Low energy Beamstrahlung at CESR and the ILC

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With:

- M. Dubrovin, M. Billings, E. Wisniewski, several REU students over the years (E. Luckwald, N. Detgen, N. Powell, M. West)

- … and much help from many LEPP people

- I will discuss both visible (incoherent) and microwave (coherent) beamstrahlung (IB and CB)

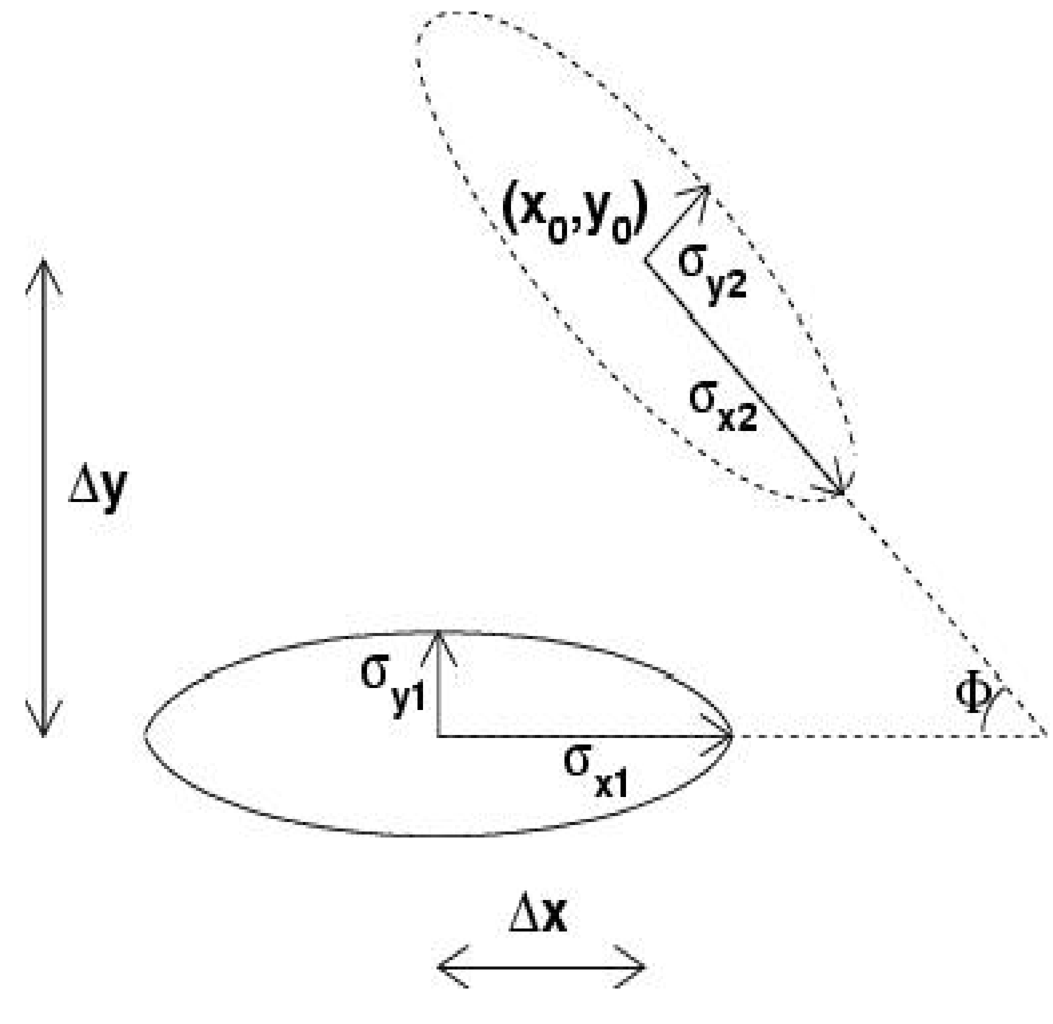
Outline

- Why develop low energy beamstrahlung
- Phenomenology of IB
- Phenomenology of CB
- ILC detector concepts
- Current status of CESR IB monitor
- Feasibility of CESR CB observation
- Summary

What is beamstrahlung

- The radiation of the particles of one beam due to the bending force of the EM field of the other beam
- Many similarities with SR but
- Also some substantial differences due to very short “magnet” ($L=\sigma_z/2\sqrt{2}$),very strong magnet (3000T at the ILC). Short magnets produce a much broader angular distribution and have different coherence properties

Beam-beam collision (BBC) transverse d.o.f. (Gaussian approximation)



BBC d.o.f. counting at the ILC

- 7 gaussian transverse d.o.f.
- 2 beam lengths
- At least 4 wake field parameters, and possibly 2 longitudinal
- (currents well measured)
- Beam energy spread not measurable by techniques described here but affected by properties of BBC
- Beam angle(s) and angular spread(s)?

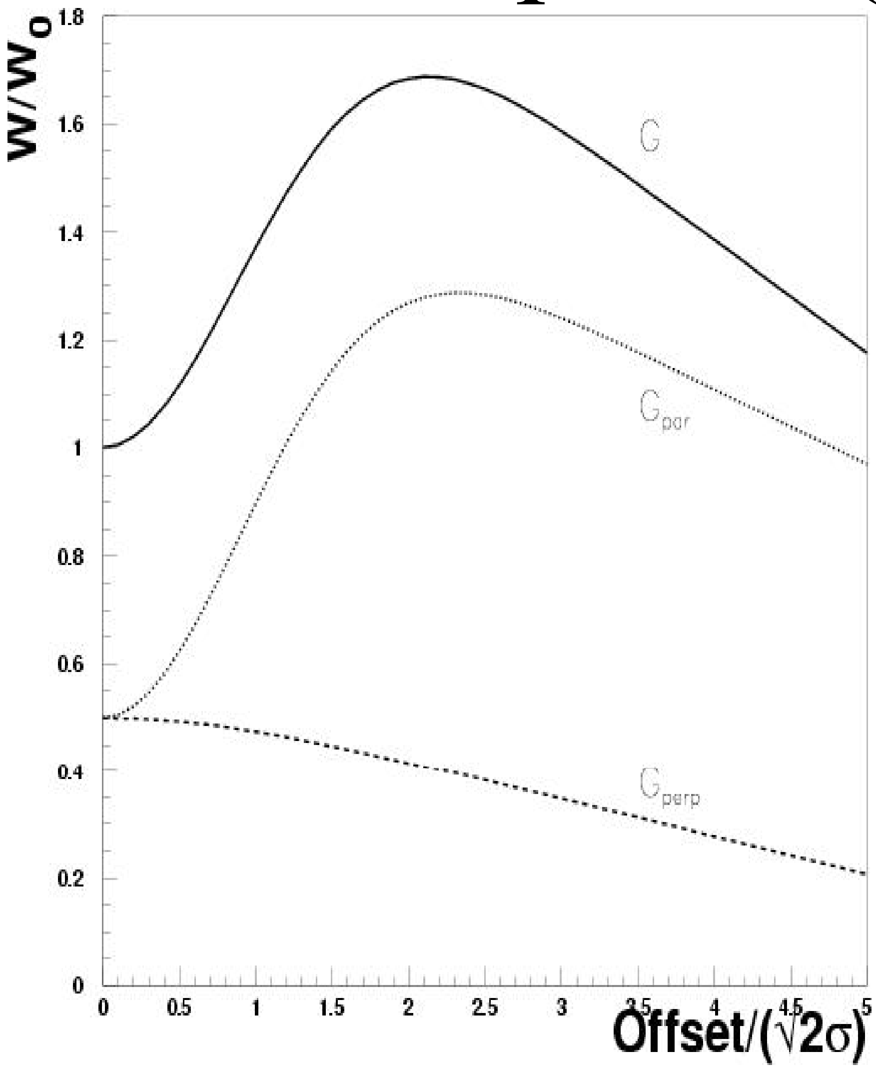
Other possible BBC detectors

- Beam-beam deflection via BPMs. Limited to 2 quantities by Newton's 3rd law. Semi-passive device sensitive to beam-beam force
- Gamma ray beamstrahlung monitor. Almost certainly a powerful device if it can be built with enough pixels, interferes with the beam dump (340kW). Also mostly sensitive to force
- Pairs spectrometer (10^5 per BBC)

The rationale for developing CB and IB

- Sensitivity to different variables than hard beamstrahlung, mainly through observation of polarization. In particular, this radiation is sensitive to beam-beam force squared
- Simple, relatively inexpensive passive devices which can be located away from the beam line
- Polarization information is recovered
- CB may provide imaging of the BBC
- CB so abundant (O(1kW)) so as to be a potential disruption for downstream sensors

IB power (stiff beams)



$$P_1(d) \approx 0.11 \frac{N_1 N_2^2}{\sigma_x^2 \sigma_z} \gamma^2 m c^2 r_e^3 (g_x(d) + g_y(d))$$

