# ML Quad Requirements and Specs

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# Latest changes in ML

**CCR#24a**: ***Change of the cryomodule (CM) layout* driven by each of the 10MW klystron RF unit.**

Previously' RF unit consisted of two 8-cavity C M's magnet and one 8-cavity CM with a magnet **(8-8-8).**

New RF unit consist of two 9-cavity CM without a magnet and one 8-cavity with a magnet **(9-8-9).**

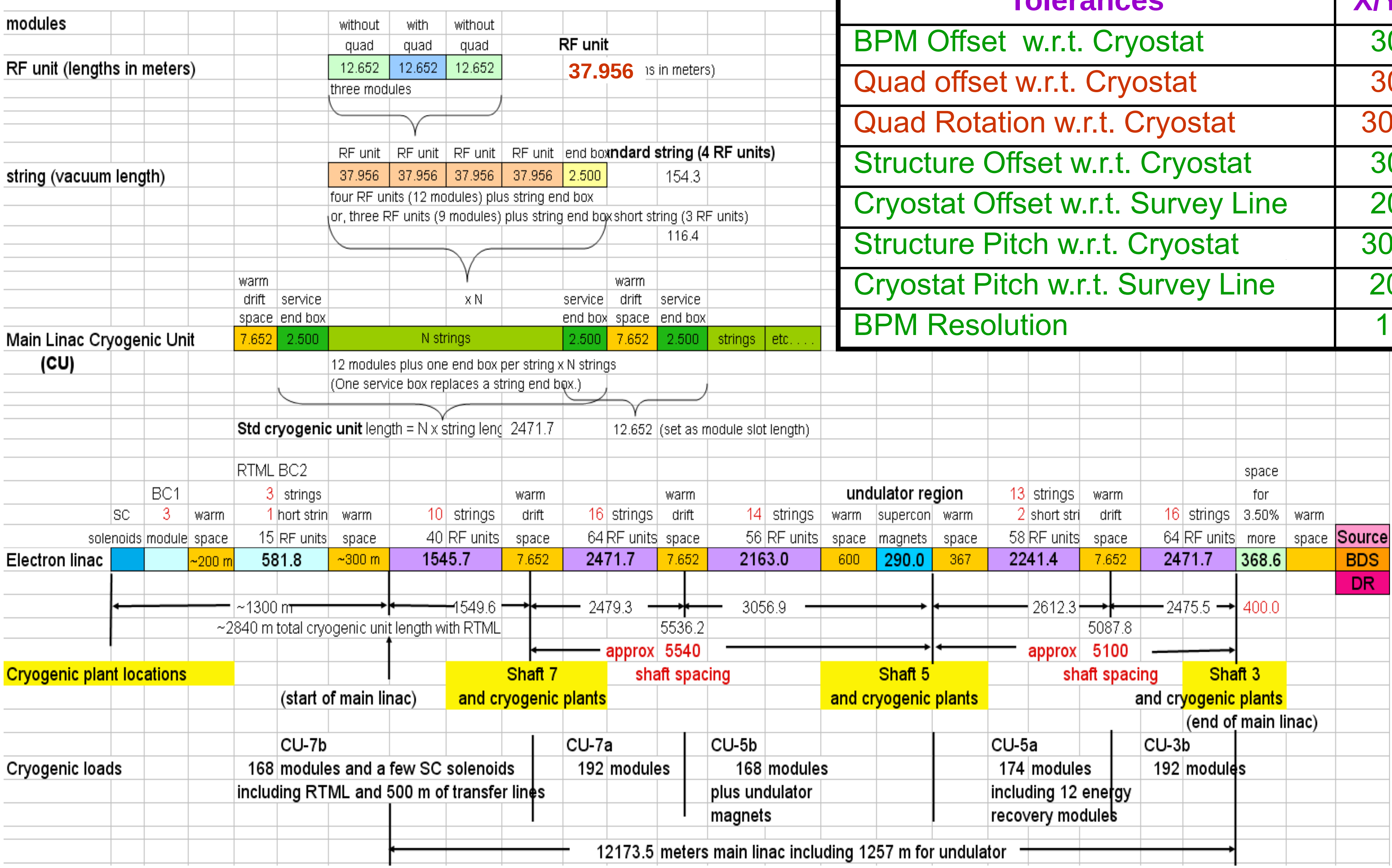
Thus, **26 cavities** are to be driven by one 10MW klystron rather than the previous 24.

