Cornell University
Laboratory for Elementary-Particle Physics

Low Emittance Tuning in CESR TA

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Objectives

Attain sufficiently low vertical emittance to enable exploration of

- dependence of electron cloud on emittance
- emittance diluting effect of e-cloud

- Design/deploy low emittance optics ($1.5 < E_{beam} < 5.0$ GeV)
  - Exploit damping wigglers to reduce damping time and emittance
- Establish efficient injection of electrons and positrons
- Develop beam based techniques for characterizing beam position monitors
  - BPM offsets, Gain mapping, ORM and transverse coupling measurements > BPM tilt
- And for measuring and minimizing sources of vertical emittance including
  - Misalignments
  - Orbit errors
  - Focusing errors
  - Transverse coupling
  - Vertical dispersion
- Develop single bunch/single pass measurement of vertical beam size
- Characterize current dependence of lifetime in terms of beam size
- Measure dependencies of beam size/lifetime on
  - Beam energy
  - Bunch current
  - Species
  - Etc.

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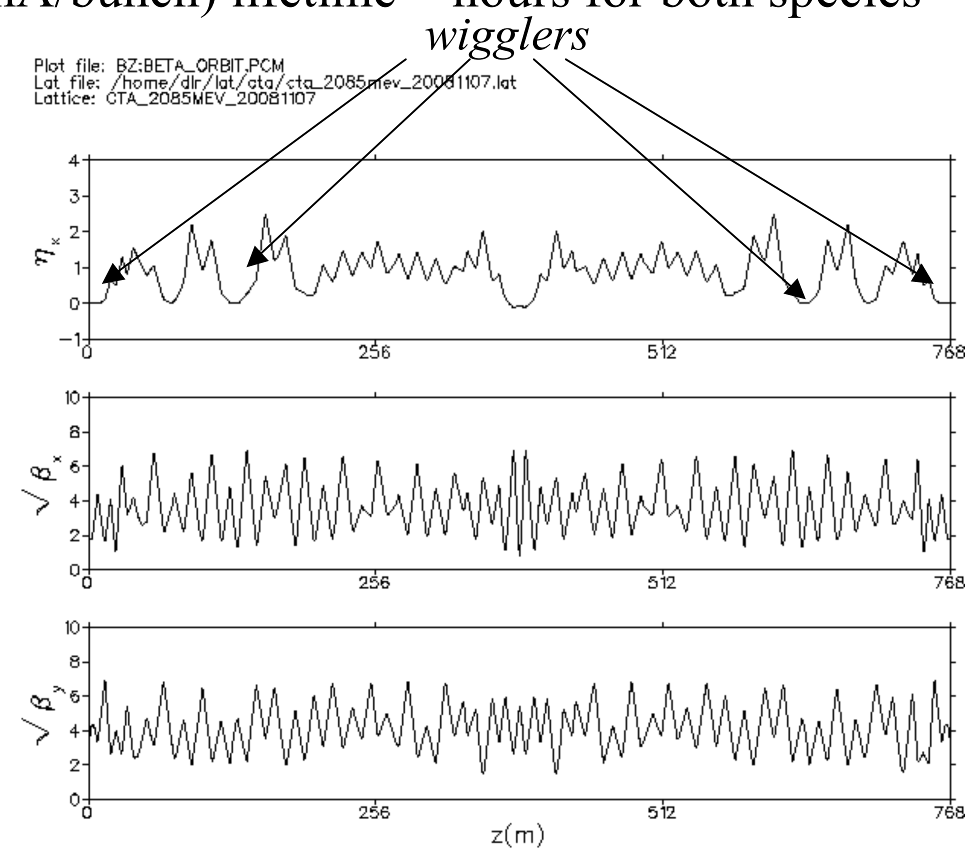
Low Emittance Optics - 2GeV

Twelve 1.9T wigglers in zero dispersion straights yield 10-fold reduction in radiation damping time and 5-fold reduction in horizontal emittance

- Conditions are well established
- Injection capture efficiency for both electrons and positrons is good
- Low current (<1mA/bunch) lifetime ~ hours for both species

Energy [GeV]	2.085
Wiggler[T]	1.9
Qx	14.57
Qy	9.6
Qz [4.5MV]	0.055
ε_x[nm]	2.6
α_p	6.76e-3
σ_l[mm]	12.2
σ_E/E[%]	0.81



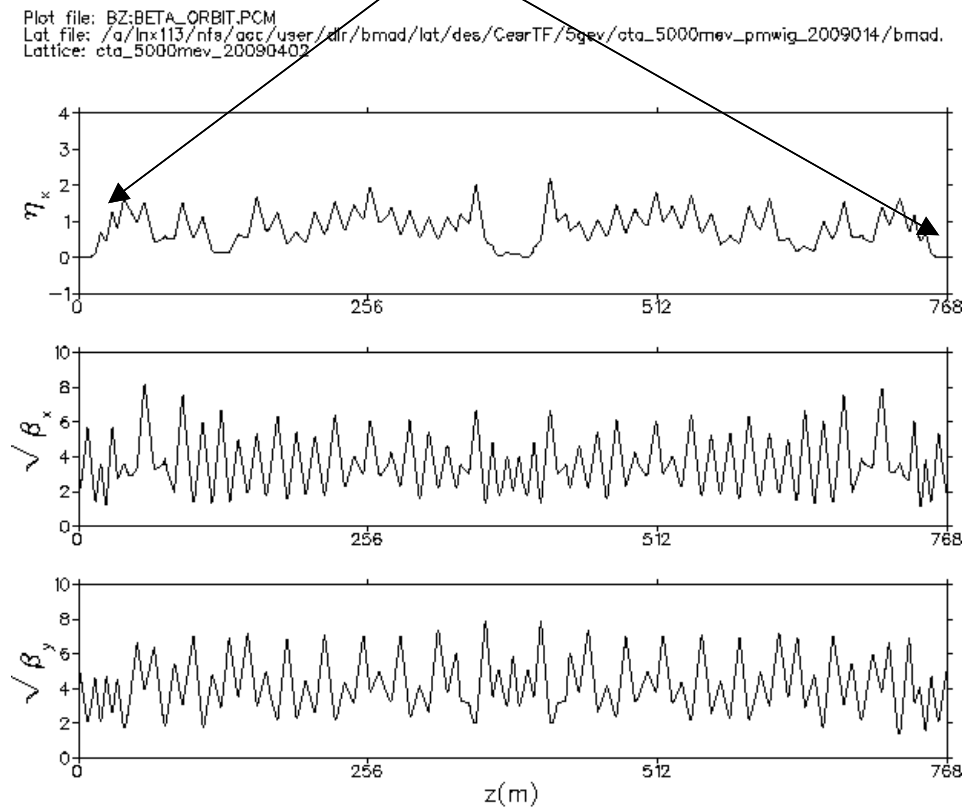
Low Emittance Optics - 5GeV

Six 1.9T wigglers in L0 - zero dispersion

(Arc vacuum chambers cannot tolerate wiggler radiation)

		(Wigglers off)
Energy [GeV]	5.0	
Wiggler[T]	1.9	0
Qx	14.57	
Qy	9.6	
Qz [8 MV]	0.043	
ε_x[nm]	35	60
α_p	6.23e-3	
σ_l[mm]	15.6	9.4
τ_{rad} [ms]	20	30
σ_E/E [%]	0.93	0.58

wigglers



Measure β-phase and coupling

Low emittance tuning

Experimental procedure

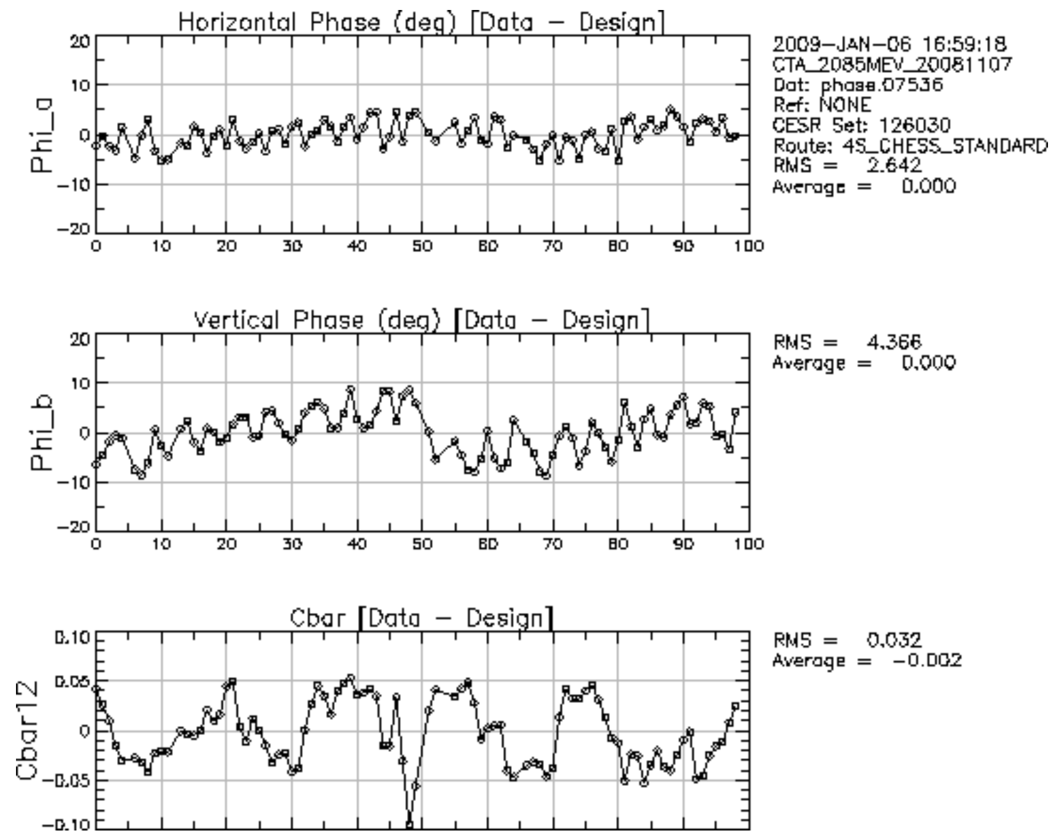
LET - initialization

-Measure and correct orbit using all dipole correctors

-Measure β-phase and transverse coupling

(Phase measurement insensitive to BPM offset, gain, and calibration errors)

