A SCHEME FOR $\mathcal{L} = 5 \times 10^{31}\ cm^{-2} s^{-1}$ IN THE TEVATRON

features:

- many bunches to minimize the number of interactions / crossing
- electrostatic separators in both planes to reduce number of crossings (to control beam-beam tune shift)
- shuttered injection / abort kickers to allow proton beam replacement. e-s separators used here, too.
- new low β insertion (Y4m) with e-s separators
- acceleration / deceleration operation to allow proton replacement and $\bar{p}$ addition or refreshment. can use the Tevatron as an additional accumulator.

Numbers of bunches:

$$\frac{n_{hits}}{x\,ing} = \frac{\mathcal{L}\sigma}{n_b f_{rev}}$$

for $\cancel{150}^{144} \times \cancel{150}^{144}$, $\frac{n_{hits}}{x\,ing} \sim \frac{2}{3} = .73$

100 mB, 5×10^{31}

why $\cancel{150}^{144}$? Jim Griffin will tell.

$$1113 = 3 \times 7 \times 53$$

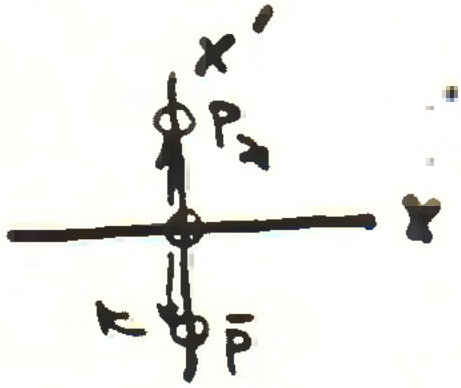
every 7th rf bucket gives 159 bunches, leave $\cancel{8}^{15}$ out for end effects. (132 ns twist most crossings)

---

1 bunch/12 rf buckets is also a possibility, but since we have a scheme for the 1/7 case and more bunches is better....

Electrostatic Separators

needed to reduce the number of head-on bunch crossings (here 3/IR ⇒ 6) with B∅ and D∅ only



$$x' \sim \theta = \frac{eVl}{E}$$

practical experience ⇒ $V \lesssim 50\,\mathrm{KV/cm}$

injection → so 5m of 50KV/cm ⇒ ~270 μr kick at 150 GeV

low β → or 4m at 1TeV ⇒ 20 μr

$$\xi(z) = \frac{\theta\sqrt{\beta_s\,\beta(z)}}{2\sin\pi\nu}\cos\left(\left|\psi_{sep} - \psi(z)\right| - \pi\nu\right)$$

≈ 1.9

$= \pm 2.3$ mm for $20\mu r$ if $\beta_s = 500$ m
if $\beta(z) = 100$ m

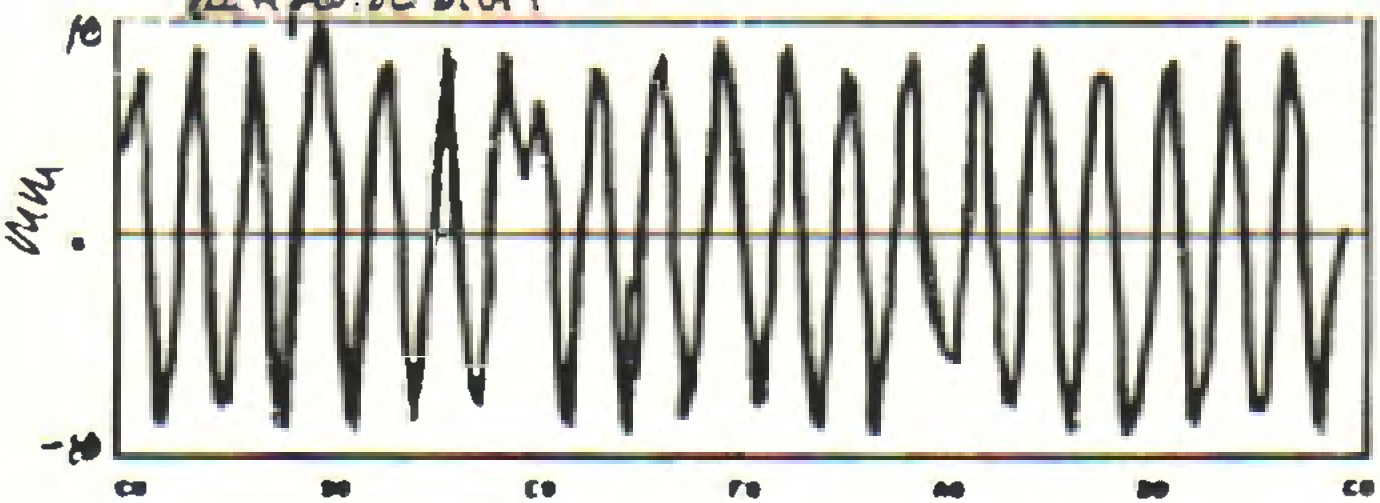
$$\sigma(z) = \sqrt{\epsilon\beta(z)} = 0.56 \text{ mm}, \quad \epsilon = 20\pi, \quad \beta(z) = 100 \text{ m}$$

$$n_\sigma = \frac{\xi}{\sigma} = \frac{\theta}{2\sin\pi\nu}\sqrt{\frac{\beta_s}{\epsilon}}\cos\left(|\psi_s - \psi| - \pi\nu\right)$$

$= \pm 4.1$ (CERN GETS BY WITH ± 2.6 IN ONLY ONE PLANE)

COMMENTS:

- NEW IDEA. USE THE HIGH β CLOSEST TO THE IR TO GET EFFECTIVE SEPARATORS WHILE GETTING THE BEAMS SEPARATED AS SOON AS POSSIBLE TO MINIMIZE HEAD-ON CROSSINGS. (3/IR + (BØ + DØ) = 6 Total)
- GO TO LOW β WITH INJECTION OPTICS (NO HEAD-ON) [illegible] COLLISION SEPARATION SCHEME (< 100



H Calculated Positions (mm)

	C	D	E	F	A	B
11	4.137	9.244	6.314	2.546	-9.430	-4.829
13	7.795	-3.995	4.589	-7.413	-5.783	6.547
15	-1.051	-8.893	[illegible]	-7.442	4.387	8.861
17	-8.586	-3.806	-8.651	1.787	8.926	.1237
19	-8.400	6.375	[illegible]	8.822	2.374	-8.304
22	4.532	8.839	7.088	4.829	-7.138	-6.302
24	8.005	-.9626	6.954	-5.162	-7.767	3.692
26	2.872	-8.432	-2.658	-8.728	1.284	9.000
28	-7.250	-5.782	-8.957	-1.374	8.733	2.082
30	-7.307	4.092	-4.877	7.711	5.432	-6.919
34	1.682	8.842	5.910	7.178	-4.792	-7.989
36	8.719	2.558	8.500	-2.336	-8.034	.9434
38	4.967	-6.936	.4468	-8.872	-1.875	8.670
42	-4.999	-7.779	-8.148	-4.387	7.455	5.613
44	-8.784	1.056	-6.578	3.438	7.465	-4.409
46	-1.929	8.595	3.189	8.598	-1.848	-8.950
48	7.683	5.352	9.182	.9441	-9.874	-2.361
49	12.61	2.625	7.634	-2.158	-7.931	.3872

