ATF2 Recent Results

Glen White, SLAC

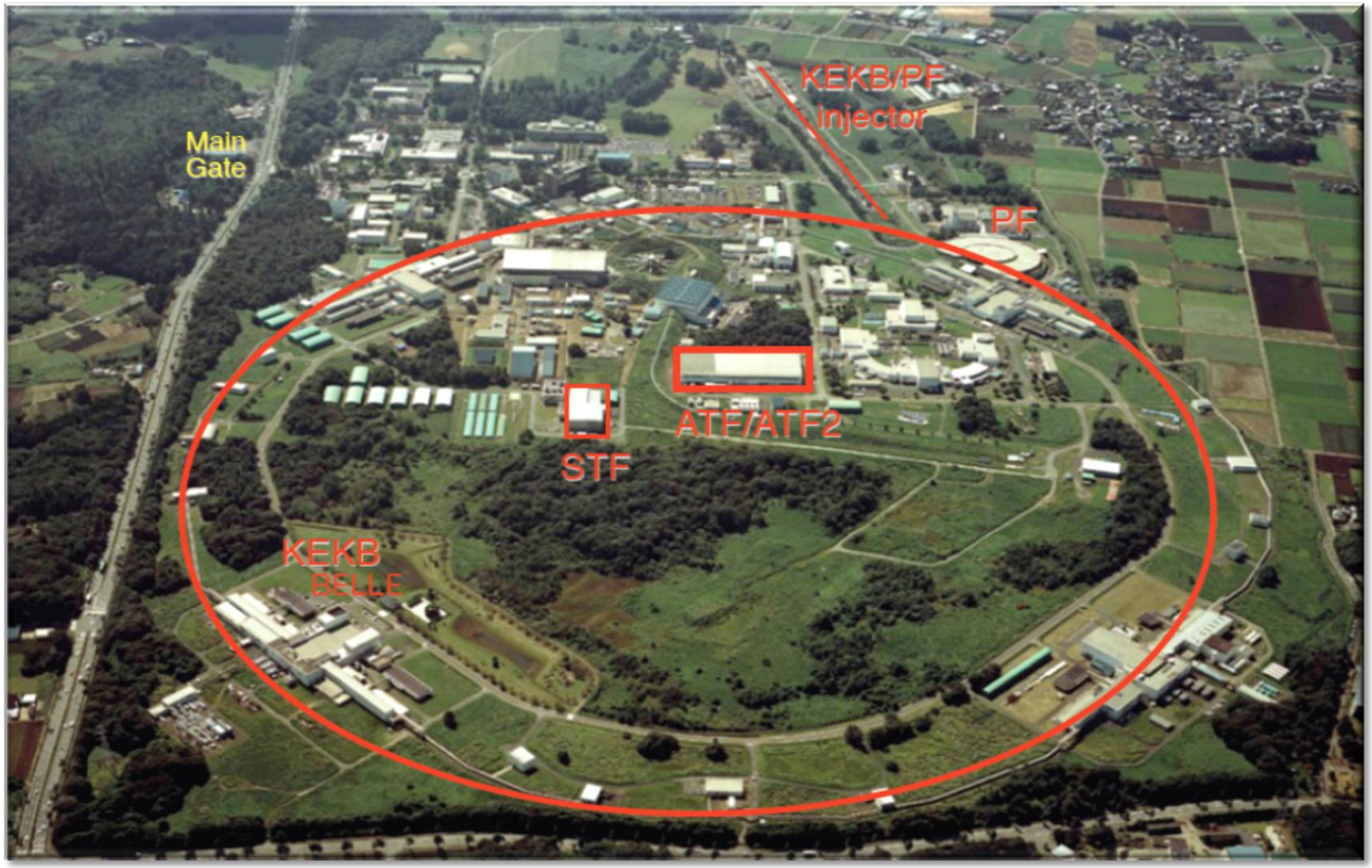
(For ATF2 collaboration members)

January 31 2013

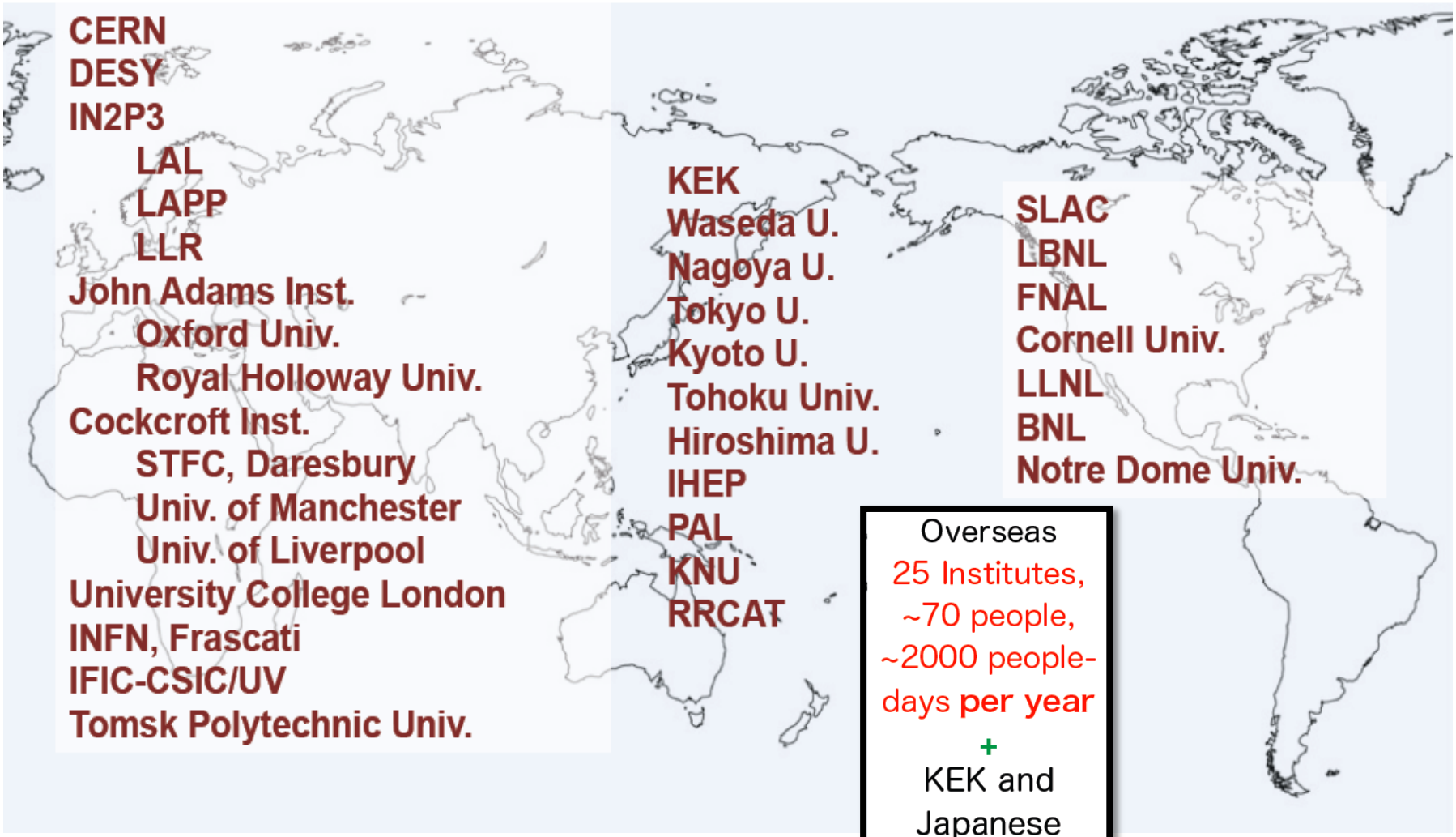
ATF2 Project Goals

- **Experimental verification of the ILC FFS scheme**
  - Development of beam tuning procedures
  - Goal A: focus vertical spot at IP to ~37nm (single bunch)
  - Goal B: maintain IP vertical position with few-nm precision (multi-bunch)
    Demonstrate long-term beam size stability
    Understand tune-ability as a function of chromaticity
- **Development of ILC instrumentation**
  - BPMs, movers, MHz feedback, 1-um Laserwire, straightness-monitor, OTRs, wirescanners, HA-PS, fast pulser, beam tilt-meter …
- **Education of young generation for future linear colliders**
  - Active participation of graduate students and post-docs
- **Operation of complex accelerator in an international setting with in-kind hardware contributions and joint efforts on commissioning & operation**

