30 Hz Harmonic/γ-t System (WBS 1.2.4 and 1.2.5)

Eric Prebys*

*Presenting studies and calculations by Jim Maclachlan and Yang, Xi

Gamma-t System

- Transition:
  - The energy at which the beam goes from being velocity dominated to momentum dominated (i.e. dT/dE switches sign)
  - At the transition energy, there is no longitudinal stability, so it's important to get through it as quickly as possible.
- Gamma-t "Jump" System":
  - Just before the beam reaches transition, a system of pulsed quadrupoles rapidly lowers the transition energy to below that of the beam, so the beam effectively "jumps" through transition.

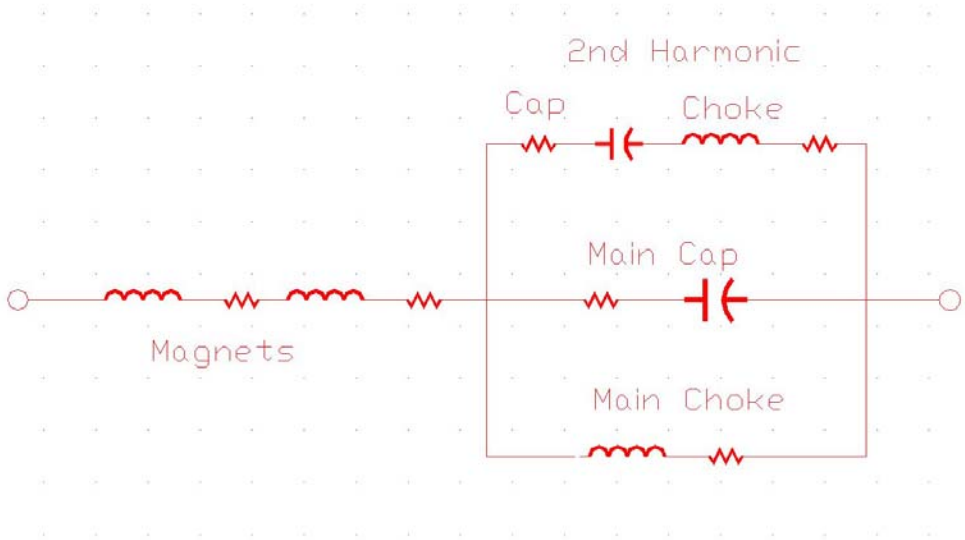
Booster Gamma-t System

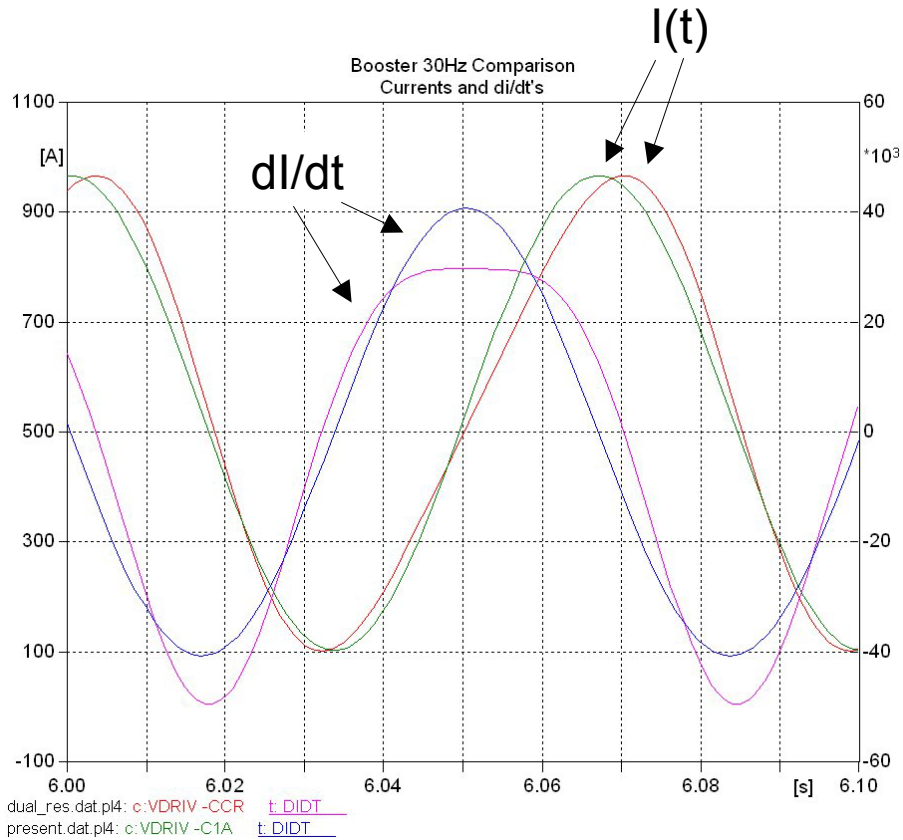
- Specifications:
  - 12 pulsed quadrupoles located in every other short straight section of the Booster
  - Capable of 1 unit of gamma-t reduction (probably too much)
  - Installed in late 80's
- Problems:
  - Difficult to align
    - Pulsing system results in beam motion
  - Works too well
    - Historically, reducing longitudinal emittance exacerbated coupled bunch oscillations after transition
    - Probably better with current damping system
  - Rate
    - Some issues running at current rate
- Never really used operationally
- Might be necessary to go to higher batch intensity
- Must coordinate with corrector system
  - Existing design incompatible with new corrector system
  - Must either remove system or replace magnets in ~2007

30 Hz Harmonic

- Lattice magnets run in 15 Hz offset resonant circuit.
- No control over ramp rate
- By adding capacitors and a choke, we could add a 30 Hz component to the cycle, with adjustable amplitude and phase.
- Dramatically increase control over ramp rate
- Compensate for Booster impedance and optimize bucket area through cycle.
- Decreases dE/dt
  - Effectively increases RF voltage, BUT
  - Slows transition crossing
  - -> 30 Hz harmonic and gamma-t jump probably go together

