Calculating β* and crossing angle from Store 3873 and 3876

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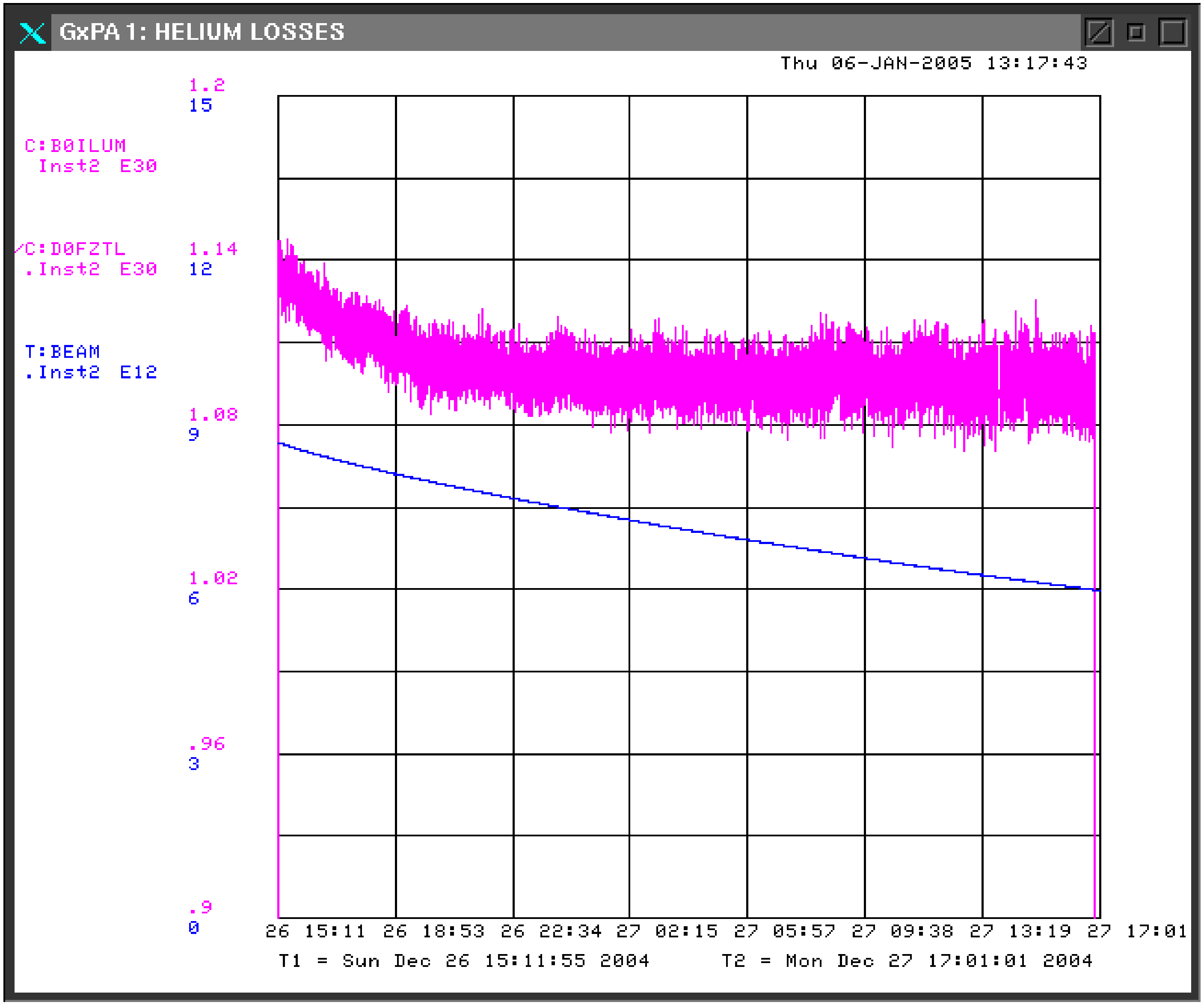
