ILC Dynamic Simulations Studies

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August 31 2010

- 5 Hz Orbit feedback Linac + BDS
- BDS Intra-pulse orbit + IP feedbacks
- FD jitter tolerance studies
- FFS dynamic de-tuning (ATF2 studies)

Intregrated 5-Hz Orbit Feedback Studies

- Look at emittance growth through Linac+BDS with distributed 5Hz feedback sytem (slow orbit drift effects).
- Work primarily done by L. Hendrickson c.2005
- Based on SLC experience and NLC simulations.
- Results based on ~Snowmass ILC design

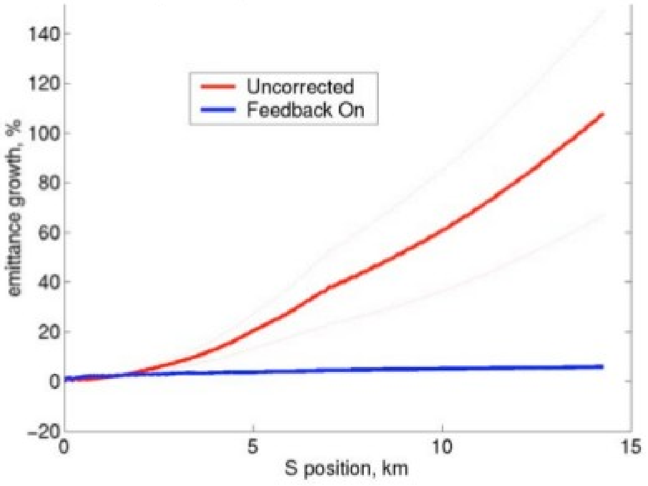
5 Hz Feedback Simulations

- **Linac feedback** distribution: 5 distributed loops per beam, each with 4 horizontal and 4 vertical dipole correctors, and 8 BPMs (X&Y). Based on SLC experience and NLC simulations by LJH.
- **BDS feedback** distribution: 1 BDS loop per beam, 9 BPMs and 9 dipole correctors, both horizontal and vertical. Based on NLC simulations by Seryi.
- Linac and BDS feedbacks **"Cascaded"** system of 6 loops per beam: loops don't overcompensate beam perturbations, but can be independently disabled for operational convenience. SLC-style "single cascade" (each loop communicates beam information to single adjacent downstream loop).
- **Linac and BDS** loops have **exponential response of 36 5-Hz pulses**.

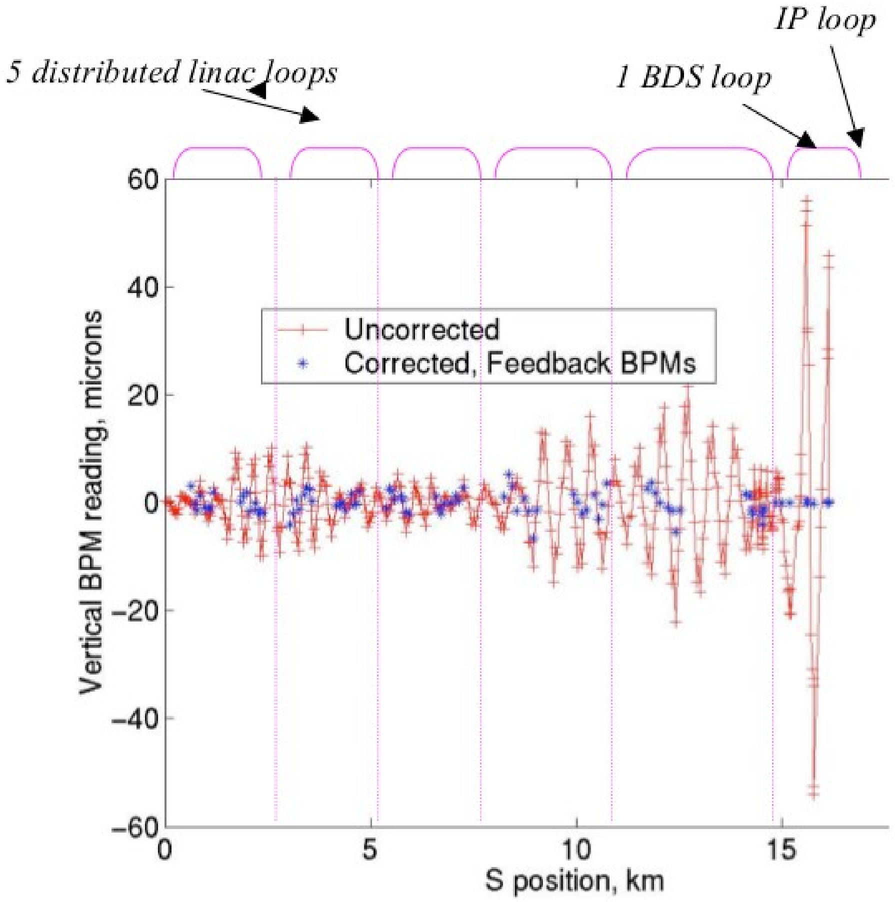
  IP deflection (X&Y), not cascaded, **exponential 6 pulses** (like SLC).
- **Matlab/liar/dimad/guinea-pig** platform. Upgraded liar/dimad for energy and current jitter, and dispersion measurements.
- **KEK-model ground** motion (noisy site). Study effects of **component jitter, energy, current, kicker jitter**. Problems: BDS beamsize very sensitive; using dispersion compensation and perfect energy measurement.

Feedback Setup

Emittance growth in linac ~100% after 30 min "KEK" ground motion + jitter for 10 seeds, 6% with feedback (3% with feedback without jitter).

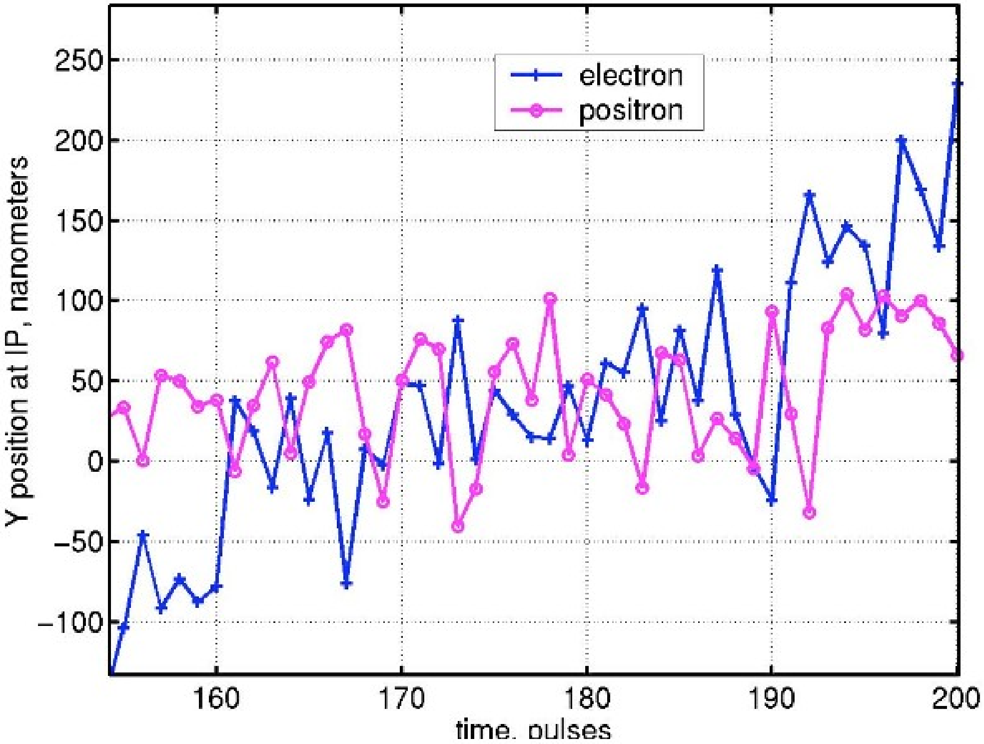


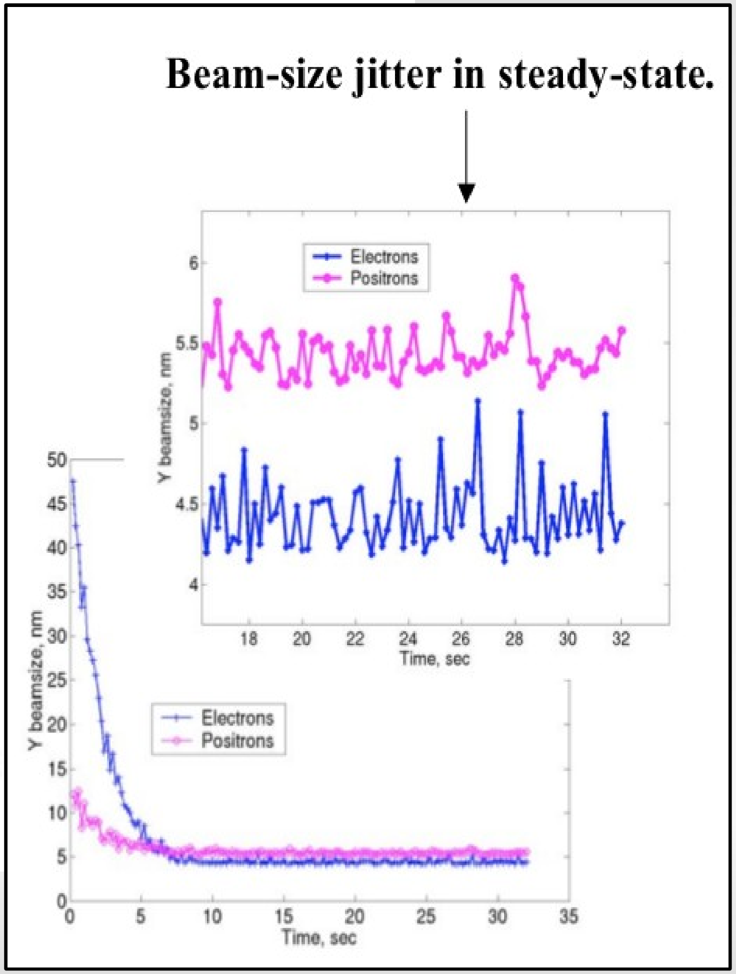
BPM readings in linac after 30 minutes ground motion



IP Position / Size During FB

Move the ground 30 minutes with model "K", apply ground motion and all other jitter sources, and sample for 200 pulses while feedback converges. The following shows the vertical beam position at the interaction point for both electrons and positrons, for a single seed.