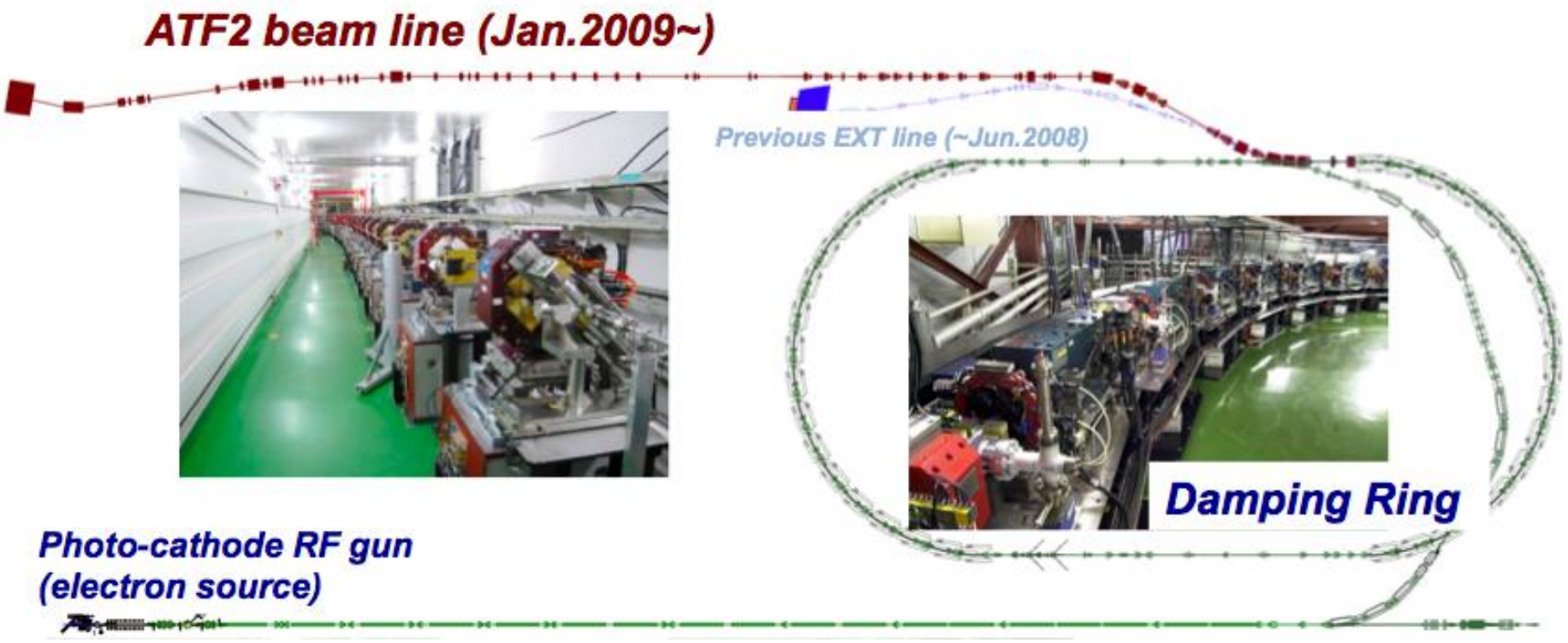
ATF2 @ KEK



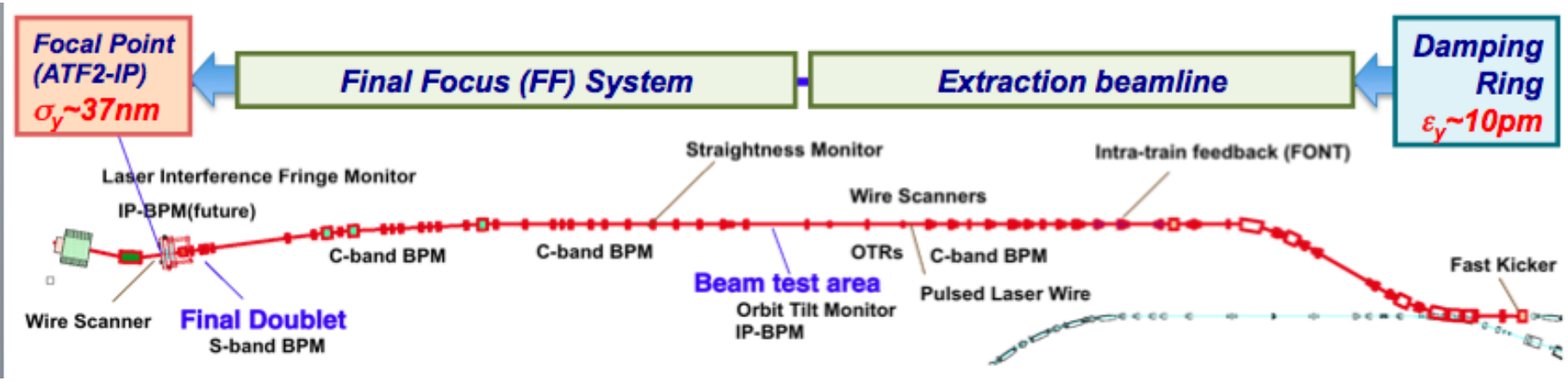
ATF International Collaboration



ATF2 Facility Layout



ATF2 Facility Layout



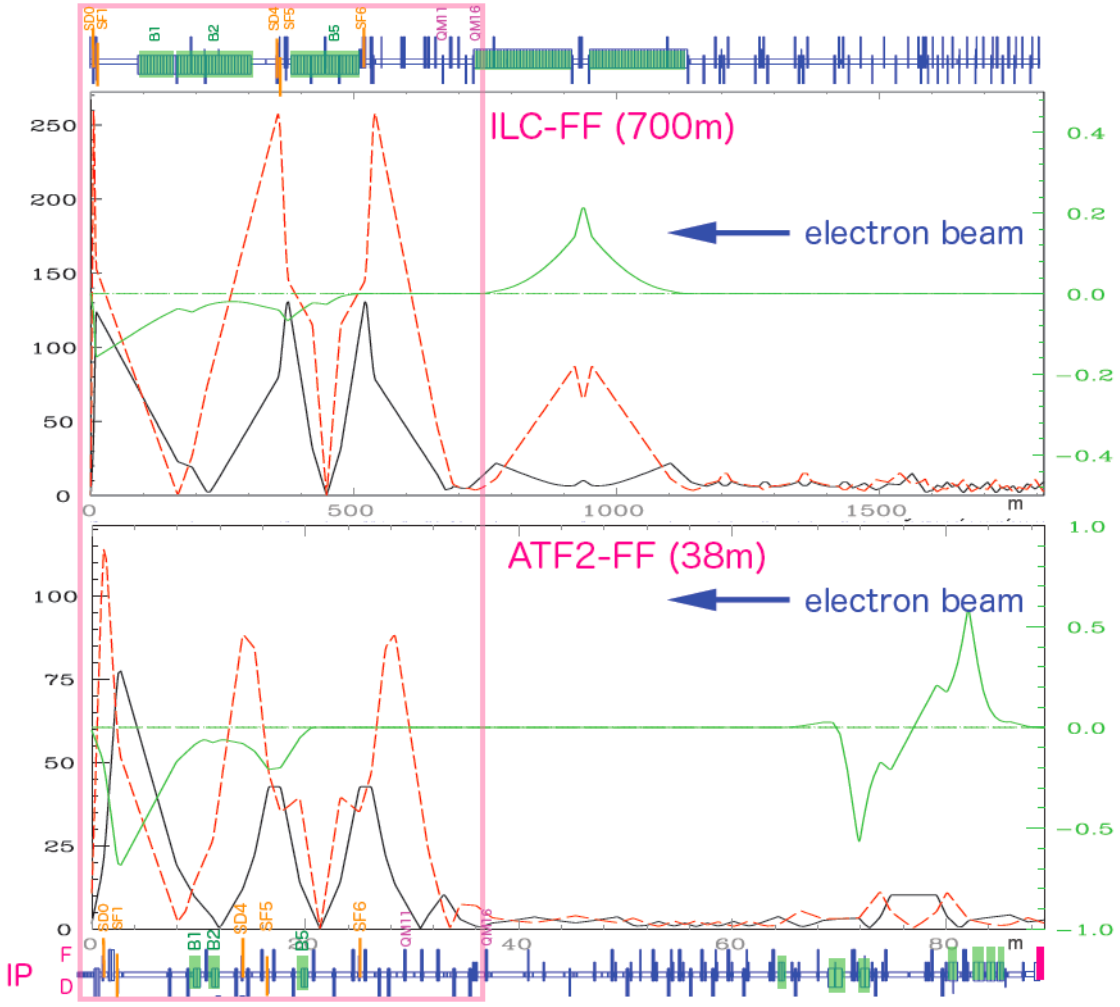
Final Focus System (FFS)

- Scale test of ILC FFS optics

Extraction Line (EXT)

- Extract beam from DR
- Correct for coupling and dispersion errors
- Correctly match beam into final focus system.

Scale Test of ILC FFS Optics



- Scaled design of ILC local-chromaticity correction style optics.
- Same chromaticity as ILC optics.
- At lower beam energy, this corresponds to goal ~37nm IP vertical beam waist.

