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# Numerical Simulation of CSR Induced Instabilities

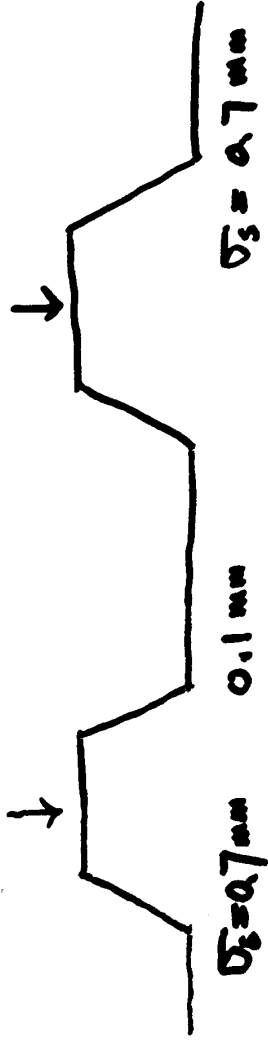
Rui Li

Jefferson Lab

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1. **Experimental Observation at Jlab (Piot)**
  2. **Simplified Simulations to Study Microbunching Instability**
  3. **Simulation Results**
  4. **Summary**

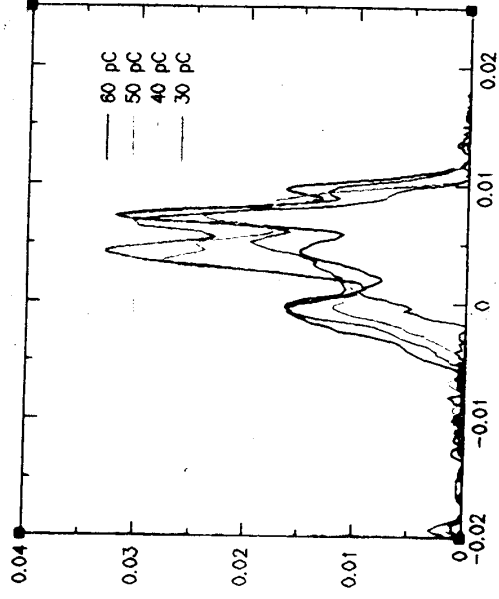
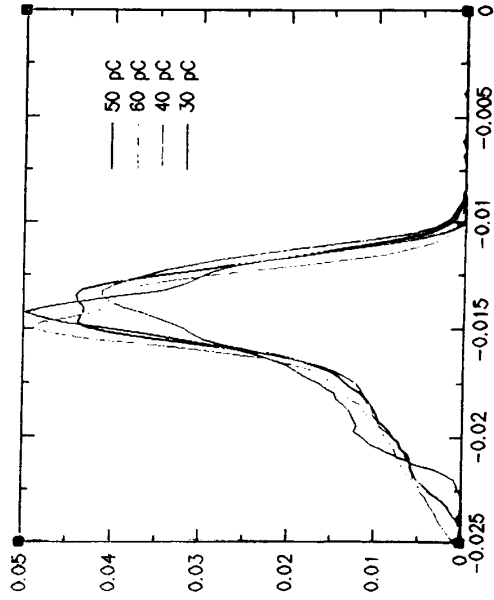
# 1. Experimental Observation at Jlab (by P. Piot)

■ Jefferson Lab IRFEL Bunch Compression Chicanes [Piot]



$Q = 60 \text{ pC}$   
 $\sigma_s = 0.7 \text{ to } 0.1 \text{ mm}$   
 $E = 45 \text{ MeV}$   
 $\sigma_\delta = 0.25 \%$   
 $R = 1 \text{ m}$

— Charge dependent energy modulation was observed in the 2<sup>nd</sup> chicane



Main INDEX  
Monthly INDEX  
PREV  
NEXT

User name Piot

Log entry time 14:23:08 on July 14,1999

Entry number 5521

keyword=energy profile in both chicanes (late entry from previous owl shift)

fig1: energy profile measured at ITV2F00 versus gang phase

fig2: energy profile measured at ITV2F06 versus gang phase

FIGURE 1

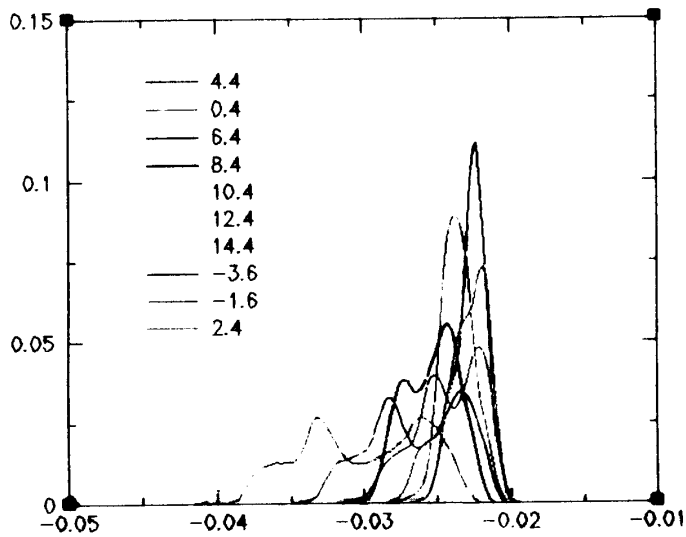
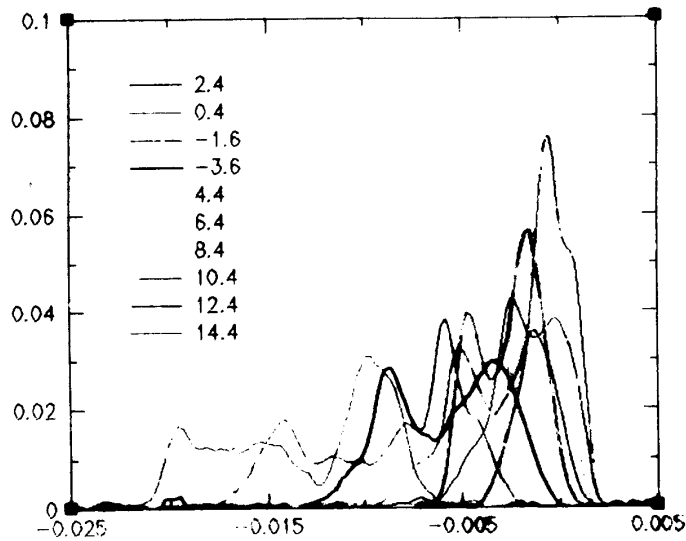


