New Power Estimate and Z Pole Running.

Recent developments in the accelerator design

Benno List
ILC @ DESY Project Meeting
27.9.2019

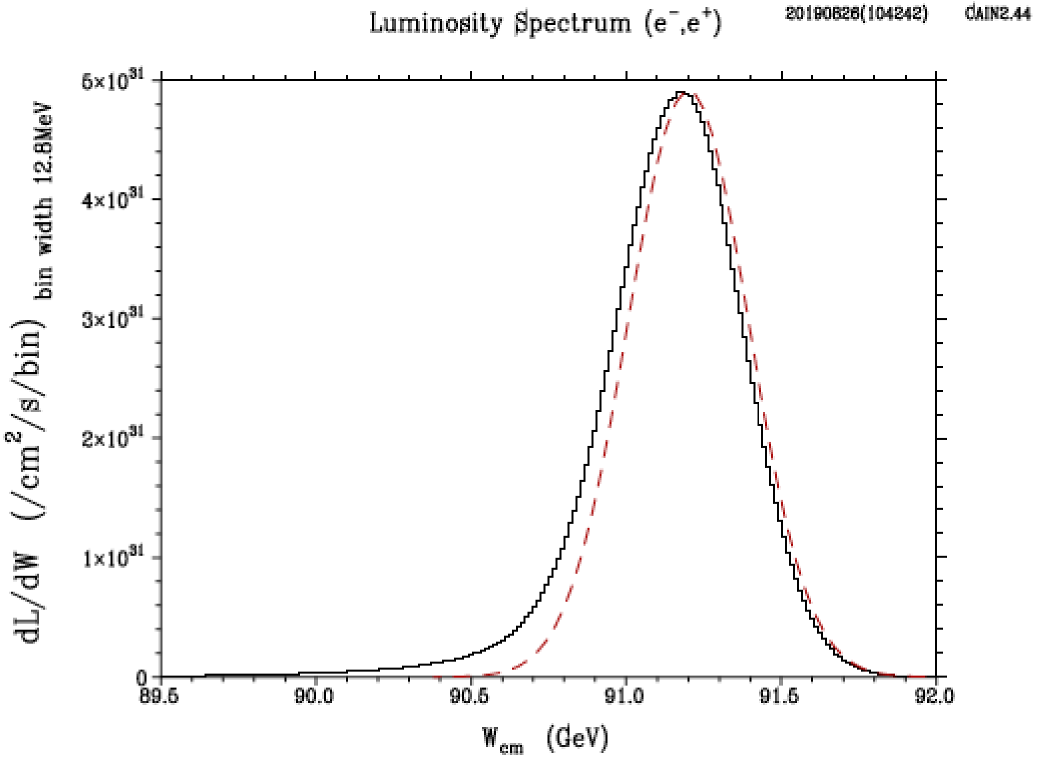
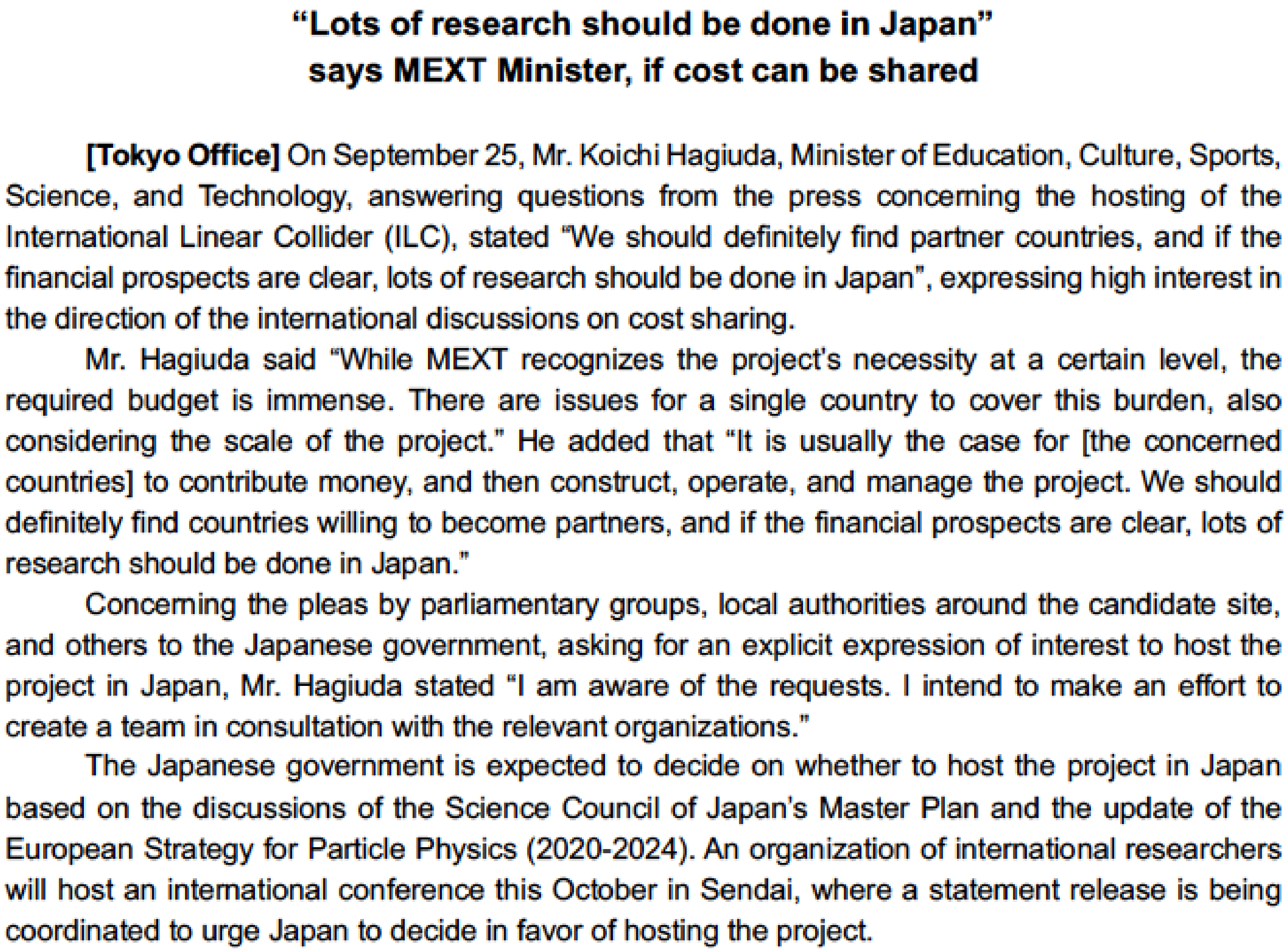


Figure 10: Luminosity spectrum. The red dashed curve shows the initial distribution normalized at the peak.

