Recent studies of the electron cloud-induced beam instability at the Los Alamos PSR

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Results since ECLOUD'07 workshop

Outline

- **Introduction: brief reminder of the main features of the e-p instability at PSR**
- **Topic 1: Results from studies exploring the recent finding that short pulses are now significantly more unstable than longer pulses, contrary to experience for many years before ~2006-7**
- **What is different now?**
  - Operating the ring at 72.070 instead of 72.000 subharmonic of the linac bunch frequency.
  - 72.000 subharmonic produces micropulse pileup in the ring that introduces some high frequency structure to the longitudinal profile of the beam pulse
  - Beam scrubbing over time changes SEY
- **Will discuss effects of these two operating conditions on several beam and e-p characteristics and why 72.070 is preferred for normal operations**
- **Topic 2: evidence that the electron cloud in drift spaces is primarily "seeded" by electrons ejected (by ExB drifts) from quadrupole magnets, subject of another talk on Monday**

PSR Layout with EC & e-p Diagnostics

Circumference = 90m

Beam energy = 798 MeV

Revolution frequency =2.8 MHz

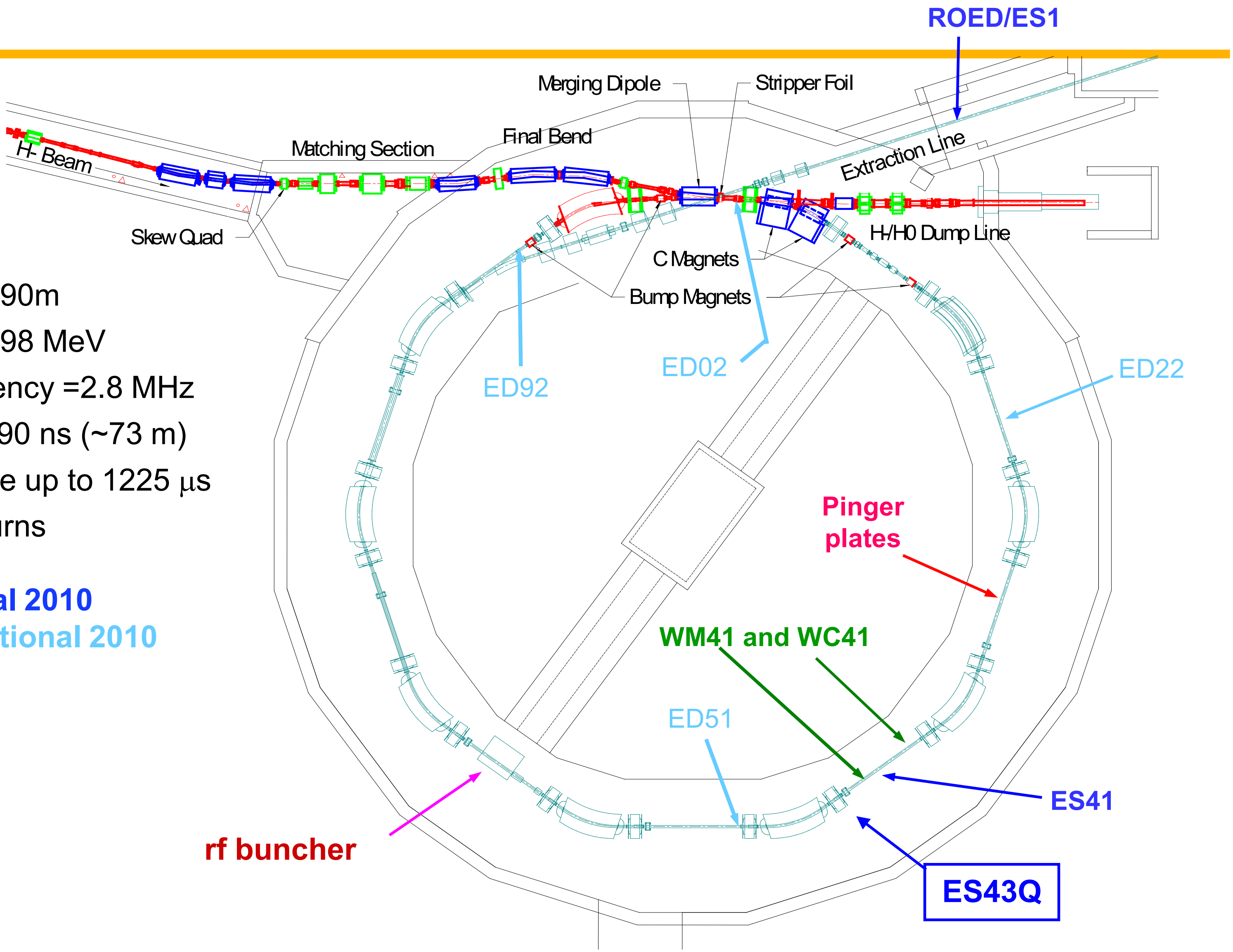
Bunch length ~ 290 ns (~73 m)

Accumulation time up to 1225 μs

i.e. up to~3400 turns

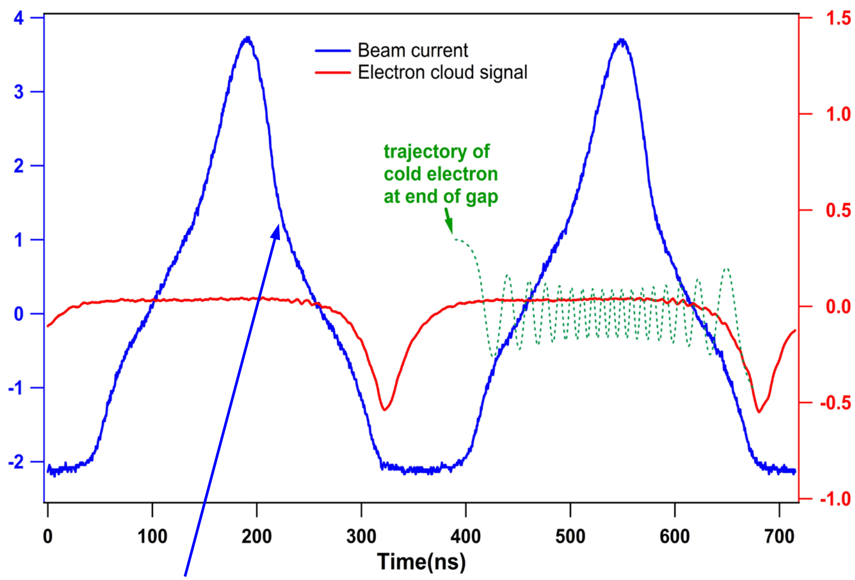
x operational 2010

x not operational 2010

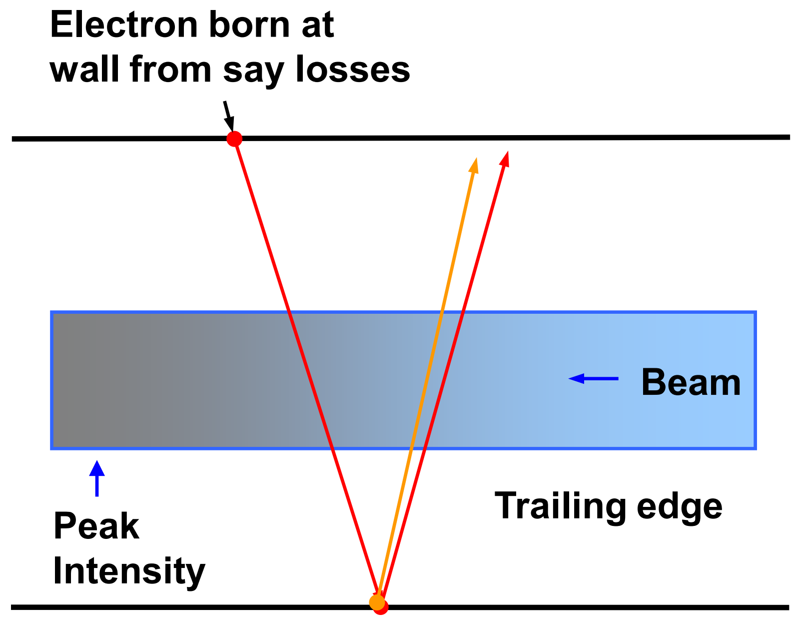


Present picture of the e-p instability at PSR

- **Available evidence points to two-stream instability from coupled motion of proton beam and low energy electron cloud**
- **Electron cloud generation**
  - Primary (aka “seed”) electrons from beam losses are amplified by multipactor on the ~140 ns long trailing edge of the ~290 ns long proton beam pulse
  - Sufficient electrons survive the ~70 ns gap between bunch passages to be captured by the following bunch and drive the instability
  - Largest uncertainty is the distribution of primary electrons at the chamber walls



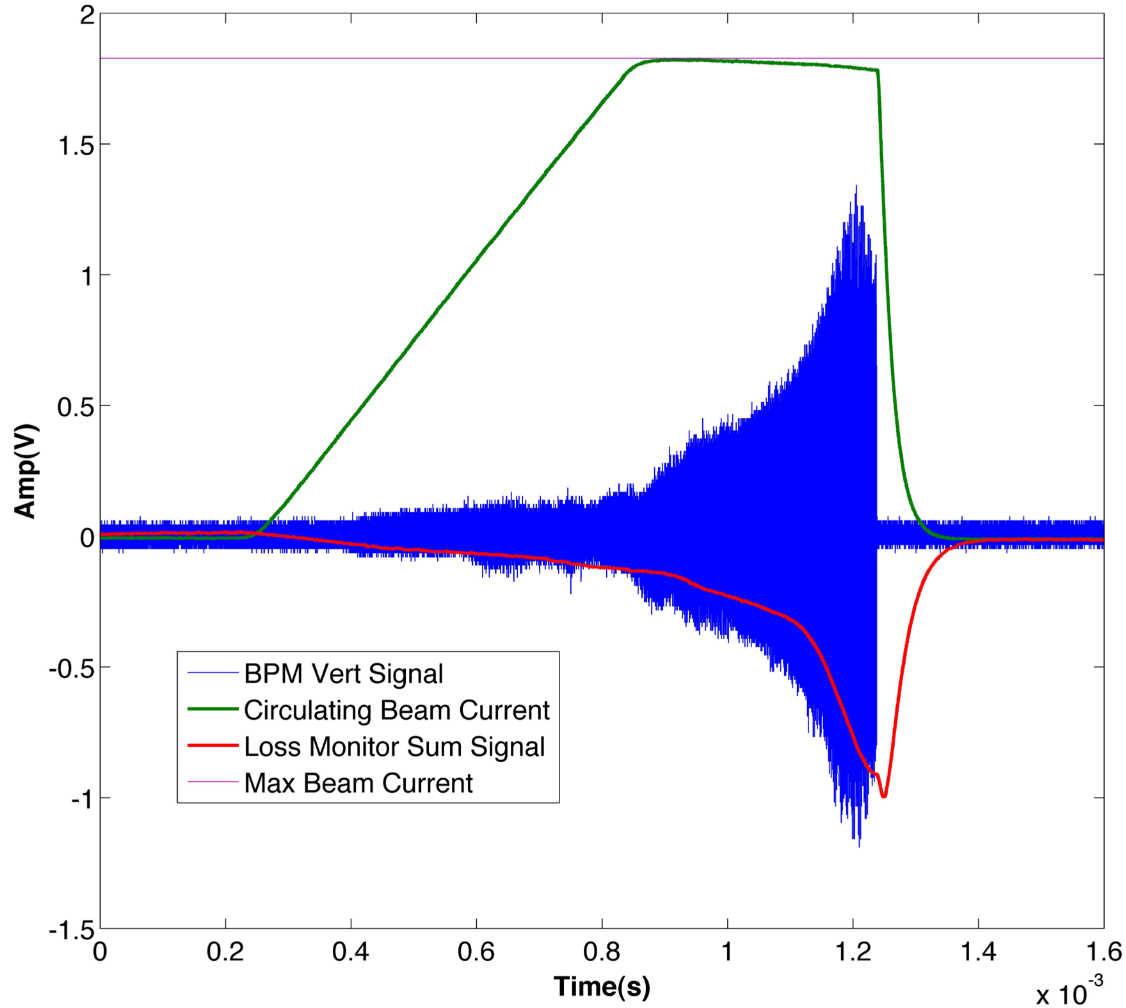
Energy gain is possible in wall-to-wall traversals on trailing part of beam pulse