**CCR#24b**: ***Elimination of RF unit overhead.***

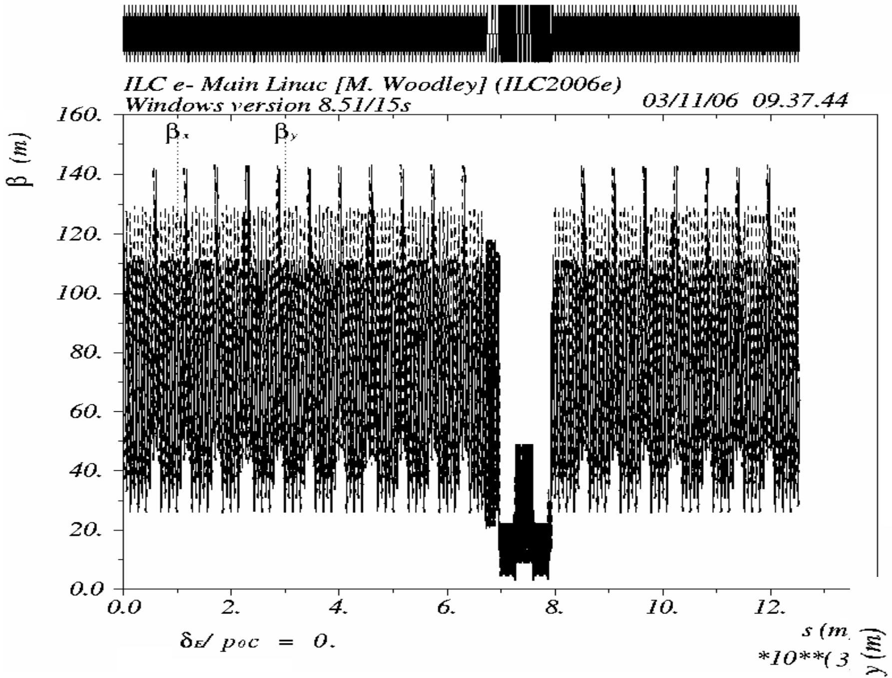
Previously, 3.5%. **Now, 0%.** However, the conventional facilities, including the tunnels, are to be maintained to accommodate the missing 3.5% worth of RF systems if/when determined needed.

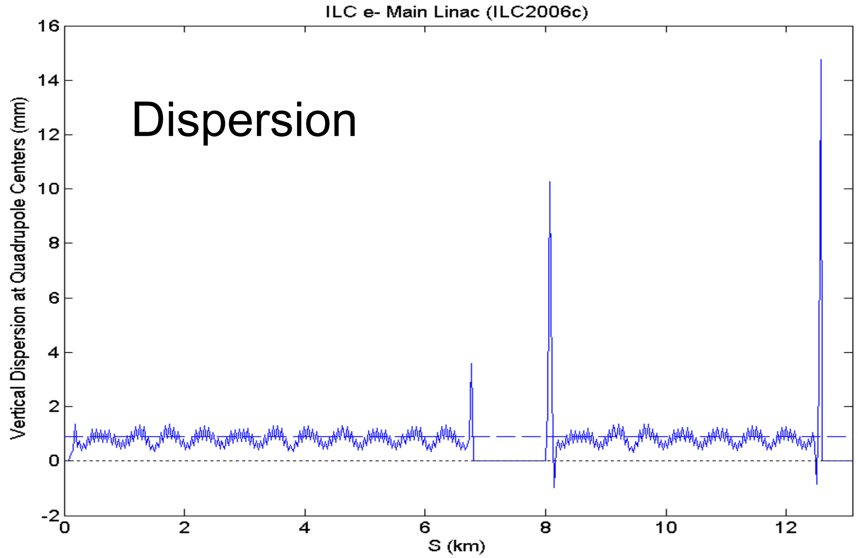
# Main Linac 9-8-9 Lattice

| Tolerances | X/Y plane |
|---|---|
| BPM Offset w.r.t. Cryostat | 300 µm |
| Quad offset w.r.t. Cryostat | 300 µm |
| Quad Rotation w.r.t. Cryostat | 300 µrad |
| Structure Offset w.r.t. Cryostat | 300 µm |
| Cryostat Offset w.r.t. Survey Line | 200 µm |
| Structure Pitch w.r.t. Cryostat | 300 µrad |
| Cryostat Pitch w.r.t. Survey Line | 20 µrad |
| BPM Resolution | 1.0 µm |

