ILC Beam Delivery System Dumps and Collimators RDR Completeness

Tom Markiewicz/SLAC

SLAC BDS Kick-Off-Meeting

11 October 2007

Charge

Assess technical maturity of RDR design and completeness of the value estimate.

Evaluate performance acceptability.

Examine cost and check for inconsistencies, inaccuracies, cross check with existing machines.

Explain what accelerator physics requirements were driving the design and how these requirements were obtained.

Contributors

SLAC

- **Dieter Walz – responsible for almost every SLAC dump/collimator**
- **Lew Keller – EGS/FLUKA/TURTLE….**
- **Eric Doyle- ILC ME responsible for 1999 NLC Lehman Dumps& Collimators costs**
- **TWM*: HEP Experimentalist: Bookkeeper; interface to Area Groups; author of RDR text on Dumps & collimators**

RAL: MEs responsible for ISIS Target

- **Chris Densham***
- **Brian Smith – Civil layouts and RAL updates of commercial costs**
- **Otto Caretta**

KEK:

- **Suichi Ban***

*** = Regional coordinators**

RDR Bottom Line on Dumps & Collimators

This technical system's cost is dominated by:

- **The 18MW full power dumps**
- **The 3-loop radioactive water processing systems**
- **The CFS infrastructure, shielding, etc.**

Technical maturity & performance acceptability of the dumps are assured based on

- **40 years of operation of SLAC 2.2 MW dump**
- **Detailed commercial studies done for TESLA dumps**

Technical maturity & performance acceptability of the collimators are assured based on fact that

- **All BDS adjustable collimators are peripherally cooled mechanical devices**
- **The high power main dump protection collimators share their corresponding dumps water system**

Cost uncertainty is dominated by

- **Lack of a self-consistent CFS/Mechanical design and fact that CFS costs will likely dominate mechanical costs**
- **Cost of additional systems not considered by SLAC or TESLA**
  - Remote replacement of water dump window, thin vacuum window & passive beam expander
  - Vessel failure mitigation
    - Venting & scrubbing system
    - Air drying & vapor recovery
    - Parking for dead dump

Component Types

Parts list corresponding to RDR

- **Dumps (6 BDS/26)**
- **Fixed aperture collimation devices (32 BDS/85)**
- **Variable aperture collimation devices (32 BDS/85)**
- **MPS and PPS stoppers (14 BDS/25)**

Basic Device Technology assigned based on incident power, beam energy and particle type

- **18MW-600kW: Pressurized water dump (4 BDS)**
- **600kW-40kW: Metal balls in water bath (6 BDS)**
- **40kW-25W Peripheral cooled solid metal (42 BDS)**
- **25W – 0W Un-cooled metal (32 BDS)**

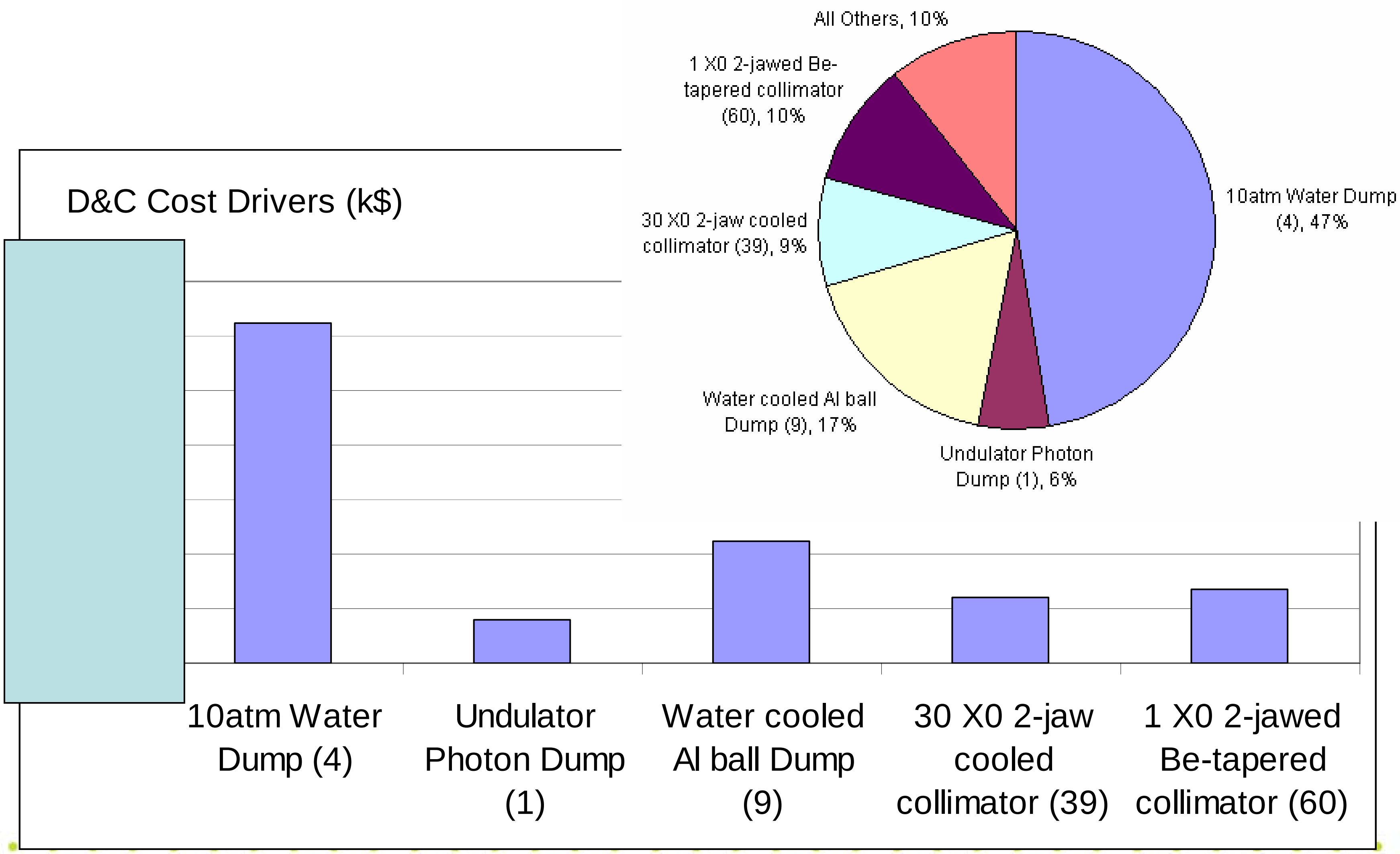
All Device Types, Counts & Costs

Class	Device Type	BDS	e-	e+	DR	RTML	LINAC	N	Unit Cost (k$)	Economy Factor	Averaged Manufactured Cost (k$)	Total Cost (k$)	ED&I ratio	ED&I	Total D&C Cost (k$)	Unit Cost w/ ED&I	Error (%)
Dump	10atm water dump	4	0	0	0	0	0	4									
Dump	Undulator Photon Dump	0	0	1	0	0	0	1									
Dump	Water cooled aluminum balls	0	1	2	0	6	0	9									
Dump	Solid aluminum block with peripheral coo	0	1	5	0	0	0	6									
Dump	Insertable W-Cu-W sandwich peripherall	2	0	0	0	0	0	2									
Dump	Faraday cup	0	1	1	0	0	0	2									
Dump	Uncooled Al, Cu or Fe block	0	0	0	2	0	0	2									
Dump	Total	6	3	9	2	6	0	26									
Ecol	100-1cm Ti disks uniformly distributed in	0	0	1	0	0	0	1									
Ecol	30cm x 30cm block with rectangular aper	2	0	0	0	0	0	2									
Ecol	Al balls in water; high Z backend	6	0	0	0	0	0	6									
Ecol	Single cooled jaw with image plate	2	0	0	0	0	0	2									
Ecol	30cm cylinder peripheral cooled	22	0	0	0	52	0	74									
Ecol	Total	32	0	1	0	52	0	85									
Rcol	Coll,long,2 jaw,cooled	0	1	6	0	0	0	7									
Rcol	Coll,long,4 jaw,cooled	16	0	0	0	0	0	16									
Rcol	Coll,short,2 jaw,uncooled	0	0	10	0	0	0	10									
Rcol	Coll,short,2 jaw,uncooled-Be_sandwich	0	0	0	0	36	0	36									
Rcol	Coll,short,4 jaw,uncooled-Be_sandwich	12	0	0	0	0	0	12									
Rcol	2cm x 5cm block with rectangular aper. &	4	0	0	0	0	0	4									
Rcol	Total	32	1	16	0	36	0	85									
Stopper	PPS_Stopper_w_BTM	6	0	2	0	6	0	14									
Stopper	MPS_Stopper_w_BTM, Fixed_Aperture	6	0	3	0	0	0	9									
Stopper	MPS_Stopper_w_BTM, Variable_Apertur	2	0	0	0	0	0	2									
Stopper	Total	14	0	5	0	6	0	25									