Beam-size jitter in steady-state.

IP Beamsize Growth

Single-beam studies of beamsize growth, with 5-hz feedback in LINAC and BDS.

Perfect initially, add 30 minutes “KEK” ground motion”, let feedback converge -> 5% beamsize growth.

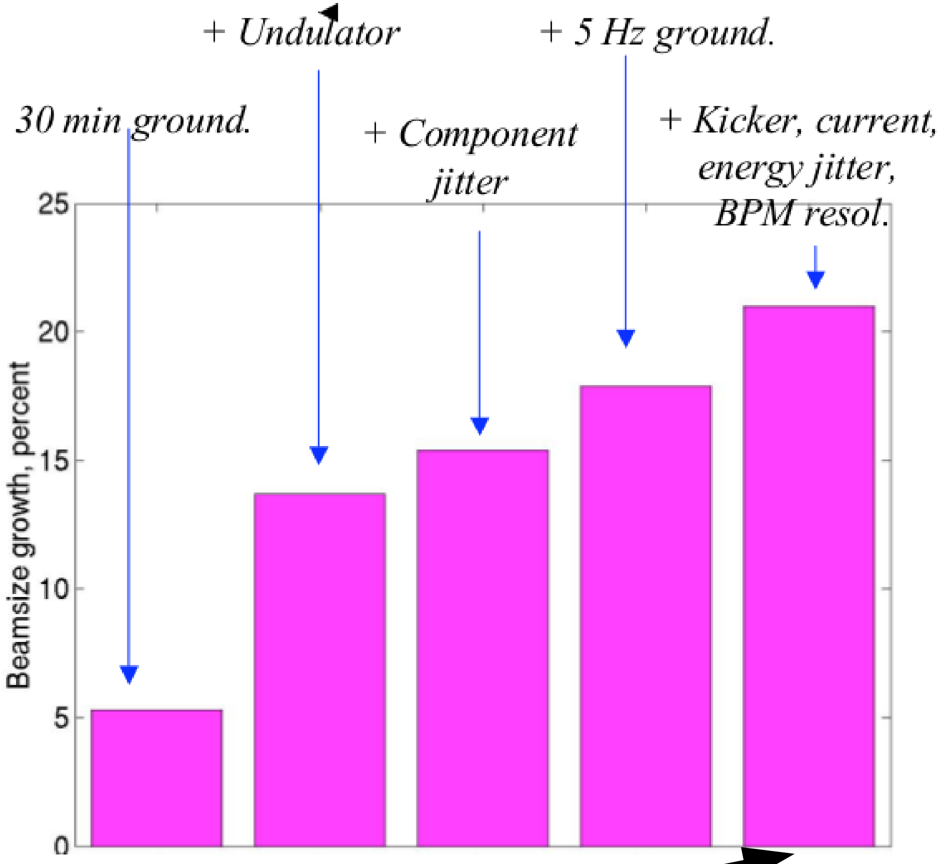
Increase energy spread for undulator (.15% end of linac; this effect needs more study!) -> 14%.

Add component jitter (25 nm BDS, 50 nm linac) -> 15%.

Add 5-Hz “KEK” ground motion -> 18%.

Add kicker jitter (.1 sigma), current jitter (5%), energy jitter (.5% uncorrelated amplitude on each klystron, 2 degrees uncorrelated phase on each klystron, 0.5 degrees correlated phase on all klystrons, BPM resolution .1 um. -> 21%

(Note: results are with respect to design beamsizes, which vary slightly with # of particles in guinea pig).

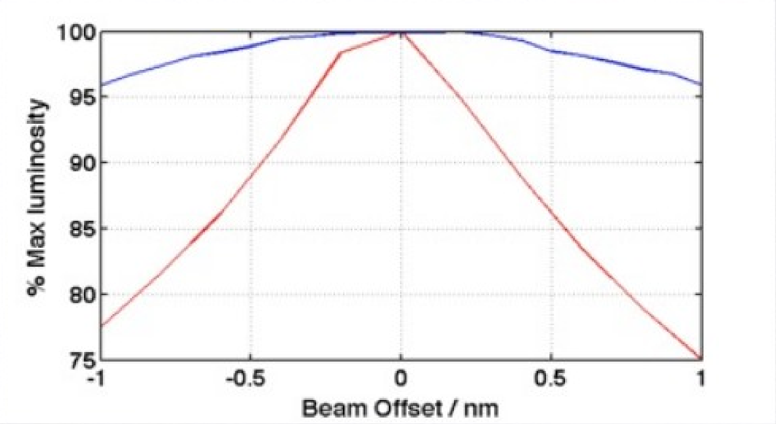


- 12% ignoring ”undulator effect”

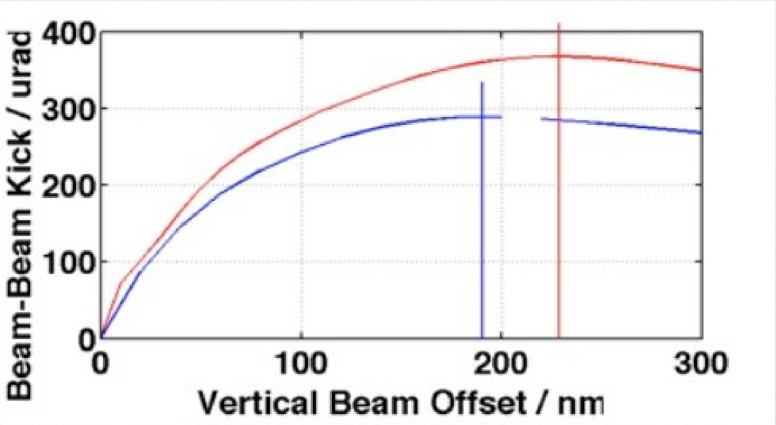
BDS Inter-Pulse Dynamics

- Understand additional contribution to luminosity loss by fast inter-pulse motion, and details of IP beam-beam interaction dynamics.
- ”Staticly” misalign machine, apply error + GM etc, tune muliple seeds with FB, pick one with ~design luminosity. Then apply 0.2s GM and mechanical vibration, apply fast intra-pulse feedbacks and look at luminosity performance across 100 seeds.
- Work done by myself on ~Snowmass → RDR timescale c.2005-2007, continued by J. Resta-Lopez @ Oxford.

