Measurement of the energy loss through the synchronous phase shift

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Synchronous phase shift

- Energy loss of the beam should be compensated by the RF system
- In the absence of acceleration the synchronous phase

$$\sin\varphi_s = W_n/(e\,V),$$

where W_n is energy loss per turn and per particle and V is the voltage amplitude

- Measurement of φ_s can be used for evaluation of energy loss due to
  - synchrotron radiation
  - resistive impedance (broad-band and narrow-band)
  - e-cloud

Synchronous phase shift

- Single bunch effects:
  - synchrotron radiation
  - broad-band resistive impedance

  → Phase shift is the same for all bunches
- Multi-bunch effects:
  - narrow-band resistive impedance
  - e-cloud

→ Phase shift is different from bunch to bunch

Synchronous phase shift in LHC

- Measurements of the average synchronous phase shift (phase loop error)

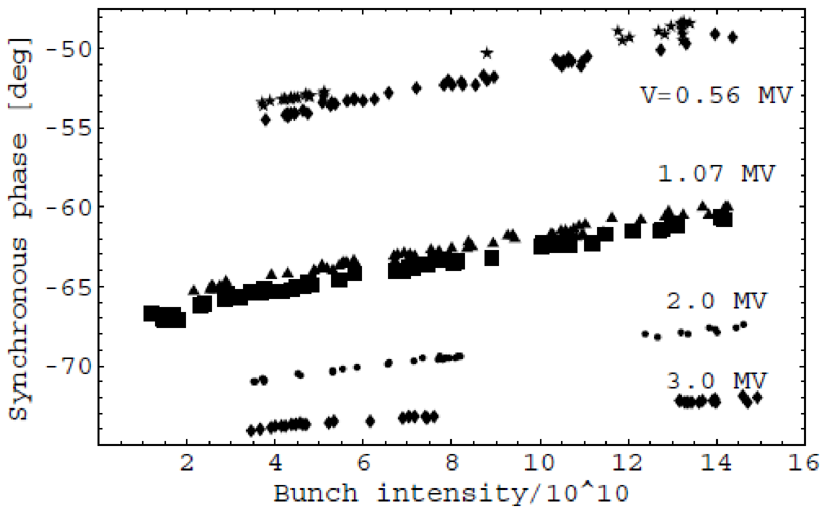
  $$\Delta\varphi_s = \sum \Delta\varphi_s / n_b = W/(e\ V\ N)$$

- For power of 1 kW, voltage V = 3.5 MV and $N = 10^{13}$ (100 nominal bunches) $\rightarrow$ $\Delta\varphi_s = 0.9$ deg
- First preliminary measurements done in 2010
- Bunch-by-bunch measurements are possible and planned for 2011 (in collaboration with OP Group)
- Effect is smaller for higher voltage (in absence of dependence on the bunch length):

  $\rightarrow$ twice smaller shift for 6 MV in 2011 (3.5 MV in 2010)

Synchronous phase shift due to energy loss of a single bunch in the SPS

Raw data, 26 GeV/c



$$\sin \phi_s = U/(eV)$$

Energy loss /turn and particle

$$U_b = -e^2 N k = -e^2 N \sum_n k_n(\sigma)$$

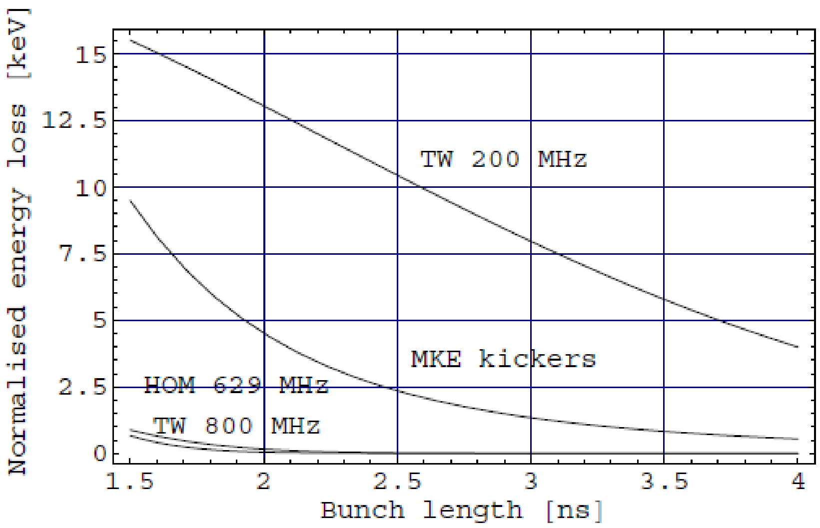
the loss factor for the Gaussian bunch

$$k_n(\sigma) = \frac{\omega_0}{\pi} \sum_{p=0}^{\infty} \mathrm{Re} Z_n(p\omega_0) \exp[-(p\omega_0\sigma)^2]$$

