Some results and data from January studies

(Caveat: it's raw unprocessed data)

John Carwardine

Primary Objectives

- Long-pulse high beam-loading (9mA) demonstration
  - **800μs pulse with 2400 bunches (3MHz)**
  - **3nC per bunch**
  - **Beam energy 700 MeV ≤ E_{beam} ≤ 1 GeV**
- Primary goals
  - **Demonstration of beam energy stability**
    - Over extended period
  - **Characterisation of energy stability limitations**
    - Operations close to gradient limits
  - **Quantification of control overhead**
    - Minimum required klystron overhead for LLRF control
  - **HOM absorber studies (cryo-load)**
  - **…**

Primarily a LLRF experiment

- Major challenge for FLASH !
  - **Pushes many current operational limits**
  - **Planning and preparation:**

January 9mA studies plans

- Main goals
  - **What can we learn about beam losses in the dump line?**
  - **LLRF studies: feed-forward, feedback gain studies**
  - **RF studies: cavity field stability for long pulses**
  - **Gradient studies: increase ACC456 to quench (or other limits)**

- Operating conditions
  - **Maximum charge per pulse: 30nC (nominal)**
  - **Try to get 3nC operation with 10 bunches, else 1nC with 30 bunches. Low rep rate (40kHz)**
  - **Long RF flat top (800us)**
  - **700MeV in 1st shift, increase ACC456 during 2nd shift**

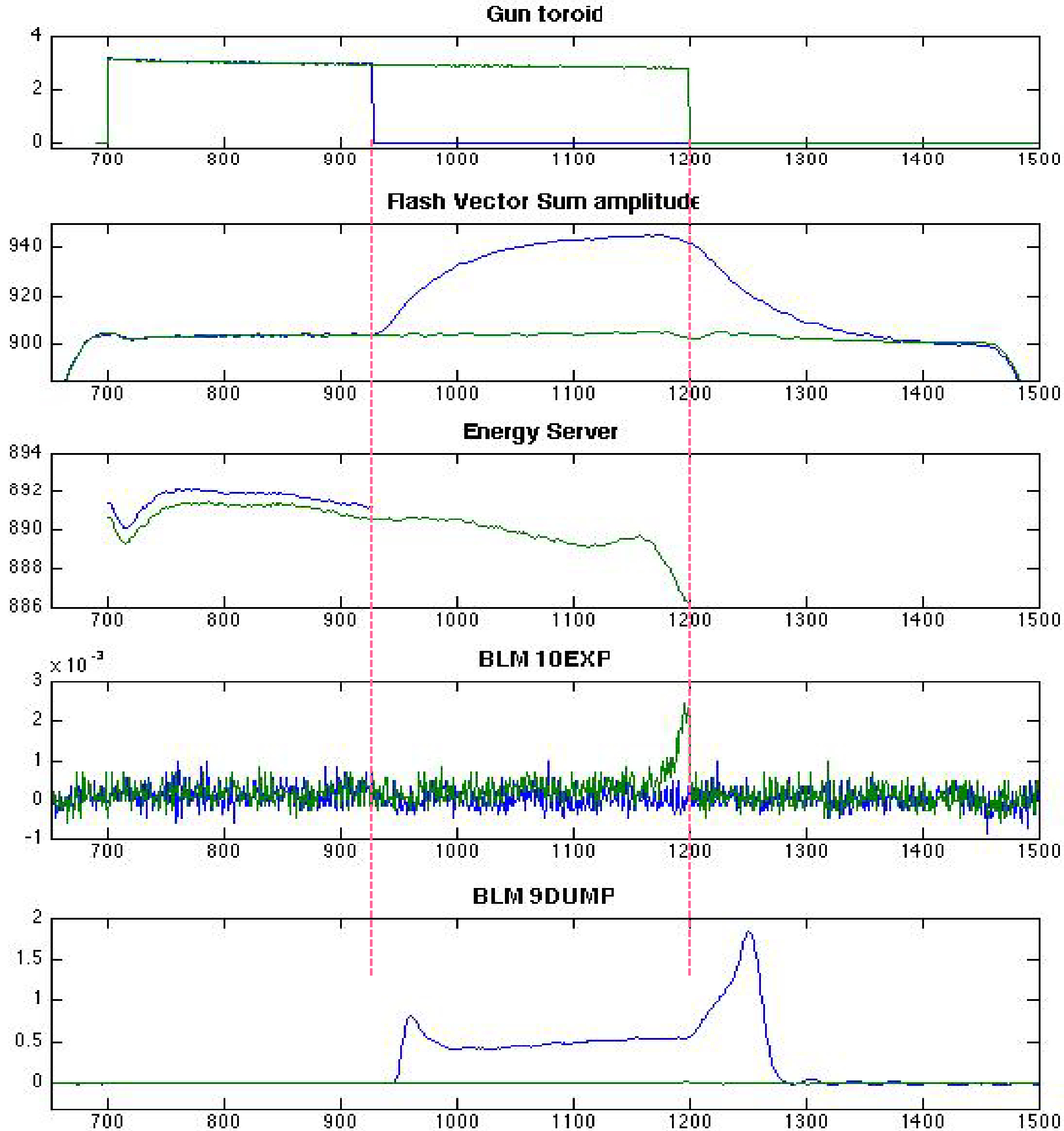
Beam loss studies

Characterize dump line beam losses, see if we can affect losses by changing correctors, quads,…

Measure energy and physical aperture.

Test response of new cerenkov blms,...

Correlation with BLMs for two consecutive pulses
(First: full 500 bunches; second: MPS inhibit after ~230 bunches)



Green traces: full 500 bunches
Blue traces: terminated early

VΣ rises when beam loading lost. Falls at end-point of adjustment to FF table for BL compensation

Energy droops at end of bunch train because BL compensation ends before bunch train

BLM signal rises as energy droops. (Energy aperture?)

