ILC Cost Estimating Activities

"Don't ask me what it costs, yet!"

Peter H. Garbincius, Fermilab
Chairman, GDE Design & Cost Board

Fermilab Food for Thought
May 16, 2006

http://www-ilcdcb.fnal.gov/LCD_Cost Est_4may06.pdf

Outline

- ILC RDR & schedules
- ILC GDE Organization
- Prior Cost Est. Studies
- Major Cost Drivers
- International Cost Ests.
- Contingency vs. Risk
- Cost Est. Guidelines
- Anticipated new Ests.
- U.S. Estimates/LCFoA

- What Will RDR Quote?
- WBS & Level of Detail
- Elements of Cost Model
- Basis of Estimate & Risk
- Working Model of Construction Schedule
- Near Term Activities
- Summary

ILC Reference Design Report (RDR)

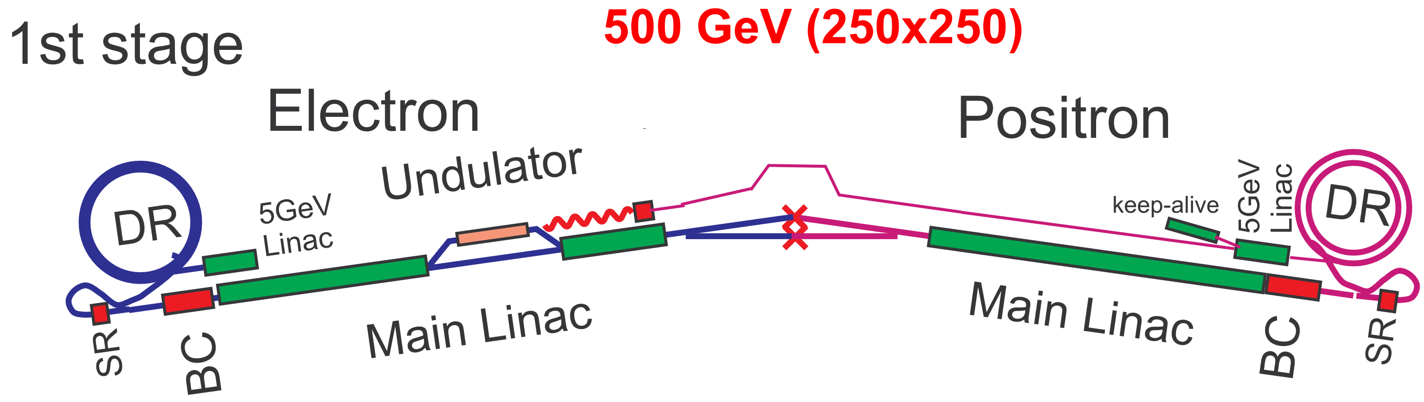
- Will include a cost estimate for the ILC as described in the
  Baseline Configuration Document (BCD)

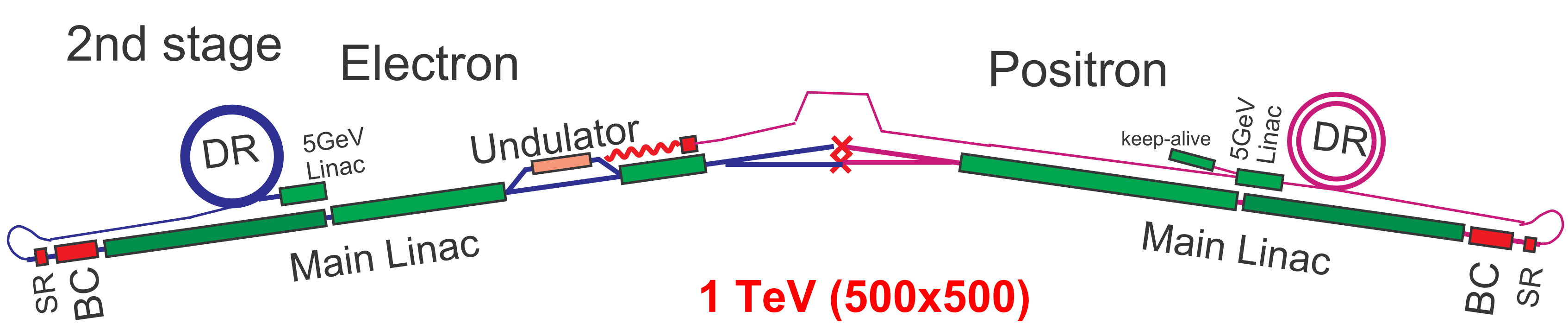
  http://www.linearcollider.org/wiki/doku.php?id=bcd:bcd_home

- Due by the end of (calendar) 2006

- Barry has goal of a ± 20% estimate
  very optimistic for this timescale!

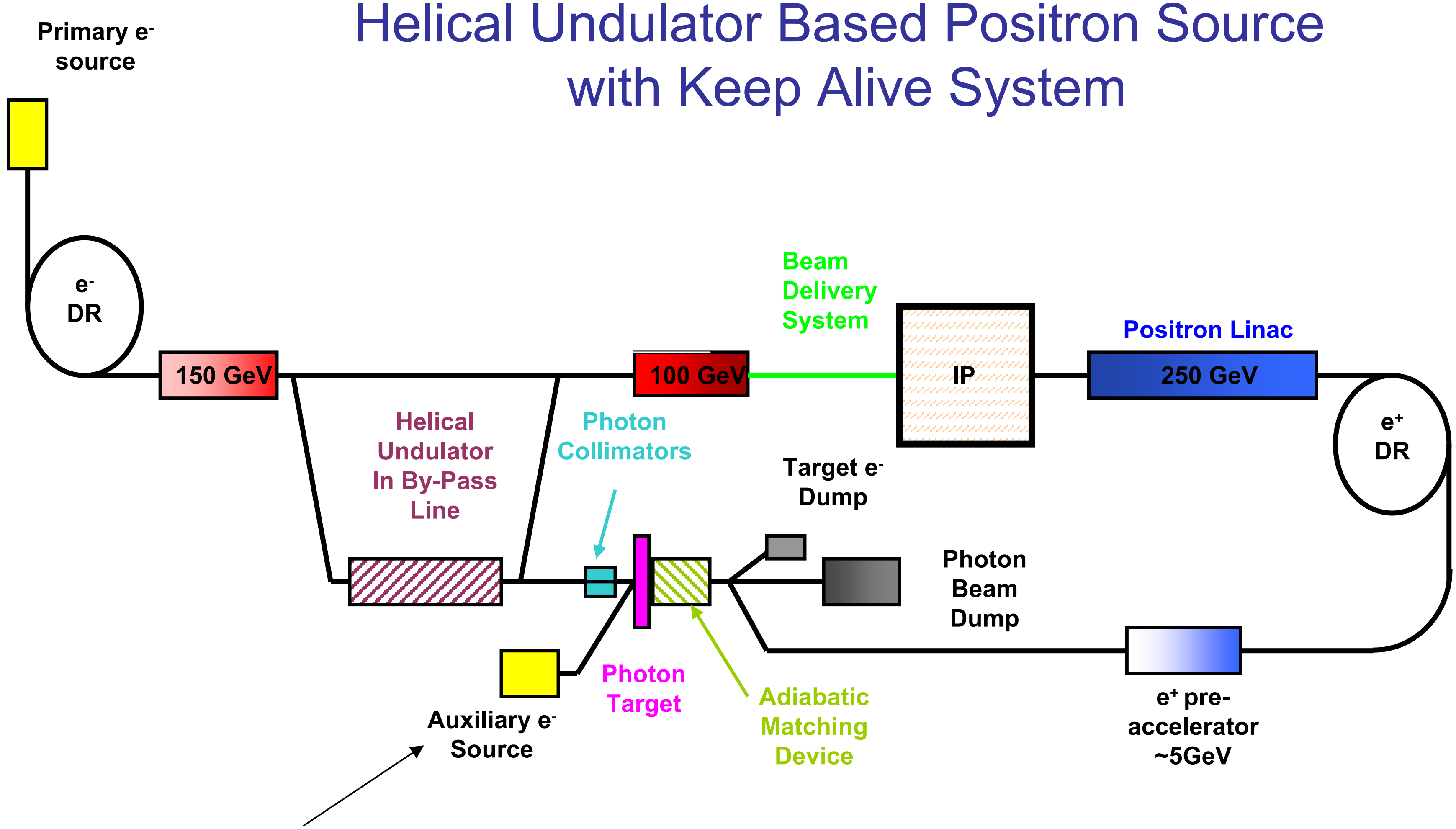
Baseline Configuration





Positron Source

Helical Undulator Based Positron Source with Keep Alive System



Keep Alive Source: This source would have all bunches filled to 10% of nominal intensity.

