PEP-II Vacuum Issues over the last year

Stan Ecklund for PEP-II team

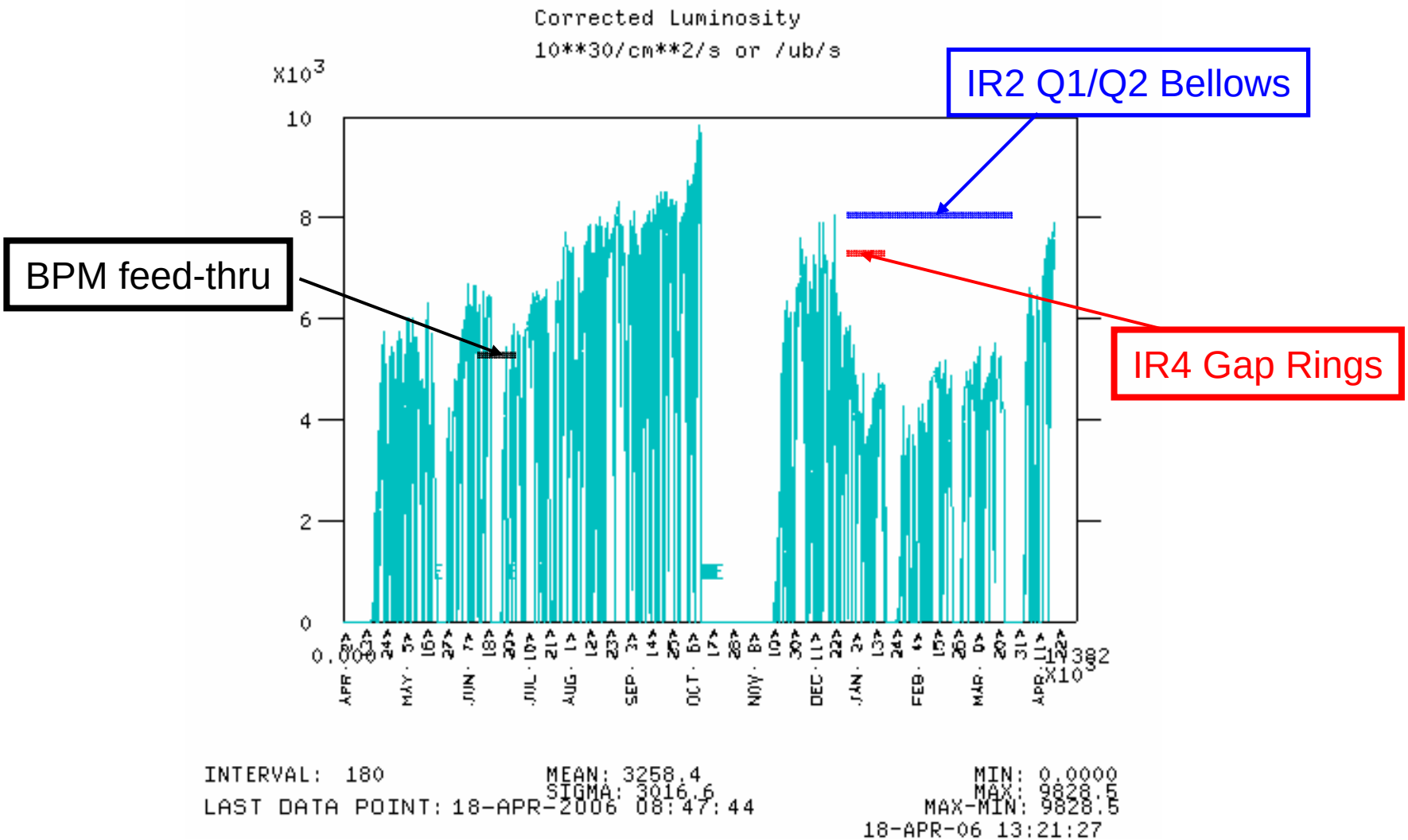
DOE Operations Review

April 26-27, 2006

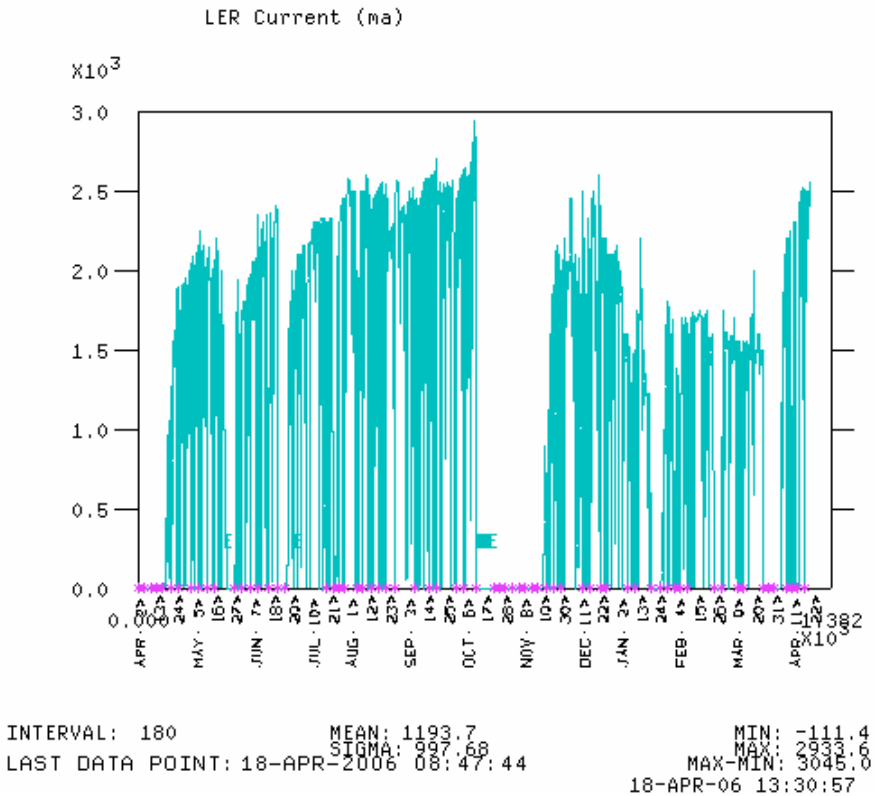
Overview of Vacuum Events

- IR2 Q1/Q2 Absorber Bellows
  - Dec. 2005 – Mar 2006
  - Cracked SiC-AlN ceramic absorber
  - Faulty RF seal design corrected Mar. 2006
- Gap Ring in IR4, near LER RF Cavities
  - Dec 2005
  - Identified and repaired in a few weeks
- NEG
  - Ongoing since 2003
  - RF screen leakage heats NEG material, releasing H_2
  - Removed NEG material in weak screens, New chambers
- BPM feed-thru
  - June 2005
  - Heating due to 7 GHz button resonance and HOM heating
  - Limit Beam Parameters: σ_z, position, bunch current
  - Smaller buttons Aug. 2006
- Various leaks

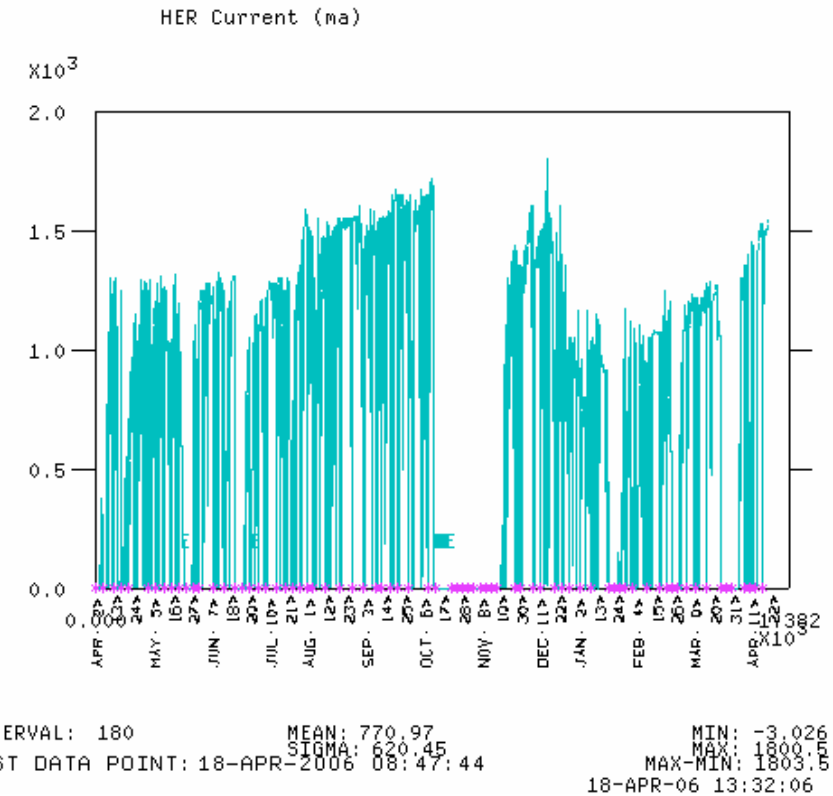
Luminosity April 2005 - 2006



LER and HER Current



INTERVAL: 180 MEAN: 1193.7 SIGMA: 997.68
LAST DATA POINT: 18-APR-2006 08:47:44
MIN: -111.4 MAX: 2933.6 MAX-MIN: 3045.0
18-APR-06 13:30:57

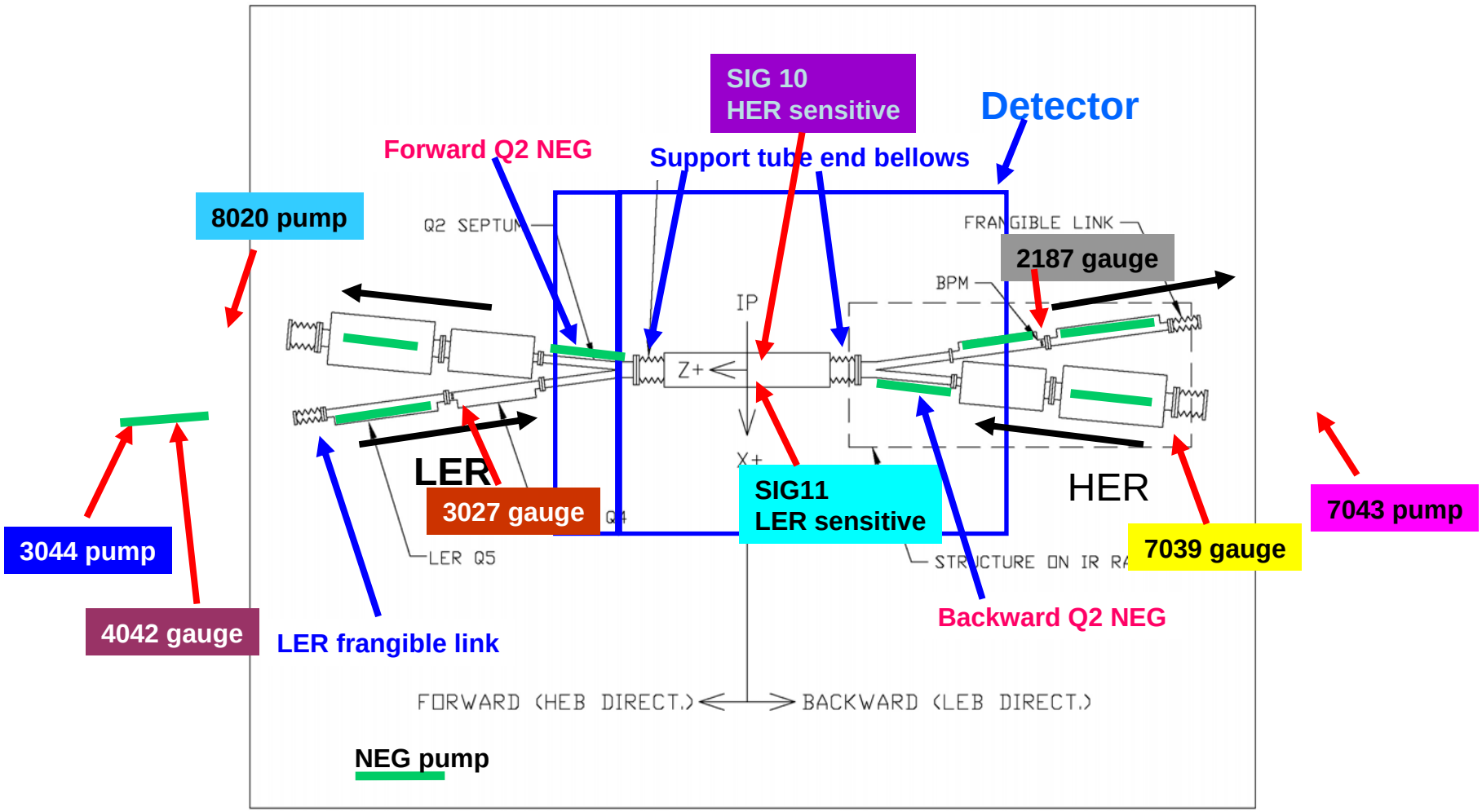


INTERVAL: 180 MEAN: 770.97 SIGMA: 620.45
LAST DATA POINT: 18-APR-2006 08:47:44
MIN: -3.026 MAX: 1800.5 MAX-MIN: 1803.5
18-APR-06 13:32:06

Q1/Q2 Absorber Bellows

- Started Dec 2005
- Observations
  - Short (few second) spikes of vacuum pressure near IP
  - Background spikes on LER sensitive monitors
  - Dip in Luminosity
  - Sometimes correlated with beam blow-up and motion.
  - BaBar Radiation aborts beam if spike large
  - Threshold on LER current, with some dependence on HER
  - Spatial profile and time points to ~ 3 m from IP, incoming LER
  - RGA indicates M=14,28 spikes
  - Single LER beam can cause events at higher threshold
  - More bunches results in higher threshold (total current)

Interaction Region Layout



Resources to Diagnose IR2 Vacuum Spikes

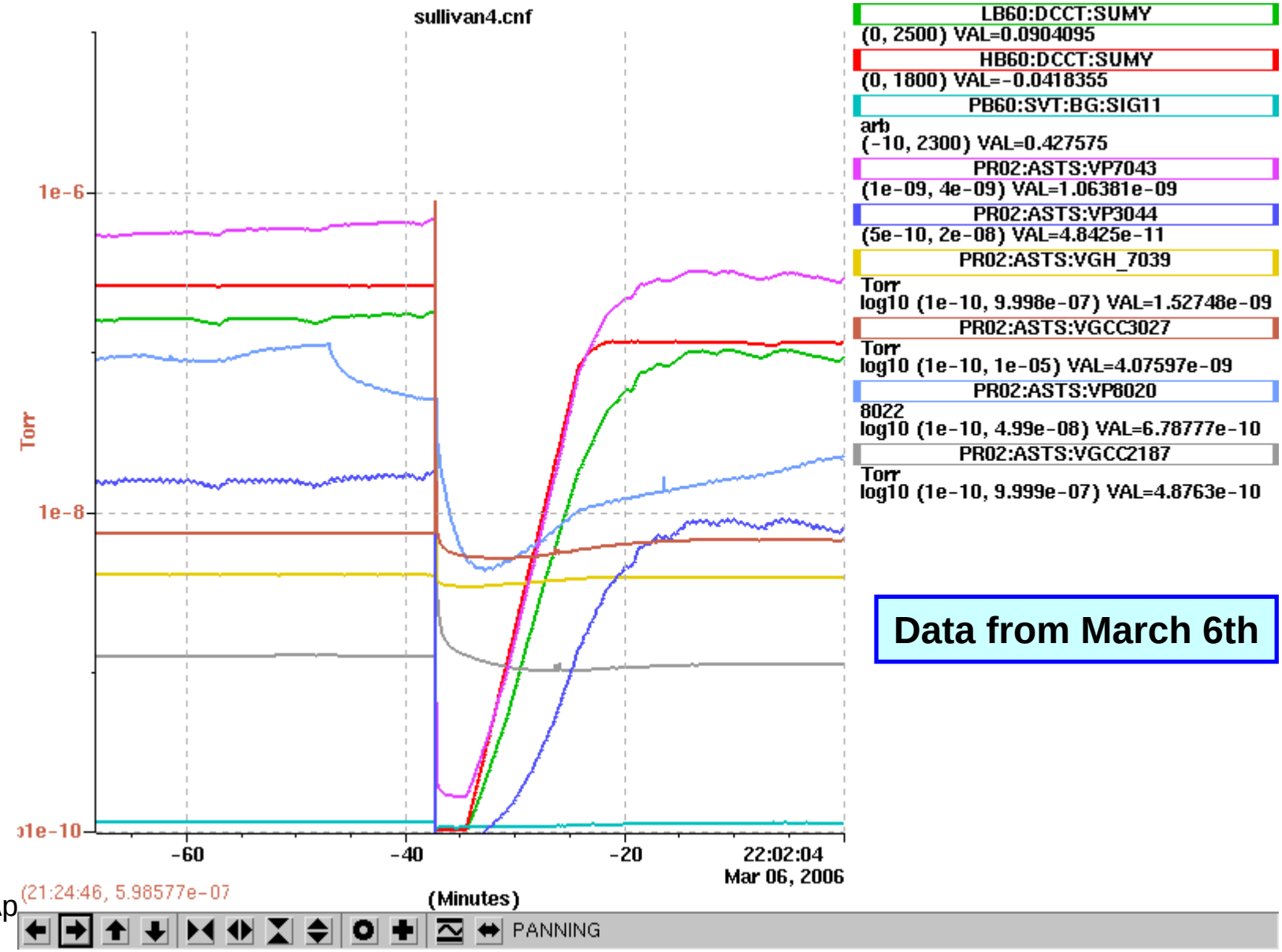
- **Help from many groups:**
  - **PEP-II, BaBar, Material Science Group, Klystron Dept., High Power RF Group, Vacuum Dept., Pulsed Kicker Group, and LBNL**

- Vacuum pump, gauge logging at 1 Hz using EPICs Archiver and Strip charts.
  - Z location from amplitude of spike
- Abort Transient Logger at 1 KHz
  - Time and vacuum model give Z location
- RGA spectra
  - Type of gas released
  - Not an air leak
- He leak check lines
  - Looked for external leaks during spike events
- Controlled Leak valve and NEG heating calibrate gauge response
- Video of synchrotron monitor beam sizes
- Bore Scope of inside chamber,
  - Identifies protruding RF fingers
  - Probed for loose tiles
- Looked for Temperature dependence of bellows, NEG
- Excited beam motion trying to induce vacuum event
- Vacuum model to understand time dependence and predict source

Most Difficult Vacuum Problem

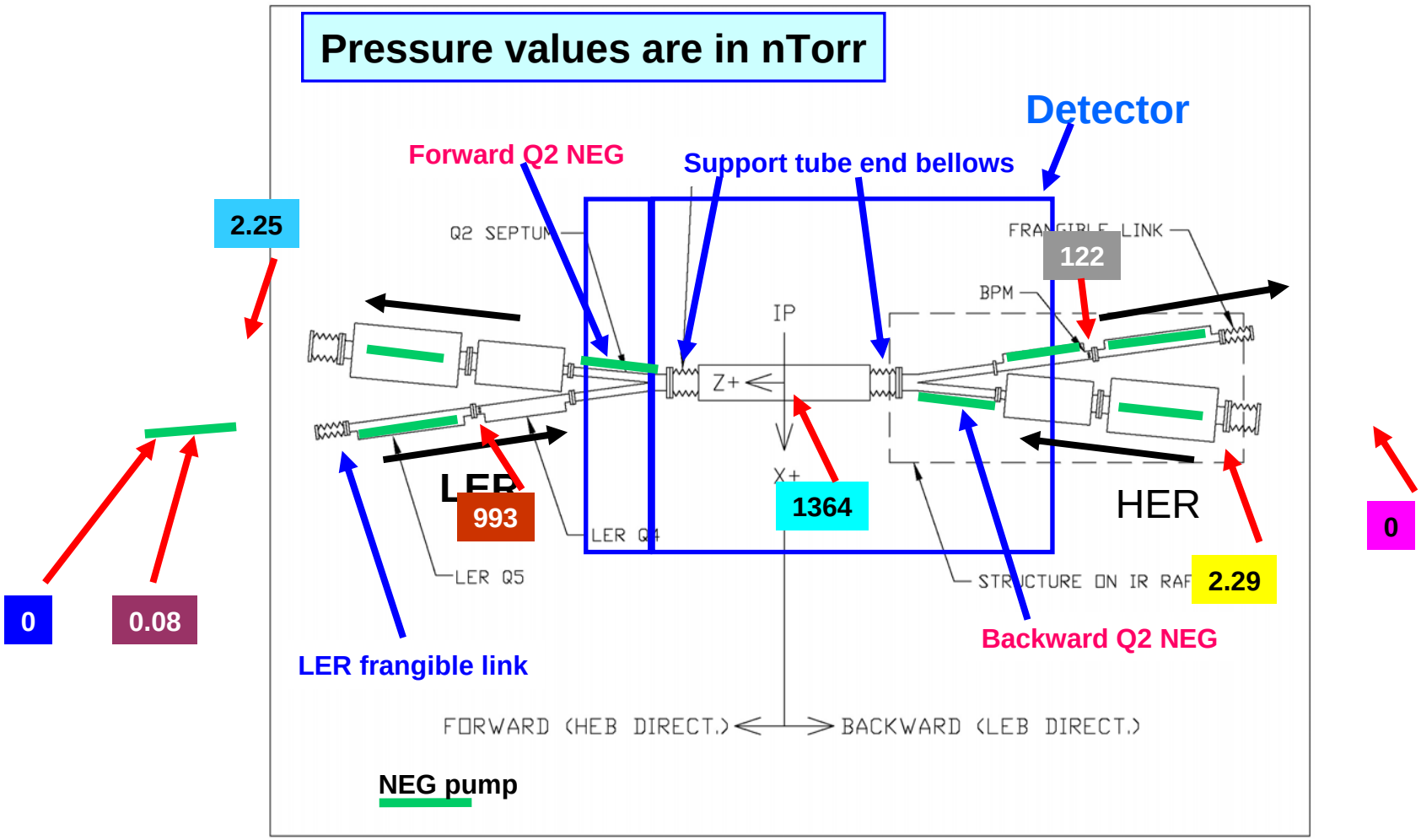
- IR4 problem started at same time as in IR2
- Transient, somewhat random behavior
- Location techniques good to about 1 m
- Both beams present in this area
- HOM from both beams affect larger area
- Required opening detector to access
- This vacuum problem was the most subtle and hard to diagnose problem PEP-II has had.
- We solved it in a timely way over two months with a strong team

