Recycler Ring Vacuum: Life Time and Emittance Growth

A Talk of Something about Nothing!

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Outline:

Introduction:

- RR Vacuum Goals
- Relevant Physical Processes
- RR Parameters
- RR Vacuum System

Before January 2003 Shutdown:

- Average Gas Composition
- Pressure Profile Simulations
- Lifetime and Emittance Estimations
- Lifetime and Emittance Results

During January 2003 Shutdown:

- Vacuum Upgrade
- Instrumentation Upgrade

After January 2003 Shutdown:

- Vacuum Composition
- Lifetime/Emittance Growth Measurements
- Present Status

Summary and Outlook

Introduction: RR Vacuum

RR Vacuum Design Goals (2×10^{12}):

- **Antiproton life time of $>$ 100 hours**
- **A Vacuum related emittance growth rate of $<$ 2 π-mm-mr/hour**
- **A total emittance growth rate of $<$ 3 π-mm-mr/hour**
- **Approach: Aim for an antiproton lifetime of 300 hours with full stochastic cooling and equilibrium emittance of 10 π-mm-mr ($\epsilon_{N95\%}$) for 2×10^{12} pbars.**

Relevant Physical Processes:

Beam lifetime is governed by four kinds of physical processes: (a) Abrupt loss of beam particles (b) Slow processes that cause beam emittance growth and potential loss of particles due to finite aperture and (c) Non-linear particle motion - slow or fast (d) Coherent instabilities

- **Abrupt processes:**
  - **Single Coloumb scattering**
  - **Nuclear scattering**
  - **Inelastic collisions (EM) - ionization, bremstrahlung**

- **Diffusive processes:**
  - **Multiple coloumb scattering**
  - **Intrabeam scattering**
  - **Repeated MI ramps**
  - **Magnet Power source noise**
  - **RF/Kicker noise**
  - **Mechanical vibrations**
  - **Ground movement/Earthquakes**

- **Resonances and Instabilities:**
  - **Nth order tune resonances**
  - *Head-tail instability (observed)*
  - *Coherent trapped ion-beam instabilities*
  - *Other instabilities***(not yet observed)**

Recycler Ring: Parameters

- **Simulation input:**

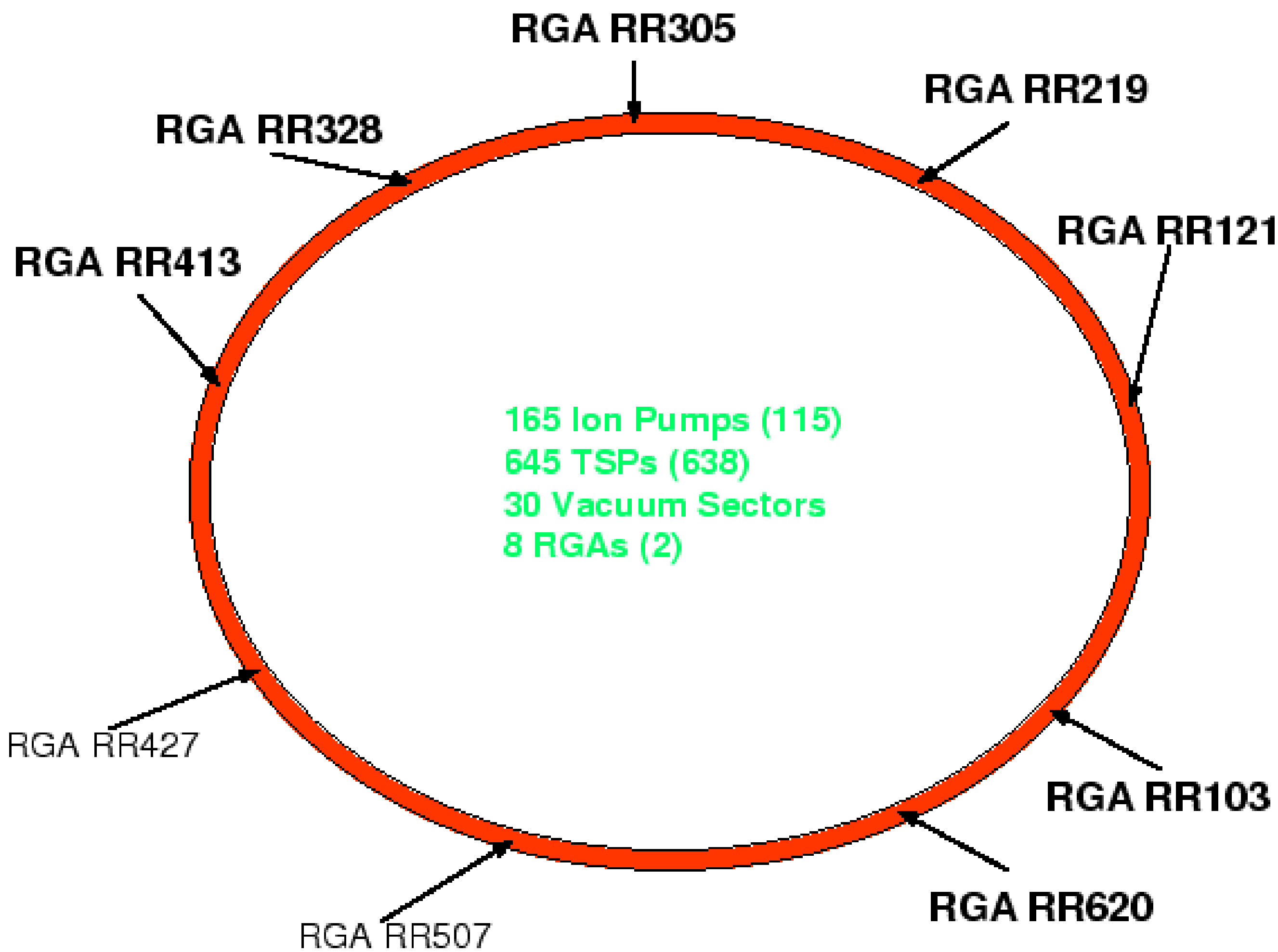
Parameter	**Value**
RR Acceptance (mm-mr)	40.0π
Average β (m)	40.0
Average beam pipe radius (in m)	0.023
Beam energy (GeV)	8.89
Average beam particle β	0.998
Average beam particle γ	9.48
Momentum aperture (GeV)	0.089
Nominal Horizontal tune	25.414
Nominal Vertical tune	24.418