Typical DR Parameters

ε_x = 1.4-1.9nm

ε_y = 10-15 pm

(20-30 pm extracted)

E = 1.269 GeV

ATF2 IP parameters

β_x / β_y = 4cm / 0.1mm

σ_x / σ_y = 9um / 37nm

Rep. Rate = 3.12 Hz

ATF2 Tuning Techniques Applicable to LC RTL and BDS Operations and Many Lessons to be Learned

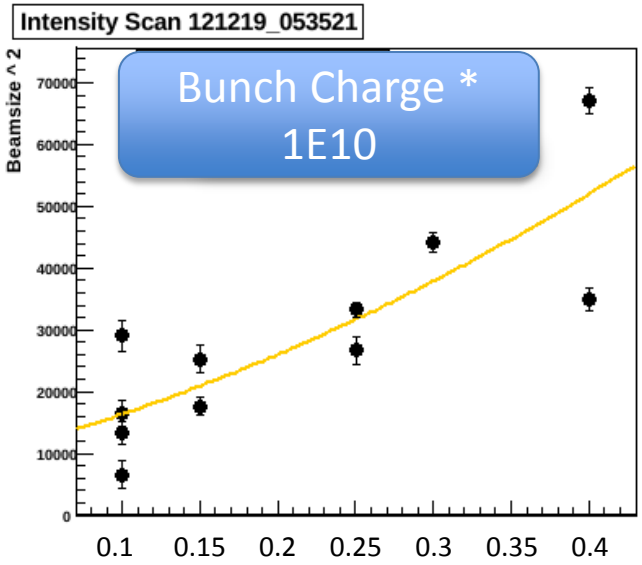
Some Highlights of Autumn 2012 Operations

- **100% ATF2 operations**
  - 8 weeks Oct, Nov, Dec
  - Include ~20 non-KEK staff as part of machine operations team
- **Continuous operations with nominal vertical beta optics**
  - Matched in extraction line with OTR system (BMAG < 1.01)
  - Confirmed correct propagation to IP
  - Low backgrounds for IP beamsize monitor system
- **Installation and use of 4 skew-sextupole magnets for non-linear IP correction knobs**
  - Y22 and Y26 used with effect
- **Replacement of QF1FF with old PEPII LER quadrupole**
  - Much improved multipole fields
  - Will allow for design IP horizontal beta function optics
    - Although still using 10X now for safety
- **Wakefield and second-order aberration domination of IP vertical beam size ~<300nm**
  - Running at low charge (~150 pC) and long bunch length (~10mm) enabled systematic beam operations and studies with IPBSM in 30-degree mode for first time.
- **First successful observation of modulation with IPBSM ("Shintake Monitor") in 174-degree mode of operations**
  - Beam tuned to **72.8nm +/- 5.4nm**

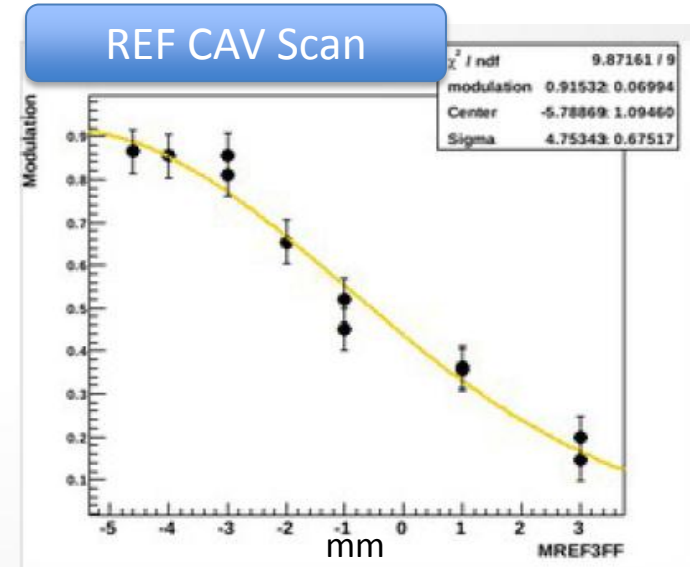
Most Important Outstanding Issues

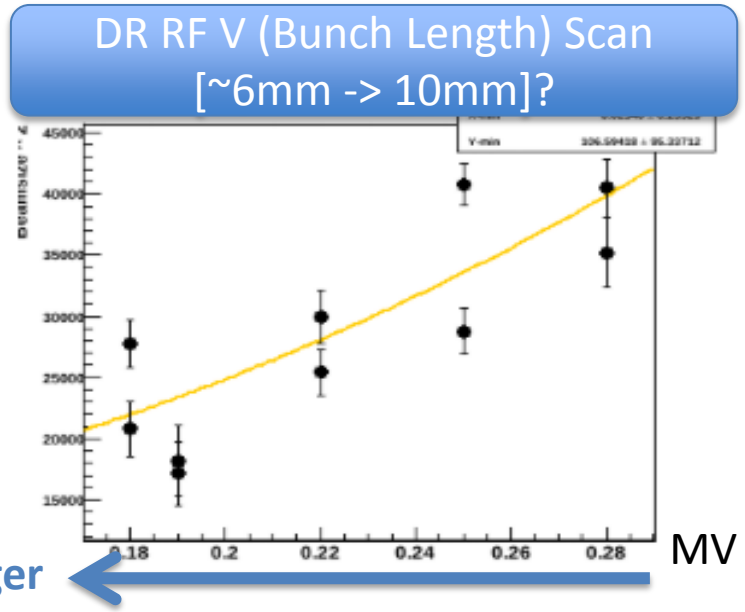
- **Full tuning treatment in IPBSM 174-degree mode**
  - Not yet completed
  - Quantify effects degrading beam size above emittance-limit.
- **Wakefields**
  - See very strong dependence of IP beam size on charge and bunch length
  - Need to identify and mitigate wakefield sources
- **Extracted emittance**
  - EXT measurements > DR
  - ~30-35pm high charge, ~20pm low charge in EXT, target is 12pm extracted emittance
  - Suspect extraction kicker/septa system alignment/orbit
    - Continue with studies to find good extraction orbit and hardware alignment (11pm extracted in 2010)

Indications of Transverse Wakefields in FFS as Measured at IP



- **Suspect strong influence of cavity BPMs in FFS**
  - But even pessimistic simulation don't account for magnitude of observed effect
  - Possibly deteriorated since early 2012?
- **Place spare reference cavities on vertical mover to test & compensate**
- **Observe IP beam size**
  - dependence with beam intensity.
    - Much larger than predicted by measurements in EXT with OTRs
  - dependence with bunch length.
    - No increase in emittance measured in EXT
- **Set operating conditions 1E9 charge and 0.2MV DR RF voltage.**

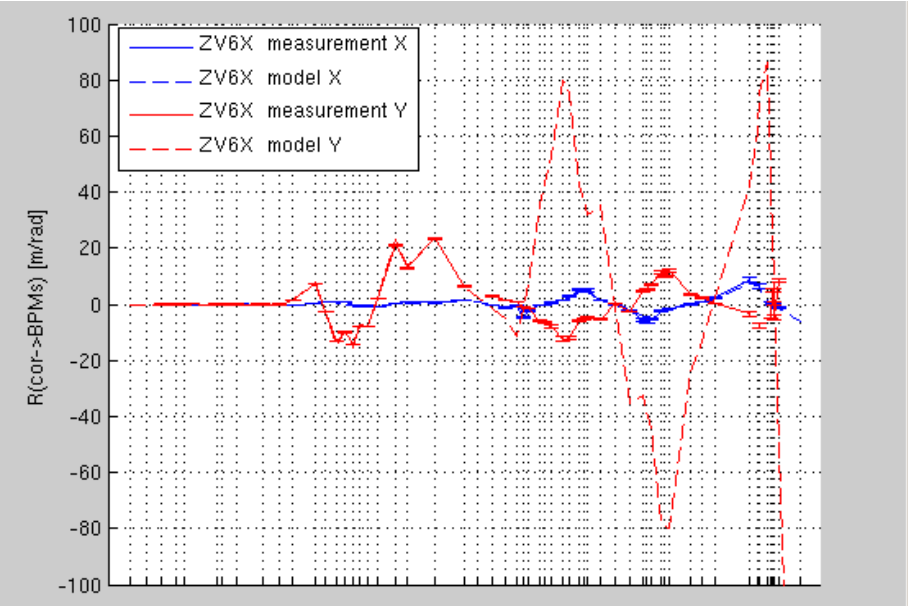


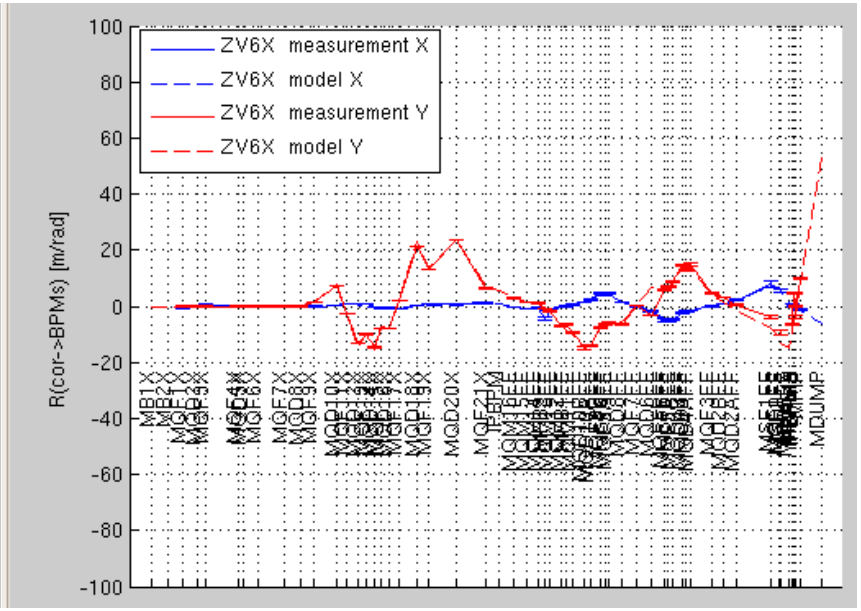


Initial Lattice Setup

- BPM Calibration
- Steering
- BBA
- Global Dispersion correction
- Extracted emittance measurement
- Extracted coupling correction
- Beta matching
- Model and optics verification

