A Compact Wakefield Measurement Facility:

An application in high-brightness beam

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Collaborators

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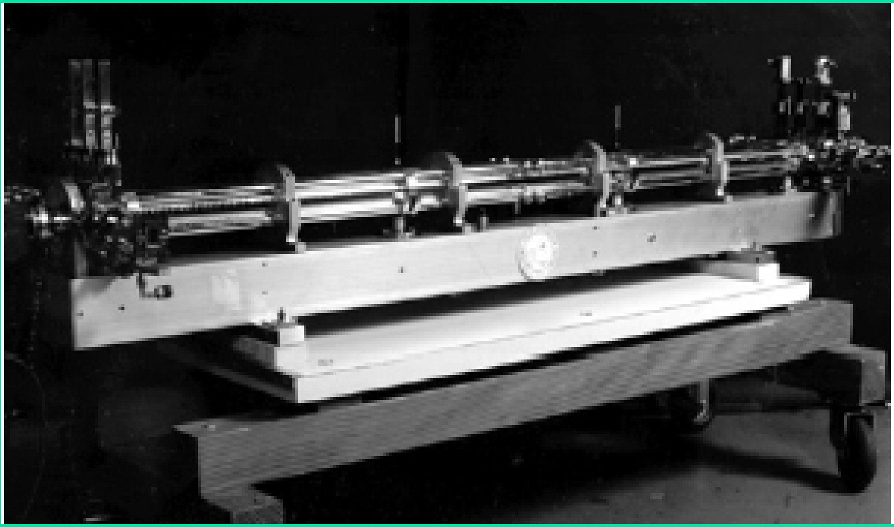
Can we make a *compact, high-resolution* wakefield measurement system?

- Quality Control Center
  - $W_\perp$ < 0.5 V/pC/m/mm for rms structure misalignment < 20 μm
- Measure structures built at FNAL or SLAC.

