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TUNE AND CHROMATICITY OF THE AGS VS. QUAD CURRENTS CALCULATED PLOTS AND FITTING COEFFICIENTS CODE QFIT

A. Luccio

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Collider Accelerator Department

Brookhaven National Laboratory

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Accelerator Division
Alternating Gradient Synchrotron Department
BROOKHAVEN NATIONAL LABORATORY
Upton, New York 11973

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Technical Note

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ABSTRACT

Tune and chromaticity of the AGS as a function of the current in a set of high field quadrupoles was calculated with the model MAD, Ref.[1]. Series of plots for the "bare machine" were created at various values of the proton momentum, between 15 and 29 GeV/c, and tables of coefficients to fit the plots were created. The coefficients are intended for the tune control programs of the AGS model-based control system. The results were compared -and found in good agreement- with some measured data.

PROCEDURE

A description of the bare AGS and tables of the quadrupole strengths of the alternating gradient magnets for various proton energies is given in Ref. [2]. Using these tables and the program MAD iteratively, we have produced a series of tables and coefficients of the tune and chromaticity of the AGS vs. the current in the "High Field Quadrupoles", HFQ's, meant to correct for the natural tune of the machine. The procedure has been made automatic, and a computer tool has been created to generate new tables, plots and coefficients, everytime that the parameters of the AGS are being changed.

To produce tables of tune, Q and chromaticity, $\xi = -\frac{1}{Q}\frac{\partial Q}{\partial p}$ as a function of the HFQ currents, MAD is simply run many times, with the currents being stepwise varied in the mad input file ("mad.in" or "DATA"). A script on the HP Apollo workstations is doing that for us. The inverse problem , i.e to find the currents needed to produce a given tune or a given chromaticity, and to produce relevant tables and coefficients can be solved using the "match" option in Mad. We prepared a script to do this, however since the procedure is time consuming, an alternate method was developed based on the inversion of the tables already created with the direct method.

The steps performed are the following:

a- Direct problem

1a- For a given proton momentum, e.g. $p = 20$ GeV/c, MAD is run in a double loop of HFQ currents, I_x and I_y for the horizontal and verical quadrupoles, respectively. For instance, both currents are varied between -1.6 and +1.6 KA in steps of 100 A. A first table is created, containing groups of records of Q and ξ, each group having a constant I_x and a range of values of I_y.

2a- The records are reordered to create another section of the table, containing groups of records of Q and ξ, each group now having a constant I_y and a range of values of I_x. At this point the table is ready to be read and plotted by the plotting program CPLOT, Ref.[3].

3a- A set of coefficients is calculated by linear fit in the first part of the just made,table for the four quantities Q_x, Q_y, ξ_x, ξ_y. Thebase for the fit is powers, up to a given degree (say, 3, 5, 7...). The least square fitting routine is LFIT, as described in Ref. [4]. The routine is applied twice. First, the coefficients of the fit are calculated in each group -with constant I_x -, for a quantity, e.g. Q_x, vs. I_y. Then the coefficients themselves are fitted vs. I_x. The result looks like this

$$\begin{cases} Q_x = a_0 + a_1 I_y + a_2 I_y^2 + a_3 I_y^3 + \ldots \\ a_0 = a_{00} + a_{01} I_x + a_{02} I_x^2 + a_{03} I_x^3 + \ldots \\ a_1 = a_{10} + a_{11} I_x + a_{12} I_x^2 + a_{13} I_x^3 + \ldots \\ a_2 = a_{20} + a_{21} I_x + \ldots \\ \quad \ldots\ldots\ldots \end{cases} \tag{1}$$

$(n+1)(n+1)$ coefficients are produced, for each variable, where n is the order of the fit.

b- Inverse problem

The tables created in the steps a-, above, are simply inverted by calculating with the expansion (1) the currents needed for the values of tune and chromaticity on equally spaced grids. In a similar way as for the direct problem, coefficients for the inverse tables are created. The result is:

$$
\begin{cases}
I_x = b_0 + b_1 Q_y + b_2 Q_y^2 + \ldots \\
b_0 = b_{00} + b_{01} Q_x + b_{02} Q_x^2 + \ldots \\
b_1 = b_{10} + b_{11} Q_x + b_{12} Q_x^2 + \ldots \\
b_2 = b_{20} + \ldots \\
\quad \ldots\ldots\ldots \\
I_y = d_2 + \ldots.
\end{cases}
\qquad
\begin{cases}
I_y = c_0 + c_1 \xi_y + c_2 \xi_y^2 + \ldots \\
c_0 = c_{00} + c_{01} \xi_x + c_{02} \xi_x^2 + \ldots \\
c_1 = c_{10} + c_{11} \xi_x + c_{12} \xi_x^2 + \ldots \\
c_2 = c_{20} + \ldots \\
\quad \ldots\ldots\ldots \\
I_y = e_2 + \ldots.
\end{cases}
\tag{2}
$$

c. Difference tables.

It is useful to have tables of the differences of the values of tune, ΔQ and chromaticity, $\Delta\xi$ with respect to the values at $I = 0$. The program is searching in the direct table to find these reference values and builds tables of the (direct) differences. Then, it inverts the table as already described in Sec. b, and finally calculates coefficients for the direct and inverse difference problem.

TABLES AND PLOTS

Tables and plots for the bare AGS, for momenta 15, 20, 29, 32 GeV/c are given. First, for the direct case: tune and chromaticity charts for constant values of the current in the horizontal and vertical HFQ in the range ±1.6 KA, then for the inverse case: current charts for constant values of the tune, in the range (7,10) and chromaticity, in the range (-4,-2) (ξ_x) and (-0.1,0.5) (ξ_y). Finally, for the difference case.

Tables 1-5 are for the direct problem, Eq. (1), 2 x 2 coefficients, proton momenta 15 to 32 GeV/c.

Tables 6-10 are for the inverse problem, Eq. (2), 2 x 2 coefficients, same momenta.

Tables 11-15 are for the difference problem, 2 x 2 coefficients, same momenta.

Figures 1-5 show charts of the tune vs. quadrupole currents for proton momenta of 15, 20, 25, 29 and 32 GeV/c, respectively.

Figures 6-10 show charts of the chromaticity vs. quadrupole currents for the same set of proton momenta.

Figures 11-15 show (inverse) charts of quadrupole currents vs. tune.

Figures 16-20 show (inverse) charts of quadrupole currents vs. chromaticity

Figures 21-25 show (inverse) charts of currents vs. tune differences.

Figures 26-30 show (inverse) charts of currents vs. chromaticity differences.

EXTENSIONS

Tables and charts, created for different values of the High Field Quadrupole Currents, can also be made with the same code for sets of values of any other parameter.

REFERENCES

1. F.Ch.Iselin and J.Niederer, "The Mad Program Version 7.2" CERN/LEP-TH/88-38, Geneva, July 13, 1988.
2. E.Auerbach "Computer models of the AGS, I: The DC Bare Machine at High Fields" AGS/AD/Tech. Note No. 297, March 7, 1988.
3. A.Luccio "CPLOT: An Apollo Plotting Program" AGS Booster Tech. Note No.156, January 9, 1990.
4. W.H.Press, B.P.Flannery, S.A.Teukolsky and W.T.Vetterling "Numerical Recipes", Cambridge University Press, Cambridge, MA 1986, p.509.

