Fast Intra-Train Feedback Systems for a Future Linear Collider

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DESY:

Nick Walker…

SLAC:

Joe Frisch, Steve Smith, Thomas Markiewicz …

CERN:

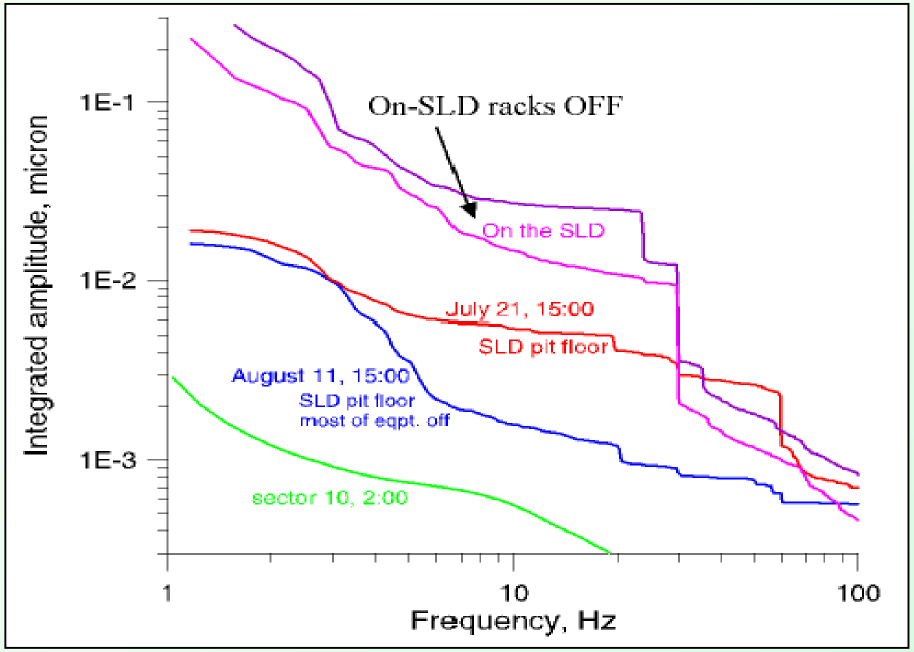
Daniel Schulte…

Nanobeams Workshop Sept. 2002

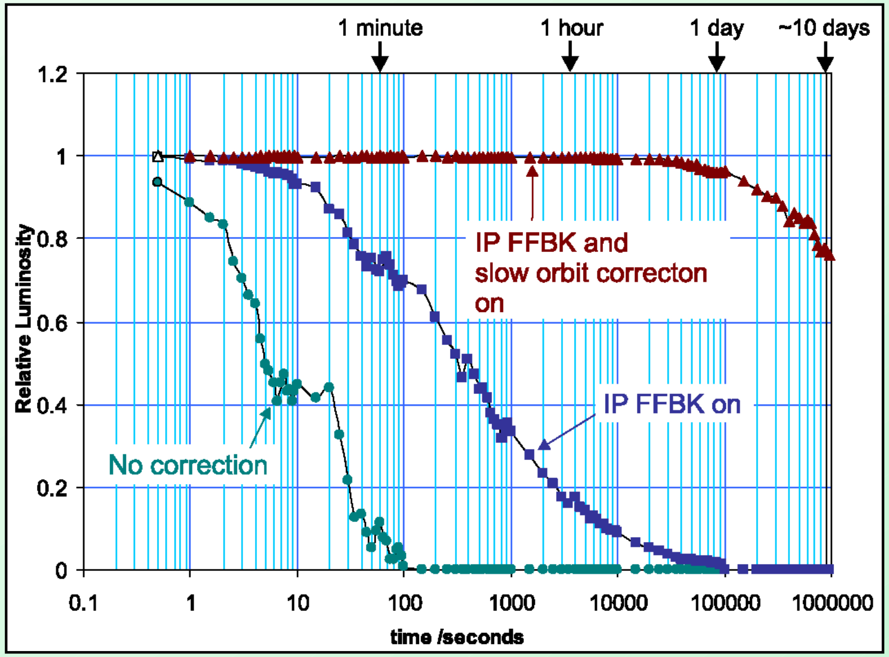
- **Requirement for a fast IP beam-based feedback system**
- **NLC, CLIC Simulations & hardware tests**
- **TESLA Simulations**
- **Summary**

GROUND MOTION

F.O.N.T.



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



From TESLA TDR

- Ground motion causes relative misalignment of magnetic beamline components- beams miss each other at interaction point (IP)
- Natural ground motion falls as ω^{-4}: ‘Fast’ motion (> few Hz) dominated by cultural noise.
- Concern for structures with tolerances at nm level (Final Quads)

G.R.White: 07/09/2002

F.O.N.T.

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
σ_x/σ_y (nm)	245 / 2.7	553 / 5	202 / 2.5
σ_z (μm)	300	110	30

- IP beam characteristics important to fast feedback system for simulated machines.
- NLC & CLIC most extreme cases for feedback technology- require extremely high bandwidth electronics (currently limited to analogue technologies).

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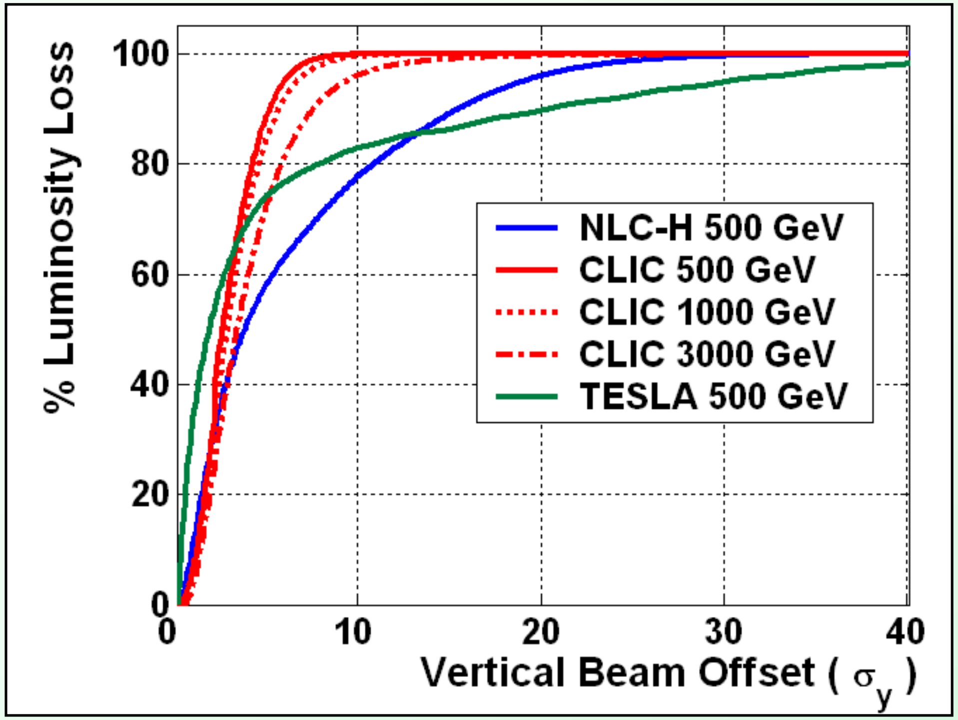
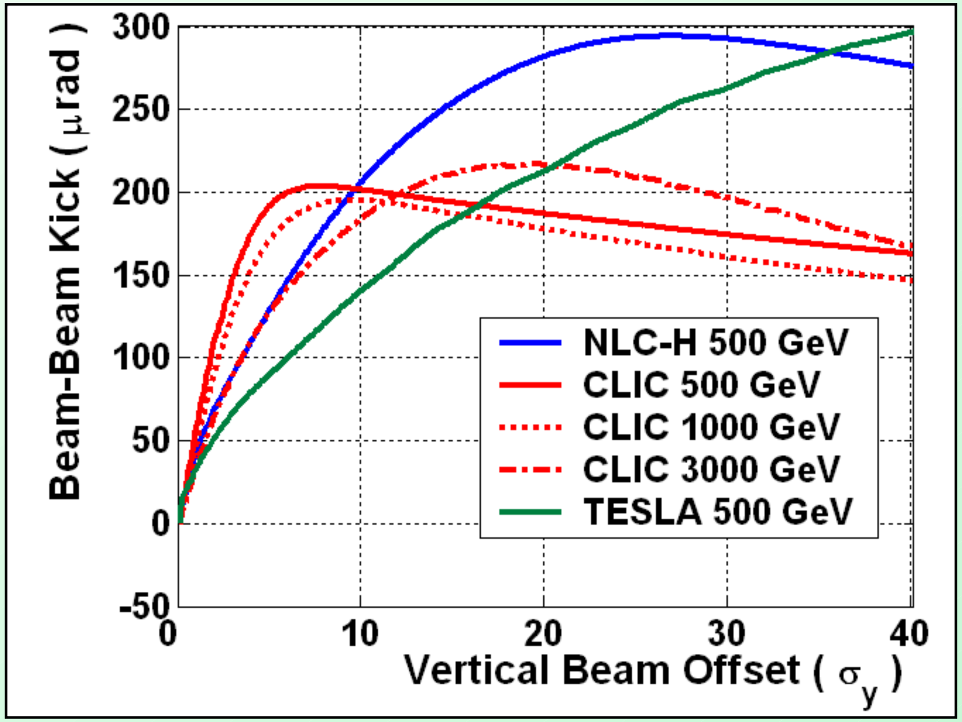
BEAM-BEAM INTERACTION





- 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 & TESLA.

