Alignment and Low Emittance Transport, July 07 Report.

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Focus: Alignment & Ground Motion.

- Recap: Low Emittance Transport 101
- Results presented at PAC07
  - Static: Methods, Options, Robustness.
  - Dynamic: Jitter, vibration, ground motions implementation.
  - Wakefields and cavity positioning tolerance..
- Recent Ground motion studies.
  - Tides At Minos.

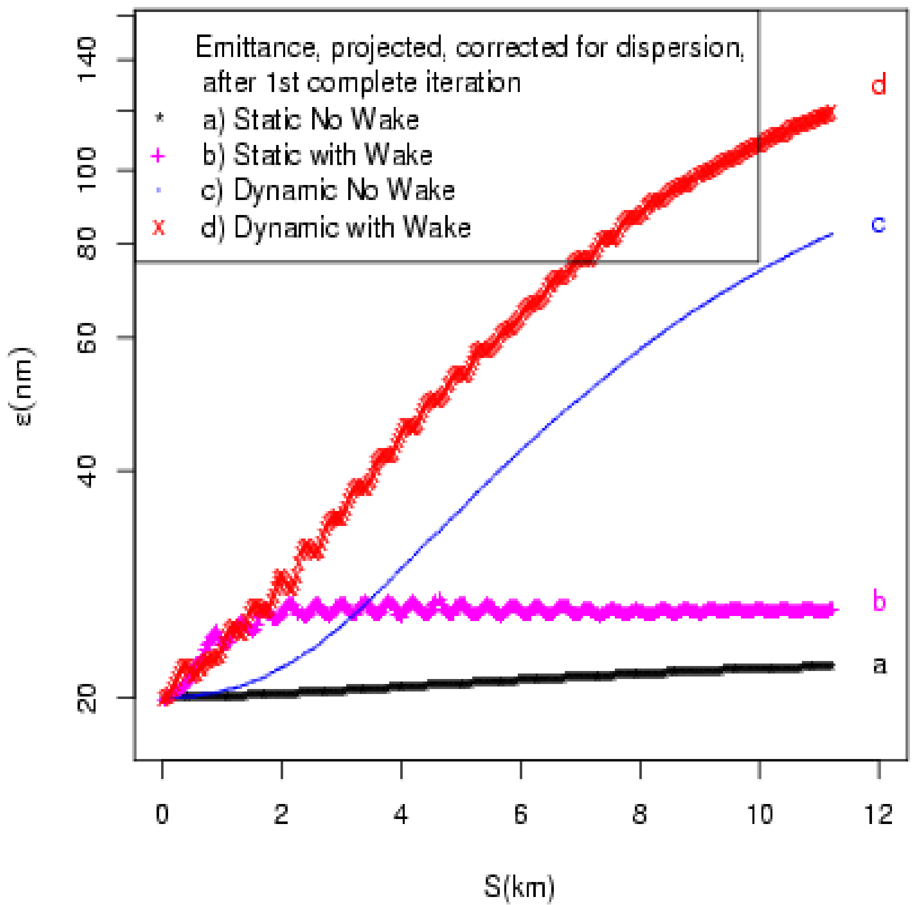
LET – Brief Introduction

- Goal: Given a set of machine imperfections, static and dynamical, design and simulate the set of algorithms to steer the beam through the machine and mitigate emittance dilution.
  - Imperfection: misalignments. Need credible model!
  - Dynamical => Vibration + Ground Motion Model
  - Simulation of instrumentation and known defects.
  - Steering Algorithms, based on the the above.
  - Feedback system..
  - Close the loop, set new tolerances for alignments.

Current recommendations (from the prudent or paranoiac)

- Written ~ 2 months ago..
  - Isolate Quadrupole/Corrector package from the r.f. cryostat, to improve vibration and measure motion.
  - Instrument HOM, to estimate misalignment and semi-qualitative estimates of wakes.
  - Remotely adjustable cavity couplers, so that relative cavity phases/impedance can be re-adjusted for greatly varying klystron output power and pulse length, as the rf power to beam changes during steering.
  - *Improve rf cavity alignment tolerance, or, if not possible, suspend them on movers.*

