Comments on Ring Colliders

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LEP3 Day, CERN

History at KEK

- Stimulated by the LEP3, Katsunobu Oide proposed possible ring collider at Ecm=240GeV in Tsukuba region in an LC meeting in January.
- Higher energy colliders Ecm=400-500GeV were also proposed in a meeting on future of KEK in February.
- I raised the issue of beamstrahlung and concluded
  - Beam energy spread induced by beamstrahlung demands large momentum aperture.
  - Ring colliders with Ecm=400-500GeV with luminosity and power consumption similar to those of ILC/CLIC are impossible
  - A collider with Ecm=240GeV is at the border of feasibility. A large mementum acceptance (several percent) would be required
- Later Valery pointed out importance of the critical energy of beamstrahlung

Reference Parameters

Name		LEP2	LEP3	SuperT RISTAN	VLCC	CW250	Summers	LEP3 IPAC
Circumference	km	26.7	26.7	60	233	233	13.82	26.7
Beam energy	GeV	104.5	120	200	200	250	120	120
Bunch population	10^10	57.5	133.3	249.2	48.5	48.5	48.5	100
Number of bunches/beam		4	3	1	114	46	3	4
Number of IP		4	2	1	1	1	1	2
Bunch collision frequency	kHz	44.91	33.69	5.00	146.68	59.19	65.07	44.91
geo.emit(x)	nm	48	20	3.2	3.09	0.9	3.6	25
geo.emit(y)	nm	0.25	0.15	0.017	0.031	0.00067	0.00099	0.1
betax	mm	1500	150	30	1000	20	20	200
betay	mm	50	1.2	0.32	10	0.6	0.6	1
sigx	micron	268	54.77	9.8	55.63	4.25	8.5	71
sigy	micron	3.536	0.4243	0.0738	0.56	0.0201	0.0244	0.32
sigz	mm	16.1	3	1.4	6.67	6.67	6.67	2.3
half.cross.angle	mrad	0	0	35	0	17	34	0
bending radius	km	3.096	2.62	7.65	32.07	32.07	1.9	2.62
radiation loss/turn	GeV	3.408	6.99	18.5	4.42	10.8	9.7	6.99
Damping partition		1.1	1.5	2	2	2	2	1.5
radiation power (2beams)	MW	22	100	74	100.7	100.7	98	100
Tune shift (x)		0.025	0.126	0.017	0.18	0.027	0.0014	0.09
Tune shift (y)		0.065	0.13	0.155	0.18	0.23	0.2	0.08
Equilibrium energy spread	%	0.22	0.232	0.196	0.096	0.120	0.236	0.23
Luminosity per IP	10^34	0.0125	1.33	5.2	0.88	9.7(4.8)	4.4(2.2)	1.07

(yellow) Not given in the reference. Computed from other values

(light blue) Not given in the reference. Assumed.

(orange) quoted(computed)