Measurement at January 09 startup after 2 month CHESS (5.3GeV) run



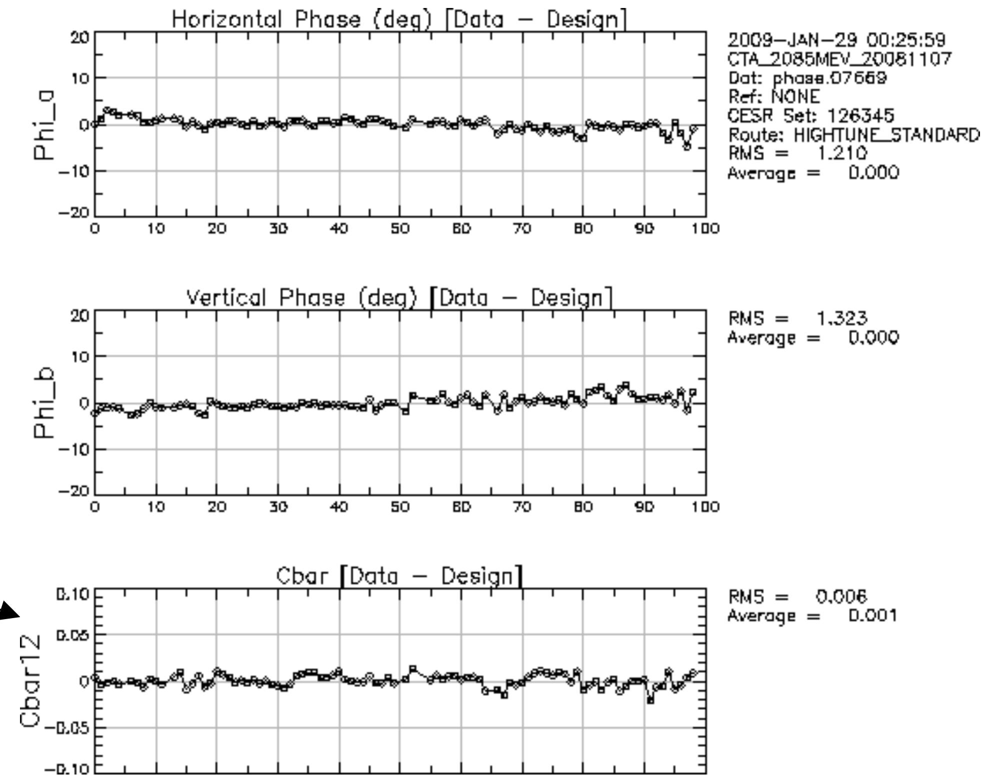
Low emittance tuning
Experimental procedure

LET - initialization

-Measure and correct orbit using all dipole correctors

- Correct β-phase using **all** 100 Remeasure - ($\sqrt{\langle \Delta\phi^2 \rangle} < 1.5^\circ$)

-Correct transverse coupling using 14 skew quads. Remeasure ($\sqrt{\langle \bar{C}_{12}^2 \rangle} \sim 0.6\%$)



β-phase and coupling after correction

Low emittance tuning

Orbit

A feature of the orbit is the closed horizontal bump required to direct xrays onto x-ray beam size monitor

-Measure and correct vertical dispersion using skew quads (14) and vertical steering (100)

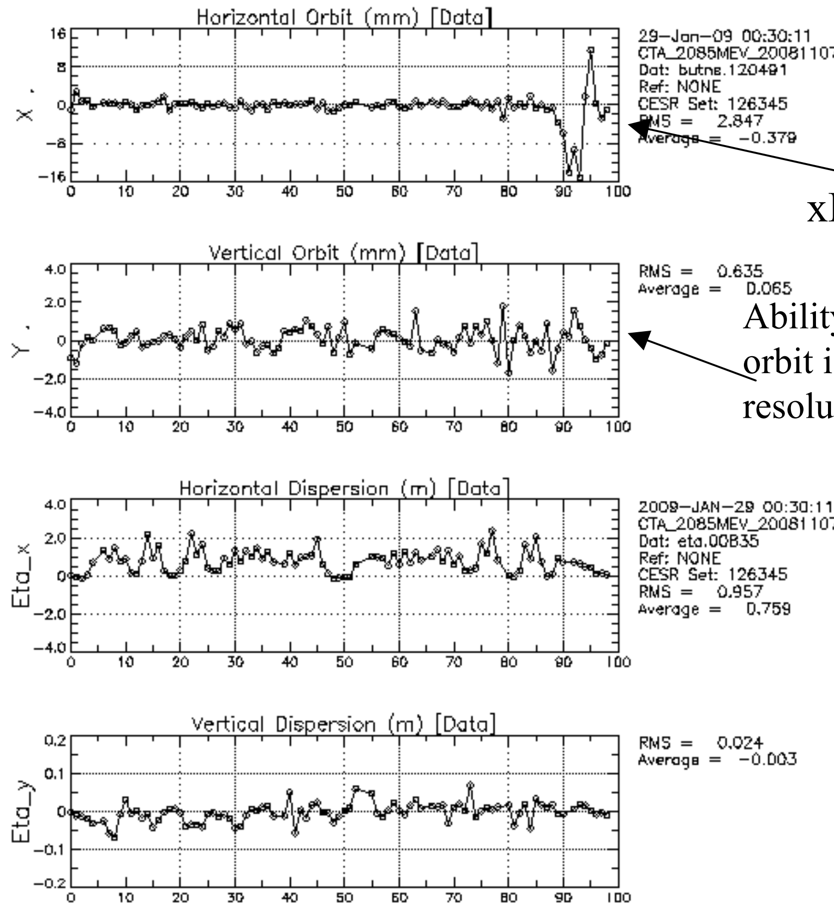
Residual vertical dispersion

RMS ~ 2.4cm - Signal or noise ?

Difficulty modeling suggests that it is noise.

Accuracy of dispersion measurement is limited by BPM systematics

2.4cm residual dispersion



xBSM bump

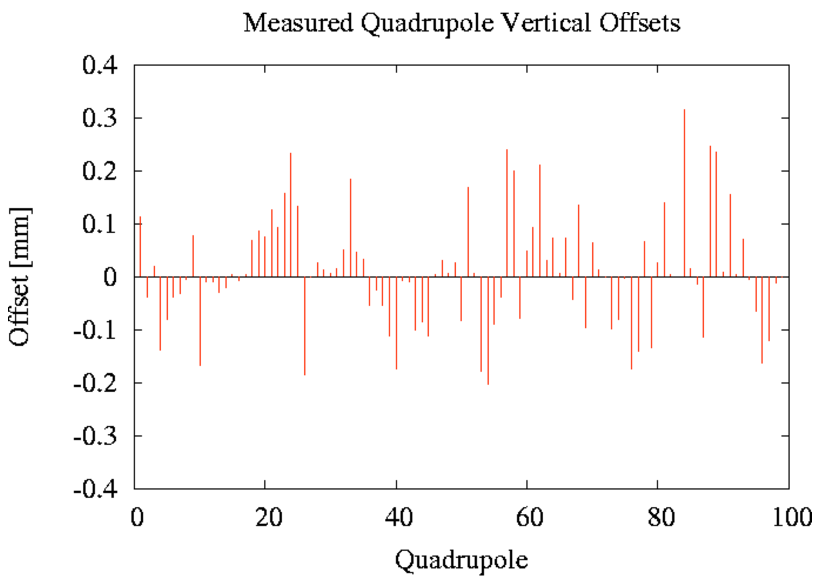
Ability to correct the vertical orbit is limited by BPM resolution and irreproducibility

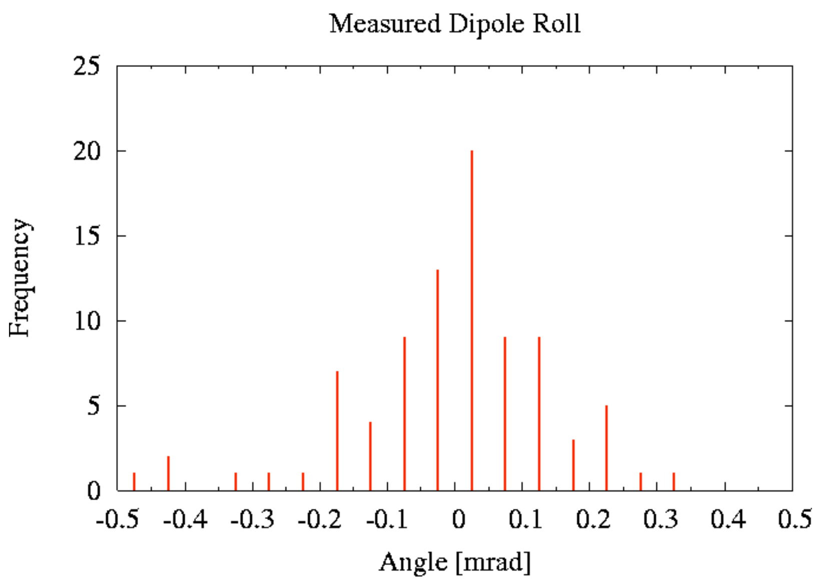
Note: Residual vertical dispersion 1cm, corresponds to $\varepsilon_v \sim 10pm$

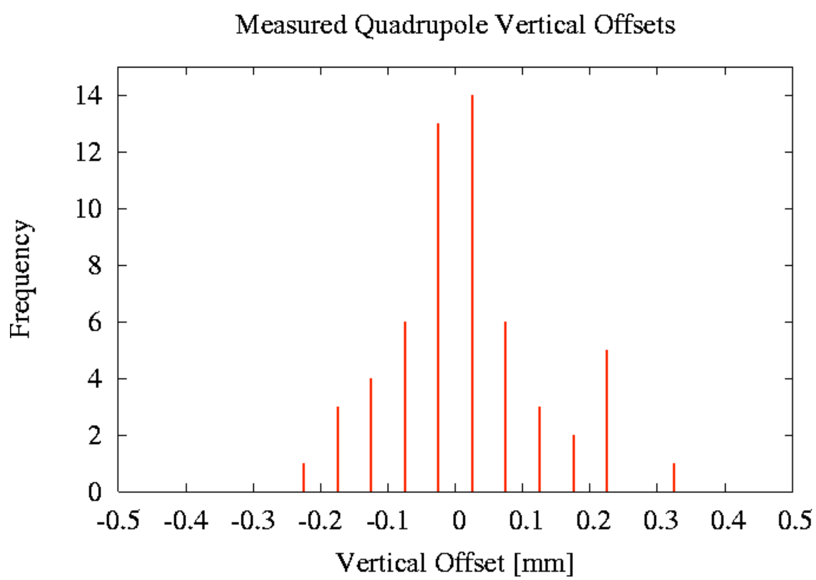
Magnet Alignment

Survey network complete
- Quad offset σ ~ 134μm
- Bend roll σ ~ 160μrad
- Sextupoles ?