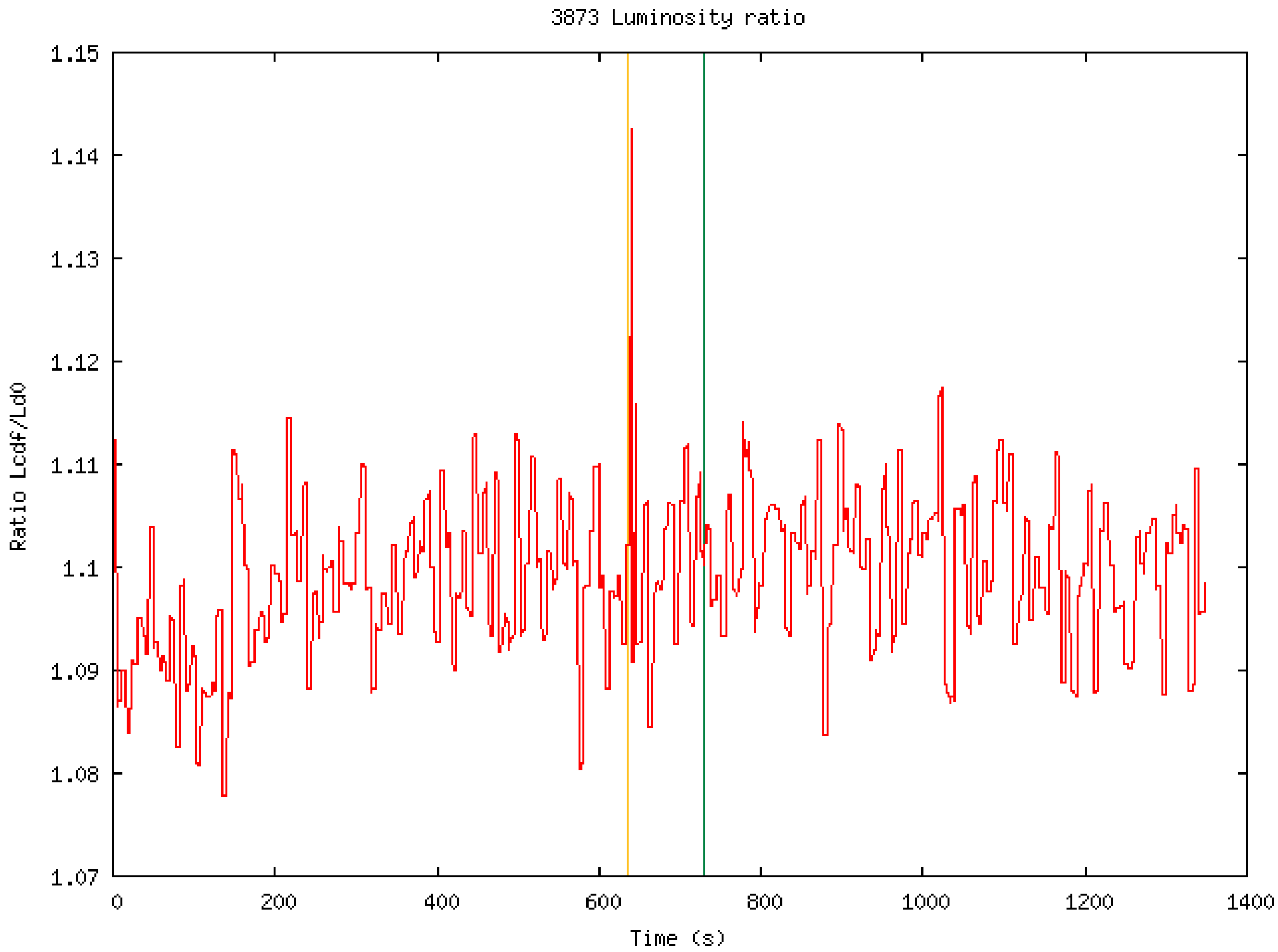
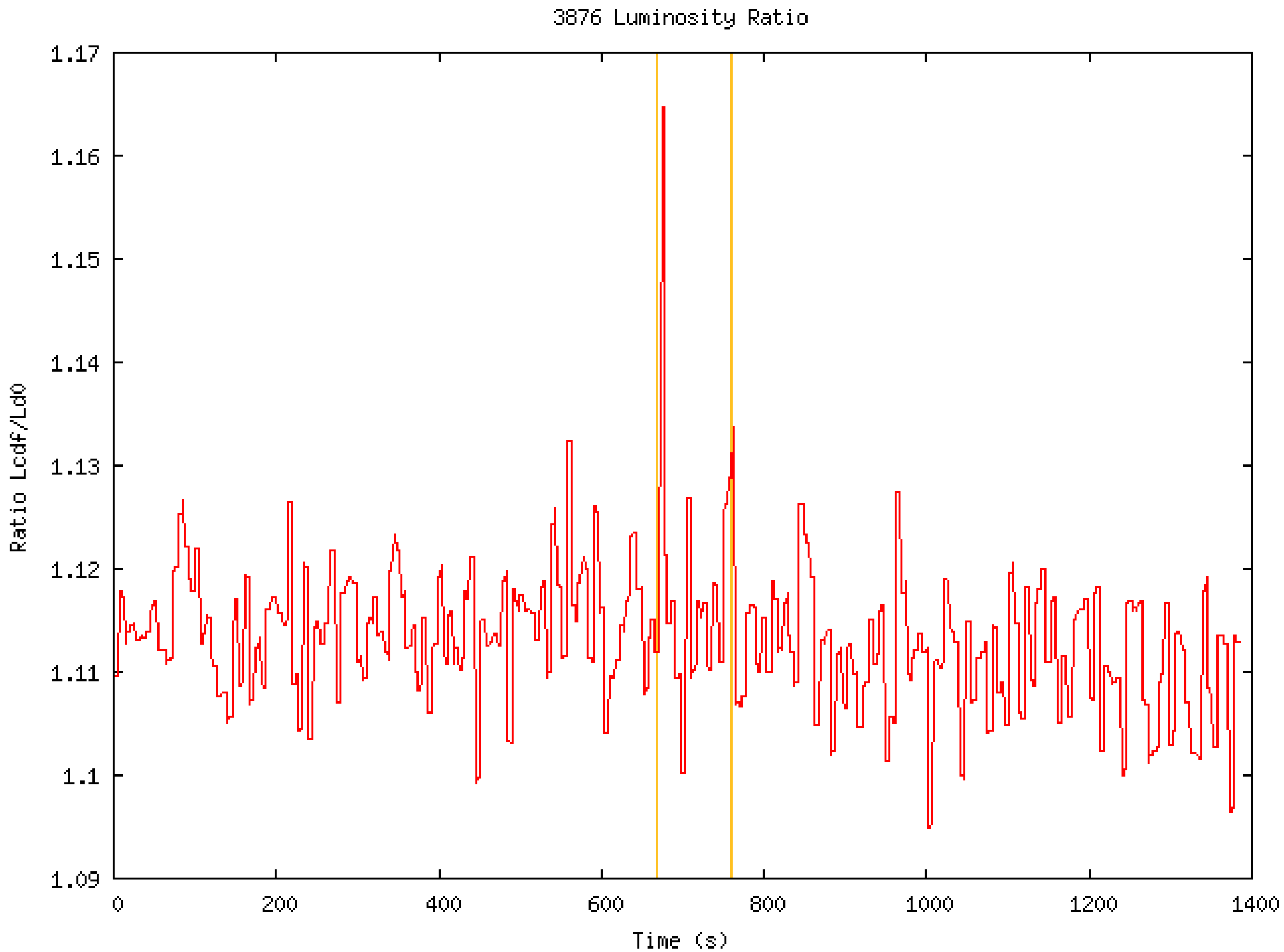
Example of L_{cdf}/L_{D0} before CDF move (store 3879)



