

# Bunch Rotation in the Booster Neutrino Beamline

BeamsDoc 6904  
available at <https://beamdocs.fnal.gov/>

# Summary

Want to clean up tails on beam in the MI8 line, not the Recycler/Main Injector.

Need to keep residual rates on MI8 collimators reasonable low (so they are serviceable).

Beam going to RR/MI is smaller – therefore, less lossy – than beam going to BNB because MI/RR beam is bunch rotated.

What is impact to SBN experiments if we bunch-rotate beam?

MI/RR

BNB Beamline

MI8 Beamline

Booster

The MI8 line connects the Booster to both the Recycler Ring/Main Injector and the Booster Neutrino Beamline. Beam going to either NuMI or BNB passes through the MI8 line.

The collimators in the MI8 line are optimized to reduce losses going into RR/MI and keep the residual dose on the collimators to a reasonable level.

Losses on the MI8 collimators differ for RR/MI and BNB beam. As total beam to NuMI increases, one way to decrease total losses on collimators is to decrease losses caused by beam to BNB.

What is different about beam to BNB? Bunch rotation.

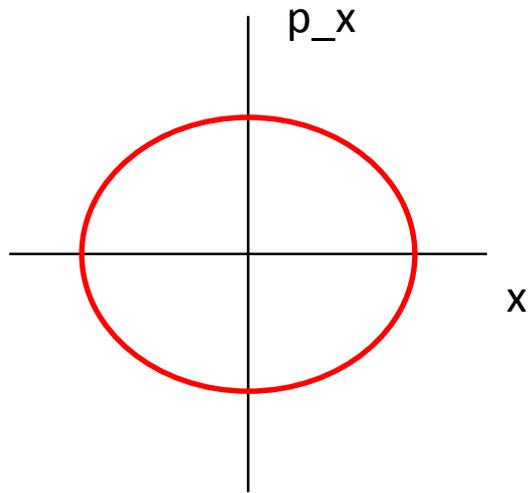
Bunch rotation occurs in the Booster.

Beam is bunch rotated to match into the Recycler/Main Injector for slip stacking. Slip stacking is what allows us to get high intensity beam to NuMI.

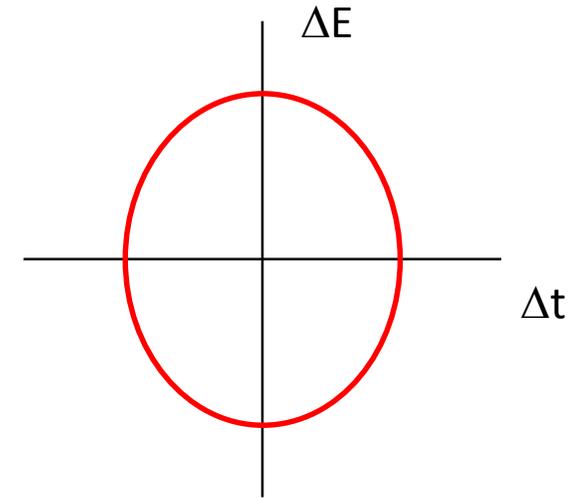
Bunch rotation is implemented on a cycle-by-cycle basis -- it can be turned ON or OFF based on the destination of the beam.

Bunch rotation does not (appreciably) affect the intensity directly. To get more beam out of the Booster, one needs to inject more beam into the Booster.

