Energy Loss Measurements With Streak Camera at ALBA

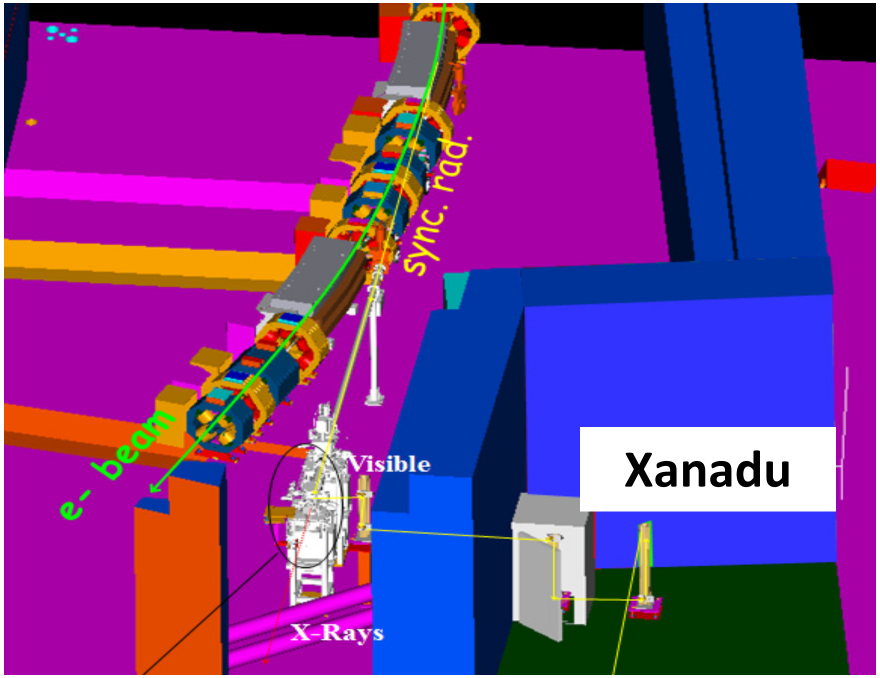
U. Iriso, B. Bravo, A. Nosych
(ALBA-CELLS)

ALBA

2018
International Beam Instrumentation Conference
SEP. 9-13, 2018 Shanghai · China
Organized by: Shanghai Institute of Applied Physics, CAS (SINAP)

Contents

Streak Camera (SC) at ALBA



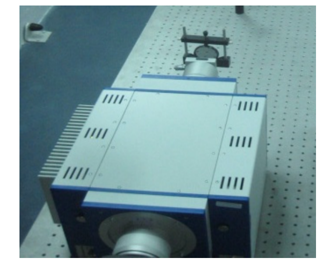
SC uses visible part of Synchrotron Radiation produced by a dipole to perform beam studies in the long. plane

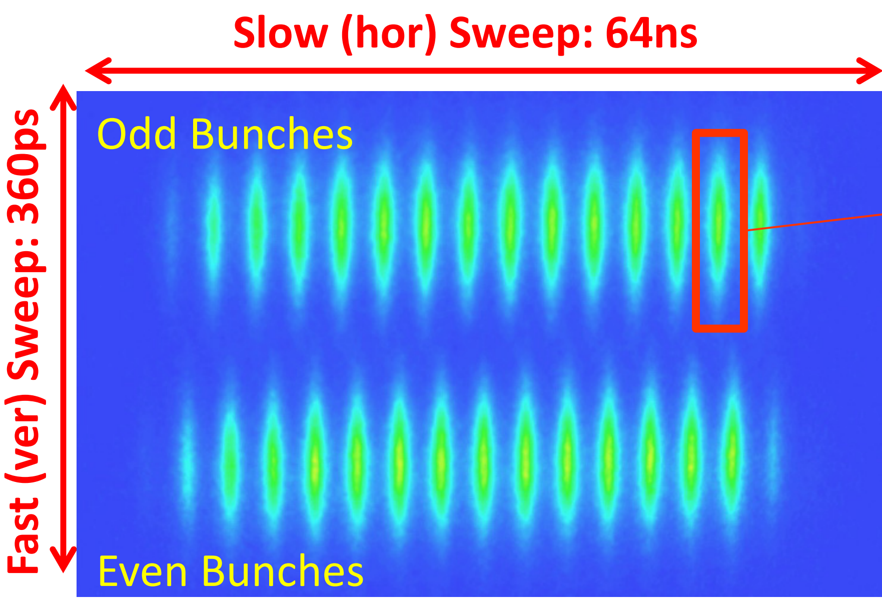
The visible light is first selected with a vertical mirror (x-rays discarded), and then guided through optical chicane until the Diagnostics BeamLine "**Xanadu**"

