

Studies of Flat Bunches in the Tevatron

Chandra Bhat Fermilab (LARP)

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Collaborators: C. Bhat, H-J. Kim, F.-J. Ostiguy, T. Sen, ...

Outline



Background

- Recent Beam Studies on Flat bunches
- Proposal:
 - Study Flat bunch beam in the Tevatron

Bunches with Uniform Line-charge Distribution

- **Theoretical Studies of Flat Bunches**
- Summary

Motivation



- There is on an going program at the LHC to upgrade the luminosity from its design value 1x10³⁴ cm⁻²sec⁻¹ to 1x10³⁵ cm⁻²sec⁻¹. This poses daunting challenges. It is, therefore, necessary to explore seriously all of the viable options.
- The Large Piwinski angle or "Flat Bunch scheme" has the potential to yield 40% higher luminosity than Gaussian bunches for the same bunch intensity and the total beam-beam tune shift if the flat-bunch line intensity is kept the same as level as the Gaussian peak intensity.
 - (F. Ruggiero and F. Zimmermann (PRST-AB-Vol. 5, 061001 (2002)

The Piwinski angle ϕ , is given by,

 $\phi = \frac{\theta_c \sigma_z}{2\sigma_x} \qquad \begin{array}{l} \theta_c \text{ is crossing angle} \\ \sigma_z \text{ is RMS bunch length} \\ \sigma_x \text{ is RMS transverse size} \end{array}$



Therefore by flattening the bunch and with an increase in bunch intensity one can reach the ultimate luminosity at LHC.

Hence the interest in flat bunches !

LHC upgrade paths with L≥ 10³⁵ cm⁻²sec⁻¹

(F. Zimmermann, CARE-HHH Workshop, 2008)



"Flat Bunches" Types and Generation



Flat Bunches come in two forms



There are two distinct methods to create flat bunches

- \Box Barrier rf \leftarrow Like that in the Recycler
- Resonant rf systems
 - Double, triple or multiple harmonic rf system
 - Longitudinal hollow bunches, Carli's technique

Historically a lot of work has been done at CERN on beam in double harmonic systems. Currently, more studies are being carried out in the SPS by Elena Shaposhnikova & collaborators It is very important to study the single and multi-bunch stability issues of beam in **Double & Triple** harmonic rf buckets.

Ideal one

Flat Bunch with Double Harmonic RF waves (A simple schematic view of the concept)

Beam in Single Harmonic RF wave Beam in Double Harmonic RF wave





Beam Stability Criterion in the Longitudinal Phase Space



inside the bucket, then the particles in the vicinity of this region can become unstable against collective instabilities. V. I. Balbekov (1987)

As the slope of the rf wave is reduced to zero at the bunch center, the bunch becomes longer and synchrotron frequency spread is greatly increased. This increases Landau damping against coupled bunch instabilities. A. Hofmann & S. Myers,

Proc. Of 11th Int. Conf. on HEA, ISR-Th-RF/80-26 (1980)





Examples from the July 09 Studies A first look





Some remarks on the PS studies:

- PS is not a storage ring and all of its RF were tuned for standard operation.
- Instability studies were carried out to a maximum duration of 140 ms.

Hence, it is important to carry out Flat Bunch studies in a storage ring.

Flat bunch beam stability at the Tevatron at 150 GeV



Tevatron is an ideal place for the flat bunch studies

- It is world's best storage ring with many hours of beam lifetime. Well understood lattice.
- Available RF: 53MHz. 106MHz and 159MHz rf systems can be added
- ❑ Multiple bunches ← one can study a few bunches to 100s of bunches with 18 nsec bunch spacing.
- □ Bunch intensity~ $6x10^{10}$ protons ← bit low but, that is fine
- Have necessary diagnostics to monitor the beam dynamics both in longitudinal as well as transverse space
 - Wall Current Monitor for measurements on longitudinal profiles
 - Flying wire and ion profile monitors
 - > Add OTR \leftarrow Alex Lumpkin is planning to add in the abort-line

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to study transverse dynamics of flat bunches

106 MHz and 159 MHz RF Cavities



106 MHz RF cavity in the MI



Currently in the MI Used during proton and pbar coalescing **Parameters:** Frequency= 106 MHz fixed, tuned at 150 GeV Vrf = ~9kV (maximum of 16kV) Need some repair on water cooling

