D0 Calorimeter design, maintenance and long term operational experience

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for the D0 collaboration

Outline

- Uranium-LAr Calorimeter
- Readout electronics (original and upgrade changes)
- Maintenance and reliability
- Noise monitoring
- Anomalous CC HV Currents

DØ LAr Calorimeter

Calorimeter Characteristics

Uranium Liquid-Argon Sampling Calorimeter

3 Cryostats	Central	2 End Cap
Weight(metric tons)	305	258 each
LAr volume(liters)	19K	12K each

Segmentation:

$\Delta\eta\times\Delta\varphi$	0.1×0.1
longitudinal	8-9 depths
EM	4 depths
shower max	3rd depth: $\Delta\eta=\Delta\varphi=0.05\times 0.05$
	2-2-7-10 X_0
Hadronic	3-4 depths fine segments
	1-3 depths coarse segments

Inter-Cryostat Region:

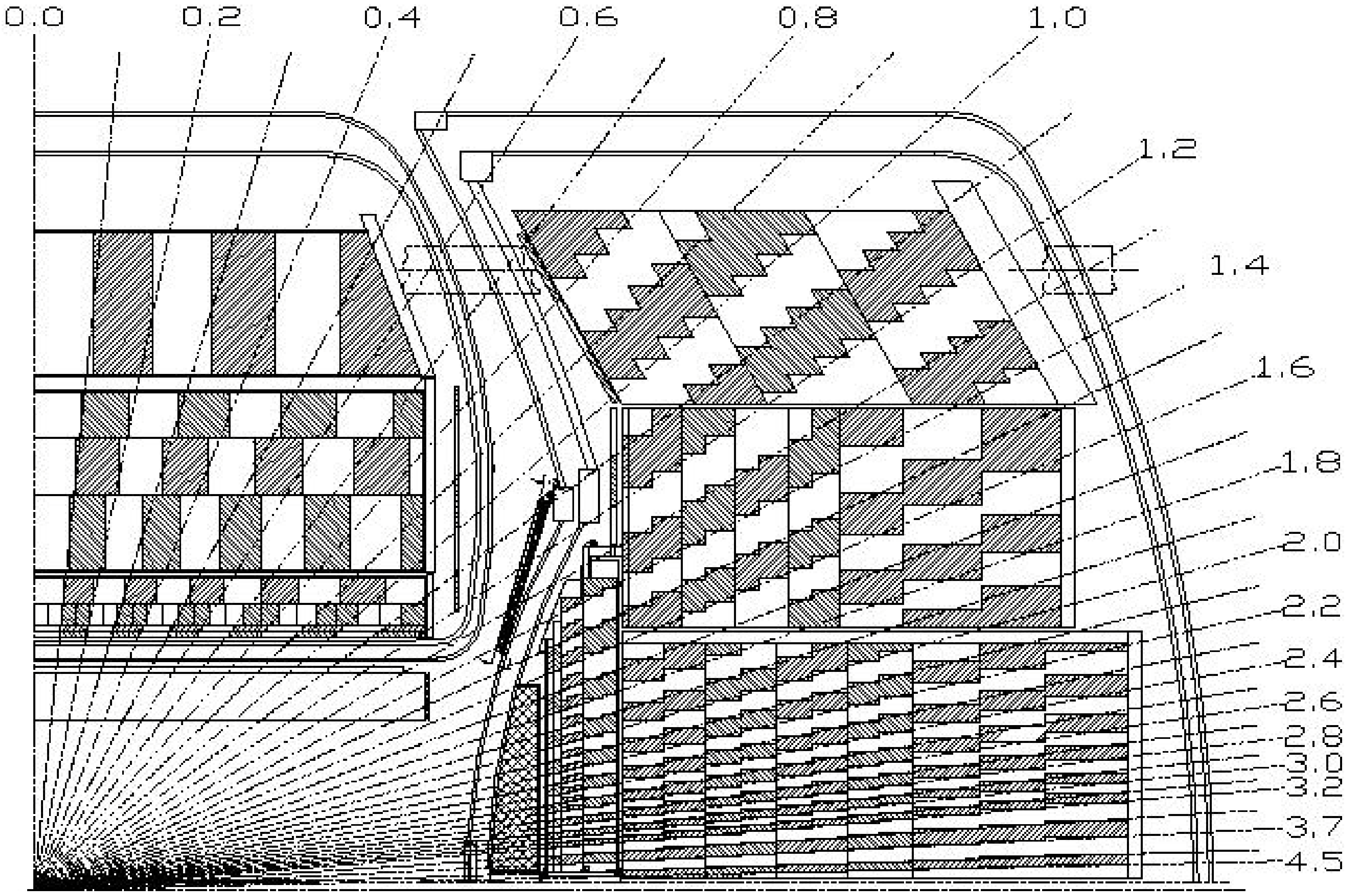
massless gaps inside cryostat
scintilators between cryostats

Semi-projective towers

47,800 readout channels

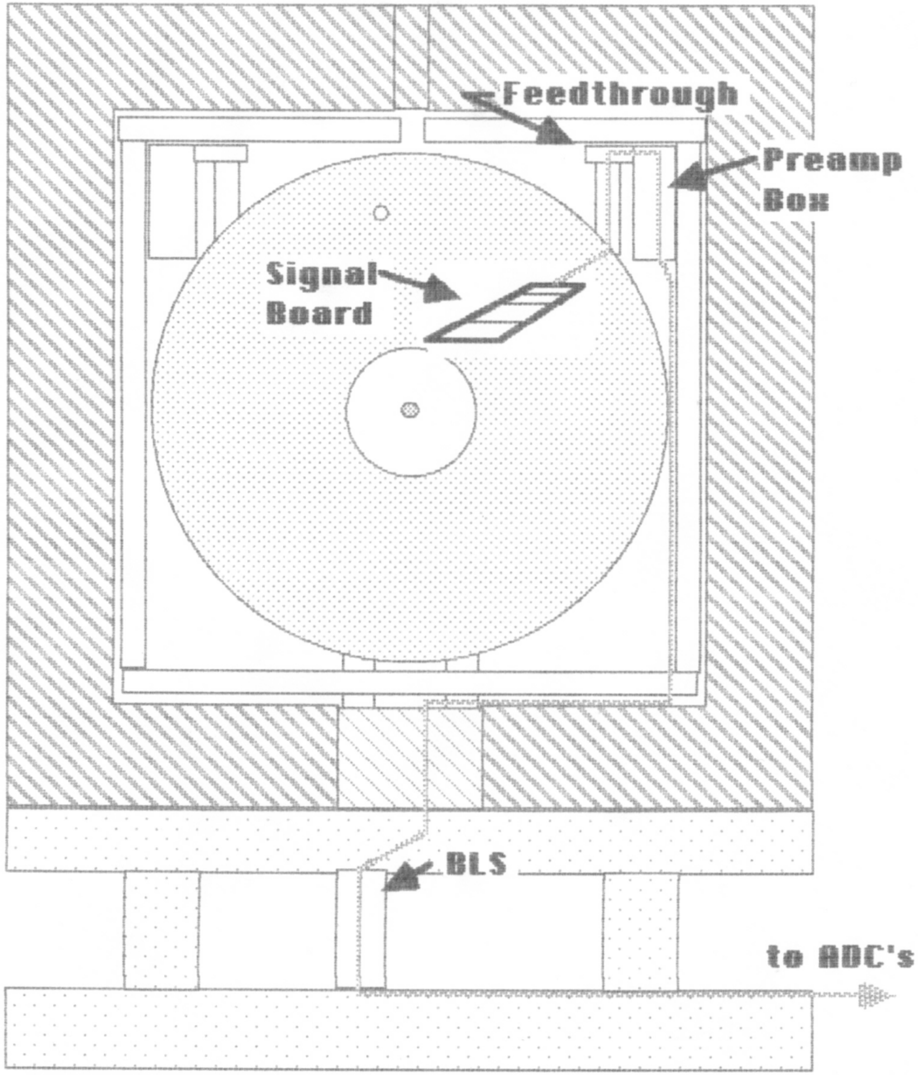
Calorimeter Properties

	EM	Hadronic Fine	Hadronic Coarse
LAr gap (mm)	2.3	2.3	2.3
⇒ drift time ≈ 450 nS			
Absorber	U^{238}	U^{238} +1.7%Nb	Cu/steel
Thickness(mm)	3.0/4.0	6.0	46.5
Rad Length(X_0)	21	95-122	31-65
Int Length(λ_0)	0.8	3.3-4.7	3.2-7.0
⇒Total Thickness		7-9 λ_0	
Resolution(σ/E)	~16%/ $\sqrt{E}$	~50%/ $\sqrt{E}$	
Ped Sigma(adc counts)	1-4	10-12	5-6
Coherent noise	Σ 4000 channels < incoherent		
Cell capacitance	**200-500pF**	**0.5-2nF**	**2-5nF**


0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.7
4.5

DØ Calorimeter Readout path

- All signals leave through feedthroughs at the top of each cryostat (total 12 ports).
- Feedthroughs reorganize signals from module organization (many etas for single layer) to physics organization (all layers for a given eta).
- Preamps are located inside the Muon iron. Harder to access/repair.
- Shaper, analog memory, correlated double sample (BLS), analog trigger summers and cable drivers located under detector between muon chambers.
- CAL ADCs (precision and trigger) and trigger control logic located outside radiation area. Accessible during data taking.



