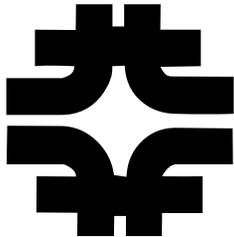


# On Emittance Growth during HEP and IBS



Paul Lebrun

Fermilab

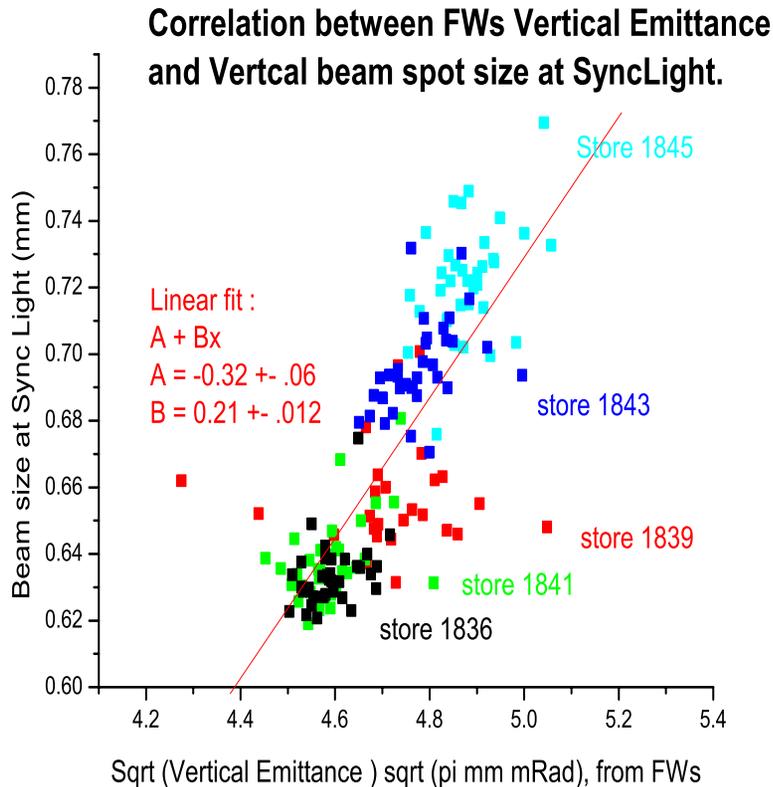
*October 23 2002*

# Emittance growth during the store: Motivation and outline.

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- While the pbar lifetime during the store is  $\sim 30$  hours, quite often consistent with the “burn rate”, the luminosity lifetime ranges from 8 to 15 hours (shorter at the beginning of the store).
- A significant contribution of this lifetime is the emittance growth. => understanding the root cause of this growth is interesting.
- The Proton Emittance is always larger than bigger, and grow faster => study proton first!
- Outline:
  - Data source: Sync Light (cross-checked with FWs) and SBD data.
  - Correlations X vs Y, slope and positions..
  - Relative Growth rate is proportional to the 6D particle density.
  - Intra-Beam Scattering (IBS) prediction
  - Correlation Longitudinal Transverse and IBS.
  - Other sources, future investigations

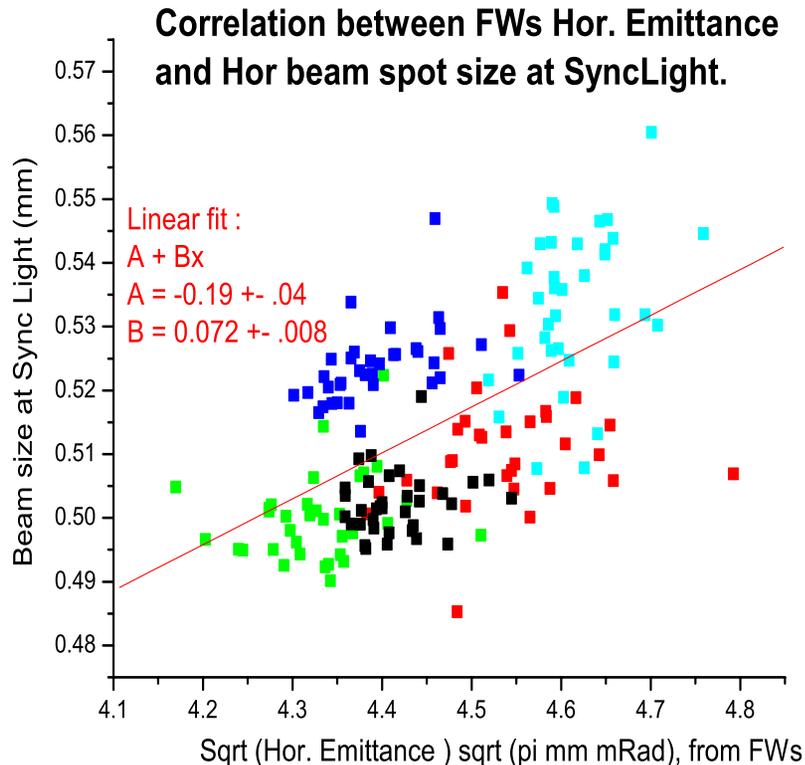
# FWs and Sync Light: Do they agree?



