# International Linear Collider Technology: Status and Challenges

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# Outline

- International View
- Performance Parameters and Layouts
- Technology Requirements and Challenges
- Fermilab View
- Fermilab Plans $\Rightarrow$ Shekhar

# International Linear Collider View

- An internationally constructed and operated electron-positron linear collider, with an initial center-of-mass energy of 500 GeV, has received strong endorsement by advisory committees in North America, Europe, and Asia as the next large High Energy Physics facility beyond LHC.

- An international panel, under the auspices of ICFA, has established performance goals (next slide) as meeting the needs of the world HEP community. The performance document is available at:

  http://www.fnal.gov/directorate/icfa/LC_parameters.pdf

- The International Technology Recommendation Panel has recommended, and ICFA has accepted the recommendation, that the linear collider design be based on superconducting rf technology.

# International Performance Specification

- Initial maximum energy of **500 GeV**, operable over the range 200-500 GeV for physics running.
- Equivalent (scaled by 500 GeV/$\sqrt{s}$) integrated luminosity for the first four years after commissioning of **500 fb$^{-1}$**.
- Ability to perform energy scans with minimal changeover times.
- Beam energy stability and precision of 0.1%.
- Capability of **80%** electron beam **polarization** over the range 200-500 GeV.
- **Two interaction regions**, at least one of which allows for a crossing angle enabling $\gamma\gamma$ collisions.
- Ability to operate at **90 GeV** for calibration running.
- Machine upgradeable to approximately **1 TeV**.

# International Linear Collider (ILC)

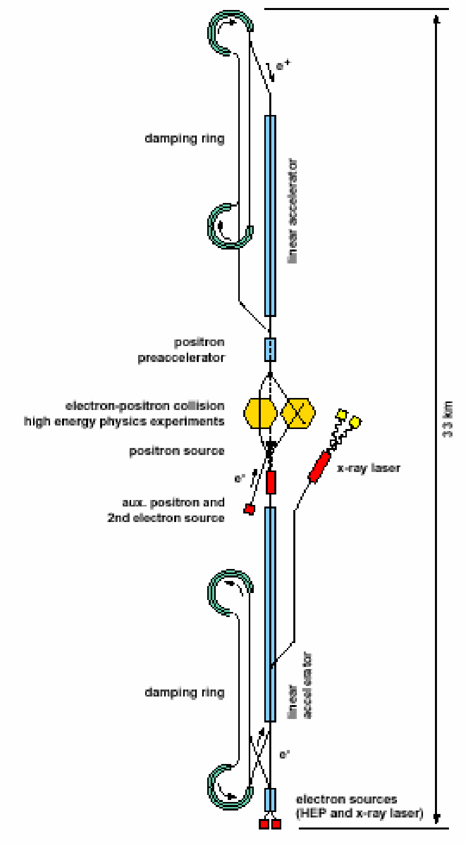
## Physical Layouts and Configurations

Two concepts developed to date:

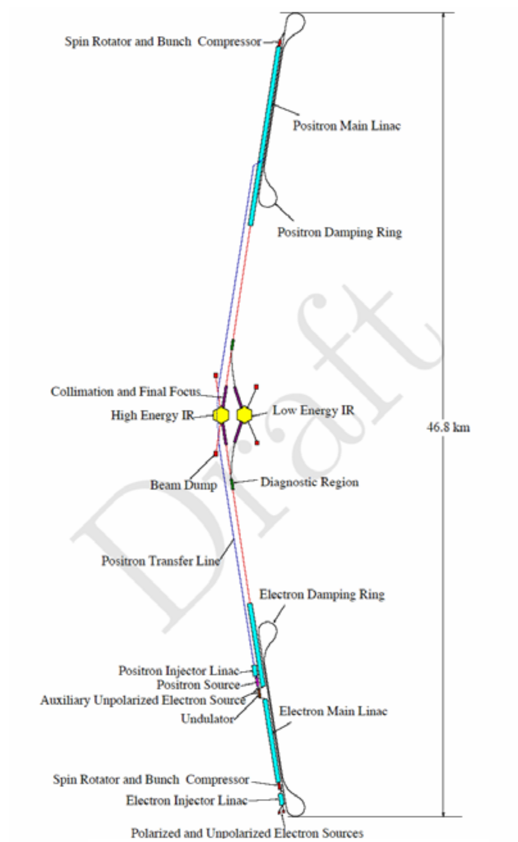
- TESLA TDR
- USLCSG Study

Possible considerations:

- Energy/luminosity tradeoffs at "500" GeV
- Undulator vs. conventional e+ source
- Upgrade energy
- Head on vs. crossing angle IR
- Upgrade injector requirements
- One vs two tunnels




TESLA TDR




USLCSG Study

# ILC Performance Parameters

| | TESLA/TRC | | U.S. Study | | | |
|---|---|---|---|---|---|---|
| Center of Mass Energy | 500 | 800 | 500 | 1000 | | GeV |
| Design Luminosity | 34 | 58 | 26 | 38 | | $10^{33}cm^{-2}sec^{-1}$ |
| | | | | | | |
| Linac rf frequency | 1.3 | | 1.3 | | | GHz |
| Unloaded/loaded gradient | 24/24 | 35/35 | 28/28 | 35/35 | | MV/m |
| Pulse repetition rate | 5 | 4 | 5 | | | Hz |
| Bunches/pulse | 2820 | 4886 | 2820 | | | |
| Bunch separation | 337 | 176 | 337 | | | nsec |
| Particles/bunch | 2 | 1.4 | 2 | | | $x10^{10}$ |
| Bunch train length | 950 | 860 | 950 | | | $\mu$sec |
| Beam power | 11 | 18 | 11 | 23 | | MW/beam |
| | | | | | | |
| $\gamma\varepsilon_H/\gamma\varepsilon_V$ at IP | 10/.03 | 8/.015 | 9.6/.04 | | | mm-mrad |
| $\sigma_x/\sigma_y$ at IP (before pinch) | 554/5 | 392/3 | 543/6 | 489/4 | | nm |
| | | | | | | |
| Site AC power | 140 | 200 | 180 | 356 | | MW |
| Site length | 33 | | 46 | | | km |
| Tunnel configuration | Single | | Double | | | |

Note: Injector upgrade not required for 1 TeV in U.S. study.

# ILC Requirements and Challenges
## Energy: 500 GeV, upgradeable to 1000 GeV

- RF Structures
  - The accelerating structures must support the desired gradient in an operational setting and there must be a cost effective means of fabrication.
    - 24-35 MV/m × 20 km
    - ~21,000 accelerating cavities/500 GeV

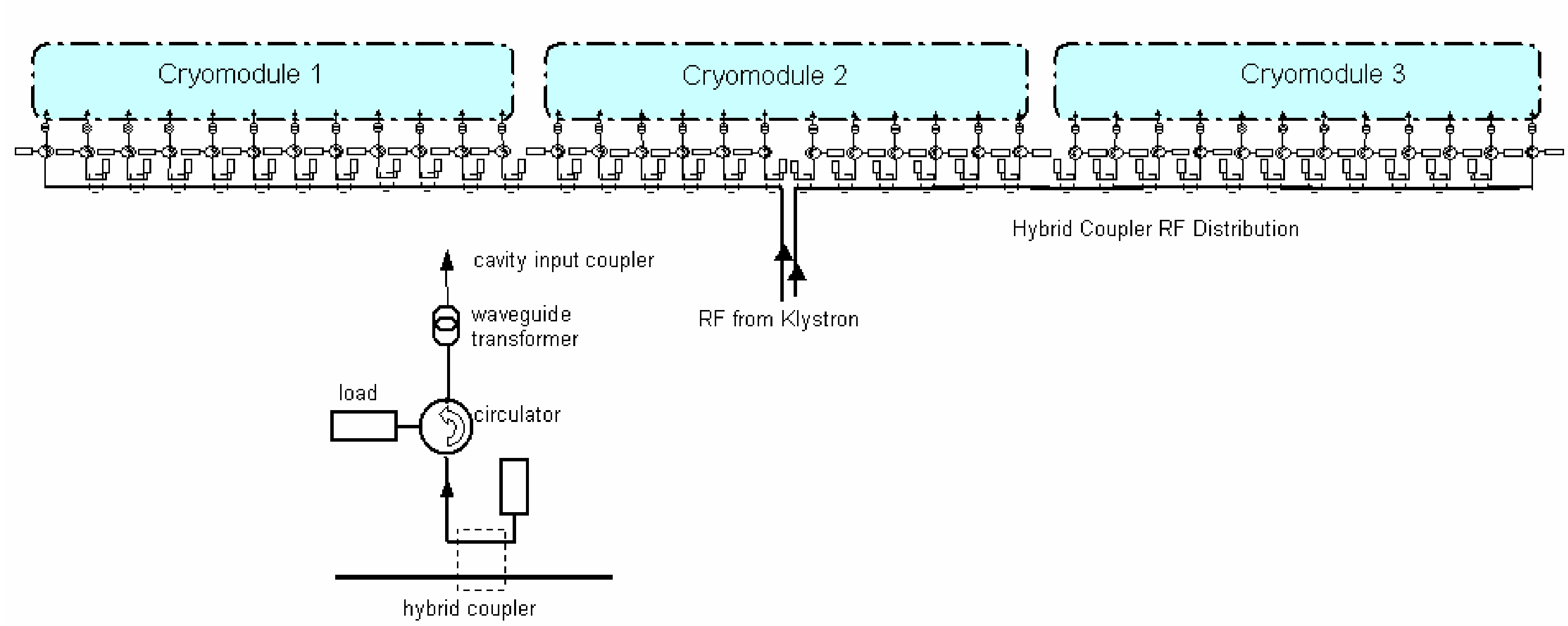
- RF power generation and delivery
  - The rf generation and distribution system must be capable of delivering the power required to sustain the design gradient
    - 10 MW × 5 Hz × 1.5 msec
    - ~600 klystrons and modulators/500 GeV
  - The rf distribution system is relatively simple, with each klystron powering 30-36 cavities.