Fixed with respect to adjacent quadrupole
Investigating systematic ~ 350 μm offset
Designing fixtures for correction





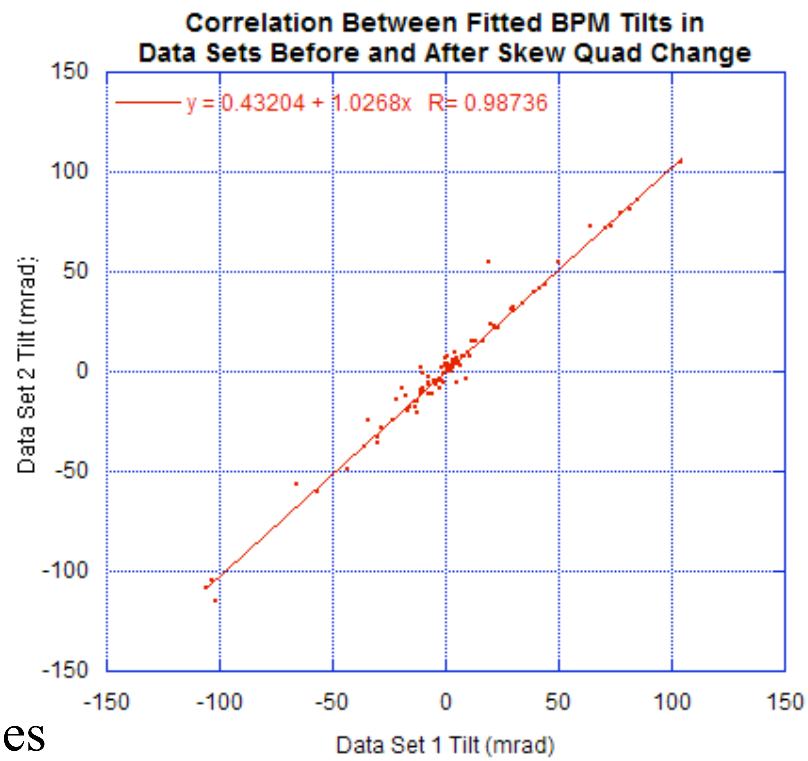


BPM tilt

- "measured" $\eta_v \sim \theta\eta_h$
  where θ = BPM tilt

Since $<\eta_h> \sim 1$m, BPM tilt must be less than 10mrad if we are to achieve η_v <1cm

We use ORM and phase/coupling measurement to determine θ.



ORM data set ~ 140 measured orbit differences

- Take data set 1
- Vary 8 skew quads and repeat
- Take data set 2

Fit each data set using all quad(k), skew(k), BPM(θ)

Correlation of fitted BPM tilt (θ)
$\Delta\theta < 10$ mrad

Consistent with $\sigma_{BPM}(\Delta x) \sim 35\mu m$

BPM upgrade

Existing BPM electronics measure stretched signal and share common signal processing via mechanical relays

New system

- Bunch by bunch/turn by turn digitization
- 4ns bunch spacing
- $\sigma(\Delta x) < 10\mu m$

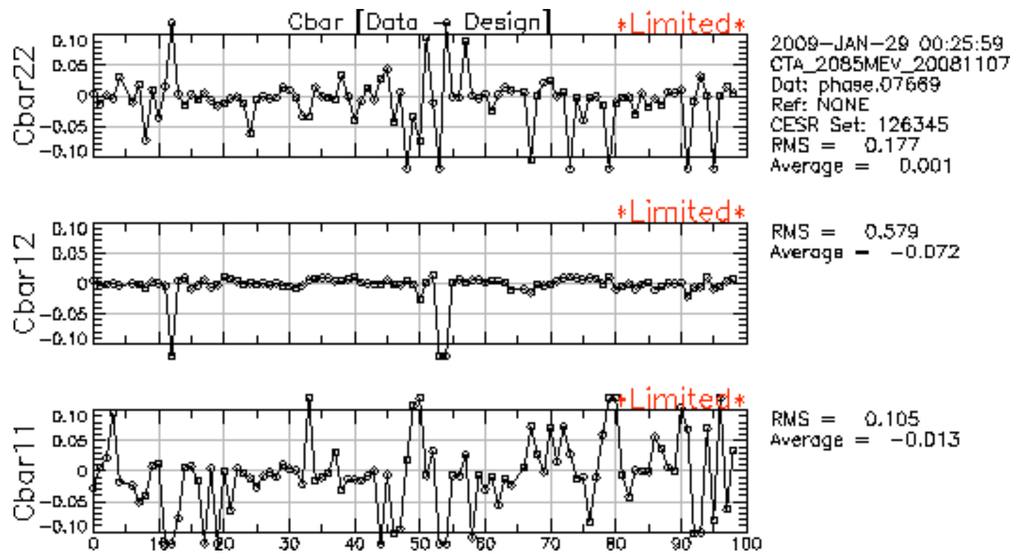
Status

Infrastructure (cables,crates, etc.) fully deployed in tunnel

Conversion from old system to new is underway - taking care to maintain full functionality during the transition

With the new system we will measure:

- Quad - BPM offset < 50 μm via beam based alignment (Vary quad K to find center)
- $\Delta\eta \sim \Delta x/(\Delta E/E) \sim 10\mu m / 10^{-3} \sim 1cm$
- Clean measurement of C_{11}, C_{12}, C_{22} discriminates BPM tilt and transverse coupling (C_{12} independent of tilt)



Lifetime

Touschek lifetime

CesrTA operates in a regime where lifetime is current dependent

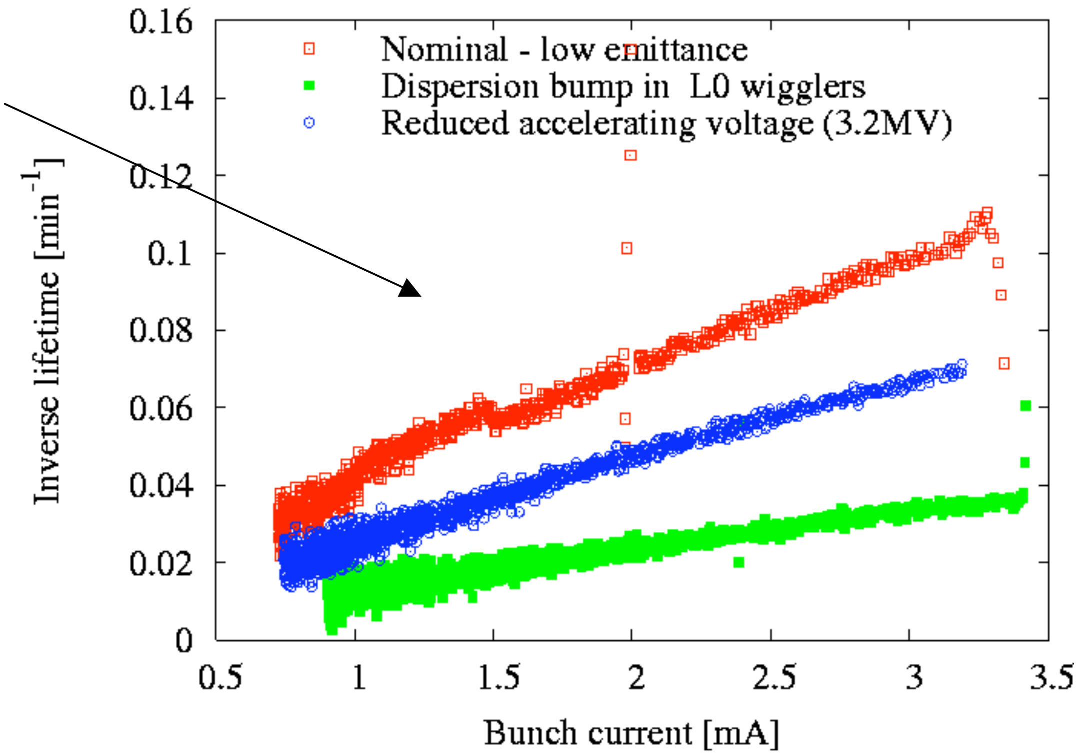
Intrabeam scattering kicks particles outside of energy aperture

Touschek lifetime depends on energy aperture

$$\frac{dI}{dt} = -\frac{1}{c}I - \frac{1}{b}I^2$$

$$1/\tau_{eff} = -\frac{1}{I}\frac{dI}{dt} = \frac{1}{c} + \frac{1}{b}I$$

The Touschek parameter (b) decreases with:
- increasing beam size
  (introducing η_v in damping wigglers)
- increasing bunch length
  (reduced accelerating voltage)

