Stability and Ground Motion Challenges in Linear Colliders

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ICFA Nanobeam 02
Lausanne, September 2, 2002

Contents

- Brief review of natural ground motion and vibrations and their influence on LC
  - Effects of fast motion
  - R&D aimed to ensure NLC stability
  - Particular case of Final Doublet (FD)

Linear Colliders – two main challenges

- **Energy** – need to reach at least 500 GeV CM (as a start)

- **Luminosity** – need to reach 10^34 level
  - and ensure stable collisions of *Nanobeams* and preservation of their small emittance

    - The second is useless if the first cannot be achieve, but is not less important

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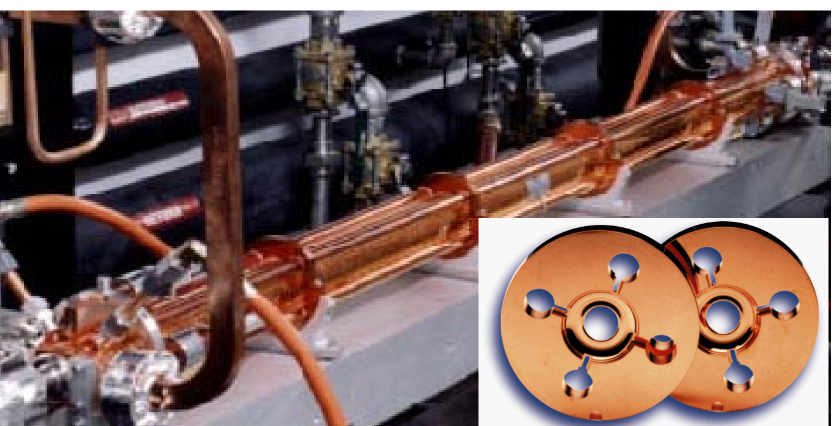
LC Challenge 1: Energy

- Goal of 250 GeV/beam (and higher)
- Normal Conducting (JLC/NLC, CLIC) and
- Super Conducting (TESLA) RF technologies

- Teams are working hard to ensure successful jump from what is achieved, to the energy goal

  - SC technology – must jump from achieved 1 GeV (factor of 250)

  - NC technology – must jump from achieved 50 GeV (factor of 5)



Significant progress along this way in the recent years

LC Challenge 2: Luminosity

- Must jump by a Factor of 10000 in Luminosity !!! (from what is achieved in the only so far linear collider SLC)
- Many improvements, to ensure this : generation of smaller emittances, their better preservation, …
- And need to provide stability
  - I.e. ensure that ground motion, remotely and locally created vibrations do not produce intolerable misalignments of LC elements

NLC

Two effects of ground motion in Linear Colliders

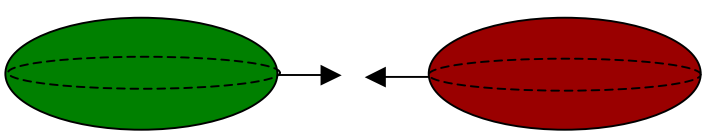
frequency

'slow motion' | 'fast motion'

$F_c \sim F_{rep}/20$

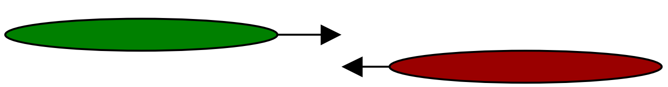
Beam offset due to **slow motion** can be compensated by feedback

May result only in beam emittance growth



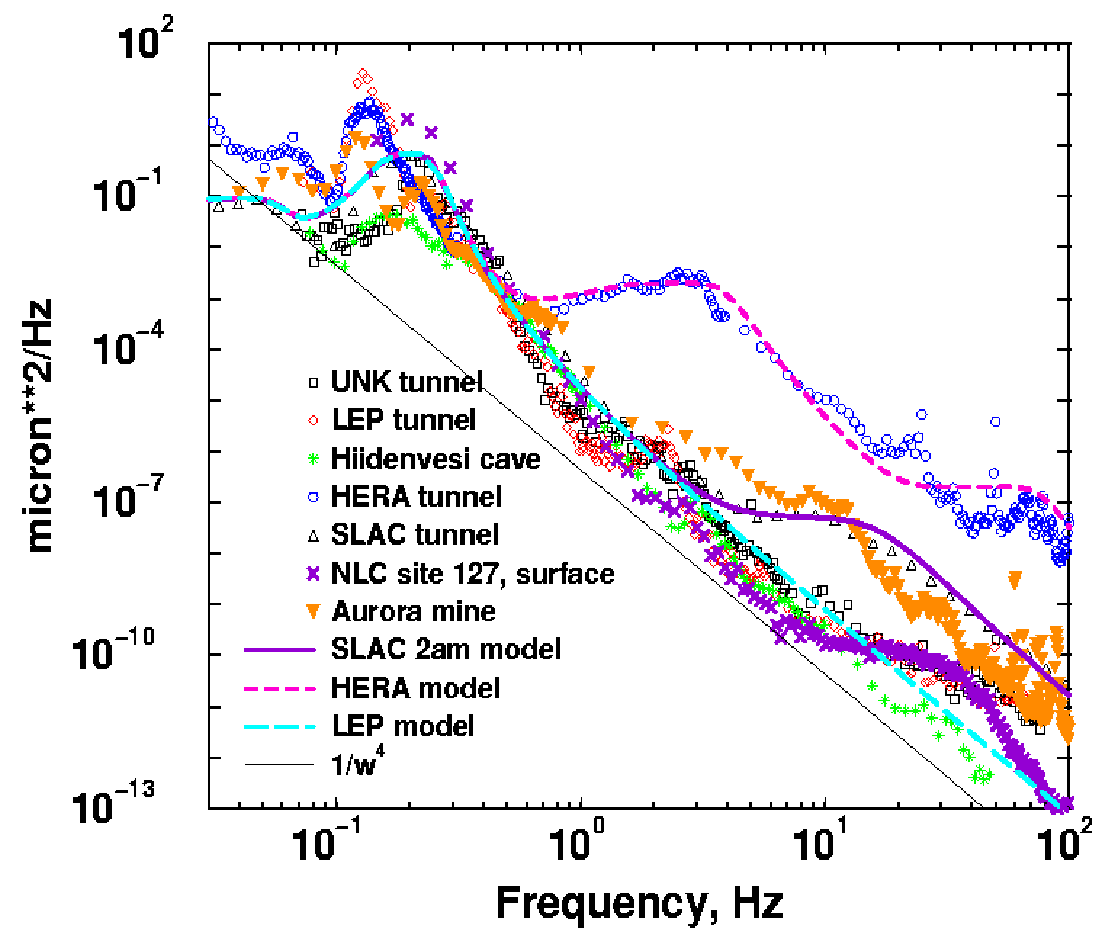
Beam offset cannot be corrected by a pulse-to-pulse feedback operating at the F_{rep}

Causes beam offsets at the IP



Evaluating effects of ground motion and vibration

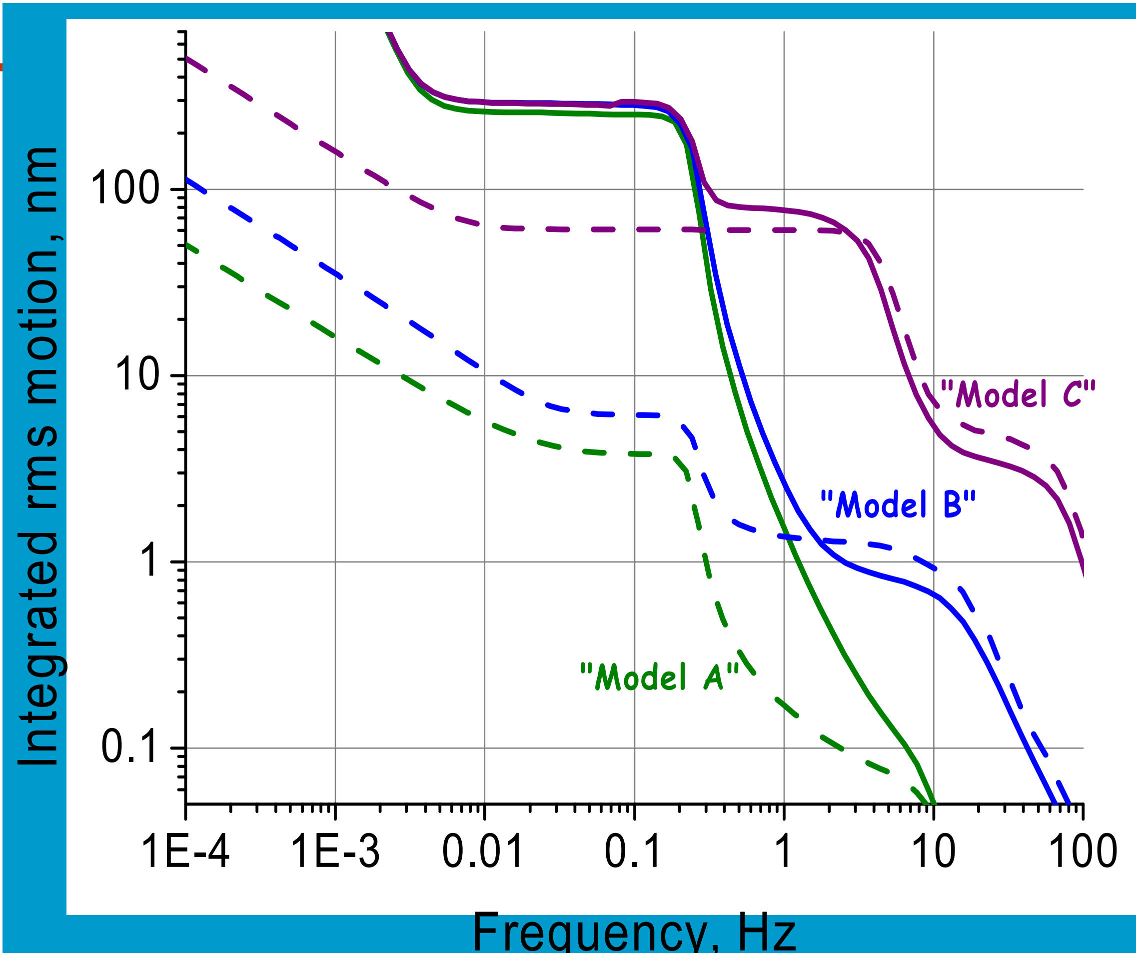
- Collect and understand data on ground motion and vibrations
- Build a model(s) of ground motion (e.g. P(ω,k) spectrum)
- Then make simulation how LC performs
  - Apply corrections, feedbacks, optimize them…
- Decide whether this ground motion or parameters of LC are acceptable



Data from different locations 1989 - 2001

Ground motion models

- Based on data, build modeling P(ω,k) spectrum of ground motion which includes:
  - Elastic waves
  - Slow ATL motion
  - Systematic motion
  - Cultural noises



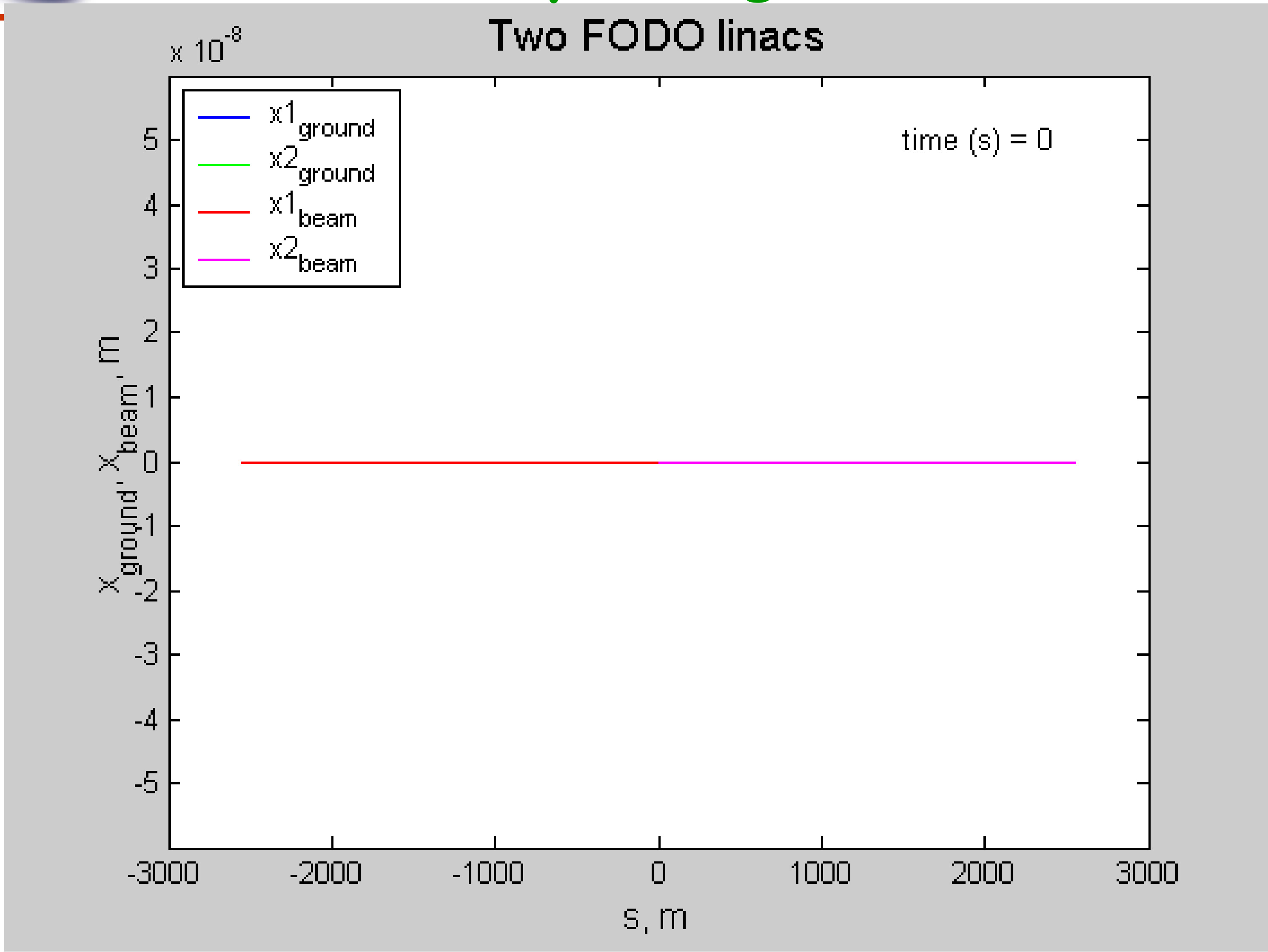
Example of integrated spectra of absolute (solid lines) and relative motion for 50m separation obtained from the models

