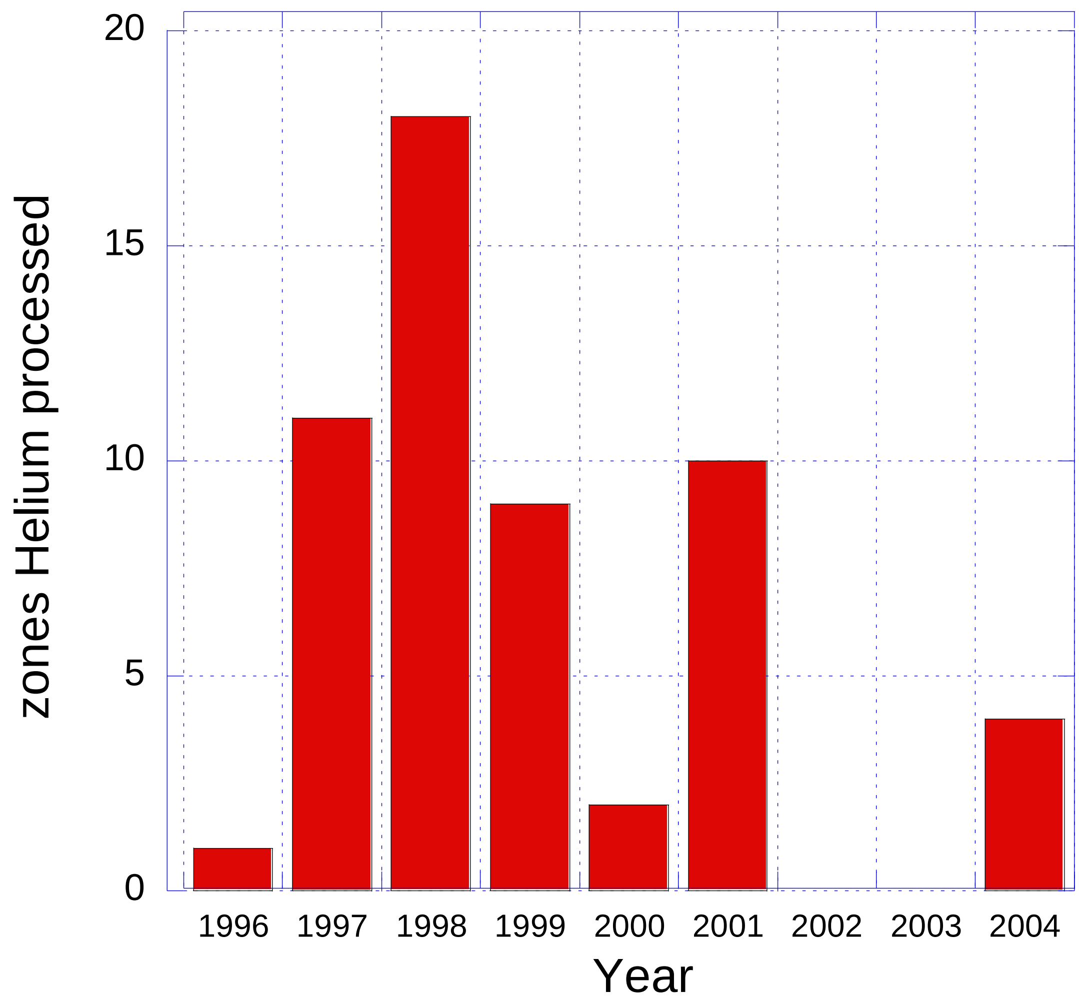
Slides from my Feb. 2013 seminar

Possible Mitigation

http://www.jlab.org/user_resources/pizza_seminars/2013/Benesch_1_13.pdf

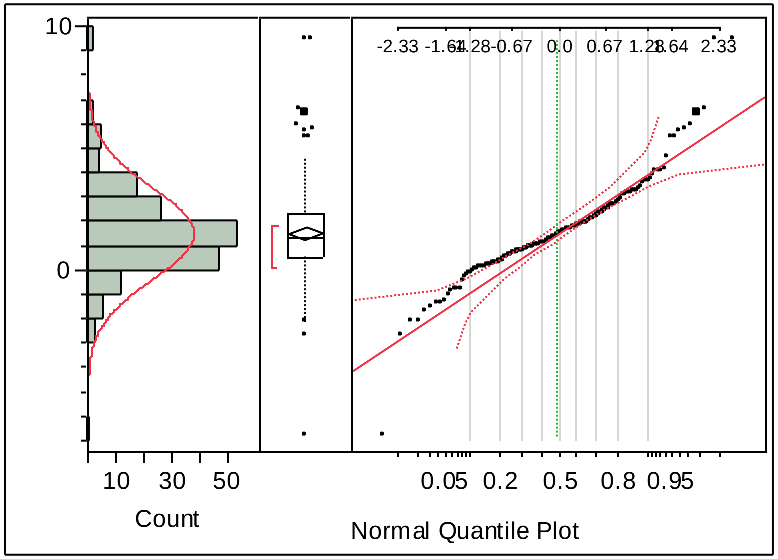
Helium processing

- 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