Luminosity at Beamstrahlung Limit

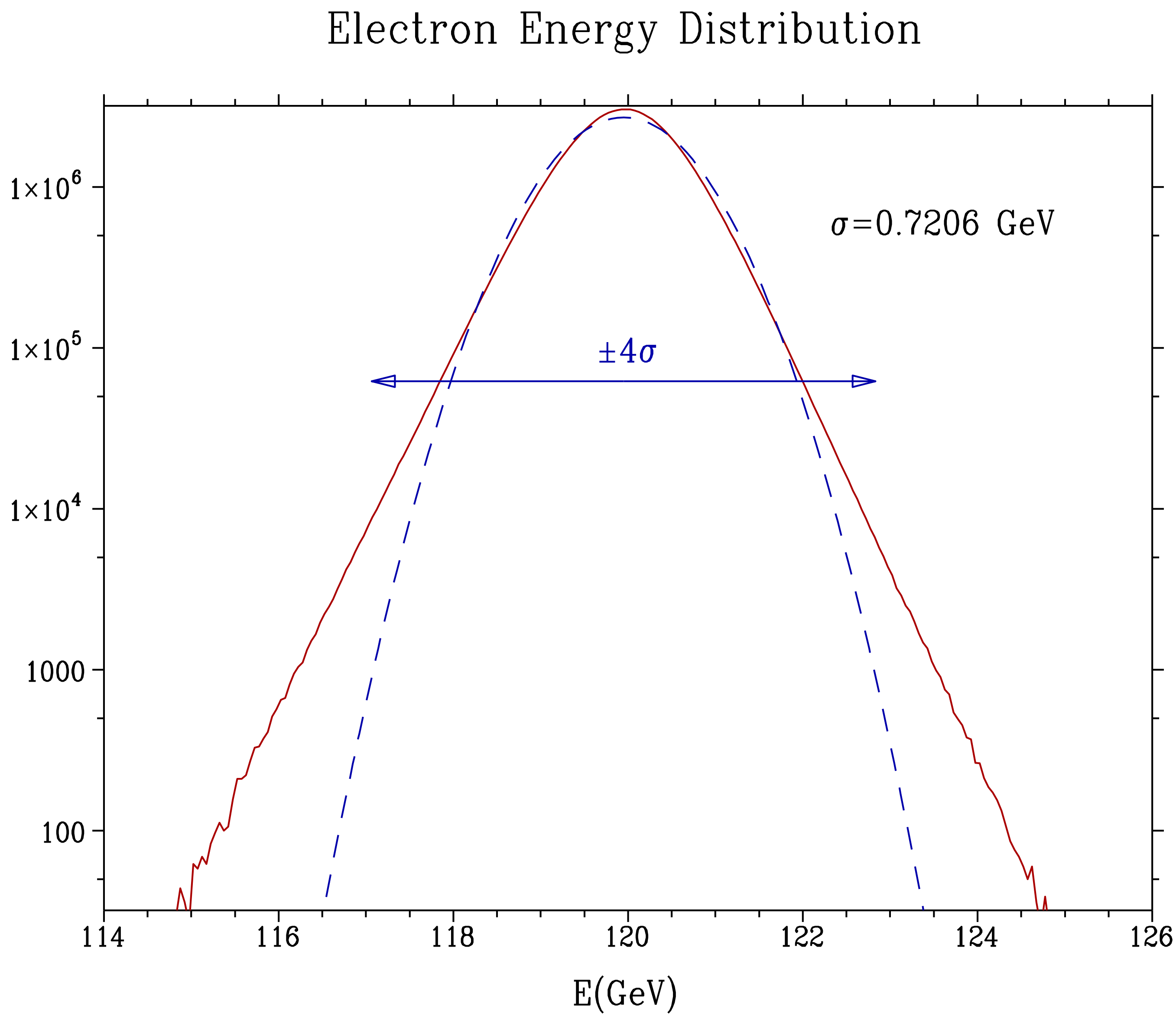
$$\mathcal{L} = \frac{c_L}{c_P\sqrt{c_\delta}}\left[\min\left(1,\frac{\sigma_z}{\beta_y},\frac{\sigma_x}{\phi\beta_y}\right)\right]^{1/2}\frac{\rho P_{SR}\sqrt{\delta_{BS}}}{E^4\sqrt{\gamma\epsilon_y}}$$

$$= 0.4565\times 10^{34}/\mathrm{cm}^2\mathrm{s}\frac{\frac{\rho}{\mathrm{km}}\frac{P_{SR}}{100\mathrm{MW}}\sqrt{\frac{\delta_{BS}}{0.1\%}}}{(E/100\mathrm{GeV})^{4.5}\sqrt{\epsilon_y/\mathrm{nm}}}$$

- Once the beamstrahlung limit is reached, the luminosity above this energy goes down as $1/E^4$（Or $1/E^{4.5}$ if geometric emittance is fixed)
- If the bunch charge is reduced to 1/n, δ_{BS} reduces by $1/n^2$ but the luminosity is also reduced by $1/n^2$. To restore the luminosity the number of bunches must be increased by n^2 times, hence the required power increases by n^2 x 1/n = n .

