Large Acceptance, Transitionless Lattice for FNAL Proton Driver

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May 22-26, 2000

Monterey, CA

LARGE ACCEPTANCE TRANSITIONLESS LATTICES

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Proton Driver Review
4/18/00

By large acceptance, what do we mean

> 50π (full beam size for < 1 GeV) transverse acceptance

> +/− 1.5% dp/p (full) longitudinal acceptance

Current Requirements:

200π (full beam size) transverse acceptance

+/− 3% dp/dp (full) longitudinal acceptance

⇨ factor of 5 over nominal transverse acceptances

factor of 3 over nominal momentum apertures

One or the other criteria is not as difficult as the combination. When both the transverse beam size and the momentum spread are large, the different momenta overlap making (traditional) correction of optical parameters as a function of momentum not straightforward.

Raising the Transition Energy

- Missing Dipole FODO Structure – Ritson lattice

A dipole is removed after a focussing quadrupole in every other cell creating a large dispersion wave. Transition is controlled by careful placement of dipoles with respect to dispersion. The higher the required transition energy, the larger the swing of the dispersion and the larger the peak value of the dispersion.

- Strong horizontal-focussing Insert – Johnstone lattice

First applied systematically in the "FMC" module, this approach uses the concept of a low βx to enhance horizontal focussing. This drives the dispersion down in part of the lattice and, potentially, even negative. Dipoles are arranged across low dispersion regions. The transition energy can be imaginary.

Achieving Large Momentum Acceptances

- Simple Lense Structure; i.e. FODO-based cell

Doublet, triplet-based structures do not have the bandwidth or cannot be properly corrected for momentum dependence of optics. The missing dipole lattice is straight FODO and the strong-focussing insert lattice is a FODO with an optically "transparent" insert.

Comparisons:

Missing Dipole:

- Dispersion at sextupoles scales with square root of transverse acceptance (have to comparably separate off-momenta from transverse beam extent)

$\Longrightarrow$ 200π is at least a factor of 4 larger than nominal design emittances and a factor of 2 larger in physical acceptance; hence dispersion must increase by a factor of 2 over typical FODO lattices (where D_x is 2-3m) to adequately separate longitudinal (momentum) from transverse beam size for sextupole or chromatic correction purposes (correction of the off-momentum optics). About 5 m of dispersion is required for a missing dipole lattice.

- The dispersion must also be large to keep sextupoles from driving the lattice too nonlinear—generating higher orders of chromaticity and tuneshifts with amplitude which vary according to the exact phasing between sextupoles. (Strength of the sextupole varies as the inverse of the dispersion squared.)