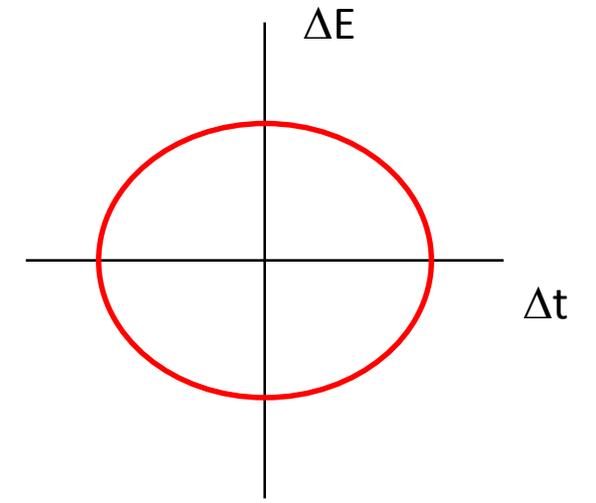
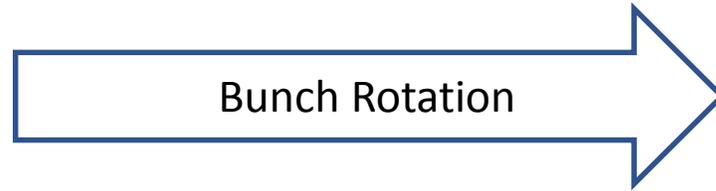
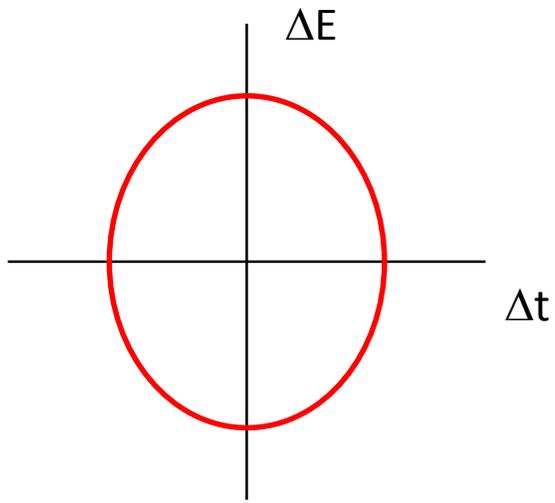
Beam coming at you



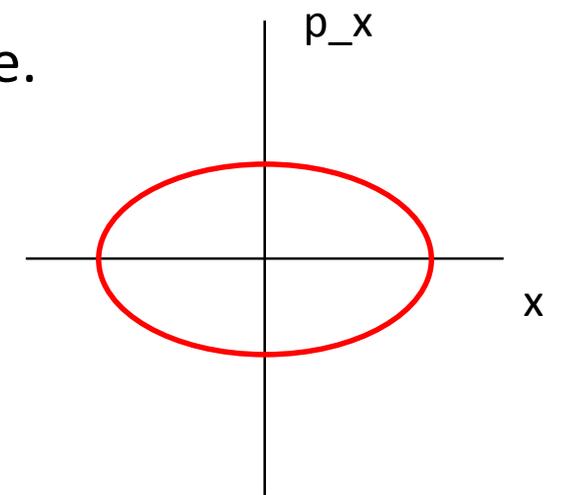
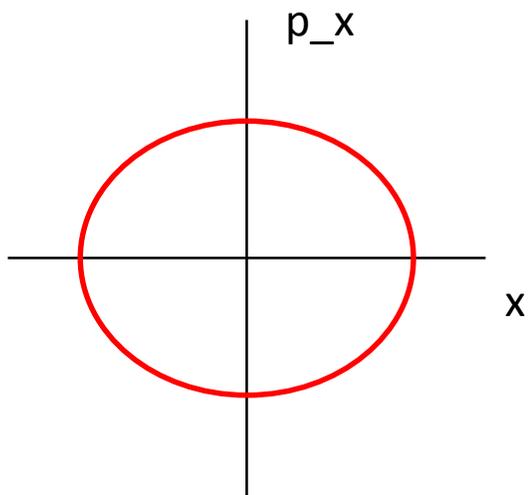
Beam going past you

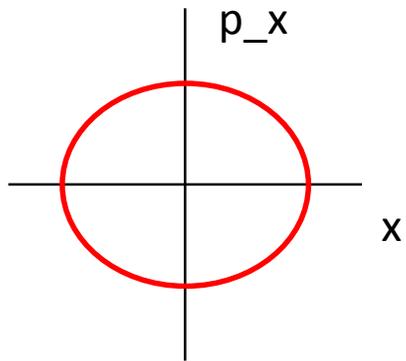


Particle beam has extent in both transverse (“coming at you”) and longitudinal (“going past you”) phase space.