Caution

- We should not forget that
  - Quads are not imbedded in a rock, but are sitting on supports or in cryostats
  - There are noise sources just on girders (e.g. from cooling water)

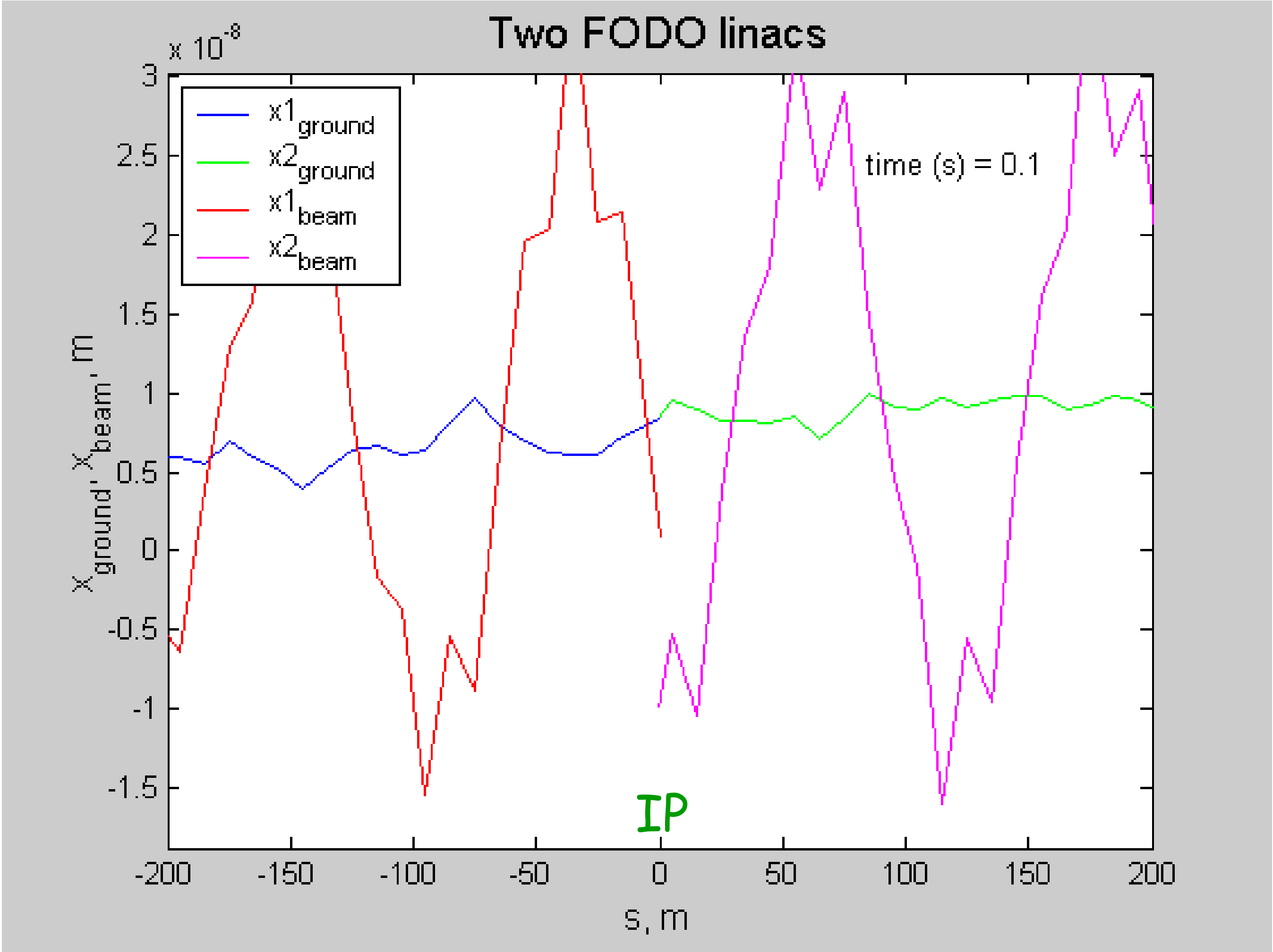
    - Even if ground motion is acceptable, it is very important to verify, that stability of collider elements is sufficient
      - Further in the talk (and later during Workshop) we will discuss ongoing R&D that should answer this question

Example: effect of ground motion on two FODO linacs pointing to each other



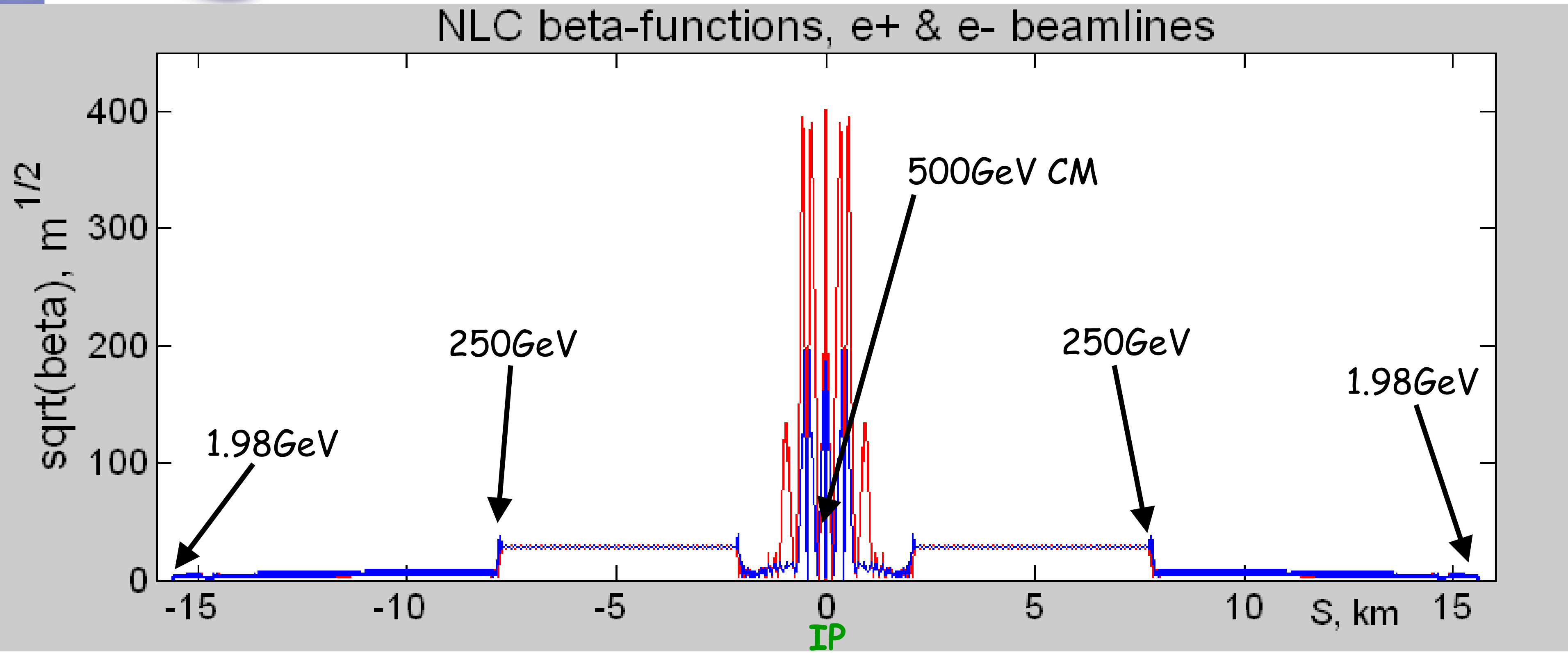
Example of Mat-LIAR modeling

Important that correlation between e+ and e- beamlines is preserved



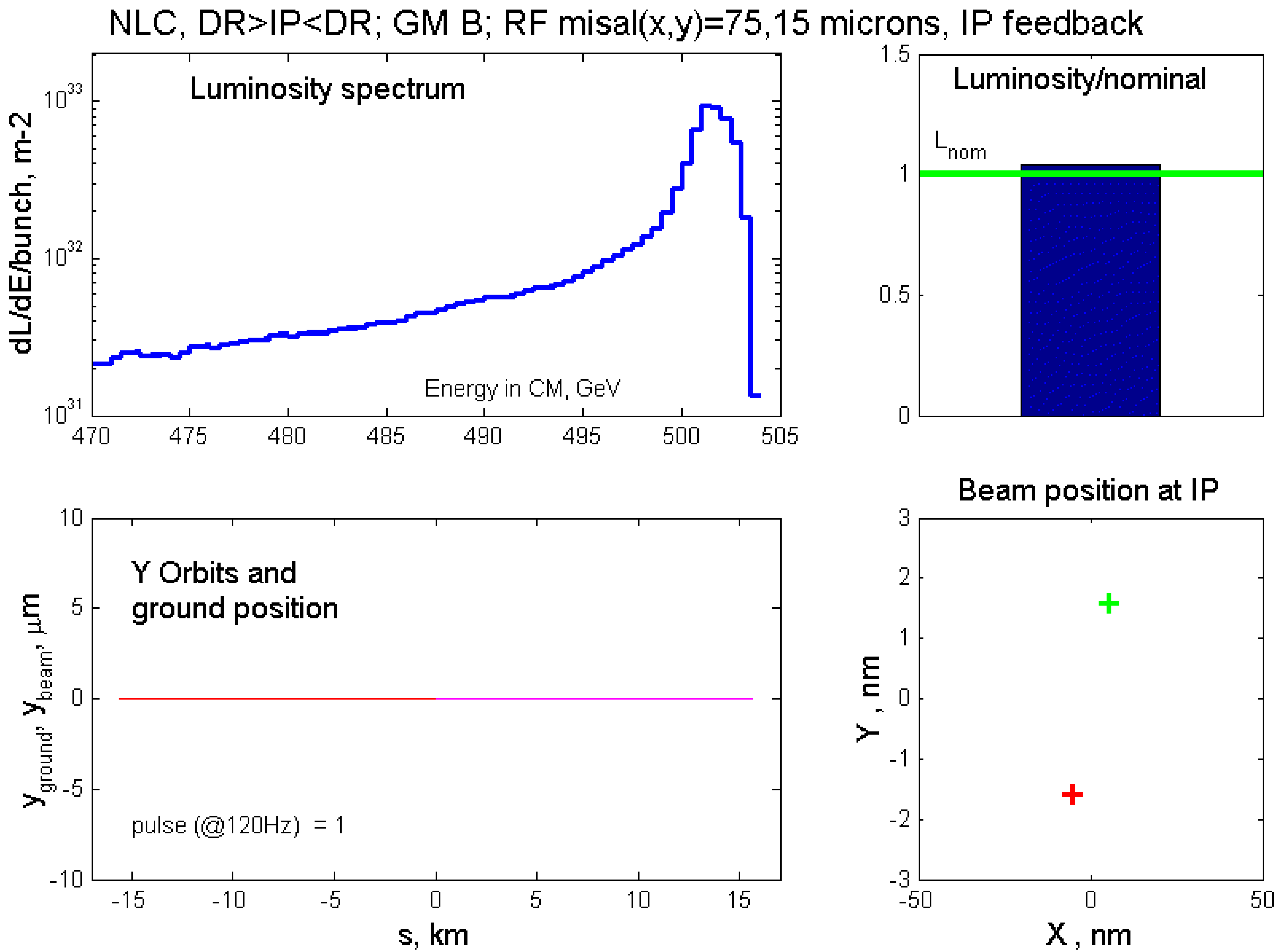
Note that ground is continuous, but beams have separation at the IP

Simulations of complete NLC
DR => IP <= DR

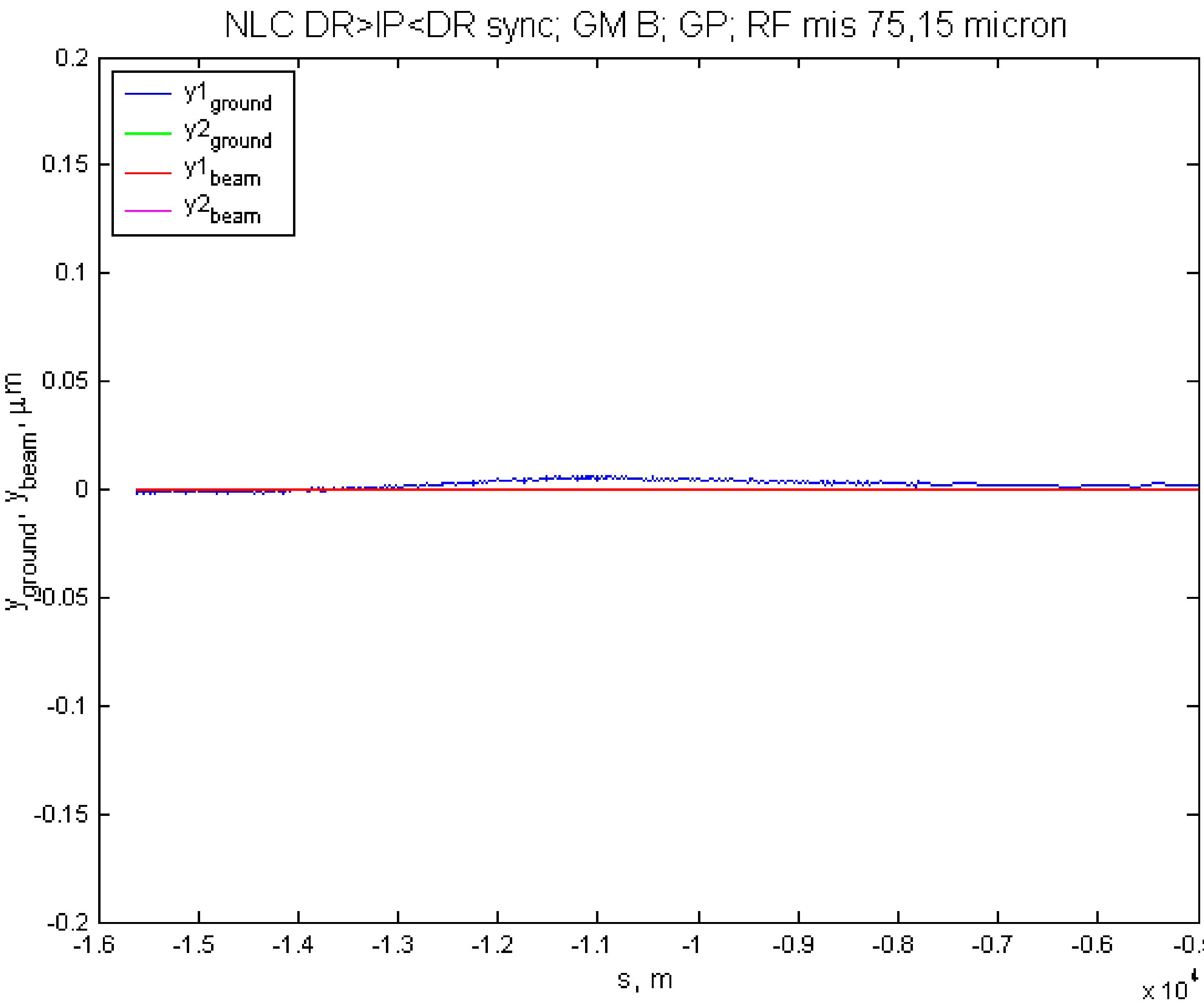


Included: ground motion
train-to-train IP feedback
Errors in the linac
Beam-beam effects ...

