

# Slip Stacking

October 2, 2007

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Fermilab

**Current operation**

**Slip stacking**

**11 batch slip stacking for Proton Plan**

**Status of beam studies**

**Beam loss**

**Injection kicker gap loss**

**Ramp loss**

**Extraction kicker gap loss**

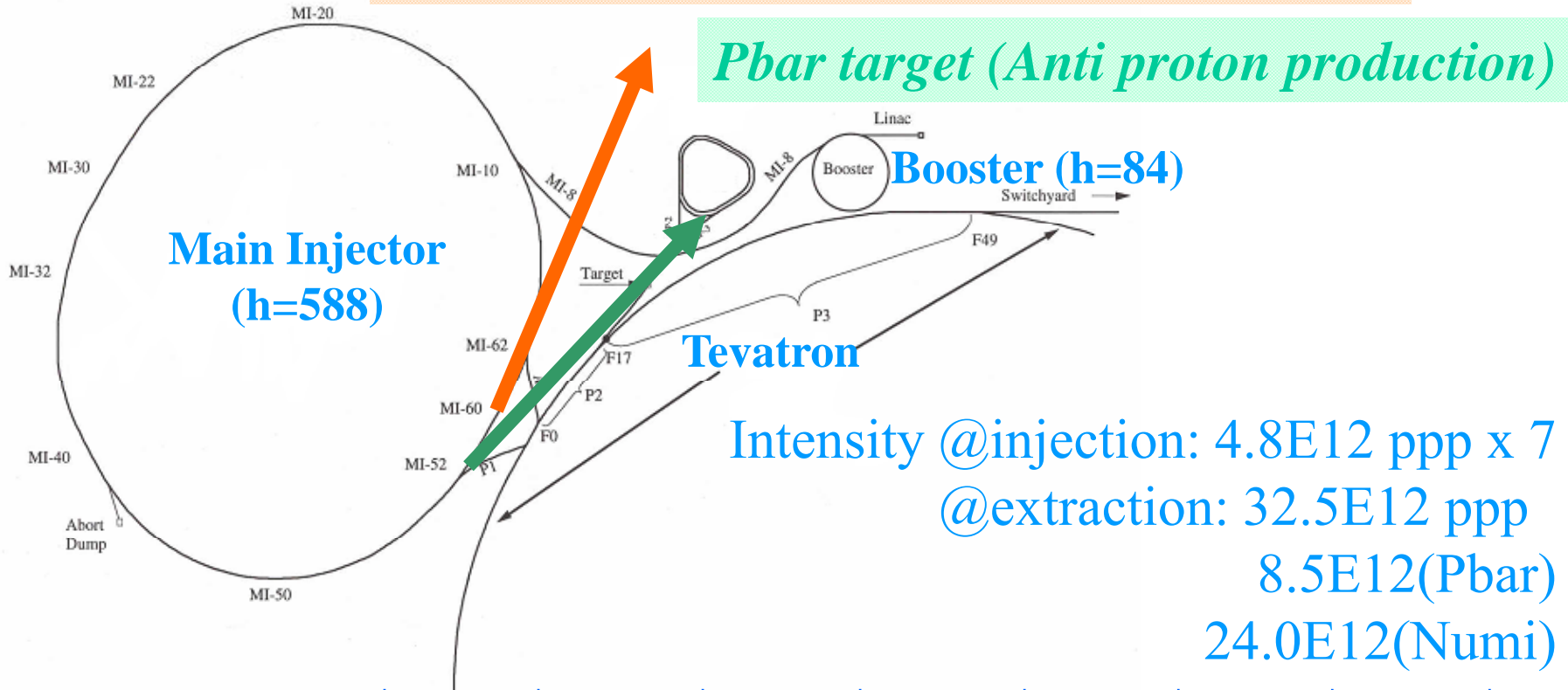
**8GeV lifetime loss**

**Summary & Plan**

# MI 120GeV cycle operations

*Numi target (MINOS Neutrino experiment)*

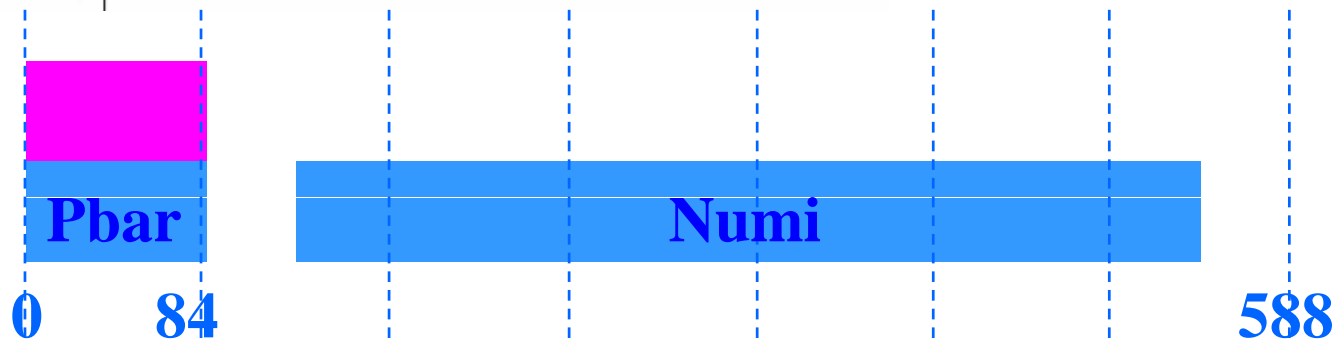
*Pbar target (Anti proton production)*



Intensity @injection:  $4.8E12$  ppp x 7  
 @extraction:  $32.5E12$  ppp  
 $8.5E12$ (Pbar)  
 $24.0E12$ (Numi)

**Current operation**

Bucket #



# Status of current operations

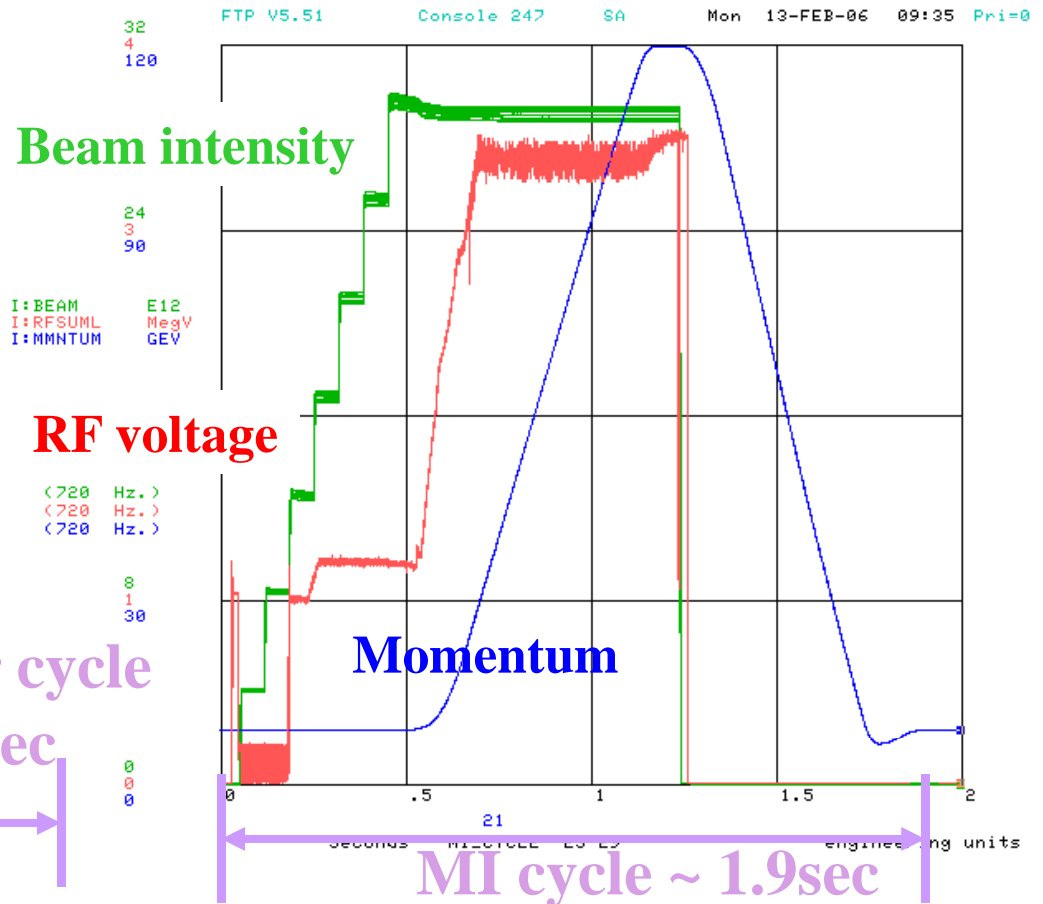
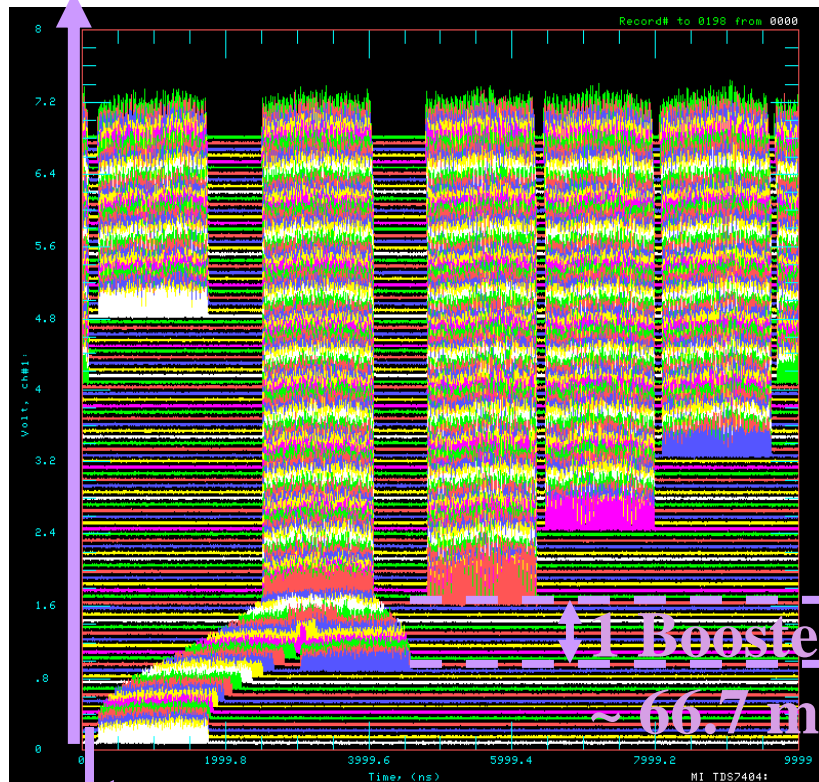
*Intensity on Pbar target: 8.5E12 ppp*

