On Lifetimes during HEP, Emittance Growth & Beam Pipe Vacuum

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Two naïve questions:

- Is the emittance growth during a store (HEP) a significant contribution to the luminosity lifetime?
- Is the beam pipe vacuum a significant contribution to this emittance growth ?
- Ancillary issues:
  - Do we understand quantitatively the Luminosity lifetime in terms of bunch intensity lifetime, emittance growth and so forth?
  - If not vacuum, what is the source of emittance growth?
  - In which planes
  - Other related topics!?

Luminosity Lifetime

– Over a short time period, the inverse of the luminosity lifetime can be approximated by:

$1/\lambda_l = 1/L\ dL/dt =$

$$1/\lambda_a + 1/\lambda_p + (2/\sigma_a\ (d\sigma_a/dt)\ /(1. + \epsilon_p/\epsilon_a)) +$$

$$(2/\sigma_p\ (d\sigma_p/dt)/(1. + \epsilon_p/\epsilon_a)) + 1/F\ dF/dt$$

where

λ_a, λ_p are the pbar and proton lifetimes,

Σ_a, σ_p are the beam width, average over both transverse planes,

ϵ_p, ϵ_a are the average over both transverse planes of the emittance.

F is the hour glass factor, (M. Church phenomenological fit formula)

$F \sim 1.1117 - 0.6254 * \sigma_{0\beta} + 0.19358 * \sigma_{0\beta} * \sigma_{0\beta} - 0.02442 * \sigma_{0\beta}^{3},$

$\sigma_{0\beta} = \sigma_t * c/\beta^*$, σ_t is the bunch length

Assumptions: round beam, about equal pbar and proton emittances.

Lifetime Components, measurement.

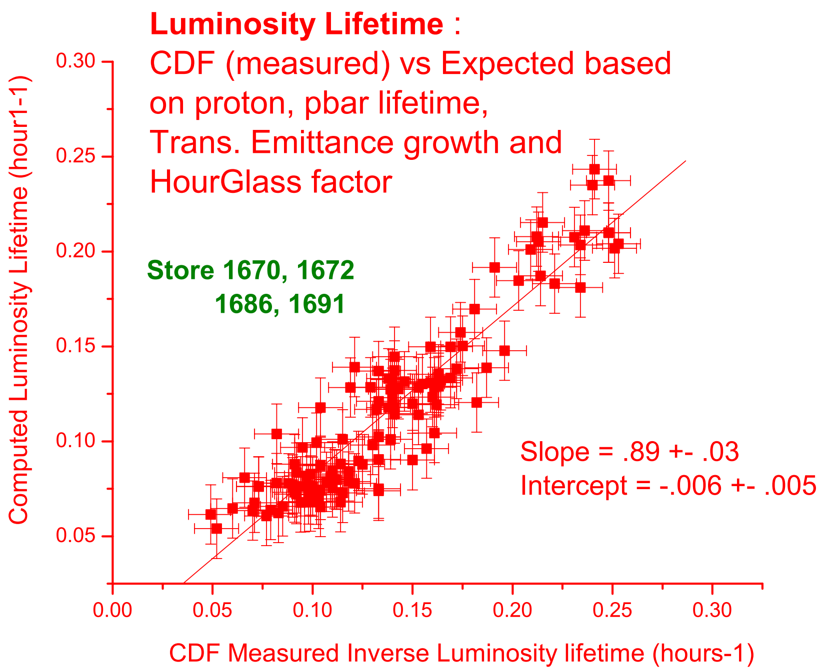
- Measurements are made during the first 2.5 hours of HEP
- $1/\lambda_l$ based on exponential fit of B0ILUM, bunch by bunch, using SDA data (D44 is more accurate, the software will be upgraded!)
- λ_a, λ_p Using FBI devices, from SDA (D44 will be used in the futur)
- σ_a, σ_p are the beam width, measured by Sync Light (D44 data)
- F is based on σ_t, coming from the SBD device (D44 data)

Beam width in all 3 planes are assumed to grow (or shrink) linearly with time.

Data taken recently for about 5 stores ~ 1668-1691.

