Summary of activities of CLIC Study Team for 2003

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Purpose of presentation – to give you brief overview (just a flavour) of all different subjects studied in 2003 by the CLIC team without giving too much detail

This summary will be published as CLIC Note 591 in a more detailed form.

In particular I will :

- Review progress made CLIC Machine Studies (CMS)
- Give results obtained with test facilities – mostly CTF3

Given large amount of work accomplished by CLIC Team during this 12-month period – faced with 2 options for this presentation

- Either to choose some particular high-lights and give detailed results with plots and photos
- Or to provide an overall picture by mentioning all activities with only a very brief statement of what we have achieved

Chosen latter because I believe :

- important that work of every Study Member is acknowledged
- once a year, we review extent and quality of our achievements

Damping ring

- Present DR design based on compact TME (Theoretical Minimum Emittance) arc cells with short-period wigglers in two long straight FODO sections - energy 2.42 GeV - ring circum 360 m. - rf 2.5 MV.
- Optimisation of ring params. takes into account effects of SR and IBS
  Present design does not, however, quite meet design goals :
  $\gamma\varepsilon x$ = 631 nm and $\gamma\varepsilon y$ = 9 nm (achieved on paper)
  $\gamma\varepsilon x$ = 450nm and $\gamma\varepsilon y$ = 3 nm (nominal)
- Only long. emit. of 4453 eVm is less than design value of 5000 eVm.
  Studies of alignment tolerances and beam-based tuning have started.
- Shown - present design can accommodate anticipated changes in particles/bunch from 4 to 3×10^9, and bunch spacing from 0.66 to 0.33 ns.
- BUT does not quite meet design goals - unlikely that a design based on TME cells and wigglers with state-of-the-art magnets will ever produce desired emittances - either target emittances have to be revised or an alternative (more exotic) approach has to be found.

Main linac beam dynamics

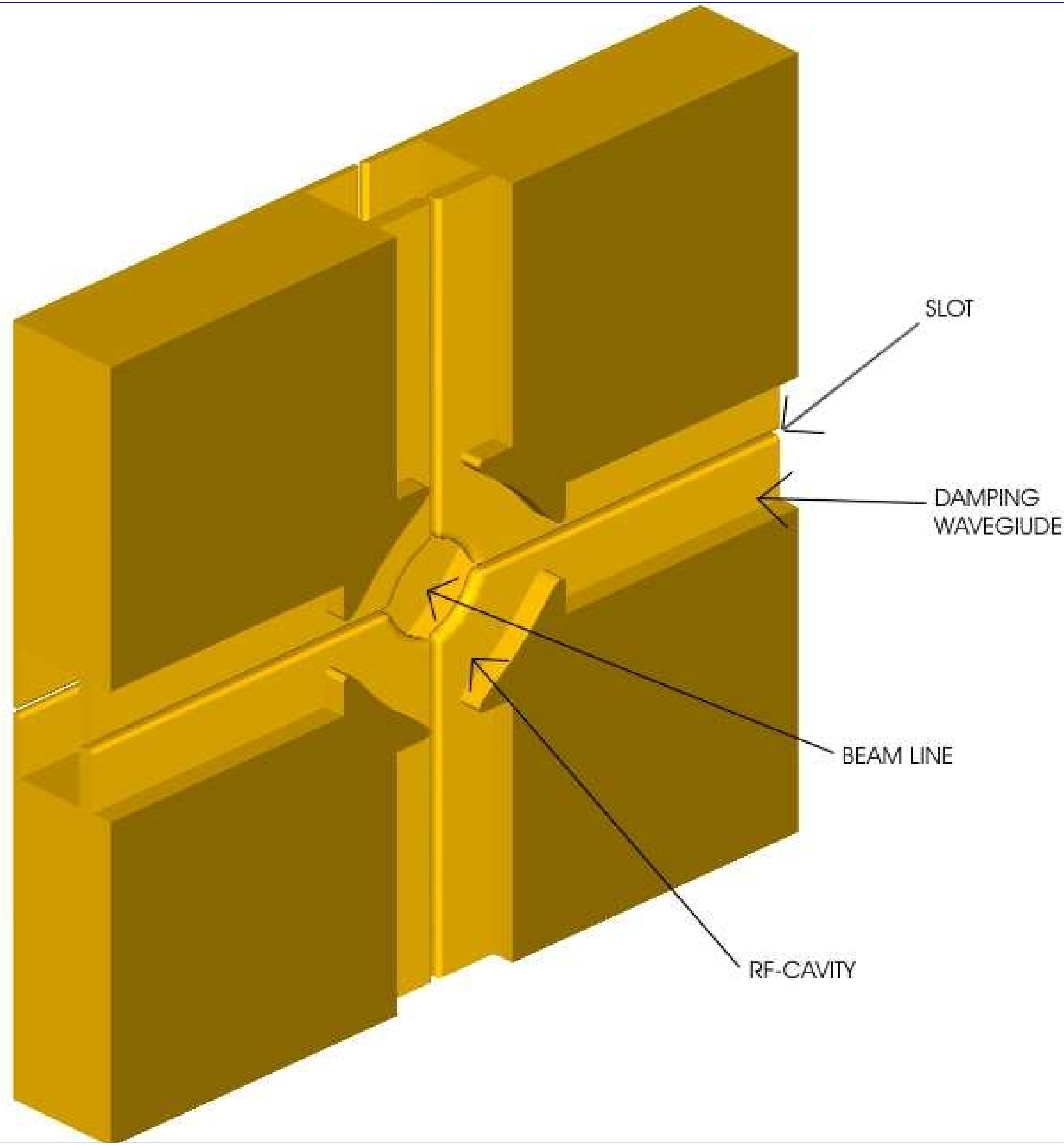
- Integrated simulations of main linac and BDS used to study lum. loss from particles with energy errors falling outside bandwidth of BDS.
- Energy errors result from phase and amplitude errors in main linac, and these come directly from phase and intensity errors of drive beam.
- Found - phase and amplitude tolerances in main linac were determined by limited bandwidth of collimation system of BDS - it's 70% larger for FF alone. Implied tolerance on drive-beam phase jitter is about 0.15 degrees at 30 GHz – this needs longitudinal feedback system.
- Developed first concept using short-cut path in drive-beam turn-around loops to correct measured incoming phase jitter on same pulse.
- Re-optimization of collimation system would very likely loosen this very tight tolerance but would almost certainly involve an increase in length.
- A study of possible sources of phase and intensity errors has started.