⇒ Demonstration projects: TTF-I and II; SMTF in conceptualization phase

# ILC Requirements and Challenges

## Energy

**Linac RF Unit (TESLA TDR):** 10MW klystron, 3 modules × 12 cavities each

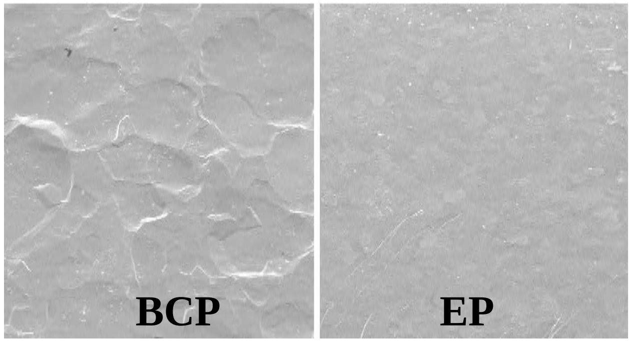



Total for 500 GeV: 584 units (includes 2% reserve for failure handling)

# ILC Technology Status

## Accelerating Structures

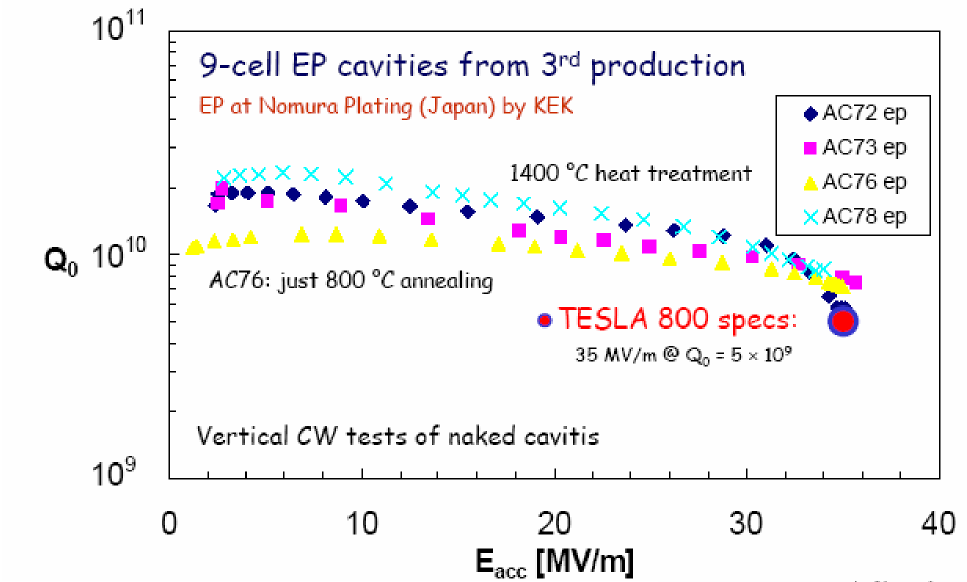
- The structure proposed for 500 GeV operation requires 24-28 MV/m.
  - 24 MV/m achieved in 1999-2000 TTF cavity production run
  - 13,000 hours operation in TTF (Two 8-cell cryomodules @ ~16 MV/m)
- The goal is to develop cavities capable of 35 MV/m for the energy upgrade to 800-1000 GeV (but installed in ILC phase 1).
- Progress over the last several years has been in the area of surface processing and quality control.
  - Multiple heat treatments
  - Buffered chemical polishing
  - Electro-polishing
  - Several single cell cavities at 40 MV/m
  - Five nine-cell cavities at >35 MV/m




