Feedback On Nano-second Timescales: IP Feedback Simulations

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DESY:

Nick Walker…

SLAC:

Steve Smith, Thomas Markiewicz …

CERN:

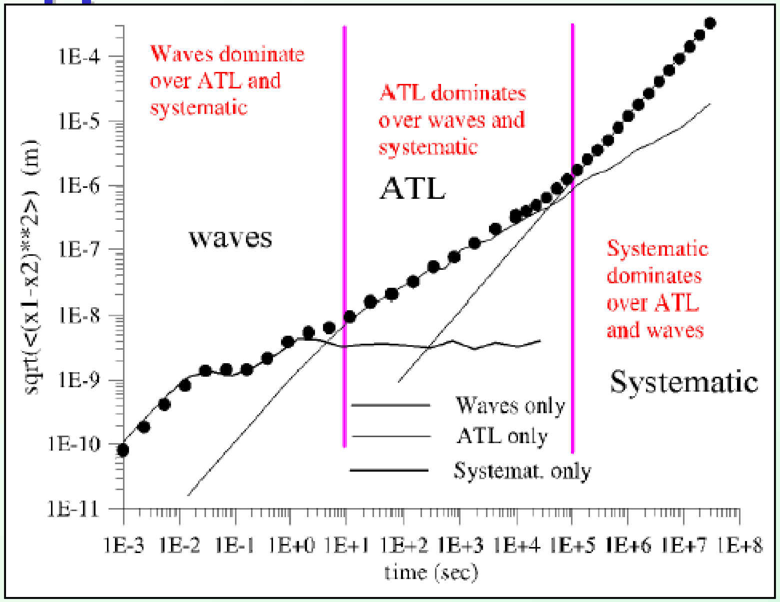
Daniel Schulte…

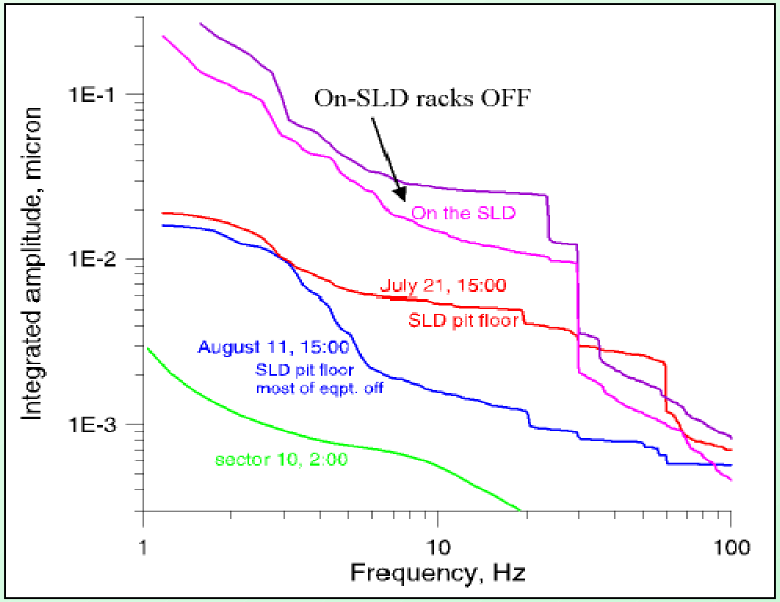
February 2002

- Requirement for a fast IP beam-based feedback system
- NLC, CLIC Simulations
- NLC Background Calculations
- TESLA Simulations

F.O.N.T.

GROUND MOTION





From Ground Motion studies by A.Seryi et al. (SLAC)

- **'Fast' motion (> few Hz) dominated by cultural noise**
- **Concern for structures with tolerances at nm level (Final Quads)**

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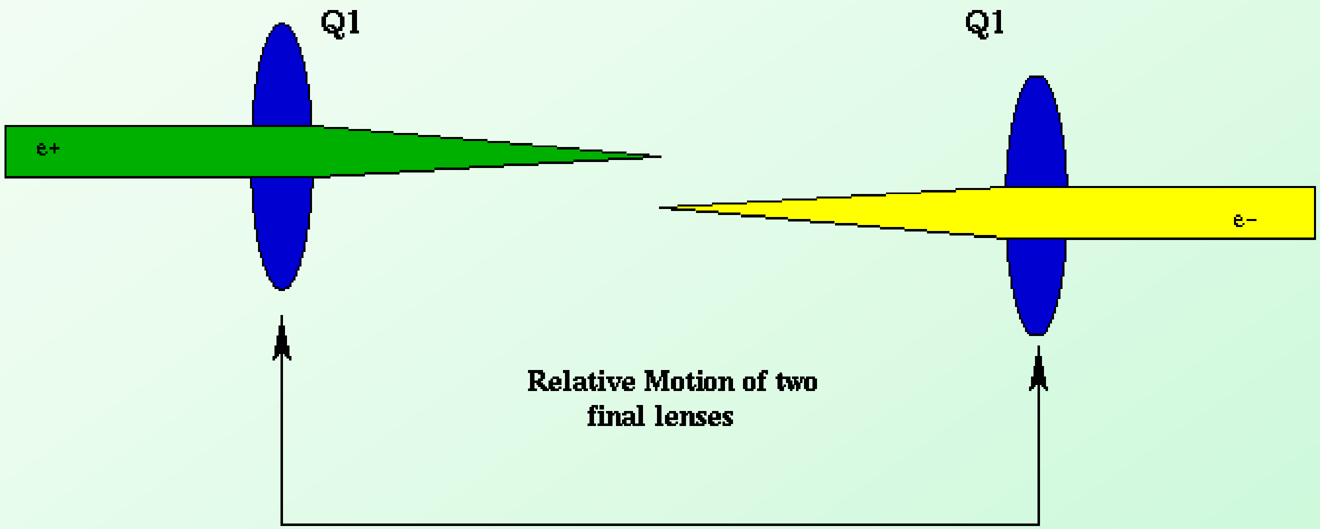
LUMINOSITY LOSS AT IP



Control position & motion of final quads and/or position of the beam to achieve/maintain collisions

- Relative offsets in final Quads due to fast ground motion leads to beam offsets of several σ_y (2.7 nm for NLC-H 500 GeV).
- Correct using beam-based feedback system near IP or by active mechanical stabilization of Quads or both.

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LC BUNCH STRUCTURE

	NLC-H 500 GeV	TESLA 500 GeV	CLIC 500 GeV
Particles/Bunch x 10^{10}	0.75	2.0	0.4
Bunches/train	190	2820	154
Bunch Sep (ns)	1.4	337	0.7
$\blacklozenge_x/\blacklozenge_y$ (nm)	245 / 2.7	553 / 5	202 / 2.5
$\blacklozenge_z$ (❍m)	300	110	30

•IP beam characteristics important to fast feedback system for simulated machines.

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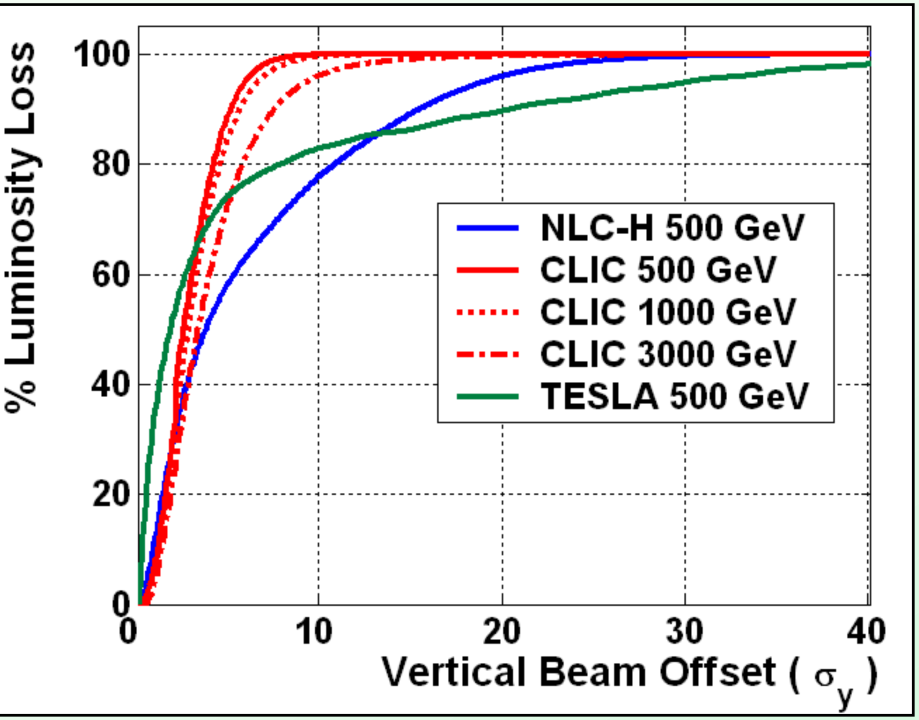
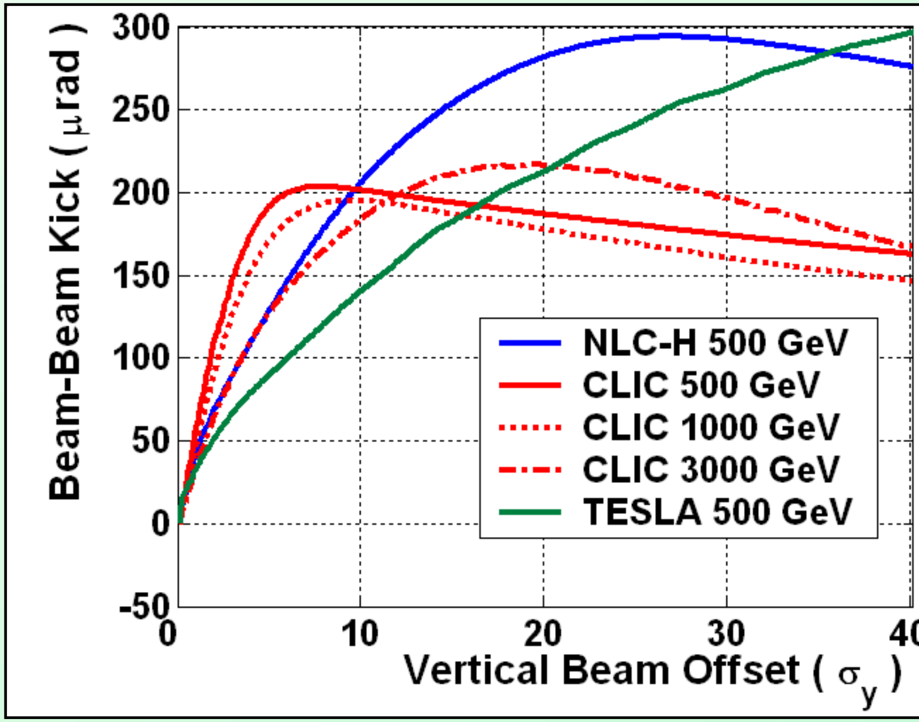
BEAM-BEAM INTERACTION





- Beam-beam EM interactions at IP provide detectable signal.
- Beam-beam interactions modelled with GUINEA-PIG.
- Kick angle and percentage luminosity loss for different vertical beam offsets shown for NLC & CLIC.

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NLC FEEDBACK OPERATION

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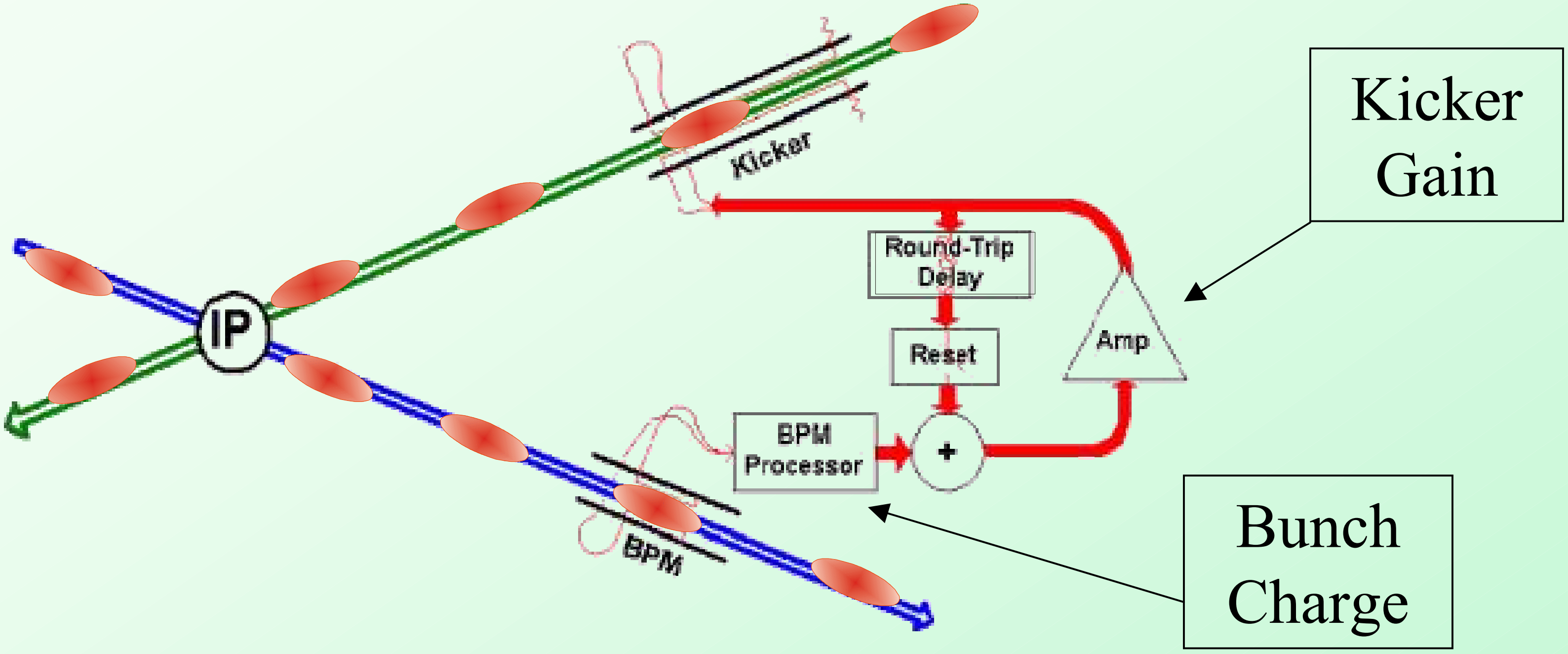

- Measure deflected bunches with BPM and kick other beam to eliminate vertical offsets at IP
- Feedback loop assesses intra-bunch performance and maintains correction signal to the kicker
- Minimise distance of components from IP to reduce latency

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NLC FEEDBACK COMPONENTS

Stripline BPM	
Distance to IP	4.3 m
Stripline radius	1 cm
Stripline Width	4.4 mm
Stripline length	10 cm
Stripline Impedance	50 Ω
Roundtrip time	0.7 ns

Stripline Kicker	
Distance to IP	4.3 m
Stripline radius	6 mm
Stripline length	75 cm
Stripline Impedance	50 Ω
Roundtrip time	5 ns
Azimuthal coverage	120 degrees
Drive voltage required	250 mV/nm
Drive Power 100nm correction	12.5 W

- BPM response peak near 714 MHz bunch spacing frequency
- Kicker rise-time represents slowest component
- System Design by Steve Smith (SLAC)

