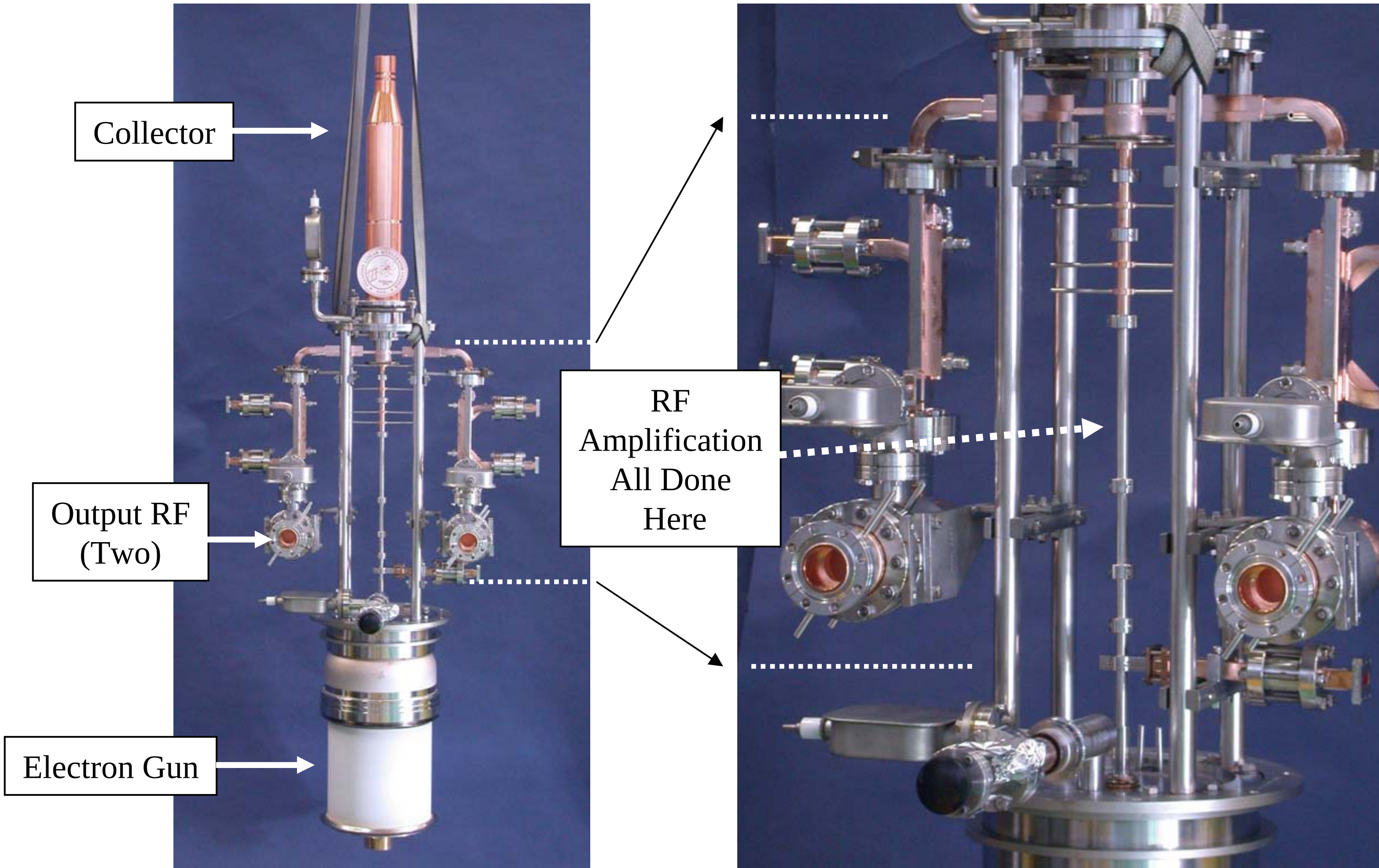
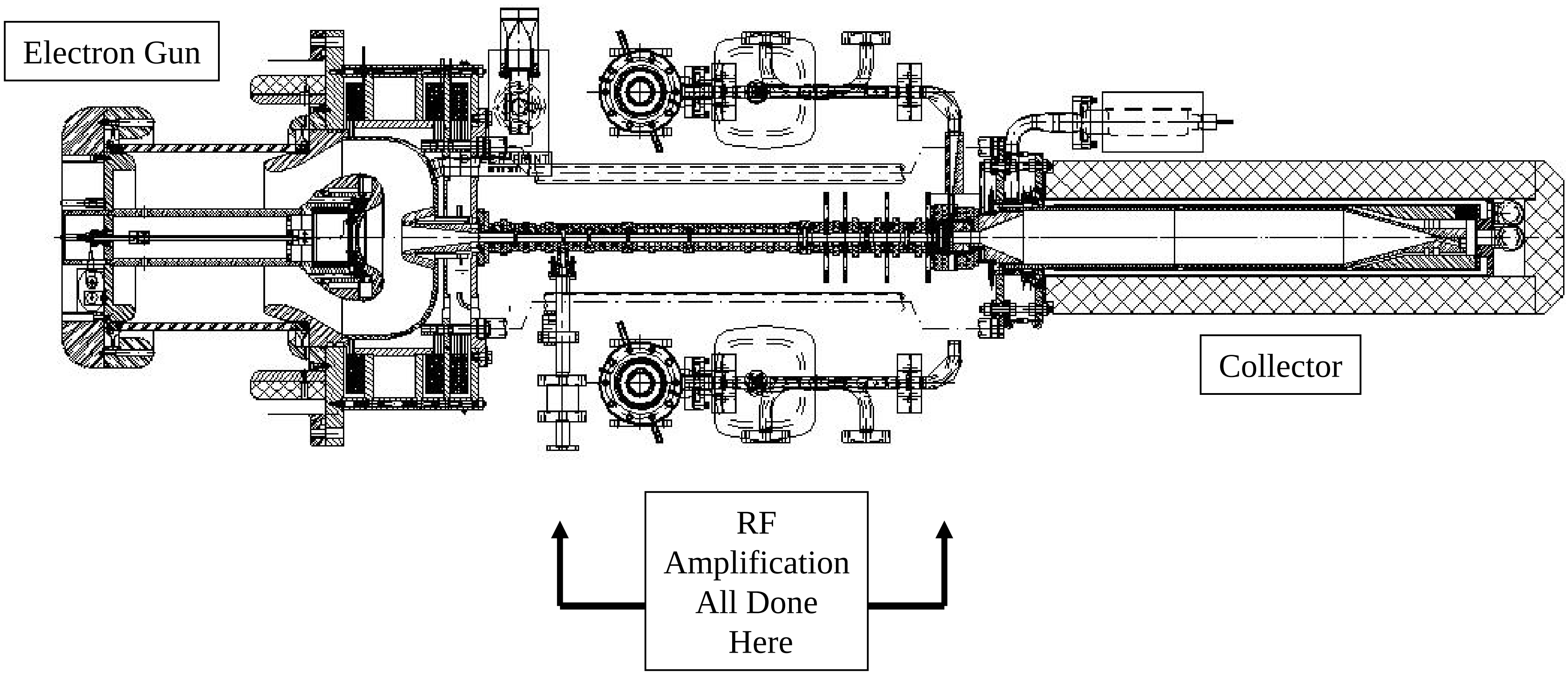
NLC Klystron Development

