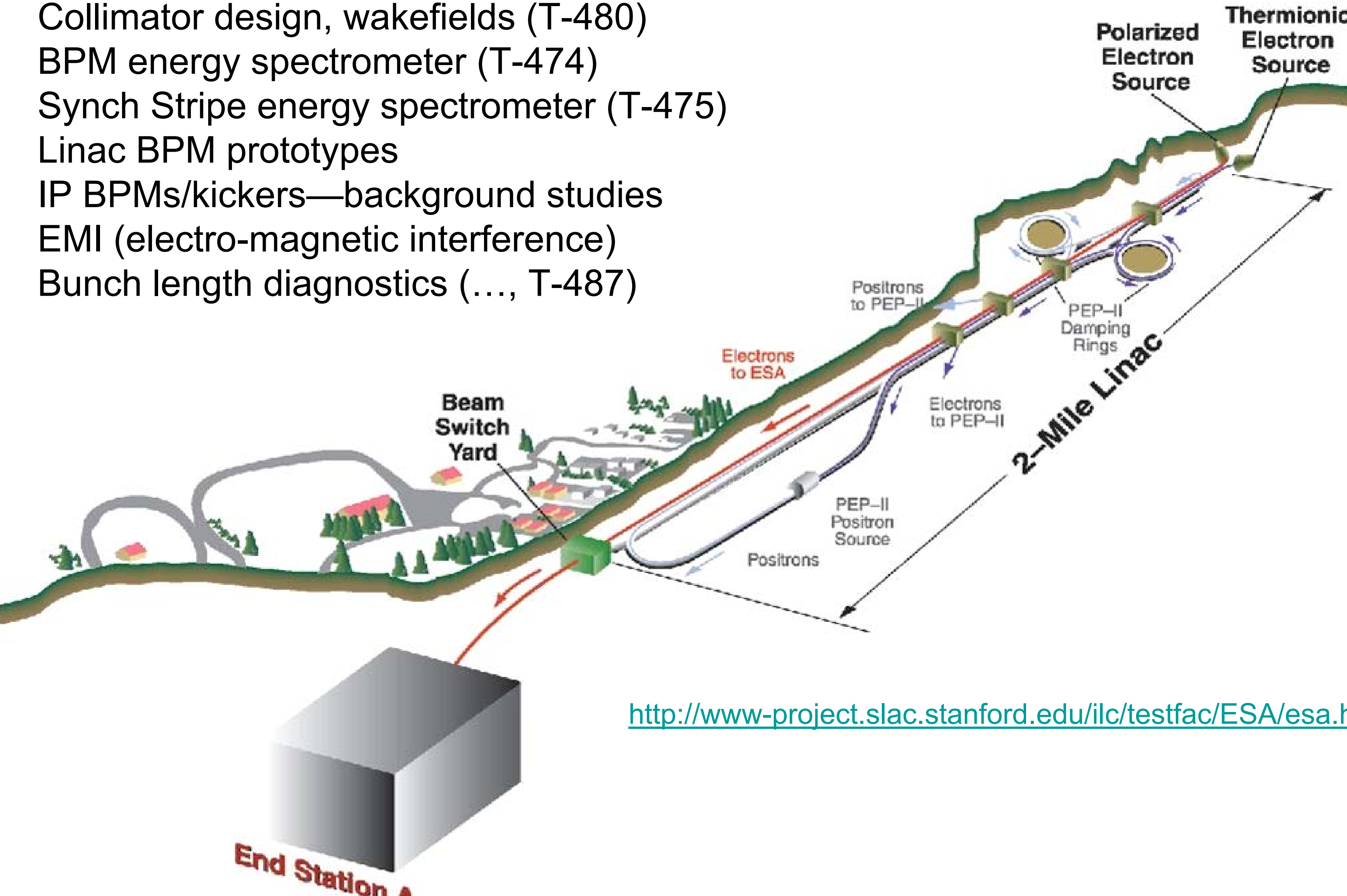
ILC Beam Tests in End Station A

SLAC LCD Meeting, June 8, 2006

M. Woods, SLAC

Collimator design, wakefields (T-480)
BPM energy spectrometer (T-474)
Synch Stripe energy spectrometer (T-475)
Linac BPM prototypes
IP BPMs/kickers—background studies
EMI (electro-magnetic interference)
Bunch length diagnostics (…, T-487)



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

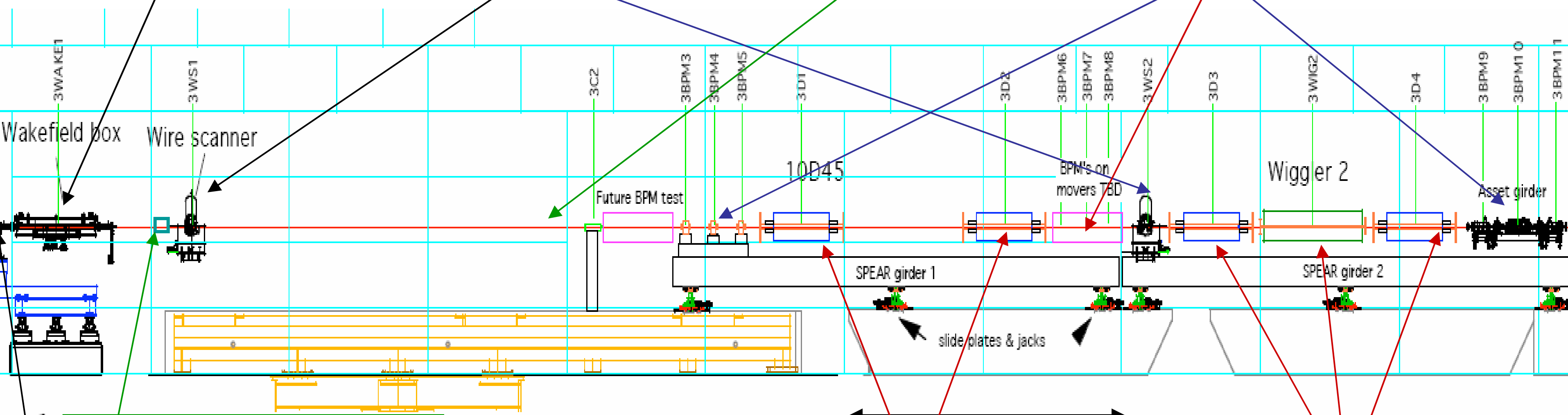
Beam Parameters at SLAC ESA and ILC

Parameter	SLAC ESA	ILC-500
Repetition Rate	10 Hz	5 Hz
Energy	28.5 GeV	250 GeV
Bunch Charge	2.0×10^{10}	2.0×10^{10}
Bunch Length	300 μm	300 μm
Energy Spread	0.2%	0.1%
Bunches per train	1 (2*)	2820
Microbunch spacing	- (20-400ns*)	337 ns

*possible, using undamped beam

ESA Equipment Layout

Wakefield box | Wire Scanners | FONT-ESA | rf BPMs



Ceramic gap BLMs

+ ceramic gap (downstream of 3BPM11, not shown) for EMI studies

Dipoles + Wiggler

Upstream

4 rf BPMs for incoming trajectory
1st Ceramic gap w/ 4 diodes (16GHz, 23GHz, 2 @ 100GHz), 2 EMI antennas

blue=April '06
green=July '06
red=FY07

+ T-487 for longitudinal bunch profile (location tbd) using pyroelectric detectors for Smith-Purcell radiation

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Installation of Beamline Components

Installation of Beamline Components

ILC Beam Tests in End Station A

Funding from:

i) SLAC ILC group, ii) UK, iii) DOE LCRD, iv) SLAC LCLS (for some of bunch length measurements)

4 test beam experiments have been approved: **T-474, T-475, T-480, T-487**

2006 Running schedule:

i. January 5-9 commissioning run
ii. April 24 – May 8, Run 1
iii. July 7-19, Run 2

T-474, T-475 T-480, EMI and Bunch Length msmts in Run 1 and Run2
FONT-ESA (IP BPM background studies) in July

Plan for two 2-week runs in each of FY07 and FY08

ILC-ESA Beam Tests
Run 1: April 24 – May 8, 2006

~40 participants from 15 institutions in the UK, U.S., Germany and Japan: Birmingham, Cambridge, Daresbury, DESY, Fermilab, KEK, Lancaster, LLNL, Notre Dame, Oxford, Royal Holloway, SLAC, UC Berkeley, UC London, U. of Oregon

1. **Energy spectrometer prototypes**
   - T-474 BPM spectrometer: M. Hildreth (Notre Dame), S. Boogert (Royal Holloway and KEK) are co-PIs
   - T-475 Synch Stripe spect.: Eric Torrence (U. Oregon) is PI
2. **Collimator wakefield studies**
   - T-480: S. Molloy (SLAC), N. Watson (Birmingham U.) co-PIs
3. **Linac BPM prototype**
   - BPM triplet – C. Adolphsen, G. Bowden, Z. Li
4. **Bunch Length diagnostics for ESA and LCLS**
   - S. Walston (LLNL) and J. Frisch, D. McCormick, M. Ross (SLAC)
5. **EMI Studies**
   - G. Bower (SLAC) + US-Japan collaboration with Y. Sugimoto (KEK)

New hardware installed since January Commissioning Run was successfully commissioned:

1. 8 sets of collimators to test in collimator wakefield box (2 sets of 4)
2. 2 bpm triplets downstream of wakefield box + bpm processors
3. 2nd wire scanner downstream of wakefield box
4. 2nd 100-GHz diode bunch length detector
5. 2 EMI antennas (broadband up to 7GHz; use with 2.5GHz bandwidth scope)

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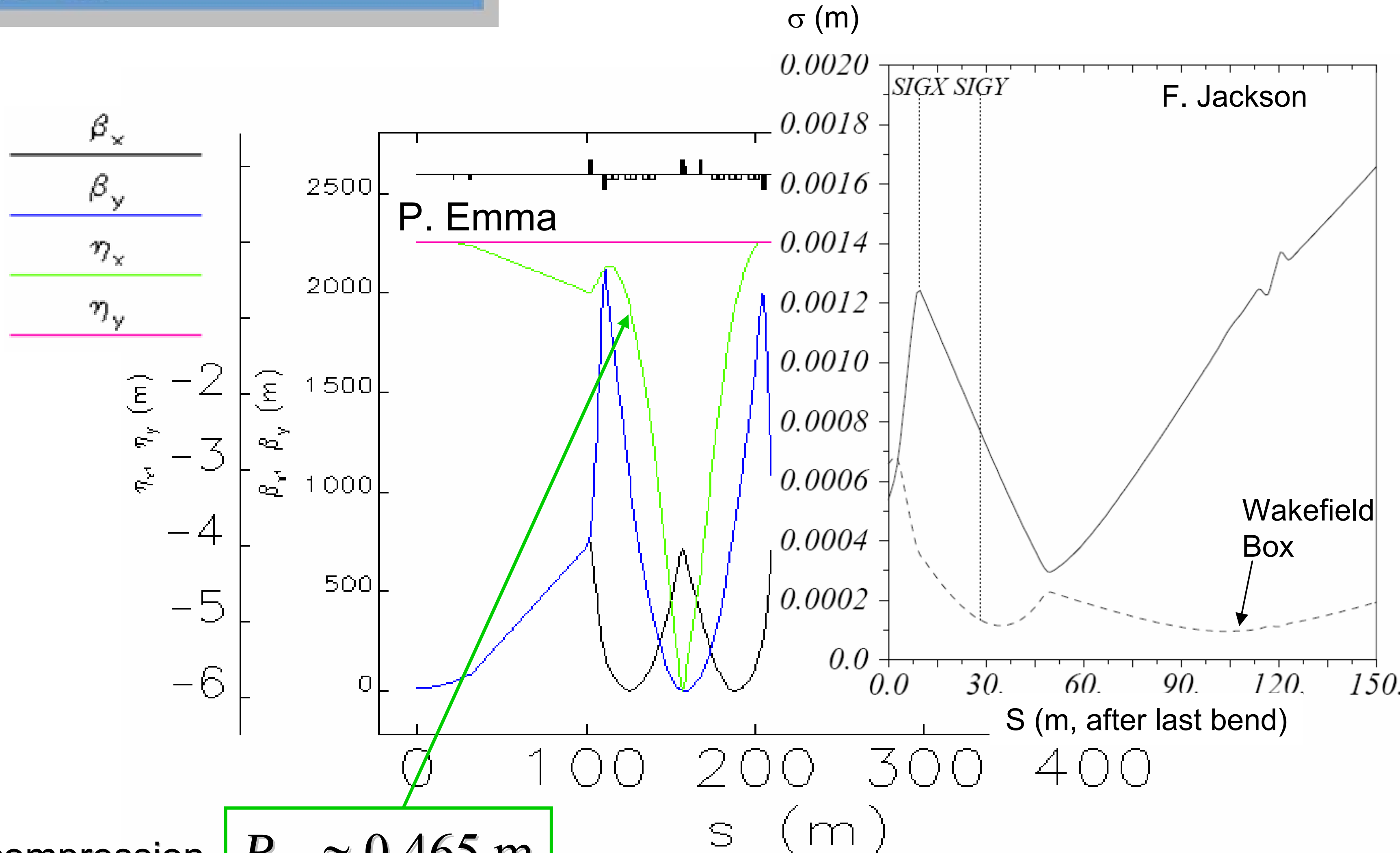
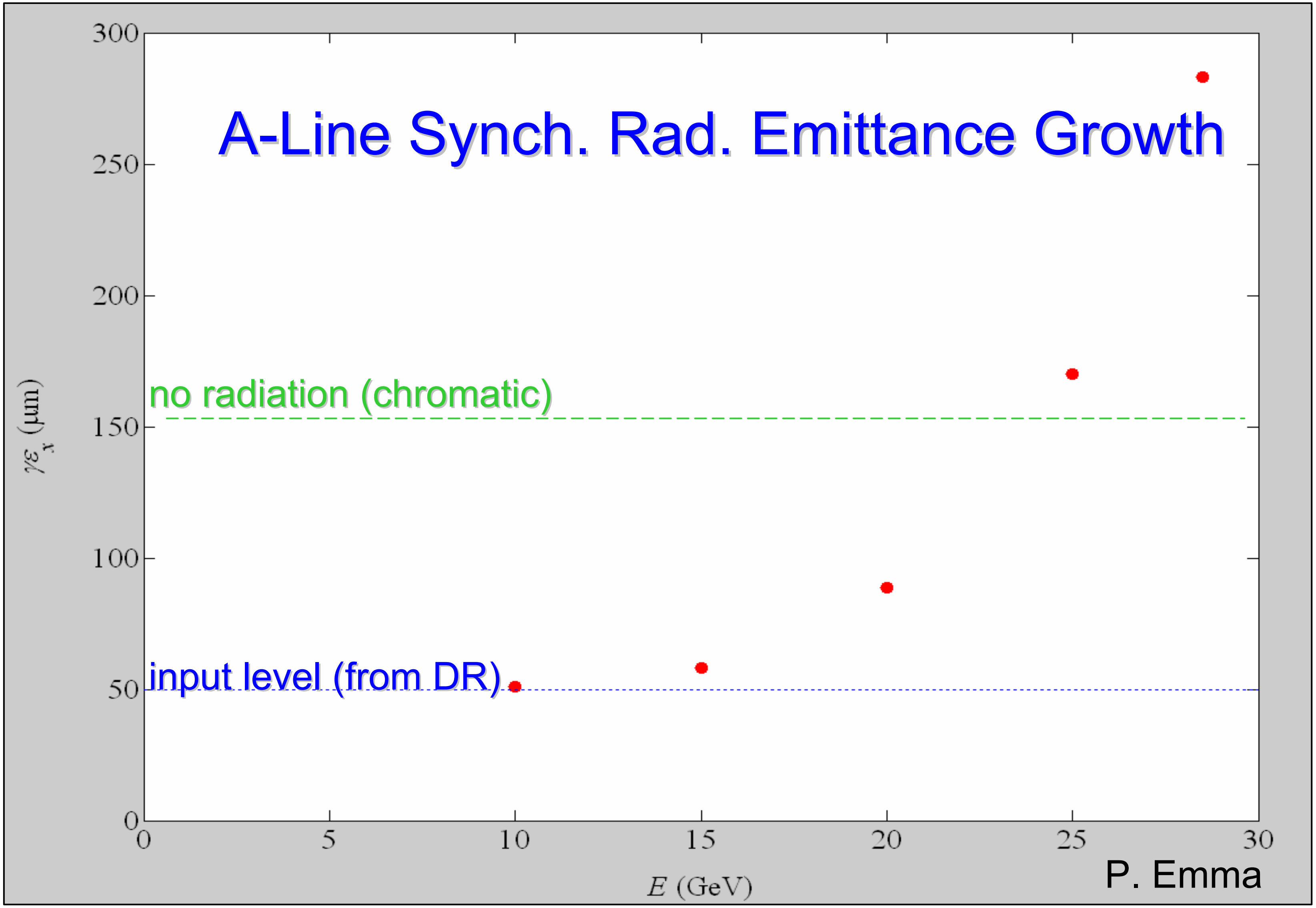
A-Line Optics



