Summary of error specs in ILC ML from beam dynamics

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Local Alignment Error. Cold section

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**

Local Alignment Error. Warm section

Error	RTML Warm	BDS Warm	with respect to
Quad Offset	150 μm	200 μm	design
Quad roll	300 μrad	300 μrad	design
BPM Offset (initial)	100 μm	100 μm	attached magnet
(after BBA)	7 μm	?	attached magnet
Bend offset	300 μm	200 μm	design
Bend Roll	300 μrad	300 μrad	design

Long range alignment spec

- Not specified yet.
- We have some models but may not be realistic enough. (?)

Magnet Strength fixed Error

	Cold Sections	RTML Warm	BDS
Quad	**0.25%**	0.25%	1E-4
Bend Strength	---	0.25%	1E-4
Corrector	?	?	?
Sext.	---	---	1E-4
Oct.	---	---	1E-4

It is not clear what determines these tolerances in RTML and ML.
0.25% looks too large.
There can be complicated but more realistic model of errors (considering calibration procedure).

1E-4 in BDS may be too tight. (?)
In BDS, this error will affect the convergence time of the tuning algorithm .

Error of beam monitors

	Cold Sections	RTML Warm	BDS
BPM Resolution	**1 μm**	1 μm	0.1 μm
BPM Dynamic range	**3 mm ?**	3 mm ?	3 mm ?
BPM Scale error	**5~10%**	---	---
Beam size monitor resolution	1 μm		
Pair monitor (single pulse)	---		1%

Results of static tuning (RTML and ML)

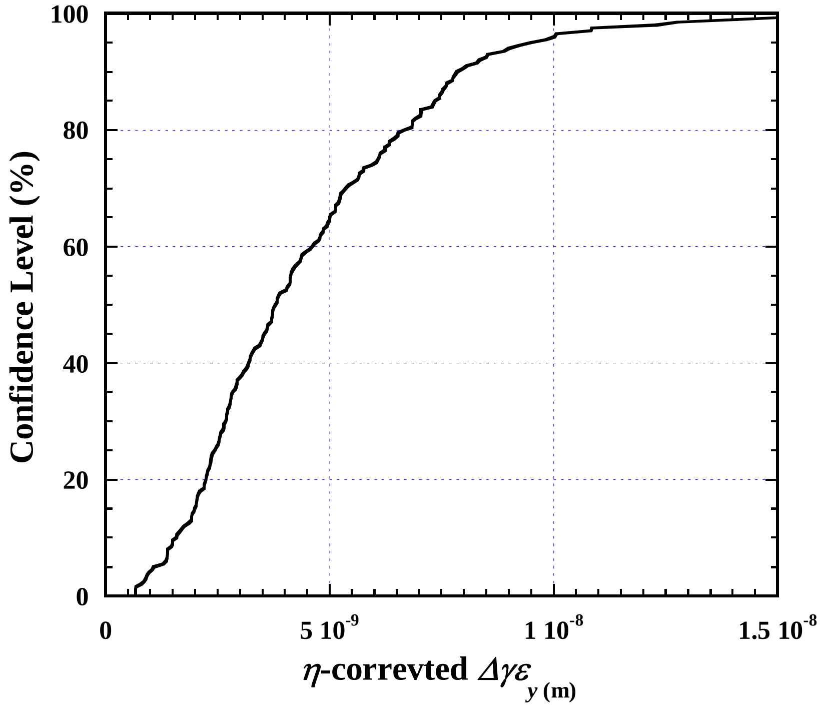
	Emittance increase (nm)		Corrections
	average	90% CL	
Return line			Kick minimization without coupling correction
Turn-around and spin rotator			Kick minimization and skew coupling correction
Bunch compressor			DFS and dispersion bumps
Main linac*	**4.5**	**8.0**	**DFS (DMS) without coupling correction**

* BPM scale error is not included here.

Numbers from:
RTML: Jeff Smith, LET Workshop at SLAC, Dec. 2007.
ML: K. Kubo.