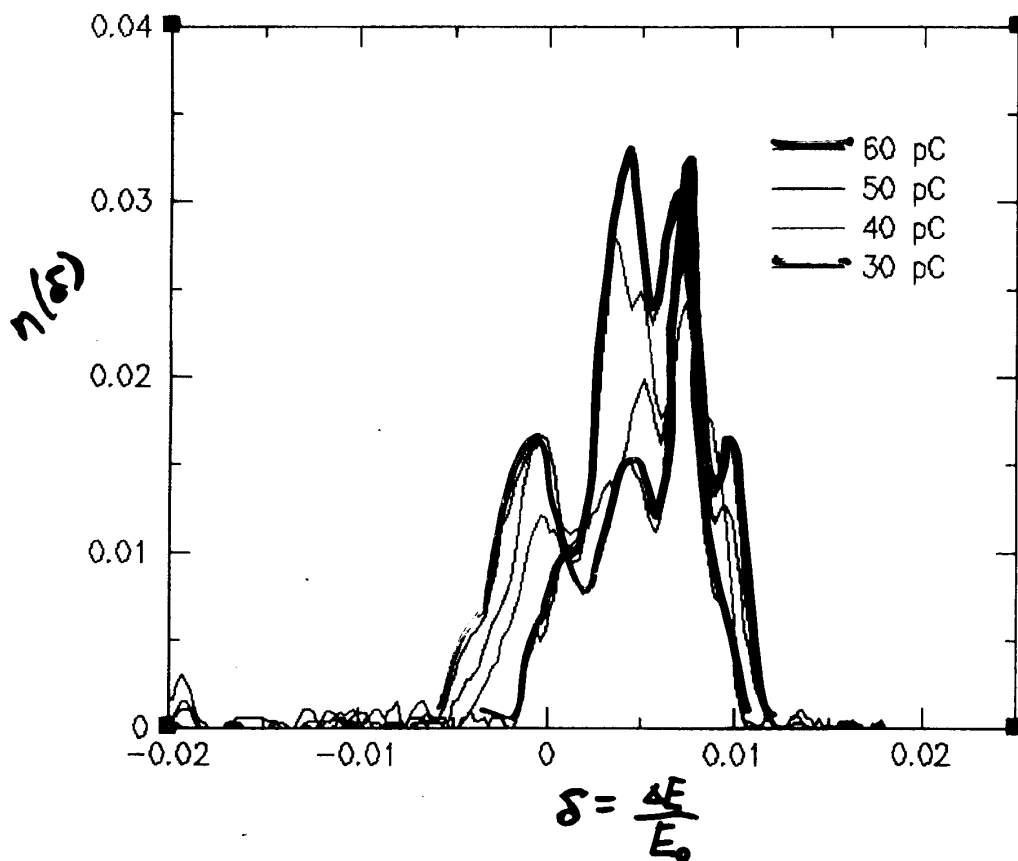
FIGURE 2



# Energy Spectrum After Chicane

[ P. Piot ]

FIGURE 1



# #. Filamentation of the Longitudinal Phase Space $Q = 1nC$

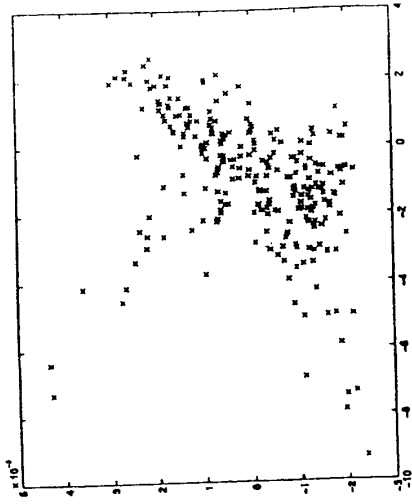
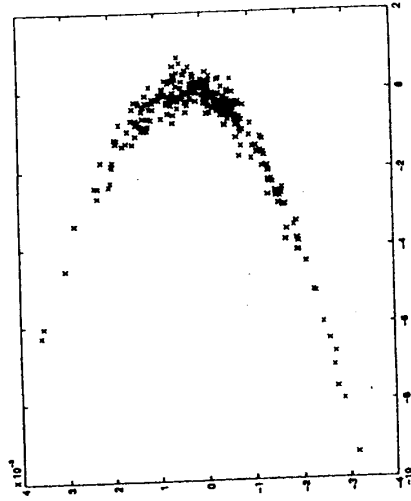
$\theta = 20^\circ, R = 1m$

$E = 150MeV$

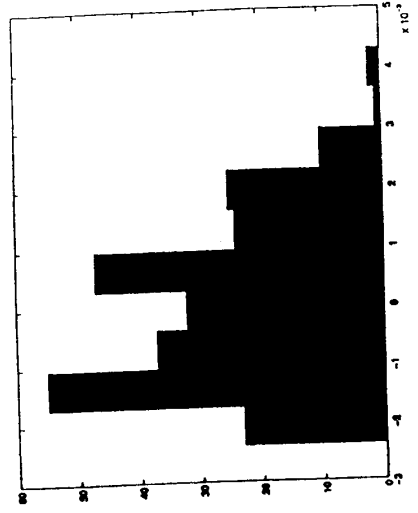
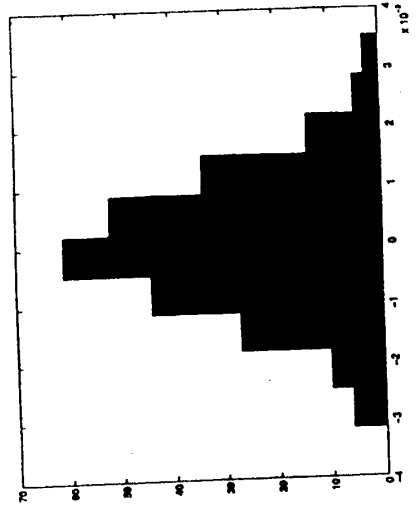
$\sigma_\delta = 0.11\%$



