CORNELL UNIVERSITY LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS

Low energy Beamstrahlung at CESR, KEKB and SuperB

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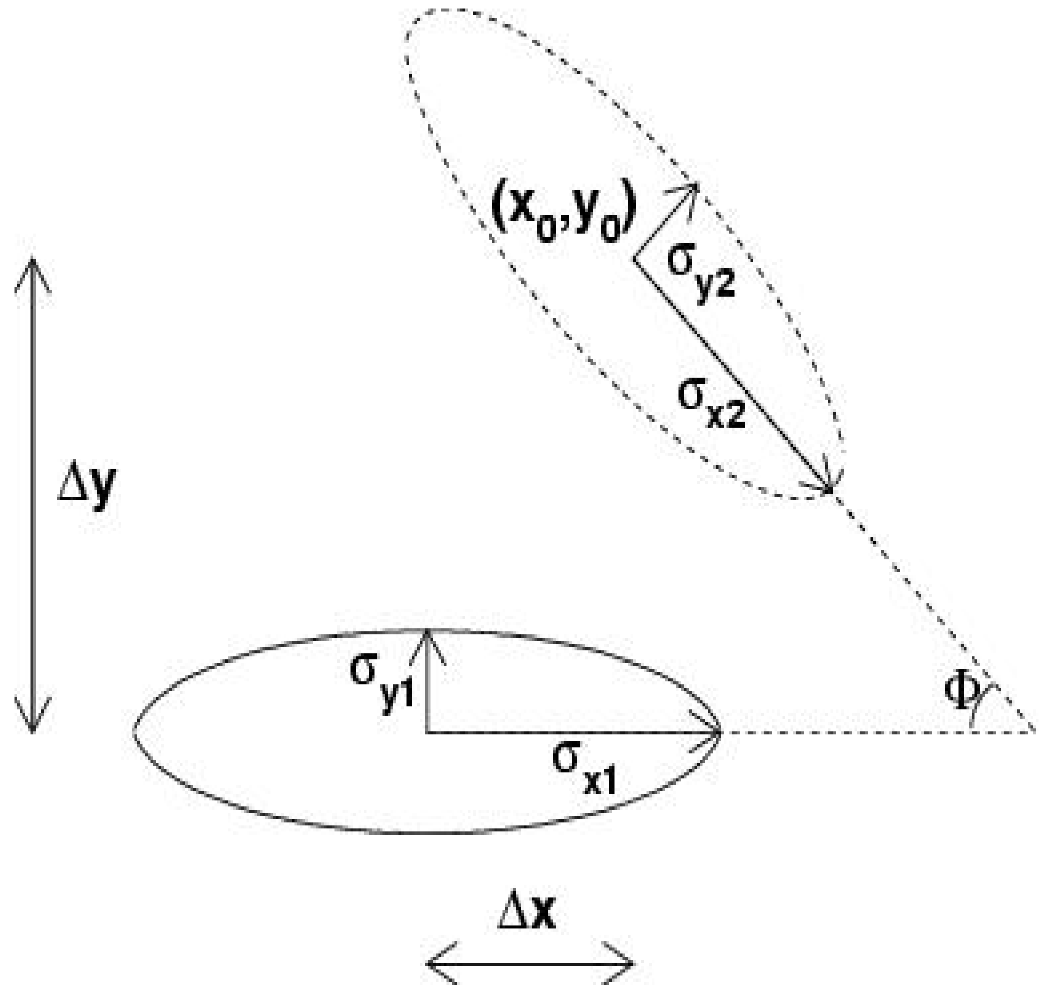
WHERE DISCOVERIES BEGIN

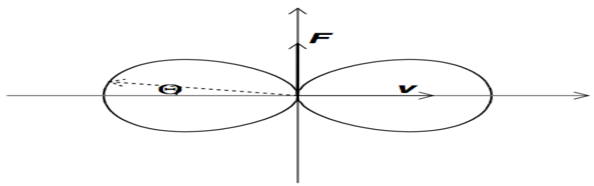
What is beamstrahlung

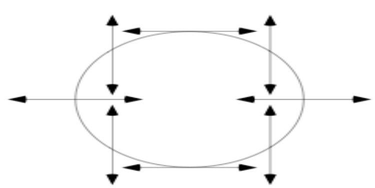
- The radiation of the particles of one beam due to the bending force of the EM field of the other beam
- Many similarities with SR but
- Also some substantial differences due to very short "magnet" ($L=\sigma_z/2\sqrt{2}$),very strong magnet (3000T at the ILC). Short magnets produce a much broader angular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

Beam-beam interaction (BBI) d.o.f. (gaussian approximation)