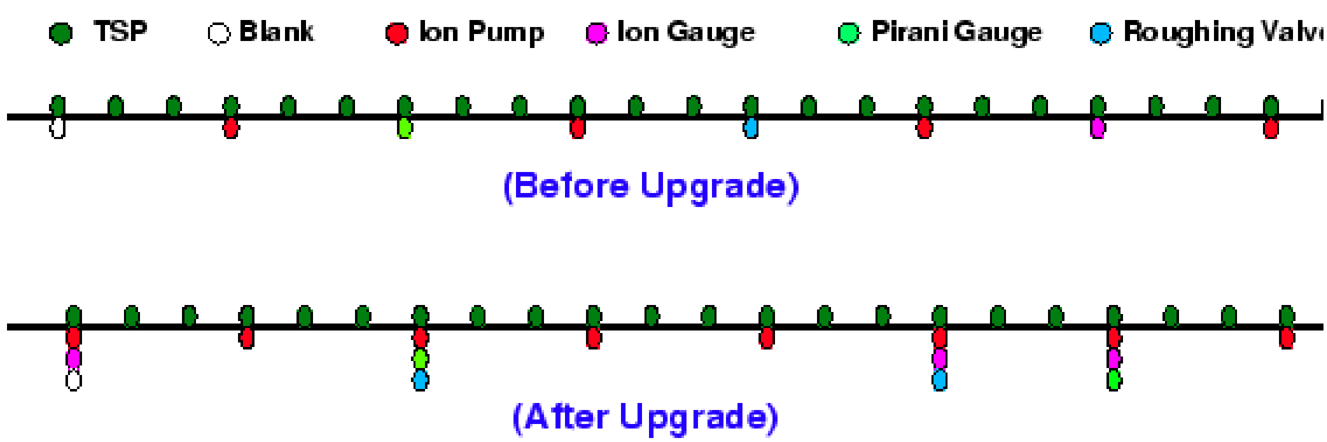
- **Initial beam distribution (Gaussian):**

$$f(Z) = \frac{a^2}{2\sigma^2} e^{-(a^2/2\sigma^2)Z}$$

with $Z = \epsilon/\epsilon_a$ ranging from 0.0 to 1.0. Here a is the half aperture (0.023 m).

Recycler Ring Vacuum System





Vacuum Gases: Pre Jan. Shutdown

Understanding the type of gases present in an ultra vacuum like that of RR quantitatively is plagued by uncertainities because of relatively sparse instrumentation and few cross-checks on possible errors. - has improved considerably now.

