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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and Preparation for
Snowmass

- WG1 Parms & layout
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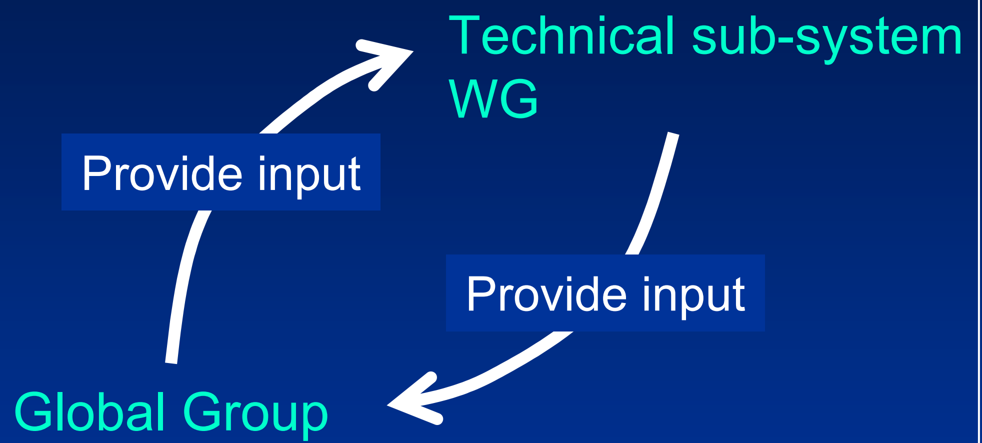
- WG3a Sources
- WG3b Damping Rings
- WG4 Beam Delivery
- WG5 SCRF Cavity Package
- WG6 Communications
- GG1 Parameters & Layout
- GG2 Instrumentation
- GG3 Operations & Reliability
- GG4 Cost Engineering
- GG5 Conventional Facilities
- GG6 Physics Options

Introduction of **G**lobal **G**roups
transition workshop → project

2nd ILC Workshop (Snowmass)



	WG5 Cavity	WG4 BDS	WG3b DR	WG3a Sources	WG2 Main Linac	WG1 LET bdyn.
GG1 Parameters						
GG2 Instrumentation						
GG3 Operations & Reliability						
GG4 Cost & Engineering						
GG5 Conventional Facilities						
GG6 Physics Options						

Goals of the 2nd 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

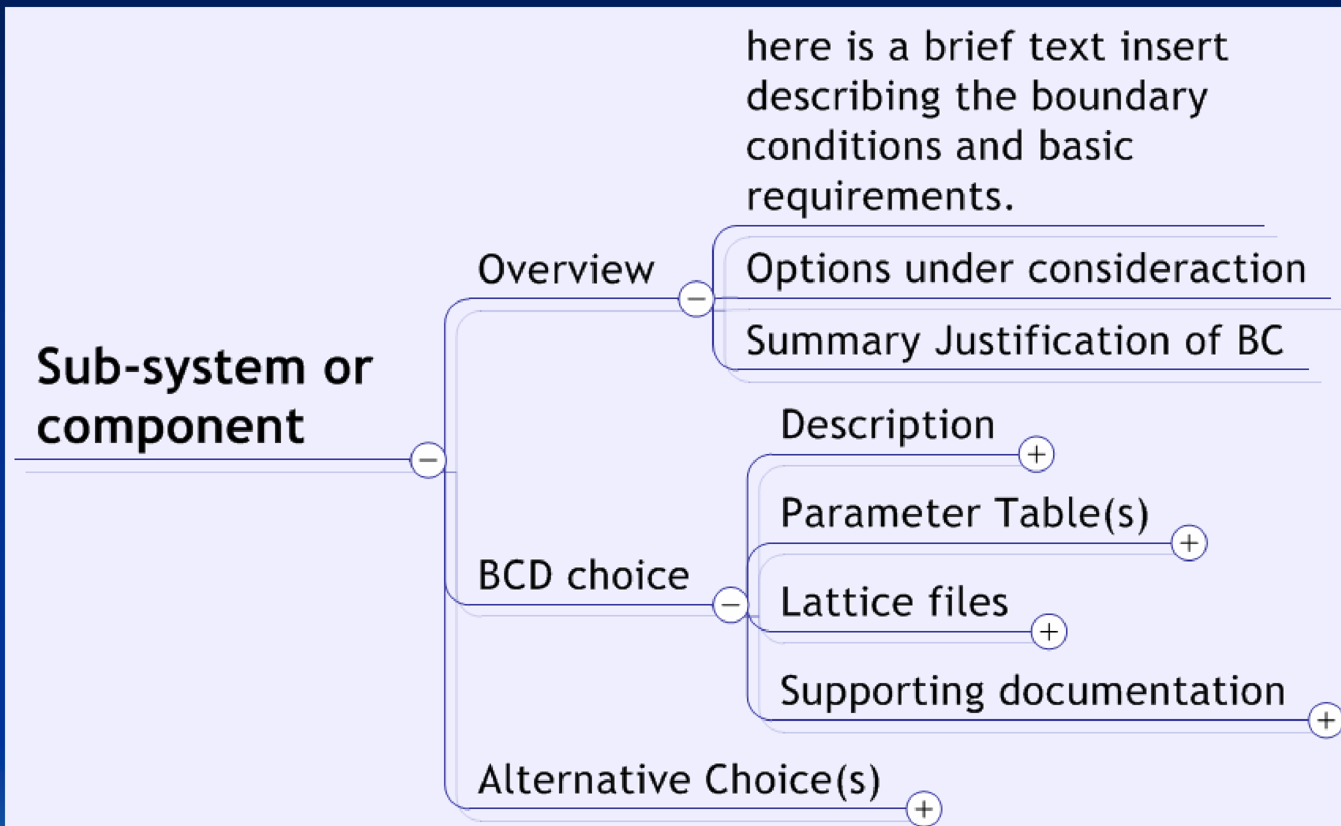
Alternate: A technology or concept which may provide a significant cost reduction, increase in performance (or both), but which will not be mature enough to be considered baseline by mid-end 2006

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)