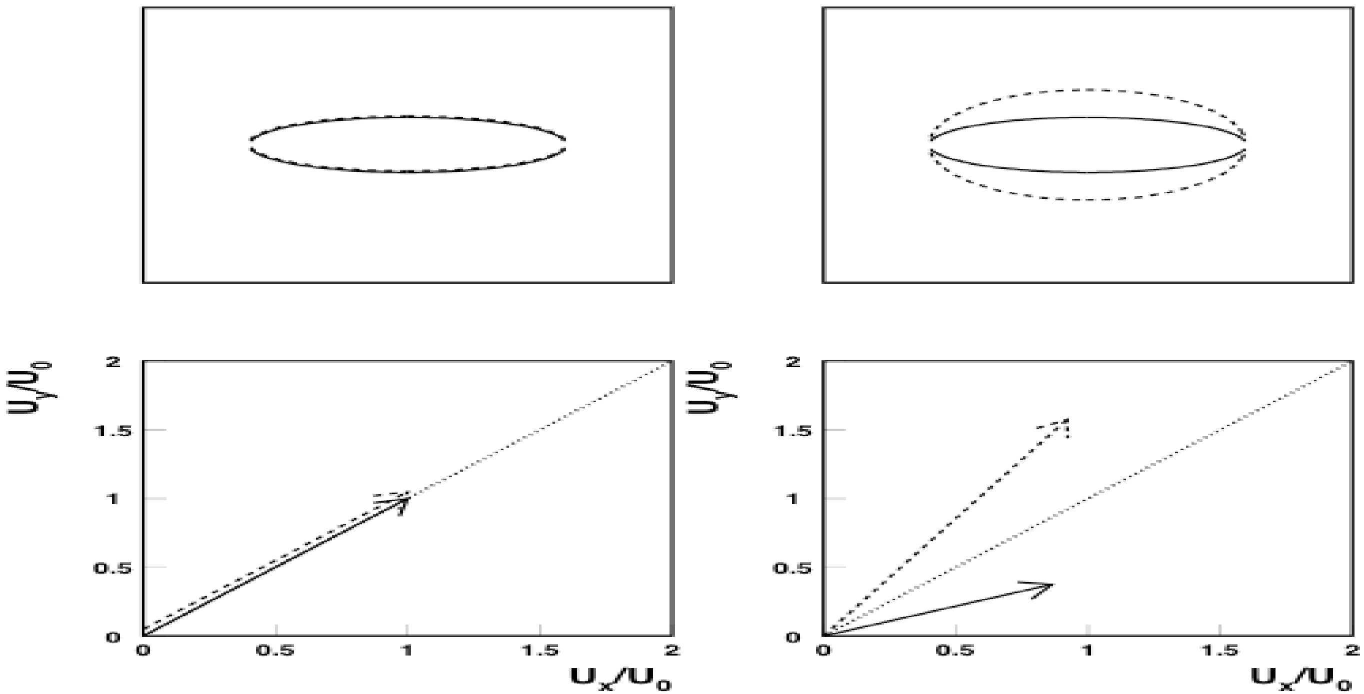
Properties of large angle radiation



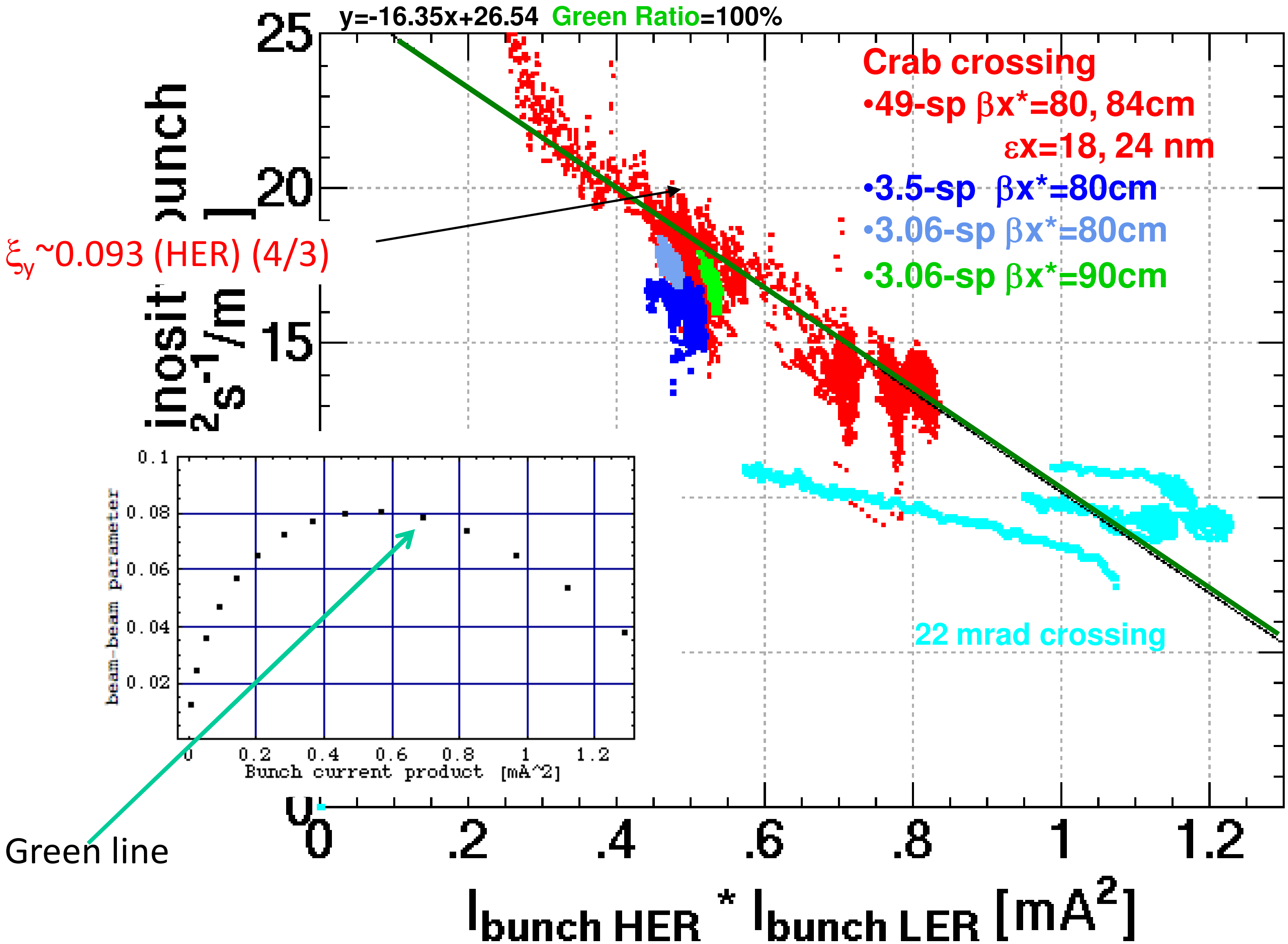


- It corresponds to the near backward direction in electron rest frame (5 degrees at CESR, 2-4 degrees at KEKB)