One point refers to 1 bunch in a store.

- => Proton data. Sync Light data comes from a fit vs time, extrapolated back to beginning of the store.
- We know we have calibration discrepancy for pbars. The discrepancy for proton is smaller.
- On the vertical plane, good linear correlation between sqrt(FWs emittance) and SyncLight beam transverse size.
- Significant scatter. Suspecting FWs, measured only one time, while we have many measurement from Sync light (one every 3 min.)

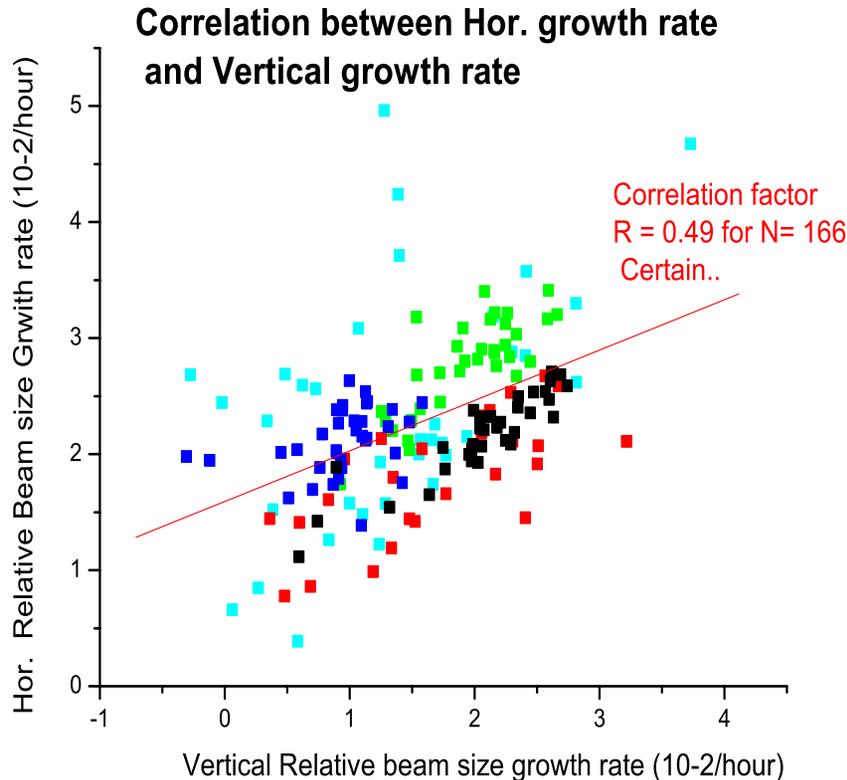
# FWs and Sync Light: Horizontal plane



- => Proton data. Sync Light data comes from a fit vs time, extrapolated back to beginning of the store.
- Quite a bit more fluctuation on the horizontal plane.
- Good correlation between good store (1841) and bad stores (1845)

