Efficient

(and not so efficient)

klystron work at Lancaster University

Dr Chris Lingwood

CLIC MBK Study

- Collaboration with CERN and Thales (Erk Jensen, Igor Syratchev, Phillipe Thouvenin, Rodohple Marchesin).
- Efficiency as main target
- Evaluated configuration options, multiple beam klystron
- Targeted a conservative (plausible) design
- Targeted TESLA/ILC specification
- Theoretical efficiency: 80% (beyond state of the art)

THALES CERN

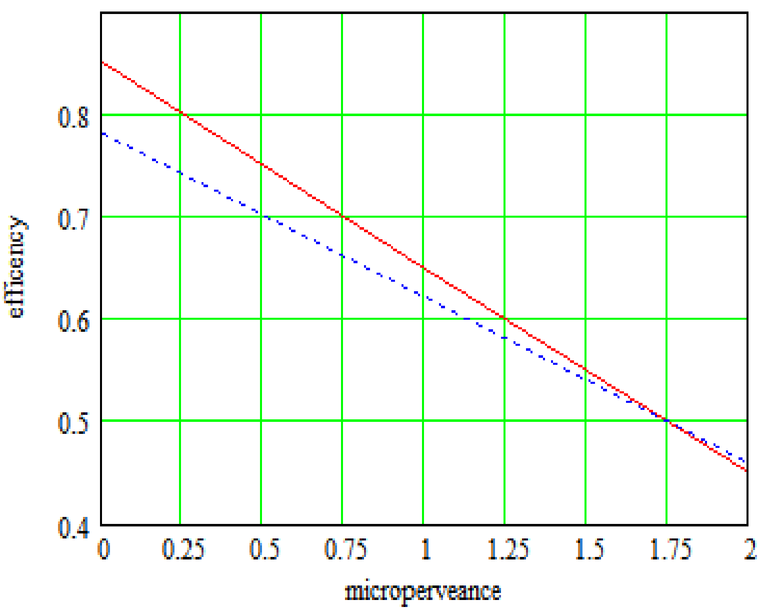
2010 **PhD High Power High Efficiency Multiple Beam Klystron**, *A design study to optimise a high efficiency, high power klystron amplifier for CLIC which focused on stability as an important issue.*

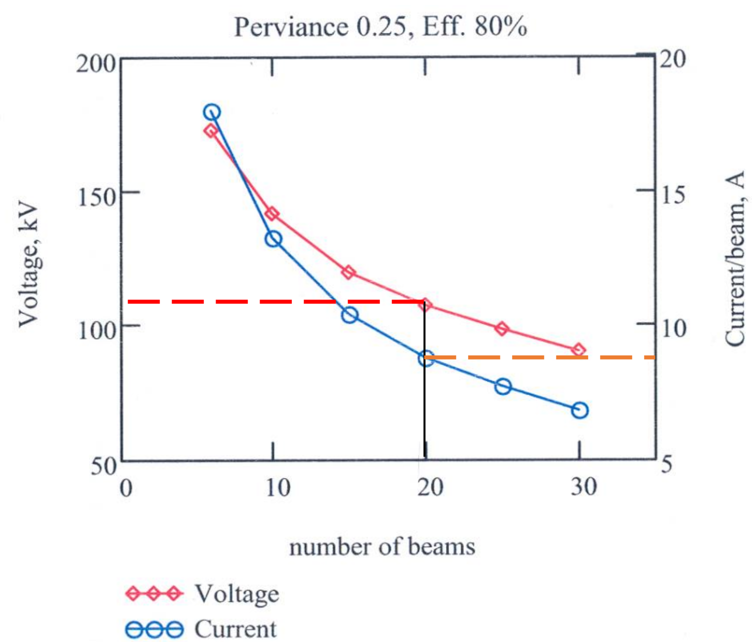
Why many beams?

- Low perveance leads to higher efficiency.

$$perveance\ K = \frac{I}{V^{3/2}}$$

- Low current -> lower space charge forces -> better bunching -> higher efficiency
- 20 beams – trade off between beam voltage and complexity due to beams



