Workshop on Novel Concepts for Linear Accelerators and Colliders

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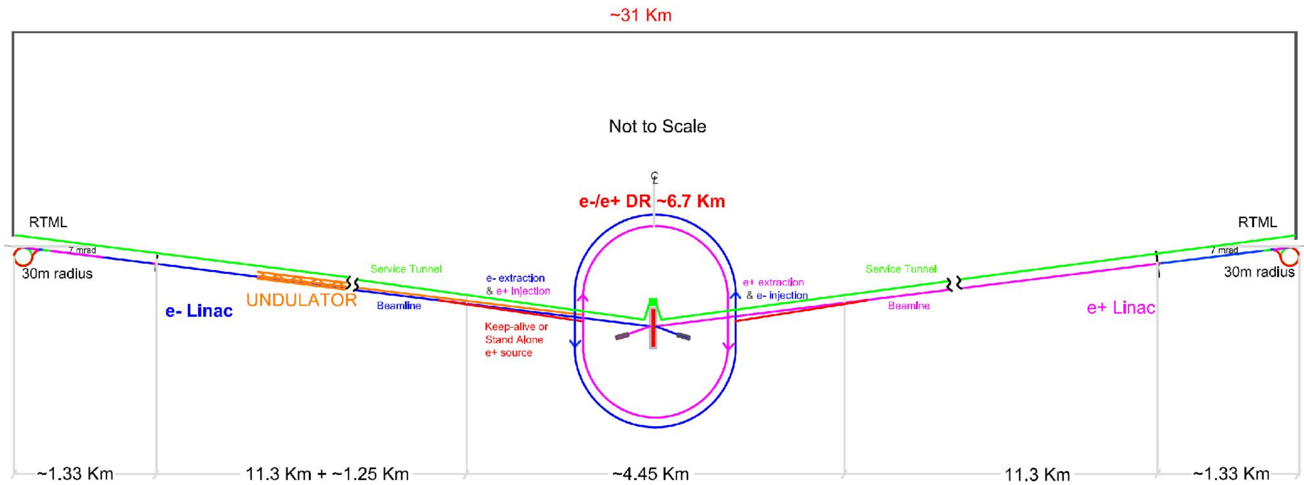
Introduction

* There has been a strong Advance Accelerator R&D program around the world for the last 30+ years
  - Concepts on new acceleration techniques
    - Rf, laser, and beam driven using dielectric, metallic, and plasmas
  - New particle sources and new methods of beam manipulation and new concepts for beam control and focusing
* There are specialized workshops to discuss these topics
  - Advanced Accelerator Concepts and High Brightness e- Beams
* Here I would like us to look at how these concepts might be applied to optimizing a linac
  - Bring the different efforts together and look at the problems from the accelerator design and systems view
* The primary example that we selected will be linear colliders but think more broadly

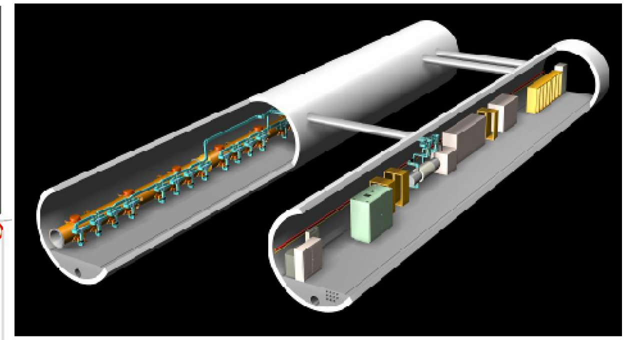
Linear Collider Status

* Strong international development program on linear collider over last 30-years
  – Designs based on ‘reasonable’ extrapolations of existing technology: ILC (1.3 GHz SC) and CLIC (12 GHz NC)
* Any linear collider is a massive project: varying between ultra-huge (10’s B$) and huge (~5 B$) in US accounting
  – Access to funding will be influenced by political processes and is inherently uncertain
* Problem: finding appropriate political support given the cost
* Given uncertainty, the program must think about new concepts and new approaches
  – LC program provides a good example for application of new ideas

