From Beam Dynamics

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Lattice choice
Number of cavities / Quad magnet

Tested Lattices for ECM 500 GeV

(Check if number of quads can be reduced from RDR)

A: 3 modules / quad (same as RDR, but 24 cavities / quad instead of 26)

B: 2 modules / quad in 1/3 upstream part and 4 modules / quad in 2/3

- Same number of quads in a linac as the case A
- Smaller beta-function (stronger focusing) in the low energy part.
- Almost the same as RDR from beam dynamics

C: 4 modules / quad

- Fewer magnets per linac than A
- Same quad strength (beam energy normalized) as A (more phase advance/cell)

D: 4 modules / quad

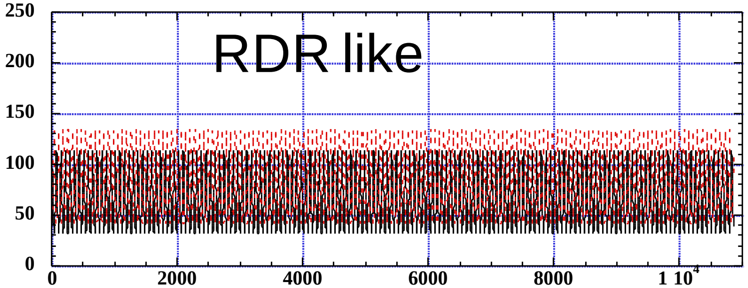
- Fewer magnets per linac than A
- Same phase advance/cell as A (weaker quad strength)

E: 5 modules / quad

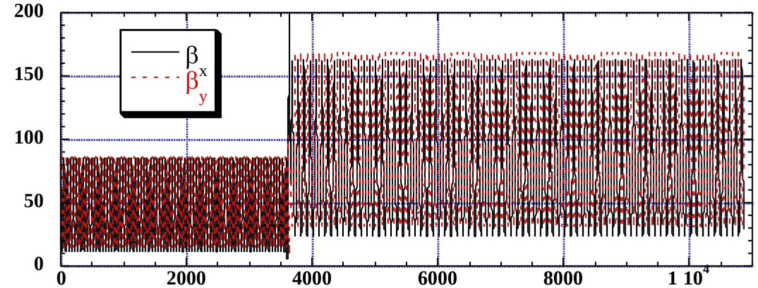
- Fewer magnets per linac than A
- Same phase advance/cell as C

Beta-functions

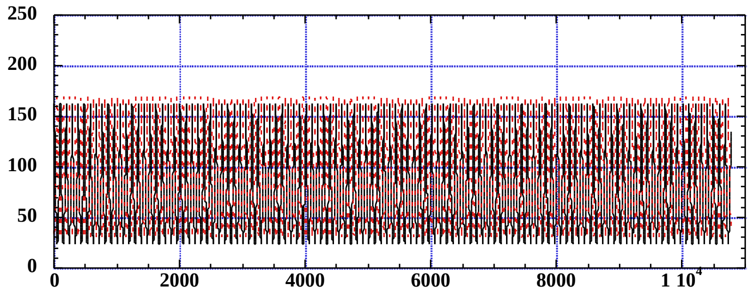
A



B



C



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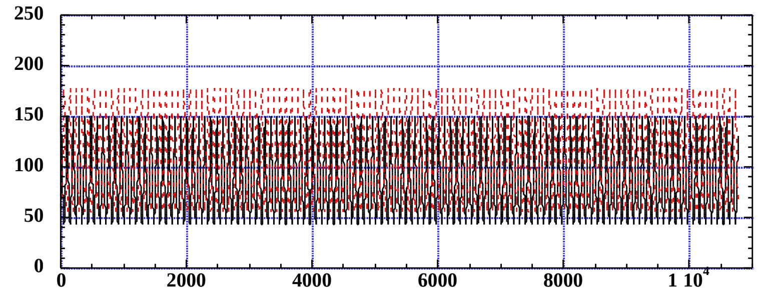

