Multivariate PreInjector Simulation With PARMELA/ROOT

Tom Schwarz, Dan Amidei
University of Michigan

James Rosenzweig
UCLA

Advisory: Marc Ross, John Sheppard, Tor Raubenheimer

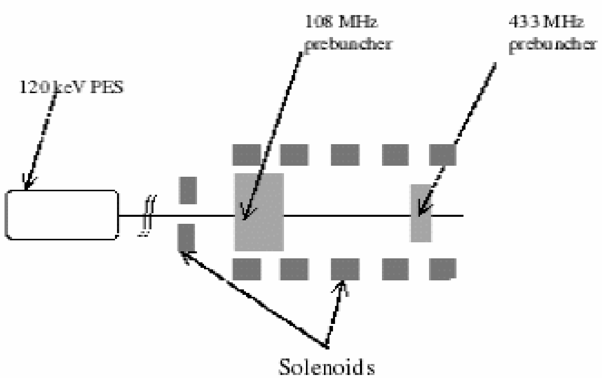
Multivariate Simulation With PARMELA/ROOT

- Bringing Particle Physics Data Handling Capabilities To Accelerator Simulation
- Perform Multiple Variable Input Scans In UCLA PARMELA And Use Data Handling Capabilities Of ROOT(CERN) For Analysis
- PARMELA Combined With AWK (A Pattern Scanning Language) Commands Used For Multivariate Scan
- ROOT Provides Analysis Capabilities To Easily Find Tolerances, Sensitivities, Performance Sweet Spots, Correlations, Etc.

The Method Allows You To Perform Large Simulations That Scan Over Several Variables, Then Do Analysis In A Framework Built For Large Amounts Of Data

PreInjector Comparison To Outside Work (Curtoni And Jablonka)

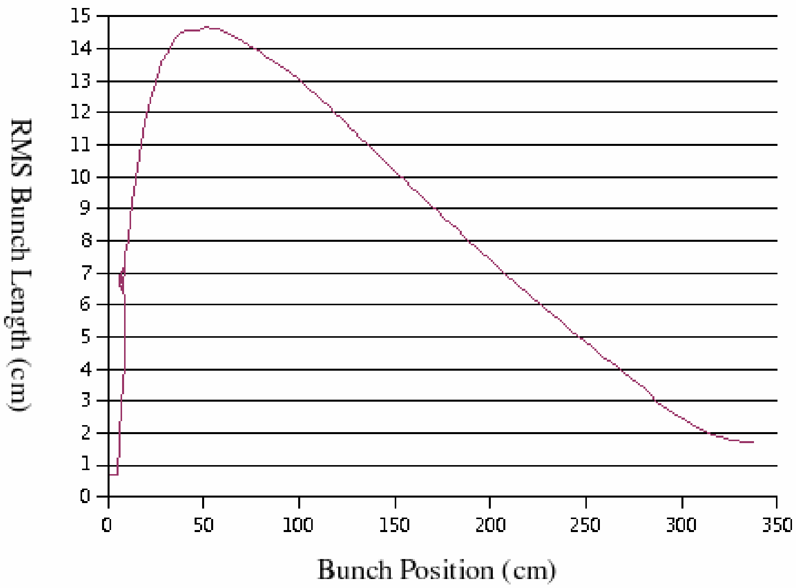
- Pre-Bunchers Simulated In TESLA PreAccelerator Study (Curtoni and Jablonka, Saclay, TESLA Note 2001-22-2)
- Used To Benchmark Our Simulations Against Published Work



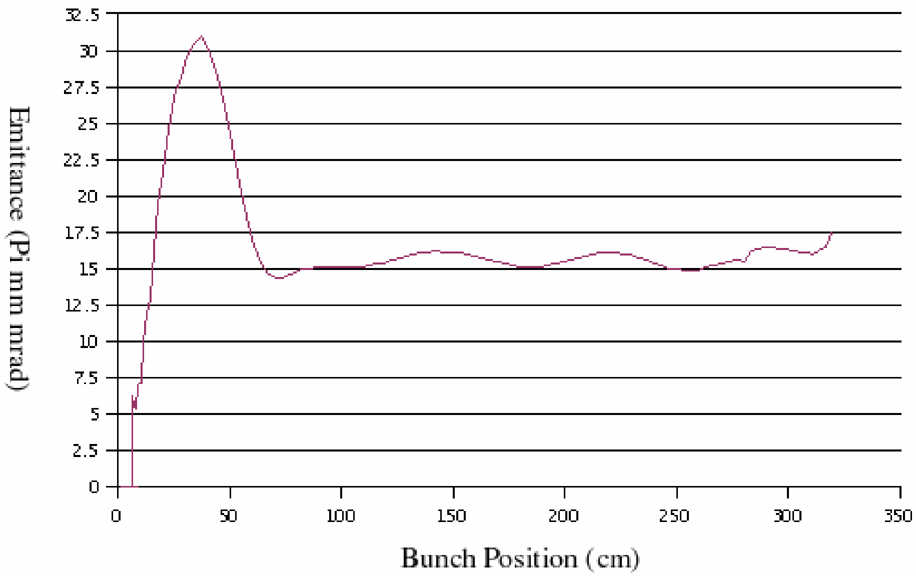
PARAMETER	VALUE	UNITS
Gun Voltage	120	KV
Bunch Length	2	ns RMS
Beam Radius	5	mm RMS
Charge	2.0E+10	Electrons
1st PreBuncher Frequency	108	Mhz
2nd PreBuncher Frequency	433	Mhz
1st PreBuncher Voltage	40	KV
2nd PreBuncher Voltage	44	KV
SHB1 Position From Cathode	78	cm
SHB2 Position From Cathode	280	cm