IP Beam-Beam Dynamics



SB2009 (lowP with trav focus)
Nominal Parameter Set



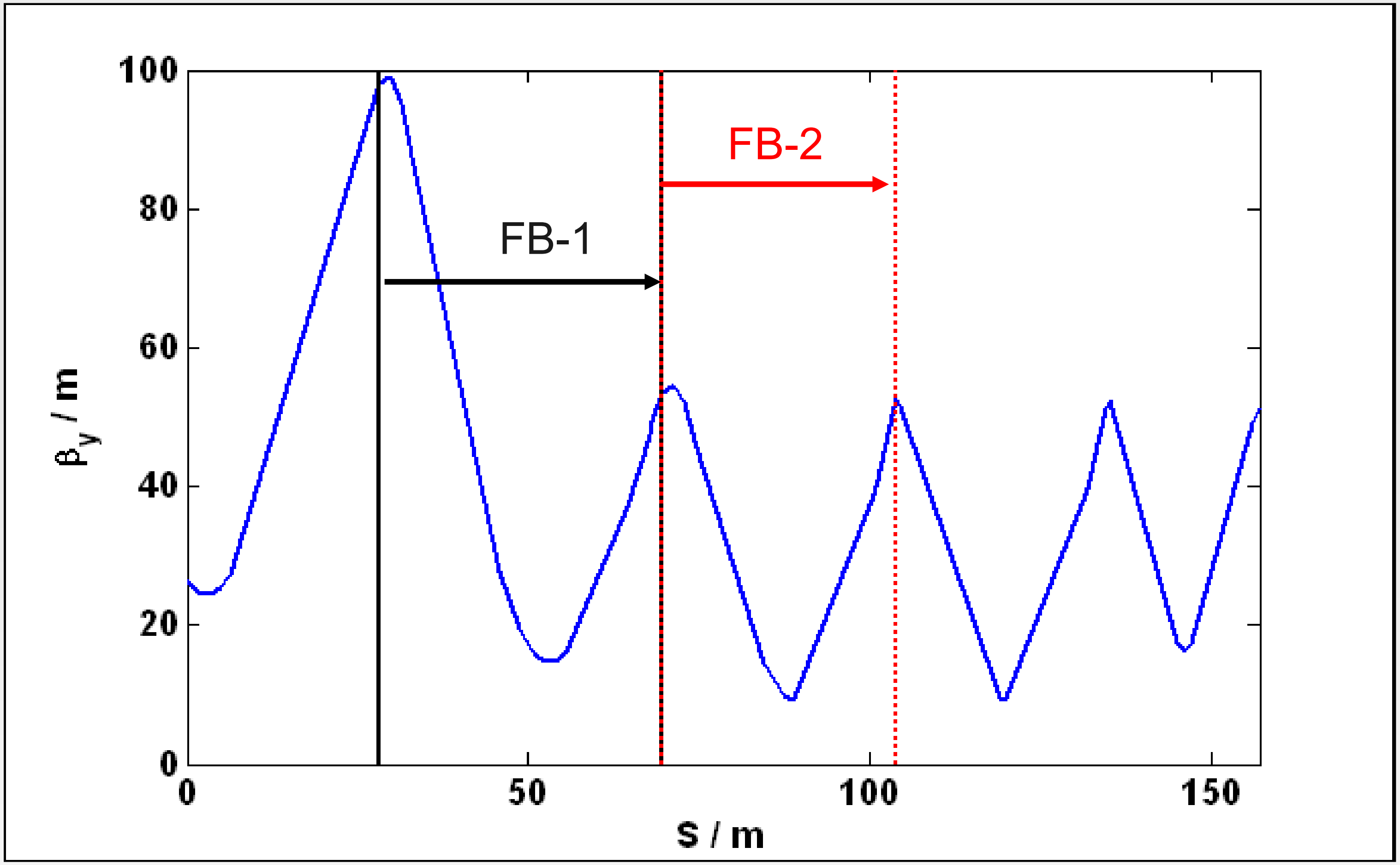
GUINEA-PIG Simulations

- IP vertical position feedback based on beam-beam kick
- "turn over" point of kick sets desired dynamic range
- SB2009 more sensitive
- Vertical beam offset must be kept <200pm for <5% lumi loss
- SB2009 parameter set gives slightly larger dynamic range for FFB system

BDS Fast Feedback Systems (1)

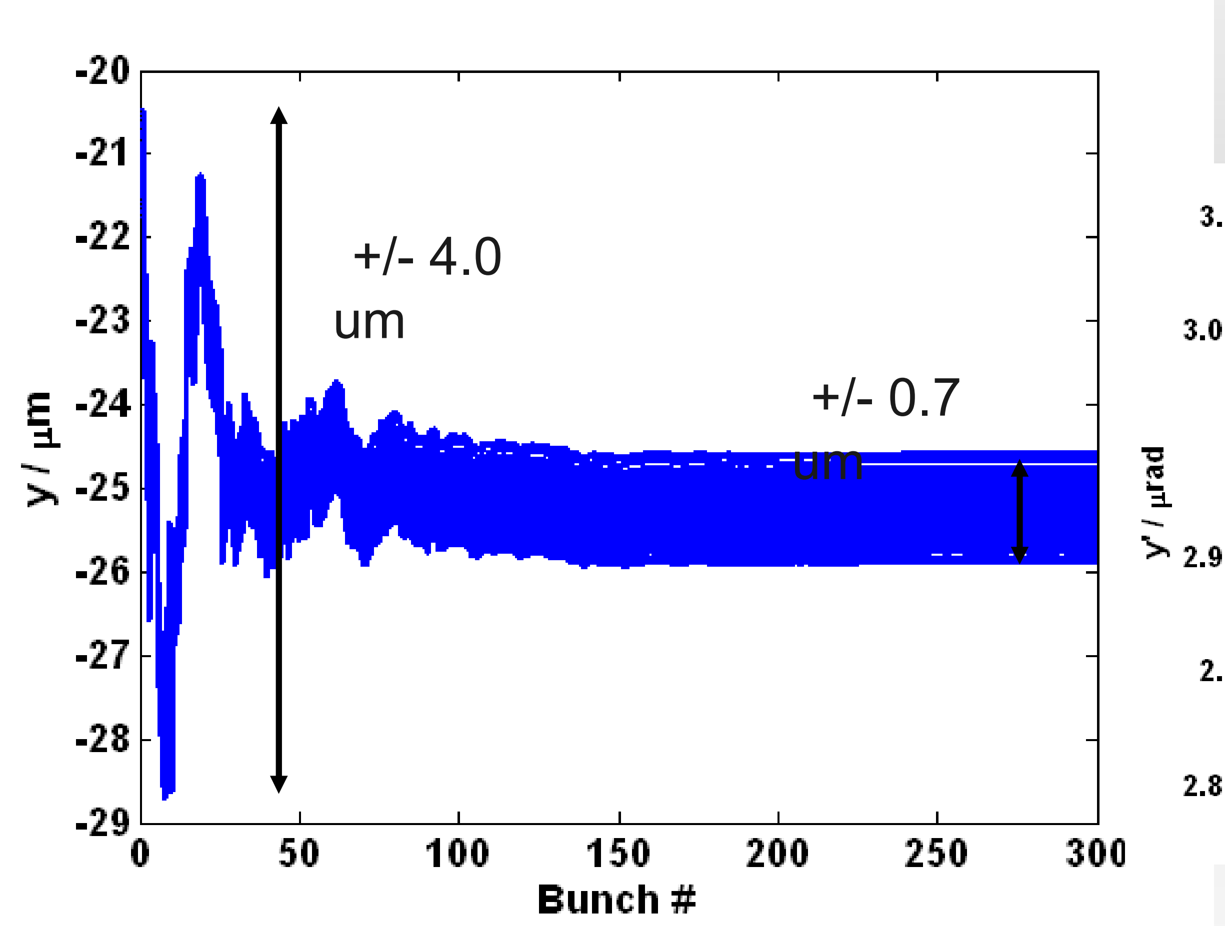
- 3 independent bunch-bunch beam-based FB systems in BDS:
  - **post-LINAC Fast Feeback**
    - 2 pairs of kickers/BPMs at different phases
    - Strong kickers (~100 times Voltage of other 2 FB kickers if same type)
    - Need ~100nm resolution on BPM’s
    - Corrects static & dynamic HOM-driven initial wiggle in train + any other systematic intra-train effects.
    - Separates BDS and LINAC 5-Hz feedback systems.
    - Not much simulation done with this, makes negligible difference to luminosity performance with studies done if keep gain low.

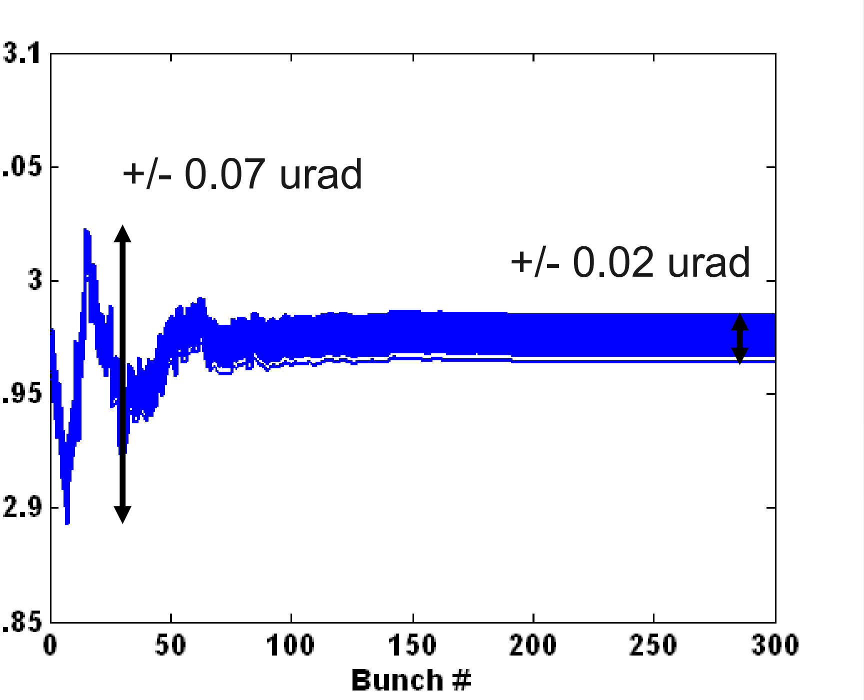
BDS FFB Location



- 2 Kicker / BPM pairs to straighten train and remove jitter at entrance to BDS.
- FB-1:
  - Kicker: upstream QMBSY2
  - BPM: upstream QD90C
- FB-2:
  - Kicker: upstream QD90C
  - BPM: upstream QD90

