Observation of the beam induced multipactoring at PEP-II*

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1 Abstract

A nonlinear current dependence pressure rise was observed in the Low Energy Ring (LER) of the PEP-II B-factory. The paper presents experimental results, discussion, and describes simple simulations which indicate that the pressure rise can be related to the beam induced multipacting.

- Observations
- Discussion
- Simulations
- Remedies

2 PEP-II LER

• The PEP-II LER is the high current (2.14 A/1.7 A reached) 3.1 GeV, 500 MHz positron ring.

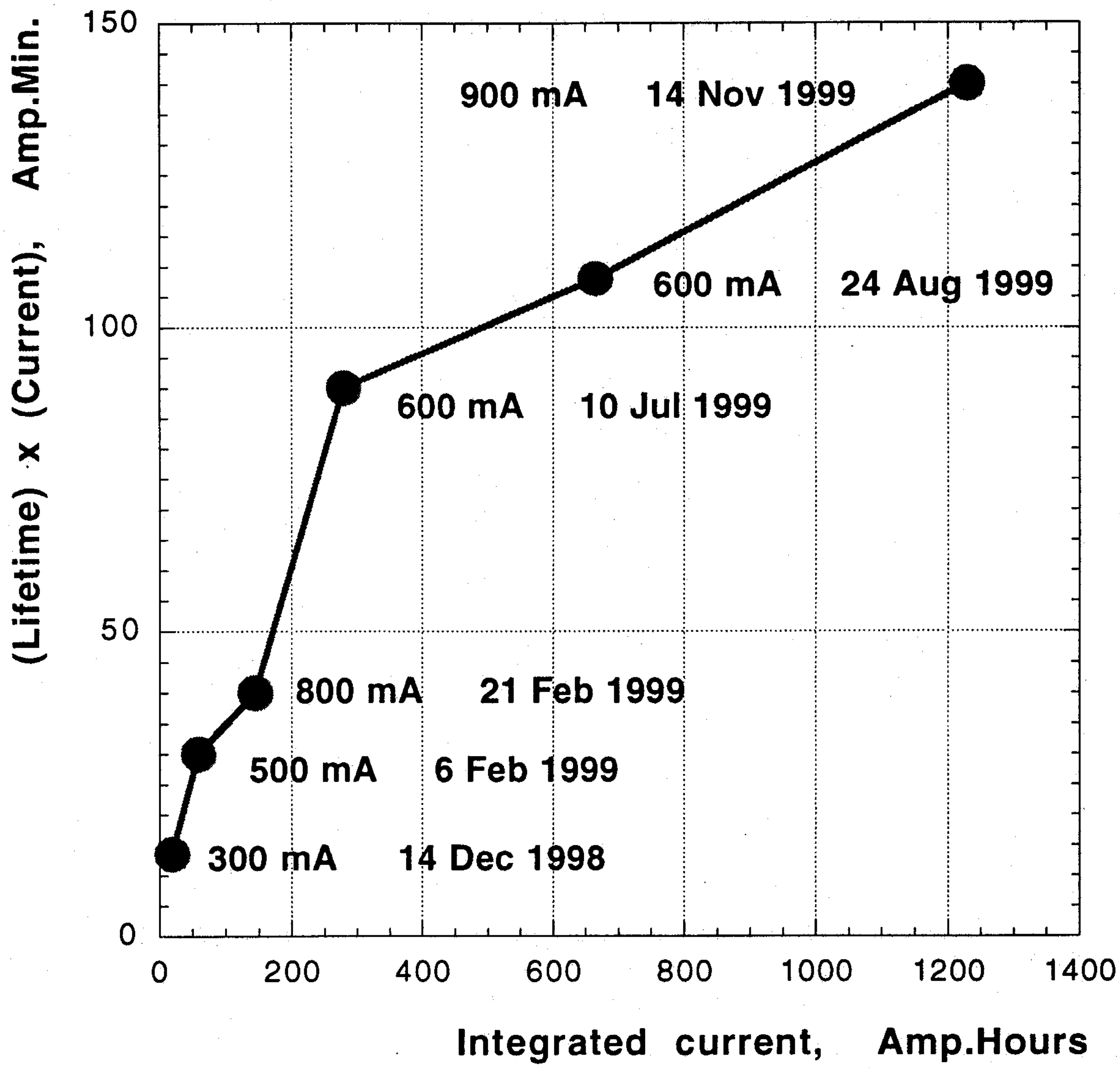
• Nominal $nb = 1658$, $\tau_B = 4.2ns$

• Approximately six-fold symmetry 6 x (Al arc + SS straight).

• Arcs: 9×4.5 cm TiN coated aluminum elliptical beam pipe with an ante-chamber.

• A straight section is made out of 4" stainless-steel round beam pipes.

Fig. 1 shows the SR cleaning effect and machine performance.



(Lifetime) x (Current), Amp.Min.
150
100
50
0
0
200
400
600
800
1000
1200
1400
Integrated current, Amp.Hours
900 mA 14 Nov 1999
600 mA 24 Aug 1999
600 mA 10 Jul 1999
800 mA 21 Feb 1999
500 mA 6 Feb 1999
300 mA 14 Dec 1998

2.1 Experimental observations

Fig. 2 shows dependence of pressure on current typical for all ion pumps in the ring.

The pump #3091 is located in the middle of the arc and the pump #2091 is in the middle of a straight section. The pressure rise is more gradual in the arcs and quite sharp in the straight sections above a certain threshold value of current.