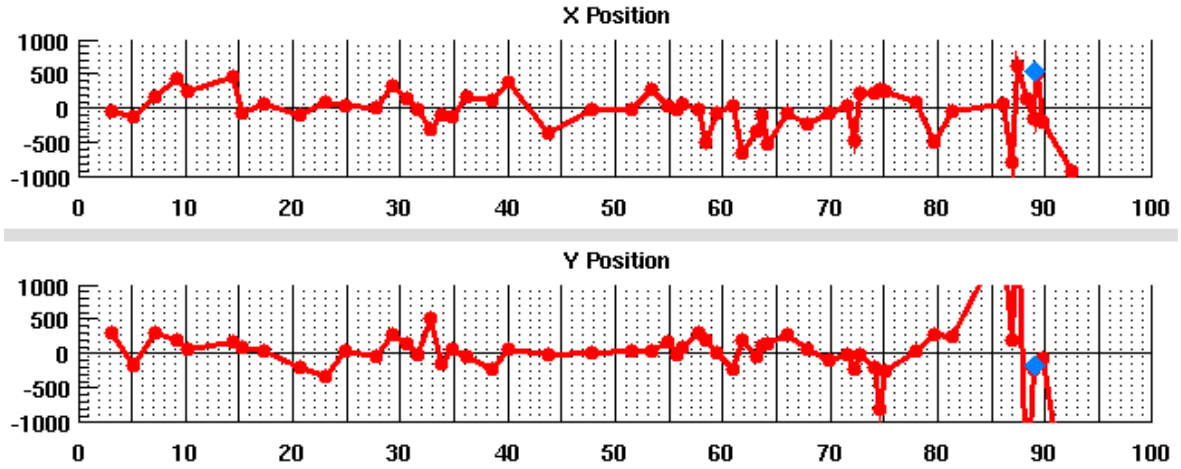
Online Model Response Matrix Checks

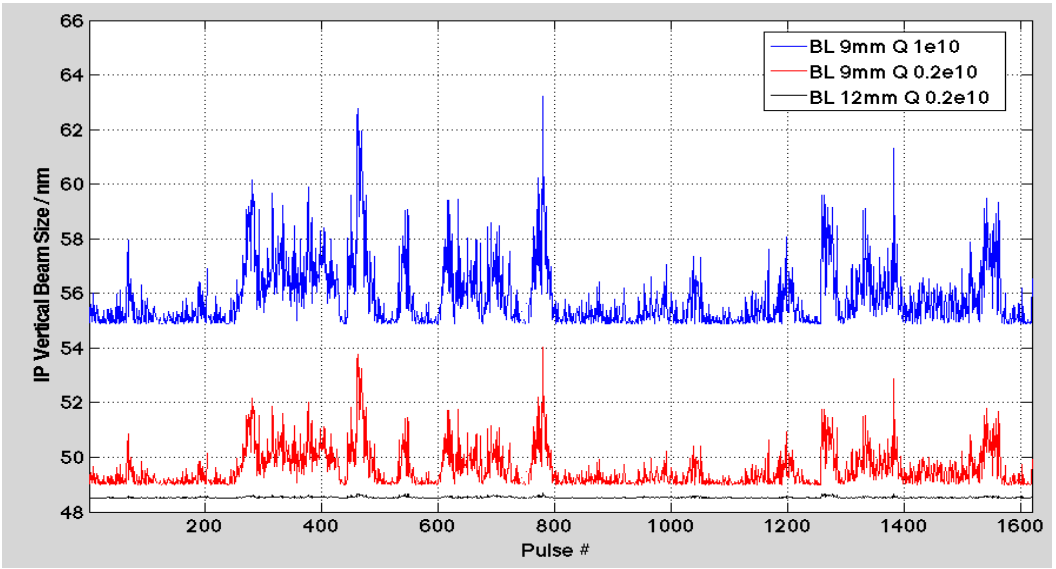




- **Automated software to sweep corrector magnets to compare measured vs. online model response matrix elements.**
- **Example here shows identification of suspected bad setting in one extraction line quadrupole.**
  - Left plot shows R34 comparison with control system readout of Quad strengths
  - Right plot shows adjustment of QD20X quadrupole (few %) to account for model discrepancy

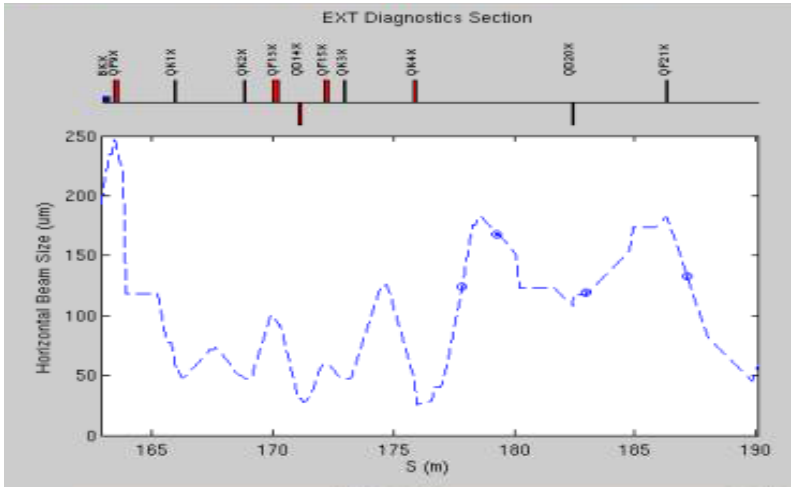
Orbit Steering

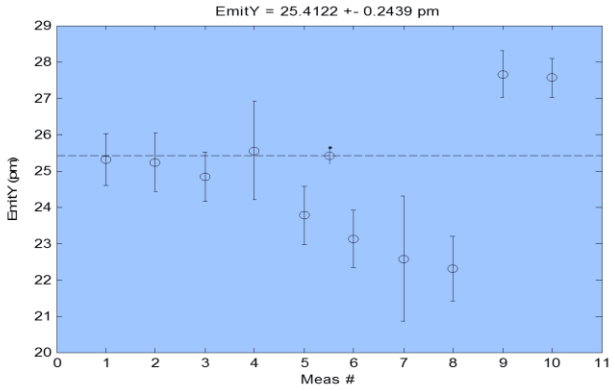




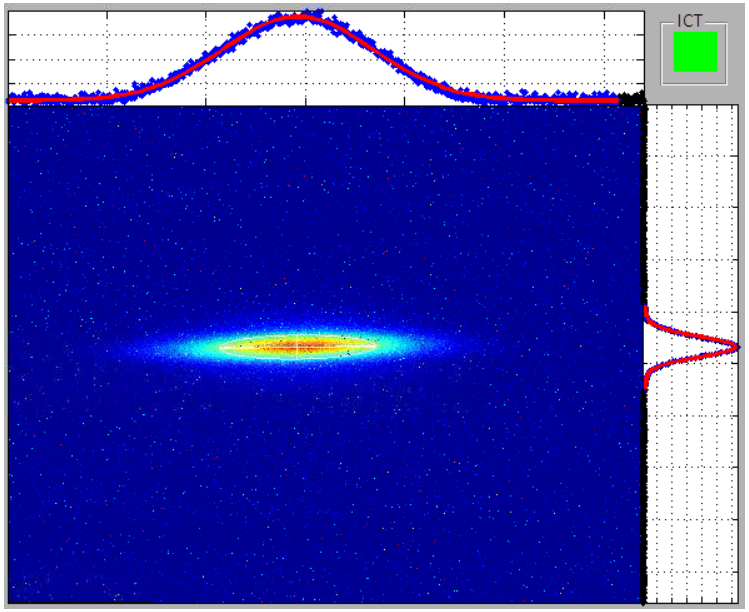
- **Orbit steering by 1-1 method**
  - Corrector dipoles in EXT
  - Quad movers in FFS
- **Steer to BBA orbit ~<500um level**
  - (top plot)
- **Simulations of wakefields induced in Cav BPMs show desire for ~<70um orbit wrt cavity centres not BBA**
  - (bottom plot)