3873 Luminosity Ratio



3876 Luminosity Ratio



Goal

- Use stores 3873 and 3876 which had TRF1 trips which caused bunch lengthening and loss in luminosity which allows us to calculate the following:
  - Expected luminosity loss from theory.
  - β^* from data.
  - Relative crossing angles between CDF and D0
- Store 3873 had TRF1 trip near middle of store.
- Store 3876 had TRF1 trip near the start of store.

Theory

Start with usual luminosity formula with the usual definitions of variables:

$$L = \frac{10^{-5} f\, B\, N_p N_{\bar{p}} (6 \beta_r \gamma_r)}{2\pi \beta^* \sqrt{(\epsilon_p + \epsilon_{\bar{p}})_x (\epsilon_p + \epsilon_{\bar{p}})_y}} H(\beta^*, \sigma_p, \sigma_{\bar{p}})$$

L = luminosity	N_p = num protons	$N_{\bar{p}}$ = num pbars
$B = 36$	$f = 47.7\,\mathrm{kHz}$	$\beta_r \gamma_r = 1045 @ 980\,\mathrm{GeV}$
$\beta^* \approx 35\,\mathrm{cm}$	ϵ_p = proton emit.	$\epsilon_{\bar{p}}$ = pbar emit.
H = hourglass factor	σ_p = proton bunch length	$\sigma_{\bar{p}}$ = pbar bunch length

Theory (cont'd)

Use phenomenological model from V. Shiltsev and V. Lebedev for *H:*

$$
\begin{aligned}
H(\beta^*, \sigma_p, \sigma_{\bar{p}}) &= \frac{1}{(1+a z^2)^{1/3}} \\
z^2 &= \frac{\sigma_p^2 + \sigma_{\bar{p}}^2}{2\beta^{*2}} \\
a &= 1.32
\end{aligned}
$$

Can show that:

$$
\frac{\Delta L}{L} = \frac{\Delta H}{H} = -\frac{1}{3} \frac{a(\sigma_p \Delta\sigma_p + \sigma_{\bar{p}} \Delta\sigma_{\bar{p}})}{\beta^{*2}(1+a z^2)}
$$