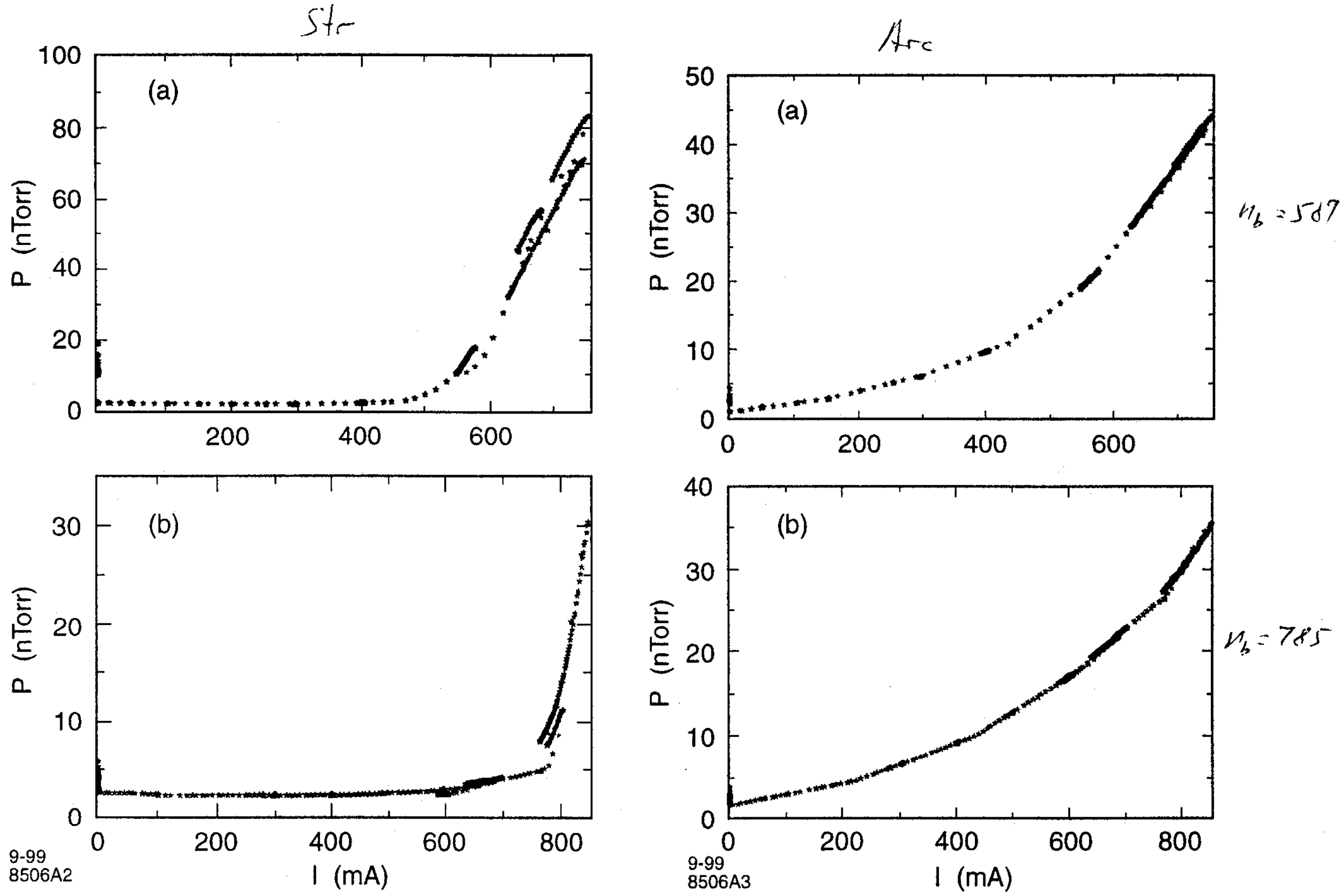


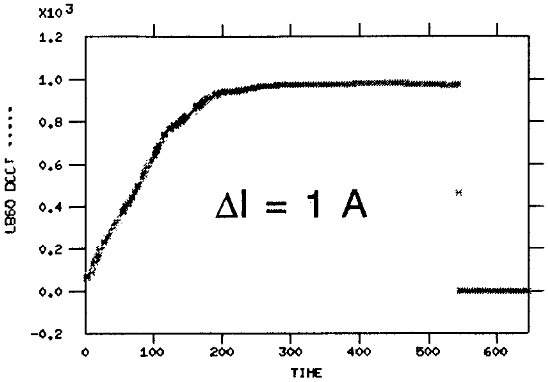
Figure 2: Dependence of pressure on beam current. Left column: pump at the beginning of the straight section. Right column: pump is in the arc. Number of bunches $n_b = 582$ (1a) and $n_b = 785$ (1b).

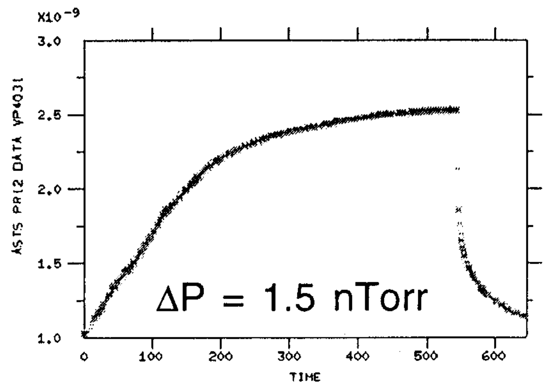
2.2 Main features:

The measurements show that the pressure rise has several specific features.

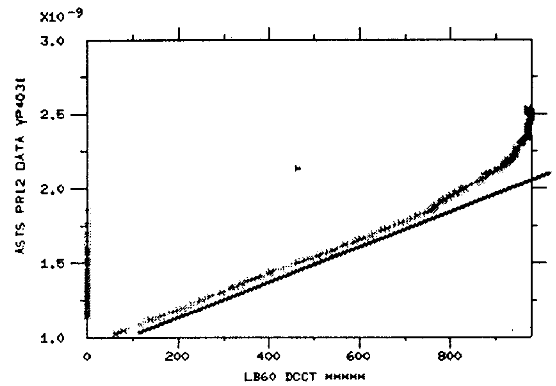
- Pressure rise is non-linear with current, Fig.2
- Effect is observed all over the ring.
- Except for the SR pedestal, there is a current threshold I_{th}, about the same in the arcs and the straights.
- I_{th} depends on the bunch pattern in the train increasing with n_b, Fig. 3 and Fig. 4
- Pressure rise ΔP depends on s_b and higher for larger s_b.
- There is substantial e-component in pump current, Fig.5
- There is effect of the B-field, Figs. 6,7. Effect of B-field is much smaller in the beginning of the straights, Fig. 8.
- Non-linear pressure rise has not been observed in the electron PEP-II ring.