DDS3 structure



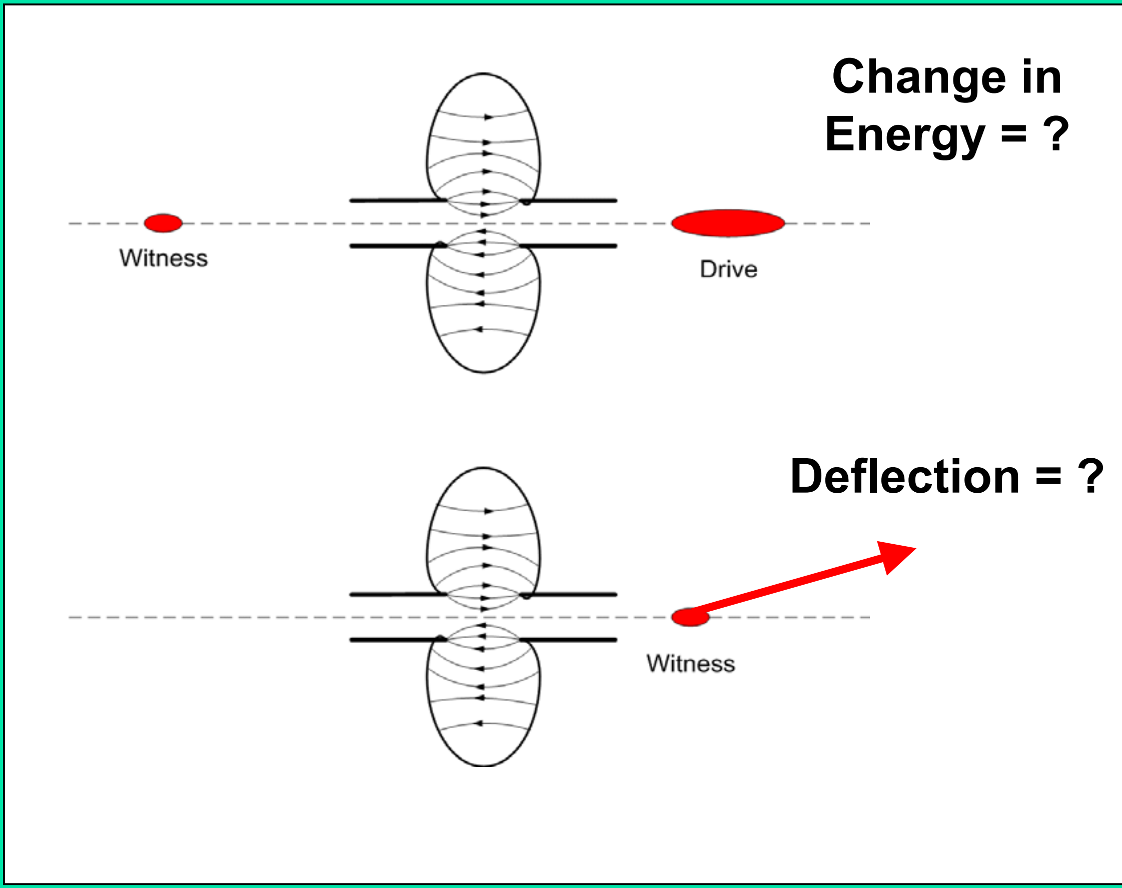
Direct Wakefield Measurement

(Brief) Overview and History

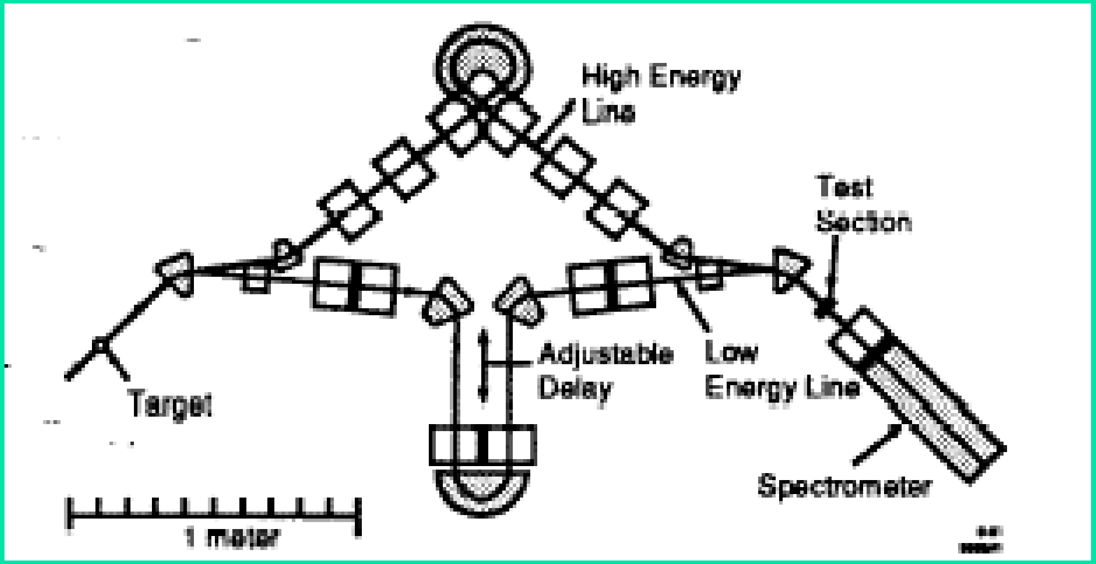
Method:
Direct Wakefield Measurement

- To find the **longitudinal wake function** measure the **change in energy** of the witness beam.

- To find the **transverse wake function** measure the **deflection** of the witness beam.



AATF at ANL (1988)



Drive Beam

E_d = 20 MeV
Q_d = 2 nC
$\varepsilon_{n,rms}$ ~ 60 mm mrad

Resolution

$$\left|W_{\parallel,0}\right| \le 15\, V/pC/m$$

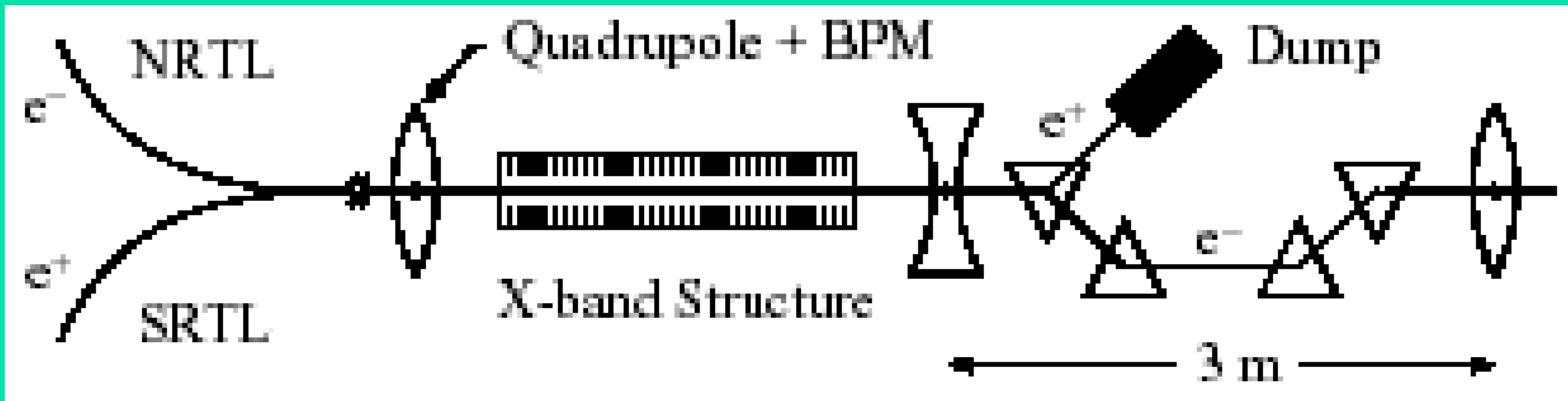
$$\left|W_{\perp}\right| \le 4\, V/pC/m/mm$$

Witness Beam

E_w = 15 Mev
Q_w = 1 nC
$\varepsilon_{n,rms}$ ~ 50 mm mrad

Compact → Yes High-Resolution → No

ASSET at SLAC (1994)



Resolution

$$\left|W_{\parallel,0}\right| \rightarrow \textit{not applicable}$$

$$\left|W_{\perp}\right| \le 0.1\ V/pC/m/mm$$

Drive Beam

Positron
E_d = 1.2 GeV
Q_d = 0.9 – 3.3 nC

Witness Beam

Electron
E_w = 1.2 GeV
Q_w = 1.6 nC

Compact → No High-Resolution → Yes

Can we build a high resolution wakefield measurement system with ~10 MeV beams?

How to get high resolution …

2. Good Angular Measurement Resolution

1. High Drive Charge

3. Low Witness Energy

Longitudinal Wake Function per unit length.

$$\Delta\theta_z(t) = \frac{\gamma}{\gamma+1}\left(\frac{-eQ_d L_s W_{\square,0}(t)}{E_w}\right)$$

Transverse Wake Function per unit length.

$$\Delta\theta_y(t) = \frac{\gamma}{\gamma+1}\left(\frac{-eQ_d L_s W_{\perp,1}(t)}{E_w}\right)\Delta y_d$$