*Acceleration efficiency: 95%*

*bunch length @ ext. < 1.8nsec after the bunch rotation*

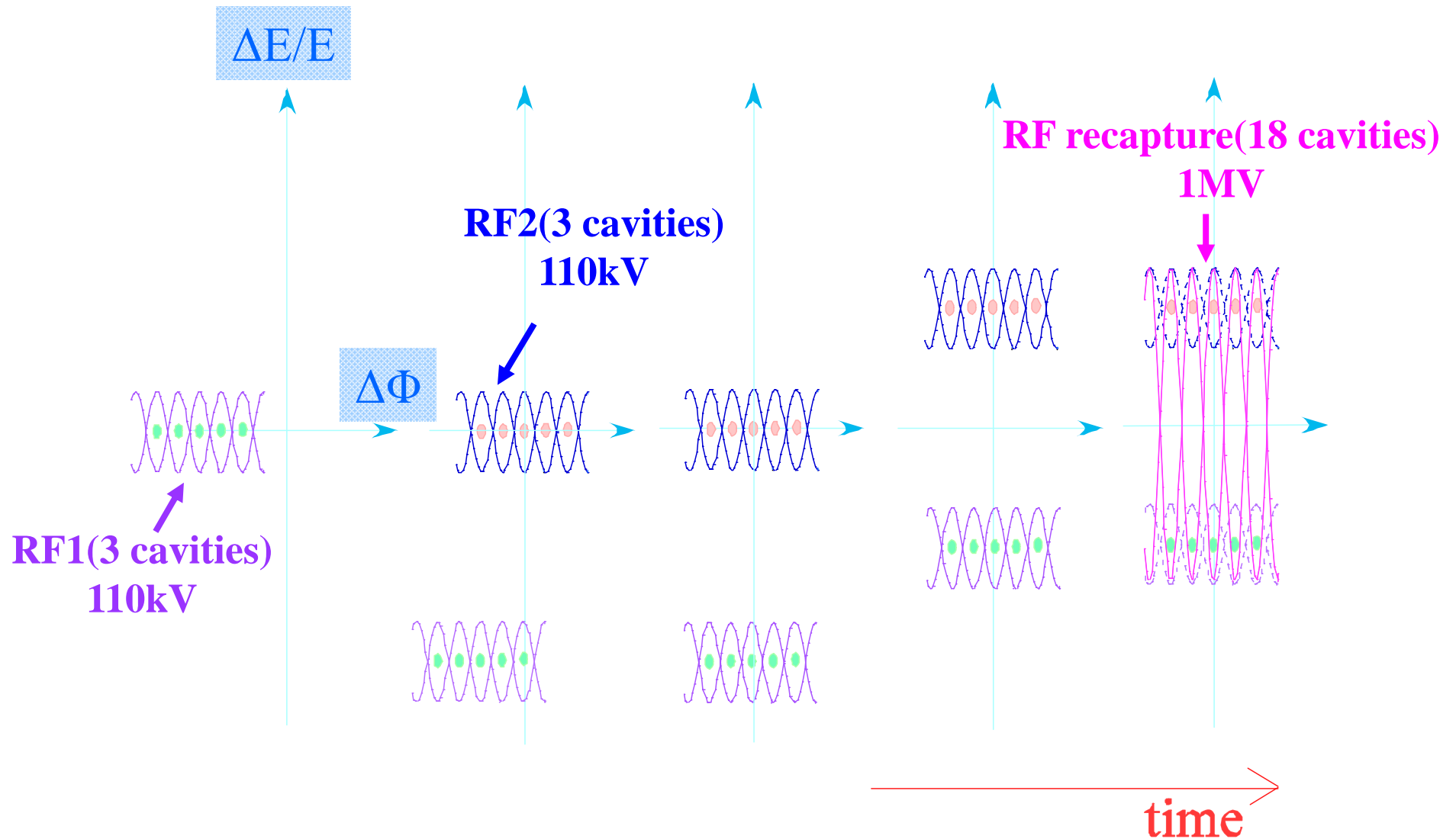
*Slip stacking time < 2 Booster cycles*

Time



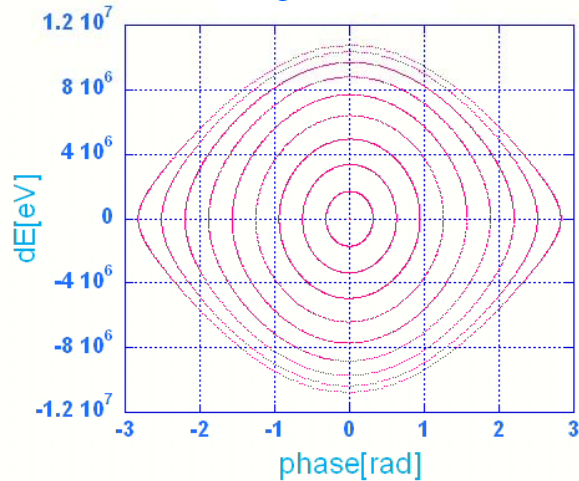
# Slip stacking procedure

(MI has 18 53MHz RF cavities)

