Energy Spectrometer R&D

Progress and Plans

Mike Hildreth

University of Notre Dame

representing

SLAC T-474/491 & T-475 and the ATF2 Collaboration

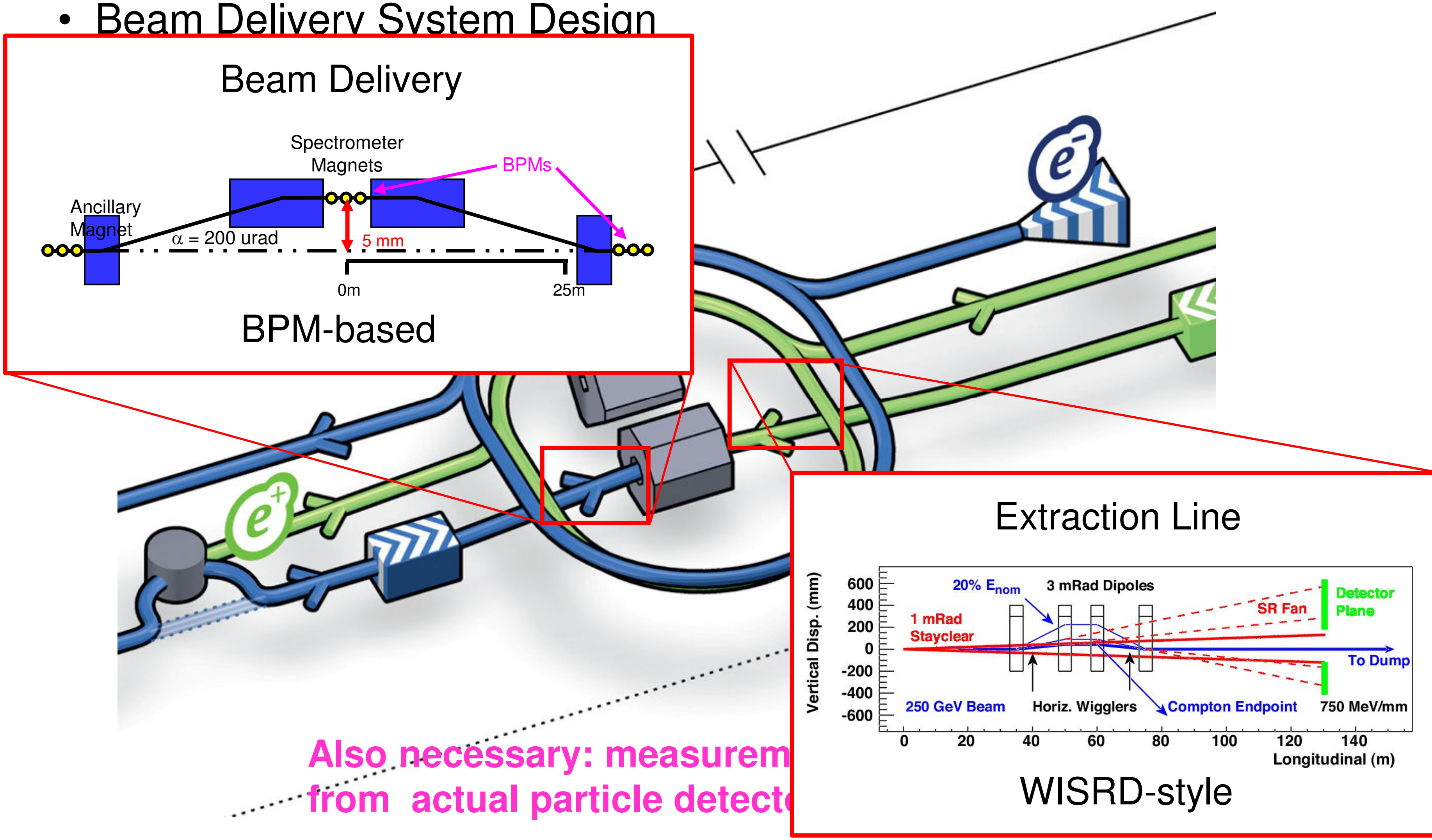
Spectrometry: A Reminder

- Required measurement precision is set by the expected statistical and systematic errors of “benchmark” measurements of m_{top}, m_{higgs}:
  - require $\delta E_{beam}/E_{beam}$ ~ 100-200 ppm
  - So far, only spectrometer techniques have come anywhere near this precision with very high energy electron beams
- Previous efforts:
  - LEP2
    - Achieved 120 ppm by combining three different methods, only one of which (BPM Spectrometer) is available at ILC
      - Spectrometer was able to do 170 ppm
  - SLC
    - WISRD systematic errors estimated at 220 ppm, σ_E/L ·· 20 MeV
    - C of M was shifted by 46 ± 25 MeV (500 ppm) compared with Z lineshape scan

⇒ Many constraints more severe at ILC than at low energy ⇒ Need R&D!

Basic Strategy: Redundant Tools

- Beam Delivery System Design

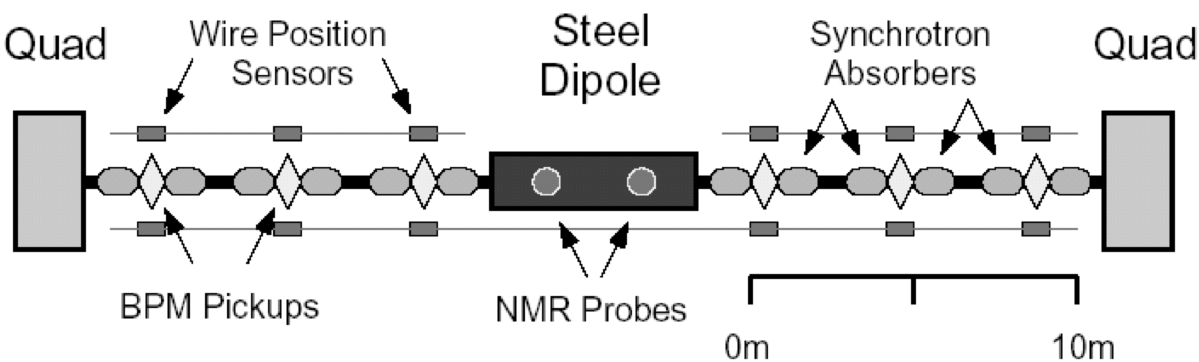


Also necessary: measurem from actual particle detecto

UNIVERSITY OF NOTRE DAME

Two Spectrometers Designed for ILC

- **"LEP-Type"**: BPM-based, bend angle measurement

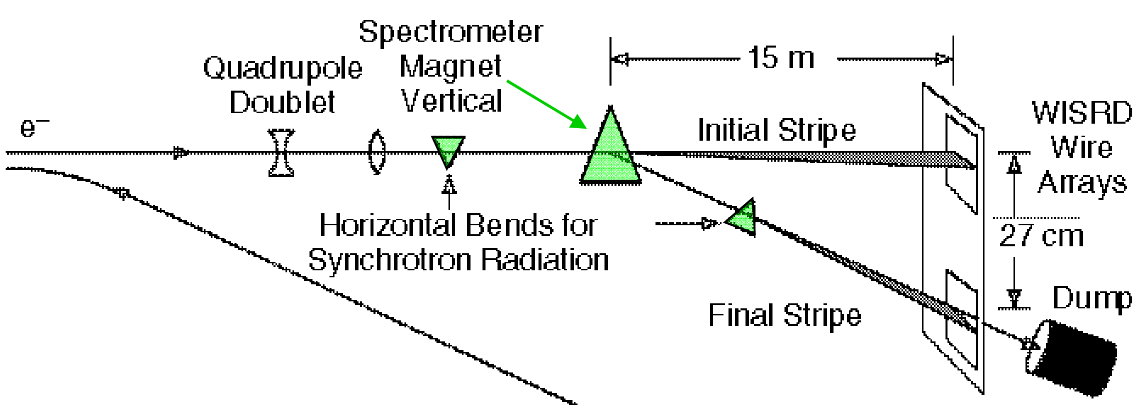


θ_{bend} = 3.8 mrad (LEP)
~ 0.2 mrad (ILC)

$$\theta = \frac{ec}{p}\int B \cdot d\ell$$

→ located in BDS, upstream of IR

- **"SLC-Type"**: SR-stripe based, bend angle measurement



$d_{SR\text{-}stripe}$ = 27 cm (SLC)
~ 35 cm (ILC)

→ located in extraction line, downstream of IR

Considerations

- Upstream Spectrometer
  - Constrained by allowed emittance growth from SR
  - Constrained by available real estate in BDS, overall size
    - These constraints determine needed BPM resolution/stability
  - Other issues drive systematic errors, diagnostics
  - Must be robust, invisible to luminosity
- Downstream Spectrometer
  - Constrained by available space in extraction line
    - larger crossing angle desired
    - background/interference-free region necessary
  - robust, rad-hard detectors necessary
  - measurements of dL/dE on disrupted beam possible
  - modelling of extraction line important to eliminate/mitigate surprise

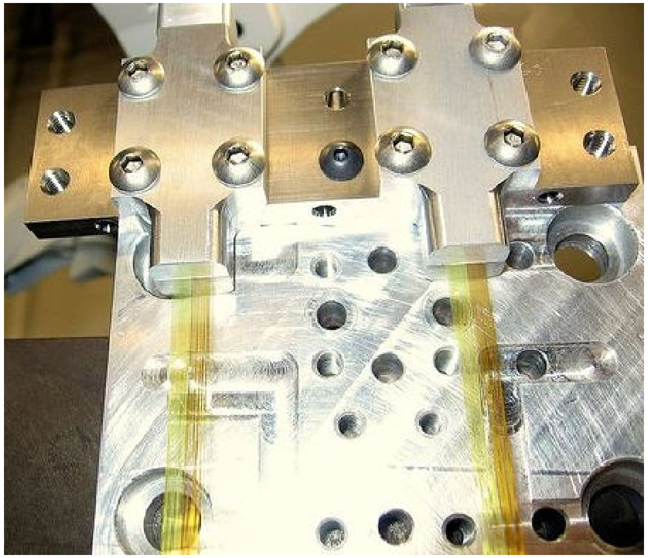
SLAC Test Beam: T-474/491 & T-475

T-474/491 BPM Energy Spectrometer

- **PIs:** M. Hildreth (Notre Dame), S. Boogert (RHUL) and Y. Kolomensky (UC Berkeley)
- **Collaborating Institutions**: Cambridge, DESY, Dubna, Royal Holloway, SLAC, UC Berkeley, UC London, Notre Dame

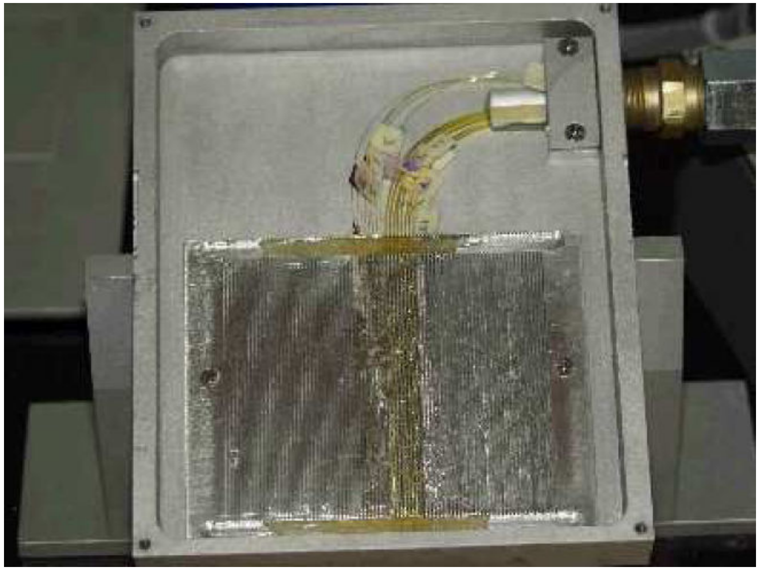
T-475 Synchrotron Stripe Energy Spectrometer

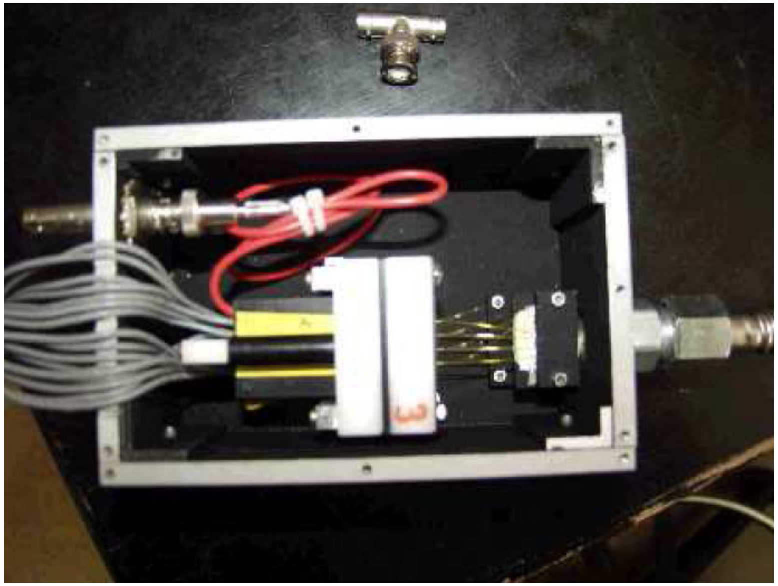
- **PI:** E. Torrence (U. of Oregon)
- **Collaborating Institutions:** SLAC, U. of Oregon
- Quartz fiber detector for readout



Detector R&D

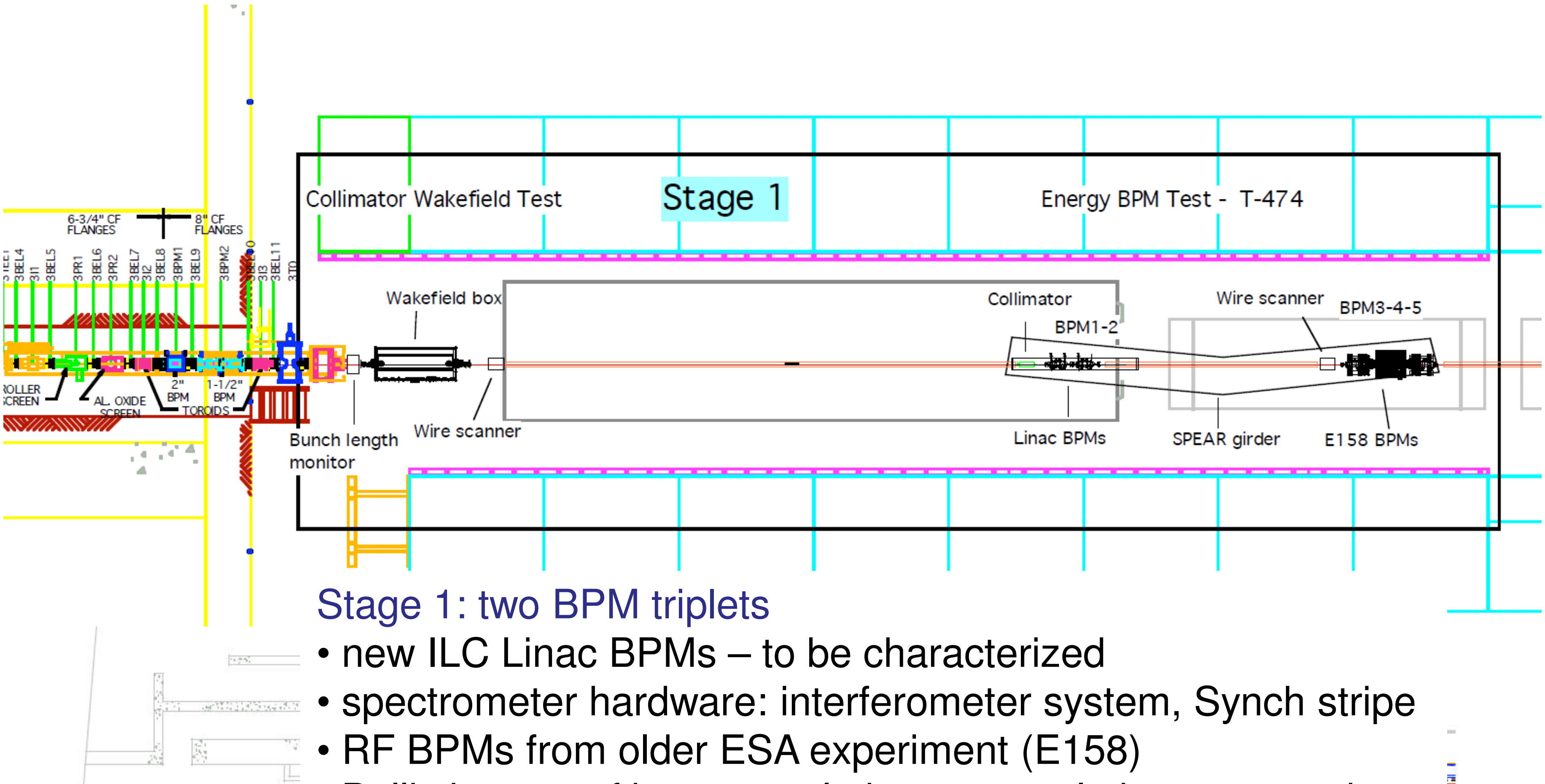
- Entirely passive, rad-hard detector ideal
  - quartz fibers
    - intrinsically fast
    - no inductive pickup, crosstalk
    - 200keV Cerenkov threshold
    - detector prototype
      - 100 μm and 600 μm fibers
      - 1mm pitch
    - second prototype with 200μm
  - Multi-anode PMT readout
    - high gain
    - simple device
    - up to 64 channels
  - was stymied by inaccessible location and large backgrounds





Newer photos?