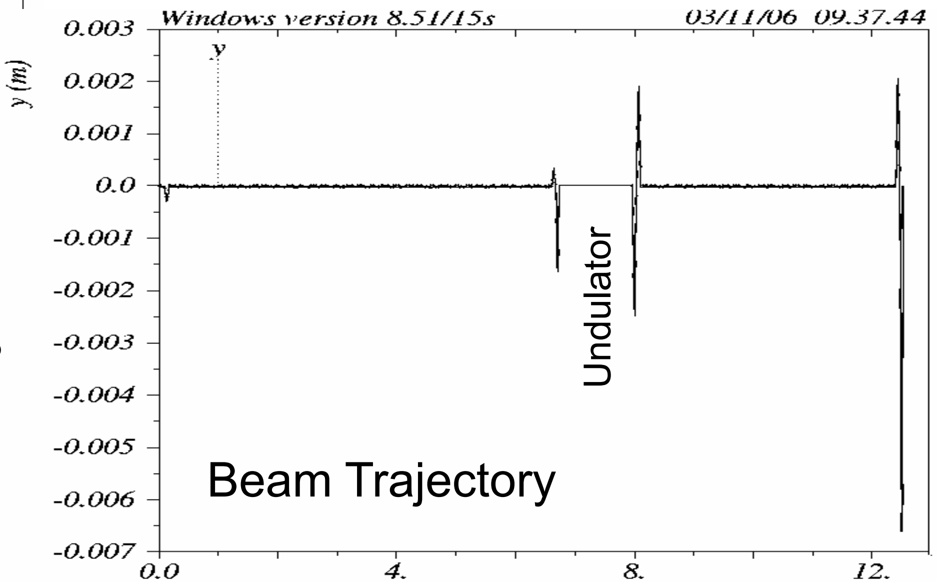


# ILC Lattice. Curved linac

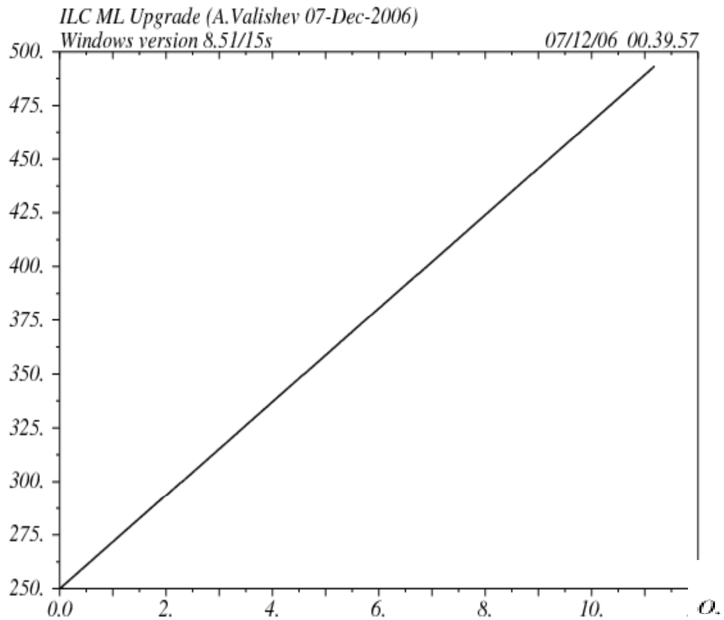


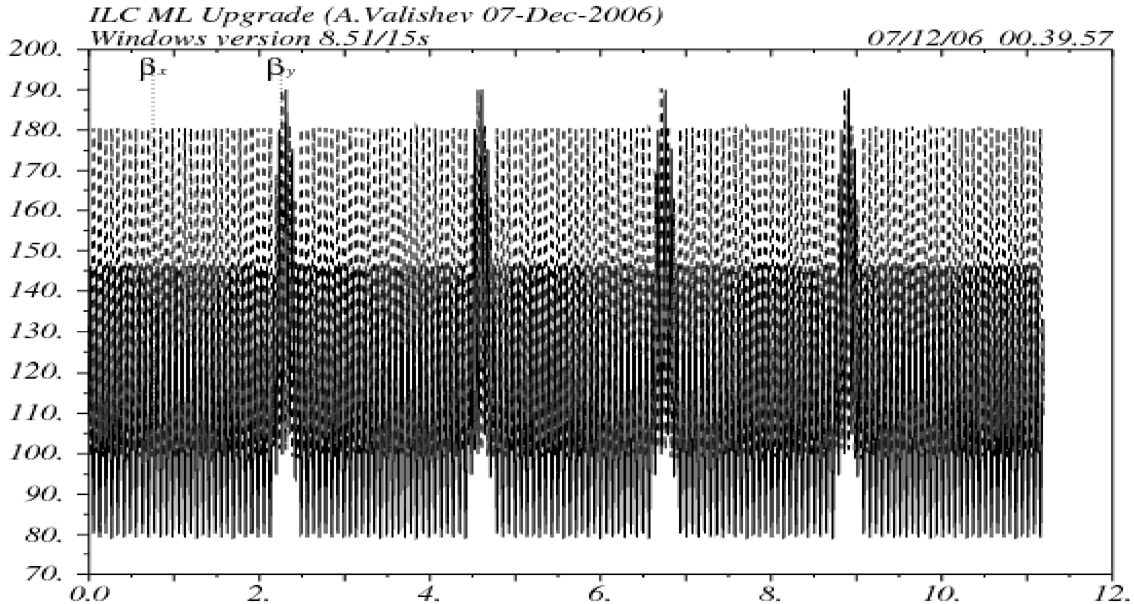



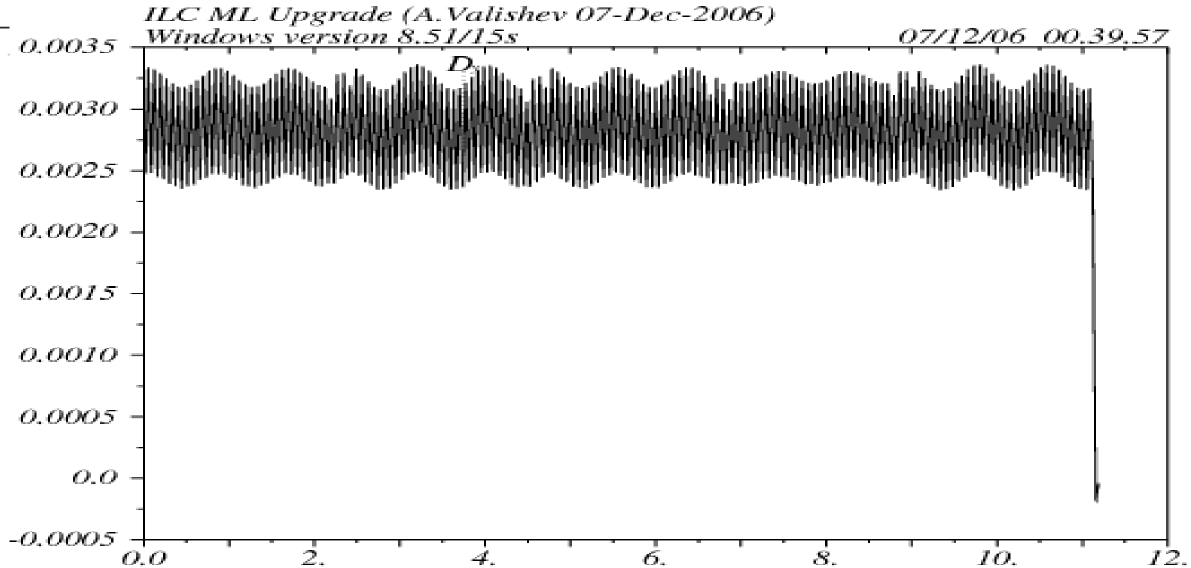

- 1Quad/3CM (9-8-9) Lattice
- Spacing ~38m
- x/y phase advance = 75°/60°
- ~10% strength variation in matching sections



# Energy Upgrade path




<u>HE Linac (250-500 GeV)</u>

- Half-phase advance, 30deg
- Same layout 1Q/3CM
- Same Quad strength
- Stronger Correctors (~10% if the same curvature)

