New low charge parameters for ILC

D. Wang (IHEP), J. Gao (IHEP)
K. Kubo (KEK)

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Advantages of SB2009

- Half bunch number per pulse reduces the peak current by a half, so the total klystrons and modulators for main linac can be reduced by almost a half.
- Beam power is reduced by a half, so the requirements for source are loosened.
- Total AC power including the power for refrigerators is lower.
- The circumference of damping ring can be reduced by a half. (The 3.2 km damping ring was accepted.)
- The one-stage bunch compressor is simpler and cheaper than the two-stage bunch compressor. (the cost reduction is small.)

Risk of SB2009

- Beam beam effects are very strong.
  - -Dy=38.4, collision stability may become a problem
  - -nγ=1.74, Nhadron=3.6, the noise background level in the detector will be high
  - -δ_B=5.6%, the uncertainty of physics experiments is large
  - -the large disruption angle (0.48 mrad) will interfere with the detection of small-angle events

- It will be difficult to reduce the bunch length further (under 300 um) with the one-stage bunch compressor. The flexibility of the whole machine is limited a lot.

Philosophy behind the new parameter list proposal

- To have better IP physics qualities
- Try to make all subsystem technically ready at the same time when the ILC is projected
- Keep the ability to transfer technical difficulty from one subsystem to another without compromising IP physics qualities

Considerations for the new parameters

- Reducing the bunch charge by a half will mitigate the difficulties for source further. (porlarized positron production may still have problem??)
- Emittance preservation in RTML and ML will be easier with the low charge parameters.
- The bunch number per train can be increased twice assuming the same 3.2 km DR.
- Try to decrease the beam beam effects in SB2009
- the two-stage bunch compressor will be needed to get 160 um bunch length. (also more flexibility)
- Keep low beam power and low AC power in SB2009

Beam parameters

	Nominal RDR	SB2009	RDR Low charge	New low charge	
E_{cm} (GeV)	500	500	500	500	
Ne	2×10^{10}	2×10^{10}	1.0×10^{10}	1.0×10^{10}	
F_{rep} (Hz)	5	5	5	5	
N_b	2625	1320	5640	2625	
P_b (MW)	10.5	5.3	11.3	5.37	
β_x (mm)	20	11	12	8	
β_y (μm)	400	200	200	166	
$\gamma\varepsilon_x$ (μm)	10	10	10	10	
$\gamma\varepsilon_y$ (nm)	40	36	30	10	15
σ_x (nm)	639	474	495	404	
σ_y (nm)	5.7	3.8	3.5	2.0	2.4
σ_z (μm)	300	300	150	166	
δ_B	0.031	0.056	0.026	0.0241	
n_γ	1.3	1.74	0.832	1.01	
Dy	19.0	38.4	10.0	24.0	
H_D	1.74	1.63?	1.56	1.6	
θ (rad)	0.00036	0.00048	0.00023	0.00029	
N_{had}	1.1	3.6	0.21	0.66	
Trav. focus	No	Yes	No	No	
L_0 ($cm^{-2}s^{-1}$)	2.0×10^{34}	1.9×10^{34}	2.0×10^{34}	2.0×10^{34}	1.6×10^{34}

TF2.4×10^{34} → TF2.0×10^{34}

AC Power estimation

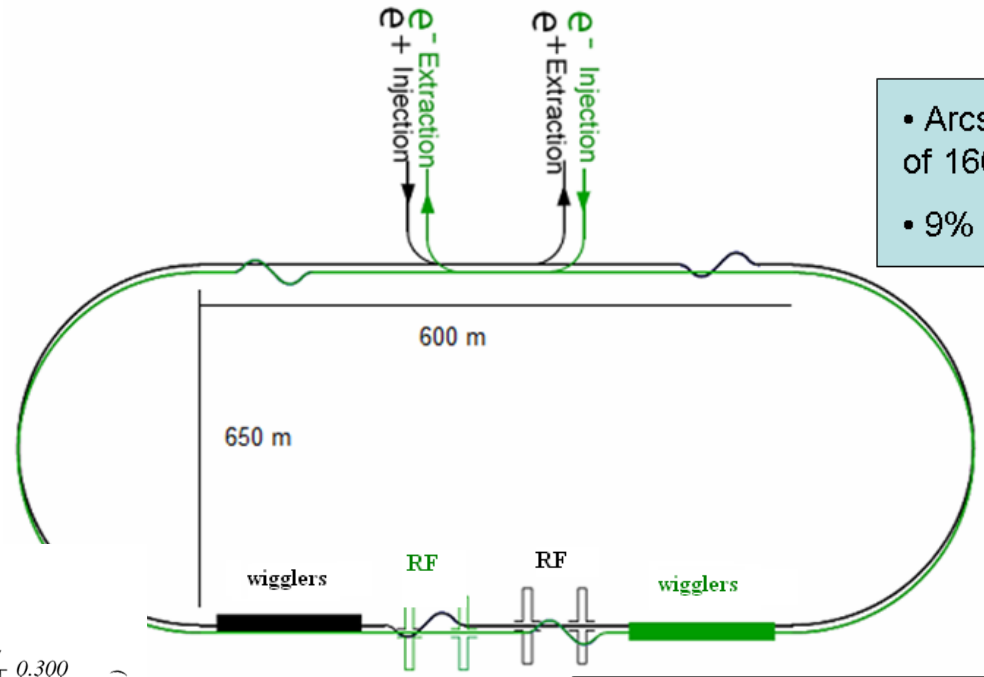
	Nominal RDR	SB2009	RDR Low charge	New low charge
Bunch separation (ns)	356	680	178	356
I_b (mA)	9	4.7	9	4.6
Efficiency form RF to beam	61%	44%	63%	44%
AC power for beam (MW)	108	76	112	76
AC power for refrigerators (MW)	9	13	10	13
Total AC power (MW)	117	89	122	89

Parameter Tables (2005)

