Machine-Detector Interface Elements for Precision Measurements and Luminosity Optimization

A Review of the US R&D Program

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Representing the MDI Research Groups

Argonne National Laboratory, June 19, 2007

Overview

- MDI: Catch-all category that includes all instrumentation:
  - necessary to do precision physics
    - Luminosity/Energy/Polarization (L-E-P)
    - measure/mitigate effects of beam-beam interaction to minimize systematic errors

  Part 1

  - or -

  - that must be installed inside the particle detector at or near the interaction point
    - e.g., beam diagnostics for luminosity optimization
    - use byproducts of beam-beam interaction to measure and correct beam parameters

  Part 2

- Common Theme:
  - instrumentation extremely close to the primary beam
    - integrated into accelerator lattice or Interaction Region

Summary of US R&D Efforts

- L-E-P:
  - Luminosity (& 2γ veto):
    - LumiCal/BeamCal: BNL/Yale/Colorado/SLAC
    - BHLumi Update: Baylor
  - Energy:
    - BPM-Based Magnetic Spectrometer: Notre Dame/SLAC/LBNL
    - Synchrotron Stripe Spectrometer: Oregon/SLAC
  - Polarization:
    - Chicane Design/Optimization: Tufts/Oregon/SLAC
    - Calorimetry: Iowa/Iowa State
- Diagnostics:
  - Luminosity Optimization:
    - BeamCal/GammaCal: BNL/Yale/Colorado
    - Coherent and Incoherent Beamstrahlung: Wayne State

Precision Beam Measurements

Precision Physics Measurements *require* precise determination of beam parameters – How well do we have to do?

Luminosity, Differential Luminosity Spectrum:

- Total cross sections: $\delta L/L \sim 0.1\%$
- Lineshape scans (Giga-Z) $\delta L/L \sim 0.02\%$
- Threshold scans (e.g., m_{top}) $\delta L/L \sim 1\%$, but additional constraints: dL/dE core to 0.1%, tails to ~1%

Energy:

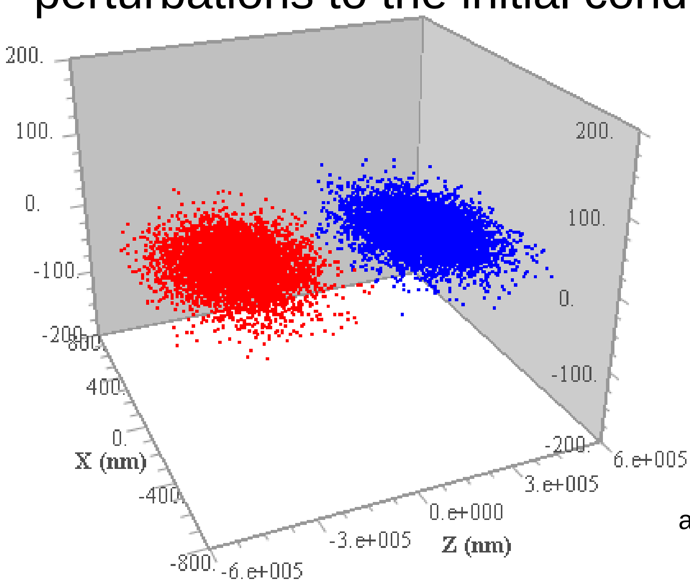
- top, higgs masses 200 ppm ($\delta m/m$ = 35 MeV for top)
- W mass with threshold scan 50 ppm (4 MeV)
- A_{LR} with Giga-Z 200 ppm (comparable to 0.25% Pol) 50 ppm (if $\delta P/P \sim 0.1\%$)

Polarization:

- Standard Model Asymmetries $\delta P/P < 0.25\%$
- A_{LR} with Giga-Z $\delta P/P < 0.1\%$

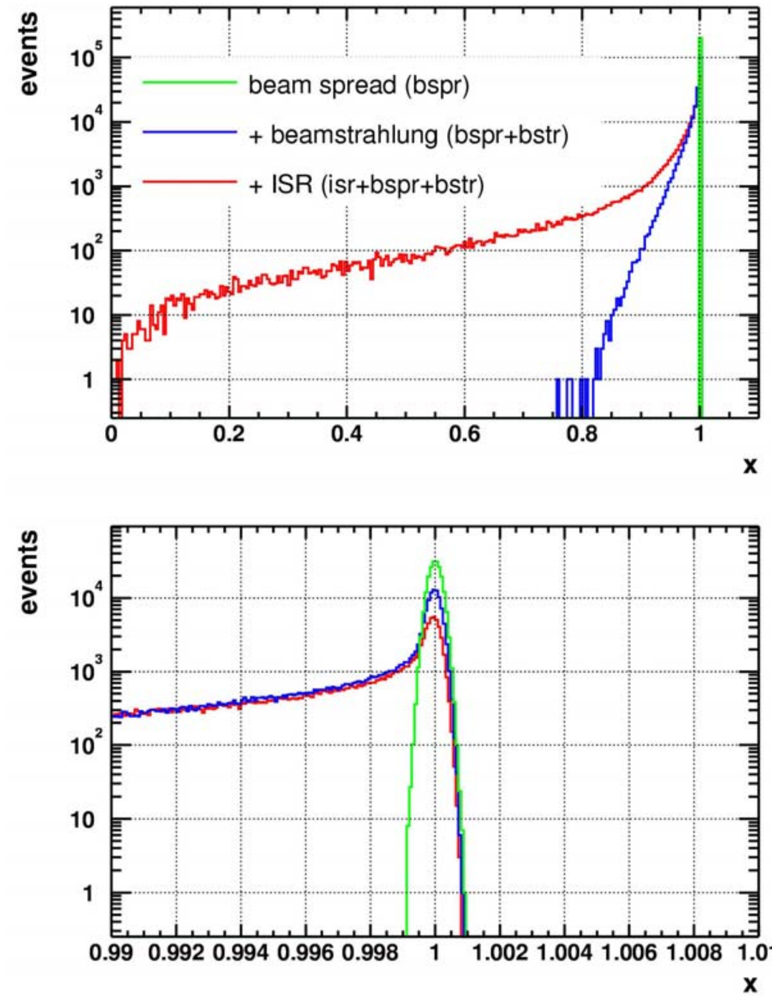
Why is this hard?

- These constraints aren't far beyond current achievements...
- But:
  – huge non-linear forces/fields in collective beam-beam interaction can cause large perturbations to the initial conditions



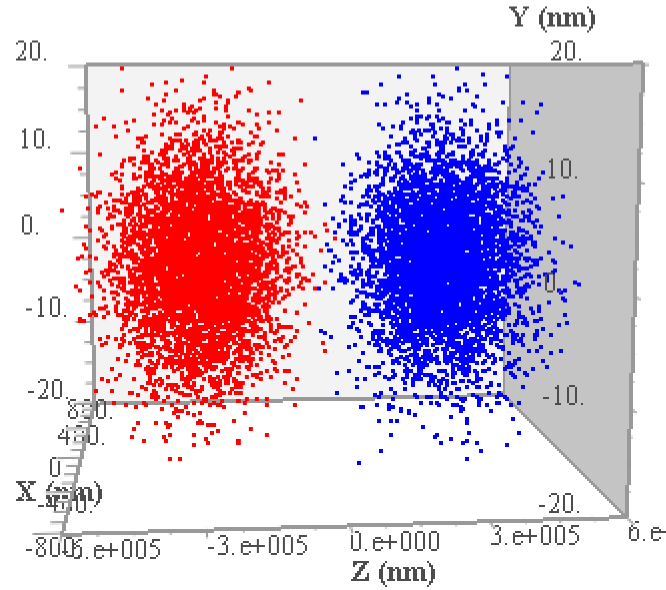
animation: A. Seryi

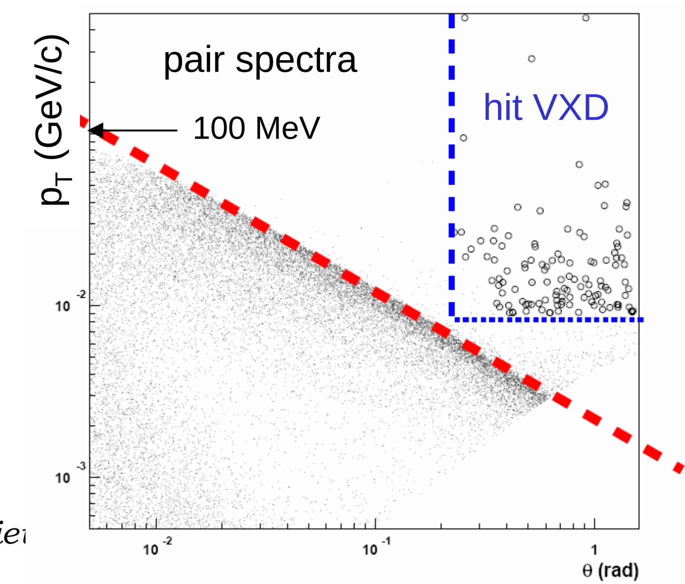
... And, we only care about the luminosity-weighted average of these effects, since that is the physics



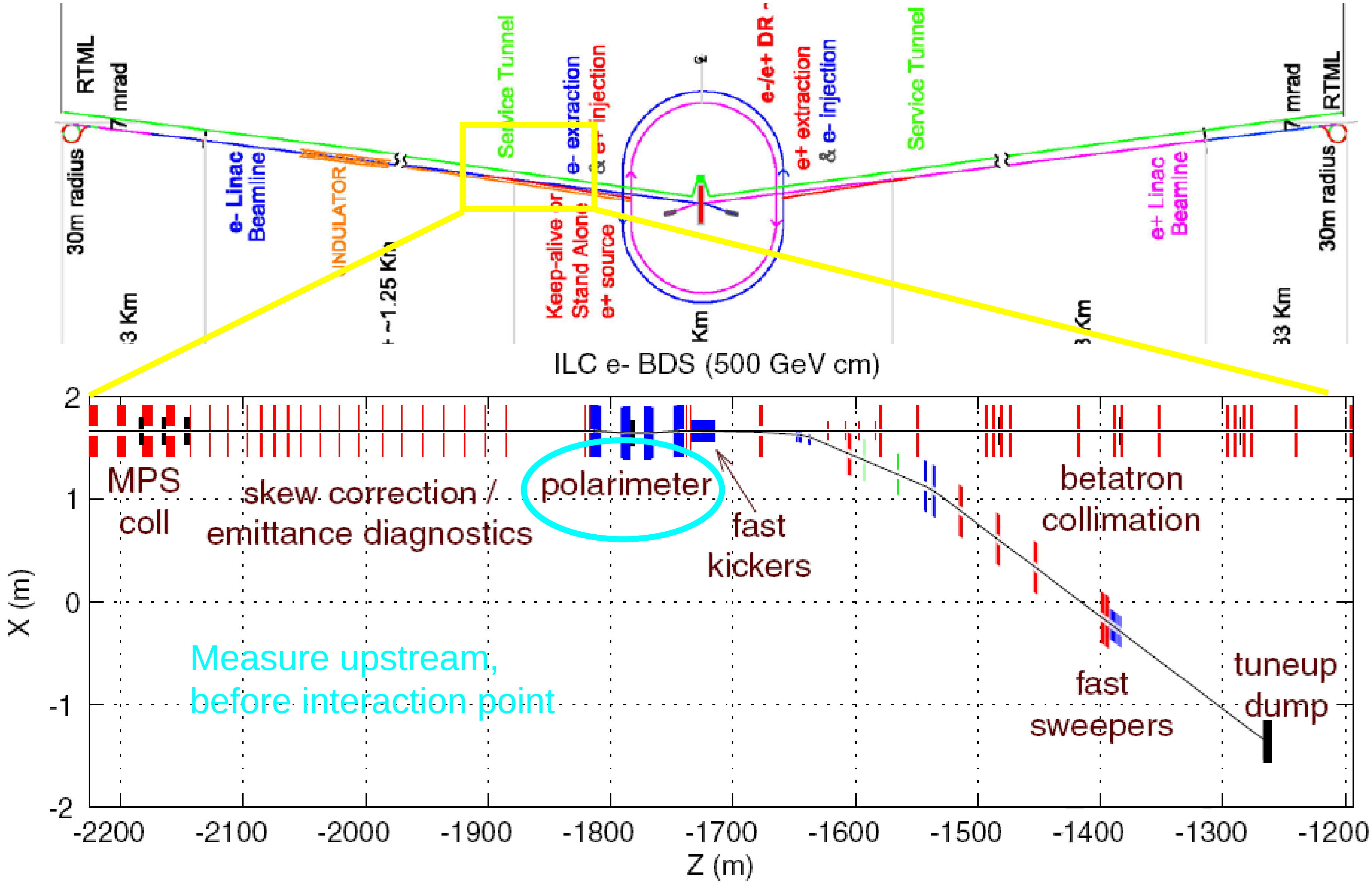
Beam-Beam Effects

- In the collision, you have
  - Disruption
    - pinch effect due to intense fields
    - enhances Luminosity
    - introduces *z*-dependance to L
  - Beamstrahlung
    - particles radiate in the collective field of the oncoming bunch
    - effects dL/dE
    - effects polarization?
    - high-intensity photon beam (to dump)
  - pair-creation
    - radiation pair-creates in the collective field of the oncoming bunch
    - >500k pairs/bunch crossing
    - have to be kept out of the detector!

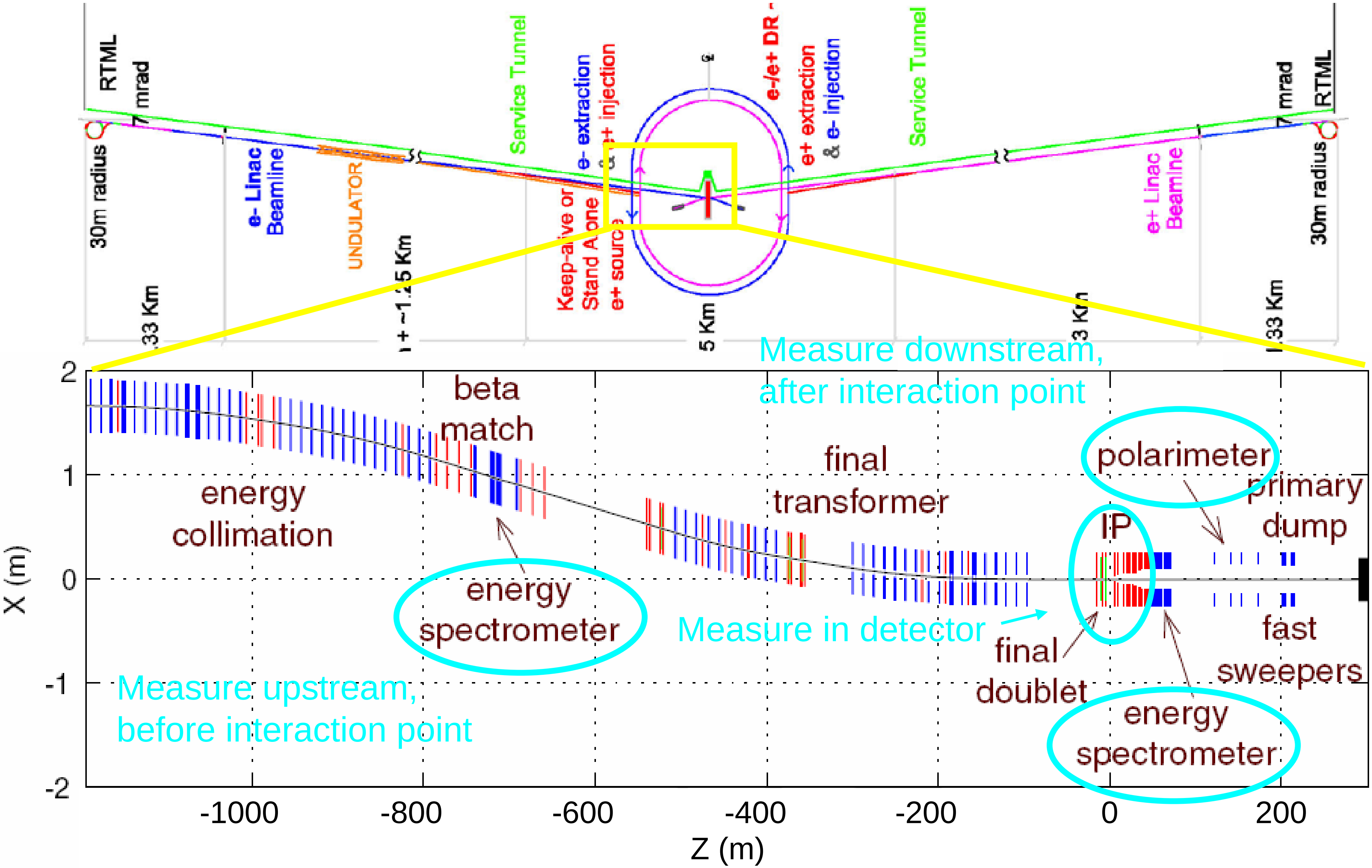




Basic Strategy: Many Redundant Tools



Basic Strategy: Many Redundant Tools



Must also include measurements of luminosity-weighted quantities from detector

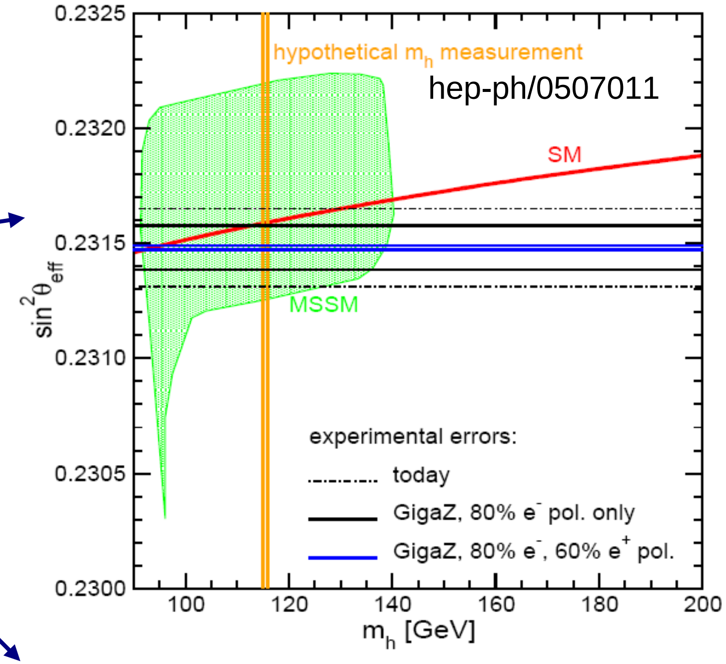
L-E-P Measurement Strategies

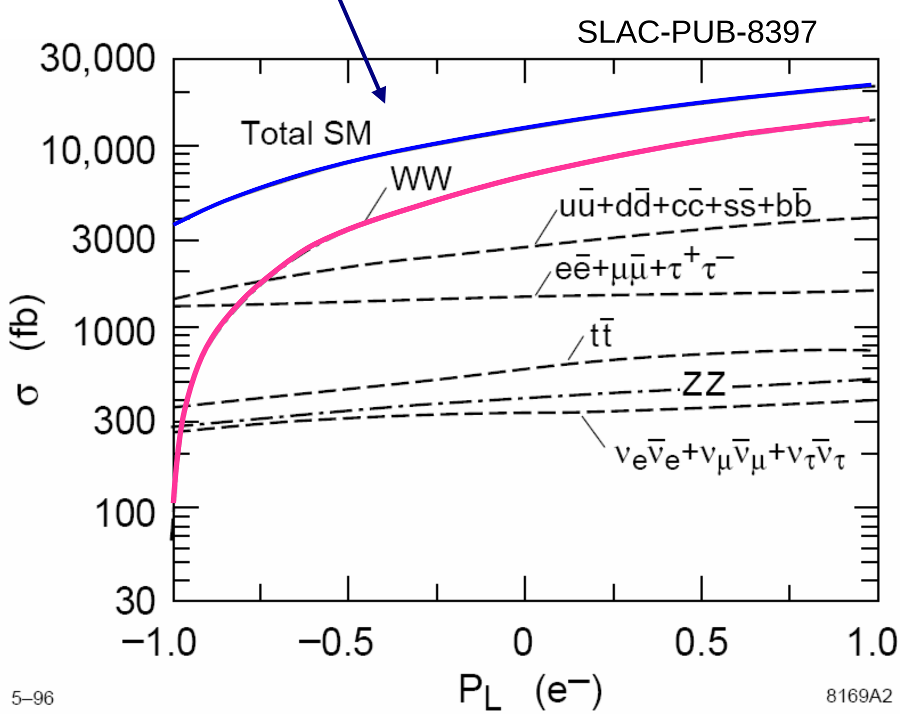
Integrated Detector + Machine efforts necessary for each

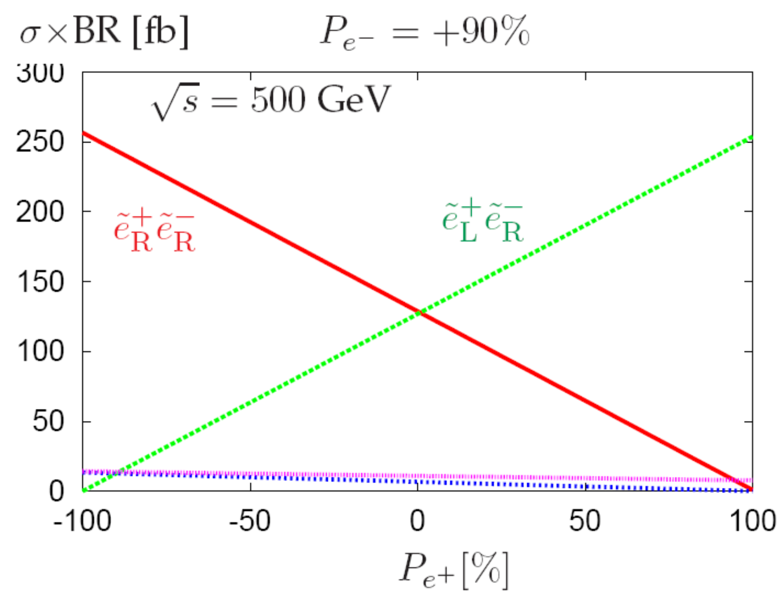
- **Luminosity and dL/dE**
  - dedicated Luminosity Calorimeter at small angles
    - "Traditional" e^+e^- luminosity measurement
  - dL/dE from bhabha acolinearity
  - Energy Spectrum from downstream Energy Spectrometer
- **Energy**
  - Upstream Spectrometer
    - BPM-type based on LEP installation
      - only sensitive to average energy
  - Downstream Spectrometer
    - Synchrotron Stripe-type based on SLC installation
      - can measure energy spectrum
  - radiative $\gamma Z \rightarrow \mu\mu$, $e+e^-$ events measured in detector
- **Polarization**
  - Compton-backscattering, based on LEP/SLC experience
  - some SM asymmetries (WW) can also be used

Polarization in Physics Processes

- Precise control and measurement of e^+ and e^- polarization provide many handles for disentangling new physics
  - precision A_{LR} complementary to measurements of higgs properties
  - direct separation of helicity states in SUSY searches
  - suppression of SM backgrounds

