# Accelerator R&D Opportunities: Sources and Linac

*D. Rubin, Cornell University*

## Electron and positron sources

- Requirements
- Status of R&D

## Linac

- Modeling of beam dynamics
- Development of diagnostic and tuning tools and algorithms
- Developing expertise

# Electron source

## Requirements

| | TESLA | NLC |
|---|---|---|
| Repitition rate [Hz] | 5 | 120 |
| Bunches/pulse | 2820 | 192 |
| Electrons/bunch | $2(10^{10})$ | $0.75(10^{10})$ |
| Bunch spacing | 337ns | 1.4ns |
| Pulse length | 950μs | 270ns |
| Bunches/sec | 14,100 | 23,040 |

# Electron source status

- TTF RF photoinjector gun
  - 1.5 cell L-band
  - 35MV/m
  - 4MeV electrons
  - CsTe photocathode, quantum efficiency ~ 1%
  - Laser - Nd:YLF rods lase at 1047nm (~270)
  - 10ps pulse length
  - Delivers to TTF charge distribution comparable to collider requirements
  - No polarization

# Polarized electron source

SLC gun yielded 80% polarization

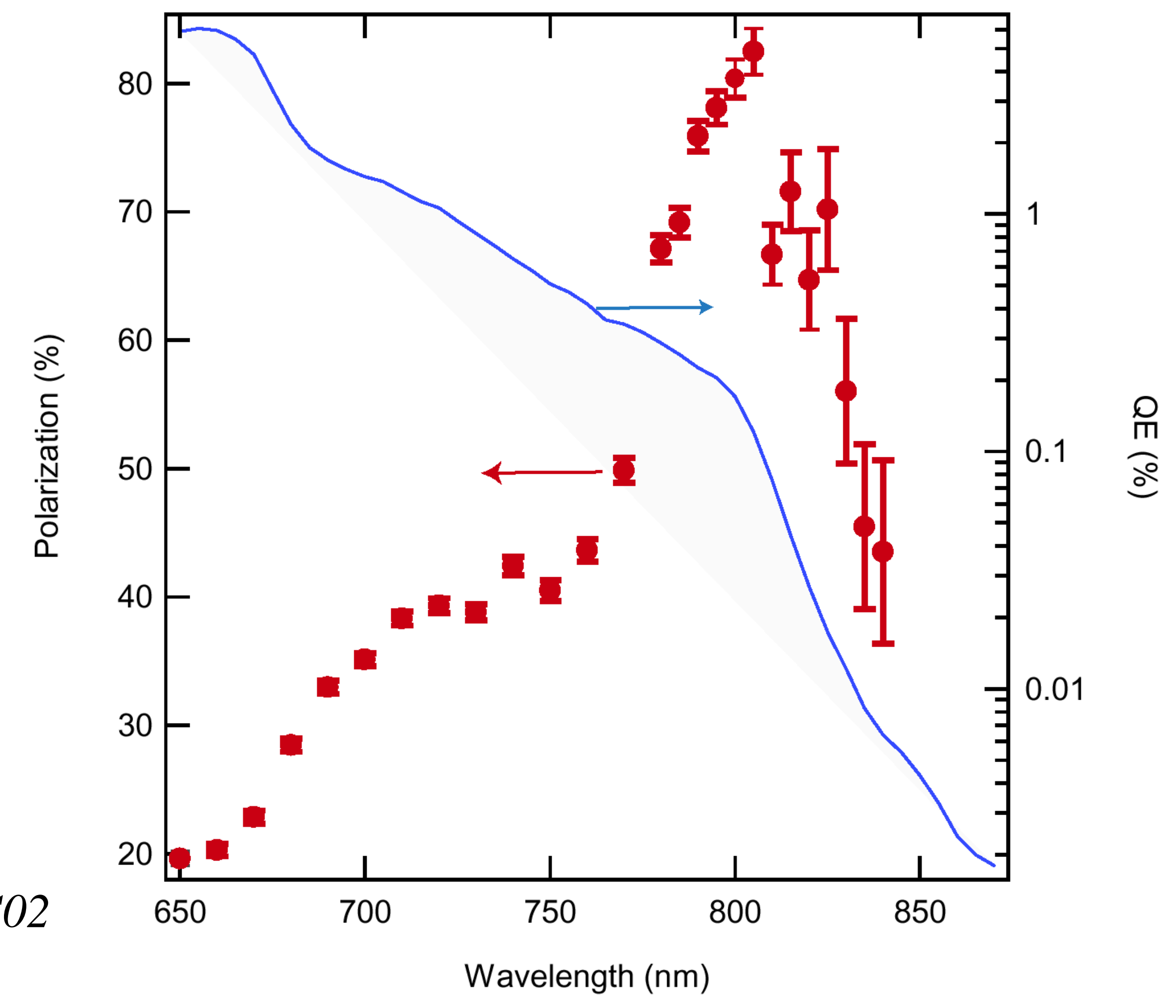
- TESLA/NLC require 10X electron production of SLC