- Lorentz transformation of EM field produces a 8-fold pattern, unpolarized as whole, but locally up to 100% polarized according to $\cos^2(2\phi)$, $\sin^2(2\phi)$

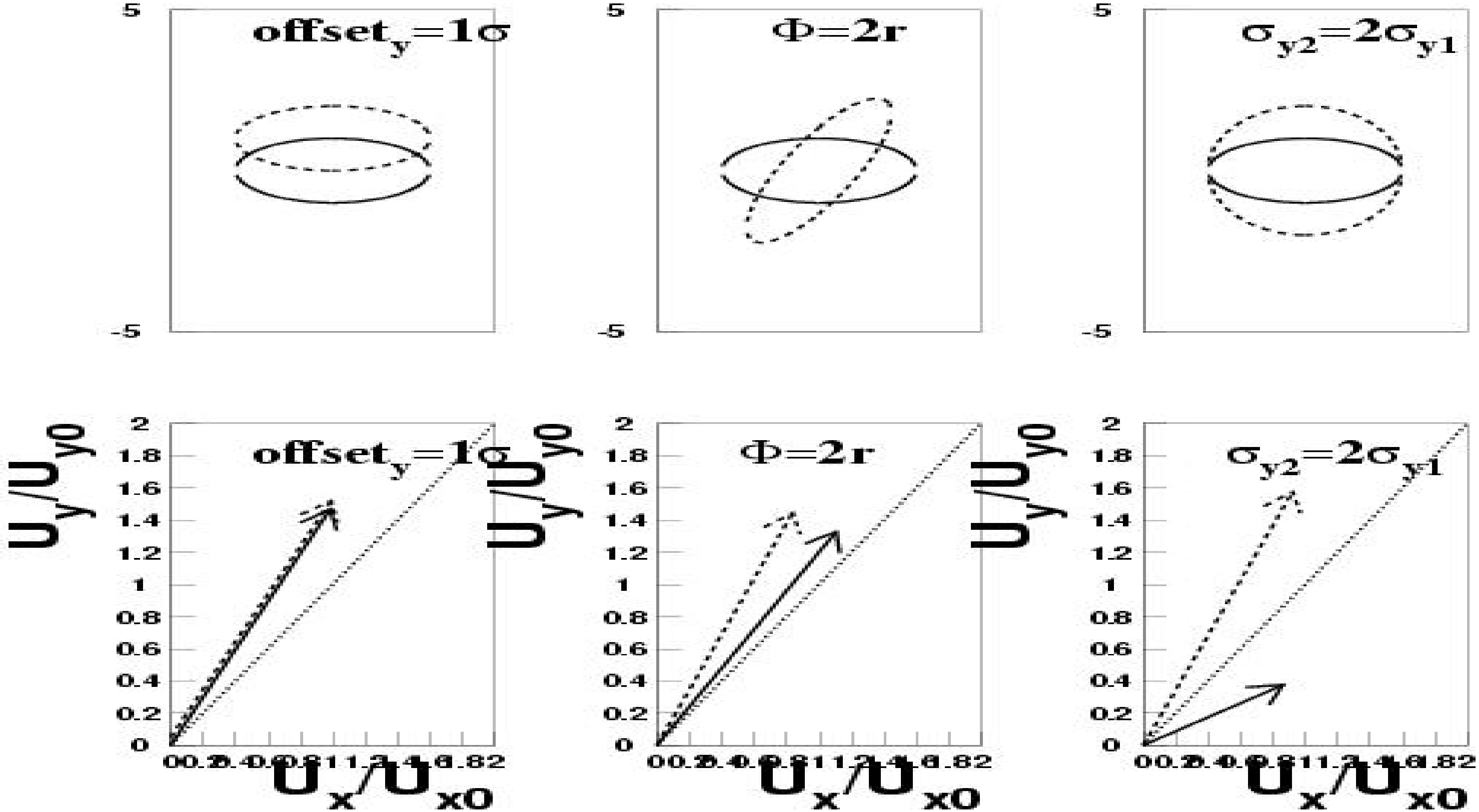
Perfect collision vs one bloated beam, as seen in large angle beamstrahlung