Comparison

Bunch Length vs. Position



Emittance vs. Position



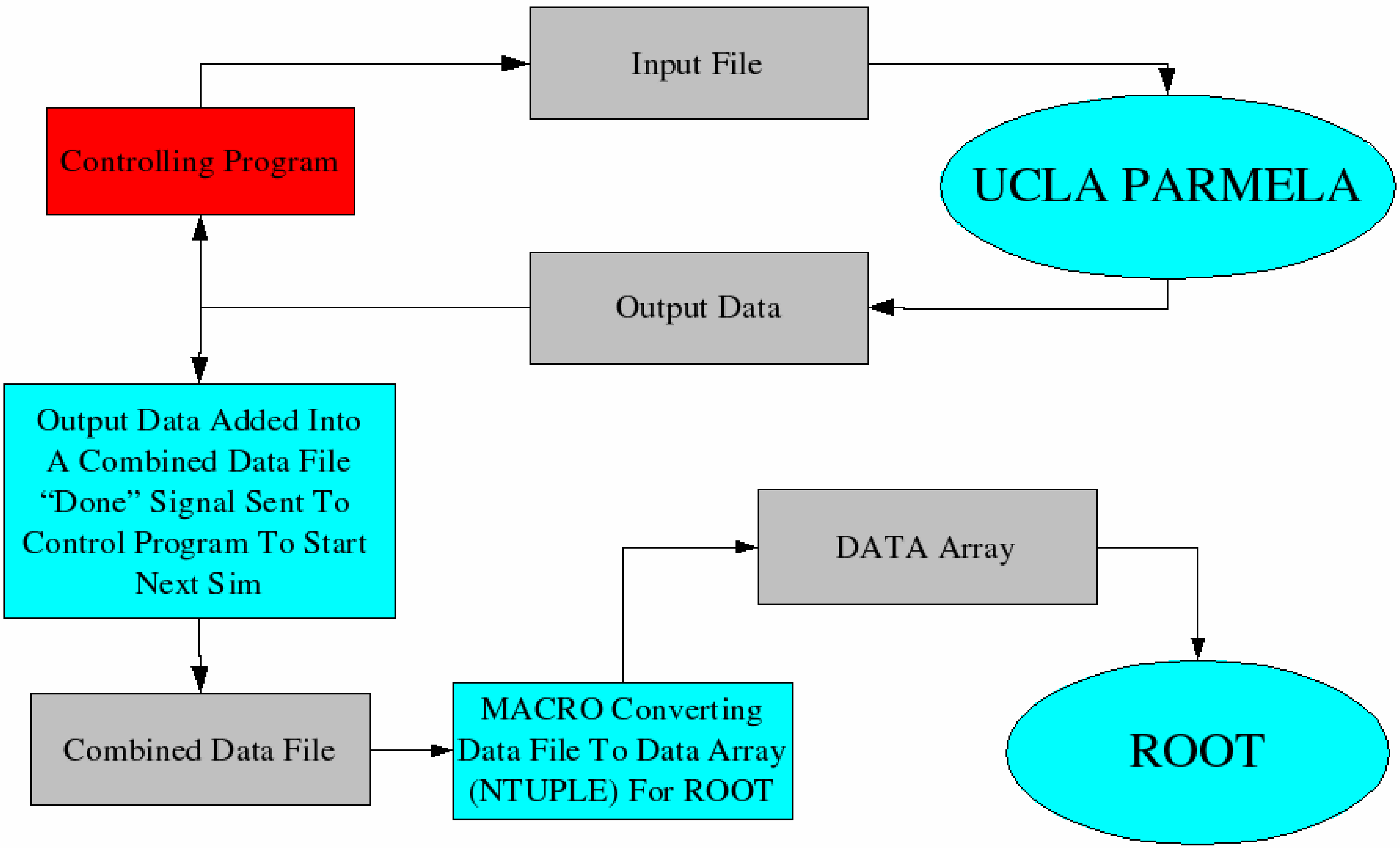
PARAMETER (END OF 2nd PreBuncher)	Jablonka/Curtoni	Our Sim	UNITS
Normalized Emittance	22	17	Pi mm mrad
Bunched Length	94	91	ps RMS
Beam Radius	6	5	mm RMS

Example: What Range Of Input Parameters Is Compatible With Performance Tolerances

- Accelerator Needs To Perform Within Certain Tolerances
  PARMELA/ROOT Used To Find Range Of Input Parameters For Operation
- DC Gun, prebunching cavity, and two solenoids
- ~ 8000 PARMELA Simulations Run
- Large CPU Allows For Fine Scan

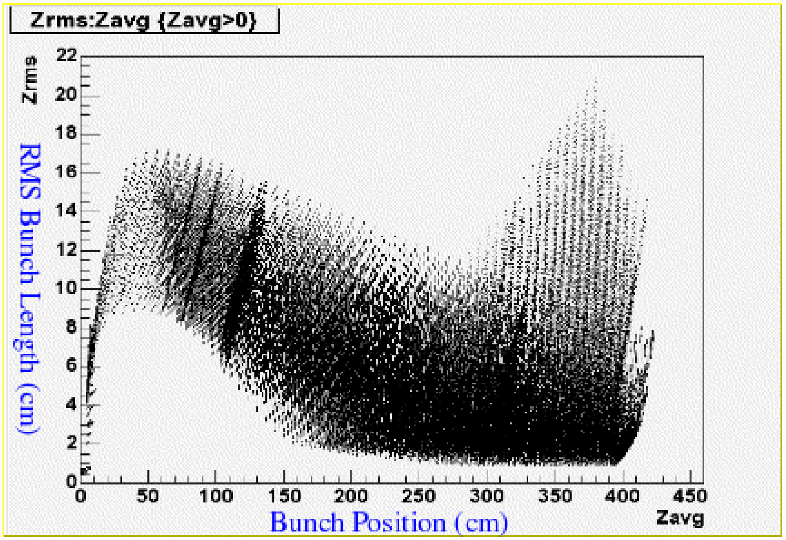
PARAMETER	Min	Max	UNITS
Gun Voltage	120	200	KV
Bunch Length	0.5	2	ns RMS
Beam Radius	5	5	mm RMS
Pre-Buncher Freq.	108	432	Mhz
Charge	1.0E+10	2.50E+10	Electrons
Buncher Efield	40	60	KV

