# Tevatron Run II Plans

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Tevatron Group

October 15, 1999

# October 1999 to March 2001 Schedule

MI Coalescing Goal of 100.e9 with 3eV·sec

Today

| CY | 1999 | | | 2000 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Oct | Nov | Dec | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. |
| Proton Source | | M&D | Operation | | M&D | Operation | | | | | M&D | |
| Main Injector | | M&D | Operation | | M&D | Operation | | | | | M&D | Run II Commissioning Run |
| Recycler | | Bake out | Installation and Commissioning | | M&D | Commissioning | Engineering Run | | | | M&D | |
| Pbar Source | | M&D | Commissioning a) | E835 Run | M&D | E835 Run | c) | | | | E-835 Removal | |
| Tevatron | | 1 TeV test | Operation | b) | Changeover to Collider Configuration | | Run II Engineering Run | | | | Detector Roll-in | |
| Switchyard | | M&D | Operation | 1/17 | OFF | | | | | | | |

Fixed Target

More 1 TeV testing

We don't expect many Pbars to be available. Mainly proton only!

At least one 36x36 store before CDF rolls in

CDF (no Silicon)

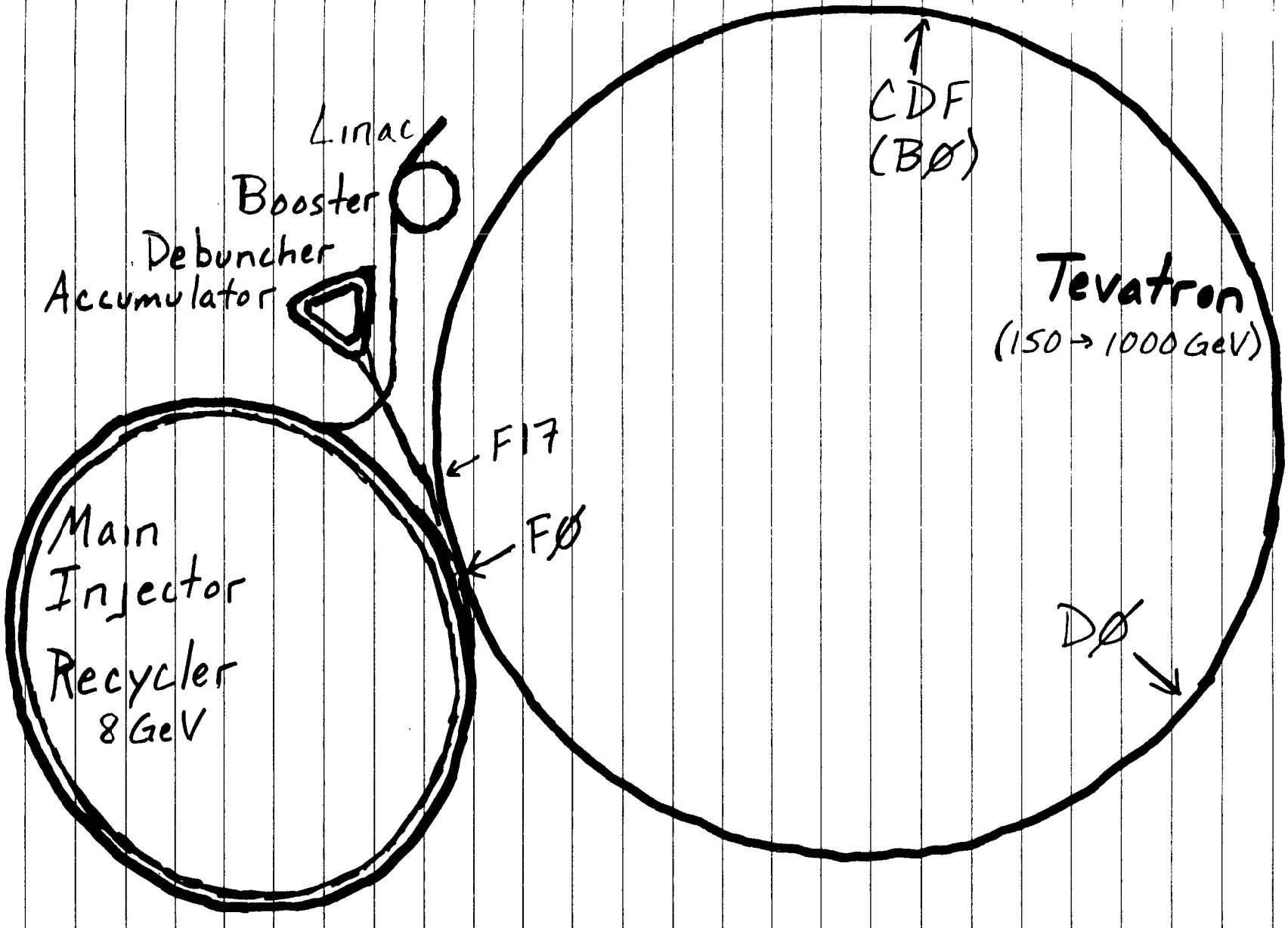
a) Band 1 [redacted] installation and E835 installation

b) [redacted] KAMI Test

c) Operation for Pbar Source Commissioning, Recycler Engineering Run, and parasitic Run of E835

| CY | 2000 | | | 2001 | | |
|---|---|---|---|---|---|---|
| Month | Oct. | Nov. | Dec. | Jan. | Feb. | March |
| Proton Source | Run II Comm. Run | M&D/Studies/Commissioning | | | | Run II |
| Main Injector | | M&D/Studies/Commissioning | | | | |
| Recycler | | M&D/Studies/Commissioning | | | | |
| Pbar Source | | M&D/Studies/Commissioning | | | | |
| Tevatron | | CDF Roll-out & Roll-in and D0 Roll-in | | | | |
| Switchyard | OFF | | | | | |

# Run II Configuration (Late 1998 → )



# Initial Run II - Lots of Uncertainties



Main Injector replaces the Main Ring
- about half the size $\left(\frac{588}{1113}\right)$ of the Main Ring and Tevatron
- Pbar production cycle has minimum length of 1.5 sec
- Should increase intensity to about 4.e12
- Coalesced proton intensity stays at about 270.e9
  (Set by "pbar tune shift limit)

Accumulator/Debuncher
- More beam, more often from MI
  - ⇒ Cooling systems have to be upgraded to keep up
    - Almost every cooling system is going to be changed.
- Accum. lattice changed.
- Target sweeping
- Stack to ≈ 40 e10 then transfer to Recycler
- Stacking goal is ≈ 20-60 e10 / hr
- ⇒ What stack rates will we get??

Recycler
- Permanent magnet pbar storage ring at 8 GeV.
- Sits above the Main Injector.
- Should allow us to recover and re-cool the pbars left at the end of a Tevatron store.
- Keeps the Accumulator at low stack sizes.
- Start with Stochastic Cooling, eventually use Electron Cooling
- ⇒ What will the recycling efficiency be??

# Tevatron Changes for Run II

Try to increase energy to 1 TeV. (≈ 30% in top production)

36 x 36 bunches (396 nsec bunch spacing)

Luminosity Leveling

Minor Lattice Change (remove Q1)

Faster Injection Kickers

Better tune measurement system

Should be able to watch pbar tunes

New Collimator System

New Damper Systems Transverse and Longitudinal

Many narrow band channels

Weak wide band system

Try for 30 min for shot setup

New system for collecting data as we are putting in a store.

New method of controlling the low $\beta$ squeeze

A New Feed down Sextupole Circuit (Differential Coupling)

Different Method for Bringing the Beams into Collision.

36 X 36

The increase in number of bunches is for the experiments to decrease the number of interactions per crossing.

No crossing angle.

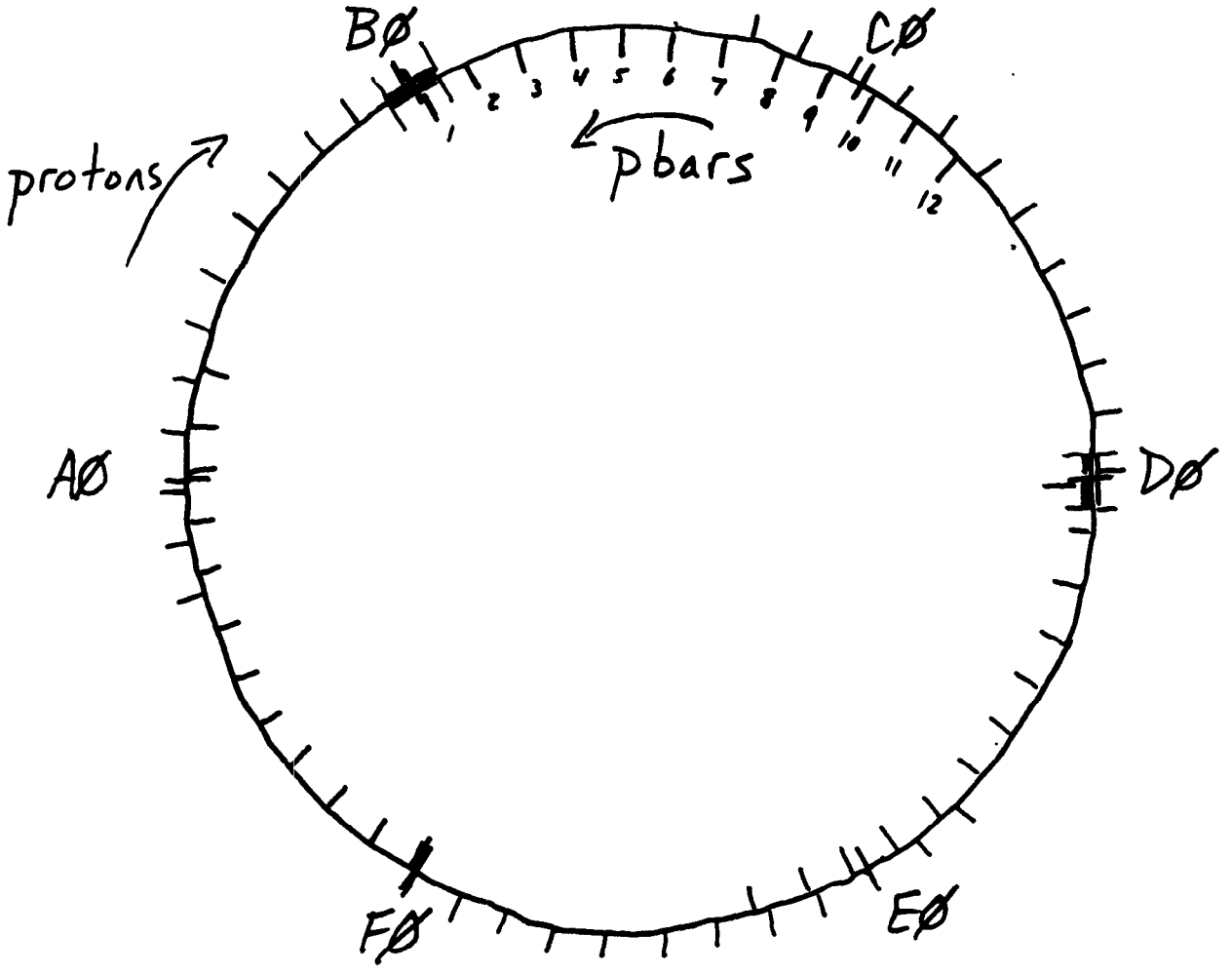
3 trains of 12 bunches

trains are separated by abort gaps of 2.6 μsec

Within a train, bunches are separated by 396 nsec

Maybe 46 x 42 ?

36 x 30




3 "trains" of 12 bunches
(396 nsec = 21 RF bucket) bunch to bunch spacing
Abort gap between "trains" of 2.617 μsec = 139 RF bucket.

Different bunches in a train encounter the opposing beam at different places in the ring.

At the end of a store, we [illegible] and start setting up for the next store.

1) Take the beams out of collision

2) Quickly remove the 36 * (240.e9) = 8.6e12 protons without quenching!
   Special dogleg using conventional magnets
   Collimator within the dogleg to scrape away the protons.
   Local loss monitors to control the speed of the collimators.

3) Turn off helix - turn off all separators

4) Un squeeze - Go back to the injection lattice

5) Decelerate from 1 TeV to 150 GeV
   Problems at 150 GeV with persistent currents.
   We'll have to compensate these better
   They change most rapidly when we first get to 150 GeV.
   Depend on the machine history.
   Also have to compensate hysteresis.

6) Extract pbars to Main Injector

7) In the Main Injector, decelerate pbars from 150 GeV to 8 GeV

8) Transfer them to Recycler

After a store, we used to do 6 ramps to reset all the fields and put us back on the same hysteresis curve.

There won't be time for this anymore.

150 GeV lifetime

It was troublesome before with only 12 crossings, now we'll have 72 crossings.

Greatly reduced chromaticities should help.

This relies on the new damper systems and better control/understanding of the persistent current effects.

We should be able to increase the separation somewhat.

Probably can increase vertical by factor of 2

" " " horizontal by 20% to 30%

Transition from the "Injection" to the "Collision" Helix

Bringing the beams into collision

Once we go to the "collision" helix, there is no cogging (no relative longitudinal placement of protons and pbars) where some bunches don't collide.

Go to collision helix + separation bumps at the IP's

When the squeeze is over, collapse the separation bumps and bring the beams into collision transversely.

Collision Conditions

By coincidence, the spacing between crossing points is almost exactly the cell length.

The phase advances between near misses will be very nearly the same for many of the near misses.

The horiz. and vert. separations change from crossing point to crossing point.

How they change is closely related to the phase advances.

First near misses on either side of the IPs.

Steve Holmes' parameter list



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Table I.1: Luminosity performance goals for Run II, both with and without the Recycler ring. The leftmost column shows parameters typical of the last collider run, Run IB. The middle column shows expected performance following the Main Injector upgrade, in the absence of the antiproton Recycler. The rightmost column shows expected performance based on operations of the Main Injector and Recycler. This report uses normalized emittances containing 95% of the beam. The horizontal and vertical emittances are assumed equal.

| RUN | IB (1993-95) | II (MI) | II (MI+ Recycler) | |
|---|---|---|---|---|
| Protons/bunch | $2.32\times10^{11}$ | $2.70\times10^{11}$ | $2.70\times10^{11}$ | |
| Antiprotons/bunch | $5.50\times10^{10}$ | $3.00\times10^{10}$ | $7.00\times10^{10}$ | |
| Total Antiprotons | $3.30\times10^{11}$ | $1.30\times10^{12}$ | $2.5\times10^{12}$ | |
| Pbar Production Rate | $6.00\times10^{10}$ | $1.70\times10^{11}$ | $2.00\times10^{11}$ | pbar/hour |
| Proton emittance | $23\pi$ | $20\pi$ | $20\pi$ | mm-mr |
| Antiproton emittance | $13\pi$ | $15\pi$ | $15\pi$ | mm-mr |
| $\beta^*$ | 0.35 | 0.35 | 0.35 | m |
| Energy | 900 | 1000 | 1000 | GeV |
| Bunches | 6 | 36 | 36 | |
| Bunch length (rms) | 0.60 | 0.43 | 0.38 | m |
| Form Factor | 0.59 | 0.70 | 0.70 | |
| | | | | |
| Typical Luminosity | $1.6\times10^{31}$ | $8.1\times10^{31}$ | $2.0\times10^{32}$ | $cm^{-2}sec^{-1}$ |
| | | | | |
| Integrated Luminosity | 3.2 | 16.3 | 41.0 | $pb^{-1}$/week |
| Bunch Spacing | ~3500 | 396 | 396 | nsec |
| Interactions/crossing | 2.7 | 2.3 | 5.8 | |
| (@ 50 mb) | | | | |
| | | | | |
| Pbar tune shift (HO) | 0.015 | 0.020 | 0.020 | |
| Proton tune shift (HO) | 0.006 | 0.003 | 0.007 | |

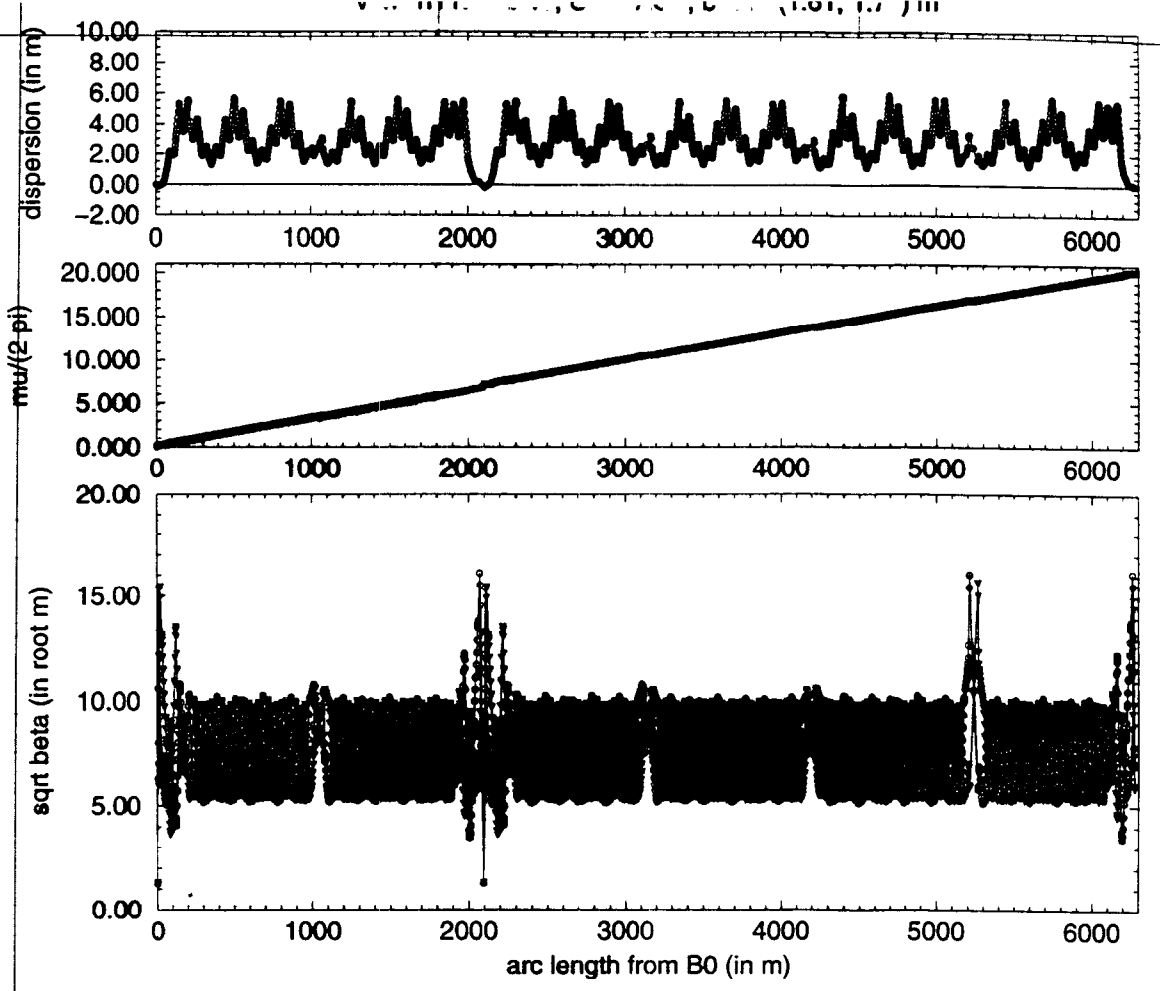
*Typical luminosity at the beginning of a store--translates to integrated luminosity with a 33% duty factor

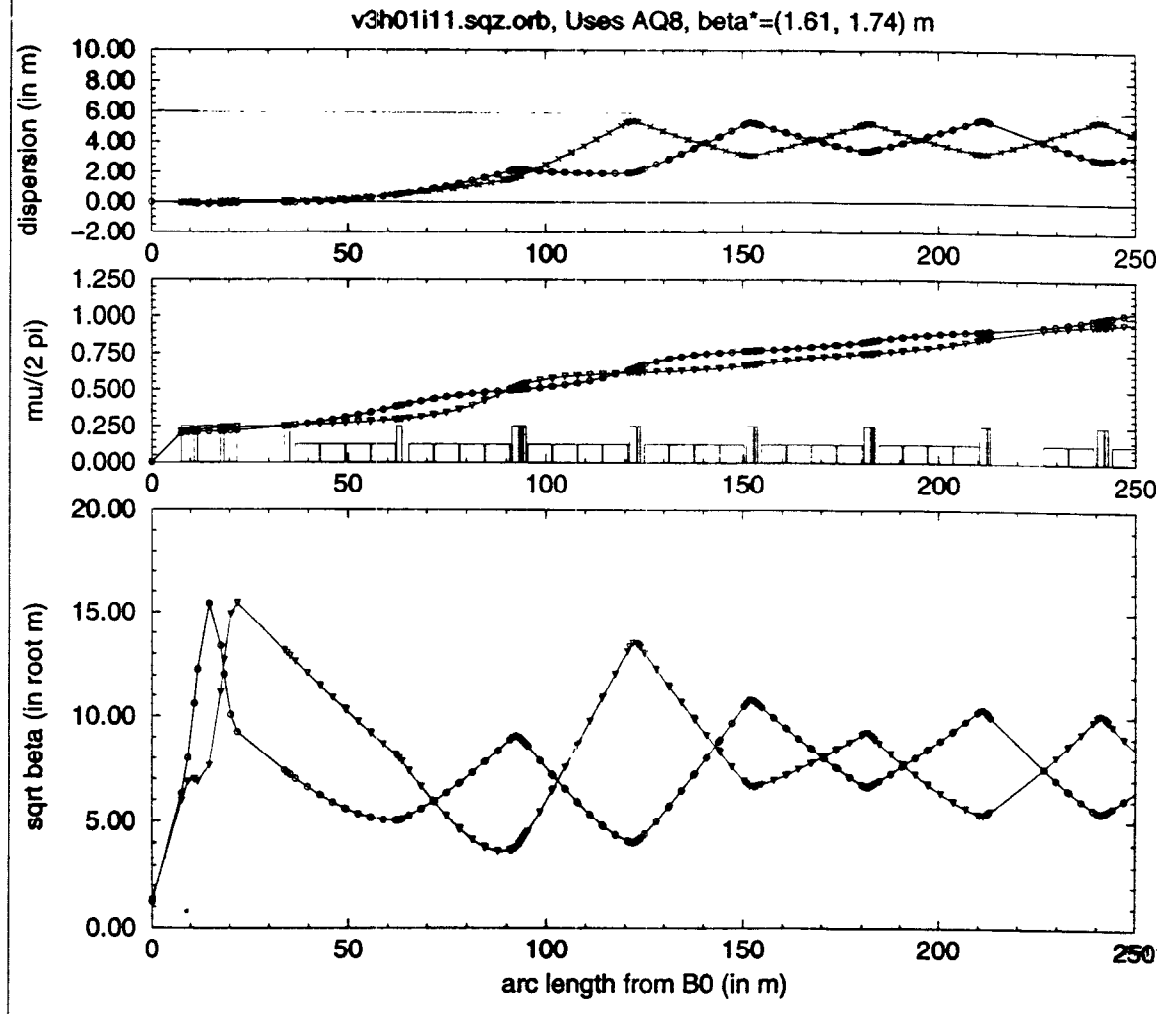
Injection Conditions

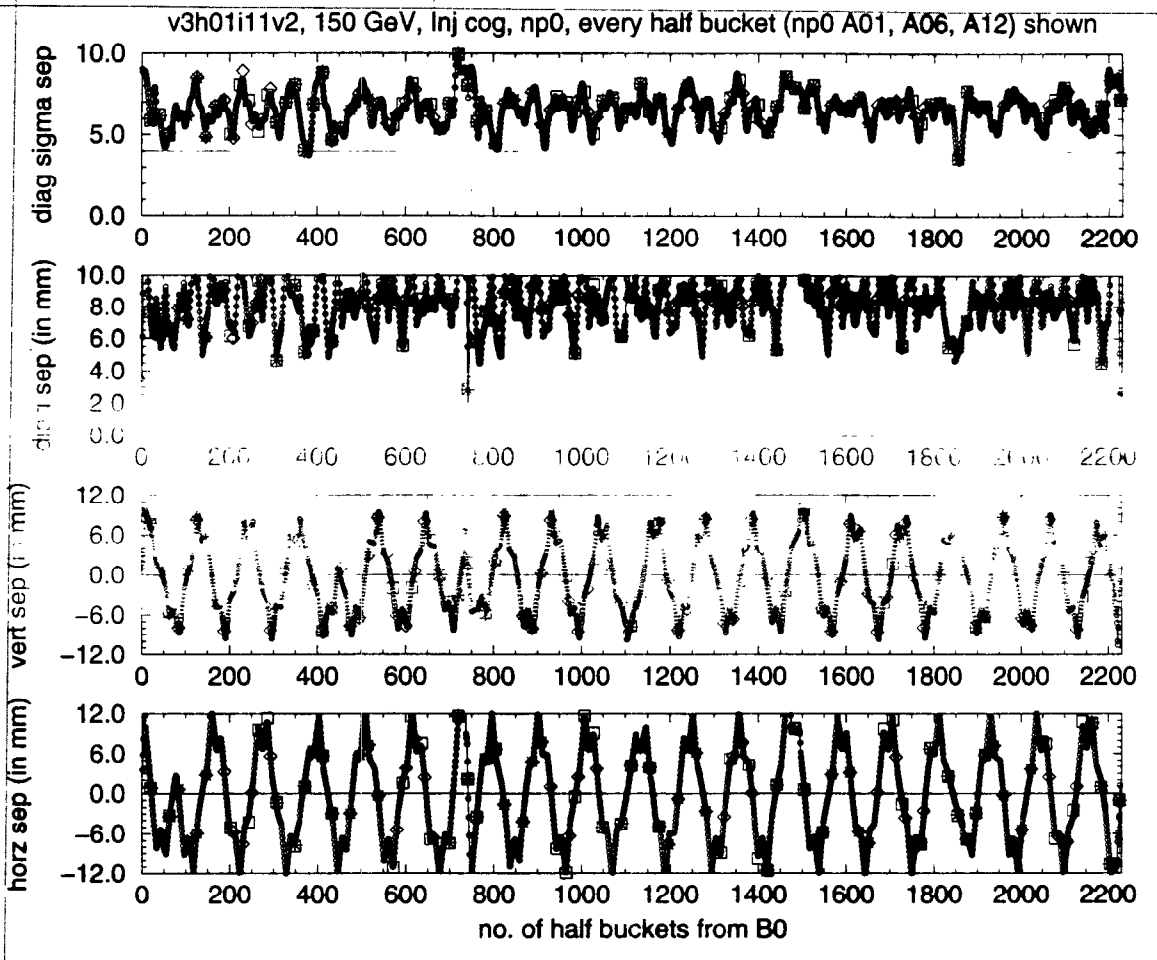
150 GeV

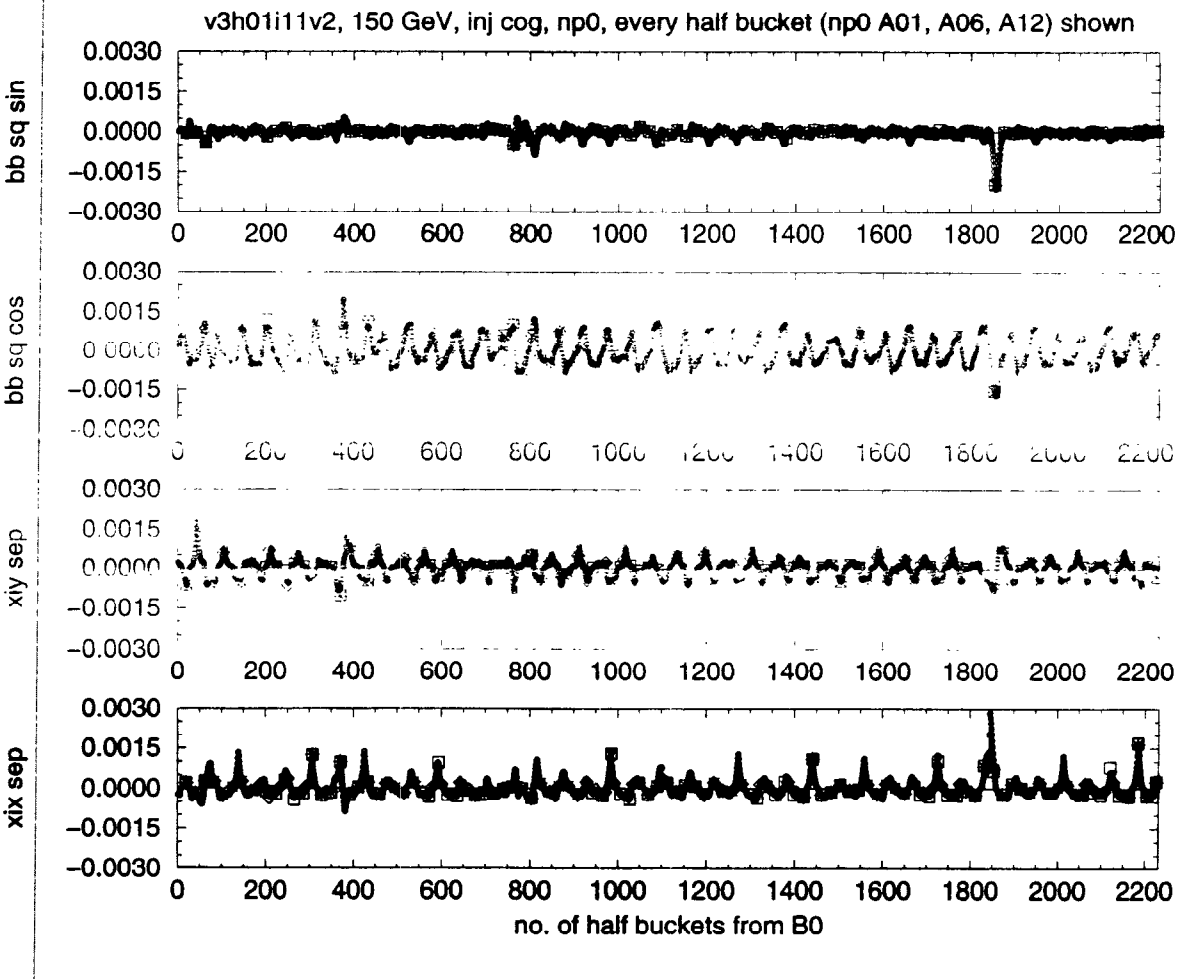
Inj Lattice

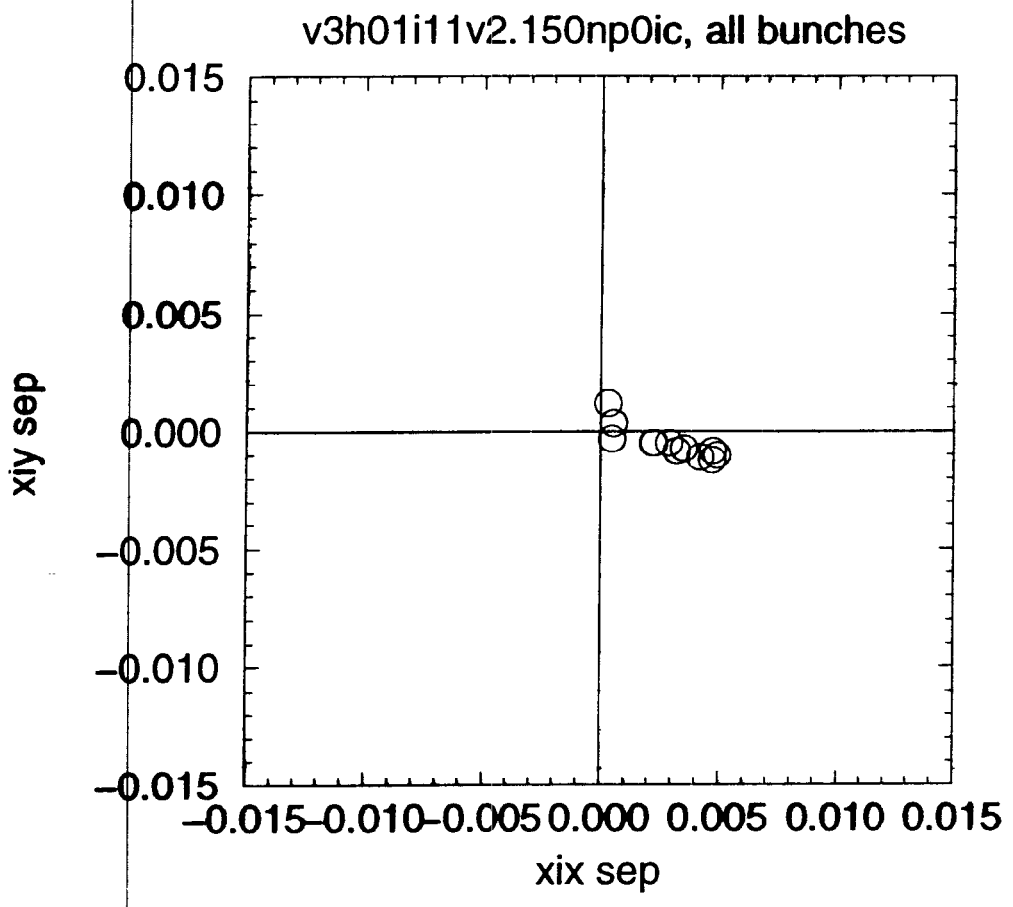
Inj Helix

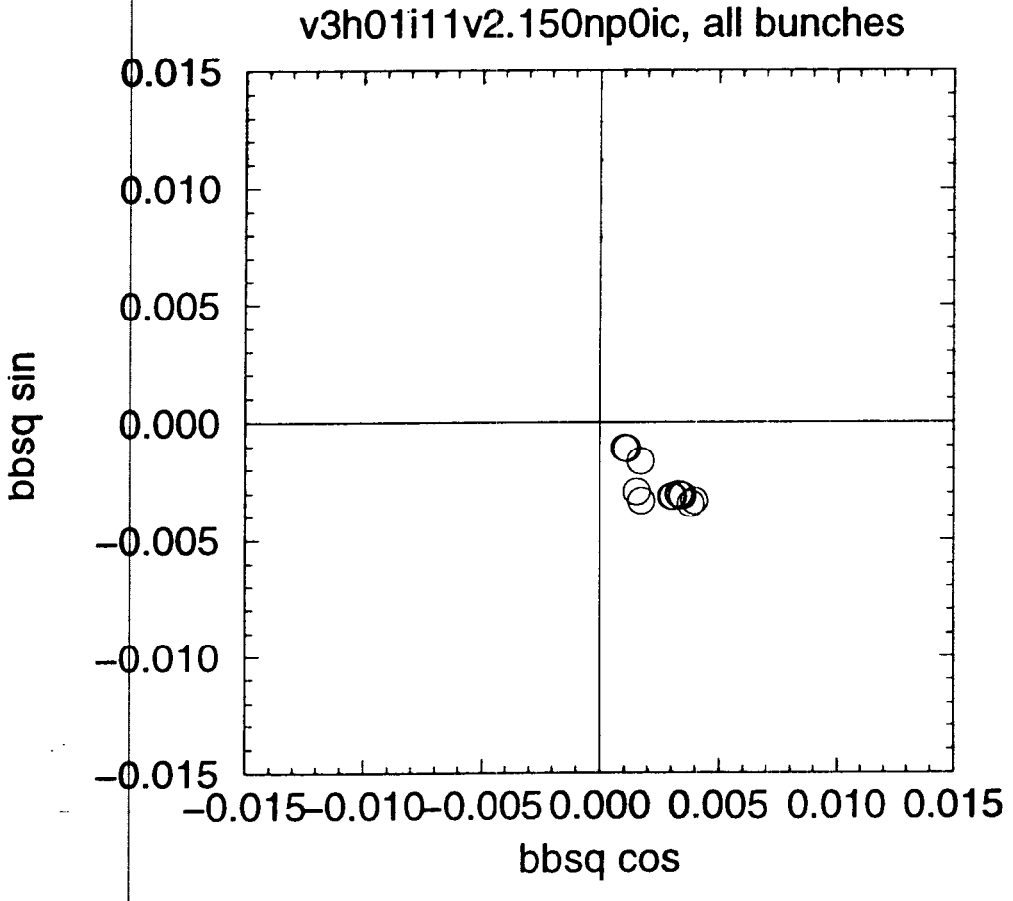

dispersion (in m)
mu/(2 pi)
sqrt beta (in root m)
arc length from B0 (in m)