Theory (cont'd) crossing angle

- If we assume round beams i.e. $(\epsilon_p+\epsilon_{\bar{p}})_x=(\epsilon_p+\epsilon_{\bar{p}})_y=\epsilon$
- It can be shown that

$$\delta L=(\Delta L_m-\Delta L_c)=-\Delta\sigma_z\frac{k}{\beta^{*4}\epsilon^2}\times\frac{3\beta^{*2}+a\sigma_z^2}{6\left(1+\frac{a\sigma_z^2}{2\beta^{*2}}\right)^{4/3}}\delta\theta^2$$

$$\begin{aligned}\Delta\sigma_z &= \Delta(\sigma_p+\sigma_{\bar{p}})\\ k &= 10^{-5} f\, B\, N_p N_{\bar{p}}(6\beta_r\gamma_r)/2\pi\\ \delta\theta &= \text{crossing angle}\end{aligned}$$

$$\begin{aligned}\Delta L_m &= \text{measured luminosity}\\ \Delta L_c &= \text{calculated luminosity}\end{aligned}$$

Theory (cont'd)

- If we assume β* are equal at both IPs we can show that

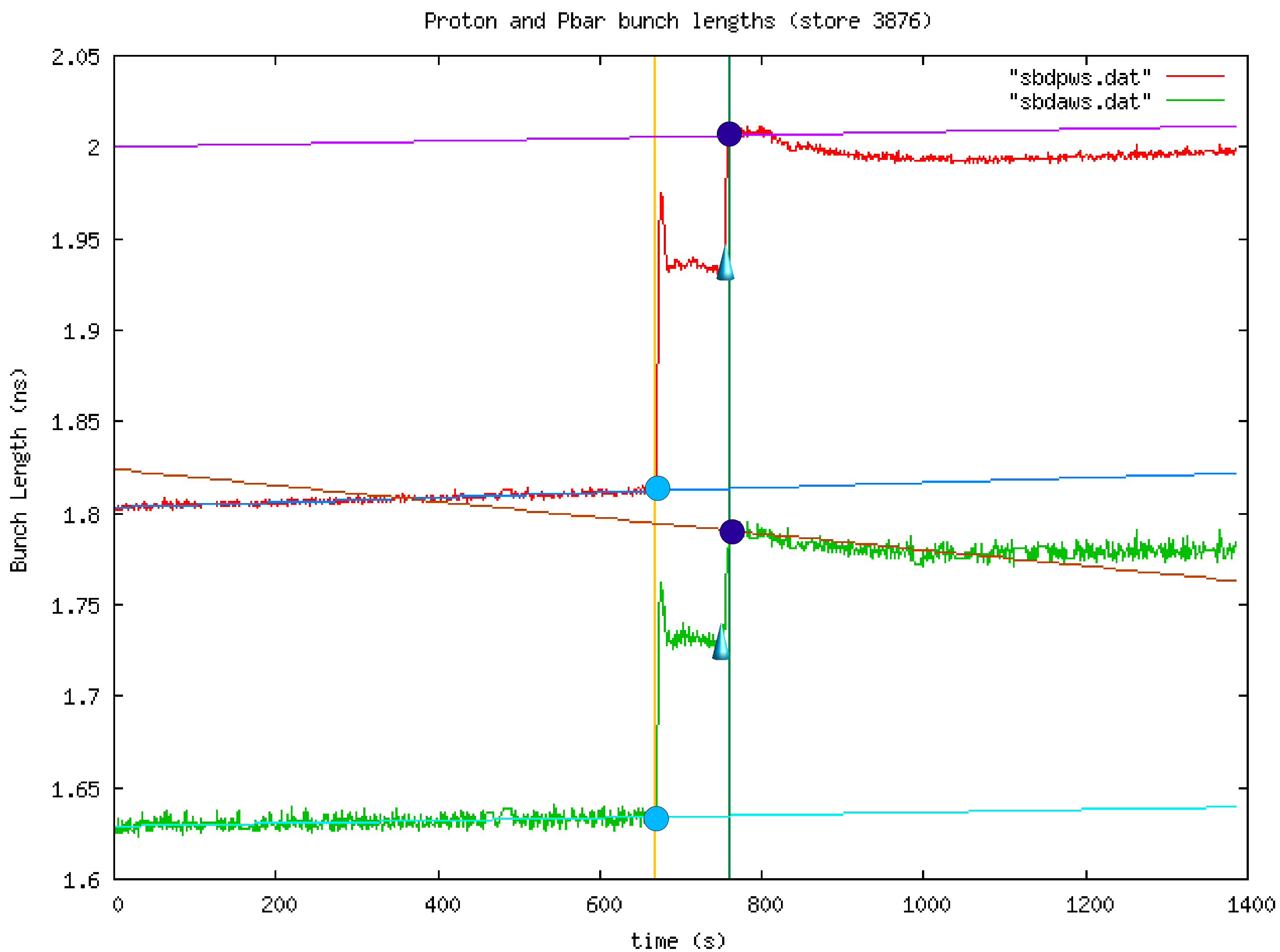
$$\frac{\delta L_{CDF}}{\delta L_{D0}} = \left(\frac{\delta \theta_{CDF}}{\delta \theta_{D0}} \right)^2$$

This will enable us to find the relative size of the crossing angle between CDF and D0 from the difference in measured and calculated ΔL.