Incoming Jitter from LINAC



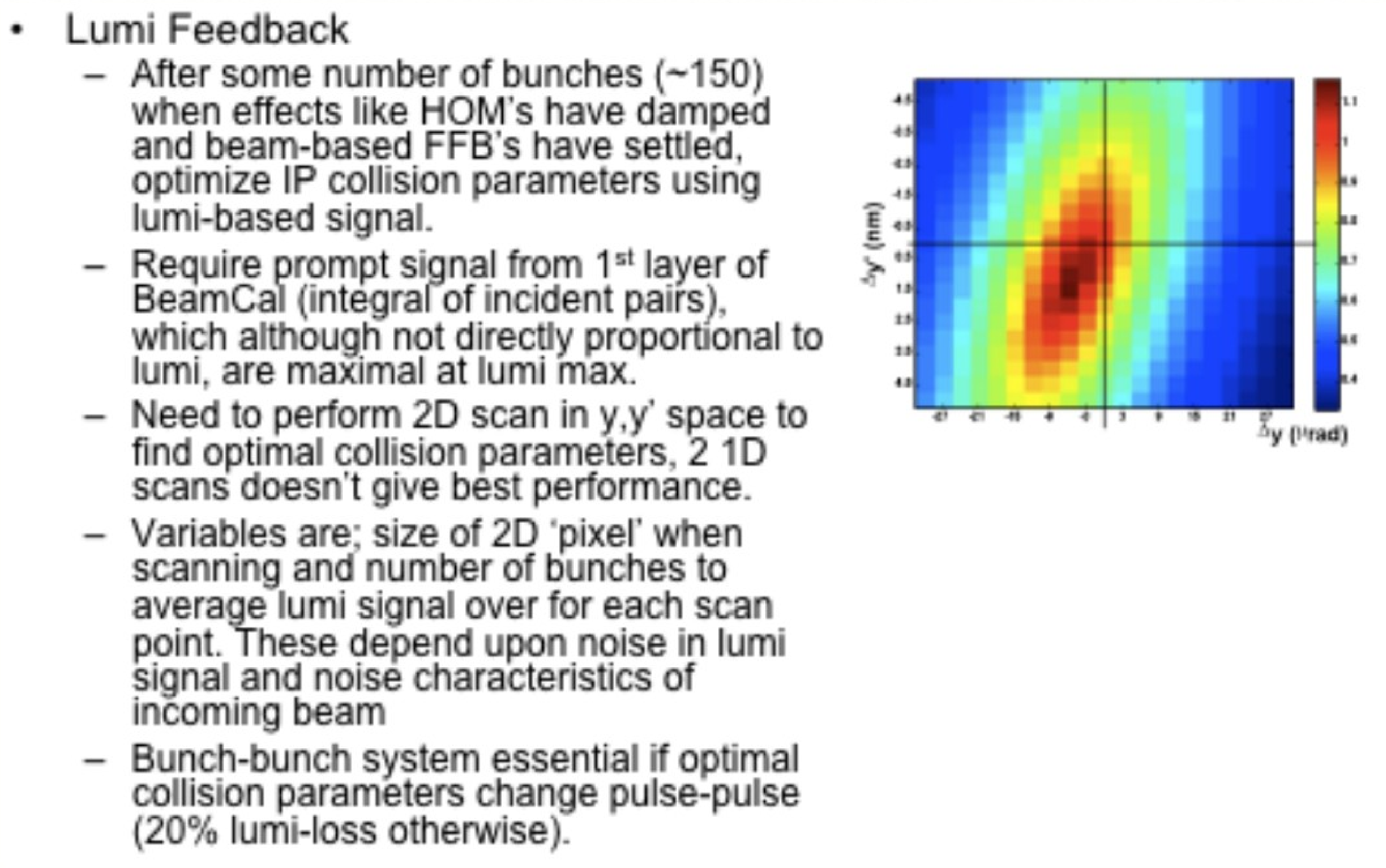


- Vertical positions/angles of bunch train exiting LINAC (subtract mean values to get real offsets- 2 bits of beamline modeled separately in simulation).
- 200 Seeds of 0.2s model ‘K’ GM + 100nm Quad jitter.
- (1 sigma y = 2.6 um at BDS entrance)

BDS Fast Feedback Systems (2)

- **IP-ANGLE Fast Feedback**
  - Corrects and optimises collision angle of bunches
  - 3 1m Stripline kickers at IP phase at start of FFS with same drive requirements as IP FFB.
  - BPM 90° downstream.
  - BPM res. Required ~ 2um (stripline)
  - If not at correct location, or if lattice errors present, cross-talk to IP-POSITION FFB possible. Can mitigate by reducing gain or interleaving
- **IP-POSITION Fast Feedback**
  - Based on beam-beam kick signal calculated with GP.
  - BPM just upstream of BeamCal, ~10um res required (stripline)
  - Kicker in the ~1m gap between SD0 and QF1.
  - Kick voltage requirements: 600 V/m for 70 sigma kick for 20 mrad crossing or 3 kV/m for 2 mrad due to larger aperture.
  - IP FFB sets tolerance for 5-Hz feedback- must keep beam in IP FFB dynamic range. Tail of beam-beam vs. offset curve goes out to 100's of nm, but prefer to be on left-side of peak for fastest convergence. For nominal beam parameter set, this is ~100nm, most constricting is low Q parameter set (~35nm).

Luminosity Feedback

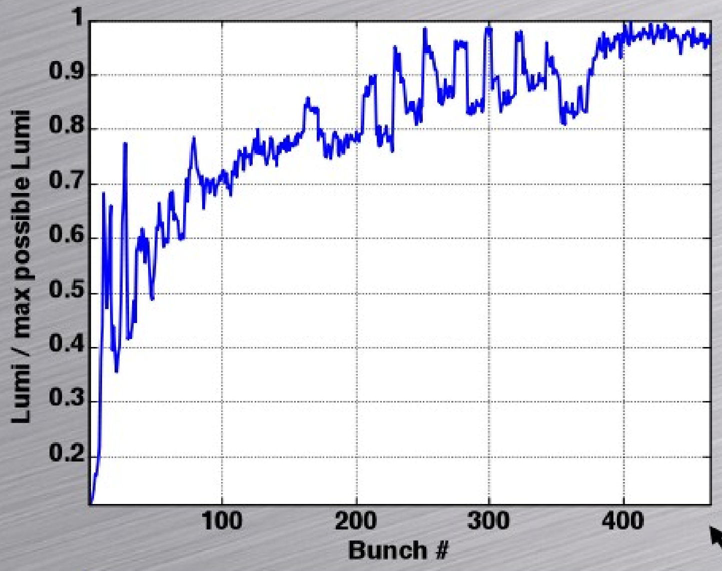


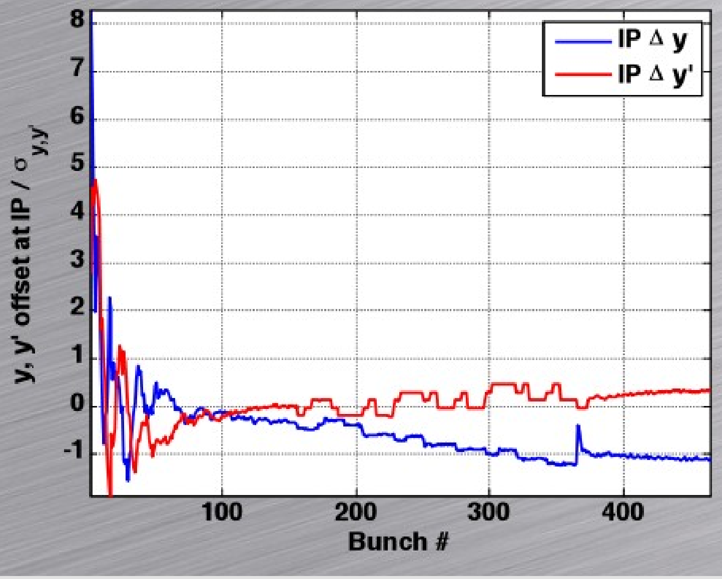
- Lumi Feedback
  - After some number of bunches (~150) when effects like HOM's have damped and beam-based FFB's have settled, optimize IP collision parameters using lumi-based signal.
  - Require prompt signal from 1st layer of BeamCal (integral of incident pairs), which although not directly proportional to lumi, are maximal at lumi max.
  - Need to perform 2D scan in y,y' space to find optimal collision parameters, 2 1D scans doesn't give best performance.
  - Variables are; size of 2D 'pixel' when scanning and number of bunches to average lumi signal over for each scan point. These depend upon noise in lumi signal and noise characteristics of incoming beam
  - Bunch-bunch system essential if optimal collision parameters change pulse-pulse (20% lumi-loss otherwise).

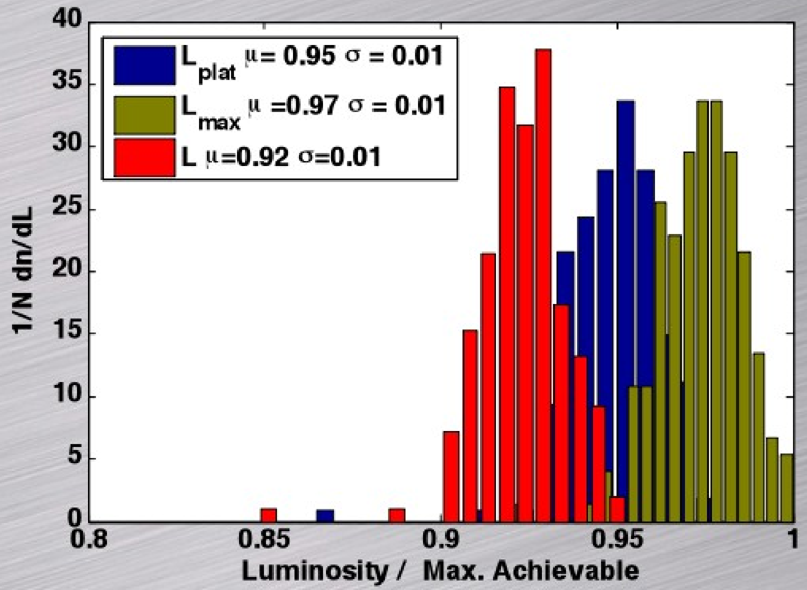
GW (<RDR) Simulation

- 200-seed study, including tracking through LINAC, BDS and IP. Using Placet, MatMerlin and GUINEA-PIG.
- Study response and performance of FFB's as described given initially tuned beamline that delivers target emittances and lumi. Then add inter-pulse effects of GM (K model) + component jitter including SR + LR WF's in Linac cavities.
- TESLA beam parameters used in simulation with Snowmass 2005 lattice (20 + 2mrad IP crossings).

