

Multi-batch Slip Stacking in the Main Injector at Fermilab

June 26, 2007

Kiyomi Seiya
Fermilab

Current operation

Our goal

Scheme of 11 batch slip stacking

Status of beam studies

Beam loss

Injection kicker gap loss

Ramp loss

Extraction kicker gap loss

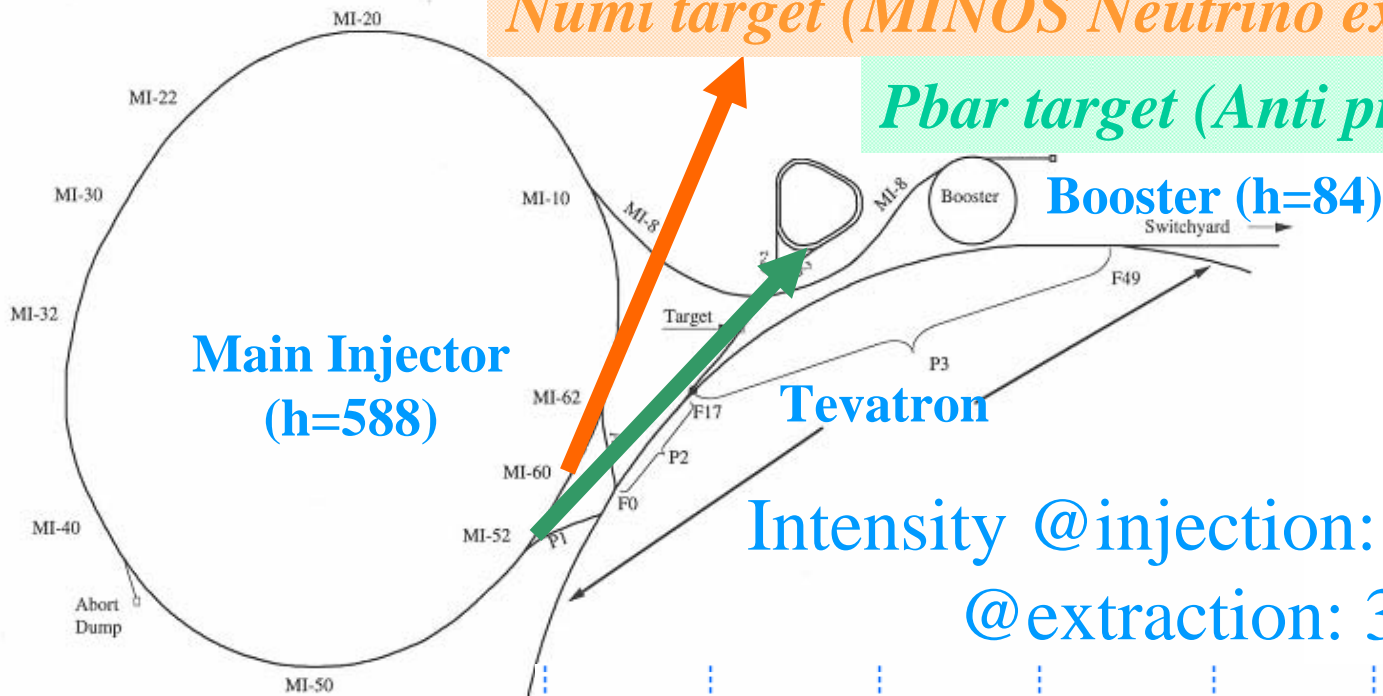
8GeV lifetime loss

Summary & Plan

MI 120GeV cycle operations

Numi target (MINOS Neutrino experiment)

Pbar target (Anti proton production)



