Beam-based vacuum observations and their consequences

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August 18, 2003

Design goals

Stochastic cooling only

- Emittance growth rate (n, 95%): 2 μm/hr
- Lifetime of 10-μm emittance pbar beam with cooling: ≥ 200 hrs

Stochastic+electron cooling

- Emittance growth rate (n, 95%): 4 μm/hr
- Lifetime of 10-μm emittance pbar beam with cooling: ≥ 200 hrs

- The lifetime cannot be greater than:

$$\tau \le 6\Lambda \frac{A_x A_y}{\dot{\varepsilon}_{n,95\%}(A_x + A_y)} \approx 30 \times \frac{A}{\dot{\varepsilon}_{n,95\%}}$$

Design goals

Stochasti
- Emitta
- Lifetim 200 hrs

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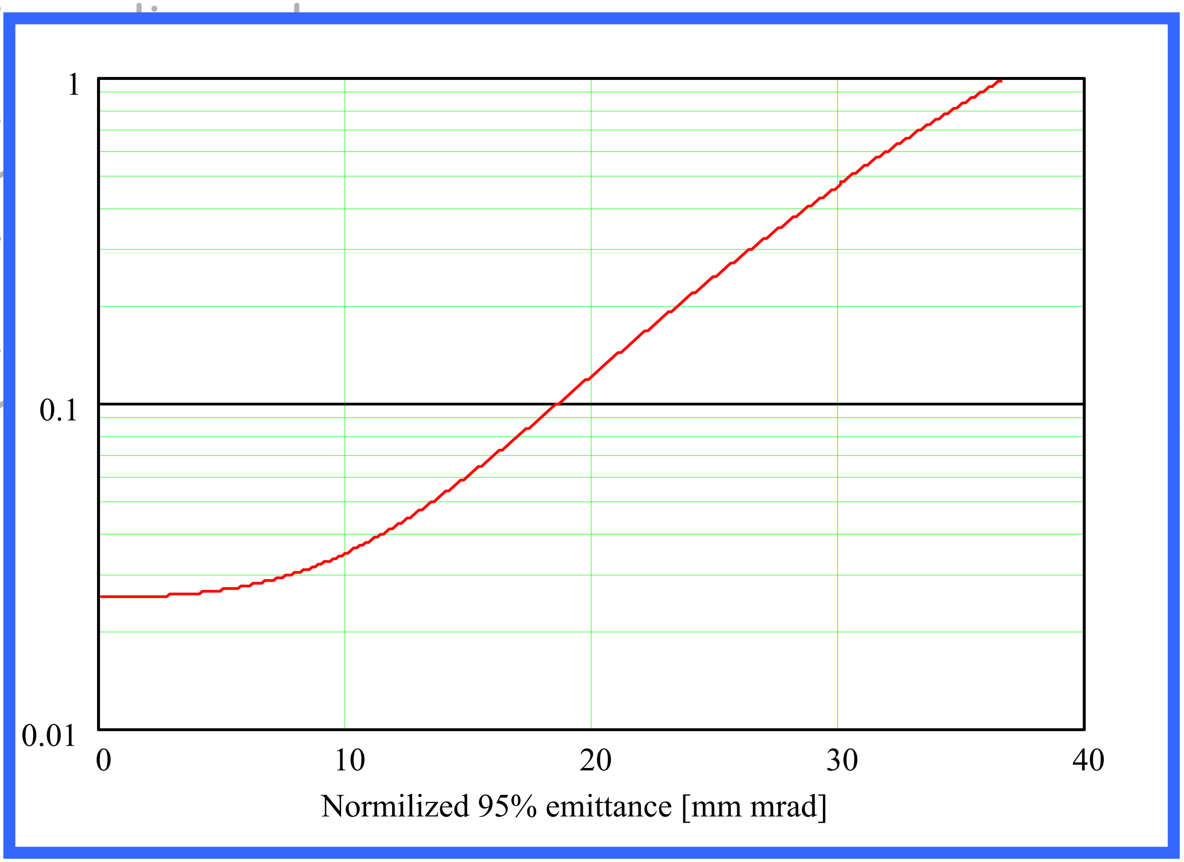

- Relative Coulomb scattering loss rate for the Recycler beam, assuming a 40-μm acceptance in both planes.
- The design emittance is 10 μm (n, 95%)

Today's menu

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- Assuming that all scattering is elastic, I will derive the partials pressures. These are an order of magnitude higher than what we obtain from our vacuum model.
- I will critique my own model and consider uncertainties.
- Finally, I will demonstrate that the goal of 4 μm/hr could be achieved with a successful bakeout.

  The goal of 2 μm/hr is likely to be unattainable with the present vacuum system.

Observations (coasting beam) Aug 2, 2003

- One hour of observations with 9E10 protons (no MI ramps)
- Initial emittance: 10 µm (95%, Schottky)
- 7 µm (100%, scraper)
- Final emttance: 20 µm (95%, Schottky)
- 17 µm (95%, scraper)
- Growth rate: 10 ± 1 µm/hr
- Zero-current, pencil beam lifetime: 90 hours
- Acceptances: $A_x = 60$ µm, $A_x = 40$ µm
- The emittance growth rate and the lifetime are selfconsistent!

Emittance growth rate

- Our measurements demonstrate that:
  - The transverse emittance growth is linear with time
  - The rate is insensitive to beam intensity and bunching structure
  - The rate does not depend on beam emittance
  - The rate does not depend on tunes (within limits)

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  - The rate does not depend on tunes (within limits)
- This all points to Coulomb scattering
- I will be using the following growth rate expression for my analysis:

$$\dot{\varepsilon}_{n,95\%} = 12\pi \frac{c r_p^2}{\beta\gamma} \beta_{ave} \sum_i n_i Z_i^2 \left(\Lambda_n(Z_i) + \frac{\Lambda_e(Z_i)}{Z_i} \right)$$