Emittance Measurement and Coupling Correction with Multi-OTR System



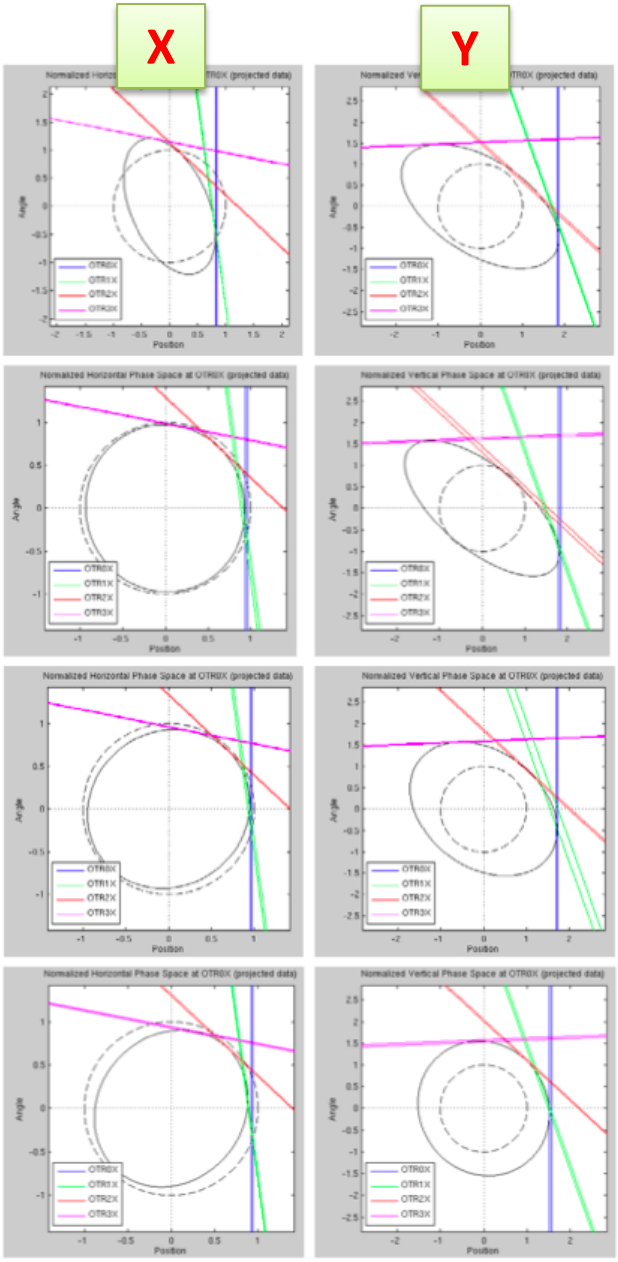


10 consecutive emit meas:
25 +/- 0.25 pm



- **Emittance (& Twiss) calculation from model fit to 4 OTR projected beam sizes**
- **Coupling correction using 4 upstream skew quadrupoles**
  - Automated model-based correction using tilt parameters from fitted 2-d OTR images and model response matrices from SQs to OTRs.
- **Initial emittances (vertical) 60-100pm**
  - Correct to 20-35pm depending on charge
  - Measure typically 10-15pm in DR
  - All images untilted, correction works. Reason for discrepancy with DR measurements needs to be found still. Suspect non-linear fields in extraction system.

Beta Matching With Multi - OTR System

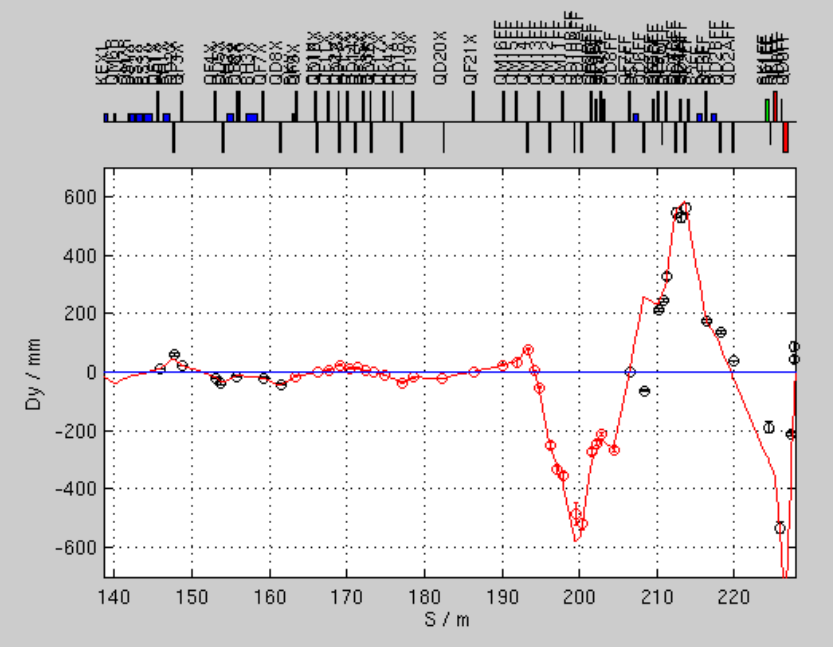


name	match0	match1	match2	match3	design
file	054152	061717	080625	084346	
EmitX	1.7894	1.8228	1.7587	1.5860	
BmagX	1.1946	1.0013	1.0026	1.0076	1.0000
EmBmX	2.1376	1.8251	1.7633	1.5981	
BetaX	4.7239	6.0386	6.4327	6.2257	6.3052
AlphaX	-2.8890	-4.2795	-4.6550	-4.5596	-4.4943
EmitY	28.4846	25.7572	30.8175	28.2300	
BmagY	1.2000	1.3489	1.0554	1.0034	1.0000
EmBmY	34.1808	34.7439	32.5253	28.3262	
BetaY	9.1308	9.4923	7.1151	6.0766	6.1903
AlphaY	4.4037	4.8369	3.2854	2.6087	2.5763

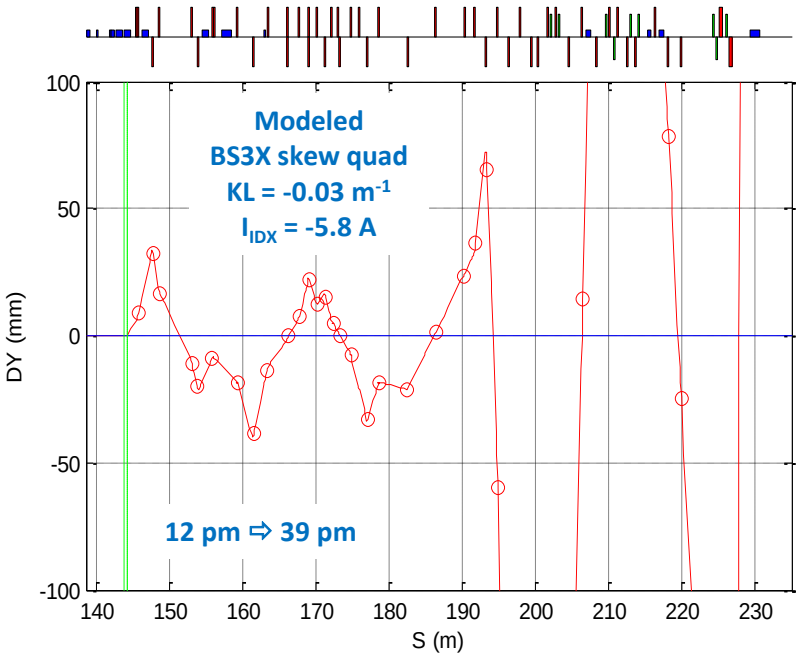
- Matching performed using quads in inflector, upstream of OTR system
  - Can easily iterate matching to converge on well matched solution
  - Have to take care not to destroy dispersion & coupling correction system
- Propagate match to IP using online model
- Check match at IP using quad scan technique
  - Scan QD0FF/QF1FF vs. IP Carbon wire scanner
- Typically find good agreement for vertical match at ~10-20% level, a little worse for horizontal