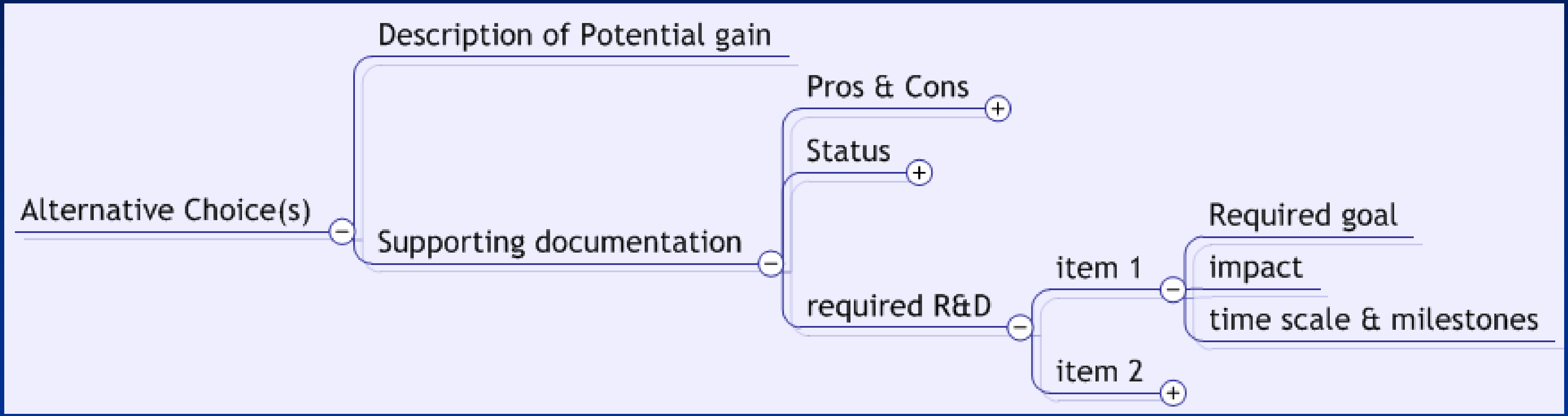
Structure of the BCD



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

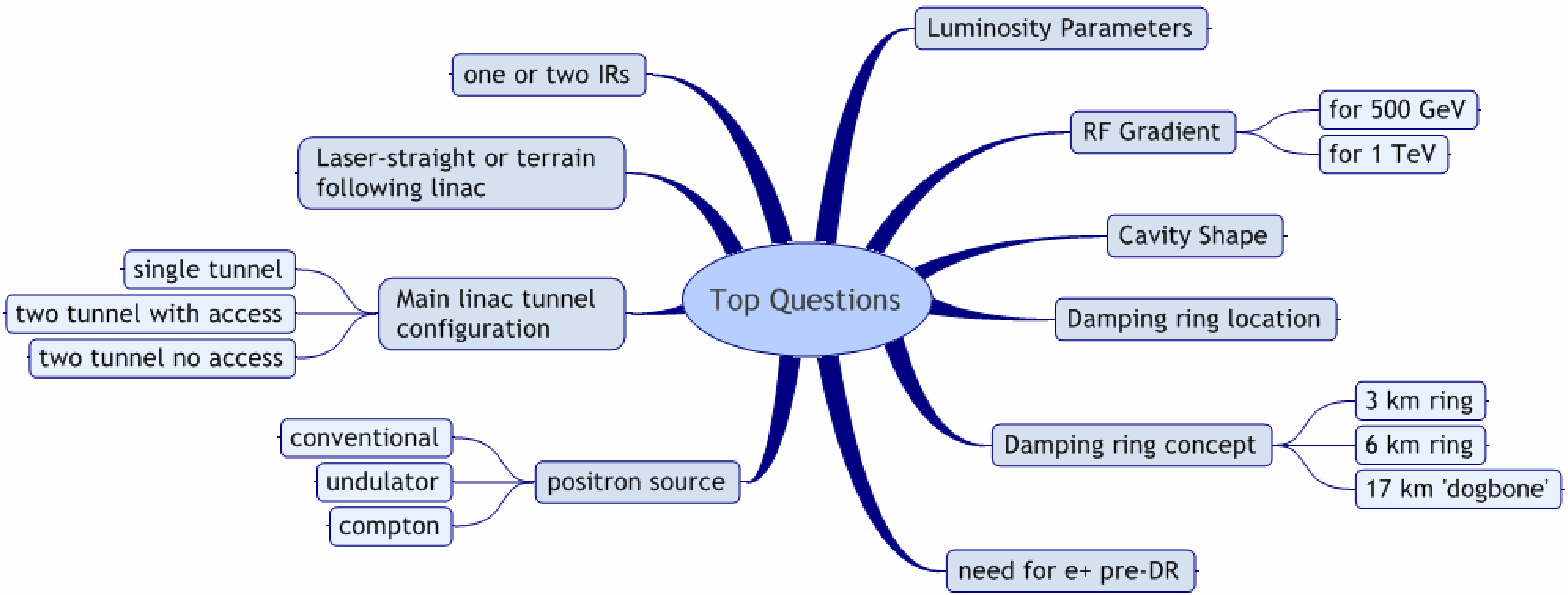
Alternatives Sections



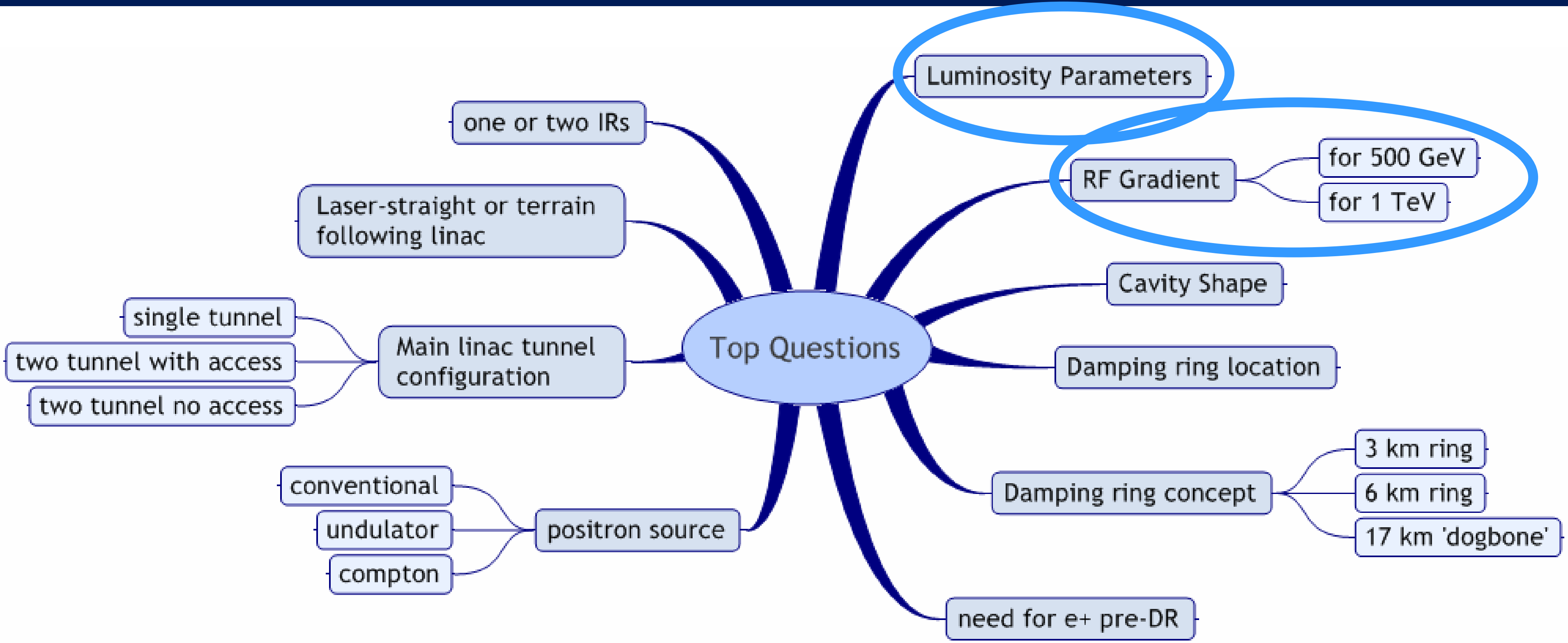
Note ACD is part of the BCD

Towards the BCD

The Hard Questions

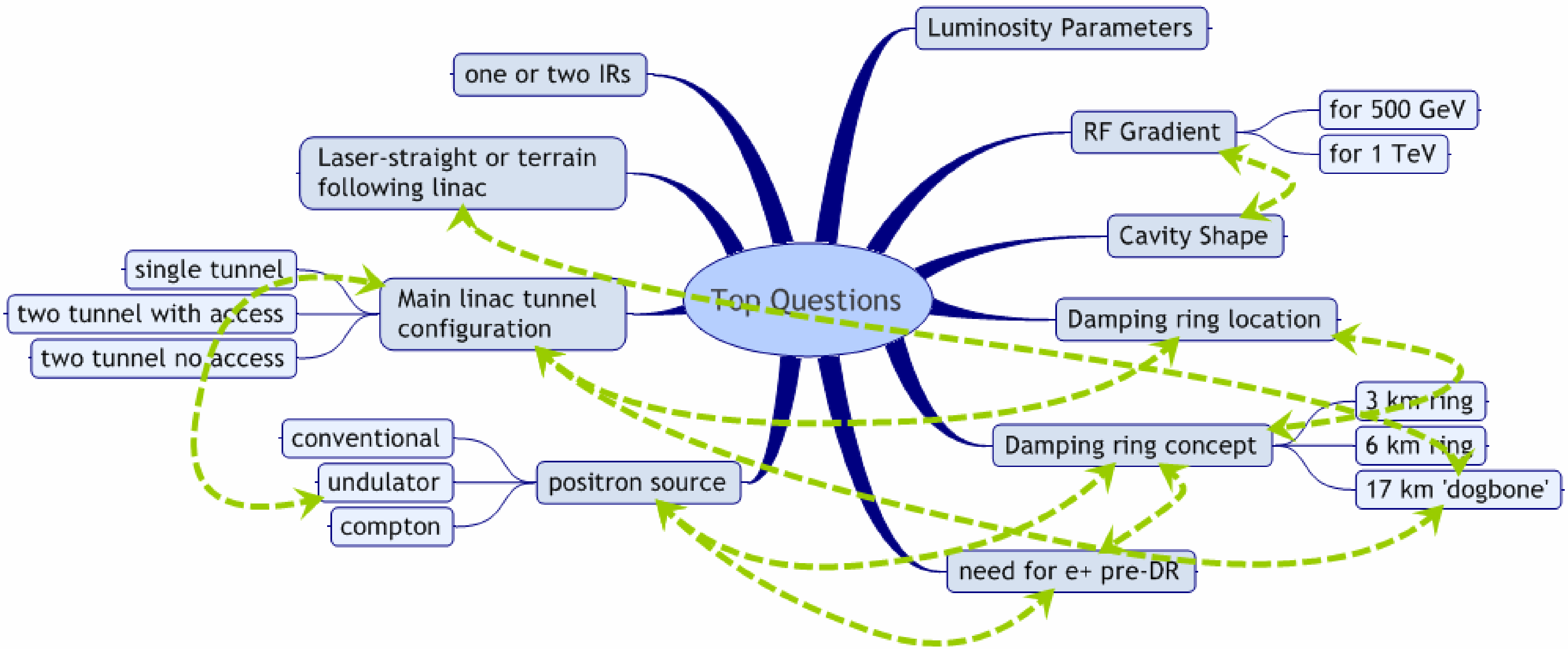


The Hard Questions



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: 2×10^{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

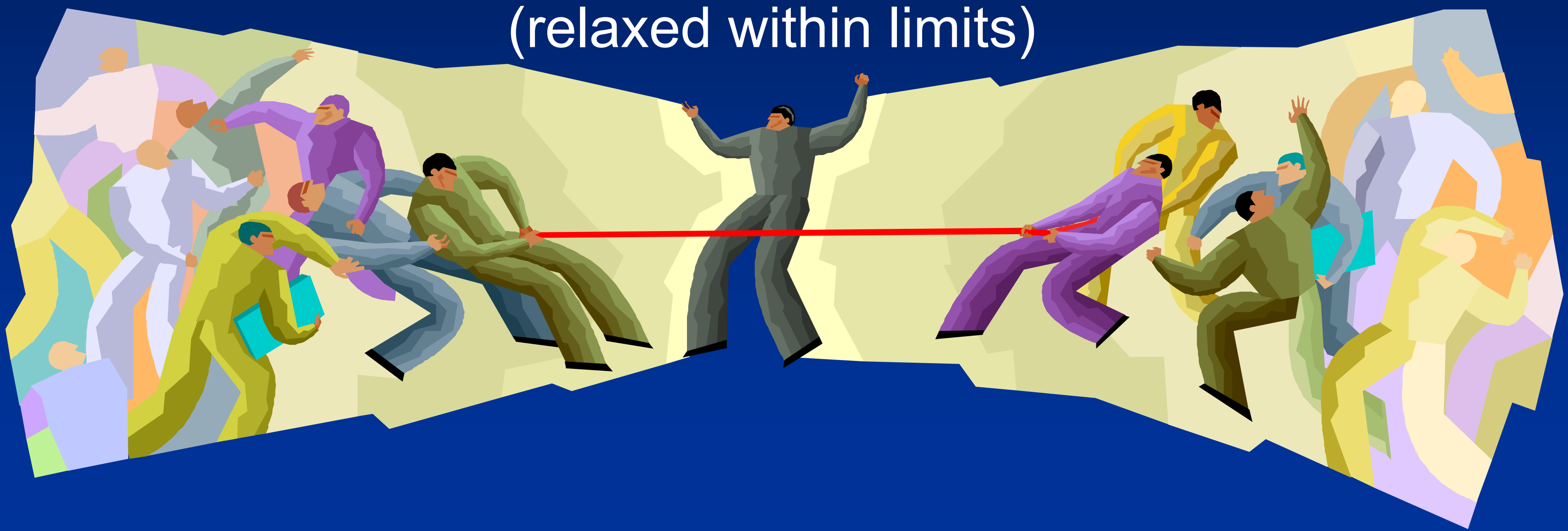
The Luminosity Plane 2×10^{34} cm^{-2}s^{-1}

		nom	low N	lrg Y	low P	High L
N	$\times10^{10}$	2	1	2	2	2
n_b		2820	5640	2820	1330	2820
$\varepsilon_{x,y}$	µm, nm	9.6, 40	10,30	12,80	10,35	10,30
$\beta_{x,y}$	cm, mm	2, 0.4	1.2, 0.2	1, 0.4	1, 0.2	1, 0.2
$\sigma_{x,y}$	nm	543, 5.7	495, 3.5	495, 8	452, 3.8	452, 3.5
D_y		18.5	10	28.6	27	22
δ_{BS}	%	2.2	1.8	2.4	5.7	7
σ_z	µm	300	150	500	200	150
P_{beam}	MW	11	11	11	5.3	11

$=5.6\times10^{34}$

Parameter Trade-Offs

Linac
(relaxed within limits)



Damping Ring
(sources)

IR (IP)
Beam extraction

Example of Discussions

Long RF Pulse

H.Padamesee 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

	Cavity type	Qualified gradient	Operational gradient	Length*	energy
		MV/m	MV/m	Km	GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