- Dark current criteria established based on <10% increase in heat load
  - 50 nA/cavity

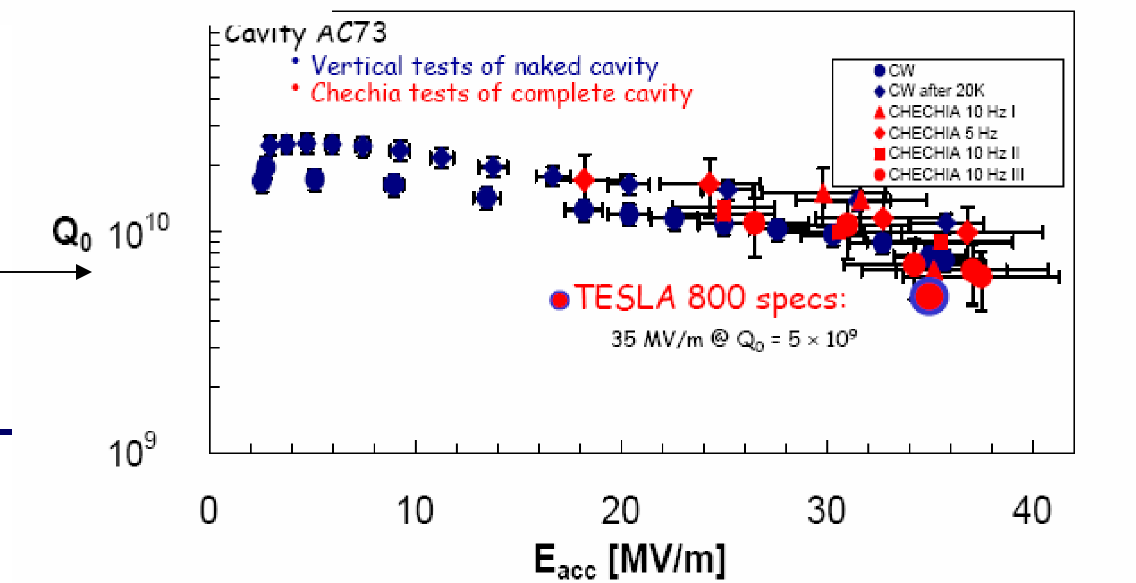
# ILC Technology Status

## Accelerating Structures




Vertical (low power test)

Comparison of low and high power tests (AC73)