RDR Schedule & Milestones

- August, 2005 – Snowmass => generate BCD
- December, 2005 – Frascati – accept BCD

  kick-off & preliminary instructions to groups
- March - Bangalore - instructions & status

  first cost estimates due June 25
- July – Vancouver – preliminary cost estimate

  iterate and optimize cost vs. design
- November – Valencia – “final” RDR cost est.
- end 2006 – complete Reference Design Report

ILC GDE Organization

- Director – Barry Barish **Executive**
- Regional Directors (3) **Committee**
- Gang of Three **(Walker, Raubenheimer, Yokoya)**
- Cost Engineers (2 + PHG) RDR
- Integration Physicist Management
  + Barry Team
- Change Control Board
- Research &Development Board
- Design & Cost Board (9 + PHG, chairman)

Cost Roll-ups

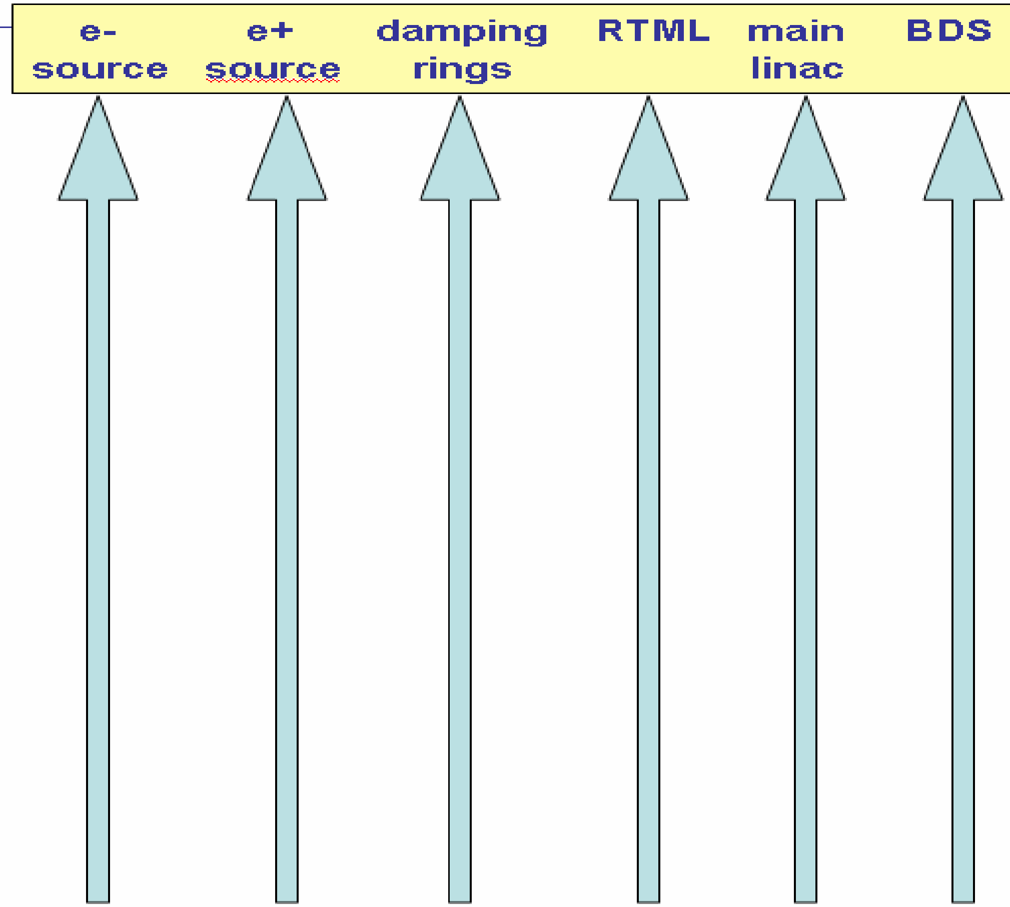
Area Systems

Technical Systems

- Vacuum systems
- Magnet systems
- Cryomodule
- Cavity Package
- RF Power
- Instrumentation
- Dumps and Collimators
- Accelerator Physics

Global Systems

- Commissioning, Operations & Reliability
- Control System
- Cryogenics
- CF&S
- Installation



Prior Cost Estimating Studies

for Cold, SC RF technology Linear Collider

- TESLA Technical Design Report (2001)
- KEK Evaluation of TESLA TDR
- US Evaluation of TESLA TDR (2002)
- USLCTOS (2004)

New & Ongoing Cost Est Studies

- Revised Euro XFEL Cost Estimate (May 06)
- TTC Studies: CM Assembly, Couplers, EP

All of these studies are Confidential

The only numbers made public were the 8 high-level roll-ups of the TESLA TDR (not incl. XFEL increments):

Main Linac Modules	**1.131 B €**
Main Linac RF System	**0.587 B €**
Tunnel & Buildings	**0.547 B €**
Machine Infrastructure	**0.336 B €**
Damping Rings	**0.215 B €**
Auxiliary Systems	**0.124 B €**
HEP Beam Delivery System	**0.101 B €**
Injection Systems	**0.097 B €**
Total TESLA Estimate	**3.136 B €**

72% (first three items)

concentrate on major cost drivers

A short course in “VALUE”-speak

The ITER “VALUE” or “CERN CORE” methodology is becoming used in international projects to equitably divide-up contributions among the collaborating parties, especially where countries are responsible for “in-kind” contributions, rather than providing funding to a central management team.

5 equal partners each contribute 20% of the total VALUE, independent of what it actually cost each individual party.

VALUE is the least-common denominator among all parties in that it is the ***barest*** cost estimate that ***any*** of their funding agencies expect. It is anticipated that individual parties will add those appropriate items to this bare VALUE estimate in order to get a meaningful estimate for what that particular country would normally internally charge to such a project.

This prevents arguments such as,
"I don't charge for internal labor, so why should your labor be considered as part of your contribution?"

If each of two countries contributes identical magnets, their VALUE contributions will be identical, even if their internal costs to produce are substantially different.

Countries can contract according to their national interest, e.g. lowest internal cost or develop new industries, etc. "finance ministers", rather than just "scientists" will call the shots

Format and Scope of European and Japanese Cost Estimates

- Different than for U.S. Cost Estimate
- Follows ITER “Value” & CERN “CORE” model for International Projects this ITER approach was reviewed by Dan Lehman *et al.* in July, 2002
- Does not include: internal (institutional) labor, contingency, escalation, R&D, G&A overheads, pre-construction, and commissioning activities.

- least common denominator -
  minimizes construction cost estimate
- **not the traditional U.S. definition!**
- at time of RDR, it will be necessary to provide translation into any country’s cost estimating metric, e.g. Basis of Estimate => contingency estimate, in-house labor, G&A, escalation, R&D, pre-construction, commissioning, etc.

No Contingency?

No! The European and Japanese methods assume that all the design and estimating has been done up-front, inclusively, so there will be no add-ons due to incomplete engineering or scope changes
(all homework done at this stage) and that the estimates are statistically robust so over-runs in one area will be compensated by under-runs in another.

Contingency (2)

At this stage of project definition,
US estimates assume that engineering and cost estimating have NOT been completed to the ultimate level of detail.

In the US, contingency is added to cover:
- the missing level of detail,
- non-symmetric cost over/under-runs,
- and minor scope changes

Internationally, use "scope contingency"

RDR cost estimate will include Risk Analysis

RDR Cost Estimating Guidelines

- just outlined here – full version at
  http://www-ilcdcb.fnal.gov/RDR_costing_guidelines.pdf
- 500 GeV (250x250) + upgrade path for 1 TeV Beam Delivery Sys. Tunnels & Beam Dumps
- construction = authorization → installation not incl. R&D, commissioning, operations, decommissioning – but need these estimates!
- construction ends for individual item when installed, before commissioning begins
- working model assumes a 7 year construction phase

- based on a world-wide call for tender:
  lowest reasonable price for required quality
- three classes of items in cost estimate:
  - Site-Specific (separate estimates for each site)
    e.g. tunnel & regional utilities (power grid, roads)
  - Conventional – global capability (single world est.)
    e.g. copper and steel magnets
  - High Tech – cavities, cryomodules, RF power -
    cost drivers – all regions want – 3 estimates

  Cost Engineers must determine algorithm to
  combine and present these multiple estimates

- Learning curve for ILC quantities $P = P_1 N^a$
  need parameters or costs for different N's
- Estimate & Prices – as of January 1, 2006:
  exchange 1 M€ = $ 1.2 M = 1.4 Oku¥
  raw materials, no taxes, no escalation
- contingency is excluded in "value" estimate
  need risk analysis → prob. dist. for cost est.
- one common design and footprint
  geologic accommodations allowed
  need a common set of rules and codes
  e.g. life safety …
  if none available, ILC may have to define

- All cost estimates must be treated as
  confidential within the GDE
  not to be publicly presented
  or posted on public web site

- GDE Executive Committee
  will determine publication policy
  for all elements of cost estimate

We anticipate cost estimates for RDR to be available from:

- TESLA TDR (2001 – high level roll-ups for RDR)
- XFEL cost estimate (May 06)

  expected to be accessible for comparisons
- current TTC studies will be too late for RDR est.
- KEK (in-house + consultant) – Cryomodule & RF

  anticipate available in mid-June
- LCFoA Cost Estimate for RF Units

  Cryomodule, Klystron, RF Distribution, etc.

  contract *still* under negotiation,

  too late for estimate by June 06 => final Nov 06

- **JLab-Fermilab-SLAC (Funk-Stanek-Larsen) in-house cost estimate study for RF unit.**
  → bottom-up based on US experience:
  JLab, SNS, FNAL, SLAC (& TTF)
  parallel to LCFoA cost estimate study.