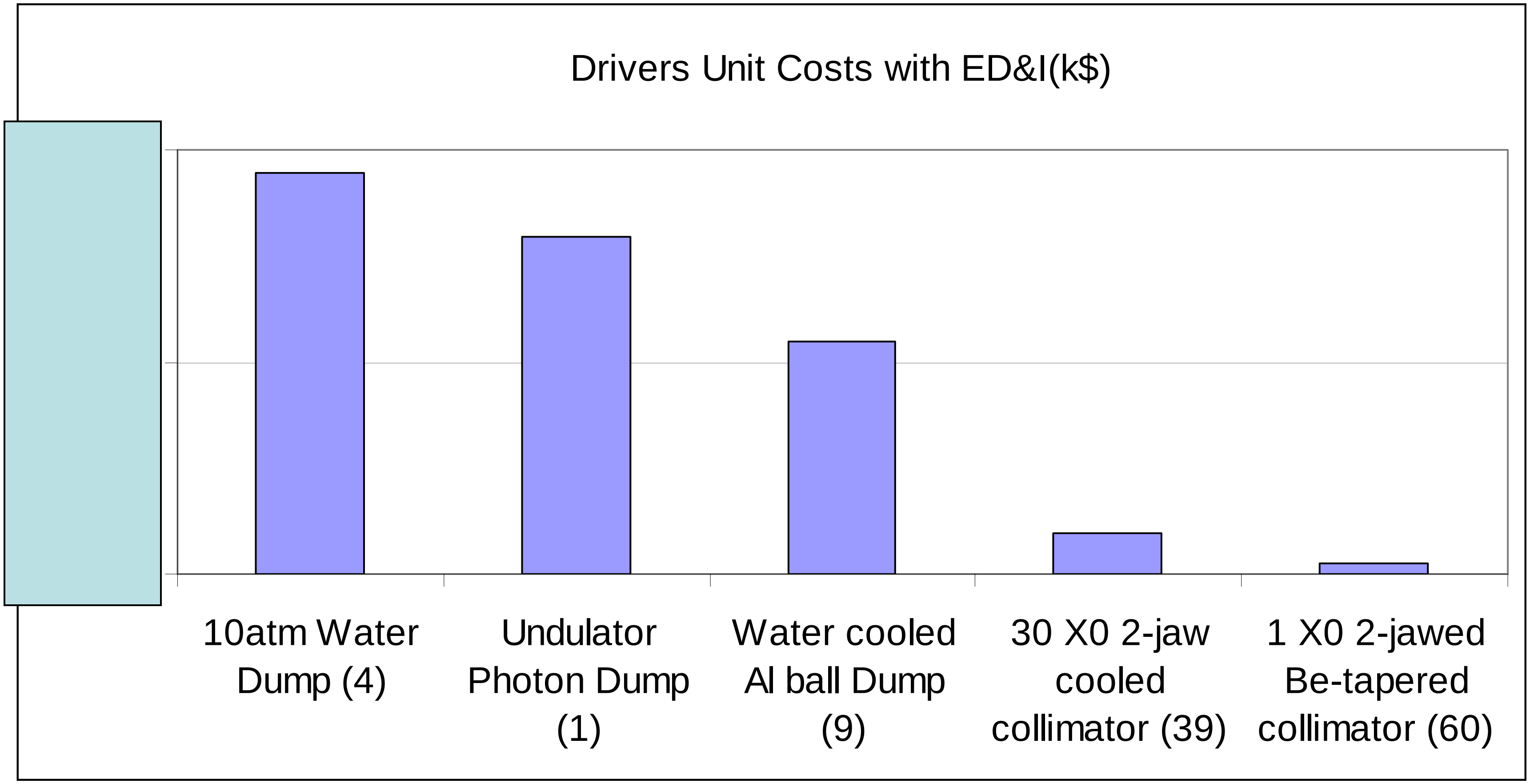
Abbreviated Device & Cost Summary

Device Type	N	Unit Cost (k$)	Economy Factor	Averaged Manufactured Cost (k$)	Total Cost (k$)	ED&I ratio	ED&I	Total D&C Cost (k$)	Unit Cost w/ ED&I	Error (%)	%
10atm Water Dump (4)	4									50%	47%
Undulator Photon Dump (1)	1									100%	6%
Water cooled Al ball Dump (9)	9									50%	17%
30 X0 2-jaw cooled collimator (39)	39									50%	9%
1 X0 2-jawed Be-tapered collimator (6(	60									50%	10%
All Others											10%
Total											100%

90% Total D&C Cost of 66M$ in 5 of 26 Device Types



Unit Costs



Drivers Unit Costs with ED&I(k$)
10atm Water Dump (4)
Undulator Photon Dump (1)
Water cooled Al ball Dump (9)
30 X0 2-jaw cooled collimator (39)
1 X0 2-jawed Be-tapered collimator (60)

18MW Water Dump Technical Issues

BDS features

- **Optics & drift to increase undisrupted beam spot size on window**
- **Raster beam in 30mm radius circle in 1 ms; interlock to MPS**
- **Hi-power donut collimators to protect vessel window**

Vessel

- **6.5m (18X_0) water followed by 1m water-cooled Cu (22X_0)**
- **1.5m diameter with vortex flow water, v=1.0-1.5 m/s , at r=30cm**
- **10 atm to prevent boiling**
- **30 cm diameter 1mm Ti vessel window with water cooling nozzles**

Rad water system

- **2300 gpm three loop water system**
- **18 MW heat exchanger & ~400HP of pumps per loop**
- **Catalytic H_2-O_2 recombiner**
- **Mixed bed ion exchange column to filter ^{7}Be**
- **Containment for tritiated water**

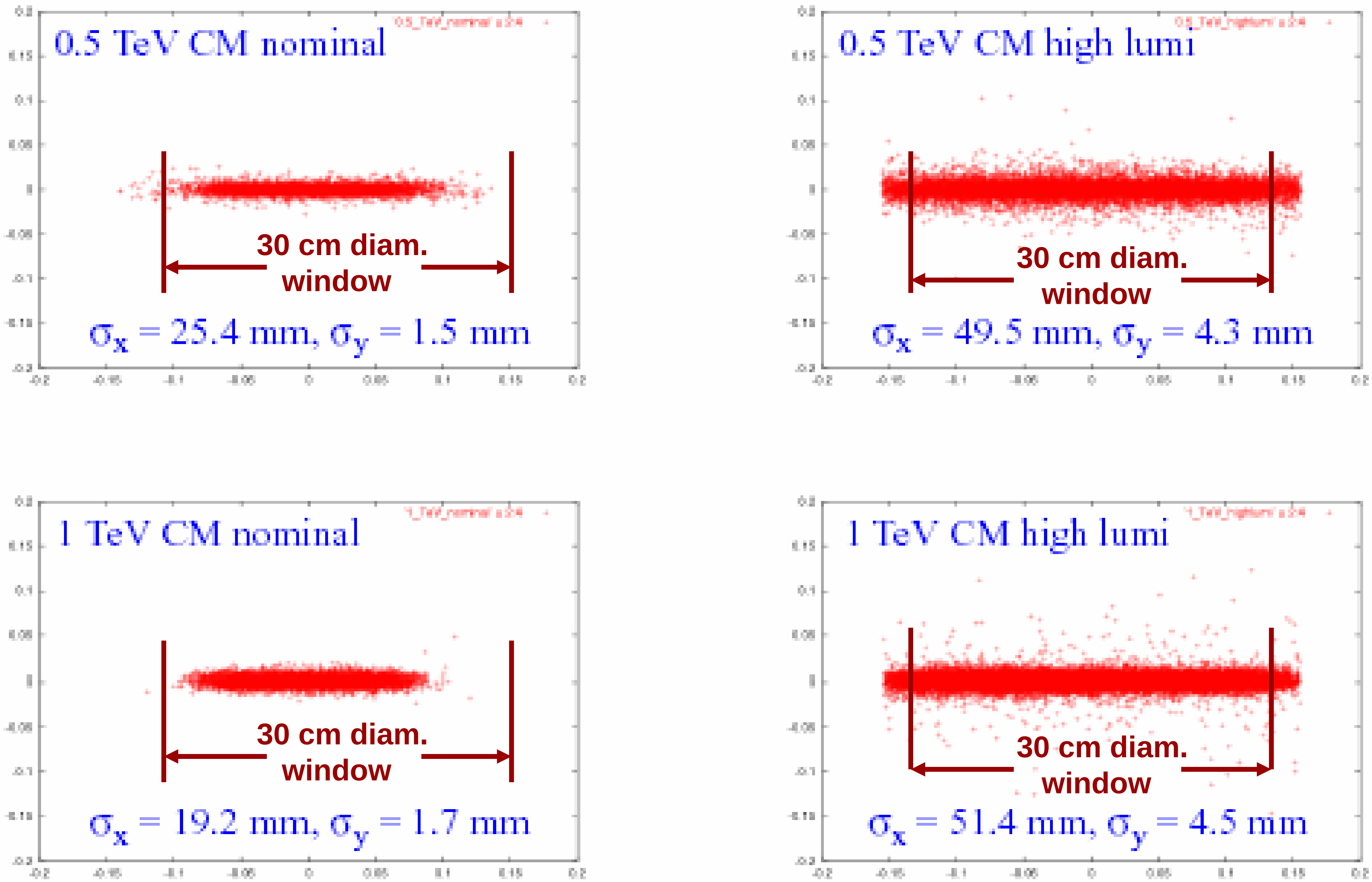
Shielding

- **50cm Fe + 150cm concrete 'local' protection for personnel & beamlines**
- **200cm site dependent to protect ground water**