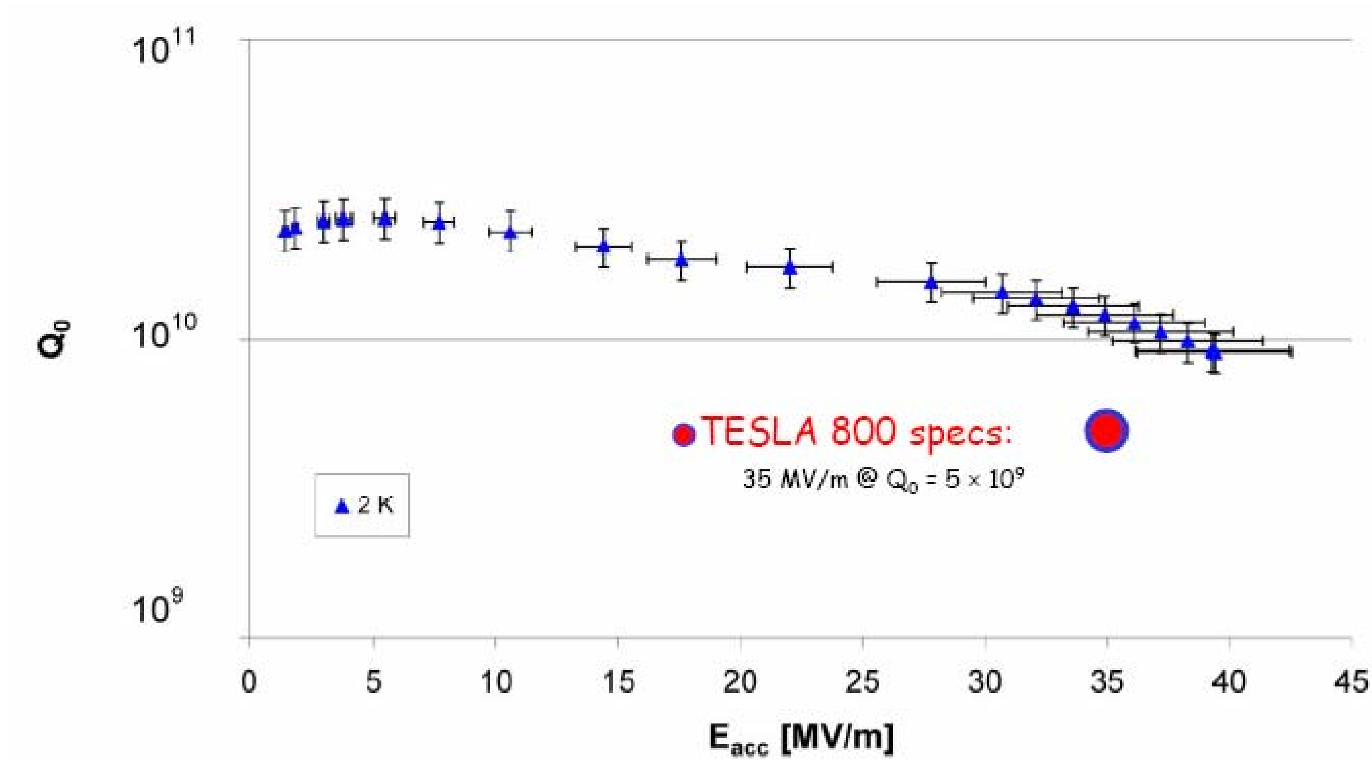


# ILC Technology Status

## Accelerating Structures

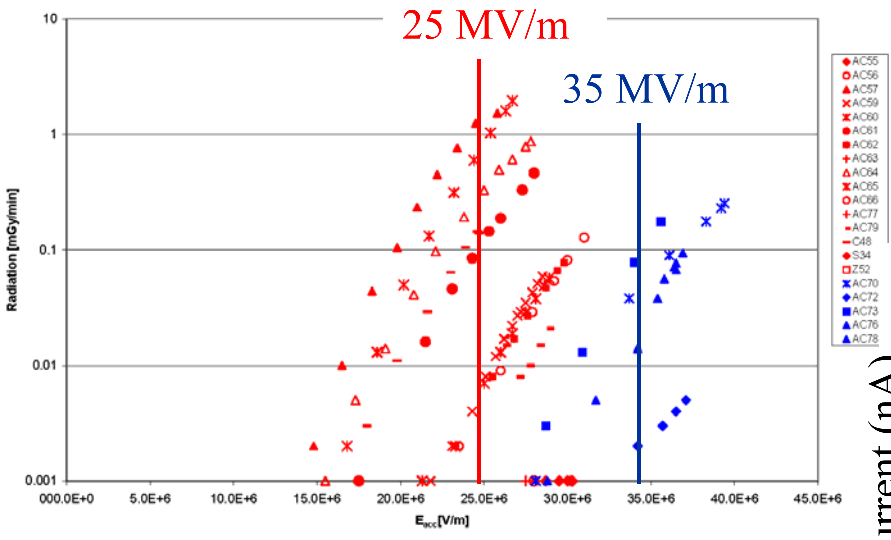
Recent results from AC70

– First cavity processed in DESY EP facility

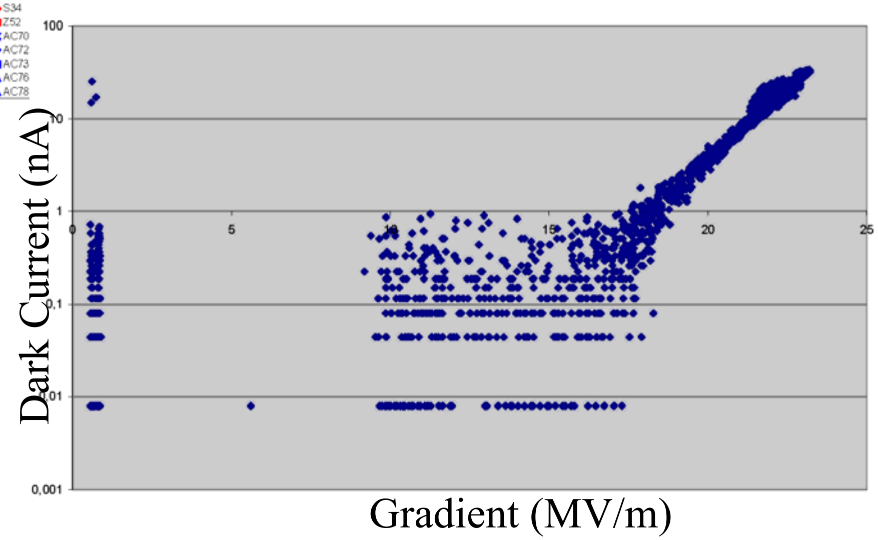