Energy gain in one traversal is high enough for multiplication

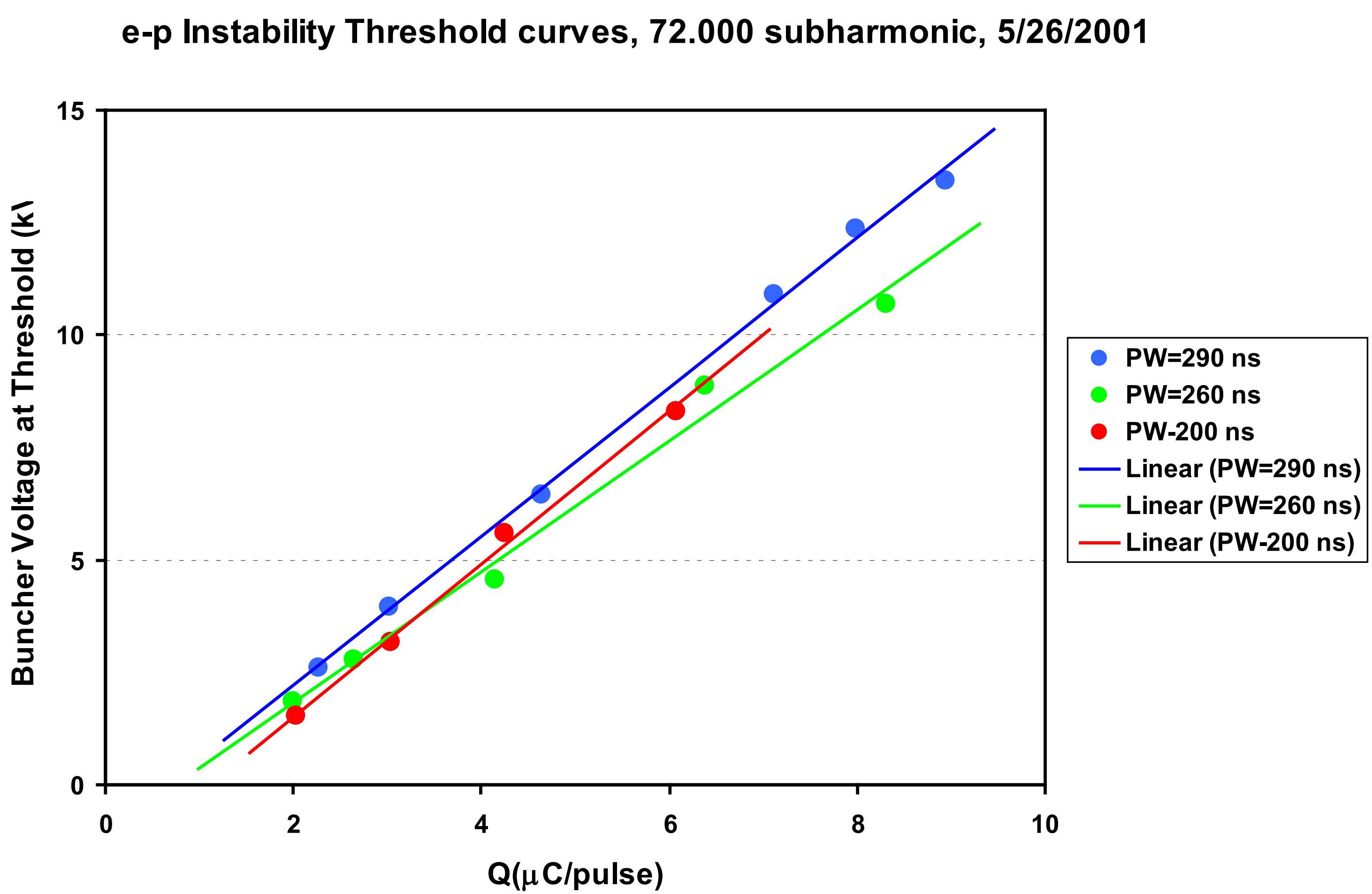
Experimental signature for e-p threshold

- Store for 400 μs after end of injection (EOI) to allow instability to develop at fixed beam current (and no losses from H0 excited states)
- Lower rf buncher voltage until
  - Exponentially growing coherent motion (BPM)
  - Significant losses as seen on LMsum signal and ~5% loss of current by time of extraction
- Thresholds under this criteria are reproducible to ~5% level on buncher voltage



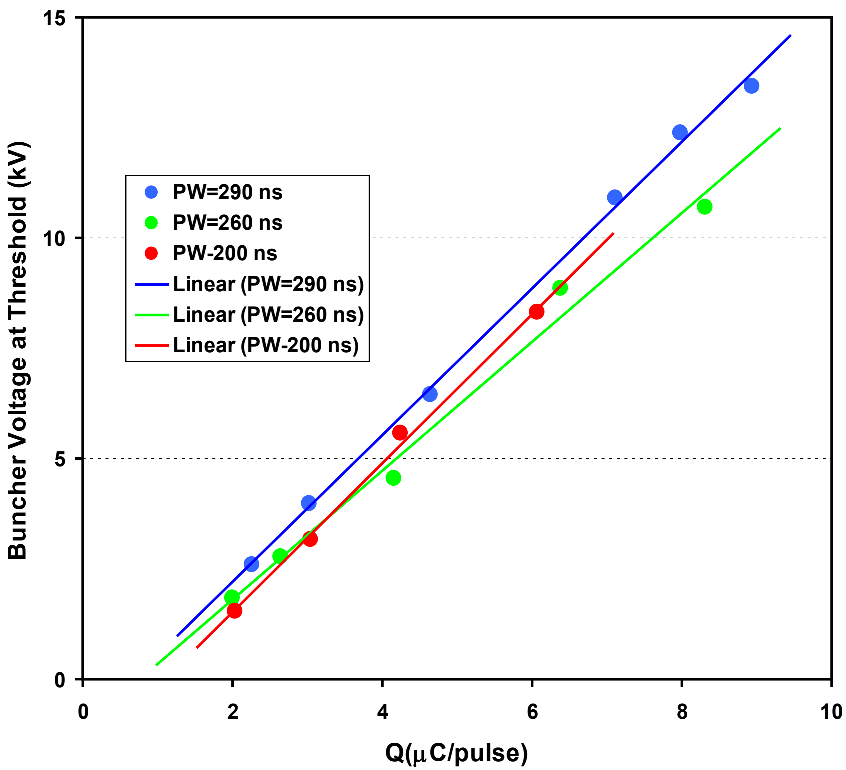
Series *c 9/25/10

Typical e-p threshold curves for different bunch widths (injection PW) prior to ~2006



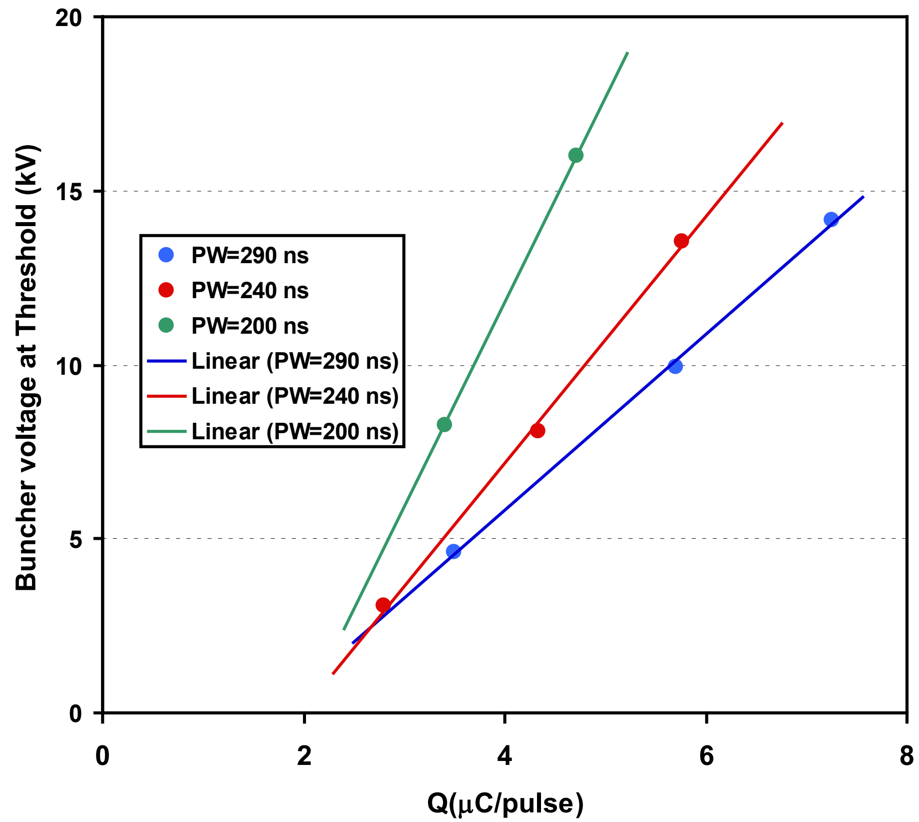
Comparison of instability threshold curves 2001 & 2010