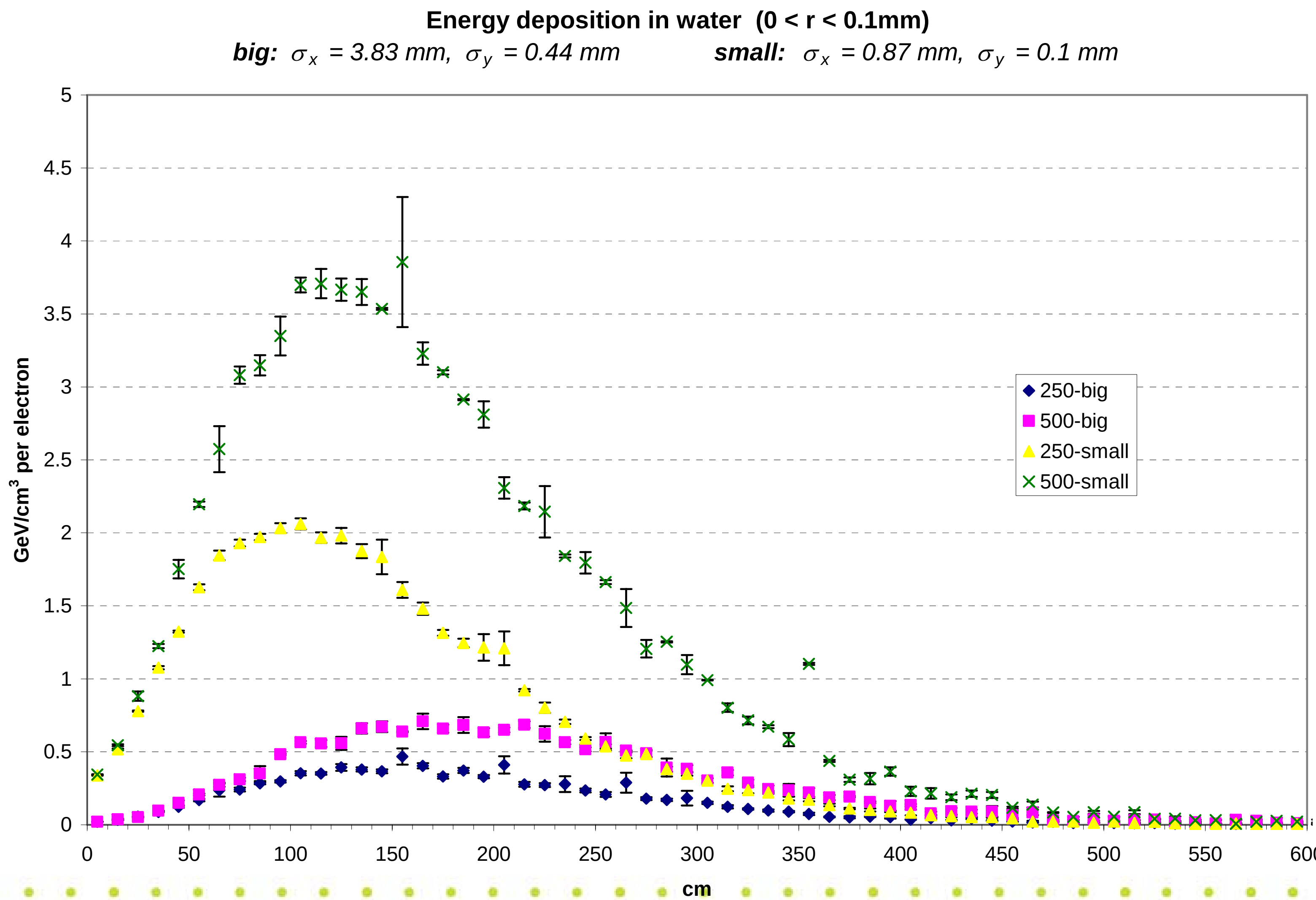
X-Y disrupted distribution at dump (no IP offset)

(scale in meters)

Protect Window for High Lum Parameter Set with Collimators



dE/dV in core vs. z for 250/500 Gev disrupted & undisrupted beam

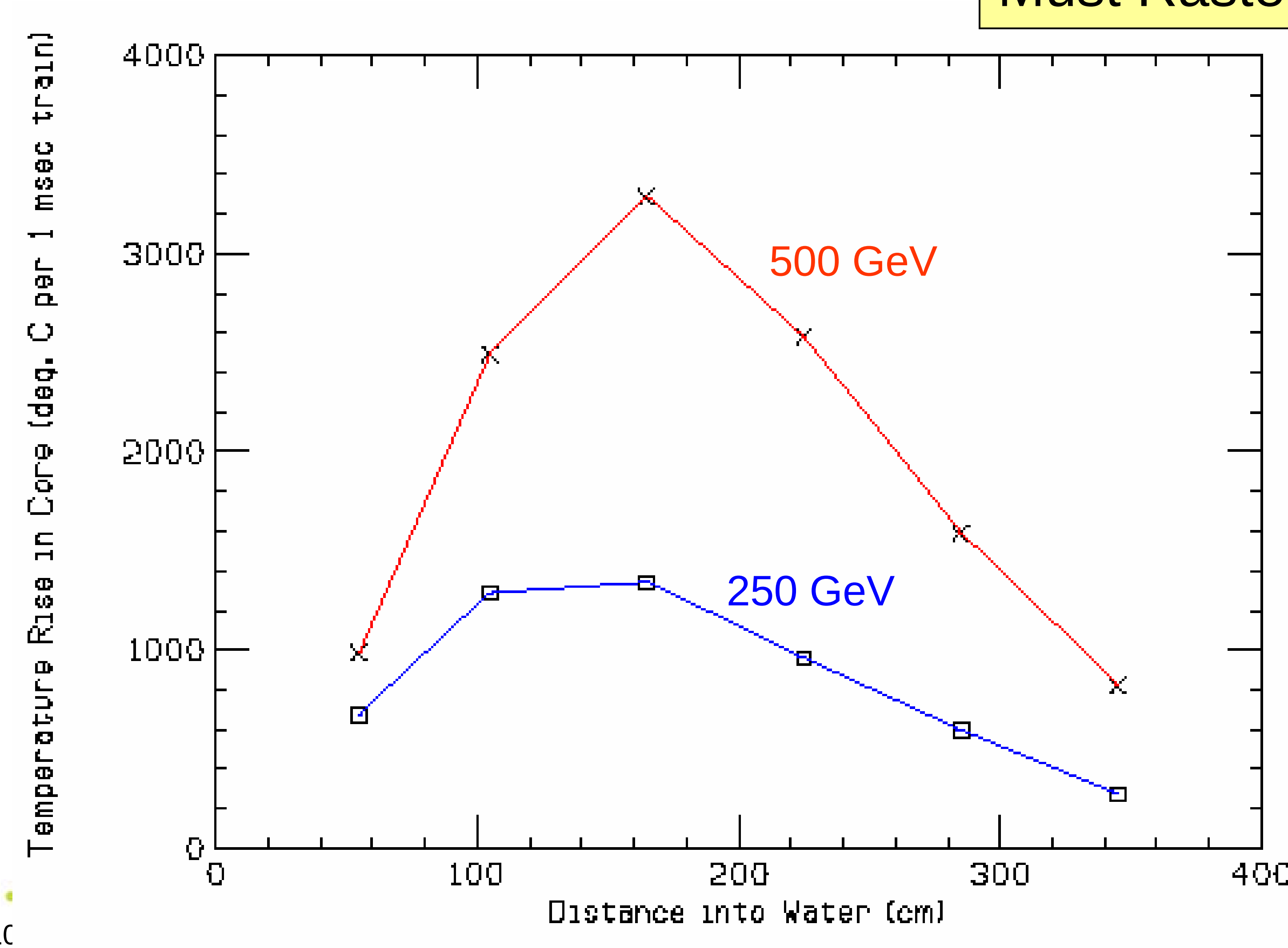


One Bunch Train Core Temperature in Water vs. Z

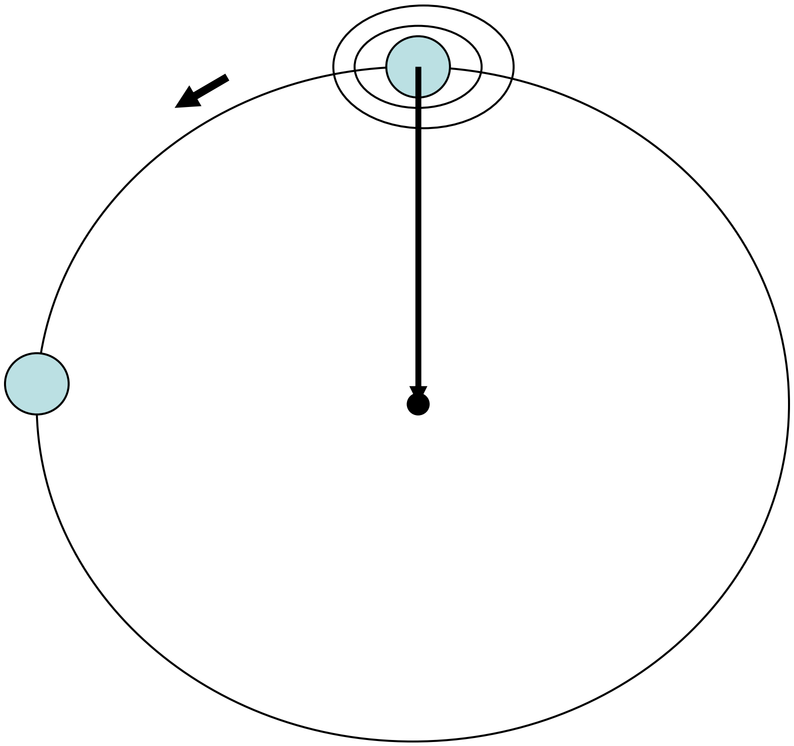
core radius = 0.5 mm

sigma_x = 2.46 mm,
sigma_y = 0.26 mm

Must Raster Beam



Raster Radius



Rraster = 31 mm @ 500 GeV COM, conservatively (**ΔT**allowed = 40 deg) and OK at 1 Tev (less conservatively, (**ΔT**allowed = 80 deg)