International Linear Collider: Cost Drivers

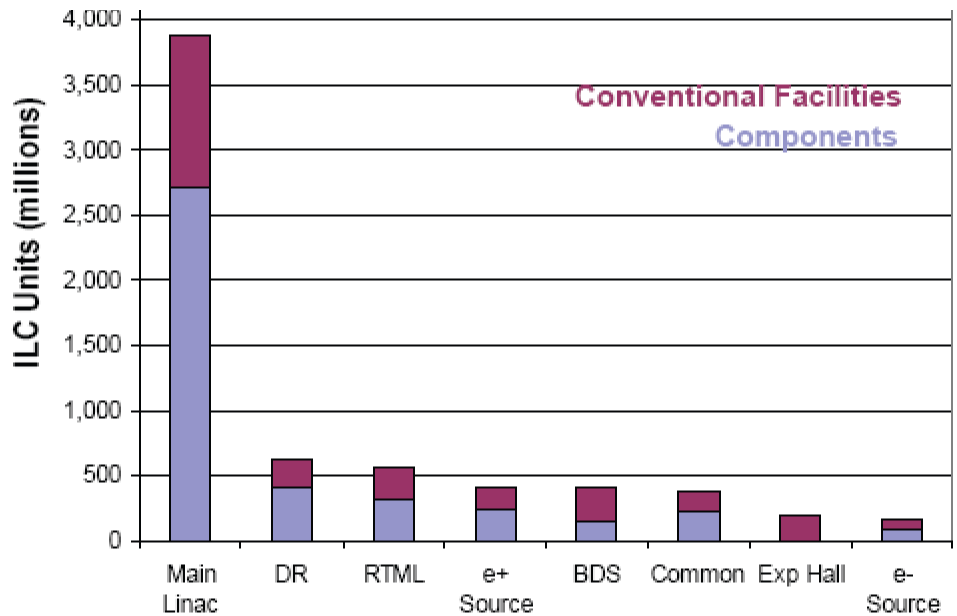


Schematic Layout of the 500 GeV Machine



* ILC costs provide basis for optimization
  – 60% of costs are in ML
  – 15~20% in the RTML and damping rings
  – Power handling ~5%
  – GDE effort is working on ‘minimal’ configuration

ILC Costs by Sub-system (from RDR)



Linear Collider Facility Cost Goals

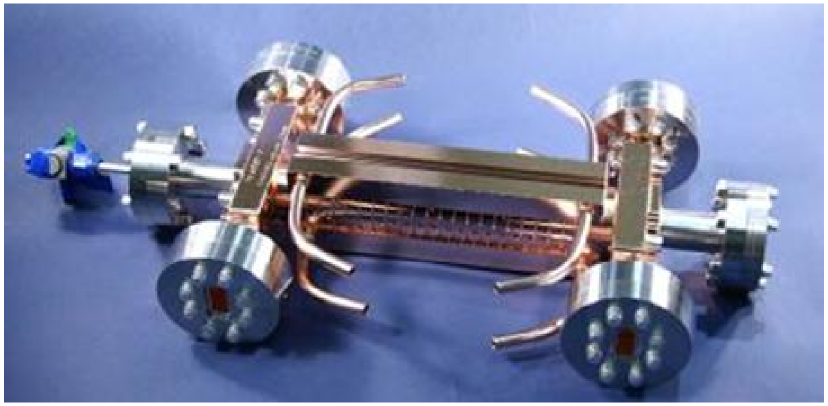
* Goal: could we reduce LC cost by an order of magnitude
  – Have to benefit from optimization all subsystems
    • New acceleration systems
    • Improved focusing concepts
    • Improved beam generation
* Facility costs scale roughly with power consumption and facility size
  – High gradient can reduce site length – are components cheaper?
  – Need improved efficiency, better sources, or improved focusing to reduce power consumption
* Future projects probably need to optimize life cycle costs
  – Inflated annual energy costs ~1$ (2020$) per Watt
  – Energy costs an order of magnitude smaller than capital cost in ILC design → important factor in a future design