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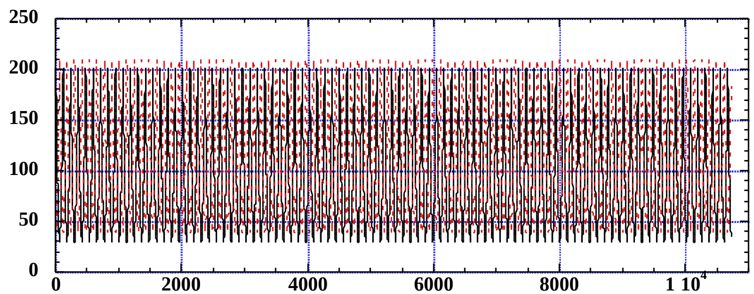
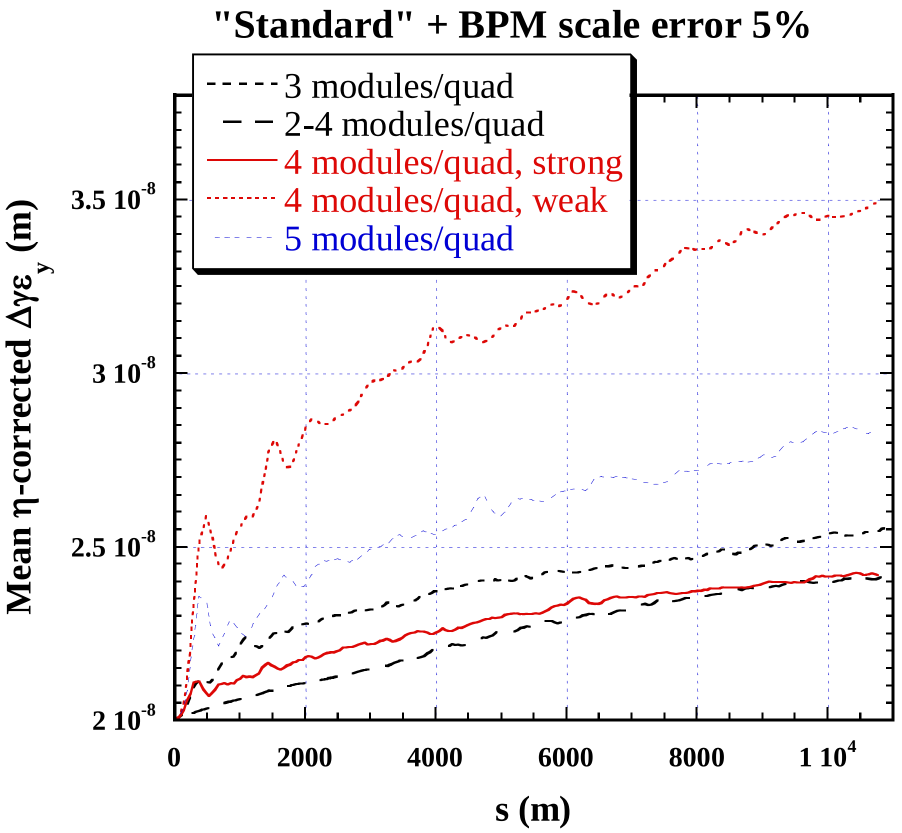


Simulation results of DFS with “standard” static errors + BPM Scale error 5%



Smaller designed dispersion is better.

For ECM up to 500 GeV

With standard errors and DMS corrections

- Emittance growth in the cases 3 modules/quad (RDR) and 4 modules/quad with same quad strength are similar
- Larger emittance growth in 2 modules/quad and 5 modules/quad with BPM scale error (5%).

→ Both 3/quad and 4/quad are OK.