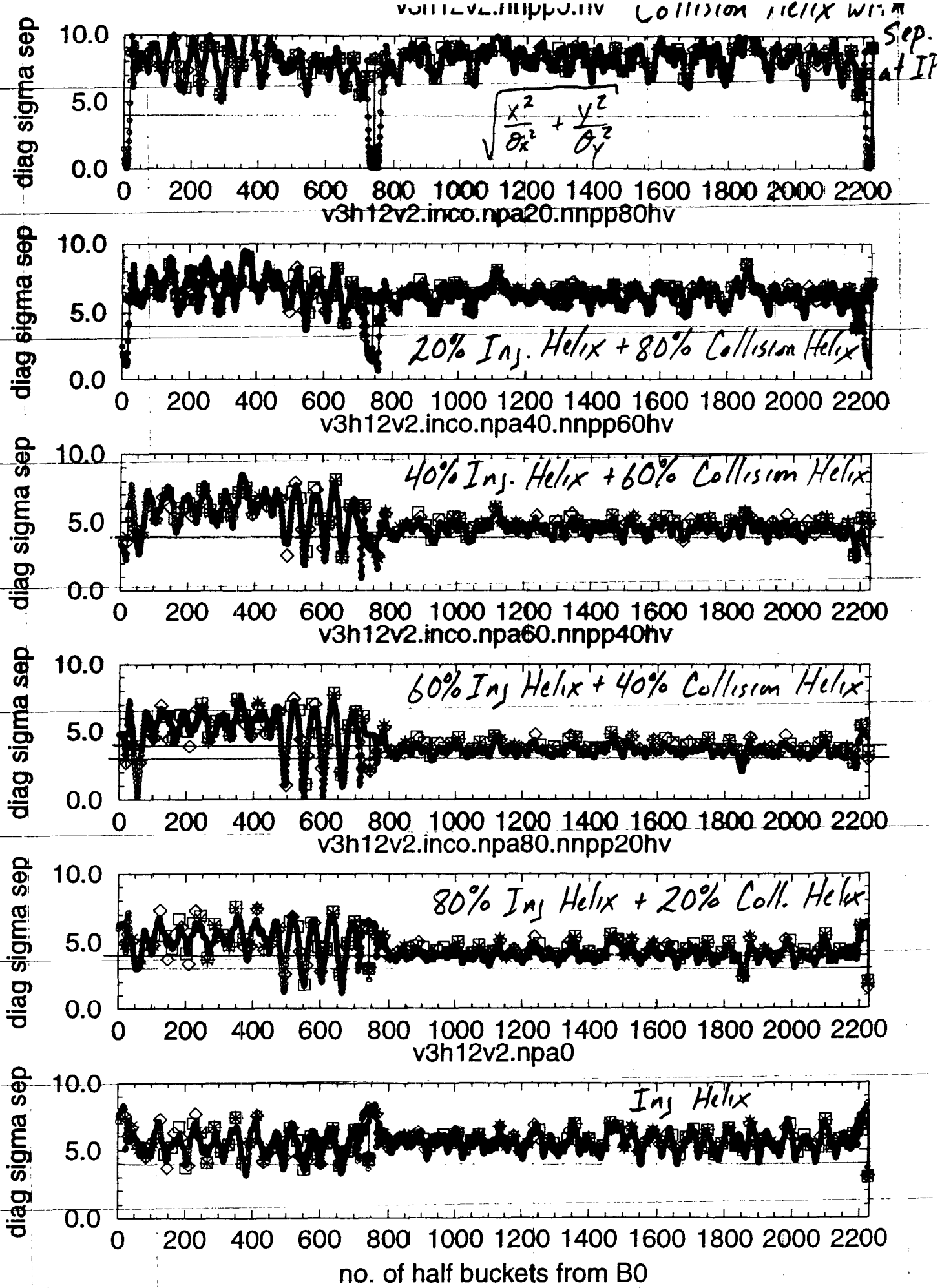

v3h01i11.sqz.orb, Uses AQ8, beta*=(1.61, 1.74) m
dispersion (in m)
mu/(2 pi)
sqrt beta (in root m)
arc length from B0 (in m)

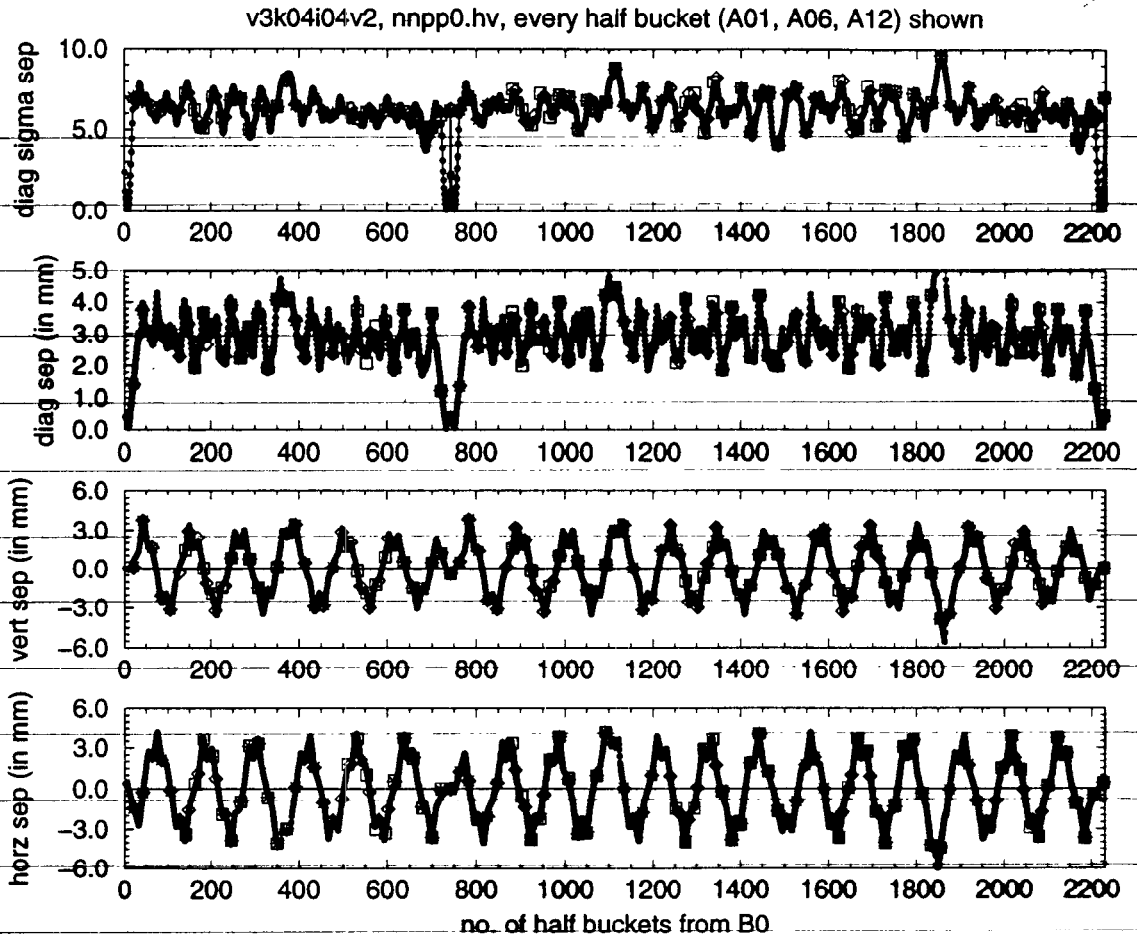

v3h01i11v2, 150 GeV, Inj cog, np0, every half bucket (np0 A01, A06, A12) shown
diag sigma sep
diag sep (in mm)
vert sep (in mm)
horz sep (in mm)
no. of half buckets from B0

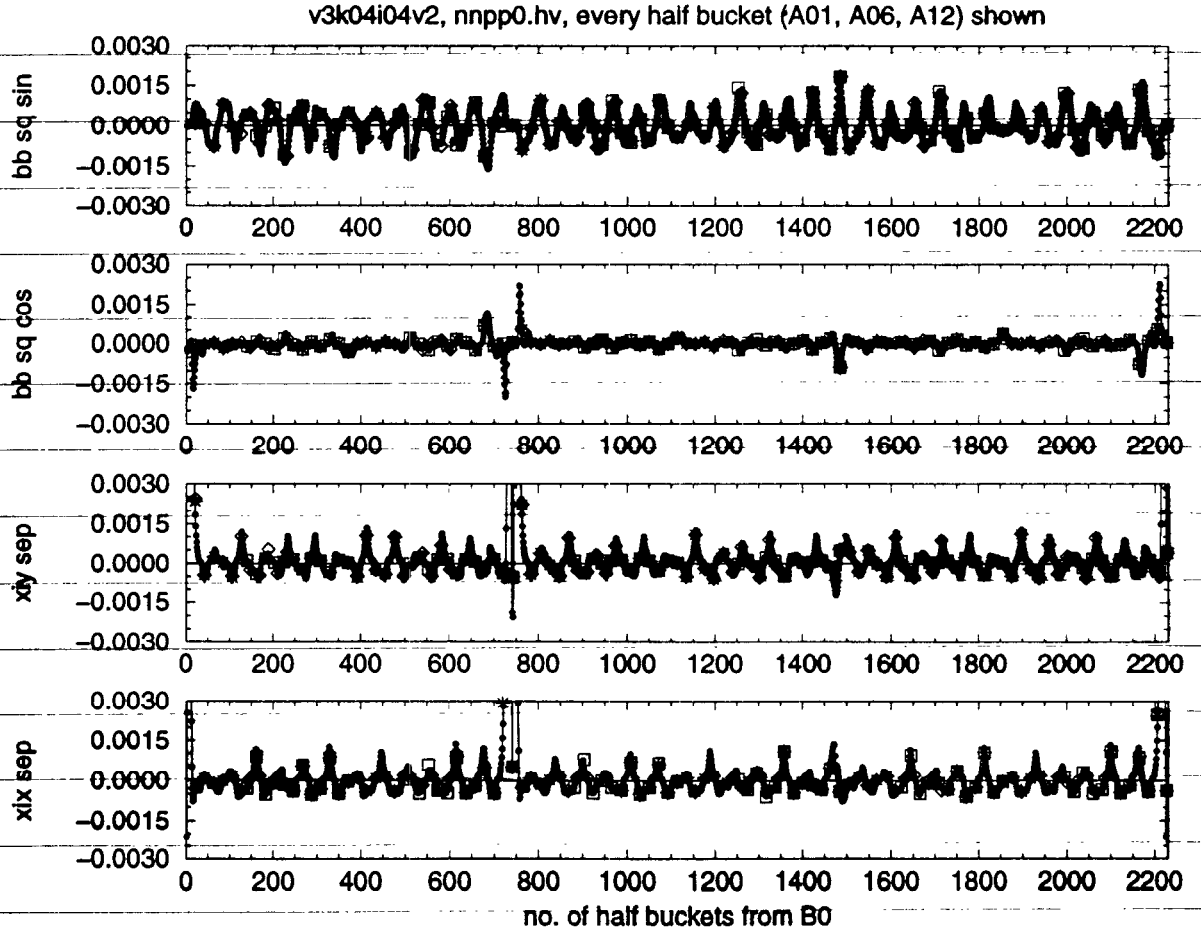

v3h01i11v2, 150 GeV, inj cog, np0, every half bucket (np0 A01, A06, A12) shown
bb sq sin
bb sq cos
xiy sep
xix sep
no. of half buckets from B0


v3h01i11v2.150np0ic, all bunches
0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
xiy sep
−0.015 −0.010 −0.005 0.000 0.005 0.010 0.015
xix sep


v3h01i11v2.150np0ic, all bunches
0.015
0.010
0.005
0.000
−0.005
−0.010
−0.015
bbsq sin
−0.015 −0.010 −0.005 0.000 0.005 0.010 0.015
bbsq cos

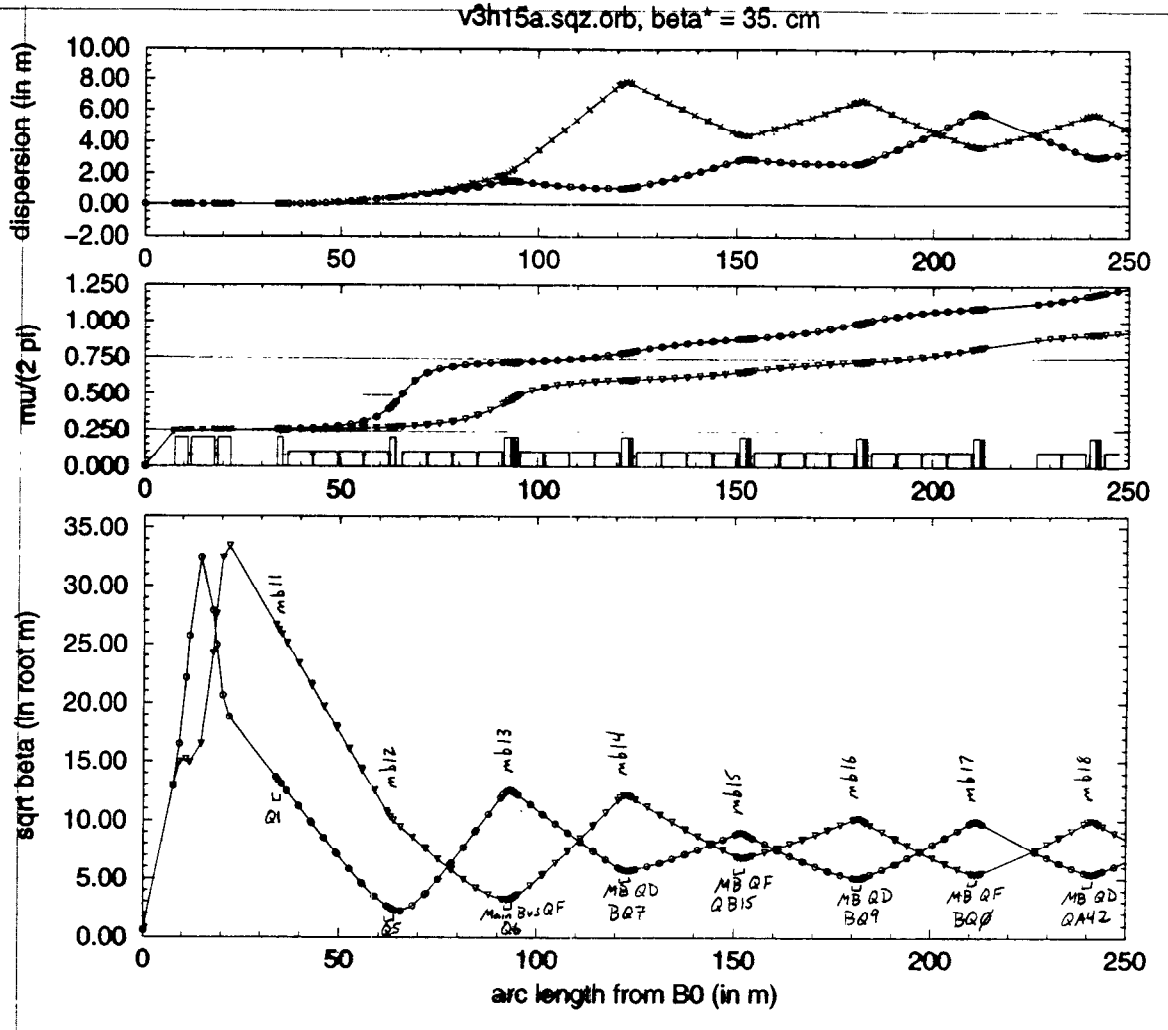

v3h12v2.nnpp0.hv
Collision Helix with Sep. at IP
diag sigma sep
10.0
5.0
0.0
$\sqrt{\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}}$
0 200 400 600 800 1000 1200 1400 1600 1800 2000 2200
v3h12v2.inco.npa20.nnpp80hv
20% Inj. Helix + 80% Collision Helix
v3h12v2.inco.npa40.nnpp60hv
40% Inj. Helix + 60% Collision Helix
v3h12v2.inco.npa60.nnpp40hv
60% Inj Helix + 40% Collision Helix
v3h12v2.inco.npa80.nnpp20hv
80% Inj Helix + 20% Coll. Helix
v3h12v2.npa0
Inj Helix
no. of half buckets from B0

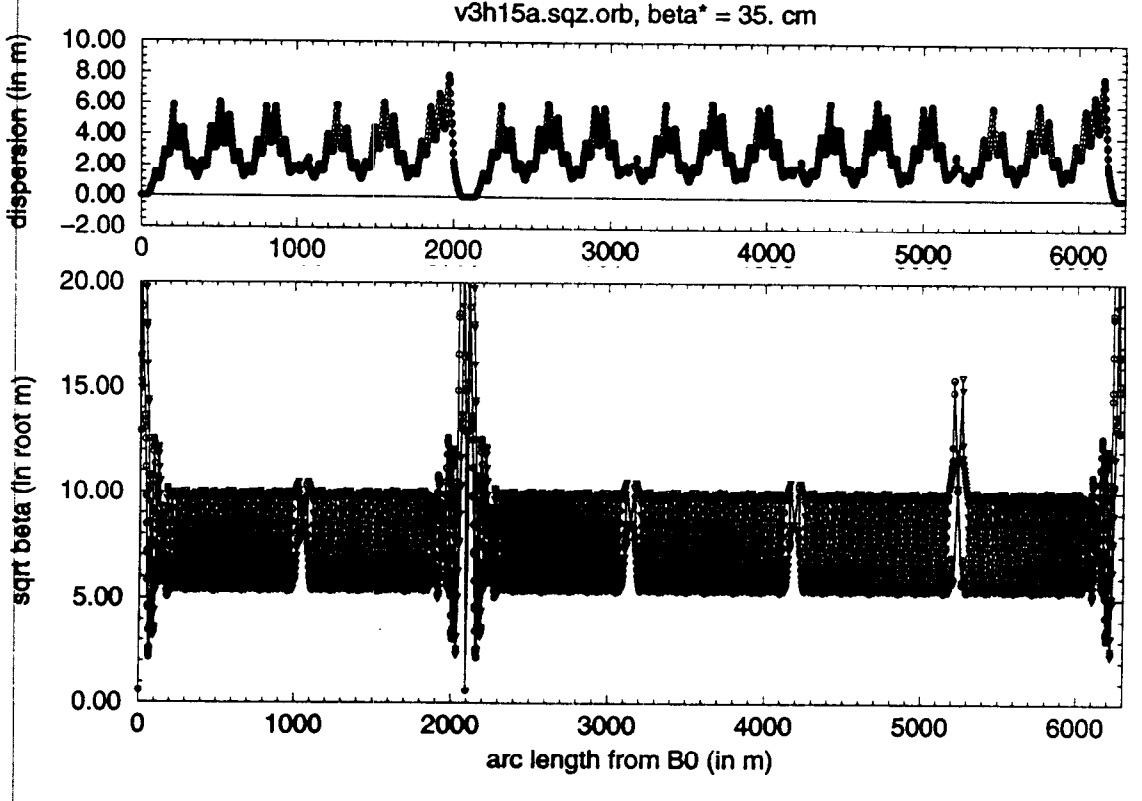

v3k04i04v2, nnpp0.hv, every half bucket (A01, A06, A12) shown
diag sigma sep
diag sep (in mm)
vert sep (in mm)
horz sep (in mm)
no. of half buckets from B0


v3k04i04v2, nnpp0.hv, every half bucket (A01, A06, A12) shown
bb sq sin
bb sq cos
xiy sep
xix sep
no. of half buckets from B0

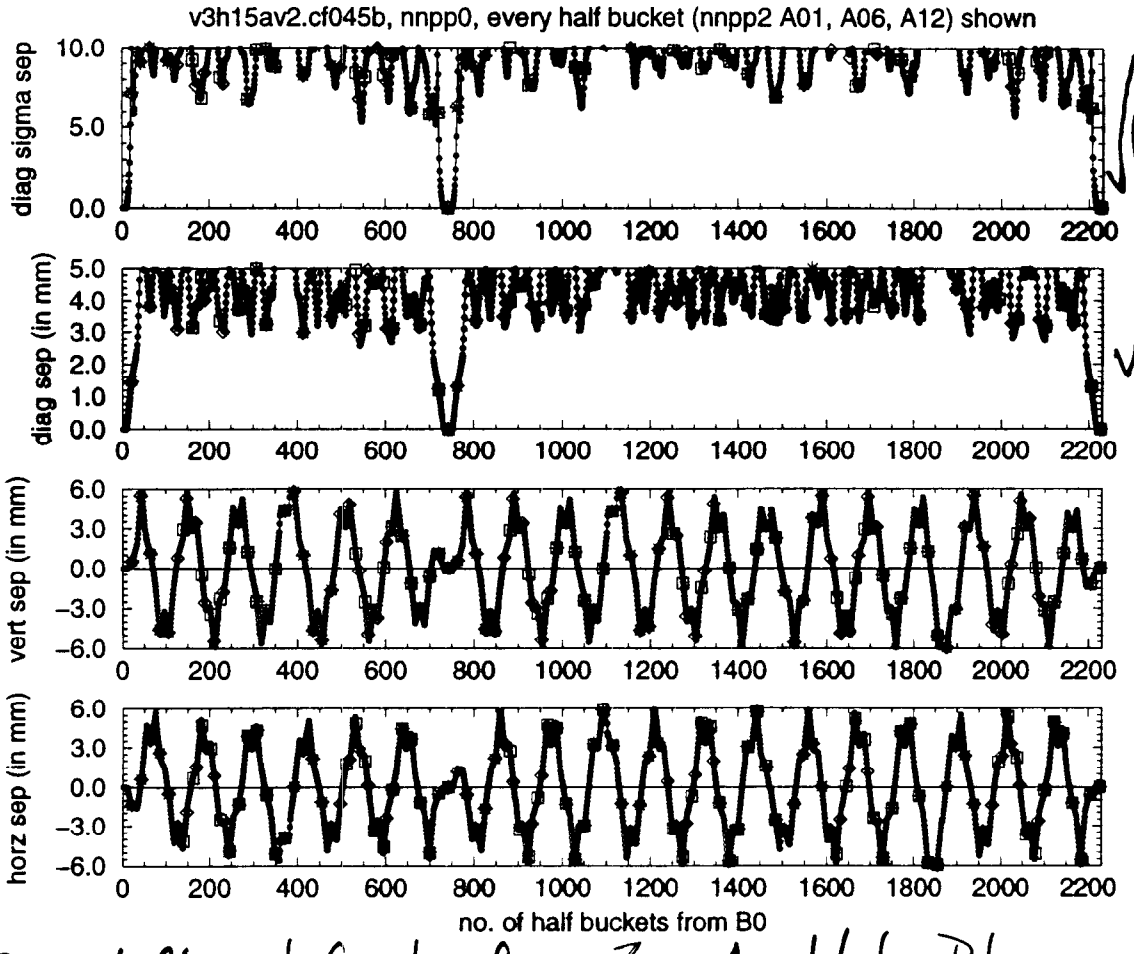
Beam Beam Calc.
for v3h15av2.cf045b

New versions for Tev Group talk
12/2/99


v3h15a.sqz.orb, beta* = 35. cm
dispersion (in m)
mu/(2 pi)
sqrt beta (in root m)
arc length from B0 (in m)
mb11
mb12
mb13
mb14
mb15
mb16
mb17
mb18
Q1
Q5
Q6
BQ7
QB15
BQ9
BQØ
QA42


v3h15a.sqz.orb, beta* = 35. cm
dispersion (in m)
sqrt beta (in root m)
arc length from B0 (in m)

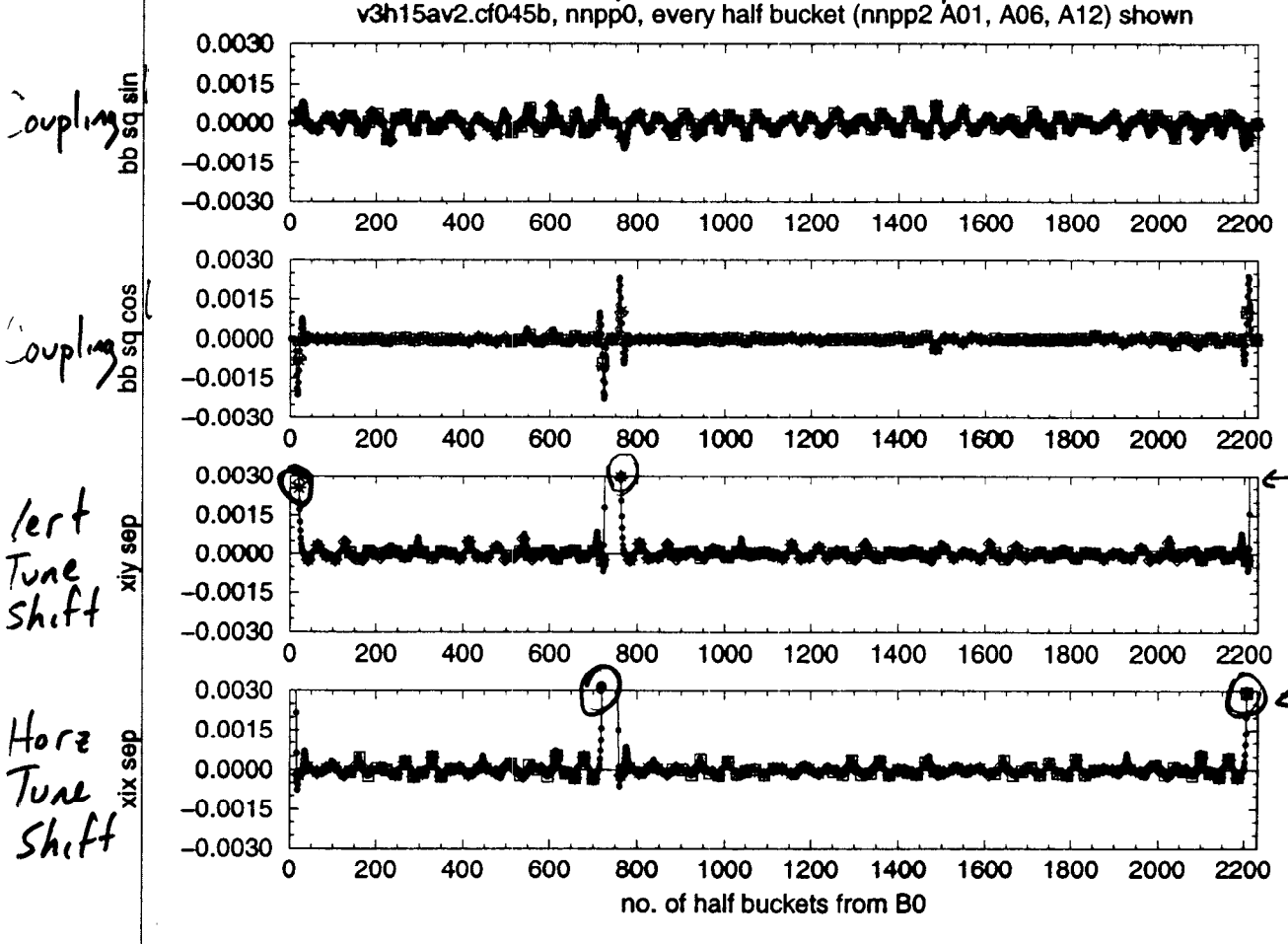
1 leV, 2UM, .06 le




$$\sqrt{\left(\frac{x}{\sigma_x}\right)^2 + \left(\frac{y}{\sigma_y}\right)^2}$$

$$\sqrt{x^2 + y^2}$$

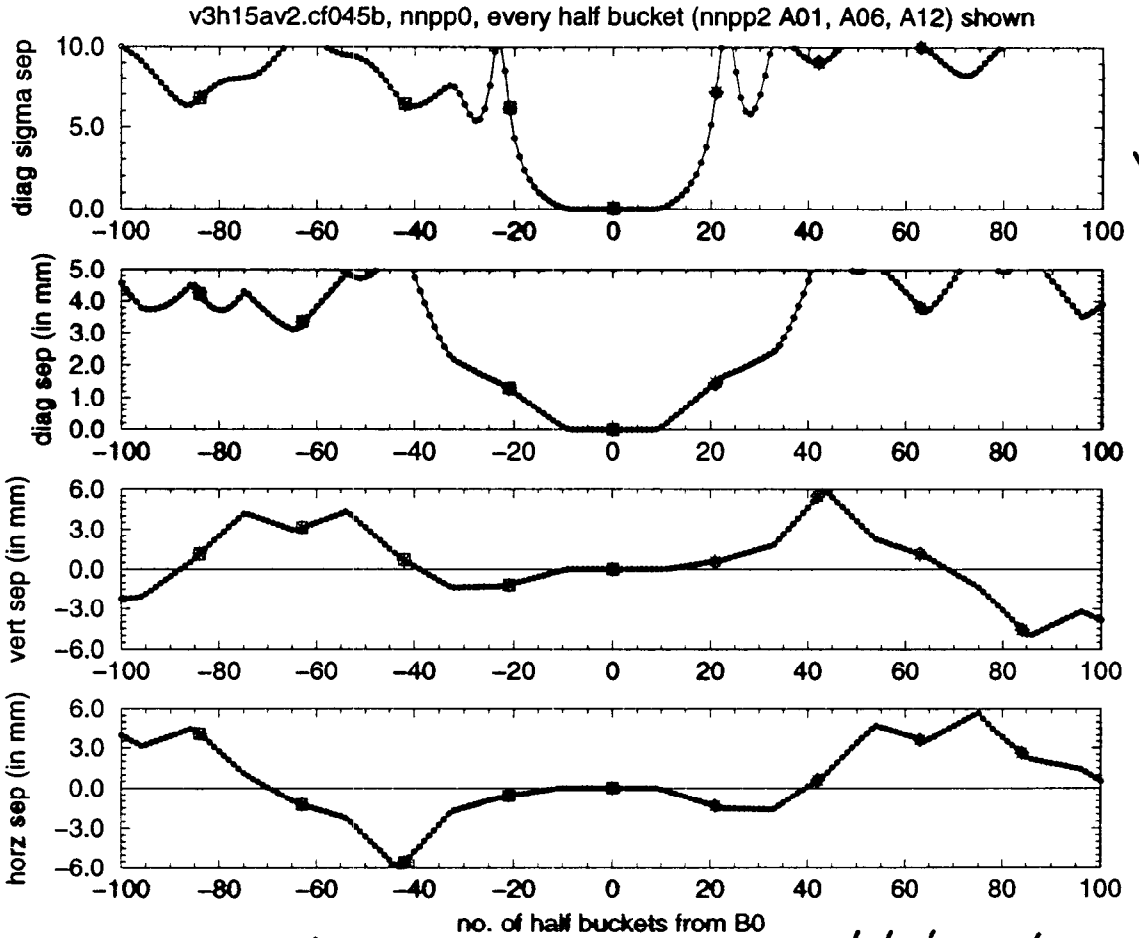
Tune shifts and Coupling for a Zero Amplitude Pbar




← A01 doesn't see these

← A12 doesn't see these.

