Status of the ILC
Accelerator Design

Barry Barish, Nick Walker
for the entire ILC machine community

2nd ILC Workshop – Snowmass, Colorado
26.08.2005
The Year After ‘Unification’

- 1st ILC workshop at KEK November 2005
- ILCSC forms 5 technical WG and 1 communications and outreach WG
  - WG1 Parameters & General Layout
  - WG2 Main Linac
  - WG3 Injectors
  - WG4 Beam Delivery & MDI
  - WG5 High gradient SCRF
  - WG6 Communications
The Year After ‘Unification’

Birth of the GDE and Preparation for Snowmass

- WG1 Parms & layout
- WG2 Linac
- WG3 Injectors
- WG4 Beam Delivery
- WG5 High Grad. SCRF
- WG6 Communications

• WG1 LET beam dynamics
• WG2 Main Linac
• WG3a Sources
• WG3b Damping Rings
• WG4 Beam Delivery
• WG5 SCRF Cavity Package
• WG6 Communications
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- WG3a Sources
- WG3b Damping Rings
- WG4 Beam Delivery
- WG5 SCRF Cavity Package
- WG6 Communications
- GG1 Parameters & Layout
- GG2 Instrumentation
- GG3 Operations & Reliability
- GG4 Cost Engineering
- GG5 Conventional Facilities
- GG6 Physics Options

Introduction of Global Groups transition workshop → project
2nd ILC Workshop (Snowmass)

Technical sub-system WG

- Provide input
- Global Group

<table>
<thead>
<tr>
<th>Technical sub-system</th>
<th>WG5 Cavity</th>
<th>WG4 BDS</th>
<th>WG3b DR</th>
<th>WG3a Sources</th>
<th>WG2 Main Linac</th>
<th>WG1 LET bdyn.</th>
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<tbody>
<tr>
<td>GG1 Parameters</td>
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<td>GG6 Physics Options</td>
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Goals of the 2\textsuperscript{nd} Workshop

- Continue process of making a recommendation on a Baseline Configuration
- Identify longer-term Alternative Configurations
- Identify necessary R\&D
  - For baseline
  - For alternatives
- Priorities for detector R\&D

This workshop has been a major step towards these milestones 😊
Baseline / Alternative: some definitions

• Primary GDE Goal:
  – Reference Design Report including costs end 2006

• Intermediate goal (follows from primary)
  – Definition of a Baseline Configuration by the end of 2005; this
    • will be designed to during 2006
    • will be the basis used for the cost estimate
    • will evolve into the machine we will build
Baseline / Alternative: some definitions

Baseline: a forward looking configuration which we are reasonably confident can achieve the required performance and can be used to give a reasonably accurate cost estimate by mid-end 2006 (→ RDR)
Baseline / Alternative: some definitions

**Alternate:** A technology or concept which may provide a significant cost reduction, increase in performance (or both), but which will not be mature enough to be considered baseline by mid-end 2006.

**Note:**
Alternatives will be part of the RDR. Alternatives are equally important.
Baseline Configuration Document

• Our ‘Deliverable’ by the end of 2005
• A structured electronic document
  – Documentation (reports, drawings etc)
  – Technical specs.
  – Parameter tables
  – …
• A ‘printable / readable’ summary document (~100 pages)
Structure of the BCD

Sub-system or component

- Overview
  - Options under consideration
    - Summary Justification of BC
- BCD choice
  - Description
    - Parameter Table(s)
  - Lattice files
  - Supporting documentation
- Alternative Choice(s)

here is a brief text insert describing the boundary conditions and basic requirements.