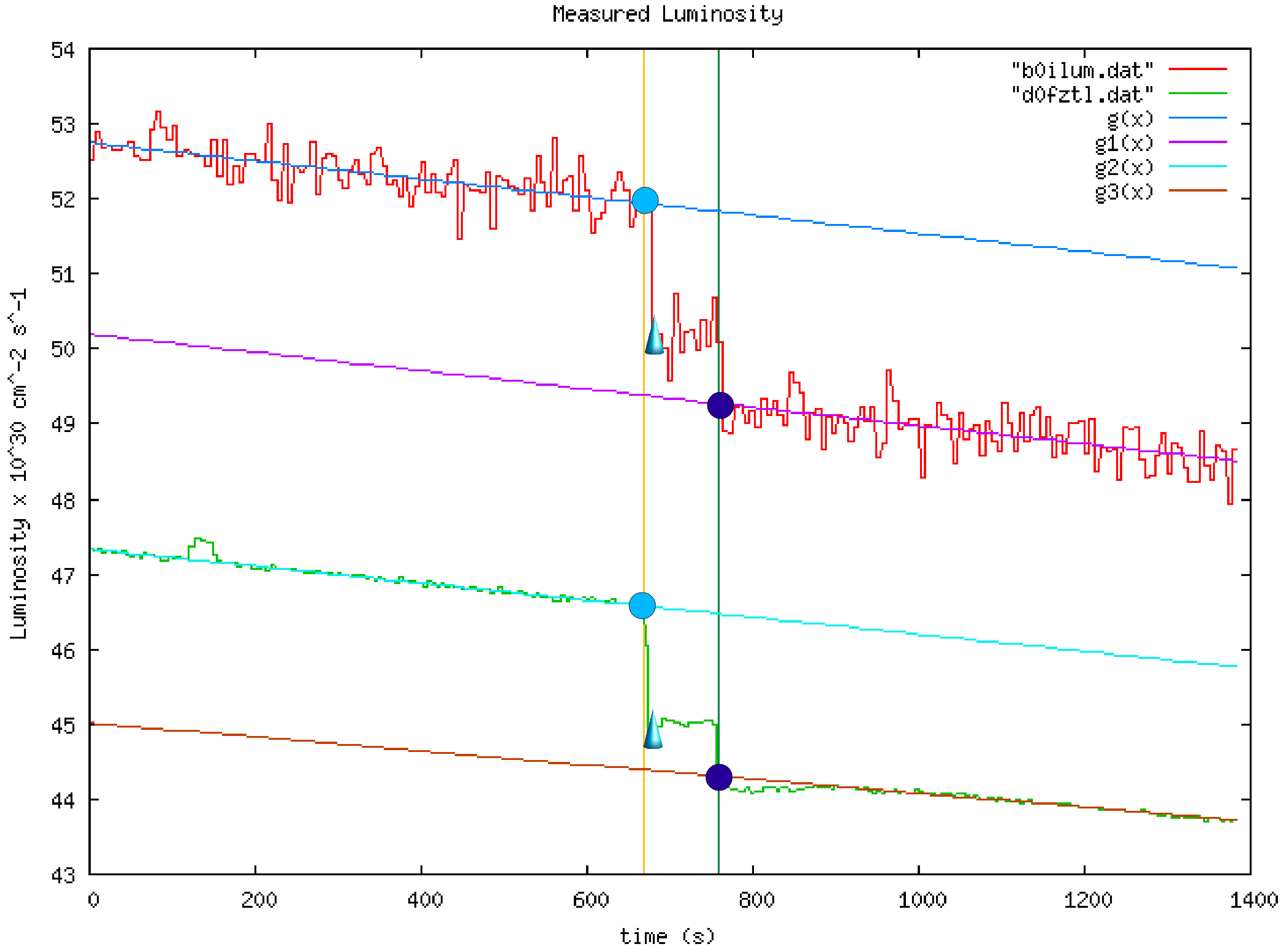
What can be calculated from ΔL

- If we assume $\beta^* = 35$ cm then we can calculate the expected loss in luminosity at both experiments from knowledge of $\sigma_p, \Delta\sigma_p, \sigma_{\bar{p}}, \Delta\sigma_{\bar{p}}$
  - From difference between ΔL measured and calculated, we can have handle on relative crossing angles at CDF and D0.
- If we assume that CDF and D0 measures ΔL correctly, then we can calculate β^* from knowledge of $\Delta L, \sigma_p, \Delta\sigma_p, \sigma_{\bar{p}}, \Delta\sigma_{\bar{p}}$