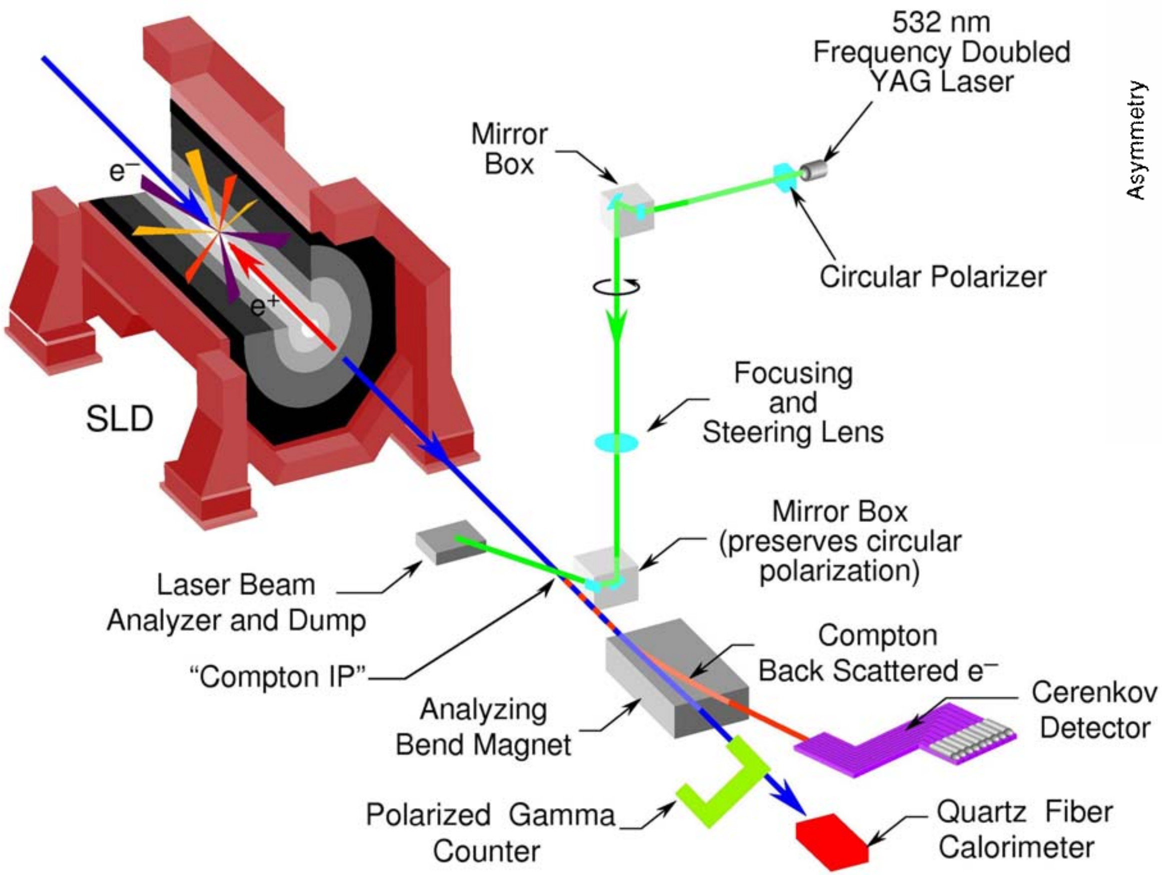


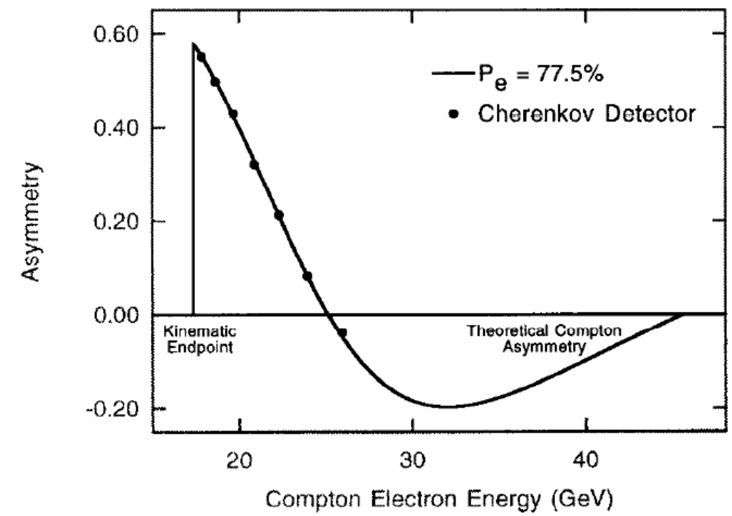




Polarimetry

- Use Compton back-scattered laser photons
  - Asymmetry in cross section is proportional to $P_\gamma \cdot P_e$
  - Reached $\delta P/P \sim 0.6\%$ in SLC/SLD





- Basic polarimeter design is believed to be sound
  - same upstream and down
    (DESY) (US)
- Focus is on better, more Radiation-hard detector technology and limiting systematic errors

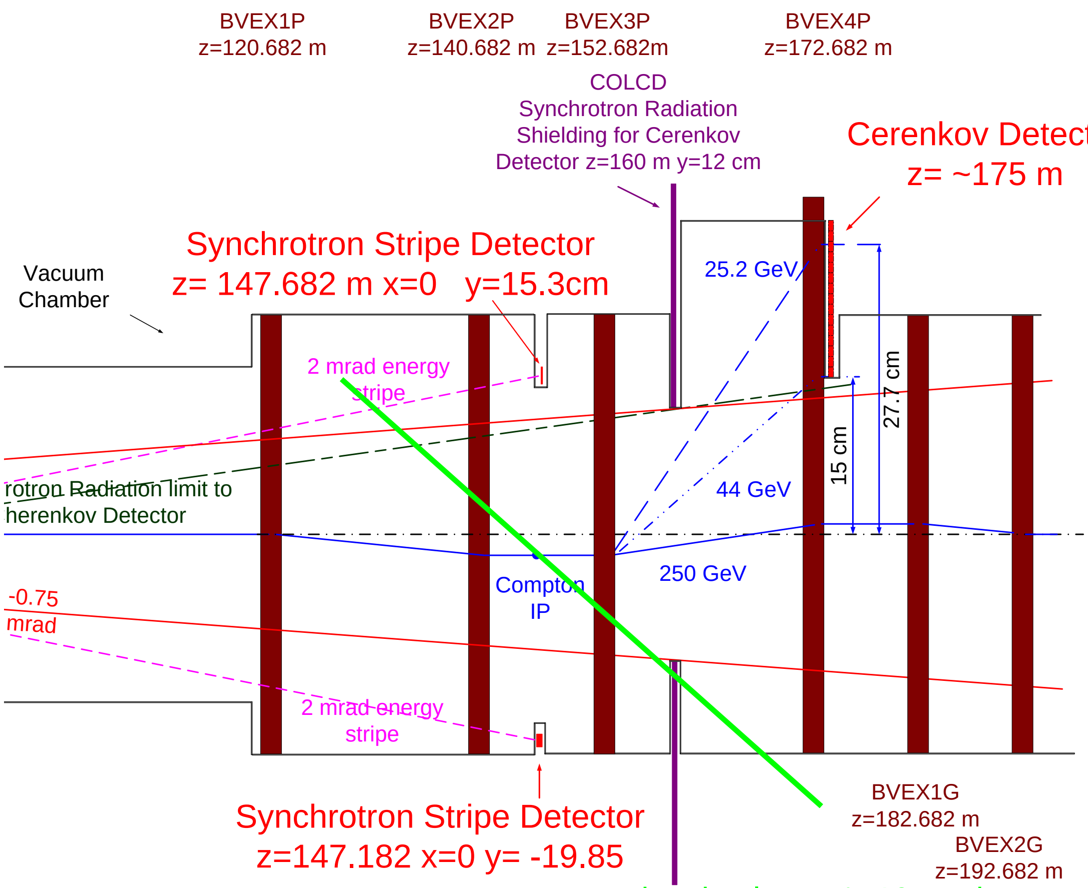
Extraction Line Polarimeter

- Extraction Line geometry is difficult

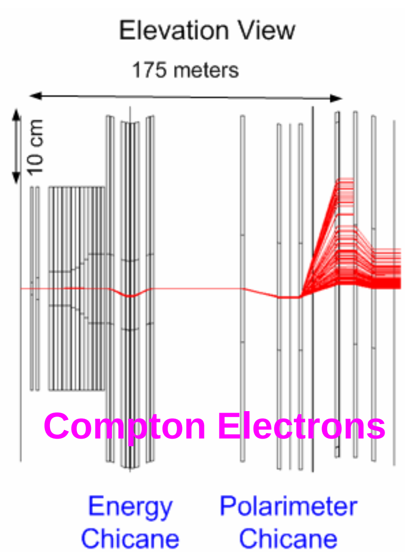
W. Oliver (Tufts University), SLAC

  - have to avoid incoming beamline, outgoing backgrounds
  - Designs have been driven by SLAC/Tufts group from beginning

Polarimeter Chicane

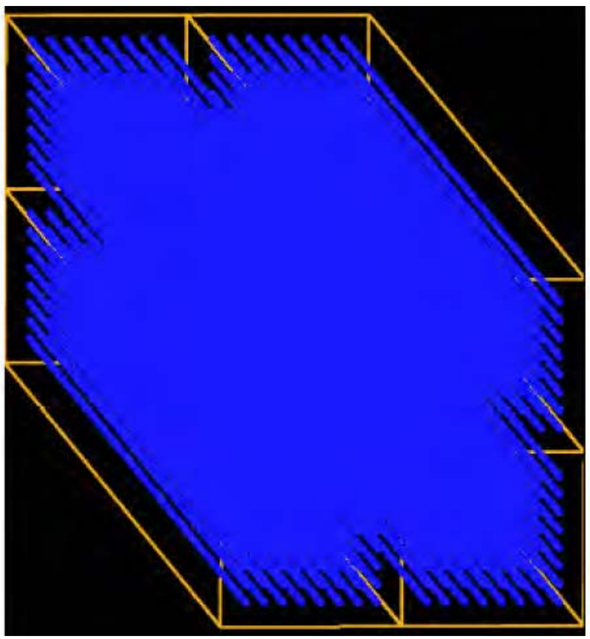


- design backed by extensive transport studies of backgrounds, compton-scattered e⁻

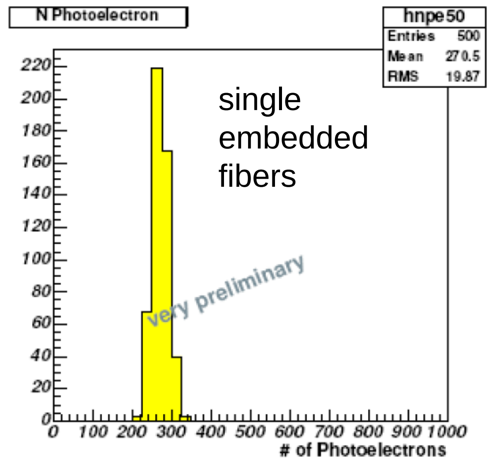


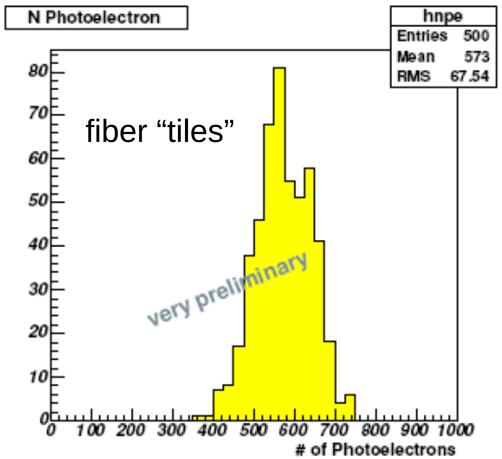
Calorimetry for Compton Polarimetry

- Exploring alternatives to “traditional” multi-channel Cerenkov detector using tungsten/quartz-fiber technology from CMS
  - maintains suppression of low energy backgrounds due to high Cerenkov threshold in fibers

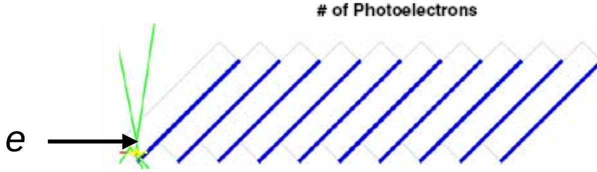


Fibers run parallel to beamline. ~1mm center-to-center spacing of 600μm fibers





GEANT4 Simulations of 50 GeV electrons with two geometries



Milestones: Finish simulations (2007), prototype construction (2008)

Needs: Sufficient support

Y. Onel (Iowa), METU (Turkey), INFN Trieste, Fairfield, Iowa State, Bogazici (Turkey), Cukurova (Turkey), Karlsruhe

Global Polarimeter Efforts

- DESY:
  - focused on upstream polarimeter
    - optics design/optimization
  - revamp/upgrade of original SLC polarimeter for beam tests

- US Groups:
  - focused on extraction line polarimeter
    - optics design/optimization
      - backgrounds simulations

Currently forming joint US/EU working groups on Polarimetry, putting together joint task lists to optimize effort

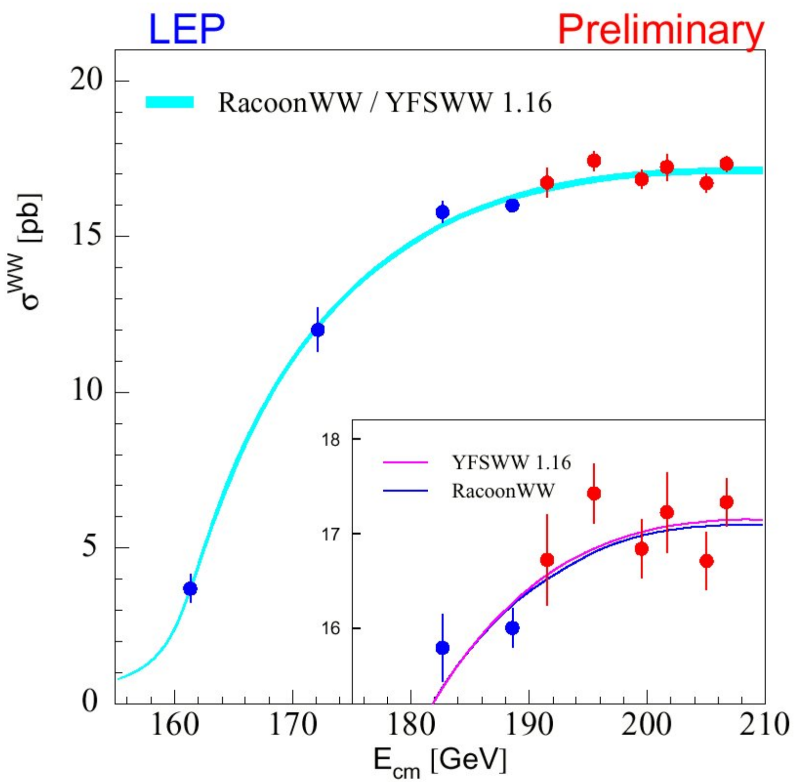
- Milestones: Finalize beamline design for RDR/EDR - 2008
- Needs: Sufficient support

$\Rightarrow$ more Global interest necessary!

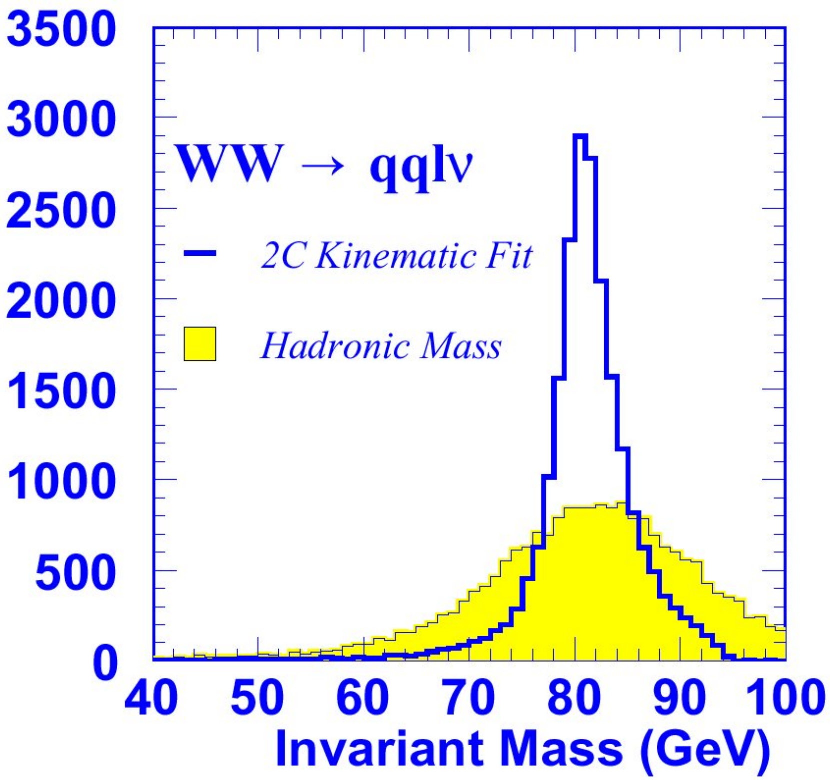
Energy Measurements

- A few words of Motivation...
  - Energy Calibration needs for Physics at a Linear Collider will be similar to what we had at LEPII:

Threshold Scans:

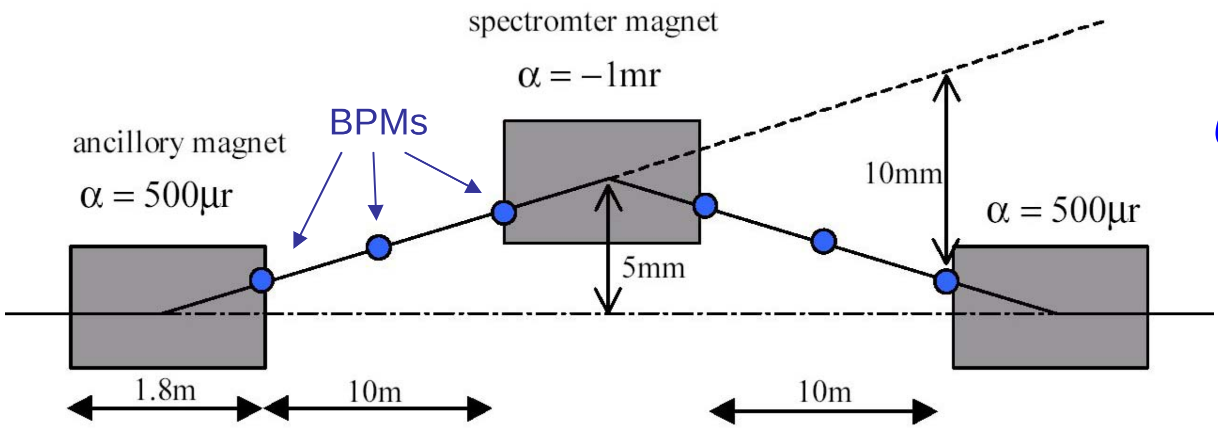


Kinematic Fits:



Prototypical Energy Spectrometers

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

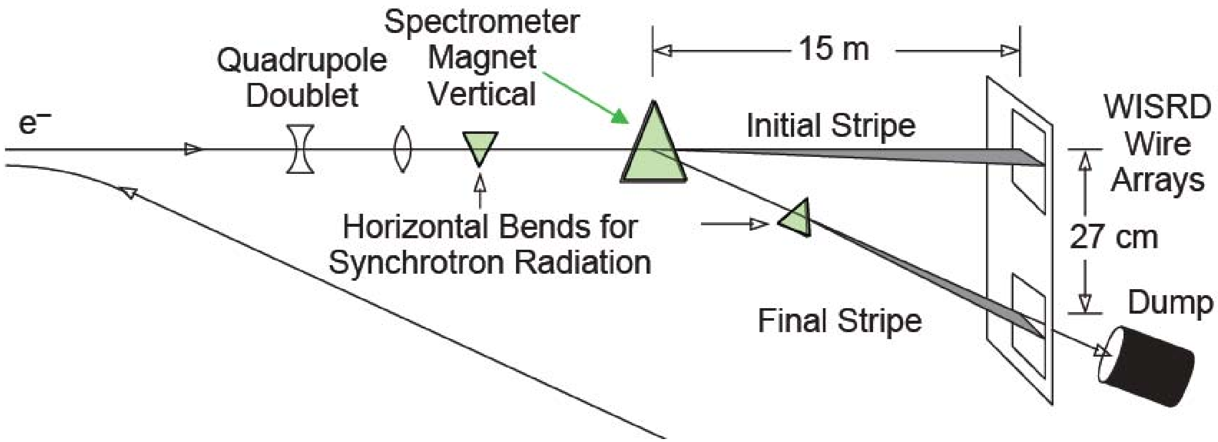


$$\theta = \frac{ec}{p}\int B \cdot d\ell$$

⇒ "upstream"

Aim for 10^{-4} Energy Measurement

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

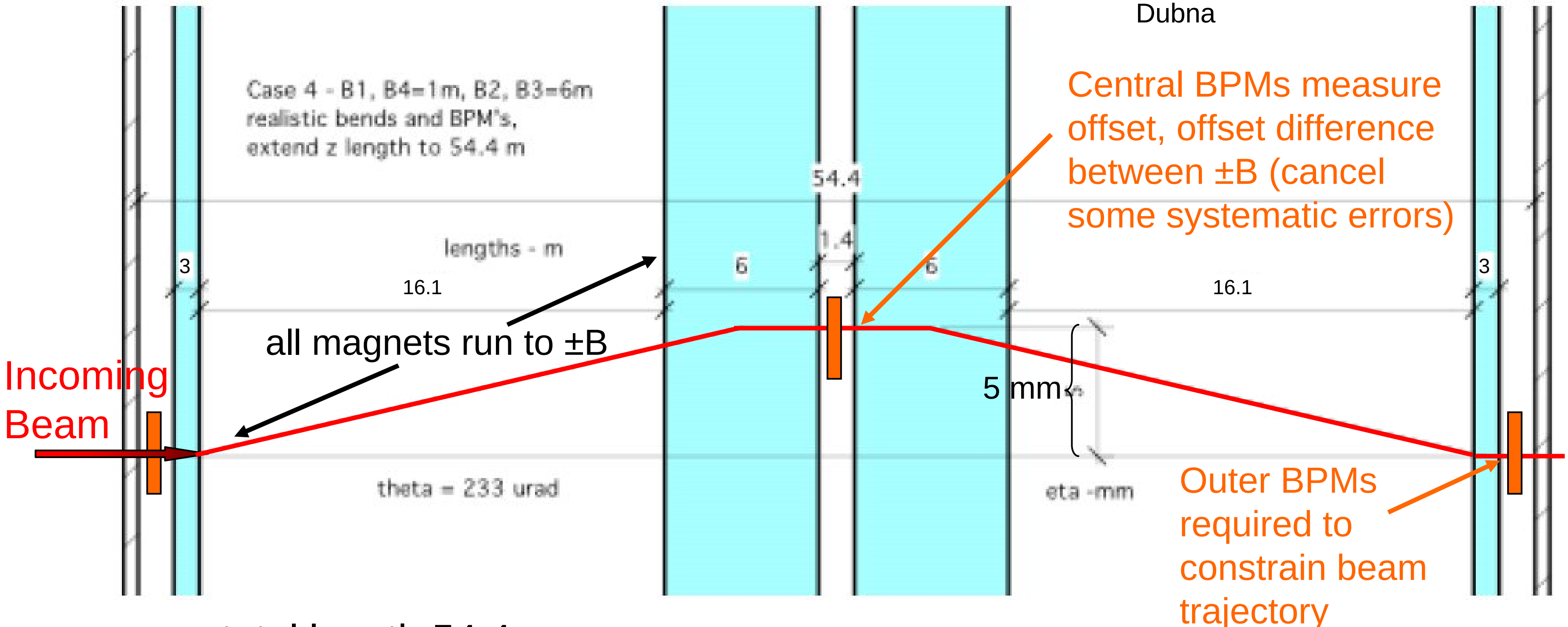


⇒ "downstream"

