SYNCHROTRON RADIATION + ELECTRON-CLOUD EFFECT

M. FURMAN
SEP 20, 2000

O. GRÖBNER
K. HARKAY
P. LIMON
M. PIVI
D. TRBOJEVIC
M. FURMAN

WE HAD SEVERAL TALKS:

- O. GRÖBNER "IMPACT OF S.R. ON LHC VACUUM SYSTEM" (PLENARY)
- K. HARKAY: "ELECTRON-CLOUD MEASUREMENTS AT APS"
- M. PIVI: "ELECTRON-CLOUD EFFECTS AT LHC + PSR"
- M. FURMAN: "ELECTRON-CLOUD SIMULATIONS"
- W. TURNER (VIA M. FURMAN): "ELECTRON-CLOUD SPREADSHEET"
- M. FURMAN: "ELECTRON-CLOUD MANIFESTATIONS AT PEP-II + KEKB"

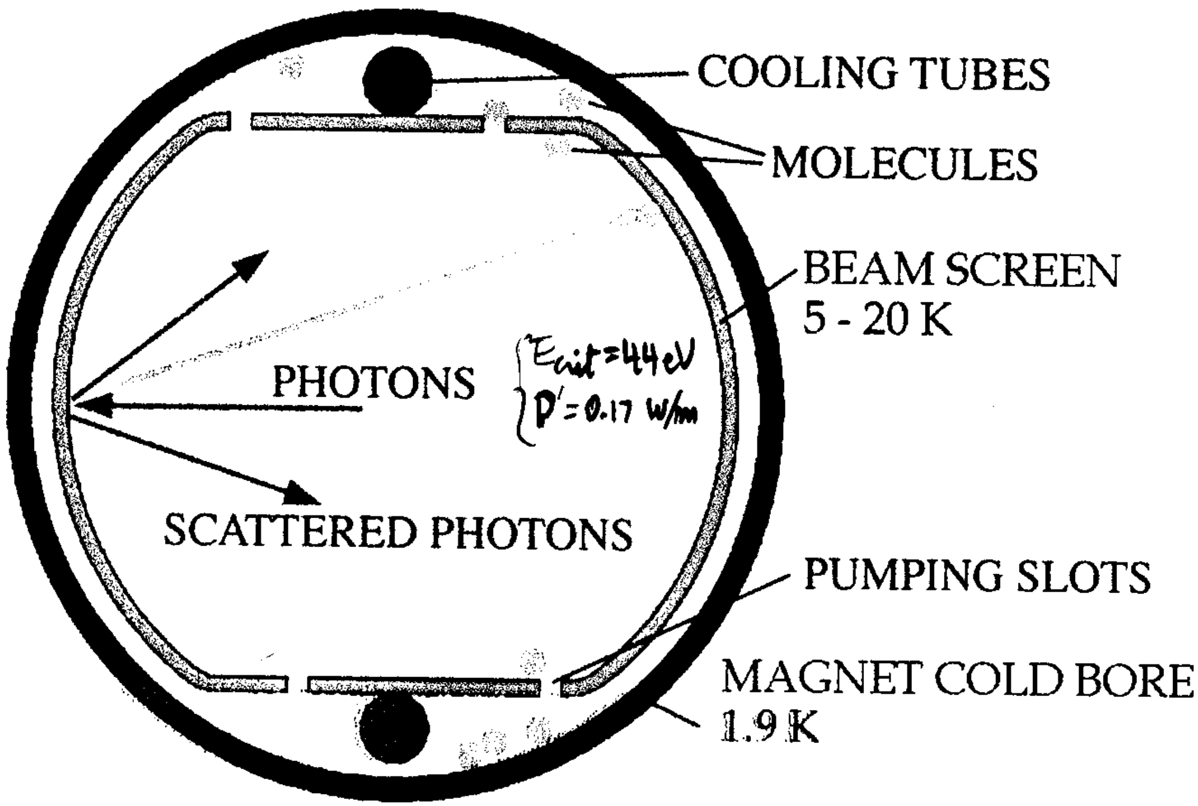
GENERAL DISCUSSIONS:

- BEAM SCREEN OR MASK FOR VLHC
- APPLICATION OF W. TURNER'S SPREADSHEET PROGRAM TO VLHC {HF, LF} + RHIC

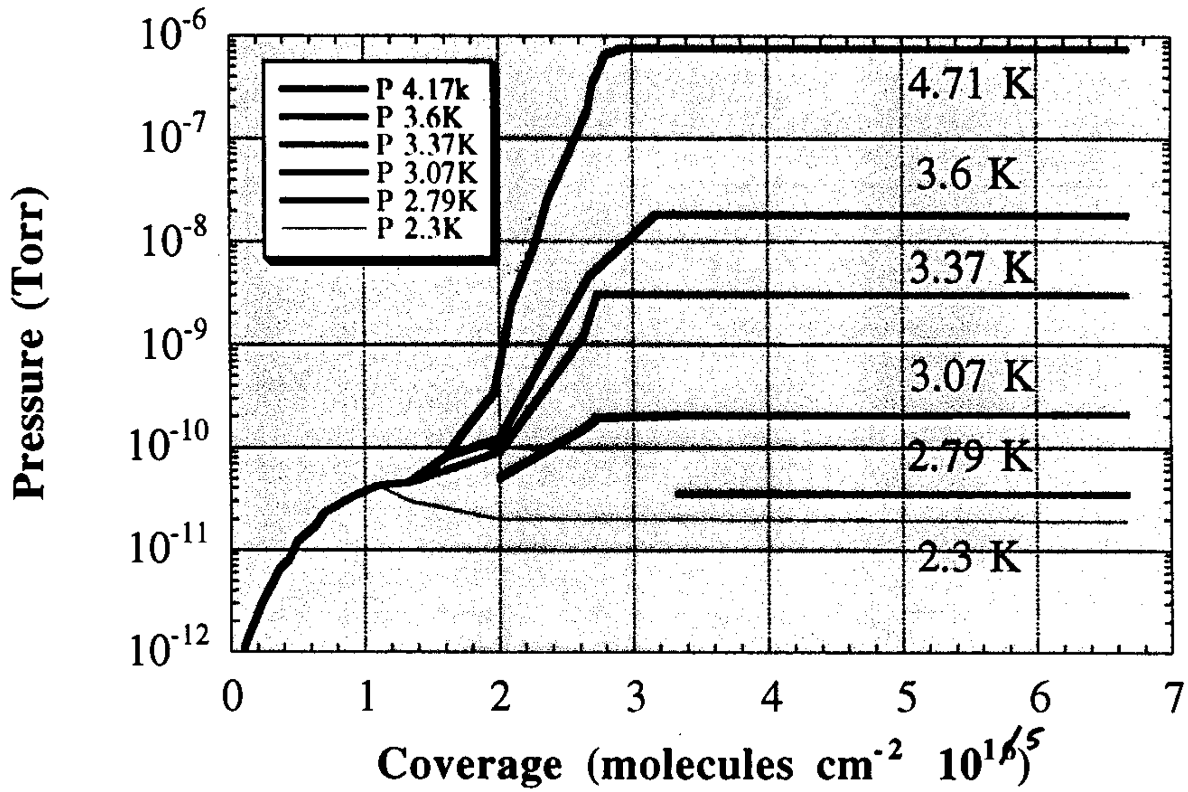
Synchrotron Radiation Effects

- S.R. Power deposition on cryogenic system
- Photon stimulated outgassing -> dynamic pressure increase
- Photoelectron production -> electron cloud effect
  - Power dissipation from beam
  - Beam Induced Multipacting (secondary electron coefficient)
  - Electron stimulated outgassing
- Beneficial effects of S.R. are :
  - Gradual cleaning of the vacuum system (beam cleaning)
  - Reduction of secondary electron coefficient by photons/electrons
  - For a VLHC : Radiation damping -> Increase of Luminosity