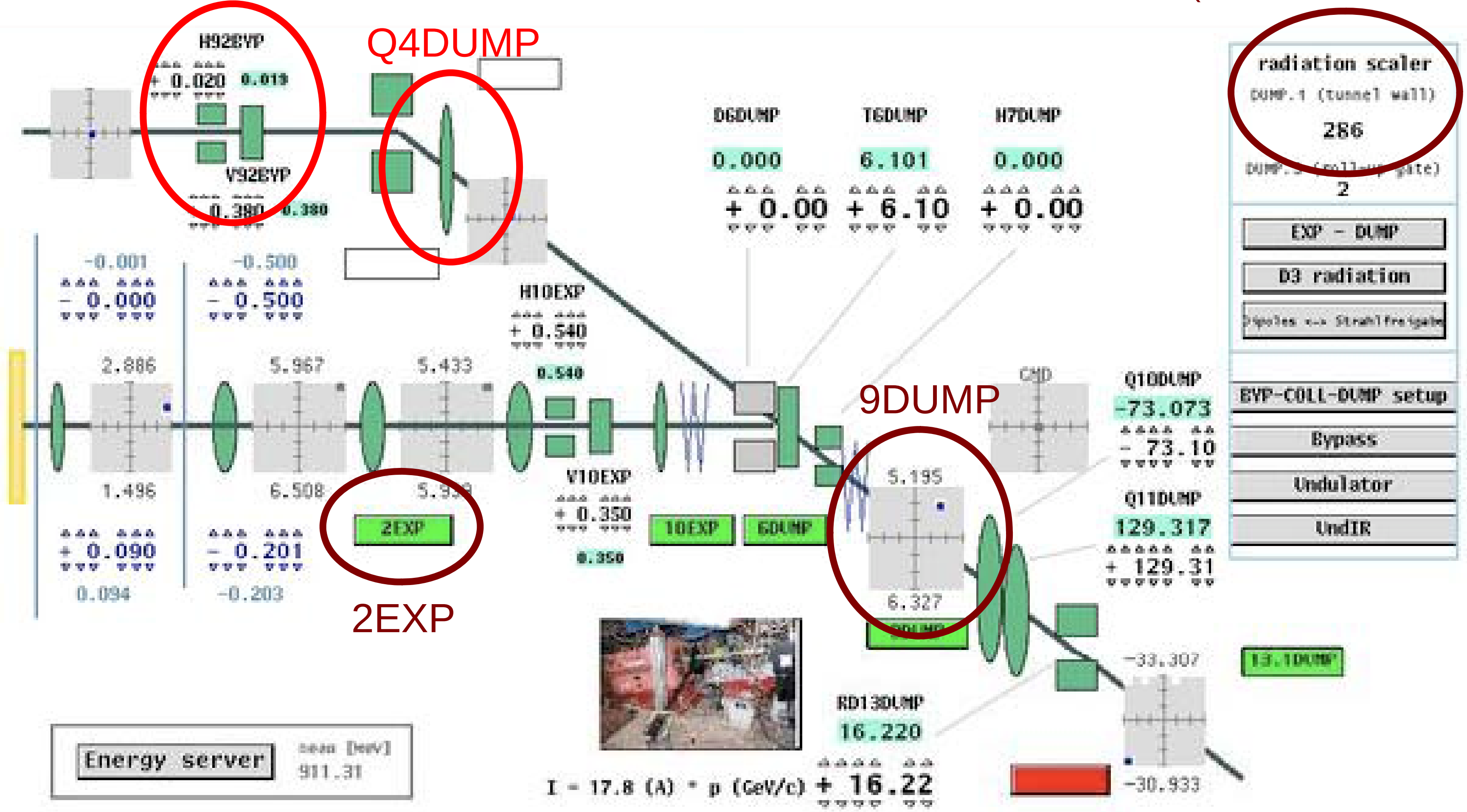
Large signal on terminated case, that starts after the bunch train terminates (dark current)

Actuators and monitors for beam loss studies

(30 bunches @ 50KHz)