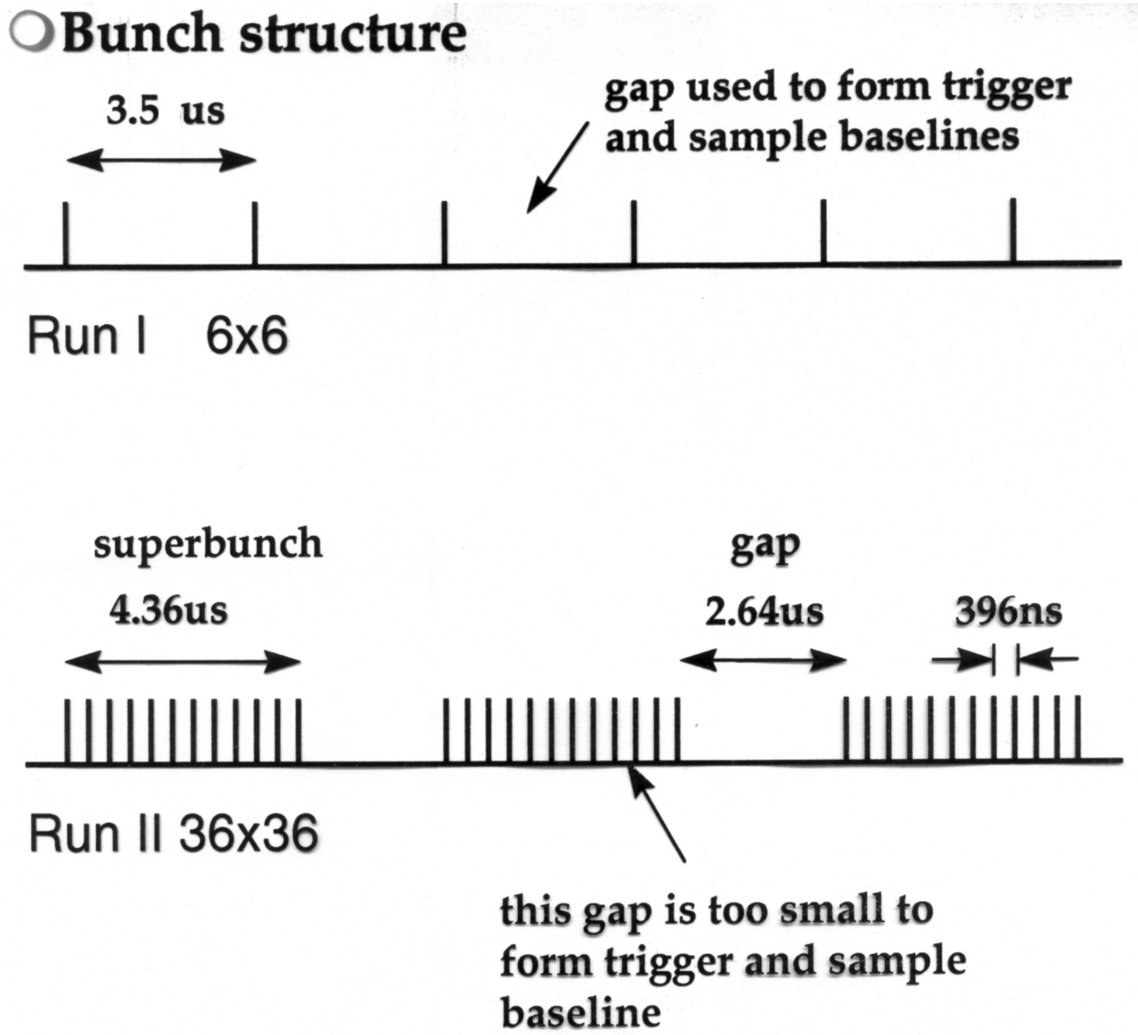
Tevatron Beam Structure

Run 1 1992-1995

Peak Luminosity ~10^{31}

Run 2 2002-2011

Peak Luminosity ~$3x10^{32}$



DØ Run 1 electronics

- Preamp
  - 2 versions (factor of 2 in charge to voltage)
  - Single ended, back terminated output
  - RC decay 100 uSec
- Electronics pulser
  - Monitor and check linearity
  - Inject charge at preamp input, not at the detector cell
- Shaper
  - 250 nSec integration
  - 30 uSec differentiation
  - Peaks at 2-2.5 uSec depending on cell capacitance
- Trigger pickoff
  - Hard differentiation to peak at ~500 nSec
  - Summed locally in 2x2 tower
  - Converted from E to E_T with fixed resistor

DØ Run 1 electronics (cont)

- Base Line Subtractor (BLS)
  - Correlated double sample
    - Baseline just before the crossing
    - Peak at 2.2 uSec (near peak)
  - Difference transferred to output buffer on L1 accept
  - Alive for next crossing (3.5 uSec spacing)
- 16 to 1 analog multiplexer
  - Reduce cabling
  - Share same ADC with 16 cells
- Differential analog cable driver
  - Optional gain 8.00 amplifier
  - Computer controlled or automatic switching modes
  - Digital gain sent on separate cable
  - 5 uSec analog settling time after 100 meters of twisted pair cable

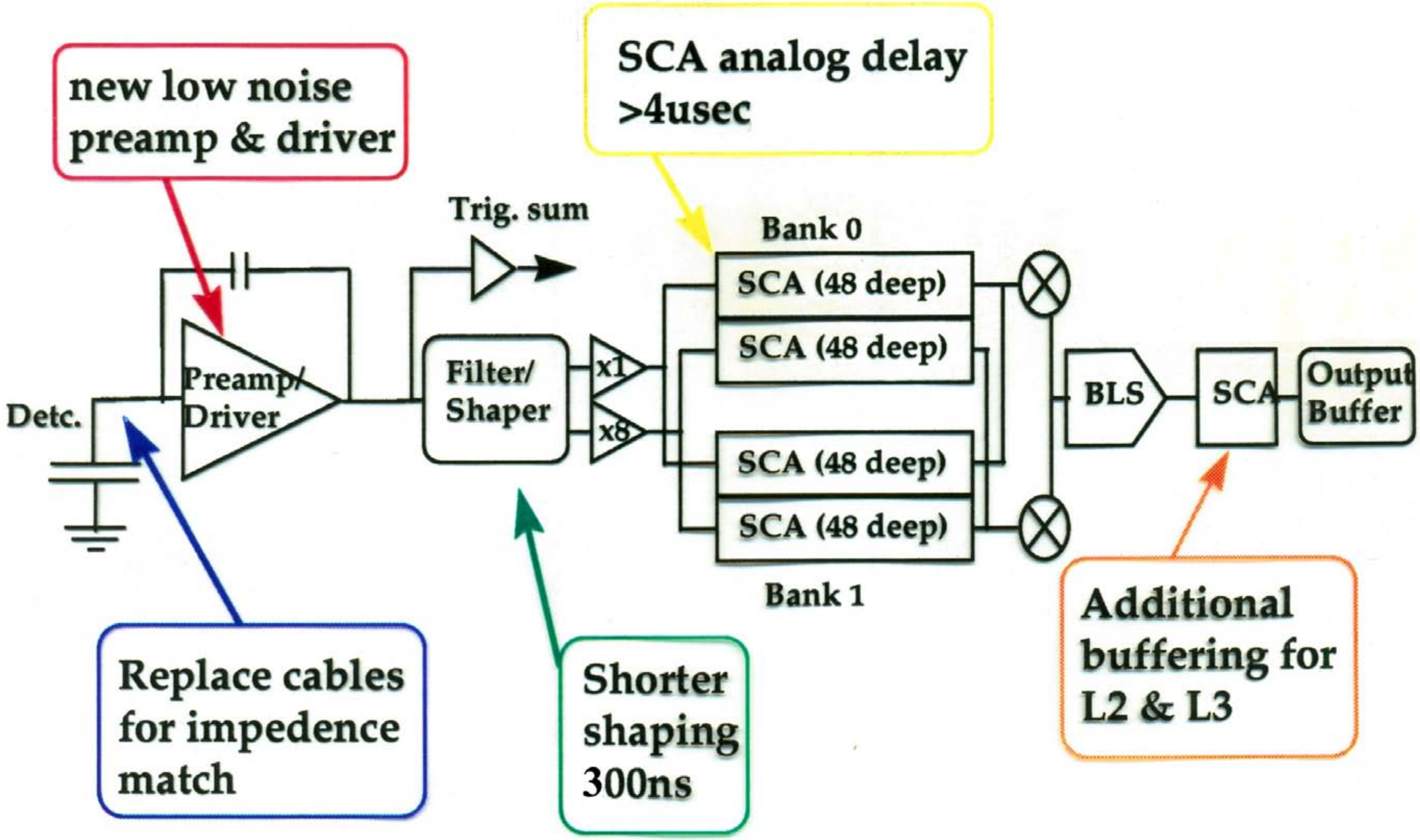
DØ Run 1 electronics (cont)

- 12 bit ADC
  - Differential input
  - Local memory for pedestal and zero suppression limits for each channel
  - 5 uSec successive approximation digitizer
  - ~ 250 uSec to process an event
  - ~300 uSec to readout zero suppressed event
  - 1.1 mSec to readout an unsuppressed event
  - Control of zero suppression on an event by event basis

Calorimeter test station

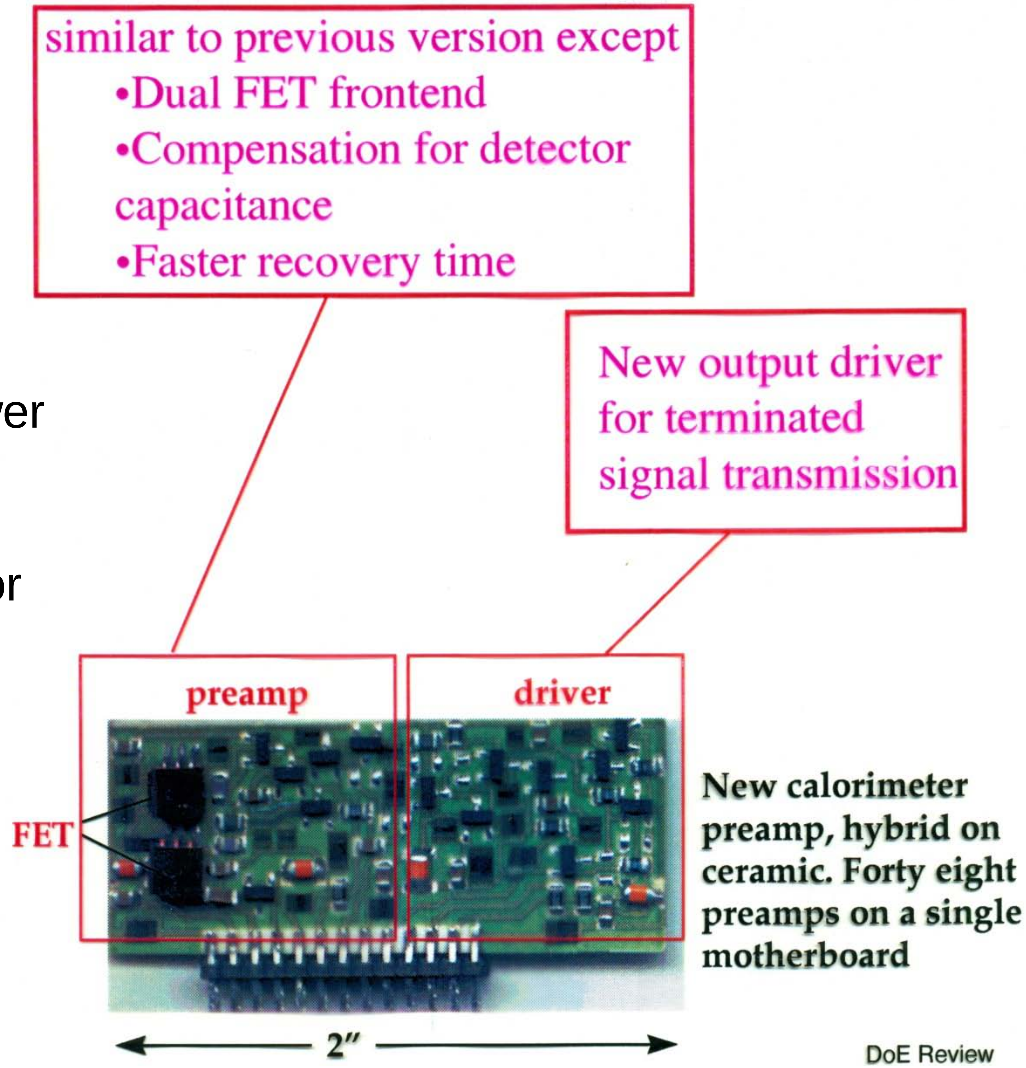
- Full mockup of one quarter of one cryostat's electronics (one feedthru port)
  - Capacitors to simulate the detector
  - All cables full length spares for the real detector
  - Crates and power supplies actual spares for the detector
  - Grounding similar to the real detector
  - Typically 25% to 50% populated with functional spares checked every few weeks
  - Upgraded along with the detector for Run 2 electronics
  - Stand alone local PC readout, but also linked to full DAQ control/readout during shutdowns

Run 2 Electronic changes



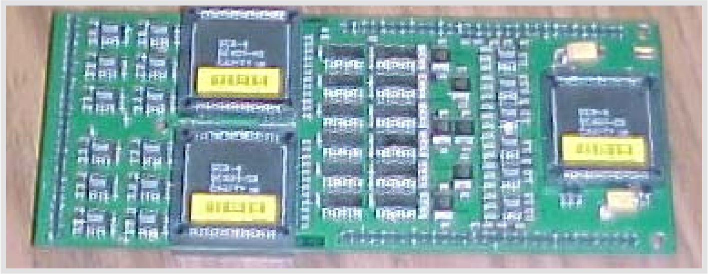
Run 2 Preamp upgrades

·Approximately twice the size
·Approximately 2.5 times the power
·New (switching) power supplies
·Upgrade to the air-water cooling
·14 types adjusted for the detector capacitance



