Low Angle Luminosity Monitoring

Benefits and possible issues of low angle Bhabha luminosity monitoring for FCC-ee

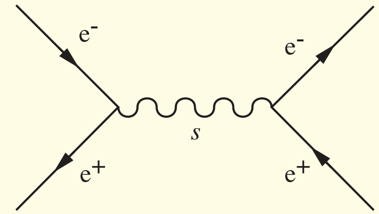
with a short review of the experience from LEP

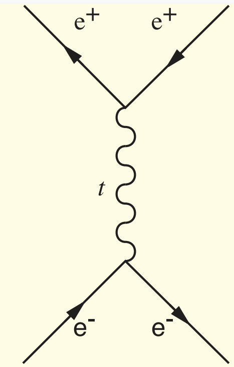
fast reliable monitoring of key parameters is of primary importance

- study and plan several independent systems to assure the availibility of fast reliable interaction and background / loss rate signals for the whole parameter space of FCC-ee running conditions
- focus on : relative luminosity, bunch by bunch capability — ns timing

typical numbers, Z-energies

Standard “elastic” Bhabha scattering





$$\sigma \approx \frac{16\pi\alpha^2}{s}\left(\theta_{min}^{-2} - \theta_{max}^{-2}\right) \quad ; \quad 16\pi\alpha^2 = 1042 \text{ nb GeV}^2$$

LEP experiments 50 - 100 mrad σ = 38 nb similar to z-cross sections

LEP machine small angle monitor : ~ **100 x** larger cross section

LEP : 4-12 bunches, **L_{IP} ~ 2e31 $cm^{-2}s^{-1}$** , rates **~ 0.7 Hz experiments** **~ 70 Hz machine monitors**

theoretical limits, rough estimate :

beam divergences ~ 100 μrad LEP, ~ 50 μrad FCC ~ same in both planes

detector acceptance, minimum angle ~ 20 × beam divergence or 2 mrad LEP, 1 mrad FCC

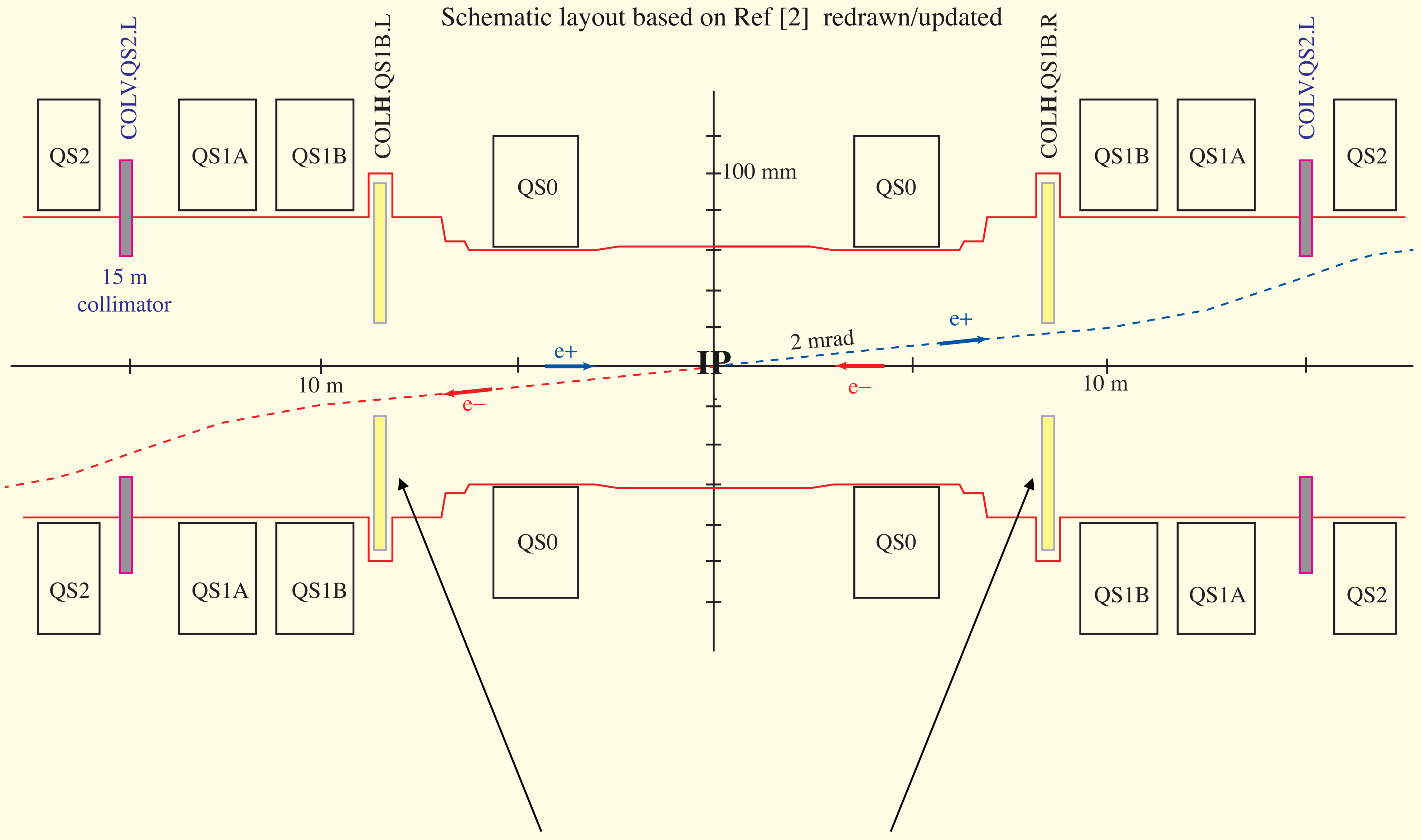
allowing for up to ~ $(25\text{-}50)^2$ or ~ 1000× larger cross section than 50 mrad experiments monitors