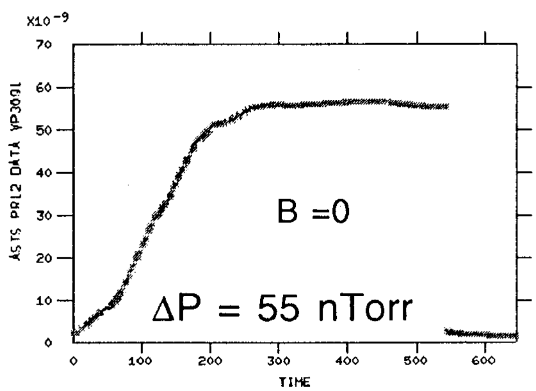
Bunch spacing - 2



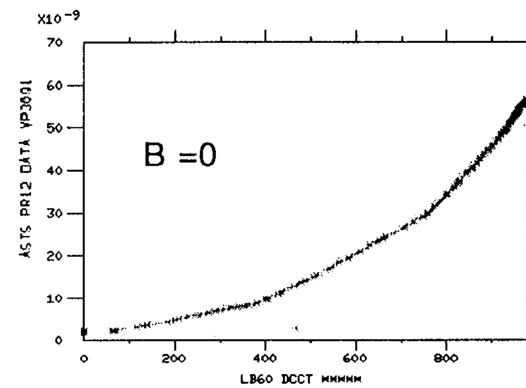


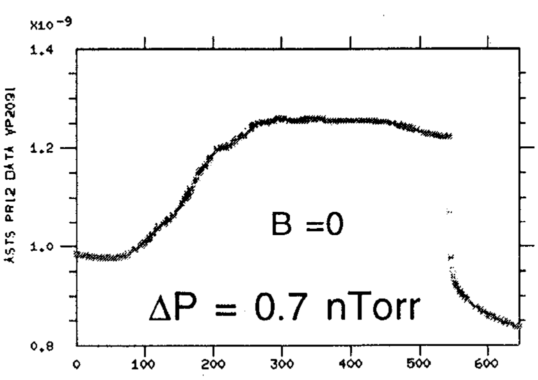
VP4031
end of arc



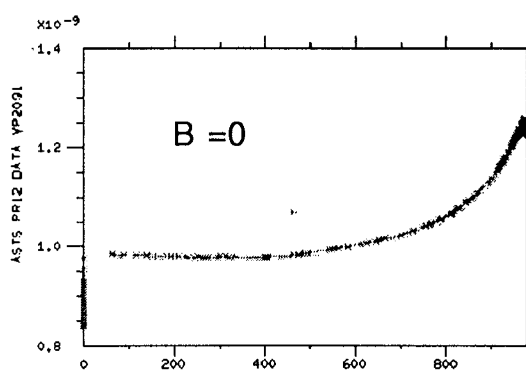


VP3091
beginning of strt

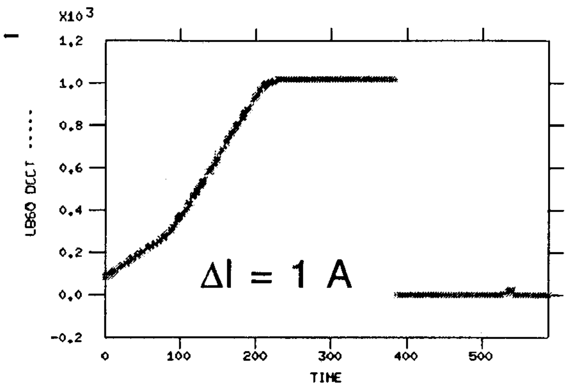




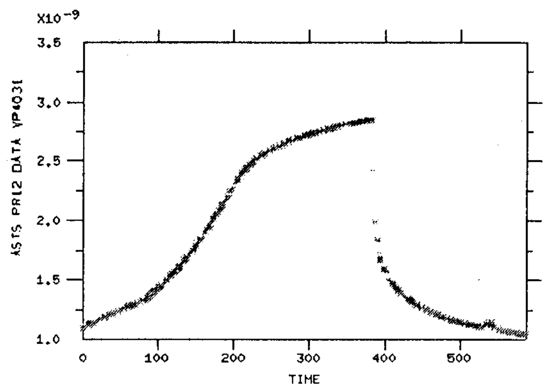
VP2091
mid strt.



F.4



Bunch spacing - 8



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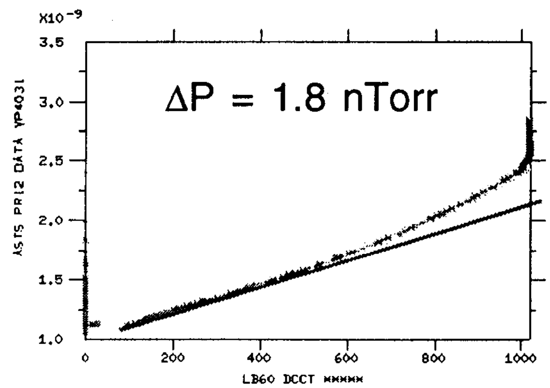
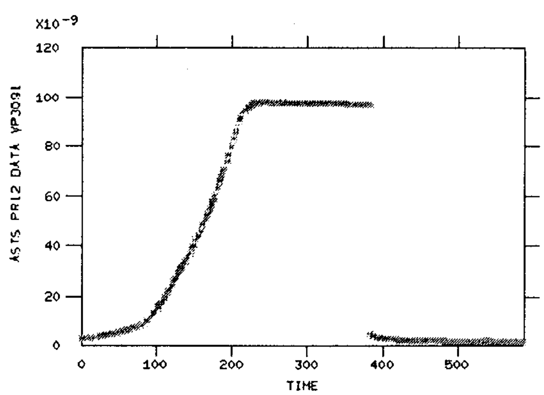
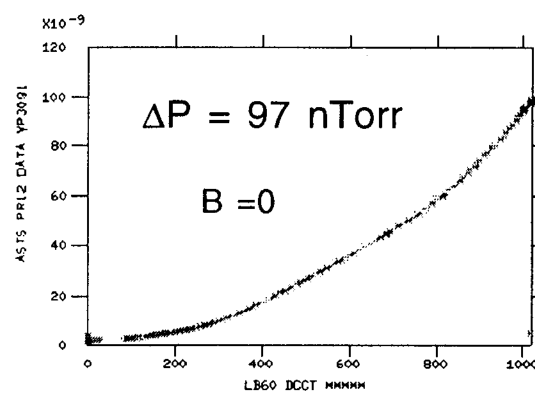
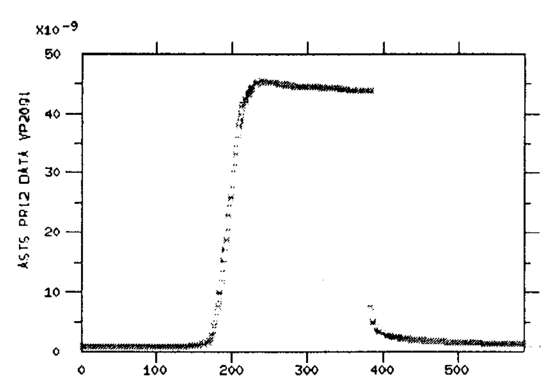