Intensity @injection: $4.5E12$ ppp x 7
@extraction: $32E12$ ppp

Mixed mode

NuMI only

Bucket # 0 84 588

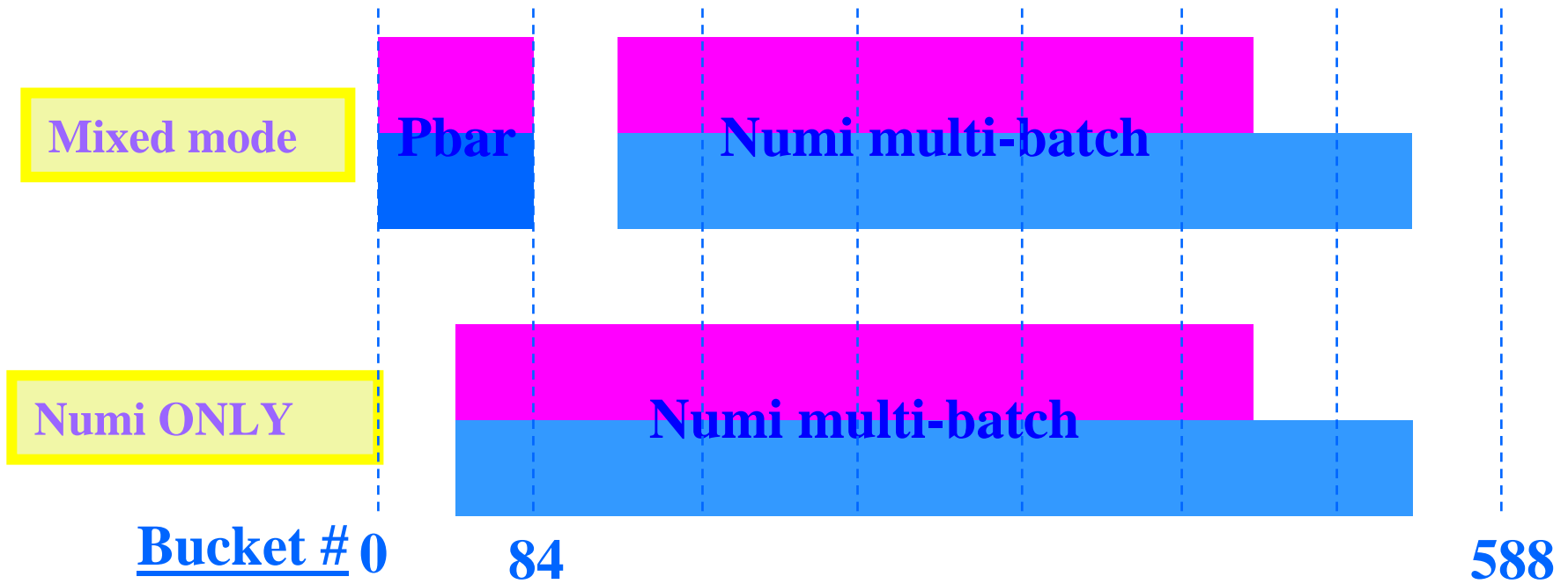
Pbar

Numi

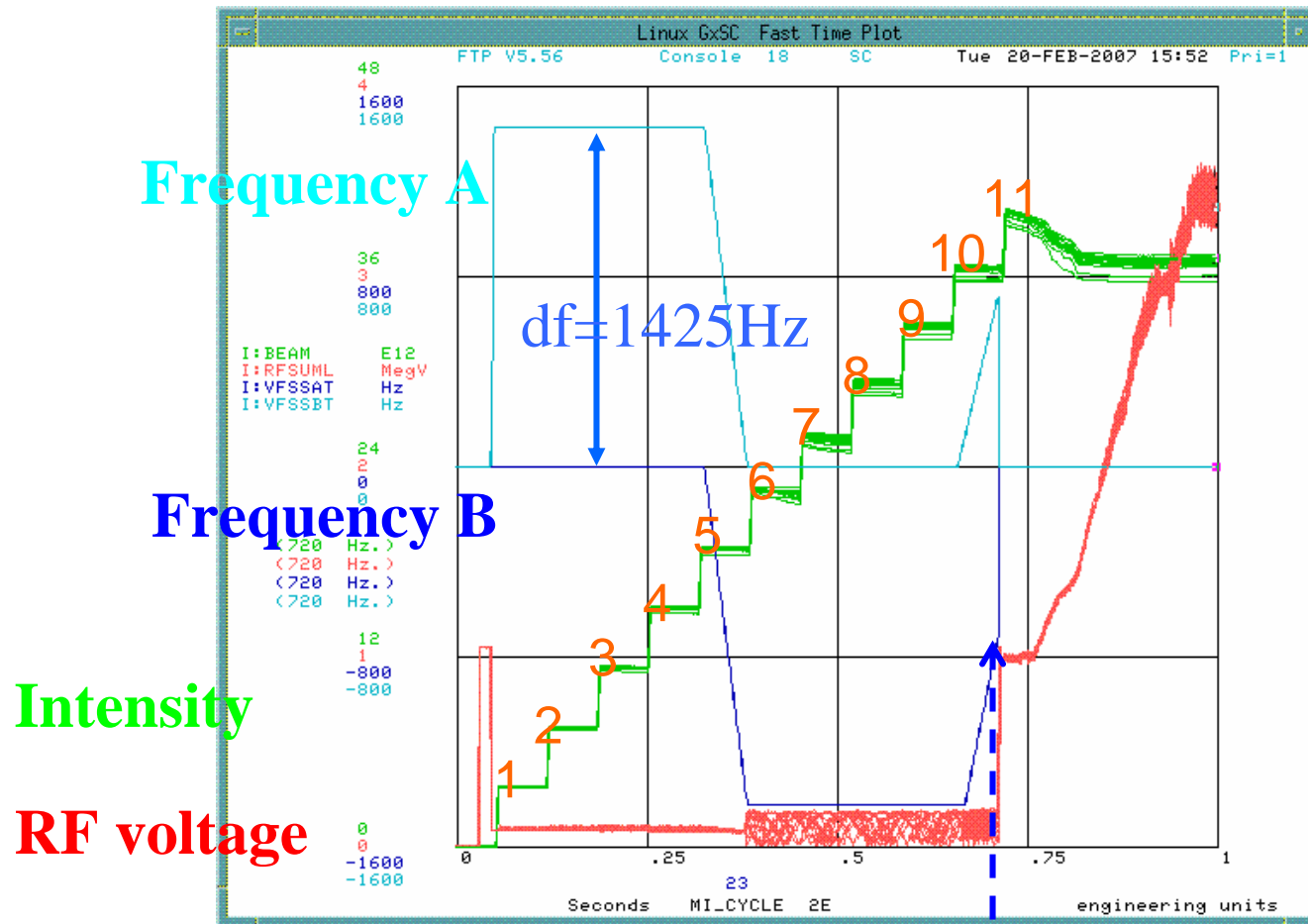
Numi

Proton Plan Goal

- **Intensity** @ injection : $4.3\text{E}12$ ppp x 11
@ extraction: $4.5\text{E}13$ ppp
- **MI cycle rate** < 2.2 sec
- **Total beam power:** 400kW 80kW → Pbar
320kW → Numi
- **Total beam loss:** < 5%