Primary parameters and analytic calculations

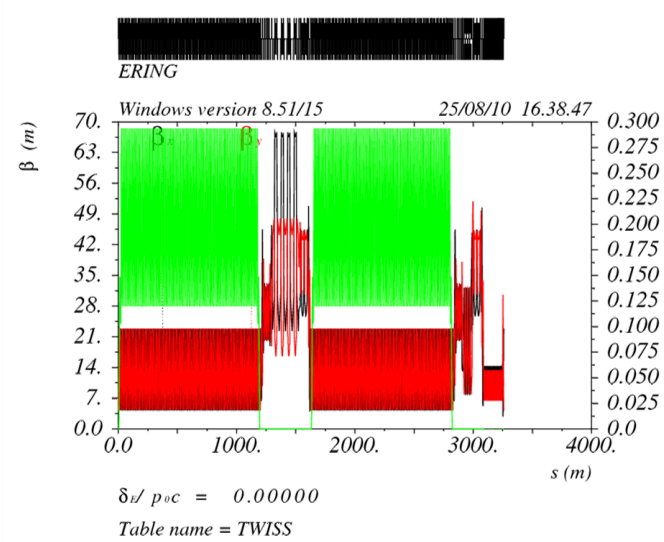
						500 GeV					
	TESLA	USSC	31 MV/m	36 MV/m	42 MV/m	Nominal	Low Q	Large Y	Low P	High Rate	High Lum
Ecms	500	500	500	500	500	500	500	500	500	500	500
gamma	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05	4.89E+05
N	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10	1.00E+10	2.00E+10	2.00E+10	2.00E+10	2.00E+10
nb	2820	2820	2820	2820	2820	2820	5640	2820	1330	1410	2820
Tsep [ns]	336.9	336.9	295.4	295.4	269.2	295.4	147.7	295.4	443.1	295.4	295.4
Buchets @ 1.3 GHz	438	438	384	384	350	384	192	384	576	384	384
Iave	0.0095	0.0095	0.0108	0.0108	0.0119	0.0108	0.0108	0.0108	0.0072	0.0108	0.0108
Gradient	23.40	28.00	31.00	36.00	42.00	31.00	31.00	31.00	31.00	31.00	31.00
Cavities / 10 MW klys	36.00	30.00	24.00	20.00	16.00	24.00	24.00	24.00	24.00	24.00	24.00
Q0	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10	1.00E+10
Qext	2.50E+06	2.99E+06	2.90E+06	3.37E+06	3.59E+06	2.90E+06	2.90E+06	2.90E+06	4.36E+06	2.90E+06	2.90E+06
Tfill (us)	420.0	502.7	487.9	566.6	602.5	487.9	487.9	487.9	731.9	487.9	487.9
Trf (ms)	1.37	1.45	1.32	1.40	1.36	1.32	1.32	1.32	1.32	0.90	1.32
f	5	5	5	5	5	5	5	5	5	10	5
Linac overhead	0	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
Pb [W]	1.13E+07	1.13E+07	1.13E+07	1.13E+07	1.13E+07	1.13E+07	1.13E+07	1.13E+07	5.33E+06	1.13E+07	1.13E+07
Pac (linacs) [W]	9.40E+07	1.05E+08	1.07E+08	1.15E+08	1.27E+08	1.07E+08	1.07E+08	1.07E+08	1.07E+08	1.44E+08	1.07E+08
gamepsX	1.00E-05	9.60E-06	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
gamepsY	3.00E-08	4.00E-08	4.00E-08	4.00E-08	4.00E-08	4.00E-08	3.00E-08	8.00E-08	3.50E-08	4.00E-08	3.00E-08
bx	1.50E-02	1.50E-02	2.10E-02	2.10E-02	2.10E-02	2.10E-02	1.20E-02	1.00E-02	1.00E-02	2.10E-02	1.00E-02
by	4.00E-04	4.00E-04	4.00E-04	4.00E-04	4.00E-04	4.00E-04	2.00E-04	5.00E-04	2.00E-04	4.00E-04	2.00E-04
sigx	5.54E-07	5.43E-07	6.55E-07	6.55E-07	6.55E-07	6.55E-07	4.95E-07	4.52E-07	4.52E-07	6.55E-07	4.52E-07
sigy	5.0E-09	5.7E-09	5.7E-09	5.7E-09	5.7E-09	5.7E-09	3.5E-09	9.0E-09	3.8E-09	5.7E-09	3.5E-09
sigxp	3.69E-05	3.62E-05	3.12E-05	3.12E-05	3.12E-05	3.12E-05	4.13E-05	4.52E-05	4.52E-05	3.12E-05	4.52E-05
sigyp	1.24E-05	1.43E-05	1.43E-05	1.43E-05	1.43E-05	1.43E-05	1.75E-05	1.81E-05	1.89E-05	1.43E-05	1.75E-05
sigz	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	3.00E-04	1.50E-04	5.00E-04	2.00E-04	3.00E-04	1.50E-04
Dx	2.26E-01	2.35E-01	1.62E-01	1.62E-01	1.62E-01	1.62E-01	7.08E-02	5.59E-01	2.26E-01	1.62E-01	1.70E-01
Dy	2.53E+01	2.23E+01	1.85E+01	1.85E+01	1.85E+01	1.85E+01	1.00E+01	2.80E+01	2.70E+01	1.85E+01	2.19E+01
Theta0	4.17E-04	4.25E-04	3.53E-04	3.53E-04	3.53E-04	3.53E-04	2.34E-04	5.05E-04	5.11E-04	3.53E-04	5.12E-04
xp_max_out	3.19E-04	3.25E-04	2.70E-04	2.70E-04	2.70E-04	2.70E-04	1.79E-04	3.87E-04	3.91E-04	2.70E-04	3.91E-04
yp_max_out	6.93E-05	7.84E-05	7.60E-05	7.60E-05	7.60E-05	7.60E-05	8.40E-05	7.72E-05	8.03E-05	7.60E-05	9.57E-05
Uave	0.054	0.055	0.046	0.046	0.046	0.046	0.061	0.039	0.100	0.046	0.133
delta_B	0.030	0.031	0.022	0.022	0.022	0.022	0.018	0.028	0.057	0.022	0.070
P_Beamstrahlung [W]	3.35E+05	3.47E+05	2.48E+05	2.48E+05	2.48E+05	2.48E+05	2.05E+05	3.14E+05	3.06E+05	2.48E+05	7.90E+05
ngamma	1.477	1.504	1.257	1.257	1.257	1.257	0.823	1.811	1.756	1.257	1.725
Hdx	1.061	1.069	1.022	1.022	1.022	1.022	1.002	1.785	1.061	1.022	1.026
Hdy	5.317	5.071	4.727	4.727	4.727	4.727	3.764	4.201	4.142	4.727	5.037
Hd	1.80E+00	1.78E+00	1.70E+00	1.70E+00	1.70E+00	1.70E+00	1.56E+00	2.16E+00	1.65E+00	1.70E+00	1.74E+00
Geo Lum	1.64E+38	1.45E+38	1.20E+38	1.20E+38	1.20E+38	1.20E+38	1.29E+38	1.10E+38	1.24E+38	1.20E+38	2.83E+38
Lum. dil.	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*	*1.00E+00*
Lum.	2.94E+38	2.57E+38	2.03E+38	2.03E+38	2.03E+38	2.03E+38	2.01E+38	2.37E+38	2.05E+38	2.03E+38	4.92E+38
Lum/bc	*2.09E+34*	*1.82E+34*	*1.44E+34*	*1.44E+34*	*1.44E+34*	*1.44E+34*	*7.14E+33*	*1.68E+34*	*3.08E+34*	*1.44E+34*	*3.49E+34*
Coherent pairs/bc	7.14E-35	4.65E-34	7.71E-43	7.71E-43	7.71E-43	7.71E-43	4.29E-31	9.12E-51	3.31E-15	7.71E-43	2.21E-09
Inc. pairs/bc (LL)	4.76E+04	4.15E+04	3.28E+04	3.28E+04	3.28E+04	3.28E+04	1.63E+04	3.82E+04	7.02E+04	3.28E+04	7.95E+04
Inc. pairs/bc (BW)	2.70E+03	2.42E+03	1.49E+03	1.49E+03	1.49E+03	1.49E+03	2.68E+02	3.94E+03	3.98E+03	1.49E+03	3.73E+03
Inc. pairs/bc (BH)	3.64E+05	3.22E+05	2.25E+05	2.25E+05	2.25E+05	2.25E+05	6.72E+04	3.94E+05	5.37E+05	2.25E+05	5.54E+05
Inc. Pairs/bc (tot)	4.14E+05	3.66E+05	2.59E+05	2.59E+05	2.59E+05	2.59E+05	8.37E+04	4.37E+05	6.12E+05	2.59E+05	6.37E+05