Shaper/BLS upgrade

- Shaper
  - Peak at ~300 nS
  - Sample ~2/3 of the total charge
- SCA
  - 12 channels per chip
  - 41 x 132 nSec = 5.41 uSec
  - Separate x1 and x8 paths
  - Second chip for “deadtime less” operation
- Second SCA for L2 storage



Run 2 noise optimization

- Re-optimized three contributions
  - Electronics noise:
    - Increase due to shorter shaping times
    - Decrease due to dual FET preamp design
  - Uranium noise:
    - Decrease due to shorter shaping time
  - Pile-up noise:
    - Same bunch
      - Increased due to luminosity
    - Neighboring bunches
      - Net increase due to closer spacing but shorter shaping time
- Net effect was about the same performance for first factor of 10 upgrade in Luminosity

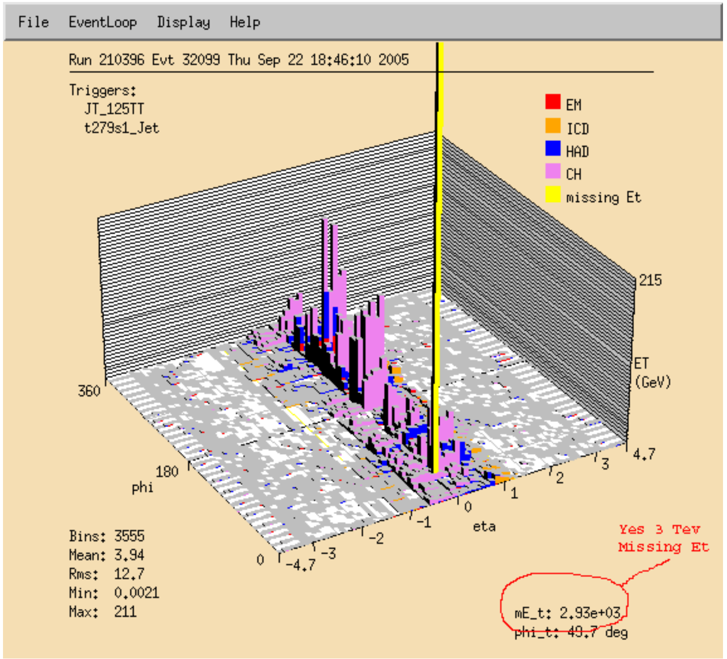
Run 1-2 reliability Comparison

	Total channels Run 1	Run 2
Total channels	47,800	47,800
if more than 384 channels bad in any run, data marked bad for CAL until fixed		
Dead Channels		
cables	37 (in cryostat)	37 + 12 (external but inaccessible)
electronics (average)	10	20-40
~30 minute access for electronics repair	1 per week	2 per week
Power Supplies (including cooling)		
ADC (total 12)	0 in 4 years	4 in 10 years (unchanged in run 2)
BLS (total 36)	1 every 6 months	1 every 3 months
Preamp (24)	1 every 6 months	1 every 2-3 months

– redundant pairs so only a few minutes to switch and resume running until second in pair fails. Then 12-16 hour machine downtime to replace

Noise

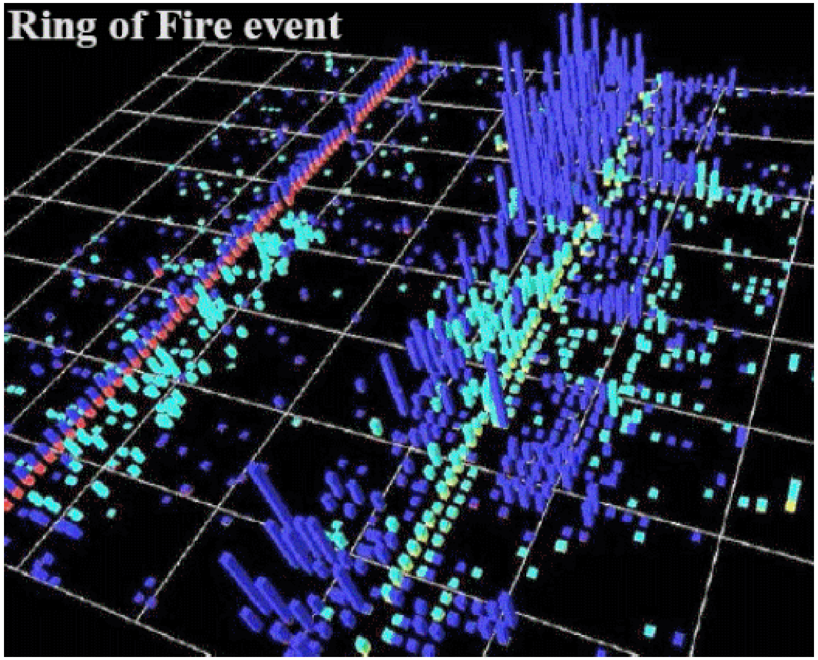
- Evolving issue as conditions changed during the 20 years of operations which required constant monitoring of conditions and development of software tools to minimize the effect on analyses
  - Ring of fire
  - Noon noise
  - Muon clock noise
  - Purple haze
  - Spanish fan
  - Coherent noise



Ring of Fire

- Distinctive signature of external noise being injected into the end cryostats do to the assembly of the EC EM modules HV distribution.
- While not seen very often, the ring of fire flag is an efficient flag.
- Grounding issues were worked on during the first two major shutdowns in run 2. DC shorts have all been eliminated (as of November 2004). AC coupling has been reduced.
- Still see the flag being set about once every 1-2 hours of running until the extra 'safety' ground was found and eliminated.

Only noise source seen in Run 1



Noon Noise

- Named because it often started about noon and stopped in the early evening. Eventually correlated with a welder working in the shop at the D0 building.
- Correlated with a higher level of Ring of Fire noise.
- Typically more apparent in the end calorimeters but no recognizable pattern.
- Greatly reduced when the accidental short between the detector and building was located and removed.

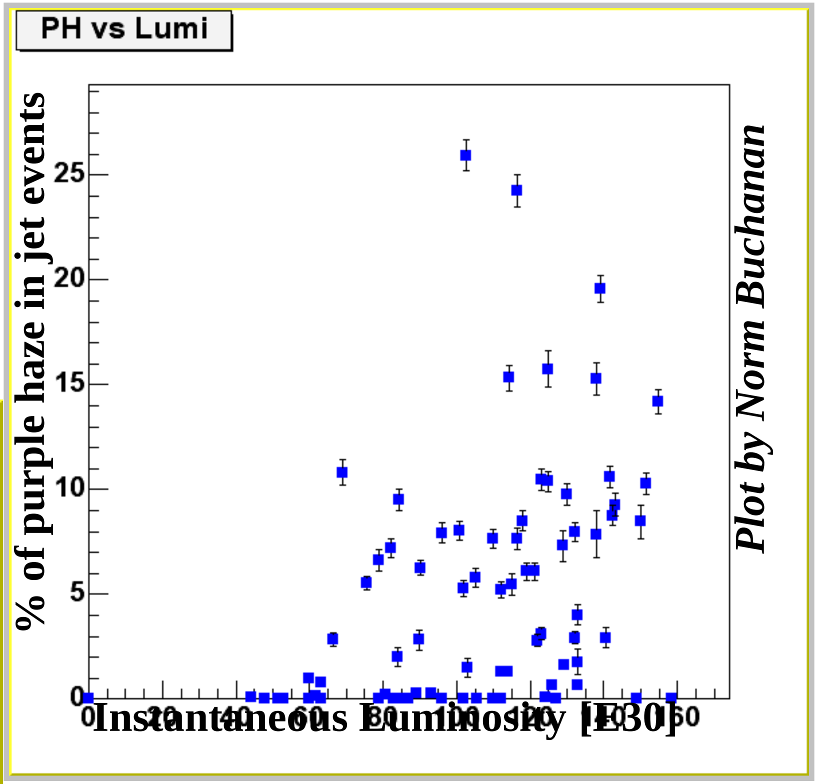
Muon clock noise

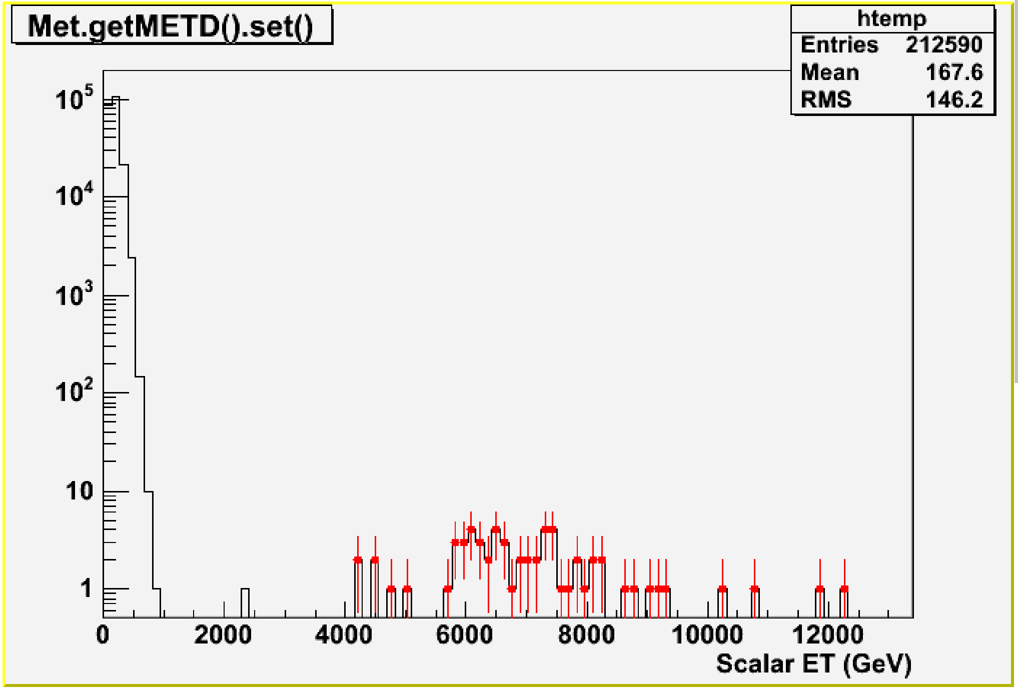
- In run 2 the Muon system started using a readout clock on their chambers located millimeters from the Calorimeter preamp crates. They choose a readout frequency which was synchronized to the accelerator RF, but not to the locations of the 36 bunches. Once we identified this as the source of the noise, they adjusted their clock to be synchronized to the 36 bunch locations. This allowed the Calorimeter correlated double sample to measure their noise pickup every 396 nS and subtract it from the Calorimeter signal. Only when there was a failure in the muon electronics synchronization to the machine clock was their noise evident. If synchronization was not re-established, the muon electronics effected by the failure was powered down until it could be repaired.

Purple Haze

What do we know about it?