Intermediate ground motion

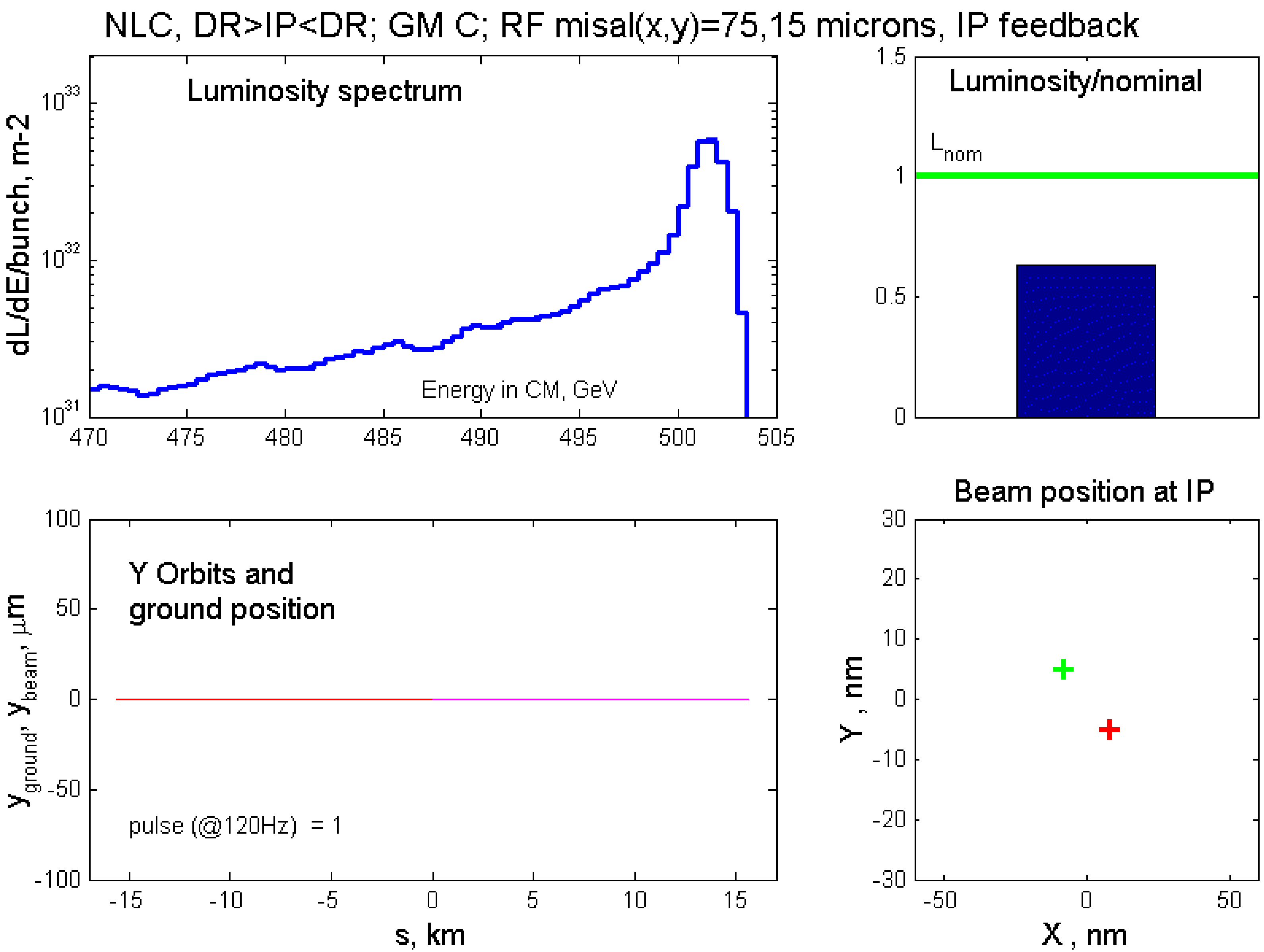


Zoom into beginning of e- linac …

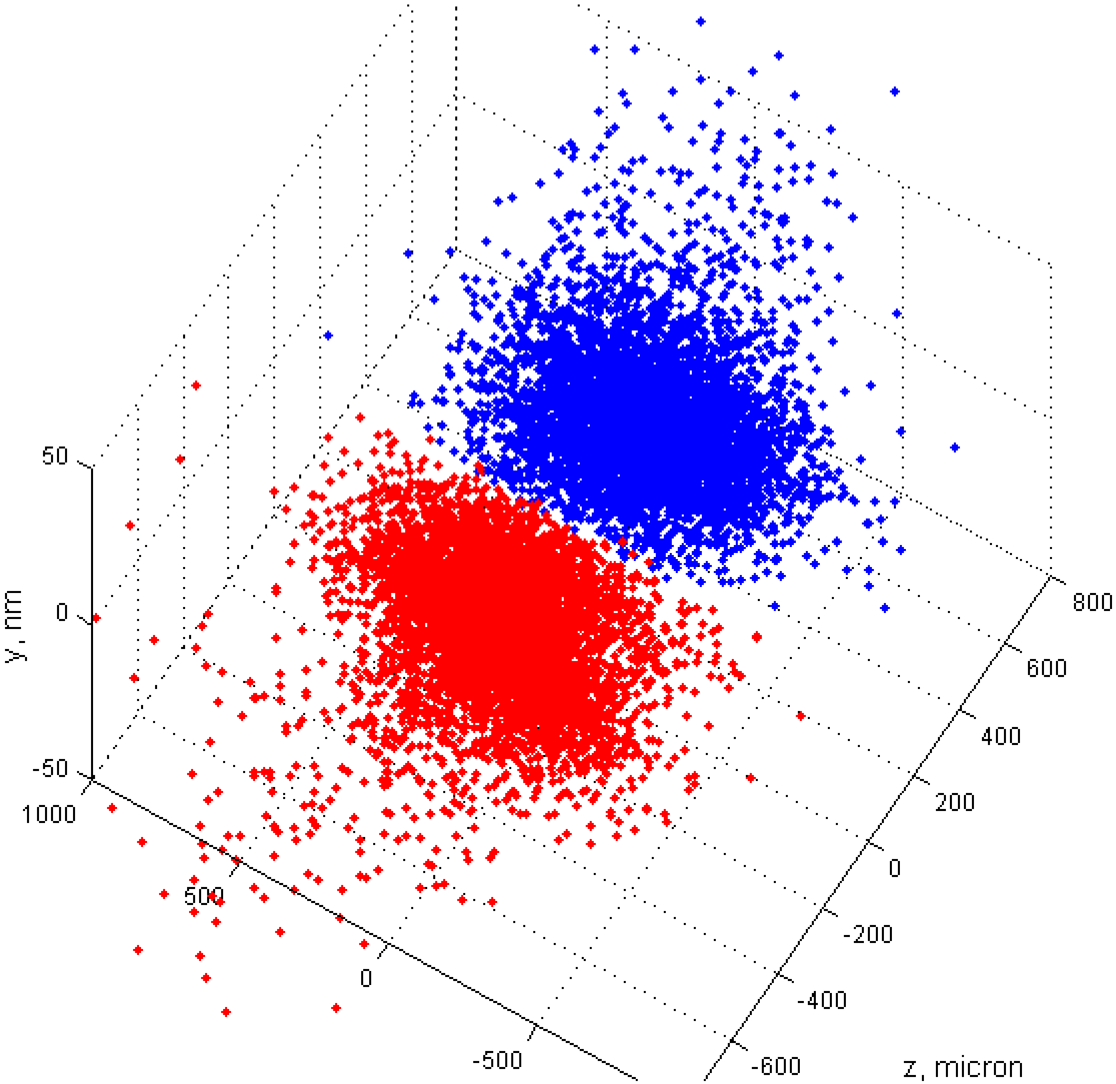


Transition from linac to transfer line

Noisy ground motion



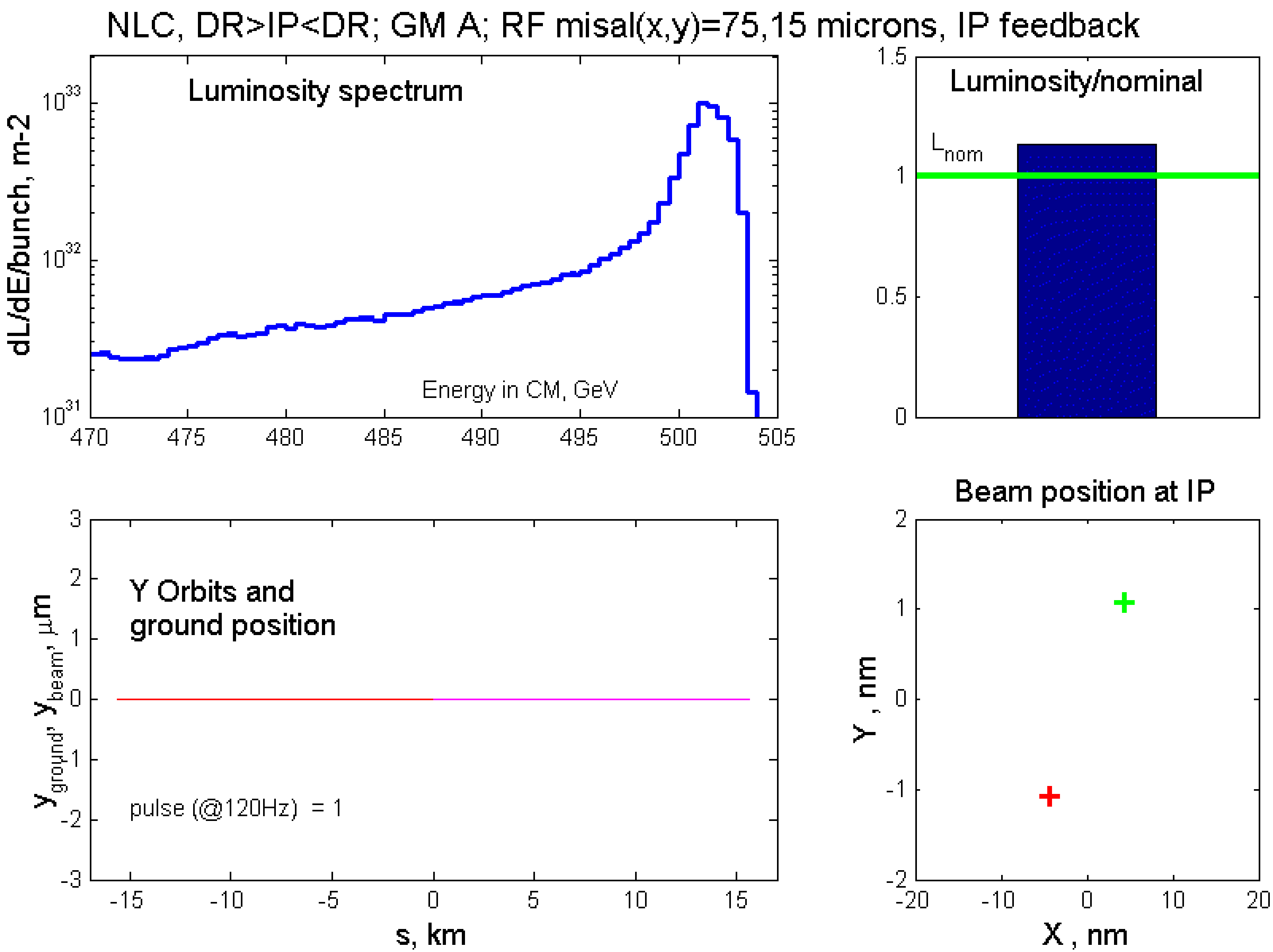
Beam-beam collisions calculated by Guinea-Pig [Daniel Schulte]



"Banana effect" is included

Daniel's talk

Quiet ground motion



IP beam-beam feedback

Colliding with offset e+ and e- beams deflect each other

Deflection is measured by BPMs

Feedback correct next pulses to zero deflection

(it uses state space, Kalman filters, etc. to do it optimally)