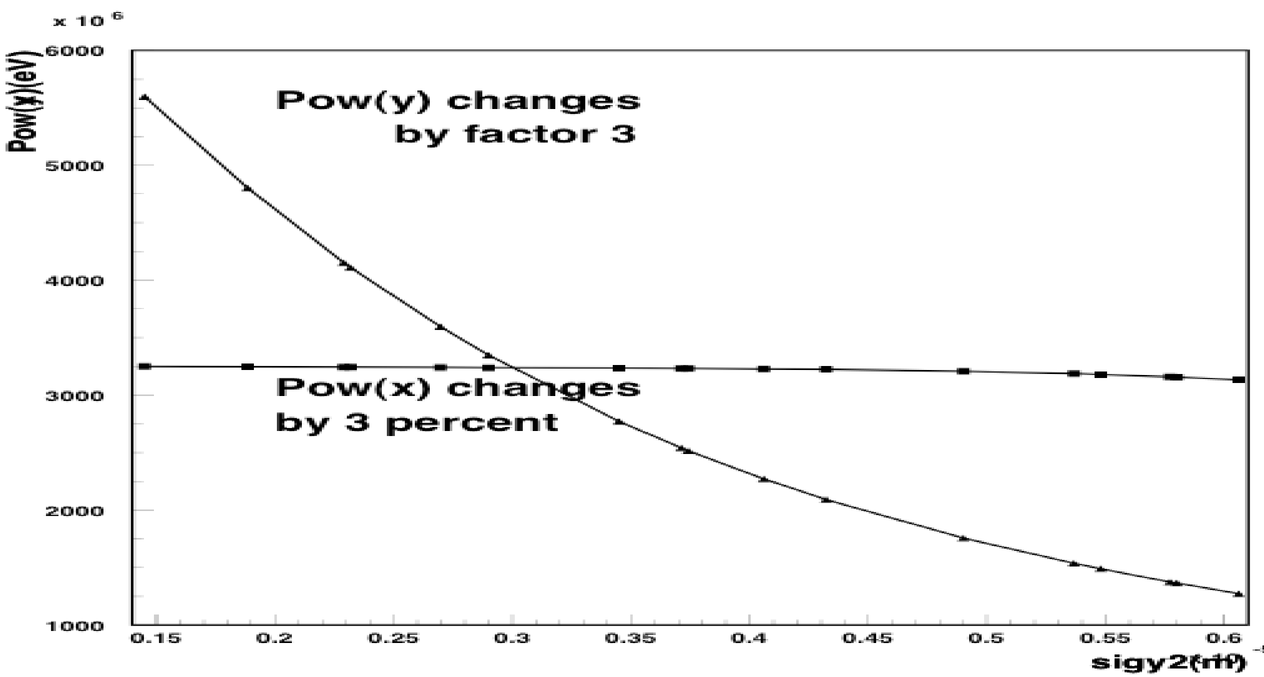
Specific Luminosity at KEK



Some examples of Large Angle BMST pattern recognition



Power by beam 1 when beam 2 changes vertical size

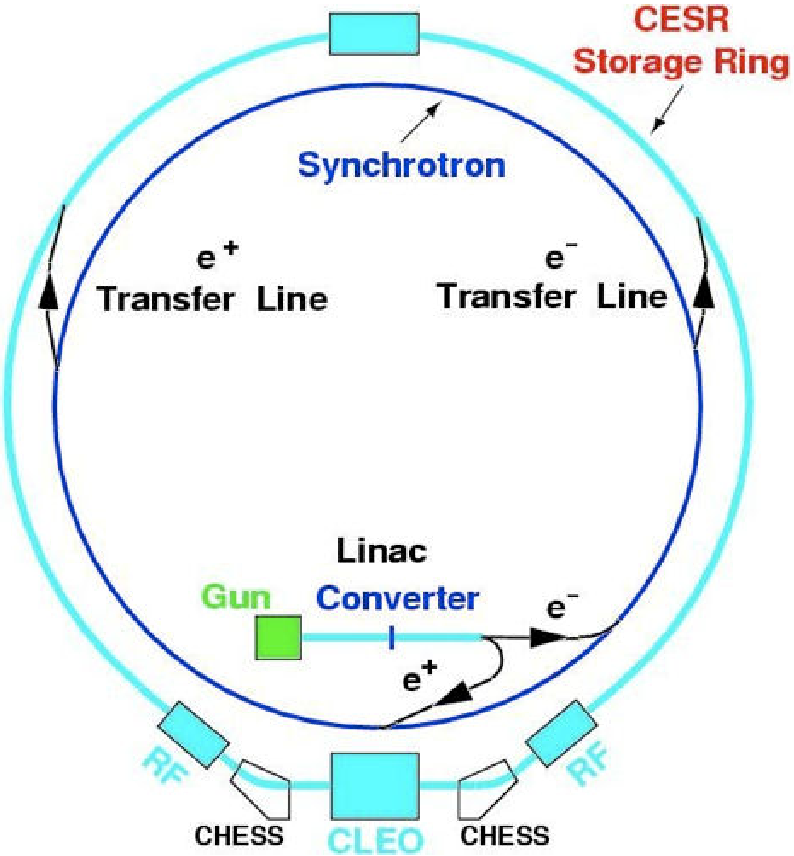


Large angle beamstrahlung power

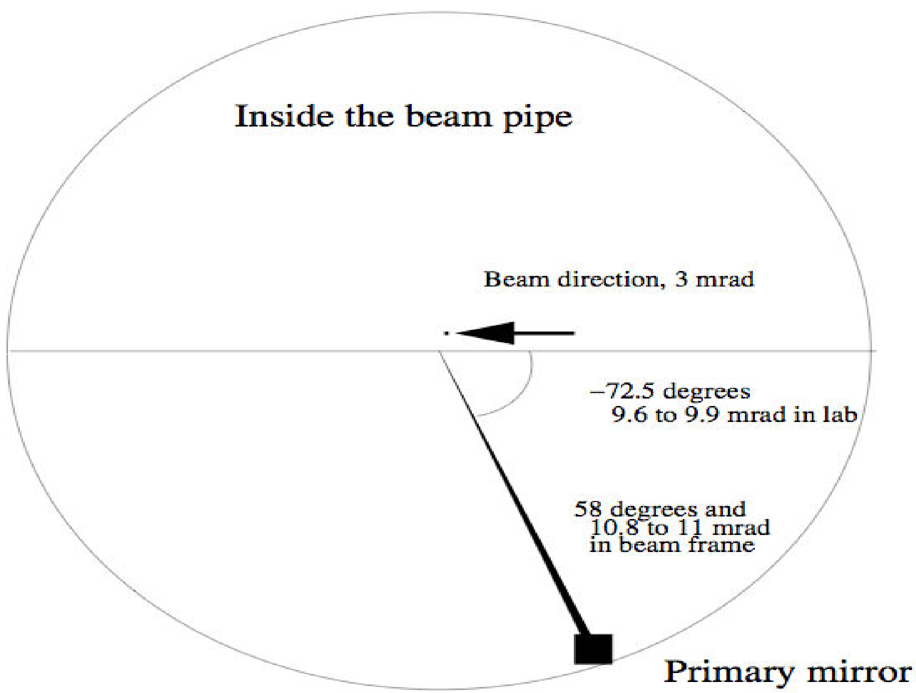
- Total energy for perfect collision by beam 1 is: $P_0=0.11\gamma^2 r_e^3 mc^2 N_1 N_2^2/(\sigma_x^2\sigma_z)$
- Wider angular distribution (compared to quadrupole SR) provides main background separation
- CESR regime: exponent is about 4.5
- ILC regime: exponent is very small