Es Kick
200μr

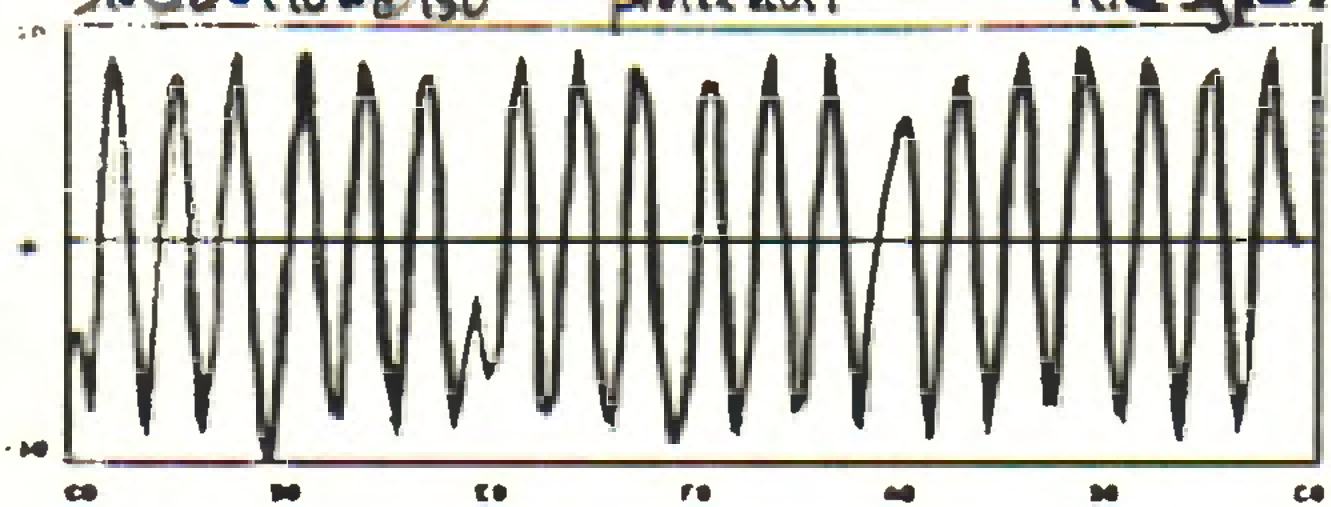
shuttered
Kicker location

TEVATRON

AVERAGE=	.213092
RMS =	6.30971
RMS = (MEAN)	6.30689
MAXIMUM=	12.6131
AT	C49
MAX/RMS= (MEAN)	1.96622

There will be 2 separators, one in each plane with 90° phase advance between.

After the beams have been injected, the shutter is removed, the beams are accelerated to 1 TeV. The "cusps" in the 2 planes stay on until the low β is on. There are no head-on collisions until the separators at the IRs are turned on.



H Calculated Positions (mm)

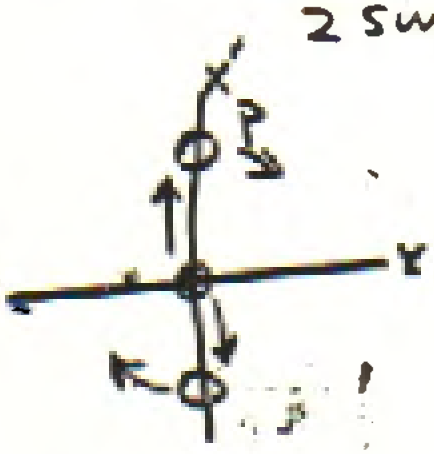
	c	b	c	f	a	b
11	-4.137	-8.244	-6.314	-2.366	5.430	4.869
13	-7.799	3.595	-4.529	7.413	9.783	-6.947
15	1.851	8.093	8.476	7.468	-4.387	-8.261
17	8.586	3.006	3.651	-1.787	-6.986	-.1257
19	5.408	-6.375	1.833	-8.022	-2.374	8.304
22	-4.532	-8.039	-7.800	-4.829	7.138	6.383
24	-8.895	.5426	-4.954	5.162	7.767	-3.692
26	-2.872	8.432	2.658	8.728	-1.264	-9.008
29	7.258	5.782	8.957	1.374	-8.733	-2.602
32	7.387	-4.892	4.877	-7.711	-3.433	6.919
34	-1.682	-8.862	-5.918	-7.178	4.792	7.989
36	-8.719	-2.958	-8.300	2.336	8.894	-.9434
38	-4.967	6.936	-.4668	8.872	1.875	-8.678
42	4.999	7.779	8.140	4.387	-7.455	-8.612
44	8.784	-1.836	6.578	-5.438	-7.465	4.489
46	1.359	-8.595	-3.189	-8.898	1.048	8.958
48	-7.683	-5.552	-9.182	-.9441	9.874	2.361
49	-12.61	-2.635	-7.634	2.158	7.931	-.3872

TEVATRON

AVERAGE=	-.212092
RMS =	6.30971
RMS = (MEAN)	6.30609
MAXIMUM=	12.6131
AT	C49
MAX/RMS= (MEAN)	2.03486

200μr at D49

$$X(z) = \frac{\theta\left(\beta_{sep}\beta(z)\right)^{1/2}}{2\sin\pi\nu}\cos\left(|\psi_{sep}-\psi(z)|-\pi\nu\right)$$



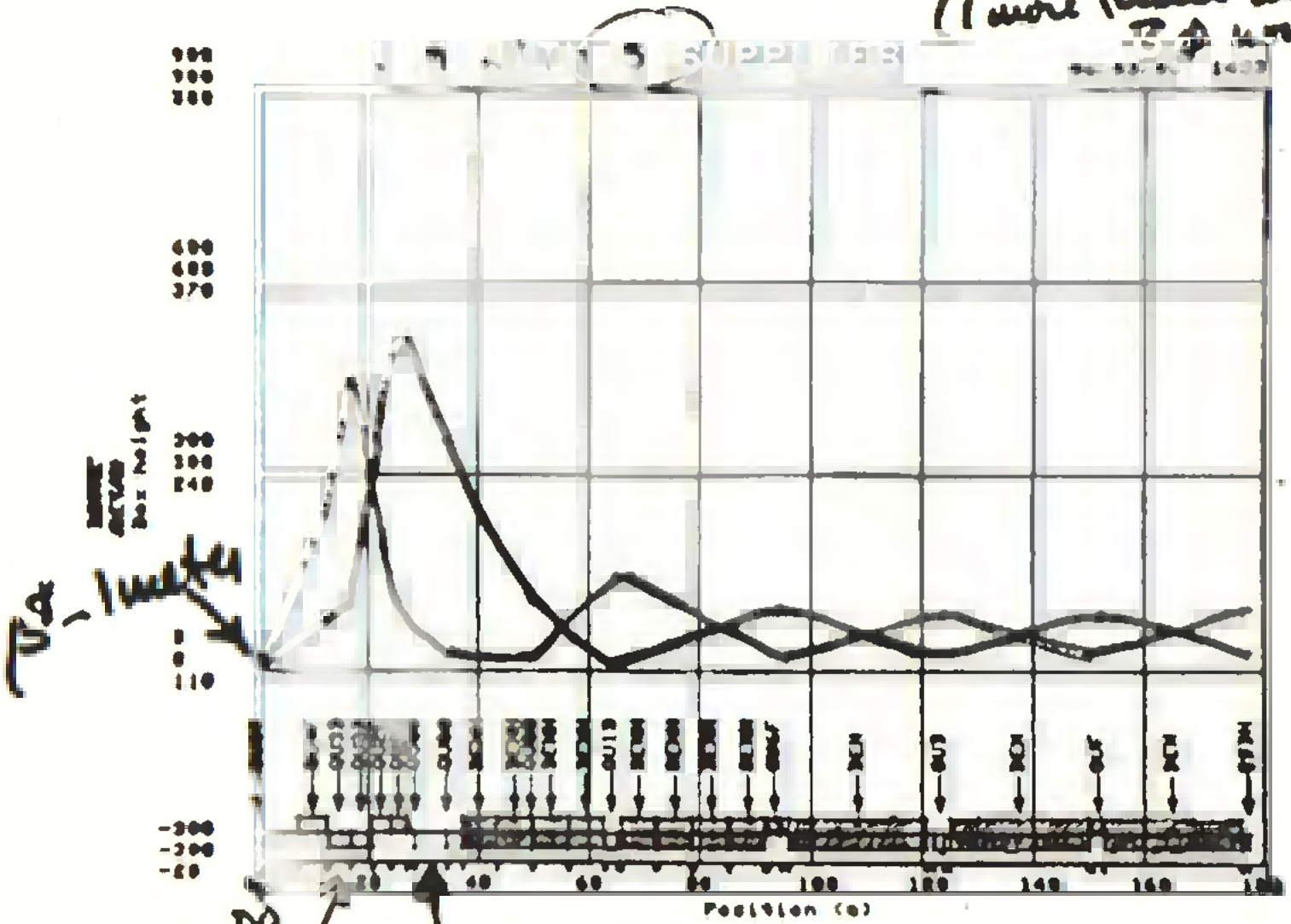
$$x' \sim \theta = \frac{eVl}{E} \qquad V \lesssim 50\,\mathrm{KV/cm}$$

<u>Injection</u> 6 m @ 50 KV/cm
150 GeV ⇒ 200 μr of Kick

<u>low β</u> 4 m @ 50 KV/cm,
1 TeV ⇒ 20 μr Kick

TOM. Feldi Willeke soln

(1 more than at B&H now)