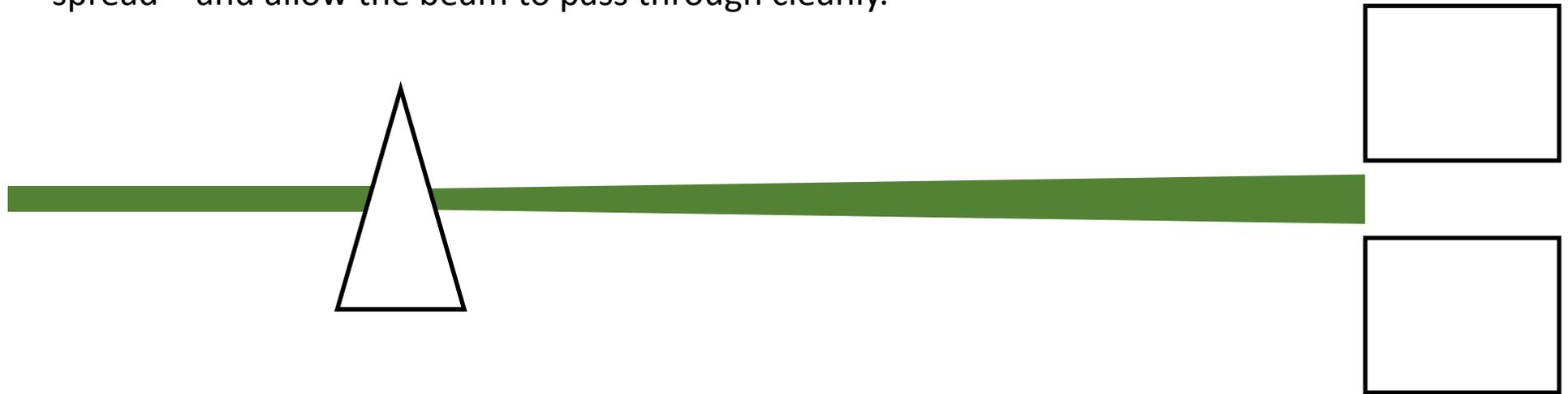
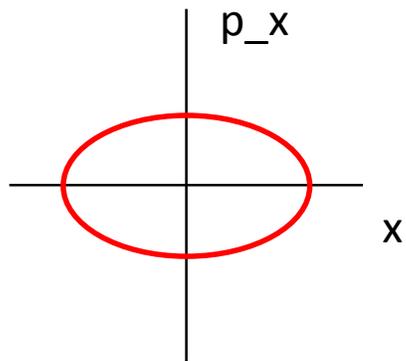


In an accelerator, we can “bunch rotate” – trade off  $\Delta E$  and  $\Delta T$  in (longitudinal) phase space. This “feeds down” into transverse phase space.