Example of LEP3 (old parameters)

- Equilibrium RMS energy spread = 0.72GeV =0.60%
- To be compared with 0.19% (e+) & 0.16% (e-) in ILC at 240GeV
- Deviates from Gaussian for >4σ



Example of LEP3 (old parameters)

- Quantum life

$$\frac{\tau_{damp}}{\tau_Q} \approx jF(j)|_{j_{max}}$$

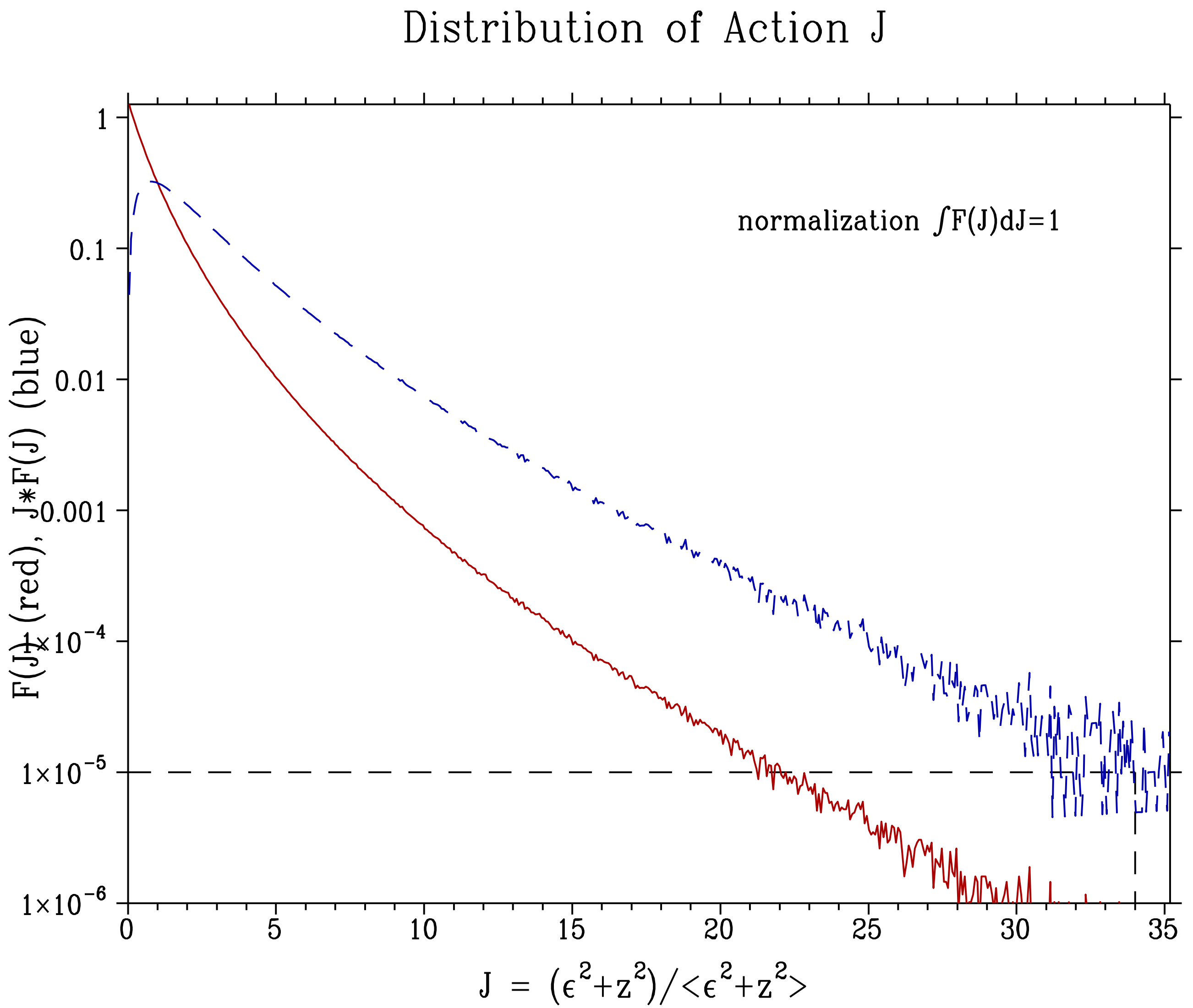
$$j = J/\langle J \rangle$$

$$\tau_{damp} \approx 2\text{ms}$$

- for quantum life 200sec

$$j_{max} > 34$$

corresponding to momentum aperture > 5.0 %



Self-Consistent Solution

- LEP3 will be a beamstrahlung dominated machine
  - Beamstrahlung changes the r.m.s. energy spread,
  - which will change the bunch length,
  - which will change beamstrahlung
- σ_z = 2.3mm, σ_ε = 0.23%
  $\rightarrow$ σ_z = 3.65mm, σ_ε = 0.365%
- This will relax the requirement of momentum acceptance but slightly reduce the luminosity (~20%) due to increased hour-glass effects
- You need more RF, if you want shorter bunch

Relevant Formulas

- number of photons per electron

$$n_\gamma = 2.16 \frac{\alpha r_e N}{\sigma_x + \sigma_y}$$

- average energy loss per electron

$$\delta_{BS} = 0.836 \frac{r_e^3 N^2 \gamma}{\sigma_z (\sigma_x + \sigma_y)^2}$$

- energy spread by one collision (K. Yokoya, NIM A251 (1986) 1-16)

$$\sigma_{BS} = \delta_{BS} \left[0.1639 + \frac{5.129}{n_\gamma} \right]^{1/2}$$

- equilibrium energy spread (synchrotron oscillation ignored)

$$\sigma_\varepsilon = \left[\sigma_{\varepsilon 0}^2 + \frac{1}{2} n_{damp} n_{IP} \sigma_{BS}^2 \right]^{1/2}$$

$$n_{damp} \equiv \text{damping time/revol.time}$$

- equilibrium bunch length

$$\sigma_z = \sigma_{z0} \times \frac{\sigma_\varepsilon}{\sigma_{\varepsilon_0}}$$

Simplified Longitudinal Tracking

A) Start from the equilibrium bunch length derived by the formulas

B) Compute single BB interaction and obtain photon spectrum

- use extrapolation (by exponential function) to higher photon energy to save computing time