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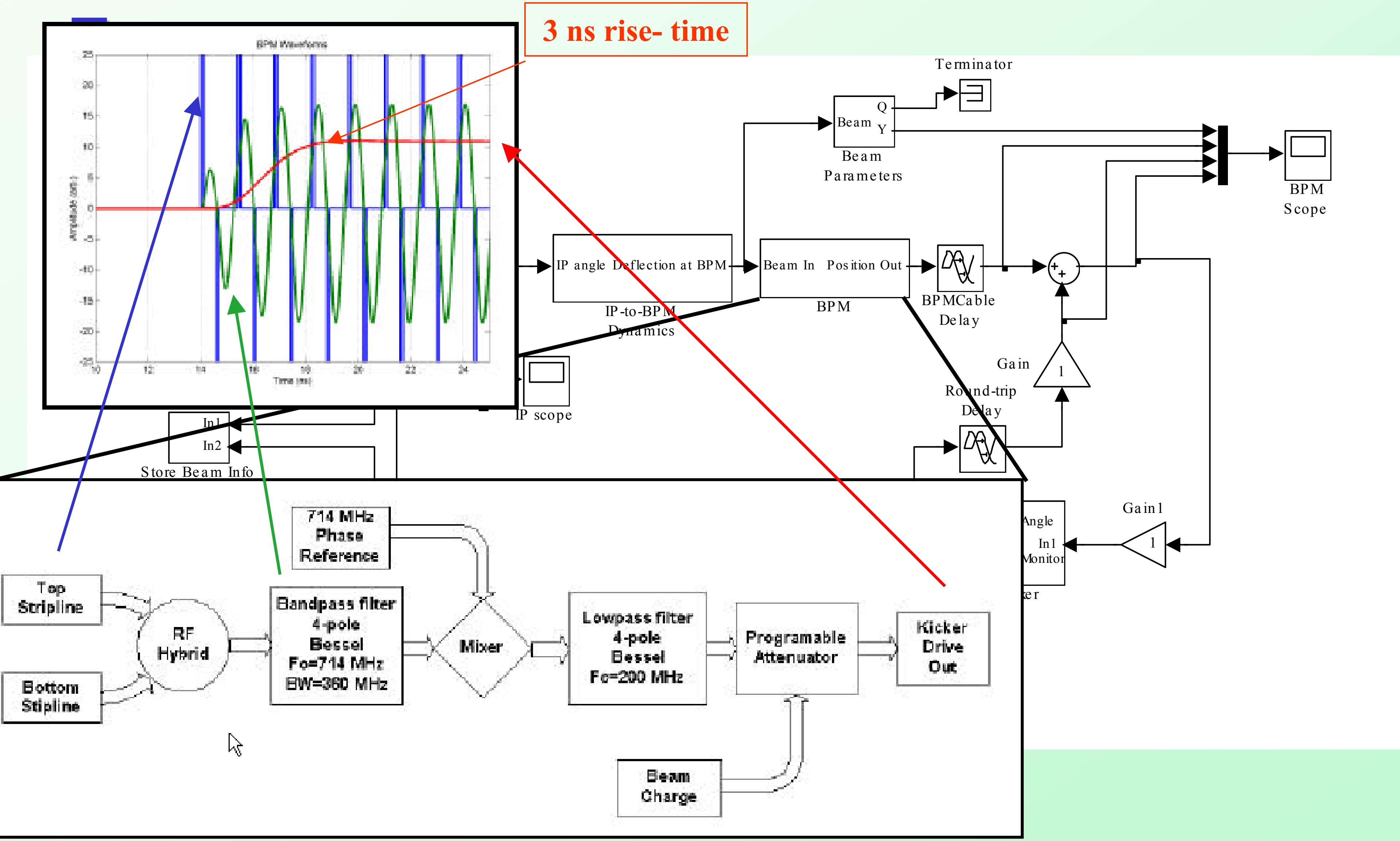
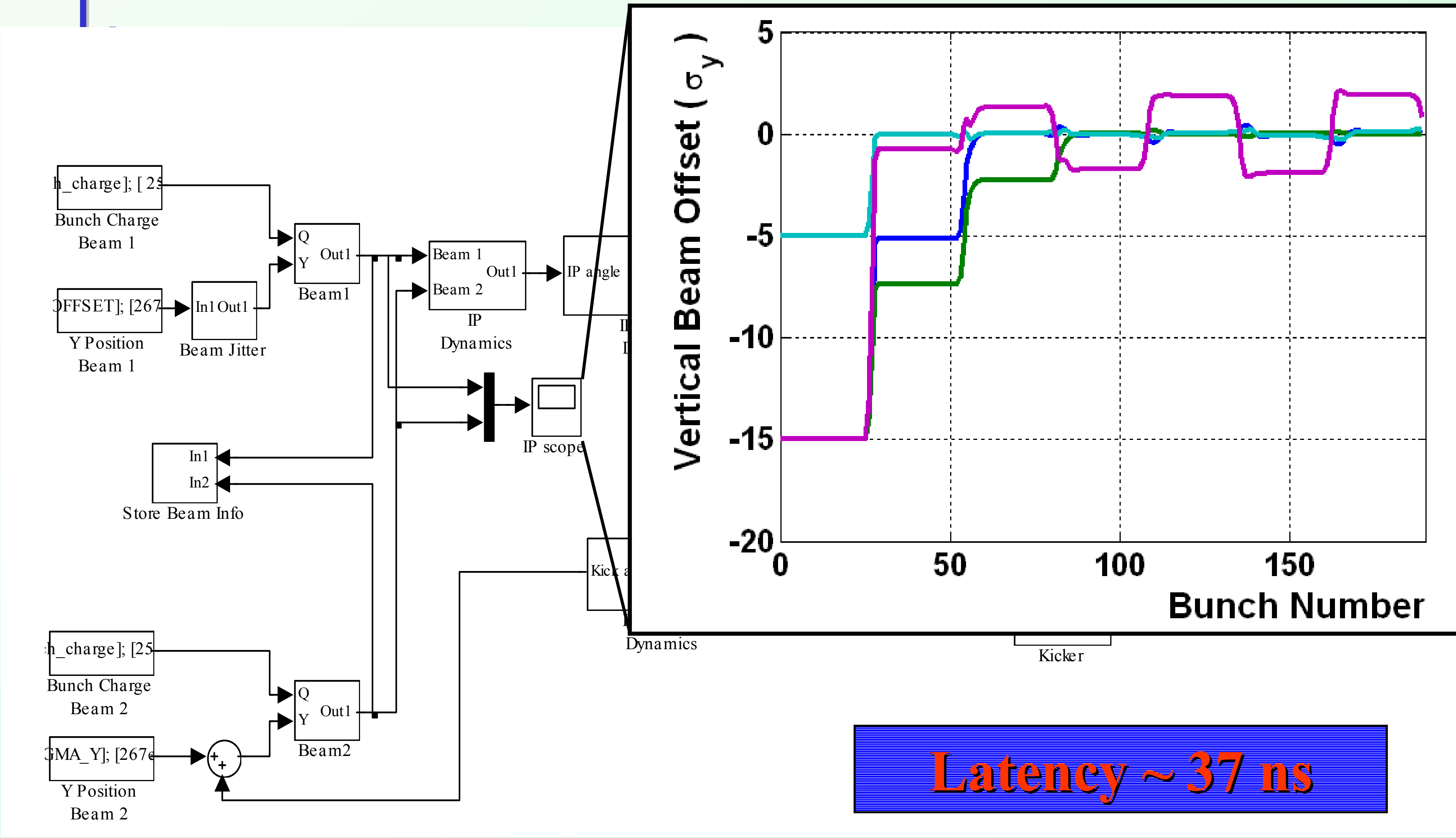
BPM PROCESSOR



FEEDBACK PERFORMANCE



Latency ~ 37 ns

KICKER GAIN OPTIMISATION

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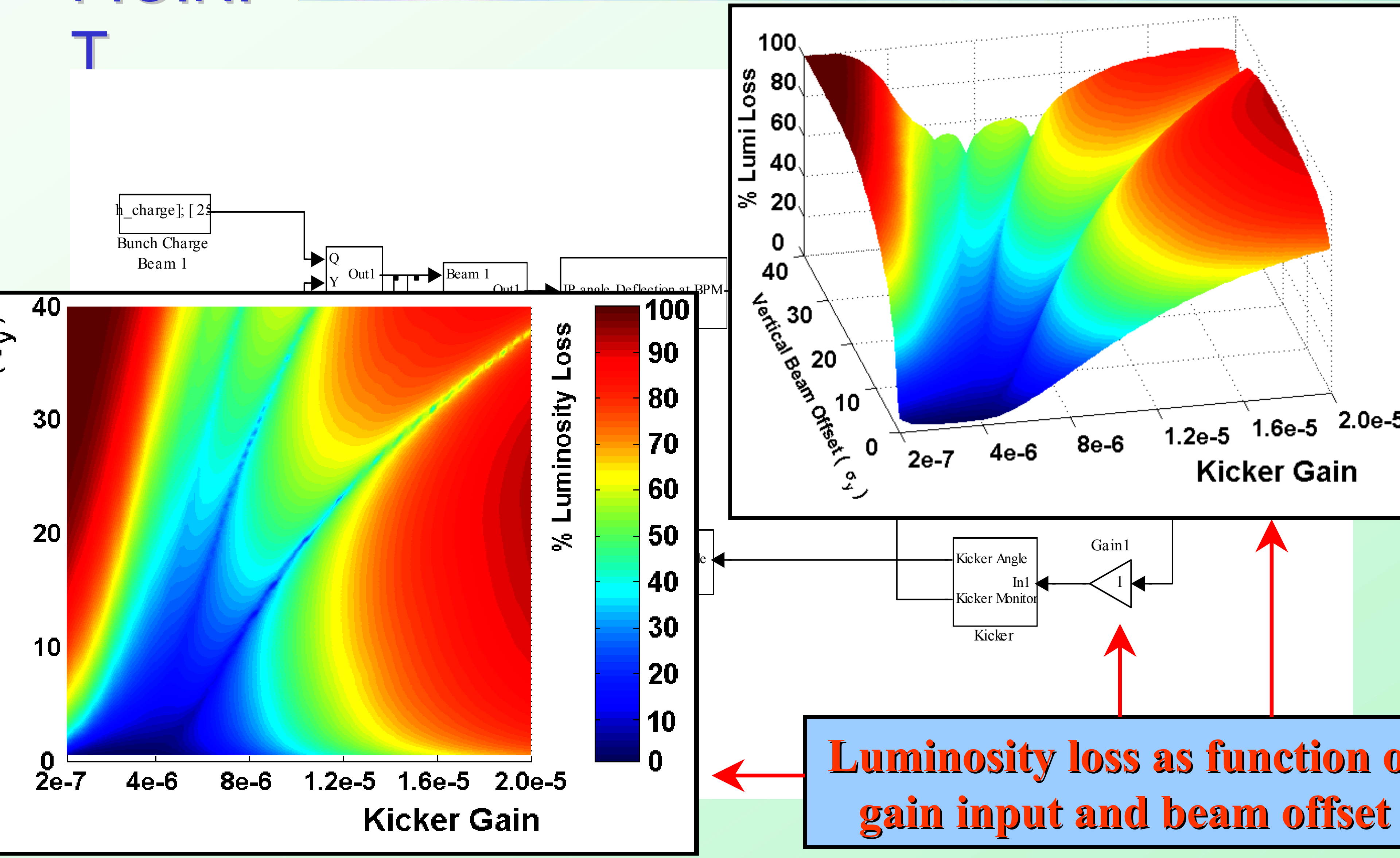

Luminosity loss as function of gain input and beam offset

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LUMINOSITY PERFORMANCE

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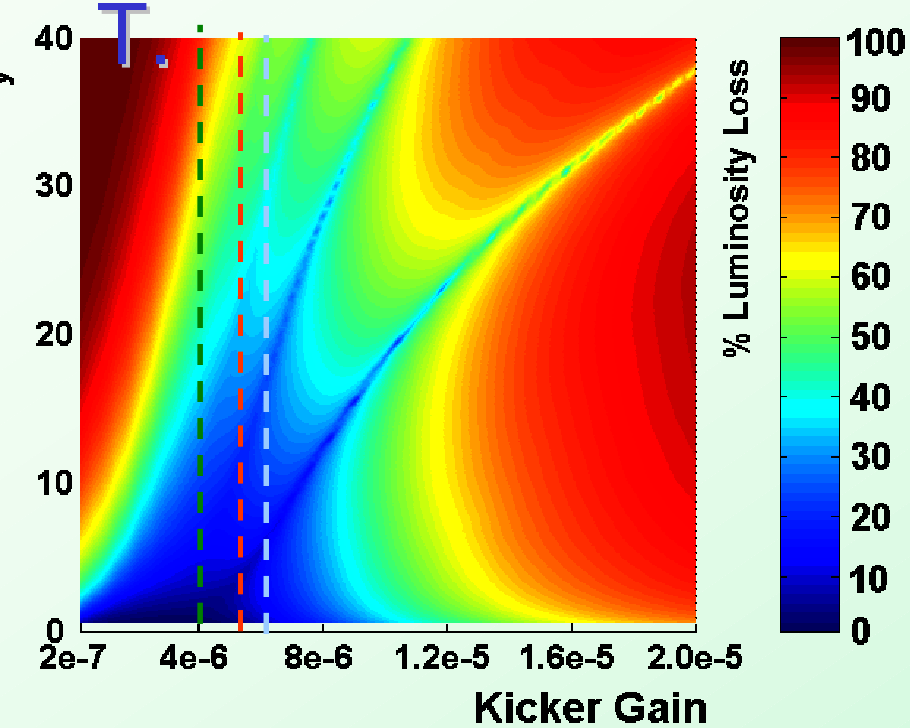

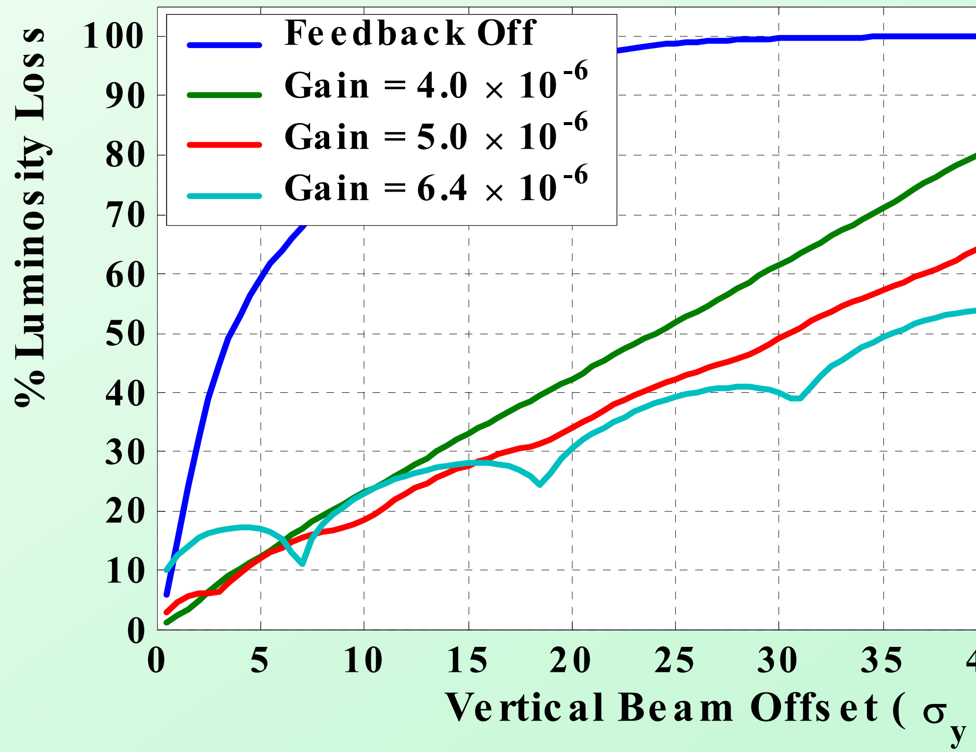

- Lower gains gives better performance at smaller offsets, higher gains give better performance at higher offsets
- Vary gain dependent on observed beam conditions