# Horizontal plane and Vertical Plane: Relative Growth Rate are correlated

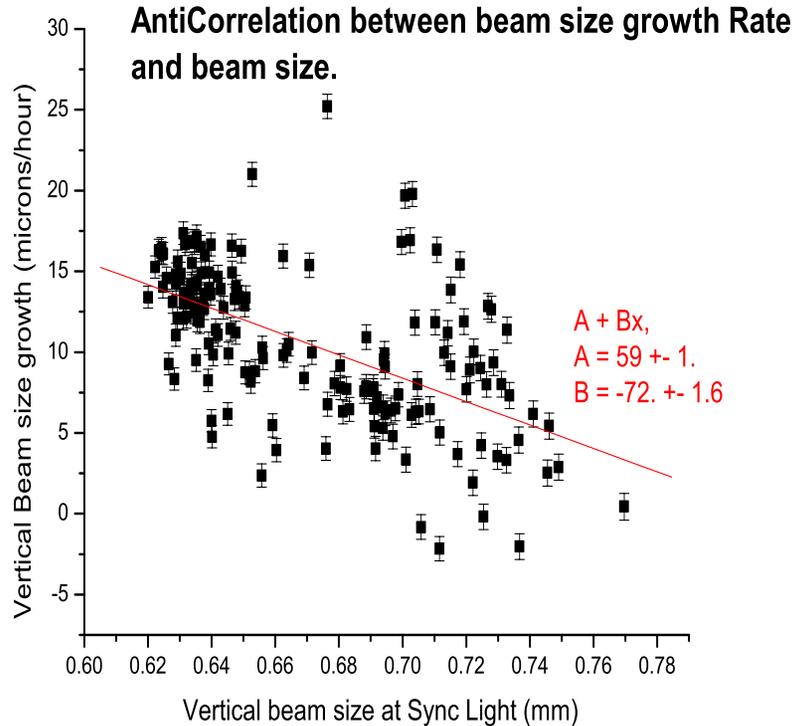
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- Relative Growth rate are defined as :  
$$1/\sigma_u \, d\sigma_u/dt ; u = x \text{ or } y$$
- Relative Growth rate are measured for the first 2.5hour of HEP
- The transverse emittances in the horizontal and vertical planes are correlated, because the TeV is somewhat “coupled” (quite often “strongly coupled”)
- Therefore, it is not surprising that the growth rate in X and Y are about the same, and are correlated, because the coupling at low beta remains significant.

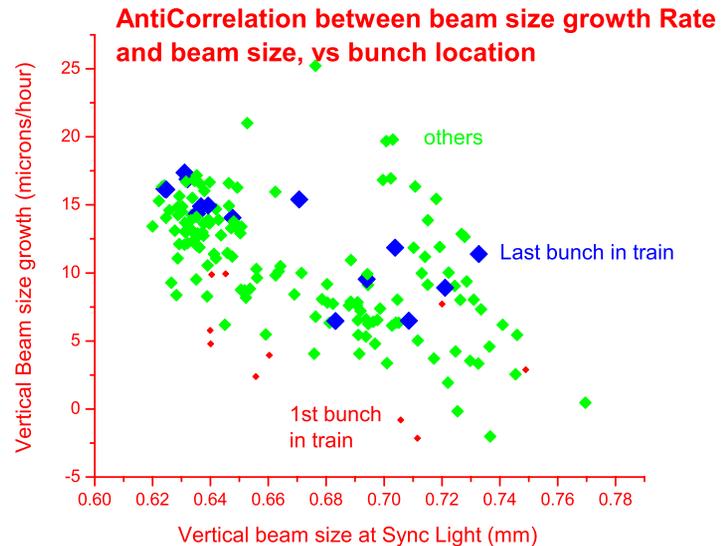
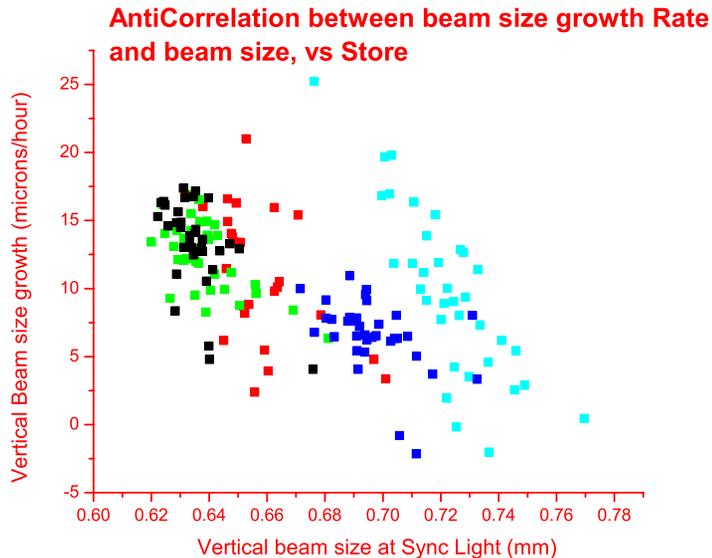
# On Transverse Relative growth rate: Observations..

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- The fitted transverse beam extrapolated at the beginning of the store is plotted against the fitted relative growth rate growth rate, measured during the first 2.5 hours (Proton data)
- The R correlation factor (ignoring error bars from linear fits) is  $-0.56$  for 166 points  $\rightarrow$  highly significant.
- Yet, large fluctuations are observed  $\Rightarrow$  more than one phenomenon is likely.