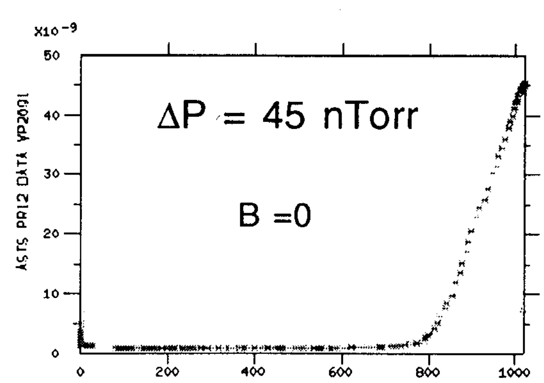


VP3091





VP2091



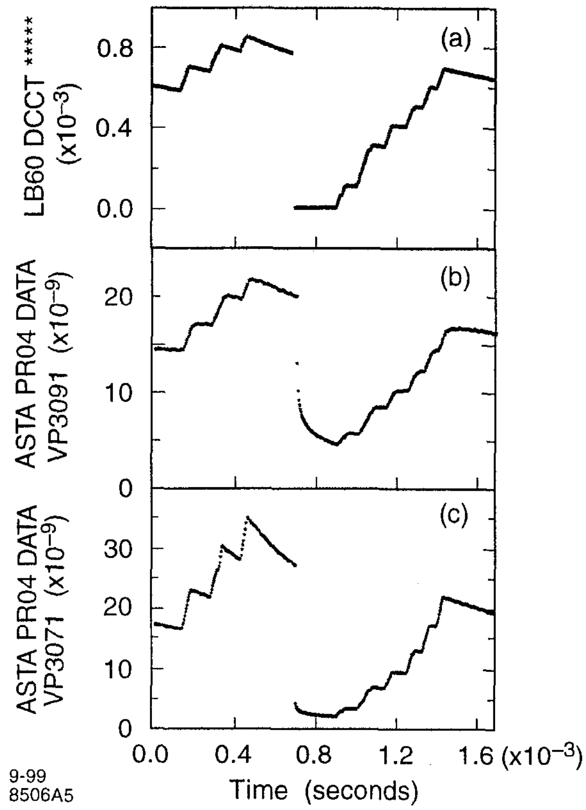
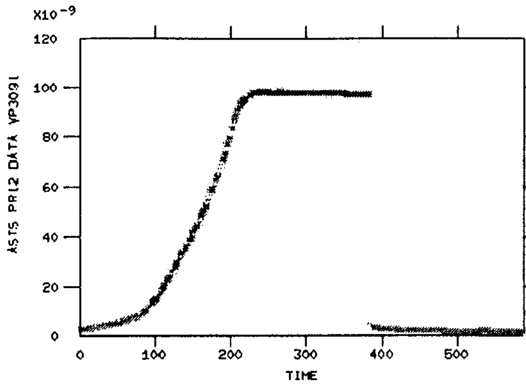
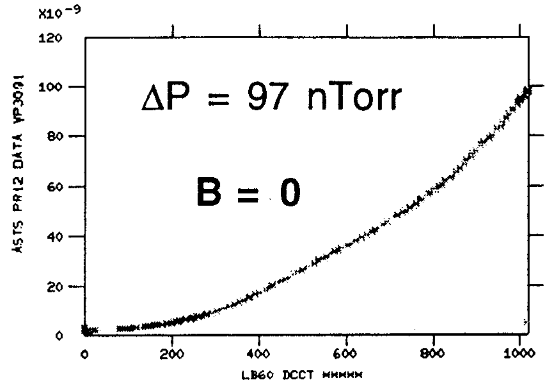


Figure 5: Variation of the ion pump current with time during the beam abort. (a): beam current vs time, (b): variation of the pump current in time for the case of pressure dominated by neutrals, (c): ion pump current vs time in the case of the pump current with substantial electron component.