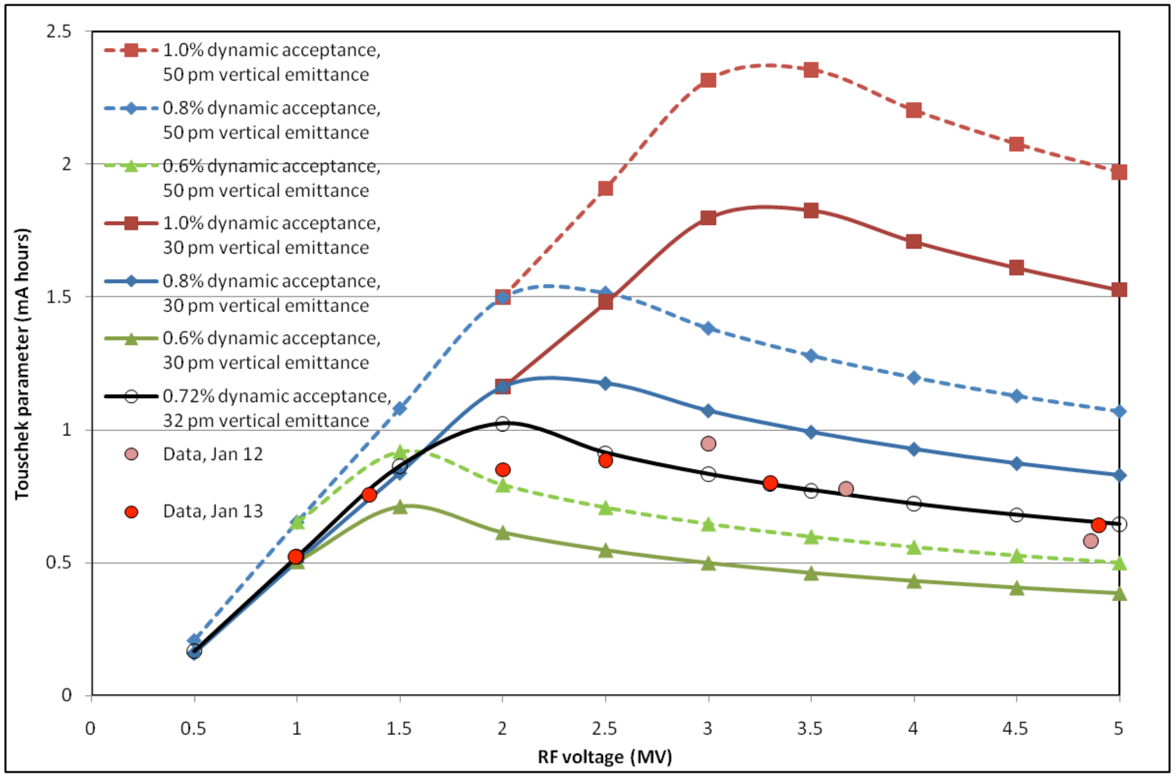


Lifetime

Touschek lifetime (and Touschek parameter [b]) depends on
- dynamic energy acceptance
- RF accelerating voltage
- vertical emittance

The curves in the plot show theoretical dependence of Touschek parameter on accelerating voltage for different combinations of dynamic acceptance and vertical emittance

The data (filled circles) are consistent with 0.72% energy acceptance and 32pm vertical emittance

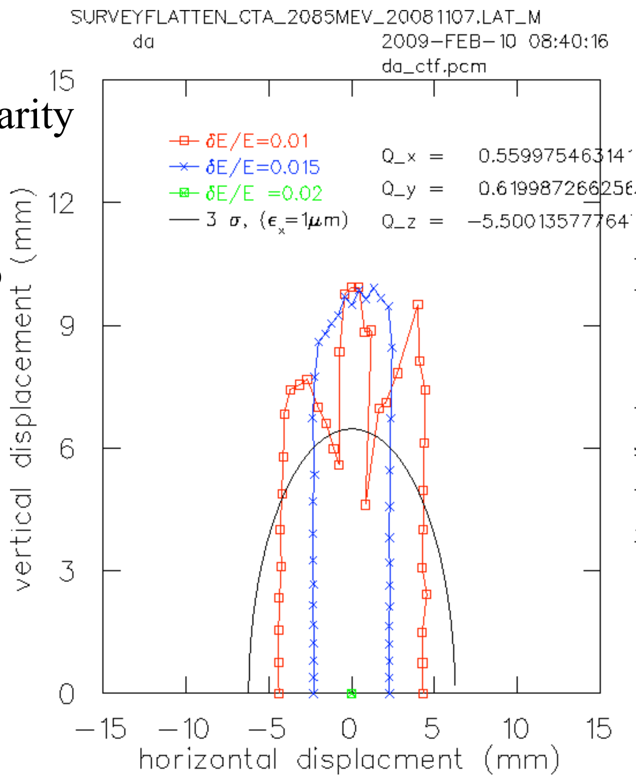


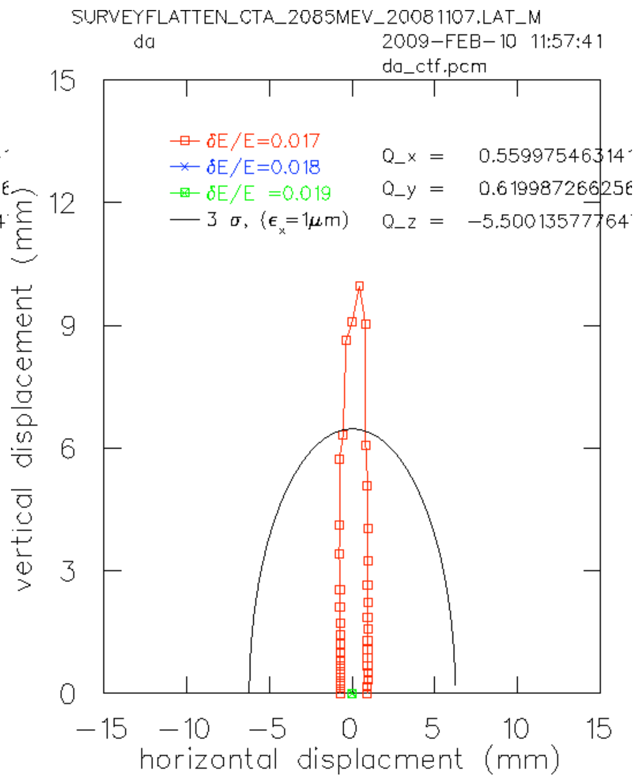
Dynamic energy aperture

Interpretation of lifetime measurements requires knowledge of dynamic energy acceptance
Tracking study indicates energy acceptance ~1.8%
(lifetime measurements suggest significantly smaller energy acceptance)

Tracking model includes:
- -magnet misalignments
- -wiggler and quadrupole nonlinearity
- -Orbit errors

→Energy acceptance ~ 1.8%



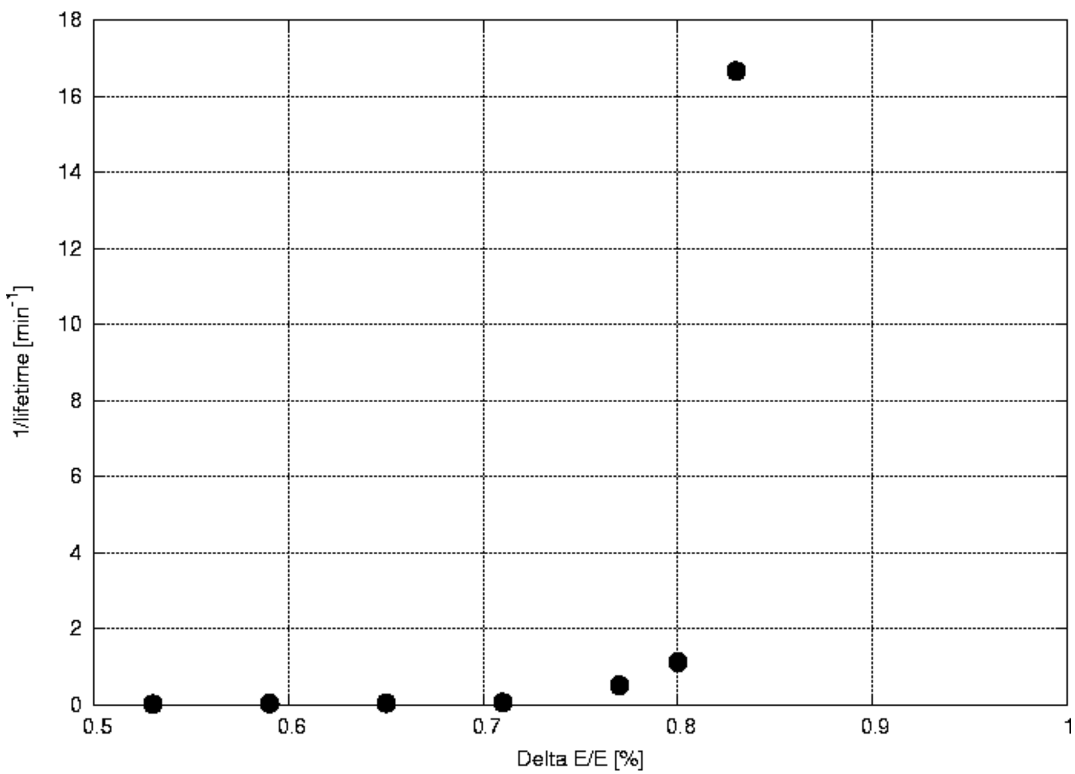


Nonlinearity of dipole correctors and sextupoles has not yet been included.