B&H - 1 meter

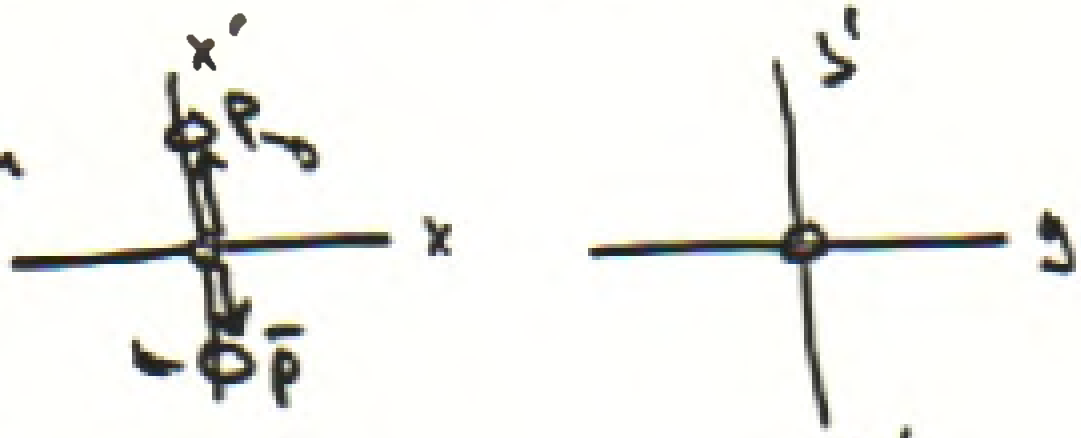
DO

Dave Finley

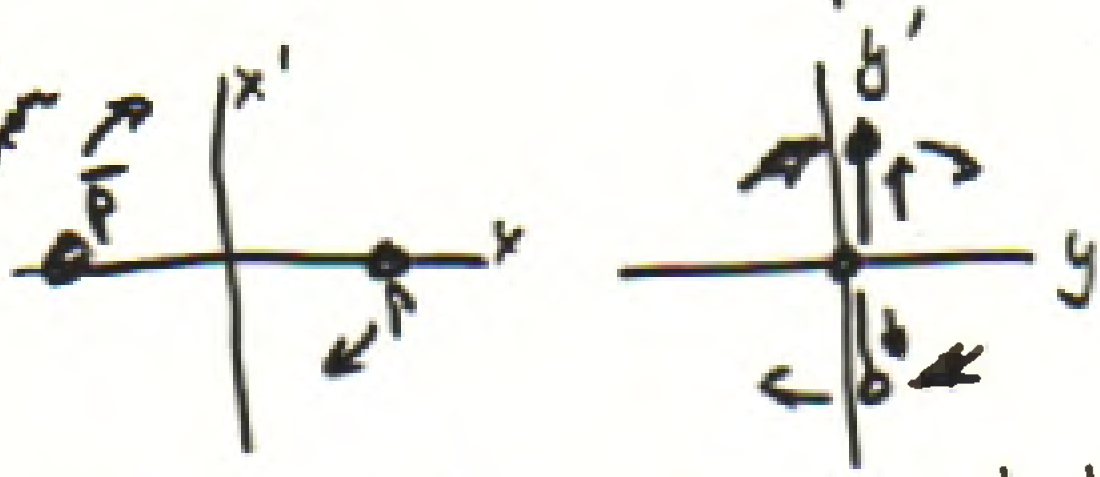
"Collins quads" removed for as separation