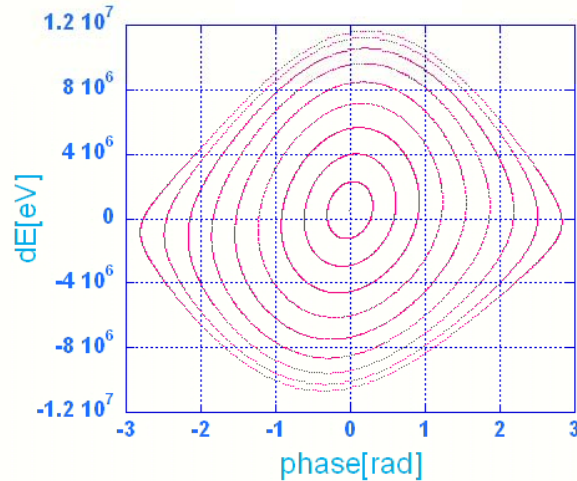


# Simulation results on phase space ( $V_{rf}=100\text{kV}$ , $df=1200\text{Hz}$ )

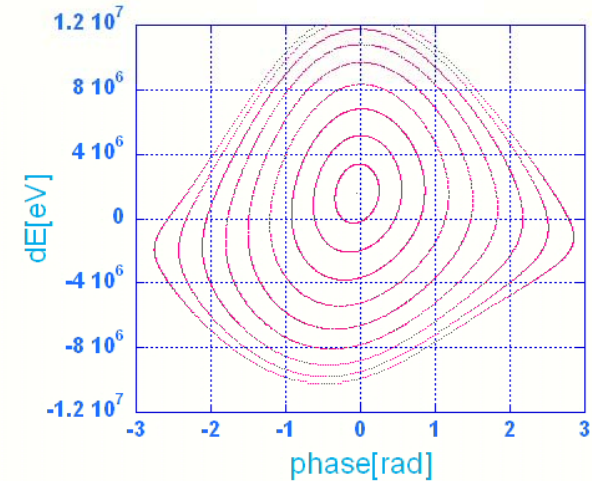
**injection**



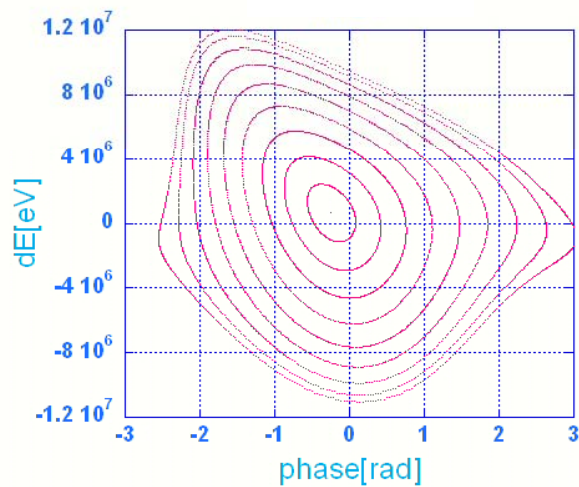
**10 turns**



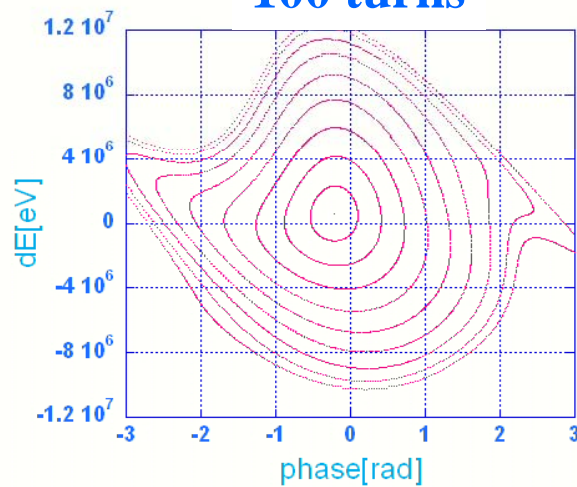
**20 turns**



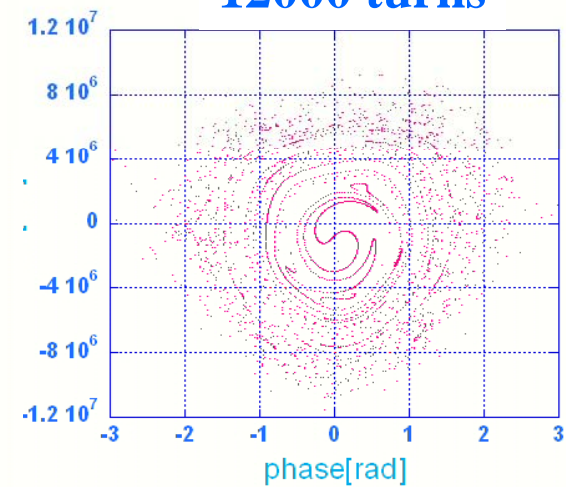
**50 turns**



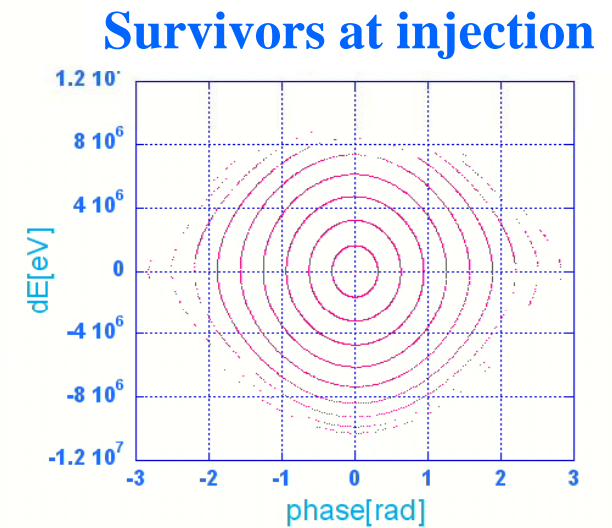
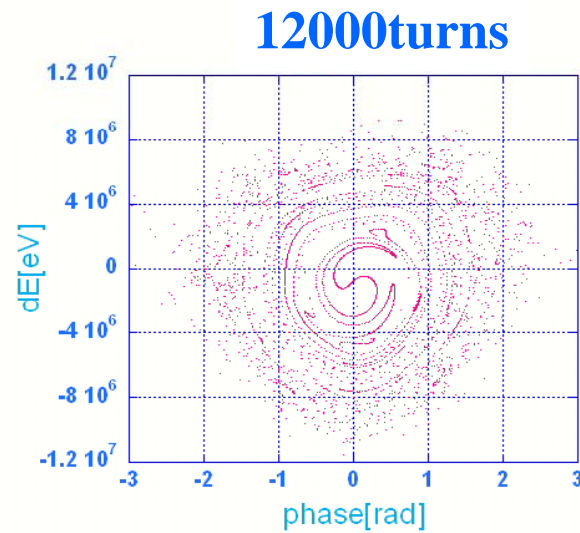
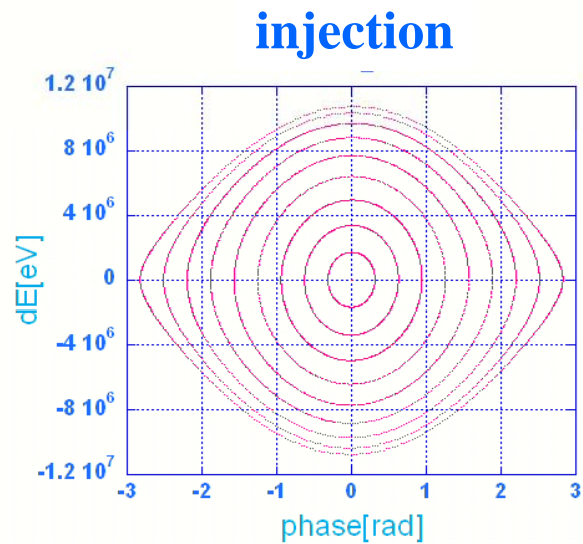
**100 turns**