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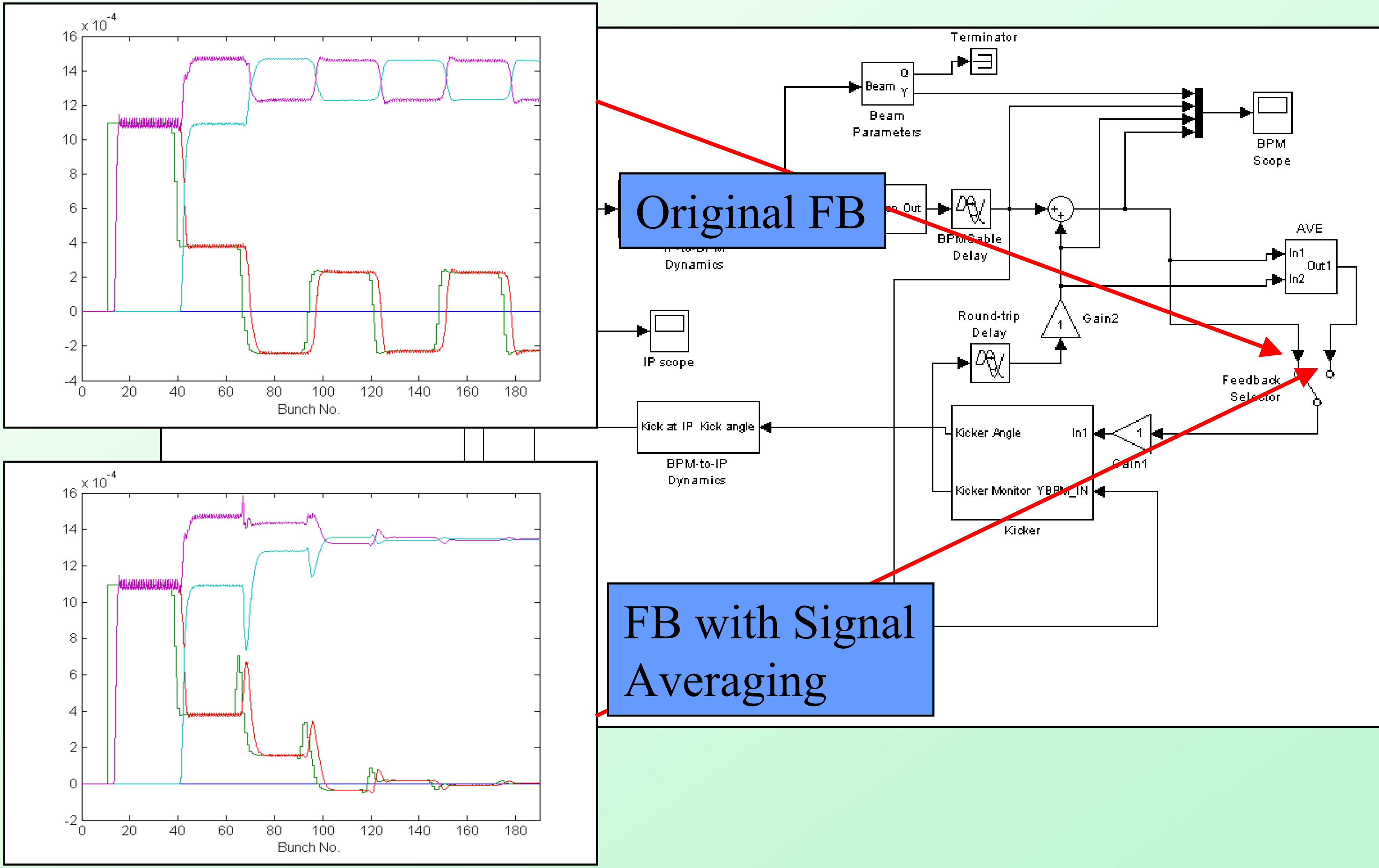
FEEDBACK ENHANCEMENTS



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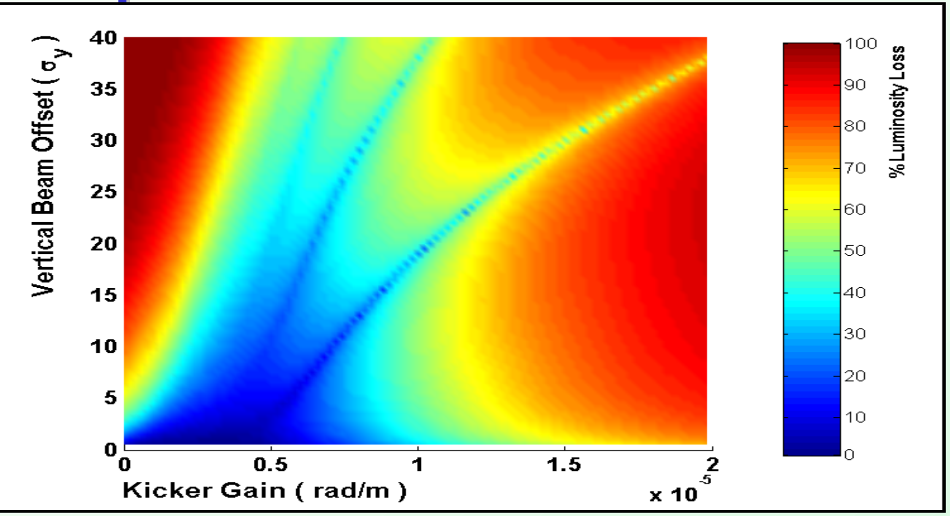
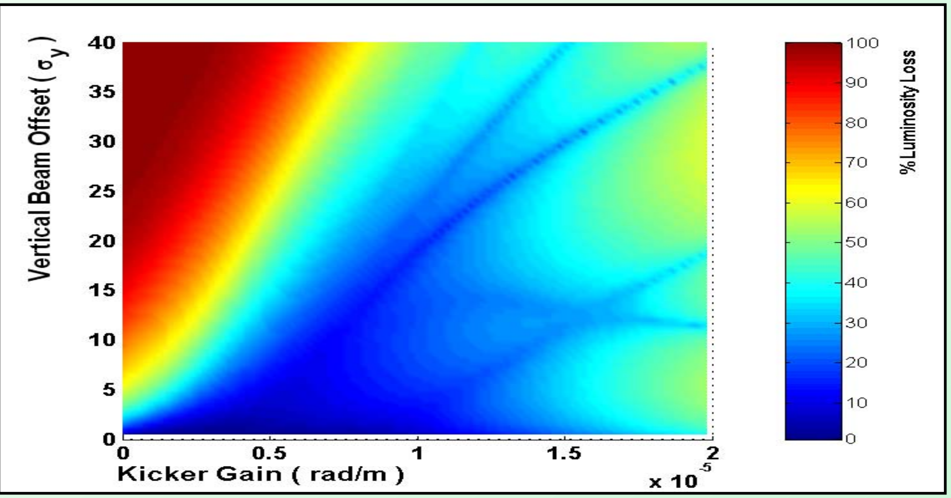
FEEDBACK ENHANCEMENTS



Original Feedback model



Feedback with signal averaging

FEEDBACK ENHANCEMENTS

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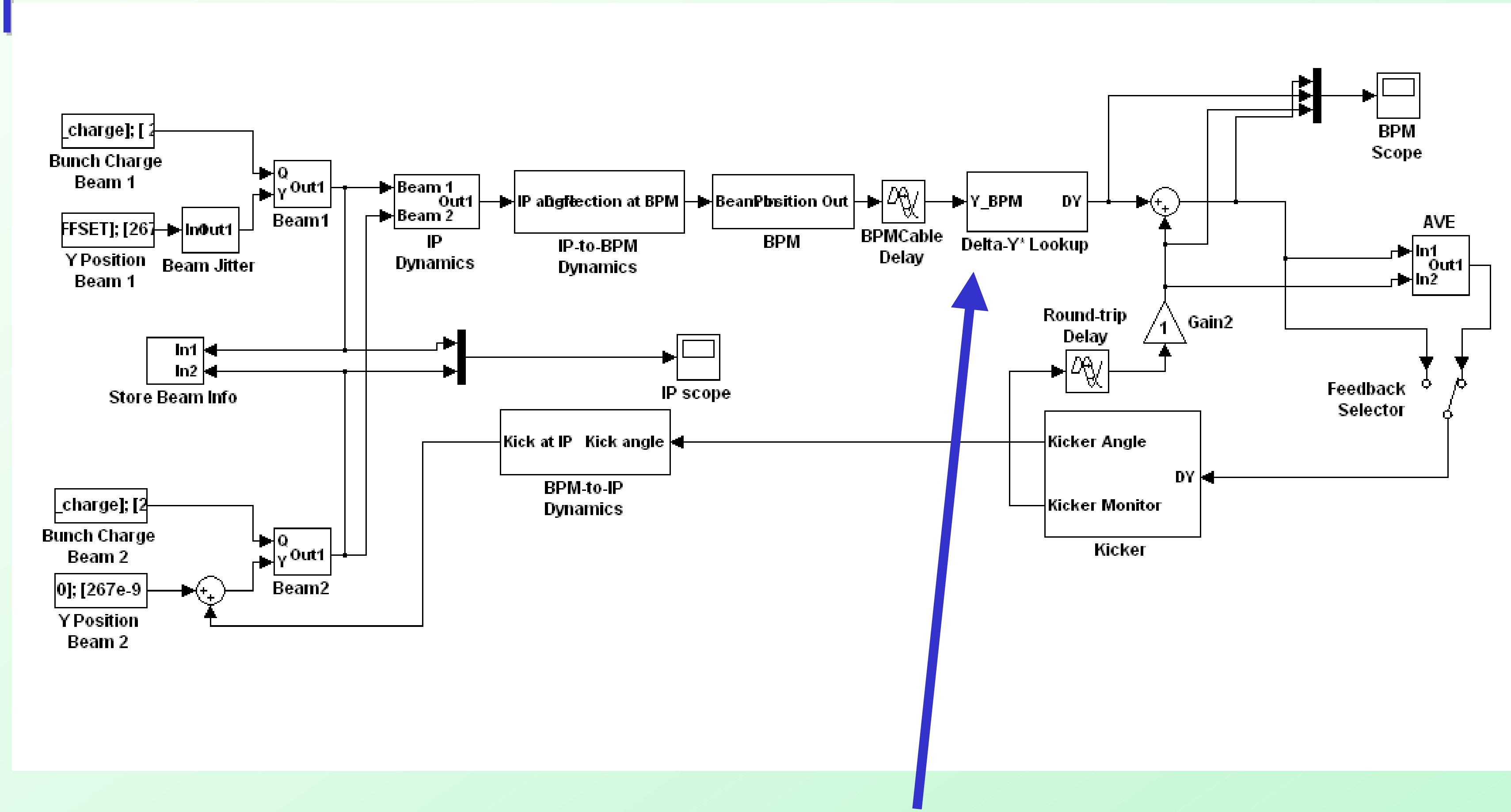

- Add pre-feedback look-up linearisation step

FEEDBACK PERFORMANCE

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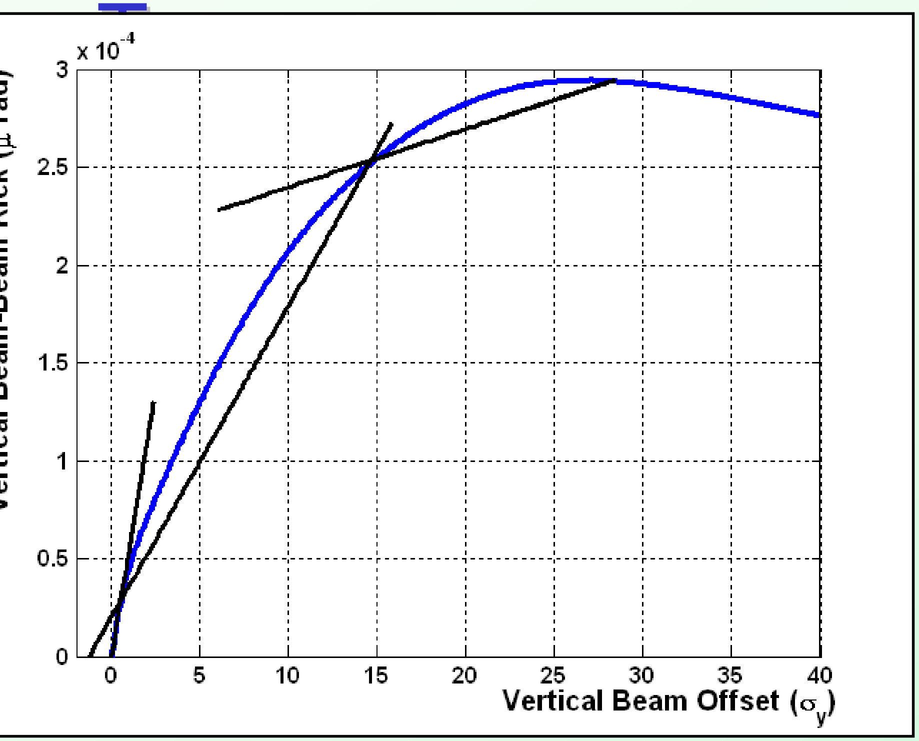

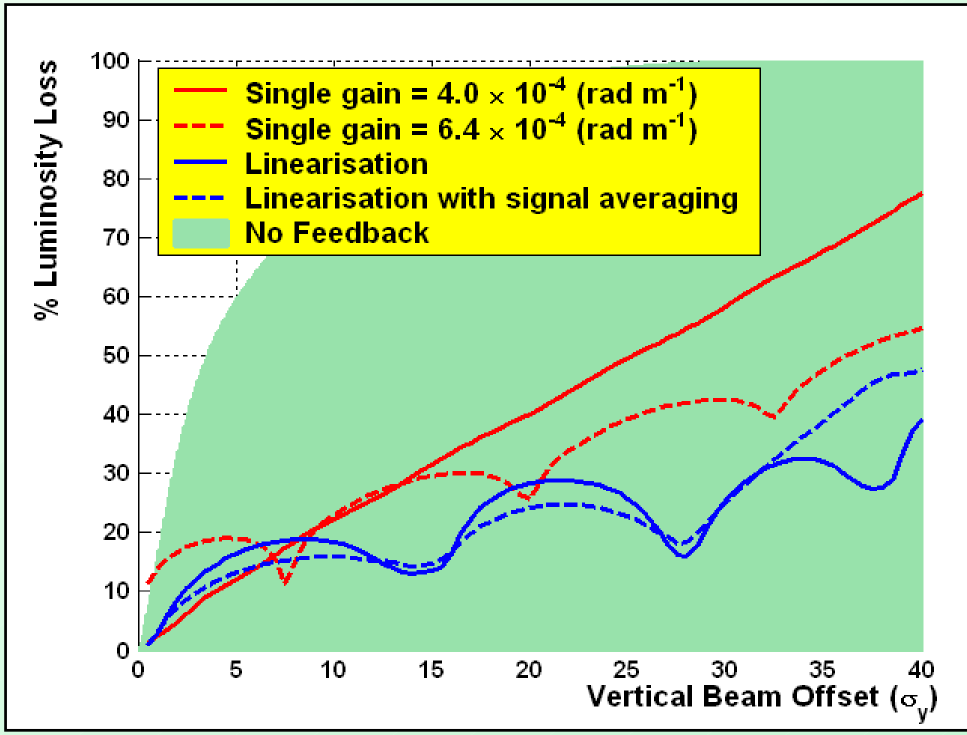

- •Gains chosen automatically based on linearisation of beam-beam kick curve.
- •Gives good luminosity performance over whole offset region.