Polarization

- GaAs cathode (and ultra high vacuum <$(10)^{-11}$mbar)
- Vacuum requirement incompatible with RF gun
- 1.8MV/m DC instead
- Minimize dark current to protect cathode (low fields)
- Low voltage limits current (space charge)
- Recovery time for cathode 10-100ns/pulse
- Quantum efficiency for GaAs ~0.1%
- Dependence of quantum efficiency and polarization on laser wavelength

    Spread out spot to get sufficient charge

Polarization and QE as a function of wavelength measured in the CTS lab.




*Maruyama - LC02*

- T. Maruyama (SLAC)
  - $2.2(10)^{12}$ electrons/pulse with 14mm laser spot
  - $4.5(10)^{12}$ with 20mm spot

  NLC needs $2.7(10)^{12}$

  *Cathode can deliver charge*

  Train bunch structure

  TESLA bunch spacing presents challenge for laser

  Requires ~1ms laser pulse train

  2800 pulses and 5 □J/pulse

  No such laser is commercially available

  Ti-sapphire is usual choice for polarized source (800nm), but lifetime of upper laser level only 3.2 □s

# Electron source - flat beam gun

- Proposed by Brinkmann, Derbenev, and Flottmann
  - Solenoid field at cathode
  - Beam emerges with angular momentum
  - Transform to emittance asymmetry with quadrupole optics