October 2, 2003

Naked 75 MW Klystron
(No Magnets, No Lead, No Wires, No Water)



75XP-3 Klystron Cross-Section



General Klystron Approach

- Base Program Must Provide a Usable Device with Little Advance Notice
  - Lack of a Viable Device Could Indicate NLC is "Not Ready"
  - Need to Obtain Industrial Suppliers Makes for a Long Lead-Time
- Undertake Smaller R&D Efforts on More Novel Devices
  - e.g. Multi-Beam Klystrons; Sheet-Beam Klystrons
- Work on Average Power, Not Peak Power
  - Historically Had Poor Results Chasing Peak Power
  - Increasing Peak Power Stresses Most All Areas of Tube
  - Average Power Stresses Thermal Issues Only in Just a Few Places – Generally Well-Understood and Tractable
    - Therefore, Lowest Relative Risk

Fundamental Background

- Klystron is Part of the Power Conversion Cycle
  - Converts Pulsed DC Power to Pulsed RF Power
- Large Quantity (4,464) Requires Either Permanent Magnet or SC Magnet Focussing
  - 110 MW if Use Electromagnet Solenoids
- Lowest Overall Collider Cost and Highest Reliability from Smallest Quantity of Klystrons
  - However, Peak Power in Single Device May be Limited to 75 MW
  - So, Extend the Klystron Pulse Width and "Store" the Power
    - Acceptably Efficient Systems Can Store the Power by Up to a Factor of Eight
      - At Snowmass, 1996 This Factor Was Five
      - At Snowmass, 2001 This Factor Was Eight
      - It is Now Four