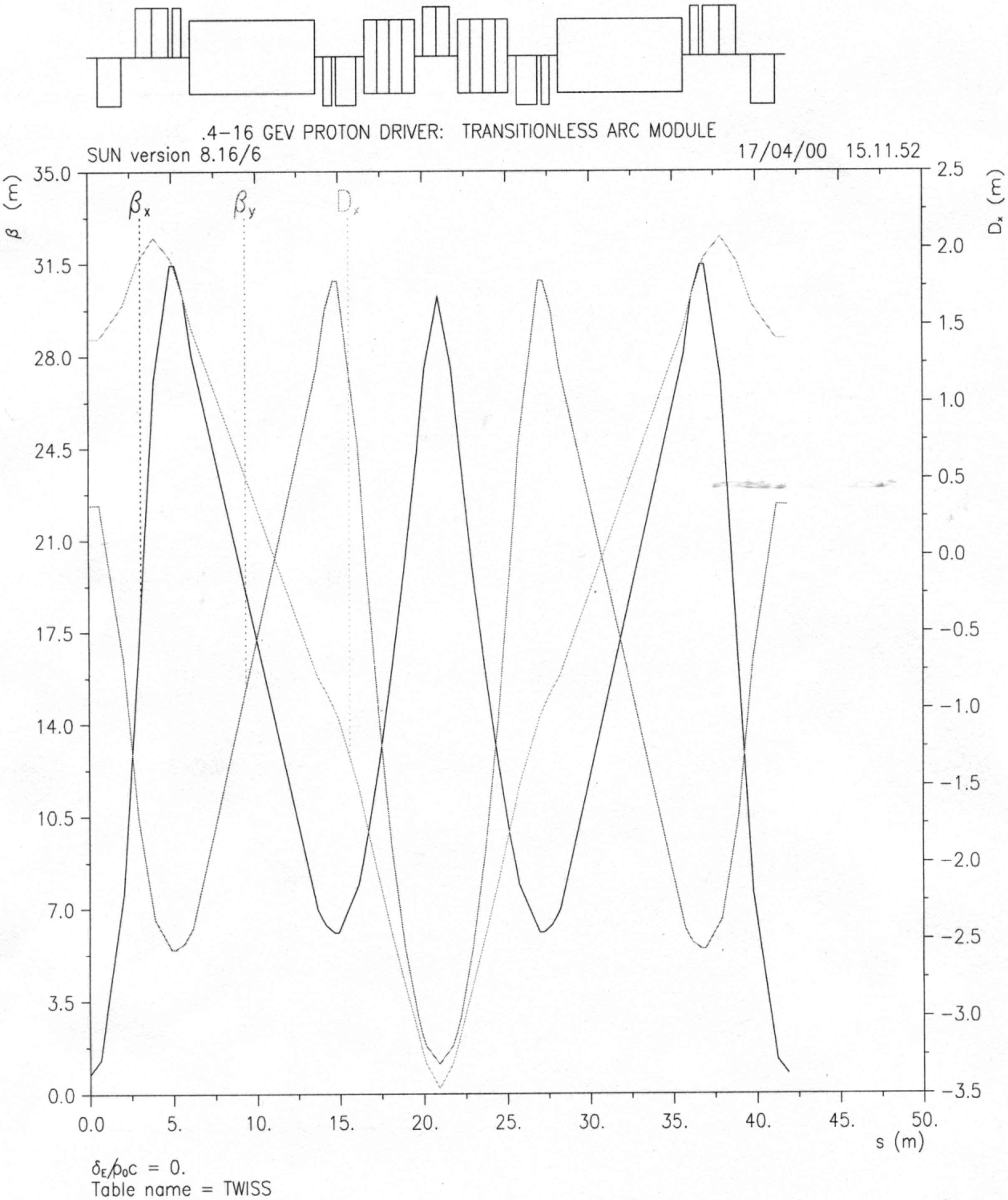
- Still, achieving +/−3% dp/p will most likely require 90 deg cells for sextupole phasing and to cancel 2nd order chromaticity locally.

Strong-focussing Insert

- The insert drives the dispersion negative with a lowered peak dispersion. The peak dispersion is driven by the sextupole strengths which can be tolerated and still achieve the required acceptances.

- Stronger sextupoles (lower dispersions and smaller magnet apertures) can be tolerated if the sextupoles are placed in pairs separated by 180 deg in phase (so-called π pairs, although $\phi \geq .8\pi$ is sufficient). Nonlinearities cancel to roughly second-order when sextupoles are paired in this fashion. Peak dispersion was initially set by the maximum sextupole strength which could be tolerated which occurred when $|D_x|$=1.5m. This dispersion value at vertical sextupole locations (although negative) set the absolute value of the peak dispersion to 2.5m (also negative). The positive peak of the dispersion is less than 2m. However, these are not the final values due to other considerations.

- Tracking studies indicated that the inserts for rf and injection and extraction cannot break the repetitive sextupole pattern; that is they need to have integer phase advance to make them "transparent" optically. Phase relations between sextupole pairs is as important as the π pairing (little known fact).