compression parameters

$$R_{56} \approx 0.465 \text{ m}$$
$$T_{566} \approx 2.74 \text{ m}$$



A-Line Synch. Rad. Emittance Growth
no radiation (chromatic)
input level (from DR)
300
250
200
150
100
50
0
0
5
10
15
20
25
30
E (GeV)
γε_x (μm)
P. Emma

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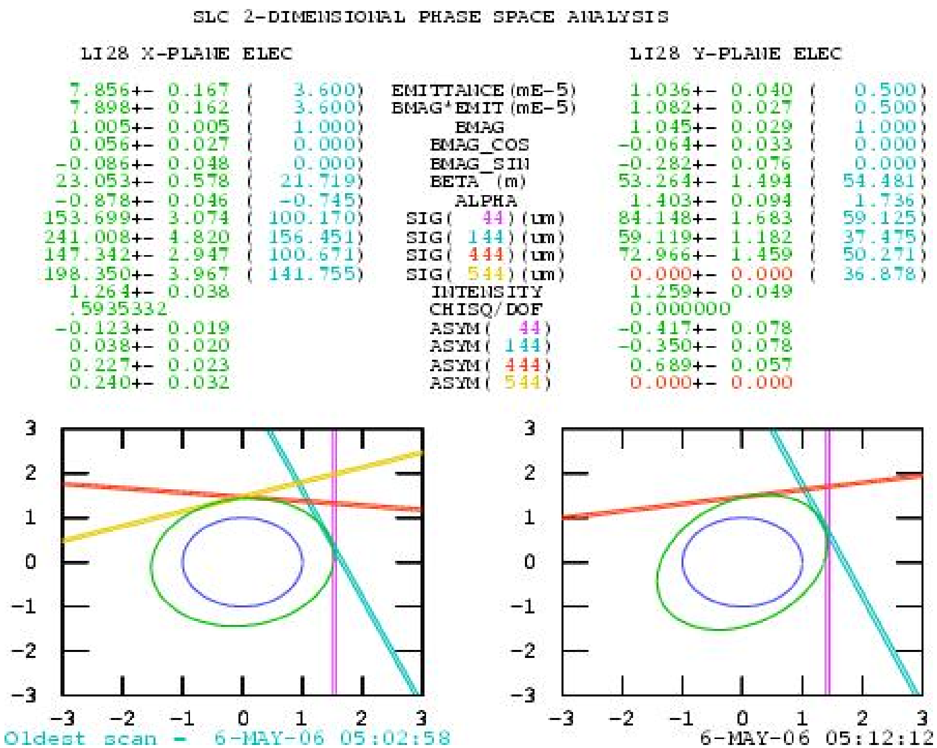
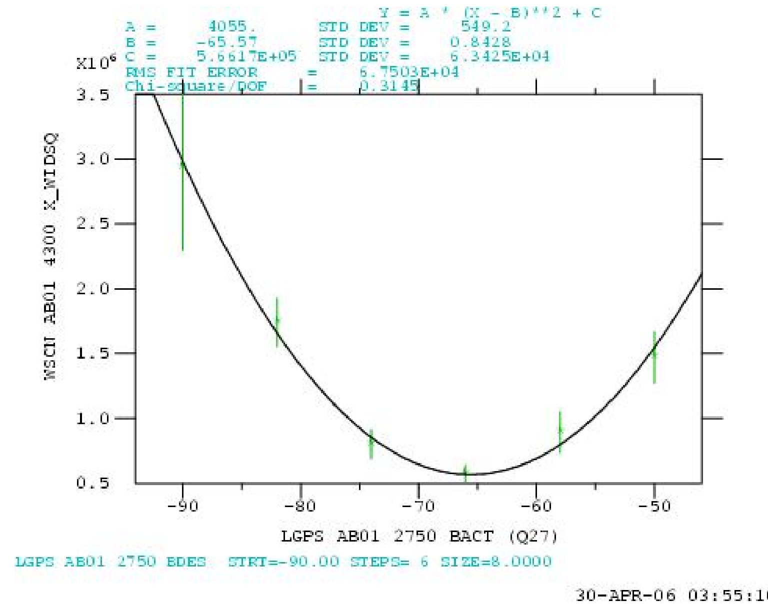
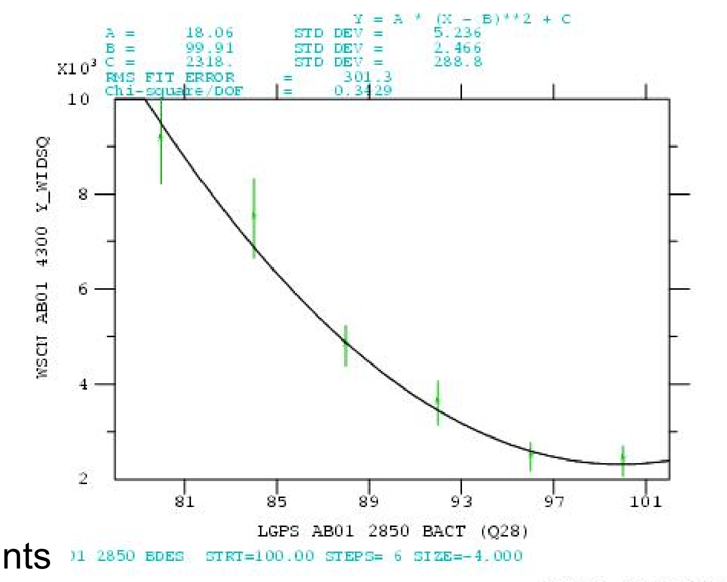
Emittance measurements in Sector 28 and ESA



SLC 2-DIMENSIONAL PHASE SPACE ANALYSIS

LI28 X-PLANE ELEC			LI28 Y-PLANE ELEC	
7.856+- 0.167	(3.600)	EMITTANCE(mE-5)	1.036+- 0.040	(0.500)
7.898+- 0.162	(3.600)	BMAG*EMIT(mE-5)	1.082+- 0.027	(0.500)
1.005+- 0.005	(1.000)	BMAG	1.045+- 0.029	(1.000)
0.056+- 0.027	(0.000)	BMAG_COS	-0.064+- 0.033	(0.000)
-0.086+- 0.048	(0.000)	BMAG_SIN	-0.282+- 0.076	(0.000)
23.053+- 0.578	(21.719)	BETA (m)	53.264+- 1.494	(54.481)
-0.878+- 0.046	(-0.745)	ALPHA	1.403+- 0.094	(1.736)
153.699+- 3.074	(100.170)	SIG(44)(um)	84.148+- 1.683	(59.125)
241.008+- 4.820	(156.451)	SIG(144)(um)	59.119+- 1.182	(37.475)
147.342+- 2.947	(100.671)	SIG(444)(um)	72.966+- 1.459	(50.271)
198.350+- 3.967	(141.755)	SIG(544)(um)	0.000+- 0.000	(36.878)
1.264+- 0.038		INTENSITY	1.259+- 0.049	
.5935332		CHISQ/DOF	0.000000	
-0.123+- 0.019		ASYM(44)	-0.417+- 0.078	
0.038+- 0.020		ASYM(144)	-0.350+- 0.078	
0.227+- 0.023		ASYM(444)	0.689+- 0.057	
0.240+- 0.032		ASYM(544)	0.000+- 0.000	





LI28 wire scans give $\gamma\varepsilon_x$ = (79 ± 1) mm-mrad

$\gamma\varepsilon_x$ = (10.8 ± 0.3) mm-mrad

ESA quad scans give $\gamma\varepsilon_x$ = (310 ± 20) mm-mrad

$\gamma\varepsilon_x$ = (13 ± 2) mm-mrad

- vertical emittance in S28 varied from 5-30 mm-mrad, usually fixed by tuning Linac steering, ex. LI06 steering feedback setpoints

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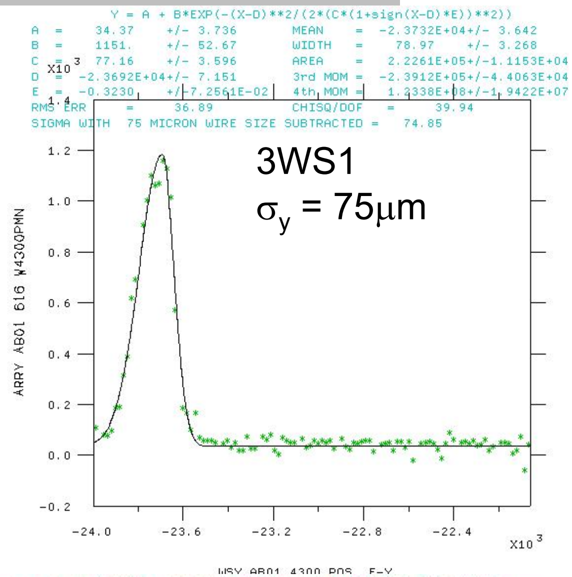
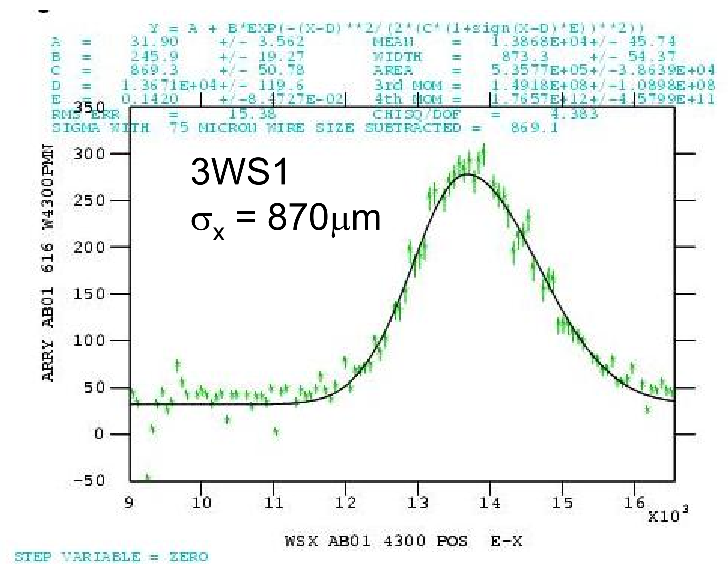
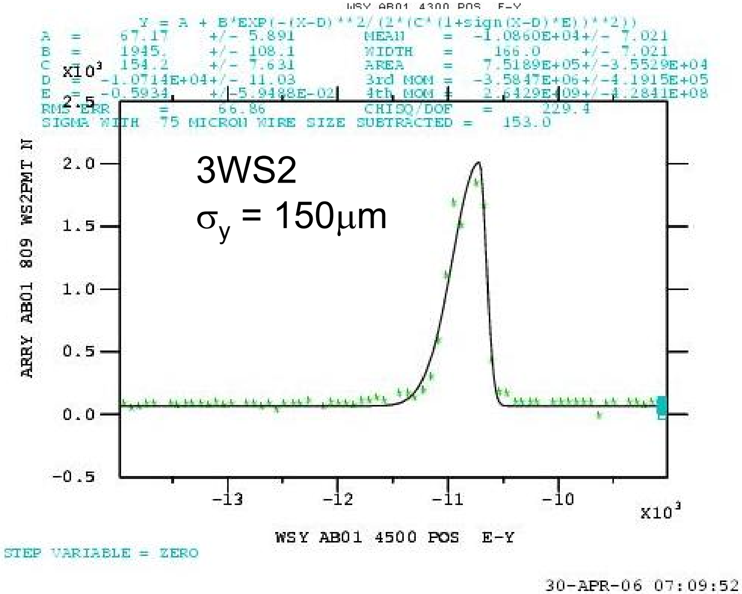
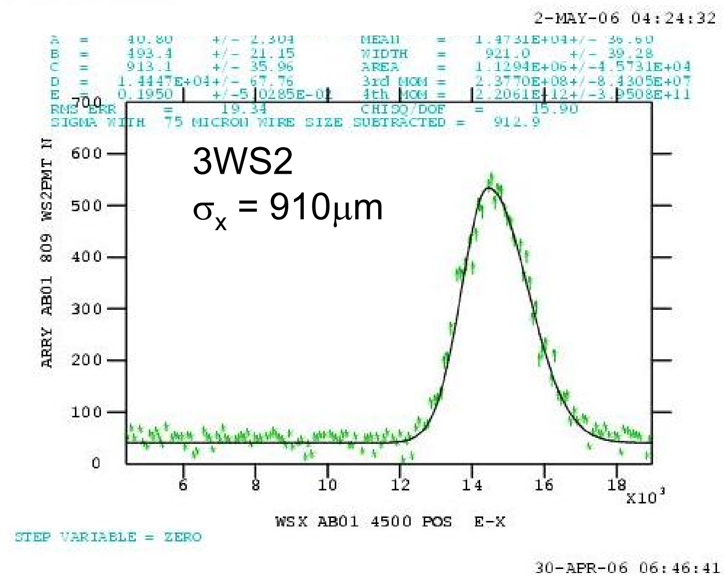
Spotsize Measurements with ESA Wirescanners







