Comments on Ring Colliders

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2012.6.11

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Proposed Ring Colliders

- Recently several authors suggested possibilities of e+e- ring colliders for Ecm>200GeV.
  A) T.Sen, J.Norem, Phys.Rev.ST-AB 5(2002)031001
     (VLCC: C=233km tunnel for VLHC)
  B) A.Blondel and F.Zimmermann, CERN-OPEN-2011-047, Jan.2012 (Version 2.9). arXiv:1112.2518.
     Revised version: IPAC12-TUPPR078. (LEP3, DLEP)
  C) K.Oide, "SuperTRISTAN: A possibility of ring collider for Higgs factory", KEK meeting on 13 Feb 2012.
     (SuperTRISTAN)
  D) G.Lyons, arXiv:1112.1105 [physics.acc-ph], Feb.2012. PhD thesis. (Nanobeam version of A)
  E) D.Summers, et.al. “Rapid Recycling Magnets - Tests & Simulations”, Muon Accelerator Program 2012 Winter Meeting, 4-8 Mar.2012. SLAC. (Small ring version of D)

Reference Parameters

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

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

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

(orange) quoted(computed)

Common Features

- For reducing synchrotron radiation
  - Large circumference
  - small number of bunches compared with B Factories
- Bunch collision frequency ranges 5kHz to ~150kHz compared with 13kHz in ILC
- Luminosity similar to ILC
- → Luminosity by one bunch collision comparable to ILC
- → Beamstrahlung similar to ILC

Beamstrahlung for Proposed Parameter Sets

Name		LEP2	LEP3	SupTRI STAN	VLCC	CW250	Summers
Circumference	km	26.7	26.7	40	233	233	13.82
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sigx	micron	268	54.77	9.8	55.63	4.25	8.5
sigy	micron	3.536	0.4243	0.0738	0.56	0.0201	0.0244
sigz	mm	16.1	3	1.4	6.67	6.67	6.67
Equilibrium energy spread	%	0.22	0.232	0.196	0.096	0.121	0.239
Luminosity per IP	10^34	0.0125	1.33	5.2	0.88	9.7	4.4
check							
Luminosity per IP	10^34	0.0125	2.050	7.129	0.881	4.858	2.200
disrup(x)		0.0036	0.0320	0.0101	0.0151	0.0029	0.0015
disrup(y)		0.2692	4.1300	9.650	1.4953	16.3397	14.0210
simulation							
assumed crossing ar	mrad	0	0	40	0	17	34
Ngamma		0.0798	1.09	4.57	0.3707	0.6706	0.3409
dE_BS	%	8.70E-05	0.092	8.6	0.008	0.153	0.019
sigE/E	%	7.06E-04	0.202	9.1	0.0323	0.5332	0.0467
sigE/E*sqrt(DampTu	%	0.0053	0.966	29.92	0.217	2.565	0.164
Luminosity per IP	10^34	0.00943	1.376	3.29	0.97	4.222	1.886

(yellow) Contribution of only oneinteraction point

Beamstrahlung Limit

- If you raise the beam energy under tuneshift limit with fixed beam structure, the power limit of synchrotron radiation is soon reached.
- If the upper limit of power is set high, beamstrahlung limit is reached soon or later.
- Beamstrahlung limit is very much different between Ring colliders and Linear colliders
  - In the case of Linear colliders, the limit comes basically from physics requirements. (Very high beamstrahlung, e.g., >20%, may also be a problem of accelerator: to safely lead the beam to the dump.)
  - In the case of Ring colliders, the beam after beamstrahlung must circulate safely over the ring. To guarantee the quantum life long enough, a very large momentum aperture is needed
  - Roughly speaking, linear colliders are more robust against beamstrahlung by 2 orders of magnitude