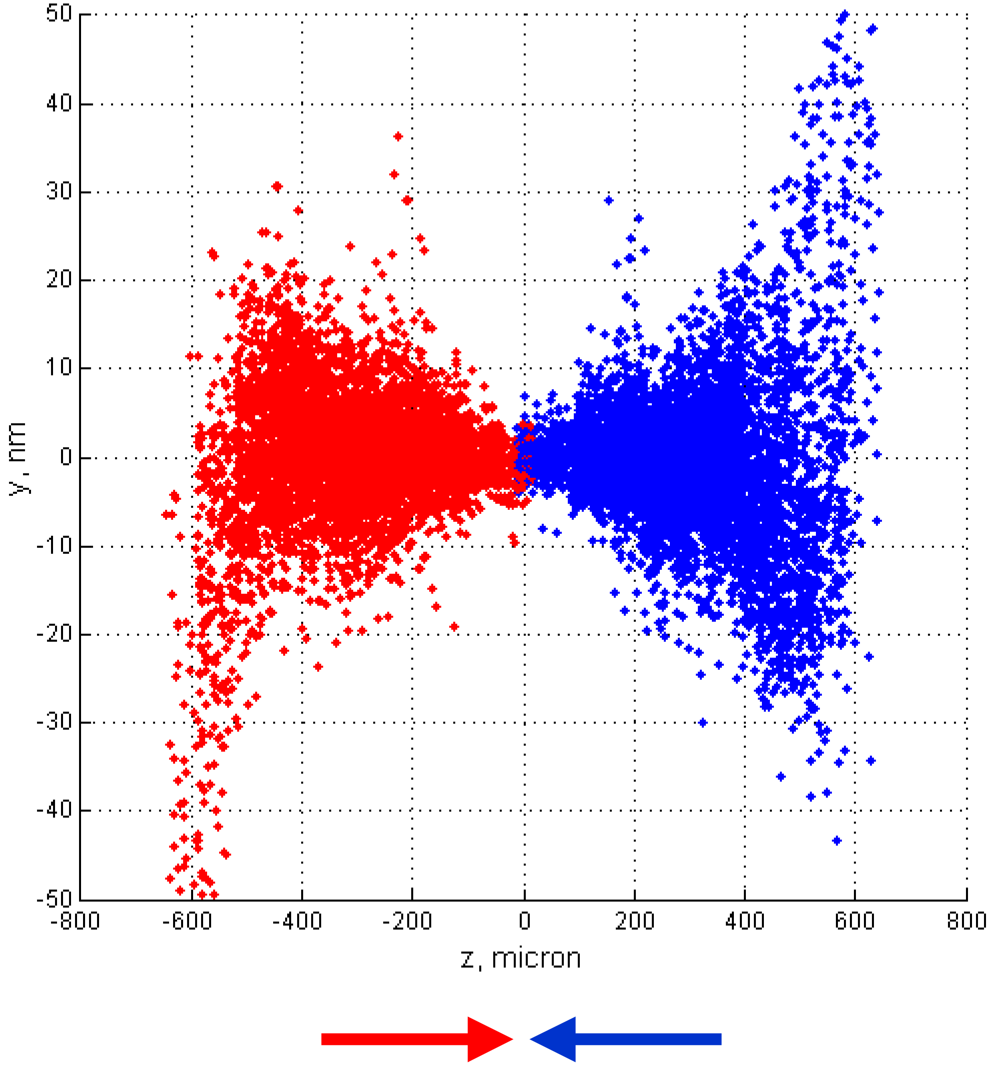
The previous page shows that feedback needs to keep nonzero offset to minimize deflection

reason: asymmetry of incoming beams

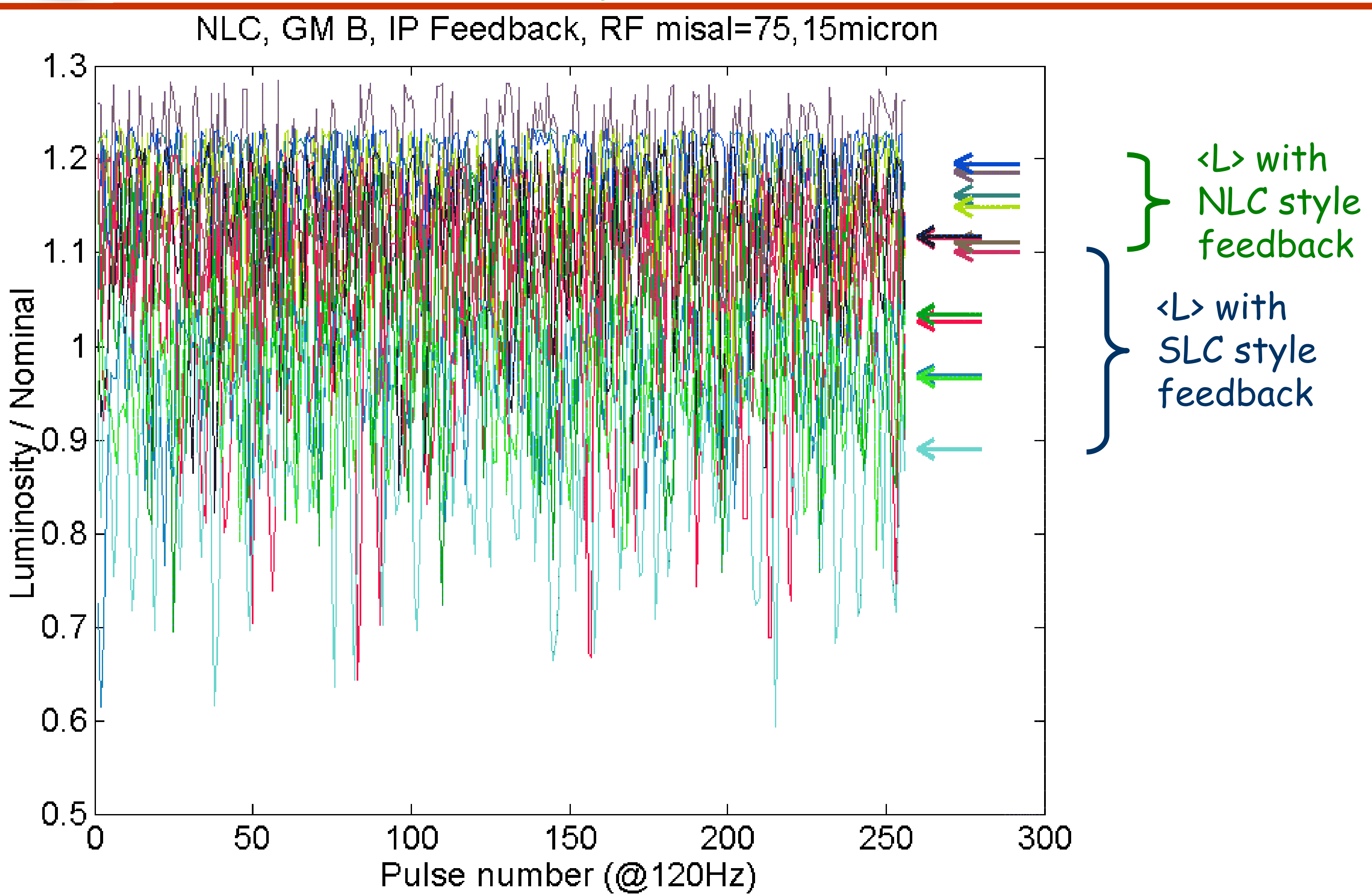
(RF structures misalignments=> wakes=> emittance growth)

NLC

Pulse #100, Z-Y

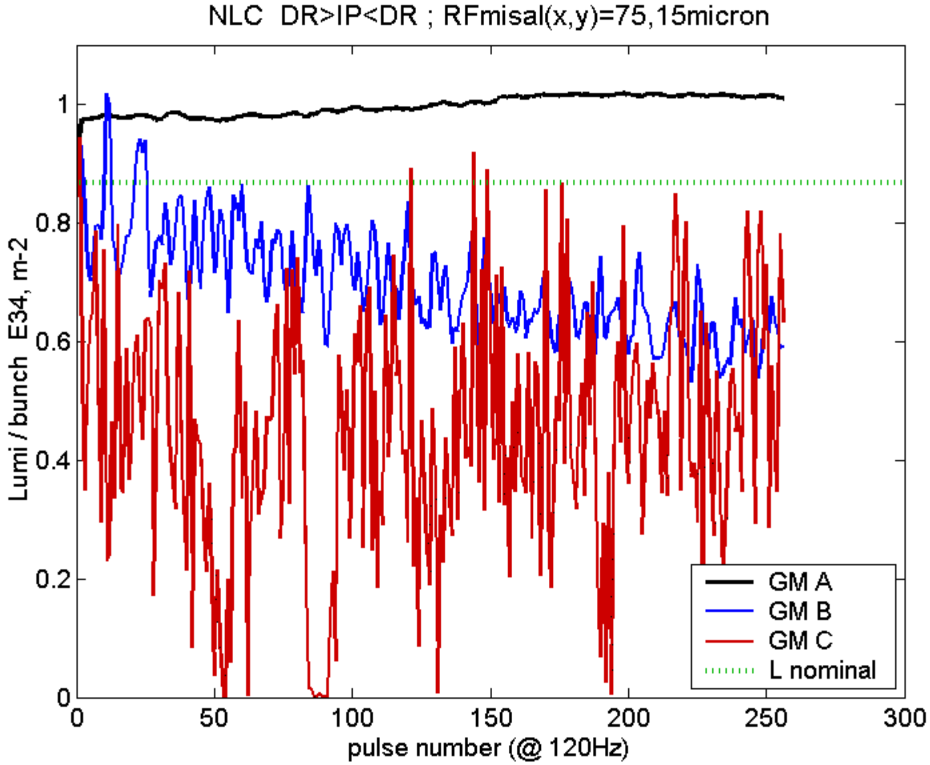


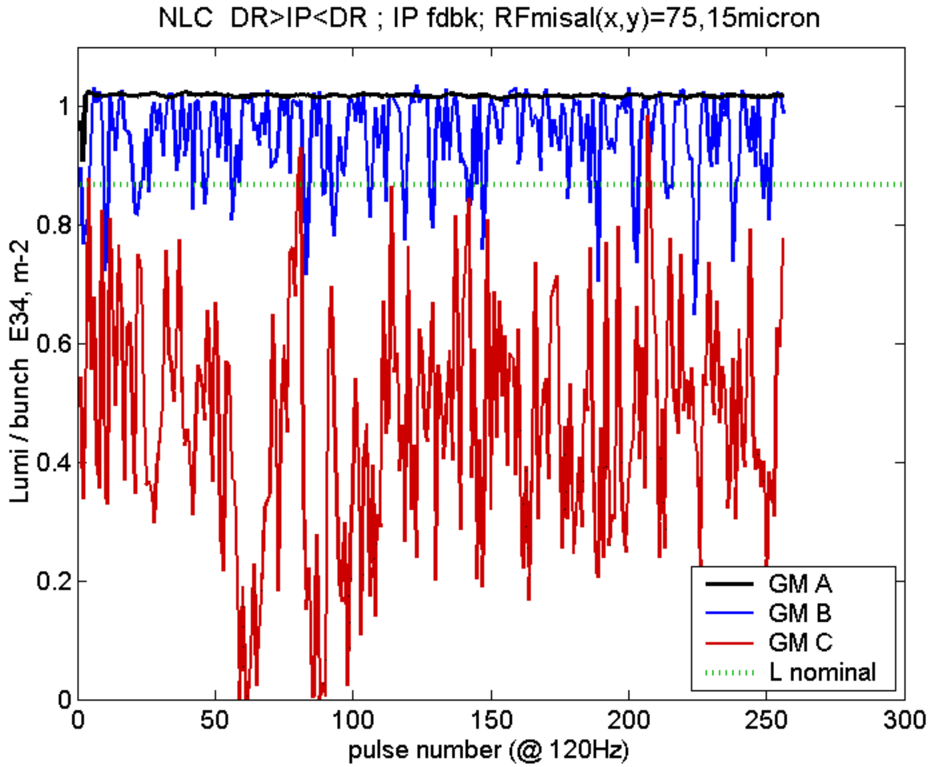
IP feedback developments and improvements



Talk of
Linda Hendrickson

With and without IP feedback, examples





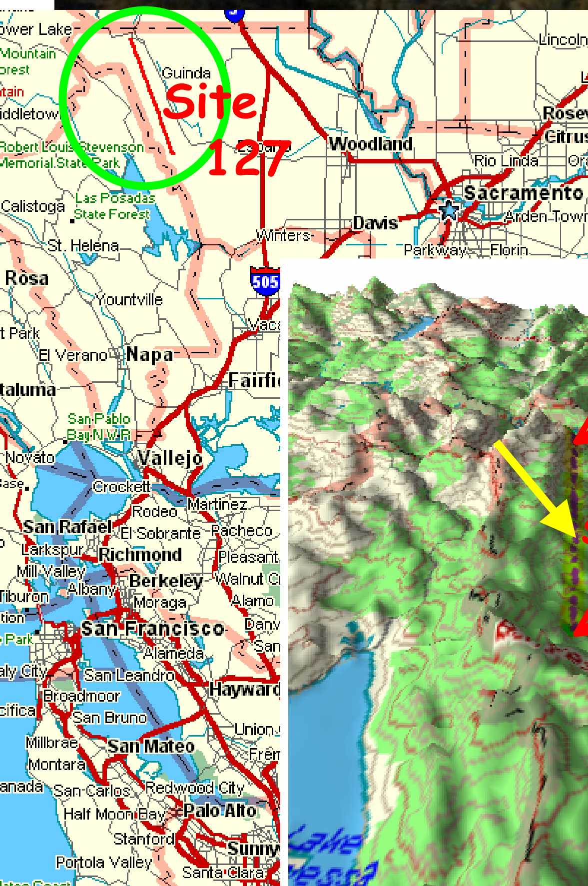
Example for one particular seed

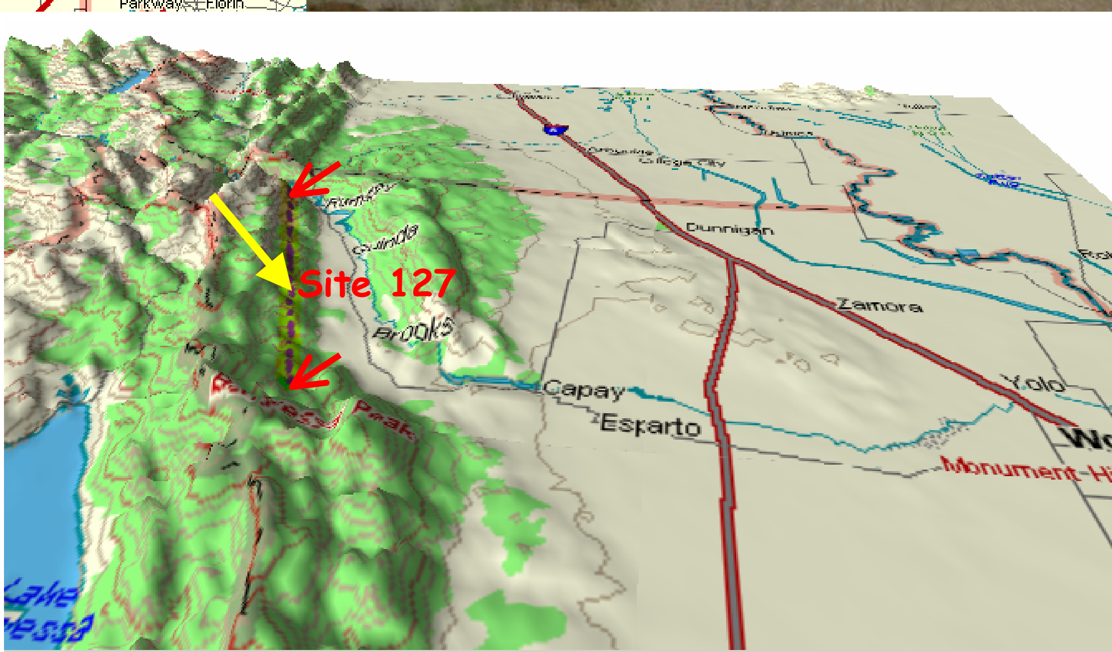
(seed is the same for the left and right plots)