2006 ESA configuration

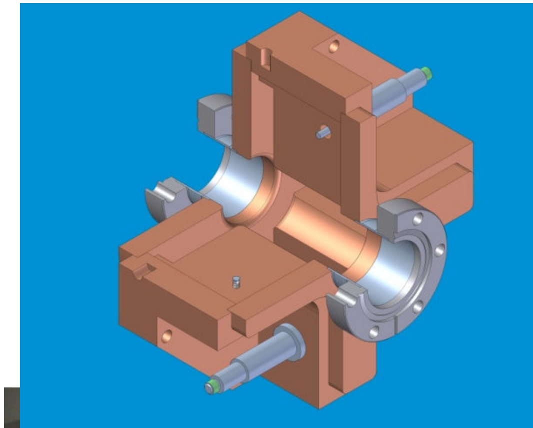


Stage 1: two BPM triplets

- new ILC Linac BPMs – to be characterized
- spectrometer hardware: interferometer system, Synch stripe
- RF BPMs from older ESA experiment (E158)
- Ballistic tests of beam resolution, extrapolation systematics

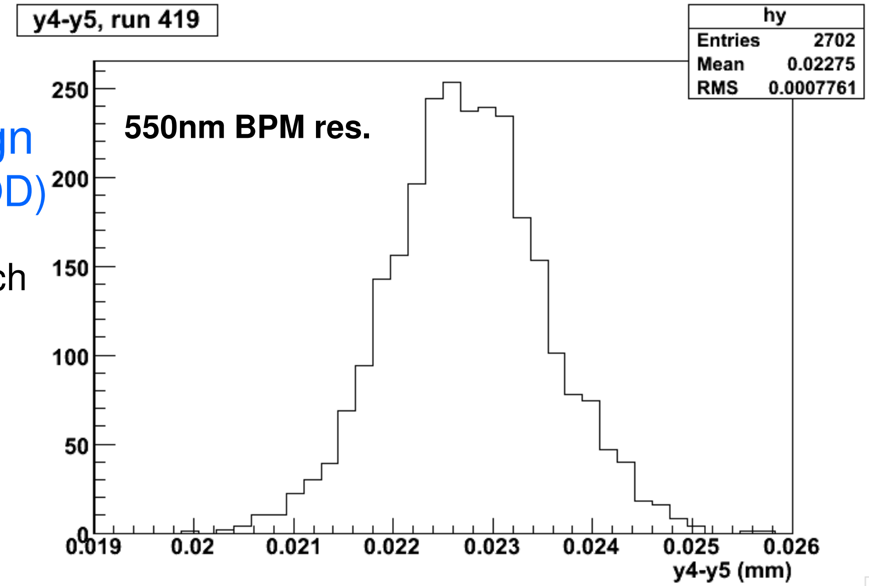
UNIVERSITY OF NOTRE DAME

T-474 Run I, Preliminary Results

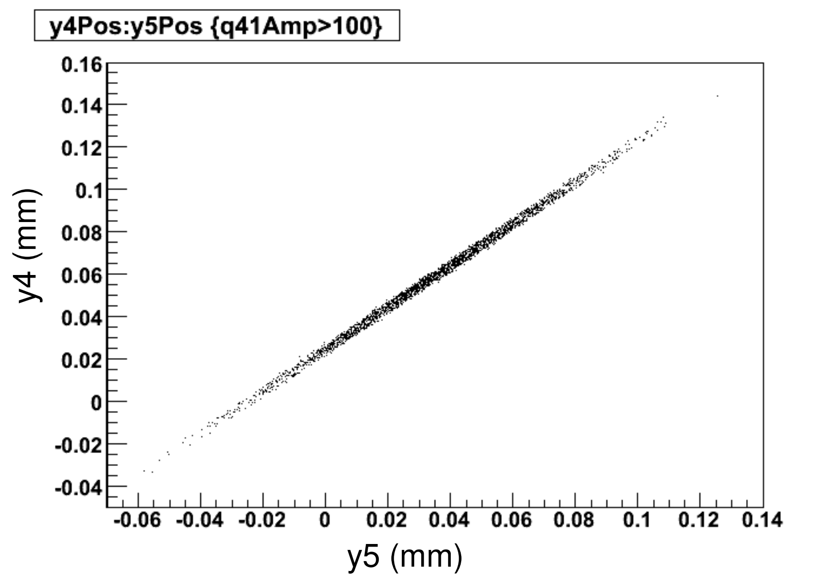


S-Band BPM Design
(36 mm ID, 126 mm OD)

Q~500 for single bunch resolution



New Linac BPM Prototype
(C. Adolphsen, G. Bowden, Z. Li)
→ **used as BPM3-5 for T-474**



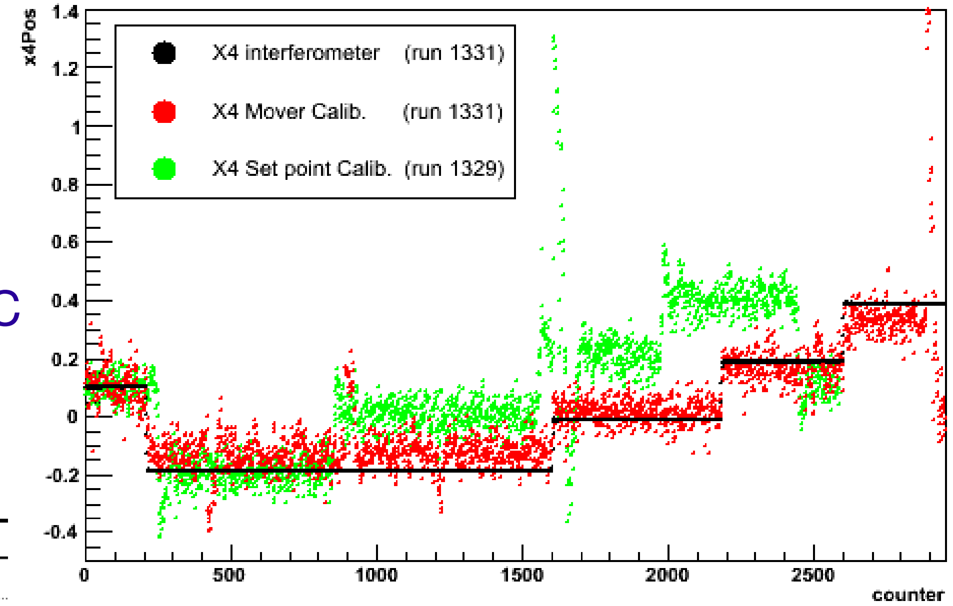
University of Notre Dame

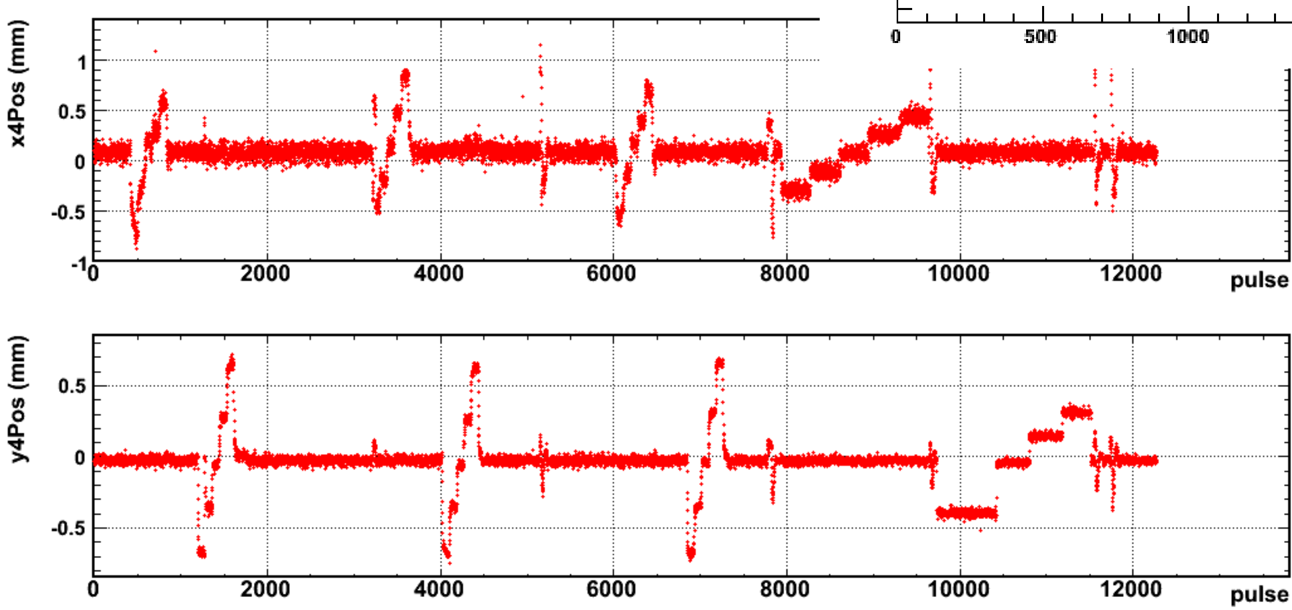
T-474: Automatic Calibration

Important aspect of future spectrometer operation

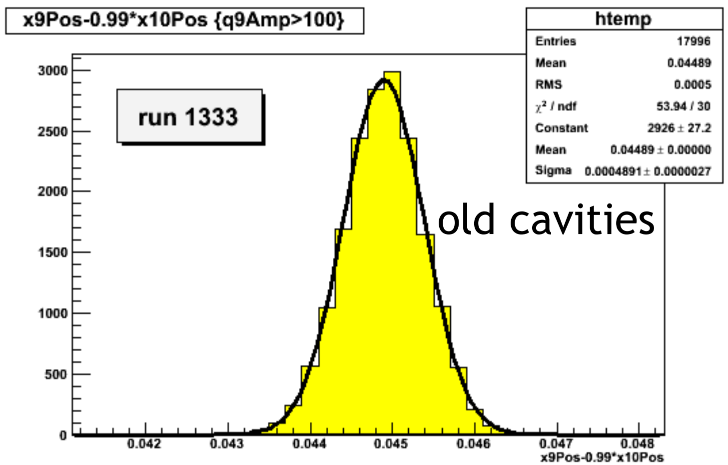
- Upstream corrector scans
- Followed by mover scan on BPM
- Set voltage level for each step in ADC

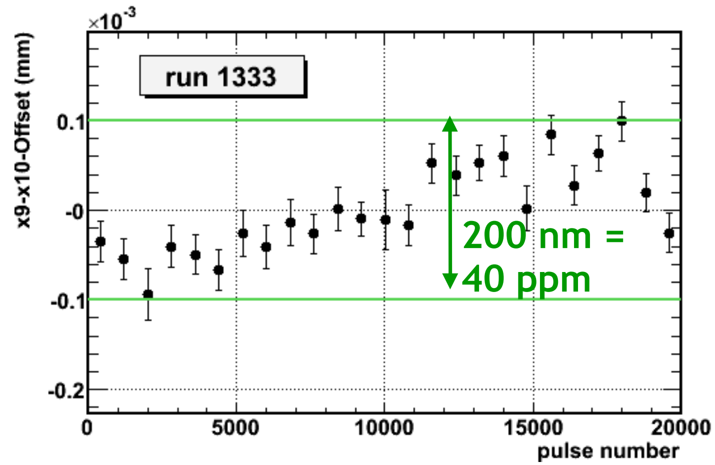
(track SCP-controlled scans in expt DAQ)





T-474: BPM Local Resolution, Stability

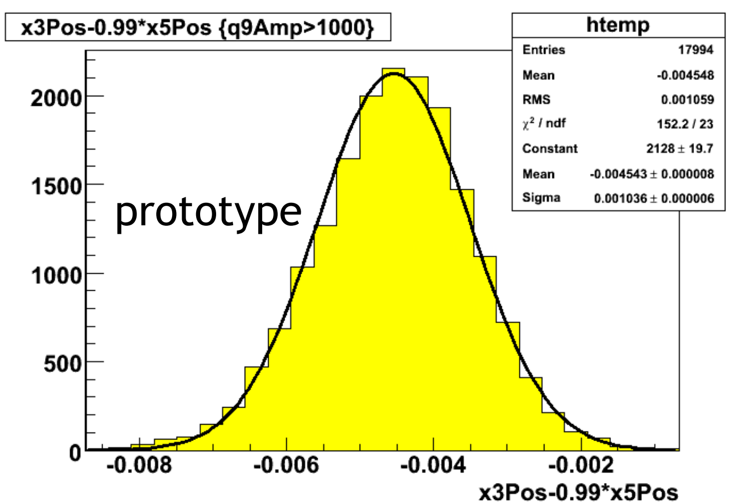


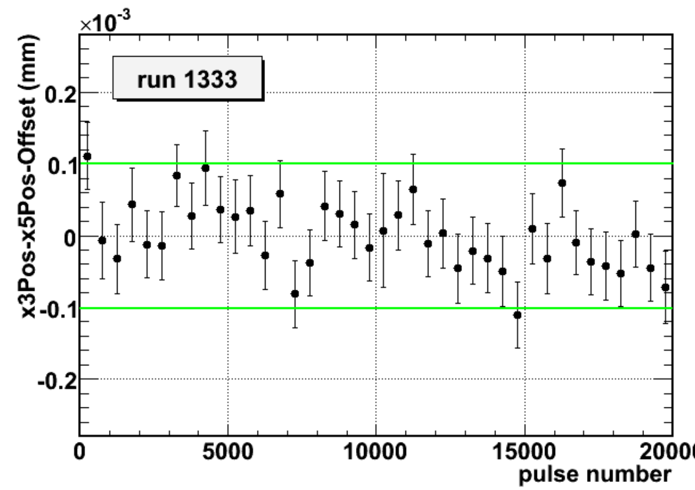


Resolution : BPM 9-11: ~350 nm in x

BPM 3-5: ~ 700 nm in x,

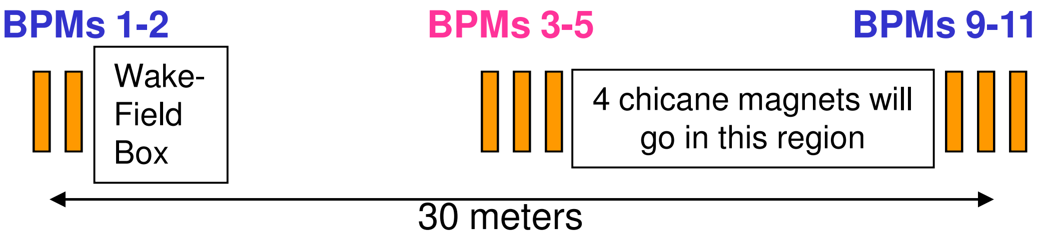
<40 ppm stability for 20k pulses ~ 30 min