Upstream Energy Spectrometer

- Pure "Displacement" Strategy: Prototype Design

M. Hildreth (Notre Dame), SLAC, Cambridge, UCL, Royal Holloway, LBNL/Berkeley, DESY-Zeuthen, Dubna

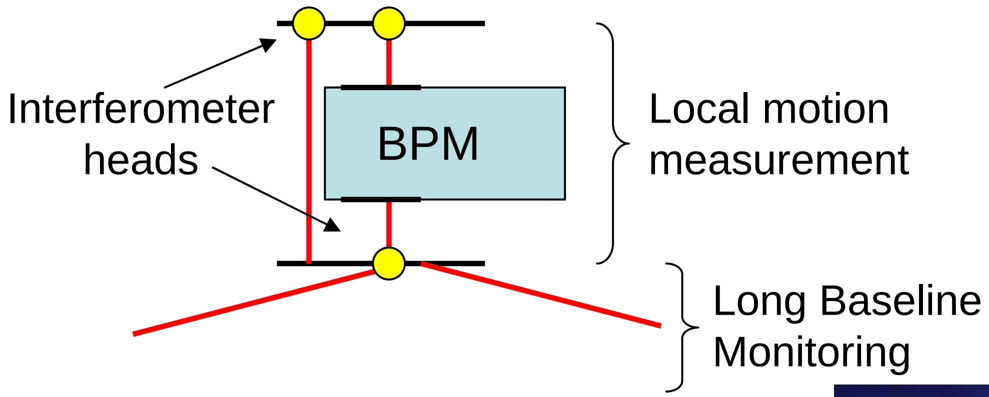


- – total length 54.4 m
- – dispersion at center = 5mm (~equal to beam displacement)
  - so, 0.5μm BPM resolution gives 1×10^{-4} measurement (per pulse)
- – Design incorporated into RDR BDS Lattice

better resolution would allow intra-train bunch energy measurements

Mechanical Stability

- Stability requirements determined by overall BPM resolution needed
- Mechanical support structure must be designed to limit vibration, and with minimal thermal expansion properties
  - Custom temperature regulation needed...
- Stability must be monitored: Developing Interferometry-based system



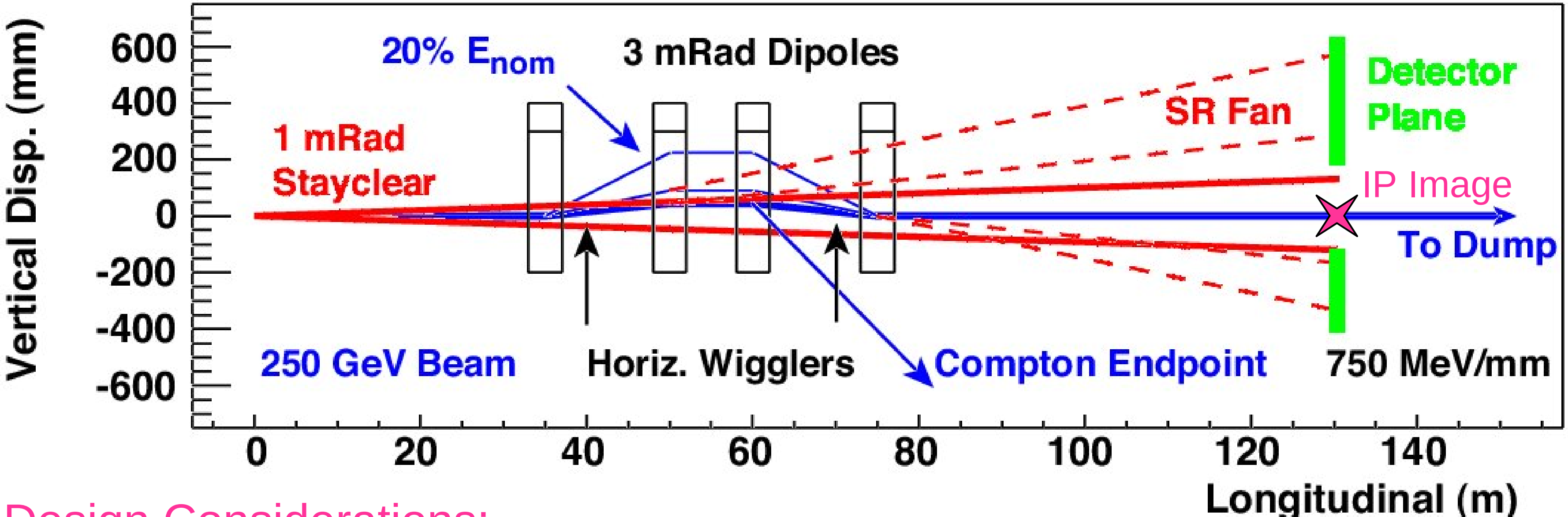
Notre Dame, SLAC, UCL, Cambridge, Royal Holloway

(⊕ Berkeley for parallel effort in electronic stability)

- Zygo 4004 Measurement System
  - Design Specs:
    - 0.3 nm single-bit resolution
    - at up to 5 m/s velocity

Synchrotron Stripe Spectrometer

E. Torrence (Oregon), SLAC



Design Considerations:

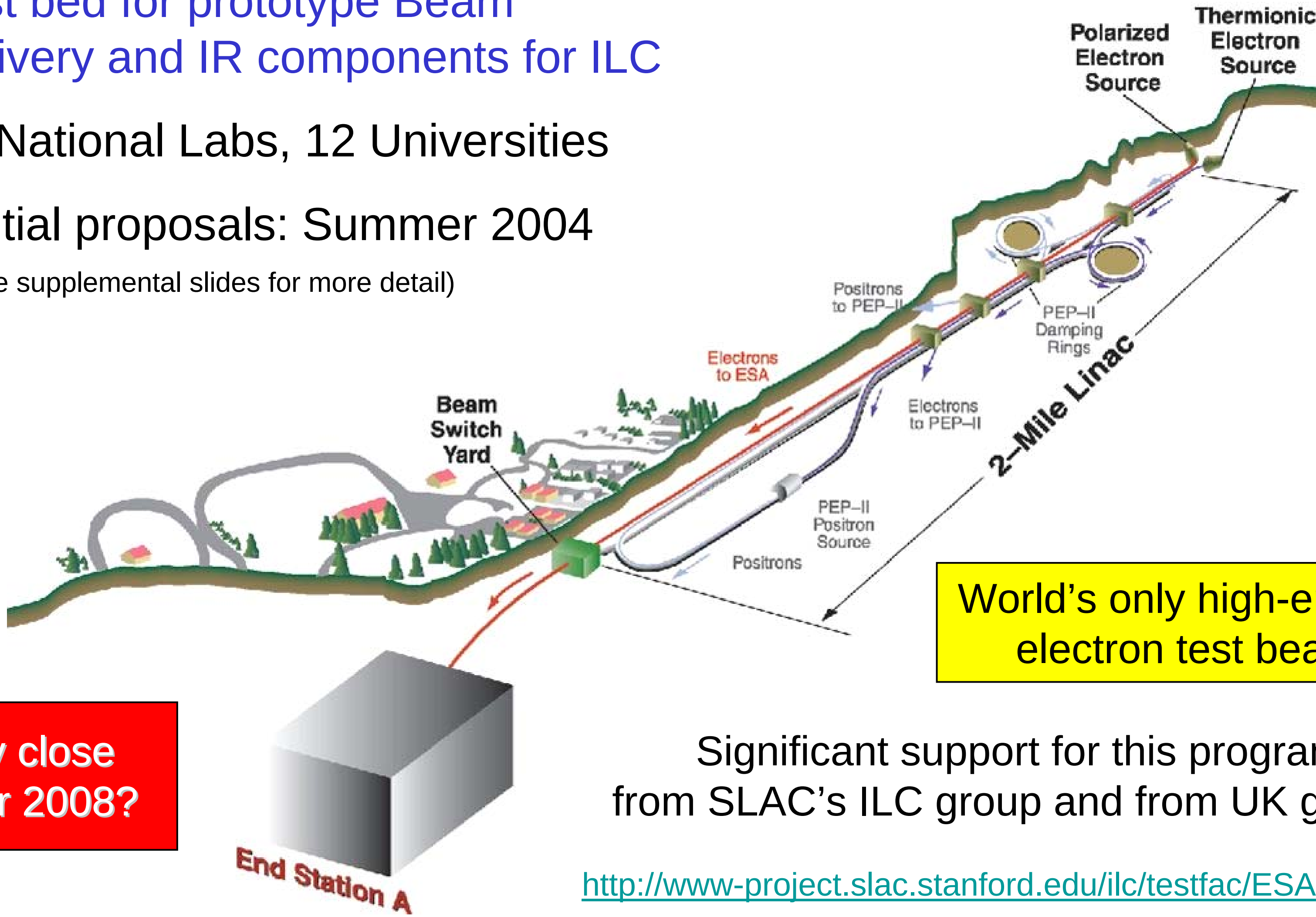
- Measure $<E_{beam}>$ and Energy Spectrum of Disrupted Beam
- 4mrad kick over 75 meters: need ~30μm position resolution
  - instrument with 100μm quartz fibers read out with multianode PMT
- Wide-aperture bends needed to extract SR fans (and Compton Endpoint) from Stayclear: Design incorporated into RDR
- Radiation hard and robust, simple detectors, fast & simple readout, very little cross talk

End Station A Test Facility

Test bed for prototype Beam Delivery and IR components for ILC

- 6 National Labs, 12 Universities
- initial proposals: Summer 2004

(see supplemental slides for more detail)



World's only high-energy electron test beam

May close after 2008?

Significant support for this program from SLAC's ILC group and from UK groups

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

(L-E-P) ESA Test Beam Experiments

(see extras for a complete list of experiments)

1. BPM Energy Spectrometer (T-474/491)

- PIs: M. Hildreth, Notre Dame, S. Boogert, Royal Holloway, Y. Kolomensky, Berkeley/LBNL
- Institutions: Cambridge, DESY, Dubna, Royal Holloway, Notre Dame, UCL, Berkeley, SLAC

– Goals:
  - Demonstrate mechanical and electrical stability at 100-nm level
  - Perform energy measurement in 4-magnet chicane
  - Develop calibration techniques, operational procedures

– multiple BPM triplets to test overall stability, new BPM designs

2. Synchrotron stripe diagnostics (T-475)

- PI: E. Torrence, Oregon
- Institutions: Oregon, SLAC

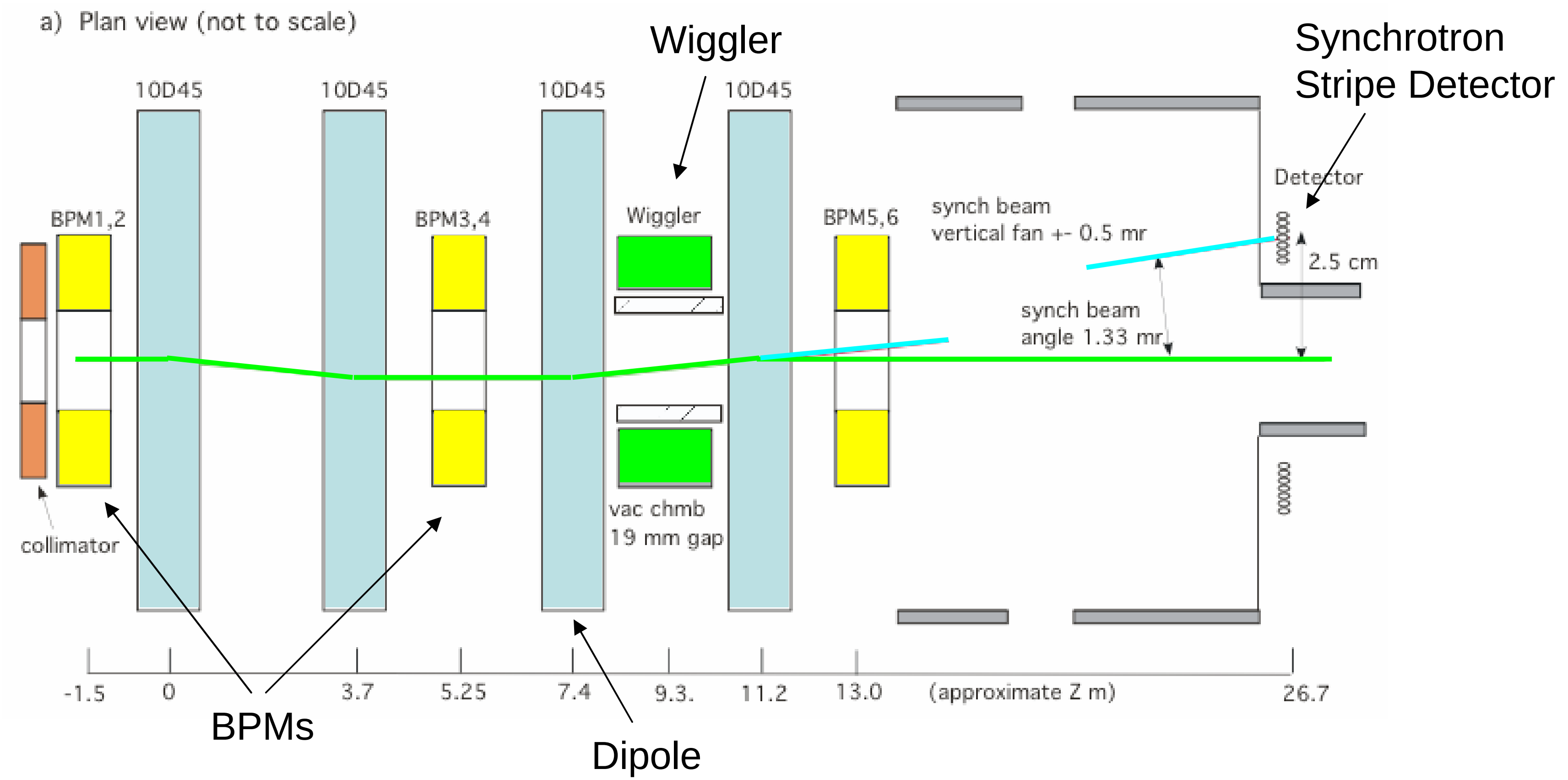
– Goals:
  - test chicane scheme with wiggler magnet
  - characterize detector (quartz fiber / other) performance and capabilities

Overall Goal:

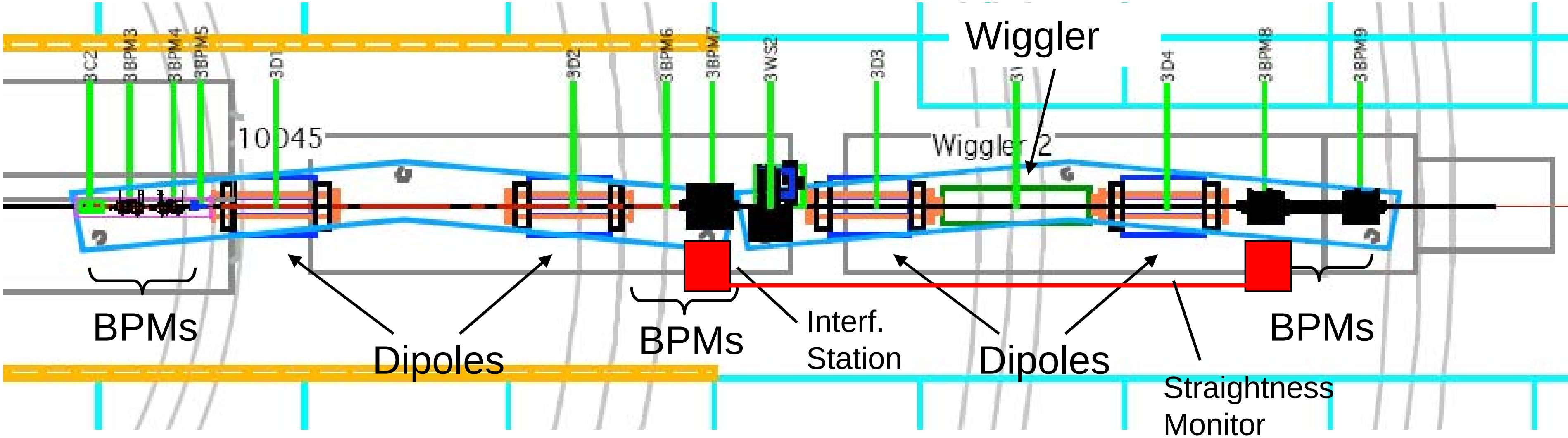
perform cross-check of two energy measurements at the ~10^{-4} level

T474 (T491), T475: Energy Spectrometers

- BPM-based and Synchrotron-Stripe Spectrometers can be evaluated in a common four-magnet chicane

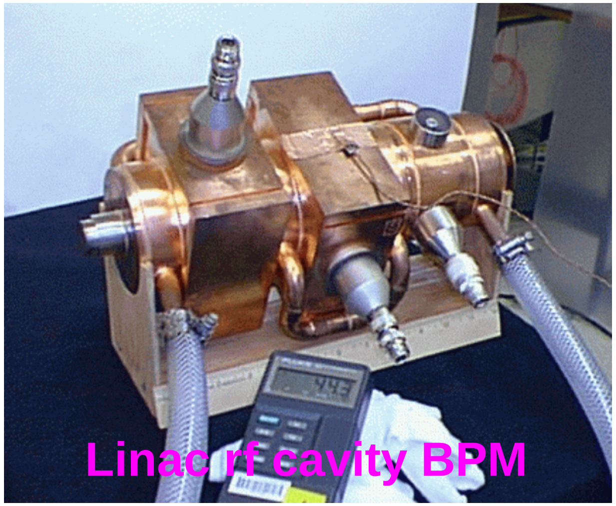


FY07 Configuration

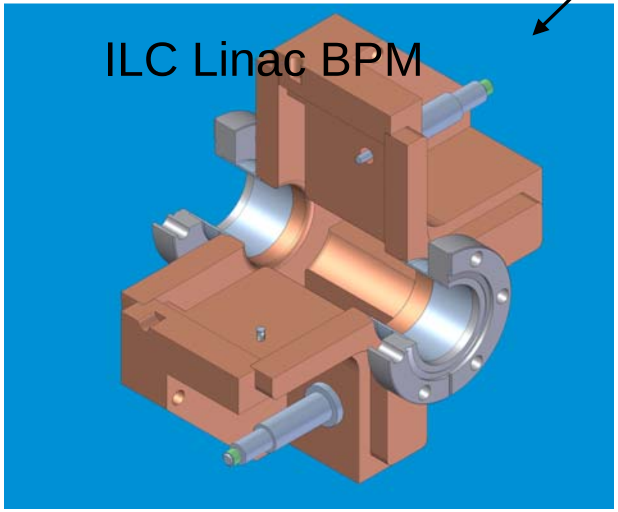


- Ran in 2006 with no dipole chicane
- Runs in March (already finished), July
- Will allow simultaneous test of BPM and Synchrotron Stripe Spectrometers
  - first beam tests for Synchrotron Detector
  - can compare measured energy, energy jitter at 100-200ppm level
  - tests of BPM movers
  - more elaborate mechanical stability monitoring

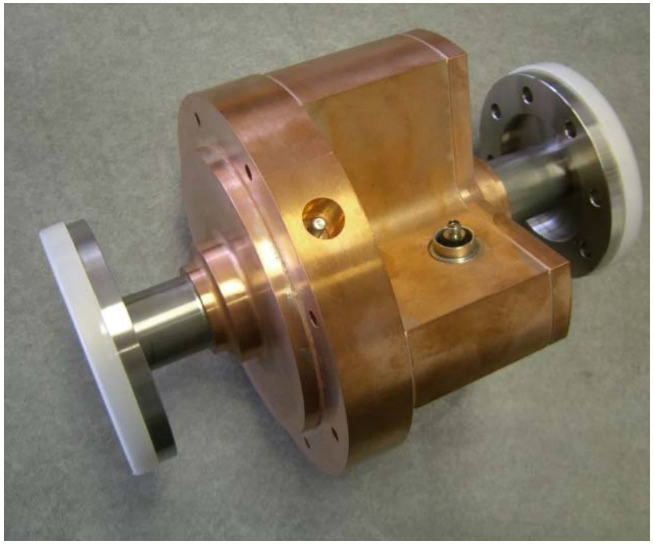
BPMs and Electronics



- SLAC Linac BPMs form main component of instrumentation
  - new electronics developed by Y. Kolomensky (Berkeley/LBNL)(LCRD Accelerator R&D)
- Also testing prototype ILC Linac BPMs developed at SLAC (C. Adolphsen)

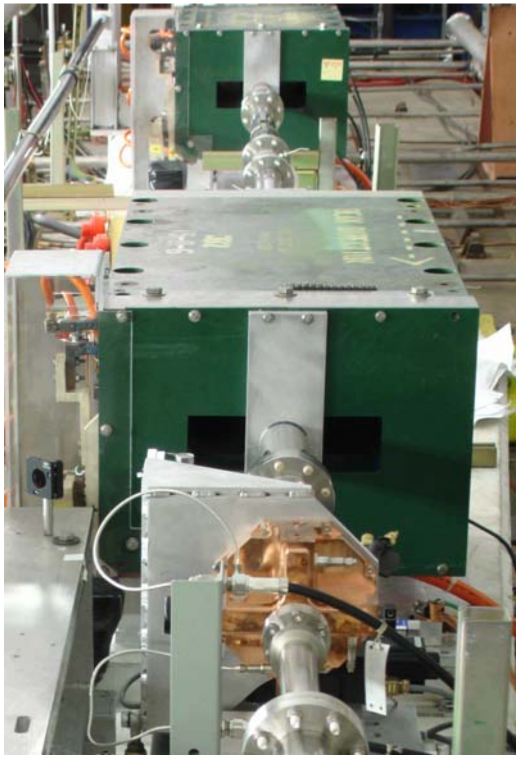


- New BPMs, optimized for energy spectrometer, designed at University College London in collaboration with BPM experts at SLAC and KEK
  - custom electronics
  - mover system
  - July 2007



Beamline Components

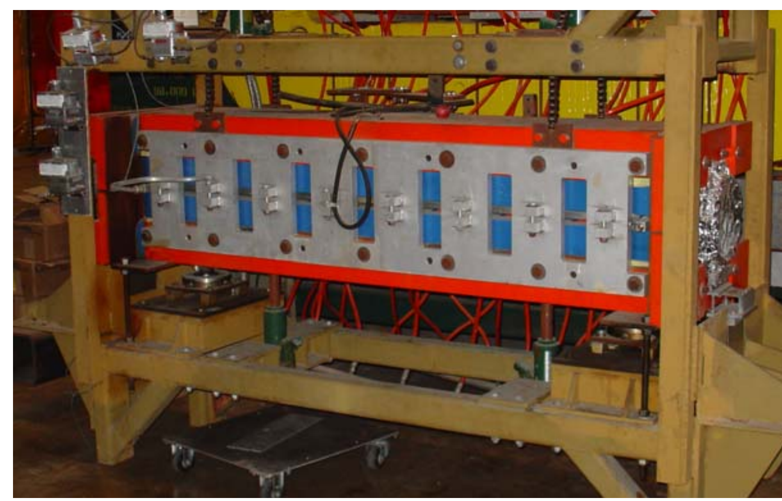
- Dipoles: Measured in SLAC Magnet Lab prior to installation



(SLAC/Dubna/Zeuthen)