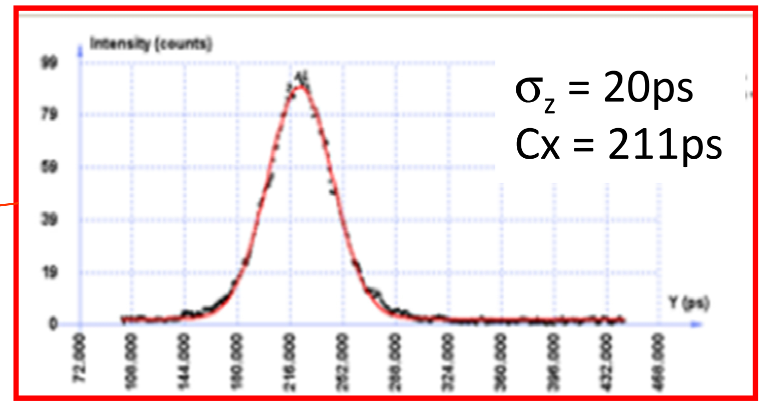
Streak Camera (SC) at ALBA

Optronis SC-20, synchroscan at 250 MHz, with 2 deflecting axis

1. Fast vertical unit: full scales [216, 360, 720] ps
2. Slow horizontal units: full scales [9ns … 72ms]



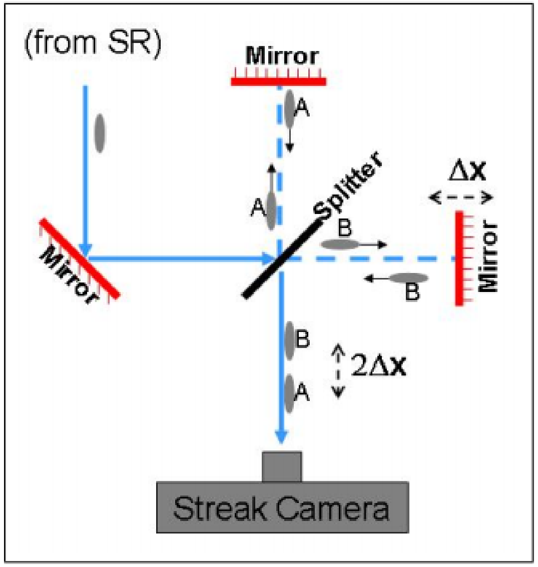




Gaussian fit:
- Bunch length
- Centroid - Relative RF phase

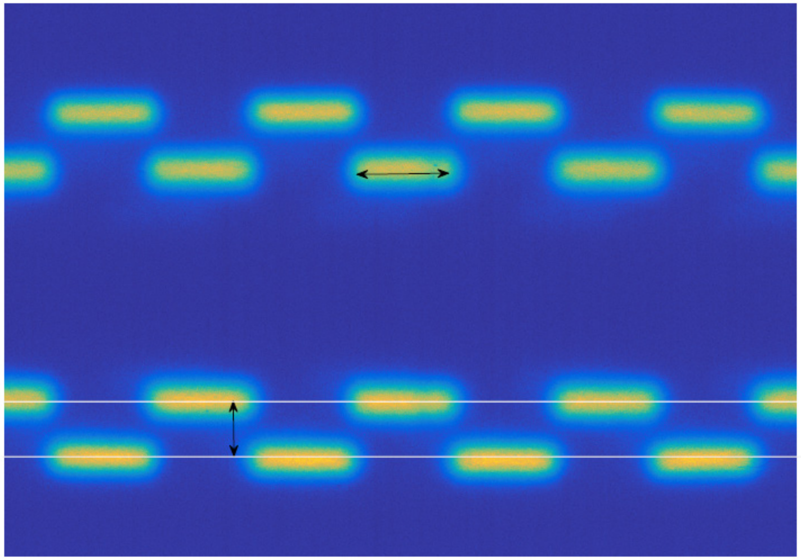
Streak Camera (SC) at ALBA: Calibration

Vertical calibration using Michelson-type interferometry setup



TUPA46, IBIC12

Horizontal calibration using RF switches:

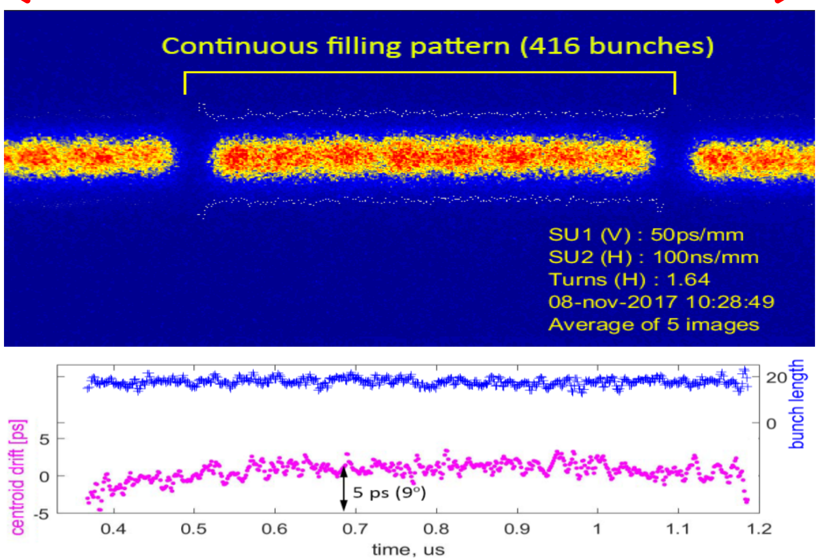


MOPG55, IBIC16

Example: Beam Loading for different Filling Patterns

416 consecutive filled buckets
Gap 32 buckets

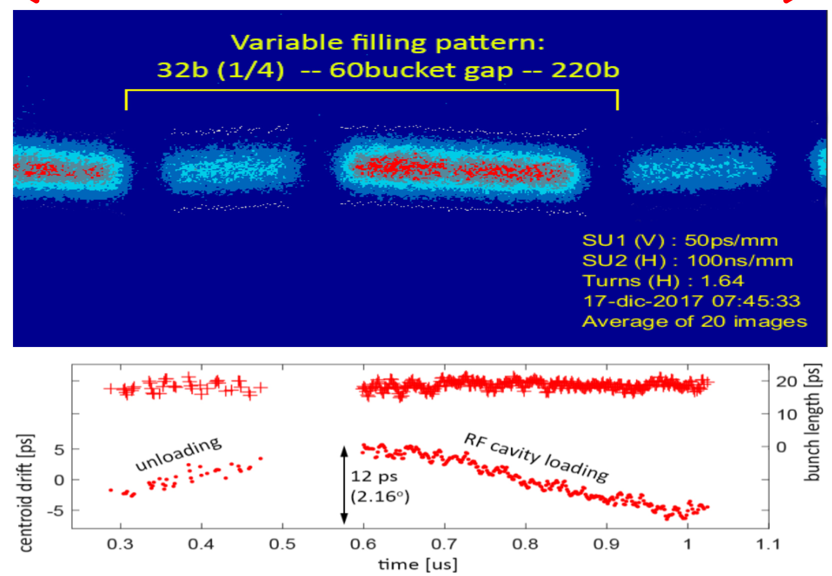
1.4 revolutions



σ_z = 19 +/-0.4 ps (for 416 bunches)
$\Delta\phi$ = 0.9deg

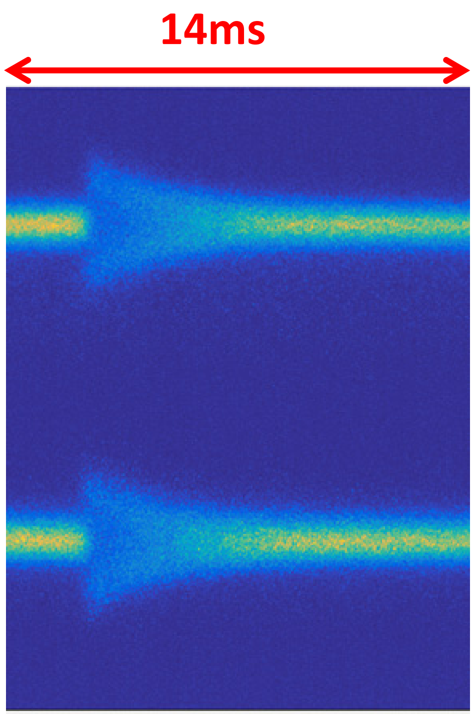
220 cons. filled bchs + empty 50 bchs
+ 32 bunches, filled ¼ + empty 50 bchs

1.4 revolutions

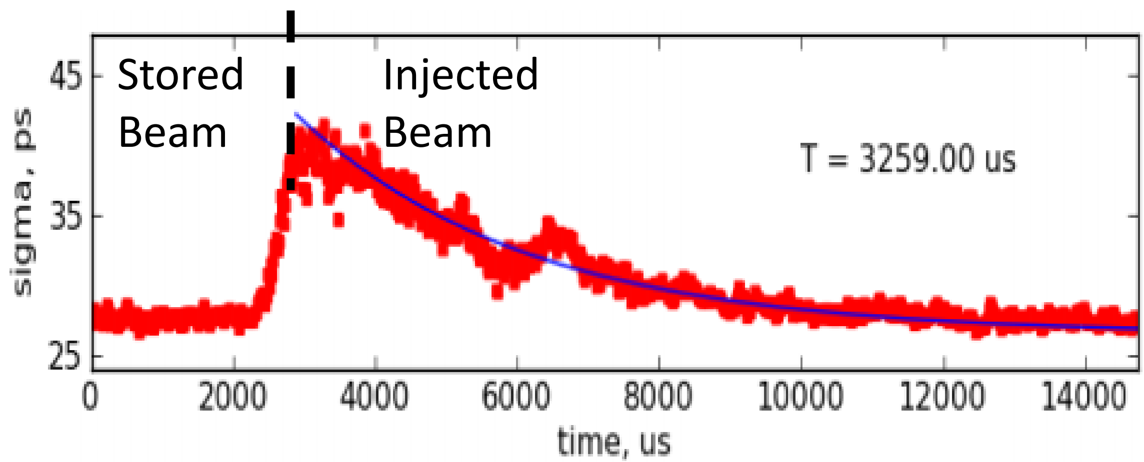


σ_z = 19 +/-0.6 ps (for 252 bunches)
$\Delta\phi$ = 2.16deg

Example: Longitudinal Damping Time



Follow bunch length after an injetion into the SR in ms scale



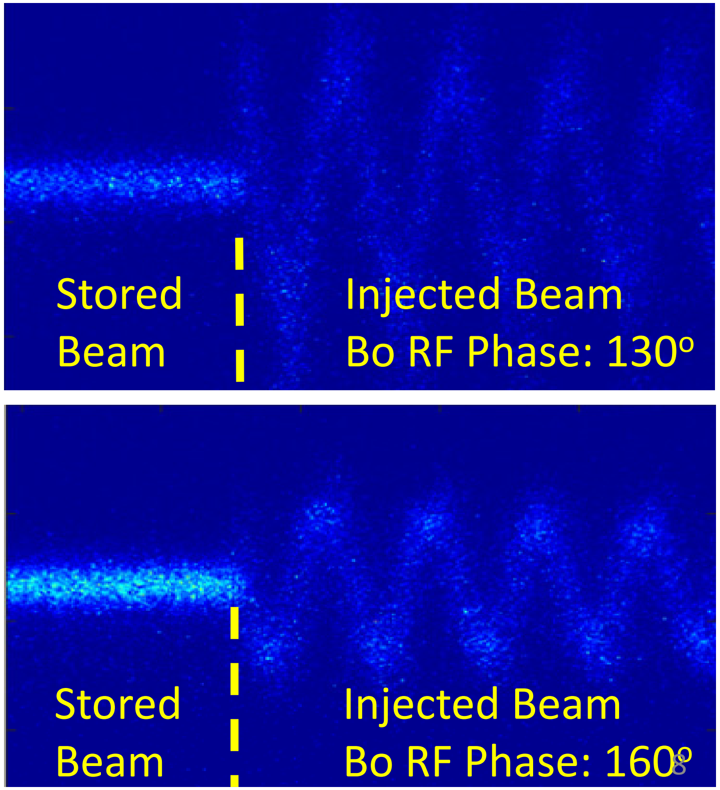
Small differences between upper/bottom plots (odd/even bunches)
In the following, we only show the **upper** plots for simplicity