Presently Proposed Lattices for upgrade to ECM 1000 GeV

- Different Quad design from15 to 25 GeV and from 25 to 250 GeV for ECM 500 GeV
- Keep most of old linac (from 25 to 250 GeV) as downstream part of new linac (275 to 500 GeV).
- Upstream part of new linac (15 to 275 GeV) has same lattice design as old linac.

Studied Lattices for upgrade to ECM 1000 GeV

- Keep old linac (15 to 250 GeV) as downstream part of new linac (265 to 500 GeV).
- Upstream part of new linac (15 to 250 GeV) identical to the old linac.

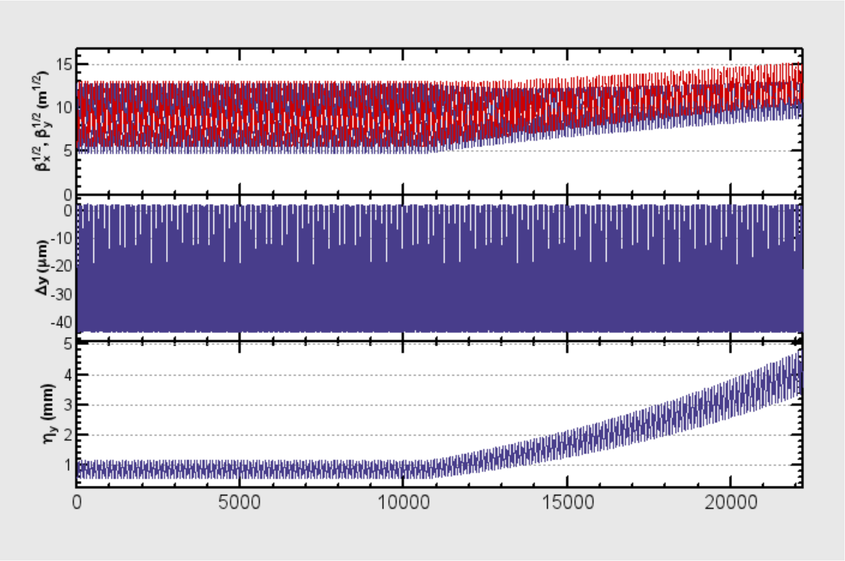
Not exactly the same as the proposed design.

But no significant difference in beam dynamics.

2 x 2 = 4 choices:

- 3 modules/quad or 4 modules/quad
- FODO or FOFODODO for E_beam > 250 GeV

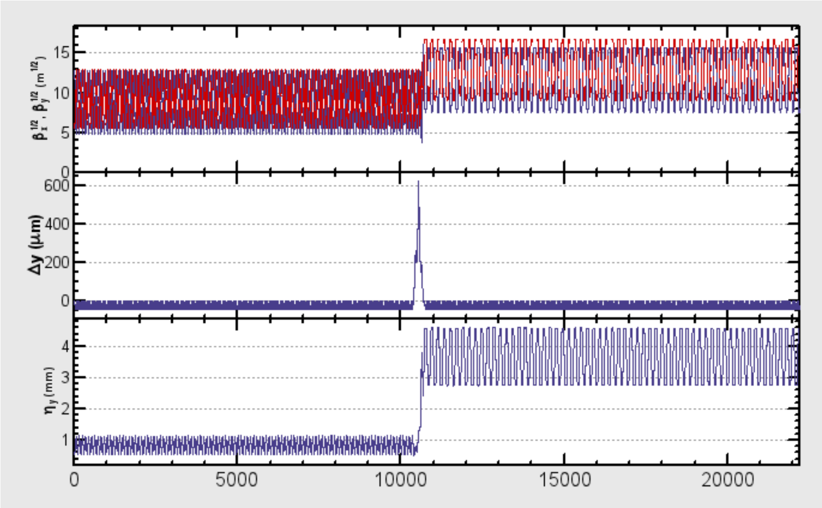
4 modules/quad FODO



Strengths of quads in E_beam > 250 = Strength at 250 GeV

Or, K1 ~ 1/E_beam

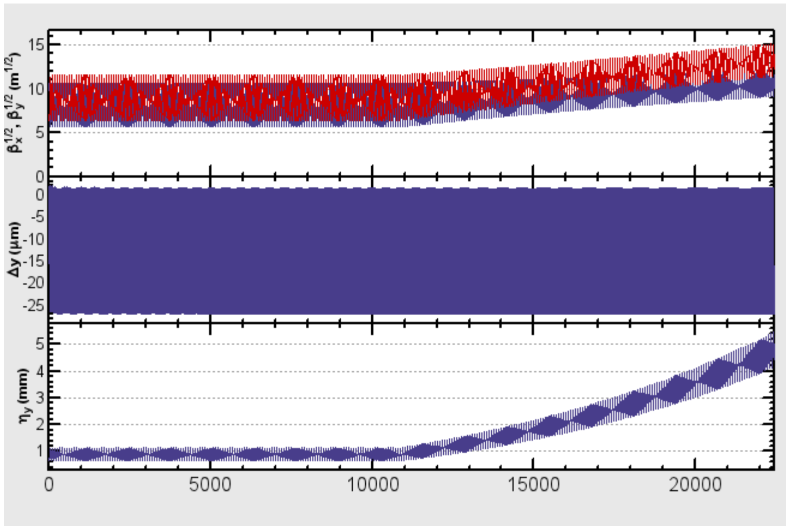
4 modules/quad FOFODODO



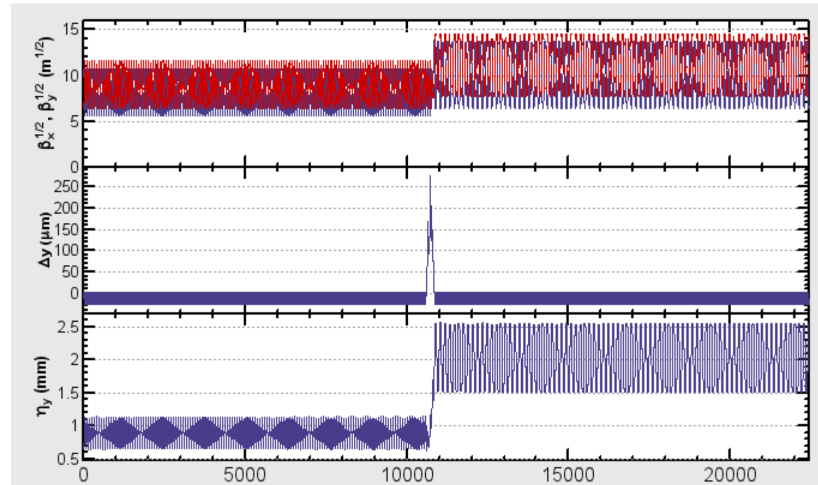
Strengths of quads at E_beam = 500 = Strength at 250 GeV

Or, K1(E_beam > 250 GeV) = 1/2 K1(E_beam < 250GeV)