High Gradient Acceleration

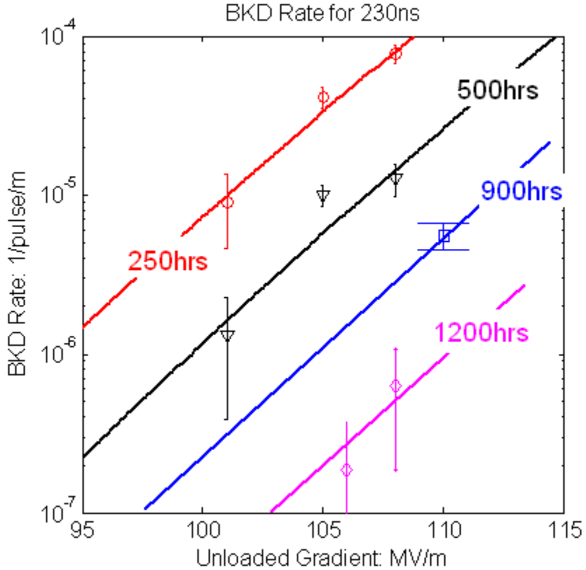
* Largest cost driver for a linear collider is the acceleration
  – ILC geometric gradient is ~20 MV/m → 50km for 1 TeV
* Size of facility is costly → higher acceleration gradients
  – High gradient acceleration requires high peak power and structures that can sustain high fields
    • Beams and lasers can be generated with high peak power
    • Dielectrics and plasmas can withstand high fields
* Many paths towards high gradient acceleration
  – RF source driven microwave structures } ~100 MV/m
  – Beam-driven microwave structures } ~100 MV/m
  – Laser-driven dielectric structures } ~1 GV/m
  – Beam-driven dielectric structures } ~1 GV/m
  – Laser-driven plasmas } ~10 GV/m
  – Beam-driven plasmas } ~10 GV/m

High Gradient RF Acceleration

* Extensive R&D on breakdown limitations in microwave structures
  - US High Gradient Collaboration
  - CERN and Japan



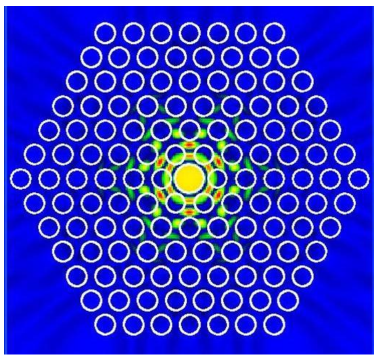
RF BKD Rate Gradient Dependence for 230ns Pulse at Different Conditioning Time



* In the last few years:
  - X-band gradients have gone from ~50 MV/m loaded to demonstrations of ~150 MV/m loaded with ~100 MV/m expected
  - C-band rf unit is operating at 37 MV/m; 8 GeV XFEL begun

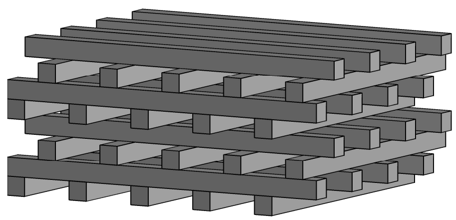
Dielectric Structures

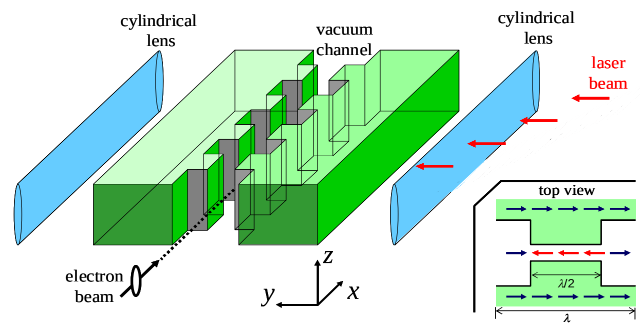
* Dielectric structures have higher breakdown limits approaching 1 GV/m at THz frequencies
  – Extensive damage measurements to characterize materials