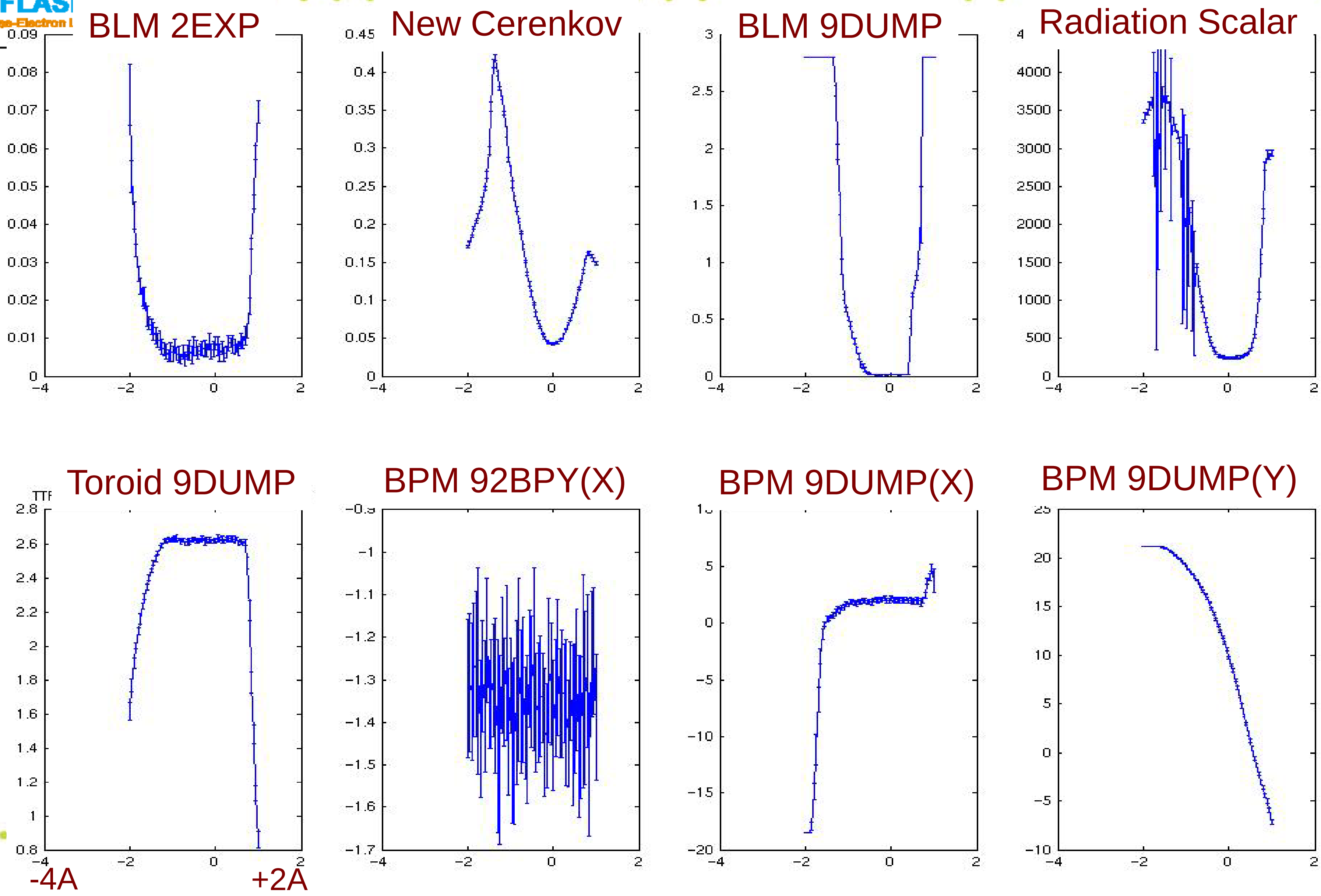
92BYP

Radiation Scalar
(located behind dump

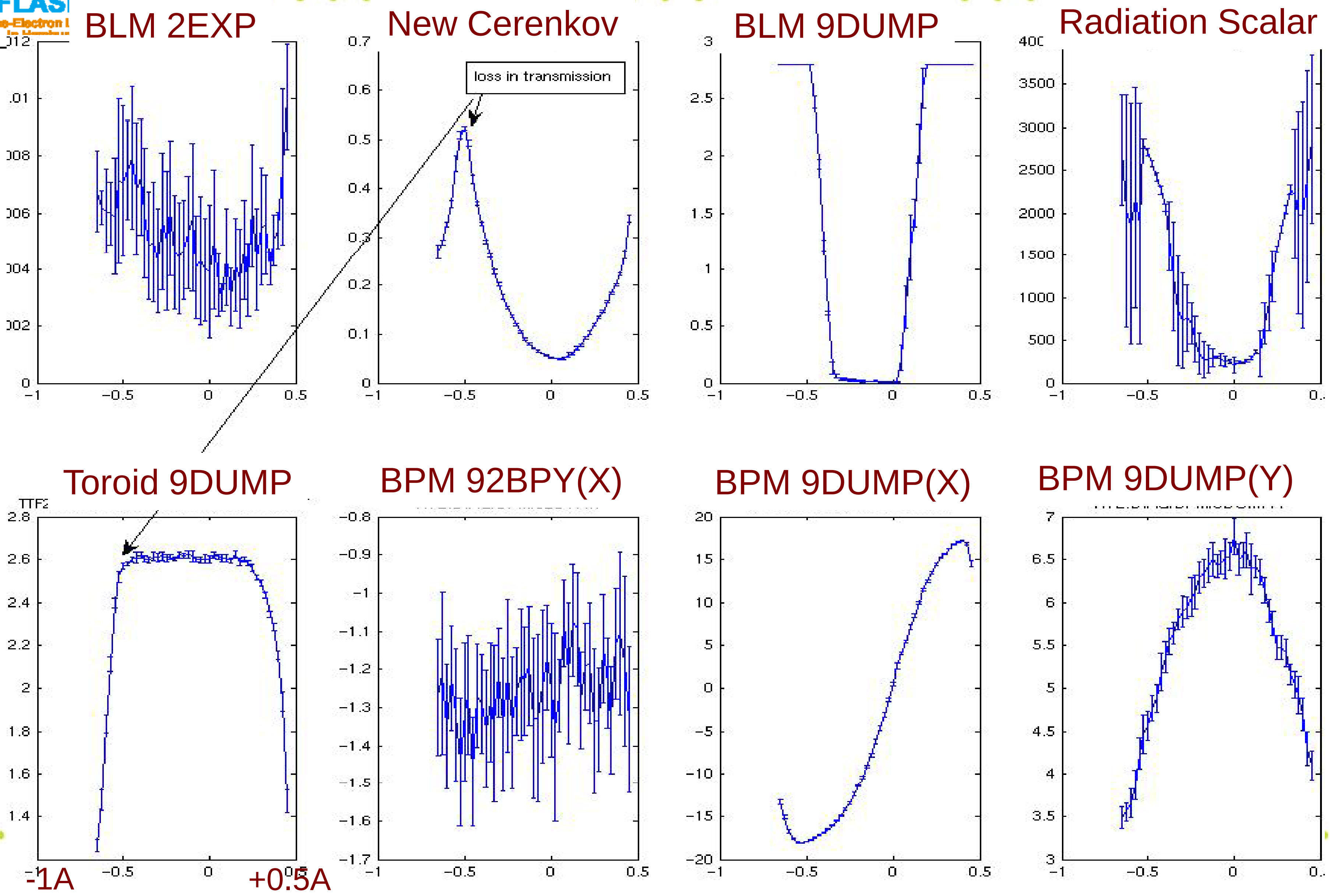


New Cerenkov fibers: along one side of the last section of dump line (2m long)