Method

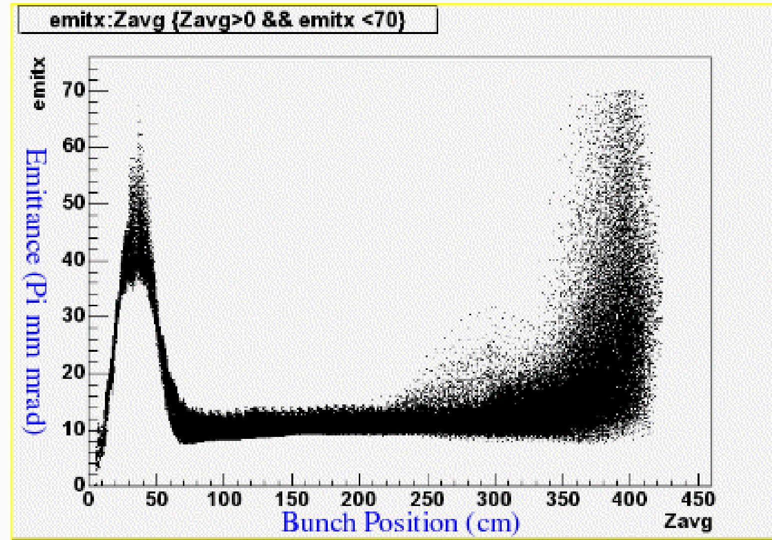

Input File
Controlling Program
UCLA PARMELA
Output Data
Output Data Added Into
A Combined Data File
“Done” Signal Sent To
Control Program To Start
Next Sim
DATA Array
Combined Data File
MACRO Converting
Data File To Data Array
(NTUPLE) For ROOT
ROOT

Cuts On Data

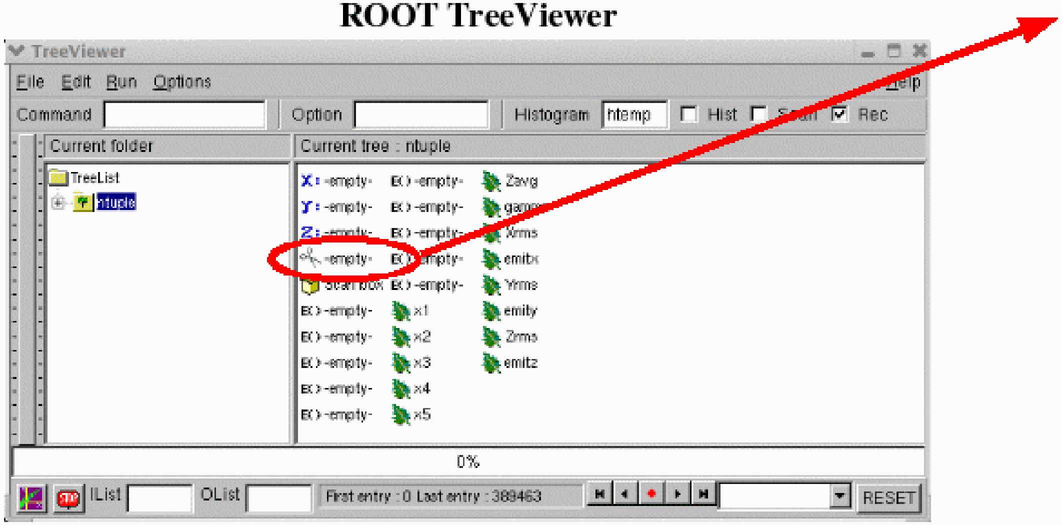
Bunch Length vs. Position



Emittance vs. Position



ROOT TreeViewer



Performance and Input Constraints:

Position ~ 250 to 260 cm

Emittance < 12 Pi mm-mrad

Bunch Length < 200 ps

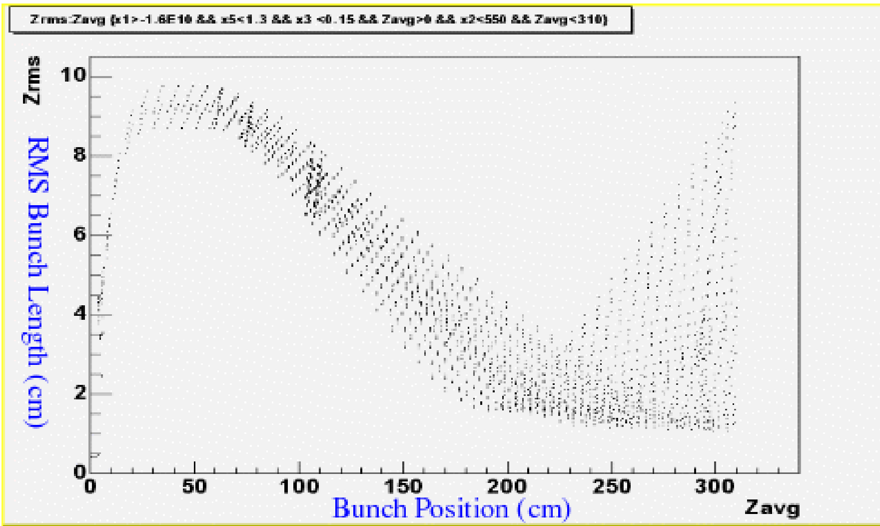
Charge < 1.6e10 e-'s

Buncher Voltage < 44 kV

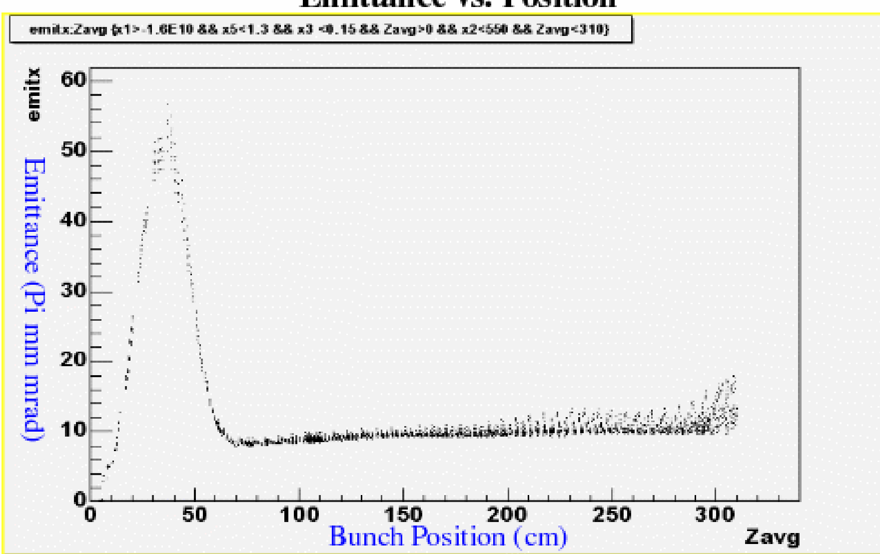
Gun Voltage < 150 kV

What Range of Inputs Satisfy This?

Bunch Length vs. Position

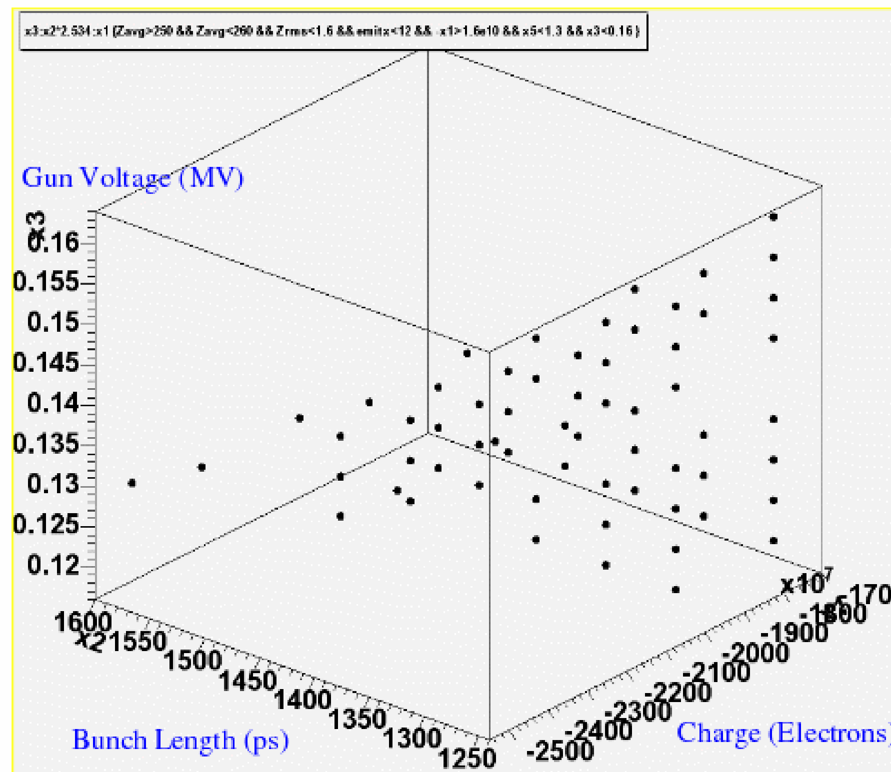


Emittance vs. Position



Range of Performance
Leads To Range Of Input

Gun Voltage vs. Charge vs. Bunch Length



Example: NLC/TESLA PreInjector Sensitivities

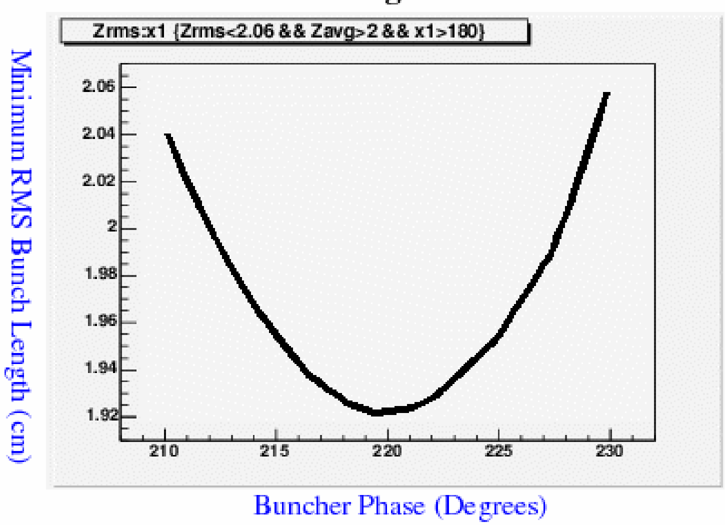
- PreBuncher Performance Sensitivity
- The Following Might Be Of Interest:
  - What is the optimum phase?
  - How quickly will buncher performance degrade if phase is unstable?
  - Are we working ourselves into too tight a tolerance?
  - If we have some jitter in frequency in the buncher how bad will buncher performance degrade?

