The International Linear Collider From RDR to TDP

XXI. Russian Particle Accelerator Conference Zvenigorod · September 29 to October 3, 2008

Wilhelm Bialowons · GDE

Historical Background

- Over 15 years active international R&D
  - NLC & JLC based on (normal conducting) Cu X-band technology (11.4 GHz)
  - CLIC two-beam accelerator (30 GHz)
  - TESLA Superconducting RF (SCRF, 1.3 GHz)
- 2002 BMBF (German Funding agency) XFEL decision
  - Request to internationalize ILC effort
- 2004 ITRP recommends SCRF Linac Technology for the ILC
  - Recommendation later endorsed by ICFA
- 2005 Global Design Effort (GDE) formed

2001

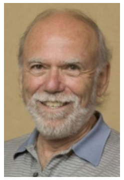
2006

ILC GDE: A Truly Global Effort

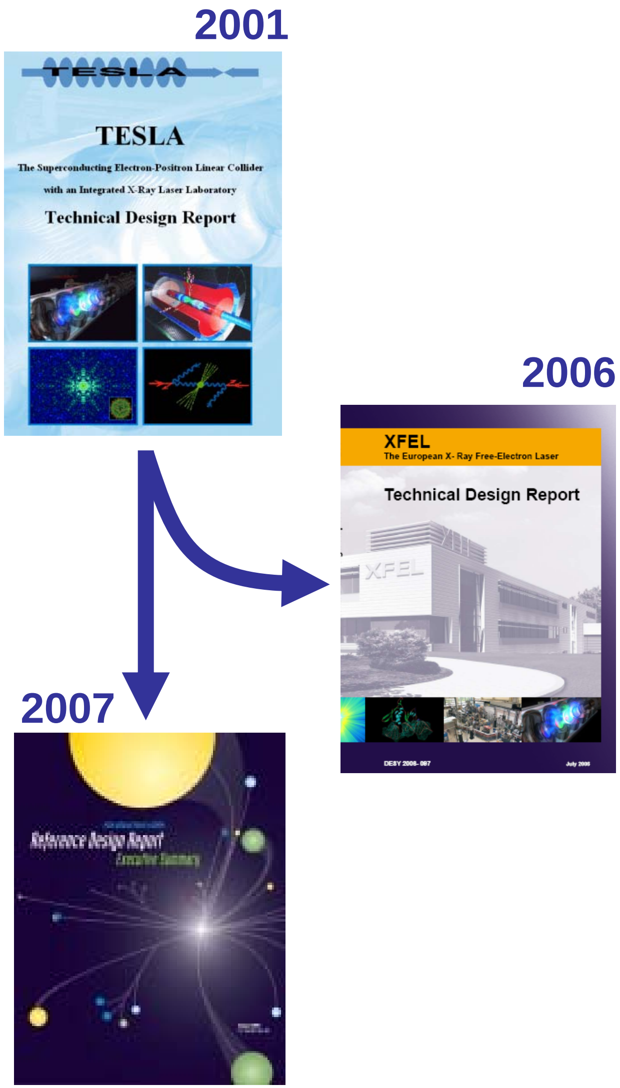
Joint Design, Implementation, Operations, Management
Host Country Provides Conventional Facilities

Global Design Effort

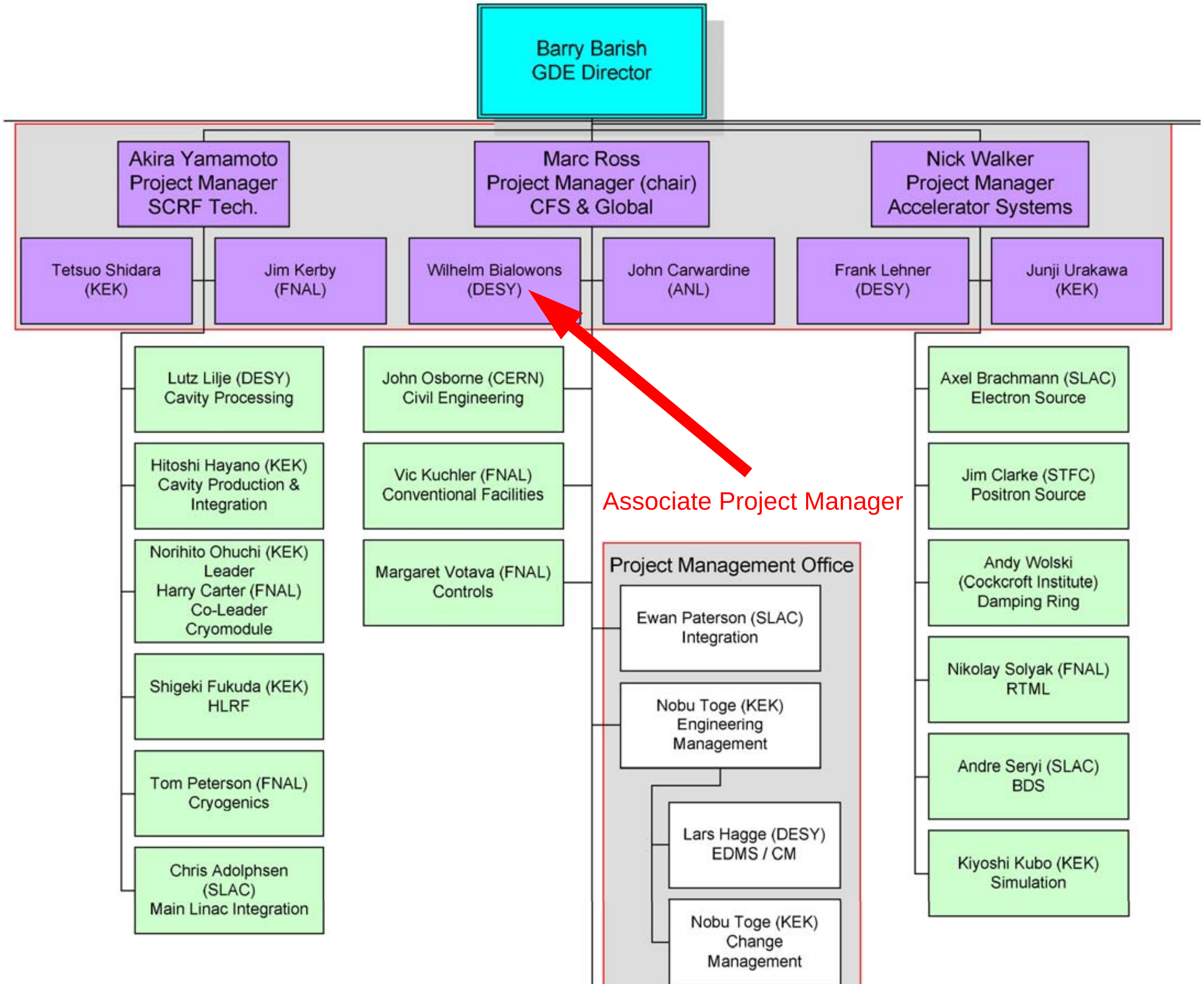
- 2005: Formation of the GDE by ICFA
  - Barry Barish – director



- History
  - Dec 2005 - Definition of baseline design
  - Dec 2006 - Completion of conceptual design with cost estimate (including first iteration cost reduction)
  - Jul 2007 – Publication of 4-volume **Reference Design Report (RDR).**
  - 2008 - restructuring for Technical Design Phase



GDE Project Structure for TDP



Outline (1)

- Introduction
- RDR Machine Requirements
  - Overall Layout
  - Parameters
- Electron Source
- Positron Source
- Damping Rings
  - Kicker Systems
  - Electron Cloud (and Fast Ion Instability)
- Ring to Main Linac

Outline (2)

- Main Linac
  - Main Linac Unit
  - Cavities
  - Modulator
  - Klystron
  - Cryogenic System
- Beam Delivery System
- Value Estimate

Outline (3)

- TDP Technical Design Phase
  - – GDE Time Line until 2012
  - – TD Phase Project Structure
  - – Plug compatibility for SCRF
  - – Clustered surface RF
  - – Minimum Machine Concept (Cost reduction)
  - – Evaluation of the three sample sites
  - – Investigation of (cut and cover) shallow sites
  - – Investigation of generic site
- Summary and Outlook

ILC Reference Design Report

~700 Contributers from 84 Institutes

ILC-REPORT-2007-01
AAI-PUB-2007-002
CHEP A07-001 (CHEP/KNU)
CLNS 07/1991
Cockcroft-07-04
DESY 07-046
FERMILAB-TM-2382-AD-CD-DO-E-FESS-TD
JAI-2007-001
JINR Dubna-E9-2007-39
JLAB-R-2007-01
KEK Report 2007-1
LNF-07/9(NT)
SLAC-R-857

DRAFT

INTERNATIONAL LINEAR COLLIDER

REFERENCE DESIGN REPORT

2007

APRIL, 2007

LIST OF CONTRIBUTORS

3:00pm, May 4, 2007

Gerald Aarons, David Adey, Chris Adolphsen, Ilya Agapov, Jung-Keun Ahn, Mitsuo Akemoto, Maria del Carmen Alabau, Michael Albrecht, David Alesini, Jim Alexander, Wade Allison, John Amann, Shozo Anami, Terry Anderson, Michael Anerella, Deepa Angal-Kalinin, Sergie Antipov, Claire Antoine, Rob Appleby, Sakae Araki, Tug Arkan, Ned Arnold, Ray Arnold, Xavier Artru, Alexander Aryshev, Fred Asiri, David B. Augustine, Derek Baars, Nigel Baddams, Ian R. Bailey, N. I. Balalykin, Jean-Luc Baldy, Maurice Ball, Philip Bambade, Syuichi Ban, Karl Bane, Bakul Banerjee, Serena Barbanotti, Desmond P. Barber, D. Yu. Bardin, Barry Barish, Roger Barlow, Maura Barone, Yuri Batygin, D. Elwyn Baynham, Carl Beard, Leo Bellantoni, Paul Bellomo, Lynn D. Bentson, Martin Berndt, Simona Bettoni, Vinod Bharadwaj, Marica Biagini, Wilhelm Bialowons, Thomas Bieler, John Bierwagen, Alison Birch, Victoria Blackmore, Grahame Blair, Christian Boffo, Courtlandt Bohn, V. I. Boiko, Eduard N. Bondarchuk, Roberto Boni, Stewart Boogert, Gary Boorman, Alessio Bosco, Pierre Bosland, Angelo Bosotti, Gordon Bowden, Gary Bower, Axel Brachmann, Tom W. Bradshaw, Hans Peter Bramer, James Brau, Steve Bricker, Craig Brooksby, Timothy A. Broome, James H. Brownell, Mélanie Bruchon, Heiner Brueck, Amanda J. Brummitt, Yu. A. Budagov, Karsten Buesser, Eugene Bulyak, Adriana Bungau, Craig Burkhart, Philip Burrows, Graeme Burt, David Burton, Yunhai Cai, Ofelia Capatina, Ruben Carcagno, F. Stephen Carr, Harry F. Carter, John Carter, John Carwardine, Richard Cassel, Giorgio Cavallari, Brian Chase, Robert Chehab, Stéphane Chel, Chiping Chen, Jian Cheng, M. Chevallier, William Chickering, Jin-hyuk Choi, Glenn Christian, Mike Church, Gianluigi Ciovati, Christine Clarke, Don G. Clarke, James A. Clarke, Elizabeth Clements, Paul Coe, John Cogan, Chris Compton, Ed Cook, Peter Cooke, Laura Corner, Clay Corvin, Curtis Crawford, James A. Crittenden, Hamid Dabiri Khah, Olivier Dadoun, Chris Damerell, Michael Danilov, Ken P. Davies, Antonio de Lira, Stefano De Santis, Laurence Deacon, Jean-Pierre Delahaye, Nicholas Delerue, Olivier Delferriere, Yu. N. Denisov, Christopher J. Densham, Guillaume Devanz, Amos Dexter, Sudhir Dixit, Ralph Dollan, George Doucas, Robert Downing, Eric Doyle, Alessandro Drago, Alex Dragt, Alexandr Drozhdin, Gerald Dugan, Viktor Duginov, Helen Edwards, Heiko Ehrlichmann, Michael Ehrlichman, Peder Eliasson, George Ellwood, Eckhard Elsen, Louis Emery, Kazuhiro Enami, Kuninori Endo, Atsushi Enomoto, Fabien Eozénou, Roger Erickson, Karen Fant, Alberto Fasso, John Fehlberg, John Ferguson, J. Luis Fernandez-Hernando, Ted Fieguth, Mike D. Fitton, Mike Foley, Richard Ford, Brian Foster, Horst Friedsam, Josef Frisch, Joel Fuerst, Masafumi Fukuda, Shigeki Fukuda, Yoshisato Funahashi, Warren Funk, Kazuro Furukawa, Fumio Furuta, Karsten Gadow, Wei Gai, Fred Gannaway, Jie Gao, Peter Garbincius, Luis Garcia-Tabares, Terry Garvey, Edward Garwin, Martin Gastal, Lixin Ge, Zhenjiao Geng, Scott Gerbick, Rod Gerig, Lawrence Gibbons, Allan Gillespie,