More or less typical event



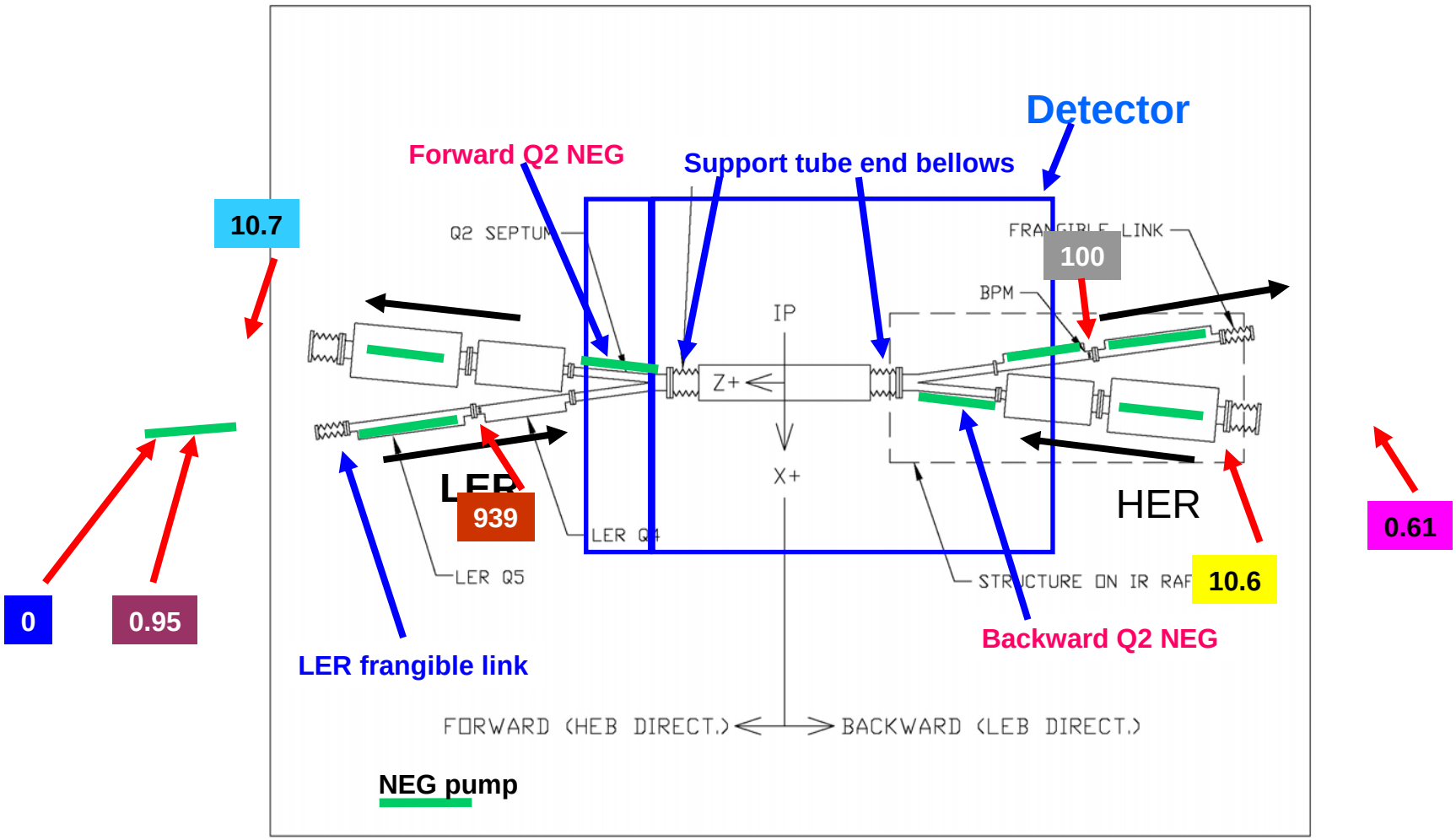
Data from March 6th

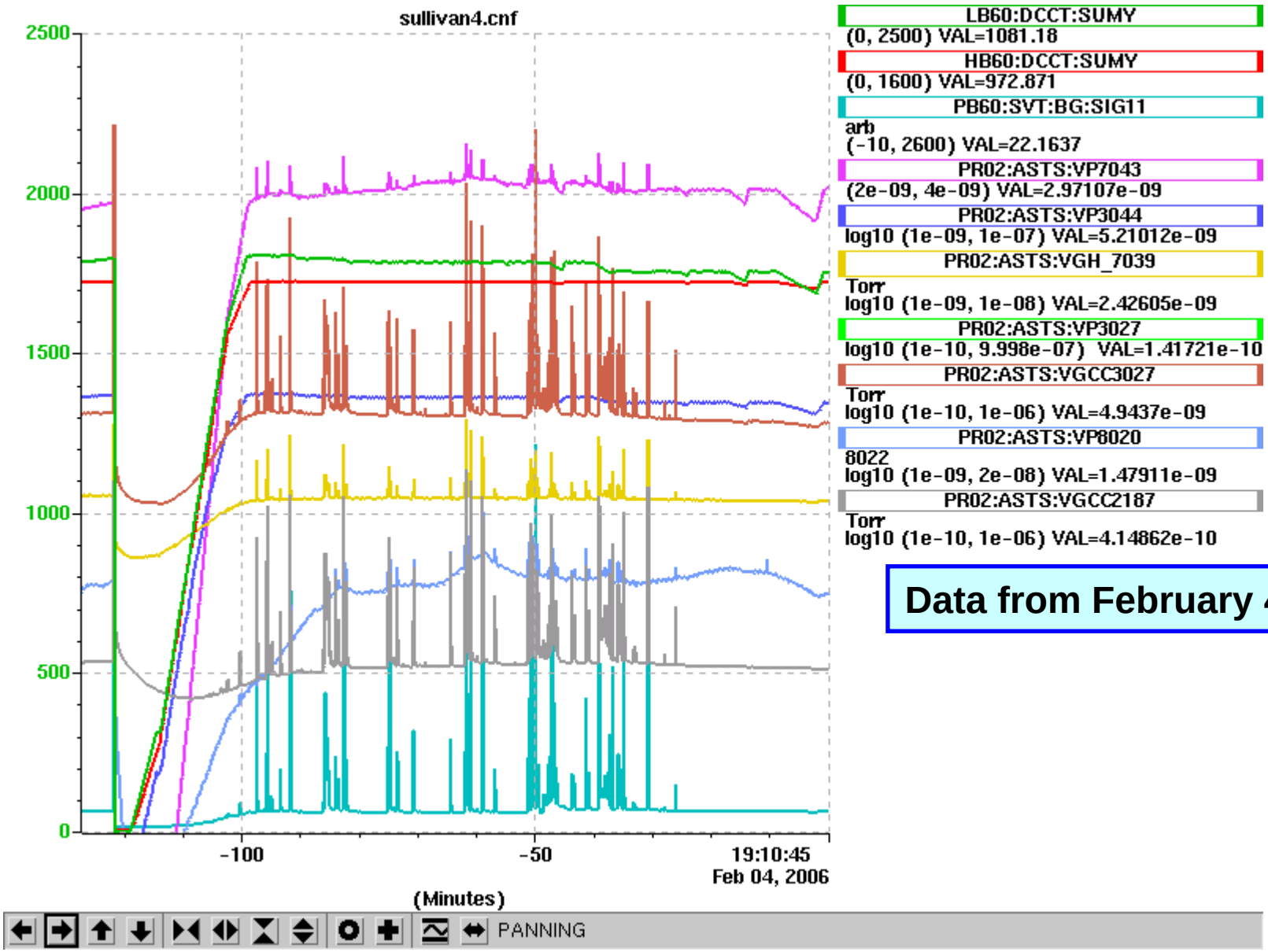
Typical event from Feb 5th



Average of 8 events

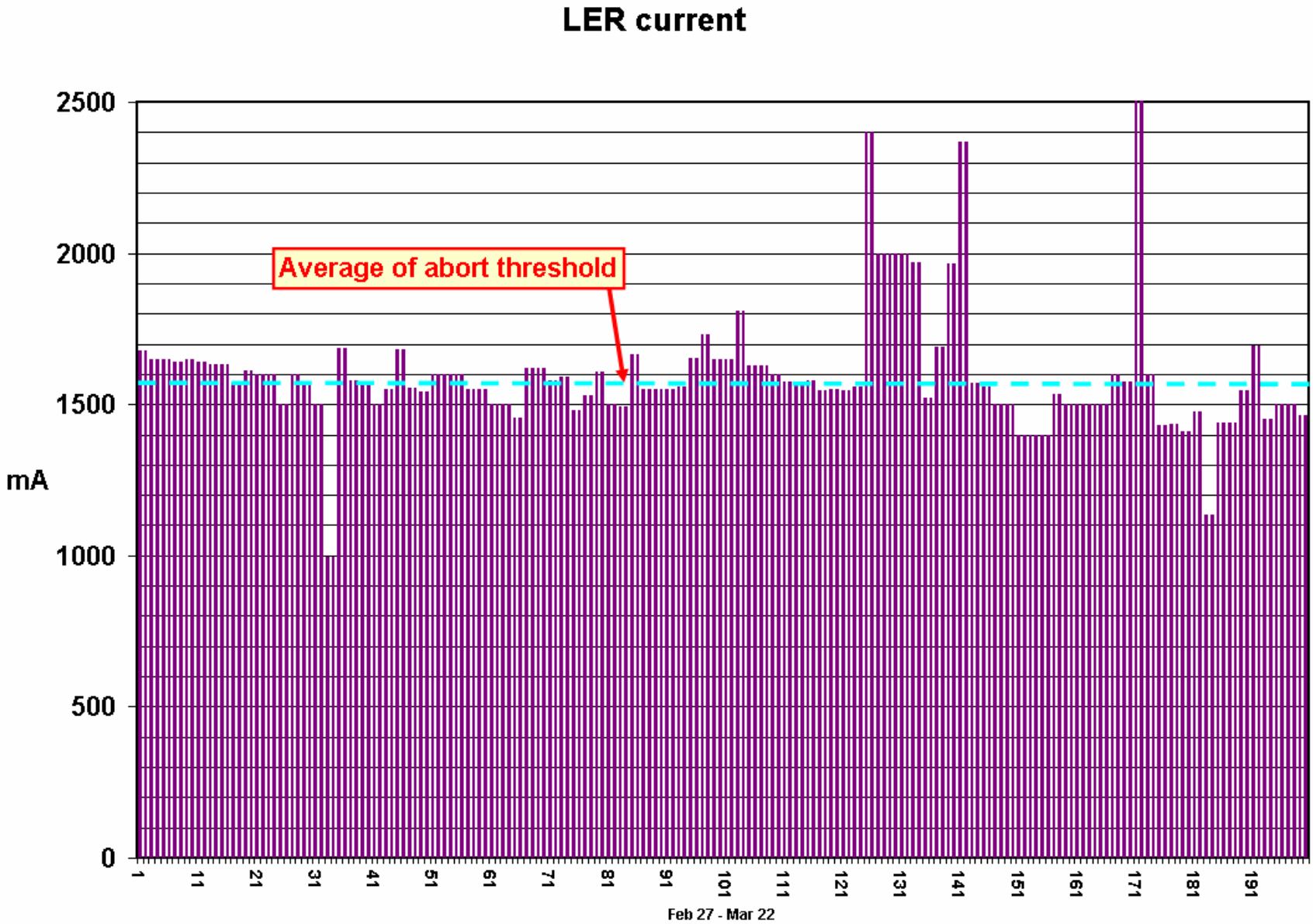
normalized to 2187 gauge





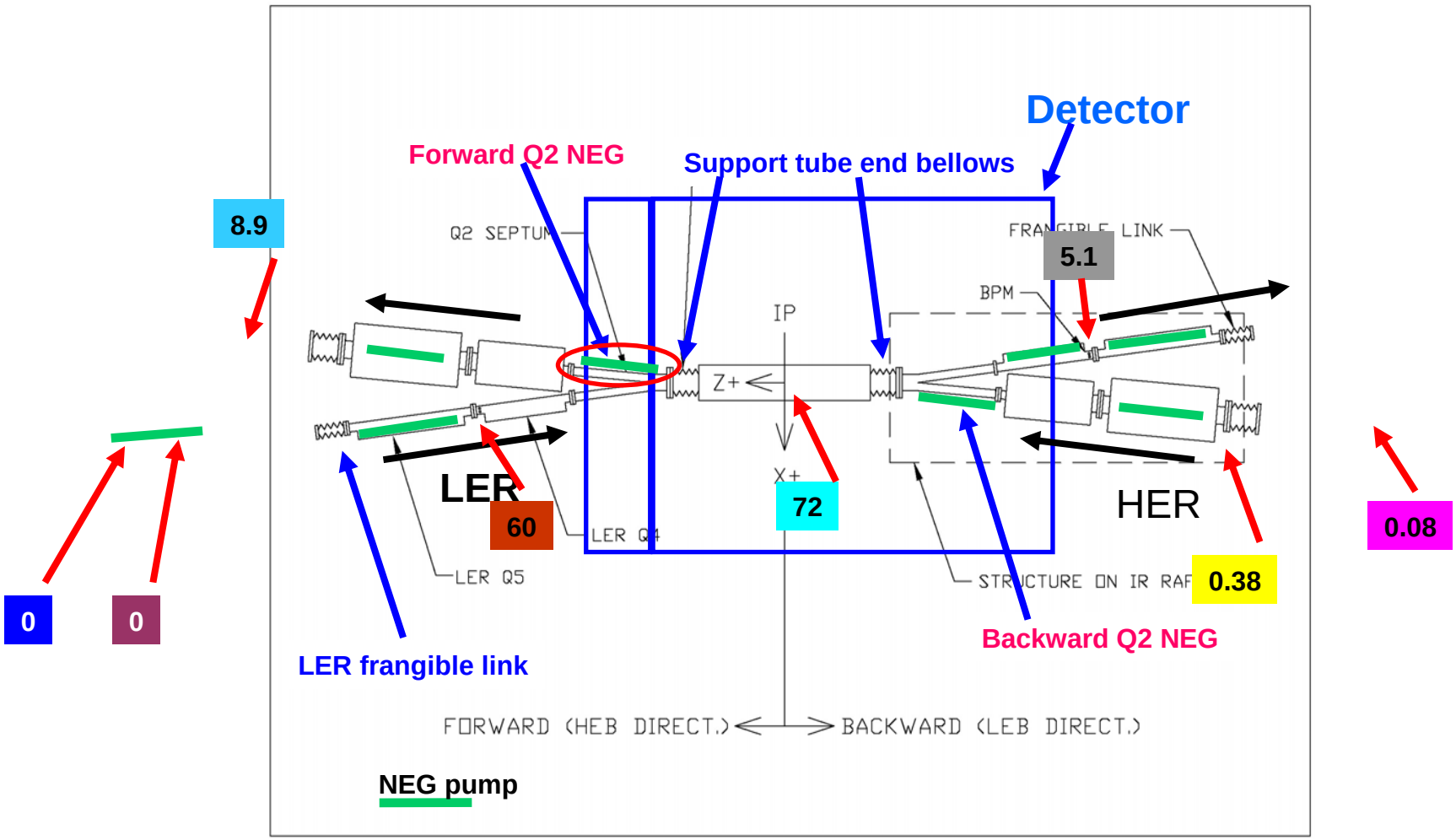
Data from February 4th

LER current when we had a vacuum spike

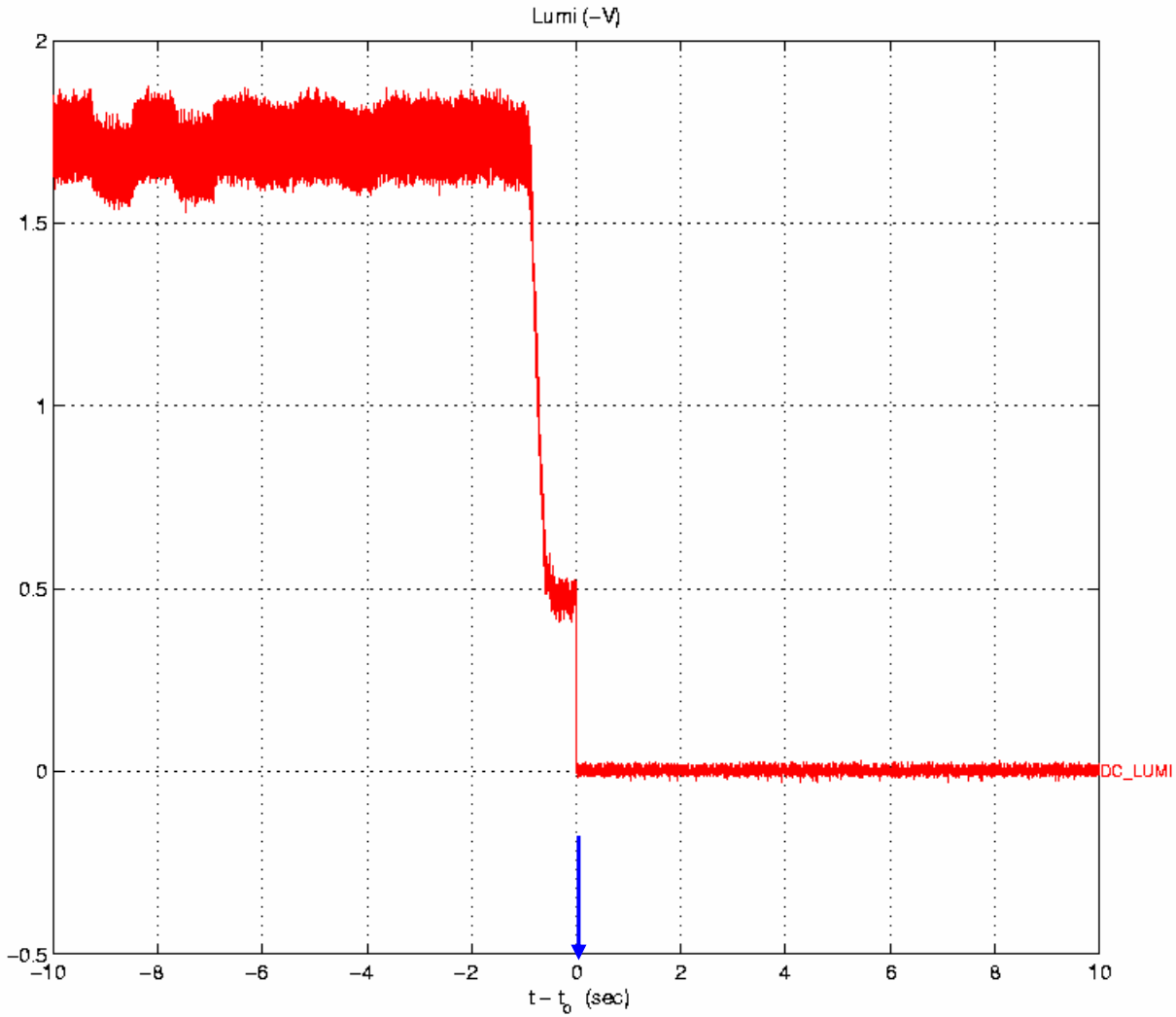


Heating NEG as a gas source

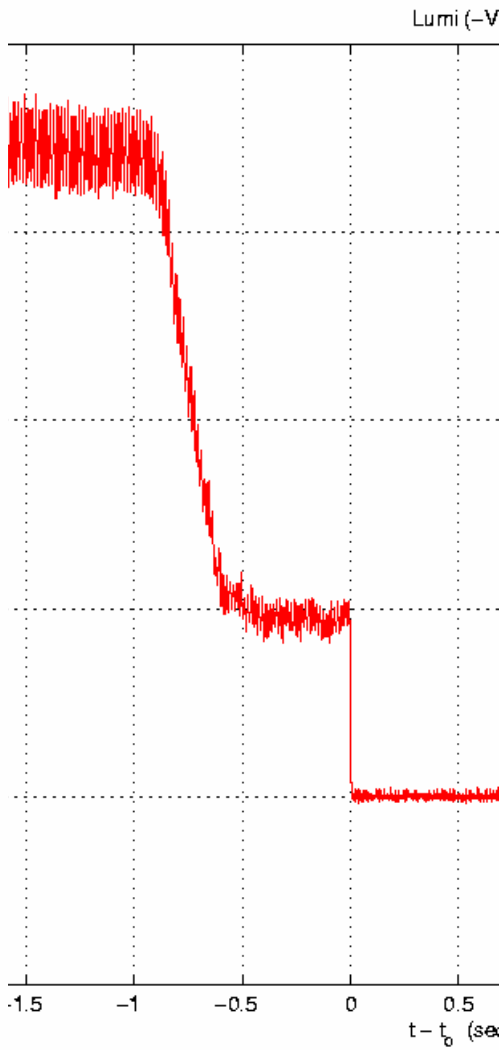
- Forward Q2 produces profile similar to spike events