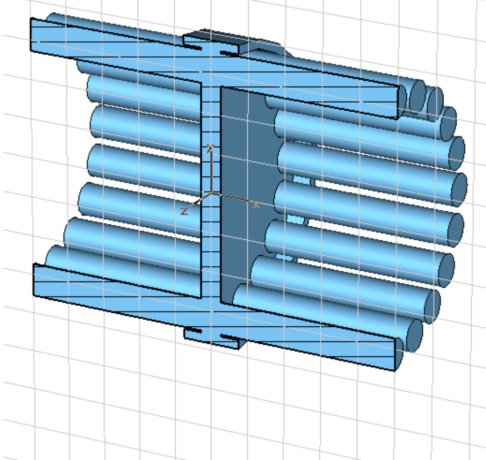


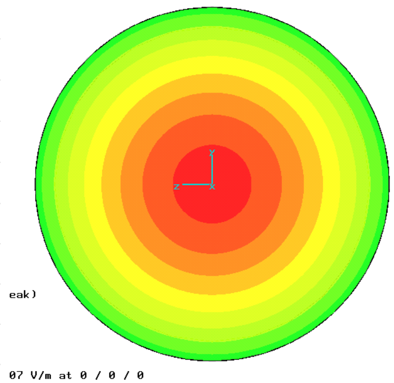
$I_b = 8.2A$

$V_b = 115V$

Cavity Choices

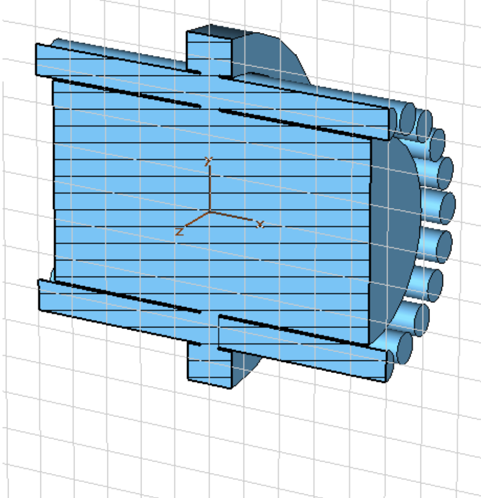
1. Reentrant Cavity

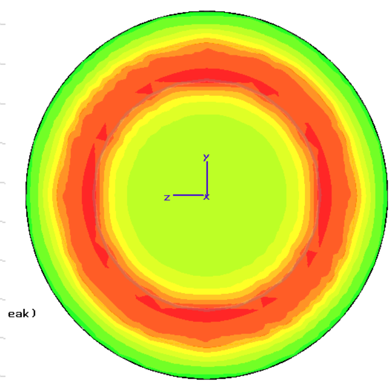




TM 0 1

2. Recessed Reentrant Cavity





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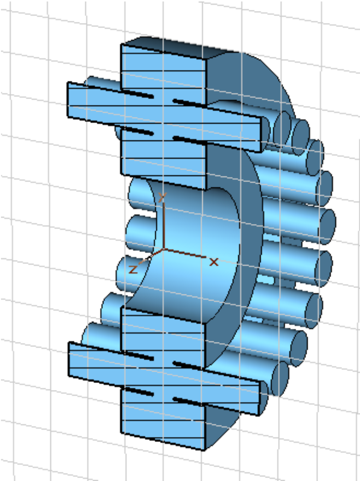
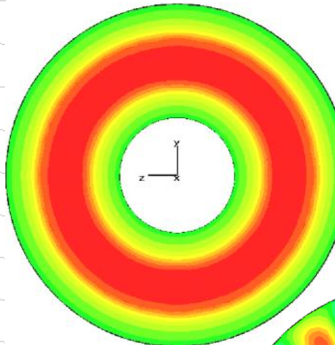
3. & 4. Coaxial Cavity





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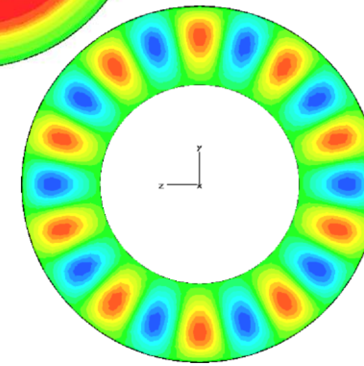
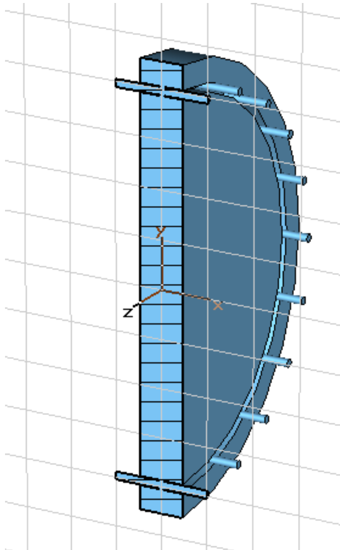
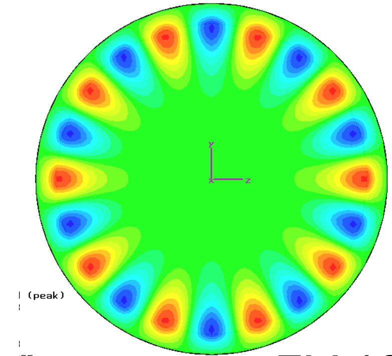