Table 1. AGS. Protons 15 GeV/c

Q_x vs. I_x, I_y		$Q_xy$vs. I_x, I_y		ξ_x vs. I_x, I_y		ξ_y vs. I_x, I_y	
8.67862	.799120	8.73773	-.376369	-2.59145	.825042	.075907	-.178643
-.382835	.064923	.790011	.058558	-.459910	.392263	-.086553	-.043684

Table 2. AGS. Protons 20GeV/c

Q_x vs. I_x, I_y		$Q_xy$vs. I_x, I_y		ξ_x vs. I_x, I_y		ξ_y vs. I_x, I_y	
8.69416	.574584	8.74664	-.268872	-2.57960	.486355	.252419	-.132769
-.271333	.030245	.570752	.026633	-.263825	.125997	-.086553	-.019944

Table 3. AGS. Protons 25 GeV/c

Q_x vs. I_x, I_y		$Q_xy$vs. I_x, I_y		ξ_x vs. I_x, I_y		ξ_y vs. I_x, I_y	
8.67995	.451972	8.72331	-.211575	-3.00630	.453298	.702600	-.124213
-.212957	.017457	.449794	.015494	-.243774	.081286	-.072167	-.013043

Table 4. AGS. Protons 29 GeV/c

Q_x vs. I_x, I_y		$Q_xy$vs. I_x, I_y		ξ_x vs. I_x, I_y		ξ_y vs. I_x, I_y	
8.62238	.389182	8.66121	-.182323	-4.38575	.633612	1.99873	-.159361
-.183360	.012381	.387522	.010966	-.335996	.098370	-.128167	-.012924

Table 5. AGS. Protons 32GeV/c

Q_x vs. I_x, I_y		$Q_xy$vs. I_x, I_y		ξ_x vs. I_x, I_y		ξ_y vs. I_x, I_y	
8.48523	.356911	8.52642	-.167345	-6.95433	1.01091	4.38981	-.236536
-.168396	.009791	.355150	.008593	-.534952	.150013	-.240013	-.015338

Table 6. AGS. Inverse. Protons 15 GeV/c

I_x vs. Q_x, Q_y		$I_x y$vs. Q_x, Q_y		I_x vs. ξ_x, ξ_y		I_y vs. ξ_x, ξ_y	
-35.9628	3.29646	-35.5415	2.38966	1.42037	.360149	-2.43793	-1.03502
2.46556	-.188710	3.26211	-.182212	-2.04281	.474527	-5.97251	-.299070

Table 7. AGS. Inverse. Protons 20 GeV/c

I_x vs. Q_x, Q_y		$I_x y$vs. Q_x, Q_y		I_x vs. ξ_x, ξ_y		I_y vs. ξ_x, ξ_y	
-47.4589	4.34669	-46.7731	3.07311	2.37179	.476774	-2.74338	-1.75981
3.16511	-.237889	4.26493	-.227760	-.638736	1.32653	-9.17930	-.704387

Table 8. AGS. Inverse. Protons 25 GeV/c

I_x vs. Q_x, Q_y		$I_x y$vs. Q_x, Q_y		I_x vs. ξ_x, ξ_y		I_y vs. ξ_x, ξ_y	
-59.1367	5.42487	-58.2904	3.81074	3.73851	.293498	.246971	-1.57852
3.92456	-.293737	5.32666	-.281378	-.706578	1.07422	-8.65562	-.495727

Table 9. AGS. Inverse. Protons 29 GeV/c

I_x vs. Q_x, Q_y		$I_x y$vs. Q_x, Q_y		I_x vs. ξ_x, ξ_y		I_y vs. ξ_x, ξ_y	
-67.5576	6.23692	-66.5794	4.36352	4.83004	-.060368	6.13197	-.733504
4.48590	-.336358	6.11429	-.321986	-.442478	.474326	-5.61284	-.210623

Table 10. AGS. Inverse. Protons 32 GeV/c

I_x vs. Q_x, Q_y		$I_x y$vs. Q_x, Q_y		I_x vs. ξ_x, ξ_y		I_y vs. ξ_x, ξ_y	
-69.2882	6.42723	-68.4266	4.40493	5.71221	-.110362	9.89902	-.297375
4.52070	-.329417	6.31574	-.315673	-.317122	.165456	-3.24934	-.074700

Table 11. AGS. Differences. Protons 15 GeV/c

Reference values for $I_x=I_y=0$: Q_x=8.72007, Q_y=8.77242, ξ_x=-2.31145, ξ_y=0.105530.

ΔQ_x vs. I_x, I_y		ΔQ_{xy} vs. I_x, I_y		$\Delta\xi_x$ vs. I_x, I_y		$\Delta\xi_y$ vs. I_x, I_y	
-.044913	.804612	-.034182	-.377164	-.409037	1.03083	-.029806	-.178348
-.387974	.073014	.790796	.057348	-.649357	.692556	-.086818	-.043259

Table 12. AGS. Differences. Protons 20 GeV/c

Reference values for $I_x=I_y=0$: Q_x=8.71350, Q_y=8.76270, ξ_x=-2.47450, ξ_y=0.258700.

ΔQ_x vs. I_x, I_y		ΔQ_{xy} vs. I_x, I_y		$\Delta\xi_x$ vs. I_x, I_y		$\Delta\xi_y$ vs. I_x, I_y	
-.019299	.000575	-.016017	-.000269	-.105076	.000486	-.006301	-.000133
-.000271	.000000	.000571	.000000	-.000264	.000000-	.000063	-.000000

Table 13. AGS. Differences. Protons 25 GeV/c

Reference values for $I_x=I_y=0$: Q_x=8.69195, Q_y=8.73368, ξ_x=-2.94135, ξ_y=0.692810.

ΔQ_x vs. I_x, I_y		ΔQ_{xy} vs. I_x, I_y		$\Delta\xi_x$ vs. I_x, I_y		$\Delta\xi_y$ vs. I_x, I_y	
-.012000	.451972	-.010370	-.211575	-.064953	.453298	.009791	-.124213
-.212957	.017457	.449794	.015494	-.243774	.081286	-.072167	-.013043

Table 14. AGS. Differences. Protons 29 GeV/c

Reference values for $I_x=I_y=0$: Q_x=8.63262, Q_y=8.67035, ξ_x=-4.32175, ξ_y=1.96050.

ΔQ_x vs. I_x, I_y		ΔQ_{xy} vs. I_x, I_y		$\Delta\xi_x$ vs. I_x, I_y		$\Delta\xi_y$ vs. I_x, I_y	
-.010241	.389182	-.009144	-.182322	-.063999	.633612	.038226	-.159361
-.183360	.012381	.387522	.010966	-.335996	.098737	-.128167	-.012924

Table 15. AGS. Differences. Protons 32 GeV/c

Reference values for $I_x=I_y=0$: Q_x=8.49678, Q_y=8.53693, ξ_x=-6.85840, ξ_y=4.29907.

ΔQ_x vs. I_x, I_y		ΔQ_{xy} vs. I_x, I_y		$\Delta\xi_x$ vs. I_x, I_y		$\Delta\xi_y$ vs. I_x, I_y	
-.011546	.356911	-.010510	-.167345	-.095934	1.01091	.090743	-.236536
-.168396	.009792	.355151	.008593	-.534952	.150013	-.240013	-.015338

Fig.1. AGS. Chart of Tunes vs. High field Quadrupole Currents. Protons 15 GeV/c.