Experiments with A0 photoinjector at FNAL

50:1 transverse emittance ratio of 17MeV beam

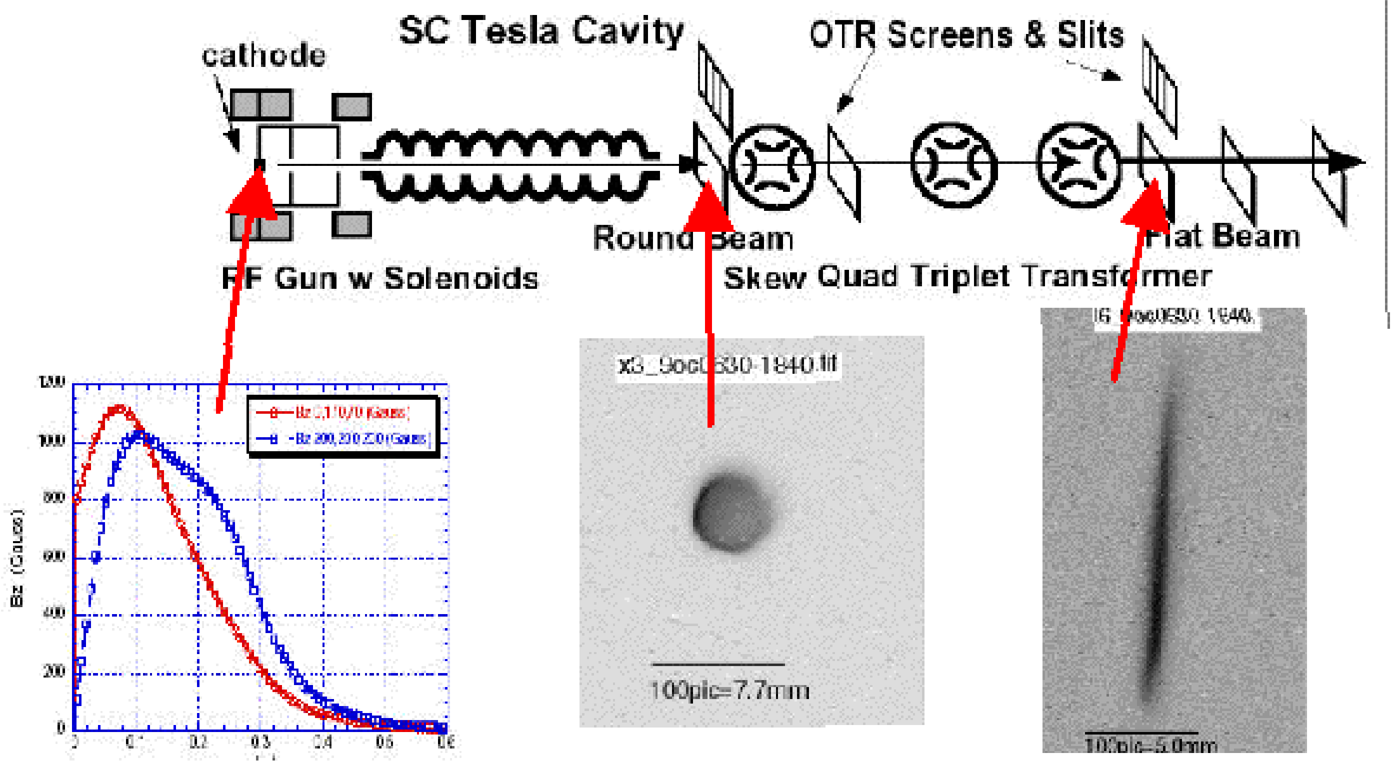
Flat emittance ~1□m (50  times too big)

Needs "emittance compensation"

and polarized electrons

# Flat Beam Experiment at A0/FERMILAB

Extract flat beam from RF-gun through combination of non-zero solenoid field on cathode surface and skew quad beam transformer




Maximum measured emittance ratio: 50/1

*W.Decking LC02*

# Positron sources

- Conventional positron production limited by stress in target

  Alternative?

  Conversion of high energy undulator radiation in thin target

  250GeV electron beam through ~100m (.75T) undulator yields 28MeV photons

  0.4 $X_0$ (1.4cm) Ti rotating target 350m from undulator

  (2□rad spot □ 0.7mm)

# Positron source

## Polarized positrons

Replace planar undulator with helical

Polarized photons  polarized positrons

Undulator parameters

- 1cm period
- B ~ 1.3T

Requires small electron beam divergence since only near axis photons are polarized.

Test?

1mm period, B=0.5T, 1m long helical undulator

 $3(10^{-3})$ positrons/electron (Sheppard/Pitthan)