30 Hz Concept



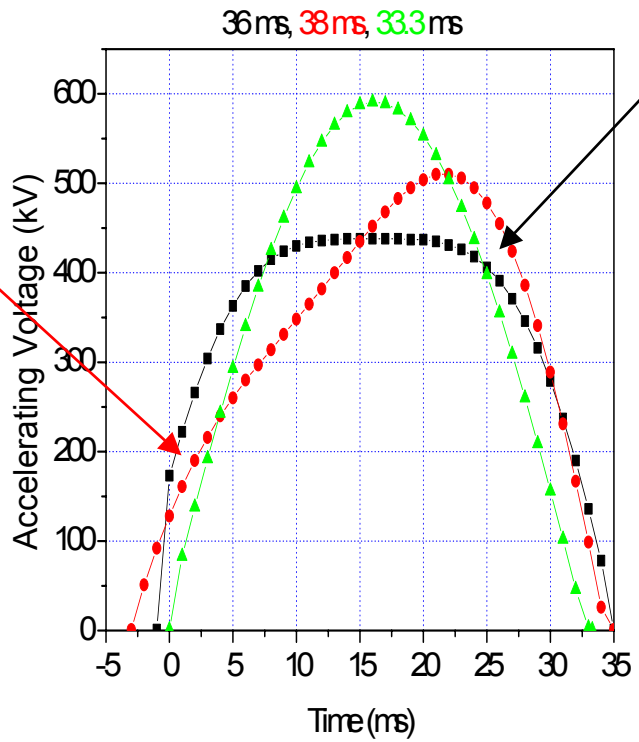


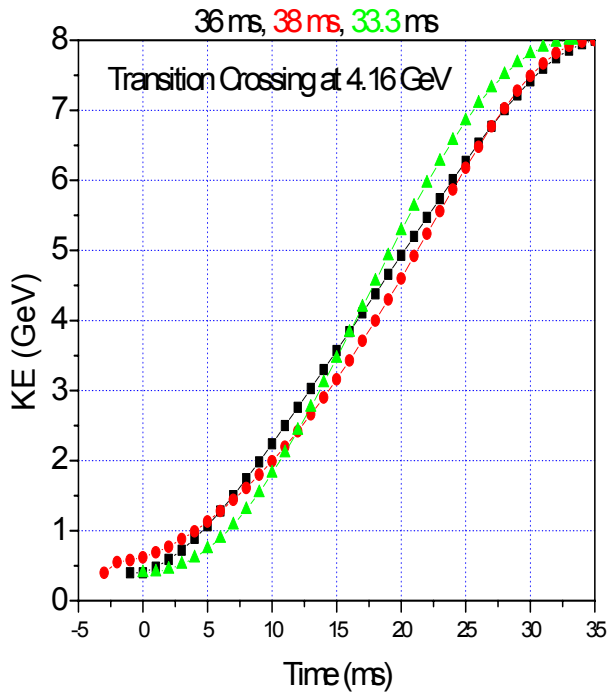
Options for 30 Hz Component

$$\sin(w\cdot t) + a\cdot\sin(2\cdot w\cdot t + \phi)$$

Maximize Bucket area early in cycles

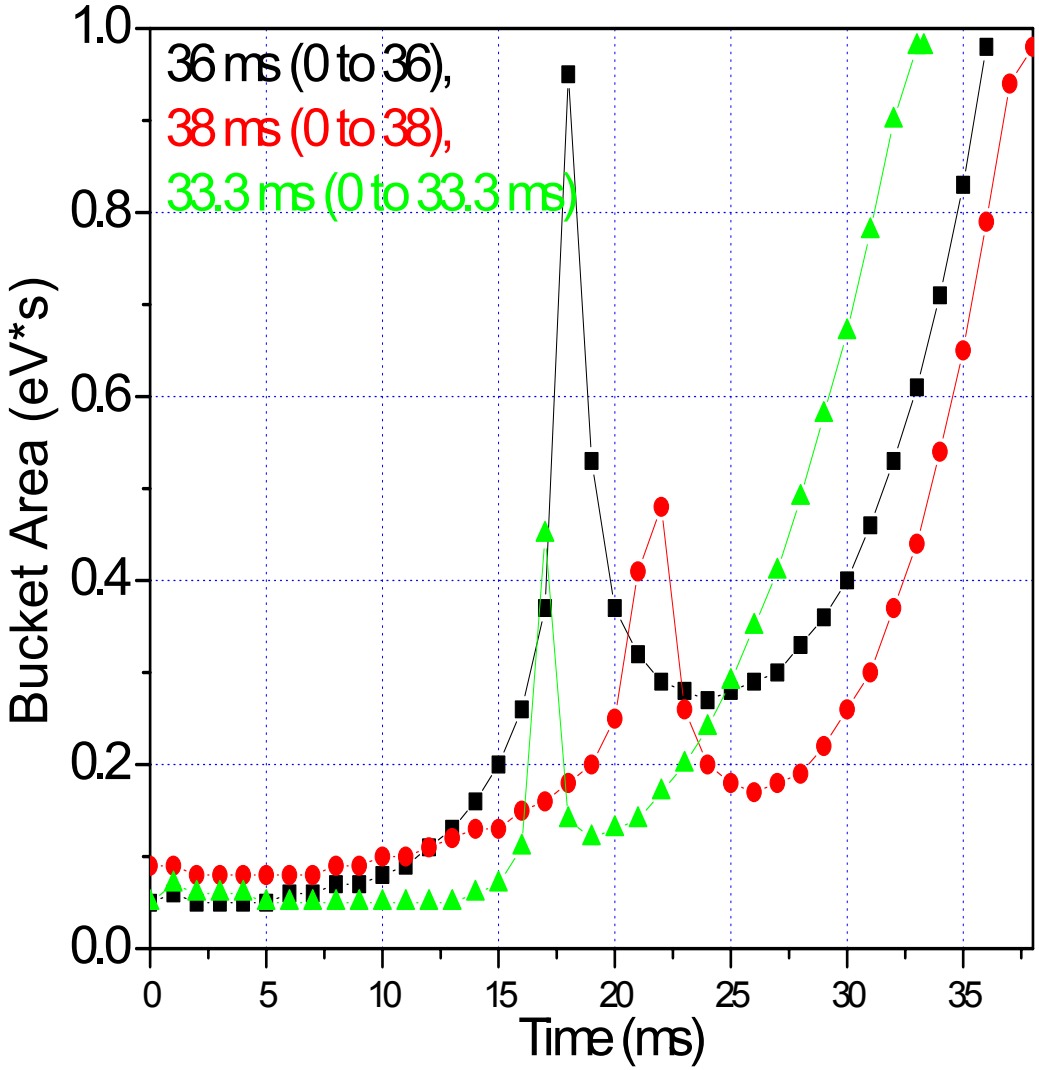
Maximize bucket area at transition