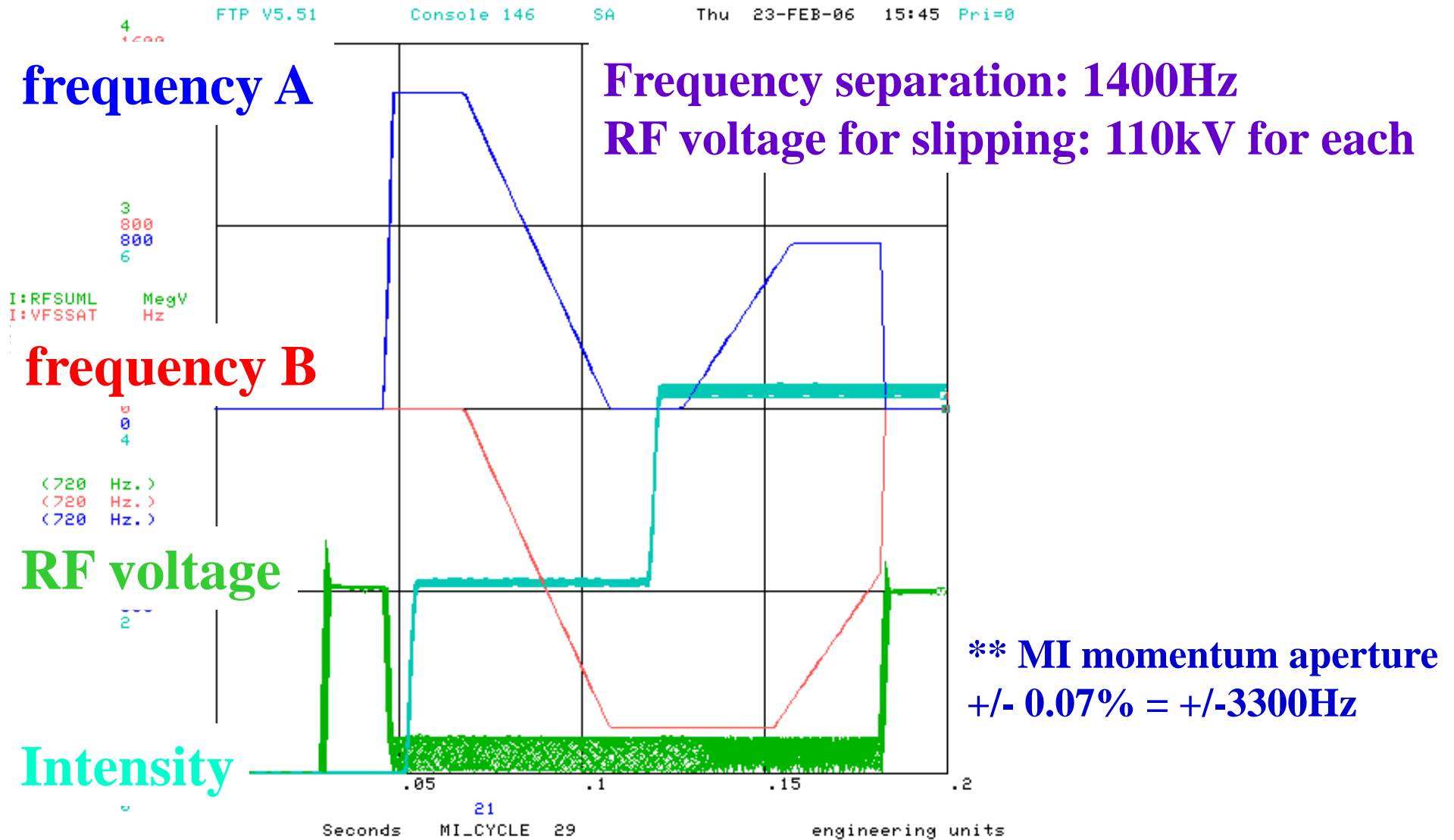
**12000 turns**



# Longitudinal phase space ( $V_{rf} = 100\text{kV}$ , $df = 1200\text{Hz}$ )



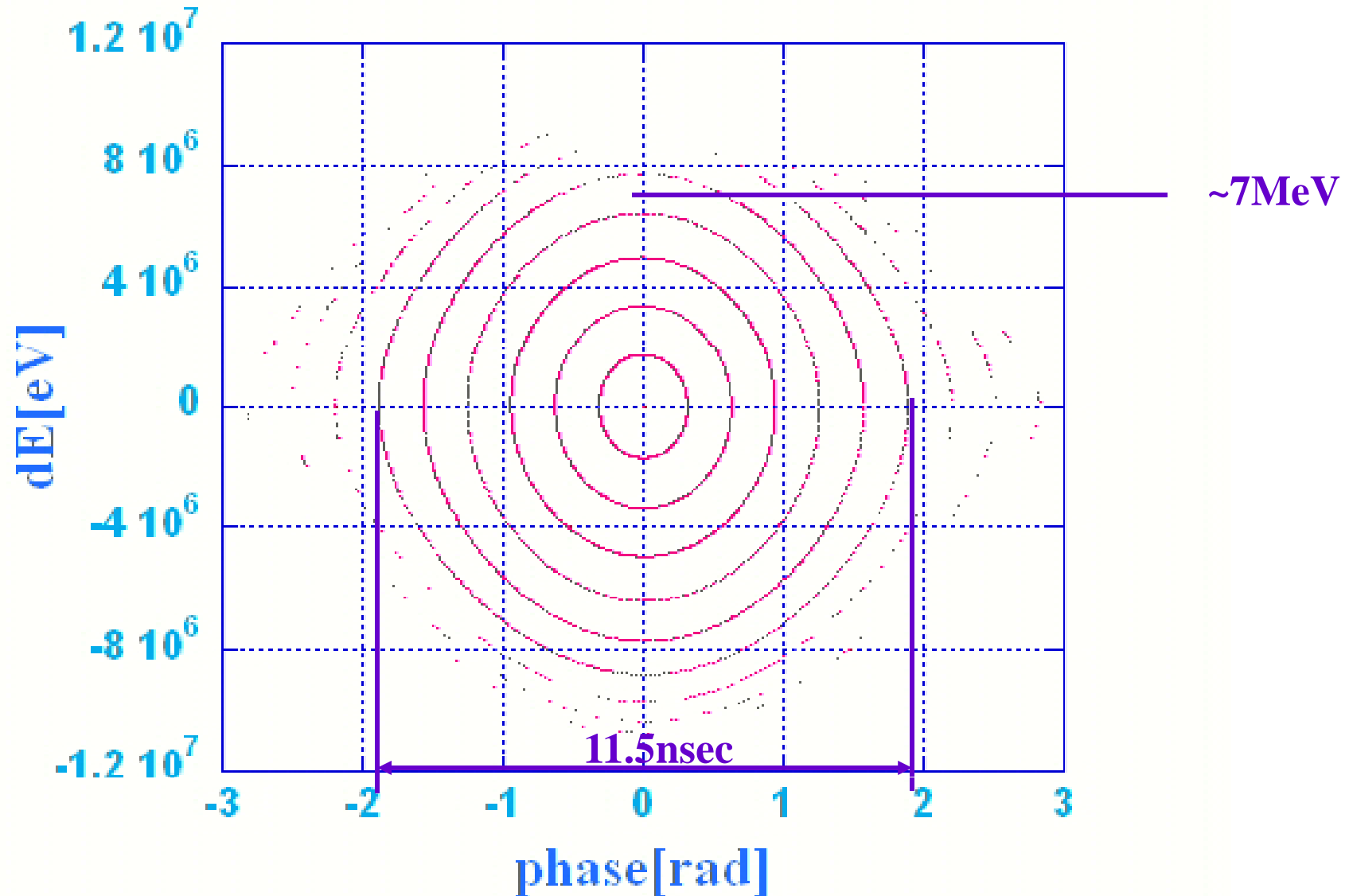
# Parameters on current operation





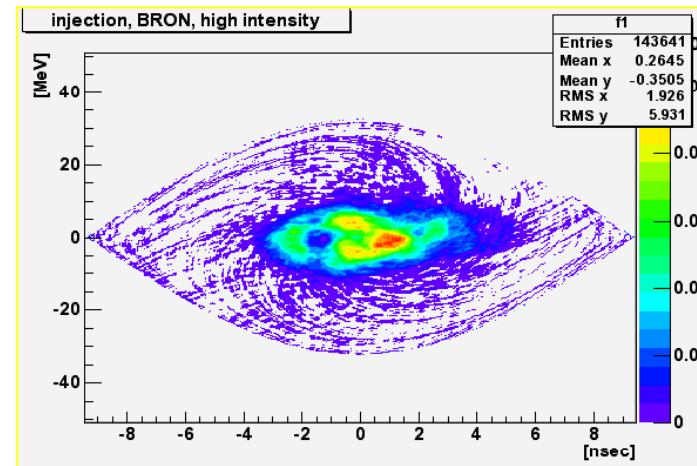
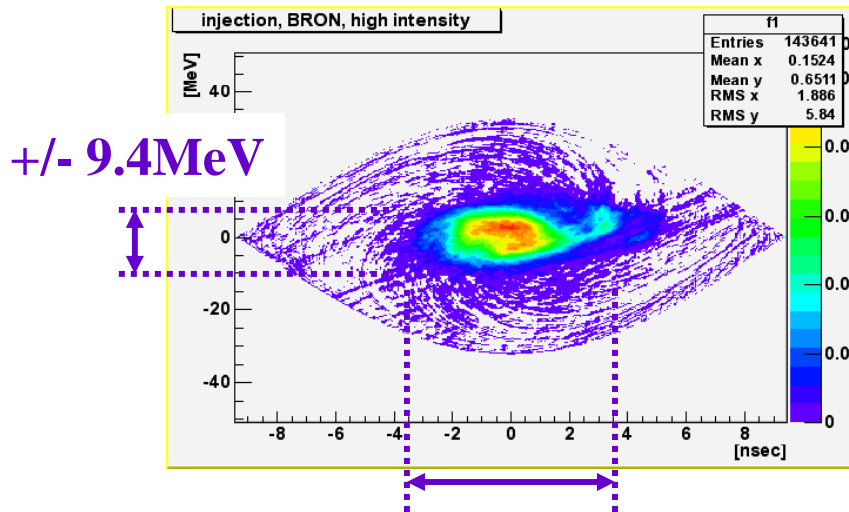
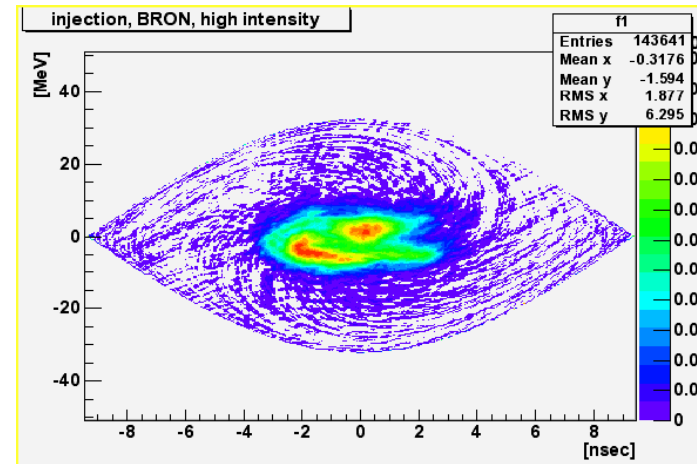
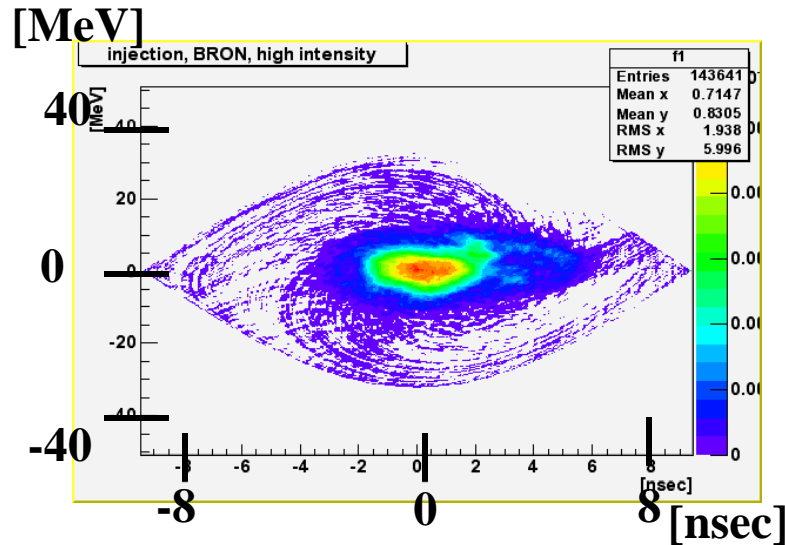
# Longitudinal acceptance