# Positron source

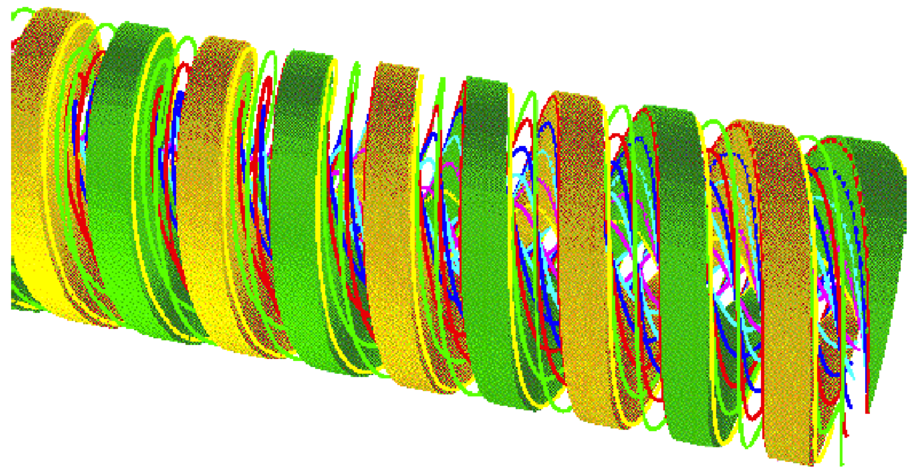
Polarized positrons

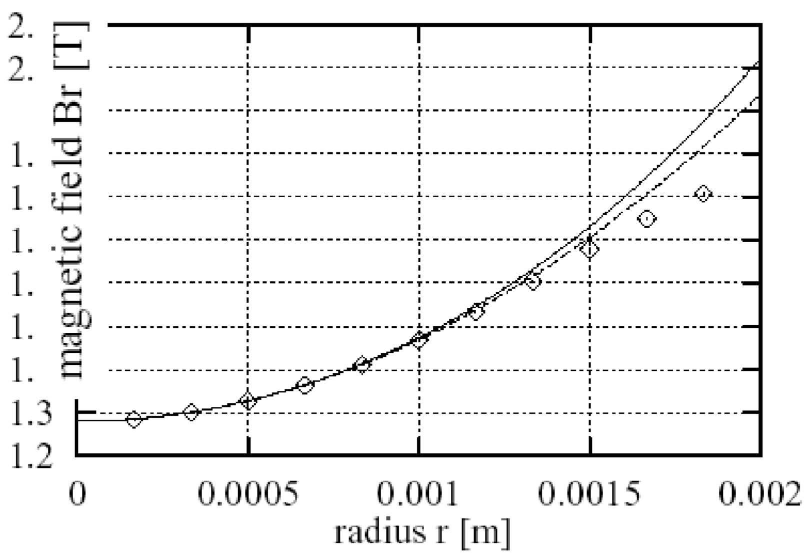
- □ = 1cm, B=1.3T helical undulator has yet to be demonstrated
  Beam requires 3mmX10mm aperture and necessarily small divergence
  Off axis photons collimated (100kW)?
  Effect of positron capture solenoids on polarization?

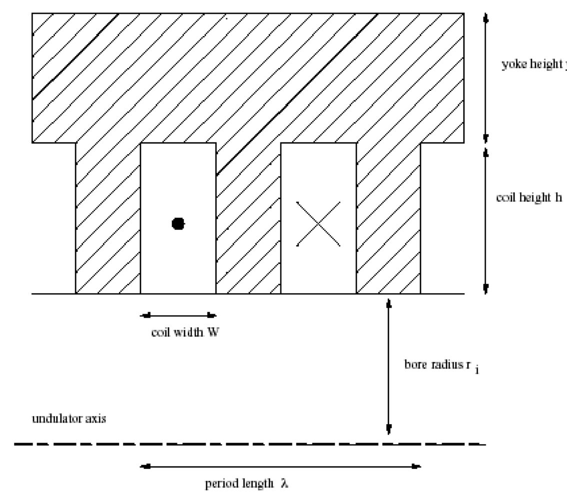
And instrumentation to measure polarization?