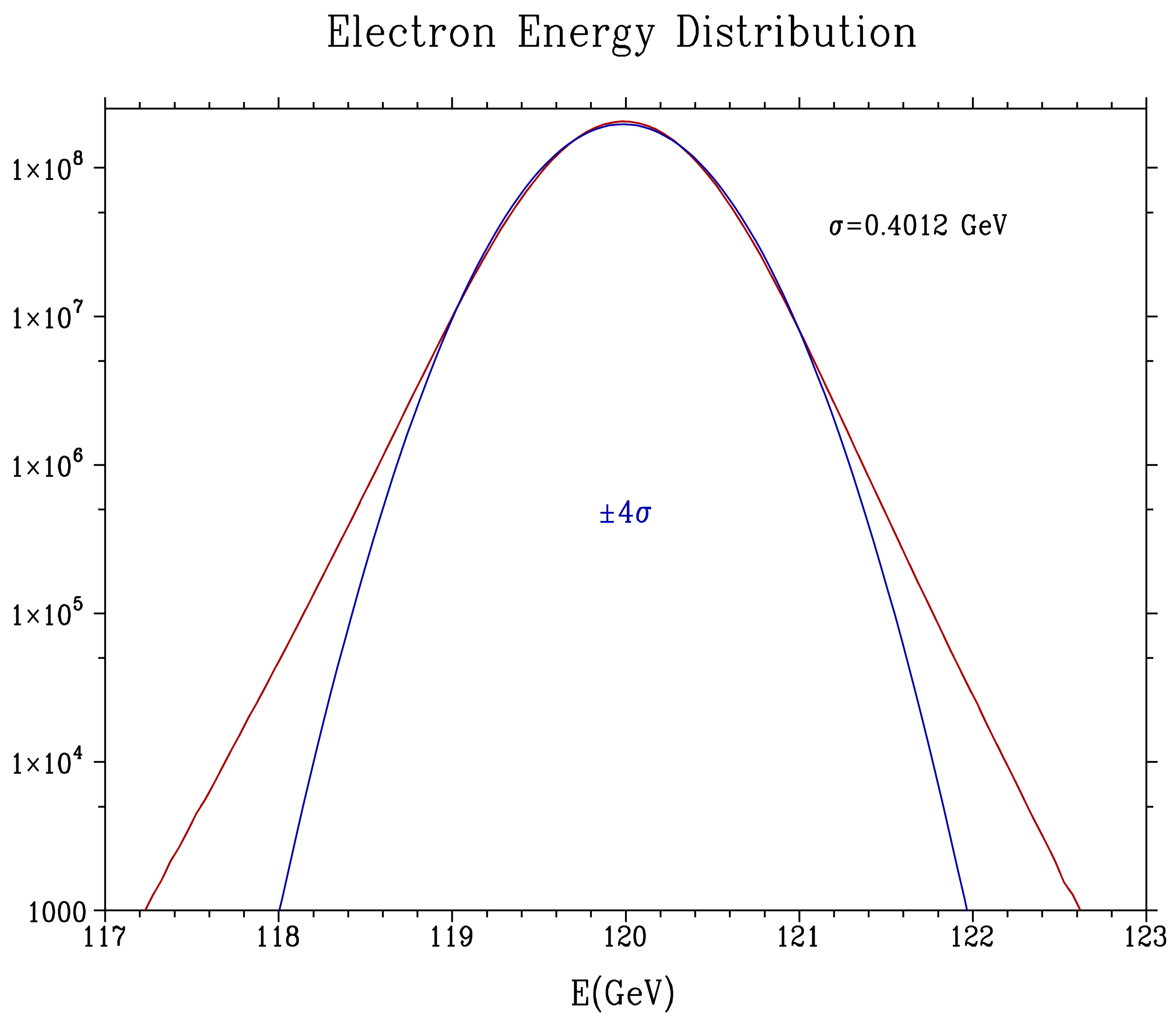
C) Track (E,z) of many particles including

- linear synchrotron oscillation
- random radiation in the arc
- beamstrahlung using the photon spectrum from B)
(This means to entirely ignore the dependence on the transvese amplitude)

D) Find equilibrium longitudinal distribution and quantum life as a function of acceptance of synchrotron oscillation amplitude

Equilibrium Energy Distribution

- Equilibrium RMS energy spread = 0.40GeV =0.334%
- Significantly eviates from Gaussian for >4σ
- correspondi ng bunch length 4mm (should be re-iterated)