Abort Logger – Luminosity Signal



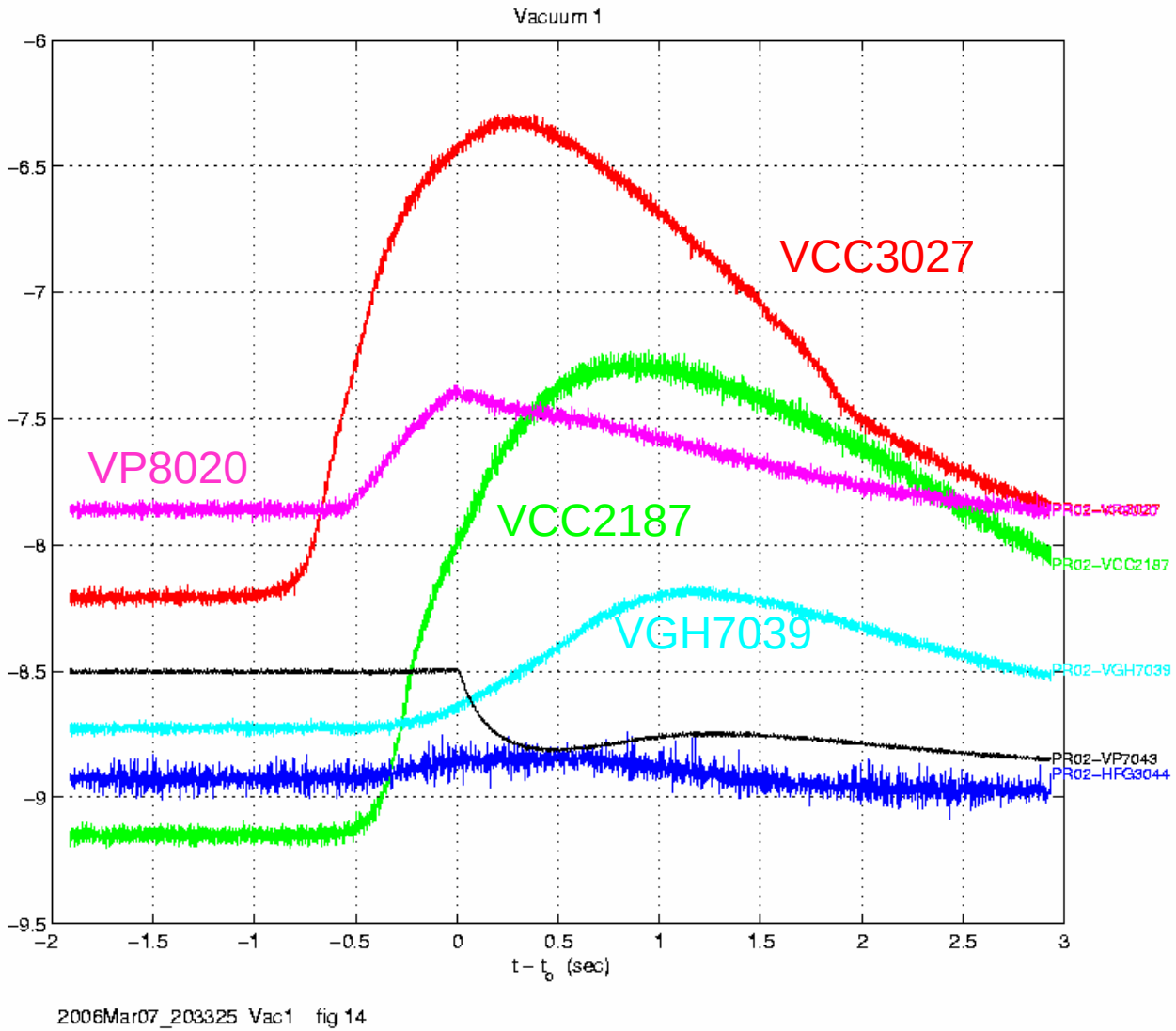
2006Mar07_203325 Lumi fig 9



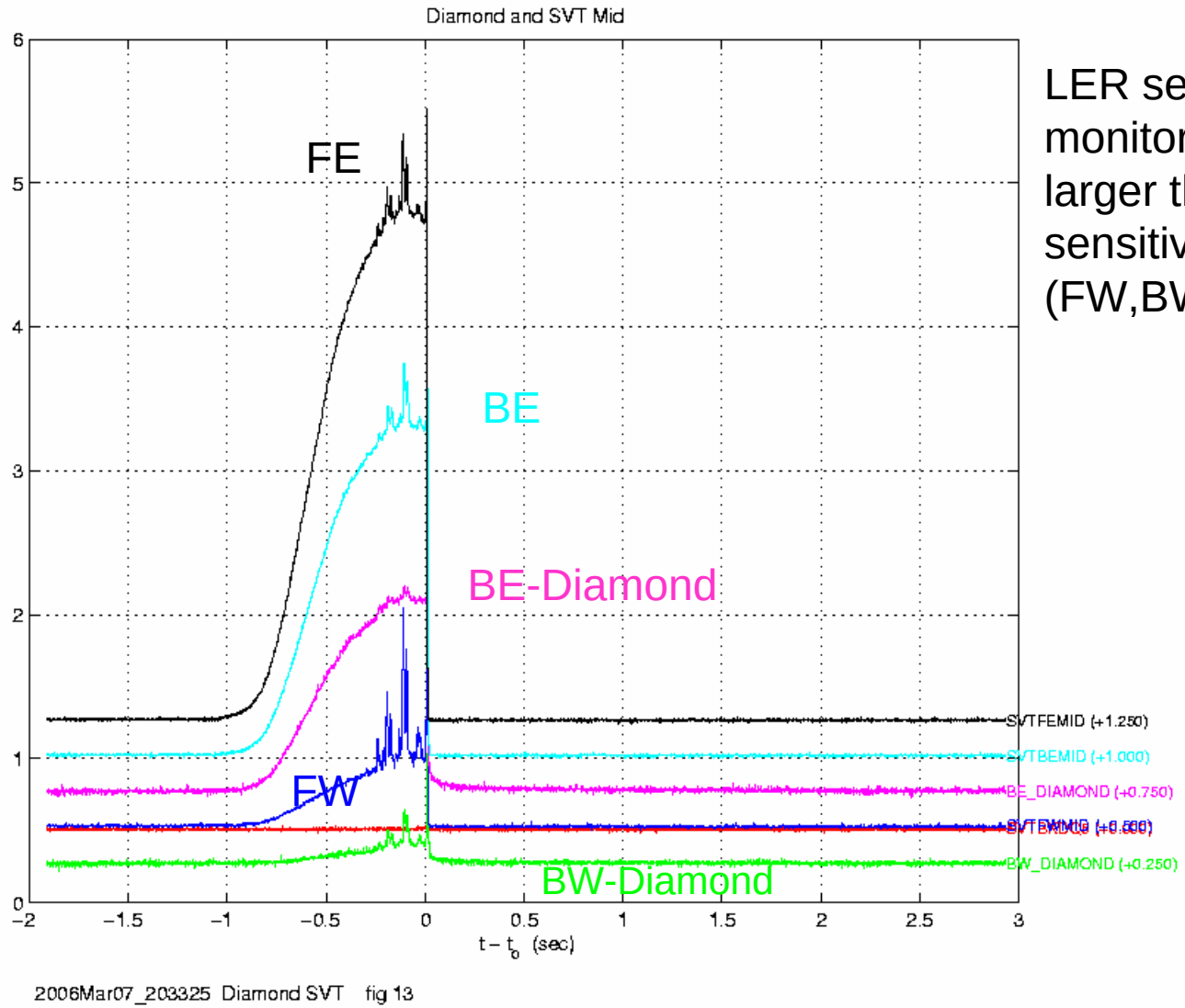
07_203325 Lumi fig 21

Abort Logger – Vacuum signals

Log (Torr)



SVT Background Signals

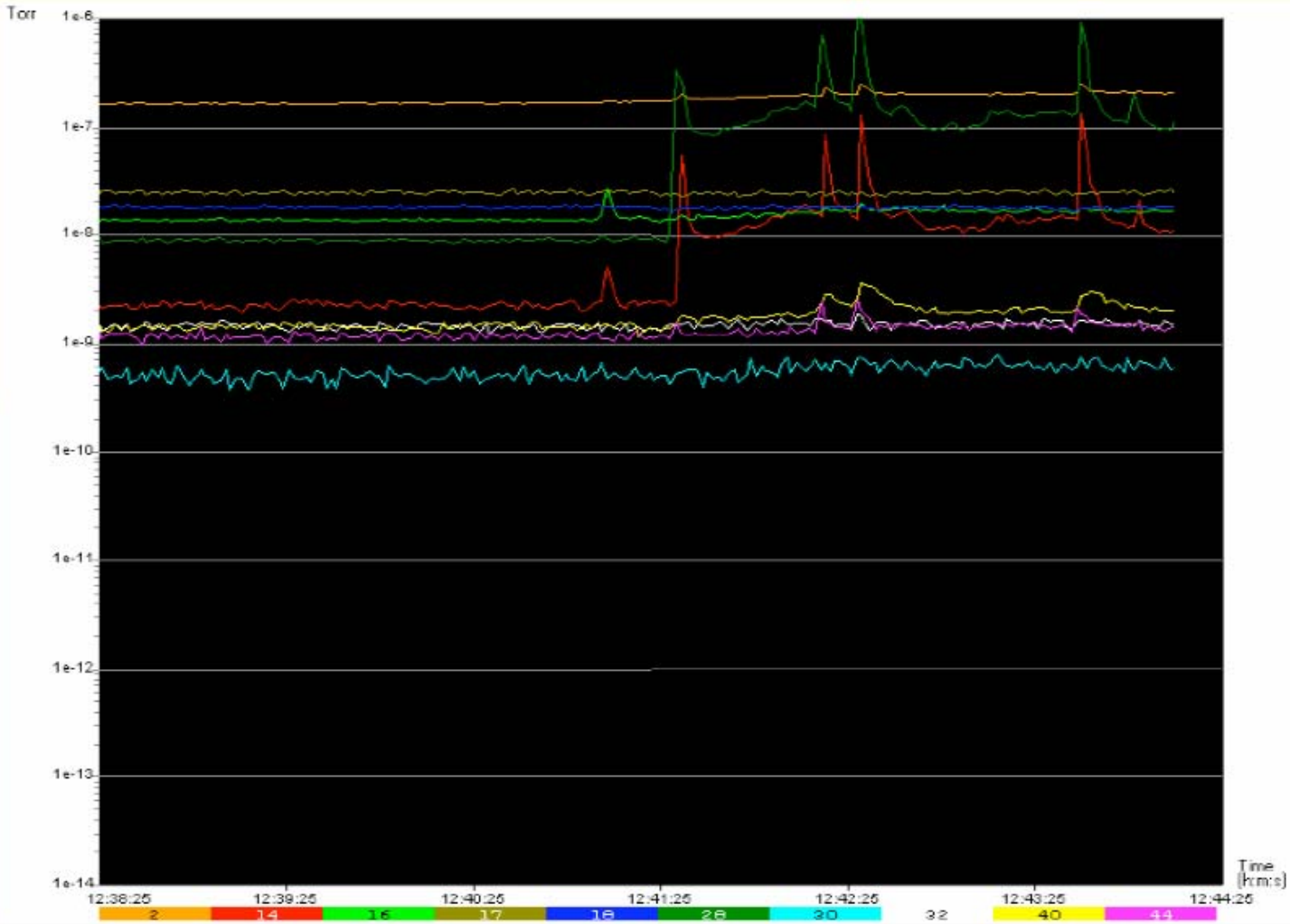


LER sensitive monitors (FE,BE) larger than HER sensitive (FW,BW)

RGA Scan Sustained Event (Jan)

Gases of note:

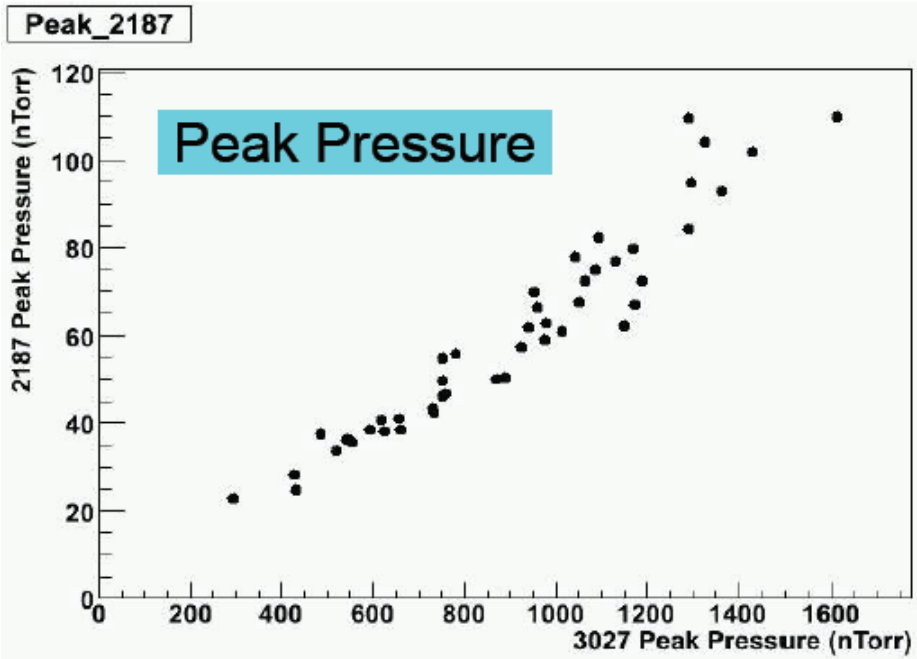
N, N_2; some Ar, possibly CO_2

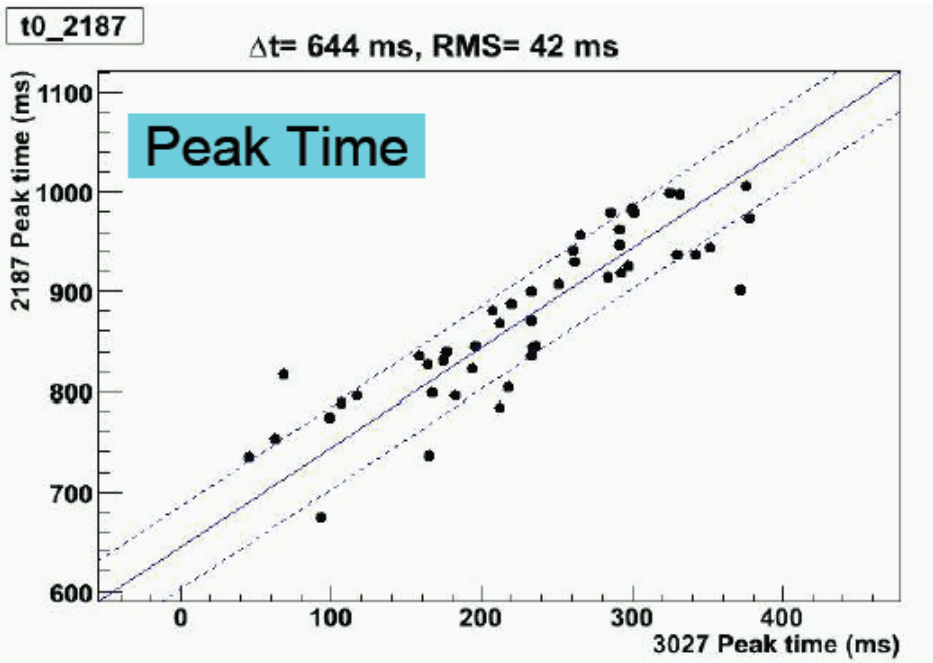


U. Wienands, SLAC-PEP-II Mtg 7-Mar-06

Correlations in Pressure Data

Compare measurements from 50 vacuum aborts to see how consistent the different aborts are:

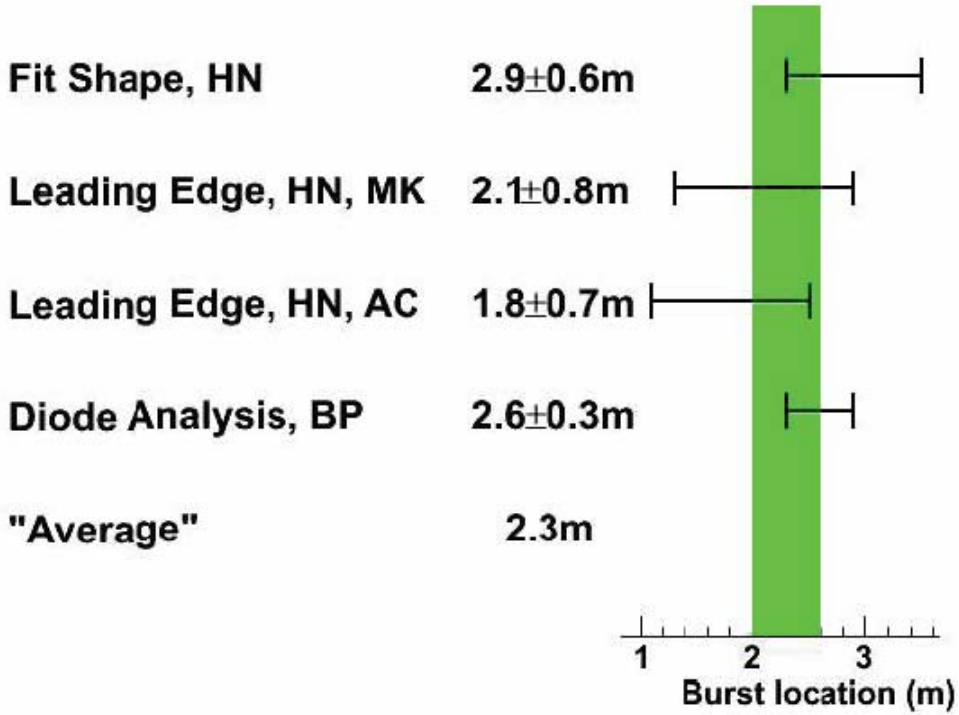




Linear correlation indicates a single source location of pressure burst with varying pressure intensity

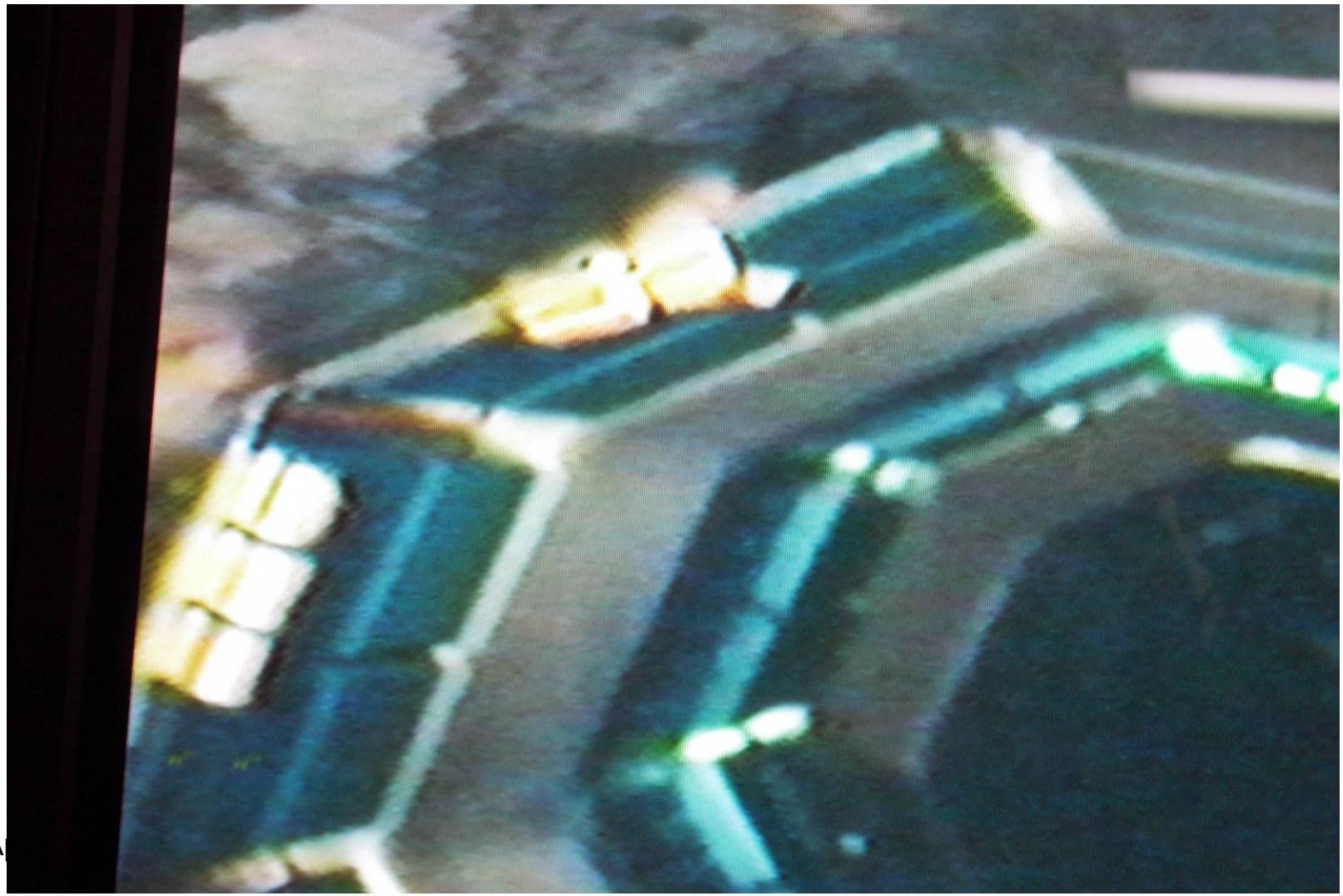
Summary

Vacuum data has been analyzed in several different ways
Analyses are within 1m of each other:

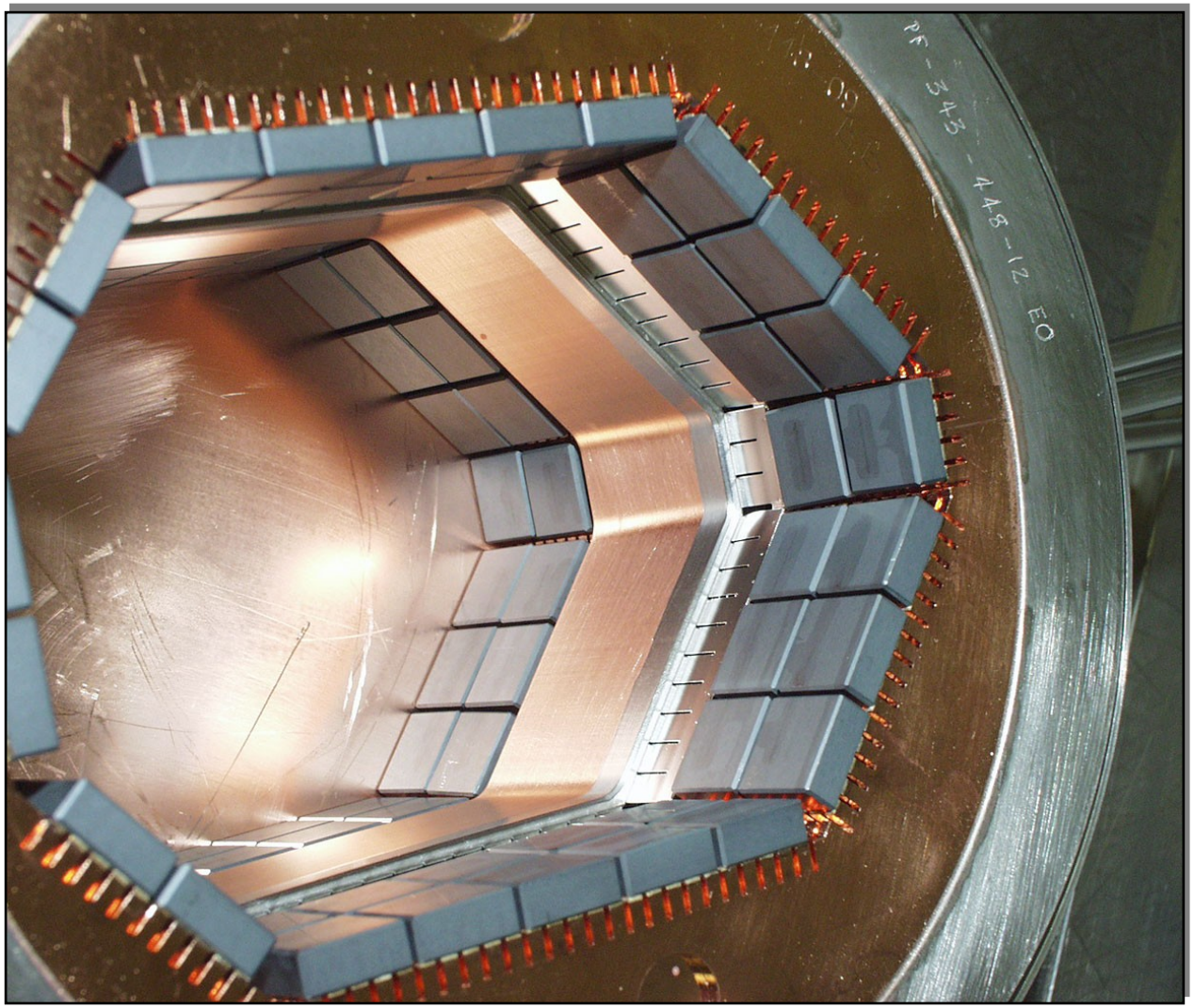


Best guess: source is in Q1/Q2 bellows

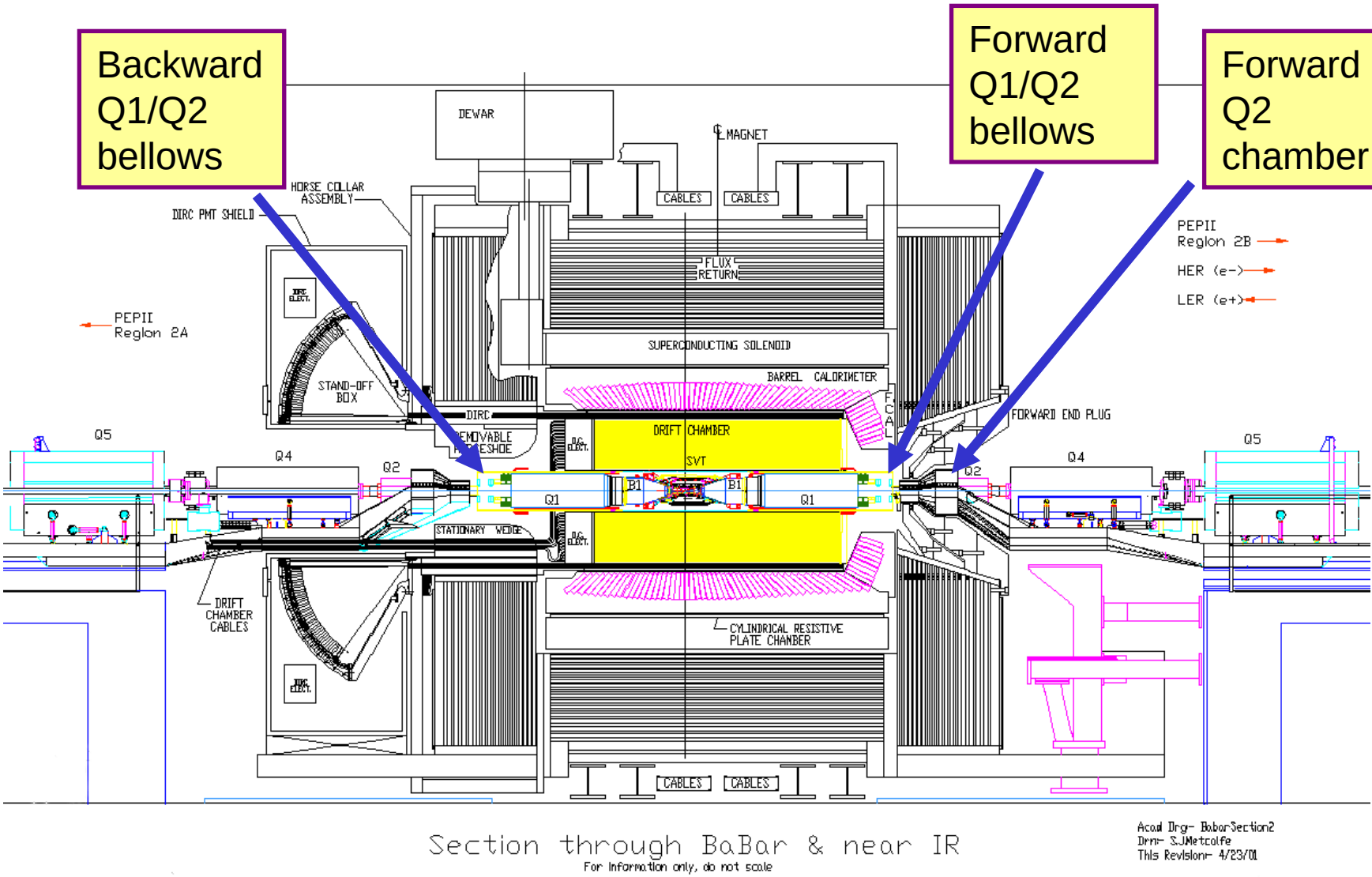
Bore Scope shows some fingers not fully engaged on the backward side (bent out into the beam aperture)



Q1/Q2R Bellows before installation (SM)



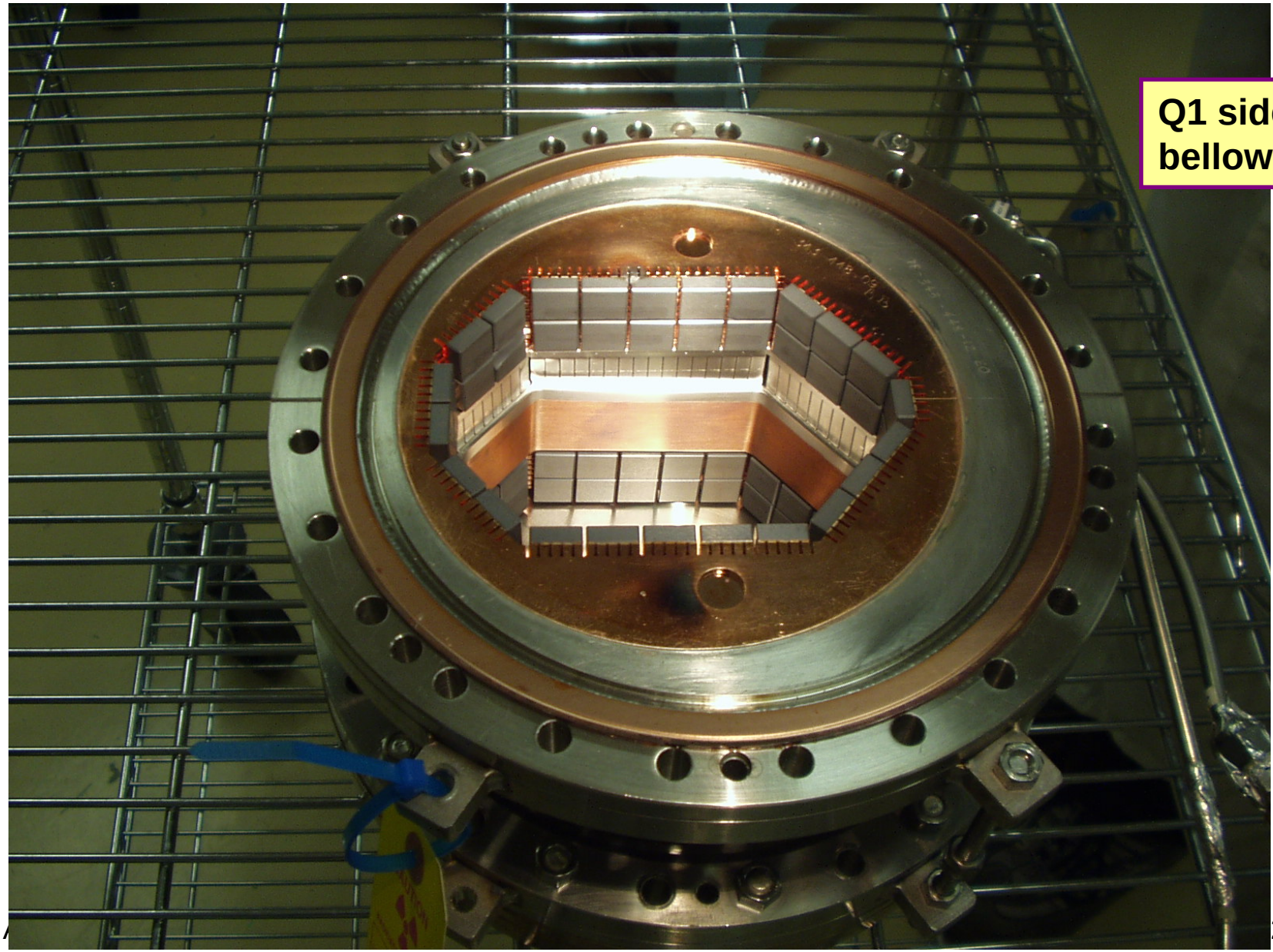
Side view of BaBar



Down Work

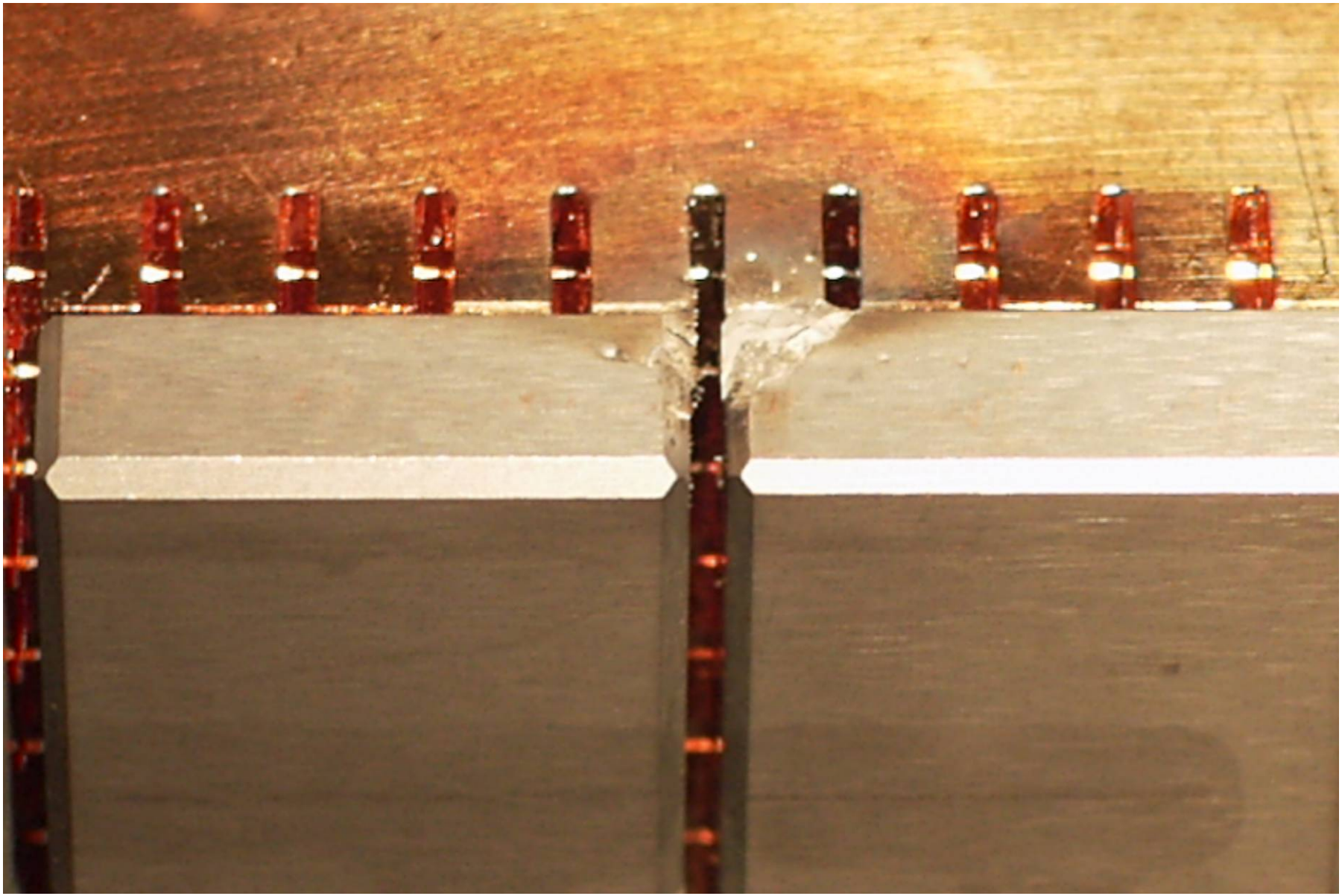
- **Jan 17-23**
  - **Bore Scope all suspect chambers**
  - **Removed pump chamber and absorber.**
  - **Installed controlled leak**
  - **Installed He leak check lines**
- **Feb 22-26**
  - **Replaced LER incoming Q4R chamber**
  - **Moved RGA closer to suspect area**
  - **Moved controlled leak closer**
  - **Bore Scope again**
- **March 22- April 1**
  - **Removed backward Q1/Q2 bellows and installed it in the forward position**
  - **Removed suspect forward Q1/Q2 bellows**
  - **Replaced forward Q2R chamber with new unit having improved design**
  - **Installed previous version(1) of Q1/Q2 bellows into backward position**
    - **2 rows of tiles instead of 4**
  - **Installed new Improved RF seals in the forward and backward position**
    - **The solution**