FCC-ee Z, **L = 1.97e32 $cm^{-2}s^{-1}$ / bunch** and IP (2.9e32 $cm^{-2}s^{-1}$ at top energy)

Exp. Lumi Bhabha rate ~ **7 Hz / bunch** (x9600 = 70 kHz all bunches)

Small angle monitor 100x more, ~ **700 Hz** useful for online monitoring bunch by bunch

LEP machine low angle Bhabha monitor, layout



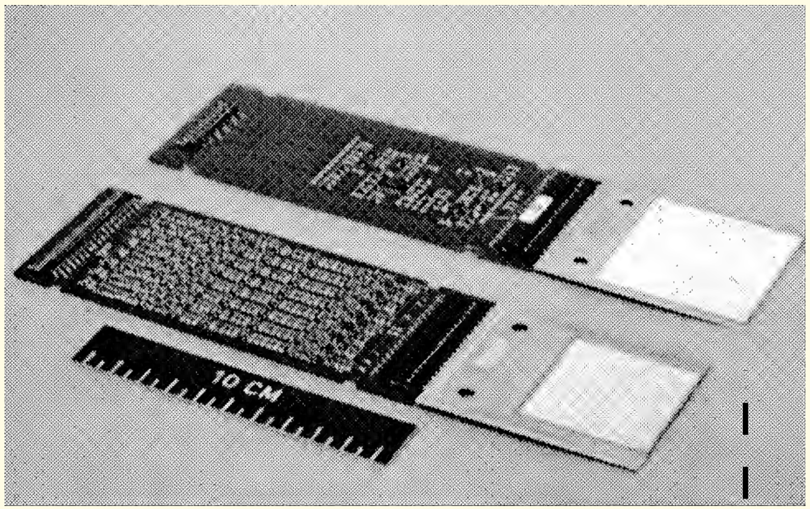
Instrumented horizontal 8.5 m collimator

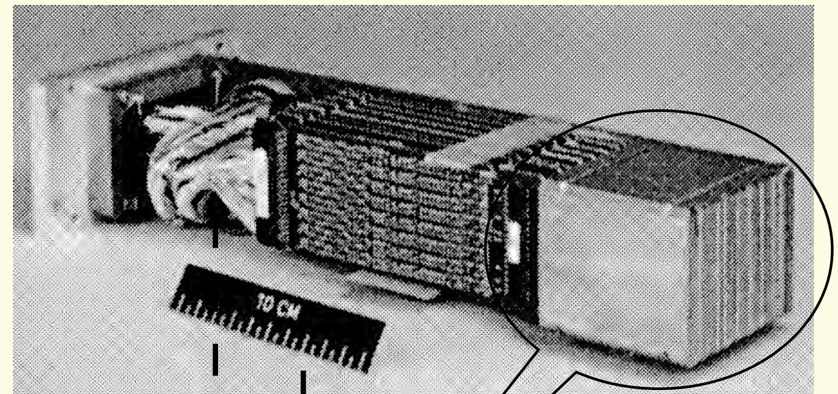
LEP machine low angle detector

compact silicon tungsten calorimeter

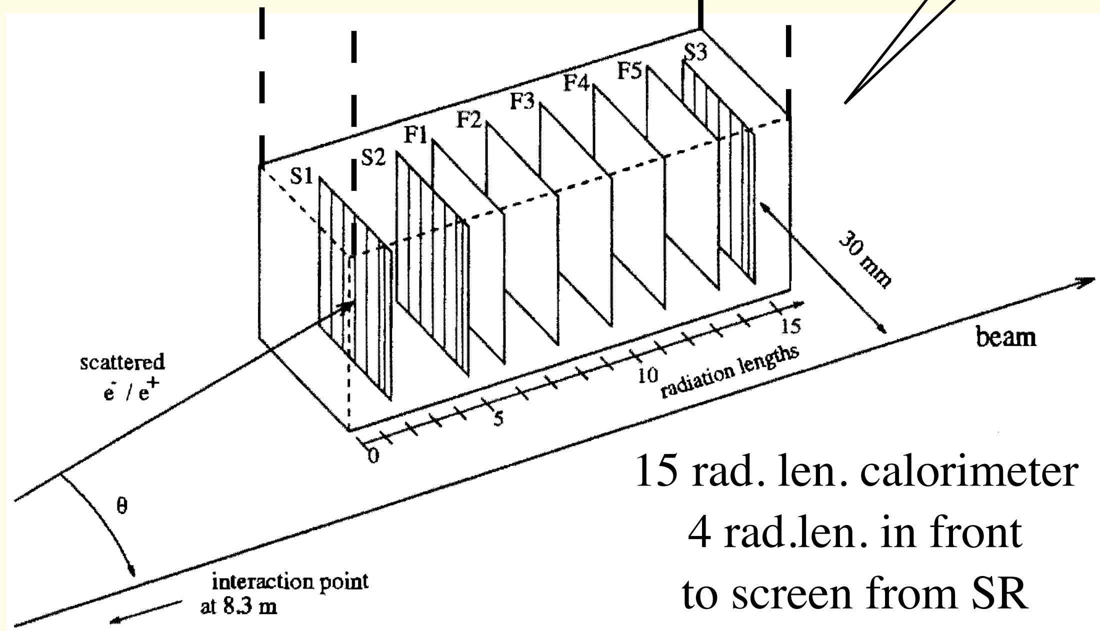
Ferri et al. Nucl. Phys. B Proc. Suppl., 23:419–432, 199