NLC/TESLA Sensitivity Plots

NLC Phase Sensitivity

PARAMETER	Value	UNITS
Gun Voltage	175	KV
Bunch Length	0.5	ns RMS
Beam Radius	5	mm RMS
Pre-Buncher Freq.	714	Mhz
# Charges	1.2E+10	Electrons
Buncher Efield	40	KV

Min Bunch Length vs Phase

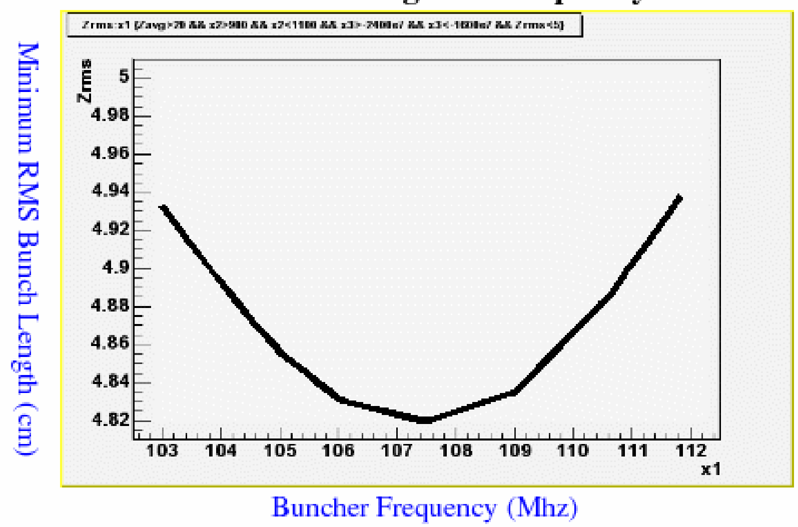


- NLC Min Bunch Length vs. phase in buncher
- 2% Change In Min Bunch Length -> +/- 6 degrees in phase

TESLA Frequency Sensitivity

PARAMETER	Value	UNITS
Gun Voltage	120	KV
Bunch Length	2	ns RMS
Beam Radius	5	mm RMS
Pre-Buncher Freq.	108	Mhz
# Charges	200E+08	Electrons
Buncher Efield	40	KV

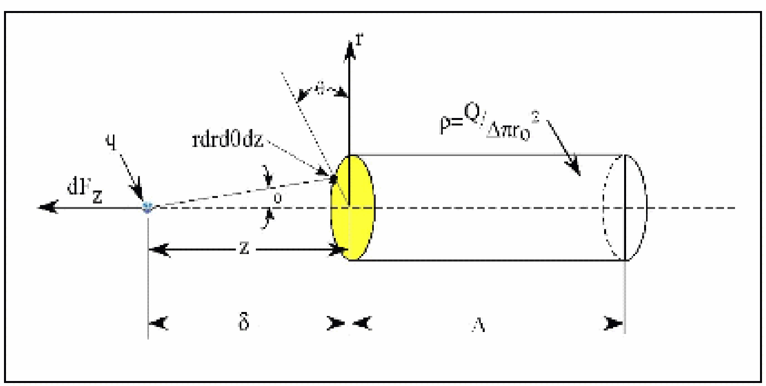
Min Bunch Length vs Frequency



- TESLA Min Bunch Length vs. Freq in buncher
- 2% Change In Min Bunch Length -> +/- 4 Mhz in Buncher Freq

Example: Testing Scaling Of PreInjectors

- Can PreInjector Performance Be Scaled From The SLC Source To NLC?
- **J. Sheppard**: Can The Force On A Charge At The End Of A Bunch Be Used As An Indicator Of Performance (Used To Scale)?
- Same Force ~ Same Performance?



$$dF_z = \frac{q}{(4\pi\epsilon_o)} \frac{Q}{(\Delta\pi r_o^2)} r\cos(\phi)\, dr\, d\Theta \frac{dz}{(z^2 + r^2)}$$

$$F_z = \gamma m \ddot{z}$$

$$\ddot{z}\ \alpha\ \frac{Q}{(\Delta\gamma)}$$

$$\ddot{z}\ \alpha\ \frac{Q}{\Delta_t}(\gamma^2 - 1)^{(-1/2)}$$

$$\boxed{\frac{Q_1}{\Delta_{t1}}(\gamma_1^2 - 1)^{(-1/2)} = \frac{Q_2}{\Delta_{t2}}(\gamma_2^2 - 1)^{(-1/2)} \equiv M}$$