- appears when lumi. > 70E30
- asymmetric in ϕ (no obvious boundaries)
- also present in L1CAL Trigger
- Only seen in CC channels
- apparently worse for 1st bunch in superbunch
- comes in bursts (maybe 50 events in an hour)

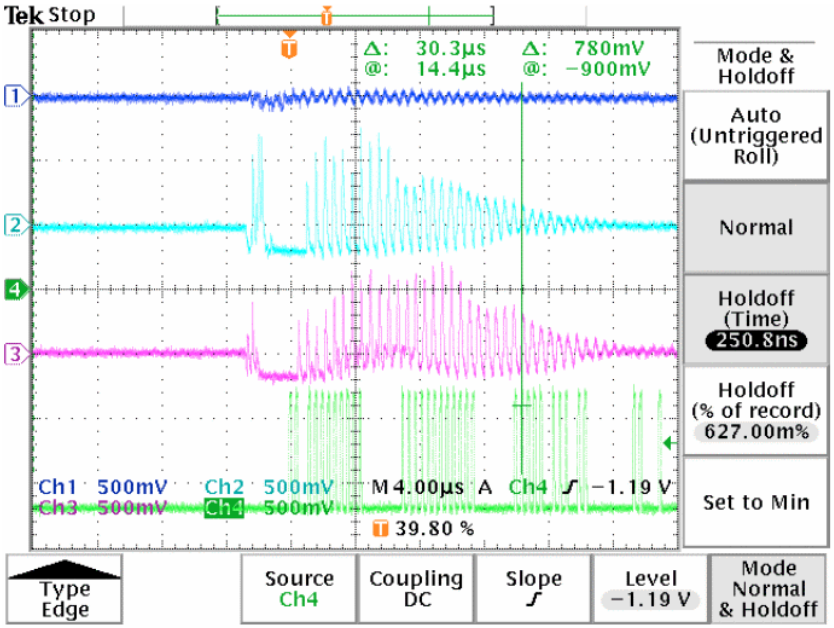




Disappeared over the spring 2006 shutdown for the Run IIb Upgrade.

Purple Haze

- Reappeared in the fall of 2008
- Use updated Cal trigger to identify in real time when the noise happened
- Recorded scope pictures of trigger signals
- Lasts about 20-40 uSec
- Starts with negative signal



Purple Haze

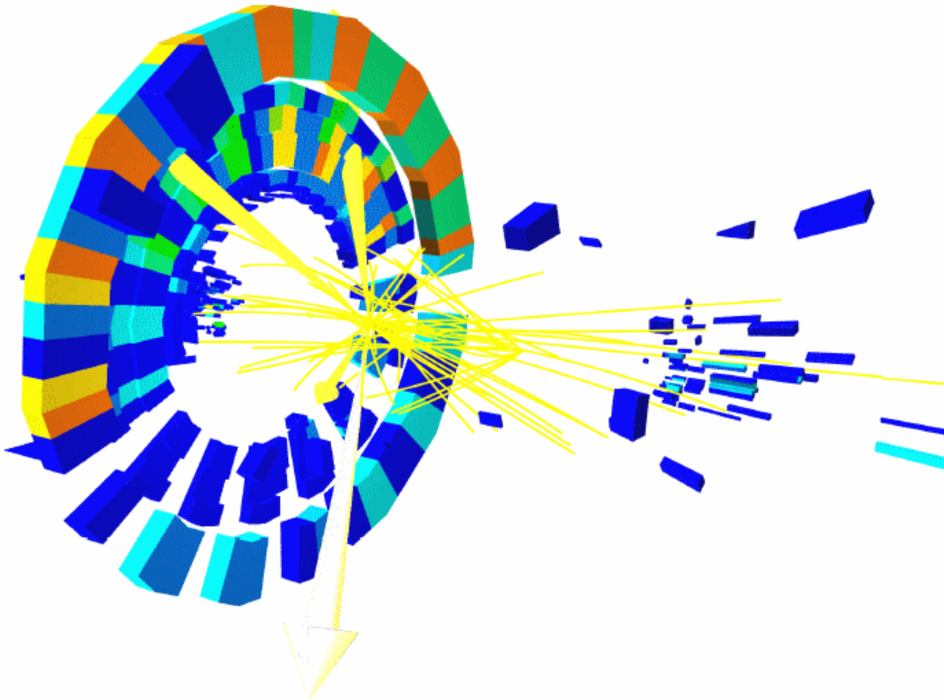
- Isolated to a single HV Supply
- Further isolated to a single feedthru entering the cryostat
- Since the CC EM modules have two HV connections, we can run that set of plates from only one end
- Disconnected until summer of 2009 summer shutdown when more tests were made
- Used TDR to locate the location of the break
  - Inside the cryostat
  - approximately 1.5 feet sooner than the other HV connections to that module
  - Approximately at the location of a crimped pin used to make the final connection between the HV wire connected to the feedthru and the internal wiring for the module

Purple Haze (cont)

- We applied HV to the working end of the module, and measured the voltage on the open end, with a 100 K resistor to ground. Between 100 and 200 Volts on the working end, a small voltage was seen across the resistor.
- A crude estimate of the gap in the connection is ~6 microns or less.
- Because the gap is very small and we apparently “fixed” the break during the 2006 shutdown, we attempted to repair the connection but applying voltage in the opposite direction to reconnect the break.
- After about 12 hours the break disappeared as confirmed by TDR measurements. Unfortunately about 2 weeks later the gap opened up again.

Spanish Fan noise

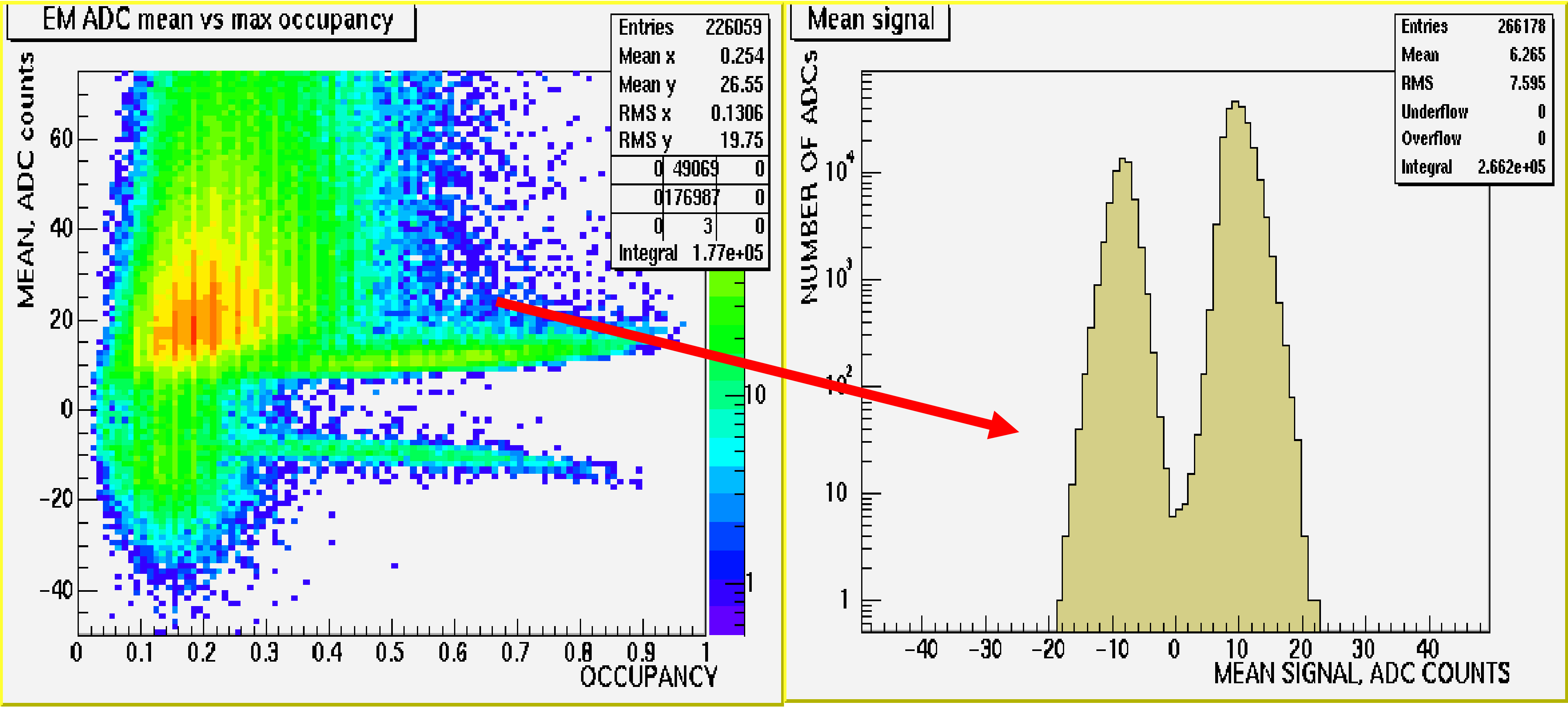
- Seen in CC channels closest to the ends of the cryostat (north or south), all layers.
- Disappeared when Purple haze noise fixed.
- Might be the very early stages of the Purple haze effect.



Run 2 Coherent Noise

- What we know
  - Generated internal to the Calorimeter readout system
  - Approximately +/- 0 to 1 millivolt offset added to all channels in a given BLS crate
  - Proportional to the L2 accept rate
    - Associated with triggers occurring while a previous trigger is being digitized
  - Effects (pairs) of ADC cards (usually more than one set)
  - On average (not including trigger bias) effects 5×10^{-5} times the L2 accept rate in Hertz (typically about 2.5% at 500 Hz)
  - Seen in the test stand but cause not identified

Run 2 Coherent Noise

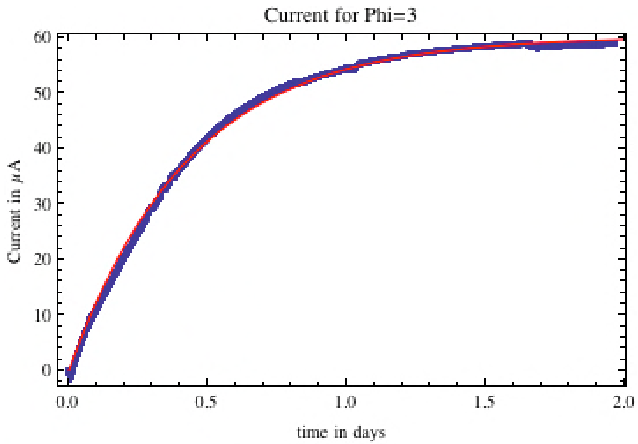


Anomalous Currents

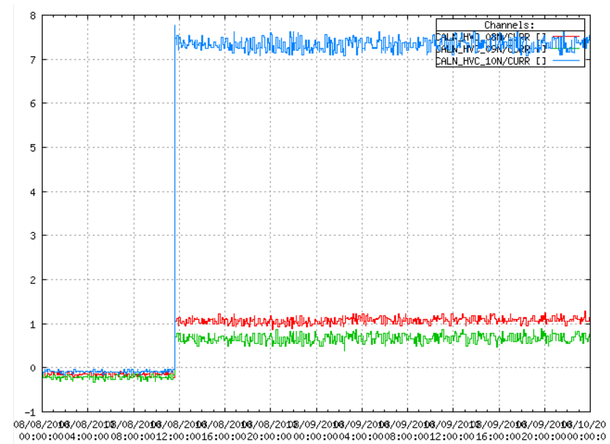
- What information do we have
  - Lots: too much show it all
- What effect does it have on data
  - Systematic change in the detector response
- Can we explain what we see?
  - With some hand waving arguments agreement with many of the observed effects can be explained

Turn on Current

- The current draw in the CC is very different from the EC
- The CC (upper plot) takes ~2 days to reach equilibrium current while the EC (lower plot) is less than 5 minutes
- Note the very good exponential fit to the CC data



CC current draw. Red curve is fit $60.3\left(1-e^{-2.32t}\right)$



EC current. The plot covers 2 days and the current goes to full scale in one 5 minute sample period

EC-CC difference

- Most likely difference between the EC and CC is in the Uranium plates

- The EC had the UO2 removed with a high pressure water jet before assembly while nothing was done to the CC plates