to monitor luminosity and off-momentum background



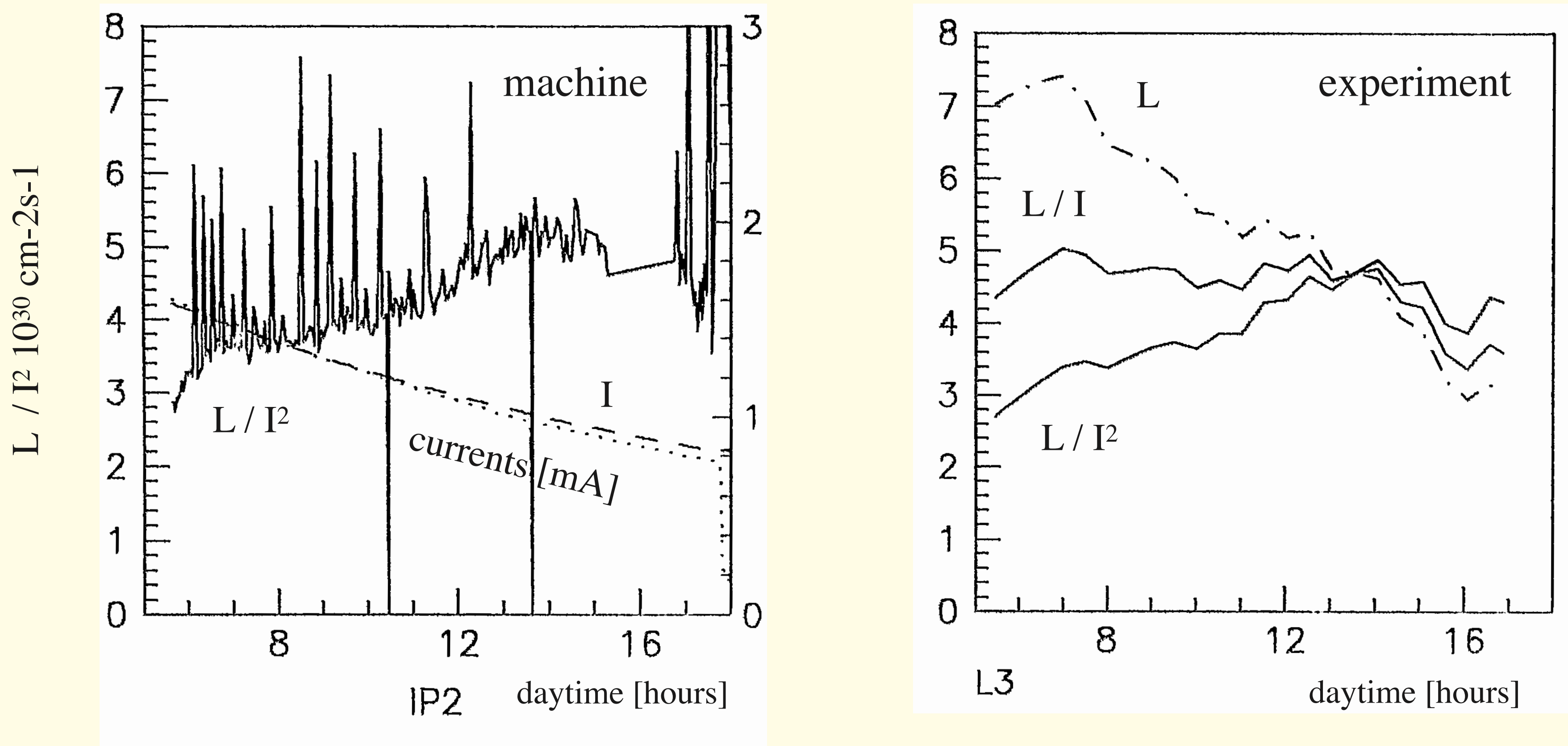


instrumented tungsten collimator jaw



Early operation, backgrounds at small angle

Example : fill 834 21 Oct 1991 (from one of my ~100 LEP shifts/year)



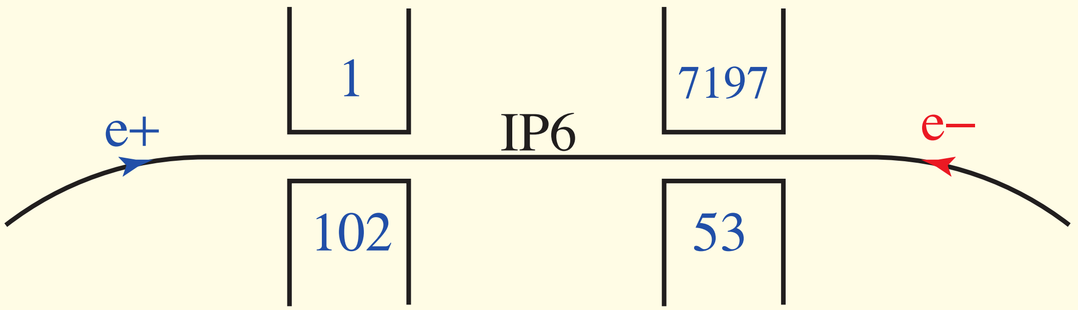
Off-momentum backgrounds at small angle

Studied in detail in 1993
Eb = 45.6 GeV, G05P46MT optics

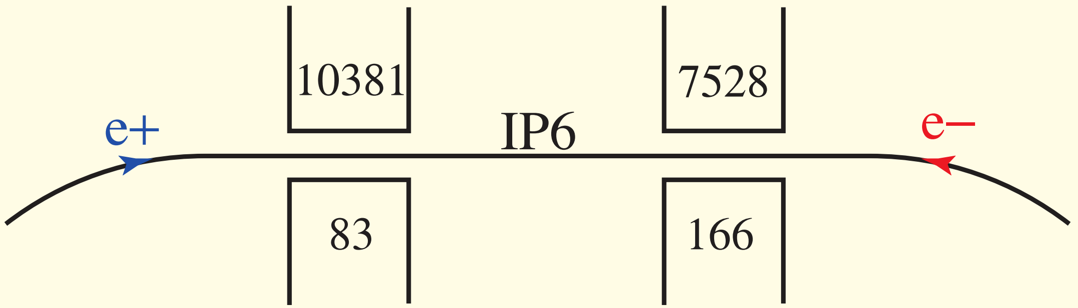
thermal photon simulation Ref 3

Rates [Hz] / beam current [mA]

prediction
single beam, thermal photon scattering
detectors at ± 32 mm
or ~ 15 nominal σ,   < E > = 43 GeV
mainly hitting outside downstream IP



example **measured**
both beams
detectors at ± 30 mm



The small angle LEP machine monitors are exposed to ~ few % off-momentum particles
"collecting the thermal photon scattered beam particles from one or several arcs"