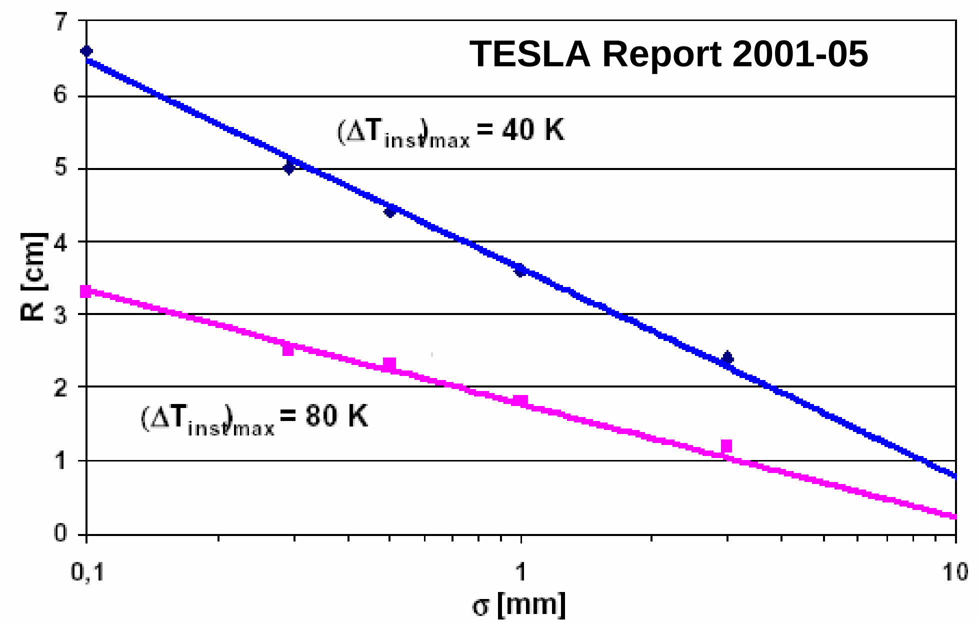


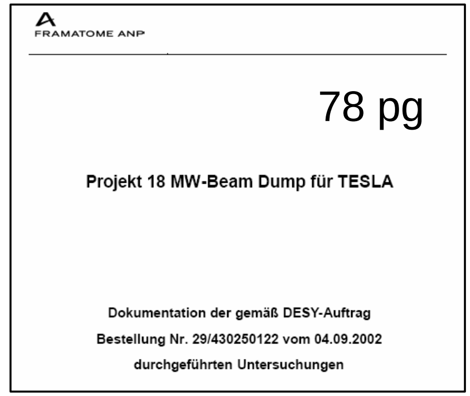
Figure 2: Sweep radius R as a function of beam size σ for a given maximum instantaneous temperature rise $(\Delta T_{inst})_{max}$ caused by one bunch train with 5.64×10^{13} e^-

If Raster Fails:

250 bunches will cause boiling in 10 atm. water @ 500 GeV CM (110 bunches @ 1 TeV CM).

18MW Dump Cost Basis

- Fichtner design/cost estimate for TESLA reworked by RAL
  - **cheaper than Framatome design/estimate**
  - **2003 prices**
- Recent vessel UK industry estimate
- Recent US quotes for heat exchangers, pumps & piping
- 40 year old SLAC 2.2 MW dump

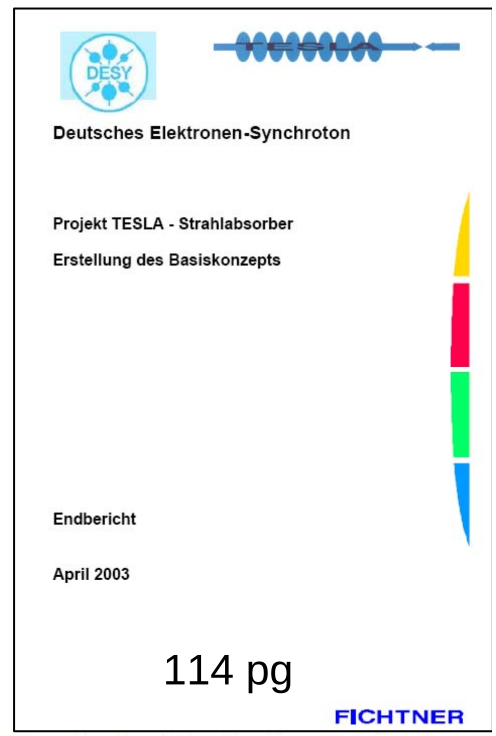

FRAMATOME ANP

78 pg

Projekt 18 MW-Beam Dump für TESLA

Dokumentation der gemäß DESY-Auftrag
Bestellung Nr. 29/430250122 vom 04.09.2002
durchgeführten Untersuchungen

Unit cost w/ED&I = 7.8M$


DESY

Deutsches Elektronen-Synchroton

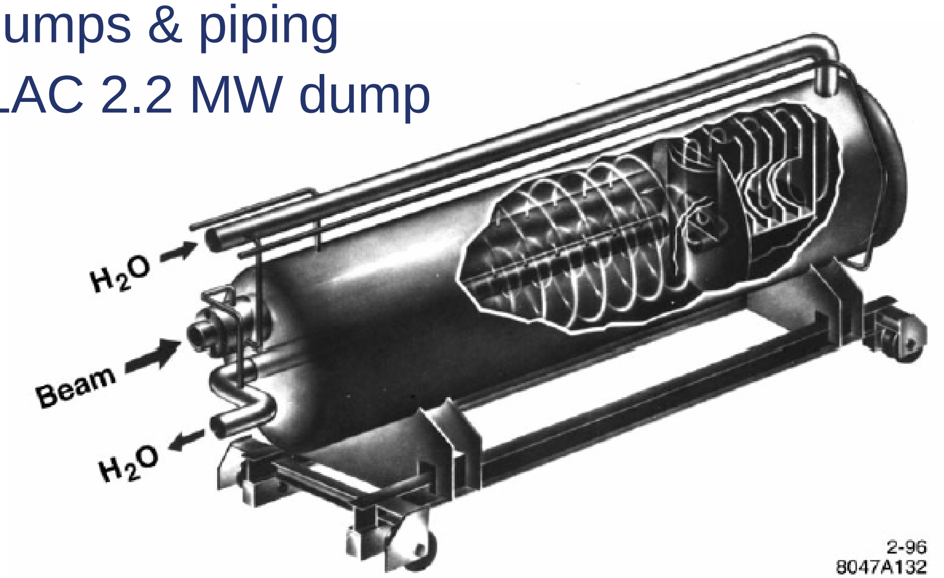
Projekt TESLA - Strahlabsorber
Erstellung des Basiskonzepts