- **The following was an average of RGA measurements during the last year mostly at RR30 where the the RGA head was located at the middle of two pumps and the overall vacuum was poor. This what would be the worst case scenario or pessimistic case.**
- **Terry Anderson's best value (last year) of average pressure for each gas component based on his his experience, measurement and modeling on normal or good vacuum sectors and also shown below - This could be the optimistic case!**

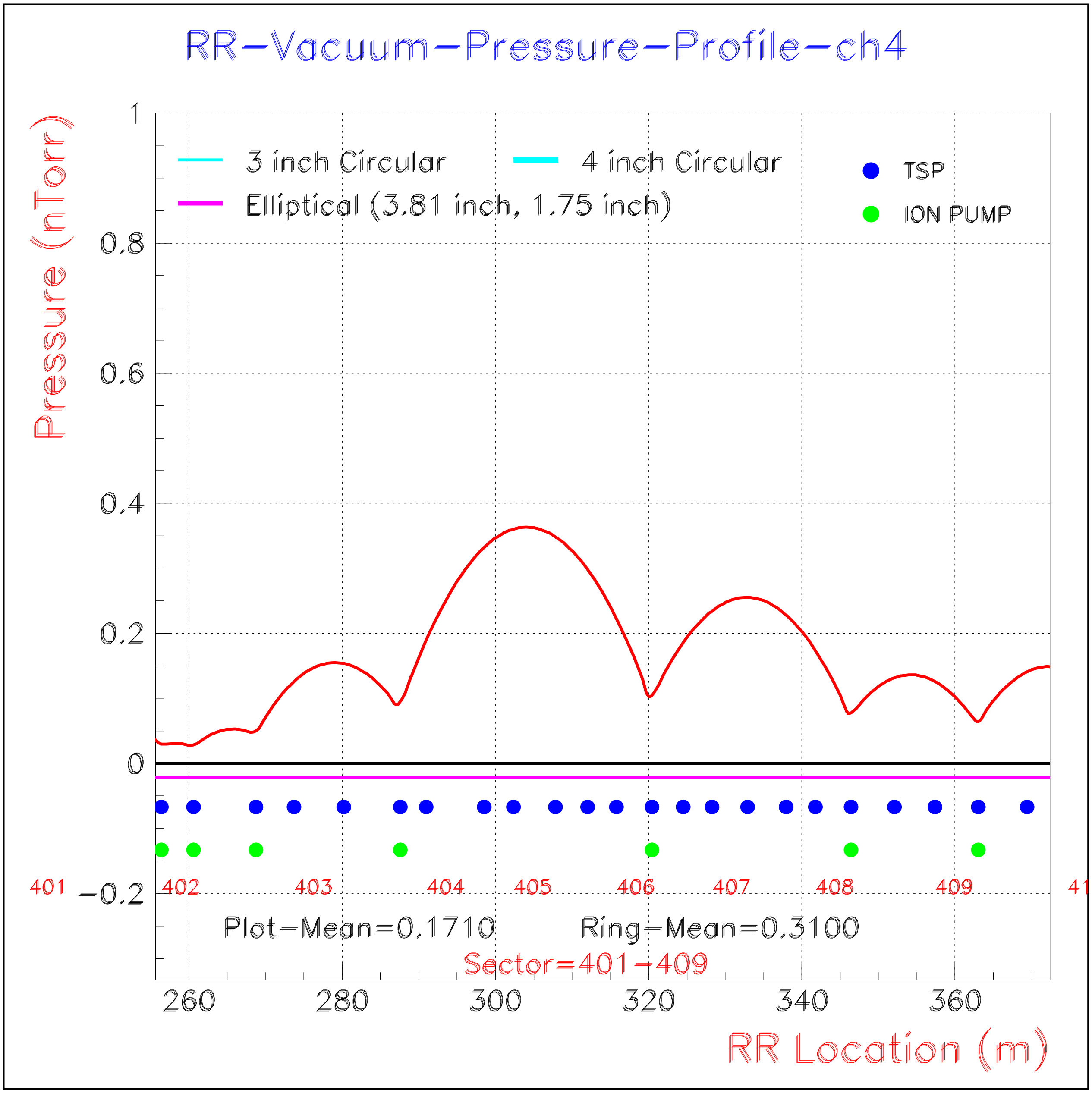
Gas	Pessimistic [Torr]	Fraction	Optimistic [Torr]	Fraction
H_2	1.0E-09	0.69	9.8E-11	0.38
H_2O	1.8E-10	0.12	5.2E-11	0.20
CO/N_2	0.7E-10	0.05	8.4E-12	0.03
Ar	1.0E-10	0.07	1.0E-11	0.04
CH_4	3.4E-11	0.02	5.3E-11	0.20
CO_2	2.6E-11	0.02	1.9E-11	0.07
$Unknown$	4.5E-11	0.03	2.2E-11	0.08
Total	1.46E-09	1.00	2.6E-10	1.00