News

New MEXT Minister gives interview



"Lots of research should be done in Japan" says MEXT Minister, if cost can be shared

[Tokyo Office] On September 25, Mr. Koichi Hagiuda, Minister of Education, Culture, Sports, Science, and Technology, answering questions from the press concerning the hosting of the International Linear Collider (ILC), stated "We should definitely find partner countries, and if the financial prospects are clear, lots of research should be done in Japan", expressing high interest in the direction of the international discussions on cost sharing.

Mr. Hagiuda said "While MEXT recognizes the project's necessity at a certain level, the required budget is immense. There are issues for a single country to cover this burden, also considering the scale of the project." He added that "It is usually the case for [the concerned countries] to contribute money, and then construct, operate, and manage the project. We should definitely find countries willing to become partners, and if the financial prospects are clear, lots of research should be done in Japan."

Concerning the pleas by parliamentary groups, local authorities around the candidate site, and others to the Japanese government, asking for an explicit expression of interest to host the project in Japan, Mr. Hagiuda stated "I am aware of the requests. I intend to make an effort to create a team in consultation with the relevant organizations."

The Japanese government is expected to decide on whether to host the project in Japan based on the discussions of the Science Council of Japan's Master Plan and the update of the European Strategy for Particle Physics (2020-2024). An organization of international researchers will host an international conference this October in Sendai, where a statement release is being coordinated to urge Japan to decide in favor of hosting the project.

「日本で大いに研究を」

文科相、費用分担前提に

R1 9.26 日報

ILC 東北誘致

【東京支社】萩生田光一文部科学相は25日、報道各社のインタビューに答え、国際リニアコライダー（ILC）誘致に関し「ぜひパートナー国を探し、財政的見通しがつくならば日本で大いに研究をしたらいい」と述べ、コスト分担を巡る国際協議の行方に高い関心を示した。

萩生田氏は「必要性は文科省として一定の認識をしているが、膨大な予算が必要だ。一国で抱えるには、ややスケールも含め問題がある」と課題を指摘した。その上で「（関係国が）互いにお金を出し合って建設や管理運営をするのが常だ。ぜひパートナーになってくれる国を探し、財政的見通しがつくならば、日本で大いに研究をしたらいい」と語った。

国会議員連盟や建設候補地の自治体などが政府に国内誘致の明確な意思表明を求めていることには「要望は承知している。関係機関と相談しながらチームを組めるよう努力したい」との意向を示した。

日本政府は国内誘致の可否について、来年策定される日本学術会議のマスタープランや次期欧州素粒子物理戦略（２０２０～24年）の議論を踏まえて判断する見込み。国際研究者組織は10月、仙台市で開く国際学会で、日本に誘致決断を促す声明をまとめる方向だ。

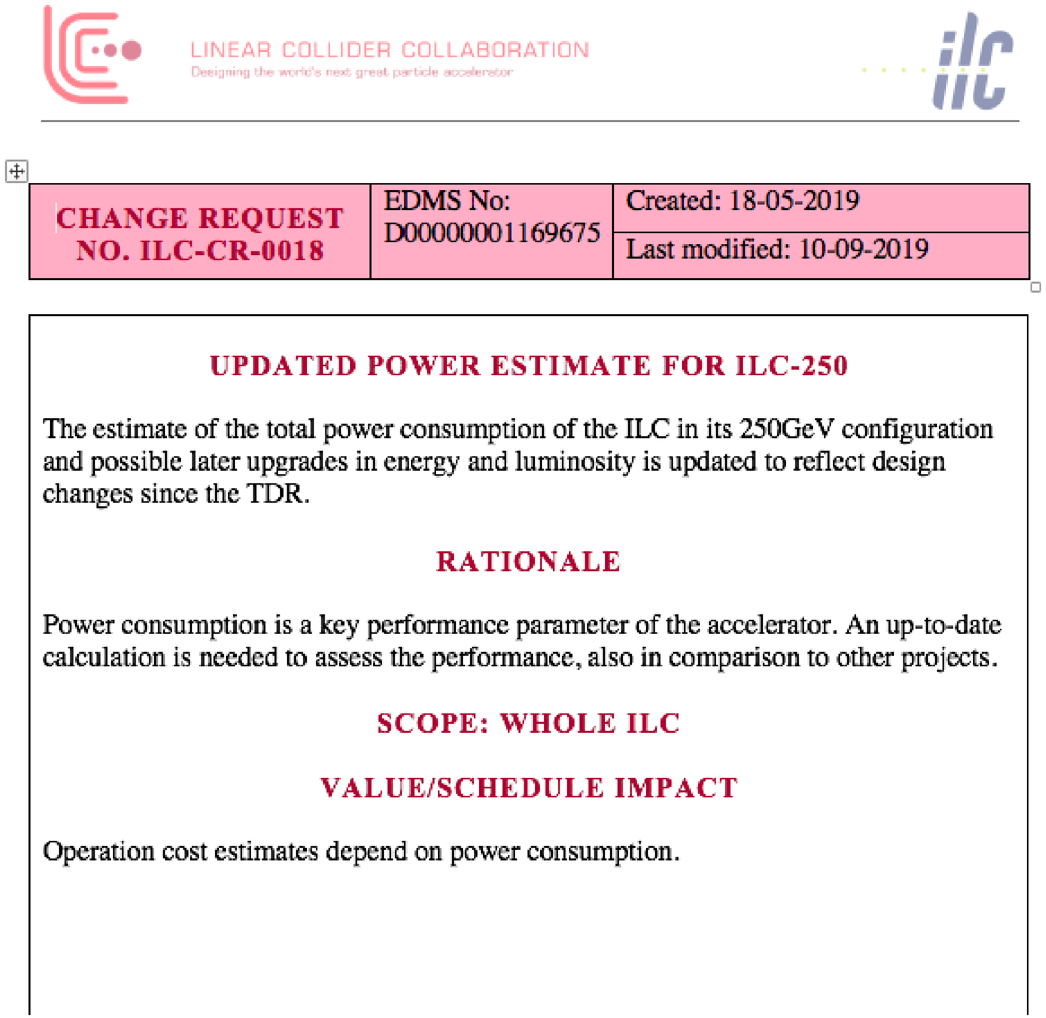
https://www.iwate-np.co.jp/article/2019/9/26/65161