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

CESR location

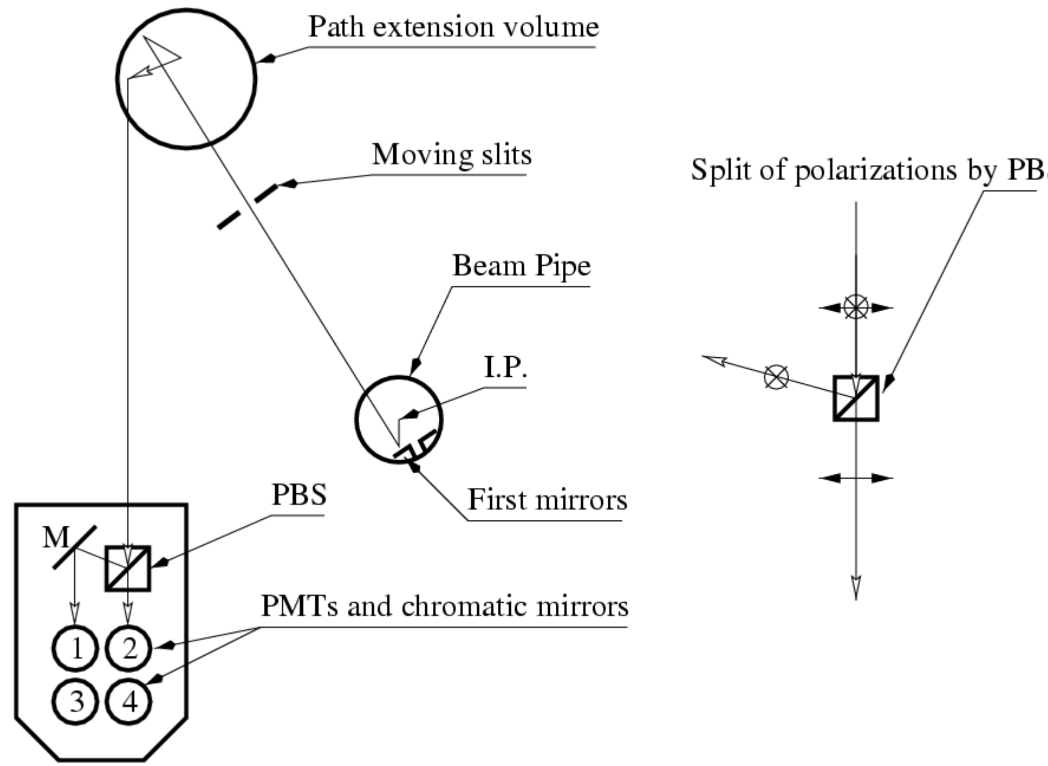


Beam pipe and primary mirror



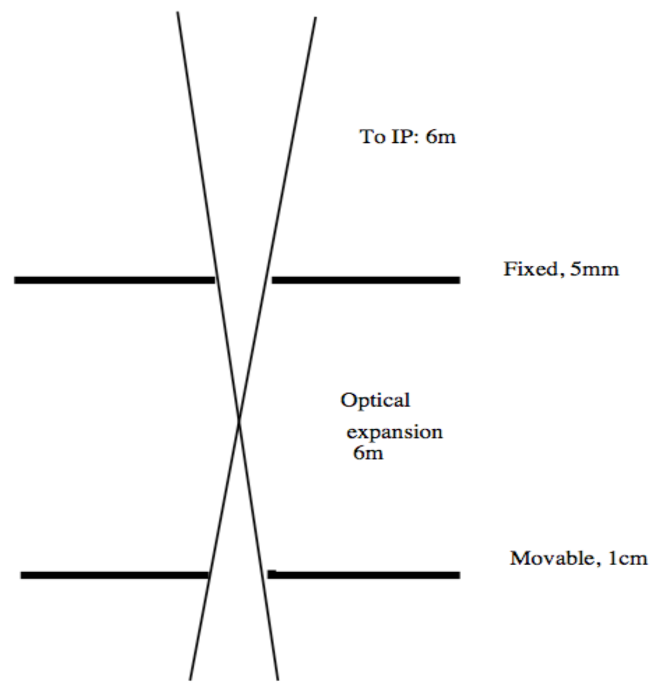
¼ Set-up principal scheme

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



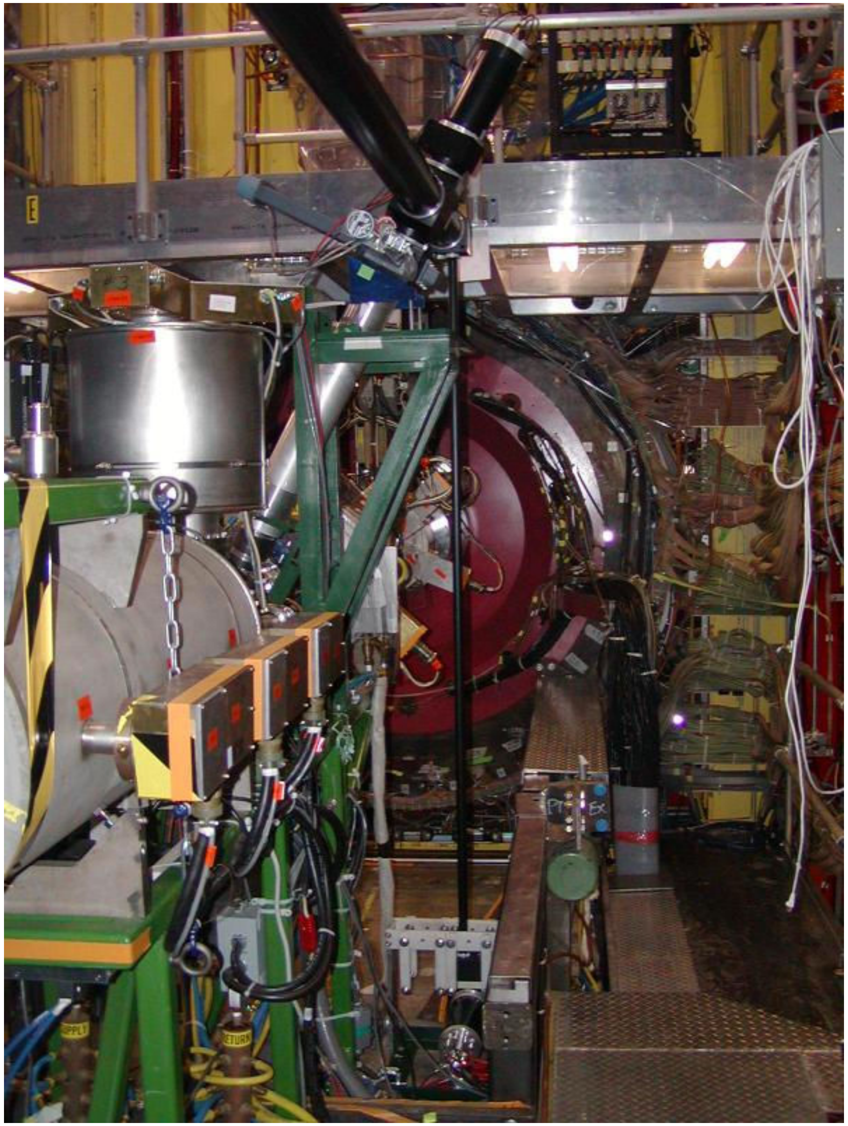
Detector parameters of interest

- Diffraction limit is 0.1 mrad. Sharp cutoff can be assumed
- Optics is double collimator. Has triangular acceptance with max width of 1.7mrad
- At IP, accepted spot is about 1cm



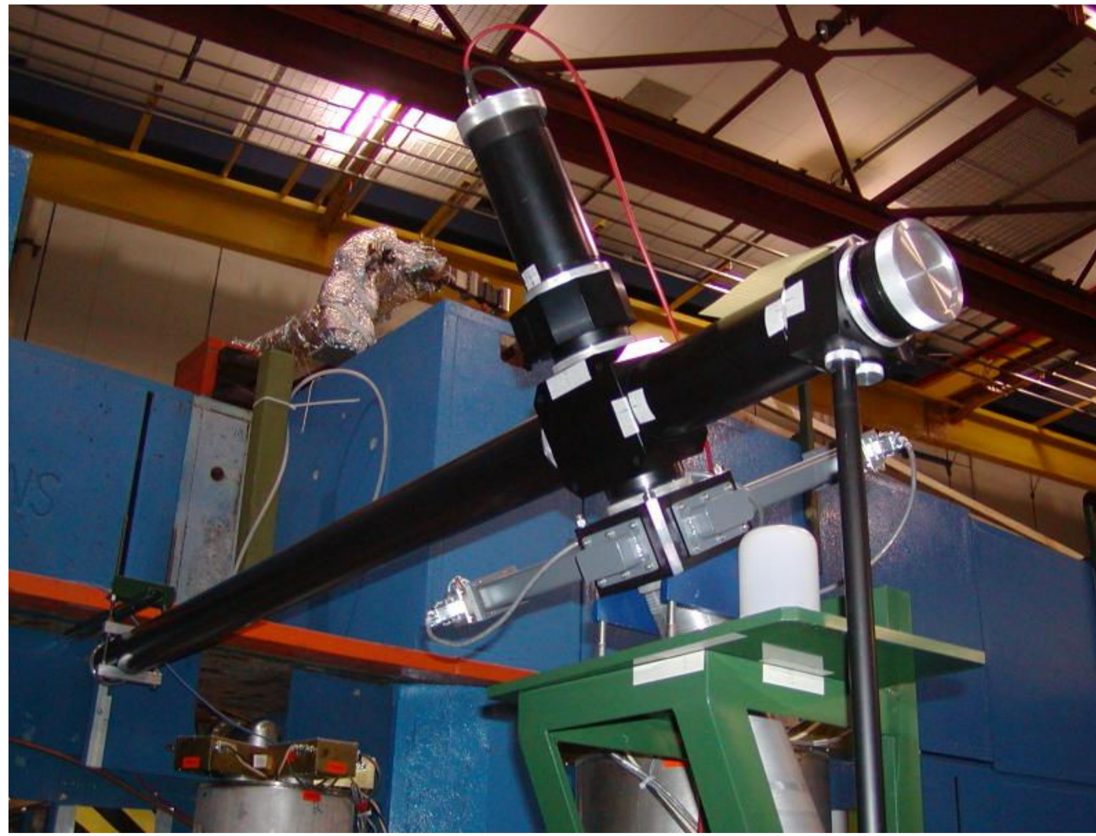
Set-up general view

- East side of CLEO
- Mirrors and optic port ~6m apart from I.P.
- Optic channel with wide band mirrors