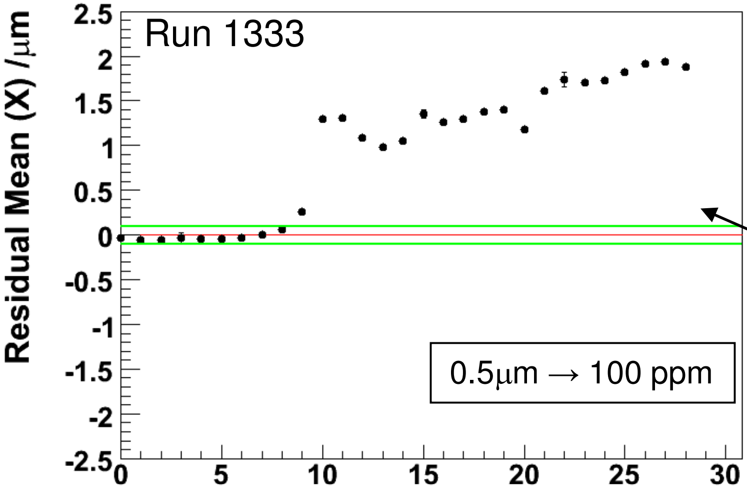




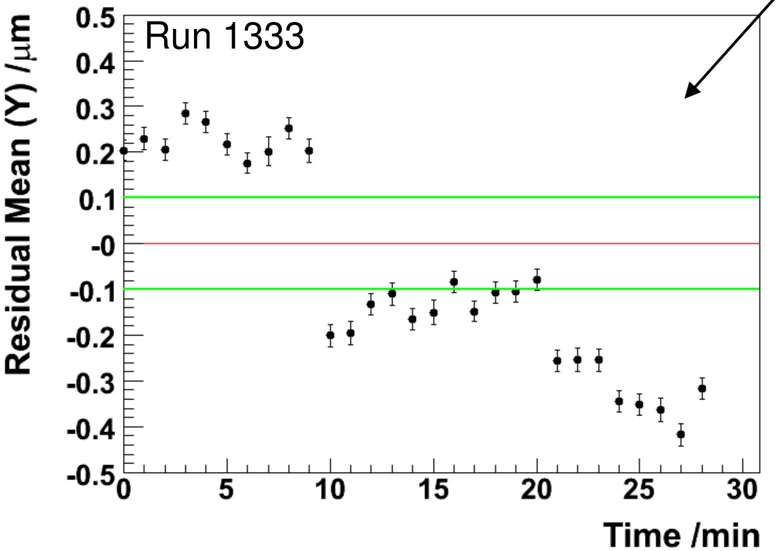
UNIVERSITY OF NOTRE DAME

T-474: Linking BPM Stations





⇒ **use BPMs 1-2 and 9-11 to fit straight line**
- predict beam position at **BPMs 3-5**
- plot residual of **BPM 5** wrt predicted position



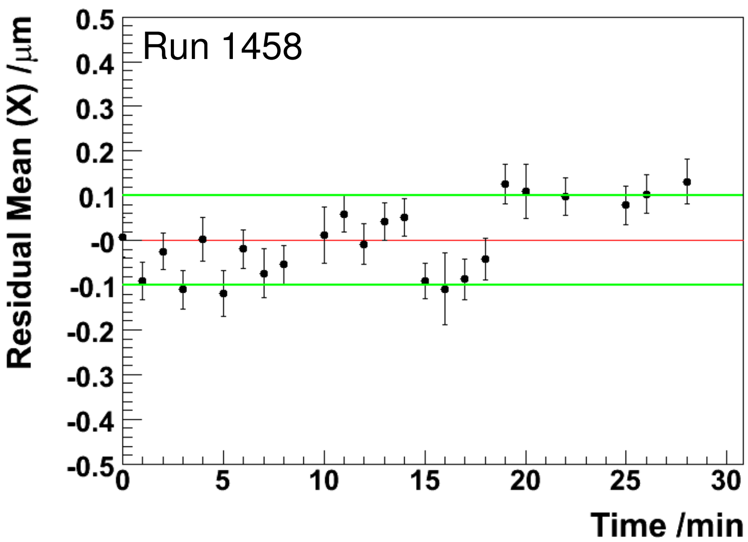
Why jumps and drifts in residuals when linking bpm stations?

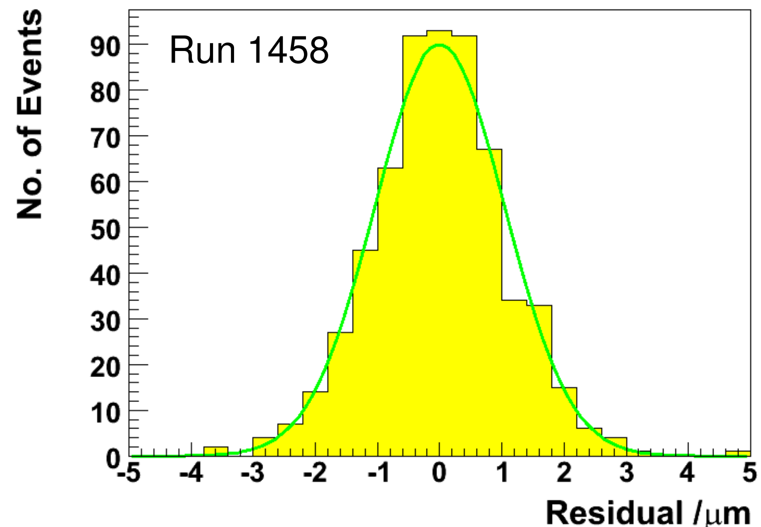
Investigate possibilities:
- analysis bug?
- changes in LO phase or BPM electronics?
- bias related to change in beam trajectory, beam energy or other beam parameters?
- relative alignment of bpm stations changed?

→ A primary goal of T-474 is to investigate sensitivity of energy measurement to changes in beam parameters and electronics stability, and whether goals for systematic errors <100ppm can be met.

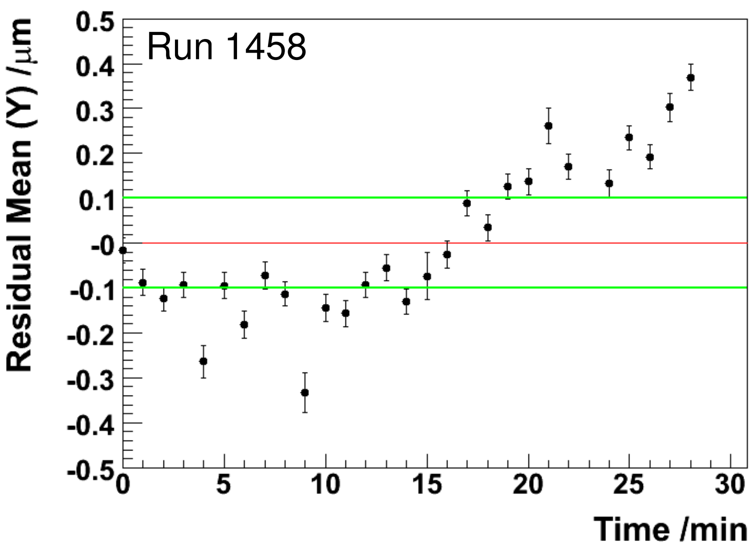
Need more data!

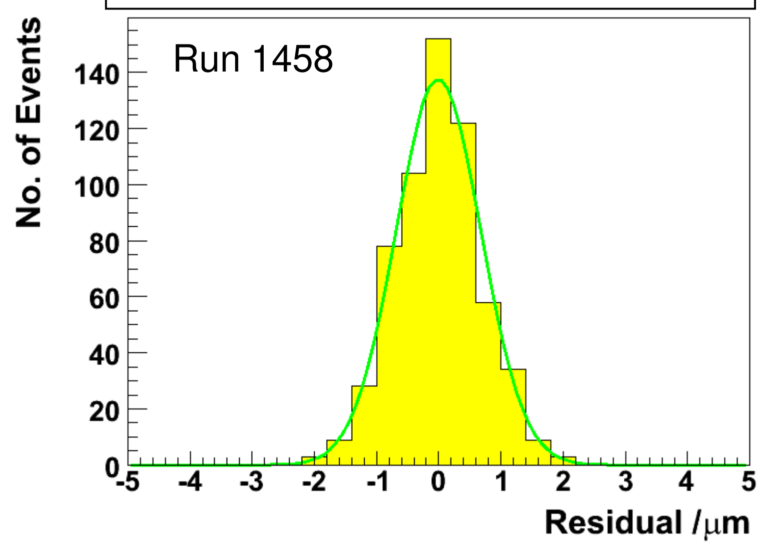
T-474: Linking BPM Stations



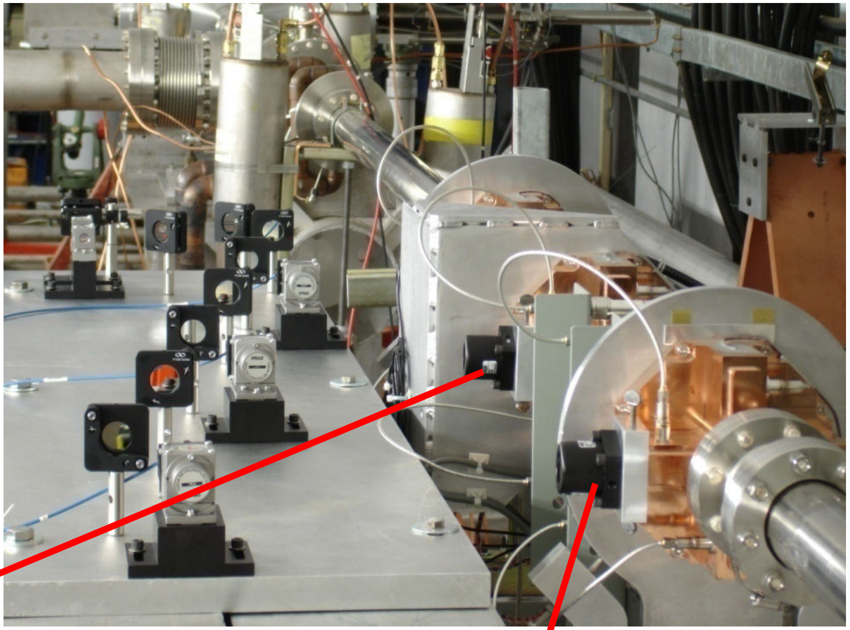


→ better stability on this run!

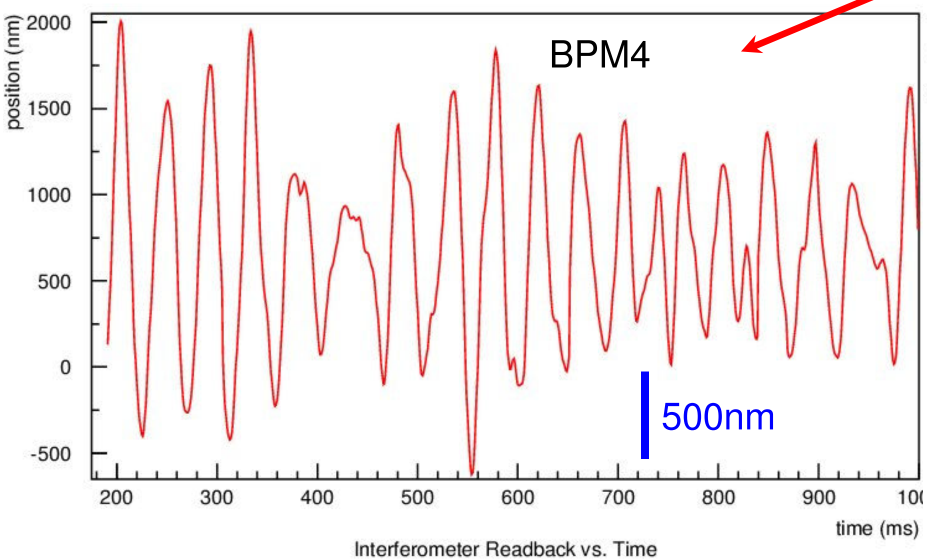


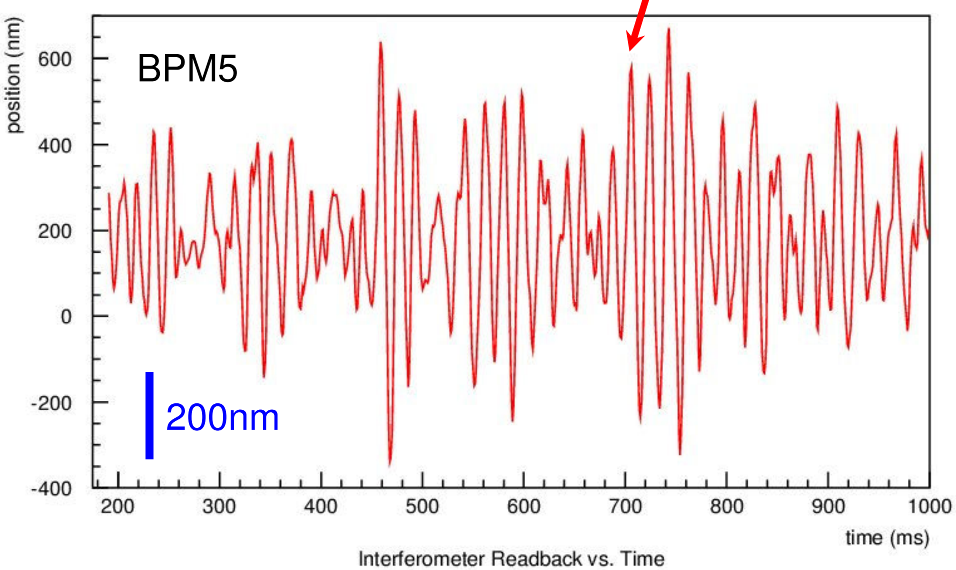


Interferometer for Position Monitoring



- Monitor mechanical stability
- Commissioned during July run
- sub-nm resolution
- installation itself stable to ~30nm over one hour with fixed mirrors
- measured large vibrations of BPM girder
  - large vibrations of BPM4 compared with BPMs 3 and 5
  - analysis underway to correct BPM meas
  - new girder design for chicane center

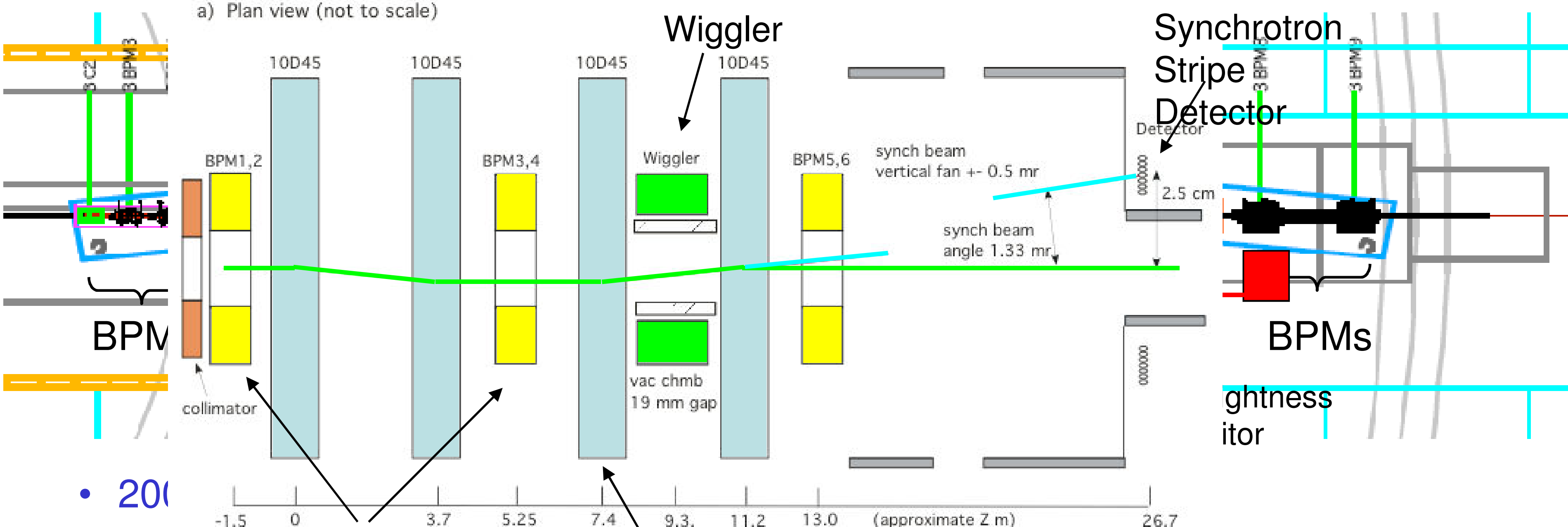




NOTRE DAME

Magnetic Spectrometer Tests

- Both Spectrometers configured together in 4-magnet chicane (2007)

