Working Session on Diagnostics

Discussion on BPM requirements,
emittance measurements, etc

TDR Topic List

- Injection System
  - Polarized gun
  - damping rings
  - spin manipulators
  - linac
  - positron converter
  - beam transfer systems

- Collider design
  - Two rings lattice
  - Polarization insertion
  - IR design
  - beam stay clear
  - ultra-low emittance tuning
  - detector solenoid compensation
  - coupling correction
  - orbit correction
  - stability
  - beam-beam simulations
  - beam dynamics and instabilities
  - single beam effects
  - operation issues
  - injection scheme

- RF System
  - RF specifications
  - RF feedbacks
  - Low level RF
  - Synchronization and timing
- Site
  - Civil construction
  - Infrastructures & buildings
  - Power plants
  - Fluids plants
  - Radiation safety

- Magnets
  - Design of missing magnets
  - Refurbishing existing magnets
  - Field measurements
  - QD0 construction
  - Power supplies
  - Injection kickers

- Mechanical layout and alignment
  - Injector
  - supports

- Vacuum system
  - Arcs pipe
  - Straights pipe
  - IR pipe
  - e-cloud remediation electrodes
  - bellows
  - impedance budget simulations
  - pumping system

- Diagnostics
  - Beam position monitors
  - Luminosity monitor
  - Current monitors
  - Synchrotron light monitor
  - R&D on diagnostics for low emittance

- Feedbacks
  - Transverse
  - Longitudinal
  - Orbit
  - Luminosity
  - Electronics & software

- Control system
  - Architecture
  - Design
  - Peripherals

Storage Ring Diagnostics

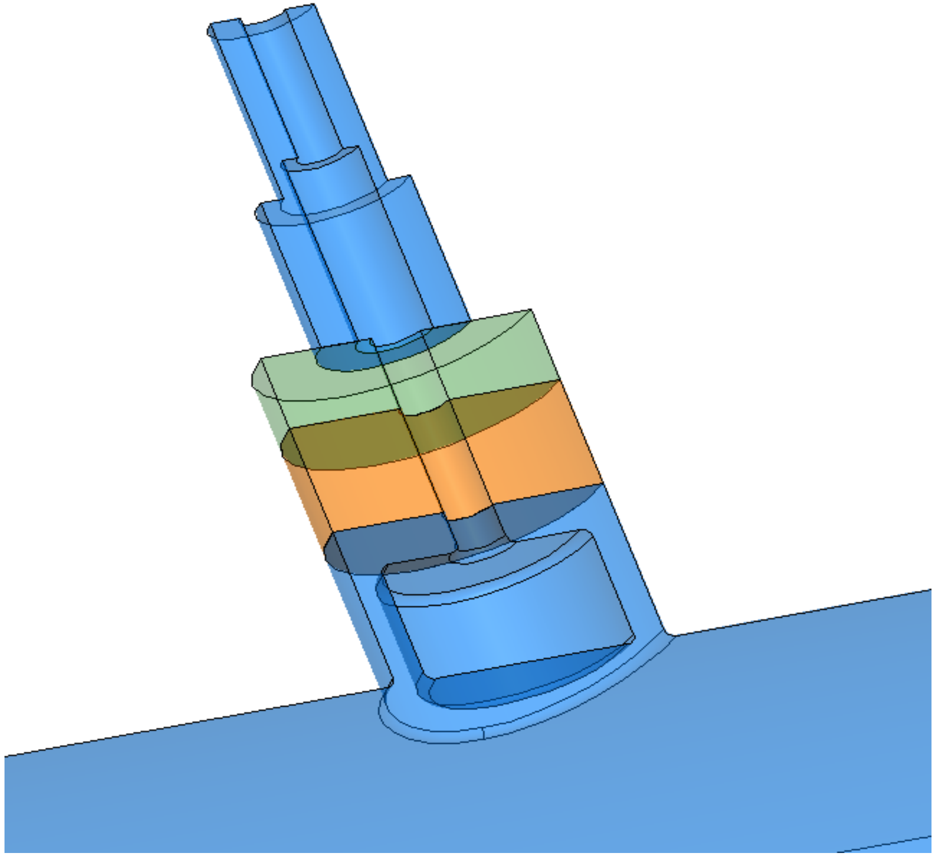
- Very small emittance
  - Coupling control
  - Closed orbit (feedback) correction
- IP stability
- High current
  - large dynamic range from *run-in* to luminosity run
  - machine protection (beam power & SR power)
- [Injection & Transfer], [Luminosity], etc

Use of Diagnostics

Type	First Turn	Run-in	Machine Studies	Luminosity Run
Dynamic range > 66 dB	< 1 mA	10-200 mA	200-2000 mA	2000 mA
Screen	x			
BPM-Single pass	Coarse	Coarse	Fine	
BPM-Stored beam		Coarse	Hi-res	Hi-res + FBK
BPM-Bunch by bunch		Coarse	x	Low noise
Beam Profile (visible light)	Coarse	Fine	Fine	Fine
Beam Size (X-ray/Laser)			Hi-res	Hi-res
Beam-beam scan			x	
Tune Monitor		x	x	x
Tune kick (H&V)		x	x	
Current-Lifetime	Coarse	Coarse	Fine	Fine
Polarization			?	?
Beam Loss	Coarse	x	x	x

BPM

- How many ?
  - Beam based alignment
  - Correction method
- Resolution
  - Dynamic range/Low HOM impedance
  - Frequency response
  - Damage
- Detector electronics/software



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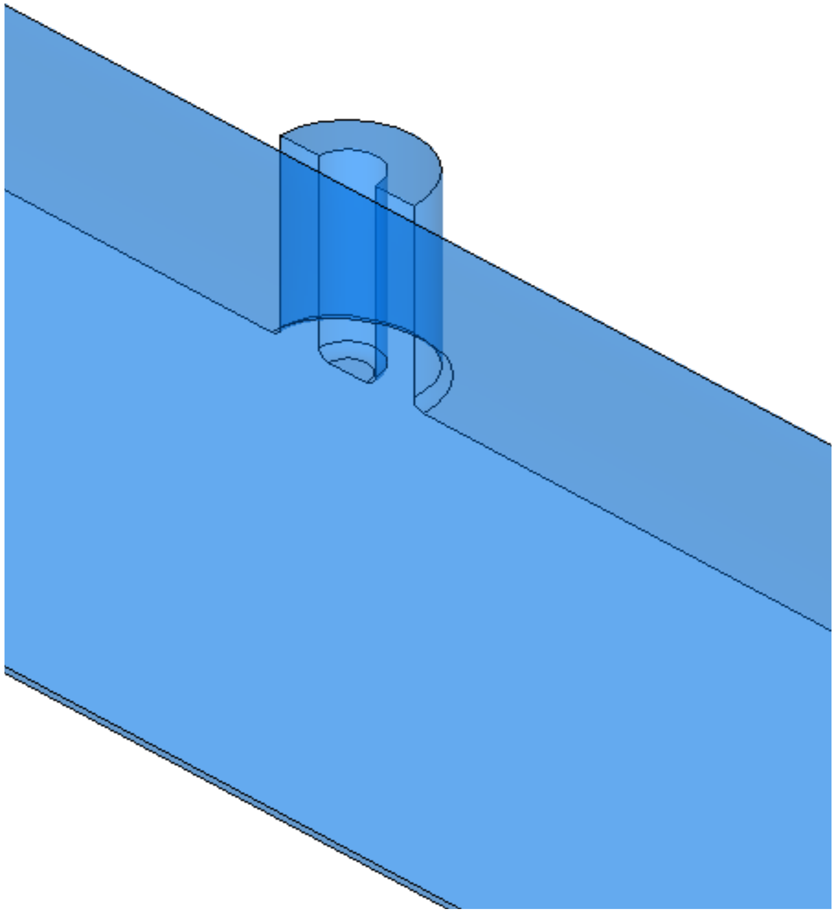
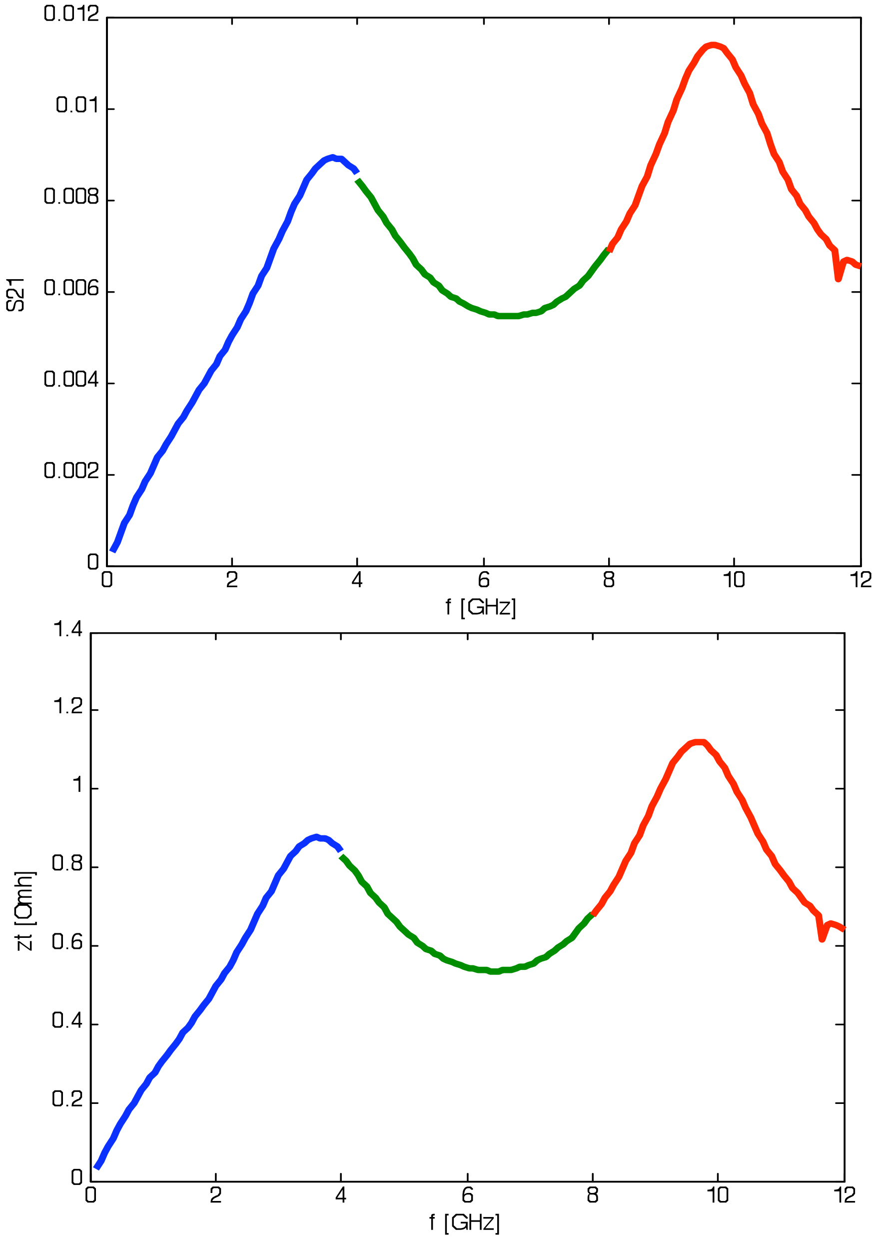


“B”

“A”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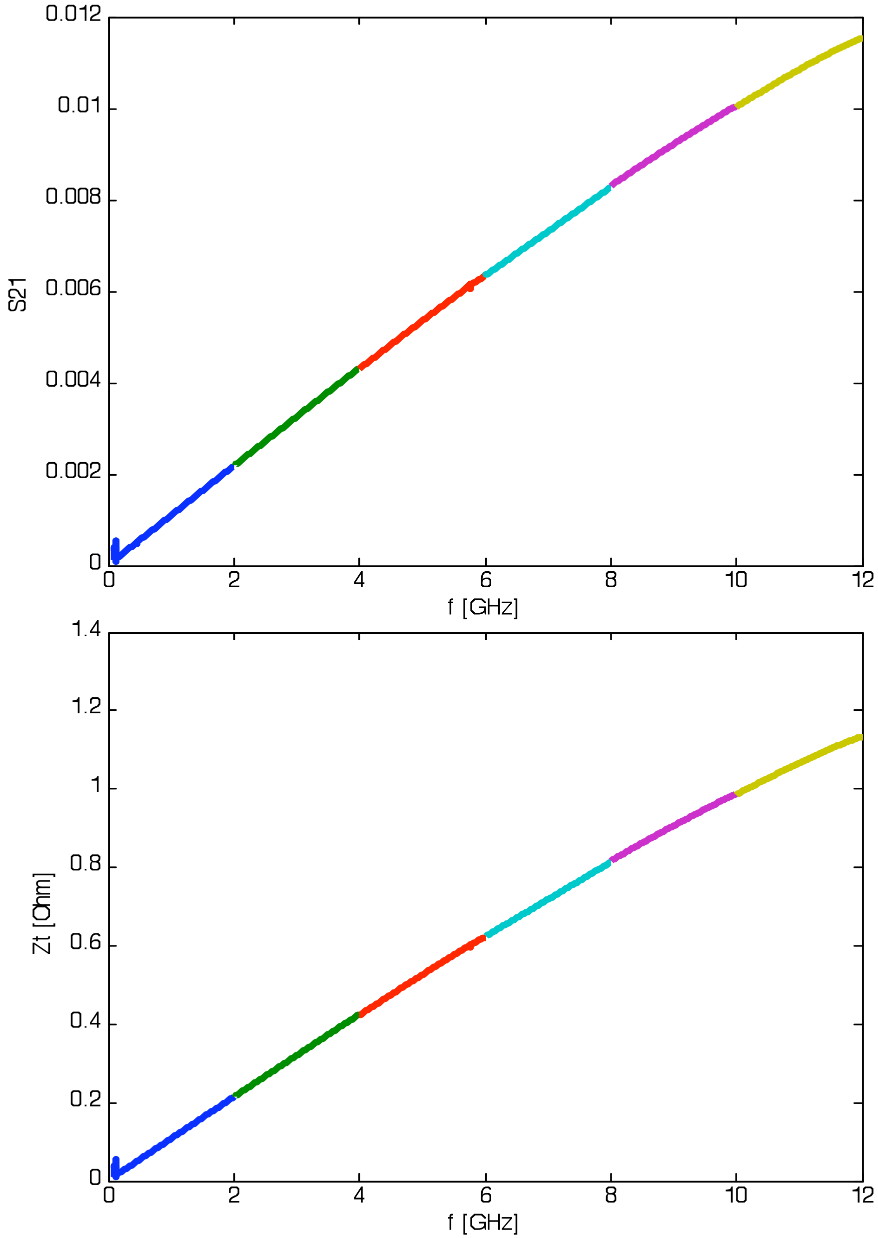
f [GHz]