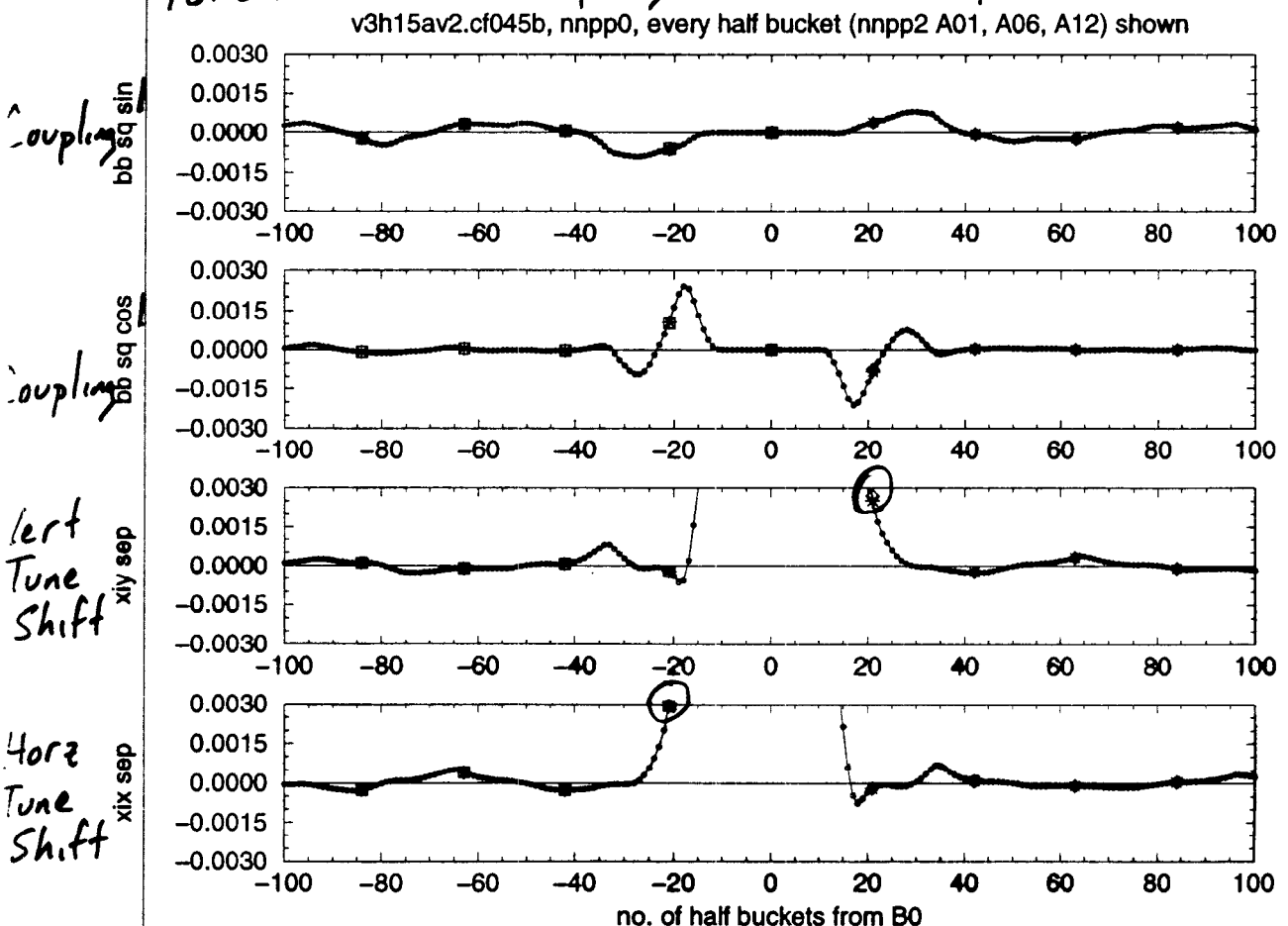
1 TeV, 20μ, 0.01e-

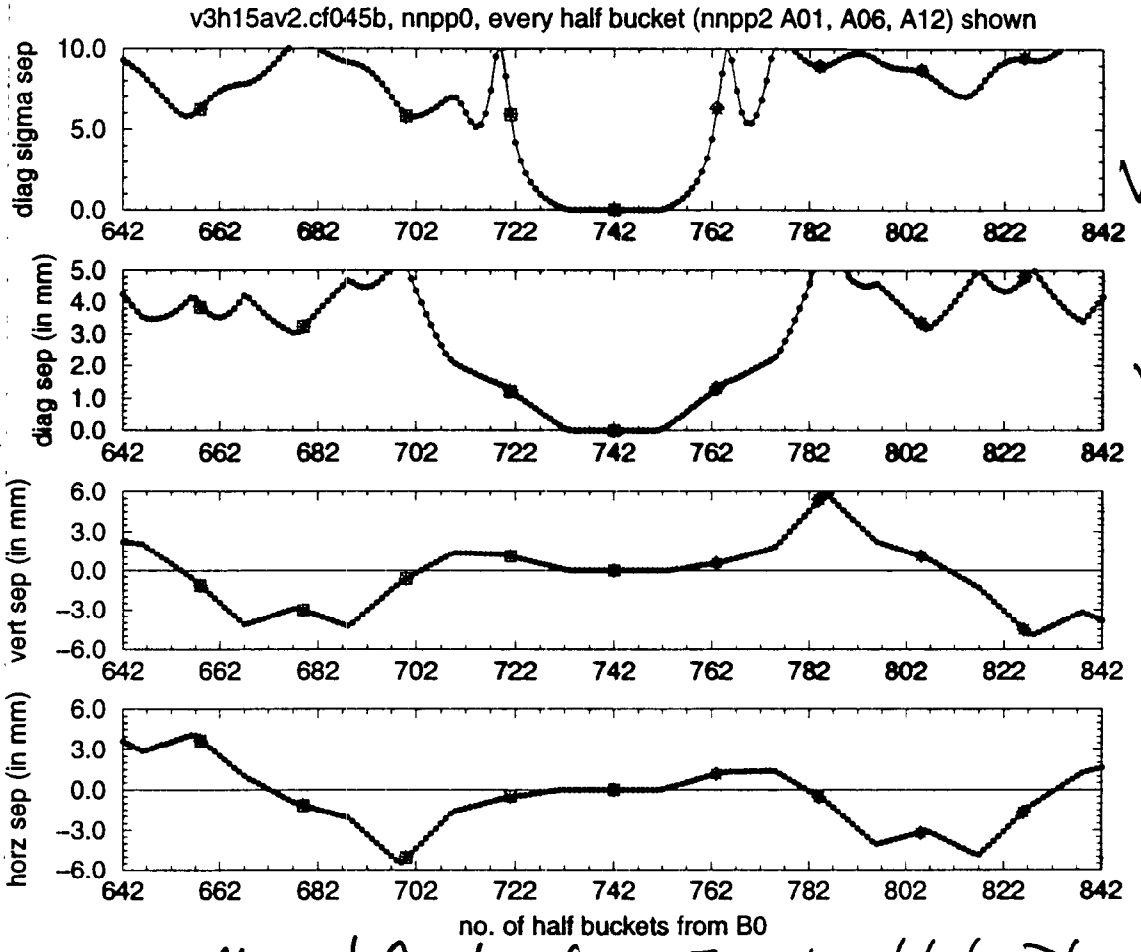



$$\sqrt{\left(\frac{x}{\sigma_x}\right)^2+\left(\frac{y}{\sigma_y}\right)^2}$$

$$\sqrt{x^2+y^2}$$

Tune Shifts and Coupling for a Zero Amplitude Pbar

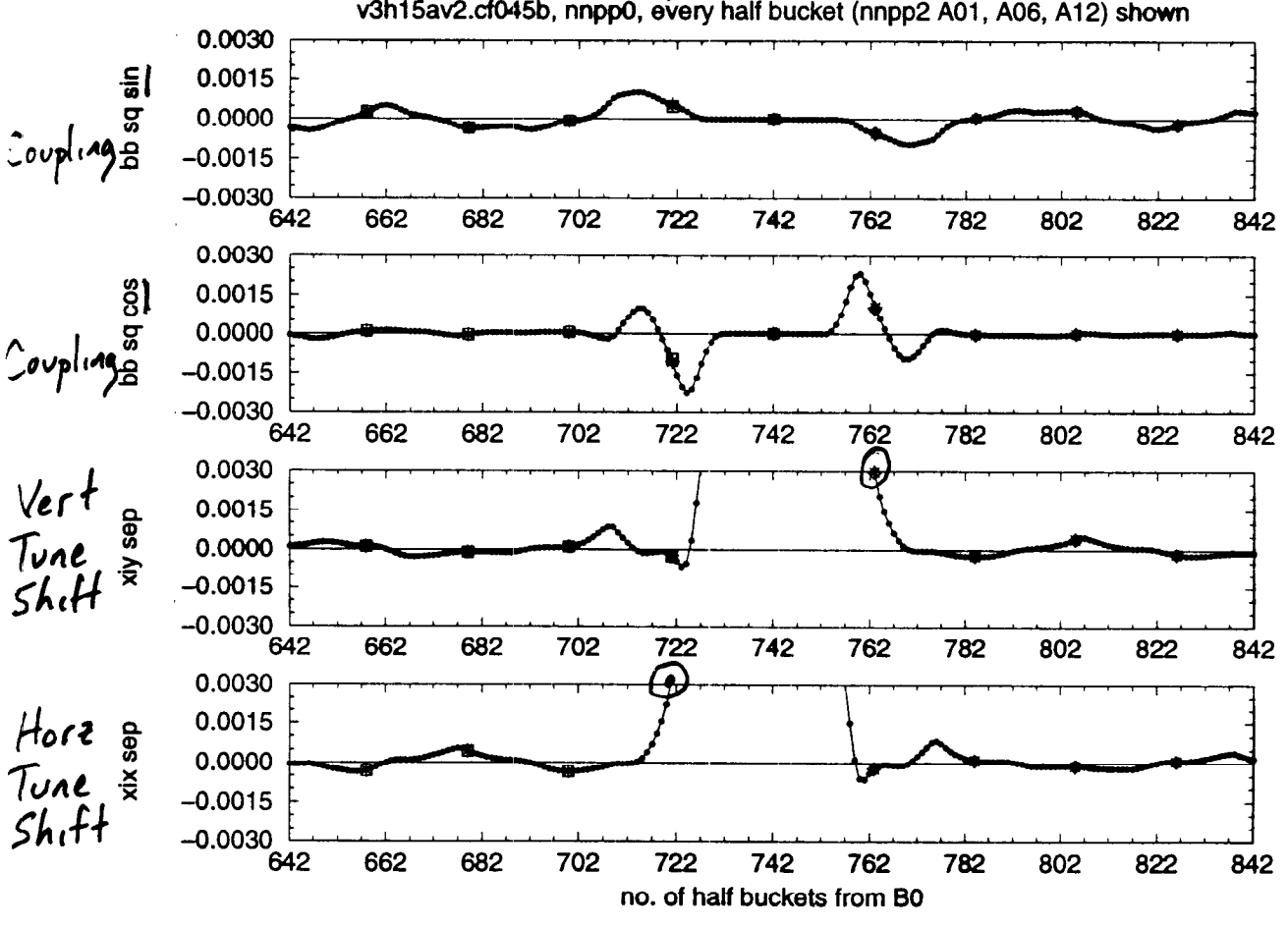


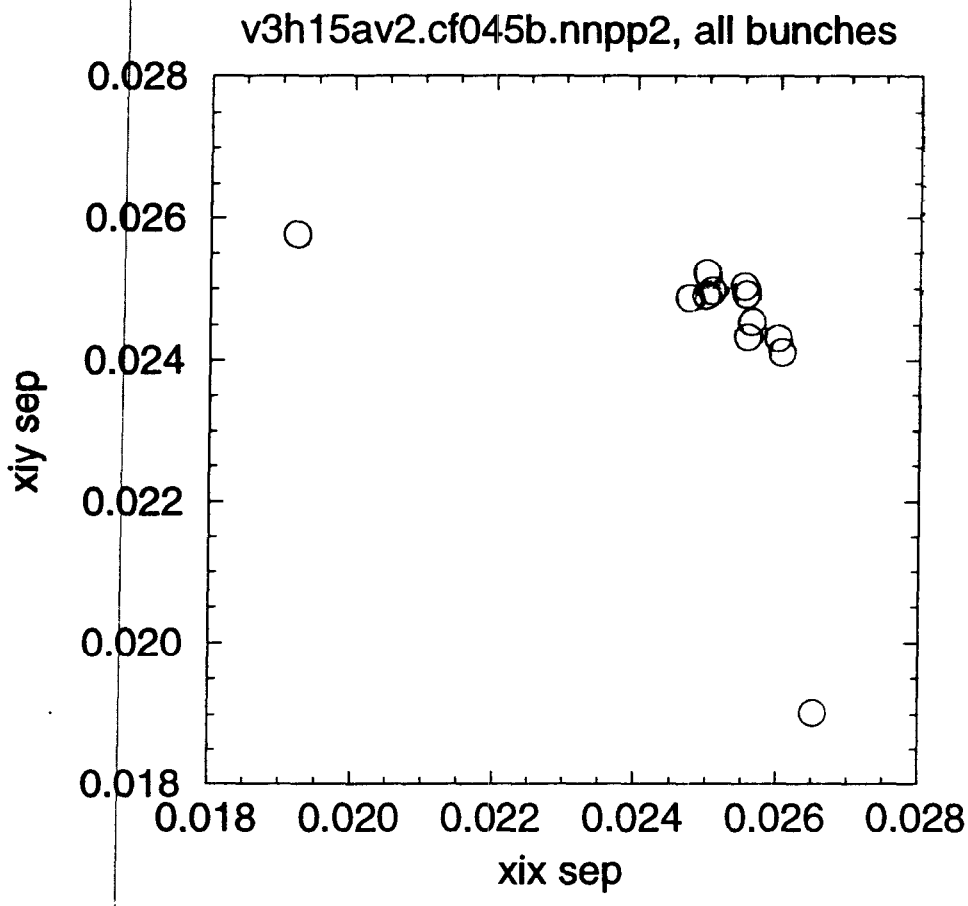


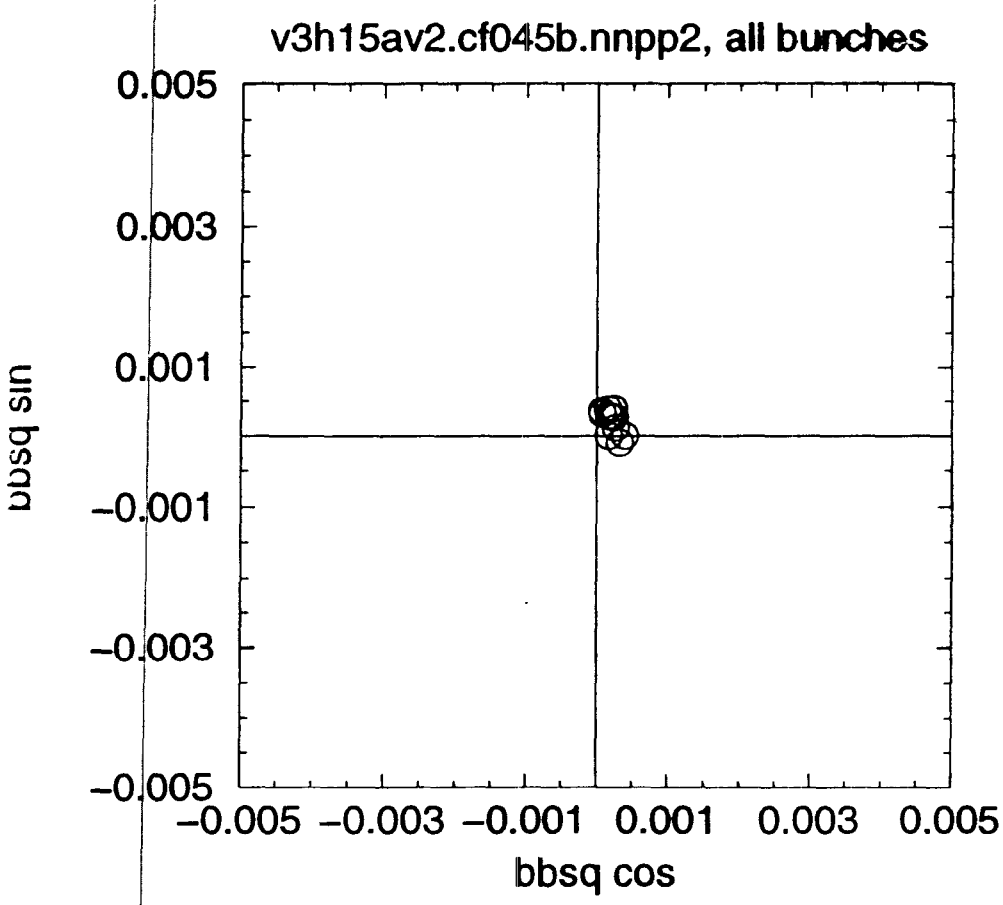

$$\sqrt{\left(\frac{x}{\sigma_x}\right)^2+\left(\frac{y}{\sigma_y}\right)^2}$$

$$\sqrt{x^2+y^2}$$

# Tune Shifts and Coupling for a Zero Amplitude Pbar

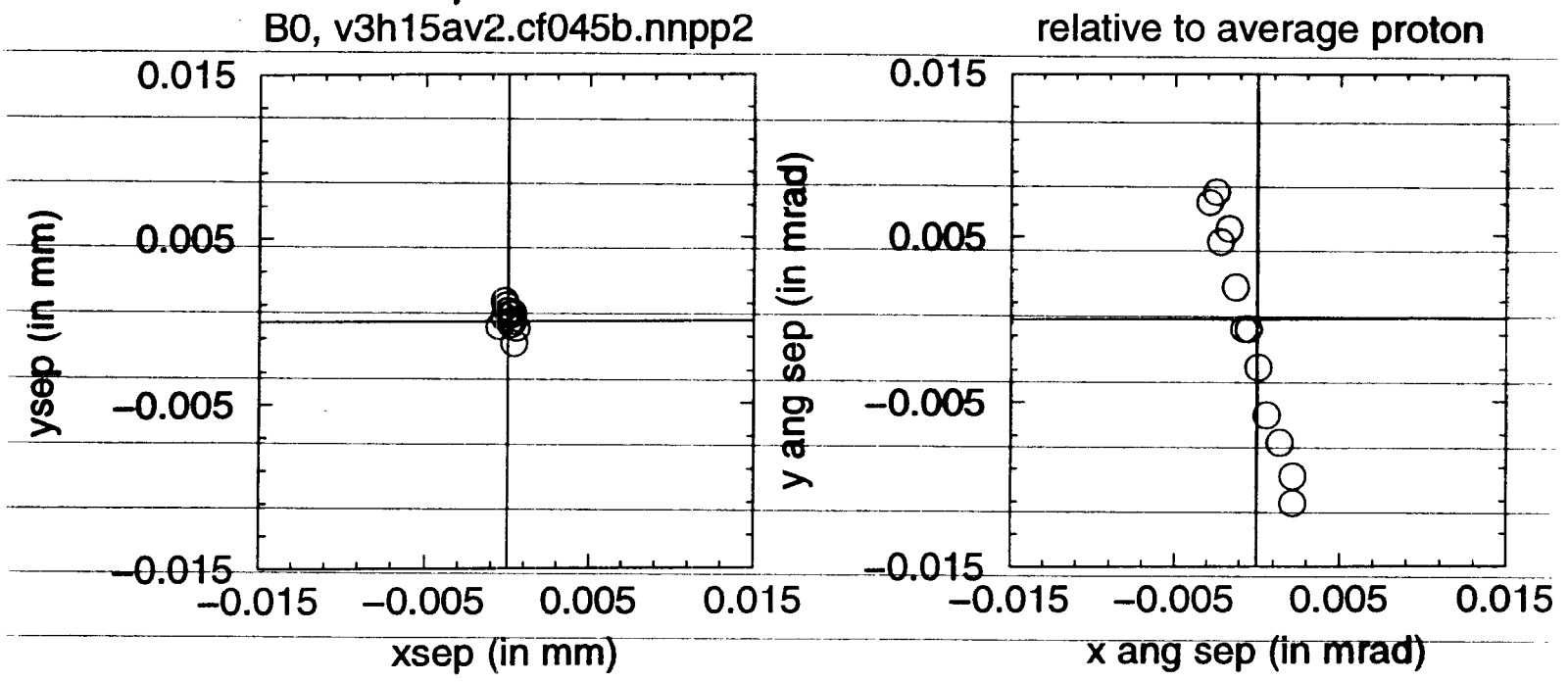


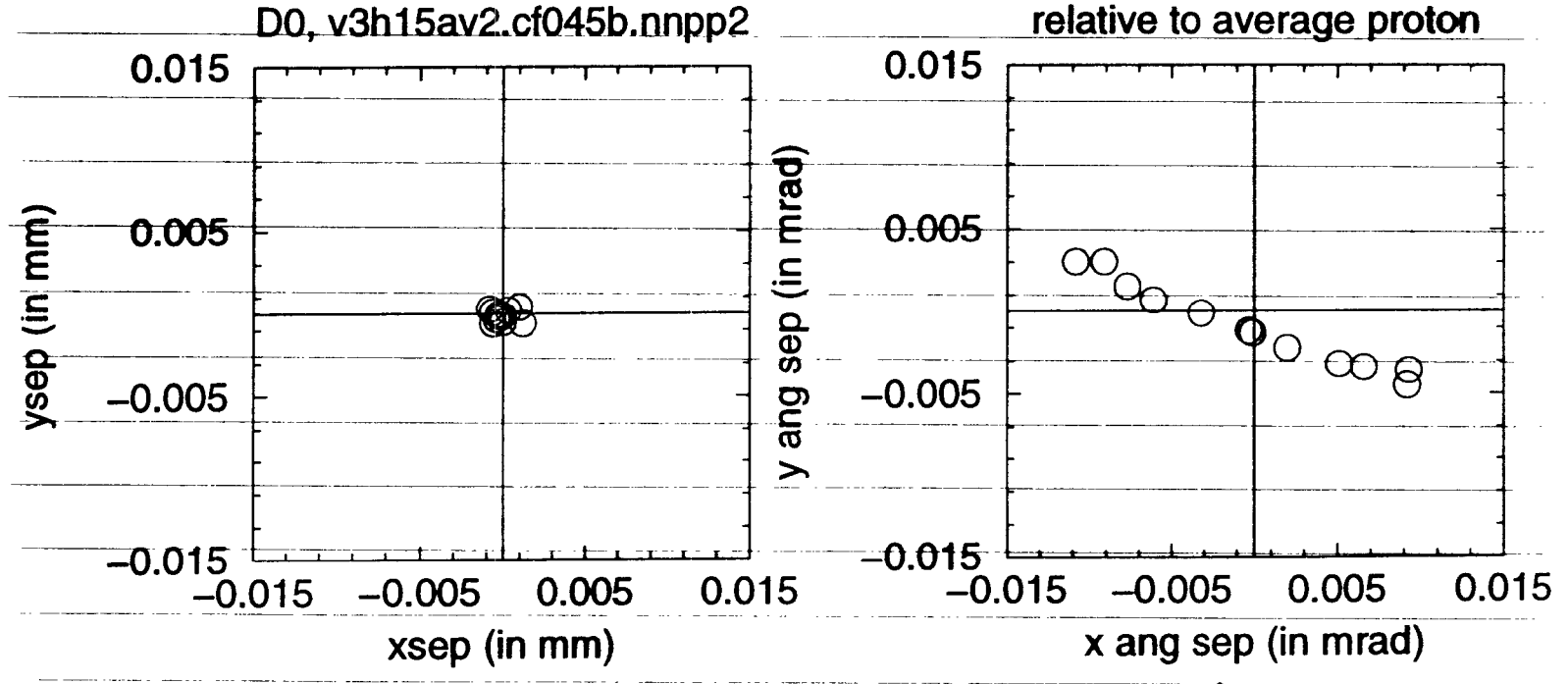

v3h15av2.cf045b.nnpp2, all bunches
0.028
0.026
0.024
0.022
0.020
0.018
xiy sep
0.018
0.020
0.022
0.024
0.026
0.028
xix sep


v3h15av2.cf045b.nnpp2, all bunches
0.005
0.003
0.001
−0.001
−0.003
−0.005
bbsq sin
−0.005
−0.003
−0.001
0.001
0.003
0.005
bbsq cos

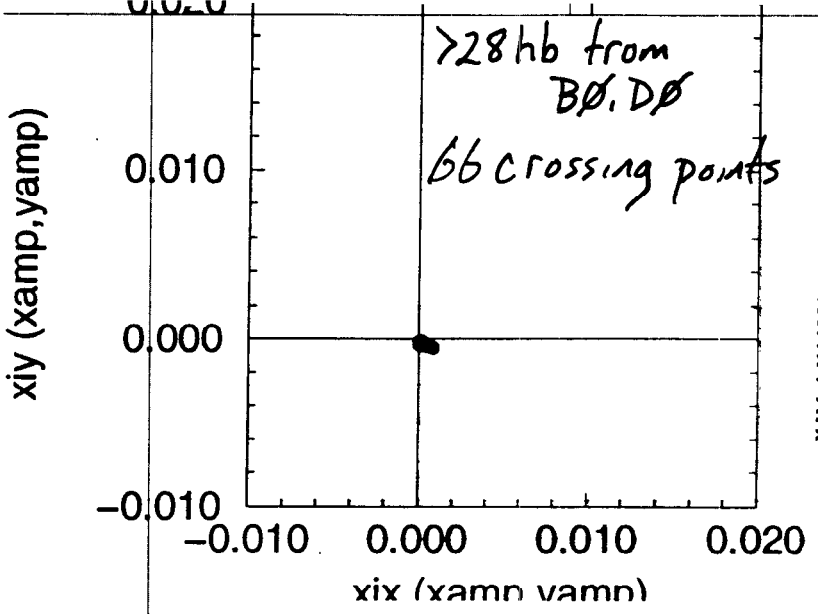
$\sigma_x = \sigma_y = 55.1\ \mu m$ = beam size at IP

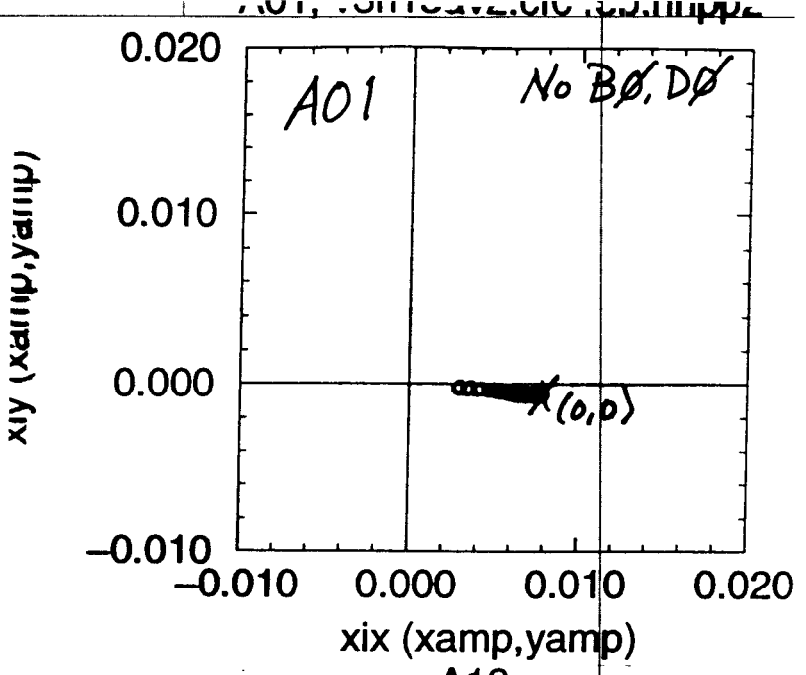
$\theta^*_{x'} = \theta^*_{y'} = 95.\ \mu rad$ = beam divergence at IP



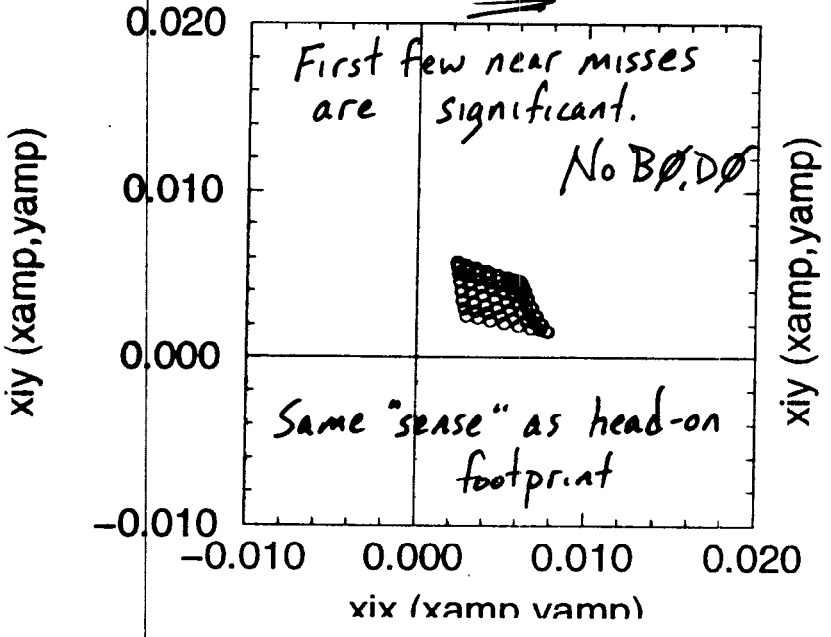




Beam beam dipole kicks change the separation by $\approx 0.5\sigma$. These are corrected with small changes to the separator settings.

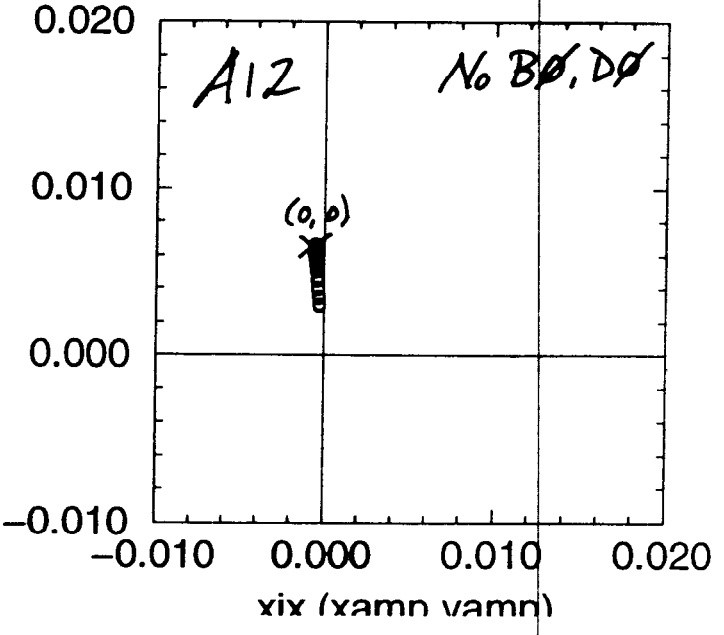


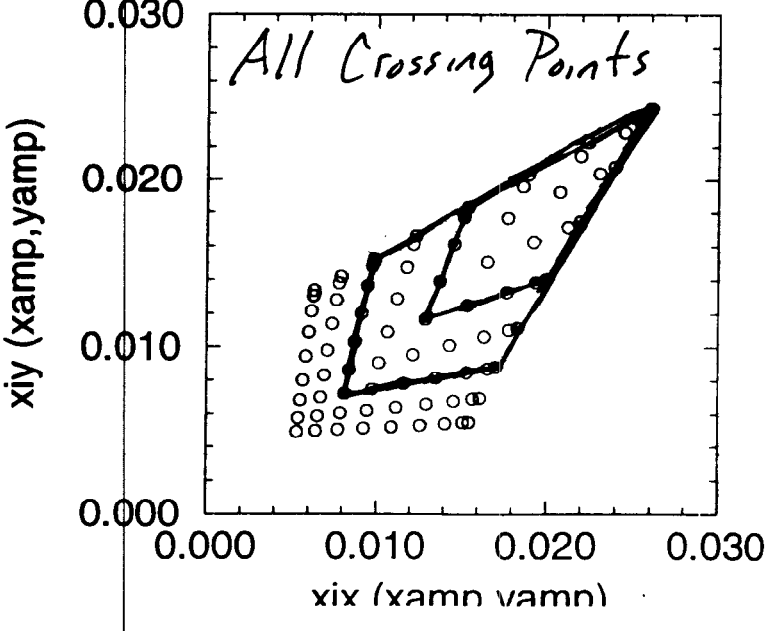

A06




A12




A06



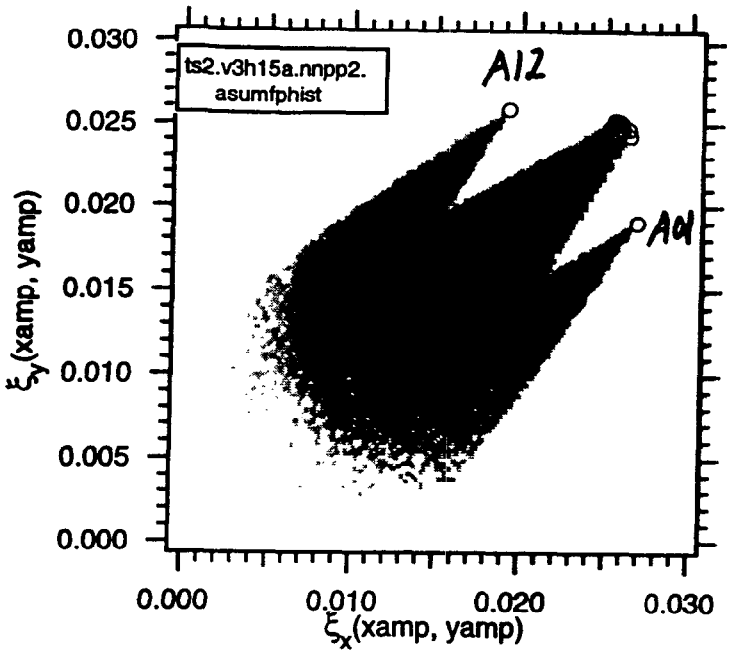

1 TeV, 20π, .087e-3
270.e9 proton intensity

$0 \to 4\theta_\beta$

Steps of $\frac{1}{2}\theta_\beta$

Contours at "$2\theta_\beta$"
"$3\theta_\beta$"

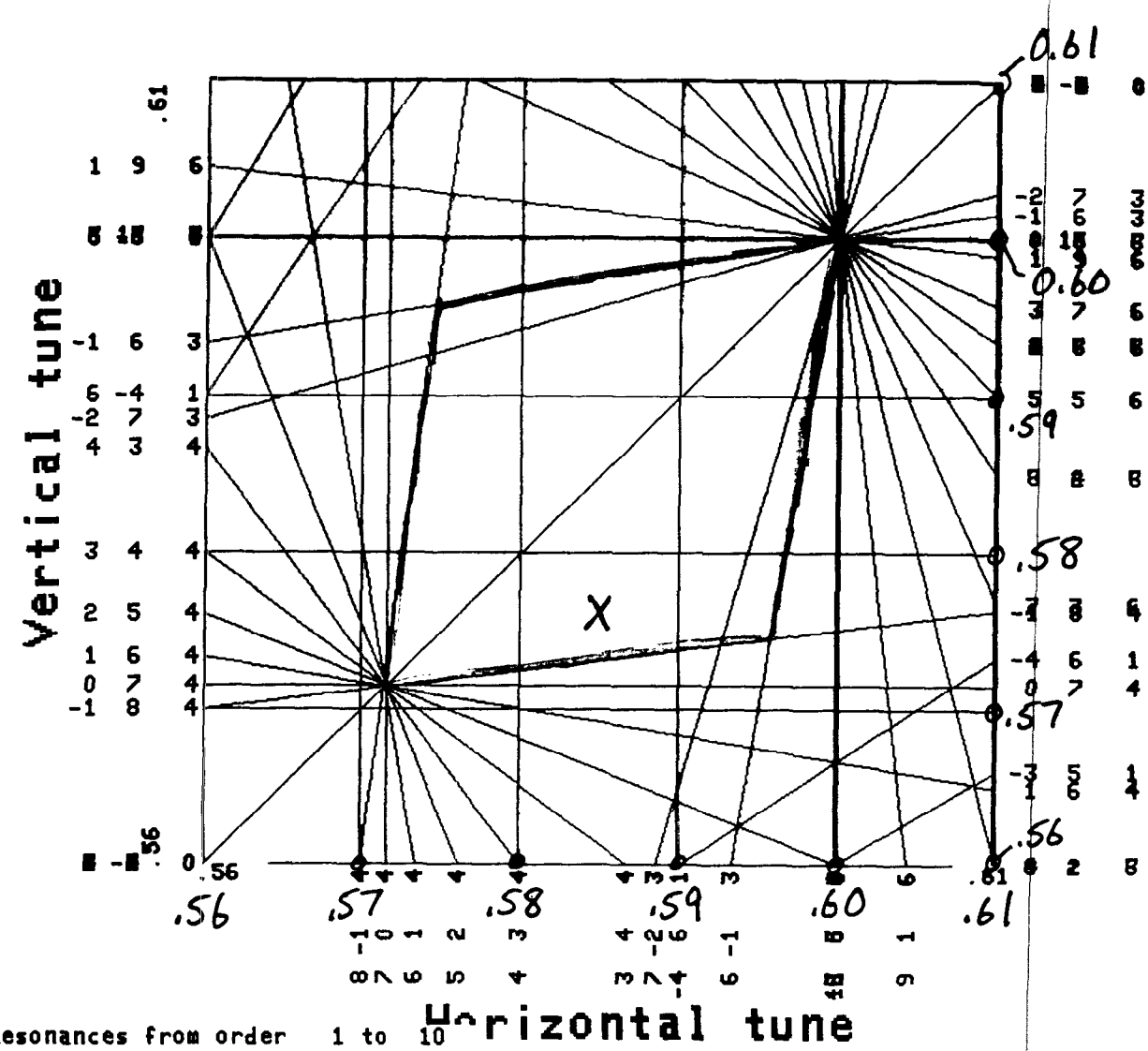
No <u>sync</u> motion




1 TeV, 20 π mm·mrad

.087e-3 = $\sigma_p/p$ for opposing beam size.