# Designed: Superconduction with Iron

- DESY double helix design (Flöttmann, Wipf)
- Designed for $\lambda_u$ = 12 mm, but can reach smaller values





# Linac

Emittance preservation

Transverse wake ~ $1/a^3$ (a = iris diameter)

- cavity and quadrupole alignment

NLC ( 7.8mm < a < 11.2mm)

300nm for quadrupole

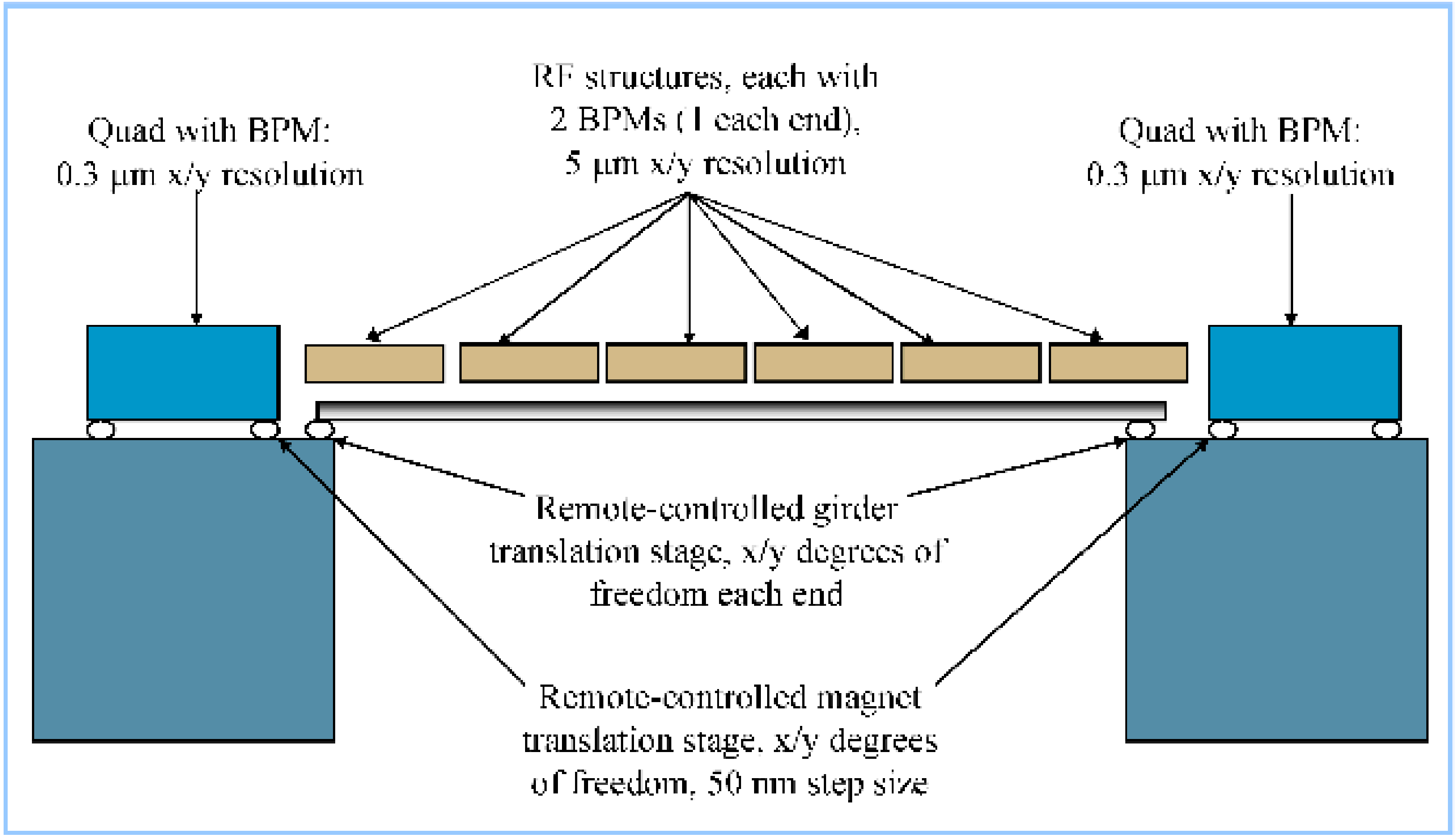
5 □m for RF structures

TESLA (a=70mm)