Ongoing and required R&D

- Studies of the sites stability
- Studies of near-tunnel noises and vibration transfer from the surface
- Studies of in tunnel noises, including vibration transfer from the parallel tunnel
- Studies of on-girder (in-cryostat) noises

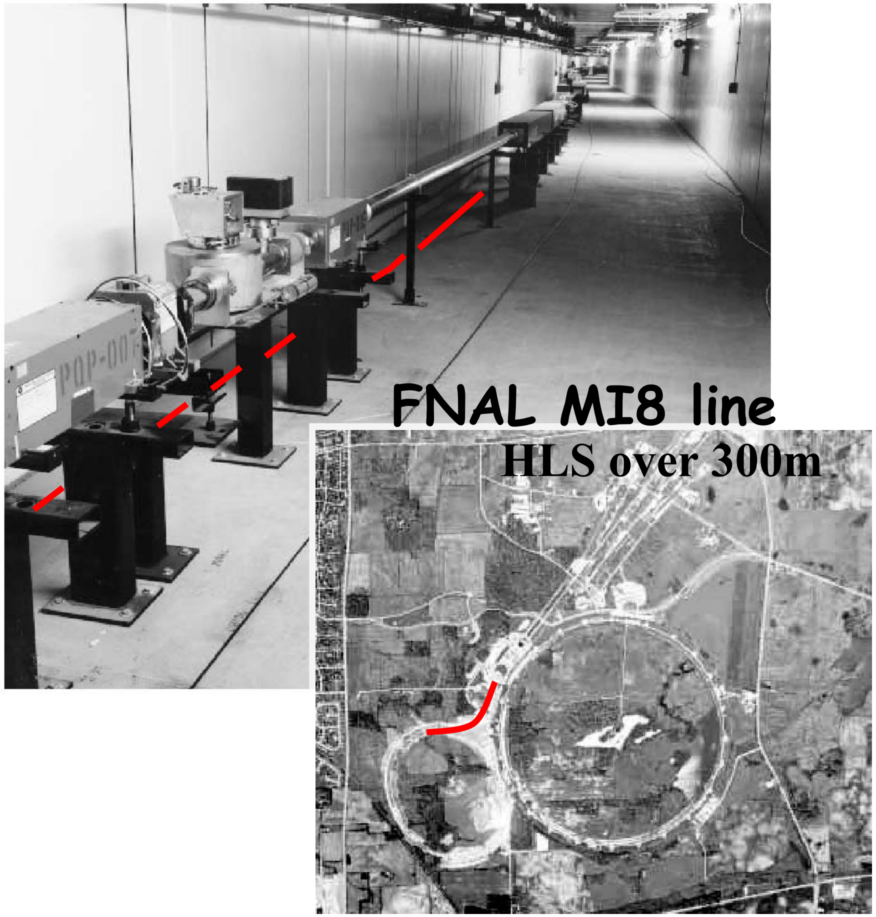
Stable NLC sites in CA





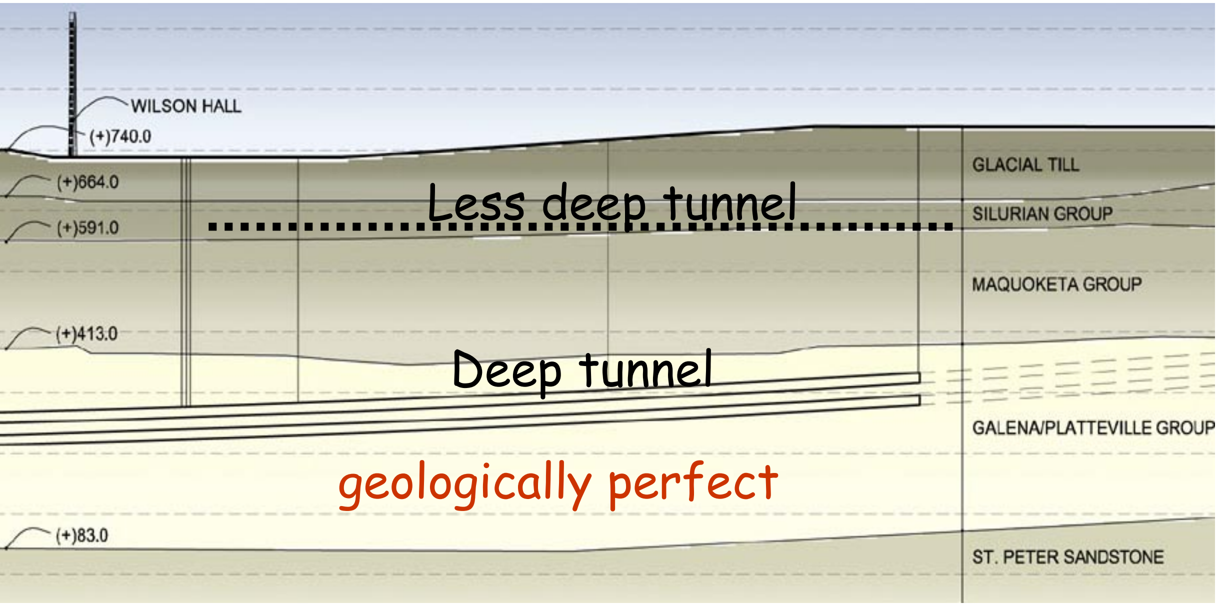
Talk of Fred Asiri

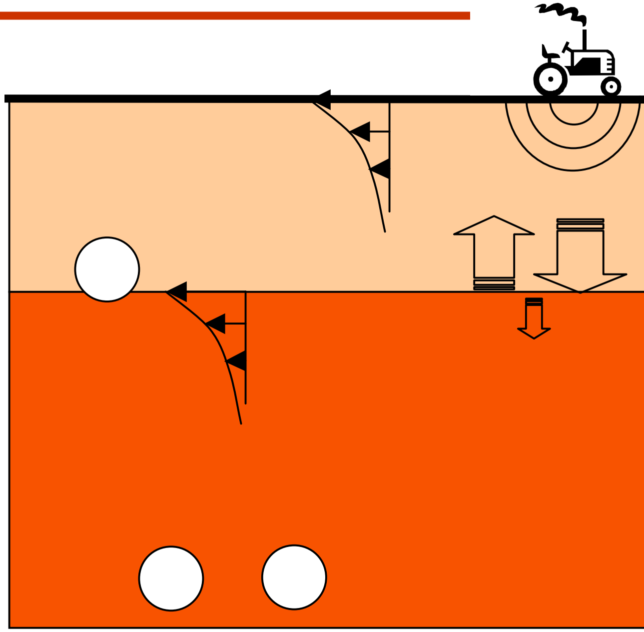
BINP-FNAL-SLAC slow motion studies and HLS R&D



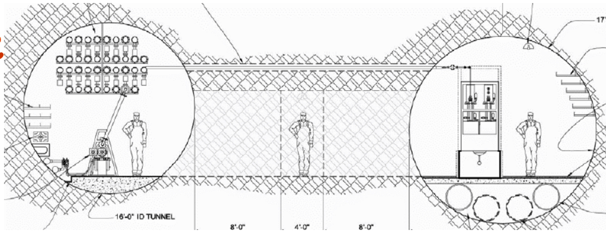
Talk of Vladimir Shiltsev

Study of noise vs depth.
Study of vibration transfer.



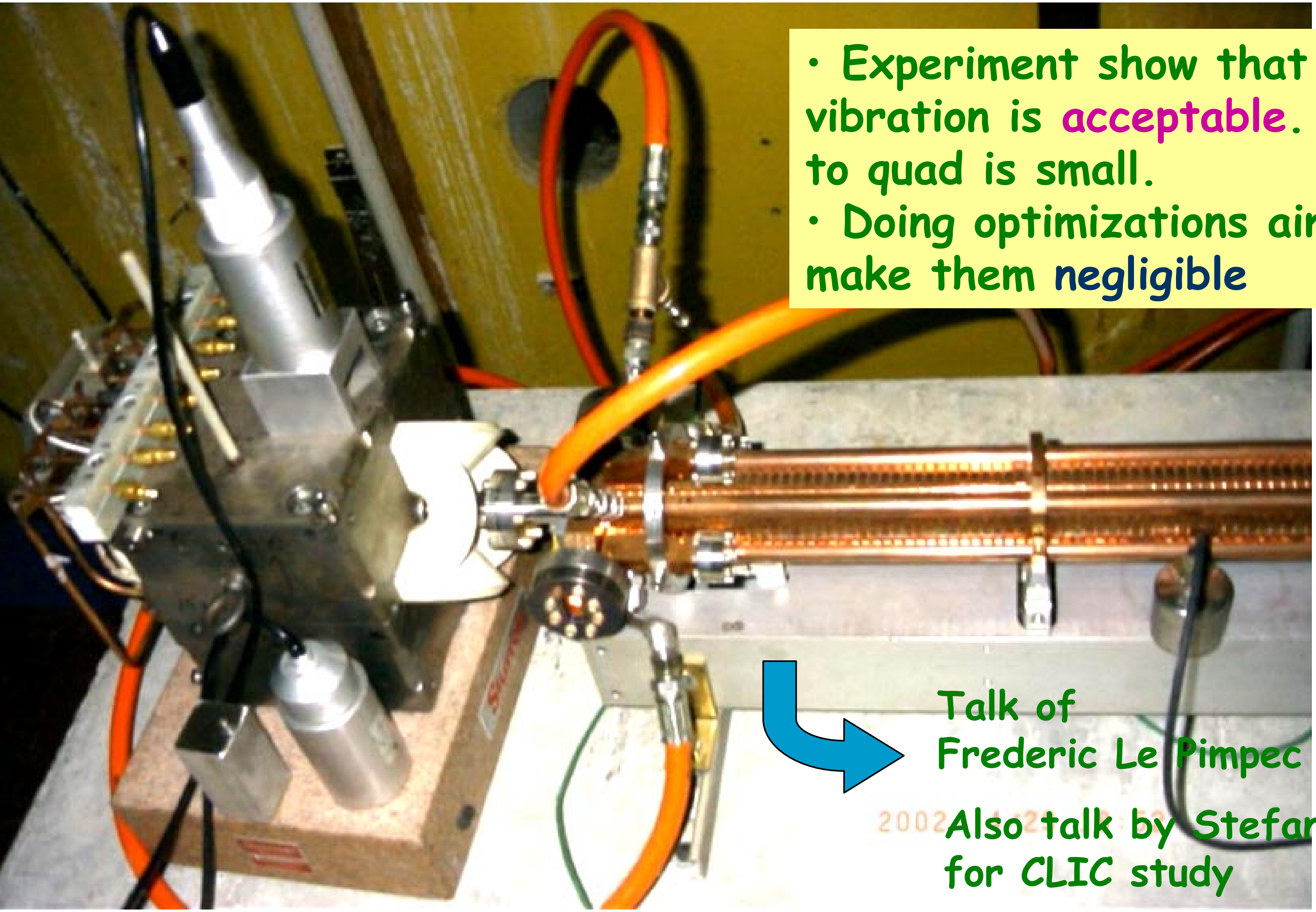


- Measurements in NUMI tunnel, noise vs depth dependence (**FNAL** and **Northwestern Univ.**)
- Vibration transfer from surface to shallow tunne
- Plan to study vibration transfer between two parallel deep tunnels