5/26/2001



72.000 subharmonic operation

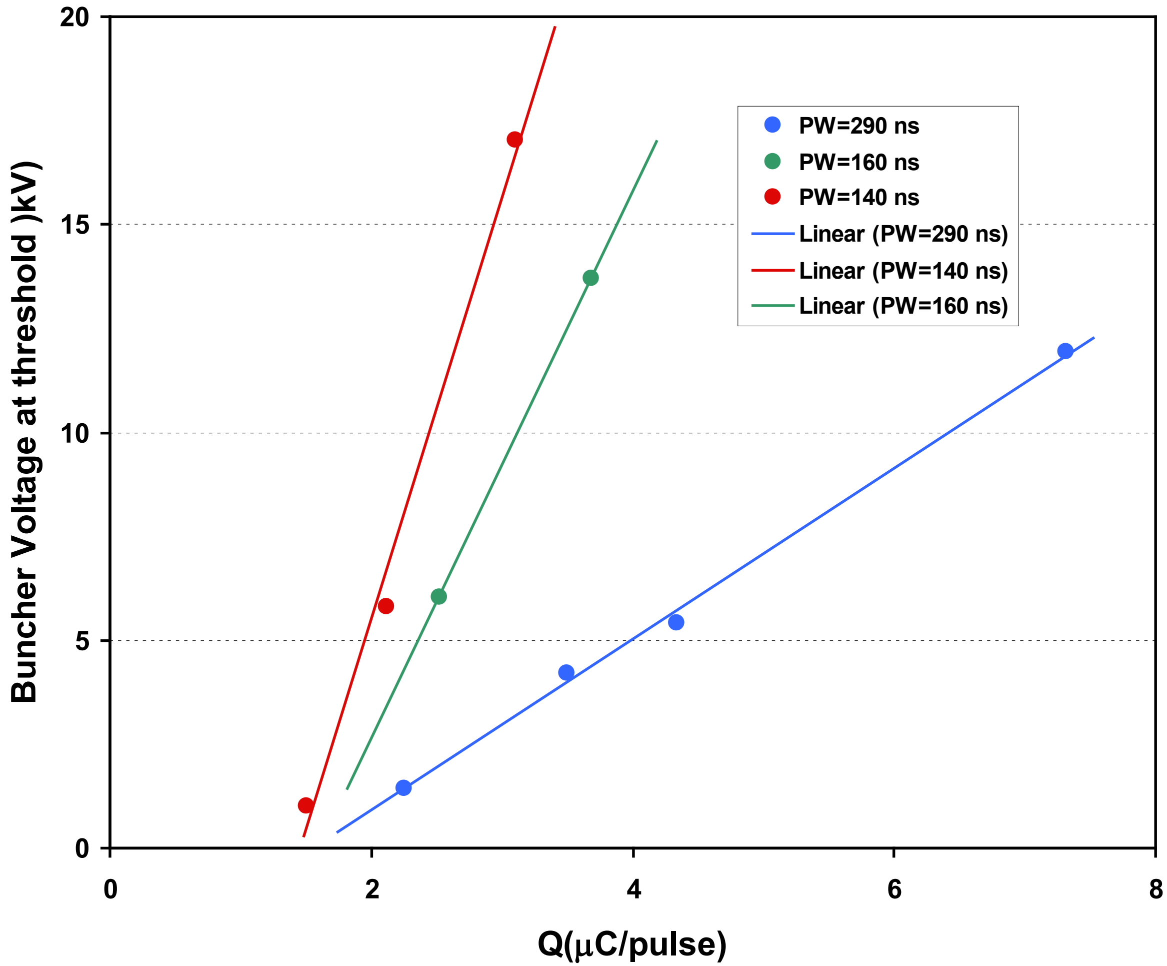
9/24/2010



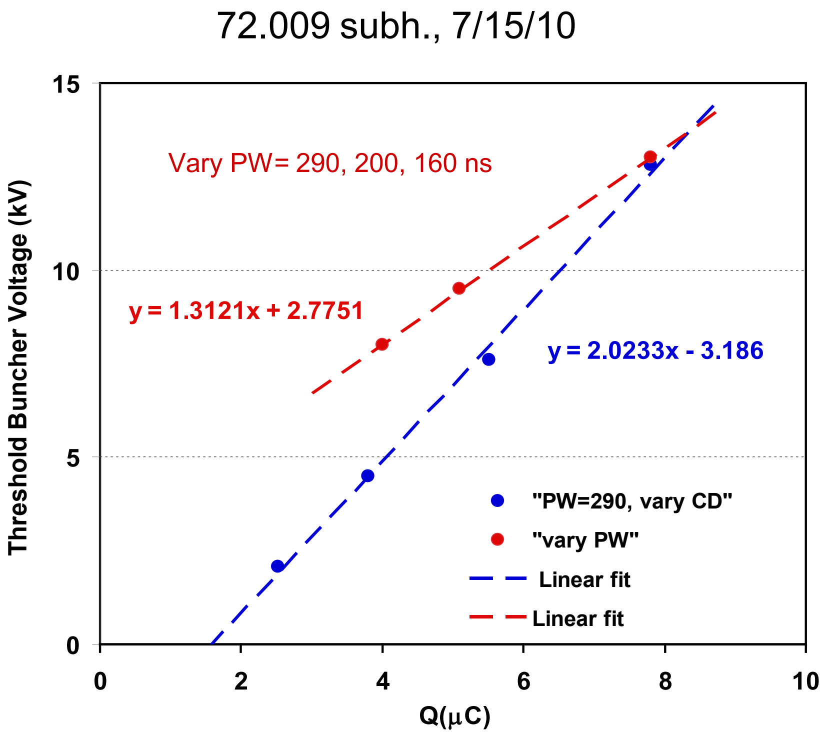
72.070 subharmonic operation

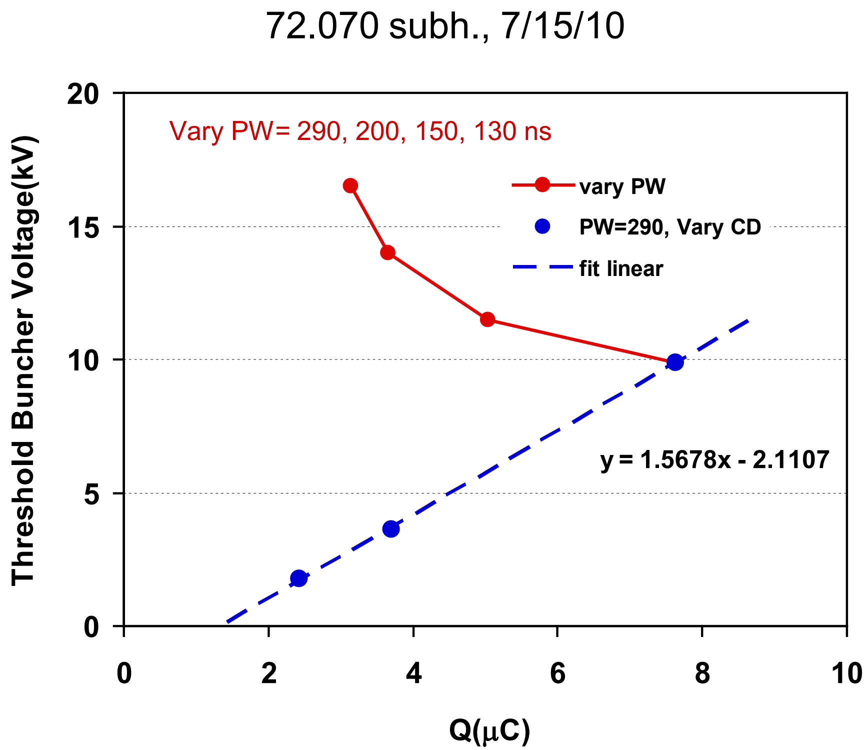
More threshold curves 9/25/10 for larger PW variation

- Data for 72.070 subh. operation
- Accumulation = 825 μs, 200 μs store



Contemporaneous comparsion of threshold data





- Short pulses are clearly are more unstable than long pulses for the 72.070 subh. case
- Blue curve for 72.009 lies above the blue curve for 72.070 subh. and has larger slope (~30%)
- Intensity for blue curves varied using the “count down” method where every “nth” turn is injected (n= 1, 2 or 3). Intermediate point, CD=“1.5”, is done using jaws in the front end of the linac to reduce current.

Notes on observations of short pulse instability at 72.07 subharmonic operation

- **The striking instability behavior for short pulses has been studied on several occasions (5 or so) in 2009 and 2010 and is a reproducible effect whenever we check for it.**
- **It was not there in June-July 2010 when we were inadvertently at 72.009 subharmonic operation!**
- **It immediately returned when we set up 72.07 subharmonic operation a few hours after taking threshold data for 72.009 case**
- **Short pulses are seldom used in routine operations, which is one reason why their instability was not encountered for ~2 years**
- **In searching for a beam dynamics explanation, we note that the e-p instability threshold is a balance between damping mechanisms (mainly Landau damping) and driving mechanisms (coupled oscillations of beam and electron cloud).**
  - Short pulses have smaller momentum spread and therefore less Landau damping which would make them more unstable, all other things being equal
  - Short pulses generally produce fewer electrons that survive the gap but these are influenced by many factors such as the primary electrons from beam losses, beam intensity, shape of trailing edge of the beam pulse, length of gap, beam in the gap, etc.
  - Present modeling tools and input parameters at our disposal are not sufficient for reliable prediction of thresholds

Comparison of beam pulse shape for various PW, 9/25/10

Blue, PW =290

RED, PW = 200

Green, PW=90

Data for 72.070
subharmonic
operation

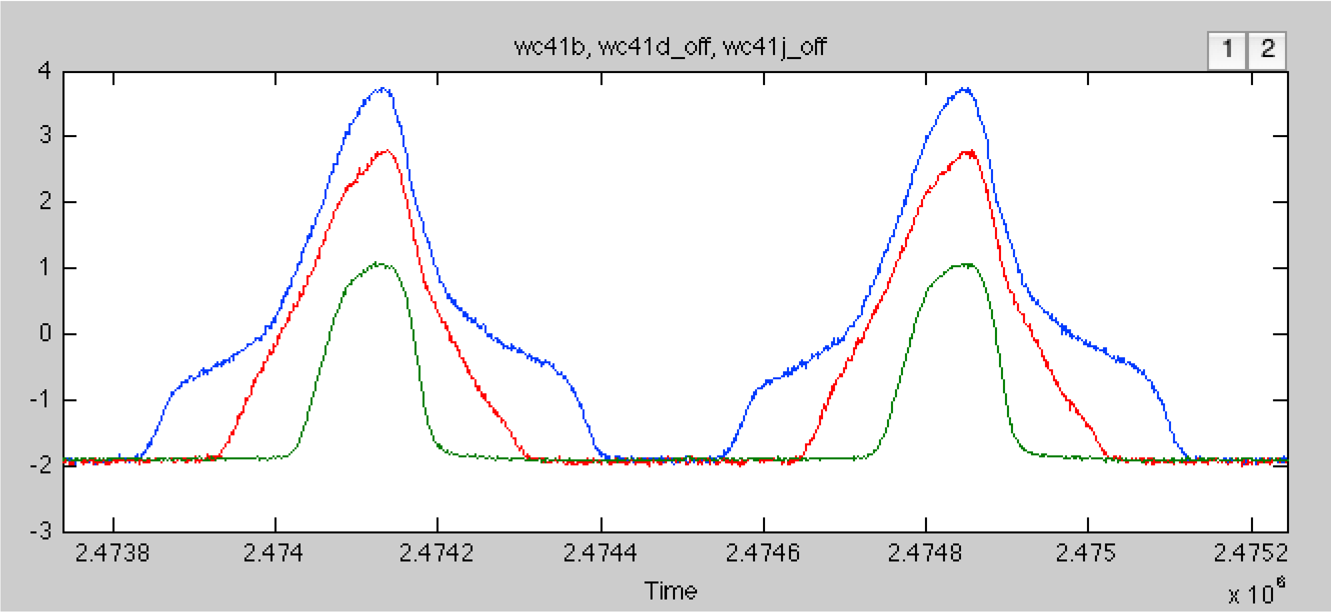


Illustration of micropulse injection patterns for 72.000 and 72.100 subharmonic operation