Energy Acceptance

Determine energy acceptance experimentally
by measuring lifetime vs energy offset

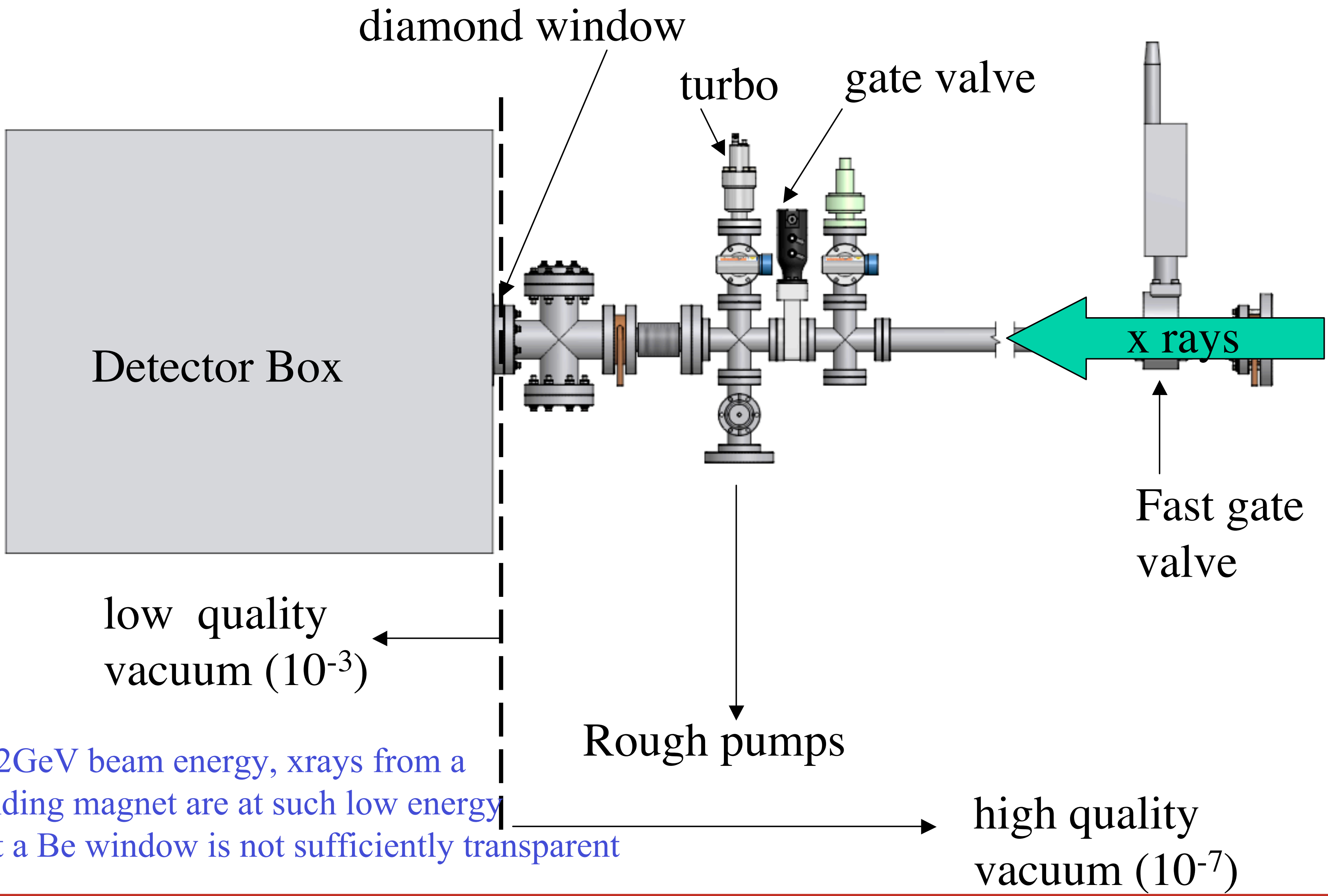
$\Delta E/E \sim 1/\alpha_p(\Delta f_{RF}/f_{RF})$
$\rightarrow$Energy acceptance ~ 0.8%



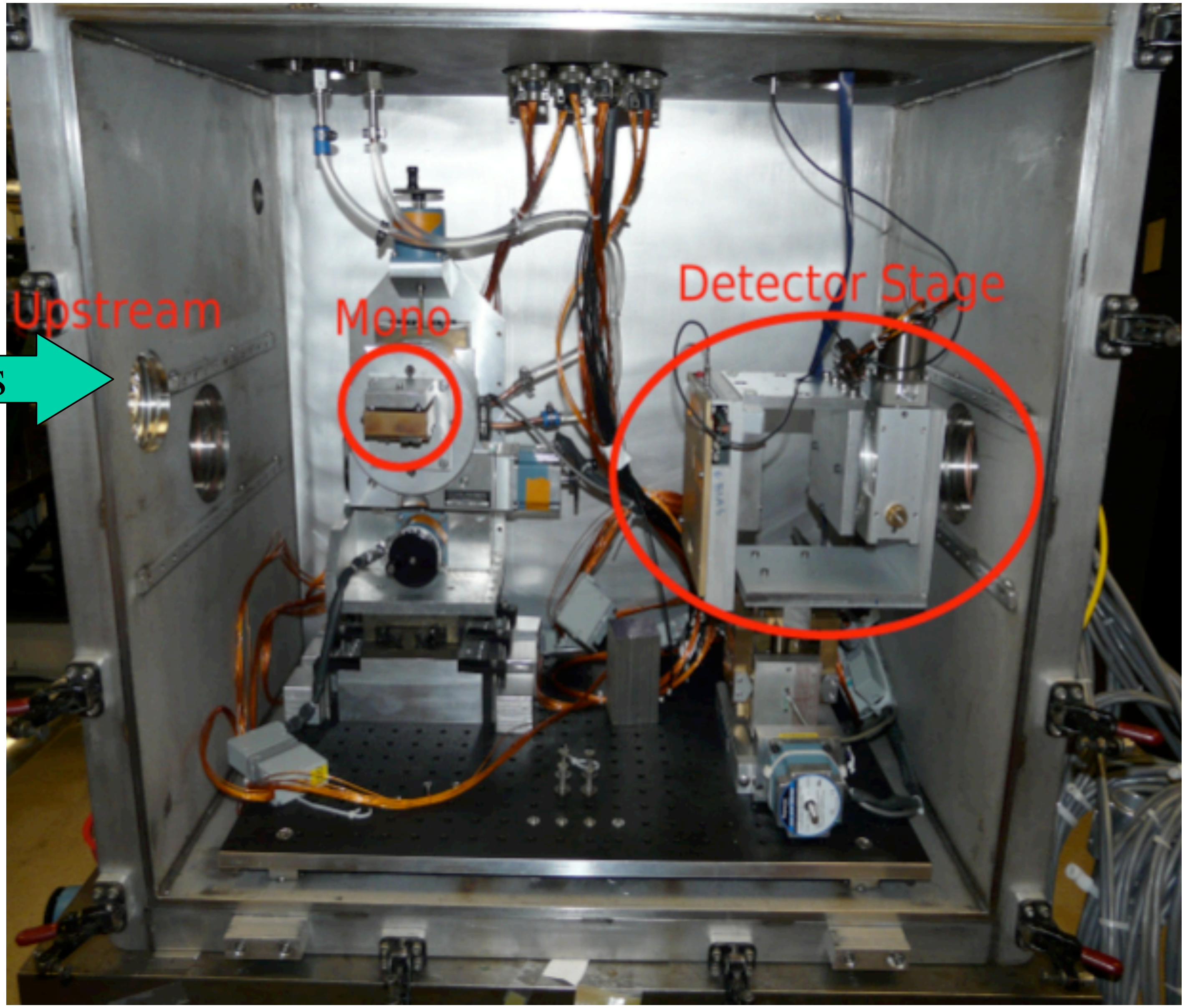
This *direct* measurement of energy acceptance is consistent with lifetime measurements and $\varepsilon_v \sim 32$pm

It remains for us to reconcile measurement and tracking calculation of energy acceptance.

Xray Beam Size Monitor



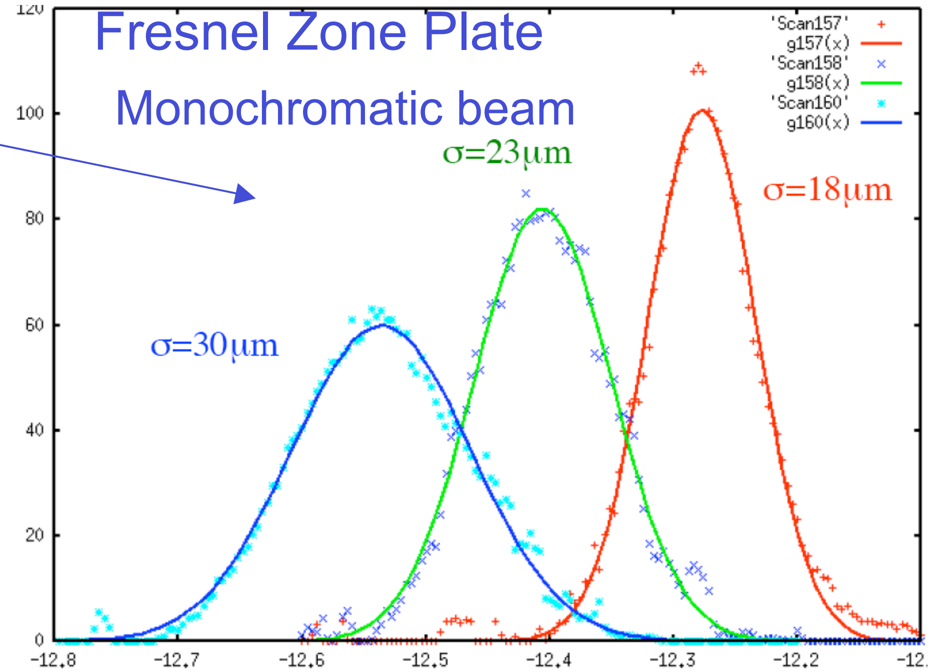
At 2GeV beam energy, xrays from a bending magnet are at such low energy that a Be window is not sufficiently transparent x rays



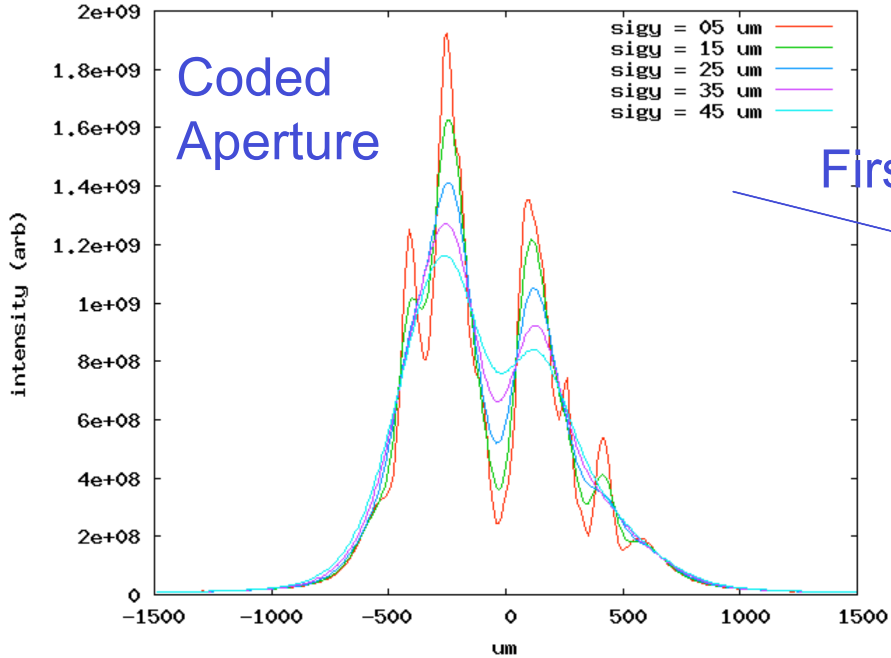
xBSM Snapshots

- Scan of coupling knob
- Coded aperture measurements
- Smallest recorded size:

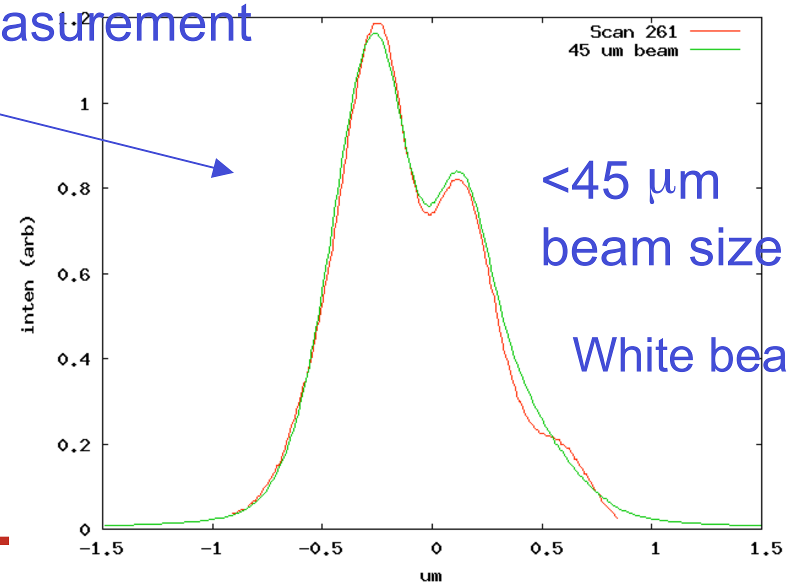
  ~15 μm →ε_y~ 37pm (preliminary)



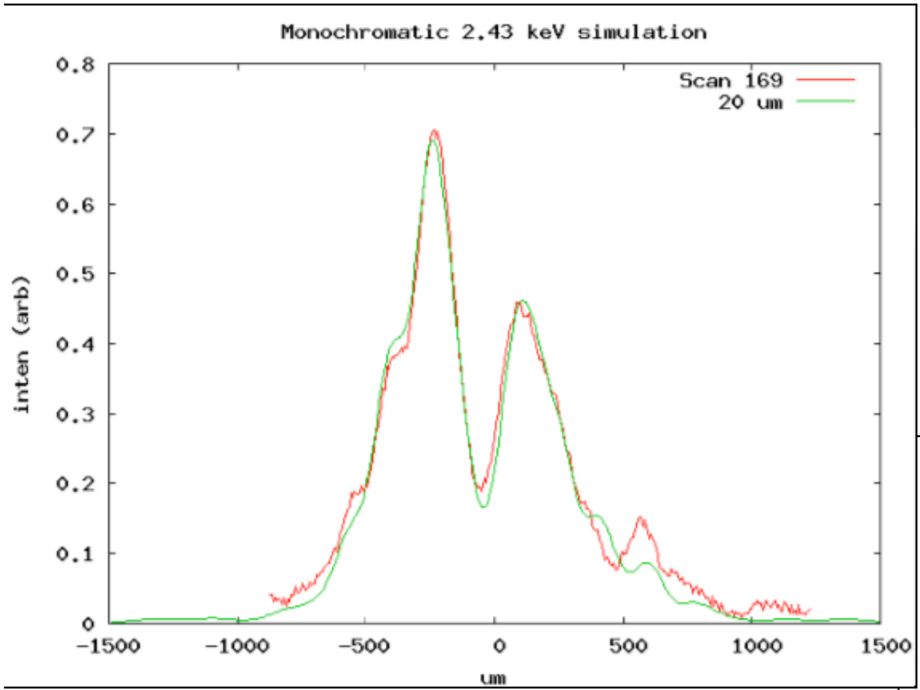
Simulations



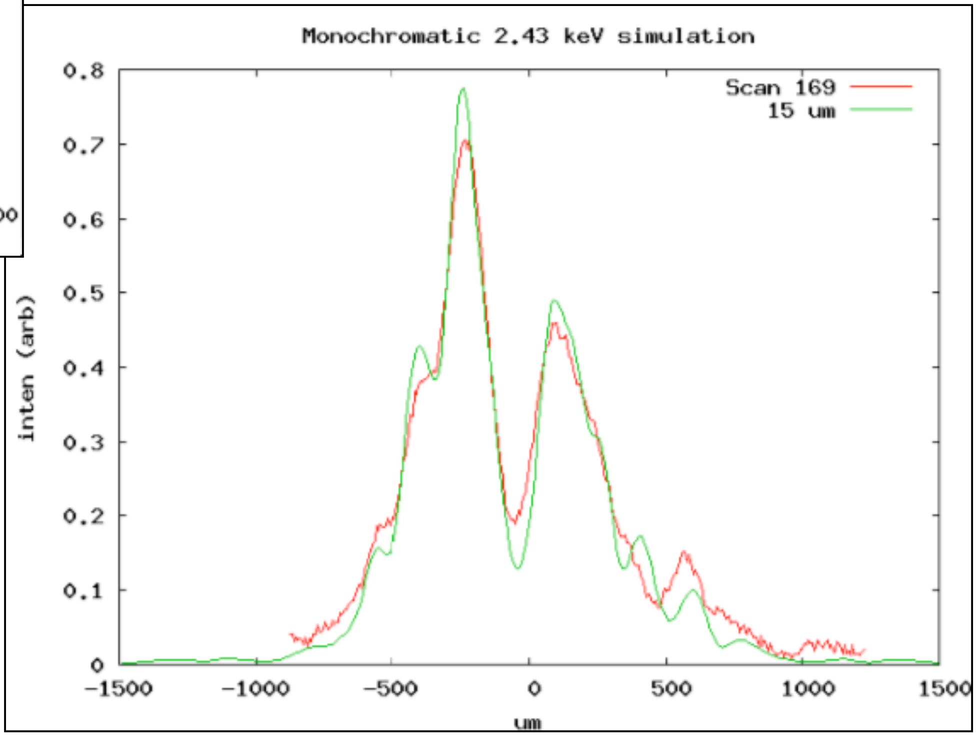
First measurement



Coded Aperture



CESR condition same as for 18um FZP



All measurements with single diode
Diode array will provide "real" time beam size measurement

Xray Beam Size Measurement

Measure beam size
vs coupling/dispersion knobs

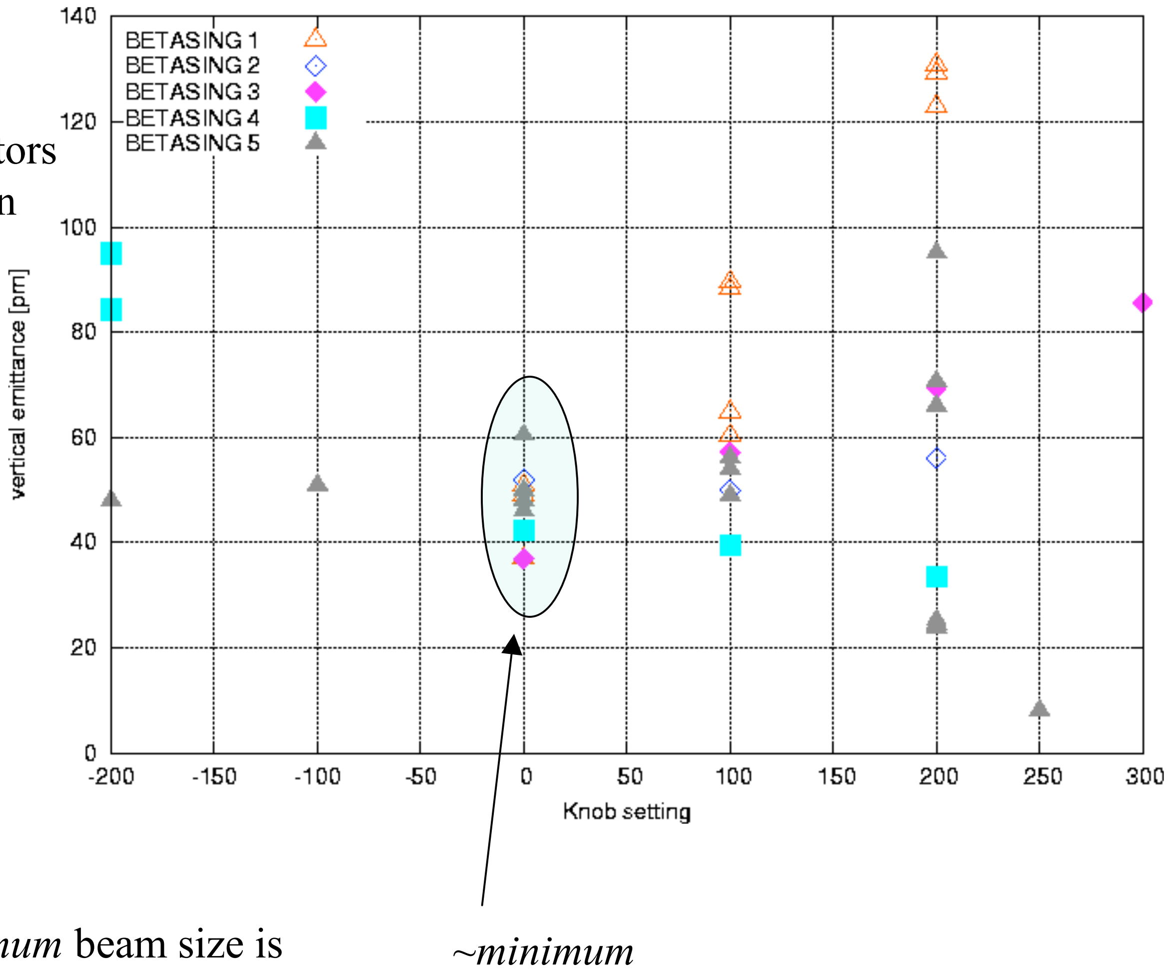
Linear combinations of skew quad correctors yield closed dispersion/coupling bumps in the damping wigglers and are used to tune vertical emittance