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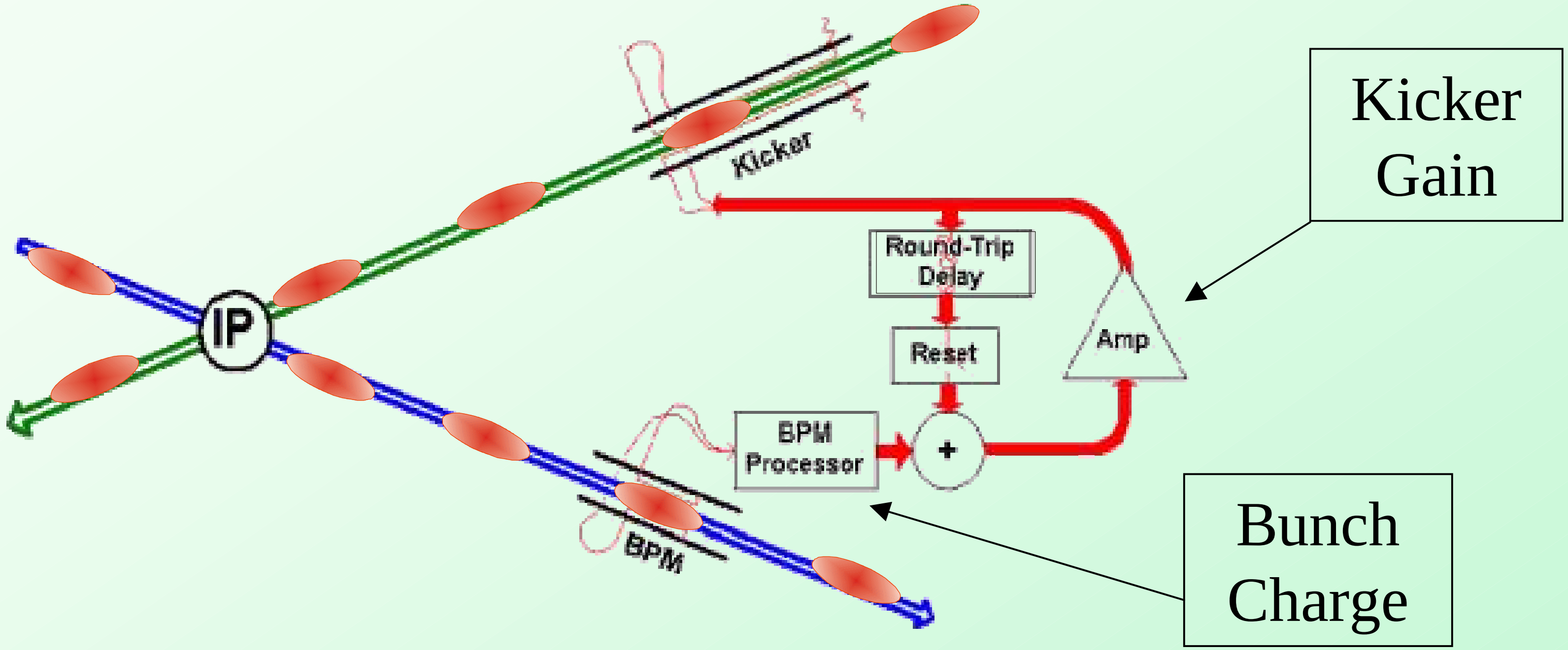
FAST FEEDBACK OPERATION



- 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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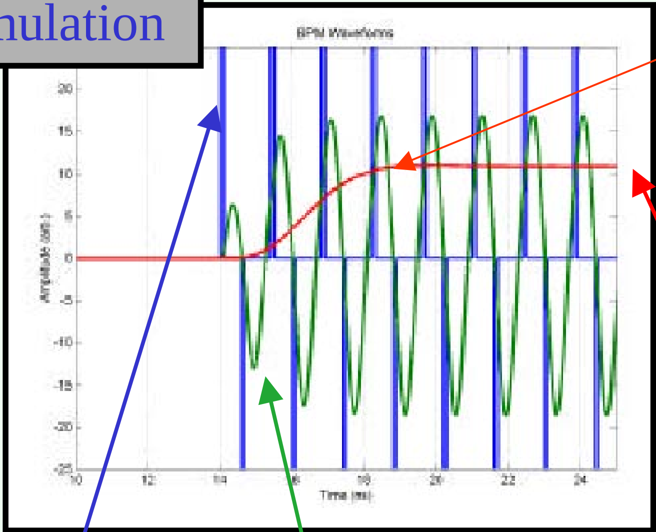
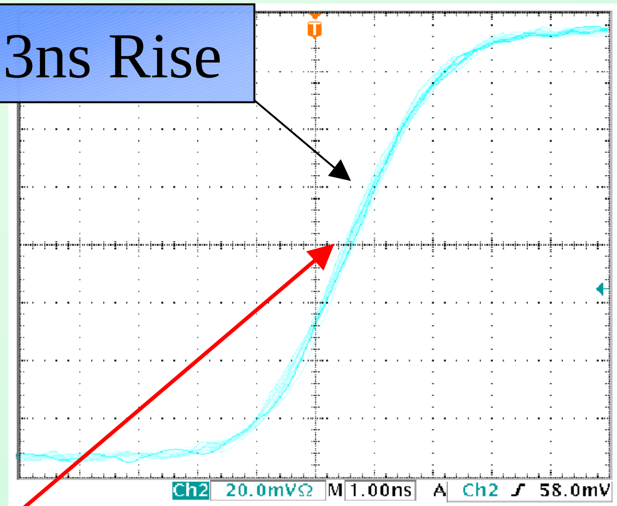
BPM PROCESSOR

Simulation

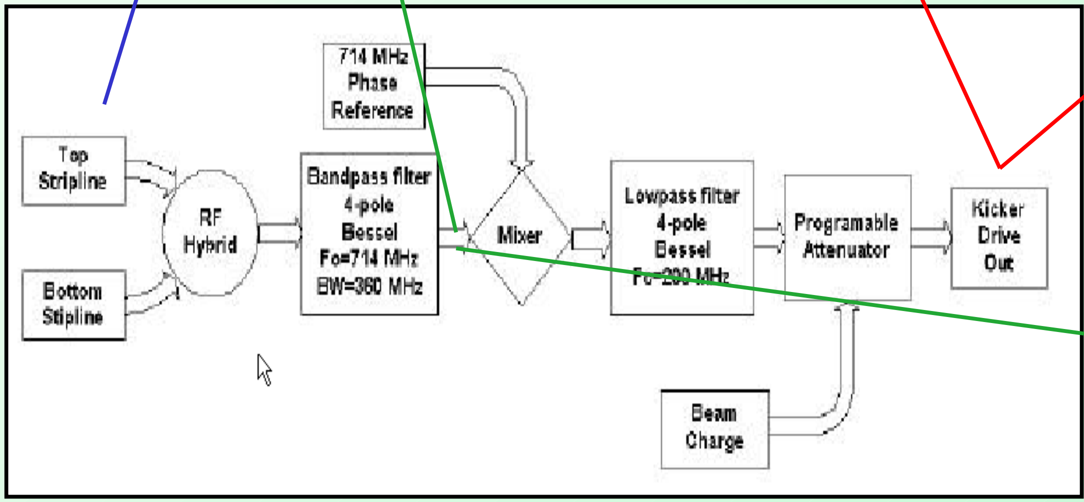
3 ns rise- time

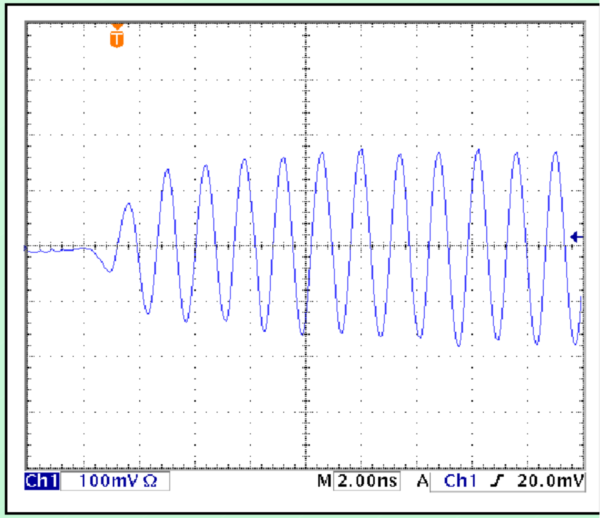


3ns Rise



Hardware Test





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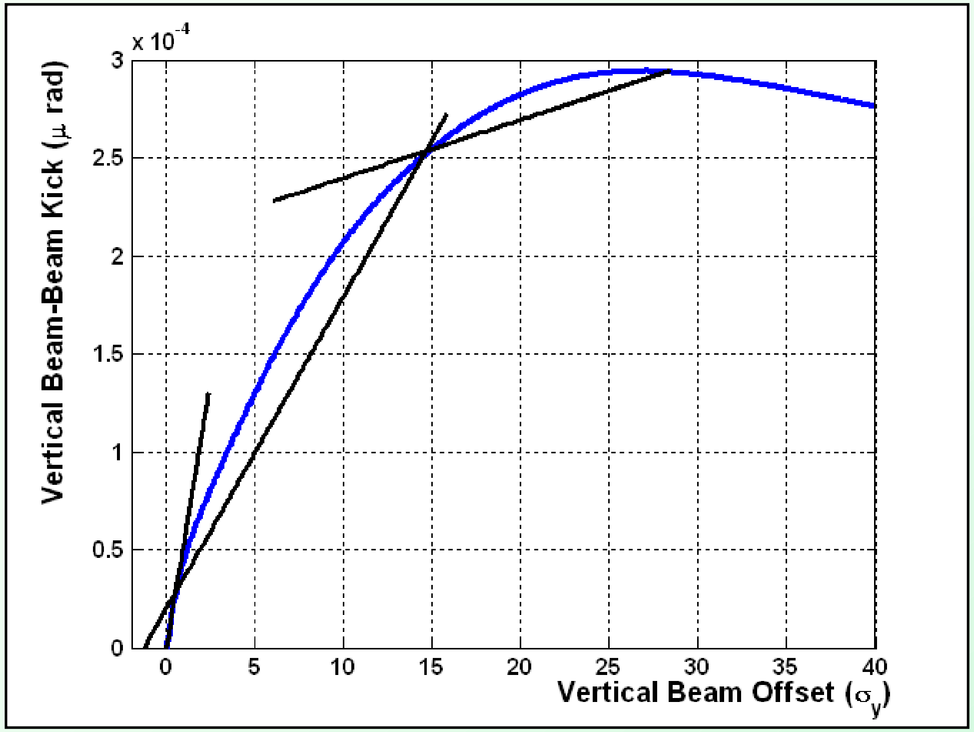
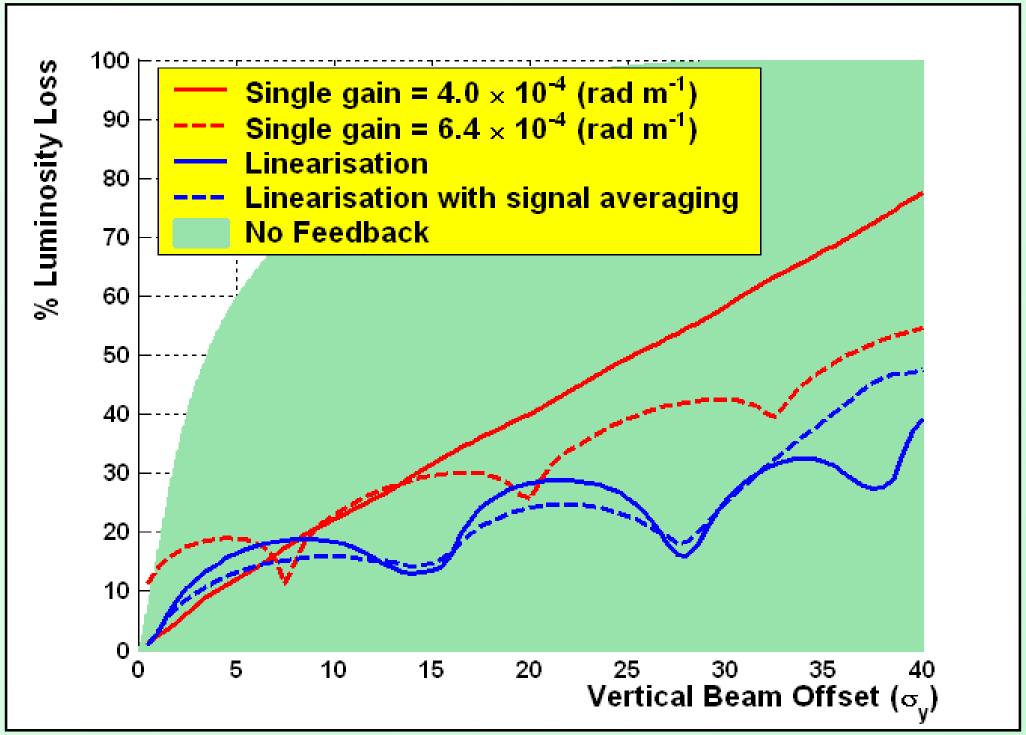
FEEDBACK PERFORMANCE