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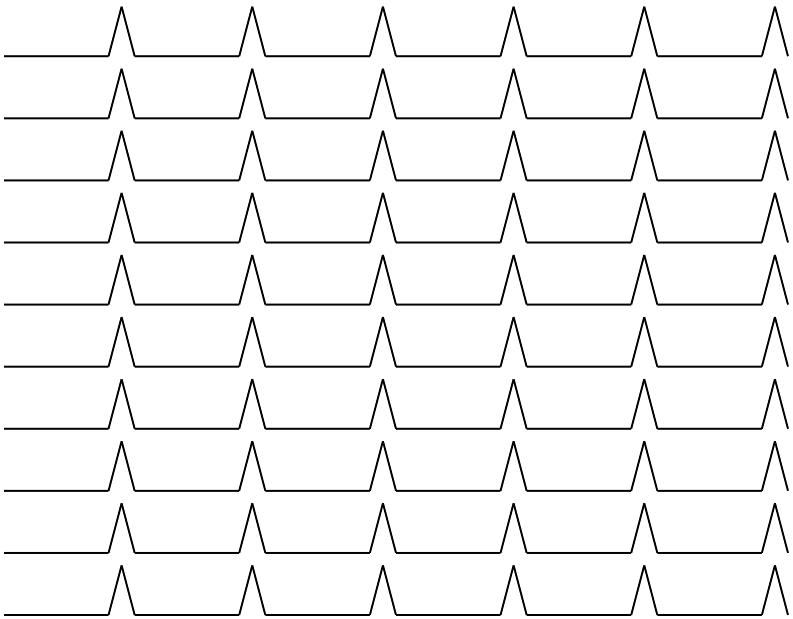
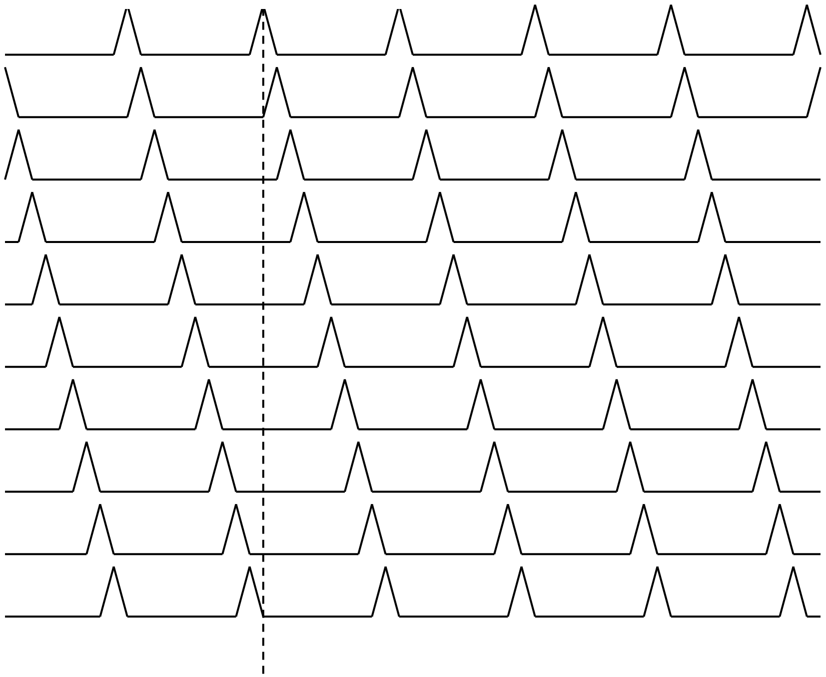
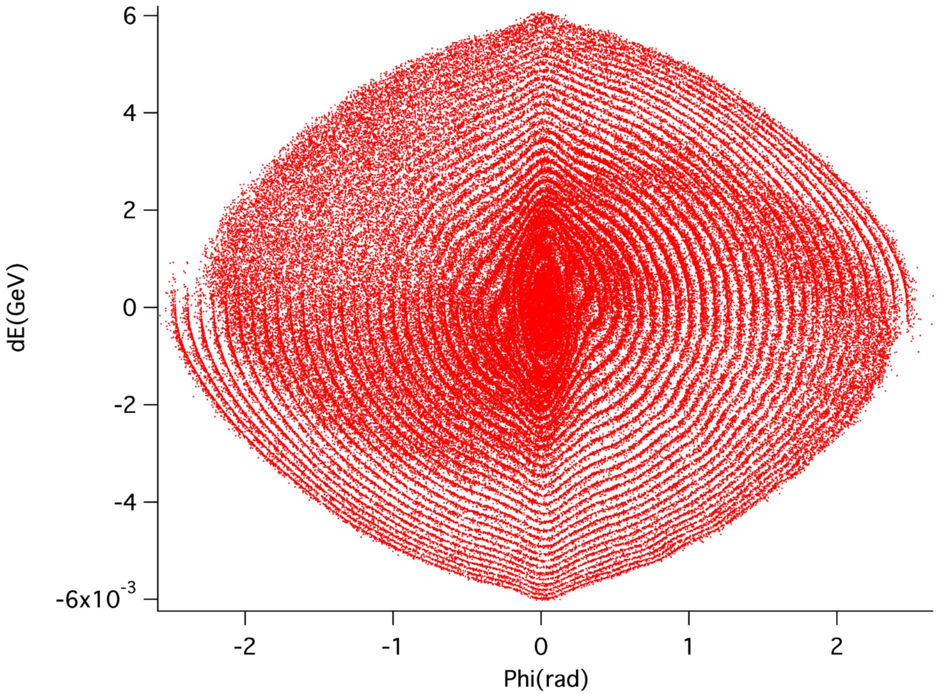


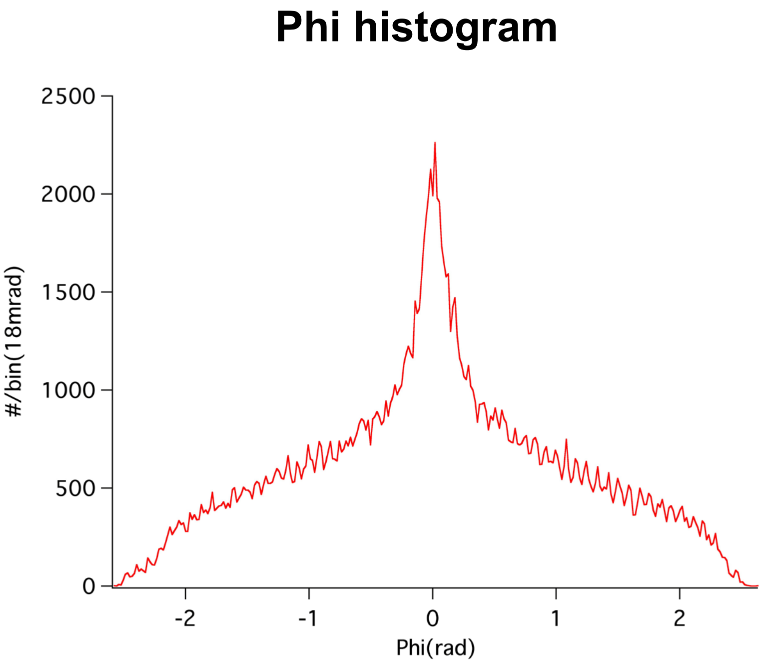
- Integer subharmonic (72.000)



- Non integer subharmonic (72.100)

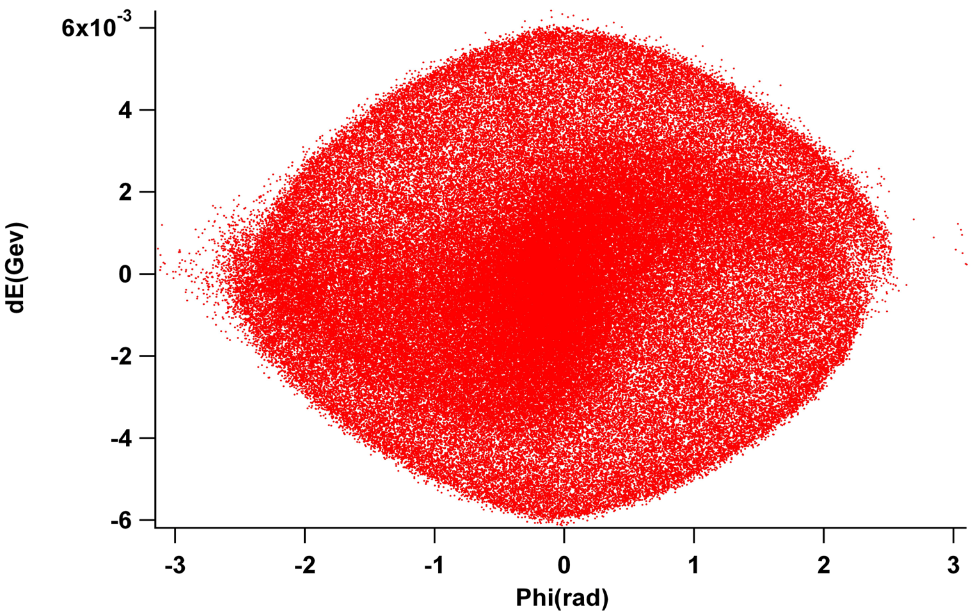
ORBIT Simulations of 72.000 subh. accumulation

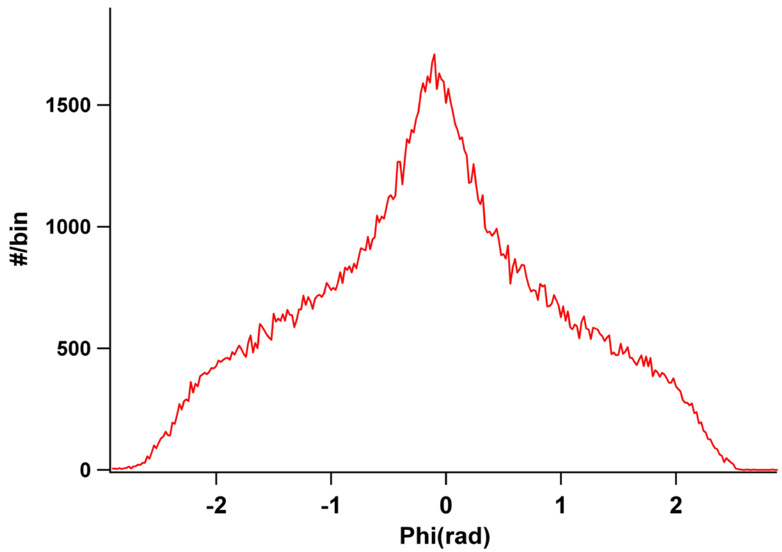




- 5 μC beam, space charge and foil energy losses included
- Linac bunch structure persists in the longitudinal phase space
- Projection of distribution on phi axis shows significant high frequency structure