http://www.iwate-ilc.jp/eng/news/minister-of-mext-do-a-lot-of-research-in-japan-after-figuring-out-how-to-share-the-costs-of-the-ilc/

New Power Estimate

A new power for ILC 250 in various configurations

- Estimate for electrical power consumption was never systematically redone for ILC-250
- Granada: Big discussion about energy efficiency / lum over AC power
- Updated power estimate is now under review by TCMI
- 5 configurations
  - TDR baseline: 500 GeV, 1312 bunches, L=1.8E34
  - 250-A: 250GeV, 1312b, L=1.35E34
  - 250-A‘ (w. R&D): 35MV/m, Q0=1.6E10
  - 250-A Lx2: 2526 bunches, L=2.7E34
  - 500@250: 500 GeV machine running at 250GeV, 14.7MV/m, 10Hz, 2625b, L=5.4E34
  - 500 Lx2: 1312b, L=3.6E34



LINEAR COLLIDER COLLABORATION
Designing the world's next great particle accelerator

CHANGE REQUEST NO. ILC-CR-0018	EDMS No: D00000001169675	Created: 18-05-2019 Last modified: 10-09-2019

UPDATED POWER ESTIMATE FOR ILC-250

The estimate of the total power consumption of the ILC in its 250GeV configuration and possible later upgrades in energy and luminosity is updated to reflect design changes since the TDR.

RATIONALE

Power consumption is a key performance parameter of the accelerator. An up-to-date calculation is needed to assess the performance, also in comparison to other projects.

SCOPE: WHOLE ILC

VALUE/SCHEDULE IMPACT

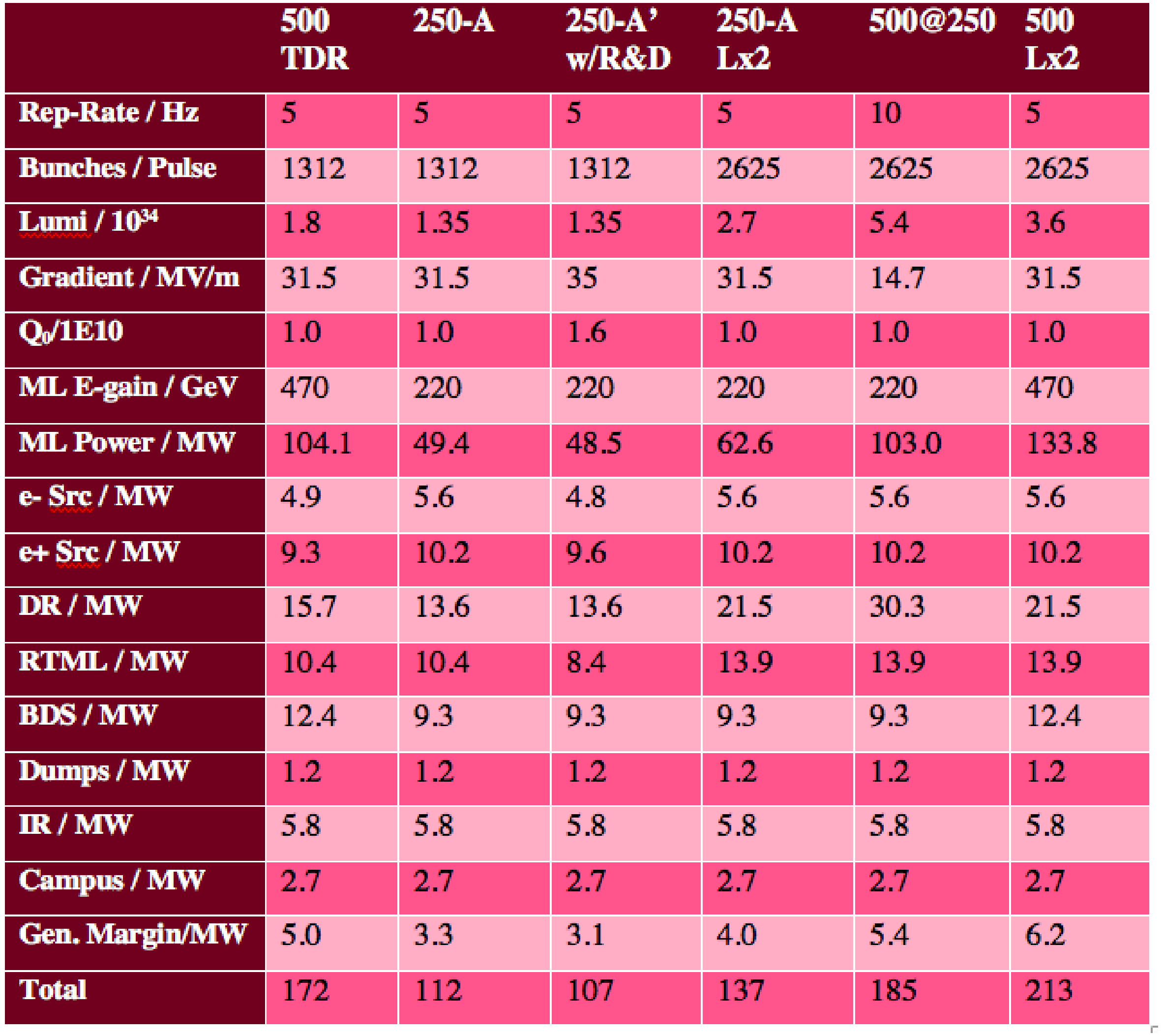
Operation cost estimates depend on power consumption.