Modeling Incoming Vertical Dispersion

Measured

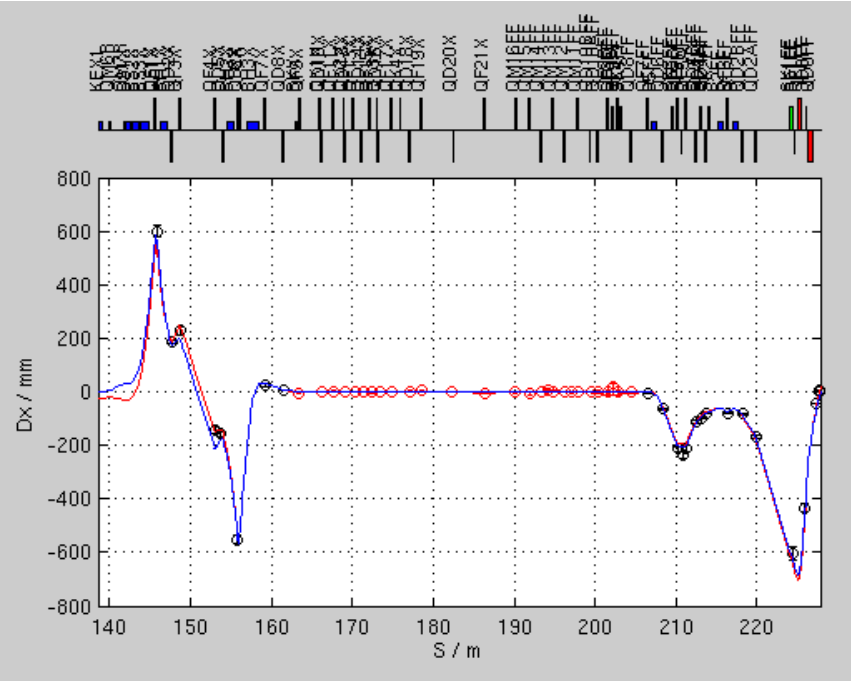


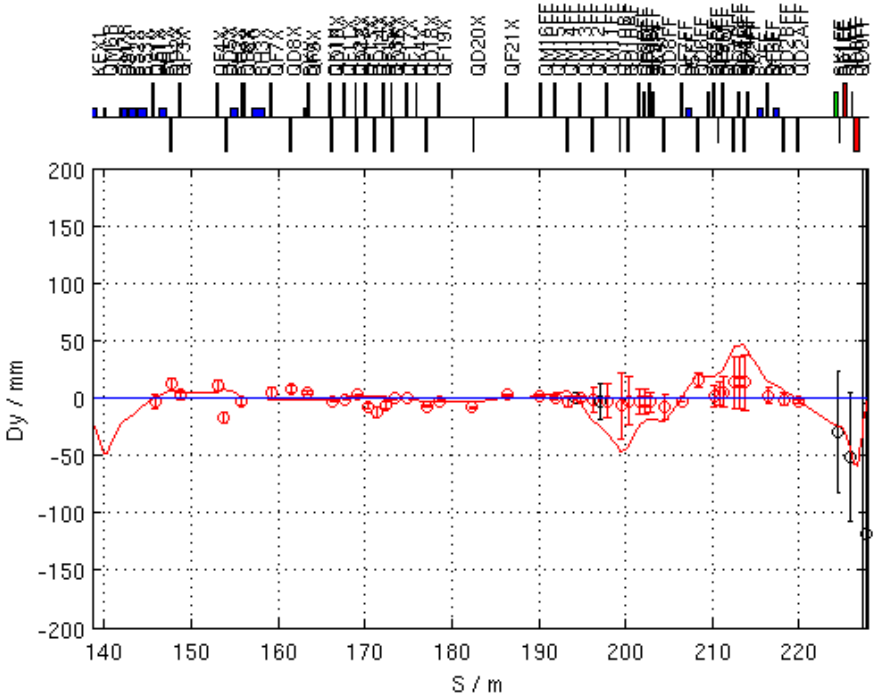
Modeled



- **Measurement shows directly measured dispersion on BPMs**
  - Slopes from energy ramp by changing DR RF freq
- **Curve shows dispersion propagation through Model using fit to BPM data points**
- **Model incoming dispersion as skew quad field in one of extraction septa devices (from horizontal offset in skew-sextupole field)**

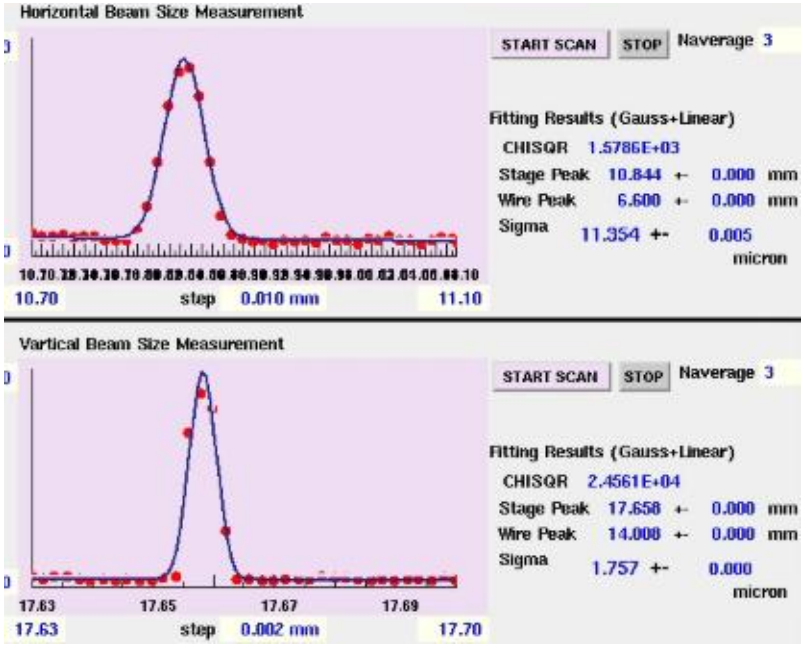
Dispersion Monitoring & Correction

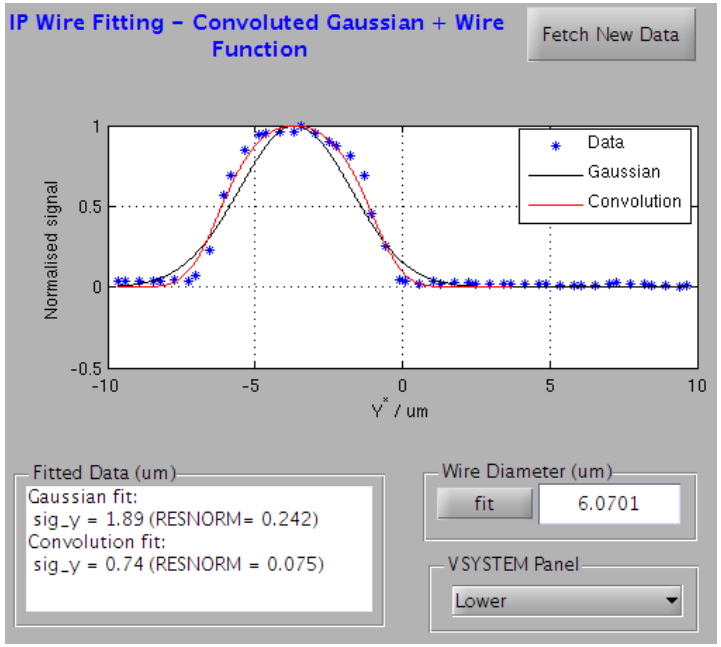




- **Automated correction system using model, skew and normal quads in EXT + steering.**
  - Use DR freq ramp to measure orbit shift to changing energy
- **Dispersion drifts with time as extraction orbit drifts. Monitor with online orbit fitting software and correct when dispersion becomes intolerably large. Most noticeable in high-beta regions of FFS.**

IP Wire Scans After Initial Setup Complete



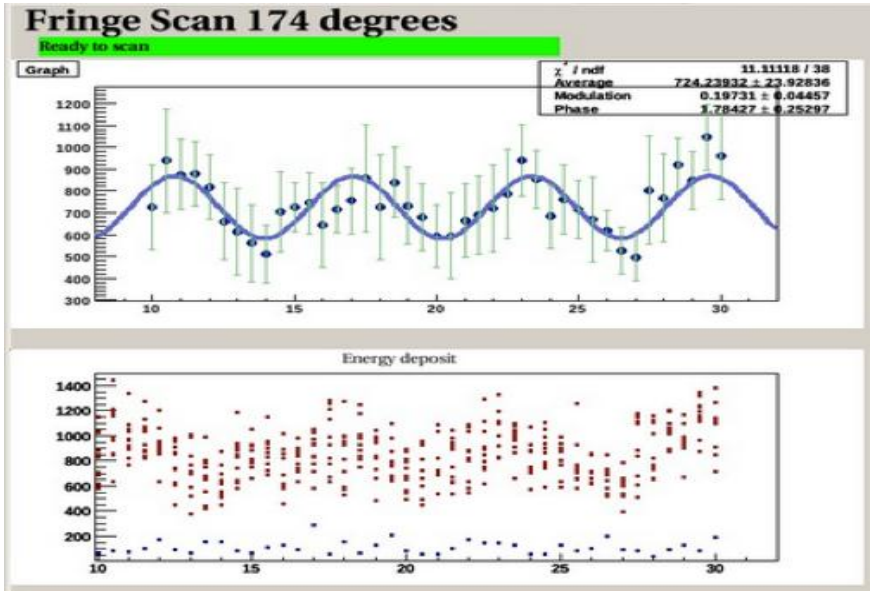


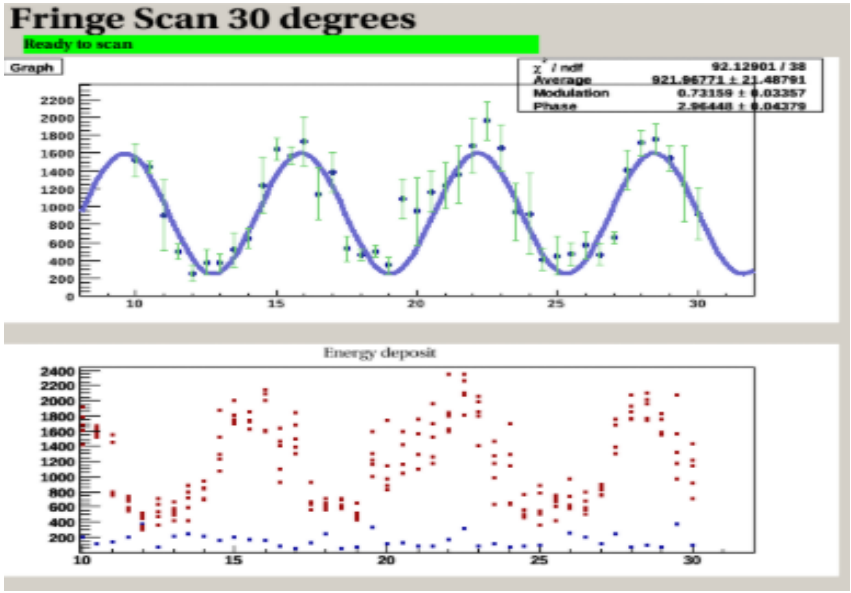
- Initial Beam sizes 11.4 um (x) [design 9] / 1.8um (y) [convolution fit = 0.74um]