- **Besides the above gases, we had minor quantities of hydro carbons such as Ethane, Etheylene etc.. Terry has more details - amount and source of their origins**

Pressure Profile Simulations

- Knowing the complete beam pipe geometry, the vacuum pump configuration and the details of gas parameters such as outgassing rates, conductances etc., we can simulate the pressure profile of each gas around the ring. This is rather cumbersome and complex, but this has been done.
- For simulation purposes, we treat the 'unknown' component as Nitrogen
- The Ion Pumps mostly pump Argon and Methane while the TSPs pump Hydrogen, Water, Carbon Monoxide, Carbon Dioxide and Nitrogen etc.
- Simulation results before January Shutdown:

Gas	Avg. Pressure (nTorr)
Hydrogen	0.811
Water	0.240
Carbon Monoxide	0.037
Carbon Dioxide	0.091
Nitrogen	0.010
Argon	0.047
Methane	0.310
Total	1.546



RR−Vacuum−Pressure−Profile−ch4
Pressure (nTorr)
1
0.8
0.6
0.4
0.2
0
−0.2
3 inch Circular
4 inch Circular
Elliptical (3.81 inch, 1.75 inch)
TSP
ION PUMP
401
402
403
404
405
406
407
408
409
41
Plot−Mean=0.1710
Ring−Mean=0.3100
Sector=401−409
260
280
300
320
340
360
RR Location (m)

Beam Lifetime

If you take the residual gases listed above, using the RR parameters given with appropriate formalism:

Physical Process	Pessimistic [hours]	Optimistic [hours]	Simulated [hours]
Single Coloumb	1.34×10^2	5.66×10^2	1.08×10^2
Inelastic Scatt.	2.71×10^2	1.09×10^3	2.62×10^2
Mult. Coloumb	1.66×10^1	6.88×10^1	1.32×10^1
Nuclear Scatt.	6.58×10^2	2.28×10^3	5.80×10^2
Total Life Time	1.37×10^1	5.66×10^1	1.10×10^1

Comparing the relative magnitude of these processes, the single coloumb scattering lifetime is important for various reasons:

- **For pbars, this is probably close to the maximum we can achieve for a given vacuum situation, provided we have adequate cooling system, and sufficiently small contributions from other mechanisms. (Nuclear, inelastic, MI ramps, lattice nonlinearities, instabilities etc.).**
- **It is also easy to measure for protons when you put a thin beam and measure the lifetime before it fills up the aperture.**

Dose of Reality - Measurements

In general measurements can be plagued by uncertainties, so we should try to choose the most reliable techniques:

Lifetime:

As mentioned before, single coloumb scattering lifetime is measured while the MI is not ramping for a low emittance beam at the start of the store or well cooled small amount of pbars.

Transverse Emittance:

Schottky and IPM measurements can be subject to uncontrolled systematic errors. The most reliable technique is by means of a scraper though it is a destructive measurement! New Schottkys (1.7 GHz) are much less sensitive!

Measurement Results:

Maximum lifetime observed for pbars is 200 hours for a beam of $2-3\times10^{10}$ and 120 hours for protons.