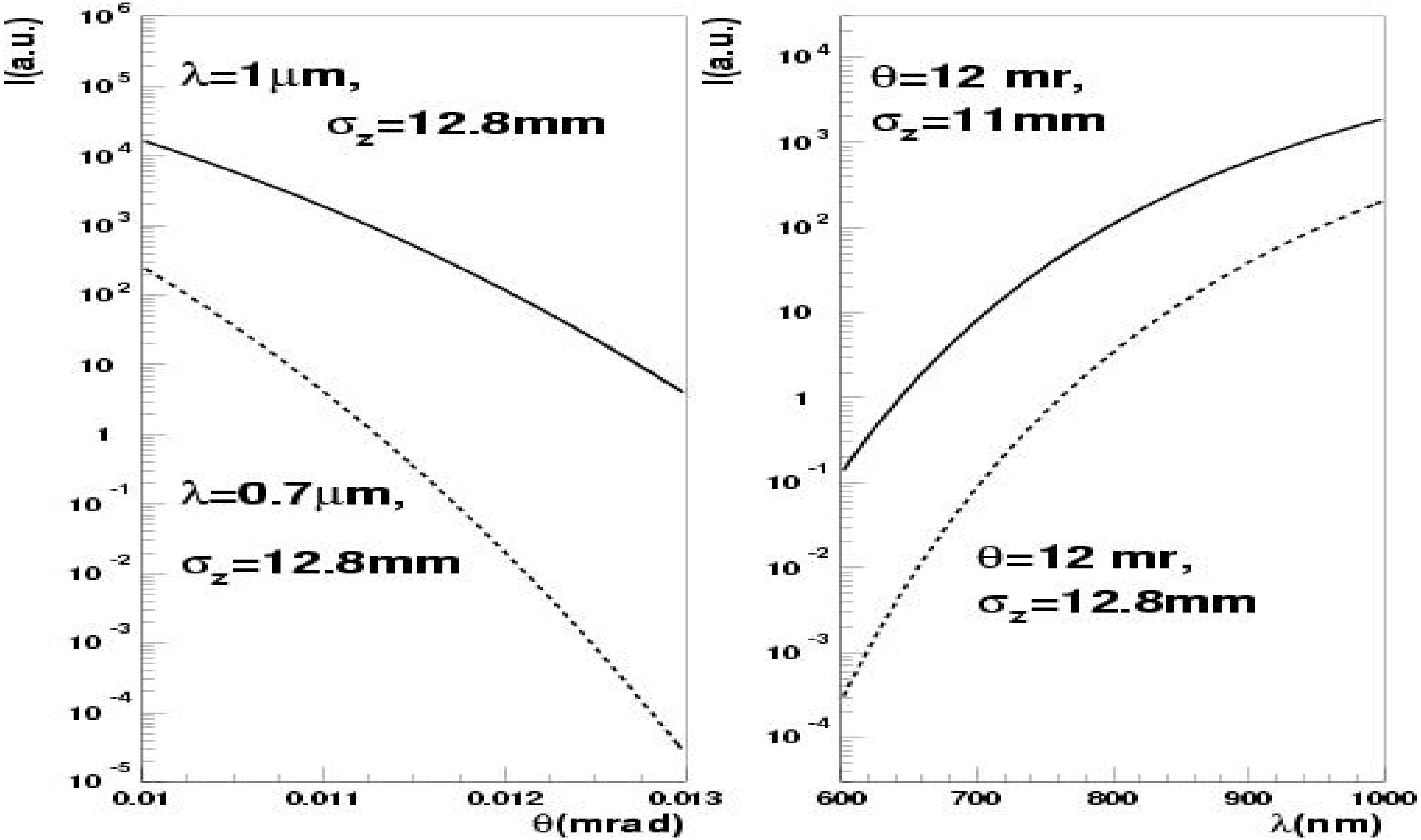
- CB largely leaves the spectrum unaffected and adds a large multiplicative factor which may be up to order N_1

Large angle incoherent power

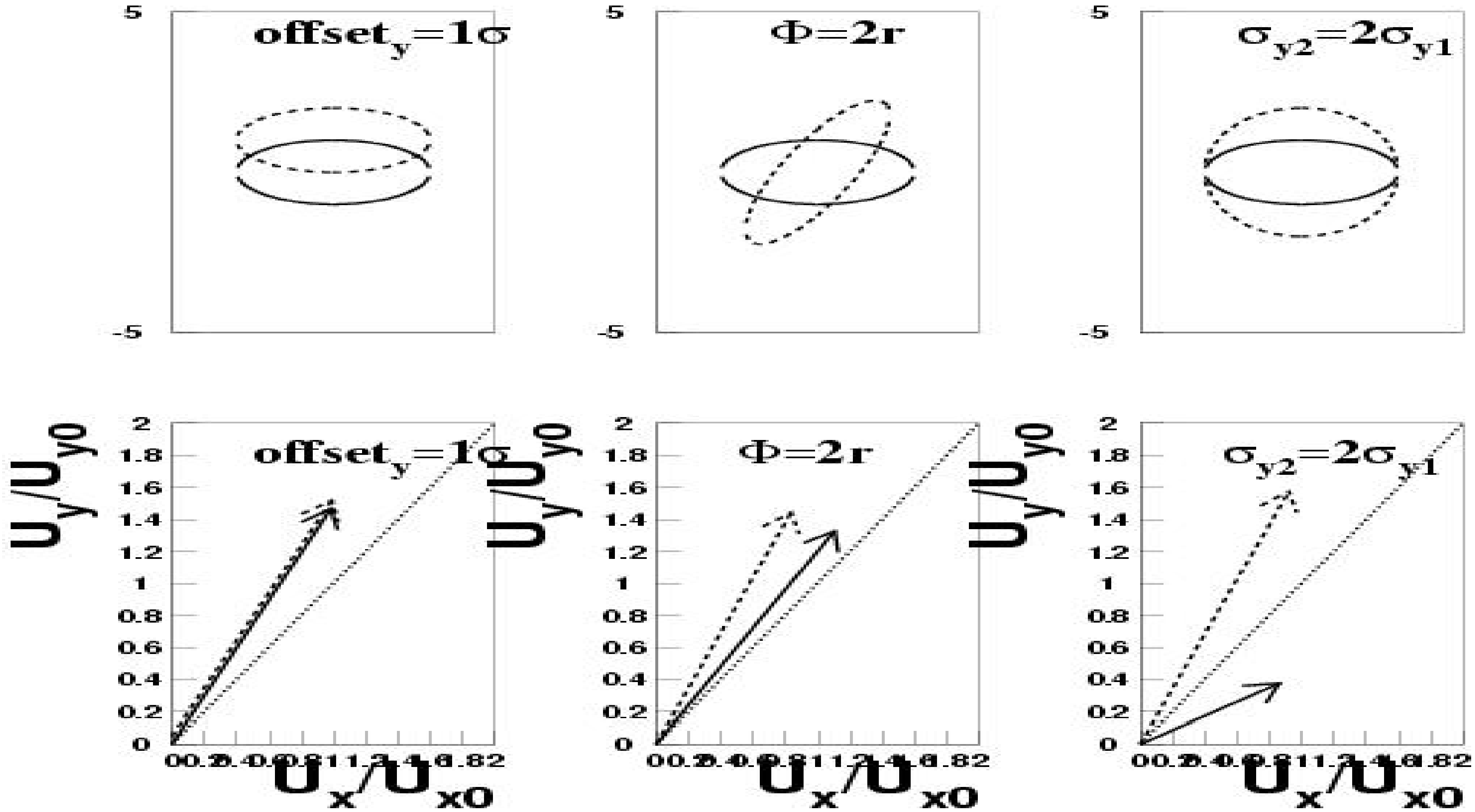
- Wider angular distribution (compared to quadrupole SR) provides main background rejection
- CESR regime: exponent is about 10
- ILC regime: exponent is very small

$$\frac{d^2 I}{d\Omega d\omega} = \frac{3\sigma_z}{4c\pi\sqrt{\pi}} P_0 \frac{1}{\gamma^4\theta^4} \exp\left(\frac{-\omega^2\theta^4\sigma_z^2}{16c^2}\right)$$

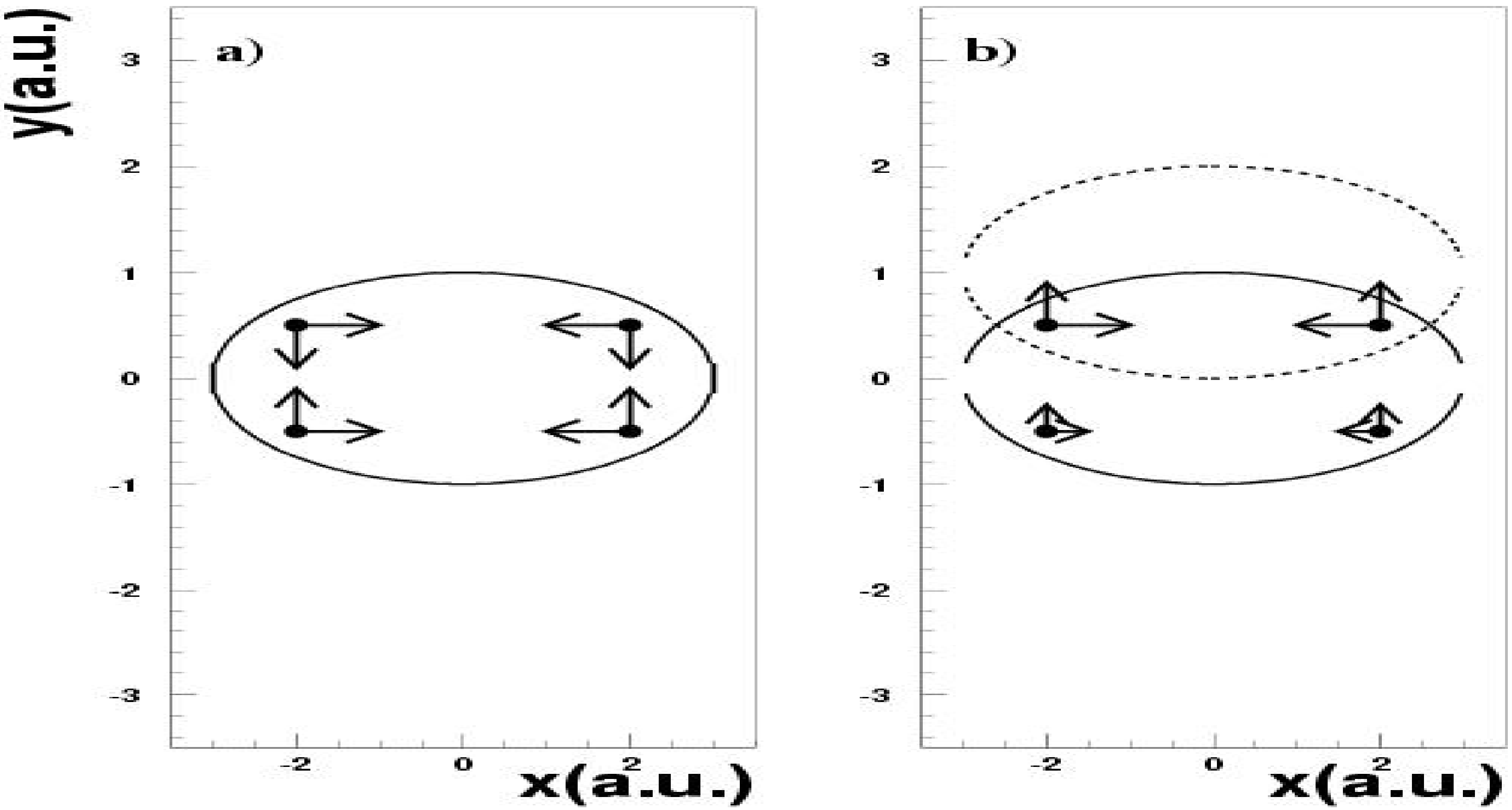
IB power dependence in CESR configuration



