Technologies for Electron-Positron Linear Colliders

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Outline

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- Status of critical technologies/energy
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- Status of critical technologies/luminosity
  - Damping Rings
- Variants as described in the U.S. warm/cold study
- CLIC
- Conclusions

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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

- An International Technology Recommendation Panel has now been convened under the auspices of ICFA with a charge to issue a technology recommendation by the end of 2004.

International Performance Specification

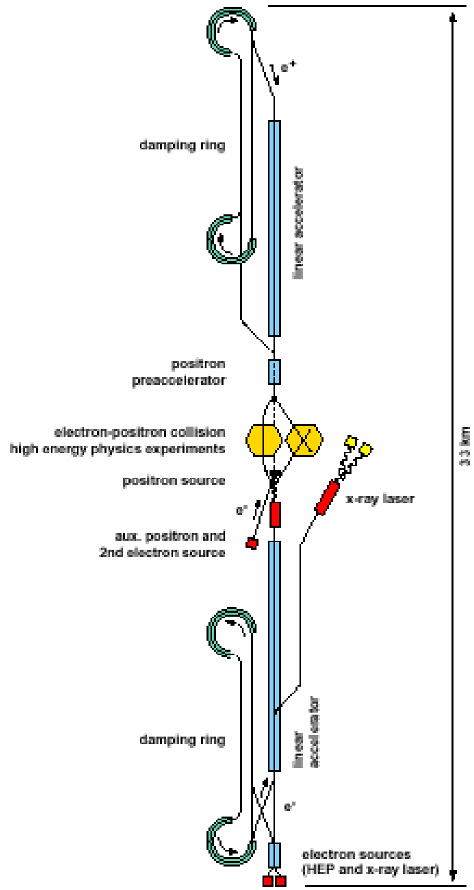
- Initial maximum energy of **500 GeV**, operable over the range 200-500 GeV for physics running.
- Equivalent (scaled by 500 GeV/$\sqrt{s}$) integrated luminosity for the first four years after commissioning of **500 fb^{-1}**.
- Ability to perform energy scans with minimal changeover times.
- Beam 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**.

Performance Parameters (TRC)

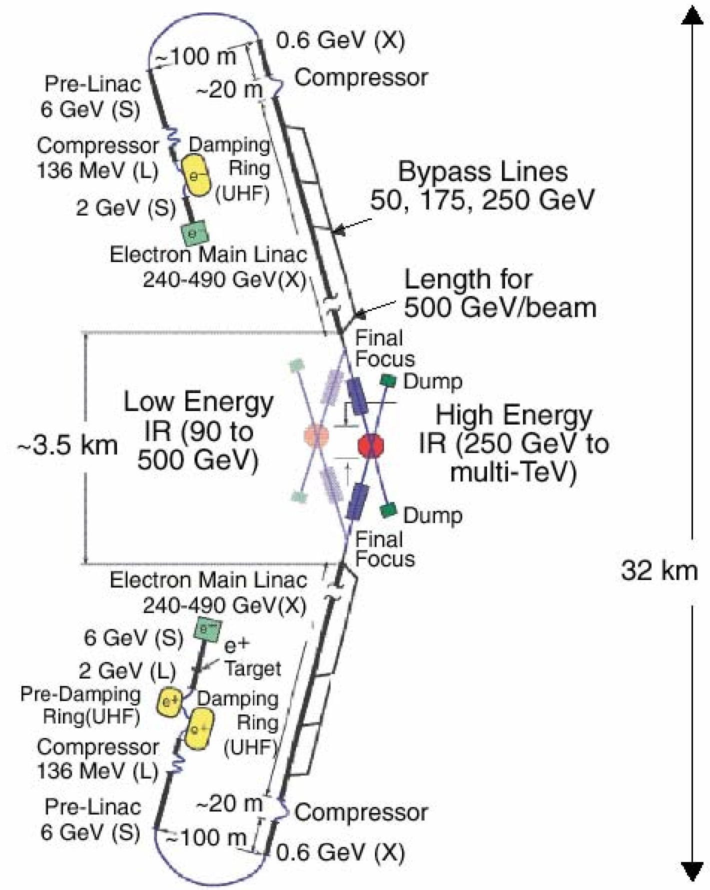
	TESLA		JLC-X/NLC		JLC-C		CLIC			
Center of Mass Energy	500	800	500	1000	500	1000	500	3000		GeV
Design Luminosity	34	58	20	30	14	25	21	81		$10^{33}cm^{-2}sec^{-1}$
Linac rf frequency	1.3		11.4		5.7	11.4*	30			GHz
Unloaded/loaded gradient	24/24	35/35	65/50		42/32	70/55	172/150			MV/m
Pulse repetition rate	5	4	120		100		200	100		Hz
Bunches/pulse	2820	4886	192		192		154			
Bunch separation	337	176	1.4		1.4		0.67			nsec
Particles/bunch	2	1.4	0.75		0.75		0.4			$x10^{10}$
Bunch train length	950	860	0.27		0.27		0.1			μsec
Beam power	11	18	7	14	6	12	5	15		MW/beam
$\gamma\varepsilon_H/\gamma\varepsilon_V$ at IP	10/.03	8/.015	3.6/.04		3.6/.04		2/.01	.7/.01		mm-mrad
σ_x/σ_y at IP (before pinch)	554/5	392/3	243/3	219/2	243/4	219/2	202/1	60/1		nm
Site AC power	140	200	195	350	233	300	175	410		MW
Site length	33		32		33		10	33		km
Tunnel configuration	Single		Double		Double		Single			

*JLC-C utilizes c-band for first 200 GeV, x-band for following 300 GeV of each linac

Current Round (ITRP) Contenders



TESLA



JLC-X/NLC

Linear Collider Performance Parameters
Technical Requirements

- 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.
      - TESLA: 24-35 MV/m
      - NLC/GLC: 65 MV/m (unloaded, 52 MV/m loaded)
  - RF power generation and delivery
    - The rf generation and distribution system must be capable of delivering the power required to sustain the design gradient