“B”


0.012
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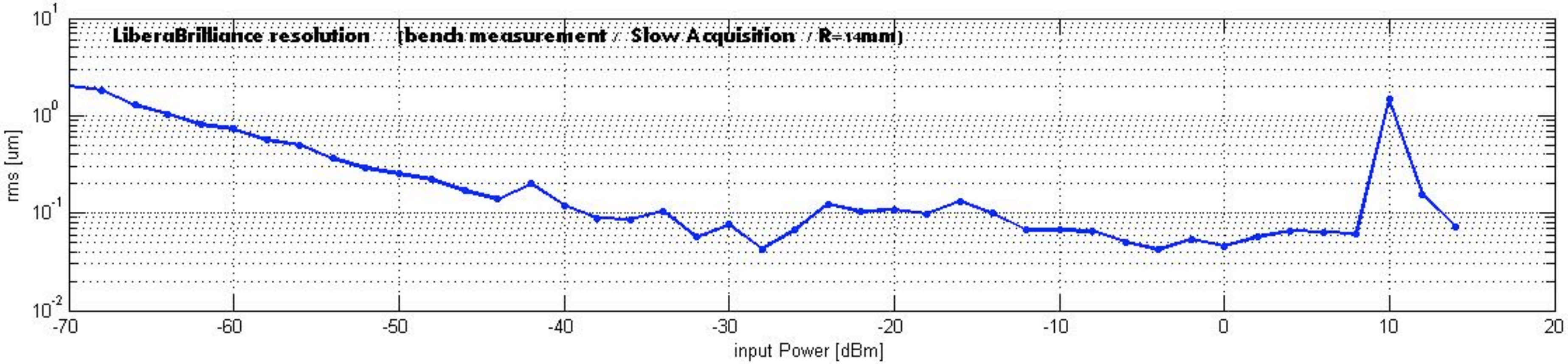
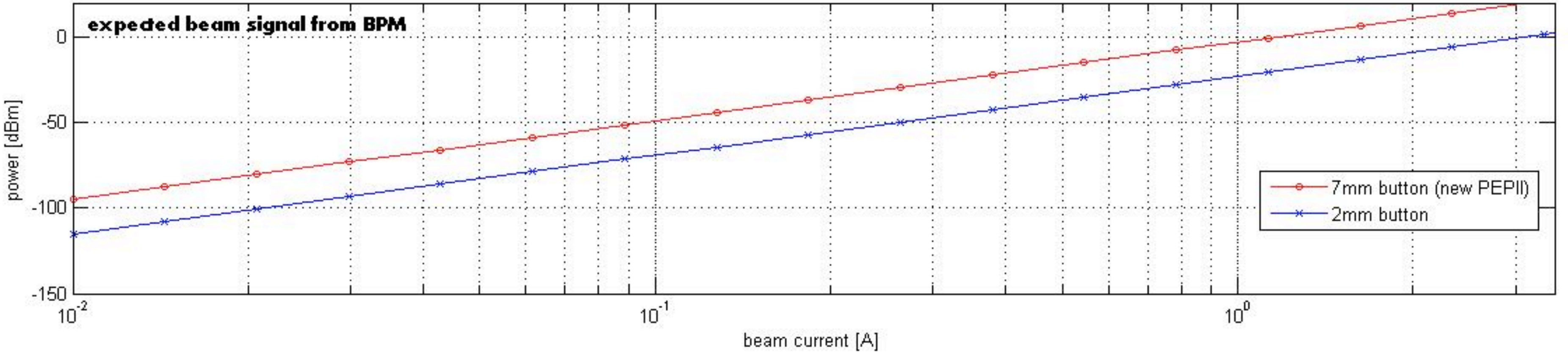
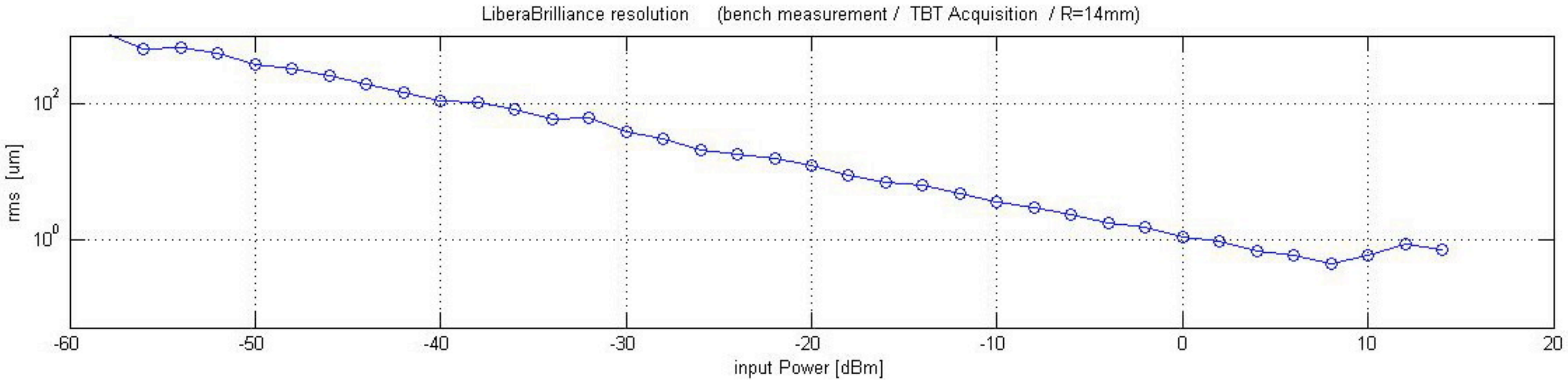
LIBERA *BRILLIANCE*
LAB MEASUREMENTS



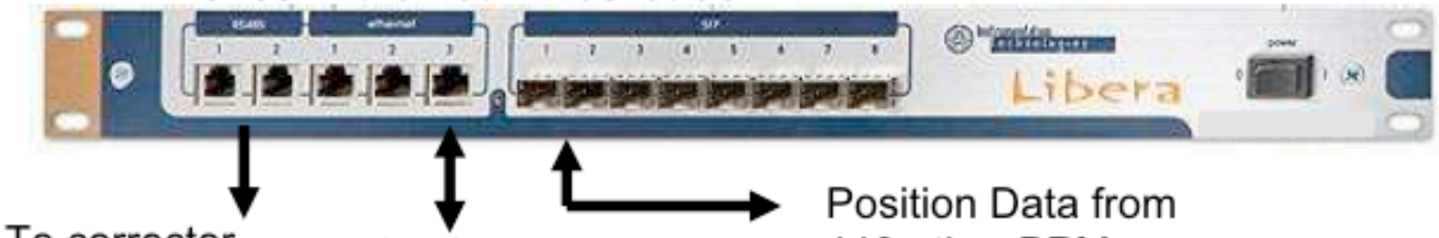


Single pass mode



FOFB Architecture

- Dedicated air coil correctors
  - over stainless steel bellows at each side of straight sections
- An 'all embedded' solution
  - All the processing of the FOFB is done in the LIBERA FPGA, on top of the position calculation provided by Instrumentation Technologies
  - Need all interfaces built in the LIBERA for data exchange.



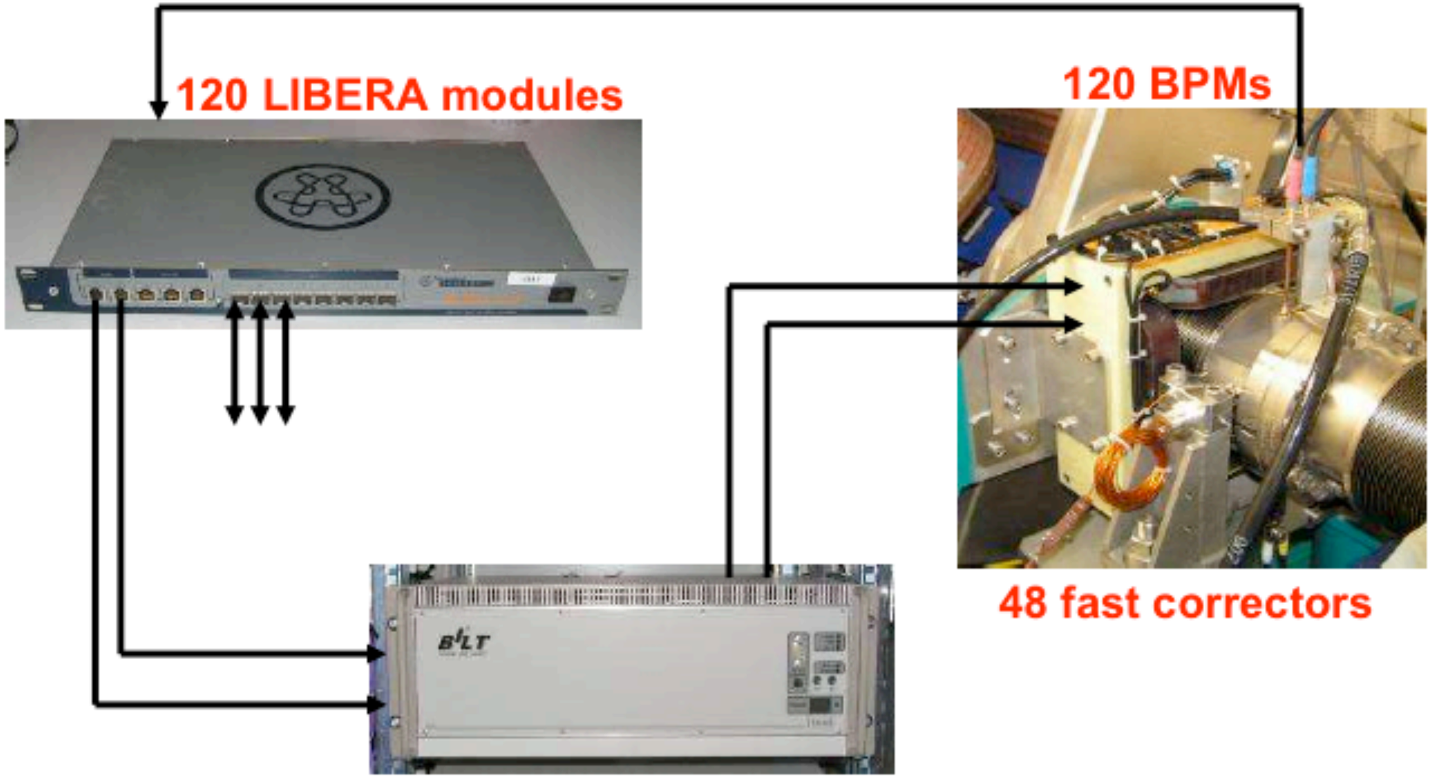
RS485 Ethernet Rocket I/O

To corrector
power supplies

Configuration
and monitoring

Position Data from
119 other BPMs

FOFB Architecture:



120 LIBERA modules

120 BPMs

48 fast correctors

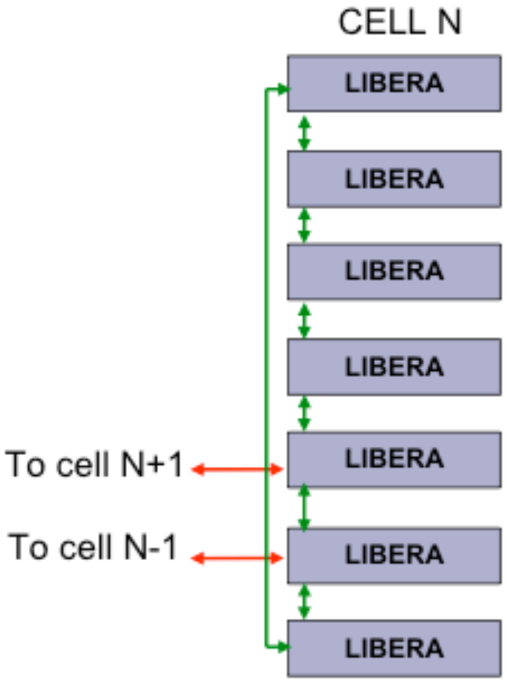
96 power-supplies

measurements, etc

FOFB Architecture:

Fast Dedicated Network

- Global Feedback:
  - Fast Acquisition data (~10 kHz) have to be delivered to all BPM modules



CELL N

LIBERA

LIBERA

LIBERA

LIBERA

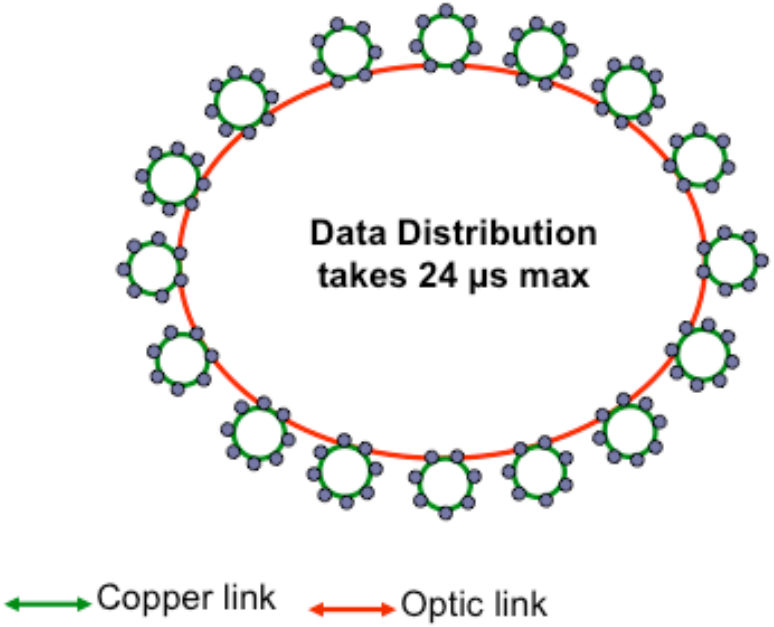
LIBERA

LIBERA

LIBERA

To cell N+1

To cell N-1



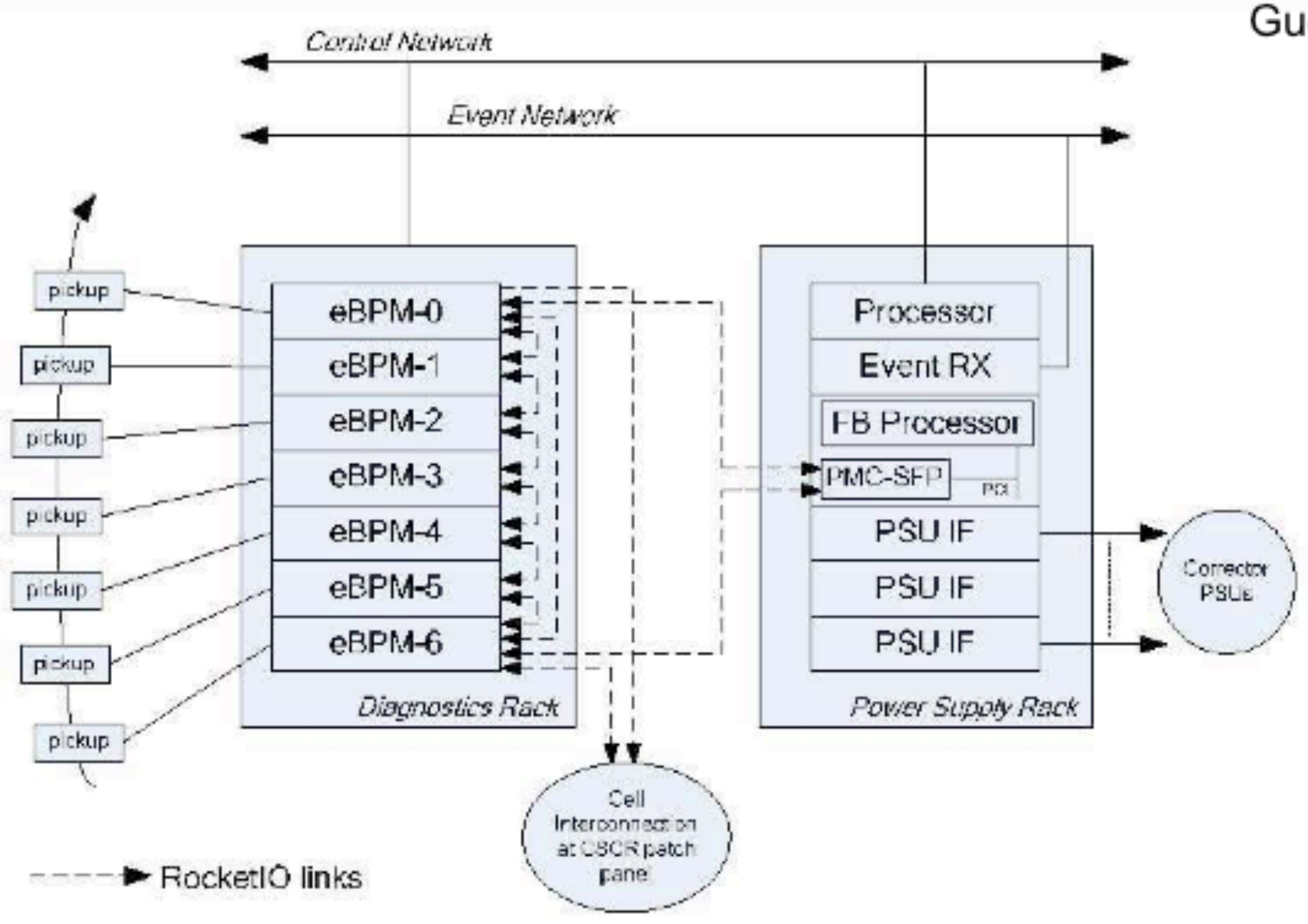
Data Distribution takes 24 µs max

Copper link

Optic link

Hybrid Example: Diamond

Courtesy of
Guenther Rehm



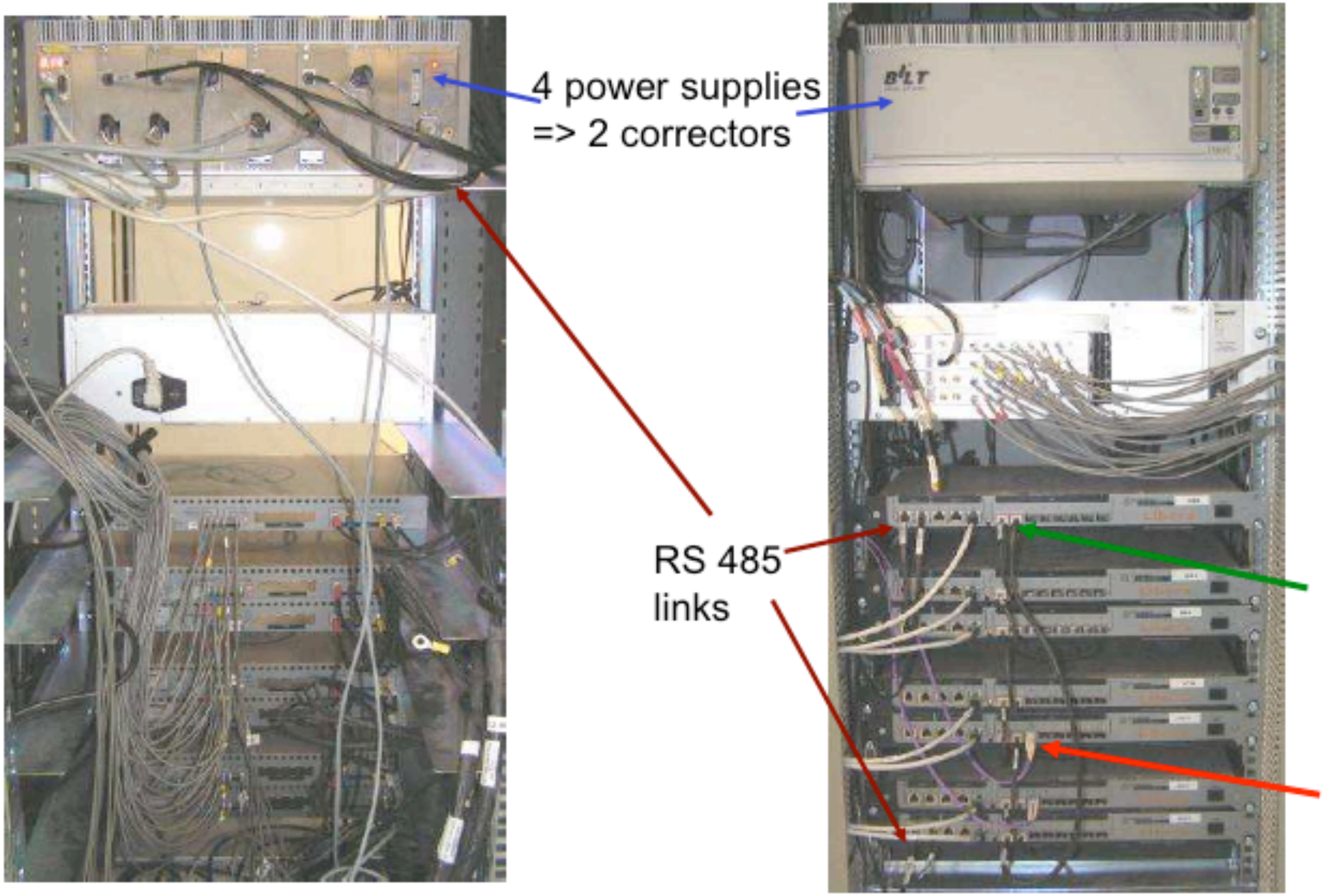
Release status

- Liberas running **release 1.82** with modified FPGA design for dedicated Fast Orbit Feedback application.

- Large amount of work for each upgrade
  - Upgrade process can be very long if Linux system is updated (1.46 to 1.60 and 1.82 to 2.0)
  - Integration and testing of FOFB application in the new FPGA design
  - Testing of all functionalities ?

- No plan for upgrade at the moment….

FOFB Architecture:



4 power supplies
=> 2 correctors

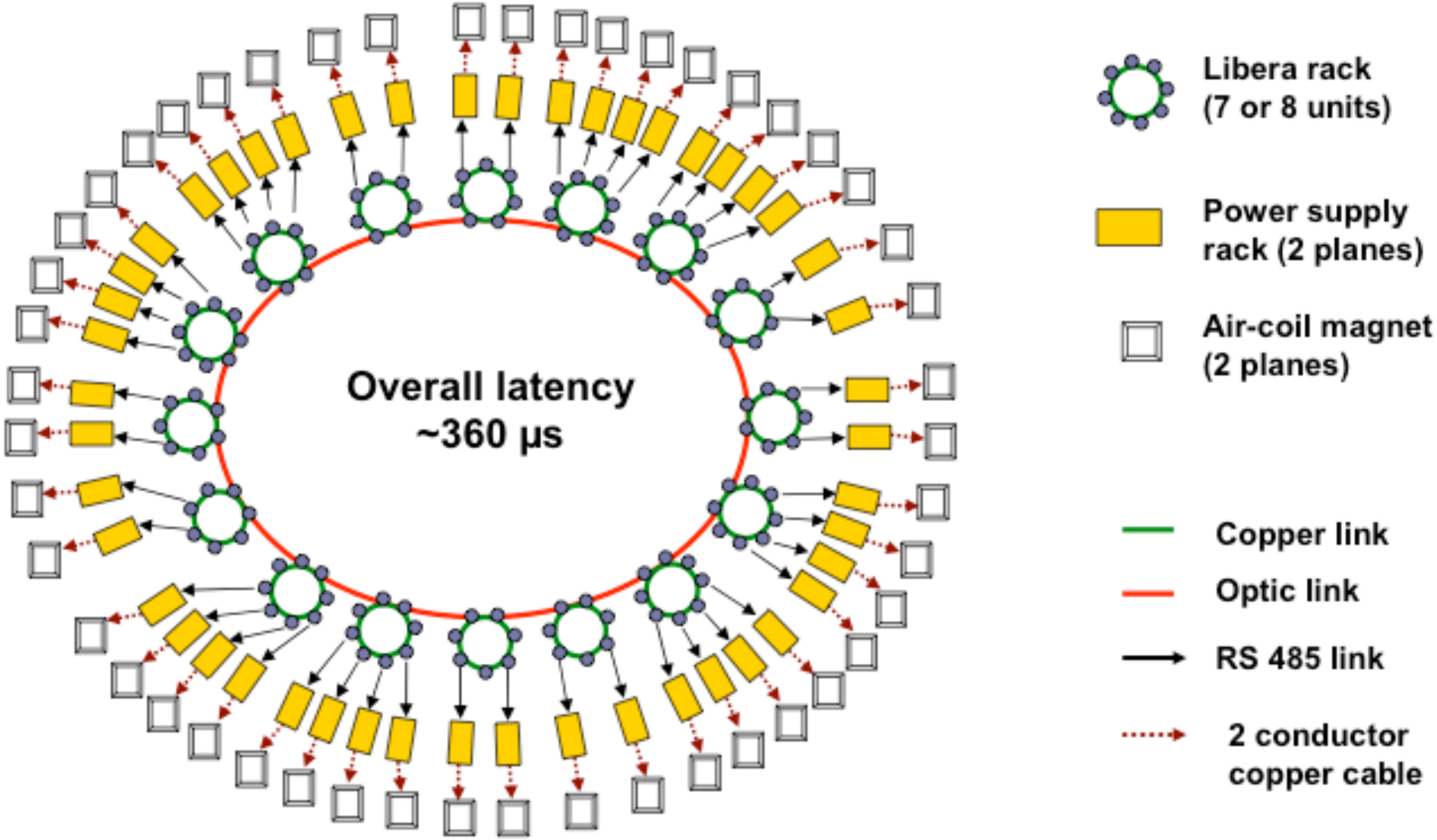
RS 485
links

Copper
links

Optic
fibers

FOFB Architecture:

Power Supply Control



Overall latency ~360 µs

- **Libera rack (7 or 8 units)**
- 🟨 **Power supply rack (2 planes)**
- ☐ **Air-coil magnet (2 planes)**
- **Copper link**
- **Optic link**
- → **RS 485 link**
- ⇢ **2 conductor copper cable**

Temperature Stabilization

- old 7 octants
  - Liberas in temperature-stabilized hutches (together with feedback electronics)

    → ± 1° C

- new experimental hall
  - hall itself is temperature-stabilized

    → ± 0.1° C

http://adweb.desy.de/mpy/FLS2006/proceedings/HTML/AUTH0130.HTM

FLS 2006

Synchrotron Radiation based transverse Emittance Diagnostics at Light Sources

Gero Kube
DESY / MDI
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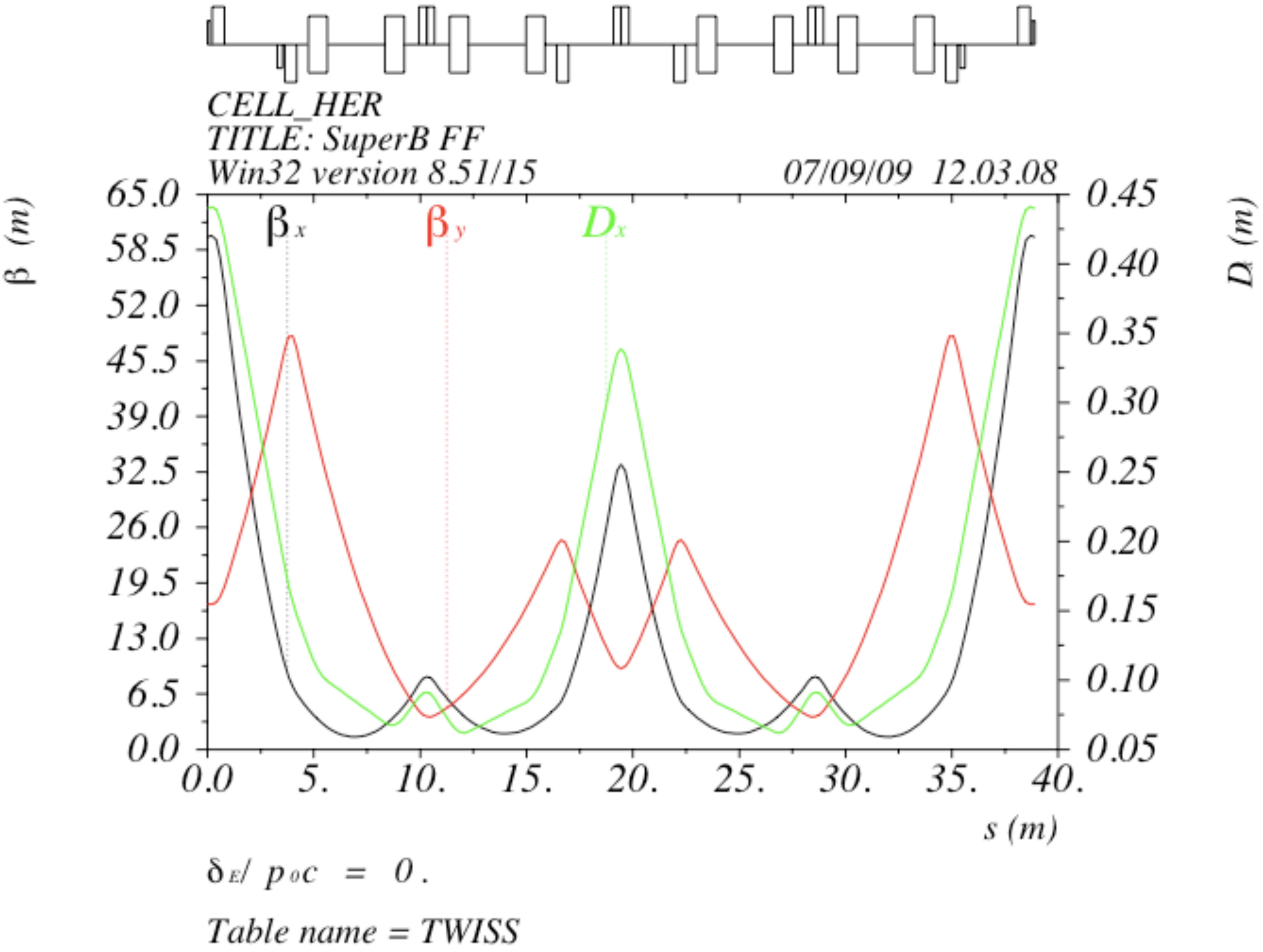
- storage rings
- bending magnets
- standard systems


CELL_HER
TITLE: SuperB FF
Win32 version 8.51/15
07/09/09 12.03.08
β (m)
65.0
58.5
52.0
45.5
39.0
32.5
26.0
19.5
13.0
6.5
0.0
βx
βy
Dx
Dx (m)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.0
5.
10.
15.
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25.
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35.
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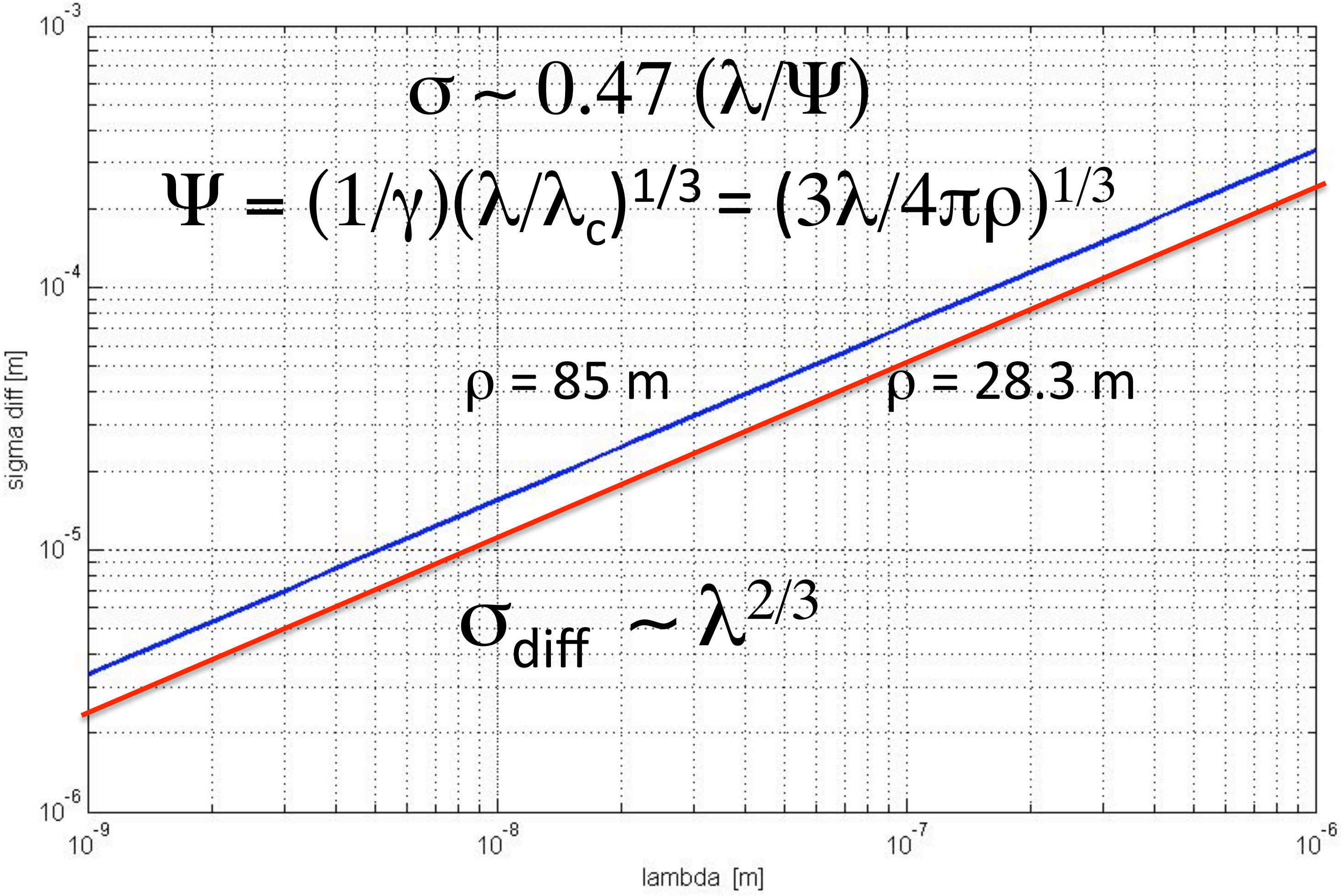
s (m)
δE/ p0c = 0.
Table name = TWISS

Diffraction Limit



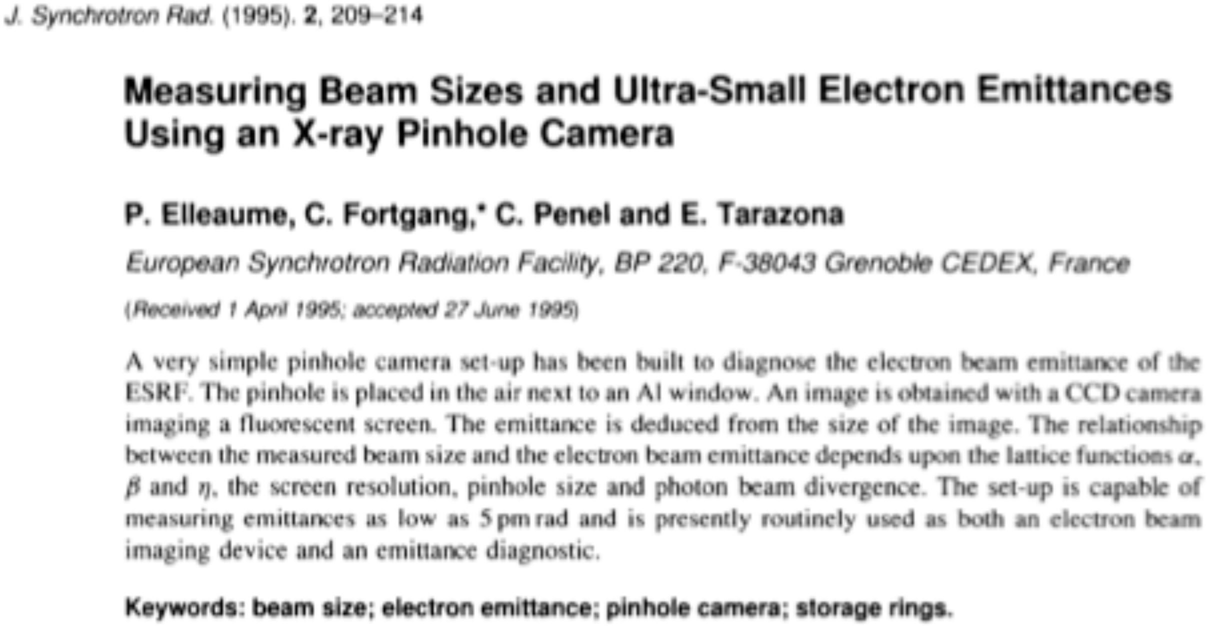
$$\sigma \sim 0.47\ (\lambda/\Psi)$$

$$\Psi = (1/\gamma)(\lambda/\lambda_c)^{1/3} = (3\lambda/4\pi\rho)^{1/3}$$

$\rho = 85$ m

$\rho = 28.3$ m

$$\sigma_{\mathrm{diff}} \sim \lambda^{2/3}$$



J. Synchrotron Rad. (1995). **2**, 209–214

Measuring Beam Sizes and Ultra-Small Electron Emittances Using an X-ray Pinhole Camera

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European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble CEDEX, France

(*Received 1 April 1995; accepted 27 June 1995*)

A very simple pinhole camera set-up has been built to diagnose the electron beam emittance of the ESRF. The pinhole is placed in the air next to an Al window. An image is obtained with a CCD camera imaging a fluorescent screen. The emittance is deduced from the size of the image. The relationship between the measured beam size and the electron beam emittance depends upon the lattice functions α, β and η, the screen resolution, pinhole size and photon beam divergence. The set-up is capable of measuring emittances as low as 5 pm rad and is presently routinely used as both an electron beam imaging device and an emittance diagnostic.