Scan of V92BPY corrector

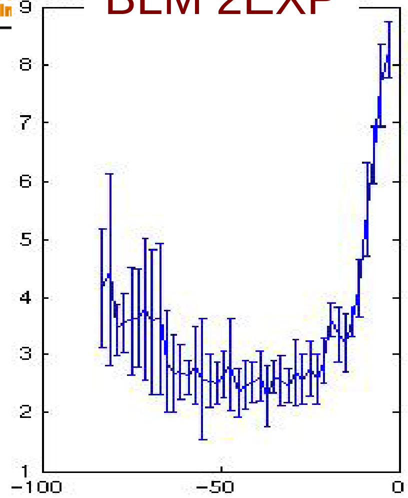


Scan of H92BPY corrector

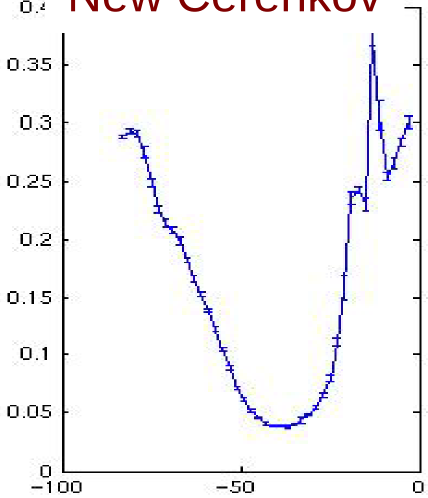


Scan of Q4DUMP

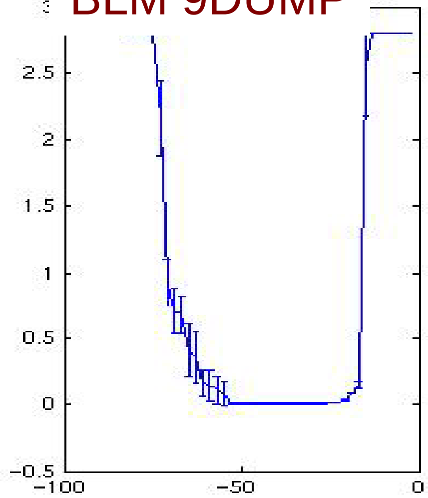
BLM 2EXP



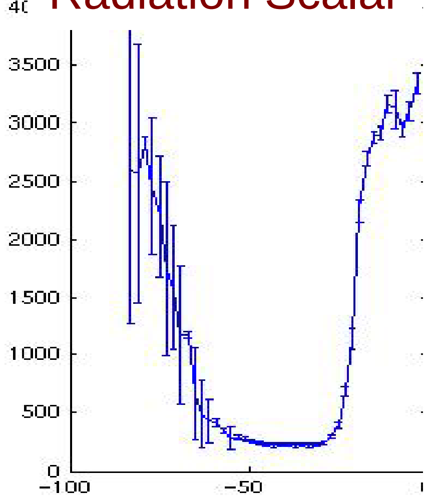
New Cerenkov



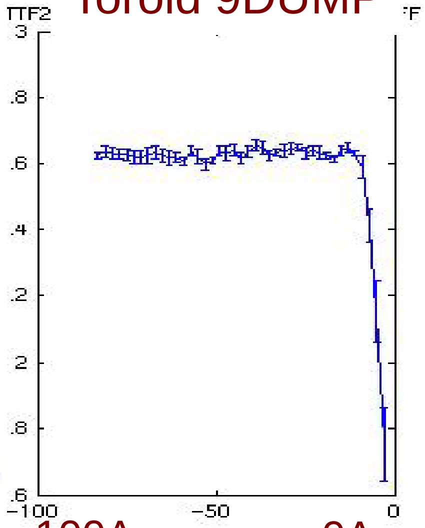
BLM 9DUMP



Radiation Scalar

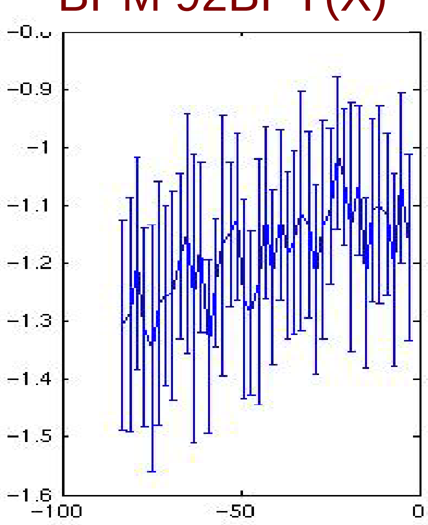


Toroid 9DUMP

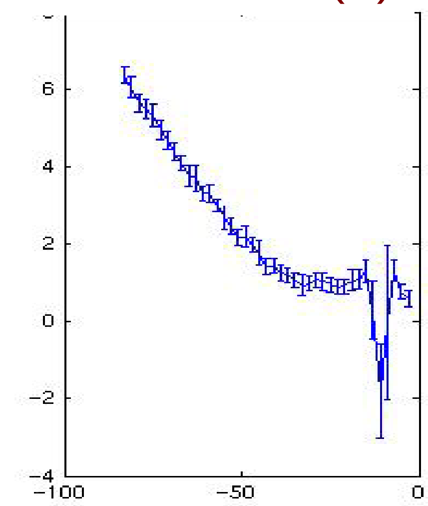


-100A 0A

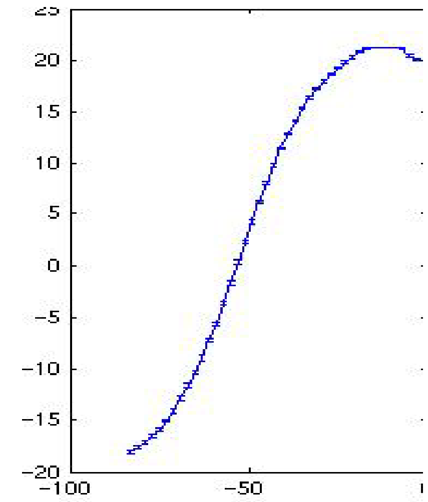
BPM 92BPY(X)