- **Regional 4 site-dependent cost estimates (CERN, DESY, Fermilab, Japan) for Conventional Facilities**

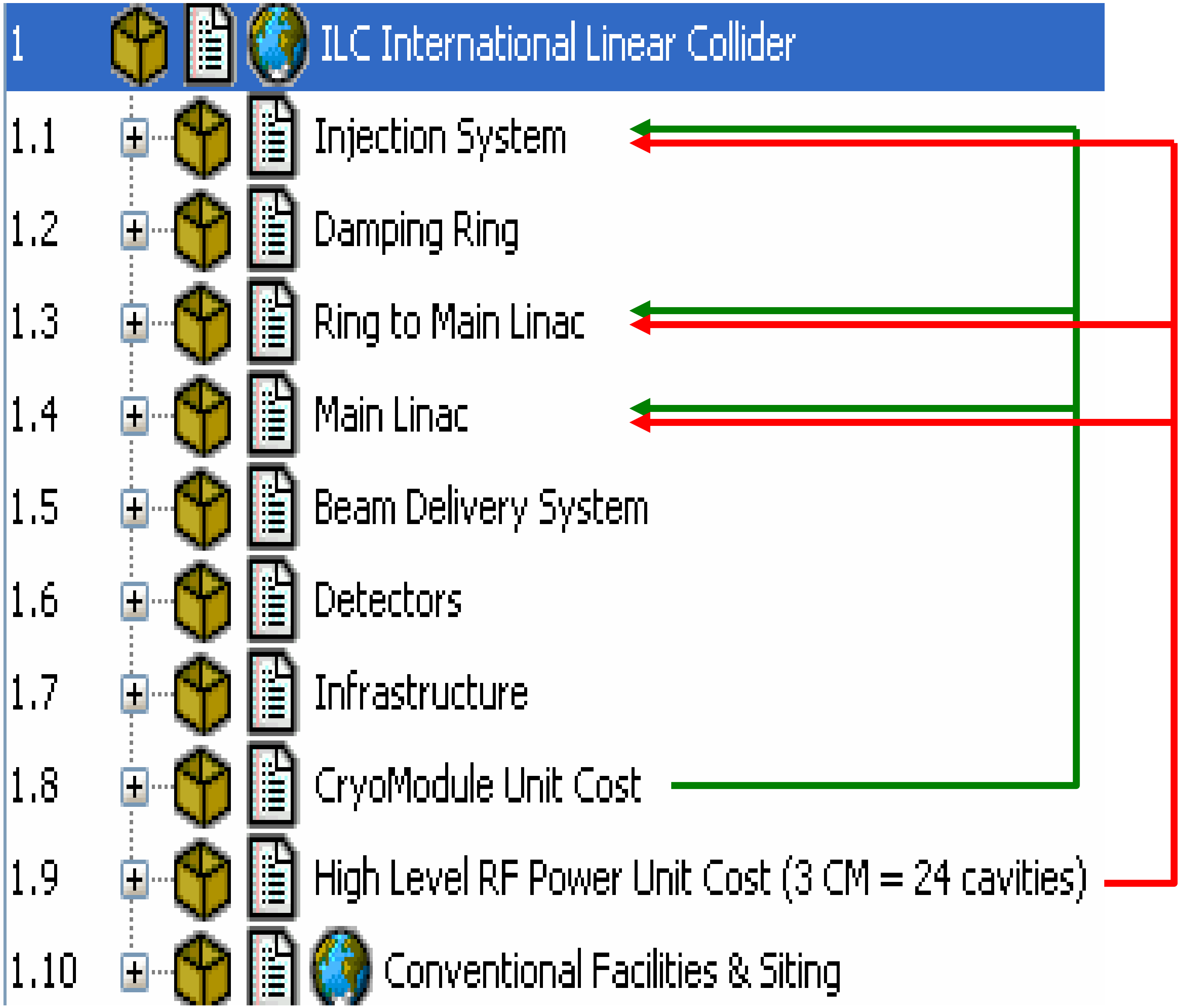
What will RDR quote?

- **Quote lowest reasonable world-market value estimate for adequate quality**

- **We worry about low-balling "VALUE":**
  no matter we say, it will be remembered as
  one, single, FINAL *cost* number,
  all notes, caveats, fine print will be ignored

- **How to combine different estimates?**
  4 sites (4 estimates or range of estimates?)
  combine Euro, US, Japan component ests
  lowest, average, or use a divisional model?

Current WBS for RDR



WBS Level of Detail Desired

- Would like to have estimates in lowest level presented to ~ a few x 0.1% of total ILC
- Graded approach, puts effort onto cost drivers
- System Groups might need lower levels of WBS in order to produce their own cost estimate
- So far, WBS are guideline examples, intend to be modified to meet System Group needs (received WBS for CF&S, Controls, RF Power)
- Examples below are for Materials & Services (not internal labor) from USLCTOS

Level of Detail Example (1)

cryogenics_WBS_28feb06.xls (other examples in backups)

LHC refrig. single units

%			percentage of total materials cost for USLCTOS 500 GeV Cold option these percentages for USLCTOS are somewhat sensitive, they are listed just to give idea of level of detail that has been attained
WB_6feb_PG_8feb (Follows USLCTOS)			This is what is on the web, the items 1.8.3.1.1.i
1.8.3 Cryogenic Plant and Distribution			were omitted. The green numbers on left are
4.08		1.8.3.1 Cryogenic Plants	percentage 4.08% of total USLCTOS 500 cold M&S
3.27		1.8.3.1.1 Cryo Refrigeration Unit (includes cryo distribution, but not civil utilities)	
This layer was not included - consider adding this layer to increase sensitivity			
	1.12	1.8.3.1.1.1 Cryo Cold Boxes	
	0.68	1.8.3.1.1.2 Cryo Warm Compressor System	
	0.12	1.8.3.1.1.3 Cryo Cold Compressor System	
	0.11	1.8.3.1.1.4 Cryo Purification System	
	0.13	1.8.3.1.1.5 Cryo Refrigeration System Controls	
	0.10	1.8.3.1.1.6 Cryo Liquid Helium Storage	
	0.17	1.8.3.1.1.7 Cryo Vertical Transfer Line	
	0.16	1.8.3.1.1.8 Cryo Distribution Boxes 1,2,8	
	0.11	1.8.3.1.1.9 Cryo Distribution Boxes 3,6,7	
	0.16	1.8.3.1.1.10 Cryo Warm He Gas Header	
	0.09	1.8.3.1.1.11 Cryo Vacuum Barriers	
	0.19	1.8.3.1.1.12 Cryo System Installation Contracts	
	0.04	1.8.3.1.1.13 Cryo Miscellaneous	
	0.05	1.8.3.1.1.14 Cryo Feed Boxes	
	0.04	1.8.3.1.1.15 Cryo End Boxes	
0.25		1.8.3.1.2 Cryo Cooling Towers	
0.04		1.8.3.1.3 Cryo Warm Helium Storage	
0.04		1.8.3.1.4 Cryo Helium Gas (initial charge) **- should this be operating, not construction?**	
0.00		1.8.3.1.5 Cryo Vacuum Barrier	
0.01		1.8.3.1.6 Cryo Feed Boxes	
0.01		1.8.3.1.7 Cryo End Boxes	
0.17		1.8.3.1.8 Cryo Load Controls	
0.30		1.8.3.1.9 Cryo Cold Bypass (1 kilometer) - what was this? fairly pricey!	
	1.8.3.2 Cryogenic Distribution **- actually included above 1.8.3.1.1.i - so can discard this element**		

Elements of the Cost Model

- Cost Engineers & RDR Management Team must determine how to select a value to be quoted for such items w/multiple estimates
- Need estimates of most probable cost per WBS element and an indication of the anticipated probability distribution for costs.
- Median (50%), $\pm\ \sigma$ points of this distribution (or 90%-95% point for upper limit) account for non-symmetric, high cost tail

  => Risk Assignment for the cost estimate

Elements of the Cost Model (2)

- Risk Assessment for Costs:
  ideally, a probability distribution
  for expected costs
  see R. Brinkmann at Snowmass 2005
  for application to Euro XFEL
- Watch out for Correlated Risks:
  labor costs, $ - ¥ - € exchange rates,
  price of materials (e.g. steel, copper),
  cost of energy (for RF processing), etc.