The Double Helix

at 1st x separator

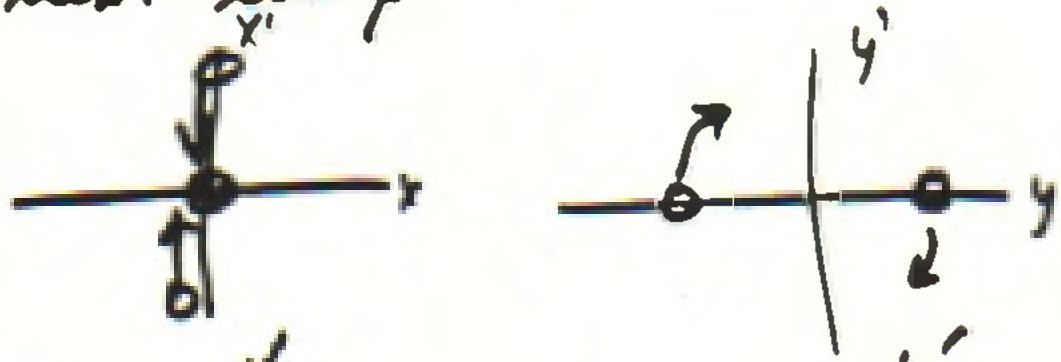


at first y separator

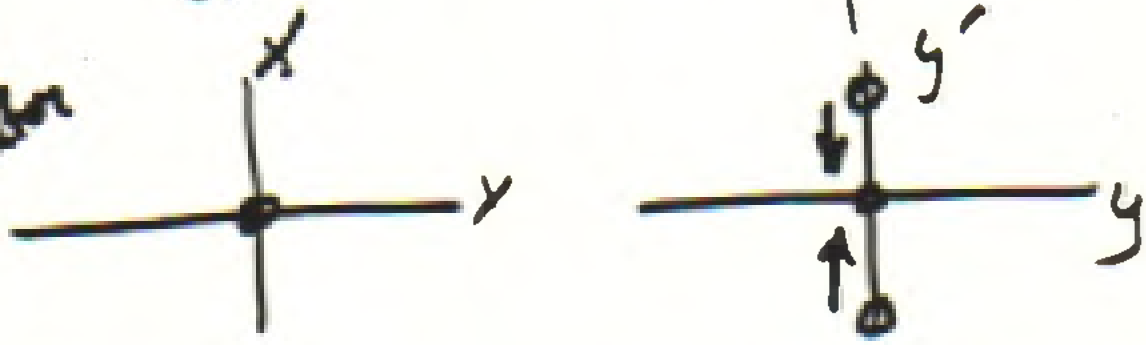


and so on through the arcs to the next low β

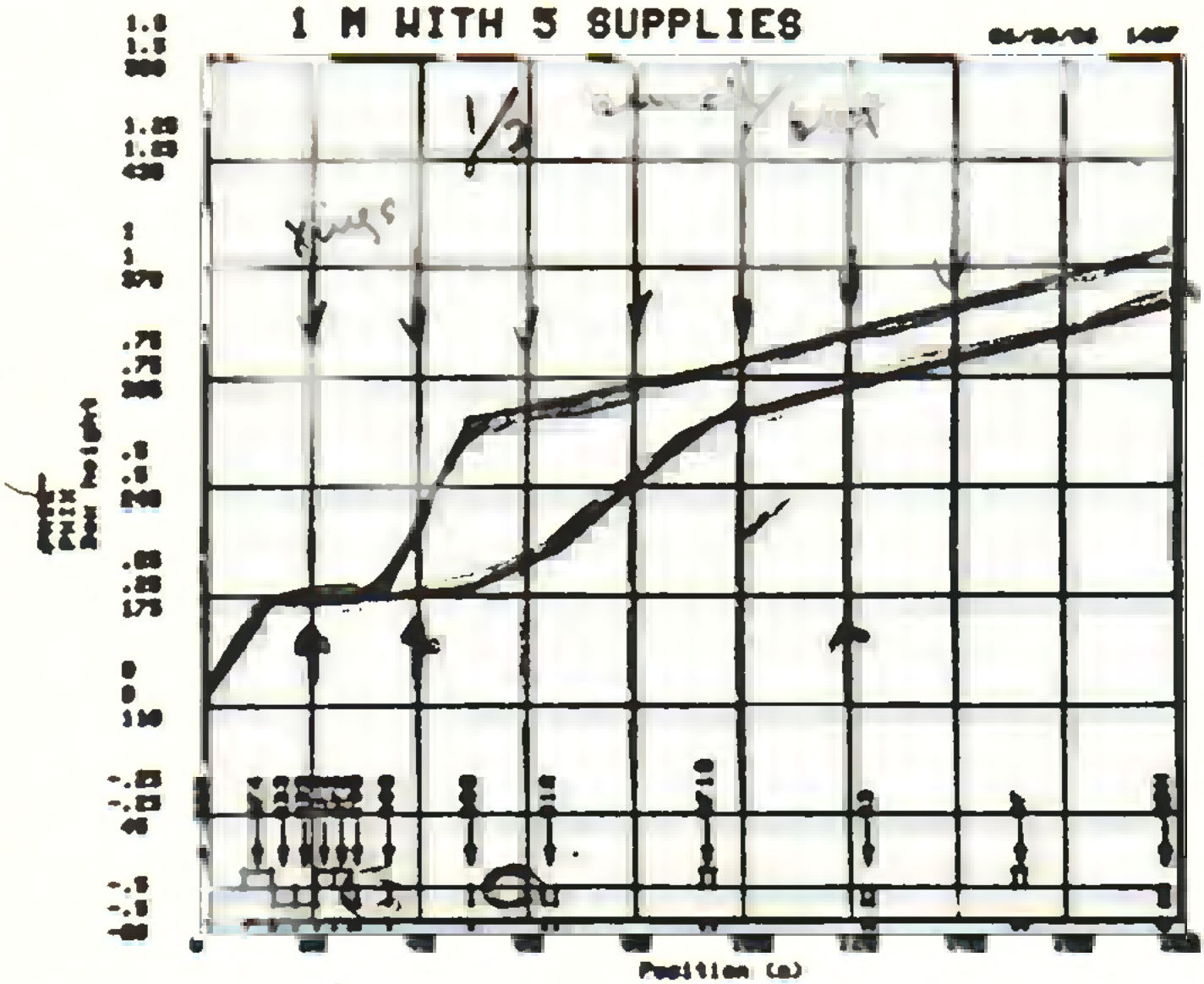
at final x sep



at final y separator



In general, there are not multiples of π phase advance and another pair of separators are needed to make honest 3-bumps in each plane.



Strategy 1 : long x sep at collins quad locn.

12-5-86

B0/D0 LOW BETA PROPOSAL

IDENTITY OF B0 AND D0

"INDEPENDENCE" OF B0 AND D0

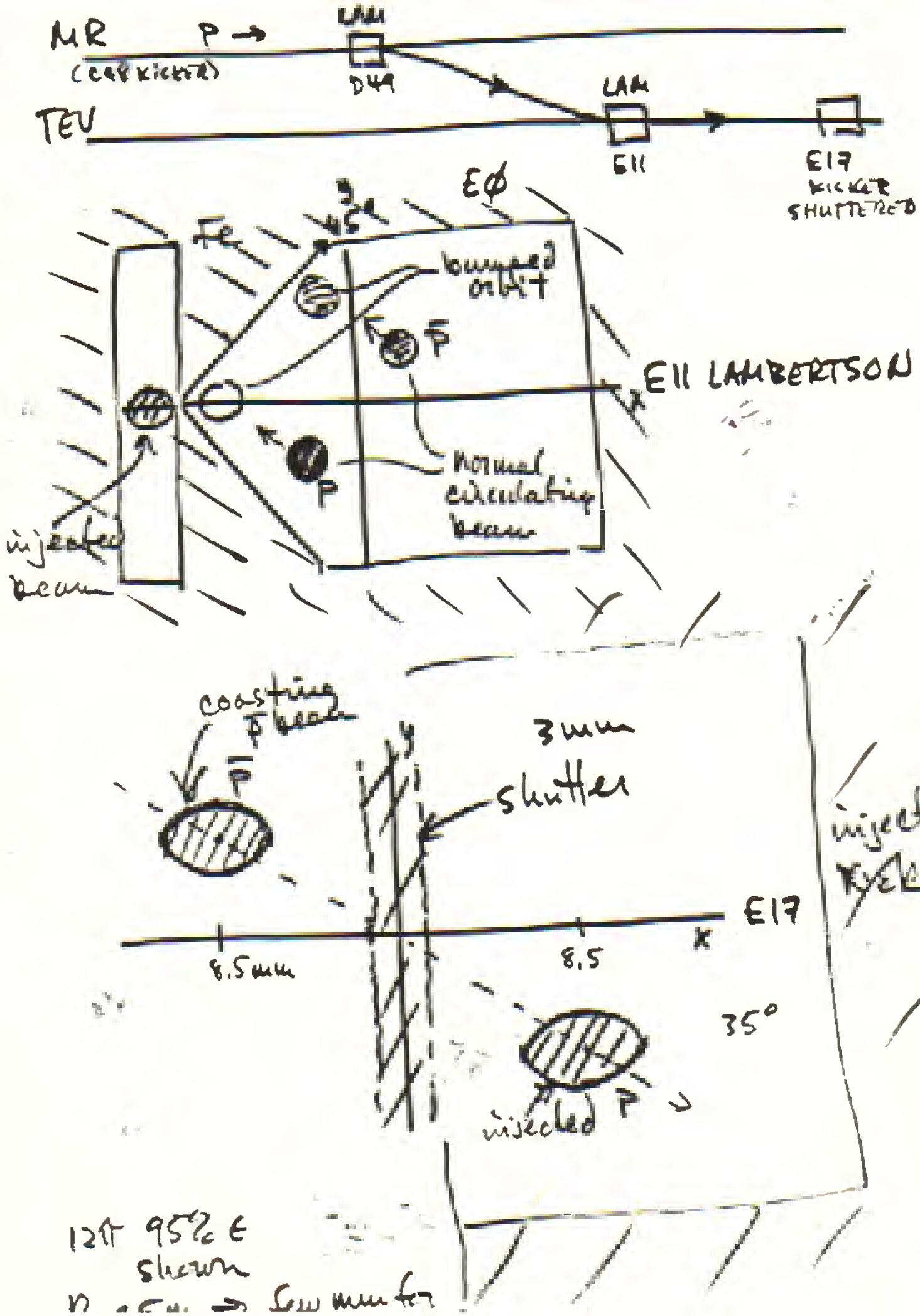
(ARC MATCHING QUADS)

225 CM > β^* > 18 CM

- 4 DEGREES GETS TO β^* = 44 CM

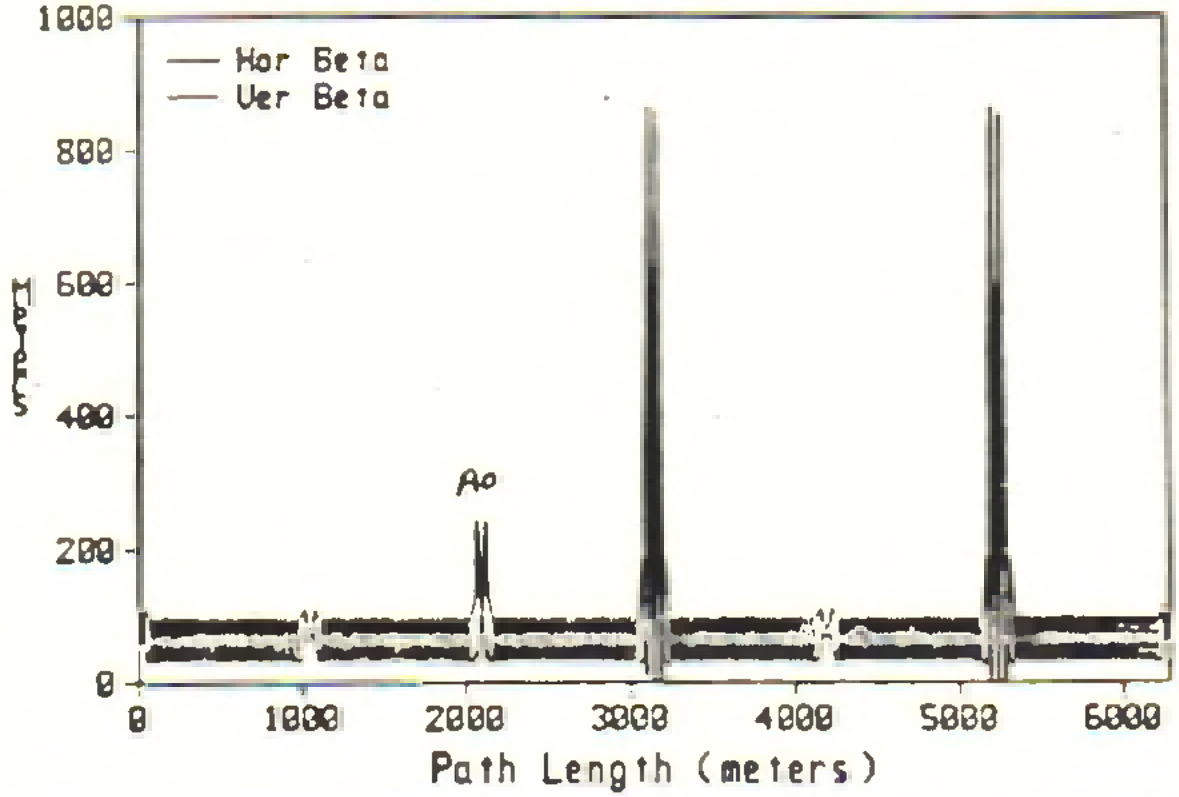
- 1.8 DEGREES GETS TO 18 CM

D0 COLLIDER VS FIXED TARGET


MR
P →
(C48 KICKER)
LAM
D49
TEV
LAM
E11
E17
KICKER
SHUTTERED
EØ
Fe
y
45°
bumped orbit
P̄
E11 LAMBERTSON
x
P
normal circulating beam
injected beam
coasting P̄ beam
P̄
y
3mm
shutter
injection kicker
E17
x
8.5mm
8.5
35°
injected
P
12π 95% ε
shown
→ few mm for