Some examples of IB pattern recognition



Coherence vs incoherence



Coherent beamstrahlung

- Coherent synchrotron radiation has been observed many times for very short beams
- A first coherence condition is given by $\lambda > \sigma_z$
- A similar situation arises when beams are separated - coherent beamstrahlung
- Coherent enhancement is in principle proportional to N

CB coherent enhancement (vacuum, no angular divergence)

- C=P(CB)/P(IB)
- $C(\lambda,\Omega)=N \exp(-(2\pi\sigma_z / \lambda)^2)$ (G. Bonvicini, unpublished)
- Angular effects reduce coherence

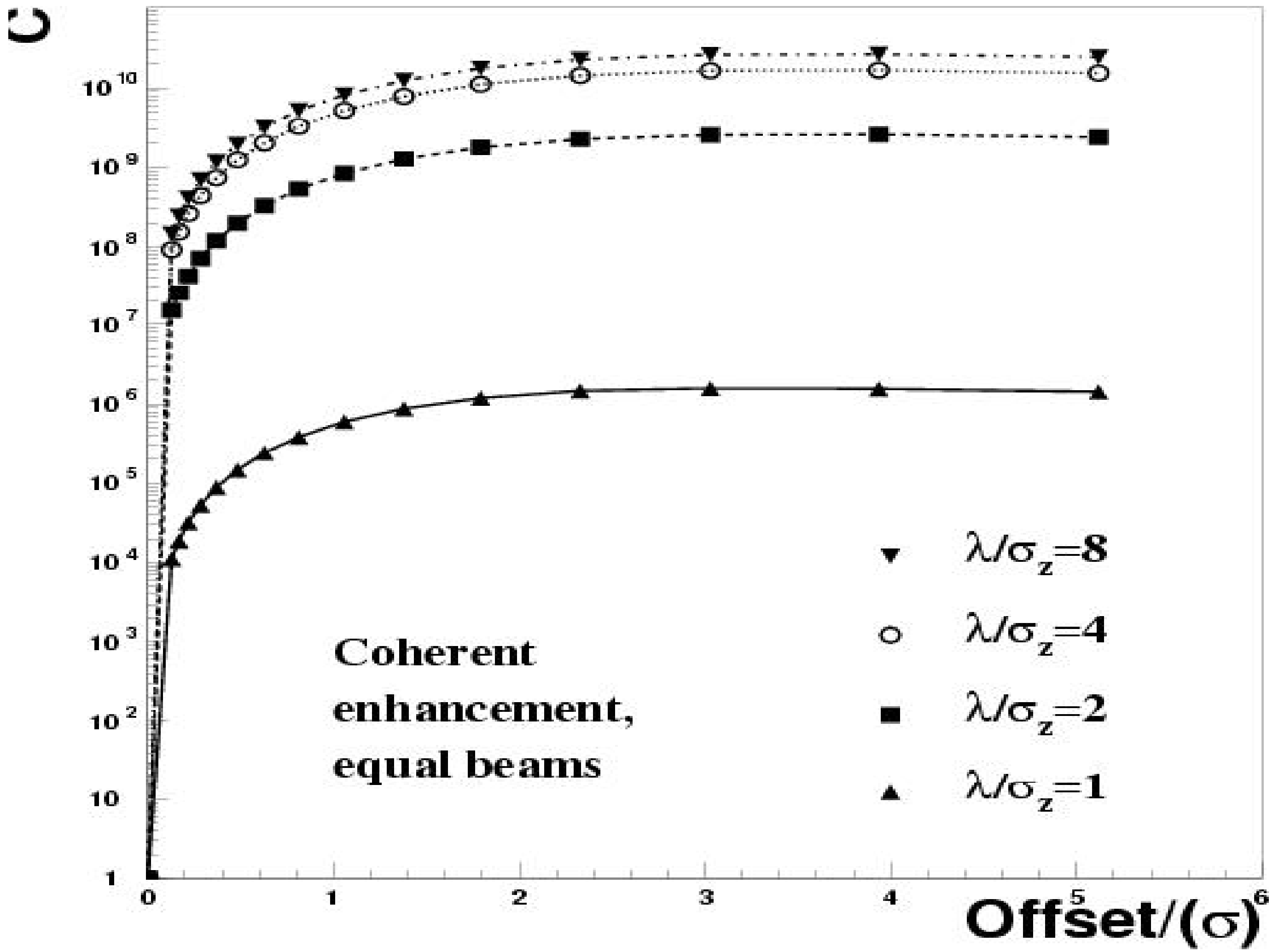
Beam pipe shielding

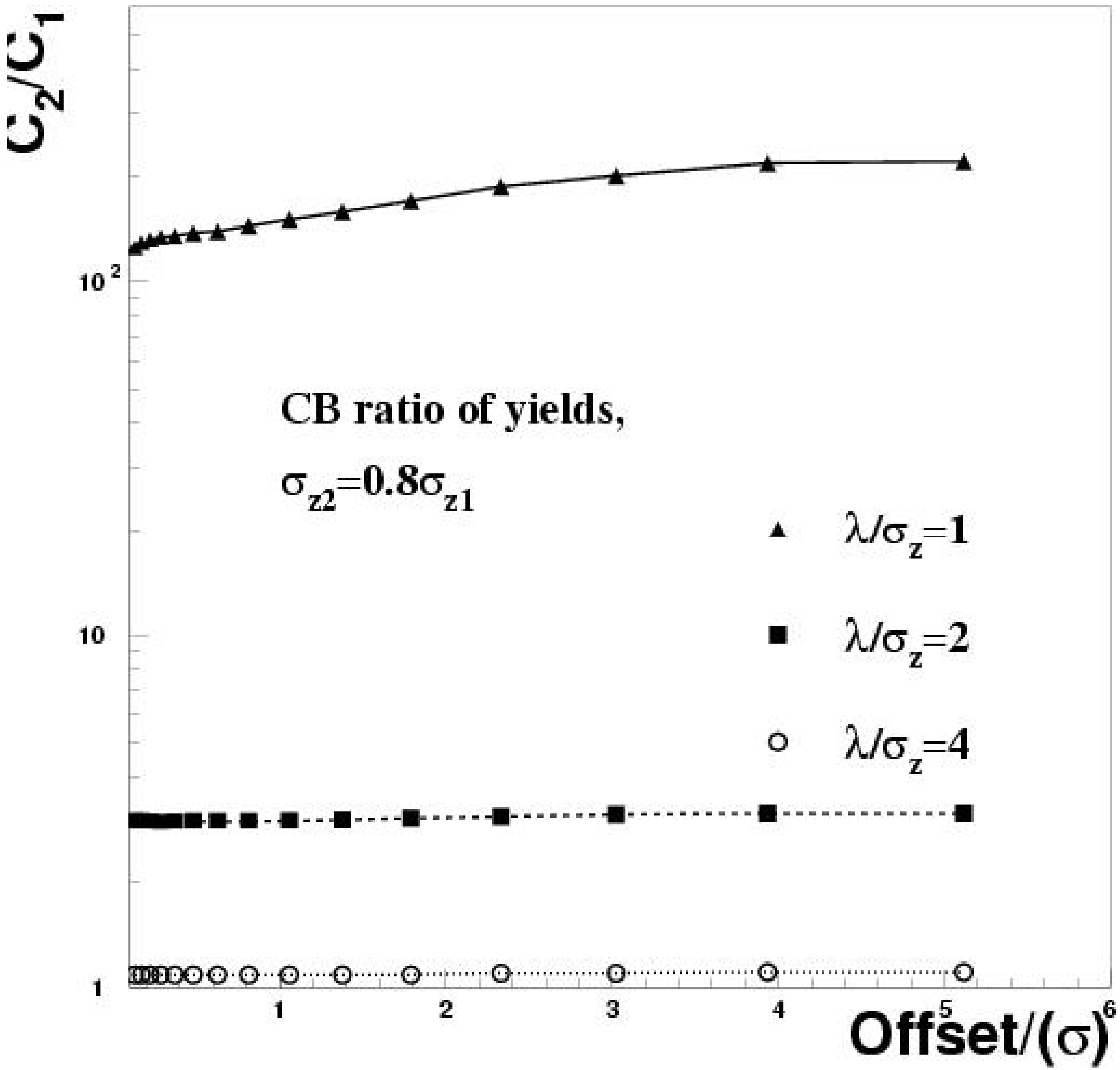
- Beam pipe effects are important for long magnets (Heifets, Mikhailichenko, SLAC-AP-083)