* assuming 75% fill factor

Total length of one 500 GeV linac $\approx$ 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 ($\sigma = 5\%$)
  - 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

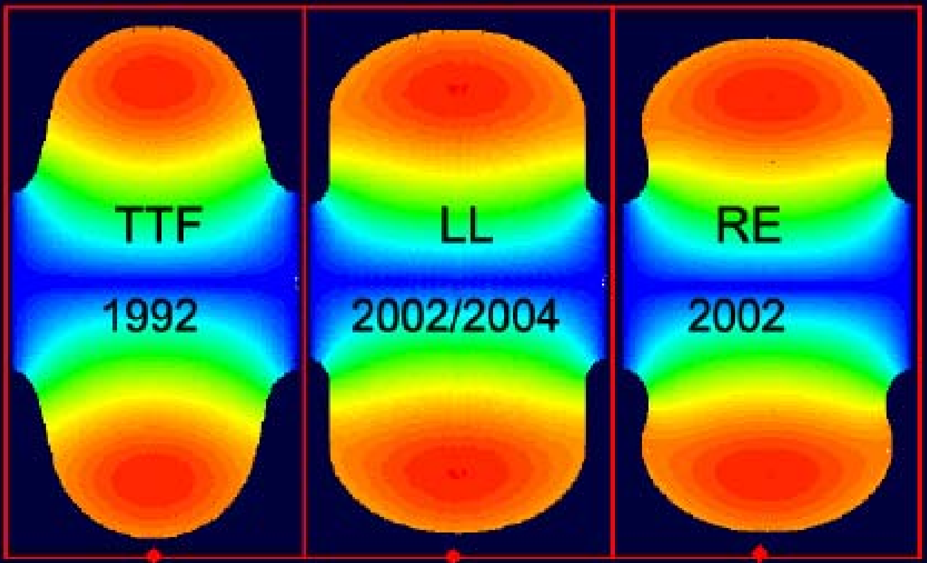
Cavity Fabrication

Improved Processing (Electropolishing)

KEK / Nomura EP

DESY EP

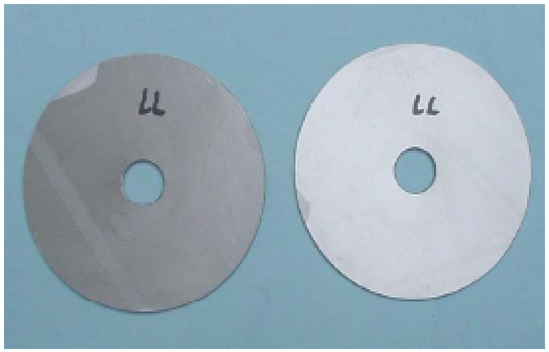
Improved Cavity Shapes

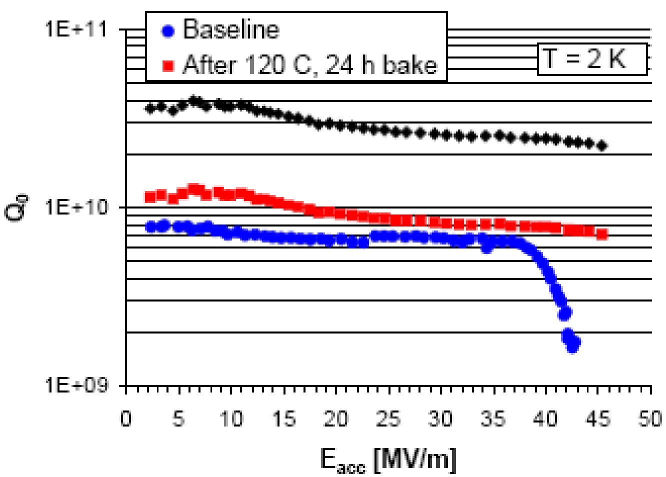


r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo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

Cavity R&D

Nb Discs





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

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

Fabrication from large grain or single-crystal Nb discs

May remove the need for electropolishing

(↓ cost!)

Baseline Klystrons

Thales

CPI

Toshiba

Specification:

10MW MBK

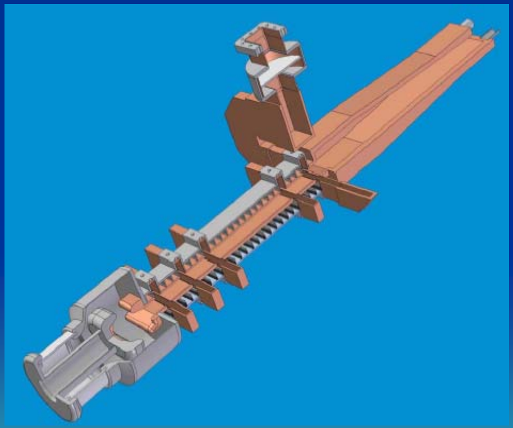
1.5ms pulse

65% efficiency

Ideas for Improved RF sources

10 MW Sheet Beam Klystron (SBK)

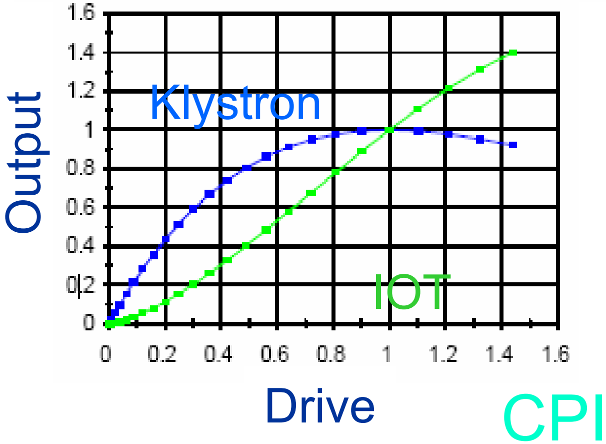
Parameters similar to
10 MW MBK



SLAC

5 MW Inductive Output Tube (IOT)

Peak Output Power	5	MW (min)
Average Output Power	75	kW (min)
Beam Voltage	115	kV (nom)
Beam Current	62	A (nom)
Current per Beam	5.17	A (nom)
Number of Beams	12	---
Frequency	1300	MHz
1dB Bandwidth	4	MHz (min)
Gain	22	dB (min)
Efficiency	70	% (nom)