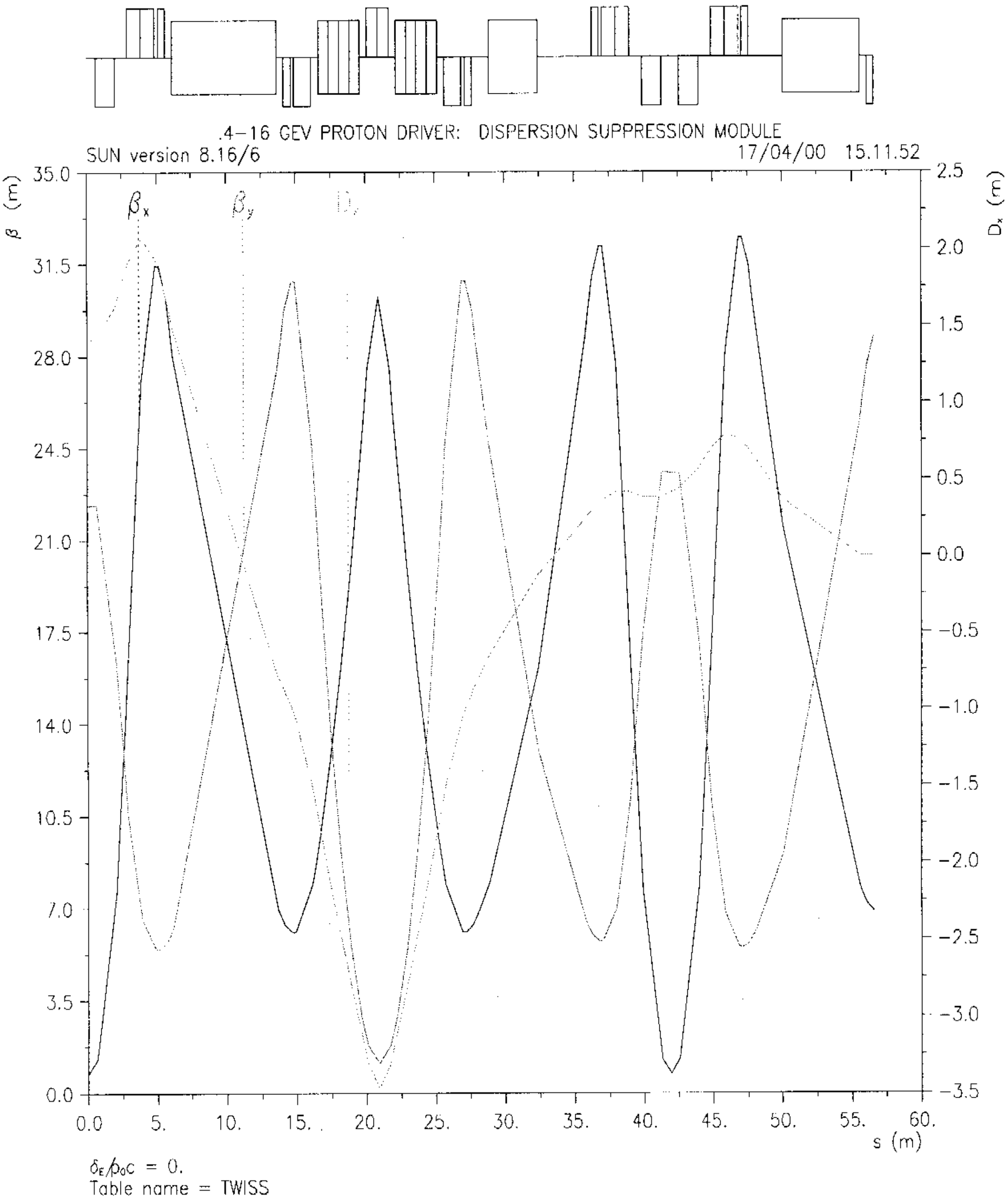
.4-16 GEV PROTON DRIVER: TRANSITIONLESS ARC MODULE
SUN version 8.16/6
17/04/00 15.11.52
β (m)
D_x (m)
β_x
β_y
D_x
35.0
31.5
28.0
24.5
21.0
17.5
14.0
10.5
7.0
3.5
0.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
0.0
5.
10.
15.
20.
25.
30.
35.
40.
45.
50.
s (m)
δ_E/p_0c = 0.
Table name = TWISS