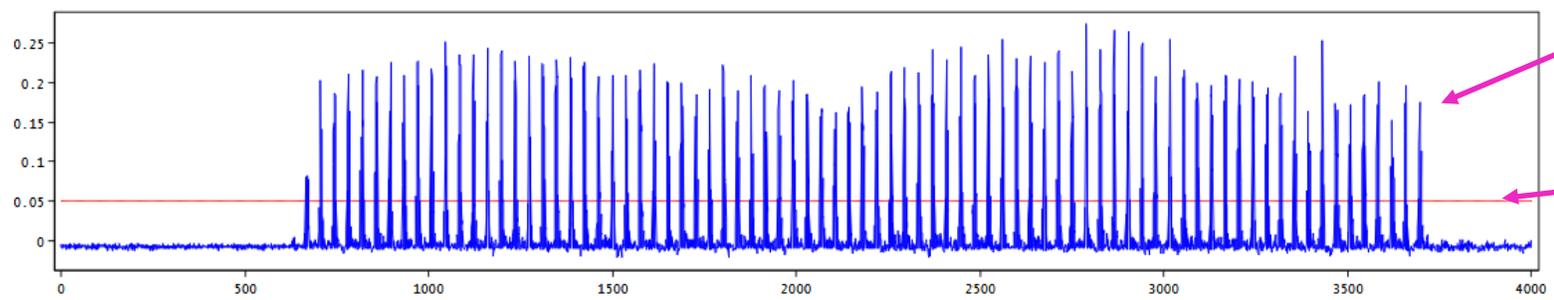


When the beam passes through a magnet, it spreads out (due to  $\Delta p$ ).  
 If the beam spreads out too much, it may hit apertures.  
 However, one may be able to bunch rotate – decrease the momentum spread – and allow the beam to pass through cleanly.



### Booster Neutrino Beam RWM

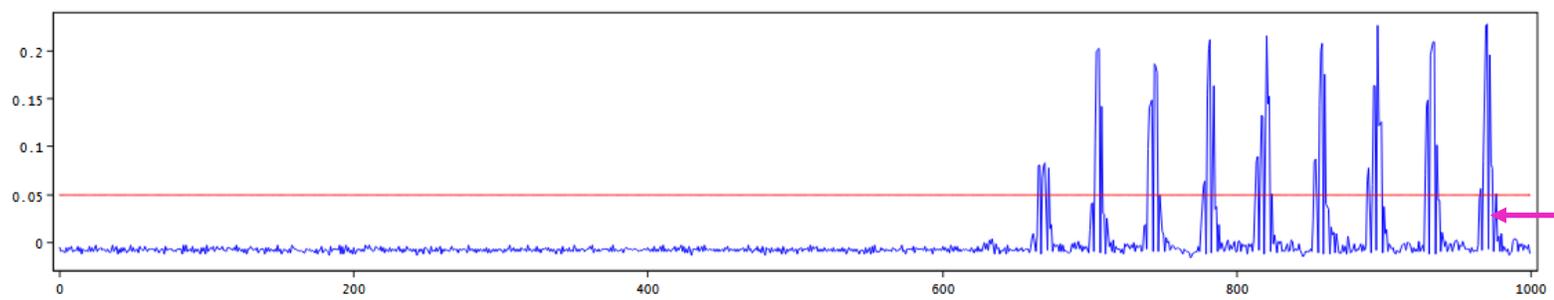
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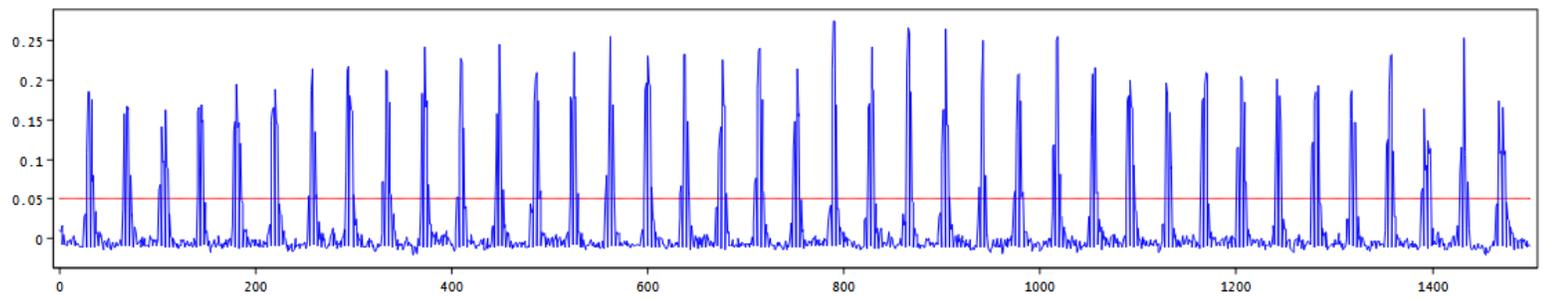
Bunch Rotation OFF