IP Aberration Tuning

- **Linear tuning knobs using pre-computed orthogonalised horizontal/vertical moves of 5 FFS Sextupole magnets.**
  - alpha_x, eta_x, alpha_y, eta_y, <x'y>
- **Non-linear tuning knobs using strength changes of 5 FFS Sextupoles & 4 skew-Sextupoles**
  - Y22, Y26, Y44, Y46

IPBSM Measurement for Tuning and Confirmation of Beam Size at IP

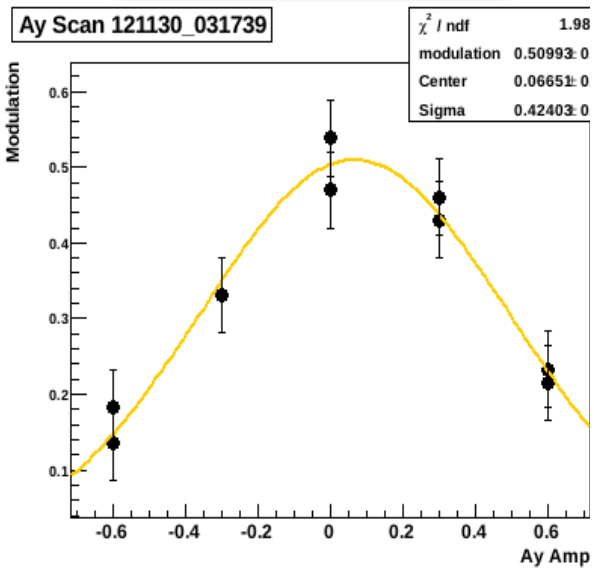




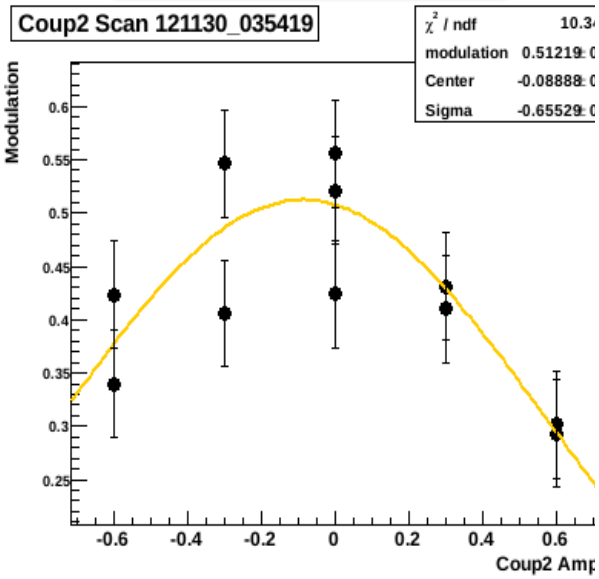
- **Beam size measured at IP by interference laser system**
- **Form interference pattern at IP, scan fringe pattern vertically through beam and infer beam size from "modulation depth" [(max-min)/mean measured compton signal]**
- **3 operating modes with differing interference spacings by changing crossing angle of 2 laser paths to give sensitivity to differing size beams**
  - 2-8 degree mode [360nm -> 3000+nm]
  - 30 degree mode [100nm -> 360nm]
  - 174 degree mode [20nm -> 100nm]

IP Multi-Knob Scans (linear)