HEP_one_change



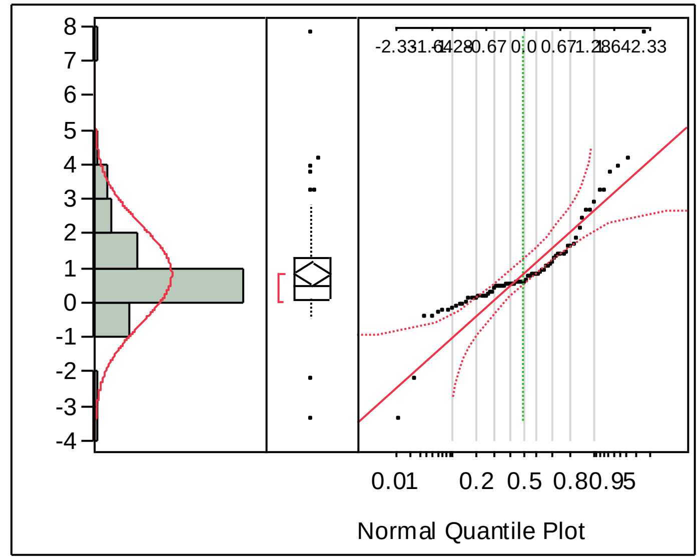
Normal(1.54503,1.89472)

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

Units MeV

delta



Normal(0.86711,1.43003)

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)