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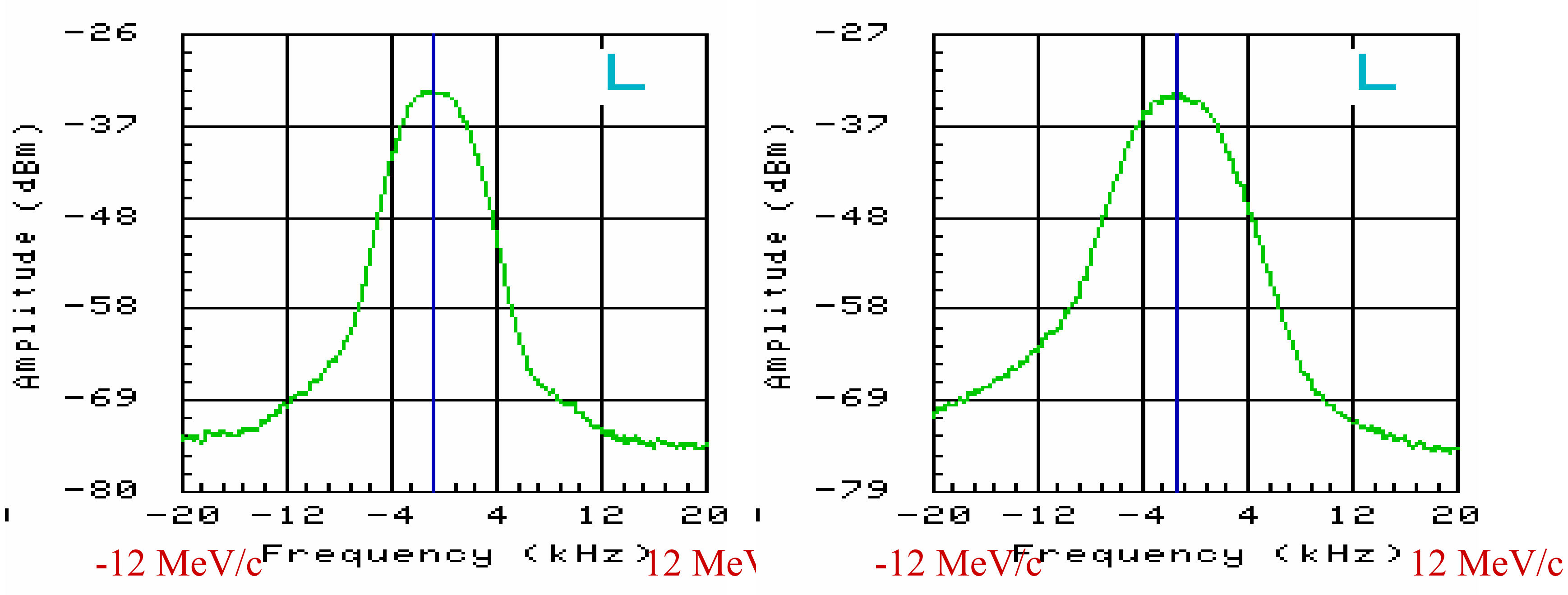
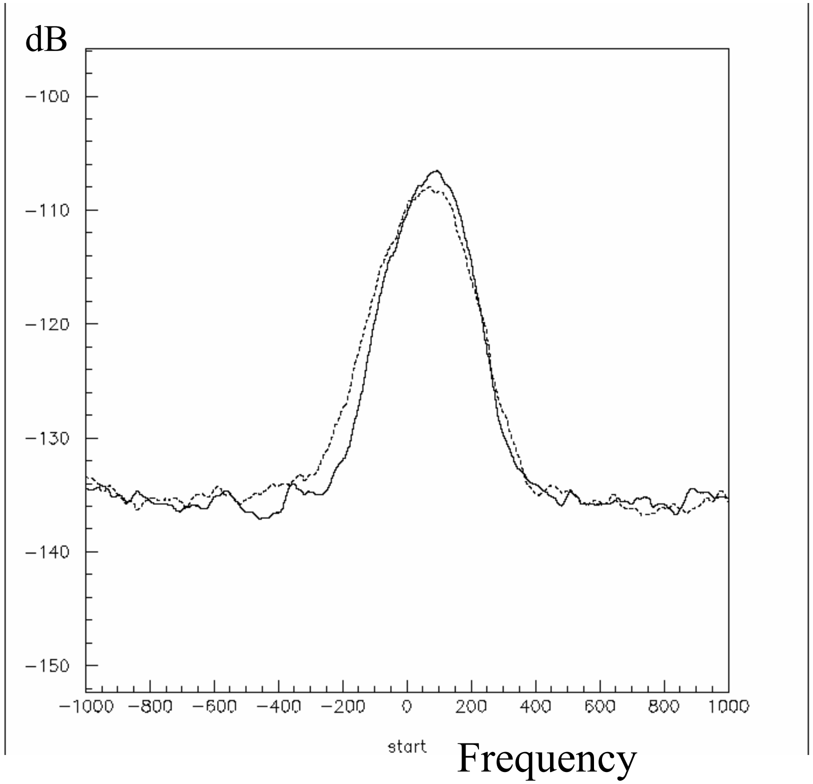


- 1 hour, 9E10 p's, long. Schottky at 1.75 GHz (no MI ramps)
- The average revolution frequency has decreased by 32 mHz
  - This corresponds to a 0.37-MeV energy shift
- The rms momentum spread has increased (1.0 to 1.3 MeV/c)
- The low energy tail has developed

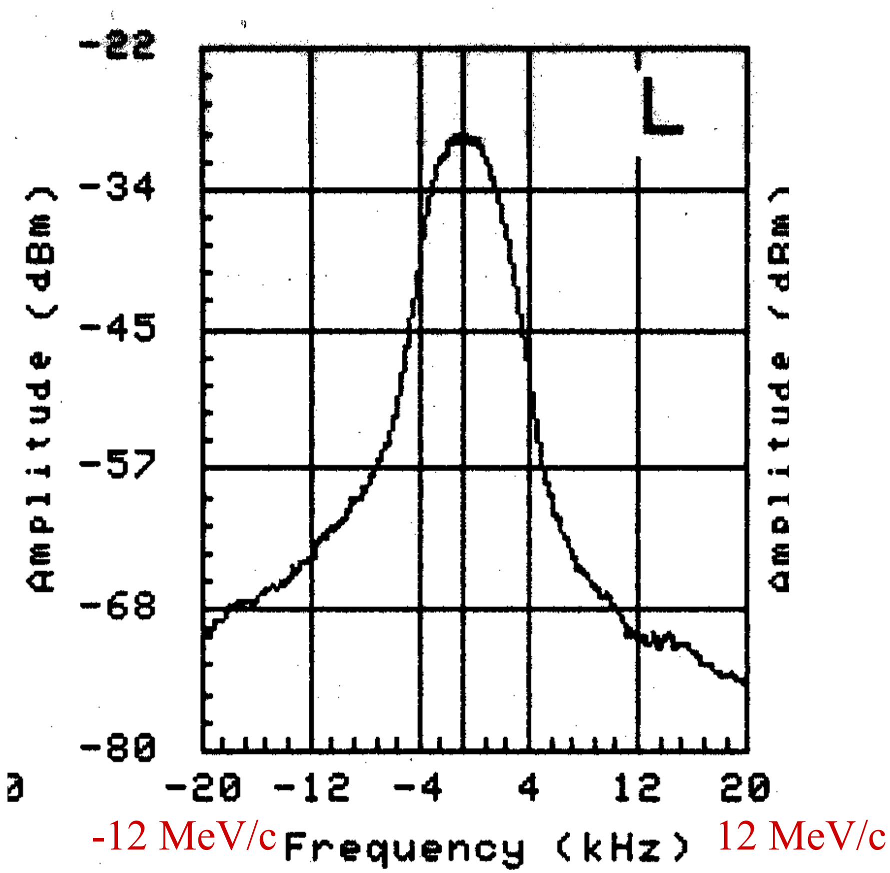
Observations (coasting beam) Aug 13, 2003