MD study, vs collimator settings

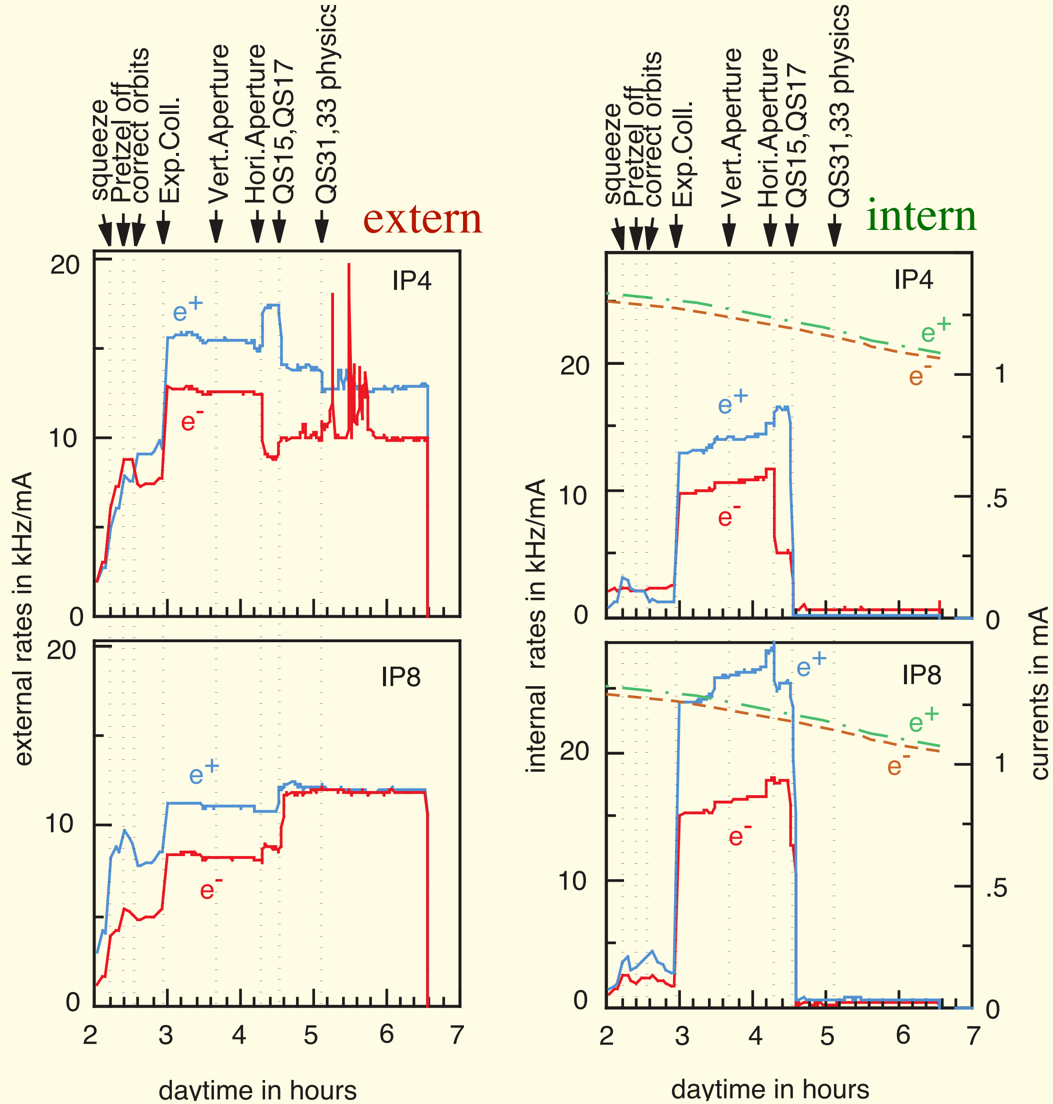
Details in MD-notes 107, 111 Ref 4-5 performed in 1993

main conclusion :

backgrounds well understood,
good match with simulations

internal rates can be strongly reduced by collimation
external not without reduction of aperture

aperture collimators important but not sufficient to eliminate off-momentum from last arc's



following theses studies much improved in later LEP operation
by extra off-momentum QD20 collimators around each IP