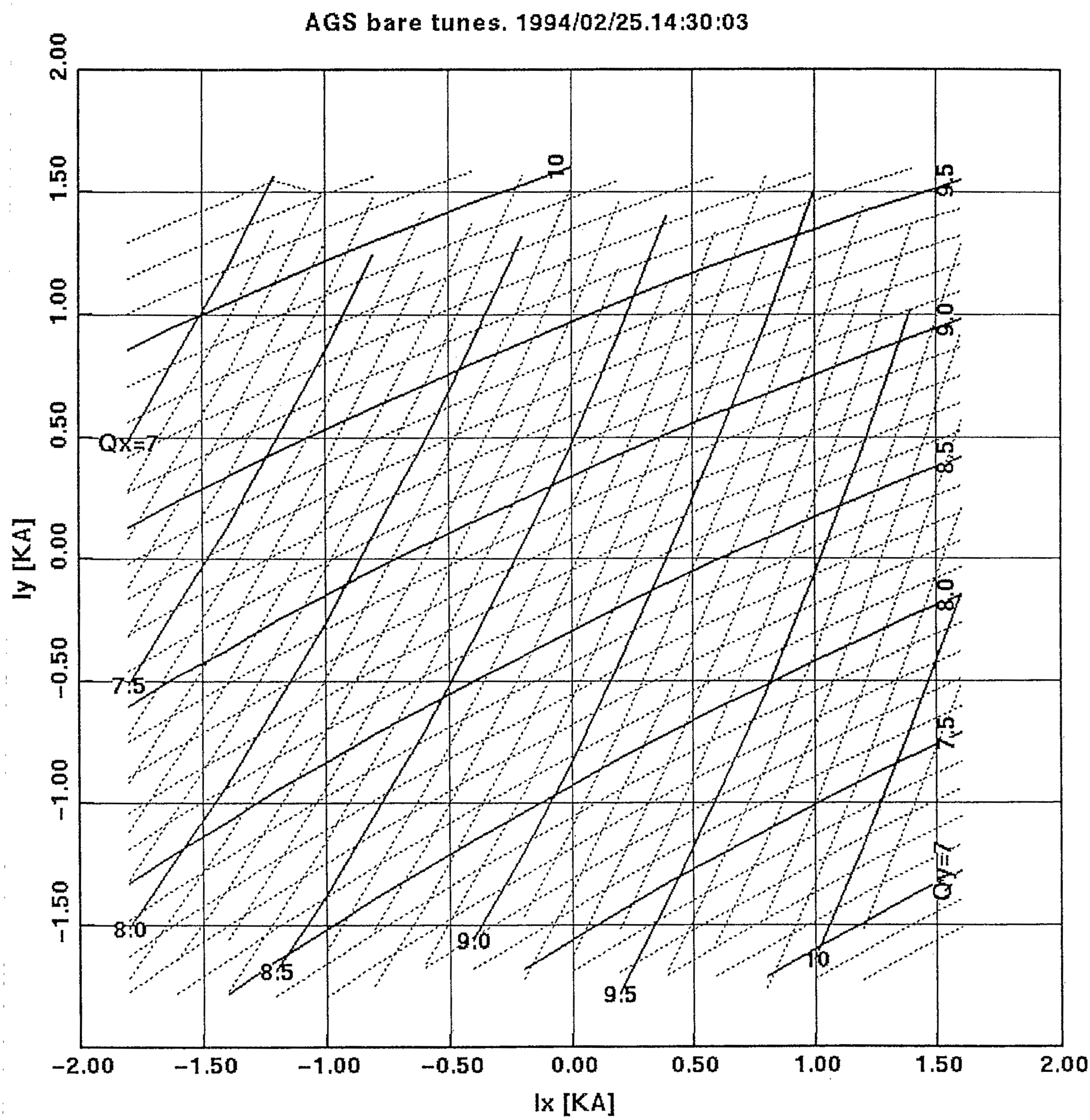

Fig.3. AGS. Chart of Tunes vs. HF Quadrupole Currents. Protons 25 GeV/c.

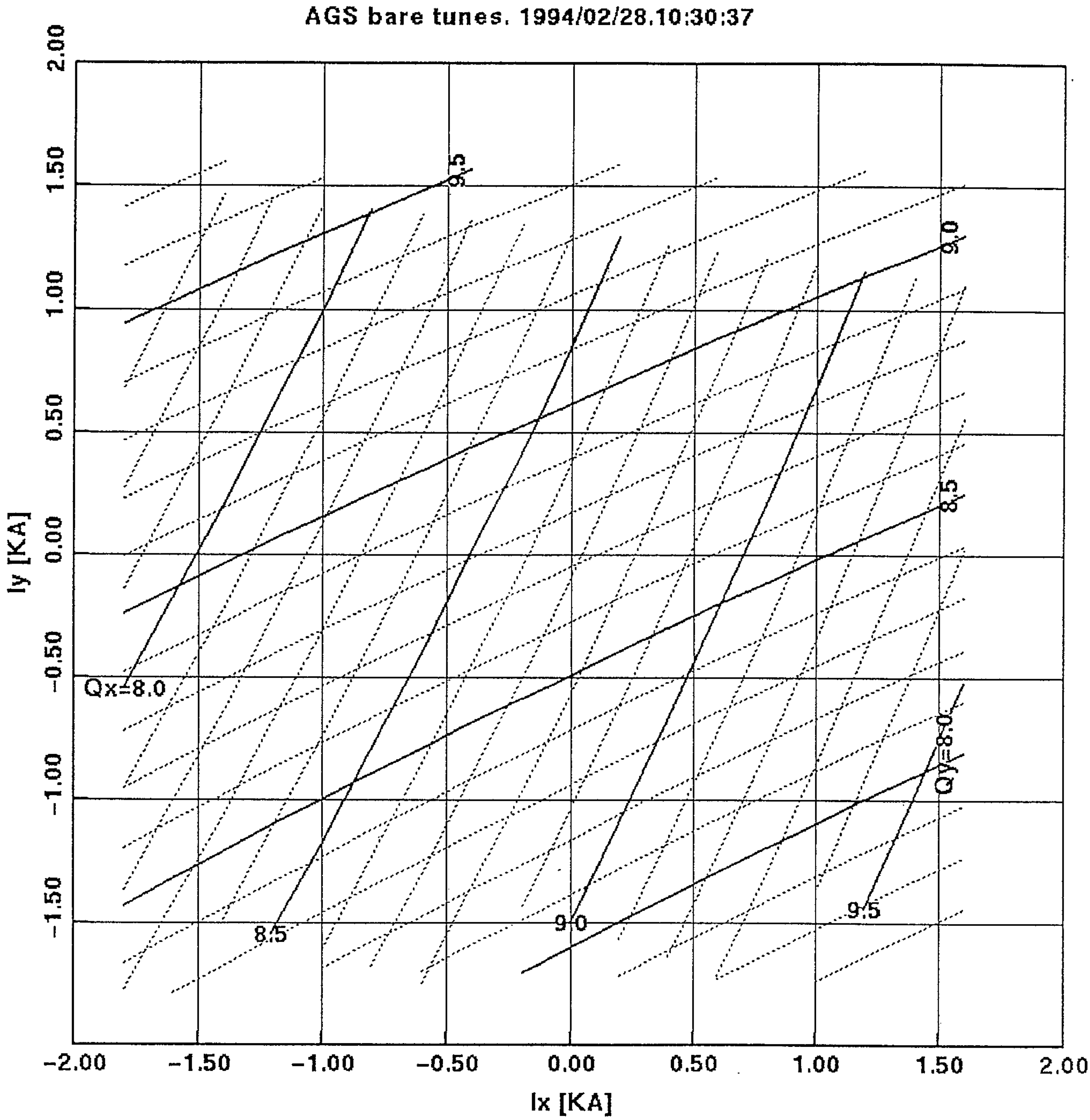

Fig.4. AGS. Chart of Tunes vs. HF Quadrupole Currents. Protons 29 GeV/c.