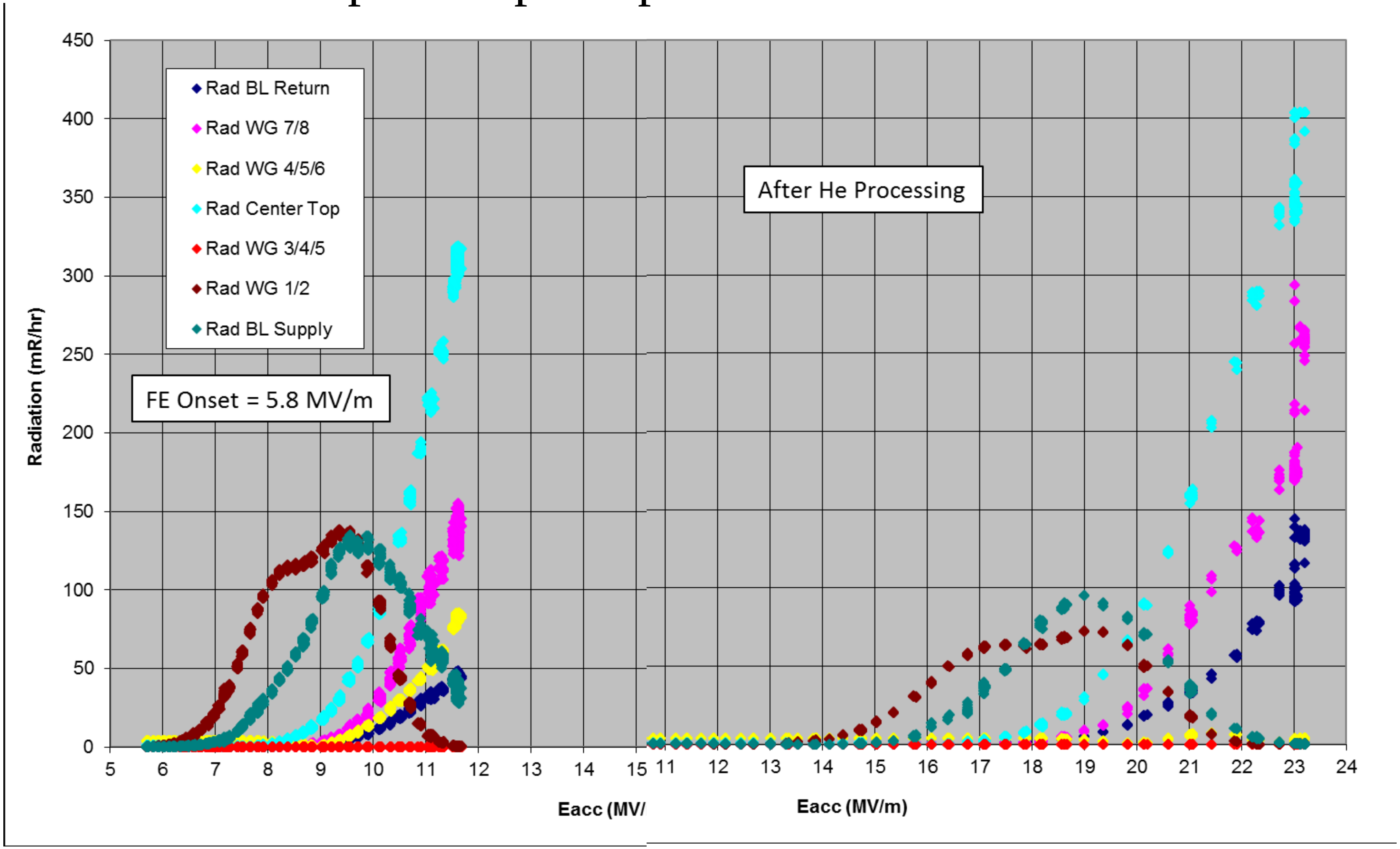
C100-4 helium processing May 2012 (M. Drury)

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 (2012) due to field emission, they might recover ~36 MeV.
- C100 ?? Substantial reductions have been made due to field emission induced girder-vacuum trips. *65 MeV down in SL Tuesday swing for 6.1 GeV run.*