Talk of Fred Asiri

Vibration of RF structure due to cooling and vibration coupling to quadrupoles



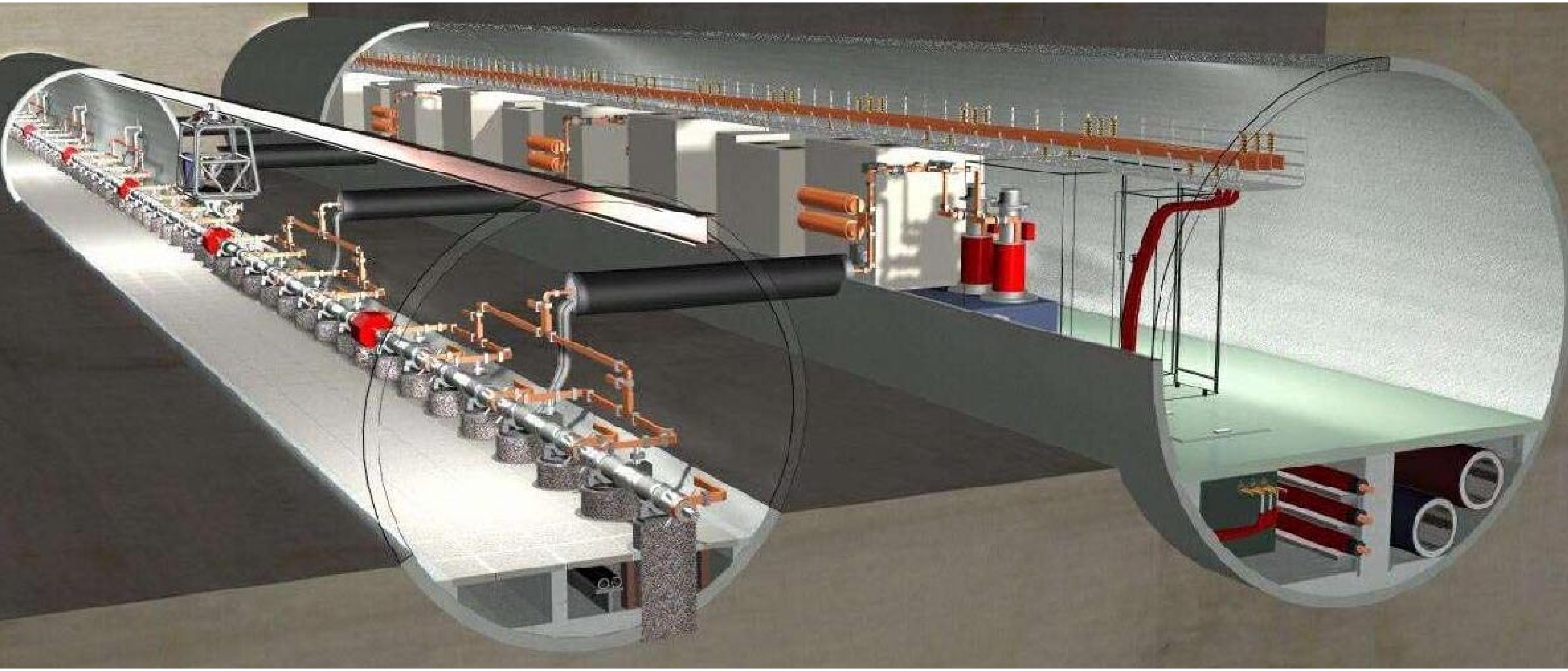
- Experiment show that additional vibration is acceptable. Coupling to quad is small.
- Doing optimizations aimed to make them negligible

Talk of Frederic Le Pimpec

Also talk by Stefano Redaelli for CLIC study

Important feature of warm LCs: quads can have separate supports

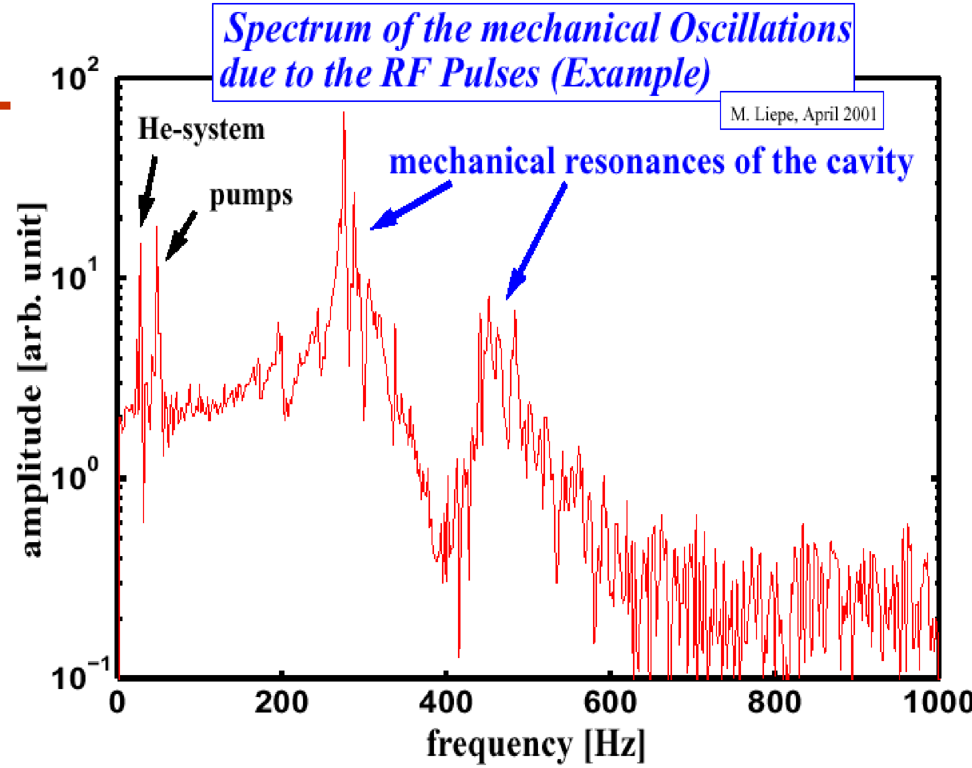
- Quads on separate supports are connected to rock
- Vibration coupling from RF structure to quad can be made very small
- This helps to achieve vibration stability requirement for linac quads

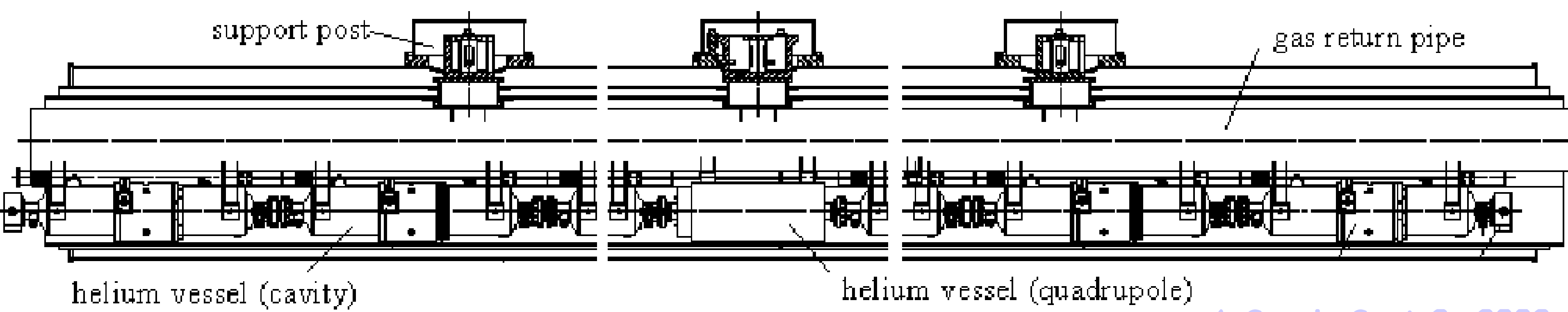


Artistic view of JLC-C [Shigeru Takeda, IWAA 99]

Quad stability in TESLA linac

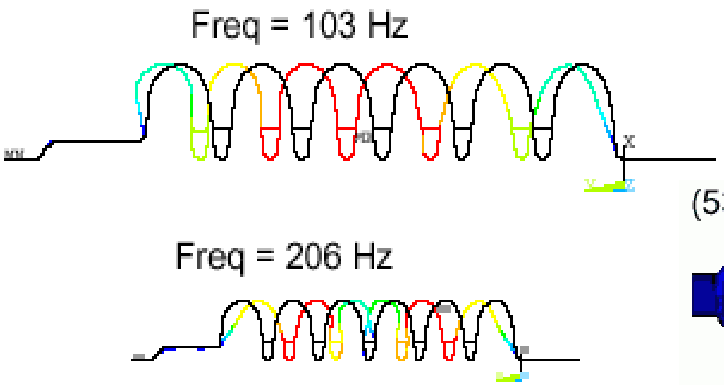
- Vibration stability requirement for SC linac are much looser than in warm LC
- Issue: common support (helium return pipe), which may be "a shaky ground"
- Noises: from RF pulse (Lorenz force); mechanical coupling to pumps, etc.
- Vibration coupling to quads need to be appropriately minimized by the design

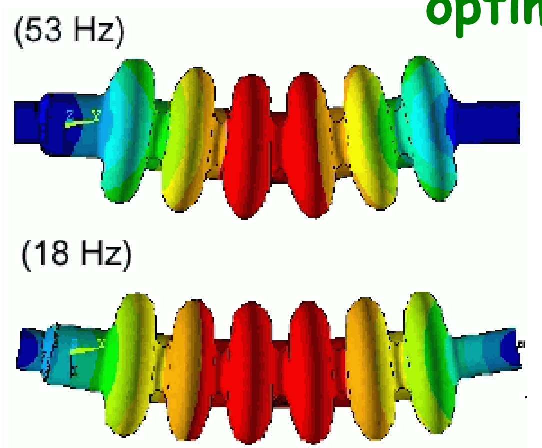




Optimization of quad stability in SC linac

- There are a lot of experience with analysis and successful optimization of vibration properties of RF structures
  - To make it stiffer, optimize positions of supports, etc., so that to decrease detuning by RF pulse
- Similar techniques could be extended to optimize design to minimize quad vibration





Example: Vibration modes of different SC cavities (for SNS) and their optimization [Carlo Pagani, Danilo Barni, SCPL 2000]

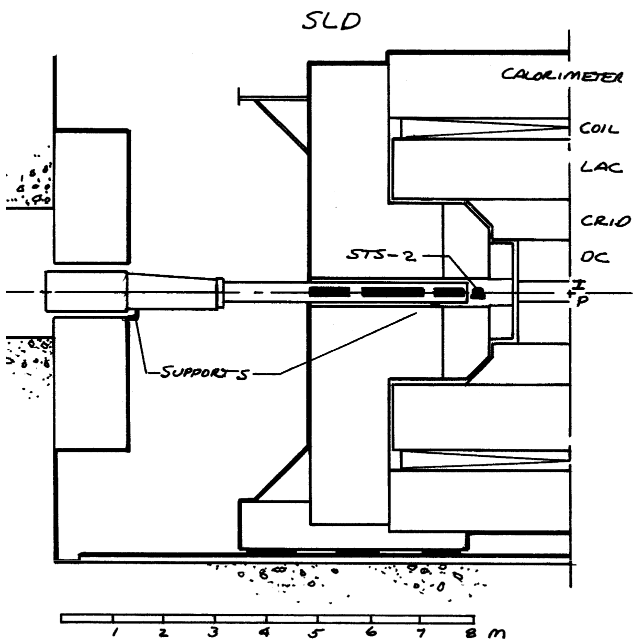
Moving to the IP…

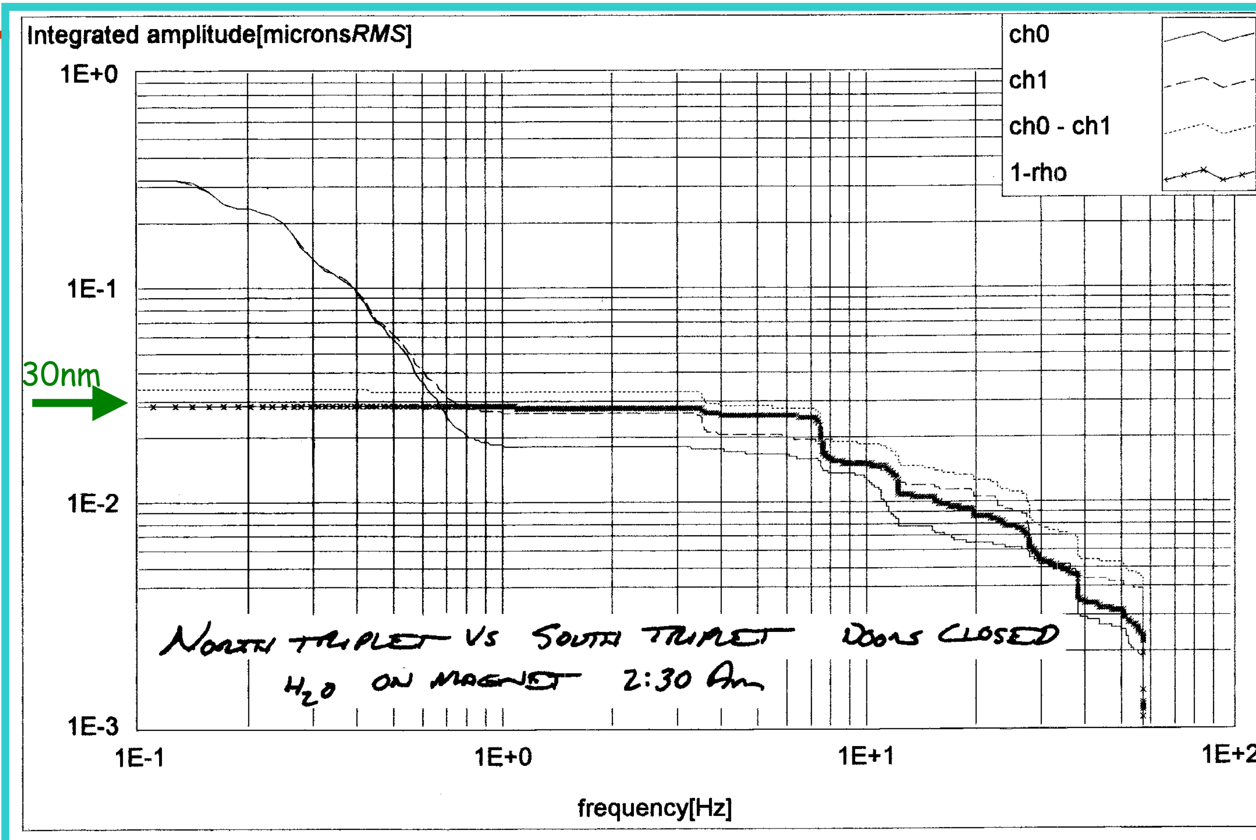
- Let's assume that we understand stability in linac
- And let's move our attention to the IP.
  What are stability problems there?
- FD has most stringent tolerances. And it may sit on a detector, which is "noisy ground"

