



ILC Power Coupler – Fabrication & Cost
CPI Beverly Microwave Division
November 12, 2013



Agenda



- CPI experience with Power Couplers
- CPI Power Couplers
- Key coupler process technology
- Analysis of Coupler fabrication difficulties
- Analysis of Coupler specification difficulties
- What can we do to provide the best product?
 - What can science labs do?
 - Procurement questions for ILC community
- Cost comparison of STF vs. TTF-III/XFEL
 - Design style comparison
 - Design part count
 - Rough cost comparison of STF and TTF couplers





CPI Experience with Power Couplers



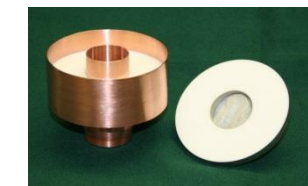
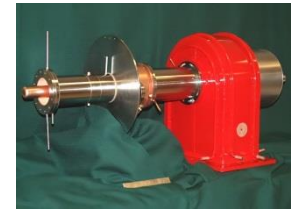
Power Couplers manufactured at CPI



Cylindrical Window Designs



Coax Planar Windows





CPI Power Couplers



Model	Accelerator Application	Freq. (MHz)	Peak and Avg. Power (kW)	Status
VWP 3097	IFMIF Prototype (CEA Saclay)	175	200 and 200	Delivered 2
VWP 3098	FRIB Prototype (MSU)	322	14 and 14	Delivered 2
VWP3107	NSLSII Upgrade	500	500 and 500	Delivered 1
VWP 3070 VWP1185/86	Free Electron Laser Injector (AES, BNL) Free Electron Laser Injector (AES, JLAB)	704 748	1000 and 1000 350 and 350	Delivered 2 Delivered 4
VWP 1133, VWP 1162	SNS (JLAB) and RIA (MSU)	805	1000 and 60	Delivered 8
VWP 3049 (TTF3)	Tesla Test Facility (CNRS Orsay, DESY), ILC (Fermi, SLAC), and Triumf	1300	1110 and 7.2	Delivered 114
VWP 3032 VWP 3069	ERL Injector Cavity (Cornell and Triumf) ERL Injector (Daresbury)	1300 1300	75 and 75 75 and 75	Delivered 14 Delivered 2
VWP3113	SRF Accelerator (Peking University)	1300	60 and 60	Delivering 4
VWP 3108	Energy Recovery Linac (Cornell)	1300	10 and 10	Delivered 2
VWP 3088	XFEL Third Harmonic Cavity (Fermi, DESY)	3900	45 and 12.5	Delivered 12 Delivering 18



Key Coupler Process Technologies



- CPI has been manufacturing power couplers for 12 years
- CPI's key process technologies qualified by DESY, CNRS-Orsay, and Cornell have been in continuous use for 10 years
- High RRR-copper plating of stainless steel – TTF3 specification met
 - Thickness and RRR carefully controlled
- TiN coating of alumina windows for multipactor suppression – TTF3 specification met
 - Thickness and composition carefully controlled
 - Secondary yield less than unity
- E-beam welding of copper cylinders
 - 100% penetration depth required
 - Complex fixtures required to protect ceramic surfaces from spattered material
- TIG welding of stainless steel components
- Vacuum brazing
 - Metal to metal seals
 - Stainless steel to stainless steel
 - Copper to stainless steel
 - Ceramic to metal joints
 - Alumina to copper



Analysis of Fabrication Difficulties with TTF-III



Fabrication Cost Drivers

- EB Welding of Copper Collars (Adds ~10% to the overall product cost)
 - Requires internal masks and complex support fixtures
 - Tests have been run to replace this process with a modified TIG weld process to reduced manufacturing costs
- High RRR Copper Plating (Adds ~ 10% - 20% to the overall product costs)
 - Requires significant control/ sampling program
- TiN coating (Adds ~5% to the overall product cost)
 - Requires significant control/ sampling program (Thickness , Composition)
- Machined Part Costs (Cost of Machined Parts is typically 1/3 of the factory cost)
 - Raw material cost, Geometric complexity, Tolerances, Part size,