$$\lambda < d\sqrt{d/R}$$

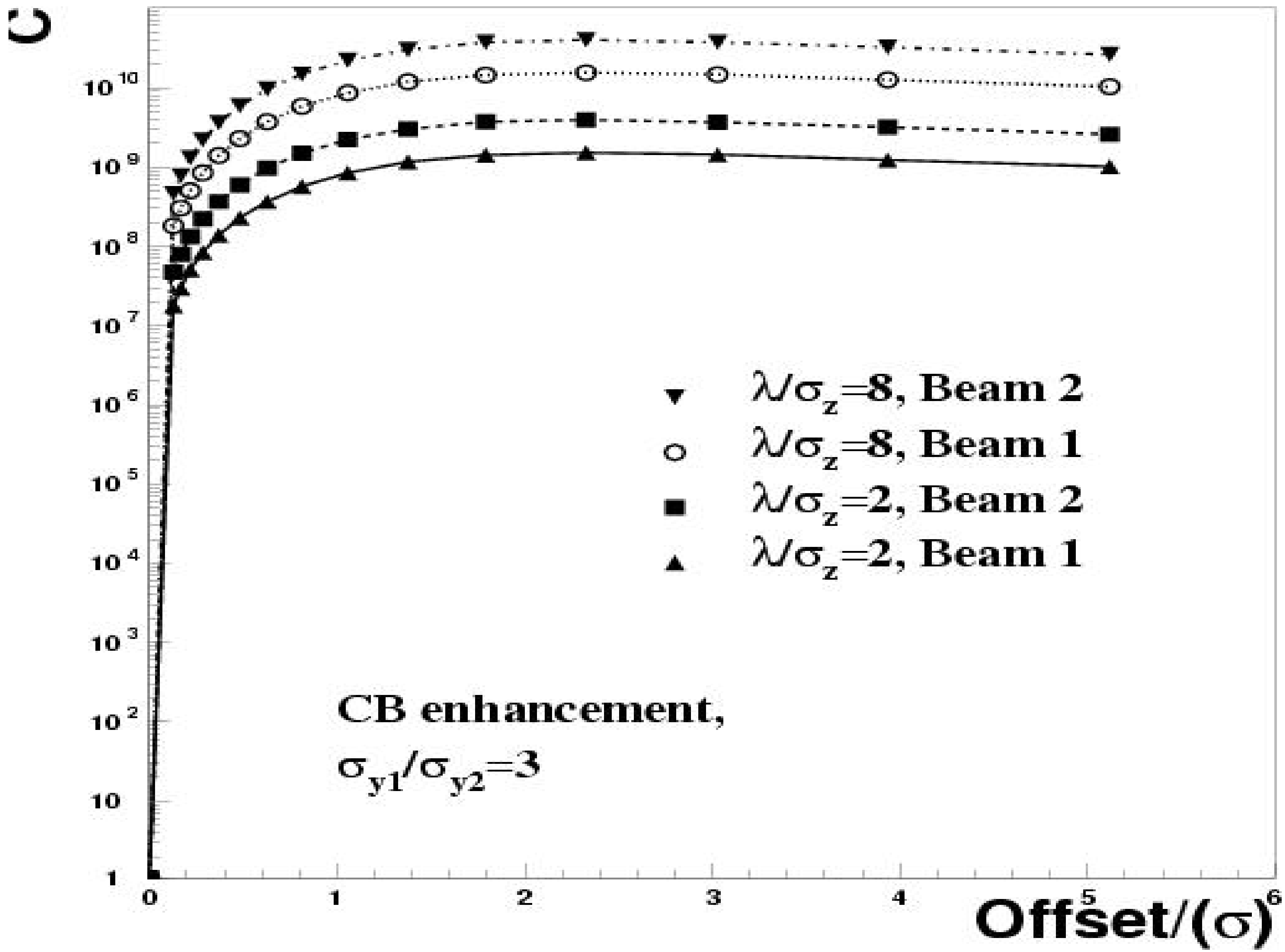
- In the case of ILC, R is of order 1meter. There is no beam pipe shielding
- In the case of CESR, R is of order 50 meters. The equation is not satisfied

Coherent enhancement (no beam pipe shielding, collinear radiation)





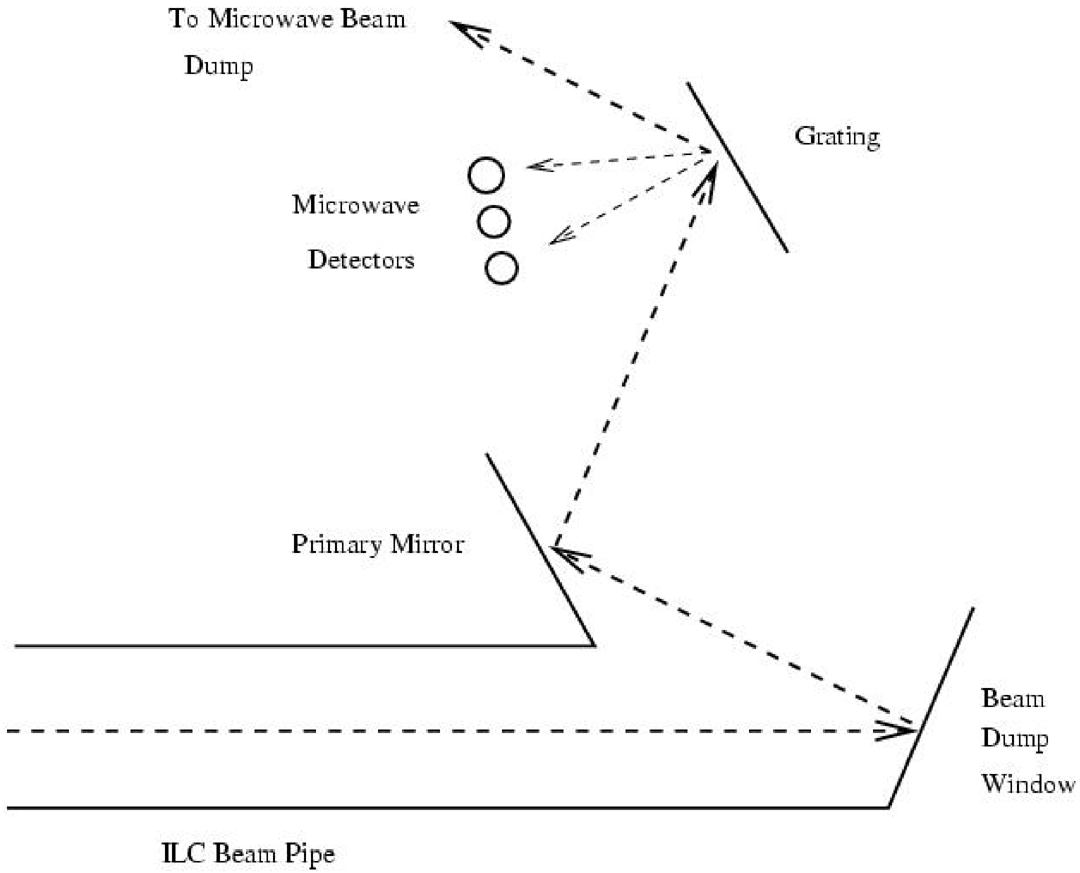
C_2/C_1
10^2
10
1
CB ratio of yields,
$\sigma_{z2}=0.8\sigma_{z1}$
$\lambda/\sigma_z=1$
$\lambda/\sigma_z=2$
$\lambda/\sigma_z=4$
1
2
3
4
5
6
Offset/(σ)


C
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0
1
2
3
4
5
6
Offset/(σ)
λ/σ_z=8, Beam 2
λ/σ_z=8, Beam 1
λ/σ_z=2, Beam 2
λ/σ_z=2, Beam 1
CB enhancement,
σ_y1/σ_y2=3

Main low energy beamstrahlung observables

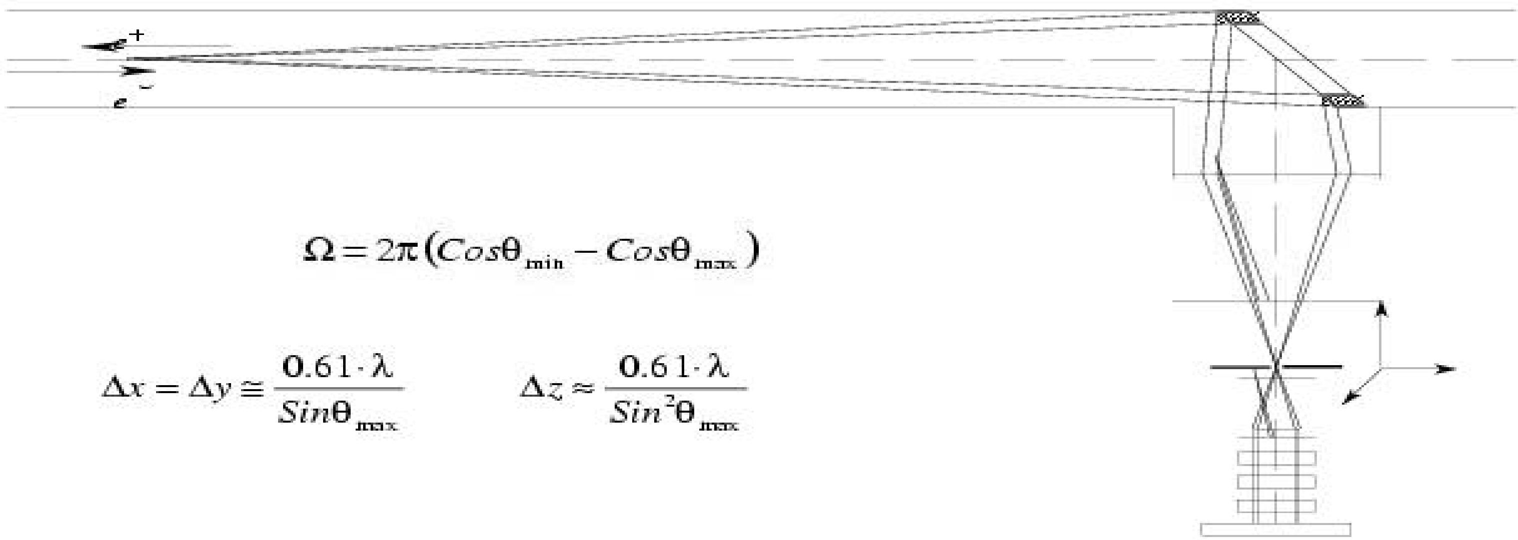
- Strong current dependence (N^3 and N^4 respectively)
- Strong σ_z dependence
- Observable dependence on beam-beam offset (very strong for CB)
- Correlated electron radiation and positron radiation
- Strongly varying frequency spectrum which peaks at lower frequencies

ILC CB detector concept



ILC IB detector concept (1-2 mrad)

Hollow mirror imaging system for detection of beamstrahlung radiation



$$\Omega = 2\pi\left(Cos\theta_{min} - Cos\theta_{max}\right)$$

$$\Delta x = \Delta y \cong \frac{0.61 \cdot \lambda}{Sin\theta_{max}} \qquad \Delta z \approx \frac{0.61 \cdot \lambda}{Sin^2\theta_{max}}$$