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

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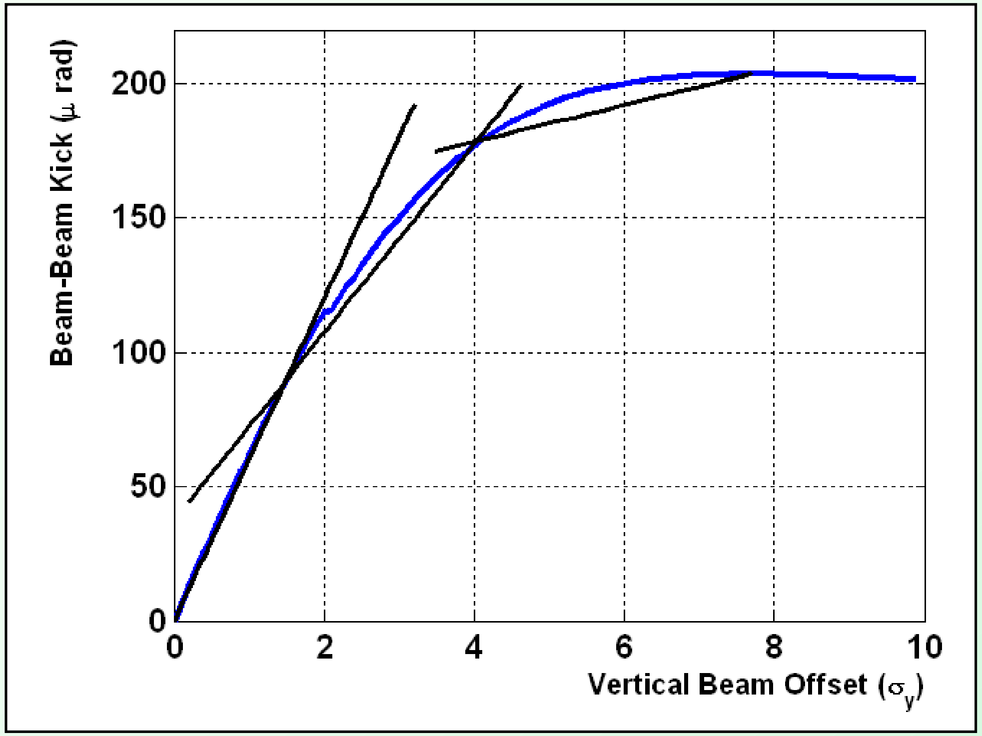
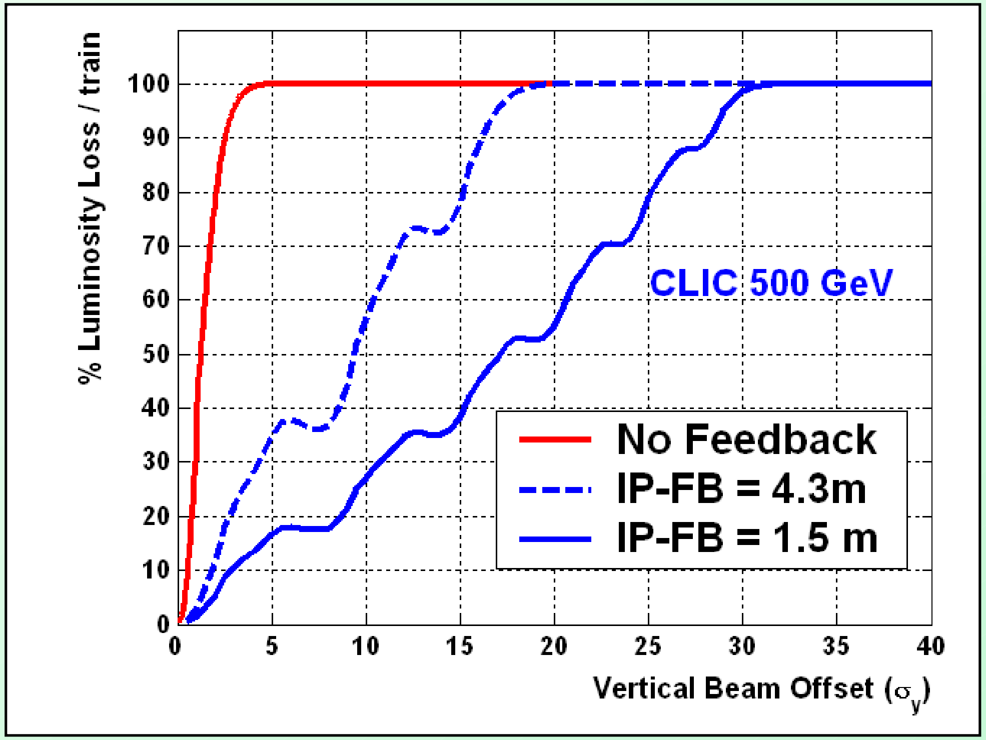
CLIC FEEDBACK





- 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).

G.R.White: 07/09/2002

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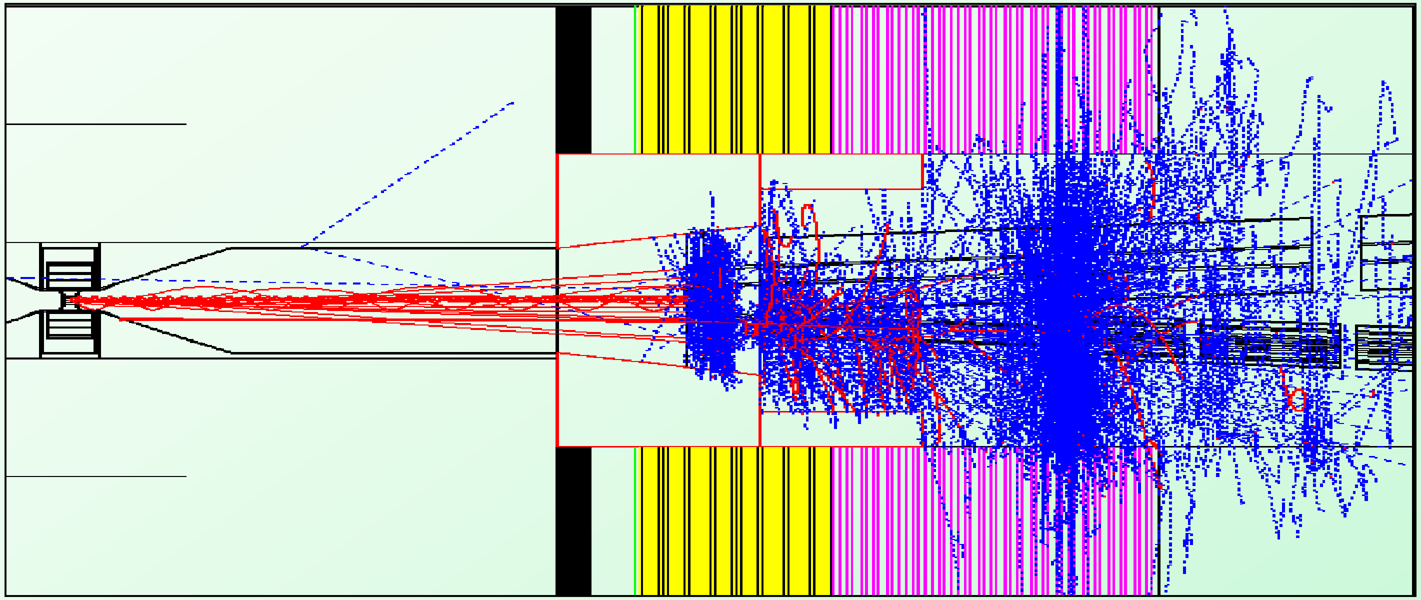
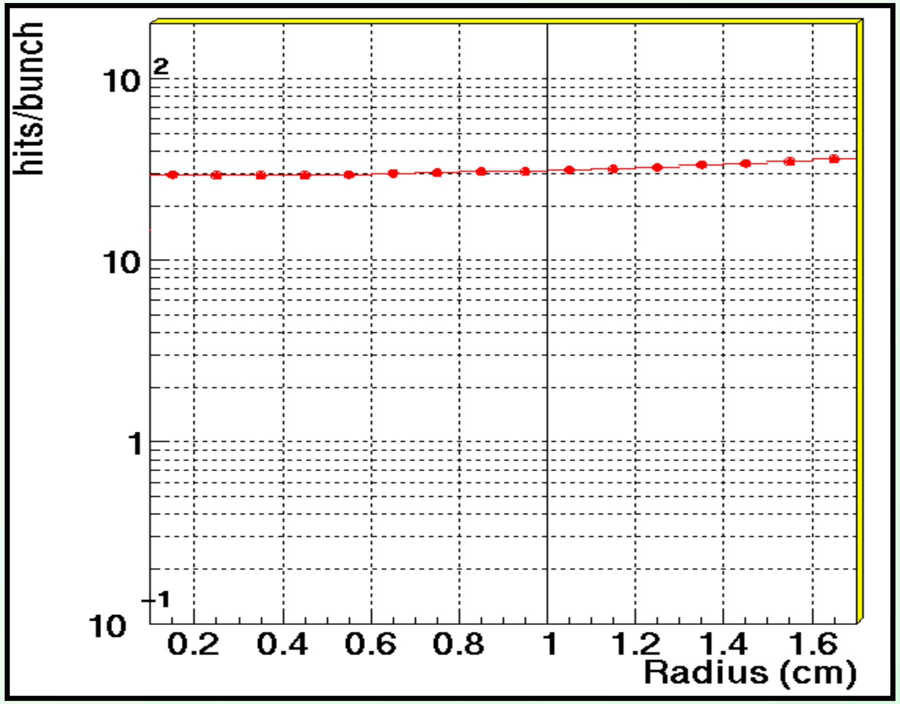
IR Pair Backgrounds