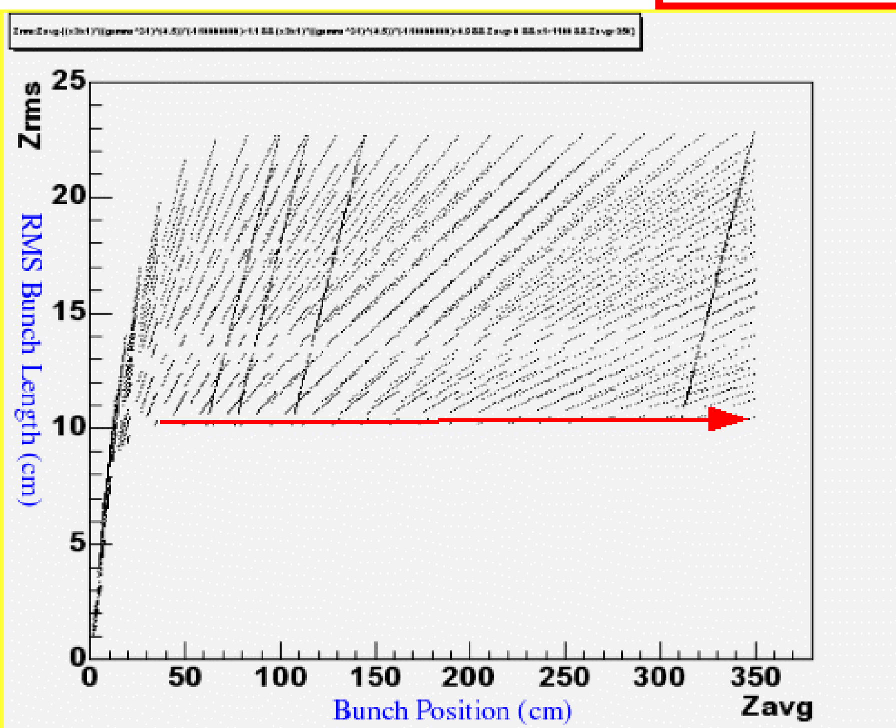
Results For Space Charge Alone

SCAN

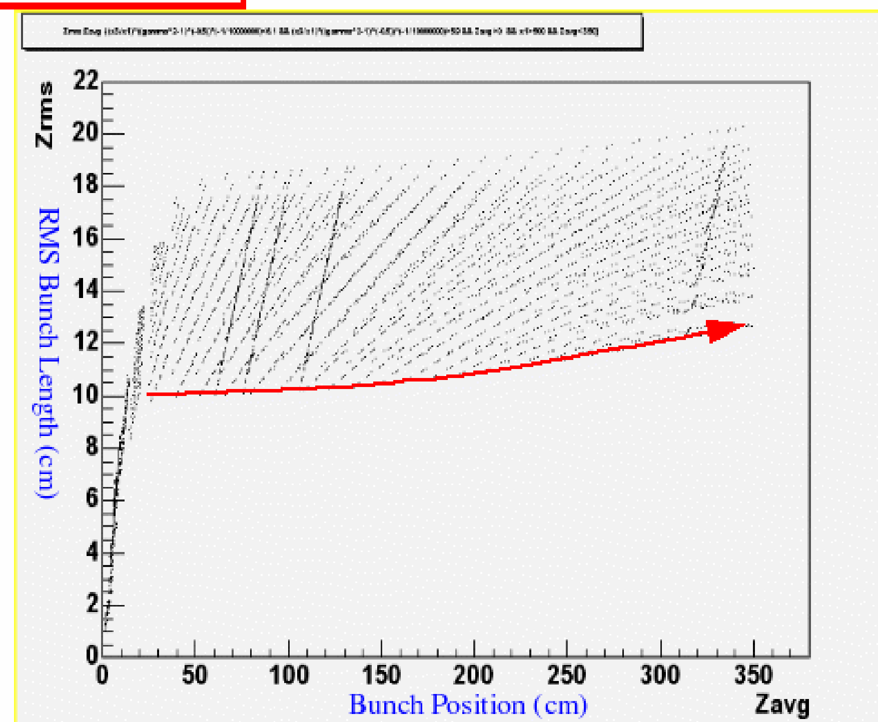
PARAMETER	Min	Max	UNITS
Gun Voltage	120	200	KV
Bunch Length	0.5	2	ns RMS
Charge	1.0E+10	5.00E+10	Electrons

$$\boxed{M = \frac{Q}{\Delta_l}(\gamma^2 - 1)^{(-1/2)} \quad \alpha \quad \ddot{z}}$$