BPM 9DUMP(X)

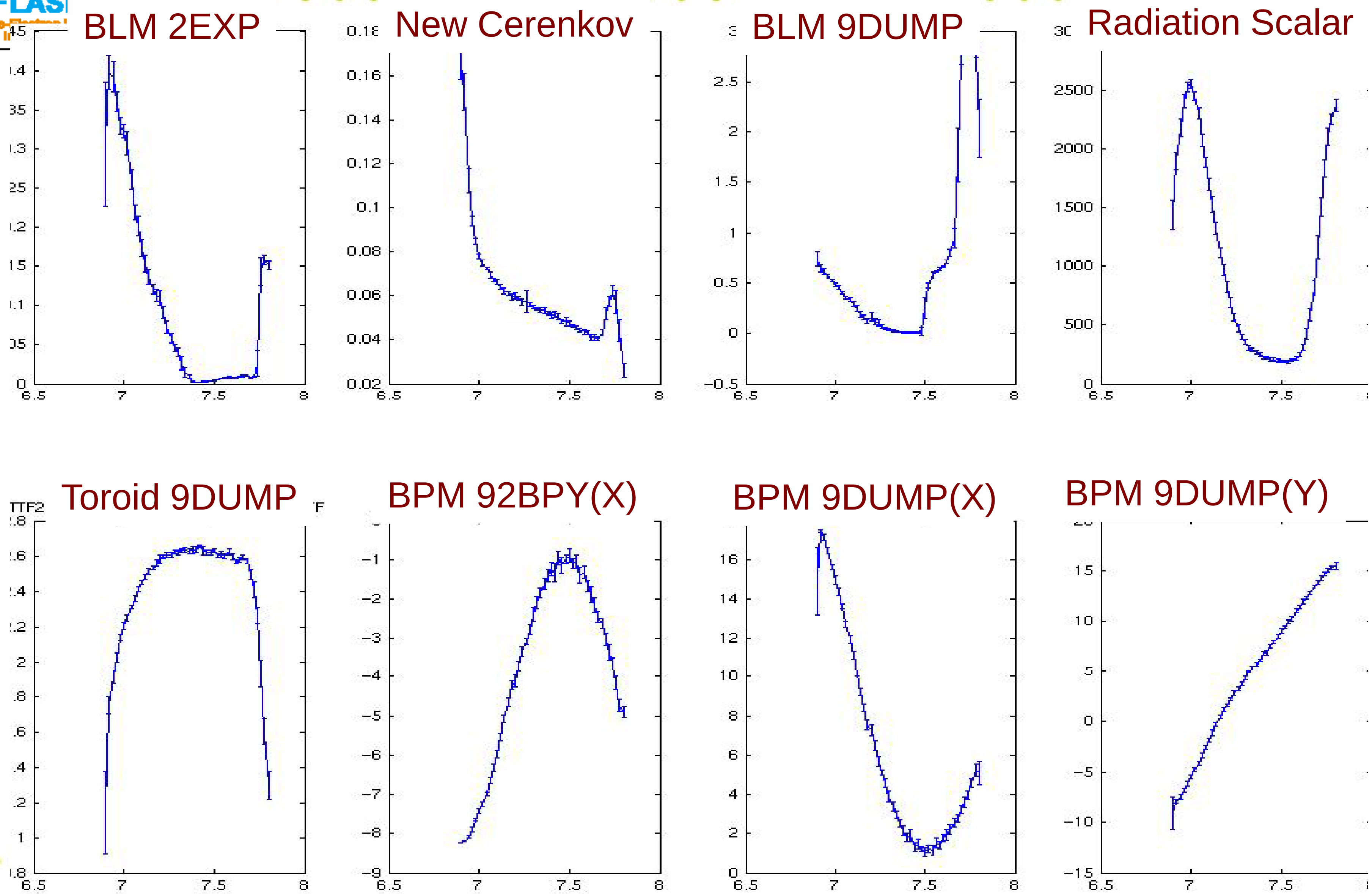


BPM 9DUMP(Y)



ACC456 Gradient Scan

(approx +/-15MeV out of 720MeV)