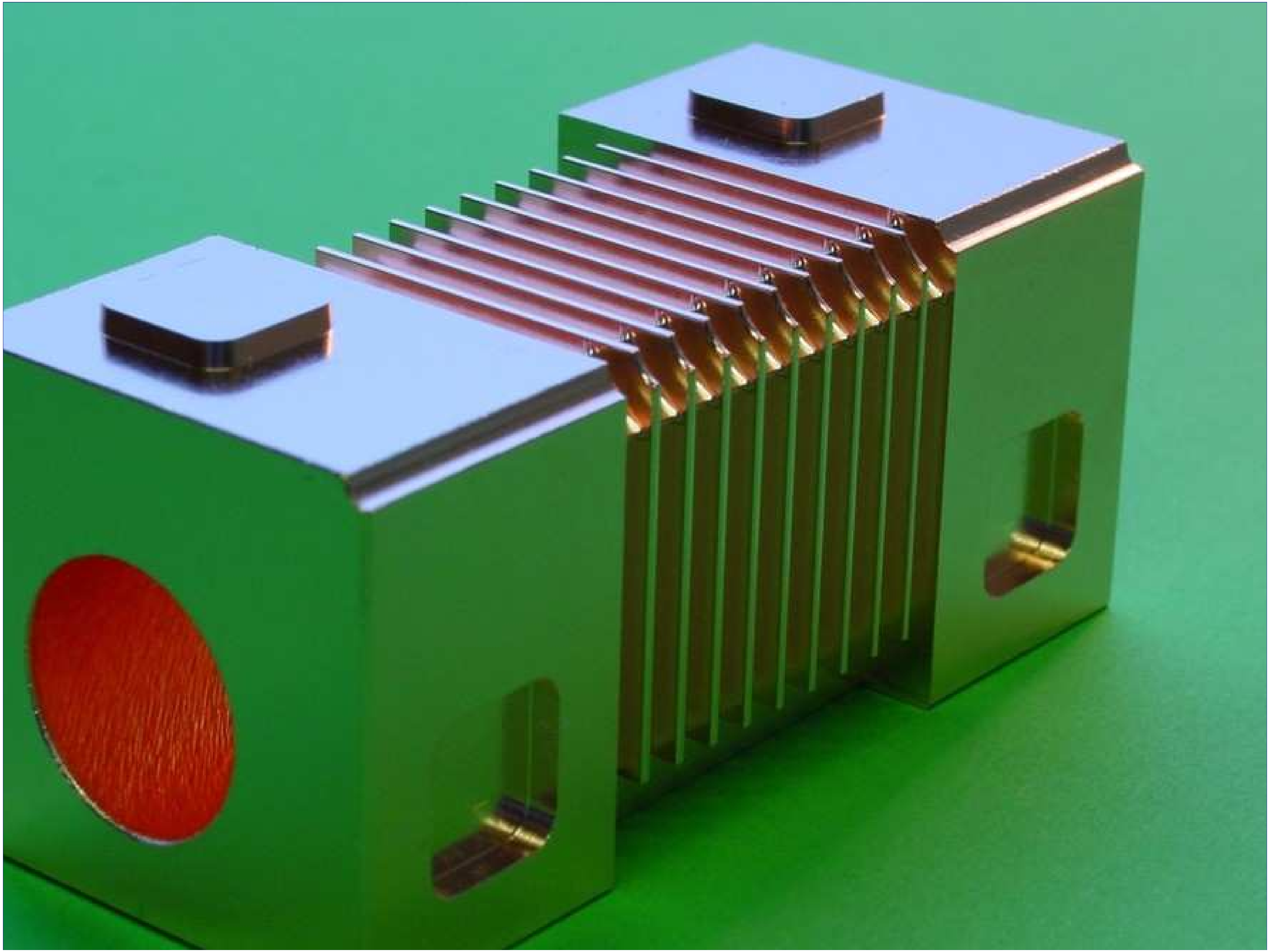
Accelerating structure design

- A very important improvement in HG performance and efficiency of main linac 30 GHz accelerating structure been achieved through a combination of a new damping topology and a new design optimization procedure.
- New structure uses both iris slots and radial damping waveguides to reduce dipole mode *Q*s to the order of 10 - this allows bunch spacing to be reduced from 20 to 10 fundamental cycles, increasing rf-to-beam efficiency from about 15% to about 26%.
- HG design performance been improved by profiling cross-sections of iris and outer cell wall, so that surface field enhancements caused by damping features are limited to below 10%.
- HG performance further improved by reducing rf pulse from 150 ns to 60 ns.

Accelerating structure design - continued

- New HDS (hybrid damped structure) has potential for substantial improvements in manufacture and assembly.
- New developments have in part made possible by purchase and installation at CERN of GdfidL - runs on cluster of 7 parallel processors (28 GB RAM)
  - can run very large jobs (300-500 million mesh points).
- GdfidL been benchmarked against CLIC 15 GHz ASSET test
  - appears to be very precise.
- Now primary tool for wakefield calculations and, along with HFSS, is main code used in structure design.


SLOT
DAMPING
WAVEGIUDE
BEAM LINE
RF-CAVITY



High-power splitters and phase shifters

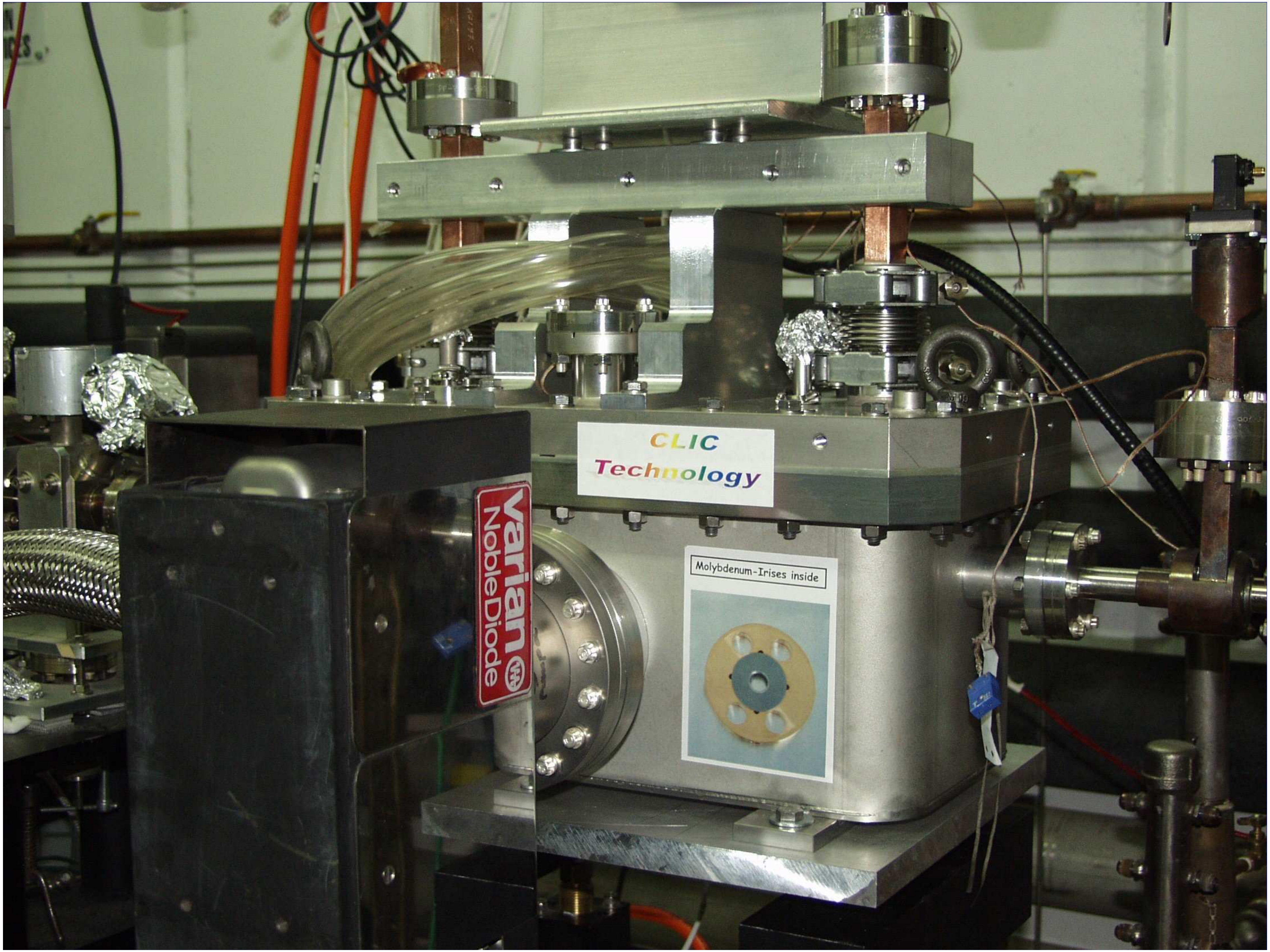
- Novel design of mechanically-driven 30 GHz rf power splitter and phase shifter developed for CLIC
- Basic idea - to exploit polarization properties of H11 mode in circular WG as the WG x-section changed from circular to elliptical.
- Split of energy between two modes depends on angle between original (circular) H11-mode polarization and orientation of axes of ellipt. WG.
- When 2 degenerate modes converted back into single mode in subseq. piece of circular WG, resulting H11 mode changed its orig. polarization.
- By rotating polarizer (elliptical WG), splitter can be used as variable divider – 45 deg. sufficient to go from total reject. to total trans.
- By putting 2 polarizer devices in series, and rotating them together, device acts as phase shifter- phase delay depends on polarizer angle