Helium processing R&D suggestions

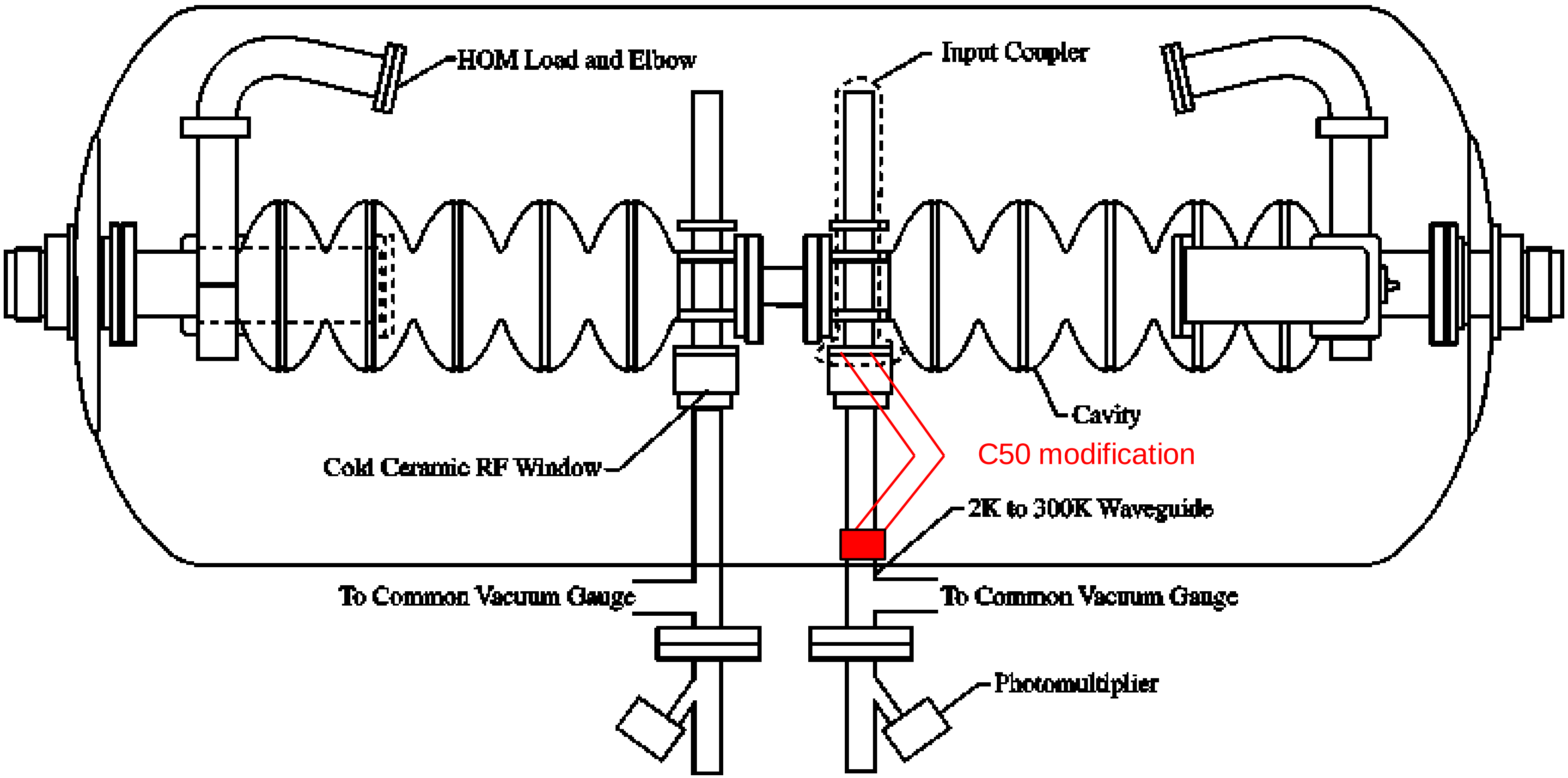
- Helium processing, aka RF discharge processing, might be investigated in CMTF or FEL.
- Field probe might also work as a Langmuir probe to measure plasma parameters since RF info is passed through a transformer for the old RFCM. New FCCs?
- Spectrometers with vacuum interfaces could be attached to the gate valves on each end for optical diagnosis of the plasma from VUV to IR.
- Plasma parameters would be varied and Q vs E results plotted with the goal of process improvement

Recommendations

- Helium process everything: 40 days, 3 shifts, 5 people = 3FTE. With two CHLs and more people, perhaps only three calendar weeks.
- In parallel with ten day lem data acquisition for C25s, determine one-day stable gradients for C50 and C100 zones.
- No SRF recommissioning: Q vs E point at one day stable gradient only, using LL sensor with JT locked.
- Remove the interlock which closes gate valves on every tunnel entry, spewing particles each time. Close them only for long SADs.
- Disable all "fast" valves. Cost:benefit ratio is too high for 3 seconds.
- Set the slow gate valve comparators to 10^{-6} torr and set a software alarm at $5*10^{-8}$ torr so Ops can continue to deliver beam while finding the cavity which is causing the girder vacuum to rise.
- Develop a large area x-ray sensor which may be permanently installed. Bundles of fiber scintillator? Tubes with liquid scintillator? Plastic plate with fiber? PMT read-out to new 12 bit ADC arc detector cards.
- Lower LL in old CMs since HOM heating less with lower current.