ML, Static tuning simulation

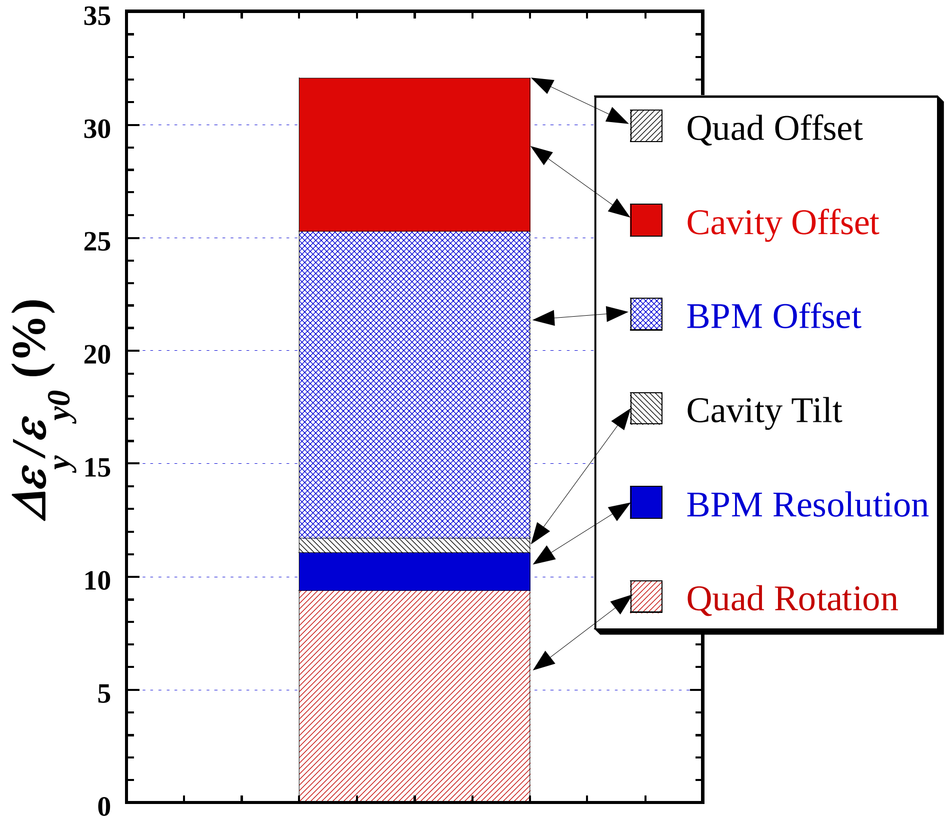
"Standard" set of errors. No BPM scale error.
DMS (test beam energy 90% of nominal, weight factor 30000) .



Confidence Level: Ratio of random seeds which give smaller emittance growth than the horizontal axis.

K. Kubo

Contributions of errors to Emittance growth



Results depend on parameters of corrections.
Shown here is not really optimized.

Mechanical fast movement (vibration)

	Cold Sections	RTML Warm	BDS Warm
Quad, Sext.	**100 nm**	10 nm	10 nm
Cavity tilt	**3 urad**	---	---

RTML Return line: Orbit change at the entrance of turn-around
Quad 10 nm → 0.02-sigma orbit: no problem
(0.75-sigma orbit in turn-around increase emittance by 5%)

RTML down stream:
Quad 10 nm should be OK ?

ML: Orbit change at linac end
Quad 80 nm → 1-sigma orbit.
Cavity tilt 3.6 urad → 1-sigma orbit.
There will be post linac (intra-pulse) feedback.

Magnet Strength Stability

Magnet to magnet independent, random

	Cold Sections	RTML Warm	BDS Warm
Quad	**1E-4**	1E-5	1E-5
Bend Strength	---	1E-5	1E-5
Corrector	**1E-4**	1E-3	1E-3
Sext.	---	---	1E-5
Oct.	---	---	1E-5

Quad 1E-5 in warm sections:

Assuming typical misalignment 100 um, equivalent to 1 nm vibration.

Should be no problem.

ML: 1E-4 → Orbit change at linac end 1 sigma.

Simulation: Set “standard error” and perform DFS steering.

Then change strength of magnets randomly.