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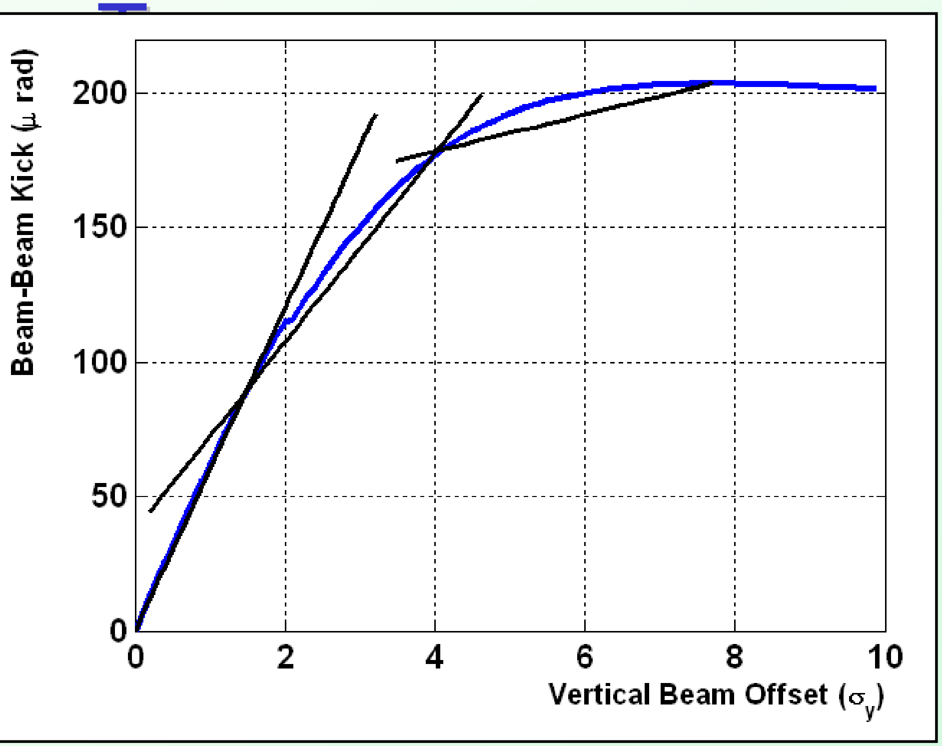
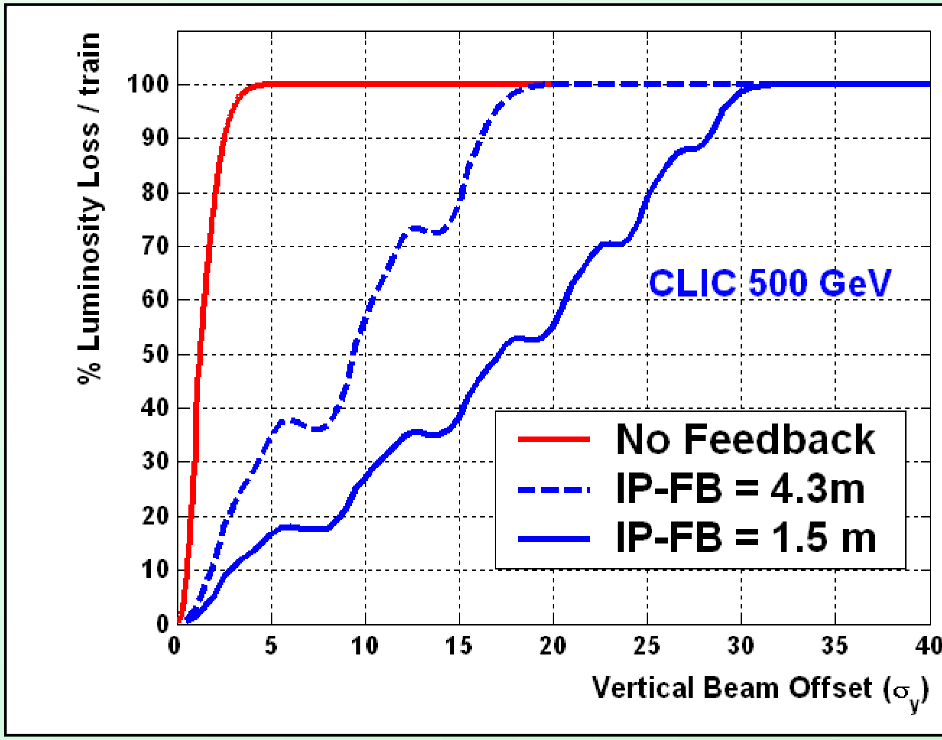
CLIC FEEDBACK





- **Gains chosen automatically based on lineariasation of beam-beam kick curve.**
- **Luminosity performance for Feedback system same distance from IP as NLC case (4.3m) and closer (1.5m).**

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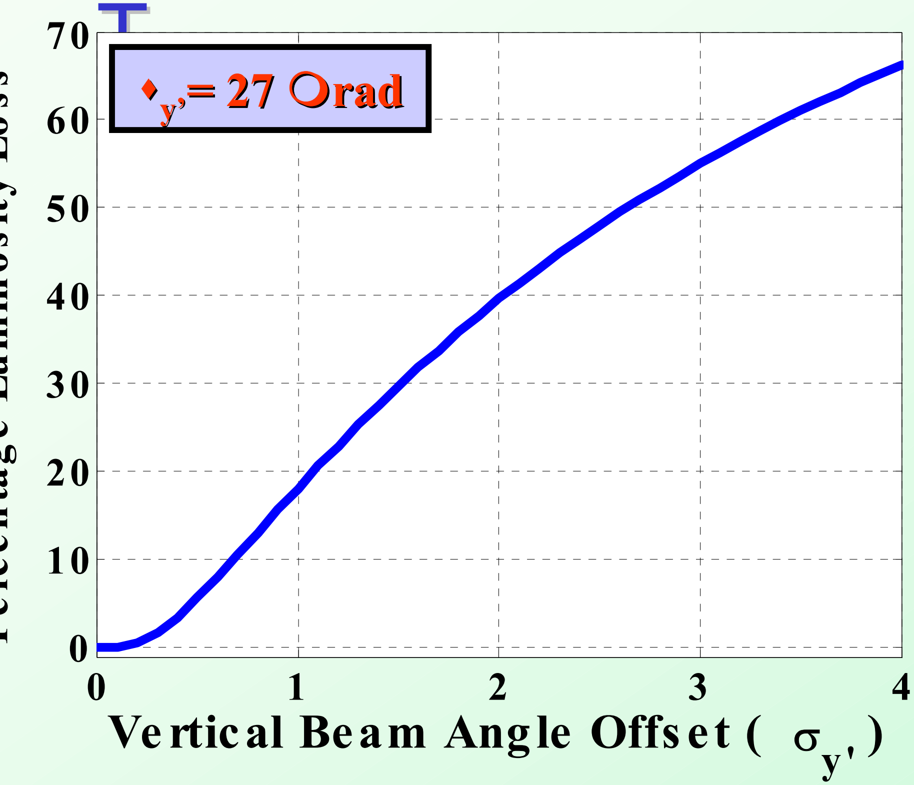
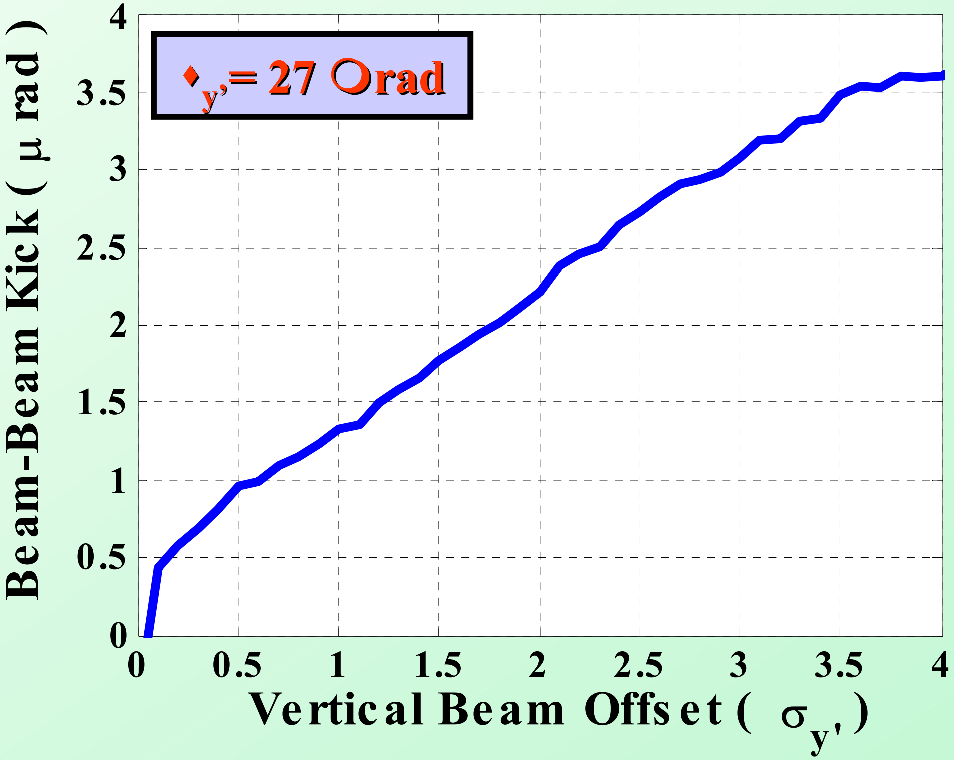
EFFECT OF ANGLE OFFSET (NLC)





- Beams get small additional kick if incoming with non-compensated crossing angle, also additional lumi loss
- Effect not addressed with this feedback system- if significant angle offset present, additional feedback system further up-stream of IP required

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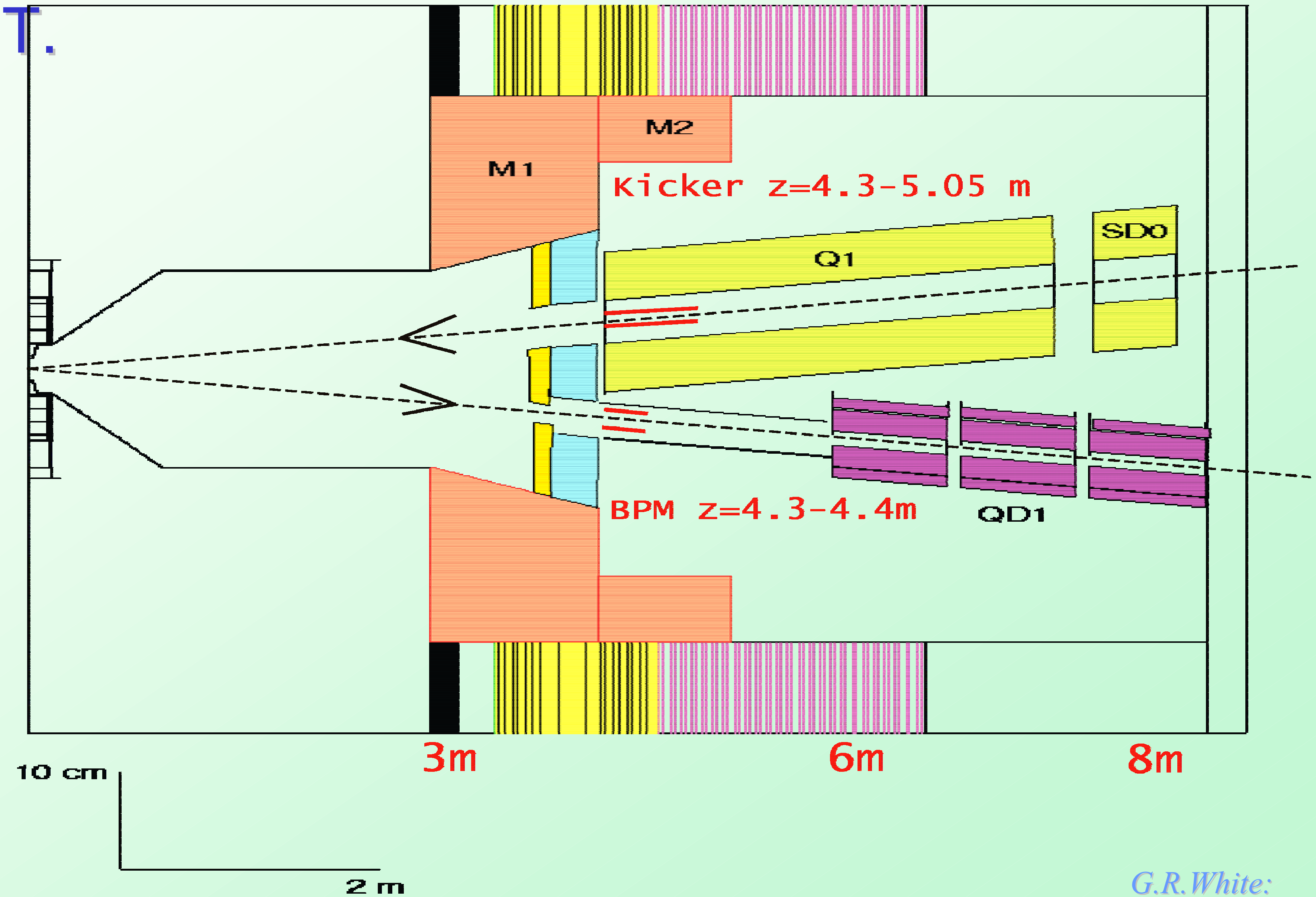
IR LAYOUT WITH FB SYSTEM



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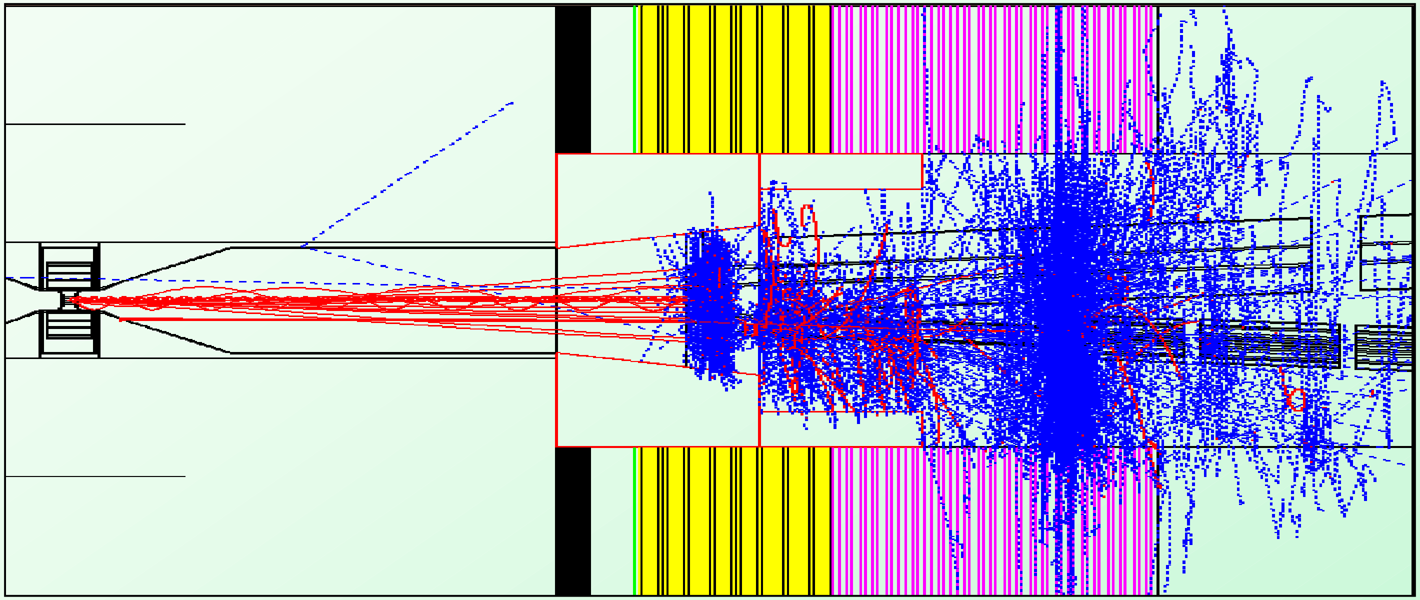
IR PAIR BACKGROUNDS