Basis of Estimate

- description how cost estimate was obtained for each WBS element
- guide used for estimating the assigned level of cost risk (contingency) in the US
- similar to that used for assigning the probability distribution for costs by XFEL for risk analysis
- example below from RSVP experiment at Brookhaven National Lab

	Risk Factor	Weight
WBS Element #___________ **Element Name** ______________________________		
Design Risk (check one of 4): **(from RSVP at BNL, similar for US CMS, NCSX)**		
__ Concept only	15%	1
__ Conceptual Design Phase: some drawings; many sketches	8%	1
__ Preliminary Design > 50 % complete; some analysis complete	4%	1
__ Detailed Design > 50% Done	0%	1
Technical Risk (check one of 8 and answer Yes or No to two questions):		
__ New design; well beyond current state-of-the art	15%	2 or 4
__ New design of new technology; advances state-of-the art	10%	2 or 4
__ New design; requires some R&D but does not advance the state-of-the-art	8%	2 or 4
__ New design; different from established designs or existing technology	6%	2 or 4
__ New design; nothing exotic	4%	2 or 4
__ Extensive modifications to an existing design	3%	2 or 4
__ Minor modifications to an existing design	2%	2 or 4
__ Existing design and off-the-shelf hardware	1%	2 or 4
Yes/No – does this element push the current state-of-art in Design?		either = 2
Yes/No – does this element push the current state-of-art in Manufacturing?		both = 4
Cost Risk (check one of 8 and answer Yes or No to two questions):		
__ Engineering judgment	15%	1 or 2
__ Top-down estimate from analogous programs	10%	1 or 2
__ In-house estimate for item with minimal experience and minimal in-house capability	8%	1 or 2
__ In-house estimate for item with minimal experience but related to existing capabilities	6%	1 or 2
__ In-house estimate based on previous similar experience	4%	1 or 2
__ Vendor quote (***or industrial study***) with some design sketches	3%	1 or 2
__ Vendor quote (***or industrial study***) with established drawings	2%	1 or 2
__ Off-the-shelf or catalog item	1%	1 or 2
Yes/No – are the material costs in doubt?		either = 1
Yes/No – are the labor costs in doubt?		both = 2
Schedule Risk (check one):		
__ Delays completion of critical path subsystem item	8%	1
__ Delays completion of non-critical path subsystem item	4%	1
__ No schedule impact on any other item	2%	1
Prepared by: _______________________ **date:** _________________		
Comments:		

Basis of Estimate – Estimate of Risk Distribution – example

1.1.2.3 Build Framistat	Category	Risk Factor	Weight	RF*Wgt
Design Risk: Conceptual Design Phase: some drawings; many sketches				
	Design Risk	8%	1	8%
Technical Risk: New design; nothing exotic				
No – does this element push the current state-of-art in Design?				
Yes – does this element push the current state-of-art in Manufacturing?				
Technical Design **OR** Manufacture Risk		4%	**2**	8%
Cost Risk: In-house estimate for item with minimal experience but related to existing capabilities				
No – are the material costs in doubt?				
Yes – are the labor costs in doubt?				
Material **OR** Labor Cost Risk		6%	**1**	6%
Schedule Risk: Delays completion of non-critical path subsystem item				
	Schedule Risk	4%	1	4%
	Suggested Risk upper limit (sum)			**26% ***

Prepared by: ______________________ **date:** ________________

Comments:

*** do we take this as upper limit, ½ upper limit, 1σ ?**

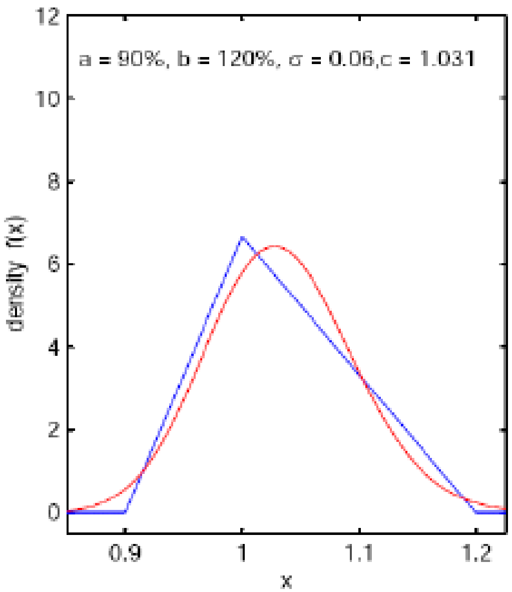
XFEL: Standard cost uncertainty categories

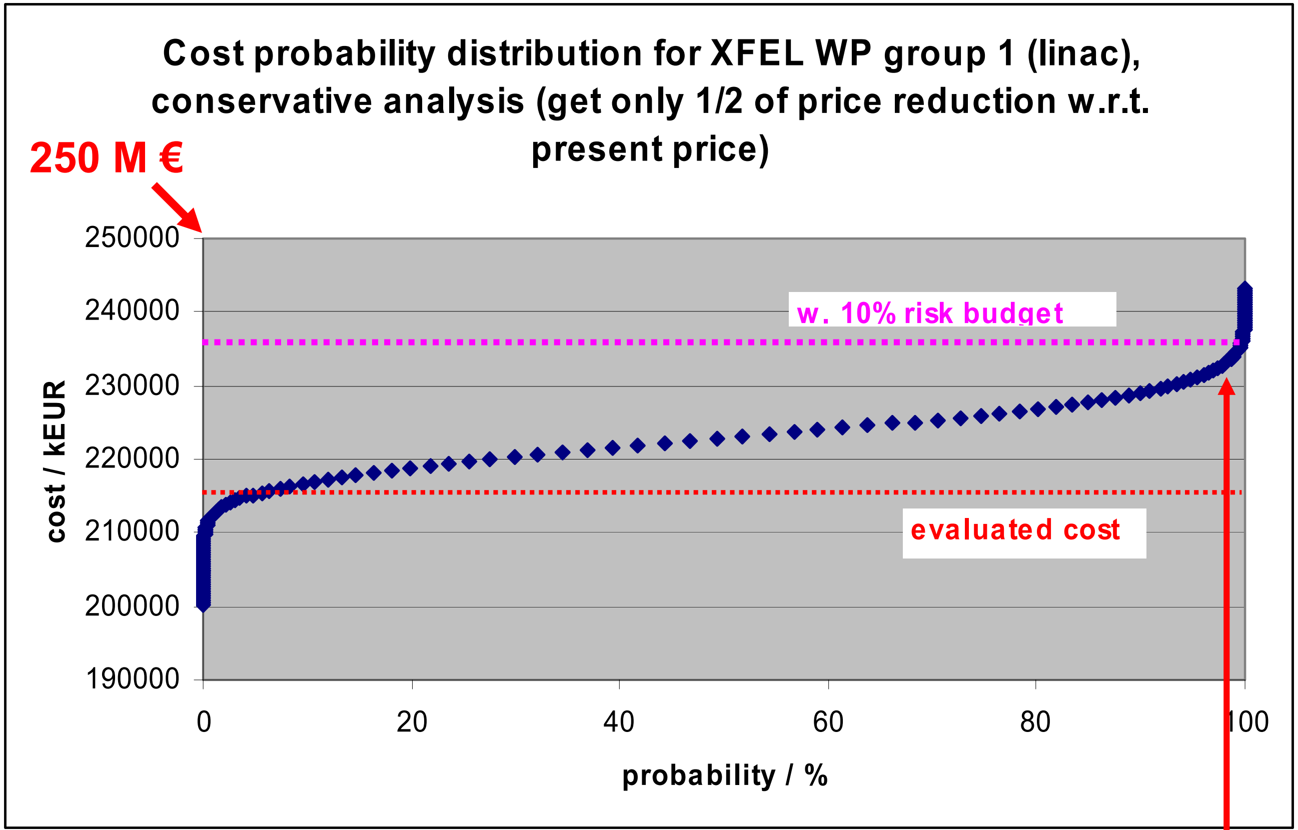
Category	definition	lower/upper range
C1	good experience and present price for this component/sub-system are available, no cost scaling for large quantities has been applied	-10% / +10%
C2	experience and present price for similar components/sub-systems are available, no or only minor scaling to large quantities has been applied	-20% / +20%
C3	present price is available, significant (>25%) cost scaling to large quantities has been applied	-10% / +20%
C4	present price is available, price from industrial study is used which results in significant (>25%) cost reduction for production of large quantities	-10% / +20%
C5	present price not available, price from industrial study is used	-10% / +20%
C6	required technology pushes state-of-the art, significant R&D still required	-10% / +50%
P1	personnel requirements well known due to present experience or with similar systems in previous large scale projects	-10% / +10%
P2	personnel requirements less certain or relatively large fraction of R&D included in this WP	-20% / +20%