RF dynamic errors

		Amplitude	Phase
BC Correlated		0.5%	0.24 deg.
Klystron-to-klystron Uncorrelated		1.6%	0.48 deg.
ML Correlated		**0.07%**	**0.35 deg**
Klystron-to-klystron Uncorrelated		**1.05%**	**5.6 deg**
Cavity-to-cavity Uncorrelated	**Flatness**	**1%***	**---**
	Jitter	**1%***	**---**
Crab e+e- Relative			0.015 deg

Correlated :same for all klystrons
Klystron-to-klystron random : klystron to klystron independent, random

What determines the tolerance?
- BC: Timing at IP
- **ML Correlated and kly-to-kly uncorrelated: Energy jitter at the end.**
- **ML Cavity-to-cavity uncorrelated: Vertical orbit jitter and emittance growth.**
- ***assuming no intra-pulse feedback in ML**

Crab: Horizontal offset at IP

Longitudinal effects of RF Dynamic errors

	For 2% luminosity reduction by arrival time jitter	
	Amplitude	Phase
BC RF, Correlated	0.5%	0.24 deg.
BC RF, Uncorrelated (kly-to-kly)	1.6%	0.48 deg.

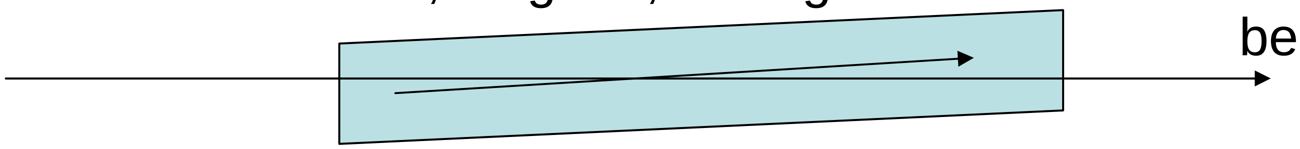
	For 0.07% Energy jitter	
	Amplitude	**Phase**
ML RF, Correlated	**0.07%**	**0.35 deg.**
ML RF, Uncorrelated (kly-to-kly)	**1.05%**	**5.6 deg.**

(from RDR)

Transverse effect of acc. field with cavity tilt

Acc. field *E*, length L, tilt angle θ

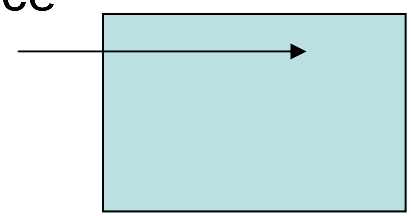
beam



Transverse kick in the cavity: $\Delta pt = \sin\theta \, eV$

Edge (de)focus

entrance



exit

offset: $y_0 + L\sin\theta/2$

offset: $y_0 - L\sin\theta/2$

Transverse kick at the entrance: $\Delta pt = -eE\,(y_0+\sin\theta\, L/2)/2$

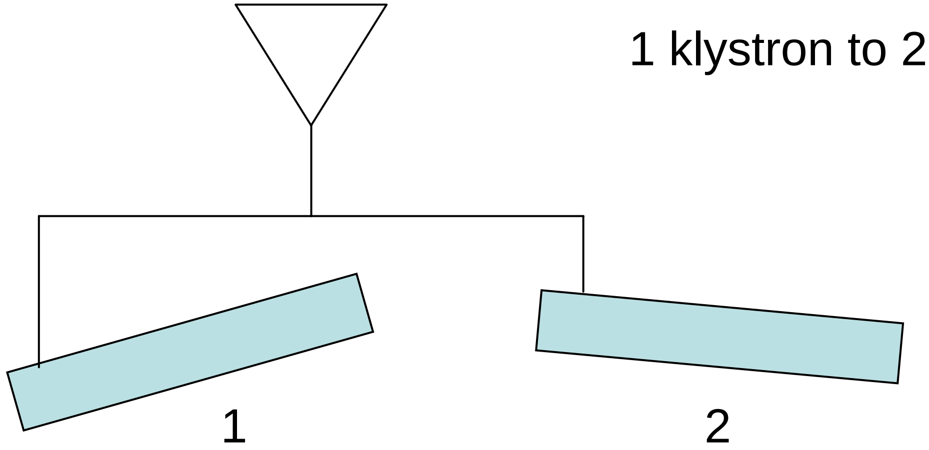
Transverse kick at the exit: $\Delta pt = eE\,(y_0-\sin\theta\, L/2)/2$