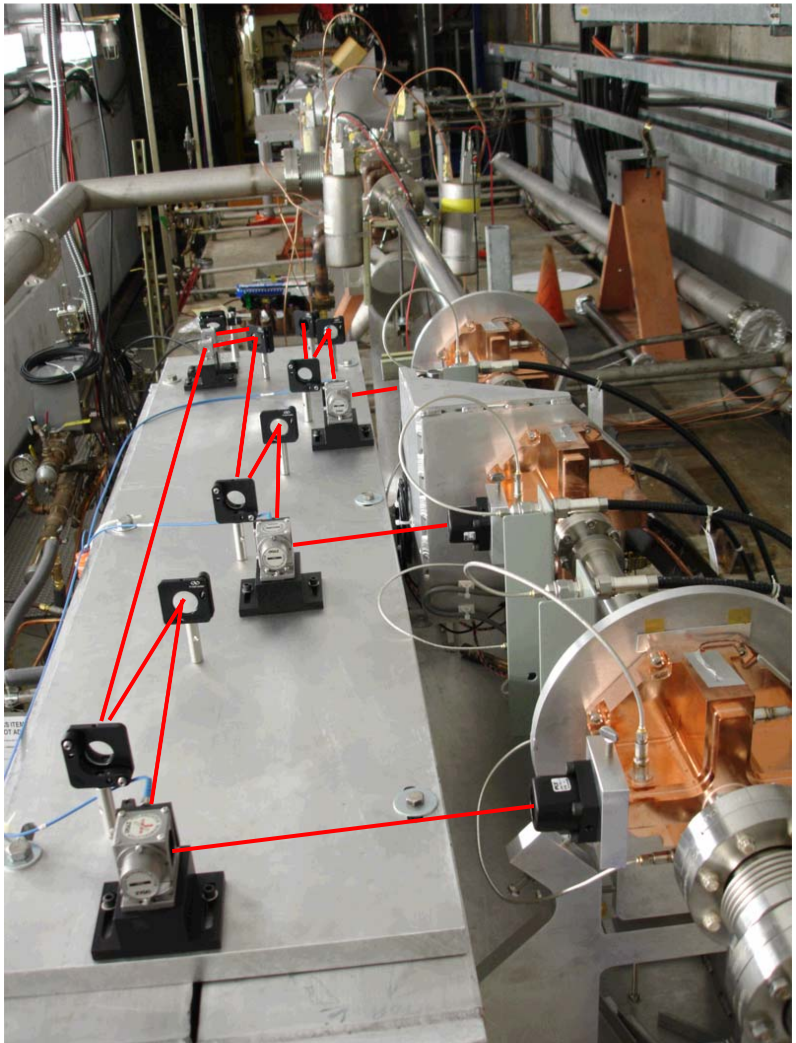
  - RMS Reproducity of field integral: 60ppm
  - RMS Agreement across working points: 100ppm
  - Temperature coefficient: $5.7 \times 10^{-5}/°C$
  - Excellent agreement between measured and simulated magnet properties
  - Also: measurements made of residual magnetic fields along entire beamline ($\int Bdl \sim 3$ Gm)

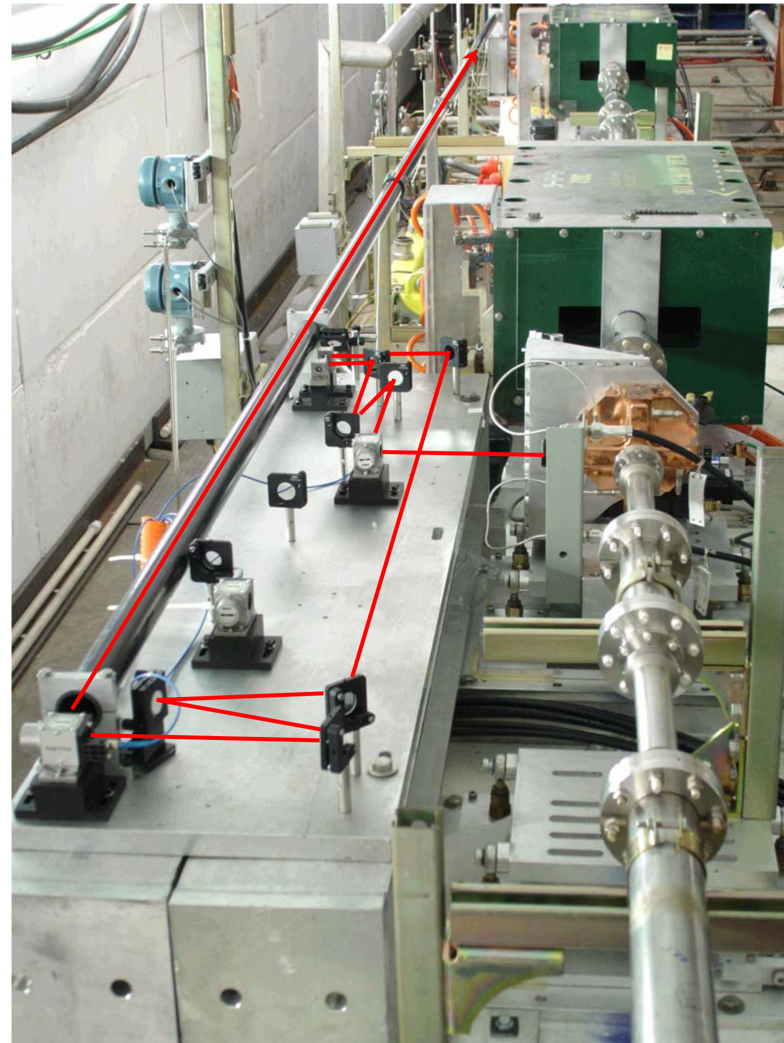
- Wiggler refurbished – now installed



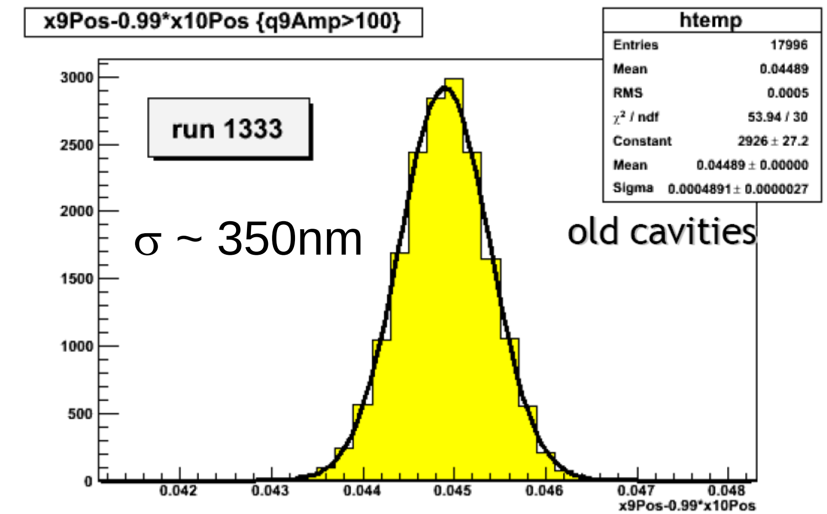
Interferometer Installations

- July 2006 single BPM station
- March 2007 link two BPM stations

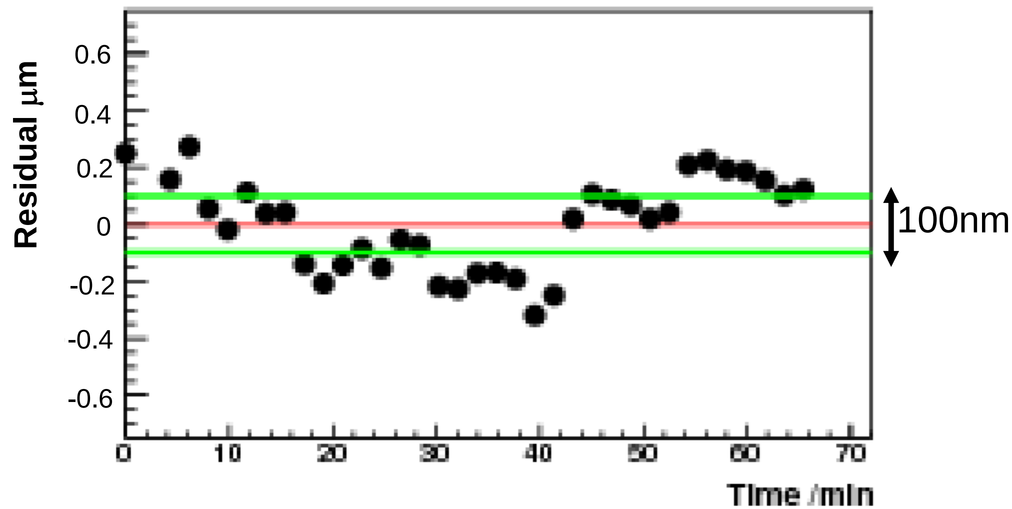


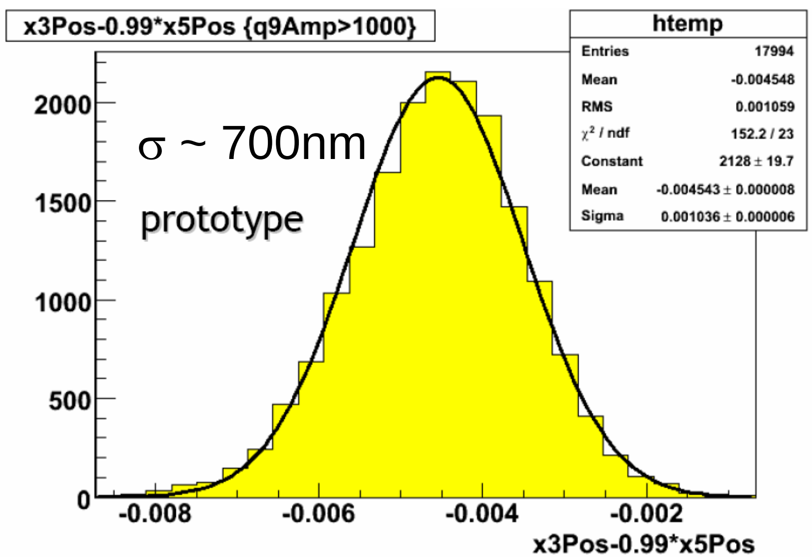


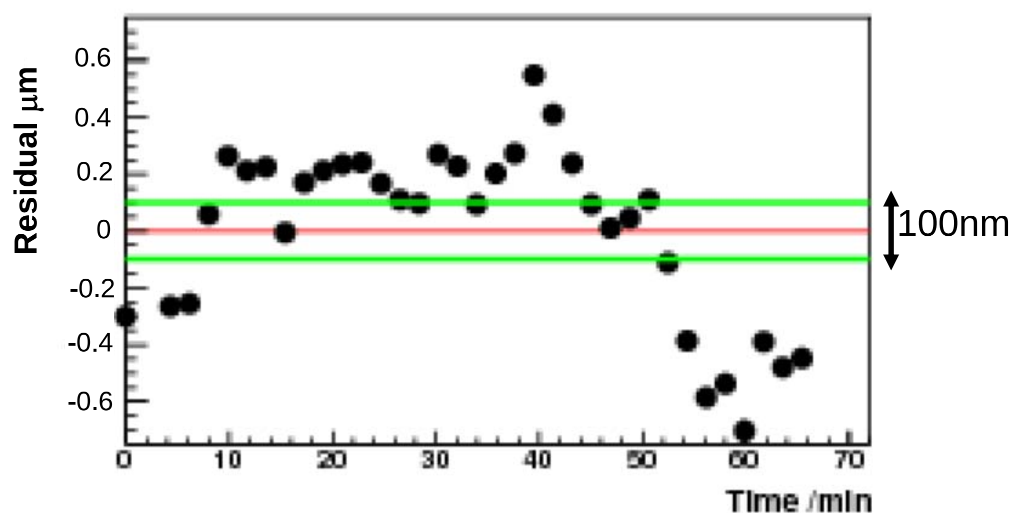
BPM Performance and Stability (2006)



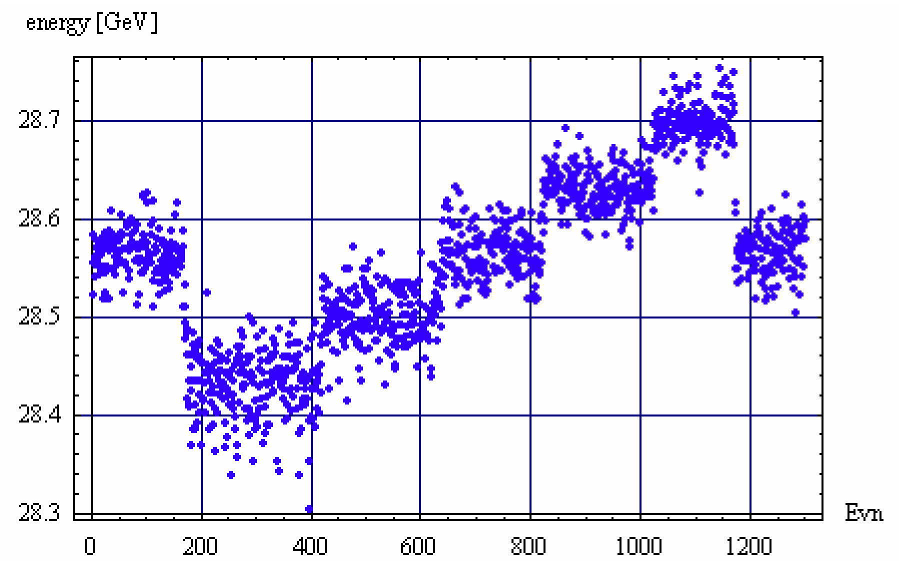
Stability of predicted position



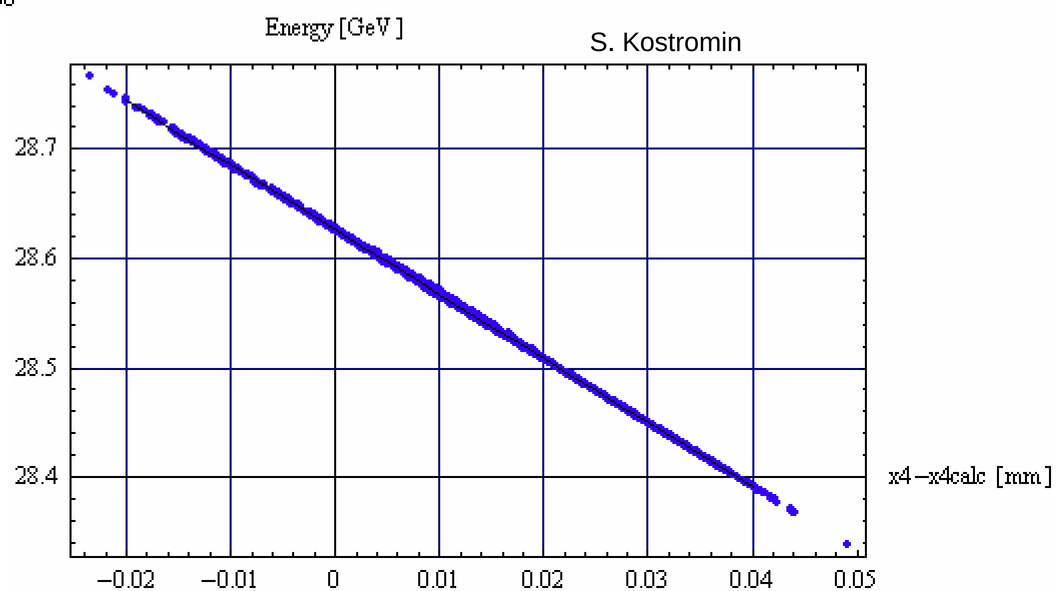




Energy Measurement with chicane (2007)



- Beam energy computed from spectrometer ∫Bdl and BPM offset measurement vs. time
  - energy variation from linac energy scan
  - large pulse-to-pulse jitter

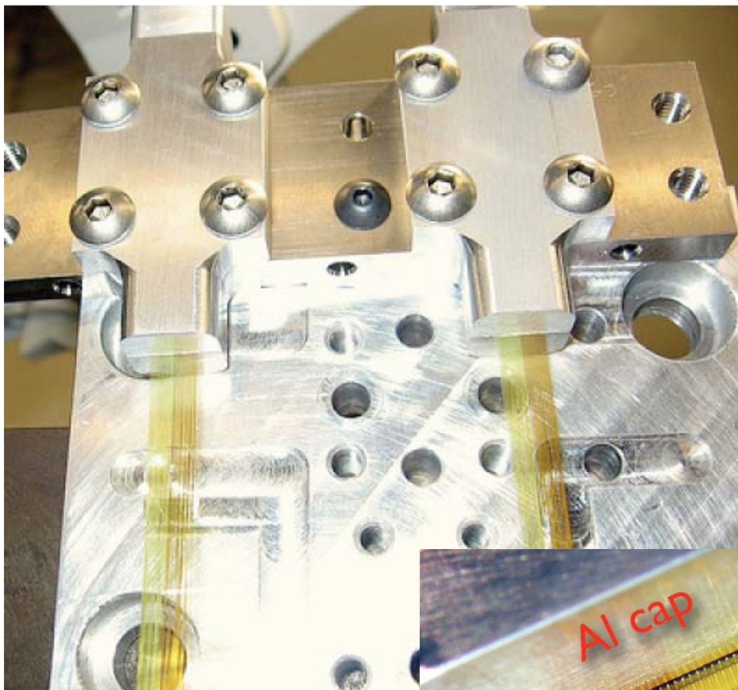


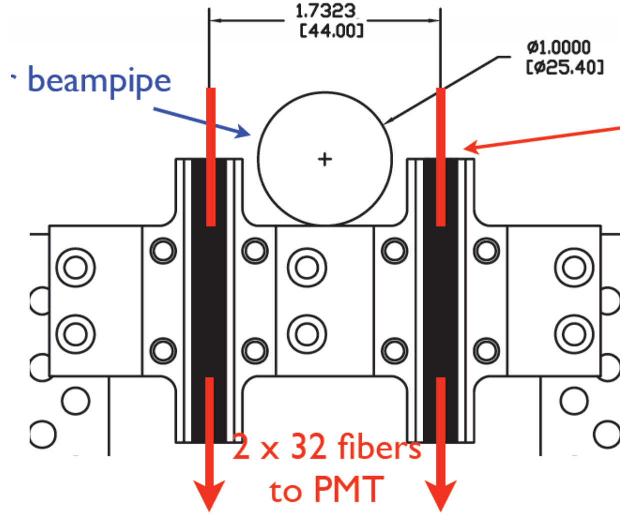
- Correlation of beam energy with measured BPM position
- Cross-calibration with beam displacement at high-dispersion BPM in A-line gives σ_E ~18 MeV
- need higher-precision test

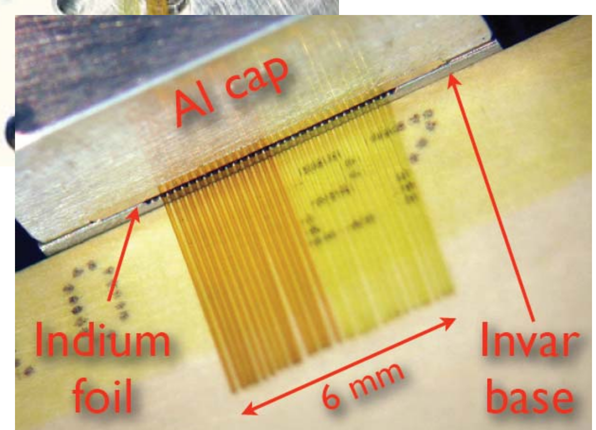
New SR Stripe Detector

E. Torrence (Oregon), SLAC

- Next-generation prototype for Energy Measurement test
  - schedule advanced in anticipation of ESA closure/hiatus due to LCLS