CORNELL UNIVERSITY LEPP

LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

Large Angle Beamstrahlung Monitor

Giovanni Bonvicini,

Mikhail Dubrovin

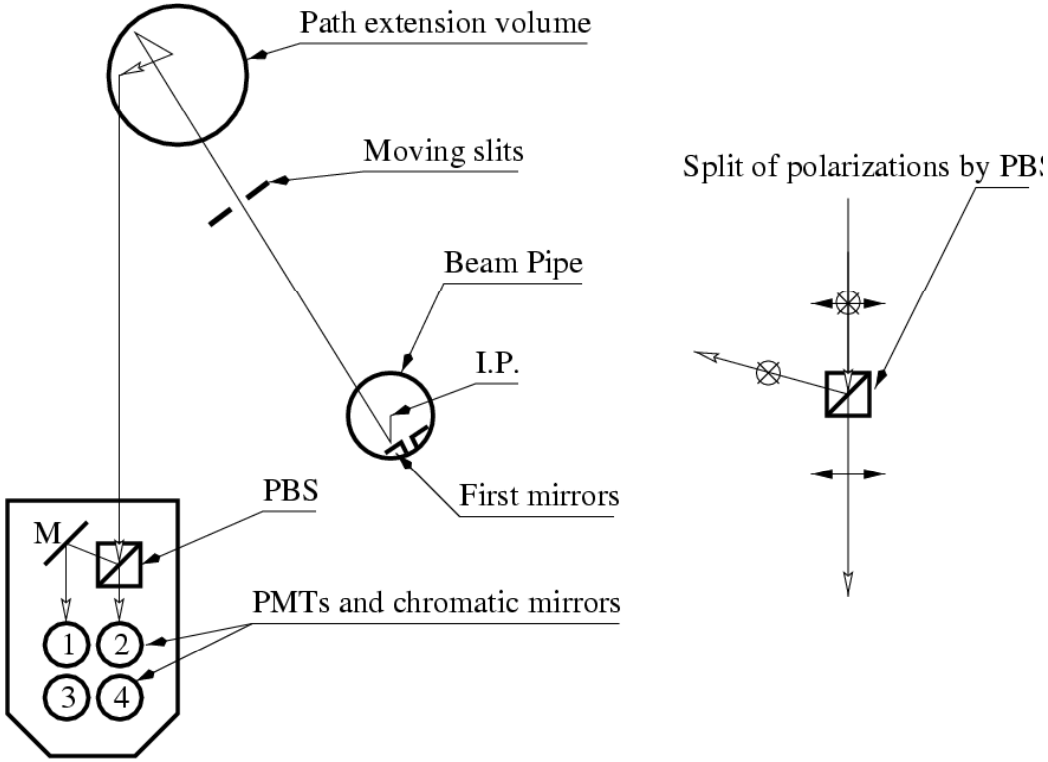
WAYNE STATE UNIVERSITY

National Science Foundation

WHERE DISCOVERIES BEGIN

¼ Set-up principal scheme

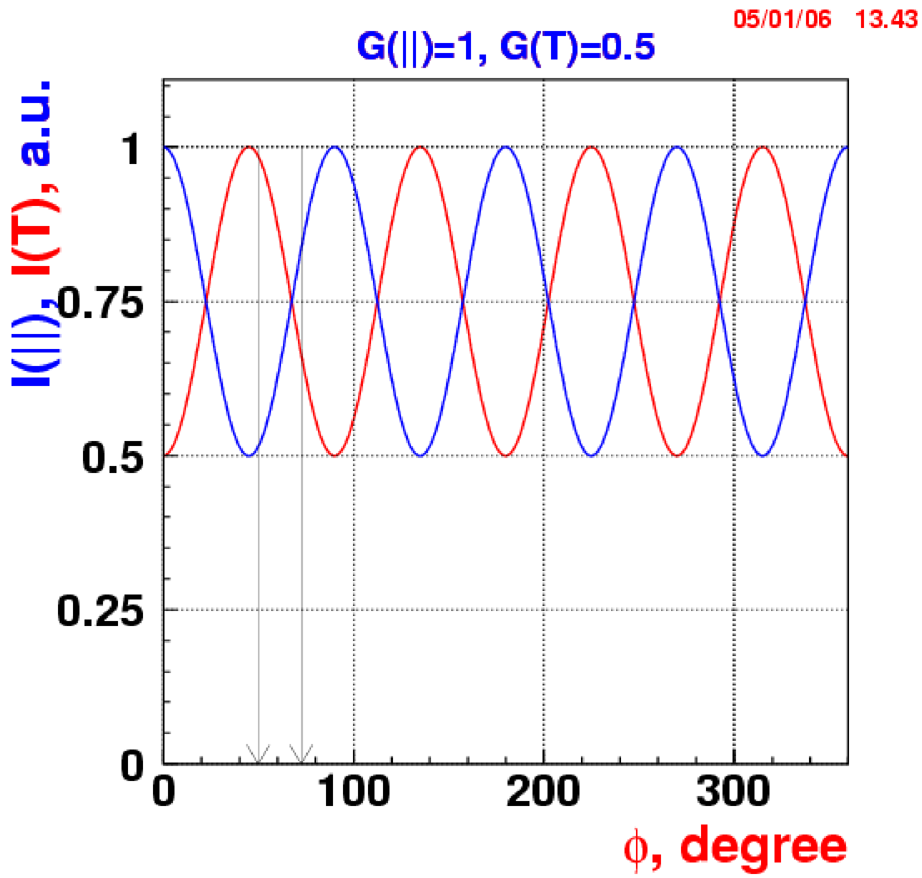
- Transverse view
- Optic channel
- Mirrors
- PBS
- Chromatic mirrors
- PMT numeration



Azimuth angle dependence of radiated power

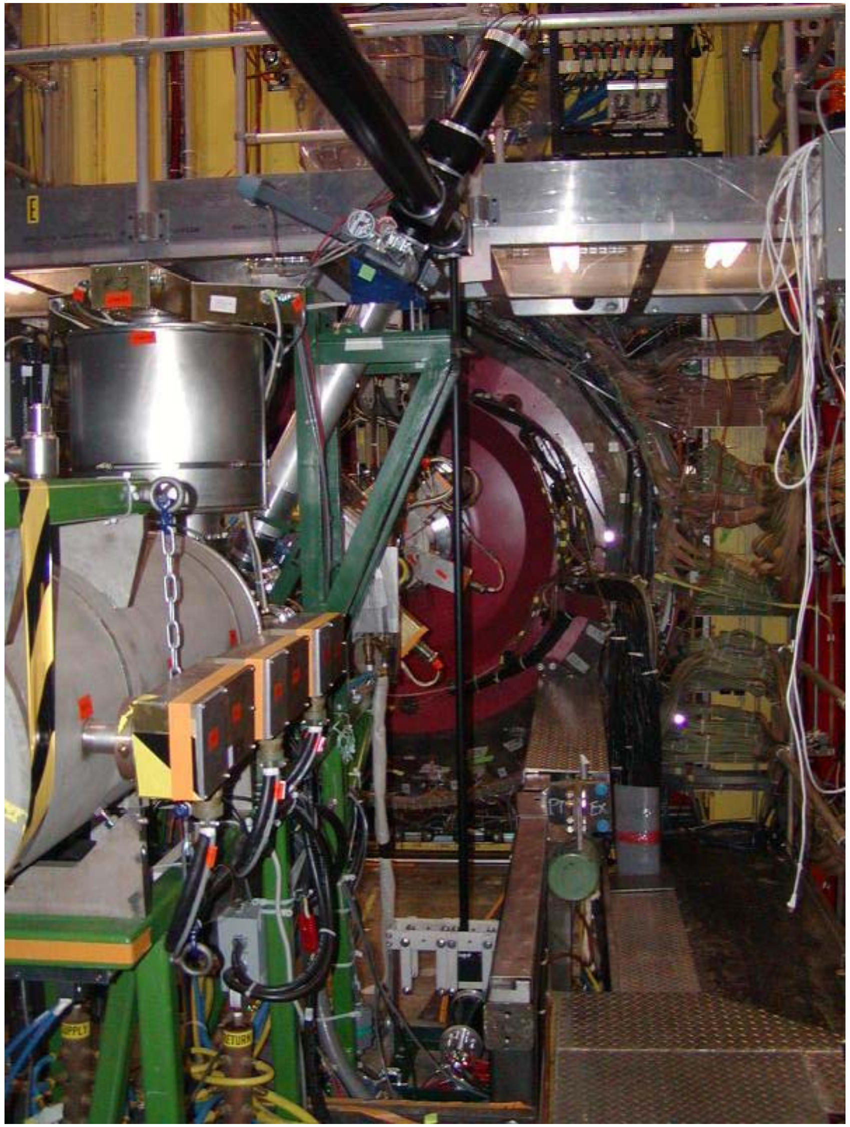
- Radiated power for horizontal and vertical polarizations

➢ Two optic ports are reserved for each direction (E and W)



Set-up general view

- East side of CLEO
- Mirrors and optic port ~6m apart from I.P.
- Optic channel with wide band mirrors
- Installed ¼ detector
- Prelim. experiments, VIS and IR PMTs