Photonic Crystal Fiber
Silica, λ=1053nm,
E_z=790 MV/m

Photonic Crystal "Woodpile"
Silicon, λ=1550nm,
E_z=240 MV/m



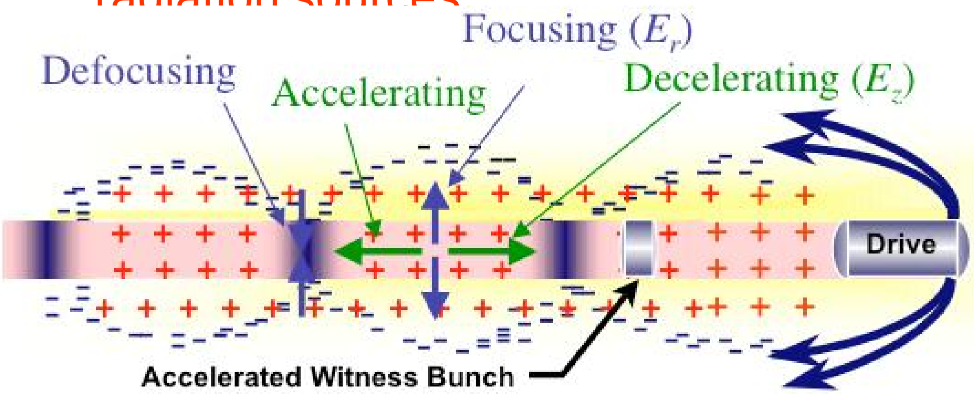


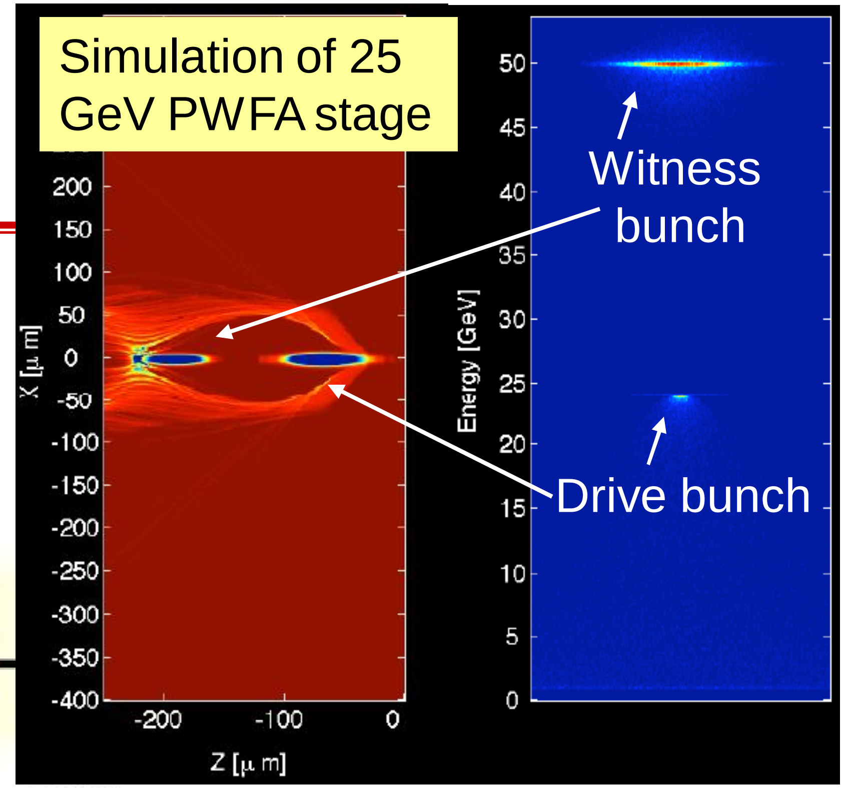
Transmission Grating Structure
Silica, λ=800nm,
E_z=830 MV/m

  – Structures can be either laser driven or beam driven
  – Will likely require new concepts for injector systems