10 □m for quadrupoles

0.5mm for cavities

# Main Linac Module




P. Tenenbaum

# Linac - Quad BPM

- Measure average position of bunch train and align quads
- NLC requirements
  - Resolution  300nm rms  @$10^{10}$ single bunch
  - Position stability  1□m  over 24 hours
  - Position accuracy  200□m  re quad center
  - Position dynamic range  ±2mm
  - Charge dynamic range  $5x10^{8}$ to $1.5x10^{10}$/bunch
  - Bunch spacing 1.4ns
  - Quantity  3000

*From S.Smith LC02*

# Linac - BPM

Structure position monitor

- Measure amplitude and phase of transverse modes in accelerating cavities
- And minimize transverse wakes to establish alignment with beam

    -22,000 required for NLC

    -Resolution 5μm

Multibunch BPM

- Measure each bunch in train and correct trajectory
    - 1.4ns apart
    - 300nm resolution

*S.Smith LC02*

# Linac - modeling

- Codes have been developed for detailed modeling

  (LIAR  Linear Accelerator Research Code)

  (Merlin)

  Include lots of physics

  Magnetic guide field

  Accelerating fields

  Structure wake fields

  Magnet movers

  …

  But not all

  No multipoles

  Fixed bunch length

  Limited flexibility

# Linac - modeling

## Modeling codes used to:

-Evaluate beam based alignment algorithms

-Determine adequacy of BPM, resolution, placement

-Develop commissioning strategy
and anticipate instrumentation requirements

-Diagnose problems and performance during startup and operation

# Linac - modeling

- Existing codes are powerful but incomplete
- Many issues to explore

  (Is 0.5mm alignment of TESLA cavities really good enough?)

  (Does beam based alignment of quads to 300nm and cavities to 5□m in NLC converge?)

By excercising modeling codes

-We train ourselves (and our students) to use and interpret them

-So we will be better prepared to address operational problems as they arise

-And to effectively exploit GAN to do machine development from afar

# Linac - banana instability

<u>Example modeling and simulation project</u>

Relatively small correlated emittance growth can lead to instability in beam-beam interaction - when disruption is high

$$D_y = \frac{\sigma_z}{f_y}$$

-Our understanding of the phenomonon is based on simulation.

-It is suggested that the problem can be at least partially compensated with feedback

-And further compensated with tuning IR correctors

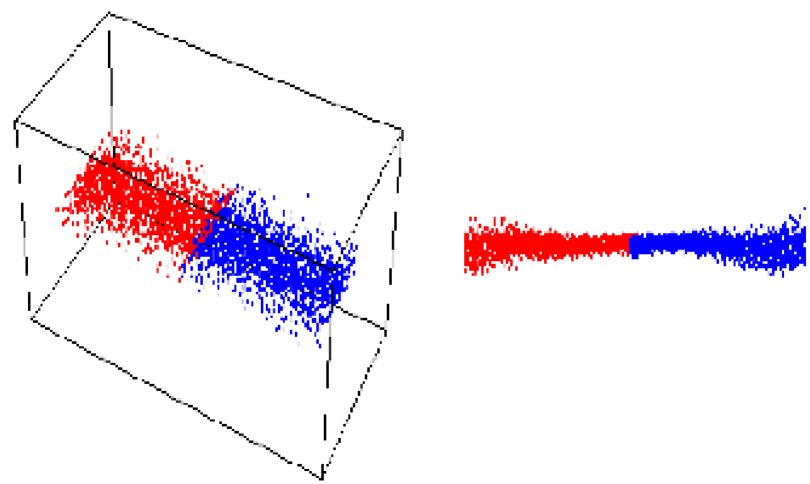
-The effect / corrective measures can (and should) be explored in much more detail through simulation