Individual bunches of beam

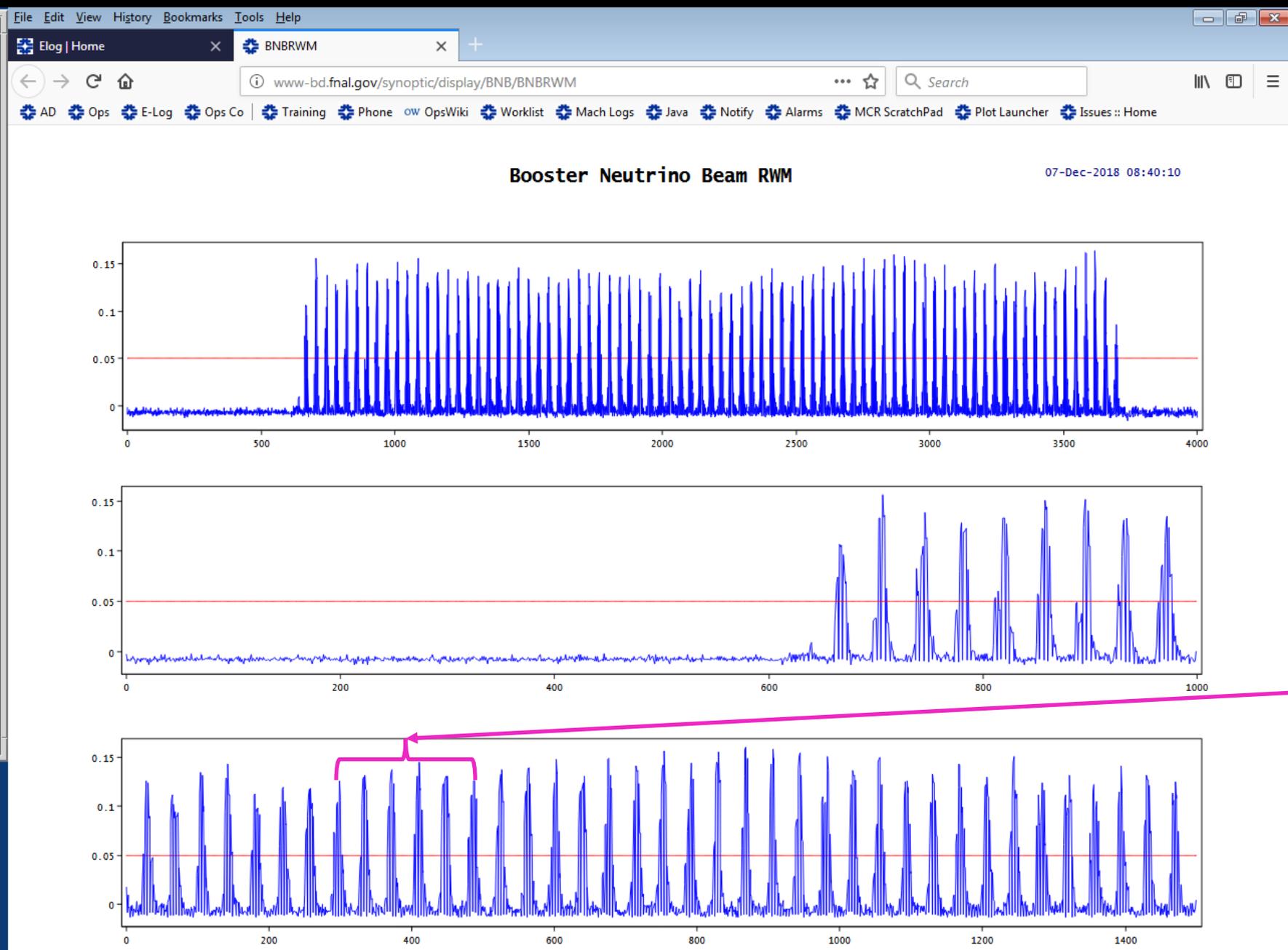
Trigger threshold



Problem with digitizer – drops every fourth record



Digitizer measures voltage induced by beam every 0.5 ns

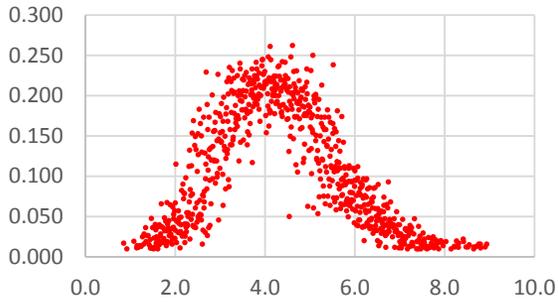


# Bunch Rotation ON

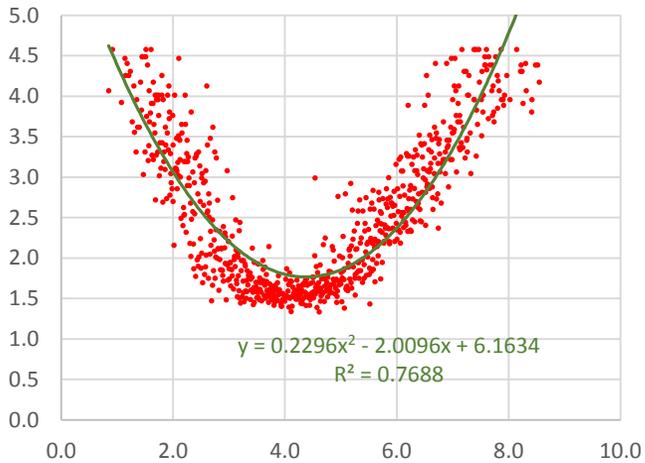
Beam looks "broader"

How much?

Spacing between bunches remains the same



For a single spill, line up all the bunches.  