Keywords: beam size; electron emittance; pinhole camera; storage rings.

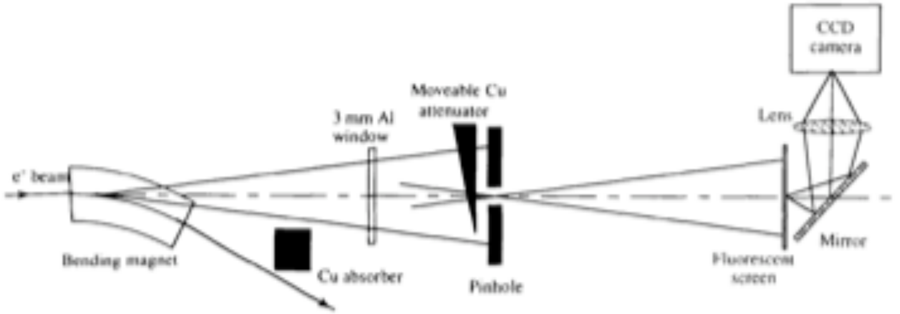
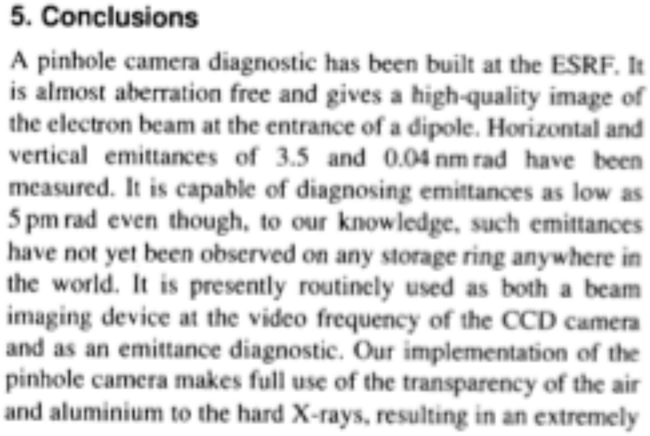
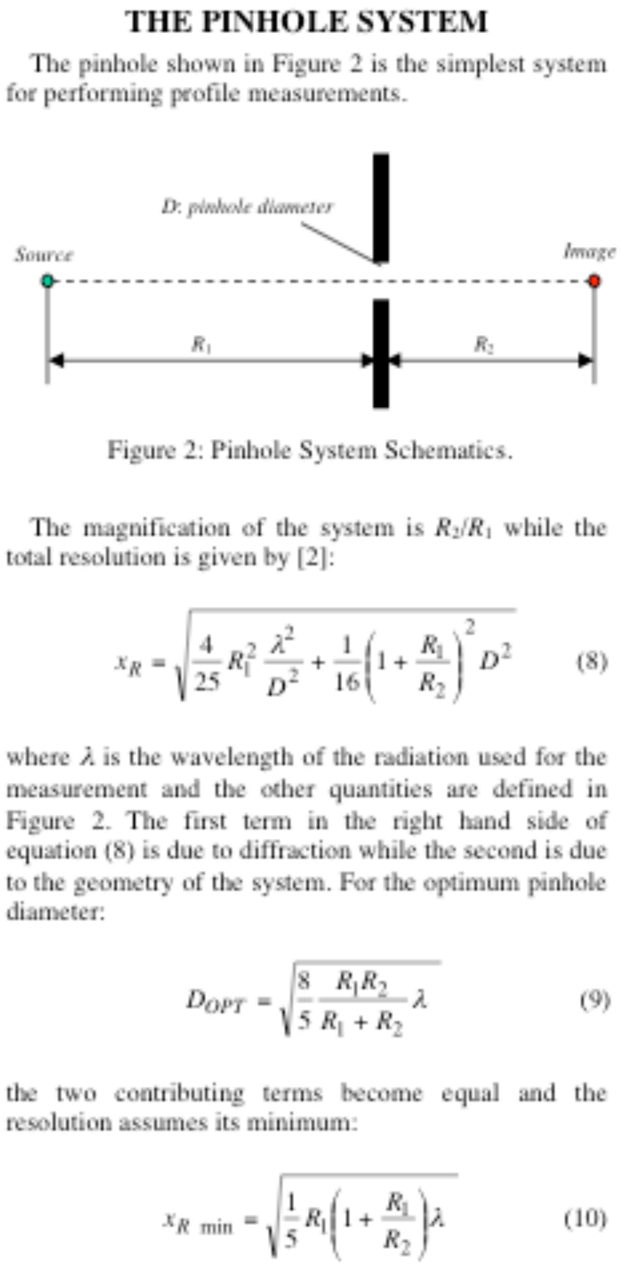


Figure 1
Schematic of the pinhole camera apparatus and the X-ray source.



5. Conclusions

A pinhole camera diagnostic has been built at the ESRF. It is almost aberration free and gives a high-quality image of the electron beam at the entrance of a dipole. Horizontal and vertical emittances of 3.5 and 0.04 nm rad have been measured. It is capable of diagnosing emittances as low as 5 pm rad even though, to our knowledge, such emittances have not yet been observed on any storage ring anywhere in the world. It is presently routinely used as both a beam imaging device at the video frequency of the CCD camera and as an emittance diagnostic. Our implementation of the pinhole camera makes full use of the transparency of the air and aluminium to the hard X-rays, resulting in an extremely



THE PINHOLE SYSTEM

The pinhole shown in Figure 2 is the simplest system for performing profile measurements.

Figure 2: Pinhole System Schematics.

The magnification of the system is R_2/R_1 while the total resolution is given by [2]:

$$x_R = \sqrt{\frac{4}{25} R_1^2 \frac{\lambda^2}{D^2} + \frac{1}{16}\left(1 + \frac{R_1}{R_2}\right)^2 D^2} \qquad (8)$$

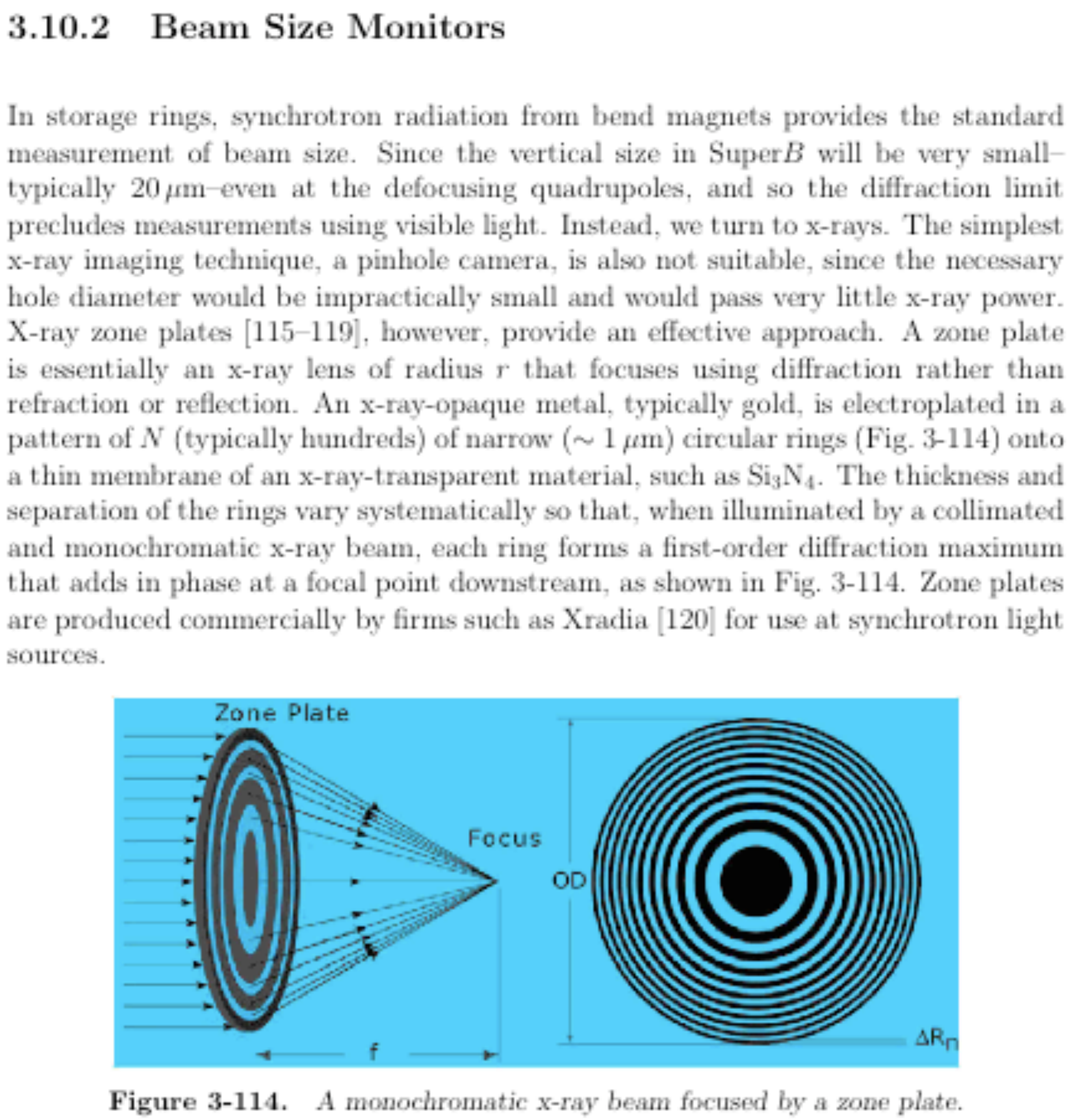
where λ is the wavelength of the radiation used for the measurement and the other quantities are defined in Figure 2. The first term in the right hand side of equation (8) is due to diffraction while the second is due to the geometry of the system. For the optimum pinhole diameter:

$$D_{OPT} = \sqrt{\frac{8}{5} \frac{R_1 R_2}{R_1 + R_2} \lambda} \qquad (9)$$

the two contributing terms become equal and the resolution assumes its minimum:

$$x_{R\ \min} = \sqrt{\frac{1}{5} R_1 \left(1 + \frac{R_1}{R_2}\right) \lambda} \qquad (10)$$

Zone Plate

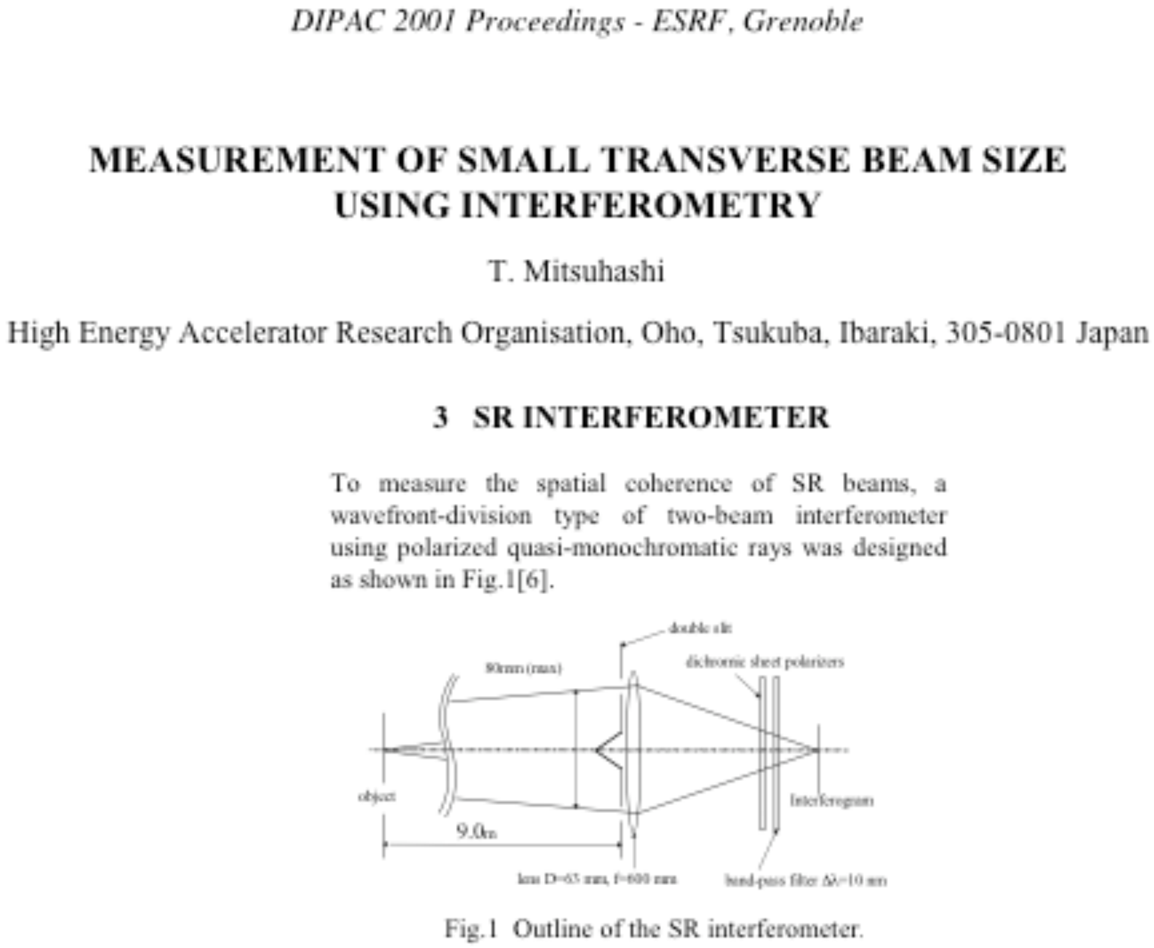


3.10.2 Beam Size Monitors

In storage rings, synchrotron radiation from bend magnets provides the standard measurement of beam size. Since the vertical size in Super$B$ will be very small–typically 20 μm–even at the defocusing quadrupoles, and so the diffraction limit precludes measurements using visible light. Instead, we turn to x-rays. The simplest x-ray imaging technique, a pinhole camera, is also not suitable, since the necessary hole diameter would be impractically small and would pass very little x-ray power. X-ray zone plates [115–119], however, provide an effective approach. A zone plate is essentially an x-ray lens of radius r that focuses using diffraction rather than refraction or reflection. An x-ray-opaque metal, typically gold, is electroplated in a pattern of N (typically hundreds) of narrow ($\sim 1\,\mu$m) circular rings (Fig. 3-114) onto a thin membrane of an x-ray-transparent material, such as Si_3N_4. The thickness and separation of the rings vary systematically so that, when illuminated by a collimated and monochromatic x-ray beam, each ring forms a first-order diffraction maximum that adds in phase at a focal point downstream, as shown in Fig. 3-114. Zone plates are produced commercially by firms such as Xradia [120] for use at synchrotron light sources.