Bunch Length vs. Position For M=1

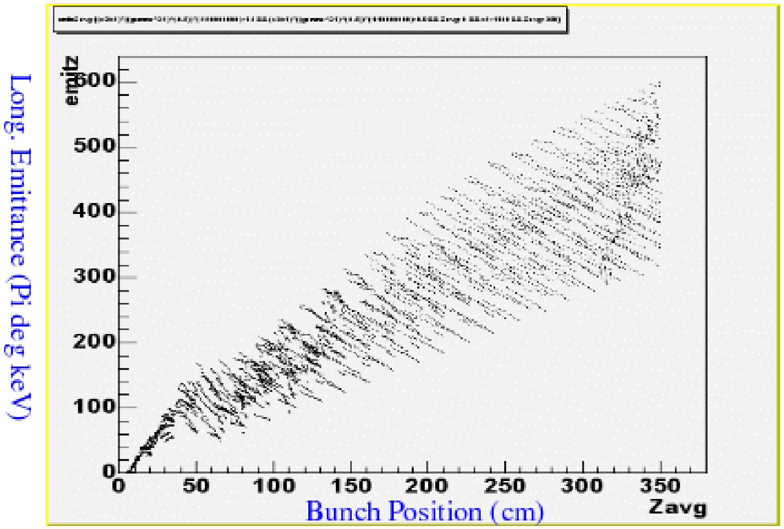


Bunch Length vs. Position For M=5

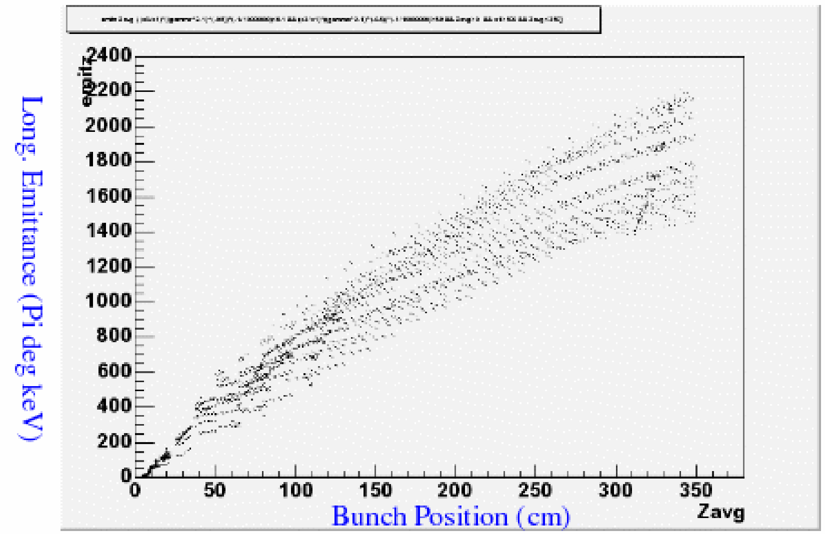


Emittance

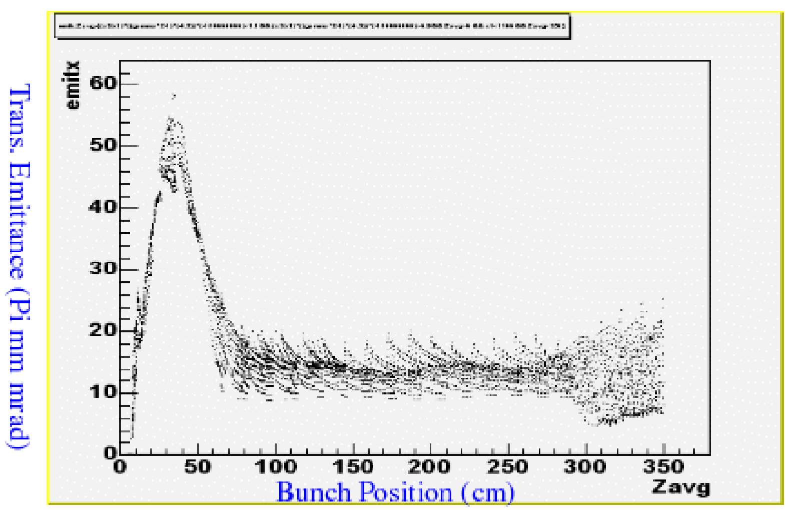
Long. Emittance vs. Position For M=1



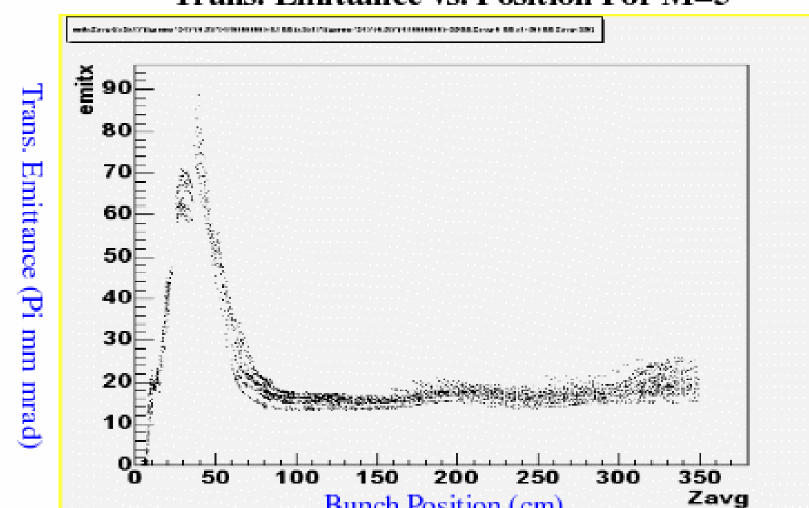
Long. Emittance vs. Position For M=5



Trans. Emittance vs. Position For M=1



Trans. Emittance vs. Position For M=5

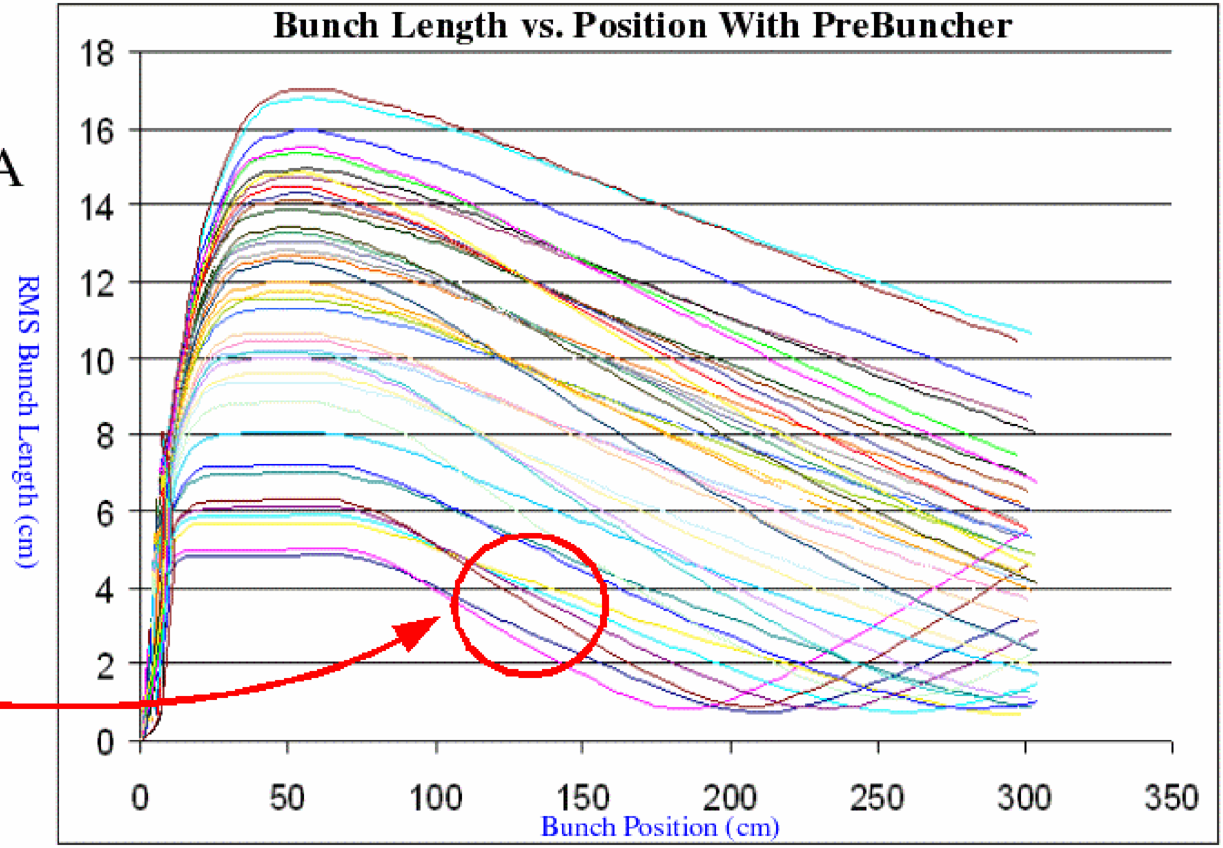


With Prebuncher

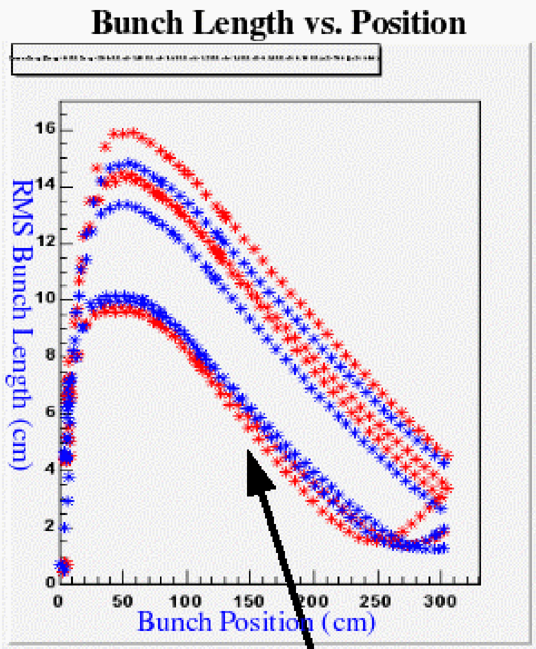
- Mostly Works Out Except For Extremes In Gun Voltage
- High Gun Voltage -> Less Time In PreBuncher
- Compensated By Raising Buncher Field, But With A Price

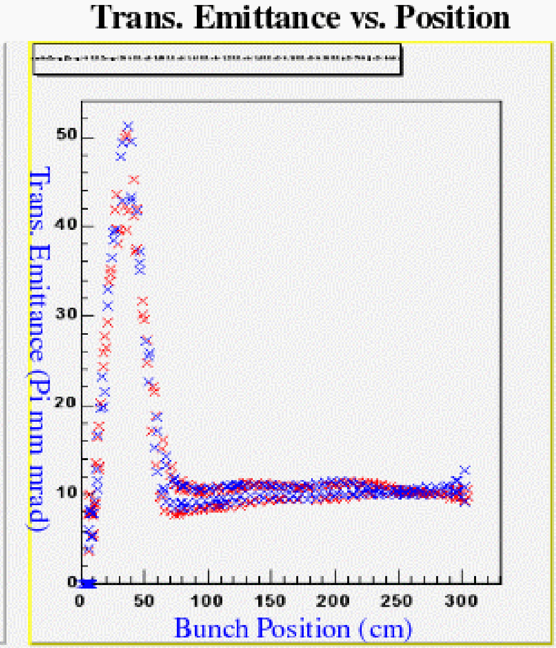
Scan

PARAMETER	Min	Max	UNITS
Gun Voltage	120	200	KV
Bunch Length	0.5	2	ns RMS
Charge	1.0E+10	5.00E+10	Electrons
Buncher Efield	40	60	KV



Lines Not Parallel