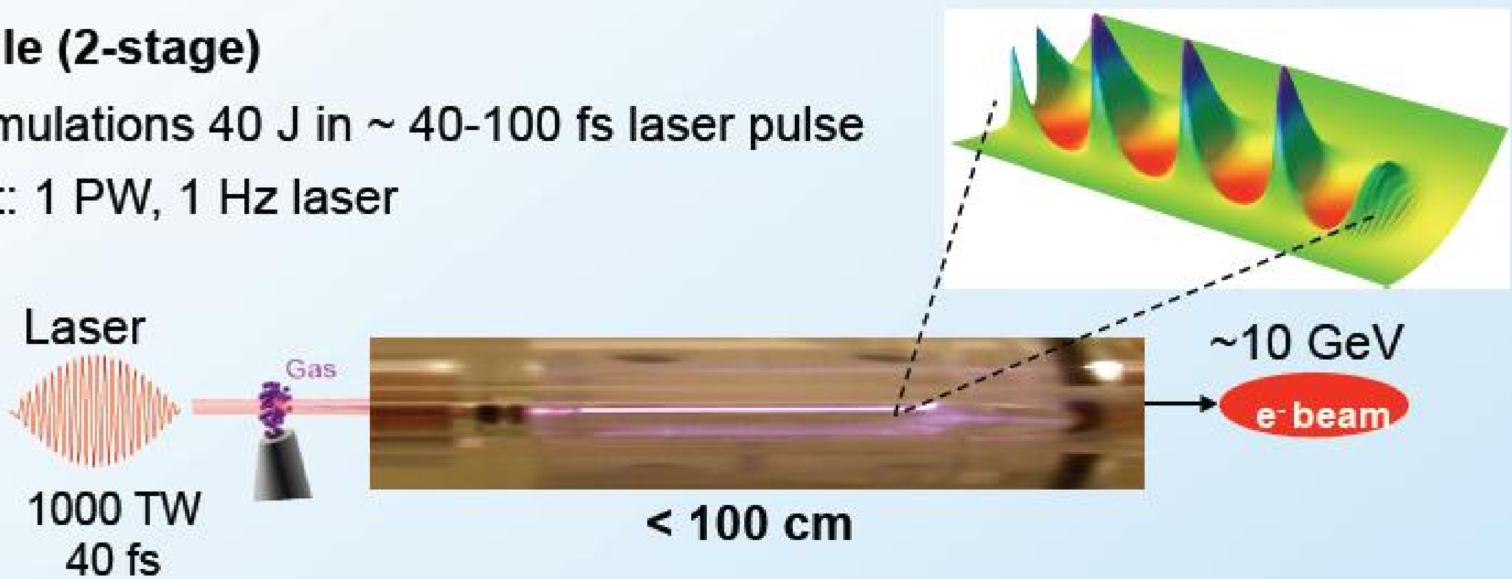
Plasma Acceleration
(Beam-driven or Laser-driven)

- 50 GV/m in FFTB experiments
  - Potential use for linear colliders and radiation sources





- **10 GeV module (2-stage)**
- Theory and simulations 40 J in ~ 40-100 fs laser pulse
- BELLA Project: 1 PW, 1 Hz laser



High Gradient Acceleration

* Need structures to sustain high acceleration fields
  – Topic of extensive R&D

* Require high peak power for high gradient acceleration
  – Pulsed power generation – efficient with low peak power
  – RF pulse compression
  – Drive beam (two beam acceleration)
  – Lasers
* High power lasers and electron beams can store and manipulate large amounts of power
  – Add power slowly and then manipulate pulse/beam to increase peak power
    • Examples: TBA and CPA
* Need to maintain efficiency throughout process

Linear Collider Parameters

* Luminosity is critical in a linear collider
  – Physics studies have been based on ~1x10^{34} cm^{-2}sec^{-1}

$$L = \frac{f_{rep}}{4\pi} \frac{N^2}{\sigma_x \sigma_y} \quad \Rightarrow \quad L = \frac{P_{beam}}{4\pi E_{beam}} \frac{N}{\sigma_x \sigma_y} H_D \sim \frac{P_{beam}}{E_{beam}} \frac{n_\gamma}{\sigma_y} H_D$$