Block diagram of the Argonne Wakefield Accelerator (AWA) facility

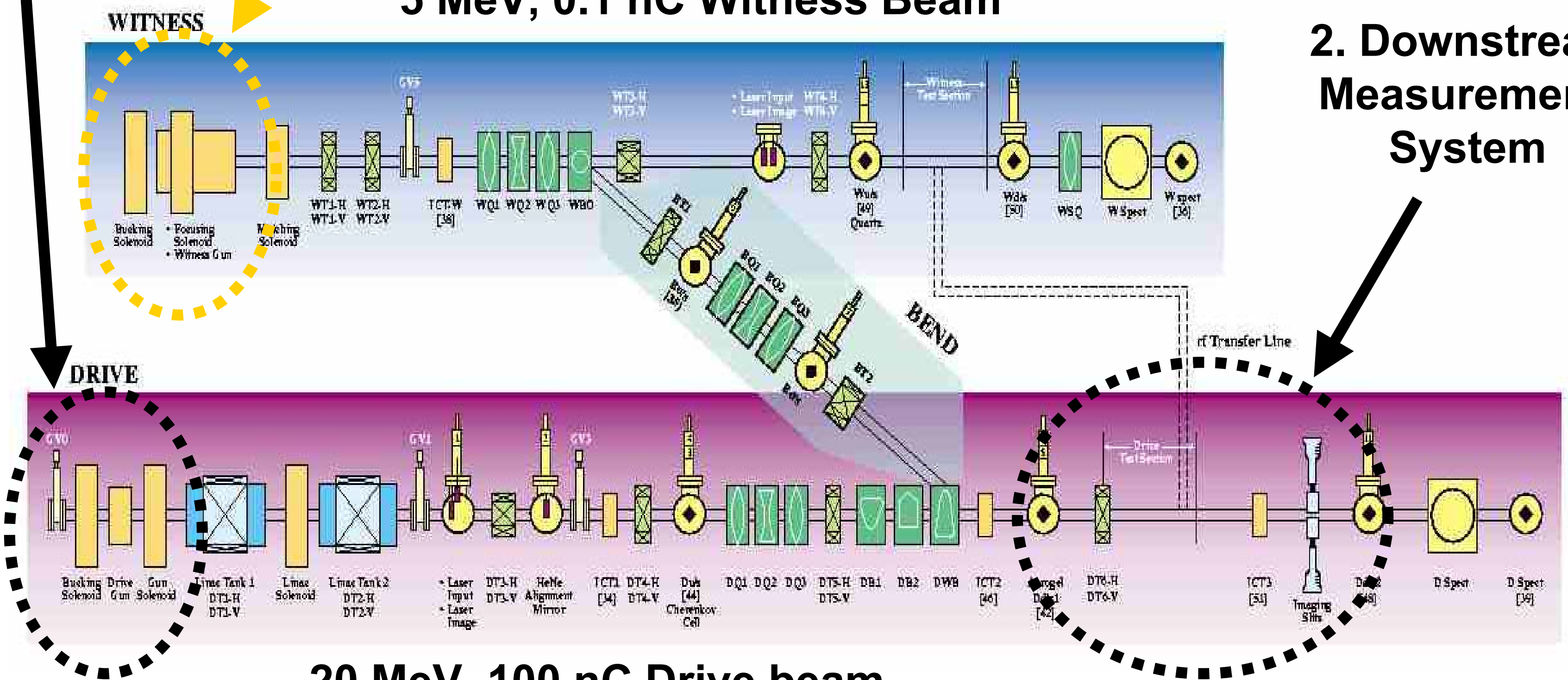
Minor Modifications

1. Drive Gun

3. Witness Gun (no modification needed)

5 MeV, 0.1 nC Witness Beam

2. Downstream Measurement System

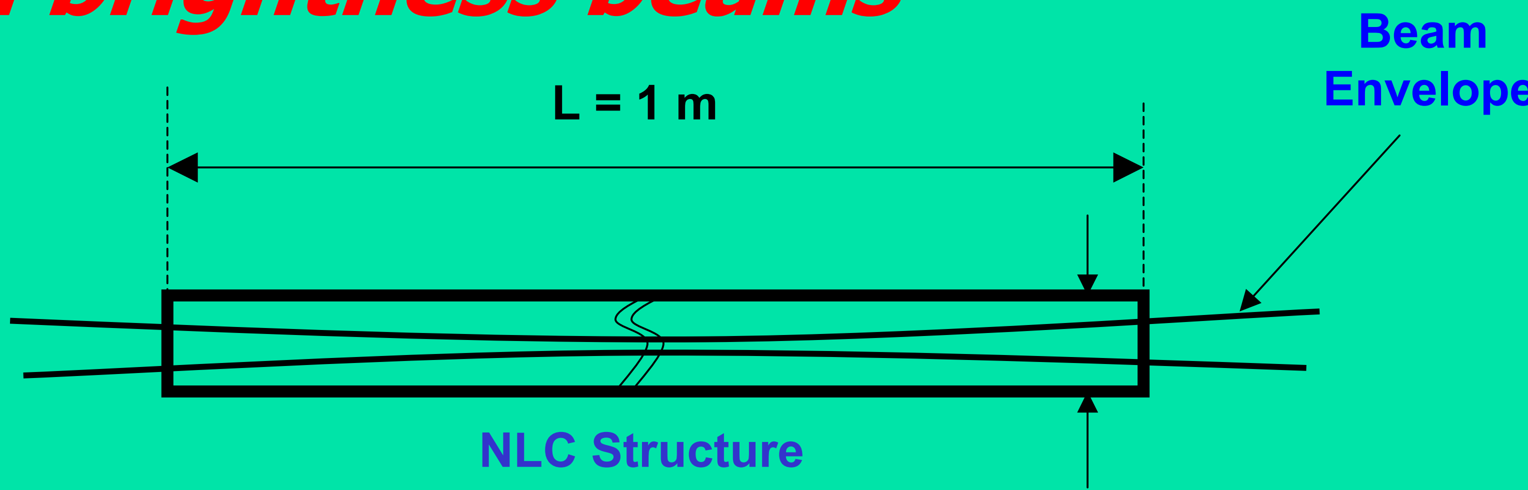


20 MeV, 100 nC Drive beam

First Modification

The Drive Gun Operating Mode

The Key:
high brightness beams



I.D. = 6 mm (radius = 3mm)