-Significant implications for beam parameters (bunch length) and performance

# ‘Banana’ Effect – Beam-Beam Simulation

- Instability driven by vertical beam profile distortion
- Strong for high disruption
- Distortion caused by transverse wakefields and quad offset – only a few percent emittance growth
- Tuning can remove static part

*W.Decking LC02*

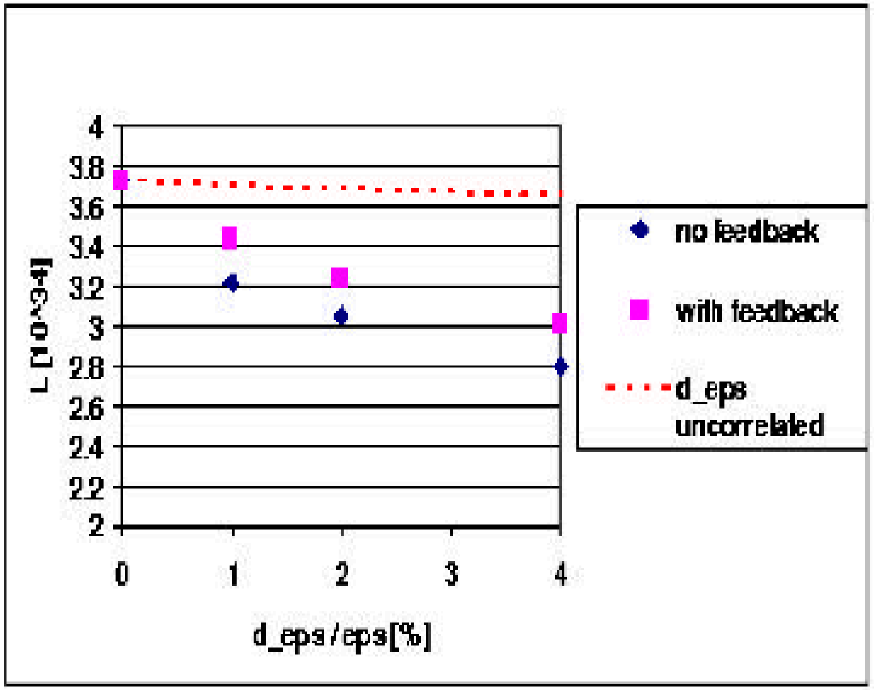


Nominal TESLA Beam Parameters +

y-z correlation (equivalent to few % projected emittance growth)