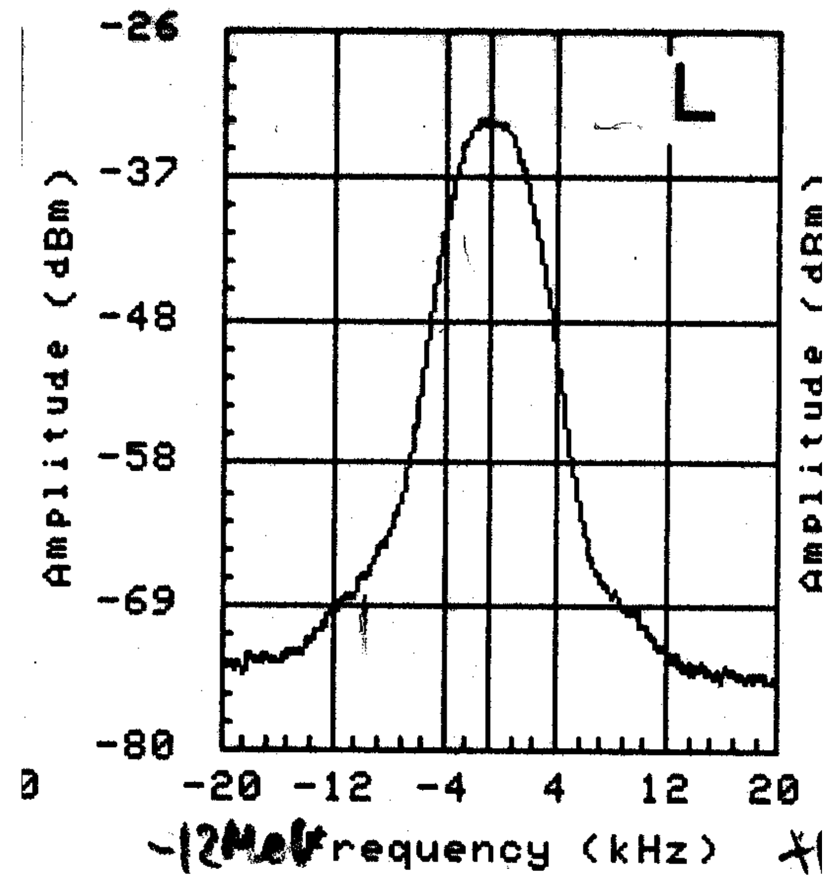
- 30 min, 1E10 p's, long. Schottky at 79 GHz (no MI ramps)
- Energy loss: 0.42 MeV/hr
- The rms momentum spread has increased.
- The low energy tail has developed.

The low-energy tail

- We've proved that the low-energy tail comes from ionization losses.



1.9E11 protons before scrape



0.9E11 protons after scrape

The low-energy tail

- The scrape was done with a horizontal scraper at a location with a horizontal beta-function of 52 m, zero dispersion (~20 cm) and with equal tunes.
- The scraper was stopped 6.2 mm away from the beam center, which corresponds to a 7-μm acceptance, and then withdrawn.
- How can one scrape the low energy tail at zero-dispersion location?

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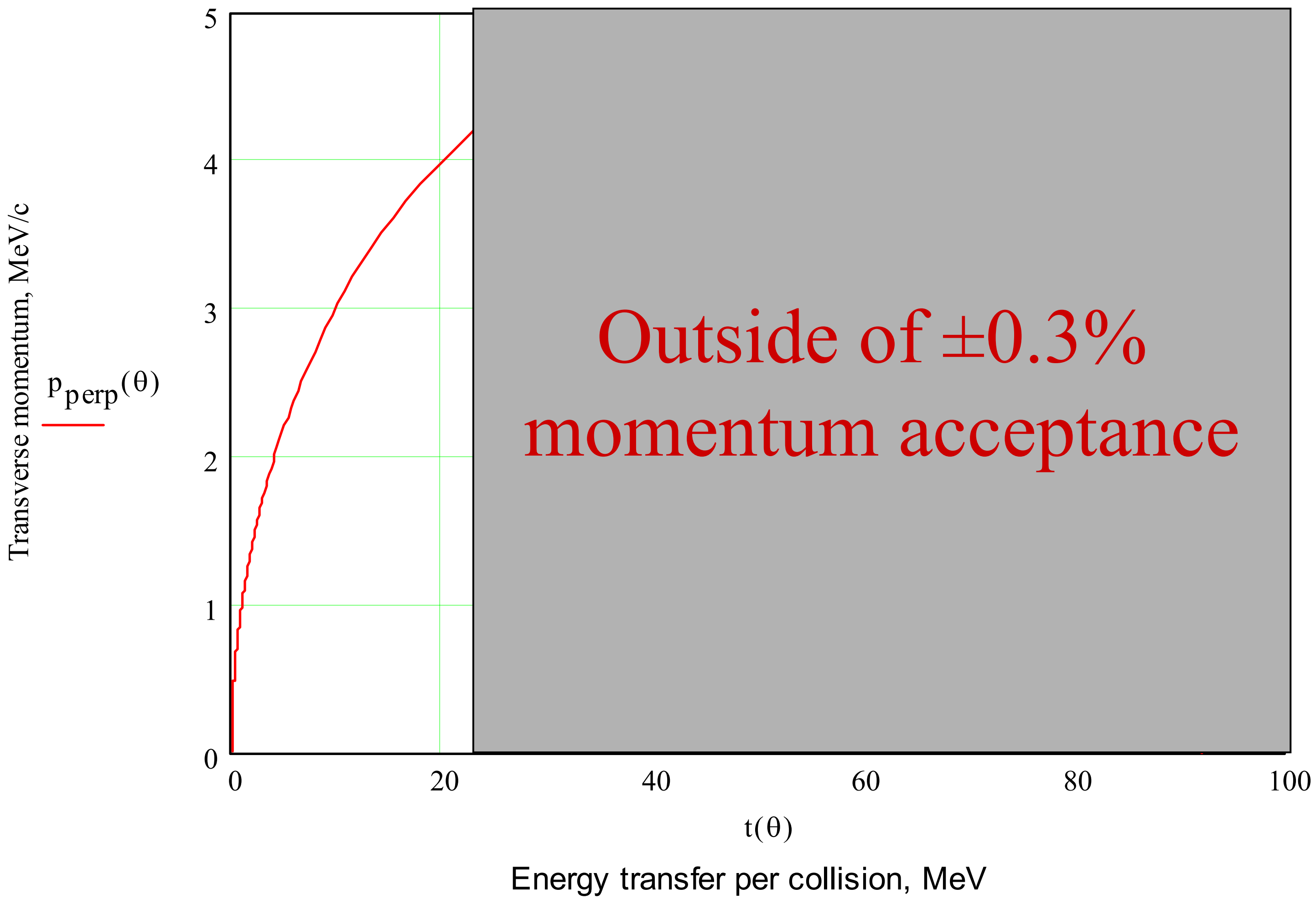
- How can one scrape the low energy tail at zero-dispersion location?
- The answer is: proton-electron collisions.