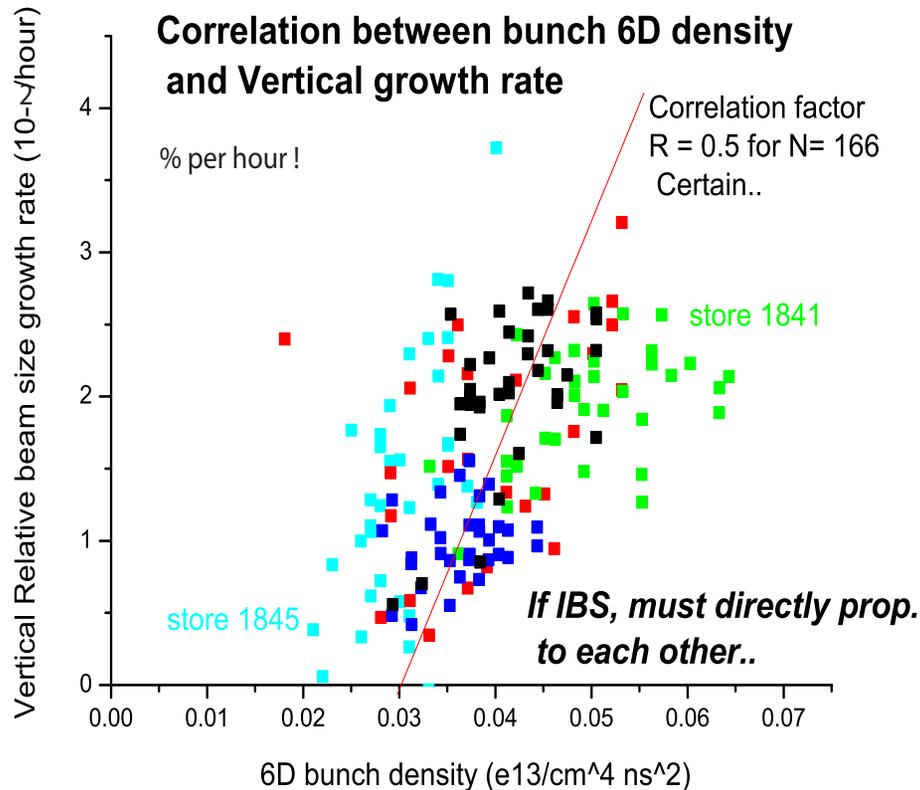
# On Transverse Relative growth rate: Observations.. II



This anti-correlation is significant only when combining different store, with different initial condition on proton beams. But such a methodology might be fair, if beam end up being just Gaussian in all 3 planes.

There seems to be significant effect on bunch position, first bunch in train being on different trajectory. Not yet significant, mode data is needed.

# Relative Growth Rate, vertical Plane, vs 6D particle density.



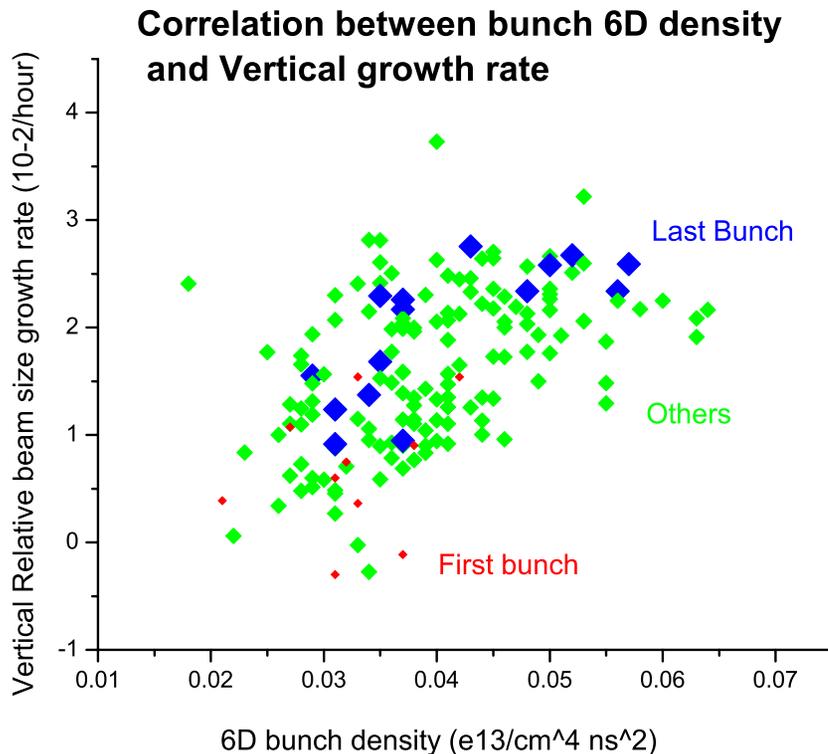
Particle density expressed in weird, mixed units for now.

