Cost Estimating for the ILC Accelerator for the RDR & TDR

ILC PAC – Taipei – May 19, 2012

Peter H. Garbincius

Fermilab

corrected 5/20 for cost of XFEL cables & terminations

(see W. Bialowons' e-mail 9/22/2010)

Outline

- Estimating Process & Timescales for RDR
- RDR Estimate – Cost Drivers
- "Cost Containment" – experience of XFEL
- SB2009 proposals – 4 approved – Cost Impacts
  What cost reductions did SB2009 hope for?
  …summary of 4+ hours of presentations
  technical discussion by Nick Walker tomorrow
- Estimating Process & Timescales for TDR
- Main Activities still to do
- CLIC Cost Estimate: delayed, will est 0.5 & 1 TeV
- Lots of backup information and tables! Can discuss

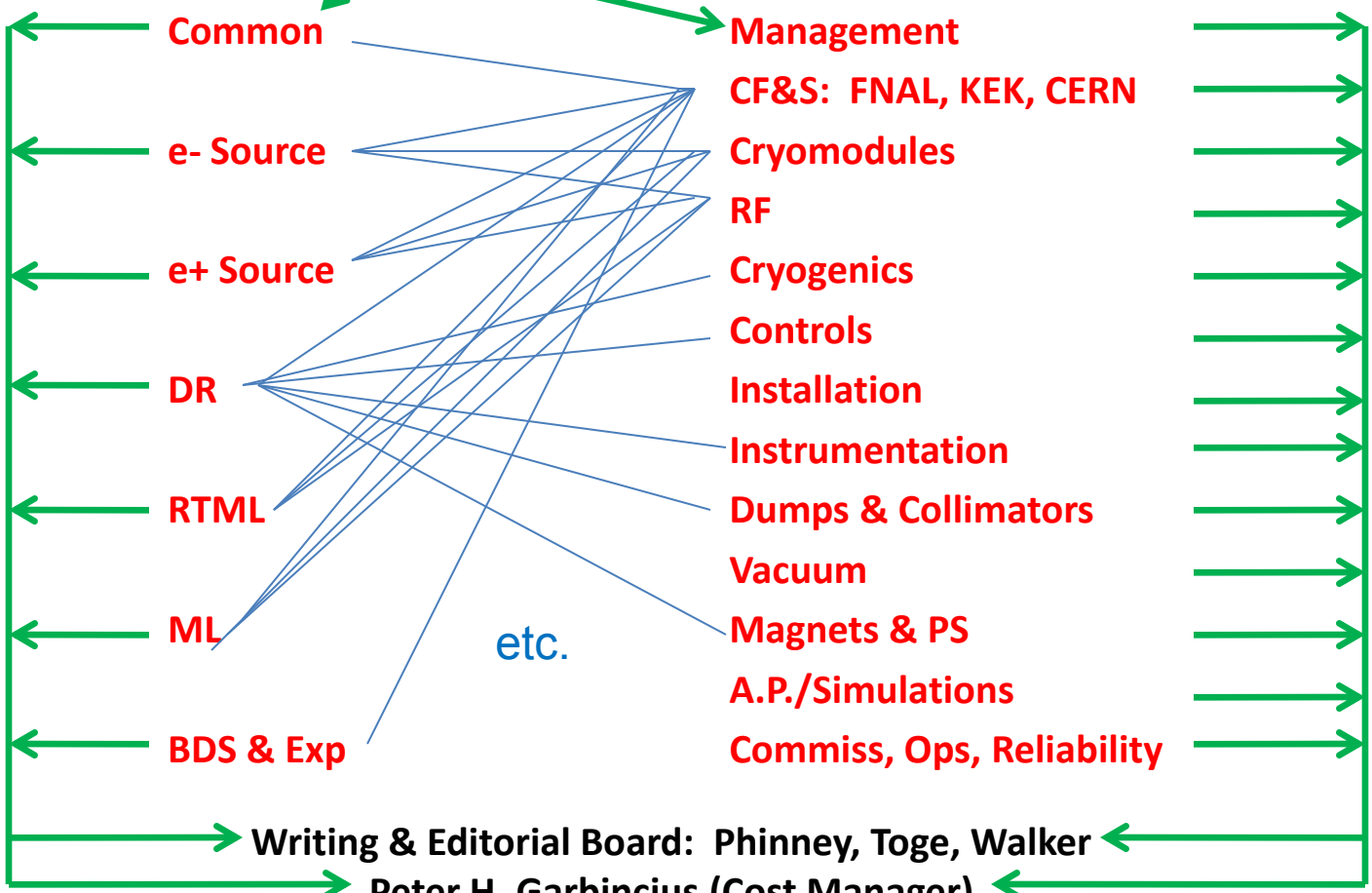
RDR Cost Estimating Experience – ILC Accelerator

Cost Engineers: Bialowons, Shidara, Garbincius

Design & Cost Board: CEs + Delahaye, Mueller, Phinney, Paterson, Kephart, Terunuma, Enomoto

active guidance by GDE Executive Committee

Guidelines (3/07) & Instructions (5/07) → Free Form EXCEL and wiki sites



compilation, coordination, consistency, checks

master EXCEL Estimate → website later → ICET → mySQL → EDMS

Key Dates (timescale) for RDR Estimate

Snowmass 2001 & 2005 – preliminary concepts

Nov 05 – assign Cost Engineers – first meeting SLAC

Dec 05 – Frascati – assign DCB – define ILC Baseline

March 06 – Bangalore & Cost Estimating Guidance

May 06 – Cost Estimating Instructions distributed

July 06 – Vancouver – cost meetings with all groups!

Nov 06 – Valencia – first view → reduce costs!

end April 07 – cost estimates close for new info

May 07 – Orsay – ILCSC Cost Review

Aug 07 – publish RDR with cost estimates

RDR Estimate

details

- ***6.6 Billion ILC Units*** (2007 US $) ***+ 24 Million hours*** of Institutional Labor (which includes laboratories and universities, but not vendors or contractors)
- TDR will quote estimate in 2012 US $, need consider:
- Difference in Exchange Rates

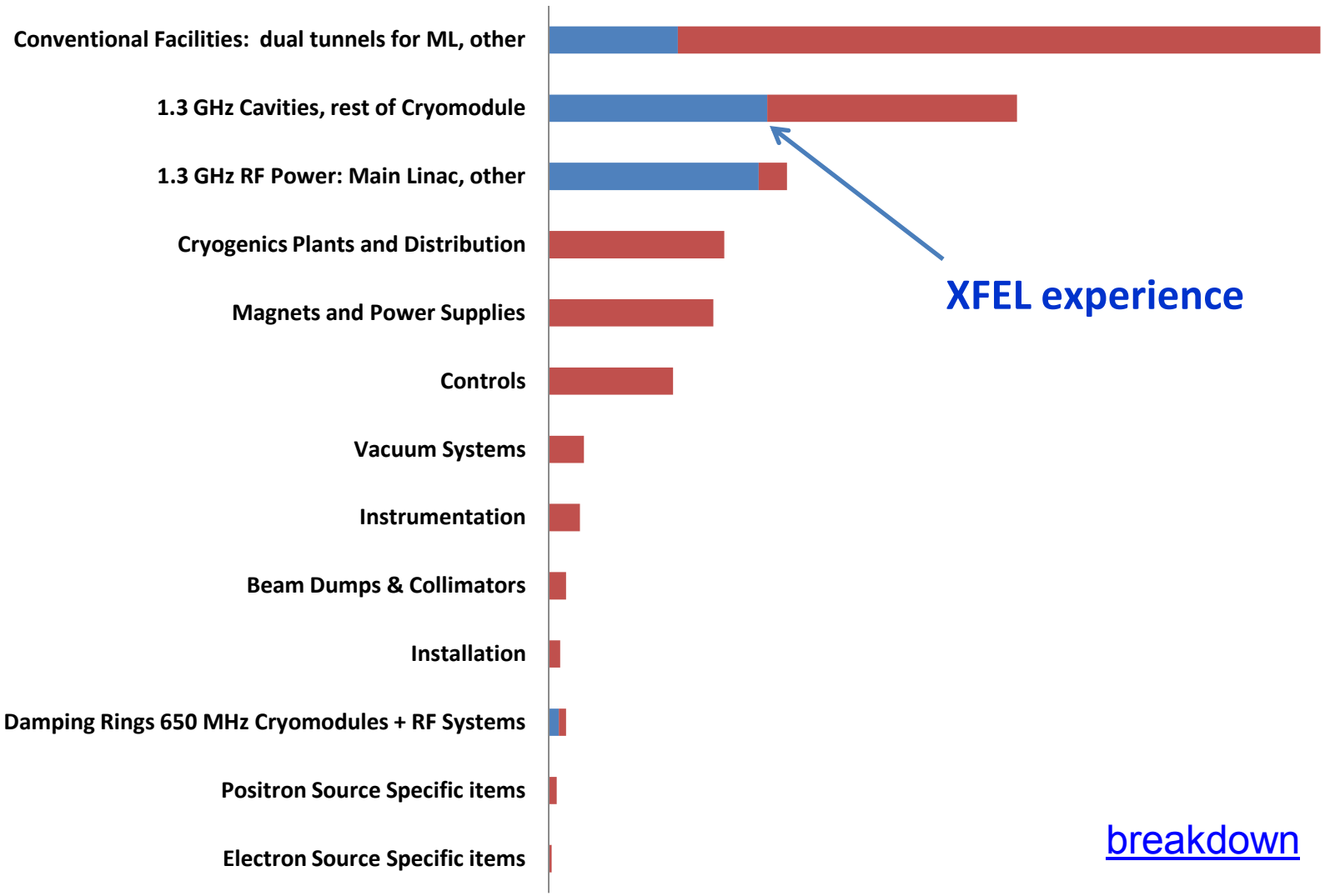
In 2006-07:	1 $ = 117 ¥	1 € = $ 1.20
1/1/2011:	1 $ = 81.5 ¥	1 € = $ 1.334
now 5/18/2011:	1$ = 81.0 ¥	1 € = $ 1.426

- 4 yr – inflation from 1/1/2007 => 1/1/2011 Index Links
  - US construction, technical goods -2.1%, 8.6%
  - Germany construct., indust. products 10.5%, 5.7%
  - Japan construction, industrial products 3.4%, 1.1%

Applying exchange & escalation to RDR est

- RDR estimate of 6.6 B ILCUs (2007) goes to
  7.6 B ILCUs (as of 1/1/2011) => ***15%***
  6% is inflation, 9% is exchange rates
- TDR will have new, current estimates as of 1/1/2012 for cavities & cryomodules, KCS, DRFS, and many elements of Conventional Facilities, especially for Americas and Asia
- For those items without a new cost estimate, the TDR will use local official national inflator indices to update the 2007 RDR estimates made in a given region to 1/1/2012, and then convert to US $ at the exchange rate on that date

RDR Cost Drivers – tornado plot



breakdown

SB2009 expectations- AAP 1/2010 – M ILCUs

• RDR estimate = starting point	6,618	Δ
• Caverns, DR & cool Value Eng.	-86	-1.3%
• 1 stage B.C. (not yet considered)	-33	-0.5%
• Alternative RF (1 tunnel for ML, ½ bunches)		
Klystron Cluster/DRFS	-400/-419	-6.2%
• DR (6.4 => 3.2 km, ½ bunches)	-191	-2.9%
• Central Injector Complex	-104	-1.6%
• Sub-total of SB2009 changes estimated		-10.7%

- Did not consider range of cavity gradients nor details of alternating e+ production at 150 GeV

GDE Change Evaluation Panel

- BAW-1 – KEK – Sept 2010 – see Nov 2010 PAC
  - TLCC-1: Average Accelerator Gradient
    - Approved 9nov10 – cost impact not evaluated (~negligible)
    - Allowing 20% spread of gradients with <G> = 31.5 MV/m decreases cost of cavities by increasing production yield but may require some additional RF & controls overheads
  - TLCC-2: Single Tunnel Main Linac Configuration
    - Alternative RF schemes: KCS & DRFS with XFEL- & RDR-like fall-backs without adding extra redundancy/energy margin
    - Approved 9nov10 – savings ***2.2%*** for DRFS, ***2.1%*** for KCS 4.5→5.2 m tunnel for DRFS & 14% more klystrons for KCS
    - avg back-ups: XFEL-like saves ***1.1%***, RDR-like saves ***2.0%***

corrected 5/20 modulators: beam-on accessible inaccessible

more info

GDE Change Evaluation Panel (2)

- BAW-2 – SLAC – Jan 2011 – since last PAC
- TLCC-3: Reduced Beam Parameter Set (½ $n_{bunches}$)
  - Lower beam current in ML, fewer klystrons, mods/PS info
  - Reduce DR circumference 6.4=>3.2 km, but larger dia. tunnel for possible 2nd e+ DR (risk mitigation) info
  - Stronger Focus at IP to maintain $\mathcal{L}$ → traveling focus
  - Path to restore full number of bunches
  - Approved 17march2011: see below for Cost Impact
- TLCC-4: Relocate e+ Source to end of Main Linac
  - sqrt(s) ≤ 250 GeV, alternate e- ML between 5 Hz for e+ production at 150 GeV and 5 Hz at lower E to I.P.
  - Considered this only for Reduced Beam Parameter Set
  - Approved 17march2011: see below for Cost Impact

summary of cost differentials for ½ $n_{bunches}$
(note that – sign → savings)

• Damping Rings	MILCUs	
– Technical elements (magnets, RF, wigglers)	- 150	
– Cryogenics	- 10	
– CFS (6.4km*5m→ 3.2km****7.5m***, power, cool)	- 32	***conservative dia.!***
– Damping Rings sub-total	- 192	***can stagger RF***

	KCS	DRFS
• Main Linac		
– # klystrons	***714***→499	7520→3746
– RF (klystrons, mods, ps, distrib)	- 150	- 345
– Cryogenics	- 9	+ 9
– CFS (civil, power, cooling)	- 43	- 27
– Main Linac sub-total	- 203	- 363
– Include DR sub-total	- 192	- 192
• Total Savings	- 395 M	- 555 M
	- 6.0%	***- 8.4%***

restoration of 2625 bunches/train

- KCS – relatively easy, increase size of RF building, install klystrons & modulators, on surface. Minimum impact on accelerator operations. Should install full Cryo plants from start
  (don't save that 9 M ILCU earlier)
- DRFS – need to add many more klystrons in tunnel, *interrupting accelerator operations*. Due to higher cryo load for DRFS reduced # bunches, larger plants were installed and will not need upgrading.
- Damping Ring – install a second Positron Ring, inj/extr e+ switches, and more cryo and power, again *interrupting accelerator operations*.

backup info

moving Positron Source & for 150 + ≤ 125x125

- Cost differentials more info MILCUs
  - Damping Rings – reduce damping time + 29
  - e- ML – 10 Hz but @ < 150 GeV + 0
  - e- Source – upgrade to 10 Hz @5 GeV + 7
  - e- RTML/BC – upgrade to 10 Hz @ 5 GeV + 1
  - Remove tunnel for separate KAS - 8
  - Remove shaft & rad handling building for KAS - 12
  - Remove KAS e+ prod. station & accel to 400 MeV - 28
  - Haven't analyzed power or cooling impacts for KAS - ???
  - Haven't designed or estimated new beamlines
    in undulator/e+ source/beam dump regions + ???
    or shortened 400 MeV e+ transport line Sum: -11 ± ???