Simulation Results



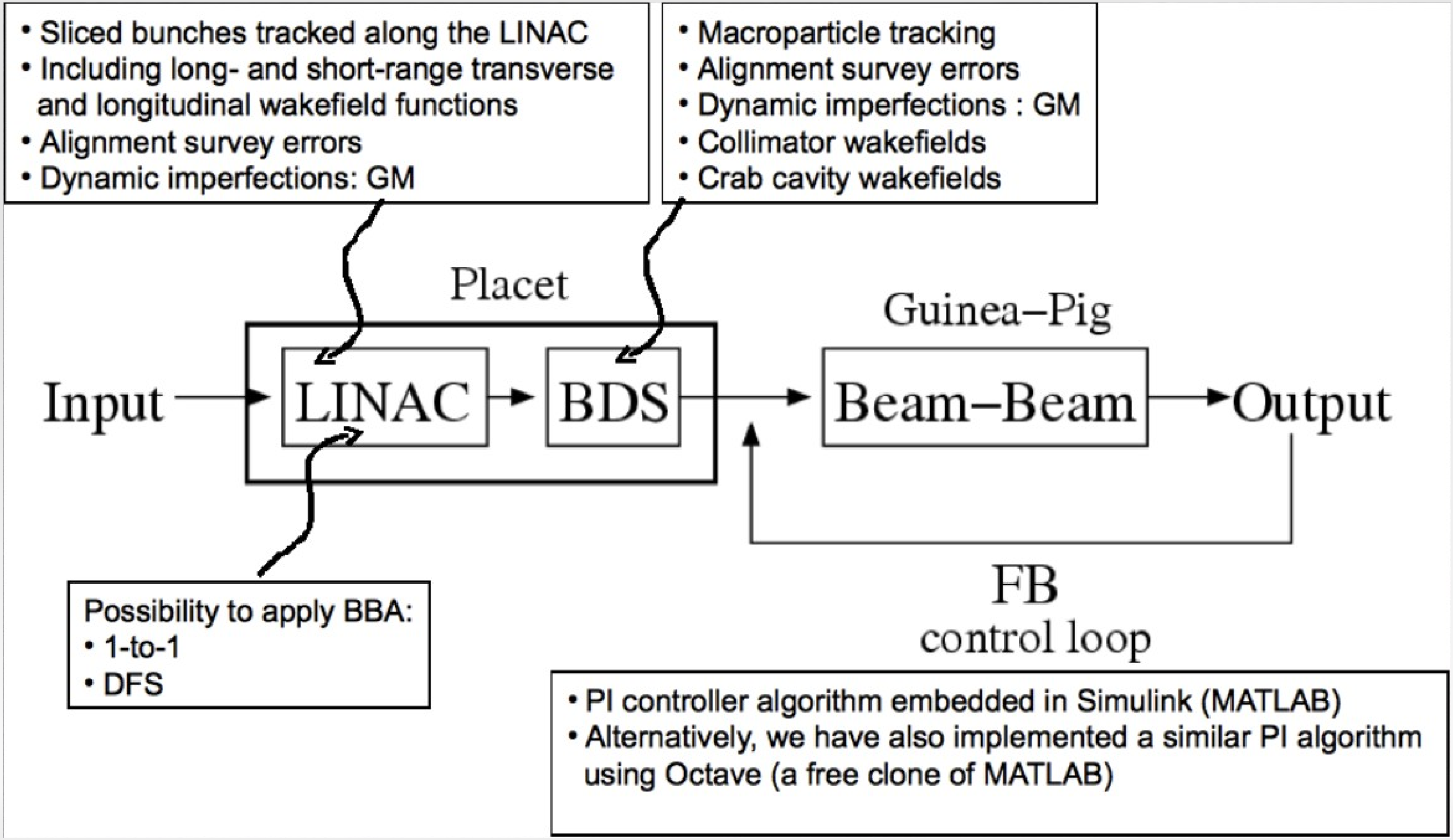




200 Seeds

- **Single Seed:**
  - **Luminosity**
  - **IP Position/Angle**

JRL Simulations (>RDR)



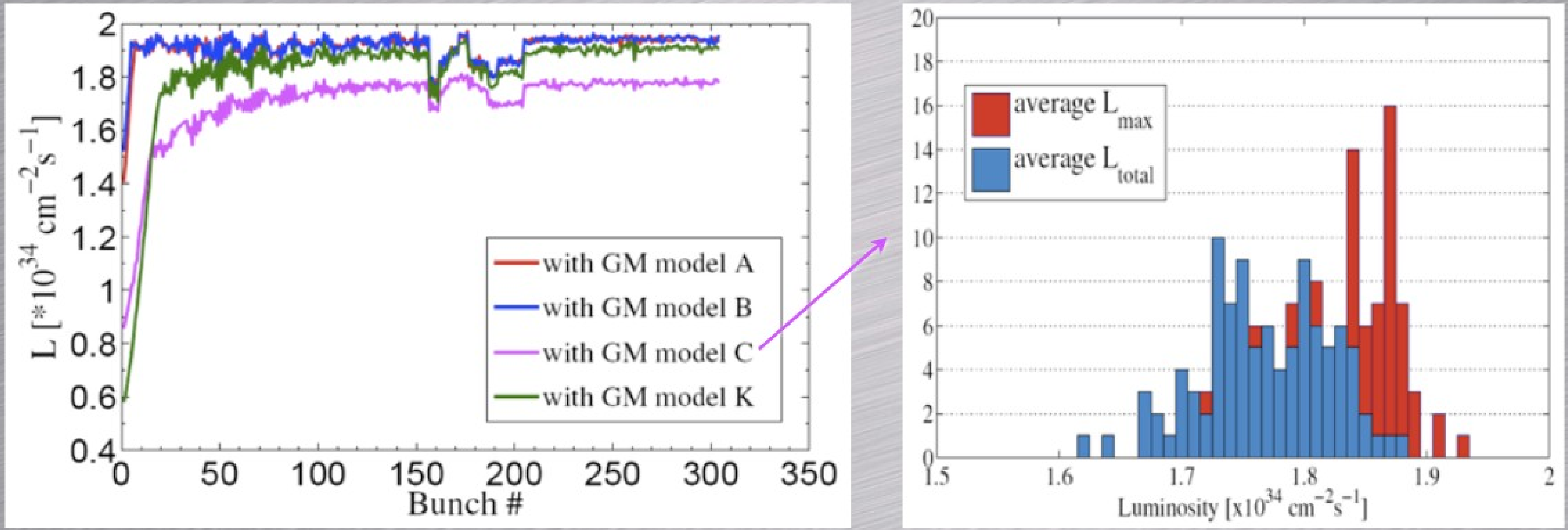
- Sliced bunches tracked along the LINAC
- Including long- and short-range transverse and longitudinal wakefield functions
- Alignment survey errors
- Dynamic imperfections: GM

- Macroparticle tracking
- Alignment survey errors
- Dynamic imperfections : GM
- Collimator wakefields
- Crab cavity wakefields

Possibility to apply BBA:
- 1-to-1
- DFS

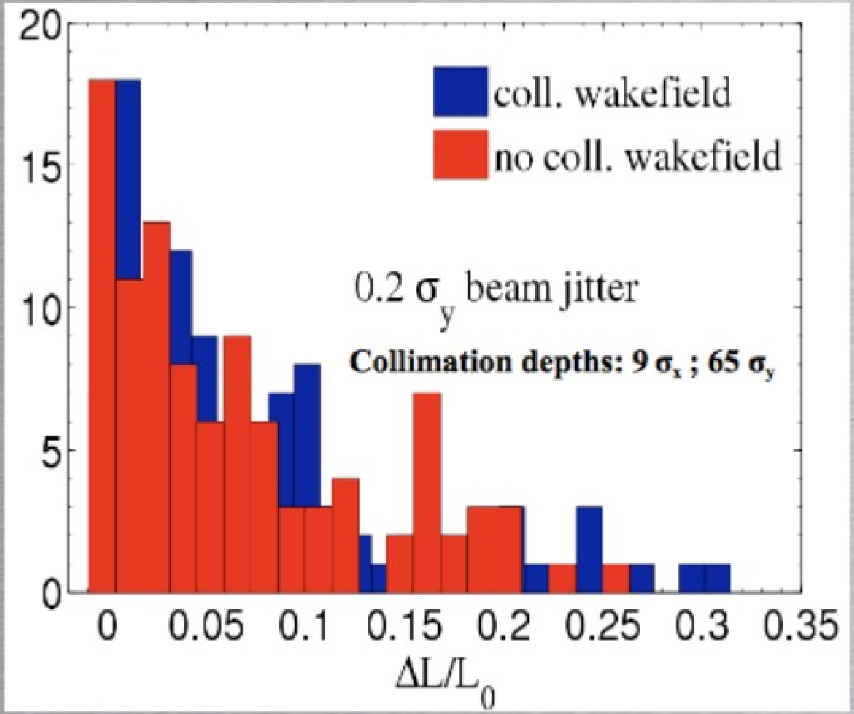
- PI controller algorithm embedded in Simulink (MATLAB)
- Alternatively, we have also implemented a similar PI algorithm using Octave (a free clone of MATLAB)

Simulation Results



- Banana effect negligible here
- Mean $L_{max} = 92\%$, $L_{total} = 88\%$

BDS Collimator Wakefields



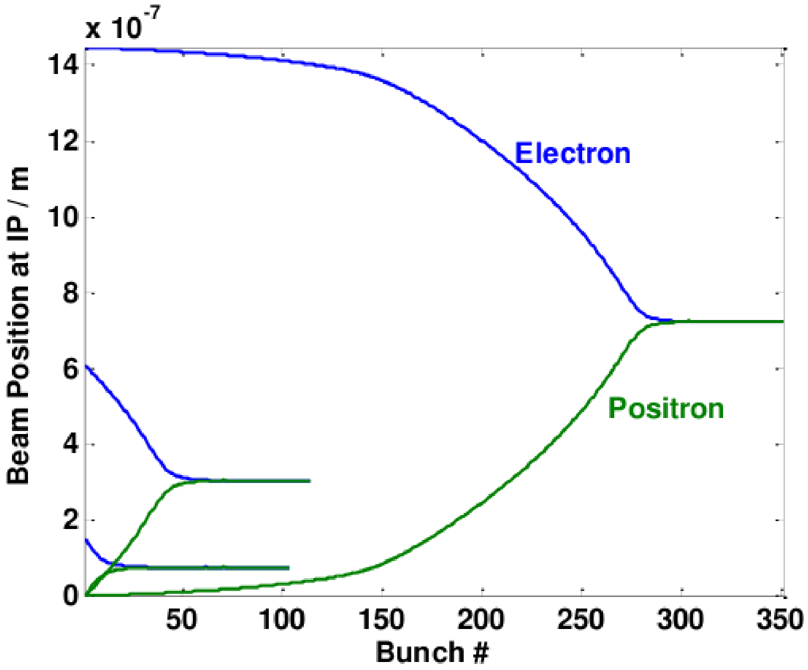
- Luminosity-loss distribution from 100 simulated seeds including collimator wakefield effects.