TM 10 1



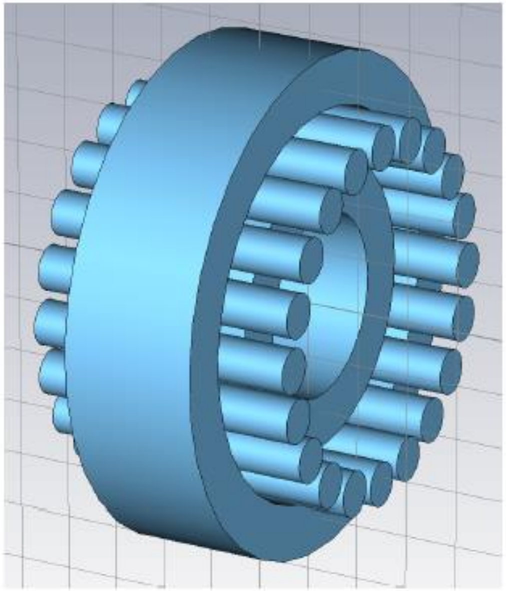


TM 10 1

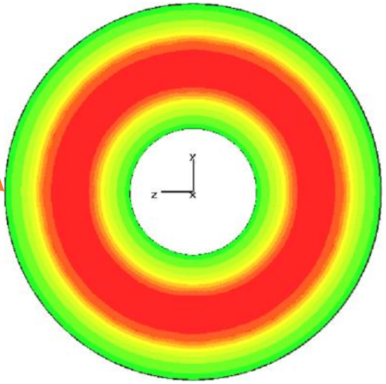
5. Whispering Gallery

Cavity choice

- Comparison of multiple cavity types.
- Re-entrant & HOM cavities -> Low R/Q
- Recessed re-entrant and coax cavity -> high R/Q



3. Coaxial Cavity

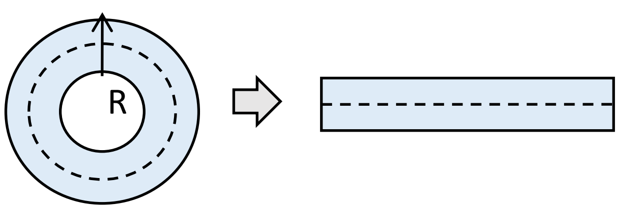


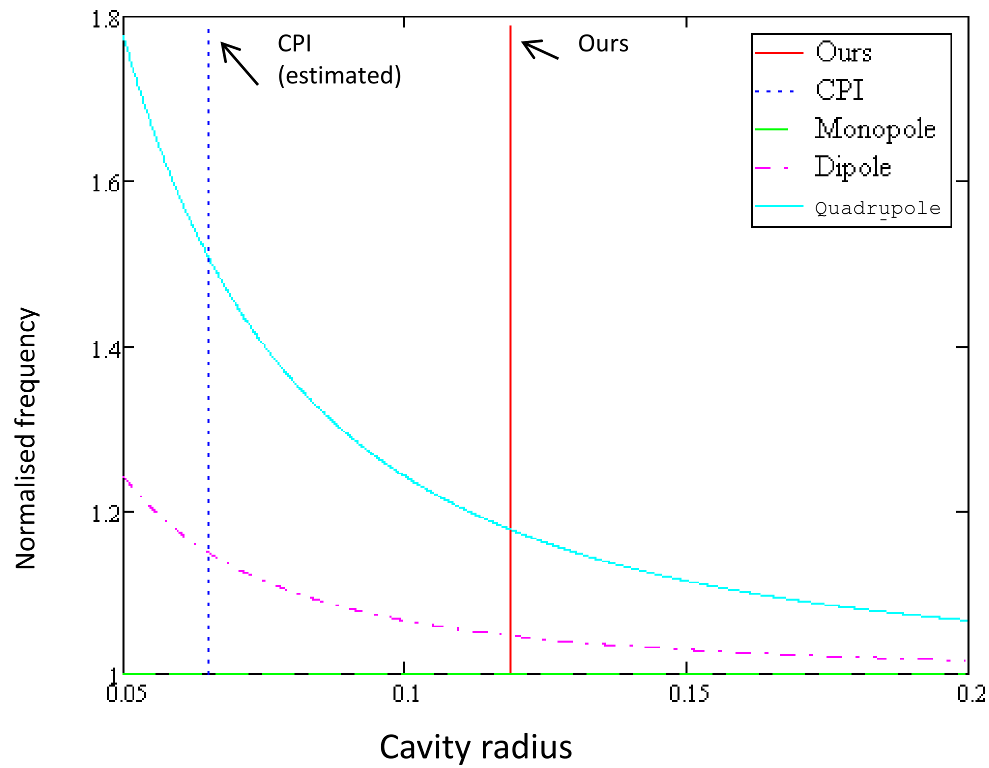
TM 0 1

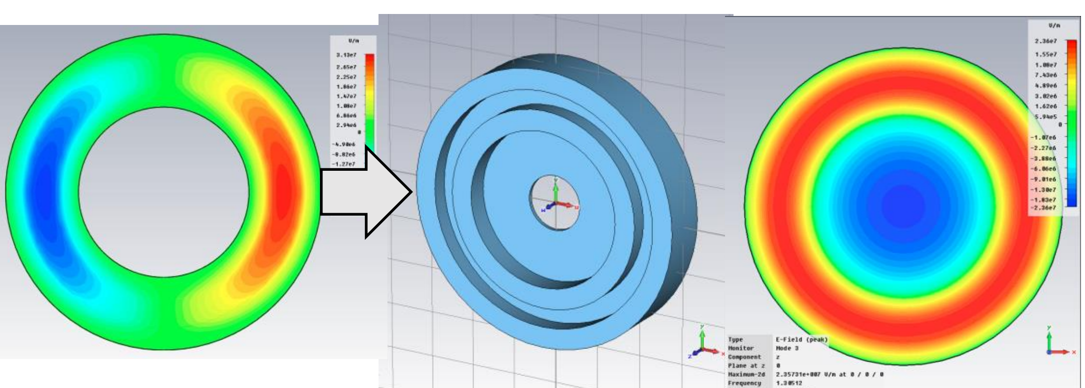
Cavity HOMs

Can model coaxial cavity as a piece of ridged waveguide
Very good agreement even for HOMs

$$\frac{\omega_0}{\omega_c} = \sqrt{1 + \frac{N^2}{R^2 \beta_c^2}} \qquad \beta_c = \omega_c / c$$