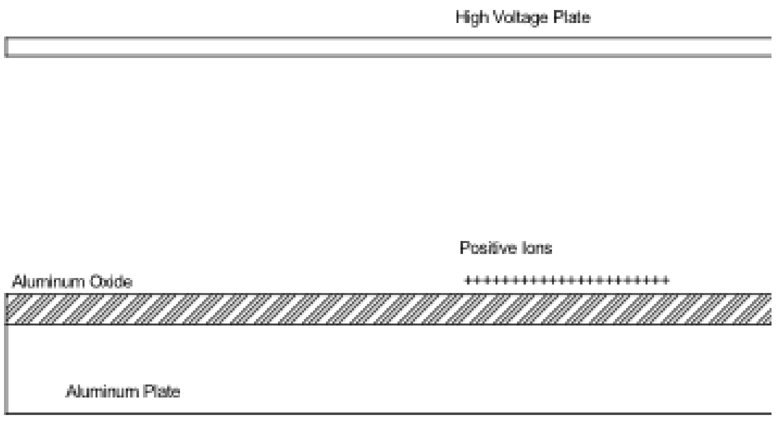
- The readout plates were processed in the same manner for both detectors

  - Shape is different (long-thin in CC, more square in EC)

- The UO2 coating can explain the unusual CC behavior

Malter Process

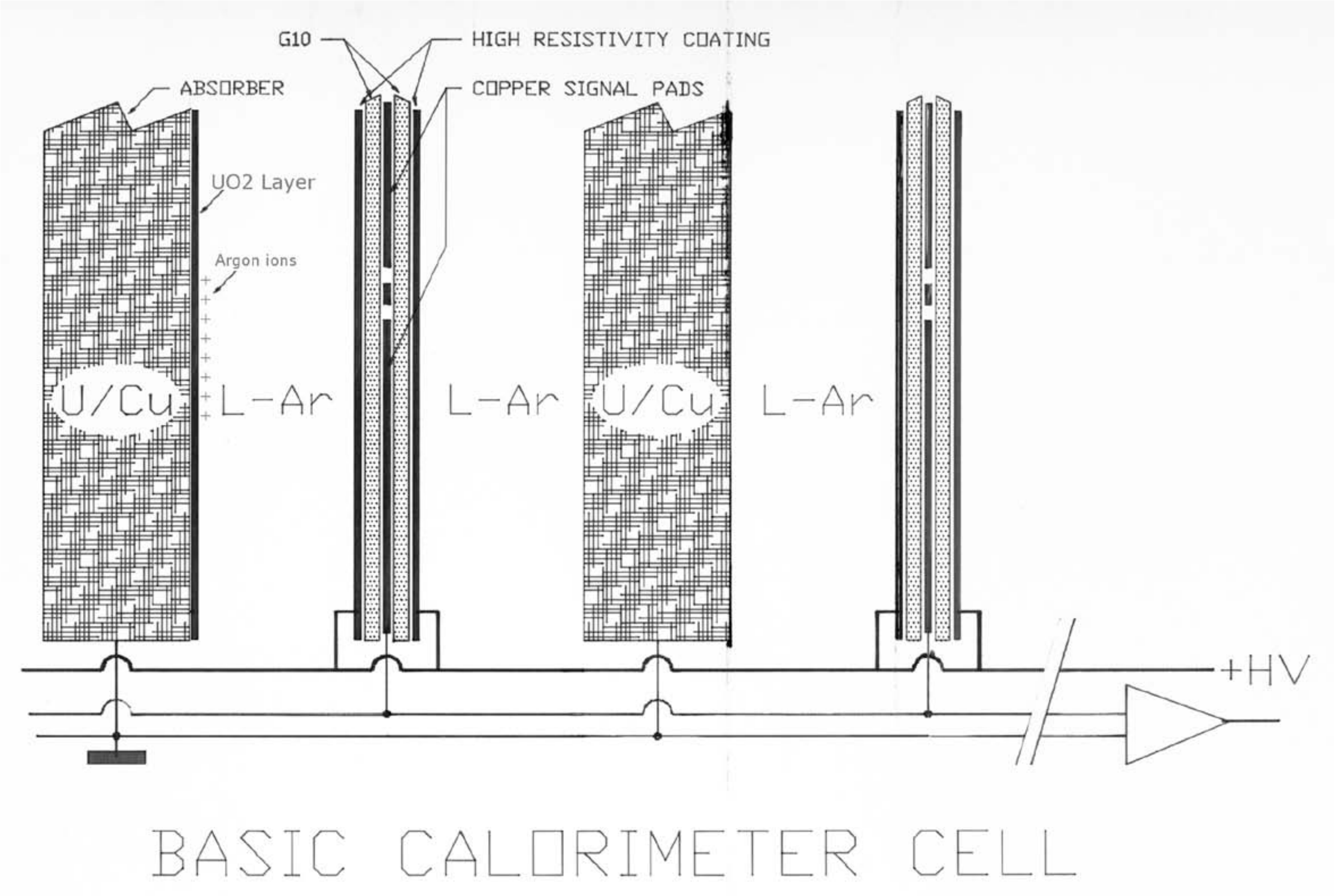
- ions accumulate on oxide layer
- field extracts electrons from base metal increasing current
- oxide eventually breaks down and discharges surface



L. Malter, Thin Film Field Emission, Phys. Rev. **50**, 48 (1936)

A Güntherschulze, Die Elektronengeschwindigkeit in Isolatoren bie hohen Ferldstärken und ihre Beiziehung zur Theorie des elektrischen Durchschlages, Zietschr. F. Physik **86**, 778 (1933)

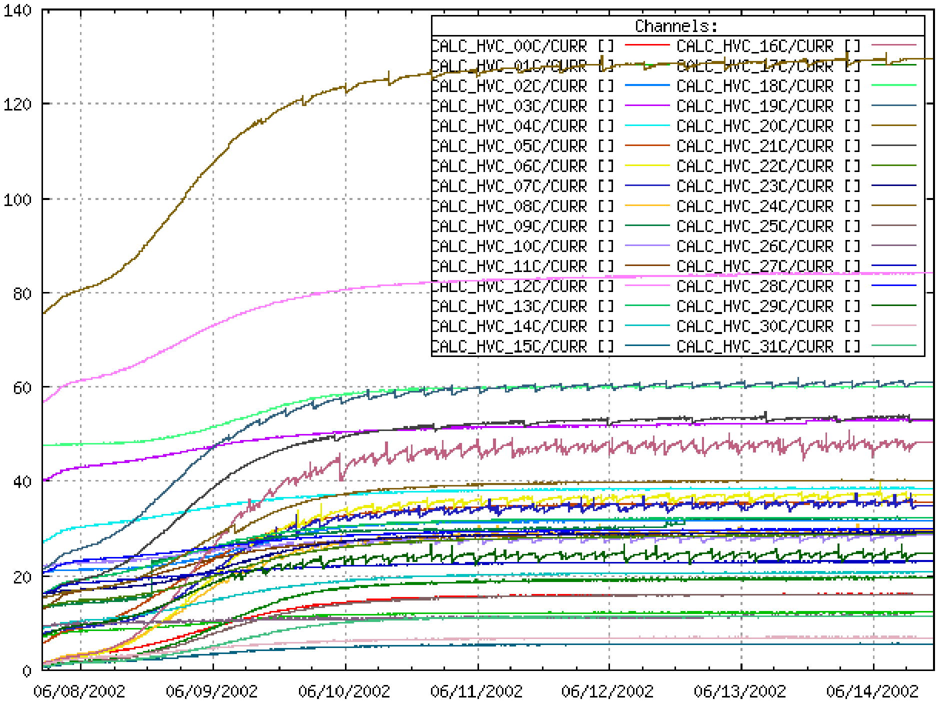
DØ readout Cell

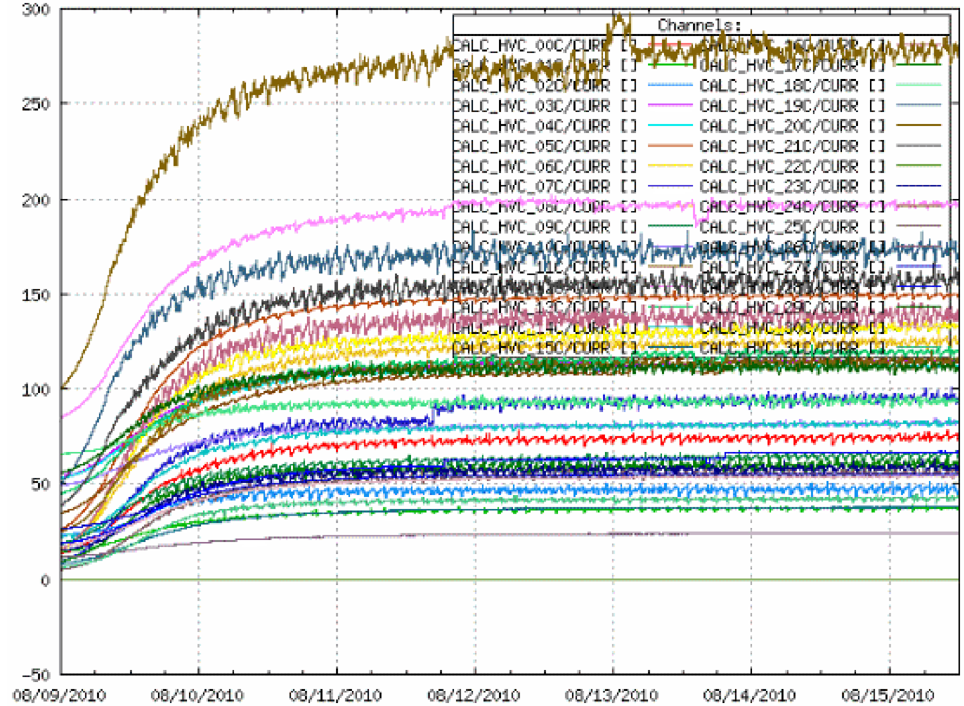


HV Current Monitoring

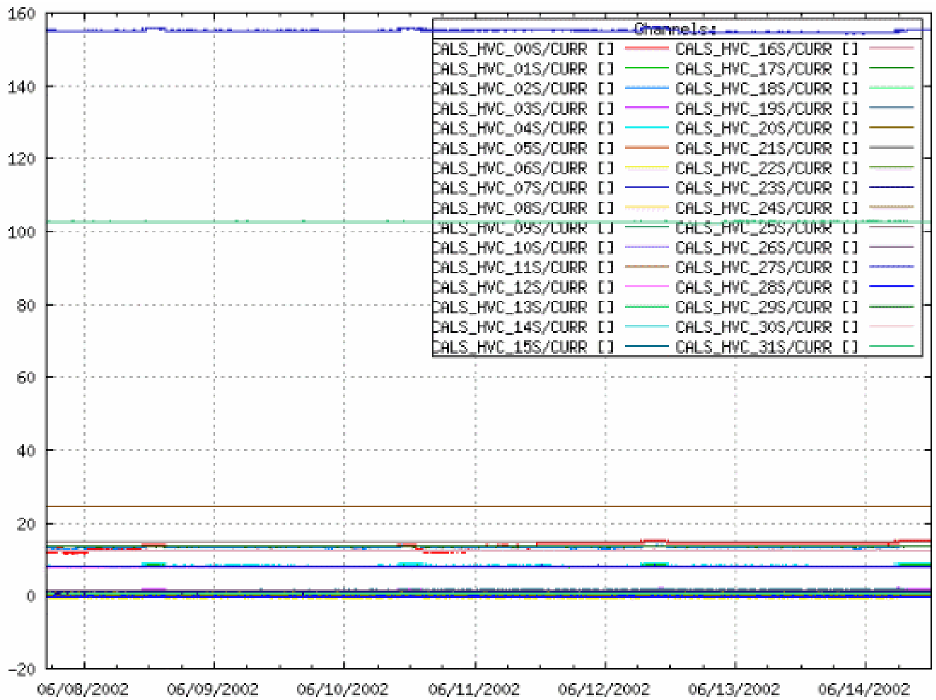
- Both Test Beam and Run I HV current monitoring data is no longer available
- Starting in about 2002 “5 minute” HV currents sampling on the 32 CC HV supplies is available
- Occasionally in 2010-2012 high sampling rate data (> 1Hz) was taken for more detailed studies
- In the fall of 2008 one HV supply was split into the 16 individual wires to “fix” the Purple haze noise. This allows use to study the current drawn from both ends of the same HV gang