(using “geometrical units”).

Although the effect is small, typically 2.5% for good stores (small emittances), the correlation is “certain” (P “not there” is  $< 0.0001$ ).

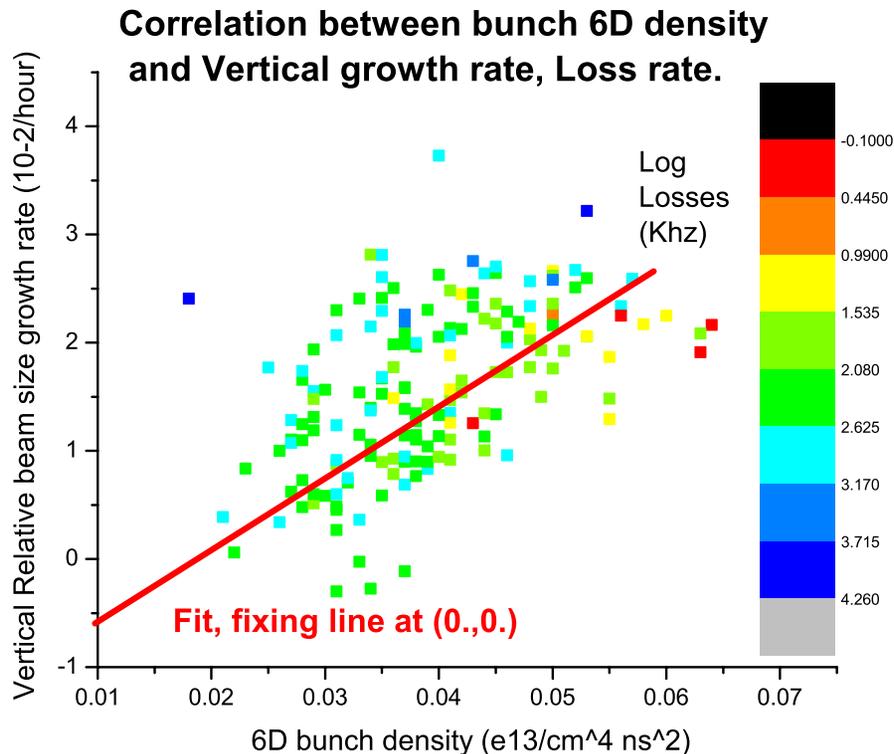
# Relative Growth Rate, vertical Plane, vs 6D particle density, vs bunch position.

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The “outlying” points are neither first in the train, nor last... The first bunches tend to have a larger emittance to start with, and therefore tend to be in the lower left corner of the plot.

# Relative Growth Rate, vertical Plane, vs 6D particle density, vs Proton Losses



Same data as the two previous slides, except that the color is now set by the proton losses. Deduced from the proton lifetime and the “burn rate” obtained from the luminosity (assuming a 70 mb X-section). Bunch with large losses, with an initial relatively small particle density, density tends to have a large transverse growth rate. (dark blue points above the red line linear fit).

# On Intra-Beam Scattering

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- The relative time derivative of the rms  $\sigma_x$  of the horizontal betatron amplitude can be written as :

$$\frac{d \sigma_x}{\sigma_x dt} = \frac{36 L_c N_0 r_0^2 d D_p}{16 \gamma \epsilon_n^2 \sigma_\tau \sigma_p \beta_x} \quad d \sim \sigma_p D_p / \sigma_x$$

- Ref:
  - J. Wei and G. Parzen IBS scaling for VLHC
  - G. Parzen IBS at High Energy (Nucl. Instr. Meth A256 231 (1987))
- Paper by Sezaki K. Mtingwa and Alvin Tollestrup, Fermilab Pub –89-224.

# On IBS expectation..

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- Assumptions :  $\gamma \gg \gamma_T$  and round beams, regular lattice, average lattice function “make sense”
- For  $\beta_x \sim 100$  m,  $D_p \sim 4$  m.,  $\varepsilon_n \sim 0.019$  mm,  $d \sim 0.75$ ,  $\sigma_p \sim 1.2 \cdot 10^{-4}$ ,  $\sigma_\tau = 2 \cdot 10^{-9}$  sec,  $L_c \sim 26$ ,  $N_0 = 1.7 \cdot 10^{11}$

➔  $d \sigma_x / \sigma_x dt \sim 2.9$  to  $2.5$  % per hour !