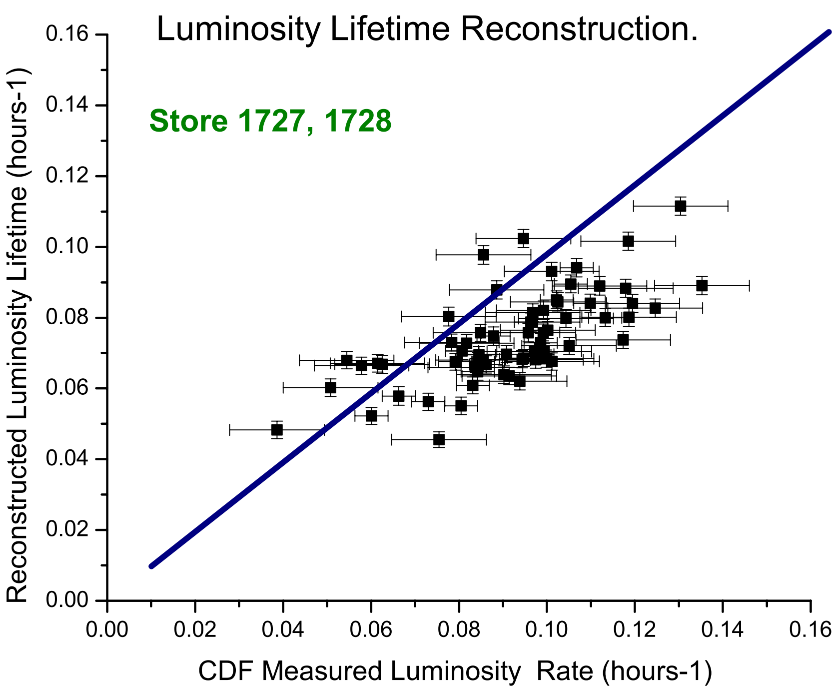
Combining 4 independent devices, comparing with CDF detector.

Comparison Measured vs Expected Lum. Lifetime



For these 4 stores, good agreement (~ 10 to 20%) is achieved. Better agreement than absolute luminosity is reached, because a scaling and systematic uncertainties almost cancel. (And we can measure time with good accuracy).

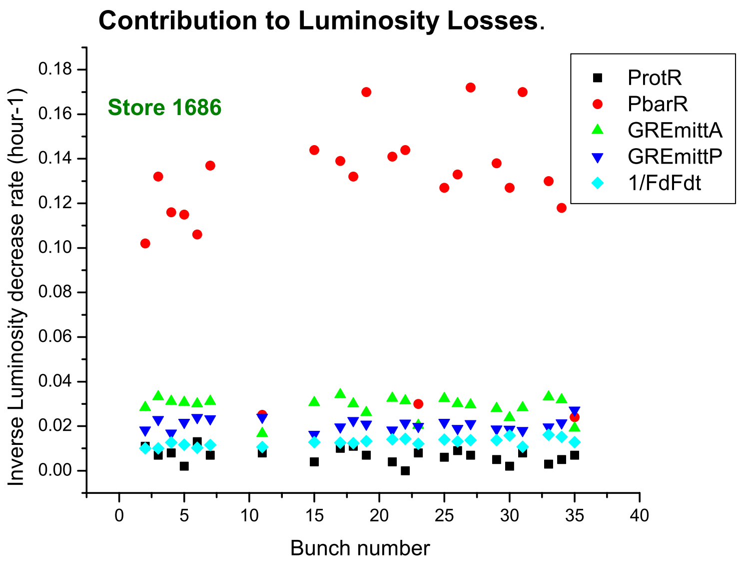
Measured vs Expected Lum. Lifetime, Recent data