-30MeV +22MeV

ACC1: 128.3MeV; ACC23: 319.7MeV; ACC456: 272.3MeV

Observations from beam loss studies

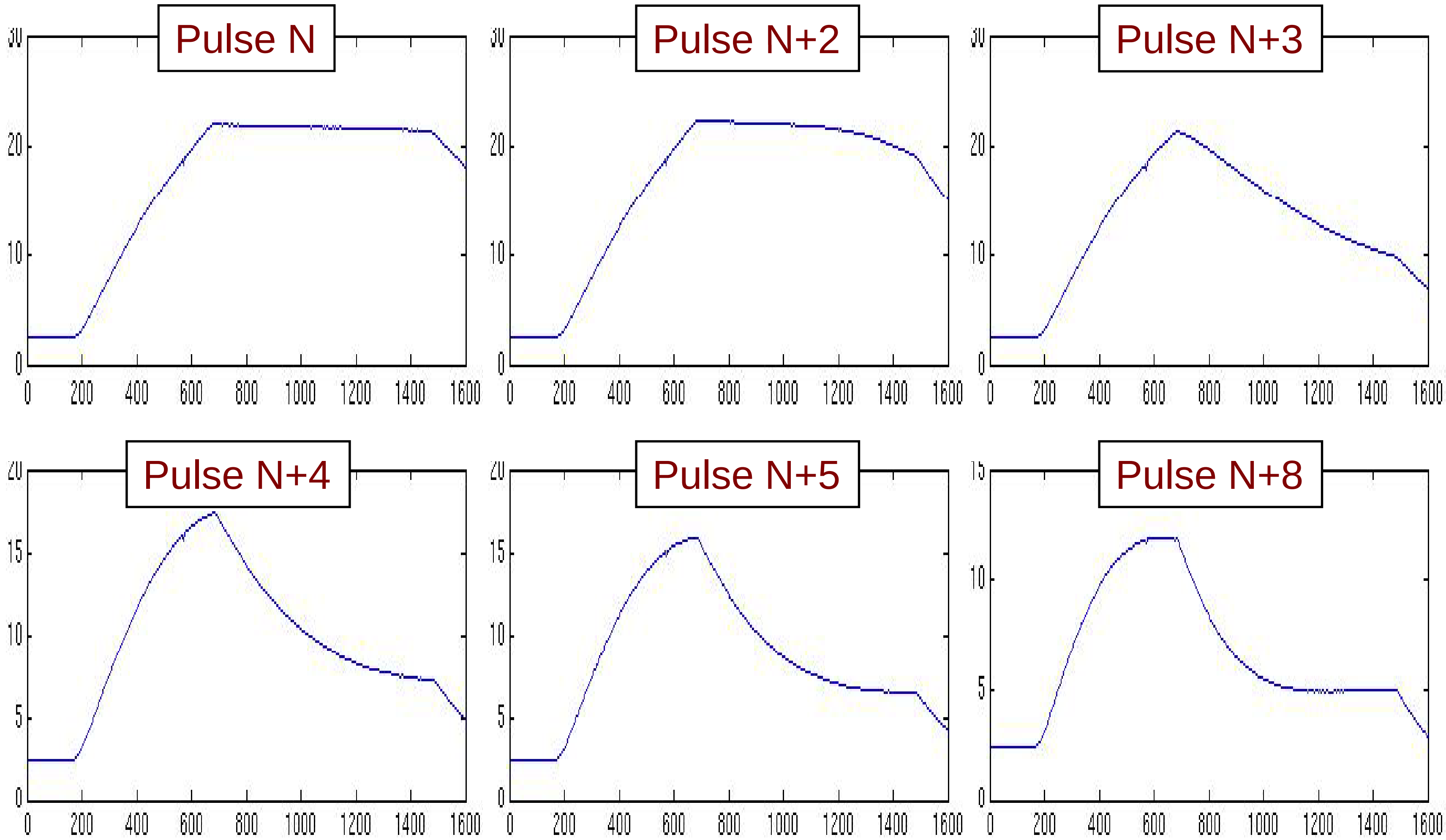
- Clearly we can influence the blm signals by moving the beam
- Q4DUMP had a large steering effect, so the beam must be off magnetic axis
- New Cerenkov detector is clearly sensitive to beam position, but
  - **Signal never goes to zero**
  - **Signal increases on both sides of a minimum instead of being asymmetrical about minimum**

Gradient studies

Push the gradients in ACC456 and ACC23

Find gradient limits, measure quench signatures, test quench detection, check coupler powers,…

ACC2 Cavity 1 probe amplitude during quench (800us flat top)



Gradient studies: ACC23

- RF systems running with 800us flat top
- Cavity 1 was the first to quench, then others in the following order (we stopped after C6):

Cavity	Quenched at: (MV/m)	Ecav max Data (MV/m)
ACC2 C1	~22	22
ACC2 C3	~24.5	25
ACC2 C7	~25.5	25
ACC2 C8	~25.5	24
ACC3 C6	~26	26

Gradient studies: ACC456

- RF systems running with 800us flat top
- Cavity 2 was the first to quench, then C8 before we ran out of time.

Cavity	Quenched at: (MV/m)	Ecav max Data (MV/m)
ACC6 C2	~32	32
ACC6 C8	~24	24

ACC456 Cavity parameters (9mA loading)

ACC4	20.9 MV/m			173 MeV		Max	191	Mev	Δ	17
Pin, MW	1.38		RF power	OK						

Qext	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		
A, dB	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	not measured	
Pcav, kW	155.2	155.2	155.2	155.2	155.2	155.2	155.2	155.2	1241.7	142
Ecav, MV/m	20.89	20.89	20.89	20.89	20.89	20.89	20.89	20.89	20.9 MV/m	
Ecav, max	23	23	23	23	23	23	23	23	23.0	
	Cav 1	Cav 2	Cav 3	Cav 4	Cav 5	Cav 6	Cav 7	Cav 8		
Δφ	not measured								beam - forward RF	

ACC5	26.4 MV/m			219 MeV		Max	231	Mev	Δ	12
Pin, MW	2.20		RF power	OK						

Qext	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0		
A, dB	9.67	9.64	9.61	9.53	9.34	9.35	9.38	9.39	measured	
Pcav, kW	237.5	239.1	240.8	245.3	256.2	255.7	253.9	253.3	1981.8	219
Ecav, MV/m	25.84	25.93	26.02	26.26	26.85	26.81	26.72	26.69	26.4 MV/m	
Ecav, max	29	27	28	28	29	28	28	26	27.9	
	Cav 1	Cav 2	Cav 3	Cav 4	Cav 5	Cav 6	Cav 7	Cav 8		
Δφ	0	-6	11	1	15	6	6	20	beam - forward RF	

ACC6	26.7 MV/m			222 MeV		Max	238	Mev	Δ	16
Pin, MW	2.21		RF power	OK						

Qext	2.95	2.97	3.00	2.98	3.00	2.98	2.99	2.98	11/21/07	
A, dB	7.85	7.54	8.16	8.31	12.27	12.03	10.28	10.37	measured	
Pcav, kW	362.8	389.7	337.8	326.4	131.1	138.6	207.4	203.1	2096.9	115
Ecav, MV/m	32.05	33.17	30.83	30.34	19.20	19.77	24.17	23.93	26.7 MV/m	
Ecav, max	34	32	34	32	21	21	29	26	28.6	

Open loop cavity field stability

Continue measurements on cavity field stability over long flat top to improve understanding of HLRF overhead requirements.