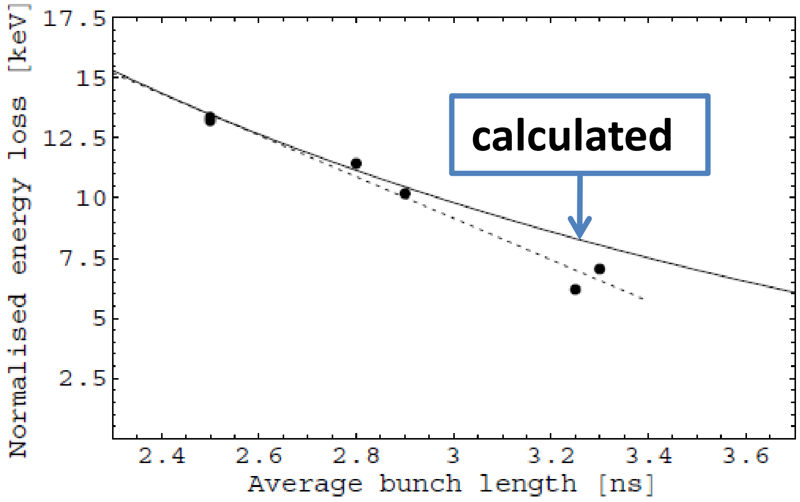
Energy loss of a single bunch in the CERN SPS, EPAC'04

SPS: energy loss from resistive impedance budget

Contributions to energy loss $U/(N/10^{10})$



Comparison with measurements

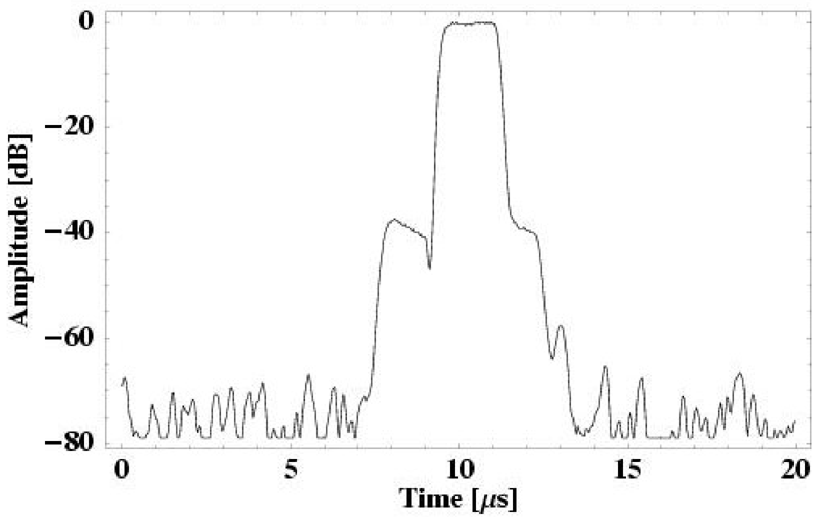


→ good agreement between calculated and measured energy loss as a function of bunch length for a single bunch

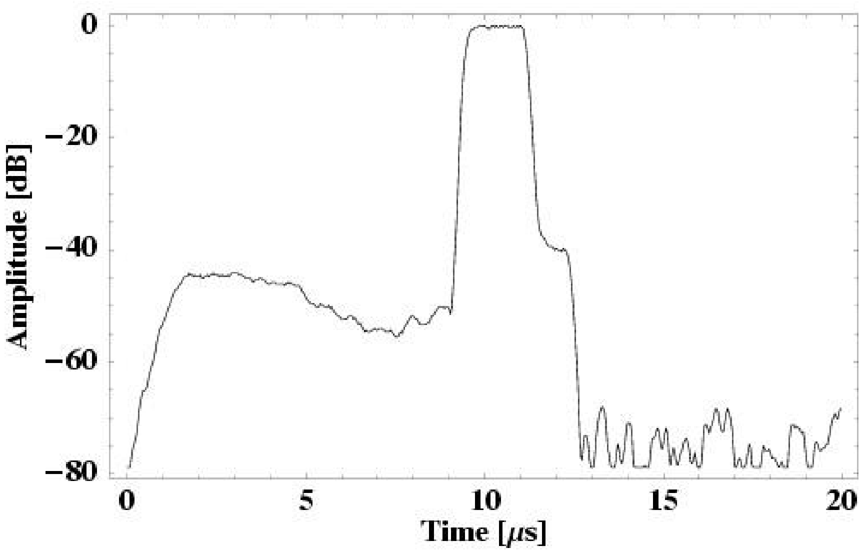
→ 70 keV energy loss for single bunch with length of 3.5 ns