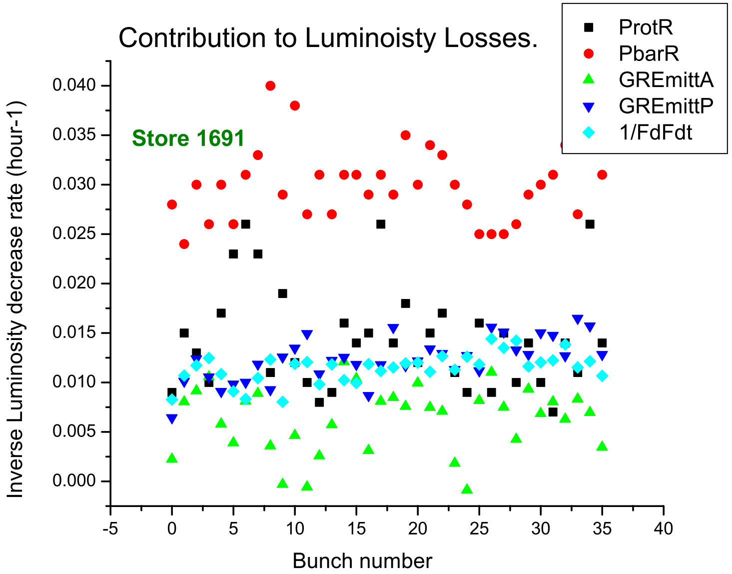


Using new data, the agreement is a bit less spectacular then hoped for. As previously, we systematically underestimate the rate at which the luminosity disappears:

May be the bunches are drifting apart at the I.P., leading to the wrong HourGlass factor time dependency.

Luminosity Lifetimes, term by term..