No sync. motion.



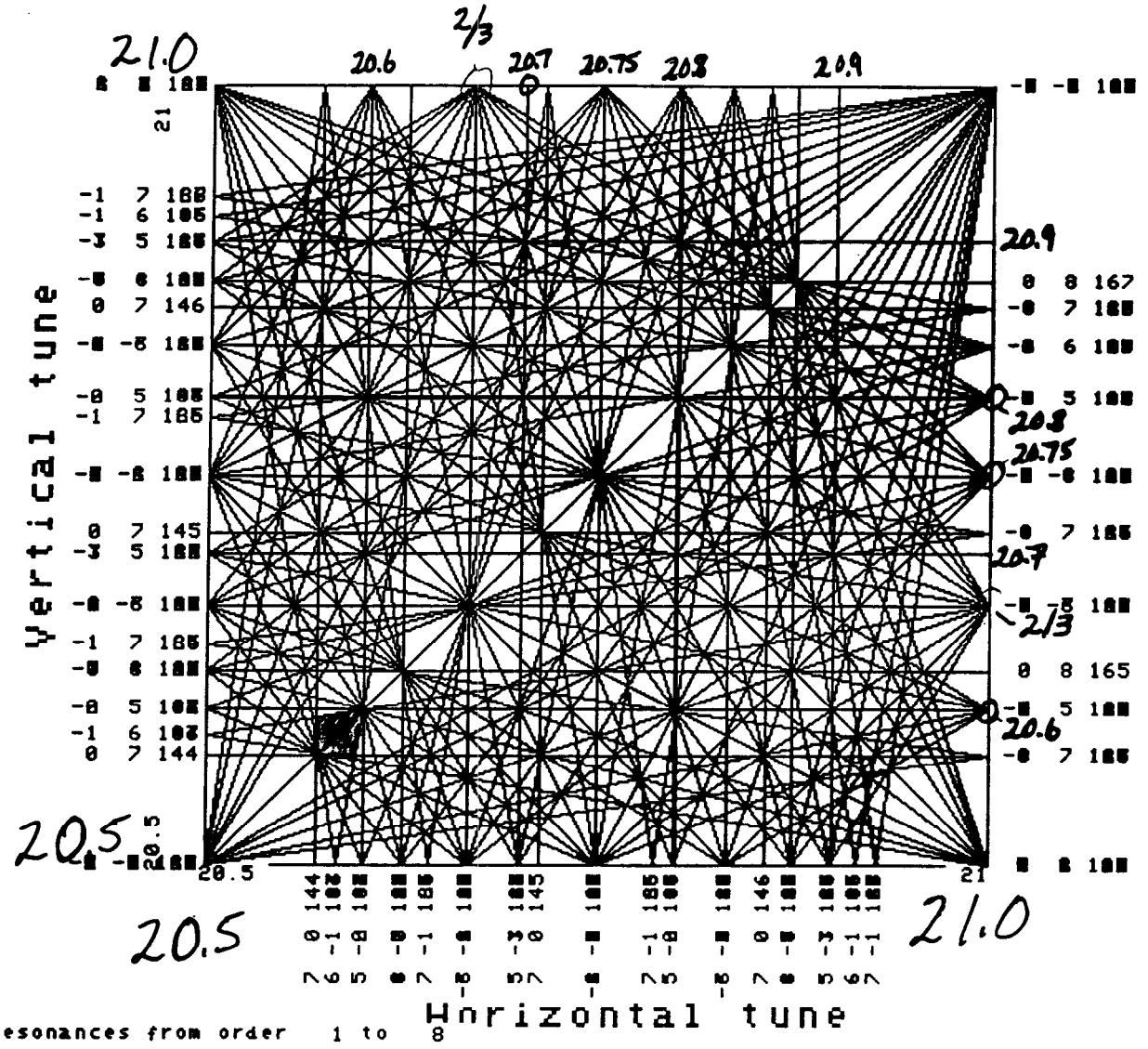

Resonances from order 1 to 10

29 res.

$$\frac{4}{7} = .5714$$

$$\frac{7}{12} = .5833$$

$$\frac{3}{5} = .6000$$


21.0
20.6
2/3
20.7
20.75
20.8
20.9
20.9
20.8
20.75
20.7
2/3
20.6
20.5
20.5
21.0
Vertical tune
Horizontal tune
20.5
21
esonances from order 1 to 8

# Late Run II (132 nsec bunch spacing with crossing angles)



Once we get to peak luminosities of 1.-2. e32
with 36 x 36 (this is 3-6 Interactions / Crossing),
we will put more effort into crossing angle studies.
We'd like to start looking in Fall/Winter 2000.

Need more kicker hardware
Need more separators
Need a coalescing upgrade for protons in Main Injector.

132 nsec bunch spacing
Crossing angles for 3-5 σ separation at the first near misses
(± 100. μrad, ± 136. μrad, ± 170. μrad per plane)
Equal horz. and vert. crossing angles.
These crossing angles have a big effect on
Luminosity and
Shape and Size of the Beam Beam Footprints in the Tune Plane.

90 x 90 ?
140 x 121 ? 140 x 103 ?

Crossing angles mean significant displacements (2. → 3.5 mm) in the final focus quads.

Total effect of the beam beam dipole kicks is not small.

$$\mathcal{L} = \left(\frac{+ B N_p N_{\bar{p}}}{4\pi \sigma_{x0}\sigma_{y0}}\right)\left(\frac{1}{\sqrt{\pi}\,\sigma_s}\right)\int_{-\infty}^{\infty}\left(\frac{ds}{1+\frac{s^2}{\beta^{*2}}}\right)\exp\left[\frac{-s^2}{\sigma_s^2} + \frac{-s^2/\sigma_{s,ang}^2}{1+\frac{s^2}{\beta^{*2}}}\right]$$ 4.

$$\sigma_{s,ang} \equiv \left[\frac{\delta_x^2}{\theta_{x0}^2} + \frac{\delta_y^2}{\theta_{y0}^2}\right]^{-1/2} = \frac{\sigma_s}{\theta_N}$$

$$\theta_N \equiv \sqrt{\frac{\delta_x^2\sigma_s^2}{\theta_{x0}^2} + \frac{\delta_y^2\sigma_s^2}{\theta_{y0}^2}} \equiv \sqrt{\theta_{Nx}^2 + \theta_{Ny}^2} = \frac{\sigma_s}{\sigma_{s,ang}}$$

$$\mathcal{L} \approx \mathcal{L}_0\left(\frac{1}{\sqrt{\pi}\,\sigma_s}\right)\int_{-\infty}^{\infty} ds\, \exp\left[\underbrace{\frac{-s^2}{\sigma_s^2} + \frac{-s^2}{\sigma_{s,ang}^2}}\right] = \frac{\mathcal{L}_0}{\sqrt{1+\sigma_s^2/\sigma_{s,ang}^2}} = \frac{\mathcal{L}_0}{\sqrt{1+\theta_N^2}}$$

$$\frac{1}{2\sigma_{s,lum}^2} \approx \frac{1}{\sigma_s^2} + \frac{1}{\sigma_{s,ang}^2}$$

Table XVII : Crossing angle parameters for bunch lengths of 14 cm and 37.1 cm. This table assumes $\sigma_x = \sigma_y = 33.1$ μm and $\beta_x^* = \beta_y^* = 35$ cm.

| $\delta_x = \delta_y$ | $\sigma_s$ | $\theta_{Nx} = \theta_{Ny}$ | $\theta_N$ | $\sigma_{s,ang}$ | $L/L_0$ | $\approx \sigma_{s,lum}$ | $\xi_x/\xi_{x0}$ |
|---|---|---|---|---|---|---|---|
| μrad | cm | | | cm | | cm | |
| ~~100~~ | ~~14.0~~ | ~~0.423~~ | ~~0.598~~ | ~~23.4~~ | ~~0.83~~ | ~~8.5~~ | ~~0.861~~ |
| ~~136~~ | ~~14.0~~ | ~~0.575~~ | ~~0.813~~ | ~~17.2~~ | ~~0.76~~ | ~~7.7~~ | ~~0.786~~ |
| ~~170~~ | ~~14.0~~ | ~~0.719~~ | ~~1.017~~ | ~~13.8~~ | ~~0.69~~ | ~~6.9~~ | ~~0.712~~ |
| 100 | 37.1 | 1.121 | 1.585 | 23.4 | 0.52 | 14.0 | 0.582 |
| 136 | 37.1 | 1.524 | 2.156 | 17.2 | 0.43 | 11.0 | 0.450 |
| 170 | 37.1 | 1.905 | 2.695 | 13.8 | 0.35 | 9.1 | 0.365 |

$\frac{14\text{cm}}{\sqrt{2}} = 9.9$ cm

$\frac{37.1\text{cm}}{\sqrt{2}} = 26.2$ cm

"length" of luminous region

Table XVII shows a summary of several crossing angle parameters for the two bunch lengths, 14 cm and 37.1 cm. The columns labeled ($\approx \sigma_{s,lum}$) and ($\xi_x/\xi_{x0}$) will be discussed in later sections.

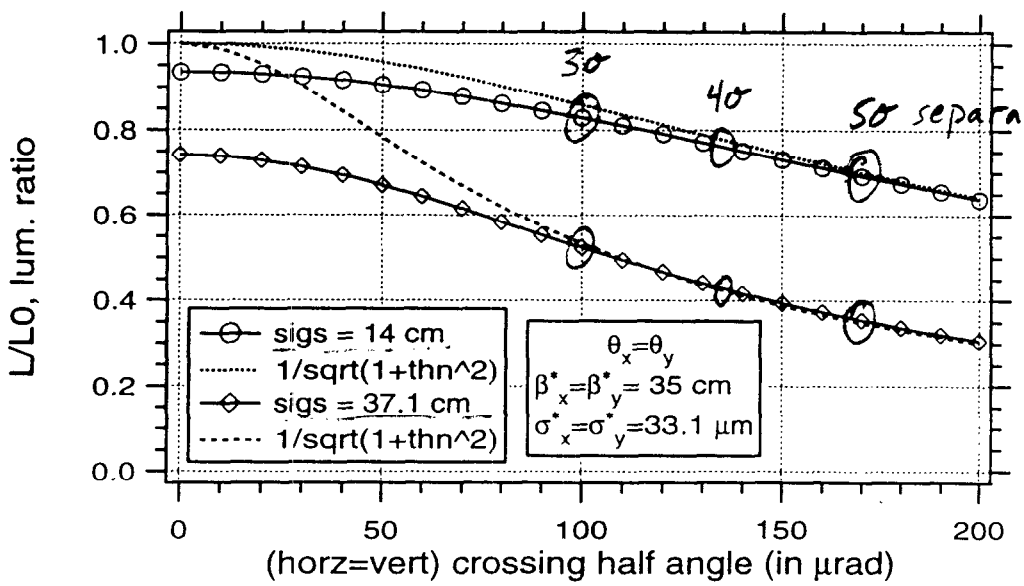
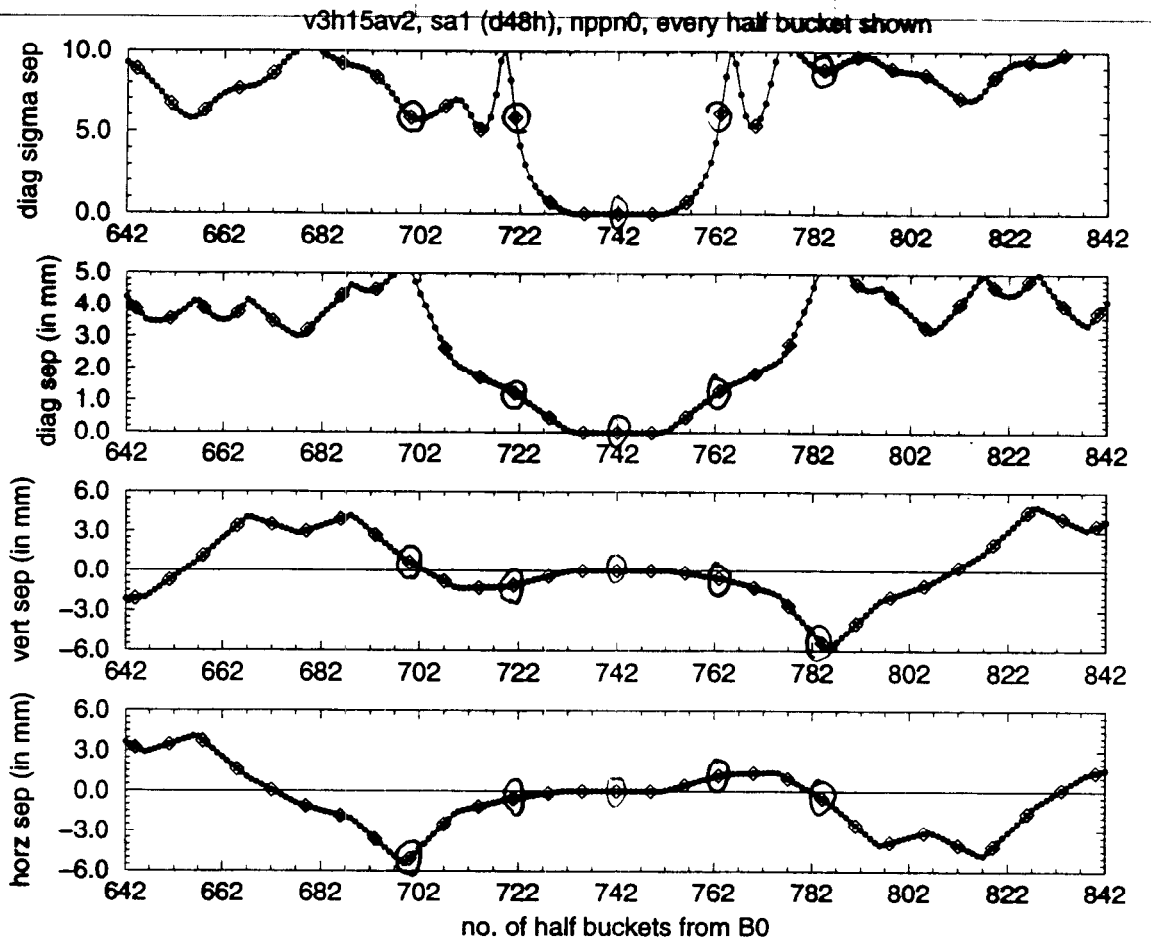
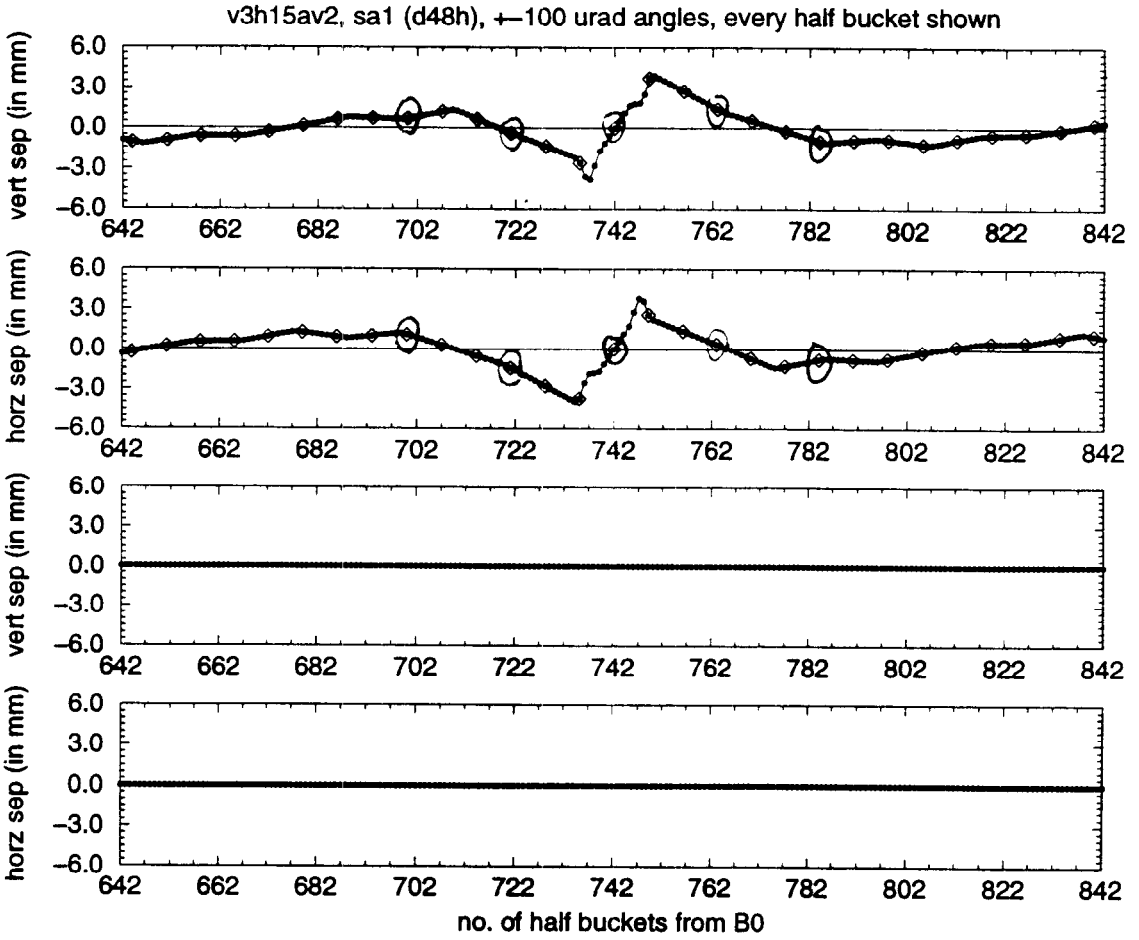


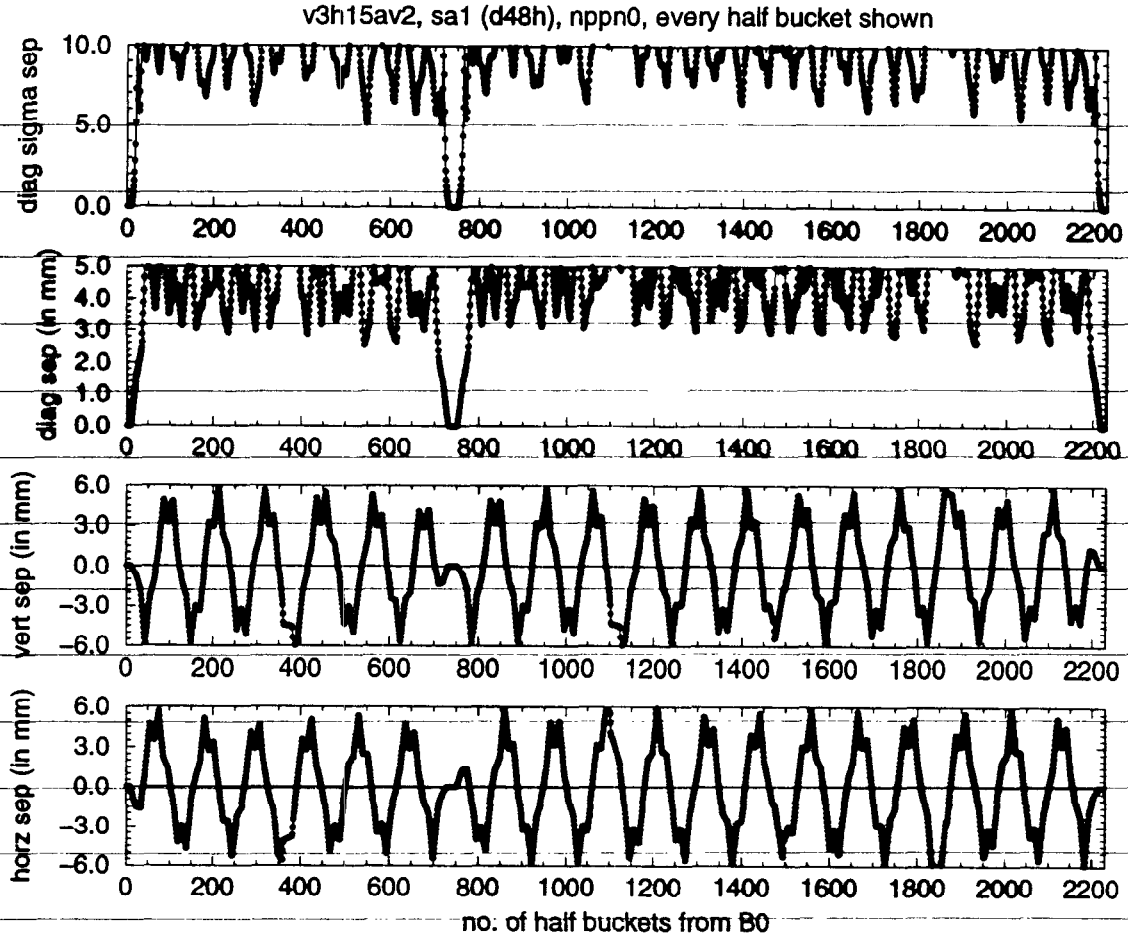

Figure 36. The dependence of luminosity ($L/L_0$) on the crossing half angle in each plane. The results for two bunch lengths (14 cm and 37.1 cm) are shown. The dotted lines show $\left(1+\theta_N^2\right)^{-1/2}$, the approximation that ignores the hourglass effect for the two bunch lengths.




$$\sqrt{\frac{X^2}{\sigma_X^2} + \frac{Y^2}{\sigma_Y^2}}$$

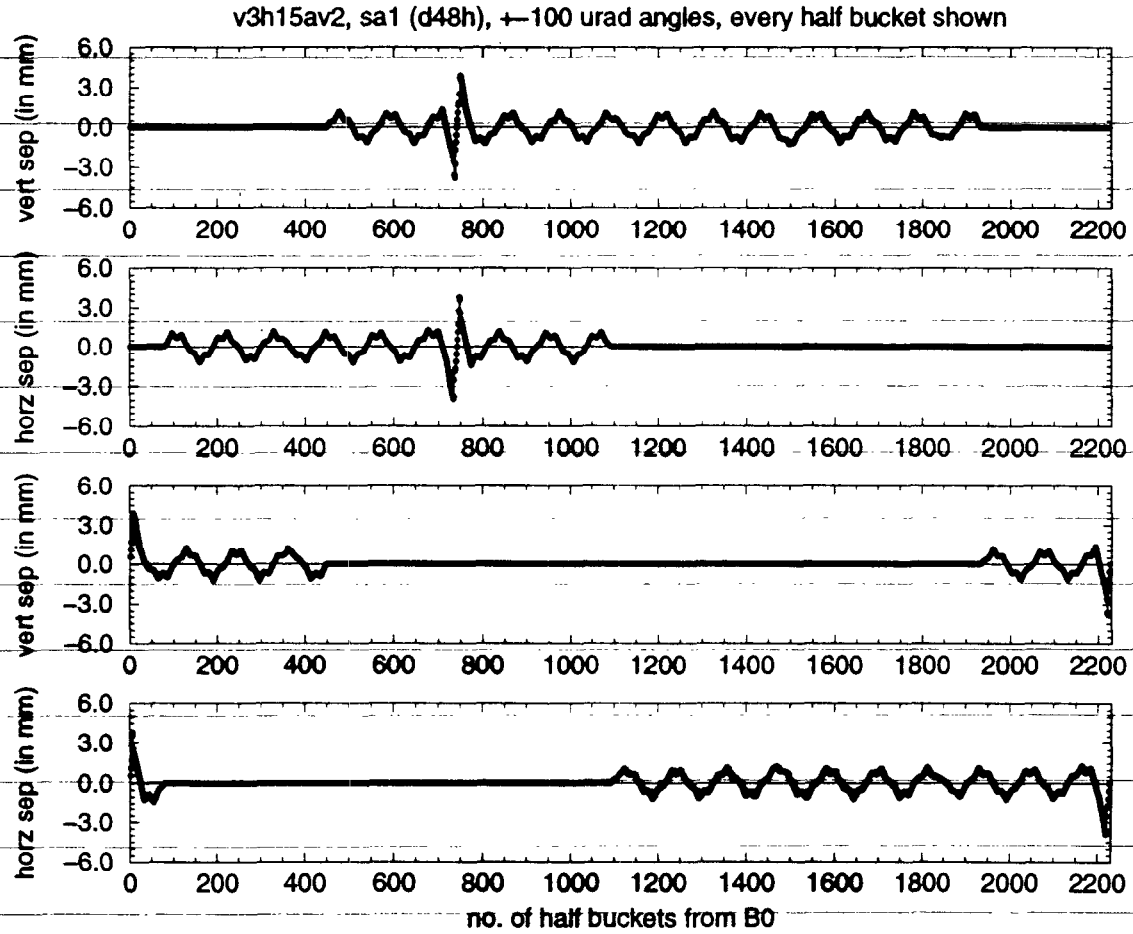
$$\sqrt{X^2 + Y^2}$$






$$\sqrt{\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}}$$

$$\sqrt{x^2+y^2}$$



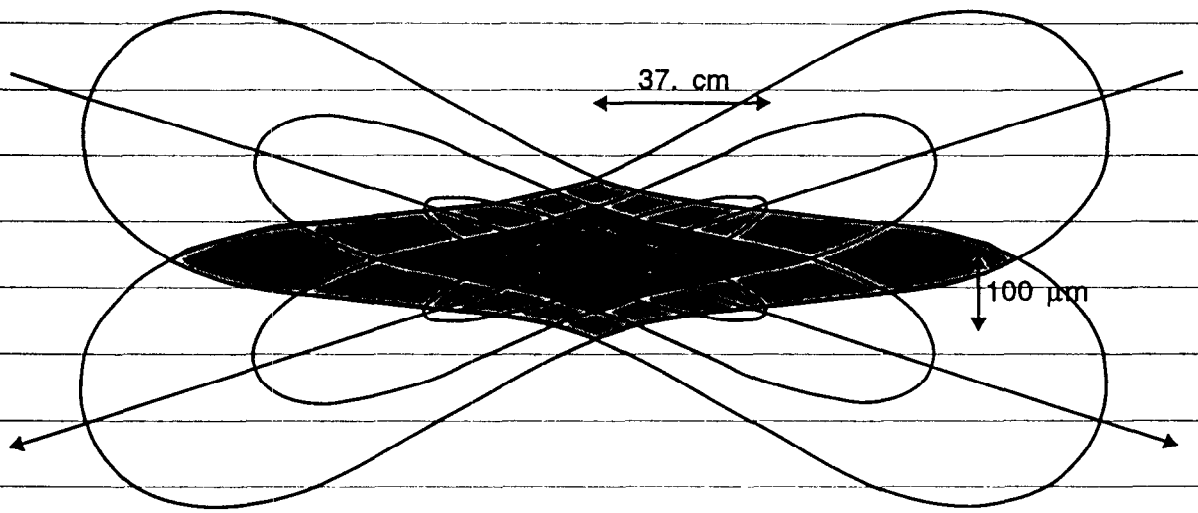



Figure 35. A sketch of two bunches crossing at an IP with $\beta^*$ of 35 cm, bunch length of 37 cm, and half crossing angle per plane of 136 μrad, corresponding to about $4\sigma$ separation at the first parasitic crossing points. The direction of motion for the two bunches is indicated by the arrows and they are viewed from the angle where the separation appears largest. This drawing is to scale, however the horizontal and vertical scales are very different, causing the crossing angle to appear to be much larger than it is. $1\sigma$, $2\sigma$, and $3\sigma$ contours are shown with the shaded areas indicating the overlap of these contours.

The length of the luminous region mainly depends on the transverse beam size and the crossing angle.

Assume a stack rate of 20.e10/hr

Cond. 2 - 396 nsec, 36 bunches, IC<=5, 1.7e32
For no recycling :
initial pbar intensities of 100.e9/bunch
about 22 hour stores
Peak luminosity is 1.70e32/(cm^2 s) => 5.0 interactions per crossing
Luminosity is saturated for the first 3.5 hours of the store.

For 60% Recycling Efficiency :
initial pbar intensities of 135.e9/bunch
about 20 hour stores
Peak luminosity is 1.70e32/(cm^2 s) => 5.0 interactions per crossing
Luminosity is saturated for the first 7.5 hours of the store.

For 80% Recycling Efficiency :
initial pbar intensities of 135.e9/bunch
about 15 hour stores
Peak luminosity is 1.70e32/(cm^2 s) => 5.0 interactions per crossing
Luminosity is saturated for the first 7.5 hours of the store.

Cond. 8 - 132 nsec, 100 bunches, +-136 urad, IC<=4, 3.8e32

For no recycling :
initial pbar intensities of 35.e9/bunch
about 21 hour stores
Peak luminosity is 1.43e32/(cm^2 s) => 1.5 interactions per crossing
Not doing any luminosity leveling here.

For 60% Recycling Efficiency :
initial pbar intensities of 70.e9/bunch
about 29 hour stores
Peak luminosity is 2.85e32/(cm^2 s) => 3.0 interactions per crossing
Not doing any luminosity leveling here.

For 80% Recycling Efficiency :
initial pbar intensities of 70.e9/bunch
about 21 hour stores
Peak luminosity is 2.85e32/(cm^2 s) => 3.0 interactions per crossing
Not doing any luminosity leveling here.

For a real stack rate of 20.e10/hr

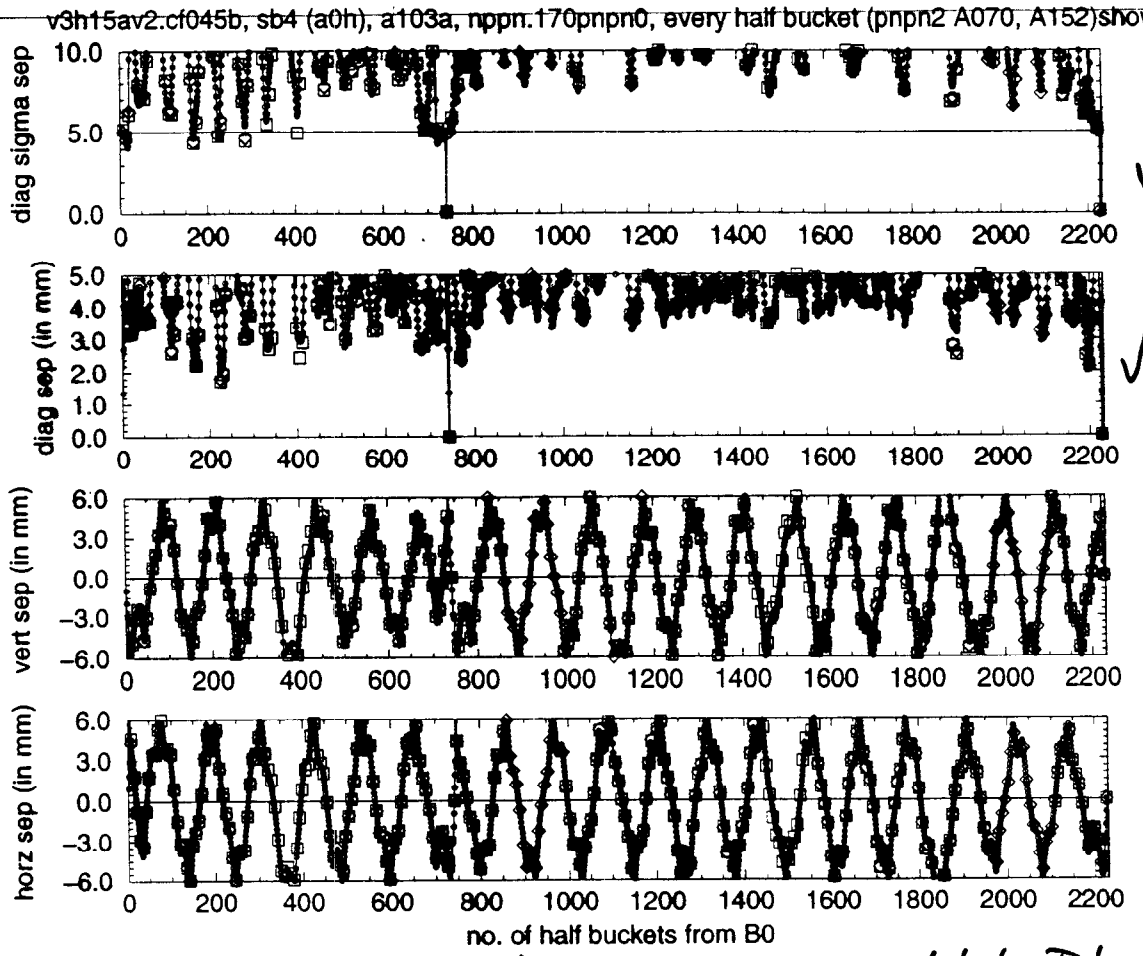
| | Cond. 2 aver lum 1/(pb-hrs) | Cond. 8 aver lum 1/(pb-hrs) | (c8-c2)/c2 |
|---|---|---|---|
| No recycling, | 0.389 | 0.266 | -32% |
| 60% Recycling Eff. | 0.487 | 0.454 | -7% |
| 80% Recycling Eff. | 0.525 | 0.514 | -2% |

If we throw away (do NOT recycle) pbars at the end of stores, we take a big hit in integrated luminosity with ~100 bunches.