Injection Matching – RF on

Booster to Storage Ring (SR) **Phase** Matching

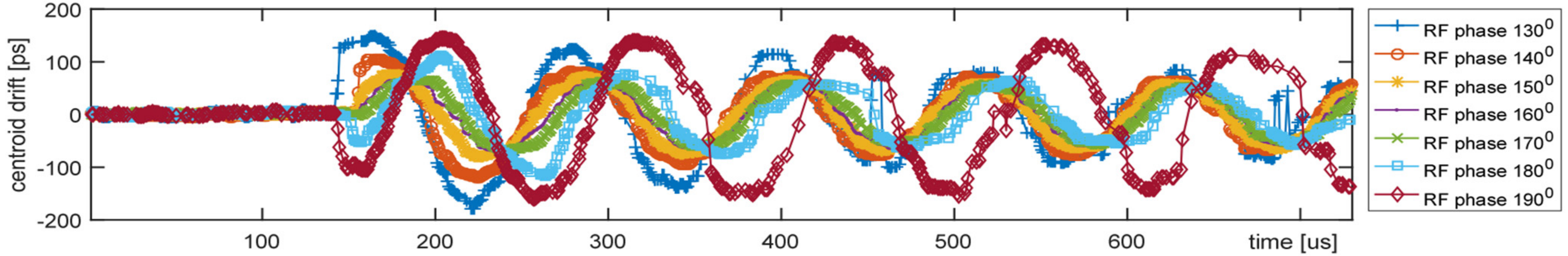
- Proper visualization of the stored and injected beams is achieved by "unclosing" the injection bump so to store the beam but not accumulate
- Scan the Booster RF phase until both beams are start oscillation at the same location
- Compare centroid position of stored and (the initial) injected beam and oscillation amplitude

time

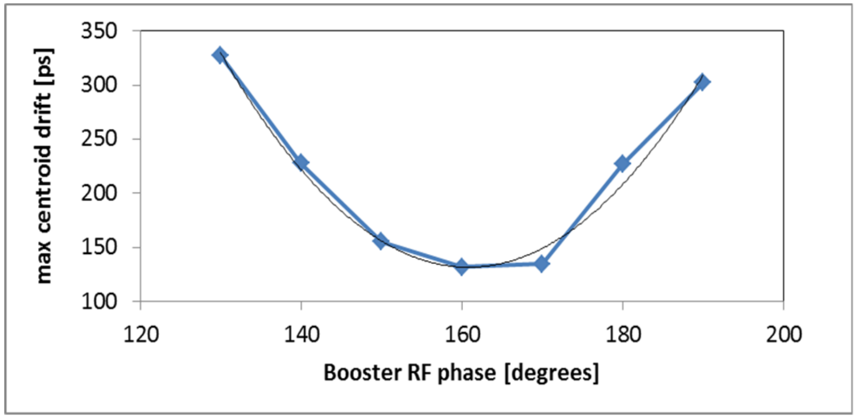


Injection Phase Matching – RF on

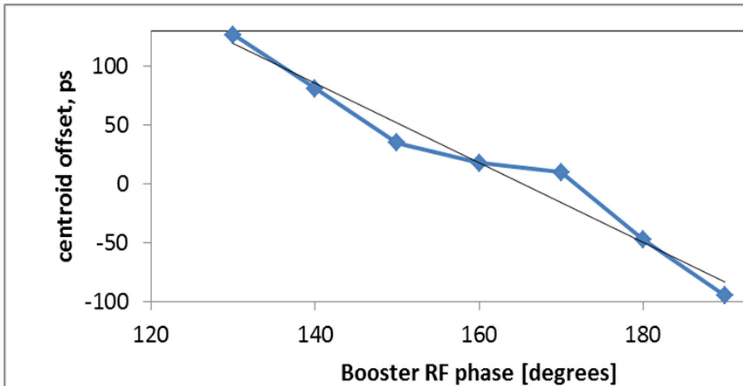
Centroid oscillations after image analysis