- e^+e^- Pairs and ♑'s produced in Beam-Beam field at IP
- Interactions with material in the IR produces secondary e^+e^-, ♑, and neutron radiation
- Study background encountered in Vertex and tracking detectors with and without FB system and background in FB system itself
- Use GEANT3 for EM radiation and Fluka99 for neutrons

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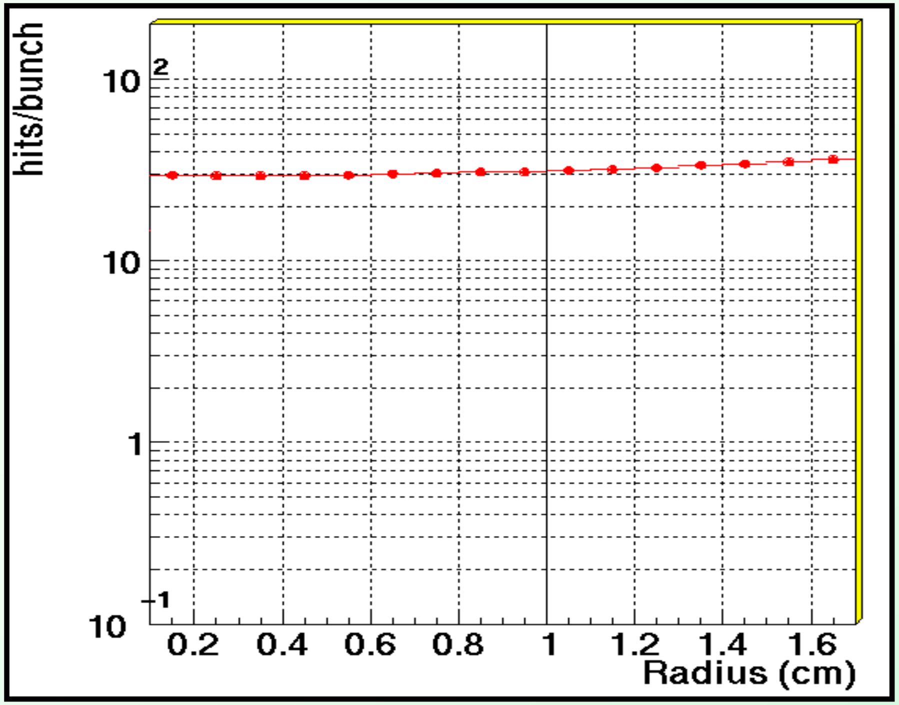
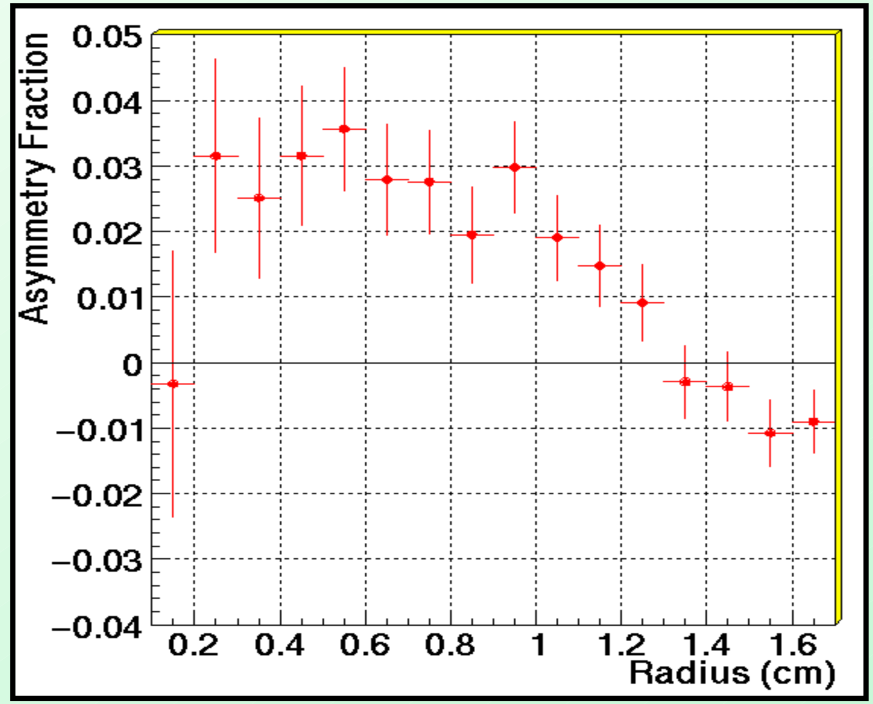
EM BACKGROUNDS AT BPM





Absorption of secondary emission in BPM striplines source of noise in Feedback system

System sensitive at level of about 3 pm per electron knocked off striplines

Hence, significant noise introduced if imbalanced intercepted spray at the level of 10^5 articles per bunch exists

GEANT simulations suggest this level of imbalance does not exist at the BPM location =4.3m for secondary spray originating from pair background

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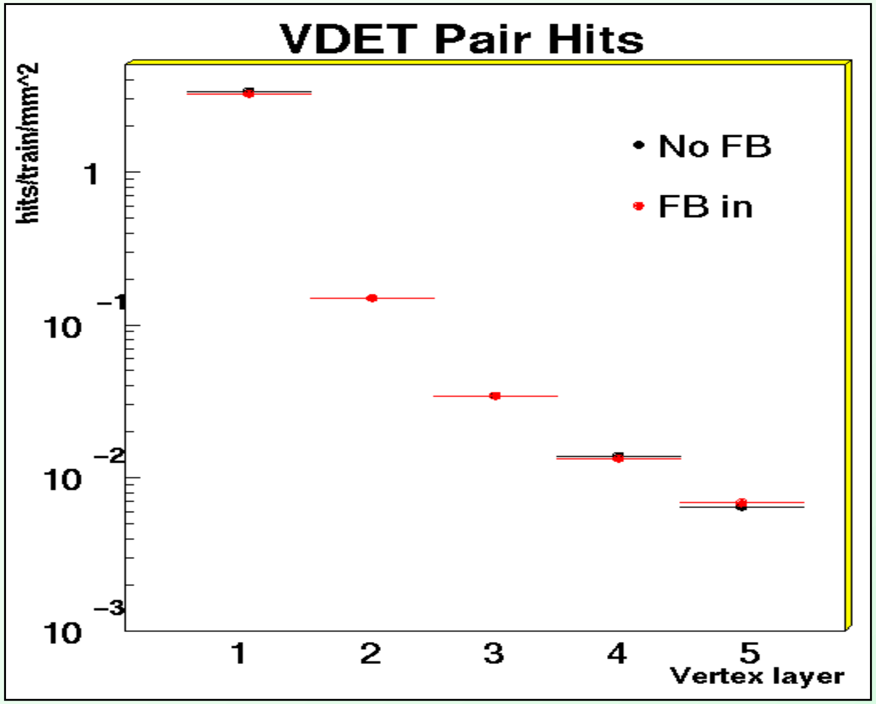
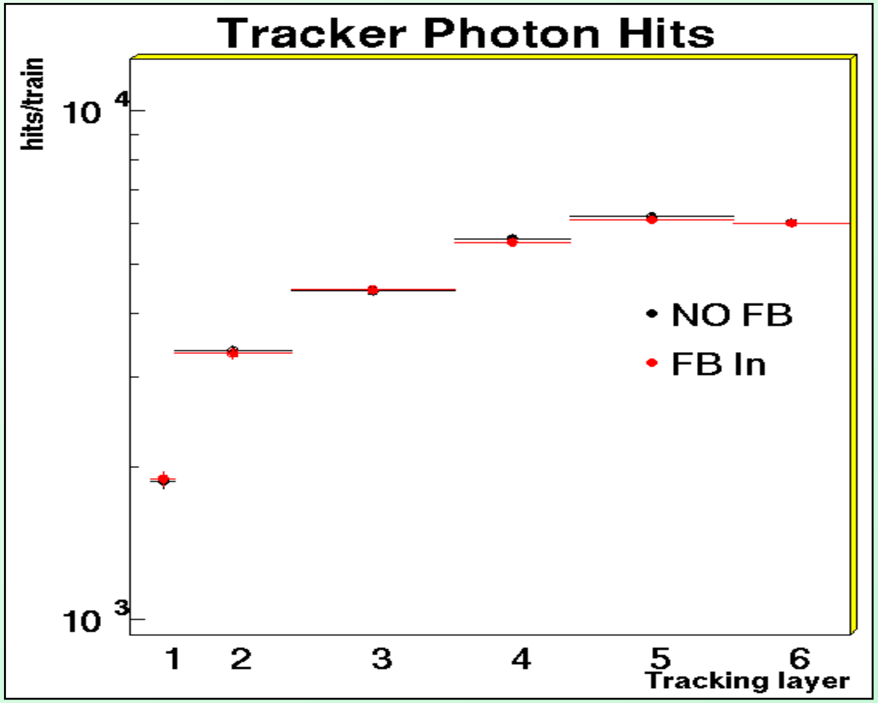
DETECTOR EM BACKGROUNDS





- Insertion of feedback system at z=4.3 m has no impact on secondary detector backgrounds arising from pair background
- Past studies suggest backgrounds adversely effected only when feedback system installed forward of z=3 m

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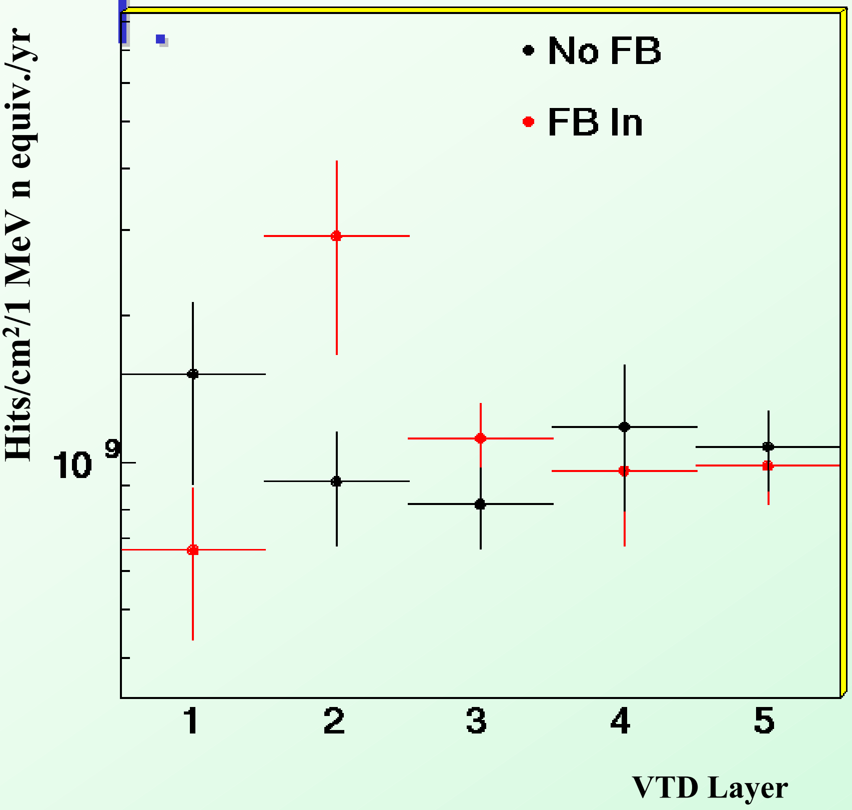
DETECTOR N BACKGROUNDS



Sum Over all Layers:

Default IR: $5.5 \pm 0.8 \times 10^9$

IR with FB: $6.6 \pm 1.3 \times 10^9$

(neutrons/cm^2/1 MeV n equiv./yr)

- **No significant increase in neutron flux in vertex detector area seen arising from pair background**
- **More statistics being generated**

TESLA SIMULATIONS

- **Combine PLACET, MERLIN and GUINEA-PIG codes with Simulink feedback algorithm to produce realistic model of TESLA beam collisions and luminosity spectra.**
- **PLACET used for simulation of beam dynamics in linac in presence of single and multi-bunch wakefields. (D. Schulte)**
- **MERLIN code incorporating BDS optics used for simulation of beam transport from end of linac to IP. (N. Walker)**
- **GUINEA-PIG reads in individual bunch data with O(10^5) particles per bunch. This allows handling of non-gaussian (banana) shaped bunches. (D. Schulte)**
- **All combined and run in Matlab/Simulink environment.**