Data from Store 3876



Data from Store 3876



Results from store 3876

Measured Before TRF1 trip

$$\sigma_p = 1.8122 \pm 0.0001\,\text{ns}$$
$$\sigma_{\bar{p}} = 1.634 \pm 0.0002\,\text{ns}$$
$$L_{CDF} = (51.94 \pm 0.02) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$L_{D0} = (46.577 \pm 0.002) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Measured after TRF1 trip

$$\Delta\sigma_p = 0.1958 \pm 0.0004\,\text{ns}$$
$$\Delta\sigma_{\bar{p}} = 0.1558 \pm 0.0008\,\text{ns}$$
$$\Delta L_{CDF} = (-2.67 \pm 0.03) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$\Delta L_{D0} = (-2.316 \pm 0.003) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Calculated drops in luminosity assuming β* = 35 cm

$$\Delta L_{CDF} = (-2.63 \pm 0.01) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$\Delta L_{D0} = (-2.361 \pm 0.006) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Calculated relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = \frac{\Delta L_{D0}}{L_{D0}} = 5.1\,\%$$

Measured relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = 5.2\,\%$$
$$\frac{\Delta L_{D0}}{L_{D0}} = 5.2\,\%$$

Results from store 3876 • →

Measured Before TRF1 trip

$$\sigma_p = 1.8122 \pm 0.0001\,\mathrm{ns}$$
$$\sigma_{\bar{p}} = 1.634 \pm 0.0002\,\mathrm{ns}$$
$$L_{CDF} = (51.94 \pm 0.02) \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$L_{D0} = (46.577 \pm 0.002) \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Measured after TRF1 trip

$$\Delta\sigma_p = 0.1244 \pm 0.0005\,\mathrm{ns}$$
$$\Delta\sigma_{\bar{p}} = 0.0980 \pm 0.0008\,\mathrm{ns}$$
$$\Delta L_{CDF} = (-1.74 \pm 0.08) \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\Delta L_{D0} = (-1.551 \pm 0.008) \times 10^{30}\,\mathrm{cm}^{-2}s^{-1}$$

Calculated drops in luminosity assuming β* = 35 cm

$$\Delta L_{CDF} = (-1.666 \pm 0.007) \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$$\Delta L_{D0} = (-1.494 \pm 0.007) \times 10^{30}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Calculated relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = \frac{\Delta L_{D0}}{L_{D0}} = 3.2\,\%$$

Measured relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = 3.4\,\%$$
$$\frac{\Delta L_{D0}}{L_{D0}} = 3.3\,\%$$

Results from store 3876

Crossing angles:

Calculated relative crossing angles, results are consistent with **zero** relative crossing angles because measured *ΔL* is really close to calculated *ΔL*, so for amusement

$$\frac{\delta\theta_{CDF}}{\delta\theta_{D0}} = \sqrt{\frac{-0.04 \pm 0.3}{0.045 \pm 0.04}} = \text{imaginary}$$

$$\frac{\delta\theta_{CDF}}{\delta\theta_{D0}} = \sqrt{\frac{-0.074 \pm 0.08}{-0.057 \pm 0.01}} = 1.1$$

Results from store 3876 cont'd

Since the difference between measured and calculated ΔL is second order in crossing angle, assume crossing angle is zero and calculate β*

$$\beta^*_{CDF} = (34 \pm 1)\,\mathrm{cm}$$
$$\beta^*_{D0} = (36.3 \pm 0.2)\,\mathrm{cm}$$

$$\beta^*_{CDF} = (32 \pm 3)\,\mathrm{cm}$$
$$\beta^*_{D0} = (32.4 \pm 0.3)\,\mathrm{cm}$$

Averaging

$$\beta^*_{CDF} = (33.5 \pm 1)\,\mathrm{cm}$$
$$\beta^*_{D0} = (34.7 \pm 0.1)\,\mathrm{cm}$$

This is consistent with β*=35 cm

Results from Store 3873

Measured Before TRF1 trip

$$\sigma_p = 2.2849 \pm 0.0001\,\text{ns}$$
$$\sigma_{\bar{p}} = 1.9734 \pm 0.0006\,\text{ns}$$
$$L_{CDF} = (19.38 \pm 0.01) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$L_{D0} = (17.586 \pm 0.001) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Measured after TRF1 trip

$$\Delta\sigma_p = 0.2062 \pm 0.0003\,\text{ns}$$
$$\Delta\sigma_{\bar{p}} = 0.173 \pm 0.001\,\text{ns}$$
$$\Delta L_{CDF} = (-1.22 \pm 0.01) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$\Delta L_{D0} = (-1.096 \pm 0.001) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Calculated drops in luminosity assuming β* = 35 cm

$$\Delta L_{CDF} = (-0.939 \pm 0.002) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$
$$\Delta L_{D0} = (-0.853 \pm 0.002) \times 10^{30}\,\text{cm}^{-2}\text{s}^{-1}$$

Calculated relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = \frac{\Delta L_{D0}}{L_{D0}} = 4.8\%$$

Measured relative luminosity drop

$$\frac{\Delta L_{CDF}}{L_{CDF}} = 6.2\%$$
$$\frac{\Delta L_{D0}}{L_{D0}} = 6.3\%$$

Results from store 3873 cont'd

Calculated relative crossing angles

$$\frac{\delta\theta_{CDF}}{\delta\theta_{D0}} = \sqrt{\frac{-0.28 \pm 0.01}{-0.243 \pm 0.002}} = 1.1 \pm 0.1$$

This means that the crossing angle are the same at both experiments.