-0.2 ± ??? %

summary of SB2009-BAWs-TLCC cost reductions

	KCS	DRFS	RDR-	XFEL-like
Gradient spread	- 0 -	- 0 -	back-ups	
Single Tunnel	-2.1%	-2.2%	-2.0%	-1.2%
½ # bunches	-6.0%	-8.4%		
e+ at end of ML, low E	-0.2%	-0.2%	±???%	***new beamlines***
Total savings	***-8.3%***	***-10.8%***		
	±???%	***±???%***		
SB2009 anticipated:	-10.7%	-10.8%		

corrected 5/20

TDR Cost Estimating Plans – ILC Accelerator

Cost Engineers: Bialowons, Shidara, Dugan
Project Managers: Ross, Yamamoto, Walker
update Guidelines (3/07) & Instructions (5/07) use ICET Templates (EXCEL) for cost inputs

Common	**Management**
	CF&S: FNAL, KEK, CERN
e- Source	**Cryomodules**
	RF – KCS and DRFS
e+ Source	**Cryogenics**
	Controls
Damping Rings	**Installation (→ Conventional Facilities Group)**
	Instrumentation
RTML	**Dumps & Collimators**
	Vacuum
Main Linac	**Magnets & PS**
	Accelerator Physics & Simulations
BDS & Exp	**Commissioning, Operations, Reliability**

Writing & Editorial Board: Project Managers
Gerry Dugan: compilation, coordination, consistency, checks
EDMS ↔ ICET → mySQL database

Key Dates (timescale) for TDR Estimate

Sept-Oct 2009 – ABQ – "cost containment" doctrine

Dec 2009 – SB2009 published

Jan 2010 – Oxford – AAP reviewed SB2009

Nov 2010 – BAW-1: 1 tunnel ML (→ RF), Gradient Spread

Jan 2011 – BAW-2: Reduced # Bunches, Relocate e+ Src

Baseline Technical Reviews – see next slide for schedule

NOW - a lotta work – meet at CalTech July 20-21 to revise & tune-up
Cost Estimating ***Strategy***, Guidelines and Instructions
(it would be nice to have at least DR-specific updates before the
first Baseline Technical Review in early July),
need intermediate reviews of estimates,
and time for re-evaluation(s) & revision(s) if necessary

July 1, 2012 – closing date (deadline) for cost estimating data

end 2012 – publish TDR

Baseline Technical Reviews (NJW's introduction)

- Review baseline-relevant R&D
- Baseline Design Decisions
  Changes since RDR & Working Assumptions
- Consolidate and sign-off Documentation
- Review Requirements for Conventional Facilities
- Review Cost
- Workshop Deliverables:
  EDMS design Documentation on agreed-upon TDR baseline,
  Updated Cost Estimate, and Draft chapters/sections for TDR
- Schedule:
  - INFN Frascati July 7-8, 2011 Damping Ring
  - DESY Oct 25-28, 2011 Sources, RTML incl. BC, BDS/MDI
  - KEK Jan 19-20, 2012 Main Linacs and SCRF
  - Fermilab Early 2012 Conventional Facilities/Global

- Need to update Instructions for Estimators
- **I**LC **C**ost **E**stimating **T**ool => ICET
- ICET **C**ost **E**stimating **M**odules => CEMs = EXCEL sheets
- Use ICET CEMs for RDR as template for TDR ests.
- ICET example CEM (showing pull-down options)
  - I can give an off-line demonstration if you are interested
- ICET guides & description in EDMS **895245*
- ICE Cost Estimating Modules (CEMs) for complete RDR Estimate are posted at EDMS **953565* with description at EDMS **953605*, both of which are accessible to ILC_Cost_Management_Team:

  Director, PMs, Cost Engineers, Integration Phys.

- Still to do (besides continuing R&D):
  - Cavities & Cryomodules cost estimate, including updated industrial estimates, fabrication models, division over regions, testing plans and facilities…
  - Inclusion of (spare, overhead) energy margin for reliability
  - Settle designs and costs for DRFS
  - Include our work on different geological sites, e.g. shallow site
  - Review of Institutional Manpower
  - Installation-Logistics (follow-up SLAC RDR study for ML RF unit)
  - Integrate Cost Estimate with Schedule and Funding Profile

finis

Back-up Slides

Comparison to CLIC Cost Estimate

- I discussed methodology, WBS, etc. at

  PAC in Vancouver in May, 2009.

  Nothing more to report at this time.

Peer Review of CLIC CDR Value Estimate originally scheduled for April 5-6, 2011

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Dr Peter Garbincius
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Batavia
60510-5011IL
USA

Geneva, 6 December 2010

Dear colleague, Peter

The CLIC study team is preparing to issue the Conceptual Design Report (CDR) of the Compact Linear Collider (CLIC) in 2011. The CLIC CDR will contain a consistent set of design parameters and a first idea of a possible technical implementation on a site close to CERN of an electron-positron collider meeting the performance requirements at center-of-mass energy of 3 TeV, with an optional first phase at 500 GeV. Consistent with the CLIC CDR, the study team will also issue corresponding value estimates. These estimates are so far unpublished and need to be peer-reviewed.

We would like to benefit from your experience in the domain of large scientific projects and ask you to act as reviewer in the

Peer Review of CLIC CDR Value Estimate,
to be held **at CERN on Tuesday 5 and Wednesday 6 April 2011.**

The charge to the reviewers, and the draft program of the Review are attached to this letter.

Your flight tickets will be reimbursed (Economy Class only) as well as your living expenses which will be covered by the CLIC study (accommodation, subsistence per day and meals according to CERN's rules).

Please let us know whether you agree to participate in this Review. We will then give you access to the available relevant documents.

Looking forward to your answer by 18 December 2010, we thank you for your help and remain

Sincerely yours,

Ph. Lebrun

Ph. Lebrun

Encl. Charge to reviewers
Draft program

Peer Review of CLIC CDR Value Estimate
Charge to reviewers

The CLIC Conceptual Design Report (CDR) contains a consistent set of design parameters and a first idea of technical implantation for CLIC on a site close to CERN, meeting the performance requirements of an electron-positron collider at a center-of-mass (CM) energy of 3 TeV, with an optional first phase at 500 GeV CM. It also includes a preliminary value estimate of the 3 TeV CM accelerator complex, and a scaled value estimate of the 500 GeV CM first phase. The value estimates are aiming at a precision level of 30 %.

The charge to the reviewers is to:
- review the methodology and assumptions of the value estimates,
- identify incorrect or missing value information,
- check the consistency of the value estimates with respect to reference work, e.g. the ILC RDR and NLC value estimates,
- review the uncertainty estimates,
- identify main areas of savings and cost mitigation for future work,
- advise the CLIC study team on matters of value estimate.

The reviewers are appointed by the CLIC study team, and will report to the CLIC Steering Committee.

The reviewers are requested to provide the following deliverables:
- an oral presentation of the preliminary conclusions at the end of the review,
- a written report within the following month.

The reviewers are committed to confidentiality.

DRAFT

/PRJ/CLIC/PhL

11 November 2010

Peer Review of CLIC CDR Value Estimate
Draft program

- Tuesday 5 April 2011, am & pm
  - Welcome, introduction to the CDR and charge to reviewers (J.P. Delahaye)
  - Scope and methodology (Ph. Lebrun)
  - General schedule (K. Foraz)
  - Main beam injectors and transport (L. Rinolfi)
  - Damping rings (Y. Papaphilippou)
  - Drive beam production (B. Jeanneret)
  - Main linacs (G. Riddone)
  - Interaction region (L. Gatignon)
  - Infrastructure and services (J. Osborne)
  - Controls and machine protection (M. Jonker)
  - Summary and cost mitigation alternatives (Ph. Lebrun)
- Wednesday 6 April 2011, am
  - Additional presentations & discussions at request of Review Panel
- Wednesday 6 April 2011, pm
  - Preparation of report
  - Oral presentation of preliminary conclusions

Peer Review of CLIC CDR Value Estimate
Reviewers to be invited

- C. Adolphsen, SLAC
- W. Bialowons, DESY
- H. Braun, PSI
- R. Brinkmann, DESY
- J. Carwardine, Fermilab
- L. Evans, Imperial College (chair?)
- P. Garbincius, Fermilab
- N. Holtkamp, SLAC
- S. Myers, CERN (ex officio)
- K. Peach, JAI (ex officio)
- T. Shidara, KEK
- M. Vretenar, CERN
- M. Yoshioka, KEK

Postpone (January 2011)

guided by LHC physics

delay Executive Summary of CLIC CDR until spring of 2012 to discuss cost & implementation issues related to range of energies justifiable by LHC physics available

Electrical Power needs at 3 TeV was also cited at Eugene, OR in March 2011

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Geneva, 21 January 2011

Peter

Dear colleague,

Following your response to our invitation letter of 6 December 2010, we thank you for your kind agreement to serve on the Peer Review of CLIC Value Estimate and keep you updated on the latest development of the CLIC Conceptual Design report (CDR) which constitutes the basis for the Value Estimate.

As you are aware of, there is good progress and improved prospects for LHC physics to guide the design of a future linear collider on the time scale of the update of the European strategy for particle physics in 2012. After discussion with the CERN Management, we have therefore adapted a changed approach and time scale for the CLIC CDR, matching better what is needed for this update.

One important consequence of this new approach is to postpone the executive summary volume of the CLIC CDR – the most relevant document for the strategy update – to the spring of 2012, and more specifically to discuss in this volume, cost and implementation issues related to the range of machine energies justifiable by LHC physics results available at that time. We firmly believe that this will provide the most consistent background information for defining the next steps of the project during the strategy update process in 2012.

Consequently, in order to adapt to these changes and thoroughly prepare the corresponding information, we unfortunately need to postpone the Peer Review of the CLIC Value Estimate, originally foreseen in April 2011, to a later date.

We apologize for such a late notice and regret any inconvenience that you may encounter as a consequence of this decision. The interest you have expressed in helping us review the CLIC Value Estimate is highly appreciated, and hoping that you can remain available at a later date, we will re-contact you as soon as our calendar of actions gets settled.

Sincerely yours,

Ph. Lebrun

Ph. Lebrun

cost matrix for the RDR estimate

- Redacted by Peter H. Garbincius – 2june2011 at request of Marc Ross

escalation details

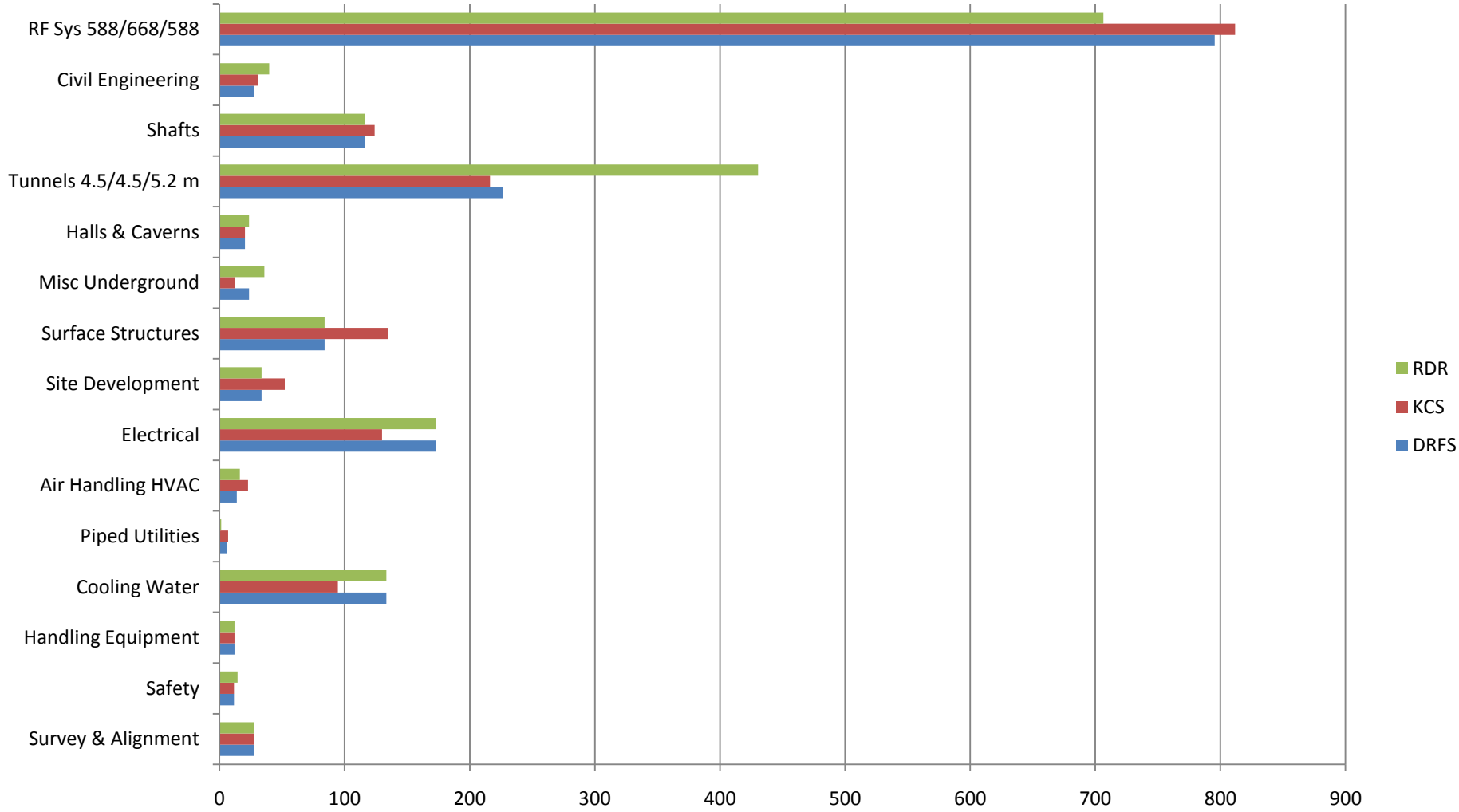
general escalator - PHG - 18april2011		1-Jan-07	date of estimate =		1-Jan-11		
fill-in the yellow boxes	1 euro =	1.20	$ 1/1/2007		1.334	exchange factor =	1.1117
	1 $ =	116.7	¥ 1/1/2007		81.5	exchange factor =	1.4319