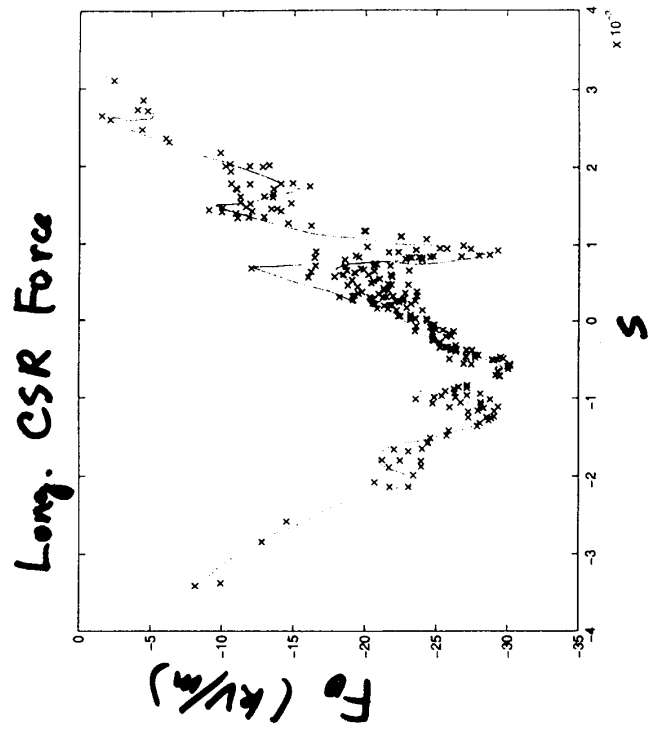
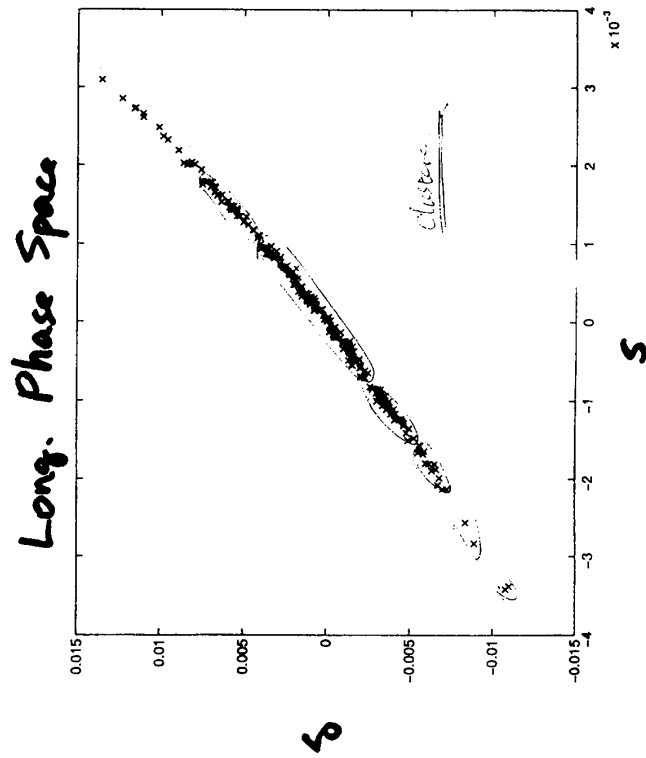
● Longitudinal Phase Space Distribution



● Energy Distribution



Strong CSR Self-force Modulation  
responding to slight density modulation



# Ideal CSR Simulation

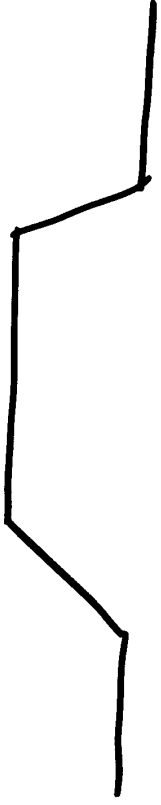
- Correct CSR Forces
- Highly Self-Consistent
- High Density Resolution

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## 2. Simplified Simulation to Study CSR Induced Modulational Instability

- 25600 particles
- Steady-State force formula inside the bends to test Heifets or Saldin's Theory
- Wavelet denoise to extract actual distribution structure out from noisy histogram

$\rho(s, \delta, t)$



Goal: Numerical solution of

$$\frac{\partial \rho}{\partial t} + \delta R s \frac{\partial \rho}{\partial s} + \frac{F_s^{CSR}}{\gamma m c^2} \frac{\partial \rho}{\partial \delta} = 0$$

for initial distribution  $\rho(s, \delta, t=0)$

$F_s^{CSR}$ : Steady-state CSR Force in Bends

## Benchmark Case

Macroparticle Model  $P(t=0) = \rho_0$  Gaussian

1D simulation  $P(t=0) = \rho_0$  Gaussian +  $\rho_1$  Numerical noise

Actual system  $P(t=0) = \rho_0$  Gaussian +  $\rho_1$  shot noise

$\rho_1$  shot noise  $\ll \rho_1$  Numerical noise

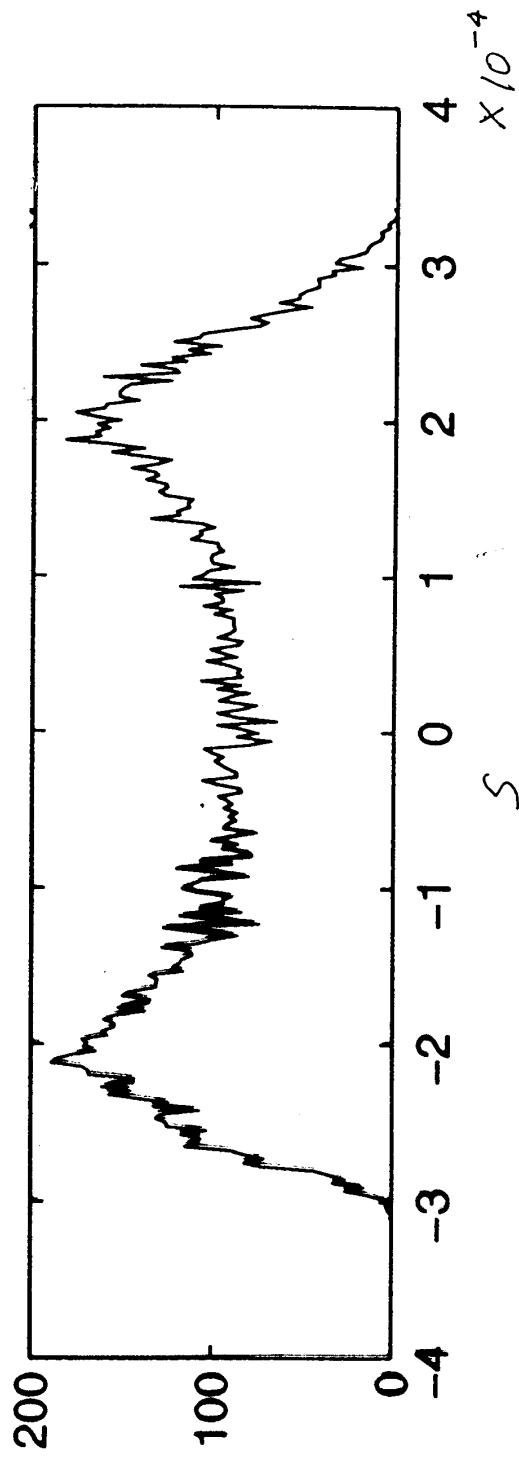
## This Study

$P(t=0) = \rho_0$  Gaussian  $(s, \sigma + \epsilon \text{ sinks}) + \rho_1$  shot noise