# Number of quads

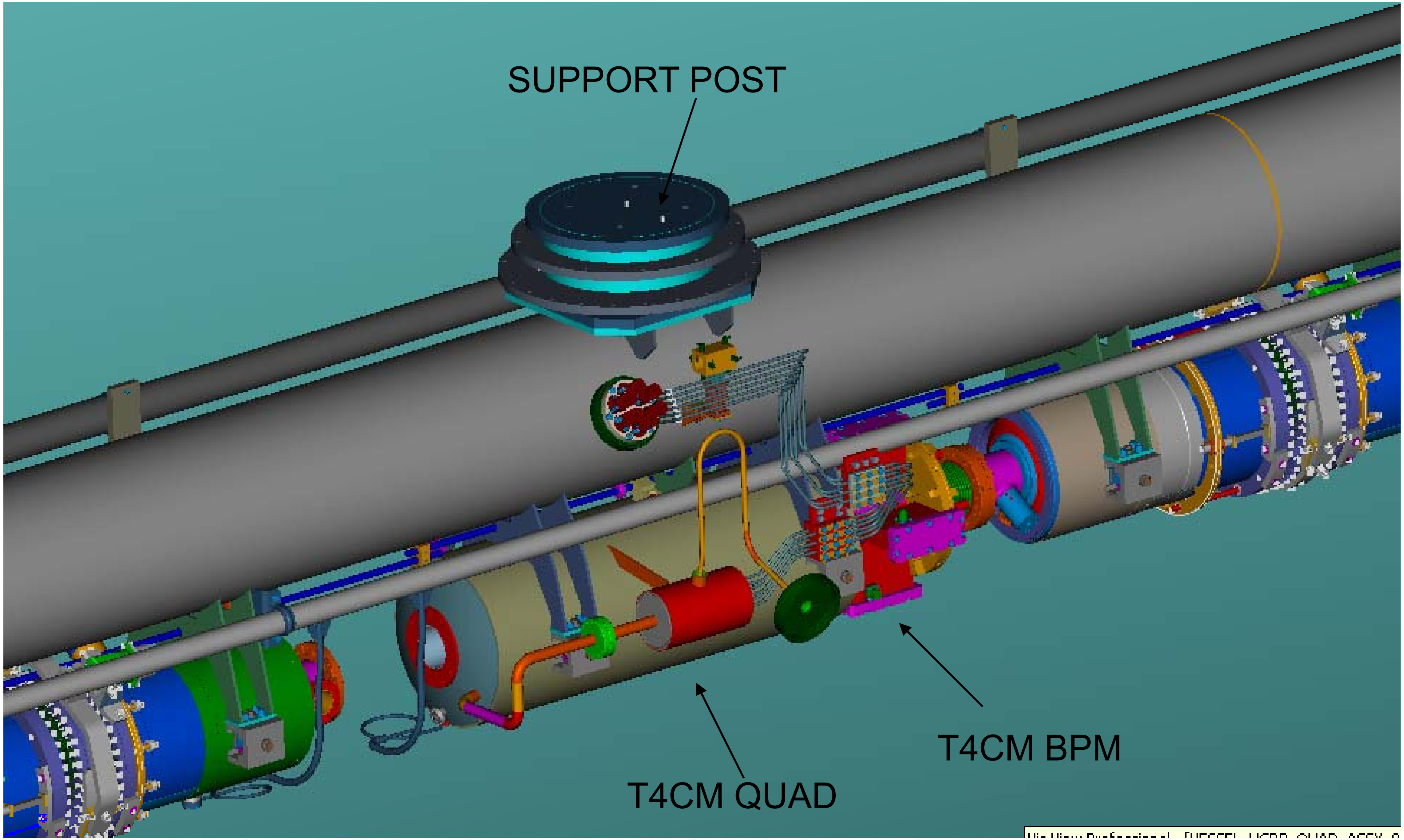
| **Main linac** (15-250 GeV) | **# CM** | **# Quad** |
|---|---|---|
| Electron Linac* | 846 | 282 |
| Positron Linac | 834 | 278 |
| Overhead (3.5%) | 30+30 | 10+10 |
| **Total** | **1680+60**** | **560+20**** |
| **RTML** | 96 | **36** |