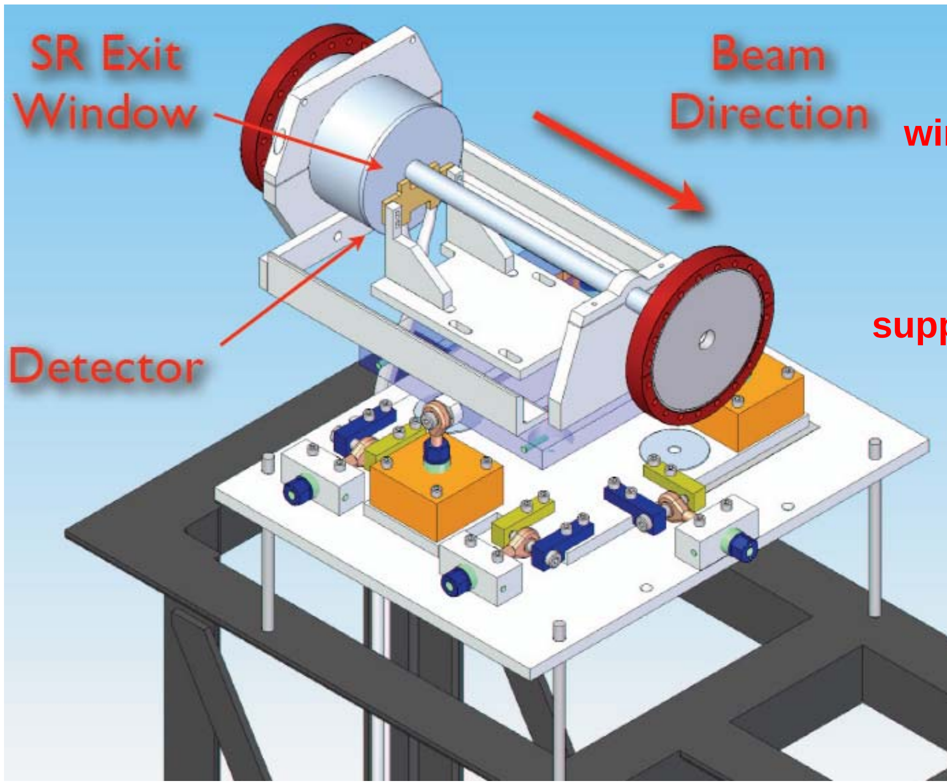


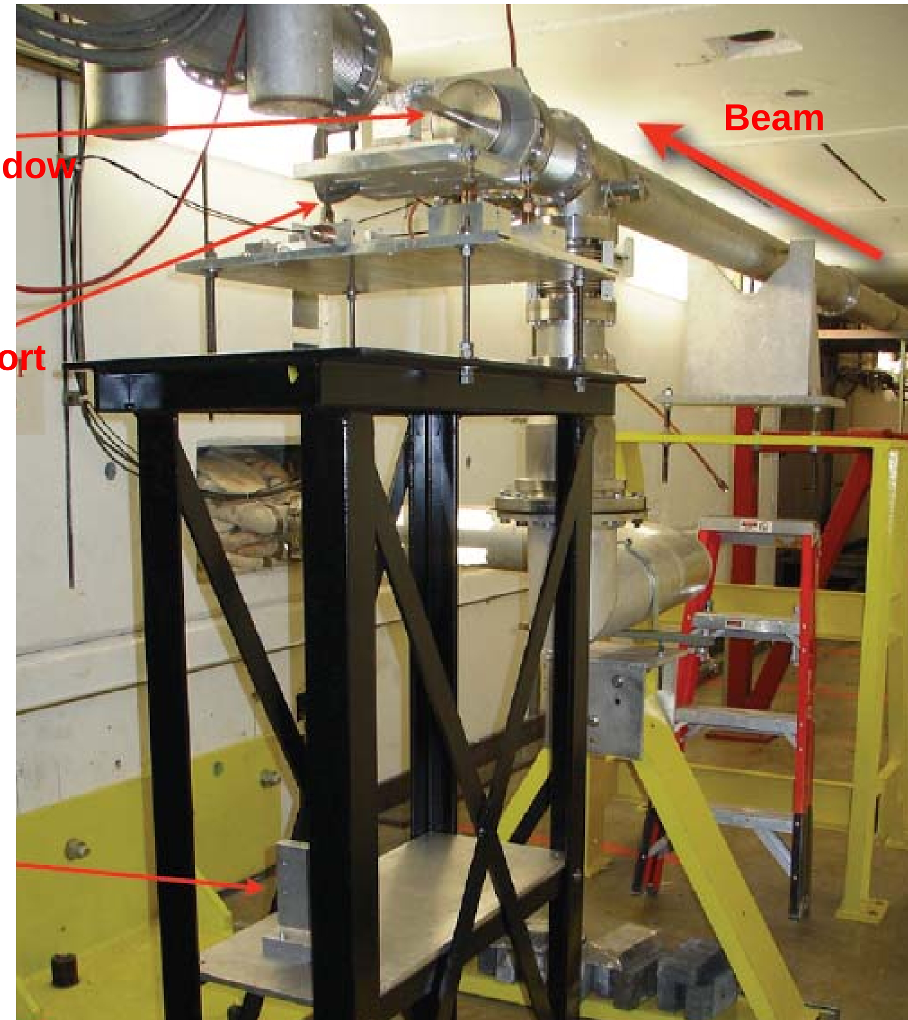


Support Stand/Photon Exit window in ESA

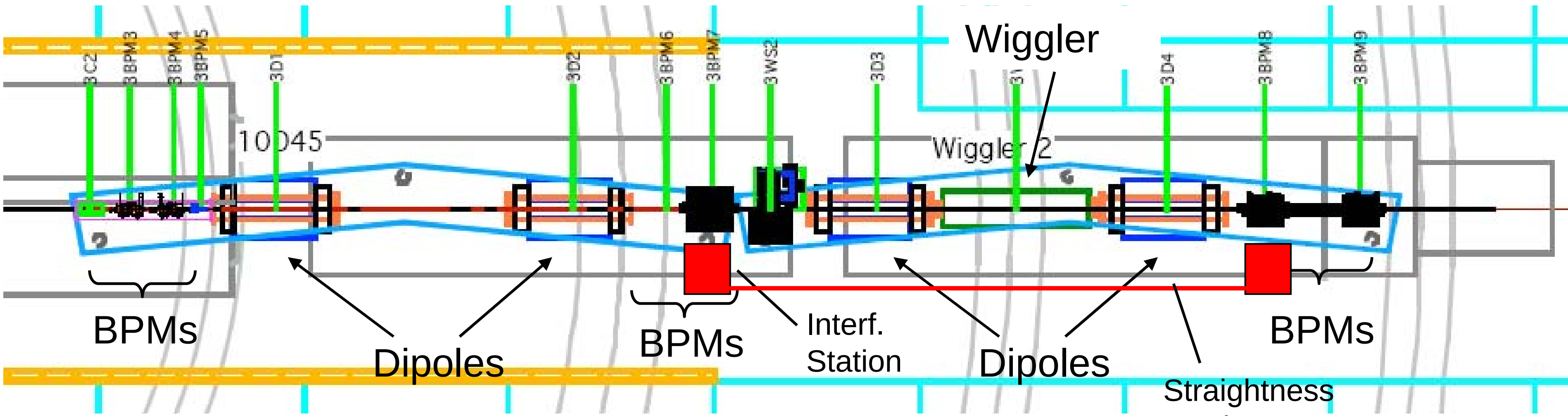
E. Torrence (Oregon), SLAC

- New installation downstream of dipole chicane

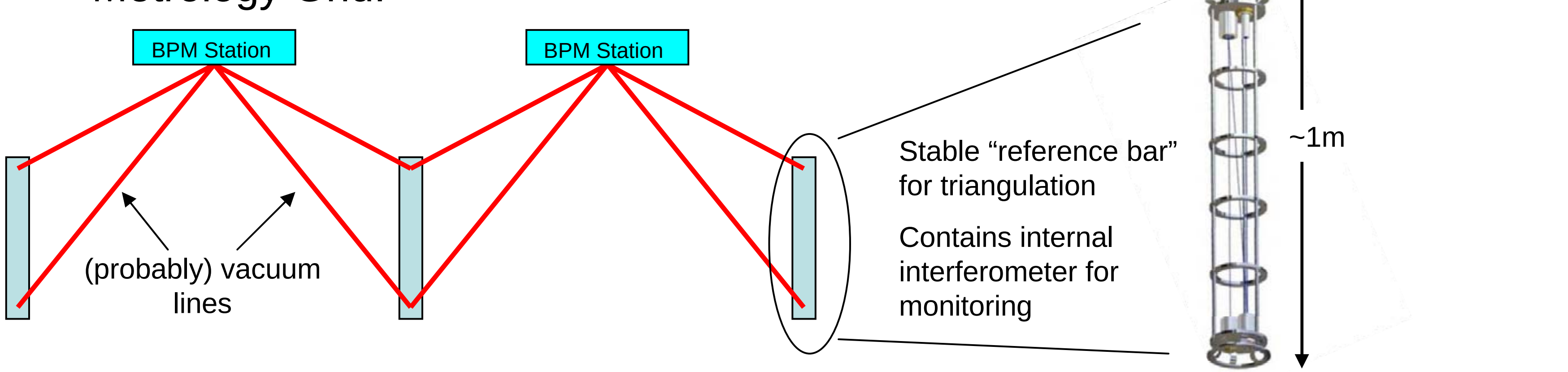




Next Steps for ESA



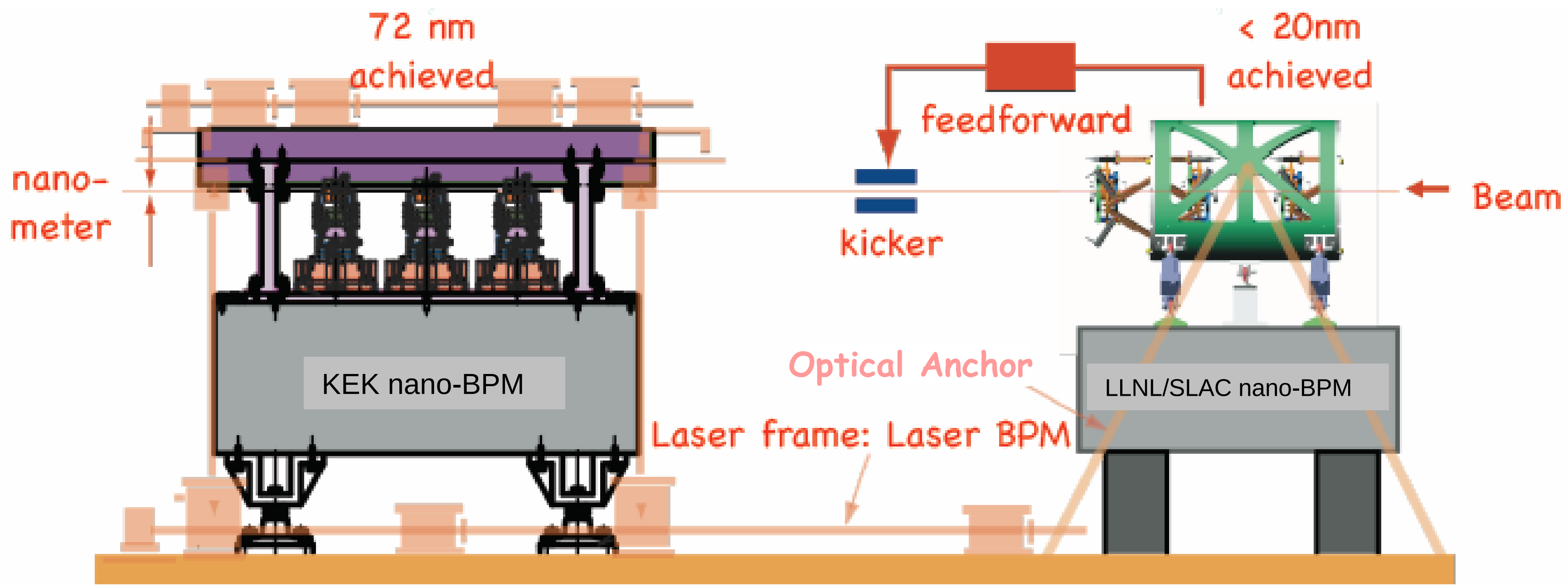
- Cross check of spectrometer energy measurements
  - evaluation of systematics ongoing
  - more new hardware/electronics for better resolution/stability
- Optical link between BPM stations for system-wide stability testing:
  - Metrology Grid:



ATF Program

SLAC, UCL, Royal Holloway, Oxford, Notre Dame, Cambridge, LBNL/Berkeley

- Many tests directly relevant to spectrometer concepts
  - nano-BPM tests of ultimate resolution (16nm achieved!)
    - nice, small beams to work with
  - "optical anchor" under construction to connect two pairs of BPM triplets
  - optical straightness monitor with ~10nm resolution under development
  - resolution and stability tests

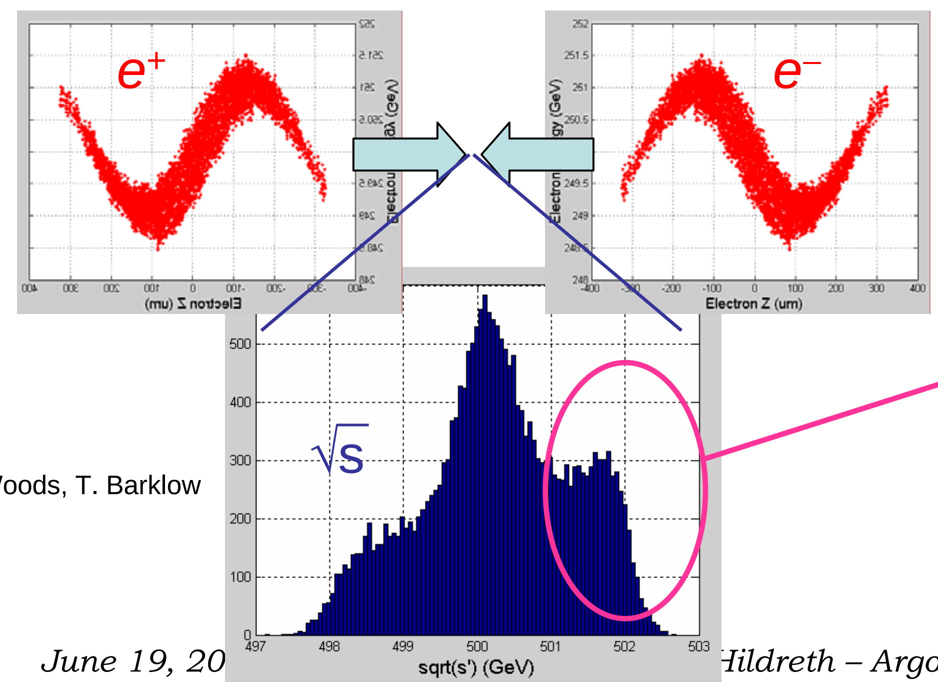


Spectrometer Program

- Large and Active R&D program
- End Station A program complementary to ATF2, other beam tests
  - high energy, "ILC"-like beam very useful
  - Essentially, all world players in this game are at KEK and ESA working on both beamlines
- Robustness tests of measurement techniques are critical
  - exposure of components to beam tails, halo, etc.
  - "Trust, but Verify"
  - Have to make sure these things work!
    - not a huge number of other ideas for many of these measurements
    - Forces re-design of serious accelerator real estate if we fail
- Milestones: Spectrometer cross-check in 2008(?)
  - Running will be needed beyond this
- Needs: Schedule limited by $$, People
  - availability of ESA beam in the LCLS era is a serious concern
  - have secured joint postdoc (R&D supplement) to drive this effort

Other Parametric Considerations

- We will also need a determination of $\delta\mathcal{L}/\delta E$, the differential luminosity spectrum, to ~1% for many of the measurements
  - it's the Luminosity-weighted $\delta\mathcal{L}/\delta E$ that matters
  - *requires* spectrometry downstream of IP **if** this is done with beam instrumentation
  - bhabha acolinearity plus bhabha energy measurements (plus muon pair measurements) may also be necessary for a full deconvolution of the spectrum

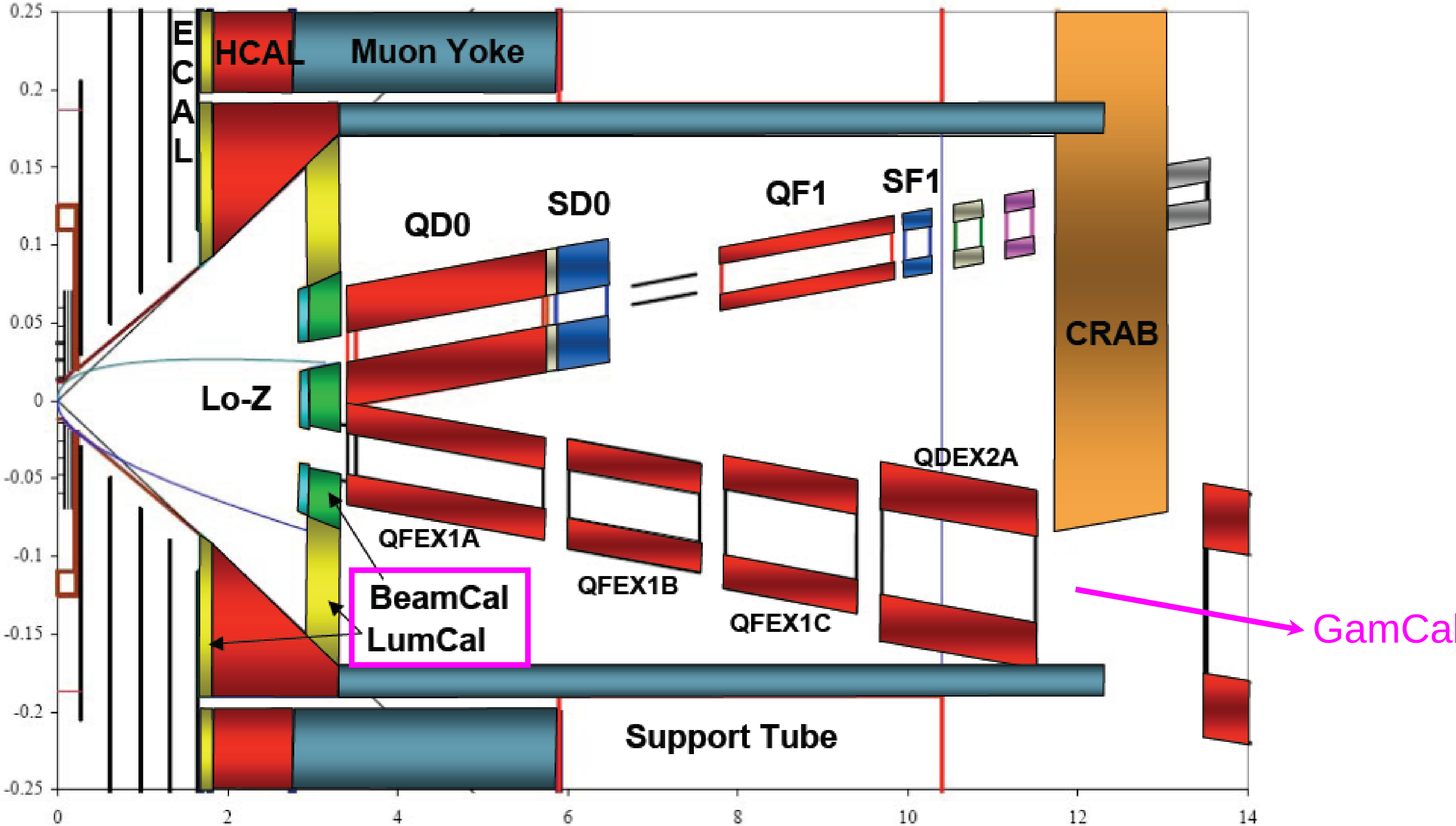


M. Woods, T. Barklow

- "Kink" effect in collision exacerbates head-tail energy differences in luminosity-weighted $\delta\mathcal{L}/\delta E$.
- Bias in the <E> distribution can be 100s of ppm
  - less severe for "cold" linac
- very sensitive to beam params.

Luminosity and Forward Instrumentation

- "Generic" Layout of IP region: (extremely complicated)
  - would like to measure luminosity somewhere between shielding and quads



Small-Angle Beam Monitors

- Segmentation of IR geometry naturally breaks into three regions:

	Coverage (rad)	Purpose	Location	Main R&D Locus
LumiCal	≈.04-.11 z ≈ 2m	precision L hermeticity	Just inside first detector shield	E.U.
BeamCal	≈.005-.04 z ≈ 3m	hermeticity beam diagnostics	Front face of entry/exit quads	E.U./U.S.
GamCal	<.005 z ≈ 180m	beam diagnostics	Far downstream	U.S.

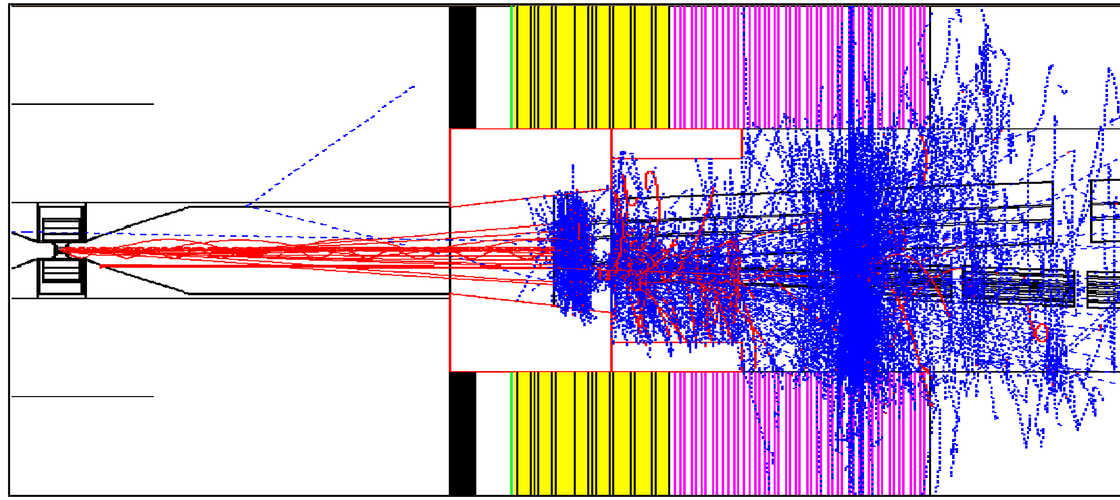
- "Hermeticity" = veto against small angle electrons (2γ background) for searches involving missing E_T
- Rates and nature of background in these regions necessitate different detector designs for each

Global Effort for Forward Calorimetry

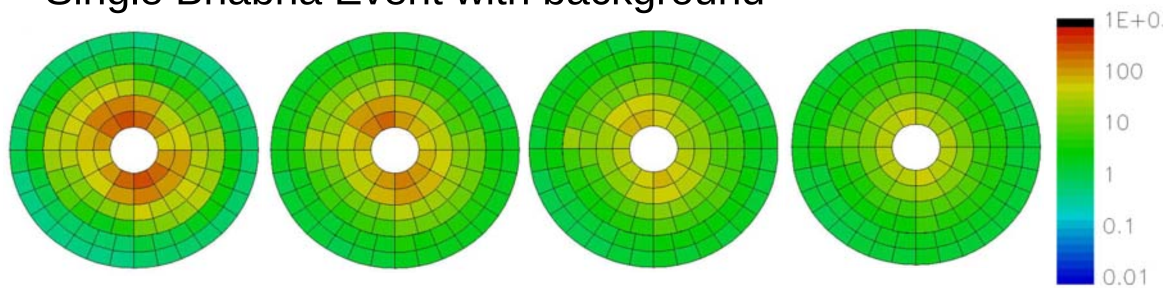
US Groups: Colorado, Yale, BNL, SLAC

Main Issue: Backgrounds!

- All of the beamstrahlung pairs smash into the forward calorimeters
- Fine segmentation in phi and depth allow high energy electrons to be seen above the huge backgrounds
- Radiation Hardness and speed of readout critical
- Here: BeamCal
  - single bhabha event (250 GeV) on top of 20 TeV of expected pair and beamstrahlung background

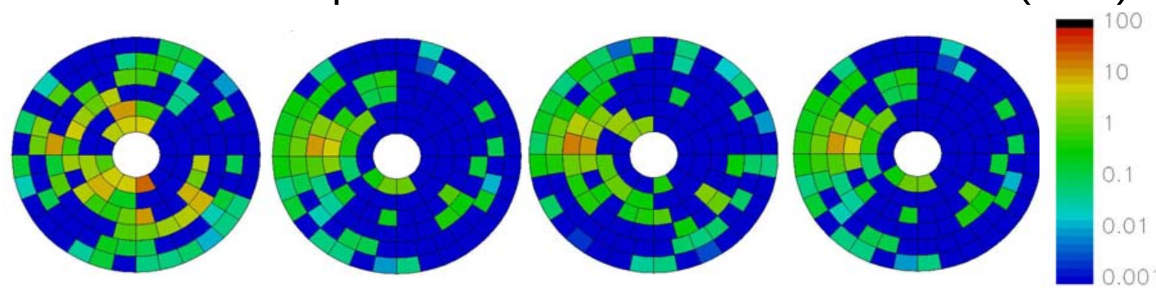


Single Bhabha Event with background



Calorimeter Depth →

E (GeV)



Background Subtracted Event

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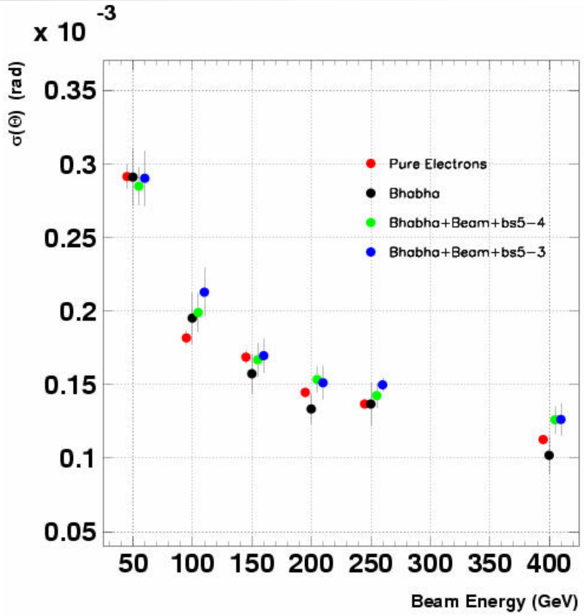
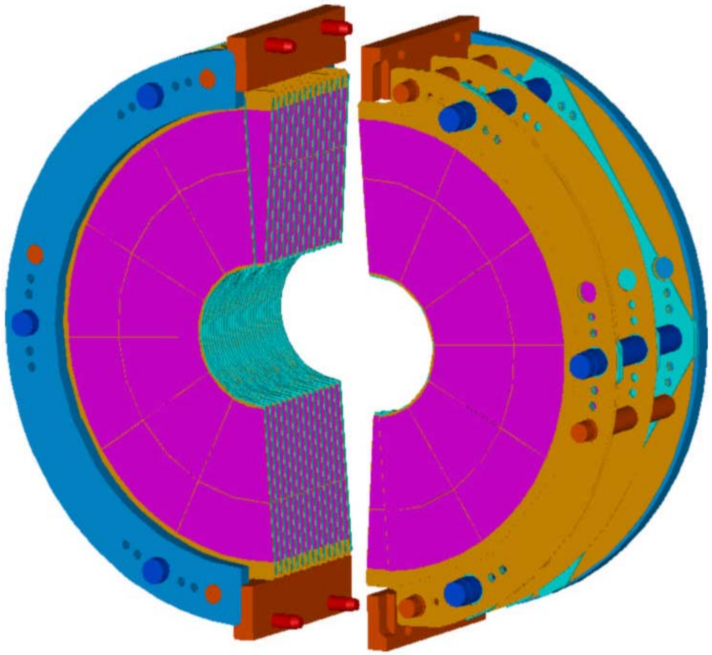
Lumical

- Precision Luminosity measurement
- Provide veto on scattered electron in 2γ events for SUSY searches
- Full Geant Model of resolution with background shows $\delta L/L \sim 1 \times 10^{-4}$ possible (GigaZ spec)
  - Si/W sandwich is leading technology choice
  - Readout electronics: DESY/SLAC collaboration