Beamstrahlung Limit での Luminosity

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

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

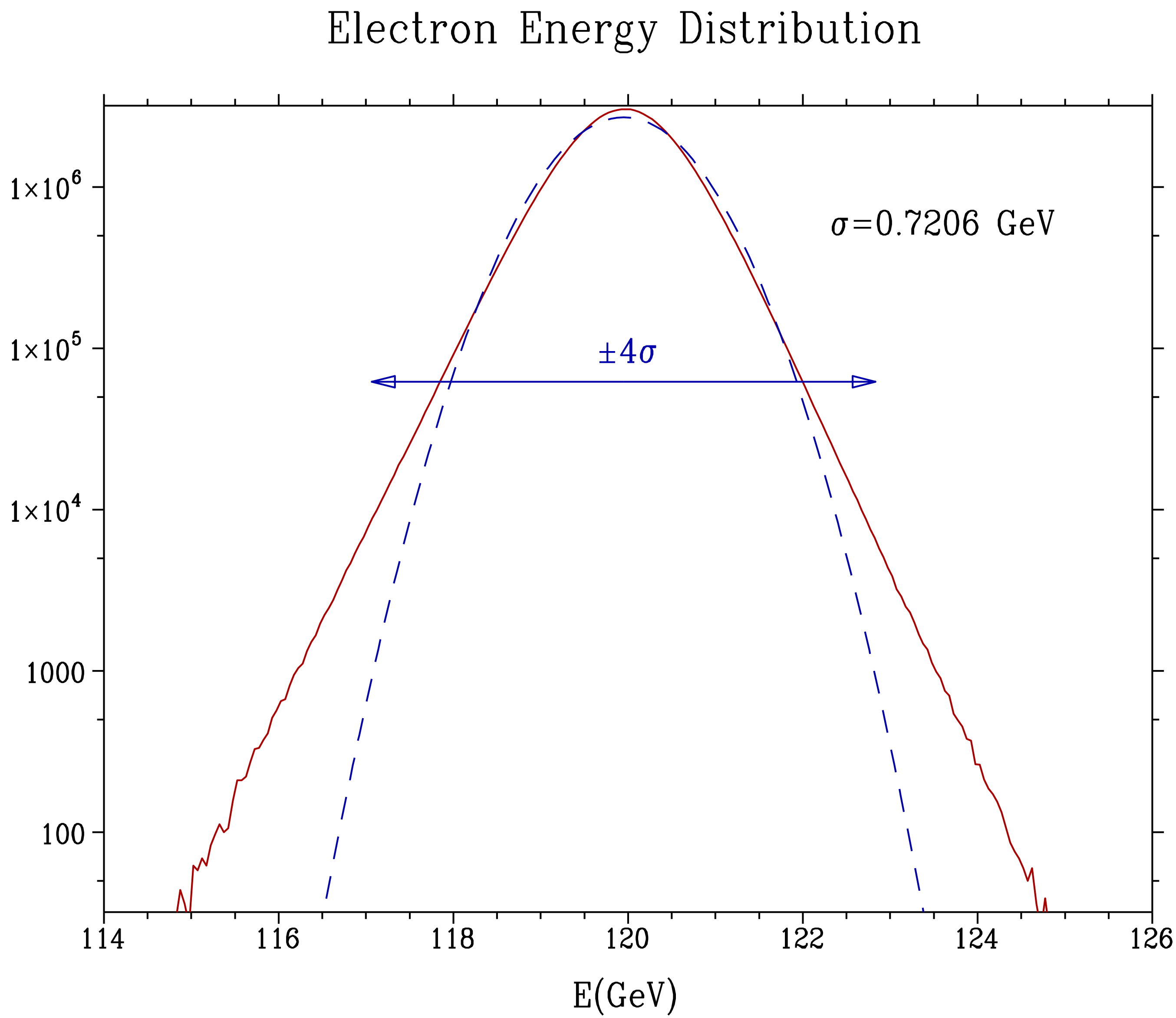
- Once the beamstrahlung limit is reached, the luminosity above this energy goes down as $1/E^4$（Or $1/E^{4.5}$ if geometric emittance is fixed)
- If the bunch charge is reduced to 1/n, δ_{BS} reduces by $1/n^2$ but the luminosity is also reduced by $1/n^2$. To restore the luminosity the number of bunches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

Telnov's Work

- V. Telnov, 'Restriction on the energy and luminosity of e+e- storage rings due to beamstrahlung,' arXiv:1203.6563v, 29 March 2012
- Emphasizes the importance of the high energy tail of beamstrahlung (determined by the 'critical energy') rather than the RMS spread.