Furthermore, raw material cost uncertainties (volatility of metal and currency markets) have been added where appropriate (e.g. Niobium sheets & parts)

XFEL: Result of maximum risk analysis

triangular & log-normal -10%,+20% cost p.d.f. for each element





Reinhard: ask for "risk" funding to cover up to 98th percentile

Reinhard Brinkmann - XFEL

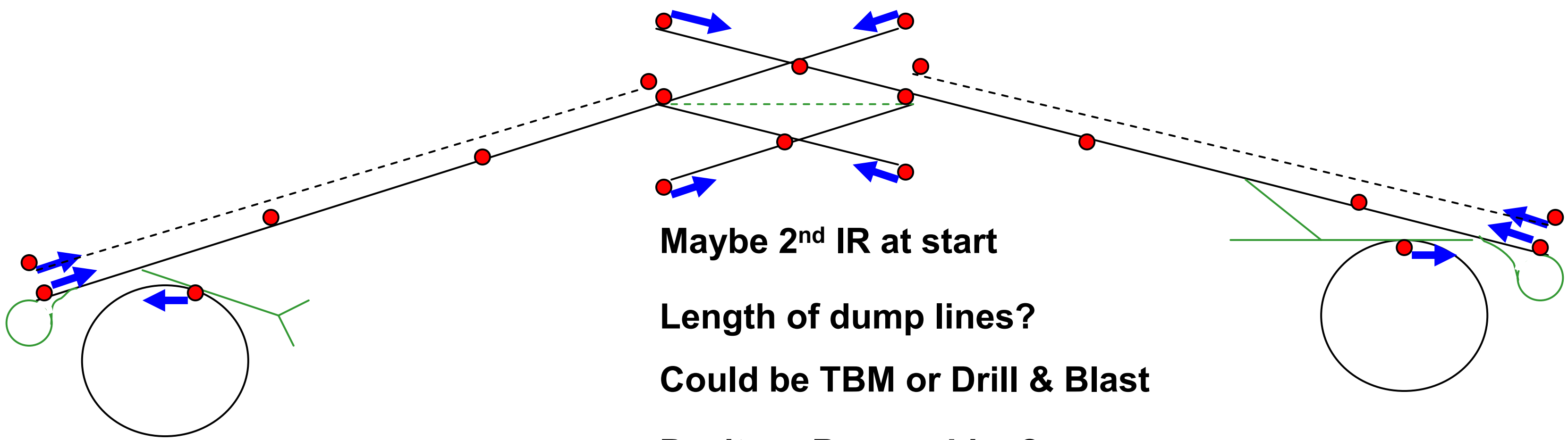
updated XFEL cost estimate now includes:

- in-house manpower
- overhead for central services & admin.
- request for "risk funding"

Sketch of Civil Construction Activities

use only for sizing production capacities for components

(my own view < 1 man-week thought – definitely not to scale)



Maybe 2nd IR at start

Length of dump lines?

Could be TBM or Drill & Blast

Positron Bypass Line?

Drill & Blast or TBM?

● **Shafts (many!)**

← **TBM tunnels (8 or 10)**

Outline of PHG Construction Schedule Model for generating component cost estimate

- only a working model – not funding limited!
- 7 years – after funding authorization => t0 through installation of all components
- need to start installation of components while civil construction continues:

t0+30 months: e- SRC, e+ Keep-Alive, RTML arcs

t0+33 months: DR   t0+47 months.: start ML

t0+65 months: last sec ML & BDS

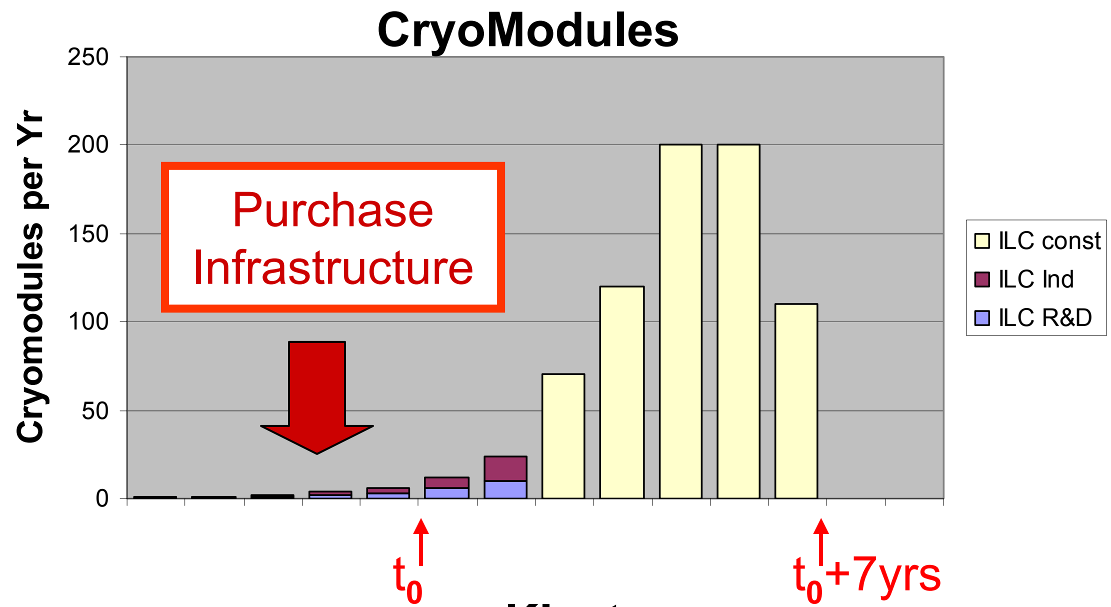
t0+78 mo.: t0+6.5 yrs.: last components delivered

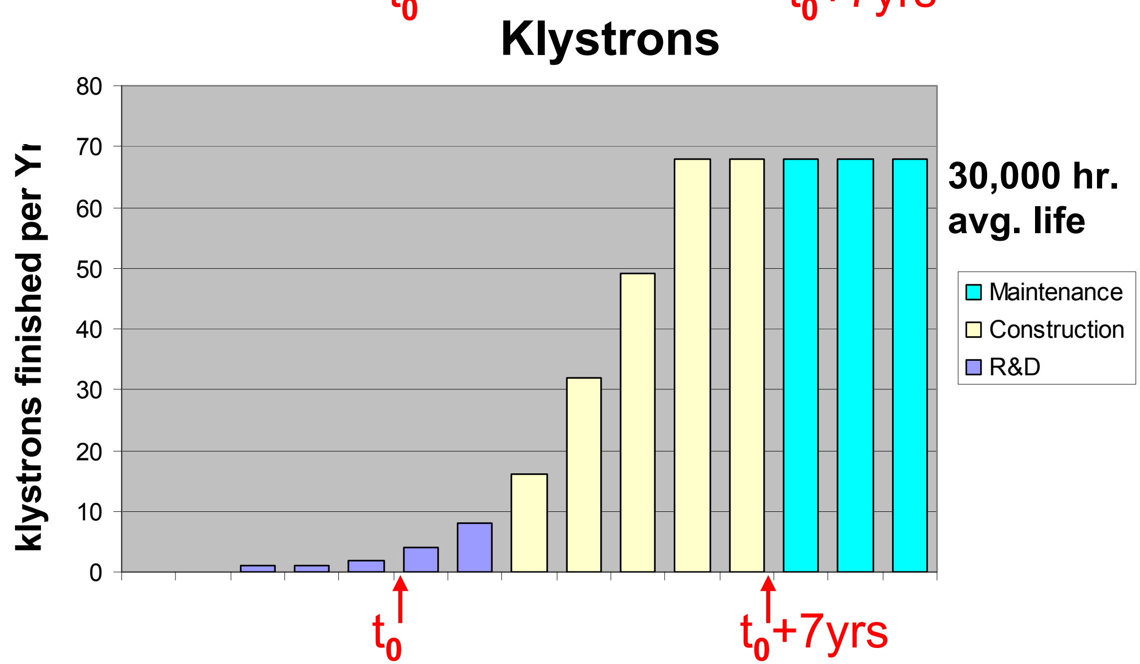
t0+84 mo.: t0+7 yrs.: last component installed

start commissioning each sub-systems (operating) as soon as its components are installed

CryoModule & Klystron Production Models

- Bob Kephart's first guess at rate for each of 3 equal vendors
- Ramp-up: R&D, Industrialization, Production





Near Term RDR Activities

- augment the RDR Cost Estimating Guidelines

  "Initial Questions for Area System Groups"
  & prior NLC/USLCTOS guidelines morph into
  "RDR Cost Estimating Instructions" 5/1 draft
  instructions & formulae for needed cost info

- RDR Management Team & DCB have been cycling through Area, Global, Technical Systs. for weekly status discussions & milestones

Summary on RDR Cost Estimating

- Organizing (still much to do) and
- Starting (just barely) on cost estimates
- Preliminary view of and begin reaction to
  estimates at Vancouver in July,
  complete ests. at Valencia in November
- Try for new cost estimate, esp. cost drivers: maybe for civil, less likely for Cav, CM, RF
- Planning to quote ITER-like “VALUE”,
  likely to be somewhat controversial in US

“Still, don’t ask me what it costs!”