Figure 3-114. *A monochromatic x-ray beam focused by a zone plate.*

Interferometer



DIPAC 2001 Proceedings - ESRF, Grenoble

MEASUREMENT OF SMALL TRANSVERSE BEAM SIZE USING INTERFEROMETRY

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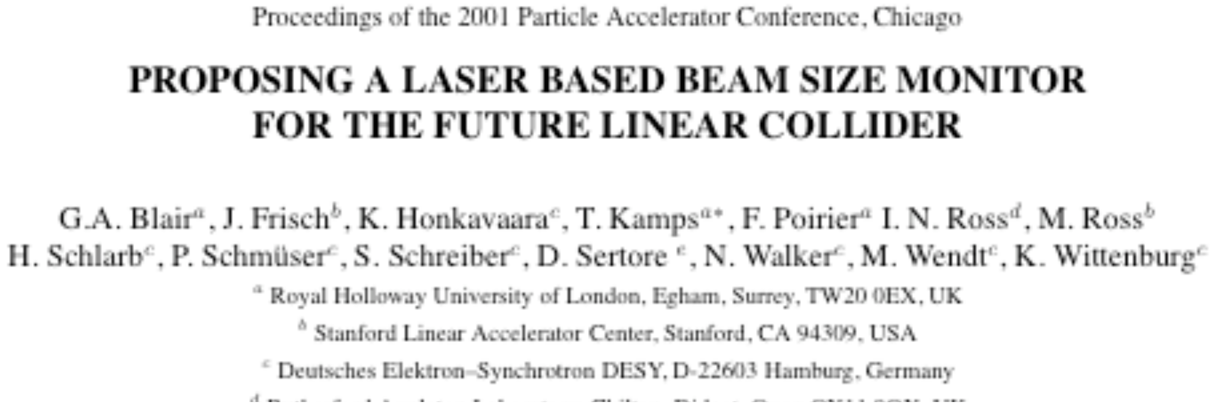
3 SR INTERFEROMETER

To measure the spatial coherence of SR beams, a wavefront-division type of two-beam interferometer using polarized quasi-monochromatic rays was designed as shown in Fig.1[6].

Fig.1 Outline of the SR interferometer.

Shintake Monitor



Proceedings of the 2001 Particle Accelerator Conference, Chicago

PROPOSING A LASER BASED BEAM SIZE MONITOR FOR THE FUTURE LINEAR COLLIDER

G.A. Blair[a], J. Frisch[b], K. Honkavaara[c], T. Kamps[a*], F. Poirier[a] I. N. Ross[d], M. Ross[b]
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Proceedings of the 2001 Particle Accelerator Conference, Chicago

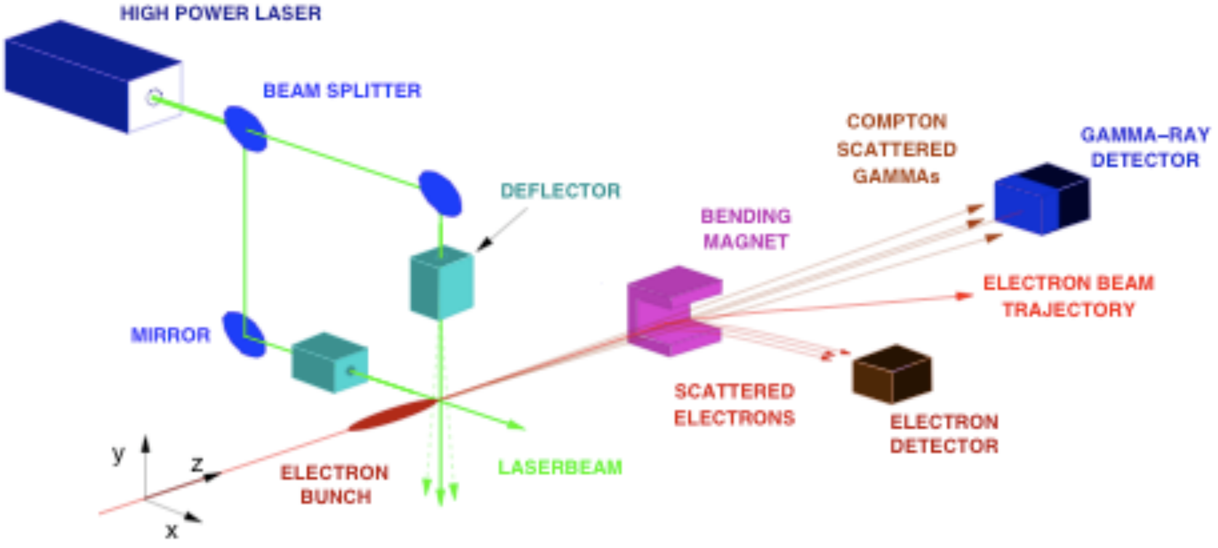
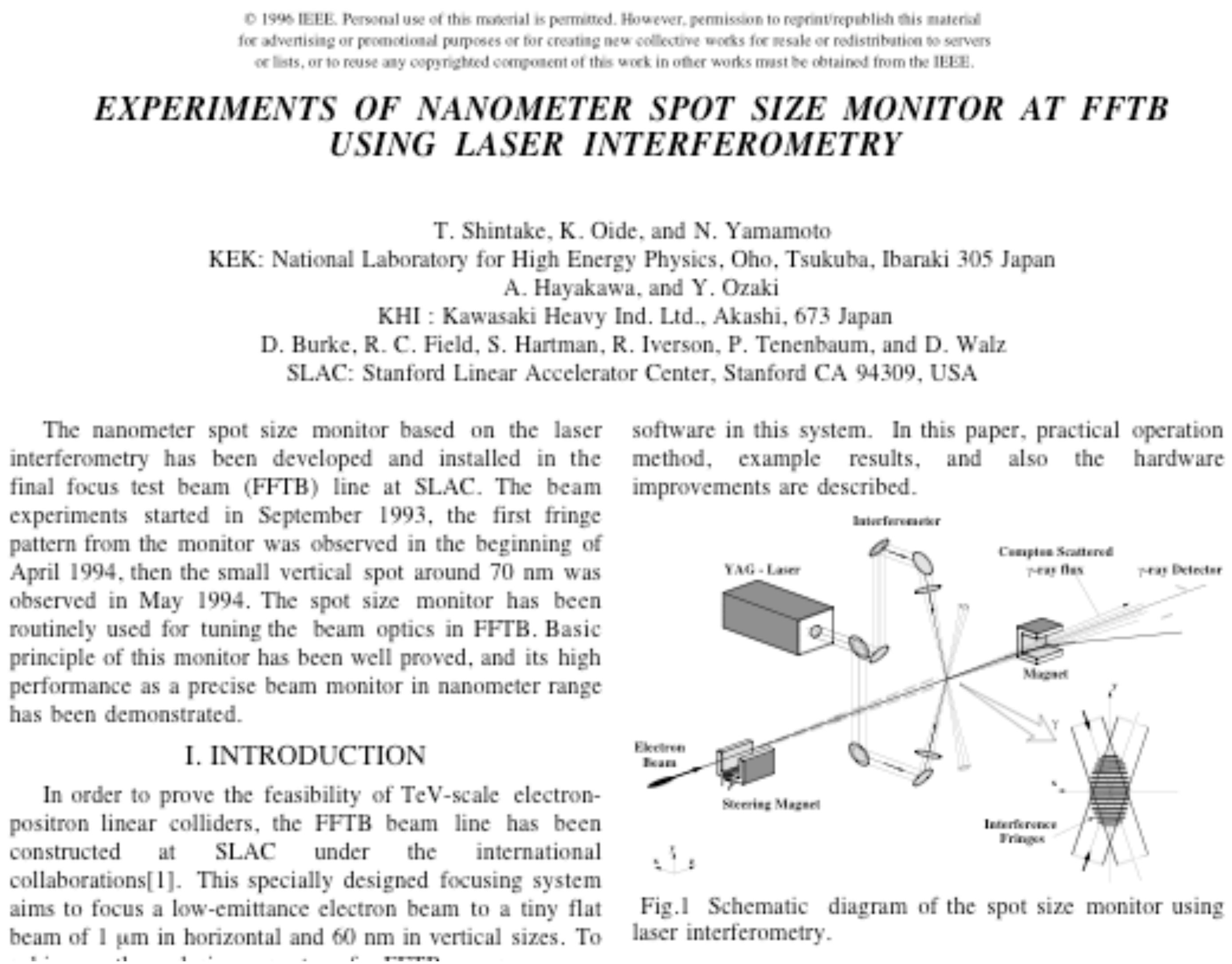


Figure 3: Schematic setup for a laser wire beam profile monitor.



EXPERIMENTS OF NANOMETER SPOT SIZE MONITOR AT FFTB USING LASER INTERFEROMETRY

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A. Hayakawa, and Y. Ozaki
KHI : Kawasaki Heavy Ind. Ltd., Akashi, 673 Japan
D. Burke, R. C. Field, S. Hartman, R. Iverson, P. Tenenbaum, and D. Walz
SLAC: Stanford Linear Accelerator Center, Stanford CA 94309, USA

The nanometer spot size monitor based on the laser interferometry has been developed and installed in the final focus test beam (FFTB) line at SLAC. The beam experiments started in September 1993, the first fringe pattern from the monitor was observed in the beginning of April 1994, then the small vertical spot around 70 nm was observed in May 1994. The spot size monitor has been routinely used for tuning the beam optics in FFTB. Basic principle of this monitor has been well proved, and its high performance as a precise beam monitor in nanometer range has been demonstrated.

I. INTRODUCTION

In order to prove the feasibility of TeV-scale electron-positron linear colliders, the FFTB beam line has been constructed at SLAC under the international collaborations[1]. This specially designed focusing system aims to focus a low-emittance electron beam to a tiny flat beam of 1 μm in horizontal and 60 nm in vertical sizes. To

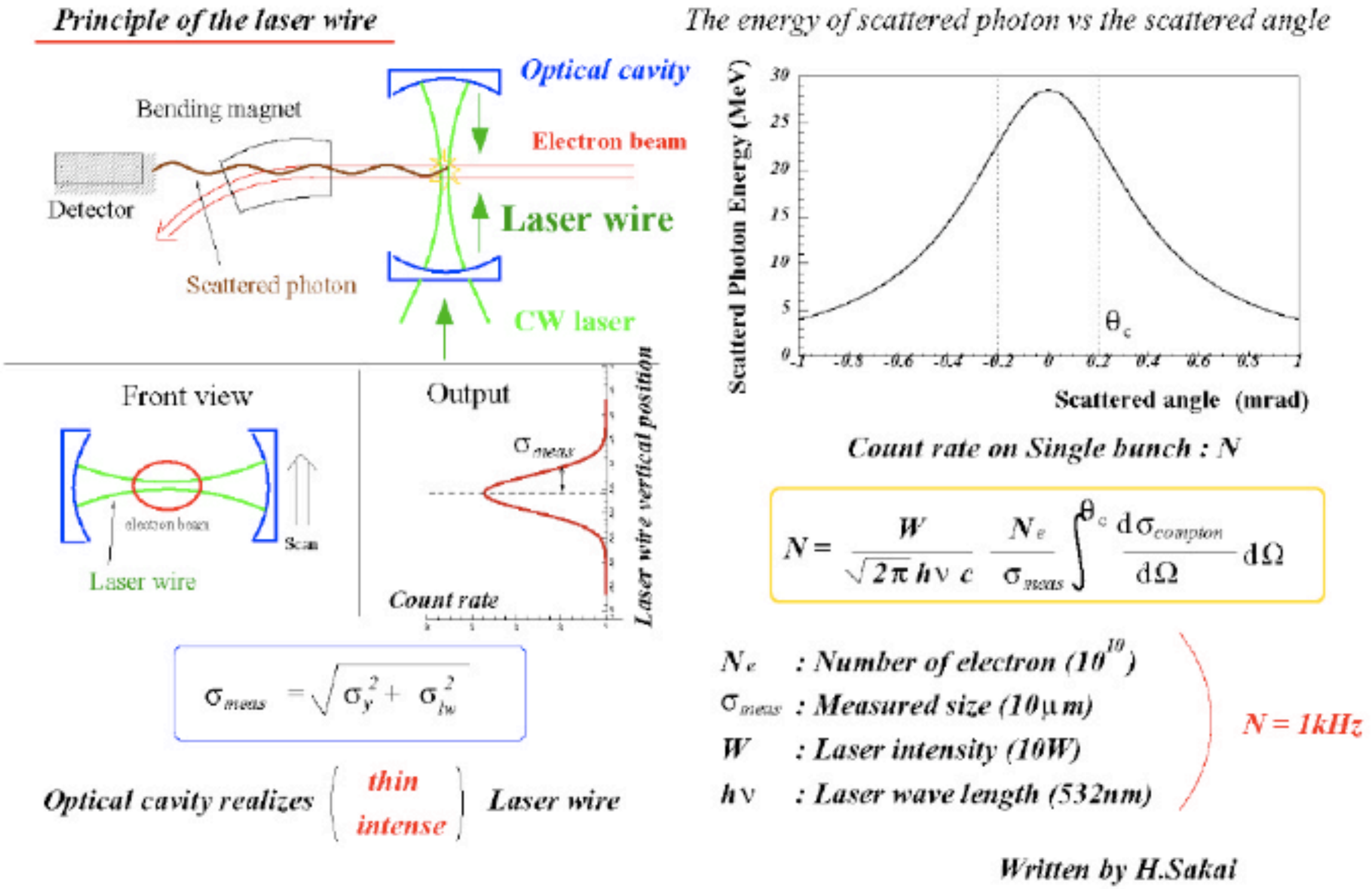
software in this system. In this paper, practical operation method, example results, and also the hardware improvements are described.