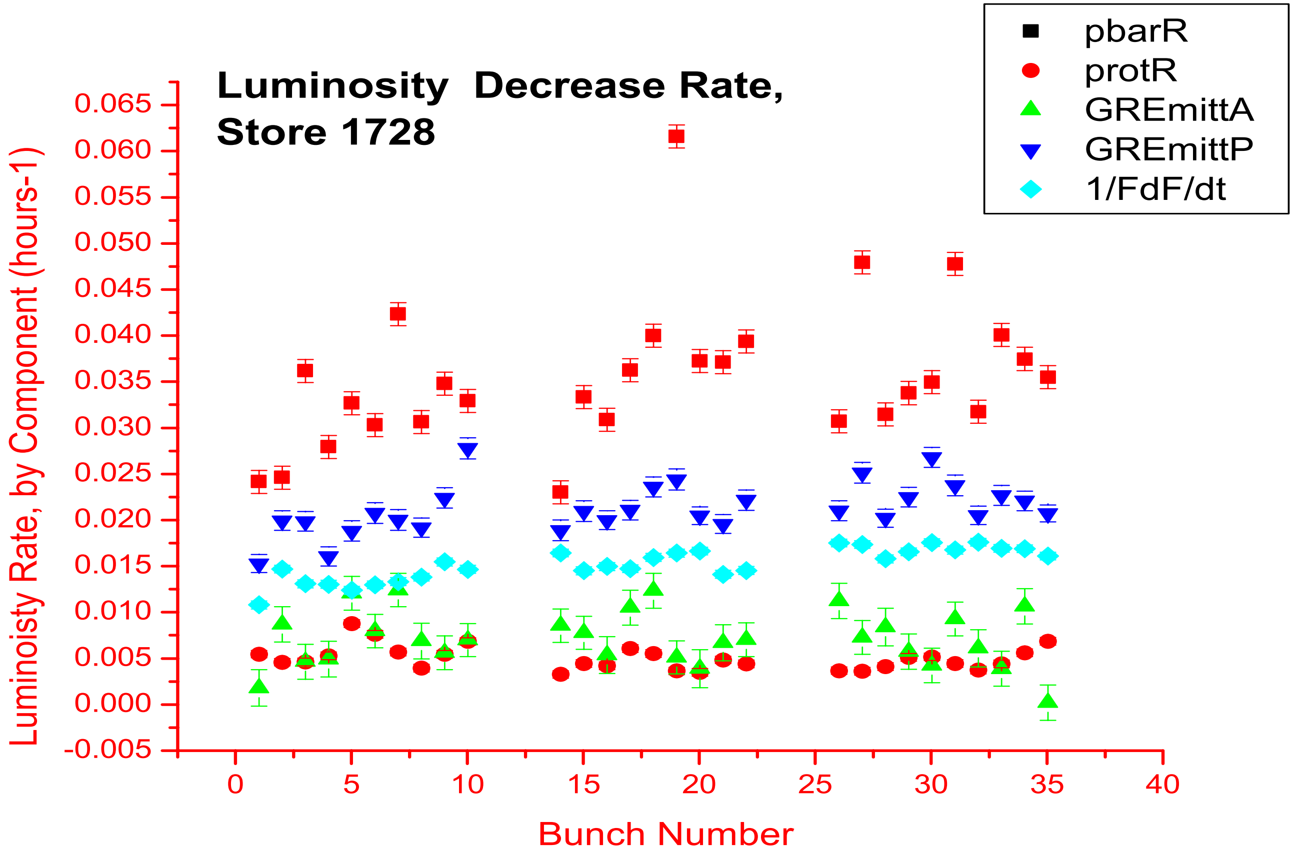




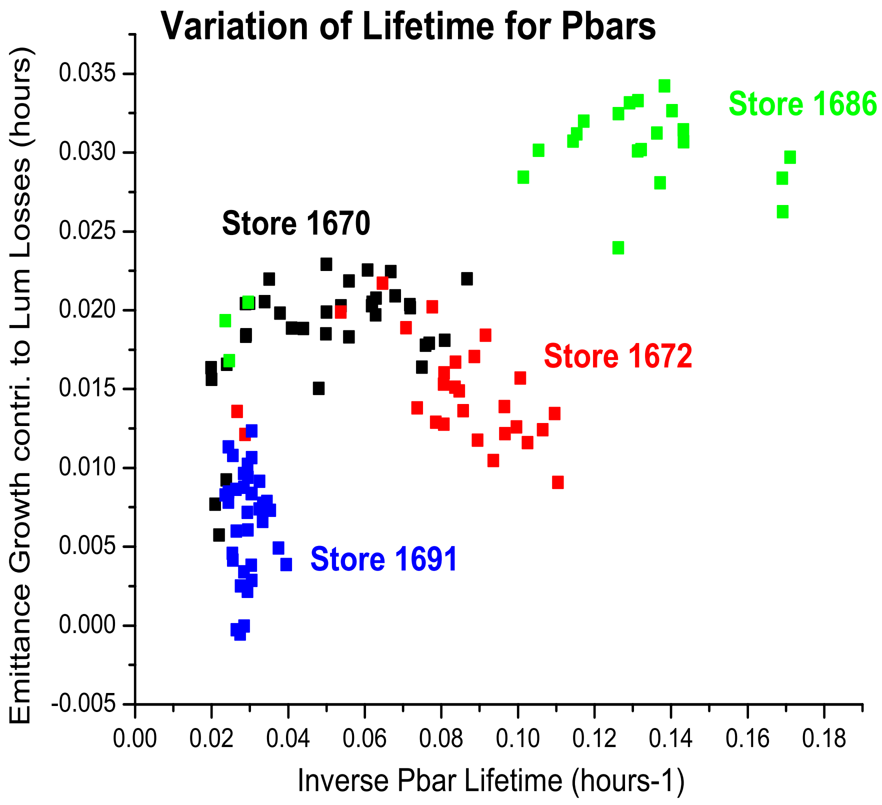
Store 1686 had an anomalously poor pbar lifetime, because the pbar emittance was too large. (We also had poor luminosity, ~15. e30) The ratio of collision rate over pbar disappearance rate was only 0.16 .

Store 1691 was more typical (L = 25. E30). About 66% of the antiproton are disappearing because of collision at B0 and D0 (assuming a cross section of 50 mB)

Luminosity Lifetimes, term by term, store 1728



On preserving the pbar emittance.