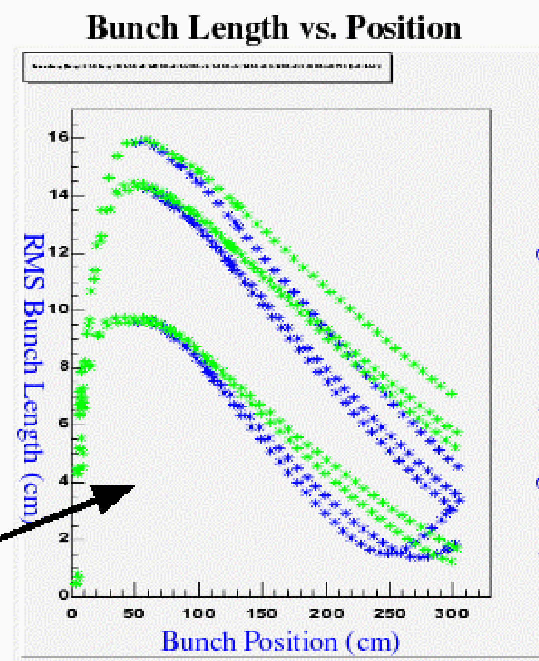


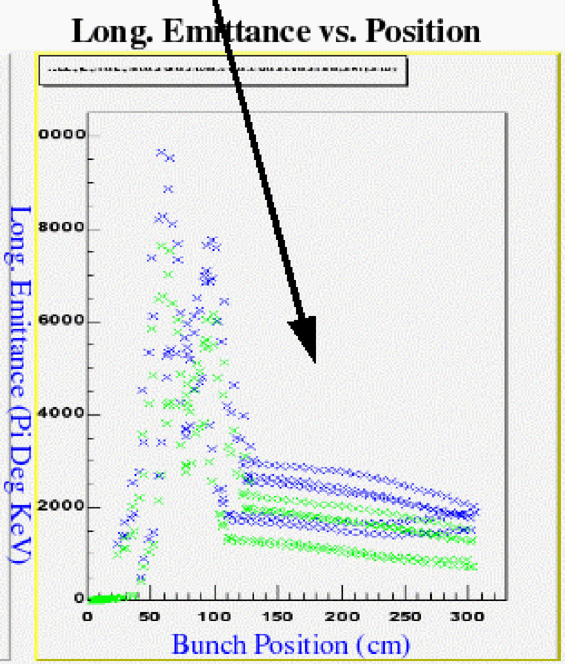
→ *Increasing The Efield In The Buncher, At Cost Of Higher Long. Emittance, Restores Bunching Rate*

Cost Of Increasing Longitudinal Emittance For The Higher Energy Bunches

Increasing Efield For Higher Energy Bunches Brings Lines Of Same "M" Parallel Again

Red Lines Are Lower Energy Bunches.
Blue Lines Are The The Higher Energy Bunches With Higher Buncher Efield.





Green Lines Are Higher Energy Bunches With Lower Buncher Field.
Blue Lines Are The The Higher Energy Bunches With Higher Buncher Field.

Conclusion

- We've Developed Code To Perform Multiple Variable Input Scans In UCLA PARMELA And Use The Data Handling Capabilities Of ROOT For Analysis
- PARMELA/ROOT Allows You To Perform Large Simulations That Scan Over Several Variables Once, Then Analyze The Data However You Wish