Removed forward Q1/Q2 bellows section

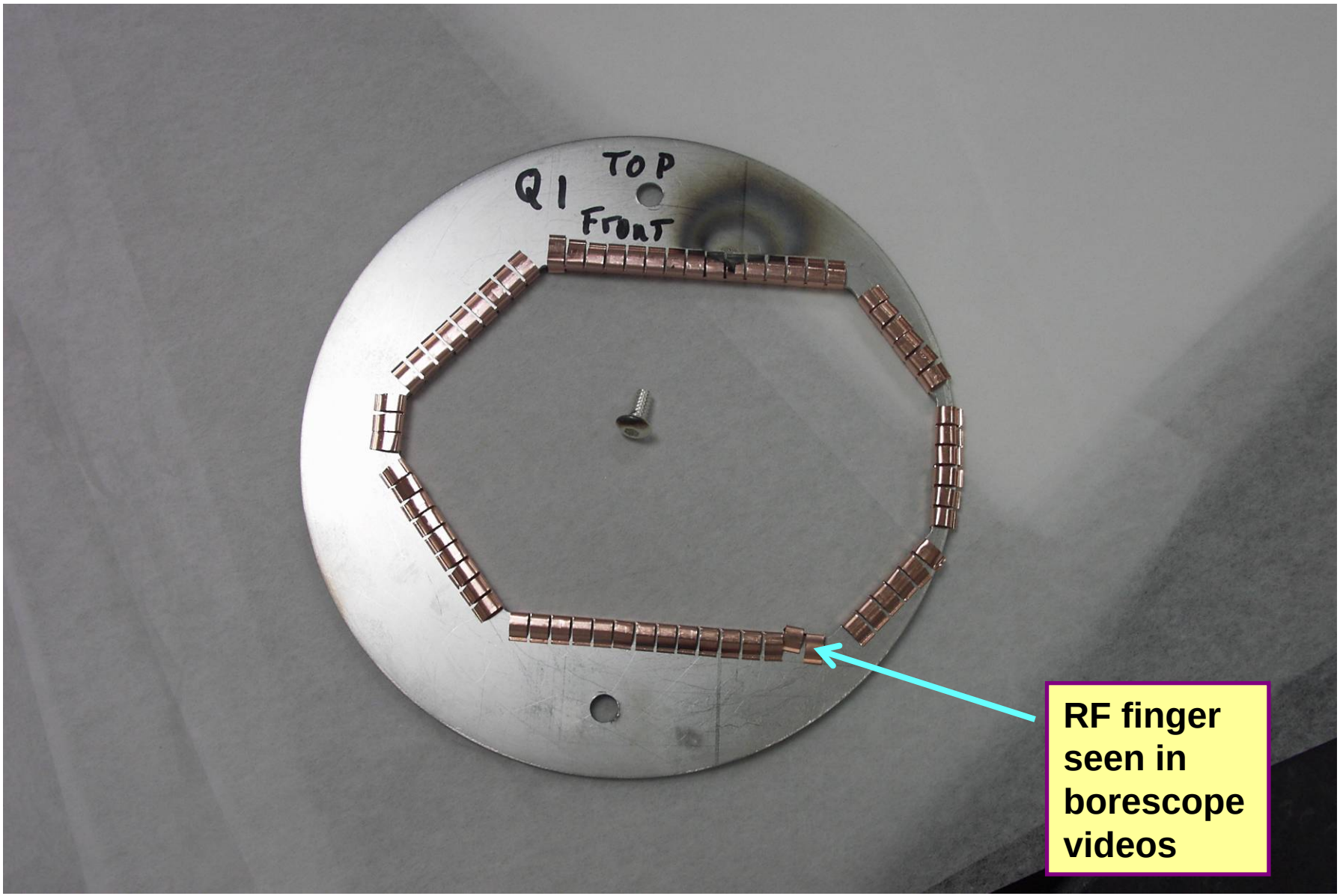


Close up of damage to the tiles

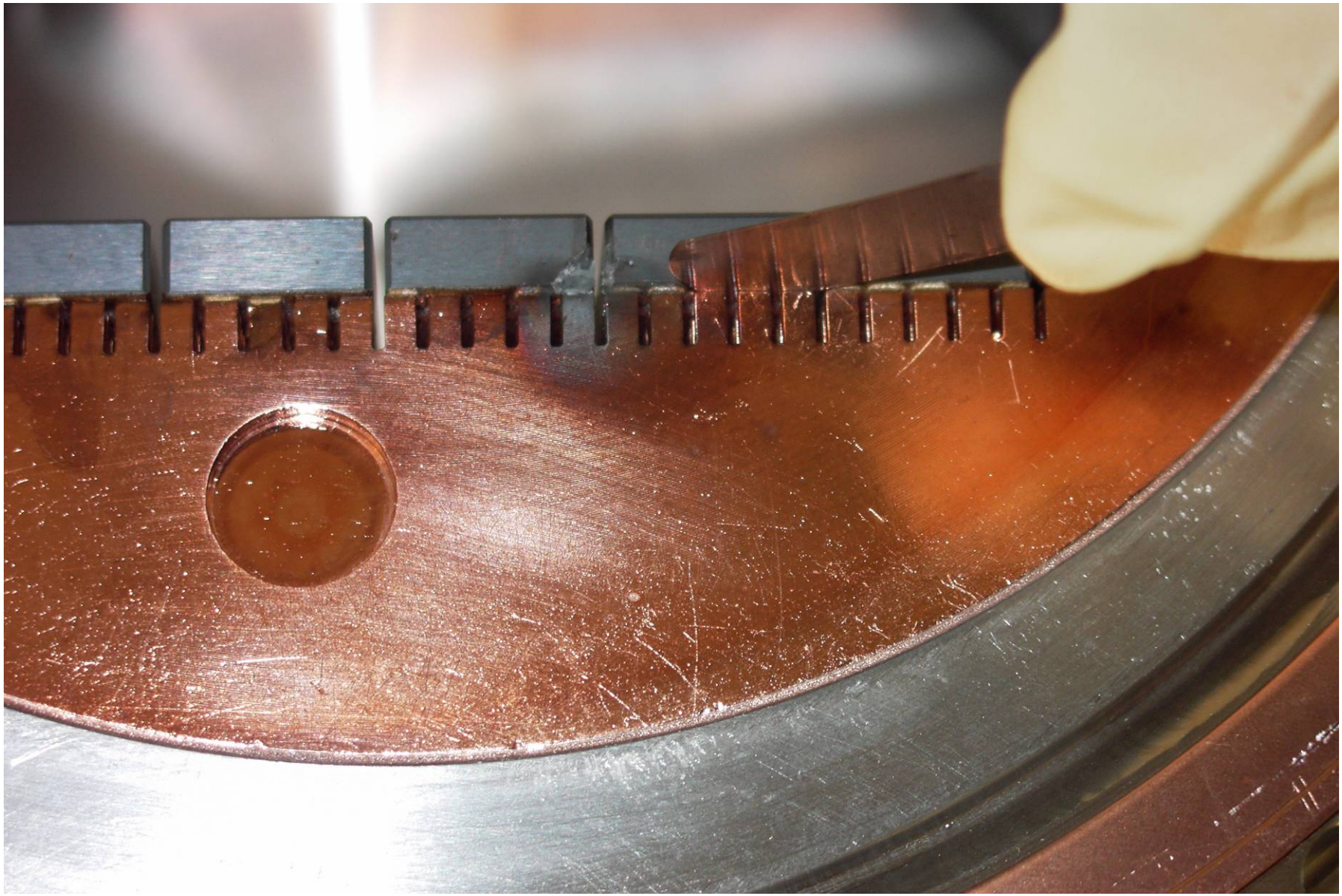
Another close up



RF seal – note the bolt head

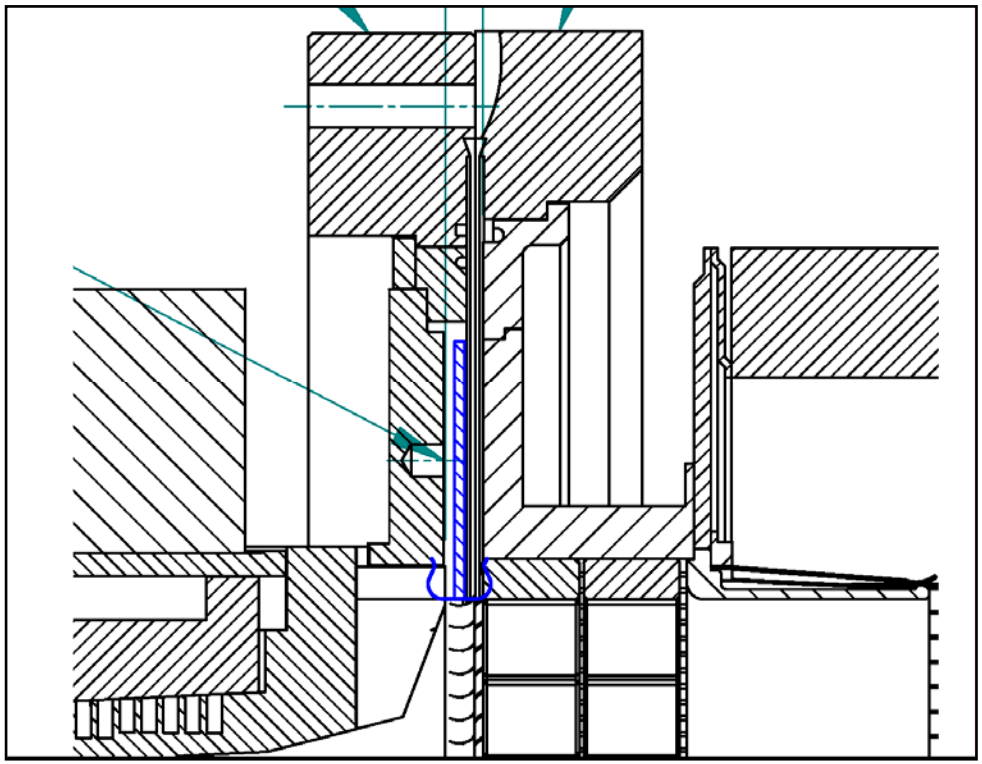


Cu posts not brazed to the tile

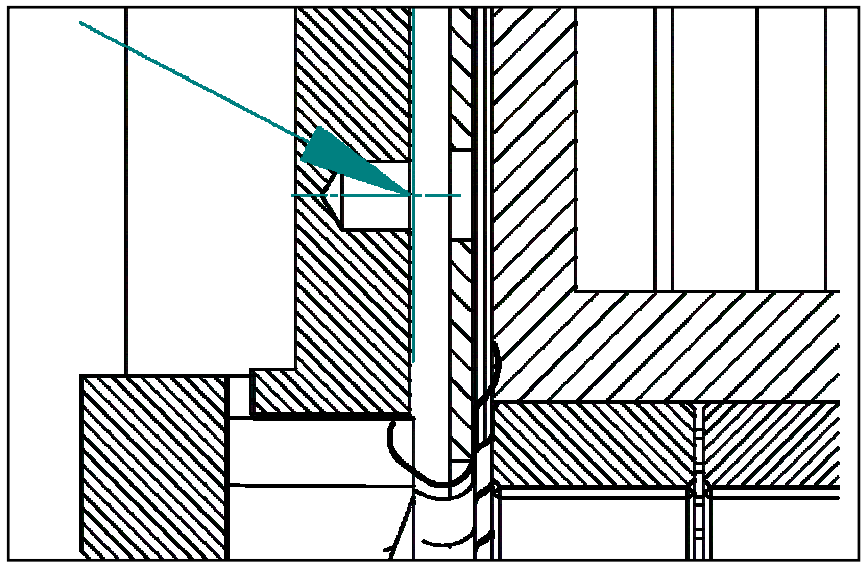


Q1/Q2 Bellows RF Seal

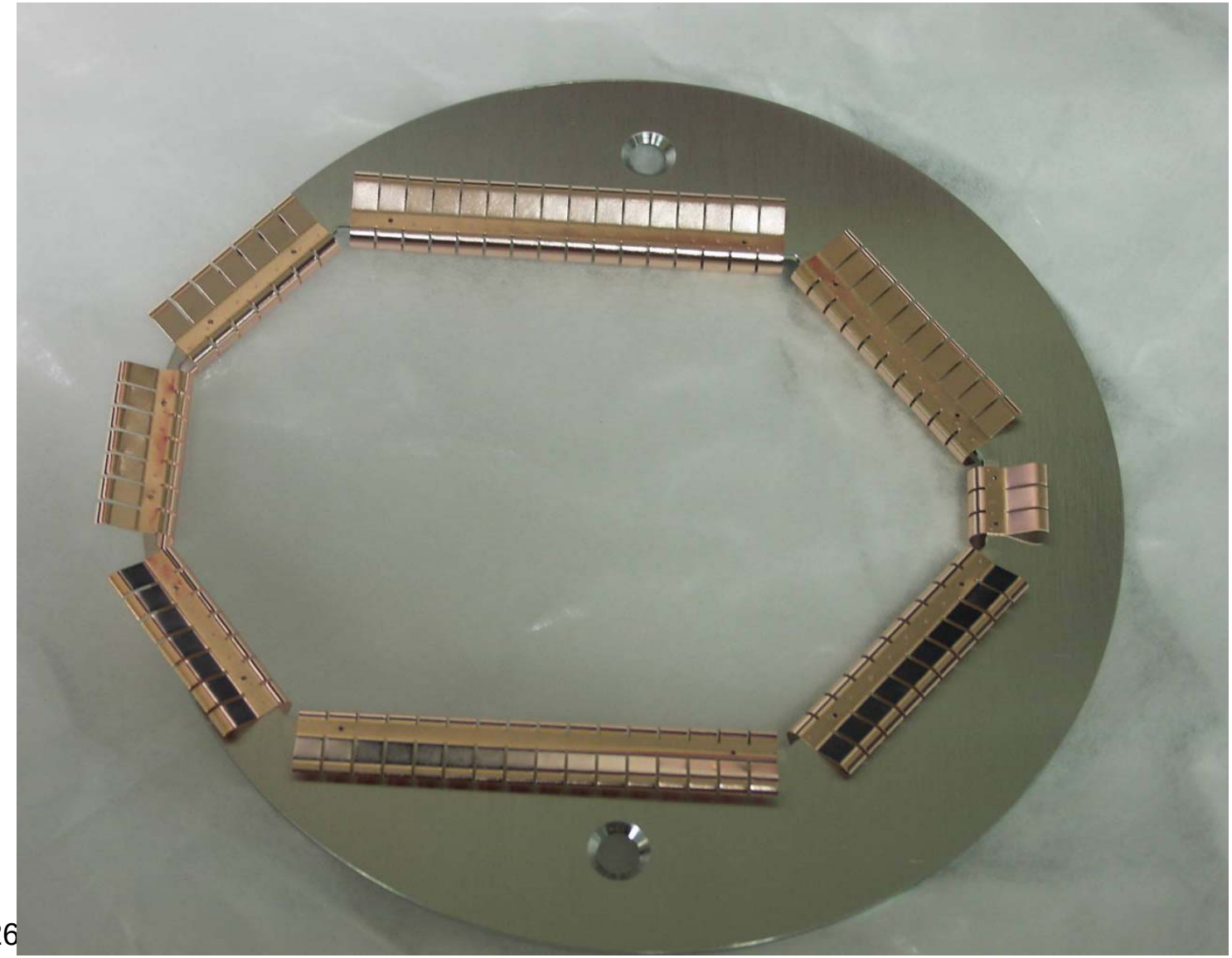
Old



New



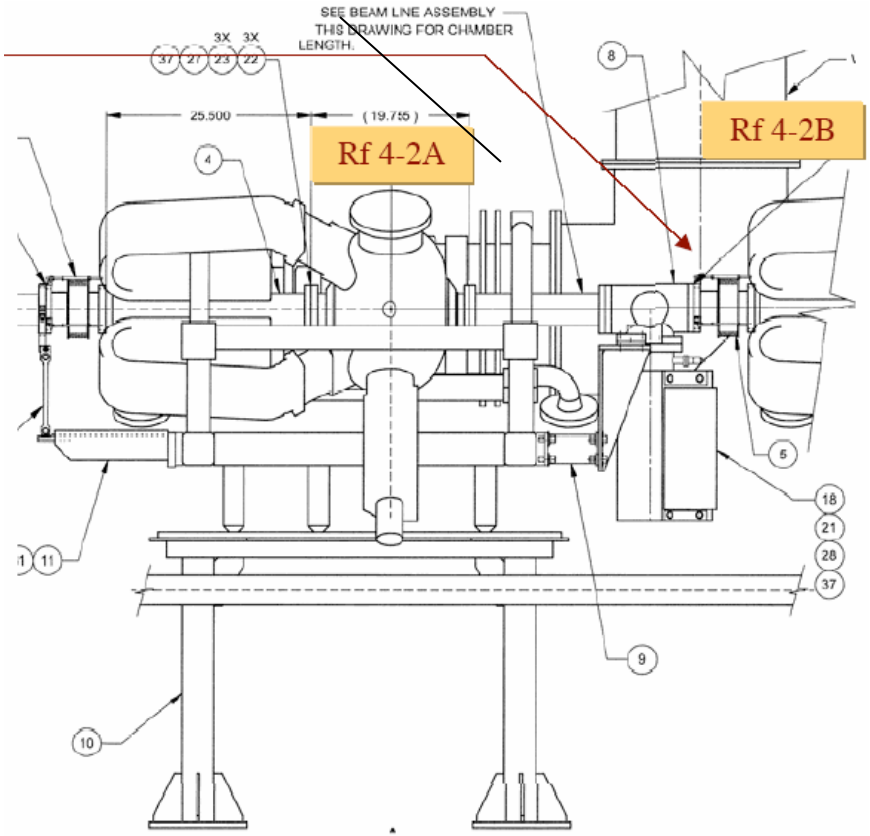
New RF seal – Compound J seal

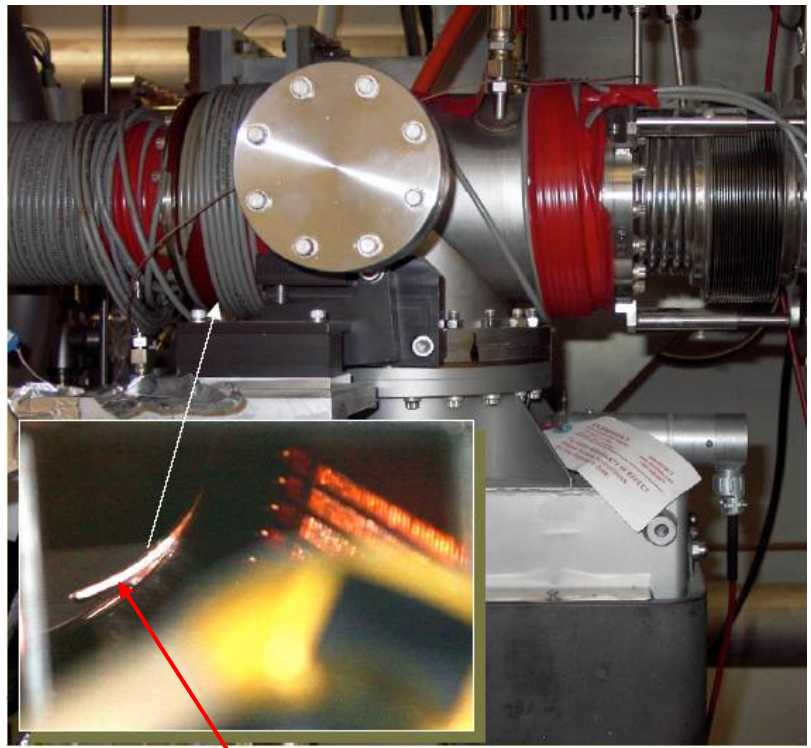


New Q2 Chamber

IR4 Vacuum Gap Ring Problem

Vacuum spike area





RF seal installation procedure problem

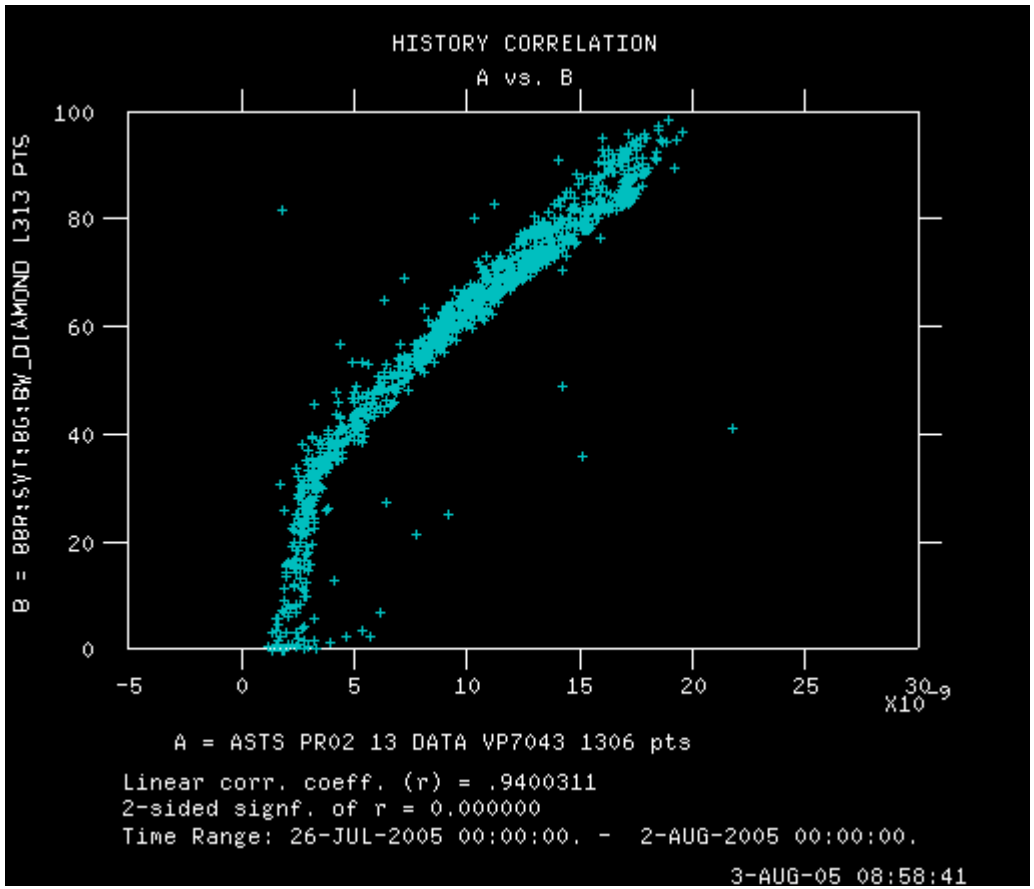
NEG Heating

- LER
  - Some (type C) IR2 LER NEG pumps became hot and out-gassed H2
  - LER type C NEG's removed 2004, 2005
  - New Q4 and Q5 chambers with improved screens 2006
- HER
  - Q5L NEG out-gassed H_2 above 1500 ma
    - Chamber replaced 2005
  - Forward Q5R chamber
    - Starting to show out-gassing
    - will be replaced 2006
  - Some similar screens in upstream chambers
    - BLF, B3 (E type)
    - Not causing a problem yet