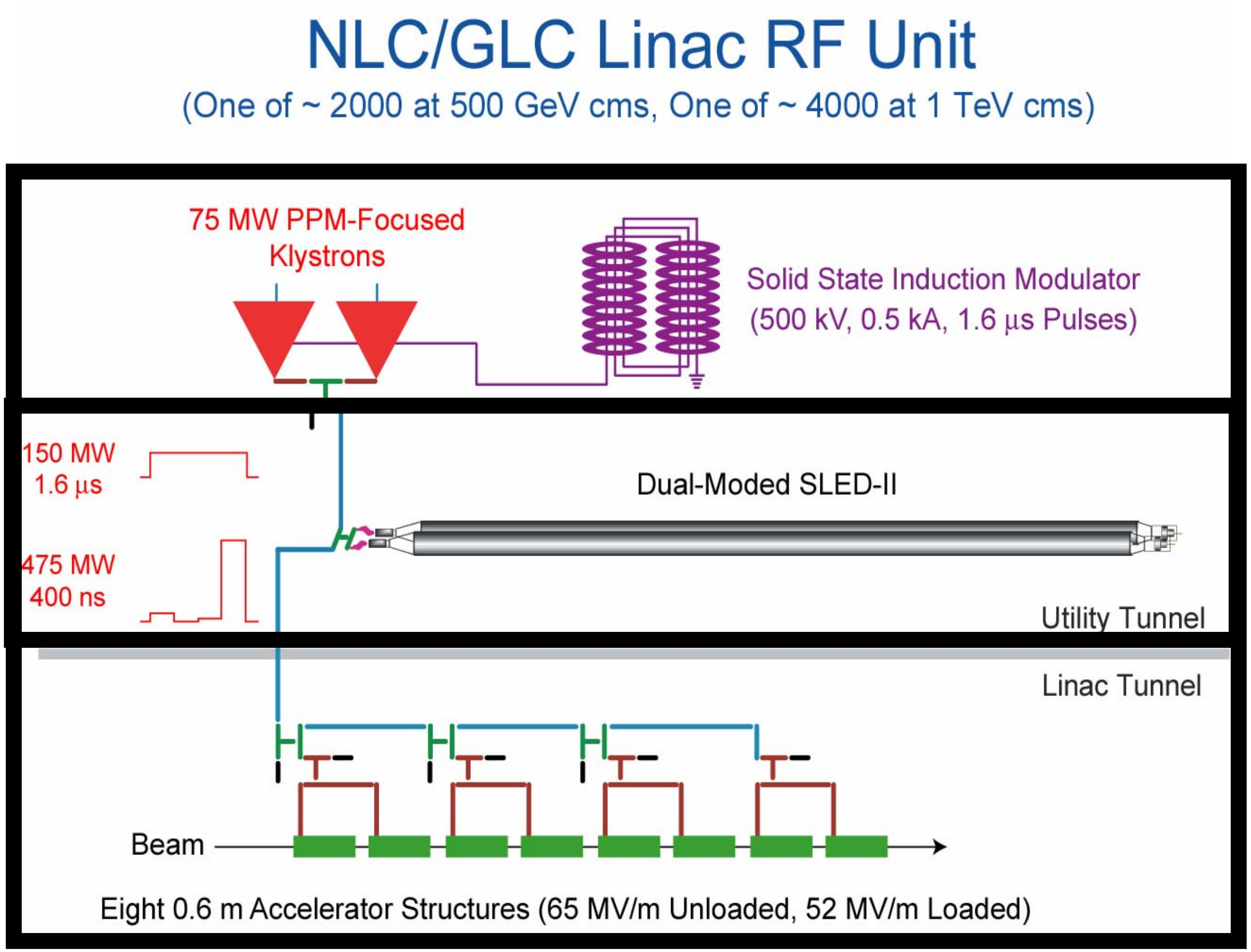
  ⇒ Demonstration projects: NLC 8-pack test, NLCTA, TTF-I and II

- 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.