Ignored

Example of histogram of  $\lambda(s)$



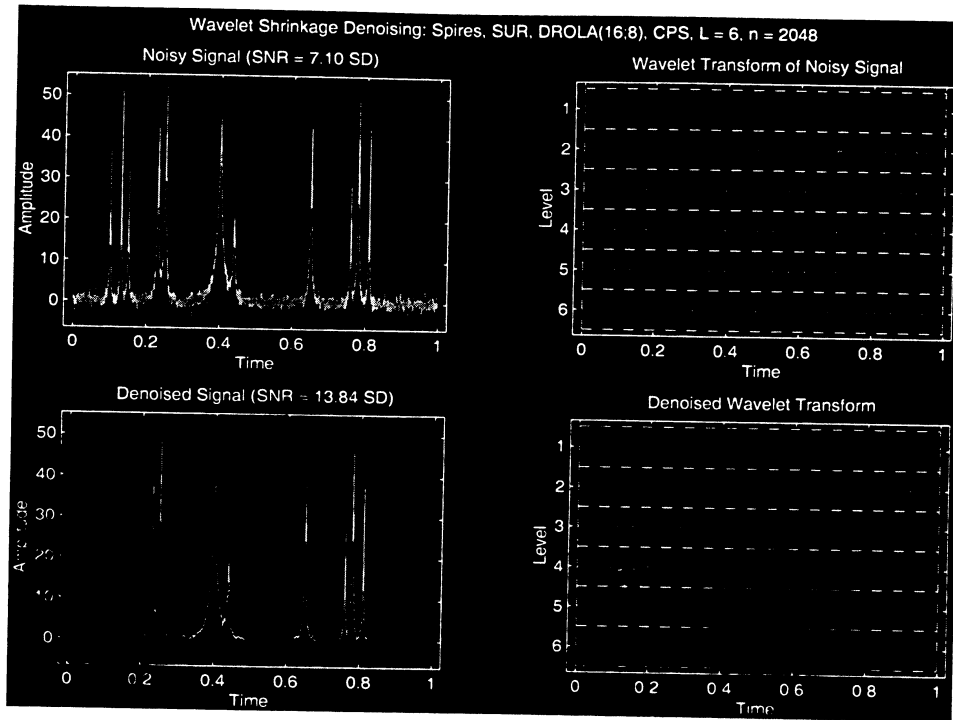


Figure 1: Wavelet shrinkage denoising: 'Spires', 'SUR',  $n = 2048$ ,  $L = 6$ , DROLA(16:8).

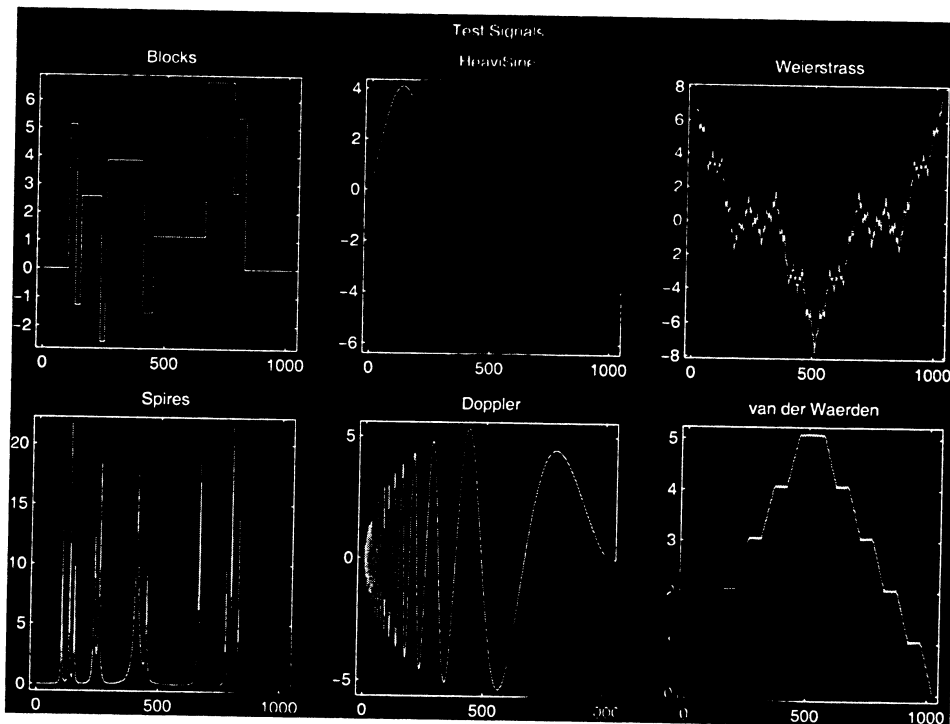


Figure 2: Standardized test signals:  $n = 1024$ .

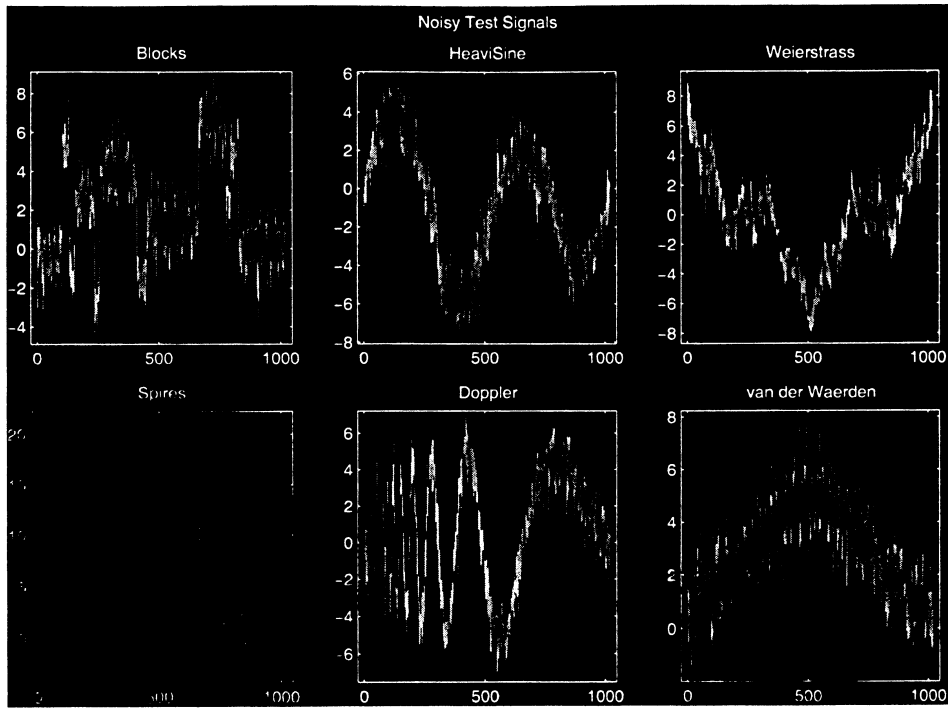


Figure 3: Noisy test signals:  $n = 1024$ ,  $\text{SNR} = 10$ .