Klystron Specification

- Pulse Width
  - With 270 ns of Bunch Train Length, 115 ns of Fill Time, and 15 ns to Switch Phase, Needed Pulse Width is 400 ns
  - Using a System that Can Delay (Compress) the Power by a Factor of Four Puts the Klystron Pulse at 4 x 400 ns = 1.6 μsecs
- Peak Power
  - Was 50 MW at Snowmass, 1996; Now 75 MW
    - Pretty Much Demonstrated That 100 MW is Impossible
- Repetition Rate
  - Set by Accelerator Physics – 120 Hz
- Other
  - Average Power is 14,400 W (Product of the Above)
  - Efficiency Set to 55% (Highest Feasible With Voltage at 500 kV)
  - Frequency is Four Times SLC Frequency – 11,424 MHz

Degree of Difficulty

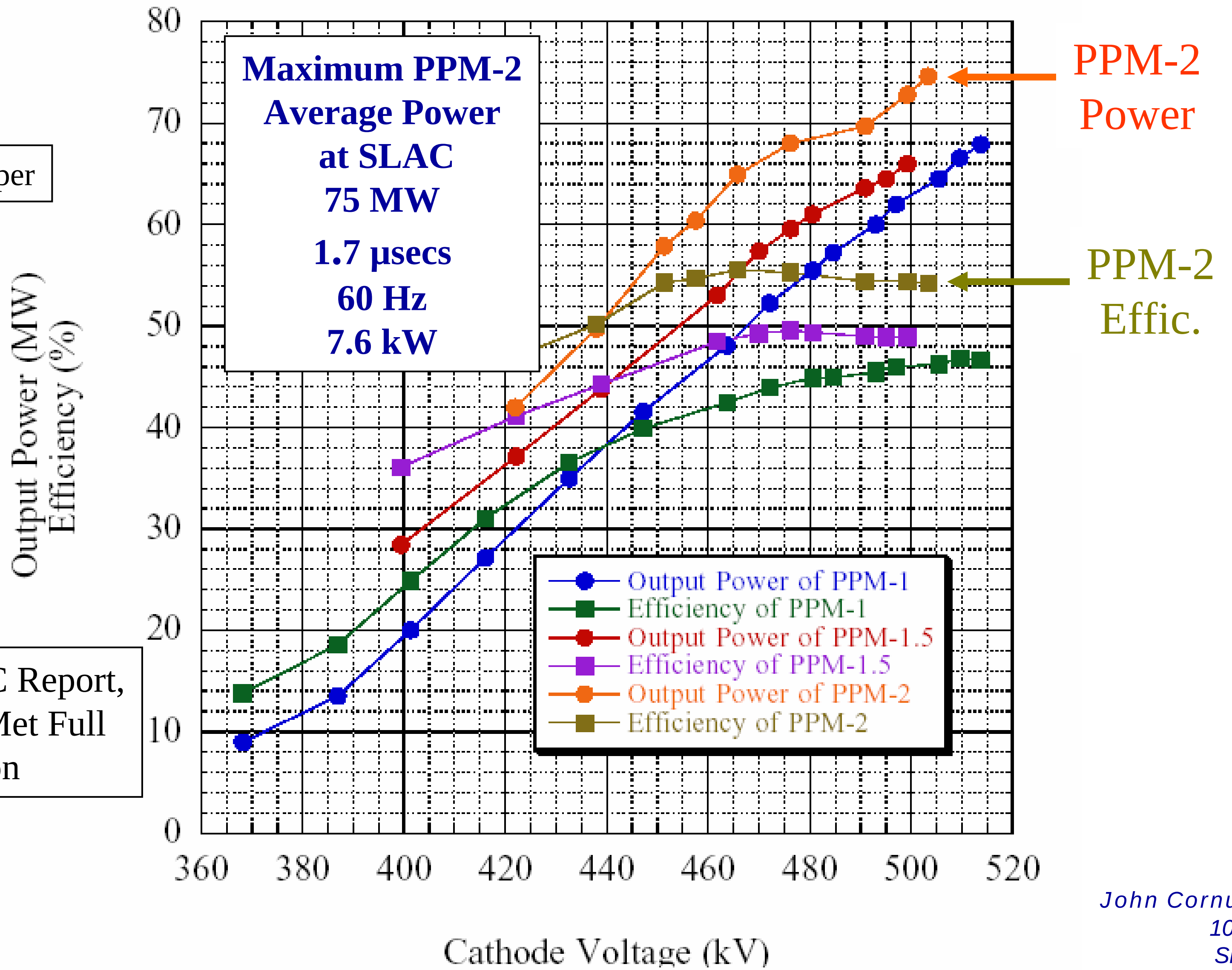
- Microwave Tube Difficulty Scales as $P_{ave}f^2$
  - 1.2 MW B-Factory Klystron at 476 MHz Scales to 2 kW
  - 65 MW S-Band SLC Linac Klystron Scales to 3 kW
- These Are Both Solenoid-Focussed Tubes
  - Solenoid to PPM Approximately Factor of Four in Difficulty
  - These Two Tubes Scale to Under One kW; 14.4 kW are Required
- Conclusion
  - This Tube on Paper is Beyond the State of the Art by Over a Decade
- Other Factors
  - For Maximum Range, All High Power Search Radars Using Klystrons Run at 3 GHz or Below
    - i.e. No Industry Experience at 11.424 GHz