High gradient testing

- No high-power 30 GHz available in 2003 because CTF2 was closed at end of 2002 and start-up of 30 GHz power production in CTF scheduled to start in 2004.
- In order to maintain momentum of experimental HG program and to test structures with long rf pulses as soon as possible - a molybdenum and a tungsten-iris X-band structure were constructed, and sent to SLAC for testing in the NLCTA.
- The X-band structures were exactly scaled versions of 30 GHz structures tested in CTF2 in 2002 in order to allow most direct comparison of results obtained at two frequencies.
- A new vacuum tank was constructed for X-band tests, and cooling system was modified in order to cope with increased heat load from longer pulse length and higher repetition rate.

High gradient testing - continued

- Due to limited testing time only molybdenum structure tested to date.
- In available testing time, accelerating gradient reached only 65 MV/m (first cell) for 100 ns pulses, distinctly less than was hoped for.
- Gradient was not, however, a limiting value, as indicated by fact that conditioning curve showed no sign of saturation and low power rf tests and a visual inspection of rf surfaces showed no signs of damage.
- This X-band gradient also consistent with 30 GHz gradient at same number of breakdowns per unit surface area, indicating that much more conditioning time was needed.
- Test does not call into question performance of molybdenum, but indicates that more needs to be learned about using this material.


CLIC
Technology
Molybdenum-Irises inside
varian
NobleDiode

Material test facilities

- Two new EST test facilities for CLIC came on line in 2003: a dc-spark test stand and a laser pulsed surface heating test stand.
- Both facilities conceived to speed-up technical development of new materials and preparation techniques - aim to make simple experiments which address relevant physical issues before making full-blown rf tests (expensive, infrequent and often limited in time)
- Both facilities benchmark tested - now ready for production use.
- New copper alloys investigated for pulsed surface heating problem.
- Copper zirconium seems to be an excellent candidate with electrical and thermal conductivities better than 92% of copper and a fatigue strength twice as high.
- A sample has been purchase and first measurements of its fatigue properties being made in laser test stand.

Material test facilities - continued

- Collaboration between CERN, JINR (Dubna) and IAP (Nizhny Novgorod) to provide pulsed surface-heating fatigue data is not progressing well.
- Despite much work it is proving extremely difficult to get > 6 MW of nominal 30 MW into test cavity, and likelihood to improve situation is very small because problems are caused by spectral impurity of radiation from 30.7 GHz free electron maser.
- This experiment is now running more than two years late and status of contract has to be critically reviewed.

Beam position monitors

- A first study to use the CLIC main-linac accelerating structures as beam-position-monitors (BPM) was written-up this year and successfully presented as a doctoral thesis.
- The work centred on an experiment to measure the beam position using signals produced by a heavily damped 3 GHz SICA structure. The data obtained showed that the resolution of this novel monitor was about 50μm.

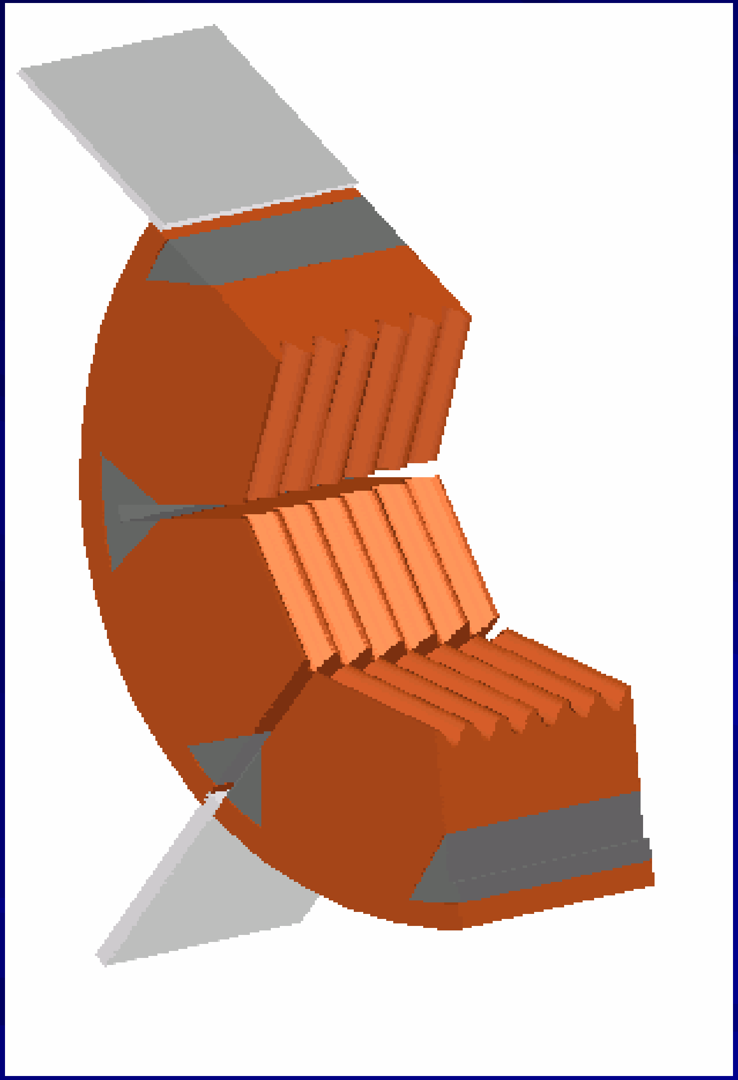
Multi-beam klystrons for CLIC drive beam accelerator

- CLIC scheme needs high efficiency 50 MW, 100 μsec 0.937 GHz klystrons to power drive beam accelerator.
- A novel design of multi-beam device in which as many as 27 beams run through individual beam lines, but interact in common RF volume, has been completed and patented.
- New design uses BOC technology - initially developed in Russia, but further developed over last few years here at CERN.
- New MBK is mechanically robust and simple to manufacture, and because its many beams have low-perveance (current divided by 3/2 power of voltage) - has a very high efficiency of 80 %.
- By extracting the power through a series of mini-windows instead of a single window, it is expected that the device will be very reliable.