ARC MODULE

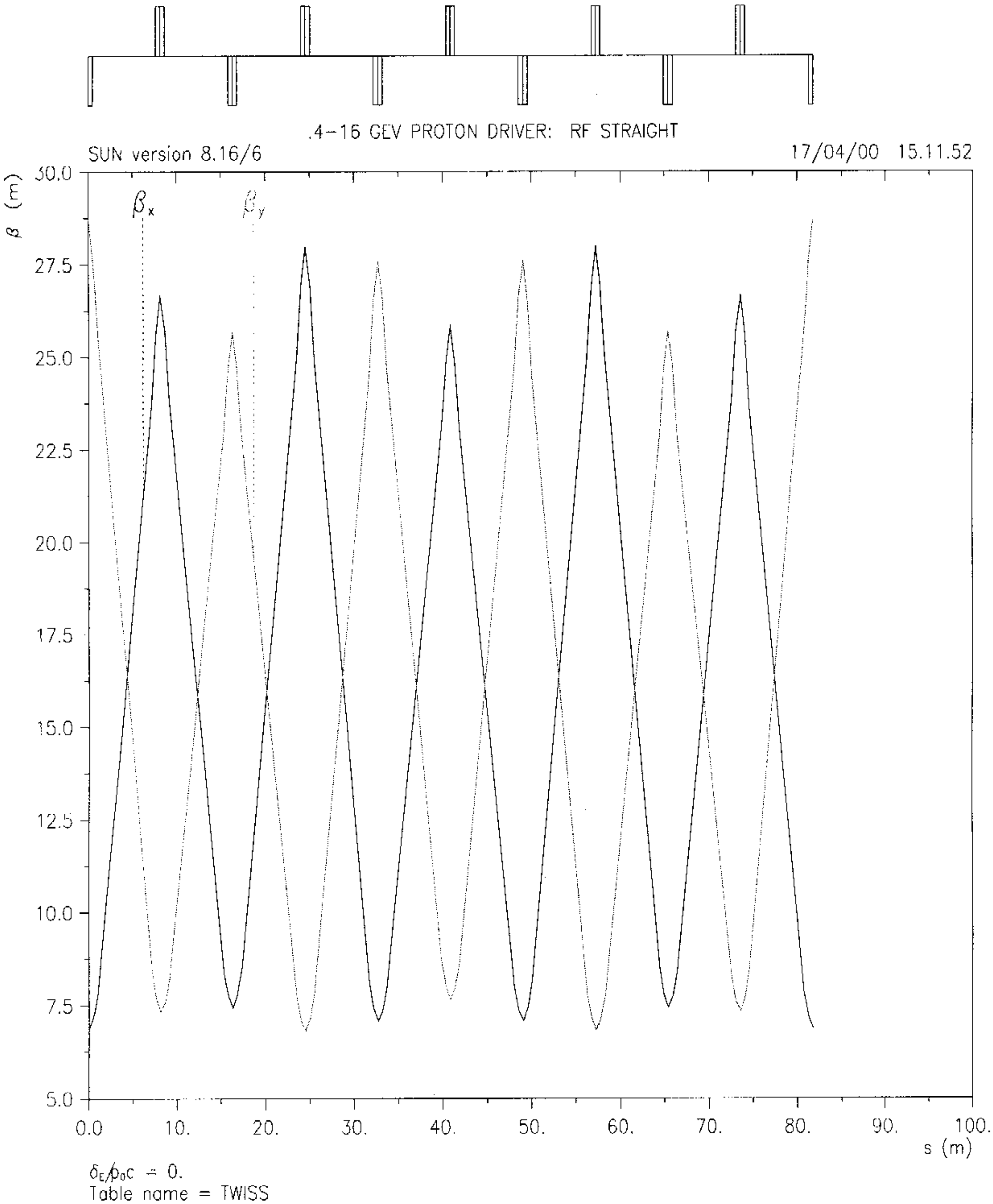
.4-16 GeV Proton Driver
Strong-Focussing Insert Lattice