F6

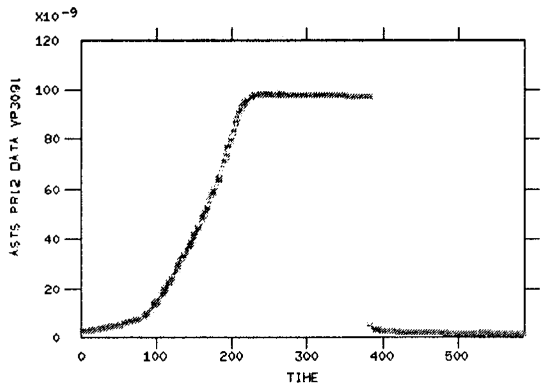
Bunch spacing - 8   ΔI = 1 A

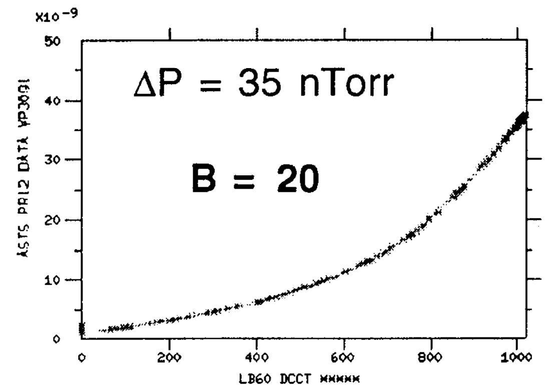




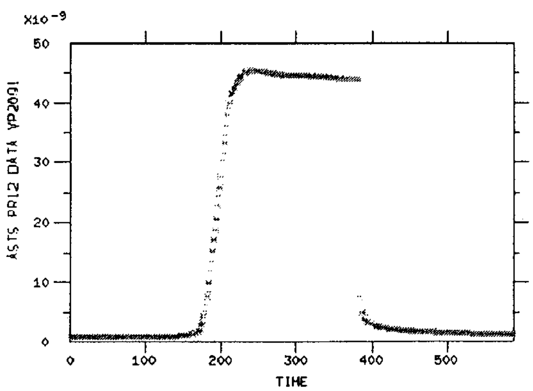
VP3091

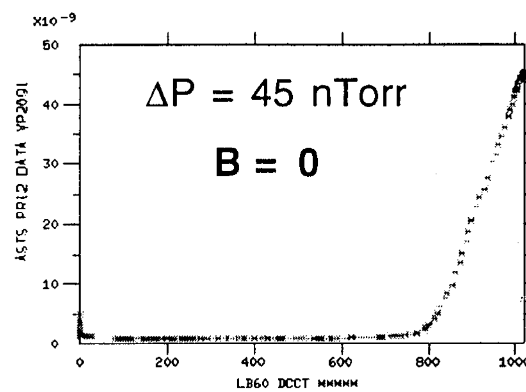
end arc





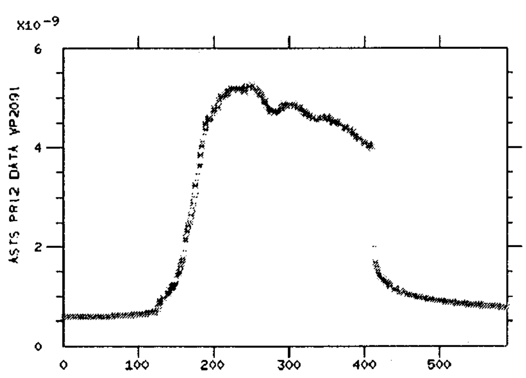
VP3091

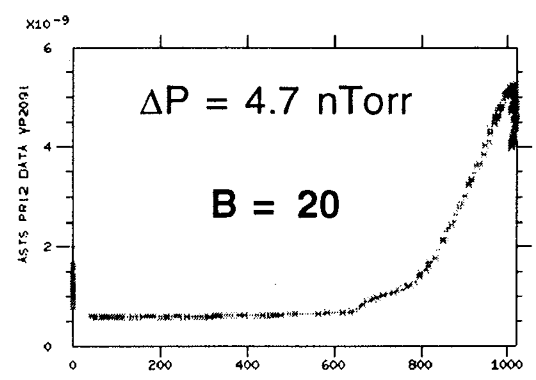




VP2091

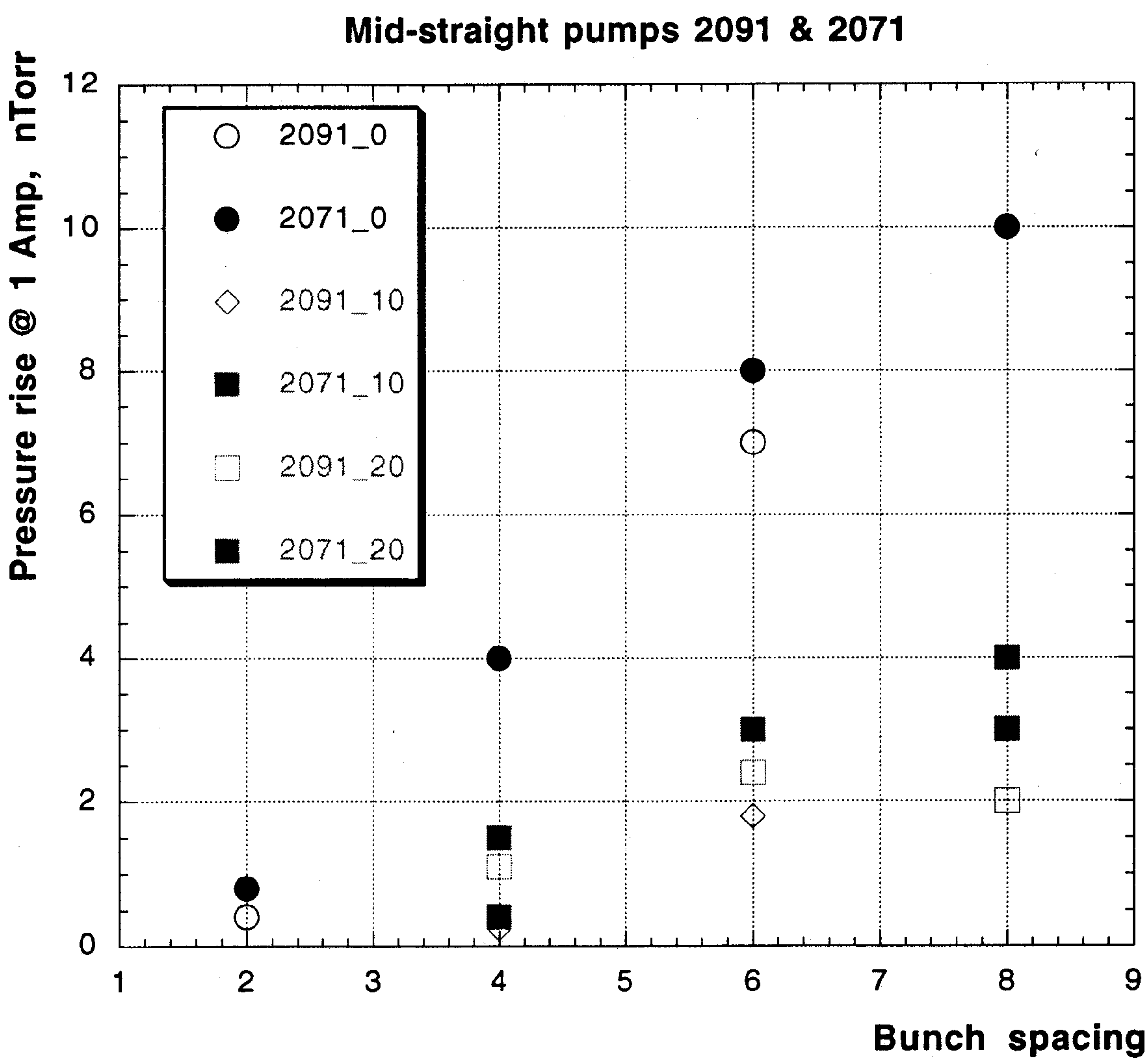
end start





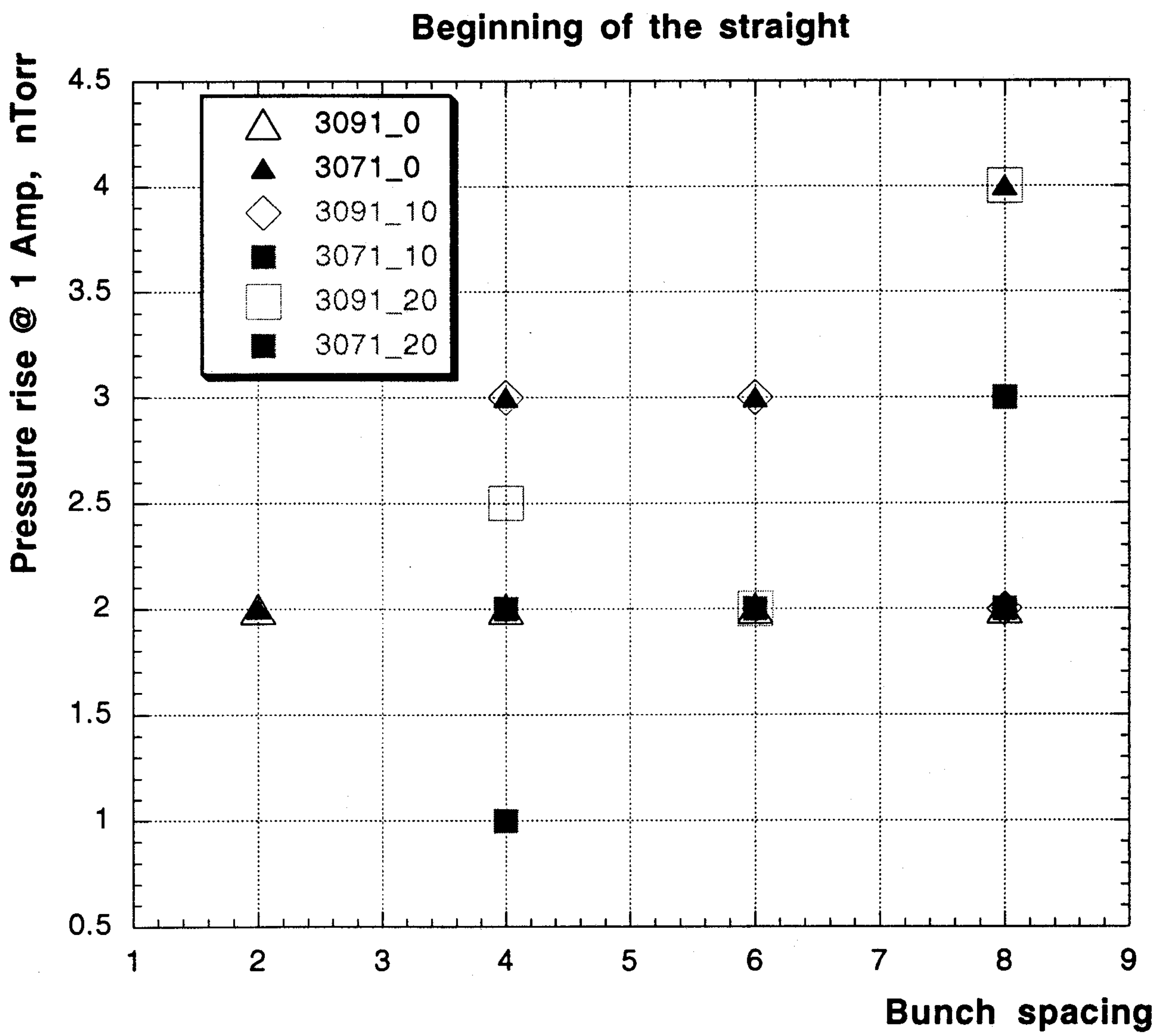
VP2091

F7



Mid-straight pumps 2091 & 2071
Pressure rise @ 1 Amp, nTorr
Bunch spacing
2091_0
2071_0
2091_10
2071_10
2091_20
2071_20
0
2
4
6
8
10
12
1
2
3
4
5
6
7
8
9

F-8


Beginning of the straight
Pressure rise @ 1 Amp, nTorr
Bunch spacing
3091_0
3071_0
3091_10
3071_10
3091_20
3071_20
0.5
1
1.5
2
2.5
3
3.5
4
4.5
1
2
3
4
5
6
7
8
9

3 Discussion

• Pressure rise with the beam current can be related to SR, gas desorption due to the wall temperature rise or gas desorption due to collisions of energetic electrons and ions with the beam pipe wall.

• Temperature variations are too slow to explain beam pattern dependence of the pressure rise.

• The ions produced in collisions with residual gas can not explain observations.

The estimate of the outgasing rate gives $2\,10^{13}$ atom/(m s) obtained from $P = 40$ nTorr with the pumping speed 100 l/s and 7 m distance between pumps.