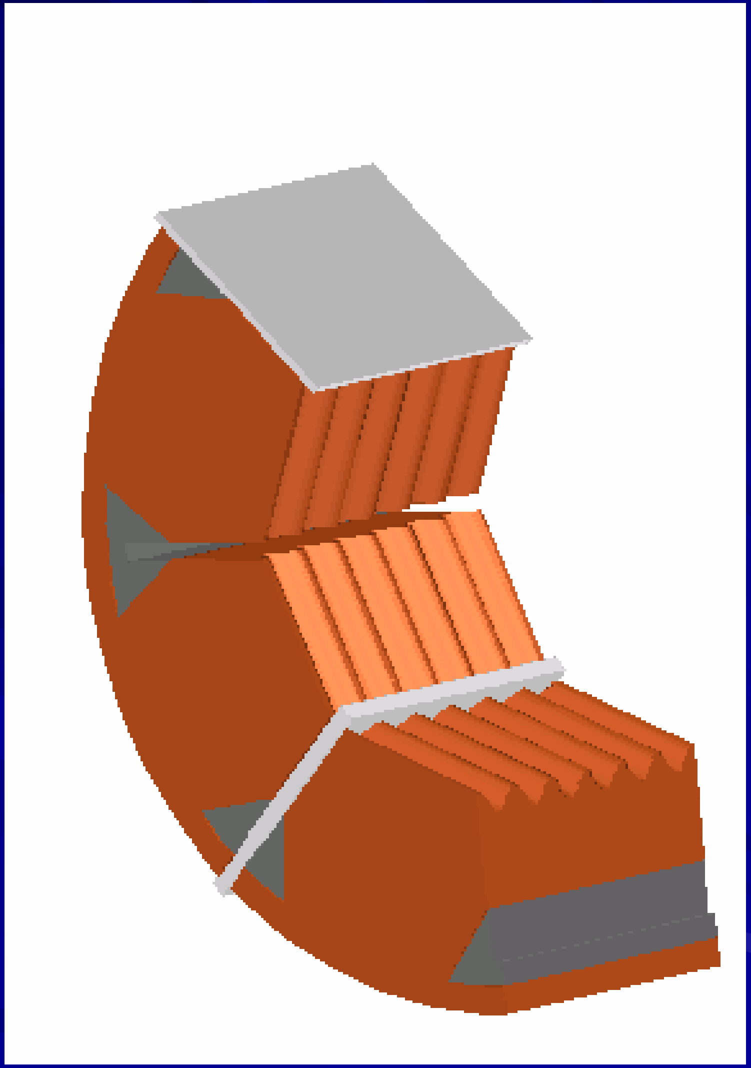
Power Extraction and Transfer Structures (PETS)

- New large aperture (25mm dia) PETS developed - has octagonal x-section composed of 8 identical racks with a flat shallow-sinusoidal corrugated surface - peak surface electric field < 100 MV/m
- 8 radial 1.4 mm wide slots cutting PETS all way along its length, channel out disruptive HOM energy to SiC loads.
- Designed to produce 560 MW from 150 A drive beam.
- Power can be turned OFF by inserting thin metal wedges thro' 4 of 8 damping slots - wedges detune synchronous mode frequency and prevent coherent build up of excited field.
- Special broad-band quasi-optical coupler designed to couple out power with efficiency of 98% - consists of 3 parts, a mode launcher, a diffractor, and a combiner section - these units provide an efficient step-by-step conversion of energy from E01 mode of the over-moded circular WG to the fundamental H10 mode of the standard rectangular WGs.

Power 'on'



Power 'off'



Parameters

- A study of opt. aperture and freq. of accel. structures made with aim to optimize sum cost of capital investment and operation for given lum.

- rf-to-beam efficiencies and wakefields for structures at different freqs. and aperture-to-wavelength ratios determined taking into account structure design constraints imposed by maximum admissible surface fields and temperature increases.

- Study showed - optimum freq. depends on limitations on achievable beam size at IP. For present parameters - optimum freq. is in range 22-26 GHz with ratio of aperture to accelerating wavelength of 0.175-0.2.

- If progress in DR and BDS design would allow smaller beam sizes at IP, this optimum will shift to higher frequencies.

- Recent structure developments have opened up possibility of reduction of bunch spacing from 20 to10 rf cycles, a reduction of particles/bunch from 4 to $3x10^9$, and a reduction of overall rf pulse length from 130 ns to possibly 65 ns - implications of these eventual param. changes are being studied.

Luminosity at the interaction point

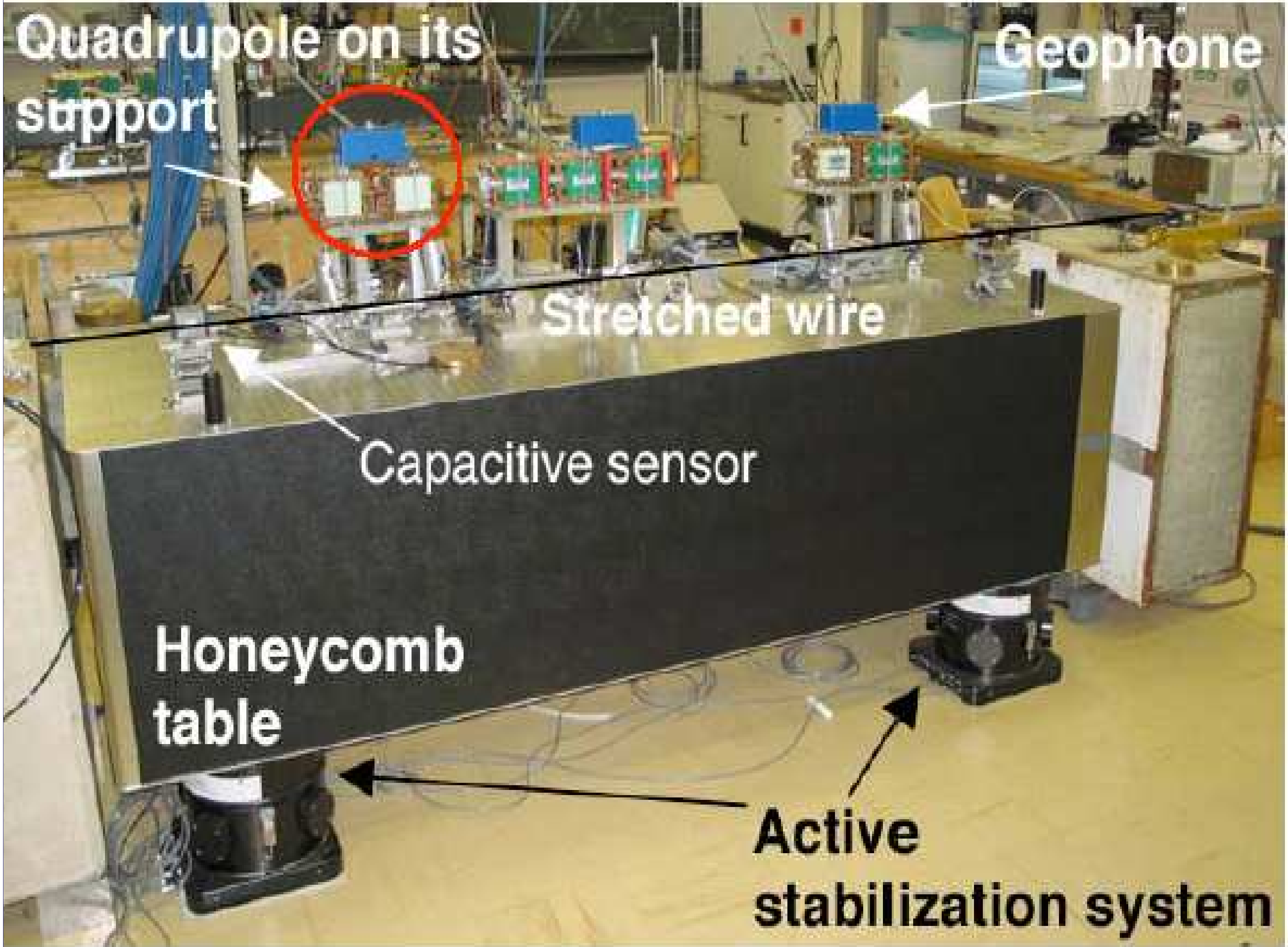
- An important challenge for CLIC will be to develop a luminosity monitor that can be used to optimize machine performance.
- Study has started to identify potential signals that could be used for this purpose - promising first results obtained using signals proportional to number of coherent pairs produced and the level of beamstrahlung.
- More work done on effects of single-bunch wakefield-induced distortion of bunches at IP (the so-called banana-effect)- shown for static misalignments at 3 TeV, luminosity loss can be almost completely compensated by optimizing both collision angle and beam offset at IP - this of course requires some sort of luminosity monitor.
- Although this looks promising, the effect of dynamic effects on this luminosity optimization procedure have however to be studied.