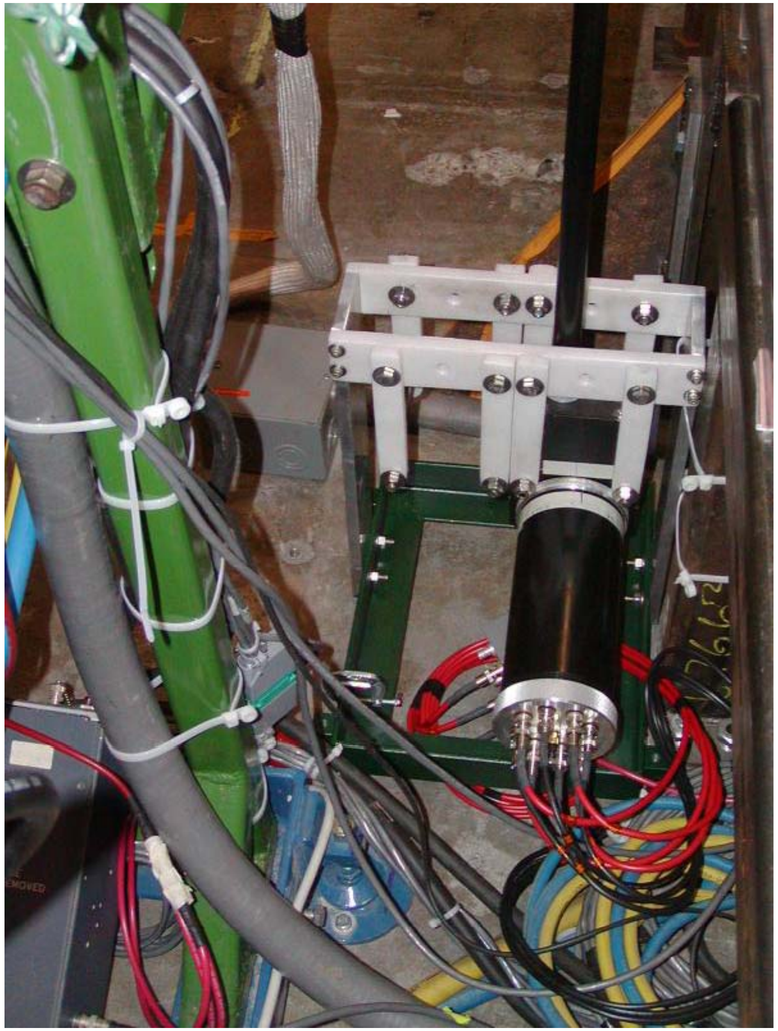


On the top of set-up

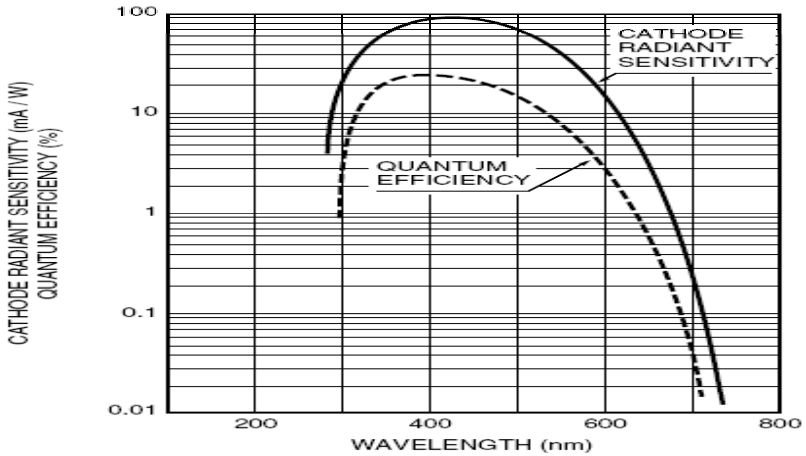
- Input optics channel
- Radiation profile scanner
- Optics path extension volume

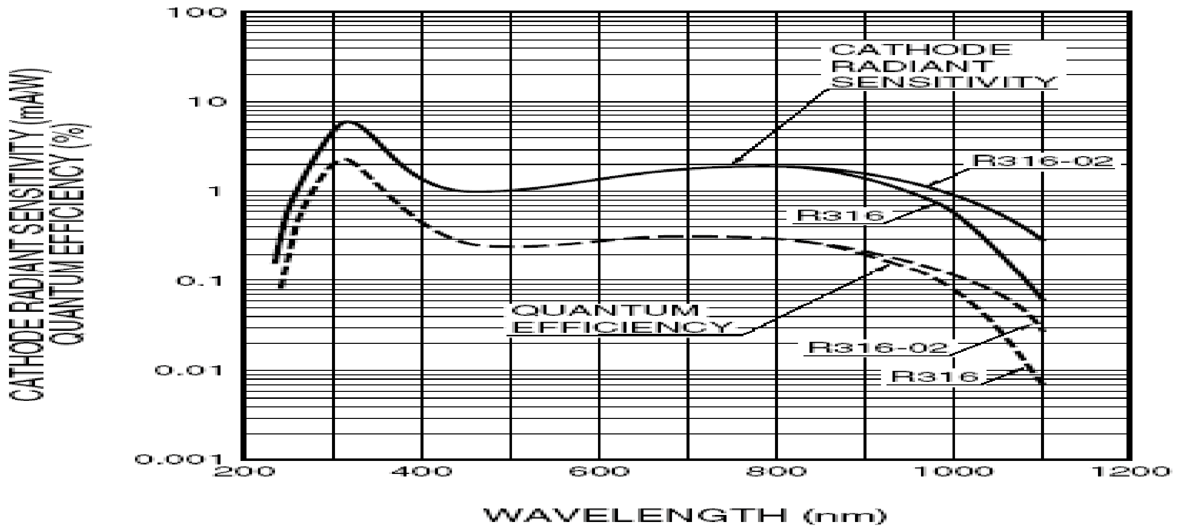
The ¼ detector

- Input channel
- Polarizing Beam Splitter
- Dichroic filters
- PMT's assembly
- Cooling…