CPI

Low Voltage 10 MW MBK

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

Perhaps use a Direct Switch Modulator

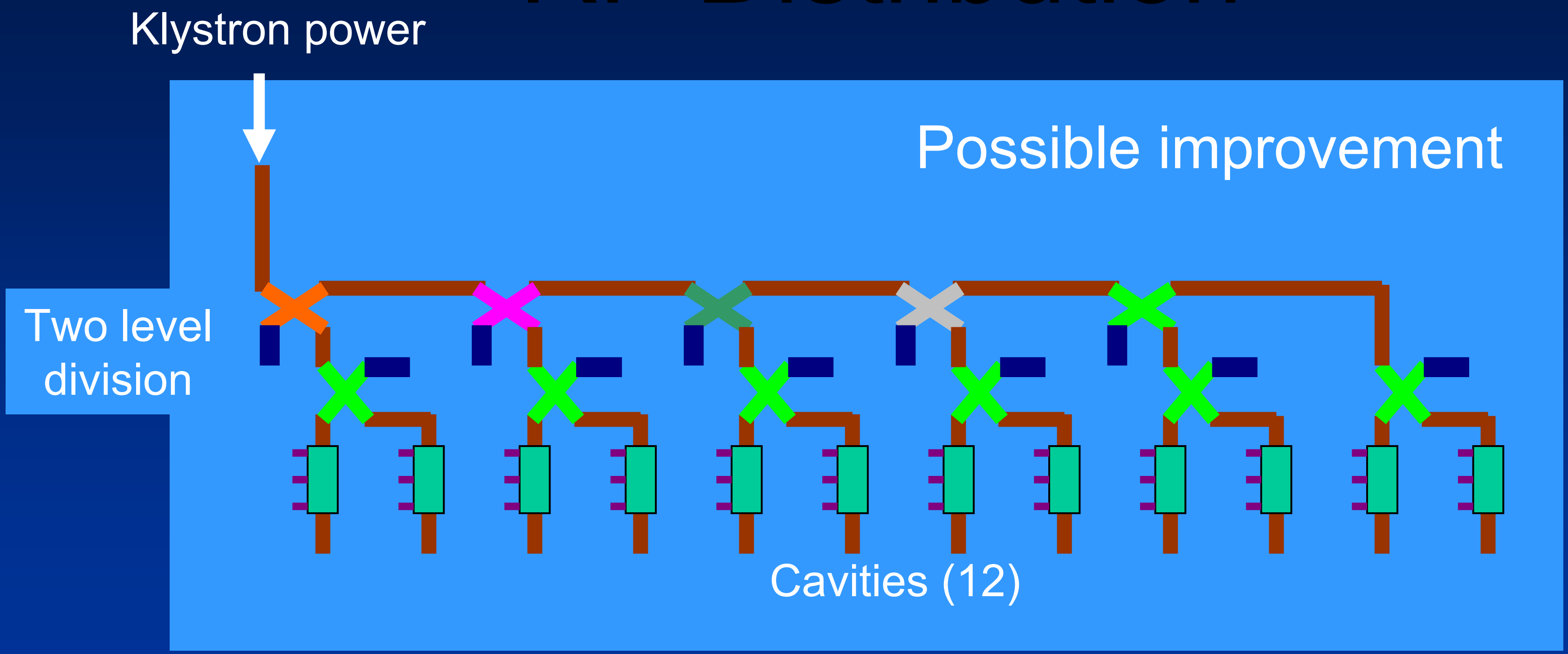
KEK

RF Distribution

TESLA TDR and XFEL solution (TTF)

Uses many circulators to protect klystron from reflected power (and isolate couplers)