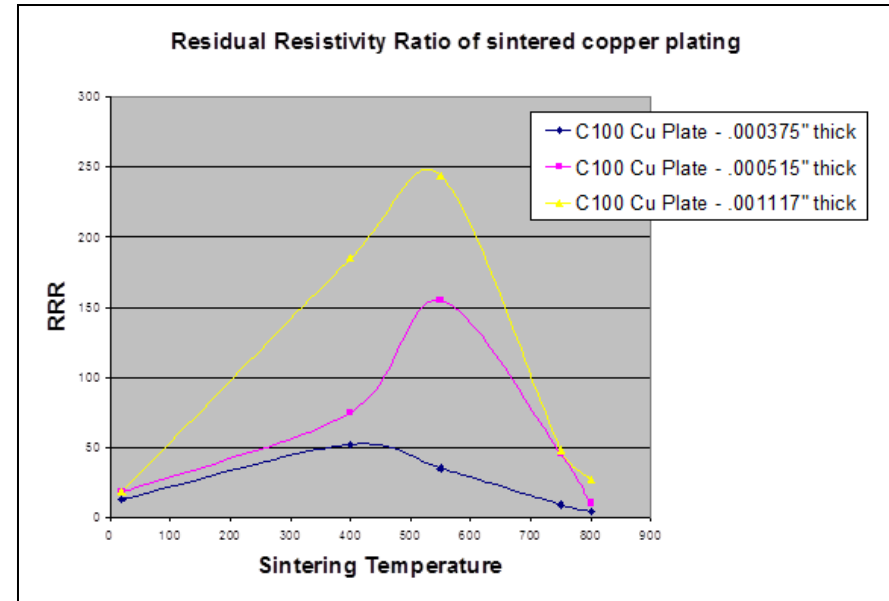


Analysis of Fabrication Difficulties



Fabrication Cost Drivers

- Brazing
 - Least expensive and usually the best overall joining process, however, RRR value of copper plated parts deteriorates if plated prior to the braze.
 - TTF-III Brazed Couplers
 - A pair of brazed TTF-III Couplers was produced many years ago, with the copper plating applied after the braze, as part of another experiment
- TIG Welding
 - Efficient manufacturing process, but requires proper joint design, fixturing, and post cleaning. Surface smoothness can be difficult to assure.
- Final Inspection by Quality Assurance adds between 2% - 4% to product cost
 - Specify based on functional requirements
 - Mechanical measurements, boroscope, visual
 - Automated inspection decreases costs





Analysis of Specification Difficulties



Specifications that increase cost or manufacturing difficulties

- Operational requirements will dictate design and costs
 - A simple single window coupler may cost 1/3 of the price of a complicated double window design
 - Size of coupler significantly affects costs
- Final Cleaning by Vendor
 - Elimination of redundant cleaning by vendor and user will have minor cost savings (2%)
 - Cleaning tougher on STF due to choke design
- Material Specifications
 - Unique material specifications that are tough to procure adds cost, risk, and uncertainty
 - Examples:
 - 316LN for XFEL coupler with three different material specifications from UNS, CERN, DESY
 - Unique hardware material specified for XFEL (silicon bronze , aluminum)
 - European material specifications may be tough to procure in US



Analysis of Specification Difficulties



Specifications that increase cost or manufacturing difficulties

- High RRR Copper plating quality
 - Requirements are costly
 - The initial TTF-III qualification of plating by DESY/CNRS/LAL involved:
 - 30+ Engineering test samples at CPI to optimize process prior to providing customer samples
 - An initial rejection of our first samples
 - An improvement program
 - Customer approval of next samples with additional work done after approval
 - Thickness uniformity and RRR specifications are the most difficult to meet but can be met with proper manufacturing controls from a well-qualified process
 - Requires significant control / sampling program to maintain stringent quality
 - Thickness uniformity - Periodic and process measurements
 - RRR value - Periodic measurements
 - Micro Thickness Uniformity - Periodic metallurgic sample preparation
 - Adhesion - Periodic LN2 Shock, ultrasonic, or mechanical stress tests
 - Surface Finish - Periodic measurements of samples
 - Cleanliness - In process inspection
 - Oxidation - In process inspection



Analysis of Specification Difficulties



Specifications that increase cost or manufacturing difficulties

- Final QC measurement requirements
 - Difficulty and cost depend on time and complexity
- TiN Coating Quality
 - Cost related to complexity of specification and geometry
- Unique testing requirements add to cost
 - Outgassing rate, RGA, material tests, Auger- Edax of coatings, thermal shock, vibration, pressure/flow rate, etc.
- Shipping requirements should be properly specified and reviewed with vendors beforehand
 - Contractually specify that shipping issues are the responsibility of the vendor