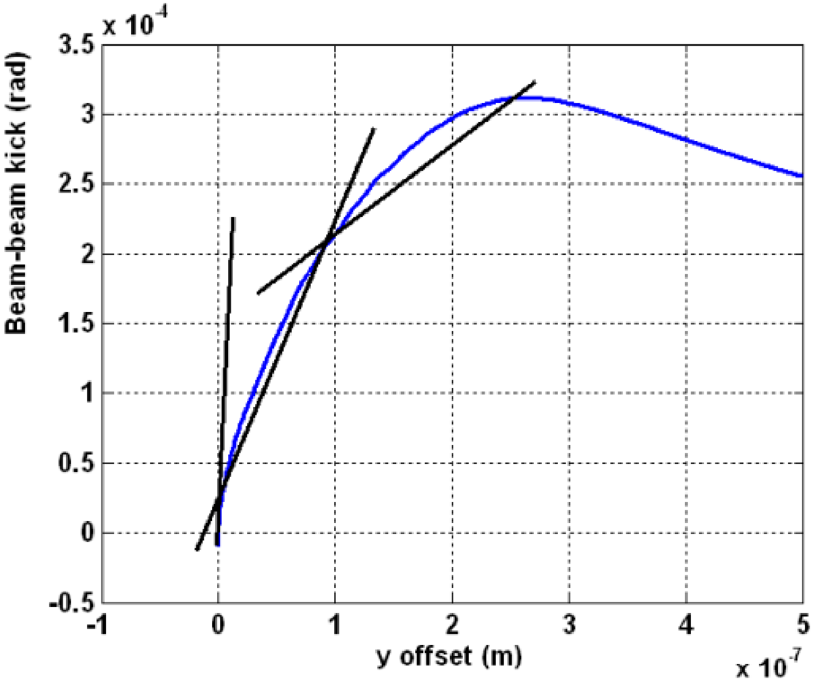
FD Jitter Tolerance Studies

- Asses jitter tolerance on final cryomodule containing QD0/SD0.
- Calculate lumi-loss based on IP beam-beam offset and beam-growth through off-center passage through SD0.
- Use Lucretia + GUINEA-PIG to measure LUMI loss criteria for QD0/SD0 offset with IP fast-feedback compensating.

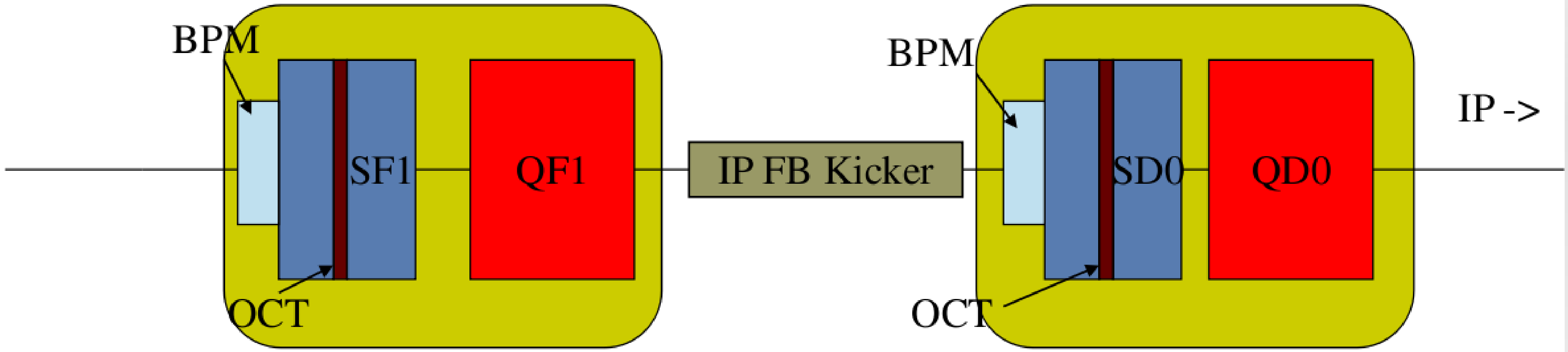
IP Fast Feedback Treatment

- Use ILC IP FFB, tuned for ‘noisy’ conditions
  - Less than 5% lumi-loss with GM ‘K’ + 25nm component vibration (pulse-pulse) & ~ 0.1 sigma intra-bunch uncorrelated beam jitter.
- Assume BDS-entrance FFB has perfectly flattened beam train (flat trajectory into Final Doublet).
- No ‘banana’ effect on bunches.
- Calculate Luminosity from measured bunches, with mean of last 50 weighted to account for the rest of the beam train (2820 bunches).