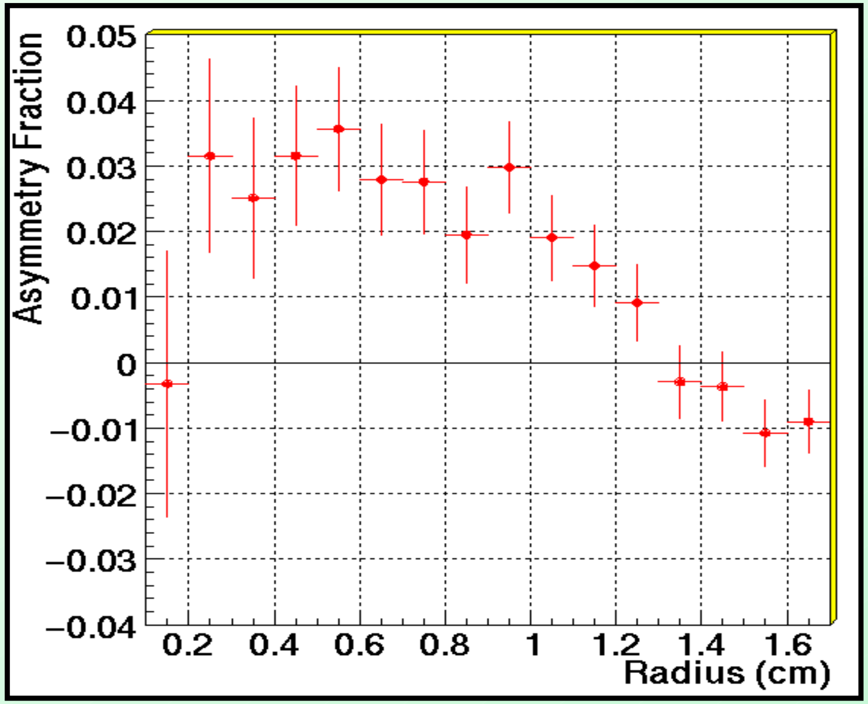


- e^+e^- Pairs and γ's produced in Beam-Beam field at IP
- Interactions with material in the IR produces secondary e^+e^- ,γ, and neutron radiation
- Study background encountered in Vertex and tracking detectors with and without FB system and background in FB system itself
- Use GEANT3 for EM radiation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

F.O.N.T.

BPM BKG (NLC)





- **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 particles per bunch exists**
- **GEANT simulations suggest this level of imbalance does not exist at the BPM location z=4.3m for secondary spray originating from pair background**

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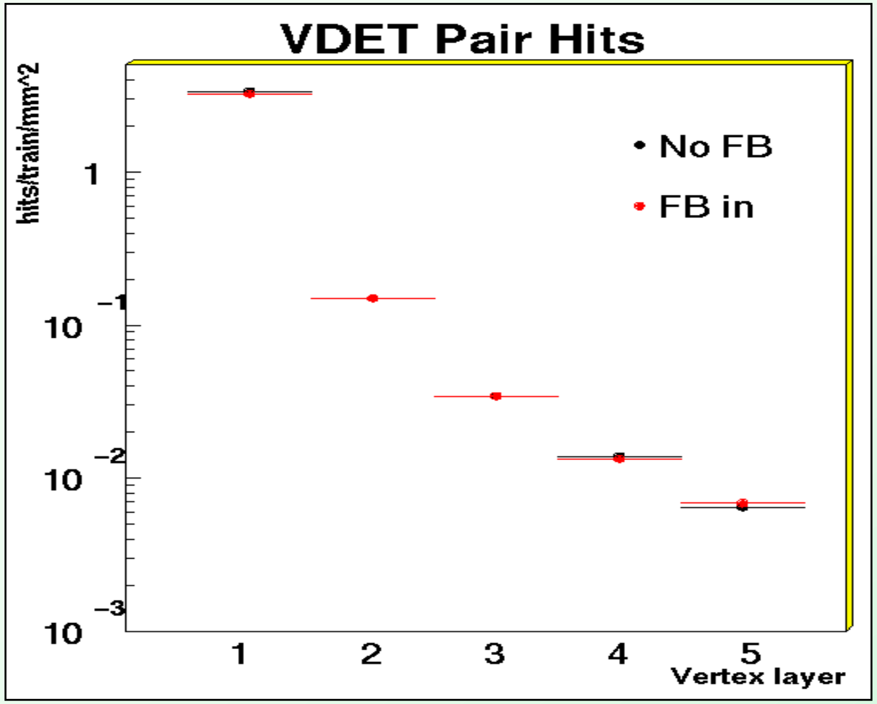
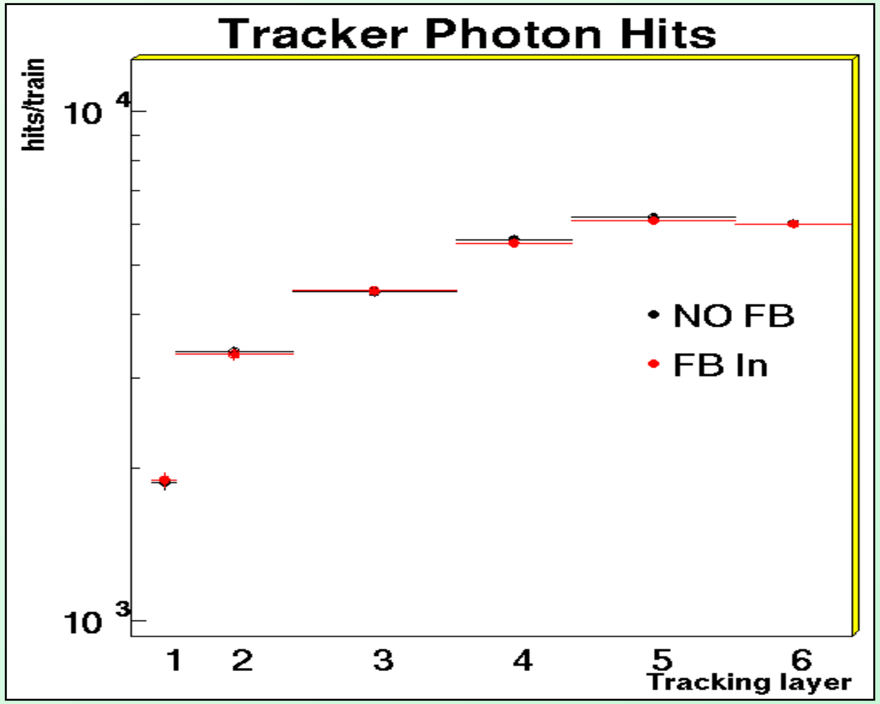
DETECTOR BKG (NLC)





- **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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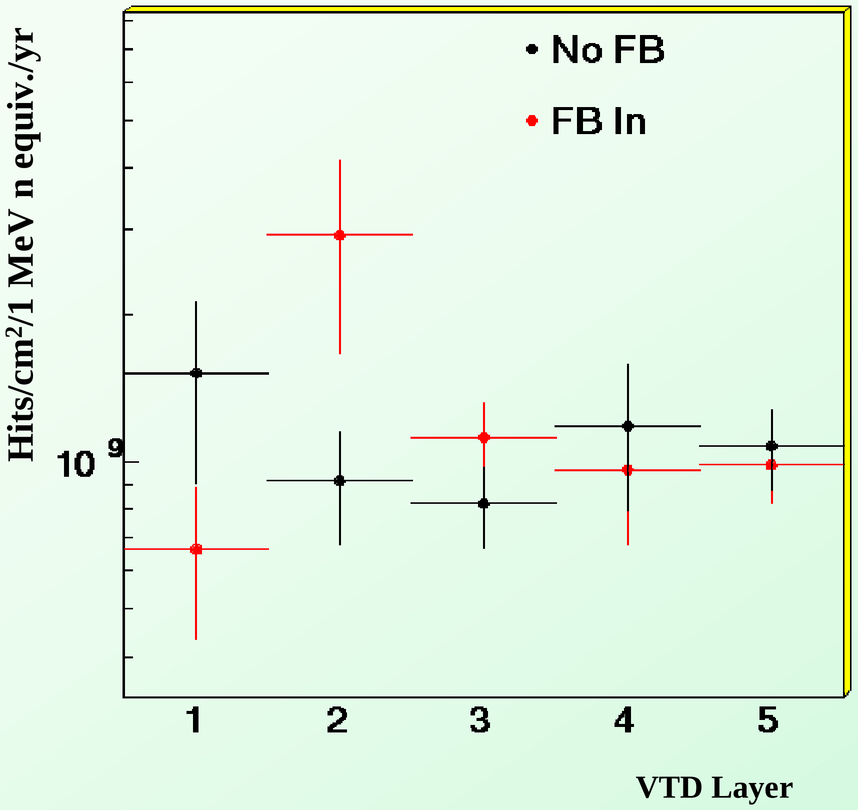
Detector n Bkg (NLC)



Sum Over all Layers:

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

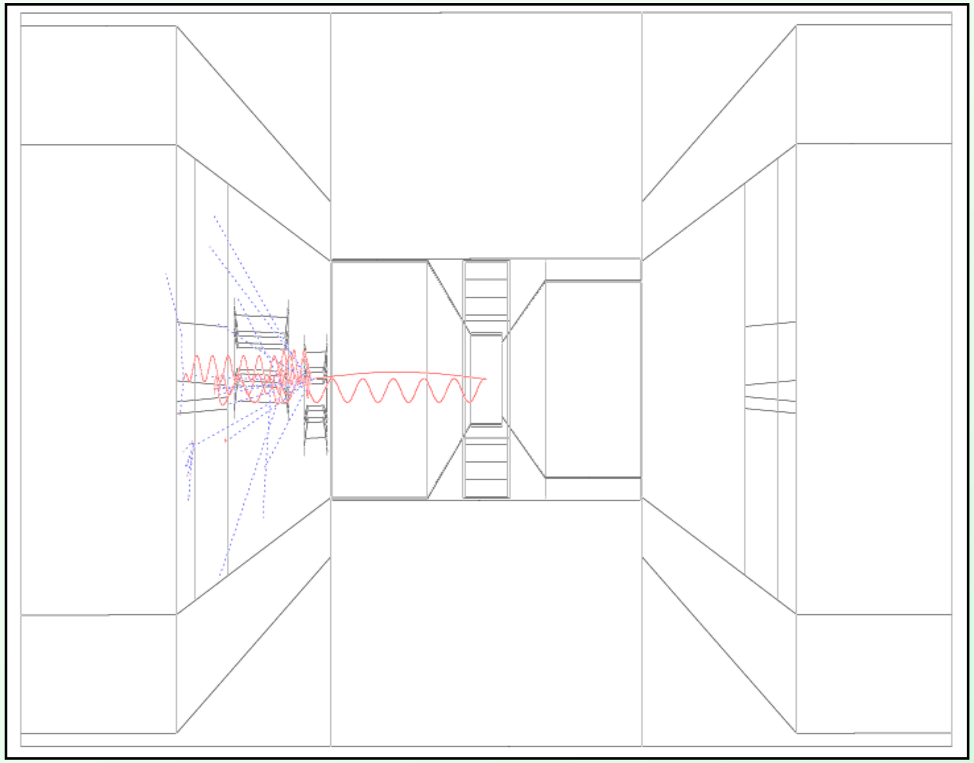
IR with FB: $6.6 \pm 1.3 \times 10^9$

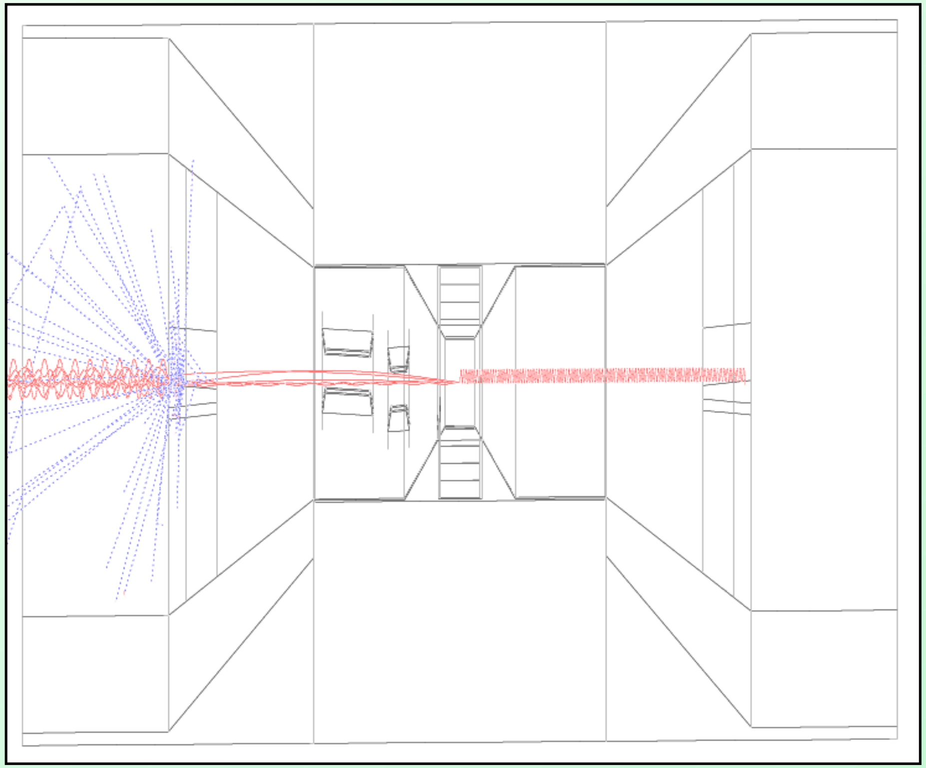
(neutrons/cm^2/1 MeV n equiv./yr)

•No significant increase in neutron flux in vertex detector area seen arising from pair background

F.O.N.T.

Backgrounds- CLIC





•CLIC background studies started by Gerald Myatt. (Continuing)

•2 Positions: 'near', in front of IP and 'far', in conical mask

•Far gives about 2 hits /mm^{-2}/ train extra in inner VXD layer, close gives negligible effect for VXD but produces considerable background at end of unprotected TPC.

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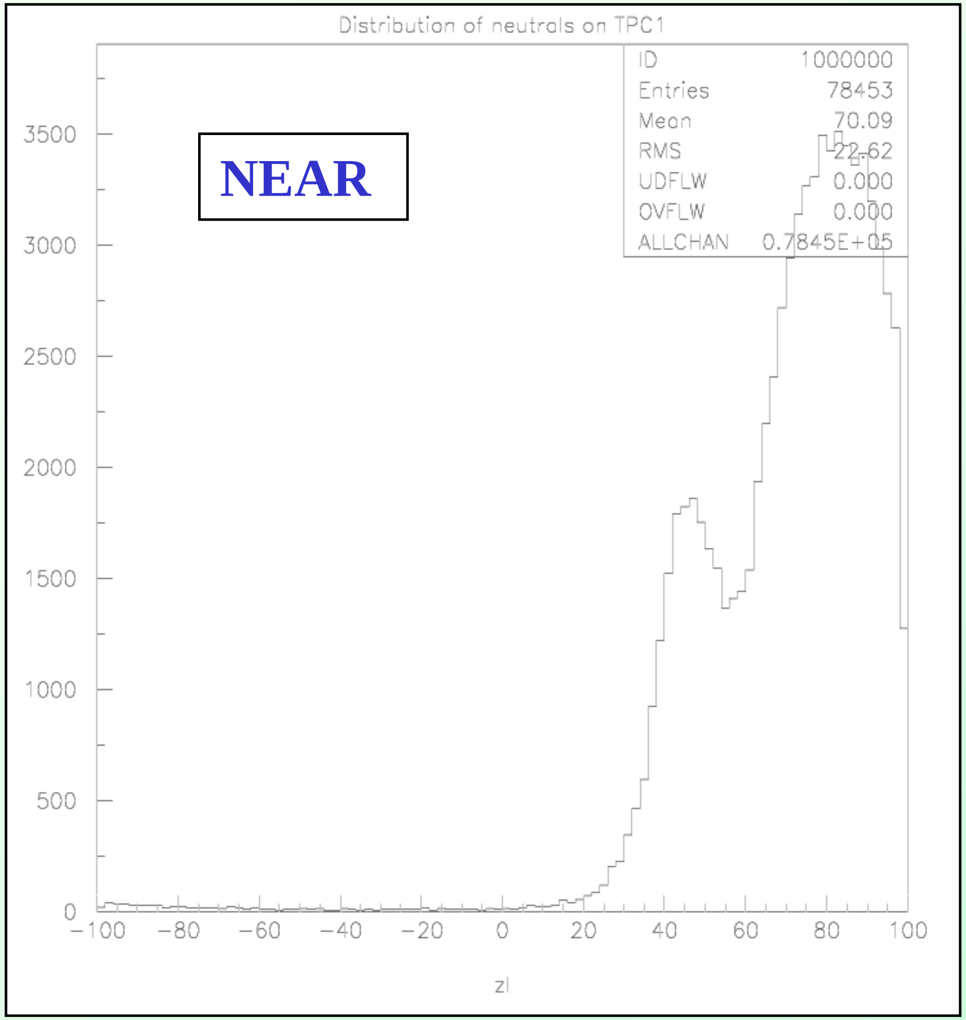
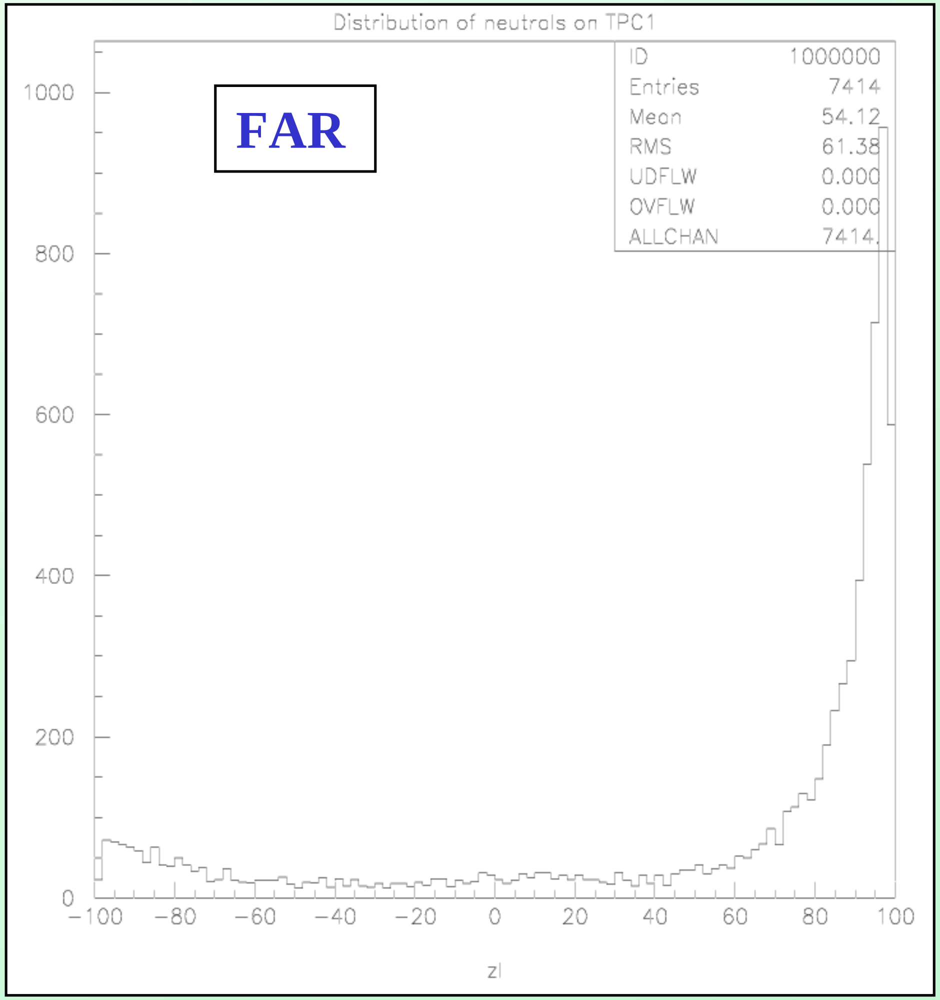
TPC BKG- CLIC