$$\phi_{red}=\frac{\pi}{1.4},\phi_{black}=\frac{\pi}{2},a=0.25$$

Available Bucket Area

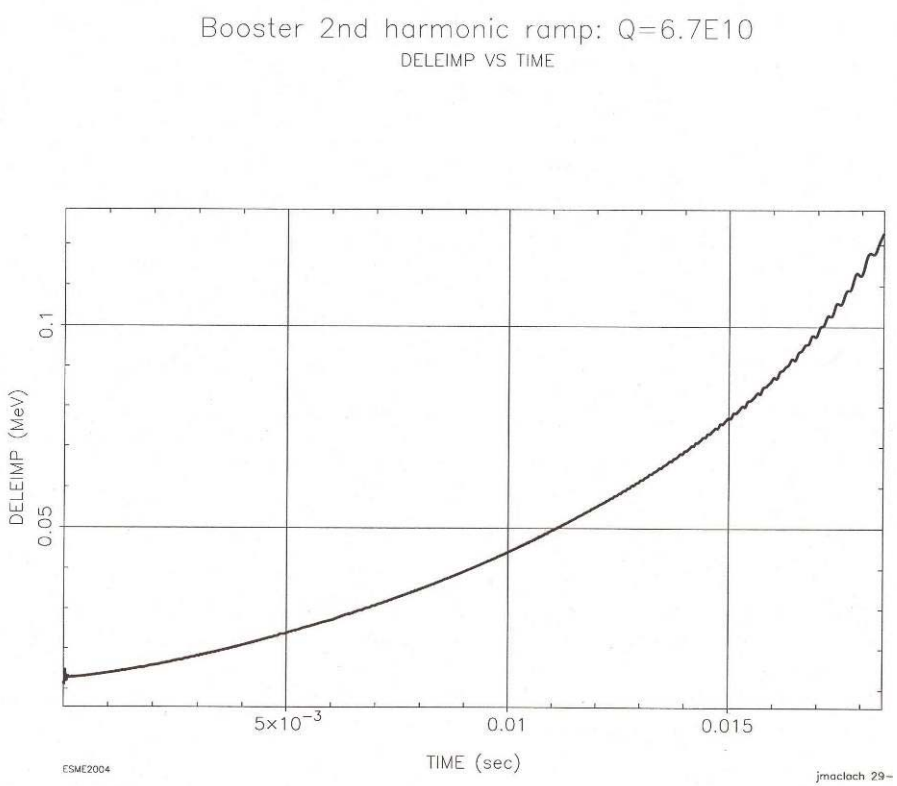


Booster Longitudinal Modeling

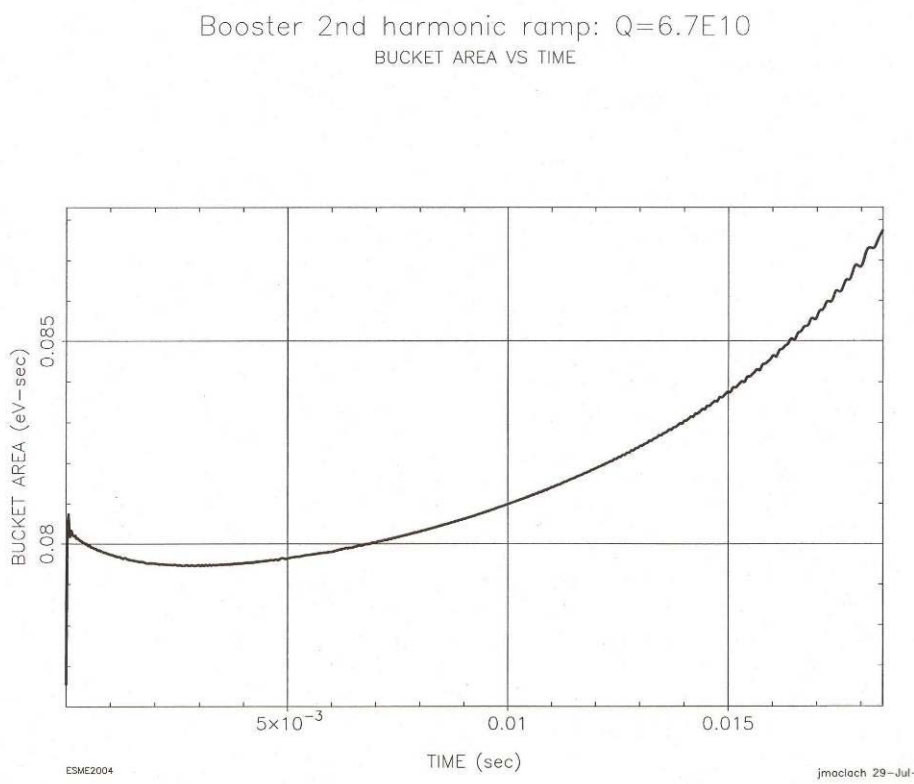
- ESME Model
- As accurate an impedance model as we have
- Realistic capture and transition

Effect of 30 Hz/gamma-t

Optimized at Transition:

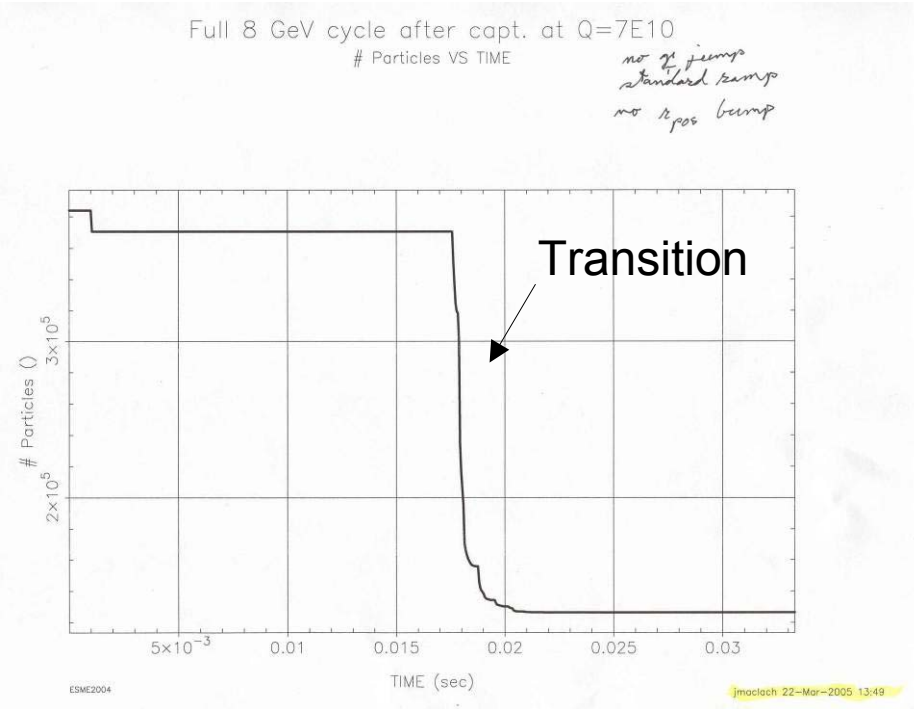


Effective RF Loss to impedance

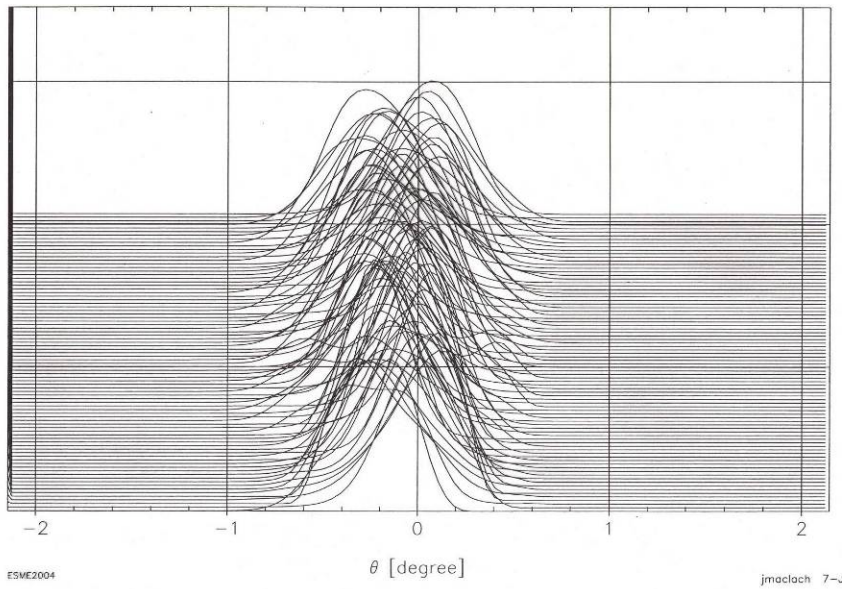


Bucket area w/2nd harmonic

Simulations at transition

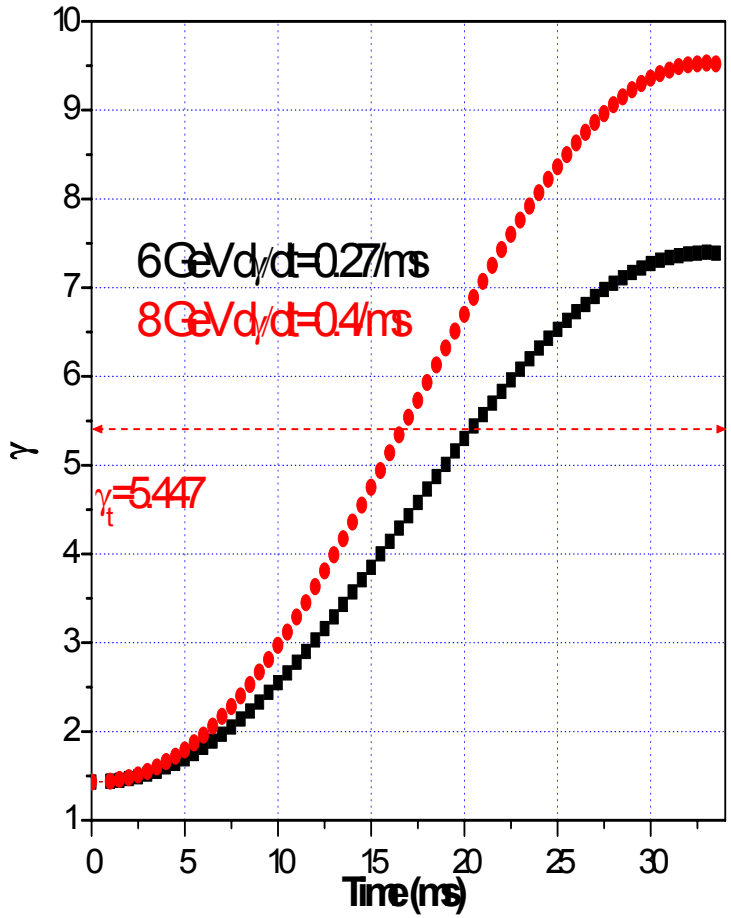