*Includes 12 CMs to recover 3 GeV energy losses in undulator

** Spares (for 3.5% overhead option)

RTML system uses the same CM and quad (LE design)

# T4CM QUAD AND BPM (Without Shield)



# Quad Strength

Integrated Quad strength is defined by quad spacing, required phase advance and beam energy.

$$B' \cdot L = \frac{Energy}{e} \cdot \frac{2}{s} \cdot \sin(\frac{\mu}{2}) = \frac{Energy(GeV)}{0.3} \cdot \frac{2}{s} \cdot \sin(\frac{\mu}{2}) \quad [Tesla]$$

- Quad spacing ***s = 38 m*** (9-8-9 cavities in RF unit)
- Designed phase advance ($\mu x / \mu y$) = 75°/ 60°. For flexibility quad should provide optics with phase advance ***$\mu$ = 90°*** up to E=250 GeV.
- Quad effective length = 0.626m

$$B' \cdot L = \frac{250}{0.3} \cdot \frac{\sqrt{2}}{38} \approx 31 \ T \qquad B'\left[\frac{T}{m}\right] \approx 50 \cdot \left[\frac{Energy}{250\,GeV}\right]$$

- Add 20% for matching, etc. $B'_{max} \approx 60 \ [T/m]$

# Magnet strength errors (K.Kubo) (quad and dipole correctors)

***1.Vertical position change due to magnet strength error.***

- ***Relative magnet strength*** < $2.10^{-5}$ ➔ $0.14\sigma$ rms beam offset

(Random 0.14 $\sigma$ offset of each beam will make average position offset 0.2 $\sigma$ between two beams at IP, which will decrease luminosity about 3%, without beam-beam force.) - Can be corrected in train

- Very tight but relevant only for ***fast jitter***, faster than orbit feedback

***2. Emittance increase due to magnet strength error.***

- ***Relative magnet strength*** < $2*10^{-3}$ ➔ $\Delta\varepsilon/\varepsilon_0$ less than 0.063

(Emittance increase by 0.063 will decrease luminosity about 3%, without beam-beam force.)

- ***Stability*** slower than orbit correction

# Quad specs

- ***Dimensions:***
  - Beam pipe diameter = 78 mm
  - Quad total length (z- slot) ~ 0.66m  (TESLA - 0.666 m)
- ***Maximum Integrated gradient:*** (if L=0.66 m)
  - (B'*L) = 37 T (B' = 60 T/m) - at 250 GeV
- ***Max current:*** (at 250 GeV) = 100A
- ***Stability***:
  - faster than orbit correction (<1 ms) < 2.e-5
  - slower than orbit correction (>0.2 s) < 1.e-3
- ***Higher harmonic tolerance***: not studied yet
  - Skew quad < 3.e-4 (at reference radius 5mm)
  - High harmonics < 1.e-3 (at r=5mm)
  - Field in cavity region <10 $\mu$T (at r=35mm, z~650 mm from quad center. Cavity has magnetic shielding)

# Quad specs (cont.)

## *Alignment tolerances (installation) :*

- *X/Y Position* < 0.3 mm *(rms)*
- Pitch, yaw, roll : < 0.3 mrad
  - **Reference: TDR alignment (angle) < 0.1 mrad (~5um@ 50mm)**
- Roll tolerance are tight, needs built-in skew corrector (?)

## *Field changes:*

- 20% of nominal for quad shunting (finding BPM-Quad offset),
- 100% for ballistic alignment
- Within a few seconds
- Center motion:  below 2 um for 20% quad strength changes

## *Upgrade Path (500GeV/linac):*

- twice weaker lattice at high energy (>250GeV)

# Correctors

- Corrector will bend beam in vertical plane to transport beam along earth curvature and correct beam offset $\Delta y$

$$H \cdot L = \frac{Energy\,[GeV]}{0.3} \cdot \left[ \frac{2\Delta y \cdot \sin(\mu/2)}{s} + \frac{s}{R} \right] \quad [T \cdot m]$$

*where **s** - quad spacing, **R = 6400 km** - Earth radius.*

- RMS Quad alignment offset: 0.3 mm; 3σ ≈ 0.9 mm;
- Corrector max field to correct ±1.5 mm beam offset @250 GeV

$$(H \cdot L) = 0.049 \quad [T \cdot m] \qquad\qquad H = 0.074 \;\; Tesla$$

- Corrector strength to deflect beam in vertical plane along earth surface is ~10 % of strength needed for beam/quad offset correction.
- One corrector for vertical beam deflection in every magnet package and one for horizontal beam deflection in every second package.