Distribution of Longitudinal Action

- Quantum life

$$\frac{\tau_{damp}}{\tau_Q} \approx jF(j)|_{j_{max}}$$

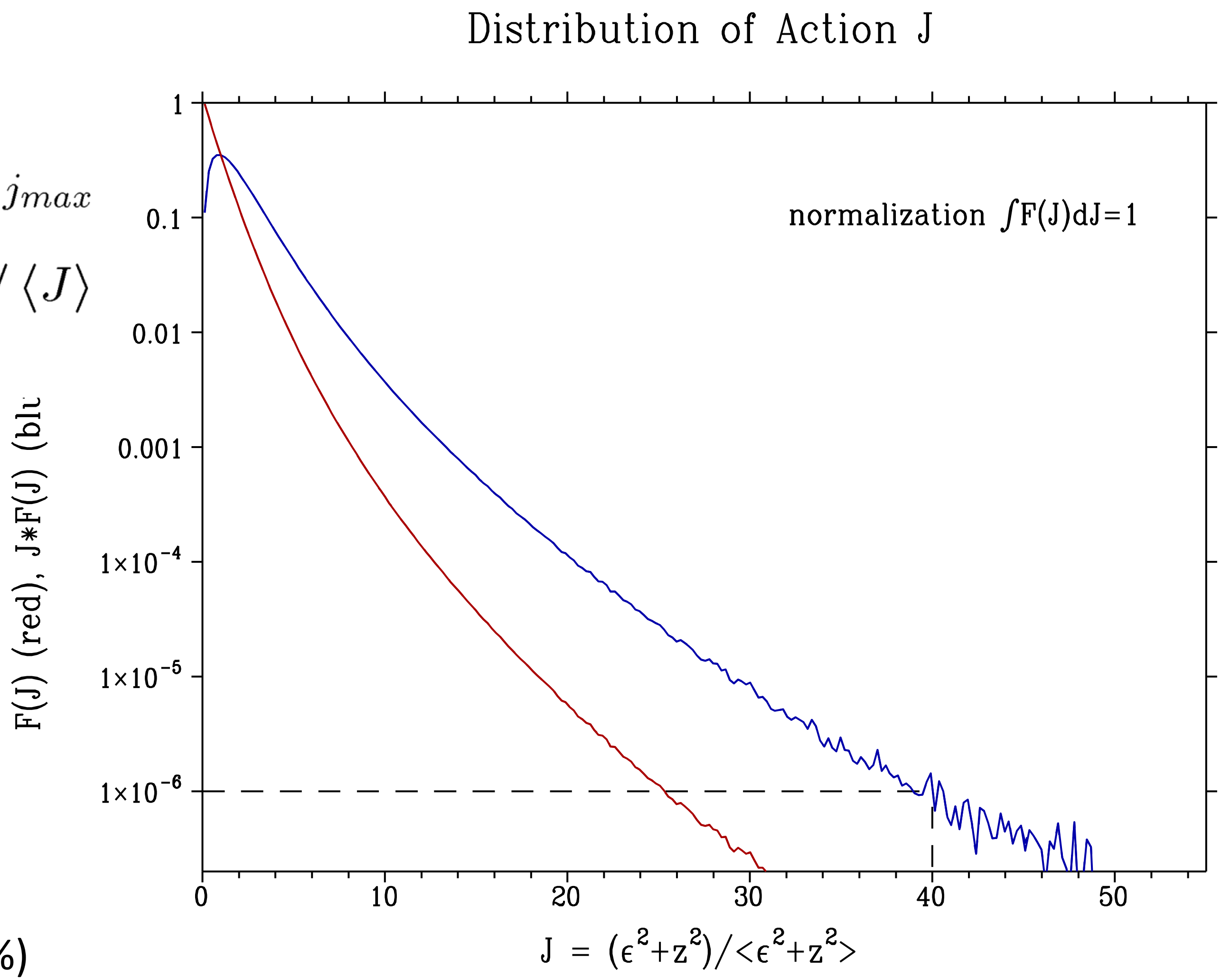
$$j = J/\langle J \rangle$$

$$\tau_{damp} \approx 2\text{ms}$$

- for quantum life 1000sec