Beam screen inside a Cryo-magnet cold bore

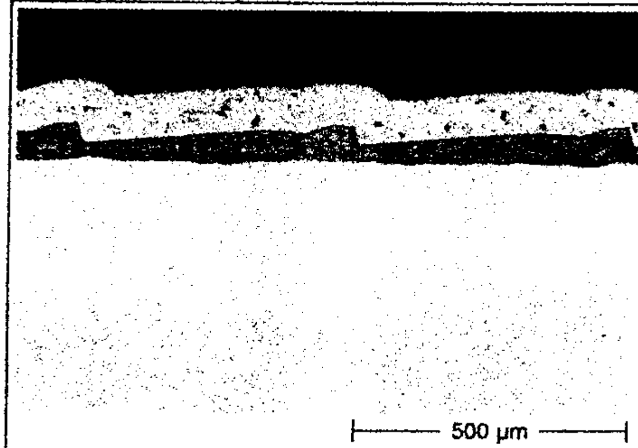


Hydrogen vapour pressure



O. Gröbner CERN-LHC/VAC, SR2000, BINP, 17-21 July 2000

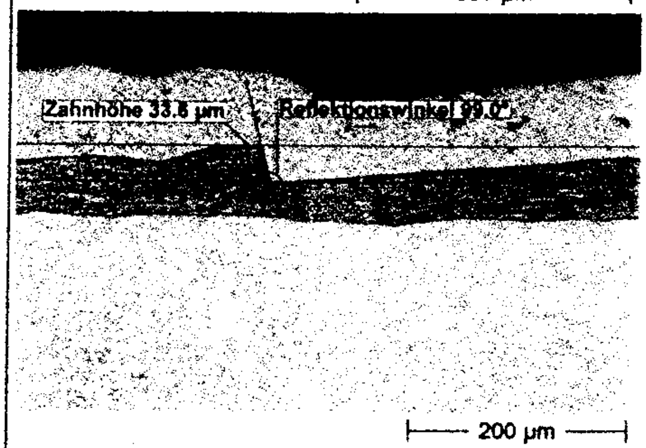
Heraeus WCH-GBM-TCS Hellenkamp Tel.: 06181/35-493 Fax. 06181/35-5316	Material: Stahl - Cu Band Allgemeines. CERN - Profilierungsversuch Ätzmittel Au-Ätzmittel	**Metallographie** P00361 22.06.1999 135 80 006 H.Eisentraut



906P0467

Probe vom 17.06.99 - Links

100 1



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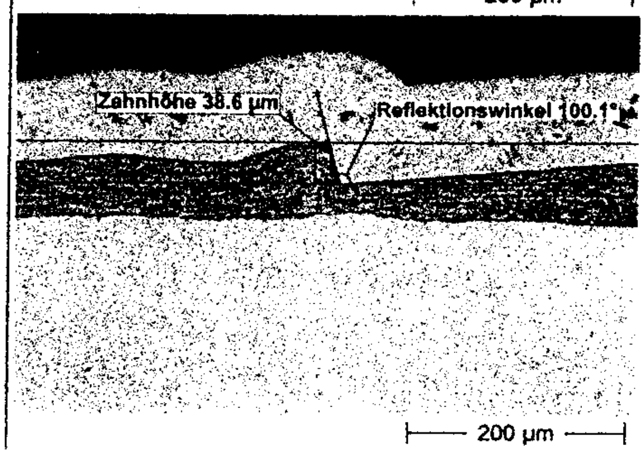
Probe vom 17.06.99 - Links

200 1

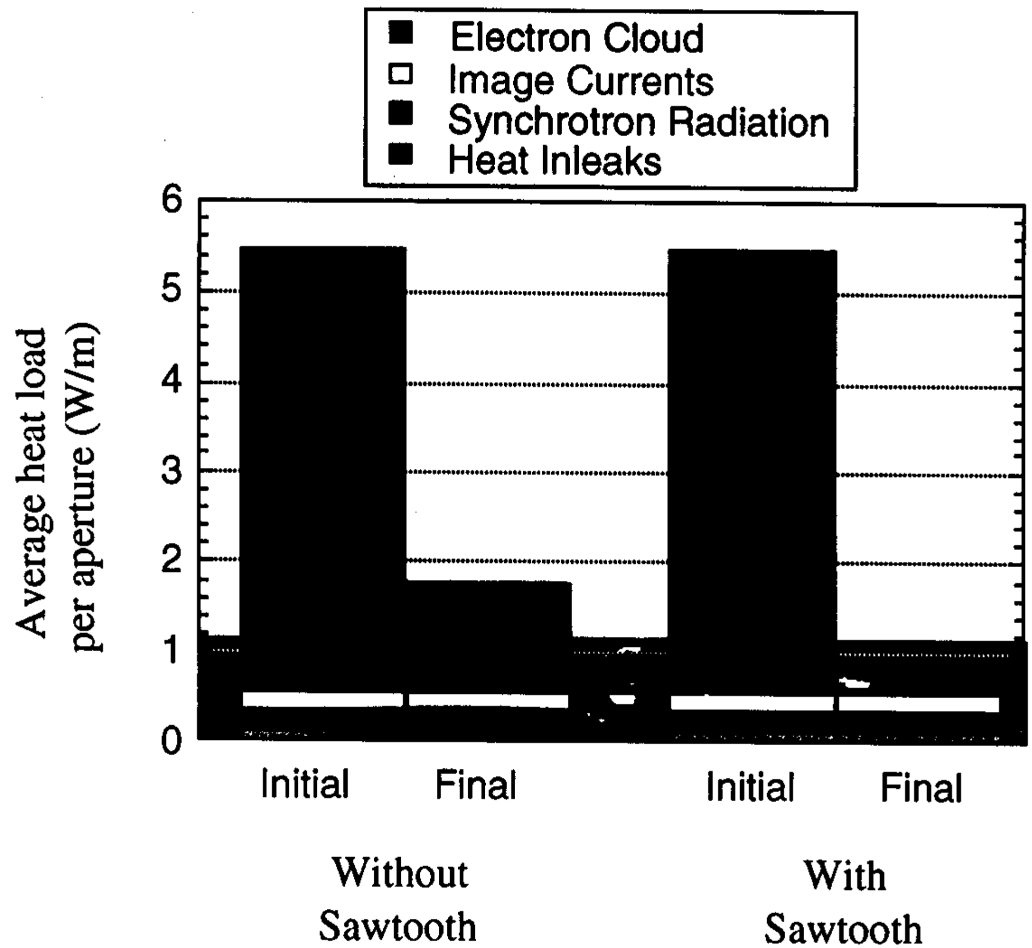


906P0471

Probe vom 17.06.99 - Links

200 1

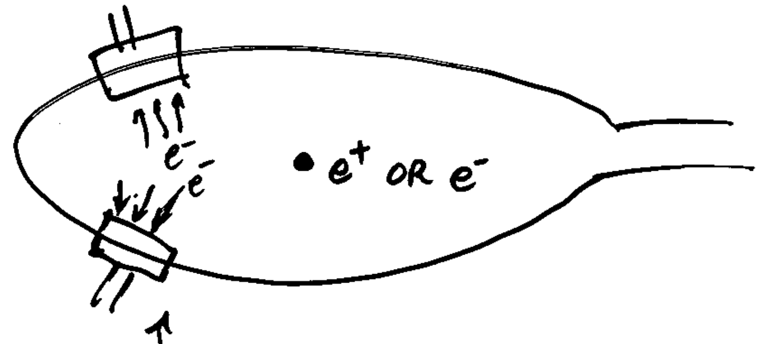
Effect of 'scrubbing' and of a 'saw-tooth' surface



ELECTRON CLOUD AT THE APS
(K. HARKAY)

- ECE NOT AN OPERATIONAL PROBLEM

~~MEAS~~
- ECE DELIBERATELY INDUCED AND MEASURED IN ORDER TO UNDERSTAND IT BETTER

-


e^- DETECTORS (R. ROSENBERG + K. HARKAY)