SPS: uncaptured beam motion
the 200 MHz signal

Injection



A few seconds later

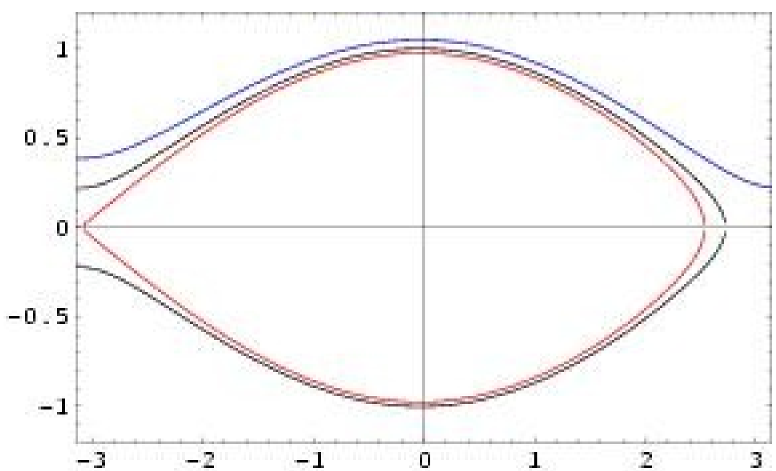


→ Energy loss due to e-cloud and impedance?

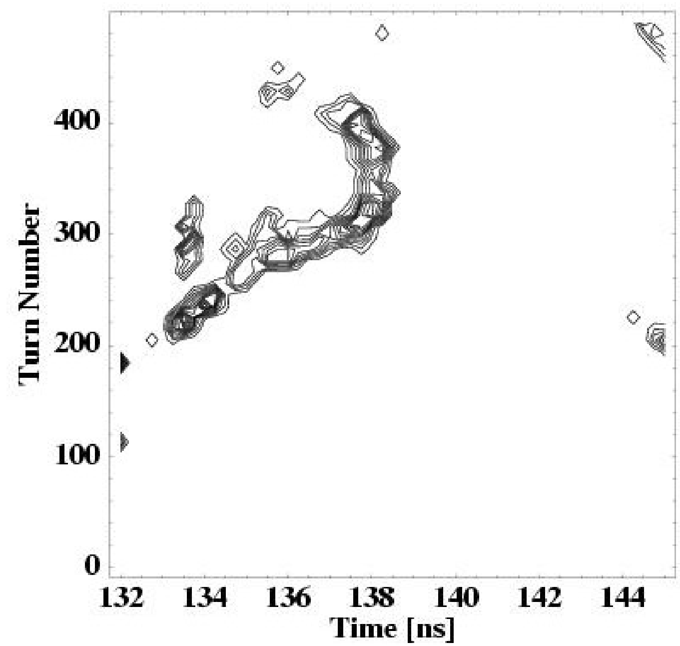
SPS: accelerating bucket on the flat bottom