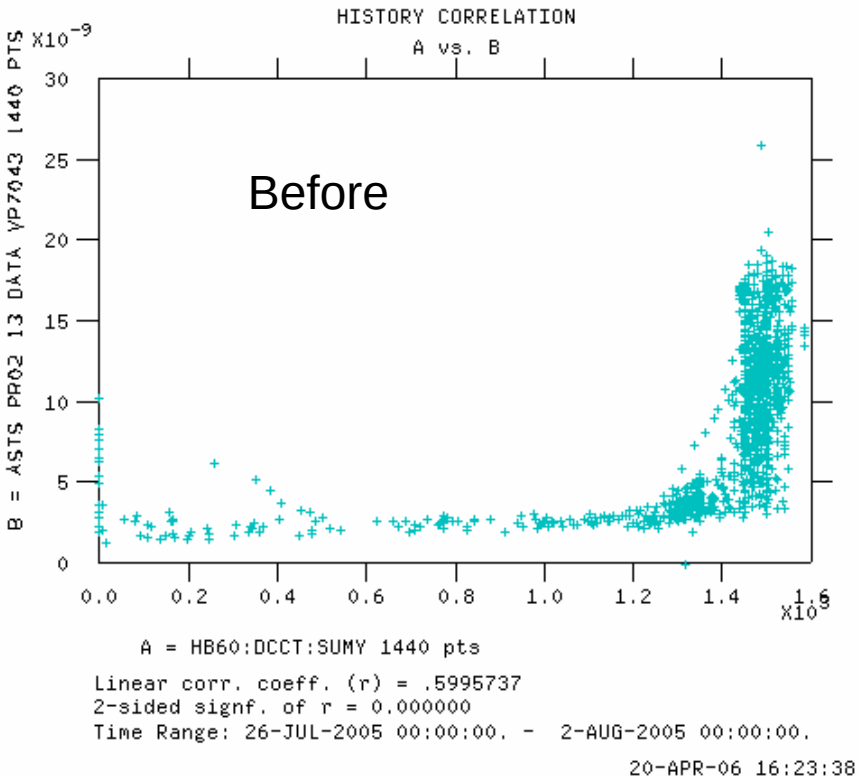
Screen Types

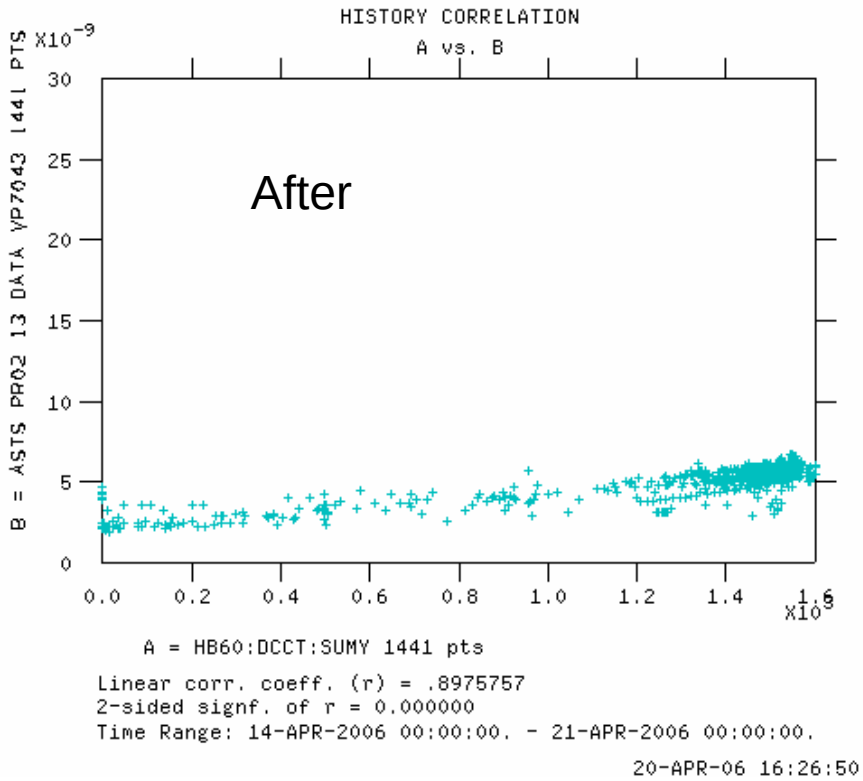
- A: Diam 0.125 holes x 0.125 deep on 0.167 centers
- B: Windows in side of chamber with welded in, 0.040" thk screens containing 0.118" square holes
- C: 8 through slots with welded in 0.020" thk screens containing 0.118" wide transverse slots [Q5L]
- D: 6 full length slots 0.145" wide x 1/4" deep and through holes within slots diam 1/4" x 1/4" deep
- E: 14 through slots with welded in 0.020" thk screens containing 0.118" wide transverse slots [BLF …]
- F: Windows in bottom of chamber with welded in, 0.080 thk screens containing 0.118 square holes [Lumi]
- W: Wiggler, screen in horiz plane +-x, 0.118 square holes, 0.088 x 0.118 at edge, 0.030 thick Cu

Background (BW) correlates with Pressure (VP7043 Lumi Pump)

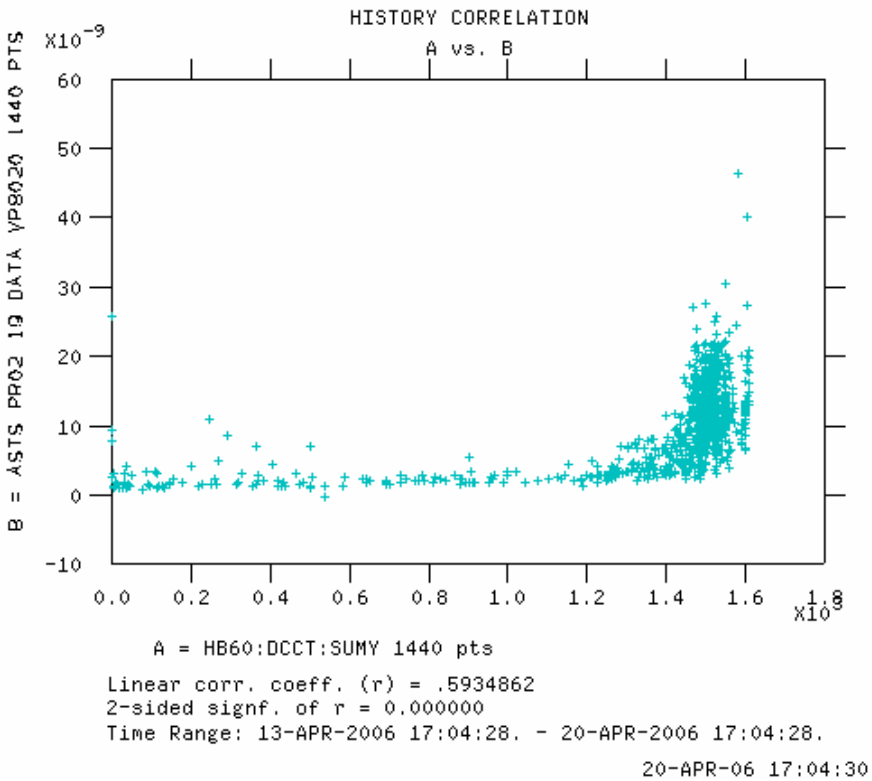


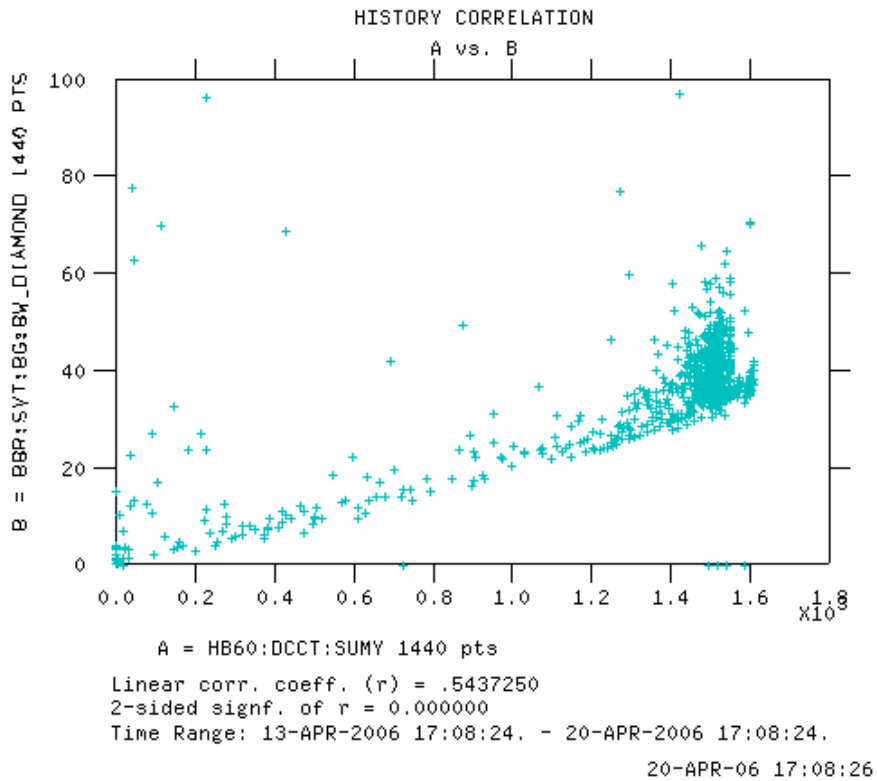
Pressure vs. Current
Before and After New Q5L Chamber





Q5R NEG Pressure and Backgrounds vs. Current. New chamber ready to install (2006)

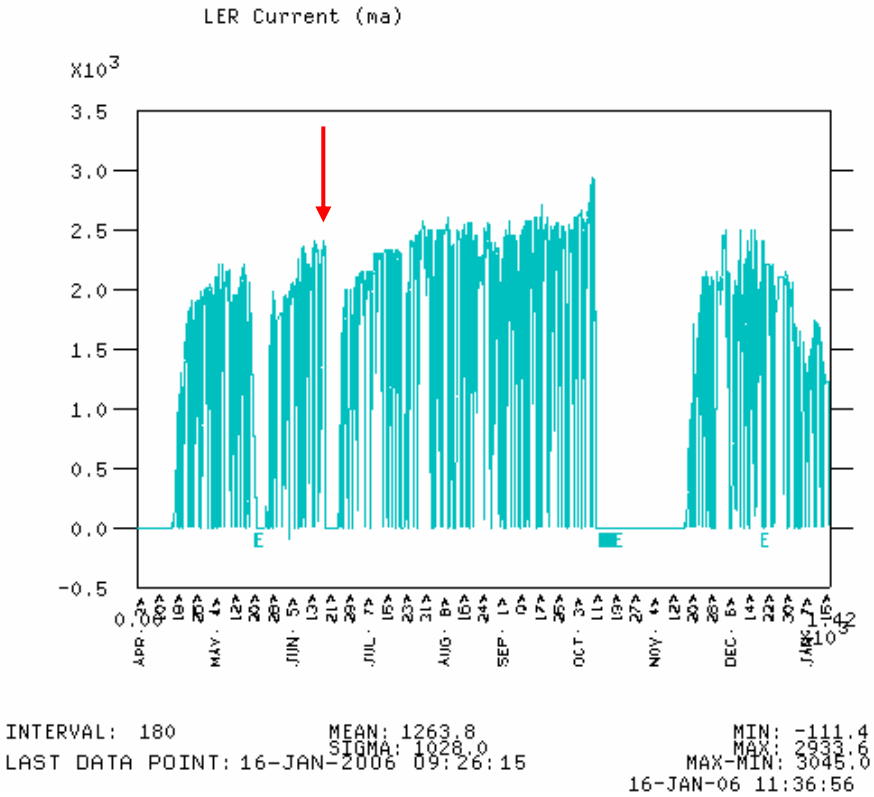


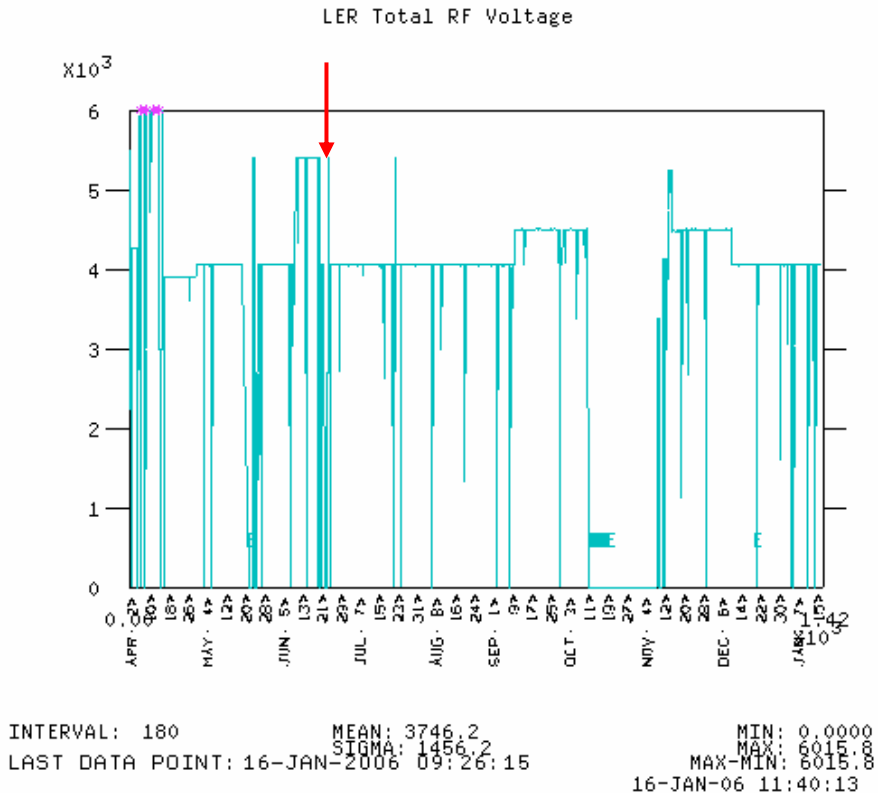


LER BPM Vacuum Feed - Thru Issues

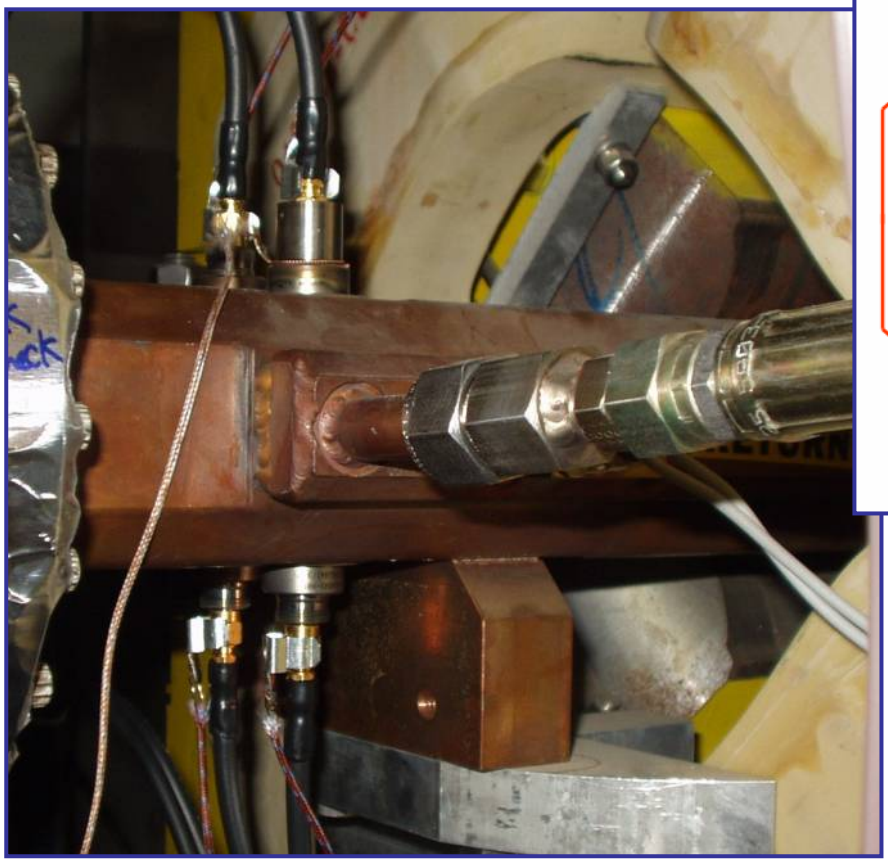
- BPM failure under high Power conditions in June 2005
  - Lost 5 buttons in IR2 outgoing LER
    - At 5.4 MV LER RF gap Voltage (6/9 – 6/19) and
    - I=2400 ma and
    - 1445 bunches
    - Large orbit excursions (10 mm)
  - Dirty vacuum vent due to failed feed-thru
    - Slow vacuum recovery over months
- Steps to ameliorate
  - Understand beam dependence including bunch length.
  - Lab. measurements
  - Beam test of new button designs.
- Future running
  - To Aug 2006
    - Reduced gap voltage 4.5 MV
    - Currents up to 3300 ma
    - More bunches 1720
  - After 2006 down, new buttons in LER ARC, pull IR2 buttons.

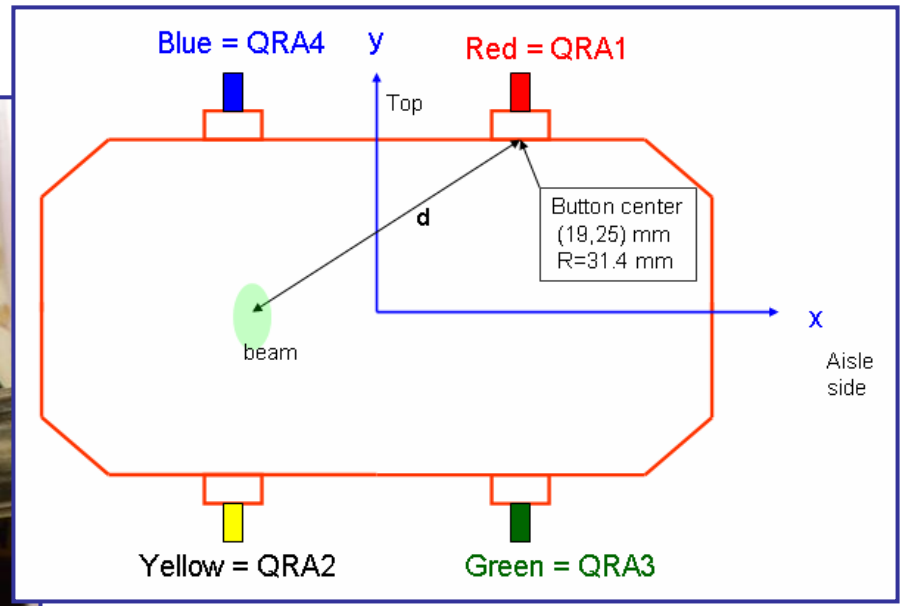
LER Beam Current and RF Voltage History





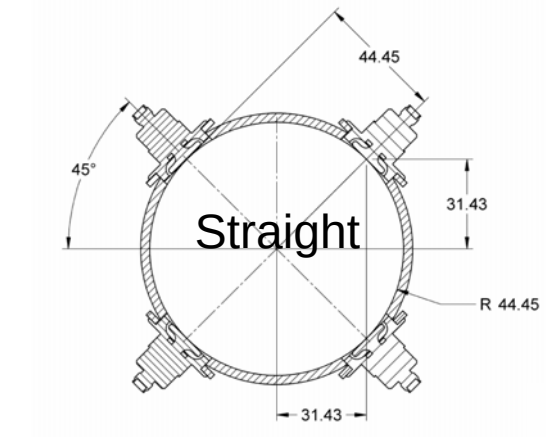
LER IR2 chamber Cu (HER) Button Geometry

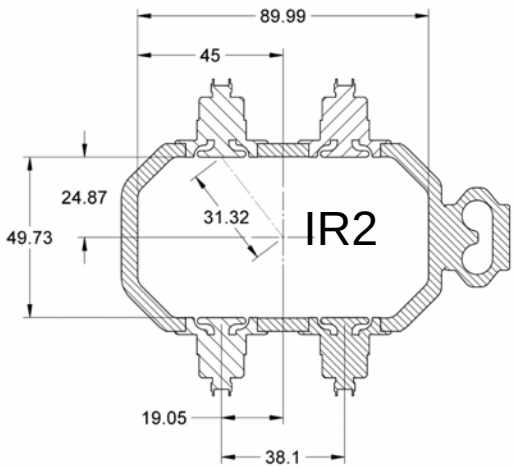


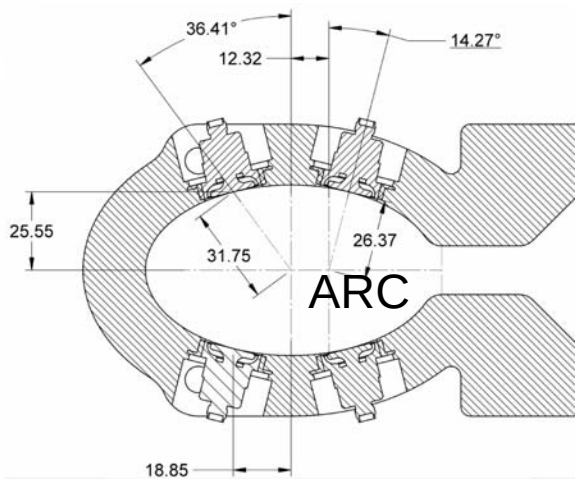


LER BPM

- Straight BPM has R = 44.45 mm vs. 31 for LER ARC and IR2
- Expect Straight BPM to have ½ the power of LER ARC and IR2 BPM's