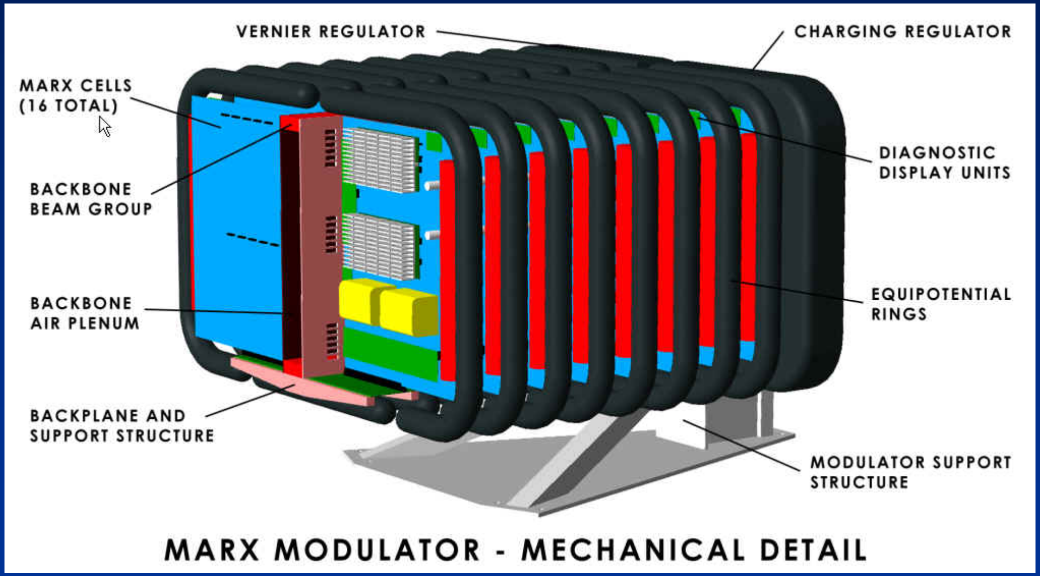
RF Distribution



- 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

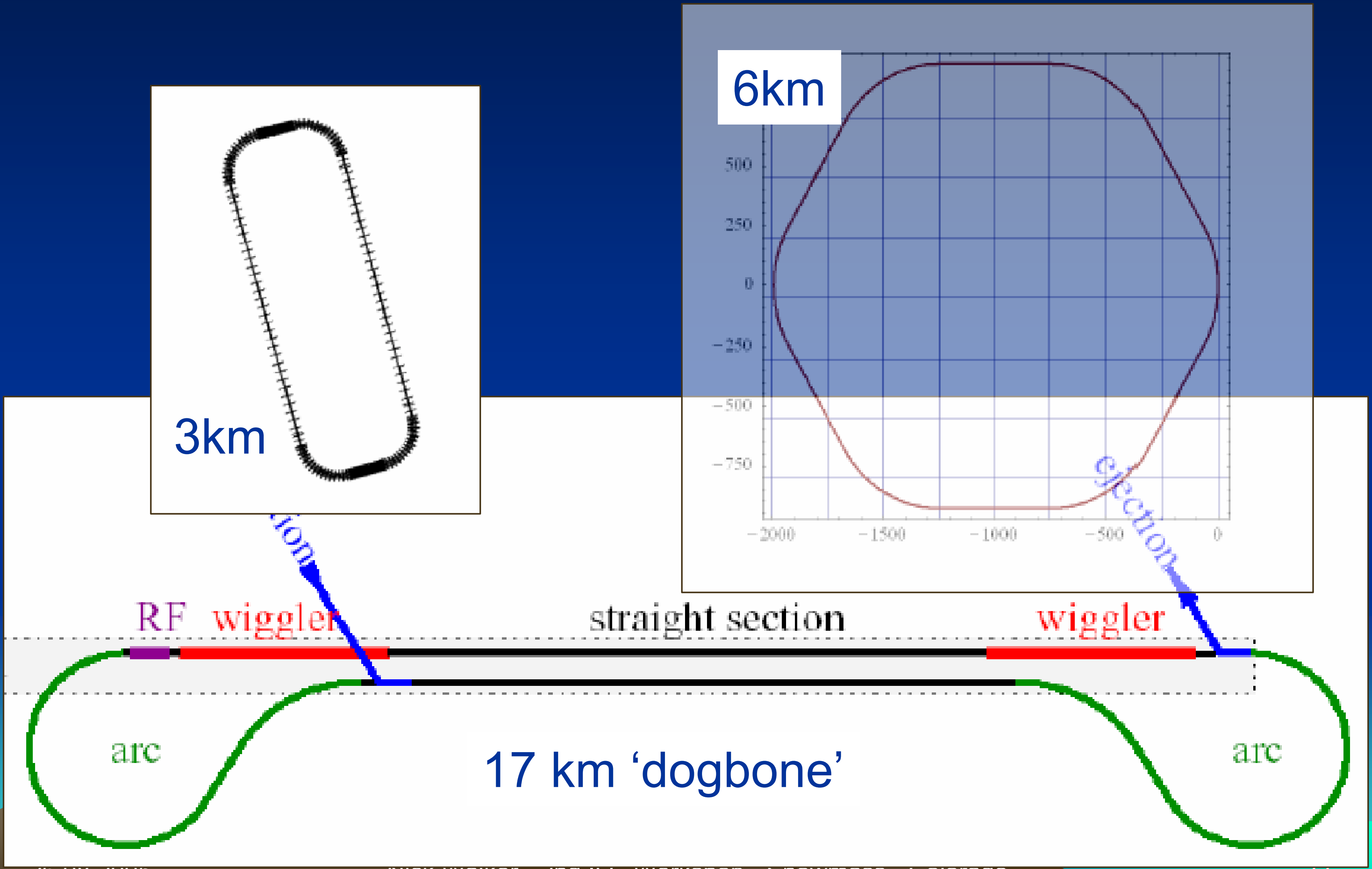


(~ 2m Long)

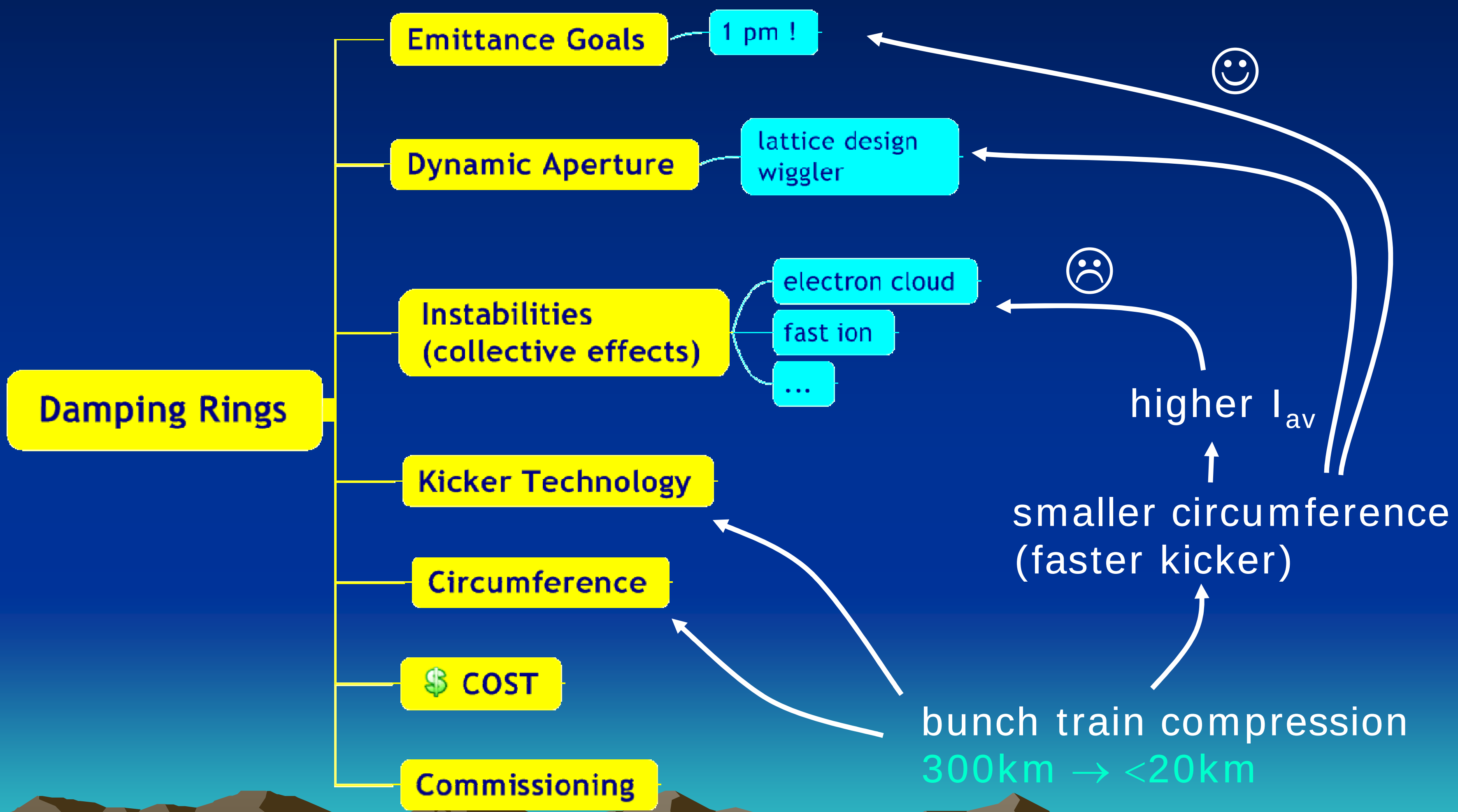
Operation: an array of capacitors is charged in parallel, discharged in series.

Will test full prototype in 2006

Damping Rings: Three variants



Damping Rings



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 ☺

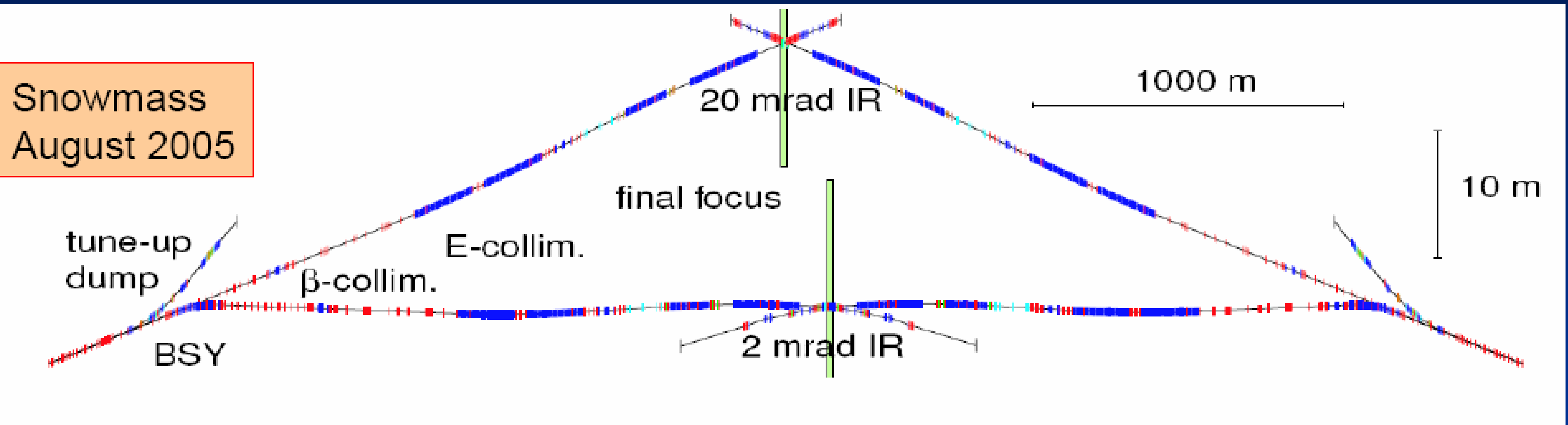
Positron Source

WG3a

Risks & Concerns

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

Beam Delivery, MDI



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.