LEP1 *"Vernier"* vertical separation Luminosity scans

used frequently in 1995

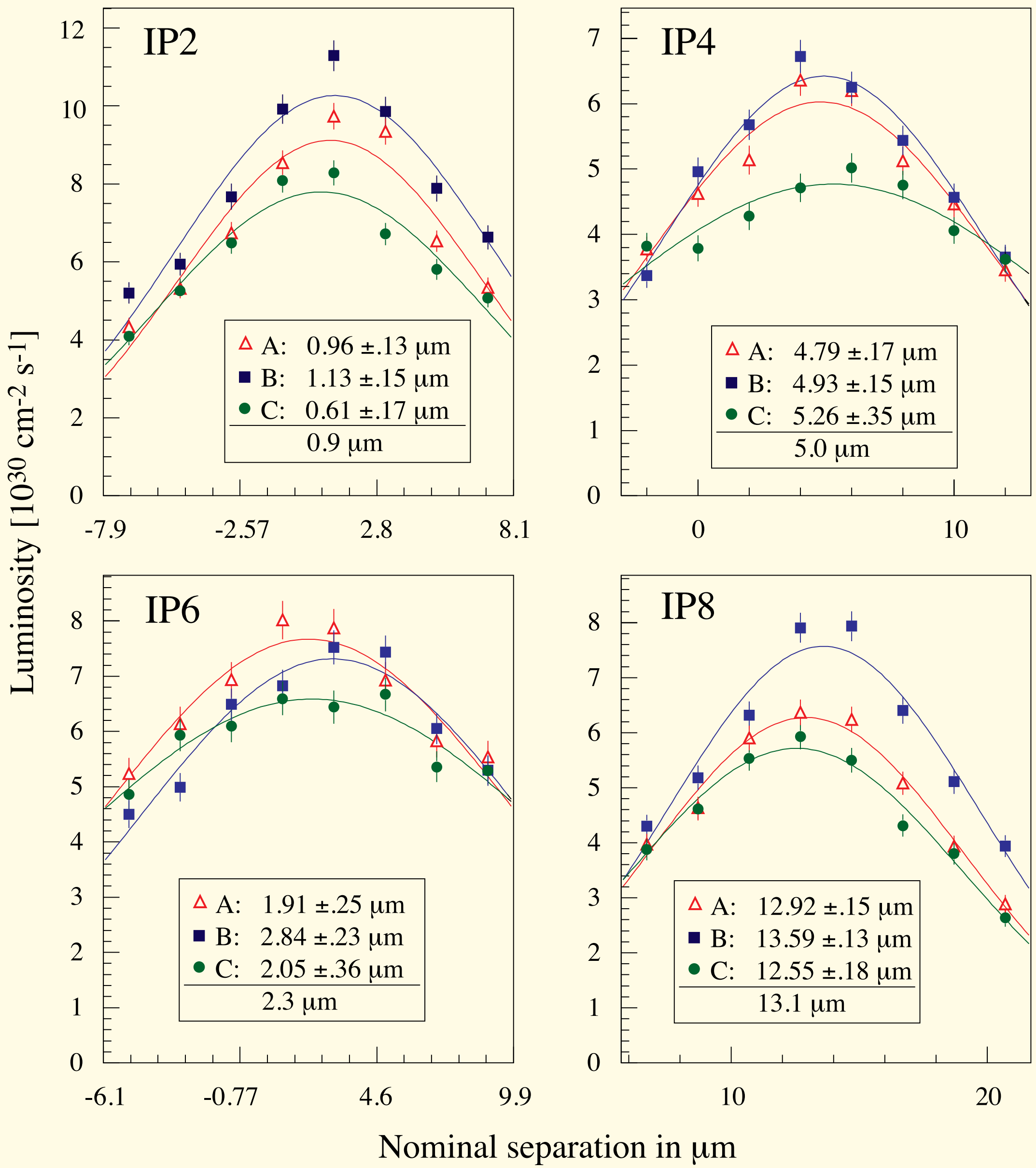
important when operating with bunch trains

good software/detector support and close follow up by PhD student Pedro Castro

Luminosity recorded by the LEP machine small angle Bhabha luminosity monitors

~ 5 min / scan

performed in the vertical plane using electrostatic separators



from Ref 7

Beam-beam deflection scans, LEP2, orbit monitors

LEP2

reduced LEP lumi

acceptance and rate

profiting from improved

orbit monitoring

and control :