Even with not very efficient recycling of pbars, the hit in integrated luminosity is not too bad, less than 10%, with ~100 bunches.

With 36 bunches, we are luminosity leveling, but we are NOT at ~100 bunches.
So higher stack rates will help ~100 bunch running more than 36 bunch running.

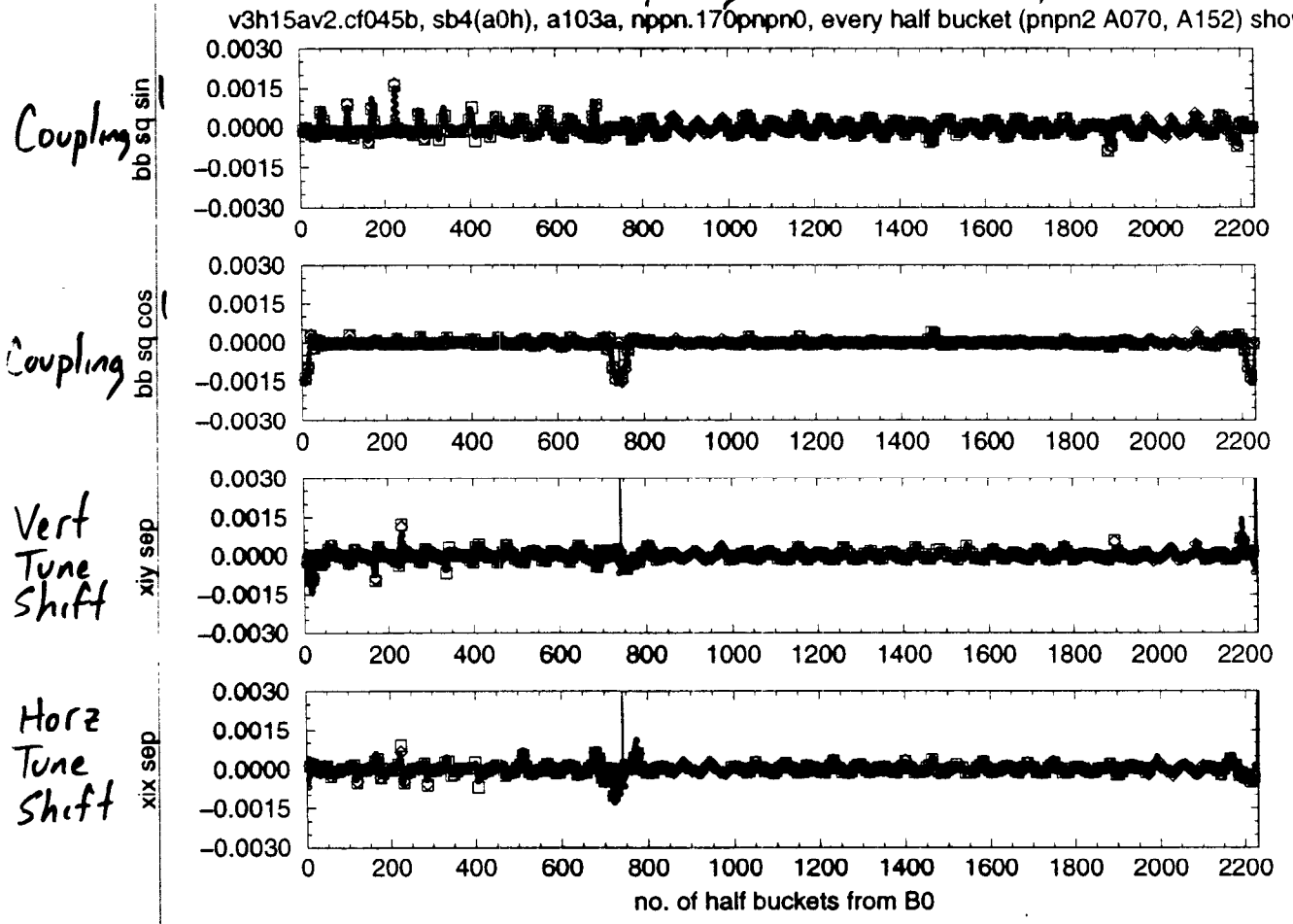
±110. μrad.




$$\sqrt{\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}}$$

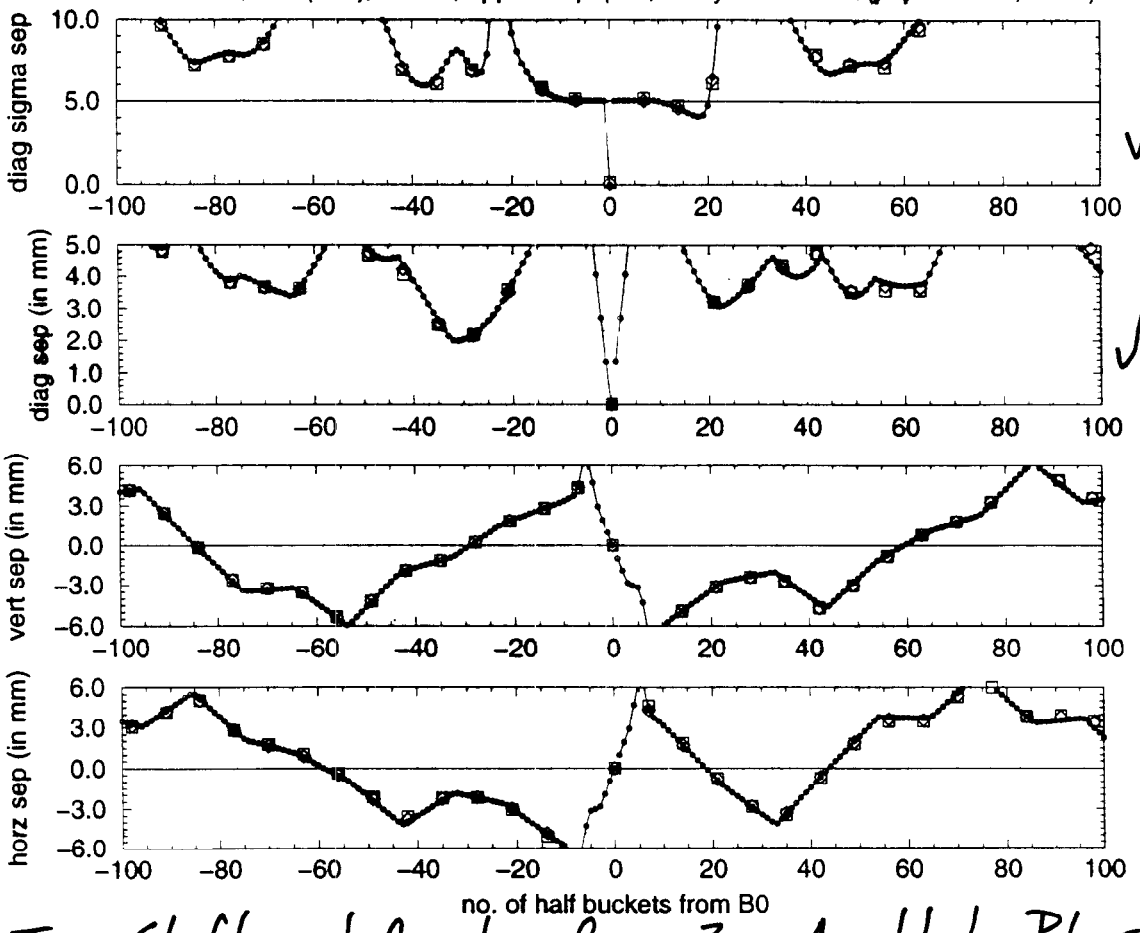
$$\sqrt{x^2+y^2}$$

Tune Shifts and Coupling for a Zero Amplitude Pbar



170 μrad

v3h15av2.cf045b, sb4 (a0h), a103a, nppn.170pnpn0, every half bucket (pnpn2 A070, A152)showr

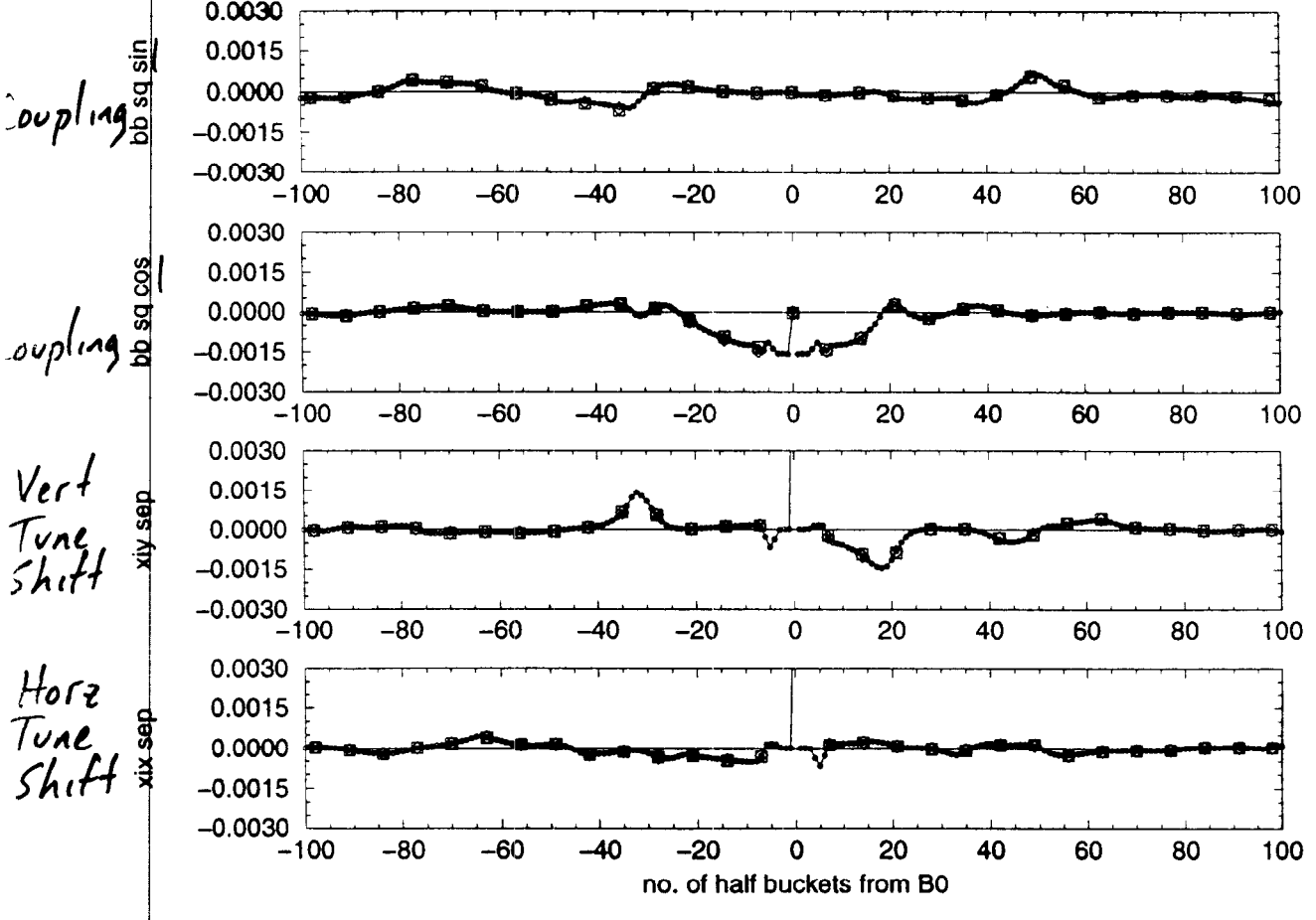



$\sqrt{\frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2}}$

$\sqrt{x^2 + y^2}$

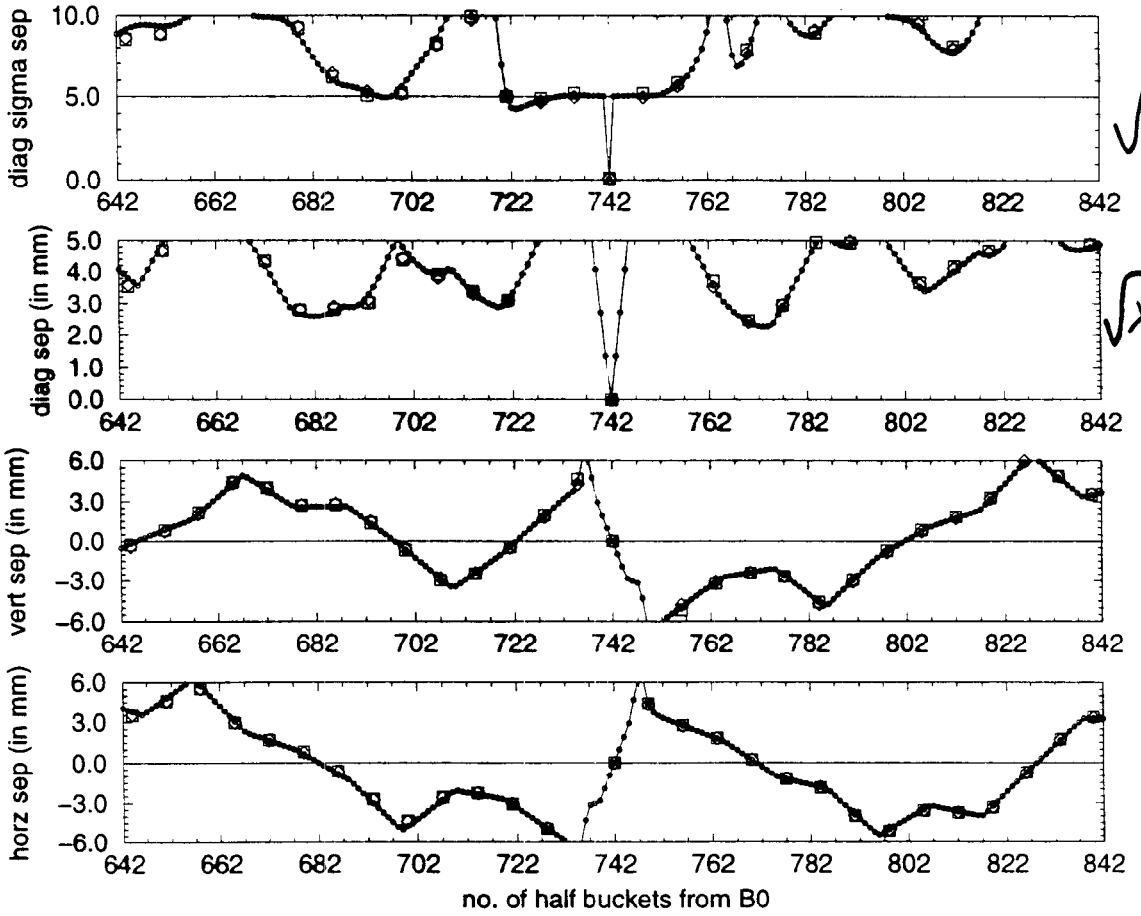
Tune Shifts and Coupling for a Zero Amplitude Pbar

v3h15av2.cf045b, sb4(a0h), a103a, nppn.170pnpn0, every half bucket (pnpn2 A070, A152) shown



± 110.μrad

v3h15av2.cf045b, sb4 (a0h), a103a, nppn.170pnpn0, every half bucket (pnpn2 A070, A152)shown

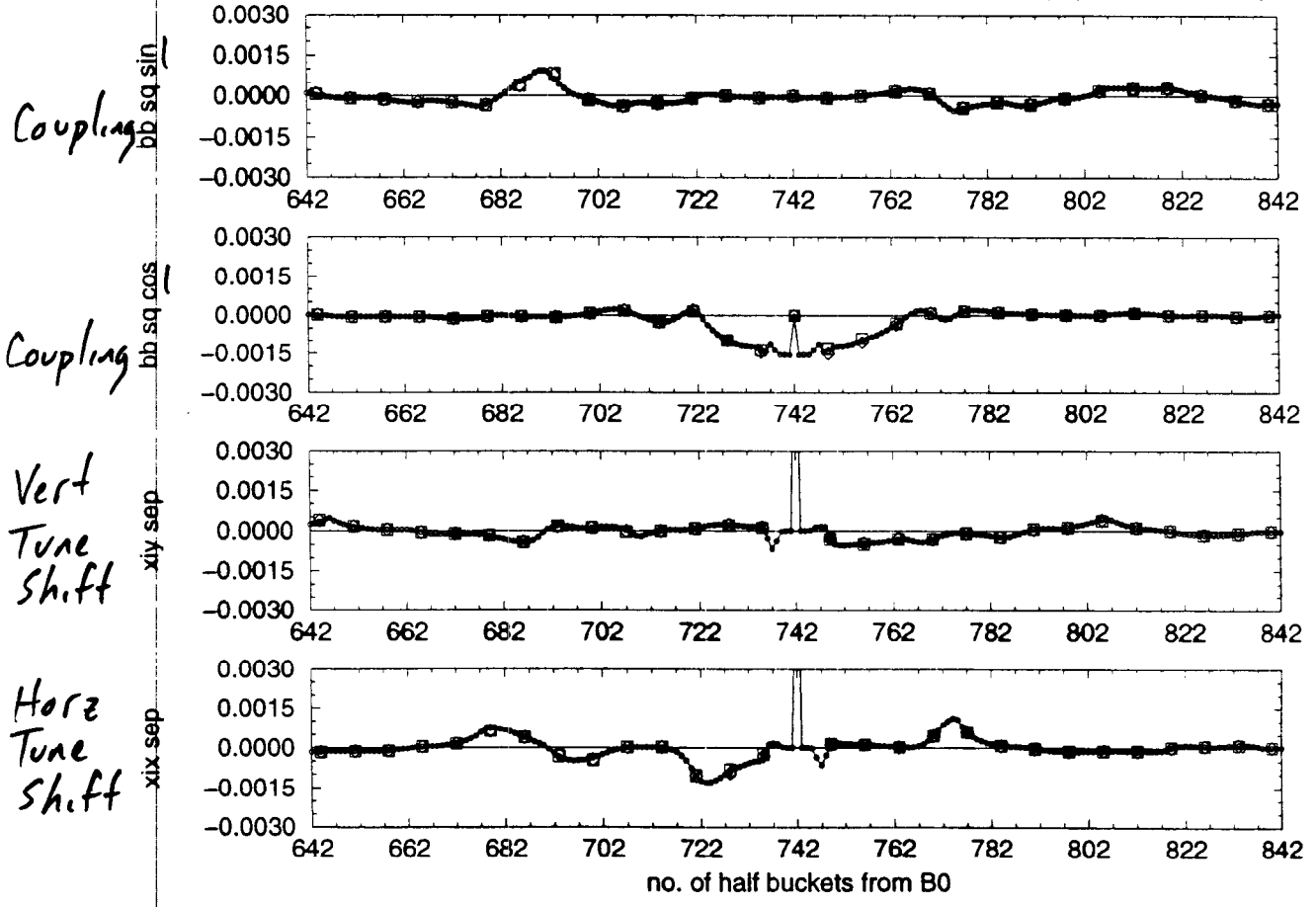


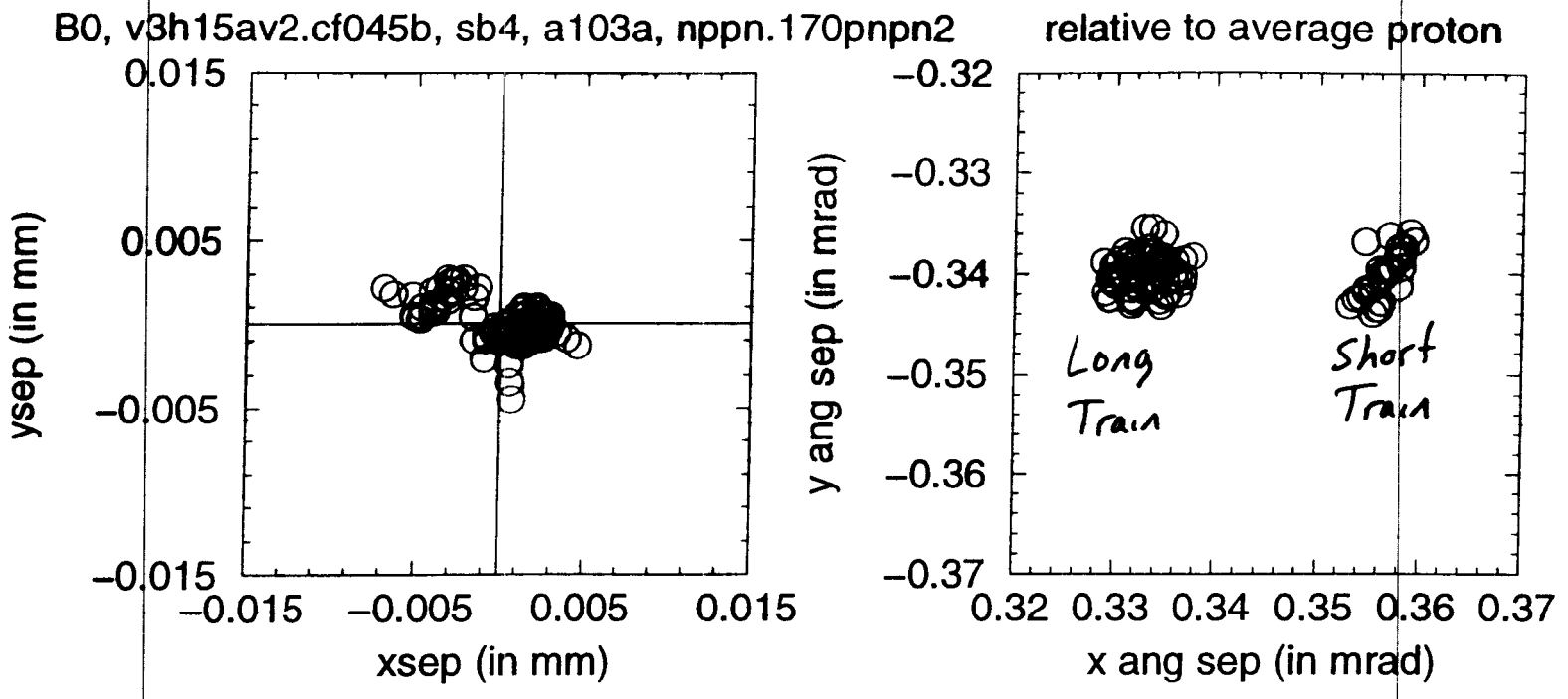

$$\sqrt{\frac{x^2}{\sigma_x^2}+\frac{y^2}{\sigma_y^2}}$$

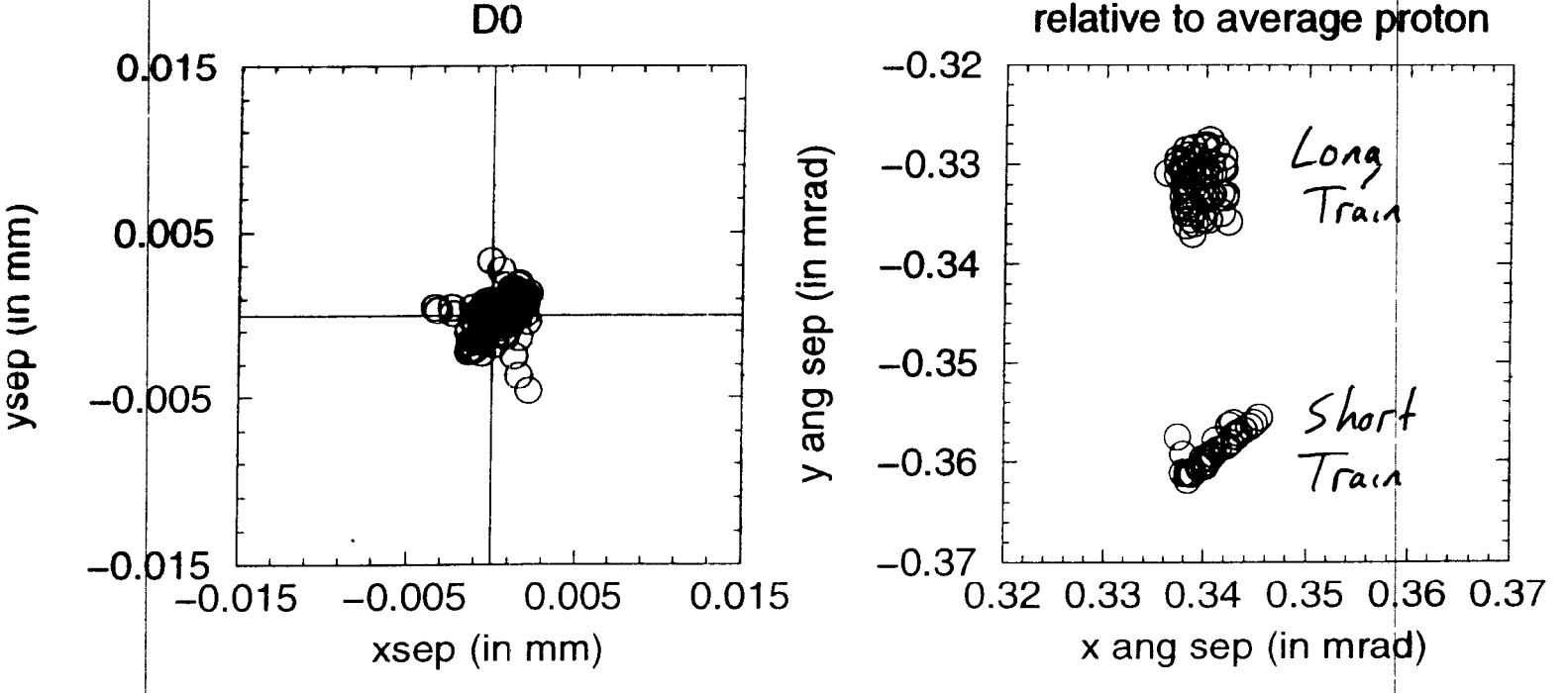
$$\sqrt{x^2+y^2}$$

# Tune Shifts and Coupling for a Zero Amplitude Pbar

v3h15av2.cf045b, sb4(a0h), a103a, nppn.170pnpn0, every half bucket (pnpn2 A070, A152) shown






beam size at IP $= \sigma_x^* = \sigma_y^* = 33.1\ \mu m$

beam divergence at IP $= \sigma_{x'}^* = \sigma_{y'}^* = 95.\ \mu rad$

A152 >28 hb from IPs

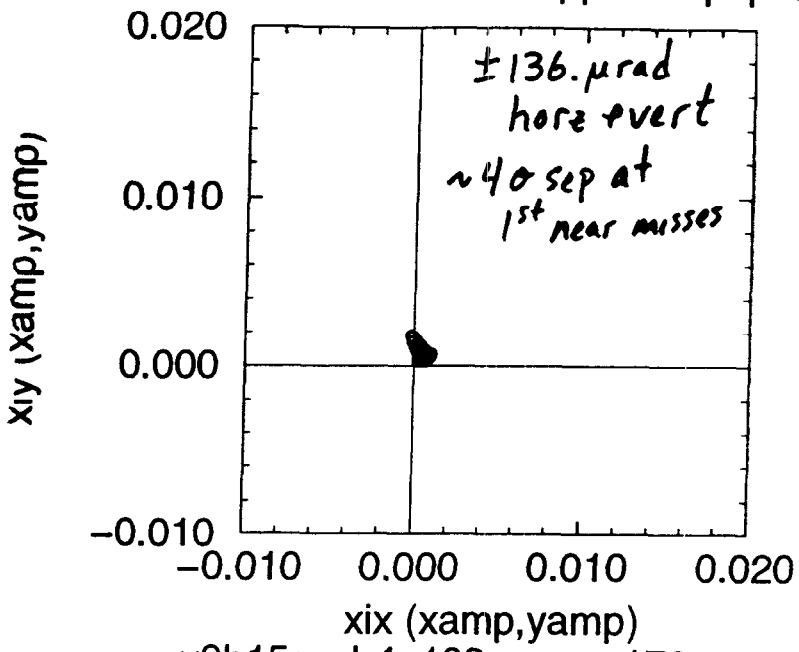
262 crossing points

Arcs don't contribute much tune spread.

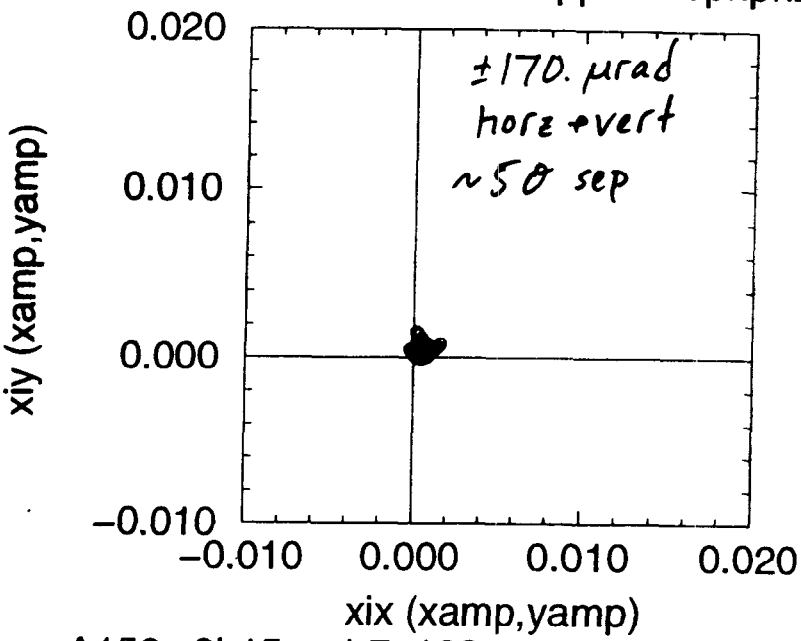
These show the tune spread contributions from all points <u>except</u>

IPs, ±1, ±2, ±3, ±4

v3h15acsb2a103a.nppn.136pnpn2




v3h15acsb4a103a.nppn.170pnpn2




No sync motion

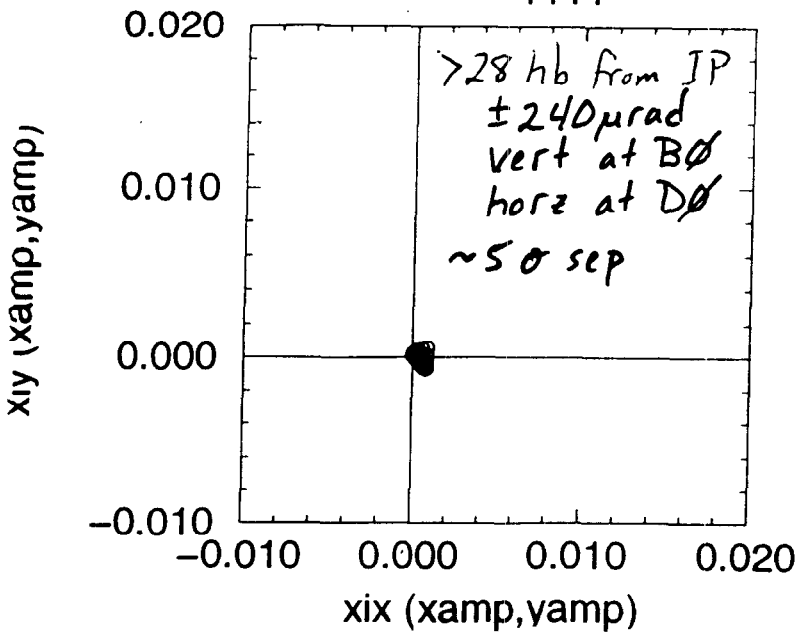
1 TeV

$20\pi$, $.087e-3 \frac{\sigma_p}{p}$

$0 \to 4\ \sigma_\beta$, $\frac{1}{2}\sigma_\beta$ spacing

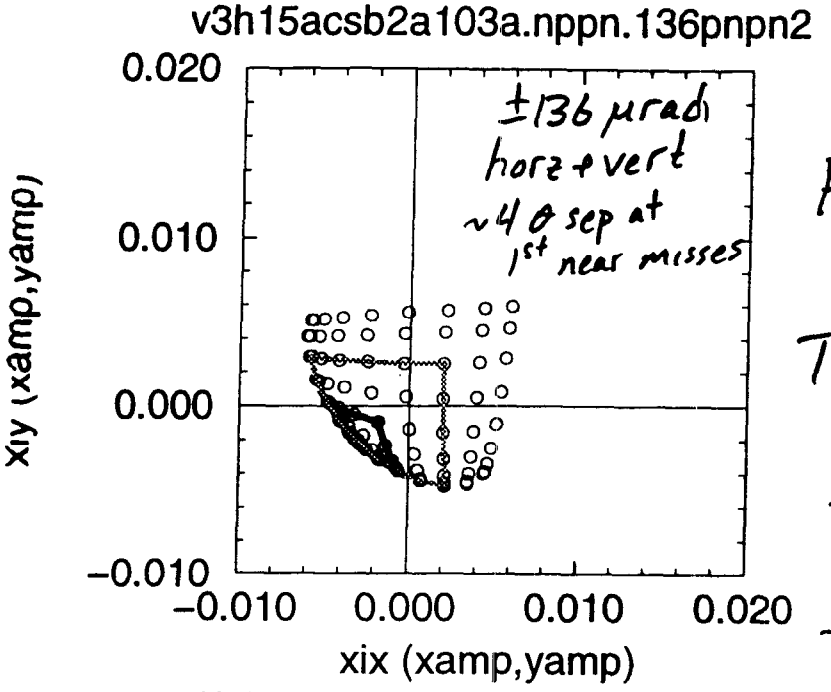
proton intensity = 270.e9/bunch

A152,v3h15acsb7a103a.pppp.240znnz2



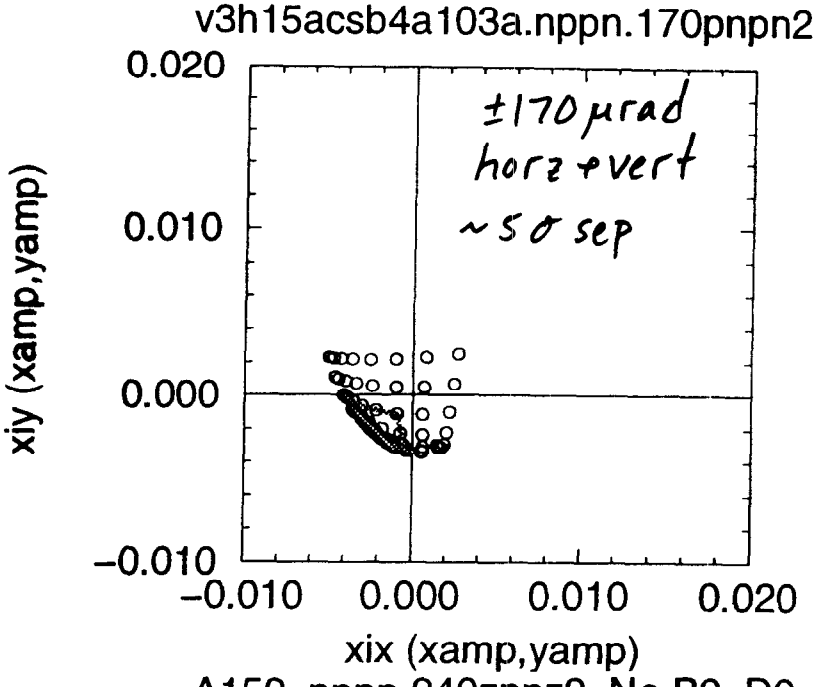
A152, No BØ, DØ

278 crossing points

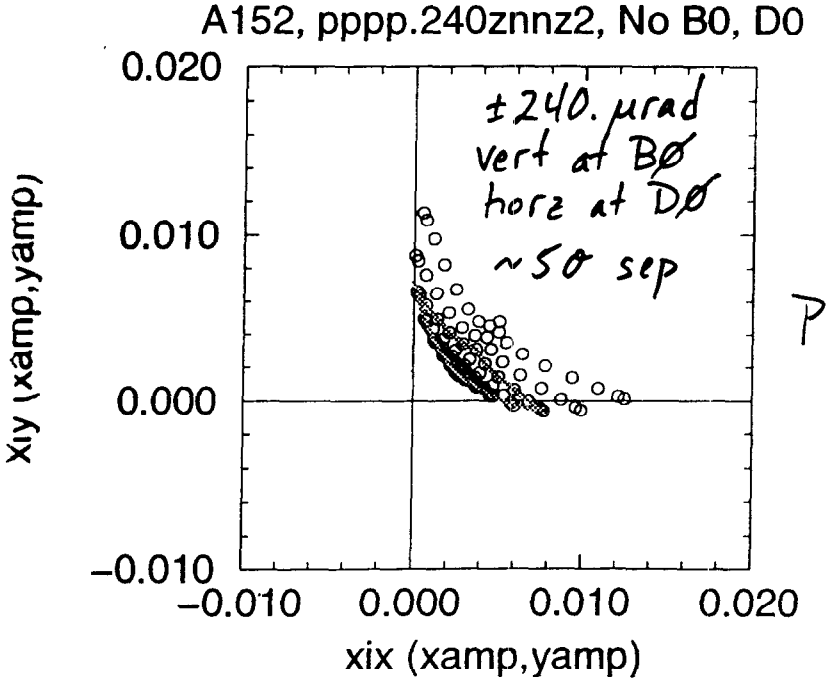



First few near misses are important.