with 110kV RF and 1400Hz frequency separation



# Injection beam from Booster

Mt.range with WCM signal  $\rightarrow$  Phase space tomography



Longitudinal emittance @ injection  $\sim 0.12 \text{ eV}\cdot\text{sec}$

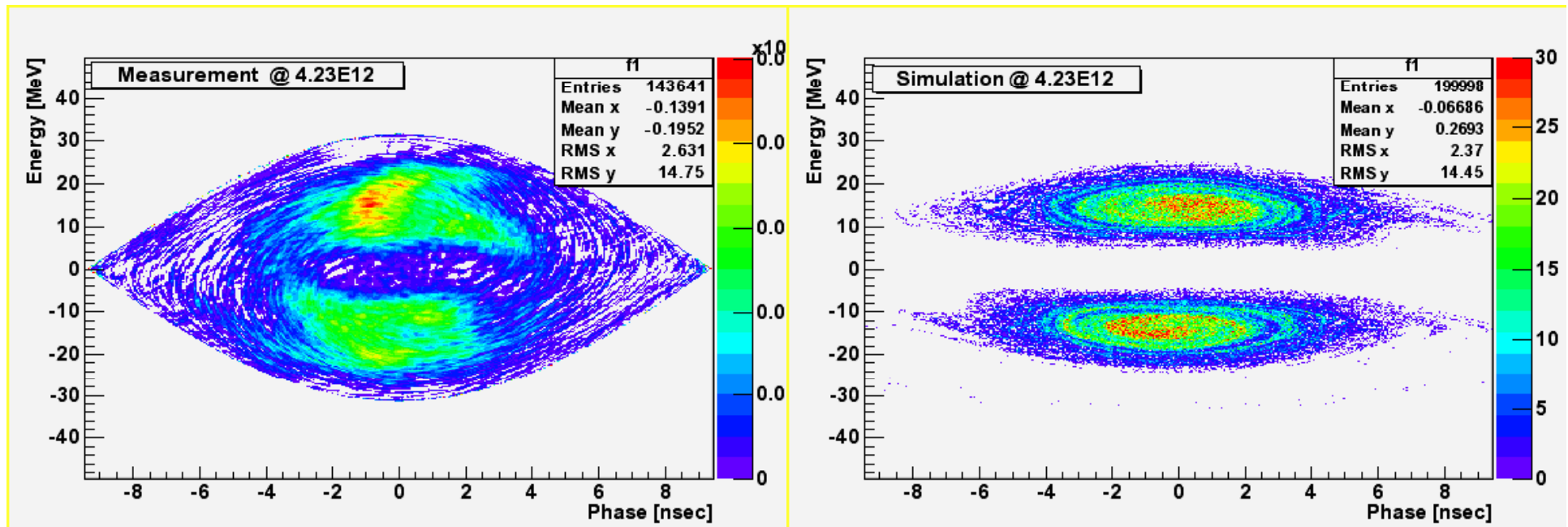
# Beam at recapture

Recapture voltage: 1MV

Intensity: 8.5E12 @ Injection

*Measurement*

*Simulation*

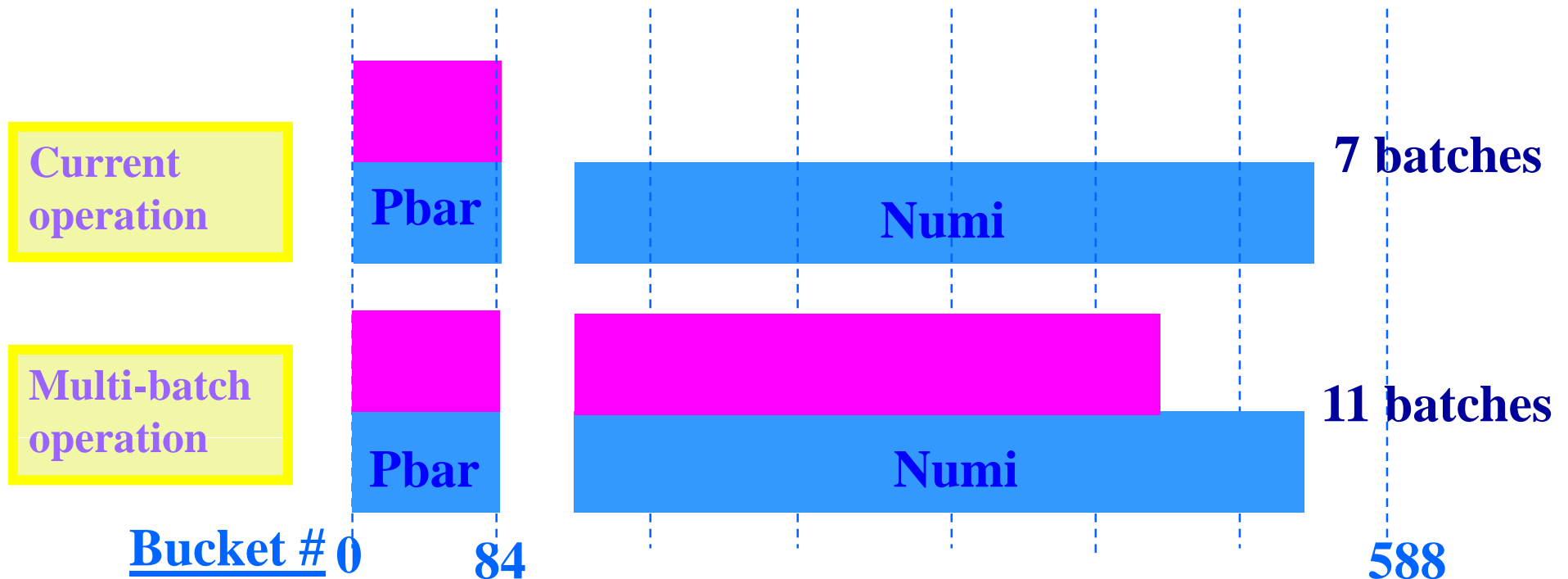


Longitudinal emittance @ recapture ~ 0.35eV-sec

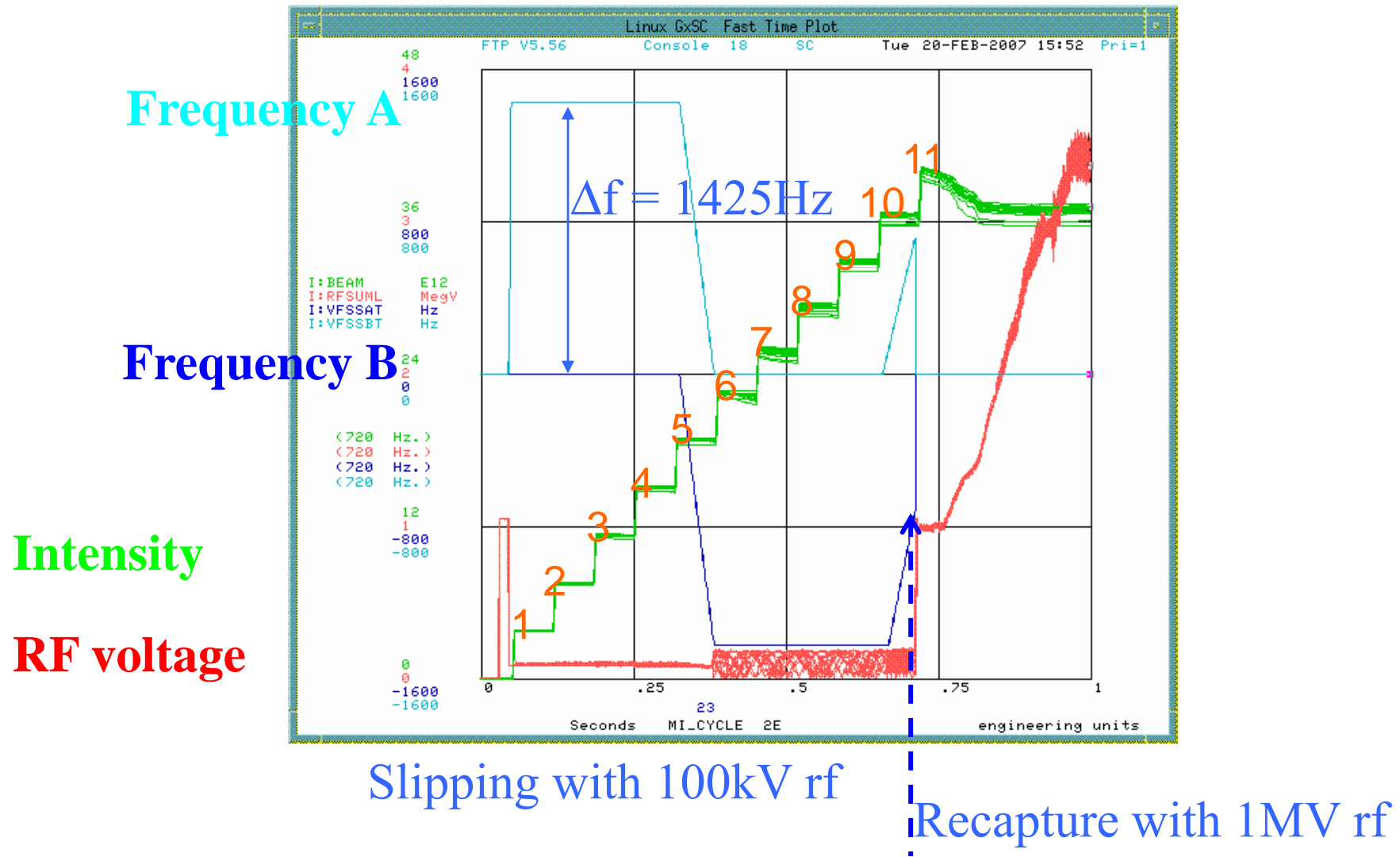
Beam loss ~ 5%

# Proton Plan Goal

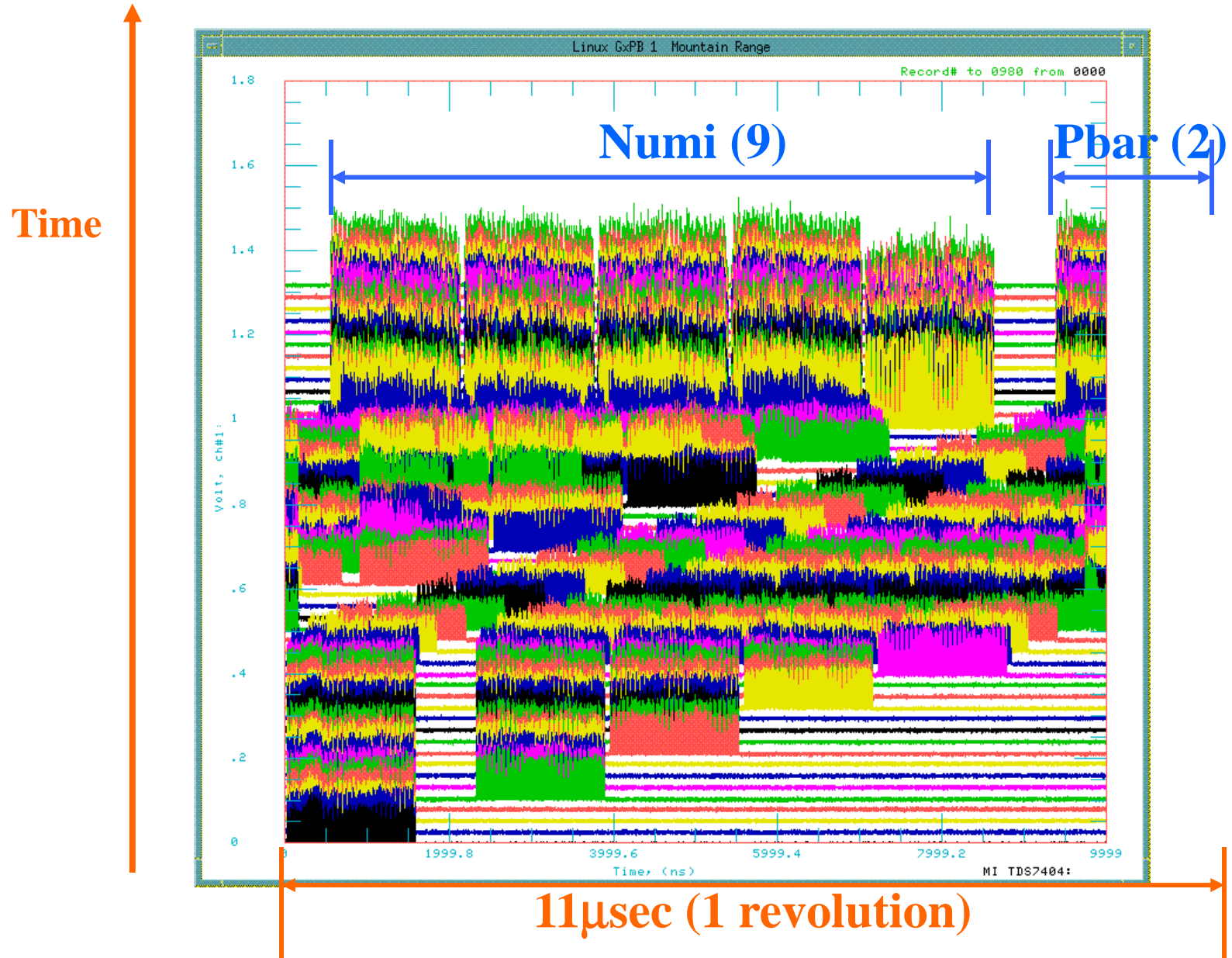
- Intensity @ injection :  $4.3E12$  ppp x 11  