Assume the distribution is gaussian.

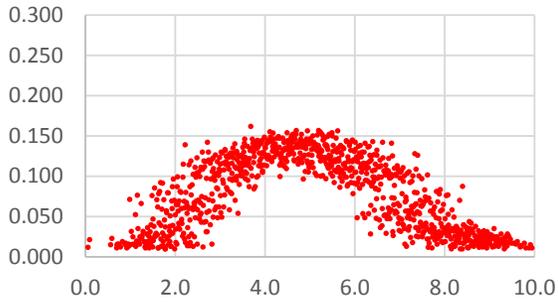


(horizontal units: ns)

Take the log and fit a parabola.  
From the fitted parameters,  
calculate the sigma.

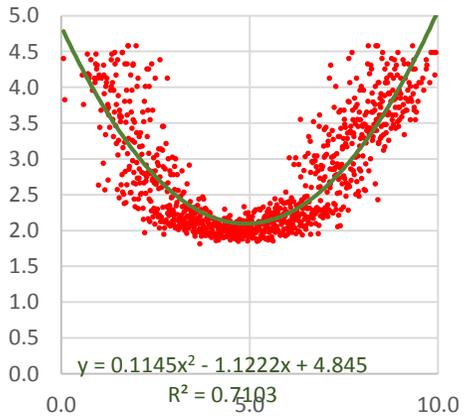
## Bunch Rotation OFF

Based on 10 measurements, the  $1\sigma$   
time spread is  $1.48 \pm 0.03$  ns.



For a single spill, line up all the bunches.  
Assume the distribution is gaussian.