ORBIT Simulations no linac time structure





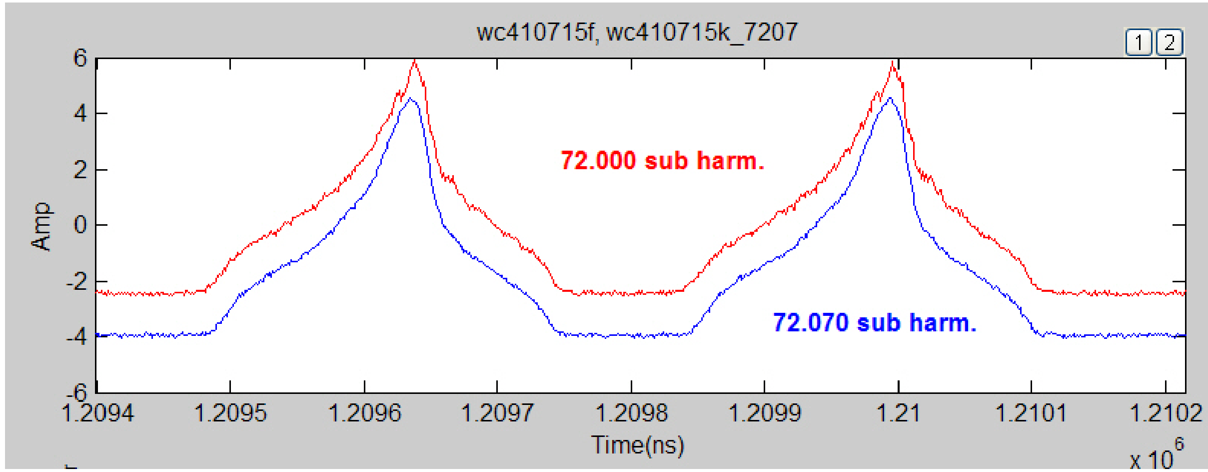
- **Good approximation to the 72.070 subharmonic accumulation**
- **Longitudinal phase space has smooth distribution**
- **Longitudinal time profile (phi distribution) is also smooth (histogram does show noise from statistical fluctuations of finite sample size)**

Comparative Studies in 2006

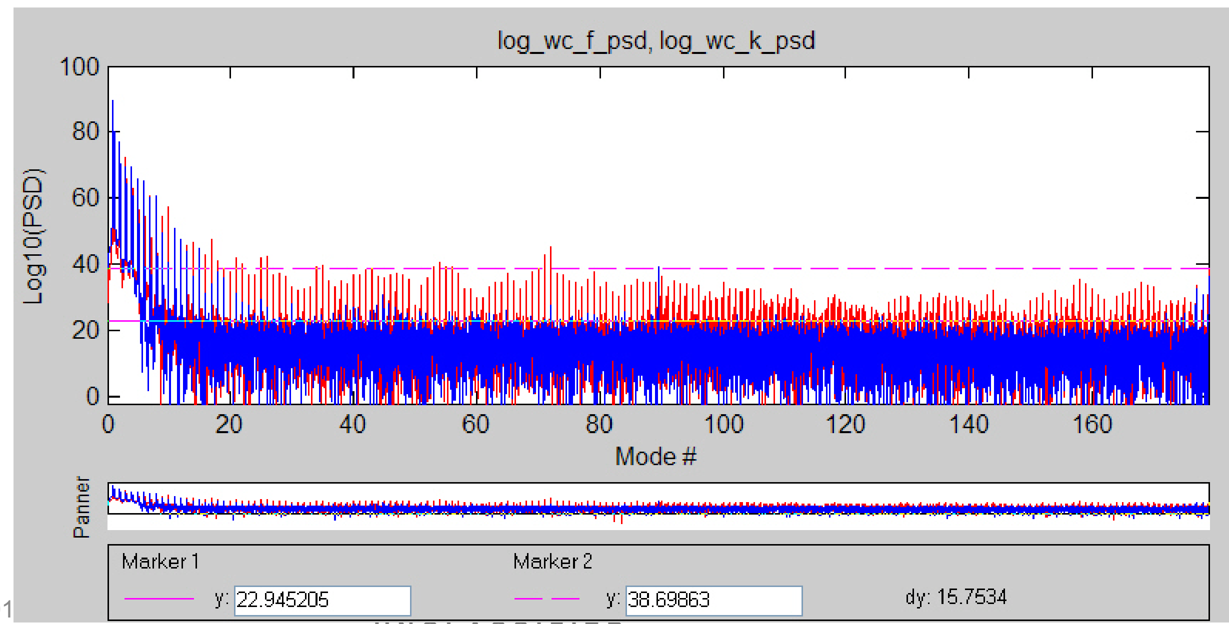
- Several tests were made before adopting the 72.070 subharmonic for routine operations at the end of 2006
- Looked at effect on longitudinal profile, BPM signals, electron cloud generation and instability thresholds