3.2 km DR design (DMC3) based on FODO lattice



- Arcs consist of a total of 166 FODO cells
- 9% radiation in arcs

- Straights are similar to 6 km DCO4
- 91% radiation in straights

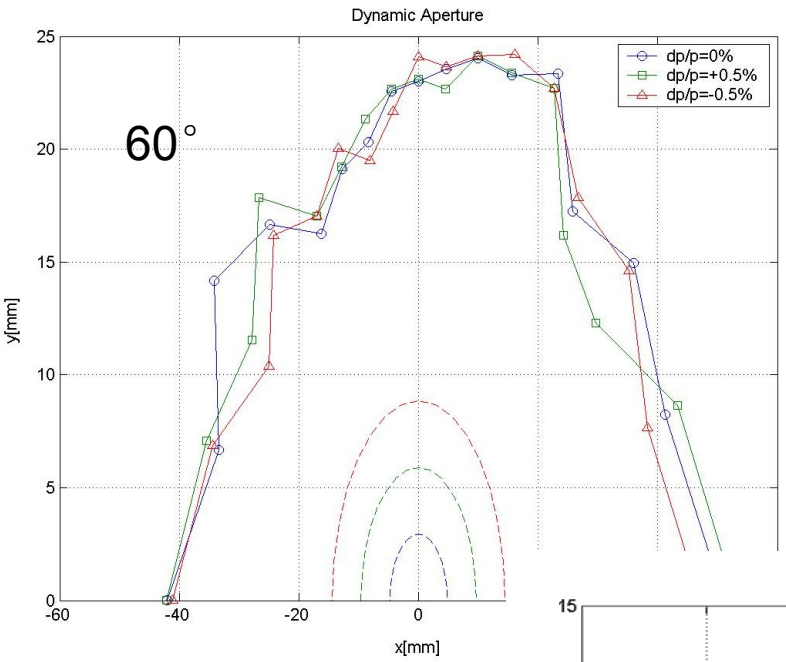


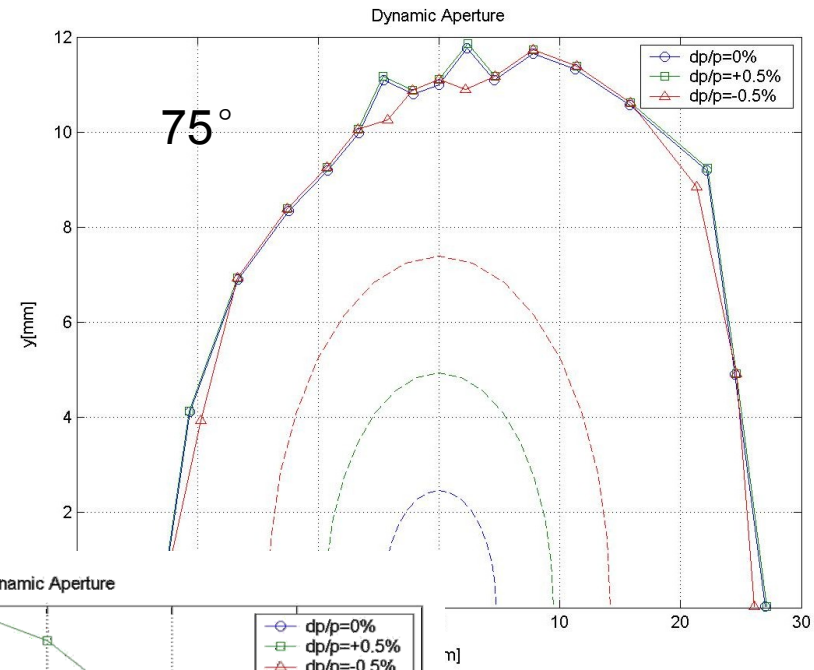
Phase advance/cell	60°	75°	90°
Mumentum compaction	6.19×10^{-4}	4.04×10^{-4}	2.77×10^{-4}

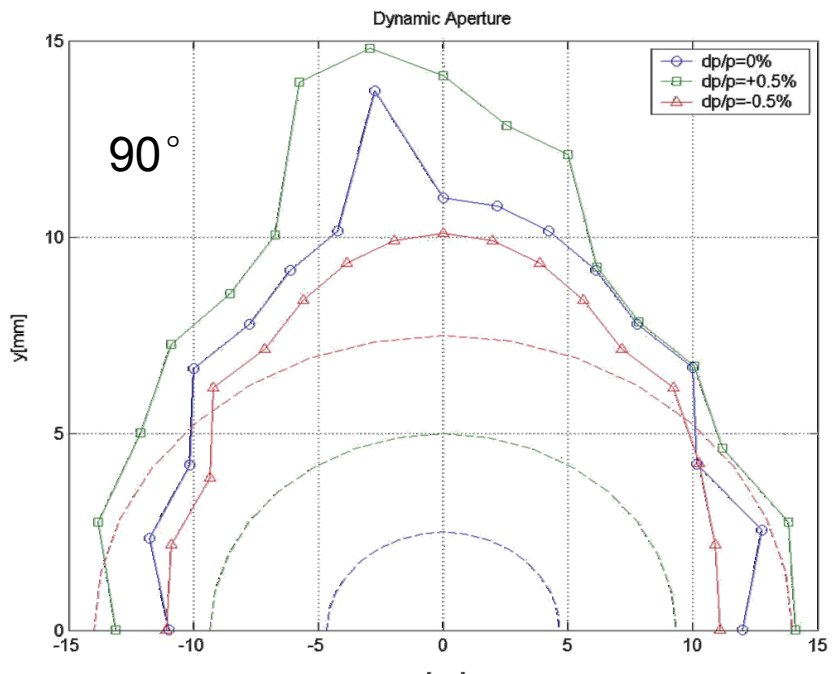
Major parameters of DMC3

Beam energy	5.0 GeV		
Circumference	3258.68 m		
RF frequency	650 MHz		
Harmonic number	7065		
Transverse damping time	23 ms		
Natural bunch length	6 mm		
Natural energy spread	1.26×10^{-3}		
Phase advance per FODO cell	60°	75°	90°
Momentum compaction factor	6.19×10^{-4}	4.04×10^{-4}	2.77×10^{-4}
Nomalised natural emittance	6.27 um	4.45 um	3.58 um
RF voltage	33.0 MV	21.84 MV	15.36 MV
RF acceptance	2.75%	2.58%	2.38%
Synchrotron tune	0.067	0.044	0.03
Working point x/y	38.28/36.21	44.35/42.30	51.23/49.36
Natural chromaticity x/y	-42.3/-41.5	-51.2/-49.9	-63.7/-61.7
Maximum quadrupole gradient	8.5 T/m	9.0 T/m	11.3 T/m
Maximum sextupole gradient	50 T/m^2	88 T/m^2	151 T/m^2

Dynamic aperture of DMC3







New design for the 2-stage bunch compressor

	BC1	BC2
Initial energy (GeV)	5	4.95
Initial energy spread (%)	0.13	0.8
Initial bunch length (mm)	6	0.95
RF voltage (GV)	0.25	13.66
RF Phase (Deg)	-101	-43
R_{56} (mm)	-738	-60
Final energy (GeV)	4.95	15
Final energy spread (%)	0.8	1.6
Final bunch length (mm)	0.95	0.16

Summary

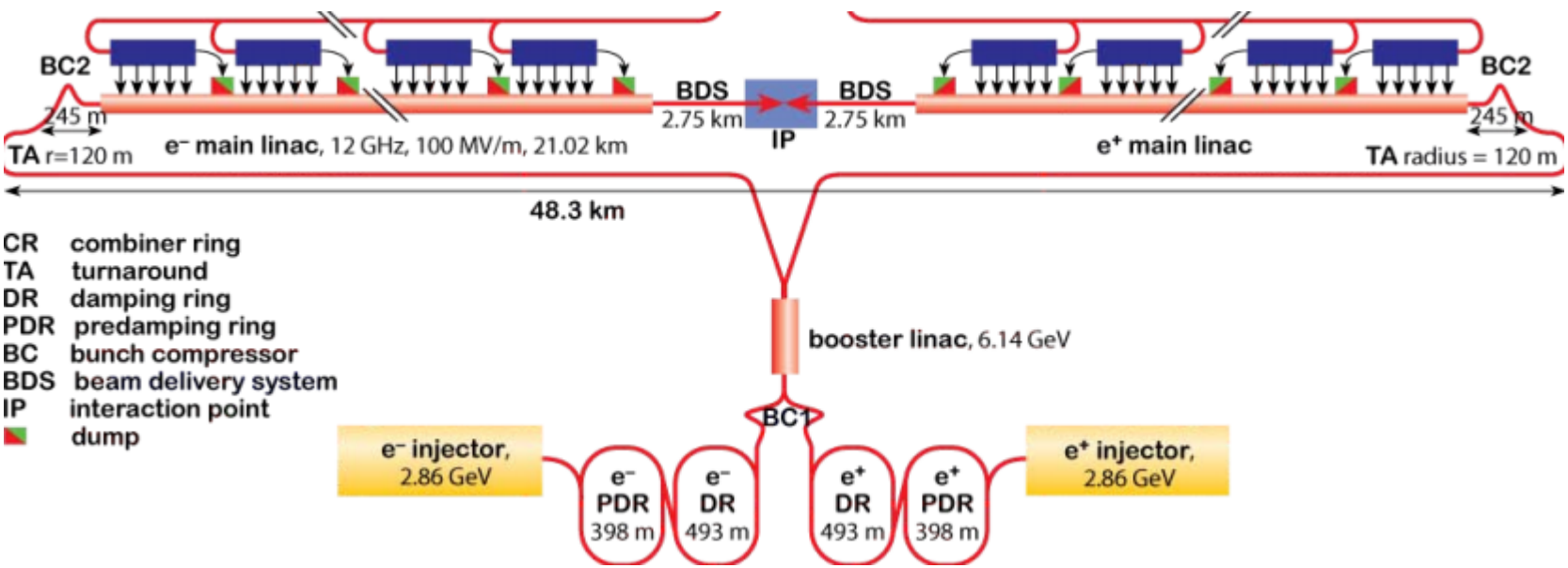
- Main changes in the new low charge parameters
  - bunch charge: 2e10→1e10
  - bunch number: 1320 →2625
  - bunch length: 300 um →166 um
- Advantages of this parameter set
  - keep the same low beam power and low AC power as SB2009
  - lower risk for source (especially for positron source)
  - easier emittance preservation in RTML and ML
  - much smaller beam beam effects
  - two-stage BC gives more flexibility to the whole machine
- New DR design and BC design were studied according to this new parameters. All the requirements can be achieved.
- Travelling focus is not needed as SB2009, but traveling focusing is good for option.
- Two bunch compressors are referable.