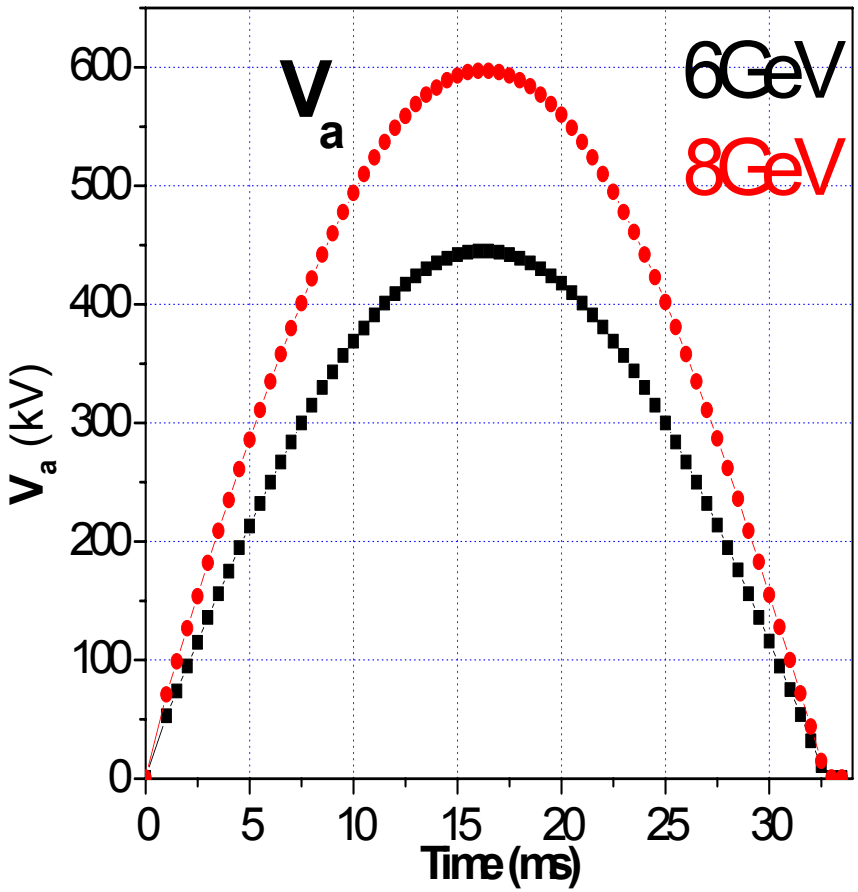
5.6E12 total protons w/o gamma-t



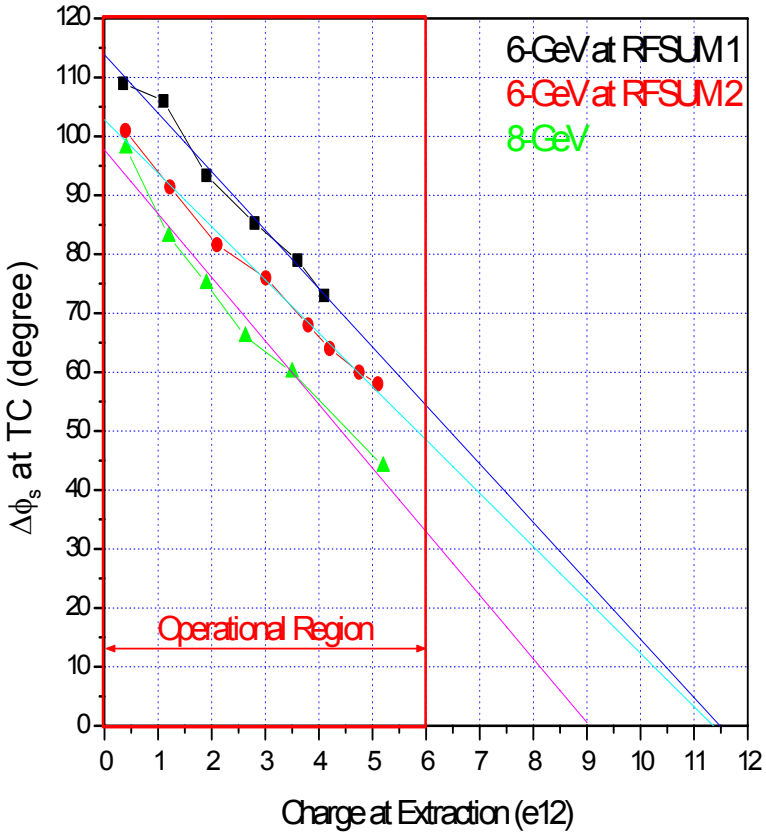
- Mountain range through transition
- 30 Hz+ .3 unit gamma-t
- 6.4E12
- <1% beam loss at transition