Beam delivery system

- Complete design of final focus and collimation reviewed for ICFA HALO'03 workshop where all design aspects considered over last four years were summarized.
- Apart from this, no new design work was made for BDS in 2003.

Stability studies

- Colliding nanometer-size beams imposes very tight tolerances on stability of magnetic guiding and focusing fields - vertical position jitter tolerance on main linac typically 1-2 nm and on FF quads 0.2 nm above 4 Hz for a 2% luminosity loss.
- As you know – in 2001 - stabilization study group started to investigate technical feasibility of stabilising these elements to these levels - set up test stand in fairly noisy location on CERN Meyrin site to do this.
- Most recent results show that vibration level of prototype quadrupole can be reduced by one order of magnitude w.r.t. supporting ground.
- Best measurements indicate transverse rms vibration amplitudes (above 4 Hz) of (0.79±0.08) nm horizontally and (0.43±0.04) nm vertically, and maximums of less than (1.47±0.15) nm and (1.00±0.10) nm, respectively, over a period of several days.
- Simulations using measured vibration spectra - shown that with this level of stabilization and the implementation of beam-based position feedback approx 70% of CLIC nominal luminosity is obtained.


Quadrupole on its support
Geophone
Stretched wire
Capacitive sensor
Honeycomb table
Active stabilization system

ILC-TRC activities

- A lot of effort was made in 2002 to prepare information, to update designs, and to make comparative simulations for International Linear Collider - Technical Review Committee (ILC-TRC).
- Since main focus of this review was a 500 GeV c.o.m. collider, many of CLIC sub-systems such as damping rings, main linac, drive-beam decelerator, and beam delivery system, had to be revisited to ensure that both parameters and hardware were downwards compatible with nominal 3 TeV design.
- The CLIC contributions to this report have been summarised and published as a CERN yellow report – for more details see

http://ps-div.web.cern.ch/ps-div/CLIC/ILC_TRC/TRC_clic500_3.pdf

ESGARD activities

- The CLIC team participated in preparation and organisation of a bid to get money from European Union within 6th framework program (FP6) for accelerator R&D - the so-called CARE project (Coordination in Accelerator Research in Europe).
- Bid - accepted and work already started.
- In particular, for CLIC, it means participation in European-wide network on linear accelerators (ELAN), and in joint research activity (JRA) to construct a photo injector for CTF3.
- CLIC team is also actively participating in preparation of new FP6 bid concerning future linear collider Design Studies.

CLIC road-map and resources studies

- Over last year or so, efforts to set-up world-wide collaboration to build 500 GeV LC in near future have intensified - therefore deemed appropriate for CLIC study team, after 17 years of CLIC studies, to take stock of what had been achieved, and where study was going.
- In particular, it was felt that management should be made aware of what could and could not be achieved with present resources.
- After gathering necessary information, report was published which proposed programme of work for CLIC study for period 2003-2008, together with necessary resources
- In particular it listed activities required to enable elaboration of CLIC Conceptual Design Report (CDR) by 2008. - it identified CLIC sub-systems currently not being studied and which could be undertaken by outside laboratories or institutes.

CLIC road-map and resources studies - continued

- In parallel with activity just described, three road-map discussions were held between CLIC Study team and the users (essentially the CLIC Physics Study Group) to look at possibilities of using CLIC two-beam technology at lower centre-of-mass energies.
- Interest centred on following (i) giga-Z factory (ii) operation at WW threshold (iii) light Higgs factory and (iv) SUSY Higgs production.
- On machine side, work consisted of proposing layouts and luminosity estimates for various centre-of-mass energies. This work is unpublished but copies of transparencies are available on request.

CLIC road-map and resources studies - continued

- In September - this time at request of CERN management - CLIC study team asked to present work programme and schedule, assuming present resources, to demonstrate 5 key technology-related feasibility issues for CLIC identified by International Linear Collider Technical Review Committee (ILC-TRC) in report (SLAC-R-606, 2003).
- CLIC study team showed - with extension to foreseen facilities, all CLIC-technology-related feasibility issues could be demonstrated in CTF3 BUT with resources foreseen - could not be completed before 2014.
- This time frame considered unacceptable by management and study asked to study an accelerated programme to demonstrate key issues before 2010.
- This was completed and preliminary proposal made by DG-designate to council in December.

CLIC Test Facility (CTF3) Studies

- Large fraction of CLIC resources devoted again in 2003 to CTF3.
- Appropriate at this moment to mention - this facility is being built in collaboration with INFN (Frascati), IN2P3 (LAL), SLAC, the University of Uppsala, the North-Western University of Illinois and Finnish Industry.
- Following chapters summarize various CTF3 activities.

CTF3 injector and linac installation

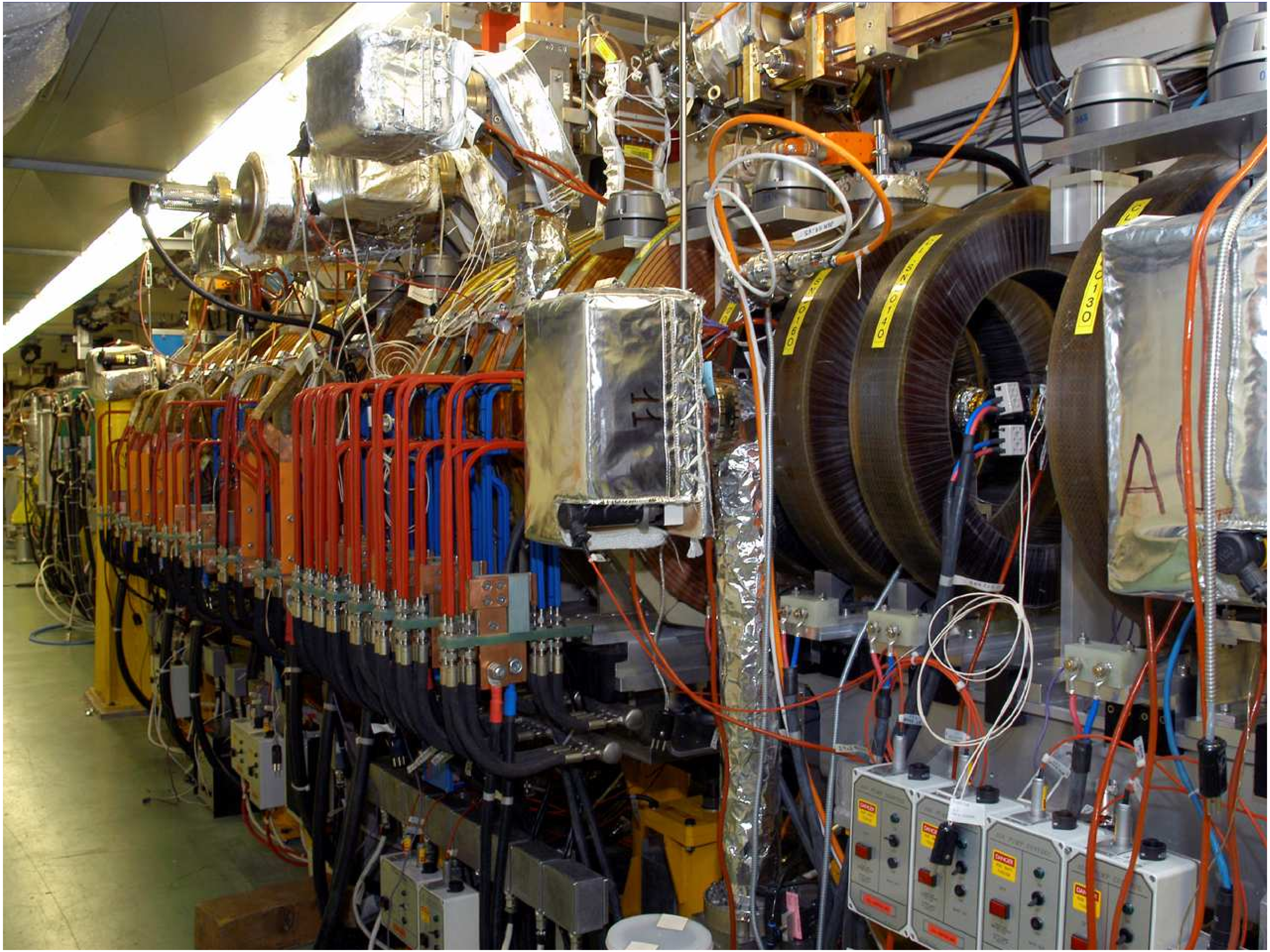
- After successful operation of "preliminary phase", LIL was completely dismantled and installation of new injector and linac began in 2003.