These have the opposite sense of the tune shift from a "head on" footprint.




These show the tune spread contribution from all points <u>except</u> the IPs.




No sync motion

1 TeV

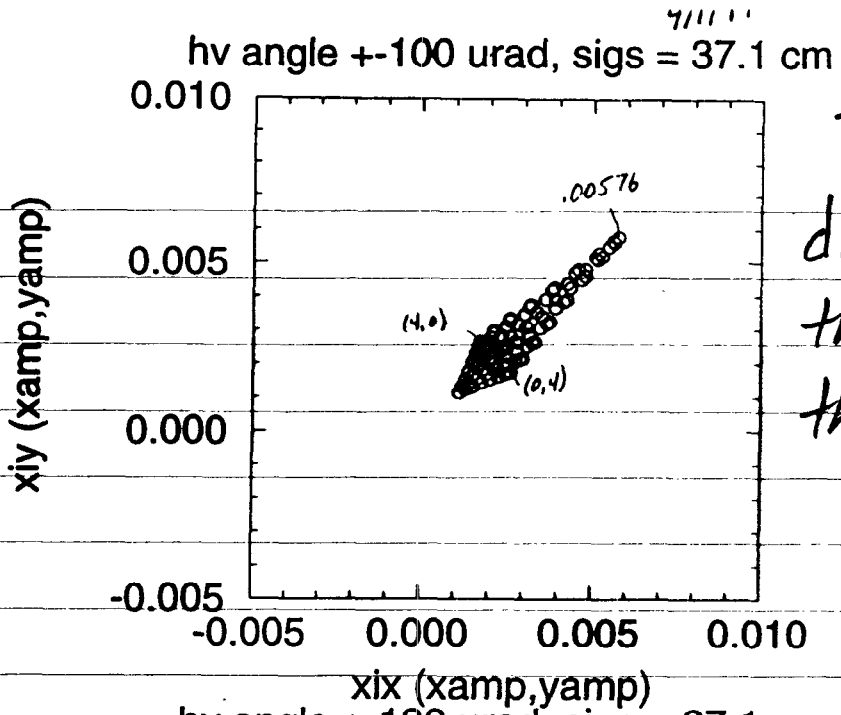
$20\pi$, $.087e-3 = \frac{\sigma_p}{p}$

$0 \to 4\,\sigma_\beta$, $\frac{1}{2}\,\sigma_\beta$ spacing

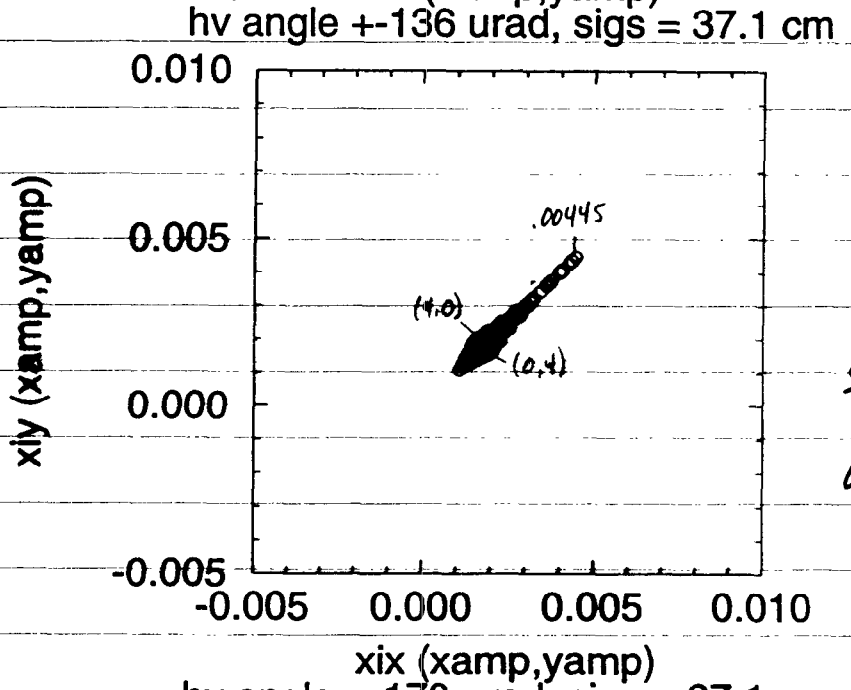
2 and 3 $\sigma_\beta$ "contours" shown

$(0,0) \to (3,0) \to (3,3) \to (0,3) \to (0,0)$

proton intensity = 270. e9/bunch

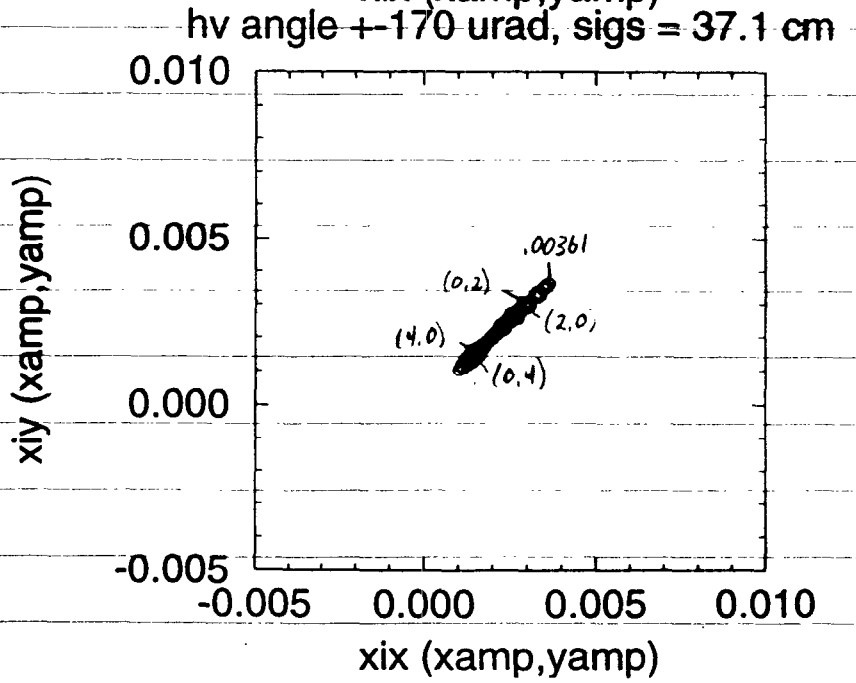


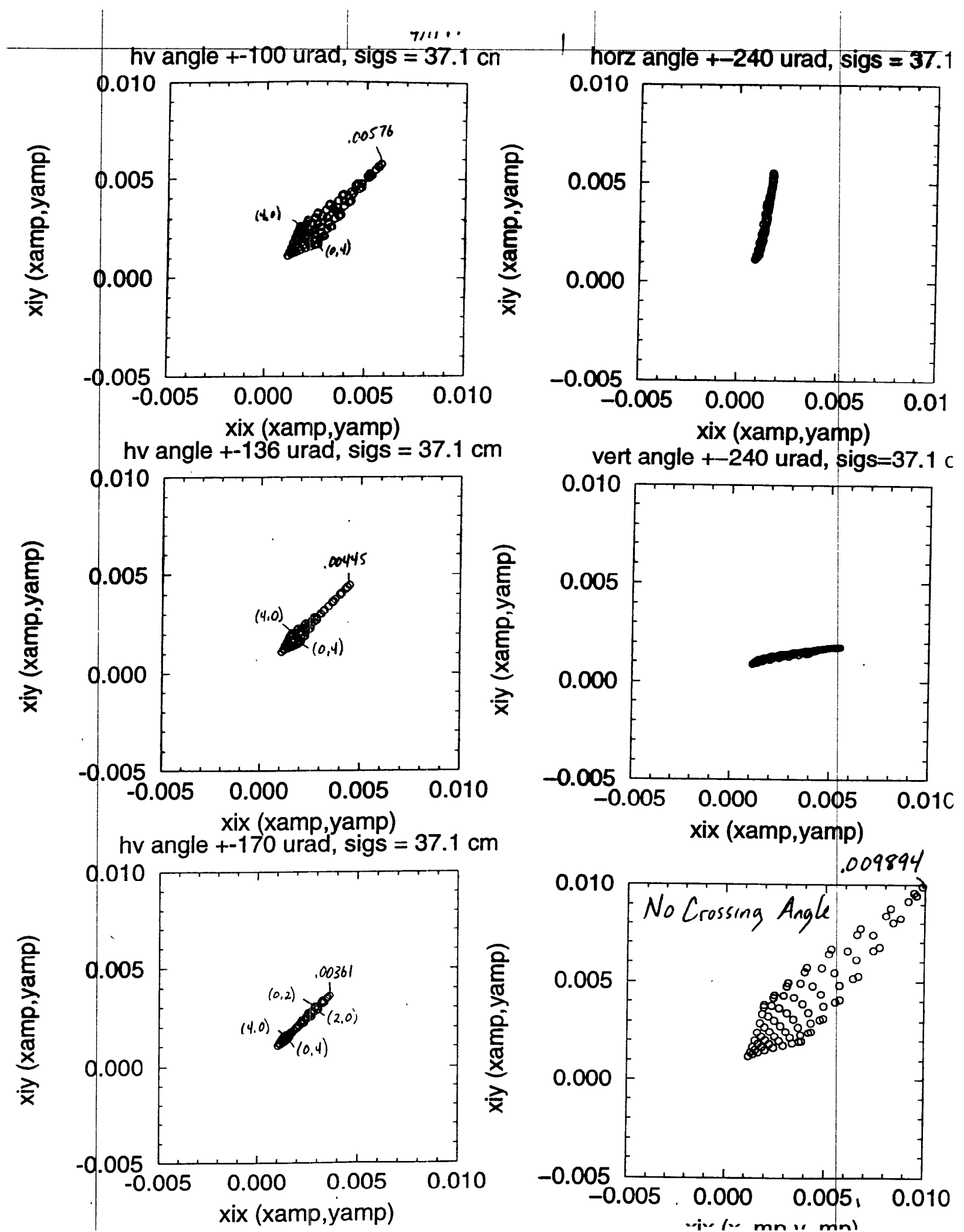

The crossing angles distort the shape of the tune footprint from the "main" beam beam interaction



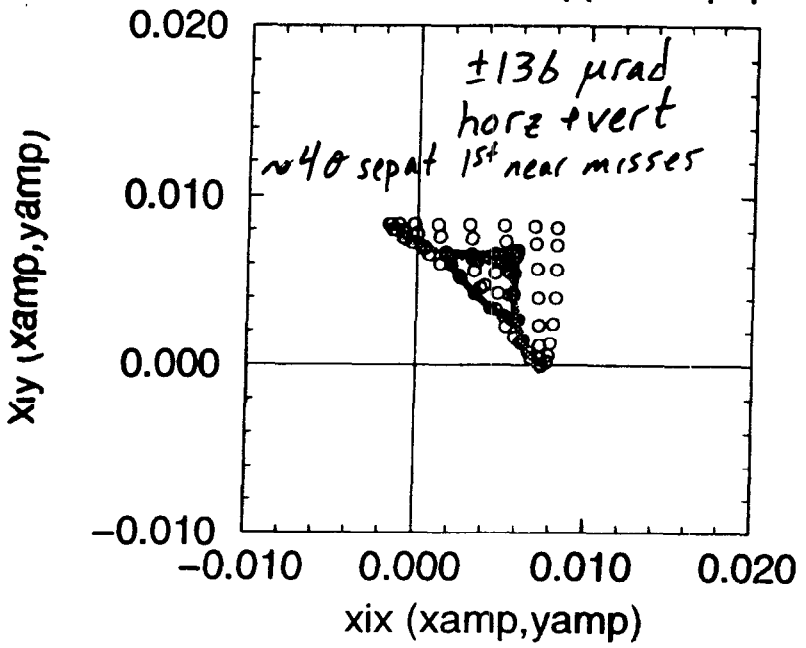

All these have equal horz and vert crossing angles.

These show the tune spread contribution from only 1 of the 2 IP's




hv angle +-100 urad, sigs = 37.1 cm
.00576
(4,0)
(0,4)
xiy (xamp,yamp)
xix (xamp,yamp)
horz angle +-240 urad, sigs = 37.1
xiy (xamp,yamp)
xix (xamp,yamp)
hv angle +-136 urad, sigs = 37.1 cm
.00445
(4,0)
(0,4)
xiy (xamp,yamp)
xix (xamp,yamp)
vert angle +-240 urad, sigs=37.1 c
xiy (xamp,yamp)
xix (xamp,yamp)
hv angle +-170 urad, sigs = 37.1 cm
.00361
(0,2)
(2,0)
(4,0)
(0,4)
xiy (xamp,yamp)
xix (xamp,yamp)
.009894
No Crossing Angle
xiy (xamp,yamp)

v3h15acsb2a103a.nppn.136pnpn2

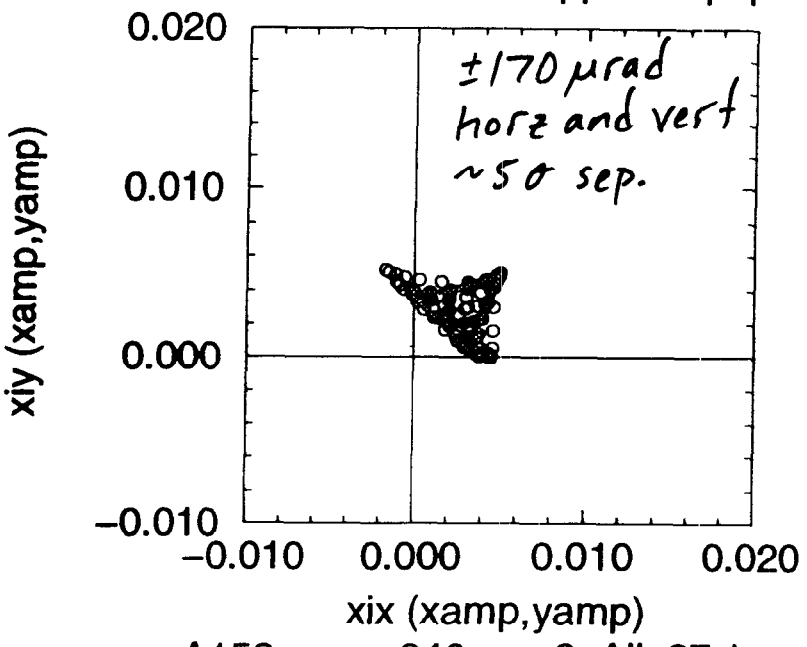



A152, All Crossing Points
$\sigma_s = 37.1$ cm
280 crossing points

These footprints have "folds".

These show the tune spread from <u>all</u> the crossing points.

v3h15acsb4a103a.nppn.170pnpn2

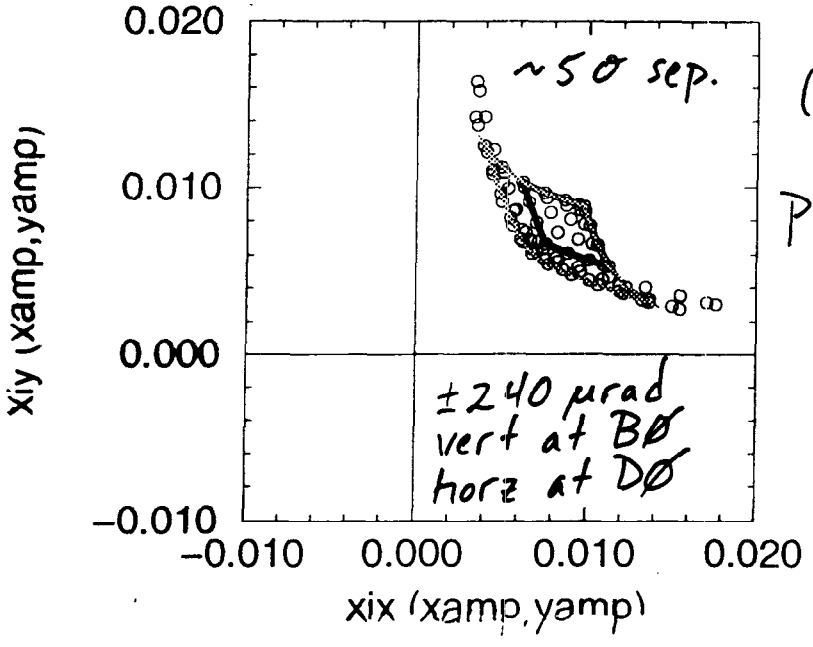


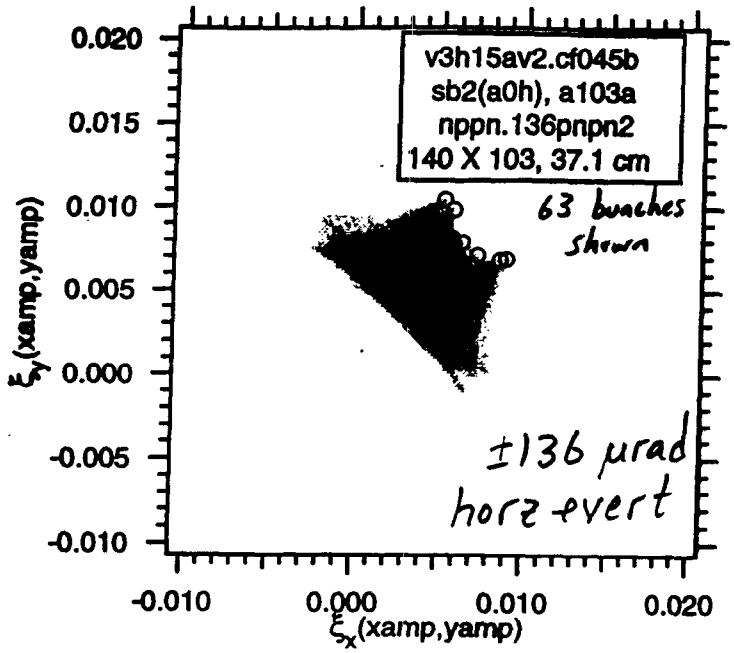

No sync motion
1 TeV
$20\pi$, $.087e-3 = \frac{\sigma_p}{p}$
$0 \to 4\sigma_\beta$, $\frac{1}{2}\sigma_\beta$ spacing

2 and $3\sigma_\beta$ "contours" shown
$(0,0) \to (3,0) \to (3,3) \to (0,3) \to (0,0)$

proton intensity = 270.e9 / bunch

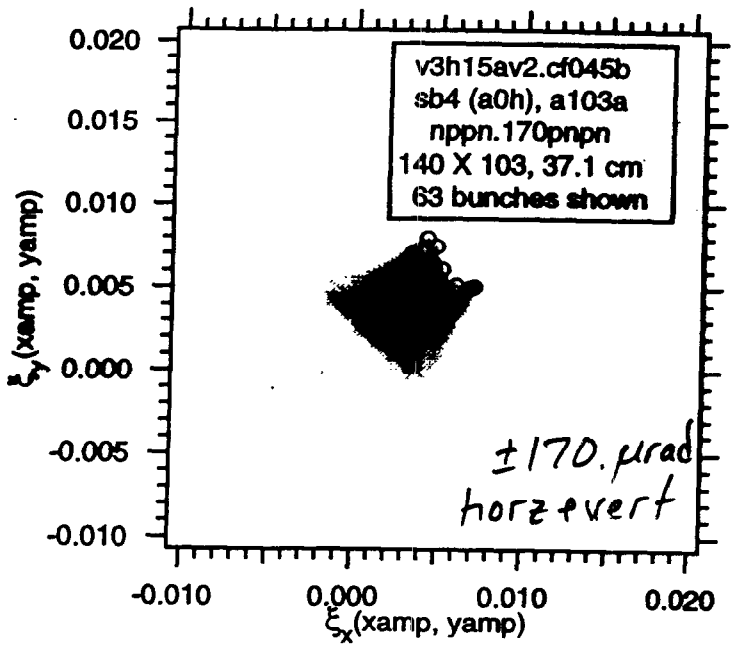
A152, pppp.240znnz2, All, 37.1 cm





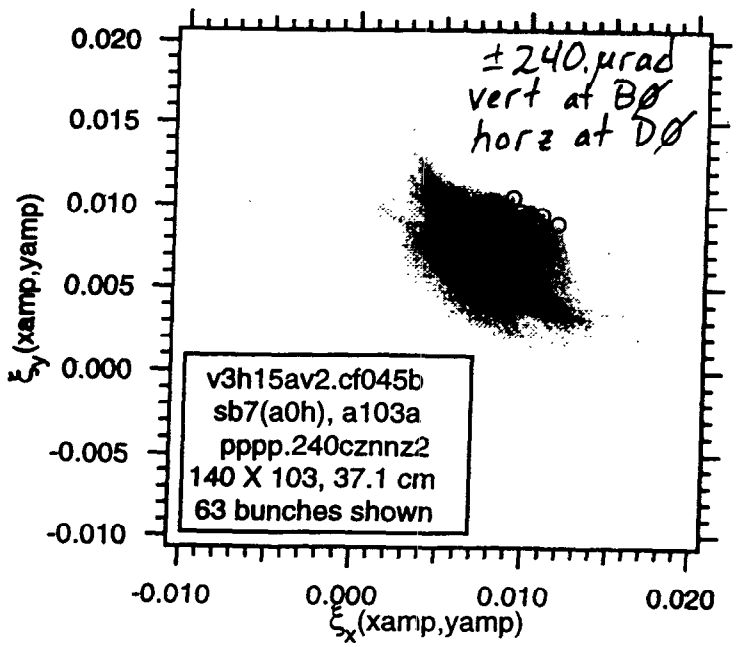

The 63 bunches are
~ the first 10
the middle 10
the last 10
in the long and short
pbar trains.

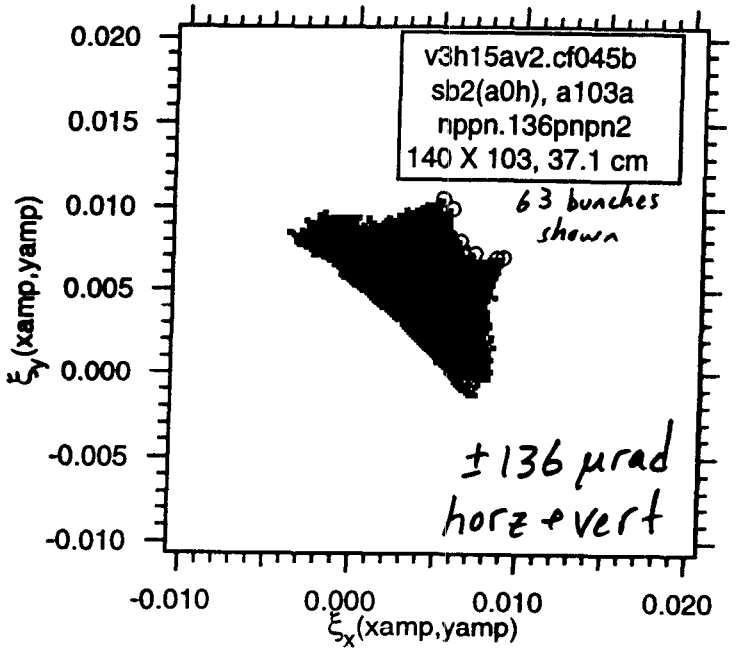
The open circles show the tune shifts for zero-amplitude pbars in each of the 103 pbar bunches.



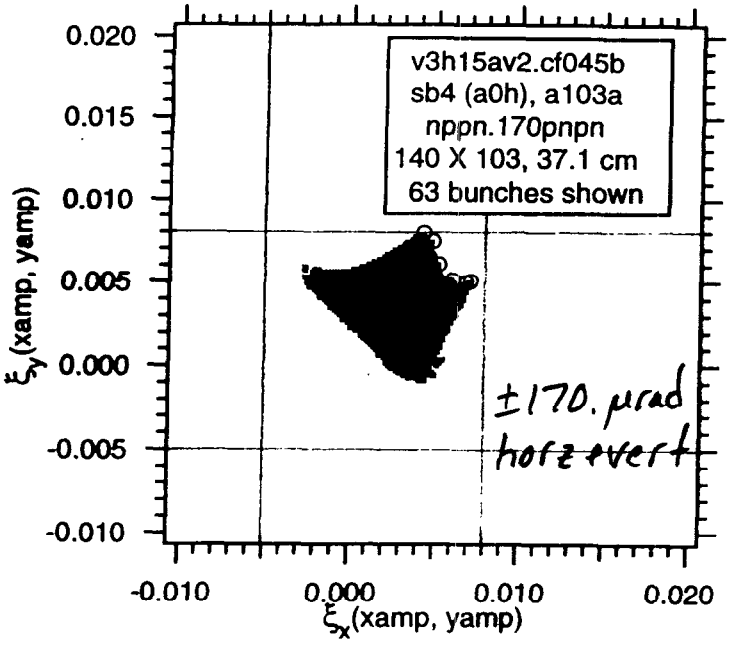

No sync motion
1 TeV
$20\pi$, $.087e-3 = \frac{\sigma_p}{p}$

proton intensity = 270.e9 /bunch

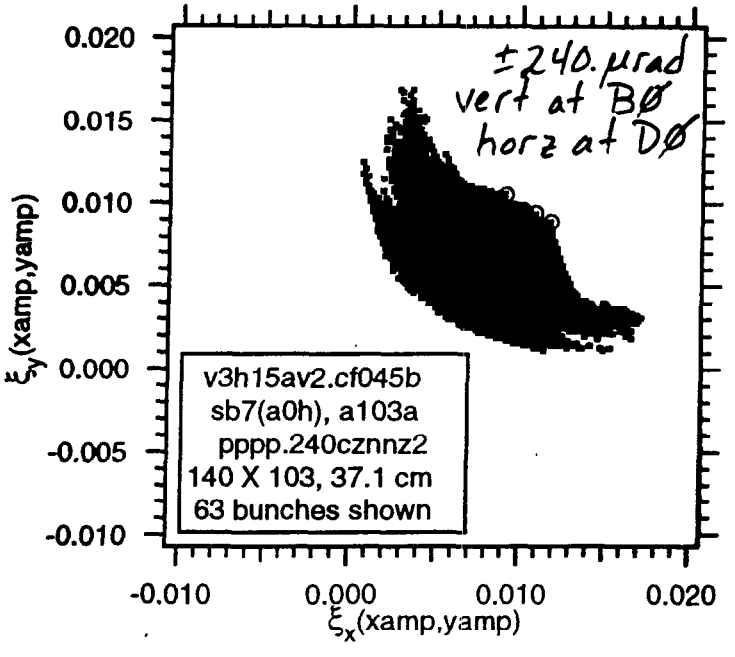





Area of "111."




Area of "74"




Area of "160"

v3h15av2.cf045b, sb2 (a0h), a103a, nppn.136pnpn
min dss is about 3.7
about 11 points with dss < 5
B+2, D-2 about 3.7 ←
B+-1, D+-1 about 4.0
B-2, D+2 about 4.7
290 (short arc) about 4.7
D-3, D-6, about 5.0
separation between about B17 and C17 is not that good, but
is probably adequate.
Need 3 vert separator modules at A17
for zero amp particles,
range in xix .00508
range in xiy .00490
range in bbsq cos .00562
range in bbsq sin .00506
max of (min tune split) after decoupling .0041
Footprint area. 111.4

v3h15av2.cf045b, sb4 (a0h), a103a, nppn.170pnpn
min dss is about 4.5 and is in the short arc
min dss near the IPs is about 4.7
6 points with dss < about 5
B+2 4.7
D-2 4.8
about 165 (short arc) about 4.5 ←
about 220 (short arc) about 4.7
about 285 (short arc) about 4.6 ←
about 402 (short arc) about 4.9
Need 4 vert separator modules at A17
for zero amp particles,
range in xix .00400
range in xiy .00416
range in bbsq cos .00394
range in bbsq sin .00495
max of (min tune split) after decoupling .0028
Footprint area 73.5

v3h15av2.cf045b, sb7 (a0h), a103a, pppp.240znnz
min dss is about 4.5
6 points with dss < about 5
B-4 about 4.6
B+4 about 4.6
D-4 about 4.4 ←
D+4 about 4.7
about 545 (short arc) about 4.5 ←
about 2095 (long arc) about 4.9
Need 3 vert separator modules at A17
for zero amp particles,
range in xix .00645
range in xiy .00509
range in bbsq cos .00180
range in bbsq sin .00383
max of (min tune split) after decoupling .0021
Footprint Area 159.9

# Recap of 15L nsec

1) Synchro-$\beta$tron resonances from crossing angle at IP
2) Small Separation at first few near misses.

Trade off with size of angle

3) Loss of <u>peak</u> Luminosity

   <u>If</u> we can recycle pbars (60% effic. or better)

   and

⟹ <u>If</u> we can find good operating conditions with the crossing angle

   Then its less than a 10% loss in <u>integrated</u> Luminosity.

4) Size of beam-beam footprint from IPs is much smaller with crossing angle.

   Shape of footprint also changes somewhat.

5) Off-center in the low $\beta$ Quads

   Worried about multipole content.