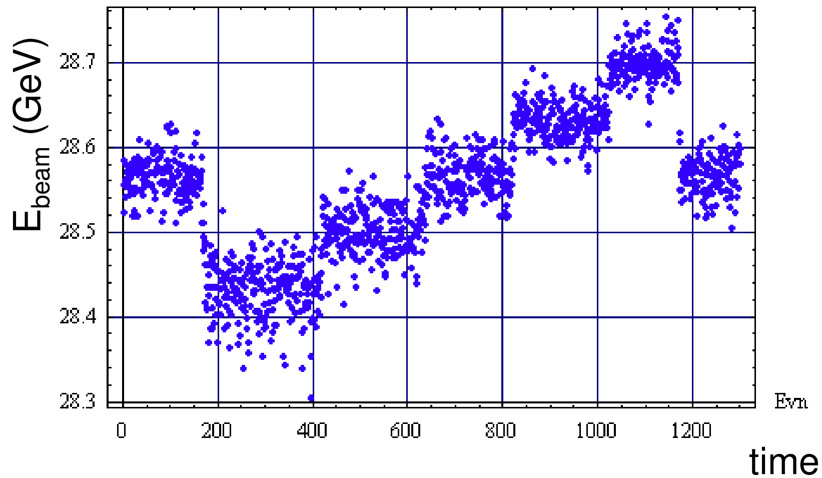


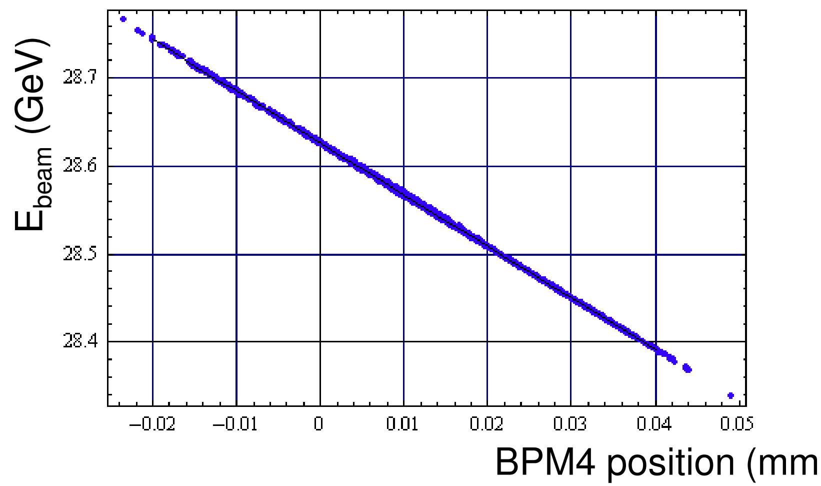
- 200

  - study calibration procedure, including reversing the chicane polarity
  - study sensitivity to: beam trajectory, beam tilt, bunch length, beam energy, beam shape, …
  - compare measured energy, energy jitter at 100-200ppm level
    - compare with A-line diagnostics (spin precession)
  - mechanical and electronic stability studies

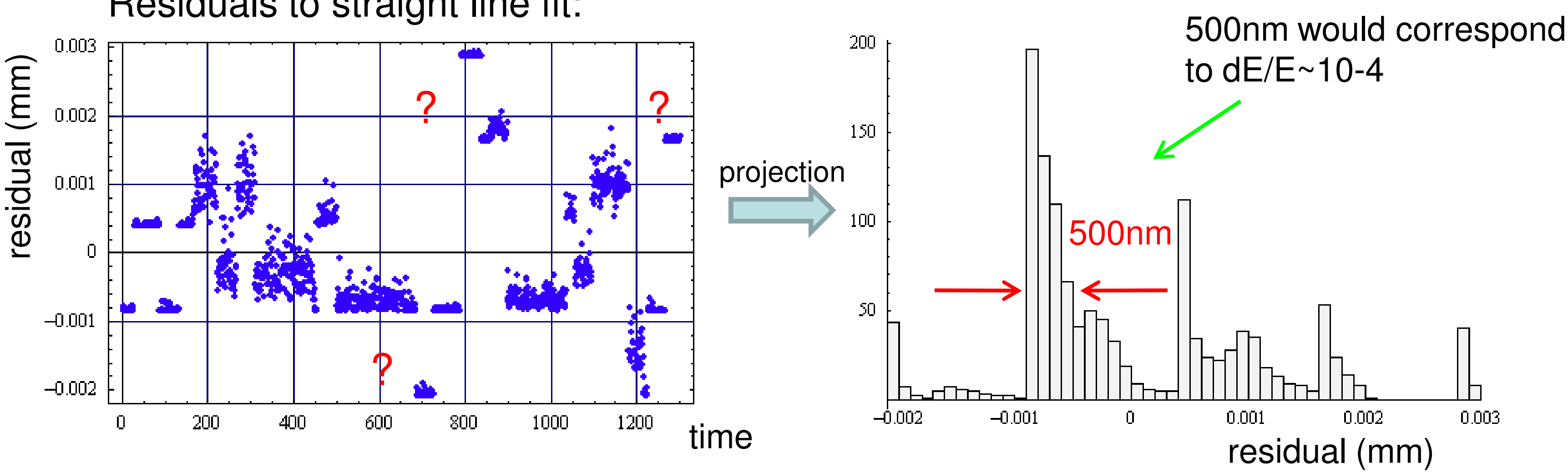
First Energy Measurements

- ~400 MeV Energy Scan by moving klystron setpoints:





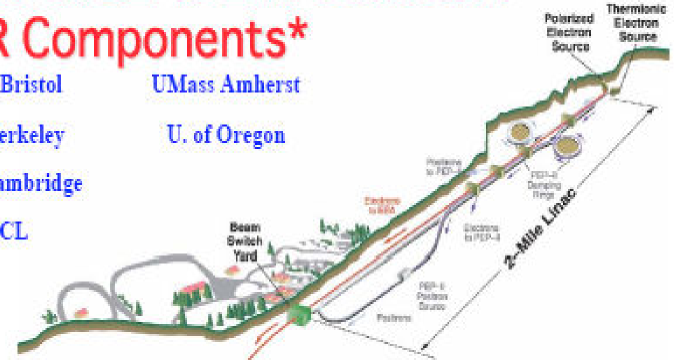
Residuals to straight line fit:



A Test Facility for the *International Linear Collider* at SLAC End Station A For Prototypes of Beam Delivery and IR Components*

International Linear Collider at Stanford Linear Accelerator Center

CCLRC | LLNL | QMUL | U. of Bristol | UMass Amherst
CERN | Lancaster U. | SLAC | UC Berkeley | U. of Oregon
DESY | Manchester U. | TEMF TU Darmstadt | U. of Cambridge
KEK | Notre Dame U. | U. of Birmingham | UCL



CANCELLED

Abstract: … http://www-project.slac.stanford.edu/ilc/testfac/ESA/esa.html

The SLAC Li… deliver damped … ILC … ters for … ch charge and bunch length to End Station A. A 10Hz beam at 28.5 … ergy can … del… ed … parasi… EP-II … eration … to use this facility to test prototype components of … am D… … erac… … W… scu… … ans f… his IL… Test Facility and preparations for carrying … ex… ments … o c… ma… … en… ds … gy spec… met… … an interaction region mockup to investigate effects from … and … ce… magnetic inter…

Collimator Wakefield Measurements

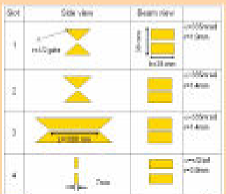


Fig. 1: Collimator insertions planned for a first set of measurements.

At the ILC, collimators are required to remove halo particles (having large amplitudes relative to the ideal orbit) to minimize damage to beam line elements and particle detectors and to achieve tolerable background levels. Short-range transverse wakefields excited by these collimators may perturb beam motion and lead to both emittance dilution and amplification of position jitter at the IP. The goal of the ESA tests is to find optimal materials and geometry for the collimator jaws to minimize wakefield effects while achieving the required performance for halo removal. The collimators will be rectangular in transverse section with a shallow longitudinal taper, long relative to the ~300μm ILC bunch length.

Initial ESA measurements will measure resistive wakes in copper and study two-step tapers. Two sets of four collimator insertions will be used, and Fig. 1 shows the first set of four collimator insertions we plan to install in the Collimator Wakefield Box. The first insertion has been used previously in measurements at 1.19 GeV.

…amline …guration

Fig. 2: A-Line from the Tune-up dump in the Beam Switchyard at the end of the Linac to End Station A. Downstream of IV-40 the beamline elements used for E158 (shown in Figure) have been removed in preparation for the ILC tests.

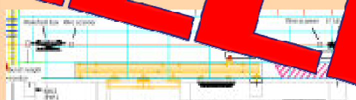


Fig. 3: Elevation View of beamline elements in ESA for Stage 1 commissioning. Chicane magnets, shown in Fig. 5, will be added for Stage 2.

A-line beam elements are shown in Fig. 2. There are six 2-degree bend magnets (B11-B16) before the SL-10 momentum slits, where the beam dispersion is 5 meters. Six additional dipoles (B21-B26) are located after SL-10. Following B26 the dispersion and dispersion gradient are zeroed using Q19 and Q20. The Synchrotron Light Monitor system images visible SR from the center of B15 onto a ccd camera for energy spread and energy jitter diagnostics.

The ESA configuration downstream of IV-41, planned for a first stage of measurements, is shown in Fig. 3. We plan to commission operation of the Collimator Wakefield Box that is being relocated from the ASSET region of Linac Sector 2. We also plan to commission of cavity BPMs being relocated from the Linac and from the E158 experiment. New signal processing electronics is being developed for that purpose. These ESA bpms will be used both for energy spectrometer commissioning and for wakefield kick diagnostics. Two wire scanners will be used for beam spotsize and emittance measurements. A bunch length monitor measuring coherent transition radiation from a thin foil is being considered.

Transverse beam sizes for the tests planned are expected to be 100-200 μm rms at either the Collimator Wakefield Box or the energy chicane BPMs. Simulation results showing 100 μm rms spotsize for collimator wakefield studies is shown in Fig. 4.

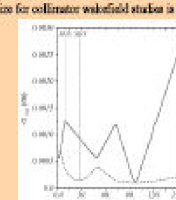


Fig. 4: Beam size in ESA after the last A-line bend. Beam has 100 μm rms spotsize at the Collimator Wakefield Box (s=85 meters).

Beam Setup to ESA

ESA beam tests are planned to run parasitically to PEP-II with single damped bunches at 10Hz, beam energy of 28.5 GeV and bunch charge of 2.0 x 10^{10} electrons. The long (6 mm rms) bunch length out of the damping ring can be compressed in the Ring-to-… transfer line and in the 24.5-degree A-line bend … the Linac to ESA to achieve ~300μm bunch length …A.

Bunch Length

Fig. 6: Energy spread and bunch length in ESA.

Fig. 6 shows results from a simulation using LiTrack of the (correlated) energy and bunch length distributions in ESA. The bunch charge is 2.0 x 10^{10} electrons. The beam energy, energy spread and bunch length at i) Damping Ring (DR) exit, ii) after Ring-to-Linac (RTL) bunch compressor, iii) end of Linac and iv) ESA are shown in Table 1.

Table 1: Energy spread and bunch length from DR to ESA.

	Beam Energy	Energy spread rms	Bunch Length rms
DR exit	1.19 GeV	0.07%	6 mm
After RTL	1.19 GeV	1.6%	720 μm
End of Linac	28.5 GeV	0.18%	720 μm
ESA	28.5 GeV	0.18%	300 μm

Bunch length diagnostics include a transverse RF deflecting cavity at the end of the Linac and a nearby off-axis screen, and the SLM energy diagnostic in the A-Line. These can be used to measure the bunch length and energy-z correlation at the end of the Linac. We plan to measure R56 in the A-line by correlating the beam phase in ESA with an energy dither we impose on the beam.

Energy Spectrometer Prototypes

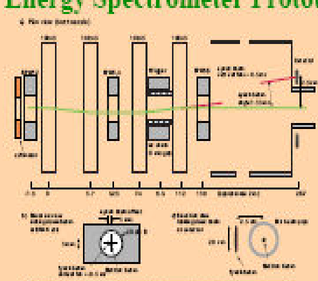


Fig. 5: Chicane configuration, beam trajectory (green) and SR stripe photons from wiggler (red) in ESA for BPM and SR stripe energy spectrometer measurements.

At the ILC, beam energy measurements with an accuracy of 100-200 parts per million (ppm) are needed for the determination of particle masses, including the top quark and Higgs boson. Energy measurements both upstream and downstream of the collision point are foreseen by two different techniques. Upstream, a LEP-style beam position monitor (BPM) spectrometer is envisioned to measure the deflection of the beam through a dipole field. Downstream of the IP, an SLC-style spectrometer is planned to detect stripes of synchrotron radiation (SR) produced as the beam passes through a string of dipole magnets.

In the ESA tests, we plan to implement the BPM and synchrotron stripe spectrometers in the same chicane (Fig. 5), which will have the same 5mm dispersion at mid-chicane and similar dipole fields (~1kG) as the currently designed upstream ILC energy chicane. The SR stripe distance from the electron beam will have an effective dispersion of 20 mm. The ILC SR stripe chicane will have a similar bend angle to the beam direction as for the ESA tests, but a longer lever arm, giving even larger effective dispersion at the detector plane. The ILC SR stripe chicane will also have an additional wiggler in the first leg of the chicane, which is a possible upgrade for the setup in ESA.

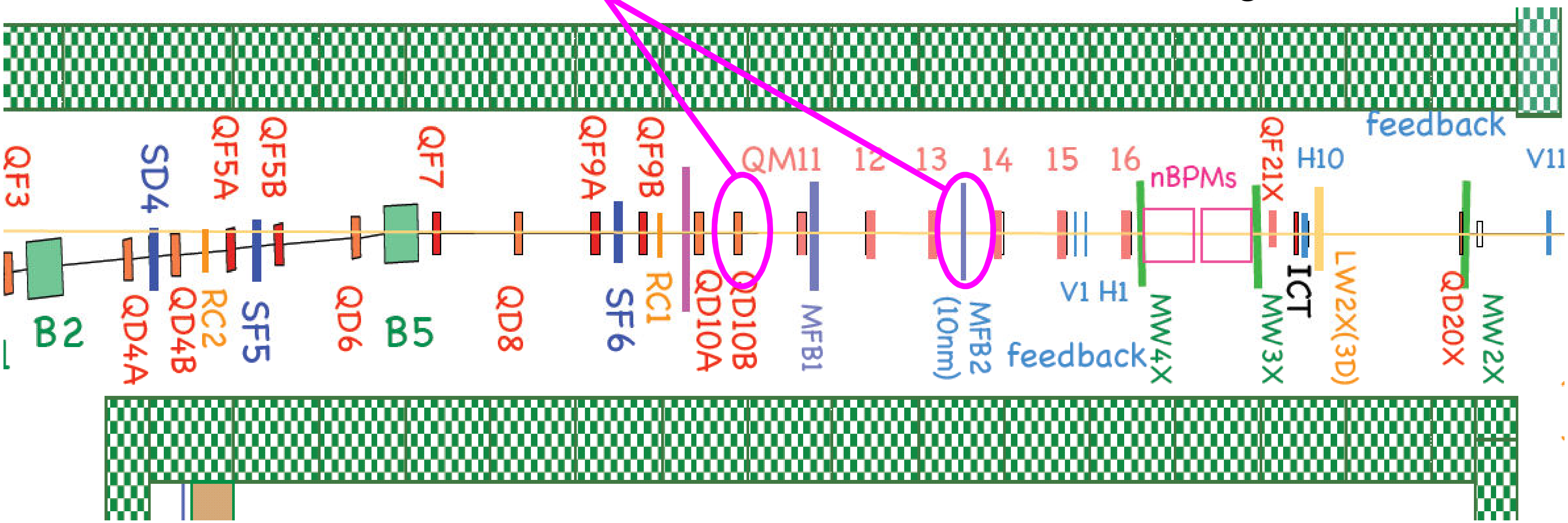
ILC-World

*Work supported in part by U.S. Department of Energy contract DE-AC02-76SF00515, and by the Commission of the European Communities under the 6th Framework Programme "Structuring the European Research Area", contract number RIDS-011899.