11 batch Slip stacking

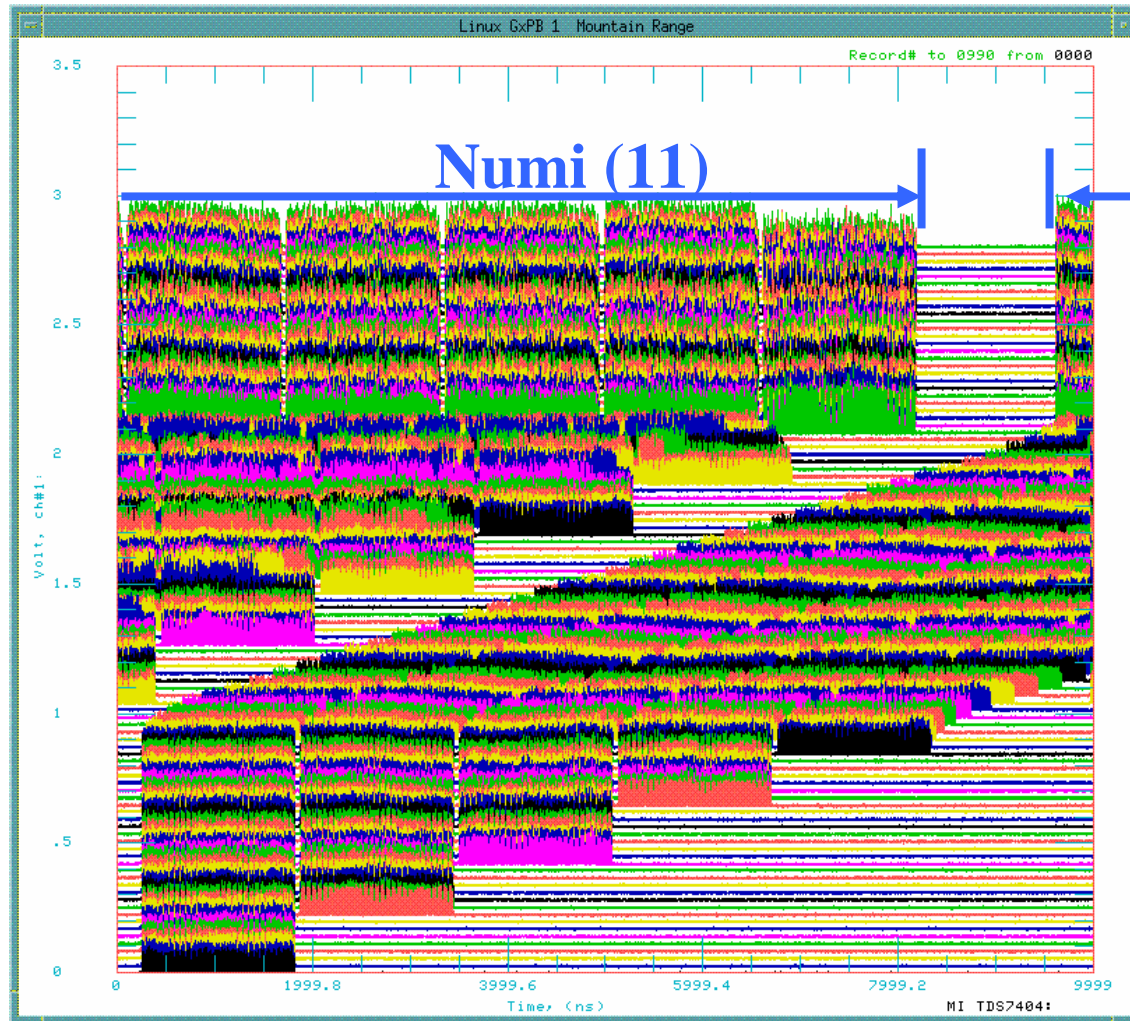


Slipping with 100kV rf

Recapture with 1MV rf

11 batch slip stacking on Numi only cycle

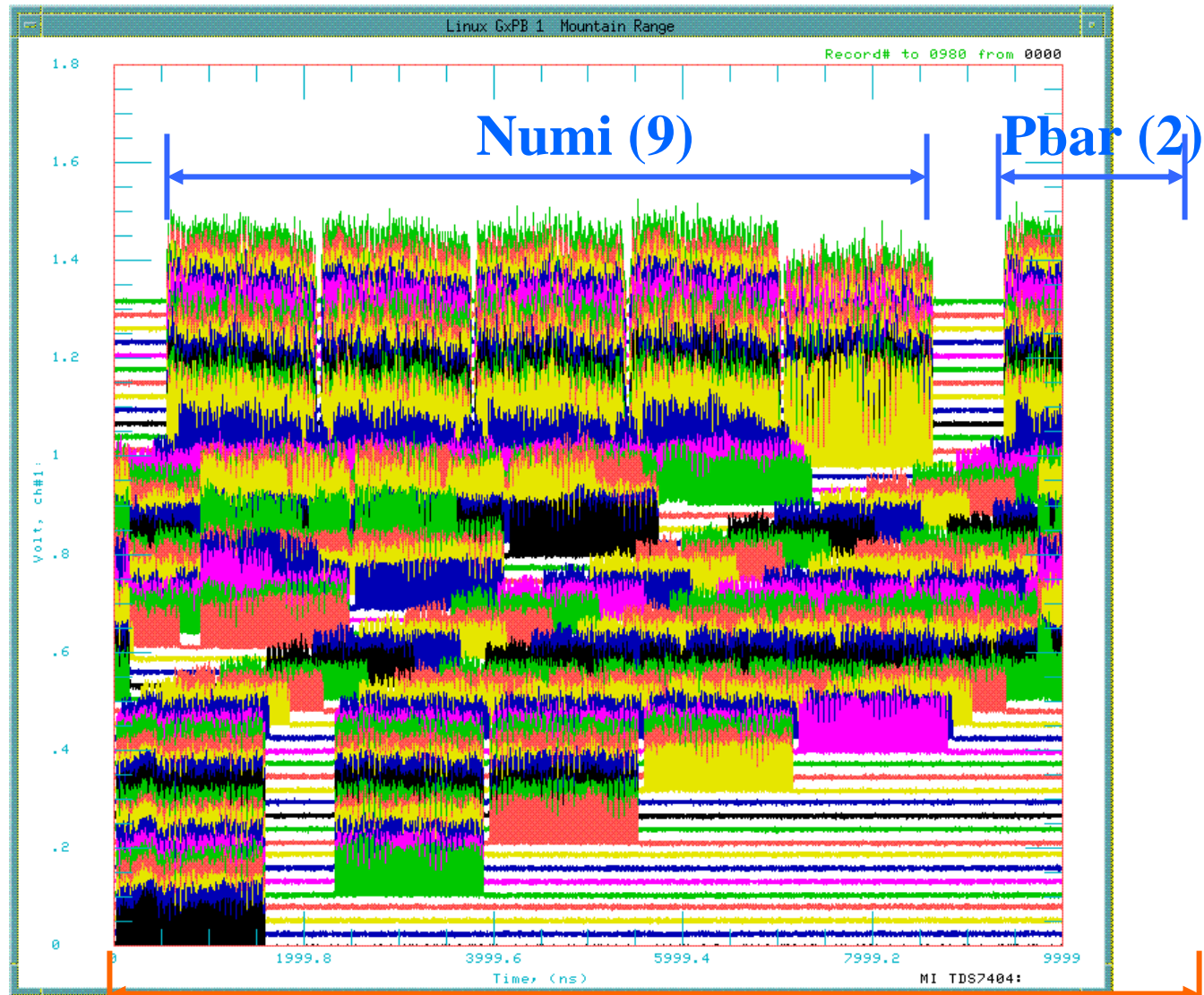
Time



11μsec (1 revolution)