Comparison of wall current monitor (WC41) signals 7/15/06

At Extraction 12kV buncher



At end of Accumulation 12 kV buncher

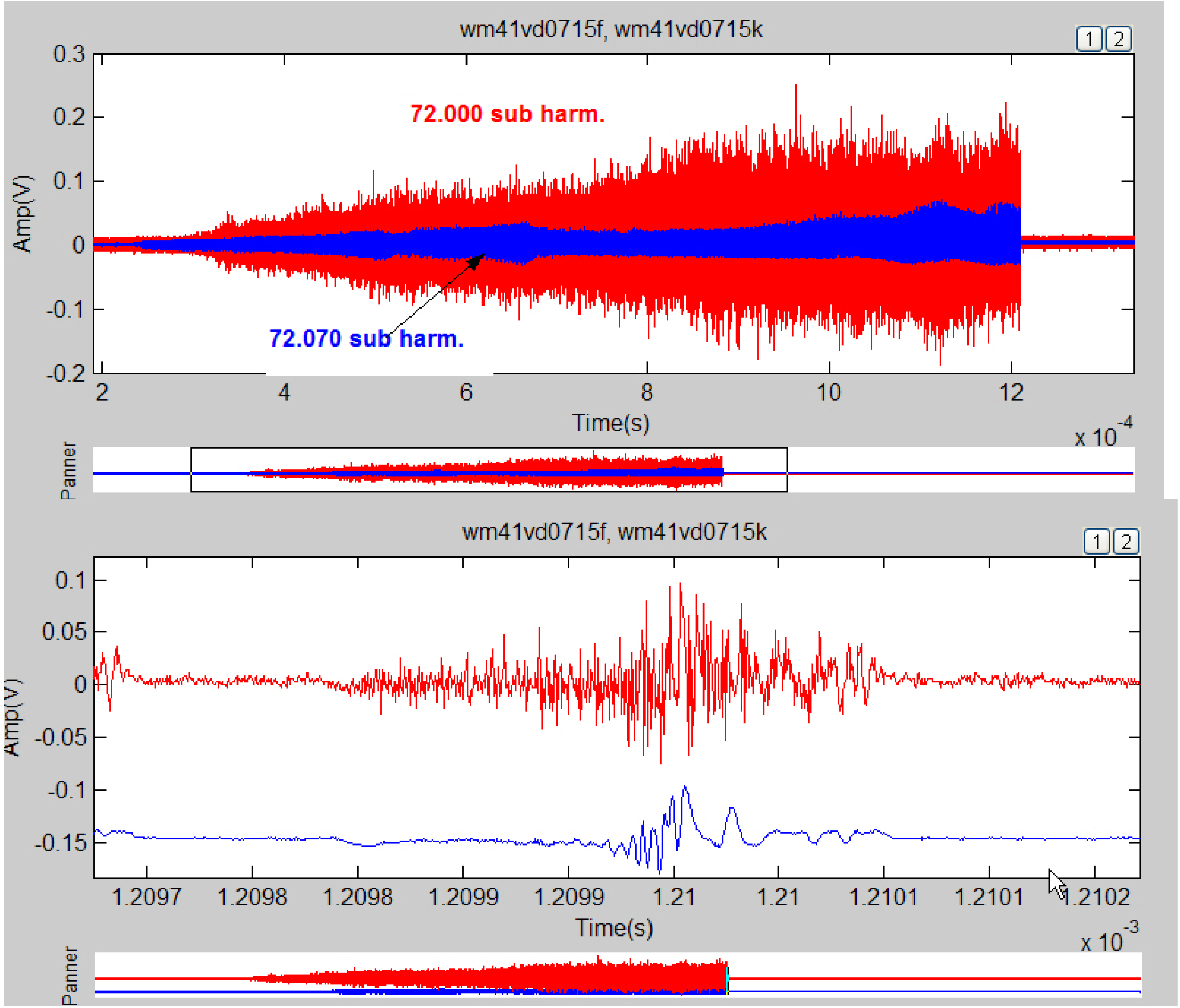


Comparison of BPM (WM41VD) signals 7/15/06

Red = 72.000 sub harmonic 12 KV buncher

Blue = 72.070 Sub harmonic 12 kV buncher

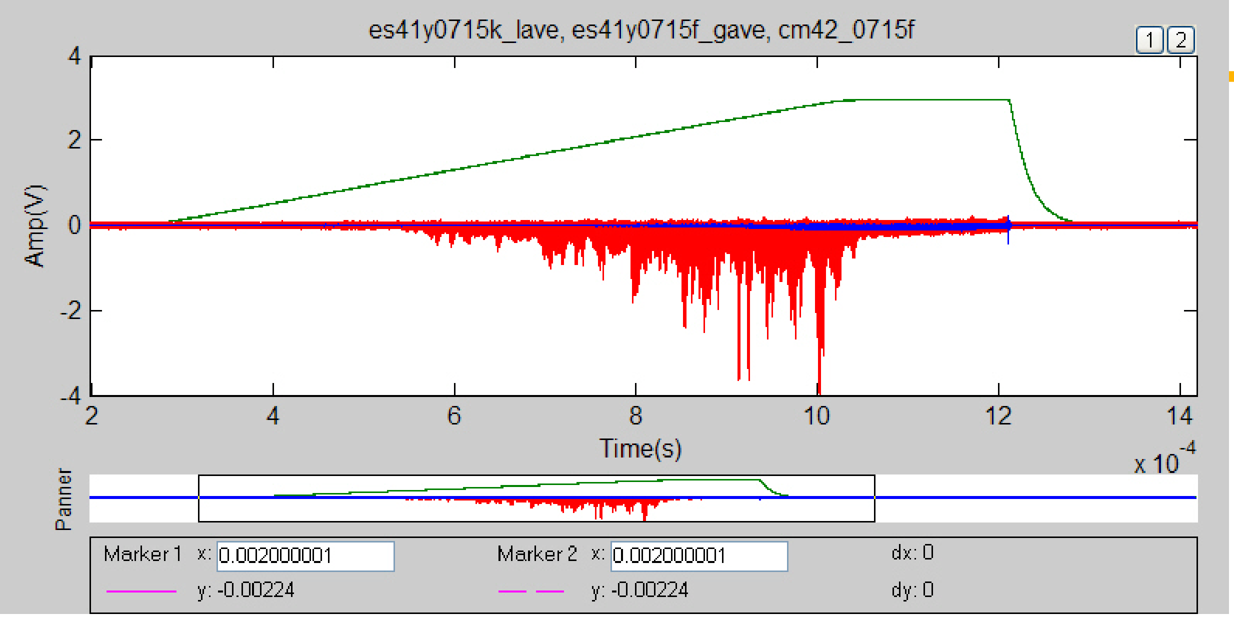
Last turn



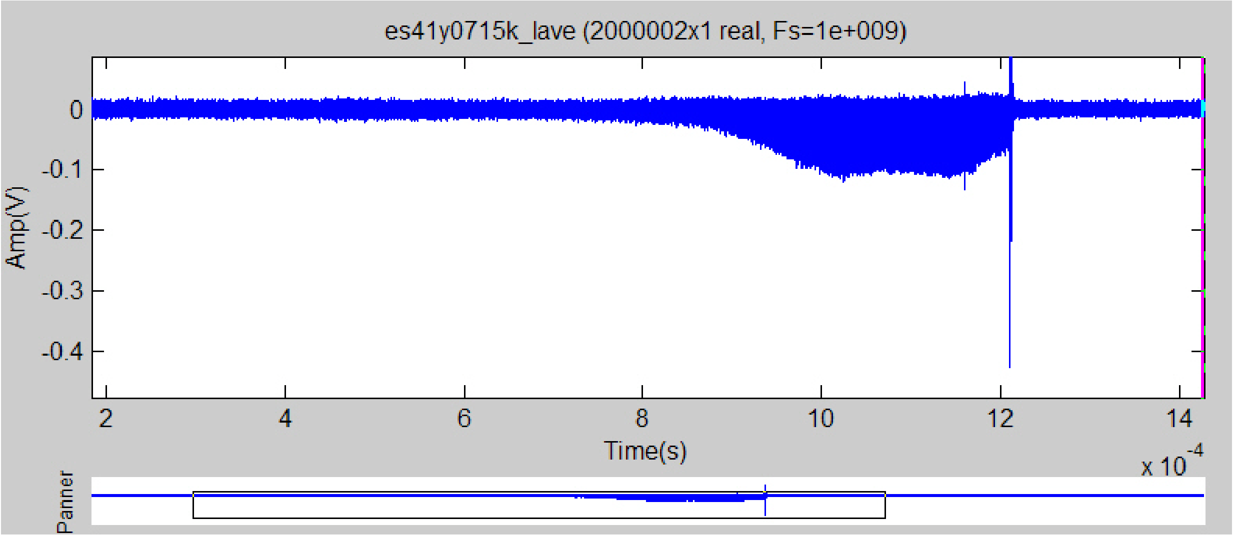
Compare ED (ES41Y) signals for single macropulse 7/15/2006

Red = 72.000 sub harmonic 12 kV buncher

Blue = 72.070 Sub harmonic 12 kV buncher



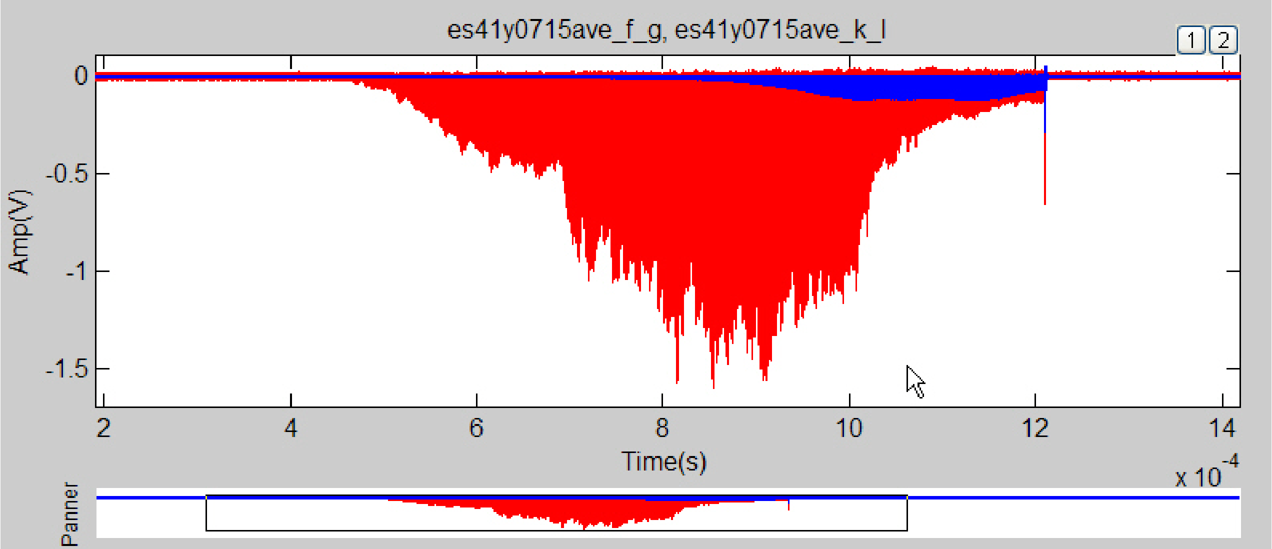
Vertical expansion of data for 72.070



Compare es41y averaged signals (32 macro pulses)

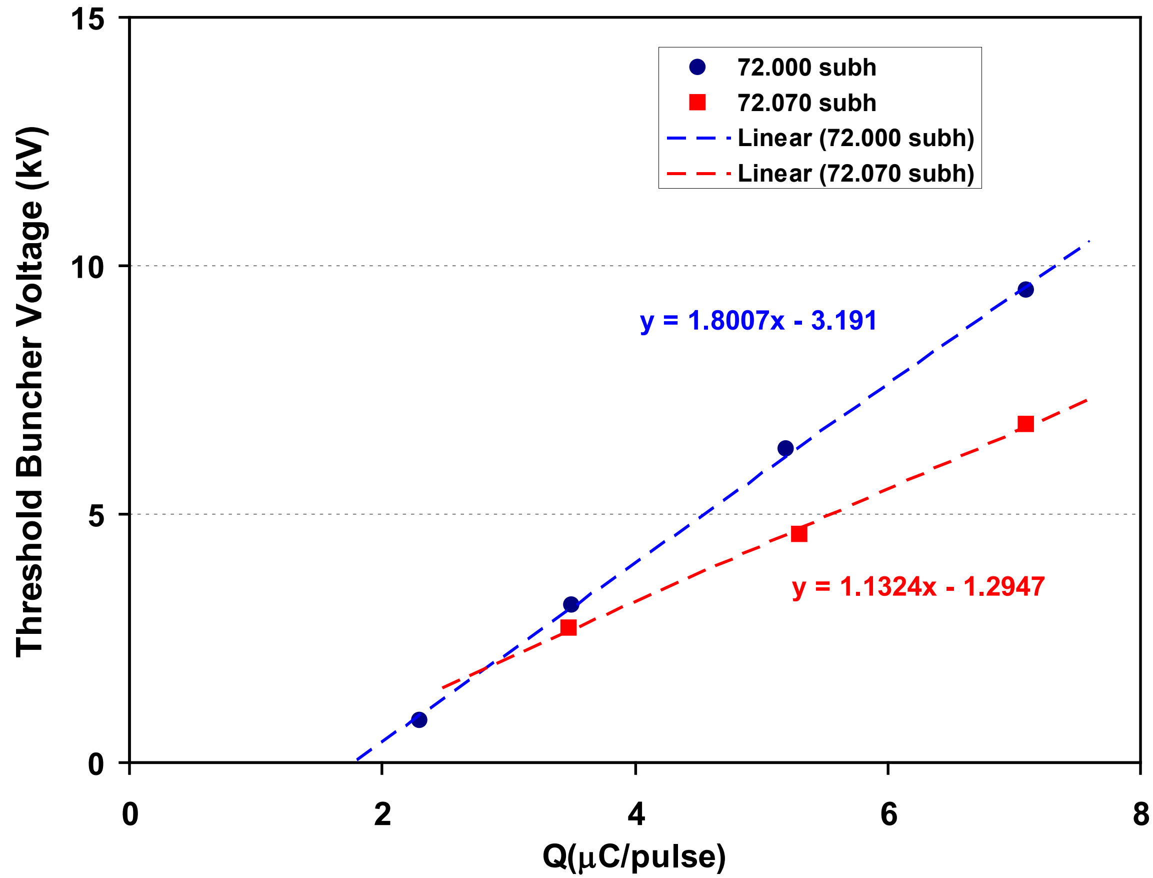
Red = 72.000
sub harmonic
12 kV Buncher

Blue = 72.070
Sub harmonic
12 kV buncher



Contemporaneous threshold curves in 8/6/06 tests

- **72.070 subh. operation is more stable for the higher currents**
- **This has been a consistent trend in the 2006 tests and again in 7/15/10 test**