ii ILC-Reference Design Report

http://www.linearcollider.org

What's RDR

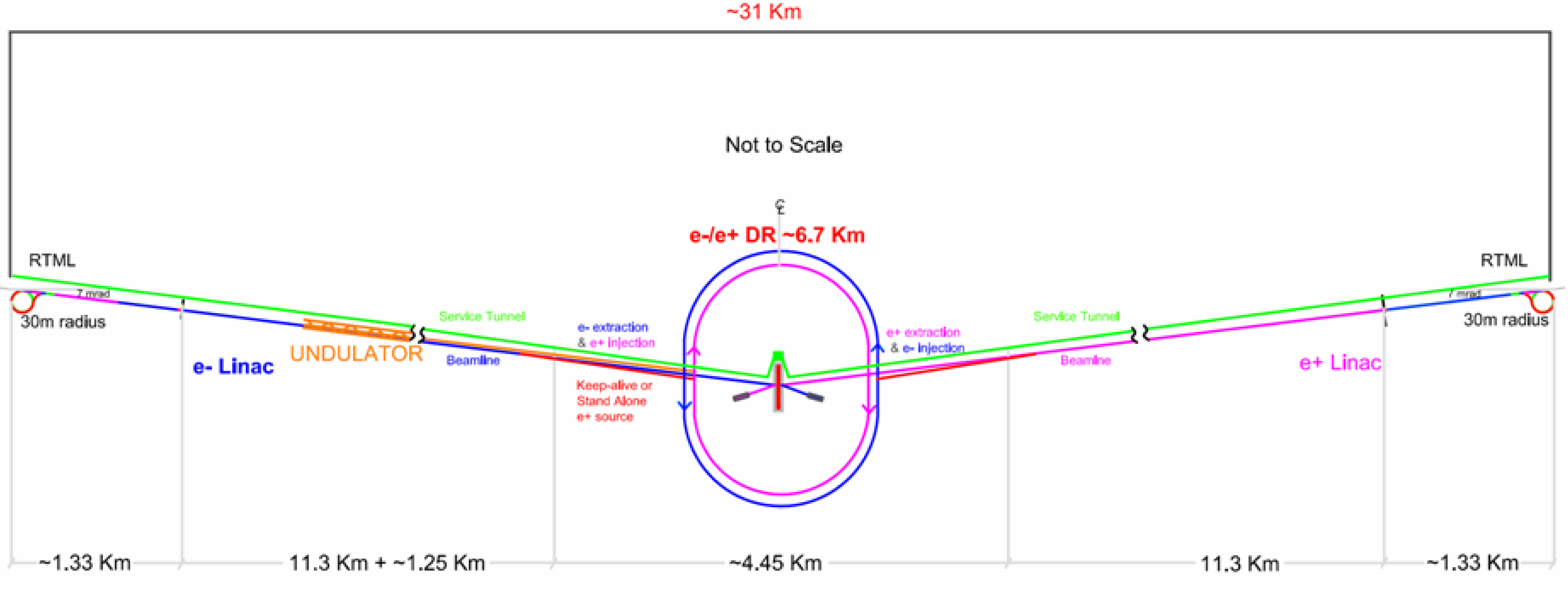
- (International) Conceptual design report
- With first-stage (reliable) cost (value & labor) estimation
- Engineering details not yet contained
- Not all based on the present technology
  - Forward-looking
  - R&D needed
- History
  - BCD (Baseline Configuration Document) published in December 2005 at Frascati meeting
  - Rules for cost estimation established in March 2006 at Bangalore meeting
  - First cost compilation in July 2006 at Vancouver meeting Cost reduction effort started
  - RDR draft published in February 2007 at Beijing meeting

ILCSC Parameters Group: Requirements

- Center-of-Mass Energy up to 500 GeV
  - upgradeable to 1 TeV.
- Integrated luminosity in the first 4 years > 500 fb^{-1} (500 GeV equivalent)
  - This corresponds to the peak luminosity ~ $2x10^{34}$ $cm^{-2}s^{-1}$
  - Assume 1/γ L scaling for < 500 GeV
- Ability of energy scan in 200 - 500 GeV
- Energy stability and precision below 0.1%
- Electron polarization of at least 80 %
- Two detectors
  - Single IR in push-pull configuration

The ILC Reference Design

1st Stage: 200 - 500 GeV, Based on accelerating gradient of 31.5 MV/m (1.3 GHz SCRF)

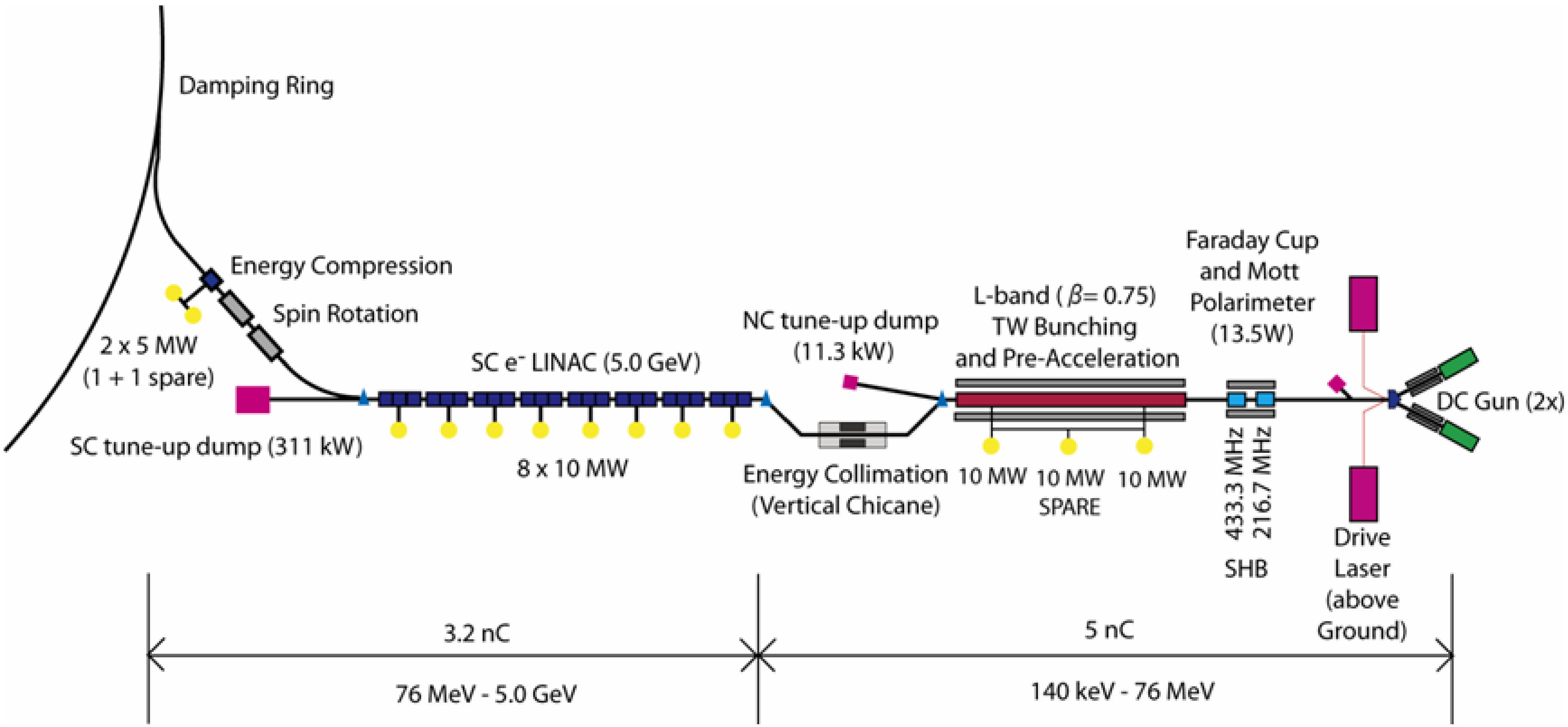


Schematic Layout of the 500 GeV Machine

Basic Global Parameters

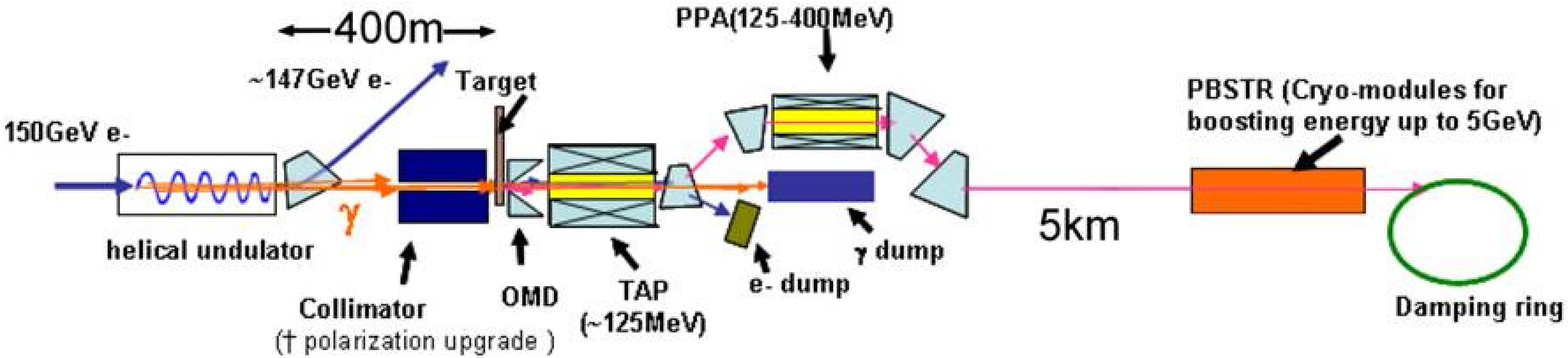
Max. Center-of-mass energy	500	GeV
Peek Luminosity	$\sim 2 \times 10^{34}$	$cm^{-2}s^{-1}$
Beam Current	9.0	mA
Repetition rate	5	Hz
Average accelerating gradient	31.5	MV/m
Beam pulse length	0.95	ms
Total Site Length	31	km
Total AC Power Consumption	~230	MW

Electron Source System



Positron Source

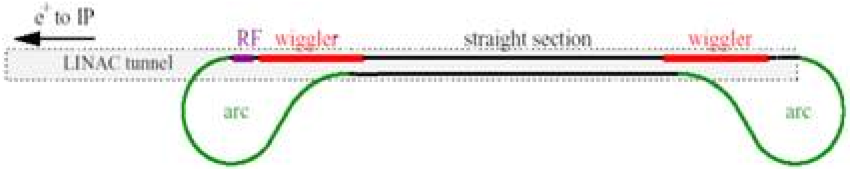
- Undulator scheme
  - Electron beam at 150 GeV

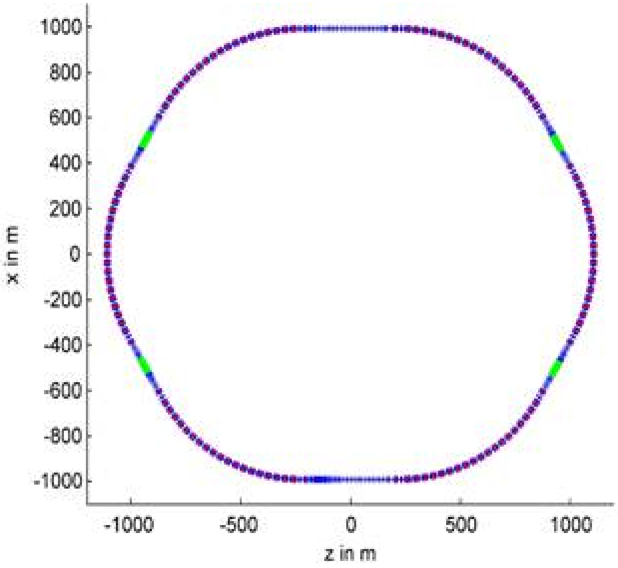


  - Undulator
    - Helical, superconducting
    - length 147 m (longer for polarized e^+)
    - K = 0.92, λ = 1.15 cm, (B = 0.86 T)
  - Needs ‘keep-alive source’
    - 10 % intensity
    - Share 5 GeV linac

Damping Rings

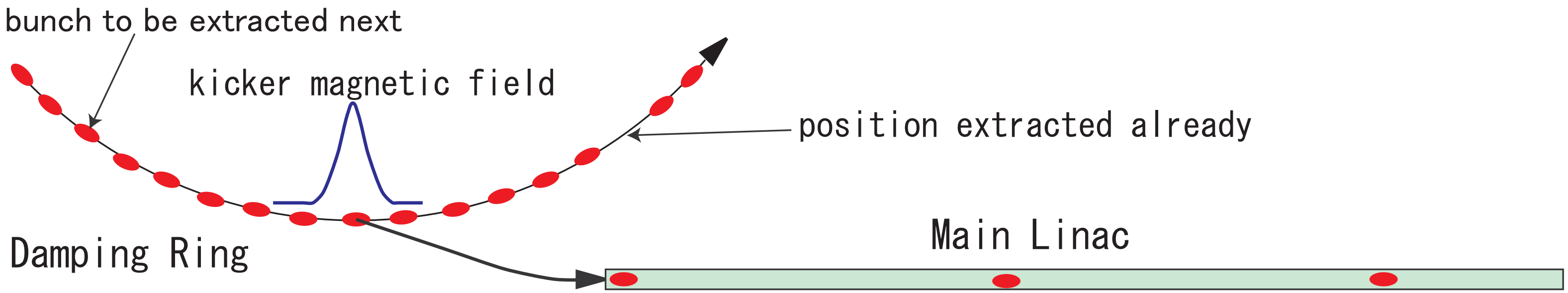
- Roles
  - Reduce transverse/longitudinal emittances
  - Beam stabilization
- Possible choices
  - Dog-bone
  - (nearly) Circular: ~ 3 km, ~ 6 km
- Baseline
  - 6.7 km circular ring
  - One for e+ and one for e-