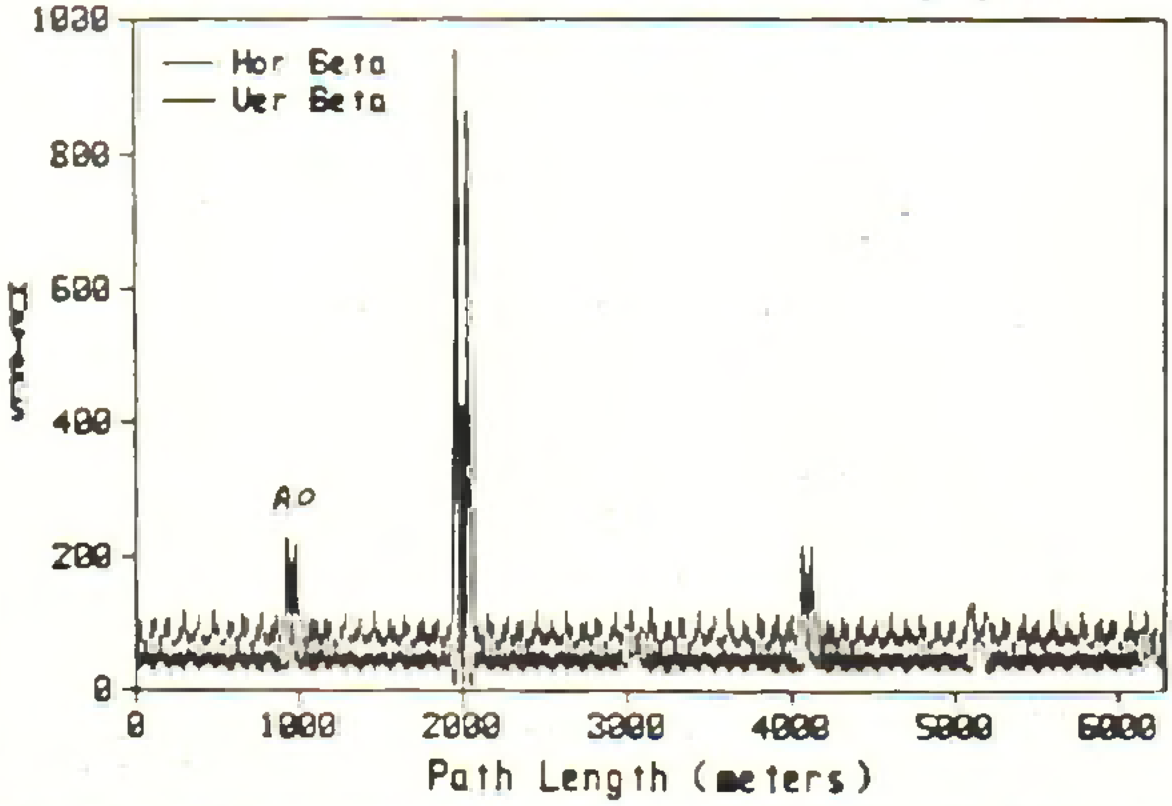
Transverse Lattice Functions

(44 cm beta* at B0 and D0, tunes 20.42,20.41)

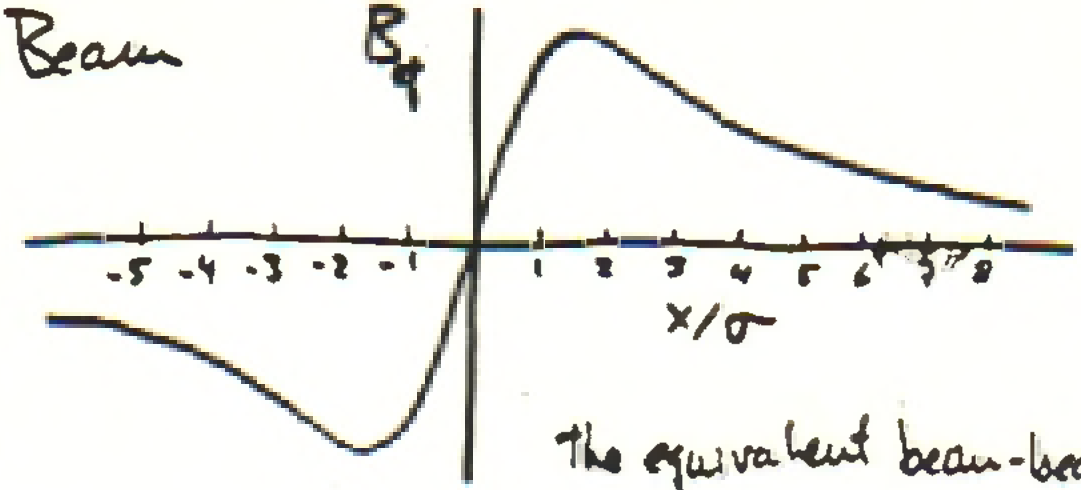


Transverse Lattice Functions

(1986 lattice without arc matching quads)



Beam-Beam



The equivalent beam-beam field

for $\frac{v}{c} \sim 1$, $eE \sim evB$

For small x, (head on) only 6 crossings.

Multipole Expansion – Long-range effects (passings)

for $r \gg$ beam radius

$$E = \frac{2e\lambda}{r} \qquad \lambda \text{ linear density}$$

let $r \to r_0 + x$

$$E = \frac{2e\lambda}{r_0+x} = \frac{2e\lambda}{r_0}\left(1 - \frac{x}{r_0} + \frac{x^2}{r_0^2} - \frac{x^3}{r_0^3} + \cdots\right)$$

need to consider each term's effect at each energy.

Beam - Beam, long range cont.

1. Dipole Effect

$$\text{Force} \hat{=} 2eE = \frac{4e^2\lambda}{r_0} = m\gamma\frac{d^2x}{dt^2} = mc^2\gamma\frac{d^2x}{ds^2}$$

$$\delta x' = 4\frac{e^2}{mc^2}\frac{1}{\gamma r_0}\int \lambda\, ds = 4r_p\frac{N}{\gamma r_0}$$

$N = 6\times10^{10}$

$r_0 = 5\text{ mm} = .005\text{ m}$

$\gamma = 1067$ @ 1 TeV

$r_p = 1.535\times10^{-18}\text{ m}$

$$\delta x' = \underset{1\text{ TeV}}{6.9\times10^{-8}} = \underset{150\text{ GeV}}{13\times10^{-8}}$$

but $2\times144-6 = 282$ nearby collisions, half x, half y acting incoherently $\Rightarrow$

$$\Delta x' = \sqrt{\frac{282}{2}}\,\delta x' = 8.2\times10^{-7}_{1\text{ TeV}} = .8\,\mu r$$

$= 1.5\,\mu r$ 150 GeV

Compare to $20\,\mu r$ dust seps at 1 TeV

" " $200\,\mu r$ " " " " 150 GeV

~ 5% effects Double Helix ...

Beam-beam, long range ctd.