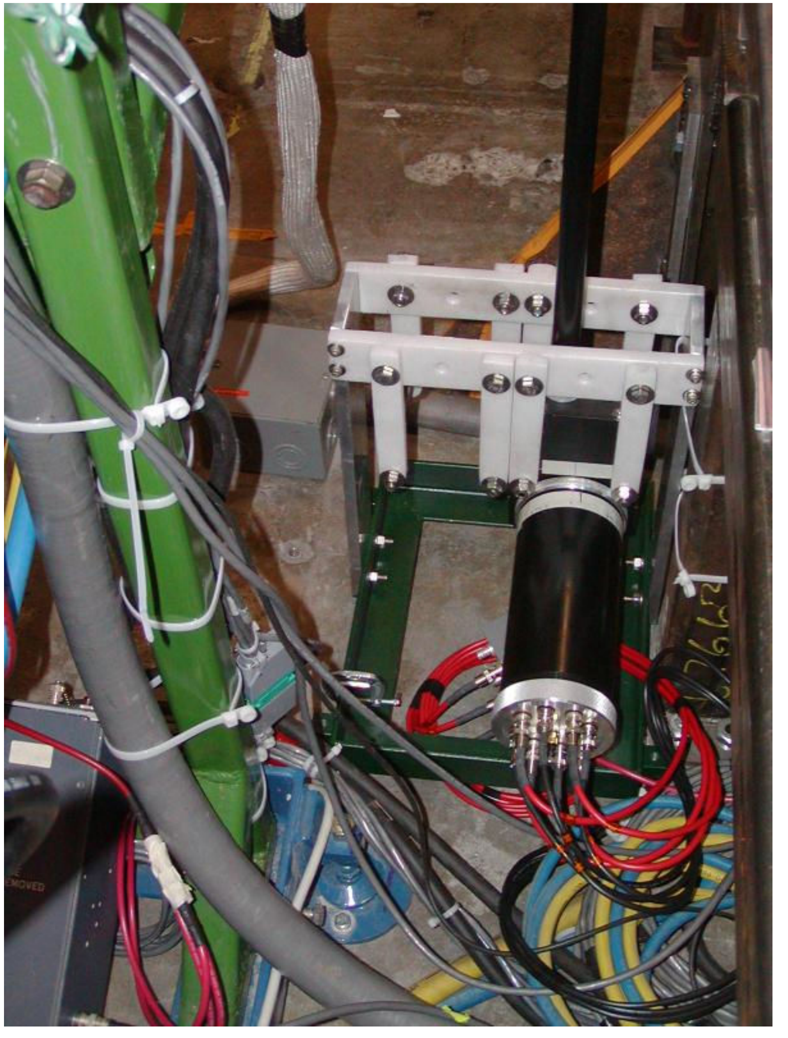
On the top of set-up

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

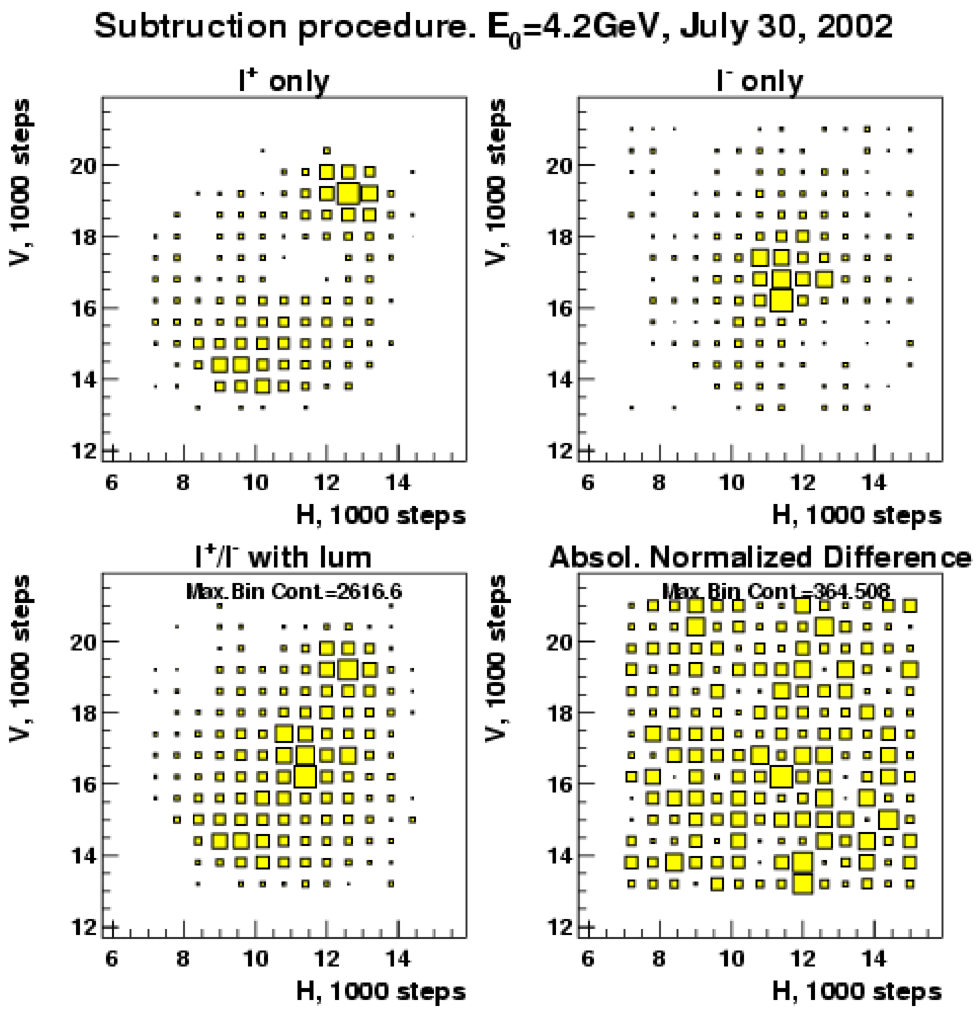


The ¼ detector

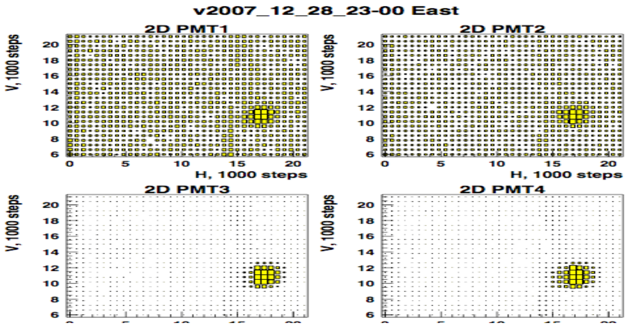
- Input channel
- Polarizing Beam Splitter
- Dichroic filters
- PMT's assembly
- Cooling…