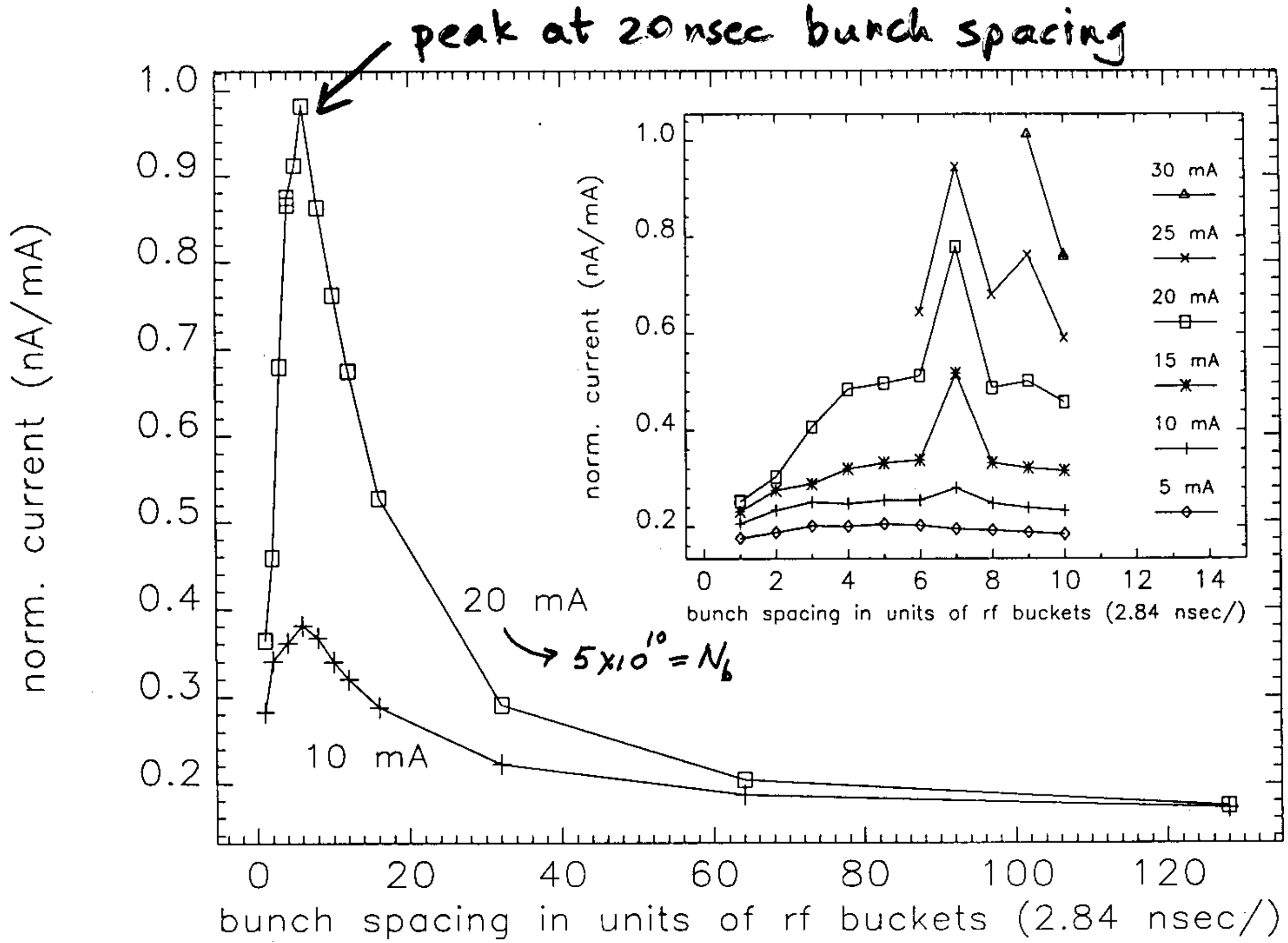
* VALUABLE TOOLS!
* MEASURE $\begin{cases} I_{e^-} \\ dN/dE \end{cases}$

* DETECTORS EXPORTED TO PSR (LANL)

- PEAK OF I_{e^-}/I_{beam} AT $S_B = 7\lambda_{RF}$ IN AGREEMENT WITH SIMPLE ESTIMATE OF TRANSIT TIME (BIM)

- COMPARISON WITH SIMULATION NEEDS MORE WORK (COMPLICATED BY VAC. CHAMBER GEOMETRY)

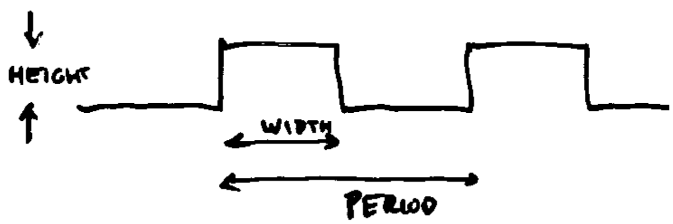
K. HARKAY



Comparison of normalized current as a function of bunch spacing and current
(10 bunches total)

M. PIVI: "ECE AT LHC + PSR"

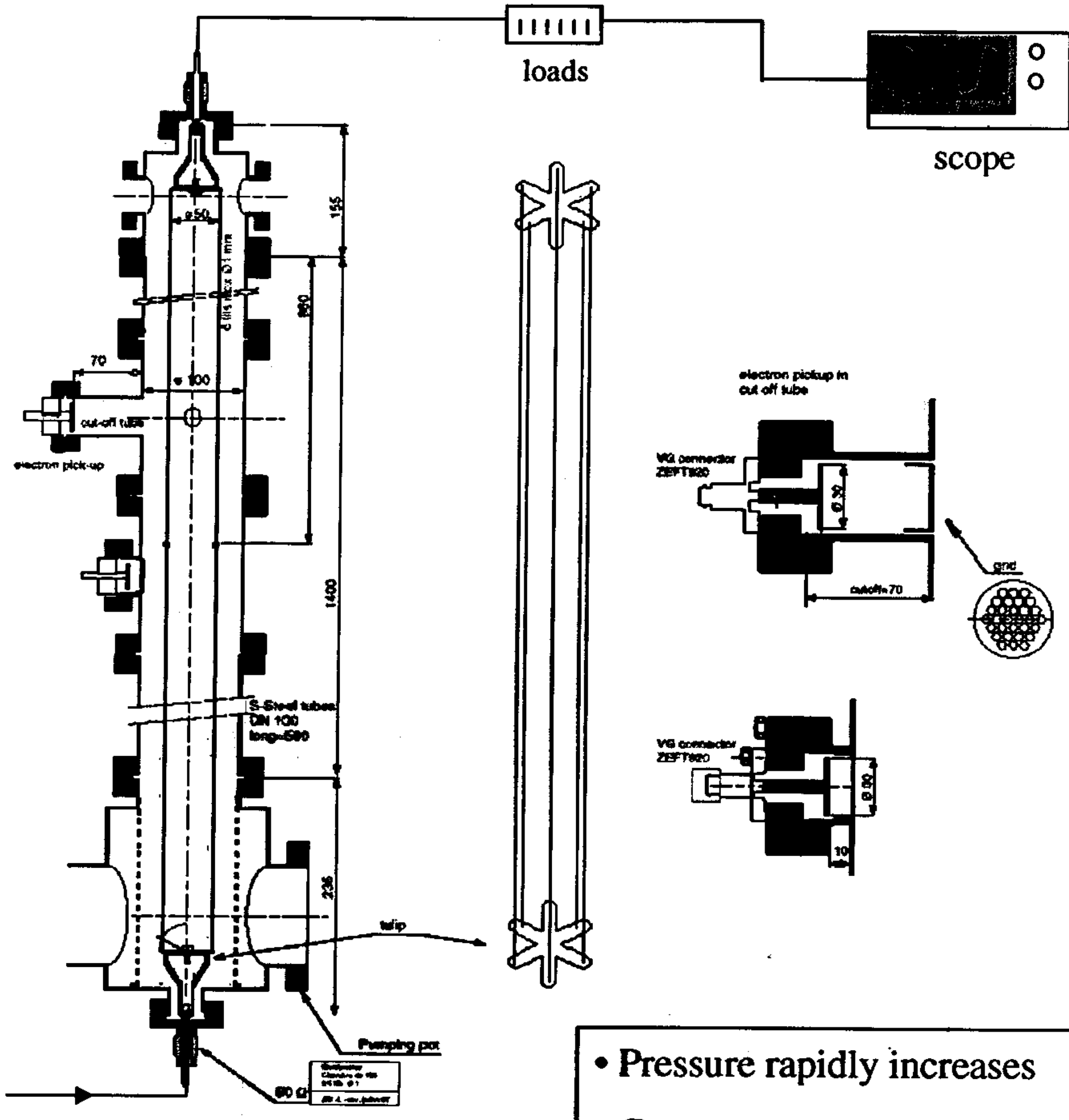
- TW TUBE (SIMULATES p BEAM)
- VARY RF PULSE PARAMETERS



- MEASURED:
  - PRESSURE
  - e^- CURRENT
  - dN/dE

- STAINLESS ST.
  - CU
  - TiZrV COATED SS.