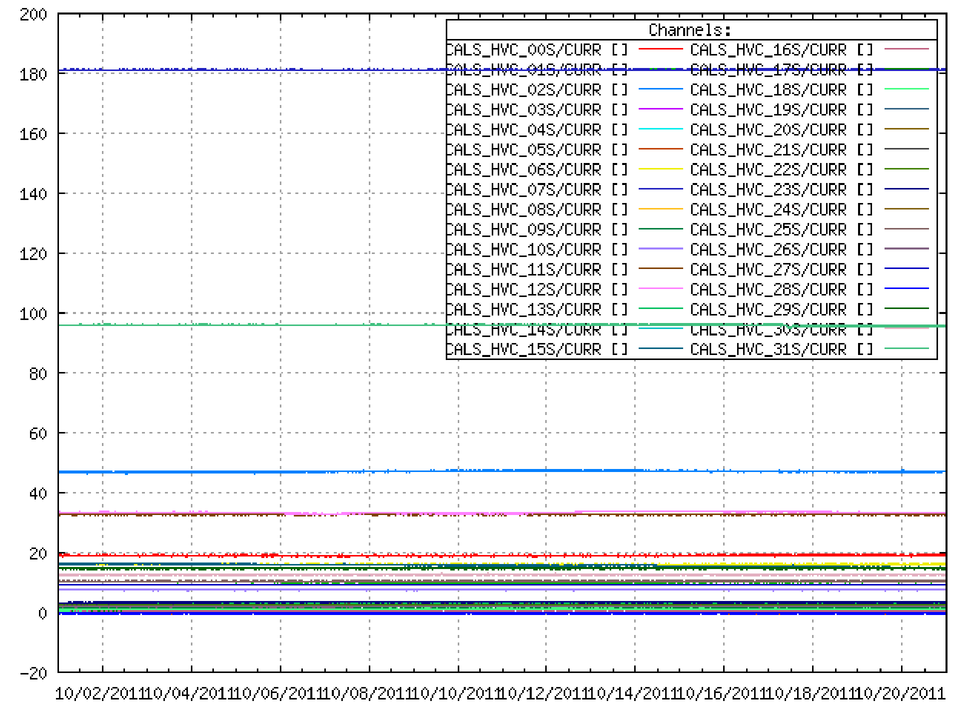
CC Currents – no beam



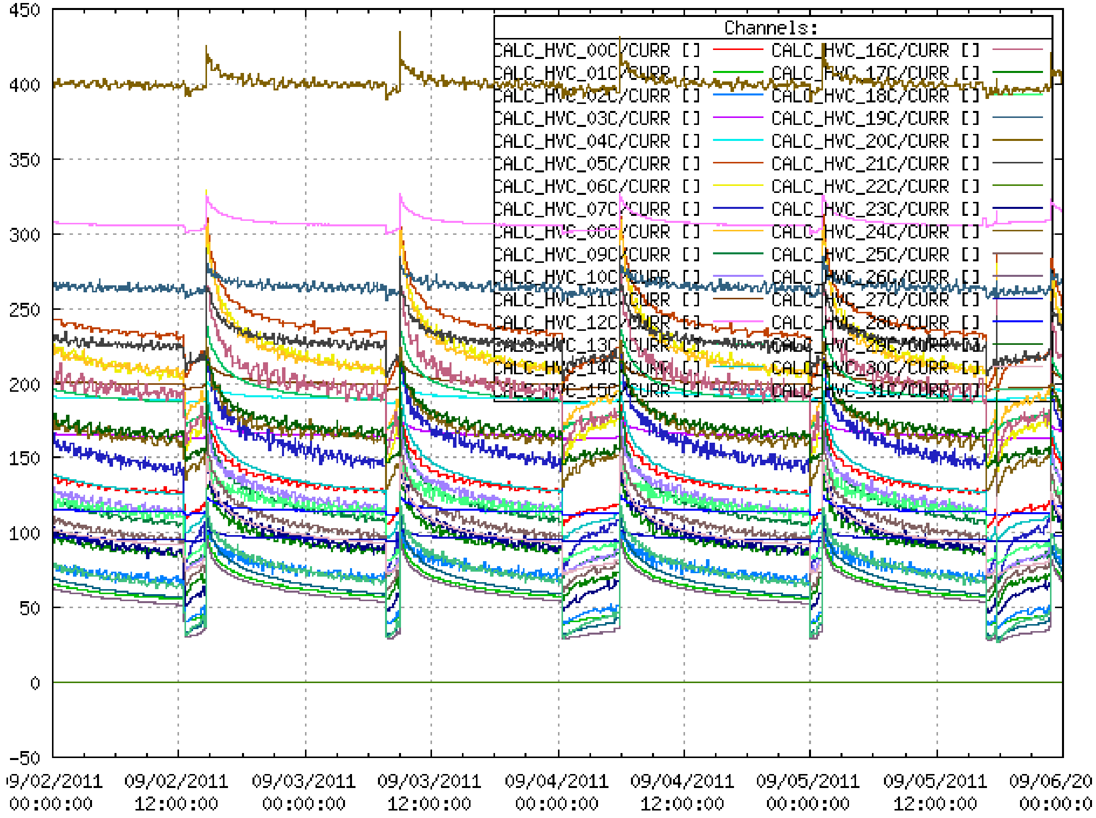


ECS Currents – no beam

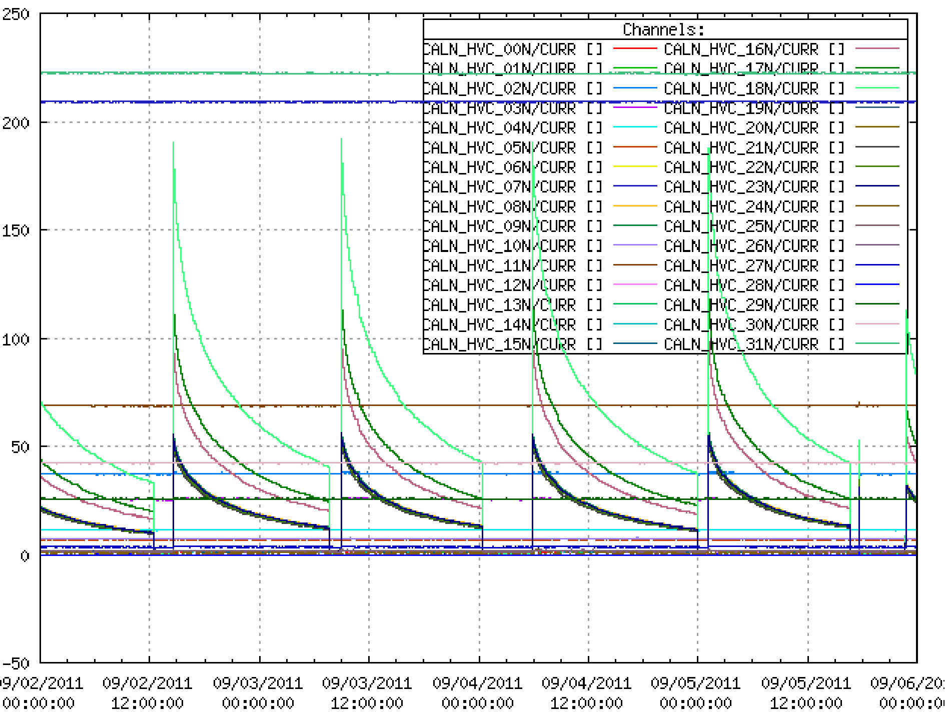


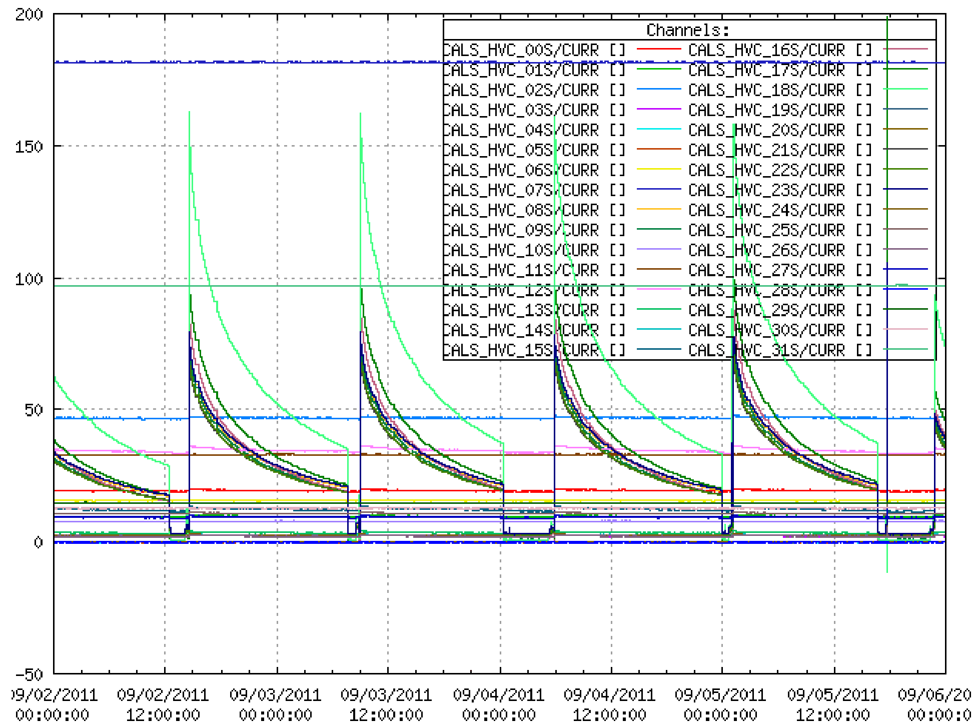


CC current – with beam



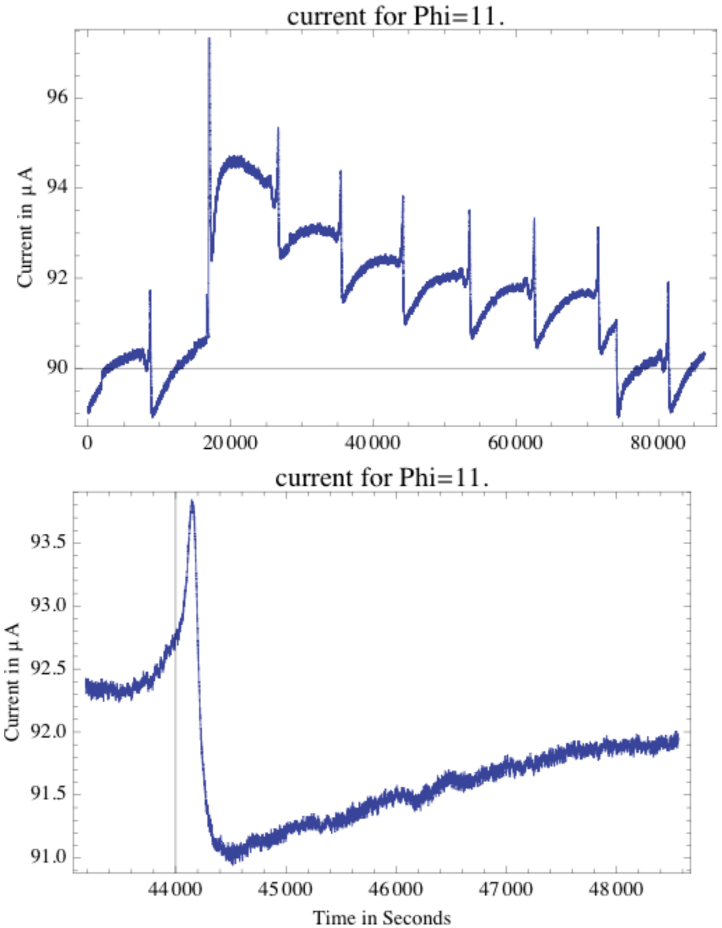
EC currents – with beam





Malter Breakdown

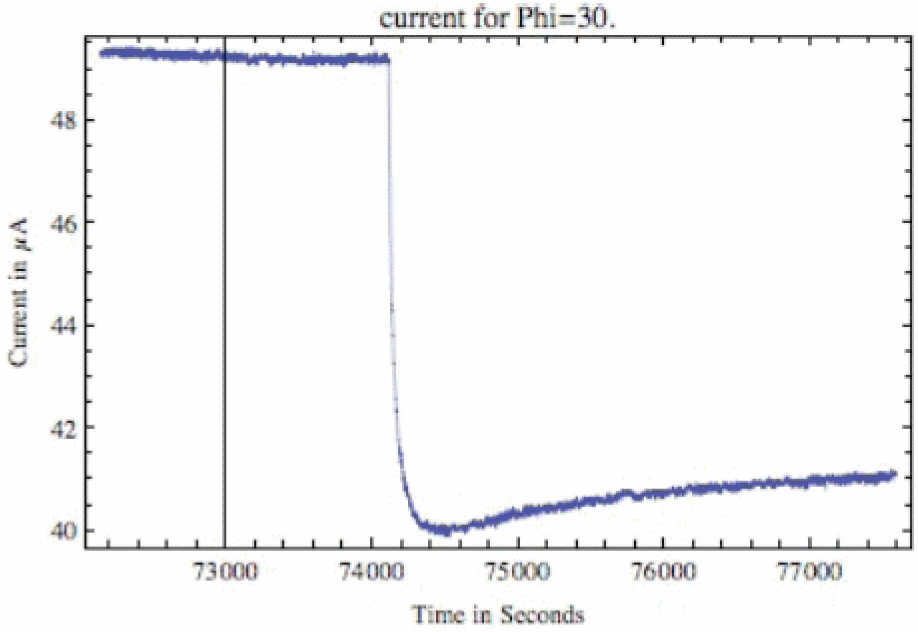
- Lower fig. shows breakdown detail
- FWHM of peak is ~200 s
- Downward slope time is ~70 sec
- RC time constant of HV supply is <10 sec
  - Not a supply affect
- Neutralizing surface charge takes longer than bringing the charge through the oxide
  - Small E field in transverse direction so charge movement is very slow

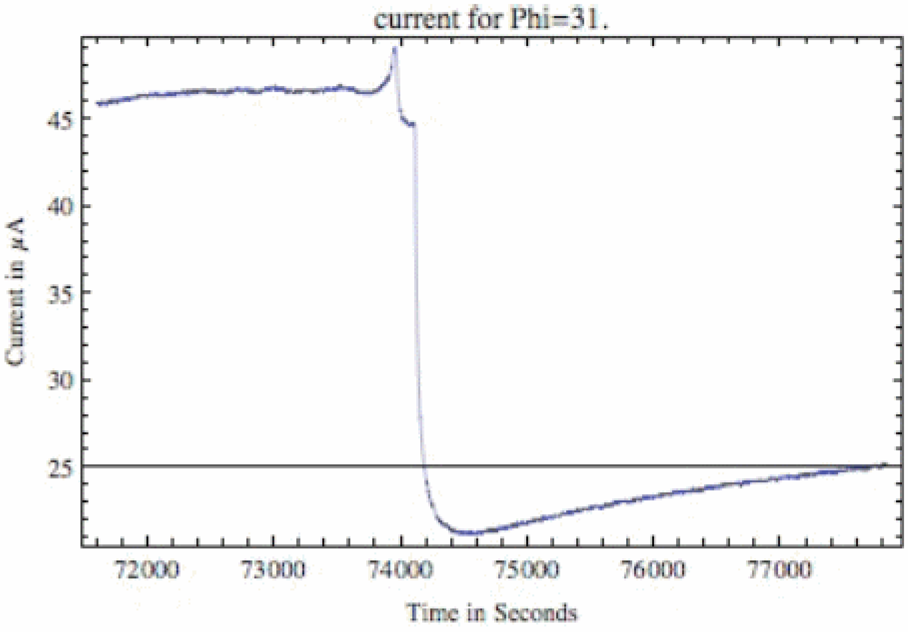


Change with Time

- Six channels had oscillations in 2002
- 22 had oscillations in 2011
- Channels in 2002 had one or two frequencies
- Almost all channels in 2011 have multiple frequencies