We require sqrt($\varepsilon\beta$) < 300 μm

DRIVE: if γ = 40 & β = 1 then we require ε_n < 4 mm mrad

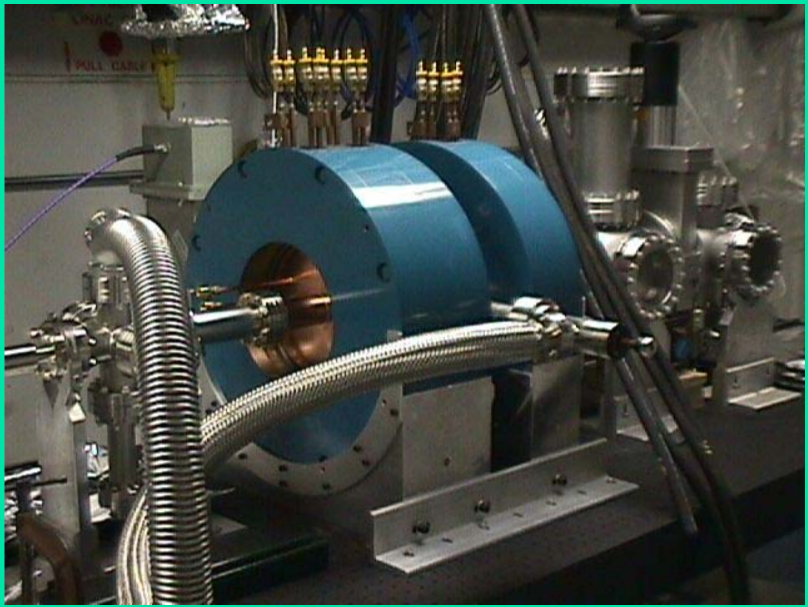
- **Hard to do since Q_d must be high**

(witness beam Is easy due to low charge)

AWA Drive Gun Upgrade *(recently commissioned)*

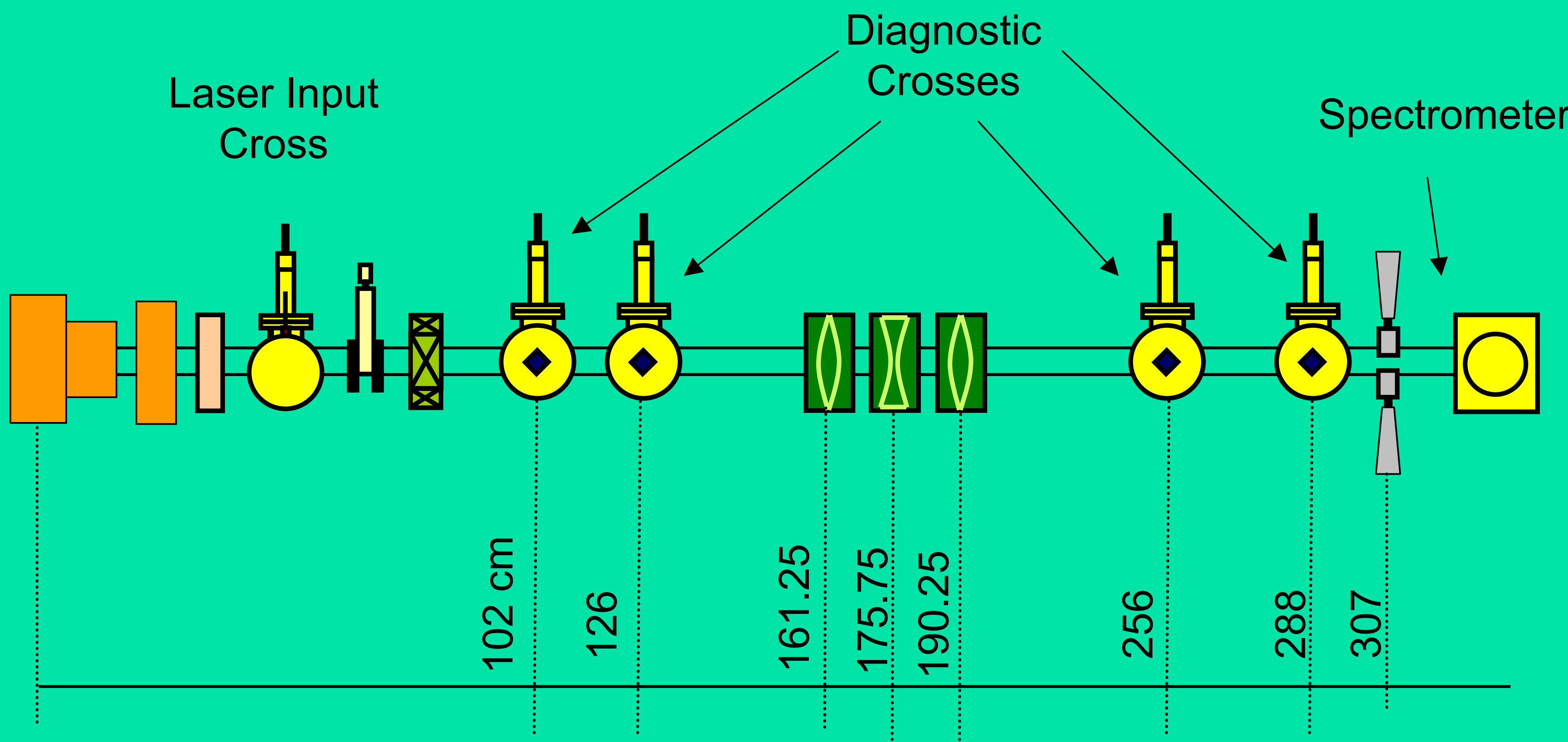
1 ½ cell L-band (1.3 GHz)

- Q_0 = 26000 (calculated), ~21000 (measured)
- 12 MW yielding 80 MV/m on cathode surface.
- Vacuum tested at $2\text{x}10^{-9}$ without baking. $4\text{x}10^{-10}$ after baking. (~ 10^{-8} for current AWA gun).