Measure cavity field stability as function of gradient and detuning

Power Overhead issues

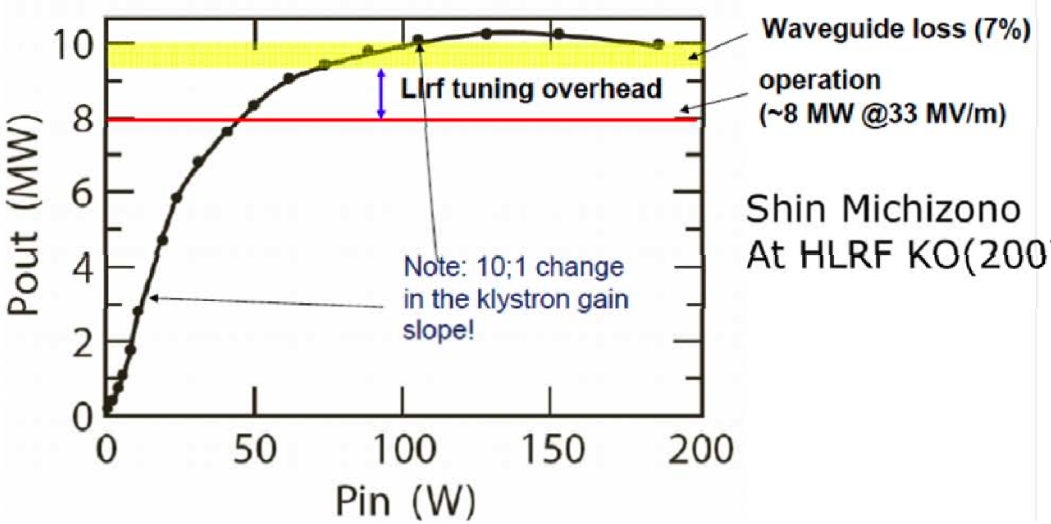
RDR

TABLE 2.6-2
RF unit parameters.

Parameter	Value	Units
Modulator overall efficiency	82.8	%
Maximum klyston output power	10	MW
Klystron efficiency	65	%
RF distribution system power loss	7	%
Number of cavities	26	
Effective cavity length	1.038	m
Nominal gradient with 22% tuning overhead	31.5	MV/m
Power limited gradient with 16% tuning overhead	33.0	MV/m
RF pulse power per cavity	293.7	kW
RF pulse length	1.565	ms
Average RF power to 26 cavities	59.8	kW
Average power transferred to beam	36.9	kW

LLRF claimed the small overhead for enough feedback margin. There are some items which make the overhead smaller such as tuning error, over coupling and so on.
→ **LLRF has a presentation.**

- As in RDR, llrf tuning overhead is only 16% in power. corresponding to 8% in driving amplitude. (too narrow!)



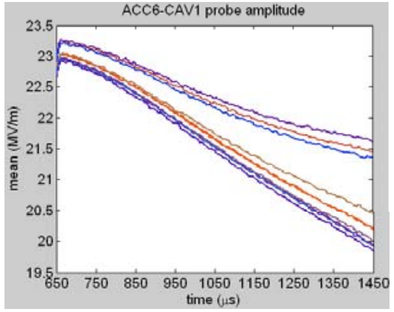
Shin Michizono
At HLRF KO(2007)

Does the RDR overhead match to the reality?
Should HLRF consider the Potential increase of overhead? (higher efficiency? More power?)

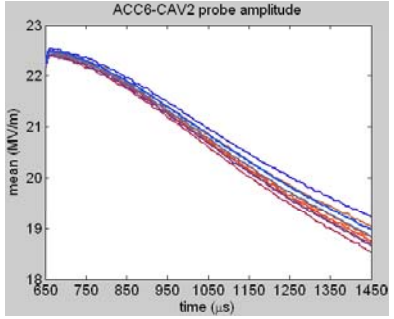
Discussion

ACC6 cavity probe amplitudes: flat-top jitter (September data)

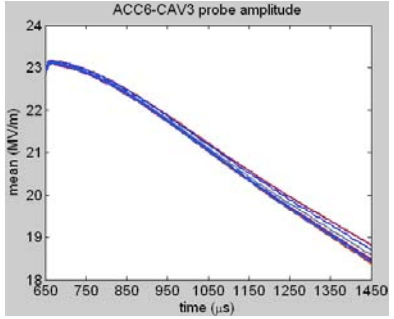
ACC6 with FB Off, AFF off, 100 pulses, 800us flat-top