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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

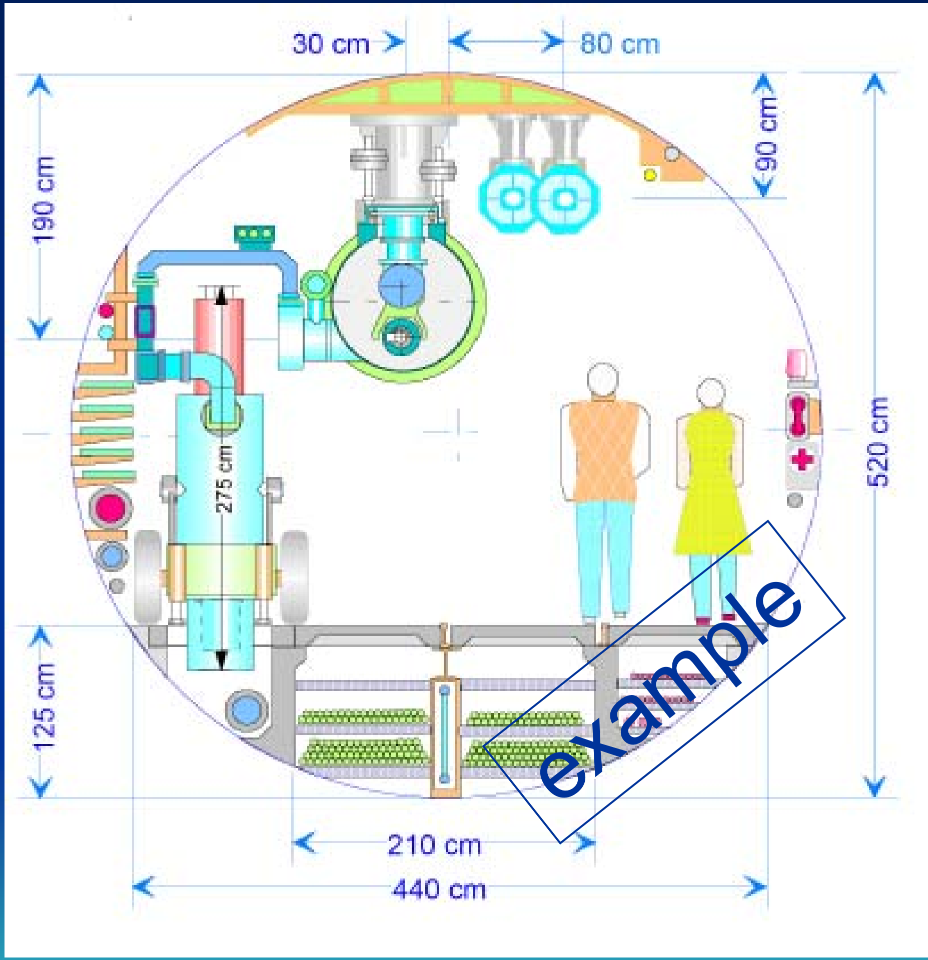
May well be influenced by site constraints

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)



One vs Two Tunnels (cont.)

Reliability studies favour 2 tunnel solution

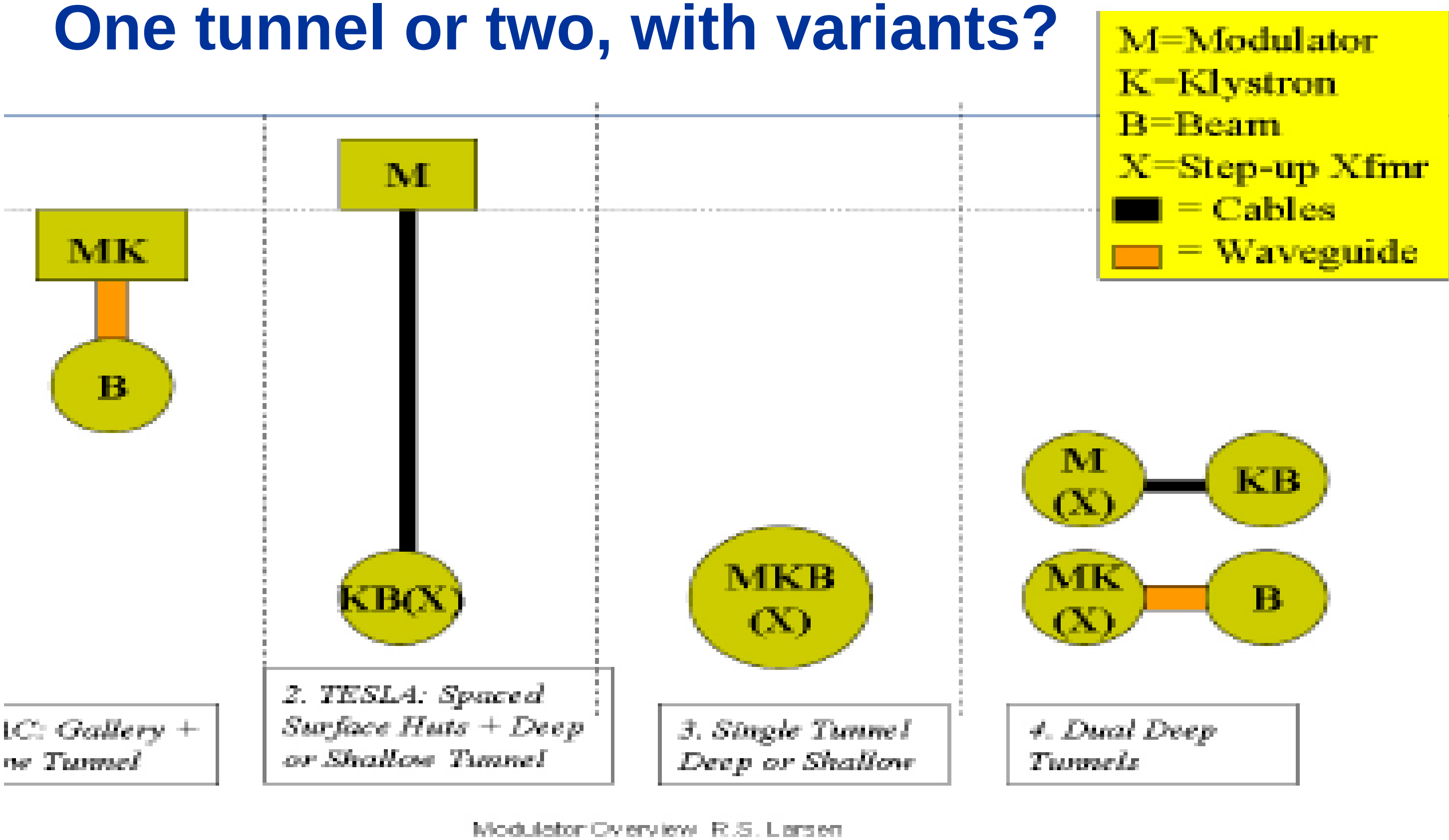
(recommendation from WG2/GG3 based on these studies)