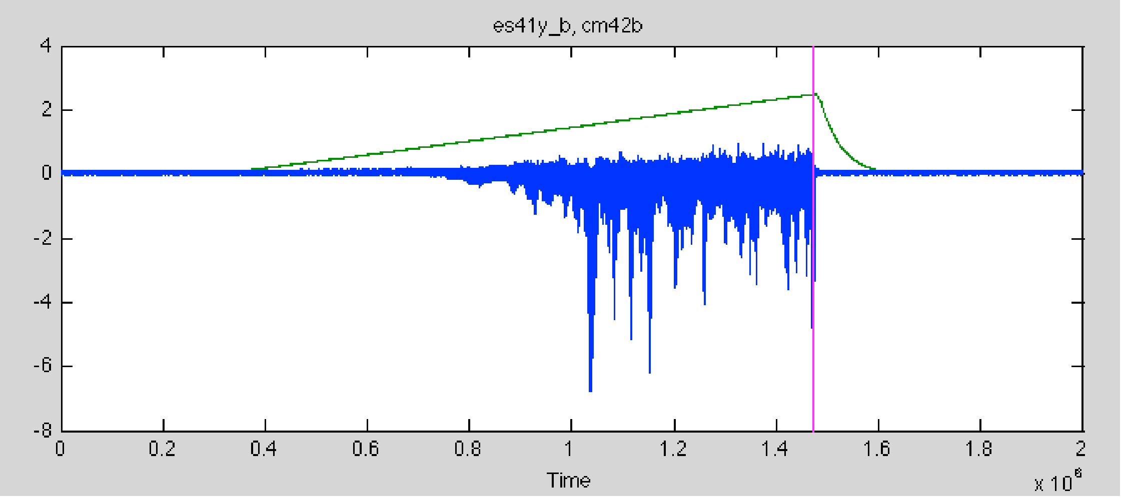


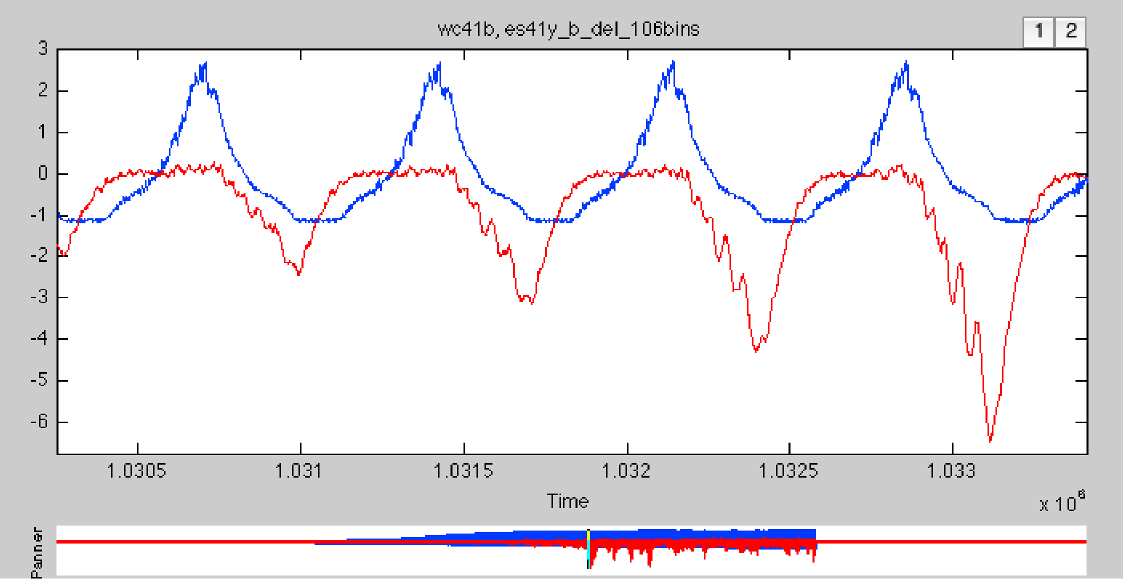
Summary of 72.000 and 72.070 subharmonic beam tests in 2006

- **The 72.070 sub-harmonic operation produced significantly less longitudinal structure on the beam in the ring and made the beam somewhat more stable against e-p (20-30% lower threshold voltage)**
  - 15 dB less revolution harmonics above 50 MHz on WC41 at EOI
- **Less high frequency noise on BPM**
- **Multipacting electrons in drift space down a factor of ~10 and no bursts**
- **Chose to make 72.070 subharmonic the standard operation for the advantages cited above after extended trial period (several weeks)**
- **Did not occur to us to look at stability of short pulses until last year when we inadvertently found the short pulse instability using PW as an easy way to change intensity!**

Electrons and longitudinal structure at 72.009 operation (7/14/10)

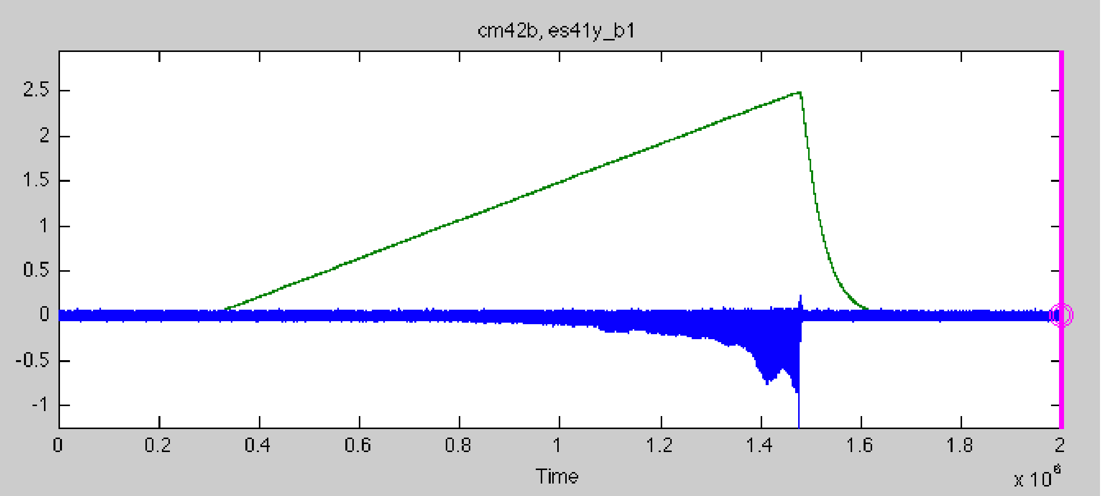
- Electron signal is fairly high and shows strong "bursts"
- Longitudinal profile of the beam has significant high frequency structure that was greatly reduced for 72.070 setup a few hours later as were electron bursts
- Electron burst activity has tended to vary significantly from day to day for the 72.009 subh. operation but is greatly subdued at 72.070

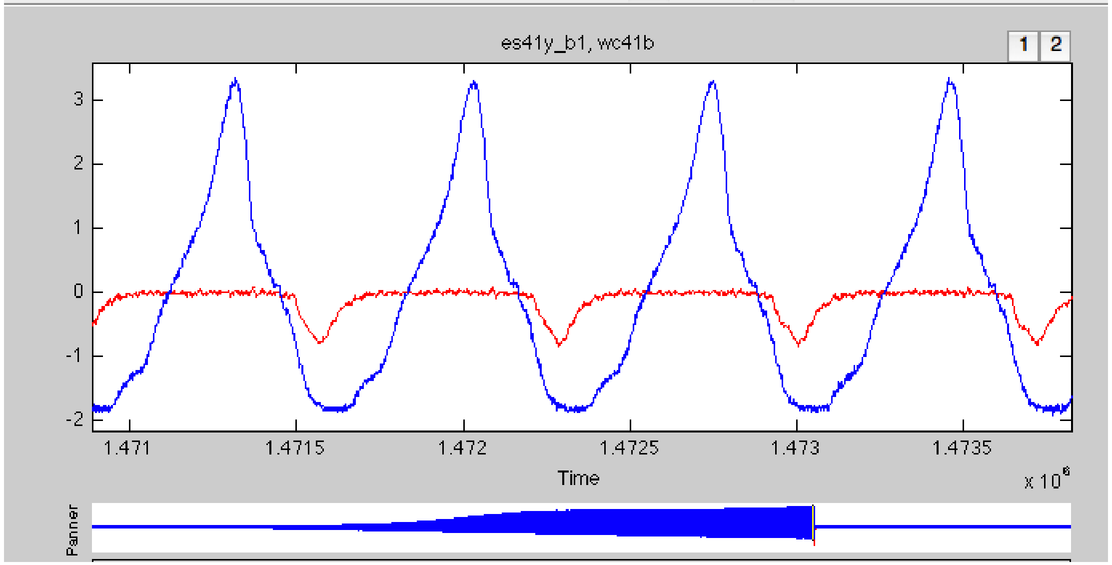




Electrons and longitudinal structure at 72.07 operation (8/5/2010)

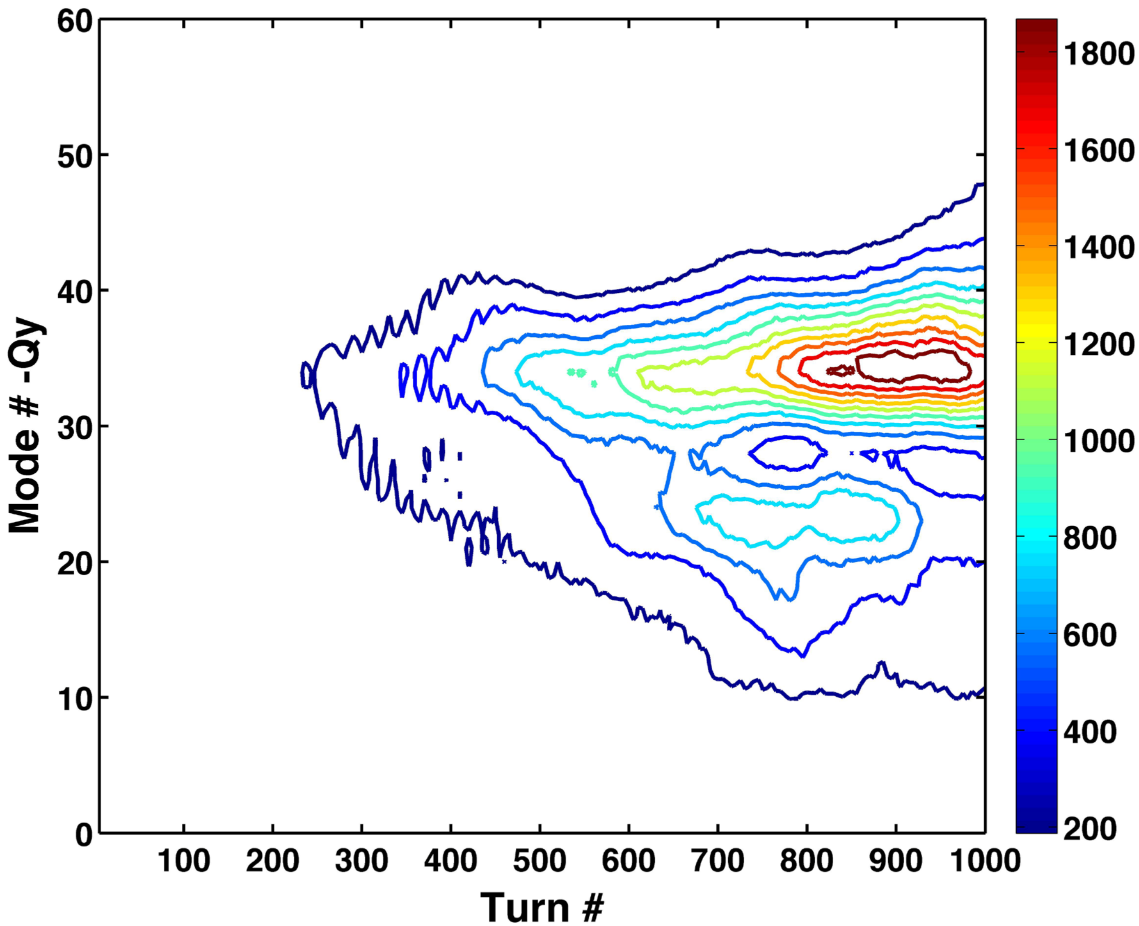
- No electron bursts
- Longitudinal profile has little high frequency structure ("hash") compared with the 7/14/2010 data at 72.009 subharmonic operation