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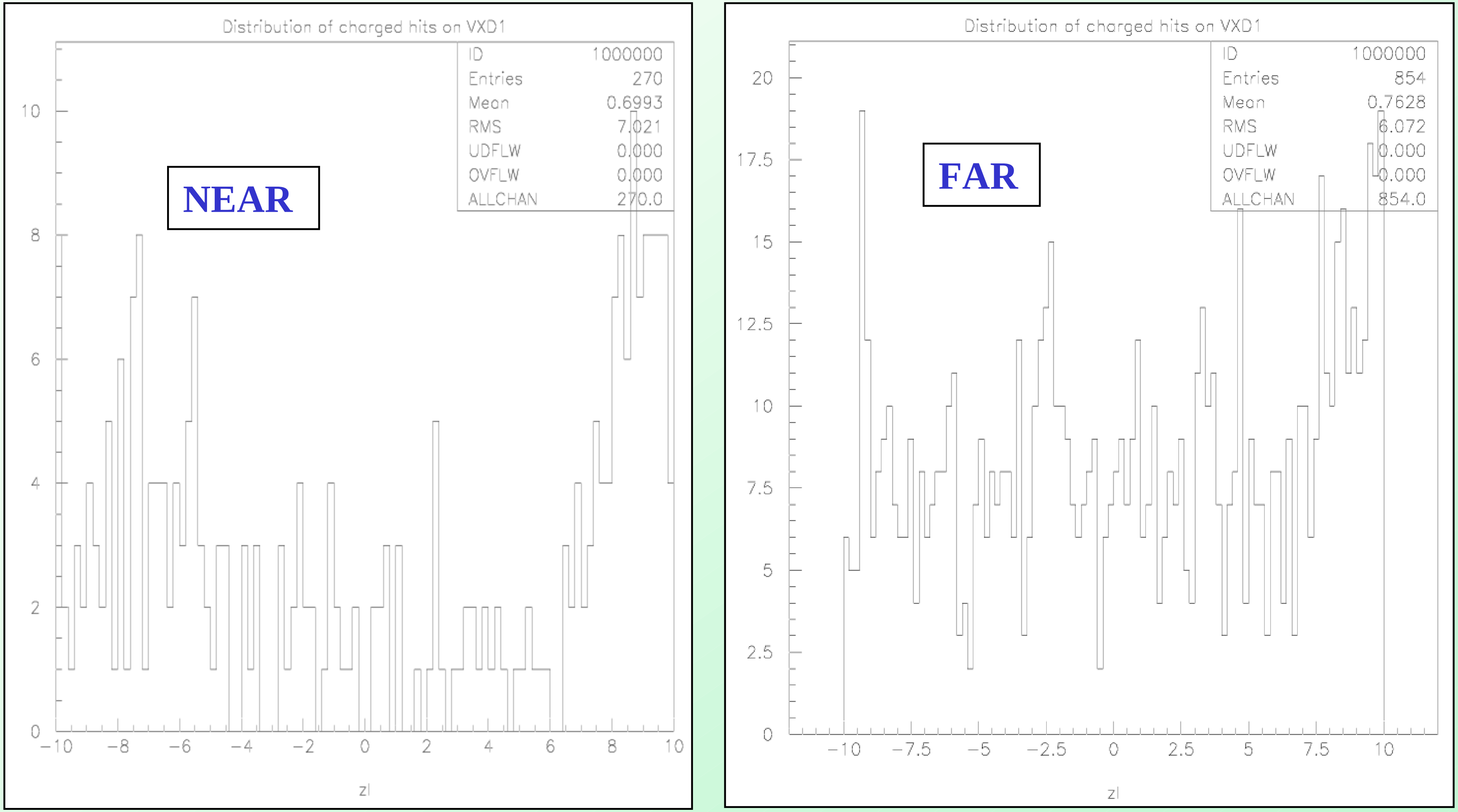
VXD BKG- CLIC

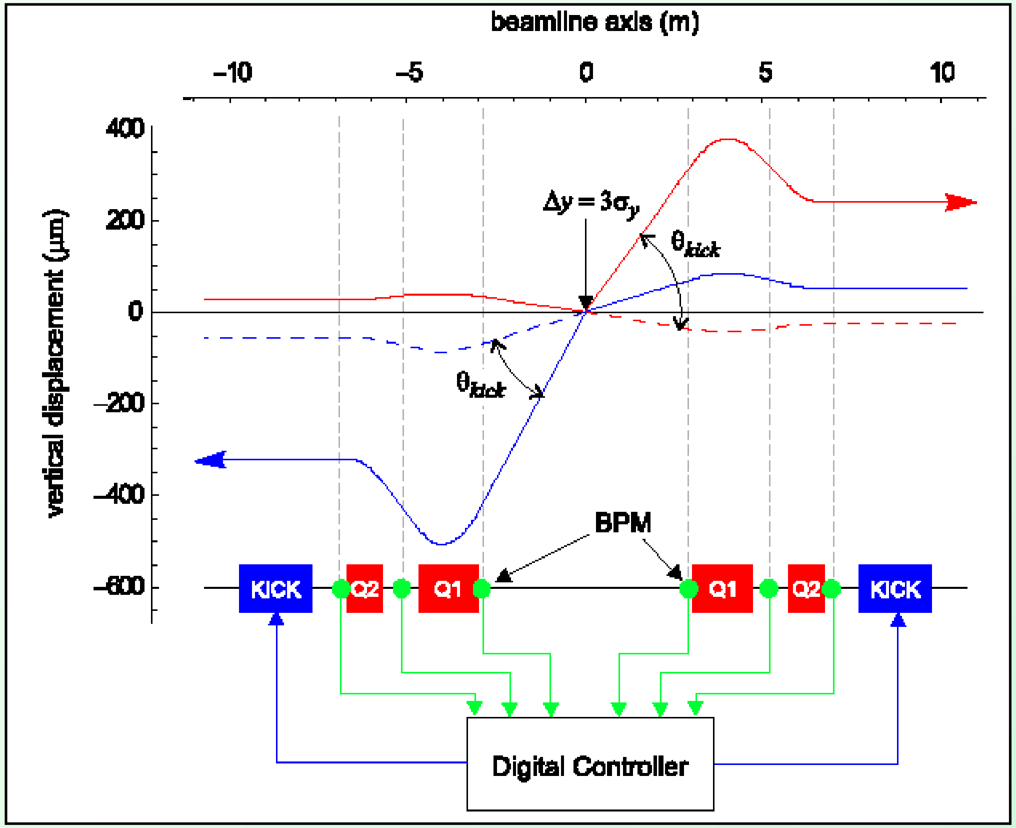


F.O.N.T.

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.**
- **Now also using MatLiar for linac-IP tracking**

F.O.N.T. TESLA FAST IP FEEDBACK



- 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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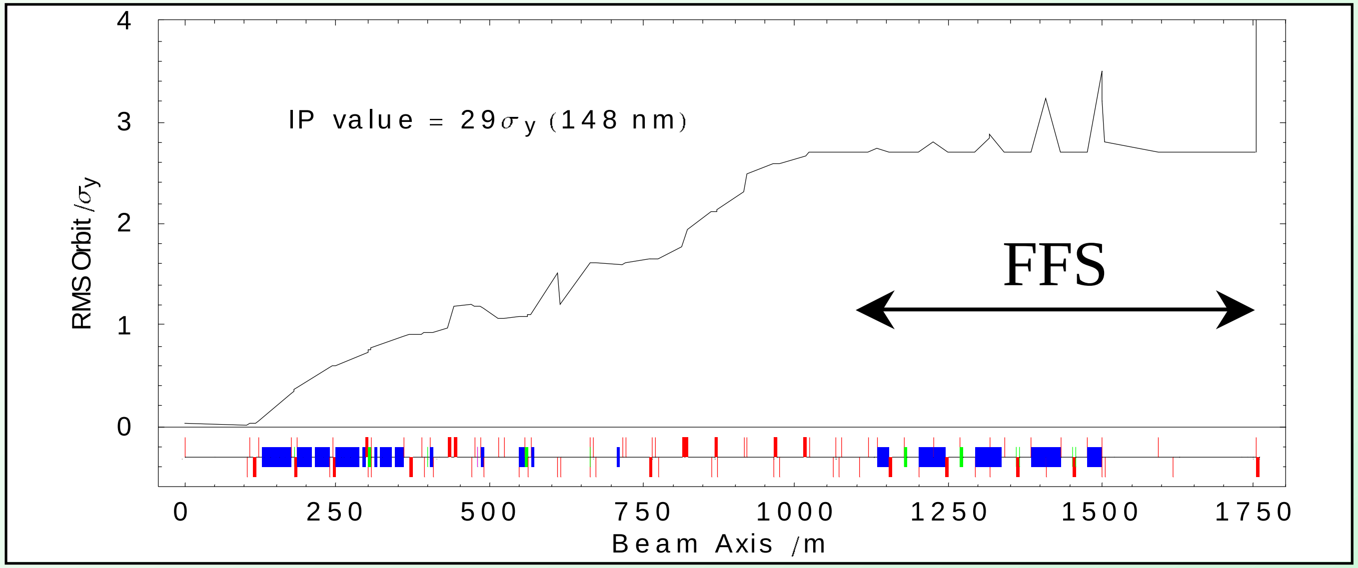
TESLA Angle Feedback