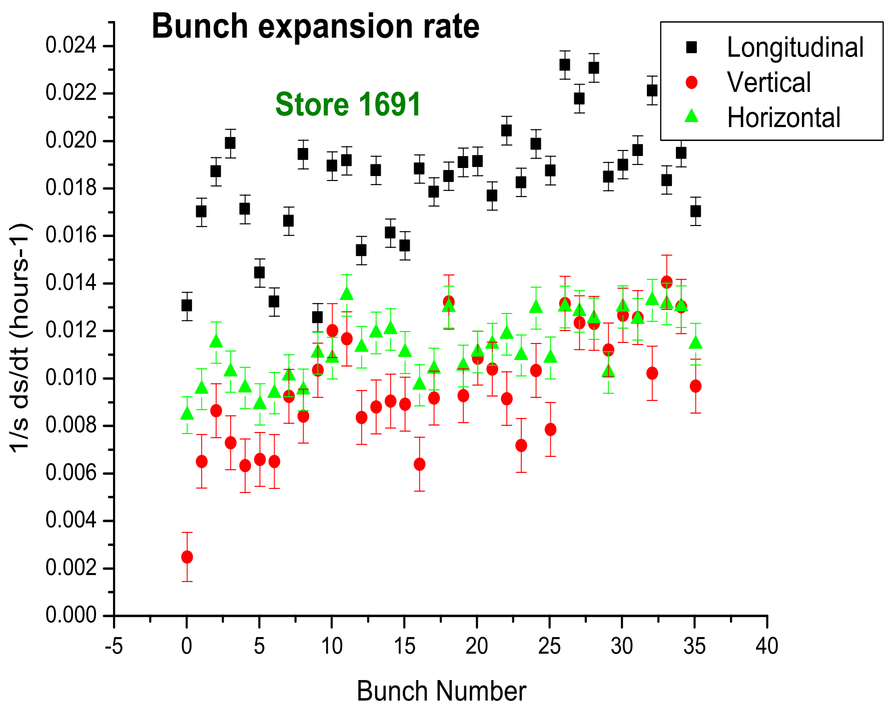
For store 1686, we not only had poor instantaneous luminosity due to large pbar emittance, we also diffuse the pbar much faster, as the contribution due to the pbar emittance growth was about twice as the one in store 1691.
The correlation between poor lifetime and emittance growth for pbar is not surprising, should be confirmed and studied in more details..

From Lifetime to Emittance Growth…

There is little one could do to mitigate the pbar loss due to collisions! (CDF and D0 want their data!)
For good stores (1691, 1583), the “unwarranted” pbar and proton losses are no longer the dominant factor for the luminosity lifetime, as the emittance grow significantly during the store.
Can we improve upon emittance growth ? What is it due to ?
During the last Friday meeting, we had a small debate on the relevance of the vacuum inside the TeV beam pipe. Could this emittance growth (in all 3 planes) could be explained by relatively poor vacuum ?
As Alvin T. pointed, this extremely unlikely, based on lifetime of proton only store (uncoalesced, if I remember correctly).

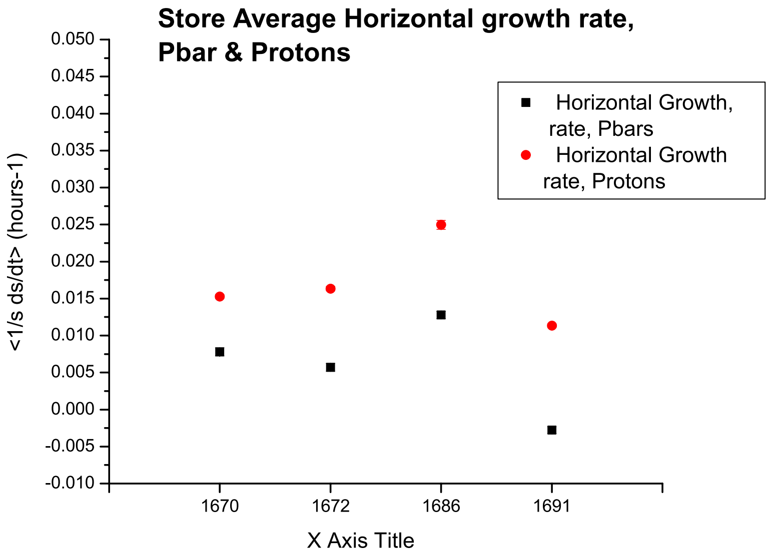
The next few slides will show that, indeed, the dominant mechanism for emittance growth is not vacuum!