Example of LEP3

- 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

- Quantum life

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

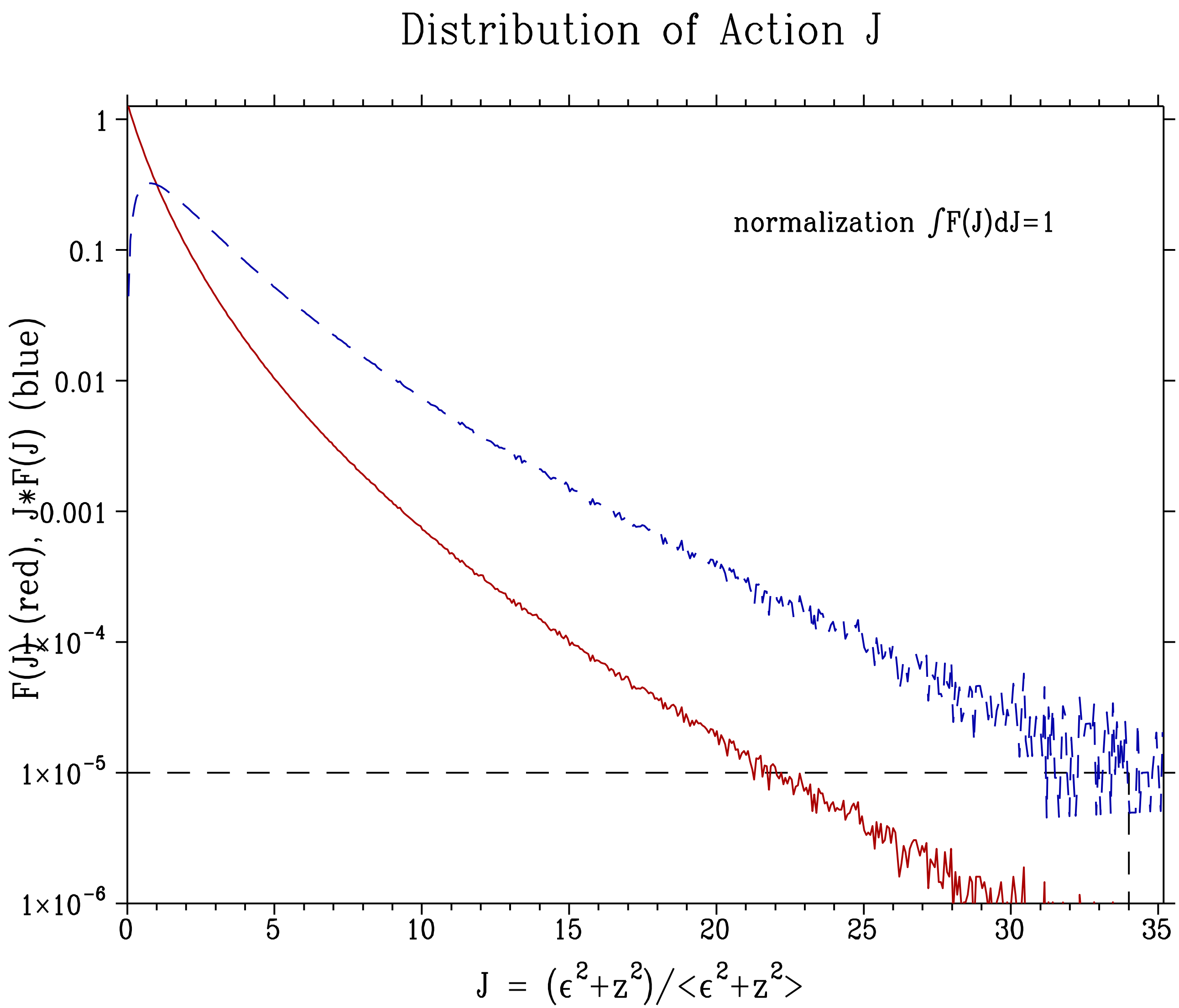
$$j = J/\langle J \rangle$$

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

- for quantum life 200sec

$$j_{max} > 34$$

corresponding to momentum aperture 5.0 %



Conclusions

- Ring collider for Ecm=240GeV with the luminosity and power consumption comparable to those of ILC/CLIC is at the border of feasibility because of the energy loss due to the beamstrahlung.
  - It is not a trivial machine.
  - It requires serious studies of lattice design with very large momentum aperture and/or very small vertical emittance.
- Ring colliders at higher energies are almost impossible . The only way to solve is
  - Huge ring (like in VLHC tunnel C~200km)
  - Extremely small vertical emittance

LEP3 Day on Jun.18 (Mon) at CERN