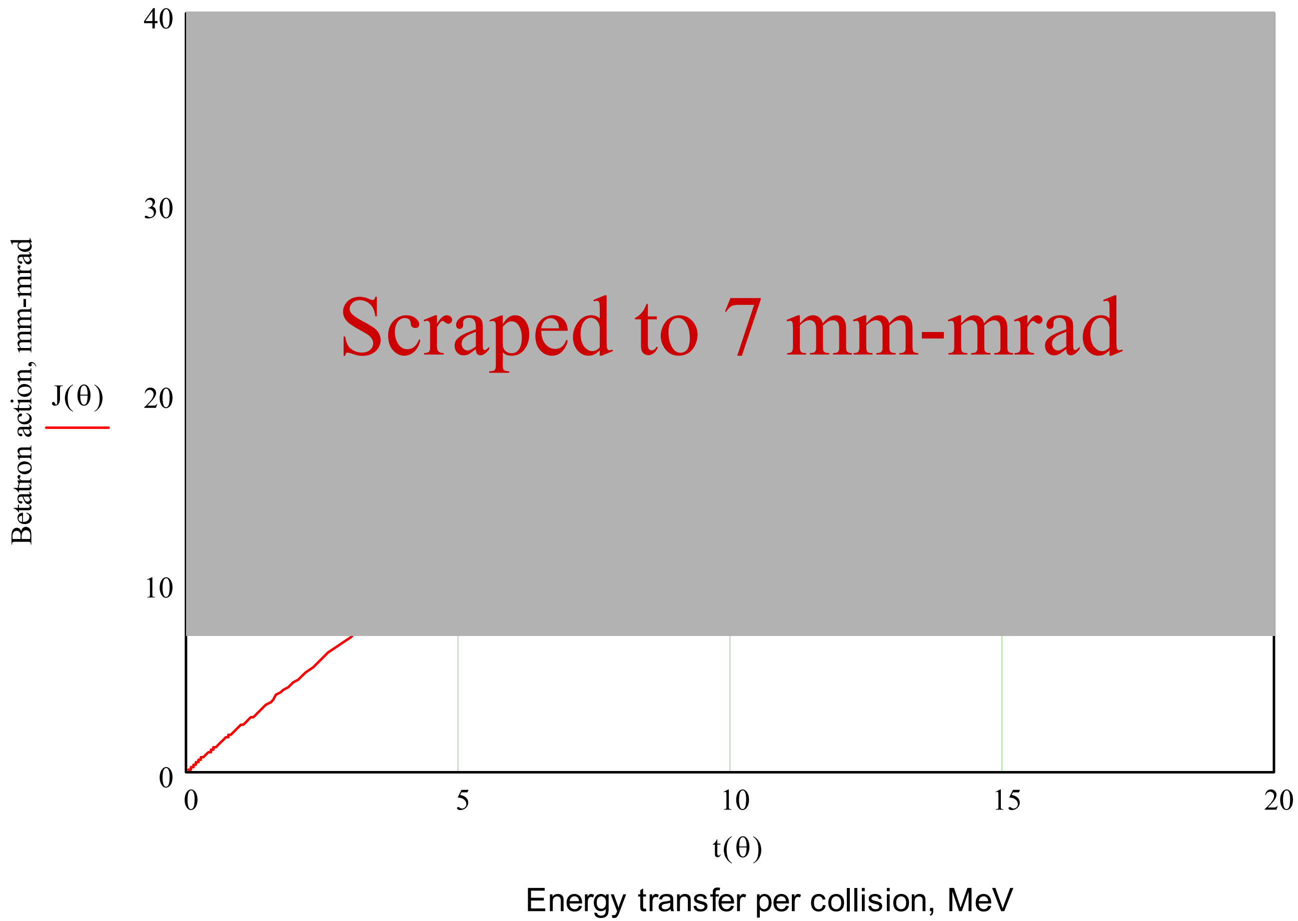
Proton collision with a stationary electron