Tunnel Scenarios

ILC8	1 tunnel, undulator e+, keep-alive 2	64.2%
ILC10	ILC8 and robotic repair	68.1%
ILC11	2 tunnel, support tunnel only accessible with RF off, keep-alive	72.3%
ILC12	2 tunnel, keep-alive source 2	78.3%

Possible Tunnel Configurations

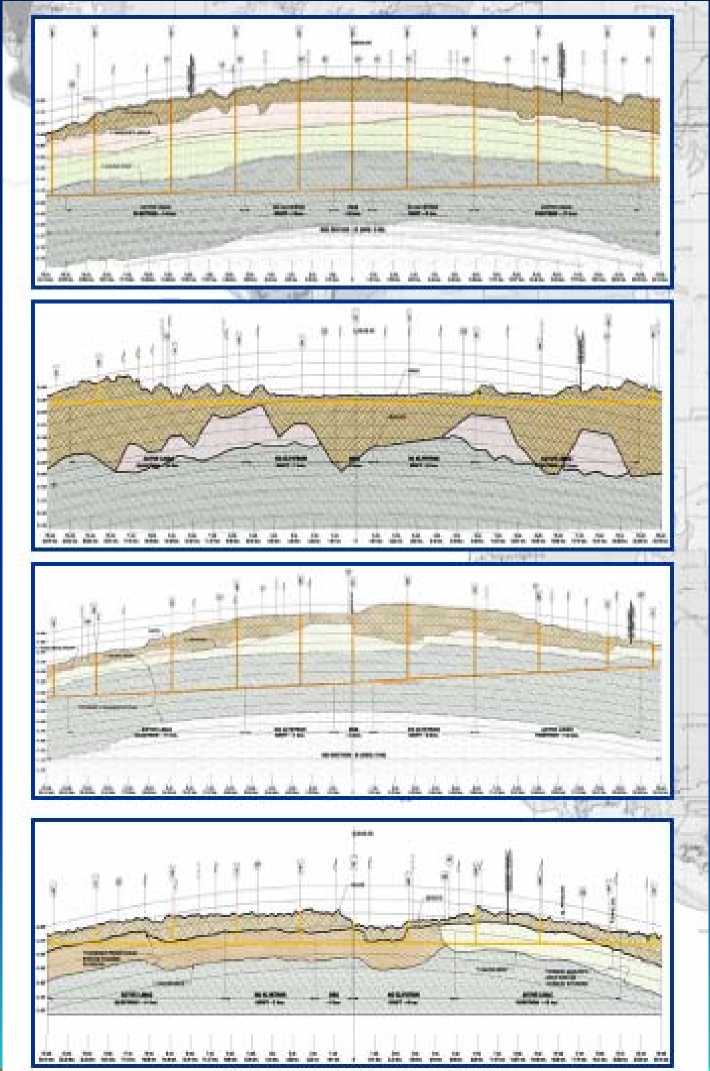
- **One tunnel or two, with variants?**



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



Typical Site Profiles Under Study

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

Critical R&D to reduce $$$$

Running out of time….

- Main accelerator beam dynamics (WG1)
- Bunch Compression (WG1)
  - Recommendation: 2 stage preferred ($6mm \rightarrow 150\mu m$ or $9mm \rightarrow 300\mu m$)
- 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

B11 fx cavity shape/material/processing

	A	B	C	D	E	F
1	Rank	Decisions	expense	impacts other decisio	decision contentiousne	product
2	1	beam and luminosity parameters	1	1	2	2
3	2	main linac starting gradient, upgrade gradient, and upgrade path	1	3	1	3
4	3	straight or follow earth's curvature?	1	1	2	2
5	4	1 or 2 IRs, if two, run interleaved?	1	3	1	3
6	5	1, 1.5, or 2 tunnel	1	1	1	1
7	6	DR size and shape	1	2	1	2
8	7	e+ source type conv/undulator	2	1	2	4
9	8	is there an e+ pre damping ring	1	2	3	6
10	9	DR location: 1st half tunnel, 2nd half, ceiling, under cryomodules, separate tunnel	1	2	1	2
11	10	cavity shape/material/processing	1	3	1	3
12		How much is a 1% change in average luminosity worth?	0	1	2	0
13		Minimize capital cost + N years of operations. N=?	0	2	2	0
14		tunnel depth	1	2	2	4
15		how many diagnostic sections in linac?	2	3	2	12
16		bunch/train structure	2	1	2	4
17		modulator type/voltage	2	2	2	8
18		crossing angle	1	2	1	2

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

* workshop WG/GG convener

Chris Adolphsen, SLAC*
Jean-Luc Baldy, CERN*
Philip Bambade, LAL, Orsay
Barry Barish, Caltech (the boss)
Wilhelm Bialowons, DESY*
Grahame Blair, Royal Holloway*
Jim Brau, University of Oregon
Karsten Buesser, DESY
Elizabeth Clements, Fermilab
Michael Danilov, ITEP
Jean-Pierre Delahaye, CERN (EU dep. dir.)
Gerald Dugan, Cornell University (US dir.)
Atsushi Enomoto, KEK*
Brian Foster, Oxford University (EU dir.)
Warren Funk, JLAB
Jie Gao, IHEP*
Terry Garvey, LAL-IN2P3*
Hitoshi Hayano, KEK*
Tom Himel, SLAC*
Bob Kephart, Fermilab*
Eun San Kim, Pohang Acc Lab
Hyoung Suk Kim, Kyungpook Nat'l Univ
Shane Koscielniak, TRIUMF
Vic Kuchler, Fermilab*
Lutz Lilje, DESY*

Tom Markiewicz, SLAC
David Miller, Univ College of London
Shekhar Mishra, Fermilab
Youhei Morita, KEK
Olivier Napoly, CEA-Saclay
Hasan Padamsee, Cornell University
Carlo Pagani, DESY
Nan Phinney, SLAC
Dieter Proch, DESY*
Pantaleo Raimondi, INFN
Tor Raubenheimer, SLAC*
Francois Richard, LAL-IN2P3
Perrine Royole-Degieux, GDE/LAL
Kenji Saito, KEK*
Daniel Schulte, CERN*
Tetsuo Shidara, KEK
Sasha Skrinsky, Budker Institute
Fumihiko Takasaki, KEK
Laurent Jean Tavian, CERN
Nobu Toge, KEK
Nick Walker, DESY (EU dep. dir.)*
Andy Wolski, LBL*
Hitoshi Yamamoto, Tohoku Univ
Kaoru Yokoya, KEK*

49 members

Towards a final BCD

we are here

2005

August	September	October	November	December

WW/GG summaries + broader input

Response to Himel list (40 questions)

all documented ‘recommendations’ publicly available on www (request community feedback)

review by BCD EC

BCD EC publishes ‘strawman’ BCD

public review

Frascati GDE meeting

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

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