  ⇒ R&D Facilities: ATF, ASSET

Linear Collider Technology Status

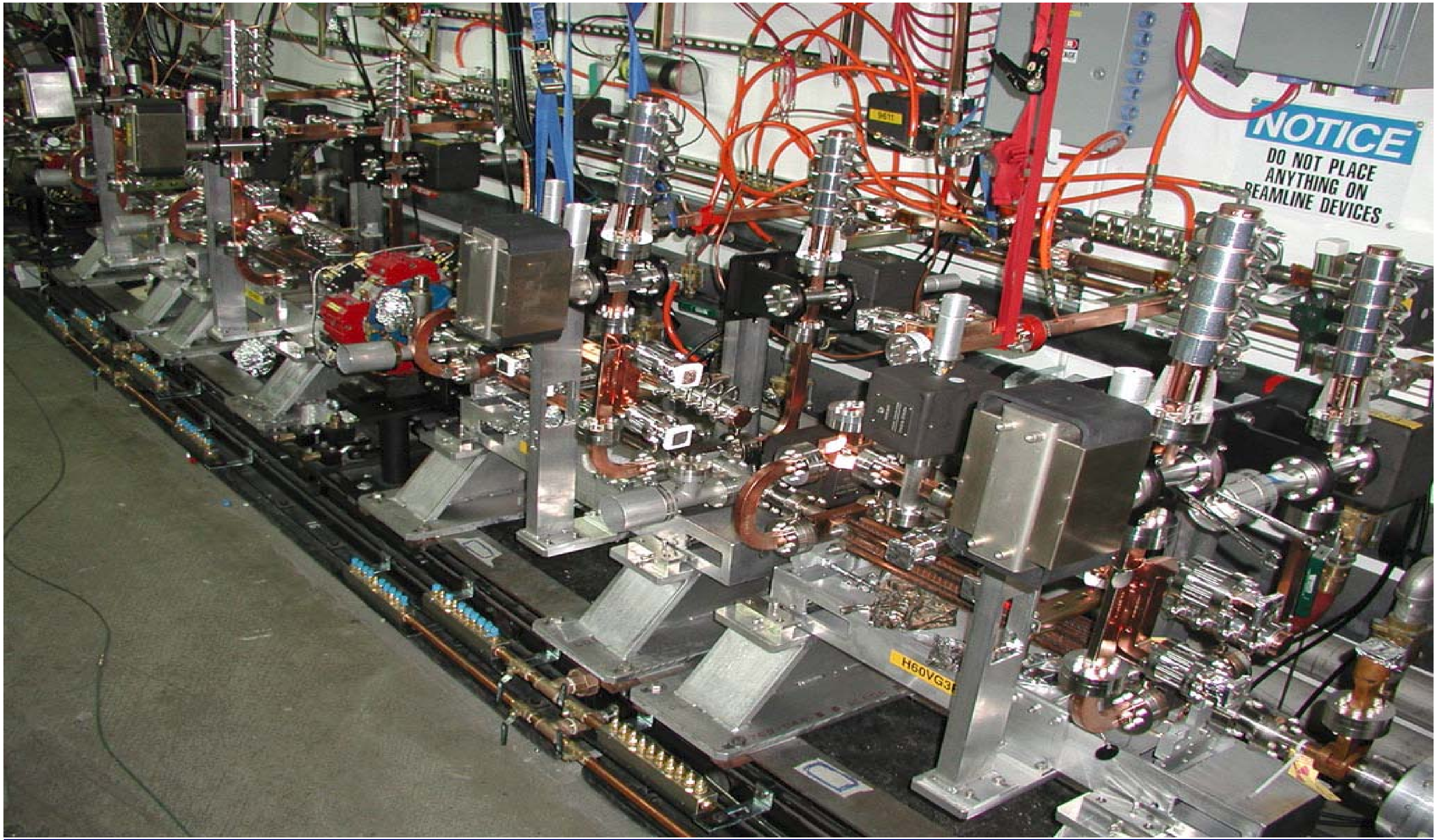
NLC/GLC Structures



Linear Collider Technology Status
NLC/GLC Structures

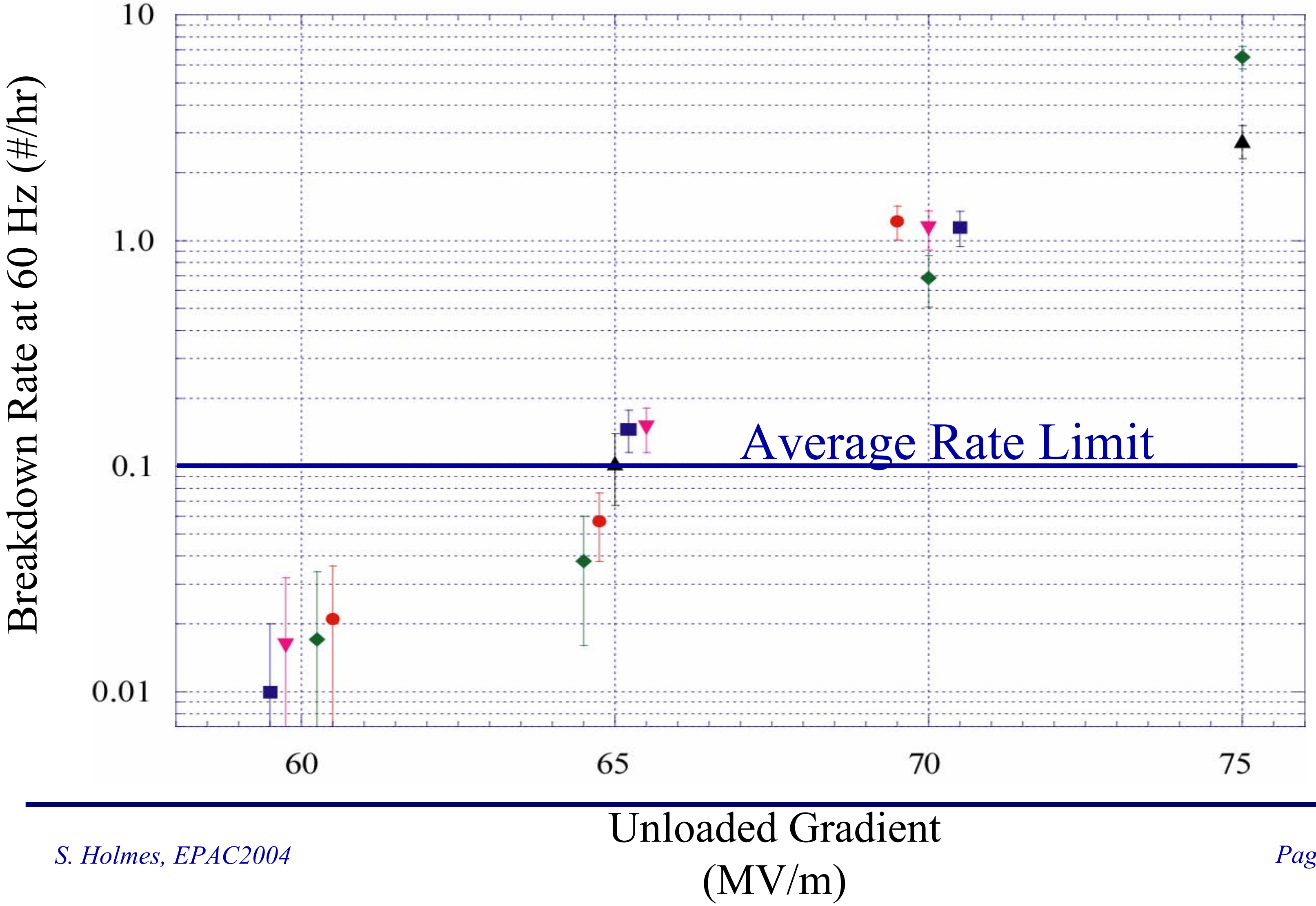
- The NLC/GLC structure has evolved over the last several years in response to difficulties encountered with structure damage after several thousand hours of operations.
  – Length = 60 cm
  – Group velocity = 3%
  – New input couplers lowering peak fields
- The resultant structure features:
  – Less stored energy, reduced ability for energy to flow within the cavity, and lower peak fields at the upstream end
- Operational criterion for breakdown rate is based on:
  – 99% availability with a 5 second recovery time (with 2% energy overhead)
  $\Rightarrow$ <1 breakdown/structure/10 hours when operated at 60 Hz and the full (400 nsec) rf pulse width
- 8 structures operating at NLCTA meet the gradient/breakdown spec

Linear Collider Technology Status
NLC Test Accelerator (NLCTA)



Linear Collider Technology Status

NLC/GLC Structures Performance (circa April 2004)