Fig.1 Schematic diagram of the spot size monitor using laser interferometry.

Laser Wire

http://www-pnp.physics.ox.ac.uk/~deleruelaserwire/bibliography.php

Ring laserwire



Principle of the laser wire

$$\sigma_{meas} = \sqrt{\sigma_y^2 + \sigma_{lw}^2}$$

Optical cavity realizes (*thin* / *intense*) *Laser wire*

The energy of scattered photon vs the scattered angle

Count rate on Single bunch : N

$$N = \frac{W}{\sqrt{2\pi}\, h\nu\, c}\,\frac{N_e}{\sigma_{meas}}\int^{\theta_c}\frac{d\sigma_{compton}}{d\Omega}\,d\Omega$$

N_e : *Number of electron* (10^{10})
σ_{meas} : *Measured size* ($10\mu m$)
W : *Laser intensity* ($10W$)
$h\nu$: *Laser wave length* ($532nm$)

N = 1kHz

Written by H.Sakai

One scattered particle per 2000 turns

SLAC-PUB-9885
May 2003

LASER-BASED PROFILE MONITOR FOR ELECTRON BEAMS*

Marc Ross[#], Stanford Linear Accelerator Center, Stanford, CA 94309, USA

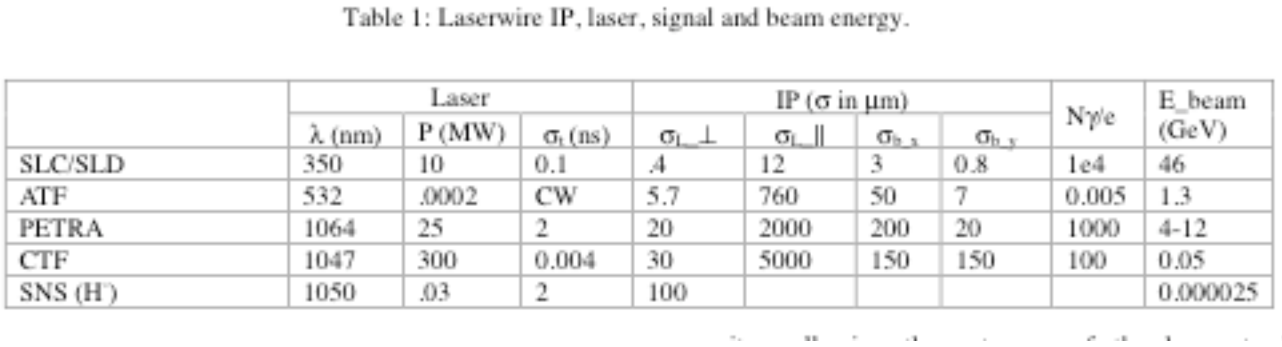


Table 1: Laserwire IP, laser, signal and beam energy.

	Laser			IP (σ in μm)				$N\gamma/e$	E_beam (GeV)
	λ (nm)	P (MW)	σ_t (ns)	$\sigma_{L\_\perp}$	$\sigma_{L\_\parallel}$	σ_{b_x}	σ_{b_y}		
SLC/SLD	350	10	0.1	.4	12	3	0.8	1e4	46
ATF	532	.0002	CW	5.7	760	50	7	0.005	1.3
PETRA	1064	25	2	20	2000	200	20	1000	4-12
CTF	1047	300	0.004	30	5000	150	150	100	0.05
SNS (H^-)	1050	.03	2	100					0.000025

BEAM PROFILE MEASUREMENTS AT PETRA WITH THE LASERWIRE COMPTON SCATTERING MONITOR

K. Balewski[a], G.A. Blair[b], S. T. Boogert[d], G. Boorman[b], J. Carter[b], T. Kamps[c*],
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[b] Royal Holloway University of London, Egham, Surrey, TW20 0EX, UK
[c] Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung BESSY, D-12489 Berlin, Germany
[d] University College London, London, WC1E 6BT, UK
[e] CERN, CH-1211 Geneve 23, Switzerland

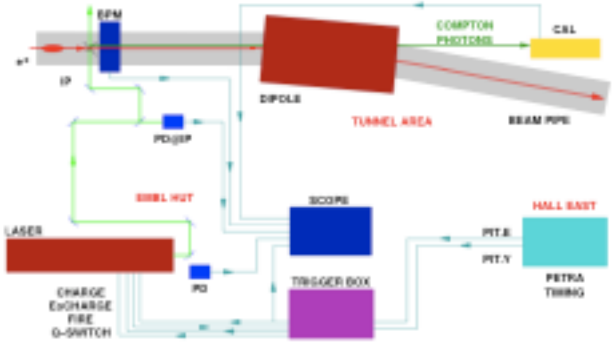


Figure 1: Positron beam, laser and trigger path for the laser-wire experimental setup.

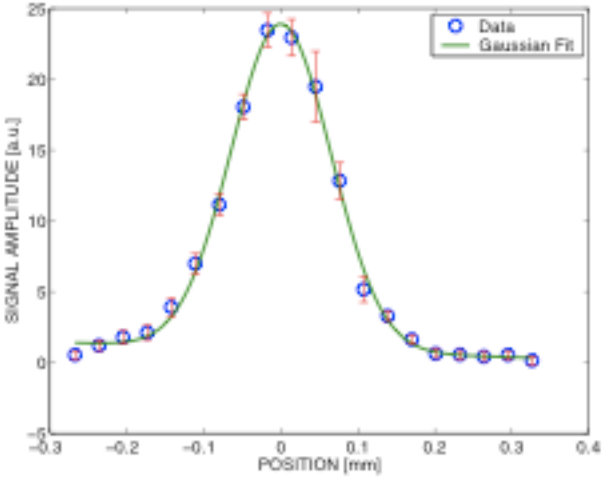
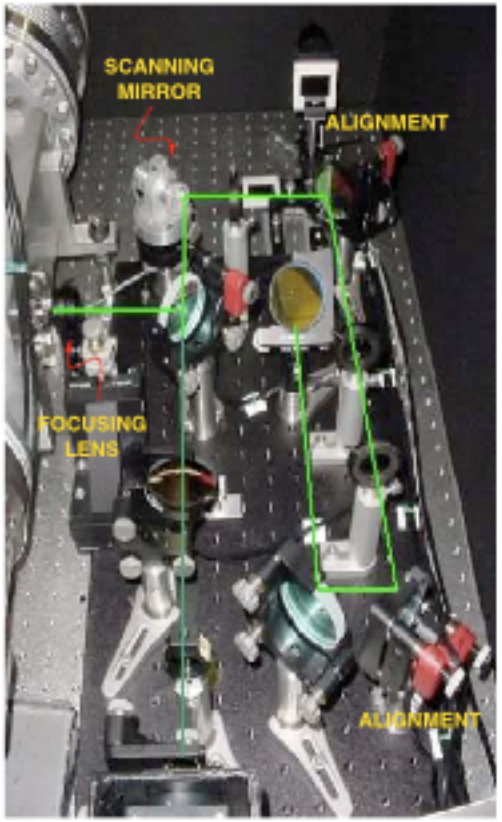


Figure 4: Spotsize measurement data and fit for the low current scan.



...e 2: Optical elements and laser pathway before the interaction point with the positron beam.