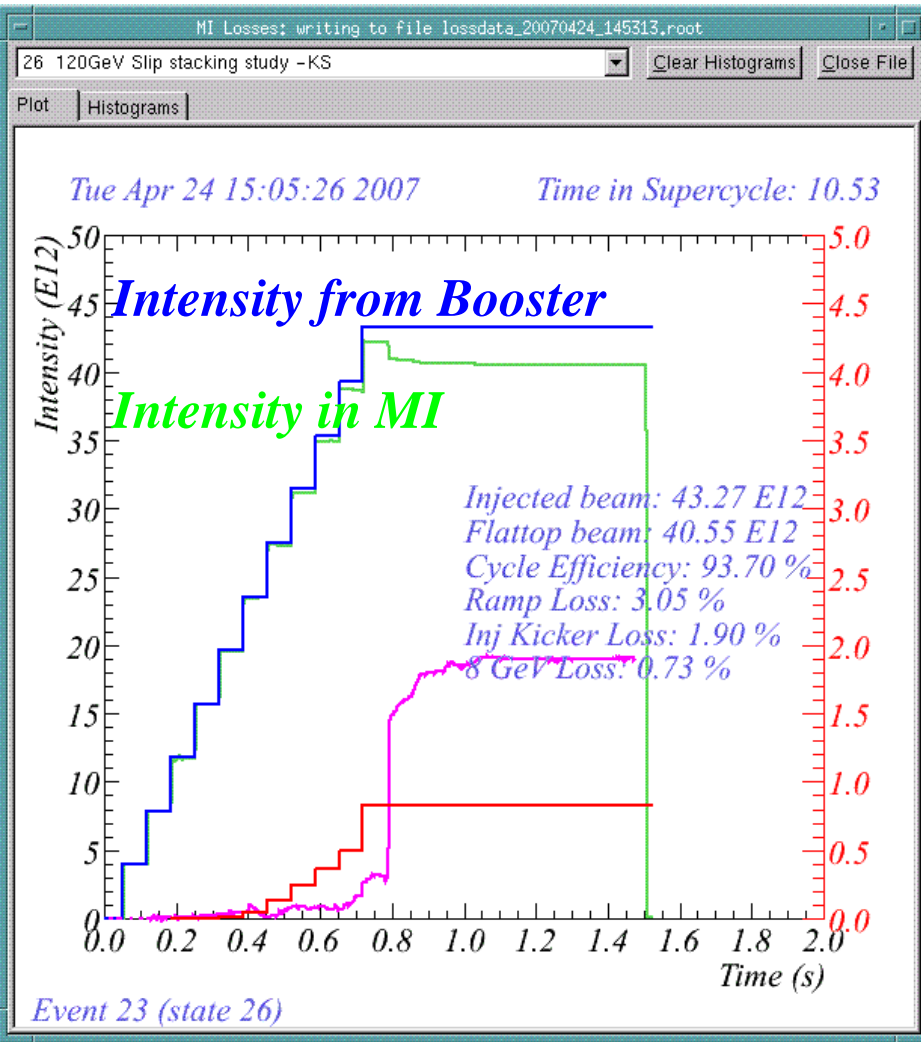
11 batch slip stacking on mixed mode cycle

Time



11 μ sec (1 revolution)

Status of 11 batch slip stacking



Numi only cycle

- Intensity: 40E12 ppp
- Cycle efficiency ~ 93%
- MI cycle rate < 2.2 sec

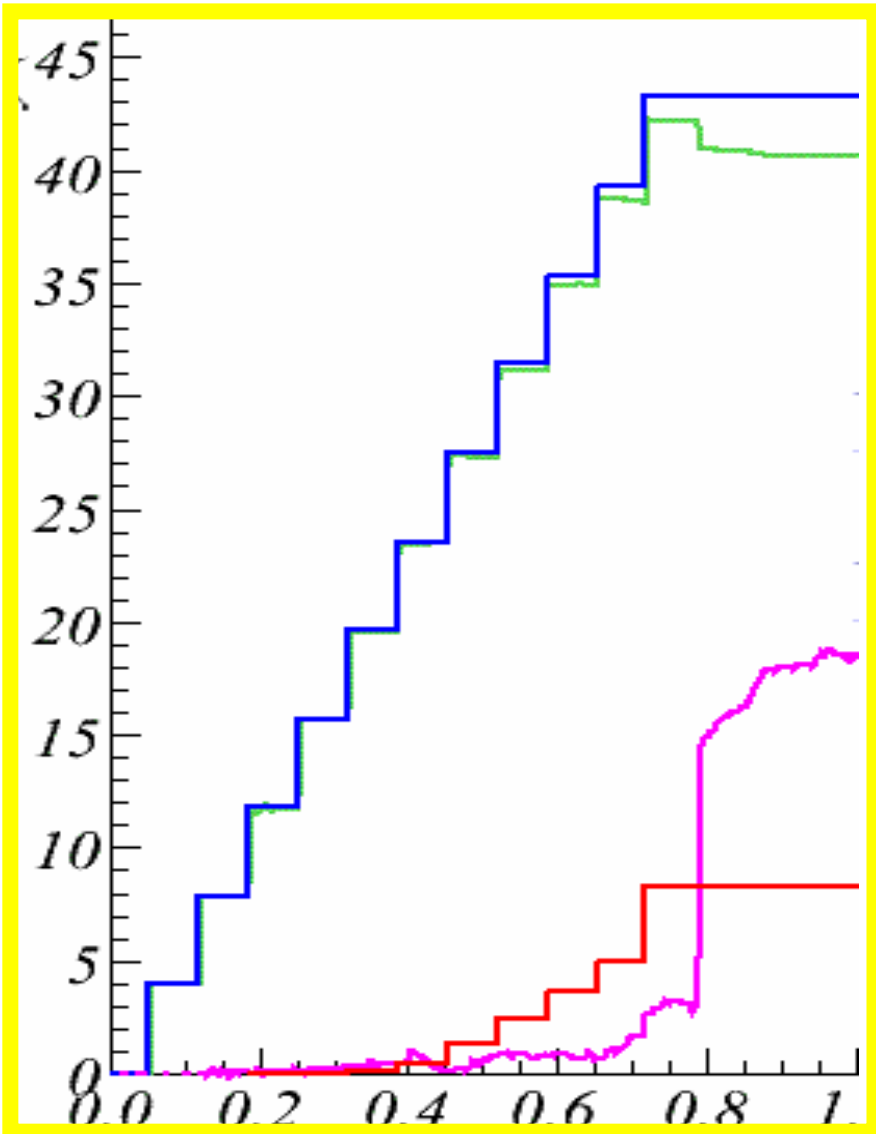
Mixed mode cycle

- Intensity:
6.5E12 ppp (pbar)
22E12 ppp (Numi)