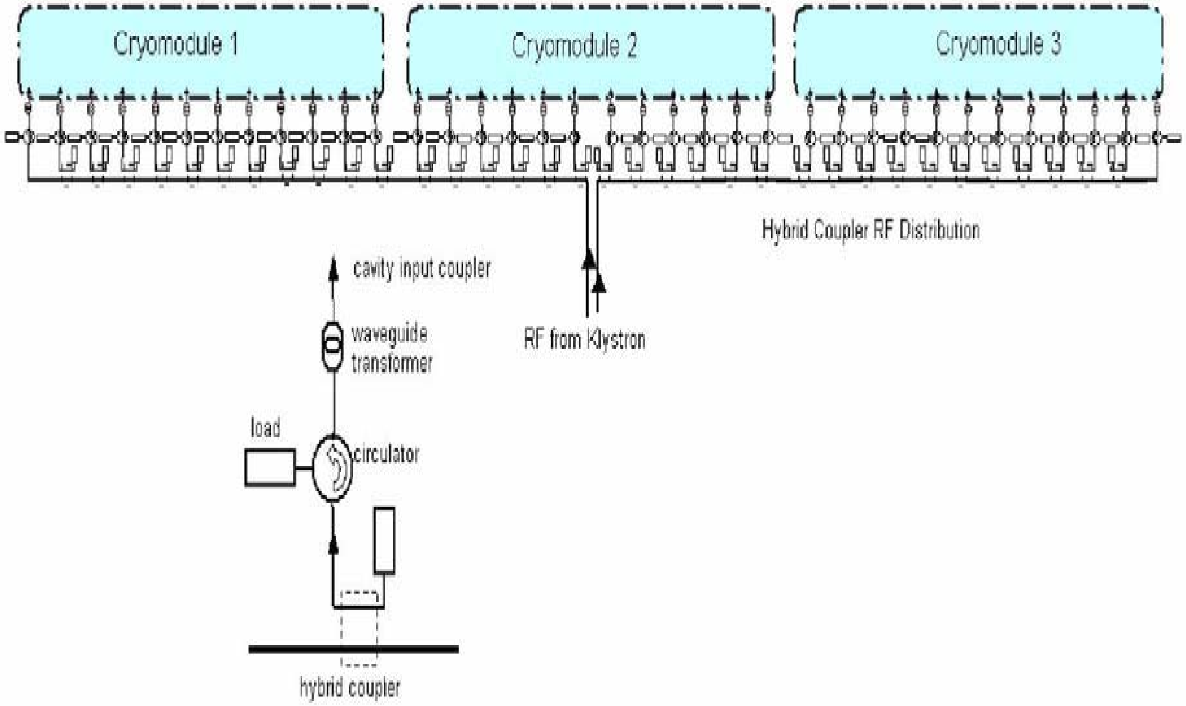
Linear Collider Technology Status

NLC/GLC Structures Performance (most recent 150 hours)

Structure	Manufacturer	Gradient (MV/m)	Trip Rate (#/hr)
H60vg4S17-FXD1A	FNAL	65.4	0.18
H60vg3S17-FXC5	FNAL	64.5	0.10
H60vg4S17-3	KEK/SLAC	65.4	0.04
H60vg3S17-FXC3	FNAL	64.5	0.04
H60vg3-FXB6	FNAL	64.8	0.00
H60vg3-FXB7	FNAL	66.7	0.19
H60vg4S17-1	KEK/SLAC	63.2	0.10
H60vg3R17	SLAC	64.8	0.04
Average (20-June-04)		64.9	0.085
Average One Month Ago		64.9	0.163

Linear Collider Technology Status
TESLA Structures

TESLA Linac RF Unit: 10MW klystron, 3 modules × 12 cavities each

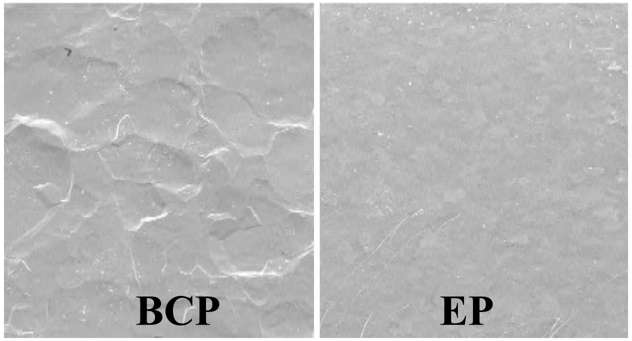


Total for 500 GeV: 572 units (includes 2% reserve for failure handling)

Linear Collider Technology Status

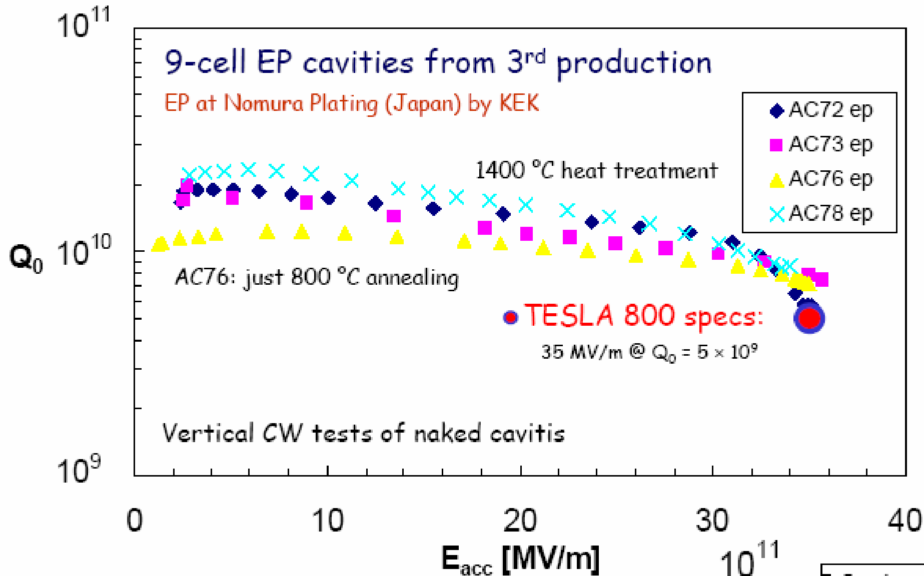
TESLA Structures

- The structure proposed for 500 GeV operation requires 24 MV/m.
  - Achieved in 1999-2000 cavity production run
  - 13,000 hours operation in TTF (not all modules at 24 MV/m)
- The goal is to develop and install cavities capable of 35 MV/m for the energy upgrade to 800-1000 GeV.
- Progress over the last several years has been in the area of surface processing and quality control.
  - Buffered chemical polishing
  - Electro-polishing
  - Several single cell cavities at 40 MV/m
  - Five nine-cell cavities at >35 MV/m