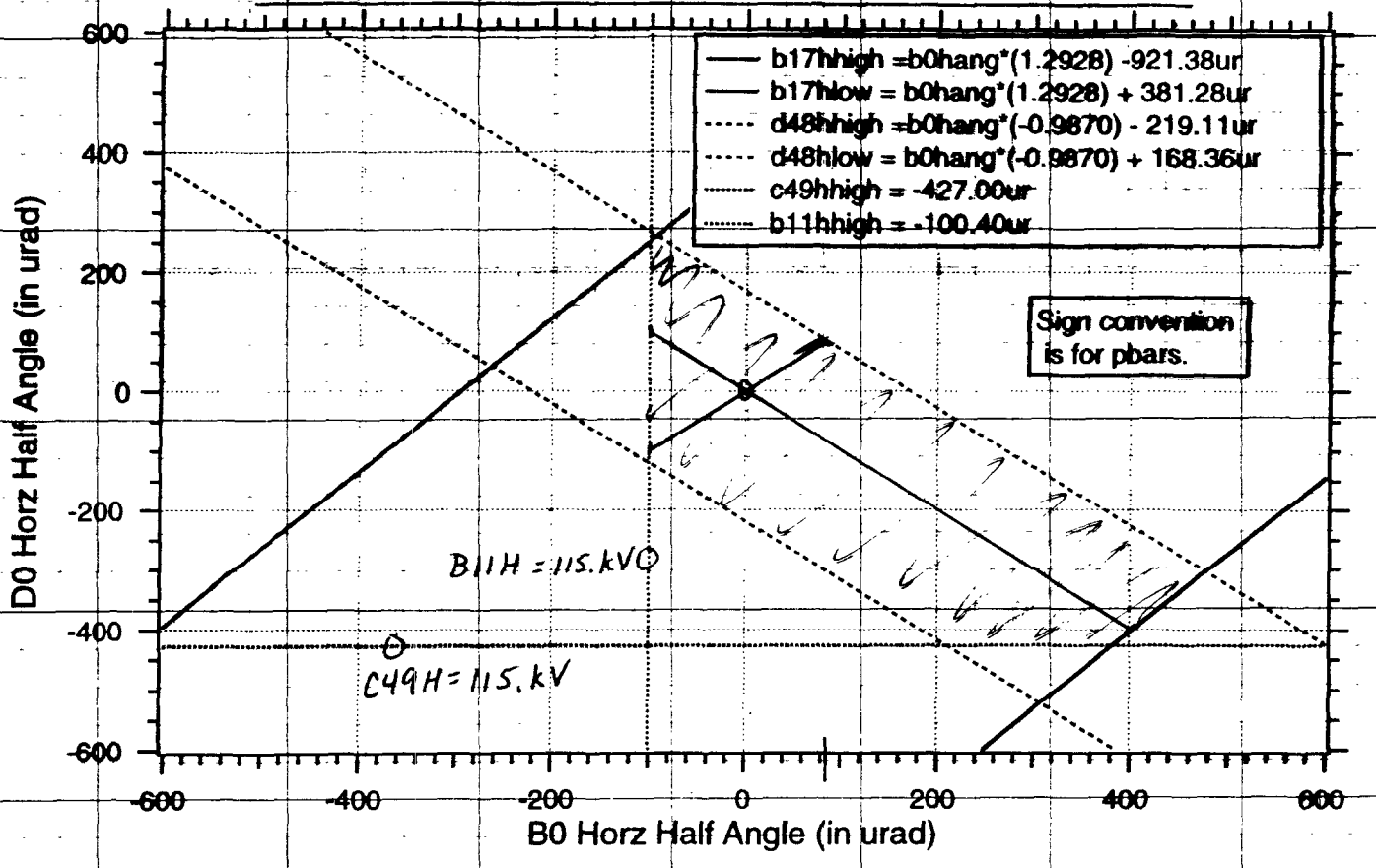
6) Significant beam beam dipole kicks with ~100 bunches/beam

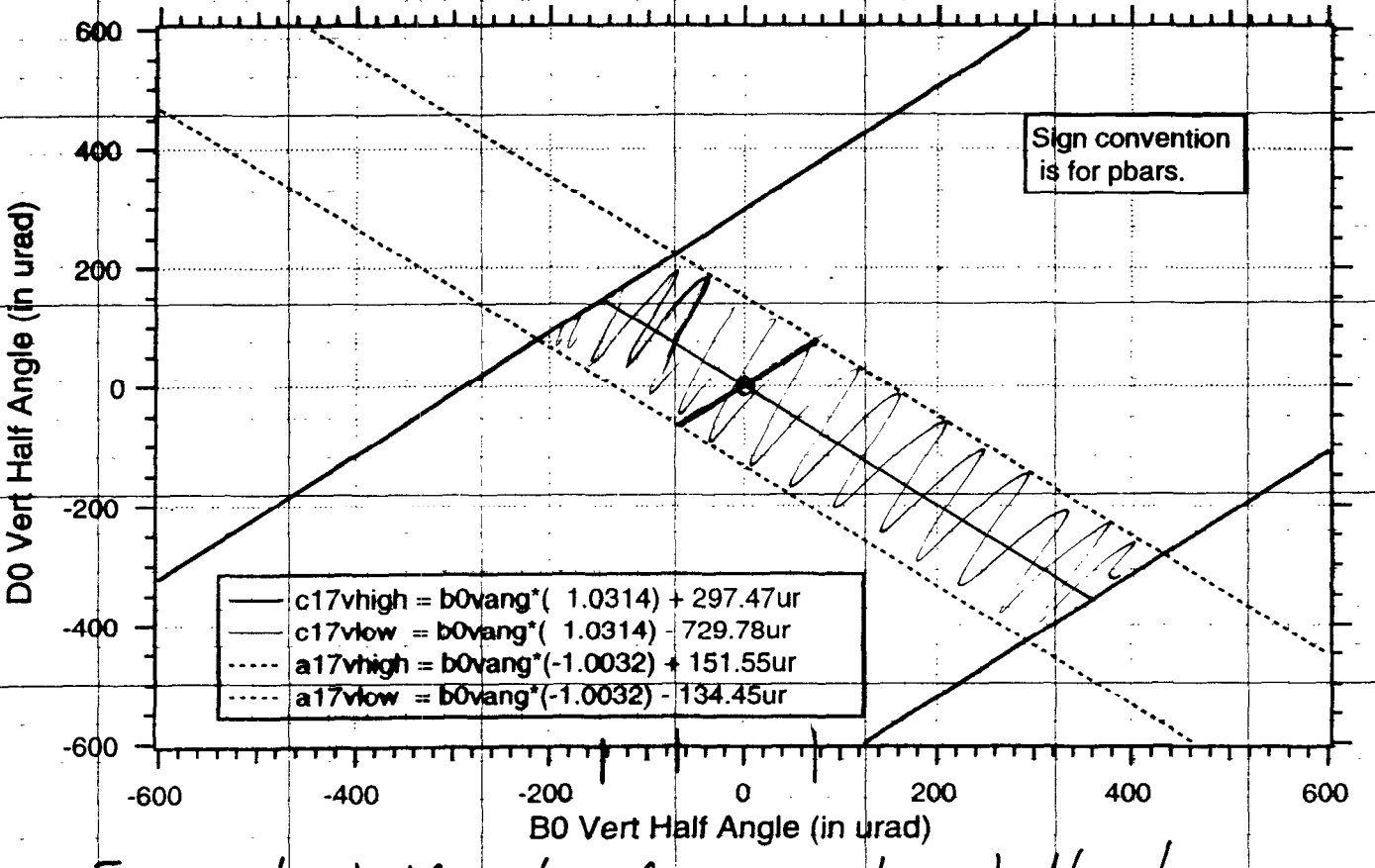
7) We've got reasonable looking collision conditions, but we do NOT have a full path (lattices and separator settings) to get a store there.

   This is NOT a problem for 36x36 studies.

v3h15av2.cf045b, nppn collision helix

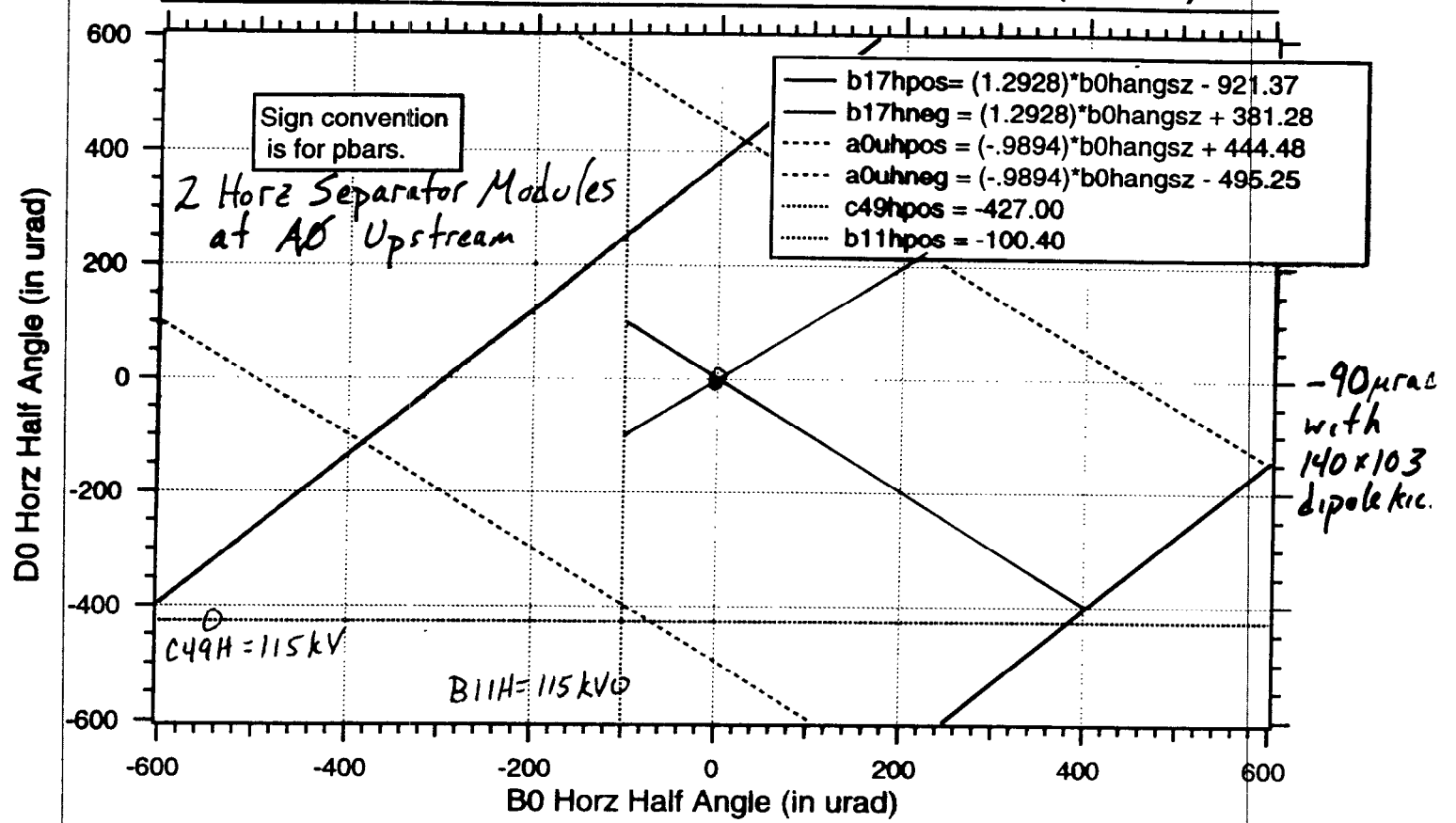
Allowed crossing angles for seps < 4.60 MV/m (115kV)

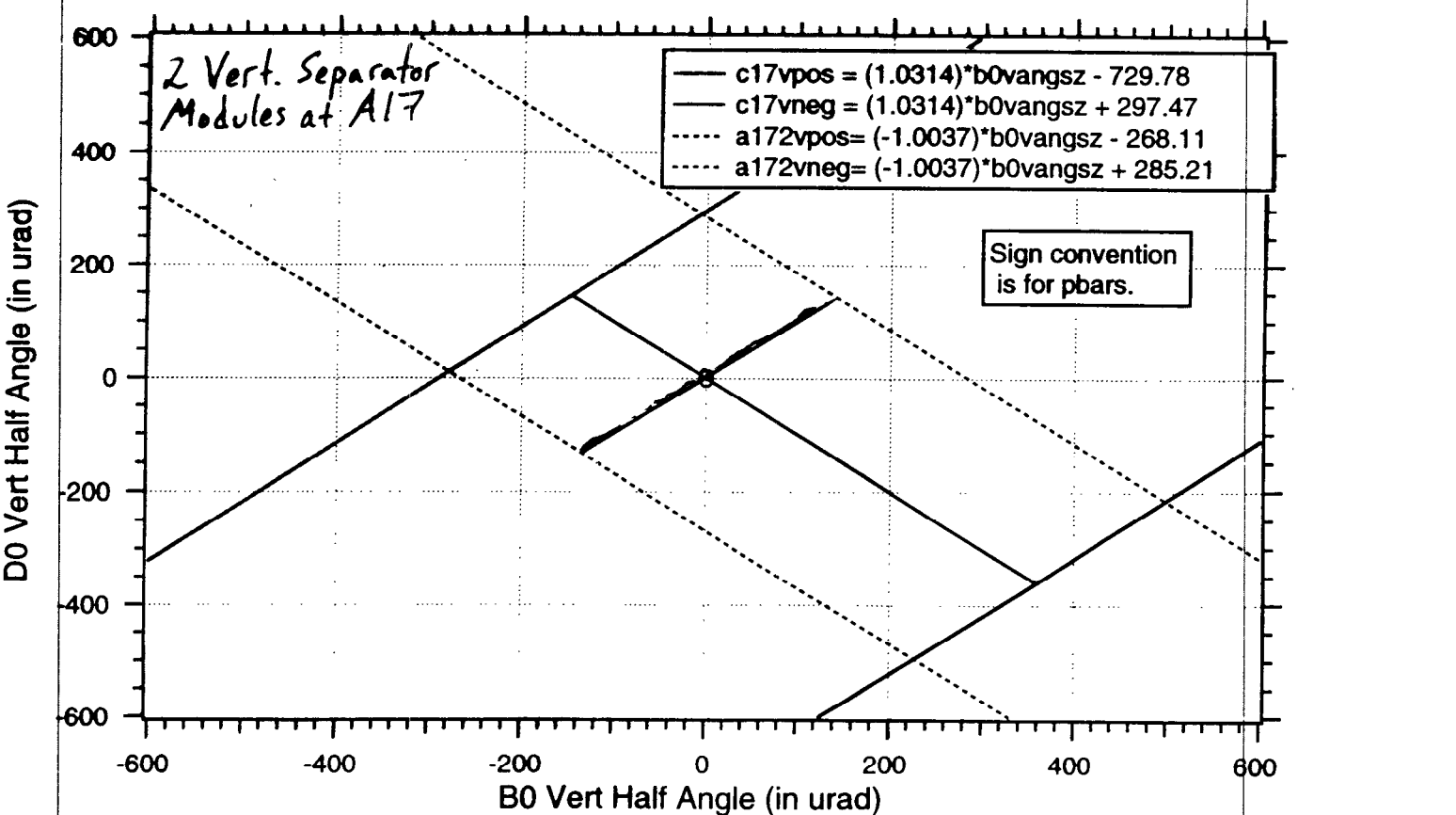


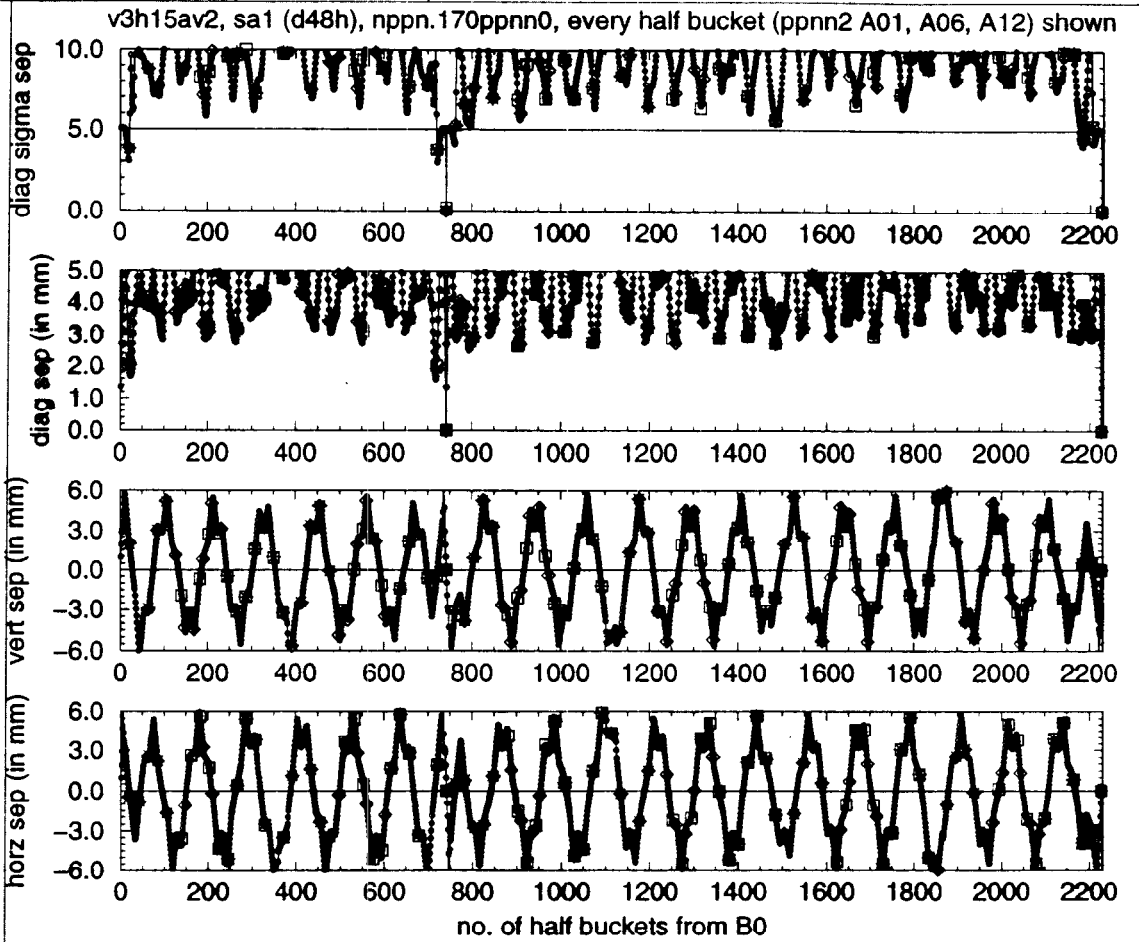

For scale half angles of 136. μrad in both planes give about 4σ separation at the first 132 nsec crossing points.

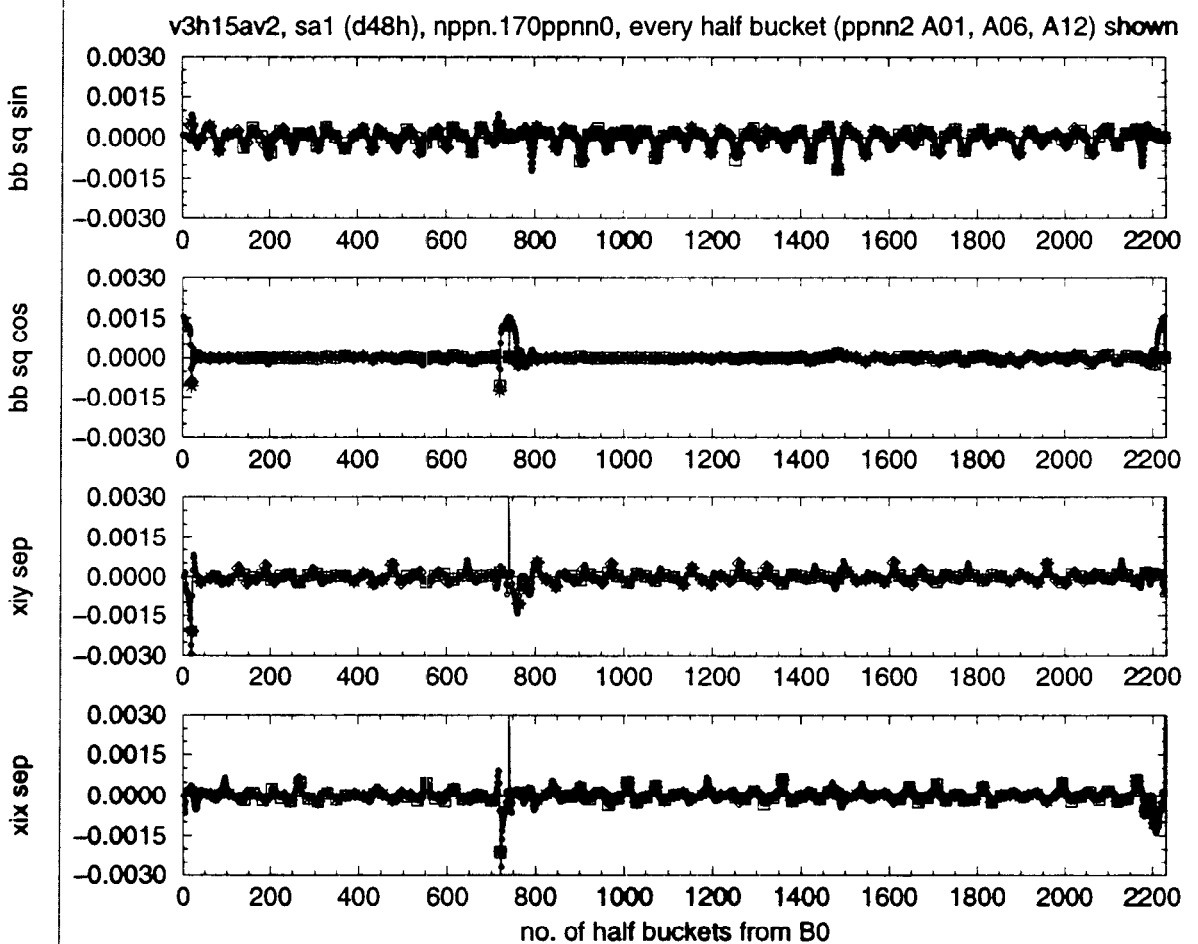
# Allowed crossing angles for seps < 4.60 MV/m (115kV)

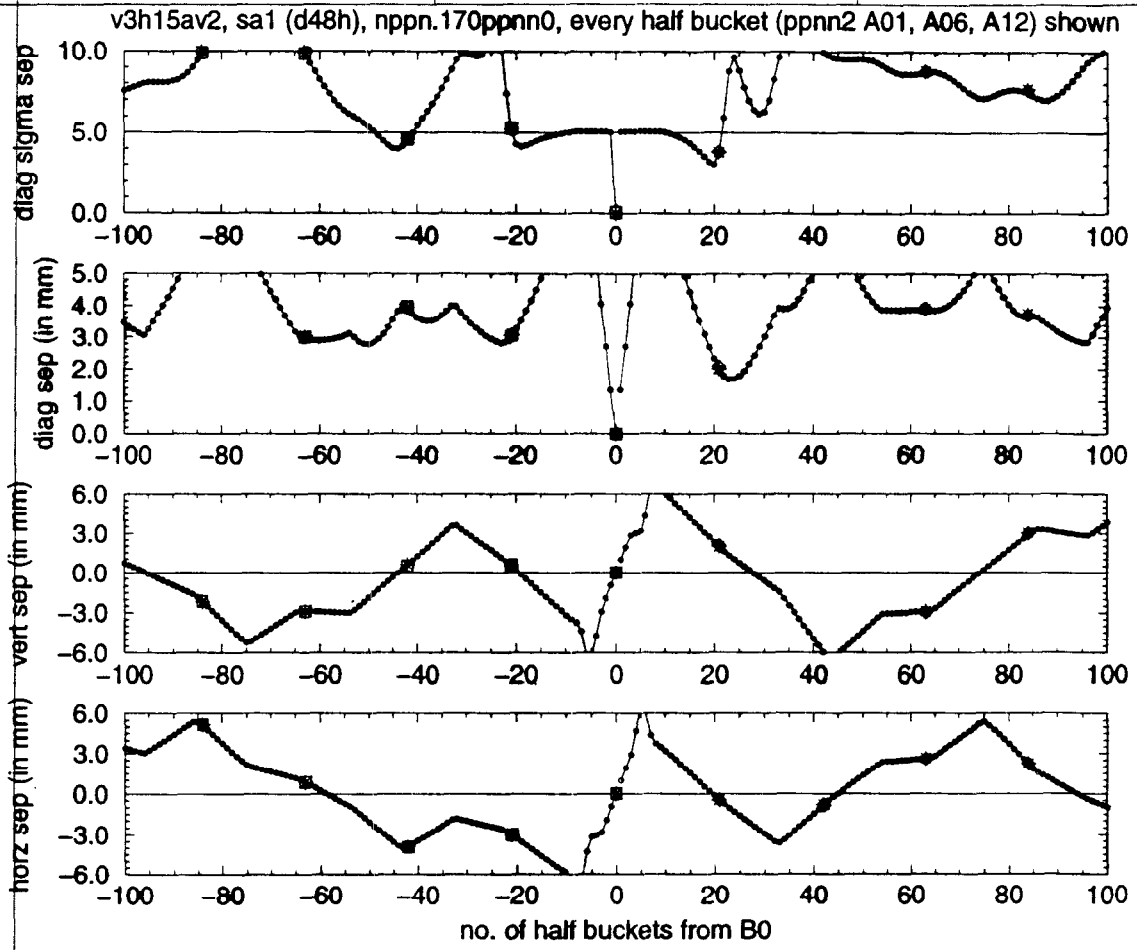


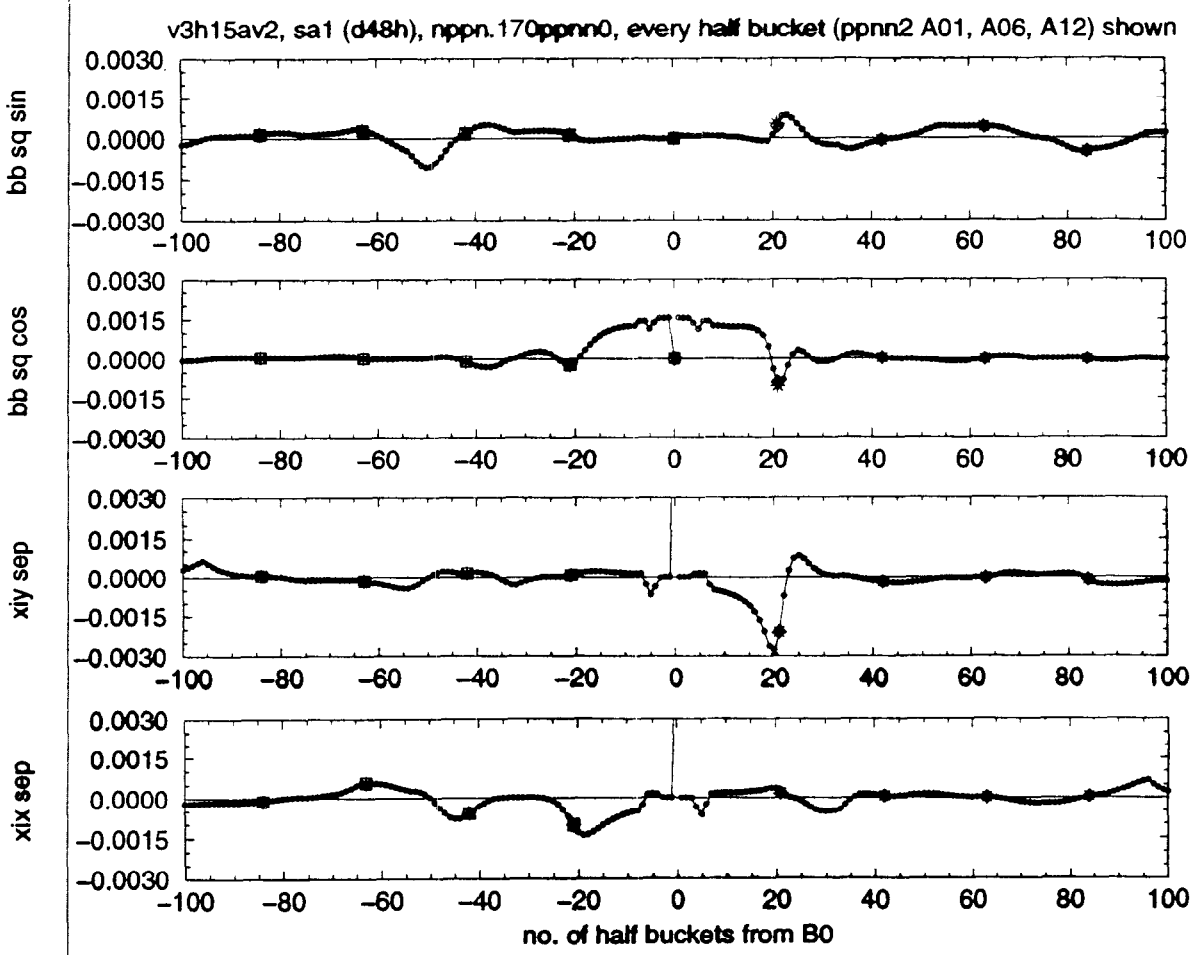



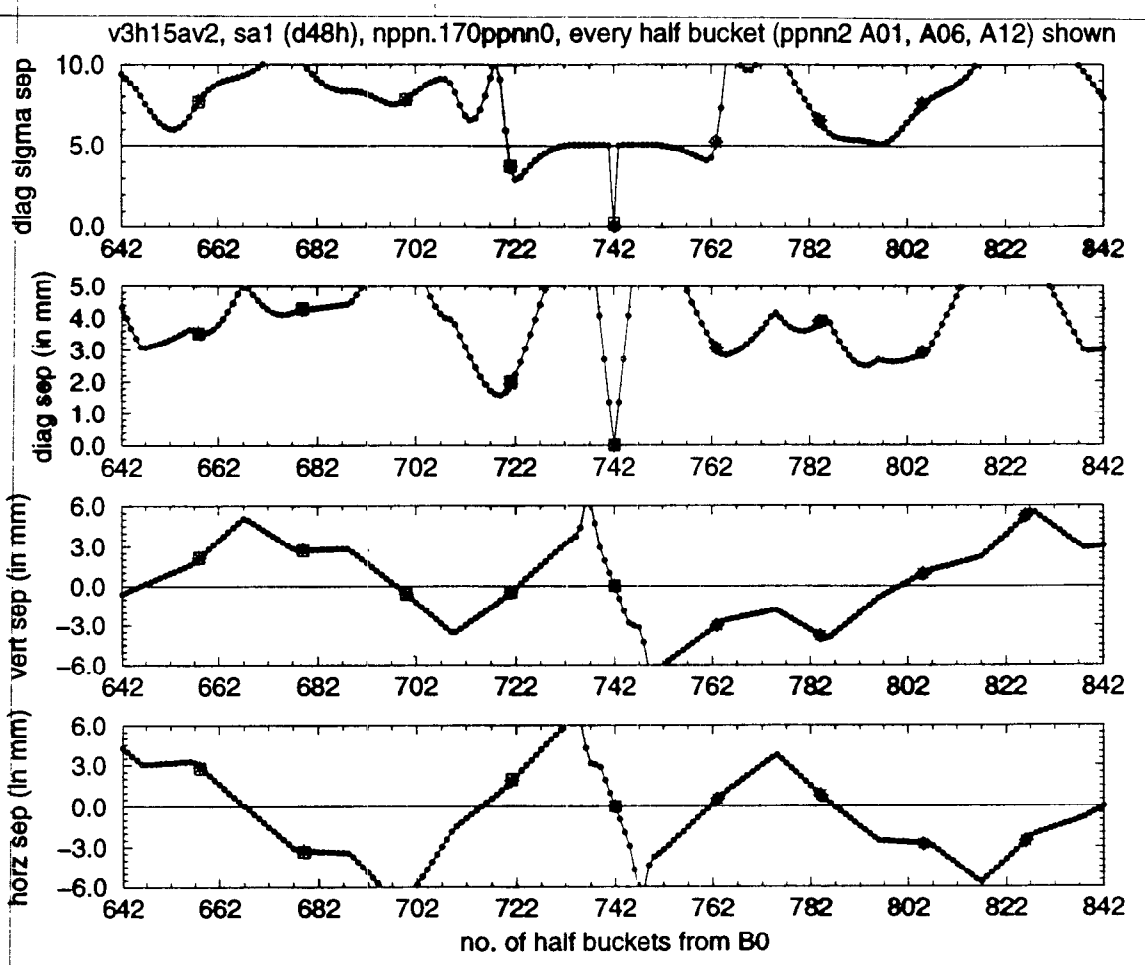

+90 μrad
with 140x103
dipole kicks

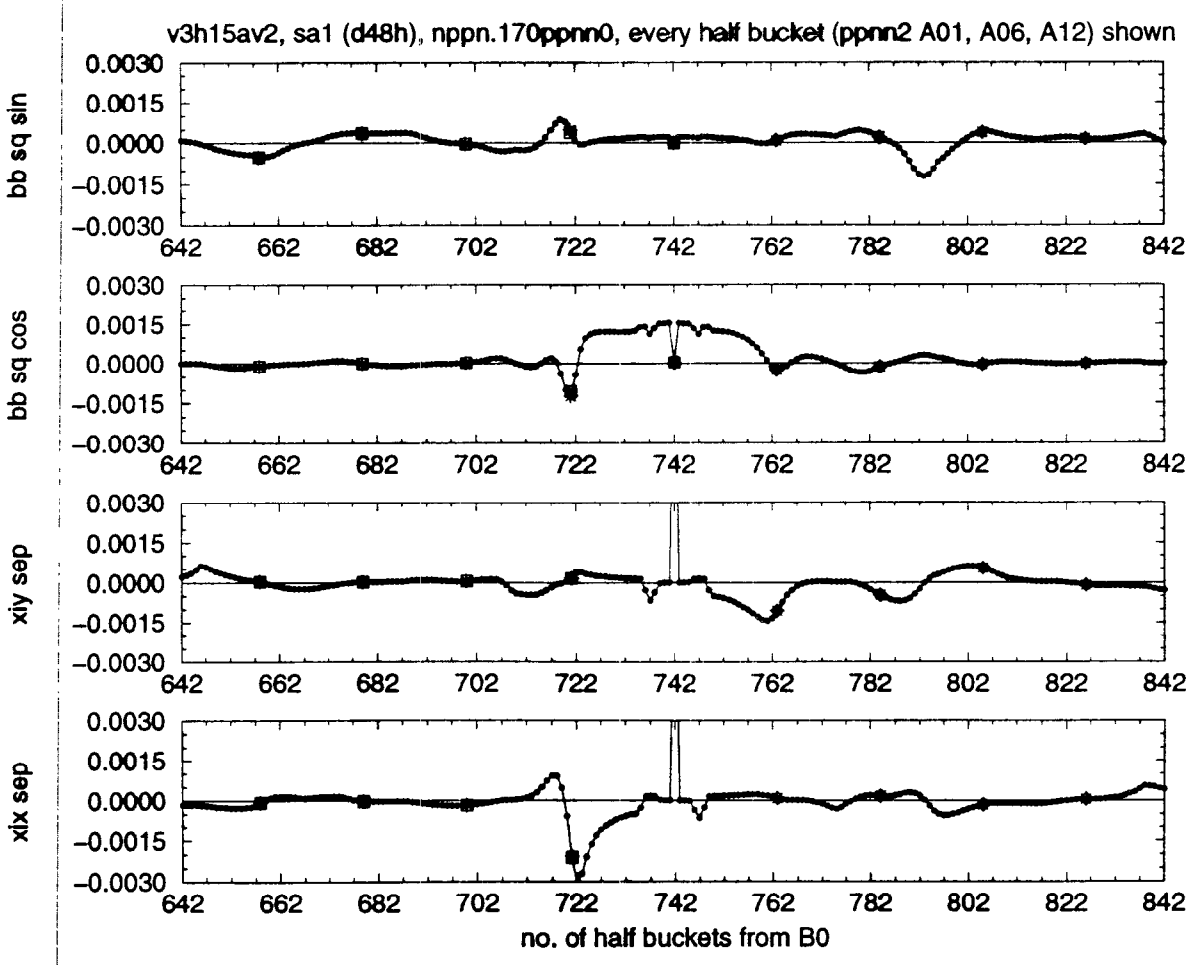

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
diag sigma sep
diag sep (in mm)
vert sep (in mm)
horz sep (in mm)
no. of half buckets from B0