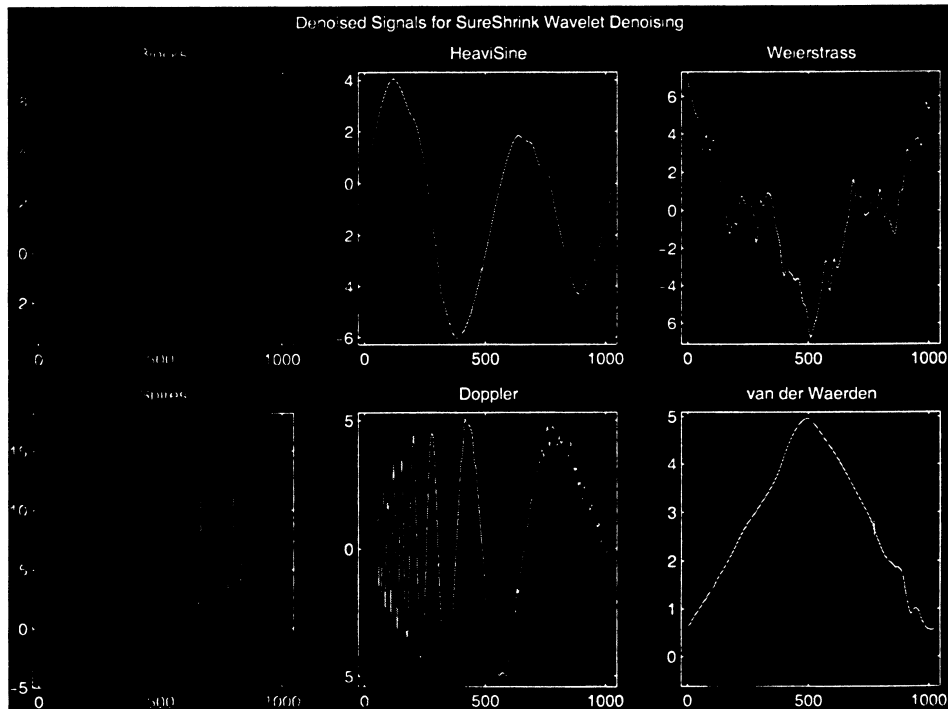
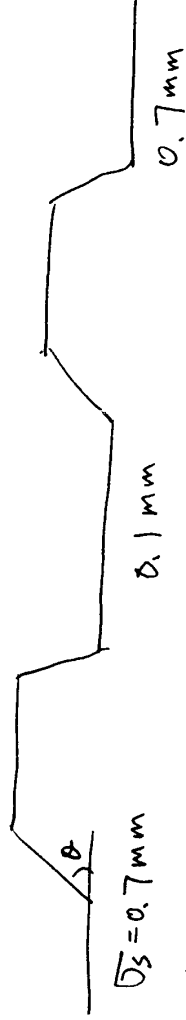


Figure 4: Wavelet shrinkage denoising: 'SUR',  $n = 2048$ ,  $L = 5$ ,  $\text{DROLA}(10;5)$ .

# Simulation Detail

## Beam Line



$$D_s = 0.7 \text{ mm}$$

$$\theta = 22^\circ$$

$$R = 1 \text{ m}$$

$R_{56} = -28 \text{ cm}$  for one chicane

## Beam Parameters

$$E = 38 \text{ MeV}, \quad Q = 0.2 \text{ nC}$$

$$C = 8.86 \text{ mm-mrad}$$

$$D_x = 0.7 \text{ mm}$$

$$D_y = -0.0025$$

### 3. Simulation Results

#### Case 1

$$\epsilon_x = 0.0088 \mu\text{m}$$

$$\sigma_{un} = 4.2 \times 10^{-5}$$

$$f = \sigma_f \left( \frac{s}{\sigma_s} \right) + 20 \sigma_{un} \sin \left( \frac{5s}{\sigma_s} \right) + \sigma_{un} \hat{r}_i$$

↑  
energy modulation

#### Case 2

$$\epsilon_x = 8.86 \mu\text{m}$$

$$\sigma_{un} = 4.2 \times 10^{-5}$$

$$f = \sigma_f \left( \frac{s}{\sigma_s} \right) + \sigma_{un} \hat{r}_i$$

(no energy modulation)

#### Case 3 (Gaussian)

$$\epsilon_x = 8.86 \mu\text{m}$$

$$\sigma_{un} = 4.2 \times 10^{-4}$$

$$f = \sigma_f \left( \frac{s}{\sigma_s} \right) + \sigma_{un} \hat{r}_i$$

(no energy modulation)