Backup

Old style cavity pair



Recent research relevant to HeP procedure

- Original HeP procedure began with 30K cycle to remove accumulated H_2.
- Work after Isabel, with mediocre results, omitted this step.
- http://arxiv.org/abs/1401.7747 shows that fast cooldown from 20K can increase Q0 a factor of three versus slow cooldown, for ILC standard cavity processing.
- SRF used slow cooldown on C50 and C100 modules.
- M. Drury provided T vs t data for SL21
- Test of whether faster cooldown to 4.2K would increase Q was cancelled as a result of Q vs position comparison.
- 2K-30K-2K cycle for GHe removal still must be checked with new CHL configuration.

Wild idea

- Peak fields at linac height due to rebar in tunnel are ~2.5G per SRF contractor survey, much more than old cryomodule shielding was designed for.
- There are epoxies and auto-repair compounds with 50% steel fill.
- One could pick a piece of the tunnel and trowel ~5 mm onto floor, walls and ceiling. This would turn the asymmetric field into something more uniformly solenoidal and perhaps low enough for the CM shielding.
- Cycle up to 20K and back down; measure Q.
- Bubble chamber NP experiment at 8.5 MeV would benefit from such field modification.

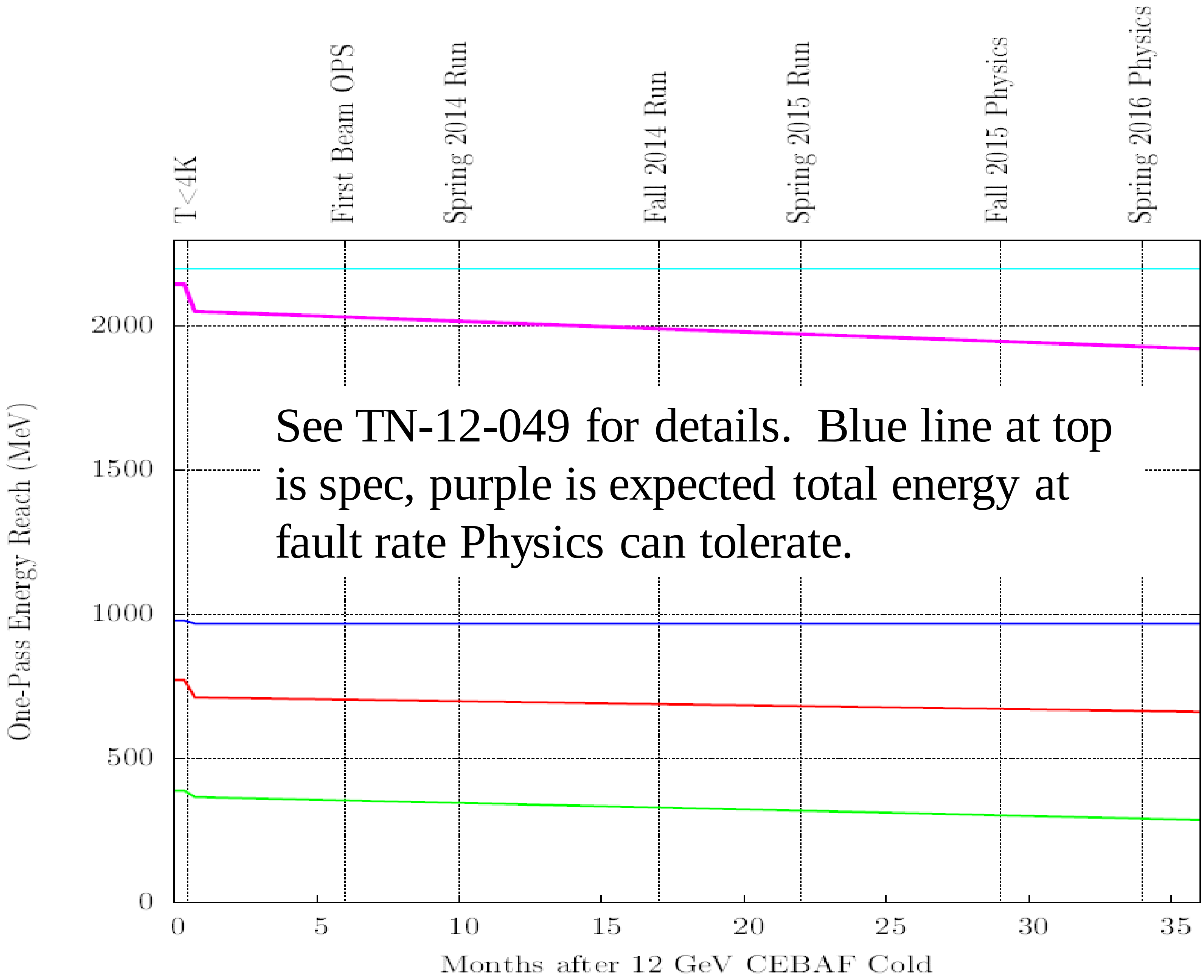
Energy Reach

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