* Need large beam powers, large bunch charges, and small spot sizes
  – For example, conventional parameters at 1 TeV:
    • 20 MW beam power, 10^{10} e+/e- per bunch, frep = 10 kHz, and σ_x/σ_y = 140 / 3 nm → 1x10^{34} cm^{-2}sec^{-1} within 1% of cms energy

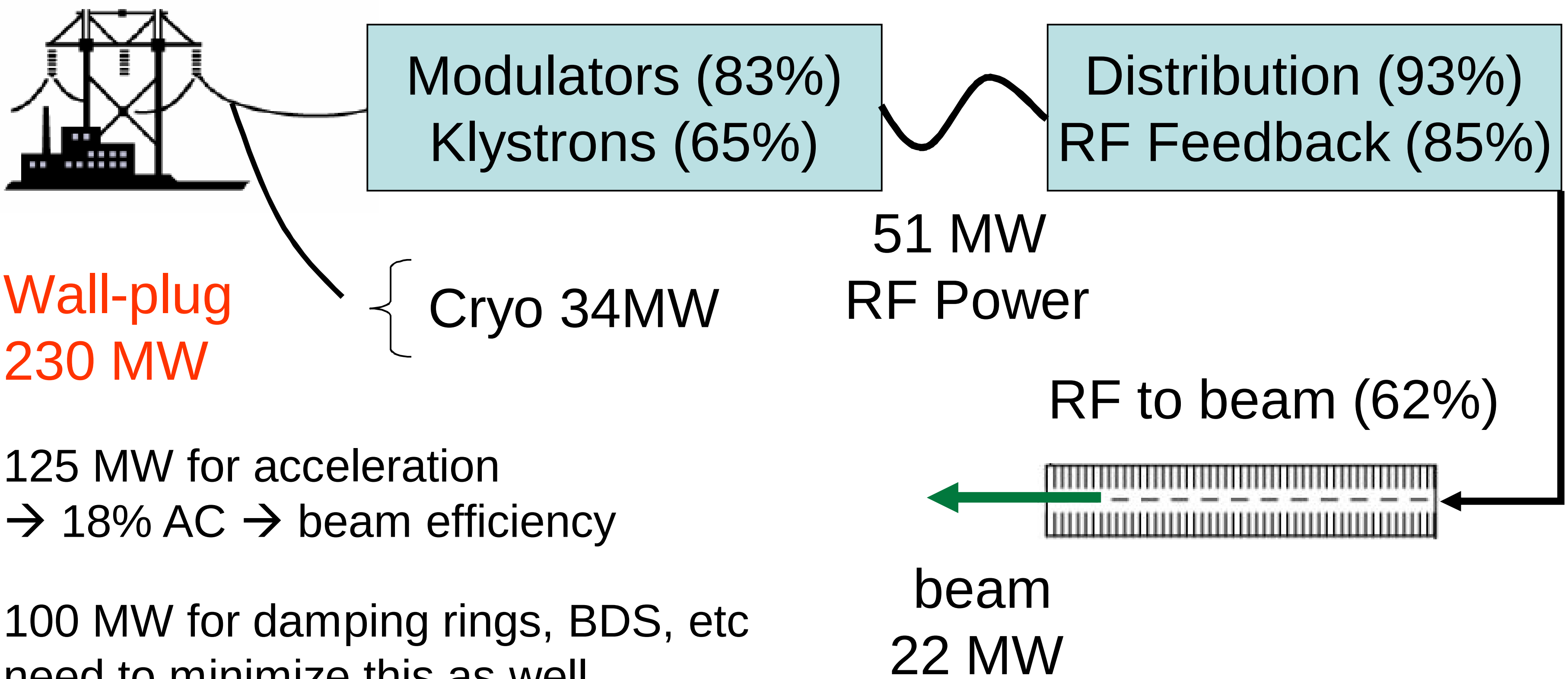
* All parameters pushed beyond state-of-the-art
  – Develop/adopt new concepts to allow rebalance of parameters