X-Band Klystron Overview

- TRC Requirement:
  - No R1 Requirement (KEK PPM-2 Klystron is Existence Proof)
  - R2 Requirement
    - Fully-Tested at Full Repetition Rate
    - Tested as Part of Linac Sub-Unit Test
- Tubes to Date:
  - Four at KEK/Toshiba, Five at SLAC, Two Industrial
  - Built Over a Span of Six Years
  - Two Tubes Now at Test at SLAC
  - One Tube to Date That Meets Spec (All Key Parameters Concurrently)
- Tube Specification Will Change Over Time
  - Major Factors are Perceived Difficulty, Date Demonstration is Needed, Status of the Competition, Cost versus Risk Tradeoff

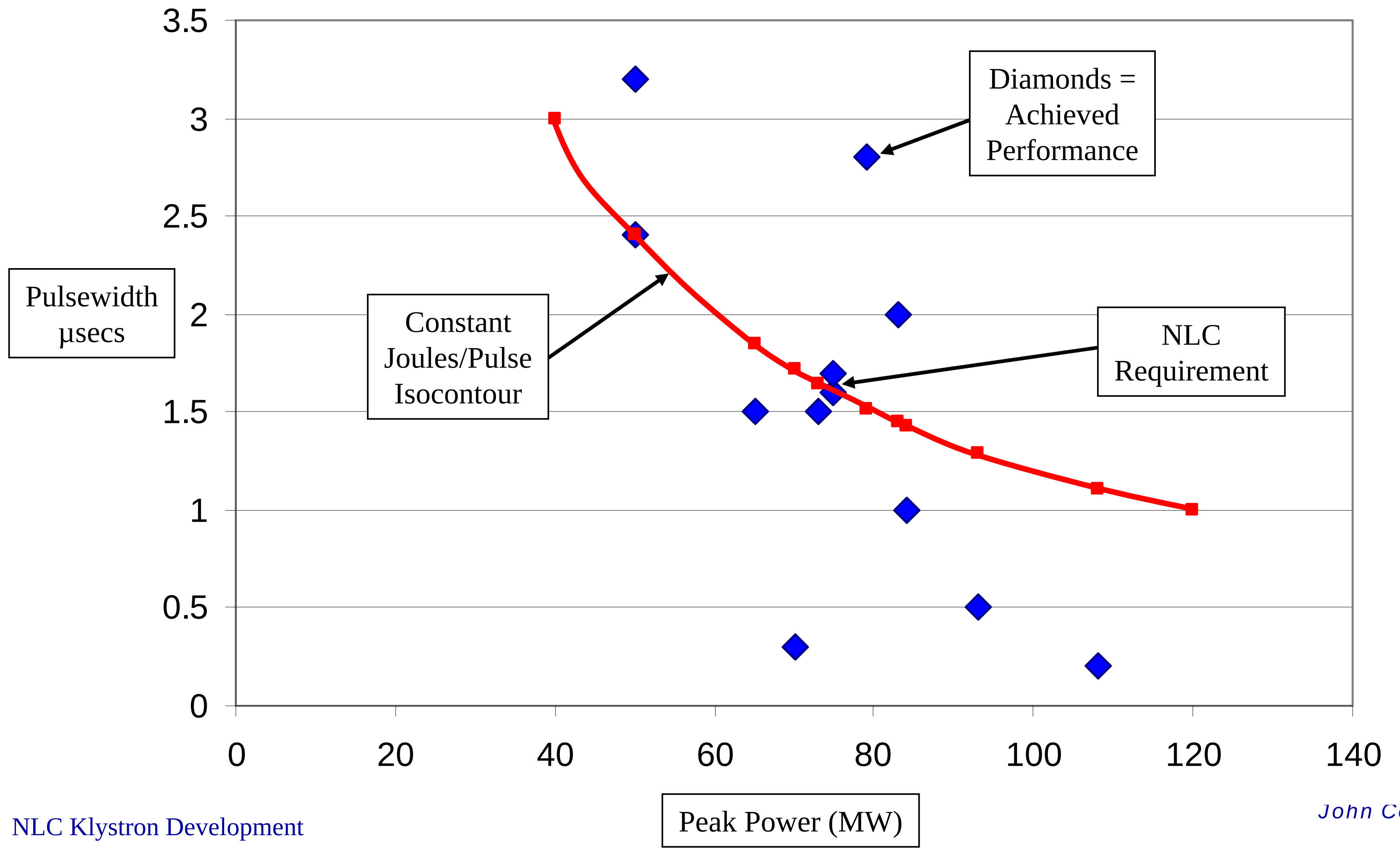
KEK Klystron Performance (R1 Requirement for TRC)