fast centering

using beam-beam

deflections

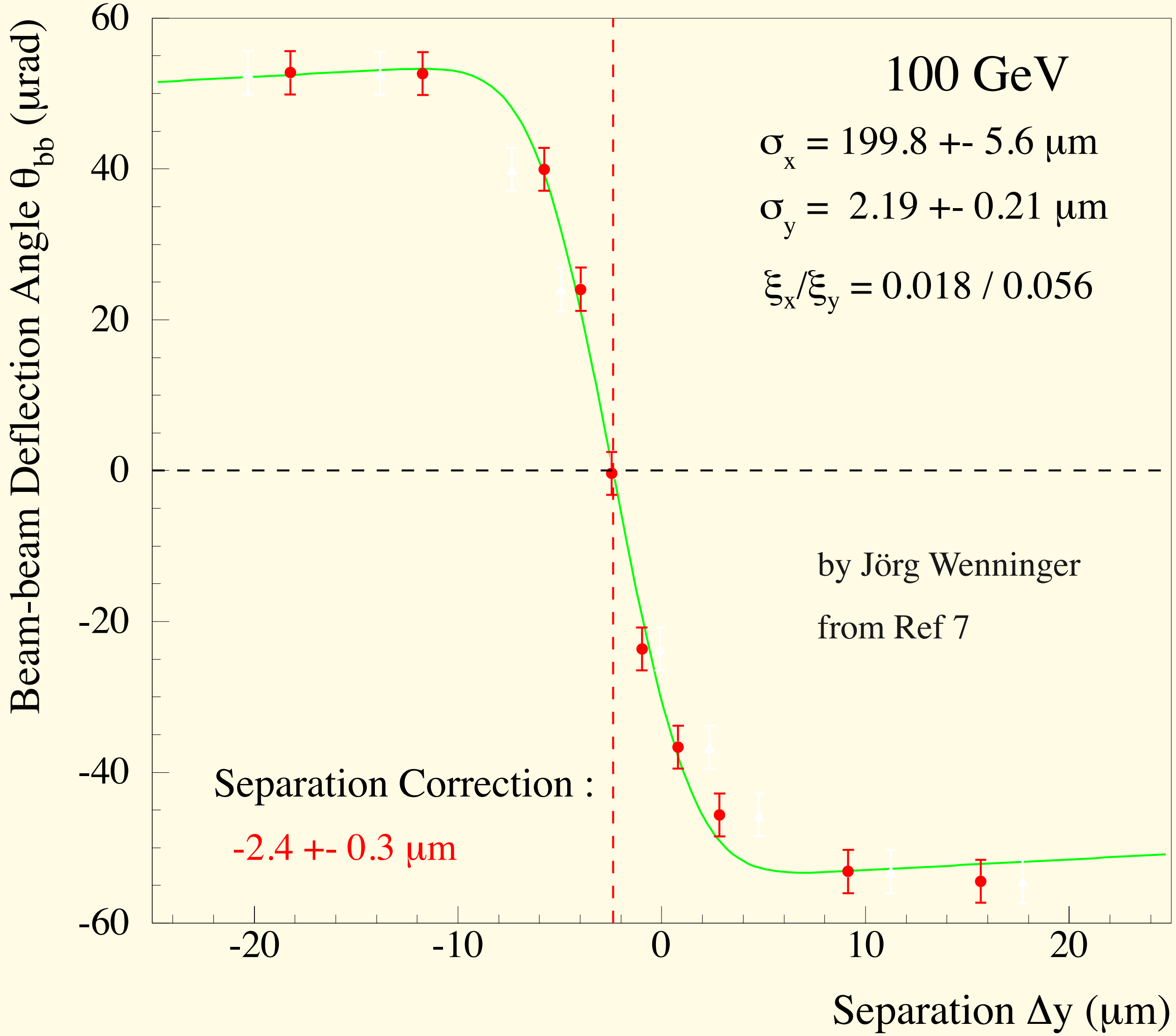
scans

also providing

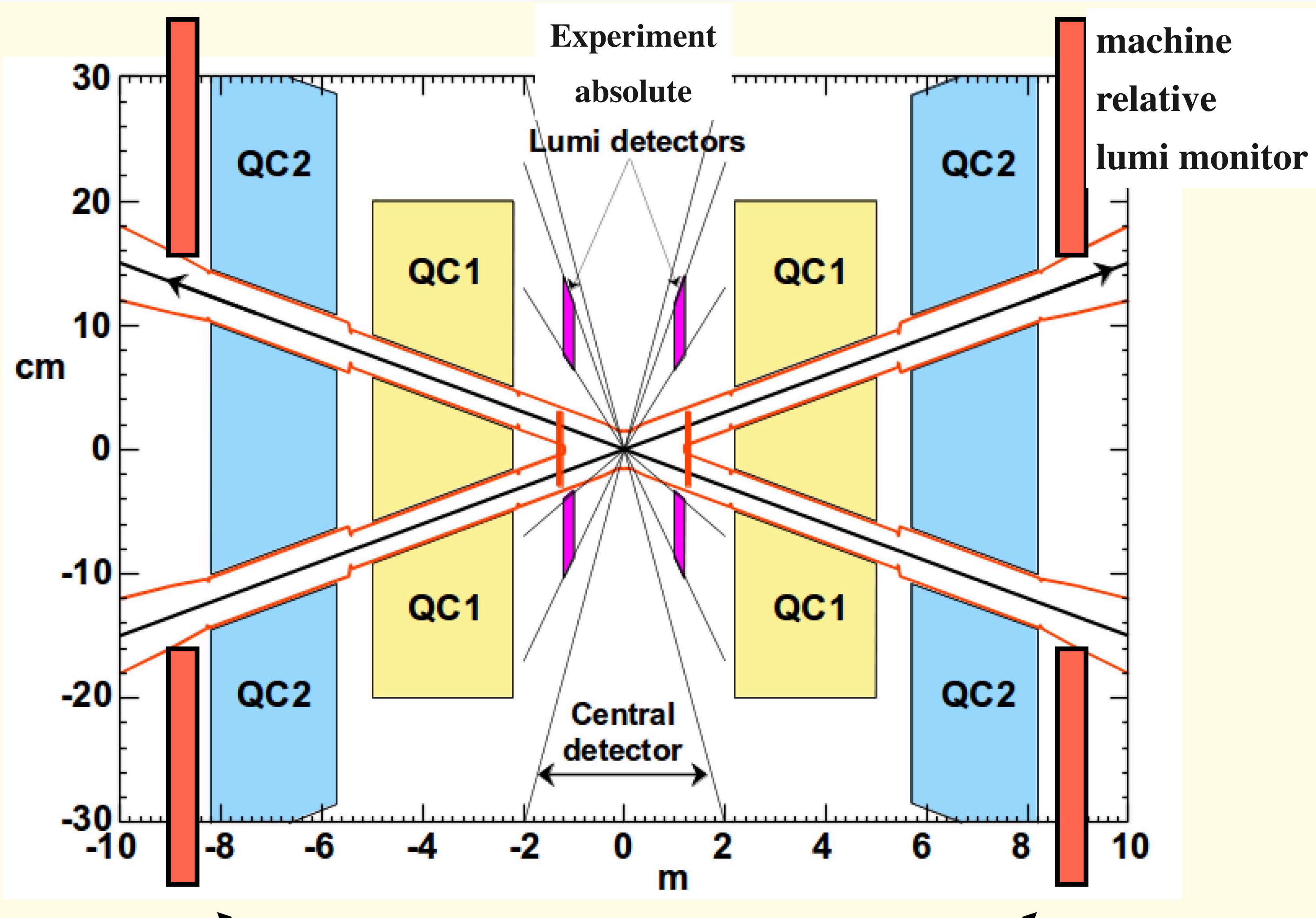
good estimate

of core beam sizes both H, V

(emittance, bb tune shift)