Examples of 1 TeV Collider Parameters

	"ILC"	CLIC	Dielectric	Plasma
CMS Energy (GeV)	1000	1000	1000	1000
Luminosity (10^{34} $cm^{-2}s^{-1}$)	2.8	2.3	1.2	3.1
Luminosity in 1% of Ecms	1.9	1.1	1.1	1.1
Bunch charge (10^{10})	2	0.37	3.80E-06	1
Bunches / train	2820	312	193	125
Repetition rate (Hz)	4	50	7.50E+06	60
Beam Power (MW)	36.2	9.2	8.8	20
Emittances $\varepsilon_{n,x}$ / $\varepsilon_{n,y}$ (mm-mrad)	10 / 0.04	0.7 / 0.02	1e-4 / 1e-4	2 / 0.02
IP Spot sizes sx/sy (nm)	554 / 3.5	140 / 2	1.0 / 1.0	140 / 2
IP bunch length sz (μm)	300	30	0.1 –> 300	10
Drive beam / Laser / RF Power (MW)	80	36.8	44	38
Gradient (MV/m)	31.5	100	400	25000
Two linac length (km)	47	14	~4	~6
Drive beam / Laser / RF generation eff.	53.95%	49%	60%	45%
Drive beam / Laser / RF coupling eff.	49.01%	25%	20%	35%
Overall efficiency	17.90%	12.10%	12%	15.70%
Site Power (MW)	~300	~150	~130	~120

Power Conversion

* Accelerators act as transformers: grid AC → beam power
* Conventional linear collider (500 GeV ILC):



125 MW for acceleration
→ 18% AC → beam efficiency

100 MW for damping rings, BDS, etc
need to minimize this as well

Goals for the Workshop

* Over the last number of years the AARD programs have developed many novel concepts which have broad application to accelerator design
  – Bring AARD community together to consider how to apply these concepts to accelerator systems

* Focus on understanding the implications of the different concepts with a goal of developing self-consistent accelerator parameters and specifying the R&D programs needed for further progress
  – Sketch self-consistent designs for a 1 TeV linear collider based on novel approaches
  – Consider R&D beyond initial development that will be needed to apply the concepts

Working Groups

1. Microwave structure-based linacs
    * Toshi Higo, Sami Tantawi, and Walter Wuensch
2. Dielectric structure-based linacs
    * Eric Colby and James Rosenzweig
3. Plasma-based linacs
    * Mark Hogan and Carl Schroeder
4. Injector and beam manipulation concepts
    * John Power and John Sheppard
5. Collimation & Focusing concepts
    * Andrei Seryi and Rogelio Tomas
6. Cost optimization and future R&D priorities
    * Jean-Pierre Delahaye and Tor Ruabenheimer

Detailed Questions for Groups: WG1 - 3

* Goals for the three acceleration working groups are to:
  1. Develop self-consistent sets of parameters aimed at a 1 TeV collider with 2e34 total luminosity (an initial version of these should be presented at the beginning of the workshop),
  2. List the critical R&D on the acceleration technology and the implied beam generation and focusing systems that are needed to utilize the technology,
  3. Consider the fundamental limits of the technology and describe the impact of approaching these, and
  4. Consider how new concepts for beam generation and focusing could have a major impact on the designs.

Detailed Questions for Groups: WG4 - 6

* Goals of the Injector and Focusing groups are to:
  1. Understand the current options and the potential of novel concepts for beam generation or focusing,
  2. Identify main R&D issues in achieving the desired parameters listed by the acceleration concepts (WG 1-3), and
  3. Understand potential of new concepts and suggest possible future R&D paths.

* Goals of the Cost and R&D group are to:
  1. Review the linac and linear collider cost drivers,
  2. Review linear collider parameters and work with groups towards self-consistent parameters,
  3. Understand luminosity versus cost for different collider options,
  4. Provide an overview of the critical R&D towards cost optimization.