- Max. energy transfer T_{max}= 91 MeV

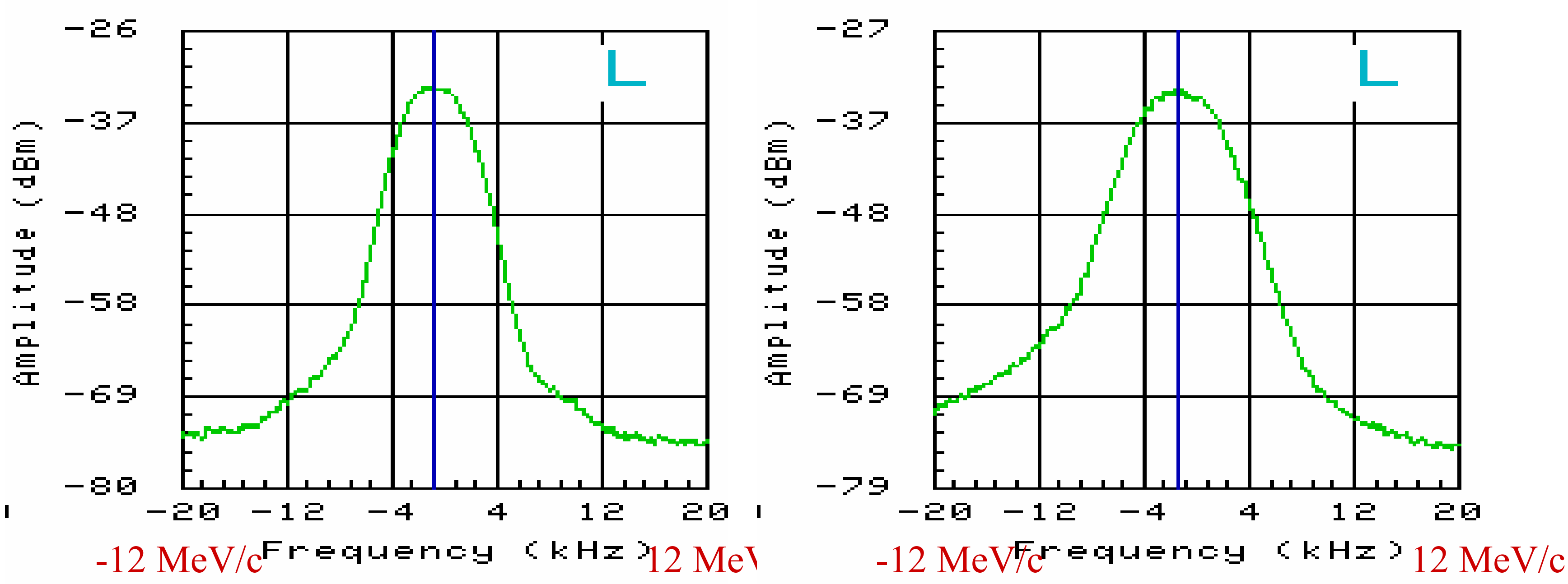


Proton collision with a stationary electron

$$J_n = \frac{1}{2}\frac{p_\perp^2}{\beta\gamma M_p^2 c^2}\beta_{ave}$$



Observations (coasting beam) Aug 2, 2003



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The rms momentum spread increase

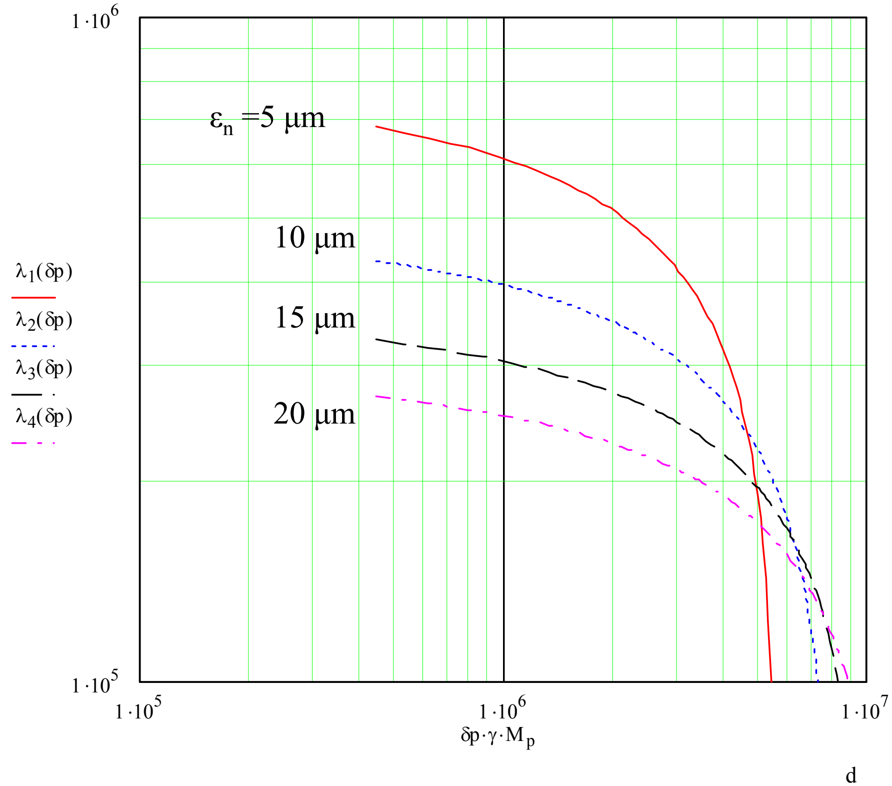
- IBS

$$\frac{d}{dt}\left(\delta_{\|}{}^{2}\right) \equiv \frac{d}{dt}\left(\frac{\overline{p_{\|}{}^{2}}}{p^{2}}\right) = \frac{\sqrt{\pi}}{2}\frac{r_p^2 cNL_C}{\gamma^3\beta^3 C\sigma^2\theta}\sqrt{1-\frac{\delta_{\|}}{\sqrt{2}\theta}}$$

- *Lc* - is the Coulomb logarithm,
- *C* – is the ring circumference,
- *σ* – is the rms beam size and
- *θ* – is the rms angular spread.

IBS (coasting beam)