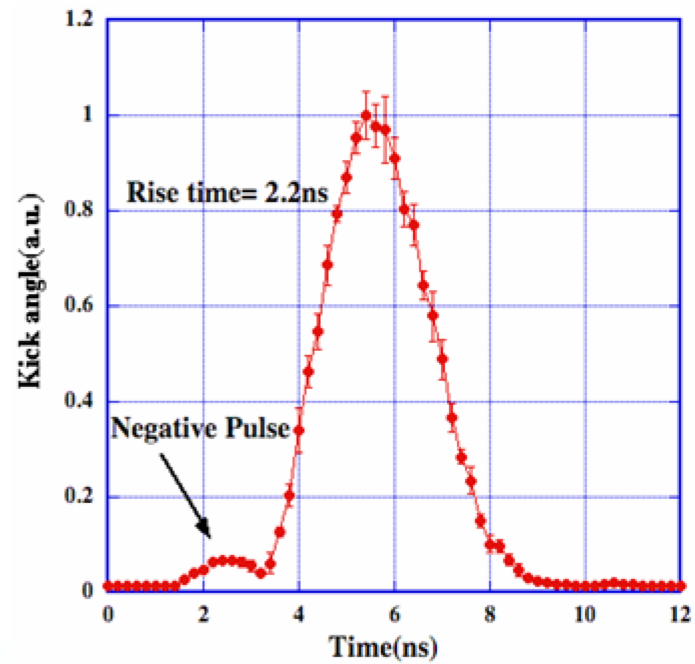
Kicker System

- Must extract bunches one-by-one



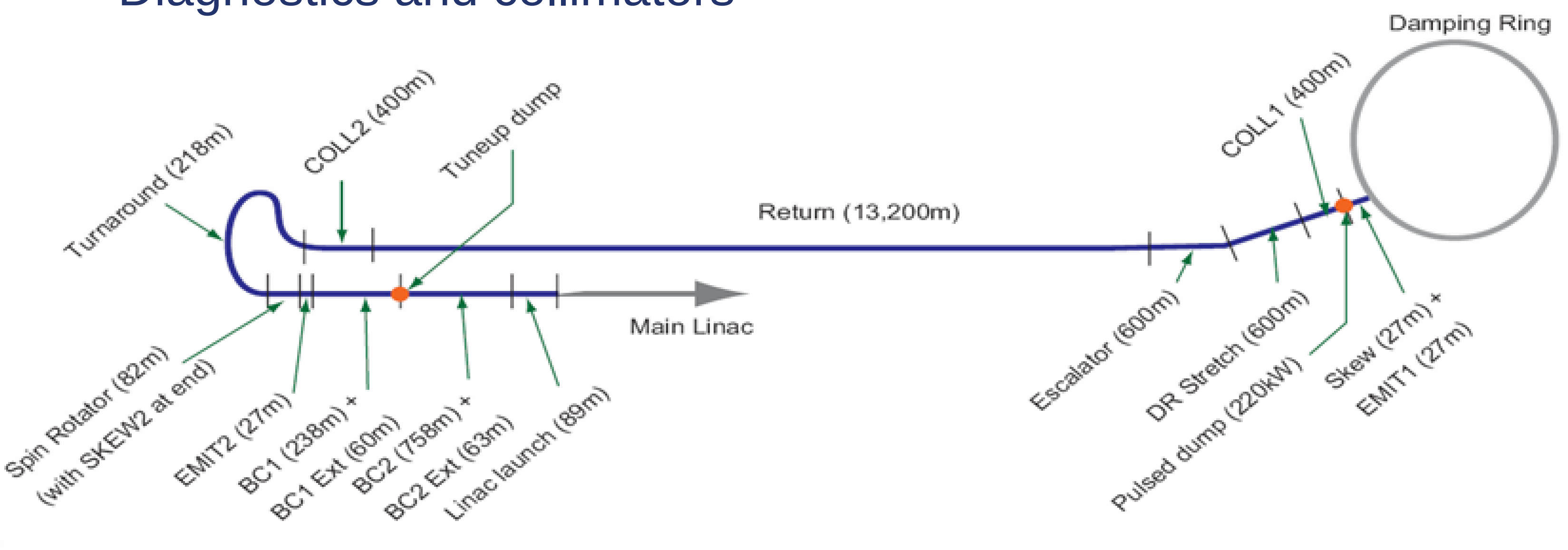
Beam pulse length 300 km

- Specification
  - rise, fall time < 3 ns
  - rep.rate 5.5 MHz
  - pulse length 1ms
  - stability < 0.1 %
    - can be relaxed by feedforward
- Fast kicker needed
  - A system with fast pulser and stripline developed at KEK.
  - Unit test done.



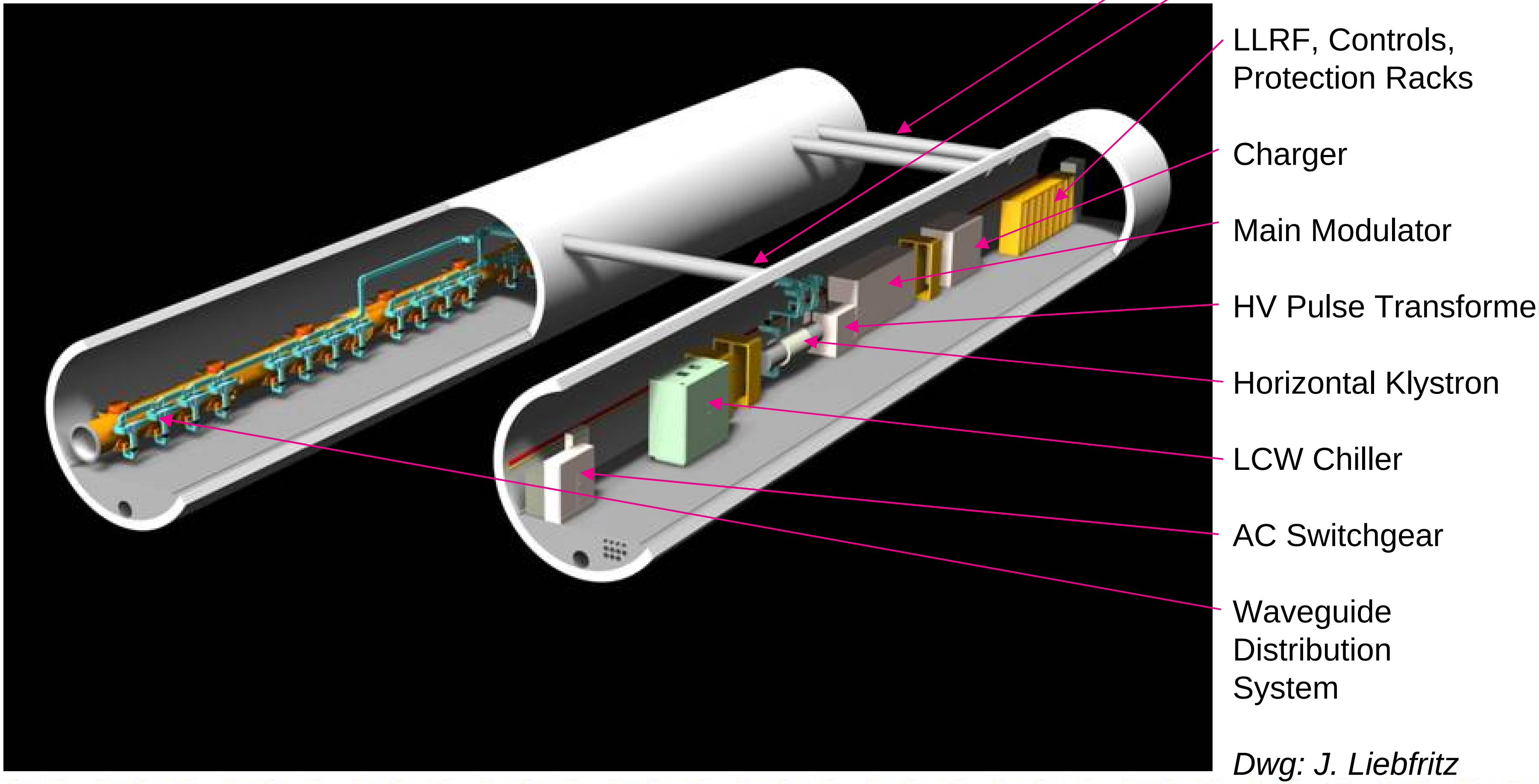
RTML

- ~14 km long transport
- Turn-around
  - needed also for feed-forward
- Spin Rotator
- Bunch compressor in 2 stages
  - 9 mm → 300 μm (nominal parameters)
  - 9 mm → 200 μm possible (Low Q parameters)
- Diagnostics and collimators



Main Linac Layout

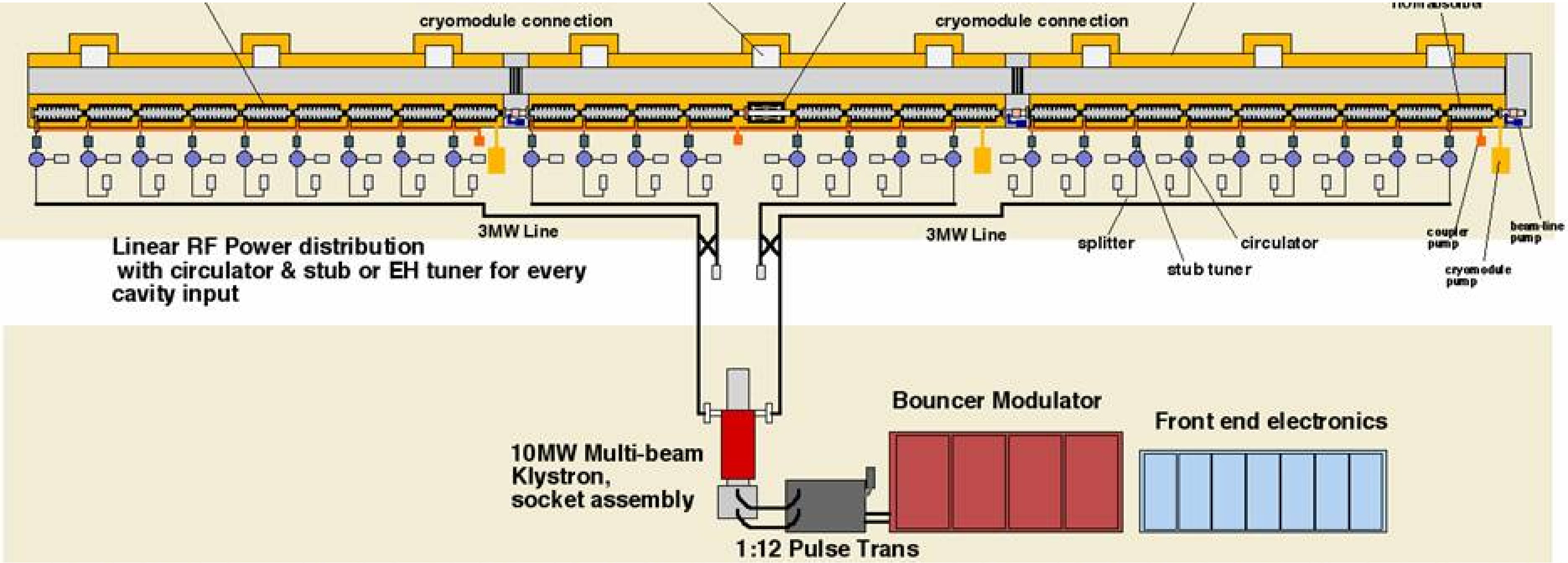
- Length ~ 11 km x 2
- Average gradient 31.5 MV/m
- 2 tunnels diameter 4.5 m