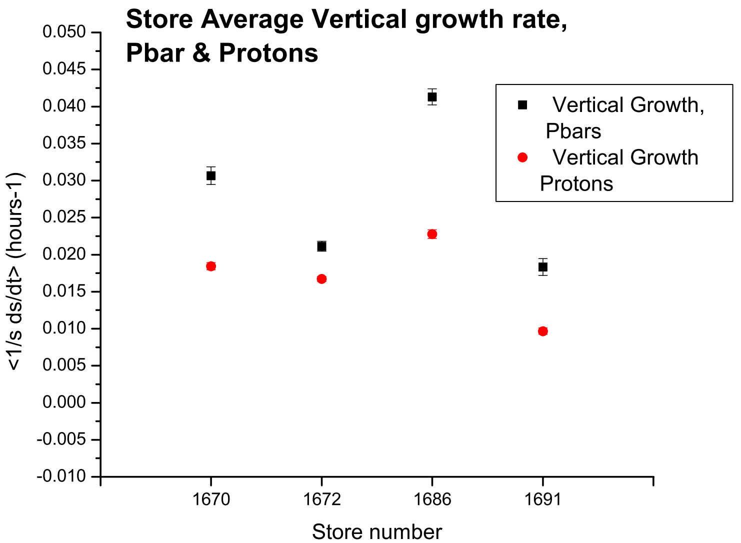
1. Emittance Growth fluctuates widely bunch to bunch, store to store.



Did we had significantly poor vacuum during store 1686? No evidence of this.. Evidently, the same vacuum is encountered for every bunches in the machine. The emittance growth should then be the same for every bunches, if vacuum plays a significant role…

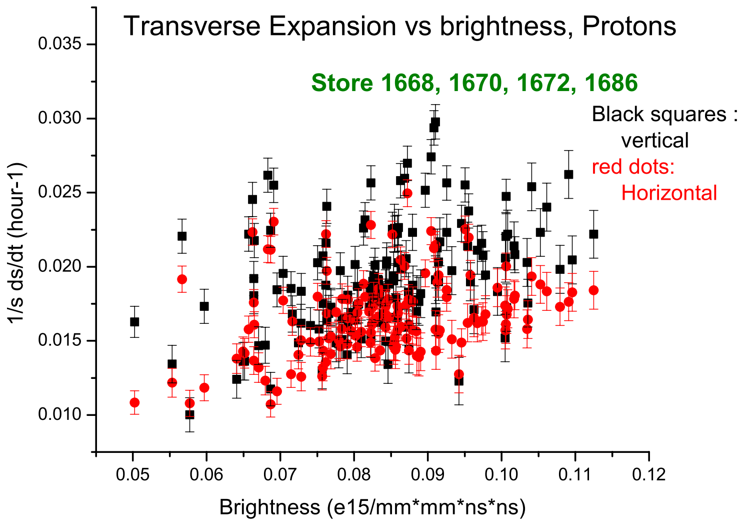
Transverse Expansion Rate, vs Store, protons and pbars

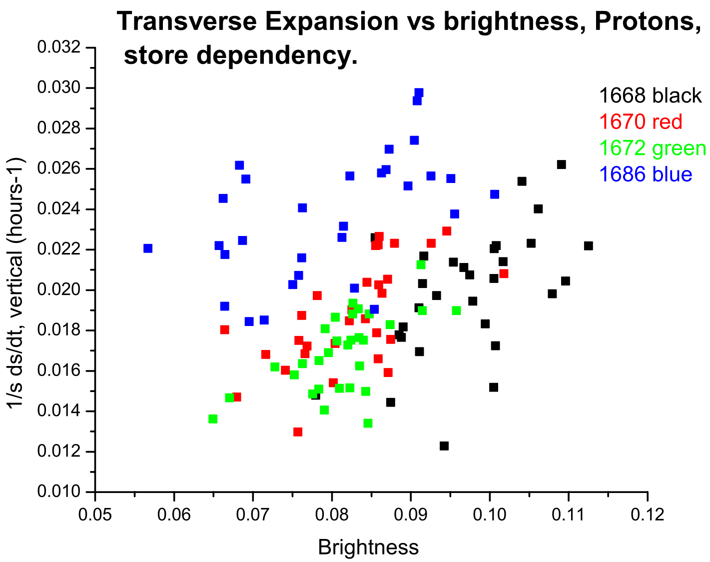




Average for all bunches, the expansion rate varies store to store, while the total beam current is approximately the same.