End of Presentation

Backup Slides

Design Cost Board Members

- Tetsuo Shidara – KEK (Cost Engineer)
- Atsushi Enomoto – KEK
- Nobuhiro Terunuma – KEK
- Alex Mueller – ORSAY
- Jean-Pierre Delahaye – CERN
- Wilhelm Bialowons – DESY (Cost Engineer)
- Nan Phinney – SLAC
- Ewan Paterson – SLAC (Integration Scientist)
- Robert Kephart – Fermilab
- Peter Garbincius, Chairman – Fermilab (C.E.)

ILC GDE Organization

Groups doing the work!

- **<u>Area Systems Groups</u>:**
  e- Source, e+ Source,
  Damping Rings, RTML,
  Main Linac,
  Beam Delivery System

- **<u>Global Systems Groups</u>:**
  Commissioning, Operations,
  & Reliability,
  Controls, Cryogenics,
  Conventional Construction,
  Installation, Integration (new)

- **<u>Technical System Groups</u>:**
  Cryomodules,
  SC RF Cavities,
  RF Power Systems,
  Vacuum Systems,
  Magnet Systems,
  Instrumentation,
  Dumps & Collimators

RDR Cost Estimating Guidelines

version 5 15march06

The following are preliminary guidelines for developing the RDR cost estimate. Since there are very different approaches to cost estimating in different parts of the world, it will be necessary to separately estimate construction costs, preparation and R&D, commissioning and operations. The center of mass energy is 500 GeV. Essential components for the 1 TeV option, which will be very difficult to add later, are included.

These estimates will be framed in terms of a common “value” of purchased components and total person hours of in-house labor. In general, the component cost estimate will be on the basis of a world-wide call for tender, i.e. the value of an item is the world market price if it exists. This also applies to the conventional construction and Consultant Engineering. The estimates should be based on the lowest price for the required quality.

There are three different classes of items which must be treated somewhat differently:

- **Site specific:** The costs for many aspects of conventional facilities will be site specific and there will be separate estimates for each sample site. These are driven by real considerations, e.g. different geology and landscape, availability of electrical power and cooling water, etc. Site dependant costs due to formalities (such as local codes and ordinances) are not included. Common items such as internal power distribution, water and air handling, etc., which are essentially identical across regions although the implementation details differ, can have a single estimate.
- **High technology:** Items such as cavities, cryomodules, and rf power sources, where there will be interest in developing expertise in all three regions (Asia, Europe and Americas), should be estimated separately for manufacture by each region. Costs should be provided for the total number of components along with parameters to specify the cost of a partial quantity. These estimates will be combined by some algorithm to be determined later.
- **Conventional**: Components which can be produced in all regions need not be estimated separately for manufacture in each region. The cost should be based on the lowest world market price.

In addition to these general comments, we list some specific guidelines:

1. The construction period extends from first funds authorization until the last component is installed and tested for each system. Necessary infrastructure must be estimated as part of the construction cost. Preparation and R&D costs should be estimated separately. The preparation phase includes the minimum items and activities needed to gain construction approval. Separate estimates are also needed for commissioning and beam tests and for operations.

2. The component cost includes external labor, EDIA, offsite QC and technical tests. In general, the estimate is the lowest world-wide cost for required quality. A single vendor is assumed, or in some cases, two vendors for risk minimization. No costs are assumed for intellectual property rights.

3. In-house labor is estimated in person-hours. Only three classes of manpower are used: engineer/scientist, technical staff, and administrative staff. Additional central staff will be needed for commissioning and operation,.

4. For large numbers of items, learning curves should be used to scale the cost decrease with quantity. The cost improvement is defined by the following equation:

$$\boldsymbol{P = P_1 N^a}$$

where ***P*** is the total price of *N* units, $\boldsymbol{P_1}$ is the first unit price and *a* is the slope of the curve related to learning [1]. The slope ***a*** is for large *N* also the ratio of the last unit price $\boldsymbol{P_N}$ and the average unit price <***P***>. This will be described in more detail in the costing instructions. The value is calculated parametrically for the assumed 7 year given construction schedule.

5. Prices for raw material are world prices as of January 1, 2006, i.e. for copper, steel and niobium, etc. Prices for electrical power are those for the region as of January 1, 2006. Quantities should be stated explicitly so the cost can be scaled later.

6. The value unit needs to be defined. For now, one currency per region with fixed exchange rates should be used. The fixed exchange rates are:

   1 M€ = 1.2 M$ = 1.4 Oku¥.

   No tax is included. No escalation is used. The costs should be estimated as of January 1, 2006.

7. Contingency is for the moment explicitly excluded. In order to include it at a later stage, the technical groups should do a risk analysis, which will be used by the DCB to generate a probability distribution for the cost estimate. This will be described in more detail in the costing instructions.

8. There will be one common design and footprint, except for unavoidable site-specific differences, such as shaft location. Regional options such as utilizing existing machines can be proposed as alternates for cost savings. A common set of rules, codes and laws to satisfy all regions is used as long as the cost impact is not too significant. Where not covered by existing codes, a set of ILC standards must be developed which specify cost effective solutions, e.g. the distance between personnel crossovers for the two tunnels,

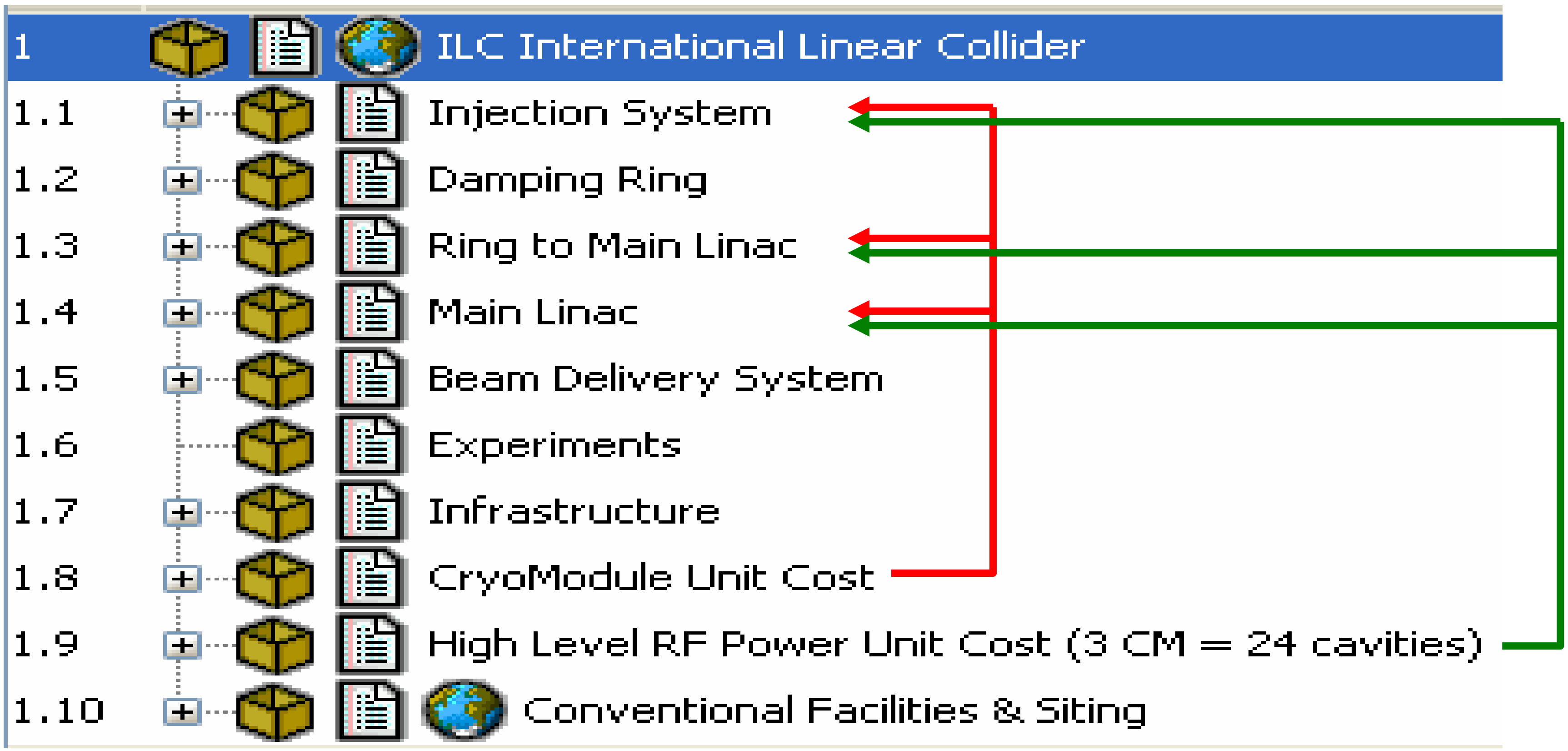
9. All cost estimates must be treated as confidential within the GDE (e.g. not to be publicly presented or listed on a publicly accessible web or wiki site). The Executive Committee shall determine the publication policy for all elements of the cost estimate.