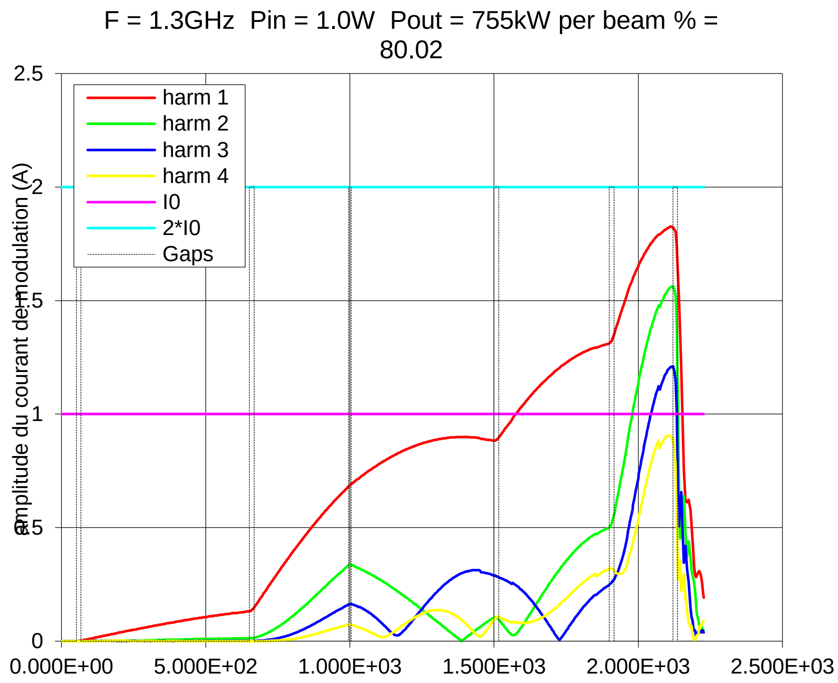




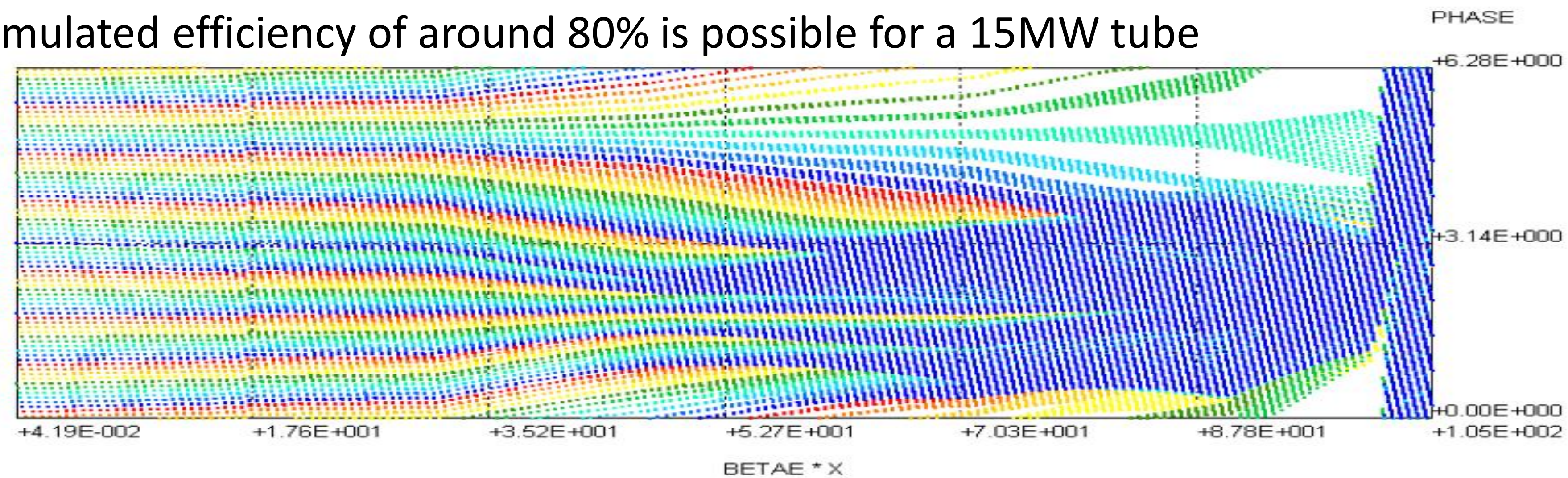
- Large diameter (35cm) at 15MW
- More power -> more beams -> larger still
  - Dipole mode gets **closer** for larger cavities