# ILC Technology Status

## Accelerating Structures: Dark Current



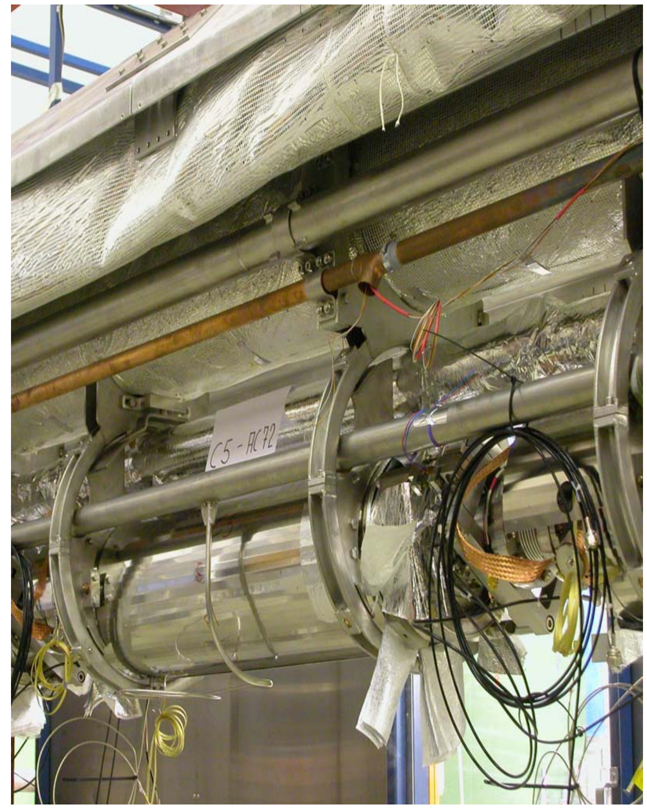

Radiation emissions of BCP and EP cavities (vertical test stand). ⇒Note: EP cavities exhibit lower emissions at 35 MV/m than do BCP at 25 MV/m.