col A	col B	col C	col D	col E	col F	col G	col H	
	RDR est components 1-Jan-07 K ILCU	exchange factor to 1-Jan-11 1-Jan-07	estimate updated for exchange D = B*C	escalation index on 1-Jan-07	escalation index on 1-Jan-11	escalation factor = G = F/E	1-Jan-11 cost * exhange * escalation H =D*G	Index used
Europe construction	900,880	1.1117	1,001,478	103.6	114.5	1.1052	1,106,846	German Ortskanäle (sewers)
Europe non-construction	2,062,323	1.1117	2,292,616	106.1	112.1	1.0566	2,422,264	German Producer Prices for Industrial Products
Asia construction	594,095	1.4319	850,685	101.4	104.8	1.0335	879,209	Japan Integrated Construction
Asia non-construction	11,602	1.4319	16,613	102.1	103.2	1.0108	16,792	Japan Manufacturing Inductry Products
Americas construction	977,328	1	977,328	818	801	0.9792	957,016	Turner Construction Building Index
Americas non-construction	2,071,725	1	2,071,725	201.8	219.2	1.0862	2,250,357	US Consumer Price Index
total	6,617,952		7,210,444				7,632,484	
		exchange ratio to RDR 2007 est =	1.0895	overall ratio to RDR 2007 est =			1.1533	1.0363 average per year
				escalation ratio to RDR 2007 est =			1.0585	which is H/D

return

backup info

SB2009 - ML: Single Tunnel - Full Power



ML CFS = 17.5%, ML RF = 10.2%, and ML Cavities & Cryomodules (not shown) = 20.9% of RDR total

return

details, can skip

CFS Cost Impact Format for Configuration Scenario Studies

- Americas' CFS provides information in format very convenient for impact studies, with easiest access to lower levels of details
- Example for evaluation of ***Klystron Cluster***

Removed	Added	Changed
22 km of tunnels	RF pipe & CTOs	power & cooling
WG penetrations	four 3 m dia shafts	sm base caverns
WGs thru pipes	28 person refuges	less safety EQ
personnel x-overs	RF bldgs & sites	scale engineering
	60 RF units to drive KCS pipe & hot-swap	

- ***DRFS***: Cost (DRFS: 13.5*750KW) > Cost (RDR: 1*10MW) and increase tunnel diameter 4.5 m => 5.2 m

ILC International Linear Collider

CONVENTIONAL FACILITIES & SITING - Americas Region

details, can skip

9/4/08

RDR MAR 30 2007

A5
Main Linac
Denotes changed item
Denotes new Item

KLY Power Cluster Scheme for Aug 29 2008

A5
Main Linac

					FINAL CONTRACT COST- in 2006 US$ (except where noted)					FINAL CONTRACT COST- in 2006 US$ (except where noted)		
					Man-Hours Total		$ Total			Man-Hours Total		$ Total
1.7	Conventional Facilities				271,161	Man-Hrs	$ 1,160,918,226			173,933	Man-Hrs	$ 821,758,793
					(still to be corrected RDR)		$ 1,116,055,056					
		QTY	Unit		Unit Cost	Extension	Section Total	QTY	Unit	Unit Cost	Extension	Section Total
1.7.1	CIVIL ENGINEERING				155,883	Man-Hrs	$ 737,794,472			111,674	Man-Hrs	$ 532,682,498
1.7.1.1	Engineering, study work and documentation						$ 38,581,023					$ 30,151,840
1.7.1.1.1	In-house Engineering	$90	/ man-hr		$14,029,463	155,883		$90	/ man-hr	$10,050,613	111,674	
	In-house Engineering	2%	%		$701,473,148	$ 14,029,463		2%	%	$502,530,659	$ 10,050,613	
1.7.1.1.2	Outsourced Consultancy Services						$ 38,581,023					$ 30,151,840
	Outsourced Engineering	6%	%		$701,473,148	$ 38,581,023		6%	%	$502,530,659	$ 30,151,840	
1.7.1.2	Underground Facilities						$ 593,008,308					$ 333,284,348
1.7.1.2.1	Shafts						$ 105,194,184					$ 112,024,494
	e- ML 14m dia. Shafts @ Points 5, 3 (2 x 425 vert ft)	259	vert m		$134,768	$ 34,904,783		259	vert m	$134,768	$ 34,904,783	
	e- ML 9m dia. Shaft @ Point 7 (1 x 425 vert ft)	130	vert m		$78,280	$ 10,137,260		130	vert m	$78,280	$ 10,137,260	
	e- ML 1500mm dia. Survey Shafts @ Points 3.1, 5.1 (2 x 425 vert ft)	259	vert m		$7,240	$ 1,875,160		259	vert m	$7,240	$ 1,875,160	
	e- ML 3 m dia shafts @ pts 14,15							259	vert m	$10,635	$ 2,754,465	
					$0					$0		
	e+ ML 14m dia. Shafts @ Points 2, 4 (2 x 425 vert ft)	259	vert m		$134,768	$ 34,904,783		259	vert m	$134,768	$ 34,904,783	
	e+ ML 9m dia. Shaft @ Point 6 (1 x 425 vert ft)	130	vert m		$78,280	$ 10,137,260		130	vert m	$78,280	$ 10,176,400	
	e+ ML 1500mm dia. Survey Shafts @ Points 2.1, 4.1 (2 x 425 vert ft)	259	vert m		$7,240	$ 1,875,160		259	vert m	$7,240	$ 1,875,160	
	e+ ML 3 m dia shafts @ pts 16,17							259	vert m	$10,635	$ 2,754,465	
					$0					$0		
	Surface Grouting of Points 2-5 14m dia. Shafts (4 x 425 vert ft)	4	ea.		$721,678	$ 2,886,710		4	ea.	$721,678	$ 2,886,710	
	Surface Grouting of Points 6-7 9m dia. Shafts (2 x 425 vert ft)	2	ea.		$541,258	$ 1,082,515		2	ea.	$541,258	$ 1,082,515	
	Surface Grouting of Points 2.1, 3.1, 4.1, 5.1 Survey Shafts (4 x 425 vert ft)	4	ea.		$270,629	$ 1,082,515		4	ea.	$270,629	$ 1,082,515	
	Points 2,3,4,5,6,7 - 14&9m dia. Shafts, finishing (stairs, conc. wall, elev.#2)	777	vert m		$7,254	$ 5,636,164		777	vert m	$7,254	$ 5,636,164	
	Surface Grouting of Points 14,15,16,17 Survey Shafts (4 x 425 vert ft)							4	ea.	$320,560	$ 1,282,240	
	ML Underground Potable Water (1/2 of Points 2 & 3)	1	ea.		$67,188	$ 67,188		1	ea.	$67,188	$ 67,188	
	ML Underground Potable Water (Points 4,5,6,7)	4	ea.		$67,188	$ 268,750		4	ea.	$67,188	$ 268,750	
	ML Underground Sanitary Sewer (1/2 of Points 2 & 3)	1	ea.		$67,188	$ 67,188		1	ea.	$67,188	$ 67,188	
	ML Underground Sanitary Sewer (Points 4,5,6,7)	4	ea.		$67,188	$ 268,750		4	ea.	$67,188	$ 268,750	
1.7.1.2.2	Tunnels						$ 389,191,025					$ 195,744,068
	e- ML 4.5m dia. Beam Tunnel, TBM Excavation (37,162 lin ft)	11,327	lin m		$7,171	$ 81,228,749		11,327	lin m	$7,171	$ 81,228,749	
	e- ML 4.5m dia. Service Tunnel, TBM Excavation (37,162 lin ft)	11,327	lin m		$7,171	$ 81,228,749		0	lin m	$0	$ -	
	e- ML 4.5m dia. Tunnels, Conc. Inv. (74,324 lin ft)	22,654	lin m		$1,351	$ 30,611,218		11,327	lin m	$1,351	$ 15,305,609	
					$0					$0		
	e+ ML 4.5m dia. Beam Tunnel, TBM Excavation (36,660 lin ft)	11,174	lin m		$7,171	$ 80,131,548		11,174	lin m	$7,171	$ 80,131,548	
	e+ ML 4.5m dia. Service Tunnel, TBM Excavation (36,660 lin ft)	11,174	lin m		$7,171	$ 80,131,548		0	lin m	$0	$ -	
	e+ ML 4.5m dia. Tunnels, Conc. Inv. (73,320 lin ft)	22,348	lin m		$1,351	$ 30,197,735		11,174	lin m	$1,351	$ 15,098,868	
					$0					$0		
	Provide Tunnel Construction Water Treatment Plant	4	ea.		$156,250	$ 625,000		4	ea.	$156,250	$ 625,000	
	Maintain and Operate Tunnel Construction Water Treatment Plant	4	ea.		$1,160,074	$ 4,640,295		4	ea.	$772,609	$ 3,090,436	
	Treatment of Tunnel Construction Water	4	ea.		$99,046	$ 396,185		4	ea.	$65,965	$ 263,859	
1.7.1.2.3	Halls											
1.7.1.2.4	Caverns						$ 66,214,274					$ 18,378,585
	e- ML Shaft Base Caverns D&B Excavation @ Points 3, 5, 7 (3 x 20,056 CY)	46,003	m^3		$605	$ 27,831,815						

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ILC International Linear Collider