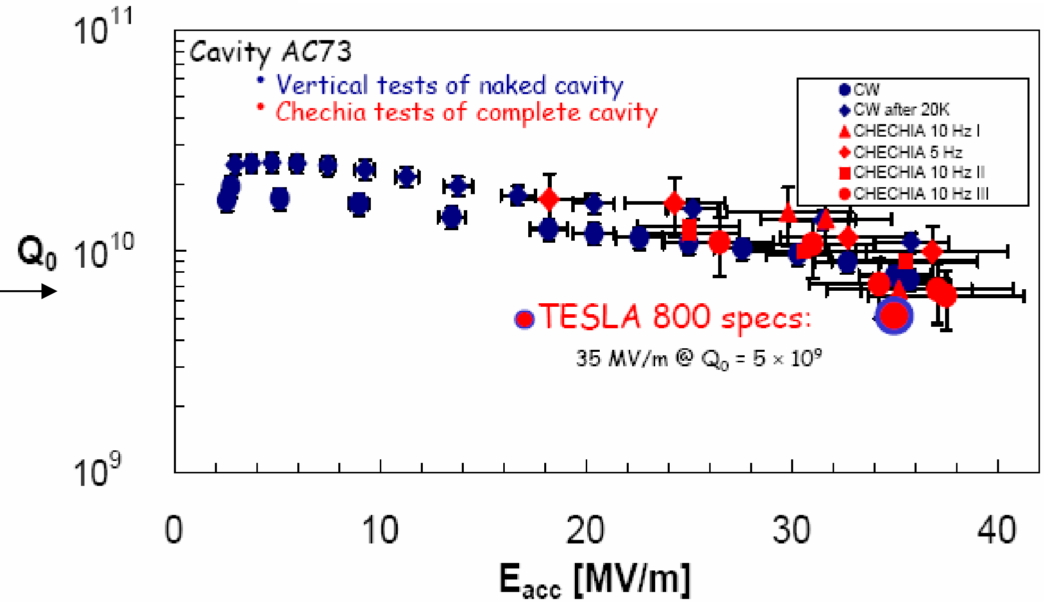
- Dark current criteria established based on <10% increase in heat load
  - 50 nA/cavity

Linear Collider Technology Status
TESLA Structures

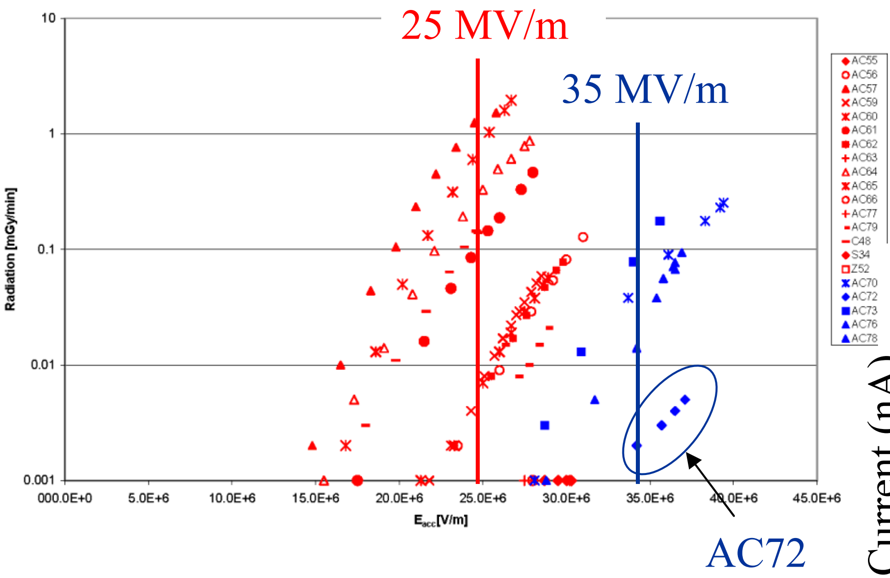


Vertical (low power test)

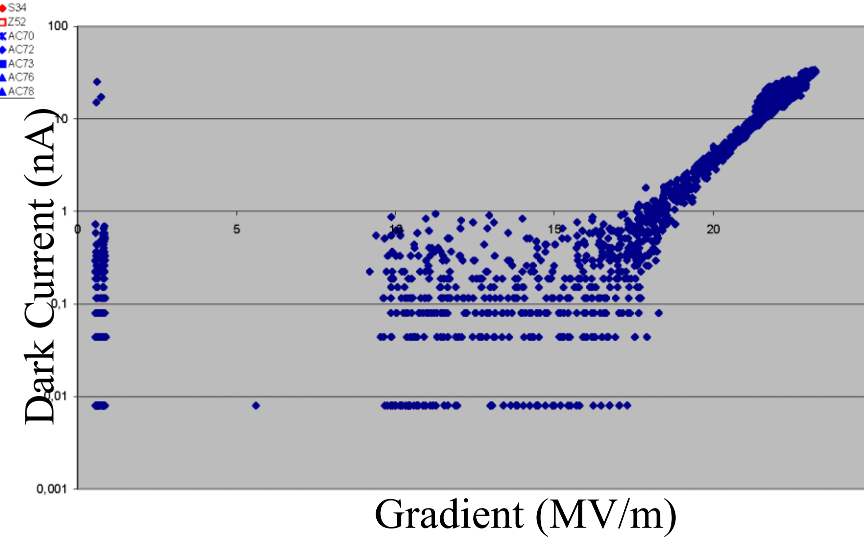
Comparison of low and high power tests (AC73)



Linear Collider Technology Status
TESLA Structures: Dark Current



Radiation emissions of BCP and EP cavities (vertical test stand)



Dark Current measurement on 8-cavity CM (ACC4)

~15 nA/cavity at 25 MV/m

Linear Collider Technology Status
TESLA Structures

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

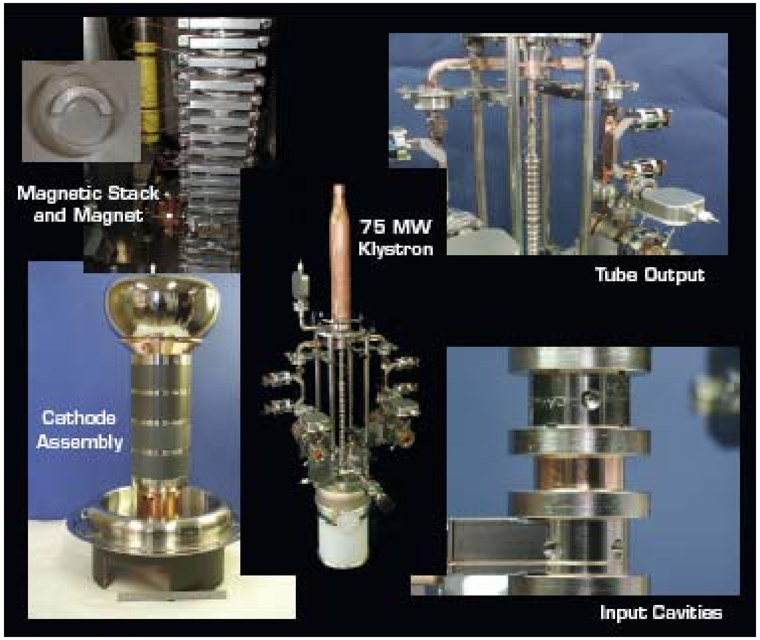
Linear Collider Technology Status
Summary: Structures