This is by an order of magnitude higher than the ion production rate in collisions with residual gas

$$\frac{d^2 N_i}{dsdt} = \sigma_i n_g \frac{N_b}{\tau_b}. \tag{1}$$

Additionally, the rate depends only on the average beam current, and therefore can not explain dependence of pressure rise on the fill pattern.

• Ionization electrons have high energy and are capable to produce neutrals but their direct flux to the wall is too low to explain the pressure rise.

• Ion impact with the wall can lead to pressure instability.

However, our estimate shows that, for the LER parameters, this can occur only at very large yield ($\eta \propto 7$).

• The only plausible process remained is the de-gasing due to impact with the walls of large number of energetic electrons produced in beam induced multipacting (Grobner).

• **The estimate for LER gives** $\frac{d^2N_e}{dsdt} = 4.6\,10^{15}\ cm^{-1}s^{-1}$.

Even if 1% of primary photons propagate to the end of the straight section, they give flux of the photo-electrons larger than that due to ionization.

• We assume that the yield of neutral atoms in electron collisions with the wall depends on the energy deposited to the wall.

• **The large drop of the ion current after beam abort in the beginning of the straight sections indicates that there is a substantial electron density, what is consistent with the high photon flux at these locations .**

The relative drop of the pump current after beam abort is less than 1% of the total pump current in the arcs and is much higher for pumps in the straights.

This result is consistent with the independent "magnet off" measurements.

• **The threshold current for LER parameters** can be determined as the second multipactoring resonance. This gives reasonable agreement with the fill pattern dependence, see Fig. 9

• **The pressure rise depends on the energy deposited to the wall and scales as** $I^2_{beam}s_b$, in agreement with dependence on s_b.

• **Beam dynamics effect is rather weak.**

The rising pressure may deteriorate beam life time.

However, condition of neutrality or comparison of the space-charge potential with the energy of secondary electrons gives the equilibrium $n_b \propto 10^6$ $1/cm^3$, 100 times smaller than n_{gas}.

The e-cloud space changes tune,

$$\Delta\nu = (2\pi R)^2 \frac{r_0 n_{tot}}{4\pi\gamma\nu}. \qquad (2)$$

For LER parameters, $\Delta\nu = 0.5\ 10^{-8} n_{tot}$, smaller than the beam-beam parameter.

This explains why the pressure rise does not apparently affects the beam stability.

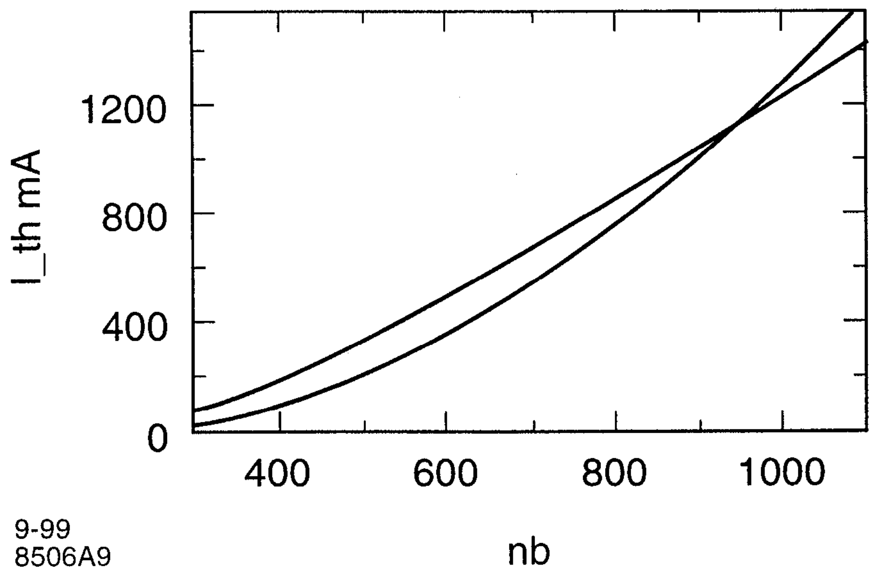


Figure 3: Threshold current vs number of bunches. Low curve: limit by time of flight, upper curve: limit by E_{th}. Current has to be above both curves. $E_0 = 5$ eV, $E_{th} = 200$ eV, $b = 4.5$ cm
. I_{th} is lower for larger s_b but ΔP is higher.

4 Simulations

•Simple simulations are carried out with a tracking PIC code for cylindrically symmetric case.

• **It takes into account:**

* constant flux of primary electrons proportional to N_b,

* initial energy spread ΔE of secondary electrons,

* production of the secondary electrons in collisions with the walls,

* space charge effect of accumulated electron cloud.

• **Results of simulations:**

• Results of simulations are consistent with measurements and show that, at moderate currents, the pressure rise is related to the photo-electrons in the beginning, and to the avalanche electrons in the end of the straight sections.

* equlibrium density of the order of 10^6 $1/cm^3$,

* dependence of the threshold on the offset of the closed orbit, Fig. 9

* threshold dependence of pressure on current, Figs. 10, 11

* the threshold dependence on s_B,

* results are sensitive to the spread ΔE due to the following kinematic smearing of the secondaries in space at the arrival of the following bunch,

* smearing out of the higher-order multipactoring resonances,

* oscillations of the e-cloud density, Fig. 12.

* Space-charge oscillations may produce $x - s$ coupling

• Missing:

* Dependence of the yield η on current due to SR cleaning and the e-cloud space-charge

* 3D geometry which adds to smearing of e^- trajectories

* Assumed $P \propto < E_{wall}$ may be too simplistic.