CONVENTIONAL FACILITIES & SITING - Americas Region

details, can skip

9/4/08

RDR MAR 30 2007

KLY Power Cluster Scheme for Aug 29 2008

								A5 Main Linac									Main Linac
								Denotes changed item									
								Denotes new item									
								FINAL CONTRACT COST- in 2006 US$ (except where noted)							FINAL CONTRACT COST- in 2006 US$ (except where noted)		
								Man-Hours Total		$ Total					Man-Hours Total		$ Total
			(STILL TO BE CORRECTED IN RDR) e- ML Shaft Base Caverns D&B Excavation @ Points 2, 4, 6 (3 x 20,056 CY)	8,926	m^3	$605	$ 5,400,230			6,469	m^3	$605	$ 3,913,745			
			e- ML Points 3,5,7 D&B Exc. for Shield Doors (in Base Caverns) (3 x 959 CY)	2,199	m^3	$753	$ 1,654,522			2,199	m^3	$753	$ 1,654,748			
			e- ML Beam Dump Cavern D&B Excavation @ Point 3 (3,034 CY)	2,320	m^3	$753	$ 1,745,800			2,320	m^3	$753	$ 1,745,800			
			e+ ML Shaft Base Caverns D&B Excavation @ Points 2, 4, 6 (3 x 20,056 CY)	46,003	m^3	$605	$ 27,831,815									
			(STILL TO BE CORRECTED IN RDR) e+ ML Shaft Base Caverns D&B Excavation @ Points 2, 4, 6 (3 x 20,056 CY)	8,926	m^3	$605	$ 5,400,230			6,469	m^3	$605	$ 3,913,745			
			e+ ML Points 2,4,6 D&B Exc. for Shield Doors (in Base Caverns) (3 x 959 CY)	2,199	m^3	$753	$ 1,654,522			2,199	m^3	$753	$ 1,654,748			
			e+ ML Beam Dump Cavern D&B Excavation @ Point 2 (3,034 CY)	2,320	m^3	$753	$ 1,745,800			2,320	m^3	$753	$ 1,745,800			
						$0						$0				
			Shield Doors @ Base Caverns @ Points 2-7	6	ea.	$625,000	$ 3,750,000			6	ea.	$625,000	$ 3,750,000			
		1.7.1.2.5	Miscellaneous works					$ 32,408,826								$ 7,137,201
			e- Refuge Areas (14 ea @ 10' x 20' x 10')							1,653	m^3	$2,158	$ 3,567,869			
			e+ Refuge Areas							1,654	m^3	$2,158	$ 3,569,332			
			e- ML Personnel Crossovers, D&B Excavation (23 X 295.5 CY)	5,196	m^3	$2,158	$ 11,213,163			0	m^3	$0	$ -			
			e- ML Waveguides, Drill Excavation (968)	968	ea.	$5,156	$ 4,991,250			0	ea.	$0	$ -			
			e+ ML Personnel Crossovers, D&B Excavation (23 X 295.5 CY)	5,196	m^3	$2,158	$ 11,213,163			0	m^3	$0	$ -			
			e+ ML Waveguides, Drill Excavation (968)	968	ea.	$5,156	$ 4,991,250			0	ea.	$0	$ -			
	1.7.1.3		Surface Structures					$ 75,914,855								$ 122,001,510
		1.7.1.3.1	Central Lab Buildings													
		1.7.1.3.2	Detector Assembly Buildings													
		1.7.1.3.3	Office Buildings					$ 5,057,150								$ 5,057,150
			Points 4-7 Office Buildings (4 x 3,750 sq ft)	1,396	sq m	$3,623	$ 5,057,150			1,396	sq m	$3,623	$ 5,057,150			
		1.7.1.3.4	Service Buildings					$ 17,981,957								$ 25,799,102
			Points 2-7 Electrical Service Buildings (6 x 1,500 sq ft)	836	sq m	$2,805	$ 2,344,863			836	sq m	$2,805	$ 2,344,863			
			Points 2-7 Cooling Towers & Pump Stations Bldgs. (6 x 7,500 sq ft)	4,181	sq m	$2,805	$ 11,727,120			6,968	sq m	$2,805	$ 19,544,264			
			Points 2-7 Cooling Ventilation Buildings (6 x 2,500 sq ft)	1,394	sq m	$2,805	$ 3,909,975			1,394	sq m	$2,805	$ 3,909,975			
		1.7.1.3.5	Cryo- Equipment Buildings					$ 24,612,619								$ 24,612,619
			Points 2-7 Cryo - Warm Compressor Building (6 x 4,500 sq ft)	2,508	sq m	$4,108	$ 10,301,811			2,508	sq m	$4,108	$ 10,301,811			
			Points 2-7 Cryo - Surface Cold Box Building (6 x 6,250 sq ft)	3,484	sq m	$4,108	$ 14,310,809			3,484	sq m	$4,108	$ 14,310,809			
		1.7.1.3.6	Control Buildings													
		1.7.1.3.7	Workshops					$ 12,822,374								$ 12,822,374
			Points 4-7 Workshop Bldg. - Machine & Detector (4 x 11,250 sq ft)	4,181	sq m	$3,067	$ 12,822,374			4,181	sq m	$3,067	$ 12,822,374			
		1.7.1.3.8	Site Access Control Buildings					$ 782,556								$ 782,556
			Points 4-7 Site Access Buildings (4 x 750 sq ft)	279	sq m	$2,805	$ 782,556			279	sq m	$2,805	$ 782,556			
		1.7.1.3.9	Shaft Access Buildings					$ 14,658,198								$ 14,658,198
			Points 2-7 Shaft Access Buildings (6 x 9,375 sq ft)	5,226	sq m	$2,805	$ 14,658,198			5,226	sq m	$2,805	$ 14,658,198			
		1.7.1.3.10	Miscellaneous Buildings													
		1.7.1.3.11	User Facilities													
			KLY Cluster Buildings (no of klystron in surface average 60 to 64)													$38,269,509.84
			Points ,16,4,17,6,7,14,5,15,							12,128	sq m	$2,805	$34,017,342			
			Points 2,3							1,516	sq m	$2,805	$4,252,168			
	1.7.1.4		Site Development					$ 30,290,286								$ 47,244,801
		1.7.1.4.1	Off-site Site work													
		1.7.1.4.2	Network of Monuments													
		1.7.1.4.3	Construction Support													
		1.7.1.4.4	Site Preparation					$ 1,215,000								$ 2,025,000

Page 2 of 5

details, can skip

Single Tunnel Backup Configurations

both: 10 MW Klystrons located near to Cryomodules

#1: RDR-like: Modulators close to Klystrons

both in tunnel => 4.5 m => 6.5 m dia

#2: XFEL-like: Modulators remote from Klystrons

Modulators are beam-on accessible

long pulsed power cables & Z-matching circuits

are very expensive: + 151 MILCUs = + 2.3 %

Europe & Americas – Modulators in service bldgs

Asia – Modulators in large underground caverns

would also like smaller parallel "pilot tunnel"

cost: + 142 MILCUs = + 2.2%

details, can skip

single tunnel back-ups averaged over regions
tunnel diameter guessed, not engineered

corrected 5/20/2011

10 MW	XFEL-like	RDR-like
modulators	accessible	non-accessible
<5.5,6.5> = 6 m	4.5 m => 6 m	4.5 m => 6.5 m
Americas	-146 M, -2.2%	-220 M, - 3.4%
Europe	-107 M, -1.6%	-112 M, -1.7%
Asia *	+ 41 M, +0.6%	-63 M, -1.0%
Average	- 98 M, -1.5%	-132 M, -2.0%

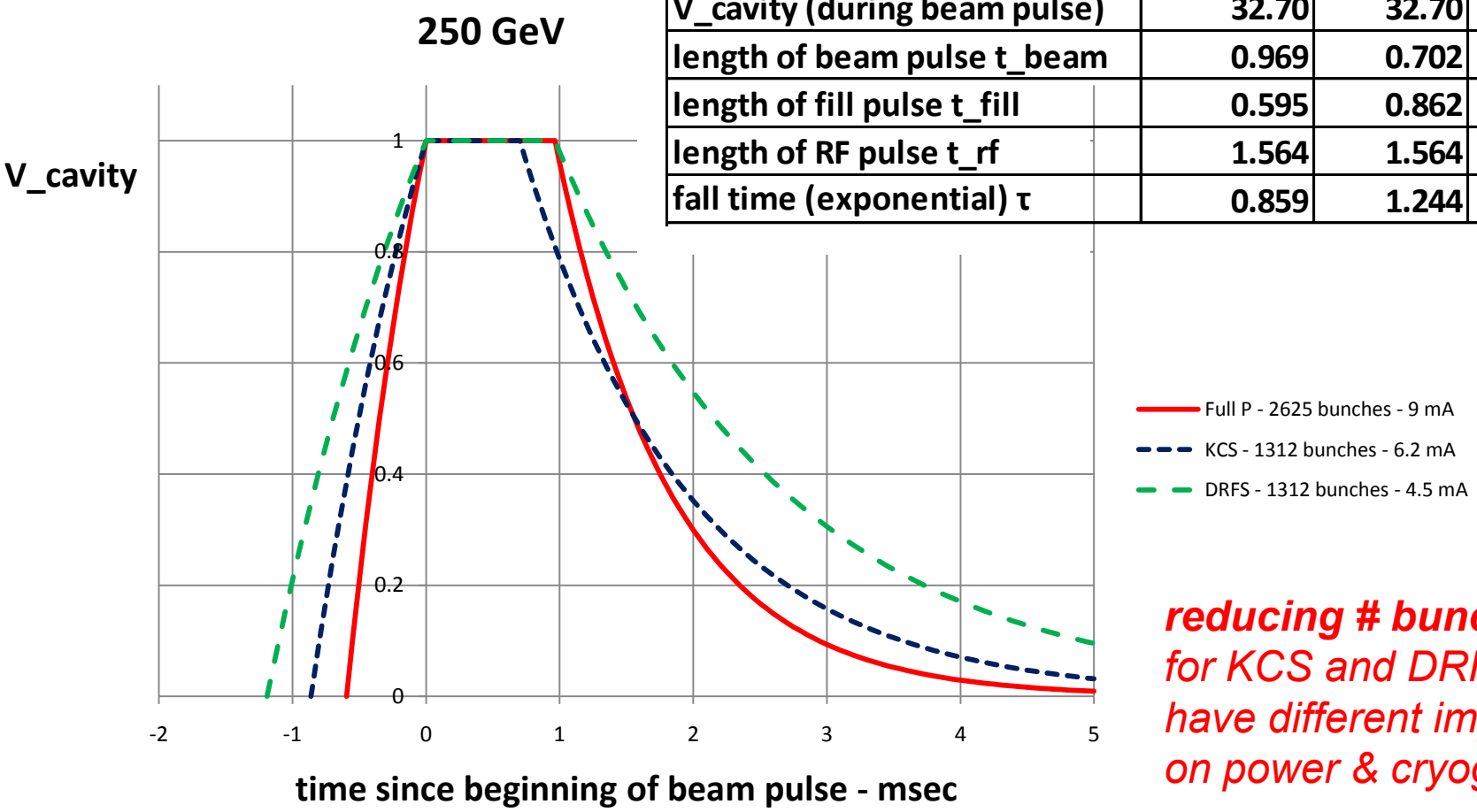
* does not include pilot tunnel for Asia

none include extra energy margin/redundancy

return to BAW-1: single tunnel

RF parameters

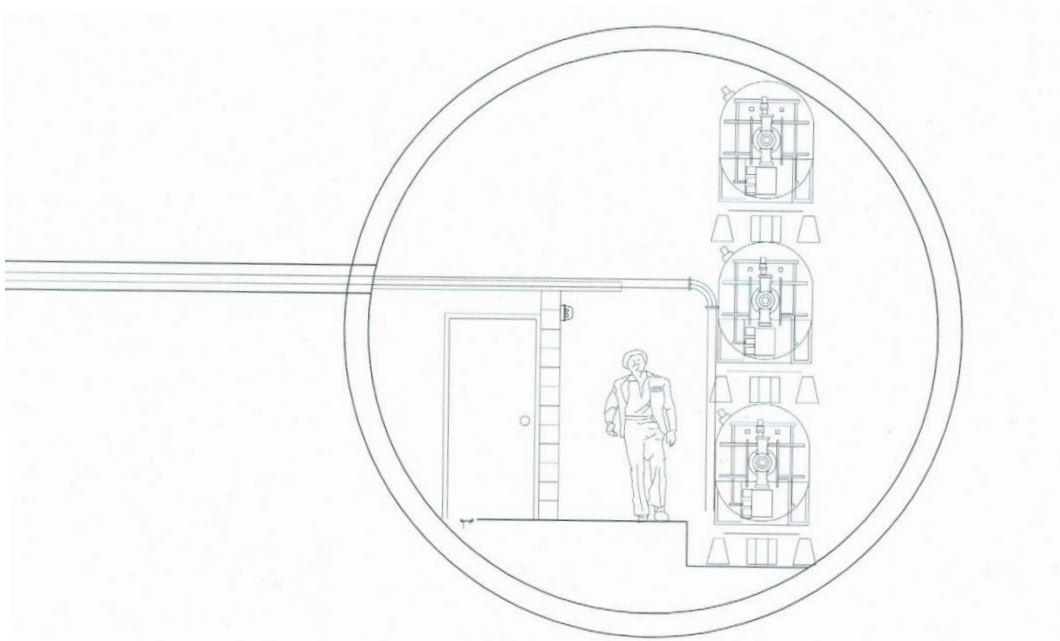
Scenario	Full Power	Reduced # bunches	
RF configuration	KCS & DRFS	KCS	DRFS
beam current I_beam	9	6.2	4.5
# bunches/train	2625	1312	1312
# trains per second	5	5	5
max energy	250	250	250
V_cavity (during beam pulse)	32.70	32.70	32.70
length of beam pulse t_beam	0.969	0.702	0.969
length of fill pulse t_fill	0.595	0.862	1.19
length of RF pulse t_rf	1.564	1.564	2.159
fall time (exponential) τ	0.859	1.244	1.717



reducing # bunches *for KCS and DRFS have different impacts on power & cryogenics*

How can 3 rings fit in the DR tunnel to mitigate e-cloud for full # e+ bunches?

CEBAF 4-ring circus



3 CM IN ONE TUNNEL
6 METER TUNNEL SHOWN WITH NOTCHED FLOOR
(VERY DIFFICULT SOLUTION)
THE OUTER CIRCLE IS 6.5 METERS

CFS goes to 7.5 m diameter DR tunnel!
CONSERVATIVE for estimate → stagger RF

details, can skip

restoring 2625 bunches/train

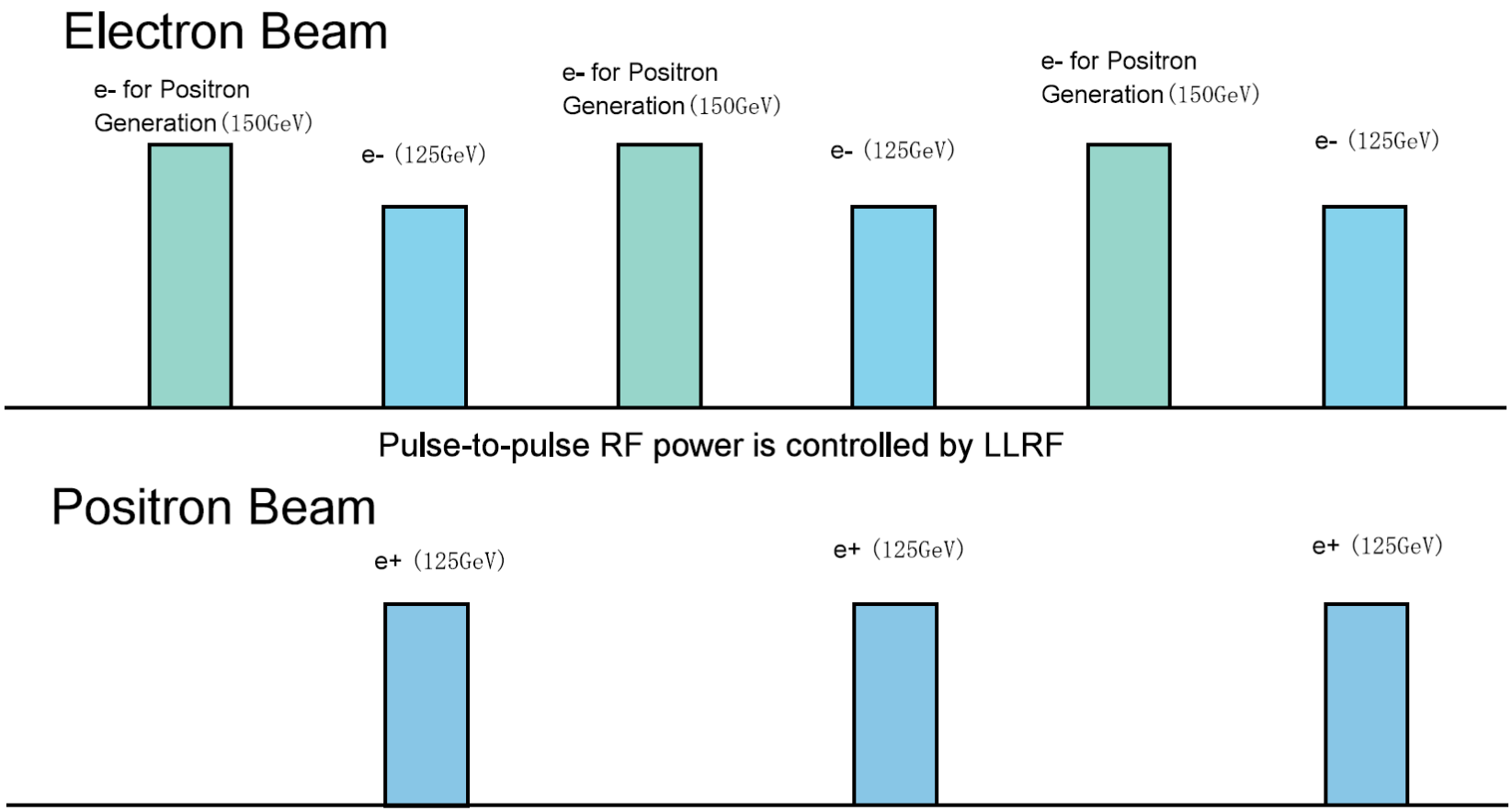
KCS only (this was not presented for DRFS)