2. Quadrupole effect

$$\delta x' = 6.9 \times 10^{-8} \frac{x}{r_0}$$ (per ~~crossing~~ passing)

$$\delta \nu = \frac{\beta_x}{4\pi} \frac{\delta x'}{x}$$ $\beta_x \cong 50\,m$

$$\Delta \nu_x = \cancel{2} \cdot 144 \frac{6.9 \times 10^{-8}}{.005} \frac{50}{4\pi} = \underline{.008}$$ 1 TeV

each plane

at 150 → .005

However, this is a tune shift (can be compensated)

there is cancellation due to the vertical and horizontal passages

Beam-beam, long range contd.

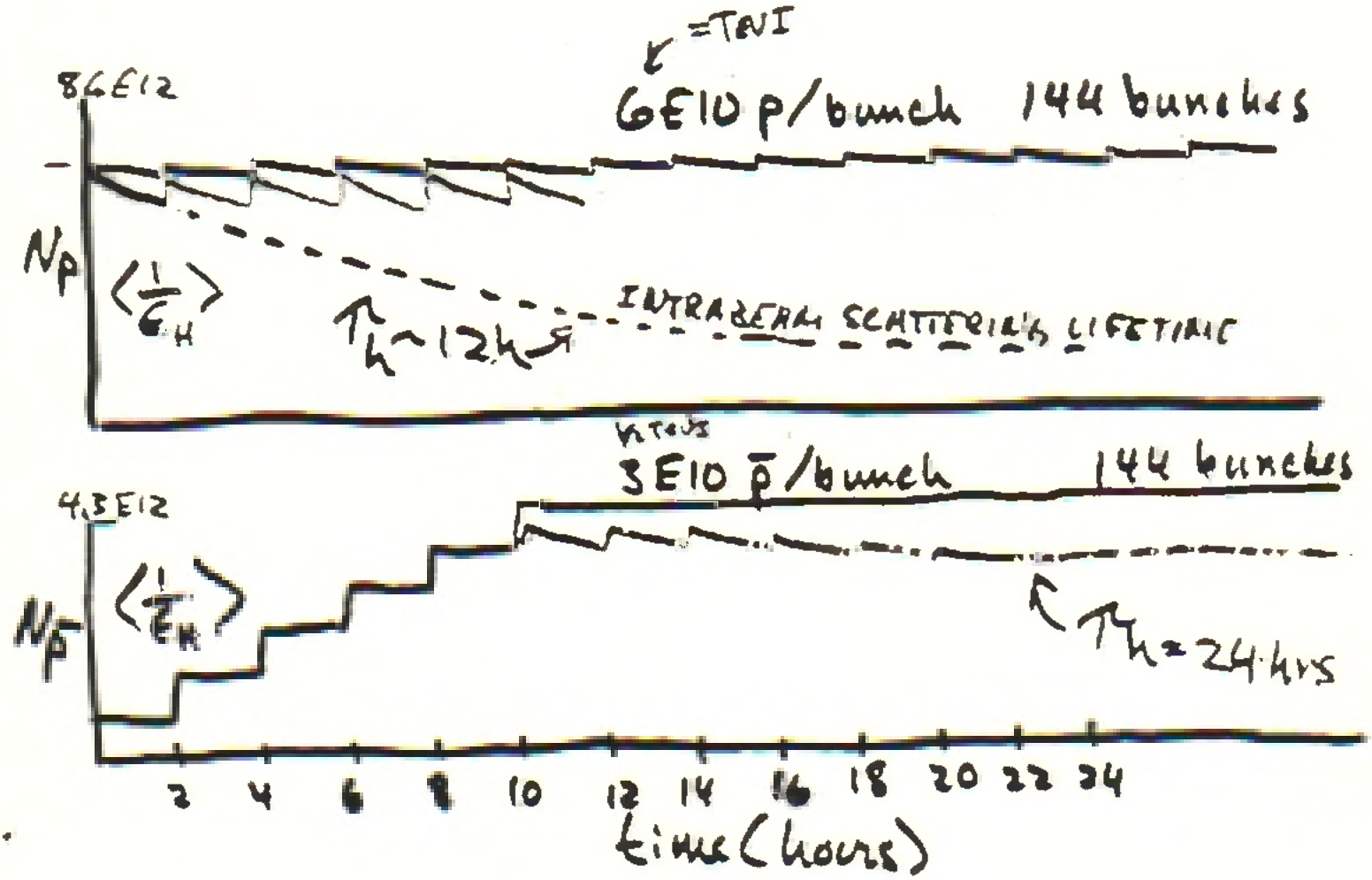
3. Sextupole and higher moments

Can compare kicks due to beam passages with those due to errors in superconducting dipoles.

in general $\frac{288 \text{ Kicks from beam-beam}}{774 \text{ Kicks from dipole multipoles}}$