- The thermionic gun is on loan from SLAC
- 160 kV high voltage supply, and high voltage deck with the gun pulsing circuit - provided by LAL.

- The gun is followed by a bunching system consisting of two single cell SW bunchers, made by LAL, and a 17-cell TW buncher made by CERN. The TW buncher has an increasing phase velocity along its length to account for increasing particle speed and has WG damped and detuned cells to suppress disruptive wakefields.

CTF3 injector and linac installation - continued

- The CTF3 buncher is followed by two accelerating structures which bring beam energy up to 20 MeV - these structures are CTF3 linac prototypes, one is a TDS (tapered, damped structure), the other is the industrial prototype of series production of SICA structures.
- Transverse focusing of CTF3 beam in injector region is done by putting all equipment in 0.2 T solenoid channel.
- Injector is followed by cleaning chicane used to remove off-energy particles but also used as a spectrometer line for diagnostics purposes.
- All this equipment was commissioned with beam in summer.
- 2 more SICA structures and more beam diagnostic equipment then installed, together with girders for more SICA structures.
- This brought total length of beam line to 28 m - this was commissioned with beam during a second 3-week operation period in Oct/Nov.

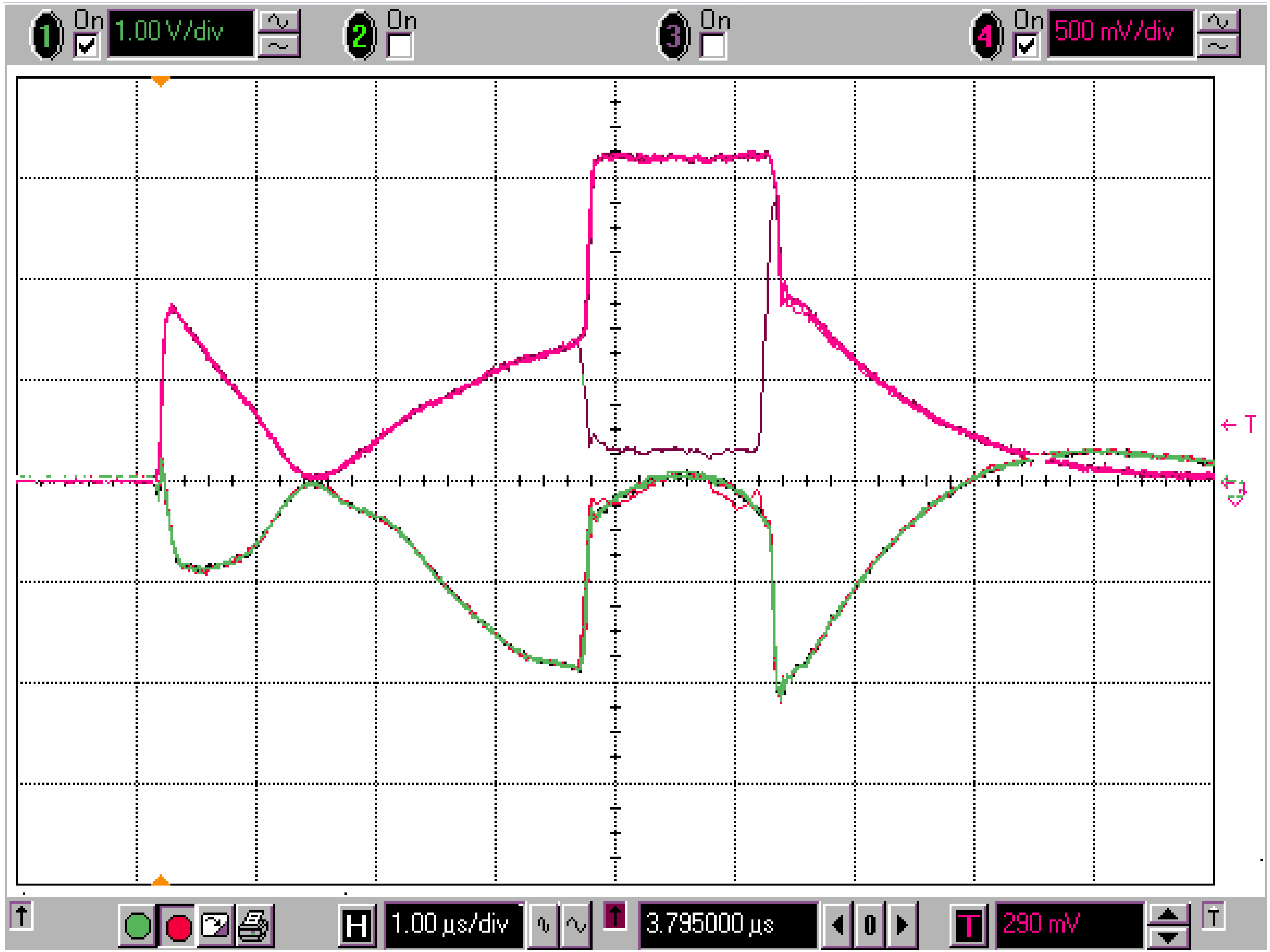


CTF3 beam diagnostic equipment

- A comprehensive beam diagnostic system either developed, or adapted, to special beam requirements of CTF3.
- Three types of BPMs are foreseen, inductive pick-ups with bandwidth of 5 decades, specially developed for long bunch trains, button pick-ups with very fast response and high frequency output for bunch length optimization, and electrostatic pick-ups for measurements inside the solenoid field.
- BPMs also used to measure beam current but when a faster time resolution is required large-band WCMs used –can almost resolve single 3 GHz bunches.
- Beam profile monitoring done using either phosphorescent, or aluminium (or graphite) OTR screens - images analyzed with either CCD or vidicon cameras, or with high time-resolution streak camera.
- The spectrometer lines equipped with SEM grids for horizontal profile measurements which are intended to give fast response to resolve fast position/energy variations within bunch train, but for moment do not work above ~ one tenth of nominal current for some unknown reason.