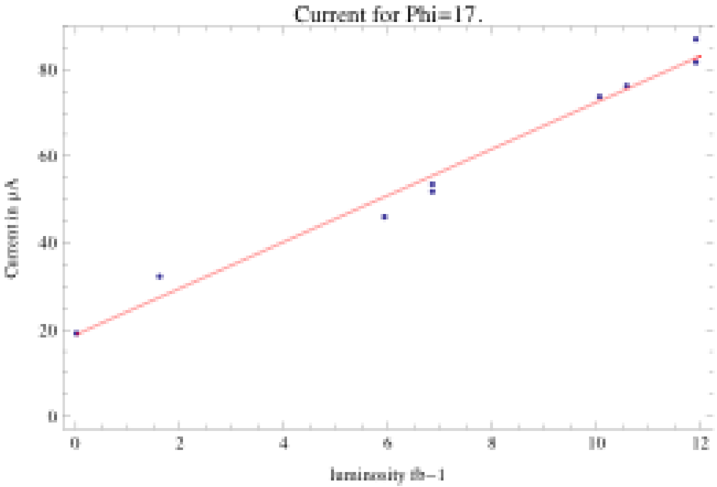
End of store Current drop

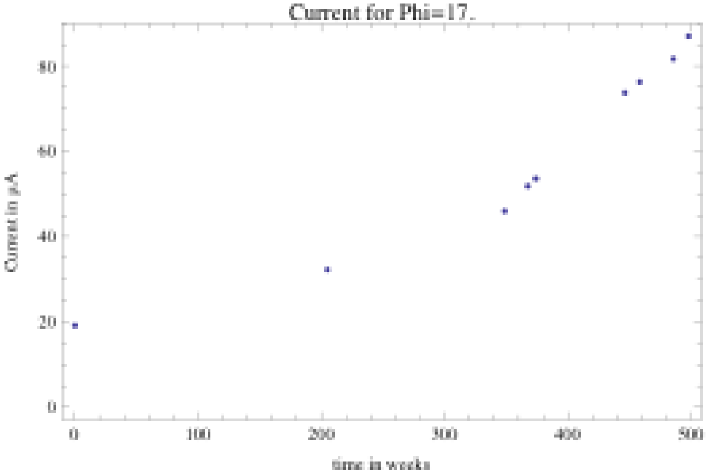




Current vs Luminosity

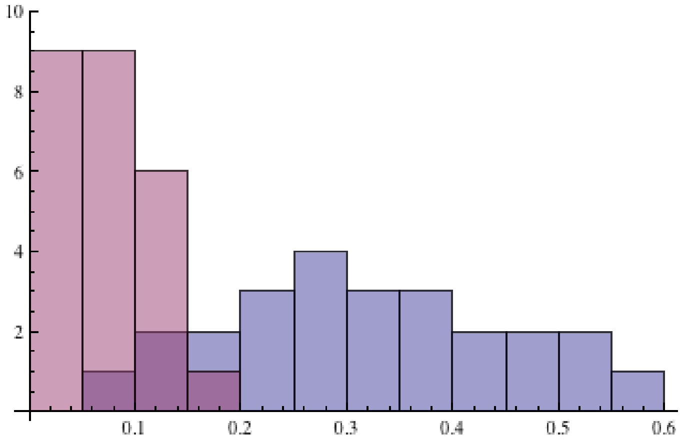
- Current increase is proportional to delivered luminosity (upper plot)
- All channels have a similar behavior
- Clearly not linear in time (lower plot)





Beam On/Beam Off Slope

- Slope (increase in current/week) is much larger during shutdowns than during beam.
- Plot on right is the slope between two shutdowns and the average of the two slopes during the two shutdowns
- No measurable change in currents when HV is off.



Blue: Average no beam slope in µA/week

Pink: Slope during beam on in µA/Week

Slower Current Increase with Beam

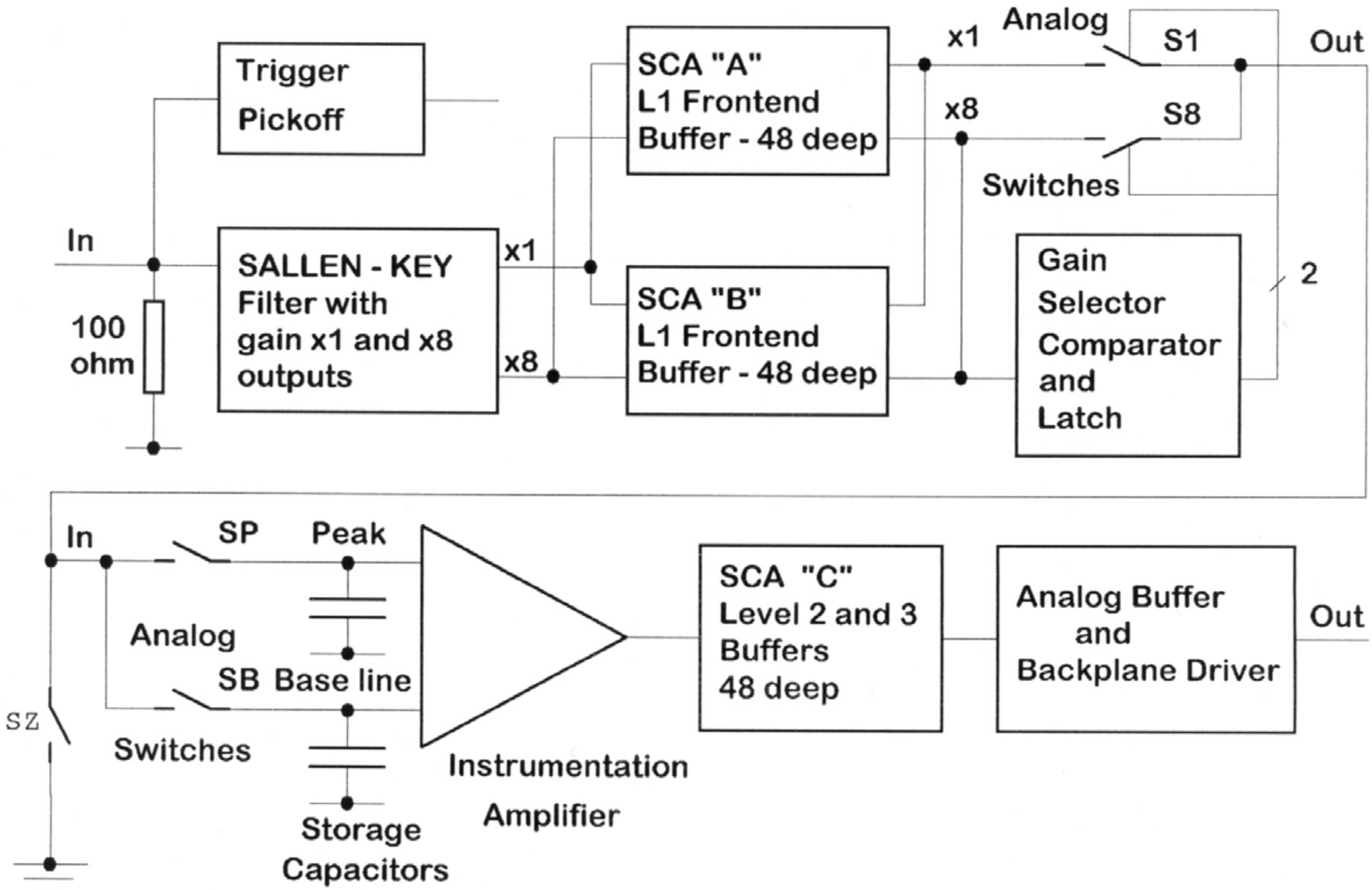
- This is just due to the radiation damage in the UO2 semiconductor.
  - Similar to silicon
  - Generate deep acceptor sites which trap electrons and thus increase the effective resistivity