Preliminary Result

Numbers are still subject to change!

- Most relevant update:
  No „5+5Hz“ running for positron production at 250
- 10% margin for cryogenic power
- 3% overall margin
- 2.7MWpower for central campus

- Takeaway:
  - 112MW for ILC-250
  - R&D saves a bit (5MW) of power
  - Double the lumi for 25MW (22%) power
  - Double the energy for 60MW (54%) power

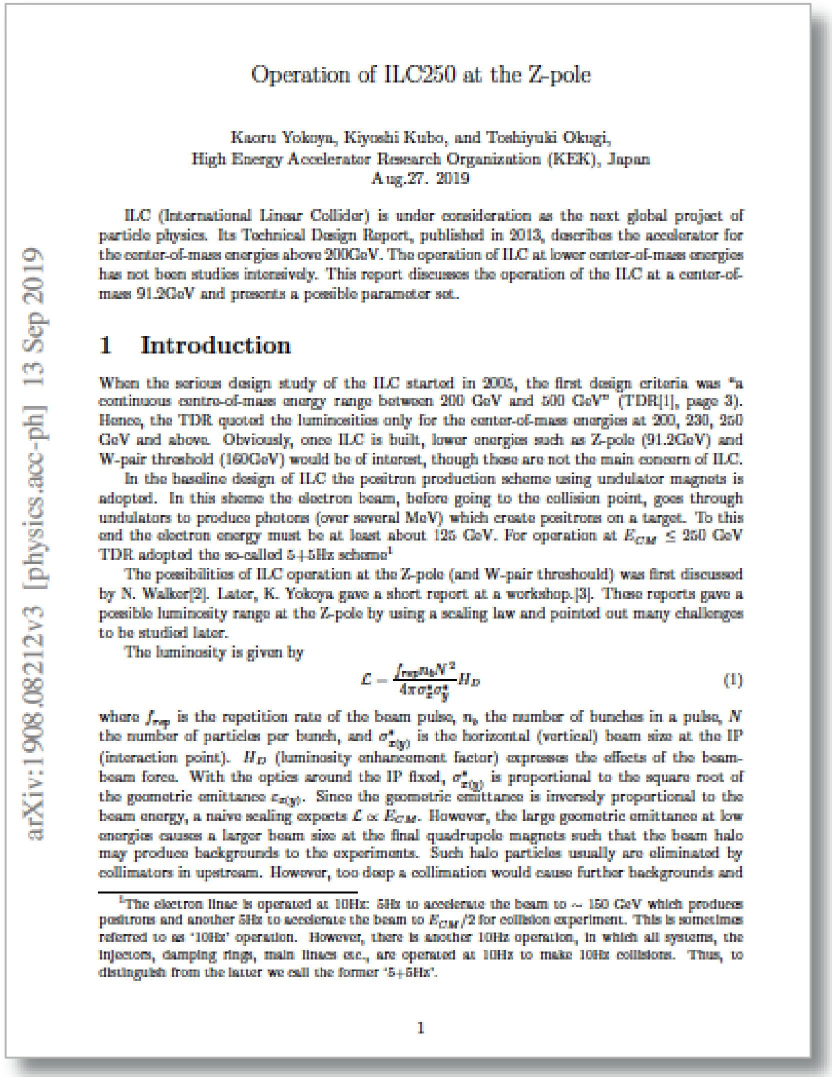


	500 TDR	250-A	250-A’ w/R&D	250-A Lx2	500@250	500 Lx2
Rep-Rate / Hz	5	5	5	5	10	5
Bunches / Pulse	1312	1312	1312	2625	2625	2625
Lumi / 10^{34}	1.8	1.35	1.35	2.7	5.4	3.6
Gradient / MV/m	31.5	31.5	35	31.5	14.7	31.5
Q_0/1E10	1.0	1.0	1.6	1.0	1.0	1.0
ML E-gain / GeV	470	220	220	220	220	470
ML Power / MW	104.1	49.4	48.5	62.6	103.0	133.8
e- Src / MW	4.9	5.6	4.8	5.6	5.6	5.6
e+ Src / MW	9.3	10.2	9.6	10.2	10.2	10.2
DR / MW	15.7	13.6	13.6	21.5	30.3	21.5
RTML / MW	10.4	10.4	8.4	13.9	13.9	13.9
BDS / MW	12.4	9.3	9.3	9.3	9.3	12.4
Dumps / MW	1.2	1.2	1.2	1.2	1.2	1.2
IR / MW	5.8	5.8	5.8	5.8	5.8	5.8
Campus / MW	2.7	2.7	2.7	2.7	2.7	2.7
Gen. Margin/MW	5.0	3.3	3.1	4.0	5.4	6.2
Total	172	112	107	137	185	213

Z Pole Running „Giga-Z“

New study from Japan

- Granada: Lots of PR from CEPC / FCC-ee on Z pole running
- Clearly the domain of circular colliders
- What can ILC do?
- Earlier study by Nick Walker (ILC-Note-2016-006):
  L = 1.0-1.5E33 (note: E33, not E44!)
- Current study adresses
  - New ILC-250 design
  - Main Linac operation and emittance budget
  - Collimation depth
  - New IP parameters
  - New DR parameters (smaller emittance)
- Result: L=2.1E33
  => approx. 30/fb per year = „1GZ“ (1E9 Z->qq)



arXiv:1908.08212v3 [physics.acc-ph] 13 Sep 2019

Operation of ILC250 at the Z-pole

Kaoru Yokoya, Kiyoshi Kubo, and Toshiyuki Okugi,
High Energy Accelerator Research Organization (KEK), Japan
Aug.27. 2019

ILC (International Linear Collider) is under consideration as the next global project of particle physics. Its Technical Design Report, published in 2013, describes the accelerator for the center-of-mass energies above 200GeV. The operation of ILC at lower center-of-mass energies has not been studies intensively. This report discusses the operation of the ILC at a center-of-mass 91.2GeV and presents a possible parameter set.