Bucket: ϕ_s=1.8 deg, α=U/(eV)=0.03

U=60 keV, V=2 MV , hole ~$2\sqrt{\pi\alpha}$ =0.6

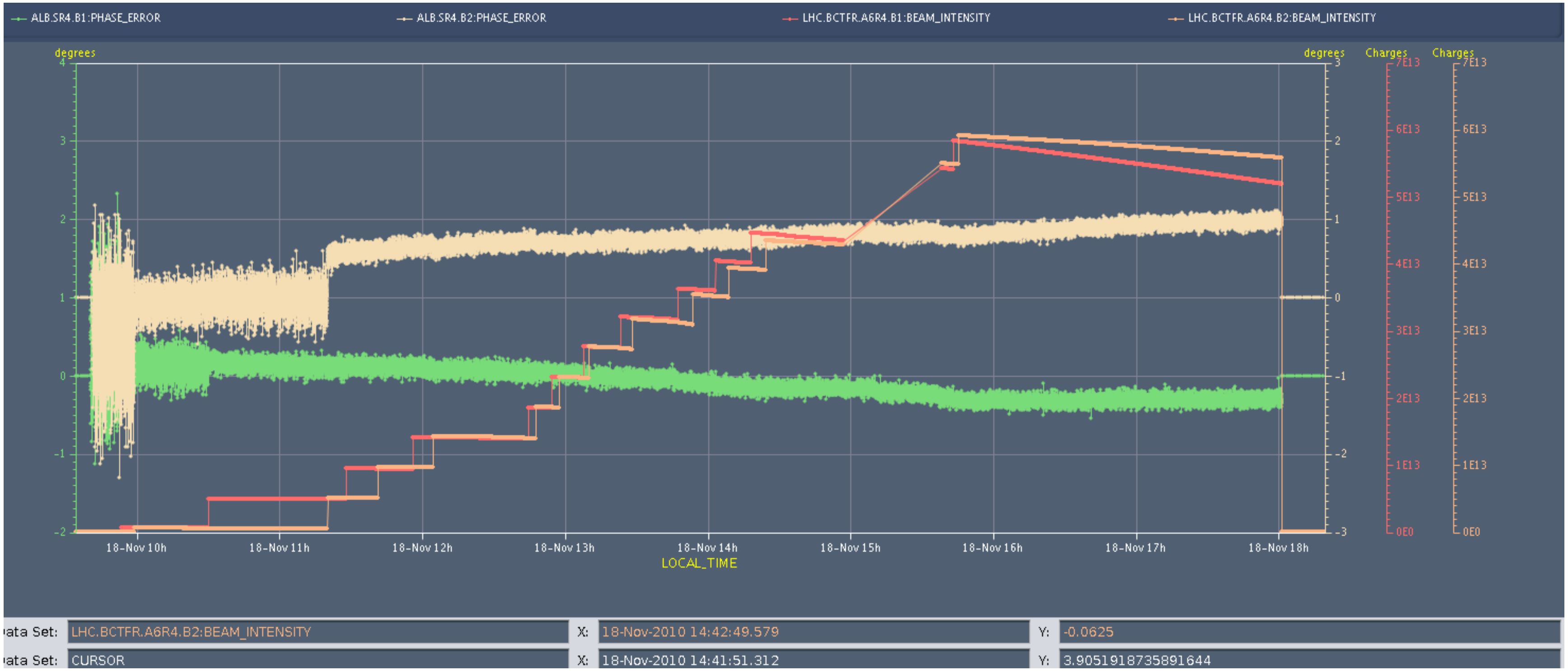


Measured density plot: particles lost at injection → $\varphi_s \neq 0$



Capture loss of the LHC beam in the CERN SPS, EPAC'04

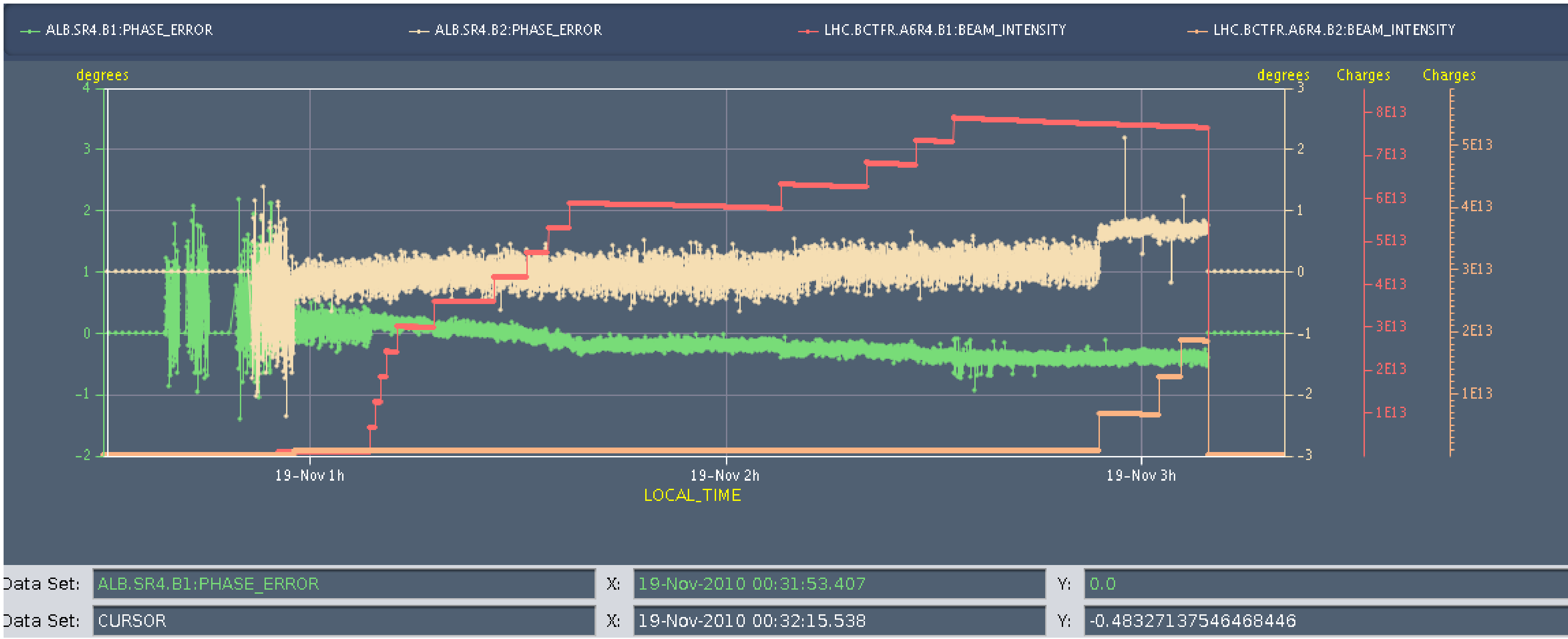