Interaction structure

- Optimised 6 cavity
- (single 2nd harmonic)
- Low R/Q structure 70%
- High R/Q structure 20 beam structure up to 80%



Simulated efficiency of around 80% is possible for a 15MW tube



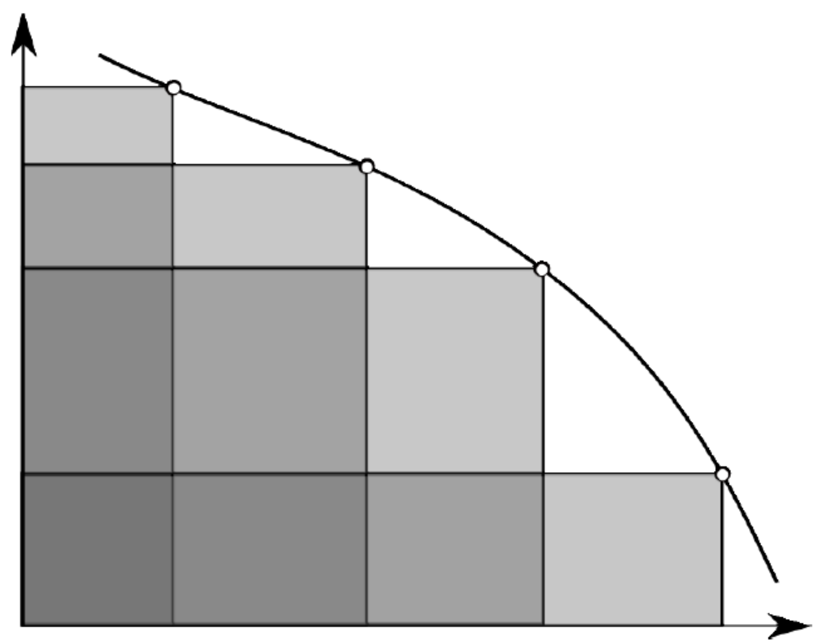
Automatic Klystron Optimisation

- Developed and published a new way to design klystron amplifiers:
  - ~14 Decisions (frequencies, drifts, Qe's)
  - 3-4 objectives (efficiency, length, bandwidth, slowest electron)
    - Multi-objective optimiser
  - 5000-10,000 evaluations
  - Impractical without high throughput computing (CI HTCondor Pool)
    - Use spare clock cycles of desktop pcs

Automatic Optimisation of a Klystron Interaction Structure , *C.J. Lingwood, G. Burt, K.J. Gunn, R.G. Carter, R. Marchesin, E. Jensen,* **IEEE Trans Electron Devices**.

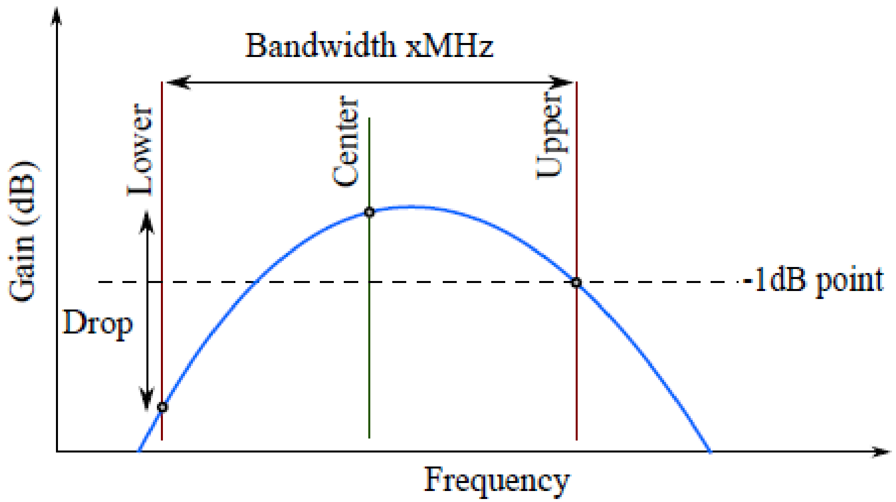
Multi Objective Optimisation

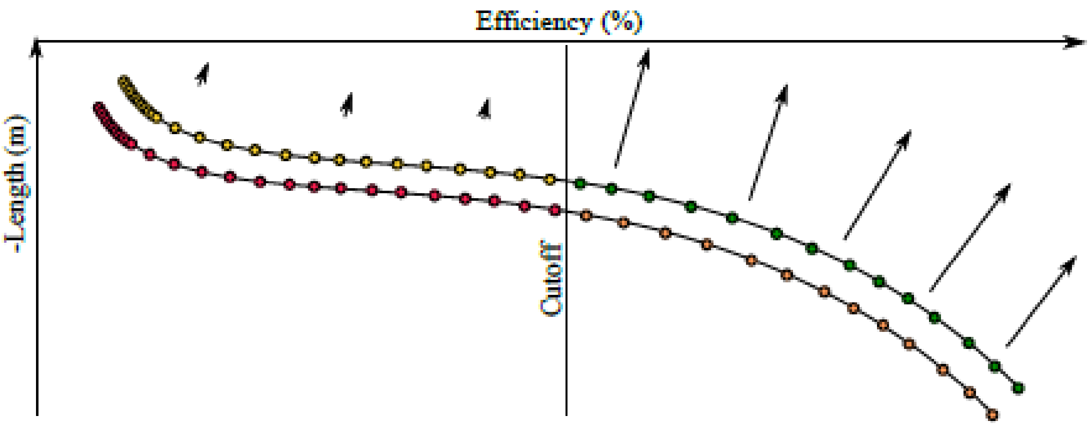
- In place we use non-dominated sorting (where a and b are solution vectors)
- Sort into groups where no one characteristic can be further optimised without detrimental effect on the other characteristics