Dwg: J. Liebfritz

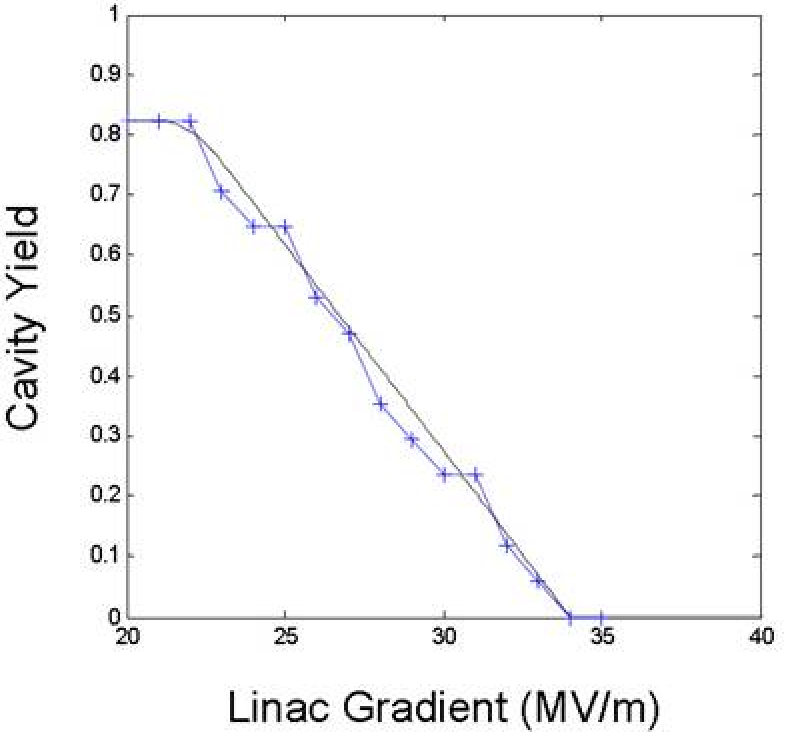
Main Linac RF Unit Overview

- Bouncer type modulator
- Multibeam klystron (10 MW, 1.6 ms)
- 3 Cryostats (9+8+9 = 26 cavities)
- 1 Quadrupole at the center

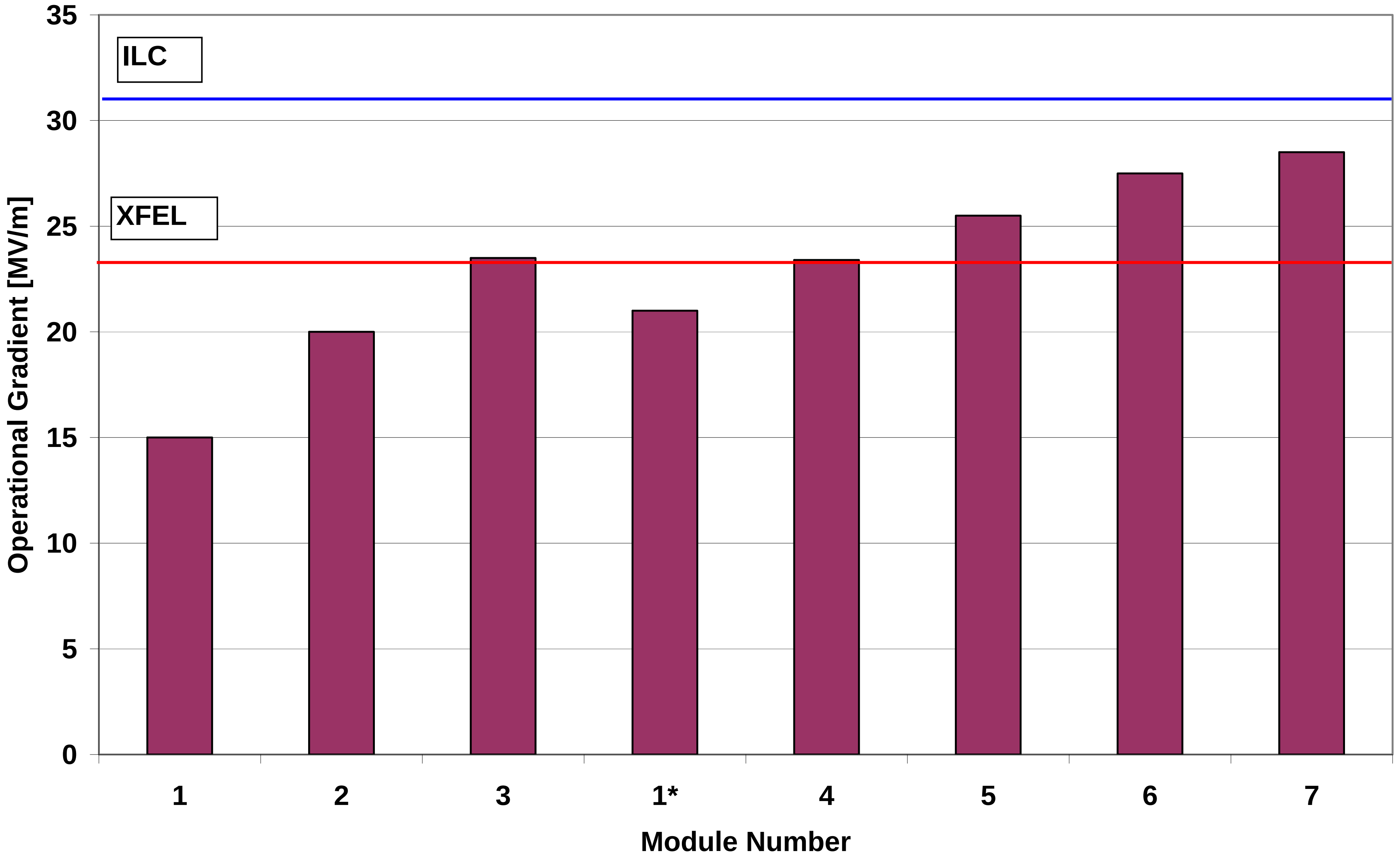


Cavities

- Baseline: TESLA-type 1.3 GHz
  - Identical to XFEL cavities
    - Only beamtubes shortened
- Accelerating gradient
  - Vertical test
    - > 35 MV/m, Q > 0.8×10^{10}
  - Average gradient in cryomodule
    - 31.5 MV/m, Q > 1×10^{10}
- With the presently available technology
  - Average gradient lower than 31.5 MV/m
  - Spread of gradient large
  - If uniform distribution in 22<G<34 MV/m, average 28 MV/m
    - Cost increase ~ 7 %

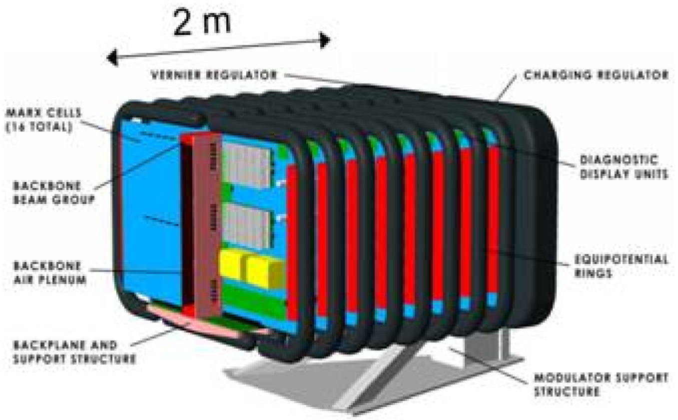


Accelerator Module Operational Gradients



Modulator

- Baseline
  - Bouncer-type modulator
    - Design at FNAL
      - Has been working for >10 years at TTF at DESY
      - No major technical issues
      - XFEL choice
  - Design improvements (within XFEL industrialisation)
    - More cost-efficient design under way
    - Redundancy of internal components for higher availability
- Alternative:
  - Marx Modulator
    - Under development at SLAC
    - Smaller size
    - No step-up transformer
    - Potentially high cost saving



MARX MODULATOR - MECHANICAL DETAIL

Klystrons


Thales

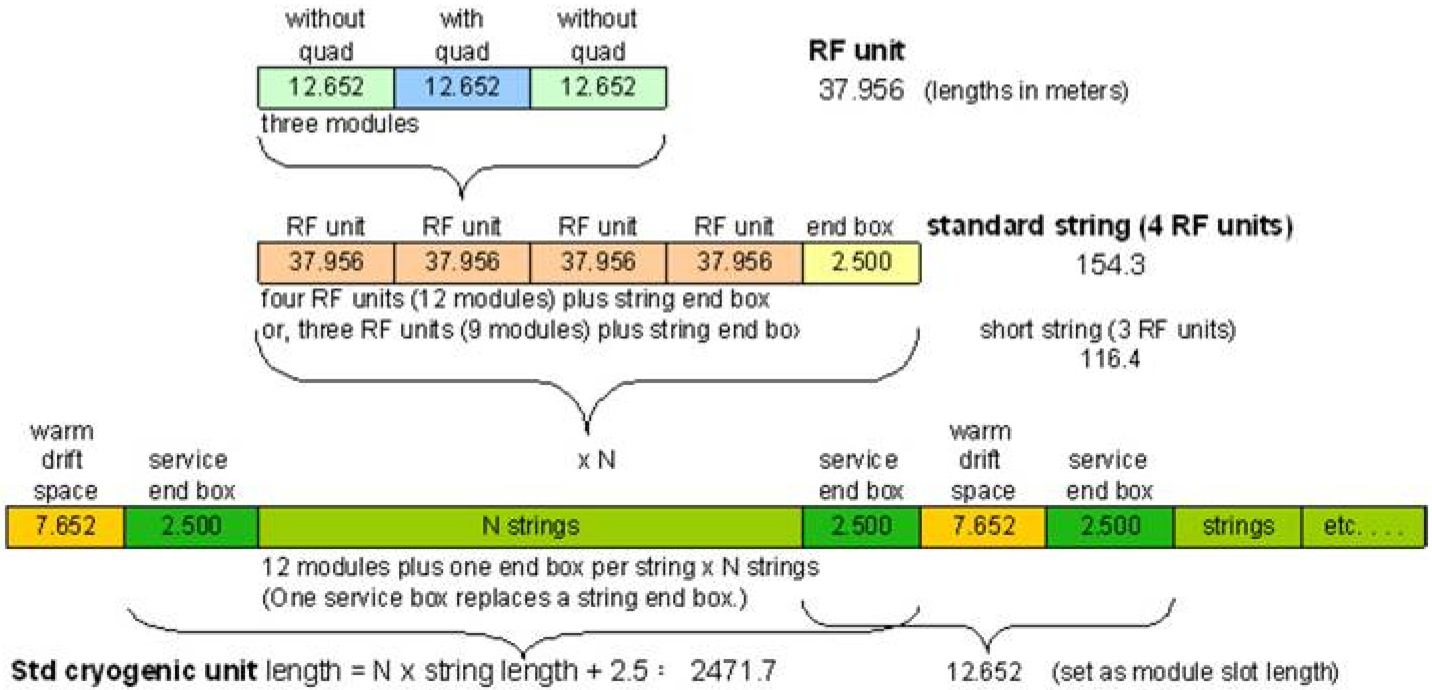

CPI


Toshiba

- Requirements:
  - 10 MW
  - 1.6 ms
  - 5 Hz
  - lifetime for full power >40000 hrs
- Baseline solution: Multi-beam klystron
  - Use multiple beams of low charge
  - Lower space-charge effects
  - Lower voltage (120 kV)
  - Higher efficiency (~65 %)
- Prototypes from 3 manufacturers for the European XFEL (higher repetition rate: 10 Hz)
  - Thales and Toshiba MBKs being successfully tested at DESY at full spec
    - for > 1000 hrs
    - Several klystrons under varying operating conditions at FLASH, PITZ and test stand
- Horizontally mounted klystron needed for small tunnel diameter
  - XFEL develops this with industry
- More lifetime testing going on (eventually also at SLAC)
  - At DESY all tubes which are now in operation do not show signs of degradation (no arcing, no perveance drops)

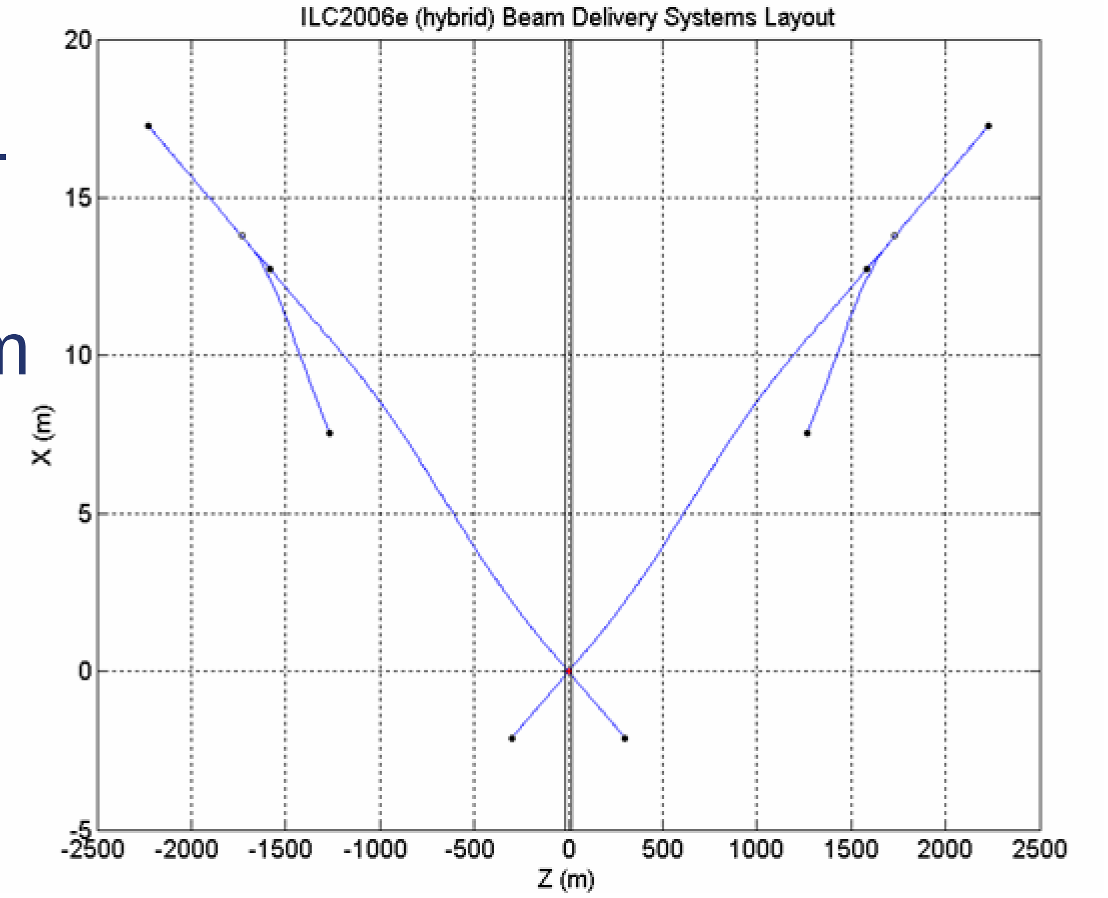
Cryogenics System

- 1 cryogenic plant covers 2.5 km linac length.
  - Installed power ~ 4.5 MW
- Total 10 plants
  - ~ 45 MW
  - comparable to LHC cryogenics system