→Total transverse kick by the cavity: $\Delta pt = \sin\theta \, eV/2$

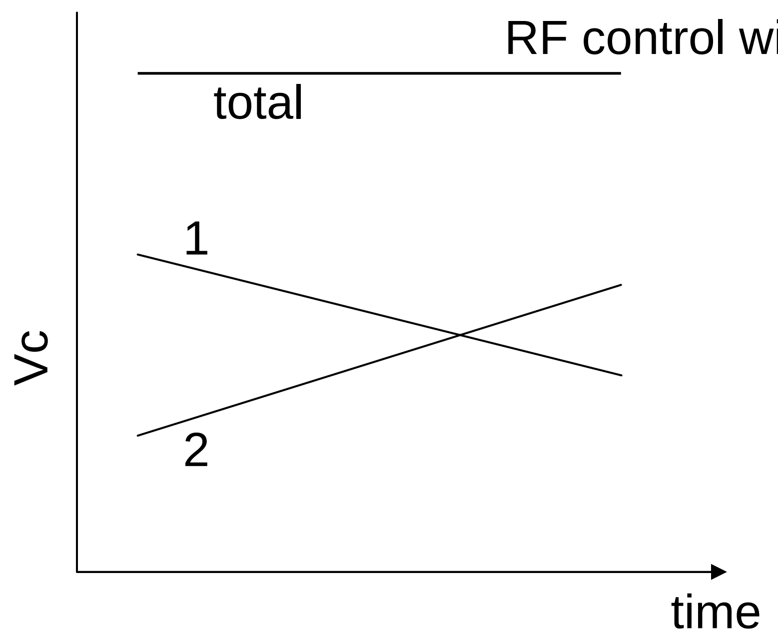
Cavity tilt change (vibration) and Fixed cavity tilt + voltage change have the same effect → orbit and emittance

- 3 micro-rad. tilt angle change, cavity to cavity random
  - → 0.8-sigma orbit change at the end of main linac
    $\propto$ tilt change
  - → 0.5 nm (2.5%) emittance growth
    $\propto (\text{tilt change})^2$
- Assuming fixed tilt angle (misalignment) RMS 300 micro-rad. 1% voltage change, cavity to cavity random
  - → Same as above.
  - – RF control stabilizes vector sum, not voltage of each cavity.
  - – Cavities with different coupling, fed by one RF source.
    → voltage change during one pulse.
  - – Different detuning (pulse to pulse)
    → pulse to pulse voltage change

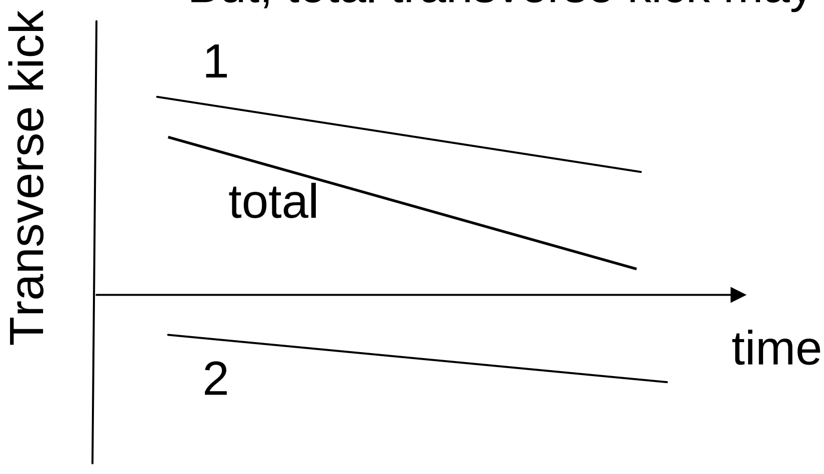
1 klystron to 2 cavities



RF control will keep total voltage flat.