LHC: first measurements with 75 ns beam (on 18.11.2010) N=6x10^13



Beam1: phase shift $\Delta\varphi_s$=0.4 deg, no/small drift

Beam2: Continuous drift, different slopes

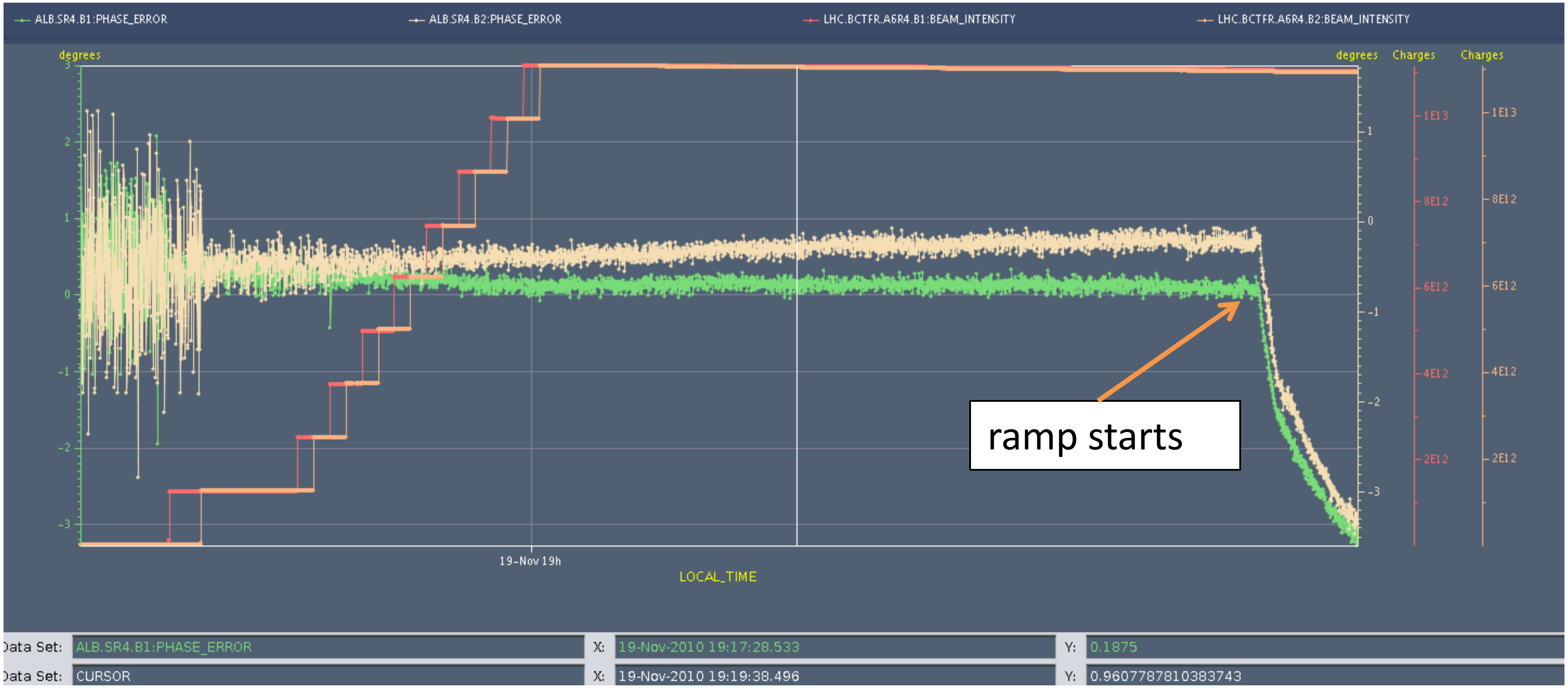
Phase shift for a 75 ns beam (on 19.11.2010) N=8x10^{13}