could we install **LEP like monitors in FCC ?**



LEP like instrumented collimator jaw

low angle Bhabha interaction rate monitors at ± 9 m

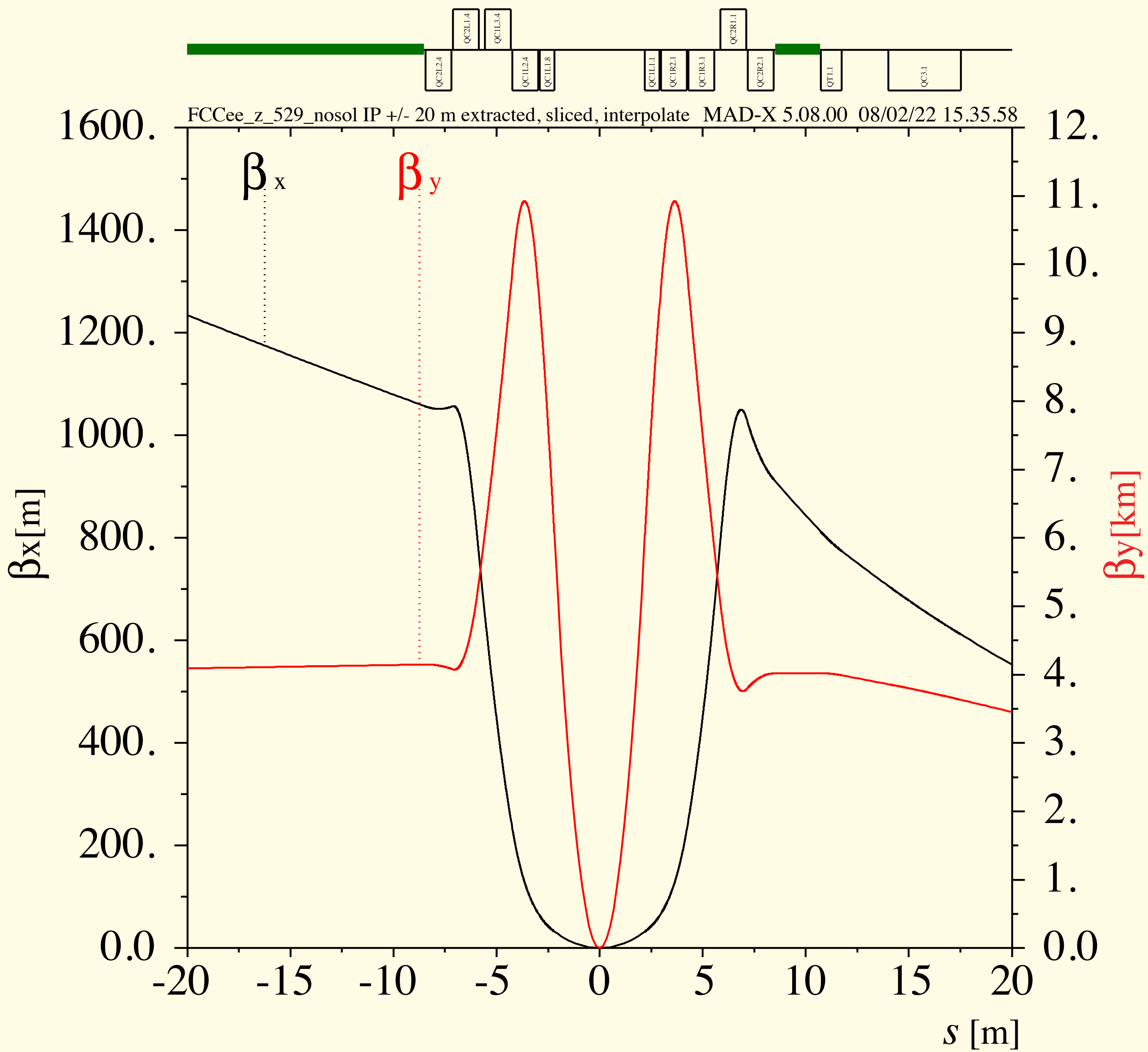
FCC-ee IP region

FCCee_z_529_nosol_4.seq

lattice has free (drift) space

-59.74 to -8.44 m

8.44 to 10.73 m



Concluding remarks

good realiable monitoring in general and of rates in the IP region in particular, very important

should be very interesting and useful to study in machine + detector collaboration the possibility of a small angle (elastic) Bhabha dectector ~ 9 m from the IP for online bunch-by-bunch interaction rate monitoring

studying the possibility of intrumenting collimators as was done for LEP may also be of more general interest

requirements, challenges :

radiation hard, robust, fast (semiconductor, diamond ?)**, cooling, low - impedance**

motorization, automatic alignment ?

off momentum background

References

[1] *An interaction rate monitor for LEP,*
J. Y. Hemery, F. Lemeilleur, G.v. Holtey, CERN-LEP-BI/86-5, 1986

[2] *Silicon detectors used for beam diagnostics in the LEP collider,*
G. P. Ferri, M. Glaser, G.v. Holtey, F. Lemeilleur, *Nucl Phys. B Proc. Suppl., 23:419–432*, 1991

[3] Monte Carlo Simulation of Beam Particles and Thermal Photons, H.B., SL Note 93-73 (OP), 1993

[4] *Protection of Bhabha monitors from electron / positron background,*
H.B., P.Castro, R.Schmidt, G.v. Holtey, SL-MD-Note-107, 1993

[5] *Effects of aperture limiting collimators,*
H.B., R.Jacobsen, G.Lutters, G.v .Holtey, SL-MD-Note-111, 1994

[6] Luminosity and β function measurement at the electron positron collider ring LEP,
P. Castro, PhD thesis, CERN-SL-96-070-BI, 1996

[7] *Accelerator Physics at LEP*,
D. Brandt, H.B., M. Lamont, S. Myers, J. Wenninger, Rept.Prog.Phys.63, 2000

MD-Note (non) availibility, currently empty entries

SL-MD Note 107

Protection of Bhabha Monitors from electron/positron Background

November 18, 1993

LEP

H. Burkhardt, P. Castro, R. Schmidt,
G. von Holtey

Keywords: BACKGROUND LUMINOSITY INSTRUMENTS

Run no.	Date
1723	2-8-93

Summary

The aim of this experiment was to measure the background received by the Bhabha monitors. In particular we wanted to compare the background rate with simulations of off-momentum background generated by collisions of thermal photons and residual gas molecules with the beam. The effect of the background shielding of the off-momentum collimators installed at QS15 quadrupoles protecting the inside calorimeters was measured and the proposed location for the second set of collimators to protect the outside calorimeters was tested.