Conclusion

- β^* are the same at both experiments
- Crossing angles are the same at both experiments
- Discrepancies in *L* cannot be explained by β^* or crossing angles.

Extra Slides

Expected blowup

Blowup formula from Syphers:

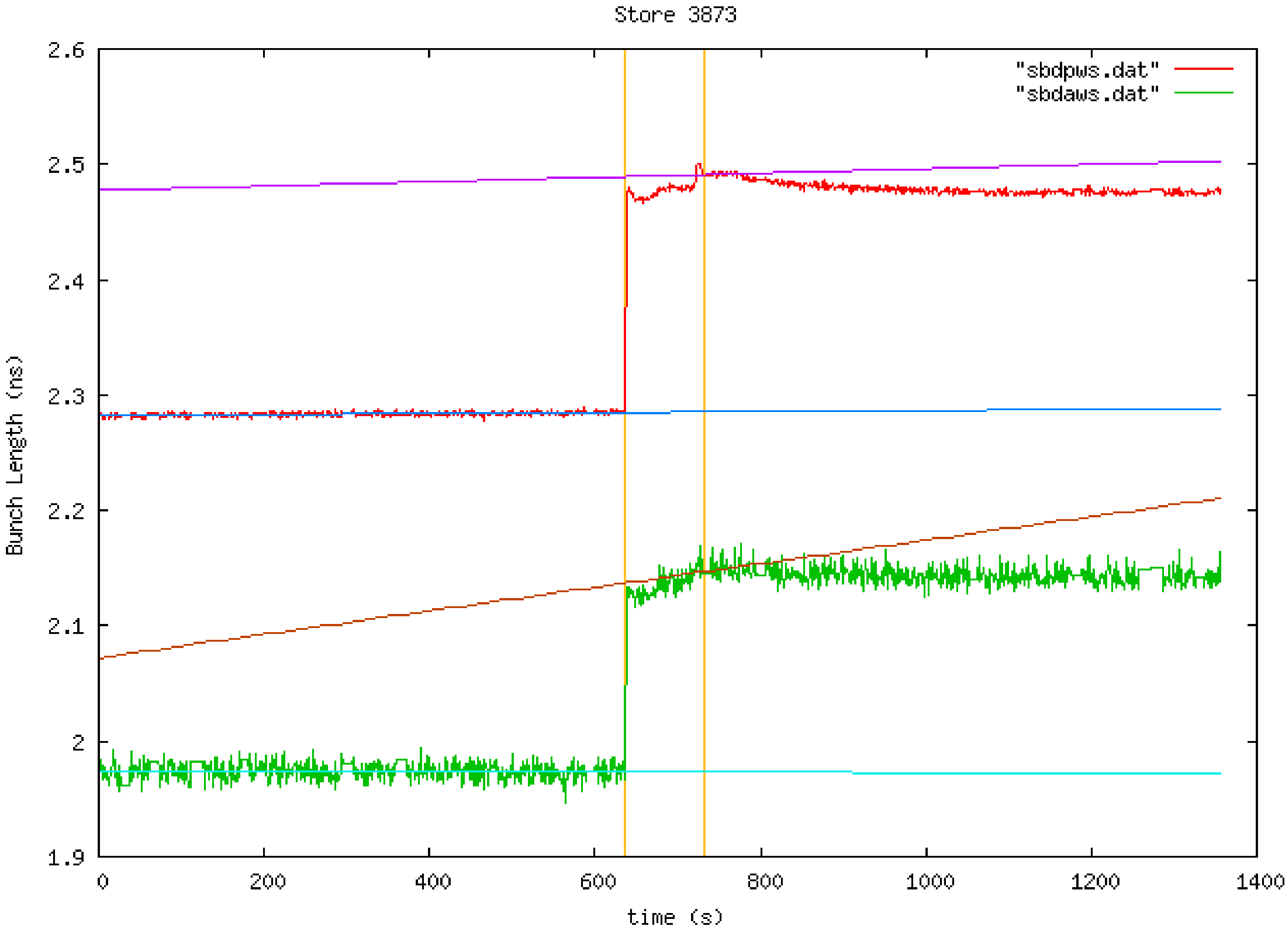
$$\frac{\Delta\sigma_z}{\sigma_z} = \frac{\left(1-\sqrt{1+\Delta V/V_f}\right)^2}{4\sqrt{1+\Delta V/V_f}}$$

$$\begin{aligned}
V_i &= \text{initial voltage} \\
V_f &= \text{final voltage} \\
\Delta V &= V_f - V_i \\
\Delta\sigma_z &= \text{change in bunch length} \\
\sigma_z &= \text{inital bunch length}
\end{aligned}$$