World-Wide Studies of ILC Physics and Detectors

Move on: ATF2 Installation

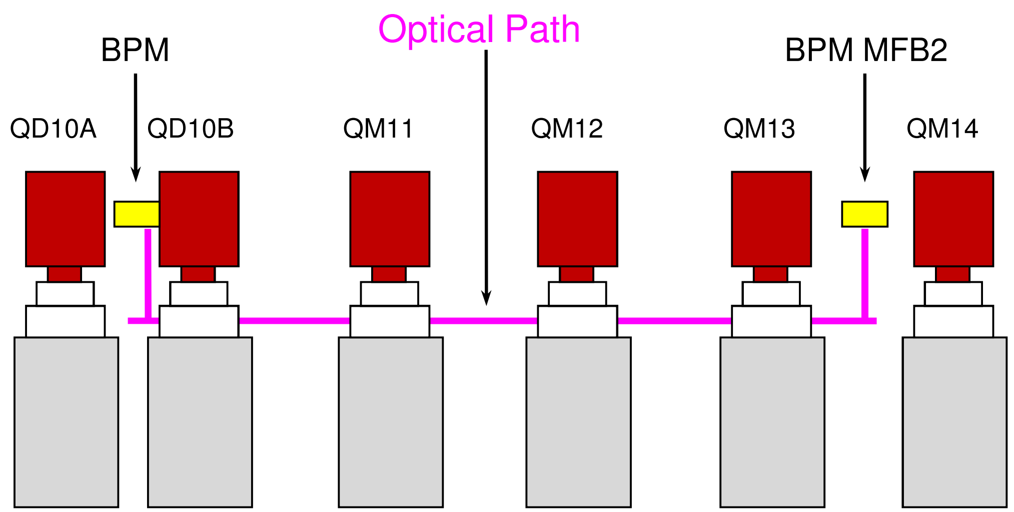
- Straightness monitor can be used to provide position measurements of BPMs used in the vertical IP steering feedback:



- BPM MFB2 is on a dedicated stand, not bolted to a quad
  - no means of monitoring mechanical drift/vibration
- Use interferometer system to measure relative heights of both BPMs, eventually feed back to steering correction

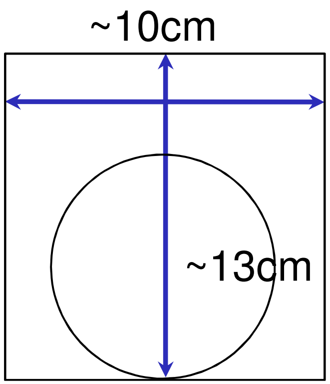
Proposed Layout

- Straightness monitor can define a line referenced to the support blocks of the quads
  - measure independent vertical displacements of BPMs relative to this horizontal line:



  - Simultaneously monitor stability of straight line

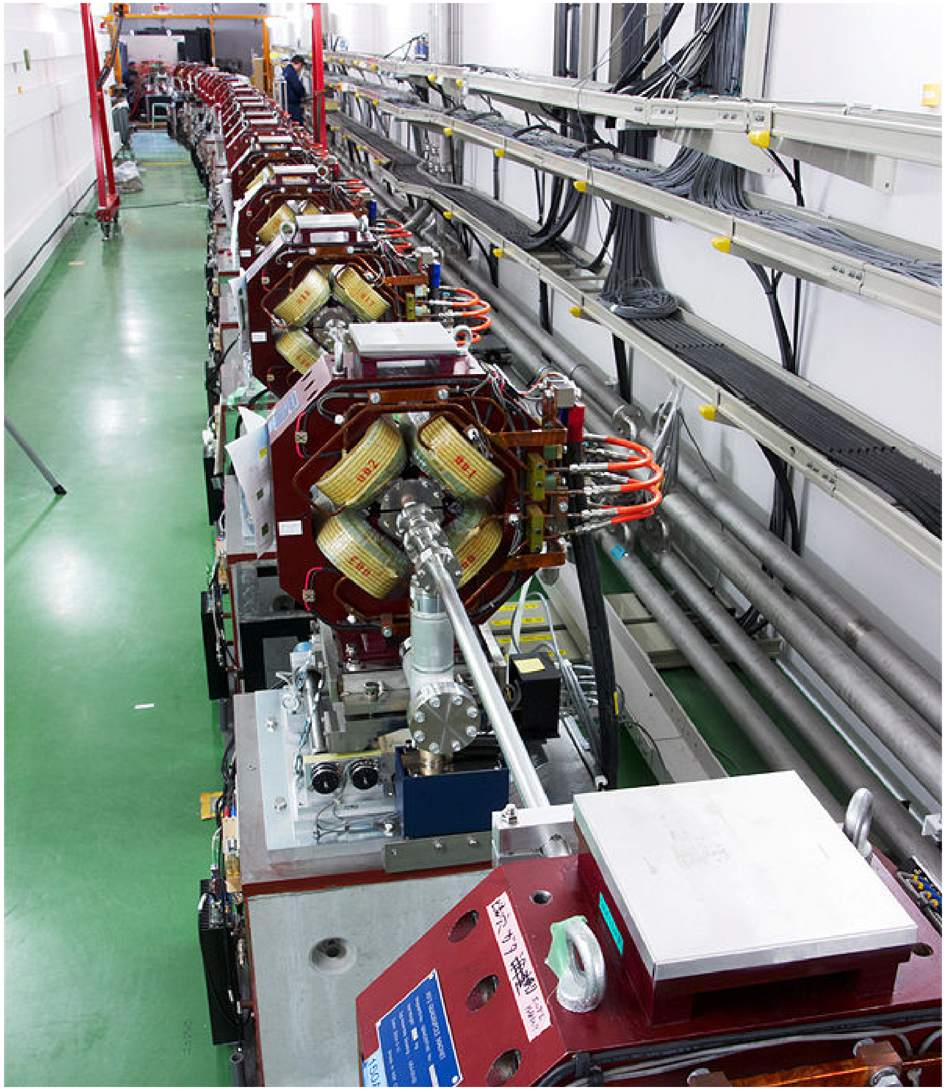
stay-clear under quads



plenty of room for a ~8cm diameter light pipe

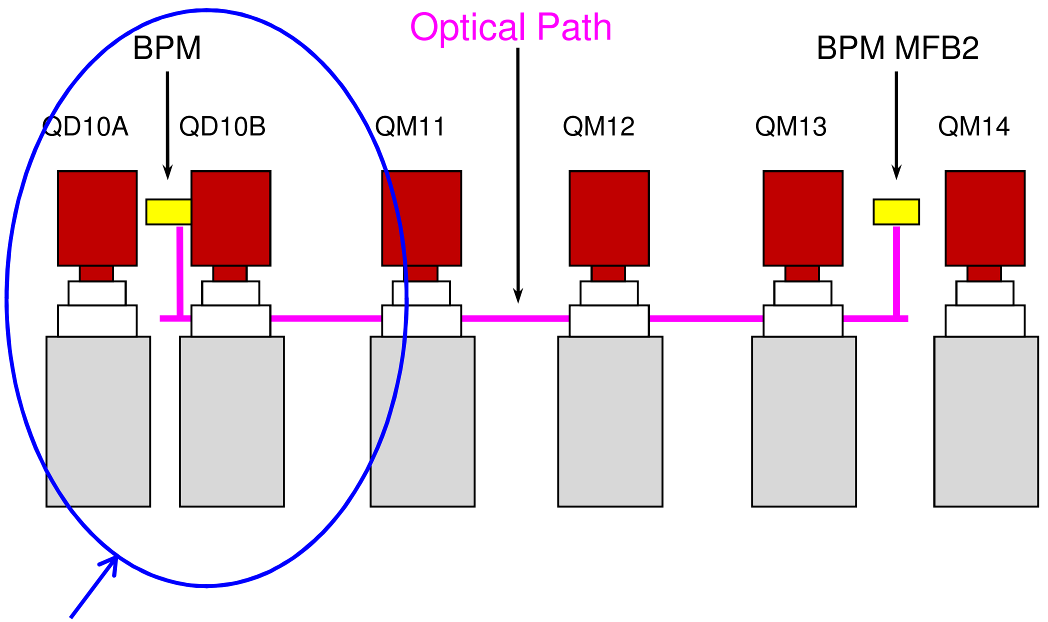
ATF2 Beamline:

- Straightness monitor installed in straight section: all quads



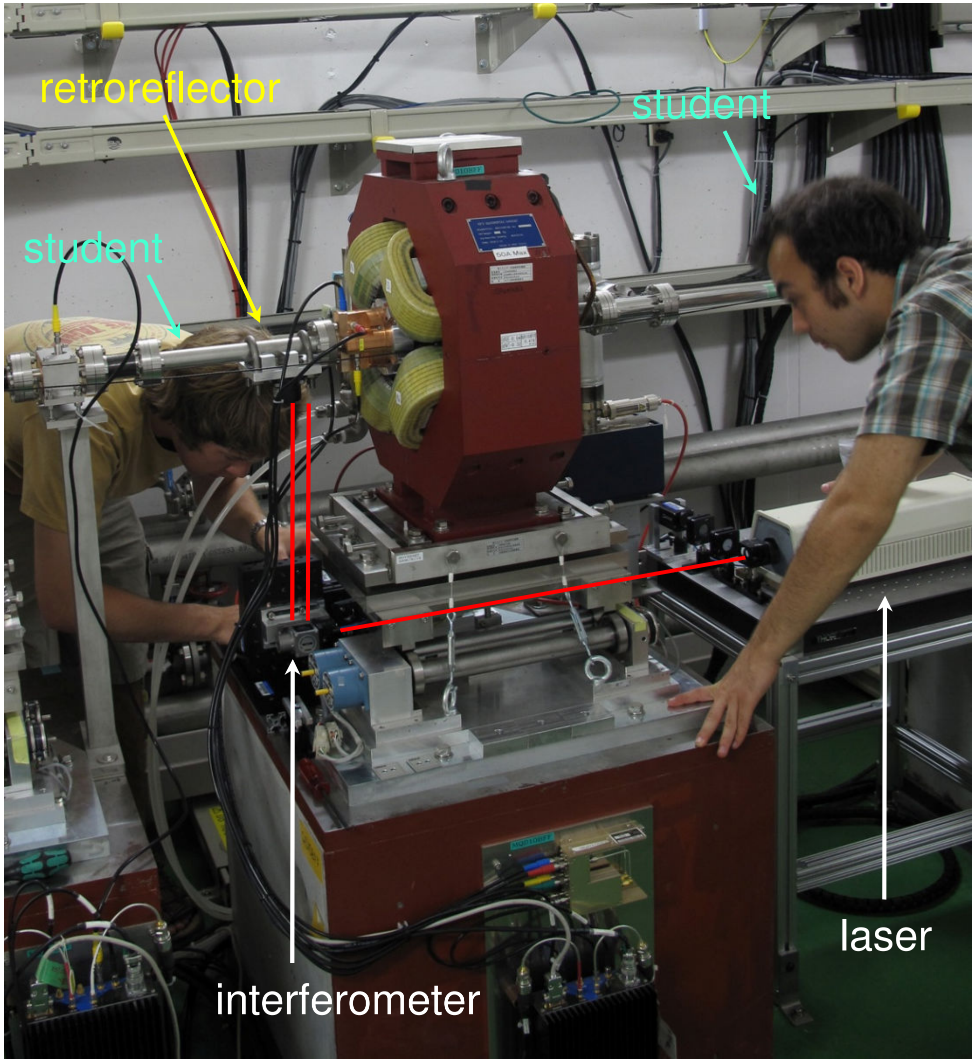
Schematic

- Full System (Later):
  - monitor relative (later, absolute) vertical positions of the two IP Steering feedback BPMs
- Optical path:



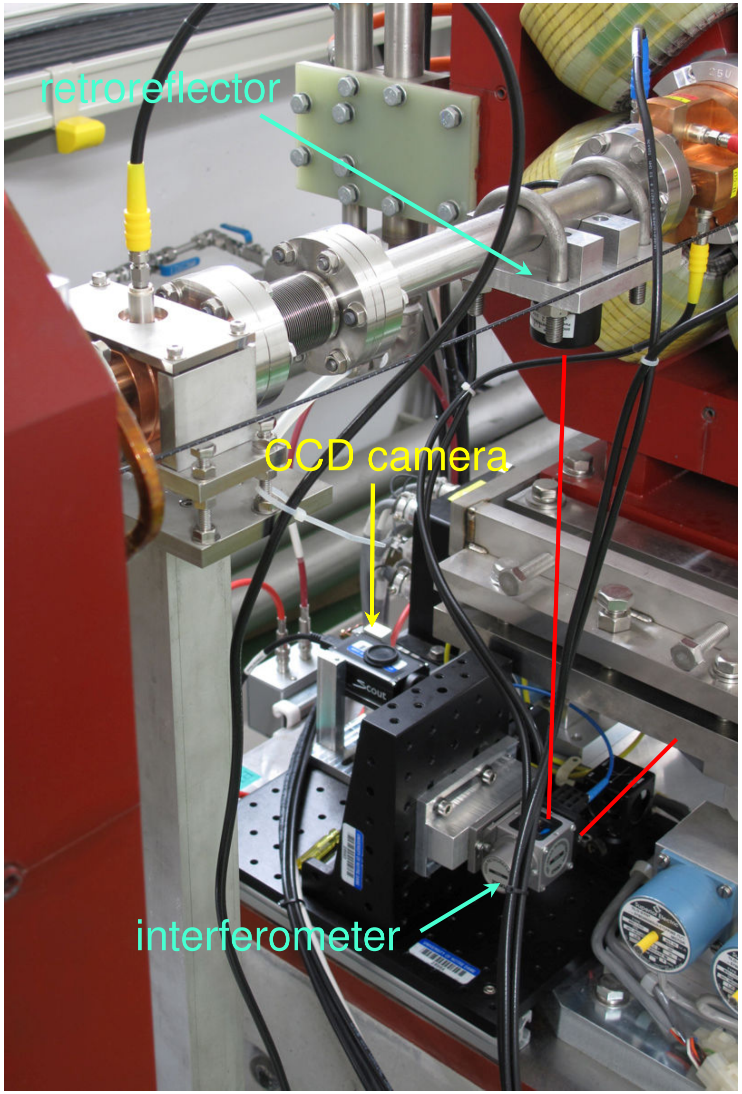
  - July installation

Photos

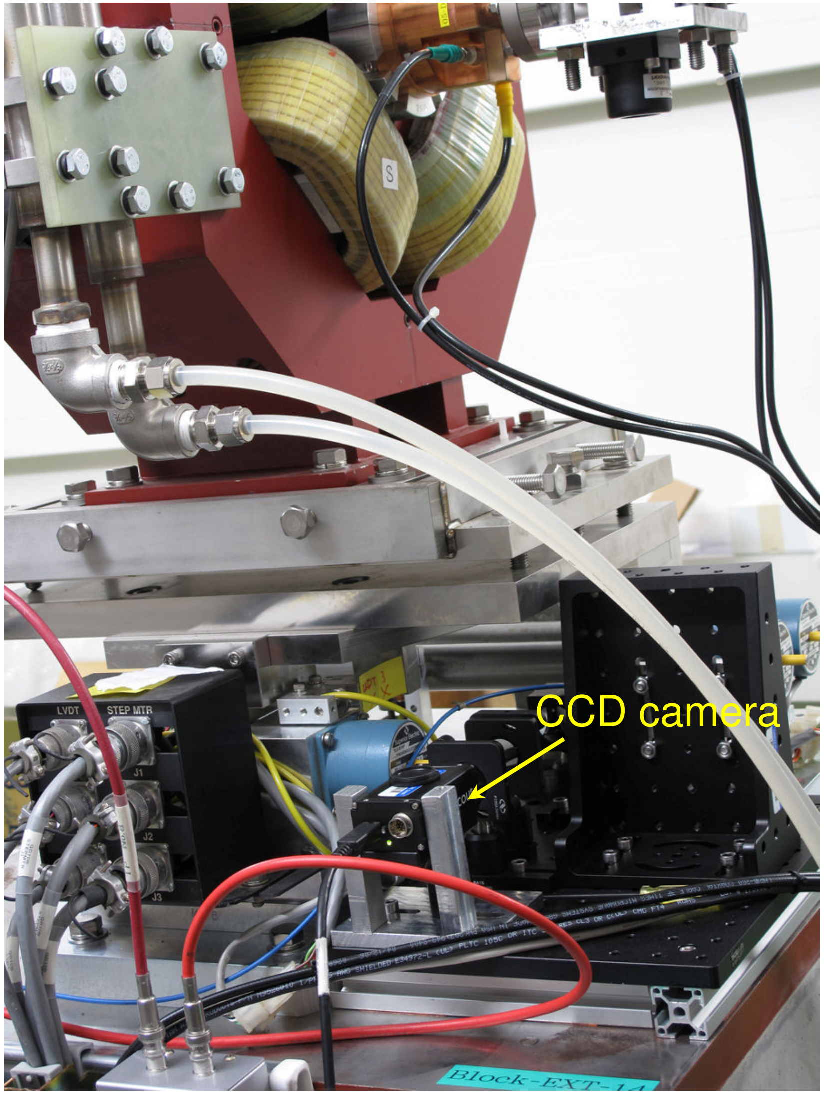

retroreflector
student
student
interferometer
laser


CCD camera
zygo
THORLABS

More Photos



view from aisle side



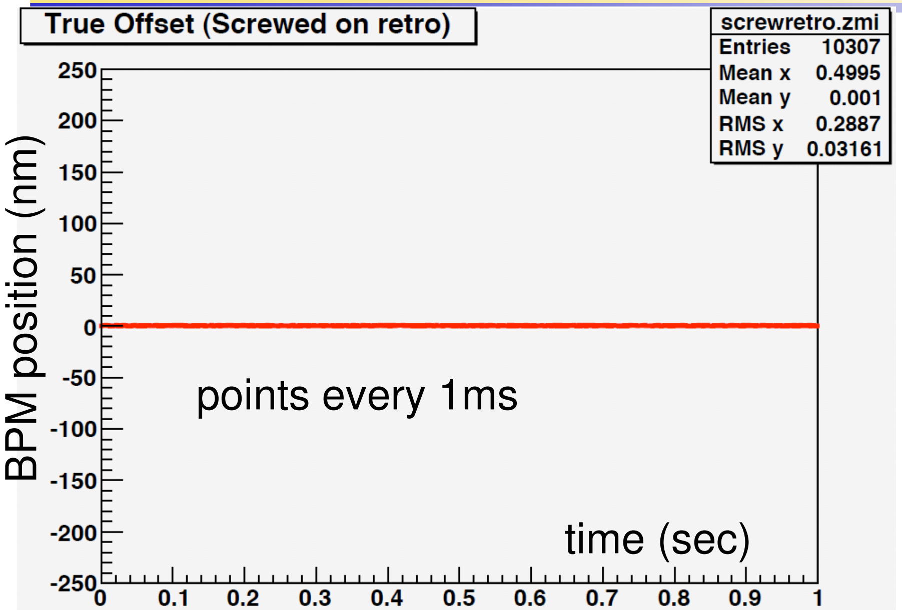
view from cable tray side

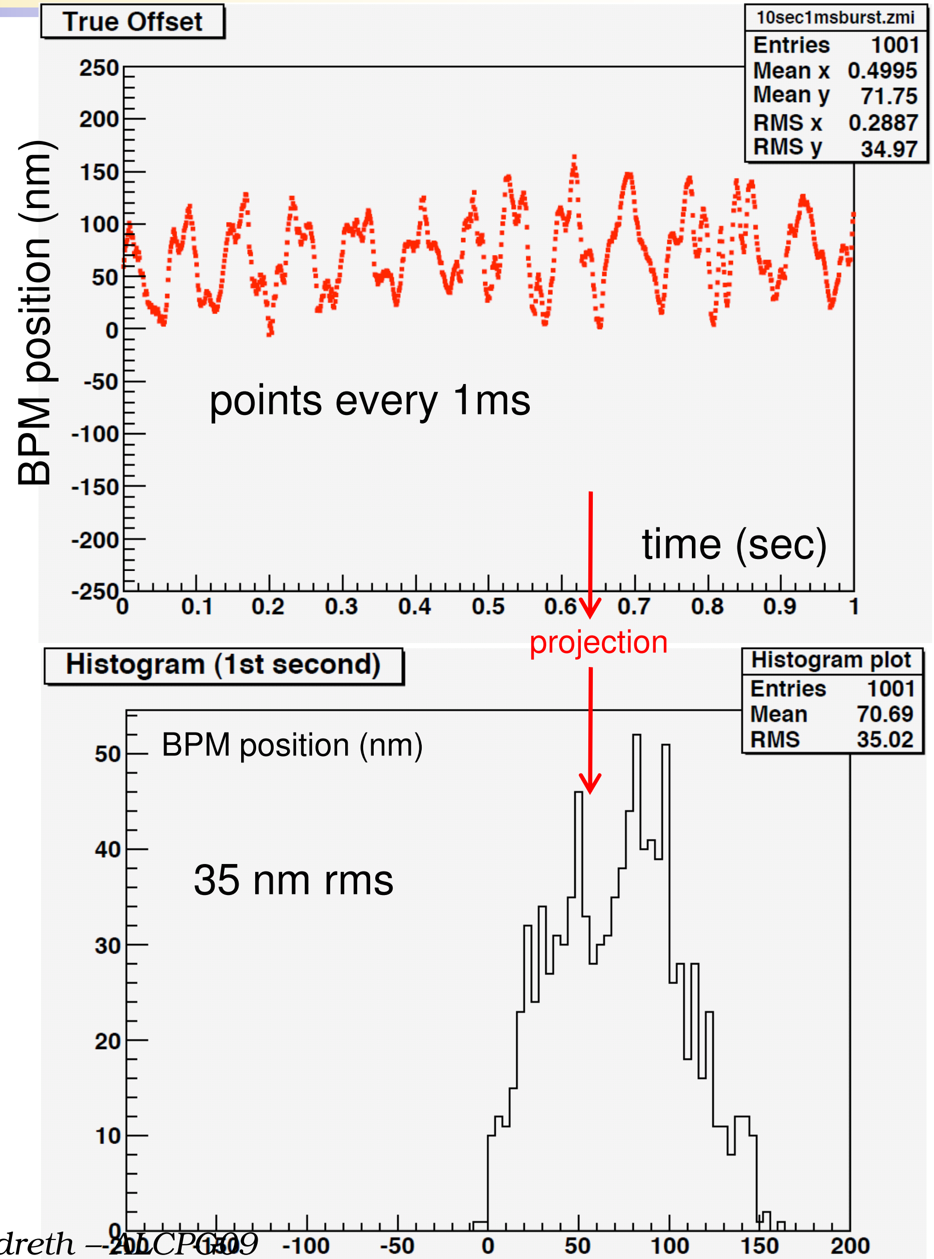
More Photos

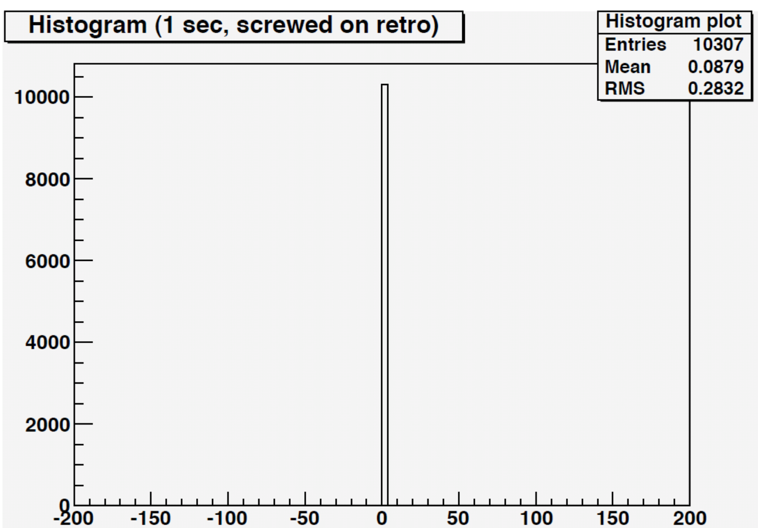
2 PCs, one for laser, one for CCDs

VME crate for interferometer DAQ

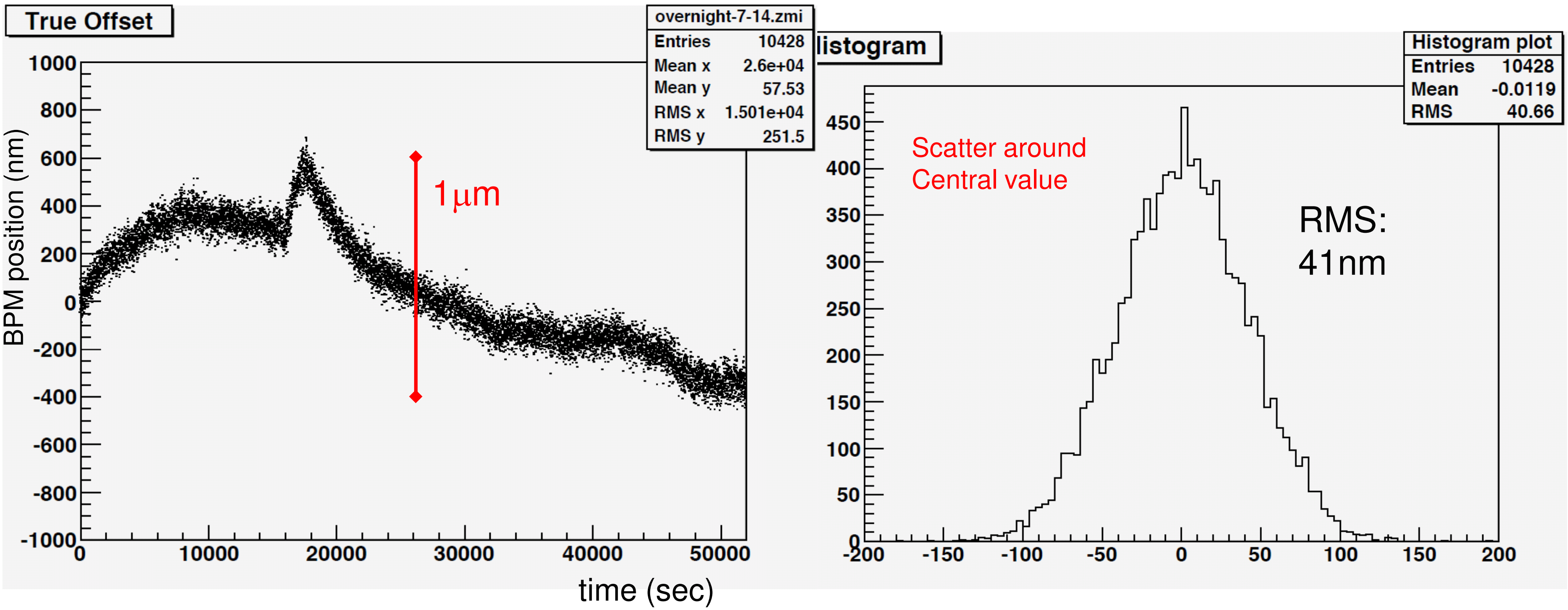
Initial Data: BPM Vibration





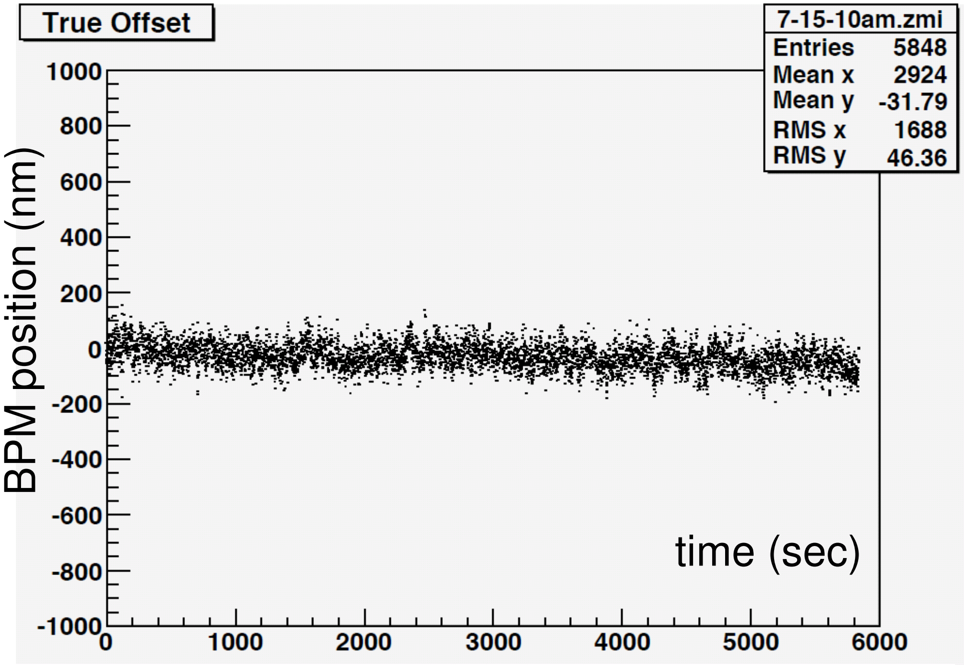


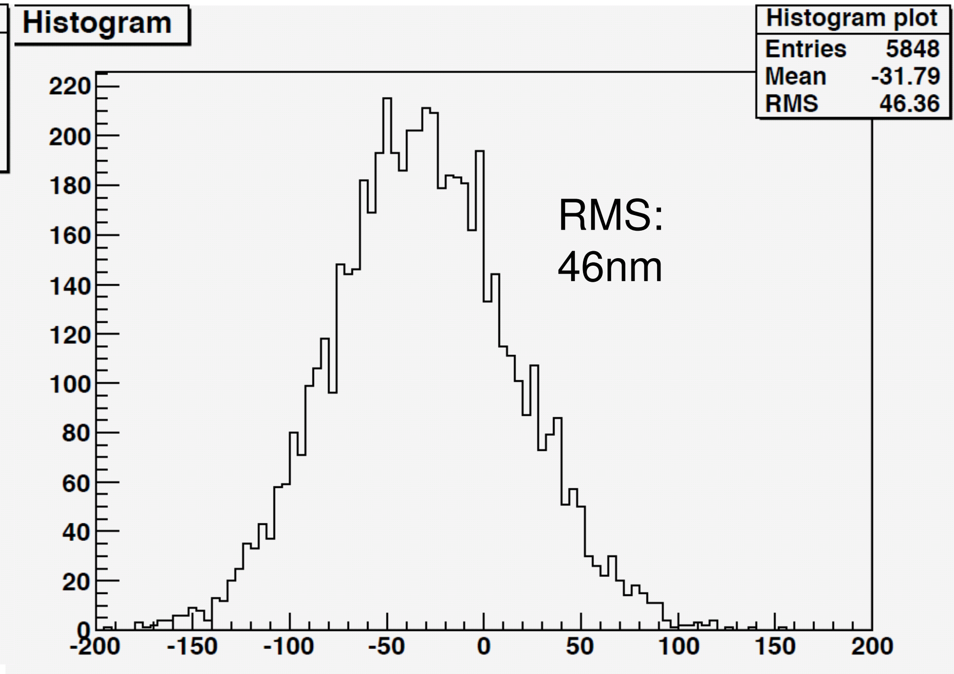
Initial Data: Overnight Stability



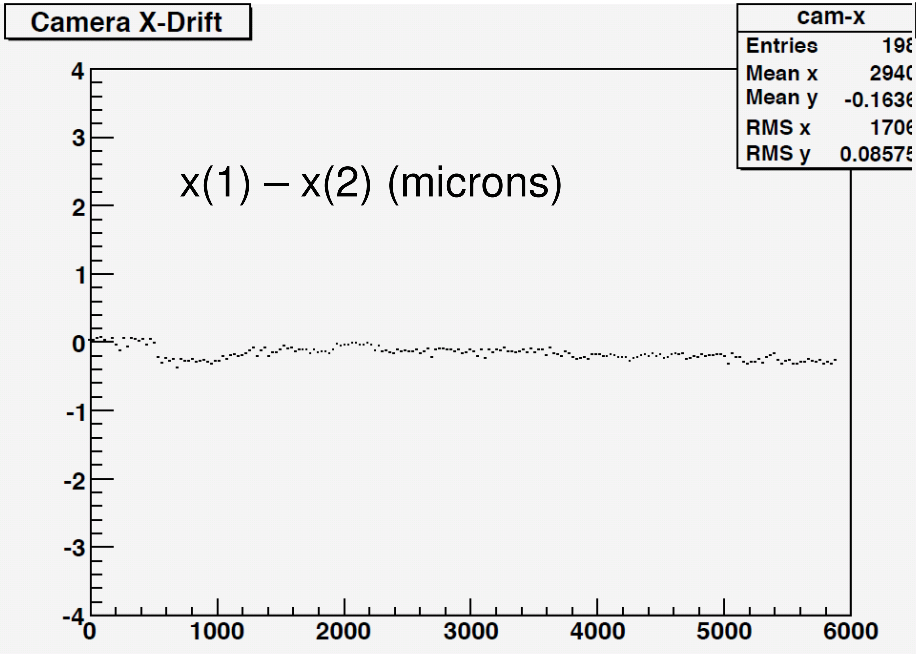
~One Hour run in daytime

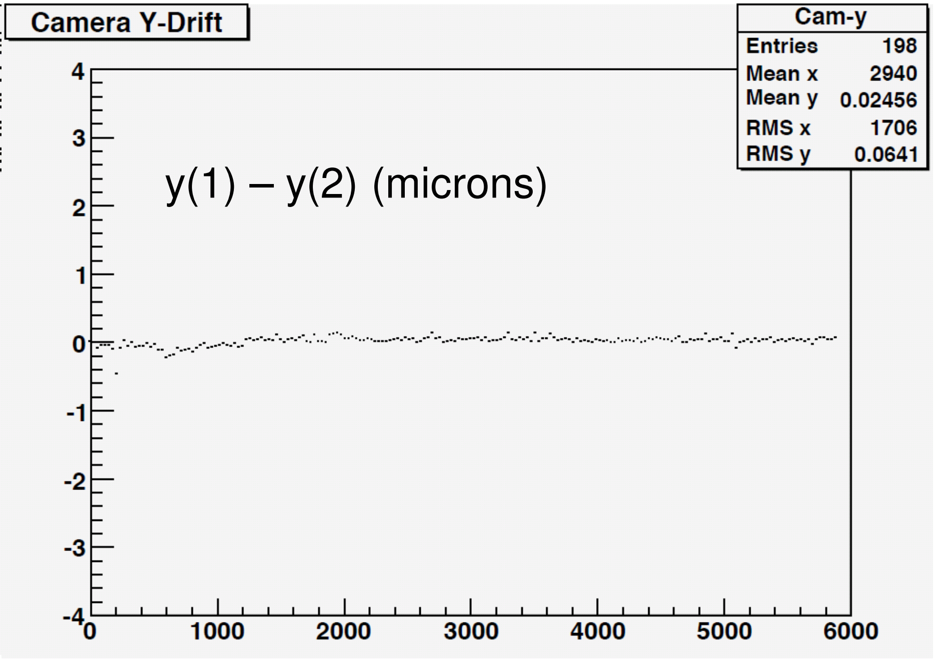
- No rolling average subtraction: raw data





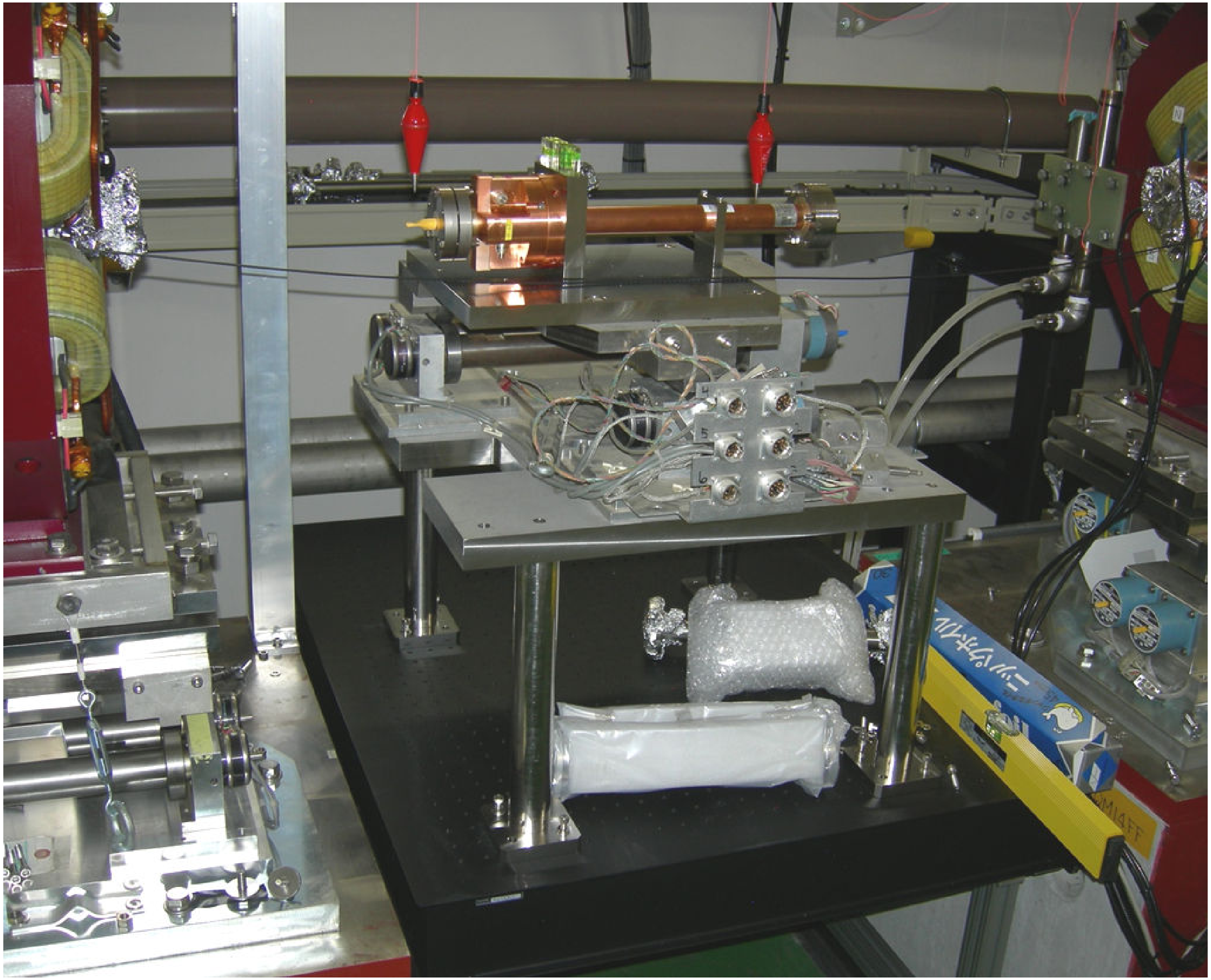
Camera Data: beam centroid





- Note: cooling water was not running for any of these measurements

MFB2 Installation



Completed
9/18/09

Status/Plans for ATF2

- Interferometer & Camera systems aligned and ready to record data
- DAQ now in final configuration for data-taking
  - For each beam pulse, we will take 3 interferometer points spaced by 0.5 ms after Kicker Fire Pre-Trigger
  - camera data will be updated every 30 seconds with an average position computed in the DAQ

- Return visit to KEK in two weeks to configure system for monitoring both Feedback BPMs
  - take advantage of MFB2 installation to gather data on correlated motion of two BPMs
  - upgrades for higher resolution/stability are possible