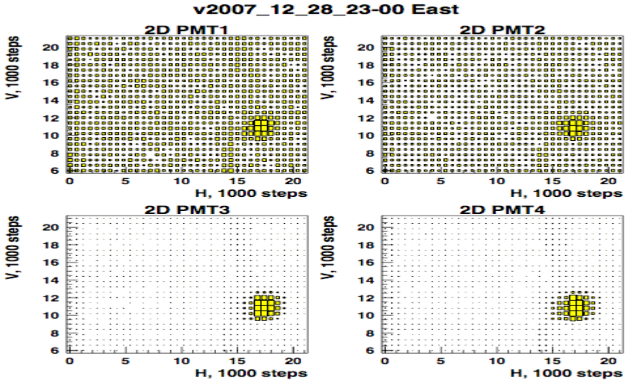


Check for alignment @ 4.2GeV



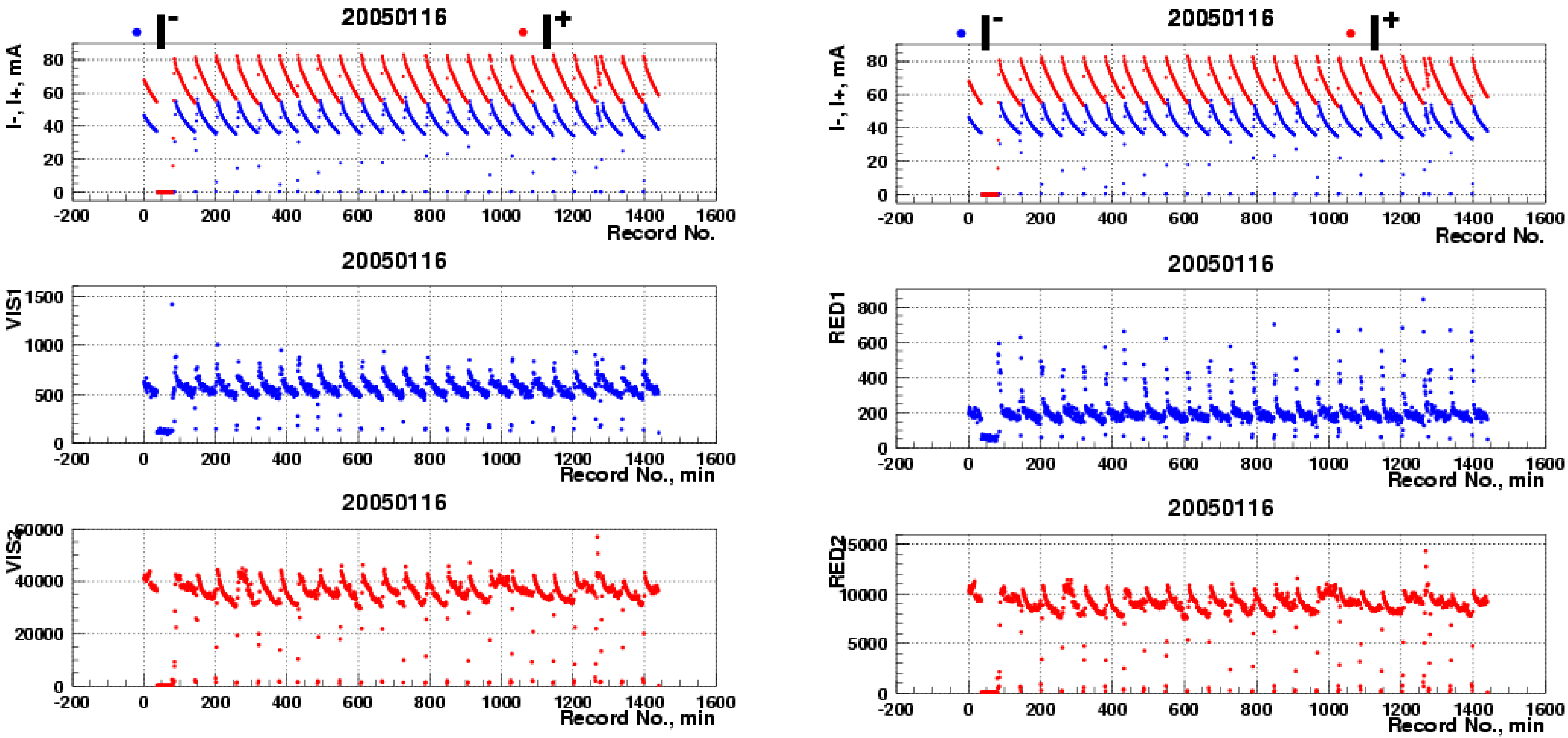
Directionality





- Scanning is routinely done to reconfirm the centroid of the luminous spot.

PMT rate correlations with beam currents



Typical rates

- At HEP conditions, VIS PMTs (West) will have a rate of about 300kHz (0.1Hz channels are used) and IR PMTs about 6kHz.
- In the East, 60kHz and 2kHz.
- Expected BMST rates are about 500Hz at the nominal theta

Detector systematics detail

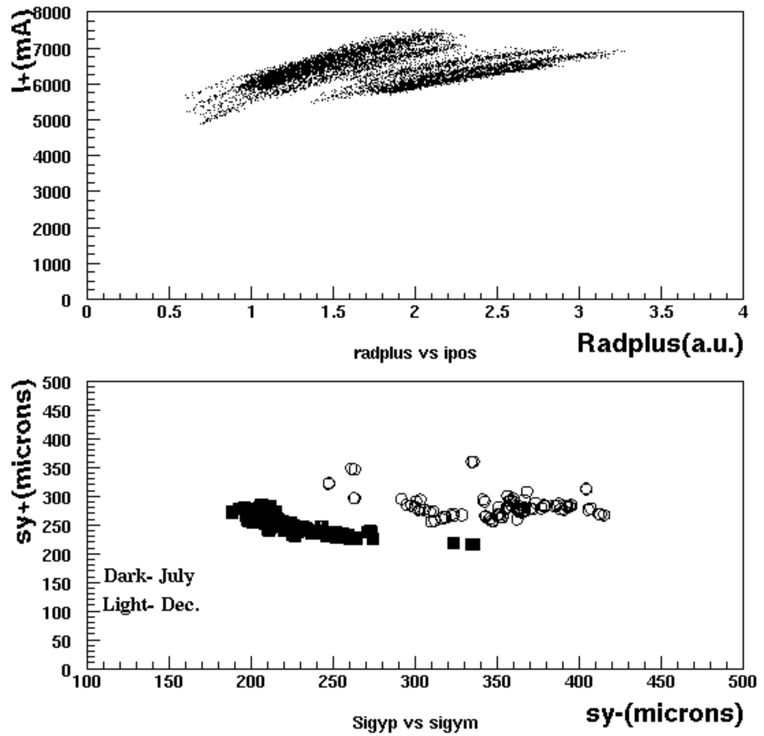
- Flashlight calibration measures all relative efficiencies to about 0.3%. Absolute efficiencies of VIS PMT >90%, optical channels assumed to be 75+-25%.
- Recurrent electronic noise problems on East side (electrons)
- Two major data taking periods in July and December 2007 (about 120 good fills each), with dark noise measured every 8 hours.

Data analysis method

- The signal sought ought to increase IR light w.r.t. VIS light when a strong beam is opposite, so $IR/VIS=k_1+k_2 I_{oppo}^2$
- The method also takes into account possible small variations of the bkg through normalization with VIS light
- The expected signal in VIS light is of the order of 10^{-4} of the rate and can be safely ignored
- Runs are minimally selected (continuous beams for at least 600 seconds) with chi square and dark noise (cleaning) cuts later to take care of noisy ones
- Much precision info from corresponding CLEO data: sigma_x, sigma_z, and crossing angle. Machine vertical emittance measurements yield sigma_y. We also use energy, and bunch-to-bunch population information

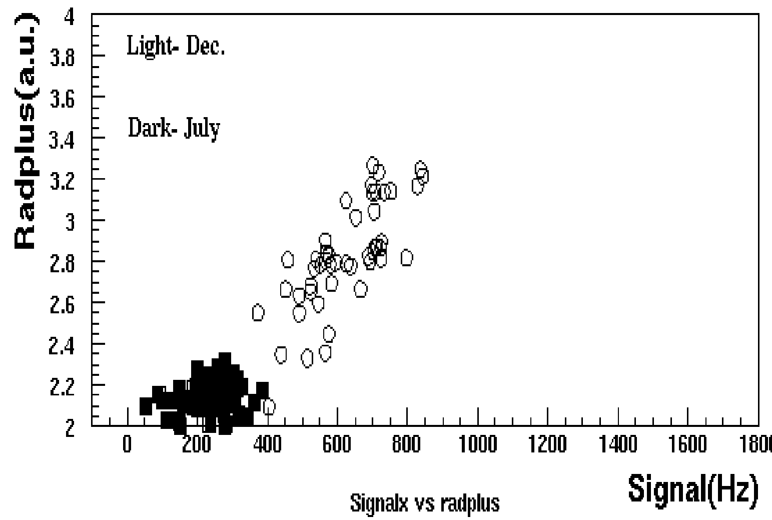
Natural variability of machine provided crucial evidence

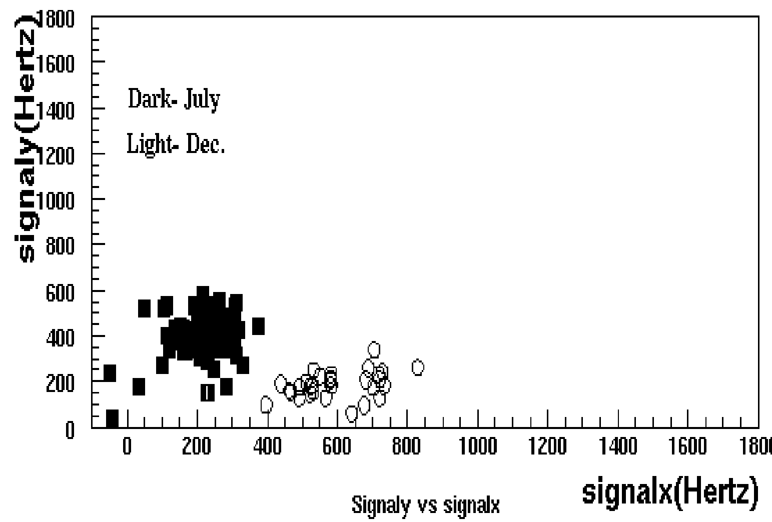
- In July, relatively high e+ current and relatively low e- current. In December, currents are more balanced, providing a stronger expected BMST signal
- In July, e- beam was smaller than e+. In December, the reverse was true. Differing polarizations expected