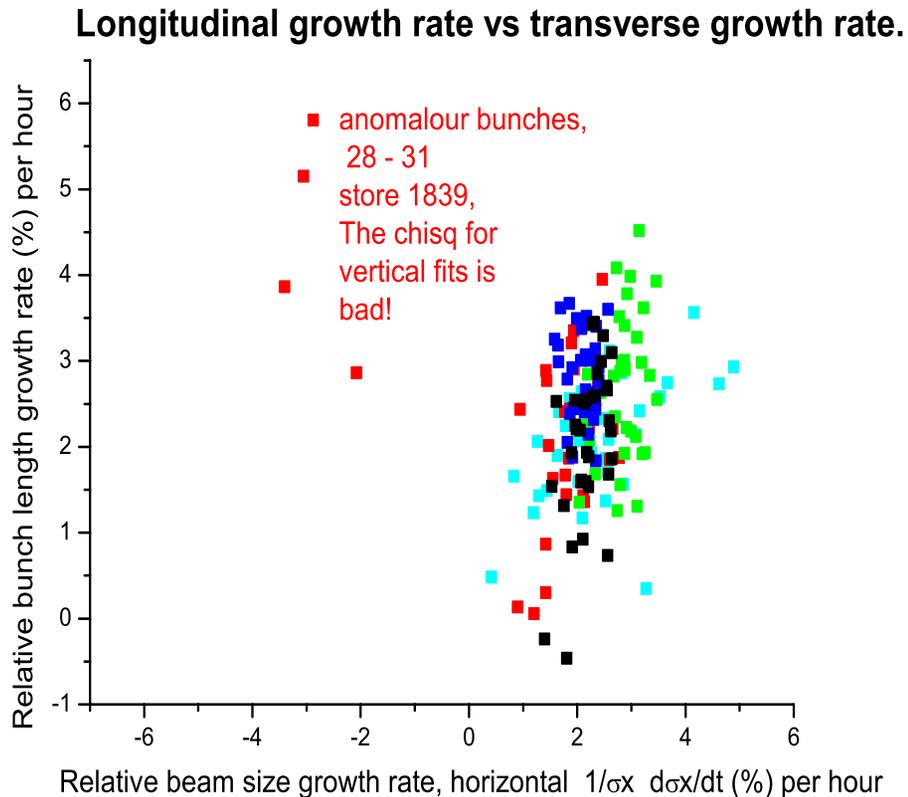
All three references leads the same result,  $\sim 20$  %

(explicit calculation done in 1987 for the TeV, by M-T)

In semi-quantitative ( $\sim 20\%$ ) agreement with curves presented in RunII handbook, and the analysis of store 5903 in RunIb.

# Longitudinal vs Horizontal Growth Rate

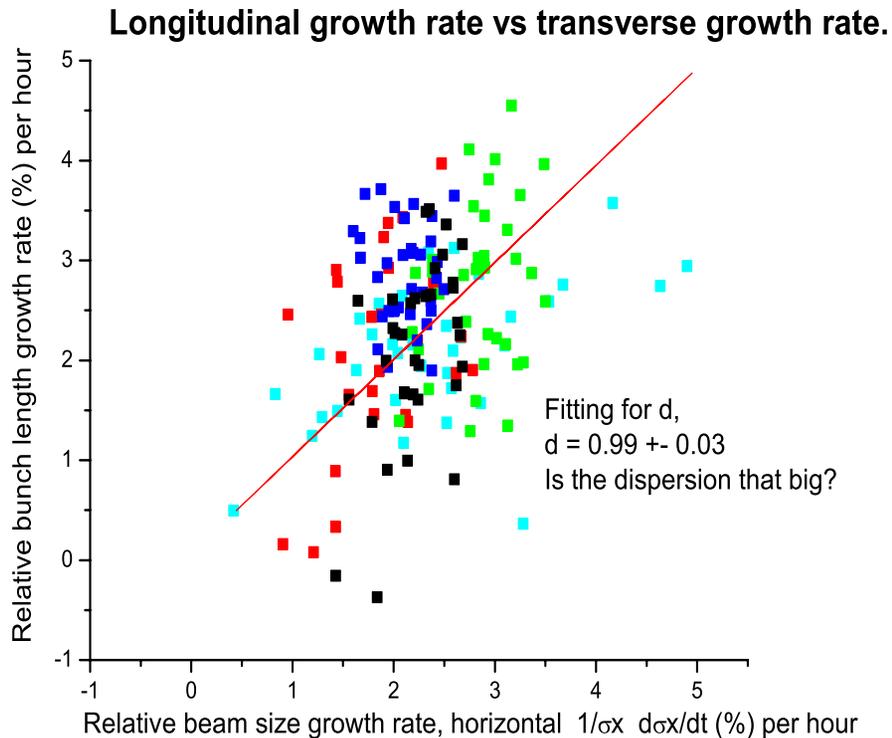
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If IBS plays a significant role,  
The ratio between the longitudinal  
and and Horizontal growth rate  
must be equal to  $d$