#### Case 1

$$\sigma_s = 0.7 \text{ mm}$$

$$\epsilon_x = 0.008 \mu\text{m}$$

$$\sigma_s = 0.2 \text{ mm}$$

$$\epsilon_x = 5.1 \mu\text{m}$$

$$\sigma_s = 0.8 \text{ mm}$$

$$\epsilon_x = 12.0 \mu\text{m}$$

#### Case 2

$$\sigma_s = 0.7 \text{ mm}$$

$$\epsilon_x = 8.86 \mu\text{m}$$

$$\sigma_s = 0.17 \text{ mm}$$

$$\epsilon_x = 10.3 \mu\text{m}$$

$$\sigma_s = 0.8 \text{ mm}$$

$$\epsilon_x = 11.3 \mu\text{m}$$

#### Case 3

$$\sigma_s = 0.7 \text{ mm}$$

$$\epsilon_x = 8.86 \mu\text{m}$$

$$\sigma_s = 0.12 \text{ mm}$$

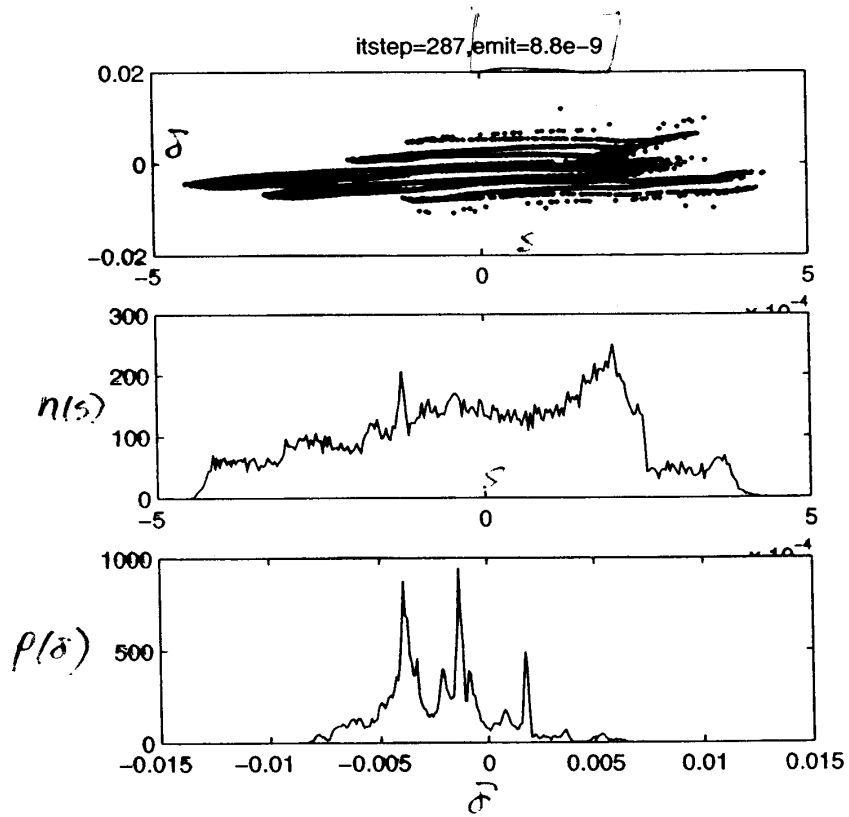
$$\epsilon_x = 10.46 \mu\text{m}$$

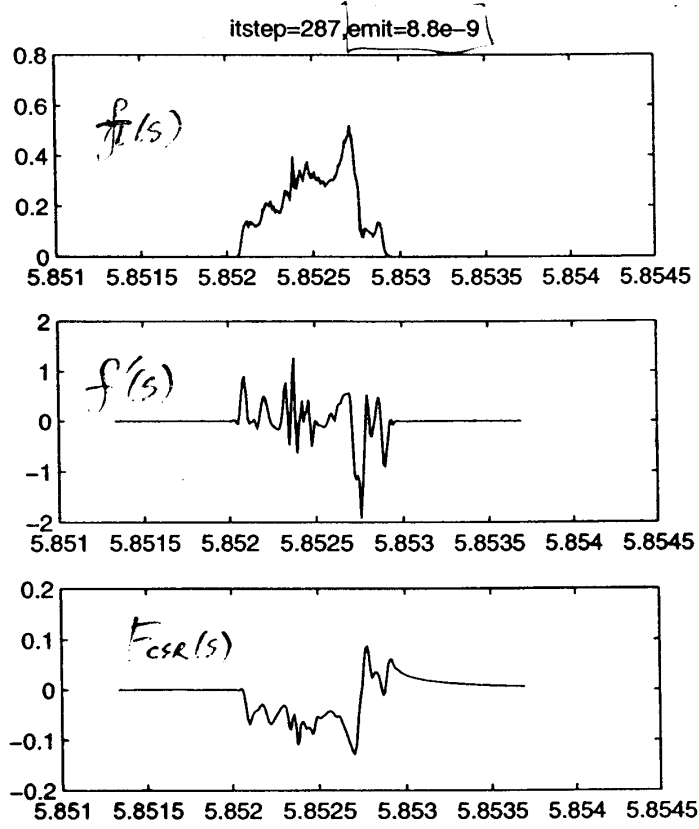
$$\sigma_s = 0.76 \text{ mm}$$

$$\epsilon_x = 12.57 \mu\text{m}$$

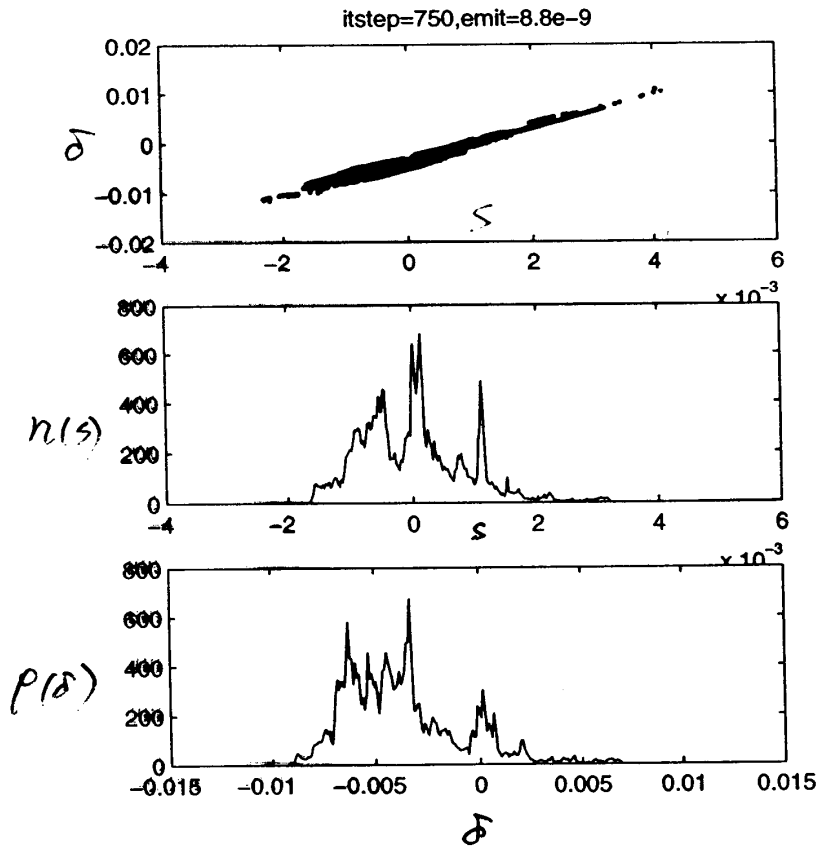
(Gaussian)