ARC MODULE PARAMETERS

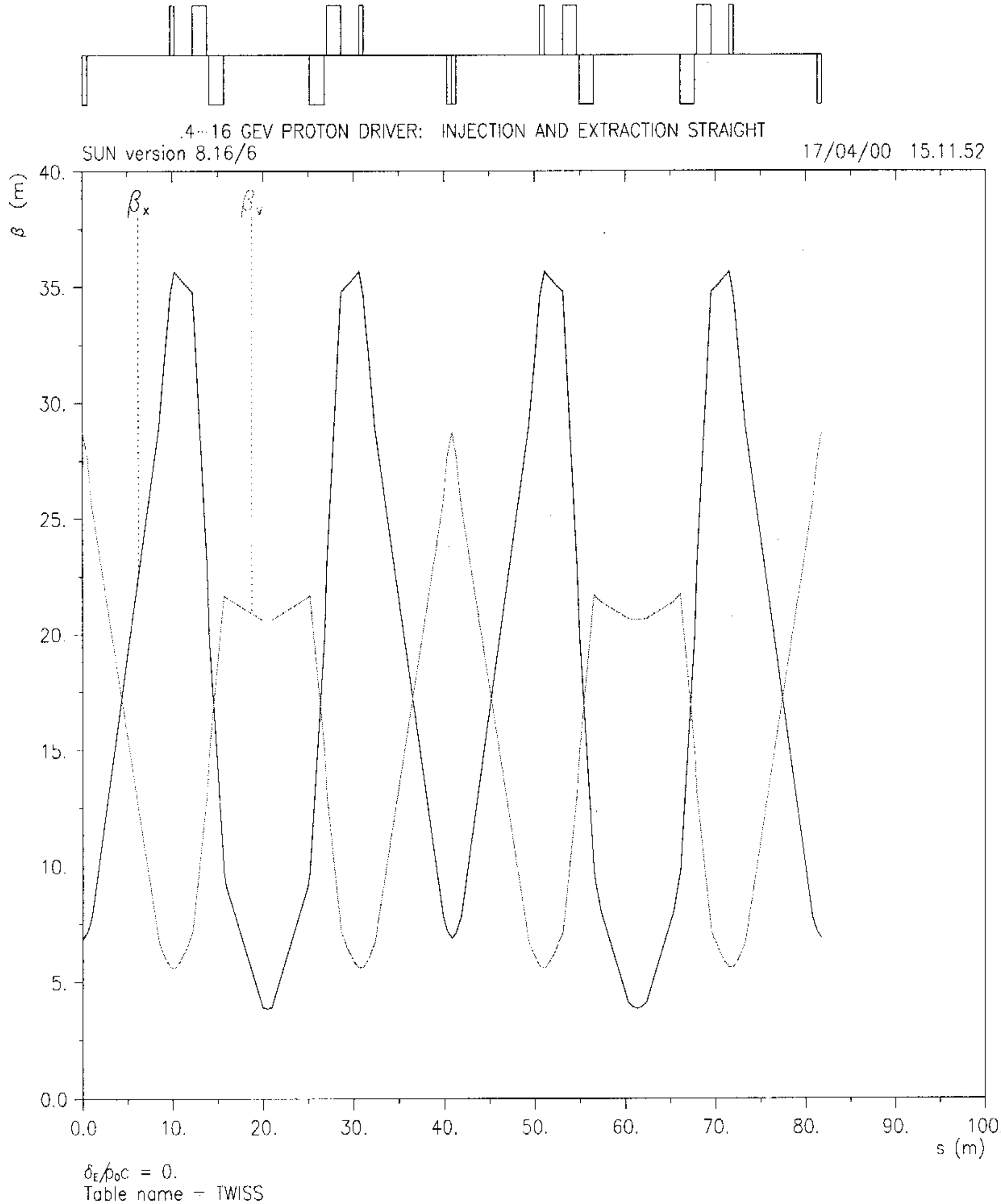
Dipoles	
Strength	1.55 T
Lengths	7.5 m
	4.5 m
Quadrupoles	
Strength	8.5 T/m
Lengths	1.4 m
	.9 m
	.5 m
Cell length	41.8 m
Total cell phase advance	300°
FODO part phase advance	~90°
$\beta_{xmax}/\beta_{ymax}$	31.4/30.9 m
$\beta_{xmin}/\beta_{ymin}$	.75/1.13 m
D_x	-3.5 m
Number of arc cells	8



Dispersion Suppressor


.4-16 GEV PROTON DRIVER: RF STRAIGHT
SUN version 8.16/6
17/04/00 15.11.52
β (m)
β_x
β_y
30.0
27.5
25.0
22.5
20.0
17.5
15.0
12.5
10.0
7.5
5.0
0.0
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.
s (m)
δE/p0c = 0.
Table name = TWISS

Rf INSERT



Injection /Extraction Insert

.4-16 GeV Proton Driver

Strong-Focussing Insert Lattice

RING PARAMETERS

Circumference	725 m
$\beta_{xmax}/\beta_{ymax}$	35.7/30.9 m
$\beta_{xmin}/\beta_{ymin}$	.75/1.13 m
ν_x/ν_y	13.58/12.92
D_{xmax}	-3.5 m
Injection: acceptance	
Transverse	200π mm-mr
dp/p	± 1.5%
Extraction: acceptance	
Transverse (full)	>200π mm-mr
dp/p (full)	± 3%
Rf straight	
Free space	75 m
Injection/extraction straight	
Free space	75 m