@ extraction:  $4.5E13$  ppp
- Total beam power: 400kW    80kW → Pbar  
320kW → Numi
- MI cycle rate < 2.2 sec
- Total beam loss: < 5%



# 11 batch Slip stacking



# 11 batch slip stacking on mixed mode cycle



# Status of 11 batch slip stacking

## Mixed mode cycle

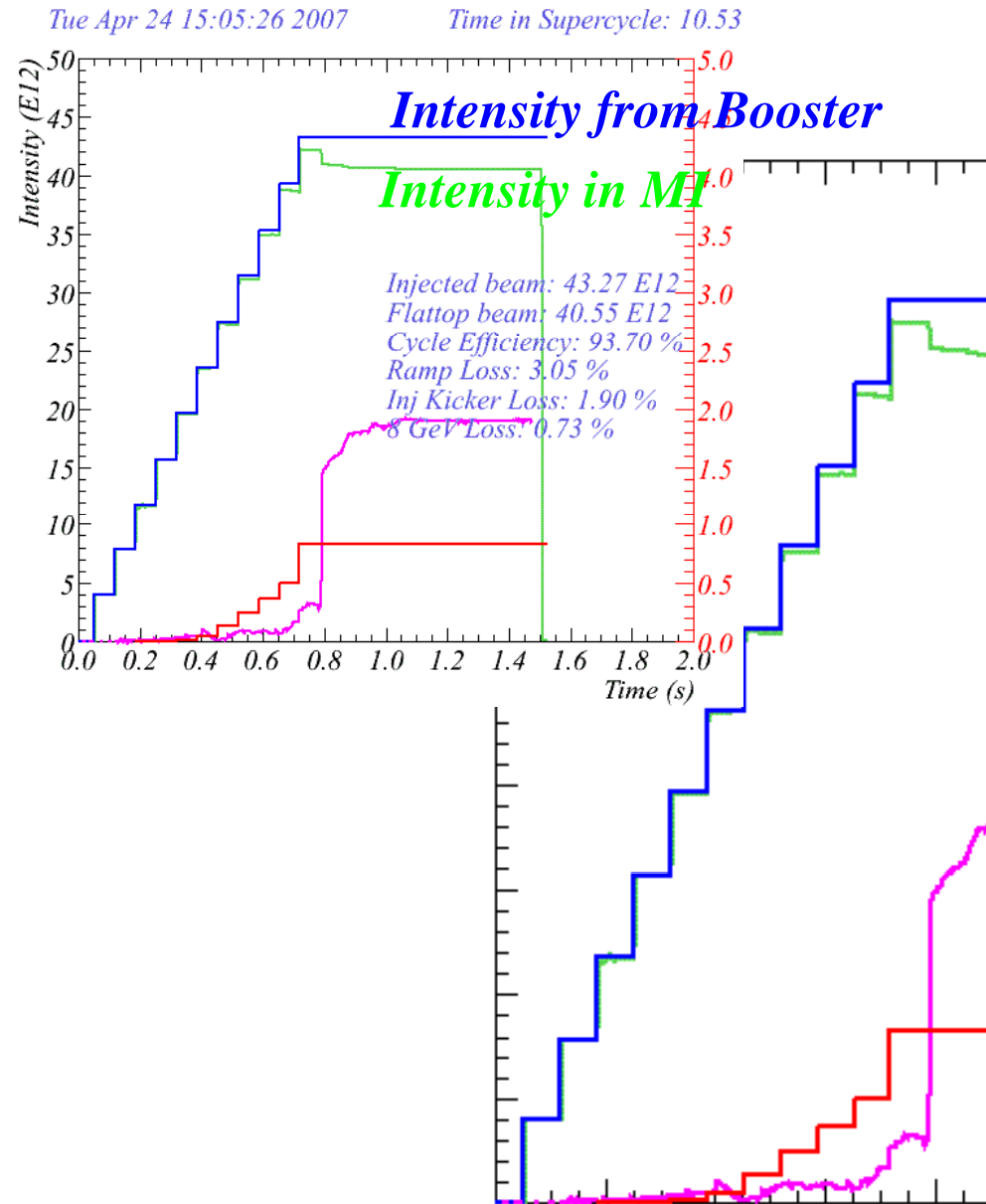
- Intensity:
  - 8.2E12 ppp (pbar)
  - 30E12 ppp (Numi)
- Cycle efficiency ~ 95.5%

## MI Intensity record

- Intensity: 46E12 @ 120GeV

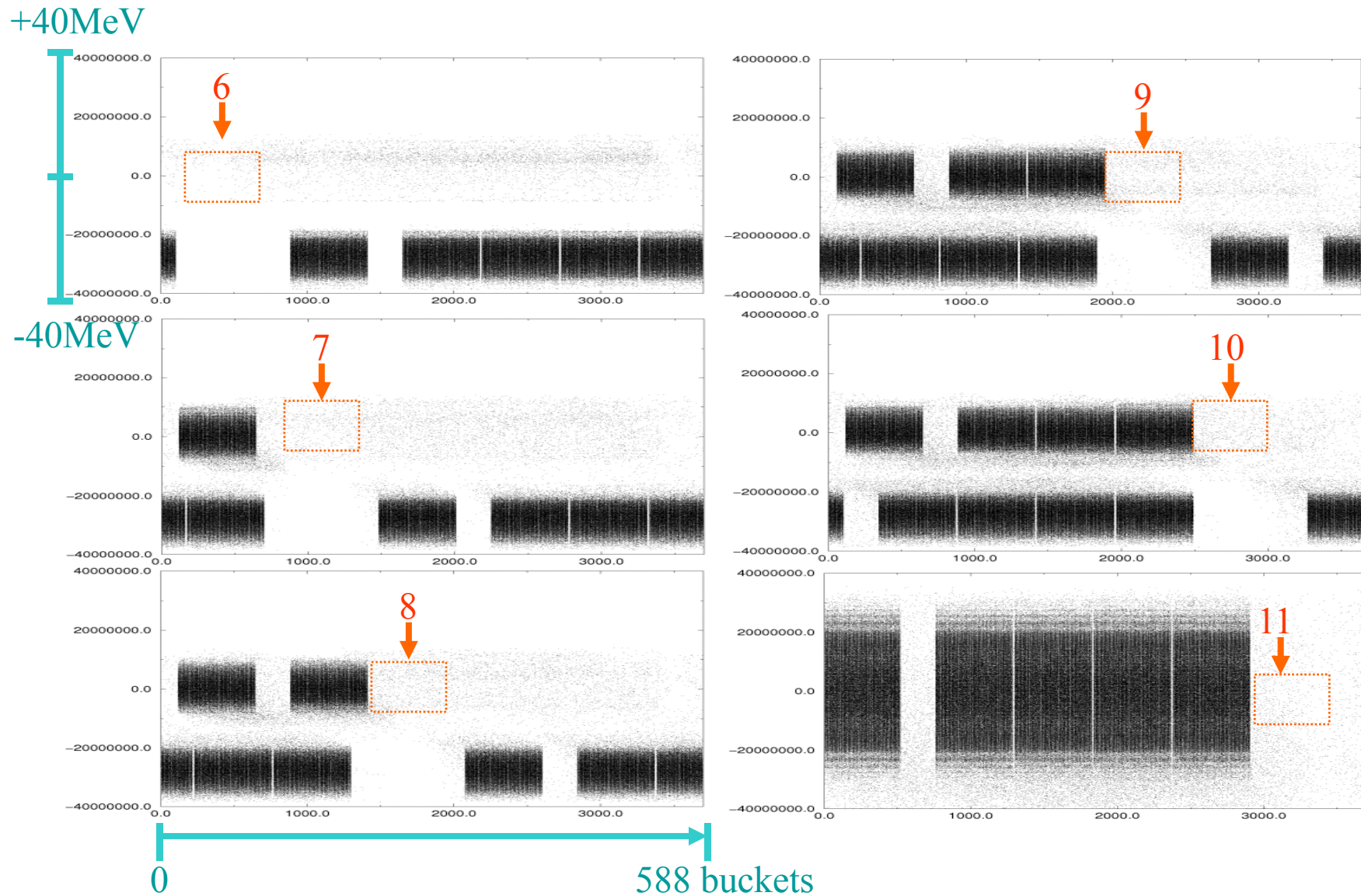
## Beam loss issues

- Injection kicker gap loss
- Ramp loss
- Extraction kicker gap loss
- 8GeV lifetime loss