Data from KEK Paper

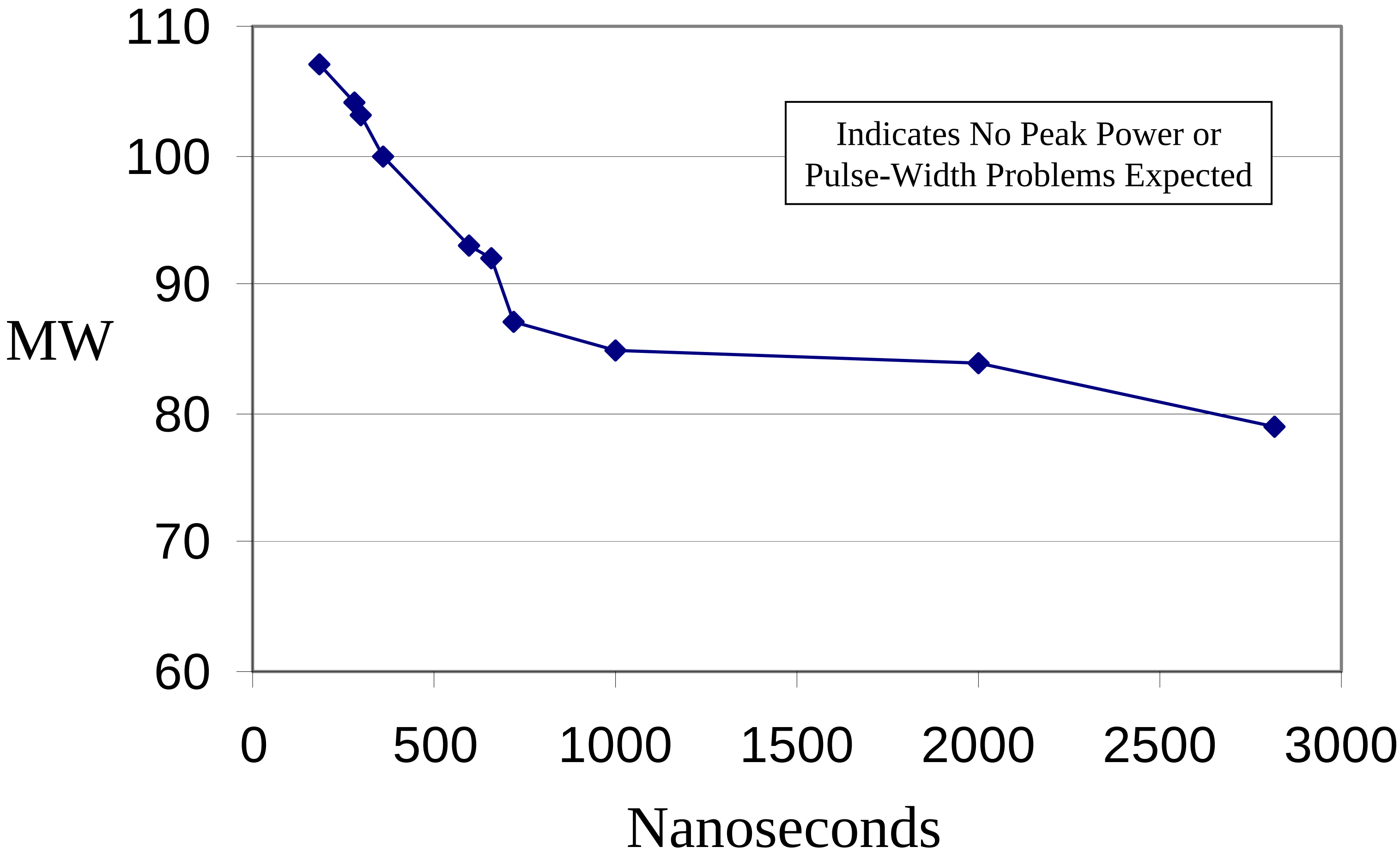


Subsequent to TRC Report, SLAC Klystron Met Full Specification

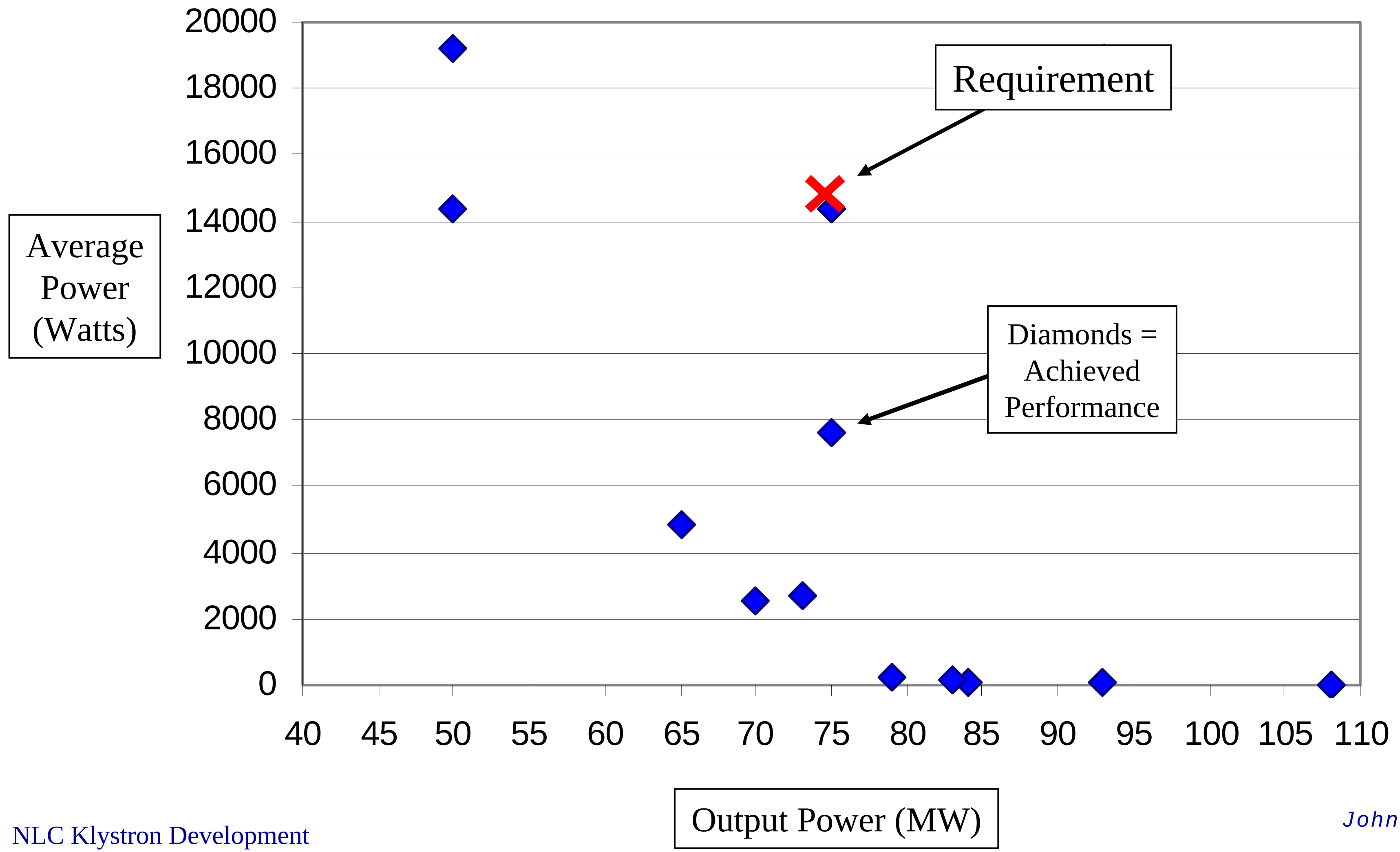
PPM Klystron Performance
Joules per Pulse/Pulse-Width



Peak Power vs. Pulse-Width
(SLAC 75XP1 Klystron)



PPM Klystron Performance
Average Power



Current Status
All Usable X-Band PPM Klystrons

- KEK/Toshiba Tubes
  - PPM-2 at Test at SLAC
    - Maximum of 75 MW, 1.7 μsecs, 60 Hz
  - PPM-4 Having Windows Replaced
    - Did 75 MW, 1.6 μsecs, 50 Hz (Modulator Limit) at KEK
  - PPM-2 and PPM-4 are Effectively Identical
  - PPM-5 (New Tube) Due in December
- SLAC Tubes
  - XP3-3 at Test
    - Maximum of 75 MW, 1.6 μsecs, 120 Hz (Full Requirement)
  - XP3-4 to Begin Test in December
  - XP4 to Begin Test in May, 2004
  - XP3-4 and XP4 Will Have Integral Polepiece Bodies and Will be Nearly Identical