Excel Parameter Sheet

* Developed an Excel-based parameter sheet that can help think about the impact

* Have asked all acceleration conveners to consider parameters for a 1 TeV cms LC with a luminosity of $2x10^{34}$ $cm^{-2}s^{-1}$

* Meant as a starting point

Versions	**100pm v1**	**100pm v2**	**100pm v3**
more details	SC	S-band	X-band or two beam
Case ID	**101**	**102**	**103**
Ecms [GeV]	1000	1000	1000
gamma	9.78E+05	9.78E+05	9.78E+05
Mode	e+ e-	e+ e-	e+ e-
Polarization	no,yes	no,yes	no,yes
Energy reach, S, GeV	1000	1000	1000
N	1.0E+09	1.0E+09	1.0E+08
nb	1200	120	120
DR kicker time [ns]	3	3	3
Min DR perimeter [km]	1.1	0.1	0.1
DR perimeter [km]	3	3	3
Number of Damping Rings	2	2	2
Length of both BDS [km]	4.5	4.5	4.5
Geographic gradient [Mev/m]	22	50	90
Length of both linacs [km]	45.5	20.0	11.1
Site length estimate [km]	50.0	24.5	15.6
Tsep in Linac [ns]	480.0	1.0	1.0
Iave in train [A]	0.0003	0.1600	0.0160
f rep [Hz]	5	50	500
Pb [MW]	**0.5**	**0.5**	**0.5**
Electron polarization, %	80	80	80
Positron polarization, %	N/A	N/A	N/A
Electron E-spread, %	0.14	0.14	0.14
Positron E-spread, %	0.07	0.07	0.07
IP Parameters:			
gamepsX [m]	1.0E-06	1.0E-06	1.0E-07
gamepsY [m]	1.0E-10	1.0E-10	1.0E-10
bx [m]	1.0E-02	1.0E-02	1.0E-03
by [m]	1.0E-04	1.0E-04	1.0E-04
Travelling focus	yes	yes	yes
Z-distribution	Gauss	Gauss	Gauss

		WG1	WG2	WG3	WG4	WG5	WG6	Extra room
		Microwave	Dielectric	Plasma	Beam generation	Collimation and focusing	Cost and R&D	for Discussion
Wednesday 7/8								
9:00 - 10:30		--		Plenary (ROB ABCD)		--		
11:00 - 12:30		--		Plenary (ROB ABCD)		--		
2:00 - 3:30		ROB AB	Yellow	Madrone				Cedar
4:00 - 5:30		ROB AB	Yellow	Madrone				Cedar
6:00 - 7:30		ROB AB (special)						
Thursday 7/9								
9:00 - 10:00		--		Plenary (ROB ABCD)		--		
10:30 - 12:30		ROB AB	Yellow		Kavli 2nd			
2:00 - 3:30					Kavli 3rd (WG2)	Yellow (WG3)	ROB AB (WG1)	Kavli 2nd
4:00 - 5:30		ROB AB	ESB Tour	Madrone				Kavli 2nd
Friday 7/10								
9:00 - 10:30					Yellow (WG3)	ROB (WG1)	Madrone (WG2)	Yellow
11:00 - 12:30					ROB AB (WG1)	Yellow (WG2)	Madrone (WG3)	Cedar
2:00 - 3:30		ROB AB	Kavli 3rd	Madrone	Fuji	Yellow	Cedar	
4:00 - 5:30		--		Summary (ROB ABCD)		--		
Every Day								
10:30 - 11:00		Coffee (Thursday 10:00 - 10:30)						
12:30 - 2:00		Lunch						
3:30 - 4:00		Coffee						
Plenary talks:		**Wednesday**						
9:00 - 9:30		Raubenheimer	Introduction and workshop goals					
9:30 - 10:00		Tantawi	Microwave-base high gradient structures and linacs					
10:00 - 10:30		Colby	Laser-driven dielectric structures and linacs					
11:00 - 11:30		Rosenzweig	Beam-driven dielectric structures and linacs					
11:30 - 12:00		Schroeder	Laser-driven plasmas and linacs					
12:00 - 12:30		Hogan	Beam-driven plasmas and linacs					