TESLA IP BEAM PROFILES

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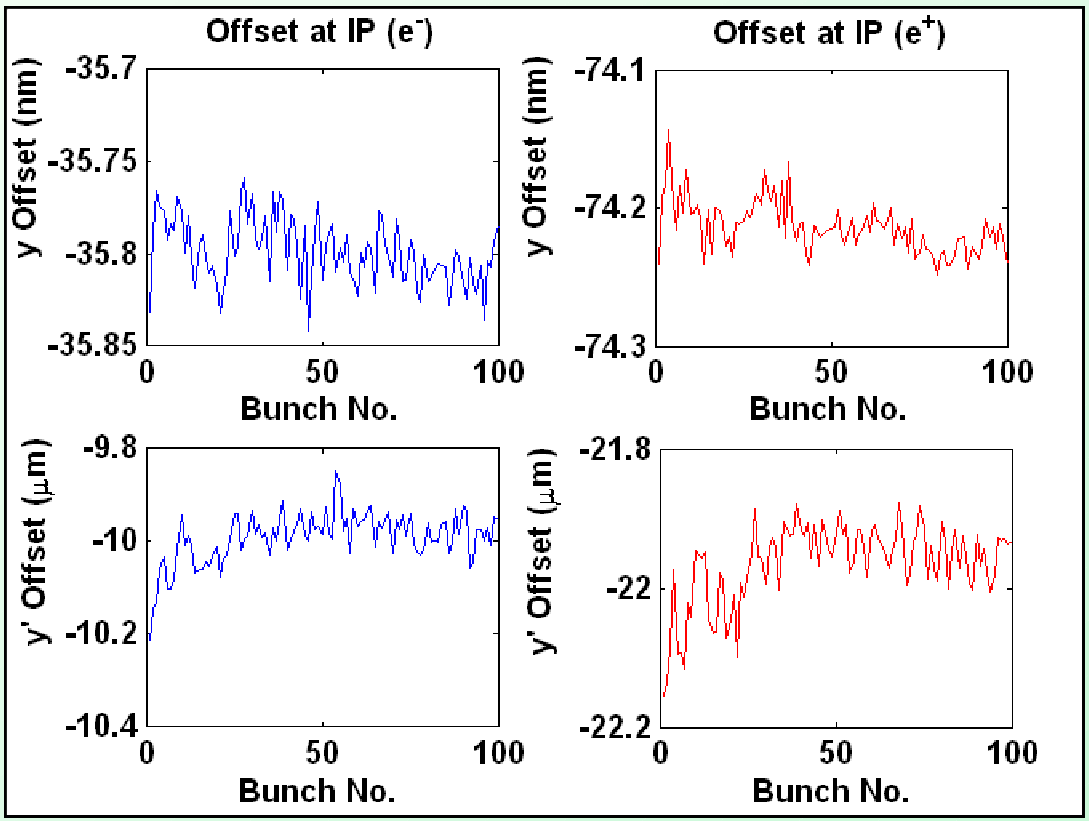
- **Test production with 100 bunches, offset at 1 ♦$_{y}$ through the linac structures and with a 35nm RMS misalignment in the BDS quads.**



$$\Delta\bar{y} = 38.4nm = 7.7\sigma_y$$

$$\Delta\bar{y}' = 12.0\mu rad = 0.96\sigma_{y'}$$

TESLA FAST IP FEEDBACK

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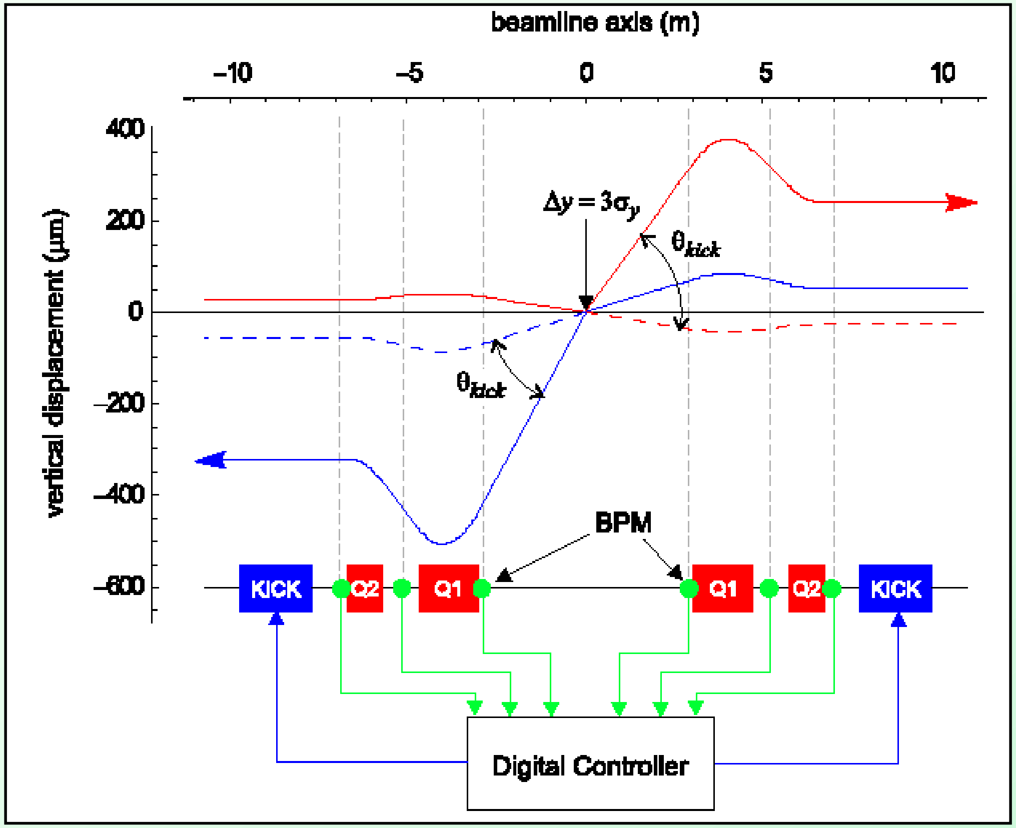

- Detect beam-beam kick with 1 or more BPM's either side of IP.
- Feed signal through digital feedback controller to fast strip-line kickers either side of IP.

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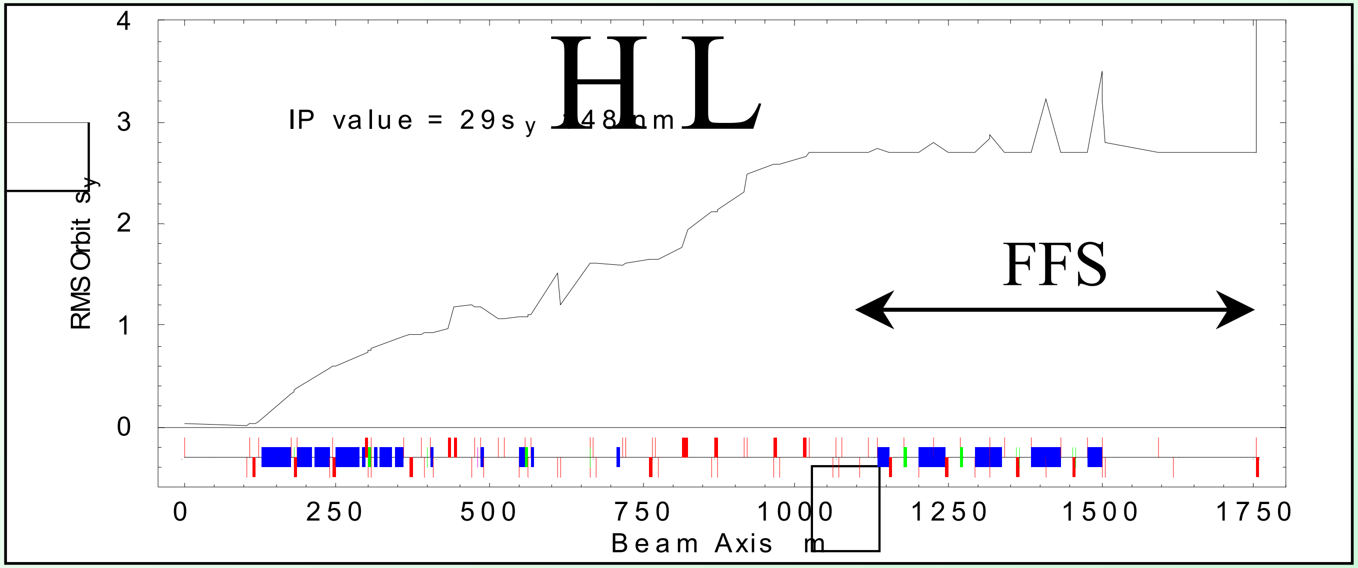
TESLA ANGLE FEEDBACK



- Normalised RMS vertical orbit in TESLA BDS due to 70nm RMS quadrupole vibrations.
- Correct betatron oscillation and therefore IP angle crossing at IP by kicking beam at entrance of FFS (~1000m).
- No significant sources of angle jitter beyond this point as all subsequent quads at same IP phase.

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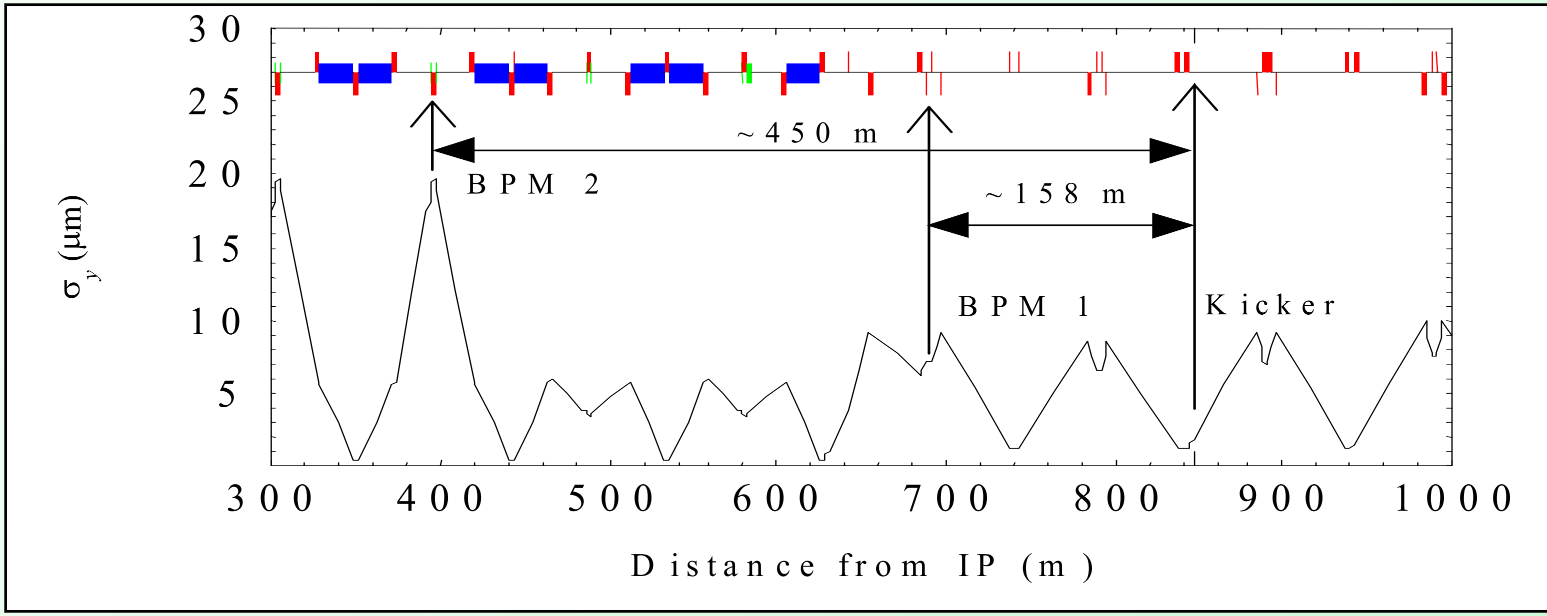
TESLA ANGLE FEEDBACK



- Place kicker at point with relatively high β function and at IP phase.
- Can correct ~130 μrad at IP (>10$\sigma_{y'}$) with 3x1m kickers.
- BPM at phase 90^0 downstream from kicker.
- To cancel angular offset at IP to 0.1$\sigma_{y'}$ level:
  - BPM 1 : required resolution ~ 0.7μm, FB latency ~ 4 bunches.
  - BPM 2 : required resolution ~ 2μm, FB latency ~ 10 bunches.

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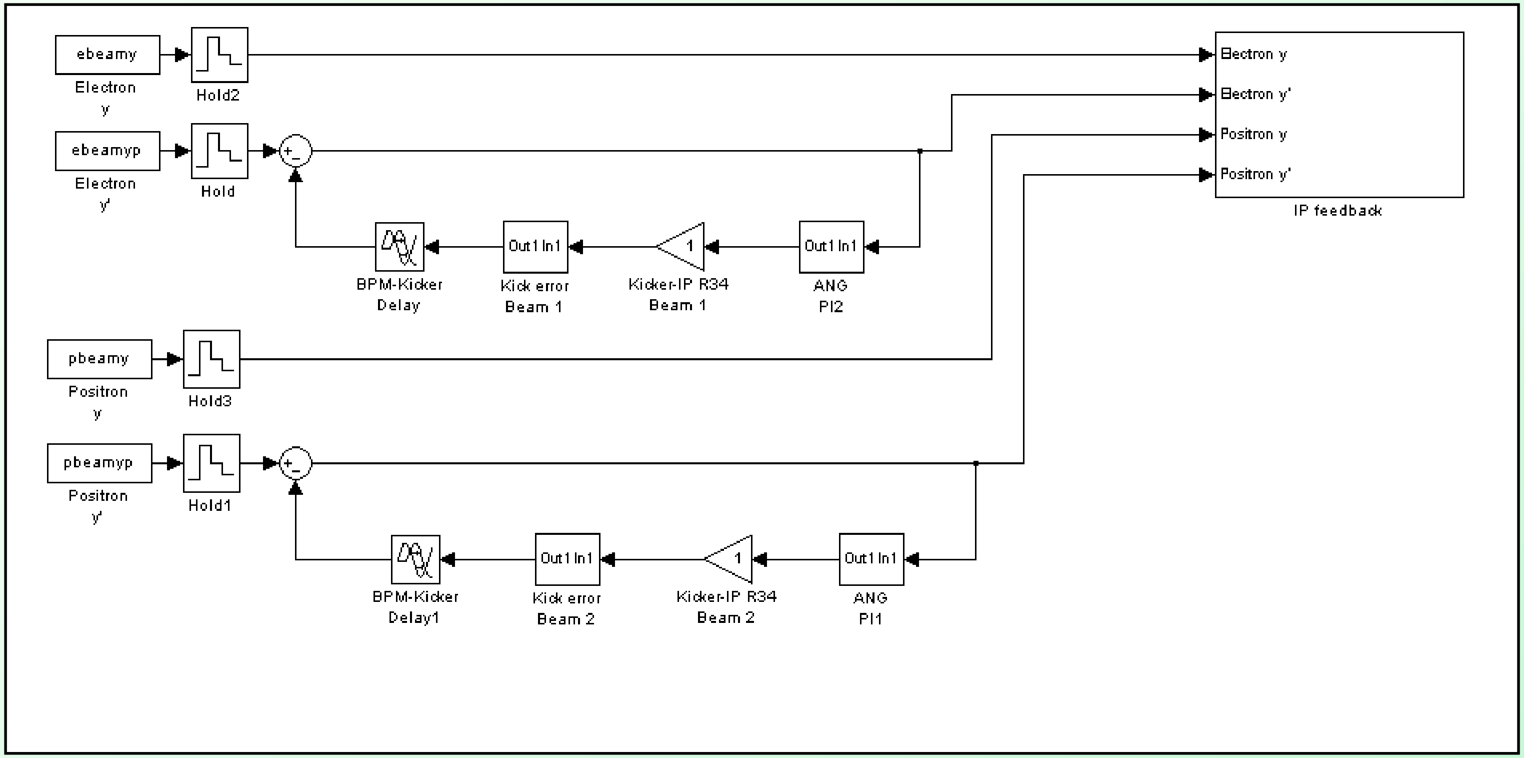
TESLA FEEDBACK SIMULATION



- **Angle feedback:** **Calculate mean y,y' for e^- e^+ bunches; pass y on to IP FB; angle feedback simulated by passing y' values through simulated PI controller with appropriate transport matrices.**
- **Add 2% RMS kicker error.**