3 modules/quad FODO



3 modules/quad FOFODODO

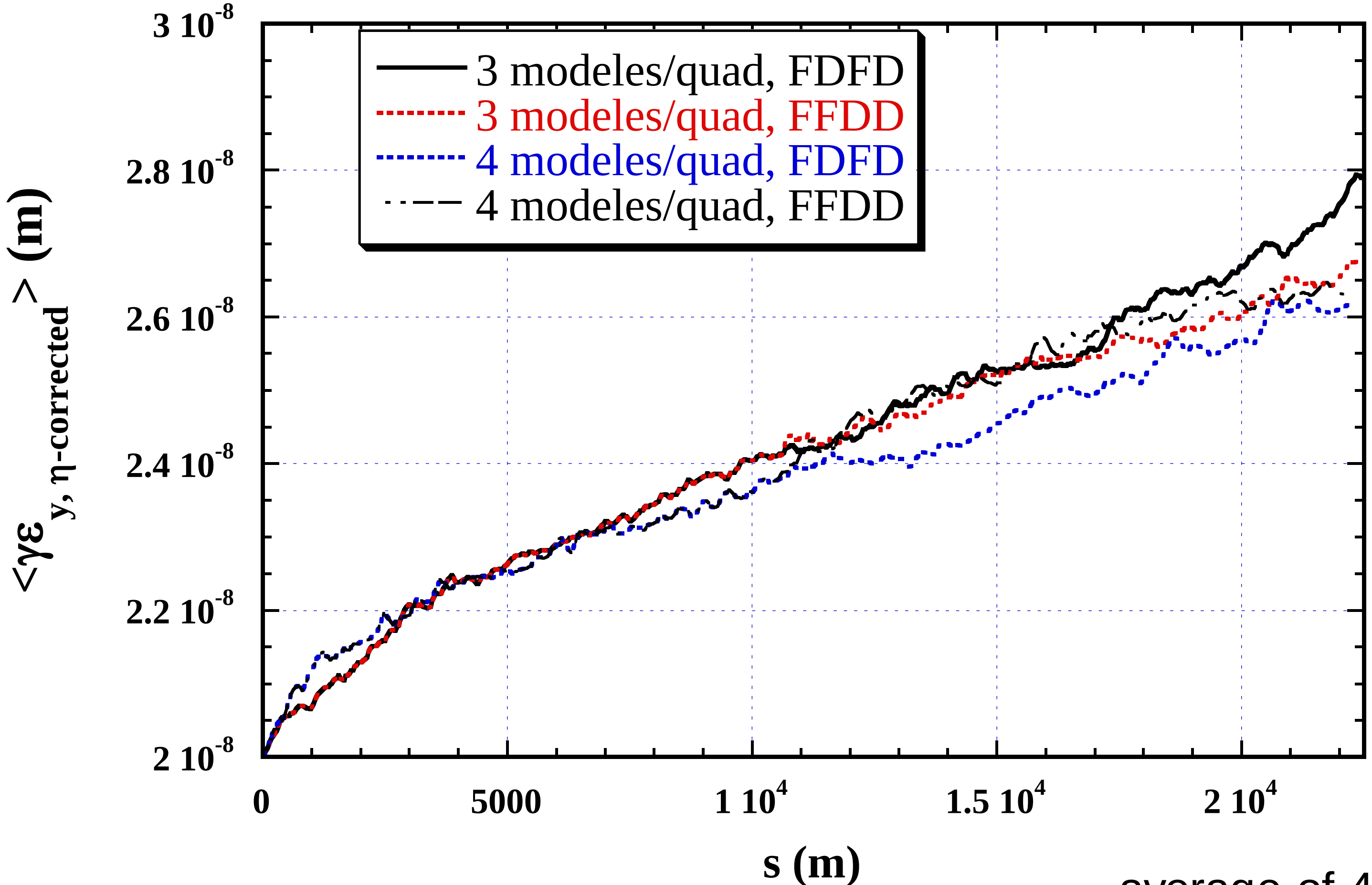


Strengths of quads in E_beam > 250 = Strength at 250 GeV
Or, K1 ~ 1/E_beam

Strengths of quads at E_beam = 500 = Strength at 250 GeV
Or, K1(E_beam > 250 GeV) = 1/2 K1(E_beam < 250GeV)