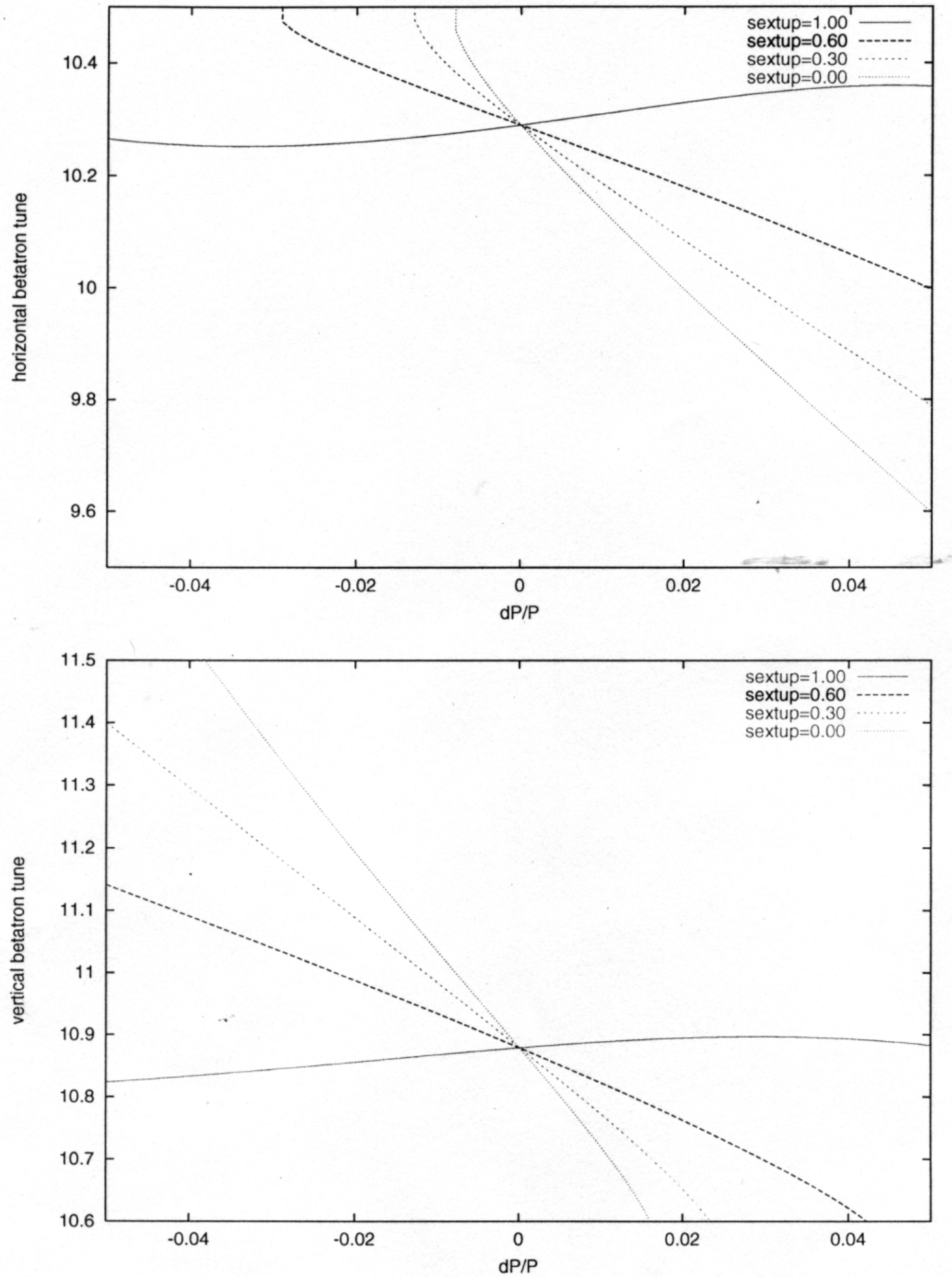


Figure 15: Proton Driver horizontal (top) and vertical (bottom) betatron tune.