TW chamber experimental setup



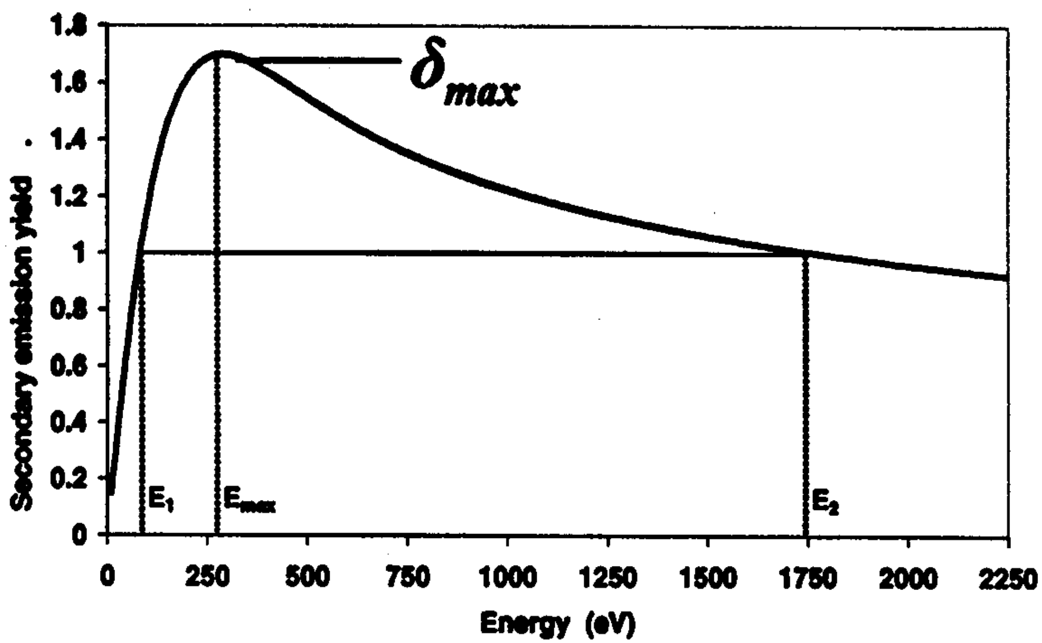
- Pressure rapidly increases
- **Current** at the pick-up

Multipacting depends strongly on the
RF pulse parameters

Analytical expression for Secondary emission yield [H.Seiler, J.Appl.Phys. 54 (11), (1983)]

$$\delta(E,\theta)=\delta_{max}\,1.11\left(\frac{E}{E_{max}}\right)^{-0.35}\frac{\left(1-e^{-2.3\left(\frac{E}{E_{max}}\right)^{1.35}}\right)}{\cos\theta}=\delta_{max}\frac{h(E/E_{0})}{\cos\theta}$$

with θ the angle of incidence to the surface normal

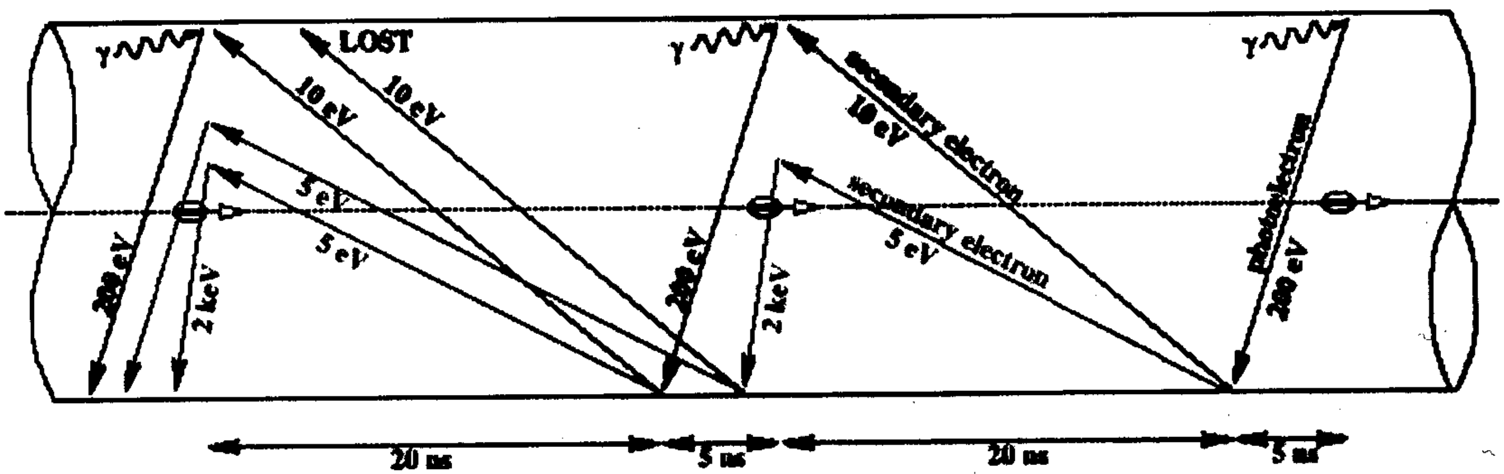


New data about SEY dependence on the incidence angle of the impinging electron, from recent measurements by R. Kirby, see "Secondary electron Emission Yields from PEP II Accelerator Materials", SLAC 2000.

LHC: photoemission from synchrotron radiation

$$N_\gamma = \frac{5}{2\sqrt{3}}\alpha\gamma \quad \frac{photons}{radian} \longrightarrow 3.5\ 10^9 \quad \frac{photoelectrons}{magnet\ \ bunch}$$

Critical photon energy: $E_{crit} = \frac{3\hbar c}{2\rho}\gamma^3 \approx 45eV$



Schematic of electron-cloud build up in the LHC beam pipe

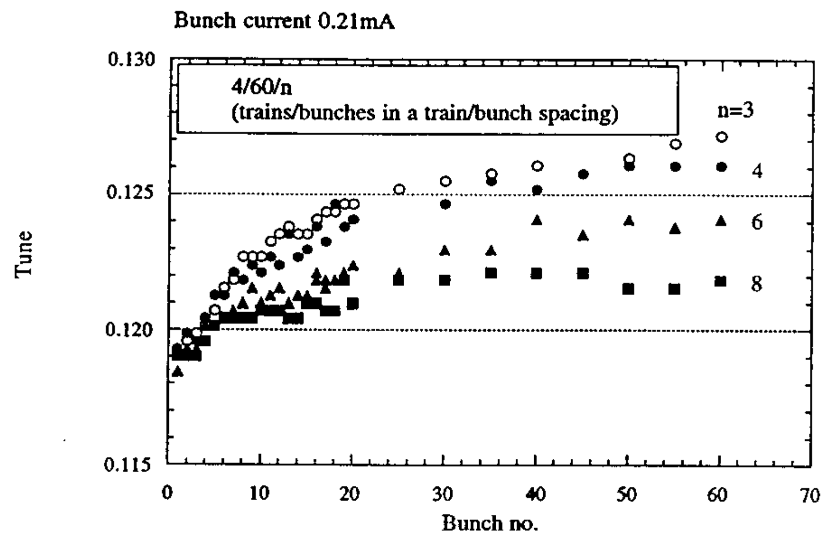
Possible Remedies against the electron cloud build-up

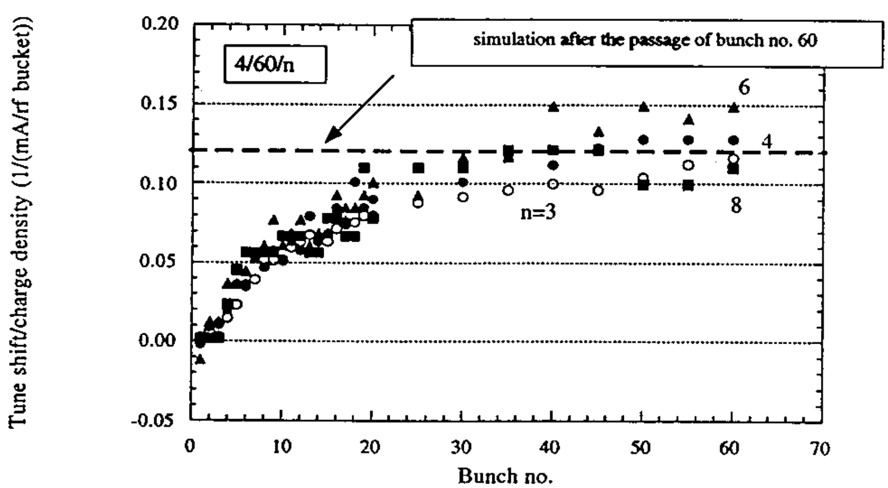
- Suppressed multipacting with a solenoid magnetic field - 5 Gauss, estimation for LHC (> 15 Gauss)

- Experimented a novel plasma RF discharge treatment using Freon11, is a promising way to suppress multipacting

- Activated TiZrV-coating in the TW chamber
  ⟶ multipacting absent, quite permanent effect

- Analyzed bake-out of the system (desorption)

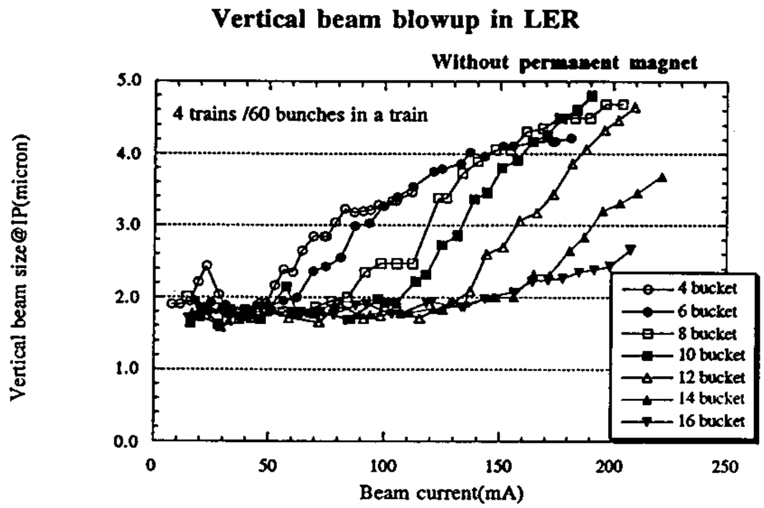

Bunch current 0.21mA
4/60/n
(trains/bunches in a train/bunch spacing)
n=3
4
6
8
Tune
0.130
0.125
0.120
0.115
0
10
20
30
40
50
60
70
Bunch no.