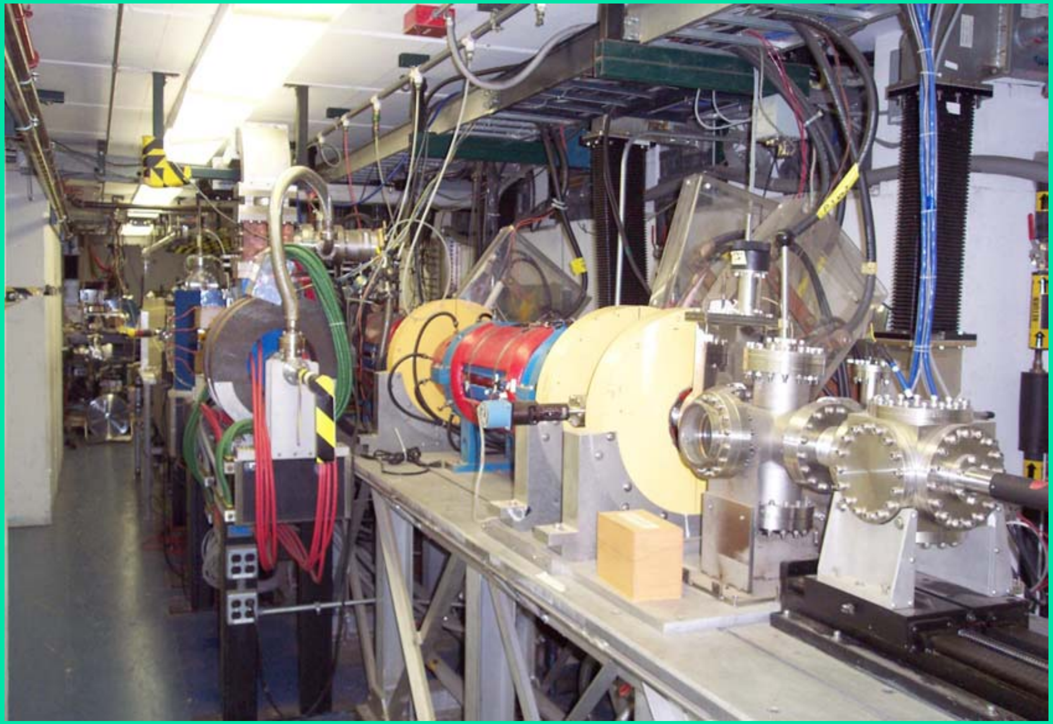


Conditioned to 14 MW or 88 MV/m. Over the design field strength (80 MV/m): No more arcing.

AWA test stand beamline



Drive Gun normal operating mode



Q ~= 100 nC

High Charge Operating Mode

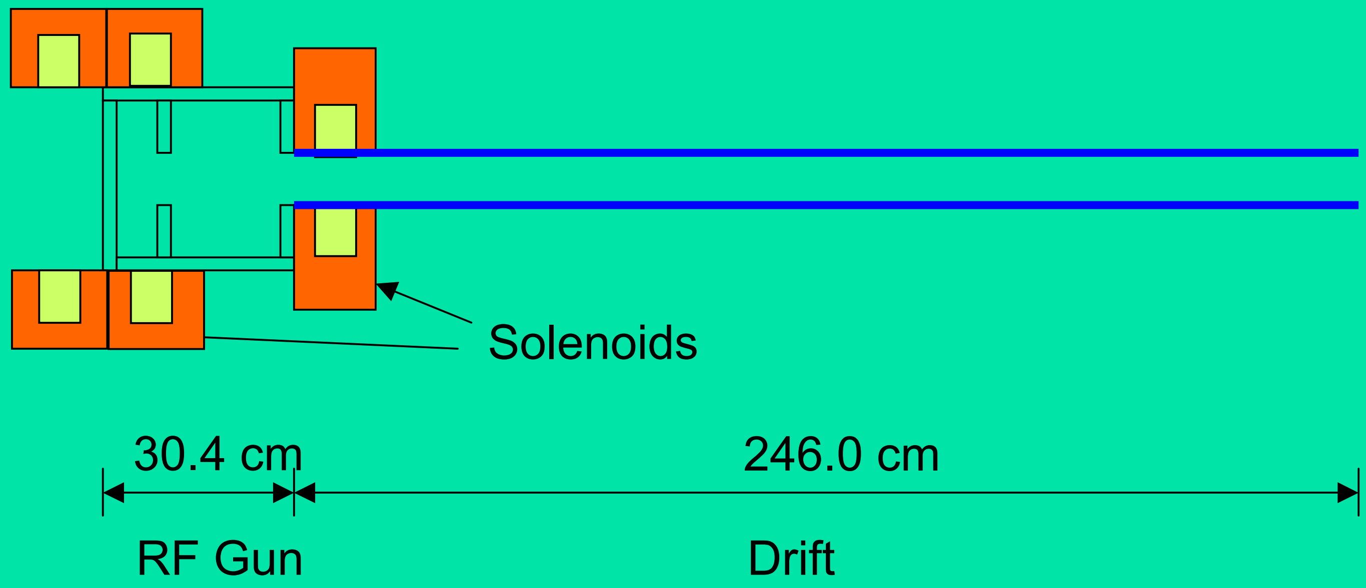
Parmela Simulation Results

Charge (nC)	100
Laser spot radius (mm)	8
Laser pulse length (psec)	8
RF launch phase (^{0})	40
Energy (MeV)	10.4
Energy spread (%)	8
Normalized r.m.s. emittance (mm mrad)	400