How Do We Provide the Best Product



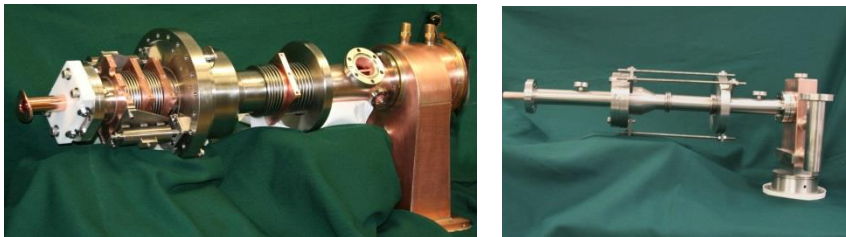
- What can Scientific Labs do to help
 - Promote prototype test programs - (Prototypes, Cost reductions, Pre-production, Production)
 - Procure ILC couplers from qualified vendors with pre-qualified processes
 - Work with industry to analyze designs, and processes and provide test result & feedback
 - Choosing design(s), and reduce risk, based on a proven demonstrations of:
 - Electrical performance (Insertion Loss, VSWR, Arcing, Multipactor ,etc.)
 - Vacuum, thermal and mechanical performance
 - Life, Reliability (MTBF)
- Procurement Questions for ILC community:
 - If the TTF-III design is chosen, will Toshiba and others be given the design drawings, and would they be willing to build the TTF design?
 - If the STF design is chosen will other participants be given the STF design to manufacture, or be given the opportunity to build a similar design?
 - Alternatively, will the functional requirements be specified, leaving the manufacturer to choose an appropriate design, which best matches their core manufacturing competencies?



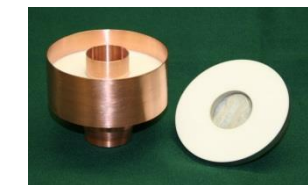
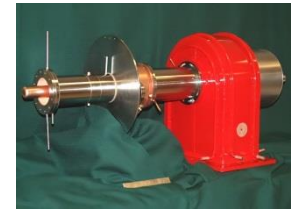
Comparison of Coupler Designs



CPI has manufacturing experience with both the TTF style and planar window style of Power Couplers, including cost related issues