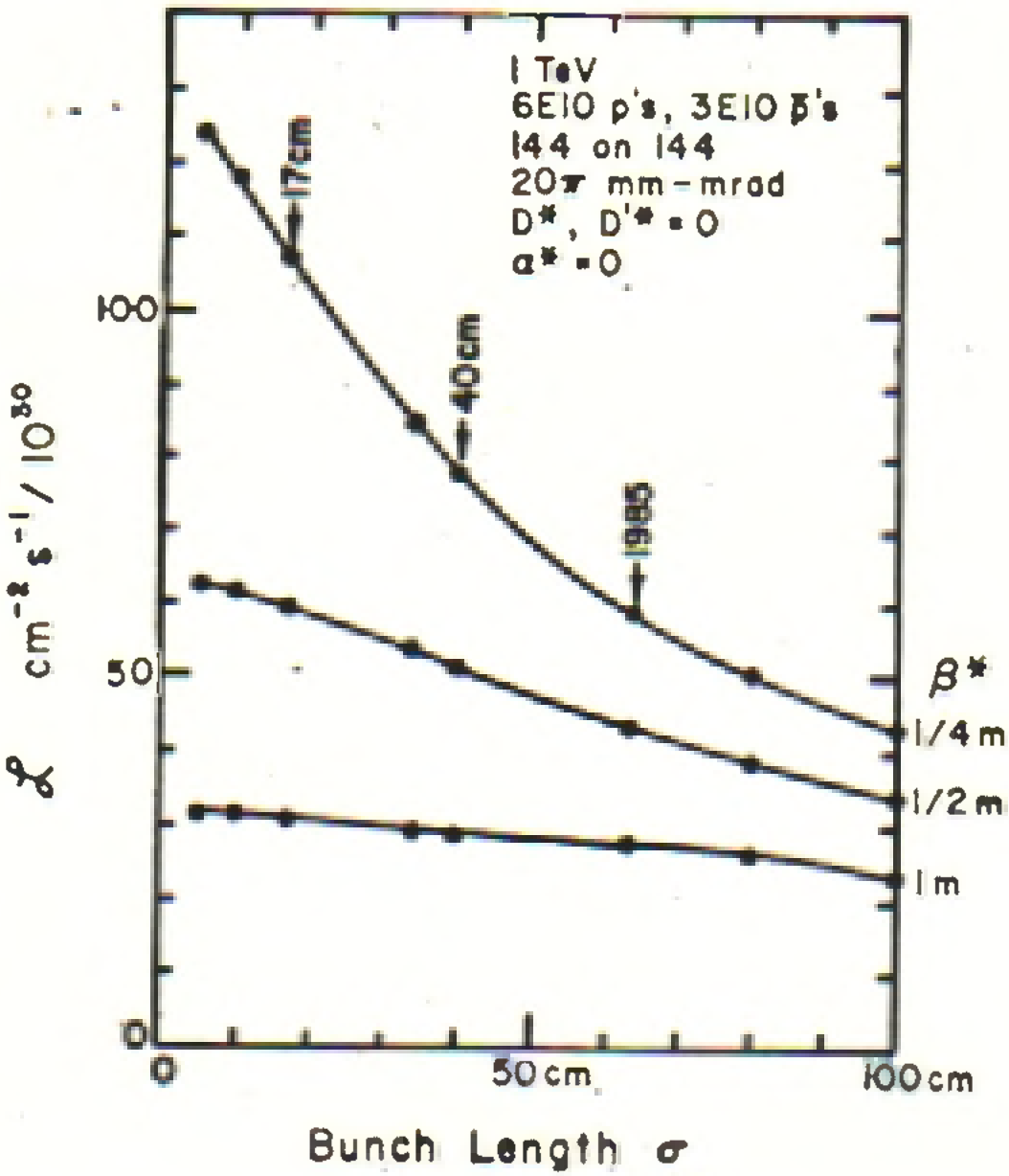
is $\lesssim 2\%$

$\Rightarrow$ Negligible or correctable



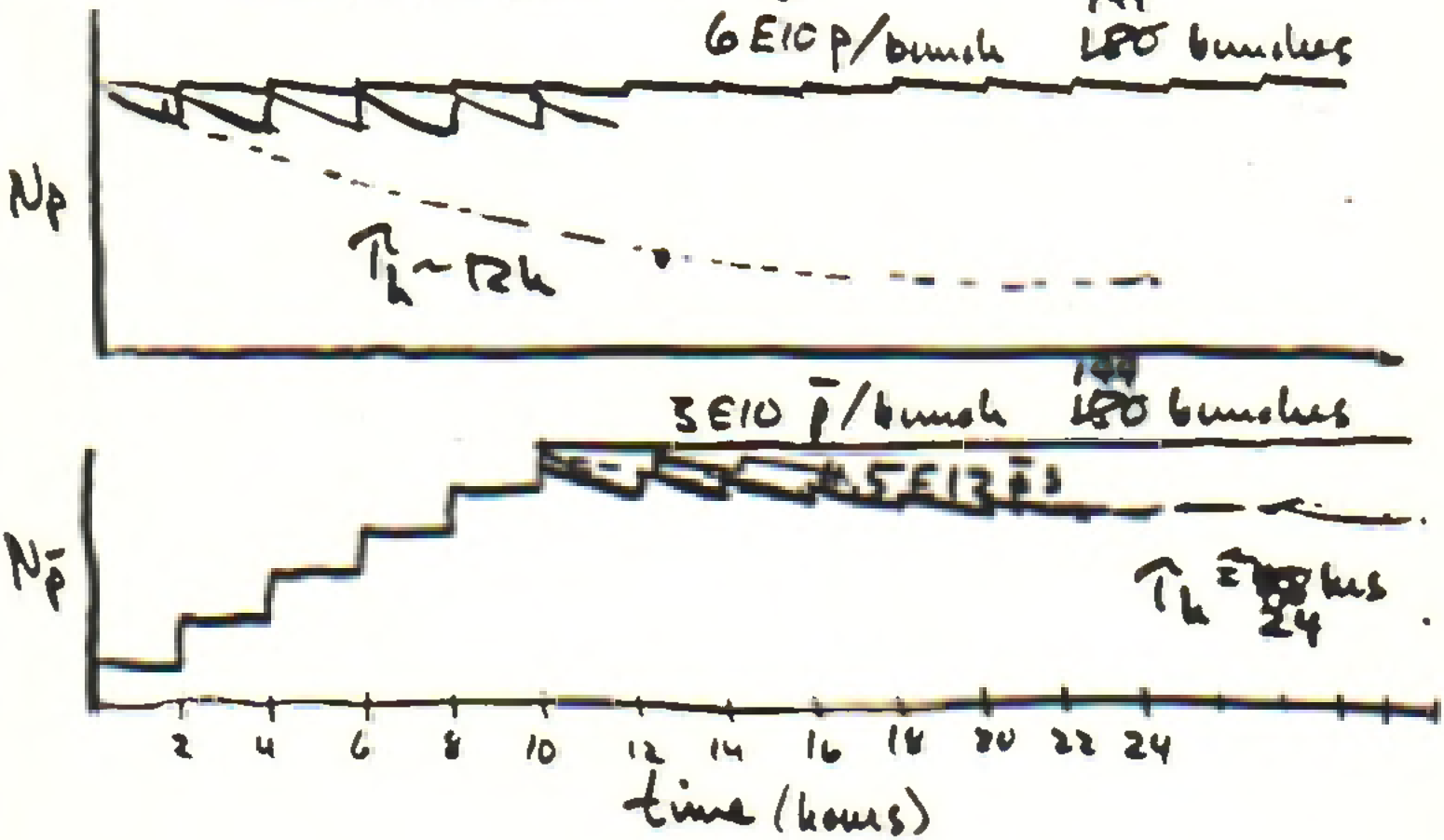
$\mathcal{L}_{peak} = 5.8E31$ for asymptotic 20π $\perp$
$\beta^* = 1/2$ m

$\langle \mathcal{L} \rangle \gtrsim 5E31$



Effectiveness of low β depends on bunch length. One problem: shorter bunch length may lead to intrabeam scattering complications.

BUT! we can have a source at $4\times10^{11}\,\bar{p}$/hr and 12π. Don't need such a stable Tevatron, can use less intense p bunches. Also less worries about intrabeam scattering.



$\mathcal{L}_{peak} = 5.8\times10^{31}$ for asymptotic 20π ε

$\beta^* = 1/2$ m

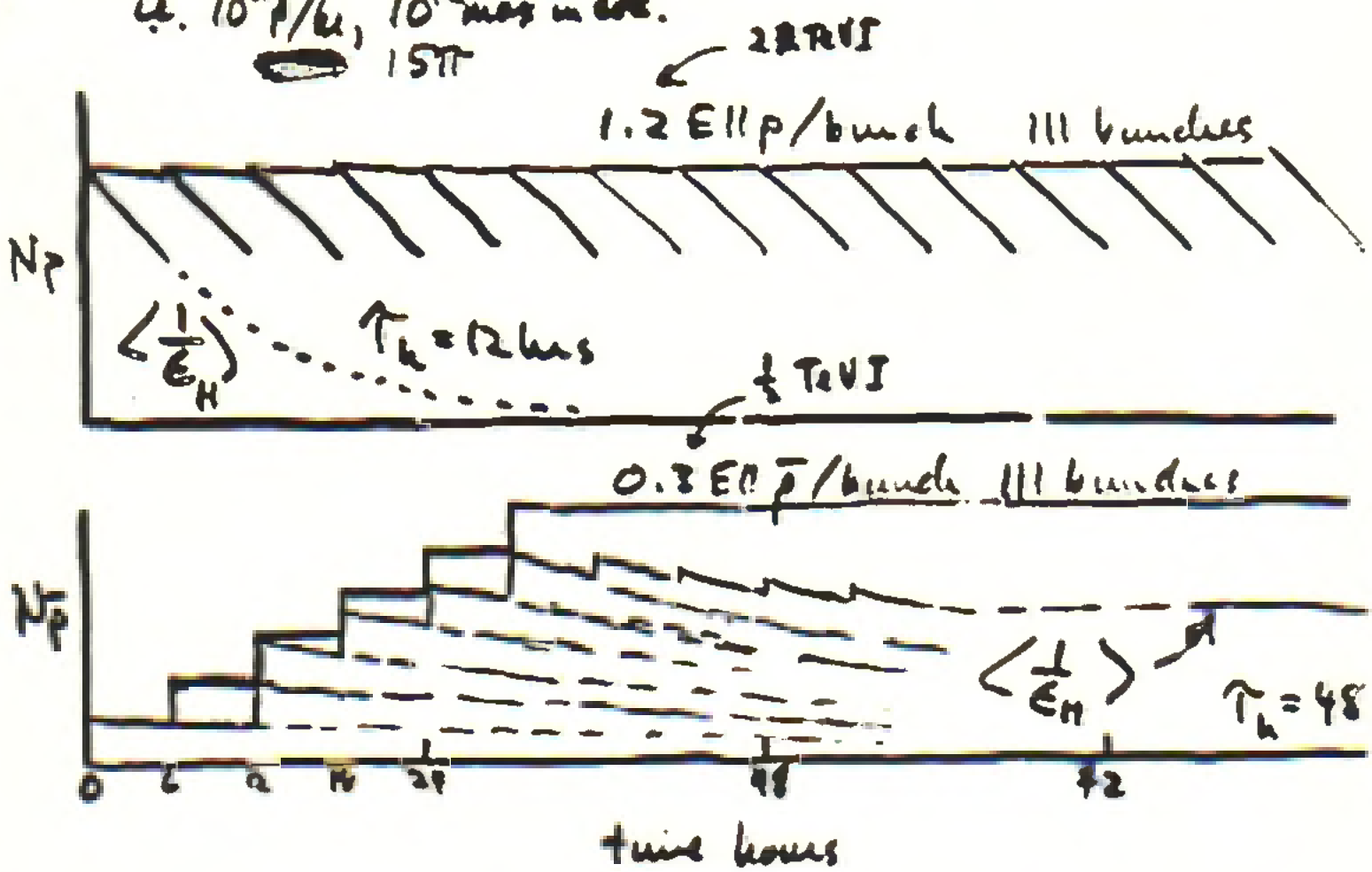
$\langle \mathcal{L} \rangle \approx 5\times10^{31}$

τ_h is intrabeam scattering lifetime

HOW IT WOULD WORK FOR A TEV I $\bar{P}$ SOURCE

i.e. $10^{11}\bar{p}/b$, 10^{12} mes in acc.