Beam 1: phase shift $\Delta\varphi_s$~0.6 deg

Beam 2: phase drift (noisy pilot)

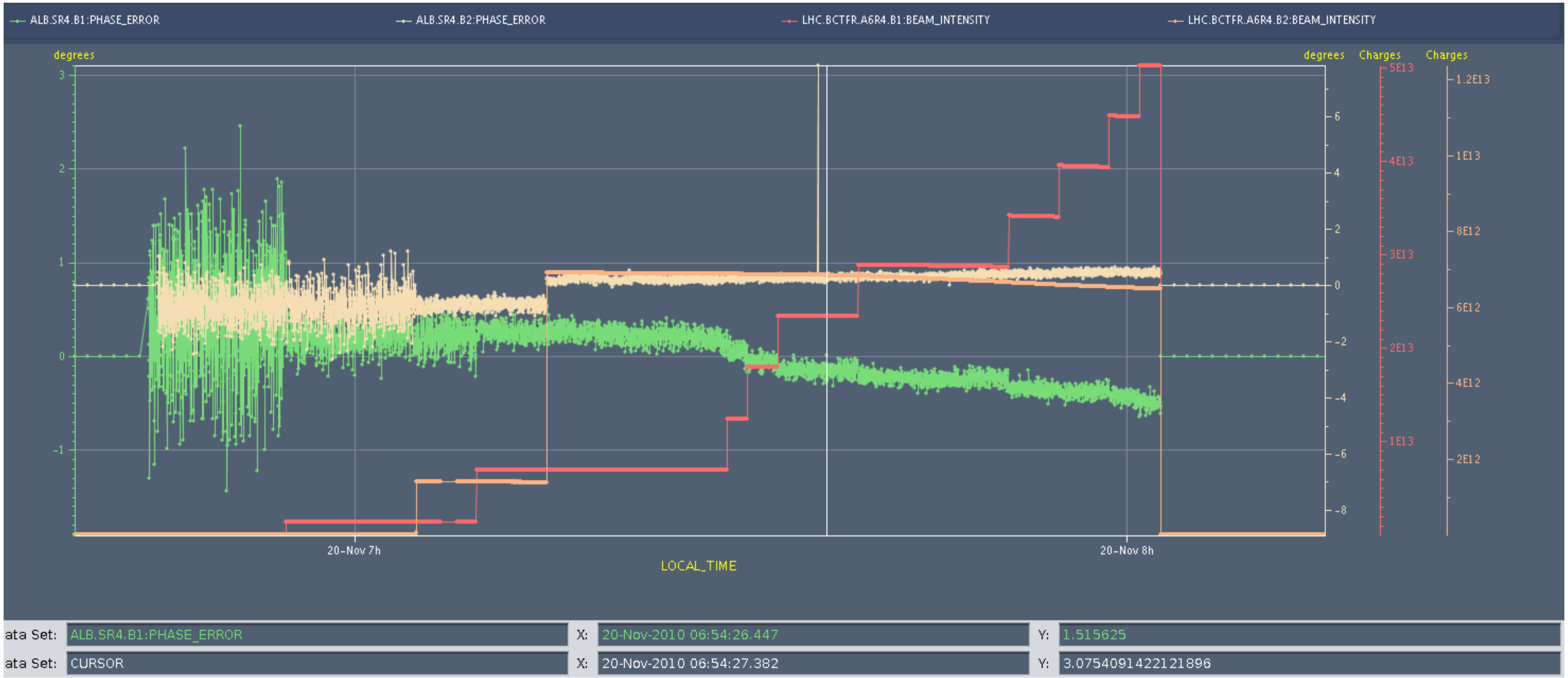
50 ns beam with energy ramp (18:30-20:00 on 19.11) N=1.1x10^{13}