6 GeV Studies (2004 Shutdown)





Transition Phase Jump vs. Intensity



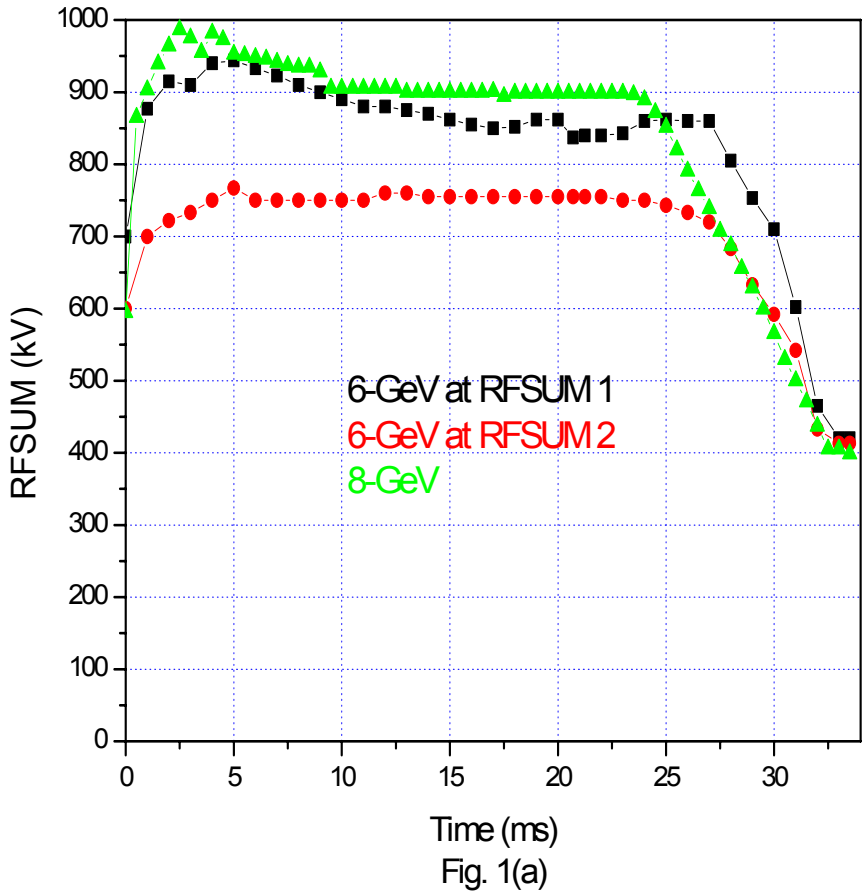


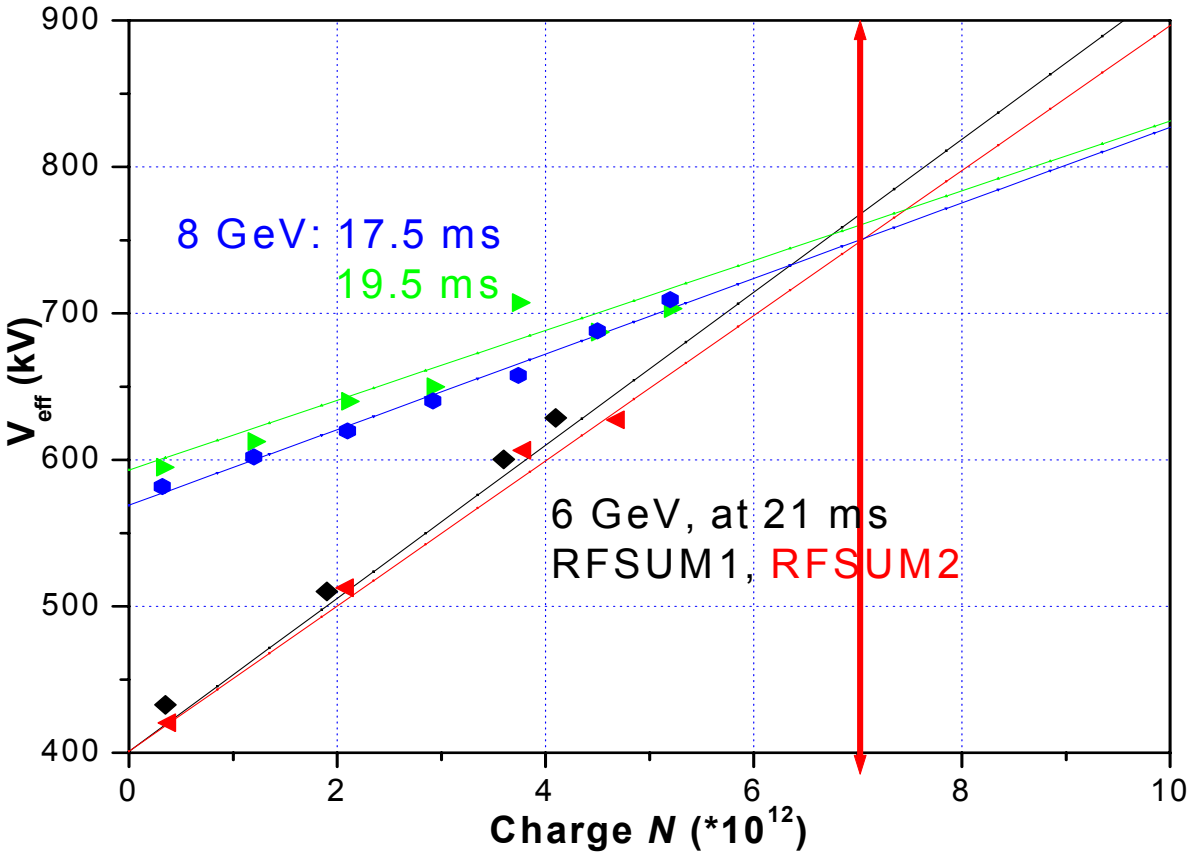
Fig. 1(a)

Effective Accelerating Voltage

$$V_{eff} = V_a + V_L = V_{RF} \times \sin(\varphi_s).$$

- V_a: the energy independent accelerating voltage required by the rate of change of the Booster magnetic field (dB/dt) in a cycle
- V_L: the beam energy loss due to the real impedance of the ring, $V_L = a \times N + b$
- V_{RF}: RF Accelerating Volage (measured)
- ϕ_s: Accelerating phase at transition (measured)
- V_{eff}: the effective accelerating voltage seen by the beam per Booster turn (derived)

Effective Accelerating Voltage

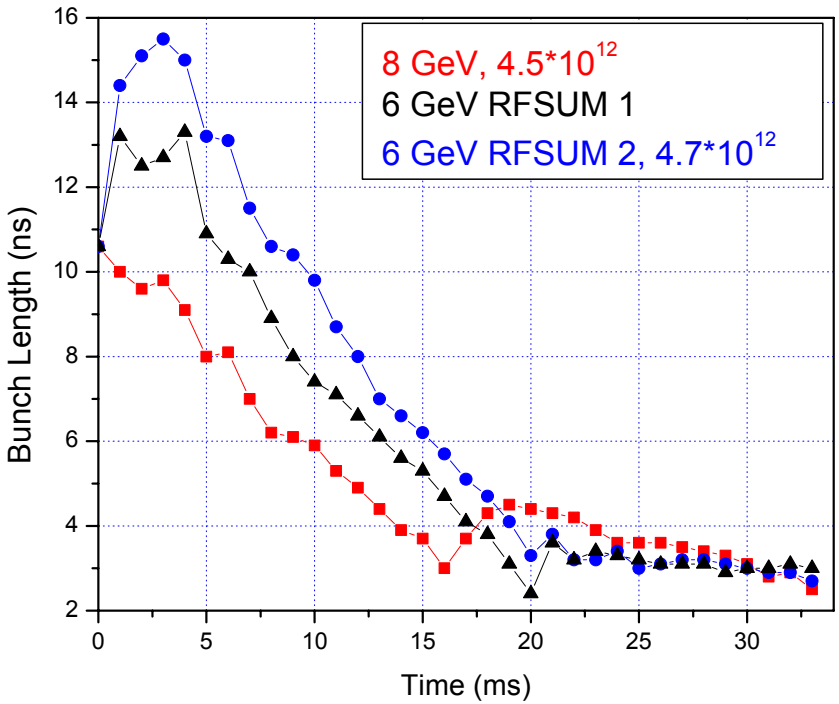


Not fully understood

$$V_L = a \times N + b$$

$$a_{8GeV} / a_{6GeV} \approx 23.8 / 49.6 \approx 0.5$$

Possible Explanation



Slower the transition crossing

↓

Shorter the bunch length

↓

Higher the peak current

↓

Higher the beam energy loss

- 8 GeV at 17.5 ms, BL 4.3 ns,
- 6 GeV at 21 ms, BL 3.2 ns,
- Peak current I_P: $N \cdot e / \sqrt{2\pi}\sigma_t$

$$\left(I_{p,8GeV}\right)/\left(I_{p,6GeV}\right) = \left(N_{8GeV} \cdot \sigma_{t,6GeV}\right)/\left(N_{6GeV} \cdot \sigma_{t,8GeV}\right)$$