# Correctors specs

•***Maximum integrated strength***
(at 250 GeV to correct ± 1.5 mm beam offset)

- **0.05 [T·m] integral strength or 0.074 T (L=0.66m) for 1Q/3CM lattice**
- **<10% of strength needs to deflect beam along the Earth curvature**

***Max current:*** (at 250 GeV) = 40A

***Stability:*** same as for quads.

- Field change: by a few percent in 0.2 s, every 0.2 s
- Change step: (~1μm of quadrupole motion)
  - **2.e-6 T*m at 15 GeV**
  - **3.e-5 T*m at 250 GeV**

# Specifications

| | | | |
|---|---|---|---|
| Quad | Beam pipe diameter | 78 | mm |
| | Inner coil diameter | 90 | mm |
| | Coil Length | 626 | mm |
| | Gradient, max | 60 | T/m |
| | Operating T | 2 | K |
| | Nominal Current | 100 | A |
| | Max Field at conductor | 3.6 | T |
| | N turns/pole | 1007* | |
| | Inductance | ~3.2* | H |
| Field quality | Skew quadrupole | 3.e-4 | |
| | Higher harmonics* | 1.e-3 | |
| | Alignment error (angle) | 0.1 | mrad (rms) |
| Dipole coil | Length (if separate) | < 350 | mm |
| | Max Current | 40 | A |
| | Max Field at conductor | 3.6 | T |
| | Max Field at axis | 0.074 | T |
| | Inductance | ~29* | mH |

**( Some specs are copied from TESLA TDR as a reference)**

*Tolerances for higher harmonics are probably looser. Need to check.

# Summary of preliminary magnet studies

- Linac SC magnets are feasible. Review - April 5, 2007.
- HE magnet design is done. LE magnet in progress.
- SC wire for Quad and correctors are available
- Prototyping are needed to confirm the specified performance, cost and efficiency
- New Cryostat are needed to upgrade existing test stand

- *Main issues:*
  - Optimal quadrupole configuration
  - Integrated field range (low:high)
  - Magnetic center stability during –20% field change
  - Combined or stand alone correctors ?
  - Fringing fields in SCRF areas from magnet package
  - Effective current leads

# HOM Absorber Efficiency at High Frequencies

$f_{rep} = 5$ Hz
$T_{HF} = 0.95$ ms

**a) Collider (500GeV)**

$\sigma_{bunch} = 400\ \mu m$
$N_{bunch} = 2820$
$q_{bunch} = 3.2$ nC (9.5 mA)

losses per module (12x9cells):

$P =$ 23.3 W
$P(f > 5\text{ GHz}) =$ 17.4 W
$P'(f > 10\text{ GHz}) =$ 12.7 W
$P'(f > 20\text{ GHz}) =$ 8.1 W
$P'(f > 50\text{ GHz}) =$ 3.0 W
$P'(f > 100\text{ GHz}) =$ 0 .7 W

(M. Dohlus, absorber_zeuthen_dohlus.pdf)

For 300 micron bunch the total losses in CM (8cav x 9cells) are about 16 W. Loss spectrum at low frequencies is about the same.