These are the general guidelines, still working on specific instructions

References

[1] Department of Defense, United States of America, *Joint Industry Government Parametric Estimating Handbook*, Second Edition, Spring 1999.

Current WBS for RDR



1.1.1	Electron Injection
1.1.1.1	Electron Source
1.1.1.1.1	Laser System for Electron Gun
1.1.1.1.2	DC Polarized Electron Gun (120 kV)
1.1.1.1.3	Electron Gun Modulator (120 kV, 1.5 ms)
1.1.1.2	Buncher System
1.1.1.2.1	Subharmonic Buncher
1.1.1.2.2	Buncher
1.1.1.2.3	Solenoid System
1.1.1.3	Electron Prelinac
1.1.1.3.1	NC 17-Cell Cavity (1.3 GHz)
1.1.1.3.2	Klystron (1.3 GHz, x MW)
1.1.1.4	Magnet System
1.1.1.4.1	Magnet
1.1.1.4.2	Power Supply
1.1.1.5	Vacuum System
1.1.1.6	Spectrometer
1.1.1.7	Electron Injection Linac
1.1.1.8	Spin Rotator
1.1.1.9	Instumentation
1.1.1.10	Collimator
1.1.1.11	Electron Source High Level RF
1.1.1.11.1	10 MW RF Stations Warm (roll-up)
1.1.1.11.2	10 MW RF Stations - 5 GeV Linac (roll-up)
1.1.1.11.3	Bunch Compressor RF
1.1.1.11.4	RF Integrated Safety Systems
1.1.2	Positron Injection

1.2	Damping Ring
1.2.1	Electron Damping Ring
1.2.1.1	Electron Damping Ring
1.2.1.2	Cavity System (0.65 GHz)
1.2.1.3	RF System (0.65 GHz - CW)
1.2.1.3.1	Klystrons
1.2.1.3.2	Waveguide
1.2.1.3.3	Cavities
1.2.1.3.4	Tuners
1.2.1.3.5	LLRF
1.2.1.3.6	Infrastructure
1.2.1.3.7	RF Integrated Safety Systems
1.2.1.4	Magnet System
1.2.1.4.1	Magnet
1.2.1.4.2	Power Supply
1.2.1.4.3	Wiggler
1.2.1.5	In- and Ejection System
1.2.1.6	Vacuum System
1.2.1.7	Feedback System
1.2.1.8	Instrumentation
1.2.2	Positron Damping Ring

from TESLA Budget Book

WBS	Item
1.8	CryoModule Unit Cost
1.8.1	CM roll-up for unit cost (from TESLA)
1.8.1.1	Cavity preparation & string assembly
1.8.1.2	Cryostat modules and sc magnets
1.8.1.2.1	vacuum vessel & cold mass
1.8.1.2.2	module interconnect beam vacuum
1.8.1.2.3	magnet package
1.8.1.2.4	module instrumentation
1.8.1.2.5	module interconnection
1.8.1.3	Cavity structures & vessel fabrication
1.8.1.3.1	structure machining
1.8.1.3.2	tuner mechanics & gear box
1.8.1.3.3	Titanium vessel, tubes, and bellows
1.8.1.3.4	tuner motor & electronics
1.8.1.3.5	assembly and EB welding
1.8.1.3.6	magentic shielding cryoperm
1.8.1.3.7	magnetic shielding fabrication
1.8.1.3.8	piezo tuner
1.8.1.4	Niobium material
1.8.1.4.1	Niobium RRR 300 material
1.8.1.4.2	Niobium RRR 30 material
1.8.1.4.3	NbTi flange material
1.8.1.5	RF Power Coupler & HOM Coupler
1.8.1.5.1	RF power coupler fabrication
1.8.1.5.2	cavity control internal

Calculate Unit Cost for RF Unit to Power 3 Cryomodules
which include 8 cavities/CM = 24 cavities.
This includes power supply, modulator, transformer,
10 MW klystron, RF distribution, etc.
LLRF (Low Level RF) is under Controls

phg - 15april06PHGL: updated 17april06
using Ray Larsen draft 033106R4

1.9	High Level RF Power Unit Cost (3 CM = 24 cavities)
1.9.1	RF roll-up for unit cost
1.9.1.1	Klystron
1.9.1.2	Modulator
1.9.1.3	RF Distribution
1.9.1.4	Integrated Controls-Diagnostics-Interlocks-Protection-PPS
1.9.1.5	RF Infrastructure
1.9.1.6	RF Integrated Fire & Safety Systems

WBS	Element
1.9.1.1	Klystron
1.9.1.1.1	Klystron 10 MW Body
1.9.1.1.2	Solenoid
1.9.1.1.3	Socket & Tank
1.9.1.1.4	Vacuum Pumps, Instrumentation
1.9.1.1.5	Power Supplies for Solenoid, Filament
1.9.1.1.6	RF Pre-Driver
1.9.1.1.7	Water Cooling
1.9.1.1.8	Local Diagnostics-Controls-Protection
1.9.1.2	Modulator
1.9.1.2.1	Modulator Assembly
1.9.1.2.2	Pulse Forming
1.9.1.2.3	Charging Supply
1.9.1.2.4	HV Cable Plant
1.9.1.2.5	Pulse Transformer
1.9.1.2.6	Water Cooling
1.9.1.2.7	Local Diagnostics-Controls-Protection
1.9.1.3	RF Distribution
1.9.1.3.1	Waveguide Distribution
1.9.1.3.2	Cavity Coupler Matching Tuners
1.9.1.3.3	Hybrids and Loads
1.9.1.3.4	Motor Drivers
1.9.1.3.5	Gas & Vacuum Systems
1.9.1.3.6	Water Cooling
1.9.1.3.7	Local Diagnostics-Controls-Protection
1.9.1.4	Integrated Controls-Diagnostics-Interlocks-Protection-PPS
1.9.1.4.1	PLC Hardware
1.9.1.4.2	Database
1.9.1.4.3	System Programming
1.9.1.4.4	System Integration
1.9.1.5	RF Infrastructure
1.9.1.5.1	Instrument Racks & Cabling
1.9.1.5.2	Cable Trays
1.9.1.5.3	Electrical Distribution - Primary & Secondary
1.9.1.5.4	Cooling Water System
1.9.1.6	RF Integrated Fire & Safety Systems

CF&S Cost Matrix

- 1.10 Conventional Facilities & Siting
  - 1.10.1 Civil Engineering
  - 1.10.2 Electrical
  - 1.10.3 Air Treatment Eq
  - 1.10.4 Piped Utilities
  - 1.10.5 Process (Cooling) Water
  - 1.10.6 Handling Equipment
  - 1.10.7 Safety Equipment
  - 1.10.8 Survey and Alignment