MI Intensity record

- Intensity: 46E12 @ 120GeV

Beam losses on 11 batch Slip stacking

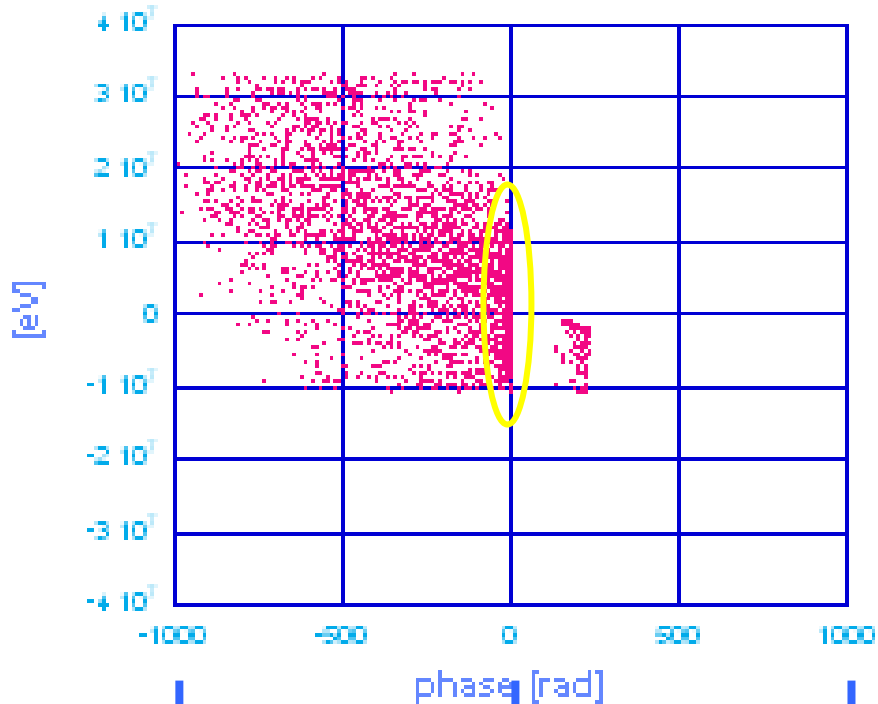


- **Injection kicker gap loss**
- **Ramp loss**
- **Extraction kicker gap loss**
- **8GeV lifetime loss**

Injection kicker gap loss(1)