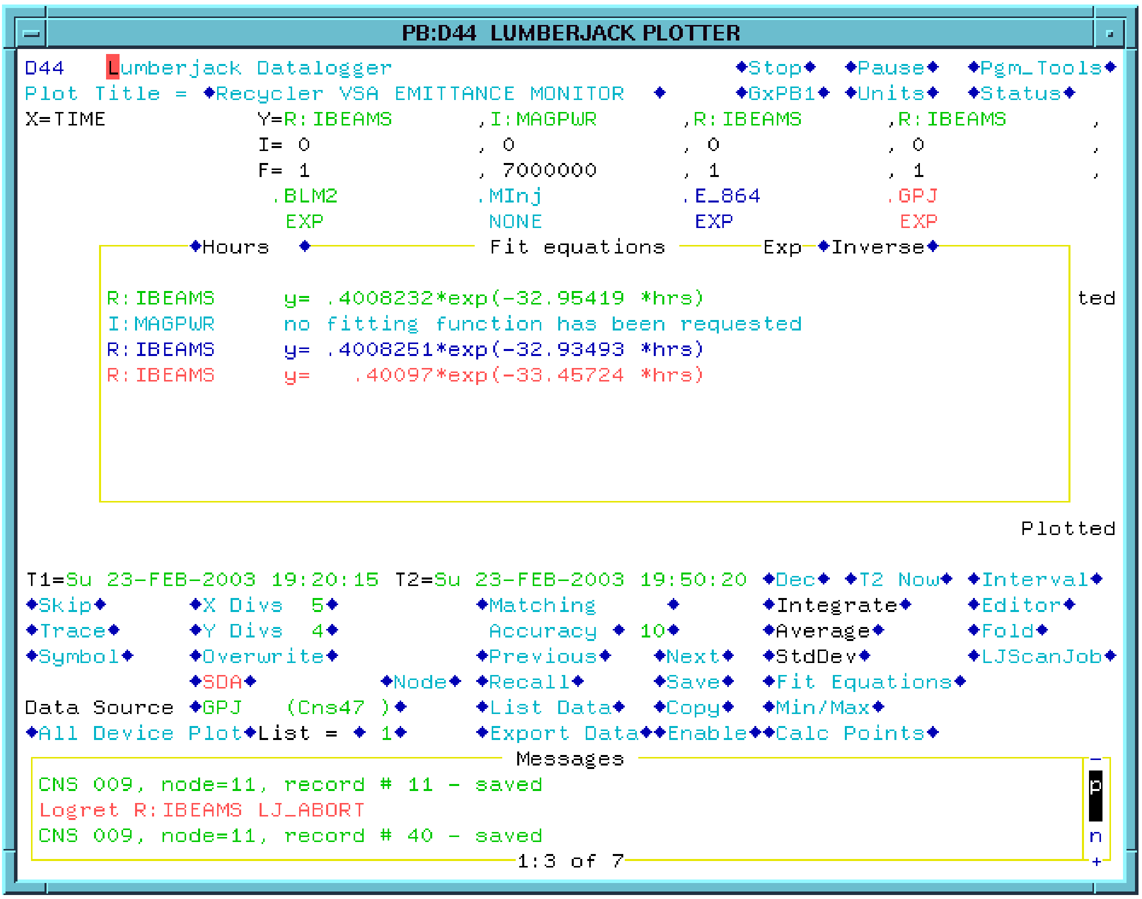
The transverse emittance growth measured using scrapers is 4-6 π-mm-mr/hr.

Summary of RR Shutdown Activities

During the January shutdown, a lot of upgrade work was done for the Recycler Ring:

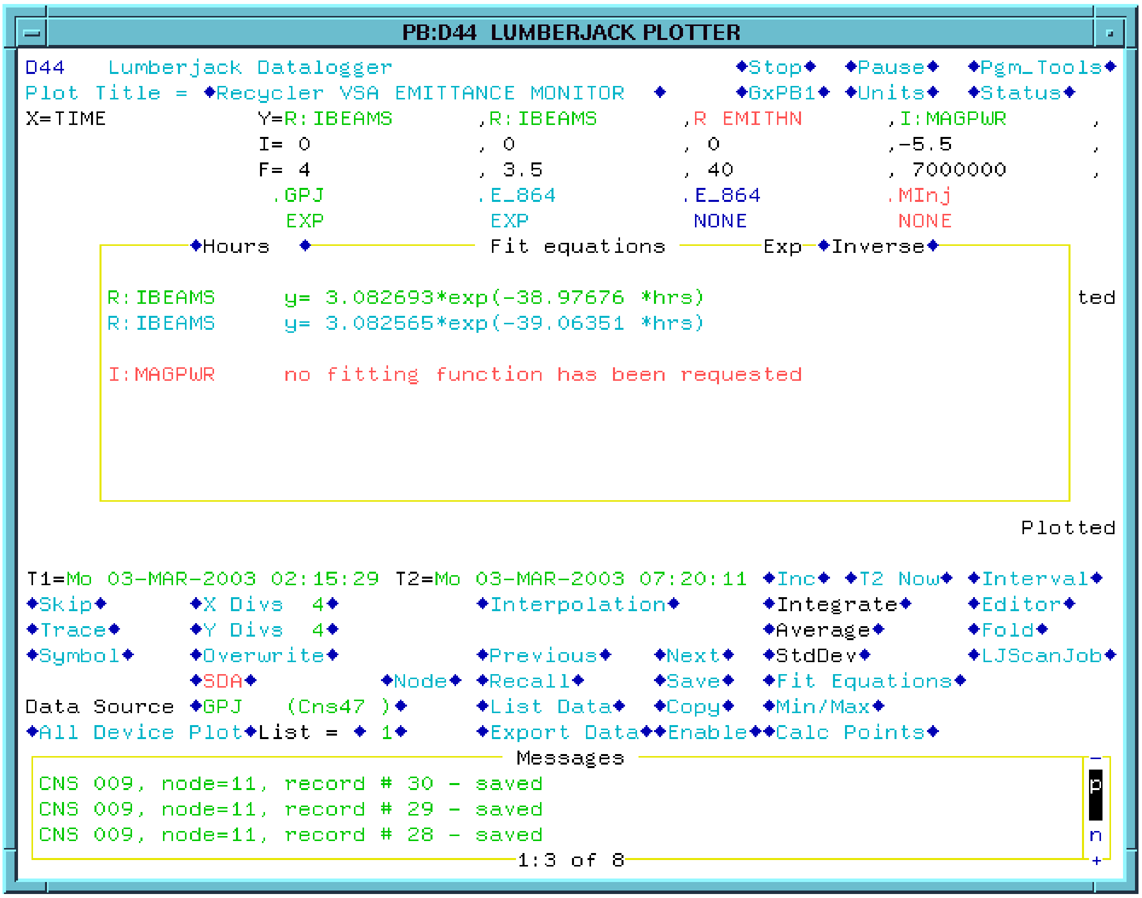
- Doubling Ion pumps around the Ring - about 65% complete. The level of Argon and Methane should be down.
- After removing the titanium windows, differential pumping was installed at the MI-RR transfer lines.
- High frequency (gated) Schottky detectors were installed - better emittance measurement tools.
- Old heater tapes were removed from several magnets - has generated lattice issues? Should be small.
- Flying wires were installed but got removed recently due to bad vacuum.
- No high temperature beam pipe baking was done - probably need to be done for getting the water level down.
- Additional RGAs were installed around the Ring and readings were taken during and after the shutdown.

Right After Shutdown - Proton Lifetime



- Thin proton beam lifetime of 33 hours - We expected over 100 hours! The tunes were close to what we had before.
- Is vacuum a suspect? Ion Gauge readings show roughly an increase of 50% compared to preshutdown values mostly dominated by the Flying wire locations!
- Other suspects: messed up lattice, energy corrections, chromaticity changes, tune spread and resonances?
- Check with pbar beam, make quiet time measurements, get as many RGA measurements as possible around the Ring!