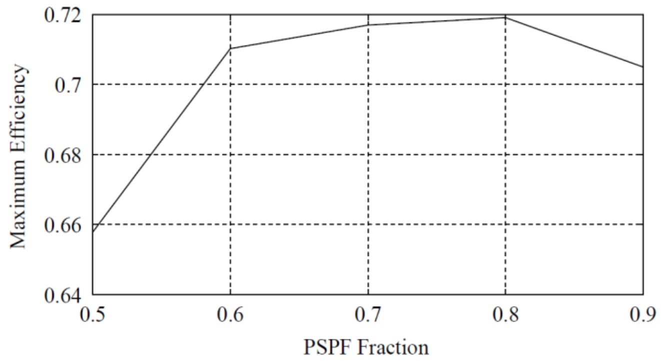


Klystron Peculiarities

- We don't want to know the gain, just whether it is in spec
- Target efficient "long" klystrons over short inefficient

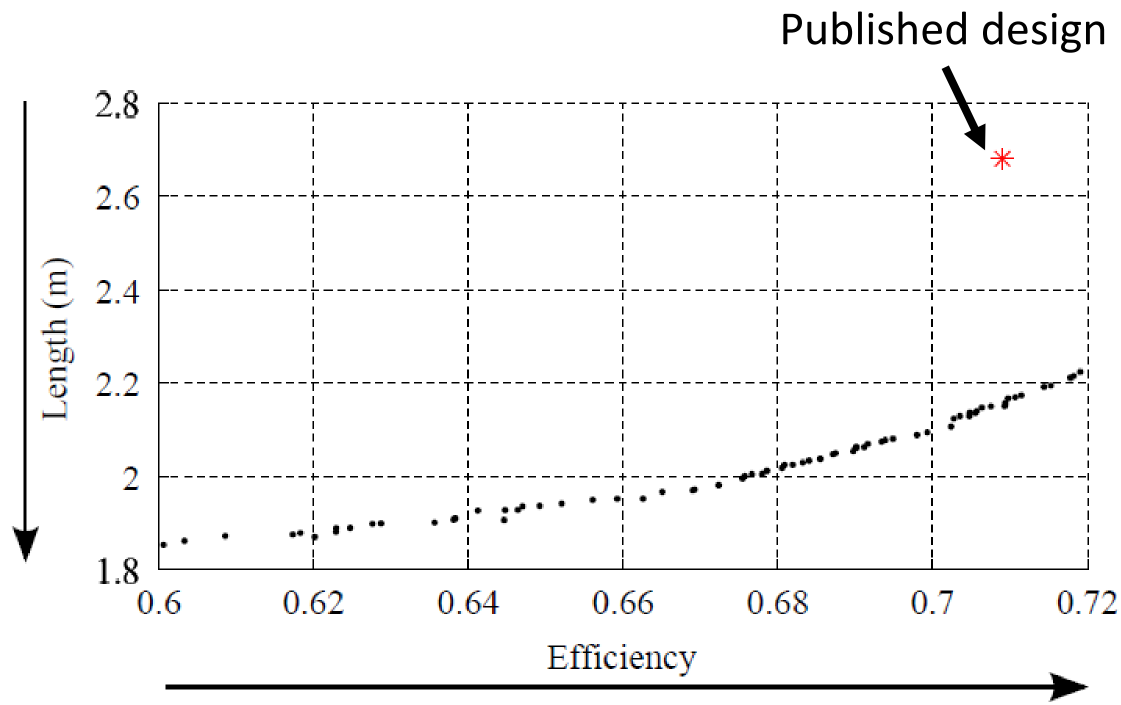






Applied to B-Factory Klystron

- 71.9% efficient
  - more or less the same
- 19.8% shorter than published design
  - might be better, might not.
- 10,000 iterations
- **Not much effort**