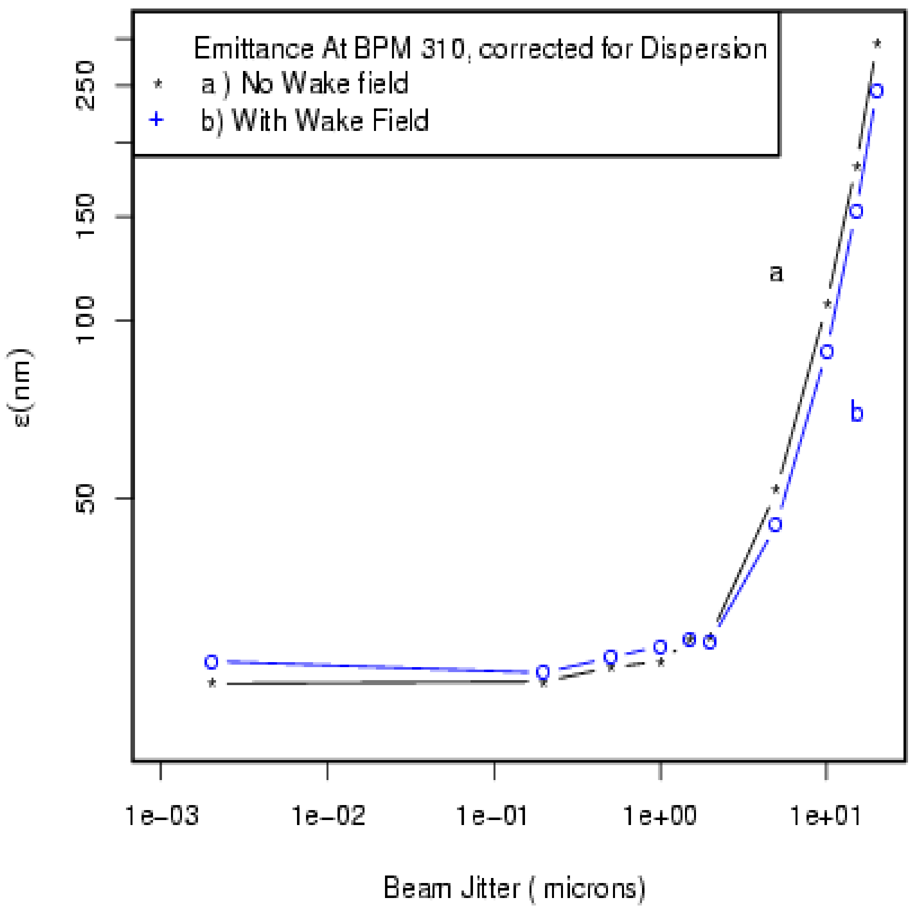
LET Result (PAC07)



- Obtained with CHEF
  - Static: almost acceptable performance.
  - Dynamic: Bad or unlucky example:
    - While steering from section to section, waited the “wrong” amount of time, got in sync with a vibration or GM harmonic.

LET-Dynamical, recent work.

"Fast" (~< few min.) steering with beam jitter



- Study of the effect of beam jitter (done by other groups..).. One micron at beam injection count. If, pulse to pulse, the jitter is ~ 2 to 5 micron, substantial performance degradation,
- Ground Motion not a concern here, "fast enough".

Relevant Details: Misalignment Model used in our Simulations

- At 2 or 3 levels: (i) Monuments (ii) Cryo-module (ii) Elements within cryo-module. In some codes only (ii) and (iii), in other just one generic level.
- Offsets are Gaussian distributed.. and truncated. (if > 3 sigma, throw again)
- No correlations at given level.
- Cold elements are assumed to be harder to align (i.e. cryo-module components -> 300 microns sigma., while 100 micron for warm elements.
- Criteria have not changed in a long time... Despite mixed success with Emittance preservation
  - Reluctance to change, cost concerns !..

r.f. Cavity misalignments: concern

- 24 (or 25) cavities for each quadrupole/corrector package. Unlike quadrupole offsets, no unique solution to steering
- While the machine is “mostly” linear, cavity rotations induce dispersive effects that are a bit tricky (next slide)
- Wakefield depends on cavity offsets or mis-steering. Wakefield are notoriously harder to simulate, and the emittance growth is not always linear in beam/cavity offsets!

Transport through rf Cavities.

- Required accuracy, single particle. Energy dependent. At 5 GeV, 20 nm radians, in a lattice similar to ML or BC2, σ y' ~ 280 nano-radians. Requiring a few percent of this figure seems adequate => ~10 to 20 nano-radians.
- Trajectory not dictated by beam envelope equation, but by misalignment tolerance!

R.F. Cavity propagator simple test case.

- Compare various models of edge focusing, w/out ponderomotive force, to brute force numerical integration. Very simple test
  - Propagate one ray with LIAR, 1st order, Rozenzweig-Serafini, CHEF, Numerical integration (Runge-Kutta, 4rth order, fine step, G4, ILC Tesla 9-cell cavity), with y' = 0.5 mradians, y = 1 mm.
  - Observe 10 to 20 nm discrepancy, corresponding to 2nd order in the ($\Delta\gamma/\gamma$) expansion.

Transport rf Cavities, Conclusion

- Satisfactory linearity for single particle optics.
- If accurate benchmarking, and mm/mRad cavity offset/tilts, 2^{nd} order in $(\Delta\gamma/\gamma)$ expansion recommended.
- CHEF authors are improving their cavity propagators.
  - And (unrelated), the implementation of Short-range wake, to improve CPU performance (via FFT convolution instead of brute force numerical integration).