$$j_{max} > 40$$

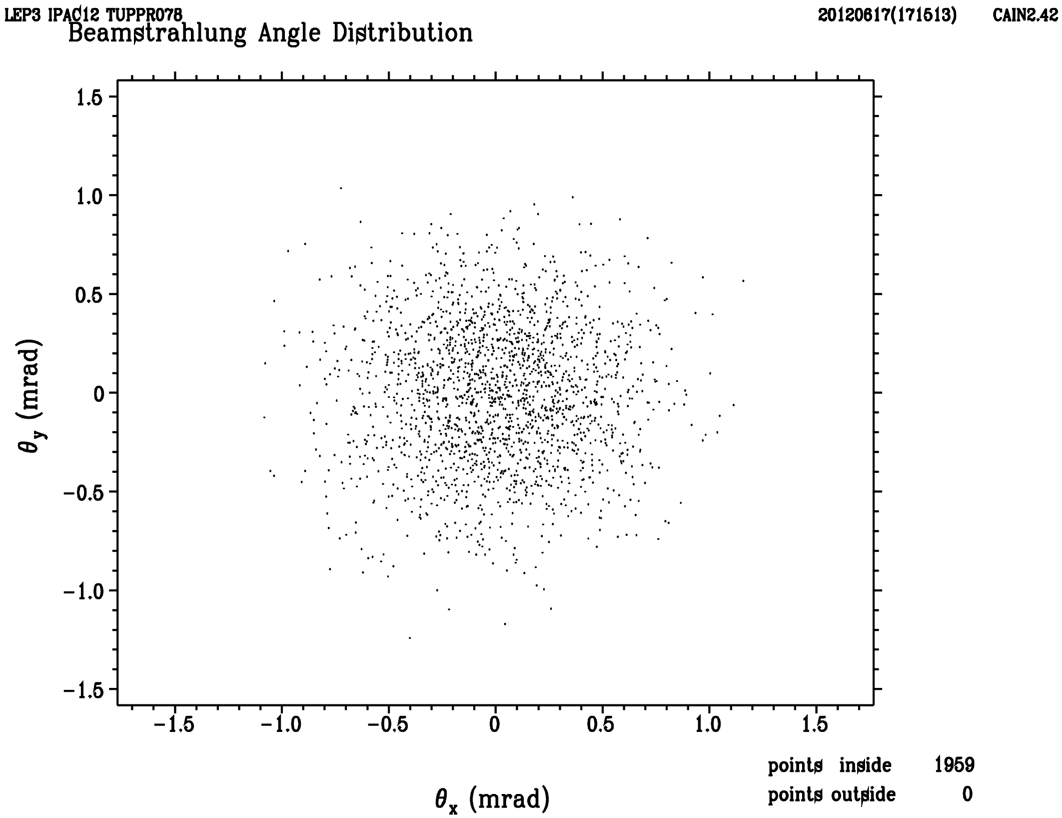
corresponding to momentum aperture 3.0 %
(σ =0.401GeV=0.334%)



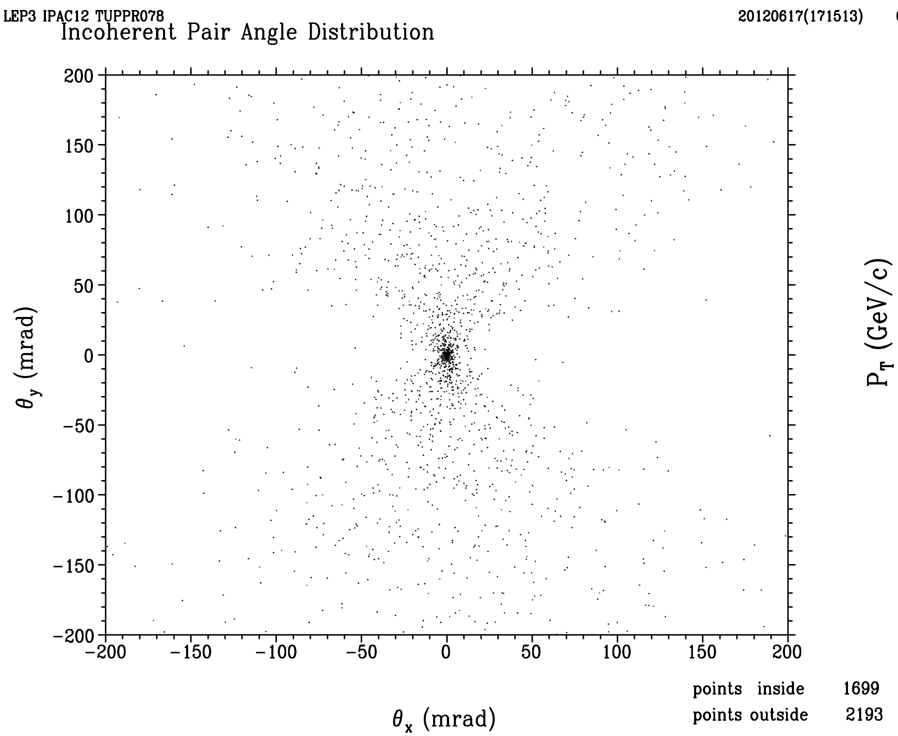
All the Beam-beam effects in LC must be re-examined