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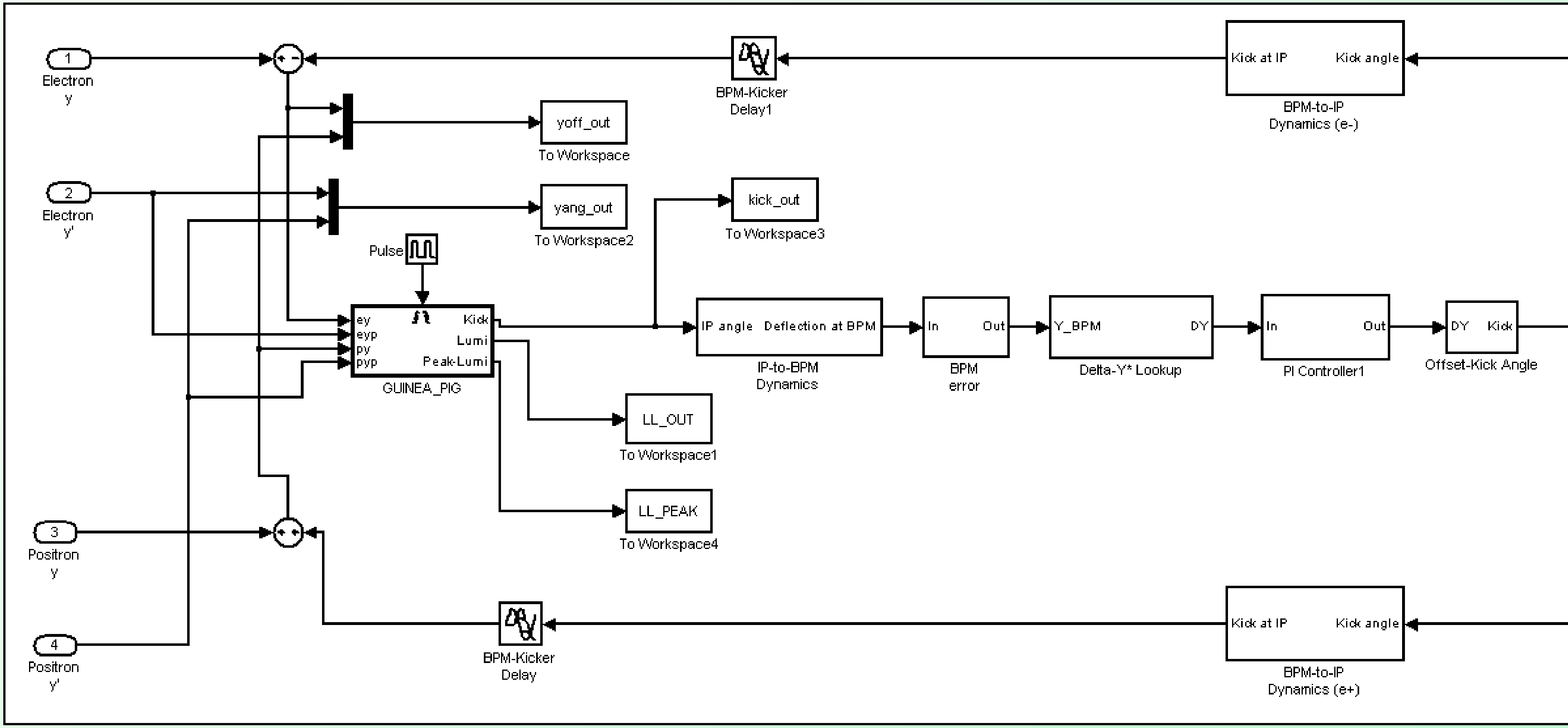
TESLA FEEDBACK SIMULATION



- **IP Feedback:** BPM signal from GUINEA-PIG output (calculated from full bunch structures), feedback on each beam.
- Resolution of each BPM set to 5Om.

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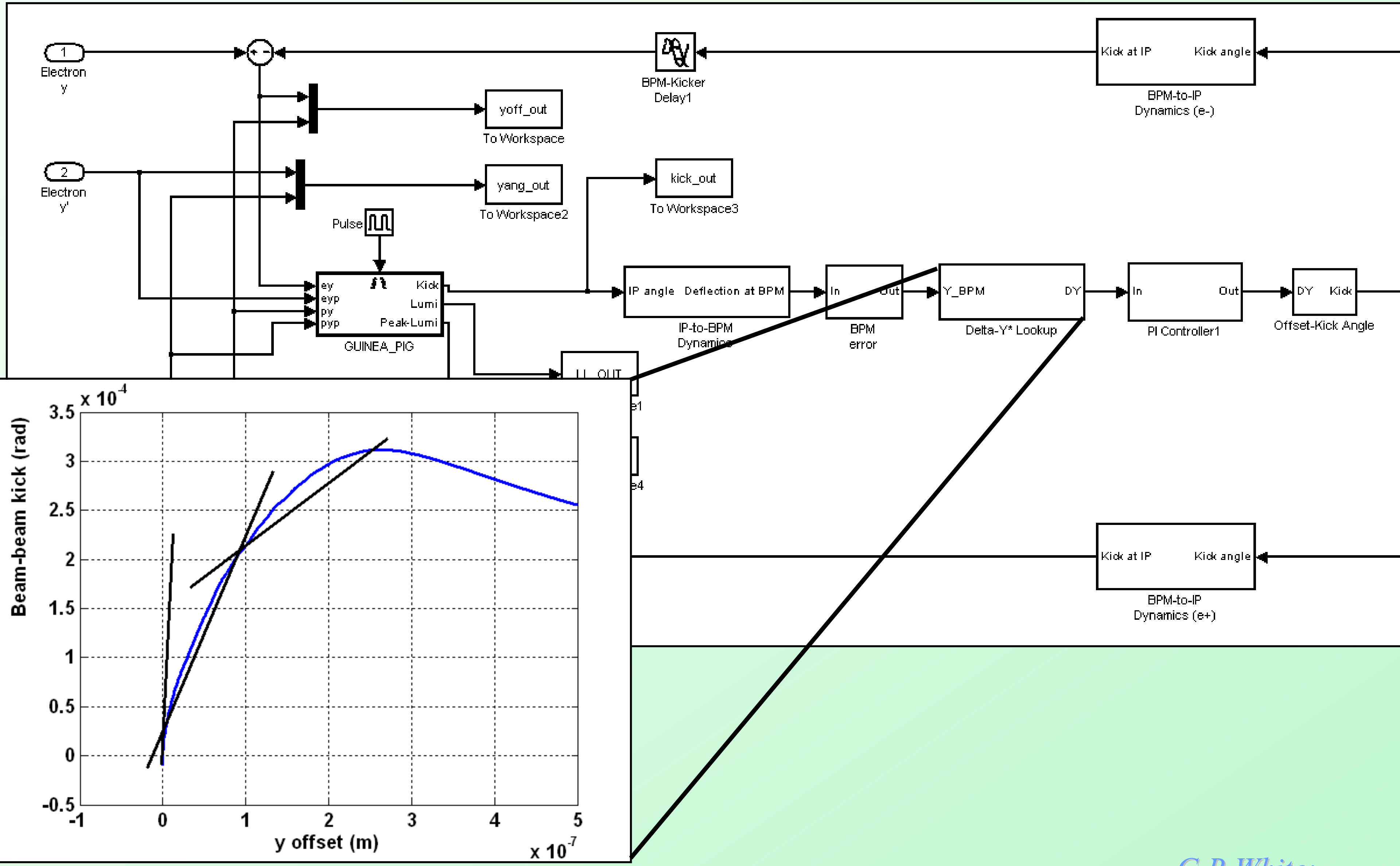
TESLA FEEDBACK SIMULATION



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TESLA FEEDBACK ALGORITHM

- **Proportional-Integral (PI) Controller:**

$$u_{PI}(k) = u_P(k) + u_I(k) = K_P e(k) + K_I \sum_{j=0}^{k-1} e(j)$$

- **Subtract $u_{PI}(k-1)$ to get recursive algorithm:**

$$u_{PI}(k) = u_{PI}(k-1) + K_P\big(e(k) - e(k-1)\big) + K_I e(k-1)$$

- **2 free parameters: gains K_P and K_I :**
  - **K_P provides fast response to error signal.**
  - **K_I cancels steady-state error.**
- **Iterate simulation to obtain optimum parameters to give fast correction and maintain collisions at 0.1♦$_y$ level.**

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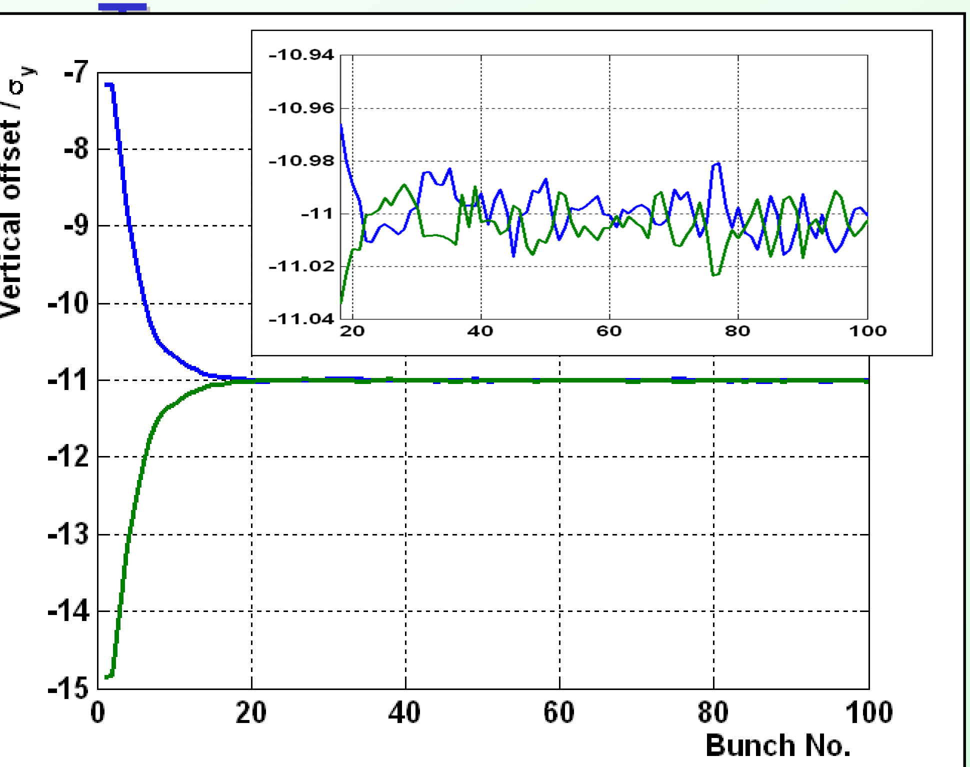
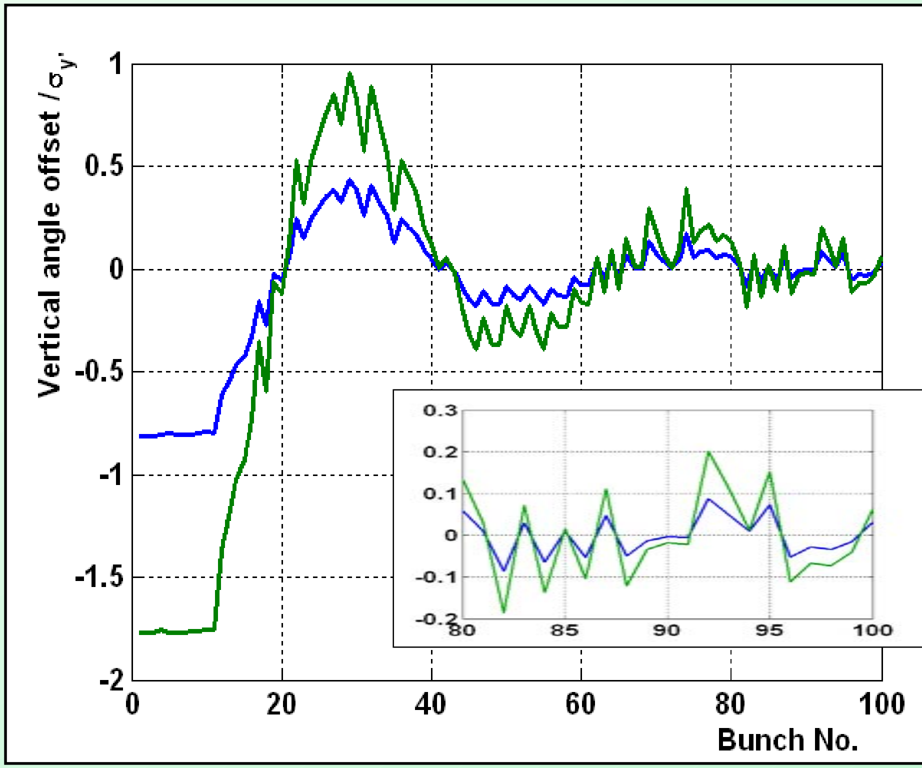
FEEDBACK RESPONSE





- Response of system to 100 test bunches with gaussian charge distributions.
- Angle feedback latency set to 3.4❍s (~ 10 bunches).

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FEEDBACK PERFORMANCE

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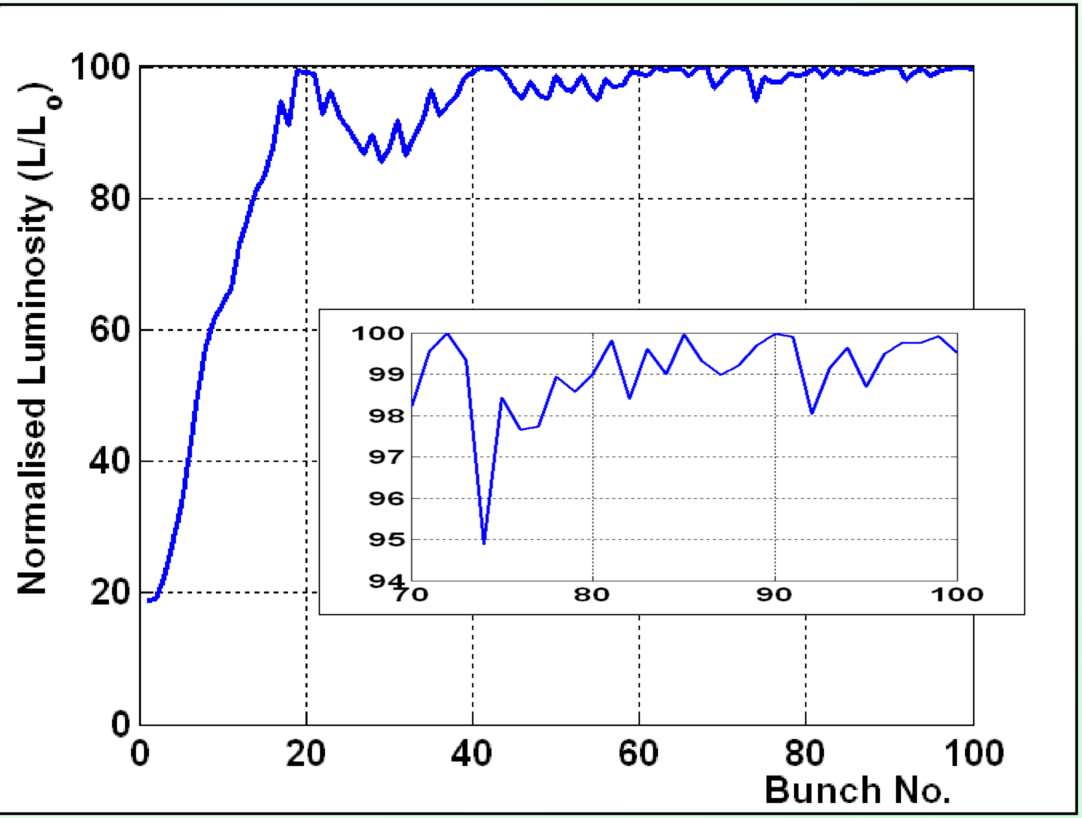


- Luminosity normalised to max luminosity with zero offset over the test 100 bunches.
- Lumi loss stabilised at 1-2% level.