ε_n is too large

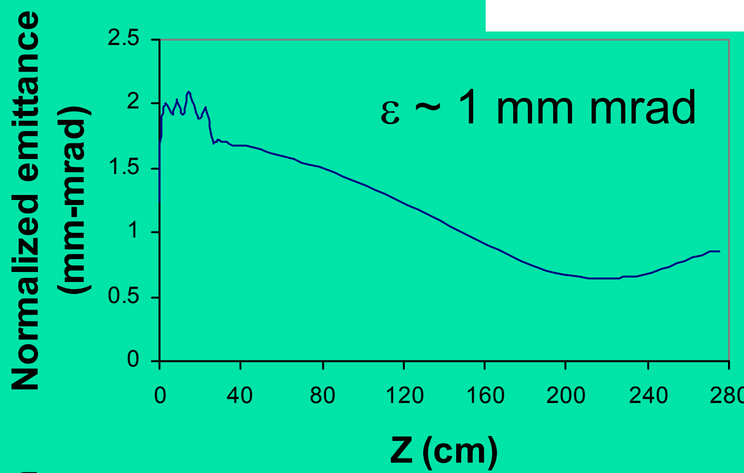
Find a new operating mode

High Brightness Operating Mode

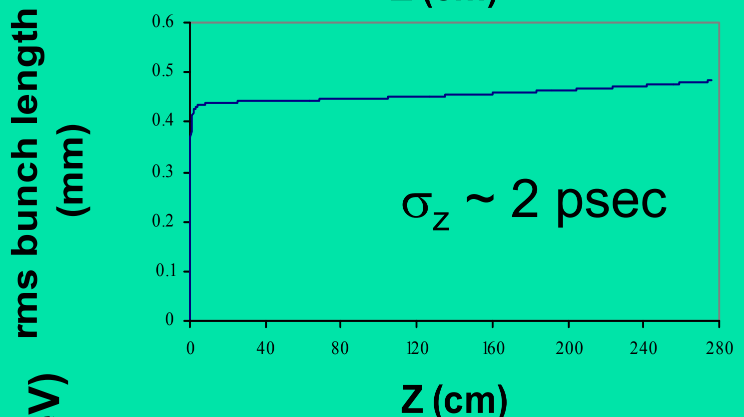


1. **Use PARMELA to determine if the gun can be operated in a high brightness mode. *(done)***
2. **Diagnose this beam. *(in progress)***

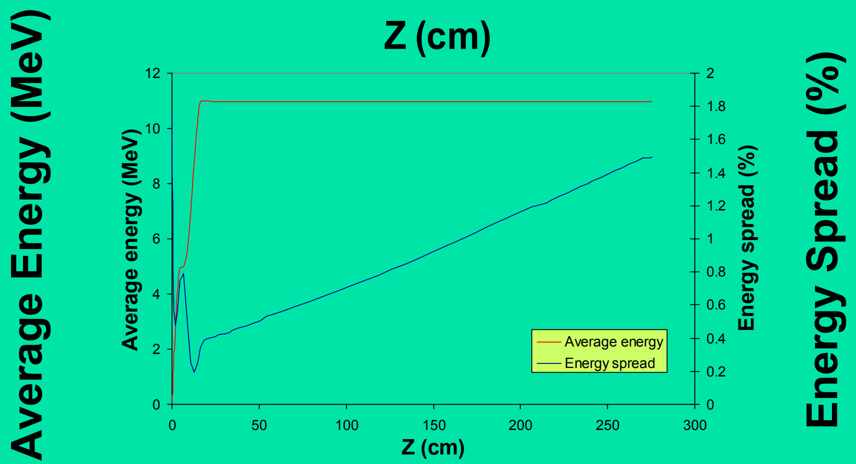
PARMELA SIMULATION



Evolution of the normalized transverse emittance for the 1 nC beam along the z-axis with the configuration (gun + long drift).



Evolution of the r.m.s. bunch length for the 1 nC beam along the z-axis with the configuration (gun + long drift).



Evolution of the average energy and energy spread for the 1 nC beam along the z-axis with the configuration (gun + long drift).

A new operating mode

High Brightness Operating Mode

Charge (nC)	2
Laser spot radius (mm)	1.6
Laser pulse length (psec)	8
RF launch phase (^{0})	40
Energy (MeV)	10.4
Energy spread (%)	0.5%
Normalized r.m.s. emittance (mm mrad)	1.9