1 Brief introduction of Bhabha monitors

The Bhabha-monitors for luminosity measurements [1] consist of 2 silicon-tungsten calorimeters in the horizontal plane at 8.5 m distance left and right from the IP. One calorimeter is inside the machine and the other outside (fig. 1). They detect Bhabha scattered e^+ and e^- pairs from bunch crossings. The Bhabha rate measured is proportional to the luminosity of the interaction between the two beams. Since the Bhabha cross-section rapidly increases with small angles as $1/\theta^3$ (where θ is the Bhabha scattering angle) the calorimeters are placed inside synchrotron radiation collimators, which are set close to the circulating beams. When beams are brought into collisions these collimators are moved into the vacuum chamber to a position ± 30 mm from the beam (about 15 sigma) to suppress synchrotron radiation (SR) photons, radiated in dipoles and straight sections quadrupoles. At 30 mm, the monitors detect Bhabha pairs with very small scattering angles (≥ 2 mrad). In this way it is possible to measure the luminosity every 40 seconds with a statistical error of 5 %.
The calorimeters are not sensitive to low energy SR photons since these are sufficiently absorbed in the 4 radiation lengths of tungsten placed in front of the detector plane. However, the energy resolution of the silicon calorimeter is not sufficient to discriminate off-momentum particles (which have lost about 1-2 GeV by Compton scattering with thermal photons or by beam-gas bremsstrahlung) from particles with beam momentum. Therefore these background particles hitting accidentally in coincidence both calorimeter

1

SL-EA/GvH

SL-MD Note 111
16.2.1994

Effects of Aperture limiting Collimators

Experimenters: H. Burkhardt, R. Jacobsen, G. Lutters and G. von Holtey

Keywords: Background, Lifetime, Collimators

date : 5.11.1993
fills: 1910

Summary
Background signals from the experimental detectors and from LEP luminosity monitors as well as beam lifetimes have been measured as a function of aperture collimator settings. A clear reduction of background rates has been observed when aperture limits were closed. Reduced lifetimes were observed with collimators in final settings but could be cured by a change in the working point.
It seems that colliding beams are more sensitive when aperture collimators are closed. Therefore, minimum settings of aperture collimators for physics should be established experimentally, in order to protect synchrotron radiation collimators around IP's from becoming aperture limits.

1.0 Beam set-up and measuring proceedure

Two beams with 4-on-4 bunches were collided at 45.6 GeV. All pretzel separators were switched off. Beam currents just after collision were i^+=1.32 mA and i^-=1.28 mA, with lifetimes well above 25 hours and all aperture limits opened. BEUV beam emittances of σ_x=1.11 mm and σ_y=0.57 mm for the positron beam and σ_x=1.16 mm and σ_y=0.73 mm for the electron beam were measured with emittance wiggler set at 0.815 Tm.

The different sets of aperture collimators were closed successively (vertical plane, horizontal plane, off-momentum and dispersion, see Table 1&2). For each step collimator loss rates, electron and photon

in case of interest : could contact CERN library and help to make these available

Backup

LEP Lumi, example of logging file

```
****************************************************************************
Time=22:34:01,Date=Sun May 30 1993,UTime=738794041,ScanP=0.000000,E=45625[MeV]
e- currents[mA]: 0.2777 0.2790 0.2870 0.2729 0.0000 0.0000 0.0000 0.0000
e+ currents[mA]: 0.2778 0.2930 0.2845 0.2844 0.0000 0.0000 0.0000 0.0000
Norm factors   : 0.2200 0.2200 0.2200 0.2200 0.2200 0.2200 0.2200 0.2200
Colpos [mm/10]:-300 300-300 300-299 300-300 300-300 300-300 300-300 300-300 300
All Monitors     IP2                IP4                IP6                IP8
All [Hz]: Mon1      Mon2      Mon1      Mon2      Mon1      Mon2      Mon1      Mon2
Intern:1551.9     68.1     981.1     278.0     175.7     313.9      96.9     343.8
Extern:10788.2  10270.6    9615.4    8314.3   14047.5   17173.0   11953.0   10871.5
TotPai: 553.3|3.2 52.7|1.0310.7|2.4101.8|1.4111.9|1.4229.3|2.1 70.8|1.1146.9|1.6
AccMea: 525.8|3.1 28.4|0.7293.5|2.4 73.6|1.2 91.9|1.3212.3|2.0 44.2|0.9118.4|1.5
AccCal: 524.5     19.6     280.8      65.6      79.9     197.1      34.6     110.8
Tot-AcMe 27.5|4.5 24.3|1.2 11.2|3.4 28.2|1.8 20.0|1.9 17.1|2.9 26.6|1.5 28.5|2.2
Tot-AcCa 28.8|4.5 33.1|1.2 29.9|3.3 36.1|1.8 31.9|1.9 32.3|2.8 36.2|1.4 36.2|2.2
Valid:     1        1        1        1        1        1        1        1
AcqTime: 54.00    54.00    54.00    54.00    54.00    54.00    54.00    54.00
Bhabha : 27.9|3.7 31.8|0.9 28.6|2.6 34.8|1.4 30.6|1.6 31.0|2.5 34.9|1.1 34.8|1.7
BhaCol : 27.89    31.80    28.53    34.78    30.63    31.02    34.89    34.83
Lumi:      6.1|0.8  7.0|0.2  6.3|0.6  7.7|0.3  6.7|0.3  6.8|0.5  7.7|0.2  7.7|0.4
SpecLum:   4.8|0.6  5.5|0.2  4.9|0.5  6.0|0.2  5.3|0.3  5.4|0.4  6.0|0.2  6.0|0.3
Average Mon1/Mon2         IP2              IP4              IP6              IP8
SpecBha               :   23.44+- 1.49   24.91+- 1.16   24.21+- 1.14   27.39+- 0.82
SpecBhaCol            :   23.44+- 1.49   24.87+- 1.16   24.21+- 1.14   27.39+- 0.82
Lumi [units 10-30]:        6.57+- 0.42    6.96+- 0.33    6.78+- 0.32    7.67+- 0.23
Specific Lumi         :    5.16+- 0.33    5.47+- 0.26    5.33+- 0.25    6.03+- 0.18
Global Luminosity :         6.99+- 0.17    7.22+- 0.12    7.28+- 0.12 Time=22:34:01
Global SpecLumi       :     5.50+- 0.13    5.67+- 0.09    5.72+- 0.09 Time=22:34:01
****************************************************************************
```