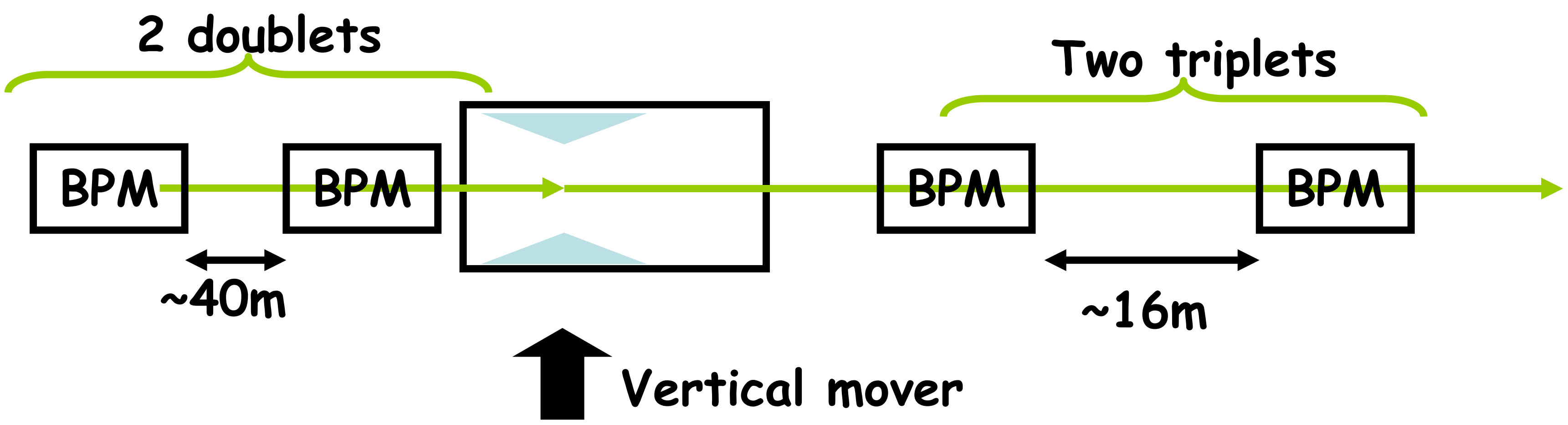


T-480: Collimator Wakefields

Collimators remove beam halo, but excite wakefields. Goal is to determine optimal collimator material and geometry. These studies address achieving the ILC design luminosity.

PIs: Steve Molloy (SLAC), Nigel Watson (U. of Birmingham)
Collaborating Institutions: U. of Birmingham, CCLRC-ASTeC + engineering, CERN, DESY, Manchester U., Lancaster U., SLAC, TEMF TU

Concept of Experiment



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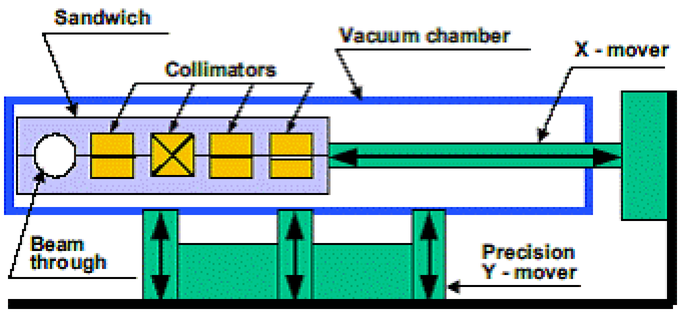
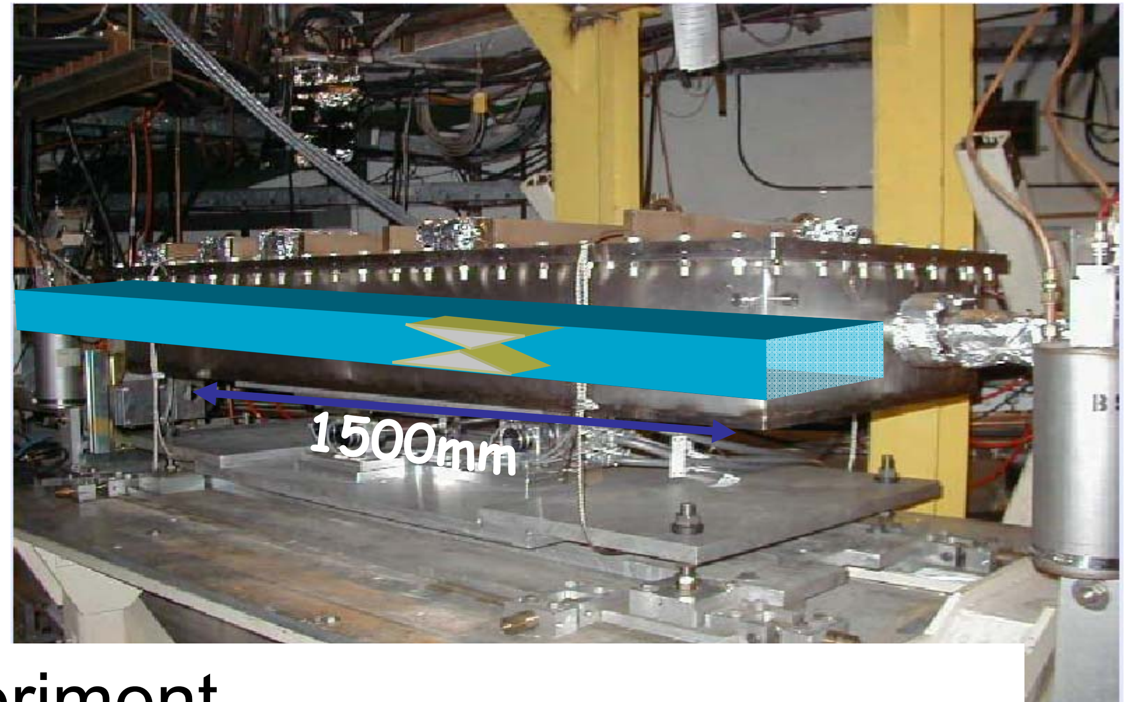
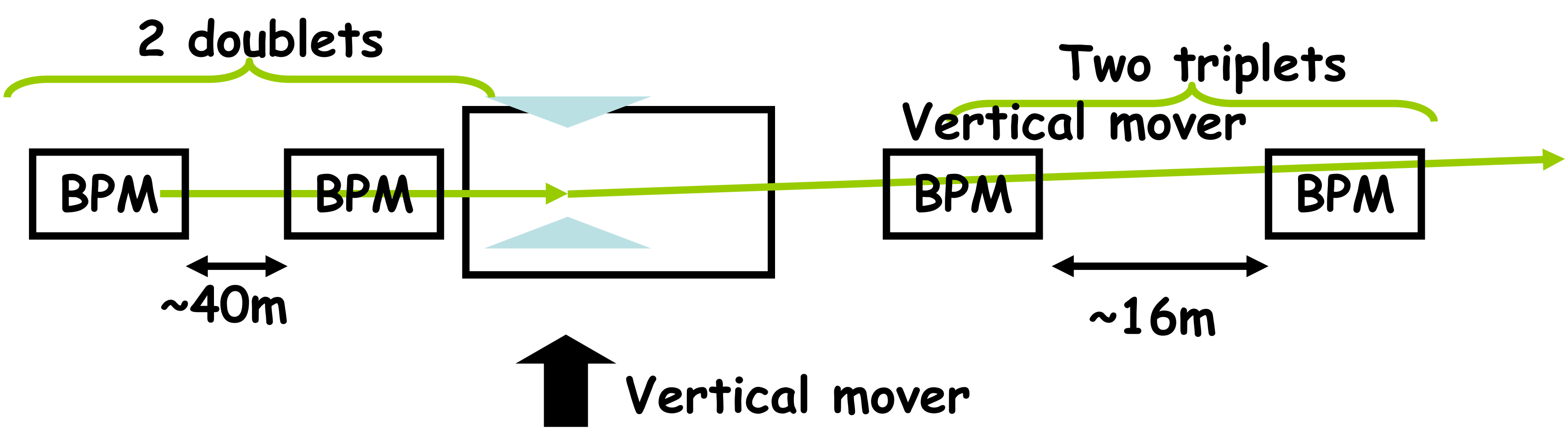
T-480: Collimator Wakefields





Concept of Experiment



T-480: Collimator Wakefields

Slot	Side view	Beam view	
1	α, r=1/2 gate	38 mm, h=38 mm	α=335mrad r=1.9mm
2			α=335mrad r=1.4mm
3	L=1000 mm		α=335mrad r=1.4mm
4	7mm		α=π/2rad r=3.8mm

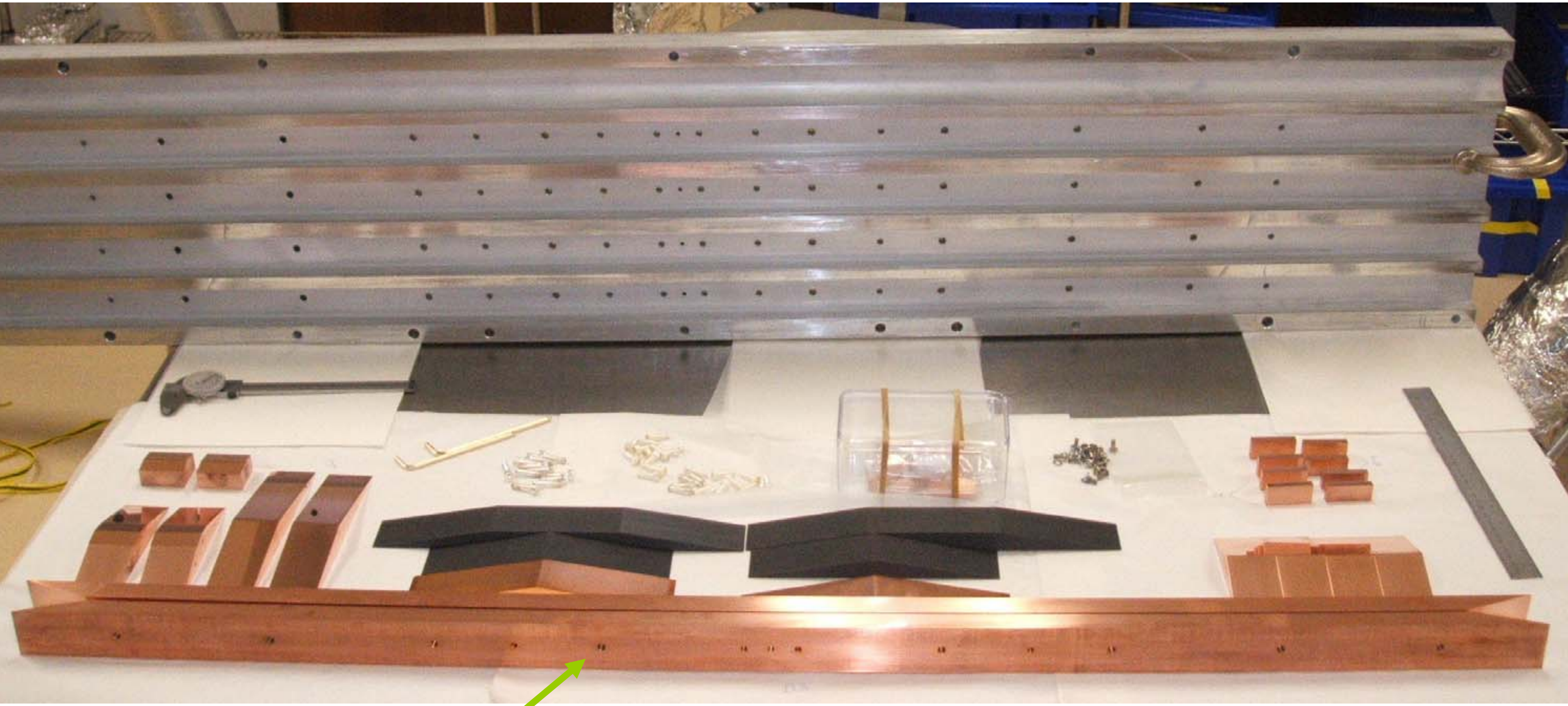
Collimators to study resistive wakefield effects in Cu

Slot	Side view	Beam view	
1	7 mm	38 mm, h=38 mm	α=π/2rad r=1.4mm
2	208mm		α=168mrad r=1.4mm
3	28mm		α_1=π/2 rad α_2=168mrad r_1=3.8mm r_2=1.4mm
4	159mm		α_1=298mrad α_2=168mrad r_1 =3.8mm r_2 =1.4mm