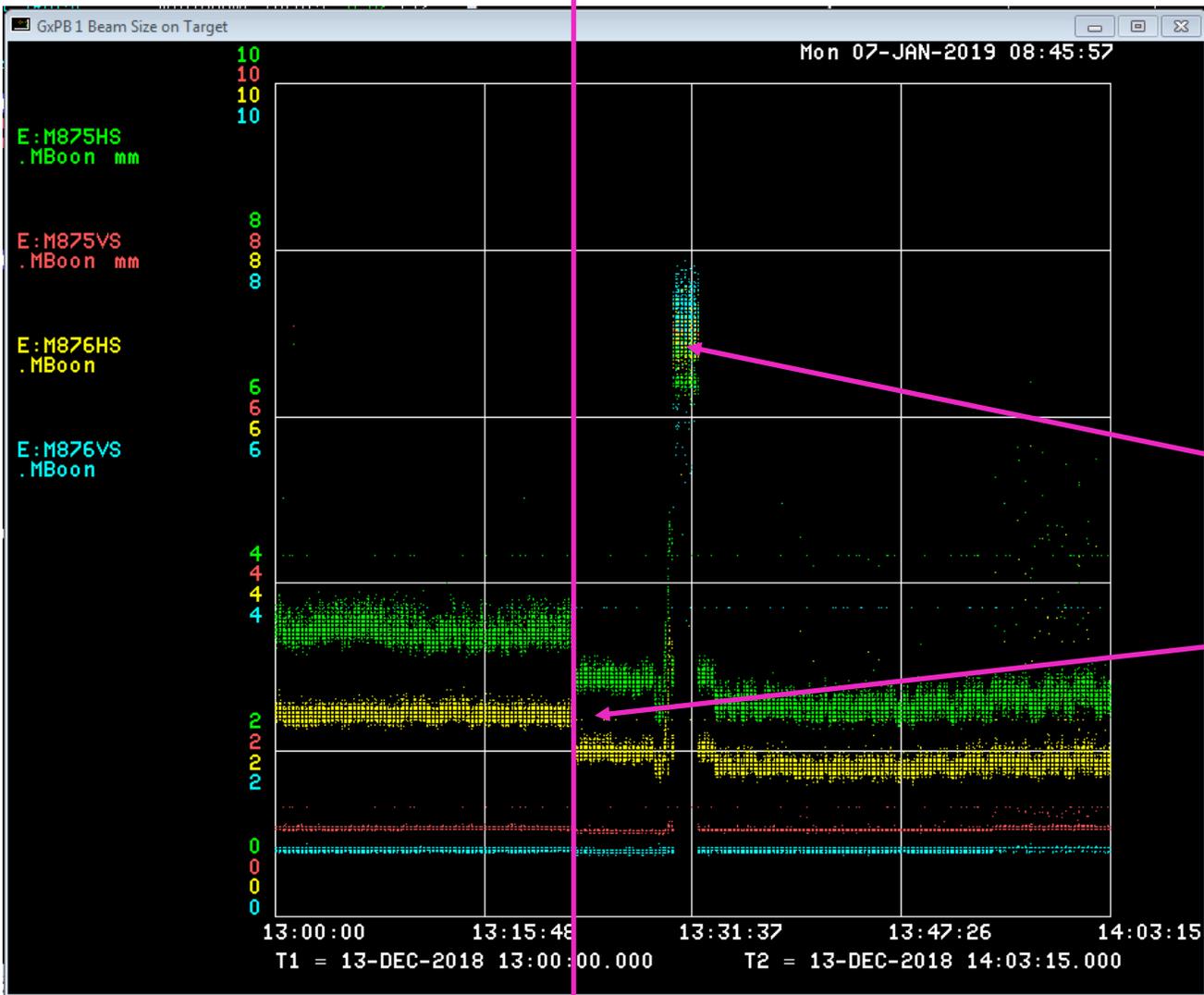
(horizontal units: ns)



Take the log and fit a parabola.  
From the fitted parameters,  
calculate the sigma.

## Bunch Rotation ON

Based on 10 measurements, the  $1\sigma$   
time spread is  $2.15 \pm 0.13$  ns.