One bunch simulation with two rf frequencies

With higher frequency

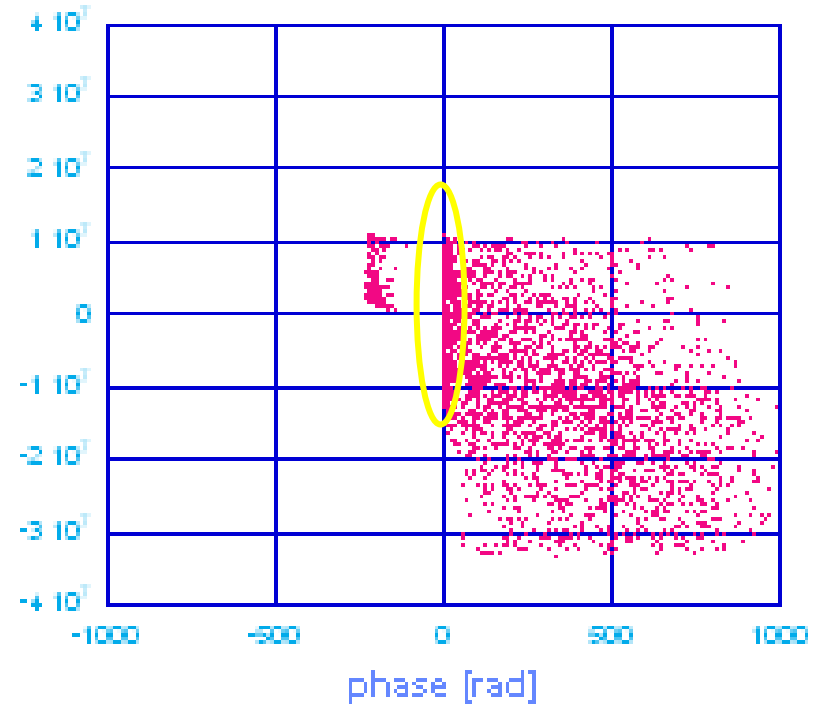


-160 buckets

0

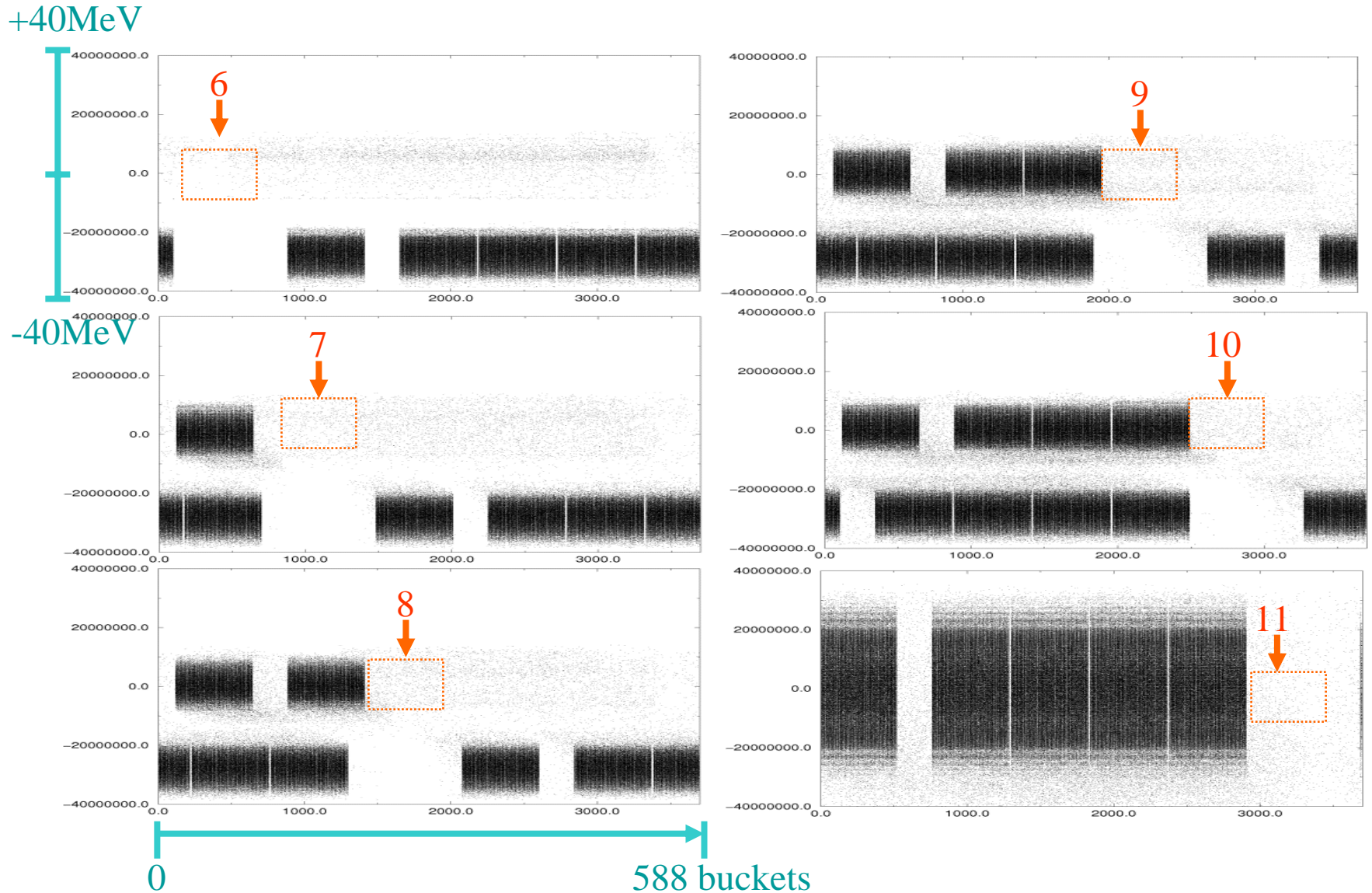
+160 buckets

With lower frequency



Injection kicker gap loss (2)

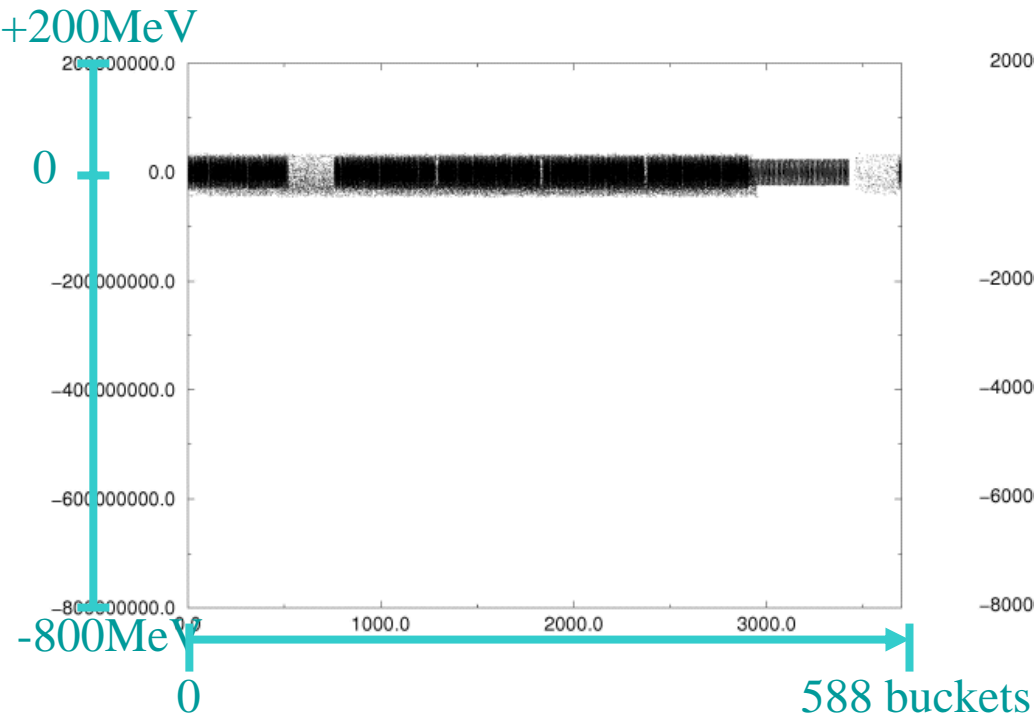
Longitudinal simulation for 11 batch slip stacking



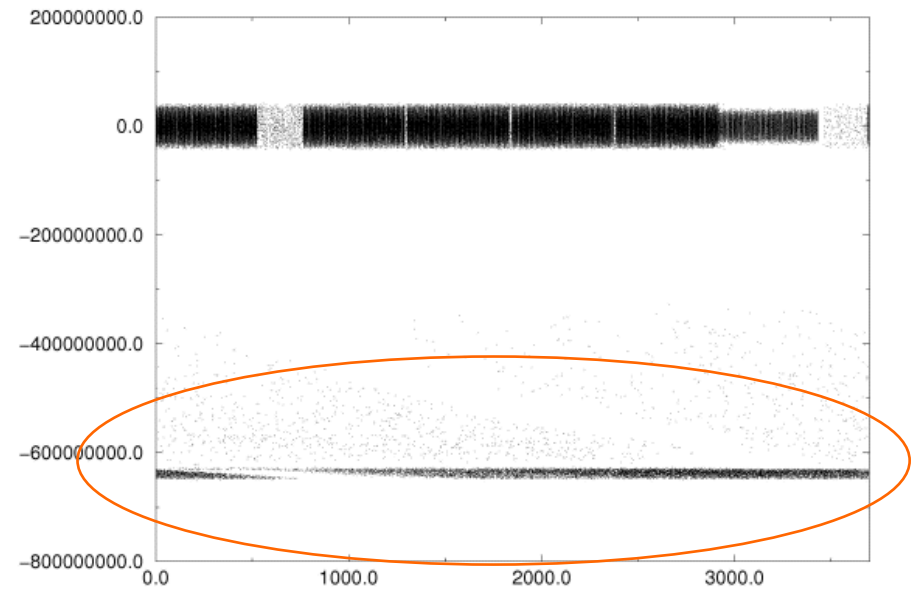
Ramp loss

Acceleration from 8.9GeV to 10 GeV

Before acceleration



After acceleration



Simulation for Injection kicker & Ramp losses (1)