Main results page

- Signal(x) strongly correlated to $I_+ I_-^2$
- Signal strongly polarized according to ratios of vertical sigmas
- Total rates consistent with expectations at 10. mrad





Numerous cross checks

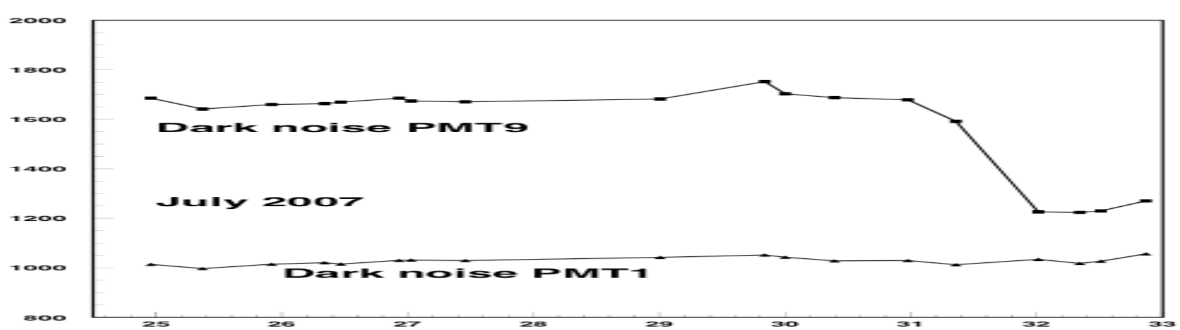
- Three one day calibration of devices (shown to be 1% accurate)
- Three zero crossing shifts (cross checked signal, background on W side, cross checked large angle on East side)
- Two day, 70 fills, 9-points angular scan confirmed signal came from point-like source
- Various chi square tests (.e.g., 90% of negative signals have unacceptable chi square)

Cross checks contd

- Only known beam motion during fill is decrease of vertical emittance with decreasing currents. Still uncorrected, can only induce a NEGATIVE signal
- Rates consistent with expectations within angular range
- Chi square of fits worsens without energy, sigma_x, sigma_z, bunch-to-bunch fluctuations and angular corrections

What went wrong: two fatal flaws on East side

- On East side, VIS rates were down one order of magnitude w.r.t. West, and IR was down some
- Calibration ruled out any significant inefficiency
- All data (including signal data) can be explained with a single 0.8 mrad misalignment between device and beam axis. Whereas expected S(West) is 100Hz, S(East) is 1Hz
- Pedestals on East side were fluctuating over several hundred Hz



Summary

- The first generation Large Angle Beamstrahlung detector was successful, but…
- This technique is dominated by systematic errors, therefore its only figure of merit is S/B

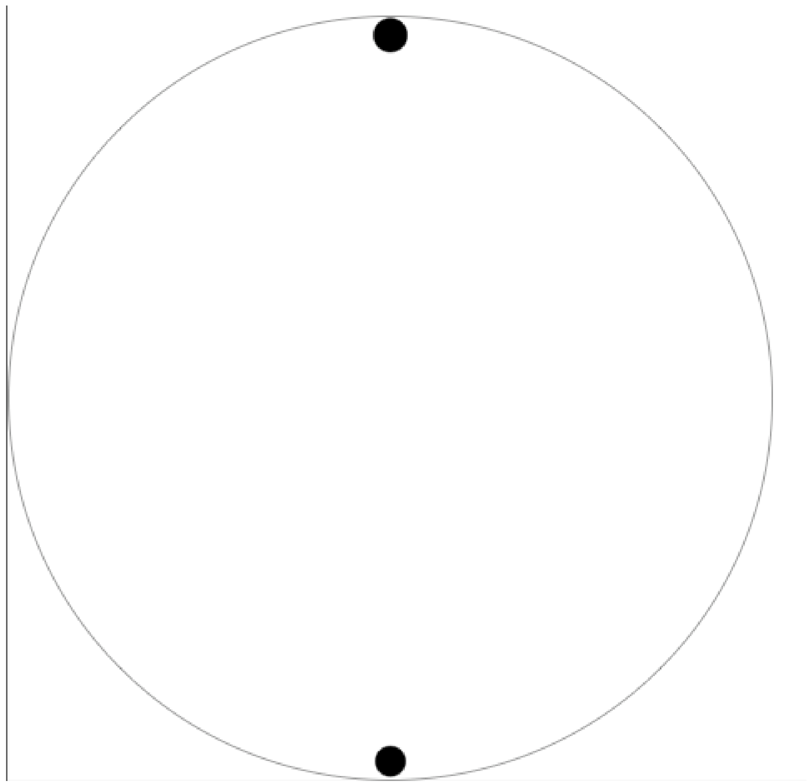
- In order to make this technique into a useful monitor, three conditions must be met:
- - S/B >>1 (it was 0.02-0.04 at CESR). We can tolerate lower S/B if the tails are proven to be constant during a fill
- - Much more beam data acquired
- A device that can monitor the beam halo directly

Signal and background at KEKB and SuperB

- KEKB is the best place where to pursue this technique further, due to short bunch length
- Signal at KEK (assume 10 mrad observation): the signal scales with $(N^3/\gamma^2\sigma_x{}^2\sigma_z)*\exp(-(\pi\sigma_z\theta^2/2\lambda)^2)$ - about 100 times higher specific signal
- The halo, assuming to be dominated by the BBI, scales like (N/γ) - close to CESR values. If it is dominated by the residual gas pressure, it should be much more constant and therefore subtractable
- Other improvements at KEK (cmp to CESR): beams cross quadrupoles near axis (less background), there is no parasitic BBI, and therefore no shifts in the crossing angle

KEKB concept for the detector

- 2 viewports at +-90 degrees: minimal backgrounds, insensitive of beam motion, insensitive of beam pipe alignment
- Look at radiation in 4 or more bands: e.g., λ< 350nm, 400nm< λ<450nm, 500nm< λ<550nm, 600nm< λ<650nm
- (this is assuming one uses only PMTs R6095)



ILC concept

Hollow mirror imaging system for detection of beamstrahlung radiation

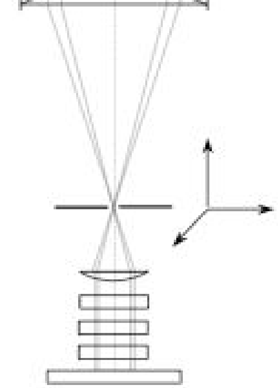
- Large solid angle to collect the beamstrahlung radiation

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

- Confocal imaging to achieve high spatial resolution

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

- Detection scheme includes optical filters, polarizers, CCD matrix to measure angular intensity distribution



Conclusions

- Large angle beamstrahlung seen at CESR
- CESR experience defines very well how next device should be designed
- Immediate future of the technique is bright. A combination of unique pattern recognition and the extreme importance of Beam-beam interaction at KEKB, SuperB
- Now funded by the Japanese government (first telescope prototype, 50k$)