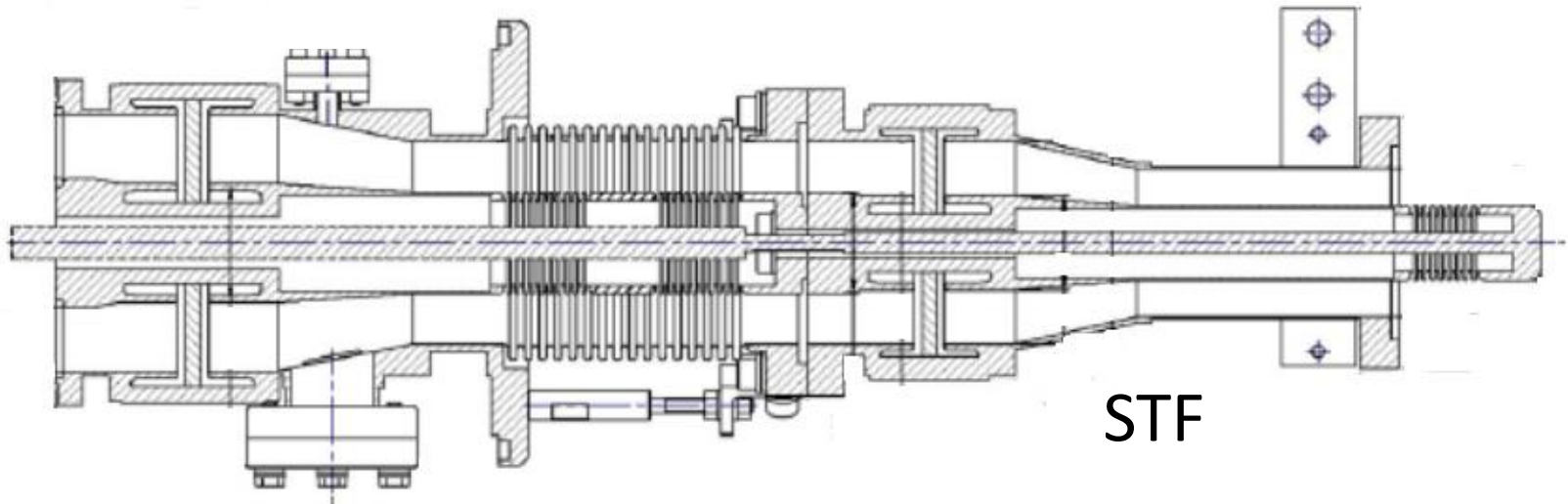
Cylindrical Window Designs



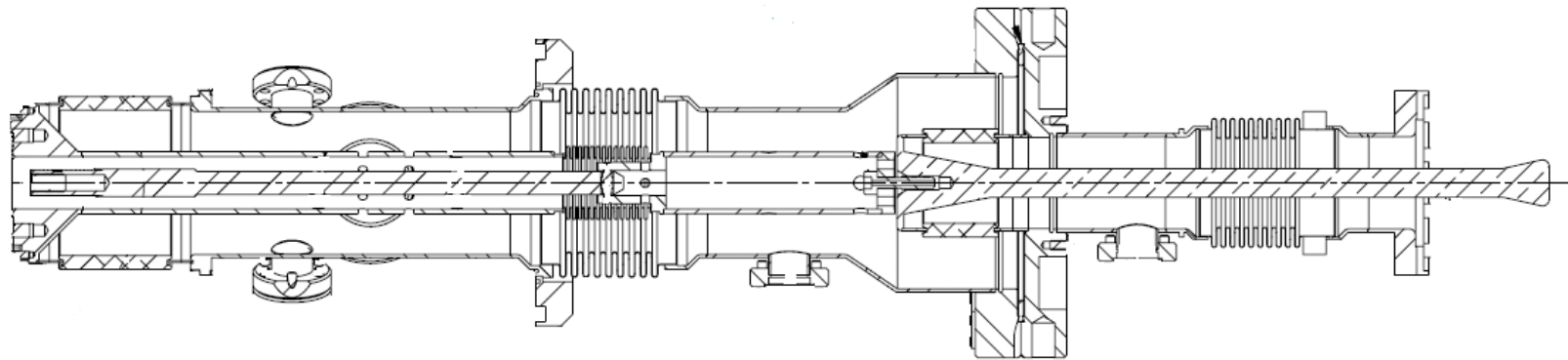
Coax Planar Windows



Design Comparison on Same Scale



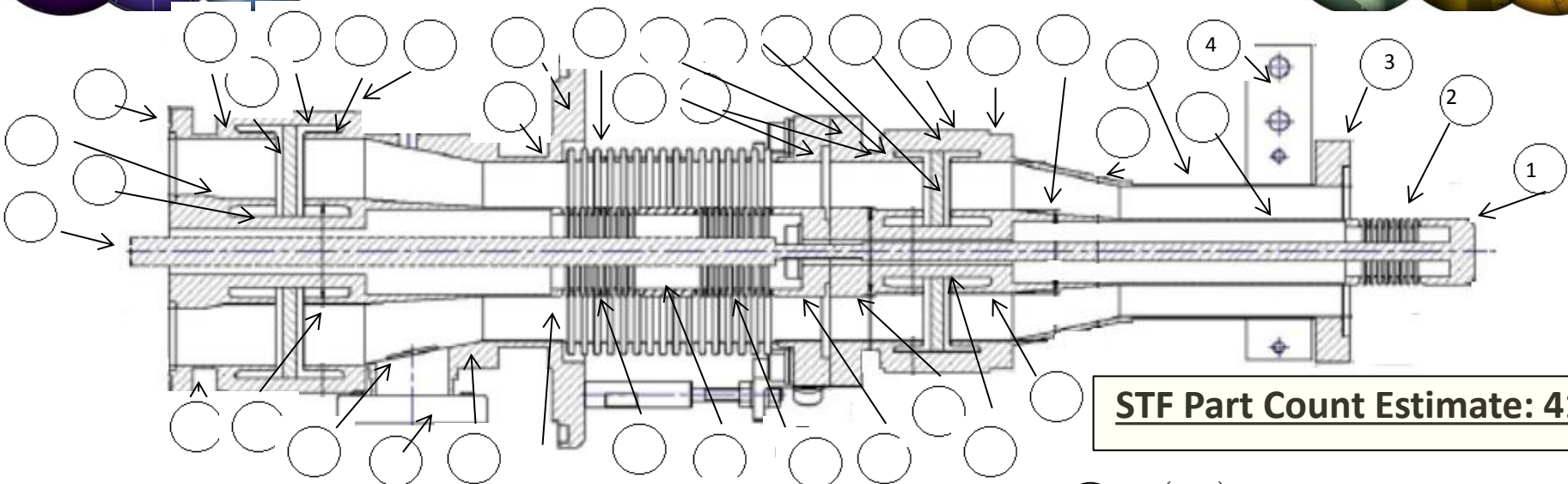
STF



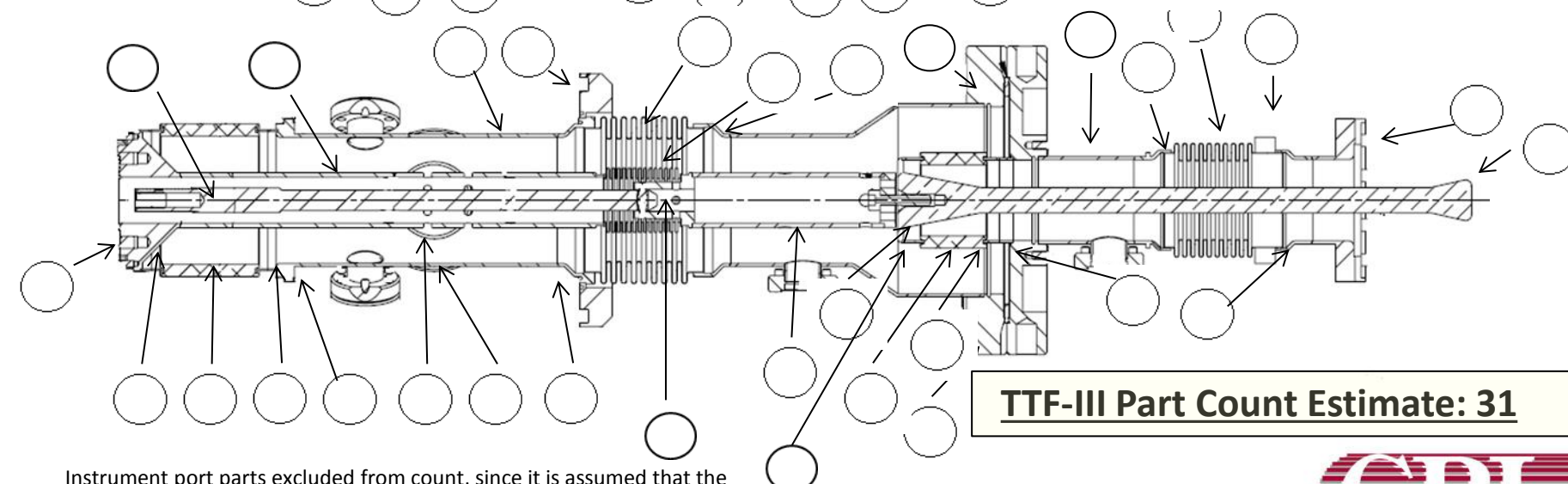
TTF-III



Cost Comparison (Material Part Count)



STF Part Count Estimate: 41



TTF-III Part Count Estimate: 31

Instrument port parts excluded from count, since it is assumed that the number of ports will be equal in both designs per ILC requirement



Rough Cost Comparison - Relative to TTF-III



Basis of Cost Estimate	TTF-III & XFEL	STF
Material Part Cost: <ul style="list-style-type: none"> Raw material cost is based on weight and therefore proportional to (diameter)² Based in same part length Machining cost is also proportional to (diameter)² 	1	$(STF \text{ Part Count}/TTF \text{ Part Count}) \times (\text{Diameter ratio})^2$ $(41/31)(1.3)^2 = 2.24 \text{ times more expensive than TTF}$
Labor Cost: <ul style="list-style-type: none"> Labor cost is related to number of parts handled and size (diameter) Processing adds cost relative to diameter 	1	$(STF \text{ Part Count}/TTF \text{ Part Count}) \times (\text{Diameter ratio})$ $(41/31)(1.3) = 1.72 \text{ times more expensive than TTF}$
Other Factors:	<ul style="list-style-type: none"> EB –Welding may add a premium of 10% 	<ul style="list-style-type: none"> TiN coating planar coax windows may add a premium of 5% Brazing of copper plated parts does not add cost, compared to plating entire assembly, but may result in excessive heat loss, due to RRR reduction
Overall Cost: <ul style="list-style-type: none"> Estimate: Cost = Material & Labor weighted equally 		$(\text{Material Cost} + \text{Labor Cost})/2 \times .95 = 1.9$ <p>The cost to produce an STF Coupler is expected to be roughly twice the cost of the TTF-III</p>