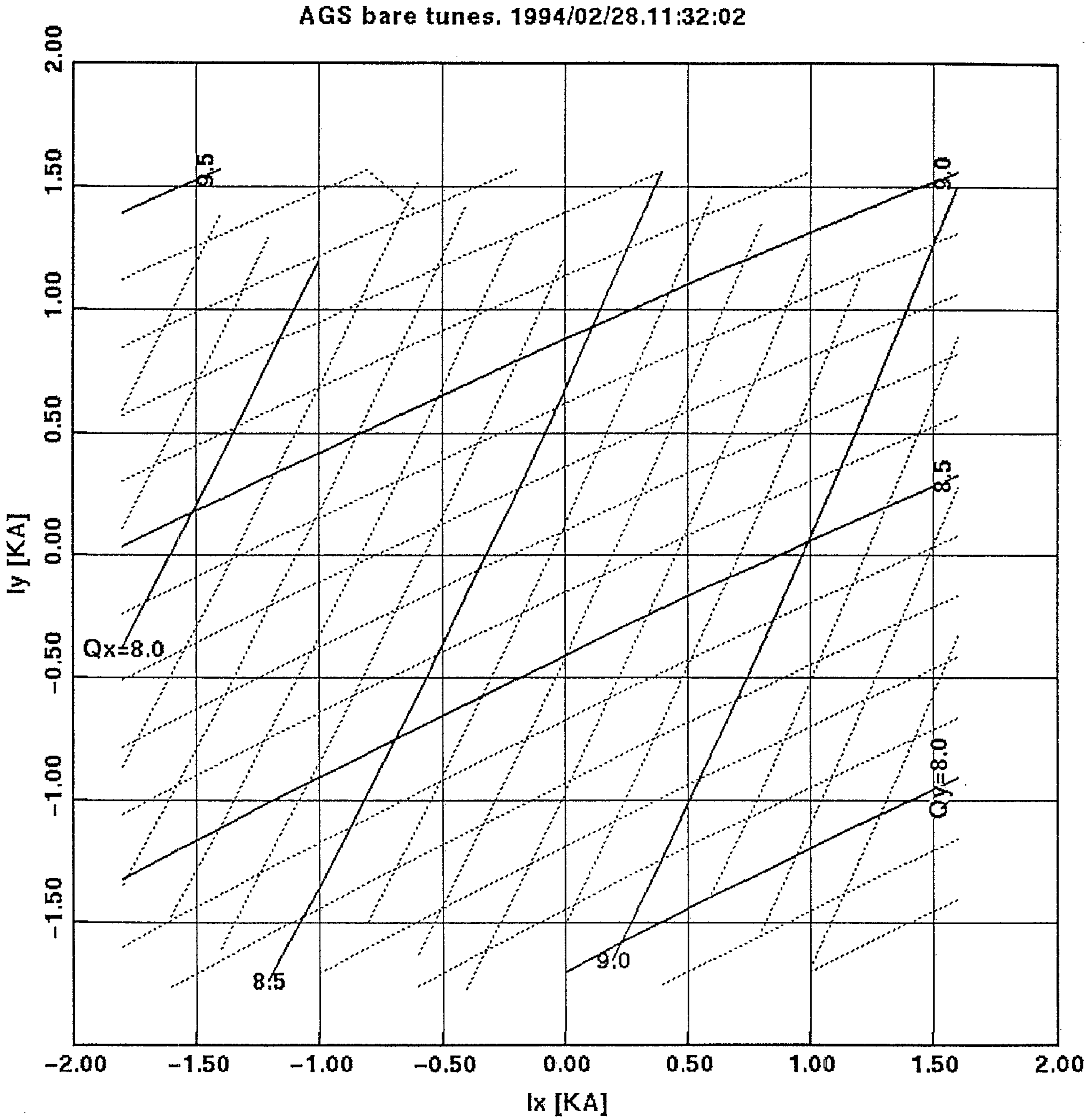

Fig.5. AGS. Chart of Tunes vs. HF Quadrupole Currents. Protons 32 GeV/c.

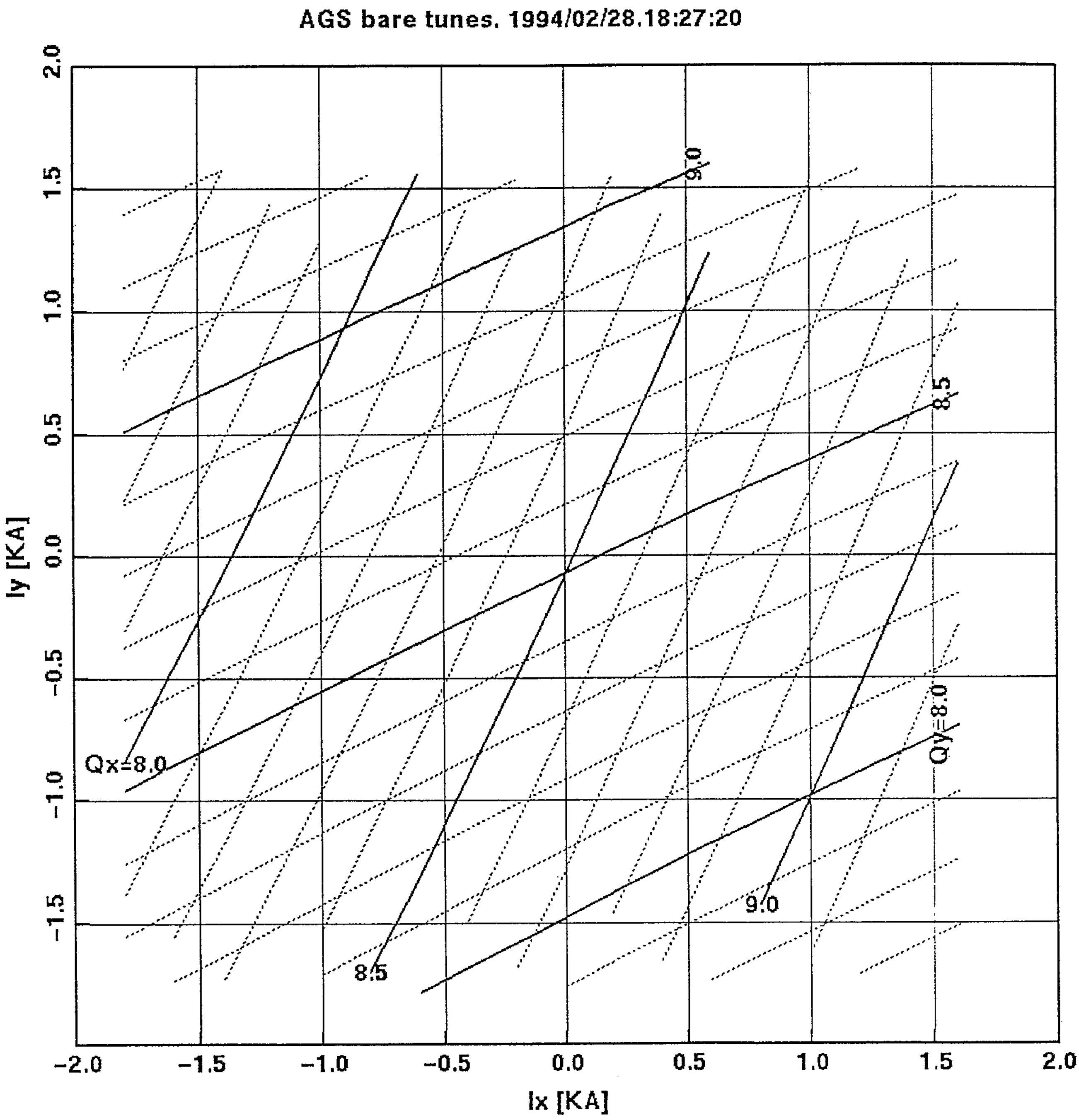

Fig.6. AGS. Chart of Chromaticity vs. HF Quadrupole Currents. Protons 15 GeV/c.