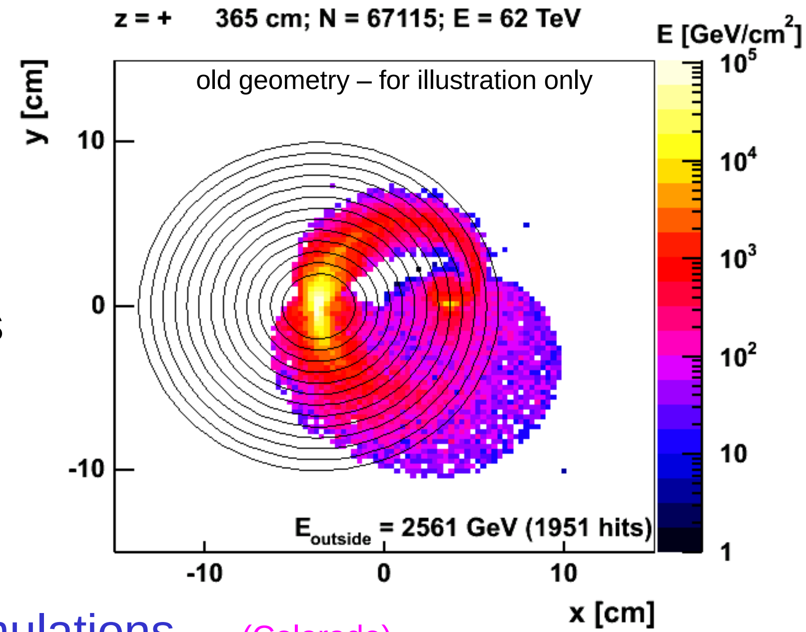


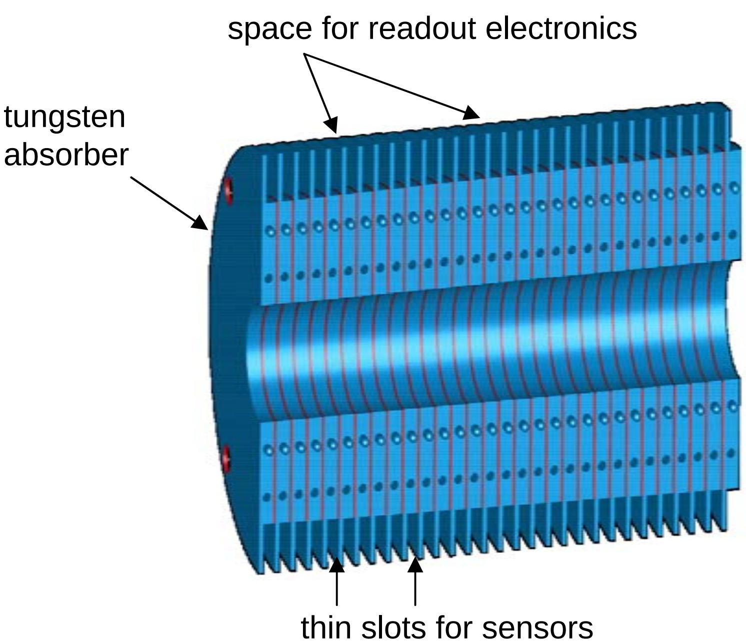


- extensive studies of alignment systematics, orientation/placement in IR, and 2γ rejection
- NB: Theory error at the Z pole still stands at $\delta L/L \sim 5 \times 10^{-4}$
  - Global support of Theory Effort will be needed to reduce this (B. Ward proposal)

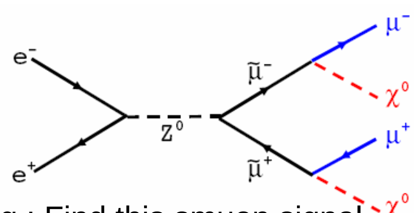
BeamCal

- Provide veto on scattered electron in 2γ events for SUSY searches
- distribution/energy of beamstrahlung pairs on calorimeter can be used for beam tuning
- huge radiation dose → ultra-rad-hard sensors
  - CVD Diamond, GaAs, SiC, radhard Si
  - global effort on sensor radiation testing

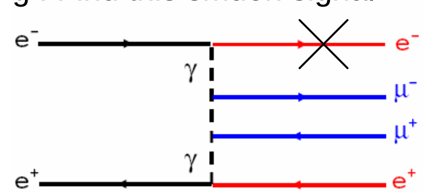




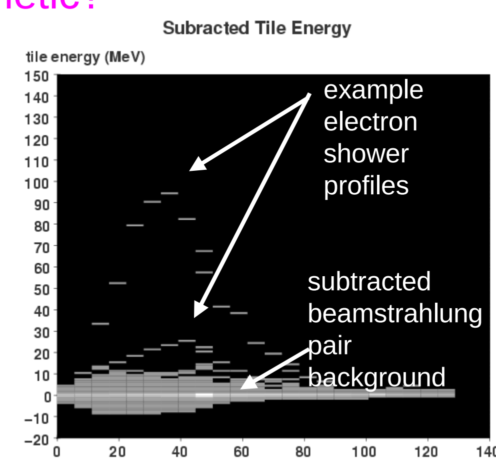
- Physics Simulations (Colorado)
  – how hermetic is hermetic?



e.g.: Find this smuon signal



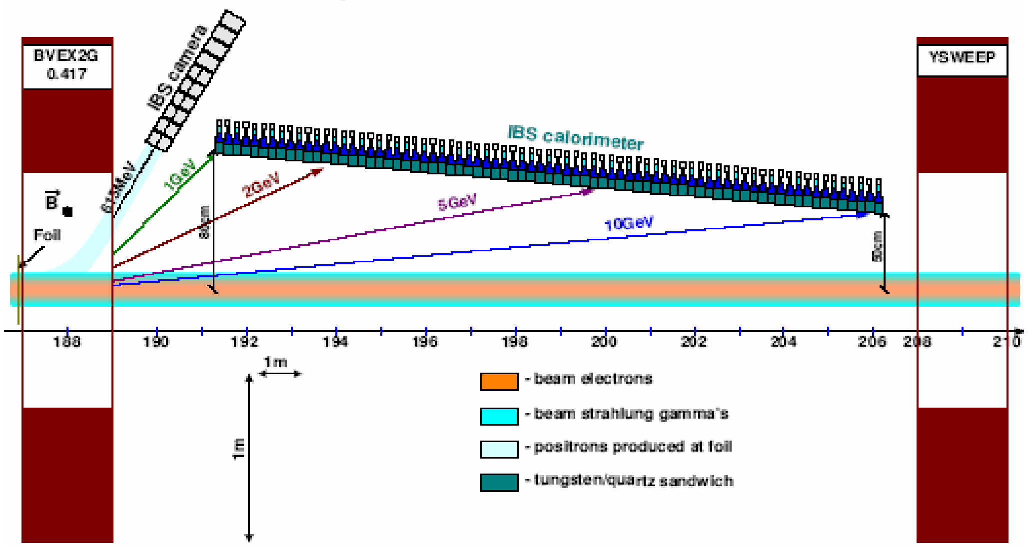
reject this background



Nice example of MDI/Physics Synergy

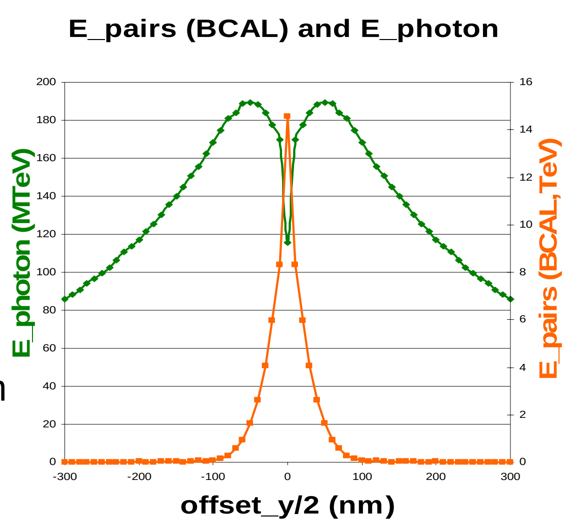
BeamCal and GammaCal: Diagnostics

- Yale Concept for GammaCal

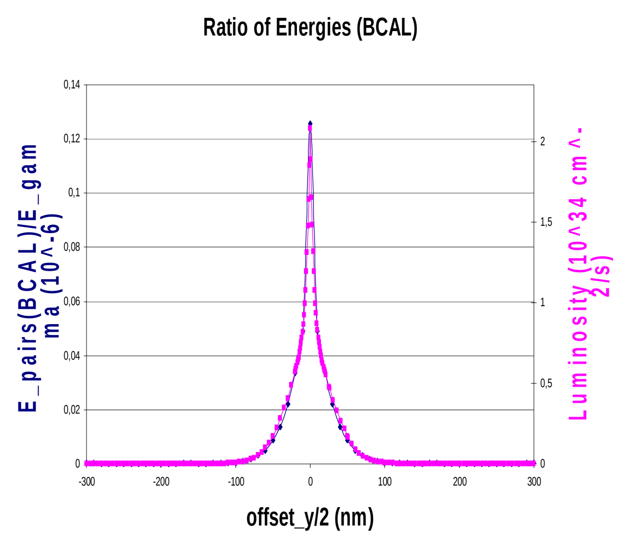


– Converter foil used to create e^+e^- pairs from beamstrahlung photons
– Measure total incident flux of beamstrahlung
– Ratio of beamstrahlung flux to pair creation probability is a **measure of instantaneous luminosity:**

Pair production (total energy) and photon production (total energy) vs beam-beam offset



Ratio of gamma energy to pair energy vs beam collision offset (blue); true luminosity vs. offset (magenta)



Ratios sensitive to other beam parameters: investigations ongoing

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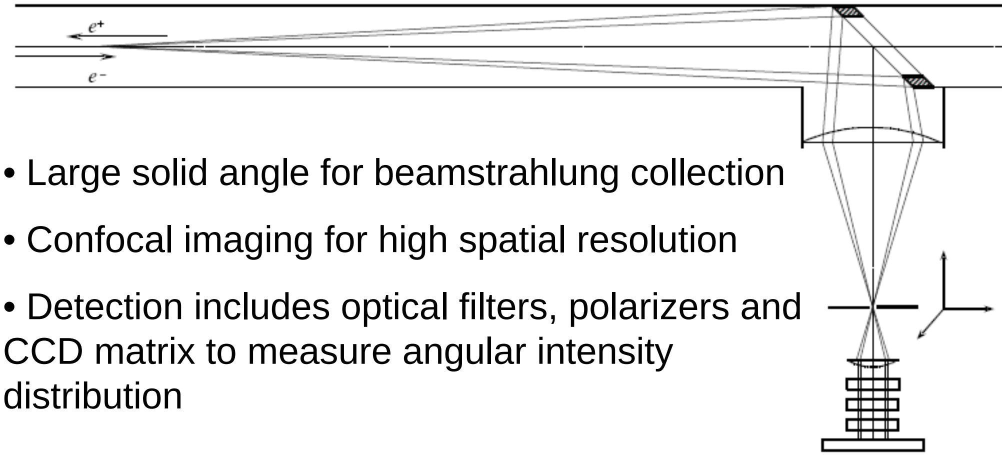
Forward Calorimetry R&D Roadmap

- LumiCal/BeamCal:
  - 2000-2006: E.U. FCAL develops detector design and interfaces with MDI for LDC 2mrad and 20mrad crossing angles
  - 2007 issues: rad damage of 2-10MGy/yr (U.S. FCAL at BNL rad-hard Si, EU FCAL diamond), hermeticity studies (CO), 14mrad push-pull SiD MDI (BNL)
  - fast read-out (SLAC): front end/ADC designs 2007-2008, prototype 2008
- GamCal:
  - 2006: Physics simulations by BNL and DESY Zeuthen defines the beam dynamics need for GamCal
  - 2006-2007: Yale develops detector concept
  - 2006-2007: Begin coordination with MDI for GamCal magnet and detector space
  - 2007-2008: Yale/BNL evaluates detector concept for backgrounds, etc.
  - 2008-2009: Construct prototype and measure in testbeam to validate backgrounds, etc.
- Needs: $$$

Other Beam Diagnostics

- Coherent and Incoherent Beamstrahlung   **G.Bonvincini (Wayne State)**, (Cornell)
  - Use properties of emitted radiation for beam diagnostics
    - beamstrahlung angular distribution and polarization can be related to beam collision offset, tilts, etc.
  - Extensive beam testing at CESR (NSF-MRI for detector installation)
    - single-bunch running, phototube optimization, beam scans
  - Detailed simulation of detector response to backgrounds, beam parameters at CESR and ILC

Telescope Design:



- Large solid angle for beamstrahlung collection
- Confocal imaging for high spatial resolution
- Detection includes optical filters, polarizers and CCD matrix to measure angular intensity distribution

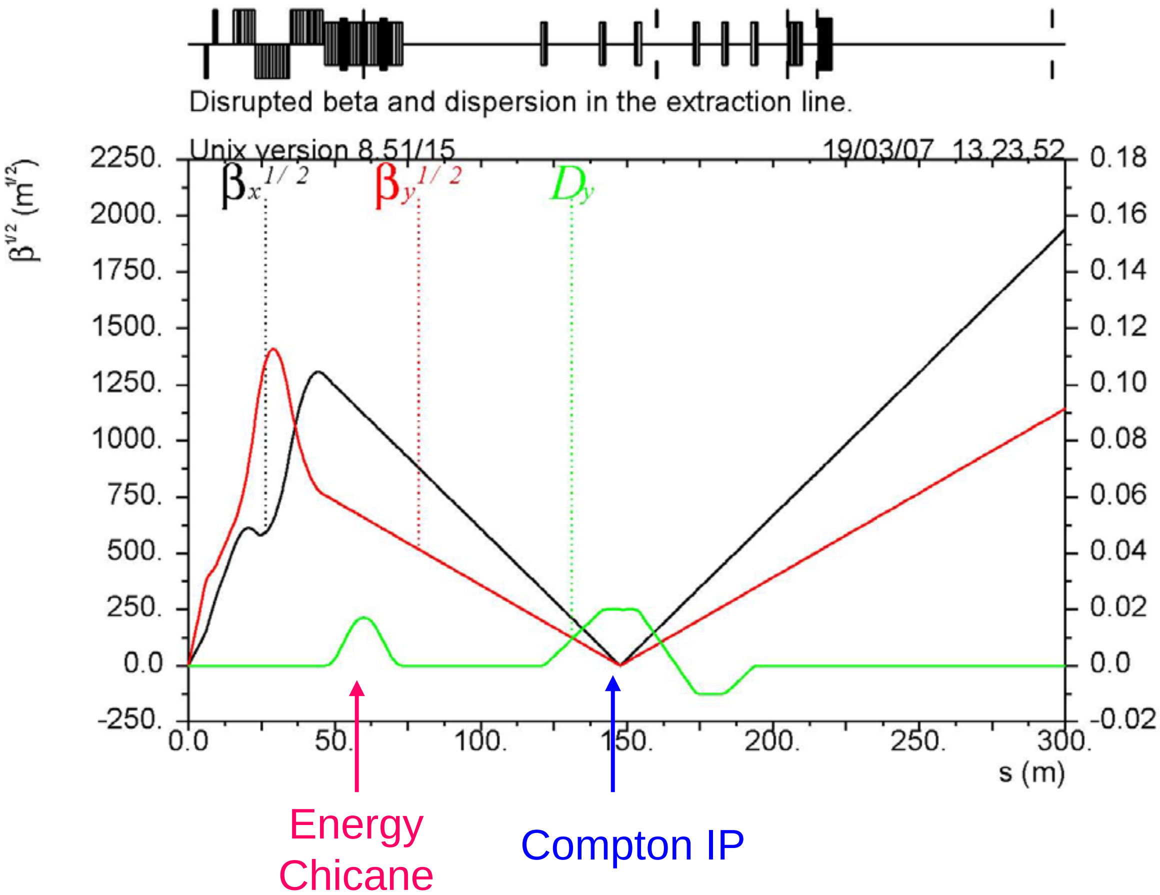
Conclusions

- The US maintains an extensive, robust MDI R&D effort
  - Many important areas are receiving attention
- Precision measurements of beam parameters are a critical component of the ILC program
  - more involvement from detector groups is needed to realize full potential of the R&D efforts
    - 10^{-4} measurements of *anything* don't come for free!
    - detailed engineering designs of forward detector elements (calorimeter, tracking, muons) must include MDI input
    - detailed engineering designs of IR region must include physics input
  - potential End Station A shutdown worrisome
    - world's only high energy electron beam for MDI tests
    - SABER isn't a drop-in replacement
- Still room for clever ideas in Beam Diagnostics
  - beamstrahlung physics is very rich
  - new elements must be included (or retrofitted) to IR designs
- Global MDI effort needs more participation (e.g. attract Asian groups)

Supplemental Material

Extraction Line Polarimeter

- Optics Design for 14mrad crossing angle, with second IP for Compton Polarimeter



- New chicane: two new dipoles added; first two magnets have 1.5xBdl of the previous version
- shown for nominal 250 GeV disrupted beam
- Has separate chicane for an Energy Spectrometer
- Difficult to accommodate small crossing angles and have extraction line diagnostics

Upstream Energy Spectrometer

M. Hildreth (Notre Dame), SLAC, Cambridge, UCL, Royal Holloway, LBNL/Berkeley, DESY-Zeuthen, Dubna

- Design Details:
  - Constrained by allowed emittance growth from Synchrotron Radiation
    - hard bending at points of large dispersion gives large emittance growth ⇒ Any bend magnets inside chicane need to be “soft”
  - Constrained by available real estate in Beam Delivery Syst, overall size
    - Relative positions of components need to be monitored
      - limits total size to ~50 m
    - These constraints determine needed BPM resolution/stability
      - overall design for BPM resolution of ~0.5μm
      - can always average over many pulses if things are stable
      - if we do much better, bunch-by-bunch diagnostics possible
  - Other issues drive systematic errors, diagnostics

  ⇒ Complicated dependence on design parameters, options

  - Must be robust, invisible to luminosity

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

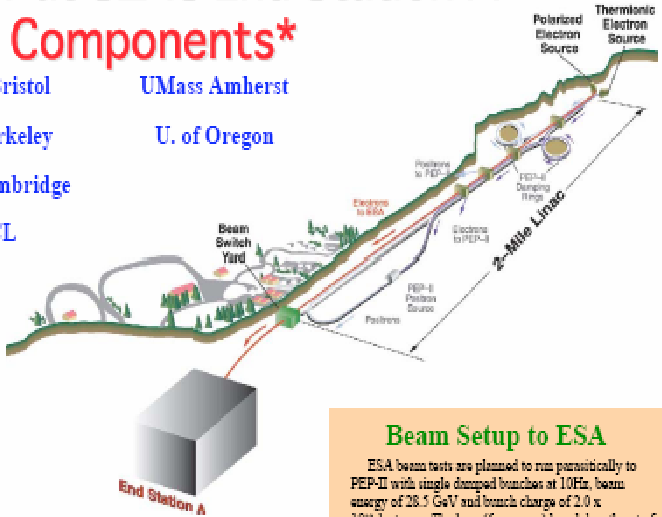
Recent PAC Poster

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



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

The SLAC Linac can deliver damped bunches with ILC parameters for bunch charge and bunch length to End Station A. A 10Hz beam at 28.5 GeV energy can be delivered there, parasitic with PEP-II operation. We plan to use this facility to test prototype components of the Beam Delivery System and Interaction Region. We discuss our plans for this ILC Test Facility and preparations for carrying out experiments related to collimator wakefields and energy spectrometers. We also plan an interaction region mockup to investigate effects from backgrounds and beam-induced electromagnetic interference.

Collimator Wakefield Measurements

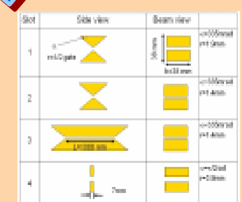


Fig. 1: Collimator insertions planned for a first set of measurements.

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.

Beamline Configuration

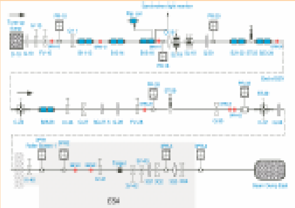


Fig. 2: A-Line from the Tune-up dump in the Beam Switchyard at the end of the Linac to End Station A. Downstream of IV-40 the beamline elements used for E158 (shown in Figure) have been removed in preparation for the ILC tests.

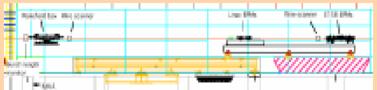


Fig. 3: Elevation View of beamline elements in ESA for Stage 1 commissioning. Chicane magnets, shown in Fig. 5, will be added for Stage 2.

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 rf 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.

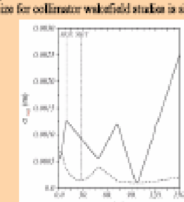


Fig. 4: Beam size in ESA after the last A-line bend. Beam has 100 μm rms spotsize at the Collimator Wakefield Box (z=85 meters).

Energy Spectrometer Prototypes

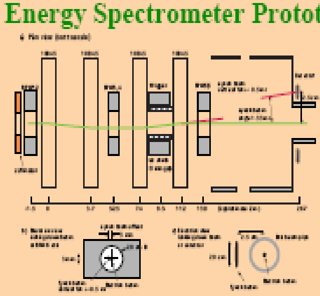


Fig. 5: Chicane configuration, beam trajectory (green) and SR stripe photons from wiggler (red) in ESA for BPM and SR stripe-energy spectrometer measurements.

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.

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-Linac transfer line and in the 24.5-degree A-line bend from the Linac to ESA to achieve ~300μm bunch length in ESA.

Bunch Length

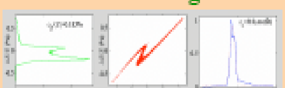


Fig. 6: Energy spread and bunch length in ESA.

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	0.10%	720 μm
ESA	28.5 GeV	0.10%	310 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.

ILC-World

World-Wide Studies of ILC Physics and Detectors

*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.