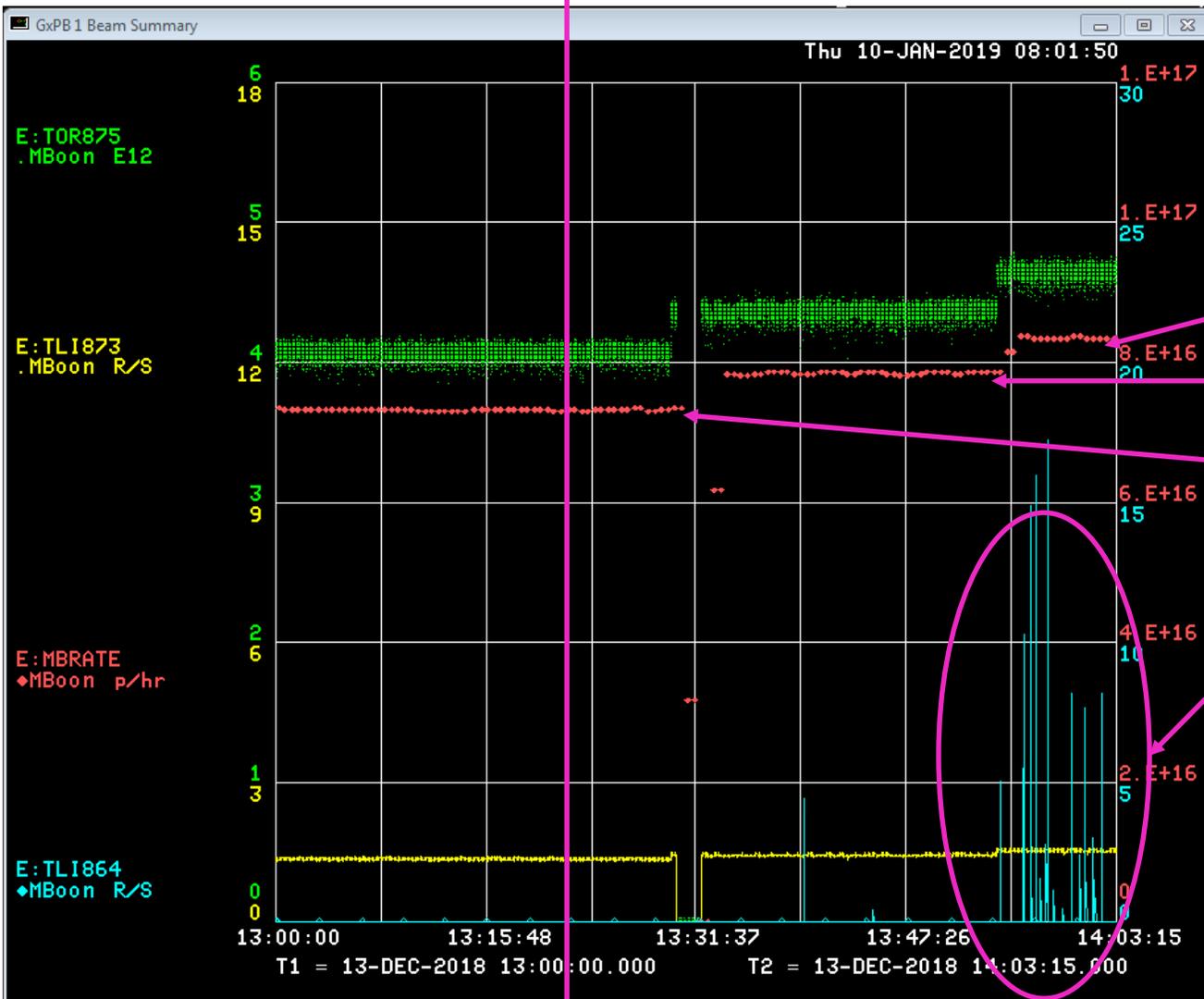
## Spot Size

If dispersion is non-zero, decreasing momentum spread will decrease spot size.

(no beam)

Turning bunch rotation ON decreases horizontal spot size.

Bunch rotation turned ON



## Intensity

Turning bunch rotation ON allows us to increase our hourly rate from 7.33E16 pph to 7.85E16 pph.

(this measurement was taken with Switchyard in the timeline and g-2 not running)

8.36E16 pph

7.85E16 pph

7.33E16 pph

Losses too high in beamline

Bunch rotation turned ON

## Conclusion

Based on 10 measurements each with bunch rotation on and off, bunch rotating the beam increases the  $1\sigma$  time-spread at the resistive wall monitor from  $1.48\pm 0.03$  ns to  $2.15\pm 0.13$  ns.

Under good conditions, the hourly rate could increase by  $\sim 7\%$ .