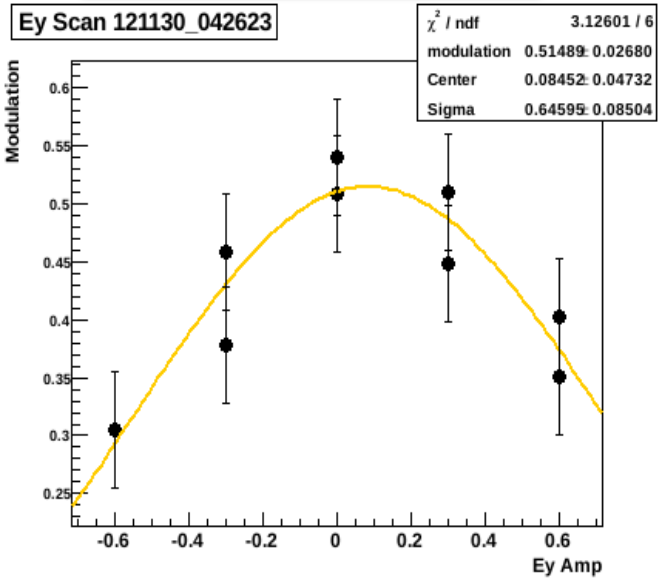
Vertical Waist



Coupling

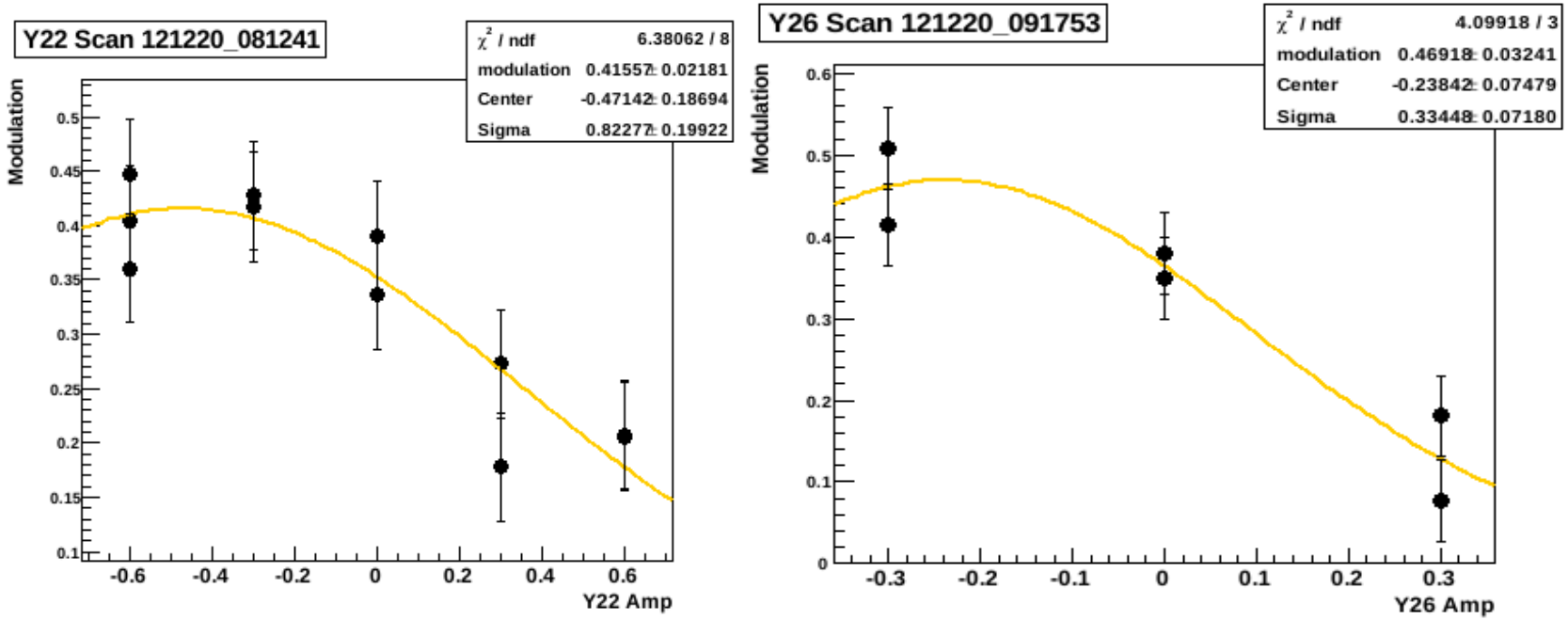


Vertical Dispersion



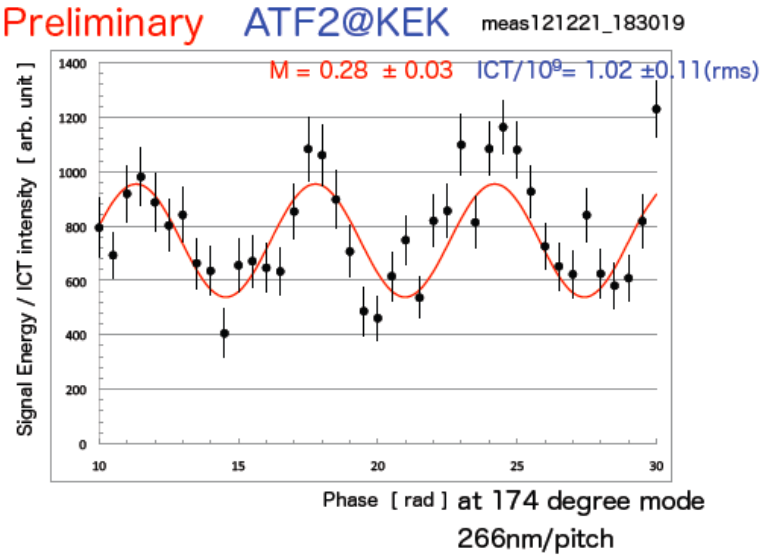
- **Design multiknobs using model to orthogonally tune waist, coupling and dispersion at IP**
  - Use coordinated horizontal and vertical moves of 5 FFS sextupoles
- **Orthogonality looks good, once a given knob set, subsequent scans are centred near zero.**

IP Multi-Knob Scans (non-linear)



- **Non-linear knobs devised using 4 skew-sextupole strengths**
- **Two effective non-linear knobs used**
  - Y22 (second-order coupling of Y from X')
  - Y26 (second-order chromo-geometric term)
- **Required larger than expected corrections with second-order knobs**
  - Currently under investigation (maybe due to a shorted sextupole coil and/or magnetised beamline components inside of bore of skew-sextupole magnets).

Preliminary Results and Comparison with FFTB



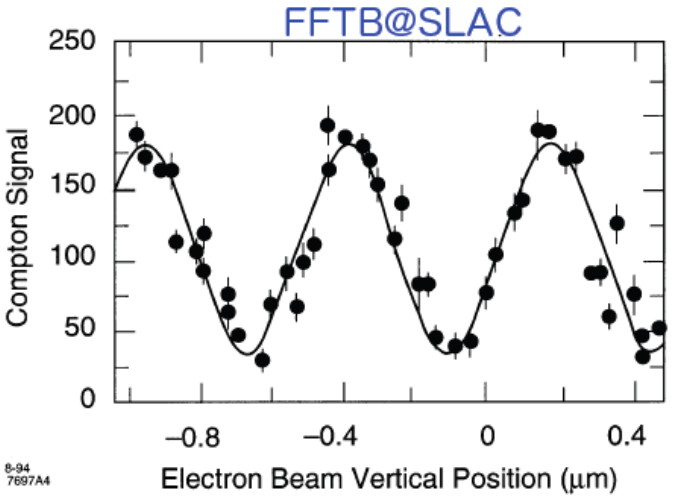
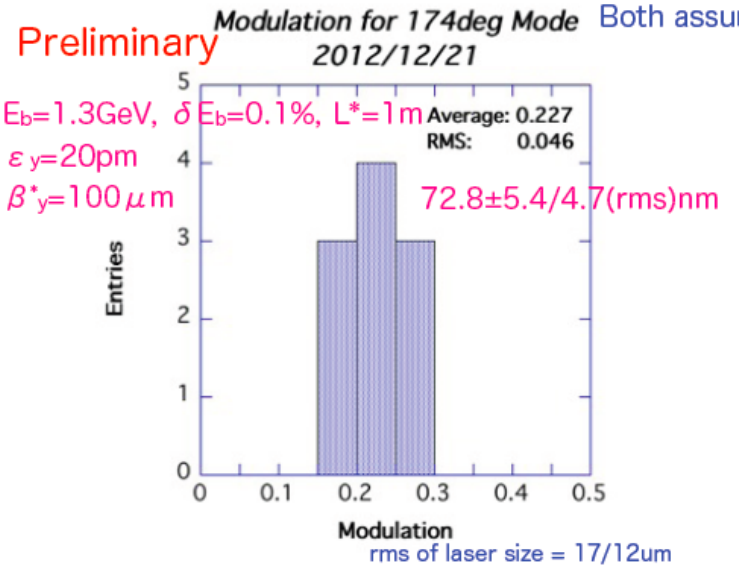


Figure 5.6: Laser-Compton beam size measurement performed in May of 1994. The measured size is 77±7 nanometers.



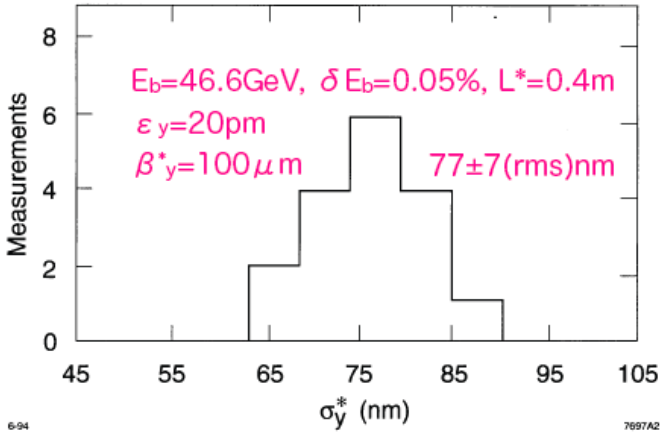


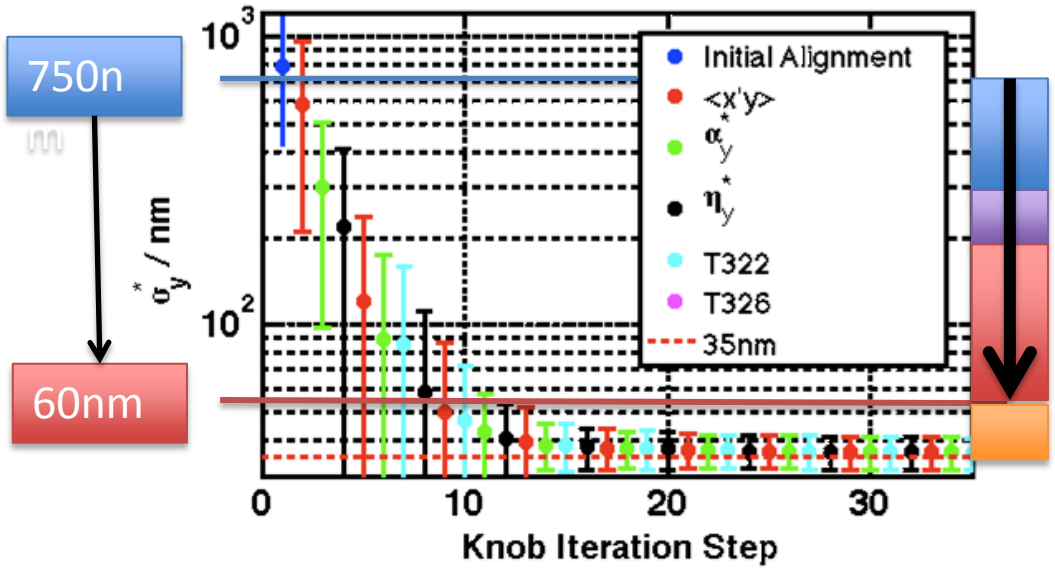
Figure 5.7: Histogram of measurements made during the last 3 hours of the May, 1994 FFTB run. Average size measured was 77 nm, with an RMS of 7 nm.

rms of laser size = 50um -> M reduction of 10%

Compare Tuning Results to Simulation

SIMULATION

Estimated Tuning Effects



linear knobs ~400nm

non-linear knobs ~100nm

wakefield + steering effects ~150nm

remaining 20nm to reach min beam size for measured emittance and IP beta

- **Measured 73nm @ 25pm == 60nm @ 12pm (min 66nm == 53nm)**
- **Estimate effect of tuning knobs from corrections actually applied over ~3 week period**
  - Corrections in this period not applied in an ideal way for this analysis
- **<70nm region not yet fully explored**
  - > next priority for 2013

Summary of Progress and Next Steps

- **Initial lattice setup works as expected**
- **Measured average of 73nm, best @ 66nm vertical beam at IP**
  - Better than FFTB with more demanding conditions
    - Initial verification that local scheme performs well
  - Equivalent best size @ 12pm == 53nm
    - Need <40nm to confirm capability of delivering ILC luminosity.
  - Multiknobs functioning as designed
  - Chromatic correction working (beam size ~500nm with no sextupoles)
- **Repeat tuning first half 2013 and determine minimum beam size after scanning all available multiknobs**
  - Iterate
- **Ascertain effects limiting lowering of beam size below 40nm if required**
  - Wakefields? Sources of non-linear fields or magnet errors driving second order terms? Breakdown in multiknobs?
- **Transition to stable delivery program**
  - Assess ability to model dynamic effects
  - Control of ground motion, vibration issues etc