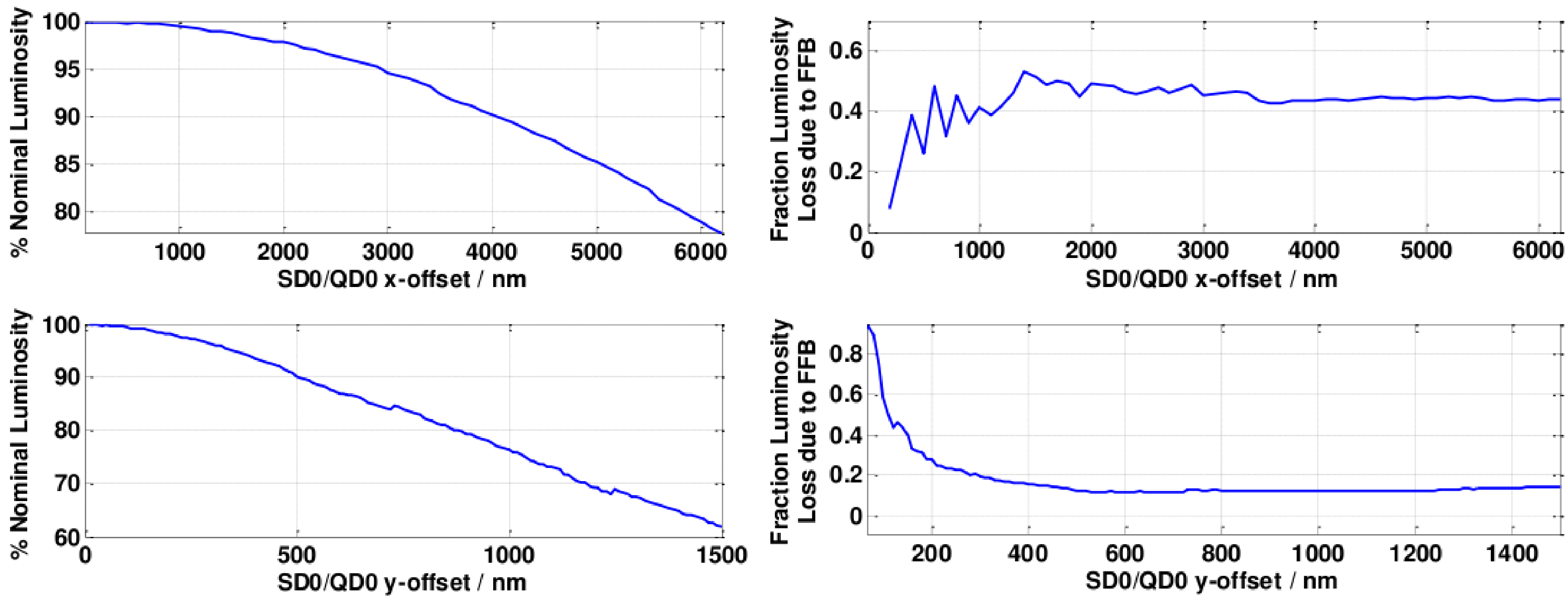


Final Doublet + Kicker Layout



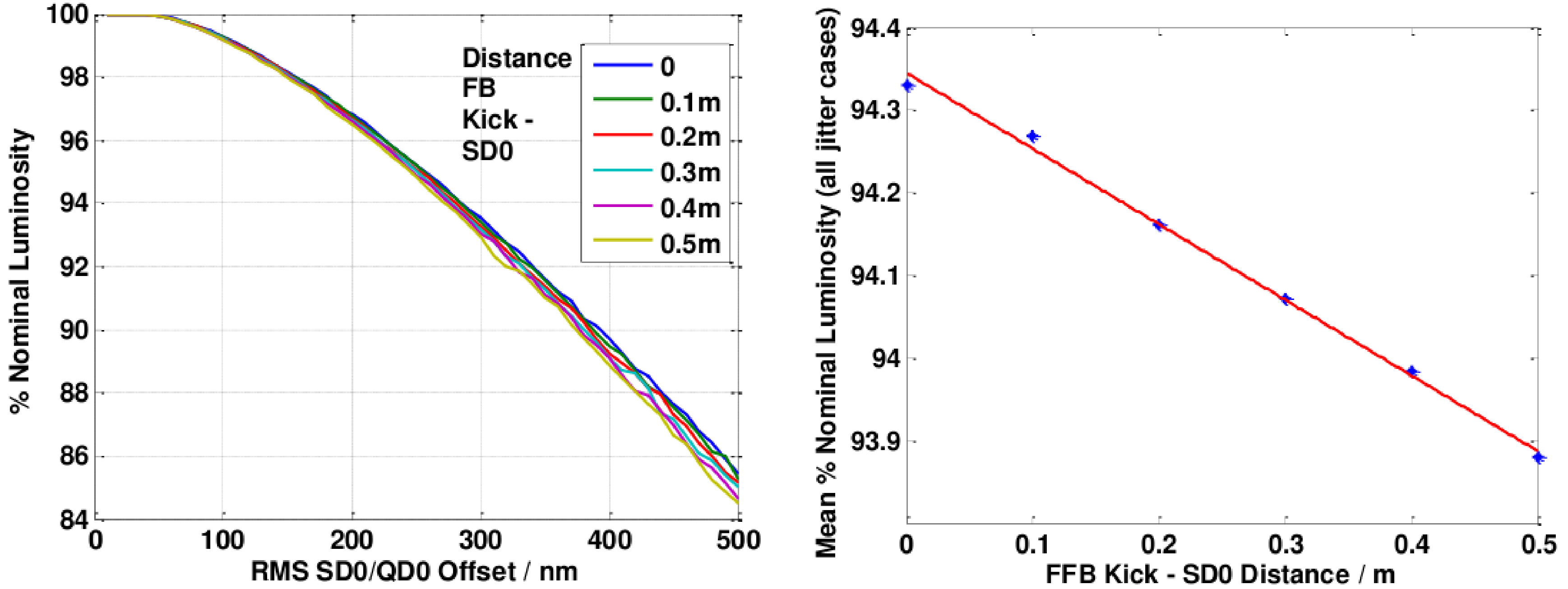
- ☐ IP FFB kicker in ~1m gap between 2 cryomodules near IP.
- ☐ Distance of kick from SD0 face effects lumi as beam is kicked off-center going through SD0.
- ☐ Advantage to using shorter kicker?

Effect of SD0/QD0 Offset



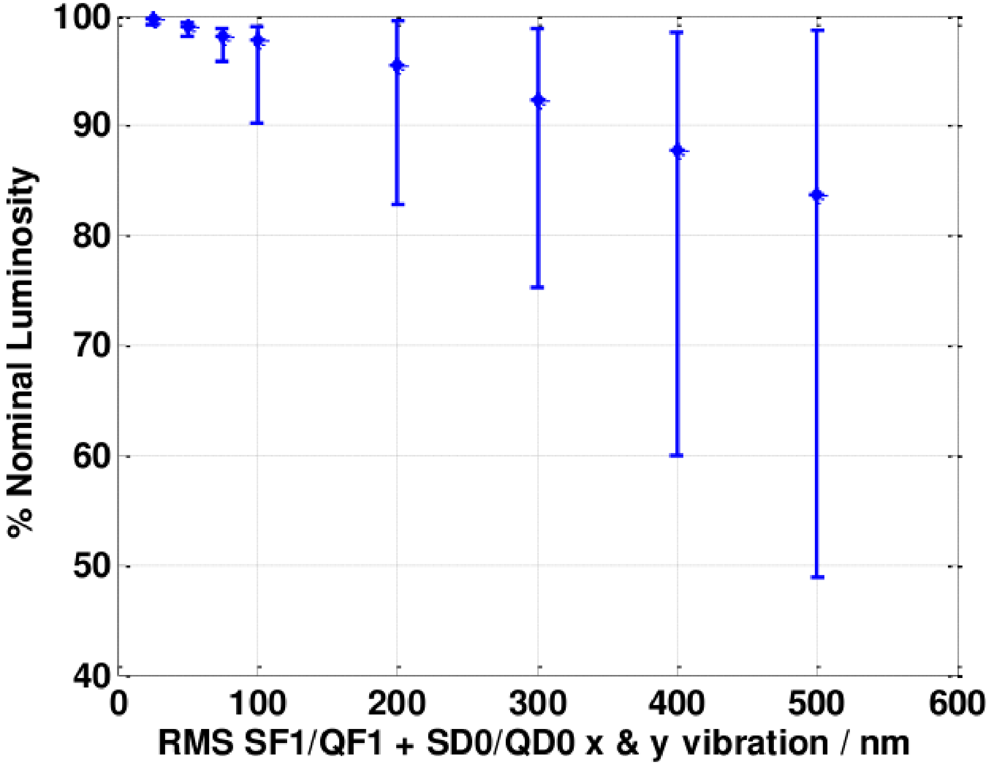
- Luminosity loss as a function of SD0/QD0 offset and relative importance of offset through SD0 vs. IP offset.
- Shows beam size growth through offset SD0 dominant over FFB beam offset conversion time (more so in vertical plane).
  - e.g. for y at 500nm offset, ~85% of luminosity loss through beamsize growth effect, 15% through conversion time of FFB system.

Luminosity vs. QD0/SD0 Jitter and Kick Distance



- Calculate Luminosity loss for different jitter / kick distance cases using 'SD0 lumi loss' and 'FFB lumi loss' look-up tables (horizontal + vertical).
- Left plot shows % nominal luminosity with given RMS SD0/QD0 jitter and varying kick-SD0 distance.
- Right plot shows all jitter cases plotted vs. kick distance and shows the expected dependence on kick distance.

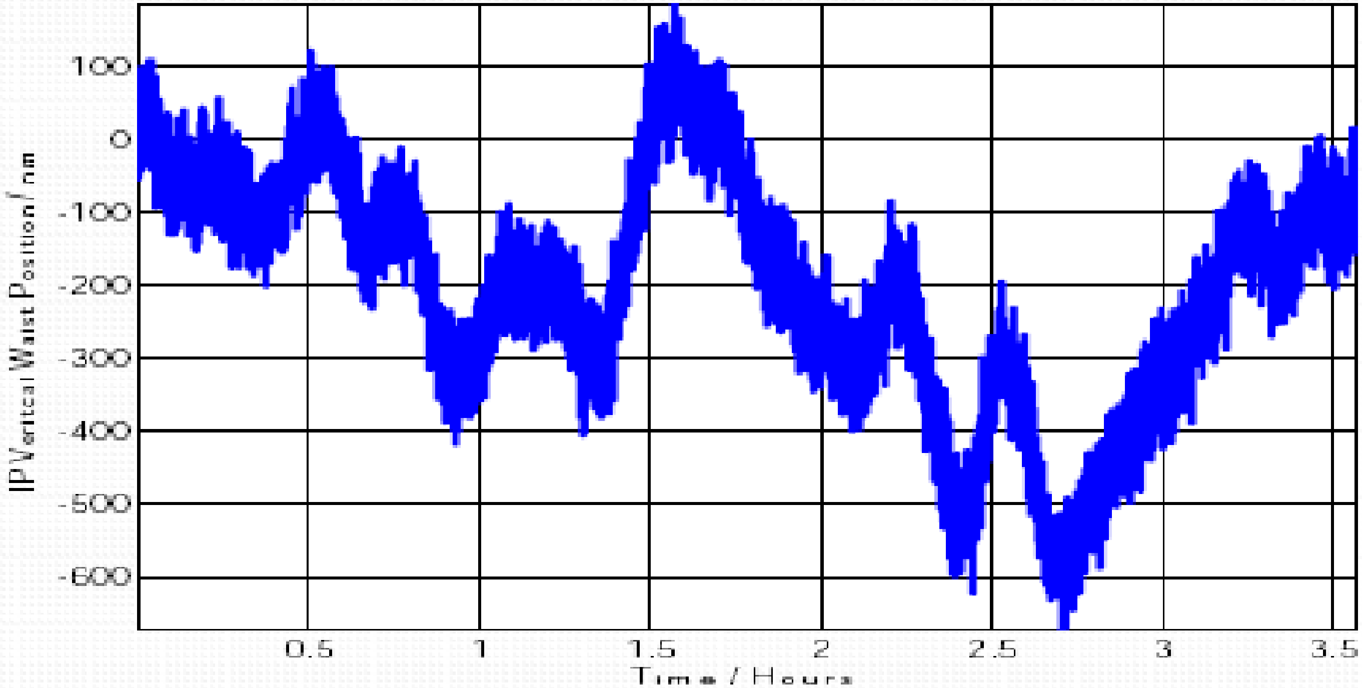
Tracking Simulation Results with RMS Offsets of Both FD Cryomodules



- Track 80K macro particles (e- & e+ side) from QF1 -> IP with RMS SF1/QF1 and SD0/QD0 vibration in horizontal and vertical planes.
- Results show mean and range of luminosities from 100 consecutive pulses.