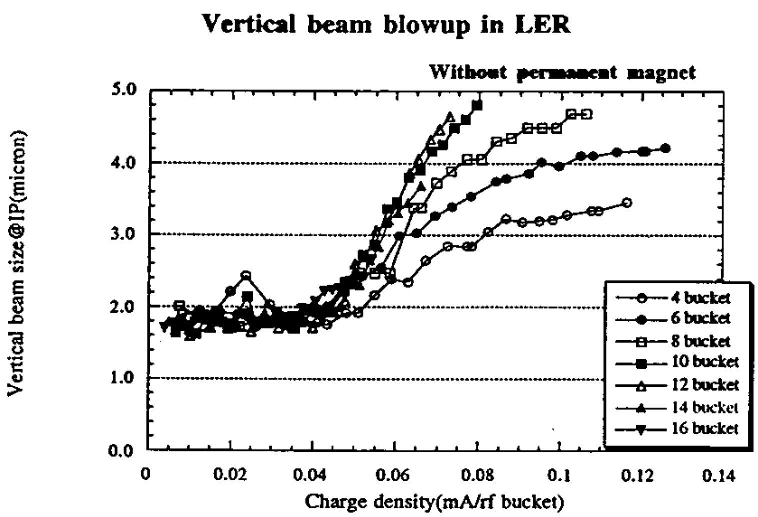

simulation after the passage of bunch no. 60
4/60/n
6
4
n=3
8
Tune shift/charge density (1/(mA/rf bucket))
0.20
0.15
0.10
0.05
0.00
-0.05
0
10
20
30
40
50
60
70
Bunch no.

FUKUMA

KEK-B
e^+ BEAM

ii) Threshold intensity of the blow-up





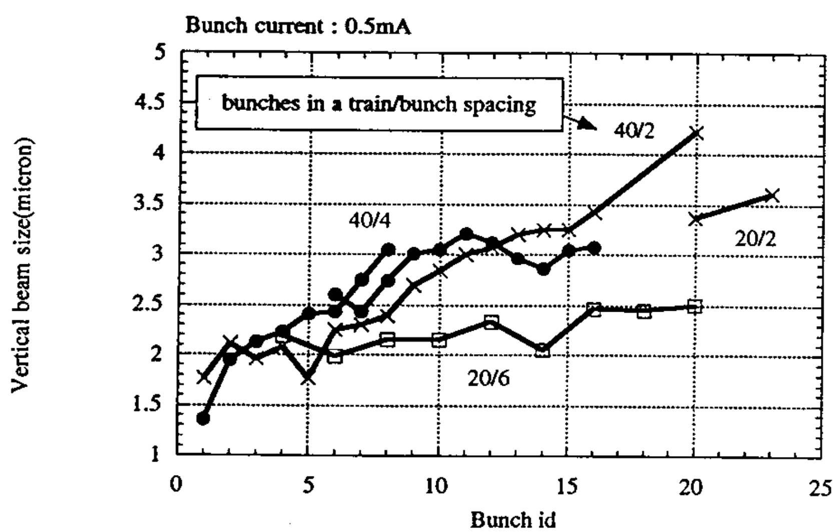
- Threshold intensity is determined by the charge density of the beam. This fact suggests the blow-up starts at a critical density of the cloud. But why the threshold is not dependent on the bunch intensity is an open question.

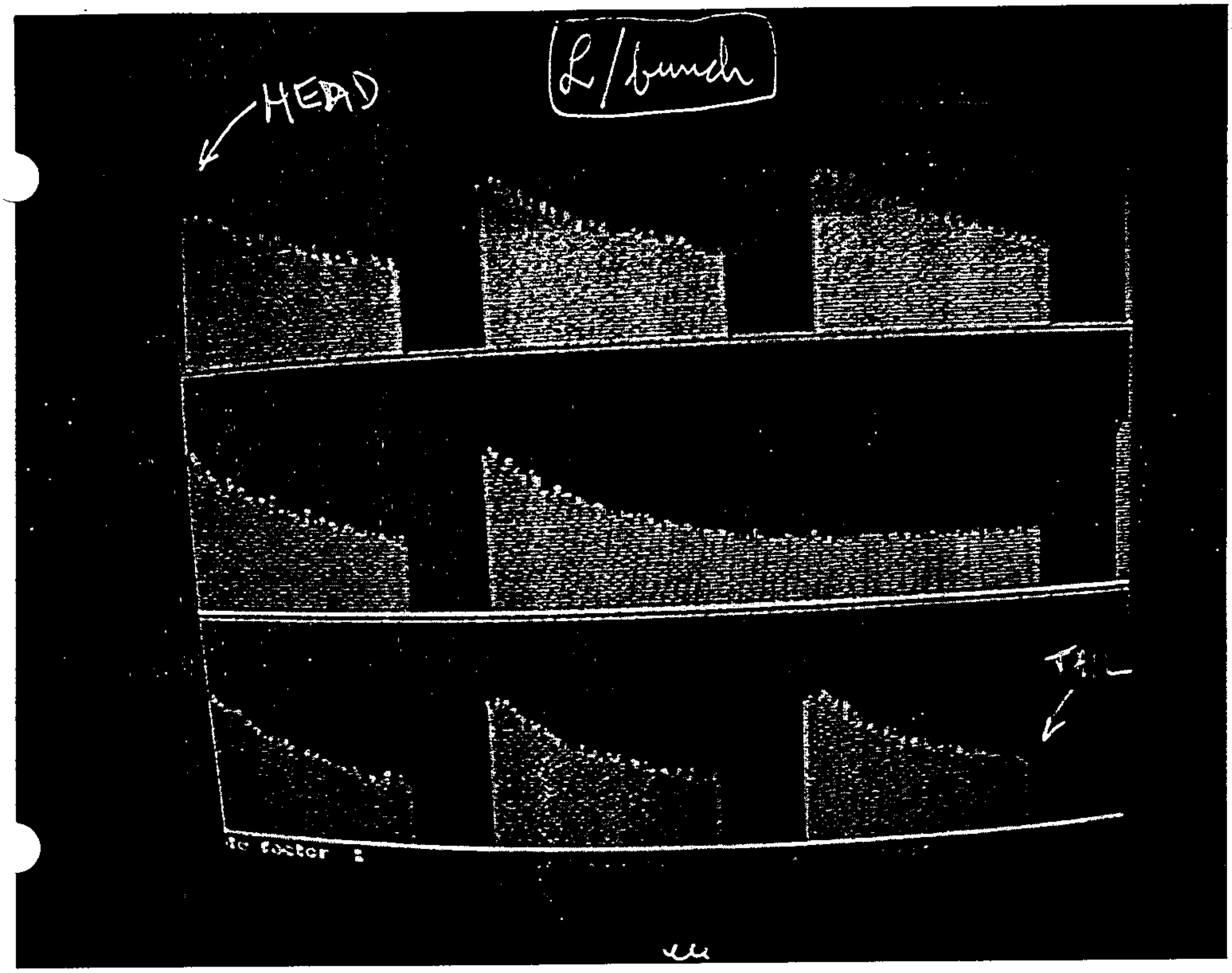
iii) Beam size of each bunch

If the blow-up is caused by the electron cloud, we expect the beam size increases along the train because the density of the cloud also increases along the train.

a) Average beam size

- •Beam size was measured by the interferometer by adding the bunch one by one to the train.
- The data shows that the average beam size increases as the length of the train increases.





This is <u>one</u> turn

obviously not BB problem
probably not RF transient

data taken July 2000 (most likely)

(data given to me by M.Z. 7/26/00)
(data probably taken during ...)