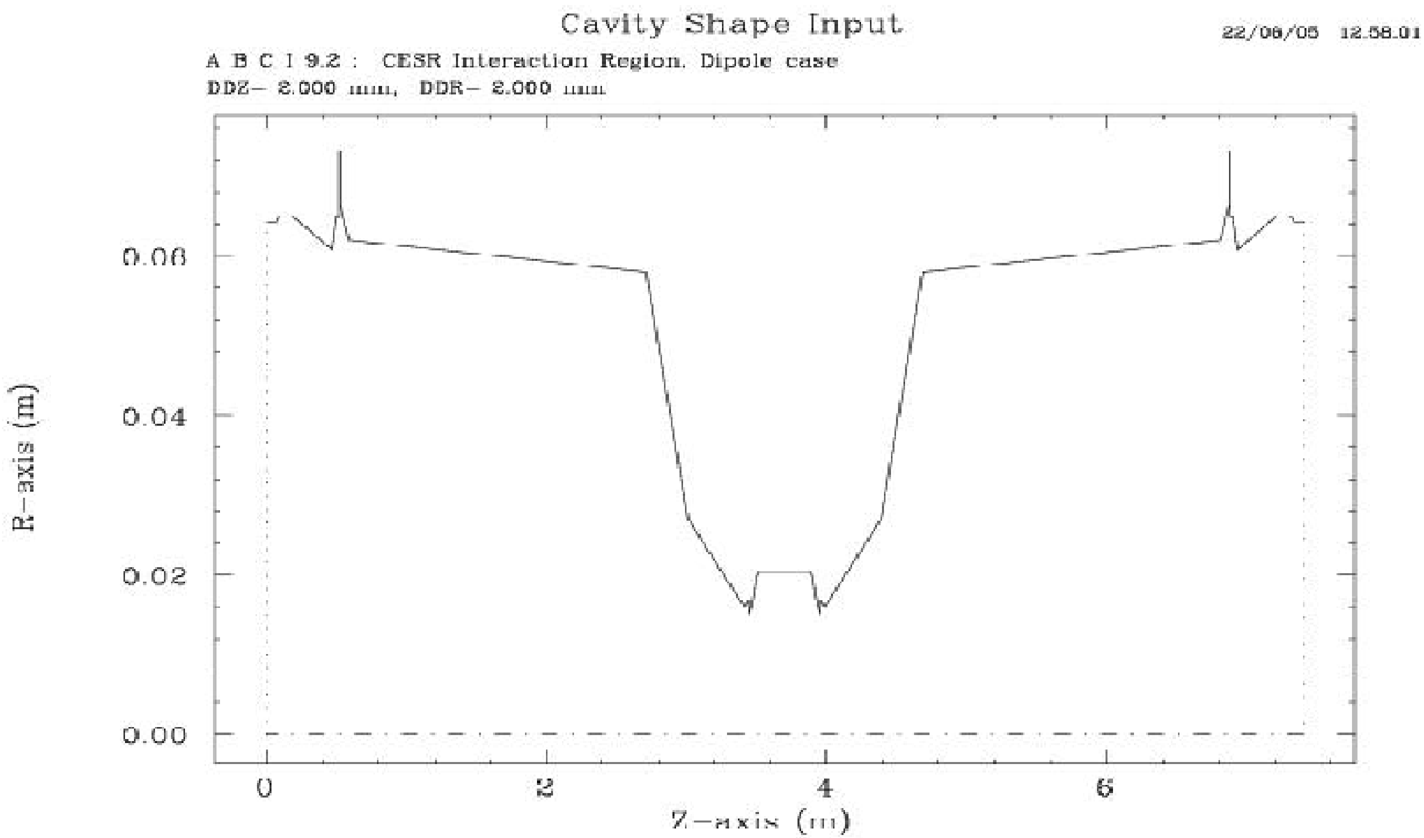


Sensitivity of R6095 vs R316-02

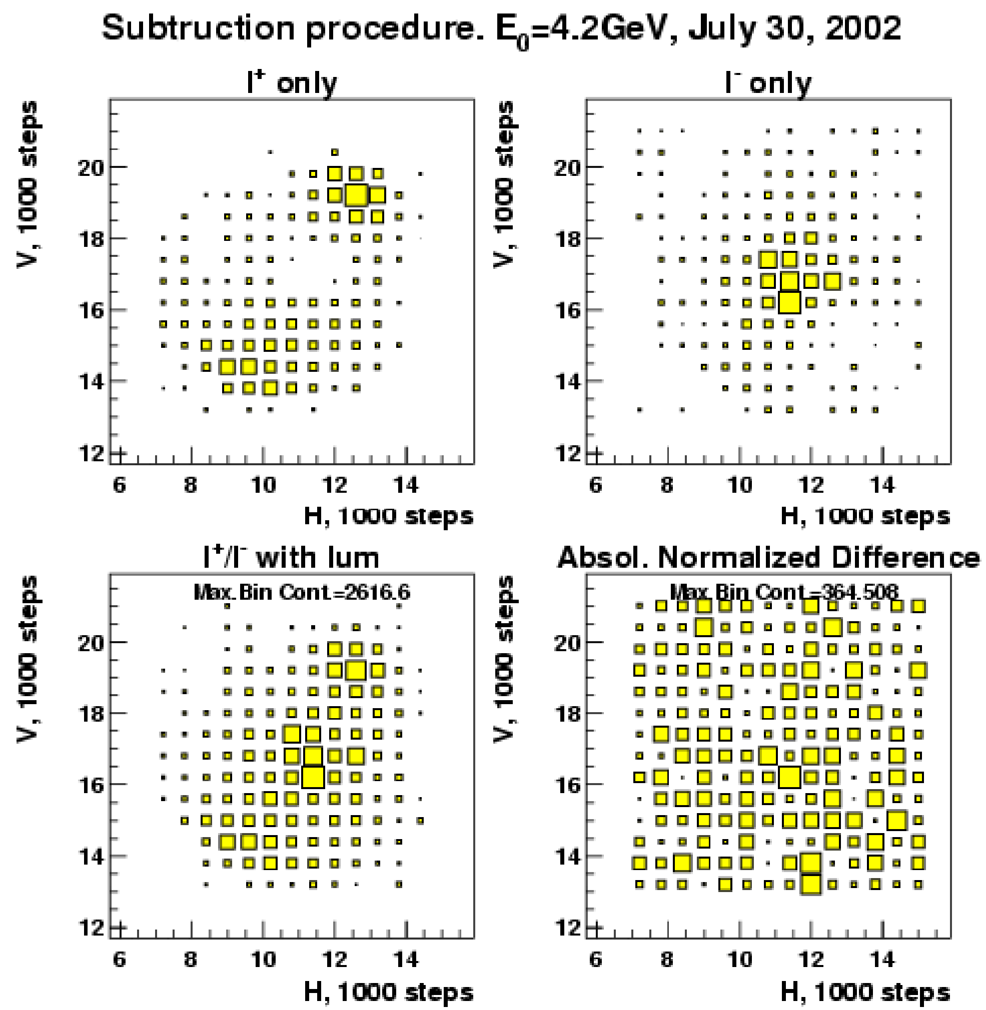




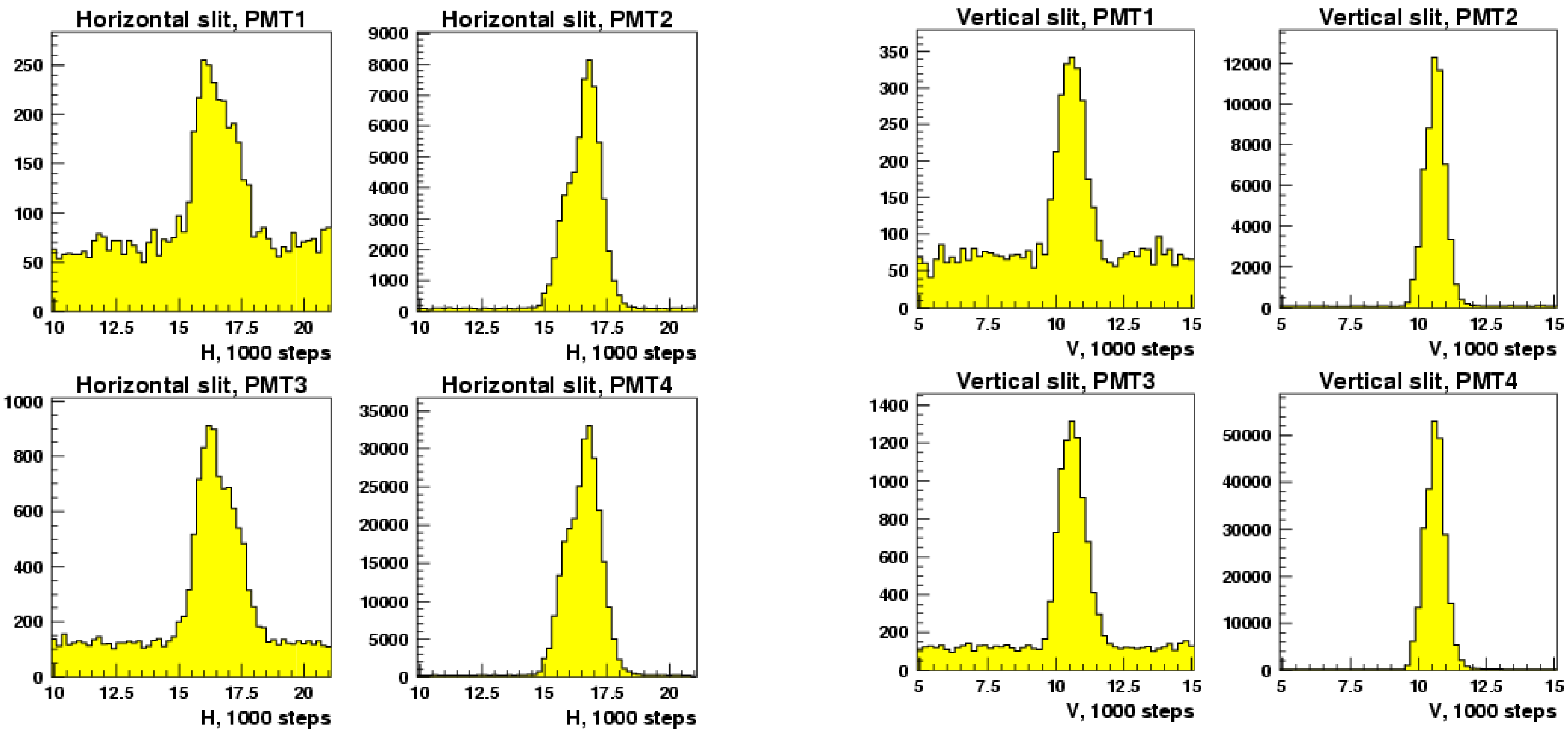
CESR beam pipe profile



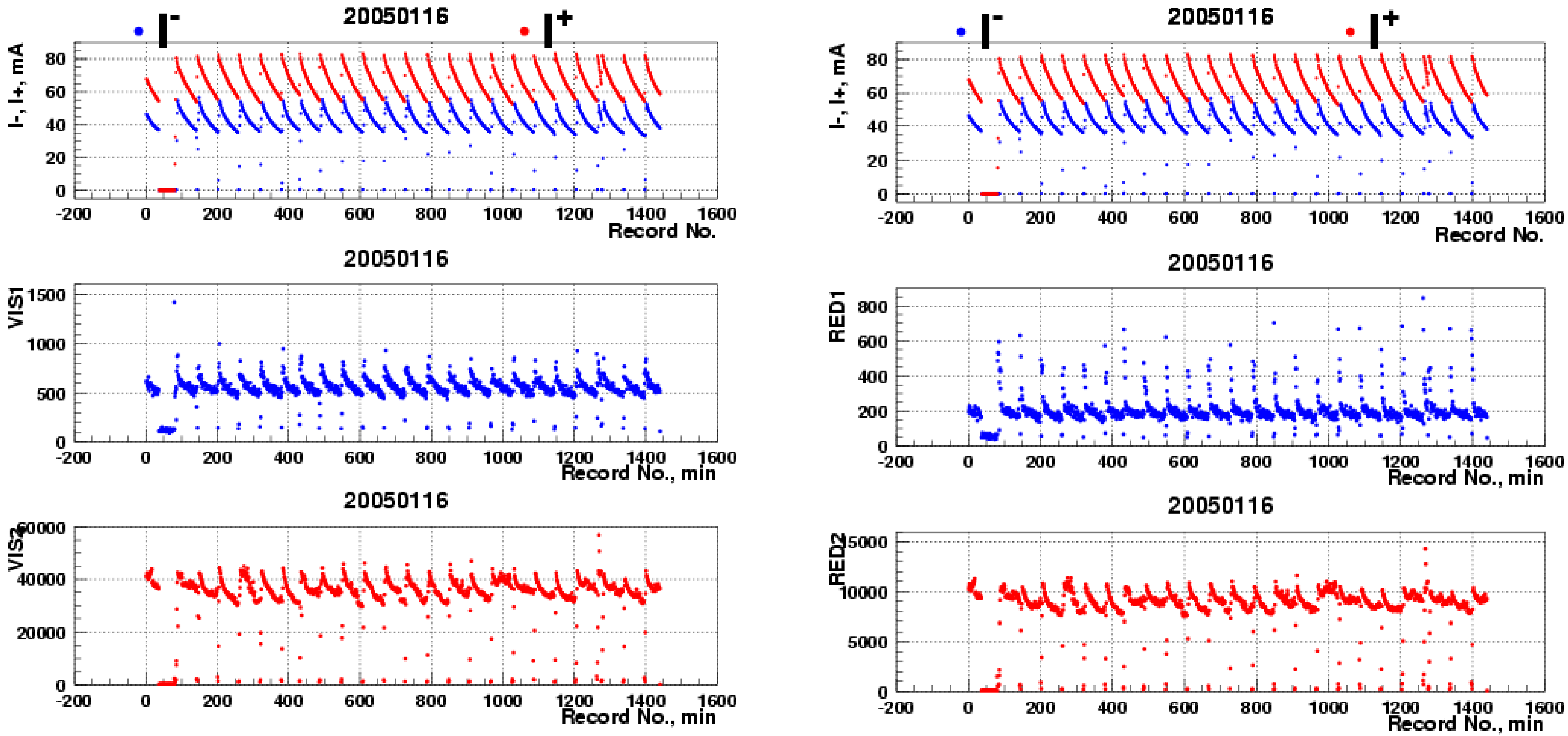
Check for alignment @ 4.2GeV



Horizontal & vertical projections



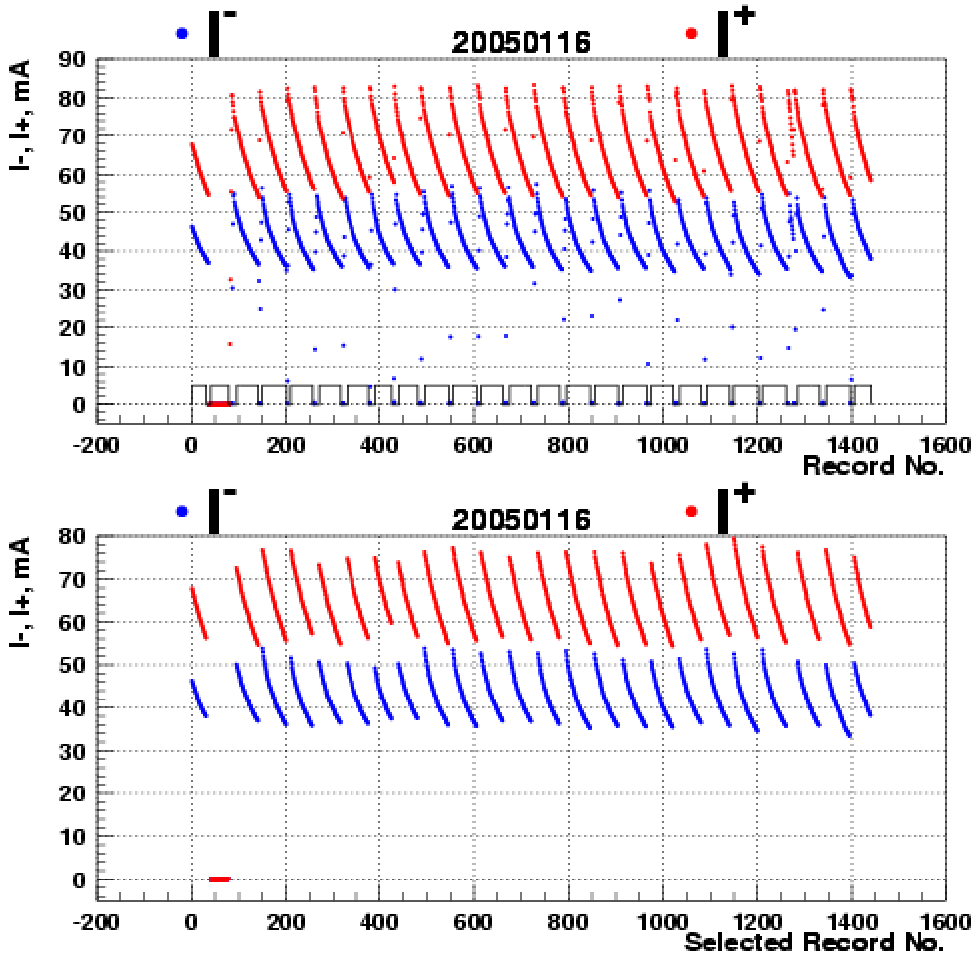
PMT rate correlations with beam currents



RED & VIS PMTs for this exp. are R6095 for visible light

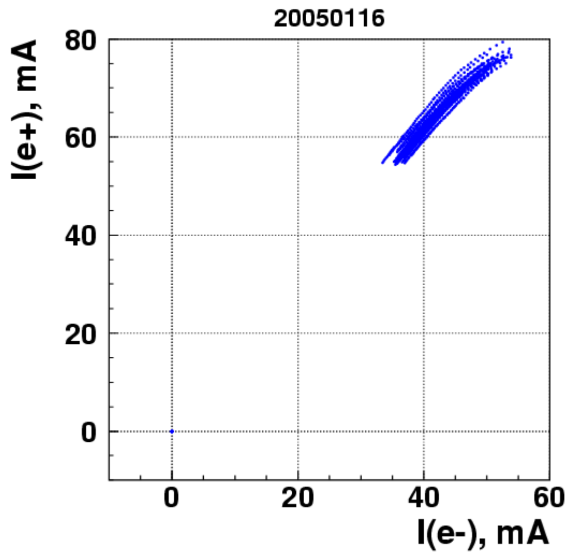
Records selection

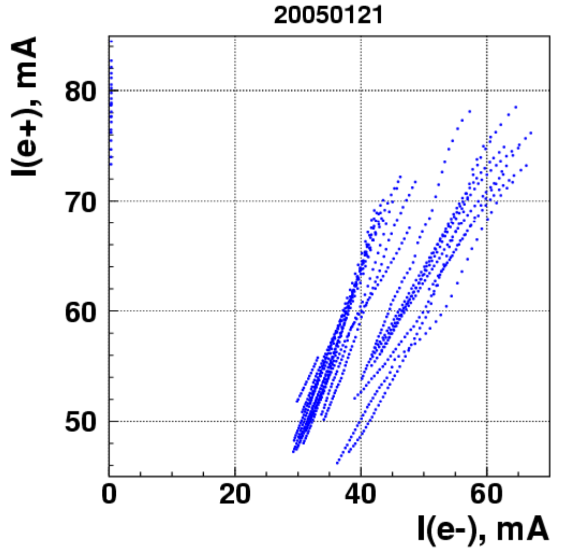
- For further analysis we exclude non-stable radiation periods at CESR currents re-fill
- In some cases we leave data for no-beam intervals



I(e+) vs I(e-)

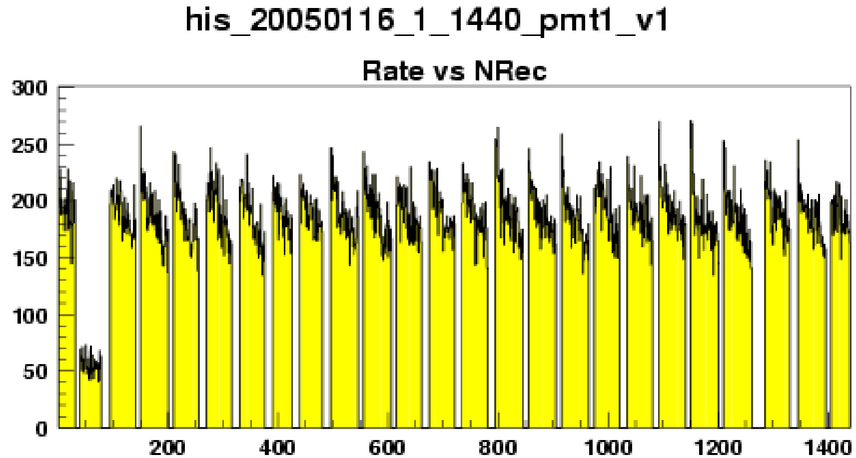
- Depending on shift the 2D plot area of CESR currents might be different
- It can be used to search for correlations with observed PMT rate



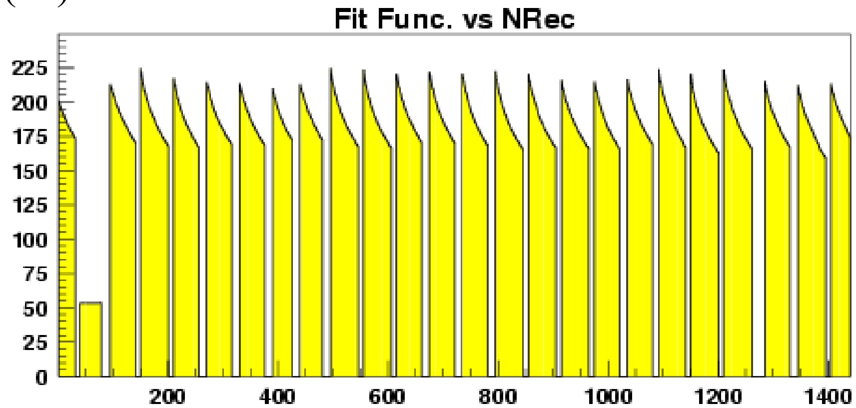


Fit to the rate for one of PMTs

- Rate vs record #
- Fit to the observed



$$R(I^+, I^-) = p_1 + p_2 \cdot I^- + p_3 \cdot I^+ + p_4 \cdot I^- I^+ + p_5 \cdot I^-(I^+)^2$$



$$\chi^2 = \sum_{\text{Rec.}} \frac{(Rate_{\text{Rec.}} - Rate(I^+, I^-))^2}{Rate_{\text{Rec.}}}$$

Acknowledgments

We appreciate many people who were involved
or helped us to work on this project:

- Mike Billing
- John Sikora
- Stu Peck
- Mike Comfort
- Yulin Li
- Sasha Temnykh
- Richard Ehrlich
- Steven Gray
- Scott Chapman
- John Dobbins
- John Galander
- Valera Mdjidzade
- Georg Trout
- Margee Carrier
- et al.

Summary

Full Setup is installed in CESR and periodically realigned

- produced entirely at WSU
- 16 PMTs, 4 for each optical port, 2 for each polarization, 2 for visible (λ<500nm), and two for IR($800<\lambda<950$ nm)

CB Observability at CESR (summer 2005)

- Radiated power is propagating essentially in waveguide mode
- A short beam is still crucial. Observability at KEK-B (σ_z =6mm) appears more promising
- Waves will probably propagate in TM mode (M. Billings). TM cutoff is 0.82d and TM maximum power (for σ_z=10mm) is 2 pJ per BBC (1.7d and 2nJ for TE mode) (IF NO BEAM PIPE SHIELDING IS PRESENT - it is probably far less)