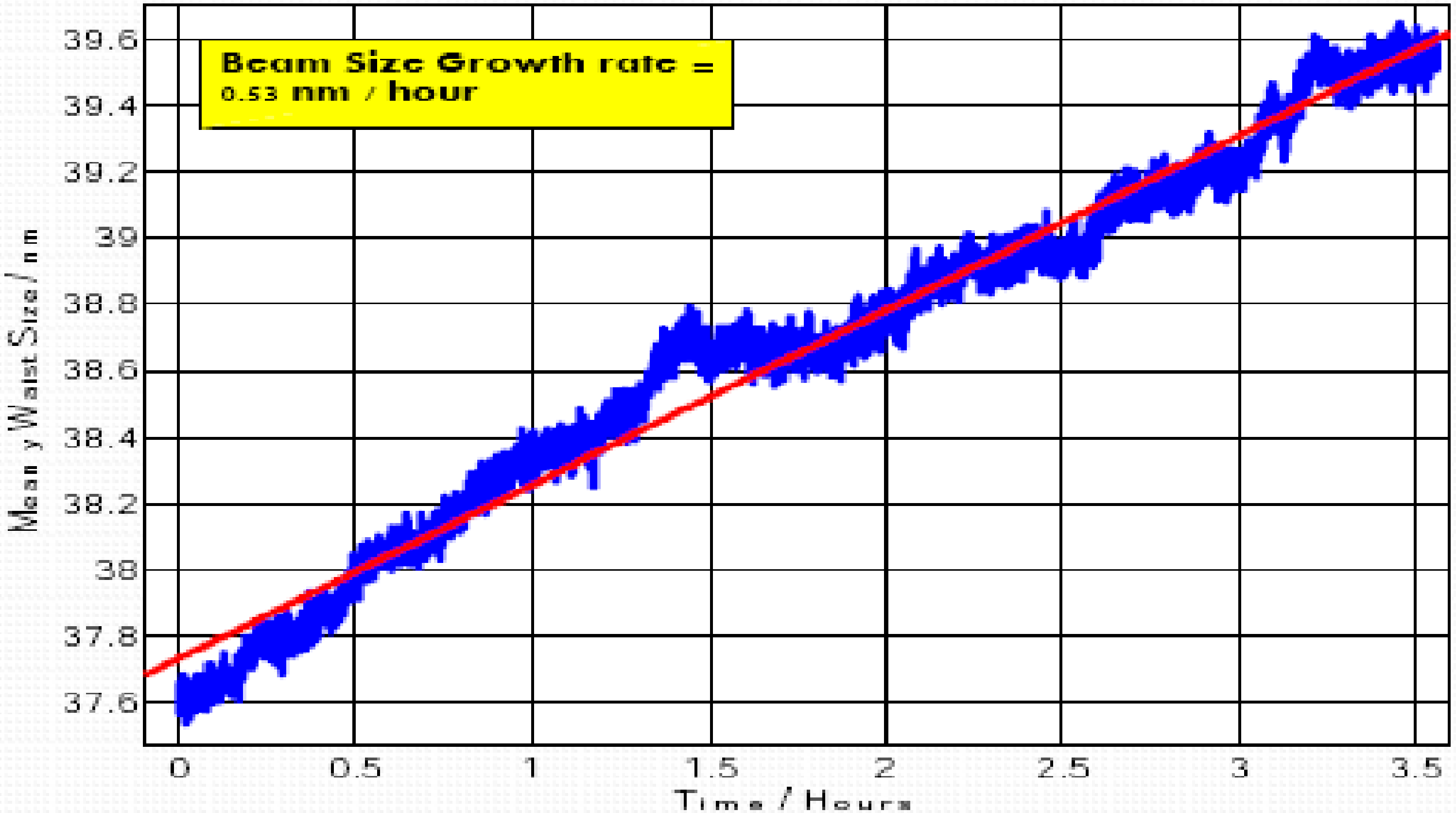
FFS De-Tuning Effect from Orbit Drift (ATF2 study)

- Simulate component jitter + GM (fitted to ATF measurements) on initially tuned beamline.
    - Include orbit feedbacks



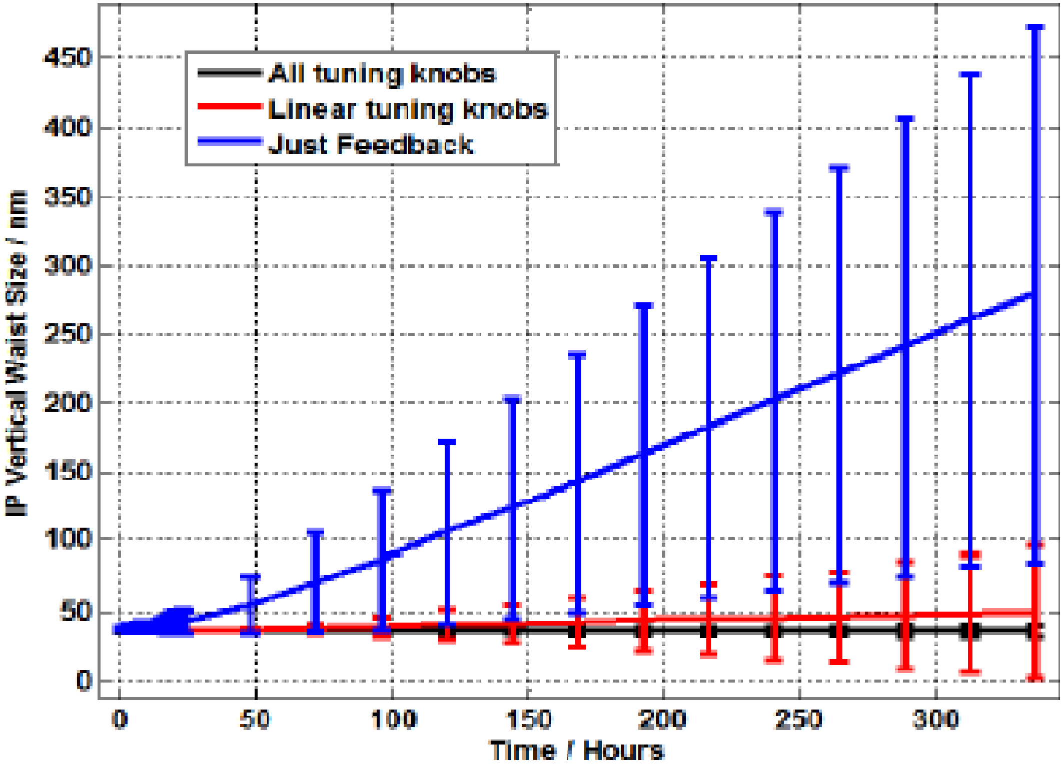
- 20,000 pulses @ 1.56 Hz (1 seed)
- IP vertical position drifts around on scales of a few 100 nm an hour.

Beam Size Growth



- With feedbacks on, y beam size at IP as a function of time
- Mean of 100 seeds shown
- Growth rate ~ 0.5 nm per hour

Long Timescale Performance

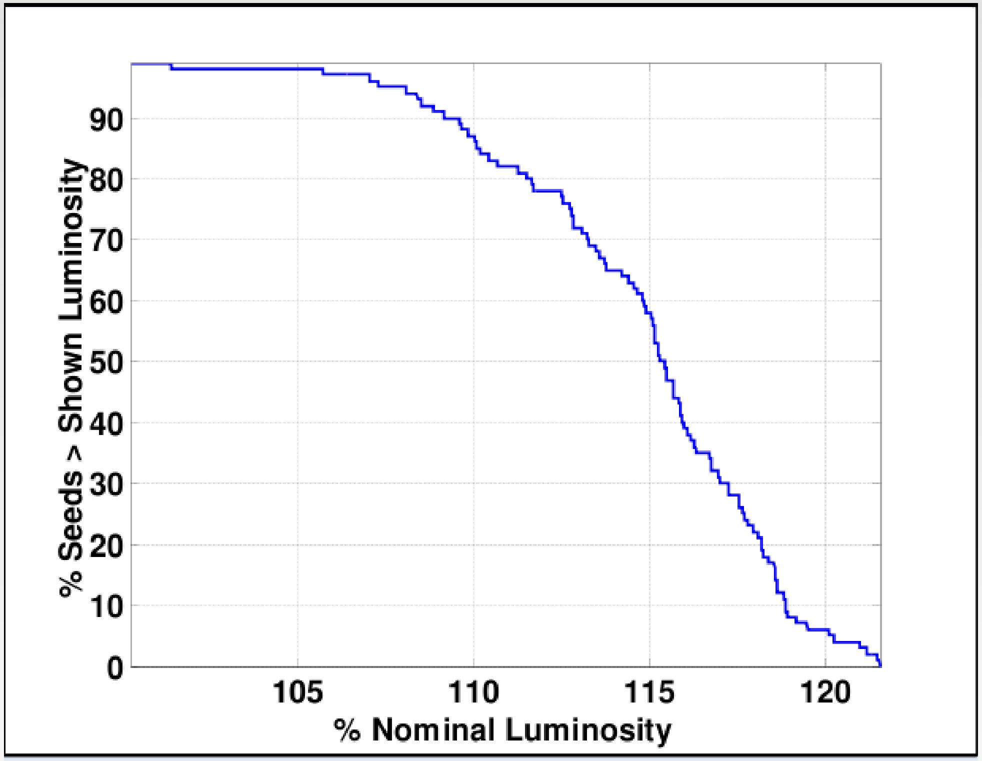


At each point, none, linear (waist, dispersion and coupling) and full tuning knobs (include sextupole strength and tilt scans) applied. For blue, red and black respectively.

- Vertical IP beam size over 2 week period
- Mean and +/- 1 sigma RMS from 100 seeds shown at each point

Summary

- BDS tuning simulation shows median lumi overhead of ~15% given 6nm emittance budget.
- Slow dynamics gives ~12% lumi loss
- Fast dynamics gives ~8 % lumi loss



Summary

- But, BDS tuning simulation done including effects of GM + jitter
  - Need to take care of FFS, including SEXT effects and dynamic detuning etc, then get better results than predicted by earlier simulations
  - Just need to absorb ~6% emittance growth from Linac section + 8% fast dyamic growth
  - This together with BDS luminosity overhead gives a simulation where ~60% of simulated seeds produce design luminosity.
- But, simulations on variety of lattices, non of which are current, needs updating...