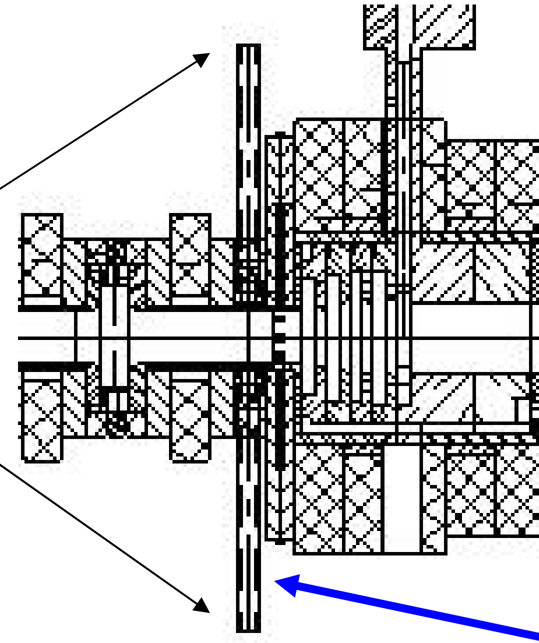
Status of Tubes at Test

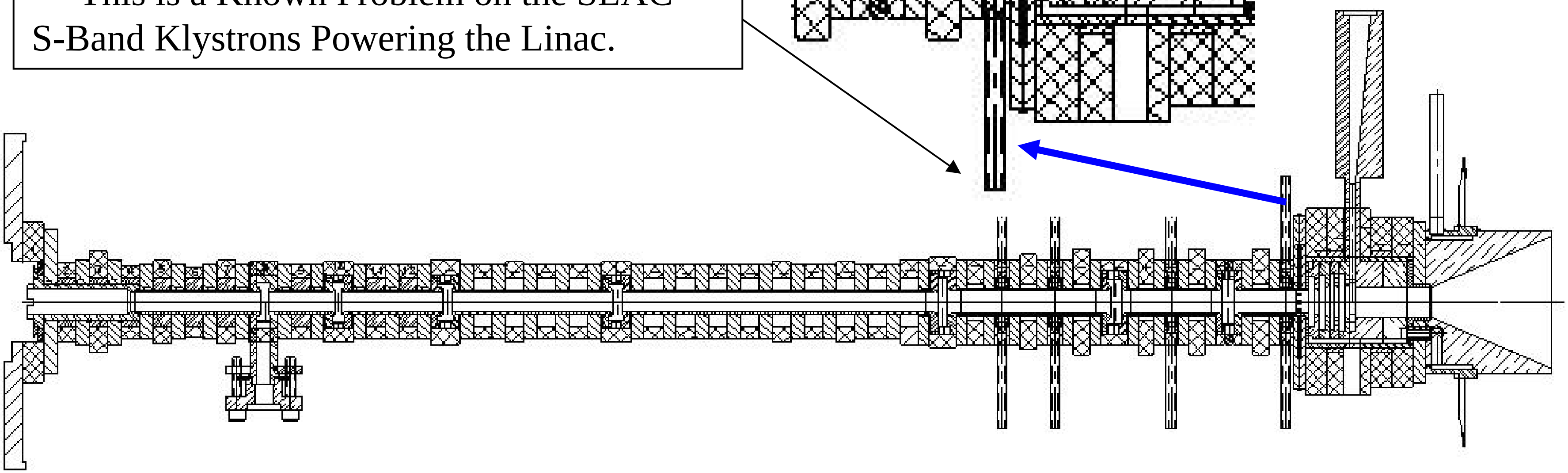
- KEK PPM-2 is Processing Very Slowly
  - Very Slow to Initially Process
    - Much Work Done to Protect Output Windows (Generic Issue)
  - Electron Gun Now Having High Voltage Ticks/Breakdowns
    - Vacuum in Gun Region Degrading
    - Cathode Emission Degrading
    - Recovery Uncertain
- XP3-3 Has Periodic Break-Up/Tearing in Output Power Pulse
  - Being Re-Processed After Attempted Repair of the Above
  - Now About Half-Way Back (50 MW at 1.6 μsecs)
  - Problem Diminished But Still Present
  - May be Further Reduced/Eliminated With Processing – Need More Time

XP3-3 Area of Concern
(More Than You Want to Know)