@ Q_d = 2 nC and ε =1.9 mm mrad → σ_d = 220 μm

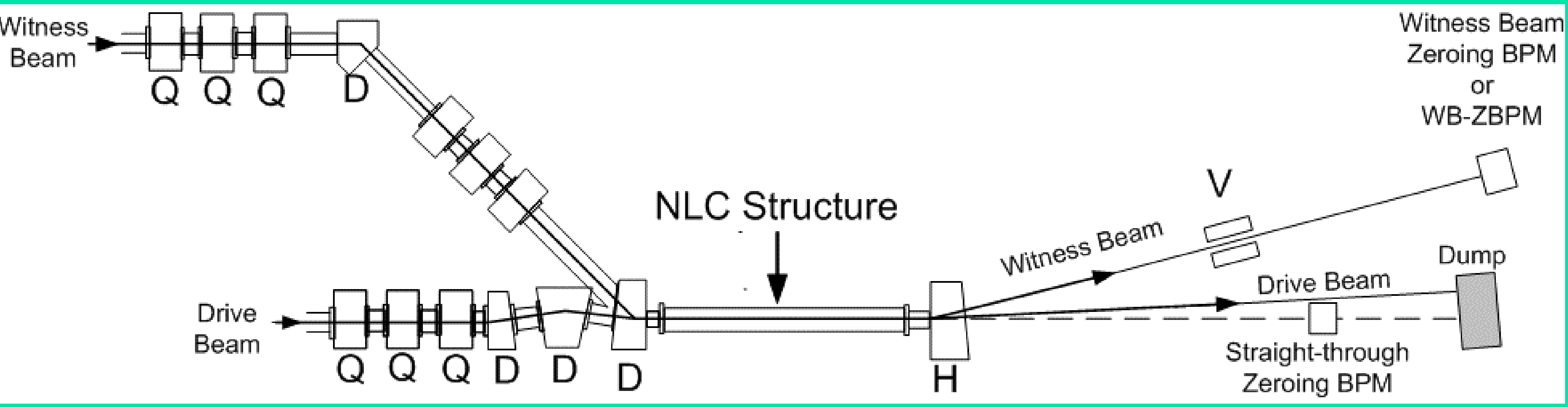
Diagnostics (…in progress)

- **Transverse Emittance Diagnostics**
  - **Pepper Pot (modified for high brightness mode.)**
    - **Thin YAG (~100 μm)**
    - **Gated Intensified CCD camera**
    - **Measure ε in three places (study ε evolution)**
  - OTR-ODR Interfermoter (R. Fiorito, PAC 2003)
  - 3D Quad Scan with Space Charge (C. Limborg, PAC 2003)
- **Longitudinal Diagnostics**
  - Cherenkov plate + Streak Camera (bunch length)
  - Spectrometer (energy/energy spread)

Second Modification

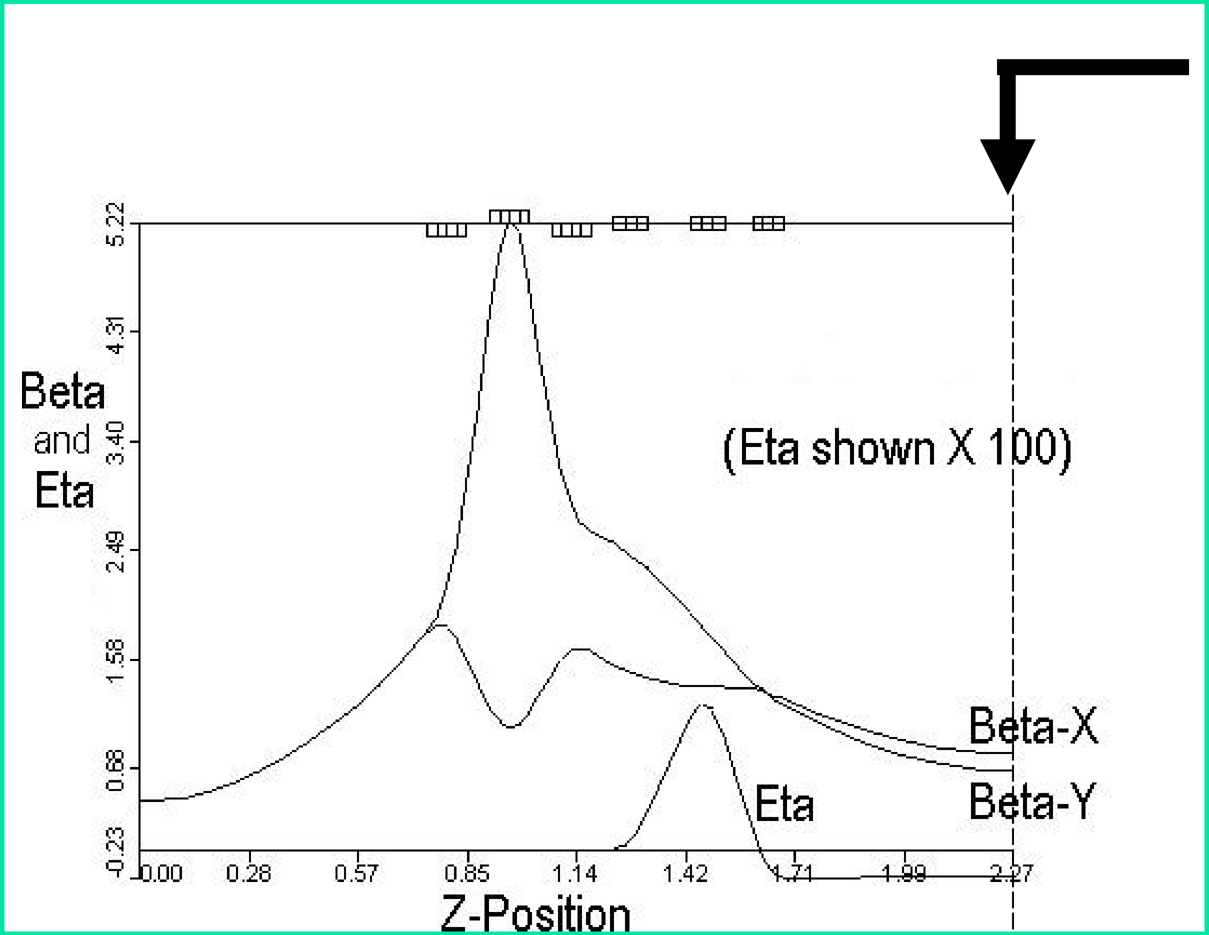
Downstream Measurement System

Downstream Measurement System



1. Pre-align beams through the NLC structure to the straight-through *Zeroing BPM*
2. Witness beam leading: Center Witness beam on *Witness Beam Zeroing BPM* using *H* and *V*
3. Witness beam trailing:
   - **W_{Π}**: Use *H* to keep witness centered on WB-ZBPM
   - **$W_{\perp}$**: Use *V* to keep witness centered on WB-ZBPM