Dark Current measurement on 8-cavity CM (ACC4)
~15 nA/cavity at 25 MV/m

# ILC Technology Status
## Accelerating Structures

- One electropolished cavity (AC72) installed into cryomodule ACC1 in TTF-II (March)
- Cavity individually tested in the accelerator with high power rf.
- Result: 35 MV/m
  - Calibrated with beam and spectrometer
  - No field emission detected
  - Good results with LLRF and piezo-tuner



# ILC Technology Status
## RF Sources

- Three Thales TH1801 Multi-beam klystrons fabricated and tested.
  - Efficiency = 65%
  - Pulse width = 1.5 msec
  - Peak power = 10 MW
  - Repetition rate = 5 Hz
  - Operational hours (at full spec) = 500 hours
  - Operational hours (<full spec) = 4500 hours

- Independent MBK R&D efforts now underway at CPI and Toshiba
- 10 Modulators have been built
  - 3 by FNAL and 7 by industry
  - 7 modulators are in operation
  - Based on FNAL design
  - 10 years operation experience

# ILC Requirements and Challenges

## Luminosity: 500 fb$^{-1}$ in the first four years of operation

- The specified beam densities must be produced within the injector system, preserved through the linac, and maintained in collision at the IR.

$$L = \frac{f_{rep} n_b N^2}{4\pi\sigma_x\sigma_y} H_D = \frac{P_b N}{4\pi\sigma_x\sigma_y E_{CM}} H_D$$

$$\delta_b \propto \frac{\gamma N^2}{\sigma_x^2 \sigma_z} \Rightarrow L \propto \frac{P_b}{E_{CM}} \sqrt{\frac{\delta_b}{\varepsilon_y}} H_D$$

Note critical role of $\varepsilon_y$ ($\delta_b$=3-5%)

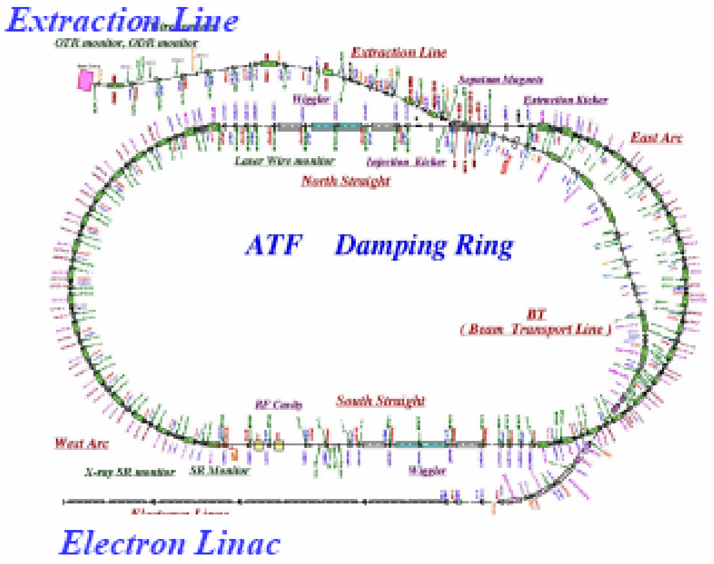
- Sources
  - 80% e- polarization
  - ~1e+/e-; polarized?
- Damping Rings
  - $\varepsilon_x/\varepsilon_y$ = 8.0/.02 μm
- Emittance preservation
  - Budget: 1.2 (horizontal), × 2 (vertical)
- Maintaining beams in collision
  - $\sigma_x/\sigma_y$ = 540/6 nm

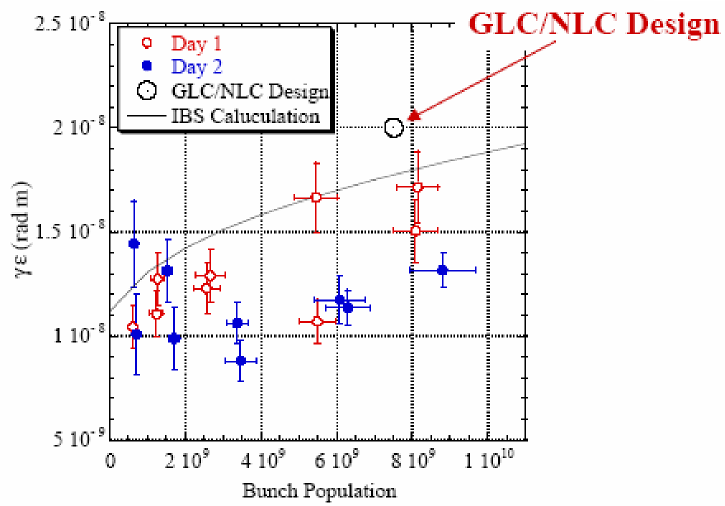
⇒ Demonstration Project: ATF

# ILC Technology Status

## Damping Rings

- The required emittances, $\varepsilon_x/\varepsilon_y = 8.0/.02\ \mu m$, have been achieved in the ATF at KEK