Summary-like overview for those who want to understand the choice and the why

Technical documentation of the baseline, for engineers and acc. phys. making studies towards RDR
Alternatives Sections

Note  ACD is part of the BCD
Towards the BCD
The Hard Questions

- Luminosity Parameters
  - one or two IRs
- RF Gradient
  - for 500 GeV
  - for 1 TeV
- Cavity Shape
- Damping ring location
- Damping ring concept
  - 3 km ring
  - 6 km ring
  - 17 km 'dogbone'
- Main linac tunnel configuration
  - single tunnel
  - two tunnel with access
  - two tunnel no access
- Positron source
  - conventional
    - undulator
    - Compton
- Need for e+ pre-DR
The Hard Questions

Critical choices: luminosity parameters & gradient
The Hard Questions

Many questions are interrelated and require input from several WG/GG groups.
Luminosity Parameters

- nominal 500 GeV luminosity: $2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- we want to design to a parameter ‘space’
- keep a range of options open
  - flexibility
  - risk mitigation
- current sets represent trade-offs between sub-systems
  - particularly Damping Ring ↔ Beam Delivery
## The Luminosity Plane 2×10^{34} cm^{-2}s^{-1}

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<thead>
<tr>
<th></th>
<th>nom</th>
<th>low N</th>
<th>lrg Y</th>
<th>low P</th>
<th>High L</th>
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<td>11</td>
<td>11</td>
<td>5.3</td>
<td>11</td>
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</table>

\(=5.6\times10^{34}\)
Parameter Trade-Offs

Linac
(relaxed within limits)

Damping Ring
(sources)

IR (IP)
Beam extraction
Example of Discussions

**Long RF Pulse**
H. Padamsee and W. Foster suggested

- Make beam pulse longer, say $\times 2$ (same charge $\Rightarrow$ half current)
- Can halve the number of modulator/klystron
  (long klystron pulse with same peak power, feed more cavities)
- RF system cost reduced
- Cryo cost increases (higher duty)
- Total cost decreases
- Biproduct: better for detector and MPS

Workshop allowed open discussion of new ideas and proposals
Gradient

• Baseline recommendation for cavity is standard TESLA 9-cell

• Alternatives (energy upgrade):
  – Low-loss,
  – Re-entrant
  – superstructure
## Gradient

<table>
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<th>Qualified gradient</th>
<th>Operational gradient</th>
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<td>initial</td>
<td>TESLA</td>
<td>35 MV/m</td>
<td>31.5 MV/m</td>
<td>10.6 Km</td>
<td>250 GeV</td>
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<td>upgrade</td>
<td>LL</td>
<td>40 MV/m</td>
<td>36.0 MV/m</td>
<td>+9.3 Km</td>
<td>500</td>
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</tbody>
</table>

* assuming 75% fill factor

Total length of one 500 GeV linac ≈ 20km
Gradient (WG5 Justification)

- Theoretical RF magnetic limit:
  - Tesla shape: 41 MV/m
  - LL, RE shape: 47 MV/m
- Present practical limit in multi-cell cavities -10%
  - TESLA shape: 37 MV/m
  - LL, RE shape: 42.3 MV/m
- Lower end of present fabrication scatter (σ = 5%)
  - TESLA shape: 35 MV/m
  - LL, RE shape: 40 MV/m
- Operations margin -10 %
  - TESLA shape: 31.5 MV/m
  - LL, RE shape: 36 MV/m
Cavity Fabrication
Improved Processing
(Electropolishing)

KEK / Nomura EP

DESY EP
Improved Cavity Shapes

| r_{irrb}  | [mm] | 35 | 30 | 33 | field flatness |
| K_{pc}    | [%]  | 1.9| 1.52| 1.8| max gradient (E limit) |
| E_{peak}/E_{acc} | - | 1.98 | 2.36 | 2.21 | max gradient (B limit) |
| B_{peak}/E_{acc} | [mT/(MV/m)] | 4.15 | 3.61 | 3.76 | stored energy |
| R/Q       | [Ω]  | 113.8| 133.7| 126.8| dissipation |
| G         | [Ω]  | 271 | 284 | 277 | dissipation (Cryo limit) |
| R/Q*G     | [Ω*Ω]| 30840| 37970| 35123| |

TTF 1992
LL 2002/2004
RE 2002
Cavity R&D

Fabrication from large grain or single-crystal Nb discs

May remove the need for electropolishing (↓ cost!)

$E_{\text{peak}}/E_{\text{acc}} = 2.072$

$H_{\text{peak}}/E_{\text{acc}} = 3.56 \text{ mT/MV/m}$

 Nb Discs

Fabrication from large grain or single-crystal Nb discs.