Analyze amplitude of oscillations: ϕ_{Bo}^{Opt} = 160º

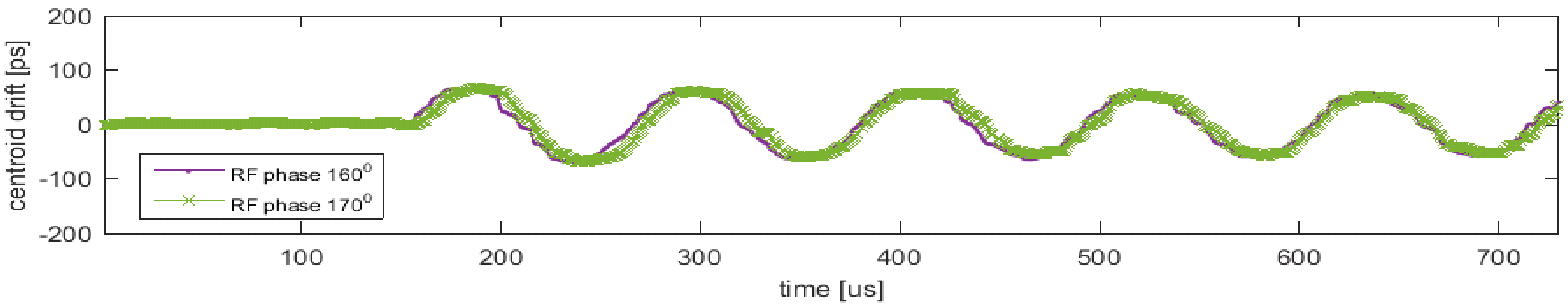


Analyze phase offset: ϕ_{Bo}^{Opt} = 165º

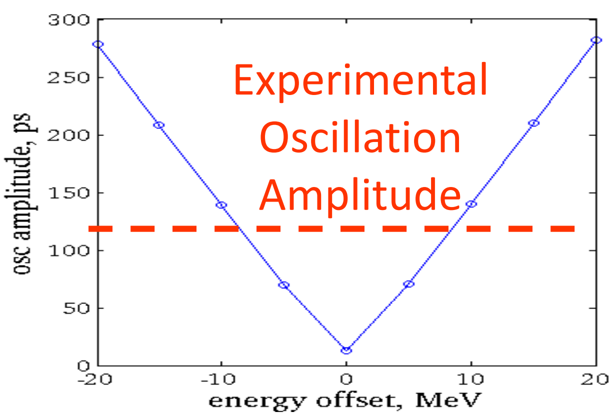


Injection Energy Matching – RF on

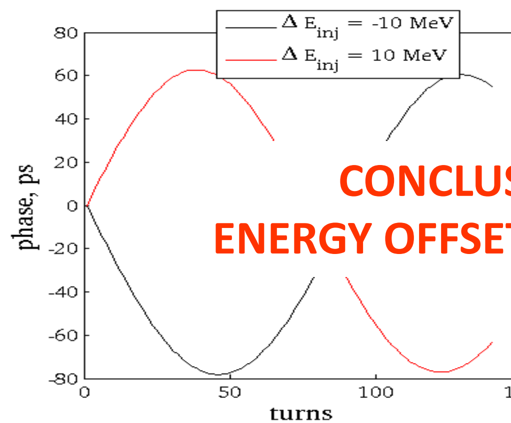
Centroid oscillations for 160º and 170º: Results compared with tracking using Matlab AT



Amplitude of oscillations – AT Sim



Direction of phase oscillations – AT Sim

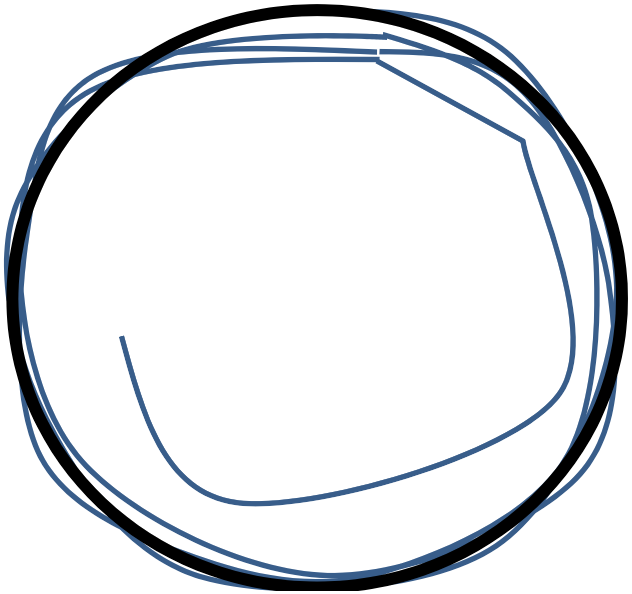


CONCLUSION:
ENERGY OFFSET = +10 MeV

Injection with RF off

An e-beam entering an accelerator with the RF system off will spiral inwards due to energy loss until the beam is completely lost.

Original idea from J.Byrd & S.De Sanctis*, but here we add the possibility of an **energy offset** between Booster and SR



The revolution time τ changes according to:

$$\tau = \tau_0 + \frac{\alpha \Delta E_{\text{inj}}}{E_0} t - \frac{\alpha U_0}{2 E_0 T_0} t^2$$