for ML & DR cost elements as above	MILCUs	
Go Directly to 2625 (6.4 km*5 m)	2,324	
Intend to stop at 1312 (3.4 km*5 m)	1,929	***-6.0%***
Go to 1312 but ***invest*** for 2625	***diff= 39***	***+0.6%***
e.g. 3.4 km * 7.5 m	1,968	***+5.4%***
• Cost to Later restore for 2625	356	
• Total: start at 1312, then restore 2625 ***~ same***	2,324	***0.0%***

return to BAW-2: reduced # bunches

Moving Positron Source to end of Main Linac: Pulse Time Structure for Low Energy Collisions

call it: ***150 + ≤ 125x125*** normally: ***250x250***

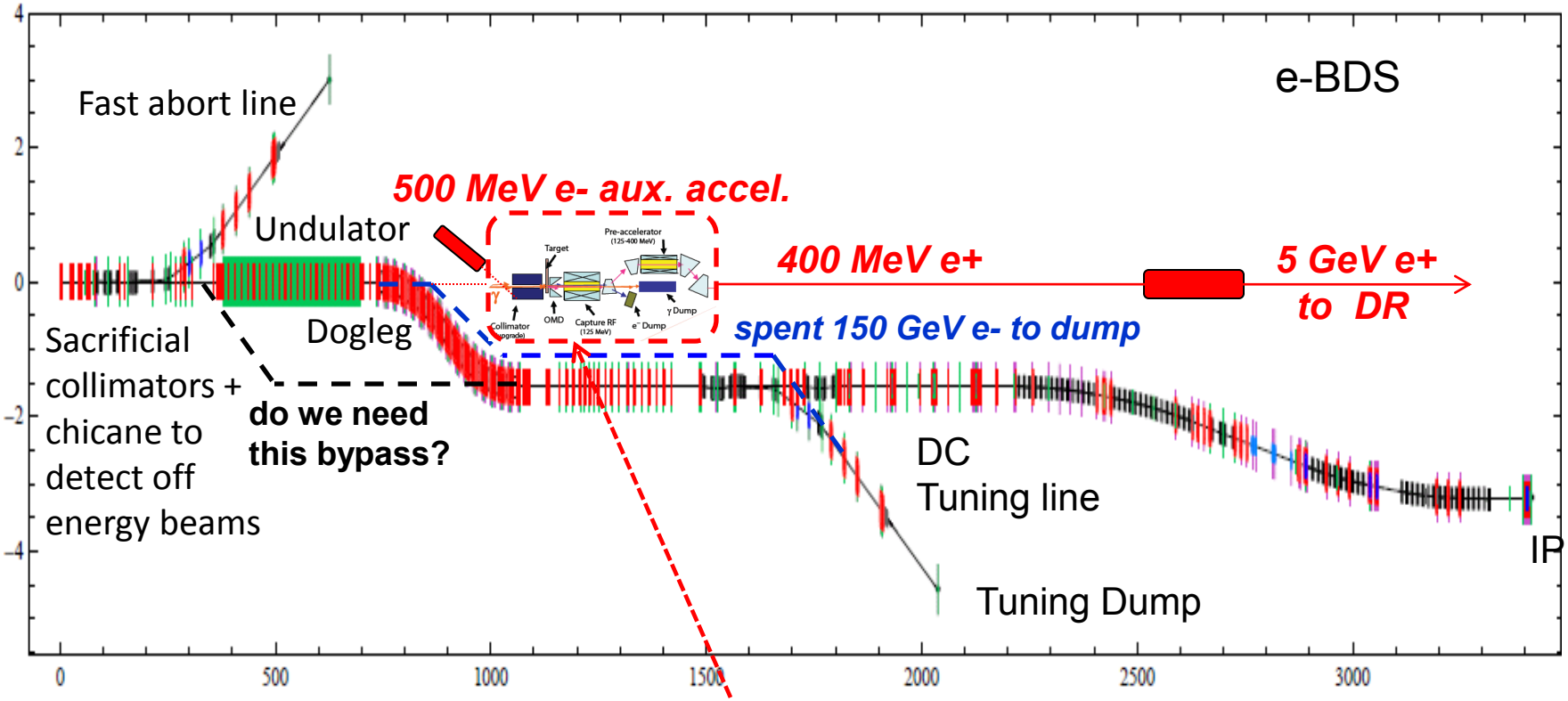


return

Centralized Positron Source

positron system is schematic only: not to scale or position

also ~ 4.5 km shorter transport line for 400 MeV e+



for Positron Source at the end of ML, just need ***one*** e+ production station, target, shielding, warm e+ acceleration to 400 MeV, target cavern, shaft, radioactive material handling sys., shorter 400 MeV e+ transport, etc., instead of a separate Keep-Alive Positron Source.

return

other backup slides

including exchange & escalation

RDR estimate	1/1/07	1/1/11	Δ
funded in US – B$	6.62	7.63	15.3%
in Germany - B€	5.51	5.72	3.7%
in Japan - B¥	772	622	-19.5%

- In this in-kind international contribution model, what the RDR estimate is and how it escalates depends on your regional point of view

PAC Pohang – Nov09: Why is 1 tunnel only ~3% less than 2 tunnels?

ML only	RDR 2 tunnels	Klys Cluster ***full Power***	diff M ILCU
no Waveguides between tunnels			- 3.2
RF Pipe			+ 26.0
Coaxial Couplers			+ 11.2
new 80 ***extra*** RF units (Nantista 2dec09)			+ 71.3
Tunnels	430.4	216.3	-214.2
Other CFS	711.4	679.8	- 31.6
Sums			***-140.5***

compared to 6,618 M of RDR => ***-2.1%*** (reduction)

Back-up for SB2009 – AAP Review

evolution of estimate
RDR → Klystron Cluster & DRFS

- America's CFS presented SB2009 estimates
  for both Klystron Cluster, and DRFS
- Asian CFS presented SB2009 estimates
  only for DRFS (***without new pilot tunnel***)
  new information will be available ~ 1 yr
- European CFS presented SB2009 estimates
  only for Klystron Cluster
- ***so I will discuss Americas CFS only***
  for the most inclusive comparison

First correct/adjust the RDR (2 tunnel) estimate

delta MILCU Commentary

start 6,618 ~ three region average CFS for RDR (2007)

6,677 Americas CFS for RDR (2007)

First correct for shaft base cavern volume error,
apply Value Engineering for higher ΔT Cooling
Water systems for Main Linac (only)
go to 6.4 km racetrack DR (stronger magnets)
* go to single stage Bunch Compressor

** proposed at Sendai – March08 – but not yet approved*

6,499 - this is Americas' ***RDR (2 tunnel) starting point***
before considering SB2009 elements:
Klystron Cluster, DRFS, or Low Power,
3.2 km DR, Central Injector Complex,
no e+ timing drift, no energy margin

SB2009 – Klystron Cluster

<u>delta</u> <u>MILCU</u> <u>Commentary</u>

6,499 RDR (2 tunnel) starting point before applying 3.2 km DR, Central Injector Complex, Klystron Cluster, DRFS, or Low Power, no e+ timing drift

-132 6,368 ***Klystron Cluster (1 tunnel – 4.5 m)*** - full Power, 6.4 km DR, no Central Injector Complex mods.

-2.0% savings wrt RDR estimate (6,618 MILCUs)

(added: -105 M, -1.6% for ***5.5 m*** dia tunnel)

- 99 6,400 ***DRFS (1 tunnel - 5.2 m dia)*** - full Power, 6.4 km DR, no Central Injector Complex mods.

-1.5% savings wrt RDR estimate (6,618 MILCUs)

(added: -86 M, -1.3% for ***5.7 m*** dia tunnel)

Back-up for BAW-1, TLCC-1&2

Single Tunnel Backup Summary depends on tunnel diameter needed not yet designed/engineered for XFEL-like

	Americas	Europe	Asia *
XFEL-like 6.5 m	- 54 M	+ 15 M	+157 M
accessible	-0.8%	+0.2%	+2.4%
XFEL-like 5.5 m	-71 M	-61 M	+ 94 M
accessible	-1.1%	-0.9%	+1.4%
RDR-like 6.5 m	-220 M	-112 M	-63 M
non-access	-3.4%	-1.7%	-1.0%

* without pilot tunnel

Single Tunnel Backup Summary depends on tunnel diameter needed not yet designed/engineered for XFEL-like

corrected 5/20 for XFEL cables & terminations

	Americas	Europe	Asia *
XFEL-like 6.5 m	-138 M	- 69 M	+ 73 M
accessible	-2.1%	-1.0%	+1.1%
XFEL-like 5.5 m	-155 M	-145 M	+ 10 M
accessible	-2.3%	-2.2%	+0.2%
RDR-like 6.5 m	-220 M	-112 M	-63 M
non-access	-3.4%	-1.7%	-1.0%

* without pilot tunnel

*(Europe *) XFEL-like: klystrons in beam tunnel, modulators on surface, with pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 236	*	remove second 4.5 m diameter tunnel 22.6 km
+153	*	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 23	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
none	*	add personnel safety refuges – ***not needed in Europe***
+ 68		pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
+ 83		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 20	*	add RF service bldgs for modulators/power supplies (<< US!)
- 3		reduced safety equipment for single tunnel
- 44		(± 44) reduced power & cooling ← physicist's scaling

+ 15 M (***± 44***) net reduction * 6.5 m dia tunnel needs engineering

+ 0.2% (***± 0.6%***) wrt RDR 6,618 M ILCUs design & estimate

- 61 M (-0.9%) for 5.5 m dia tunnel, you can interpolate between 5.5 – 6.5 m

reference: pulsed_HV_cable-PHG-7sept2010.xls

corrected
5/20/2011

*(Europe *) XFEL-like: klystrons in beam tunnel, modulators on surface, with pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 236	*	remove second 4.5 m diameter tunnel 22.6 km
+153	*	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 23	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
none	*	add personnel safety refuges – ***not needed in Europe***
+ 59		pulsed HV cables – 2,834 km! **$ 20.7/m** may be over-estimated
+ 8		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 20	*	add RF service bldgs for modulators/power supplies (<< US!)
- 3		reduced safety equipment for single tunnel
- 44		(± 44) reduced power & cooling ← physicist's scaling

- 69 M (***± 44***) net reduction * 6.5 m dia tunnel needs engineering

-1.0% (***± 0.6%***) wrt RDR 6,618 M ILCUs design & estimate

- 145 M (-2.2%) for 5.5 m dia tunnel, you can interpolate between 5.5 – 6.5 m

reference: pulsed_HV_cable-PHG-7sept2010.xls

*(Americas *) RDR-like*
Klystrons & Modulators in single tunnel

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 221	*	remove second 4.5 m diameter tunnel 22.6 km
+ 34	*	increase tunnel diameter from 4.5 => 6.5 m (***15%***) ***corrected 9/20***
- 37	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
+ 8	*	add personnel safety refuges
none		pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
none		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
none	*	add RF service buildings for modulators and power supplies
- 3		reduced safety equipment for single tunnel
none		reduced power & cooling
- 222 M		net reduction * 6.5 m dia tunnel
- 3.4%		wrt RDR 6,618 M ILCUs

reference: pulsed_HV_cable-PHG-7sept2010.xls

*(Europe *) RDR-like*
Klystrons & Modulators in single tunnel

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 237	*	remove second 4.5 m diameter tunnel 22.6 km
+153	*	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 23	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
none	*	add personnel safety refuges – ***not needed in Europe***
none		pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
none		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
none	*	add RF service buildings for modulators and power supplies
- 3		reduced safety equipment for single tunnel
none		reduced power & cooling
- 112 M		net reduction * 6.5 m dia tunnel
- 1.7%		wrt RDR 6,618 M ILCUs

reference: pulsed_HV_cable-PHG-7sept2010.xls

*(Americas *) XFEL-like: klystrons in beam tunnel, modulators on surface, with pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 221	*	remove second 4.5 m diameter tunnel 22.6 km
+ 34	*	increase tunnel diameter from 4.5 => 6.5 m (***15%***) ***corrected 9/20***
- 37	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
+ 8	*	add personnel safety refuges
+ 68		pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
+ 83		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 62	*	add RF service buildings for modulators and power supplies
- 3		reduced safety equipment for single tunnel
- 44		(± 44) reduced power & cooling ← physicist's scaling
- 54 M (***± 44***) net reduction * 6.5 m dia tunnel		needs engineering
- 0.8% (***± 0.6%***) wrt RDR 6,618 M ILCUs		design & estimate
- 71 M (-1.1%) for 5.5 m dia tunnel, you can interpolate between 5.5 – 6.5 m		

reference: pulsed_HV_cable-PHG-7sept2010.xls

corrected
5/20/2011

*(Americas *) XFEL-like: klystrons in beam tunnel, modulators on surface, with pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 221	*	remove second 4.5 m diameter tunnel 22.6 km
+ 34	*	increase tunnel diameter from 4.5 => 6.5 m (***15%***) ***corrected 9/20***
- 37	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
+ 8	*	add personnel safety refuges
+ 59		pulsed HV cables – 2,834 km! **$ 20.7/m** may be over-estimated
+ 8		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 62	*	add RF service buildings for modulators and power supplies
- 3		reduced safety equipment for single tunnel
- 44		(± 44) reduced power & cooling ← physicist's scaling