Betasing 1/2 - L0 wigglers
Betasing 3/4 - East arc wigglers
Betasing 5/6 - West arc wigglers

Beam size is measured with the Xray beam size monitor

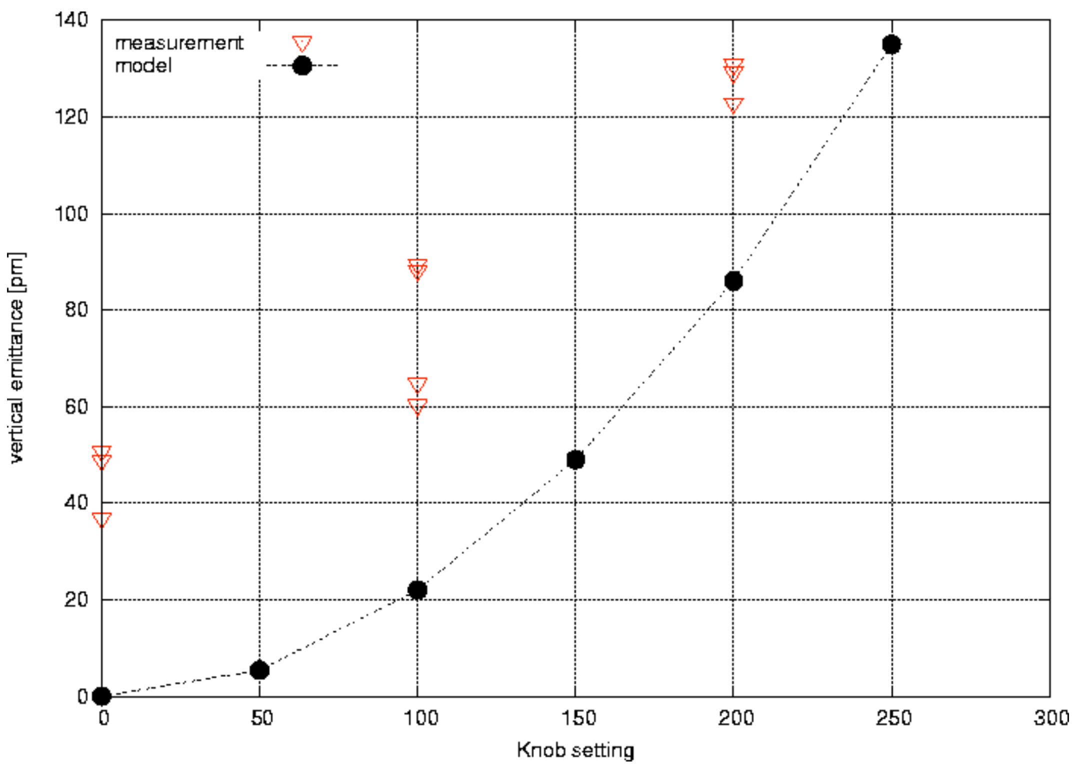
Knob setting = 0 corresponds to conditions after low emittance tuning procedure.

The spread (37pm < ε_v < 60pm) in *minimum* beam size is presumably due to knob hysterisis



Xray beam size Measurement

Consider the dependence of beam size on *Betasing 1* (the knob that effects η,η' in the L0 wigglers)



Model dependence of vertical emittance on *Betasing 1* is indicated by the black circles in the plot.

We assume *Betasing 1* = 0 corresponds to zero vertical emittance. (The model machine)

$(\varepsilon \sim \eta_v^2)$

The measured beam size is indicated by the triangles

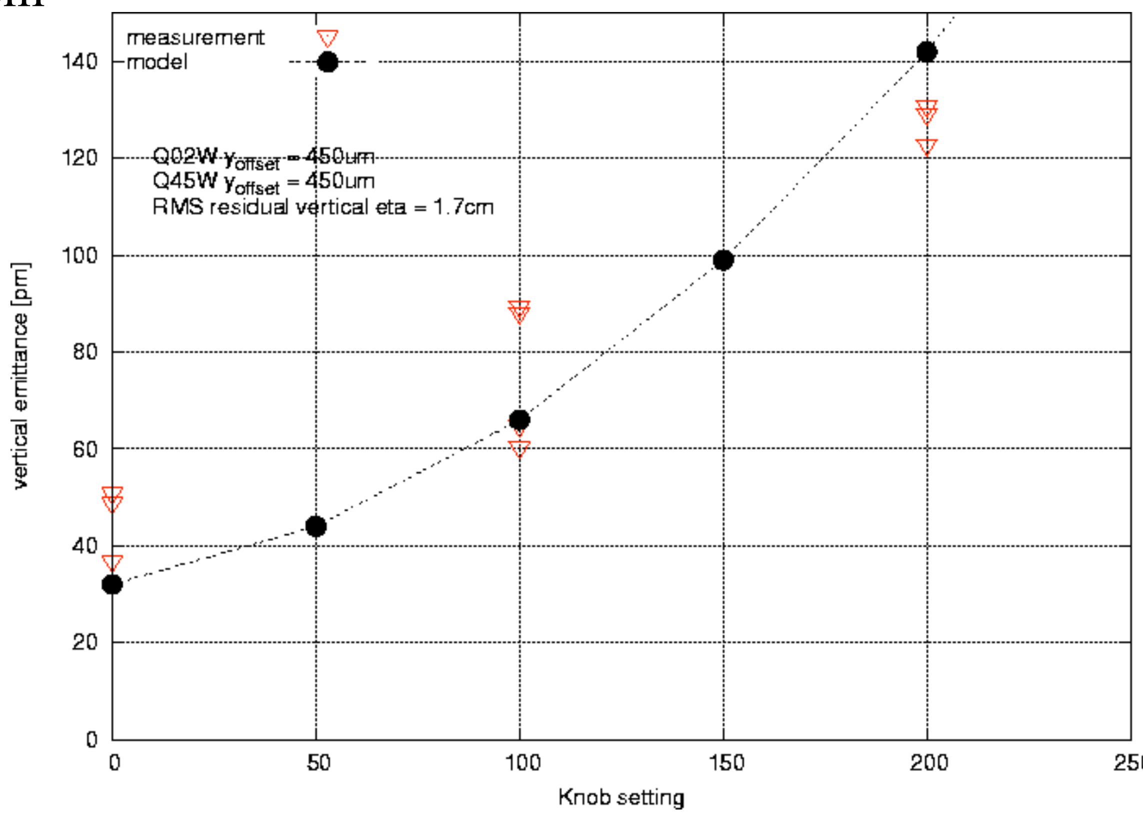
Xray beam size Measurement

If we assume a residual $\eta_v \sim 1.7$cm
then $\varepsilon_v(0) \sim 35$pm
(we measure residual $\eta_v \sim 2$cm)

Again, according to the model calculation, dependence of ε_v on *Betasing 1* is black circles

Model and measurement are in reasonable agreement

Conclusion from lifetime and Xbsm measurements is that
$\varepsilon_v \sim 35$pm



Low emittance tuning

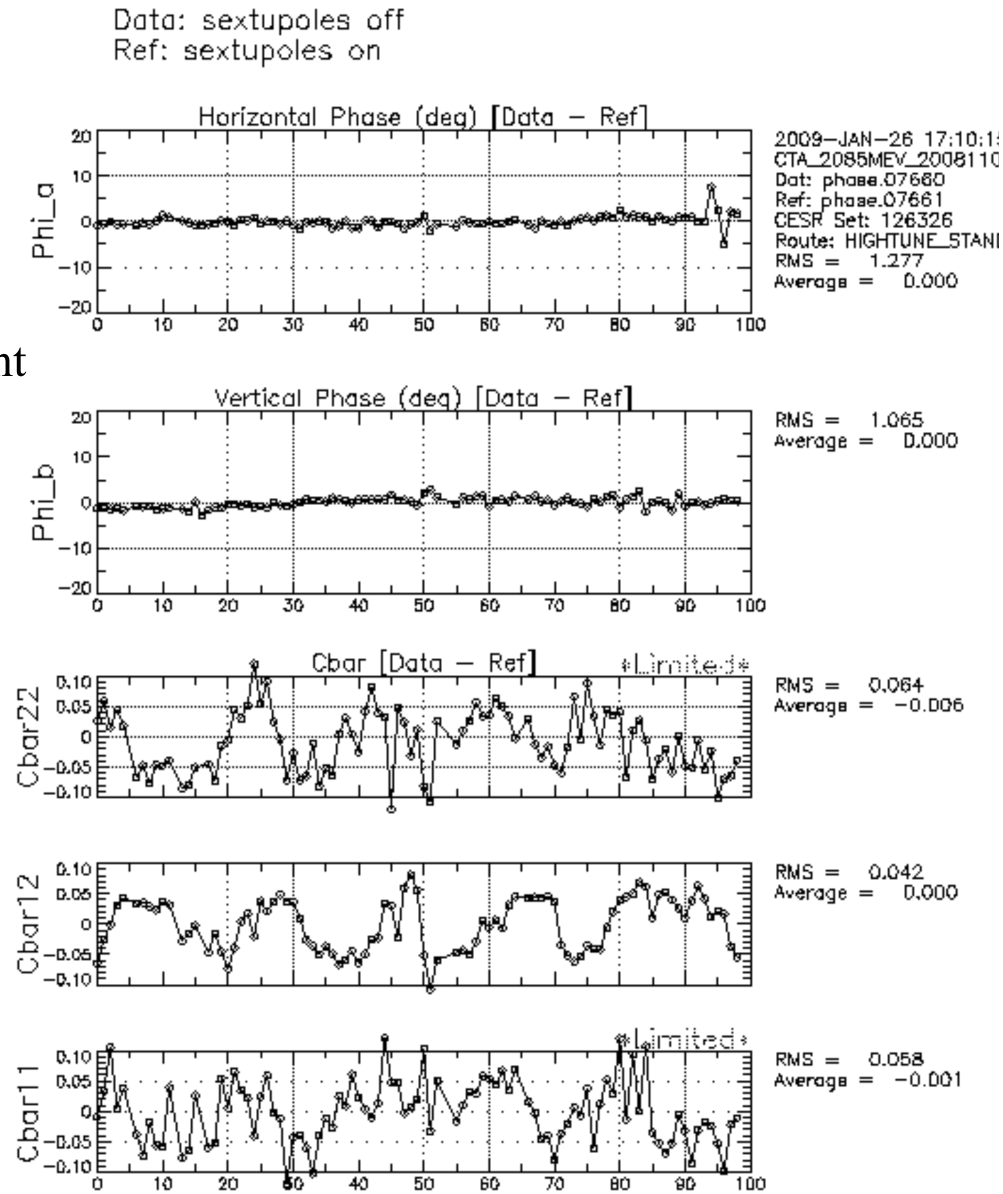
- limited by finite η_v
- Identification of the source requires better measurement

Consider the effect of sextupole misalignment

The measurement

1. Correct (flatten) orbit
2. Correct coupling with skew quads
3. Measure β-phase and coupling
4. Turn off all sextupoles and re-Measure β-phase and coupling

The RMS phase difference is ~ 1°
The RMS coupling difference is~ 4.2%



The measured coupling corresponds to systematic sextupole vertical offset of ~1mm

Direct measurement suggest some such offset!