Endbericht

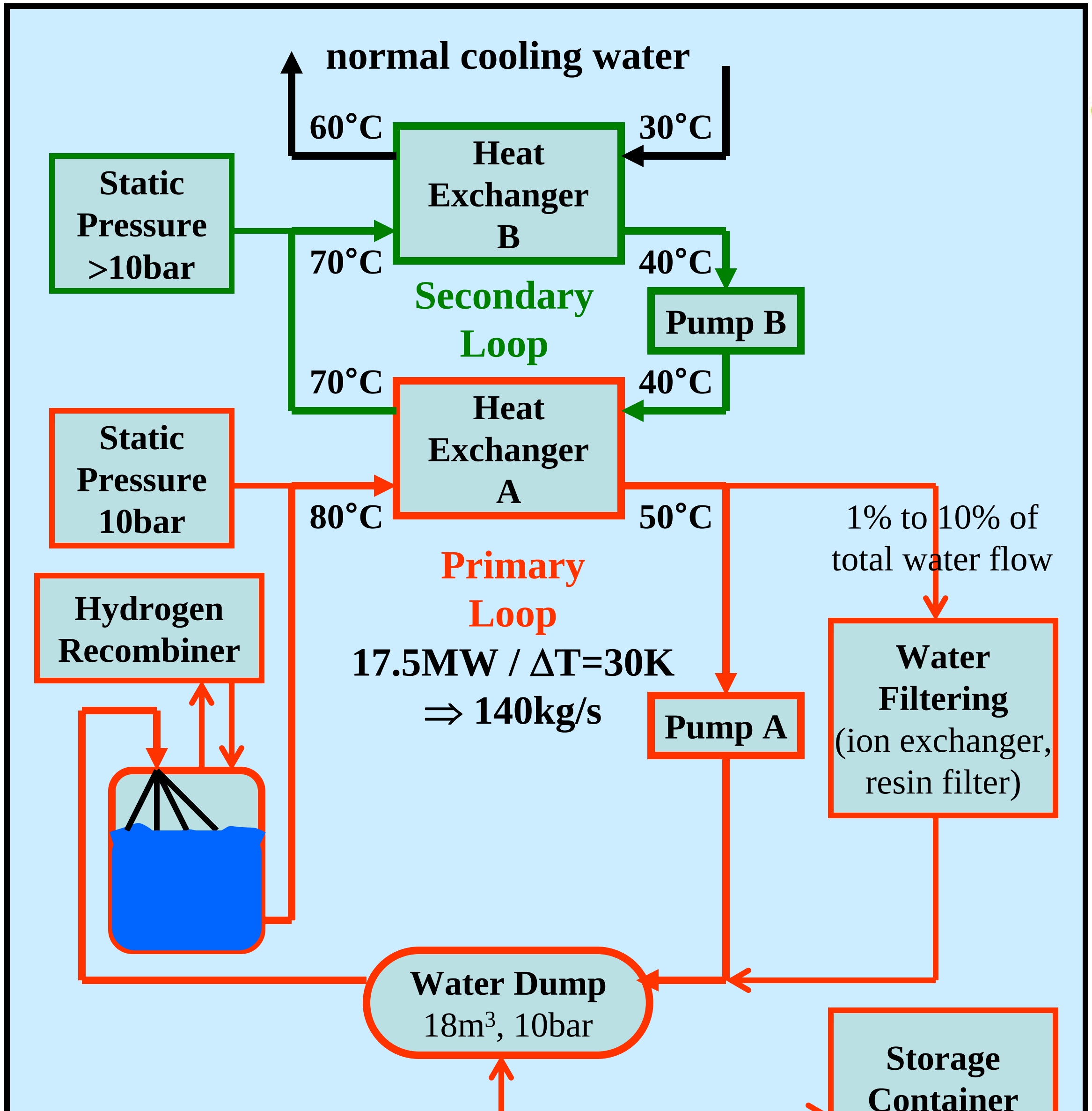
April 2003

114 pg

FICHTNER



10 bar H2O Dump Plumbing



Scheme of Water System

2003 Fitchner Estimate

April 2003 , Table 3-18	kEuros		k$
Strahlabsorber (ohne Fenster)		Ray absorber (without window)	
Wärmetauscher des Primärkühlkreislaufes		Primary cooling loop heat exchanger	
Druckhaltung, Rekombinator im Primärkühlkreislauf		Primary cooling loop pressure regulation & recombiner	
Sonstige Komponenten des Primärkühlkreislaufes (Pumpen, Rohrleitungen, Armaturen)		Various instruments of the primary cooling loop (pumps, pipes, meters)	
Wärmetauscher des Zwischenkühlkreislaufes		Intermediate loop heat exchanger	
Sonstige Komponenten des Zwischenkühlkreis laufes (Pumpen, Druckhaltung, Rohrleitungen, Armaturen)		Various instruments of the intermediate cooling loop (pumps, pressure regulators, pipes, meters)	
Wasseraufbereitung und Auffangbehälter incl.Verrohrung		Water containment and preparation (installed plumbing)	
Abschirmung des Absorbers (Stahl und Schwerbeton)		Shielding (Steel and Concrete)	
Containment		Containment	
Sonstige Abschirmungen		Various radiation protection devices	
Strahlenmonitore		Radiation Monitors	
Unvorhergesehenes		Unforeseen (Contingency)	
Gesamt			

3 years escalation @ 2.5%

$/Euro = 1.25

Contingency removed

Costed additions to Fitchner

- Window lifetime & vessel maintenance
  - **Remotely replaceable thin vacuum window**
  - **Remotely replaceable water dump window**
  - **Remotely replaceable passive beam expander**
  - **Air exchange & control system**
- Vessel Failure
  - **Vent & scrubbing system**
  - **Air drying & vapor recovery system**
  - **Parking area for dead dump**

RAL Rework/Detailing of Fitchner

	10 ATM WATER DUMP SYSTEM - BASIC ITEMS	Qty	T
G	Vessel manufacture to BS55000 or ASME	4	
E	Stand manufacture (estimate)	4	
E	Internal High pressure water Jet system manufacture	4	
E	Set Internal plates	4	
E	Delivery and return pipe work to cooling system	4	
E	Back Stop in vessel	4	
E	Installation, Commissioning and Testing	4	

	WATER COOLING SYSTEM (Fichtner 18MW)		
E	Primary Cooling Loop (PCL) - heat exchanger & Storage Tank	4	
E	PCL - pressure regulation system & hydrogen catalysor	4	
E	PCL - Pumps, pipes, instrumentation and meters	4	
E	Secondary Cooling Loop (SCL) includes heat exchanger	4	
E	SCL - Pumps, pipes, instrumentation and meters	4	
E	Control Electronics (estimate of ISIS design)	4	
E	Local Shielding - (Steel and Concrete)	4	
E	Sealing (Containment) to prevent leaking of contaminated water	4	
E	Installation, Commissioning and Testing	4	
E	Radiation monitoring systems	4	
E	Radiation Protection devices (to protect systems?) (shielding?)	4	

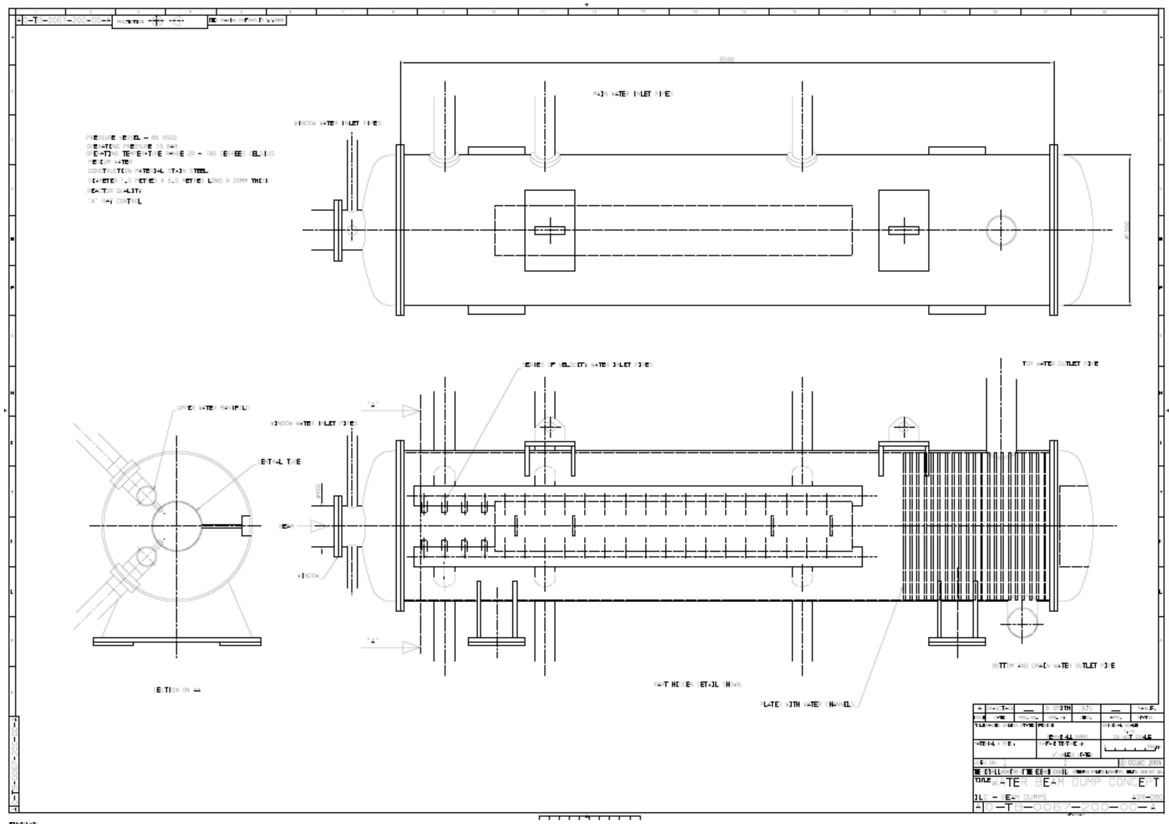
RAL Additions to Fitchner

	REPLACEABLE WATER DUMP WINDOW			
E	Replaceable water dump window		4	
E	Hydraulic Pillow Seal System		4	
E	Remote Handing System		4	
E	Window Cooling System - addition to water dump		4	
E	Electronic Control System		4	
E	Installation, Commissioning and Testing		4	
	REPLACEABLE FIRST WINDOW (VACUUM)			
E	Thin window mechanics etc		4	
E	Vacuum Pillow Seals		4	
E	Pneumatic System		4	
E	Cooling System		4	
E	Electronic Control System		4	
E	Remote Handling System		4	
E	Installation, Commissioning and Testing		4	
	REPLACEABLE BEAM EXPANDER - WINDOW PROTECTION			
E	Vacuum Tank		4	
E	Disposable Beam Expander Target (Carbon)		4	
E	Pillow Seals (2)		4	
E	Pneumatic System		4	
E	Cooling System		4	
E	Shielding		4	
E	Remote Handling System		4	
	ADDITIONAL REQUIREMENTS			
E	Air Change and Control System		4	
E	Vent System - 20 metre chimney and Scrubber?		4	
E	Drying System (Dry Air - Heaters?) - Recovery?		4	

RAL ED& I Estimate

	Institute and Contractor - staff years required…..	Staff Years		
	ONE OFF COST ITEMS - value x time (man years of effort)	**V**	**Time**	**Tot**
E	Project Engineering and Control		5	
E	FEA of window design		2	
E	Computational Fluid Dynamics (CFD)		2	
E	Window development and prototyping		3	
E	Development of Systems and the Designs		4	
E	Cooling System Scheme Design		2	
E	Analysis of systems including radiation and shielding		2	
E	Contracts and Supervision		0.6	
E	Design schemes of remote handling systems		5	
	Contract Design Effort			
E	Design Vessel & Support - 1 man year @ £90,000		2	
E	Design vessel replaceable window		2	
E	Design upstream replaceable window		2	
E	Design Approval of pressure vessels (@ £300/hr)		0.6	
E	Design of a upstream beam enlargement target		2	
E	Design of Cooling System		2	
E	Design of remote handling systems		3	
		S	**34.2**	**6**
	Estimate @25% of consumable cost = $6,255,000 (time reduced due to new higher value)			