CEBAF Energy Reach and Gradient Maintenance Needs

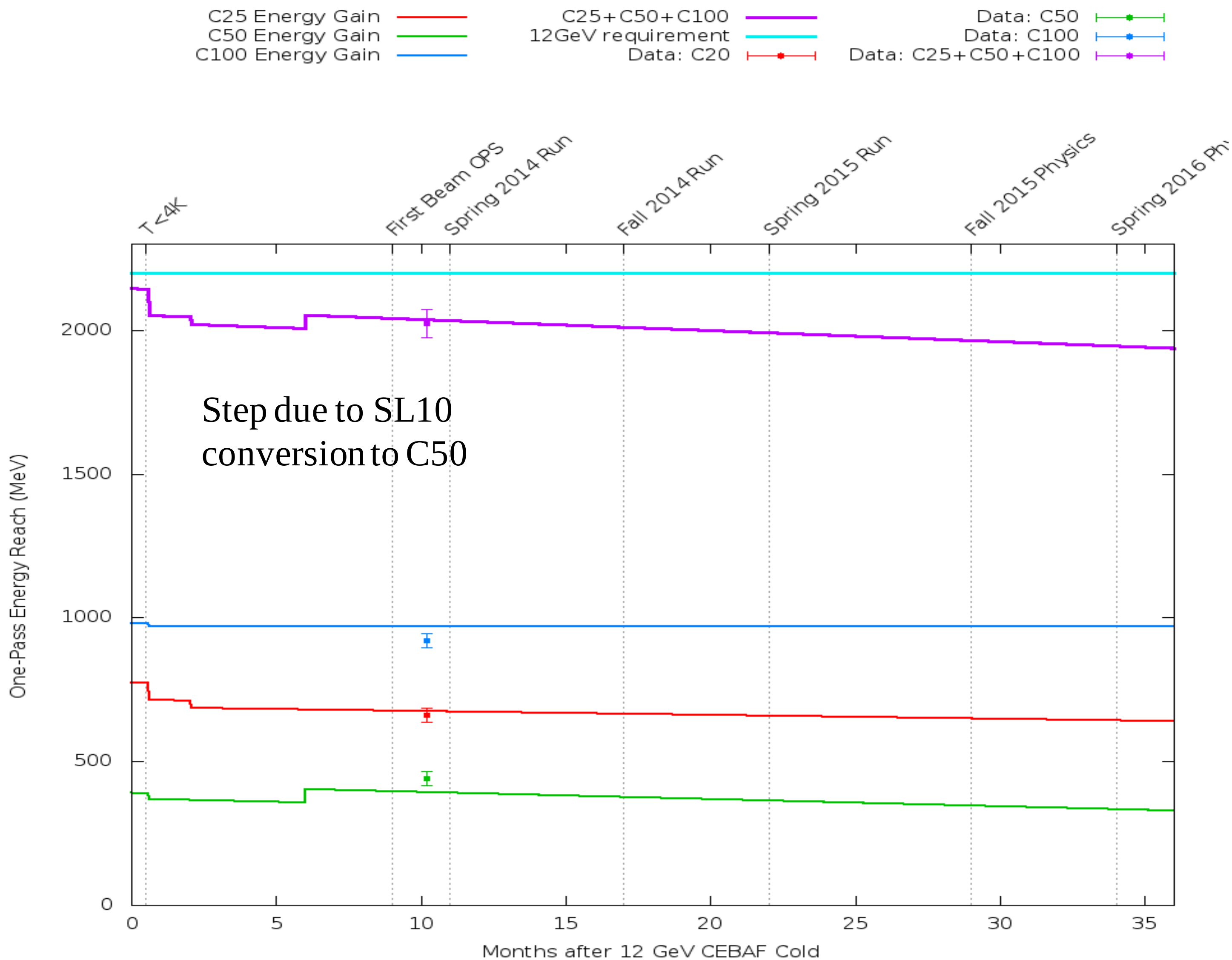
Jay Benesch and Arne Freyberger

Oct. 15, 2012



T<4K
First Beam OPS
Spring 2014 Run
Fall 2014 Run
Spring 2015 Run
Fall 2015 Physics
Spring 2016 Physics
One-Pass Energy Reach (MeV)
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
Months after 12 GeV CEBAF Cold
See TN-12-049 for details. Blue line at top is spec, purple is expected total energy at fault rate Physics can tolerate.

Updated with February 1 GeV/linac data



General recommendations

- 2K LHe mass should be 60-100% of cavity mass
- Cavity frequency response to pressure changes shall be less than 4 Hz/mbar
- Magnetic field shall be measured at a site comparable to final location, including expected tunnel steel and rebar. Magnetic shielding shall be designed for twice the measured value. Magnetic materials may not be used structurally in the cryomodule; some feedthroughs may include them. Magnetic shielding must also take into account the fields of the lattice quadrupoles and steering magnets.
- Mechanical vibration shall be measured at mounting points of a cryostat mockup with proper mass in final location or best available substitute.
- FEA analysis shall demonstrate for the measured vibration spectrum (0-1000 Hz) that the cavity frequency will change less than 4 Hz (via damping through the cryomodule mounting and internals.)
- FEA fatigue analysis on cryomodule system for 20 year life shall be done using measured spectrum.
- Cavity to cavity mechanical coupling shall be such that quenching one cavity at specified E field will not put an impulse on another more than a 4 Hz change
- Fundamental power coupler shall have thermal capability to deal with a factor of two increase in RF input (not input plus reflected, input)
- Sheet metal input Q should be set about a factor of two below theoretical power balance optimum to allow for fabrication variance. Use stub tuners or another type of RF transformer to increase Q to desired value.
- HOM damping shall be designed with at least a factor of 100 safety margin to allow for fabrication variation
- Use waveguide HOM couplers, eliminating chance of beam hitting coupler
- Liquid level sensors shall have no thermal shorts (readback jumps) 80-95%
- Ceramic parts may not be in line of sight to any cavity cell inner surface
- Helium transport should be internal to the modules as in the LHC magnet systems – no end cans. Cold, high-RRR aluminum conductor with steel yoke magnets should be placed in insulation vacuum between modules.
- The cryomodule structure and helium transport system shall allow for 1K/minute cooldown from 150K to 50K and 2K/minute cooldown 50K to 4K.