Discussion Materials
(back up)

CLIC Injector Complex

Main Beam at linac injection			
Energy	$E_{b,\mathrm{inj}}$	9	GeV
No. of particles / bunch	N_b	3.72	10^9
Bunch length	$\sigma_{s,\mathrm{inj}}$	44	μm
Energy spread	$\Delta E/E_{\mathrm{inj}}$	1.3	%
Transverse horizontal emittance	$\gamma\varepsilon_{x,\mathrm{inj}}$	600	nm rad
Transverse vertical emittance	$\gamma\varepsilon_{y,\mathrm{inj}}$	10	nm rad

- Bunch length very short -Two bunch compressors
- Emittance very low - PDR+DR



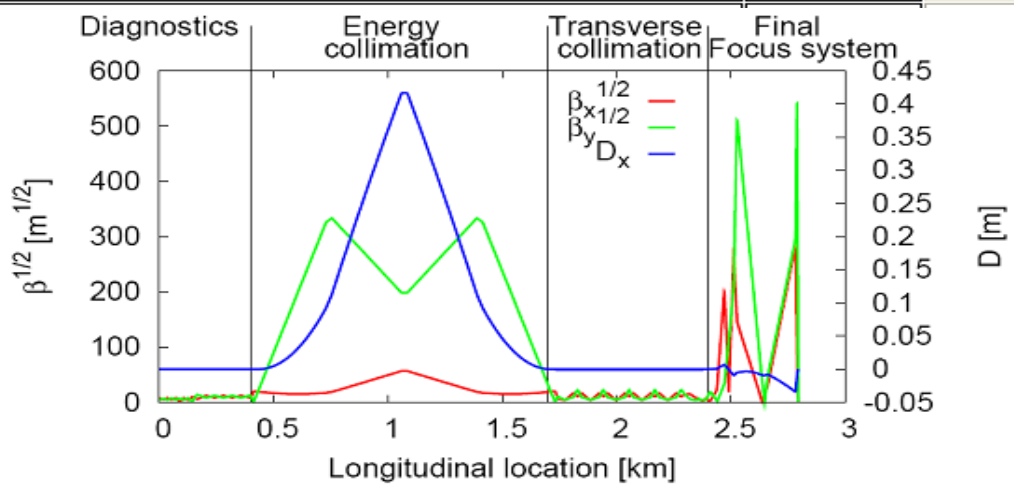
CLIC DR Parameters

Main Beam in damping ring before extraction			
Energy	$E_{b,DR}$	2.86	GeV
No. of particles / bunch	N_b	4.1	10^9
Bunch length	$\sigma_{s,DR}$	1.4	mm
Energy spread	$\sigma E/E_{DR}$	0.13	%
Transverse horizontal emittance (norm.)	$\gamma\varepsilon_{x,DR}$	480	nm rad
Transverse vertical emittance (norm.)	$\gamma\varepsilon_{y,DR}$	4.5	nm rad
Longitudinal emittance		5960	eVm
Electron / positron damping ring			
Ring circumference	C_{DR}	420.56	m
Number of trains stored	N_{train}	2	
Number of bunches / train	$k_{b,DR}$	156	
Bunch separation	$\Delta t_{b,DR}$	1	ns
RF frequency	f_{DR}	999.5	MHz
Wiggler length	l_{wig}	104	m
Damping times	$\tau_x / \tau_y / \tau_z$	1.88/1.91/0.96	ms
Tunes	Q_x / Q_y	55.46 / 11.6	

CLIC Beam Delivery System

- BDS parameters and Twiss Parameters

Beam Delivery System + IP			
Total diagnostic section length	l_{diag}	2 x 0.37	km
Total collimation system length	l_{coll}	2 x 1.92	km
Total final Focus system length	l_{FF}	2 x 0.46	km
Input transverse horizontal emittance (norm.)	$\gamma\varepsilon_x$	660	nm rad
Input transverse vertical emittance (norm.)	$\gamma\varepsilon_y$	20	nm rad
Nominal horizontal IP beta function	β^*_x	6.9	mm
Nominal vertical IP beta function	β^*_y	0.068	mm
Horizontal IP beam size before pinch	σ^*_x	45	nm
Vertical IP beam size before pinch	σ^*_y	1	nm
Bunch length	$\sigma_{s.inj}$	44	um



CLIC Physics Requirement

- **The constraint parameters at IP of CLIC**

Initial RMS Energy spread	$\sigma^*_{\Delta E/E}$	0.29	%
Total Energy spread		1	%
Crossing angle at IP	θ_C	20	mrad
Beamstrahlung mom. spread	δ_B	29	%
No. of photons / electron	n_γ	2.2	
No. of coherent pairs / bunch crossing	$N_{\rm coh}$	38	10^7
No. of incoherent pairs / bunch crossing	$N_{\rm incoh}$	0.03	10^7
Hadronic events / crossing	$N_{\rm hadron}$	2.7	
Total luminosity	$L_{\rm pk}$	6.0	$10^{34}{\rm cm}^{-2}{\rm s}^{-1}$
Luminosity (in 1% of energy)	$L_{99\%}$	2.0	$10^{34}{\rm cm}^{-2}{\rm s}^{-1}$

- **The beam parameters at IP of CLIC (constraint by the IP physics requirement, also driven by the the main Linac)**

σ^*_x	σ^*_y	$\sigma^*_{s.inj}$	$\gamma\varepsilon^*_x$	$\gamma\varepsilon^*_y$
45nm	1nm	44um	861nm rad	43nm rad
β^*_x	β^*_y	**Ne**	f_{rep}	N_b
6.9mm	0.068mm	3.72 e9	50Hz	312

Feedbacks

Damping Ring:

Sussana:
your proposal is interesting, for the Damping Ring performance the low power with 2620 bunches (1e10 part/bunch) should be similar or even better than 1310 bunches and 2e10 part/bunch; the current is the same but the bunch density is lower.

Mark:
From Low emittance working group, damping
Produce 10nm vertical emittance seems feasible

Positron source:

Omori-san:
I think that you proposition is interesting. Your new parameter ease the potential problem of the ILC e+ source in all scheme (in undulator, in Compton and in conventionals). As you mentioned in the slides, the new parameter also ease the beam-beam interaction.
I don't know the effect of the new parameter on the DR.

Wei:
This is an interesting proposition. From undulator scheme point of view, it reduces the peak power deposition in the target (which could help on the issue, but we need to investigate further to see there was a problem there or not), but the average power stays the same. There is no impact on undulator length, and also on capturing devices. Anything else on your mind that I am missing?

Feedback Cont'd

Final focus:

Tauchi:
I append the excel file with the GP and CAIN results.
Also, results of CAIN (v240) are appended. Both simulations agree.
The luminosity is 1.9E34/cm^2/s even without traveling focus.

Ultra-low vertical emittance is an issue to be discussed, while it is nice as an option.