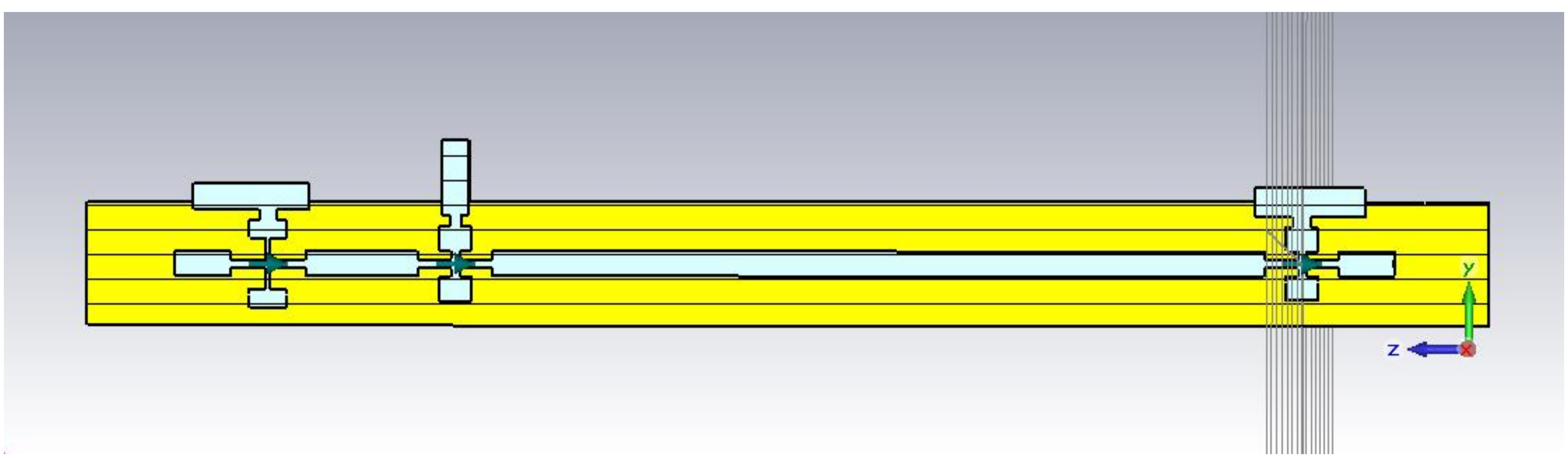
The Future

- Secured funding to continuing efficient RF source work for CLIC
  - 2 years RA
  - PhD student
- Open 1.5D Klystron Code
- Benchmark Vorpal (the new magic?)
- Investigate new techniques for efficiency
- New collaborations.