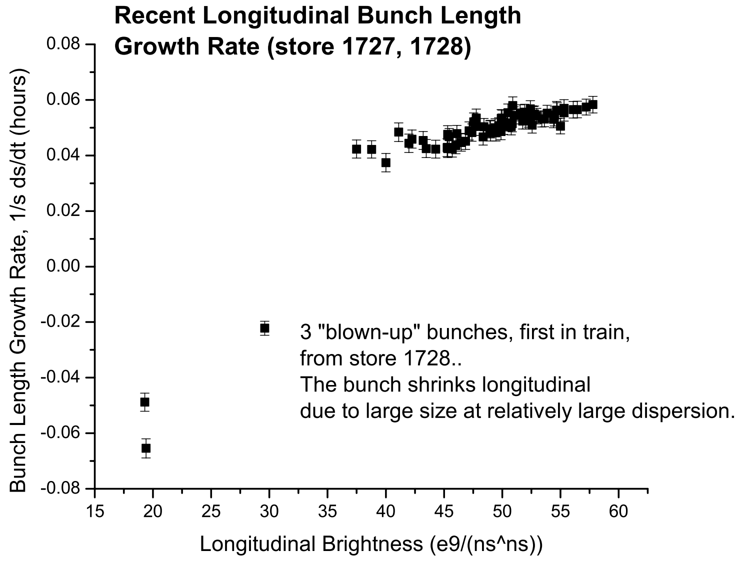
2. The 1/s ds/dt expansion rate depends on the bunch brightness.

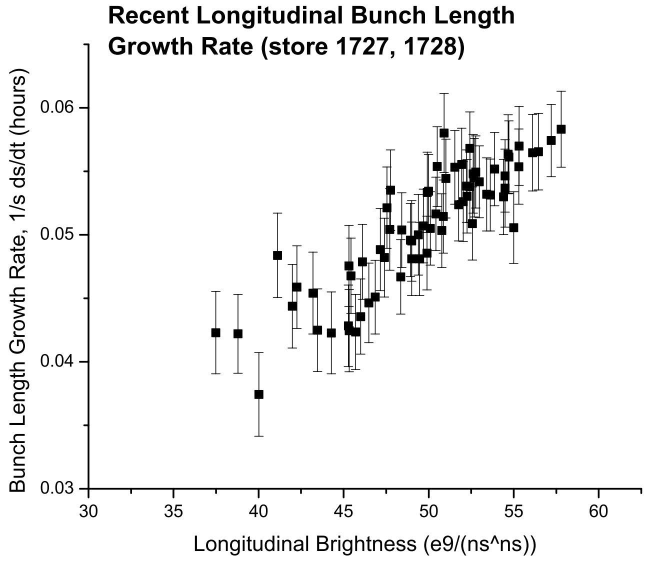




Both Pbar and Proton bunches grow in size, and the growth rate seems to depend on the bunch brightness.
This rate seems also to depend on store condition.