CTF3 commissioning

- Apart from difficulties with first pre-buncher which experienced multipactor problems and was finally disabled with only very minor changes in performance, the commissioning of CTF3 injector and first part of linac went very smoothly.
- Nominal beam parameters were reached and in some cases even exceeded – obtained 5A of beam current, for example, compared to nominal current of 3.5 A, and rms bunch length was about 4 ps compared to nominal value of 5 ps.
- One of main results was successful and stable operation of SICA structures with their novel HOM damping geometry under full-beam loading conditions. In this regime more than 90 % of RF power from klystrons transferred to beam.
- Important result for CLIC scheme because operation of CLIC drive beam linac in fully-loaded condition is key feature which had to be demonstrated.
- Finally - automatic correction procedure successfully tested in last running period - will hopefully simplify steering manoeuvres in future.



1
On
1.00 V/div
2
On
3
On
4
On
500 mV/div
T
H
1.00 µs/div
3.795000 µs
0
T
290 mV

Preparation for the next CTF3 stages

- Good progress was made in parallel with installation and test programme, to prepare for next CTF3 installation phases.
- Most of equipment been designed, build and ordered.
- Following sections summarize this preparatory work.

Preparation – linac structures, waveguides and loads

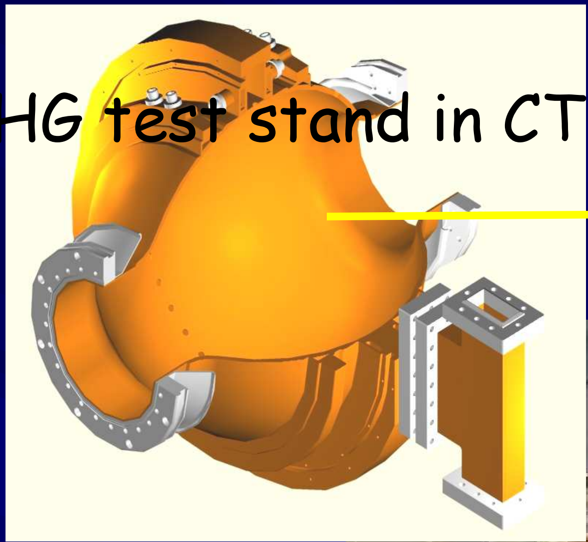
- Industrial manufacturing of SICA structures for drive beam linac now at specified rate, and 5 of 18 structures ordered already at CERN.
- Progress made on development at CERN of high-power loads for SICA structures (industry declined) - first prototype load consisting of two SiC absorber plates electrolytically-bonded to copper WG tested up to 35 MW and 2 μs. Very promising first result but since nominal requirement is for 60 MW and 1.5μs more work required to reach final design.
- Layout of rf power distribution system now frozen, and new design of pumping port developed and ready for tendering.

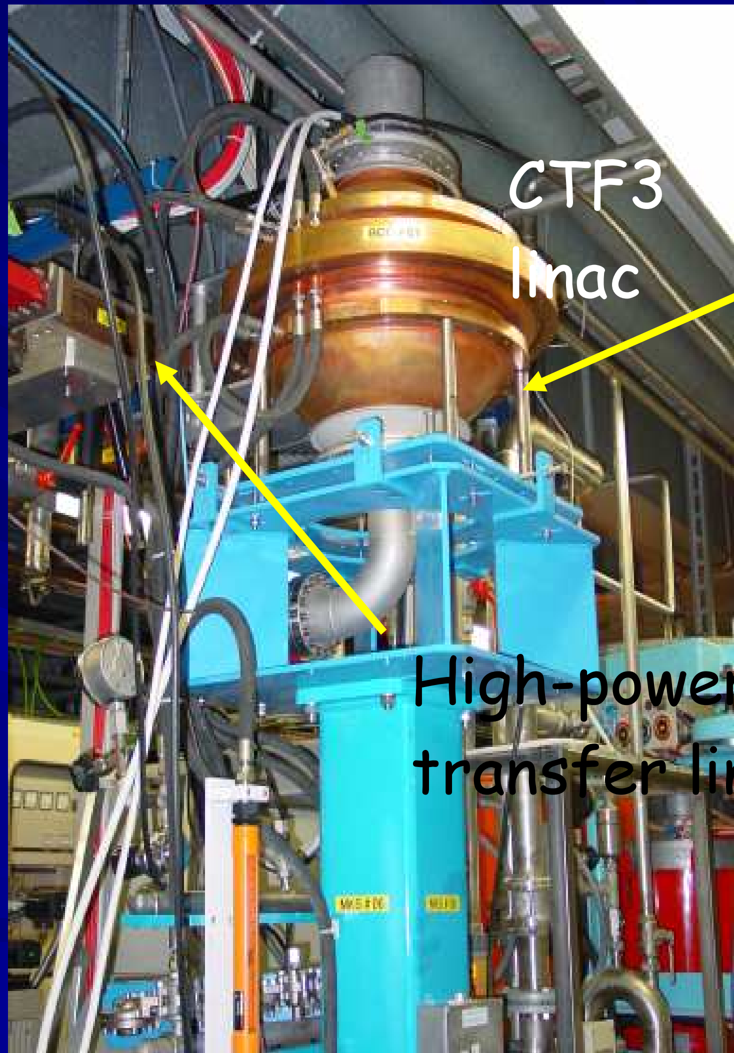
First industrial prototype of the 3 GHz Drive Beam Accelerator Structure for CTF3
being mounted at CERN's high power test stand for acceptance tests.

Preparation – rf power system

- Good progress made with new BOC pulse compression system developed to complement and partly replace existing LIPS systems.
- Prototype systems built including mechanical detuning system to disable these cavities under special operating conditions and a SiC absorber to remove unwanted resonances.
- Prototypes power tested to nominal parameters of 68 MW and 1.5 μs.
- Production of series of 6 BOC cavities underway at CERN.
- Finally - additional modulator constructed this year to complete total number required for CTF3 to 10.