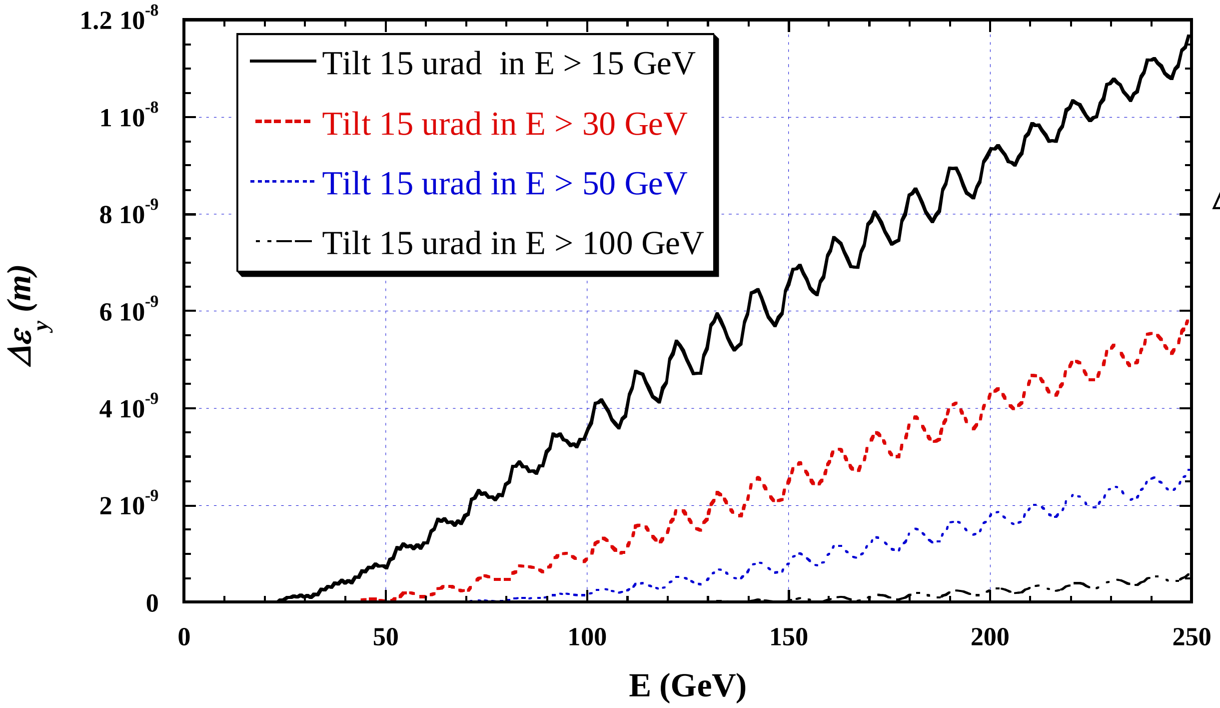


But, total transverse kick may change.



Result of simulation

Cavity tilt change 15 urad, equivalent to Fixed 300 urad + 5% gradient change (numbers are RMS)



$$\Delta\gamma\varepsilon \propto [\ln(E/E_0)]^3$$

Starting linac at different energies (to see effective ness of orbit correction)

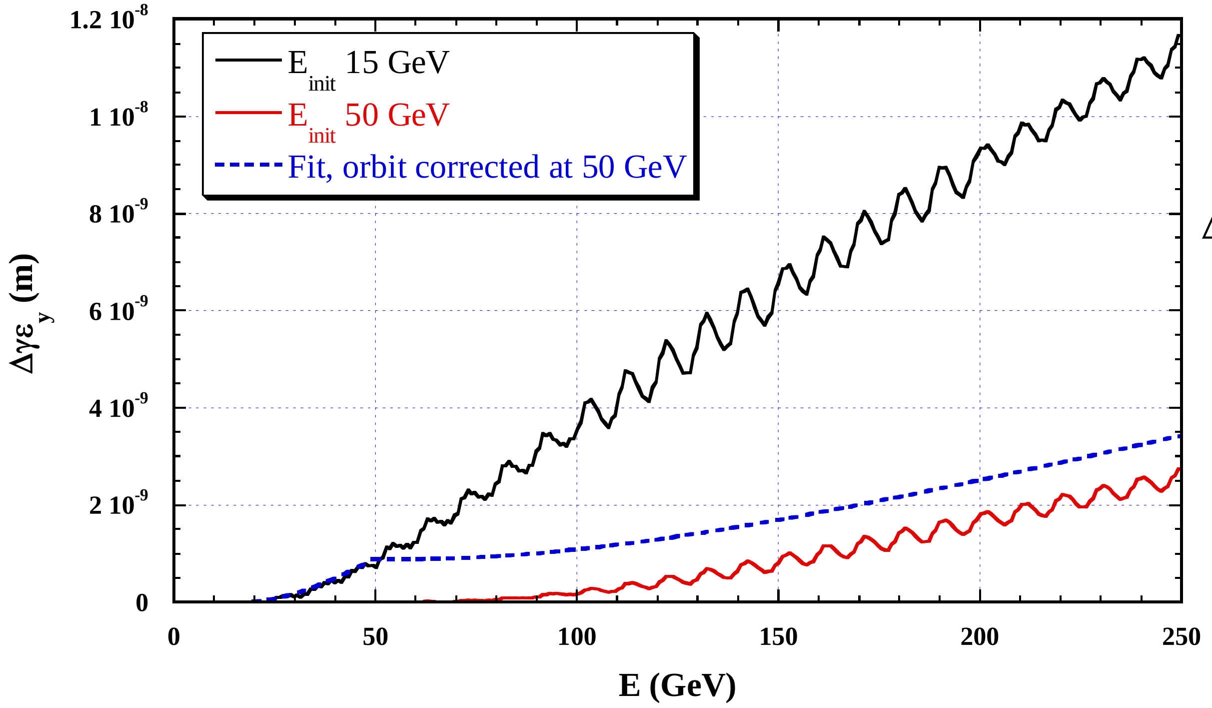
E.g. if orbit is corrected at 50 GeV, emittance growth will be