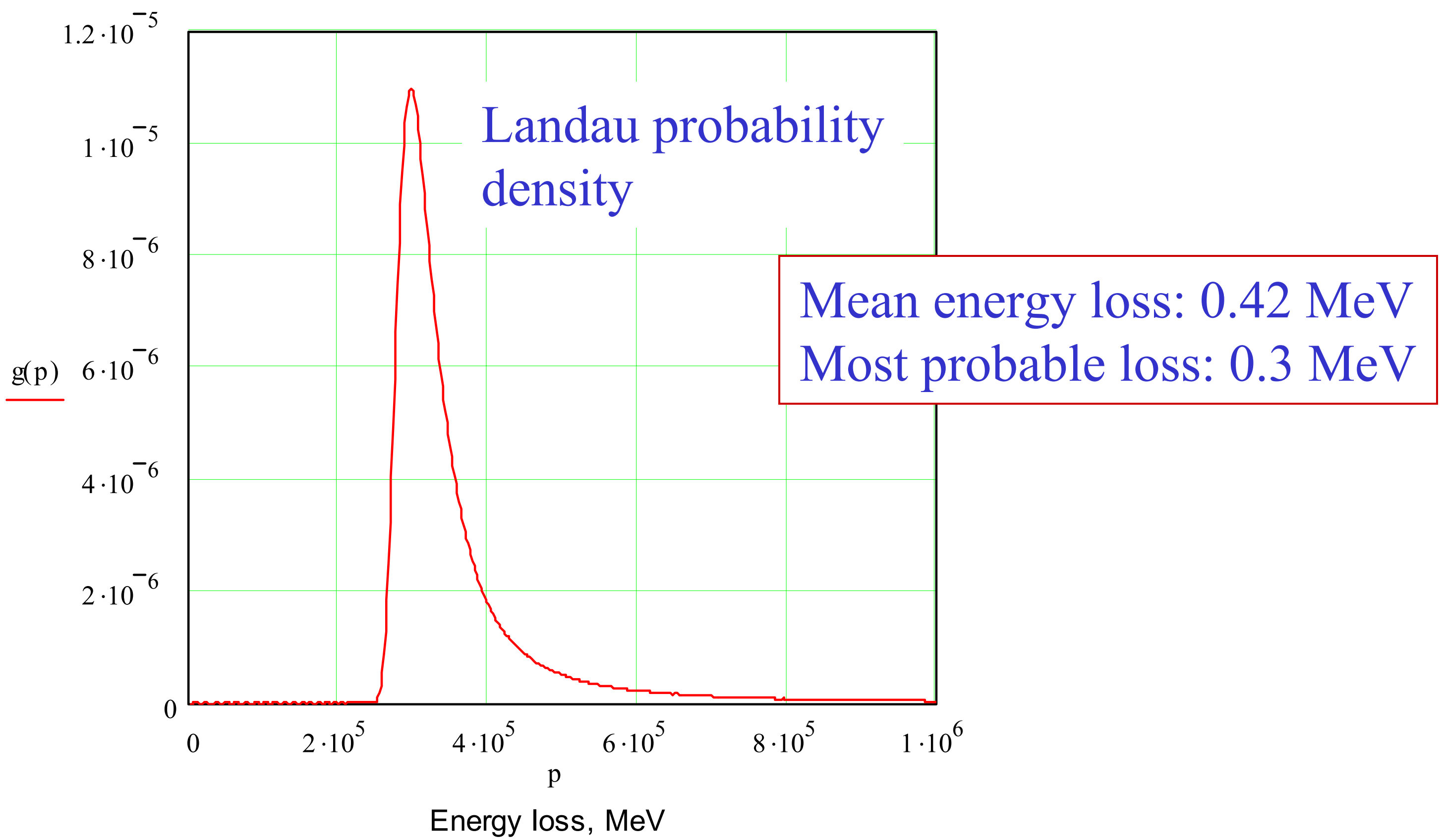
- The rms momentum growth rate (MeV/c per hour) as a function of the rms momentum spread (MeV/c) for various transverse (n,95%) emittances.
- N = 9×10^{10} protons
- Measured:
  - Initial 1.0 MeV/c
  - Final 1.3 MeV/c
- Need to add rms spreads in quadrature!
- The ibs can explain a portion (0.1-0.2 MeV/c) of the measured momentum spread.



The rms momentum spread increase

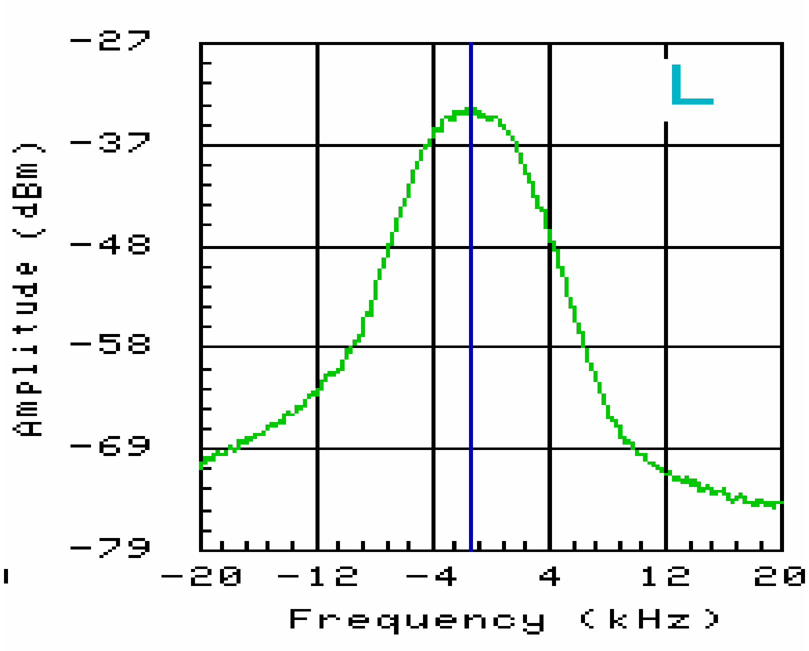
- IBS

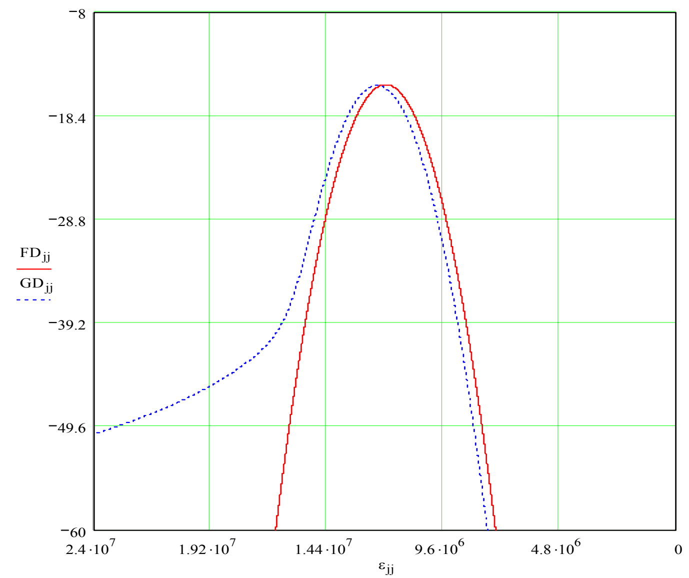
- Energy-loss straggling



Momentum distribution

- A Gaussian(σ=1 MeV/c) distr. is folded with the Landau probability density.