15π



$\mathcal{L}_{peak} \sim 3E31$ Assuming TeV I params

$\mathcal{L}_{min} \approx \frac{2}{3}$ " i.e. $\beta^* = 1$ m

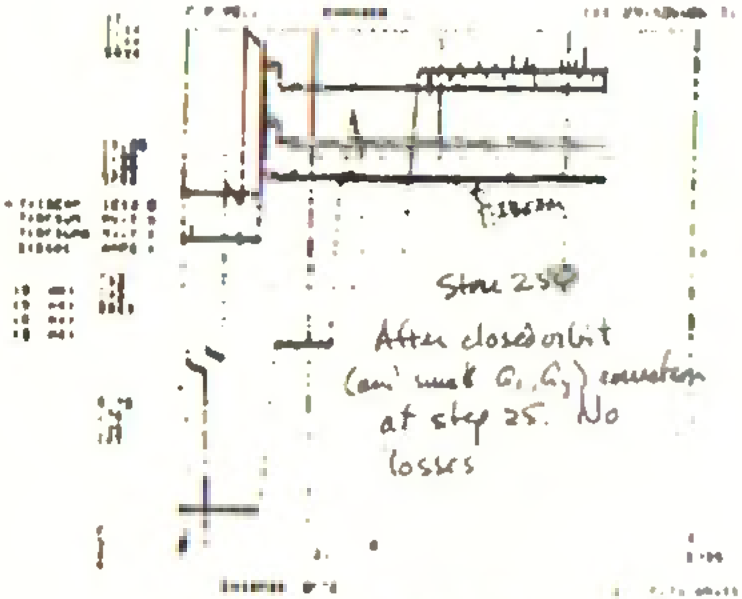
$\epsilon_{95\ ASYMP} = 24\pi$

$\mathcal{L}_{ave} \sim 2.5E31$

If $\beta^* = \frac{1}{3}$ m, $\langle \mathcal{L} \rangle = 5E31$

@ 3E31 $\tau_{coll\ \bar{p}} \sim 60$ hrs

This requires a very reliable Tevatron



0315 Go on to store 251 while TeV of #3 be[illegible] looked at.
see injection times of 0.446 and [illegible]94 ← [illegible]
(Δ=.012) [illegible]

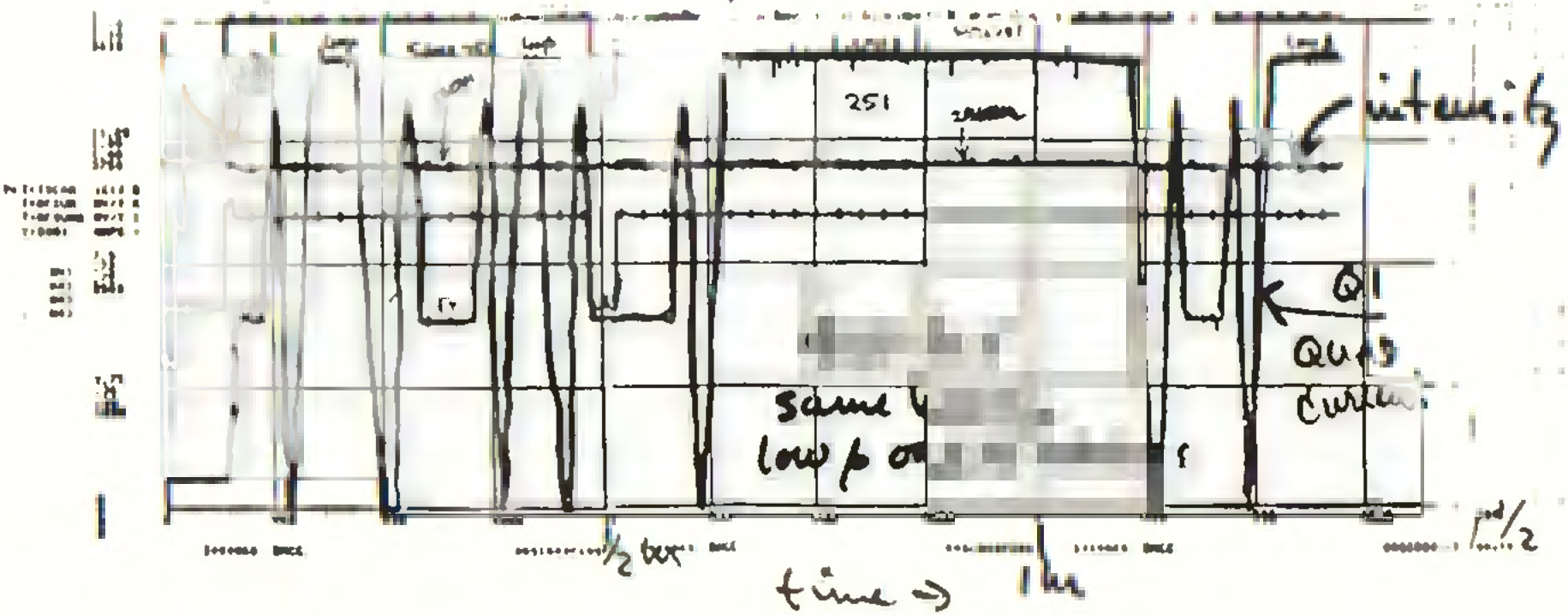
0318 GO TO LOW β
GO TO FT LATTICE
0333 GO TO LOW β
GO TO FT LATTICE
0347 GO TO LOW β
GO TO FT LATTICE
0425 GO TO LOW β

Testing new [illegible] of T111.
(no bea[illegible]ss — see FW
for proof [illegible]ance docinte[illegible]
— [illegible]ge —

0440 Okay — so we see no beam losses with coalesce [illegible]. Even whe[illegible]
we squeeze and unsqueeze the same beam 4 t[illegible]. Flying wires
show about 2π in the vertical, with no [illegible] change of [illegible]
for VC48. The story for HC48 is more co[illegible]

(note that TeV RF #3 is in need of repair - [illegible]ided to wai[illegible]
for daylight to call someone in)

0520 Store 251 ends. E1 BLM. Due to F17 MR [illegible]ction lamputs
top.



What has to be done for deceleration/ac

4 mins
- turn off low β, keep beams separated (switch to 2 separators)
- decelerate, don't let losses quench magnets

1 min
- kill proton beam with shuttered abort
- add $\bar{p}$ bars — $\gtrsim 2$ MR cycles
- add protons — $< \frac{11}{8} = 1\frac{3}{8}$ MR cycles

5 mins
- accelerate to $\gtrsim 900$ — compensate lack of 90 GeV reset
- turn on low β, switch to 12 separators
- scrape beams

10 minutes overhead / $\frac{1}{2}$ hour cycle

$\sim \frac{1}{8}\%$

Kickers

need ~ 250 ns rise/fall to get best boxcar stacking.

- have E17 Medium straight for proton shuttered kicker. D48 $\bar{p}$ kicker harder but don't need shutter.
- haven't looked at abort shutter. may need fast $\bar{p}$ abort too.

Worries

— Long range beam-beam effects.

$\frac{1}{r^2}$ force at each passing ⇒

dipole distorts double helix
quad shifts tunes
sext shifts ξ
etc.

these are intensity dependent effects and weak-strong may cause problems.
(SSC study of $\bar{p}p$ ⇒ for 600-1200 bunches at 5×10^{32} need 15 mm separation.
We have lower $\mathcal{L}$, fewer bunches and 15 mm.)

— Different ~~tune~~ parameters for each beam due to different closed orbits.

e.g. Tunes are different due to orbit differences through sextupoles. Similar "feed down" of multipoles exists for all multipoles.
Most worrysome is "feed down" for skew multipoles

- may need clever inventions for independent coupling adjustments for the 2 beams.
(e.g. skew quads, shuttered skew quad

— Deflection Problem.

Conclusions:

$\langle \mathcal{L} \rangle = 5 \times 10^{31}$ (not just $\mathcal{L}_{peak}$)

looks good. There is a scheme without real technological extrapolations.

(the Double Helix and consequences may be one — needs more work)

Why not $> 5 \times 10^{31}$?