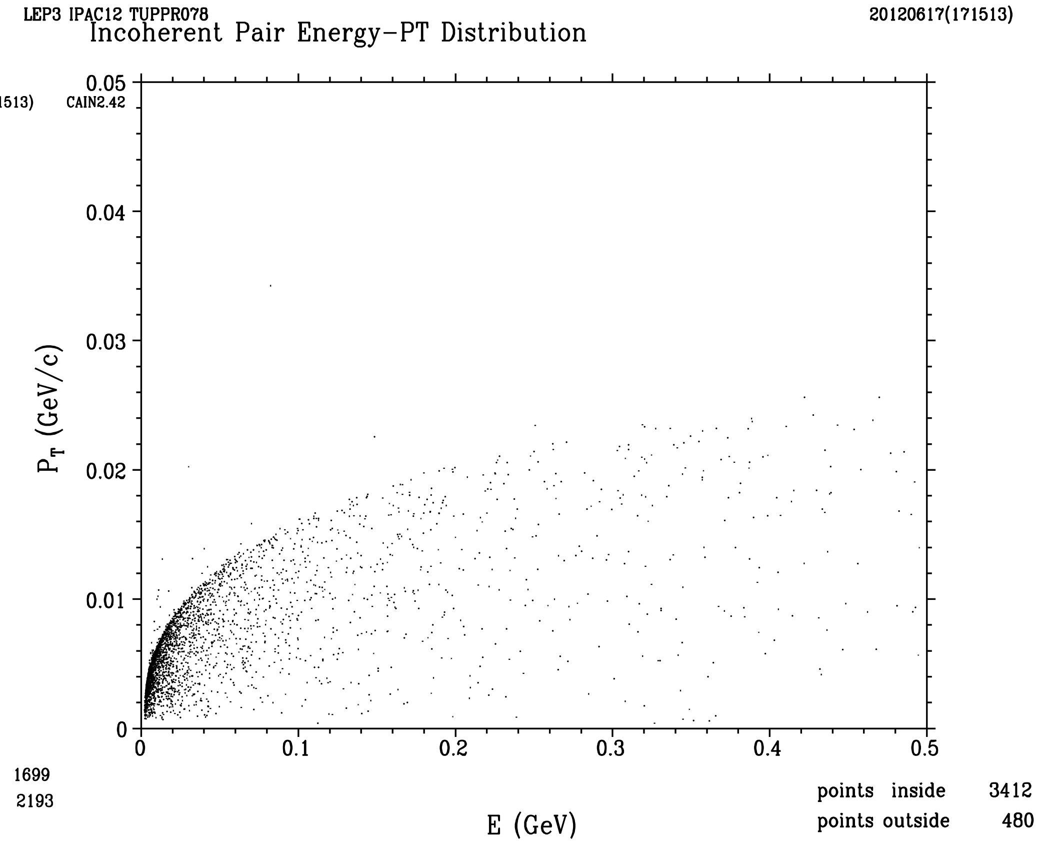
For example

- Beamstrahlung power
  - beam power ~200kW/IP/beam
  - angle ~ 0.5mrad (~ same as beam angle)
- Where do they go in head-on configuration?



- Incoherent pairs
  - ~4000 /IP/beam





Conclusions

- LEP3 is a beamstrahlung-dominated machine
- Consistent solution needed including beam-beam
  - At least longitudinally
- The lattice must accept synchrotron oscillation amplitude ~3%
- Debris from beam-beam should be taken into account in IR region design