- 138 M (***± 44***) net reduction * 6.5 m dia tunnel — needs engineering

- 2.1% (***± 0.6%***) wrt RDR 6,618 M ILCUs — design & estimate

- 155 M (-2.3%) for 5.5 m dia tunnel, you can interpolate between 5.5 – 6.5 m

reference: pulsed_HV_cable-PHG-7sept2010.xls

*(Asia *) XFEL-like: klystrons in beam tunnel, modulators in accessible caverns, w pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 187	*	remove second 4.5 m diameter tunnel 22.6 km
+126	*	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 3	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
none	*	add personnel safety refuges – ***not needed in Asia***
+ 68		pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
+ 83		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 76	*	add RF service ***caverns*** for modulators/power supplies (~ US!)
- 3		reduced safety equipment for single tunnel
none		reduced power & cooling – same amount of underground cooling

+ 157 M net addition for 6.5 m dia tunnel

+ 2.4% wrt RDR 6,618 M ILCUs

+ 94 M (+1.4%) for 5.5 m dia tunnel, interpolate between 5.5 – 6.5 m

reference: pulsed_HV_cable-PHG-7sept2010.xls

corrected
5/20/2011

*(Asia *) XFEL-like: klystrons in beam tunnel, modulators in accessible caverns, w pulsed HV cables*

Δ MILCUs		Description (for ML + BC2 region = 1.043 * ML)
- 187	*	remove second 4.5 m diameter tunnel 22.6 km
+126	*	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 3	*	remove WG penetrations & cross-overs
- 3		remove WGs from these penetrations
none	*	add personnel safety refuges – ***not needed in Asia***
+ 59		pulsed HV cables – 2,834 km! **$ 20.7/m** may be over-estimated
+ 8		impedence matching for pulsed HV cables (***added by mcrec 9/22***)
+ 76	*	add RF service ***caverns*** for modulators/power supplies (~ US!)
- 3		reduced safety equipment for single tunnel
none		reduced power & cooling – same amount of underground cooling

+ 73 M net addition for 6.5 m dia tunnel

+ 1.1% wrt RDR 6,618 M ILCUs

+ 10 M (+0.2%) for 5.5 m dia tunnel, interpolate between 5.5 – 6.5 m

reference: pulsed_HV_cable-PHG-7sept2010.xls

*(Asia (no pilot tunnel) *) RDR-like Klystrons & Modulators in single tunnel*

Δ MILCUs	Description (for ML + BC2 region = 1.043 * ML)
- 187 *	remove second 4.5 m diameter tunnel 22.6 km
+126 *	increase tunnel diameter from 4.5 => 6.5 m – ***PHG scaling***
- 3 *	remove WG penetrations & cross-overs
- 3	remove WGs from these penetrations
none *	add personnel safety refuges – ***not needed in Asia***
none	pulsed HV cables – 2,834 km! $ 23/m may be over-estimated
none	impedence matching for pulsed HV cables (***added by mcrec 9/22***)
none *	add RF service buildings for modulators and power supplies
- 3	reduced safety equipment for single tunnel
none	reduced power & cooling
- 63 M	net reduction * 6.5 m dia tunnel
- 1.0%	wrt RDR 6,618 M ILCUs

reference: pulsed_HV_cable-PHG-7sept2010.xls

Asia pilot tunnel

2007 $ = ILCU for ML+BC2 (1.043)

138 M ILCUs – 4.5 m unfinished tunnel based on PHG fraction 0.74 based on VLHC estimates

1 M ILCUs - simple 7m long personnel x-overs

3 M ILCUs – add back safety eq for 2nd tunnel for egress to pilot tunnel

142 M ILCUs

+ 2.2% relative to 6,618 M ILCUs RDR estimate

Notes for above XFEL-like estimate

- This assumes 6.5 m dia tunnel from Asian CFS for both Klystron & Modulators/PS in single tunnel. Atsushi has not done layout for only Klystron in tunnel and Modulators/PS in accessible caverns or surface buildings (as for XFEL-like).
- What is required diameter for Klystrons in tunnel and Modulators/PS elsewhere? ***Do it parametrically?***
- Need to say what is impact in Japan (greater 6.5/4.5 cost ratio) for single tunnel, both options
  (without "pilot tunnel" – can add that increment at end)

XFEL-like RF Power System in 1 tunnel including Asian and European CFS

- Strong function of Tunnel Cost (6.5m)/(4.5m)

Region	**C(6.5m)**/C(4.5m)	Reduction *correct 9/20*
Americas	***1.153***	- ***137*** M ILCUs -***2.07***%
Europe *	1.65	- 28 M ILCUs -0.43%
Asia **	***1.595***	- ***32*** M ILCUs -***0.48***%
Average		- ***66*** M ILCUs -***0.99%***

* scaling tunnel costs for Euro DR(5m)/ML(4.5m)

** not including 4.5 m unfinished pilot tunnel in Asia

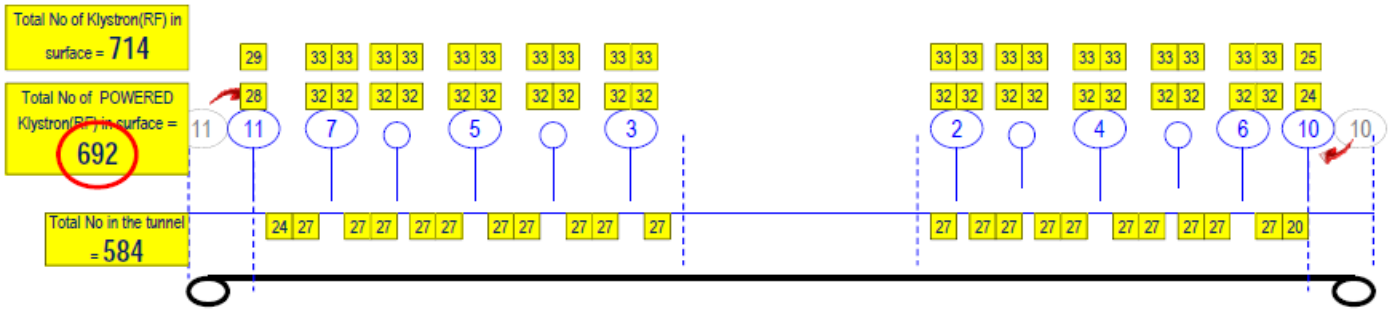
Cost of add 1 unfinished Asian 4.5 m "pilot" tunnel

f = unfinished/finished = ***0.74 VLHC*** => ***+ 2.1 %***

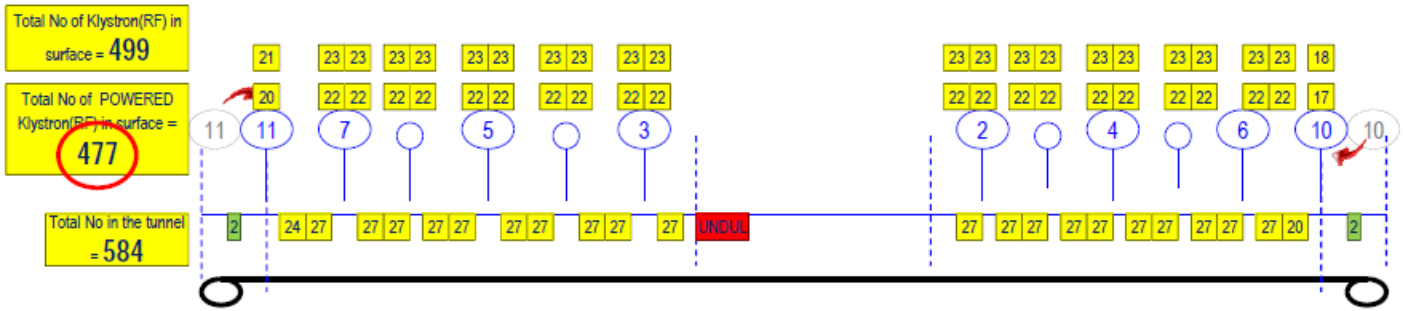
Back-up for BAW-2, TLCC-3&4

KCS configurations

KCS



A. FULL POWER



B. LOW POWER

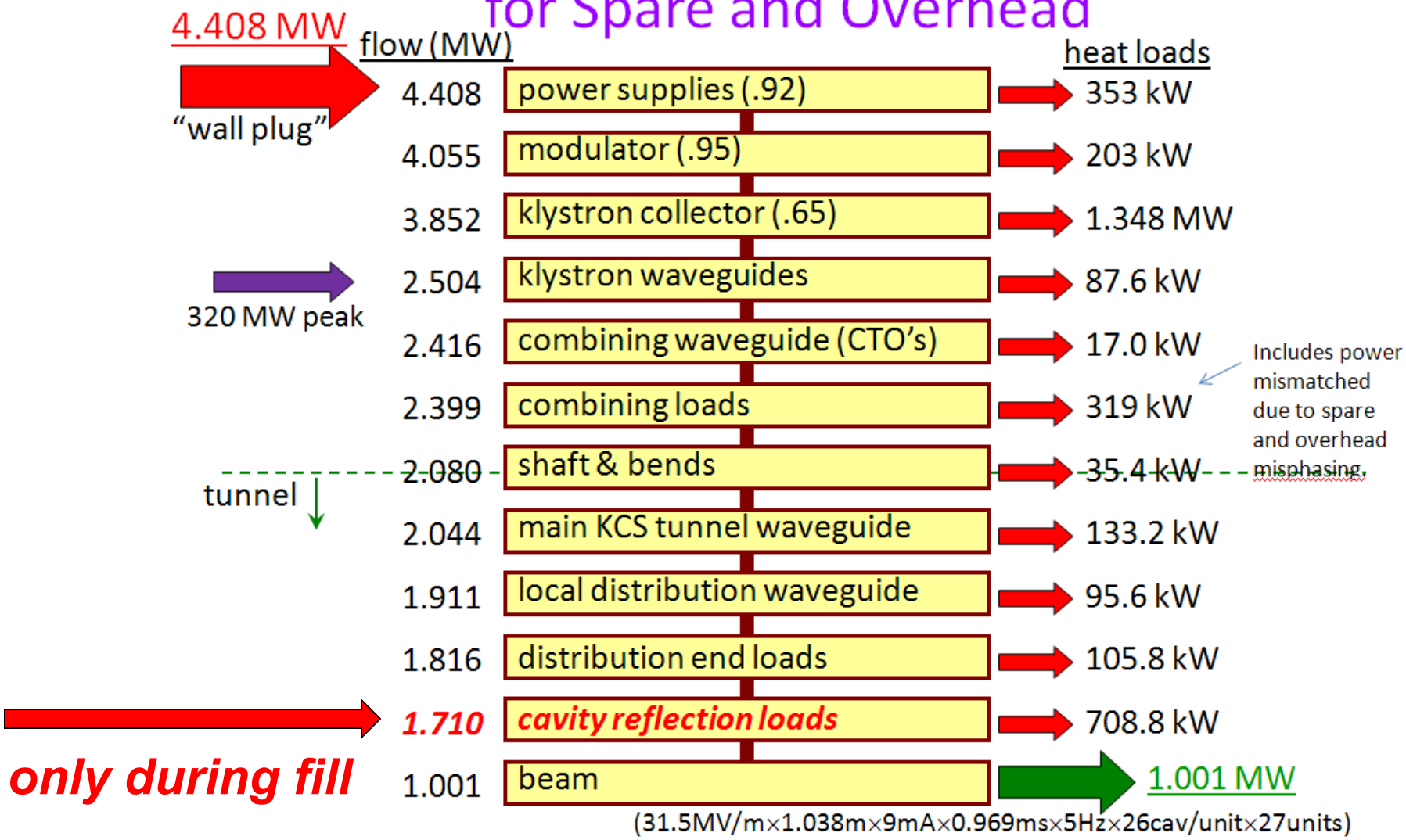
(our interpretation)