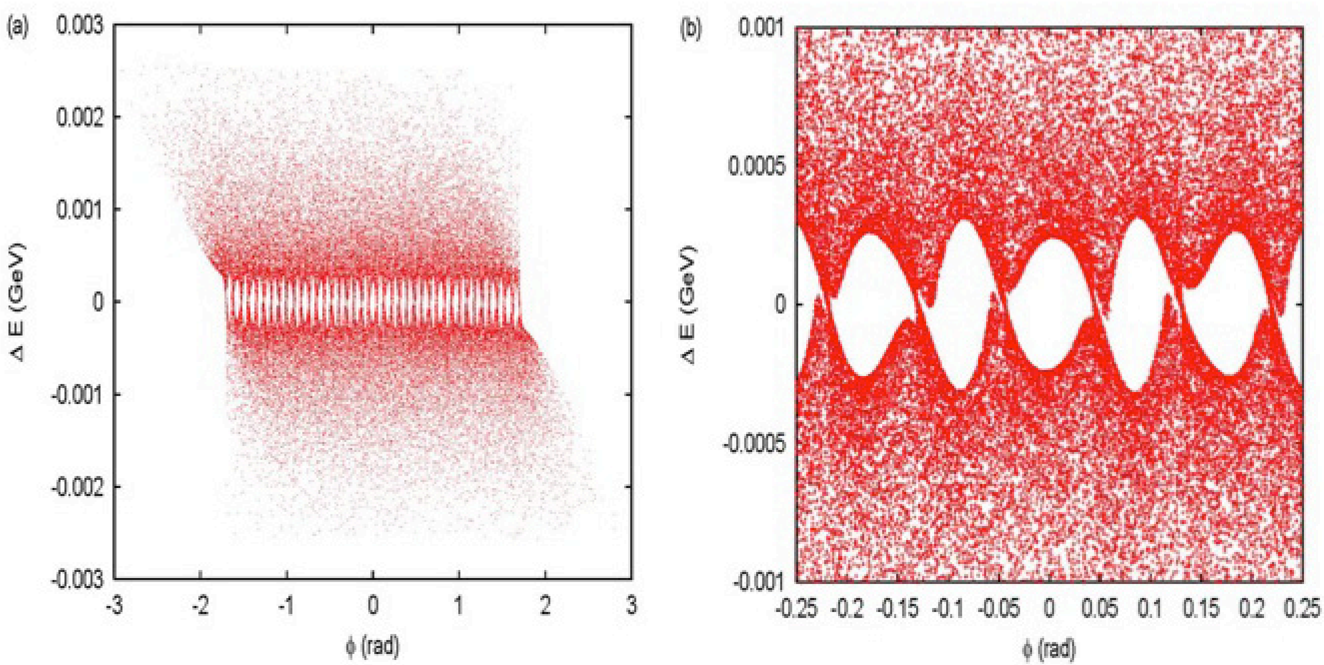
Sample PSD plot for unstable beam PW=200, 9/25/2010

- Data for 72.070 subharmonic operation and 3.5 μC accumulated charge in the ring
- Mode 35 corresponds to a frequency around 100 MHz for the unstable motion
- Fairly typical spectrum but with somewhat slower growth rate
- Need a systematic study of unstable motion, mode spectra and growth rates to see any trends between the 72.000 and 72.070 subharmonic regimes



Interesting (related?) results for coasting beam in PSR at 72.000

- **For years it was observed that the 201.25 MHz linac rf structure persisted in a long bunch coasting beam (rf buncher off) long after one expected it to be washed out by the momentum spread of the beam**
- **S. Cousineau, et al* found the space charge effect explanation in longitudinal simulations using ORBIT for 559 turns of injection and 800 turns of storage**



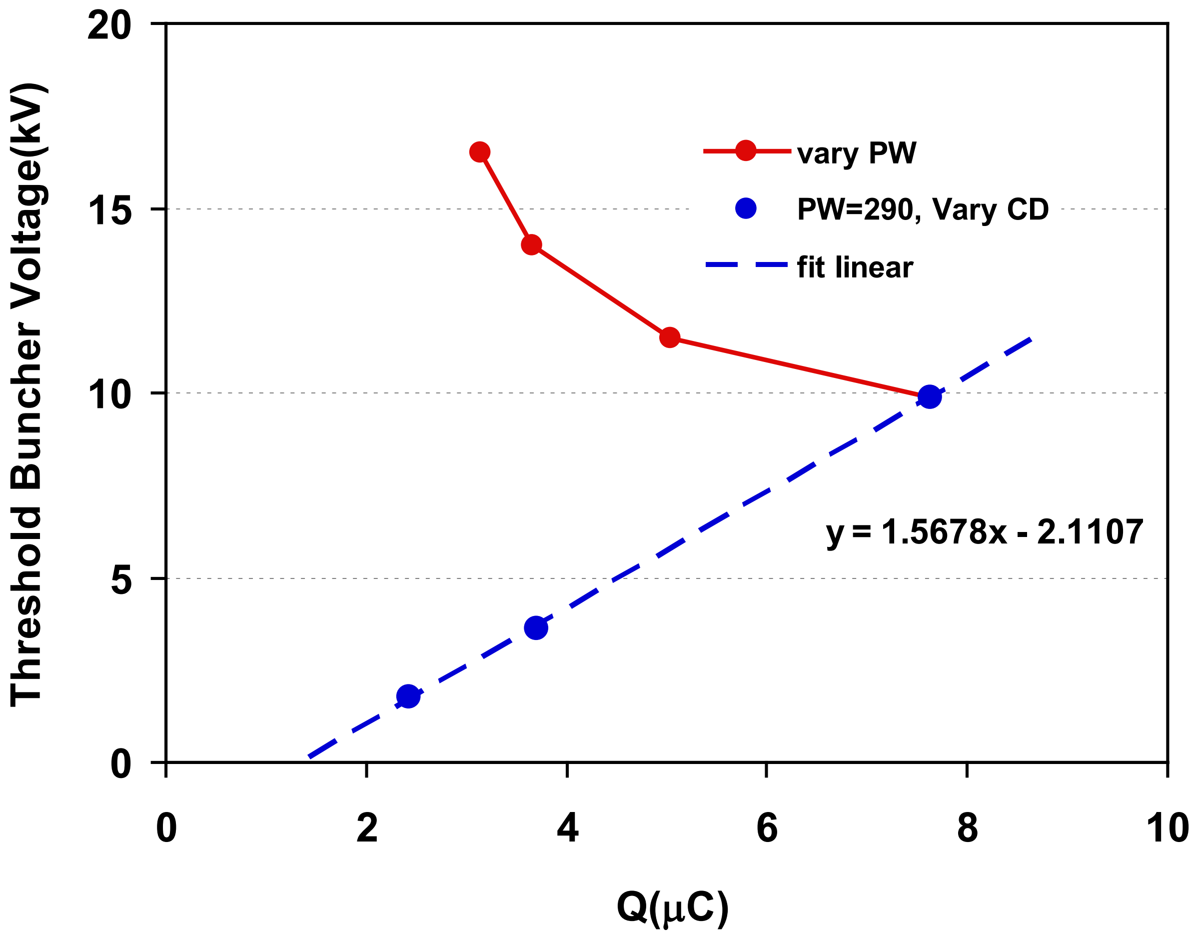
***PRST-AB vol 7, 094201 (2004) fig 6.**

Comments and Preliminary Conclusions

- **The short pulse instability phenomenon for the present operation at 72.070 subharmonic ring frequency was unexpected and is not well understood**
  - We still have some interesting beam physics to uncover regarding the "short pulse instability"
- **As noted earlier, the e-p instability threshold is a delicate balance between damping mechanisms (mainly Landau damping) and driving mechanisms (coupled oscillations of beam and electron cloud).**
- **Perhaps the right question is why were short pulses more stable when operating at the exact 72.000 subharmonic?**
- **We have collected digitized BPM, beam current and electron cloud signals under a variety of conditions but have yet to systematically analyze for further clues**
- **Also plan to work on simulations of electron cloud for a sequence of measured beam profiles**

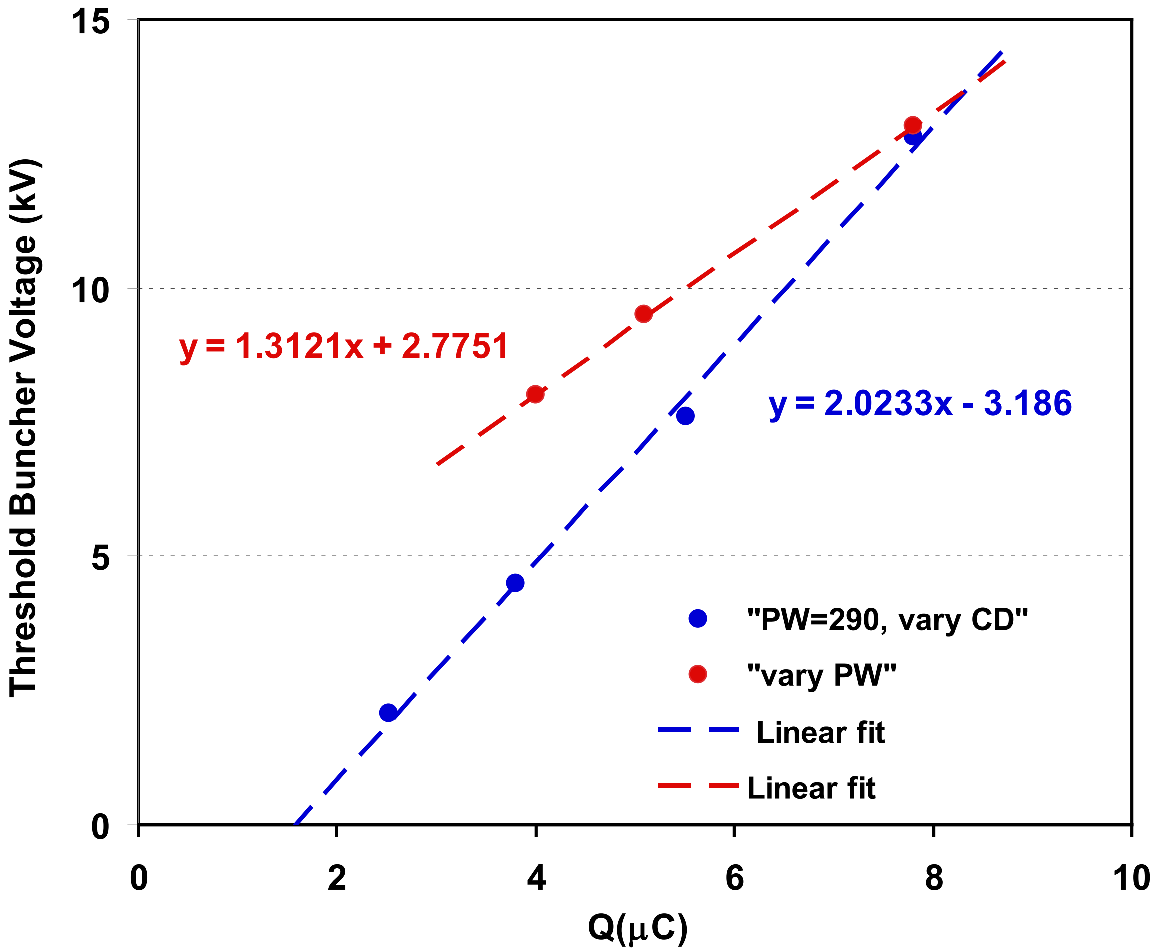
backups

Data for 72.070 subharmonic conditions 7/15/2010



Vary PW = 290, 200, 150, 130 ns

Some results for 72.009 subharmonic, 7/15/2010



Vary PW =
290, 200, 160 ns