Collimators to study 2-step tapers in Cu

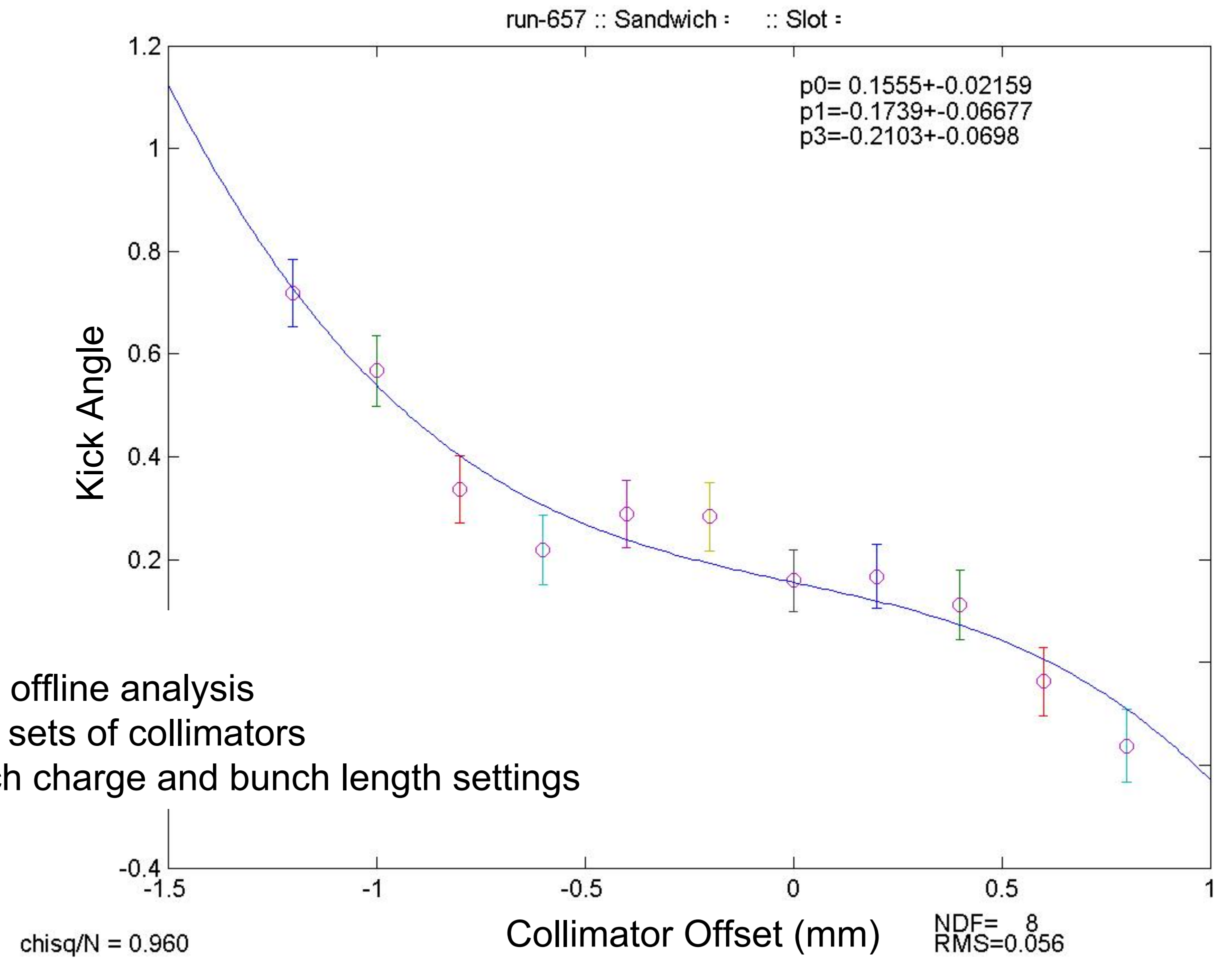
8 new collimators,
fabricated in UK,
were tested in Run 1

Collimators for Wakefield Kick Measurements



1000mm OFE Cu, ½ gap 1.4mm

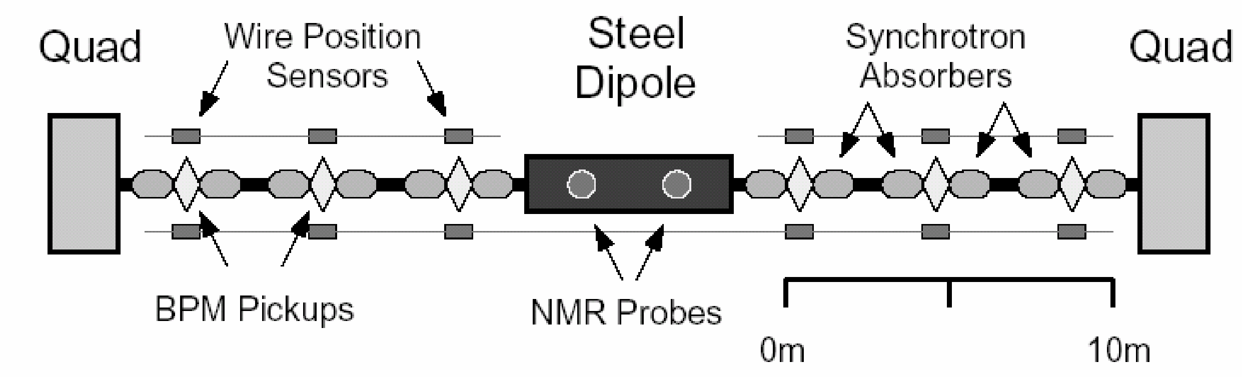
First results on Collimator Wakefield Kicks (Run 1 Data)



- Online results during Run 1
- Error bars will come down w/ offline analysis
- Have measurements on all 8 sets of collimators
- Took data with different bunch charge and bunch length settings

2 Energy Spectrometers proposed for ILC

- **"LEP-Type"**: BPM-based, bend angle measurement w/ θ = 3.77

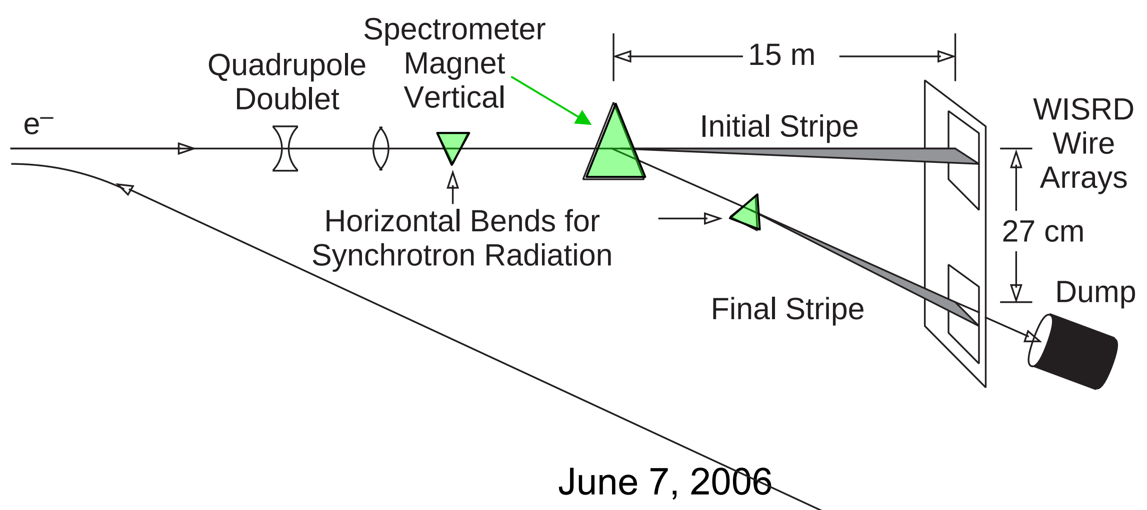


BEAM OPTICAL ELEMENTS
(Electron ELS Shown)

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

⇒ "upstream"

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



⇒ "downstream"

Beam Energy Measurements at LEP-II (~120 ppm accuracy achieved)

Primary Method: "NMR Magnetic Model"

$$E_b = \frac{ec}{2\pi} \oint B ds$$

- Uses **resonant depolarization (RDP)** data to calibrate at 40-60 GeV
- Uses 16 NMR probes to determine B-fields
- Uses rf frequency and BPM measurements to determine closed orbit length

Additional methods / cross checks:

1. **Flux loop measurements to compare with NMR measurements**
2. **BPM Energy Spectrometer**
3. **Synchrotron tune**

NMR magnetic model, RDP and Synchrotron tune methods can't be used at ILC!

Beam Energy Measurements at SLC

Primary Method: WISRD Synchrotron Stripe Spectrometer

- systematic error estimated to be 220 ppm
- estimated E_{CM} uncertainty 20 MeV

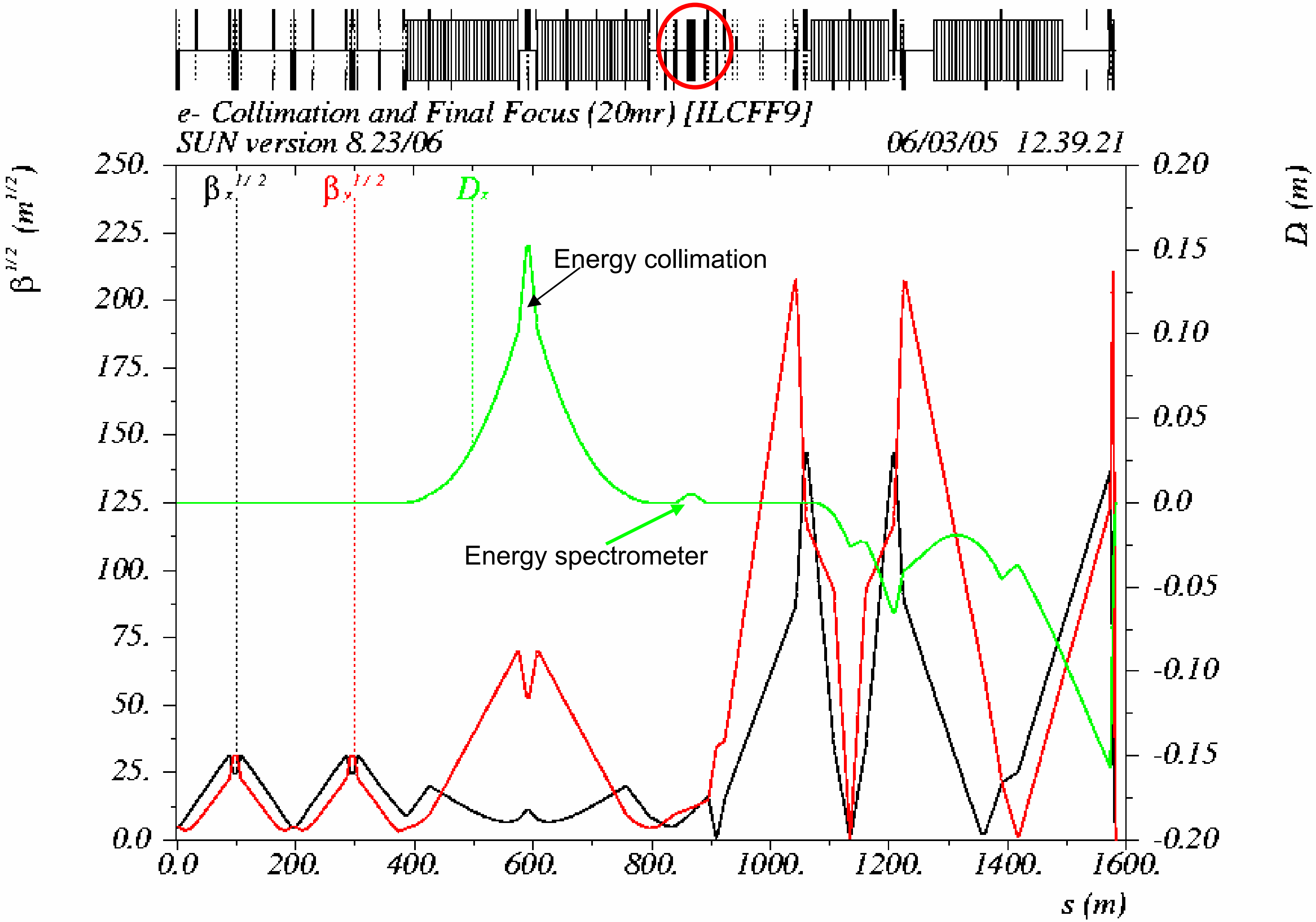
Z-pole calibration scan performed, using m_Z measurement from LEP-I

→ Determined that WISRD E_{CM} result needed to be corrected by 46 ± 25 MeV (SLD Note 264); (500 ppm correction)

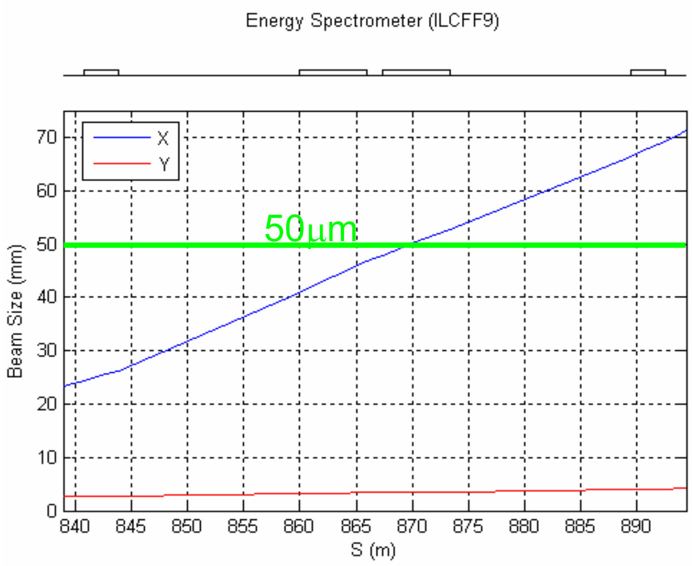
Lessons from LEP-II and SLC:

more than one technique is required for precision measurements!