1 Introduction

When the serious design study of the ILC started in 2005, the first design criteria was "a continuous centre-of-mass energy range between 200 GeV and 500 GeV" (TDR[1], page 3). Hence, the TDR quoted the luminosities only for the center-of-mass energies at 200, 230, 250 GeV and above. Obviously, once ILC is built, lower energies such as Z-pole (91.2GeV) and W-pair threshold (160GeV) would be of interest, though these are not the main concern of ILC.

In the baseline design of ILC the positron production scheme using undulator magnets is adopted. In this sheme the electron beam, before going to the collision point, goes through undulators to produce photons (over several MeV) which create positrons on a target. To this end the electron energy must be at least about 125 GeV. For operation at $E_{CM} \leq 250$ GeV TDR adopted the so-called 5+5Hz scheme[1]

The possibilities of ILC operation at the Z-pole (and W-pair threshould) was first discussed by N. Walker[2]. Later, K. Yokoya gave a short report at a workshop.[3]. These reports gave a possible luminosity range at the Z-pole by using a scaling law and pointed out many challenges to be studied later.

The luminosity is given by

$$\mathcal{L} = \frac{f_{rep} n_b N^2}{4\pi\sigma_x^*\sigma_y^*} H_D \tag{1}$$

where f_{rep} is the repetition rate of the beam pulse, n_b the number of bunches in a pulse, N the number of particles per bunch, and $\sigma^*_{x(y)}$ is the horizontal (vertical) beam size at the IP (interaction point). H_D (luminosity enhancement factor) expresses the effects of the beam-beam force. With the optics around the IP fixed, $\sigma^*_{x(y)}$ is proportional to the square root of the geometric emittance $\epsilon_{x(y)}$. Since the geometric emittance is inversely proportional to the beam energy, a naive scaling expects $\mathcal{L} \propto E_{CM}$. However, the large geometric emittance at low energies causes a larger beam size at the final quadrupole magnets such that the beam halo may produce backgrounds to the experiments. Such halo particles usually are eliminated by collimators in upstream. However, too deep a collimation would cause further backgrounds and

---

[1] The electron linac is operated at 10Hz: 5Hz to accelerate the beam to ~ 150 GeV which produces positrons and another 5Hz to accelerate the beam to $E_{CM}/2$ for collision experiment. This is sometimes referred to as '10Hz' operation. However, there is another 10Hz operation, in which all systems, the injectors, damping rings, main linacs etc., are operated at 10Hz to make 10Hz collisions. Thus, to distinguish from the latter we call the former '5+5Hz'.

arXiv:1908.08212

Main Linac Operation

- Assume „5+5Hz“ operation for positron production: e- linac provides alternating beams
  - 125GeV for undulator source
  - 46GeV for collisions
- Assuming constant el power for RF: 3.7Hz rep rate (note: cryo capacity not considered)
- Low energy beam: uniform gradient 8.7MV/m
- ML follows earth curvature -> small vertical bend! Magnets are set up for low energy
  -> 1cm vertical deviation for 125GeV beam
  -> requires correction before undulator entrance
  -> not a show stopper

Table 2: RF system parameters for alternating operation of 125GeV and 45.6GeV

	e^+ production	collision	
Final beam energy	125	45.6	GeV
Average accelerating gradient	31.5	8.76	MV/m
Peak power per cavity	189	77.2	kW
Klystron peak power	9.82	4.15	MW
Klystron efficiency	67	53	%
Modulator output	14.66	7.83	MW
Fill time	0.927	0.328	ms
Beam pulse length	0.727	0.727	ms
RF pulse length	1.65	1.06	ms
Repetition rate	3.7	3.7	Hz

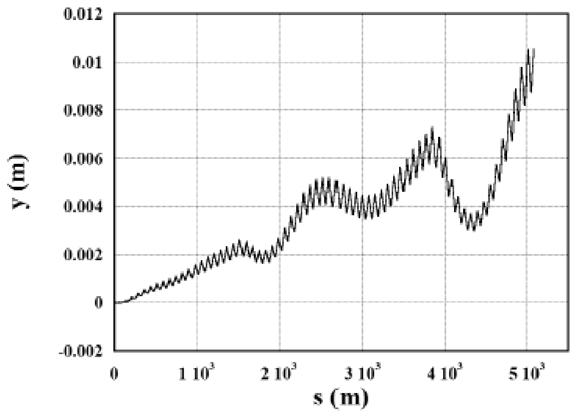


Figure 4: The vertical orbit difference between 45.6 and 125GeV beams as a function of the length s along the linac. No errors included.

Main Linac Emittance Increase

New study on emittance increase in ML for 46GeV beam

- Emittance increases in ML due to wakefield effects (component misalignment -> beam not centered at aperture changes -> wakefields blow up beam)
- Low energy beam is more sensitive to wakefield effects
- Study ensemble of 100 machines
- Vertical emittance at entrance: 20nm
- Emittance increase: 6.3nm (average), 13nm (90%) CL
  -> a bit over 10nm budget
  -> increase budget to 15nm

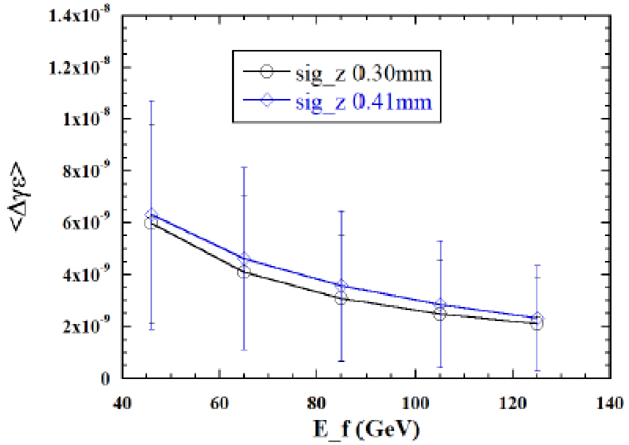


Figure 5: The vertical emittance increase in the main linacs as a function of the final beam energy. Two cases of different σ_z are shown. The error bars indicate one standard deviation in 100 runs with different random number seeds.