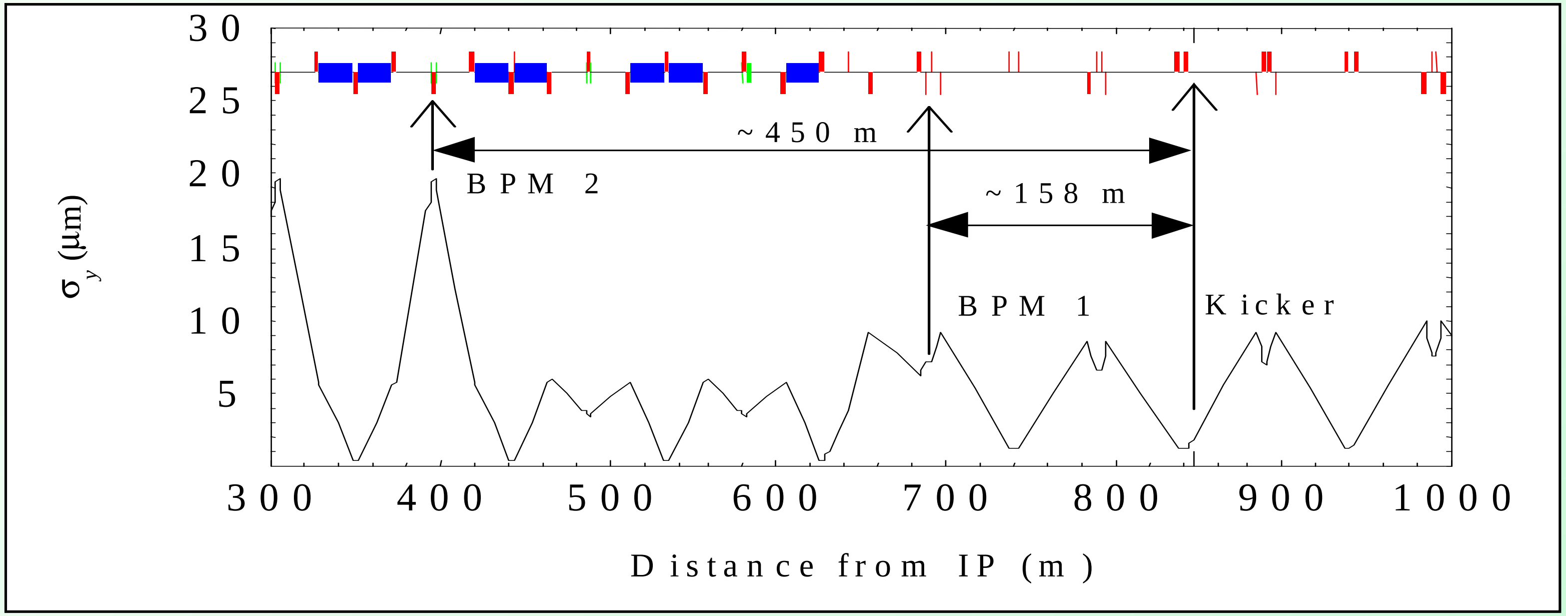
•Normalised RMS vertical orbit in TESLA BDS due to 70nm RMS quadrupole vibrations.

•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.

TESLA ANGLE FEEDBACK

F.O.N.T.

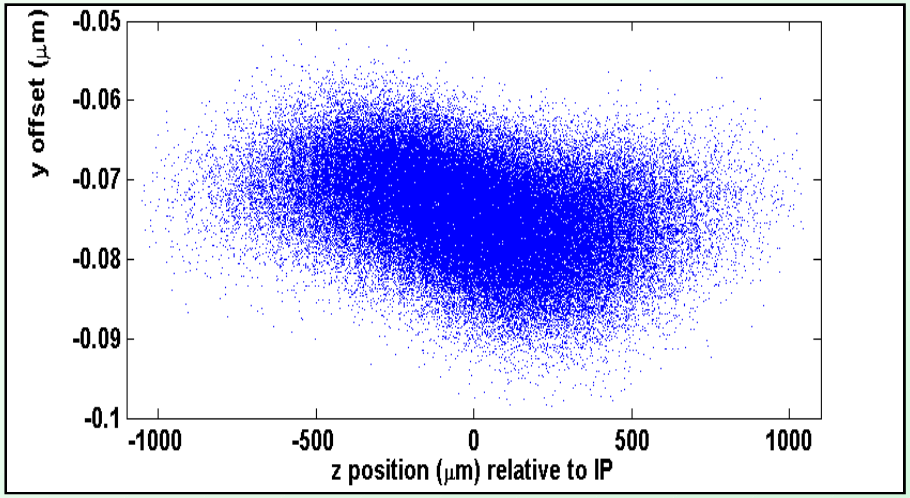


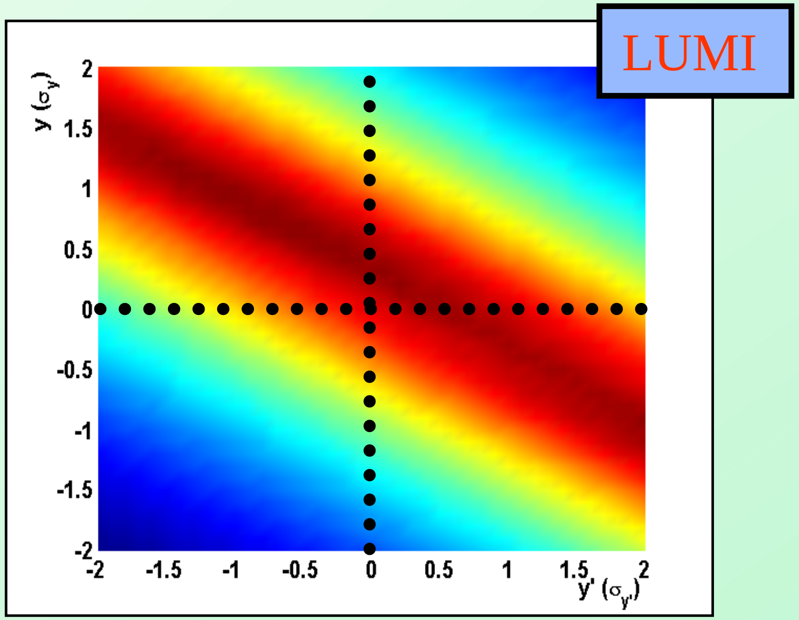
- Place kicker at point with relatively high β function and at IP phase.
- Can correct ~130 μrad at IP (>10$\sigma_{y'}$) with 3x1m kickers.
- BPM at phase 90^0 downstream from kicker.
- To cancel angular offset at IP to 0.1$\sigma_{y'}$ level:
    - BPM 1 : required resolution ~ 0.7μm, FB latency ~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

F.O.N.T.

BANANAS

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



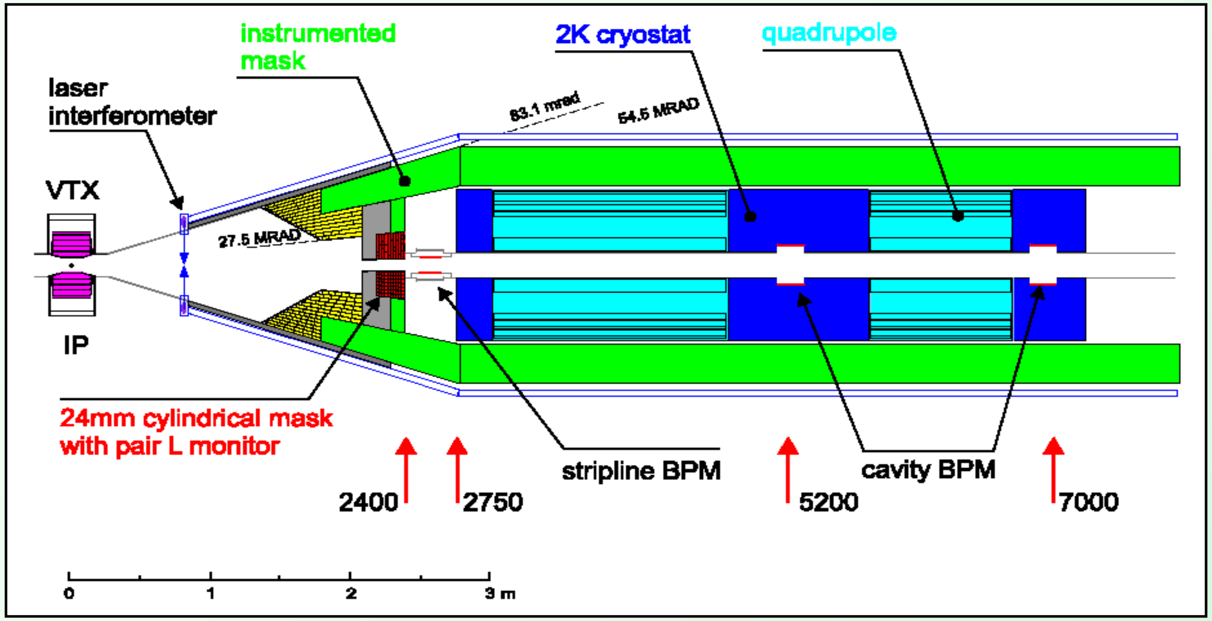


•**Only small increase in vertical emittance, but large loss in luminosity performance with head-on collisions.**

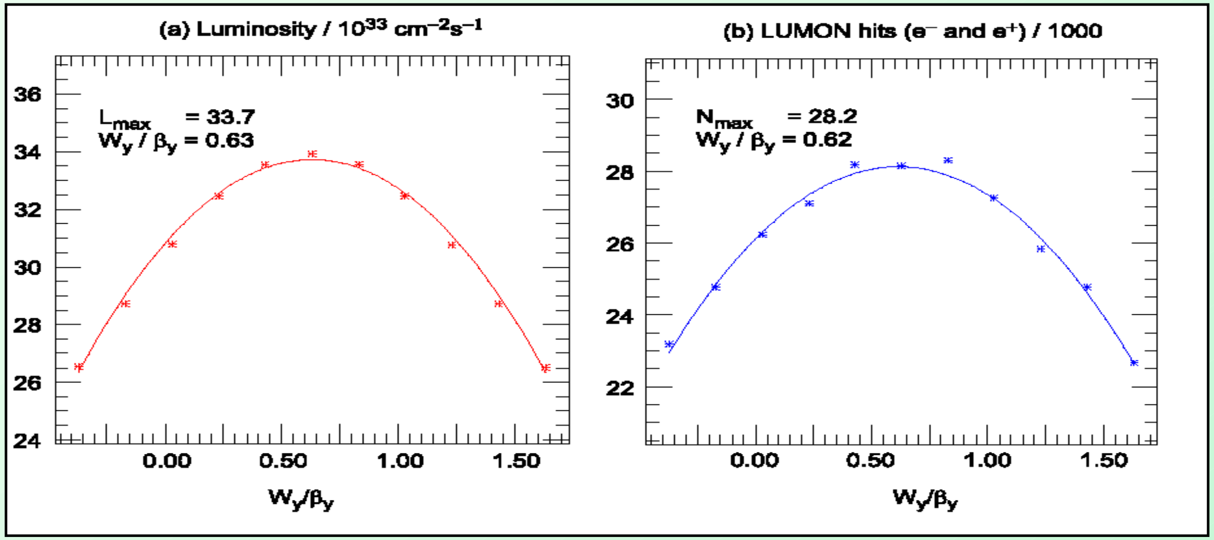
•**Change in beam-beam dynamics from gaussian bunches.**

PAIR LUMI MONITOR

F.O.N.T.