$E_{\text{peak}}/E_{\text{acc}} = 2.072$

$H_{\text{peak}}/E_{\text{acc}} = 3.56 \text{ mT/MV/m}$

May remove the need for electropolishing (↓ cost!)
Baseline Klystrons

Specification:
10MW MBK
1.5ms pulse
65% efficiency
Ideas for Improved RF sources

10 MW Sheet Beam Klystron (SBK)

Parameters similar to 10 MW MBK

5 MW Inductive Output Tube (IOT)

Low Voltage
10 MW MBK

Voltage e.g. 65 kV
Current 238A
More beams

Perhaps use a Direct Switch Modulator

Peak Output Power
Average Output Power
Beam Voltage
Beam Current
Current per Beam
Number of Beams
Frequency
1dB Bandwidth
Gain
Efficiency

SLAC

KEK
RF Distribution

Klystron power

Cavities (12)

circulator

TESLA TDR and XFEL solution (TTF)
Uses many circulators to protect klystron from reflected power (and isolate couplers)
RF Distribution

Klystron power

Two level division

Possible improvement

Cavities (12)

- Expensive circulators eliminated
- Fewer types of hybrid couplers
- Proper phasing causes reflections from pairs of cavities to be directed to loads
- Small increase risk to klystron
Modulators (115 kV, 135 A, 1.5 ms, 5 Hz)

Pulse Transformer Style

Operation: an array of capacitors is charged in parallel, discharged in series.

Will test full prototype in 2006
Damping Rings: Three variants

- **3km**
- **6km**
- **17 km ‘dogbone’**
Damping Rings

- Emittance Goals
  - 1 pm!

- Dynamic Aperture
  - lattice design
  - wiggler

- Instabilities (collective effects)
  - electron cloud
  - fast ion
  - ...

- Kicker Technology
  - higher $I_{av}$

- Circumference
  - smaller circumference
    - (faster kicker)

- Cost
  - bunch train compression
    - 300km → <20km

- Commissioning

26.08.2005 Nick Walker - 2nd ILC Workshop - Snowmass - Colorado
Damping Rings: Recommendation

• Not Yet!
• Systematic analysis of all rings being made
  – Dynamic aperture
  – Emittance performance (tolerances)
  – Electron cloud
  – Fast ion instability
  – …
• Positive R&D on fast kickers will allow smaller circumference than TESLA dogbone
• Recommendation to be made this Autumn
Positron Source

- **Undulator source**
  - Uses main electron beam (150-250 GeV)
  - Coupled operation 😞
  - Efficient source 😊
  - Relatively low neutron activation 😊
  - Polarisation 😊
  - WG3a recommendation for baseline
  - Will need ‘keep alive source’ due reliability issues

- **Laser Compton source**
  - Independent polarised source 😊
  - Relatively complex source
  - Multi-laser cavity system required
  - Damping ring stacking required
  - Large acceptance ring (for stacking) 😞
  - Needs R&D
  - WG3a recommended alternative.
  - Strong R&D programme needed

- **Conventional Source**
  - Single target solution exists
  - Close to (at?) limits 😞
  - Independent source 😊
  - Currently on-hold as a backup solution