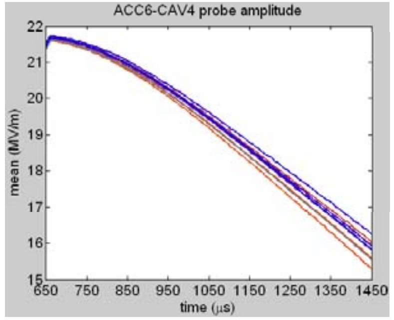
CAV1



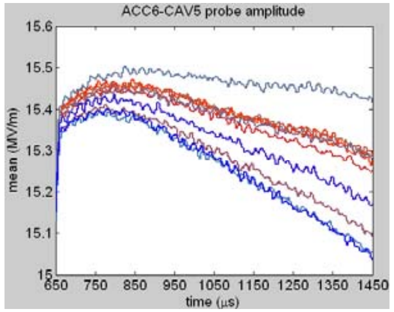
CAV2



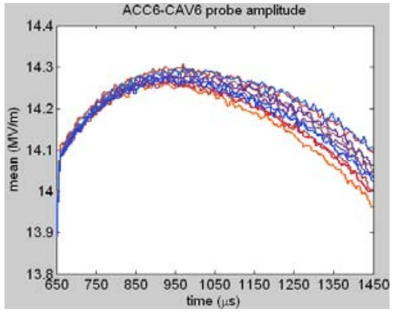
CAV3



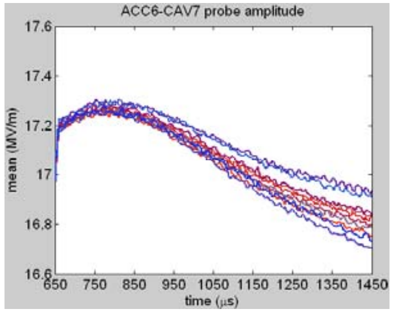
CAV4



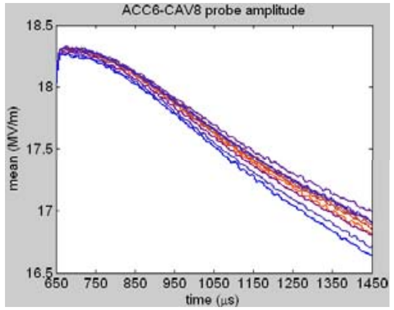
CAV5



CAV6



CAV7



CAV8

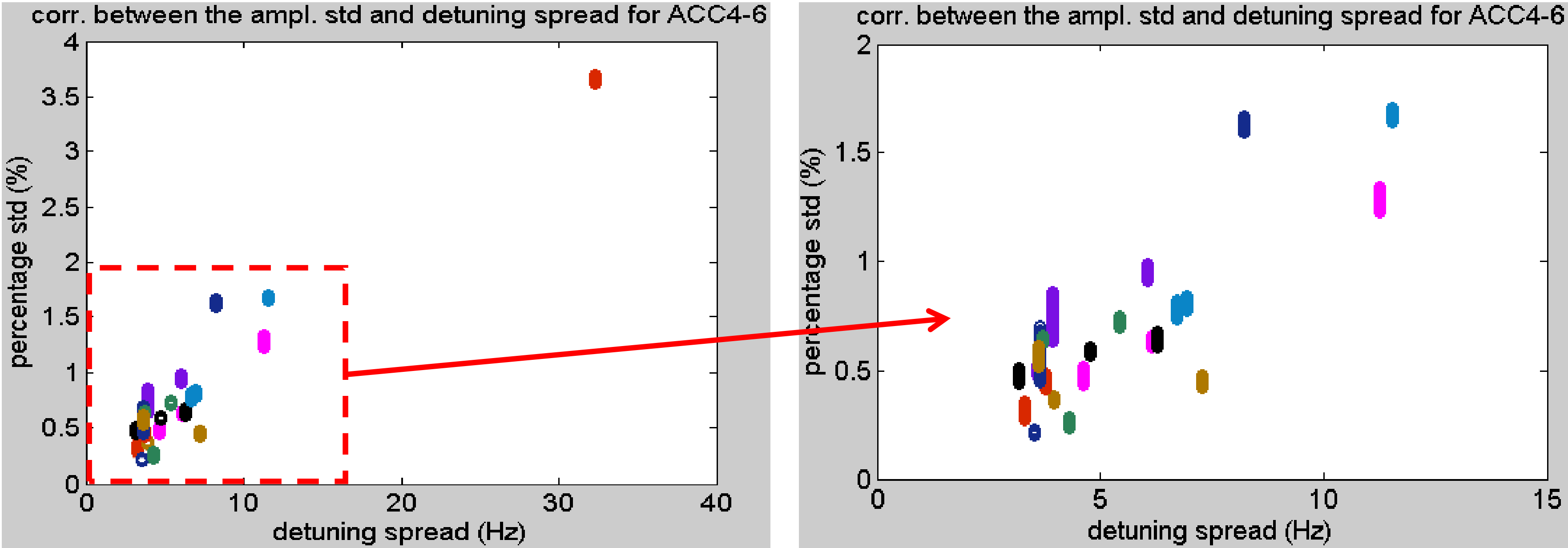
Gradient slope is different for different cavities

Jitter increases along the flat top

Some cavities have worse jitter than others (worst is cavity 1)

Correlation of amplitude & detuning jitter (September data)

- Strong correlation between jitter in flat top amplitude and detuning jitter at the <u>end of the pulse</u>



Open loop data taken during January studies

- Additional data taken on ACC456 for several gradient settings and several detunings
- Used online measurement system from piezo controller to measure detuning during pulses.
- Took dataset with piezos running on ACC6
  (See M. Grecki talk for results of piezo tuner studies)

LLRF feedback and feed-forward studies

(V. Ayvazyan)

- Feed-forward table generation
  - **Smooth the edges of the feed-forward tables to reduce transient RF peak power during fill.**
  - **An enabler for running higher feedback gain**
- Beam Loading Compensation
  - **Improve manual beam loading compensation**
- Variable gain studies
  - **Ramp up gain during fill time**
- Feedback gain studies
  - **Able to run ACC456 with gains up to 180**
  - **Settled on gain of 60 for best performance**
  - **Higher gain should reduce reliance on adaptive feed-forward**