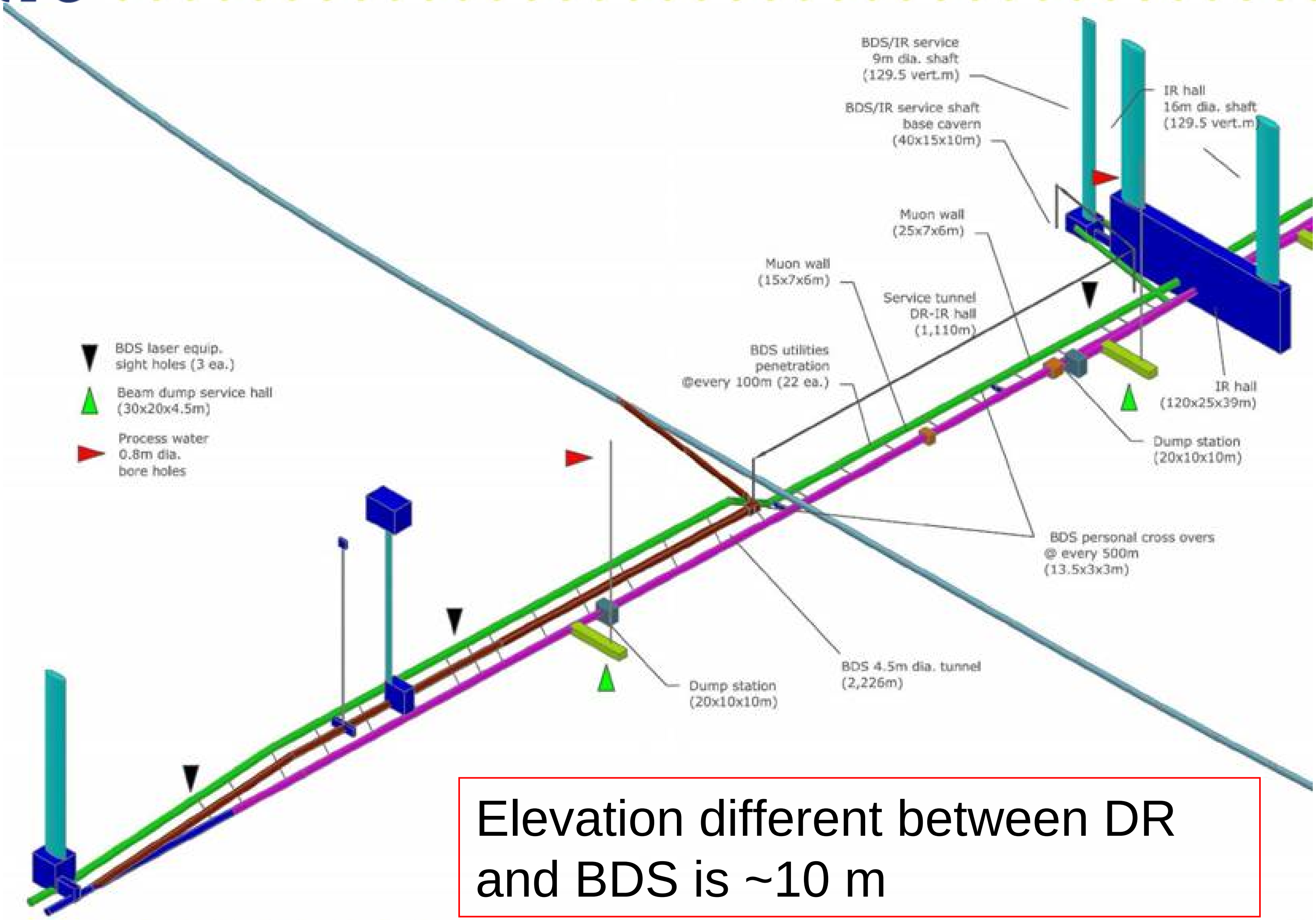


BDS

- Single IR and push-pull detector
- Total length 4.45 km
- 1 TeV upgrade by inserting some components (no geometry change)



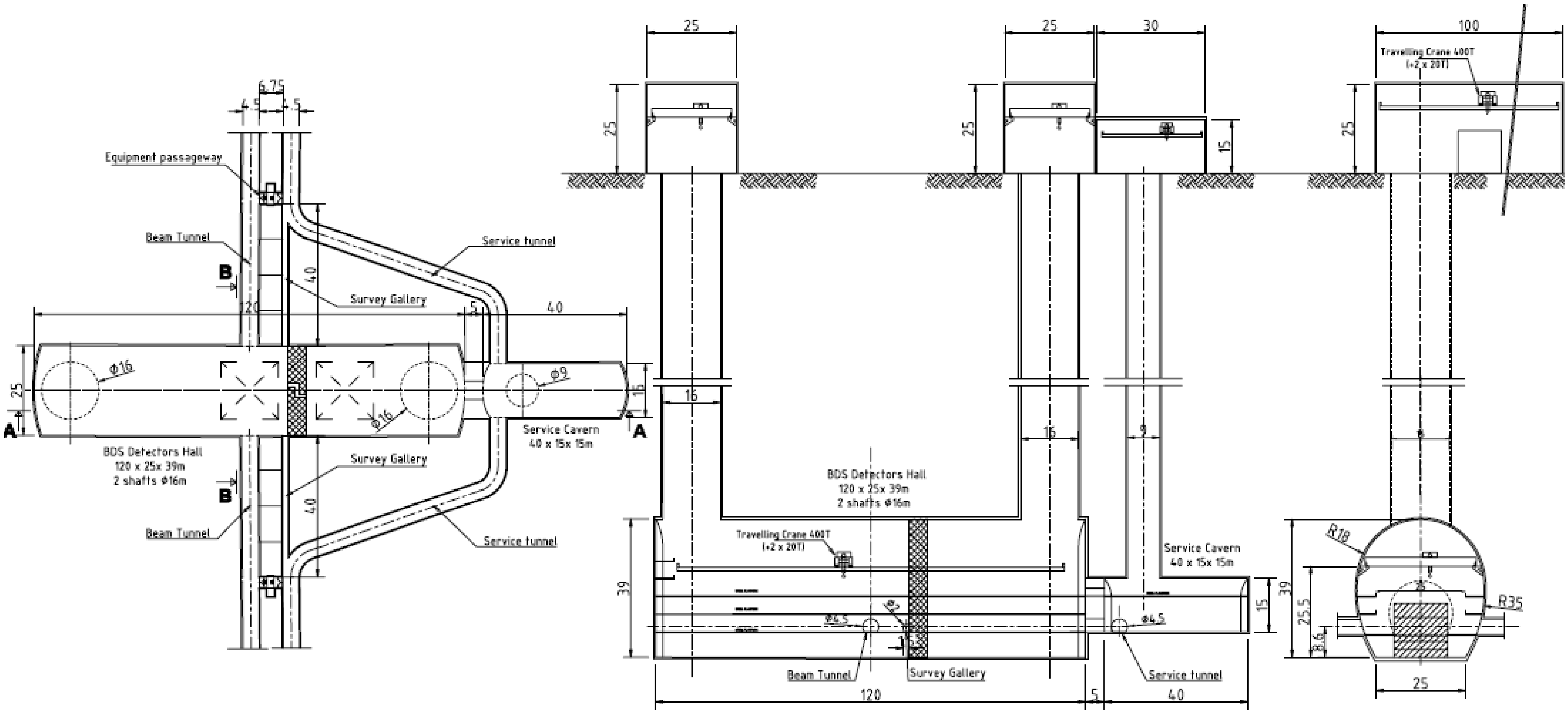
Layout of BDS+DR



Elevation different between DR and BDS is ~10 m

Layout of Detector Hall Complex

Detector Hall, Service Cavern, Access Shafts and Surface Buildings
Plan View and Sections



Scale of International Linear Collider

16,088 SC Cavities: 9 cell, 1.3 GHz

1848 CryoModules: 2/3 containing 9 cavities,
1/3 with 8 cavities + Quad/Correctors/BPM

613 RF Units: 10 MW klystron, modulator, RF distribution

72.5 km tunnels ~ 100-150 meters underground

13 major shafts ≥ 9 meter diameter

443 k cu. m. underground excavation: caverns, alcoves, halls

10 Cryogenic plants, 20 KW @ 4.5^{o} K each

plus smaller cryo plants for e-/e+ (1 each), DR (2), BDS (1)