Estimates of Vessel Cost

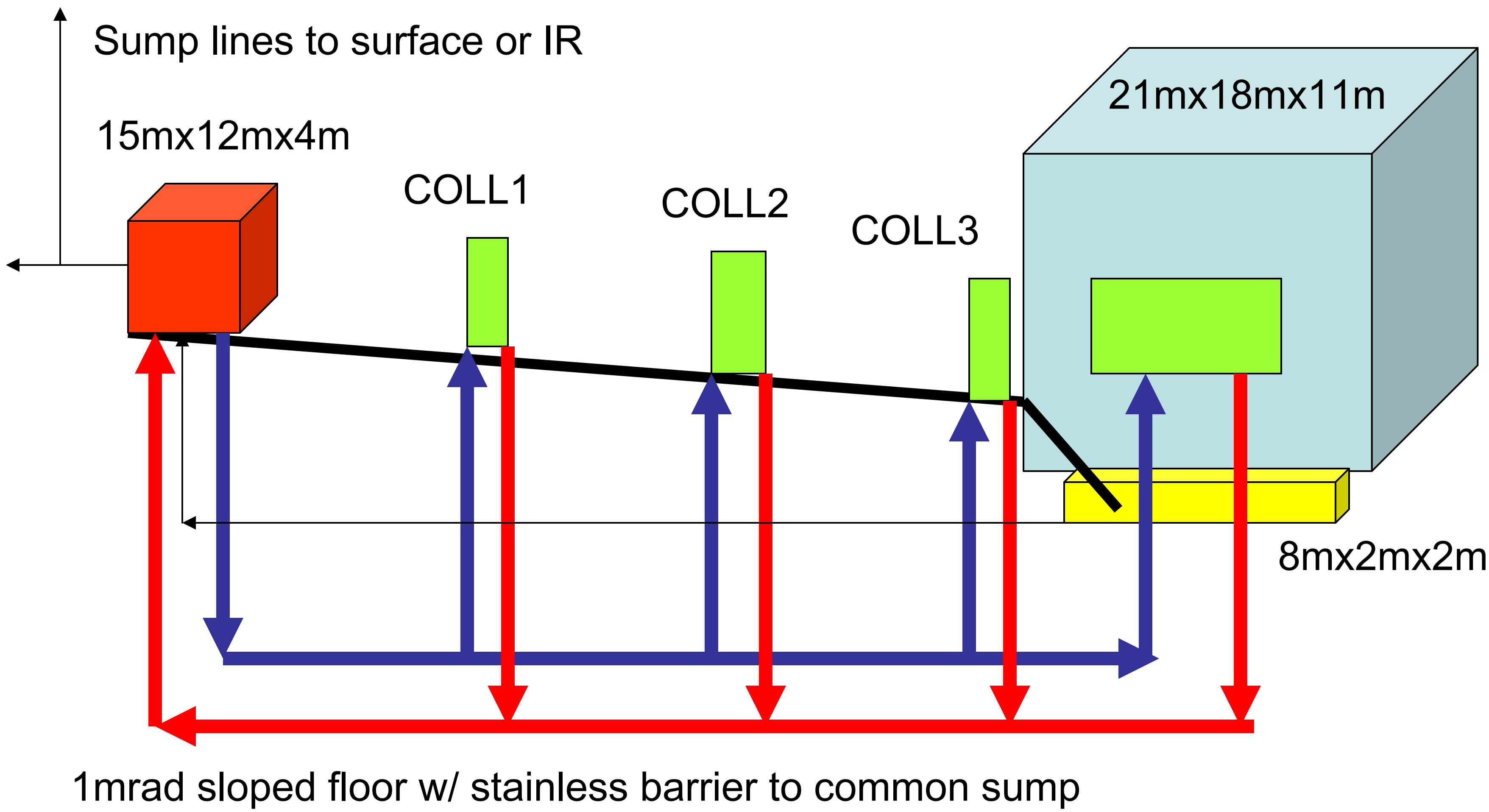


10-2006 UK Industry-supplied estimate for vessel:

“Raw” Fitchner

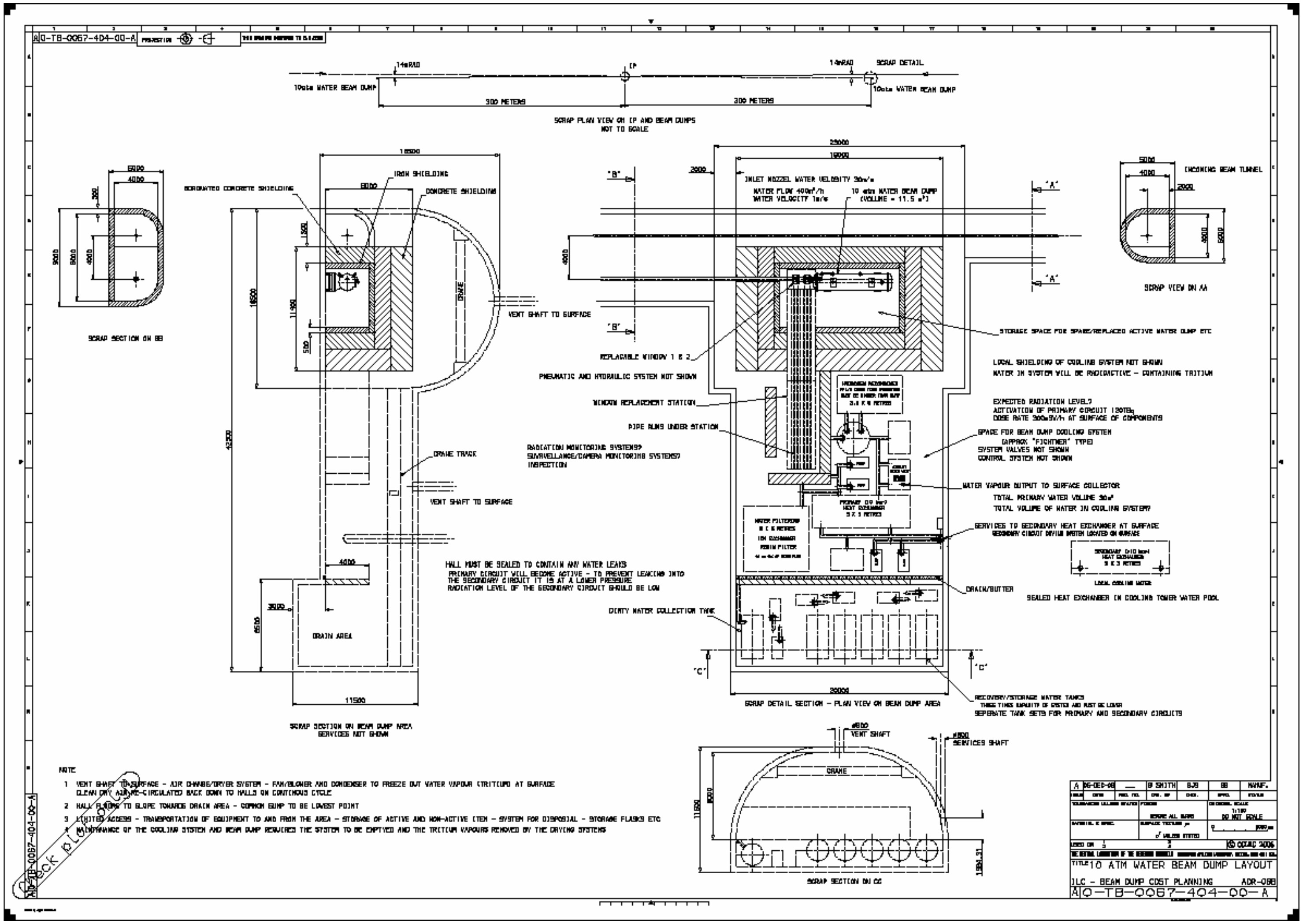
RAL supplemented Fitchner

Plumbing near 10bar H2O dumps



6” Supply/Return with ~2200gpm

Current 42m x 20m Service Cavern Layout

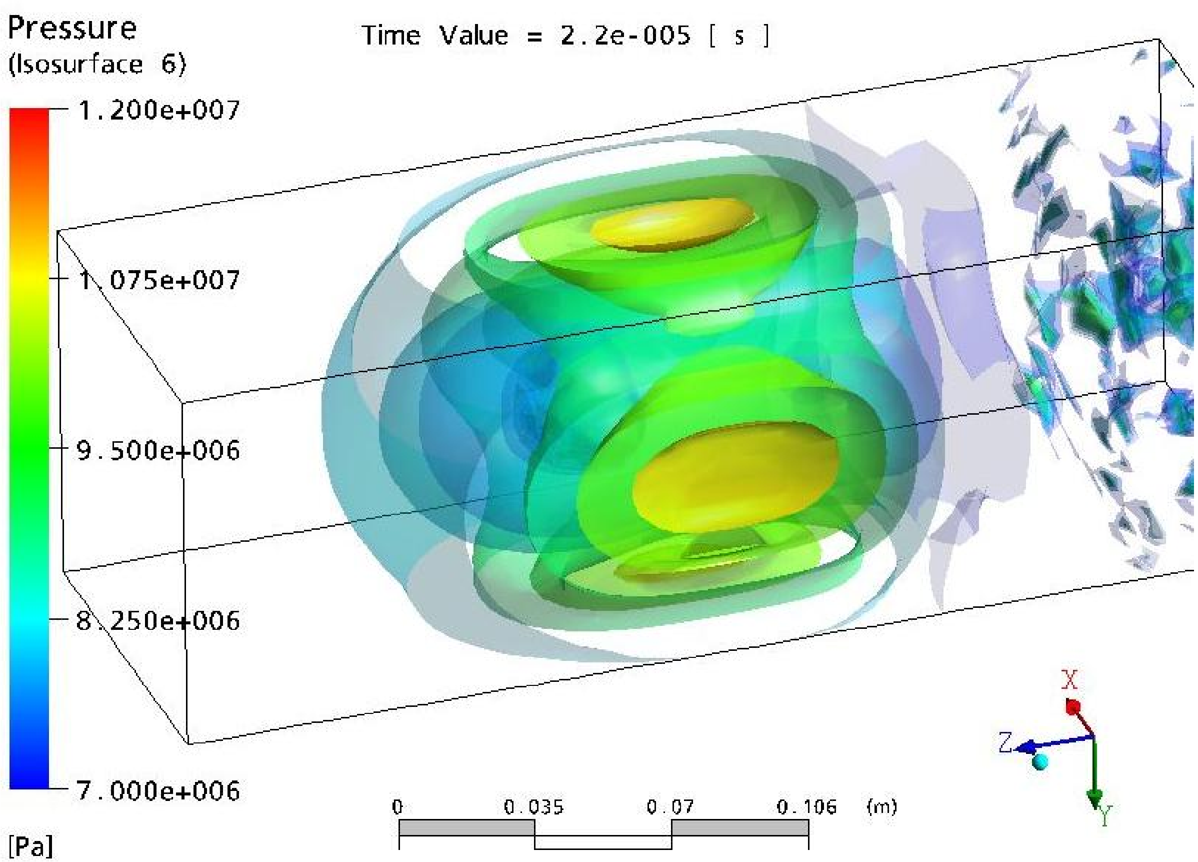


Other ‘known unknowns’*
from Chris Densham

- Potential need to plan for MPS, window or vessel failure
- Regulatory costs – concerns re high tritium production and radiolysis of water.
- Disposal of active water. System for solidification of waste may need to be included in construction.
- Requirements for remote handling of activated dumps and collimators. Hot cell and special tooling? Active ventilation systems? What is remote handling philosophy for ILC? Small allowance made for 18MW dump window replacement only.
- Are civil engineering specifications adequate? No ‘handshake’ on civil engineering requirements yet. Detailed physics & engineering simulations may reveal necessity to increase space to reduce power density on dumps.
- Post-ILC disposal of dumps

* D.Rumsfeld

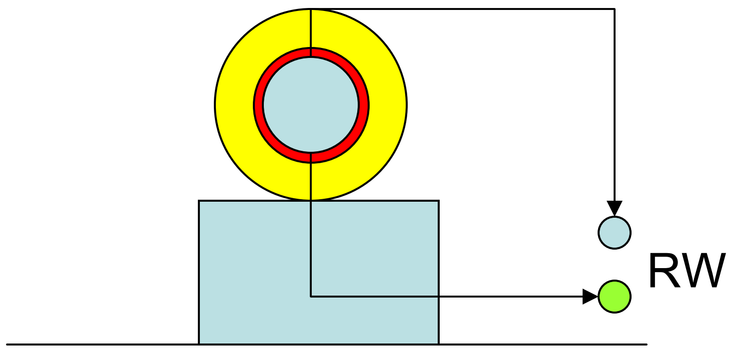
Shock wave generation in 18 MW water dumps: baseline technology choice



- Pressure wave in water vessel 22 µs after a 20°C rise in temperature over 10µs beam pulse
- Similar to ILC beam dump parameters at shower maximum with rastered beam
- Maximum pressure = 120 bar

9 ~240kW Aluminum Ball Dumps

50cm Diameter x 2m long Aluminum Ball Dump with Local Shielding

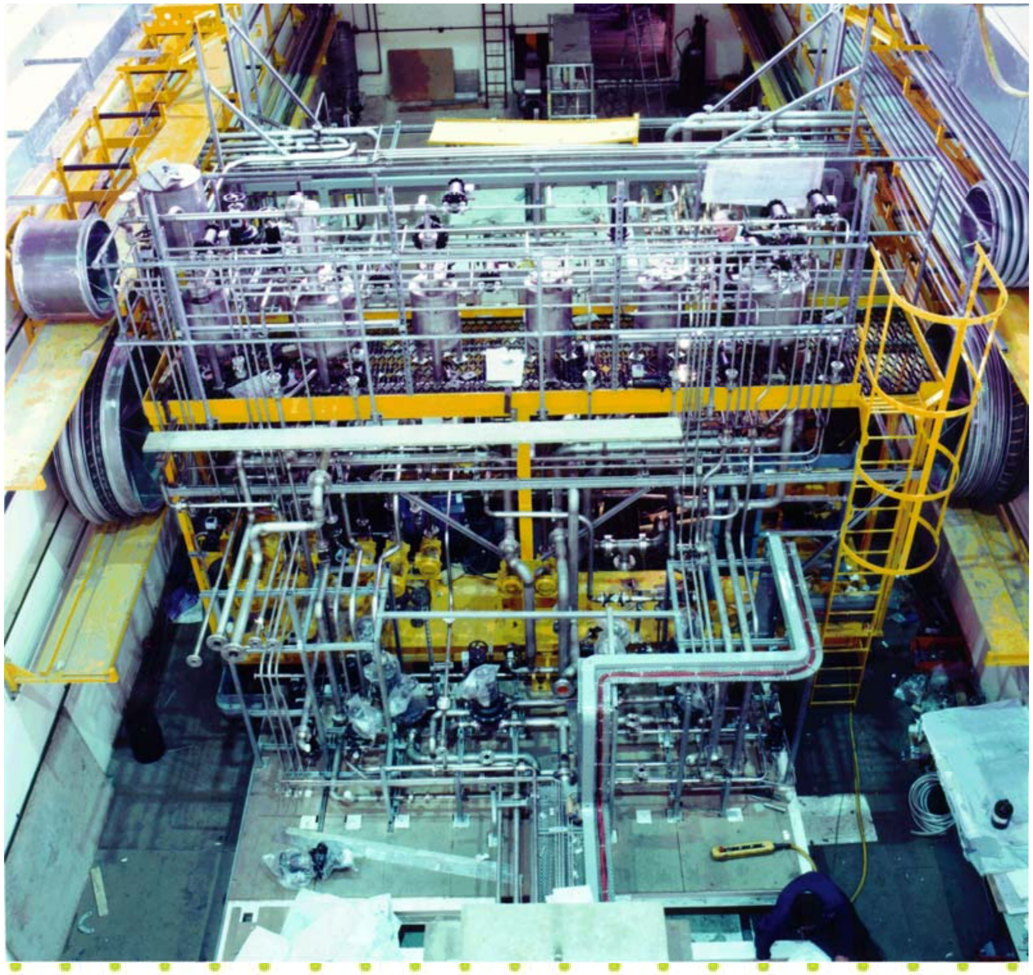


Cost Basis

- **100k$ vessel (Walz)**
- **300k£ ISIS plumbing**
- **150k£ ISIS controls & monitoring**

Total $1M each

50kW 3-loop 2006 Rad Water Cooling for ISIS Neutron Spallation Targets



Reality Check

12-2006 US Quotes (Walz)

- **18MW Parallel plate heat exchanger (API)**

  (gasketed: request for welded quote requested)
  - 2.5m x 1.2m x 3.5m
- **200HP, 1150gpm pumps w/ motors (4/6 needed)**

  each
  - 1m x 3m x 1m
- **Schedule 12 Stainless Pipe, 316L , Installed**
  -

D&C group will continue a self-designed & costed effort which we hope will lower space requirements and overall cost

Collimators, Absorbers & Beam Stoppers
Basis of Estimate

Long Collimator costs

- based on SLAC sector 30 linac collimator costs=
  - 1991 price escalated to 2006 =
  - FFTB mover + fixed base

All other dump & cooling system costs derive from Dieter Walz's 40 years experience

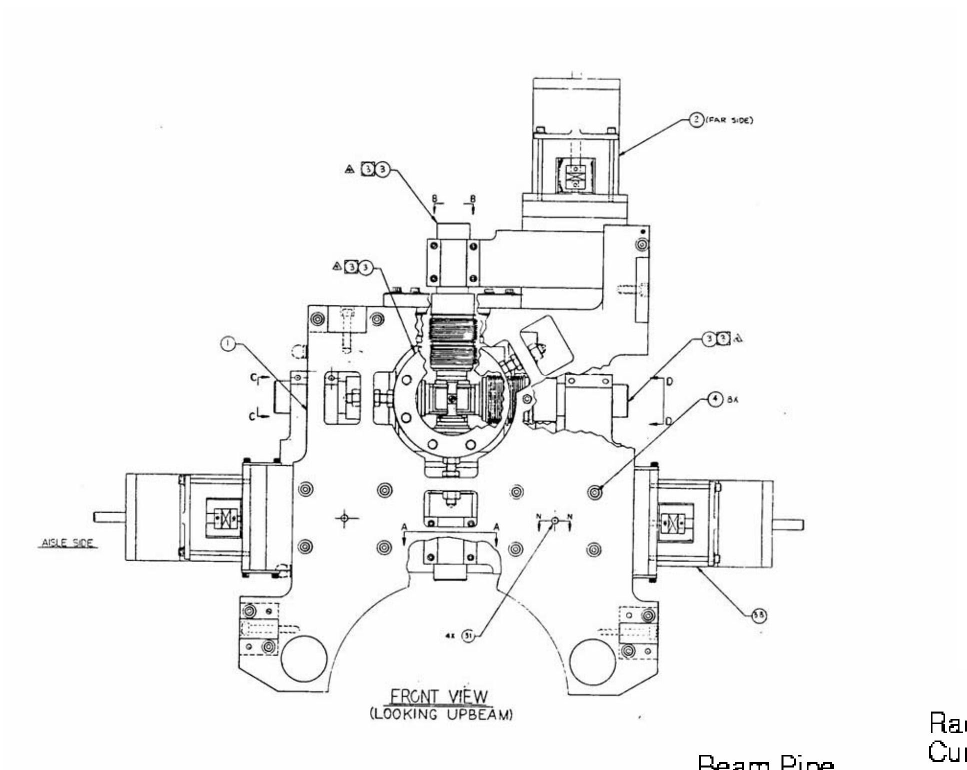
- All peripheral cooled devices connect directly to LCW: No plumbing expense