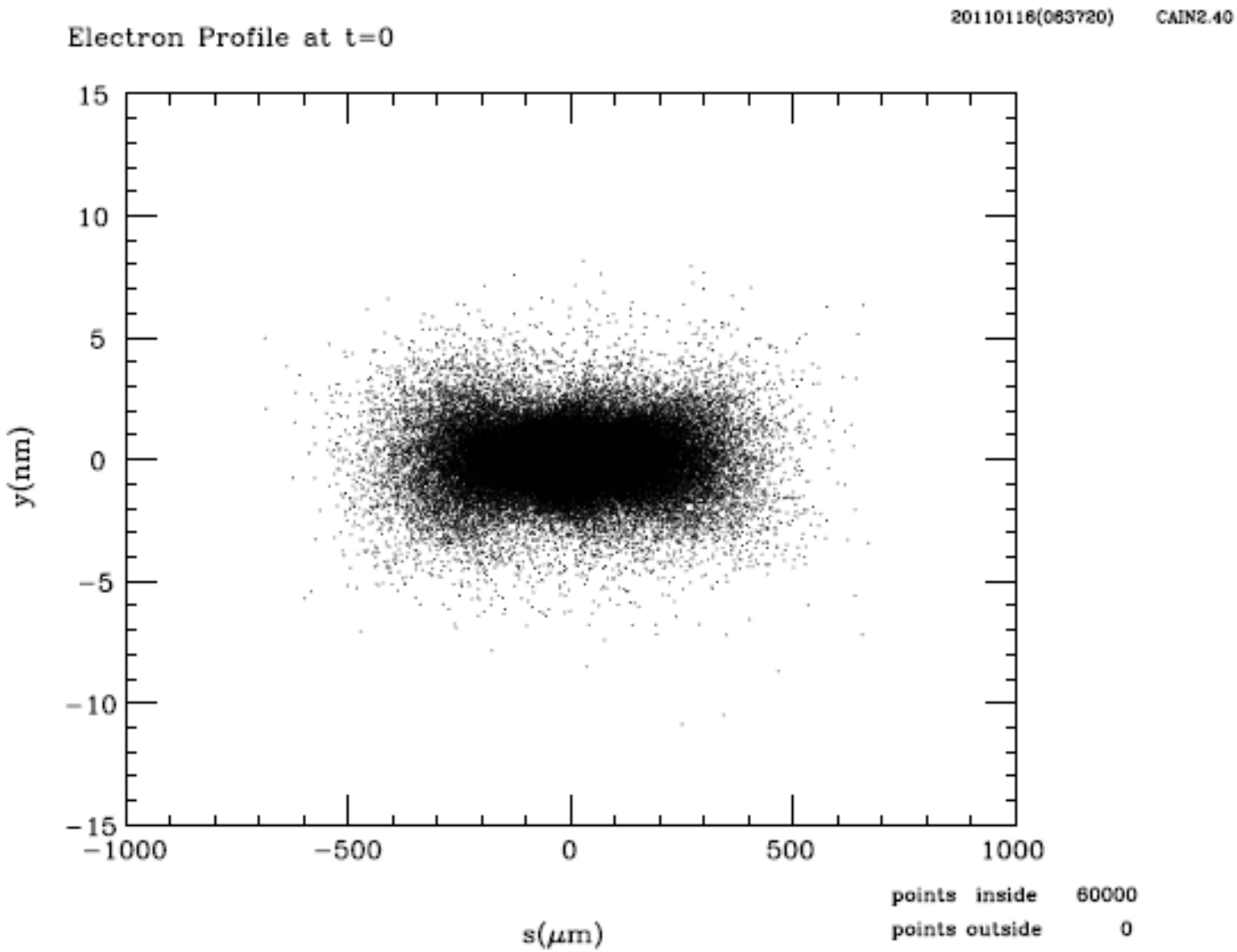
Philip:
Certainly the proposed parameters have many advantages, for the DR and sources, and for IP and MDI as you point out. Probably it could also ease the spent beam transport, thanks to the smaller disruption and beamstrahlung induced energy spread. However this is at the expense of tighter requirements both on betax and betay, more similar to those of CLIC. This could perhaps be tested at ATF2 with the ultra-low proposal advocated by the CERN people. However the added risk involved should be quantified, and the ATF2 demonstration will also be important.

Feedback Cont'd

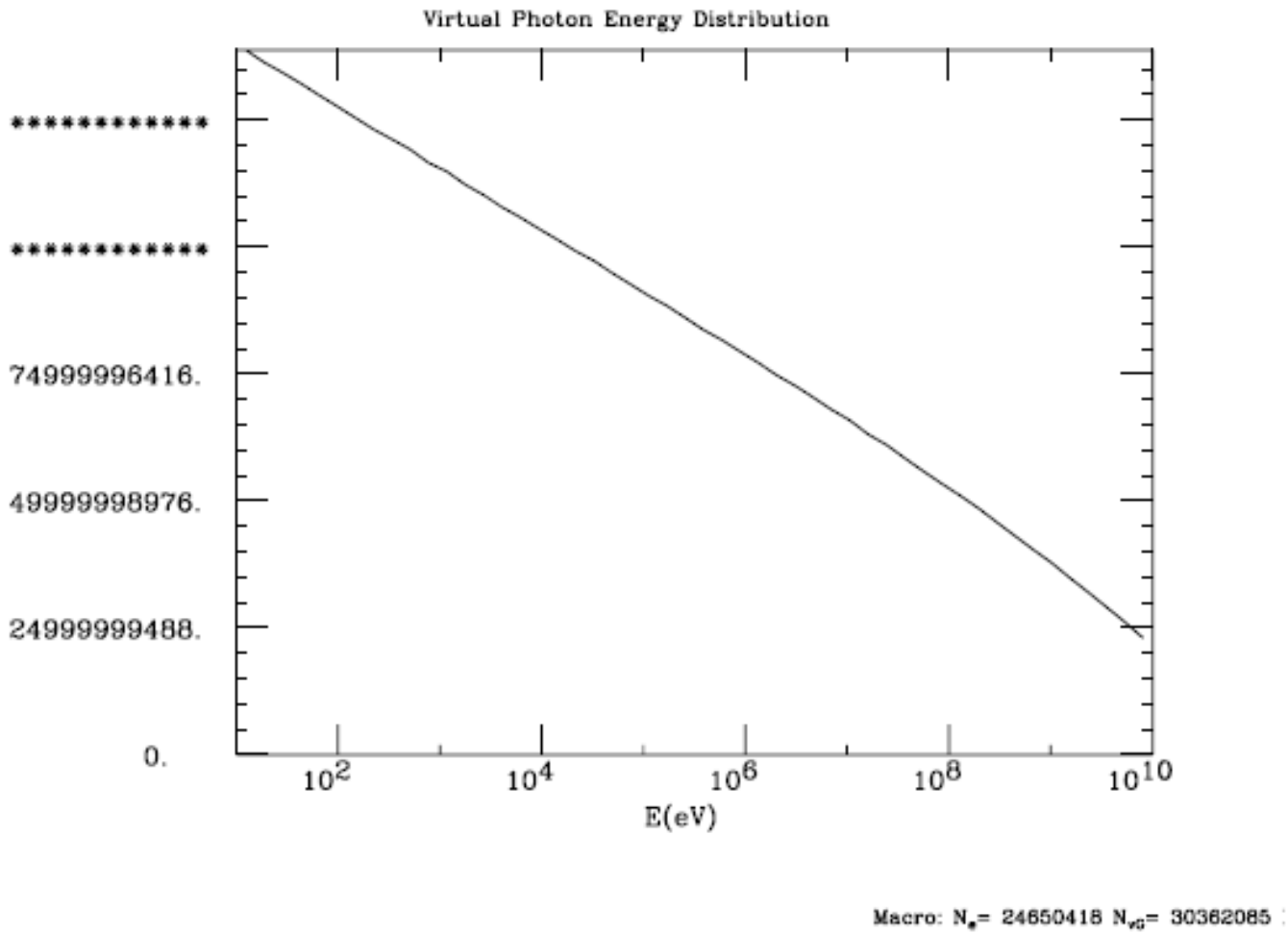
Beam Dynamics:

Andrei Sergei:
The luminosity with TF indeed gets to 2E34 with travelling focus, so your calculations are correct.
Some of the nasty beam-beam effects and sensitivities are indeed eased.
The additional issues with this set is stronger focusing and tighter collimation depth and large wakes effect of the beam and the need of 2 stage bunch compressor, but I guess you have ideas and design for that. In terms of the cost saving, I do not know how this would compare with SB2009, but it is interesting to have a look.