TESLA IR

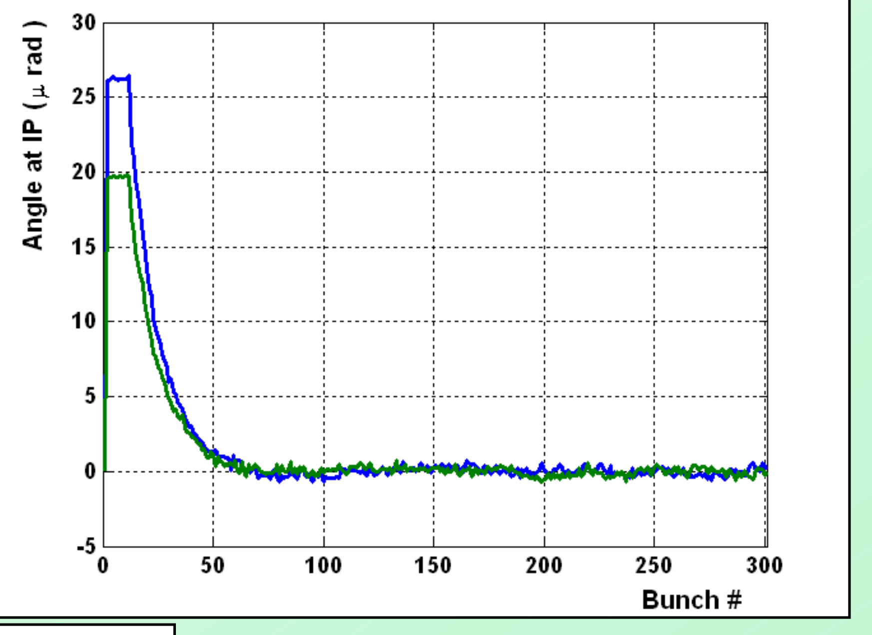


Fast Lumi monitor allows bunch-bunch readout of e+e- pair hits which are at Max at Max lumi

F.O.N.T.

TEST RUN

- Results from 1 run with Simulation parameters:
- PI feedback controller.
- 300 bunches at IP (from 100 PLACET bunches)
- 70nm RMS quad vibration
- Add 1.4ppm E spread on e- bunches prior to tracking through bds
- BPM res.: 5μm (IP FB) 2μm (ANG FB)
- Field errors for kickers (bunch-bunch RMS) 0.1%
- Angle FB latency= 3.4 μs (10 bunches)
- LUMI FB: (use GP lumi as input (not pairs))
    - Start after 100 bunches
    - Ave. 10 bunches per reading
    - Ramp in 0.1 σ_y steps
    - Use BPM signal of optimum lumi as FB set-point

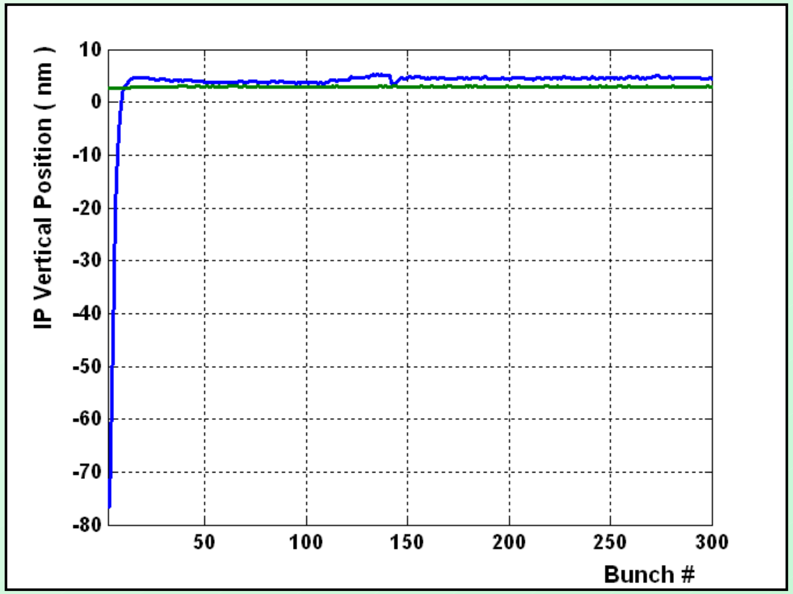


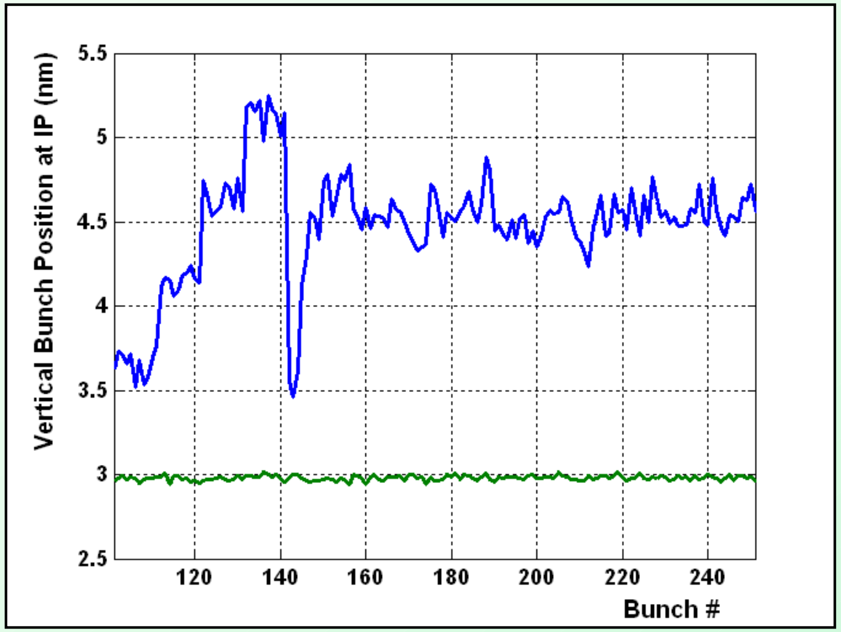
Mean angle of bunch particles at IP.
RMS angle separation of beam bunches 200-300 = 0.51 μrad (0.04 $\sigma_{y'}$).

F.O.N.T.

TEST RUN

Mean y of bunch particles at IP.
Mean position offset at IP (bunches 200-300): 1.59 nm (0.32 σ_y) +/- 0.13nm (0.03 σ_y).



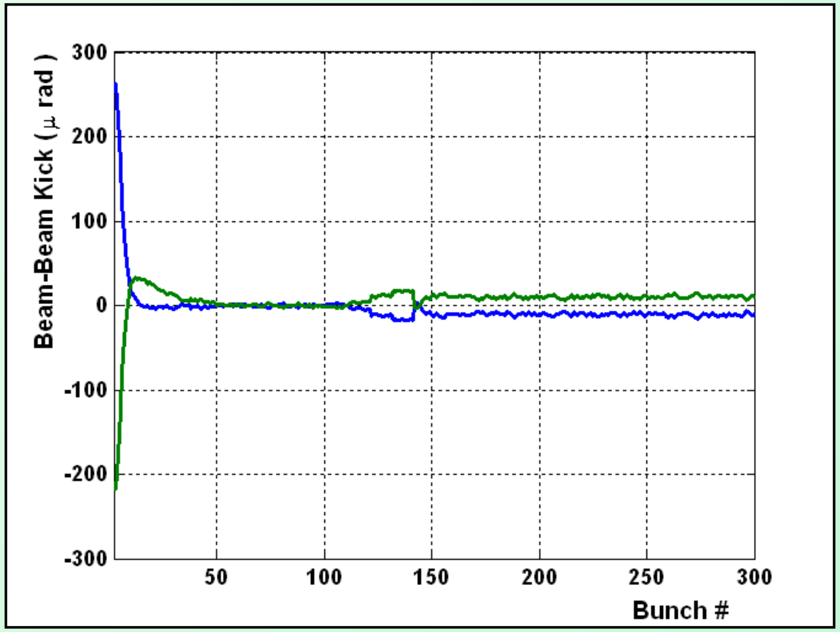


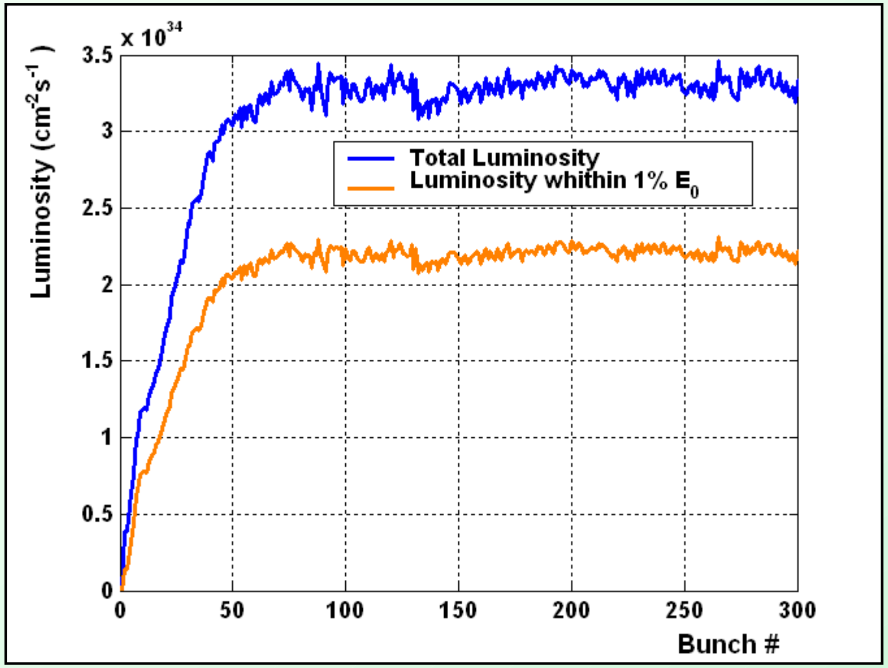
LUMI FB finds optimum collision.

F.O.N.T.

TEST RUN

Beam-Beam Kick -> IP FB BPM signal & set-point.
Luminosity per bunch across the 300 simulated bunches:





Luminosity (taking last 100 bunches as representative of rest of bunch train):
(SUM(L(b1-300))+SUM(L(b200-300))*25.2)/2820= 3.32×10^{34} $cm^{-2}s^{-1}$.
Lumi within 1% of nominal beam energy = 2.22×10^{34} $cm^{-2}s^{-1}$ (67% of total Lumi).
Relative lumi bunch-bunch jitter on last 100 bunches= 2%.

G.R.White: 07/09/2002

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. Work started on NLC FB-matliar integration.

•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. Simulations include particle tracking from start of linac through BDS to IP, using PLACET and matmerlin or matliar.

NLCTA HARDWARE TESTS