F. J. Decker
also M. Sullivan

... Inj Efficiency

0:3320:4:36:3320:48=0:40:3320:48=0:44:3
320:96=0:720:768=0:1104:1152=0:1488:153
6=0:1872:1920=0:2256:2304=0:2640:2688=0

0:3320:4:36:3320:48=0:40:3320:48=0:44:3
320:96=0:720:768=0:1104:1152=0:1488:153
6=0:1872:1920=0:2256:2304=0:2640:2688=0

all 117 charac...
spaces used up

← 8/~~cell~~ bunch

{4 bucket
{spacing
no wiggles

One train missing ↗ 9 3 10 2 9 3 10 2
Bunch ... Gaps

Started SLM correlation plots ⇒ 15

5 |||||× |||||×

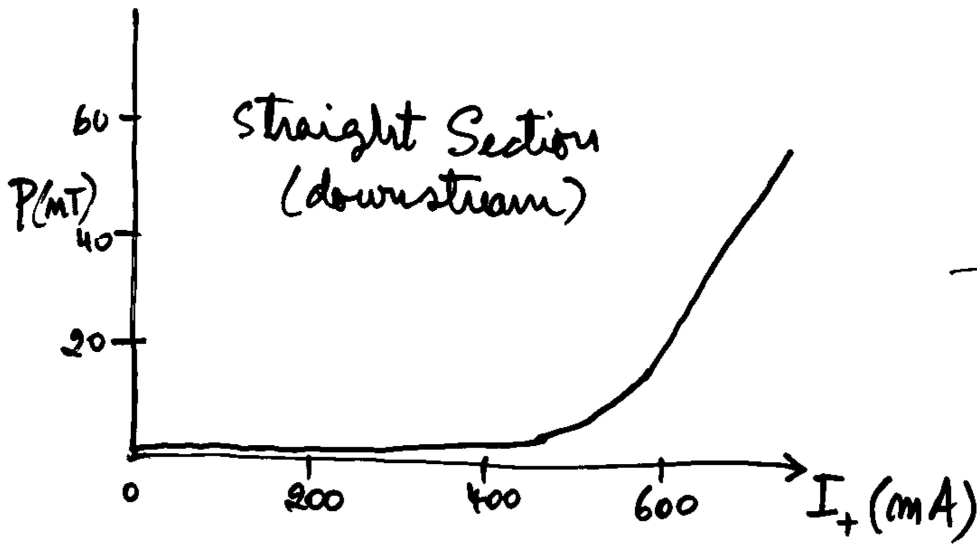
+ many (every 14) mini gaps

0:3320:4:20:3320:24=0:72:3320:144=0:
76:3320:144=0:80:3320:144=0:84:3320:
144=0:88:3320:144=0

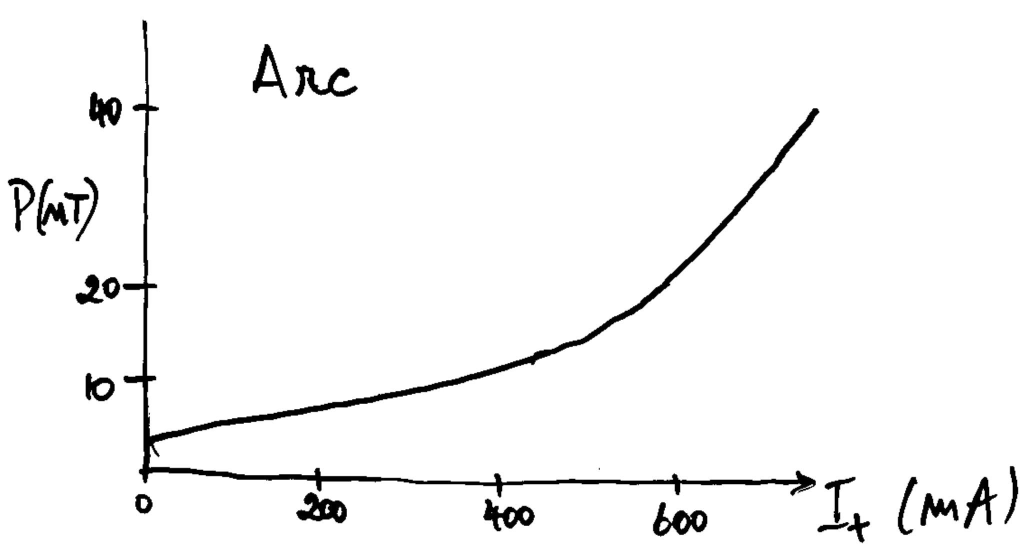
0:3320:4:20:3320:24=0:72:3320:144=0:
76:3320:144=0:80:3320:144=0:84:3320:
144=0:88:3320:144=0

Filling first mini-gap

PEP-II e+ RING



→ BIM



PEP-II

- HAVE WRAPPED ~~20~~ 10 G SOLENOIDS IN ALL STRAIGHT SECTIONS
  (HELPS BY A FACTOR ~ 2)
- CONSIDERING WRAPPING SOLENOIDS EVERYWHERE
- $\mathcal{L}$ REACHED 2.6×10^{33} (NOMINAL = 3×10^{33})

KEK-B

- C-YOKE MAGNETS IN STRAIGHTS DON'T WORK
- SOLENOIDS (~~10~~ 20 G) HELP

  $\mathcal{L}$ = ?

LHC Project Note 150

July 1998

Electron Cloud : an Analytic View

L. Vos SL/AP

Keywords : electron cloud

Summary

Electron cloud activity has been observed in some positron storage rings but not in others. It is a major concern for the LHC. In this paper the electron cloud problematics is treated purely analytically. The equilibrium electron cloud density is derived from the standard photon production rate, taking into account the photo-electric yield and the process of secondary emission. A fundamental ingredient in the derivation is the Kollath[2] energy spectrum of the secondary emission. The phenomenon of space charge is discussed as well. The transverse acceleration of the electrons by the bunches is used to introduce the concept of *closely* and *sparsely* bunched beams. There is a fundamental difference between them, especially from the point of view of power deposition. Expressions for an equivalent transverse impedance and imaginary tune shift are derived. Finally the analysis is confronted with electron cloud observations in existing positron machines (DAΦNE, PF, BEPC) before it is applied to the LHC. It comes out rather clearly that the nominal 25 *ns* bunch spacing in the LHC does not offer enough safety margin in terms of power deposition in the beam screen and that the alternative of 50 *ns* deserves serious consideration.

1 Introduction

The aim of this report is to study the effects related to an electron cloud created by the synchrotron radiation of a positively charged particle beam. It can be considered complementary to earlier papers [4,5]. The analysis is applied to the LHC but also extended to other machines. The build-up of the electron cloud is a two-stage process. It starts with the production of a photo-electron which then can trigger one or several secondary emissions. The creation and recombination of electrons will reach an equilibrium. The effects of the cloud on the beam and its environment can be derived from the equilibrium state.