- Performance is consistent with IBS, however,
  - Single bunch, $e^-$
  - Circumference = 138 m

# ILC Technology Status
## Damping Rings

- The total length of the ILC beam pulse is:

  $2820 \times 337$ nsec = 950 μsec = 285 km.

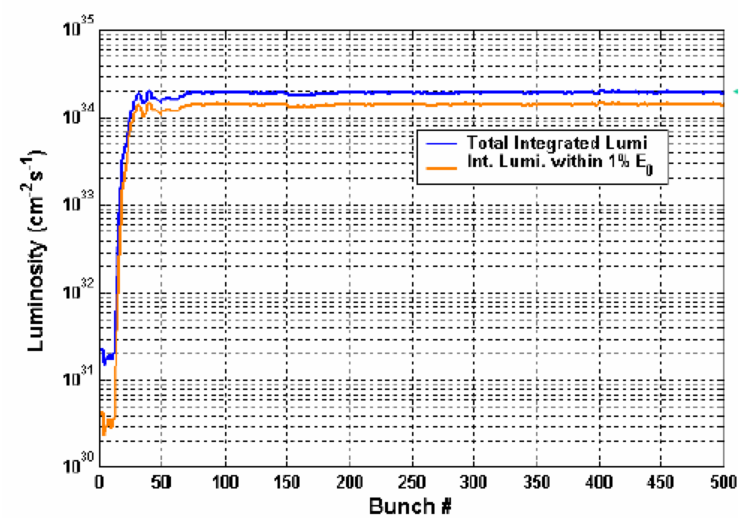
- This creates many unique challenges in the ILC damping ring design:
  - Multiplexing the beam (×16 in the TELSA TDR)
    - Requires fast (~20 nsec rise/fall time kicker for single bunch extraction)
  - Circumference is still ~285/16 = 18 km
    - Space-charge is an issue because of the large $C/\varepsilon_y$ (a first for an electron storage ring).
    - X/Y "transformer" used to mitigate.

- A number of ideas exist for reducing the circumference and associated challenges (see Shekhar).

# ILC Technology Status

## Emittance Preservation

- Emittance growth budget from DR to IR is:
  - ×1.2 (horizontal), × 2.0 (vertical)
- Sources of emittance growth include:
  - Wakes
    - Single bunch controlled by BNS damping
    - Multibunch controlled by HOM dampers and tune spread
  - Alignment and jitter
    - Vertical dispersion × momentum spread = emittance growth
    - Controlled by alignment and correction algorithms (feedback)
    - Alignment tolerances ~300 μm, 300 μrad; BPM resolution ~10 μm
- Maintaining beams in collision
  - Intra-train feedback



# Linear Collider Technology Status

## Examples of Outstanding Issues

- RF Structures and Source
  - Establish gradient goal
  - Develop US capability for fabricating high gradient cavities
  - Coupler design
  - Controls/LLRF
  - Industrialization
- Particle Sources
  - Conventional e+
- Damping Rings
  - New design concepts to reduce circumference
- Emittance Preservation
  - Alignment of structures inside cryomodules
  - Instrumentation and feedback systems
- Maintaining Beams in Collision
  - Feedback
  - Head-on IR?
- Civil
  - 1 tunnel vs. 2
  - Near surface vs. deep

# Fermilab Viewpoint

- We have been investing roughly $2.5 M each in X-band and SCRF technologies over the last several years. By consolidating we can double the investment in ILC in FY2005.
- Need to double again in ’06 and ’07 to support the program Shekhar will outline.
- We have assembled a team that can be immediately redirected to support the SCRF work.
- We stated before the ITRP that “In the event of a cold decision Fermilab would be ready and able to assume the leadership role in establishing a U.S. collaboration to push the SCRF development under the aegis of an international LC organization.”

**We have a responsibility to follow through on this commitment and this is what we have started to do.**