~ 1 nm from 15 to 50 GeV plus ~ 2.5 nm from 50 to 250 GeV

Total 3.5 nm, instead of 11 nm without such correction.

Orbit correction in main linac

Cavity tilt change 15 urad, equivalent to Fixed 300 urad + 5% gradient change (numbers are RMS)
Correct orbit at 50 GeV



$$\Delta\gamma\varepsilon \propto \left[\ln(E / E_0)\right]^3$$

Summary of Cavity tilt + RF jitter

- Fast tilt change should be < 3 urad (mechanical motion)
- (Fixed tilt) x (Relative gradient change of each cavity) should be < 3 urad
- If gradient change is predicted, or slow enough, intra-pulse orbit correction will loosen the tolerance.

We assume fixed cavity tilt 300 urad, then, gradient of each cavity flatness in a pulse should be (roughly)

- < 1% for pulse to pulse without intra-pulse correction
  - This are not far tighter than requirement for efficient use of cavities near quench limit. (max. 5%)
- < 5 % with intra-pulse correction in ML (looser than max. 5%)

(Numbers are RMS)

Dynamic sources of orbit jitter and emittance growth

	Source	Assumption	Induced orbit	Induced emittance growth
RTML Return Line	Quad vibration (offset change)	10 nm	0.02 sigma	small
RTML Return Line	Stray field	2 nT (5 nT)	0.2 sigma (0.5 sigma)	0.15 nm (1 nm) in turnaround
ML	**Quad vibration (offset change)**	**100 nm**	**1.5 sigma**	**0.2 nm**
ML	**Quad+steering strength jitter**	**1E-4** **(too big?)**	**1 sigma**	**0.1 nm**
ML	**Cavity tilt change**	**3 urad** **(too big?)**	**0.8 sigma**	**0.5 nm**
ML	**Cavity to cavity strength change, assuming 300 urad fixed tilt**	**1% (without correction in ML)**	**0.8 sigma**	**0.5 nm**
Warm sections	Quad strength jitter	1E-5	small	small

sigma: nominal beam size assuming $\gamma\varepsilon$ = 20 nm.

Comments on orbit jitter and emittance growth

- Orbit jitter at ML end will be comparable to beam size (vertical).
  - BDS will not accept such jitter.
  - Post linac intra-pulse feedback will be needed.
- Emittance growth due to orbit jitter in ML will (should) be small enough.

Summary

- Static alignment
  - Spec of local misalignment have been well studied and presented.
  - Long range alignment requirement has not yet specified.
    - Assumed to be OK (?). But we will need help from survey/alignment experts.
- Other static errors
  - Specs are presented, but have not studied in details.
  - Not considered to be serious problem.
- Dynamic errors
  - Specs (assumptions) and effects have been presented.
  - Some of them (e.g. RF jitter) are not easy but probably achievable.
  - Need post ML intra-pulse feedback.
  - (Dynamic error effects are dominant in BDS.)

Comments

- We received comment on alignment of cavities, (from Noguchi(KEK)):
  - Offset 300 μm and Tilt 300 μrad will be difficult.
  - It will be difficult to confirm alignment of cooled down cavities.

We may loosen the cavity alignment tolerance, with tightening others. (?)