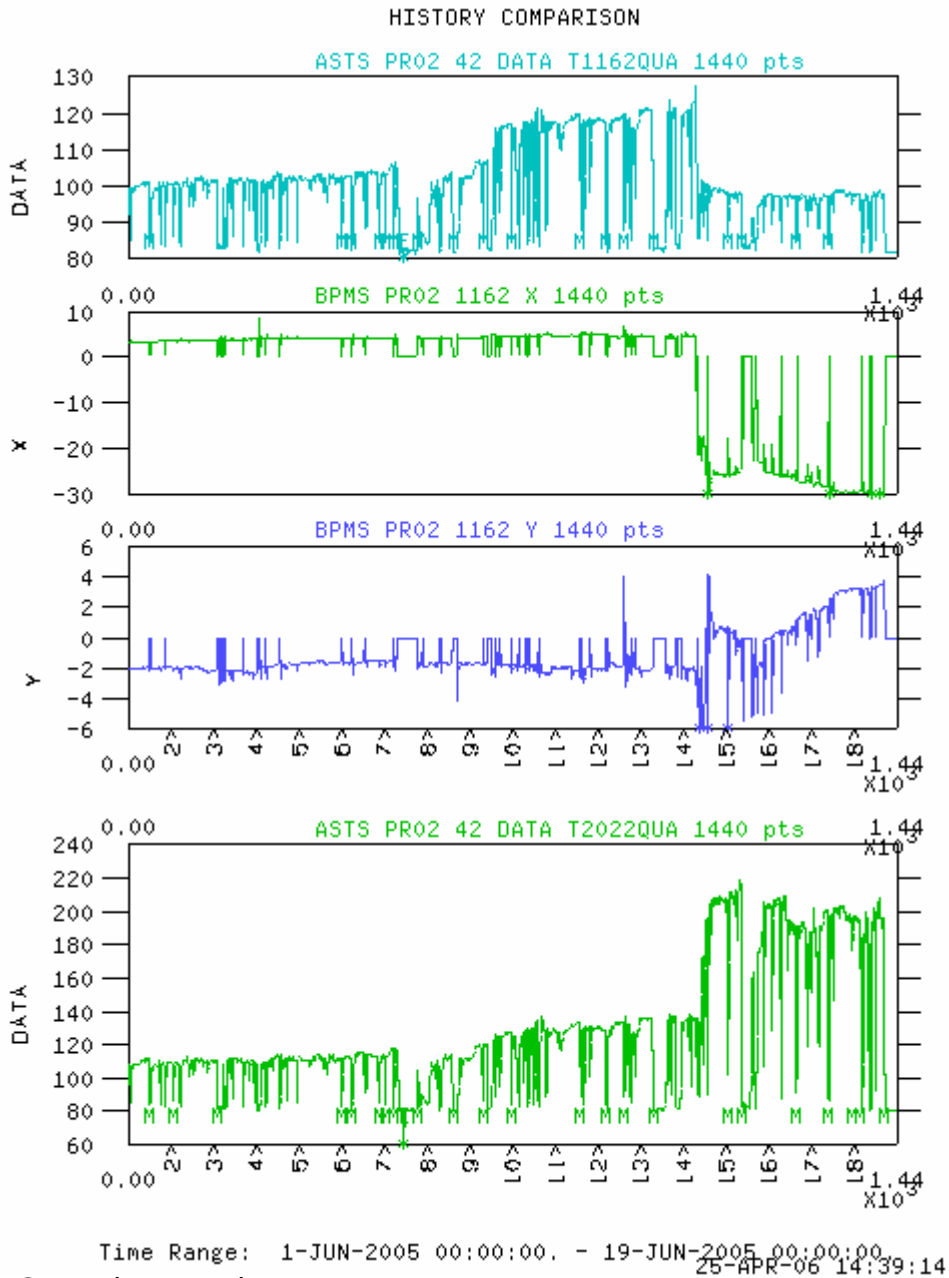






June 2005 Event

- Thermocouple T1162QUA indicates R btn falls 14 June
- beam orbit at (5,-2)
- 2022 heats up when 1162 falls due to HOM
- Ran with fallen button till vacuum leak



Vacuum leak at BPM

- PR02 1162
  - LER outgoing
  - In HER arc-type duct
    - Hexagonal Cu
- Burned Cable
  - Lower aisle side
  - Vac leak through center of coax

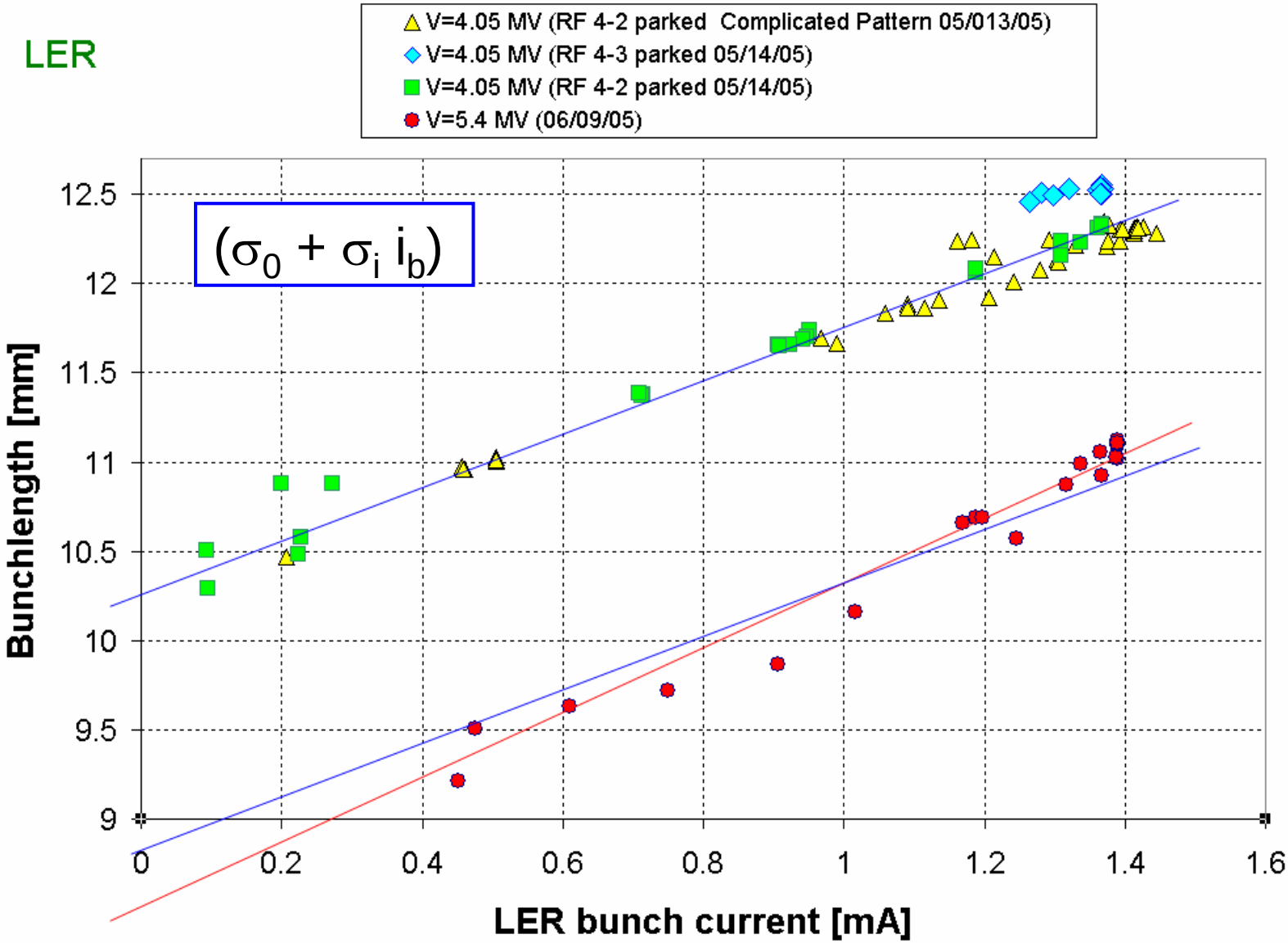
Understanding BPM absorbed Power – Assumptions

- dT ~ Power ~ $\Sigma\ i_b^2\ f(\sigma_z)\ g(x,y)$
  $= N_b\ i_b^2\ f(\sigma_z)\ g(x,y)$
- Assume power absorbed at one frequency (7 GHz)
  $f(\sigma_z) = \exp(-(\omega_r\ \sigma_z/c)^2) / \exp(-(\omega_r\ \sigma_0/c)^2)$
- Bunch lengthening and scale with $V_{rf}^{-1/2}$
  $\sigma_z = \mathrm{sqrt}(V_0/V_{rf})\ (\sigma_0 + \sigma_i\ i_b)$

$f(\sigma_z) = \exp(-\omega_r^2\ (V_0/V_{rf})\ ((\sigma_0 + \sigma_i\ i_b)/c)^2\ ) / \exp(-(\omega_r\ \sigma_0/c)^2)$

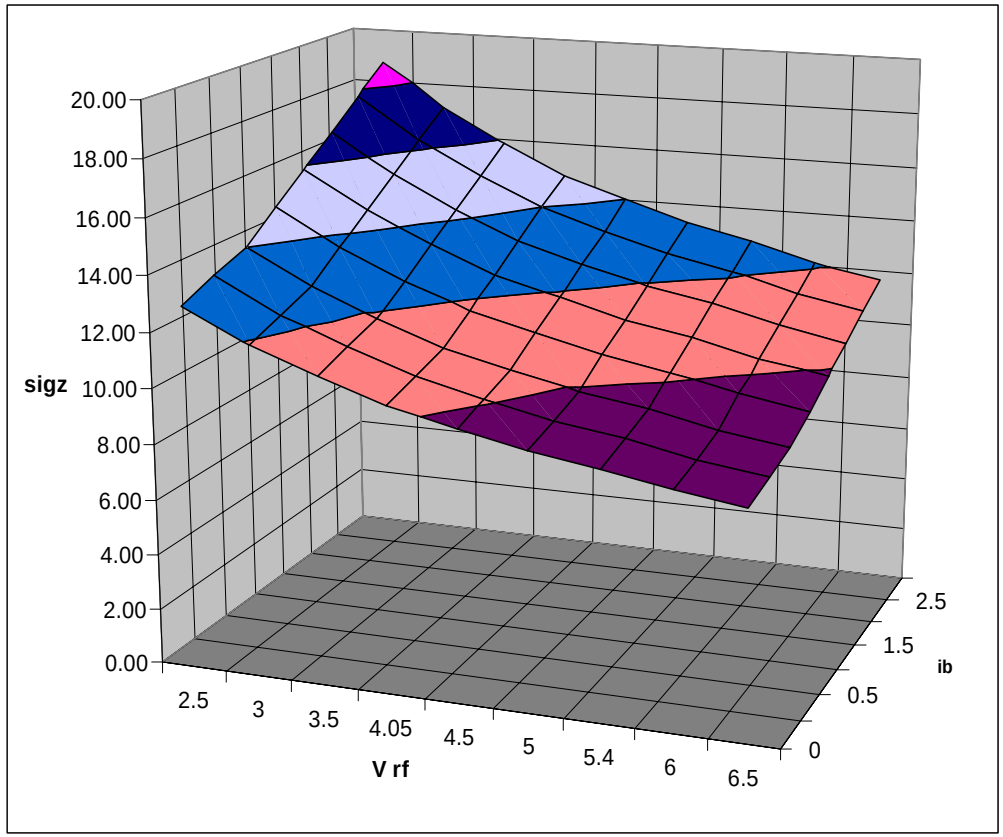
- Position dependence from calculated signal
  $g(x,y) \sim \mathrm{signal}^2$

LER Bunch Lengthening with current (from Sasha Novokhatski)



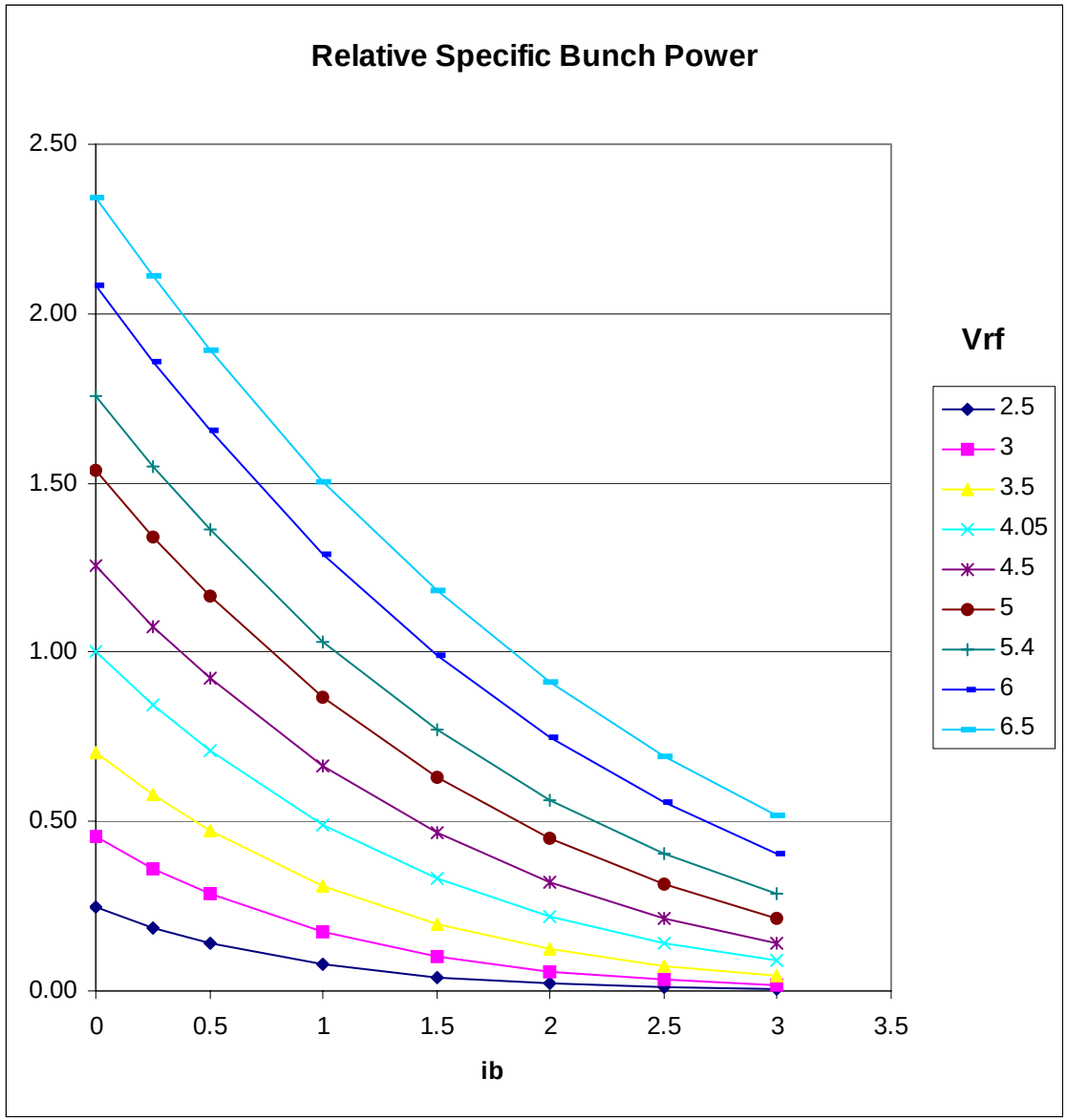
σ_z

Input		
Bunch L sigz=	10.25	mm
	3.42E-11	sec
at Vrf=	4.05	MV
Fourier at	0.323325	
Resonant f=	7.00E+09	Hz
wr=	4.40E+10	
d sigz / d ib	1.5	mm/ma

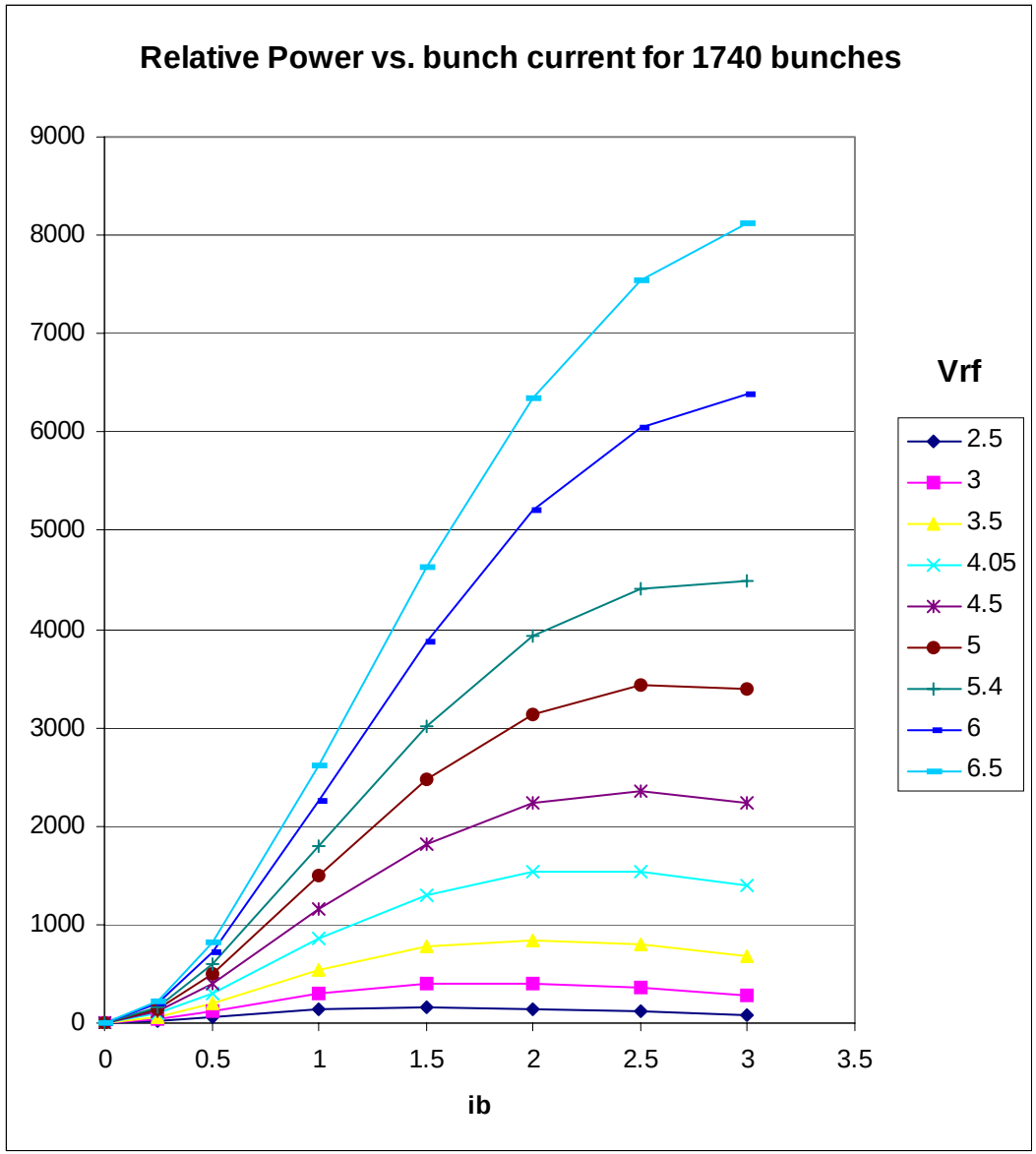


	Sigma Z table							
V rf	ib							
	0	0.25	0.5	1	1.5	2	2.5	3
2.5	13.05	13.52	14.00	14.96	15.91	16.86	17.82	18.77
3	11.91	12.35	12.78	13.65	14.52	15.40	16.27	17.14
3.5	11.03	11.43	11.83	12.64	13.45	14.25	15.06	15.87
4.05	10.25	10.63	11.00	11.75	12.50	13.25	14.00	14.75
4.5	9.72	10.08	10.44	11.15	11.86	12.57	13.28	13.99
5	9.23	9.56	9.90	10.58	11.25	11.93	12.60	13.28
5.4	8.88	9.20	9.53	10.18	10.83	11.47	12.12	12.77
6	8.42	8.73	9.04	9.65	10.27	10.89	11.50	12.12
6.5	8.09	8.39	8.68	9.27	9.87	10.46	11.05	11.64

$f(\sigma_z)$


Relative Specific Bunch Power
2.50
2.00
1.50
1.00
0.50
0.00
0
0.5
1
1.5
2
2.5
3
3.5
ib
Vrf
2.5
3
3.5
4.05
4.5
5
5.4
6
6.5

$N_b\ i_b^2\ f(\sigma_z)$

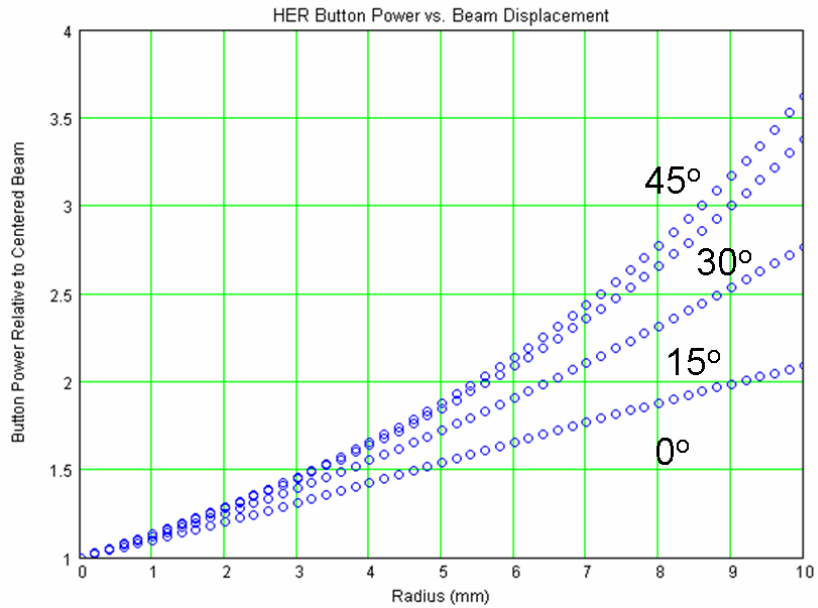


Position Dependence g(x,y) from (Steve Smith)

HER Arc Chamber Power Ratio vs. Position

Normalized to Centered Beam

(for beam within 20 mm of duct center)