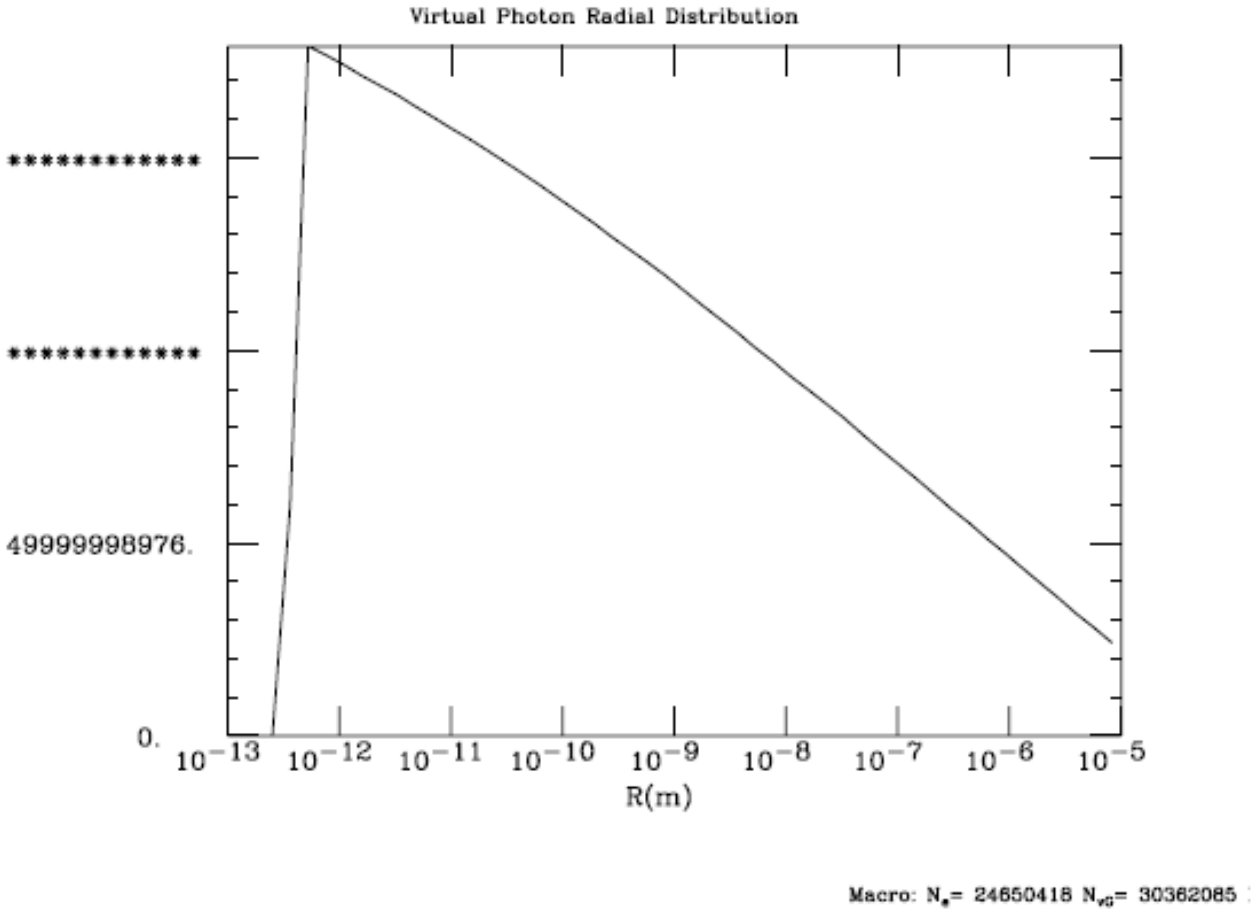
Tauchi-san's simulation results



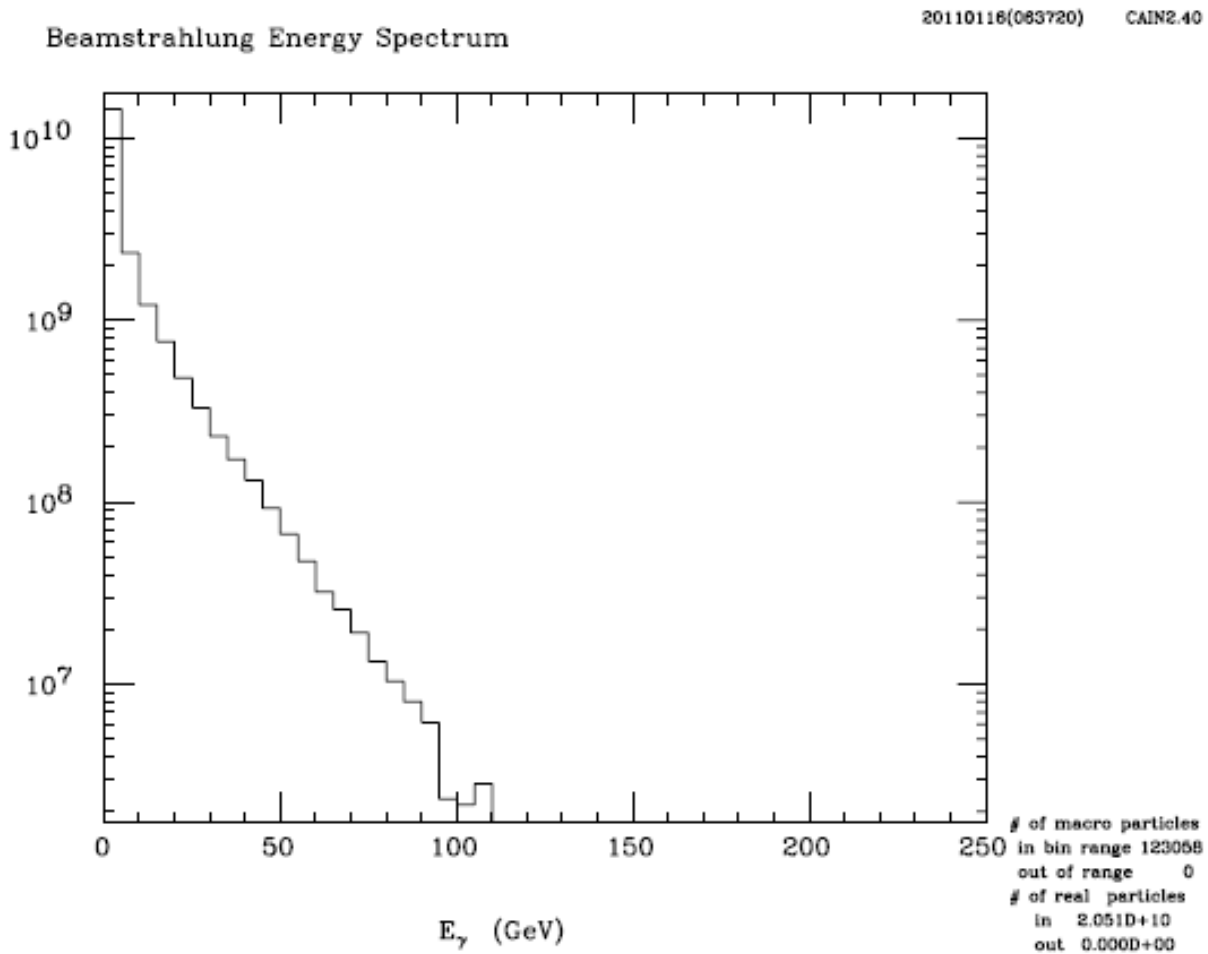
Tauchi-san's simulation results



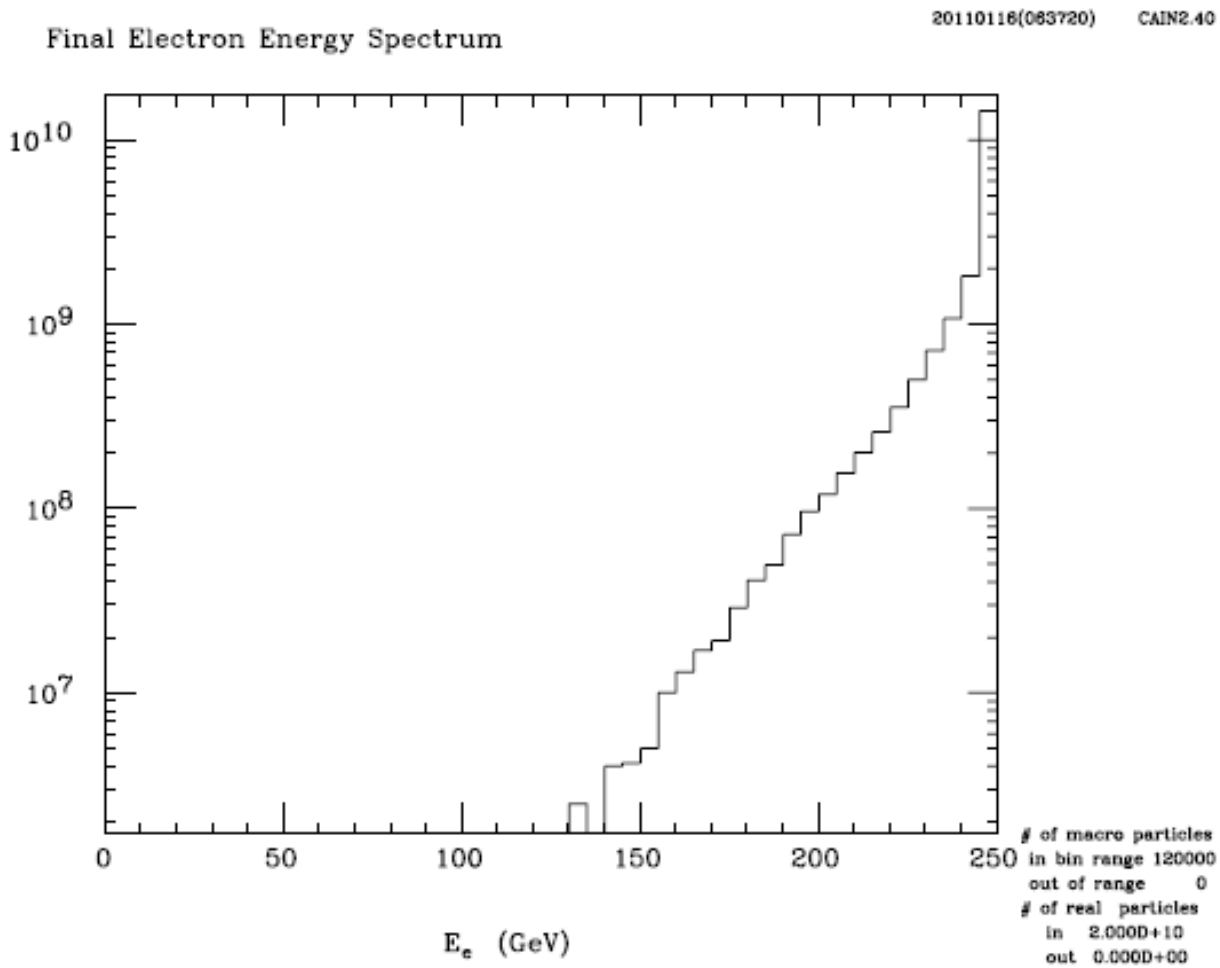