    - evacuated tubes, reference to ATF floor, etc.

    $\Rightarrow$ depends on what the 2009 data reveal

Future Plans(?)

- Basic Goal: Performance tests of realistic spectrometers
  - Investigate calibration procedures and systematics due to
    - BPM electronics stability
    - mechanical stability
    - magnetic fields
    - sensitivity to beam parameters

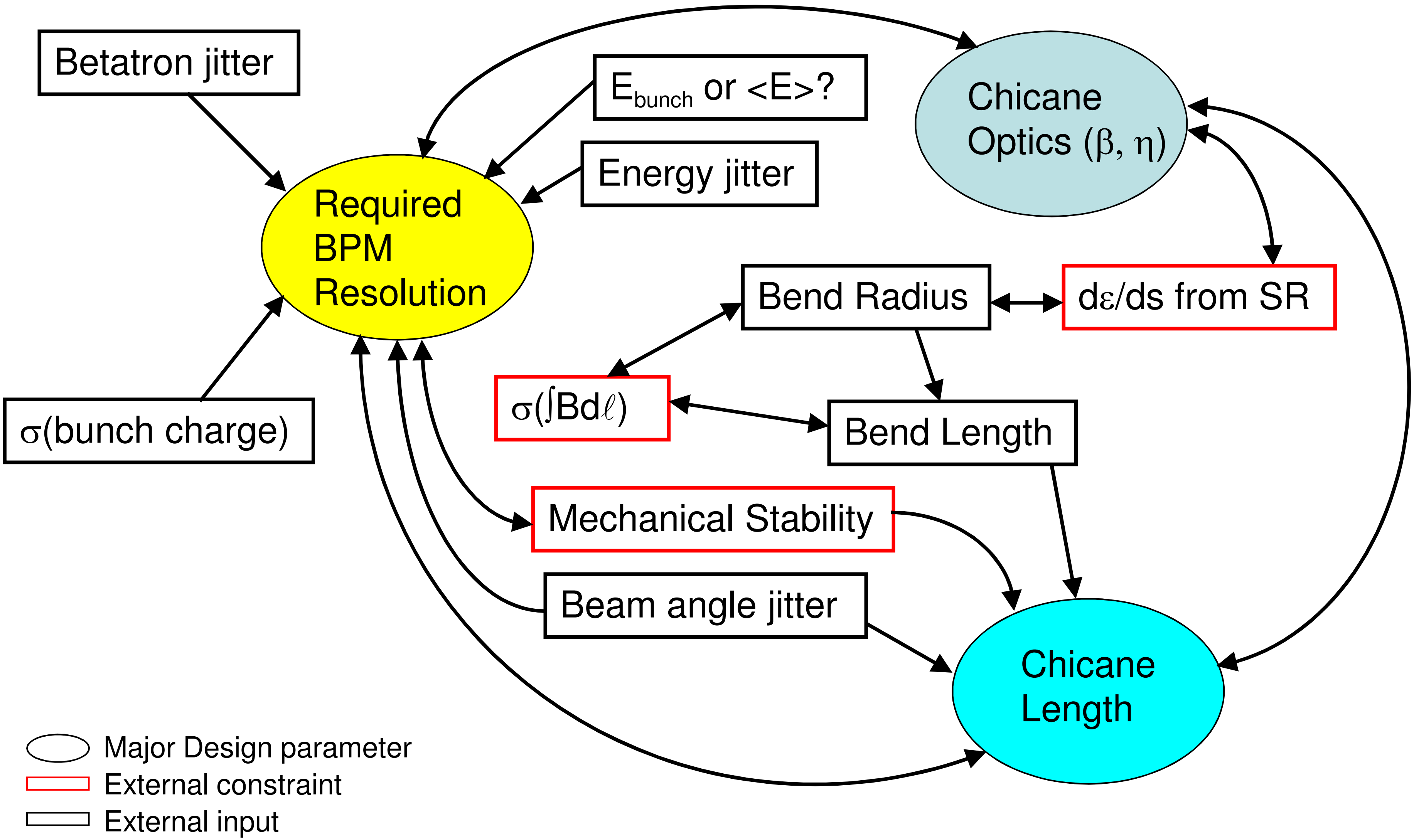
    Integrated System test is critical; examples of individual elements with << 100ppm resolution already exist
  - compare results from BPM, synch stripe measurements and upstream beam diagnostics
- Rate of progress funding- and facility-limited
  - do not have any designs with proven resolution
    - complicated, multi-element systems working at tiny resolutions
    - components slow to fabricate/build/install/understand
  - do not have primary electron test beam facility with sufficient beamline space for system testing, comparison of techniques

Beam/Facility Requirements

- NLC-like beam:
  - ~1-2x10^{10} e/bunch to get adequate beam diagnostics
  - similar bunch lengths
  - ideally, approximate beam sizes that will be found in BDS
  - "high" energy (>10 GeV) desirable
    - "scale" bend angles at realistic dipole fields
    - get some approximation of SR backgrounds, showering, etc.
  - multi-bunch capability could be useful
- Real Estate:
  - current chicane will be 30m long, systems are about 2m wide
  - crane: will end up moving magnets at some point
  - provides realistic test of system integration in beamline environment
    - e.g.: girder vibration, etc.