Case 1. End of Compression Chicanes

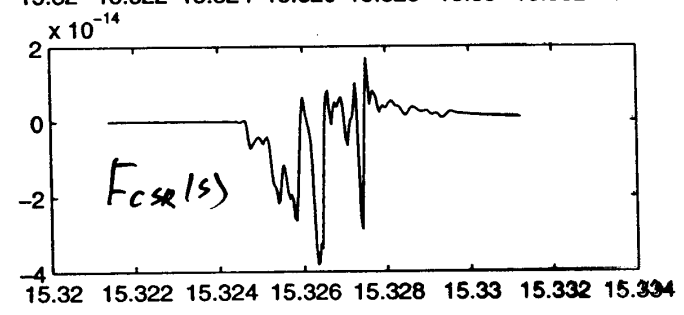
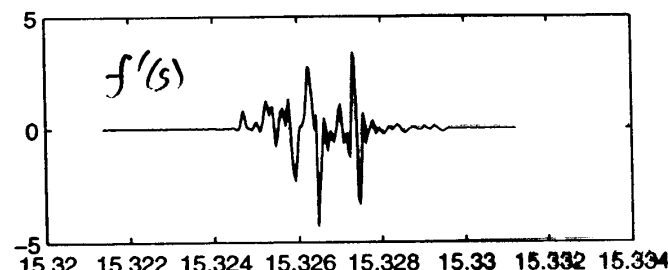
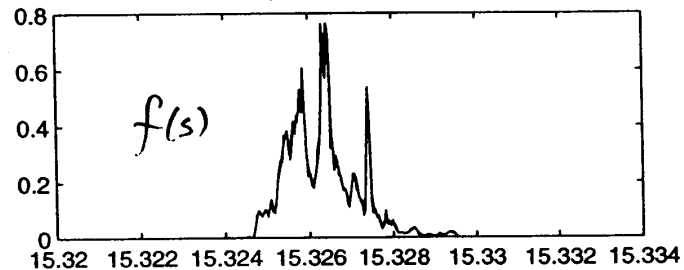




# End of Decompression Chicane

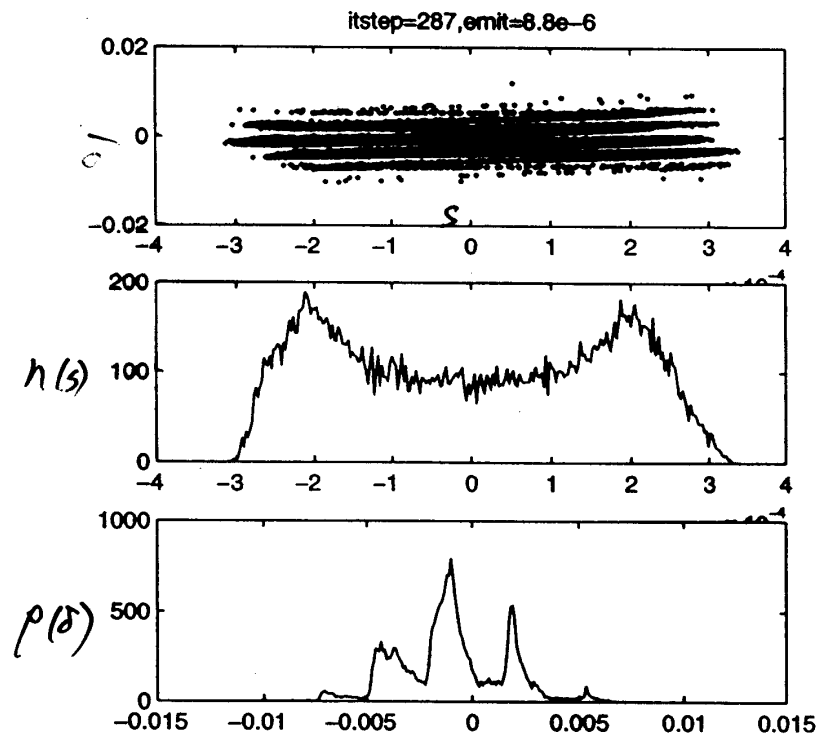


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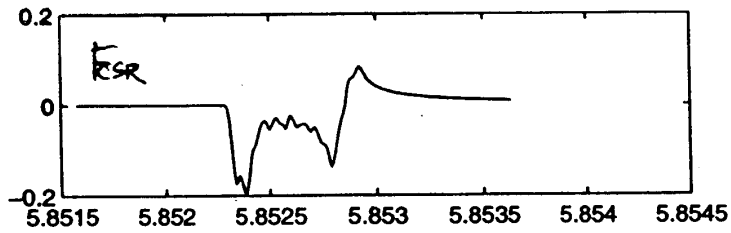
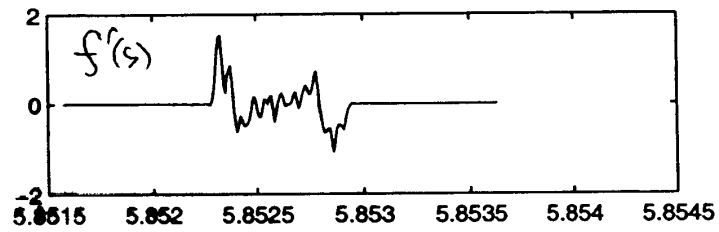
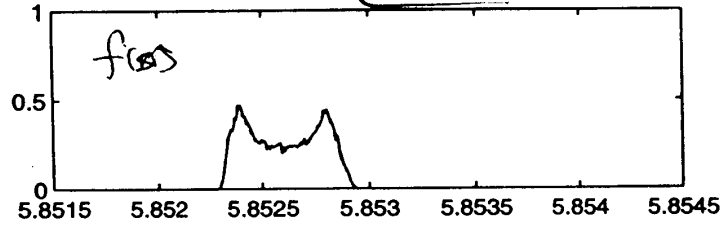