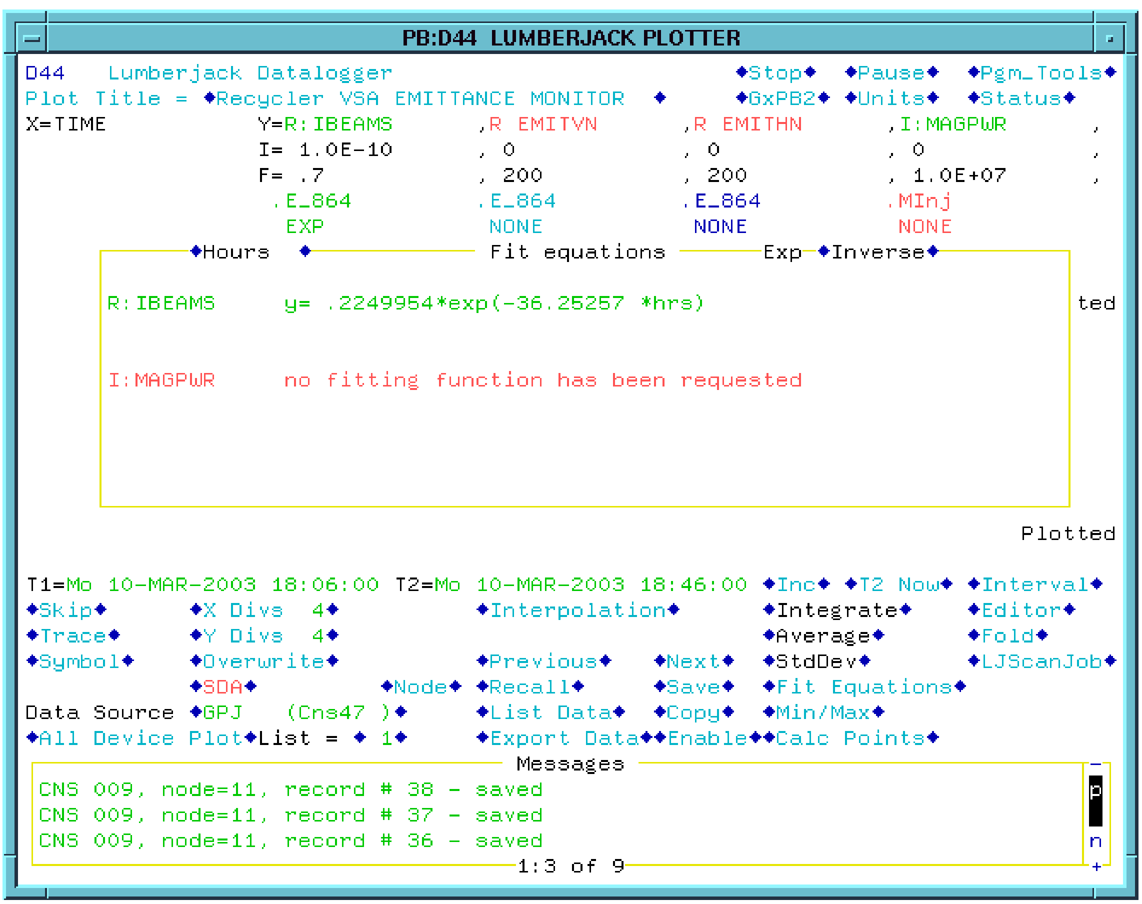
Pbar Lifetime - 03/03/03



- Thin cooled pbar lifetime of 39 hours during quiet time!
- The transverse emittance growth measured during quiet time using scraping technique - 18-20 π-mm-mr/hour!
- The admittance measurements show similar values both before and after shutdown - $\epsilon_N \approx$ 60(H)/40(V) $pi - mm - mr$!
- While the orbit is certainly different, the chromaticities show only a small change - 1/2 unit!

March 3-7/3/03 Tunnel Access

- The Flying wire cans were removed - average vacuum got better
- RGA measurements were taken at 7 of possible locations around the Ring.
- TSPs were fired at suspicious locations.
- The overall vacuum got to preshutdown levels but ...



Vacuum Gas Composition

The procedure for determining the actual partial pressures of residual gases is rather complex and involves many steps, computations and approximations. We have taken the following into consideration:

- Gas fractions from RGA measurements at selected locations around the ring. One has to untangle RGA mass peaks.
- Nearest Ion Gauge average pressue readings for the normalization at each RGA location - 2-3 RGAs on each side. RGA calibrations can be different.
- Ion Gauges are calibrated for Nitrogen. Need to apply correction for other gases.
- Depending on the location, Ion Gauge readings have to be corrected for Ion Gauge-TSP assembly - pressure difference between the beam pipe and Ion Gauge location. If an RGA is located between two TSP/IGs, a different procedure has to be followed.
- Average beam pipe gas pressure is different from those closest to Ion Gauge locations - usual parabolic pressure variation.