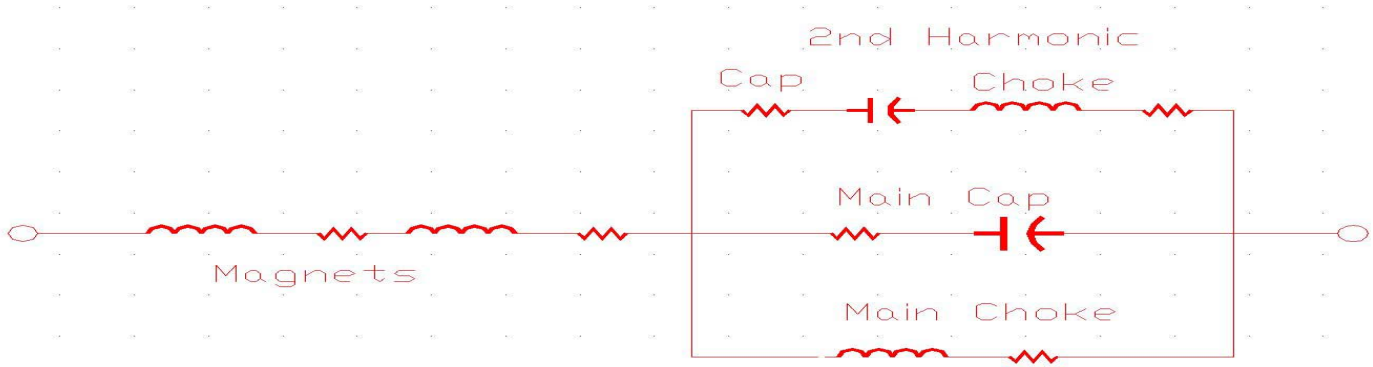
$$\approx \left(4.5/4.7\right) \cdot \left(3.2/4.3\right) \approx 0.71$$

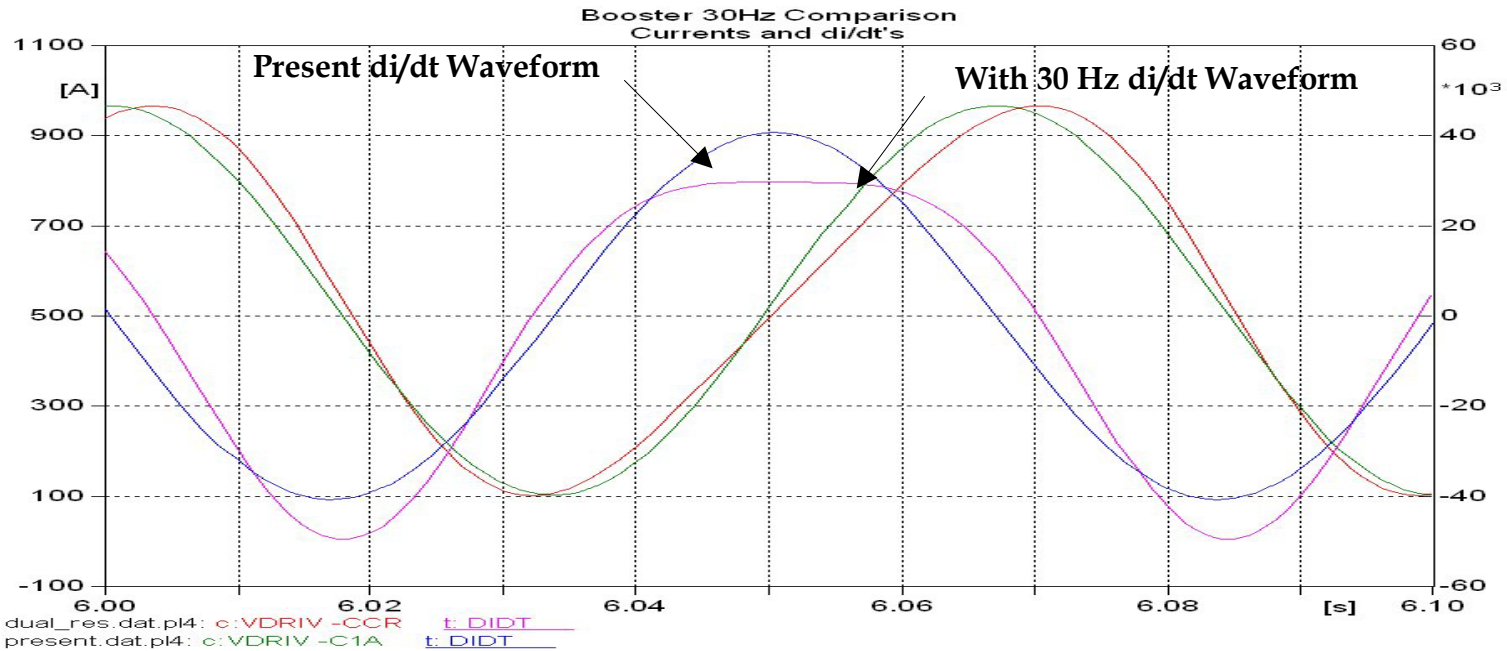
30 Hertz Harmonic - GMPS WBS 1.2.4

- If decision is made to proceed with project…
- Goal is to keep present magnets, chokes, and capacitors.
- Add additional components as necessary
  - Power Supply Changes
    - Power supplies need to invert
    - All 4 existing power supplies will be needed for normal operation.
    - Possible modifications to PS passive filter.
    - New second harmonic cap bank is needed.
    - New second harmonic choke is needed.
    - New regulation system needs to be developed.
- Power Supply constraints will need to be considered
  - New setup will require all supplies to be on (only 3 needed now)
  - Voltage to ground will be higher
  - Currently being studied in prototype girder

D. Wolff, J Maclachlan,Xi Yang

GMPS Girder Modifications





D. Wolff, J Maclachlan,Xi Yang

Cost of 30 Hz Modifications

D. Wolff, J Maclachlan,Xi Yang

Cost Summary (FY05 M&S):