Beam 1: phase shift $\Delta\varphi_s$=0.2 deg

Beam 2: continuous phase drift (~2 deg)

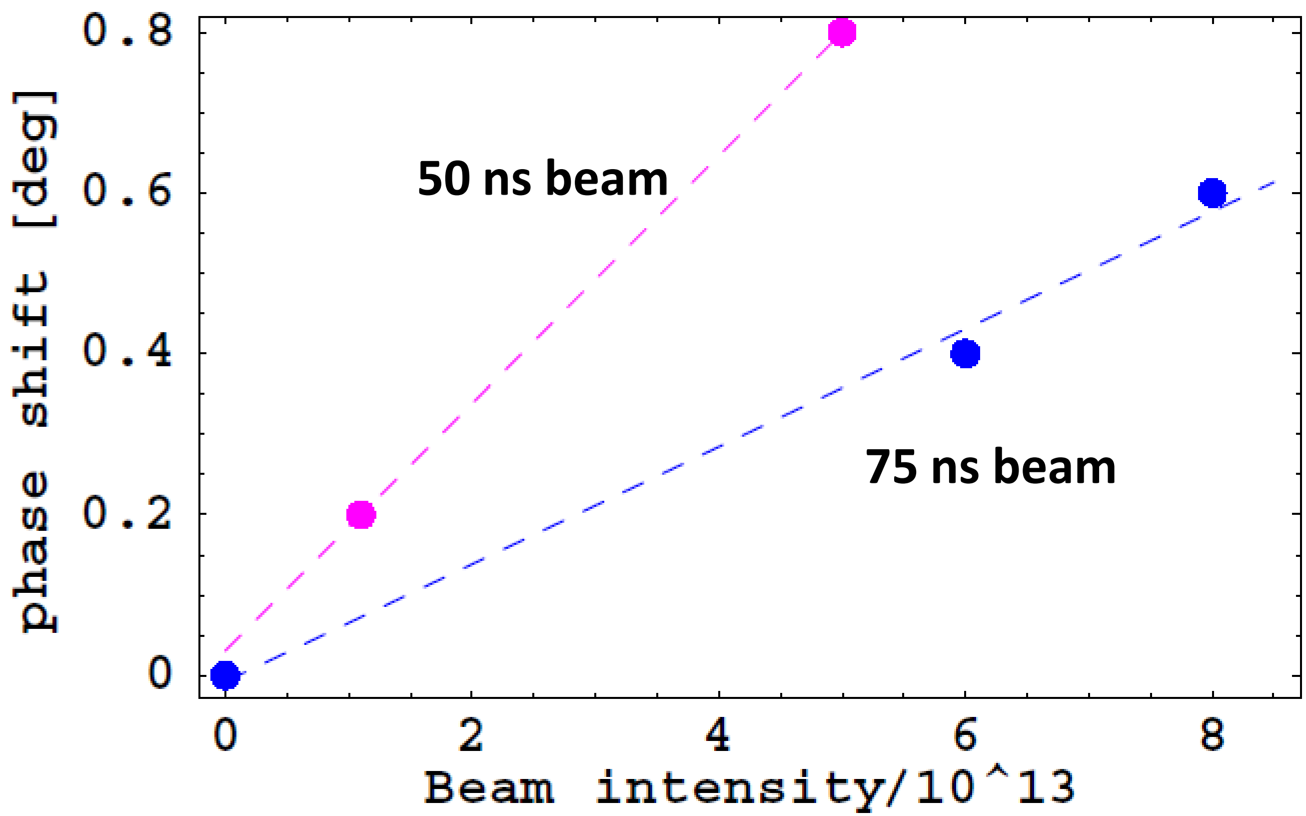
The last fill with 50 ns beam (6:30-8:00 on 20.11) $N=5x10^{13}$