Expected blowup (cont'd)

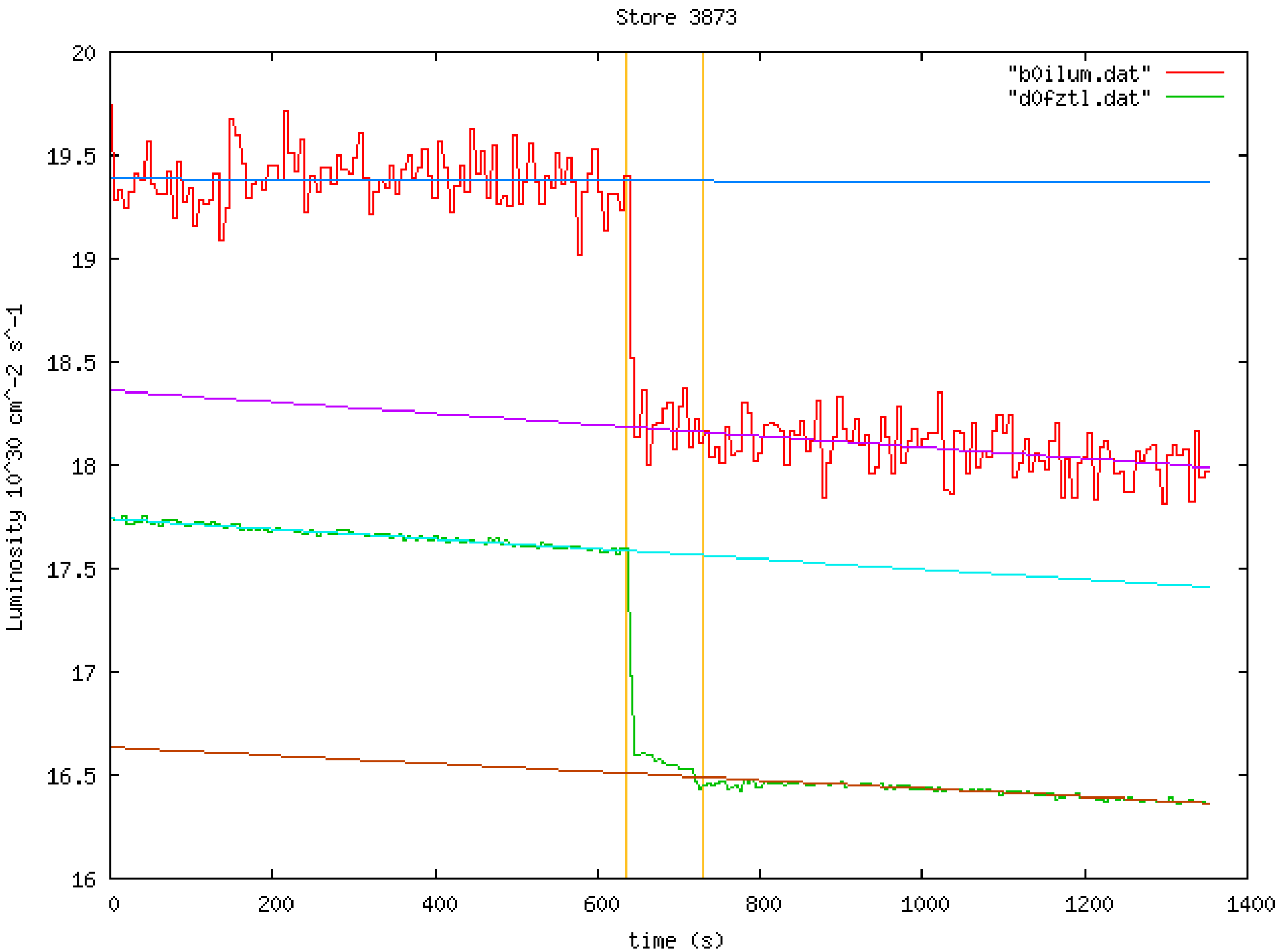
Does not agree with theory, observed blowup is much larger. Example for 3876 we get 1% blowup from theory but 7% from observation.

Store 3873



Store 3873
"sbdpws.dat"
"sbdaws.dat"
Bunch Length (ns)
time (s)
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
0
200
400
600
800
1000
1200
1400

Store 3873


Store 3873
"b0ilum.dat"
"d0fztl.dat"
Luminosity 10^30 cm^-2 s^-1
time (s)
20
19.5
19
18.5
18
17.5
17
16.5
16
0
200
400
600
800
1000
1200
1400

Ratio After B1Q3 Unroll