Upstream E-spectrometer chicane



Upstream Energy Spectrometer Chicane



$$\frac{d\varepsilon}{ds} \approx \frac{\gamma^5}{R^3}\frac{\eta^2}{\beta}$$

Amount of Synch Rad — Dammage to emittance

ds = path in bend field of radius R

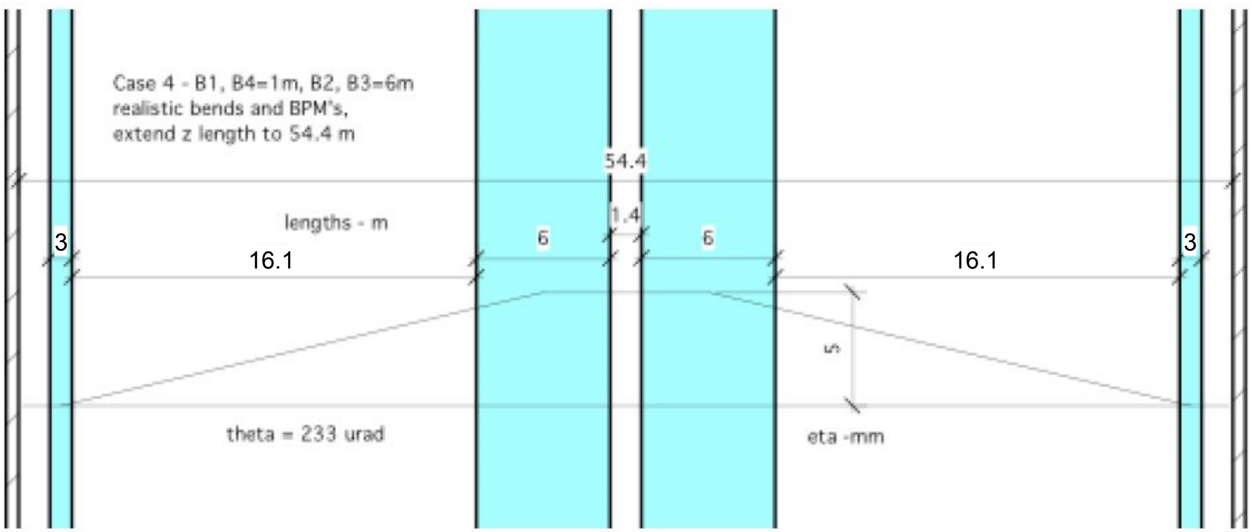
$\gamma = E/m_e c^2$

η= local dispersion

β = local betatron function

➡ Long magnets, low B fields where η is large

- 230 µrad bend angle
  (LEP-II was 3.8mrad)
- 5mm dispersion at mid-chicane
  (100ppm : 500nm!)
- reverse polarity for calibration
- ~55 meters z-space required



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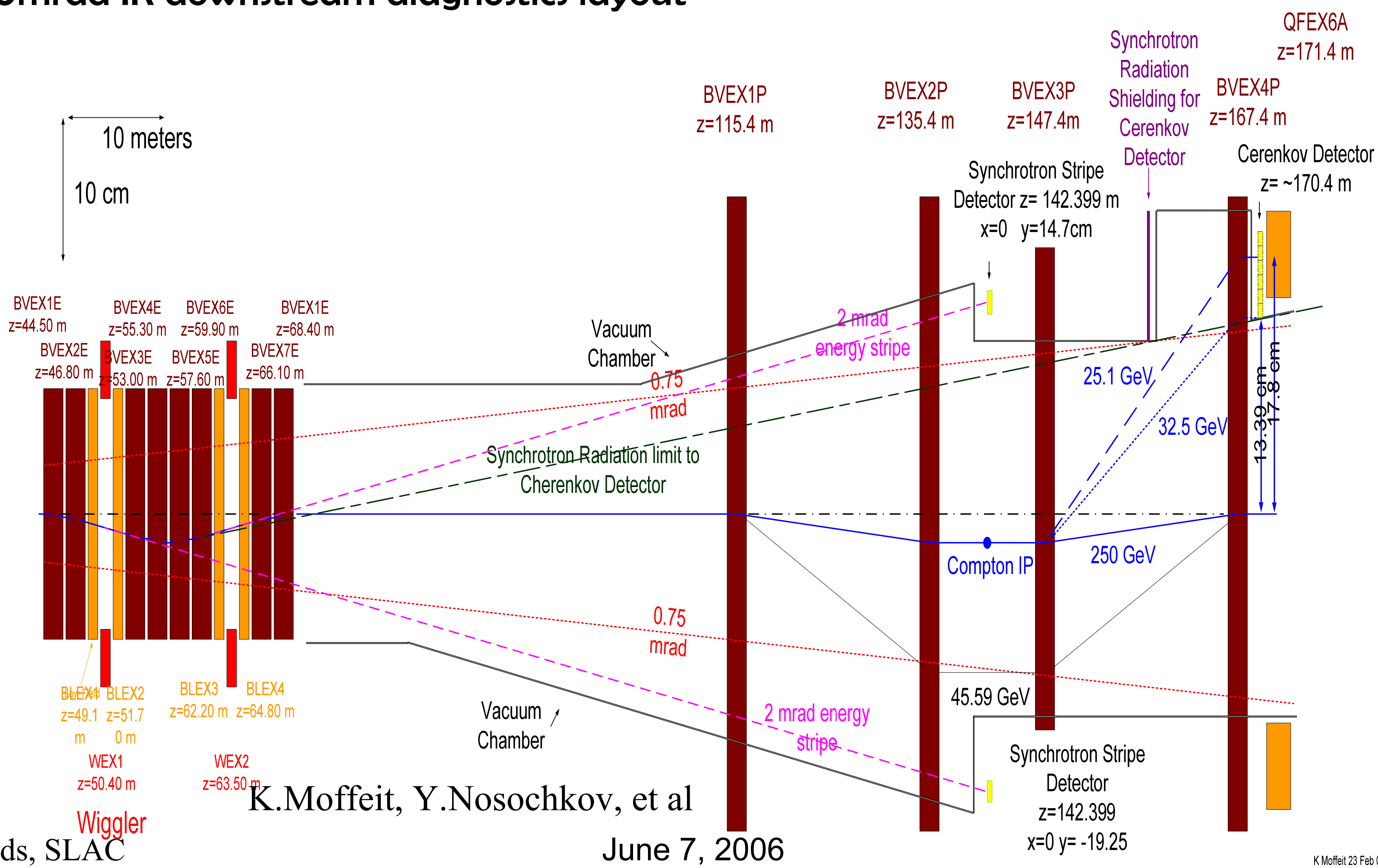
ILC Extraction Line Diagnostics for 20mrad IR

Energy Chicane

Polarimeter Chicane

20mrad IR downstream diagnostics layout



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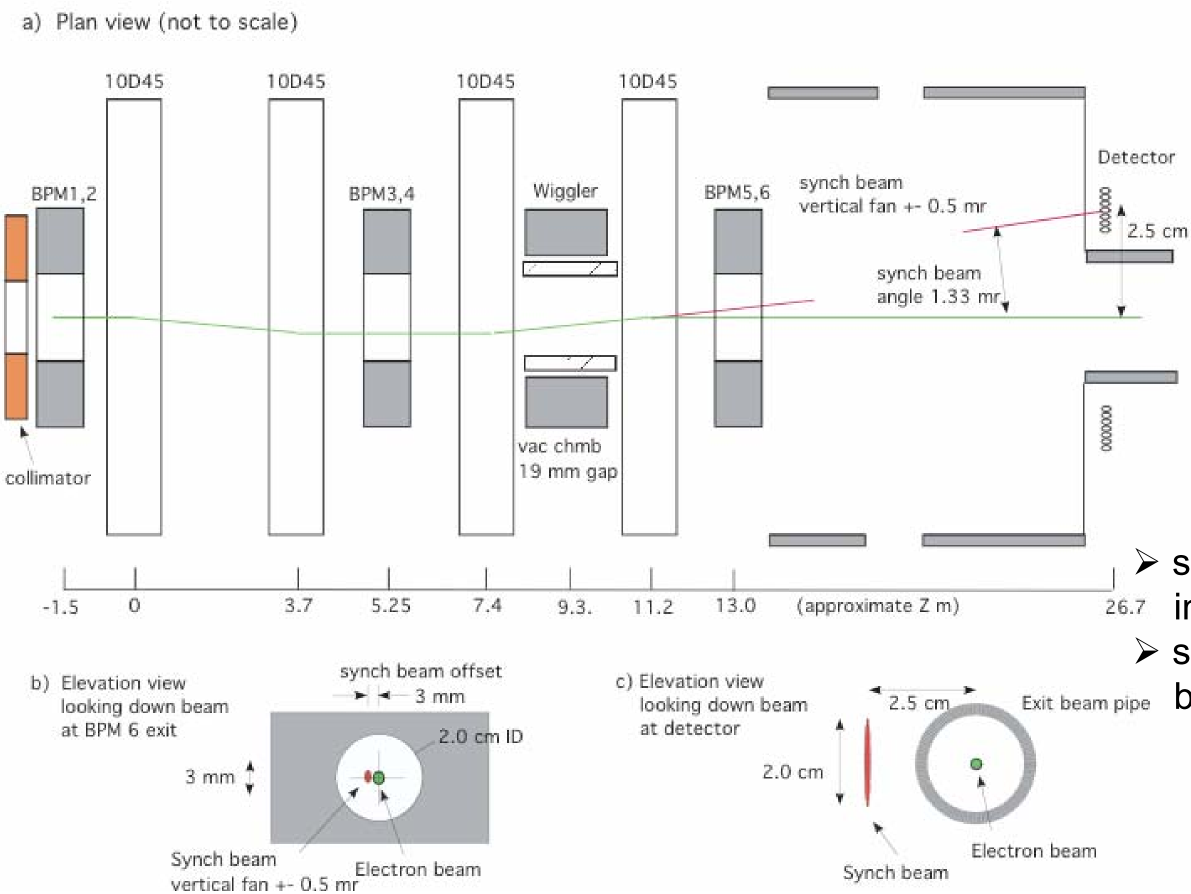
T-474, T-475: Energy Spectrometers

- Precision energy measurements, 50-200 parts per million, needed for Higgs boson and top quark mass msmts
- BPM (T-474) & synch. stripe (T-475) spectrometers will be evaluated in a common 4-magnet chicane.
- These studies address achieving the ILC precise energy measurement goals: resolution, stability & systematics



<u>For BPM spectrometer</u>,

$\delta E/E = 100\text{ppm} \rightarrow \delta x = 500\text{nm}$, at BPMs 3-4

(same as for ILC design)

- ➢ study calibration procedure, which includes reversing the chicane polarity,
- ➢ study sensitivity to: beam trajectory, beam tilt, bunch length, beam shape, …

T-474 and T-475

T-474 BPM Energy Spectrometer:

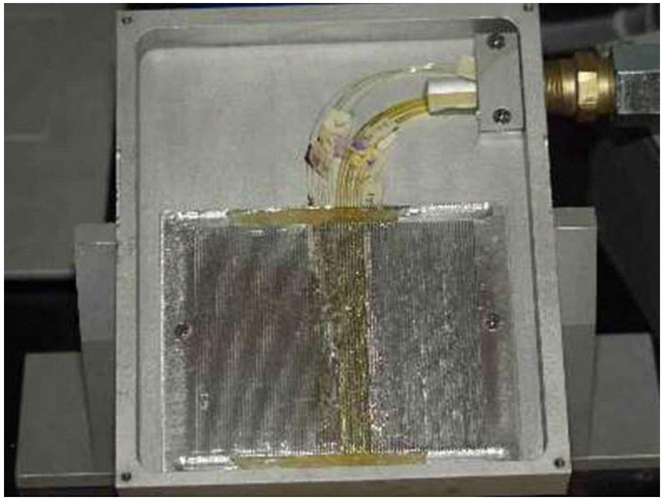
PIs: Mike Hildreth (U. of Notre Dame) & Stewart Boogert (RHUL)

Collaborating Institutions: U. of Cambridge, DESY, Dubna, Royal Holloway, SLAC, UC Berkeley, UC London, U. of Notre Dame

T-475 Synchrotron Stripe Energy Spectrometer:

PI: Eric Torrence (U. of Oregon)

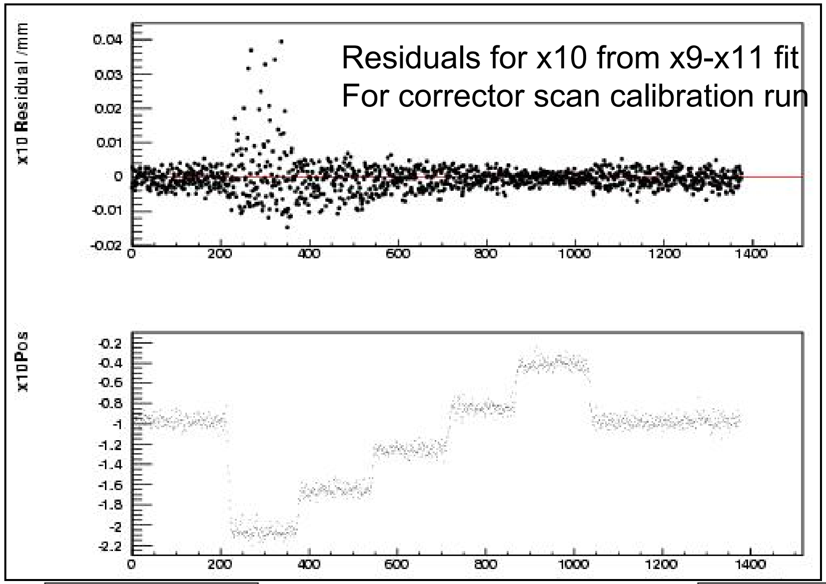
Collaborating Institutions: SLAC, U. of Oregon

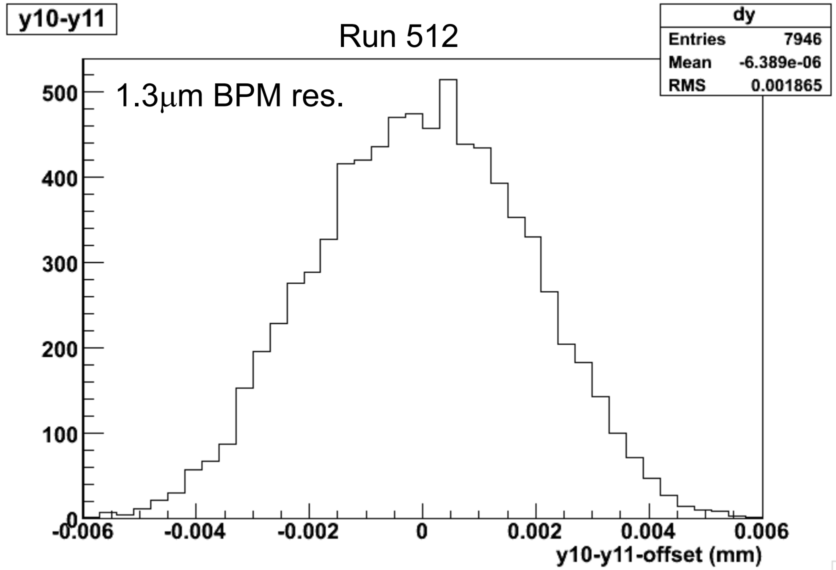


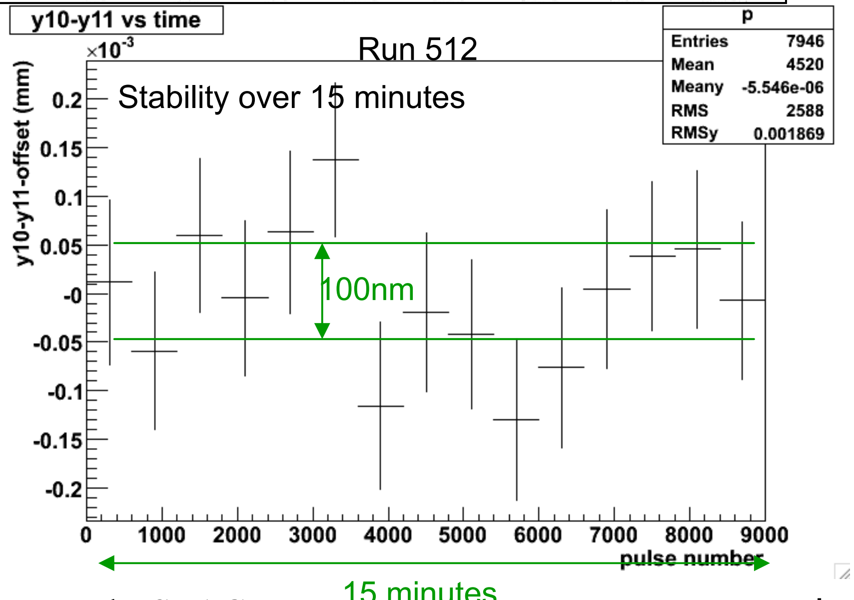
Prototype quartz fiber detector:

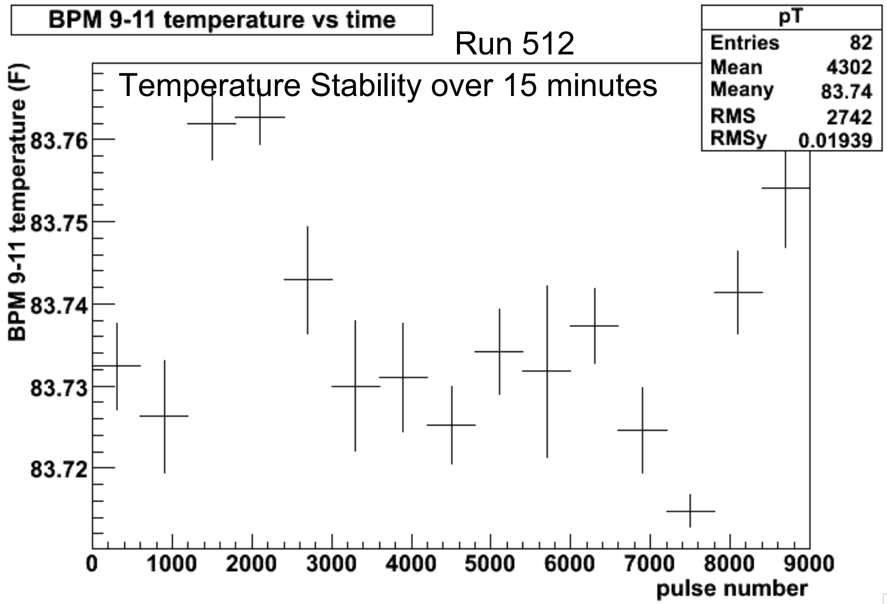
8 100-micron fibers + 8 600-micron fibers w/ multi-anode PMT readout

T-474 Run 1 Prelim. Results









T-474 Run 1 Prelim. Results

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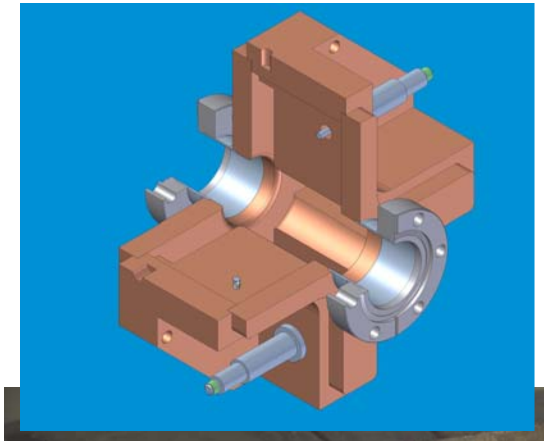
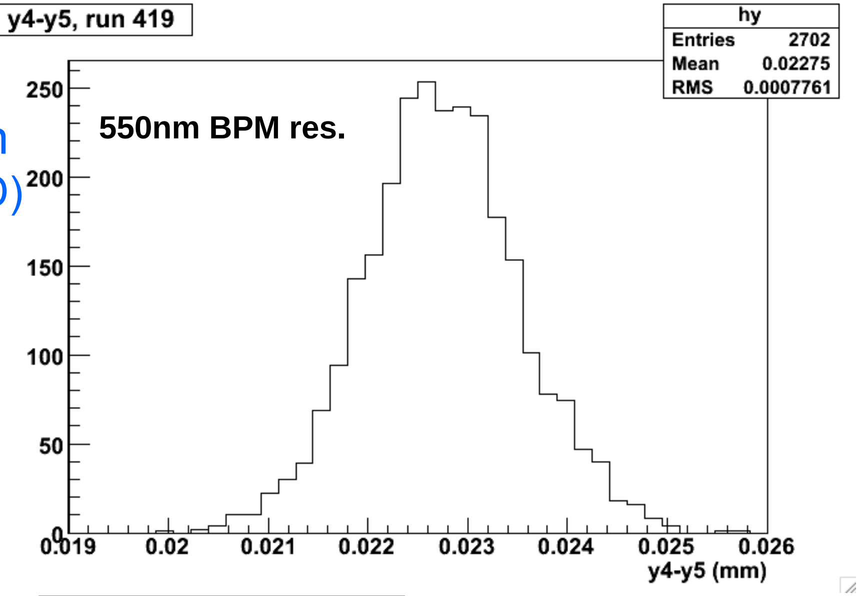
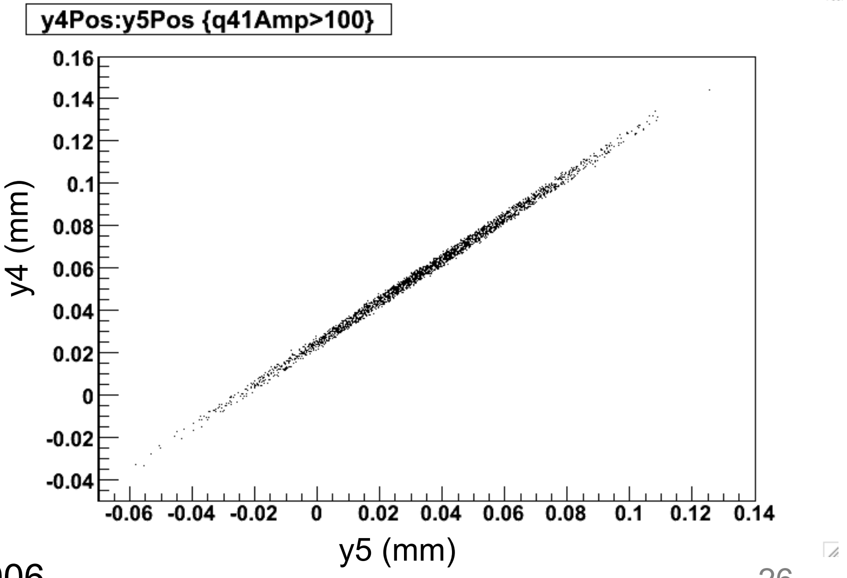
Resolution for new Linac BPM Prototype, 3BPM3-5



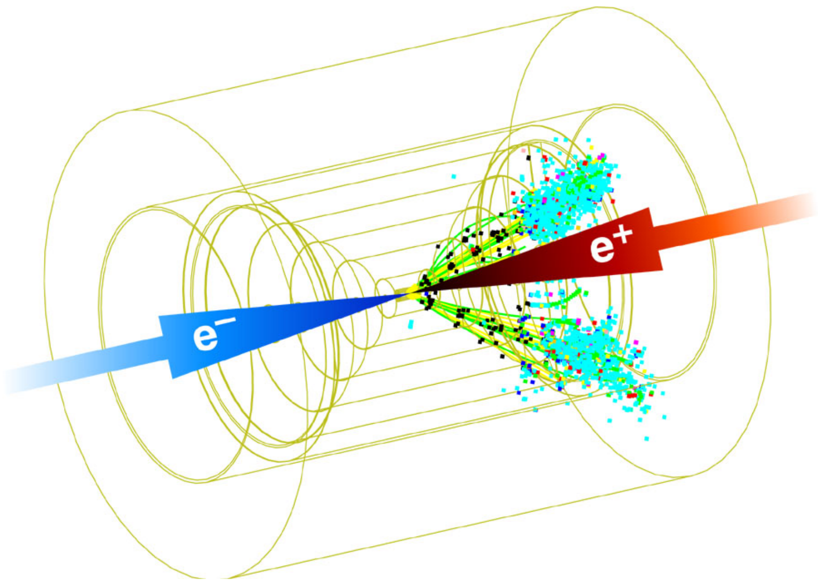
S-Band BPM Design
(36 mm ID, 126 mm OD)

Q~500 for single bunch resolution





IR Background Studies



Electro-Magnetic Interference (EMI) and Beam RF Effects

Effects of Beamsstrahlung Pair Backgrounds and EMI for IP Feedback BPMs

Beam RF effects at Colliders

SLC

Problem with EMI for SLD's VXD3 Vertex Detector

- Loss of lock between front end boards and DAQ boards
- Solved with 10 μsec blanking around beamtime – front end boards ignore commands during this period

PEP-II

Heating of beamline components near IR due to High-order Modes (HOMs)

- S. Ecklund et al., *High Order Mode Heating Observations in the PEP-II IR*, SLAC-PUB-9372 (2002).
- A. Novokhatski and S. Weathersby, *RF Modes in the PEP-II Shielded Vertex Bellows,* SLAC-PUB-9952 (2003).
- Heating of button BPMs, sensitive to 7GHz HOM, causes BPMs to fall out

HERA

Beampipe heating and beam-gas backgrounds

- HOM-heating related to short positron bunch length

UA1

Initial beam pipe at IP too thin

- not enough skin depths for higher beam rf harmonics

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Beam RF effects at ILC IR?

	SLC	PEP-II e^+	ILC
Electrons/Bunch, Q	4.0×10^{10}	5.0×10^{10}	2.0×10^{10}
Bunch Length, σ_Z	1 mm	12 mm	0.3 mm
Bunch Spacing	8 ms	4.2 ns	337 ns
Average Current	7 nA	1.7 A	50 μA
$(Q/\sigma_Z)^2$ relative	92	1	256

PEP-II experience

- HOM heating scales as $(Q/\sigma_Z)^2$
    - same scaling for EMI affecting detector electronics?
    - does scaling extend to mm and sub-mm bunch lengths?
    - need a cavity of suitable dimensions to excite
- IR geometry (aperture transitions, BPMs) has similar complexity as for ILC
- VXD and other readout systems ok for EMI in signal processing

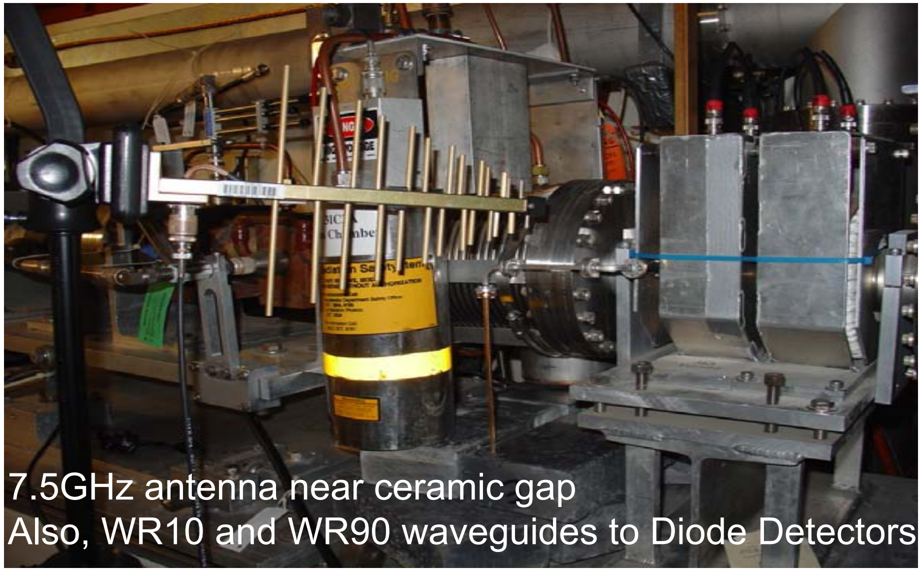
ILC Considerations

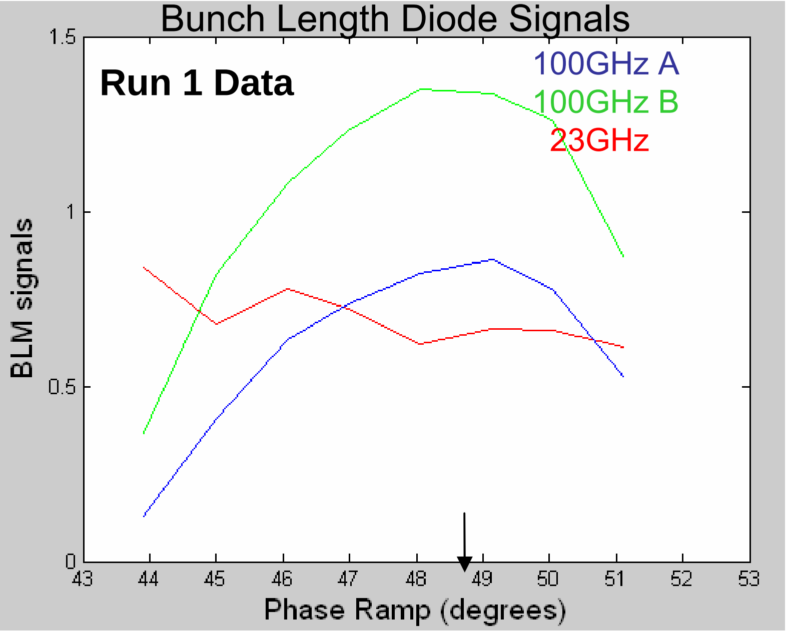
- HOM heating ok because of small average beam current
- EMI affecting Signal Processing and DAQ? Impact on Detector Design and Signal Processing Architecture?