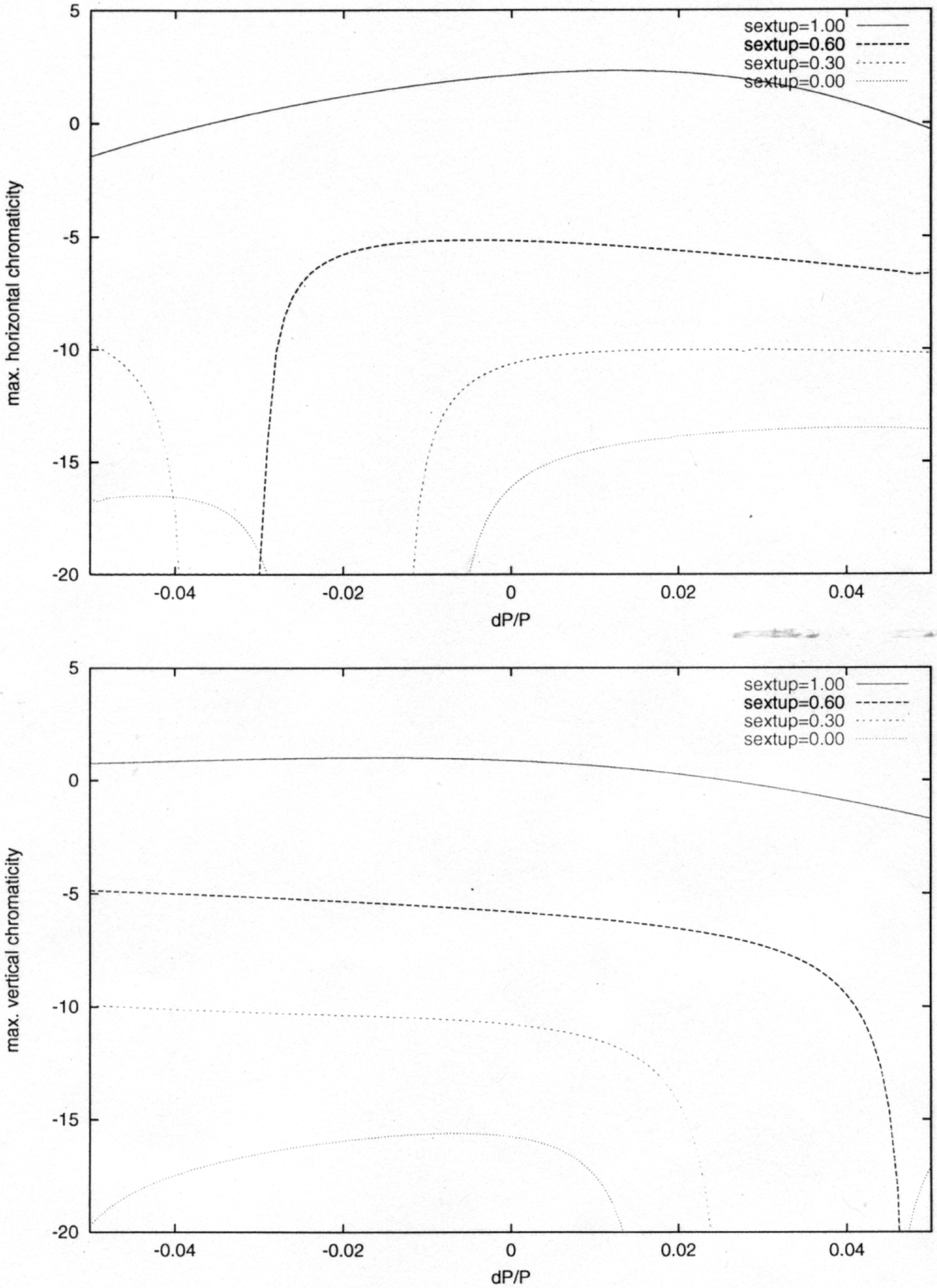


Figure 14: Proton Driver horizontal (top) and vertical (bottom) chromaticity.