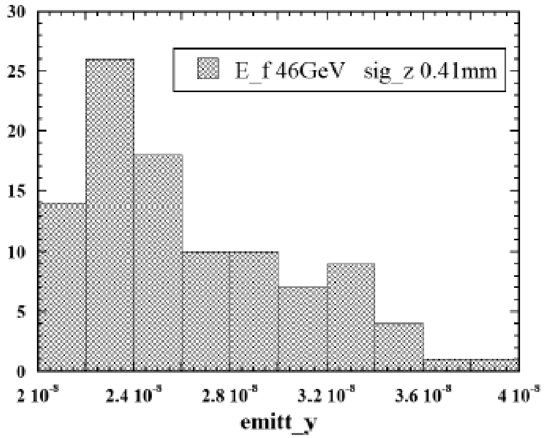


Figure 6: Distribution of the vertical emittance at the linac end over 100 different random number seeds. Final beam energy 45.6GeV. σ_z =0.41mm.

Collimation Depth

How strong can the beam be demagnified?

- Beta function grows quadratically around IP:
  $\beta(s) = \beta^* + s^2/\beta^*$
  -> beam size in FF Quad: $\sqrt{(\varepsilon\, (\beta^{*2} + L^{*2})/\beta^*)}$
- Synchrotron radiation from beam edges in FF quad makes background in detector
- Beam has to be collimated to be small enough in FF quad. Smaller β^* needs deeper collimation
- Reasonable collimation depth: 6 sigma
  => horizontal $\beta^* = 18\text{mm}$

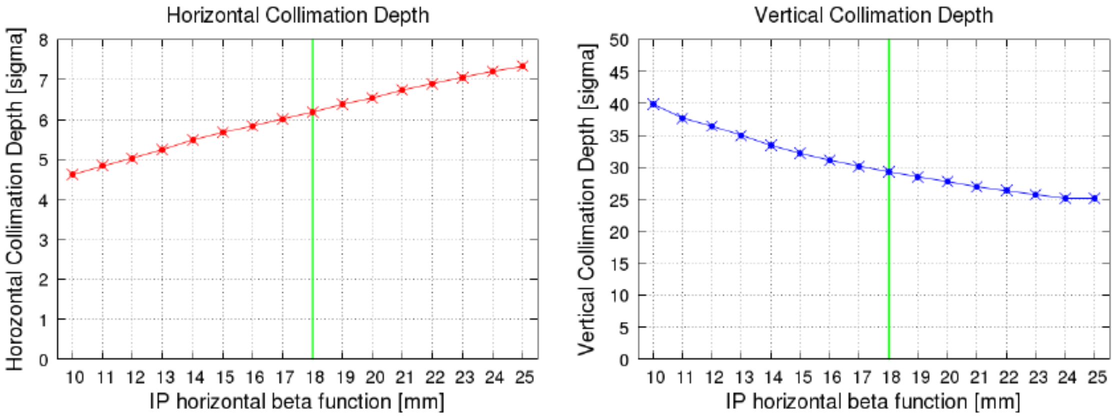


Figure 7: Collimation depth as a function of the horizontal beta function. The left(right)-hand-side is the depth in the horizontal (vertical) plane. The same beam pipe aperture is used as in ILC 250GeV. $\beta^*_x \times \beta^*_y$ is fixed.

Beam Delivery System

Energy spread vs bunch length

- To reach nm vertical beam sizes, many effects need to be corrected
- Magnets have „chromatic aberration“:
  bending power ~ 1/E -> focus length ~E
- Longitudinal phase space: δz × δE = const
- Energy spread δE larger at 46GeV
  (0.41% vs 0.15% at 125GeV)
  -> chromatic effects more important
- Study shows that 0.3% is maximum
  -> go from 300µm × 0.41% to 410µm × 0.3%
- Also: Emittance increase studied.
  ~ 15nm increase (at 125GeV: 5nm)