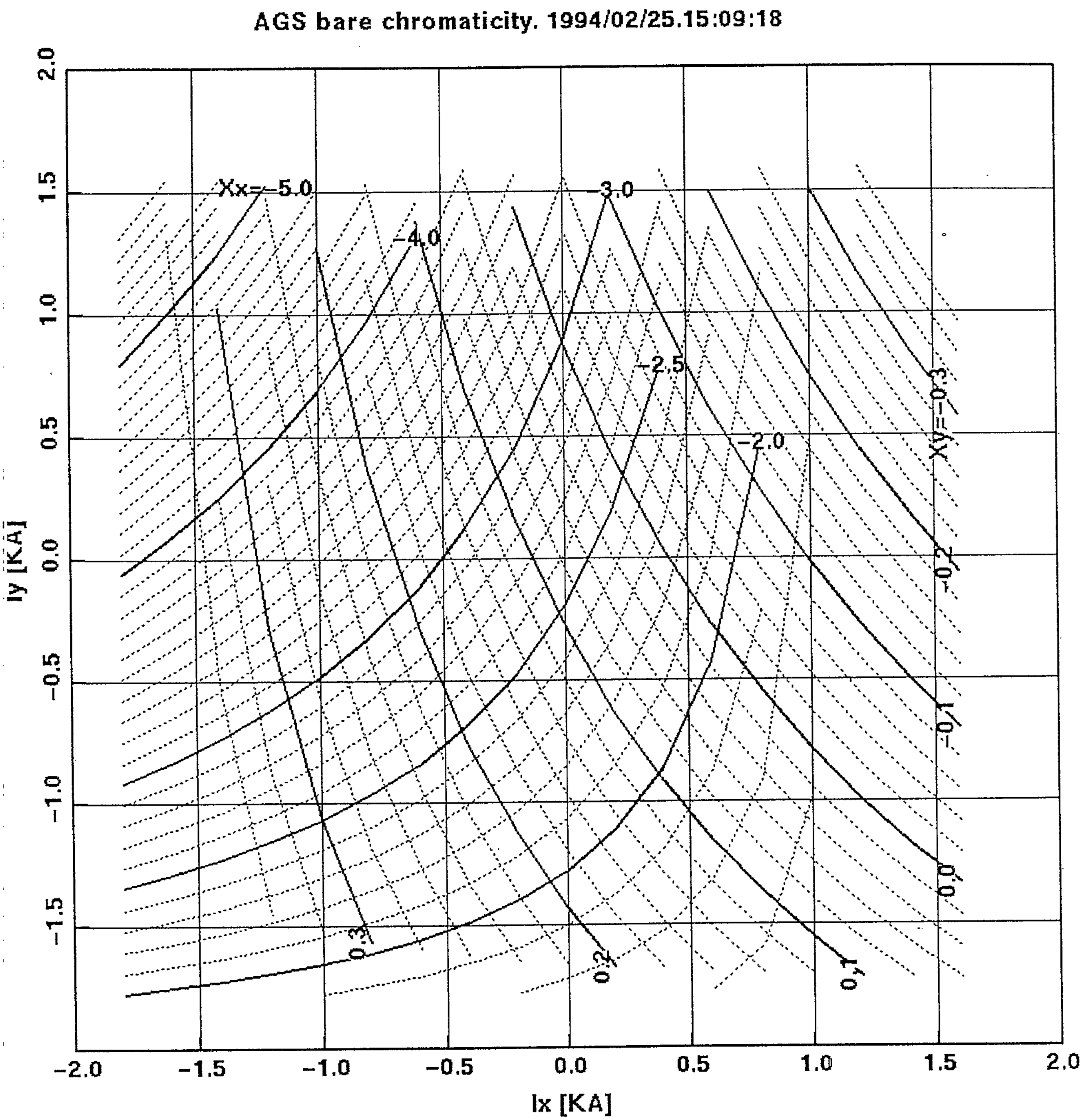

Fig.7. AGS. Chart of Chromaticity vs. HF Quadrupole Currents. Protons 20 GeV/c.

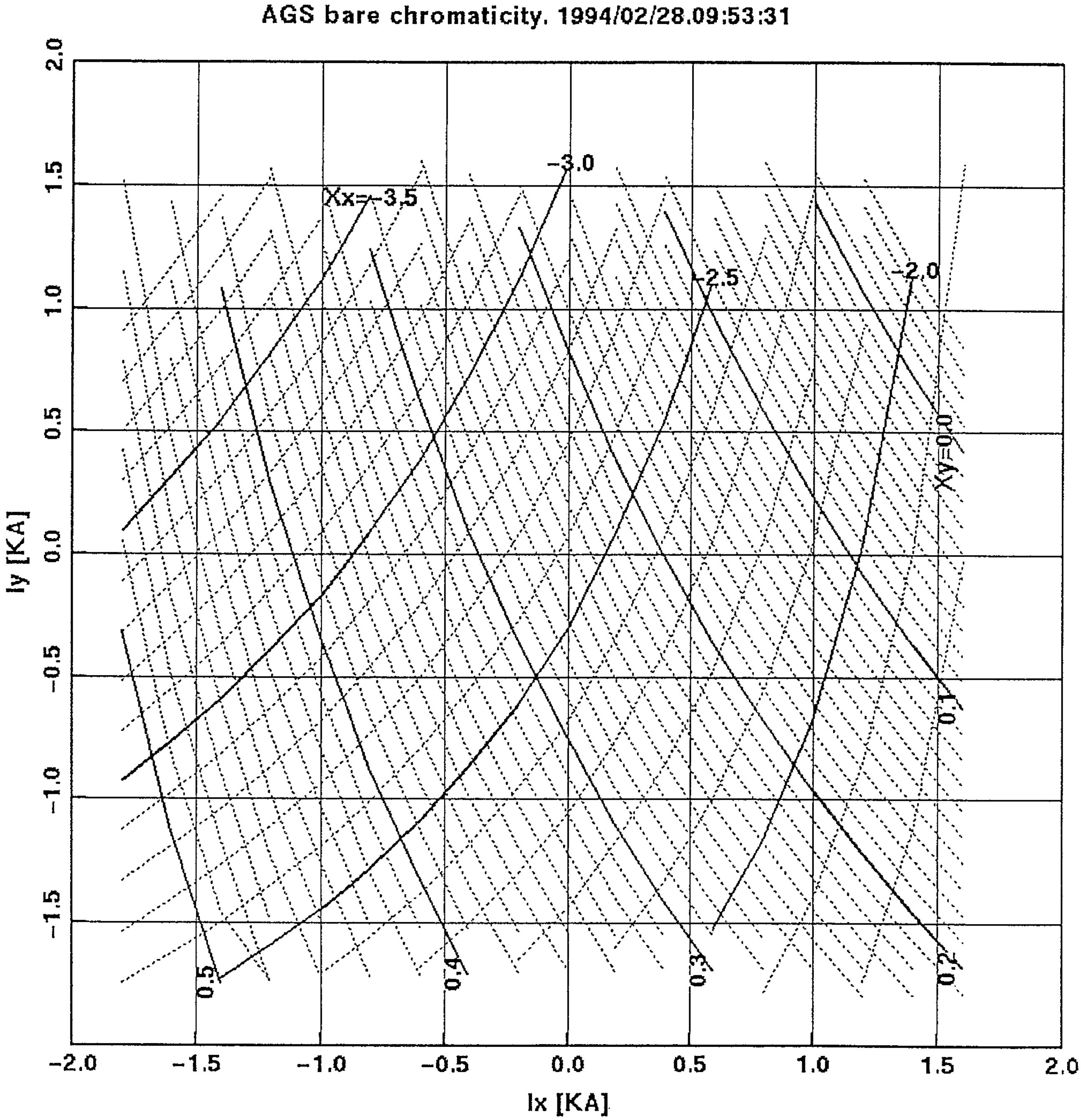

Fig.8. AGS. Chart of Chromaticity vs. HF Quadrupole Currents. Protons 25 GeV/c.