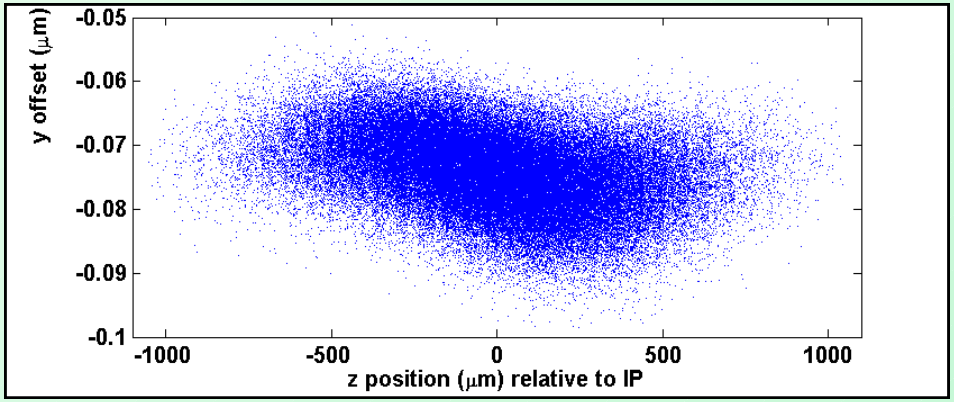
- Taking last 20 bunches as representative of rest of 1 TESLA pulse (2820 bunches):
  - $L/L_o = 0.9906$

F.O.N.T

BANANAS

•Short-range wakefields caused by bunches travelling through cavities in linac disrupt themselves if not aligned with cavity centre:

- •Z-Y plane of typical positron bunch from test 100 bunch production:



•Only small increase in vertical emittance, but large loss in luminosity performance with head-on collisions.

•Change in beam-beam dynamics from gaussian bunches.

BANANA BEAM DYNAMICS

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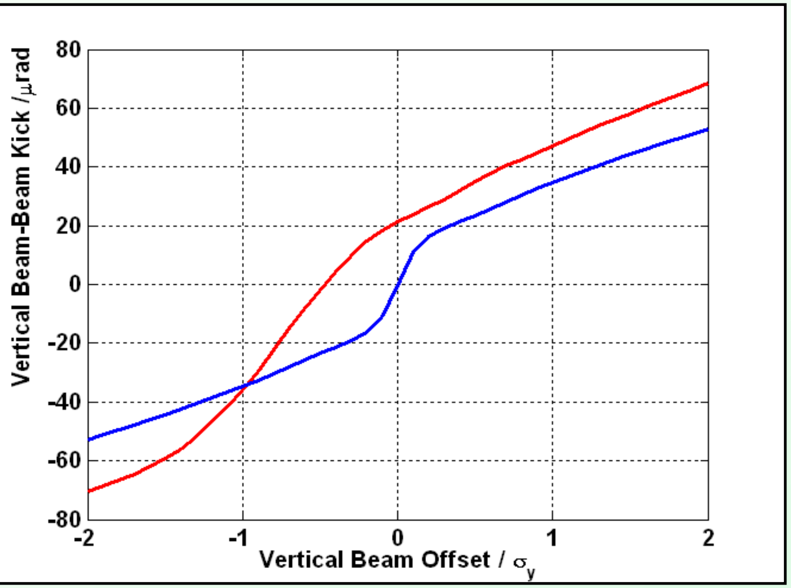

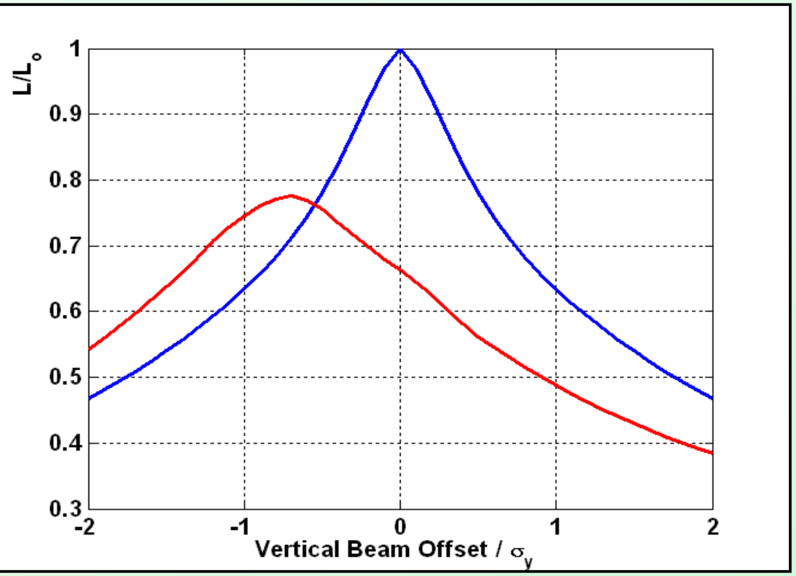

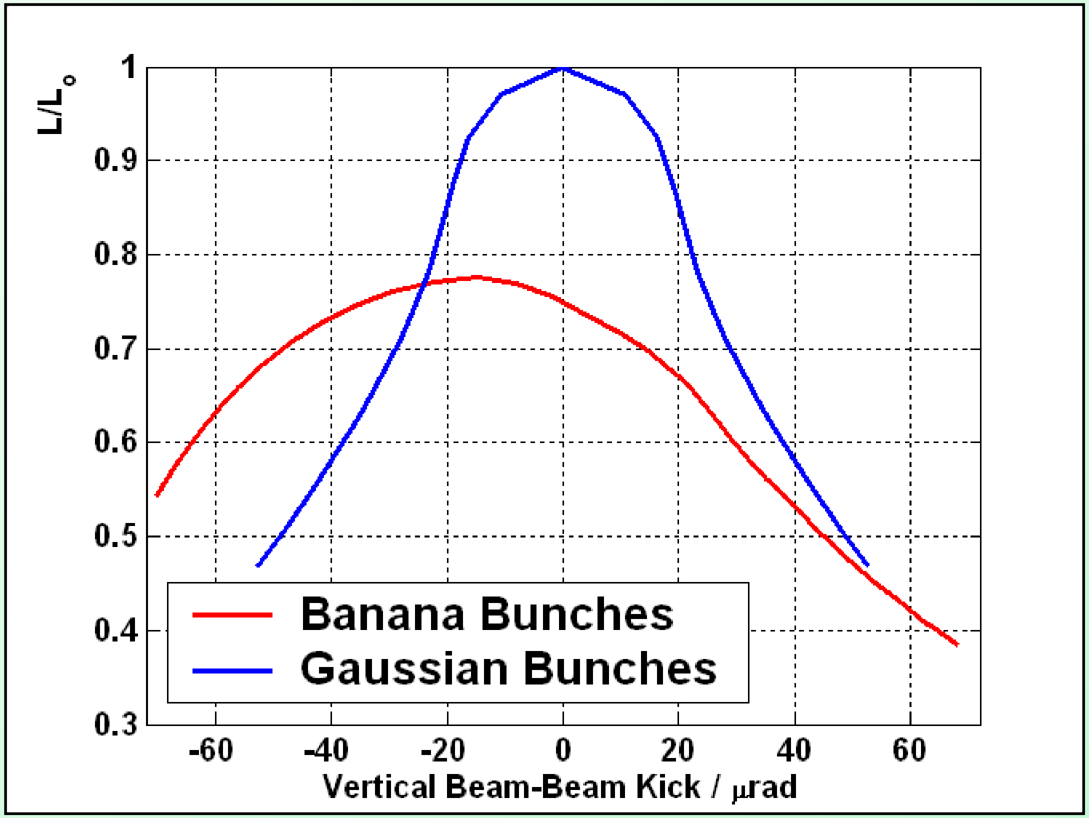

- Feedback algorithm corrects to zero kick angle- no longer optimal lumi.

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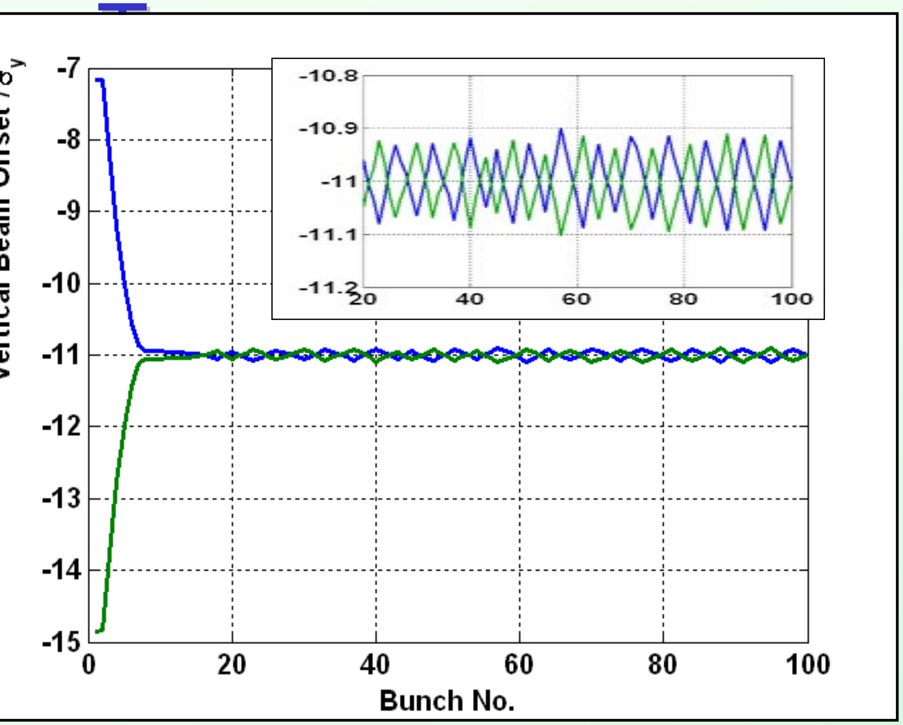
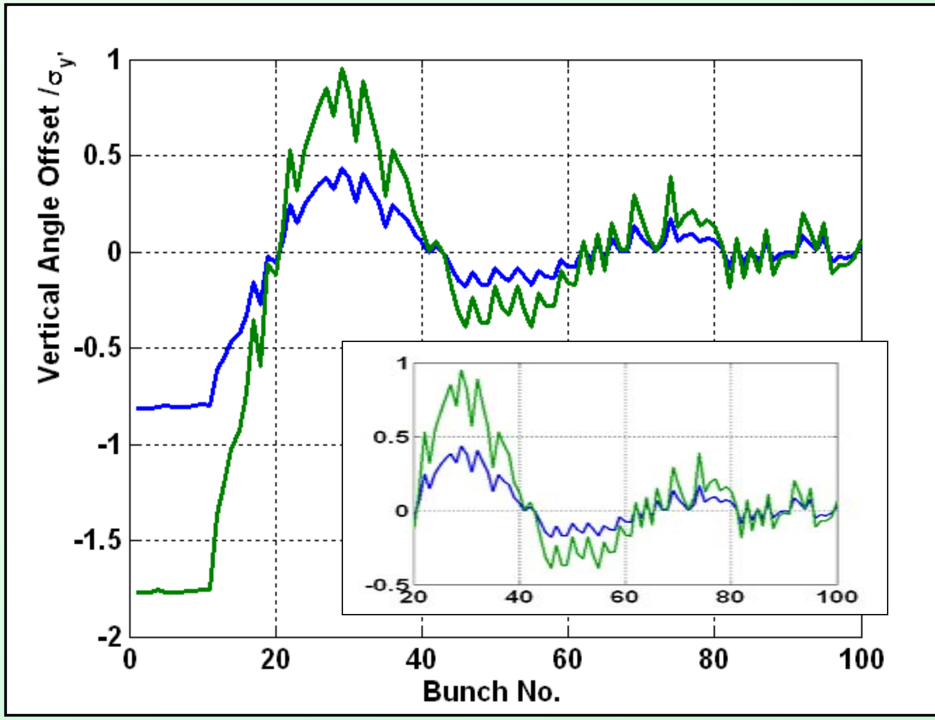
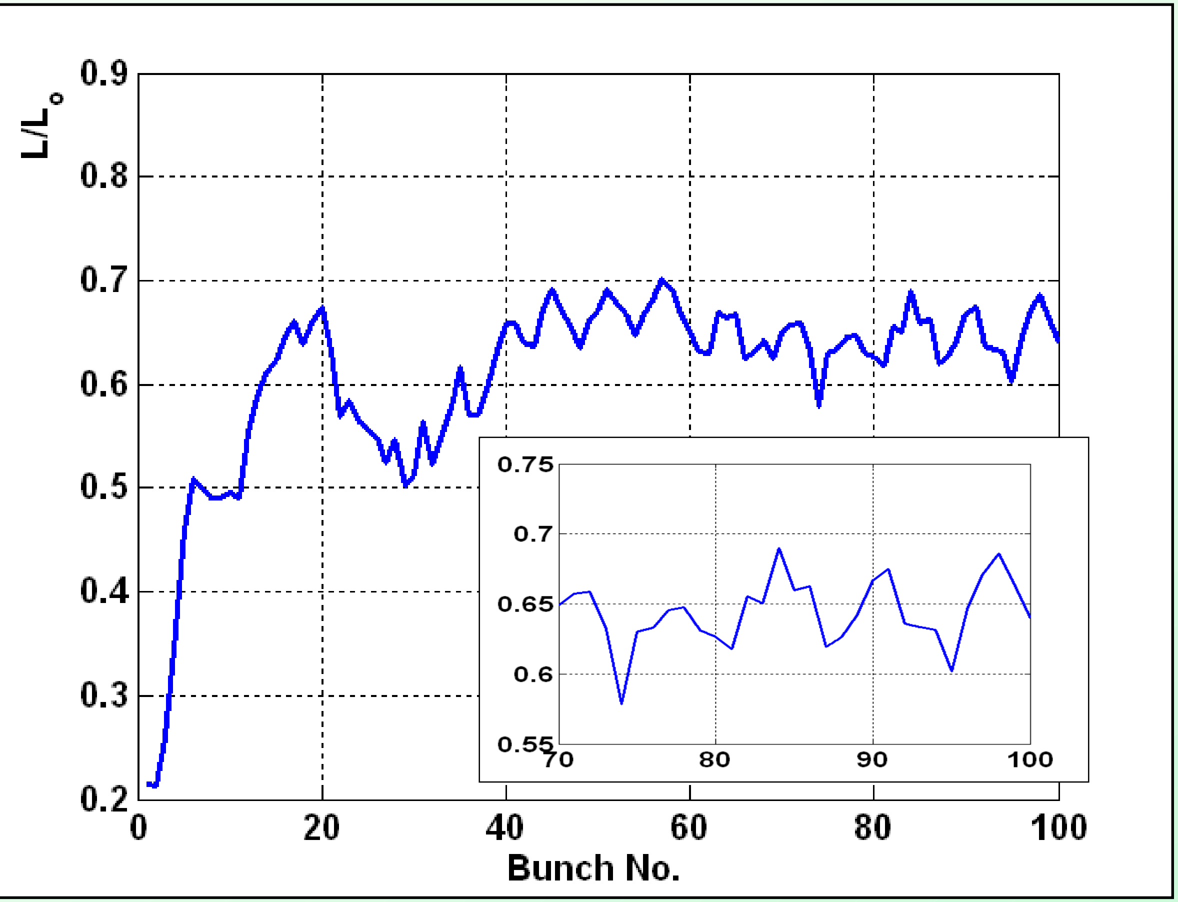
FEEDBACK WITH BANANAS





- Feedback with banana bunches
- Feedback parameters no longer optimal

FEEDBACK PERFORMANCE



- **Lumi performance with banana bunches**

- **$L/L_o = 0.6473$**

SUMMARY

- Fast Ground motion moving quads near IP major source of luminosity loss at a future linear collider.
- NLC, CLIC fast analogue-based IP beam offset feedback systems recover large percentage of lost lumi.
- Backgrounds for FB system or detector components no problem if FB positioning carefully selected.
- Hardware tests ongoing at NLCTA.
- TESLA FB simulated including effects of banana bunches. Improvements to be made- e.g. investigate possibility of including lumi feedback and improved realism of feedback simulations.