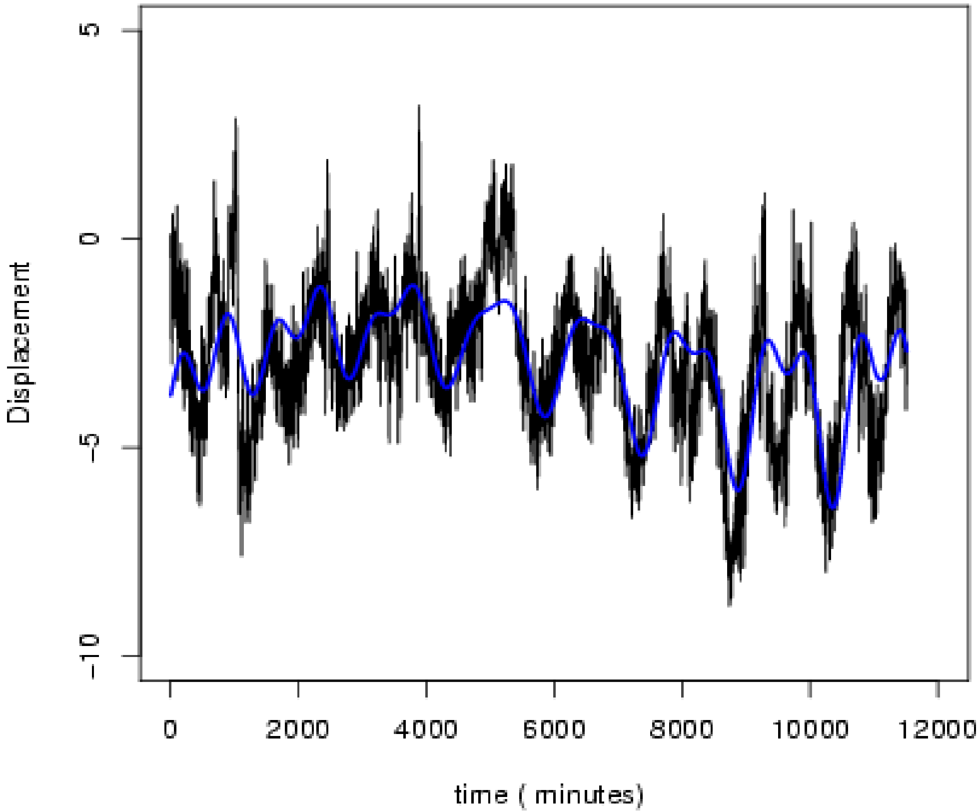
Ground Motion Analysis

- ATL model works fairly well, but..
  - Finite resolution for HLS: ~ one micron, means we don't have validation for short time scales (~ minutes to ½ hour)
  - Since we see tides (next few slides), can't be completely random.
  - If cultural or technical noise driven, also not random.
- => Need to improve our model.

Tides: Minos Data, $\delta(t)$ =P4-P1

- Fit
  - Term linearly proportional to the Moon + Sun tide vector (Dennis Milbert GPS software page, with references therein, check against Geophys. Inst. At Bern.)
  - Relative time offset is free.. Expect null value, in average for this parameter..
  - Cubic “background polynomial

Example: Feb 18 2006, for 8 days.