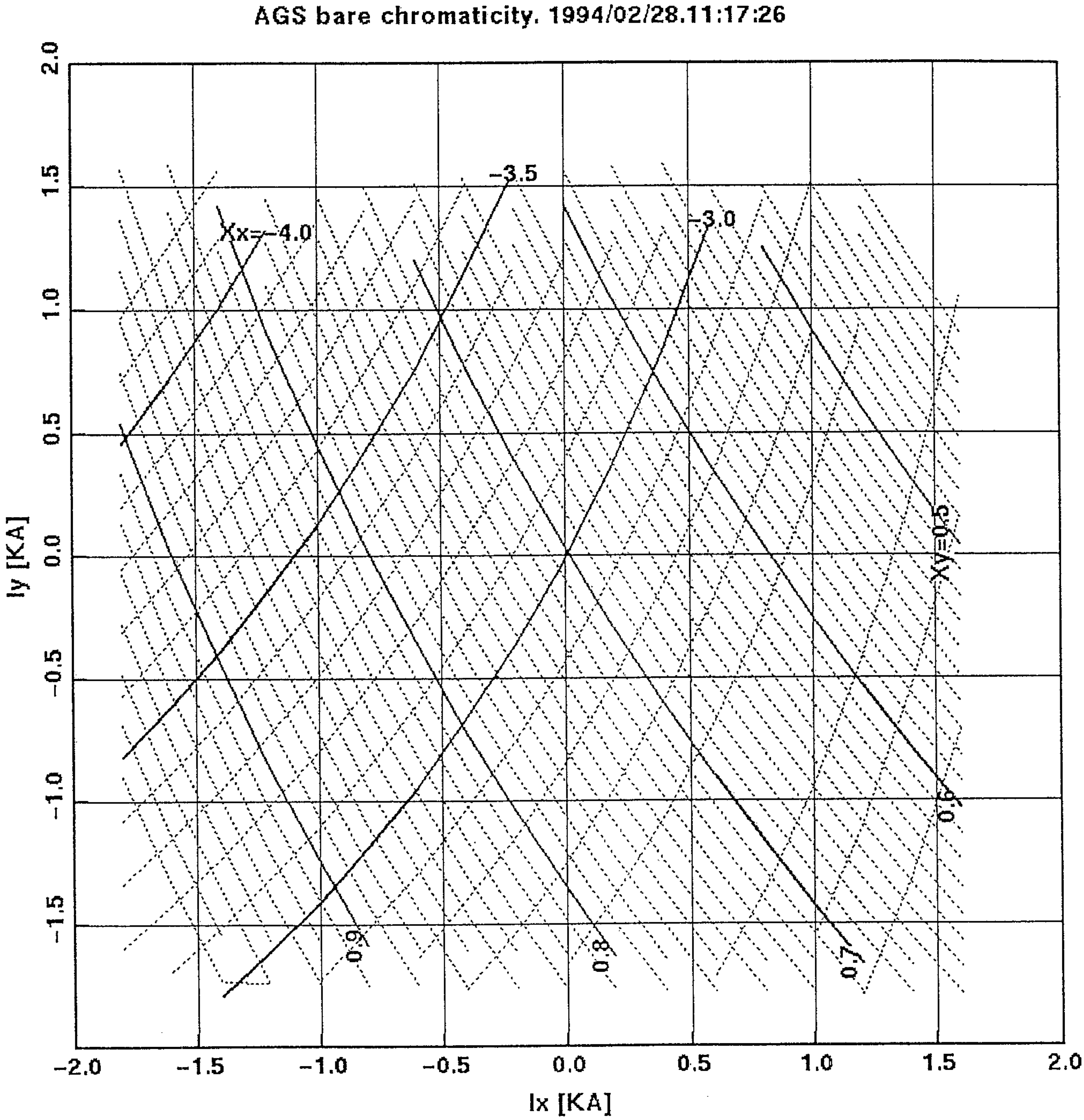

Fig.9. AGS. Chart of Chromaticity vs. HF Quadrupole Currents. Protons 29 GeV/c.

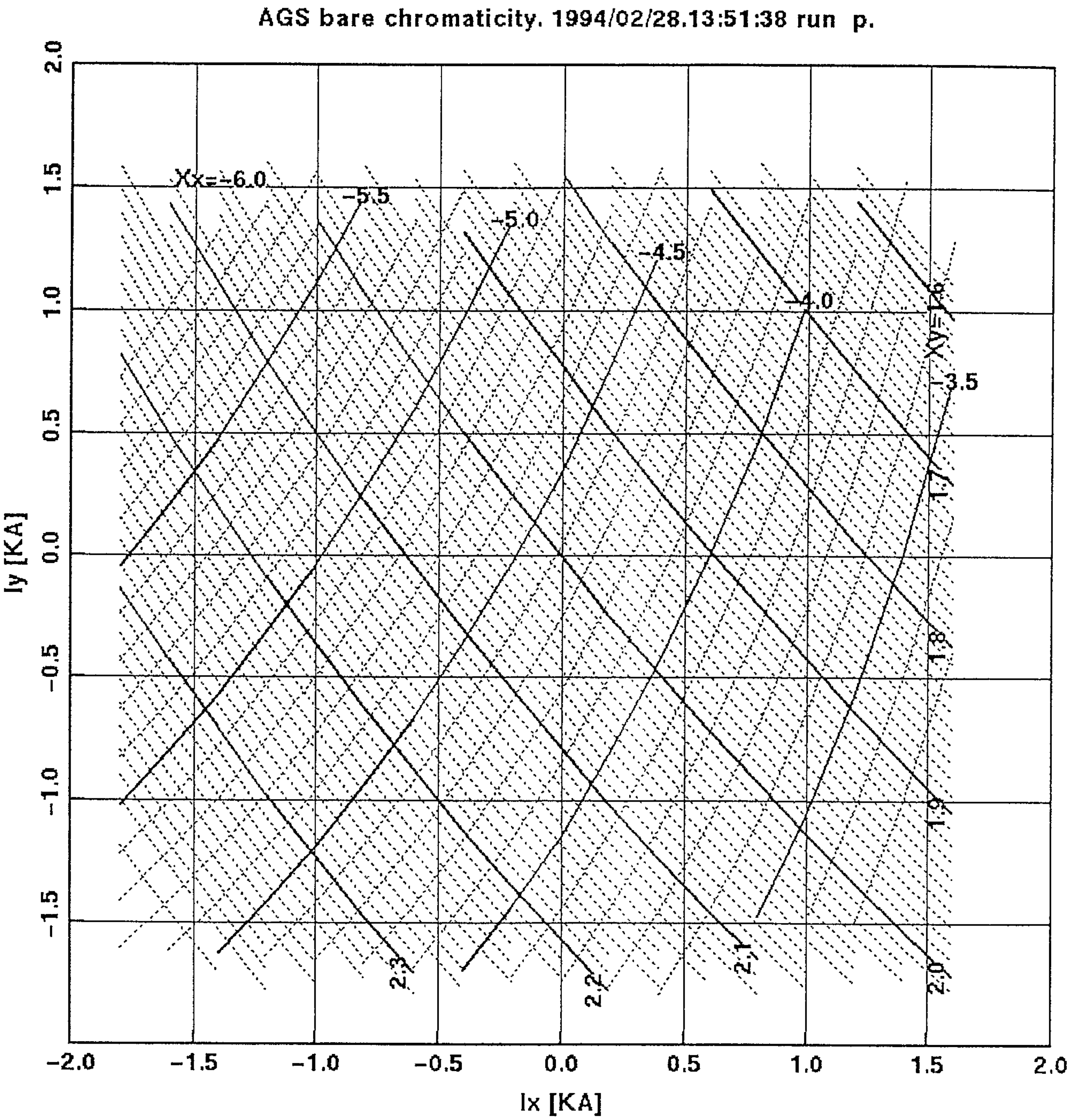

Fig.10. AGS. Chart of Chromaticity vs. HF Quadrupole Currents. Protons 32 GeV/c.