Anomalous Currents Summary/Conclusions

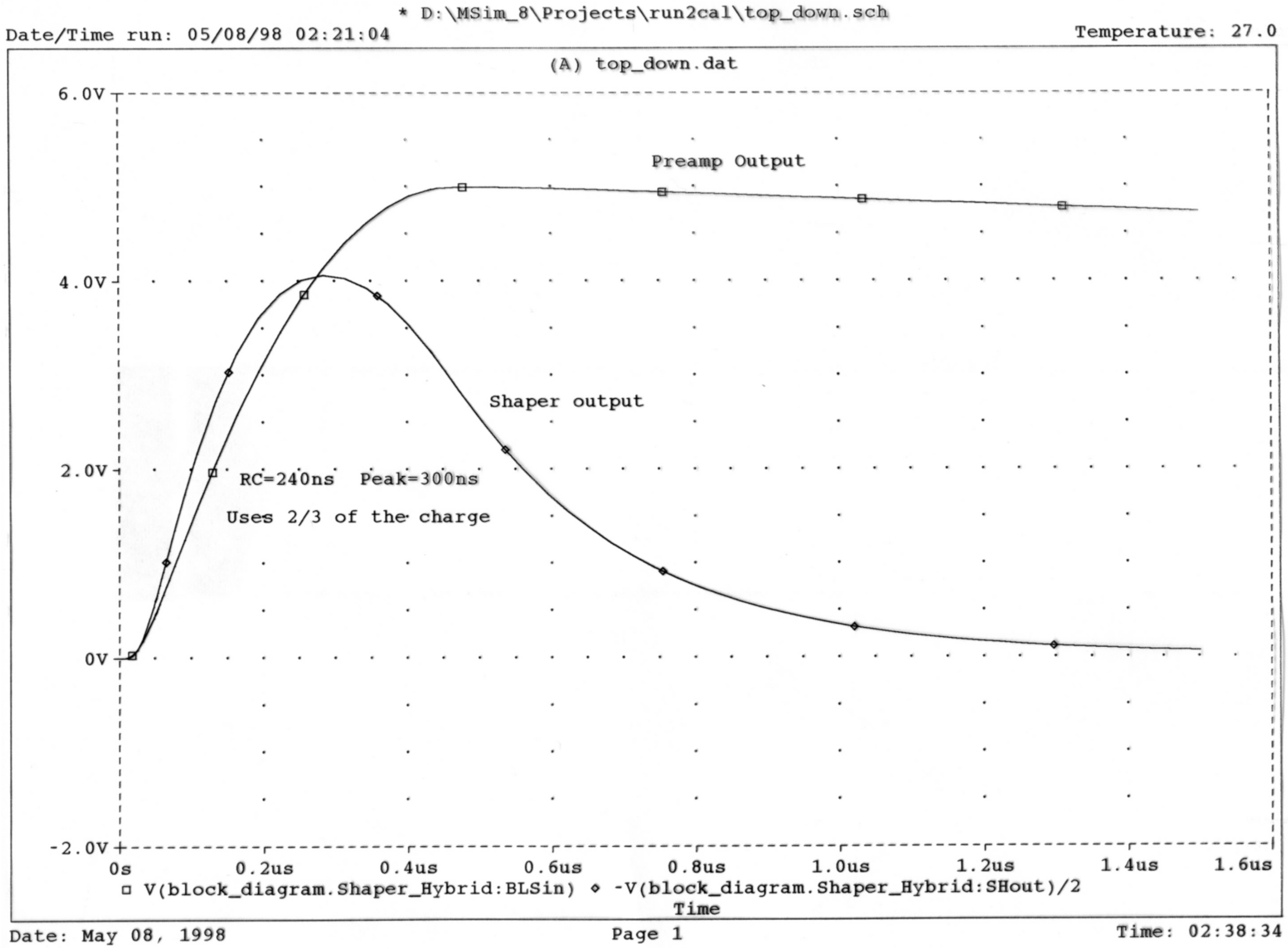
- Two types of Malter current effects:
  - Continuous
  - Breakdown
- Most of the CC Cal currents are likely caused by UO2 left on the surface of the plates.
- Beam slows down the rate of increase.
- Increase only occurs when HV is on.
- HV sag after 10 fb^{-1} of running is significant (even at low luminosity).

Supplemental

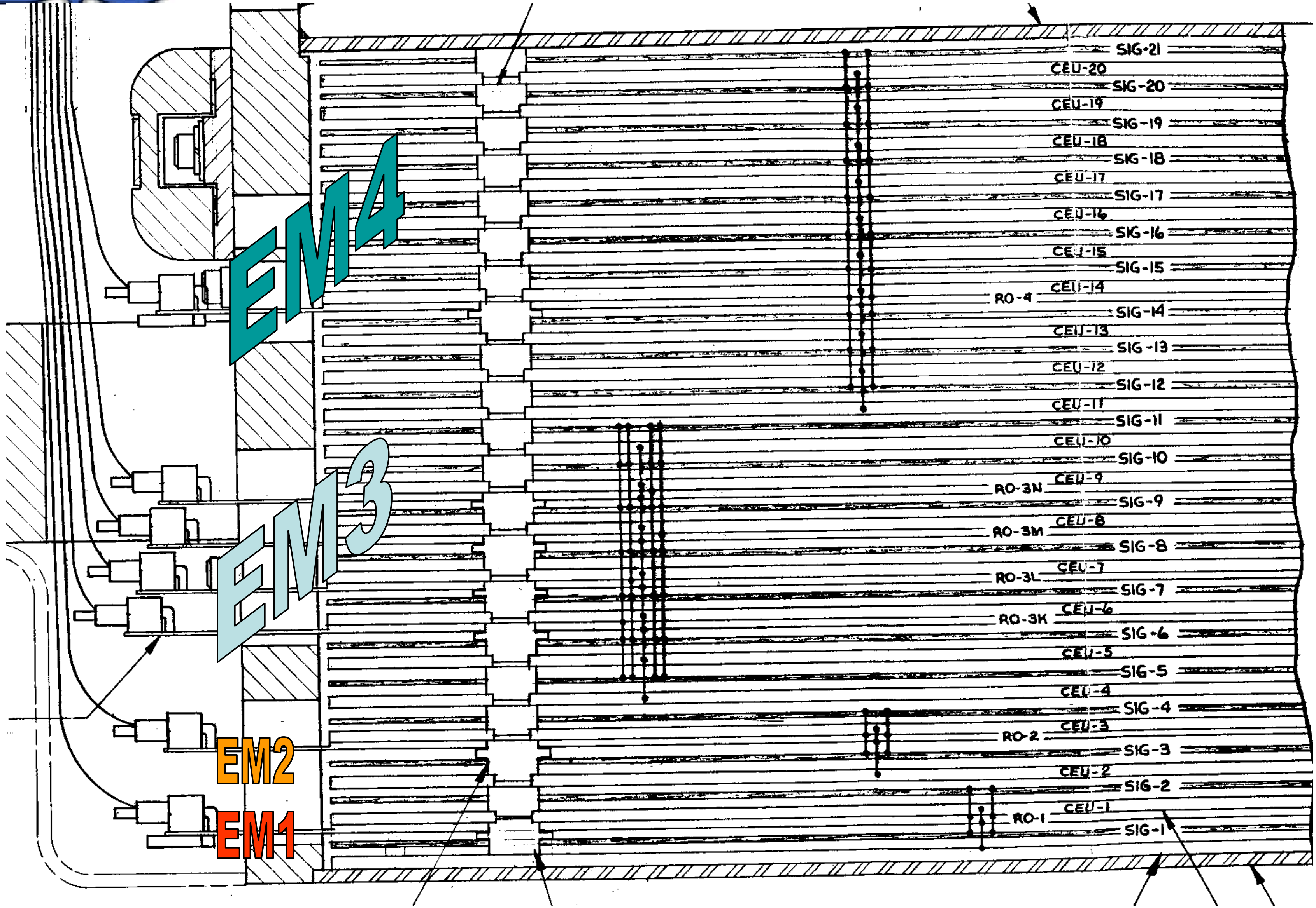
Run 2 BLS details



Run 2 signal shaping



Side view of CC EM Module



Resistance Measurements

Measurements (plot) are for ten surfaces in parallel

Table lists the single surface Resistance

Expected ~0.4 from the Nim Article description

Now understand we should have expected ~1.5 +/- 25%

Resistance essentially unchanged from when we built the detector

Table II

Supply	Resistance (G Ohms)	Deviation from Mean
LAR7N	1.4	-0.4
LAR6N	1.9	0.1
LAR5N	1.8	0
LAR4N	2.1	0.3
Average	1.8	

Table II Resistance of individual resistive coat surfaces.

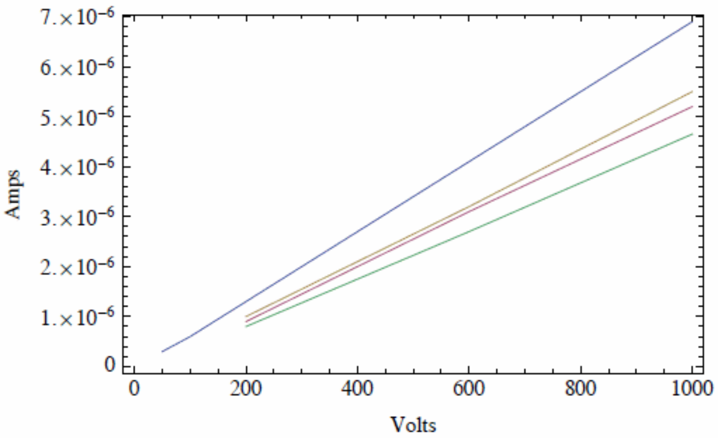
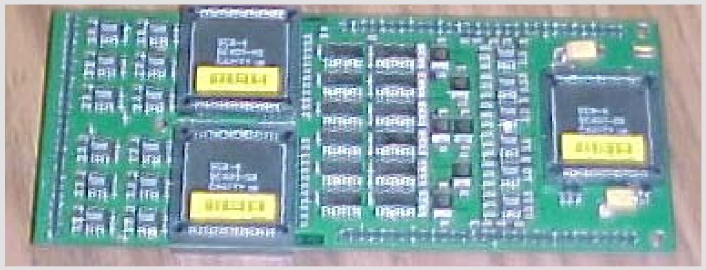


Fig. 13. Plot of current versus voltage for LAR7N (blue), LAR5N (brown), LAR6N (red) and LAR4N (green).

Hardware maintenance

- Typical failure rate near end of D0 running
  - about 2 component failures per week (up from a few years ago)
  - Usually effect 6-48 channels (out of 45K)
  - Fixed between stores – component replaced
  - Unless it is in the preamp subsystem which requires the muon iron open



L1cal Status

- All trigger towers currently enabled
  - About 5 towers have one cell removed from the trigger sum due to high noise.
- Occasional trigger rate spike
  - Disabled only when it effects the global busy
  - When it lasts long enough to find the tower it is excluded until it either goes quiet or we locate the noisy cell and remove it from the trigger sum (requires access)