Analysis tools

CESRV is the code that provides

- access to control system to make measurements of
  orbit, β-phase, transverse coupling, dispersion
- analysis of measurements
  (wave analysis, fitting [model to measurement], calibration, etc.)
- access to the control system to load corrections to
  steerings, quadrupoles, skew quads, sextupoles …
- data manipulation - plotting, comparison, bookkeeping, etc.

CESRV runs on linux (as well as VMS)

- Linux / control system communication is transparent to user

> Real time measurement/analysis/correction

LET Status

- Survey and alignment
  Quadrupole offsets and rolls, and bend rolls within tolerances
- Quadrupole focusing errors corrected
- Coupling corrected < 1%
- Vertical dispersion ~ 2cm (the goal is 1cm)
- Measured vertical emittance (lifetime and XBSM) ~ 35pm
  (→ corresponds to η_v(RMS)~ 1.8cm)

→ Residual vertical dispersion dominates vertical emittance

- Our ability to correct vertical dispersion limited by BPM resolution
- Implementation of digital BPM electronics (May-June 09 run) will provide required resolution/reproducibility
  [Candidate source of dispersion is sextupole misalignment
  (Developing a plan for measuring and correcting offset errors)]

- Analysis software and infrastructure is flexible, well tested, and mature

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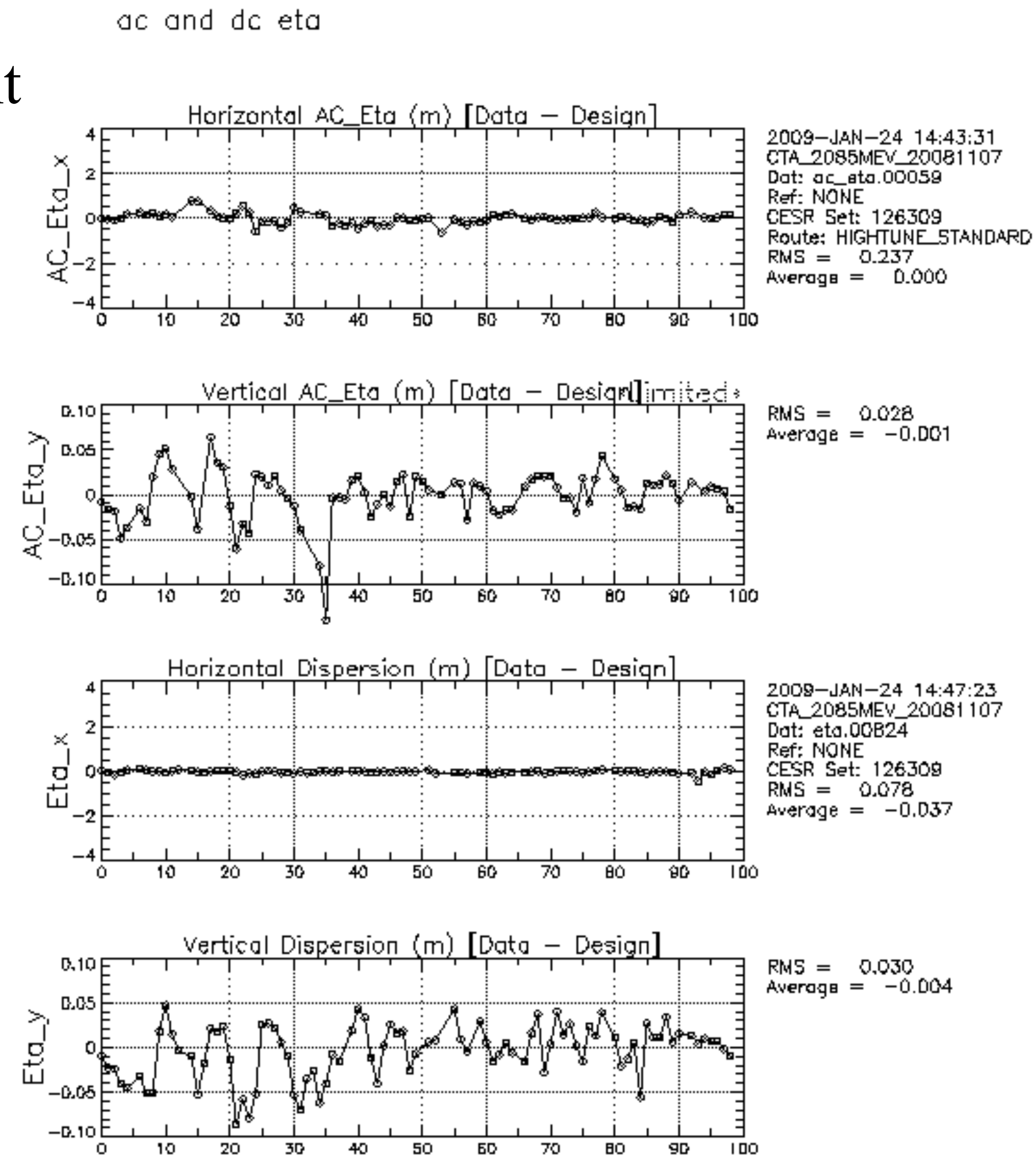
AC dispersion measurement

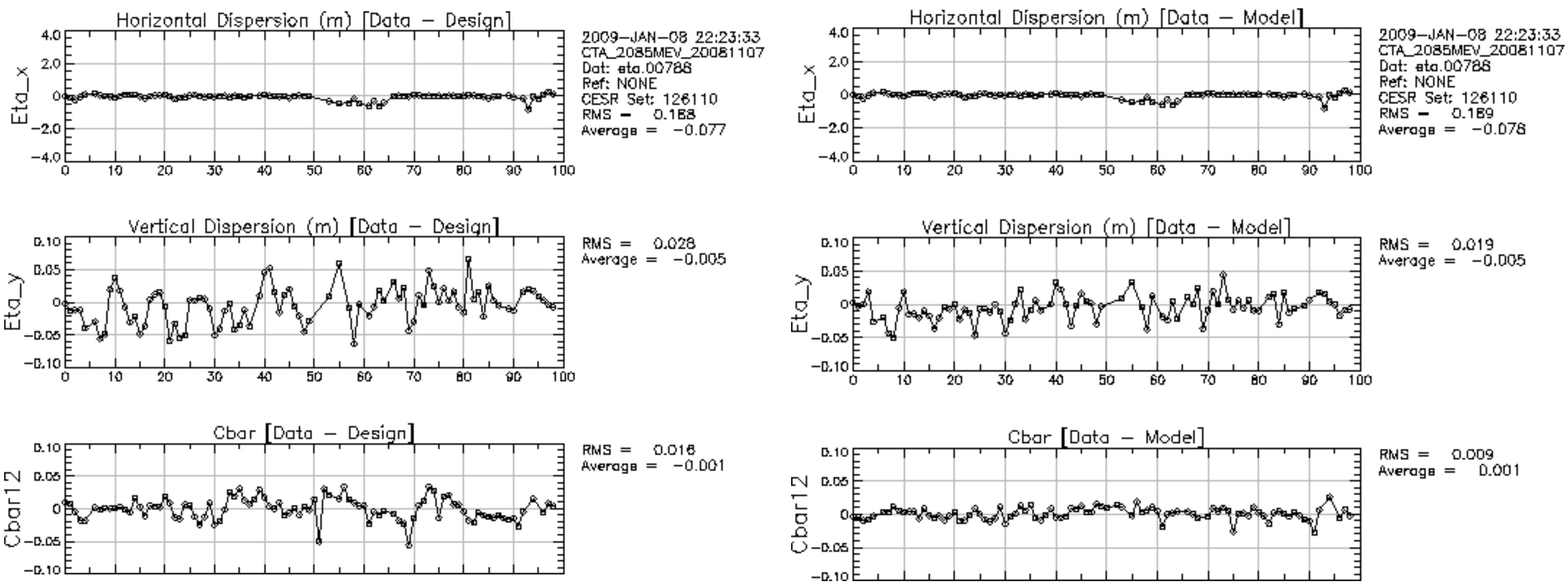
η_v(AC)

Achieving emittance target depends on reducing vertical dispersion to < 1cm. Presently limited by marginal quality of measurement

AC technique may give Requisite resolution but not yet

η_v(DC)




Horizontal Dispersion (m) [Data – Design]
Eta_x
2009–JAN–08 22:23:33
CTA_2085MEV_20081107
Dat: eta.00788
Ref: NONE
CESR Set: 126110
RMS = 0.188
Average = –0.077
Horizontal Dispersion (m) [Data – Model]
Eta_x
2009–JAN–08 22:23:33
CTA_2085MEV_20081107
Dat: eta.00788
Ref: NONE
CESR Set: 126110
RMS = 0.189
Average = –0.078
Vertical Dispersion (m) [Data – Design]
Eta_y
RMS = 0.028
Average = –0.005
Vertical Dispersion (m) [Data – Model]
Eta_y
RMS = 0.019
Average = –0.005
Cbar [Data – Design]
Cbar12
RMS = 0.016
Average = –0.001
Cbar [Data – Model]
Cbar12
RMS = 0.009
Average = 0.001