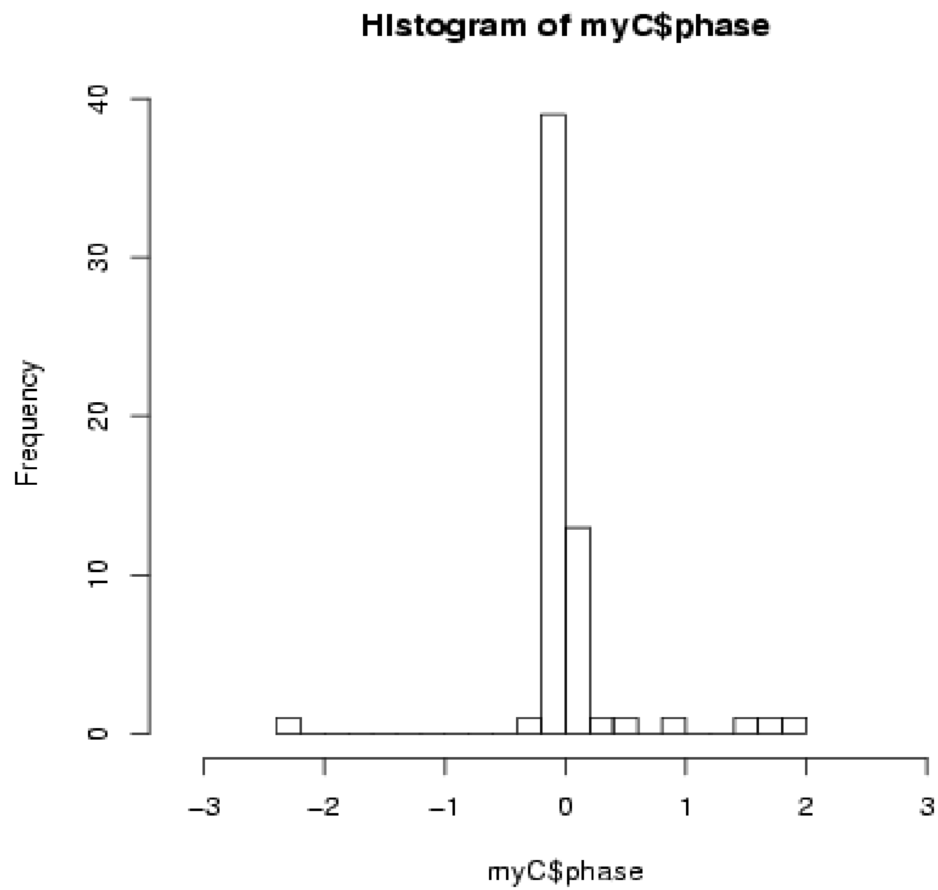


Black, spiky is data,

blue, smooth is the fit.

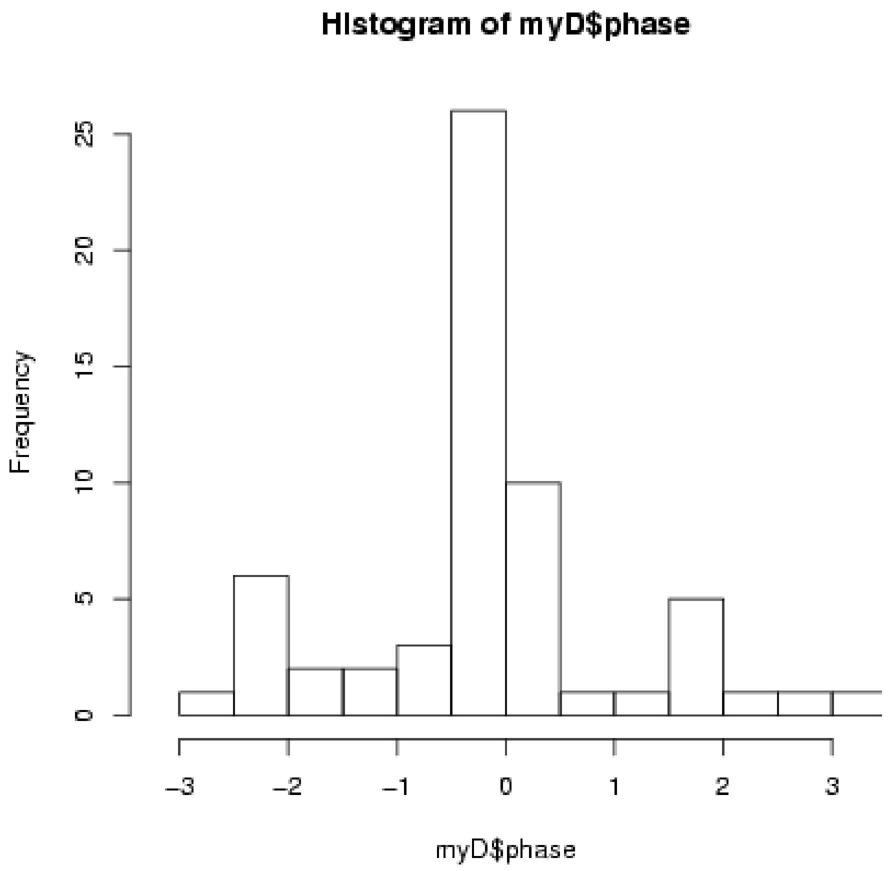
- Phase consistent with zero.
- Fit imperfect (and it is one of the best ones !)
- Fit provides a bit more info than simpe FFT.

Histogram of the phase for 60 8-day periods.



- When Pump3 is on, reject data from fits
- Both frequency and phase are predictable. Not Random!

$\Delta\delta$ = (p1-p2) – (p3-p4), Hist. Phase.



- Signal still visible
- At the scale of ~100 meters, rock does not move as a solid with inf. Rigidity.

Outlook

- These were just teaser plots.. More work remains to be done to characterized better the ground motion.
- Need Ground Motion data
  - Frequency Fraction of one Hz to few minutes.
  - Sensitivity: ~100 nm scale precision, over ~ 30 m.
  - Site dependent!
- Current mechanical tolerance for module assembly + placement in the tunnel are likely to be not quite adequate for RTML and front-end of Main Linac. (more documentation needed!)