- Eight NLC/GLC structures are operating per performance specification in the NLCTA.
  - Built by three different institutions on two continents
  - Keys to success were reducing length, reducing group velocity, improving input coupler design.
- Five TESLA cavities have met the 35 MV/m performance specification
  - One has seen beam in a complete cryomodule
  - Key to success has been advancement in surface treatment procedures (BCP and EP)

Linear Collider Technology Status
NLC/GLC Power Sources

- 75 MW PPM Klystron
  - (Nearly) full specification performance by two tubes

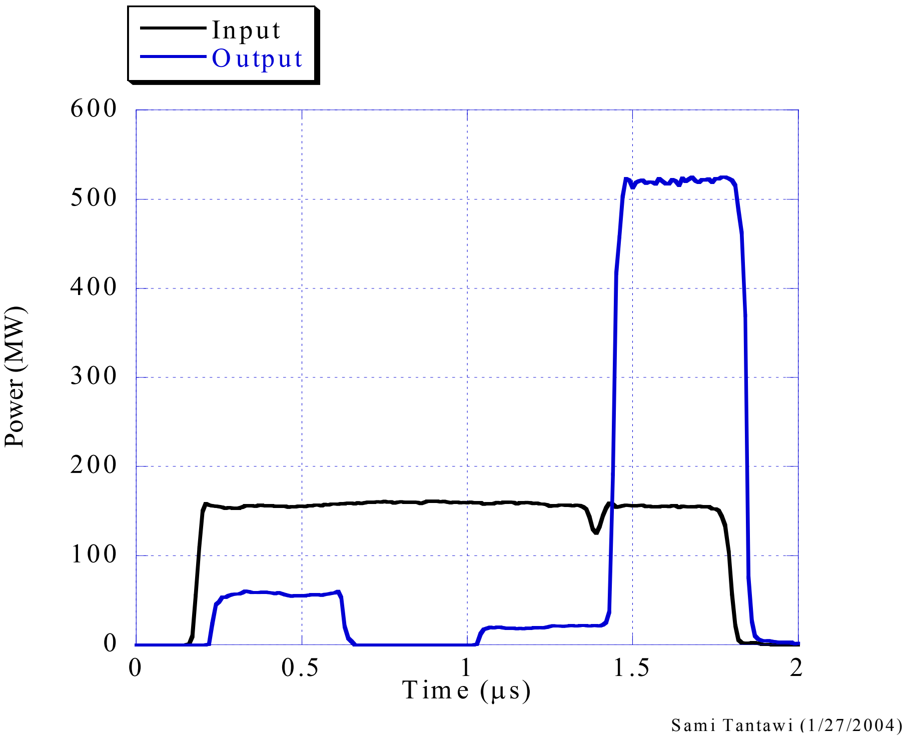
Klystron	Peak Power	Pulse-Width	Repetition Rate
SLAC XP3 S/N 3	75 MW	1.6 mu s	120 Hz
KEK PPM S/N 2	75 MW	1.7 mu s	60 Hz
	68 MW	1.7 mu s	120 Hz
KEK PPM S/N 3	65 MW	1.5 mu s	50 Hz
KEK PPM S/N 4	75 MW	1.6 mu s	25 Hz
SLAC 75 MW Prototype	75 MW	1.5 mu s	1 Hz
	79 MW	2.8 mu s	1 Hz
KEK PPM S/N 1	68 MW	1.5 mu s	5 Hz
SLAC 50 MW	50 MW	1.5 mu s	120 Hz
	55 MW	2.4 mu s	60 Hz
	75 MW	1.5 mu s	120 Hz



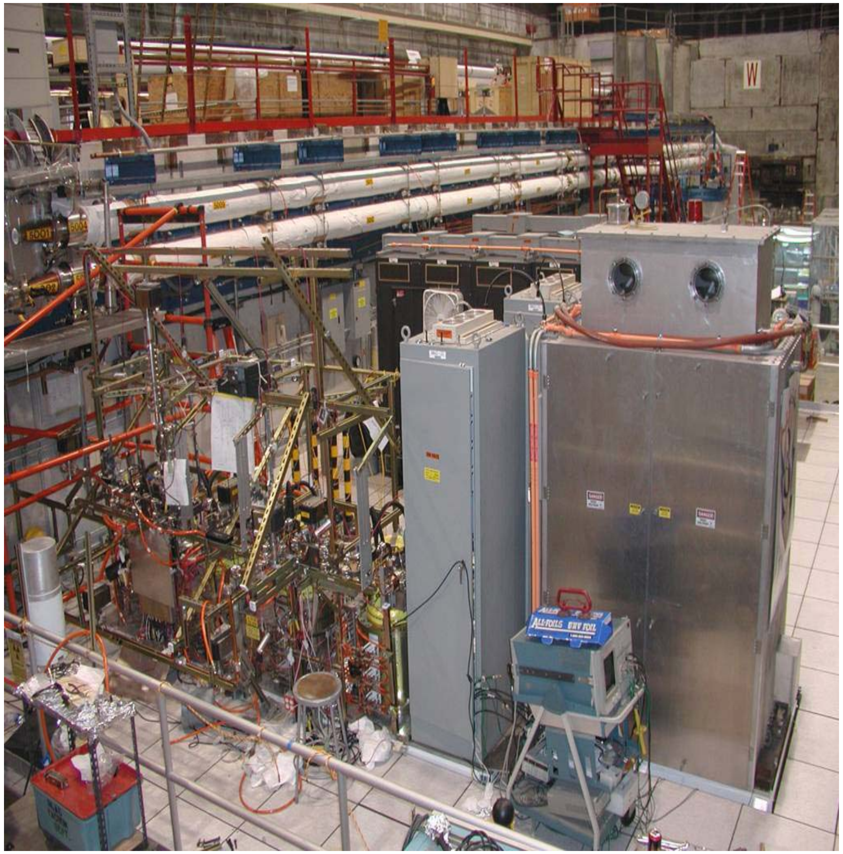
- Full-specification induction modulator operating in support of the 8–pack test.