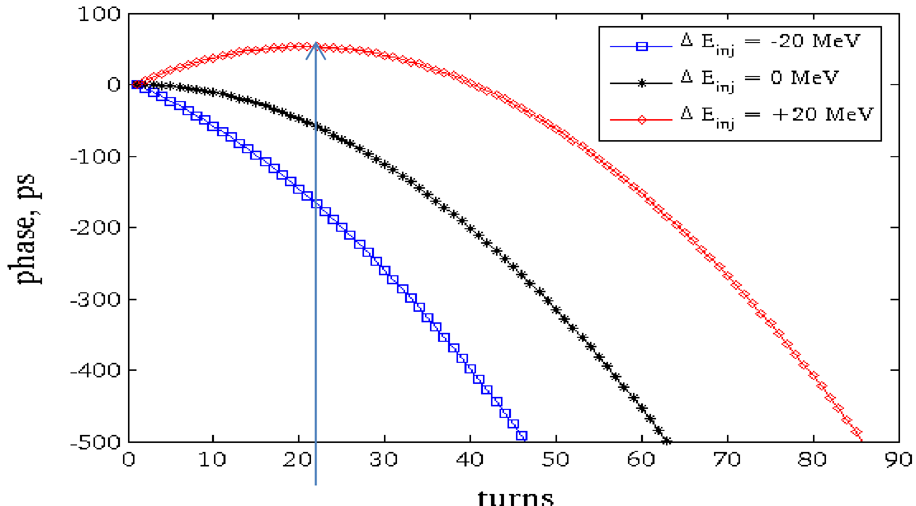
ΔE_{inj} = energy offset between Bo – SR
E_0 = equilibrium beam energy
T_0 = revolution period for E0
U_0 = energy loss per turn
α = momentum compaction factor

*J.Byrd et al, PRST-AB, v4, N024401 (2001)

Injection with RF off

Longitudinal Centroid Motion - Tracking Simulation for different energy offsets

$$\tau = \tau_0 + \frac{\alpha \Delta E_{\text{inj}}}{E_0} t - \frac{\alpha U_0}{2 E_0 T_0} t^2$$



$$\tau_1 = \frac{\Delta E_{\text{inj}}}{U_0} \cdot T_0$$

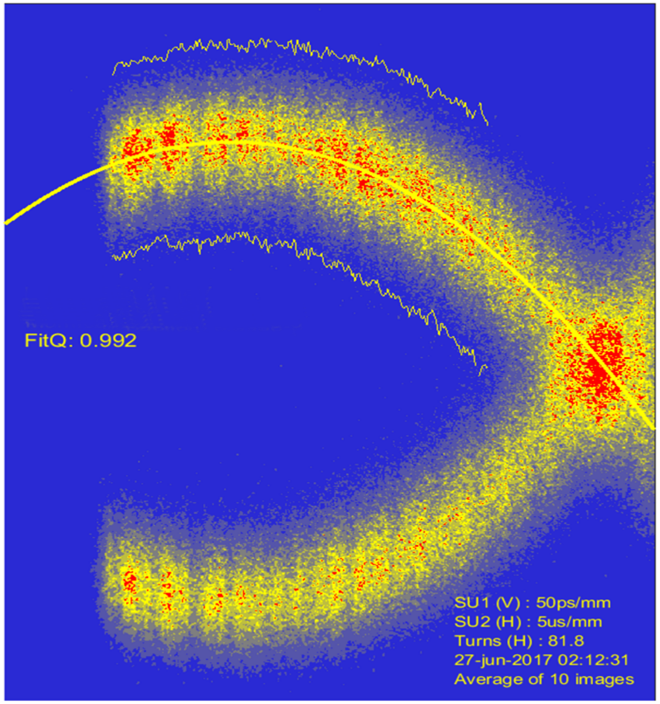
The beam arrival time describes a parabola

If the energy offset is positive, this offset can be found from the position of the maximum of the parabola.

Provided that α and E_0 are precisely known, this technique allows to get U_0 and ΔE_{inj} with only one fit.

Injection with RF off: SC Images

72us -> ~80 turns



Example: Injection of 0.5mA in 40bunches

Centroid of odd and even bunches obtained assuming Gaussian profiles, but the fits complicate when odd/even bunches overlap

Results agree with theoretical predictions:

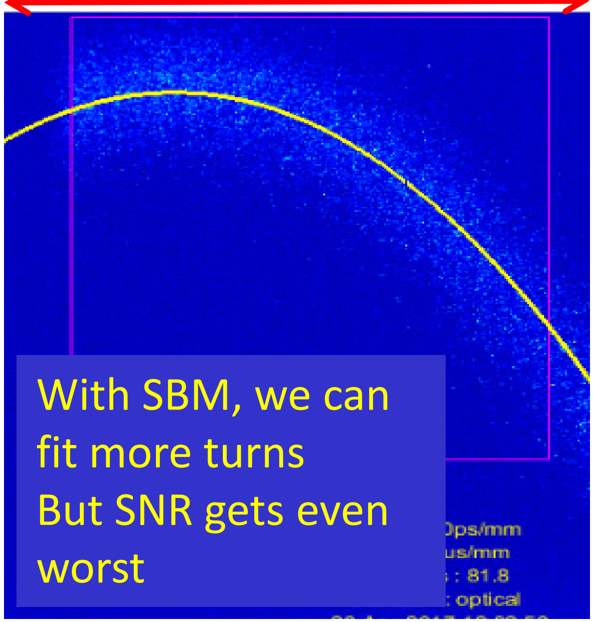
- **U_0=1.03 MeV (1.02 MeV)**
- **ΔE_{inj}= 18.3 MeV (not comparable with previous!)**

Repeatibility is an issue due to poor SNR and the injector chain jitter (due to Booster power supplies).