Drive Beam Optics



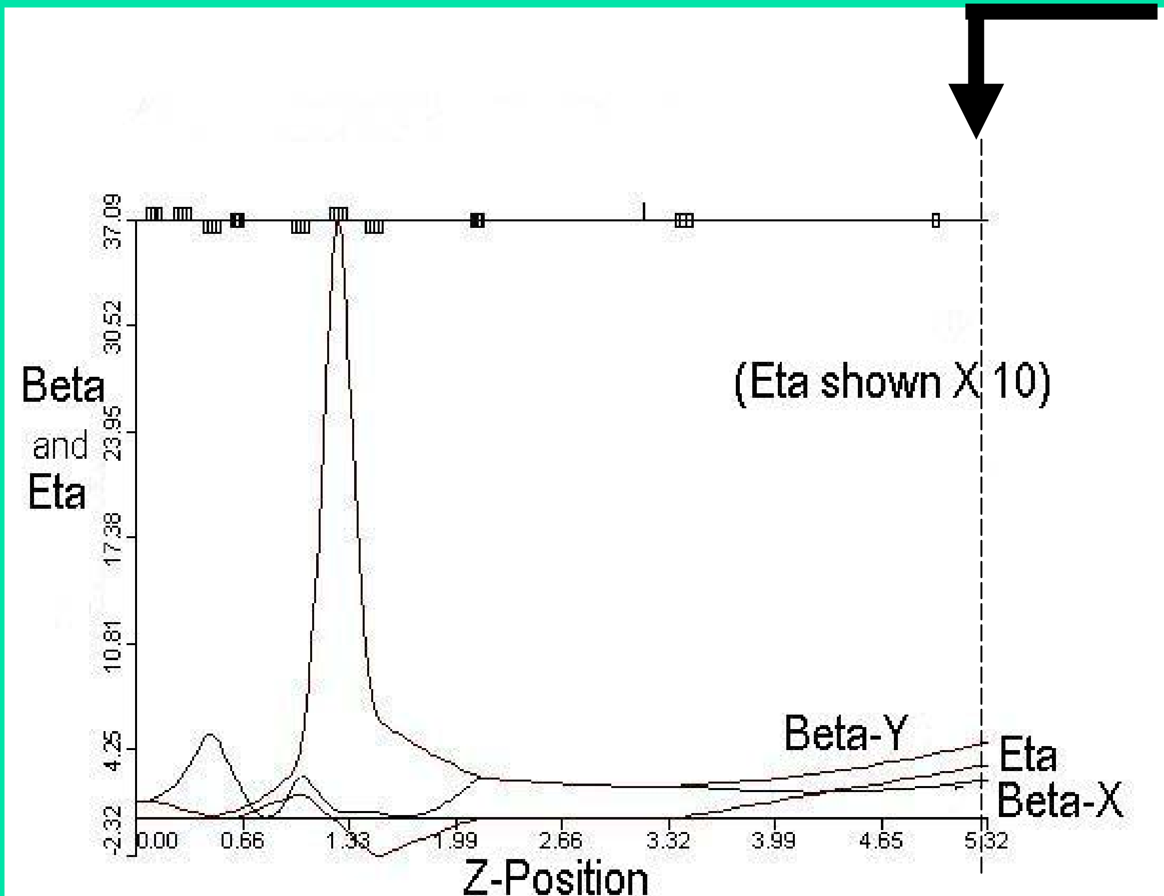
At Center of the NLC structure:

β_x **= 1 m**

β_y **= 1 m**

η_x **= 0.002 m**

Witness Beam Optics



At WB-ZBPM:

β_x = 4.6 m

β_y = 2.5 m

η_x = 0.2 m

Longitudinal Wake Resolution

Energy measurement resolution

1. Q_w = 10 pC, →
   normalized r.m.s. emittance of 0.3 mm mrad
   momentum spread of 1%.
2. Machine Functions at WB-ZBPM →
   β_x = 2.6 m → σ_β = 1.0 mm
   η_x = 0.2 m → σ_η = 2.0 mm
   σ_{tot} = 2.2 mm (total width)
3. WB-ZBPM resolution 1/10th of σ_{tot} = 220 μm
4. $\Delta E_z/E \sim 0.1\%$

Minimum measurable monopole longitudinal wake function

$$\frac{\Delta E}{E} = \left(\frac{-e Q_d L_s W_{\parallel,0}(t)}{E_w} \right) \longrightarrow W_{ll,0} = 2.5 \text{ V/pC/m}$$

Transverse Wake Resolution

Angular measurement resolution

1. Q_w = 10 pC, →
   normalized r.m.s. emittance of 0.3 mm mrad
   momentum spread of 1%.
2. Machine Functions at WB-ZBPM →
   $\beta_y = 4.6$ m → $\sigma_\beta = 1.1$ mm (total width)
3. WB-ZBPM resolution 1/10th of σ_{tot}; resolution = 110 μm
4. $\Delta\theta \sim 55$ μrad

Minimum measurable dipole transverse wake function

$$\Delta\theta_y(t) = \frac{\gamma}{\gamma+1}\left(\frac{-eQ_d L_s W_{\perp,1}(t)}{E_w}\right)\Delta y_d \longrightarrow W_{\perp,1}(t) = 0.3 \text{ V/pC/m/mm}$$

Summary of a zeroth-order conceptual design

- **Compact** and **high-precision**.
  - Longitudinal resolution → 2.5 V/pC/m
  - Transverse resolution → 0.3 V/pC/m/mm (~equivalent to ASSET).
- **Next Steps**
  - Diagnose high-brightness beam
  - More thorough design of downstream measurement system (optics)
  - Install hardware: 2 BPM's, 2 magnets, vacuum chamber, etc.
- The AWA facility could be used to build a prototype version of this facility.