Linear Collider Technology Status

NLC/GLC Power Sources



- Power to loads 580 MW at 400 ns (design is 475 MW)
- Operated 500 hours at ~500 MW



"8-pack" test at SLAC

Linear Collider Technology Status
TESLA Power Sources

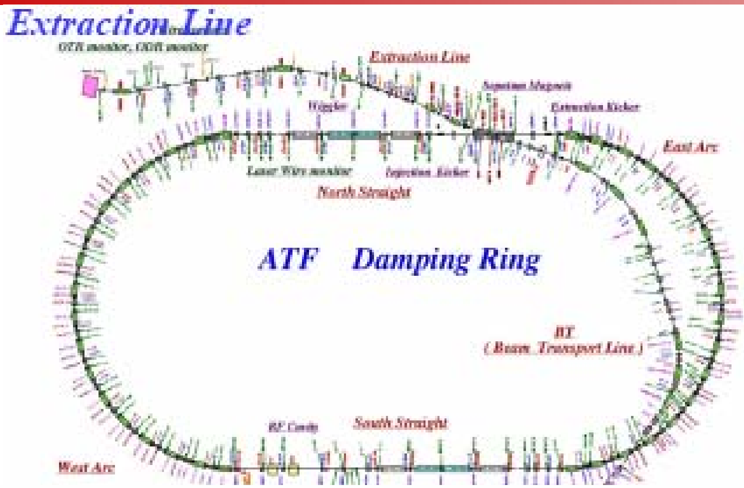
- Three Thales TH1801 Multi-beam klystrons fabricated and test.
  - Efficiency = 65%
  - Pulse width = 1.5 msec
  - Peak power = 10 MW
  - Repetition rate = 5 Hz
  - Operational hours (at full spec) = 500 hours
- Independent R&D efforts now underway at CPI and Toshiba

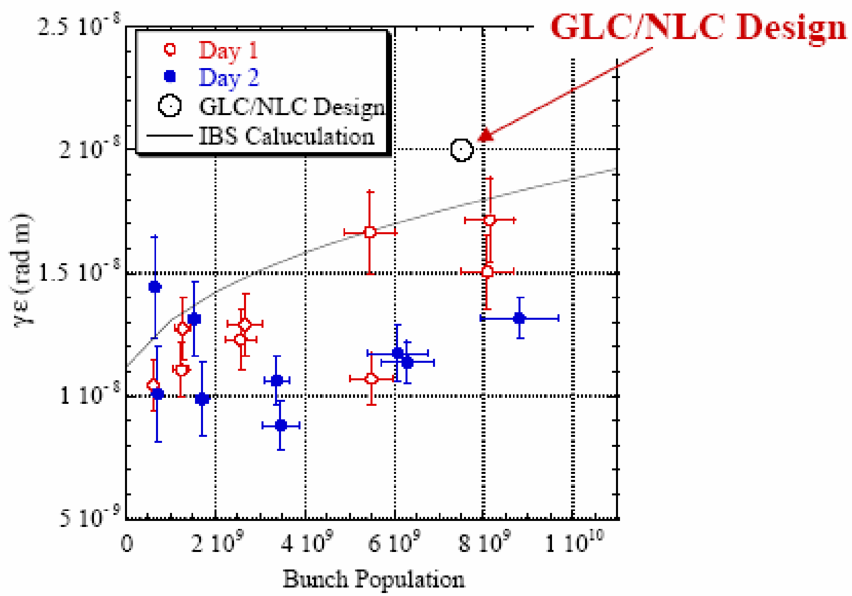
- 10 Modulators have been built
  - 3 by FNAL and 7 by industry
  - 7 modulators are in operation
  - 10 years operation experience

Linear Collider Technology Status
Summary: RF Sources

- Modulators for both NLC/GLC and TESLA have been demonstrated and do not appear to have major issues.
- Klystrons remain a challenge
  - Modest numbers of klystrons meeting specs exist for both NLC/GLC and TESLA.
  - R&D programs are continuing to develop units that can meet requirements in a reproducible manner.

Linear Collider Technology Status
Damping Rings: ATF





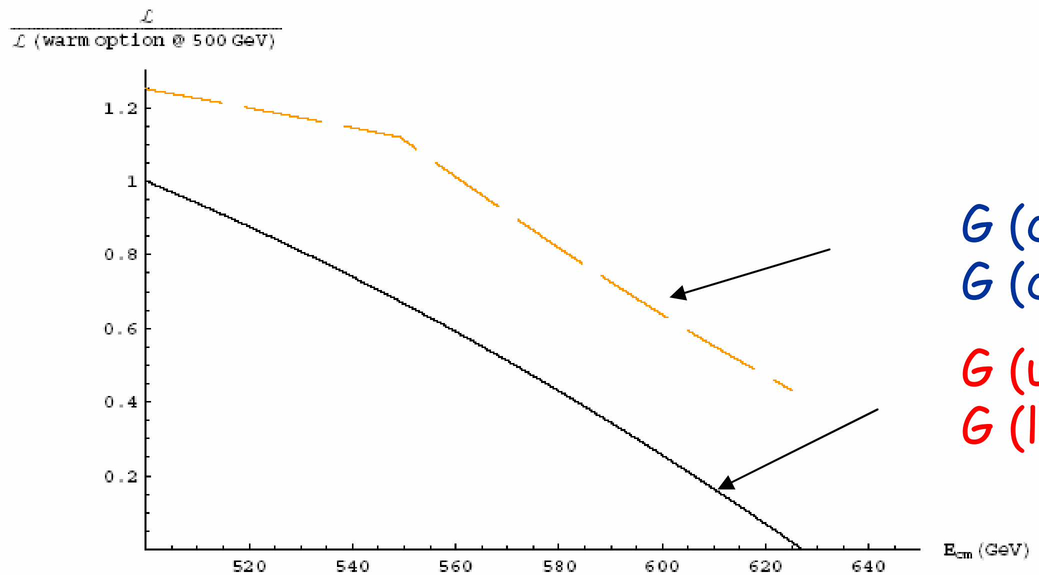
- NLC/GLC requirement met
  - electrons, single bunch
- Performance consistent with intra-beam scattering

⇒Need to move to multi-bunch; Better understanding of e-cloud; Alternatives to TESLA dogbone

Design Variants (from the U.S. Study)

(www.slac.stanford.edu/xorg/accelops/Full/LC_opts_full.pdf)

- Luminosity vs energy: The opportunity exists to build a "500 GeV" collider in which luminosity can be traded for higher energy.
  - This happens naturally in the warm machine because beam loading is an inherent part of the design.
  - This can happen in the cold machine if the installed cavity capability is greater than the 500 GeV gradient.