# Injection kicker gap loss (2)

## Longitudinal simulation for 11 batch slip stacking



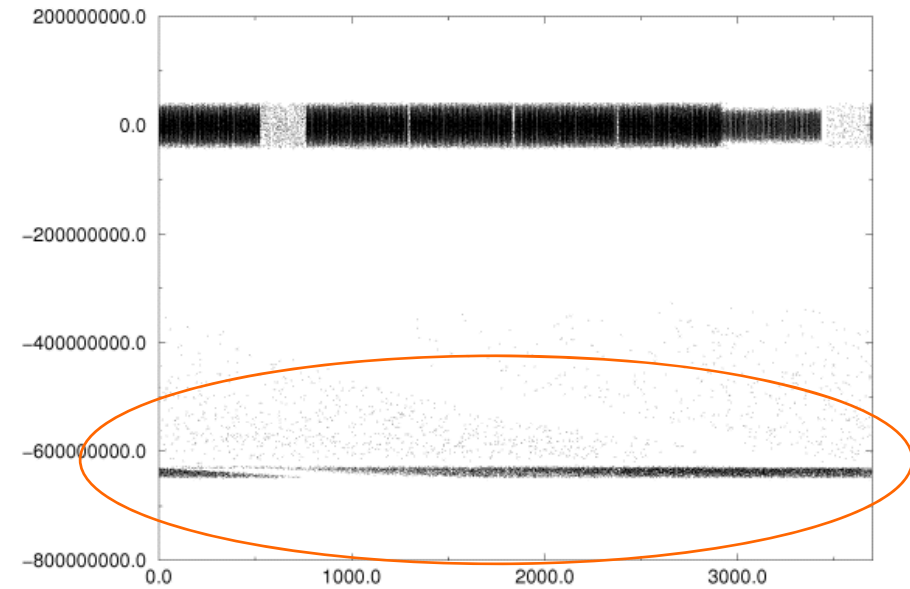
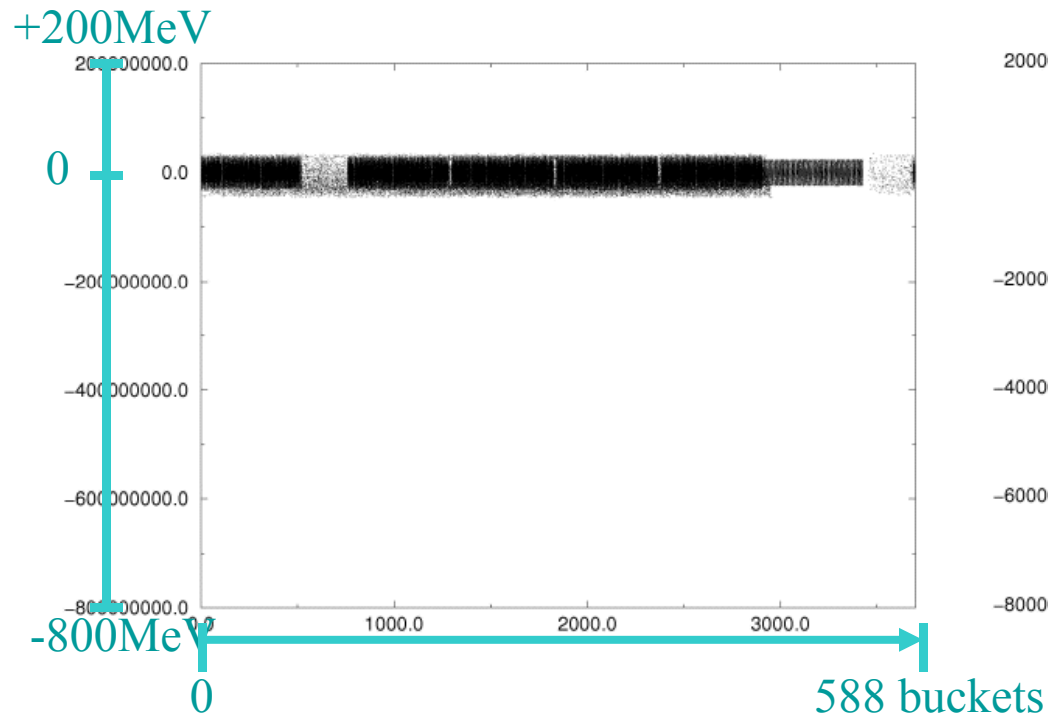


# Ramp loss

## Acceleration from 8.9 GeV to 10 GeV

Before acceleration

After acceleration



# Simulation for Injection kicker & Ramp losses (1)

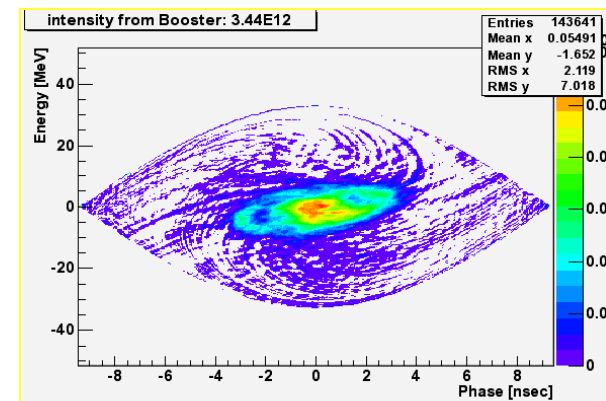
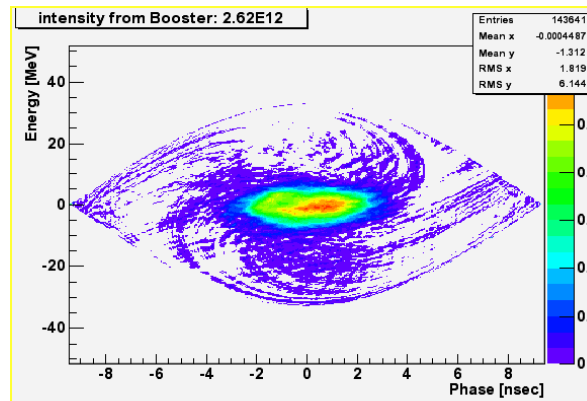
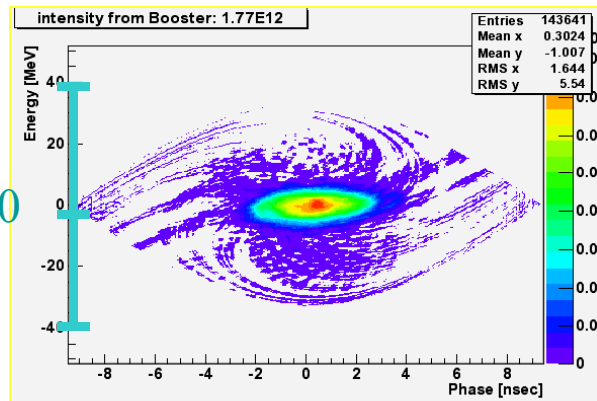
## Longitudinal phase tomography with measurement results