Vacuum Gas - Present

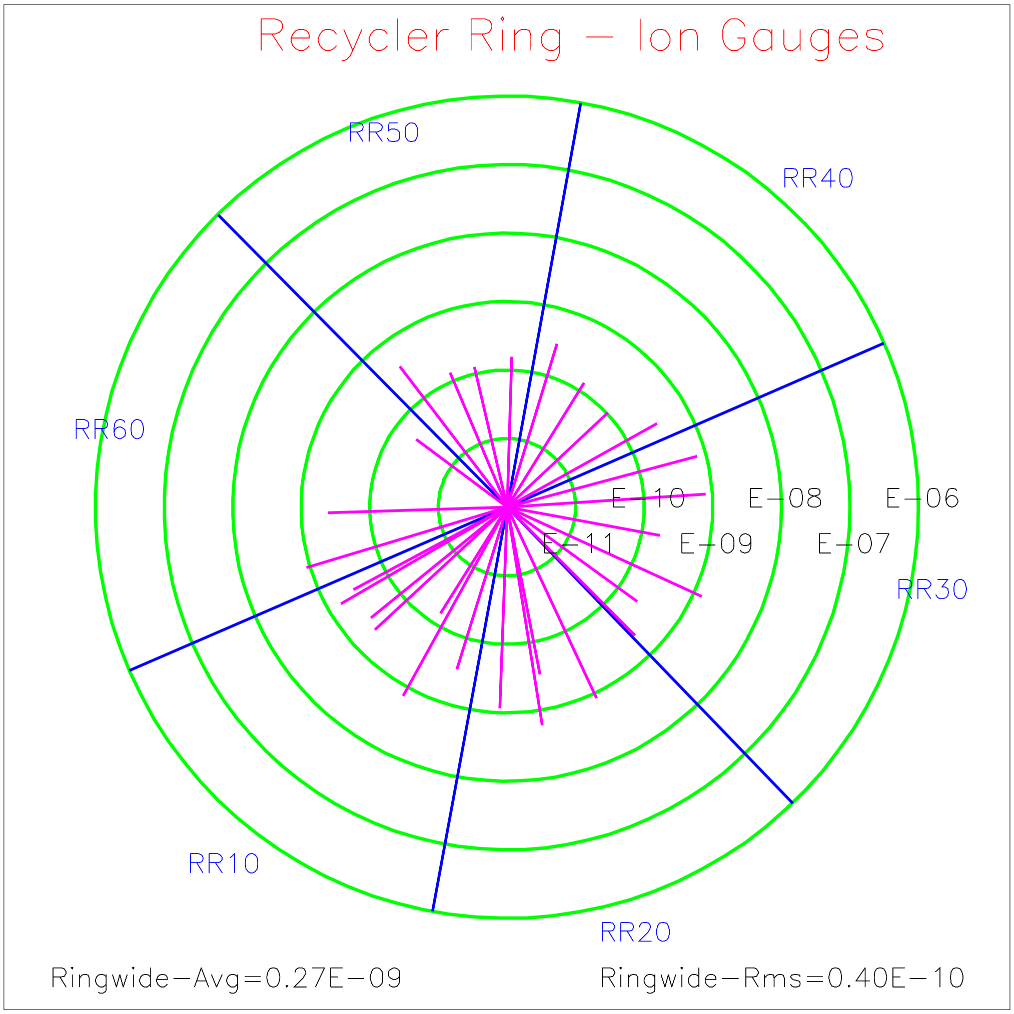
- **After a detailed analysis of RGA readings and projections:**

Gas	Avg. Pressure (nTorr)
Hydrogen	0.354
Water	0.038
Carbon Monoxide	0.019
Carbon Dioxide	0.015
Nitrogen	0.105
Argon	0.001
Methane	0.005
Total	0.537

- **With above gas composition, the thin beam lifetime should be $\approx$ 400 hours:**

Physical Process	Lifetime [hours]
Single Coloumb	4.76×10^2
Inelastic Scatt.	8.25×10^2
Mult. Coloumb	5.69×10^1
Nuclear Scatt.	1.64×10^3
Total Life Time	4.65×10^1

- **Predicted emittance growth: 4.6 π-mm-mr/hr.**
- **So the culprit does not appear to be vacuum provided the Ion gauge and RGA measurements are reliable!**


Recycler Ring – Ion Gauges
RR50
RR40
RR60
E–10
E–08
E–06
E–11
E–09
E–07
RR30
RR10
RR20
Ringwide–Avg=0.27E–09
Ringwide–Rms=0.40E–10

Summary - Action Plan:

Possibilities:

- The trim settings were messed up - G Table and H Table entries are in disarray. Some R453 cards are going on their own!
- Rapid tune shifts due to system noise leading to resonance crossings of the tune spreads
- Dynamic aperture being small - beam size/intensity vs lifetime.
- Pockets of heavy gases in locations not measurable: Existing vacuum gauges are not reliable?
- Noise sources (magnet power supply, RF, kicker etc.)?
- Other possible explanations?

Planned Measures:

- Reimplement the energy correction settings - proper G and H table settings - almost completed!
- Make sure all R453 behave as supposed to be - no ramping while not authorized - almost completed!
- Restore the old orbit, tunes and chromaticity as far as possible (BPMs reliable?)
- The new Schottky's need calibrations and can be used for emittance growth measurements - almost done.

Action Plan - Continued

- Look for noise sources.
- Characterize $d\epsilon/dt$ - Repeat the emittance growth mechanism checks done before the shutdown.
- Repeat the spoiled vacuum experiments
- Study time evolution of beam distrbution
- Study lifetime vs intensity, beam size, tunes, chromaticity, amplitude, momentum spread etc..
- Ask Ron/Mike for some quiet time if necessary!
- We solicit your inputs - Have another hill to climb!