Pre-damping ring **not** required 😊
# Risks & Concerns

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Conventional</th>
<th>Undulator</th>
<th>Compton</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>L-band warm structure 1ms operation</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>It is likely to be safe according to the calculation.</td>
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<tr>
<td>Target thermal damage</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>It can be relieved by multi-targets.</td>
</tr>
<tr>
<td>Target radiation damage</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>It can be controlled by periodic maintenance.</td>
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<tr>
<td>Thermal load to the capture section</td>
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<td>0</td>
<td>75kW/m acceptable?</td>
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<td>Damage or failure by fast ion instability in the undulator.</td>
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<td>0</td>
<td>Estimates look ok but more investigation needed</td>
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<td>Field quality of helical undulator</td>
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<td>0</td>
<td>Helical prototype. Can be solved with the planar undulator</td>
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<td>Positron Stacking in DR</td>
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<td>0</td>
<td>2</td>
<td>Need investigation</td>
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<tr>
<td>e beam stability in Compton Ring</td>
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<td>0</td>
<td>2</td>
<td>Need investigation</td>
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<tr>
<td>Vacuum pumping</td>
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<td>1</td>
<td>0</td>
<td>Needs vacuum specification to check if problem</td>
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<td>Stability of integration of optical cavities</td>
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<td>2</td>
<td>It is going to be demonstrated experimentally with 2 cavities.</td>
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<tr>
<td>Mechanical failure on the rotation target</td>
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<td>1</td>
<td>0</td>
<td>Need investigation/demonstration</td>
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<tr>
<td>Kicker difficulty</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>Undulator scheme need special care for the injection kicker.</td>
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</table>
Strawman solution (BCD recommendation)

Appears to work for nearly all suggested parameter sets:

Exceptions:

- 1 TeV high-luminosity (new parameter set suggested for 20mrad)
- 2 mrad extraction has problems with high disruption sets
Beam Delivery System

- Baseline recommendation
  - Two IRs (20mrad, 2mrad) + 2 detectors
  - Longitudinally separated halls
- Alternatives 1
  - Two IRs (20mrad, 2mrad) + 2 detectors with
    - No longitudinal separation
- Alternative 2
  - Single IR with push-pull capability for two detectors
    (cost favoured)
- 10-12mrad crossing angle also being considered
- zero-crossing angle being revisited
Conventional Facilities and Siting

Milestone One: Snowmass 2005 Conference
- Successfully Initiate the Global Civil and Siting Effort
- Complete Comparative Site Assessment Matrix Format

Milestone Two: December, 2005
- Identify Regional Sample Sites for Inclusion into the Baseline Configuration Document

Milestone Three: December, 2006
- Complete Conventional Facilities and Siting Portion of the Reference Design Document
Sample Site Study (1 of 10)

**Conventional Facilities Site Considerations**, 16 Aug. 2005

1. Site Impacts on Critical Science Parameters

*Description:* This sub-heading will evaluate site-specific factors that affect critical science parameters.

*Consideration:* The site should permit the highest level of research productivity and overall effectiveness at a reasonable cost of construction and operation and with a minimal impact on the environment.

1A. Configuration (Physical Dimensions and Layout)

The topography and geology of a site strongly influences machine configuration, tunnel alignment, tunnel depth, tunnel access and penetrations as well as the flexibility for design optimization options.

1B. Performance (Vibration and Stability)

Micro-seismic ground motion and cultural noise (man-made vibrations) may affect the operations of the beamline apparatus. To minimize impact upon beam position, the ILC beam line should be oriented to minimize ground waves at a given site. A quiet site which has low levels of micro-seismicity and cultural noise will avoid the need for passive or active damping systems to achieve required stability during operation.
Conventional Facilities and Siting

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Conventional Facilities and Siting

Outstanding Issues with Direct Impact on CFS Progress that will Require Further Discussion and Resolution with Other Working Groups

- 1 Tunnel vs 2 Tunnel
- Laser Straight vs Curved or Segmented
- Shape and Length of Damping Rings
- Shape and Configuration of Sources
- 1 vs 2 Interaction Regions

5 of our 10 critical design questions
May well be influenced by site constraints

GDE ILC Design will be done to samples sites in the three regions
North American sample site will be near Fermilab
Japan and Europe are to determine sample sites by the end of 2005
1 or 2 Linac Tunnels

- Tunnel must contain
  - Linac Cryomodule
  - RF system
  - Damping Ring Lines (dogbone case)

- Potential cost saving

- Issues
  - Maintenance
  - Safety
  - Duty Cycle
  - Availability/Commissioning (studies currently favour 2)
Reliability studies favour 2 tunnel solution
(recommendation from WG2/GG3 based on these studies)
Possible Tunnel Configurations

• One tunnel or two, with variants?
ILC Civil Program

Civil engineers from all three regions working to develop methods of analyzing the siting issues and comparing sites.