G (cold, capability) = 35 MV/m
G (cold, operational)=28 MV/m

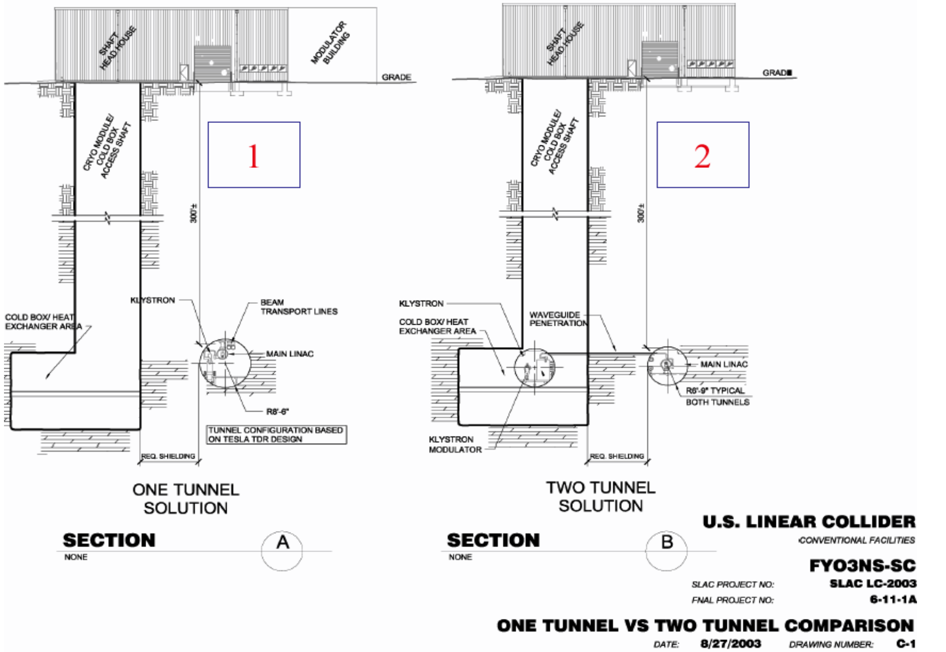
G (unloaded, warm)=65 MV/m
G (loaded, warm)=52 MV/m

Design Variants (from the U.S. Study)

- One vs. two tunnels
  - Single tunnel saves ~5% on total project cost.
  - Estimated impact on machine availability is ~10%.

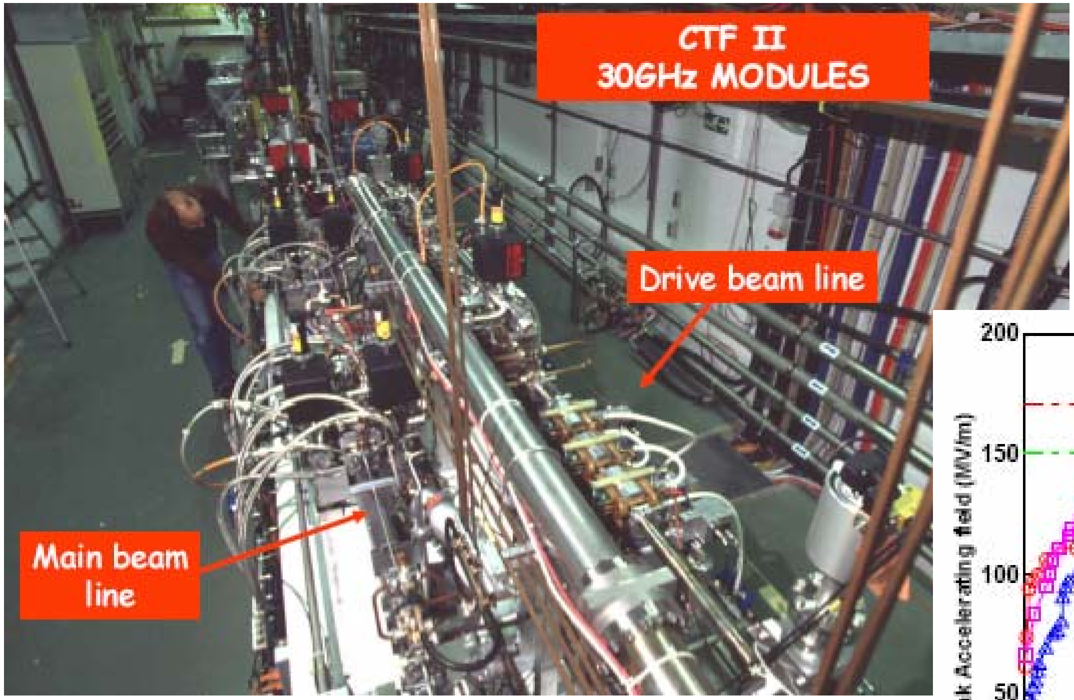
⇒Increase energy overhead and/or improve component reliability (×10)

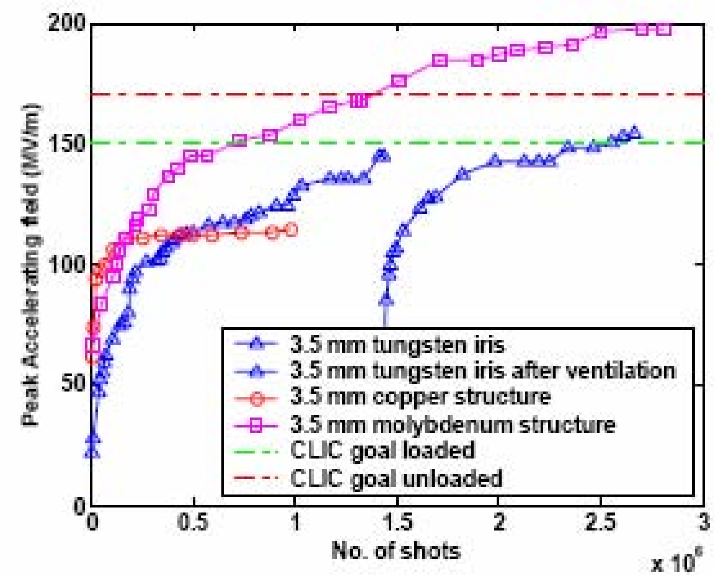
⇒“Right” answer may be site specific



- Undulator vs. conventional source
  - Advocate starting with a conventional source (more efficient startup commissioning) but leave space for undulator upgrade
- Reliability analysis
  - Monte Carlo analysis indicates modern MTBFs need to be improved by up to ×10 to achieve availability of 85%

Beyond the Next Generation
CLIC





Conclusions

- The technologies required to support either a room temperature or superconducting rf-based linear collider have made substantial progress over the last two years. It is my conclusion that a linear collider meeting the needs of the world HEP community could be built and operated based on either warm or cold technology.
- Our community should be very happy if given the opportunity to construct and operate a 500-1000 GeV linear collider based on either technology, no matter where it is situated in the world. So,…

Let’s support the decision of the ITRP when it is released later this year and do everything in our power to realize this forefront machine.