- The result is that by fitting the energy loss alone, I am able to reproduce both the low-energy tail and the rms spread increase
- Energy loss due to resistive impedance is negligible

Summary of beam-based measurements

Emittance growth rate:

$$\dot{\varepsilon}_{n,95\%} = 12\pi \frac{c r_p^2}{\beta\gamma} \beta_{ave} \sum_i n_i Z_i^2 \left(\Lambda_n(Z_i) + \frac{\Lambda_e(Z_i)}{Z_i} \right) = 10 \pm 1 \;\; \mu\text{m/hr}$$

Beam average energy loss: 0.40±0.04 MeV/hr

This corresponds to a mean energy loss of 0.42±0.04 MeV/hr

$$\Delta[\text{MeV}] = \frac{0.307}{\beta^2} \sum_i \frac{Z_i}{A_i} x_i [\text{g/cm}^2] \left(\ln\left(\frac{T_{\max}}{I_i} \right) - \beta^2 \right) = 0.42 \pm 0.04\,\text{MeV}$$

Partial pressures model

- Assume that the residual gas consists only of Z=1 and Z=8 atoms (H_2 and H_2O)
- Solving equations for 10±1 μm/hr and 0.42±0.04 MeV results in:
  - $p_H = 3.3 \pm 1.7 \times 10^{-9}$ Torr
  - $p_W = 1.0 \pm 0.2 \times 10^{-9}$ Torr

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- If I assume that one of the gases is hydrogen with a know concentration n_H, and then try looking for another gas with a new Z ($A = 2Z$), $n_Z \le n_H$, I am unable to find any solution unless $p_H > 1.5\times10^{-9}$ Torr and $Z \sim 5$.

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- "Water" alone contributes 8.3 μm/hr to the emittance growth
- Before Jan 2003 shutdown the measured emittance growth rate was 5 μm/hr. There were no beam energy loss measurements.
- Present measurements are consistent with the water content doubled after the shutdown.

What could have increased the water content?

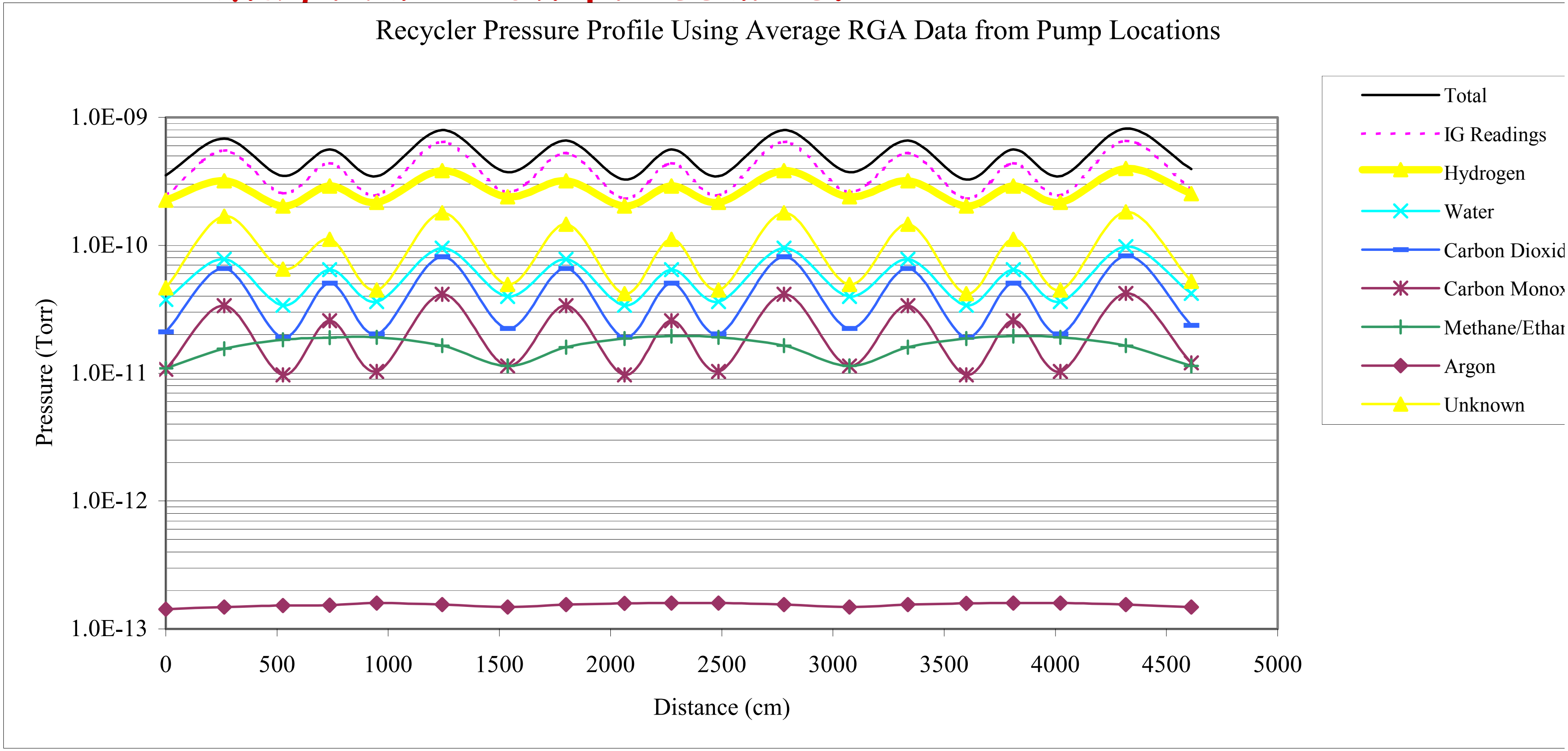
- Work done during Jan 2003 shutdown:
- Installed new ion pumps, capable of pumping Ar at a higher rate. Installed some diagnostics (RGAs, ion gauges).
- Out of 27 vacuum sectors, 20 were vented with "dry" nitrogen and then only 5 sectors baked to 120C. Of these five, three have been vented since then without a bake.
- Many new ion pumps were not baked in situ.

- Unrelated to the Jan 2003 shutdown:
  - BPMs and bellows (total equiv. length of about 500m) were never baked at all.

So, what's the problem with this model??

- There are two problems with my pressure model.