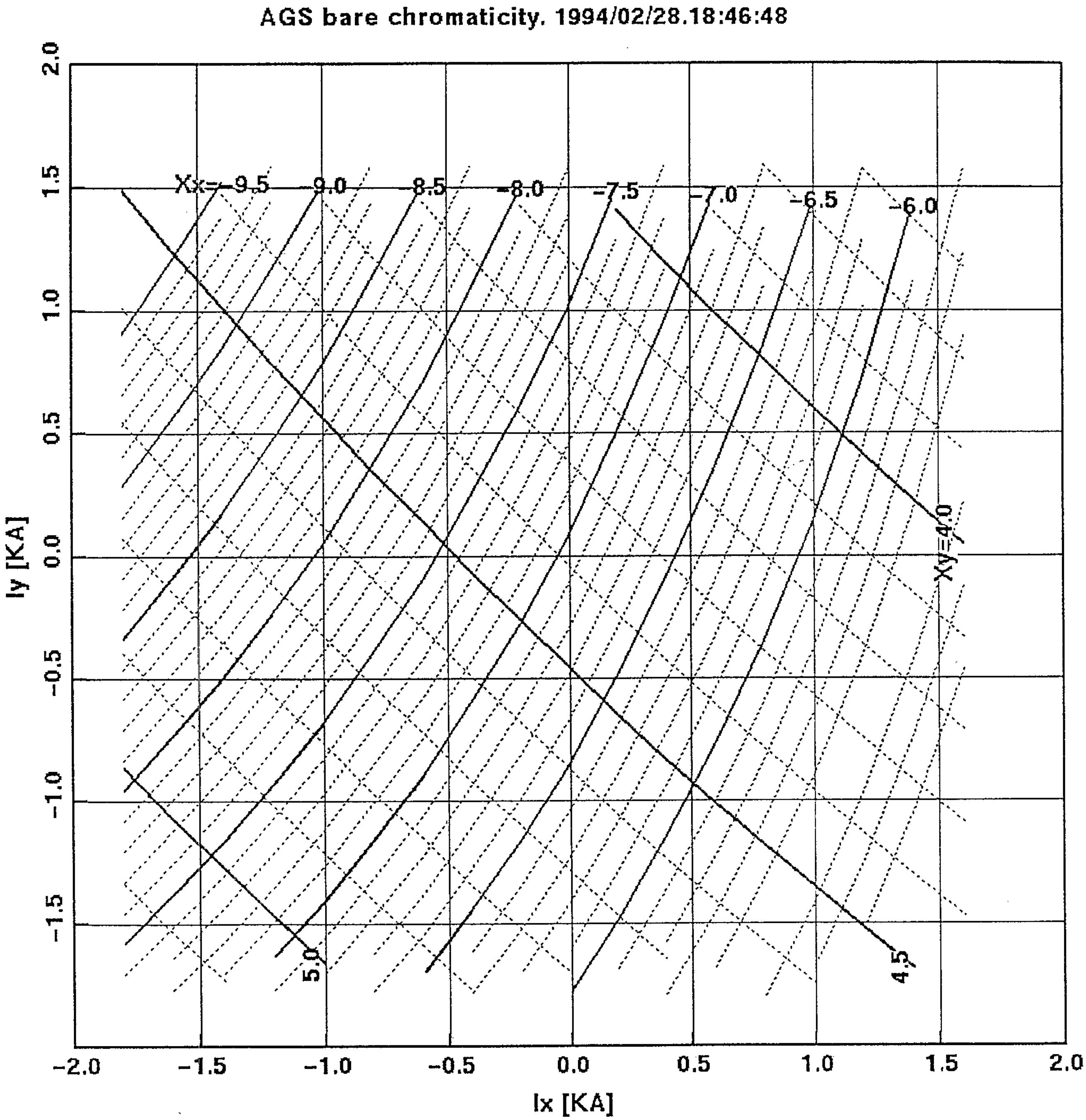

Fig.11. AGS. Chart of HF Quadrupole Currents vs. Tunes. Protons 15 GeV/c.

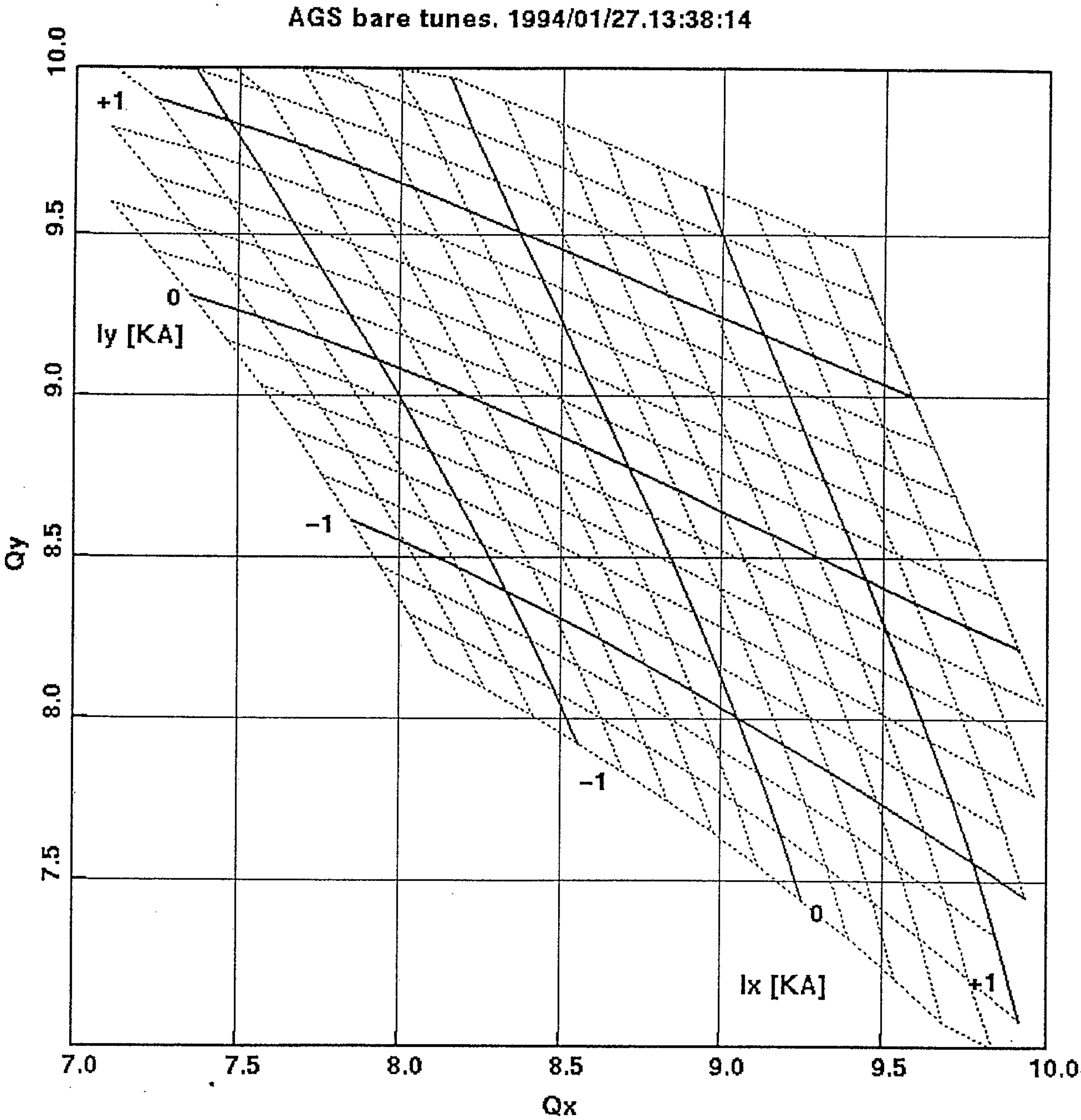

Fig.12. AGS. Chart of HF Quadrupole Currents vs. Tunes. Protons 20 GeV/c.