Injection with RF off: SC Images

Single bunch injection (0.1mA)

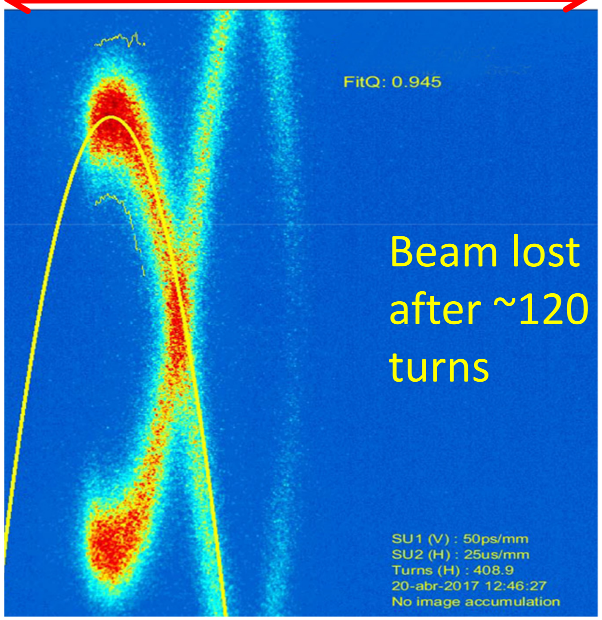
72us -> ~80 turns



With SBM, we can fit more turns
But SNR gets even worst

0.5mA in 40 bunches

360us -> ~400 turns

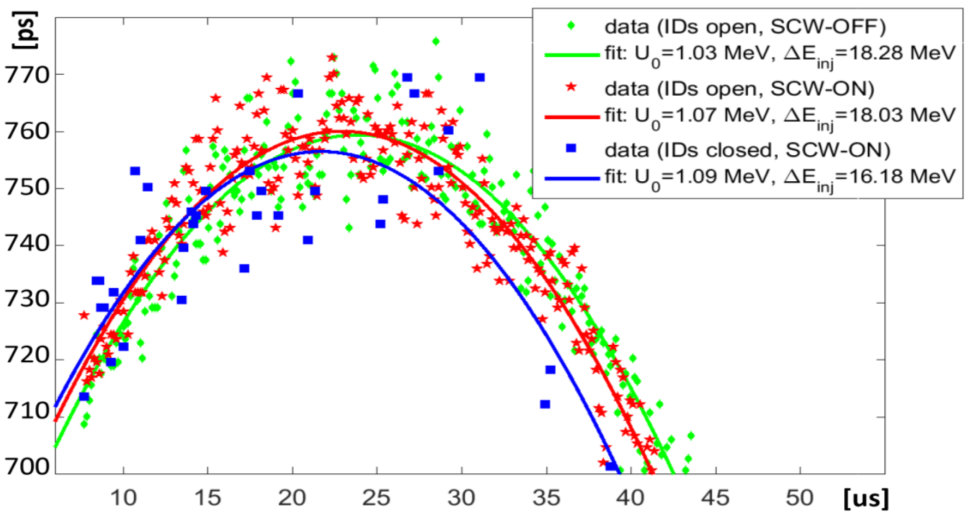


Beam lost after ~120 turns

Energy Loss for Different ID Configurations

Change U_0 by increasing SR losses by changing the Insertion Devices (IDs) configurations

- Minimum U_0: Bare Machine: all IDs open, and SuperConducting Wiggler (SCW) off*
- Intermidate U_0: Only SuperConducting Wiggler (SCW) on
- Maximum U_0 : All IDs closed, and SuperConducting Wiggler (SCW) on

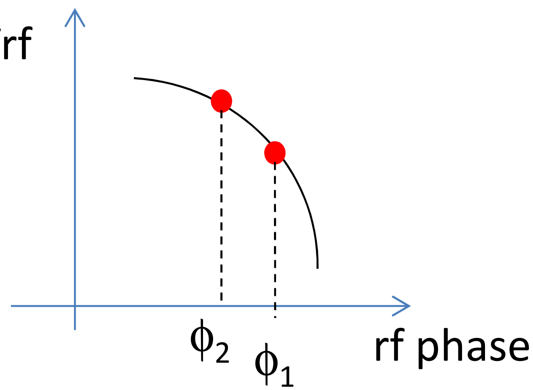


ΔE_{inj} coincides for the three cases

It cannot be compared with ΔE_{inj} with rf on because it passed 1year between measurements

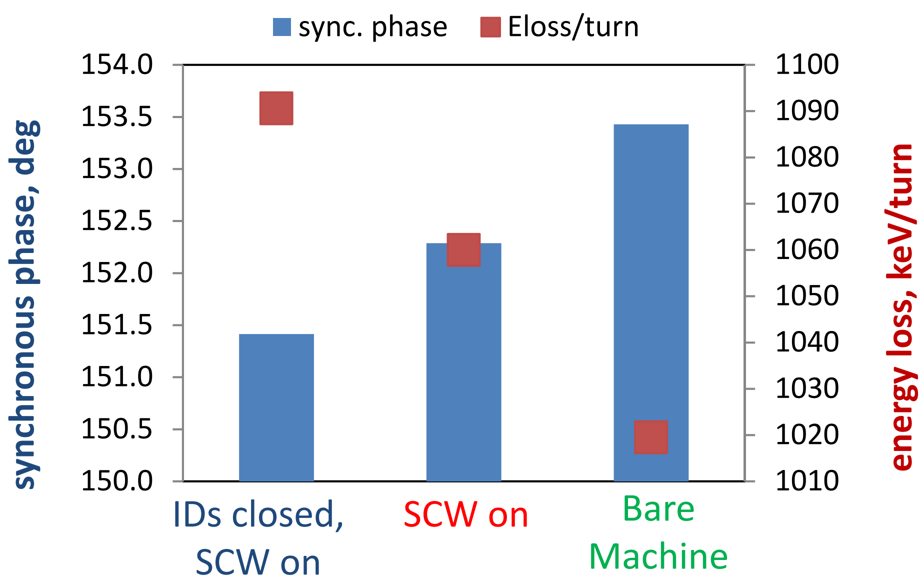
Data with IDs closed and SCW on very noisy due to low SNR