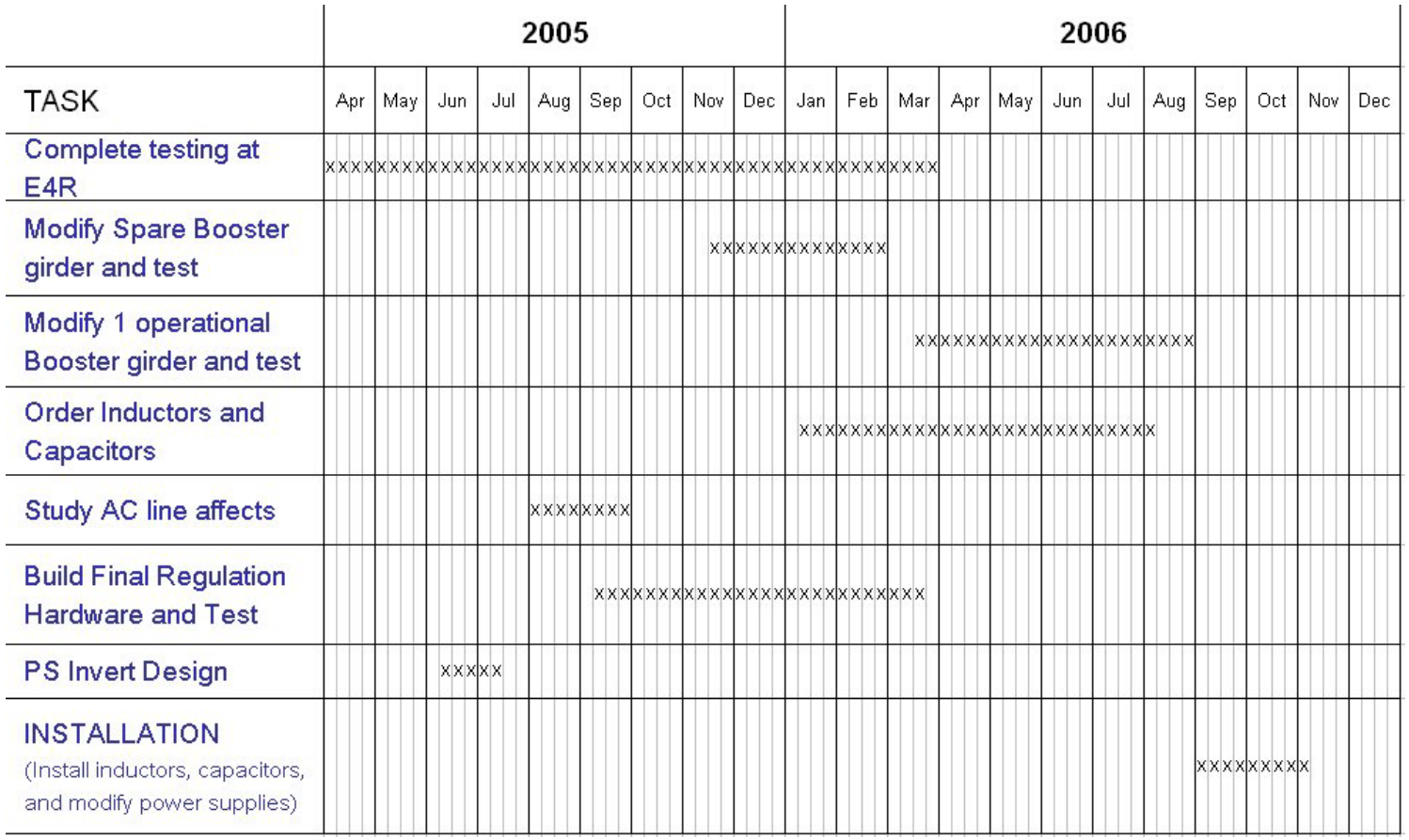
Prototype (E4R):		$50k
Chokes (quote soon):	$11k ea.	$550k
Capacitors (quote received):	$7k/girder	$350k
Misc.:	$2.2k/girder	$110k

Labor Summary:

Prototype:	Monthly, 1.5MY	Weekly, 1.0MY
Production:	Monthly, .75MY	Weekly, 1.0MY

279	**1.2.4.1**	**30 Hz Harmonic Prototype**	**$360,378**	**$50,258**	**40%**
234	1.2.4.1.1	GMPS Modification	$200,357	$0	**40%**
214	1.2.4.1.2	30 Hz Harmonic Prototype	$125,393	$50,258	**40%**
426	1.2.4.1.3	Review 30 Hz Harmonic Prototype	$0	$0	**0%**
233	1.2.4.1.4	30 Hz Harmonic Project Decision	$0	$0	**0%**
230	1.2.4.1.5	30Hz Girder Design	$34,627	$0	**40%**
280	**1.2.4.2**	**30 Hz Harmonic Production**	**$241,270**	**$1,034,168**	**40%**
232	1.2.4.2.1	30Hz Procurement	$1,741	$953,984	**40%**
333	1.2.4.2.2	30Hz Delivery	$0	$0	**0%**
231	1.2.4.2.3	30Hz Installation	$239,529	$80,184	**40%**
316	1.2.4.2.4	30Hz Installation Complete	$0	$0	**0%**

Schedule of 30 Hz Modification (shift ~1 year)



Critical Path: Beam Physics Study!
E4R testing (waiting for chokes and caps)
Ordering and receiving production units

D. Wolff, J Maclachlan,Xi Yang

Gamma-t project (WBS 1.2.5)

- If we decide to proceed with project, the 12 existing gamma-t magnets will be replaced during the corrector upgrade
  - Install ~2007
  - Allocated total $321 K in plan, based on TD estimate
  - Schedule not worked out yet
  - Not considered a major project

Conclusions

- We've made great progress in understanding the longitudinal dynamics of the Booster
- Simulations look very promising for gamma-t/30 Hz combination
  - Could potentially accelerate ~6.5E12 protons
- Working to find optimum configuration
- 6 GeV studies somewhat ambiguous
  - Hope to repeat and augment after upcoming shutdown
- Decision date for project ~1/06
  - Gamma-t system would require new magnets installed along with new corrector system
  - Plan in place for 30 Hz Upgrade if decision is made