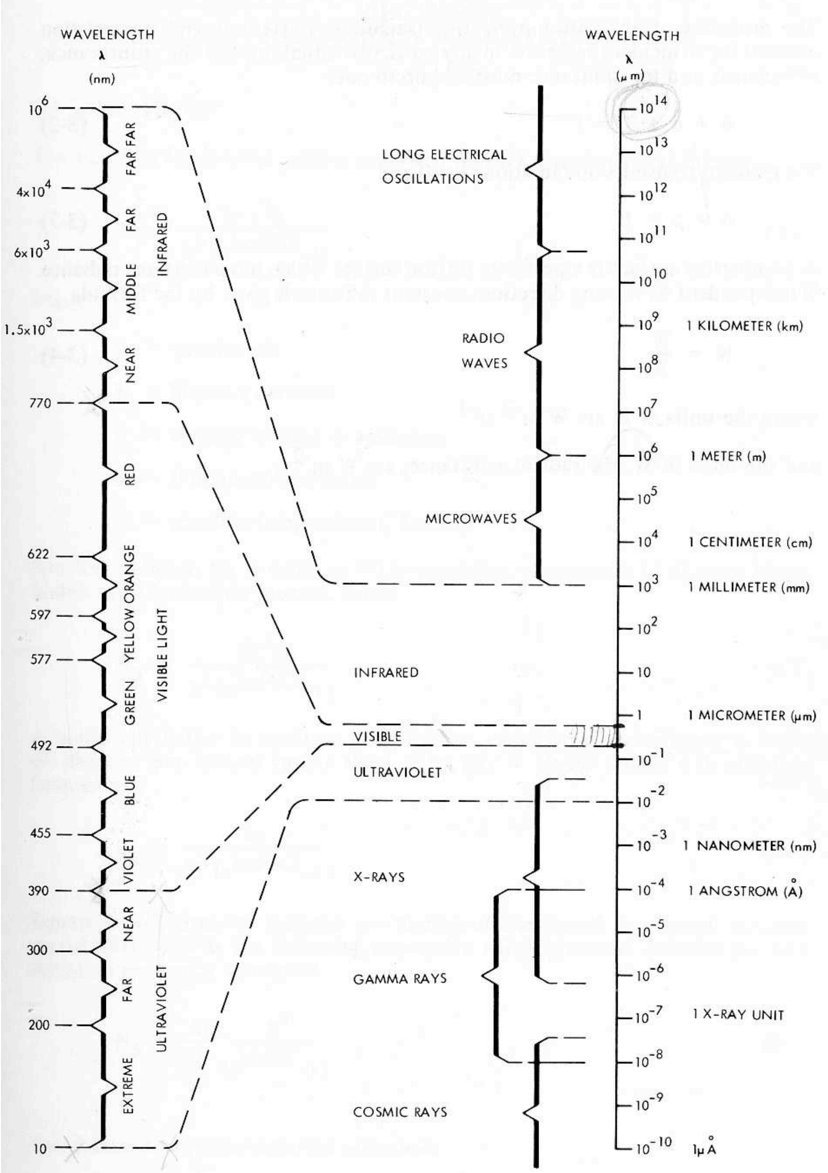


Figure 3-2. Electromagnetic Spectrum

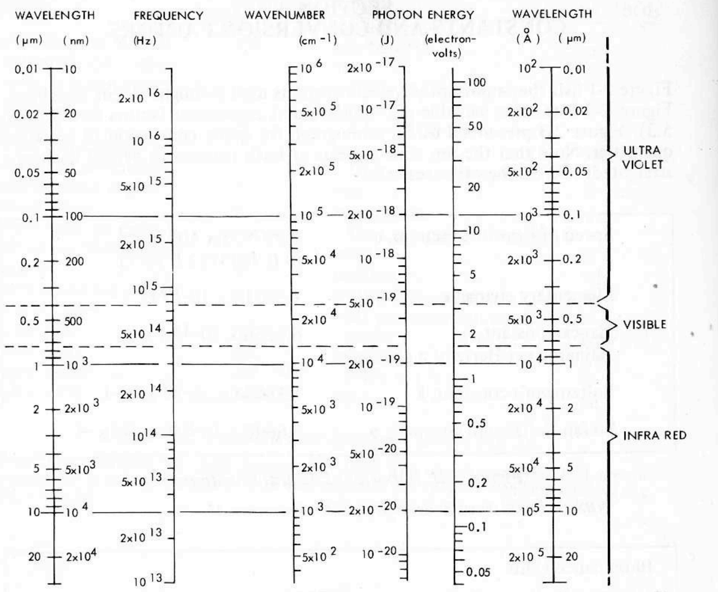
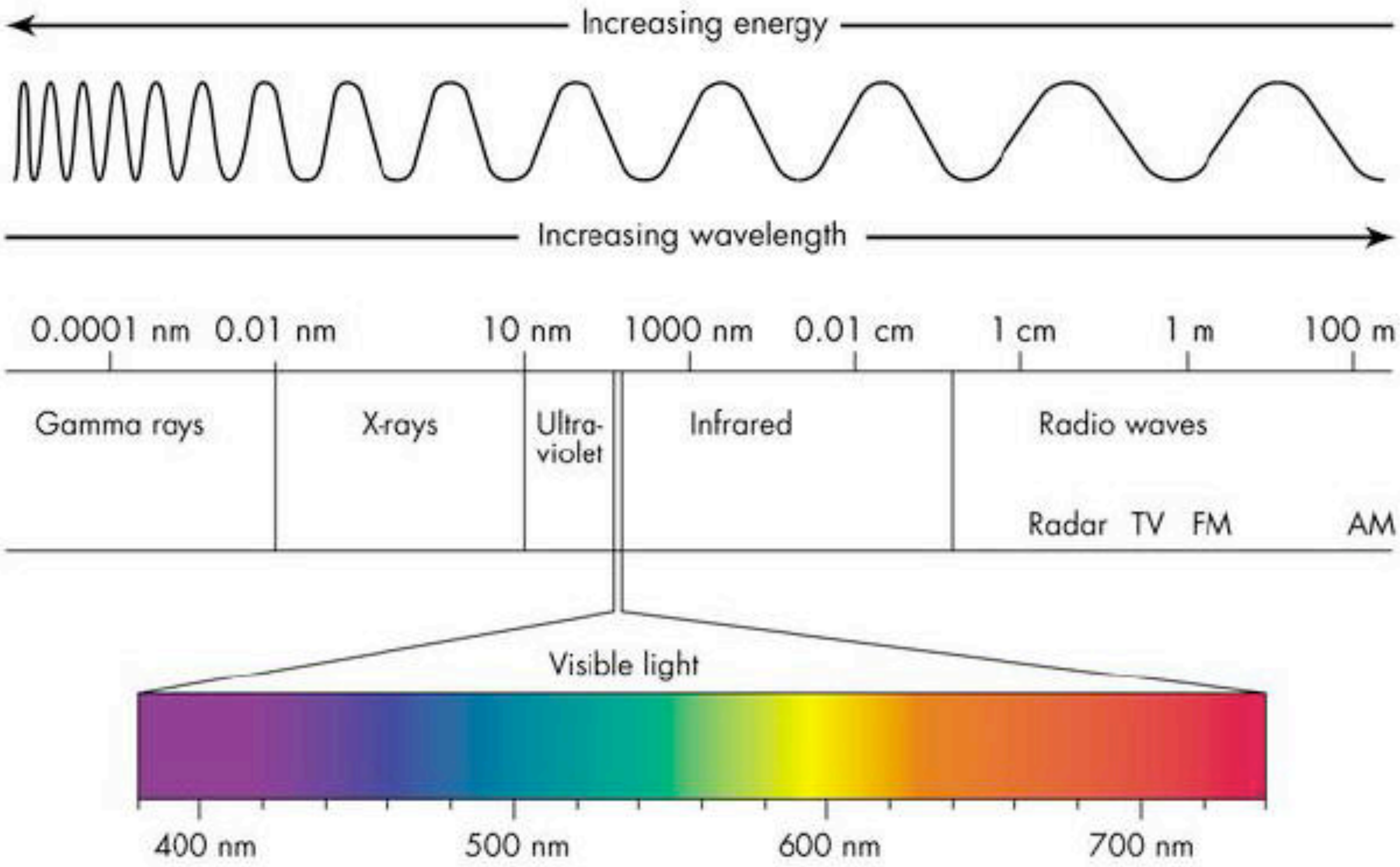


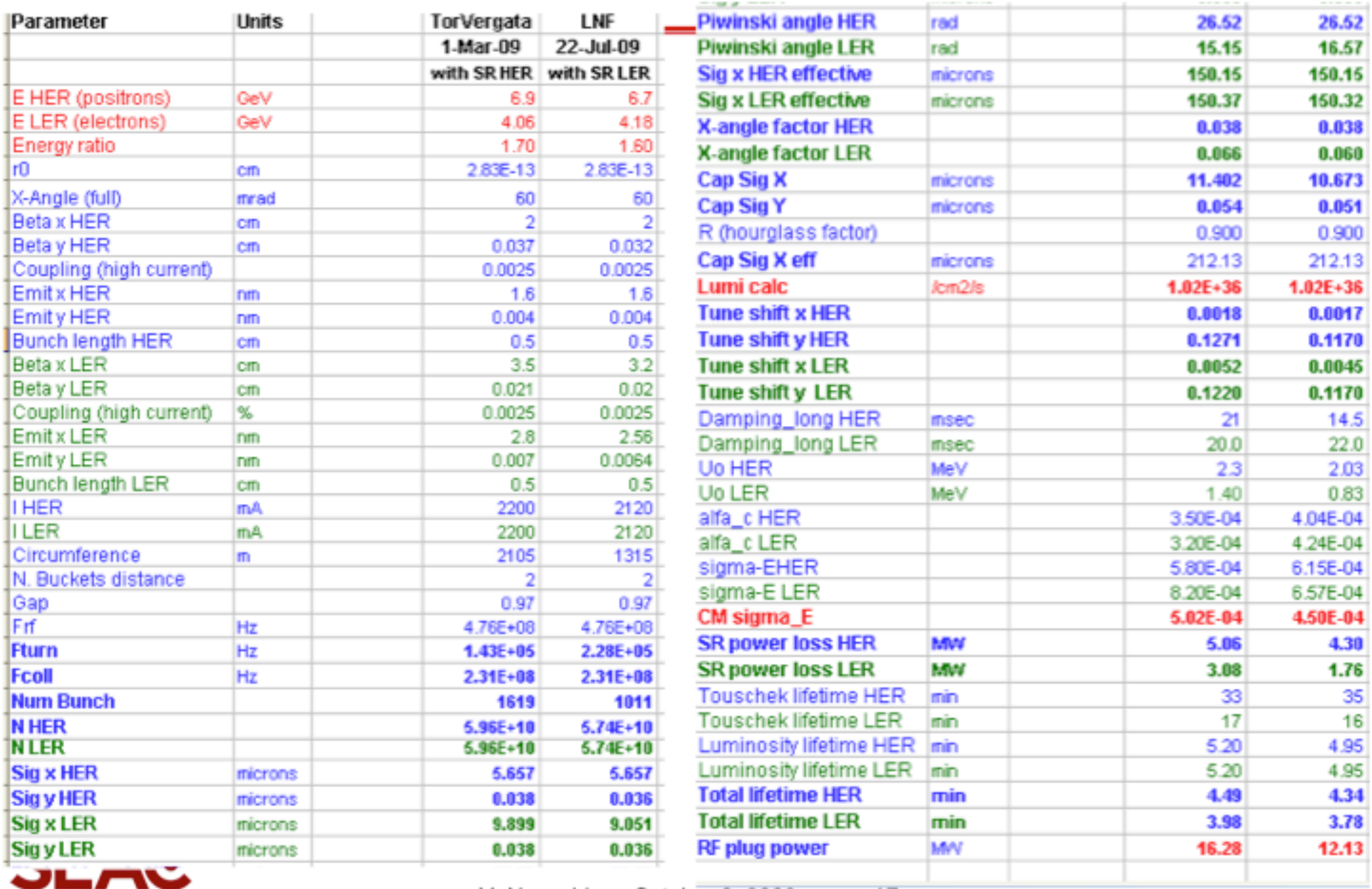
Figure 2-3. Radiation Conversion Chart (Adapted from Reference 5).


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-violet
Infrared
Radio waves
Radar
TV
FM
AM
Visible light
400 nm
500 nm
600 nm
700 nm

LER/HER	Unit	June 2008	Jan. 2009	March 2009	LNF site	July 2009
E+/E-	GeV	4/7	4/7	4/7	4/7	4.18/6.7
L	$cm^{-2}\ s^{-1}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$	$1x10^{36}$
I^+/I^-	Amp	1.85 /1.85	2.00/2.00	2.80/2.80	2.70/2.70	2.12/2.12
N_{part}	$x10^{10}$	5.55 /5.55	6/6	4.37/4.37	4.53/4.53	5.7/5.7
N_{bun}		1250	1250	2400	1740	1011
I_{bunch}	mA	1.48	1.6	1.17	1.6	
$\theta/2$	mrad	25	30	30	30	
β_x^*	mm	35/20	35/20	35/20	35/20	
β_y^*	mm	0.22 /0.39	0.21 /0.37	0.21 /0.37	0.21 /0.37	
ε_x	nm	2.8/1.6	2.8/1.6	2.8/1.6	2.8/1.6	
ε_y	pm	7/4	7/4	7/4	7/4	
σ_x	μm	9.9/5.7	9.9/5.7	9.9/5.7	9.9/5.7	
σ_y	nm	39/39	38/38	38/38	38/38	
σ_z	mm	5/5	5/5	5/5	5/5	
ξ_x	X tune shift	0.007/0.002	0.005/0.0017	0.004/0.0013	0.004/0.0013	0.0045/0.0017
ξ_y	Y tune shift	0.14 /0.14	0.125/0.126	0.091/0.092	0.094/0.095	0.1170/0.1170
RF stations	LER/HER	5/6	5/6	5/8	6/9	
RF wall plug power	MW	16.2	18	25.5	30.	17.0
Circumference	m	1800	1800	1800	1400	1315

measurements, etc

SuperB parameter list (July 2009) (P. Raimondi)



Parameter	Units		TorVergata	LNF
			1-Mar-09	22-Jul-09
			with SR HER	with SR LER
E HER (positrons)	GeV		6.9	6.7
E LER (electrons)	GeV		4.06	4.18
Energy ratio			1.70	1.60
r0	cm		2.83E-13	2.83E-13
X-Angle (full)	mrad		60	60
Beta x HER	cm		2	2
Beta y HER	cm		0.037	0.032
Coupling (high current)			0.0025	0.0025
Emit x HER	nm		1.6	1.6
Emit y HER	nm		0.004	0.004
Bunch length HER	cm		0.5	0.5
Beta x LER	cm		3.5	3.2
Beta y LER	cm		0.021	0.02
Coupling (high current)	%		0.0025	0.0025
Emit x LER	nm		2.8	2.56
Emit y LER	nm		0.007	0.0064
Bunch length LER	cm		0.5	0.5
I HER	mA		2200	2120
I LER	mA		2200	2120
Circumference	m		2105	1315
N. Buckets distance			2	2
Gap			0.97	0.97
Frf	Hz		4.76E+08	4.76E+08
Fturn	Hz		**1.43E+05**	**2.28E+05**
Fcoll	Hz		**2.31E+08**	**2.31E+08**
Num Bunch			**1619**	**1011**
N HER			**5.96E+10**	**5.74E+10**
N LER			**5.96E+10**	**5.74E+10**
Sig x HER	microns		**5.657**	**5.657**
Sig y HER	microns		**0.038**	**0.036**
Sig x LER	microns		**9.899**	**9.051**
Sig y LER	microns		**0.038**	**0.036**
Piwinski angle HER	rad		**26.52**	**26.52**
Piwinski angle LER	rad		**15.15**	**16.57**
Sig x HER effective	microns		**150.15**	**150.15**
Sig x LER effective	microns		**150.37**	**150.32**
X-angle factor HER			**0.038**	**0.038**
X-angle factor LER			**0.066**	**0.060**
Cap Sig X	microns		**11.402**	**10.673**
Cap Sig Y	microns		**0.054**	**0.051**
R (hourglass factor)			0.900	0.900
Cap Sig X eff	microns		212.13	212.13
Lumi calc	/cm2/s		**1.02E+36**	**1.02E+36**
Tune shift x HER			**0.0018**	**0.0017**
Tune shift y HER			**0.1271**	**0.1170**
Tune shift x LER			**0.0052**	**0.0045**
Tune shift y LER			**0.1220**	**0.1170**
Damping_long HER	msec		21	14.5
Damping_long LER	msec		20.0	22.0
Uo HER	MeV		2.3	2.03
Uo LER	MeV		1.40	0.83
alfa_c HER			3.50E-04	4.04E-04
alfa_c LER			3.20E-04	4.24E-04
sigma-EHER			5.80E-04	6.15E-04
sigma-E LER			8.20E-04	6.57E-04
CM sigma_E			**5.02E-04**	**4.50E-04**
SR power loss HER	**MW**		**5.06**	**4.30**
SR power loss LER	**MW**		**3.08**	**1.76**
Touschek lifetime HER	min		33	35
Touschek lifetime LER	min		17	16
Luminosity lifetime HER	min		5.20	4.95
Luminosity lifetime LER	min		5.20	4.95
Total lifetime HER	**min**		**4.49**	**4.34**
Total lifetime LER	**min**		**3.98**	**3.78**
RF plug power	MW		**16.28**	**12.13**