2 Photo-electron production rate

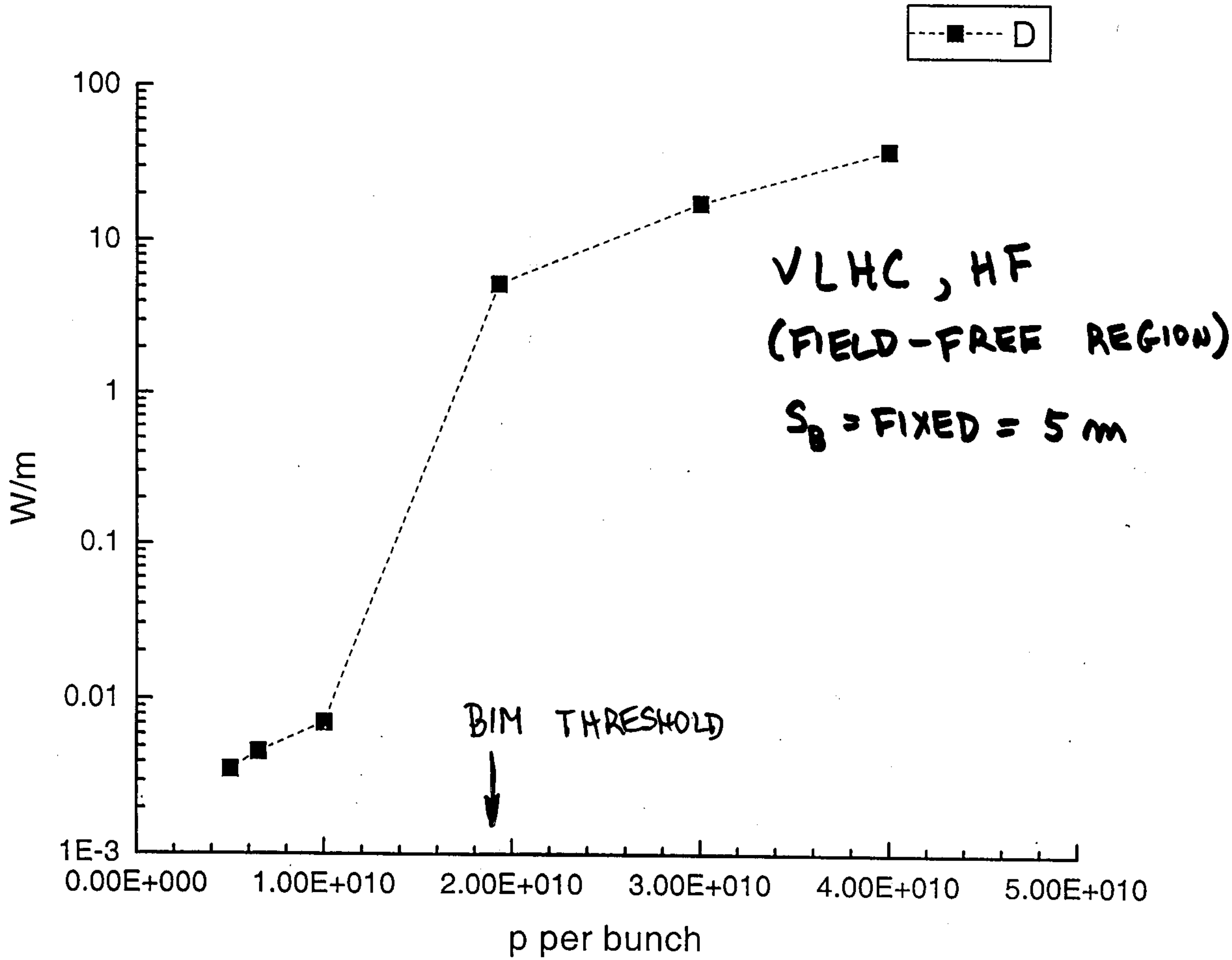
A single particle circulating in a machine with revolution period T and relativistic factor γ will produce photons per unit length at the following rate [1] :