Short Be-tapered spoilers

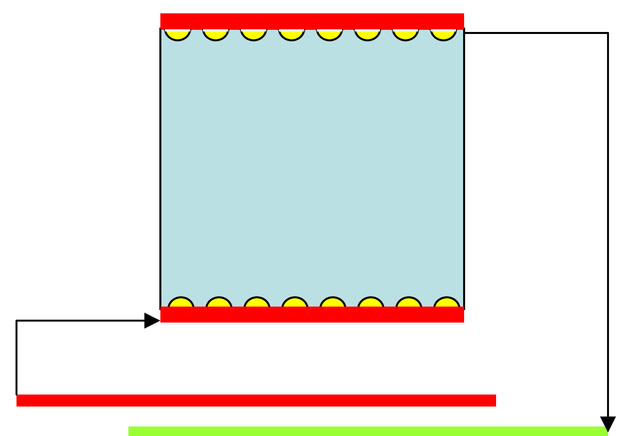
- basic unit cost per 2-jaw system

Collimator Cartoons

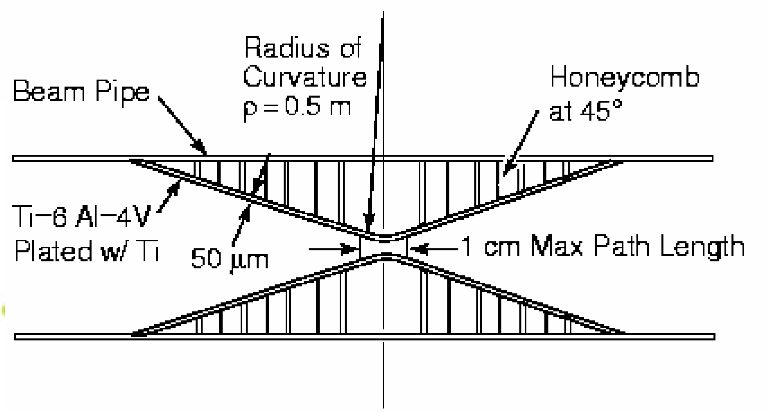
SLC Sector 30 4-Jaw collimator



50cm Diameter x 50cm long Peripherally-cooled Solid Cu or Aluminum Dump (before local shielding added)

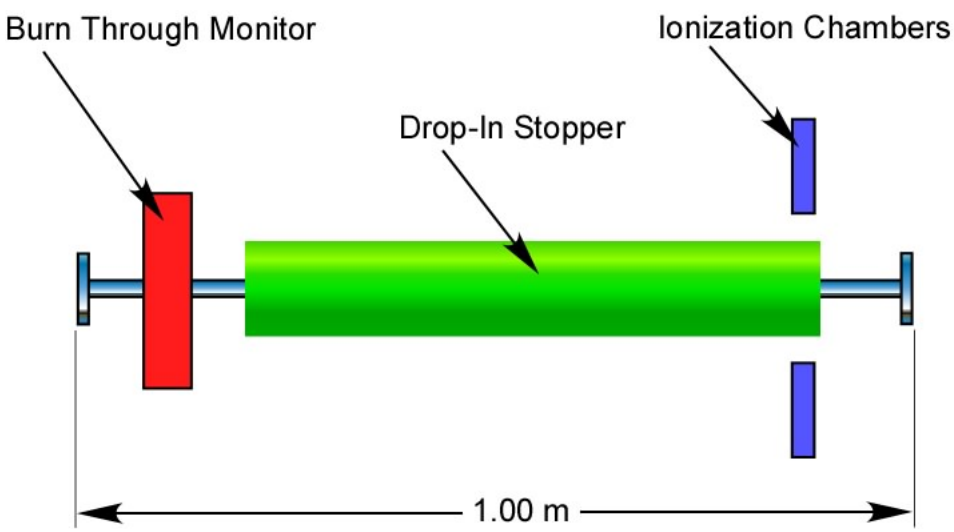


LCW

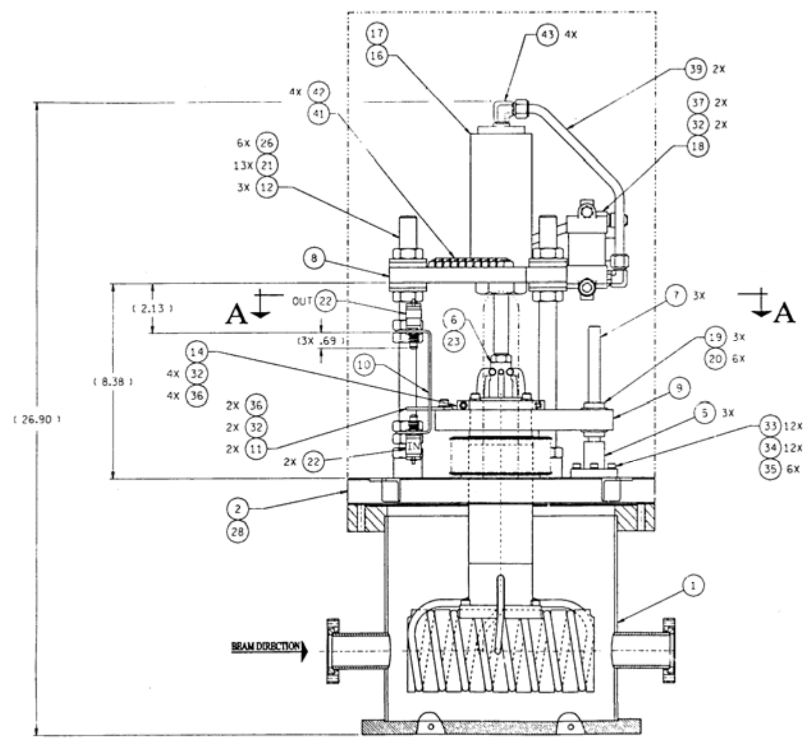


Tapered NLC Spoilers & Absorbers

Stopper Cartoons



JC Sheppard Stopper



PEP-II Stopper

Cost Methodology

Economy of scale factor for each device type

- **Learning curve not applied**
- **Minimum=60% for 72 H_2O-cooled protection collimators**

ED&I baseline set to 25% and adjusted upward for difficult one-off devices

- **NOT estimated bottom's up except for 18MW dump**
  - even this was "constrained" to fit 25% "rule"

Cost Uncertainty

Fitchner + RAL estimate for 18MW dump differ from a Walz estimate by x2

ISIS 50KW water system seems 10x SLAC experience

Also concerned that CF&S related costs will dominate total D&C related costs

- **beam line plus civil housing drawings do not exist except for BDS**
- **tighter hand shake required**

Largest cost risks:

- **items falling through cracks**
  - installation/replacement model
- **implications from technical risk of difficult devices or regulatory issues that we have not begun to consider**

No real effort yet to estimate accurately ED&I, economies of scale or required site resources

Summary & Future

International team agreed to today's numbers and will diligently work for an ILC design & cost

- **Manpower requested from US manager in current US FY'07 budget discussion**
- **UK personnel for engineering design studies & R&D less clear (my understanding)**

There is no reason baseline design can't be adequately engineered and costed for the EDR

R&D to reduce risk will be discussed Saturday.

Recent Dump Documentation (in ILCDOC, naturally)

1. **On the Possibility of Adding Boron to the ILC Main Water Dump System** / Walz, D. [ILC-NOTE-2007-031]
   The suggestion that boron be added to the water of the ILC Main Dump in order to limit the number of neutrons backscattered to the detector is examined. [...] Fulltext
   Detailed record - Similar records
2. **Radiolysis in the ILC Main Beam Dumps** / Walz, D. [ILC-NOTE-2007-030]
   Modest amounts of catalyst will remove H2 from the beam dump water system at the atmospheric pressure surge tank. [...] Fulltext
   Detailed record - Similar records
3. **Pressure Vessel and Shockwave Issues in the ILC Main Beam Dumps** / Walz, D. [ILC-NOTE-2007-029]
   The bunch structure of the ILC, the asymmetric location of the beam relative to the dump axis, the speed of water flow and the speed of sound all contribute to keep the ILC main water beam dumps well beyond the region where pressure wave induced shocks could damage the dump or cause and explosion, even at modest vessel wall thicknesses of 0. [...] Fulltext
   Detailed record - Similar records
4. **Radioisotope Production and Management in the ILC Main Beam Dumps** / Walz, D [ILC-NOTE-2007-028]
   Radioisotope production and management in the 18MW ILC main charged particle beam dumps are described. [...] Fulltext
   Detailed record - Similar records
5. **Design Requirements for the Undulator Photon Dump** / Keller, L; Markiewicz, T; Walz, D [ILC-NOTE-2007-015]
   This note describes the calculations leading to the design specifications and location of the photon dump in the ILC positron source system. [...] Fulltext
   Detailed record - Similar records