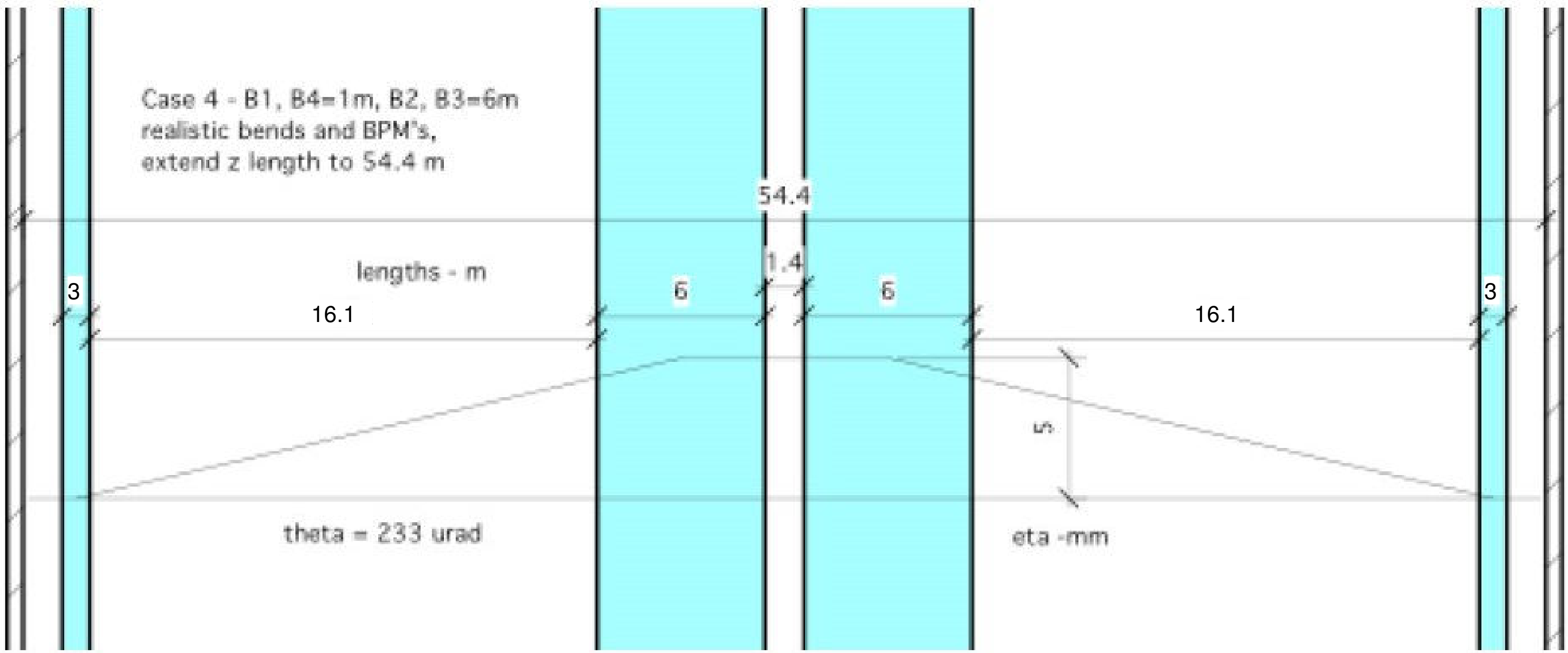
Additional Slides

Upstream: Design Constraints



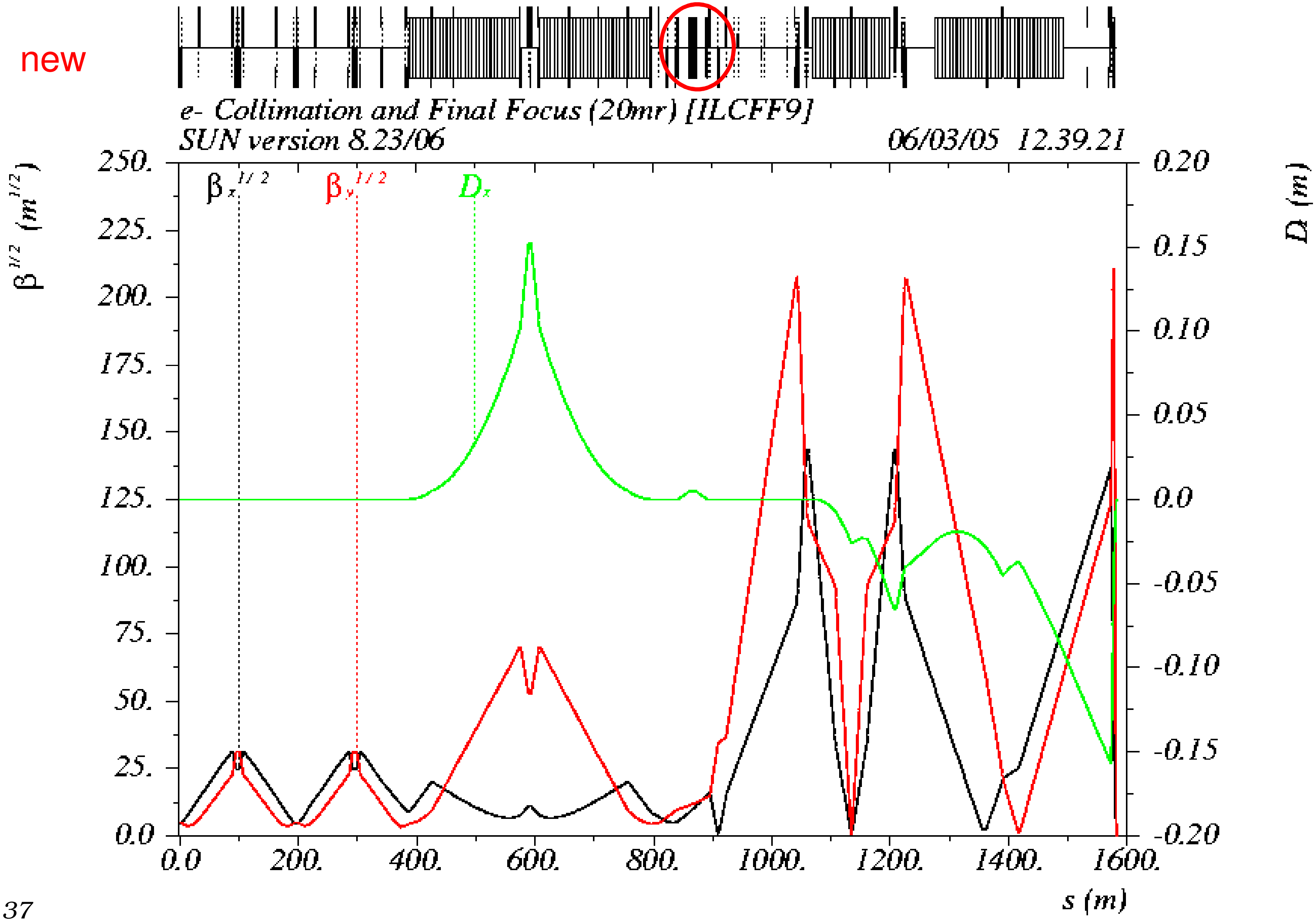
Prototype

- Presented at Jan 2005 MDI Workshop at SLAC
  - first attempt at an optimization within the available parameter space
  - large, softer bends at high-dispersion point to minimize emittance growth from synchrotron radiation

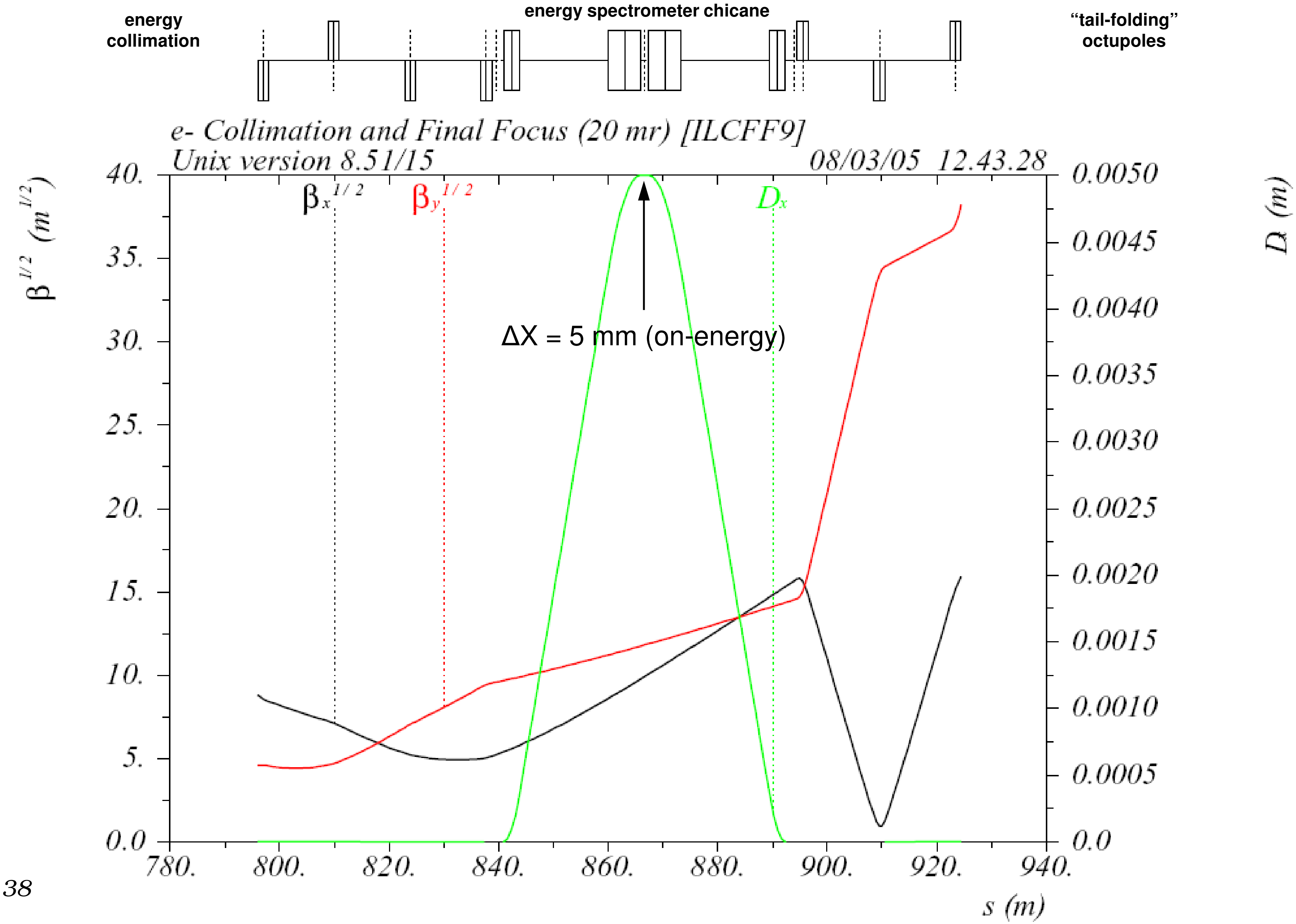


Progress: New Optics!

new

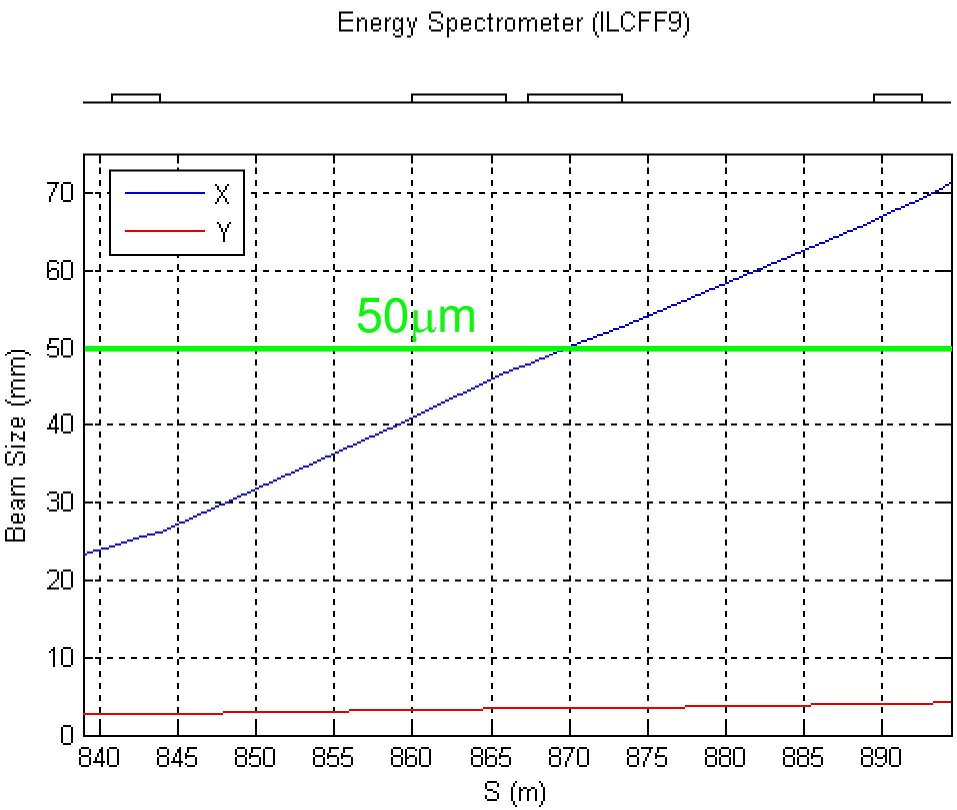


Optics: details



Optics: more details

Comments:



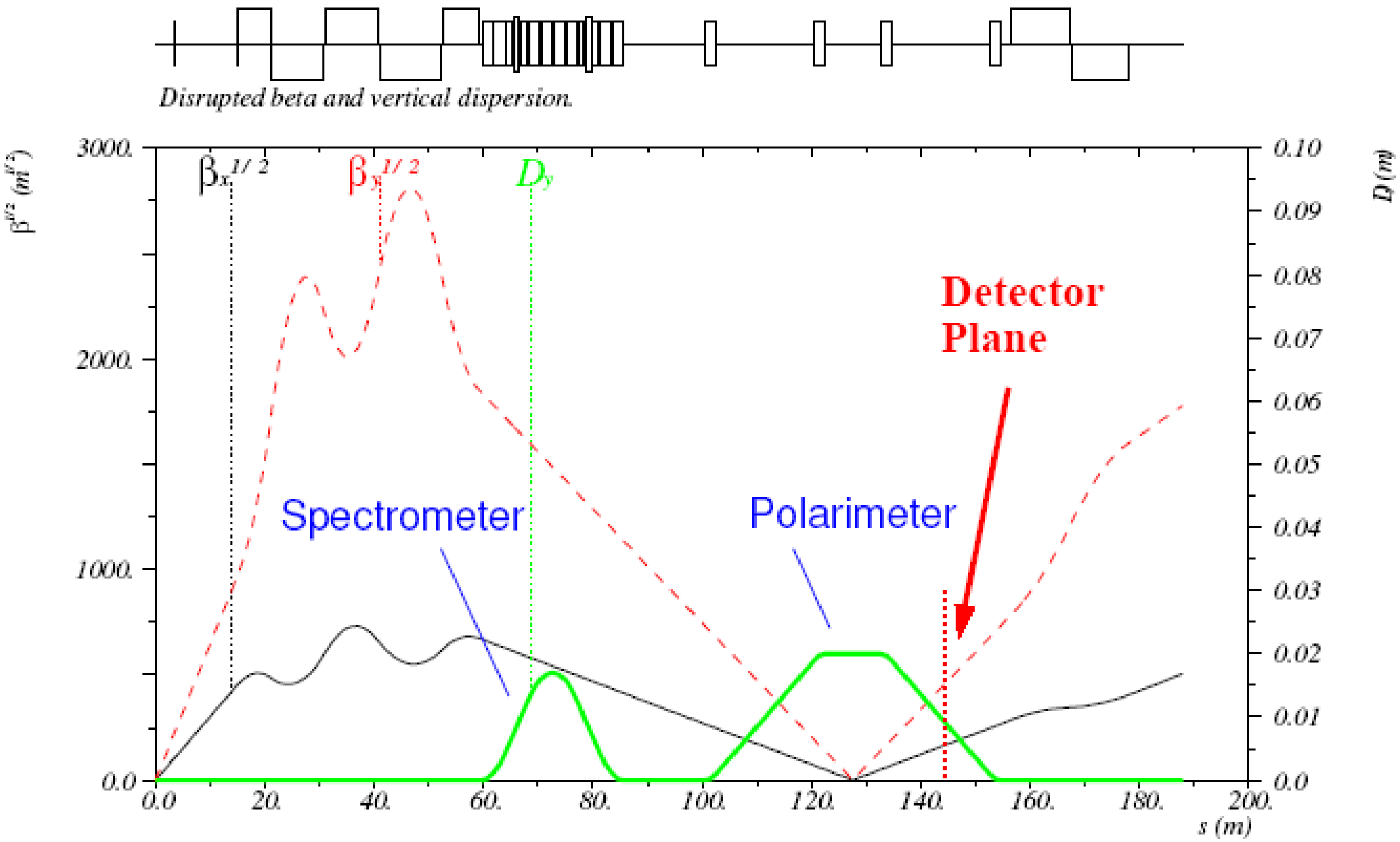
$\Delta\gamma\varepsilon_x = 1.2\times10^{-10}$ @ 250 GeV
$= 7.5\times10^{-9}$ @ 500 GeV

⇒ small beam growth due to SR

- much smaller beam sizes than previous sketch (x5)
- high dispersion
  - makes measurement easier
- longer (~55m)
  - ditto
- Basically, meets many of the constraints on spect design
- betatron phase issues while scanning B field?

Downstream Spectrometer

- Also, new optics (20 mrad)



ESA Program

- ESA provides “ILC-like” beam in “realistic” conditions:

Parameter	**SLAC ESA**	**ILC-500**
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
e^- Polarization	(85%)	>80%
Train Length	up to 400 ns	1 ms
Microbunch spacing	20-400 ns	337 ns
Bunches per train	1 or 2	2820
Bunch Charge	2.0×10^{10}	2.0×10^{10}
Energy Spread	0.15%	0.1%

  - Can always tweak jitter parameters to make things worse
  - Can “simulate” beamstrahlung pair production by using radiators
  - Complementary to ATF tests