NLC

Cultural noise at detector

1995 SLD measurements [Gordon Bowden]

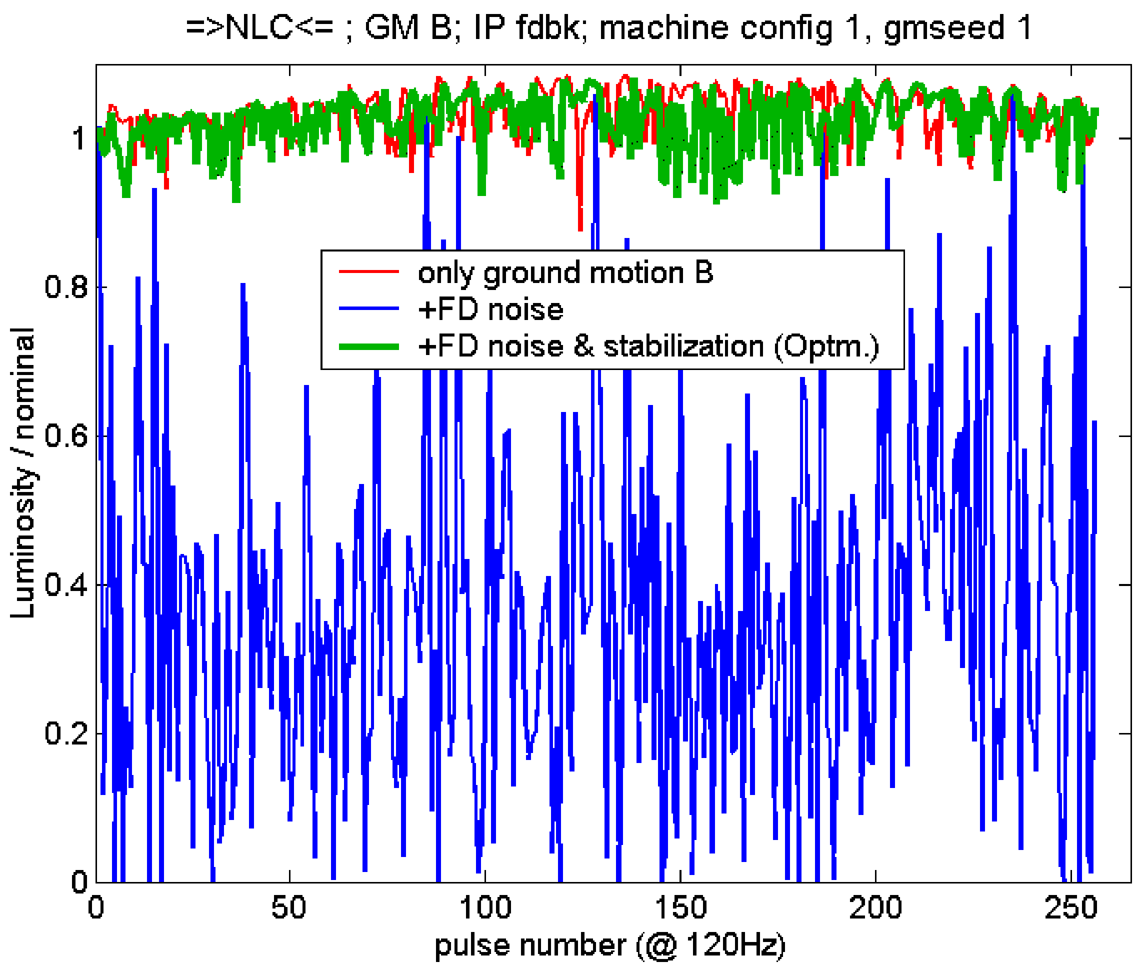




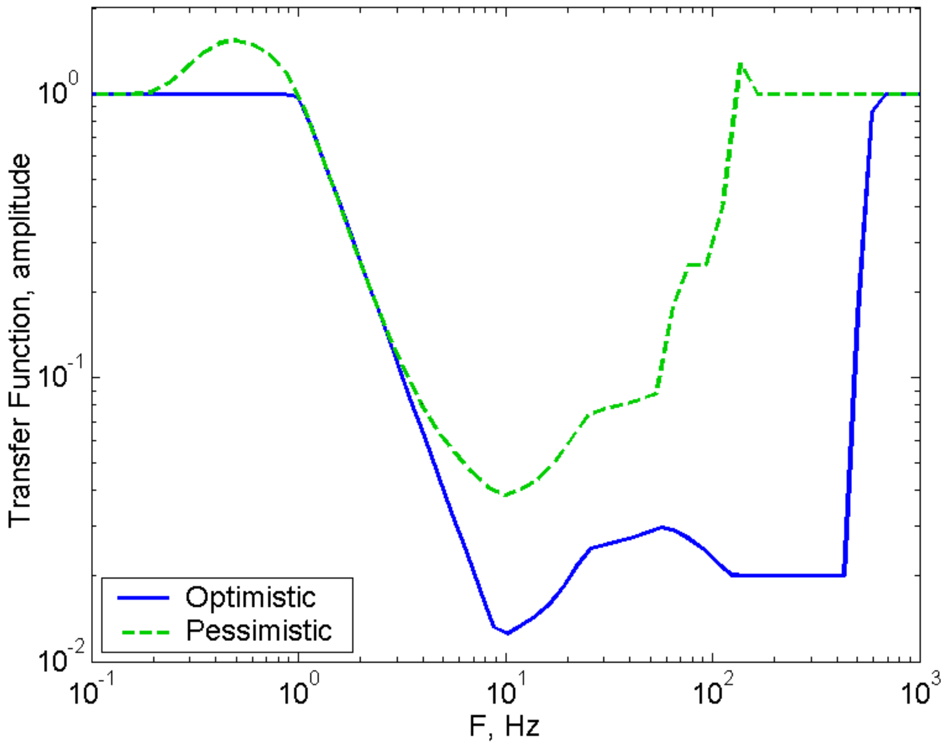
- Measured ~30nm relative motion between South and North final triplets
  Magnetic field was OFF (magnetic field ON could have increases detector rigidity). North triplet (Ch1) noisier – this side of the building is closer to ventilation and compressor stations. Resonances (3.5Hz, 7Hz) are likely to be resonances of detector structure.
- More quiet detector certainly possible.

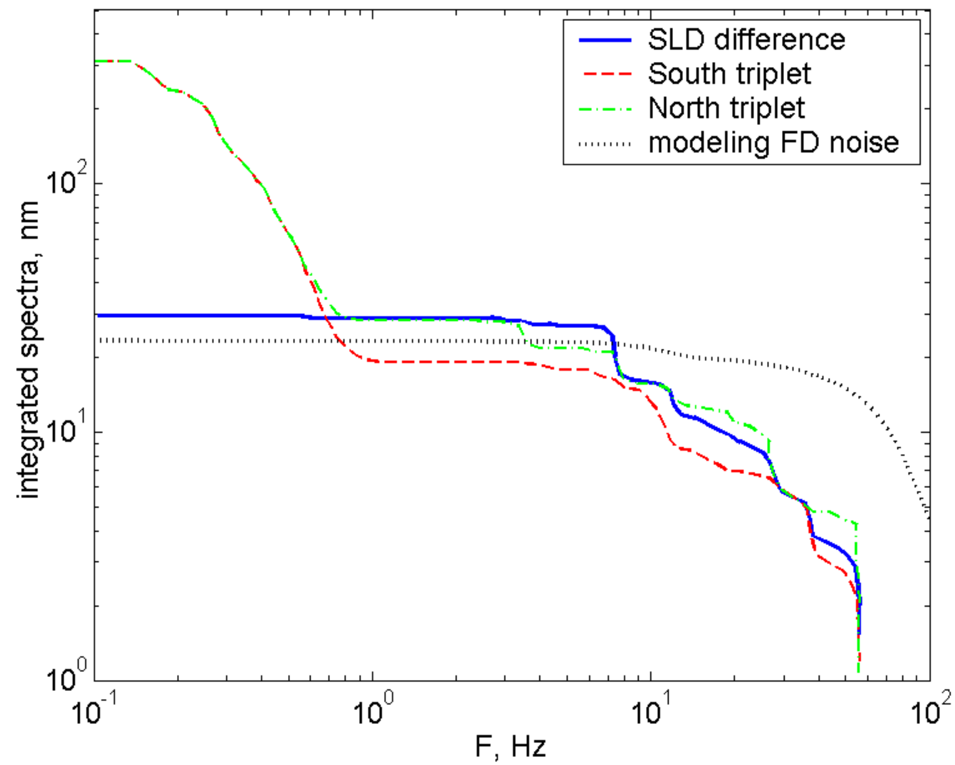
Performance with and without FD stabilization

- Assume pessimistic, SLD-like FD vibration
- Then luminosity drops significantly (to ~1/3)
- If FD is actively stabilized or corrected, luminosity is restored



FD stabilization modeling assumption





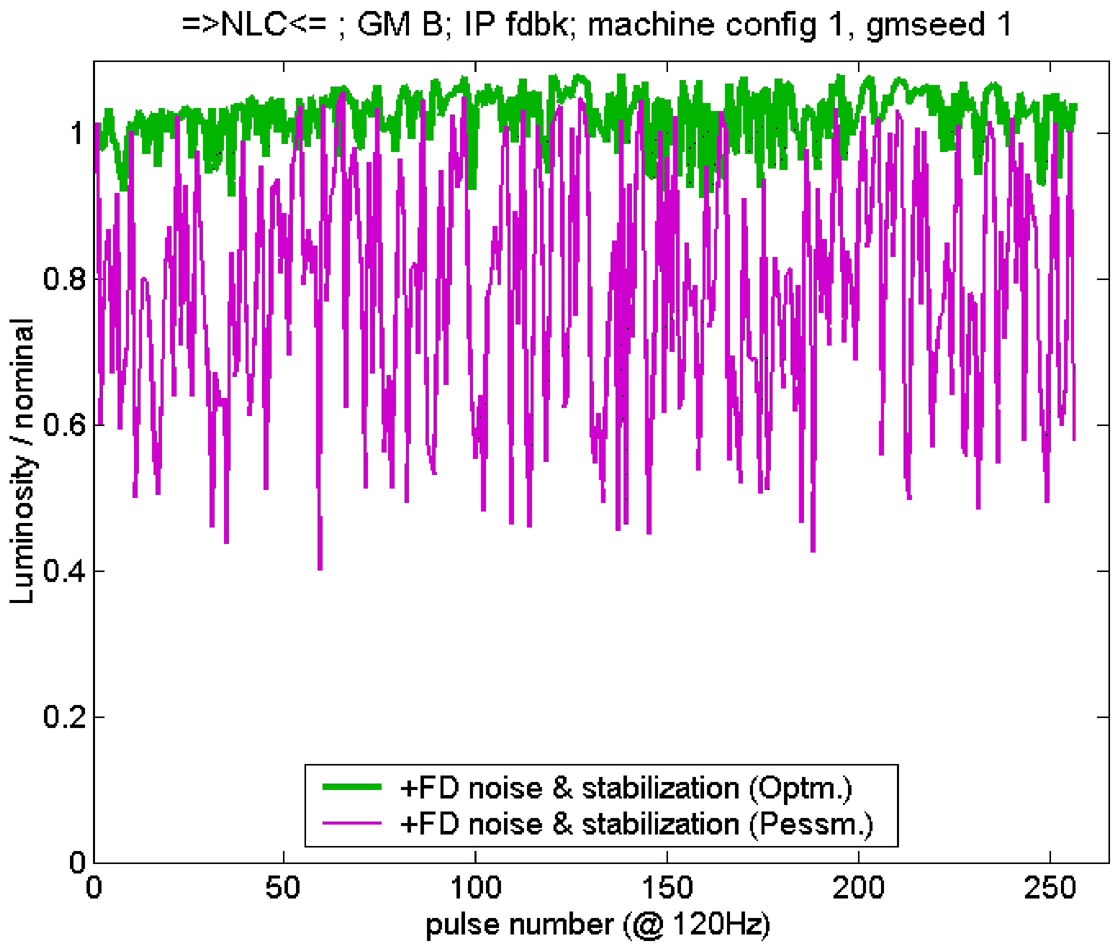
FD active stabilization (correction) is represented by Transfer Functions. Optimistic and pessimistic curves. The curves do not necessarily imply a particular stabilization or correction choice.

Noise measured at SLD [Bowden,95] and FD noise modeling spectrum. Same amplitude as in SLD is pessimistically assumed. The noise is shifted to higher frequencies (assuming the detector structural resonances are improved).