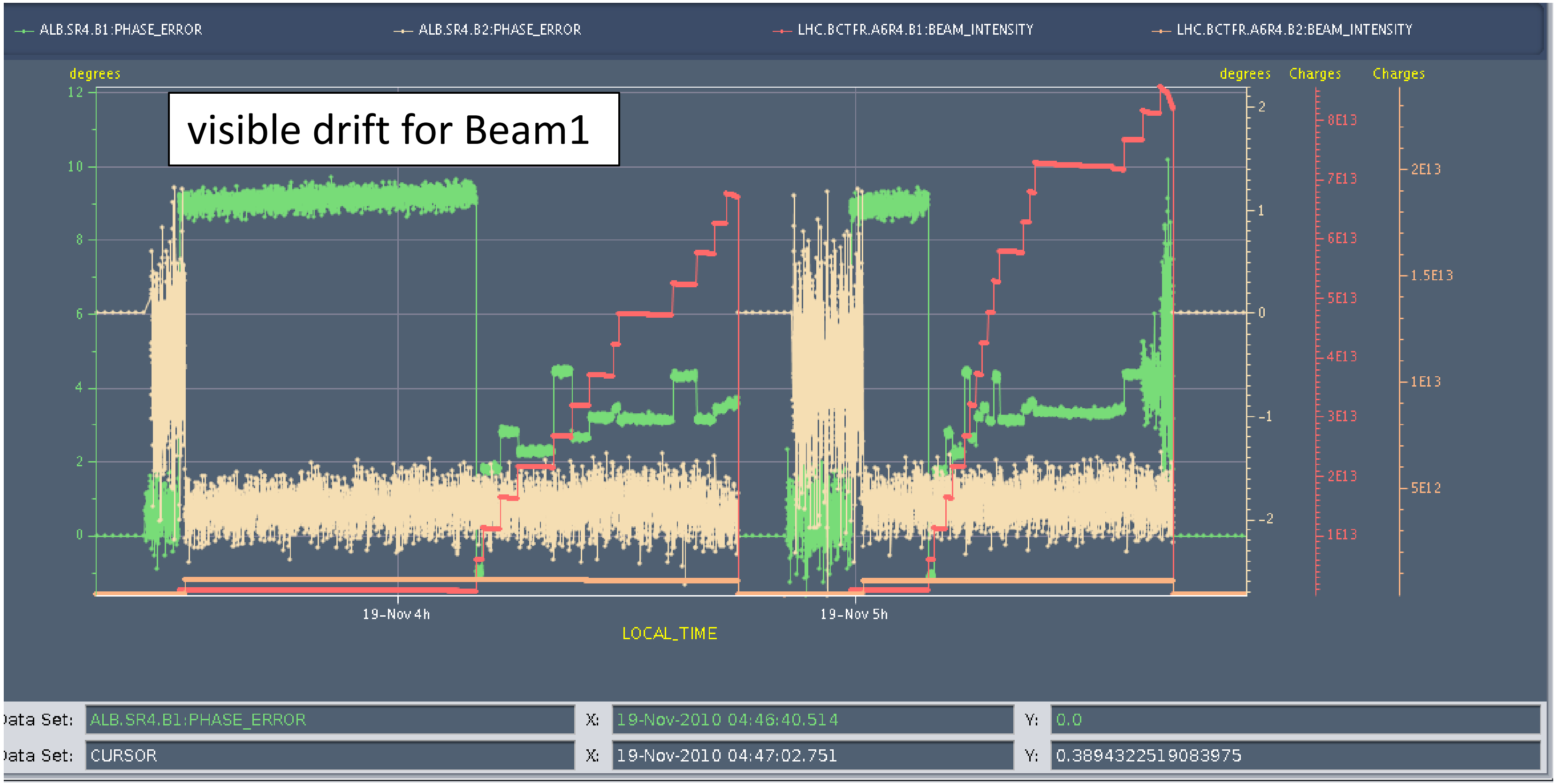
Beam 1: $\Delta\varphi_s=0.8$ deg, increases faster for $N > 10^{13}$

Beam 2: phase drift

Summary of 2010 stable phase measurements for Beam1



Last fills with 75 ns beam



- different phase drift during night and with/without beam
- large steps in phase due to the filling scheme (1.005 μs gaps)

Summary and future steps

- First observations show visible phase shift for Beam1:
  - phase shift is larger with 50 ns spacing than with 75 ns for even smaller beam intensity
  - nonlinear dependence of phase shift on total beam intensity both for 75 ns and 50 ns bunch spacings → threshold
  - more data is available, for 150 ns spacing also
- Need calibration/understanding vs cryogenic measurements
- Precision of measurements can be increased by data post-processing (now) and by using filter (in future) – P.B.
- Beam2 phase drift should be investigated, systematics for Beam1 also
- Measurements in the SPS for beam with different spacings