Low Power to be checked

DRAFT 12/06/2010 E. Huedem

KCS power flow

27 Unit KCS Average Power Diagram Corrected for Spare and Overhead



7.5 m diameter DR tunnel for 3 rings

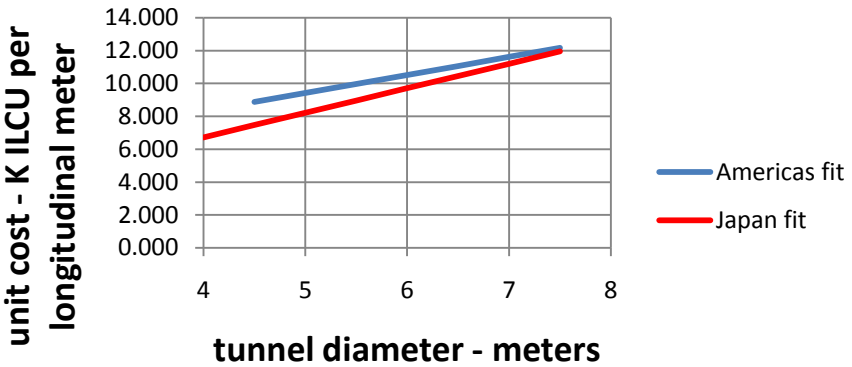
- Prior SB2009 had 6.5 m dia DR tunnel
- US 6.5 m 11.067 K/m, Asia 6.5 m 10.458 K/m
- US 7.5 m 12.166 K/m, Asia 7.5 m 11.952 K/m
- Difference between 7.5 m and 6.5 m diameter tunnel for for 3,223 meter DR:
  US 3.6 M ILCU, Asia 4.8 M ILCU
- Both US and Asia estimates include excavation & concrete finishes
- This above analysis of US estimate did ***NOT*** include extra costs for tighter turning TBM for 3.2 km DR, although detailed CFS estimate did

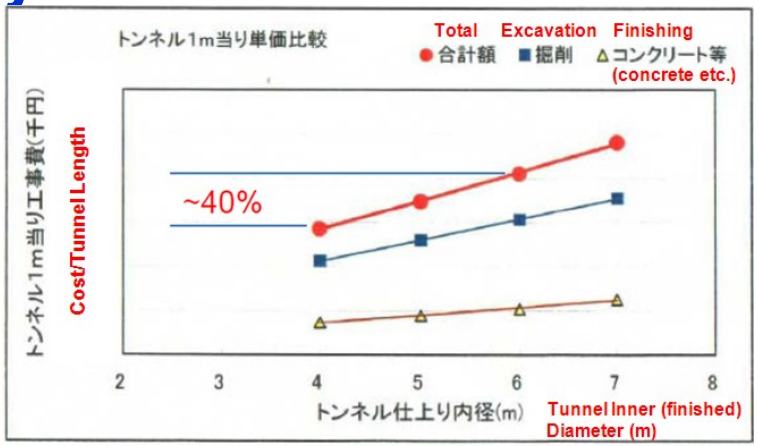
TBM Tunnel Cost vs. Diameter

– PHG – 10jan2011

TBM tunnel + finishing cost

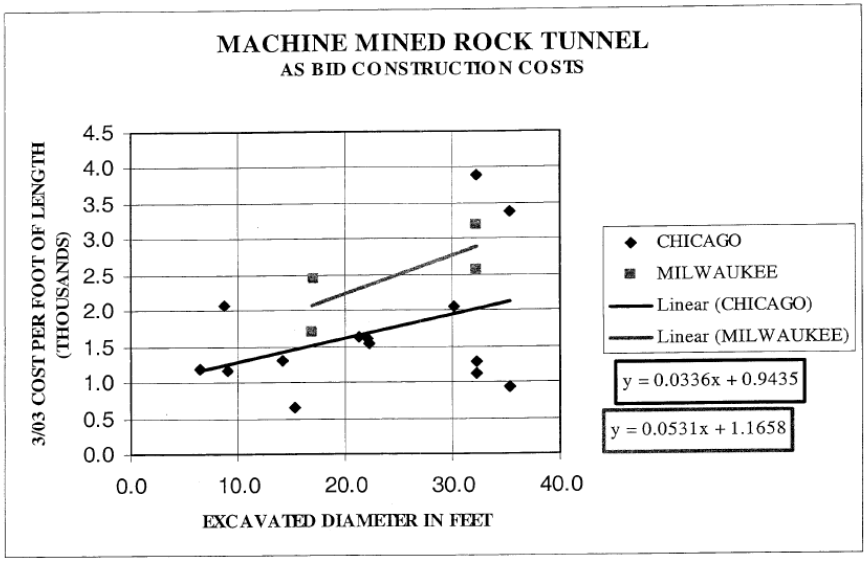
Japan fit normalized at dia = 5 m to RDR value



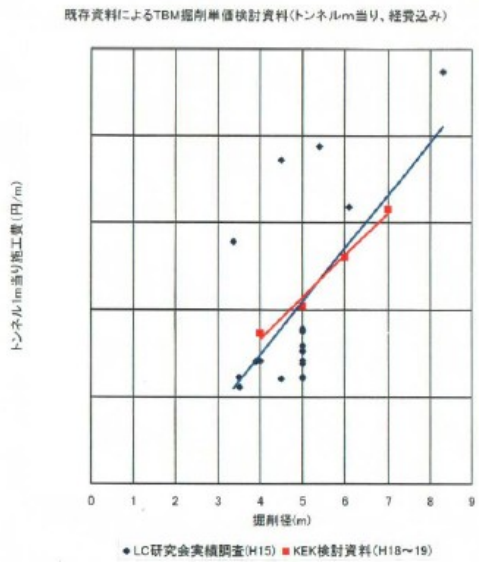


(This does not include land developing cost.)

Hanson/Tracy Lundin: Chicago TARP – Deep Tunnel



Atsushi @ BAW-1



Cost Impact Matrix

Reduce # bunches 2625 => 1312 @ 250x250 GeV

reduced # bunches	Tech. Comps.	RF Power	Cryo Power	Civil Tunnels	Civil Cavern*	Civil Buildings	Electrial Power	Thermal Cooling	Notes * includes alcoves & tunnel widenings
e- source	√	√	√				√	√	reduced laser and cryo RF
e+ source	√	√	√				√	√	cryo RF and cooling of photon dump
DR	√	√	√	√	√	√	√	√	reduced circumference to 3.2 km
RTML	√	√	√				√	√	only BC1 (BC-2 included under ML)
ML (& BC-2)	√	√	√			KCS	√	√	# HLRF components (LLRF impact)
BDS	√	slight	slight				slight	slight	traveling focus components only
Exp Hall									no impact yet
Common							√		only Master Substation

Major costs are for ***Main Linacs*** & ***Damping Rings***,

so we will concentrate only on these systems.

e- & e+ Sources, and RTML have reduced power

BDS traveling focus systems ~ small extra costs

CFS did include impact on Master Substation

Damping Ring Magnets

RF cavities & wigglers on next page

Positron-Source-Location-PHG-19nov2010.xls/DR-counts				1.0323					dipole KLs are OK						3. how do the cost of sextupoles scale with Sx term? F					
Peter H. Garbincius - re-do damping ring counts			**7dec2010-3:30 PM**																	
https://wiki.lepp.cornell.edu/ilc/bin/view/Public/DampingRings/#Damping_Rings_Parameters_and_Lat																				
		from RDR table		k1 arcs =		0.287	k max=		max k1 =		0.585	all quads are 0.3 m								
per ring - 5 GeV	OCS6 - RDR DR & Magnets - 6.7 hex						per ea	per tot	DCO4 - Susanna 10/09 - 6.4 race				per ea	per tot	SB2009 - 14dec09 - 3.2 race				per ea	per tot
Main e- DR & e+ DR each	#	length m	max KL	unit	field		K 2006	K 2006	#	lgt	field		2006	2006	#	lgt	field		2006	2006
RDR Dipoles 6 m	114	6	0.0524	1	0.145	T	63.66	7,257												
RDR Dipoles 3 m	12	3	0.0262	1	0.145	T	38.82	466												
DCO4 arc dipoles			above is		about right				200	2	0.27	T	39.51	7,902						
DSB3 arc dipoles - type 1			bend angle												68	2.7	0.26	T	51.36	3,493
DSB3 arc dipoles - type 2			at 1 m per												60	2.7	0.36	T	71.12	4,267
chicane dipoles - 1 m - 0.27	**no chicanes?**		6 m dipole	**Susanna: chicanes omitted but needed**					48	1	0.27	T	19.76	948	48	1	0.27	T	19.76	948
Quads V1	551	0.3	0.31	1/m	6.1	T/m	12.24	6,747												
Quads V2-V3-V4	196	0.3	0.31	1/m	17.3	T/m	16.84	3,301												
Quadrupoles - 0.3 m - 12 T/m		Q is bend at 1 m			right range				692	0.3	12	T/m	16.84	11,654						
Quadrupoles # 1 Q30L300 V2	**but RDR was Q60 L30 but pole tip radius was 0.03 m**								all = 0.3 m		interpolate below				204	0.3	11	T/m	14.31	2,920
Quadrupoles # 2			K1 V1 =	0.287		2.8361				are these quads all the same?					128	0.56	8.3	T/m	26.95	3,449
Quadrupoles # 3			K1 V2-4 =	0.725	0.3 m	2.5261				use same cost as RDR V2					128	0.73	11.9	T/m	32.84	4,204
Quadrupoles # 4				0.939	0.15 m						Gmax=	12.434	close!		4	0.215	16.9	T/m	10.44	42
Quadrupoles # 5															30	0.43	14.7	T/m	20.71	621
sum # main Quadrupoles =	747								692						494		interpolate below			
sextupoles	480	0.25	0.24	1/m^2	16.76	T/m^2	4.799	2,303	392	0.25	215	T/m^2	11.22	4,400	280	0.25	150	T/m^2	9.956	2,788
orbit corrector magnets	300	0.25	0.002	1	0.133	T	4.756	1,427	300	0.25	0.133	T	4.756	1,427	300	0.25	0.133	T	4.756	1,427
skew quads	240	0.25	0.03	1/m	2.0	T/m	12.1	2,903	240	0.25	2.2	T/m	12.1	2,903	240	0.25	2.2	T/m	12.1	2,903
check arc dipoles int B*dL (T-m)	104	expect	104.4	T-m	sum07	25,192	sum06	24,404	108	T-m - (	sum07	30,179	sum06	29,234	106	close	sum07	27,936	sum06	27,062
Common Injection/Extraction/Abort																				
RTML6 dipoles (inj/extr/abort	3	D60L2000							same						same					
Quads V2 (inj/extr)	12								same						same					
inj/extr kickers	40								same						same					
inj/extr septa	4								same						same					
abort kickers	1								same						same					
abort septa	1								same						same					

RF & wigglers for DRs – 5 Hz

full P – 3 rings

lattice	RDR-OCS 6	DCO 4	SB2009	SB2009	SB2009
	20-Apr-07	full-P 5 Hz	LowP 5 Hz	full-P 5 Hz	full-P 5 Hz
beams	e+/e-	e+/e-	e+/e-	e-	2* e+
reference-page	ref 3 p 31	ref 4 p 3	4-11,30	ref 4 p 30	ref 4 p 30
Circumference (m)	6695	6476	3238	3238	3238
# bunches per DR	2610	2610	1305	2610	1305
damping time ms	26	21	24	24	24
RF Voltage MV/DR	24	21	7.5	7.5	3.75
# RF cavities/DR	18	16	6	12	6
# klystrons/DR	5	4	2	4	2
Wiggler B (Tesla)	1.67	1.6	1.6	1.6	1.6
Wiggler period (m)	0.4	0.4	0.4	0.4	0.4
Wiggler lgt ea (m)	2.45	2.45	2.45	2.45	2.45
Wiggler lgt/DR (m)	200	216	78	78	78
# wigglers/DR	80	88	32	32	32

DR & Summary Cost Differentials

Damping Rings	Full Power 2625		Reduced # 1312		cost	restore 2625 bunches 1 e- & 2 e+ DRs		Notes:
	Quantity	Cost - M	Quantity	Cost - M	diff - M	Quantity	Cost - M	
Technical Elements		425.8		276.3	-149.5		426.1	see DR detail sheet(s)
Cryogenic Plants - MW	2.16	19.9	0.77	9.6	-10.3	need info	need info	two cryo plants
Cryogenic Distribution		8.5		8.3	-0.2		12.8	50% more for 3 rings
CFS: Civil	6.4 @ 5	127.8	3.2 @ 7.5	107.3	-20.5		107.3	note 7.5 m tunnel to allow 3 rings
CFS: Electrical - MW	26.3	20.1	12.8	16.3	-3.8	19.2	18.1	
CFS: Air + Cooling - MW	19.5	32.0	8.5	24.2	-7.8	14.8	30.3	
totals		634.1		442.0	-192.1		594.5	

Summary (in M ILCU)	ML	DR	Total	wrt 6,618 M ILCU
Savings with KCS	-203	-192	-395	-6.0%
Savings with DRFS	-363	-192	-555	-8.4%

tab: low-P

restoring 2625 bunches/train

Main Linac -KCS	Full Power 2625	to restore 2625 initiallly	defer	terminate at 1312	Notes
	Cost - M	Cost - M	Cost - M	Cost - M	red = PHG guess
Klystrons - 10 MW	206	154	53	154	
Modulators & PS	378	282	95	282	
KCS Pipe - meters	1	1	0	1	
CTO Couplers - pairs	7	5	2	5	
W.G. Switches - pairs					
Cryogenics Plants - MW	228	228	0	219	could defer some compressors
CFS: Civil	610	593	17	593	defer buildings
CFS: Electrical - MW	143	134	9	126	assume some fraction ~ 50%
CFS: Air + Cooling - MW	117	112	5	107	assume some fraction ~ 50%
totals	1690	1510	180	1487	

Damping Rings - 3.2 km 1 e+ & 1 e- => 2 e+ & 1 e-	Full Power 2625	to restore 2625 initiallly	defer	terminate at 1312	Notes
	Cost - M	Cost - M	Cost - M	Cost - M	red = PHG guess
Technical Elements	426	276	150	276	maybe some extra/reconfigure
Cryogenic Plants - MW	20	20		10	could defer some compressors
Cryogenic Distribution	9	8	0	8	minor # new boxes
CFS: Civil	128	107	21	107	already paid for 7.5 m tunnel
CFS: Electrical - MW	20	18	2	16	assume some fraction ~ 50%
CFS: Air + Cooling - MW	32	28	4	24	assume some fraction ~ 50%
totals	634	458	176	442	
sums ML (KCS) + DR	2324	1968	356	1929	
difference = extra investiment cost =		1968	minus	1929	39 M ILCU (= 0.6% of 6.6 B ILCU)