InEfficient RF Sources Workshop

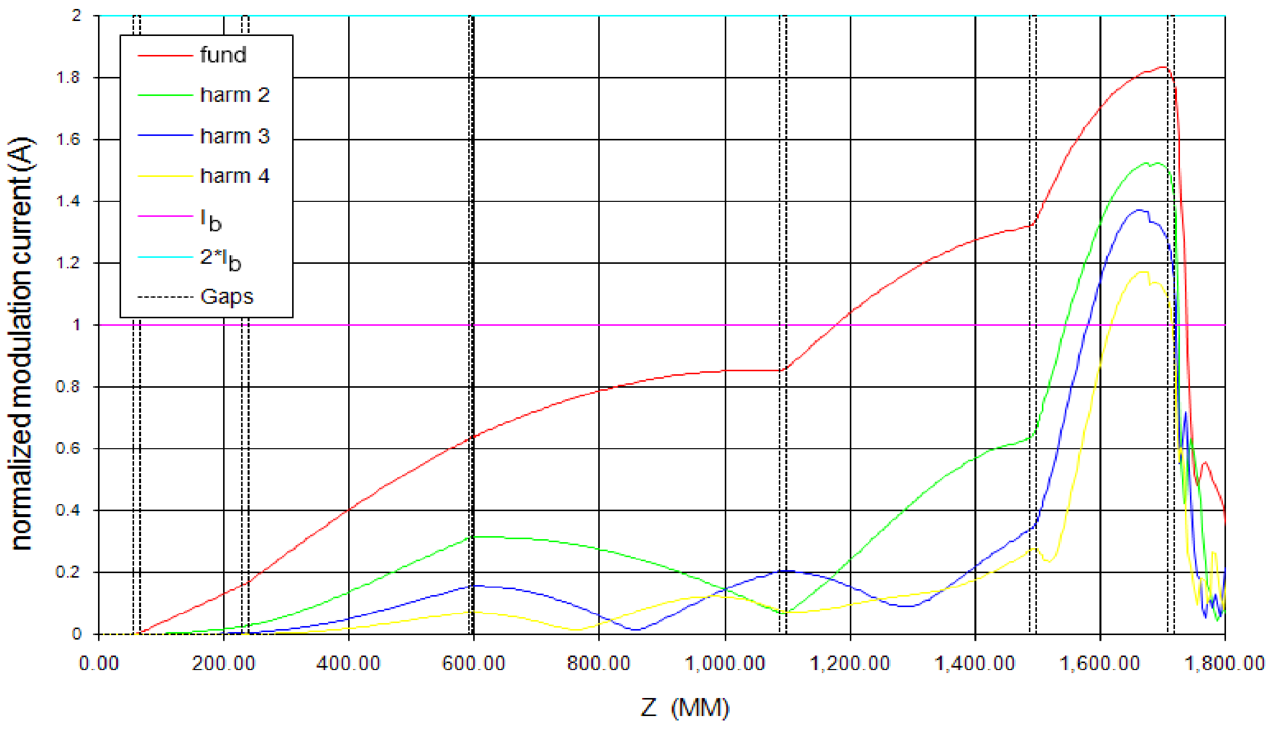
mm-Wave Upconverting Klystron

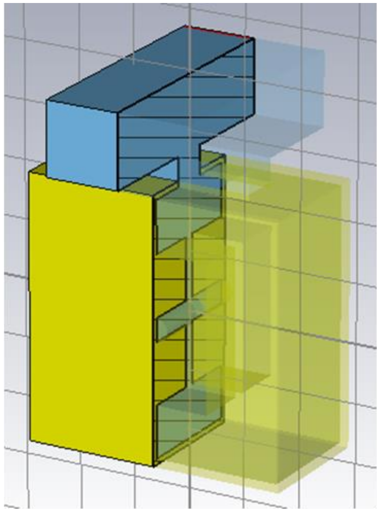
- Conventional klystron with a 3rd harmonic output cavity
- Input 1W at 31GHz
- Potential to output 200W @ 94GHz
  - 6 cavities
- Designed to be cheap to manufacture.



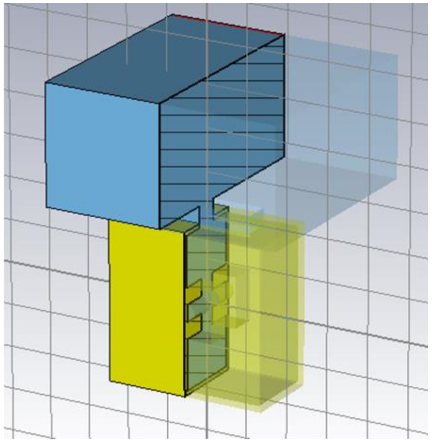
Operating Principal

- When beam is modulated with first harmonic the third harmonic exists anyway
- Just put in a 3rd harmonic cavity





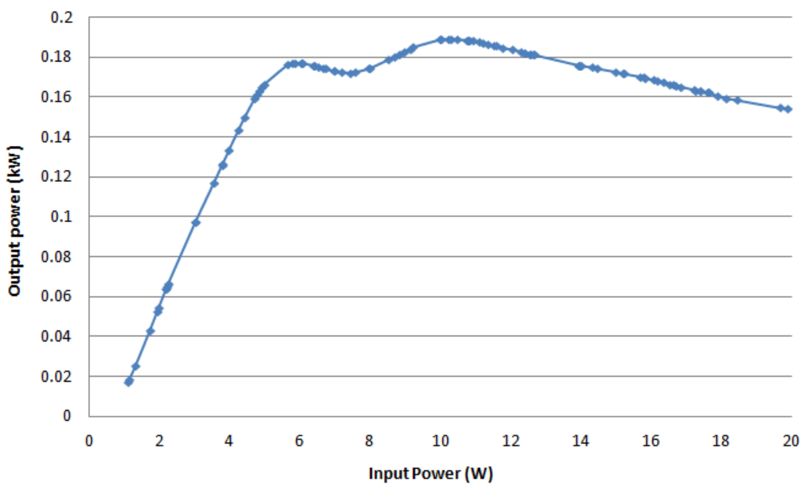
Output coupler 94GHz

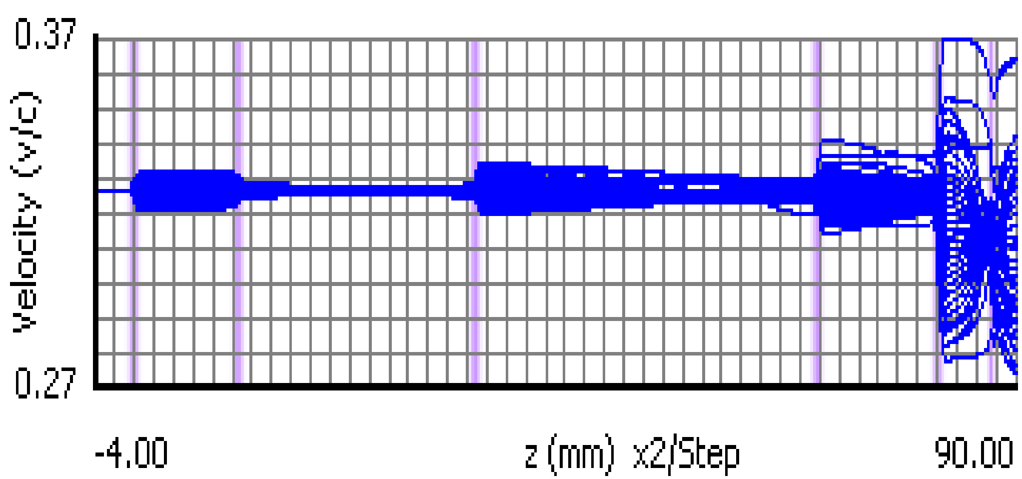


Input coupler 31GHz

mm-Wave Upconverting Klystron

- First upconverter at these frequencies
- Has been built
- Hot test planned
- Collaboration with Strathclyde University
- Requires 9kW electron beam
  - 2% efficient
- 3 cavity proof of principal (0.2% efficient)





Announcements

- Bus Leaves the Cockcroft at 5:30
- Dinner Begins at 7pm in the hotels restaurant.