1. Terry's vacuum model predicts an order of magnitude low pressures.



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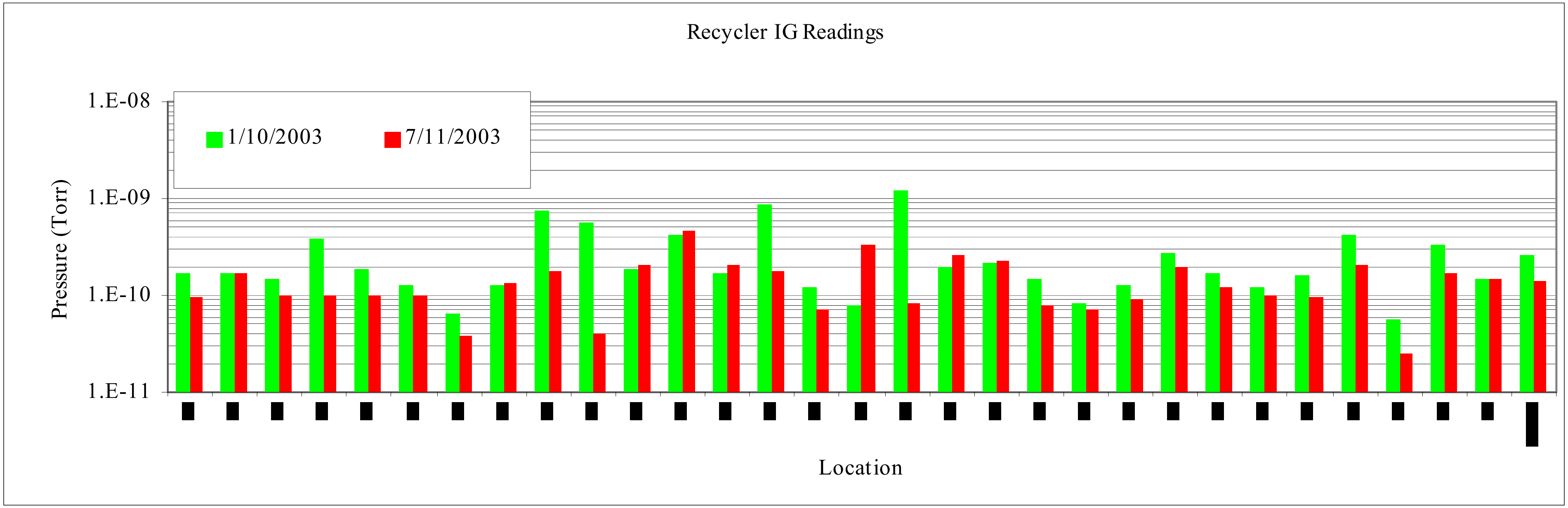
   None of the ion gauges show pressures above 5x10^{-10} Torr



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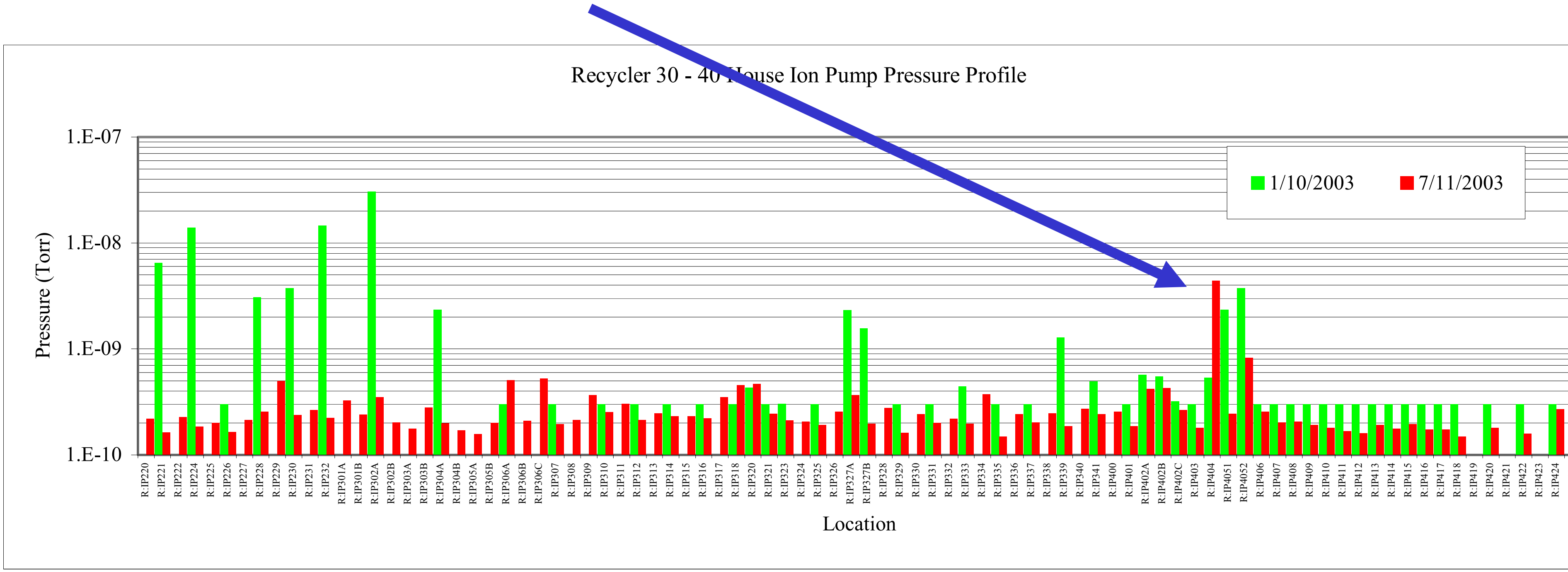
There is only one ion pump that show pressures above 1x10^{-9} Torr.



So, what's the problem with this model??

2. We know that the total gas capacity of our TSPs is 0.2-0.4 Torr-L. Assuming we understand the TSP's pumping speed at the beam pipe, pressures of 3×10^{-9} Torr would saturate the TSPs in 10-20 days, yet the TSPs last on the average 100 days.

Conclusions

- The evidence for the residual gas scattering from beam-based measurements is overwhelming.
- I can not reconcile the beam-based measurements with the instrument measurements.
- All beam-based measurements point to the fact that amount of heavy molecules (most likely water) in the system has doubled after the Jan 2003 shutdown.
- The model can not answer how much CH_4, CO or CO_2 is in the system. If I assume that all heavy molecules are water, eliminating them completely reduces the emittance growth rate to 2 μm/hr. It is likely that we will never reach this value with a present system. I estimate that reaching a 4-μm/hr rate is possible with a successful bakeout.