Beam centroids head on

# ‘Banana’ Effect

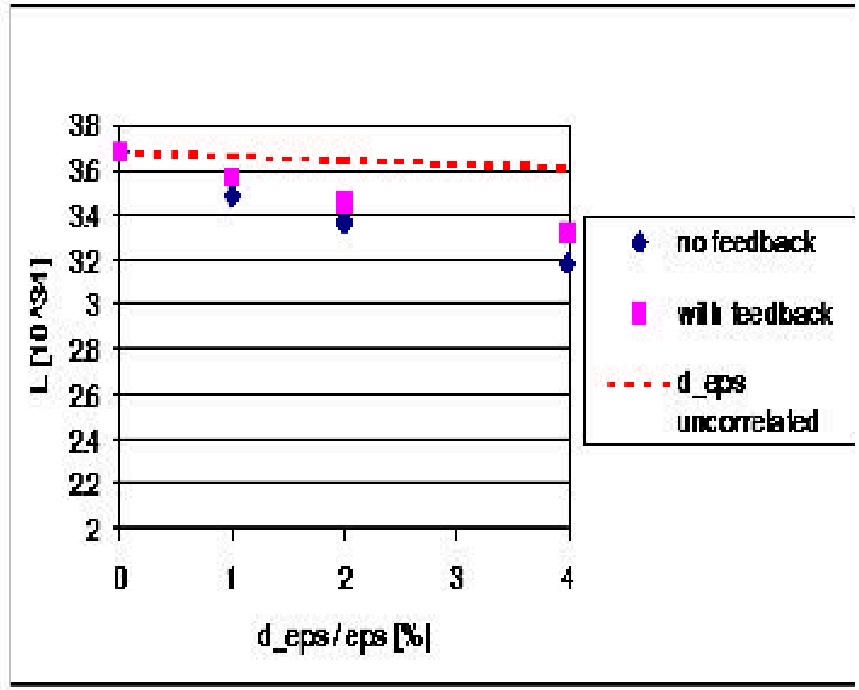



TDR Parameters

$\sigma_s = 300\ \mu m$

$\beta_x = 15$ mm

$\beta_y = 0.4$ mm




Bunch length shortened

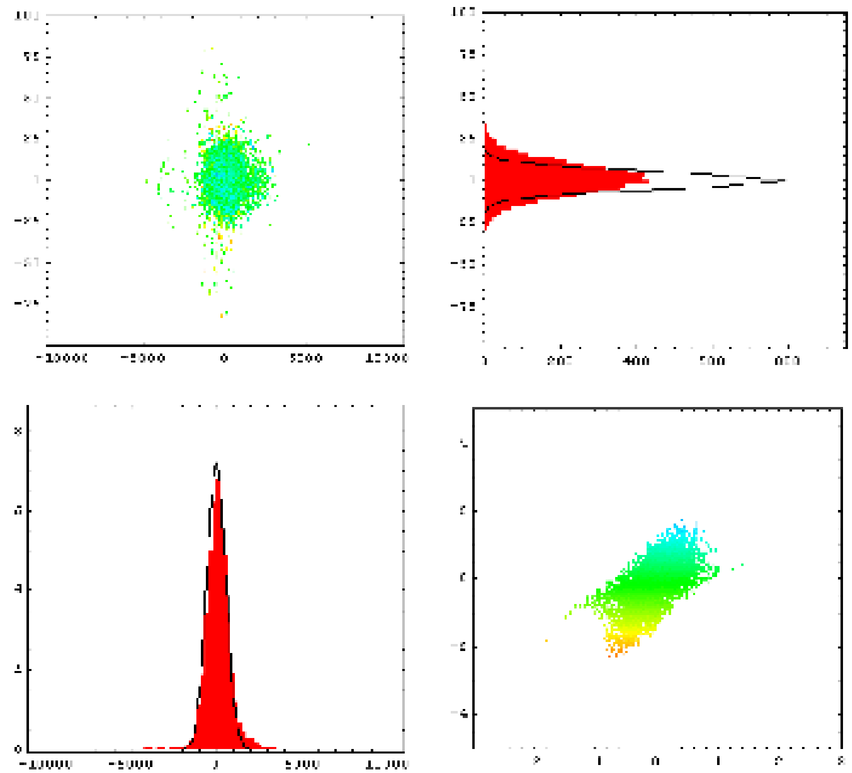
$\sigma_s = 150\ \mu m$

$\beta_x = 20$ mm

$\beta_y = 0.3$ mm

*W.Decking LC02*

# DR to IP Simulations



Gaussian bunch from DR

Ideal machine

Change of bunch compressor phase by $\pm$ 2.5 deg (powerfull knob at the SLC)

This is just an example what one can (and will) do now

# Linac - parameter space

- Explore possibilities
  - Is 5Hz rep rate with 950$\mu$s pulse length and large damping ring optimum
  - Perhaps 10Hz X 425$\mu$s and smaller damping ring would be advantageous
- Implications of improvements in cavity performance (*Padamsee*)
  - Increase Q from 1 to $5\times10^{10}$

    Then 10Hz rep rate and 950$\mu$s pulse length

    $\Rightarrow$ twice the luminosity

    with 60% increase in wall plug power
  - Increase Q from 1 to $5\times10^{10}$, and gradient from 23 to 35MV/m

    $\Rightarrow$ 20% reduction in capital cost and no increase in operating cost