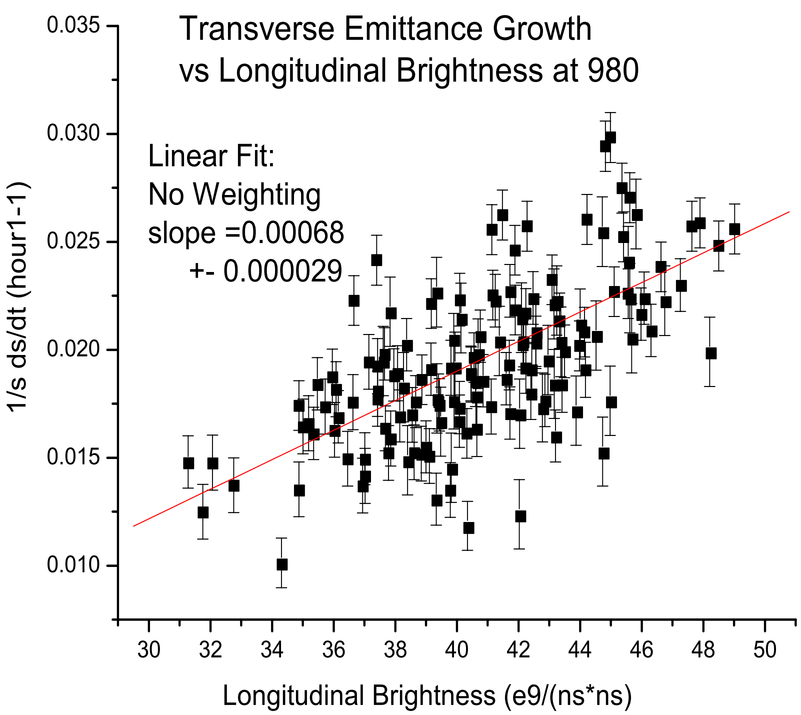
2. The 1/s ds/dt Longitudinal Expansion rate depends on the bunch brightness.





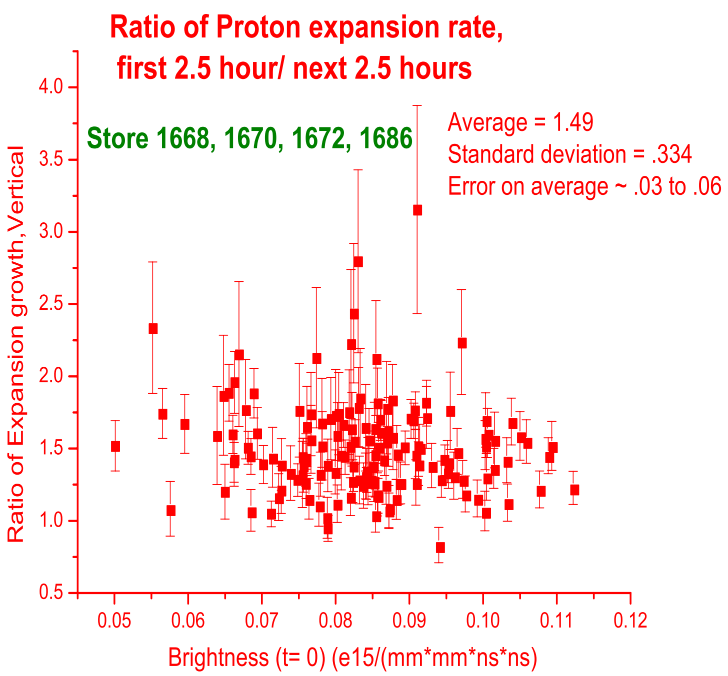
This has been previously mentioned. Using D44 data, we now have better accuracy. This is recent data.

2. The expansion rate vs brightness: Longitudinal or 3D brightness?



The Proton transverse emittance is rather stable, bunch to bunch, store to store. Due to coalescing efficiency, the longitudinal emittance fluctuate a bt more. So it is hard to distinguish.
Nevertheless, the dependency of the vertical growth rate for proton on longitudinal brightness is statistically established: if we increase the measurement error shown on this plot by a factor 3 to 4, the slope is 4 to 5 sigma away from zero.

3. The bunch expansion rates decrease with time, faster than the total current.



Poor vacuum could be beam induced, (wall heating due to microwave power…)
However, the bunch diffusion rate ($1/\sigma \; d\sigma/dt$) significantly decreases versus time, faster than the beam current does. (Proton lifetime is ~100 hours)

Conclusion/Action items

- Luminosity Lifetime "makes sense", given the measured losses and emittance growth.
- The terms due to emittance growth, for good store are significant, and the losses are correlated with large emittance.=> let preserve these emittance (obvious!)
- Poor vacuum is not the dominant source of bunch diffusion!
- The correlation between longitudinal brightness and transverse emittance growth is established.
- And we got to make more plots.. (pbar, X-Y growth rate correlations…)