W. TURNER'S SPREADSHEET (LUC VOS'S FORMULAS, LHC-NOTE-150 (7/98))

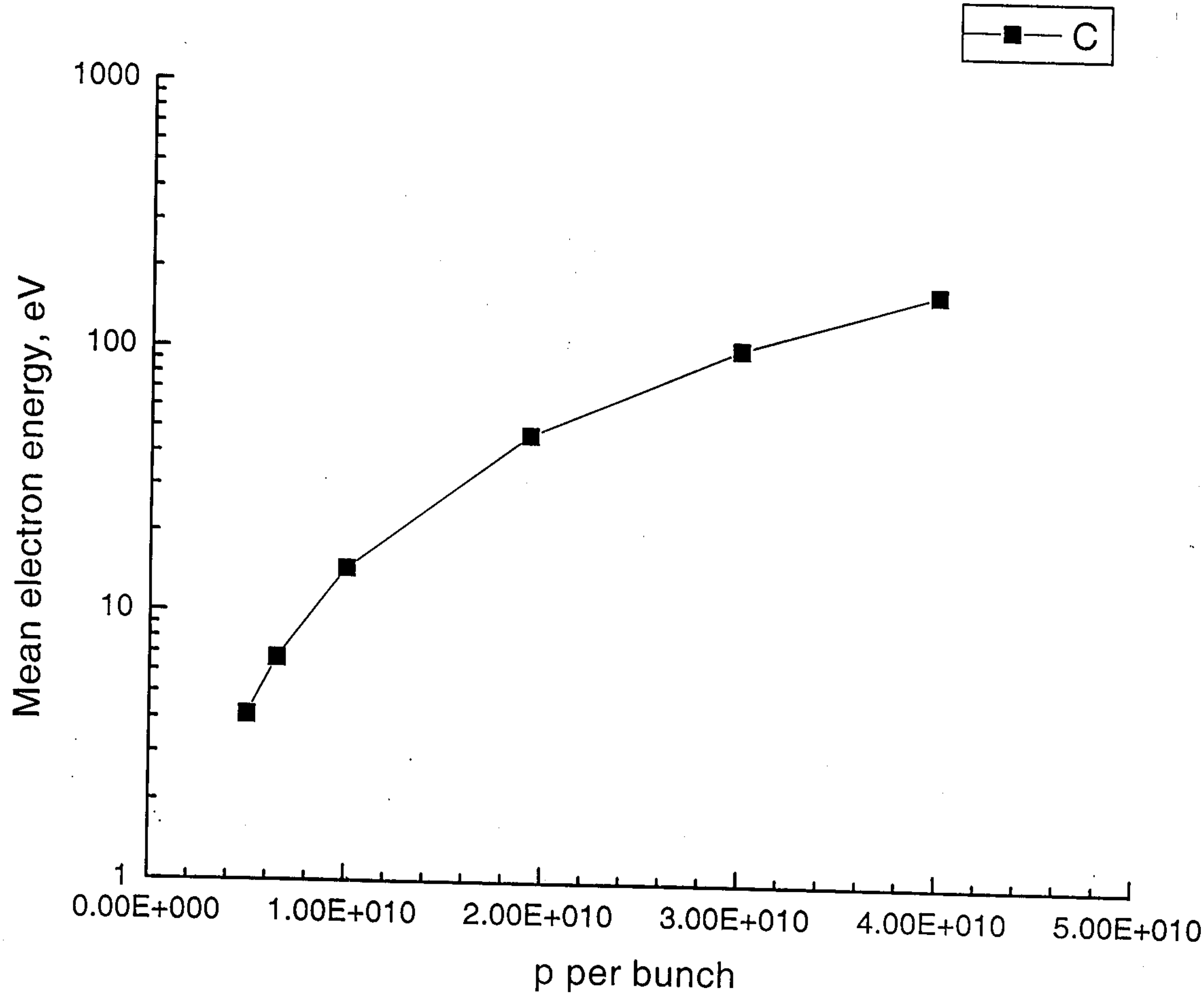
FIELD-FREE REGIONS

Model calculations of electron cloud parameters
11-Sep-00

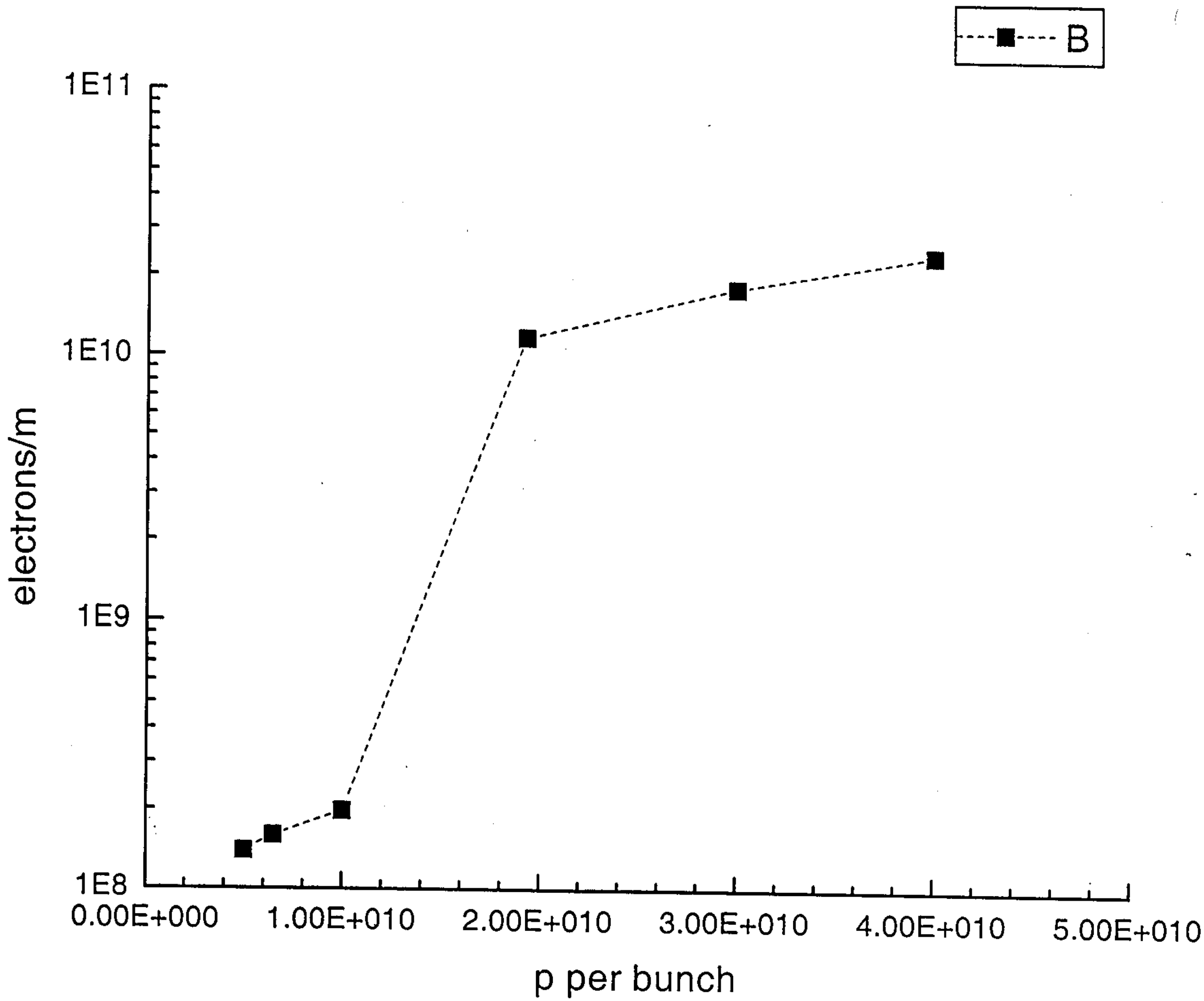
Parameter	KEK-LER	PEPII-LER	LHC	SSC	VLHC-HF	VLHC-LF	RHIC	RDM+ ~~RHIC~~ II	
E, GeV	3.5	3.1	7.00E+03	2.00E+04	5.00E+04	5.00E+04	1.00E+02		
γ	6.85E+03	6.07E+03	7.46E+03	2.13E+04	5.33E+04	5.33E+04	1.07E+02		
C, km	3.02	2.2	26.66	87.12	104.00	646.00	3.83		
ρ, m	16.3	13.75	2.78E+03	1.02E+04	13214.28571	9.25E+04	2.38E+02		
n_b	3.30E+10	5.90E+10	1.05E+11	7.50E+09	5.00E+09	9.40E+09	7.90E+10		
N_b	4950	1658	2835	17333	20690	128594	60	120	
σ_z, cm	0.4	1	7.7	7	1.42	1.42	10		
t_{bb}, nsec	1.97	4.2	24.95	16.67	16.67	16.67	228.4	114.2	
I, A	2.60E+00	2.13E+00	5.36E-01	7.16E-02	4.77E-02	8.98E-02	5.94E-02		
I_{bt}, A	2.68E+00	2.25E+00	6.73E-01	7.20E-02	4.80E-02	9.02E-02	5.94E-02		
$I_{bt,res}$, A	107.75	6.71	9.85E-02	1.74E-01	1.85E-01	6.81E-02	4.45E-03		← $1.7\times10^4 (b/s_B)^2$
b, cm	4.7	2.5	1.8	1.6	1.65	1	3.5		
photons/m-sec	2.52E+18	2.56E+16	7.79E+16	7.28E+15	1.02E+16	3.08E+15	-		
E_c, eV	5.85E+03	4.82E+03	4.43E+01	2.81E+02	3.40E+03	4.85E+02	1.51E-03		
$\langle E\rangle_\nu$, eV	1.80E+03	1.48E+01	1.36E+01	8.65E+01	1.05E+03	1.49E+02	-		
$P'_{\nu,bt}$ W/m	7.25E+02	6.08E-02	1.70E-01	1.01E-01	1.70E+00	7.36E-02	-		← S.R. POWER
g	3.54E+00	2.16E+00	5.22E-01	1.77E+00	2.80E+00	1.99E+00	1.20E+00		
$\langle\Delta E\rangle$, eV	2.83E+01	1.95E+02	2.88E+02	6.31E+00	4.17E+00	2.84E+01	9.89E+01		
$\Delta E(b)$, eV	3.99E+00	4.51E+01	2.76E+02	1.78E+00	7.44E-01	7.16E+00	4.13E+01		
t_{bb}/t_{tr}	2.49E-02	3.36E-01	6.85E+00	4.14E-01	2.59E-01	1.33E+00	1.25E+01	6.24E+00	← IMPORTANT
$f_{eb}(2t_{bb})$	1.58E-01	5.78E-01	2.61E+00	6.42E-01	5.08E-01	1.15E+00	3.65E+00		
Matl	Cu	Al(TiN)	Cu(cond.)	Cu	Cu	Al (warm)	SS		
α	1	1	0.66	1	1	0.9	0.1		
κ	0	0	0	0	0	0	0		
δ_ν	0.2	0.2	0.2	0.2	0.2	0.2	0.2		
δ_{se}	2.1	1.1	1.1	2.1	2.1	3.5	2.7		
kT_{se}(eV)	3.5	3.5	3.5	3.5	3.5	3.5	3.5		
N'_{ec}, e/m	1.32E+10	4.10E+07	1.03E+09	7.94E+07	1.40E+08	-	-		
$N'_{ec,sc}$, e/m	3.65E+09	3.65E+09	3.65E+09	3.65E+09	3.65E+09	3.65E+09	3.65E+09		
P'_{ec}, W/m	8.88E-01	4.74E-03	1.90E+00	2.57E-03	3.59E-03	-	-		
$P'_{ec,sc}$, W/m	2.45E-01	-	6.74E+00	-	-	9.96E-01	2.53E-01	5.06E-01	


D
100
10
1
0.1
0.01
1E-3
W/m
0.00E+000
1.00E+010
2.00E+010
3.00E+010
4.00E+010
5.00E+010
p per bunch
VLHC, HF
(FIELD-FREE REGION)
S_B = FIXED = 5 m
BIM THRESHOLD

n_b	N'_{ec} e/m	$\langle \Delta E \rangle$,eV	P'_{ec} W/m
5.00E+09	1.40E+08	4.14E+00	3.59E-03
6.50E+09	1.60E+08	6.72	4.66E-03
1.00E+10	1.98E+08	14.6	7.18E-03
1.93E+10	1.17E+10	47.2	5.28
3.00E+10	1.81E+10	102	17.8
4.00E+10	2.42E+10	168	38.9



C
1000
100
10
1
Mean electron energy, eV
0.00E+000
1.00E+010
2.00E+010
3.00E+010
4.00E+010
5.00E+010
p per bunch



B
1E11
1E10
1E9
1E8
electrons/m
0.00E+000
1.00E+010
2.00E+010
3.00E+010
4.00E+010
5.00E+010
p per bunch

BNL Brookhaven National Laboratory
RHIC Accelerator Physics Group

RHIC/AP/150

Beam Induced Electron Clouds at RHIC

Kirsten A. Drees

Abstract

The development of a beam induced electron cloud in the vacuum pipe of RHIC depends mainly on three parameters: the radius of the beam pipe, the secondary emission yield of the vacuum chamber material and the time gap between two consecutive bunches. A simple model estimates the mean survival probability of electrons in the beam pipe, the effective yield and the dissipated power in the chamber wall due to the electron cloud. Calculations are made taking into account two different operation schemes with 60 and 120 bunches respectively. No effect is expected for an operation with 60 bunches while the potential RHIC upgrade with 120 bunches runs the risk to produce an unacceptable heat load in the chamber wall.

March 13, 1998

CONCLUSIONS

- ECE IS IMPORTANT
  * LIMITING PERFORMANCE OF PEP-II + KEKB
  * SERIOUS ISSUE FOR LHC
  * SEEN AT SPS WITH LHC-TYPE BEAMS
  * IMPLICATED IN PSR INSTABILITY
  * ISR, PHOTON FACTORY

- VLHC - HF:
  * $P'_{e^-} \simeq 4$ mW/m (← @ 5×10^9 ppb), $P'_\gamma \simeq 1.7$ W/m
  * GROWS QUICKLY IF $N \gtrsim 2\times10^{10}$ → ~10 W/m

- VLHC - LF
  * $P'_{e^-} \sim 1$ W/m, $P'_\gamma \simeq 7\times10^{-2}$ W/m
  * RED ~~LIGHT~~ FLAG: CLOSE TO BIM THRESHOLD
    VAC. ISSUE, BEAM STABILITY ISSUE

- RHIC @ 60 BUNCHES:
  * $P'_{e^-} \simeq 0.25$ W/m

- SPREASHEET FORMULAS NEED TO BE VALIDATED
  * MANY SIMPLIFYING ASSUMPTIONS → ROUGH FIRST CUT

- ECE ALSO LEADS TO INSTABILITIES
  * MULTIBUNCH DIPOLE } SIMULATIONS
  * SINGLE BUNCH: ε-BLOWUP } SIMULATIONS
  → NO TIME TO DO THIS AT THIS WORKSHOP
  → HOPEFULLY BEFORE THE VLHC IS BUILT