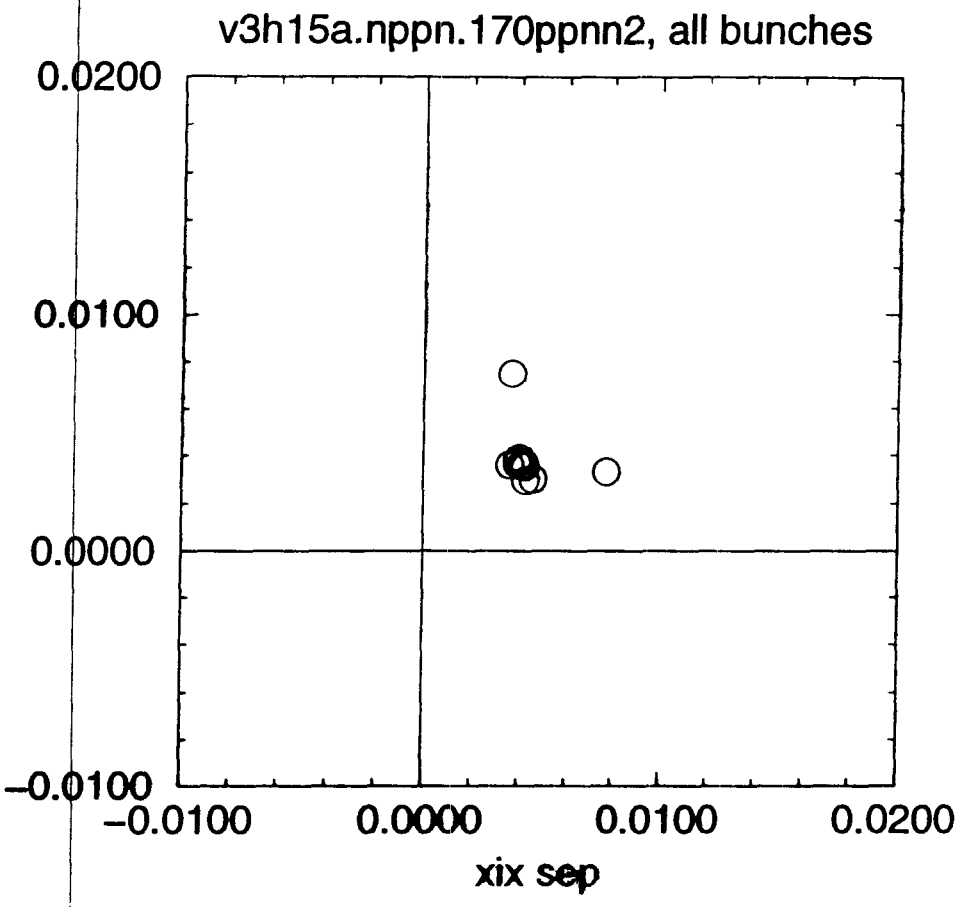

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
bb sq sin
bb sq cos
xiy sep
xix sep
no. of half buckets from B0

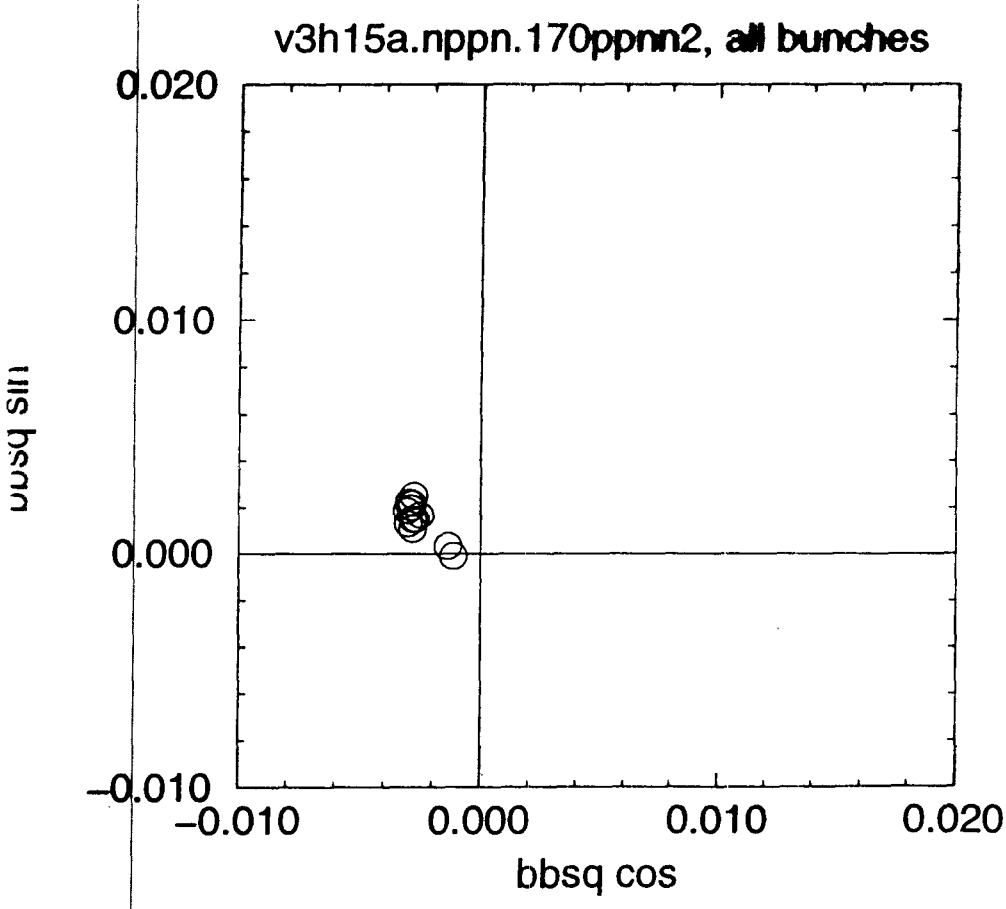

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
diag sigma sep
diag sep (in mm)
vert sep (in mm)
horz sep (in mm)
no. of half buckets from B0

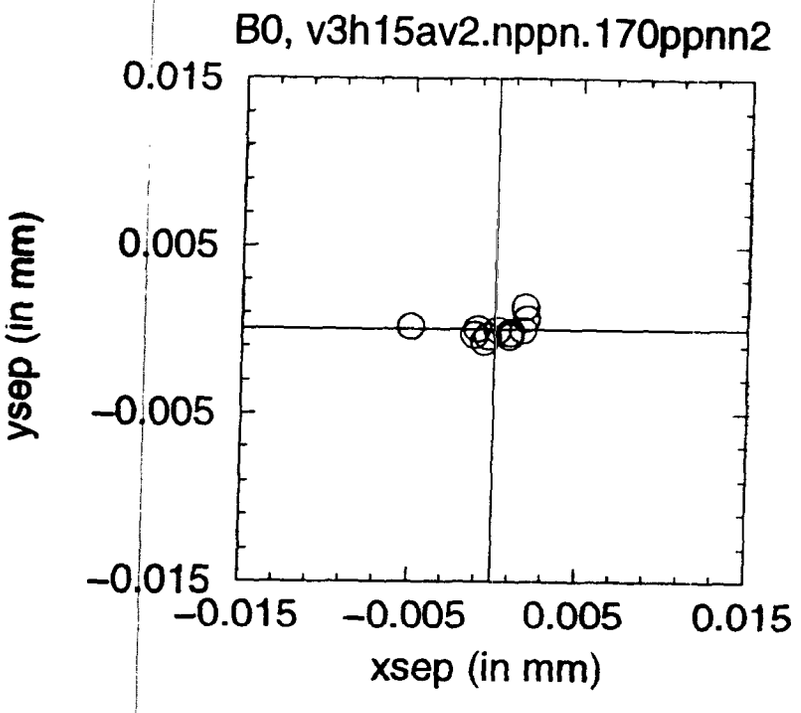

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
bb sq sin
bb sq cos
xiy sep
xix sep
no. of half buckets from B0

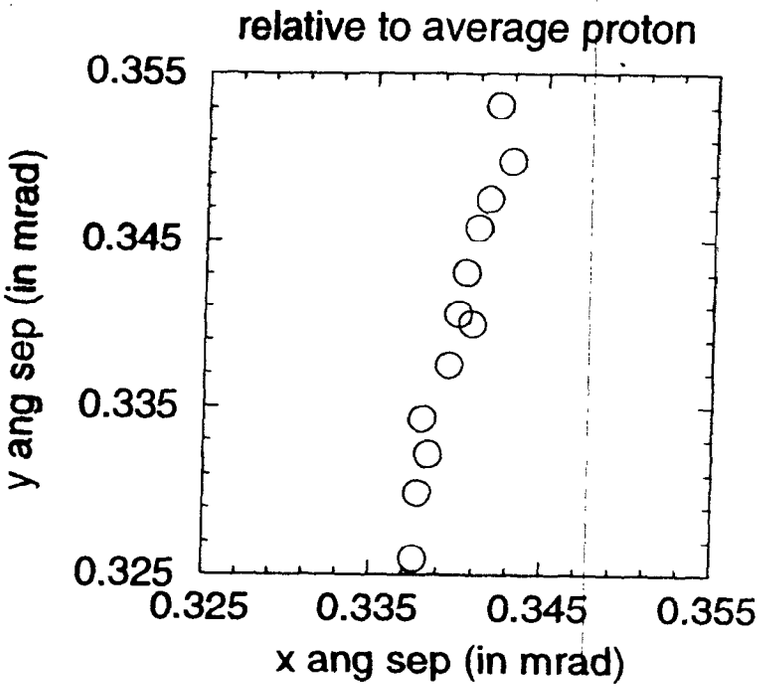

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
diag sigma sep
diag sep (in mm)
vert sep (in mm)
horz sep (in mm)
no. of half buckets from B0

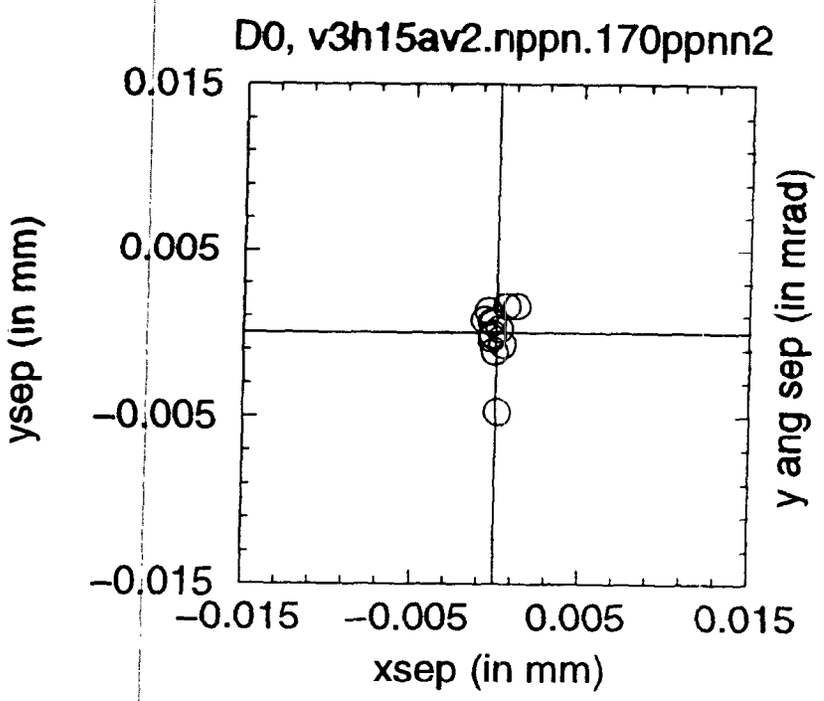

v3h15av2, sa1 (d48h), nppn.170ppnn0, every half bucket (ppnn2 A01, A06, A12) shown
bb sq sin
bb sq cos
xiy sep
xix sep
no. of half buckets from B0

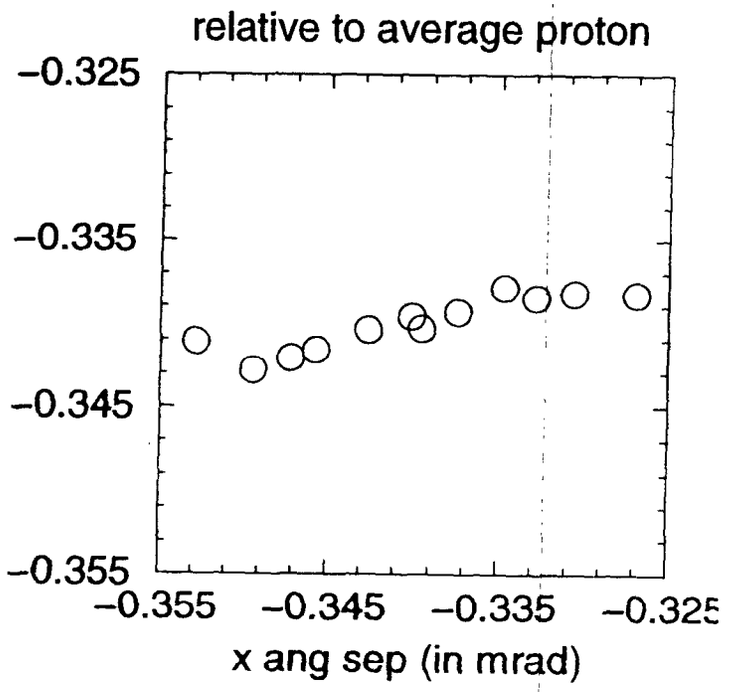

v3h15a.nppn.170ppnn2, all bunches
0.0200
0.0100
0.0000
−0.0100
−0.0100
0.0000
0.0100
0.0200
xix sep

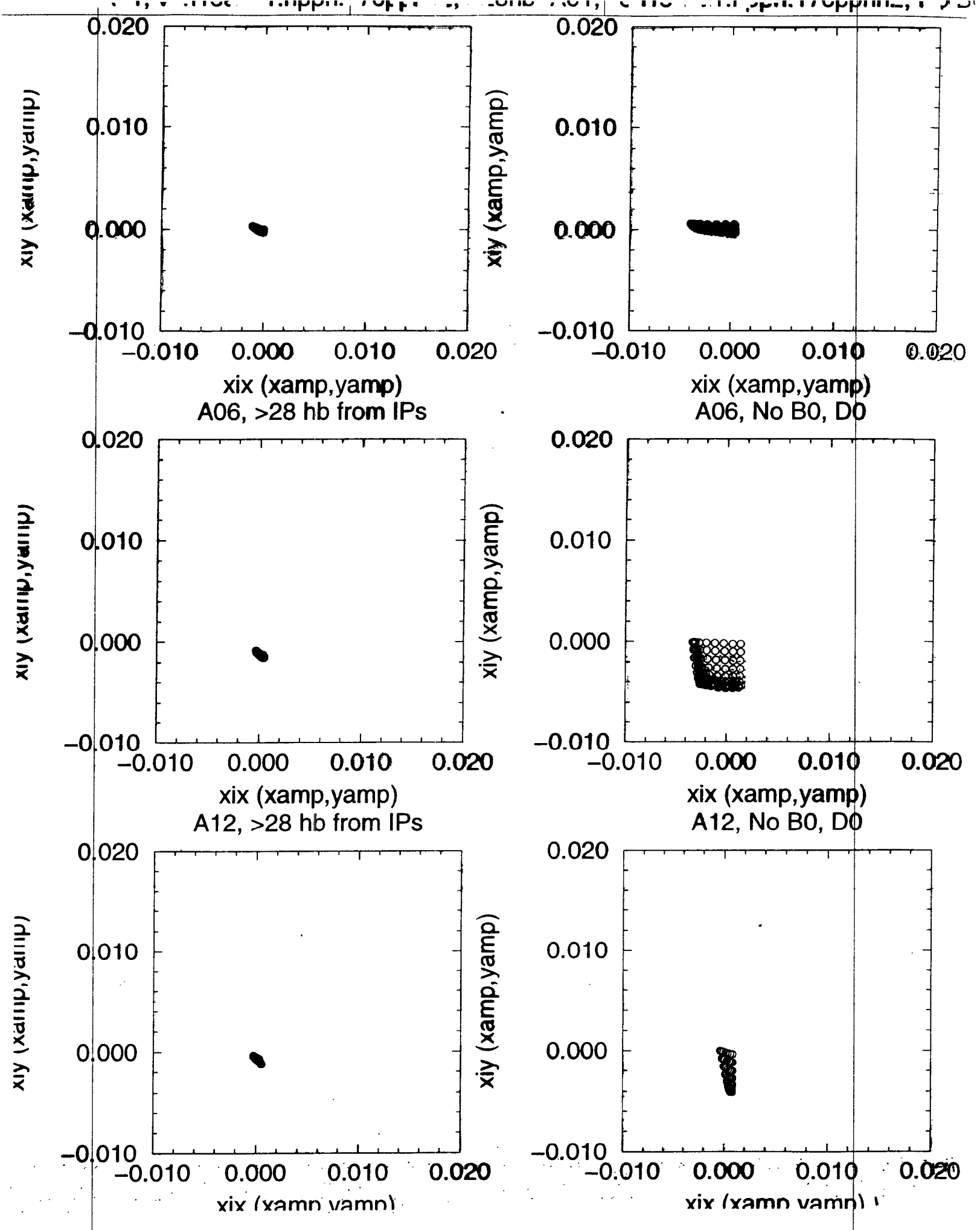

v3h15a.nppn.170ppnn2, all bunches
0.020
0.010
0.000
−0.010
−0.010
0.000
0.010
0.020
bbsq cos
bbsq sin


B0, v3h15av2.nppn.170ppnn2
0.015
0.005
−0.005
−0.015
ysep (in mm)
−0.015
−0.005
0.005
0.015
xsep (in mm)

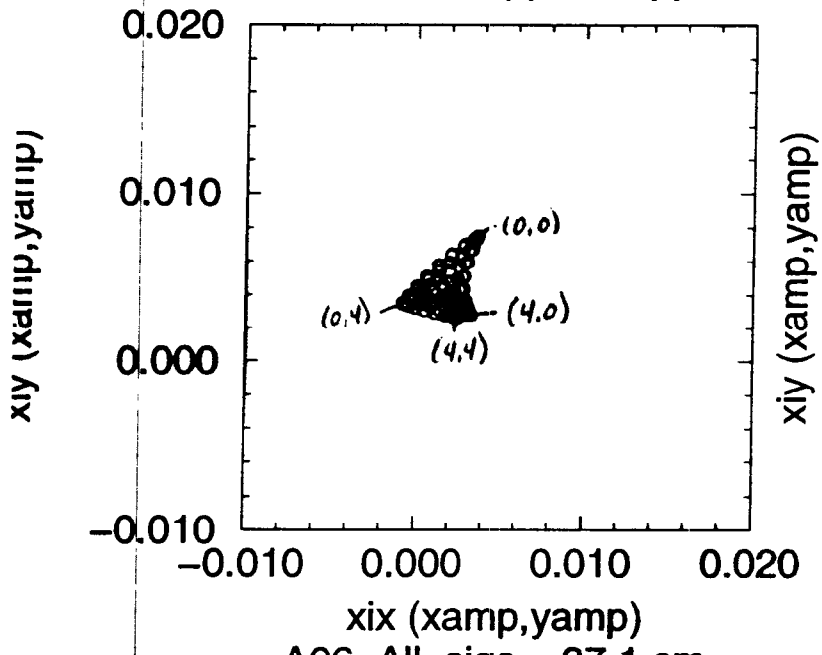

relative to average proton
0.355
0.345
0.335
0.325
y ang sep (in mrad)
0.325
0.335
0.345
0.355
x ang sep (in mrad)


D0, v3h15av2.nppn.170ppnn2
0.015
0.005
−0.005
−0.015
ysep (in mm)
−0.015
−0.005
0.005
0.015
xsep (in mm)

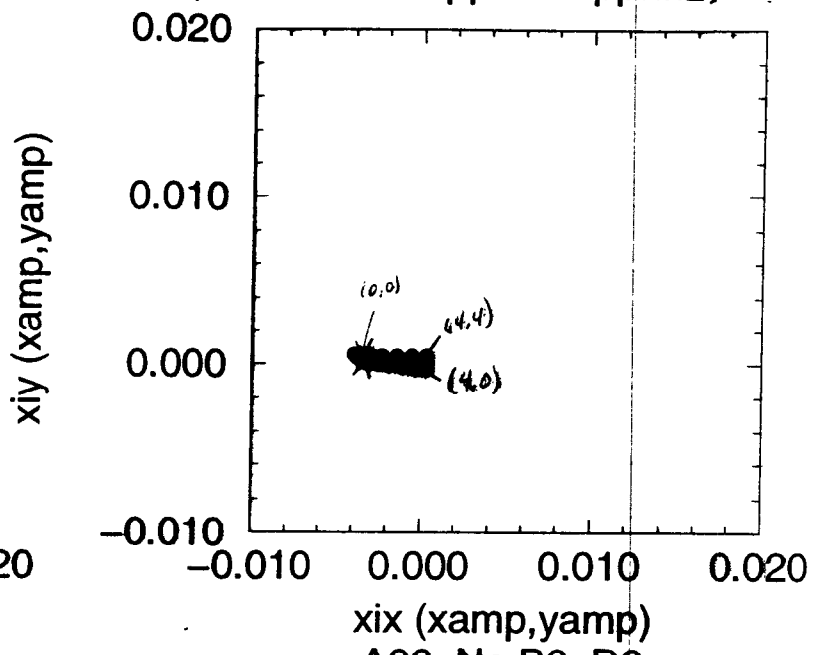

relative to average proton
−0.325
−0.335
−0.345
−0.355
y ang sep (in mrad)
−0.355
−0.345
−0.335
−0.325
x ang sep (in mrad)


0.020
0.010
0.000
−0.010
−0.010
0.000
0.010
0.020
xix (xamp,yamp)
xiy (xamp,yamp)
A06, >28 hb from IPs
A06, No B0, D0
A12, >28 hb from IPs
A12, No B0, D0

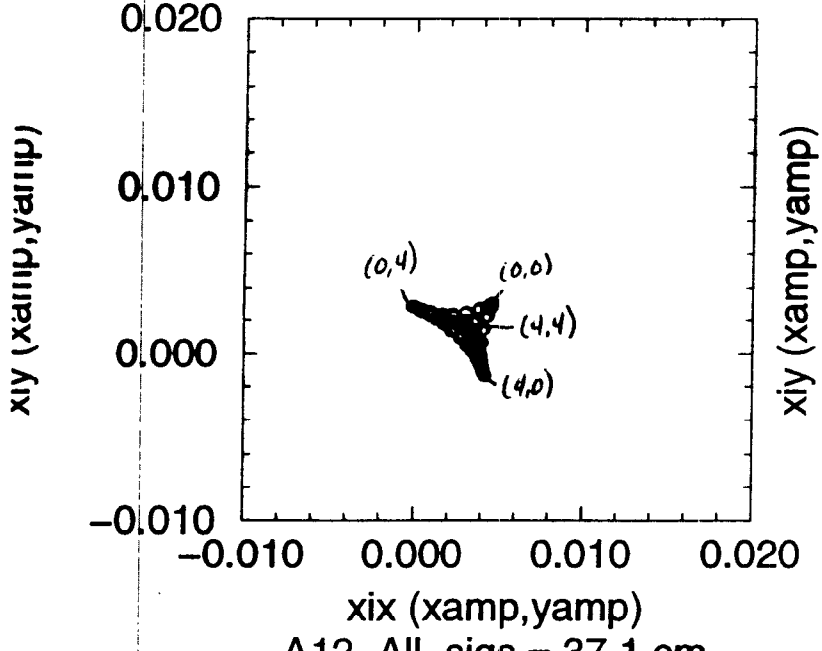
A01, v3h15asa1.nppn.170ppnn2, All



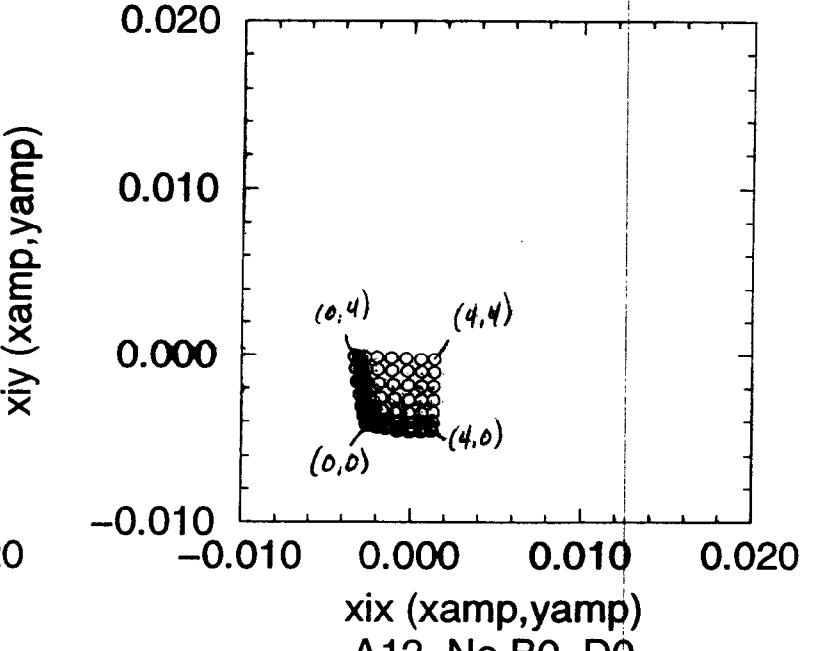

A01, v3h15asa1.nppn.170ppnn2, No B



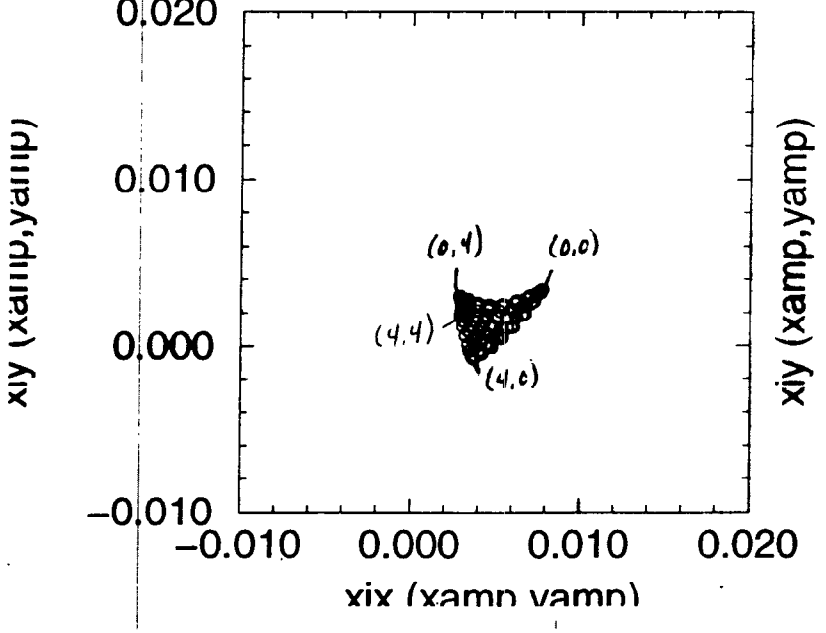

A06, All, sigs = 37.1 cm



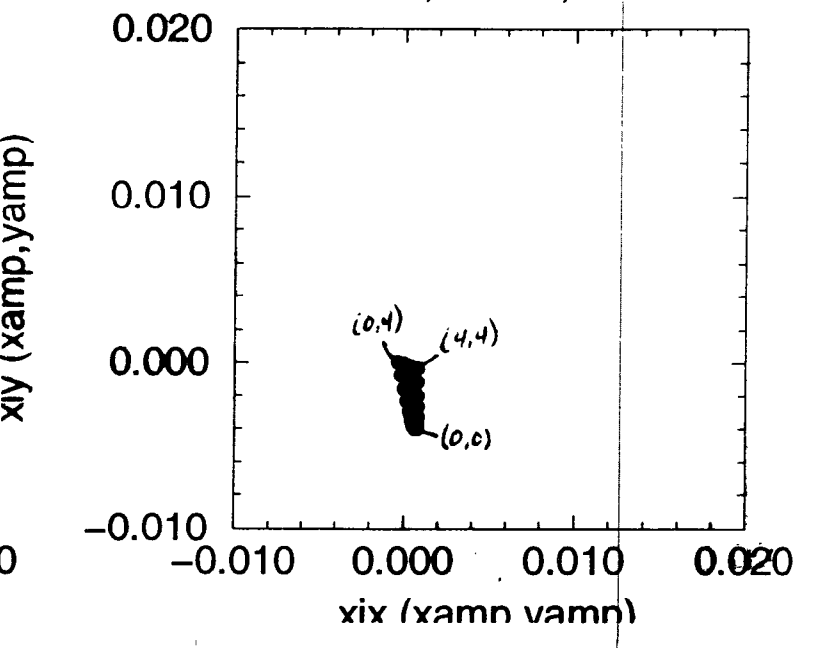

A06, No B0, D0




A12, All, sigs = 37.1 cm




A12, No B0, D0



Start from head-on colliding beam conditions
(~1 TeV, $\beta^* = 35.$ cm)

Turn up crossing angle until losses/lifetimes get bad.

Retune to try to bring down losses, improve lifetimes

Separation Bumps
Tunes, Differential Tunes
Chromaticity
Coupling
Cogging, etc.

Sextupole Distribution?
Octupoles??
Rescrape
Orbit bumps

If successful, continue increasing crossing angle
Try for $\approx$ $\pm 136.\ \mu rad$/plane
$\pm 170.\ \mu rad$/plane.

Depending on how often we have to re-tune, maybe just try "jumping" to these angles.

If things are really bad, maybe try with:
smaller proton intensities.
larger $\beta^*$

0) Get to the point where you can try it.

We should be <u>wary</u> of beam beam experiments or studies <u>before</u> we've established "reasonable" colliding beam conditions.

For beam beam experiments, almost everything has to be working.

When will we have ~200.e9 proton intensities?

Pbars may be fine against 100.e9 protons, but falling out against 300.e9 protons.

We don't expect to get many pbars during the engineering run (May → July 2000).

Most of what we get will probably go to establishing 36 x 36 conditions.

1) Give it a try. Put in the crossing angle and see what happens.

(Many of the suggested studies <u>assume</u> "reasonable, somewhat stable" conditions. e.g. at least 1-2 hr lifetimes)

In my experience, for many beam-beam experiments that basically try out an idea:

If it "works" or looks promising with more tuning

⇒ Great, its adopted.

But if it doesn't work, its dropped, usually without much effort at understanding <u>why</u> it didn't work.

With crossing angles we may not have the luxury of dropping it.

1.5) Are conditions pretty [illegible] expected [illegible]

to be? Is something really wrong?

This is a big part of why we need to establish "reasonable" 36×36 (Head On) colliding beam conditions before starting crossing angle studies.

Are the linear optics OK?

Check for $\beta$ waves, tune $\alpha^*$ bumps, check $\eta^*$

Separation between beams at IP

Check cogging, Is the separation in the arcs OK?

Do the separator bumps do what's expected?

Single beam resonances?

$\mathcal{L}$ as a function of crossing angle

Tunes and tune spectra as a function of crossing angle.

Tune shifts with amplitude??

2) If things are still bad even with expected conditions, then we've got to try to <u>understand</u> what's happening.

From simulations, what are the <u>mechanisms</u> by which particles get to large amplitudes?

What are the important resonances and particle amplitudes?

What drives these resonances? Main IP? First few near misses?

Many crossings in the arcs?

The conditions in the simulations will <u>never</u> be quite the same as what we have in the machine.

We need to have a feel for <u>why</u> the simulations behave as they do.

# End of store studies vs. Dedicated stores.

End of stores

Slightly bigger emittances, Smaller intensities

Saves an hour or two of shot setup

Has been easier to get

Slightly less prone to downtime

Get handed a working machine with beams in a "reasonable "stable condition

How much emphasis on trying to recycle pbars?

We may at least start with end of stores.

Dedicated Stores

Have to do a full shot setup.

If something breaks during shot setup, the clock is still running.

Could do 2 x 1 bunches, "unusual" conditions

If we're doing unusual conditions, may have trouble getting beam to colliding beam conditions.

Will have smaller emittances, higher intensities.

Pbar intensity could be much higher if we only take a single bunch.

In crossing case

How do we get to crossing angle configuration?

Knob separators?

Ramps to take out lattice modifications for the collimation scheme?

Is the collimation scheme OK for our proposed configuration?

Try it with a single beam first.

Make sure the mechanics work before we try it with colliding beams.

Make sure any special instrumentation, diagnostics, or <u>techniques</u> are already checked out and working.

If we're trying something special establish the technique as much as possible with single beams in "easy conditions"

A simple example:

We don't want to establish pbar tune measurements on crossing angle studies time.

Games we can play to try to separate contributions
But combinations may be important!

Synchro-betatron resonances from main IPs
vary size of crossing angle.

Off center in low $\beta$ quads ↑ linked to size of angle.
If there is enough aperture, we could try to center the pbars and push the protons twice as far off the centerline.

First few near misses - Not an issue with 2×1
With 36×36 have 2 with dss ≈ 3.7

Beam beam dipole kicks - Smaller effect with 36×36
Not an issue with 2×1

Larger $\beta^*$ smaller divergence at IP
less crossing angle needed for given separation

$\theta^*$ is larger by $\sqrt{\beta}$

$\frac{\delta\theta_s}{\theta^*}$ is smaller by $\frac{1}{\beta}$

Linked

- Synchro-Betron - vary size of crossing angle
- First near misses → Not an issue with 2x1
- Off center in low $\beta$ Quads - If there is enough aperture could center the pbars. push protons twice as far off.
- Beam beam dipole kicks → Not as much of an issue with 36x36
  Not an issue with 2x1

Larger $\beta^*$ - smaller divergence at IP
- less crossing angle needed for given separation
  $\theta^*$ is larger by $\sqrt{\beta}$
  $\frac{\delta\theta_s}{\theta_x^*}$ is smaller by $\frac{1}{\beta}$