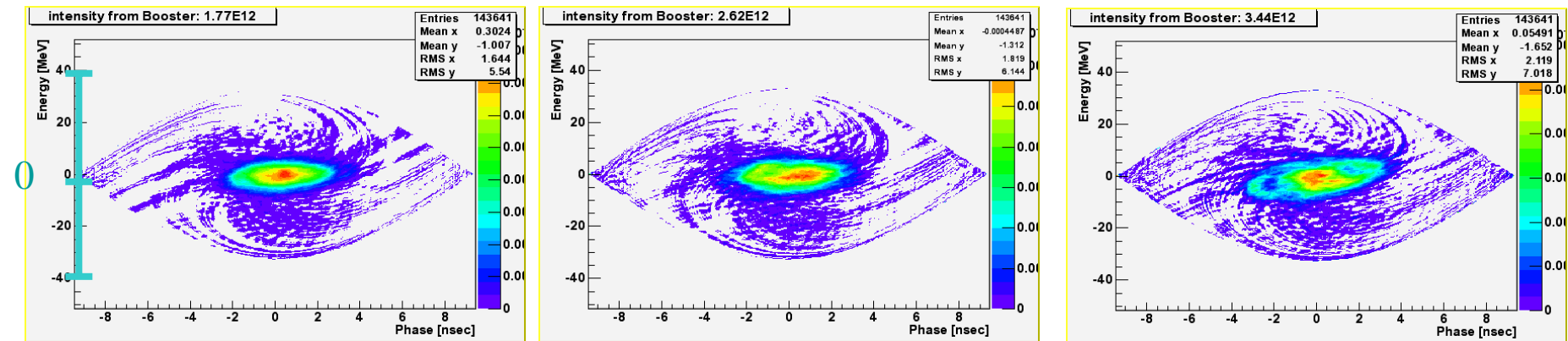
Longitudinal phase tomography with measurement results

1.77E12 ppp

2.65E12 ppp

3.44E12 ppp

+40MeV



-40MeV

-9nsecc 0 +9nsecc

$\Delta\phi$: $\pm 1.47\text{nsec}$

$\Delta p/p$: $\pm 6.88\text{MeV}$

$\pm 1.68\text{nsec}$

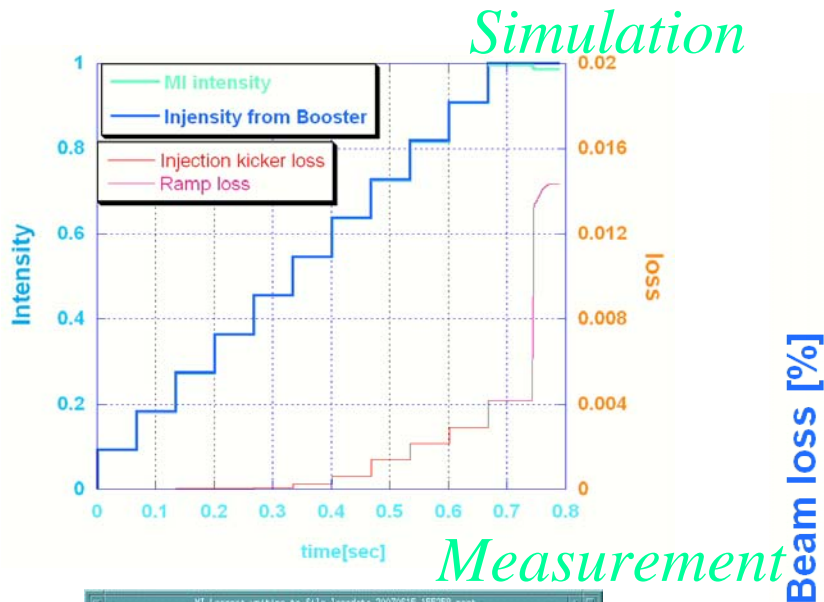
$\pm 7.62\text{MeV}$

$\pm 1.78\text{nsec}$

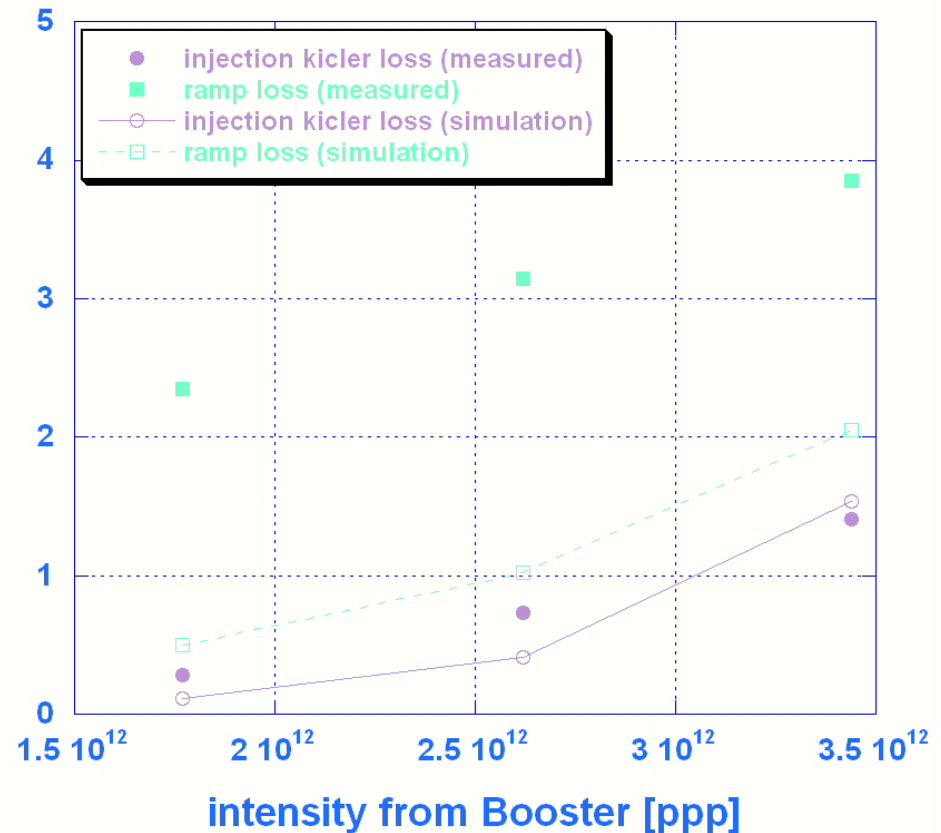
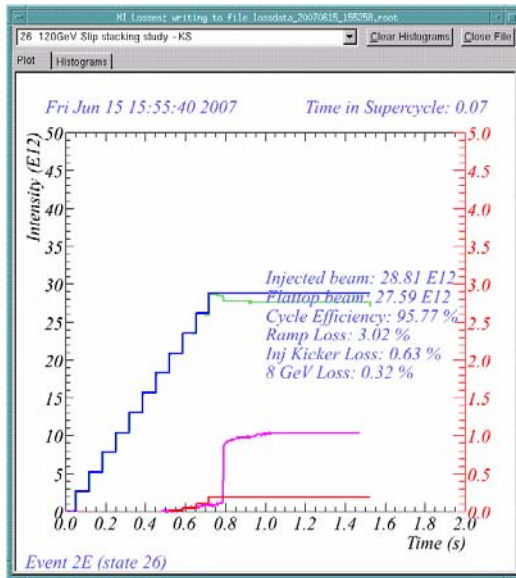
$\pm 8.99\text{MeV}$