There are significant amount of  
scattering in the data!  
4 bunches (at least) seems  
anomalous..

# Longitudinal vs Horizontal Growth Rate, II

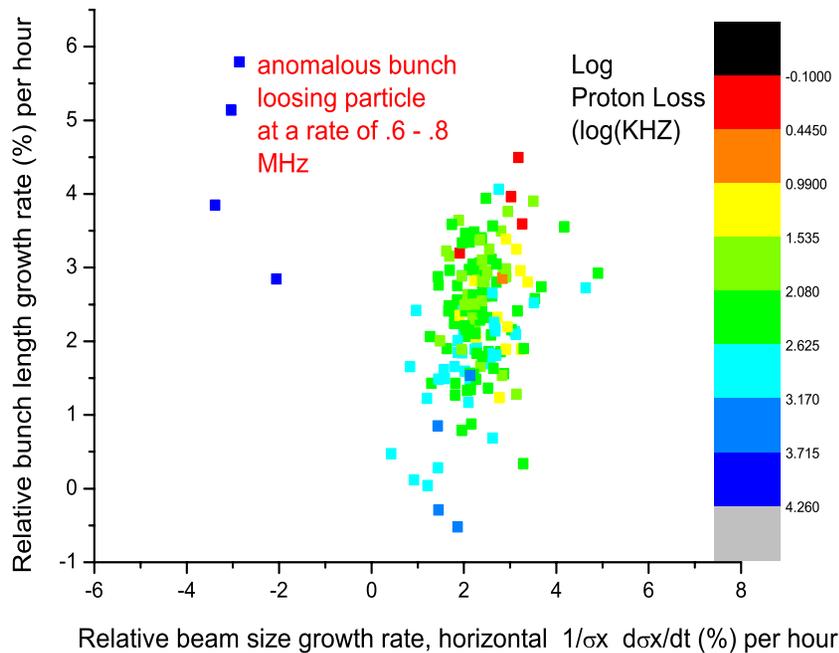


Rejecting these 4 points, we have a significant correlation (coef R is 0.35 for 166 Pts, P “No Correl” is  $<0.0001$ )

The slope is 0.99, not too far off from the guessed value of 0.75.  
-> The average horizontal beam size is almost entirely set by the Dispersion.

# Longitudinal vs Horizontal Growth Rate and Loss Rate.

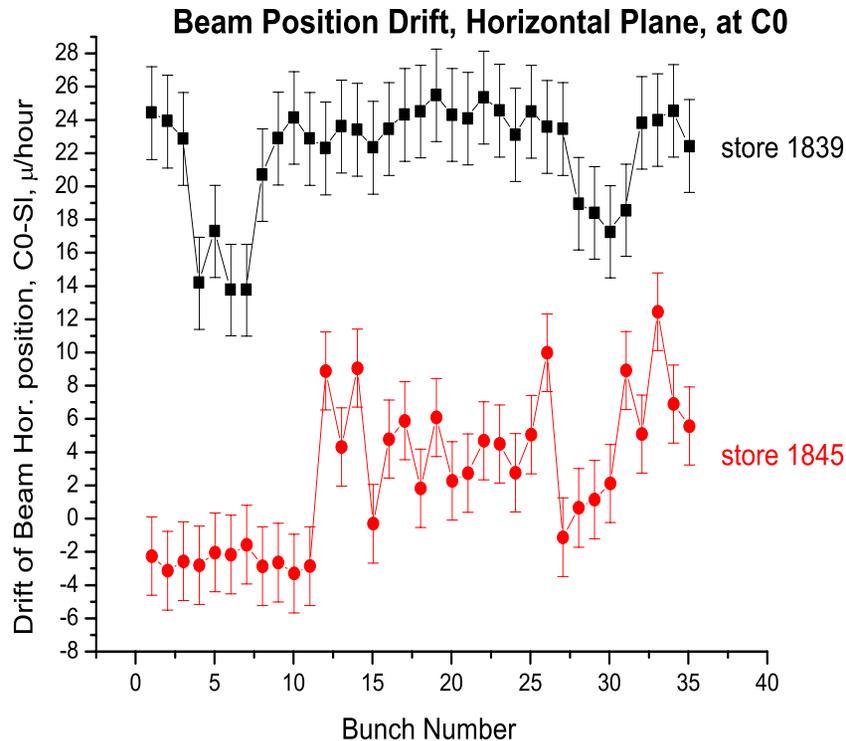
Longitudinal growth rate vs transverse growth rate.