- Observation possible at two BPM stations, located at 0.68m and 3.6m from the IP respectively(M. Billings). One can look at both time and frequency domain
- Beam pipe bottleneck at SR mask a potential problem
- E. Wisniewski, S. Belomestnykh, M. Billings, computed the magnetic wake fields at the BPMs

2006 activities

- Progress in understanding/publishing IB delayed by wrong type of IR PMTs (we changed them, now using R2228),
- strong dependence on σ_z , (now measured on a run-to-run basis by using vertex distributions of Bhabha+ hadronic events in CLEO. New CESR configuration after April 2006 produced a near constant σ_z =10.2mm)
- potential diffraction effects in the collimators (we extracted, enlarged, and re-installed the collimators, in the process improving the S/sqrt(B) by a factor of 5)

2006 activities (contd)

- backgrounds that were not consistent with previous simulations (new, independent SR simulation written from scratch with help from M. Forster and D. Sagan. This new program should be relatively easy to adapt to the ILC)
- strong CESR differences between single beam mode and physics mode (method for background measuring finally abandoned, now relying on mapping the whole beam pipe for simulation validation)
- Data taking rate increased by factor of 10 to improve sensitivity, plus numerous quantities from CESR data stream added to our data taking routines

2007 activities/Current Status

- At this stage the expected signal is many times the observed statistical error
- Data fitting procedure is well established
- The major issues are the exact angle of observation, the exact radiator to use in our background simulations, and the stability of the beam angle over one day

Conclusions

- Some progress in IB.
- CB at the ILC will certainly be present. Potentially extremely useful for BBC imaging
- CB observation at present accelerators would be most useful but may not happen
- If both these techniques develop, there is a tremendous amount of work to do