Tauchi-san's simulation results



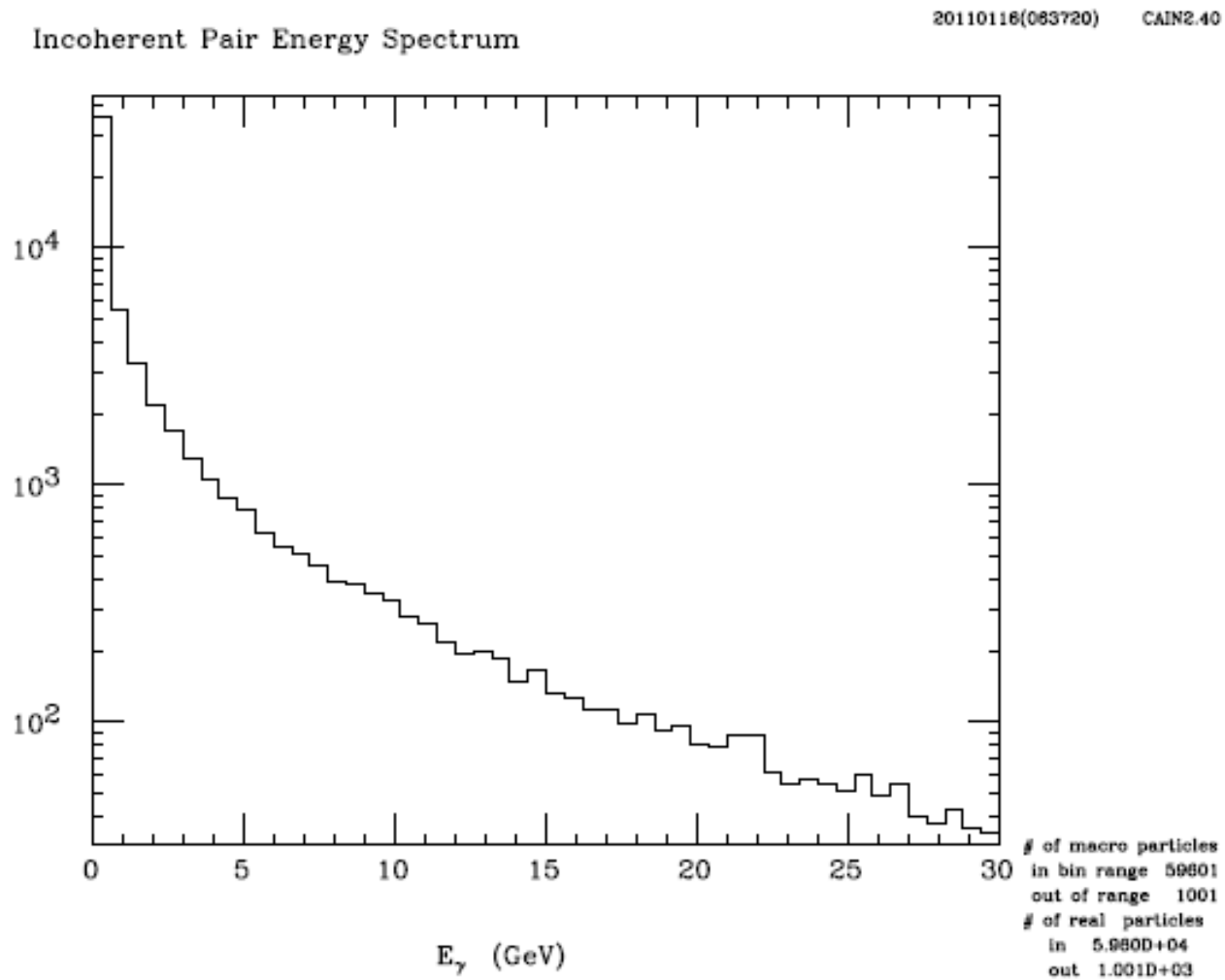
Tauchi-san's simulation results



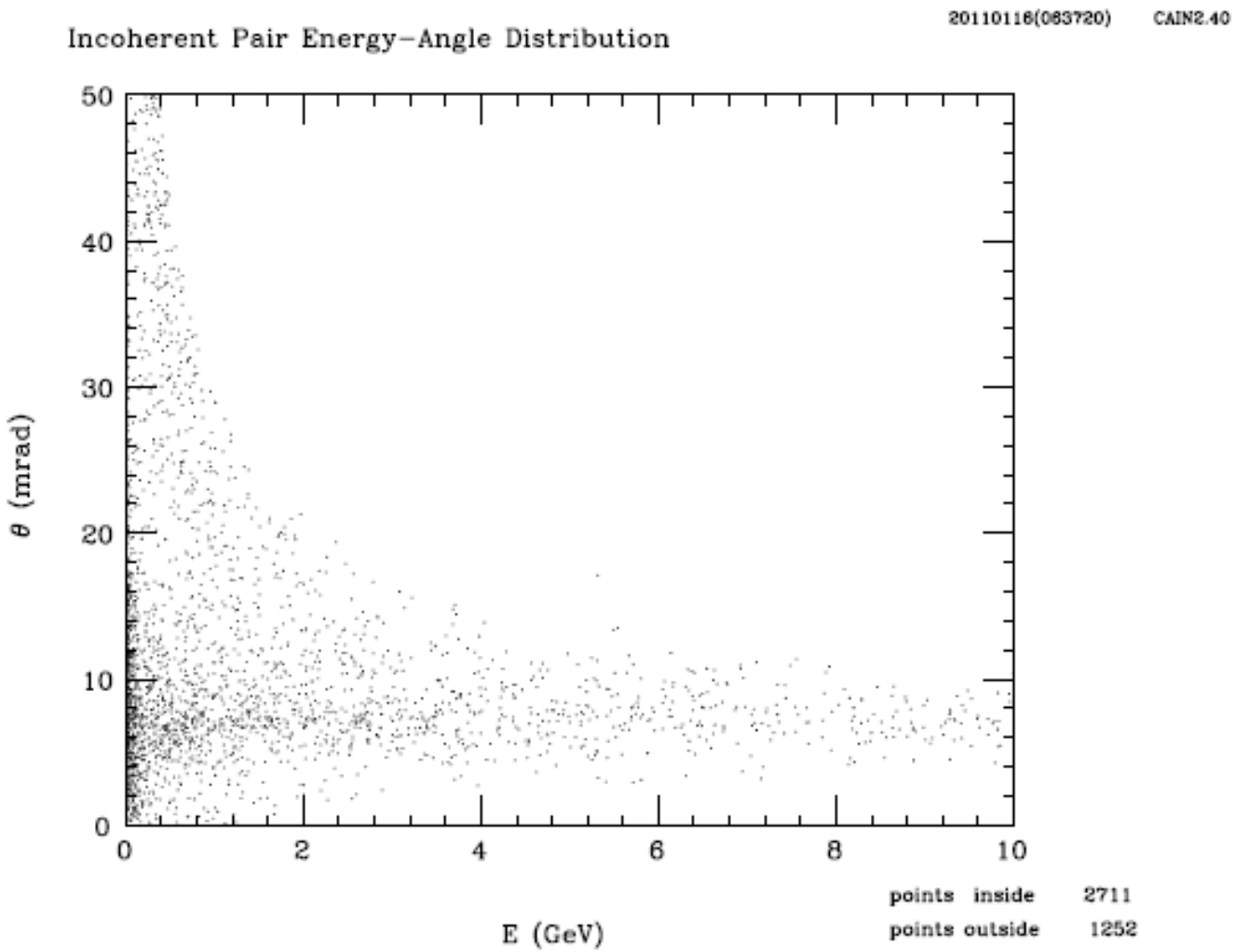
Tauchi-san's simulation results