- 1.10.1 Civil Engineering
  - 1.10.1.1 Engineering, Study Work, Documentation
  - 1.10.1.2 Underground Facilities
    - 1.10.1.2.1 Shafts
    - 1.10.1.2.2 Tunnels
    - 1.10.1.2.3 Halls
    - 1.10.1.2.4 Caverns
    - 1.10.1.2.5 Miscellanous Works
  - 1.10.1.3 Surface Structures
    - 1.10.1.3.1 Central Lab Buildings
    - 1.10.1.3.2 Detector Assembly Buildings
    - 1.10.1.3.3 Office Buildings
    - 1.10.1.3.4 Service Buildings
    - 1.10.1.3.5 Cryogenic Equipment Buildings
    - 1.10.1.3.6 Control Buildings
    - 1.10.1.3.7 Workshops
    - 1.10.1.3.8 Site Access Control Buildings
    - 1.10.1.3.9 Shaft Access Buildings
    - 1.10.1.3.10 Miscellaneous Buildings
    - 1.10.1.3.11 User Facilities
  - 1.10.1.4 Site Development
    - 1.10.1.4.1 Off-site Site Work
    - 1.10.1.4.2 Network of Monumentsg
    - 1.10.1.4.3 Construction Support
    - 1.10.1.4.4 Site Preparation
    - 1.10.1.4.5 Utility Distribution
    - 1.10.1.4.6 Road, Sidewalk, Parking Areas
    - 1.10.1.4.7 Landscaping
    - 1.10.1.4.8 Environment
    - 1.10.1.4.9 Miscellaneous Site Work

1.10.1.2	Underground Facilities
1.10.1.2.1	Shafts
1.10.1.2.1.1	General & Infrastructure
1.10.1.2.1.2	Electron Source
1.10.1.2.1.3	Positron Source
1.10.1.2.1.4	Damping Rings
1.10.1.2.1.5	RTML
1.10.1.2.1.6	Main Linac
1.10.1.2.1.7	Beam Delivery System
1.10.1.2.1.8	Experiments

1.10.2 Electrical
1.10.2.1 Engineering, Study Work, Documentation
1.10.2.2 High Voltage Eq, Power Distribution
1.10.2.3 Low Voltage Eq. Power Distribution
1.10.2.4 Emergency Power Sources
1.10.2.5 Power Network Monitoring
1.10.2.6 Power Networking Monitoring (identical)
1.10.2.7 Communication Equipment
1.10.3 Air Treatment Eq
1.10.3.1 Engineering, Study, Work Documentation
1.10.3.2 HVAC Equipment
1.10.4 Piped Utilities
1.10.4.1 Engineering, Study Work, Documentation
1.10.4.2 Plumbing
1.10.4.3 Fire Suppression
1.10.4.4 Fuel System Distribution

1.10.4 Piped Utilities
1.10.5 Process (Cooling) Water
1.10.5.1 Engineering, Study Work, Documentation
1.10.5.2 Primary Stations
1.10.5.3 Secondary Stations
1.10.6 Handling Equipment
1.10.6.1 Engineering, Study Work, Documentation
1.10.6.2 Lifts
1.10.6.3 Electrical Overhead Traveling Cranes
1.10.6.4 Hoists
1.10.6.5 Auxiliary Lifting Equipment
1.10.6.6 Road Transport and Handling Eq
1.10.6.7 Underground Transport Eq
1.10.7 Safety Equipment
1.10.7.1 Engineering, Study Work, Documentation
1.10.7.2 Safety Alarms
1.10.7.3 Safety Access Control
1.10.7.4 Other Safety Equipment
1.10.8 Survey and Alignment

1.7	Infrastructure
1.7.1	Administration
1.7.2	Cryogenic System
1.7.3	Power Distribution
1.7.4	Water Cooling
1.7.5	Tunnel Installations
1.7.5.1	Injection Linac Tunnels
1.7.5.2	RTML Tunnnels
1.7.5.3	Damping Ring Tunnels
1.7.5.4	Main Linac Tunnels
1.7.5.5	Beam Delivery System Tunnels
1.7.5.6	Service Tunnels
1.7.6	Survey and Alignment
1.7.7	Controls (and Protection) System
1.7.8	Commissioning, Operations, & Reliability
1.7.9	Accelerator Physics
1.7.10	Safety Systems
1.7.11	Module Test Facility
1.7.12	RF Test Facility

1.7.2	Cryogenic System
1.7.2.1	Cryogenic Plant
1.7.2.1.1	Cryogenic Plant (24 kW @ 4.5
1.7.2.1.2	Warm Compressor Station
1.7.2.1.3	Upper Cold Box
1.7.2.1.4	Lower Cold Box
1.7.2.1.5	Cryogenic Distribution Box
1.7.2.1.6	Helium Dryer
1.7.2.1.7	Cryogenic Transfer Line
1.7.2.1.8	Helium Storage
1.7.2.1.9	Nitrogen Storage
1.7.2.1.10	Warm Pipe
1.7.2.1.11	Water Cooling
1.7.2.2	Cryogenic Control System

Level of Detail Example (2)

RF_WBS_phg_1march06.xls

USLCTOS - 2003 - similar to WB_6feb_PG_8feb06.wbs				**% of hardware**
	(not including contract installaiton or CF&S for RF)			**from USLCTOS**
1.5. 8.1	**RF System**		894	15.70%
	1.5.8.1.1 Modulator		894	6.68%
no	1.5.8.1.2 Pulse Transformer	not here		0.00%
	1.5.8.1.3 Klystron		894	3.68%
	1.5.8.1.3.1 Klystron Tube		894	3.10%
	1.5.8.1.3.2 Solenoid		894	0.28%
	1.5.8.1.3.3 Socket		894	0.06%
	1.5.8.1.3.4 Roughing Pump/Controls		894	0.08%
	1.5.8.1.3.5 Dry Nitrogen Backfill System		894	0.16%
	1.5.8.1.4 RF Power Distribution and Interlocks		894	2.97%
	1.5.8.1.4.1 High Power Phase Shifter		894	0.13%
	1.5.8.1.4.2 High Power Splitter		0	0.00%
	1.5.8.1.4 3 Intertunnel Waveguide		1788	0.10%
	1.5.8.1.4.4 Waveguide to Feed Cavity #1		0	0.00%
	1.5.8.1.4.5 Cavity Feeds		894	2.80%
need to add	1.5.8.1.4.5.1 Circulators		14304	0.53%
need to add	1.5.8.1.4.5.2 Power Hybrid Couplers		14304	0.38%
need to add	1.5.8.1.4.5.3 Wavegude Small Sections		14304	0.36%
need to add	1.5.8.1.4.5.4 Three-Stub Tuner		14304	0.76%
need to add	1.5.8.1.4.5.5 RF Bellows		14304	0.25%
need to add	1.5.8.1.4.5.6 RF Signal Couplers		14304	0.00%
need to add	1.5.8.1.4.5.7 Low Power Loads		14304	0.51%
move	1.5.8.1.5 Low Level RF		894	1.91%
need	1.5.8.1.6 RF Drivers		894	0.34%
need	1.5.8.1.7 Auxiliary Equipment		894	0.13%

Total RF

Major RF Items

Still >> few * 0.1% can they be reduced?

Level of Detail Example (3)

cryomodule_WBS_phg_7march06.xls

1.2	Cryomodule							% of hardware	
	1.2.1	Cryomodule		(same as above)				from USLCTOS	
		1.2.1.1	SC Cavity Fabrication						
			1.2.1.1.1	Material				**2.43%**	
				1.2.1.1.1.1	Niobium RRR 300				
				1.2.1.1.1.2	Niobium RRR 30				
				1.2.1.1.1.3	Niobium Titanium				
				1.2.1.1.1.4	Cryoperm				
			1.2.1.1.2	Resonator Production				**3.57%**	
				1.2.1.1.2.1	Resonator Machining				
				1.2.1.1.2.2	electron-beam welding				
				1.2.1.1.2.3	Resonator Assembly				
			1.2.1.1.3	Tuners				0.80%	
				1.2.1.1.3.1	Tuner Mechanics				
				1.2.1.1.3.2	Tuner Electronics				
				1.2.1.1.3.3	Piezo Tuner				
			1.2.1.1.4	Helium Vessel				**1.00%**	
				1.2.4.1	Titanium Vessel				
		1.2.1.2	SC Cavity Assembly (above 1.2.2)						
		1.2.1.3	Cryostat Assembly (below 1.6)						
		1.2.1.4	Cryostat					0.84%	
			1.2.1.4.1	Material					
				1.2.1.4.1.1	Black (Ferromagnetic) Steel				
			1.2.1.4.2	Vacuum Vessel					
		1.2.1.5	Cryostat Assembly					**4.14%**	
		1.2.1.6	RF Power Couplers					**3.48%**	
		1.2.1.7	HOM Couplers					0.13%	
	1.2.2	SC Quadrupole, Corrector, Instrumentation						0.27%	
		1.2.2.1	SC Quadrupole						
		1.2.2.2	Corrector Magnet						
		1.2.2.3	Beam Position Montor						
							total =	16.66%	