		X (mm)																				
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Y (mm)	0	1.0	1.1	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.3	2.4	2.4	2.4	2.4	2.4	2.4	2.3
	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0	2.1	2.2	2.3	2.5	2.6	2.6	2.7	2.7	2.8	2.8	2.7	2.7	0.0
	2	1.2	1.3	1.4	1.6	1.7	1.9	2.0	2.2	2.3	2.5	2.6	2.8	2.9	3.0	3.1	3.1	3.1	3.2	3.1	3.1	0.0
	3	1.3	1.4	1.5	1.7	1.9	2.1	2.2	2.4	2.6	2.8	3.0	3.1	3.3	3.4	3.5	3.5	3.6	3.6	3.6	3.5	0.0
	4	1.3	1.5	1.7	1.9	2.0	2.2	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.8	3.9	4.0	4.1	4.1	4.1	4.0	0.0
	5	1.4	1.6	1.8	2.0	2.2	2.5	2.7	3.0	3.2	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.7	4.7	4.6	4.6	0.0
	6	1.5	1.7	1.9	2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.1	4.4	4.7	4.9	5.1	5.2	5.3	5.3	5.3	5.2	0.0
	7	1.6	1.8	2.0	2.3	2.6	2.9	3.2	3.6	3.9	4.3	4.6	5.0	5.3	5.6	5.8	6.0	6.1	6.1	6.1	0.0	0.0
	8	1.6	1.9	2.2	2.4	2.8	3.1	3.5	3.9	4.3	4.8	5.2	5.6	6.0	6.3	6.6	6.8	7.0	7.0	7.0	0.0	0.0
	9	1.7	2.0	2.3	2.6	3.0	3.4	3.8	4.3	4.8	5.3	5.8	6.3	6.8	7.2	7.5	7.8	8.0	8.1	0.0	0.0	0.0
	10	1.7	2.0	2.4	2.7	3.1	3.6	4.1	4.7	5.3	5.9	6.5	7.1	7.7	8.2	8.6	9.0	9.2	9.3	0.0	0.0	0.0
	11	1.8	2.1	2.4	2.8	3.3	3.8	4.4	5.1	5.8	6.5	7.3	8.0	8.7	9.4	9.9	10.4	10.7	0.0	0.0	0.0	0.0
	12	1.8	2.1	2.5	2.9	3.5	4.1	4.7	5.5	6.3	7.2	8.1	9.0	9.9	10.7	11.4	12.0	12.4	0.0	0.0	0.0	0.0
	13	1.8	2.1	2.5	3.0	3.6	4.3	5.0	5.9	6.9	8.0	9.1	10.2	11.3	12.3	13.2	13.9	0.0	0.0	0.0	0.0	0.0
	14	1.7	2.1	2.5	3.0	3.7	4.4	5.3	6.3	7.5	8.8	10.1	11.5	12.9	14.2	15.3	0.0	0.0	0.0	0.0	0.0	0.0
	15	1.6	2.0	2.4	3.0	3.7	4.5	5.5	6.7	8.1	9.6	11.3	13.1	14.8	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	16	1.5	1.9	2.3	2.9	3.6	4.5	5.7	7.0	8.7	10.6	12.6	14.8	17.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	17	1.4	1.7	2.2	2.7	3.5	4.5	5.7	7.3	9.2	11.5	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	18	1.2	1.5	1.9	2.5	3.2	4.3	5.6	7.4	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	19	1.0	1.2	1.6	2.2	2.9	3.9	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	20	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Parameters where BPM buttons fell off

	Date	Micr	BPM unit	Button	LER I	Nb	ib	Vrf	x	y	g= geom. power factor	T fall	T ok	T amb	dT fall	Sum ib^2	f=relative bunch shape Power	relative P= sum(ib^2) *f*g
Drop failure	14-Jun-05	PR02	1162	R	2400	1440	1.67	5.4	5	-2	1.1	127	120	81	46	4000	0.70	3063
Drop failure	9-Jun-05	PR02	2062	R	2350	1440	1.63	5.4	7	5	3.0	160	150	82	78	3835	0.71	8181
Drop failure	10-Jun-05	PR02	2062	B	2350	1440	1.63	5.4	7	5	3.0					3835	0.71	8181
Drop failure	10-Jun-05	PR12	1012	R	2350	1440	1.63	5.4	0	-3	1	116	111	96	20	3835	0.71	2727
Leak (TC on pin)	9-Dec-05	PR02	2062	Y	2600	1589	1.64	4.5	-1.5	-0.1	1.2	500		90	410	4254	0.42	2152
Did it Move?	14-Jun-05	PR02	2022	R	2400	1440	1.67	5.4	11	8	5.6		220 140	80		4000	0.70	15591
Did it Move?	16-Jun-05	PR02	2052	R	2400	1440	1.67	5.4	6.5	9	4.05		118	79		4000	0.70	11276
suspect	14-Jun-05	PR02	3149	B	2400	1440	1.67	5.4	1	2.6	1.35		130	77		4000	0.70	3759
Future																		
Now	22-Apr-06	PR02			2600	1727	1.51	4.5	5	5	2.5					3914	0.46	4538
proposed running	1-Jul-06	PR02			3300	1727	1.91	4.5	5	5	2.5					6306	0.34	5409
Next Run 6	1-Dec-06	PR02			4000	1740	2.30	6	3	3	1.7					9195	0.63	9827

LER Test New BPM Buttons

- Installed 3 new (modified) buttons in LER during October 2005 down
  - Short on 15 mm button
  - 7 mm no insert
  - 7 mm with insert
  - Feed-through, no button
  - Compare with normal 15 mm button
- Measured
  - Temperature Rise at collar
  - Power out cable to Filter-Isolator (FIB) Load Resistor

Test Button Results at I = 2.2 A
7 mm button with insert is winner

Unit	FIB dT (F)	FIB Power = dT/1.3	Button collar dT (F)
BPM 1022 15 mm shorted	76	58	8 to 10
BPM 1032 15 mm Normal	35	27	<= 11
BPM 1052 7 mm without insert	45	35	5
BPM 1092 7 mm with insert	17	13	3
BPM 2152 feed-thrus only	?	?	2 to 3

200 Watt FIB Rating

BPM Button Heating - Summary

- No clear threshold for all buttons to fall
- Have a formula, but
  - HOM's are a complication not included
  - Assumes f=7 GHz absorption in 15 mm button
- Monitoring BPM signals for a fallen button
- Monitoring thermocouples in IR2 incoming LER
- Stay below parameters of June failure till buttons are improved in 2006 down.
- Run 5B
  - Limit Current to 3.3 A
  - Limit LER RF V to 4.5 MV
  - Limit Orbit offset to 3 mm
  - Watch TC and raw signal for change
- Run 6
  - LER ARC – Install new 7 mm buttons
    - Expect smaller 7 mm buttons to receive ¼ Power
    - Button resonance 2 x higher
  - IR2 Straight - bare feed-through
  - LER Straight should be OK with ½ power in larger chamber

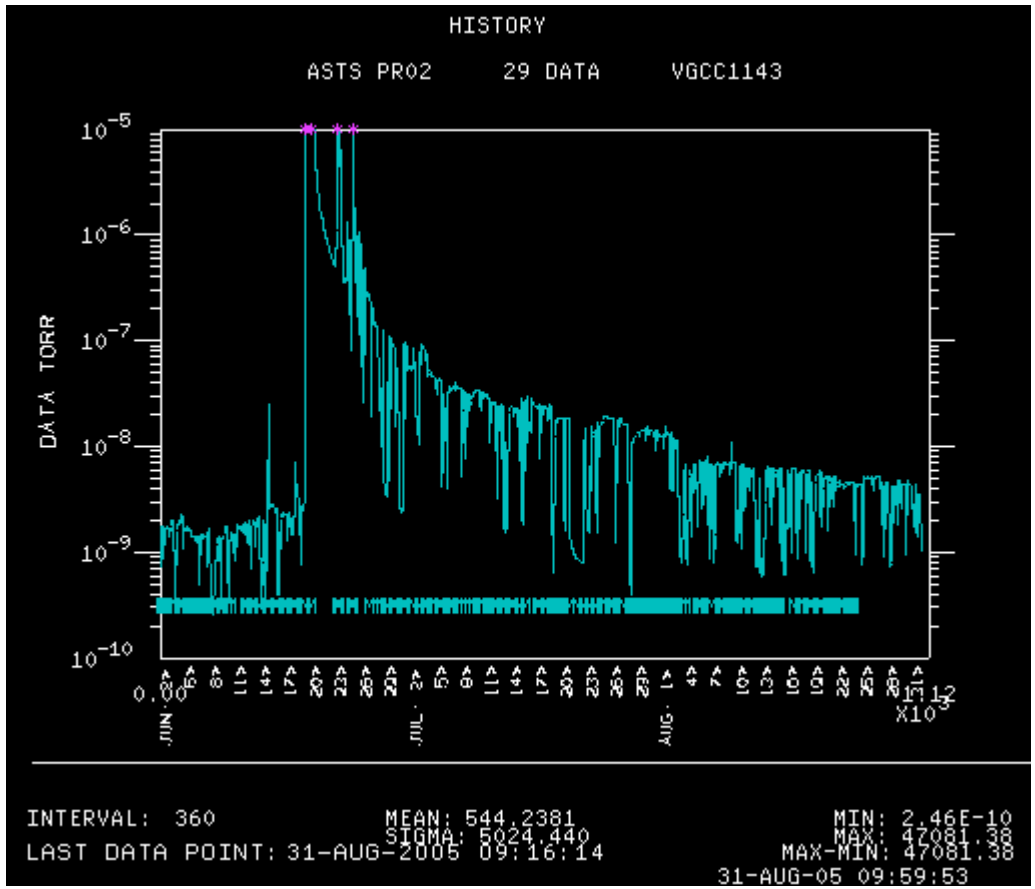
Vacuum Summary

- We have encountered some difficult vacuum problems
- Which we diagnosed the effectively
- Involving expert help.
- We built improved components to install in a timely manner
- Have new components coming for Aug. 2006 downtime
- Plan to operate efficiently and safely at increased luminosity and beam currents.

Extra Slides

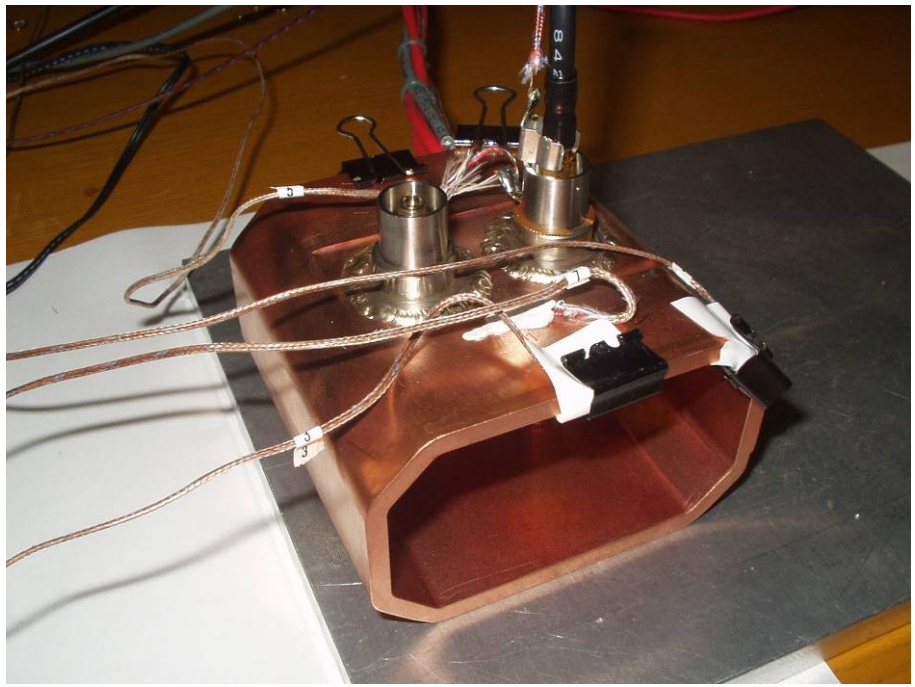
Pump down after dirty vents

- Slow months time scale for recovery
- Outgoing beam-line more tolerant than ingoing!

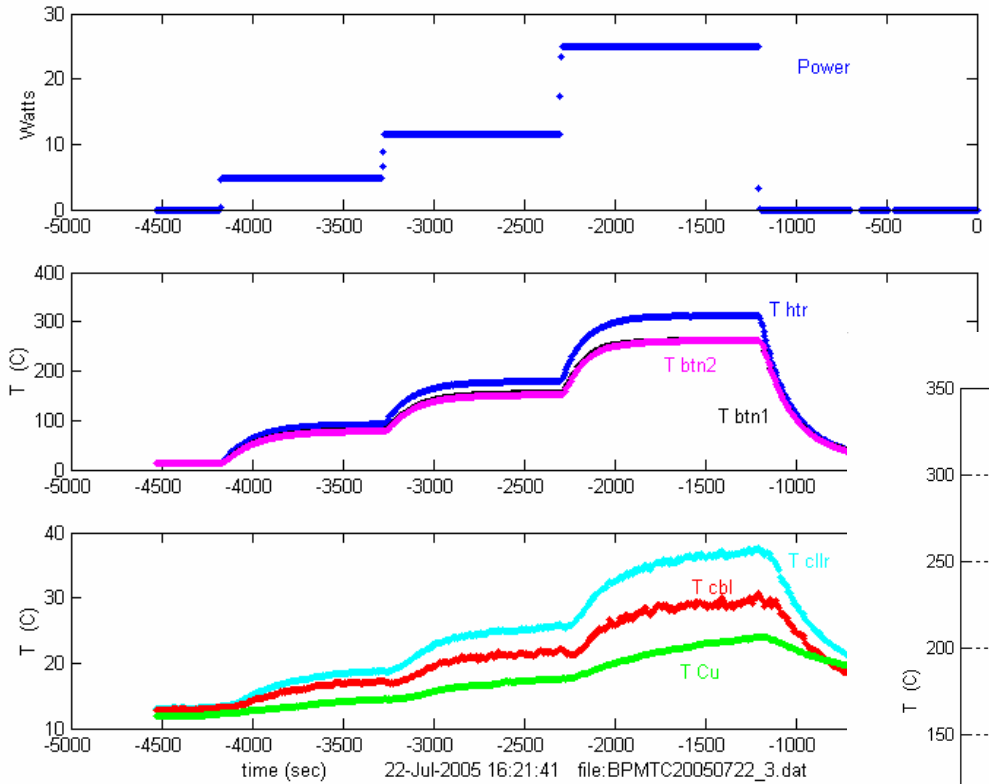


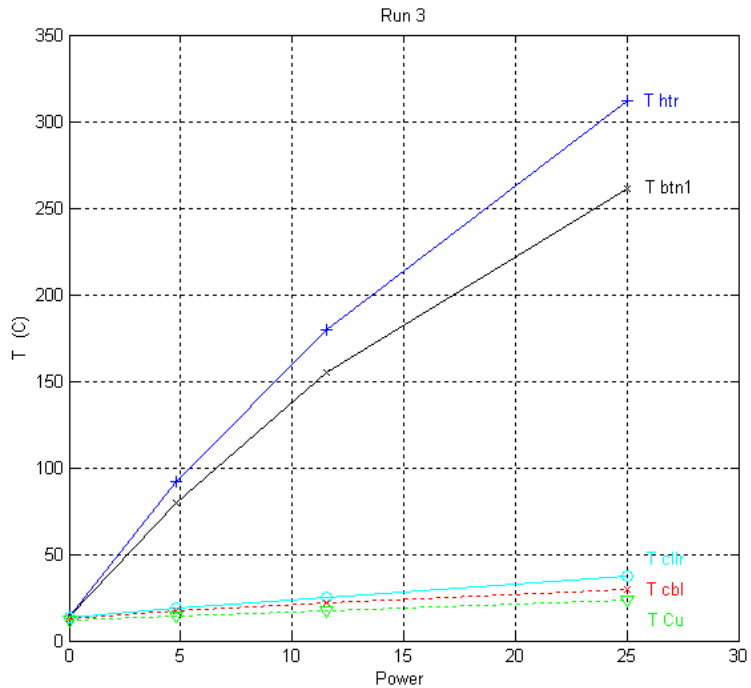
Lab Test - BPM Heating Experiment

- Power applied to button with 25 ohm, 25 W resistor as a heater.
- Measured current and voltage.
- Thermocouples (6) measured:
  - Heater resistor
  - Button (2)
  - BPM collar (normal QUA location)
  - BPM cable (new RGBY tc) or center pin of connector
  - Cu Chamber about 1 inch from BPM



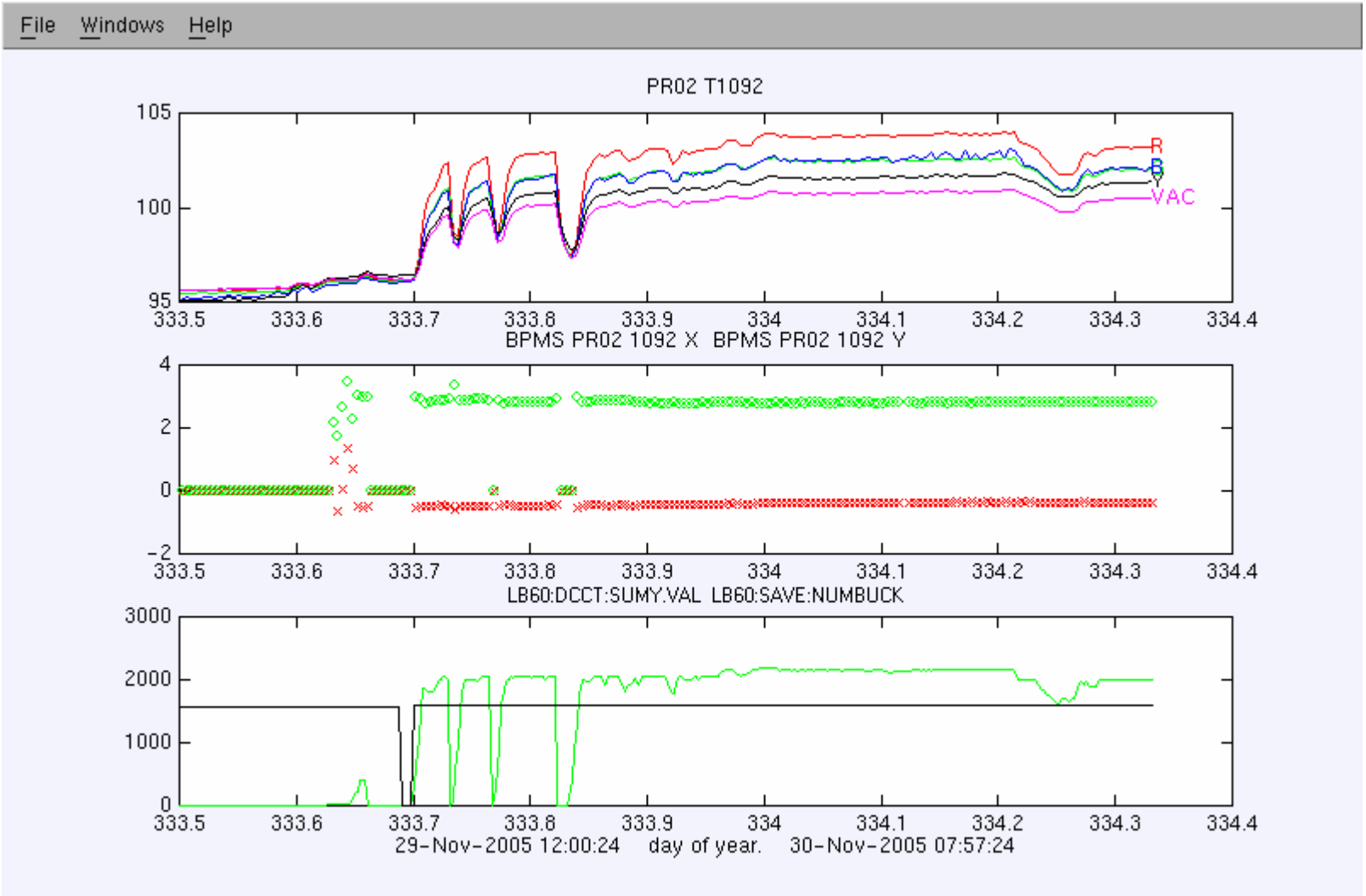
Lab Test - Run 3 Data





Lab Test - Run 3 Results

T btn1	T btn2	T cllr	T cbl	T Cu	Power	dT cllr-Cu	dT cbl-Cu	dT btn-Cu	ratio btn / cllr	dT btn / Power	ratio btn / cbl
14.0	13.9	13.2	13.0	12.0	0	1.1	0.95	2.0			
79.4	77.7	18.7	17.0	14.3	4.8	4.4	2.71	65.1	15	13.6	24
155.1	151.8	25.4	21.5	17.4	11.53	8.0	4.16	137.8	17	11.9	33
261.5	261.2	37.1	29.5	23.7	25	13.4	5.8	237.8	18	9.5	41

- Button dT / Collar dT = 15 to 18
- Button dT/Power = 9 to 14 deg C / Watt
- T vs. Power not linear
  - Convective cooling
  - Radiative cooling

BPM 1092 7 mm, with insert