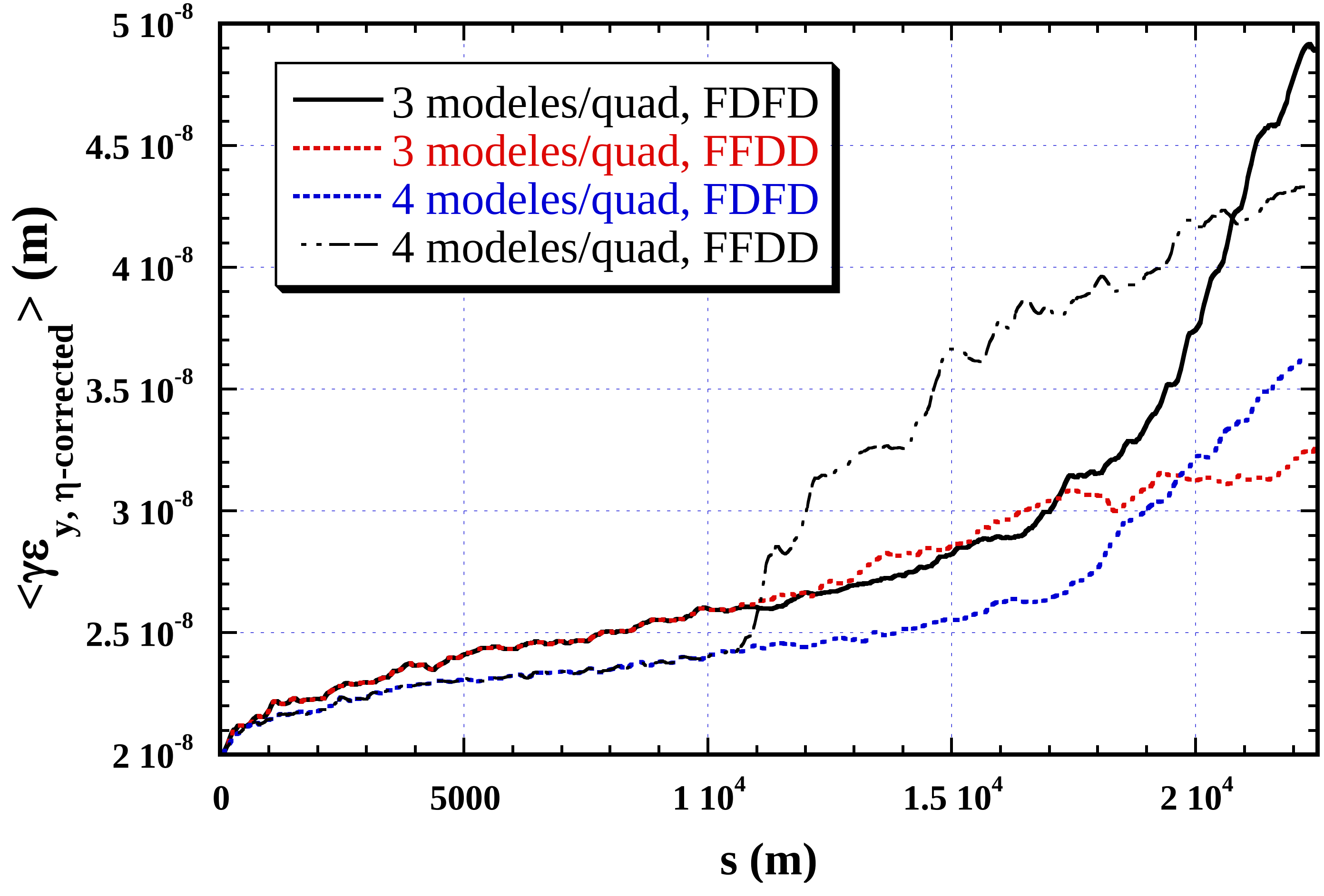
FFDD has smaller beta and dispersion compare with FDFD with the same quad strengths.

Simulation results of DMS (Dispersion Matching Steering) with “standard” static errors



average of 40 seeds

Simulation results of DMS with "standard" static errors + BPM Scale error 5%



average of 40 seeds

Summary for lattice design including ECM 1 TeV upgrade

With standard errors and DMS corrections

- 4 modules/quad will have larger emittance growth with BPM scale error (5%), (because of larger designed dispersion)

→ Choose 3 modules/quad (same as RDR),

→ FFDD for downstream part of 1 TeV.