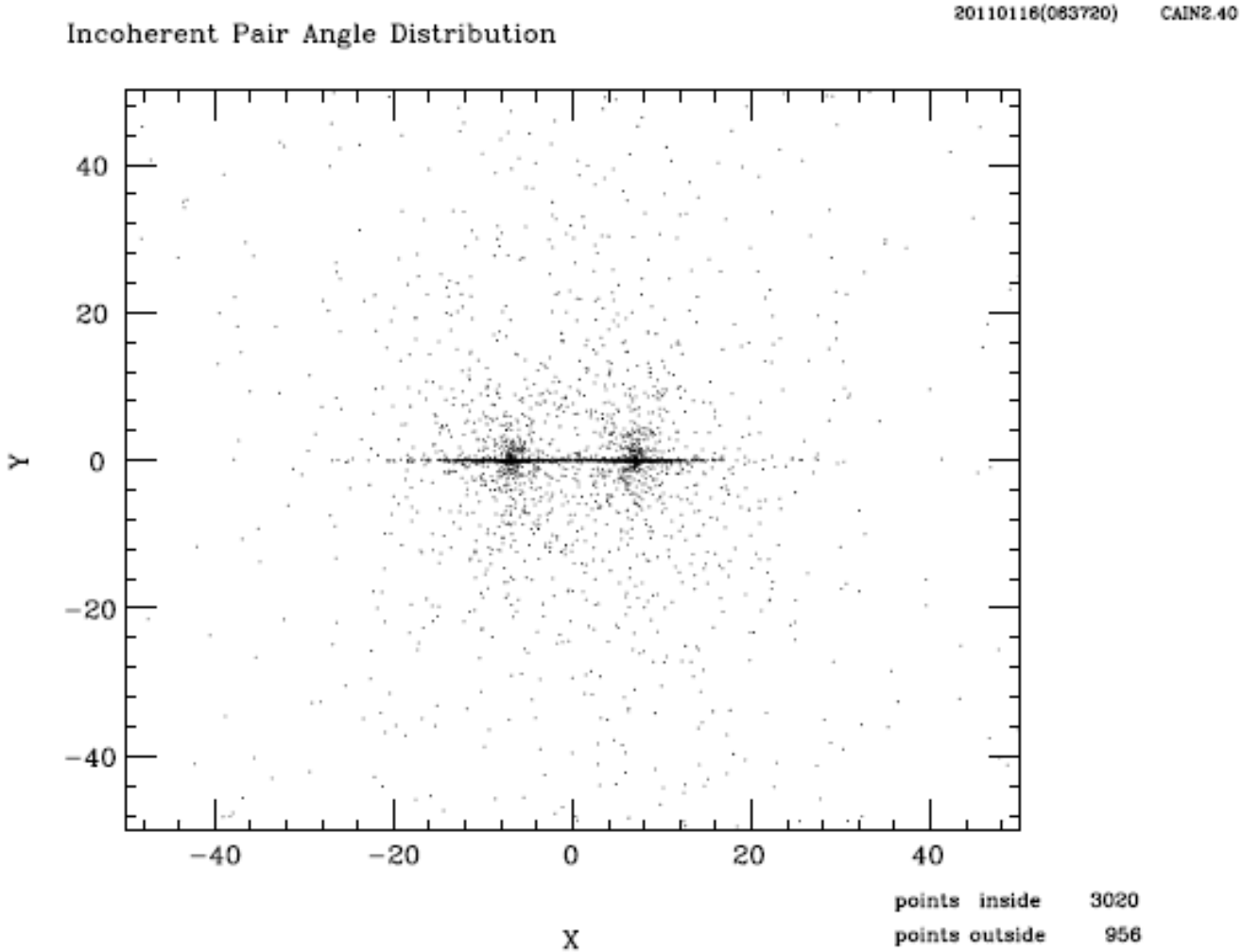
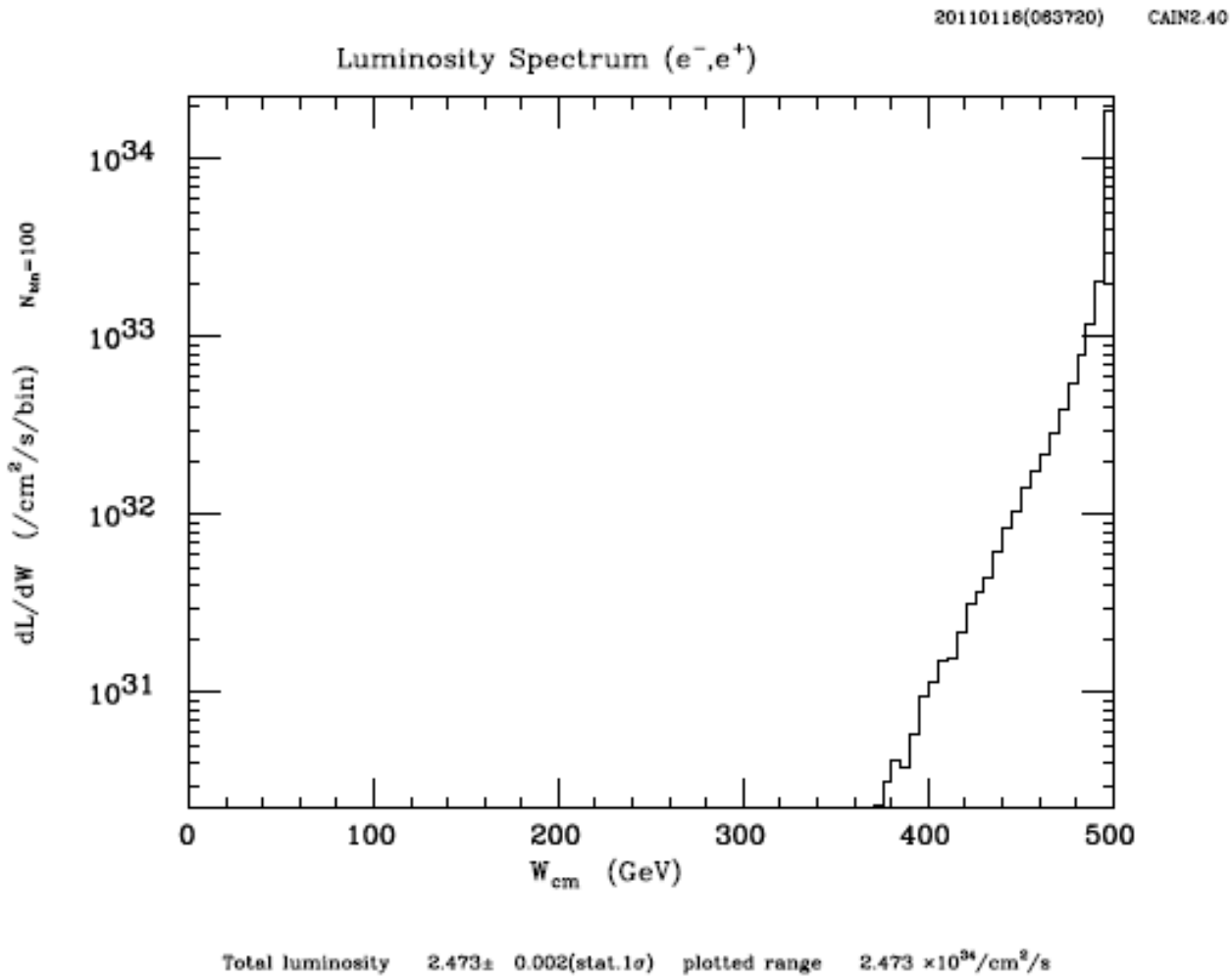
Tauchi-san's simulation results



Tauchi-san's simulation results



Tauchi-san's simulation results



Tauchi-san's simulation results