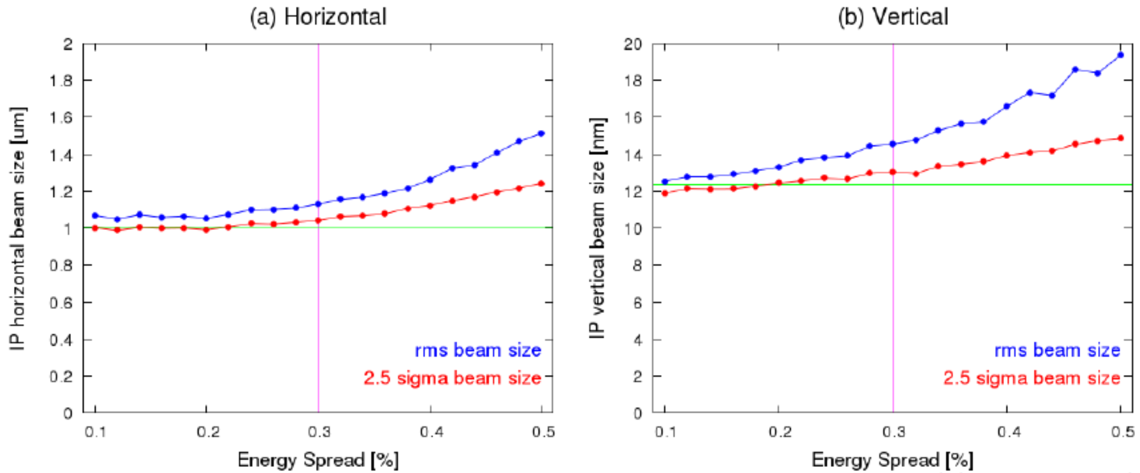


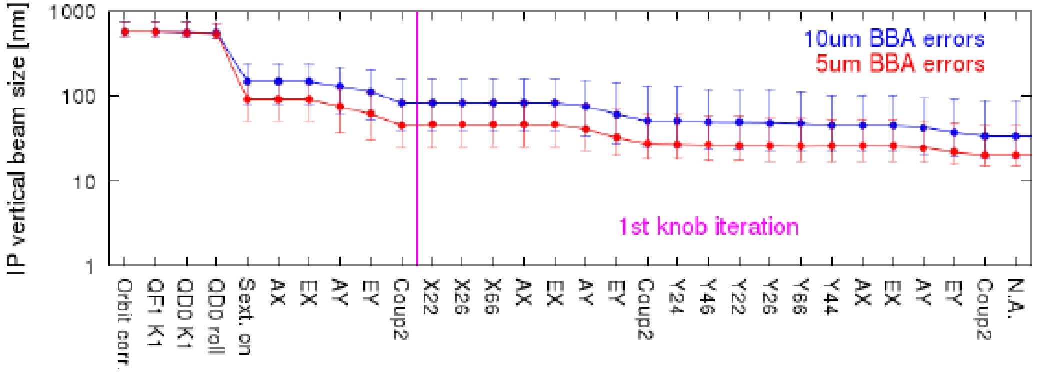
Figure 8: The beam size at the IP as a function of the energy spread. (a) horizontal (b) vertical. The blue spots show the r.m.s. of the whole beam size and . the red spots show the r.m.s.=size with $> 2.5\sigma$ tail cut off.

Beam Delivery System

Tuning the beam size at the IP

- Many correctiosn have to be applid in final focus system to correct all adverse effects
- Study how all „knobs“ (magnet settings) can be used to correct all effects one by one
  -> was learned at ATF-2
- Result: can focus beam to 14.6nm
  (15% larger than without errors)

(a) Tuning trend of vertical beam size (first 30 knob scan)



(b) Tuning trend of vertical beam size (all knob scan)

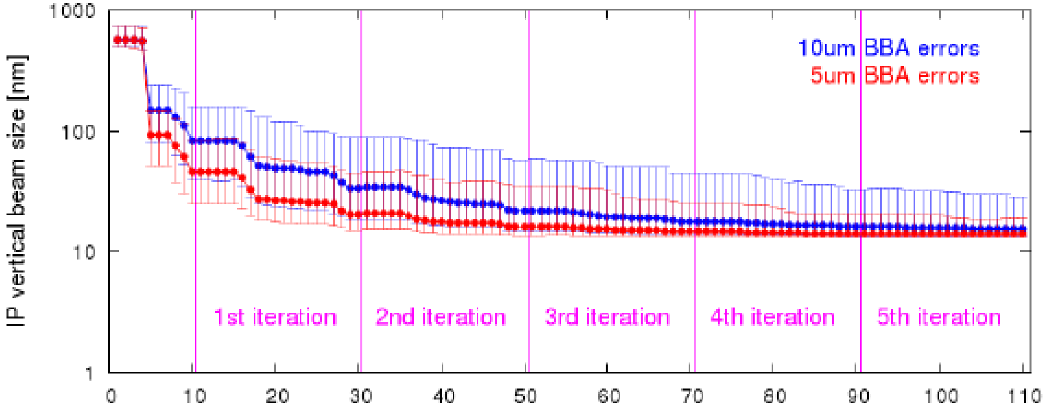


Figure 9: Vertical beam size vs. number of knob scans in the process of BDS tuning. (a) shows the first 30 knobs. (b) shows all knobs.

Table 4:
Simulation results of the vertical beam sizes.
The offset 300μm of the wake sources is used for the row (3) and (4).

	σ_x^* (μm)	σ_y^* (nm)
(1) No errors	1.04	12.7
(2) Magnet errors and correction	1.12	14.0
(3) Magnet errors + static wake + correction		14.3
(4) Magnet errors + static&dynamic wake + correction		14.6

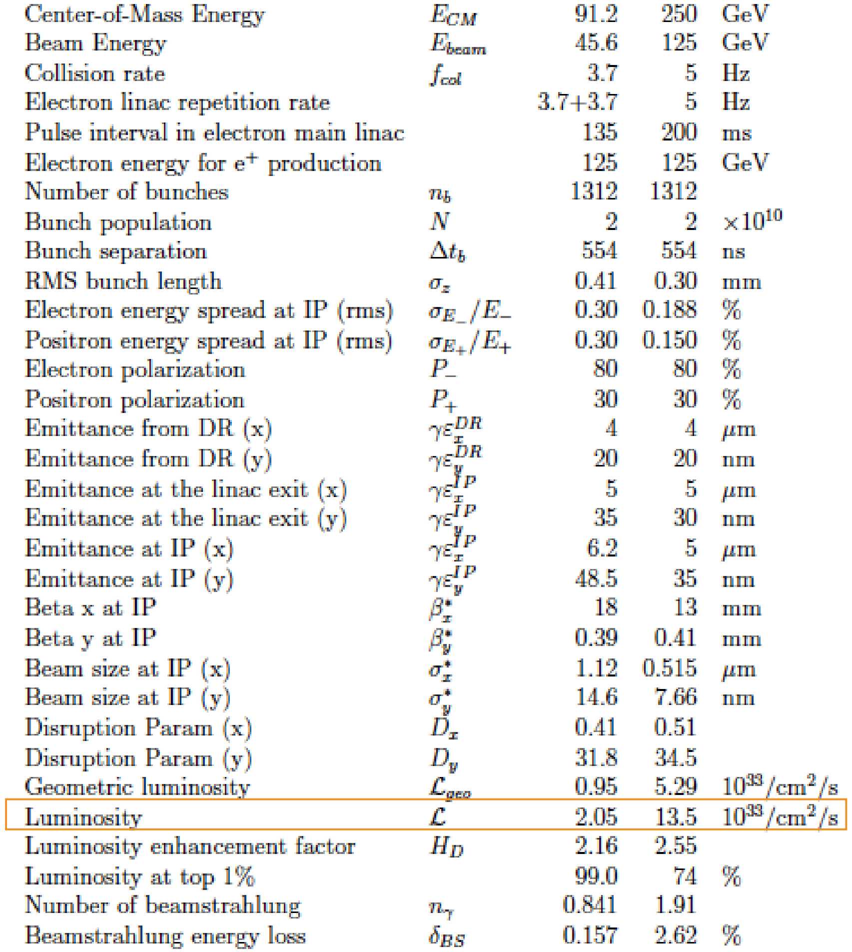
Result

Putting it all together

Table 1:

Proposed Parameters for Operation at Z-pole

The baseline parameters for 250GeV is listed for reference.



Center-of-Mass Energy	E_{CM}	91.2	250	GeV
Beam Energy	E_{beam}	45.6	125	GeV
Collision rate	f_{col}	3.7	5	Hz
Electron linac repetition rate		3.7+3.7	5	Hz
Pulse interval in electron main linac		135	200	ms
Electron energy for e^+ production		125	125	GeV
Number of bunches	n_b	1312	1312	
Bunch population	N	2	2	$\times 10^{10}$
Bunch separation	Δt_b	554	554	ns
RMS bunch length	σ_z	0.41	0.30	mm
Electron energy spread at IP (rms)	$\sigma_{E\_}/E_-$	0.30	0.188	%
Positron energy spread at IP (rms)	σ_{E_+}/E_+	0.30	0.150	%
Electron polarization	P_-	80	80	%
Positron polarization	P_+	30	30	%
Emittance from DR (x)	$\gamma\varepsilon_x^{DR}$	4	4	μm
Emittance from DR (y)	$\gamma\varepsilon_y^{DR}$	20	20	nm
Emittance at the linac exit (x)	$\gamma\varepsilon_x^{IP}$	5	5	μm
Emittance at the linac exit (y)	$\gamma\varepsilon_y^{IP}$	35	30	nm
Emittance at IP (x)	$\gamma\varepsilon_x^{IP}$	6.2	5	μm
Emittance at IP (y)	$\gamma\varepsilon_y^{IP}$	48.5	35	nm
Beta x at IP	β_x^*	18	13	mm
Beta y at IP	β_y^*	0.39	0.41	mm
Beam size at IP (x)	σ_x^*	1.12	0.515	μm
Beam size at IP (y)	σ_y^*	14.6	7.66	nm
Disruption Param (x)	D_x	0.41	0.51	
Disruption Param (y)	D_y	31.8	34.5	
Geometric luminosity	$\mathcal{L}_{geo}$	0.95	5.29	$10^{33}/\mathrm{cm}^2/\mathrm{s}$
Luminosity	$\mathcal{L}$	2.05	13.5	$10^{33}/\mathrm{cm}^2/\mathrm{s}$
Luminosity enhancement factor	H_D	2.16	2.55	
Luminosity at top 1%		99.0	74	%
Number of beamstrahlung	n_γ	0.841	1.91	
Beamstrahlung energy loss	δ_{BS}	0.157	2.62	%

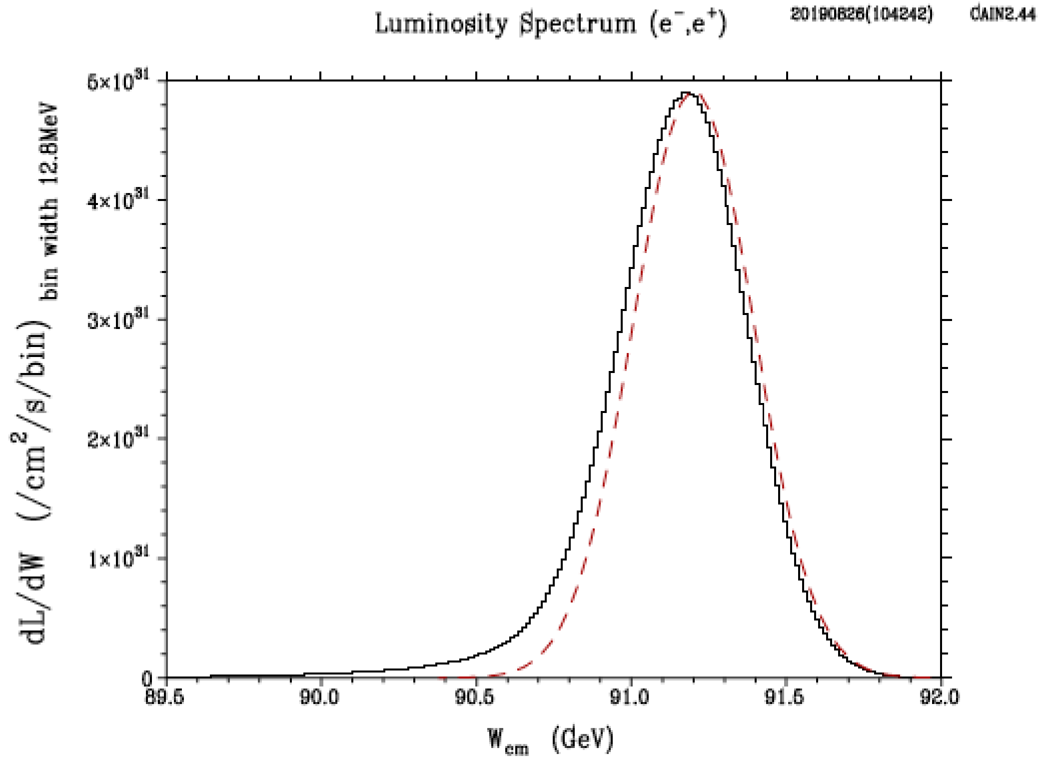


Figure 10: Luminosity spectrum. The red dashed curve shows the initial distribution normalized at the peak.