$s$

## Case 2. End of Compression Chicane

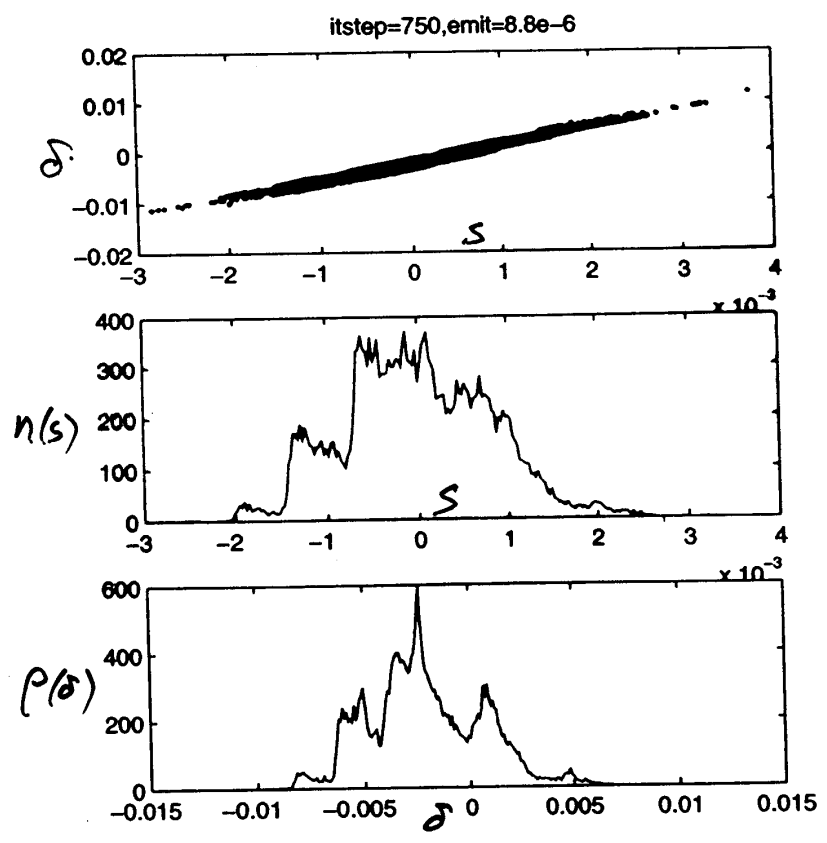


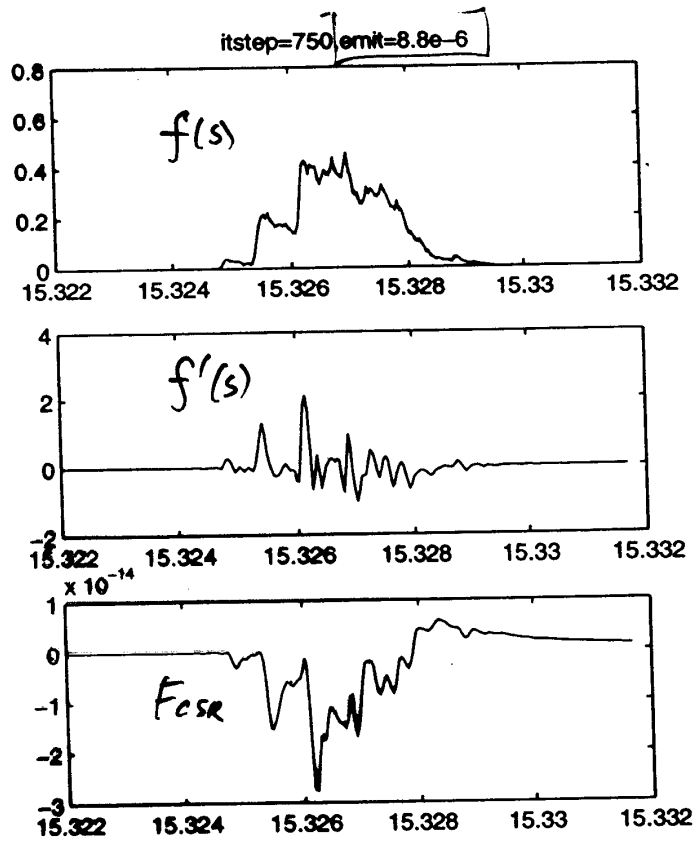
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s

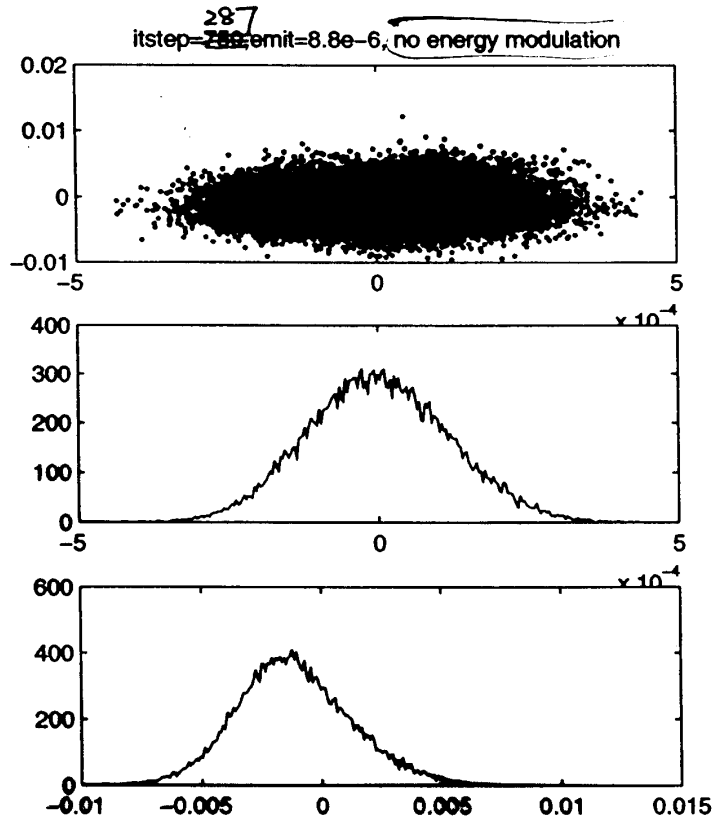
# Case 2. End of Recompression Chicane



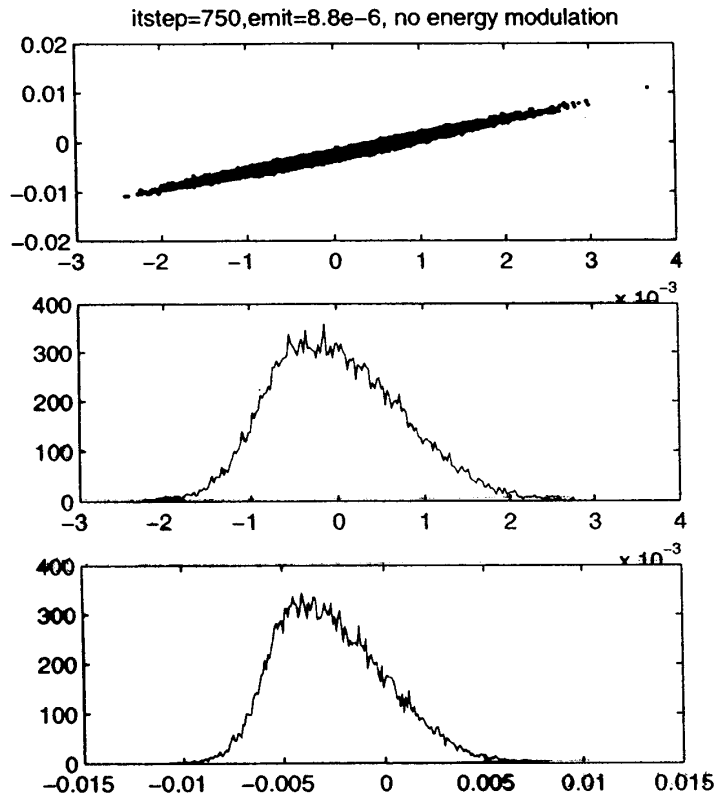


s.

Case 3. End of 1st chicane



# End of 2nd Chicane



## 4. Summary

- Microbunching due to energy modulation, studied analytically by Saldin, et al., is here simulated using simplified simulation.
- The simulation showed that the growth of fine structures in the bunch longitudinal distribution and emittance growth is fastest for the case with initial zero transverse emittance.
- None-zero transverse emittance tends to smear the longitudinal distribution through  $R_{51}$  and  $R_{52}$ .