End Station A Beam Parameters

- Aside from total number of bunches (and the energy), most parameters can be made very similar to ILC

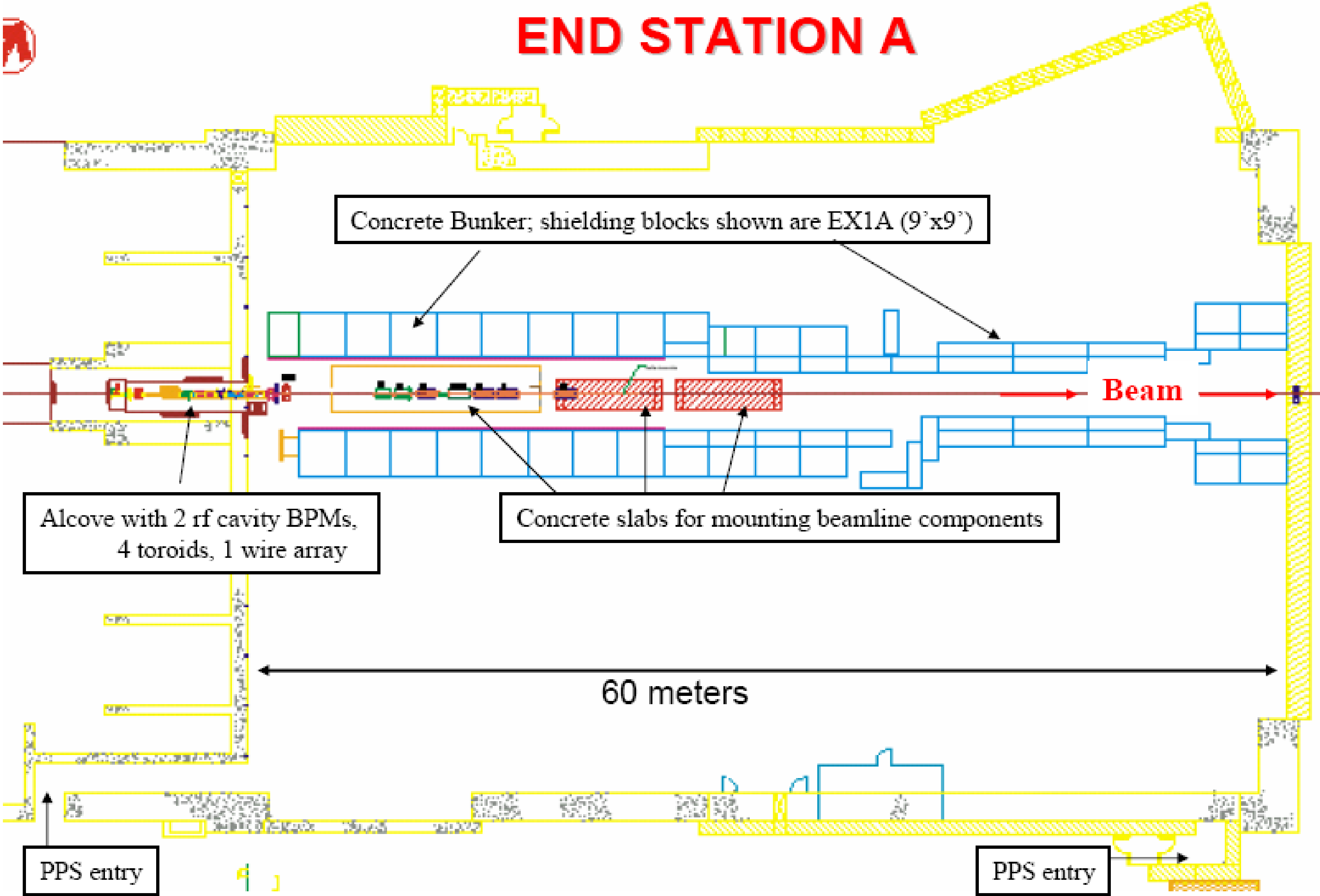
Parameter	**SLAC ESA**	**ILC-500**
Repetition Rate	10 (up to 30) Hz	5 Hz
Energy	28.5 GeV	250 GeV
e^- Polarization	(85%)	>80%
Train Length	Single bunch; (up to 400 ns possible)	1 ms
Microbunch spacing	20-400 ns	337 ns
Bunches per train	1 (or 2)	2820
Bunch Charge	2.0×10^{10}	2.0×10^{10}
Energy Spread	0.15%	0.1%

  – beam can also be made arbitrarily ugly if desired

Beam and Beamline Equipment

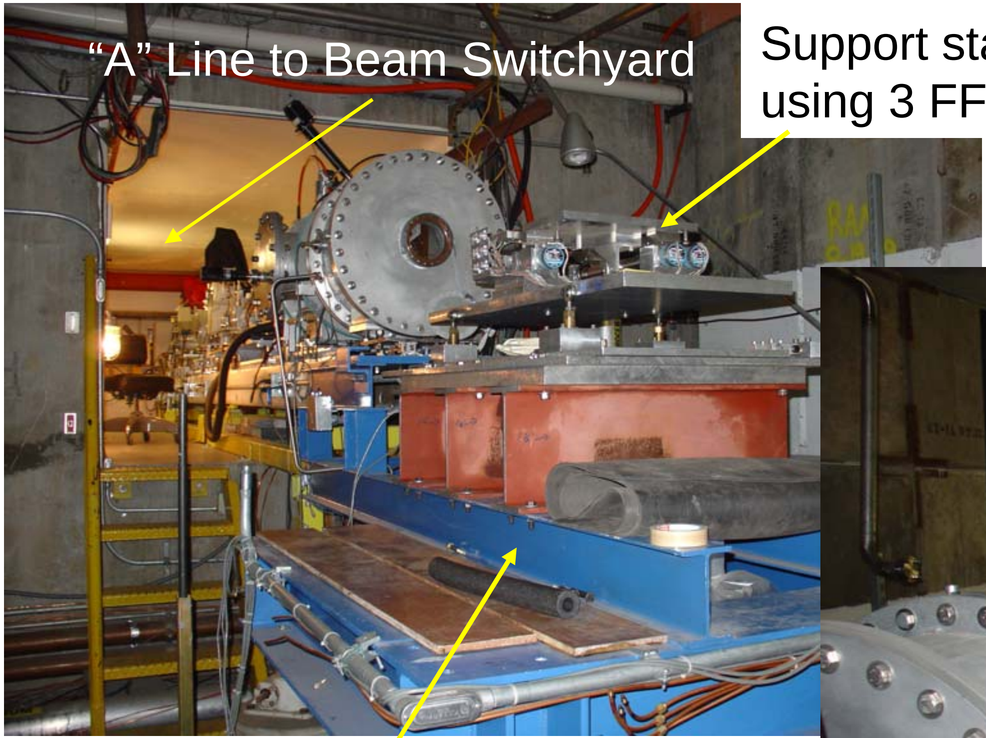
- Beam
  - 28 GeV, (1-2)·10^{10} e^{-}/pulse, 10 Hz
  - Compatible with PEP2 and BaBar
  - Beam to Beam Dump East
- Equipment
  - Many components from SPEAR, SLC, ESA programs
  - Some new detectors, BPM's, electronics, cables, sensors, etc.
  - Redesigned beamline, support stands, electronics
- Infrastructure
  - Standard A-line
  - E158 huts, AC power, DC power, LCW
  - ESA alcove instrumentation (beam containment, BPM's)
  - E158 beam containment and rad protection ion chambers
  - Standard Beam Dump East systems

Test Beam Layout

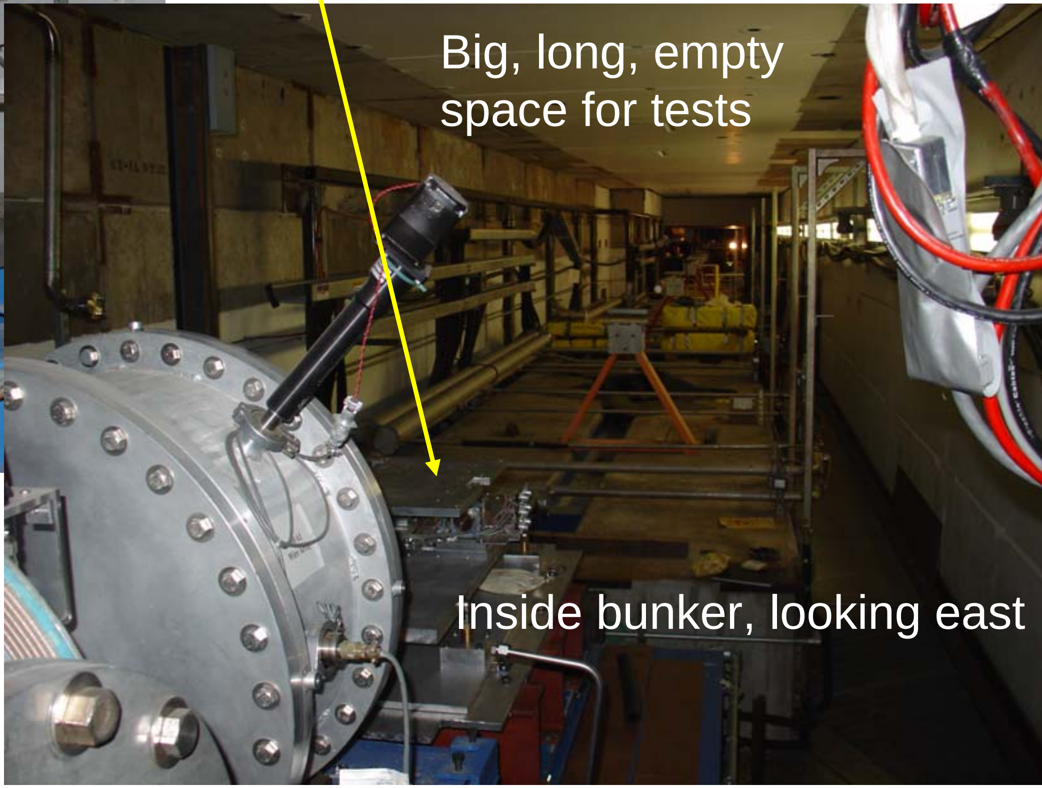


View of Beamline

Support stand for Collimator Wakefield Box, using 3 FFTB movers



E158 Target stand from previous fixed-target experiment

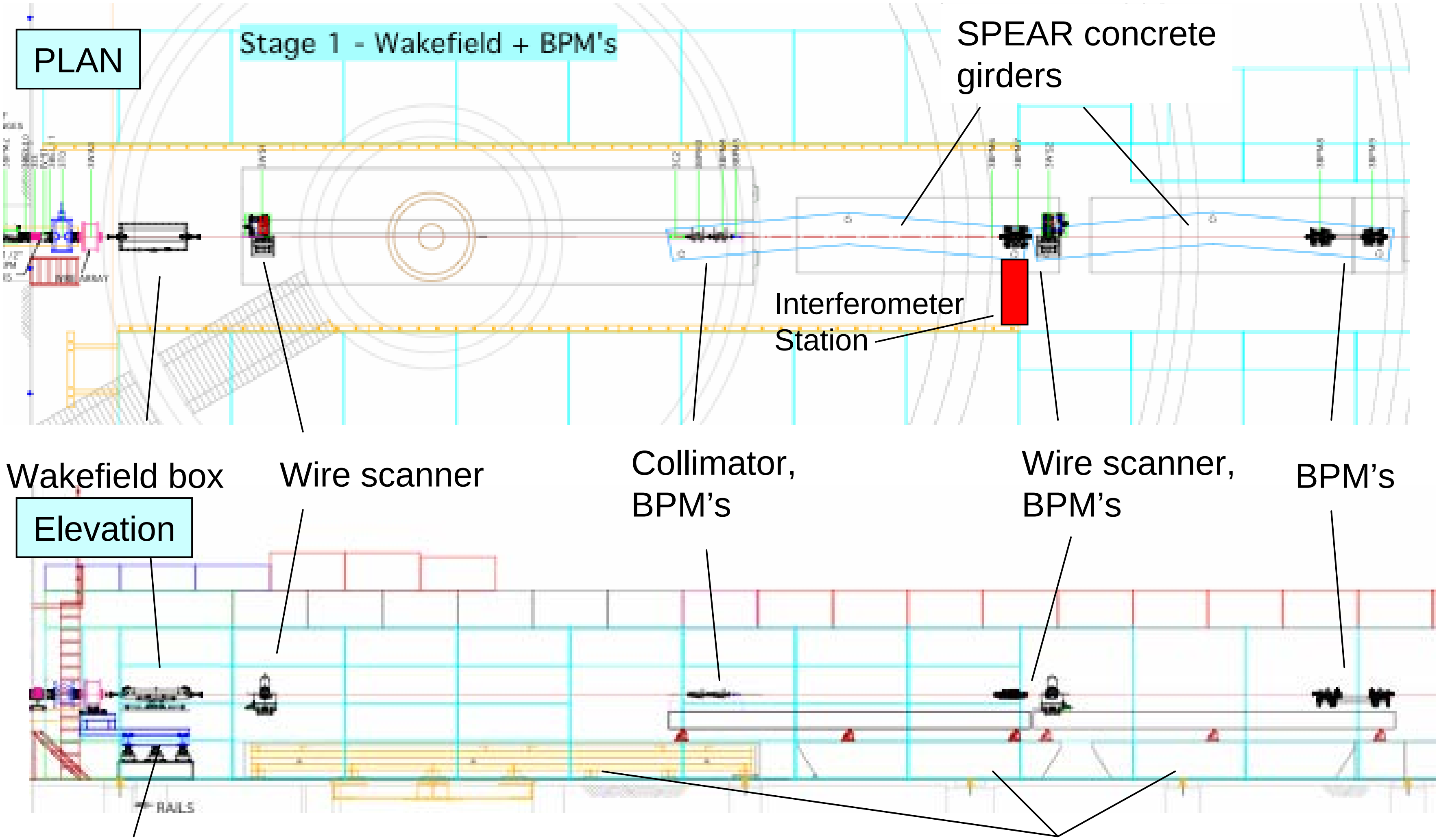


Other (ongoing) Beam Tests

- **BPM test stations**
  - **nanobpms for ATF?**
- **IP BPMs/kickers (necessary for fast inter-train and intra-train feedbacks)**
  - **Sensitivity to backgrounds, rf pickup**
  - **FONT Tests**
- **EMI impact on beam instrumentation or Detector electronics**
  - **Plans to characterize EMI along ESA beamline in progress using**
  - **antennas and fast scopes (D. Bailey, U. of Bristol); SLD VXD3 tests?**
- **Bunch length and longitudinal profile measurements**
  - **electro-optic, Smith-Purcell, coherent transition radiation, other?**
- **Spray beam or fixed target to mimic pairs, beamsstrahlung, disrupted beam**
  - **for testing synchrotron stripe energy spectrometer, IP BPMs, BEAMCAL**
- **IR Mockup?**
  - **Mimick beamline geometry at IP within ±5 meters in z and ±20 cm radially**
- **Single Particles (electrons, photons, pions)**
  - **1-25 GeV particles with 1 or less particles/bunch at 10Hz for ILC Detector tests**

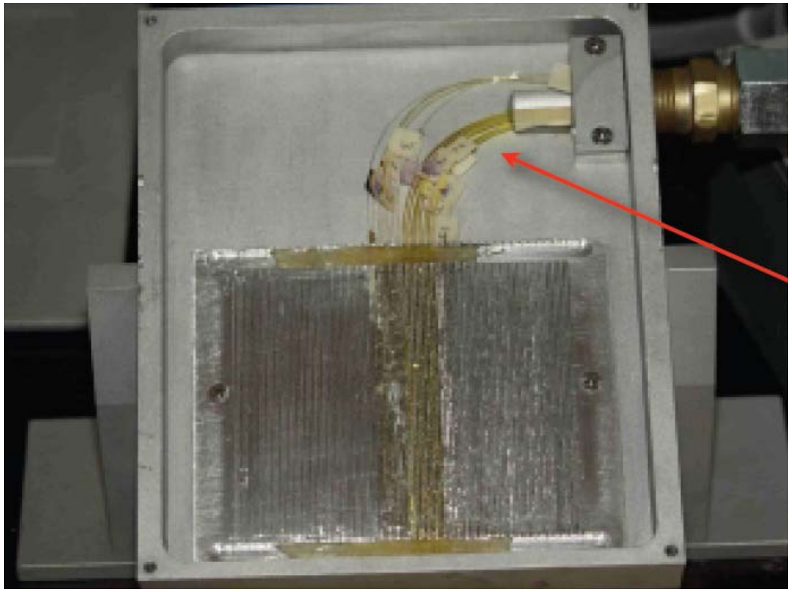
Hopefully, the ESA program will survive into the LCLS Era...

Equipment Layout for 2006 (Stage 1: no magnets)



2006 Running: Jan, April/May, July

Synchrotron Stripe Hardware (pre-2007)



E. Torrence (Oregon), SLAC

8 x 100 μm quartz fibers

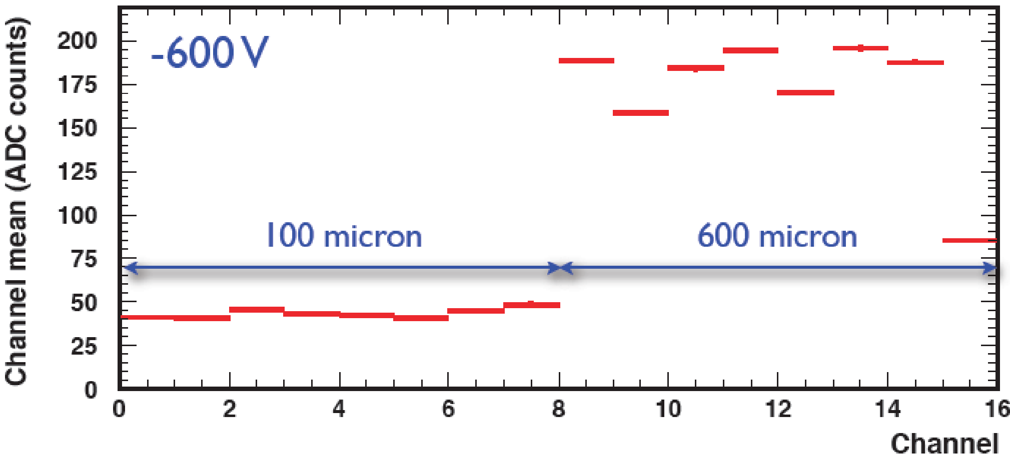
8 x 600 μm fibers

1mm pitch

(one cut at entry for background monitoring)

Some indications that it is seeing light:

- Up until now, the quartz fiber box has been buried upstream in the beam switchyard. (No access during test beam running!)
- Now moved to the endstation proper for the dual spectrometer tests



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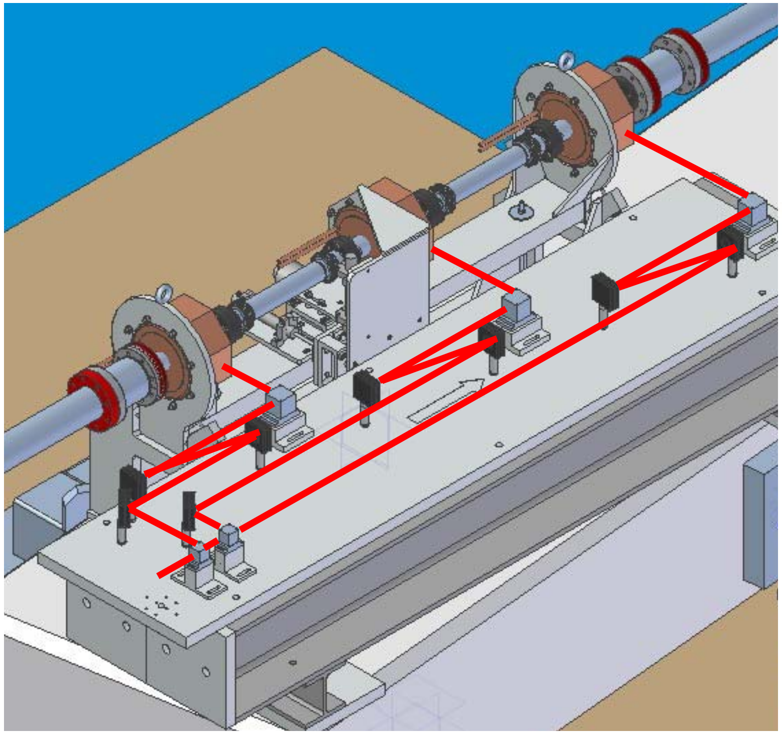
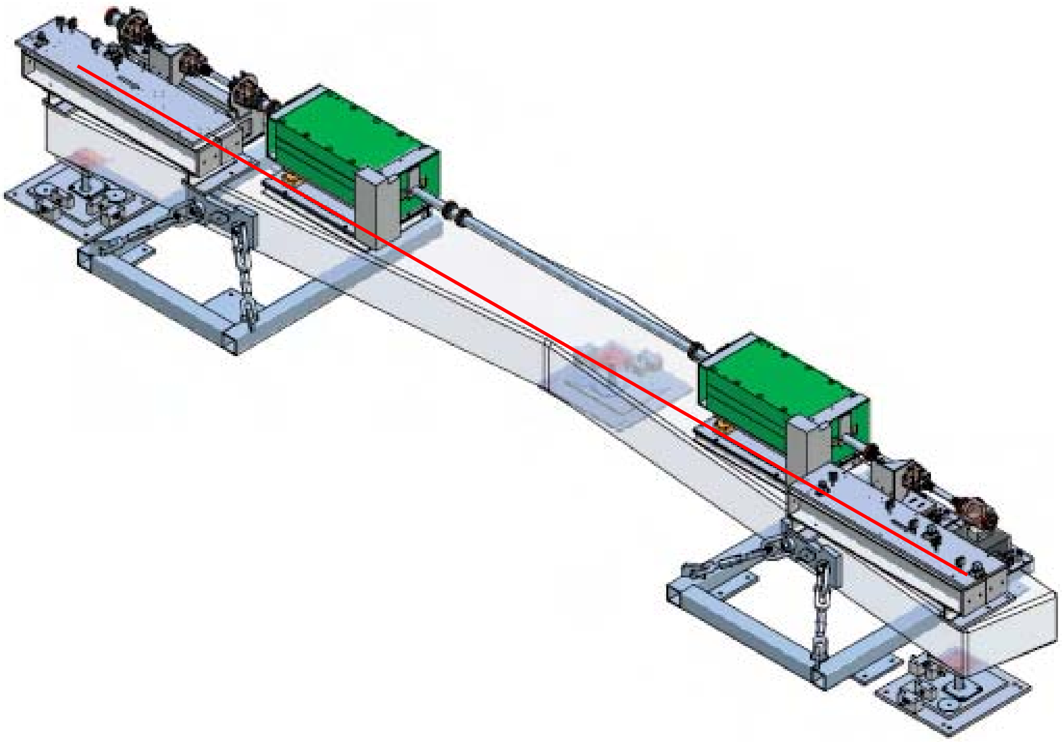
Interferometer Installation

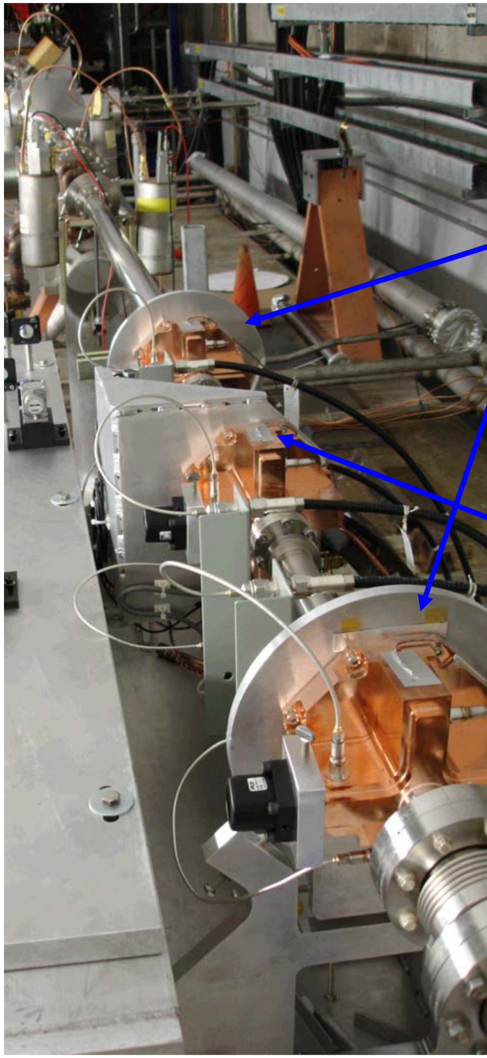
July 2006

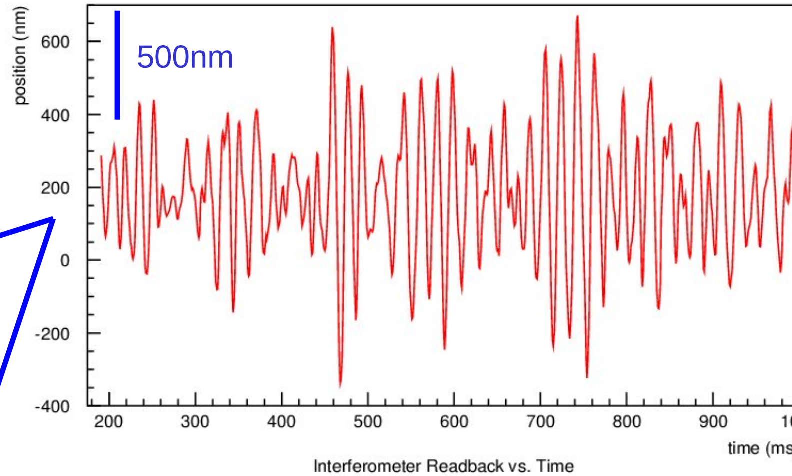


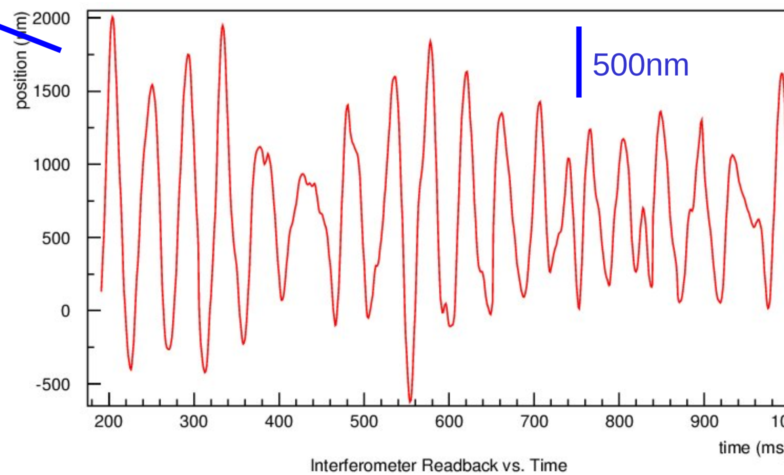
March 2007



Interferometer Data from End Station







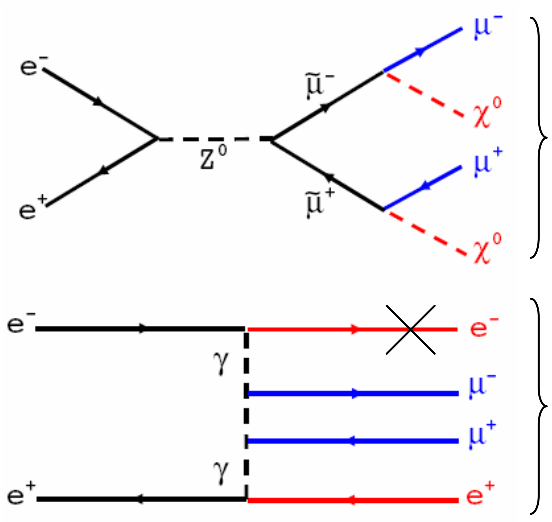
- Vibrations with amplitudes close to or exceeding expected BPM resolution seen on support girder
- Synchronous data acquisition allows interferometer measurement of BPM position to be subtracted in later data analysis
- Resolution of central BPM improved by ~700nm (added in quadrature) after vibration subtraction

BPM support girder clearly needs to be redesigned if we want to do any sort of stability testing...