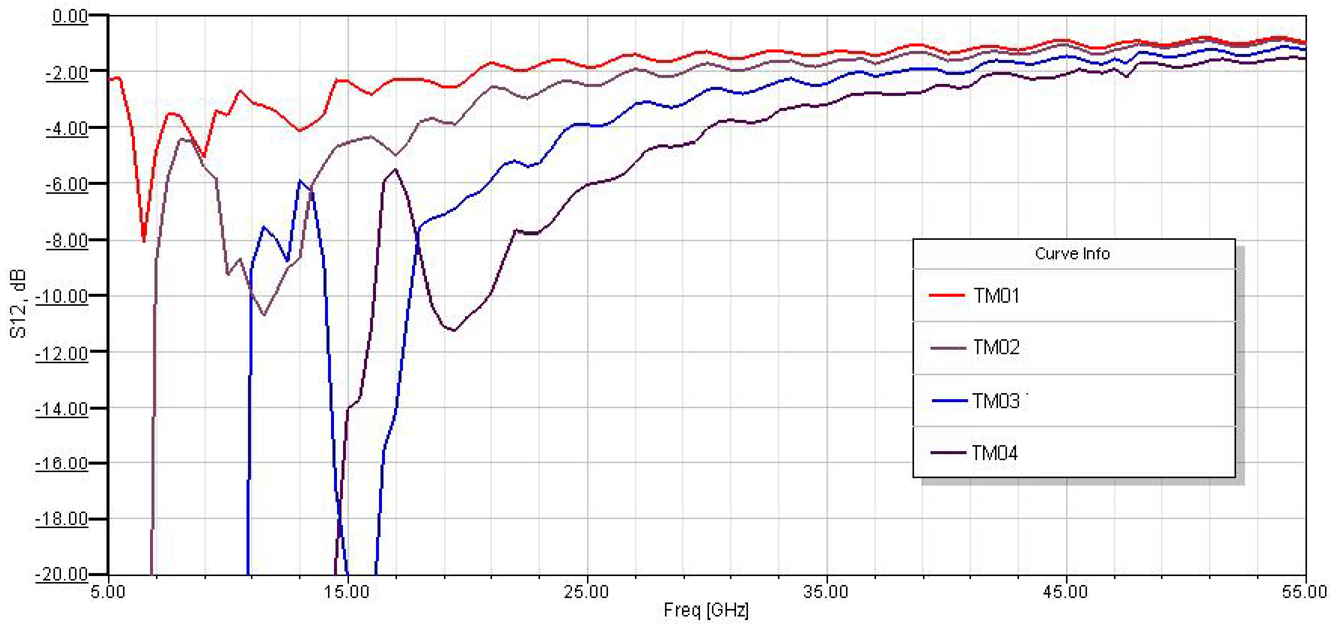
## Absorbing efficiency estimations at high frequencies:

$$\eta \approx \frac{2L\lambda^2}{\pi^2 a^3}$$

L- length of the absorbing ceramic ring, a – it's internal radius, λ –wavelength.

Efficiency drops with the wavelength!

Simple mode of HOM absorber




At the frequencies ~30 GHz absorption is about 20% and 10% at 50 GHz. It drops when the frequency increases (not as fast as $f^{-2}$ because of mode transformation)

Ceramics ring diameter should be higher than beam pipe diameter in order to improve efficiency at low frequencies

Further HOM absorber investigations are desired in order to improve its properties at HF.

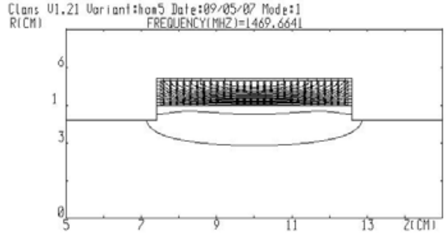
## Losses caused by the beam in ceramics are small, ~0.15 W.

No high Q trapped modes, no coherent excitation.

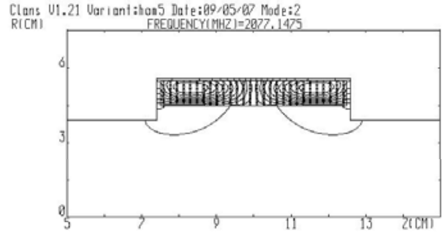
Trapped modes:

| Mode | Frequency, MHz | Q | Time constant, nsec |
|---|---|---|---|
| $TM_{010}$ (ceramics) | 1.469 | 8.8 | 1.9 |
| $TM_{011}$ (ceramics) | 2.077 | 10.2 | 1.6 |
| $TM_{012}$ (ceramics) | 2.674 | 9.5 | 1.1 |
| $TM_{010}$ (vacuum) | 2.835 | 21.2 | 2.4 |

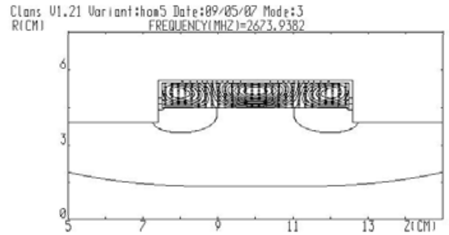
TM010 (ceramics)



TM011 (ceramics)



TM012 (ceramics)



TM010 (vacuum)