Keep 25~250 GeV part of 250 GeV ML as 275~500 GeV.

(Same spec for magnets of 25~250 GeV. Special design for 15~25 GeV)

- No significant difference between 26 and 24 cavities /quad magnet

Assumed Tolerances

Orbit jitter sources in ML

Source	Assumption (Tolerance?)	Induced orbit jitter	Induced emittance growth
Quad vibration (offset change)	100 nm	1.5 sigma	0.2 nm
Quad+steering strength jitter	1E-4	1 sigma	0.1 nm
Cavity tilt change	3 urad	0.8 sigma	0.5 nm
Cavity to cavity strength change, assuming 300 urad fixed tilt	**1%**	**0.8 sigma**	**0.5 nm**

Tolerances, tolerable timescale depend on feedback performance.
We will need post linac (between ML and BDS) intra-pulse feedback.

Local Alignment Error in ML

Error	RTML and ML Cold	with respect to
Quad Offset	300 µm	cryo-module
Quad roll	300 µrad	design
RF Cavity Offset	300 µm	cryo-module
RF Cavity tilt	300 µrad	cryo-module
BPM Offset (initial)	300 µm	cryo-module
Cryomoduloe Offset	200 μm	design
Cryomodule Pitch	20 µrad	design

maybe x3 for horizontal

Required magnet strength change speed 1

Quadrupole magnet

- Max. strength 30 T/m*m (at beam energy 250 GeV, proportional to beam energy)

- **RF failure,**
  - Energy profile along linac will change and need to change quad strength
  - Luminosity loss < 0.1%
  - Applied only for RDR type RF system (not for KCS and DRFS)
  - **Max. speed of change ~ 0.0008 T/m*m/s**

- **Quad shunting (BBA)**
  - Perform BBA (measurement quad field center w.r.t. BPM center) in reasonable time (1 day for all magnets.)
  - **Max. speed of change ~ 0.01 T/m*m/s (0.03%/s)**

Required magnet strength change speed 2

Steering magnet

- Max. strength 0.05 T*m (at beam energy 250 GeV, proportional to beam energy)

- **Continuous correction, slow feedback**
  - Consider ground motion assuming very noisy place
  - **Max. speed of change ~ 5E-6 T*m/s**

- **Recovery after long shutdown in reasonable time**
  - 10 iterations of corrections and 100% change of max. strength in 30 min.
  - **Max. speed of change ~ 3E-4 T*m/s (0.6%/s)**

Required quad field center movement in strength change

- In BBA by quad shunting, field center should be stable within required accuracy of the BBA.

- DMS (Dispersion Matching Steering) does not require information of BBA by quad shunting, but
  - Good BBA is strongly desirable for consistency check, for backup correction methods.

- A backup correction method, MKS (Minimum Kick Steering) require BBA accuracy ~5 um (~ 3nm (~15%) emittance growth)

Field Quality of magnet

- Beam - magnet center offset:
  - ~misalignment < 1 mm rms (horizontal)
  - Requiring r<6 mm “good filed region” will be safe.
- Tolerable multi-pole fields (n>=2, sextupole and higher), around beam center are very large (compare with next).
- Tolerable skew Q field ~ 0.00033 of main Q field (rms)
  - For < 2% vertical emittance growth
  - Rotation error of main quad field (330 urad misalign.)
  - Induced by multi-pole field with beam offset
    - Ratio of multi-pole field to quad field at offset

      ~ 0.00033 (for safety, at 3 mm)

Summary for Magnets

	Quad	Steering
Change speed	**0.01 T/m*m/s (0.03%/s)**	**3E-4 T*m/s (0.6%/s)**
Good field region	**r < 6 mm**	
Skew Q field (including rotation error)	**3E-4 of main Q field**	
Multi-pole	**3E-4 of Q field at r=3mm**	