BeamCal Physics Simulations

Colorado

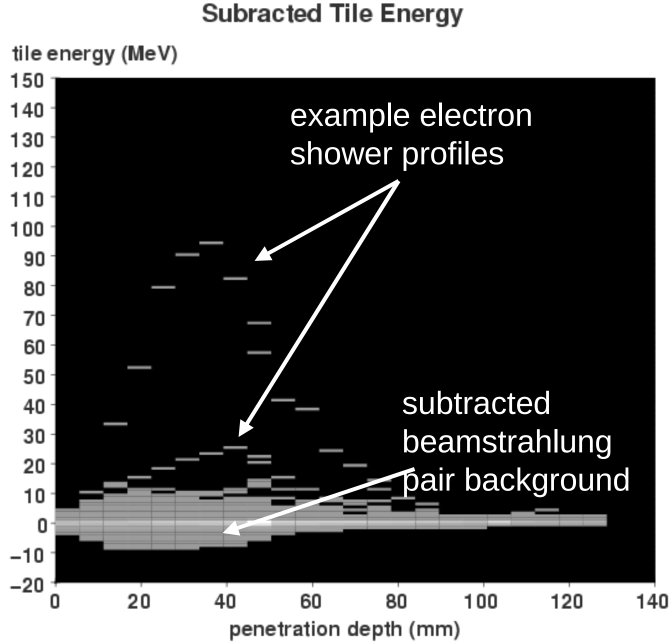
- Studies of optimal placement, segmentation, background rejection
- The task: hermeticity

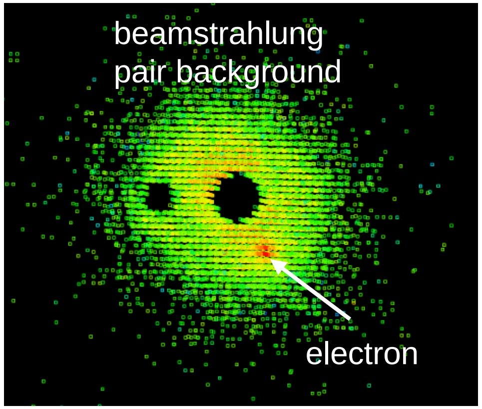


e.g.: Find this smuon signal

reject this background

in the presence of 10^4 e^+e^- pairs/crossing

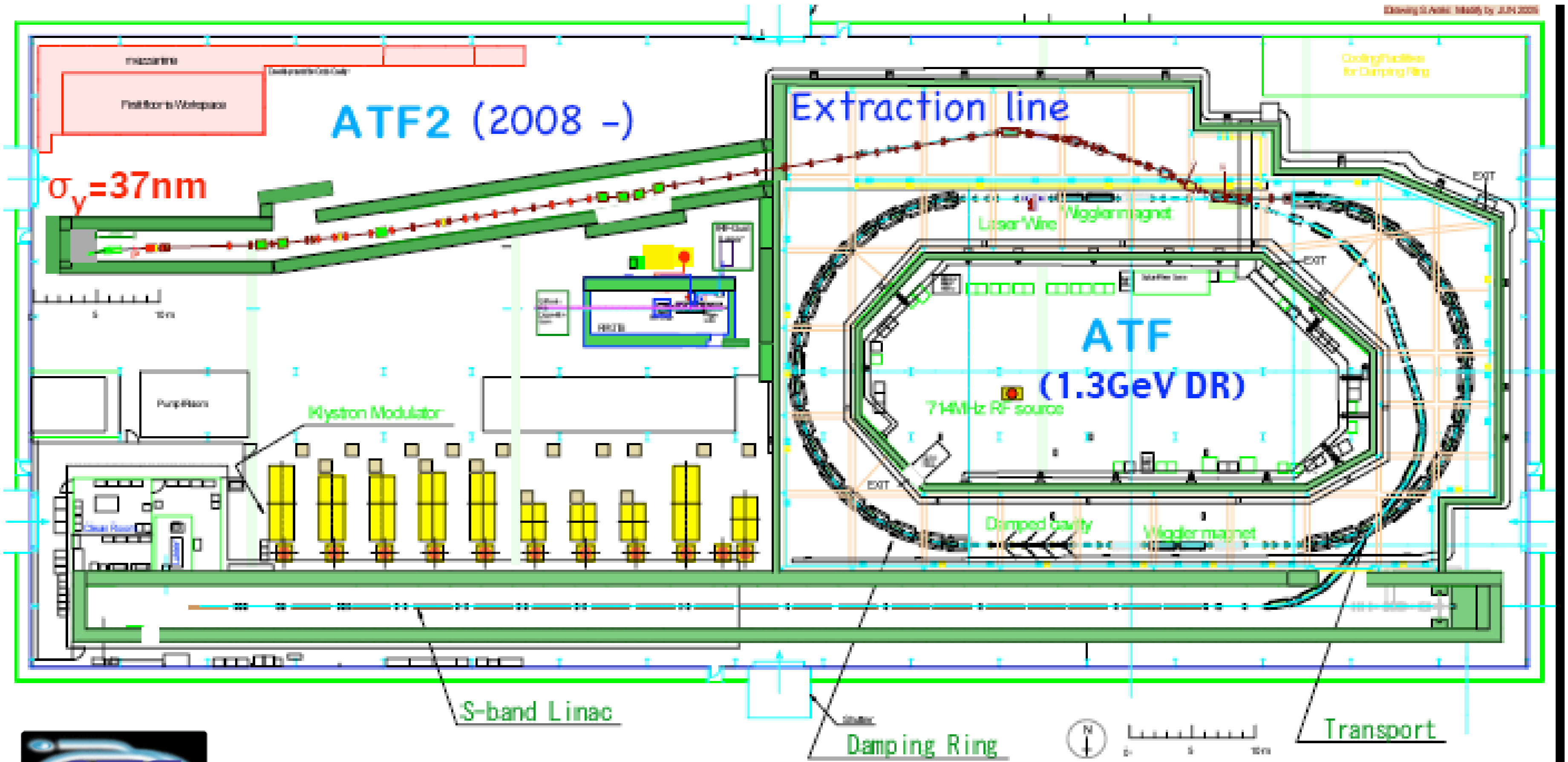




- Initial results look promising
- Studies will continue
  - energy loss (beampipe) corrections
  - calorimeter response/resolution
- Nice example of MDI/Physics Synergy

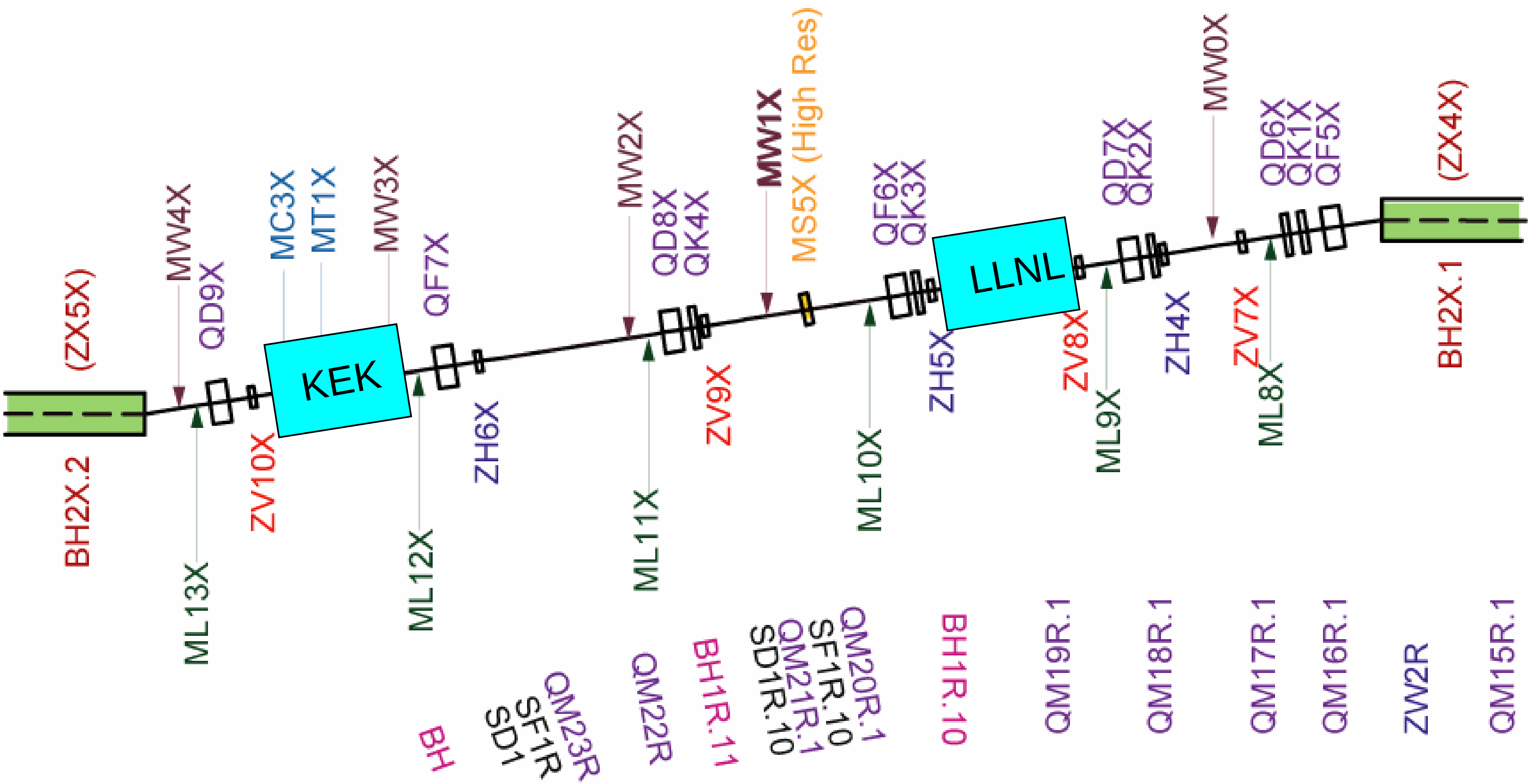
ATF at KEK

- Prototype (warm ILC) Damping Ring (ATF), linac, and new prototype Final Focus (ATF2)



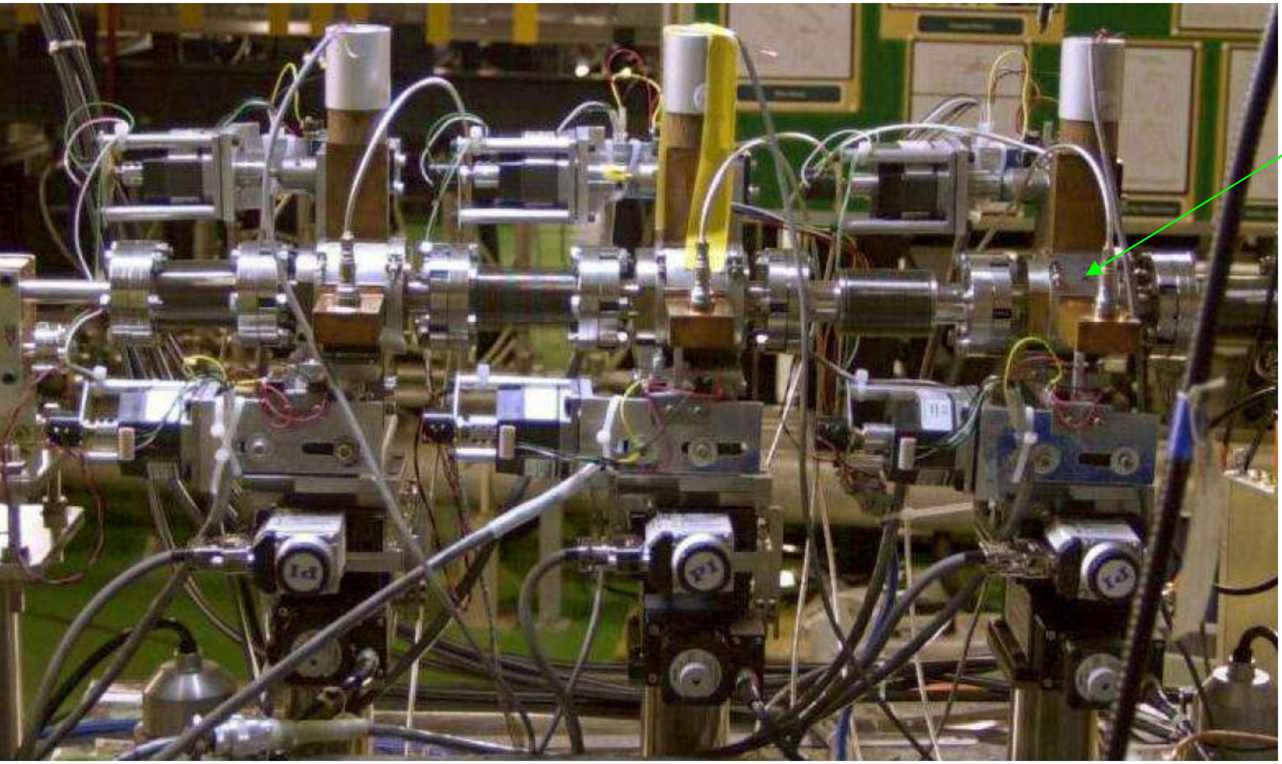
ATF Extraction Line

- Two sets of precision BPMs, separated by 5m



ATF BPM Program

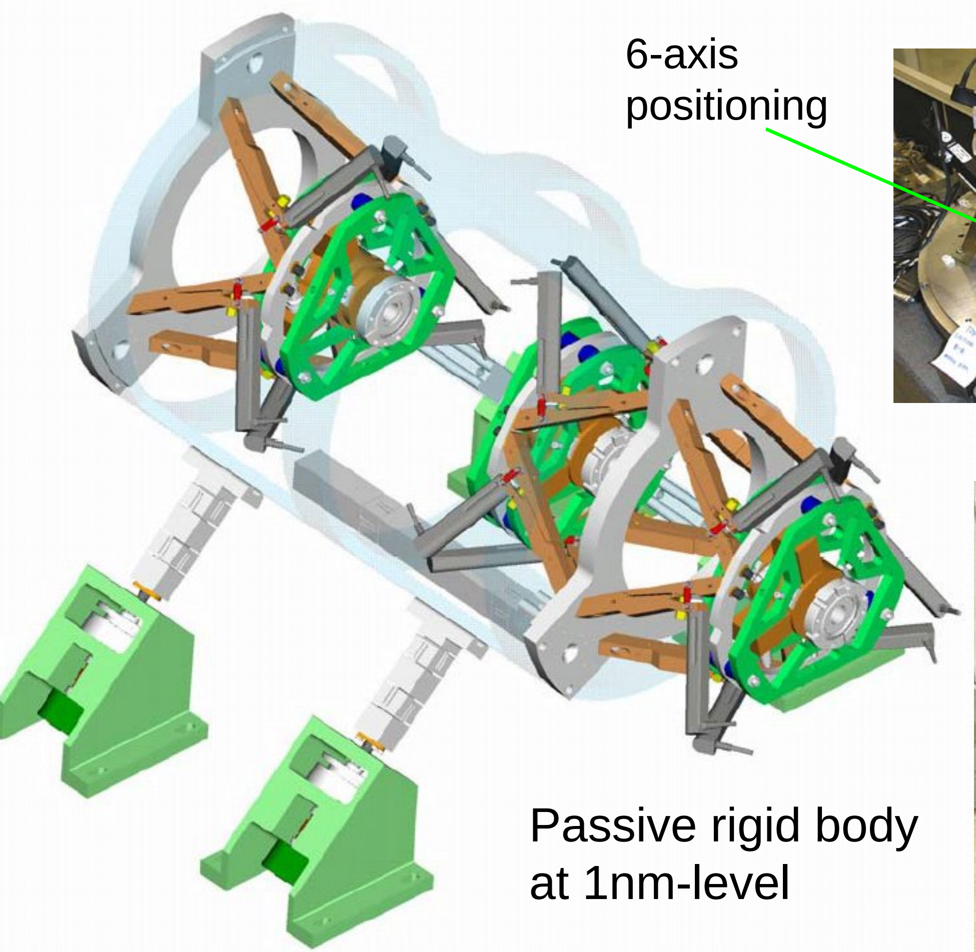
- Nano-BPM Collaboration between US & Japan
- Extensive tests at ATF in the extraction line:

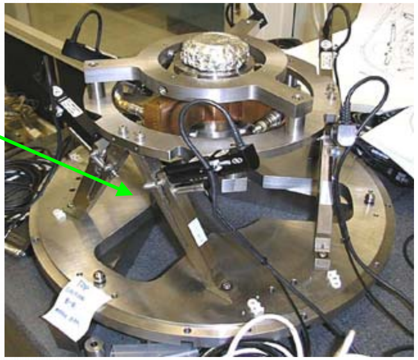


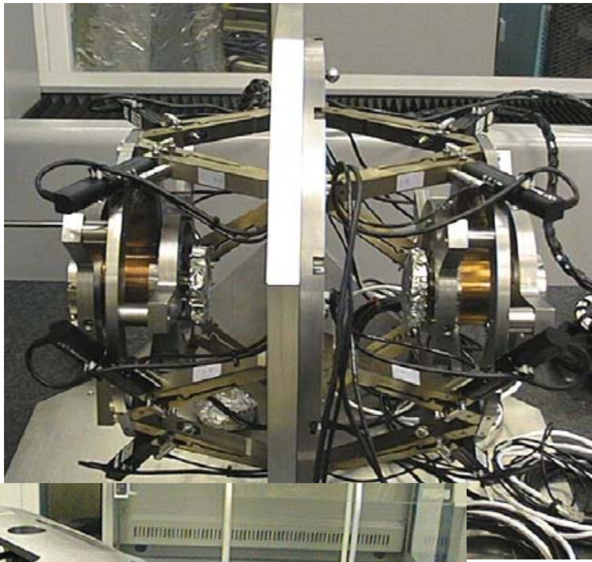
- 3 SLAC BPMs
- “pristine” beam
- multibunch capable
- Tests of resolutions, stability
- R&D on electronics, signal processing
- beam tilt monitoring

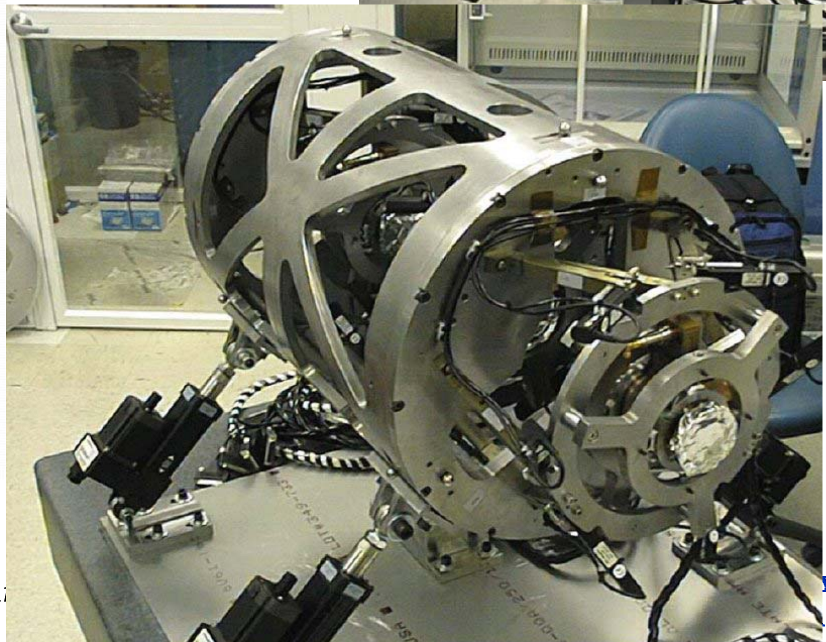
Mechanical Stability

- Rigid Supports $\Rightarrow$ **LLNL Girder**





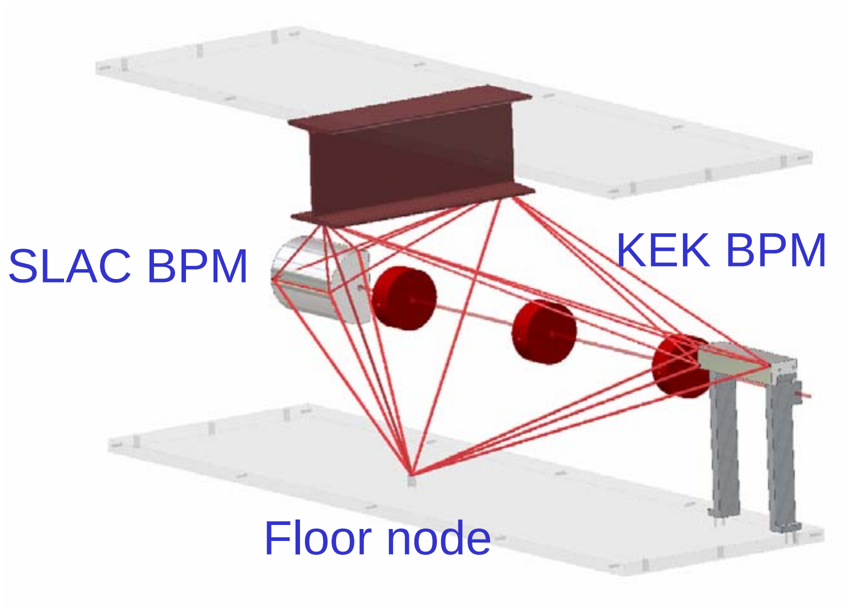




Optical Monitoring Tests

- Optical Anchor System:
  - more in later talks, but 6-D measurements
  - Should give ~2 nm resolution in y and z (=x), more like 40nm in x
  - will be very interesting to give baseline numbers on absolute movements of components
  - cross reference with Honda-san's Straightness Monitor

  ⇒ stability, and more stability
    - how well do we need to do?
    - What optical system is necessary?



- position monitoring system is a critical component for Energy Spectrometry
- Planned installations will be *the* test bed for these systems