EMI Studies in ESA

US-Japan funds; Y. Sugimoto (KEK),
G. Bower (SLAC), N. Sinev (U. of Oregon)

- Characterize EMI along ESA beamline using antennas & fast 2.5GHz scope
- Measured dependence of EMI antenna signals on bunch charge, bunch length
  - Linear dependence on bunch charge
  - No dependence on bunch length (only see dependence for 100GHz detectors)
- Will test failure mode observed with SLD's vertex detector in July run





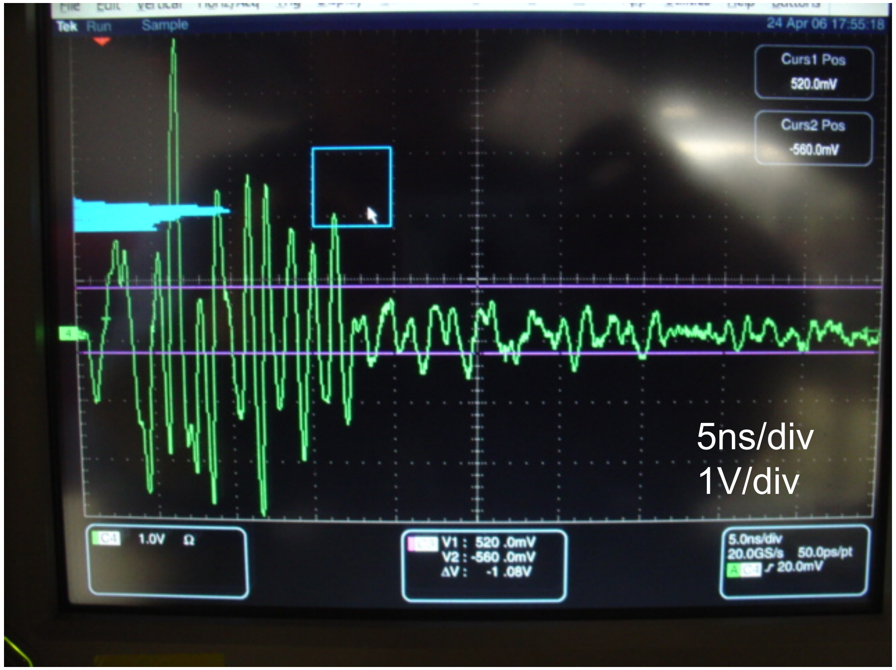
Bunch length has strong dependence on beam phase wrt Linac rf (phaseramp)

Radiated Power Spectrum

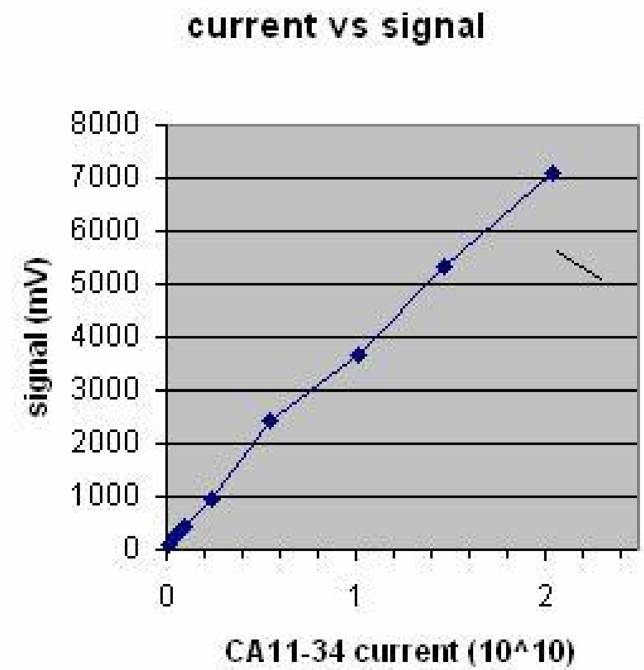
$$P(\omega) \propto Q^2 \cdot \exp\left(-\frac{\omega^2 \sigma_z^2}{c^2}\right)$$

for σ_z=500um, 1/e decrease is at f=100GHz

EMI Studies in ESA



EMI Antenna Signal on 1.5GHz Bandwidth Scope
(w/ ~x10 signal attenuation due to RG58 cable extension in Counting House on 3/8” heliax cable from ESA to ChA)

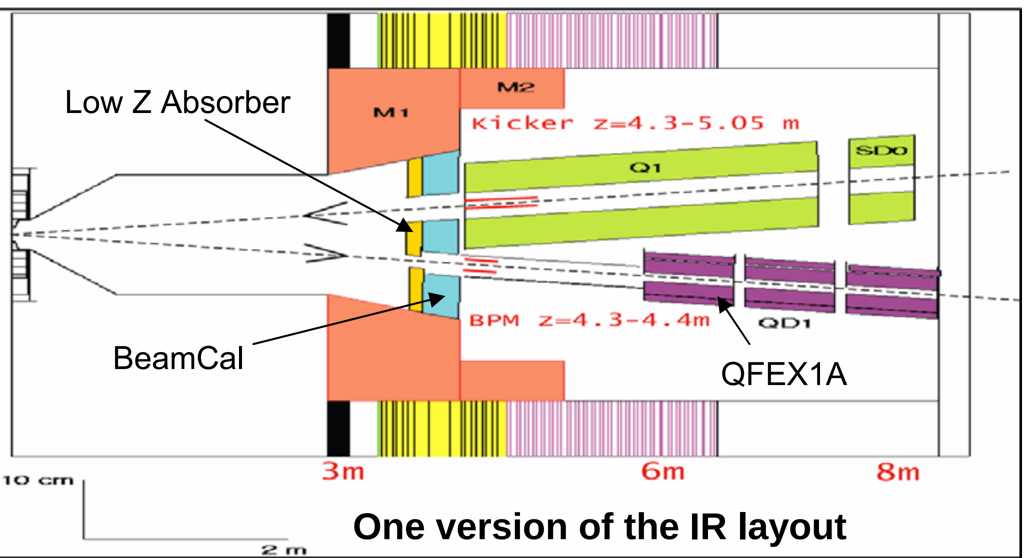


- waveform insensitive to beam conditions and bunch length
- amplitude has linear dependence on bunch charge
- data taken at different beamline locations; timing studies done to look for different sources
- dominant source is exposed ceramic gap; smaller source from upstream toroid

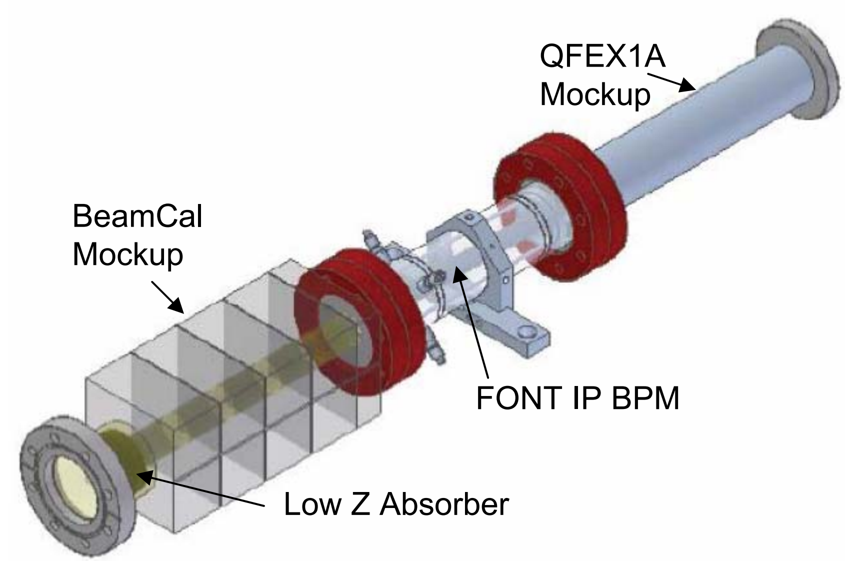
IR Mockup in ESA for FONT IP BPM studies

PI: Phil Burrows, U. of Oxford
Collaboration: U. of Oxford, Daresbury Lab, SLAC

- commission IP BPM with primary beam
- simulate ILC pairs hitting components in forward region of ILC Detector near IP bpms, exceeding maximum ILC energy density of 1000 GeV/mm^2 by up to factor 100
- can vary ESA beam energies from 4-28.5 GeV
- can use primary beam or secondary beam from Be target in Linac



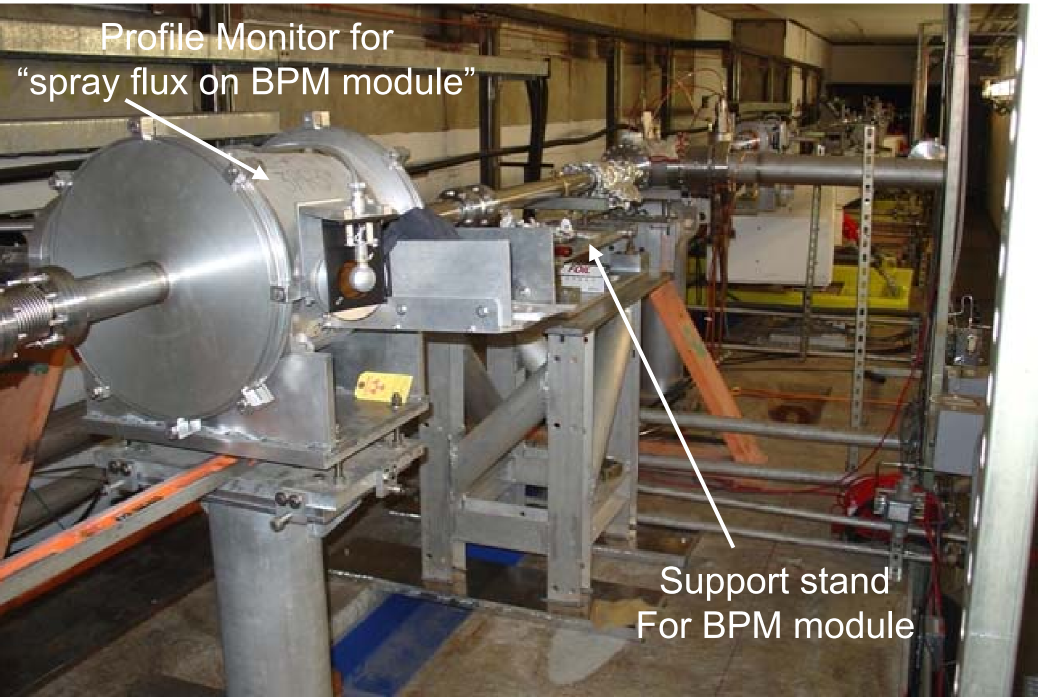
One version of the IR layout



"BPM Module" for ESA Tests

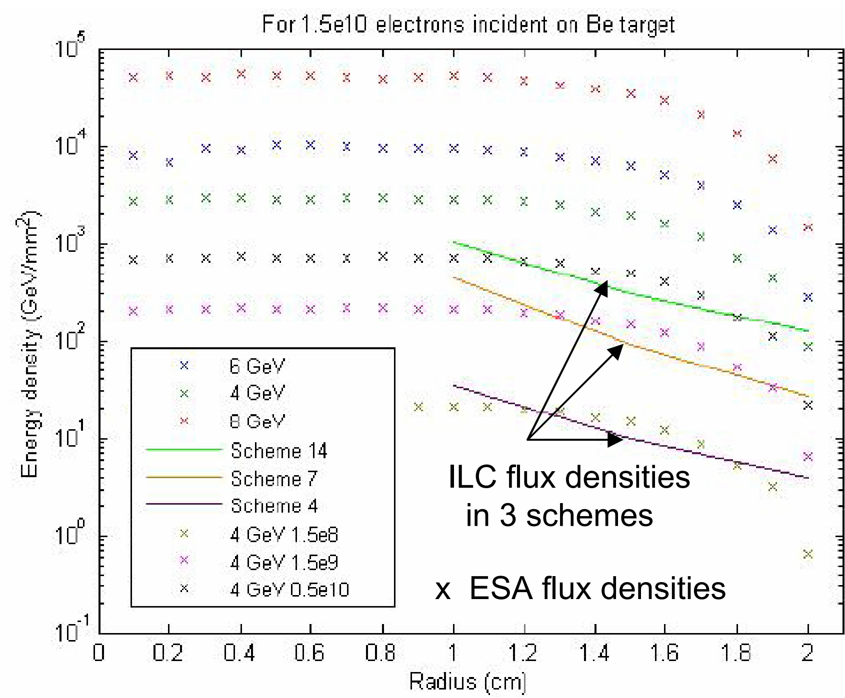
IR Mockup in ESA for FONT IP BPM studies

PI: Phil Burrows, U. of Oxford
Collaboration: U. of Oxford, Daresbury Lab, SLAC



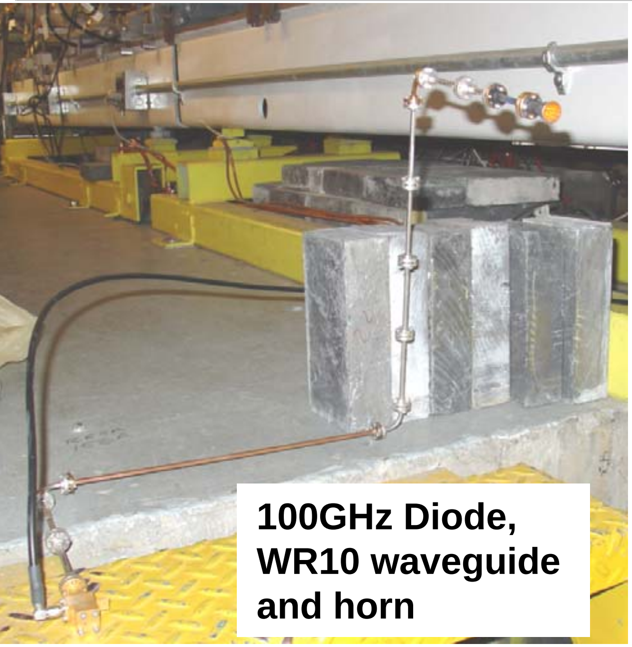
FONT Setup Preparations in ESA

Energy Densities at Low Z Absorber



International Linear Collider
at Stanford Linear Accelerator Center

Bunch length detectors at ceramic gap


100GHz Diode, WR10 waveguide and horn

WR10 and WR90 waveguides at ceramic gap


WR90 waveguide to 16GHz and 23GHz diodes in Counting House

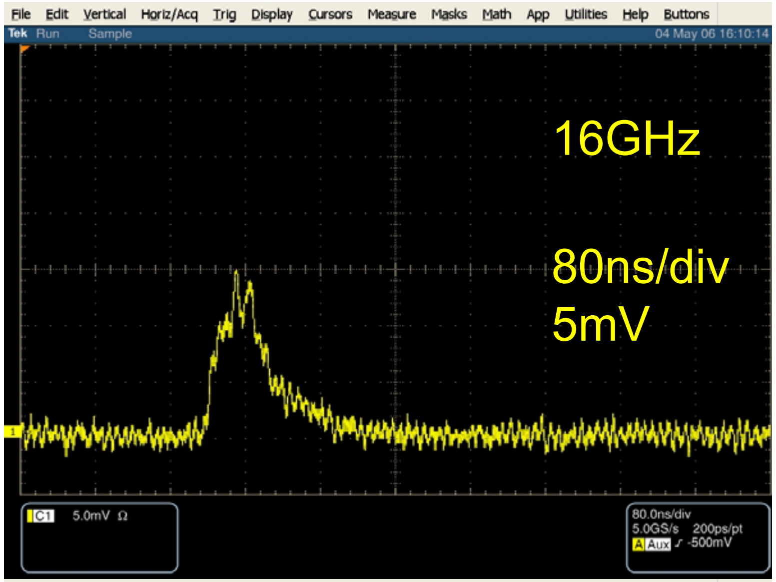
- too much signal on 100GHz diodes necessitated removing horn and backing waveguide ~4” away from ceramic gap
- WR90 waveguide also against ceramic gap; 30-meter length of this to 2 diode detectors in ChA