159 MHz RF cavity in the MR



Currently in MI60 building Used for Focus-Free Tran. crossing studies **Parameters:** Frequency= 159 MHz, tunable Vrf = up to 250kV

Tevatron Flat bunch Studies Scenario-I





Beam Energy = 150 GeV Beam Bunch Area $\approx 0.1 \text{ eVs}$ (Beam from the Booster+a few% growth in the MI) Available Bucket Area = 0.7 eVs (53MHz RF wave) = 0.57 eVs (53MHz+106MHz) RF waves) = 0.47 eVs (53MHz+106MHz+159MHz RF waves) Limits the available Bucket Area

Tevatron Flat bunch Studies Scenario-II





Beam Energy = 150 GeV Beam Bunch Area $\approx 0.1 \text{ eVs}$ (Beam from the Booster+a few% growth in the MI) Available Bucket Area = 2.98 eVs (53MHz RF wave) = 2.66 eVs (53MHz+159MHz RF waves)

This may be more favorable and need to phase only two RF systems



As a part of LARP program we have a

Proposal Theoretical Investigations of Flat Bunch Scenarios for the LHC Luminosity Upgrade

C. Bhat, H-J. Kim, F.-J. Ostiguy, T. Sen

Issues for Theoretical Investigations



Proposing to do theoretical investigations on the following issues --

- For creation of flat bunches, investigate the use of
 multiple harmonic cavities (perhaps 2 to 3 harmonics) and
 - Specify
 - Optimal RF parameters
 - Beam intensity limits
 - Reevaluate impedance budget and constraints
- If flat bunches are to be produced in one of the LHC upstream machines, explore beam instability issues for acceleration up to 7 TeV.
- Single-bunch and multi-bunch instability issues.

Issues for Theoretical Investigations (cont.)

- What are the optimal bunch and beam parameters for the LPA scheme with due consideration of the following
 - □ Integrated luminosity (i.e. luminosity and lifetime)
 - □ Emittance growth from beam-beam interactions, IBS
 - Instability growth rates
 - Beam loading compensation
 - Event pile-up: number, space and time resolution of events per bunch crossing
 - Beam losses
- Investigate possible locations and effects due the cavities in the machine lattices.
- A hybrid scheme that would allow the FCC scheme to benefit from some of the advantages of flat bunches. This would be worth exploring.
 - □ Lower peak intensity decreases the e-cloud effect and space-charge effects
 - Lower momentum spread
 - **D** Possibly better event resolution (spatial and time) in the detectors

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- □ Elias Metral, Giovanni Rumolo ← Accelerator operation issues

□ Jim MacLachlan ← Simulation issues

Summary

- We propose to carry out flat bunch studies in the Tevatron using multiple harmonic rf systems
- Tevatron is an ideal place for the flat bunch studies
 - □ It is world's best high energy storage ring
 - Available RF for beam studies are : 53MHz, 106MHz and 159MHz rf systems
 - Double harmonic rf
 - Triple harmonic rf
 - Multiple bunches
 - Have necessary diagnostics to monitor both longitudinal as well as transverse dynamics
- This effort will be the one of the most important contribution to the LHC luminosity upgrade using LPA scheme

Existing Simulation Tools

ESME

- □ This is a 2D code to study longitudinal beam dynamics in (ΔE , Δt)-phase space in synchrotrons. We will use it to address
 - Flat bunch creation and acceleration with single and multiple harmonic rf systems,
 - Longitudinal single and multi-bunch instability
 - Beam loading issues.

Beam-beam code BBSIM

□ This code will be used to study the impact of beam-beam interactions on the emittance growth. Comparisons between a longitudinal Gaussian profile and a flat profile will be made for the LPA and for the FCC schemes.

Vlasov solver

This will be used to investigate long term beam stability and particle losses. Also,
 1) extract spectral information and 2) help establish the optimal ratio of harmonic amplitudes and bunch length, in the presence of realistic impedances.

Average Heat Load 2nd Batch

Frank Zimmermann (CERN) and Humberto Maury Cuna, (CINVESTAV, Mexico)

Conclusions:

The estimated heat load from the e-cloud effects on LHC cryogenics with flat bunches is about two times smaller than that with Gaussian bunches at the same bunch int..