The current effort is not intended to select a potential site, but rather to understand from the beginning how the features of sites will effect the design, performance and cost.
Discussions on SCRF Test Facilities

• Regional test facilities are needed to enhance the technology base and enable each region to significantly participate in ILC Main Linac and be a possible host of ILC.

• The three regions are working towards developing collaborations on how to build regional test facilities.
  – TTF Facility (DESY) established facility, 30% allocated to ILC
  – ILC Test Facility (Fermilab)
  – STF (KEK)

• International collaborative activities are progressing on
  – Cavity fabrication, processing and testing to achieve 35 MV/m at Q ~0.5-1 e10.
  – Design and fabrication of ILC Cryomodule
  – LLRF development for ILC
  – Development and processing of Couplers
  – Industrial development of the Main Linac components
Running out of time…. 

- Main accelerator beam dynamics (WG1)
- Bunch Compression (WG1)
  - Recommendation: 2 stage preferred
    (6mm → 150μm or 9mm → 300μm)
- Instrumentation (GG2)
  - BPMs, wire scanners (laser-wire), MPS issues, etc.
- Machine Protection System (GG3+GG2+WG1)
  - Very high risk (US LC options study)
- Operations, reliability, commissioning (GG3)
  - Major issue for complex machine
- Cost & Engineering (GG4)
  - Cost is everything!
- Much much more…. 

An incredible amount of work has been done/presented at this workshop!
Himel’s List

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<tr>
<th>Rank</th>
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<th>E</th>
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<td>is there an e+ pre damping ring</td>
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<td>3</td>
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<td>9</td>
<td>DR location: 1st half tunnel, 2nd half, ceiling, under cryomodules, separate tunnel</td>
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<td>2</td>
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<td>How much is a 1% change in average luminosity worth?</td>
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<td>2</td>
<td>0</td>
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40 critical BCD questions assembled by Tom Himel have effectively been answered. List can be found on the web.
Transition to the GDE
Transition to the GDE

• Three regional directors have identified GDE members (with agreement from BB)
• 49 (current) members representing approximately 20 FTE
• GDE group consists of
  – core accelerator physics experts
  – 3 CFS experts (1 per region)
  – 3 costing engineers (1 per region)
  – 3 communicators (1 per region)
  – representatives from WWS
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<thead>
<tr>
<th>Name</th>
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<tr>
<td>Chris Adolphsen</td>
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<td>Tohoku Univ</td>
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49 members

* workshop WG/GG convener
Towards a final BCD

- **August:**
  - WW/GG summaries + broader input

- **September:**
  - Response to Himel list (40 questions)
  - all documented ‘recommendations’ publicly available on www (request community feedback)

- **October:**
  - review by BCD EC

- **November:**
  - BCD EC publishes ‘strawman’ BCD

- **December:**
  - public review

**BCD Executive Committee (EC):**
- Barish
- Dugan, Foster, Takasaki (regional directors)
- Raubenheimer, Yokoya, Walker (gang of three)

**Frascati GDE meeting**
BCD review process

- BCD Executive Committee (EC) will monitor BCD progress
  - Review WG/GG summary write-ups (recommendations)
  - Review each question on the Himel list
- BCD EC will identify needed additional input
  - additional (missing) expertise (members) of the GDE
- Strawman BCD available mid-November (web)
- Presentation of strawman BCD at Frascati GDE meeting (Dec. 7-10)
- Final agreed BCD to be documented
- Final BCD becomes property of 'Change Control Board'
  end 2005 / beginning 2006

... and then the real hard work starts 😊
Final Comments

• A great deal of work has been accomplished this workshop
  – big thanks to all the WG/GG conveners and participants
• We are close to having the necessary recommendations for the BCD
  – Still many ‘details’ to be worked out
• We must keep up this momentum until the GDE Frascati meeting
  – publication of the BCD will be the GDE’s first real milestone
• The GDE must start to plan for the hard work of preparing the Reference Design Report (RDR), due the end of 2006.
Final Comments (cont.)

- The ILC project has attracted many of the best accelerator engineers and physicists in the world!

- Let us all (continue to) work together on this great adventure.

Thank you for your attention.