30 GHz power production in CTF3





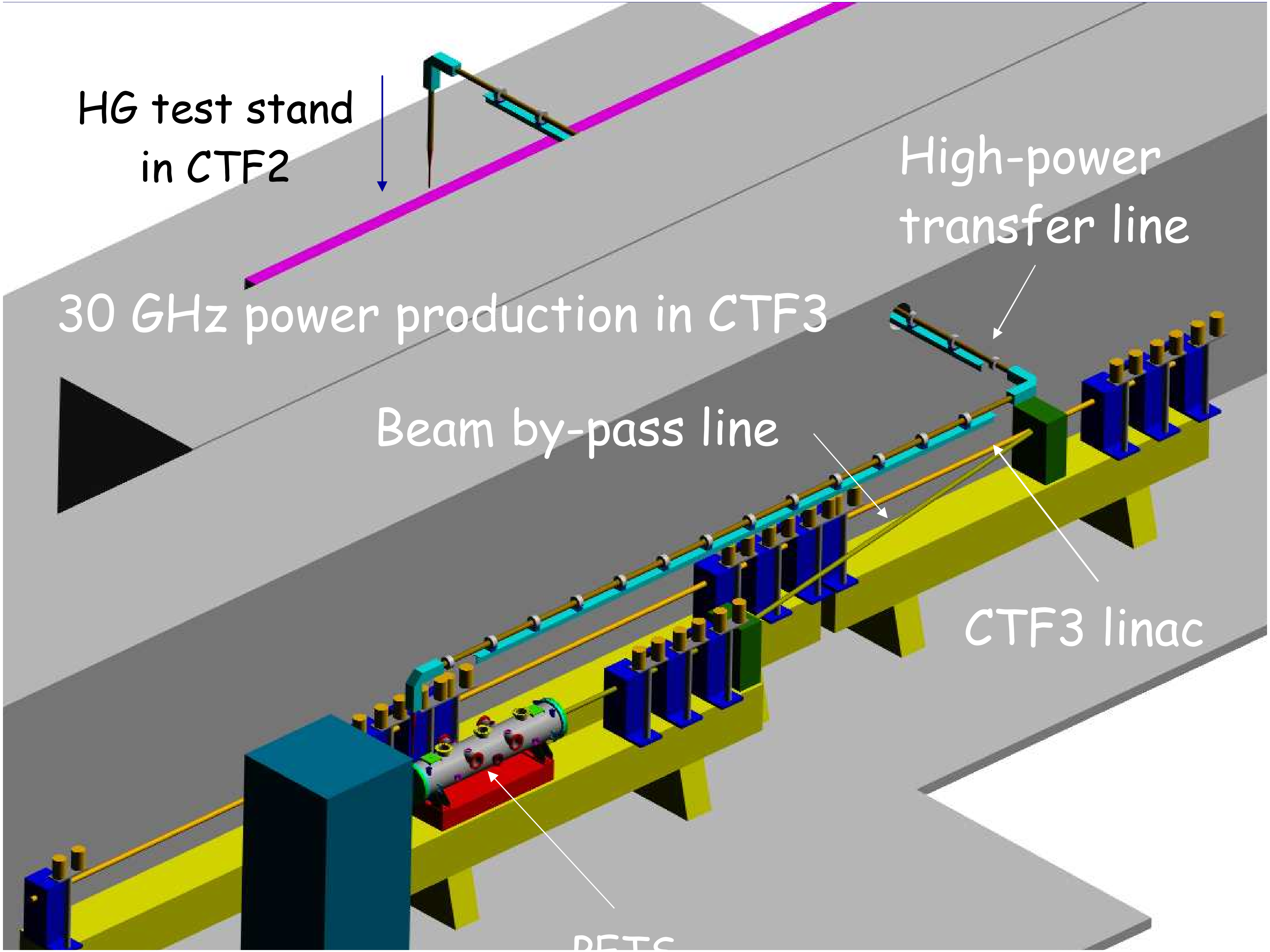
Preparation – sub harmonic bunching system

- One of main CTF3 goals is to demonstrate bunch interleaving technique of CLIC drive-beam generation scheme - to do this, bunches have to be "phase-coded" i.e. subsequent bunch trains have to alternatively occupy even and odd RF buckets.

- For CTF3 this requires 1.5 GHz wide-band (10%) bunching system to enable phase of bunching voltage to be changed very quickly (typically 10-20 ns) - developed low-power cost-effective system for this consisting of three 6-cell large-aperture TW structures each powered by commercially available 40 kW TW tube (Poland).

Preparation – 30 GHz power source

- Since CTF2 closed down at end of 2002, no 30 GHz high-power source available at CERN for testing of CLIC prototype equipment - important to provide new 30 GHz source with nominal length RF pulses ASAP.
- To satisfy this need – planning to build a 30 GHz power-generating line alongside CTF3 linac into which the 300 ns 5A CTF3 beam at ~70 MeV can be switched in a by-pass configuration when required.
- 30 GHz power produced by 1.5 m copper PETS made from 3 segments with 9, 6.7 and 9 mm diameter apertures to match waist of drive beam. In later stage foreseen to replace critical Cu parts by W or Mo.
- Although - potential to produce ~ 100 MW power, output will probably be initially limited to ~ 50 MW to prevent damage to copper PETS.
- Power transferred via low-loss (<5%) line to CTF2 building where HG testing will be done – line is essentially a circular TE01 mode waveguide All parts of line defined and ordered from Russian firm GYCOM.


HG test stand
in CTF2
High-power
transfer line
30 GHz power production in CTF3
Beam by-pass line
CTF3 linac

Preparation – 30 GHz power source - continued

- Test to produce a phase jump of 18 degrees in CTF3 3 GHz bunch train successfully made during one of running periods with view to producing 180 degree phase jump in 30 GHz power pulse for a possible future implementation of SLED-like rf pulse compressor.
- Calculated however that even without a phase shift, a SLED-like pulse compressor would increase 30 GHz peak power from a 4.5 A 700 ns drive beam from 80 MW to 170 MW – enough power to generate gradient of 150 MV/m in latest HDS design of accelerating structure.

CTF3 photo-injector studies

- Eventually planned to replace CTF3 thermionic injector by PI.
- A major step towards this was made in Spring 2003 with the PILOT test (Photo-Injector Long Train) which used existing CTF2 RF gun, and diode-pumped laser amplifier built by RAL to produce long train of 250 electron pulses.
- As well as demonstrating technical feasibility of this scheme – it also served to identify and find solutions for the different sources of instability, and to demonstrate the validity of the simulations.
- Following this test confidence high that CTF3 specification can be met.
- Also took advantage of this test to do some more dark current measurements. Found that up to 100 MV/m, the caesium telluride layer does not produce a significant increase of dark current.
- Several Pockels cells also tested to check ability to produce required temporal behaviour - nominal phase coding produced with 20 ns rise and fall times, but with 2% residual signal, due to acoustic vibrations.

  Believed this can be improved by collaborating with manufacturers.

Construction of a CTF3 photo-injector

- A demand to finance construction of photo-injector for CTF3 made within European Union FP6 programme as a CARE JRA entitled "Charge Production with Photo-injectors" (PHIN).
- JRA which involves participations from 8 European collaborating institutes was accepted.
- CTF3 PI part divided into 3 parts: laser - to be developed and built by RAL, RF gun by LAL, and PCs, installed and commissioned by CERN. JRA also aims to improve performance of present caesium telluride photocathodes and to develop new photocathode materials.
- In light of above, second part of 2003 dedicated to dismantling of former CTF2 to prepare for installation of laser room and new PI.

CTF3 collaborations and external resources

- A collaboration meeting with all partners was held at CERN in September, where impressive progress was reported by all collaborators.
- Important step taken in December with signature of CERN/INFN collaboration agreement - INFN takes responsibility for design and construction of DL and TL from linac to DL which includes magnetic chicane for bunch length manipulations.
- Status - layout finalized, detailed technical work underway, all necessary components being manufactured. In particular, fabrication of all components of magnetic chicane well advanced, and installation planned during 2004.
- LAL - 2 pre-bunchers, gun HV system (+ pulser), installed and commissioned.
- Uppsala – contd. work on bunch phase monitor - provided operations support.
- NW University (Illinois) joined project as new collaboration partner - have part paid for one SICA structure - now developing fast beam-loss monitoring system. Prototype beam-loss monitors already tested in CTF3 during 2003.
- SLAC – in 2003 participated in commissioning of injector (+ loan of triode)

Interfacing with CLIC Physics Study Group

- CLIC physics study group again very active in 2003 simulating collisions using latest CLIC parameters and luminosity spectra provided by the CLIC Machine Study Members.

- A report on physics potential of CLIC has been written and will be published early 2004.

Technical publications of the CLIC Study Group

- More than 49 CLIC Notes written
  http://ps-div.web.cern.ch/ps-div/CLIC/Publications/2003.html
- 8 CTF3 Technical Notes
  http://ps-div.web.cern.ch/ps-div/CTF3/Lists/2000.html

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