92 surface “buildings”, 52.7 K sq. meters = 567 K sq-ft total

240 M Watts connected power, 345 MW installed capacity

13,200 magnets – 18 % superconducting

Total ILC Value and Explicit Manpower

- Total ILC Value Cost **ILCU* 6.62 B**

ILCU 4.79 B shared + **ILCU 1.83 B** <site specific>#

plus 14.2 k person-years **Explicit Manpower**

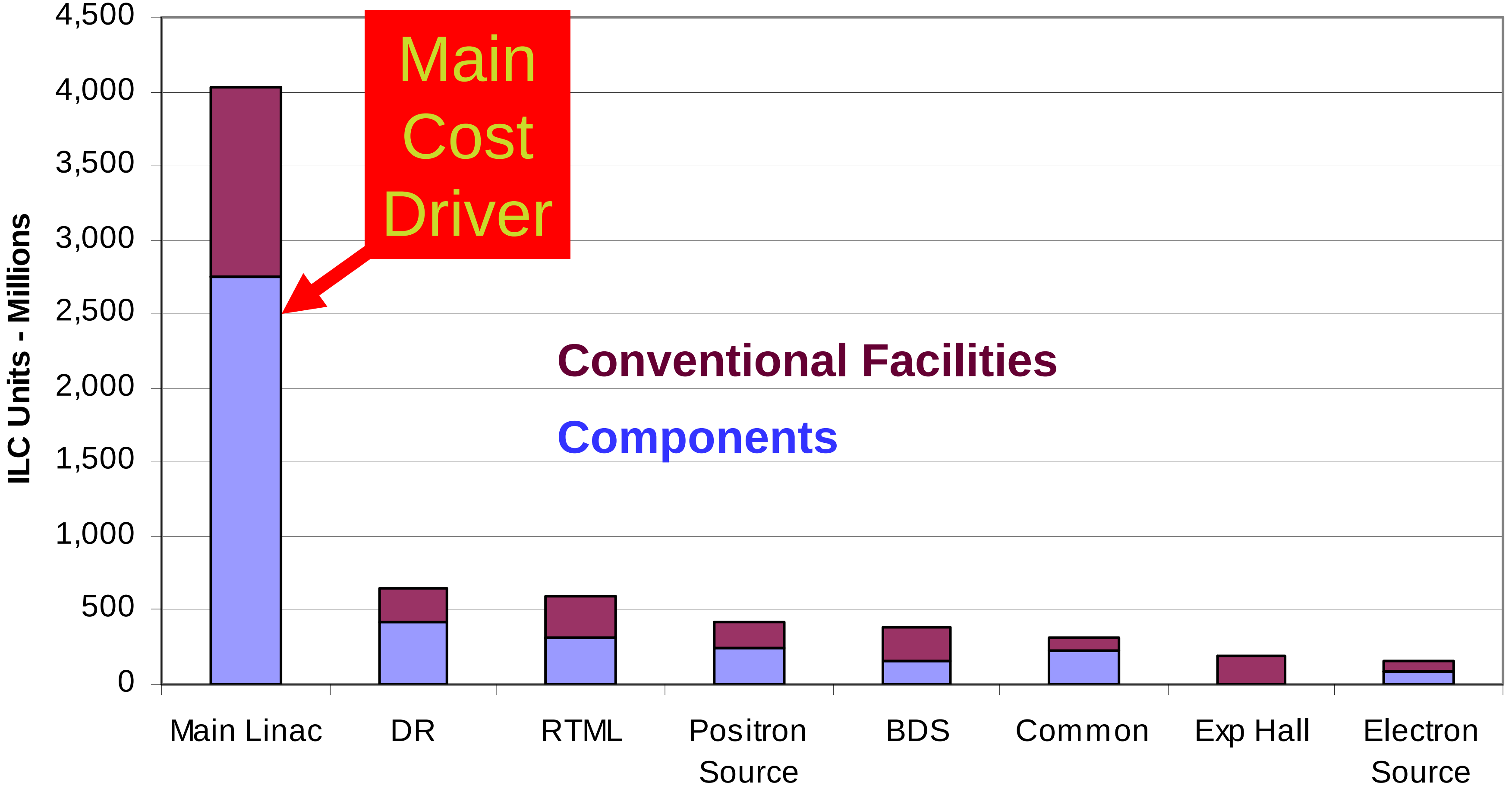
= 24.2 M person-hours

@ 1,700 person-hr/person-yr

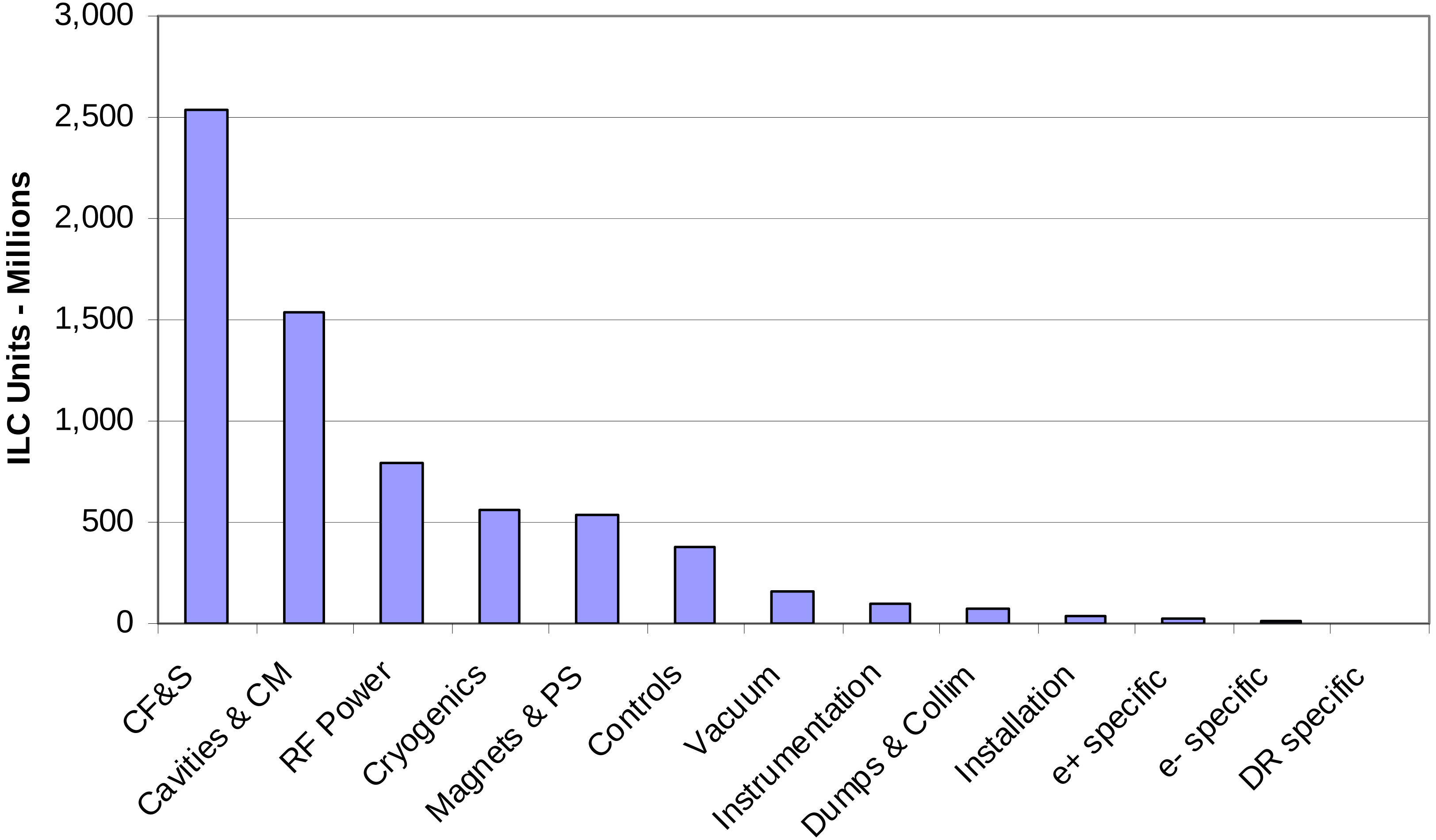
*ILCU(nit) = $ (January 2, 2007)

#<site specific> = average of the three site specific costs

ILC Value – by Area Systems



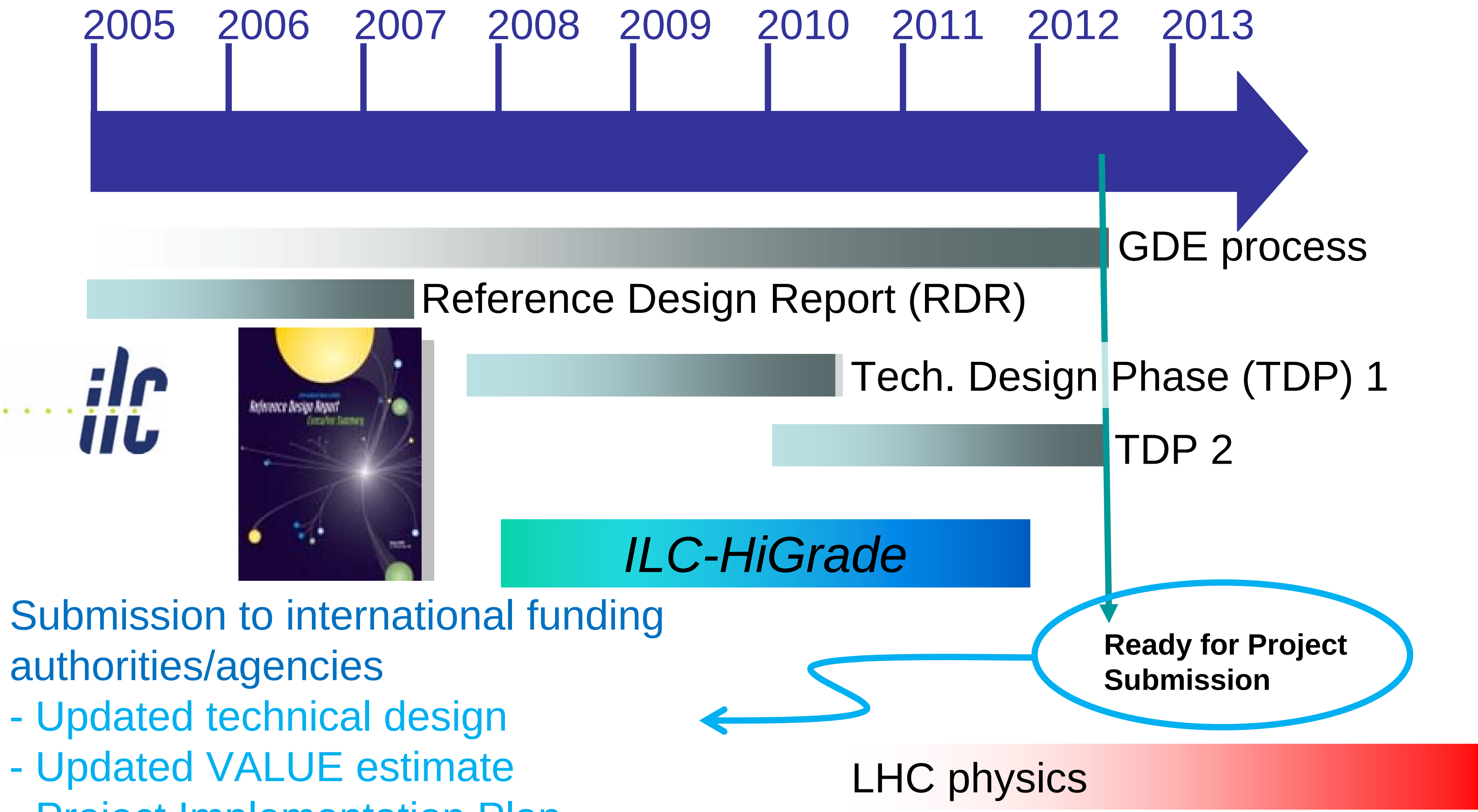
ILC Value – by Technical Systems



The GDE Post-RDR

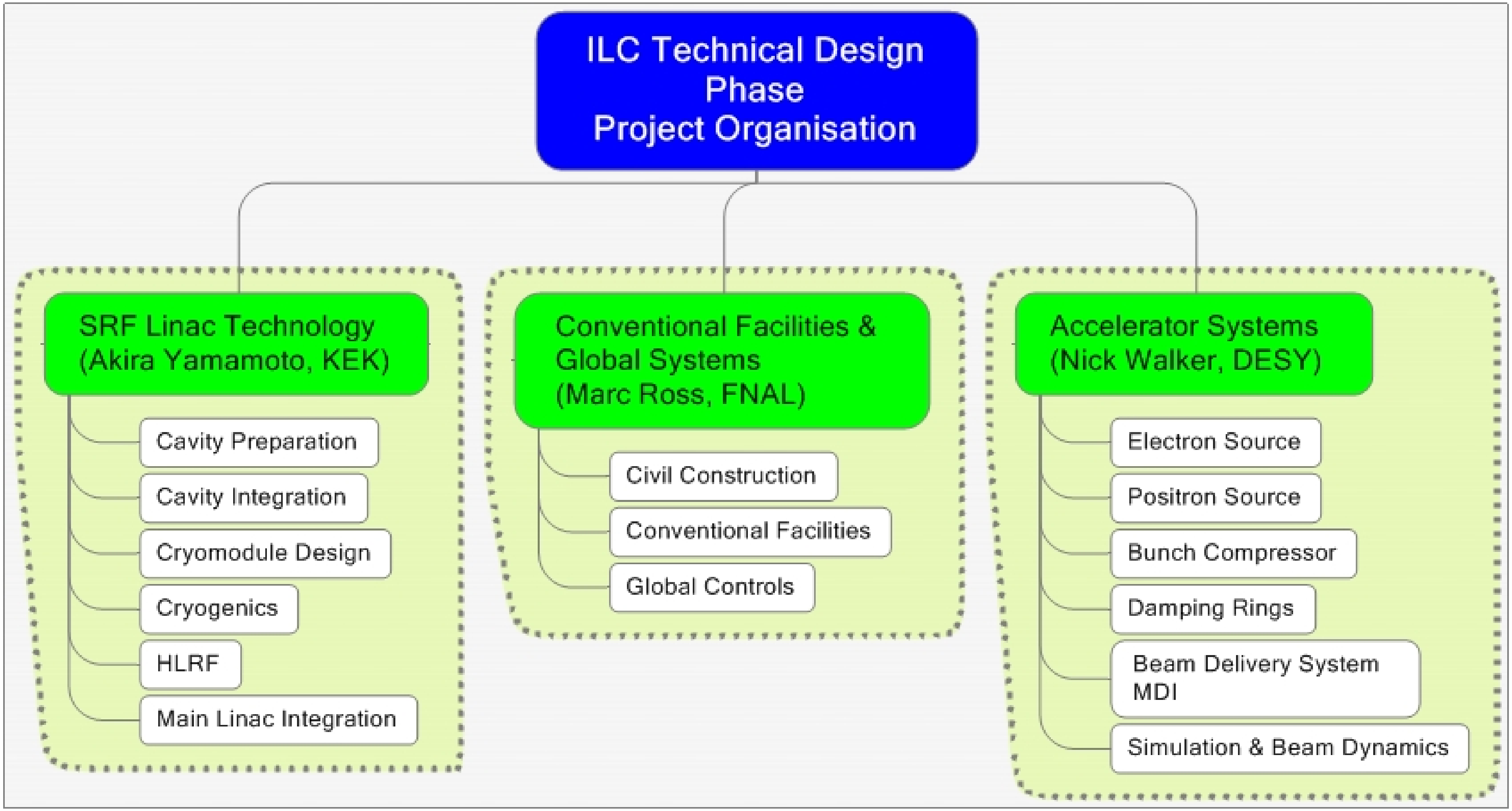
- Publication of the RDR was a major milestone
- Analysis of the RDR design/cost $\rightarrow$ priorities for Technical Design Phase
- Re-structuring of GDE into a more traditional Project Structure
  - Hierarchal org. chart
  - Project Management Team
- Focus of TDP work:
  - Risk mitigating R&D
  - Overall Cost Reduction / Containment (optimisation)
  - Project Implementation Plan (PIP)

GDE Time Line until 2012



Submission to international funding authorities/agencies
- Updated technical design
- Updated VALUE estimate
- Project Implementation Plan
- (Updated physics case [LHC])