1.77E12 ppp

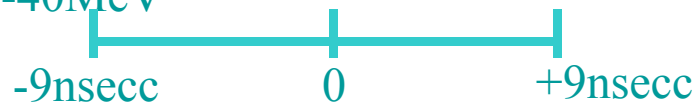
2.65E12 ppp

3.44E12 ppp

+40MeV



-40MeV



$\Delta\phi$ :  $\pm 1.47$ nsec

$\Delta p/p$ :  $\pm 6.88$ MeV

$\pm 1.68$ nsec

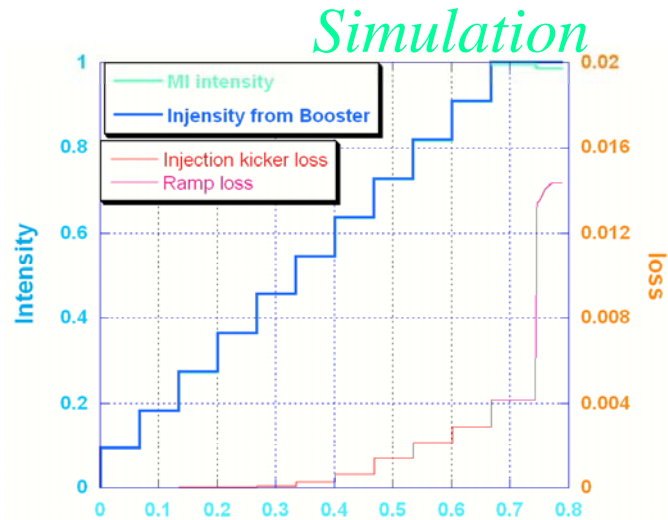
$\pm 7.62$ MeV

$\pm 1.78$ nsec

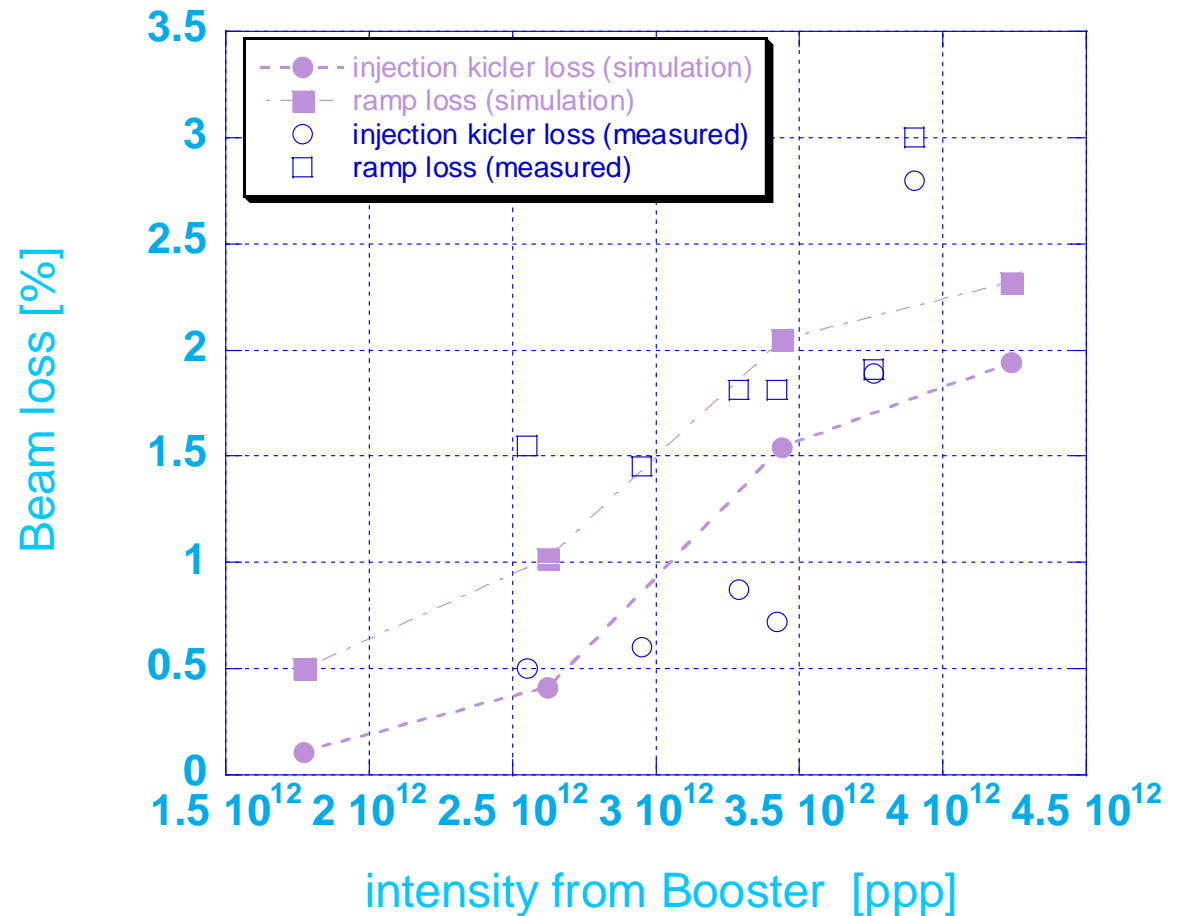
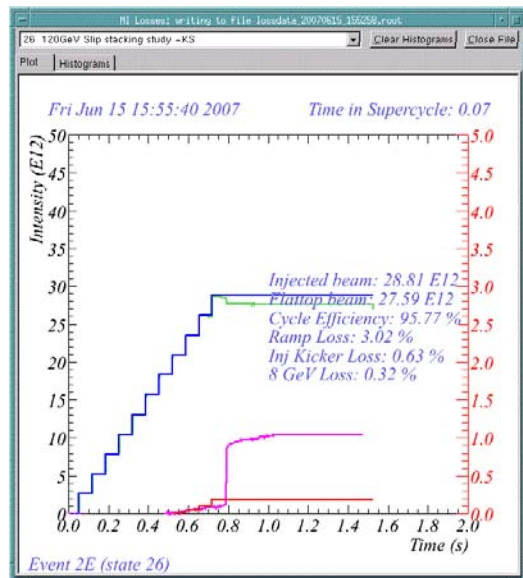
$\pm 8.99$ MeV

# Simulation for Injection kicker & Ramp losses (2)

## Comparison between measurements and simulation



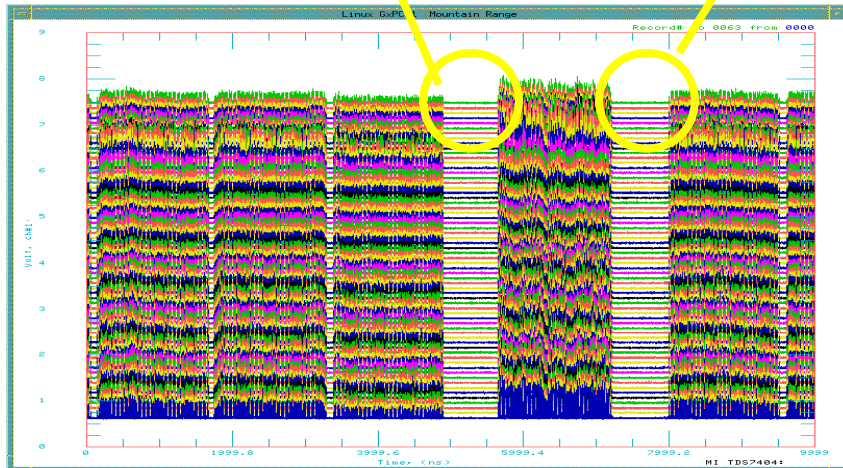
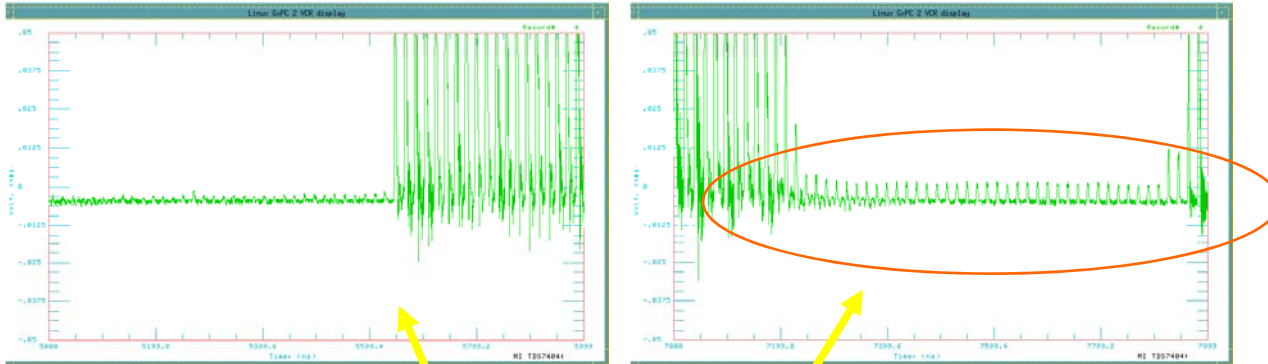
*Measurement*



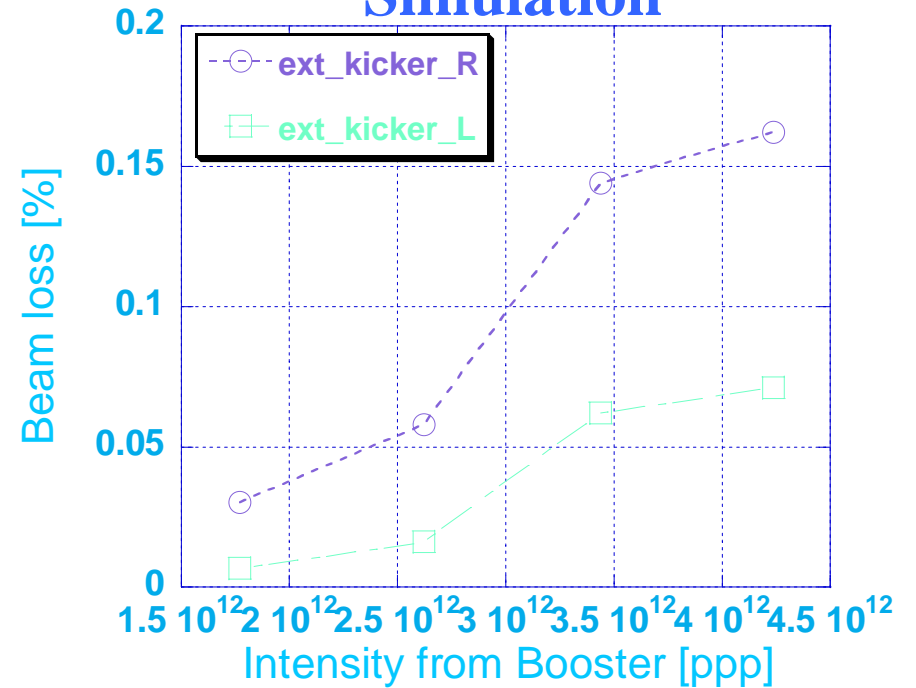
No transverse effects in the simulation.

# Extraction kicker gap loss

## Wall current monitor signal @ extraction



## Simulation



# Summary and Plans

Slip stacking is in operation for pbar stacking since December 2004 and increased proton intensity on target by 70%.

11 batch slip stacking scheme have already verified.

Beam was sent to Pbar and NuMI target:

Intensity ; 8.2E12 (Pbar), 30E12 (Numi).

Efficiency: 95.5%.

Record intensity: 4.6E13 ppp accelerated to 120 GeV.

Beam loss issues

injection kicker loss

ramp loss

extraction kicker loss

Require small emittance beam from Booster.

Anti-damp beam on ext. kicker gap with bunch by bunch damper.

8GeV lifetime loss

Lower chromaticity with damper.