Outline of this presentation

- call it: ***150 + 125x125*** normally: ***250x250***
- factorize: 150 + 125x125, then Centralized e+ Source
- pulse structure – starting point
- limitations in this analysis
- Impact Matrix, more details for e- ML & DRs (τ_{damp})
- Cost Impact Table for 150 + 125x125
- My hallucinations on Centralized e+ Source
- A little bit clearer picture
- Cost Impact Table for Centralized e+ Source
- Summary

Cost Impact Matrix for 150 + ≤ 125x125 relative to 250x250 @ reduced # bunches

150 plus 125*125	Tech. Comps.	RF Power	Cryo Power	Civil Tunnels	Civil Cavern*	Civil Buildings	Electrial Power	Thermal Cooling	Notes * includes alcoves & tunnel widenings
e- source	√	√	√		?		√	√	must provide 10 Hz pulses
e+ source	√				√		√	√	none, no extra load on γ target/dump
e- DR	√	√	√				√	√	provides 150 and ≤ 125 GeV pulses
e+ DR	√	√	√				√	√	needs more peak RF power for 50% df
e- RTML		√	√				√	√	must double pulse BC-1
e+ RTML									no impact
e- ML (&BC2)	√	√	√			KCS	√	√	must provide 125 and ≤ 125 GeV pulses
e+ ML (&BC2)									no impact
e- BDS				√	√			√	MPS & spent 150 GeV e- beam to dump
e+ BDS									no impact
Exp Hall									no impact
Common							√		only Master Substation

- Major costs are for ***e- Main Linac*** & ***both Damping Rings***, so we will concentrate only on these systems
- Different civil construction (enclosures) for e+ Source
- e- Source, e- RTML (BC-1) and e- BDS (dump only) have small increased power ~ small extra costs

RF & wigglers for DRs

conventional components are the same

lattice	SB2009	SB2009	SB2009
	LowP 5 Hz	LowP 10 Hz	LowP 10 Hz
beams	e+/e- ea	e+ Ring	e- Ring
reference-page	4-11,30	4-28,30	ref 4 p 30
Circumference (m)	3238	3238	3238
# bunches per DR	1305	1305	1305
damping time ms	24	13	18
RF Voltage MV/DR	7.5	13.4	10.4
# RF cavities/DR	6	9	9
# klystrons/DR	2	3	3
Wiggler B (Tesla)	1.6	2.4	2.4
Wiggler period (m)	0.4	0.28	0.28
Wiggler lgt ea (m)	2.45	1.72	1.72
Wiggler lgt/DR (m)	78	75	75
# wigglers/DR	32	44	44

tab: DR-info

different wigglers
assume same cost - MP

1312 bunches	250x250		150+125*125		Cost diff M ILCU	Notes
	Quantity	Cost M ILCU	Quantity	Cost M ILCU		
Main Linac - KCS						
modulators & PS for e- ML	499/2	76.9	499/2	77.0	0.2	ChrisJ estimate (+0.2%) & ChrisA note
cryogenics plants e- ML	5*4.12 MW		5*3.35 MW		0	lower, so no impact
cryogenics plants e+ ML	5*4.12 MW		5*2.65 MW		0	lower, so no impact
RF power	66 MW		59 MW		0	no impact, PHG => Emil 12jan2011
other electrical power	54 MW		54 MW		0	same, no impact
thermal cooling	64 MW		57 MW		0	lower, so no impact
Damping Rings - 2 rings - 3.2 km						
technical components		276.3		298.4	22.1	see detailed RF & wiggler change list
cryogenic plant e- DR	1.18 KW 4.5K	3.5	1.64 KW 4.5 K	4.3	0.8	100% df + 2*50% duty factor
cryogenic plant e+ DR	1.18 KW 4.5K	3.5	1.55 KW 4.5 K	4.1	0.6	100% duty factor & 50% duty factor
cryo accessories e- DR		3.1		3.1	0	same, no impact
cryo accessories e+ DR		3.1		3.1	0	same, no impact
cryo distribution e- DR		4.2		4.2	0	same since # end boxes the same
cryo distribution e+ DR		4.2		4.2	0	same since # end boxes the same
CFS: Civil		107.3		107.3	0	same, no impact
CFS: Electrical Power	12.8 MW	16.3	16.8 MW	17.4	1.1	CFS did this better than PHG's P^{α}
CFS: Thermal Cooling	8.5 MW	24.1	12.4 MW	28.2	4.1	CFS did this better than PHG's P^{β}
e- Src - Modulators & PS					1.2	need to double pulse, same E
e- Src - Electrical & Cooling					3.2	PHG guess/scale for RF & Cryo
e- Cryogenics capacity					2.9	2X dynamic cryogenics load
e- RTML Modulators & PS					0.2	need to double pulse BC-1 at 5 GeV
e- RTML Electrical & Cooling					0.2	PHG guess/scale for RF & Cryo
e- RTML Cryogenics capacity					0.4	2X dynamic cryogenics load
				total increase =	37	M divide by 6,618 M ILCU = +0.56%

tab: 10 Hz summary

cost impacts of moving of e+ source

Cost Differentials for Centralized e+ Source - M ILCUs	Savings	Additions	Notes:
one set of MPS sacrifical collimators, abort, & dump	???		never estimated for RDR
301 m tunnel (for above)	3.0		
301 m tunnel widening (for above)	4.7		
4 m dia rad material handling shaft & grouting	9.5		
Radioactive Materials Handling & Storage Bldg	3.1		
KAS e+ target station & acceleration to 400 MeV	28.2		- see next page for details
electrical power	???	???	not considered yet by CFS
thermal cooling	???	???	not considered yet by CFS
spent 150 GeV e- from undulator => dump 1,166 m dogleg, min FODO, min instrumentation, rastering?		???	to e- tune up dump or to e+ primary dump (backwards)?
100 msec beam switches		???	
corrector magnets for dual energy trajectories		???	
LET bypass around undulator for beam to I.P. (620 m)		???	- do we need/want this?
total change (= savings minus additions) - M ILCU	48.5	???	M ILCU

150 + ≤ 125x125 **+ 37 M ILCU (more) – from prior page**

Centralized e+ Source **- 48 M ± ??? – this page**

Summary **- 11 ± ??? M ILCU**

tab: needs

RDR Keep-Alive Source Estimates

Cost Estimating of KAS - components

John Shepard - RDR	K ILCU - 2007	Notes
KAS laser (0.5)	0	also needed for aux. source, no differential
KAS gun (0.5)	0	also needed for aux. source, no differential
Sub-Harmonic Buncher (2)	0	also needed for aux. source, no differential
500 MeV KAS e- accelerator	0	also needed for aux. source, no differential
everything below was needed for second e+ production station & acceleration to 400 MeV		
e+ production target	3,937	
Adiabatic Matching Device	2,329	
Target & AMD housing/shield	1,123	
SW Cavities (2)	124	
TW Cavities (12)	3,097	
Warm Station High Level RF (14)	10,839	
SW HL RF distribution (2)	380	
TW HL RF distribution (12)	1,388	
Controls - pro-rated	657	
KAS Instrumentation	968	
KAS Dumps & Collim	210	
KAS Vacuum	780	
KAS Conventional Magnets	1,177	pro-rate KAS magnet costs from PS costs
KAS Power Supplies	1,180	
totals	28,189	K ILCU - 2007

tab: needs

Cost Differentials for ML

Main Linac -KCS	Full Power 2625		Reduced # 1312		cost	Notes: basis = ChrisA's cartoon
	Quantity	Cost - M	Quantity	Cost - M	diff - M	27unitKCSpowerflow.pptx
Klystrons - 10 MW	714	206.3	499	153.7	-52.6	cost includes Learning Curve
Modulators & PS	714	377.7	499	282.4	-95.3	assumes same performance
KCS Pipe - meters	1428	1.4	998	1.0	-0.4	differential in RF Building
CTO Couplers - pairs	714	7.1	499	5	-2.1	klystrons to pipe in building
W.G. Switches - pairs	714		499			safety - have no unit cost
Cryogenics Plants - MW	10*4.42	228.1	10*4.12	218.8	-9.3	same cryo accessories & distrib
CFS: Civil		609.5		593	-16.5	
CFS: Electrical - MW	151.6	142.5	119.7	125.5	-17.0	red = changed since draft
CFS: Air + Cooling - MW	79.8	117.3	63.6	107.49	-9.8	
totals		1689.9		1486.9	-203.0	

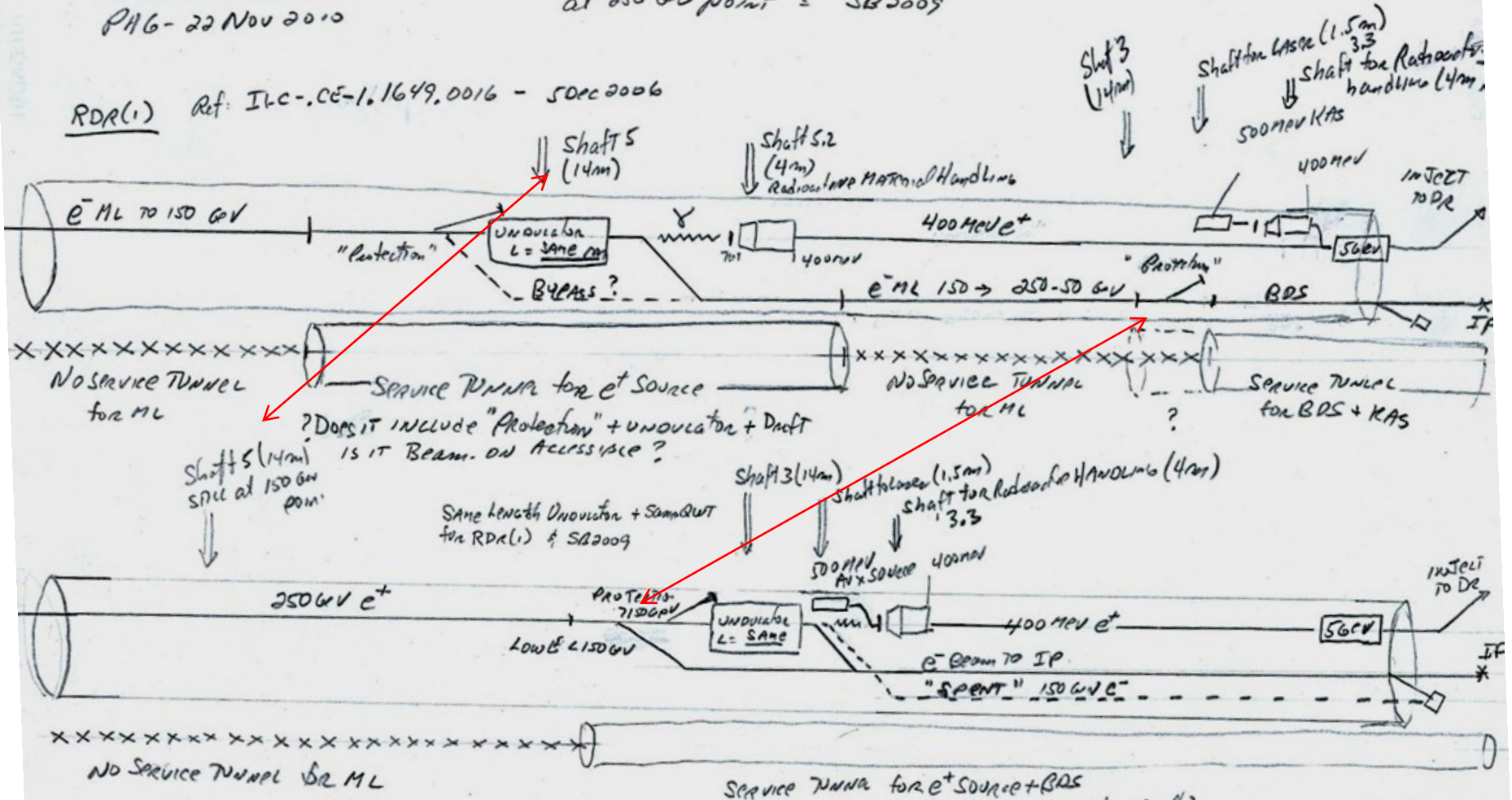
Main Linac - DRFS	Full Power 2625		Reduced # 1312		cost	Notes:
modified 18jan2011	Quantity	Cost - M	Quantity	Cost - M	diff - M	based on DRF-Cost 110115A
Klystrons - 800 KW	7592	493.5	3796	247.0	-246.5	includes extra capaity for Low P
Magic Tees - Hybrids	7592	52.0	11690	80.0	28.0	for DC PS and Modulators
DC PS (incl backup)	584	174.0	584	65.1	-108.9	did not include "learning curves"
MA Pulser (incl backup)	876	52.6	437	35.0	-17.6	
Cryogenics Plants - MW	10*4.42	228.1	10*4.72	237.2	9.1	same cryo accessories & distrib
CFS: Civil		632.9		632.9	0.0	
CFS: Electrical - MW	164.2	186.7	130.8	171.8	-14.9	corrected power typo - 28jan2011
CFS: Air + Cooling - MW	92.8	171.1	61.3	159.1	-12.0	
totals		1990.9		1628.1	-362.8	

tab: low-P

Cost Difference for e^+ Source at 150 GeV point = RDR(1) = Single Tunnel RDR
at 250 GeV point = SB2009

PHG - 22 Nov 2010

RDR(1) Ref: ILC-.CE-1.1649.0016 - 5 Dec 2006



Tunnels	RDR(1)	SB2009	diff
Beam from 150 GeV	8327 m	7969 m	358 m
Service tunnel inc Protection undulator γ drift/dogleg	3594 m	3236 m	358 m
TOT	11,921 m	11,205 m	716 m

But watch tunnel widenings!

SB2009: Ref 6-11-BCD - 20 Nov 2009
Some consistencies with Norbert Collomb - 12 July 2010 drawings