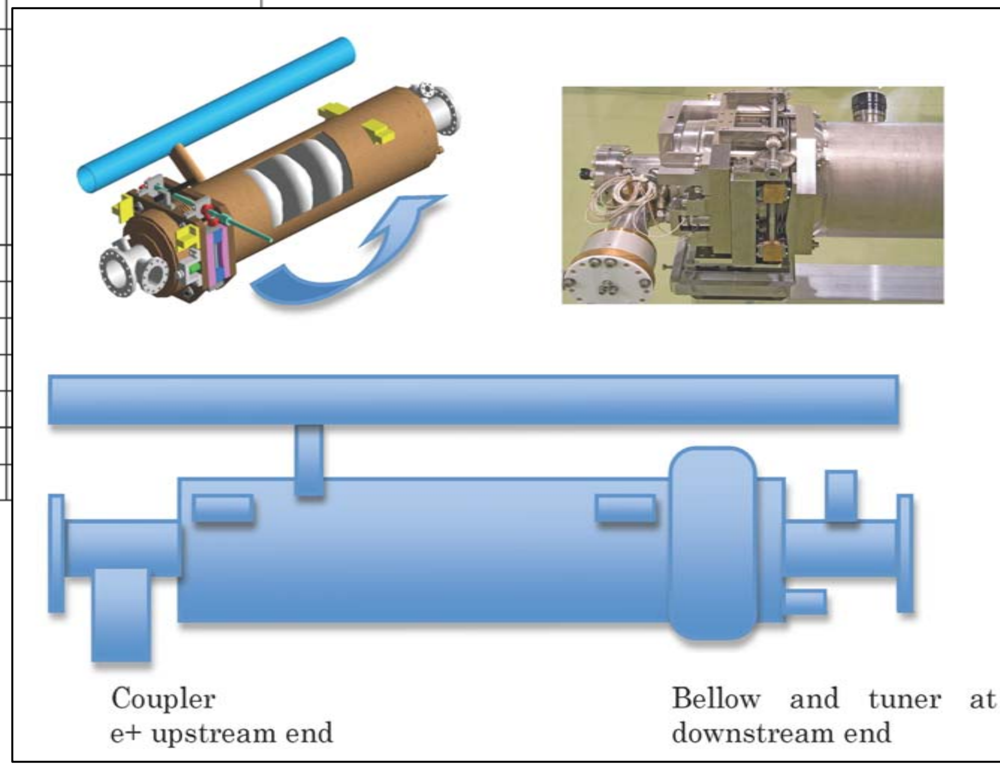
TD Phase Project Structure



Plug Compatibility for SCRF

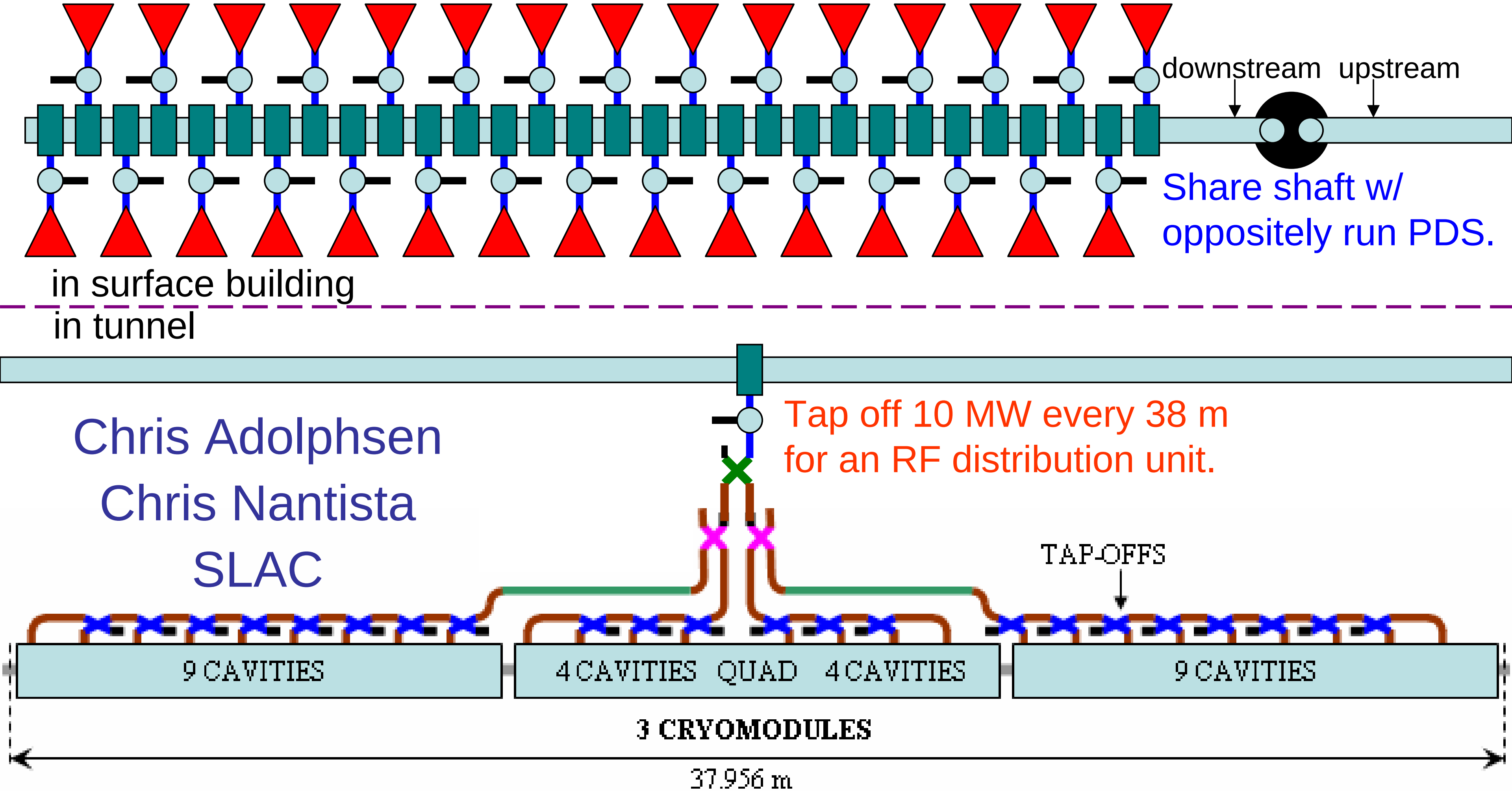
Cavity

Cavity	Plug-compatibility Standard	Can be flexible R&D remain	Alternate design need to fit to
Material		large/fine grain	
Shape		TESLA/LL/RE	
Length	1,247		
Beam pipe dia.	78 mm		(80 mm)
Beam pipe seal	Al-hex,		(In, Helicoflex)
Jacket/cone	NbTi / Ti		SUS
He-vessel OD	xxx		
Tuner type		Blade / slide-jack	
Tuner slow	Control/wiring spec.		
Tuner fast (piezo)	Control/wiring spec.		
Mag. shield		Inside / outside	
Coupler position	e-: downstream-end e+: upstream end		
Type	Fixed/tunable		
Diameter (cold)			
(warm)			
High pr. code			
Design pressure	2 bar (delta-P)		
Material	Nb, ... SUS	NbTi, Ti,	



Layout Clustered Surface RF

Combine 300 MW from thirty 10 MW klystrons into one circular TE_{01}-mode evacuated waveguide on the surface. With extra transmission losses one shaft serves ~2 km.



Chris Adolphsen
Chris Nantista
SLAC

Minimum Machine Concepts

Tentative
under discussion

1. Removal of service tunnel
   - XFEL-like solution
   - Surface klystron solutions
2. Integration of e+/e- sources with upstream beam delivery system (same tunnel)
   - Move e+ undulator source to end of linac (250 GeV point)
   - e- source and 5 GeV injector linacs share BDS tunnel
3. Main Linac - Novel high-power RF distribution
   - "klystron-clusters" on surface (30 klystrons/cluster)
   - 300 MW "pipe" distribution over 1 km using over-moded wave-guide
   - (single tunnel solution)
4. Main Linac – adoption of Marx modulator
5. Reduced beam-power parameter set
   - Half klystron/modulators
   - 6km → 3km damping ring
6. Two-stage → single-stage bunch compressor
7. Remove all support for TeV upgrade
   - Mostly impacts BDS

Potential cost savings primarily via reduced CFS requirements

SEVENTH FRAMEWORK PROGRAMME
RESEARCH INFRASTRUCTURES
Construction of new infrastructures – preparatory phase

Combination of Collaborative Project and
Coordination and Support Action

ILC-HiGrade

International Linear Collider and
High Gradient Superconducting RF-Cavities

www.ilc-higrade.eu

Grant agreement number 206711

Annex I – "Description of Work"

Three Regional Sample Sites

- Only one LC will be constructed in the world
- In the RDR are deep site proposals in the three regions namely in Japan, Illinois and at CERN. (The design is optimized for deep tunnels.)
- Their benefits will be evaluated
- ILC-HiGrade encompasses the European side of the endeavour
- The organization to allow site development and selection must be specified
- Site choice has to be technically prepared

Basis of CFS Cost Estimates

Underground Construction Unit Costs by Region / Site

12.12.2006

	Size	Americas	Units	European	Units	Asian	Units	Comments
Tunnels	4							Includes excavation, muck disposal, rock support, grouting, lining, invert, drainage invert, and all other work processes associated with the tunnel.
	5							
	6							
	7							
	7.5							
Vertical Shaft	9							Includes excavation, muck disposal, rock support, grouting, lining, and all other work processes associated with the shaft.
	14							
	15							
	16	$151'749	/ M					
Sloped Access Tunnels								
	35 Sq. M							
Waveguide Penetrations								43 CM Diameter
Caverns	Small							Small caverns based on roughly 3M x 3M cross section, medium caverns on 6m x 6 M cross section, large caverns on 9M x 9M. Extra large based on 32M wide, 35M high and 54M long. (particular to Americas Region but other regions similar)
	Medium							
	Large							
	Extra large							
Passageway								
Electrical								
Mechanical								Includes ventilation, piped utilities and processed water.

20 MILCU / shaft

Notes:

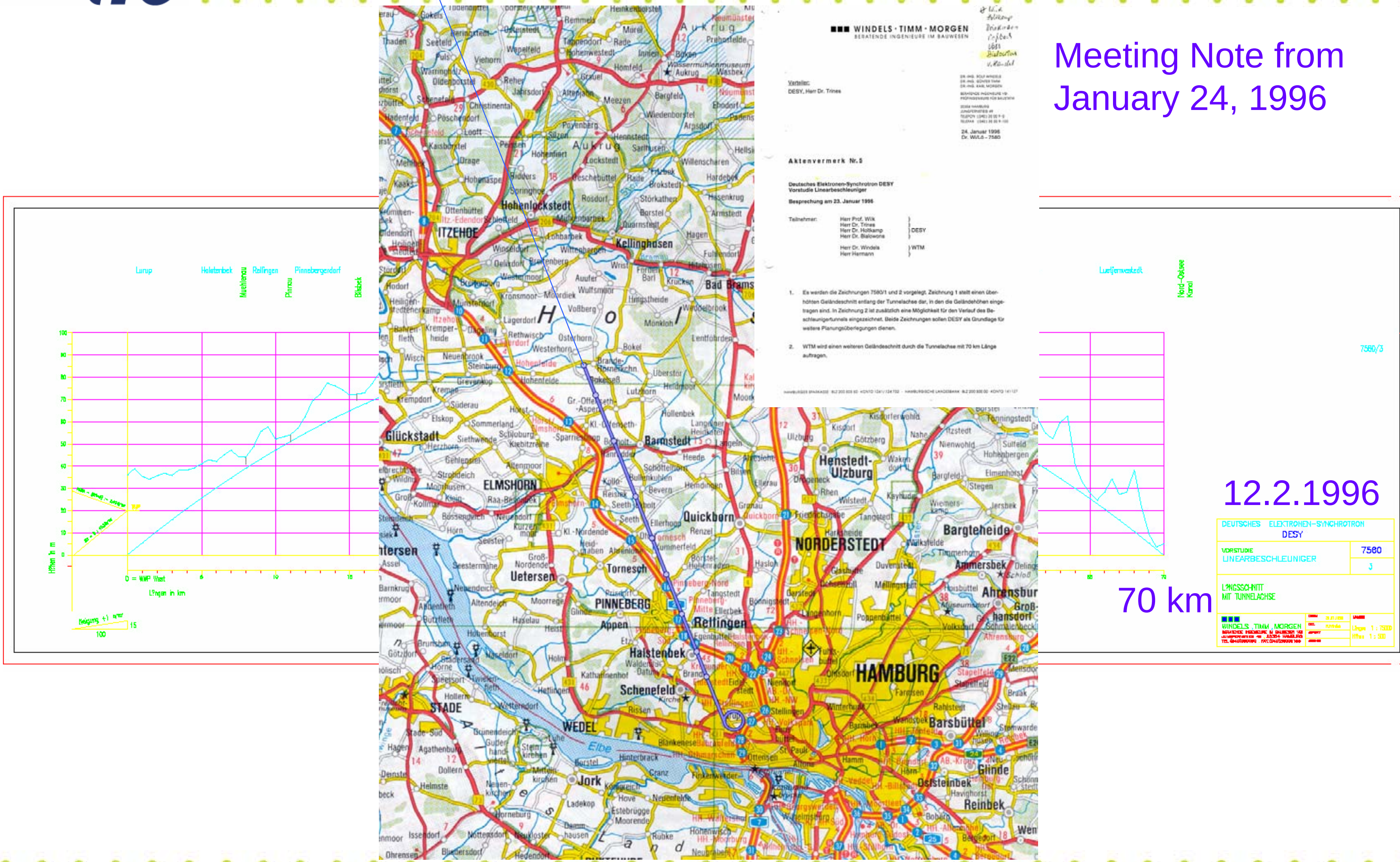
1.) Cost represent the final construction contract cost.