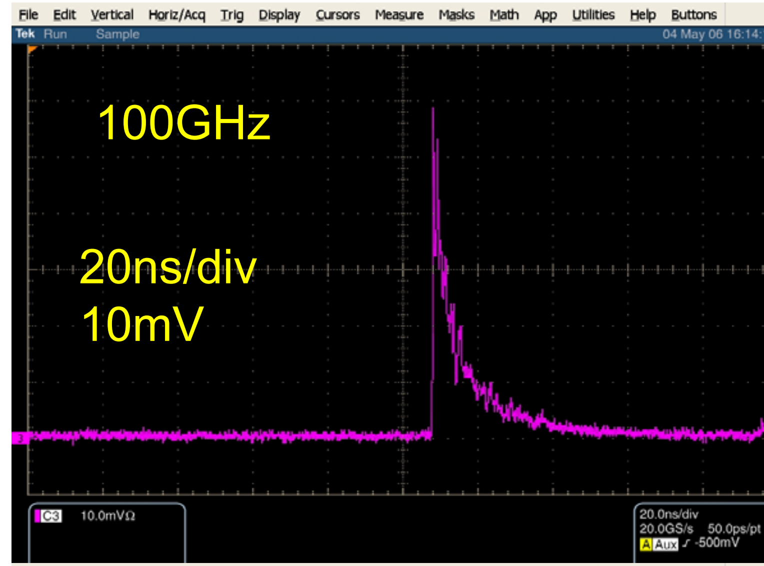
<u>Radiated Power Spectrum</u>

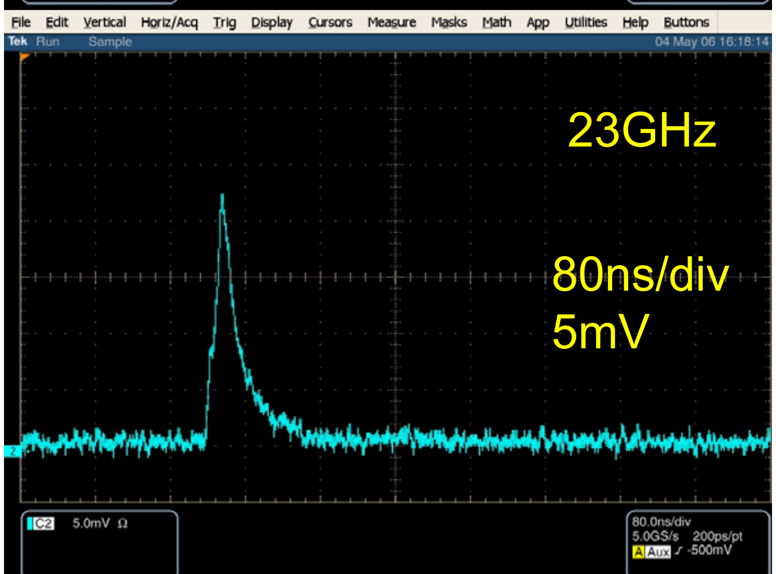
$$P(\omega) \propto Q^2 \cdot \exp\left(-\frac{\omega^2\sigma_z^2}{c^2}\right)$$

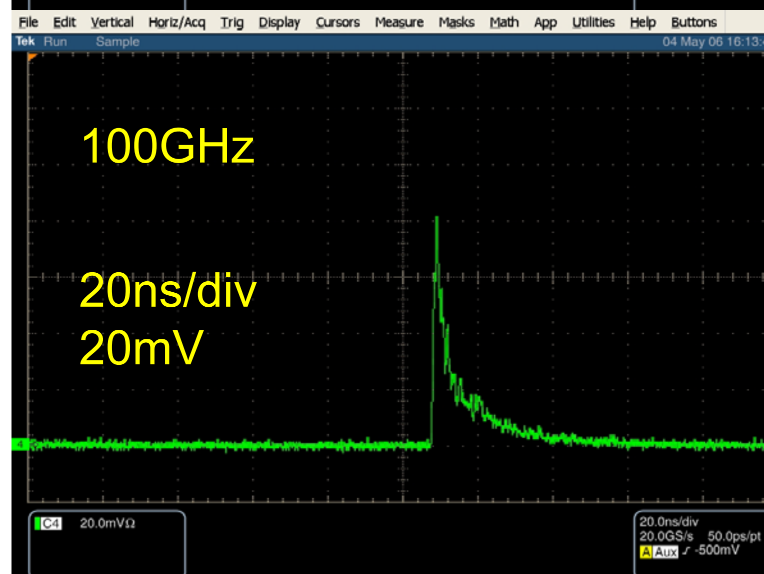
for σ_z=500um, 1/e decrease is at f=100GHz

Raw Signals (5Gs/s Scope)



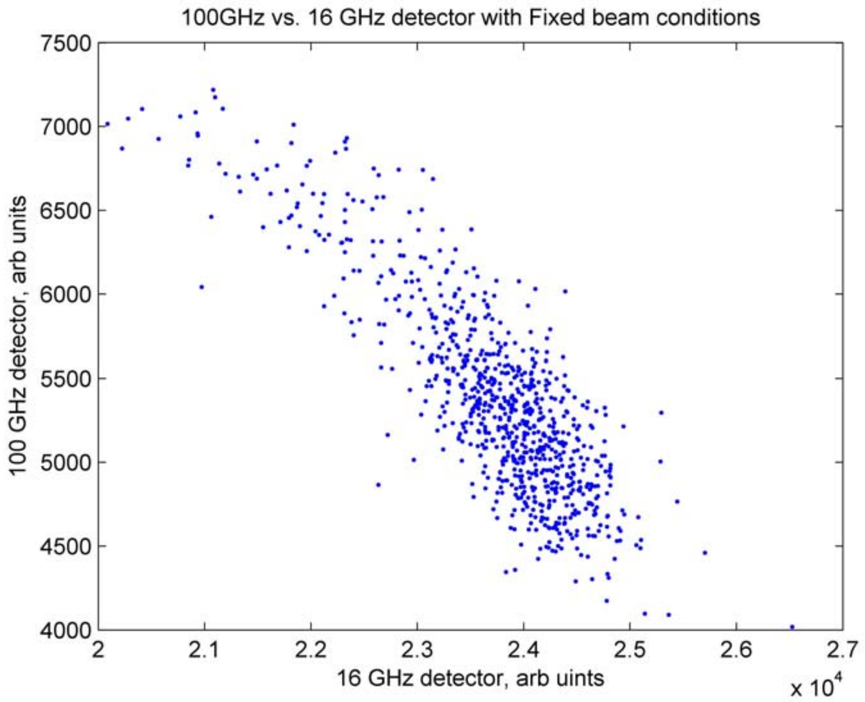


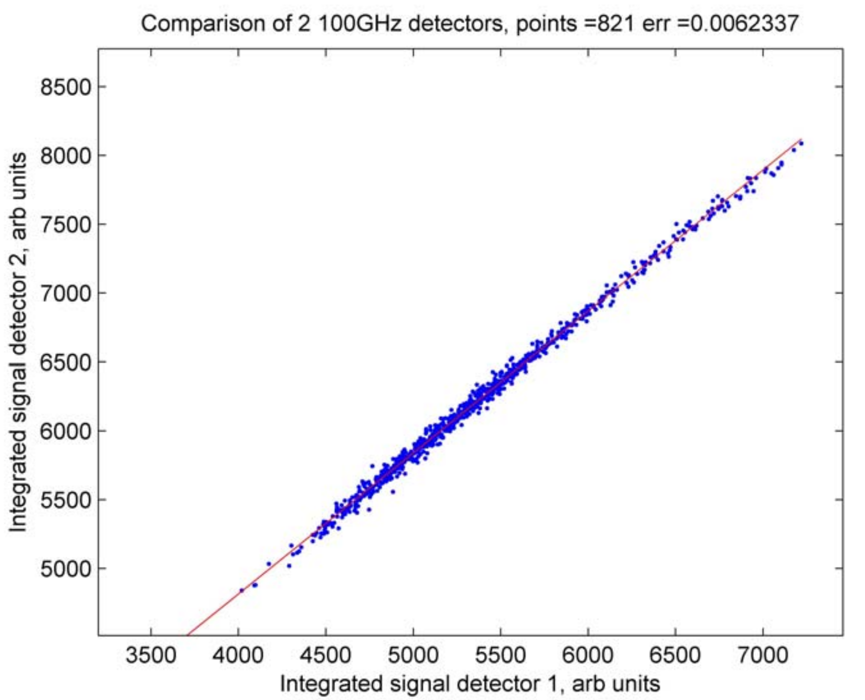




Bunch Length Detector Data with fixed beam conditions

See good correlation, 100GHz detectors track to 0.6% difference rms





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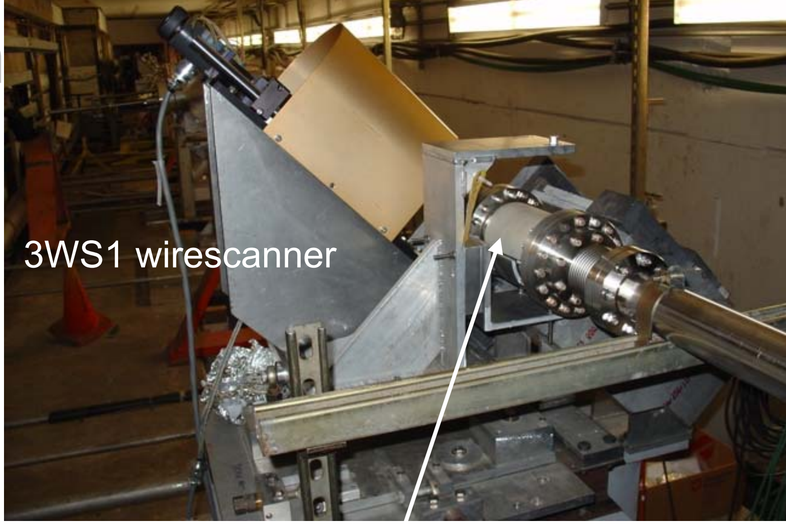
Bunch length msmts



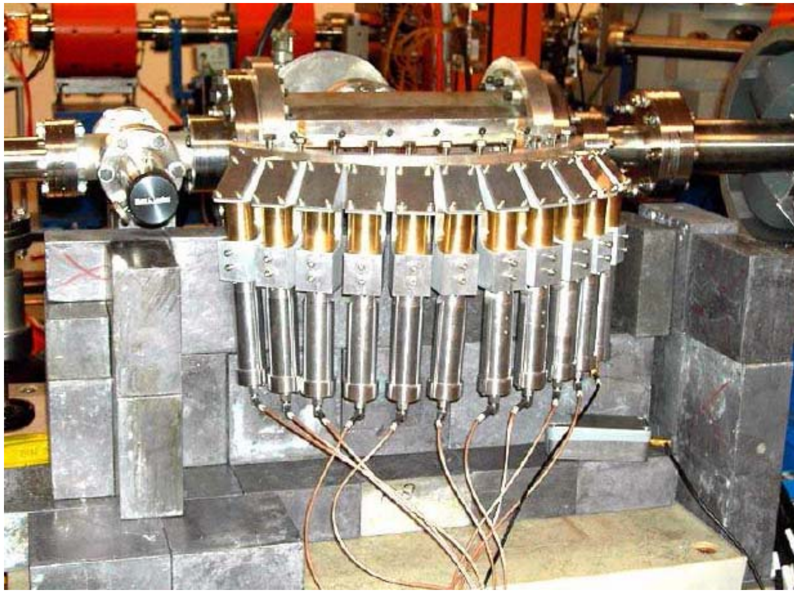
New ceramic gap for July Run

For July Run:

- additional detectors: two 220-330 GHz diodes at existing gap
  three broadband pyroelectrics at new ceramic gap
- Linac intensity feedback to better stabilize beam
- Phaseramp feedback? also for stability
  - ❖ tried this for E158 to minimize SLM energy spread; was too difficult to be useful
  - ❖ may be easier to stabilize diode signal
- need to model better Linac setup for beam phase wrt rf

T-487 in FY07

- array of 11 pyroelectric detectors to measure frequency spectrum of Smith-Purcell radiation (coherent radiation from beam passing close to periodic structure), to allow determination of bunch longitudinal profile
- PI is G. Doucas at U. of Oxford



Also for FY07:

- discussing proposal with with Allan Gillespie (Dundee) and others for electro-optic bunch length msmts

Summary

- strong collaborations for important ILC beam tests, addressing ILC luminosity and ILC precision
- energy spectrometer R&D and beam tests are necessary to test capability for 100ppm accuracy; significant impact on machine design
- 4 test beam experiments have been approved; additional ones in preparation or under study
- Successful 5-day commissioning run in January 2006 and 2-week Run 1 in April/May; Run 2 is July 7-19, 2006
- Plans to continue into FY07 andFY08, parasitic with PEP-II operation. Studying possibilities to continue into LCLS era.