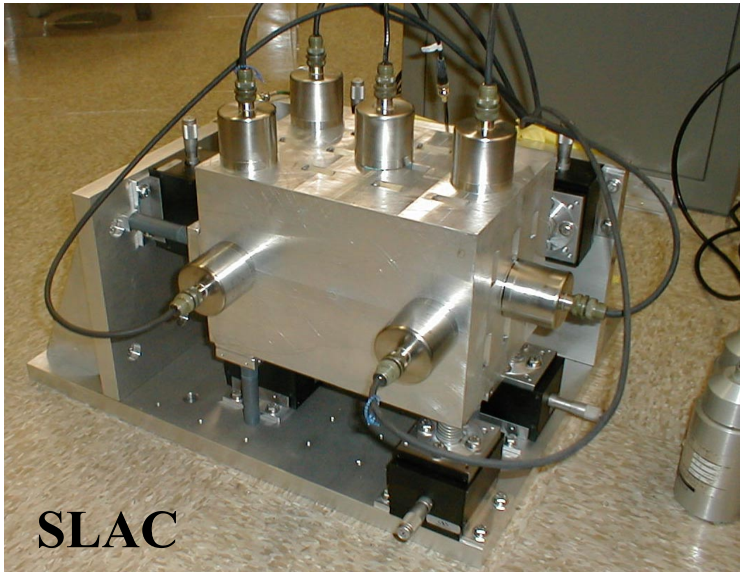
Performance with different optimism about FD stabilization

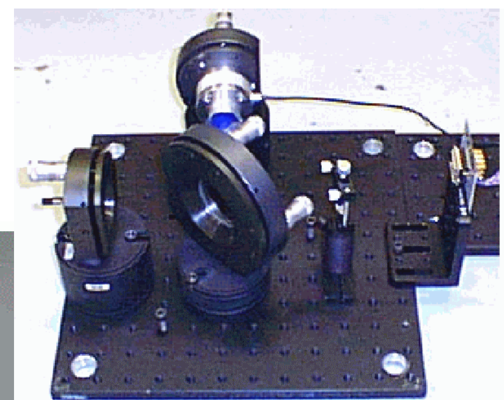
- With optimistic FD stabilization (correction) performance the luminosity is restored almost completely (<1% reduction)

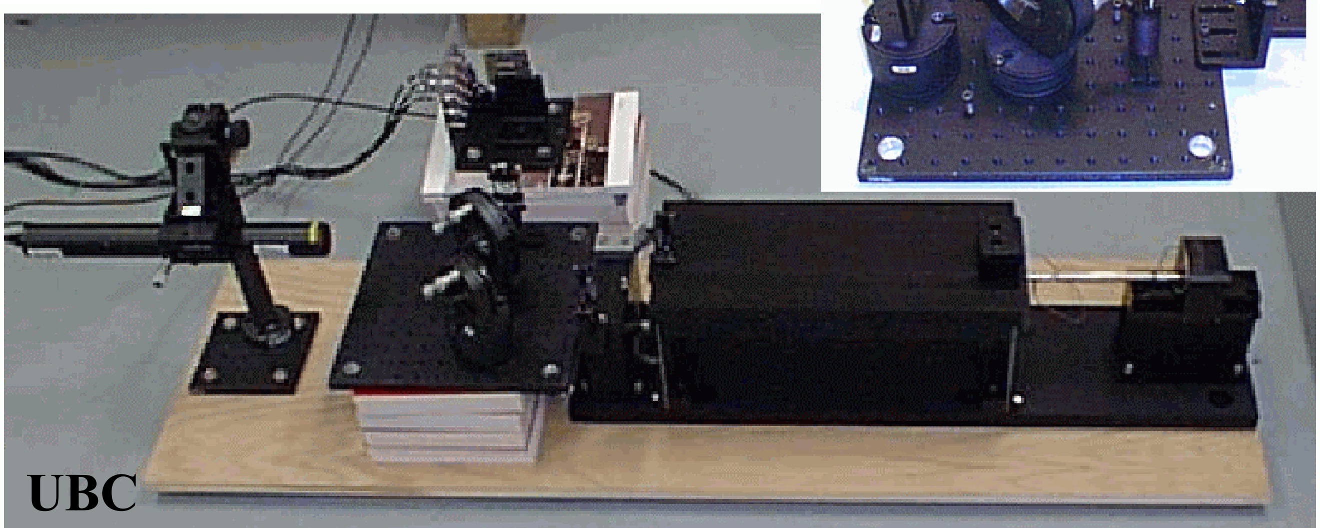
- With pessimistic stabilization (correction) performance, the reduction of luminosity is ~25%



R&D on mechanical stabilization with inertial and optical sensing





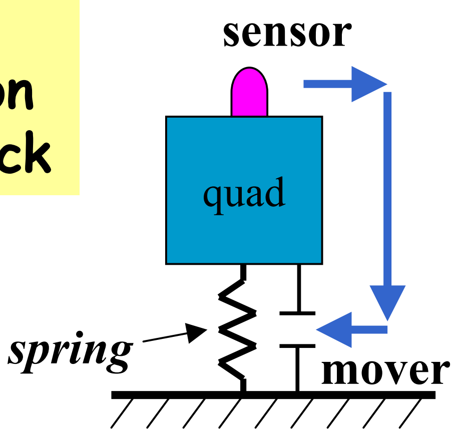


Talks of
Joe Frisch
Tom Mattison

and also
Ralph Assmann
for CLIC
stabilization
study

Some questions on mechanical stabilization or field correction

Position stabilization via feedback

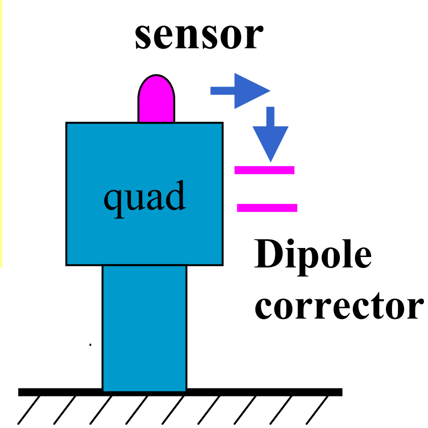


If FD is PM quad, how to deal with forces from the solenoid?

Estimated force on a PM quad can be 300 N to 2500 N, depending on configuration [John Hodgson]
(The force is due to μ>1 of PM material)

SC quad: talk of Brett Parker

Correction of magnetic center via feedforward

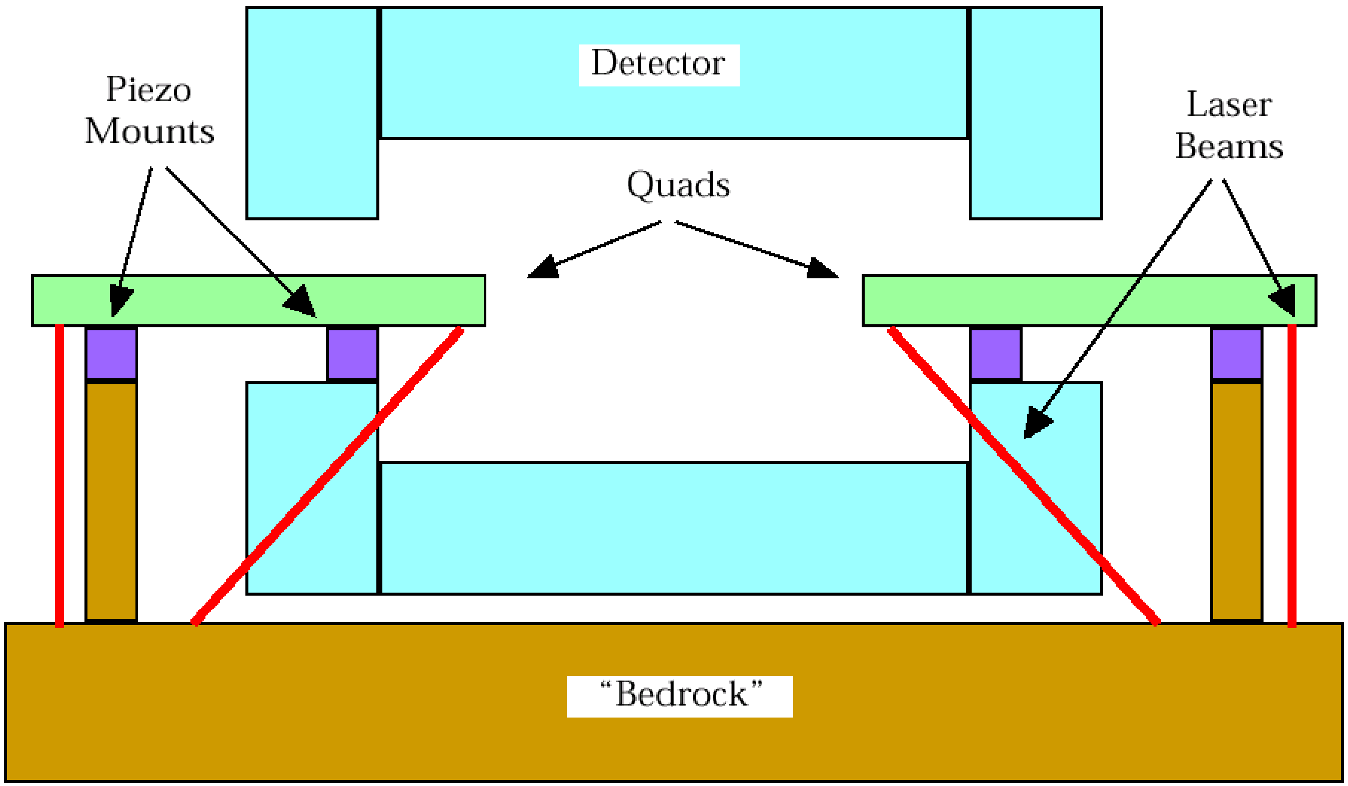


Possibly that much more vibration modes need to be controlled, more sensors, more complex algorithm?

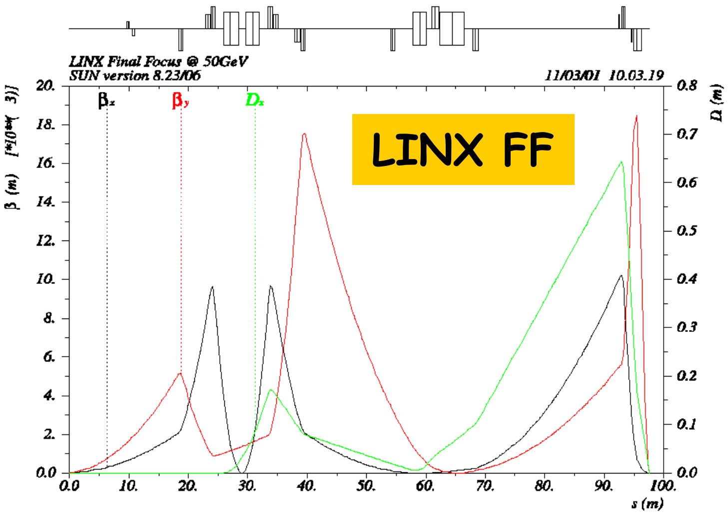
Less effective than feedback?

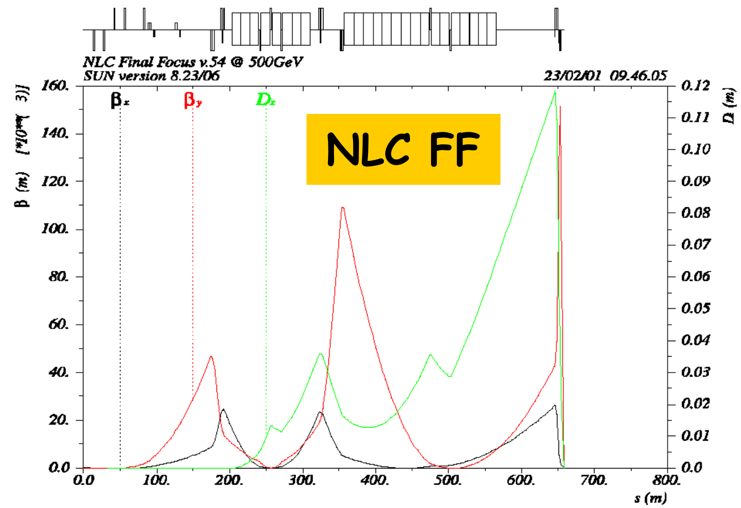
Other questions to FD stability

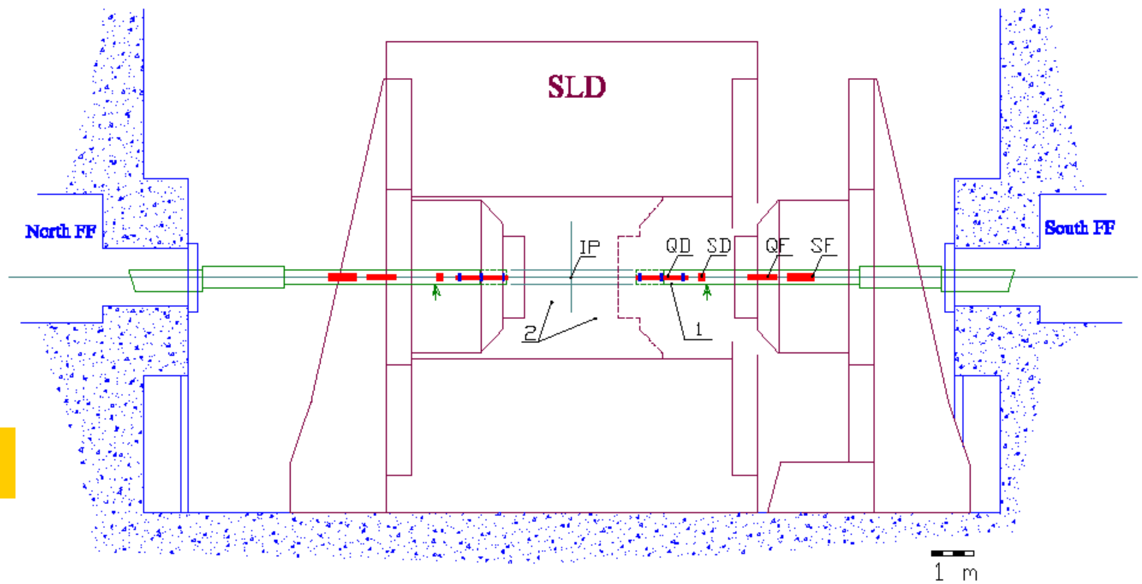
Do we support FD from noisier detector or only from tunnel, for the cost of much lower resonance frequency of the supporting girder? Other options?



One of the goals of LINX facility is to master FD stabilization







LINX IR

Discussion on Tue PM and Thu AM, Talks of Tom Markiewicz, Mayda Velasco

Joint efforts of many people

SLAC
Chris Adolphsen
Fred Asiri
Gordon Bowden
Marty Breidenbach
John Cogan
Carlos Damian
Eric Doyle
Leif Eriksson
Joe Frisch
Linda Hendrickson
Tom Himel
Frederic Le Pimpec
Tom Markiewicz
Rainer Pitthan
Tor Raubenheimer
Robert Ruland
Andrei Seryi
Steve Smith
Peter Tenenbaum
Mike Woods
Nancy Yu

CERN
Ralph Assmann
Stefano Redaelli

FNAL
Joe Lach
Chris Laughton
Duane Plant
Vladimir Shiltsev

BINP
Andrei Chupira
Anatoly Medvedko
Mikhail Kandaurov
Vasili Parkhomchuk
Shavkat Singatulin
Evgeny Shubin

Northwestern Univ.
Heidi Shellman
Mayda Velasco

et al.

UBC
Tom Mattison
Russ Greenall
Parry Fung

Oxford
Phil Burrows
Simon Jolly
Gerald Myatt
Gavin Nesom
Colin Perry
Glen White

Brookhaven
Nick Simos

Stanford
Sri Adiga

Summary

- There is good understanding of ground motion and vibration, and it is improving
  - But there may always be surprises
- There is a fair possibility that stability of LC luminosity can be provided
  - Provided that important issues are not left forgotten and are vigilantly pursued
- There are a lot of important details and particular concerns, that we should discuss during this Workshop