2.) Costs are based on the estimates established for the VLCW06 meeting

3.) The dimensions of the small excavation (3M x 3M) requires labor intensive small hand held equipment and / or small inefficient machines for a drill and blast excavation. The size of tunnel needed to use efficient mechanized machines for drill an

4.) All values are in $USD.

TESLA Site at DESY in HH



WINDELS · TIMM · MORGEN
BERATENDE INGENIEURE IM BAUWESEN

Verteiler:
DESY, Herr Dr. Trines

24. Januar 1996
Dr. Wi/Lö – 7580

Aktenvermerk Nr. 5

Deutsches Elektronen-Synchrotron DESY
Vorstudie Linearbeschleuniger

Besprechung am 23. Januar 1996

Teilnehmer:
Herr Prof. Wiik, Herr Dr. Trines, Herr Dr. Holtkamp, Herr Dr. Bialowons } DESY
Herr Dr. Windels, Herr Hermann } WTM

1. Es werden die Zeichnungen 7580/1 und 2 vorgelegt. Zeichnung 1 stellt einen überhöhten Geländeschnitt entlang der Tunnelachse dar, in den die Geländehöhen eingetragen sind. In Zeichnung 2 ist zusätzlich eine Möglichkeit für den Verlauf des Beschleunigertunnels eingezeichnet. Beide Zeichnungen sollen DESY als Grundlage für weitere Planungsüberlegungen dienen.

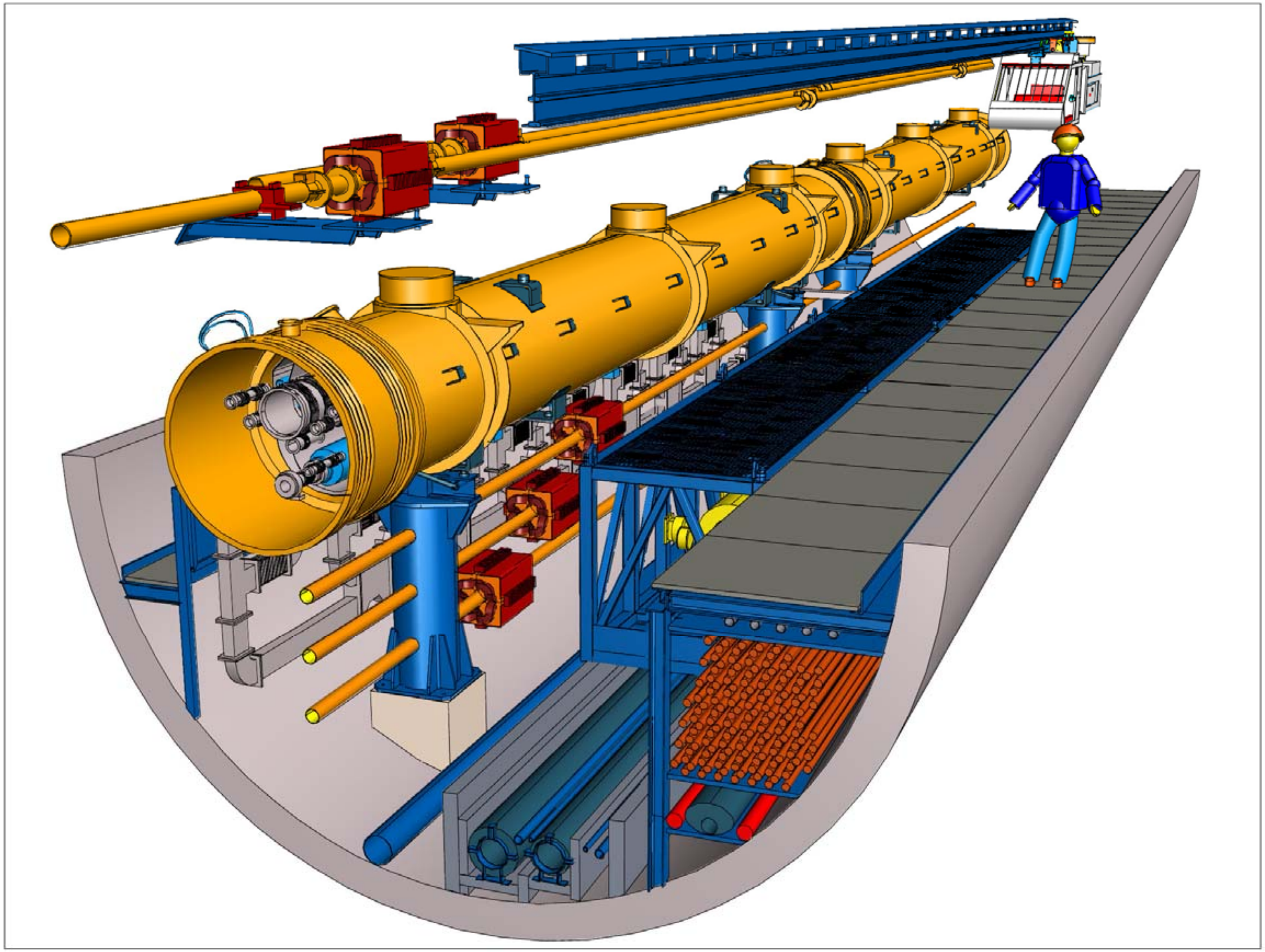
2. WTM wird einen weiteren Geländeschnitt durch die Tunnelachse mit 70 km Länge auftragen.

Meeting Note from January 24, 1996

12.2.1996

70 km

Sketch of the TESLA Tunnel (TDR)

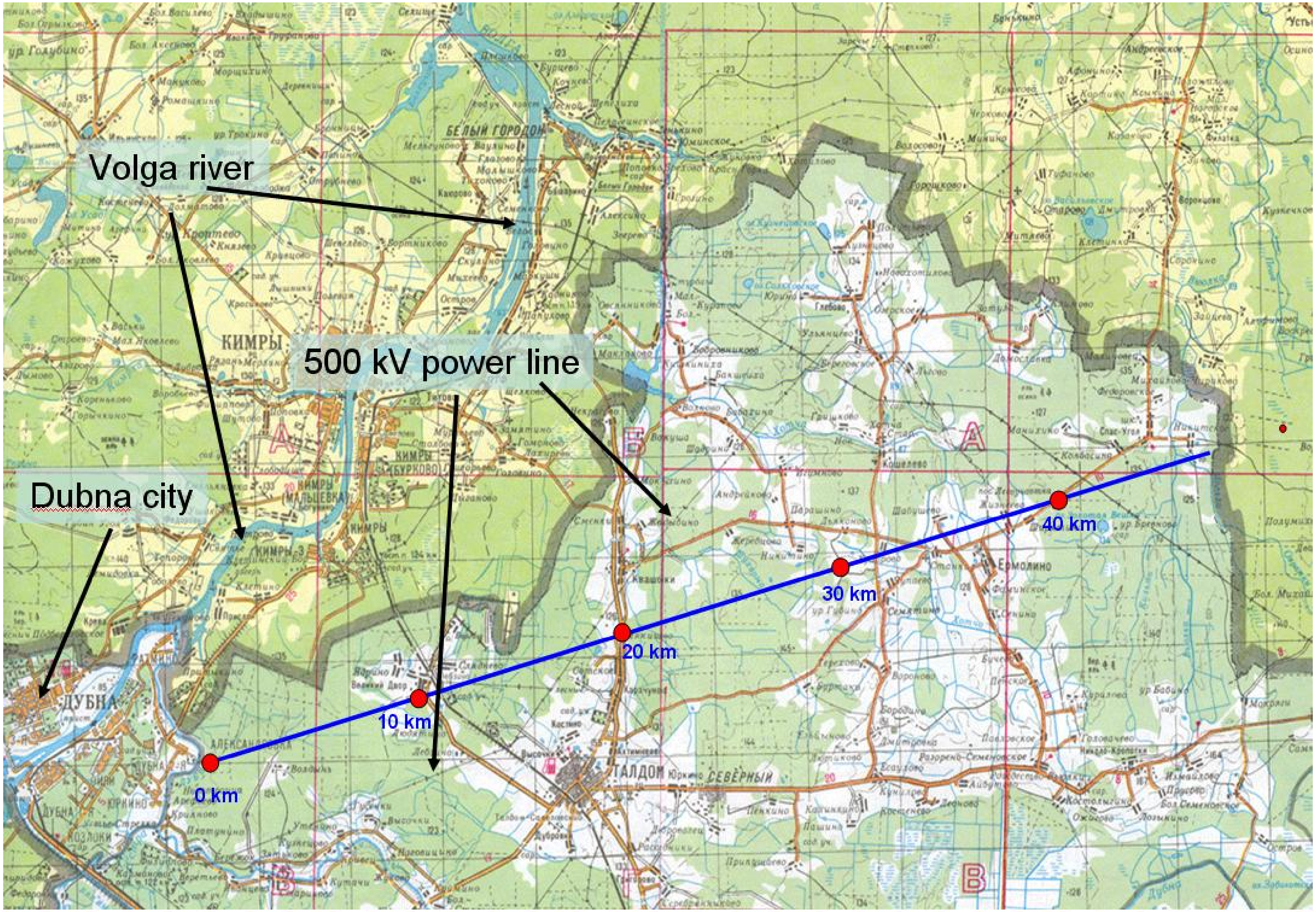


Potential ILC Site at Dubna in Russia

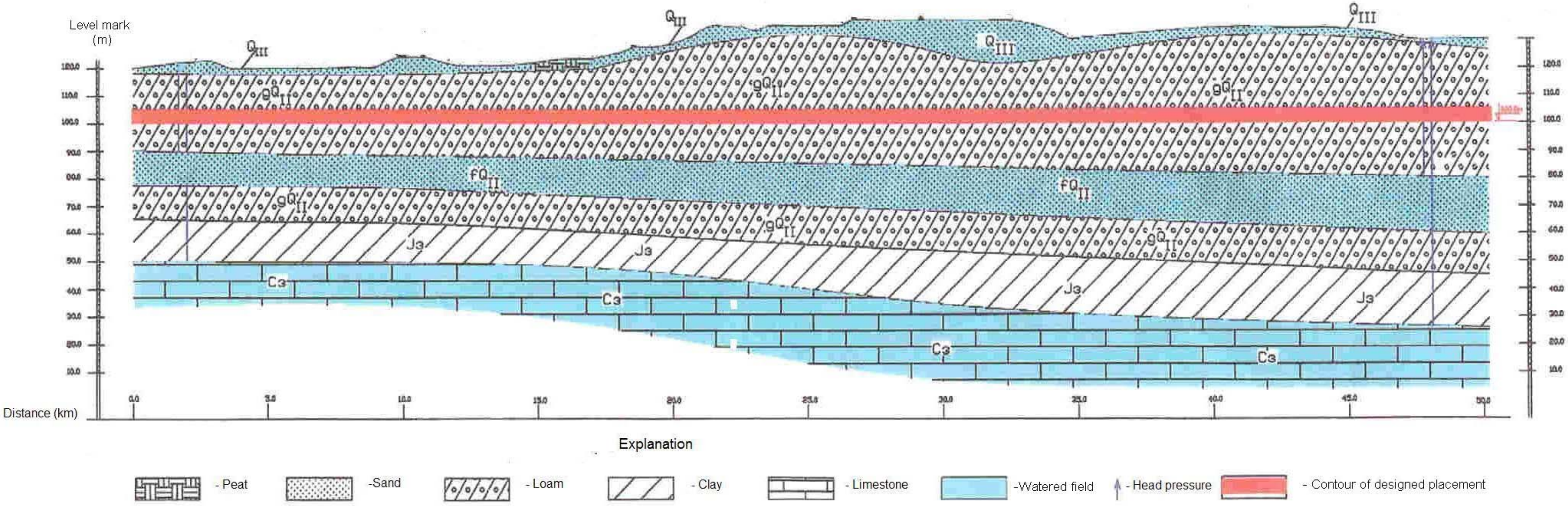
Siting Studies in Europe

The Joint Institute of Nuclear Research (JINR) in Dubna has proposed a site near their institute, south of the Volga river. That proposal comprises a machine close to the surface but constructed using tunnel-boring machines. Sufficient power from the Russian national grid is available. The project will assess the potential of such a site and conclude on the benefits and risks.

General Layout of the Site Near Dubna



Geological Cut of the Dubna Sample Site



Summary and Outlook

- Reference Design Report published in August 2007
  - Consistent design, though details are still lacking
  - Significant cost savings since the original version of BCD (Dec 2005)
  - Physics scope not reduced (energy, luminosity)
  - Risk assessments underway
- R&D and engineering design issues still remain
  - The next document will contain much more technical detail: Technical Design Phase Report due 2010 / 2012
- The XFEL (with significant Russian contribution) is a very important stepping stone towards the ILC!