Is it fair to reject these 4 pts?  
What is special about them

***Anomalous large Loss Rate!***  
The loss is obtained from  
The bunch Lifetime, subtracting  
the “burn rate”.  
The red points have a slightly  
negative loss rate, due to a  
slight overestimate of the  
interaction rate at CDF and  
D0.  
For those, the correlation should  
hold.!

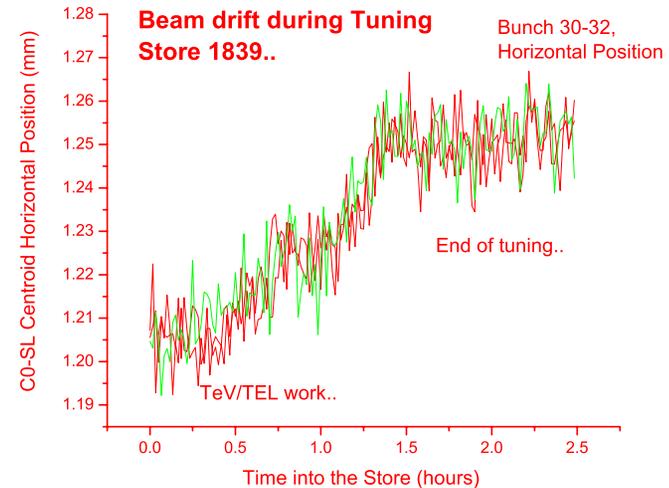
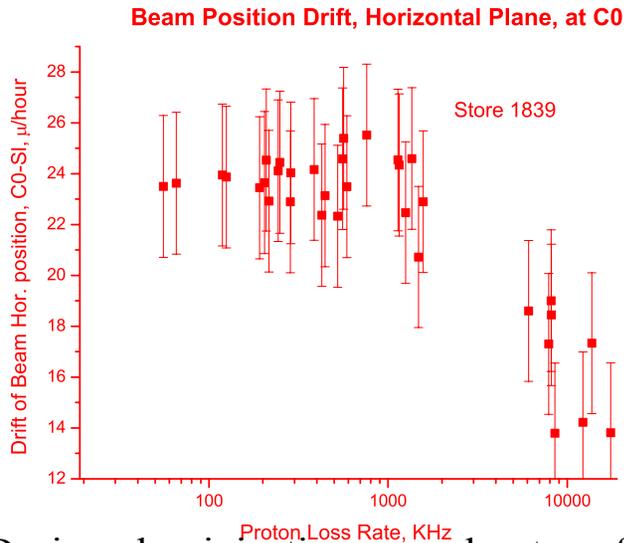
# Store 1839 vs Store 1845



Let us look at the position of Bunch at C0-SI (centroid of the Gaussian vs time)

For the “good” store 1845, The drift is very small (few micron per hours), while it is significant for store 1839,

# Store 1839 is indeed anomalous..



During pbar injection, one pbar transfer has been seriously “blown-up” transversely, causing unacceptable pbar losses. TeV experts did some surgery on these bunch, using TEL. TEL caused tune shift, even displacement some of the proton bunches!, and anomalously large proton loss as well. Approximately after one hour of such tuning, the TEL was restored to it’s normal configuration, and the drift stopped. Keeping such good records in the Log book helps!.

# Summary

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1. The accurate D44 data, in conjunction with SDA data, has been used to characterize the emittance growth during the store.
2. Intra-Beam Scattering, as anticipated, starts playing a significant role in reducing Luminosity Lifetime. The relative growth rate of either the bunch length or the transverse beam size increases roughly by 2.5% per hour, in semi-quantitative agreement with IBS theory.
3. There are unexplained deviations. Presumably, this is due to scraping, or shaving, when the bunch are “disturbed”. We probably should:
  1. Characterize such deviations from IBS..
  2. Correlate with longitudinal motion, e.g. are such bunch “dancing”?
  3. Correlate with losses, or other behaviors...