Simulation for Injection kicker & Ramp losses (2)

Comparison between measurements and simulation



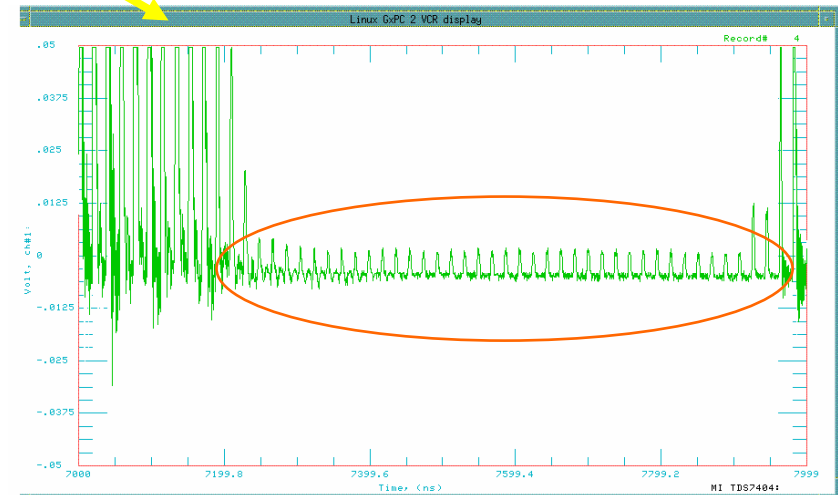
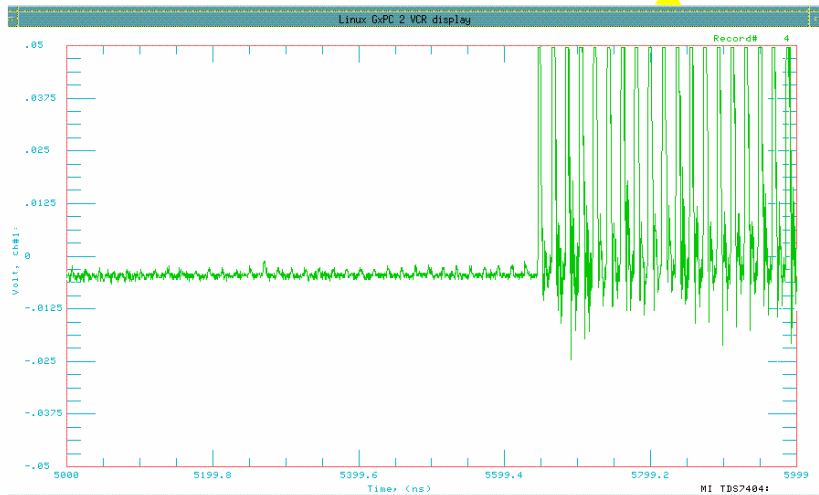
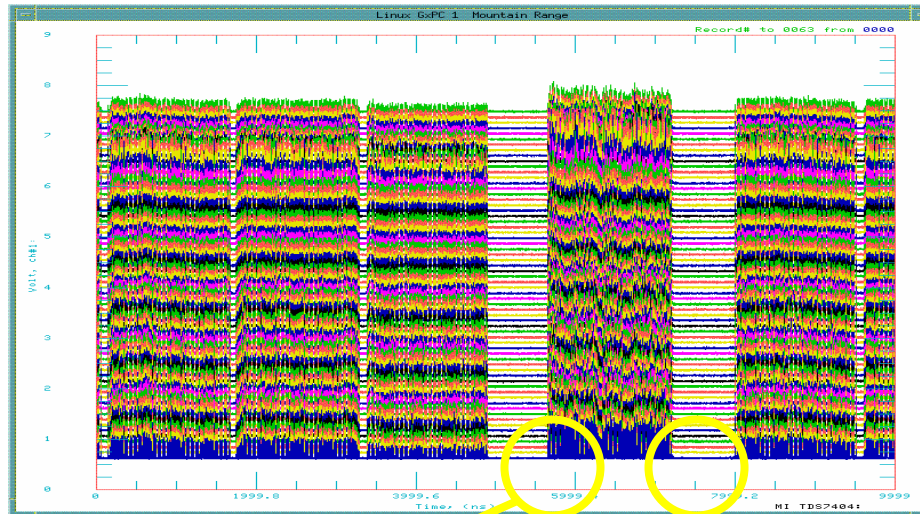
Beam loss [%]



No transverse effects in the simulation

Extraction kicker gap loss

Wall current monitor signal @ extraction



Summary and Plans

11 batch slip stacking scheme have already verified for both mixed mode and NuMI-only cycle.

Beam to NuMI target: (Intensity) $4.0\text{E}13$ (efficiency) 93%.

Record intensity: $4.6\text{E}13$ ppp to 120 GeV.

Beam loss issues

injection kicker loss

ramp loss

Require small emittance beam from Booster.

Need more beam studies for transverse effects.

extraction kicker loss

Anti damp with MI bunch by bunch damper.

8GeV lifetime loss

Lower chromaticity with damper.