Energy Loss Measurement with RF Phase Shift



When U_0 increases, the synchronous phase decreases (from ϕ_1 to ϕ_2) to recover the required energy

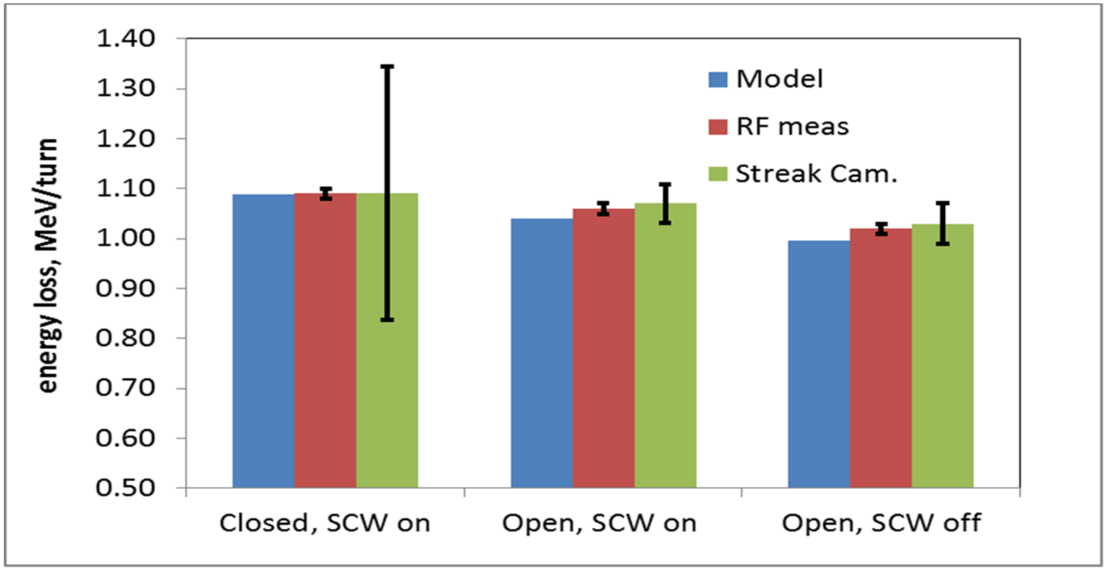
This phase shift is measured either by the LLRF (or by SC)



Measurement with 100mA in the machine

Energy Loss for Different ID Configurations

Comparison with Energy Loss measured using RF phase shift



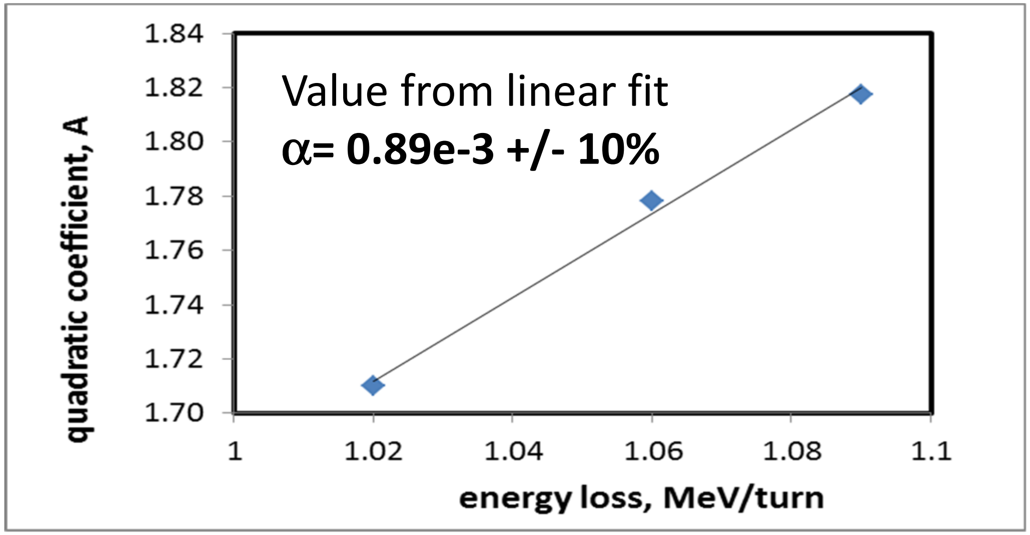
Very good agreement between RF measurements and SC measurements with RF off
Losses due to SCW identified 40keV/turn (44 keV/turn theoretical)
Disagreement with the model to be understood

Calculation of α (mom. comp. factor)

Measuring U_0 with the shift in the sync. phase), fitting injections with rf off for different IDs configurations provides an alternative measurement of α

$$\tau = \tau_0 + \frac{\alpha \Delta E_{\rm inj}}{E_0} t - \frac{\alpha U_0}{2 E_0 T_0} t^2$$

=A



Good agreement with theoretical value:

α= 0.887e-3

Conclusions

- With the RF system on, longitudinal injection phase matching between Booster (BO) and Storage Ring (SR) has been successfully performed
- By switching the RF off at SR, we show how to infer both energy offset and energy loss per turn, and we can even distinguish several configurations of the Insertion Devices
- This method is limited by the low SNR, but nevertheless good agreement is found between this method and RF phase methods
- By combining this method with other means, also α can be inferred with good agreement