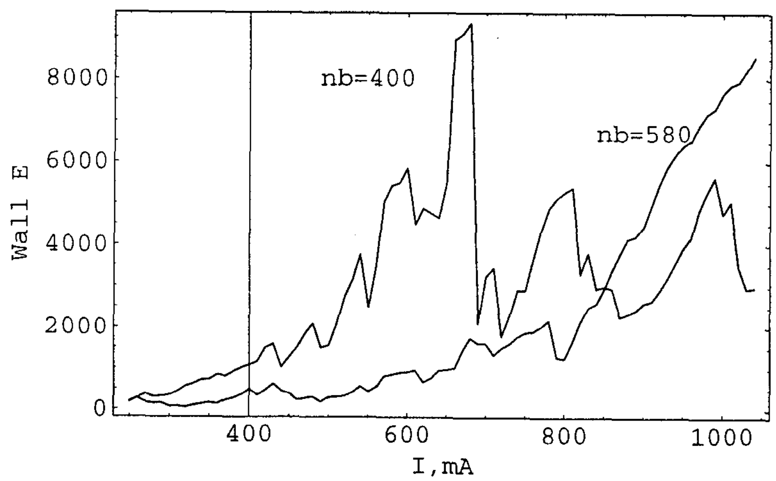


Figure 10: Energy deposited to the wall vs beam current. High flux, $\eta = 1.2$, $E_0 = 10$ eV, $E_{th} = 200$ eV, $b = 4.5$ cm for number of bunches $n_b = 400$ and $n_b = 580$.

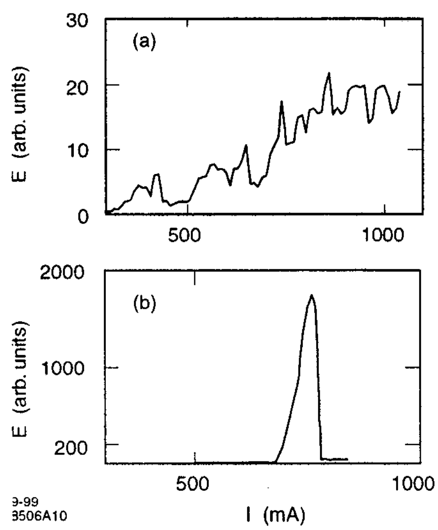


Figure 11: Energy deposited to the wall vs beam current. Low flux, $\eta = 0.8$ (a) and $\eta = 1.2$ (b). Note scaling. $n_b = 582$, $E_0 = 10$ eV, $E_{th} = 200$ eV, $b = 4.5$ cm.

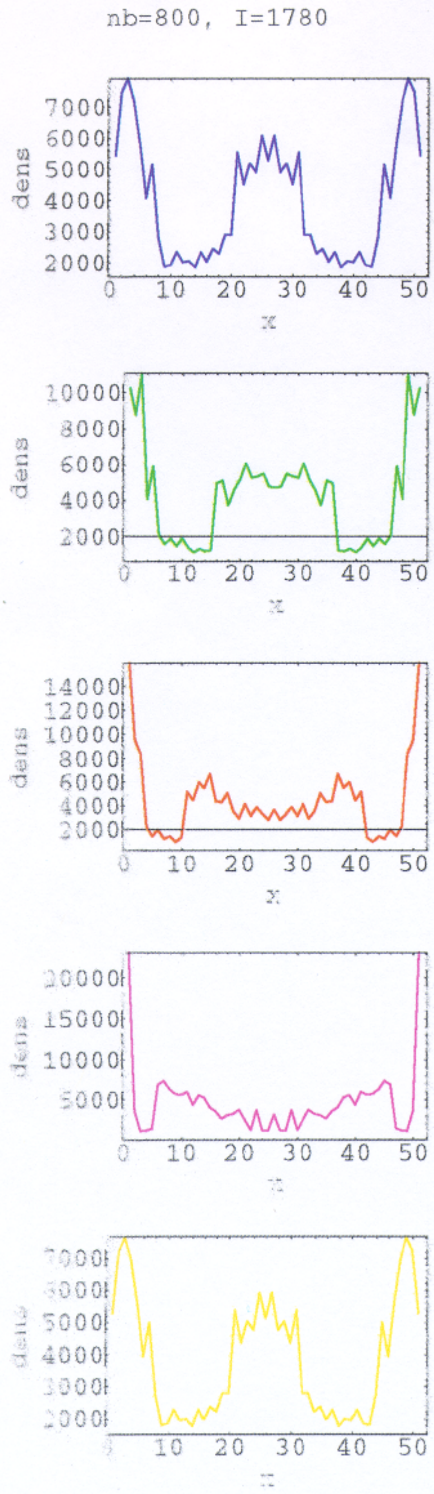


Figure 6: Variation of distribution of the electron cloud in time. Each snapshot is taken at 1/4 of bunch spacing.

5 Remedies

• The surface cleaning by the SR and related change of the yield η in the beginning of the straight sections may be essential in explaining why the pressure at the end of the straight sections is higher than that in the beginning at high currents.

• A solenoidal longitudinal field was suggested to confine secondary electrons at the walls.

* To make Larmor radius small, $r << b$, the magnetic field has to be strong enough,

$$B >> 2\,10^{-6}\,(\frac{I_{beam}}{[mA]})\,(\frac{\sigma_l\sqrt{2\pi}}{b^2})\text{ Gauss m.} \tag{3}$$

For LER parameters, B of 3 Gauss would be enough.

Another criterion is given by condition of adiabaticity of the kick. If bunch length is large compared to the Larmor period,$eB\sigma_l\sqrt{2\pi}/mc^2 >> 1$, a Larmor radius is adiabat invariant and preserved. The Larmor circle in this case moves as a macroparticle. To avoid this, B should be small enough,

$$B << 700\text{ Gauss.} \tag{4}$$

6 Conclusion

• Beam life time reached 2 h at 1 A (11/99).

• Outgasing rate in arcs decreased with Amp-hours from 10 nT/A at 100 A-h to 3.5 nT/A at 1200 A-h.

• Arcs pressure has significant (30% at 1A) nonlinear component which is consistent with thermal outgasing.

• In the straight sections, $\Delta P \propto I_{bunch}$ is induced by beam multipactoring.

• Outgasing rate can be as high as 10 nT/A at 1 A, $s_b = 8$.

• Simulations are consistent with experiment.
Oscillations of the e-cloud density may lead to x-s coupling and emittance degradation.

• B-field decreases beam induced ΔP by a factor of four.