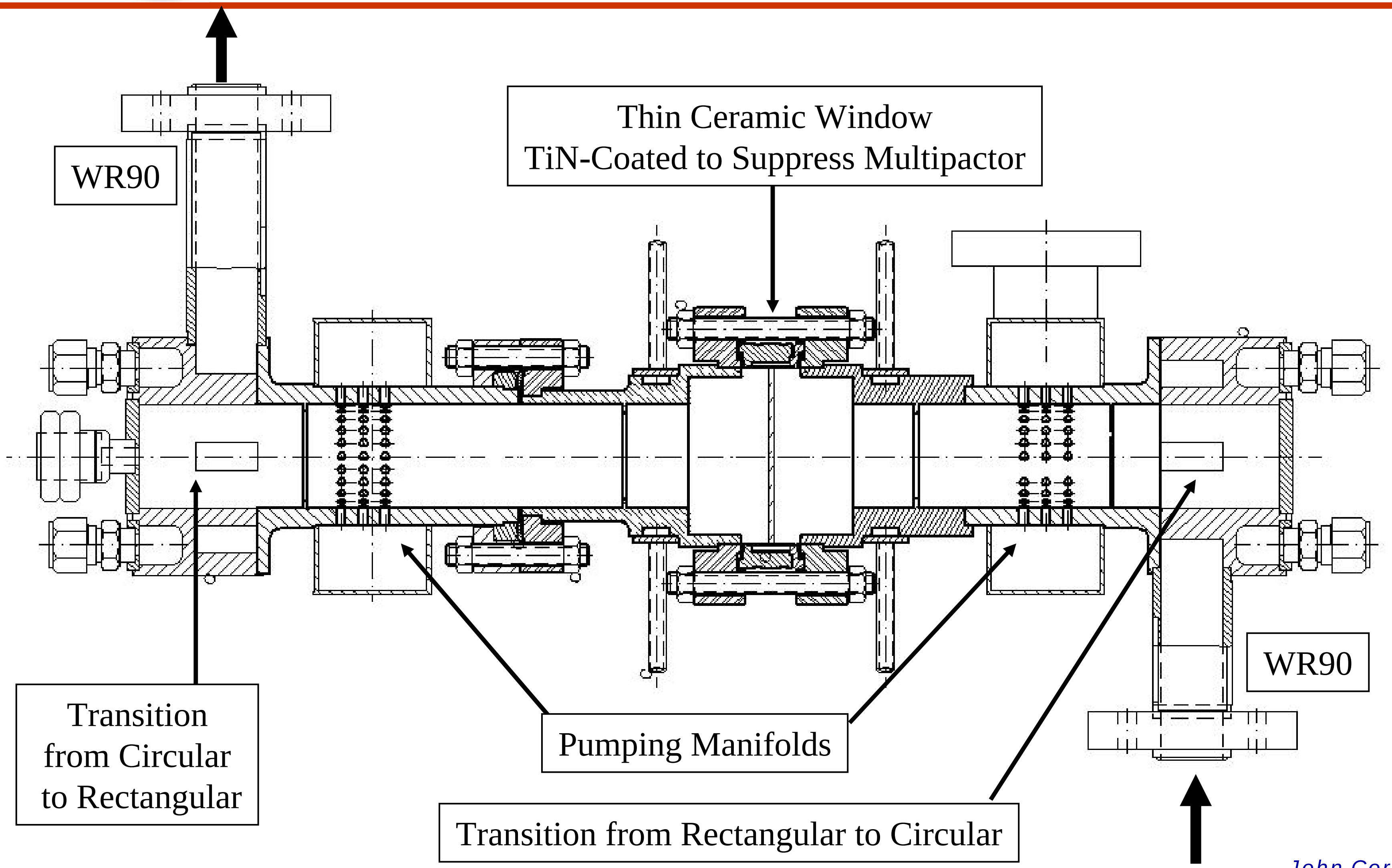
This Seal is Welded on the Outside Diameter. It May Have Opened in "Z" Enough to Allow Electric Fields to Enter and to Cause Arcing. The Arcing Often Does Not Produce Gas.

This is a Known Problem on the SLAC S-Band Klystrons Powering the Linac.





PPM-2 Area of Concern
(Also More Than You Want to Know)



Conclusions

- Any Conclusions are Tentative at This Stage, But -
- Although Device is Well-Beyond State of the Art
  - All Key Parameters Have Been Met
  - Performance Beyond That Required Has Been Demonstrated
  - Tubes From Industry Already Work
  - Problems That Appear Are Not Related to State of the Art
    - i.e. Tubes Do Not Seem to be on the Edge of a Technical Precipice
    - Toshiba Tubes Have Vulnerable Windows But SLAC Does Not
    - Holding Off Voltage in a Gun is Just Good Design and Good Manufacturing Practice
    - Exciting Unwanted Resonances Can Happen in Any Klystron
      - Need to Isolate and Short Out or Loss Out

Plans

- PPM-2
  - Continue to Process to Maximum Performance
  - Rebuild if Necessary
- PPM-4
  - Send to SLAC for Additional Testing When Windows Rebuilt
- PPM-5
  - Not Yet Decided Who Will Test First
- XP3-3
  - Continue to Process to Maximum Performance
    - Reserve Tube for Two-Pack Modulator Due March, 2004
- XP3-4 and XP4
  - Reserve XP3-4 For Two-Pack Test