SUMMARY

- Lattice design
  - 3 modules/quad is the best choice
  - Keep most part (from 25GeV) of old linac for 1 TeV upgrade (with FFDD lattice)
- Some assumed Tolerances, specifications are shown
  - Orbit jitter sources
    - Need post linac intra-pulse feedback
  - Alignment
  - Speed of magnet strength change
  - Movement of quad filed center
  - Field quality of magnet

Back up slides

Quadrupole magnet (1)

Strength change in RF failure

- RF failure changes energy profile along the linac.
- Assume that we need to change quadrupole magnet strengths when one RF unit fails. (This assumption may be too pessimistic. Small change of energy profile may be acceptable.)
- How much:
  - Total acc. voltage of one RF unit ~ 0.9 GeV.
  - Then, required strength change ~ 0.11 [T]
- How fast: (Use RDR parameters and assumptions)
  - MTBF of klystron: 40,000 h. MTBF of modulator: 50,000 h.
  - 280 RF units/linac, total 560 RF units.
  - Mean number of failure per hour ~ 560/40000 + 560/50000 = 1/40
  - Then, **we have one failure per 40 h (2400 min)**
  - Requiring **Lumi. Loss < 0.1 %,** need to recover in less than 2.4 min.
- Then, max. required speed ~ 8E-4 T/s

Quadrupole magnet (2)

Note for DRFS and KCS:

- In the case of DRFS, mean number of failure per hour will be much larger but failure of small number of RF units will not require quadrupole strength change. (We have had no quantitative estimation.)
- In the case of KCS, failures of small number of klystron will be compensated by spare klystrons. Then, no need to change quadrupole strength. (?)

Quadrupole magnet (3)

Strength change in BBA (Quad shunting)

- Change 10 %. Max. 3 T/m*m at 250 GeV.
- Number of Quads ~ 300/linac
- If we want to do BBA in a day, Time per quad should be ~ 5 [min] or less.
- Then, max. speed ~ 0.01 (T/m*m)/s
  - much faster than for RF failure

Steering magnet (1)

(Steering Max. strength 0.05 Tm at 250 GeV)

Strength change in RF failure

- The same effect as for quadrupole.
- How much: From similar consideration as for quadrupole,
  - 2E-4 * 0.9 ~ 2E-4 Tm

  (Integrated strength [Tm] ~ 2E-4 * E_beam [GeV])
- How fast: Same a Quads
  - 2.4 min
- Then, max. changing speed 1.4E-6 Tm/s

Steering magnet (2)

Strength change following Ground motion

- Assume ground motion following ATL law
- Orbit will be corrected by NC dipole magnets downstream. Then, emittance growth in ML should be considered.
- Emittance growth vs. A*T:

  Emittance growth (normalized) [m] ~ 4E5 * (A*T) [m]
- How fast:
  - Assuming A = 1E-17 m/s (model 'C', noisy site)
  - and requiring **emittance growth < 0.2 nm** (1% of nominal),
    - AT < 5E-16 m, T < 50 s
  - **Conservative assumption: A = 1E-16 m/s (10 times model 'C', too pessimistic?)**
    - **T < 5 s**
- How much:
  - Between 2 steering magnets, L = 40 m, ATL ~ 2E-14 m^2 = sigma_y^2.
  - **Taking 8 sigma, required angle change ~ 8*sigma_y/L ~ 0.03 micro-rad. This corresponds to integrated strength of 2.5E-5 Tm at 250 GeV. (0.05% of max. strength.)**
- **Then, max. changing speed ~ 5E-6 Tm/s**

Steering magnet (3)

Recovery after long shutdown

- If Assume ATL, A = 1E-16 m/s (10 times of A in model C)
- After 10 days shut down, strength change should be 20% of max. strength (taking 8 sigma)
- Rough estimation
  - Assume need to change 100% of max. strength
  - Assume need 10 iterations of orbit measurement and correction
  - Require them in 30 min.

  10 * 100%/1800s ~ 0.6%/s (3E-4 Tm/s)