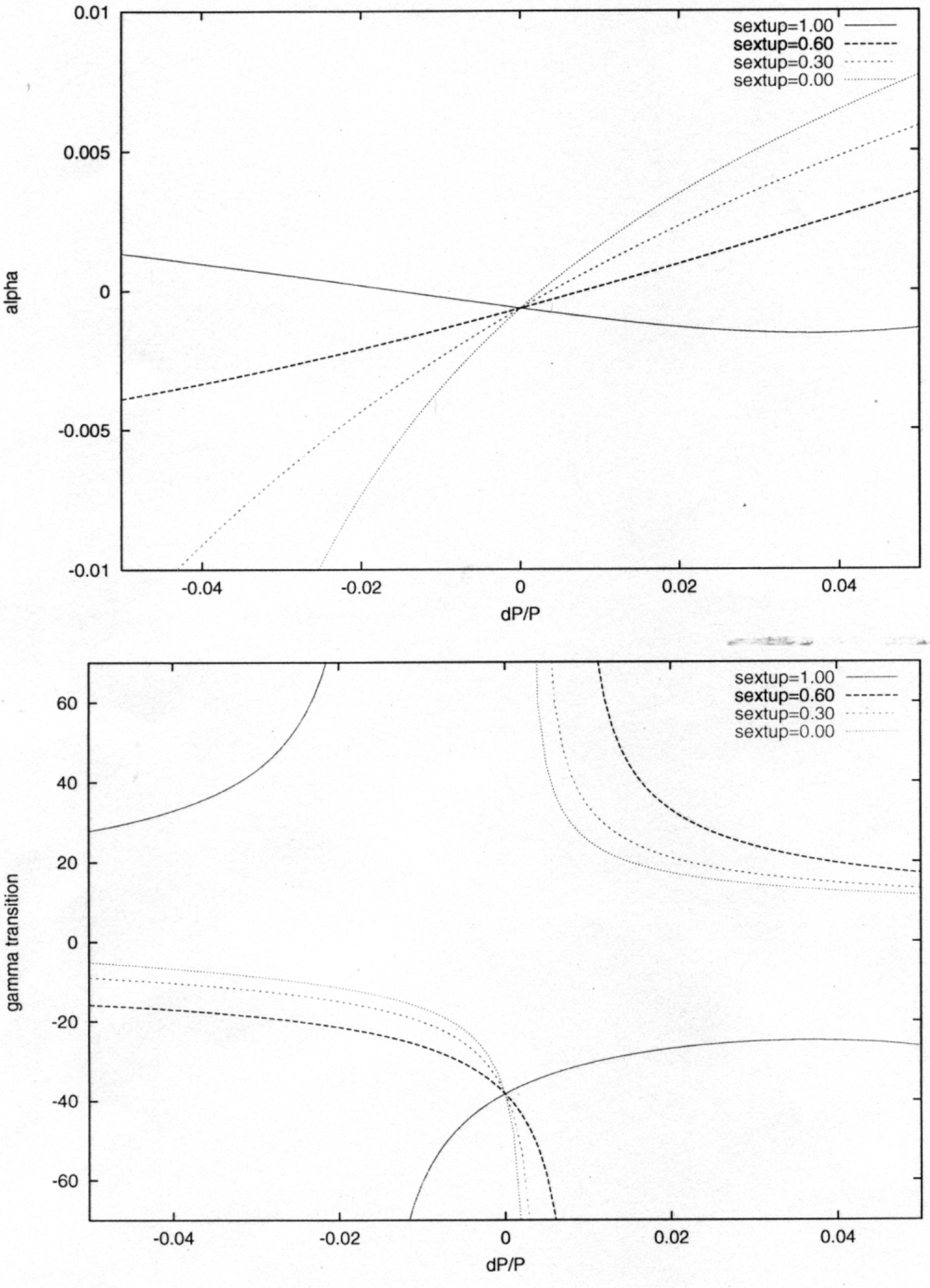


Figure 16: Proton Driver α (top) and γ transition (bottom).

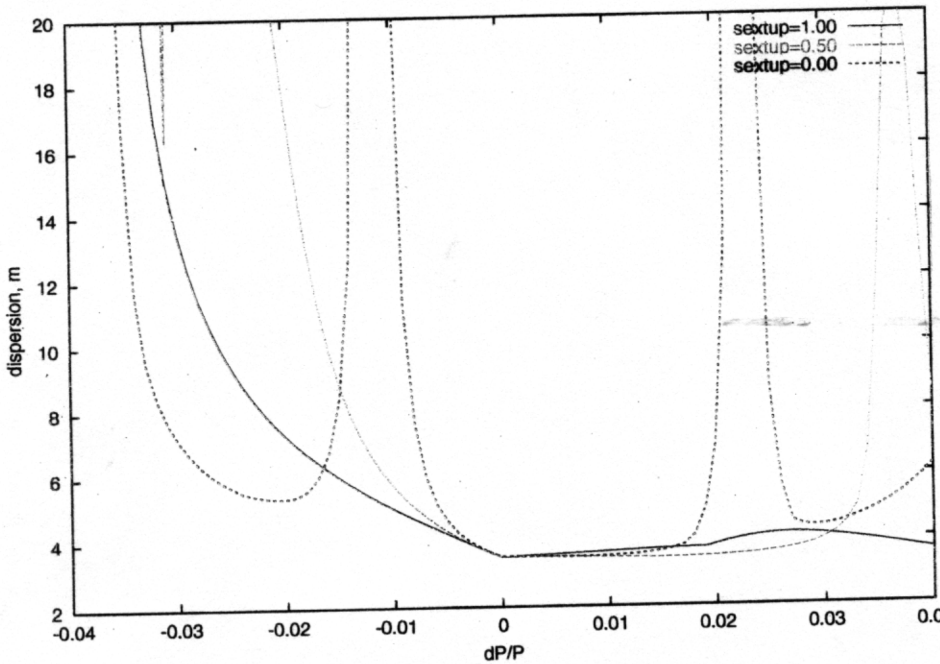


Figure 5: Proton Driver maximum dispersion.