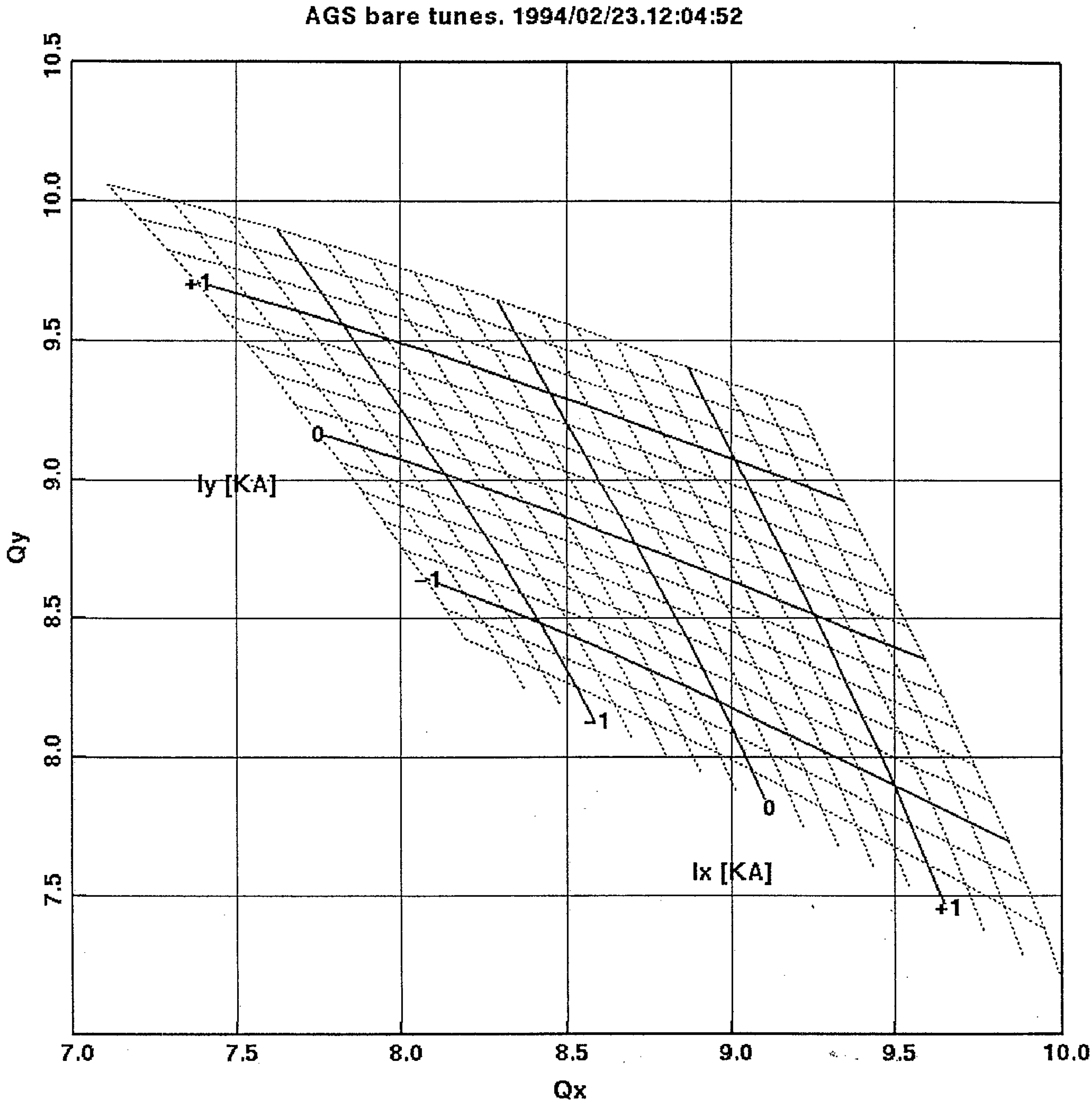

Fig.13. AGS. Chart of HF Quadrupole Currents vs. Tunes. Protons 25 GeV/c.

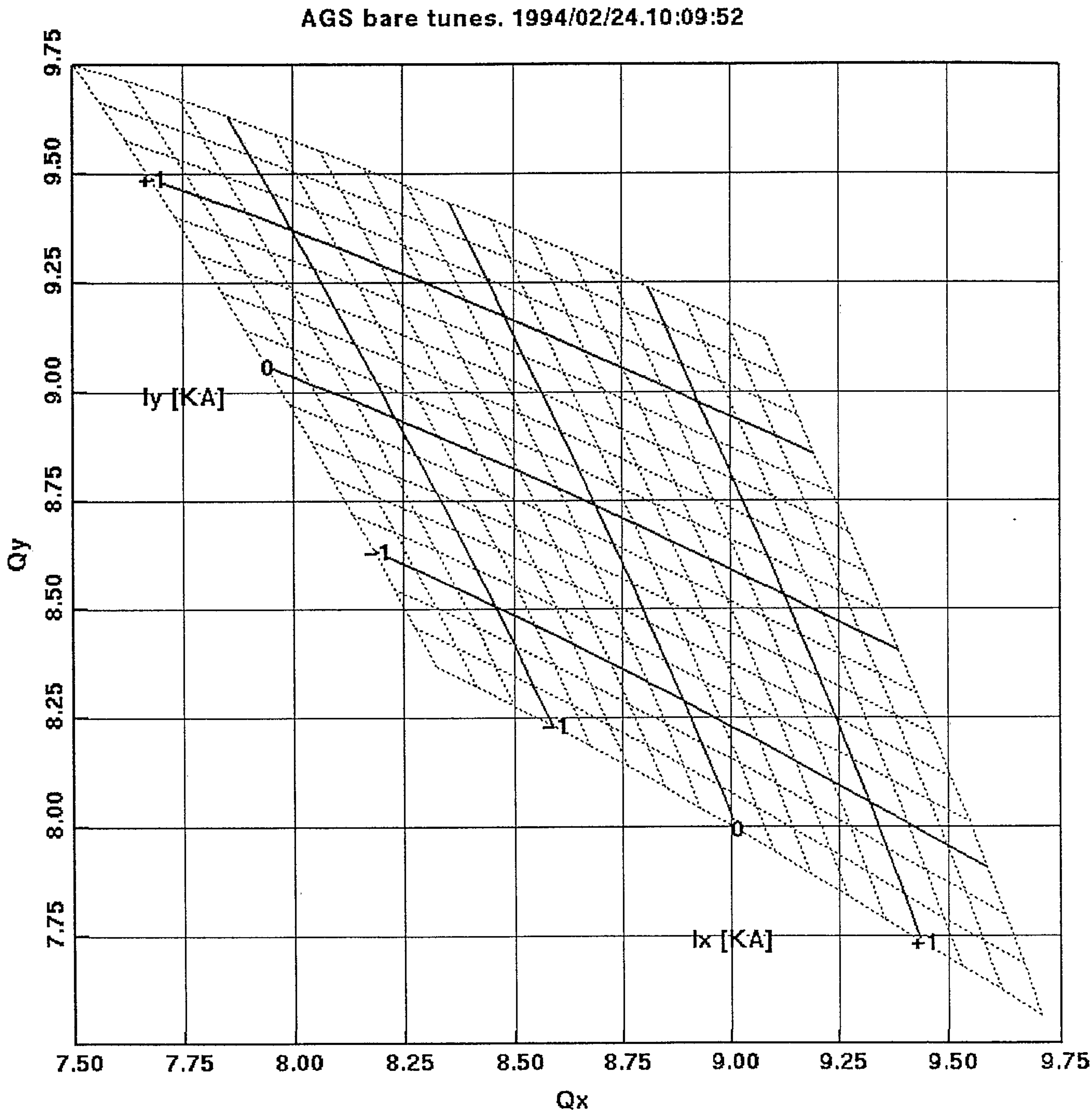

Fig.14. AGS. Chart of HF Quadrupole Currents vs. Tunes. Protons 29 GeV/c.

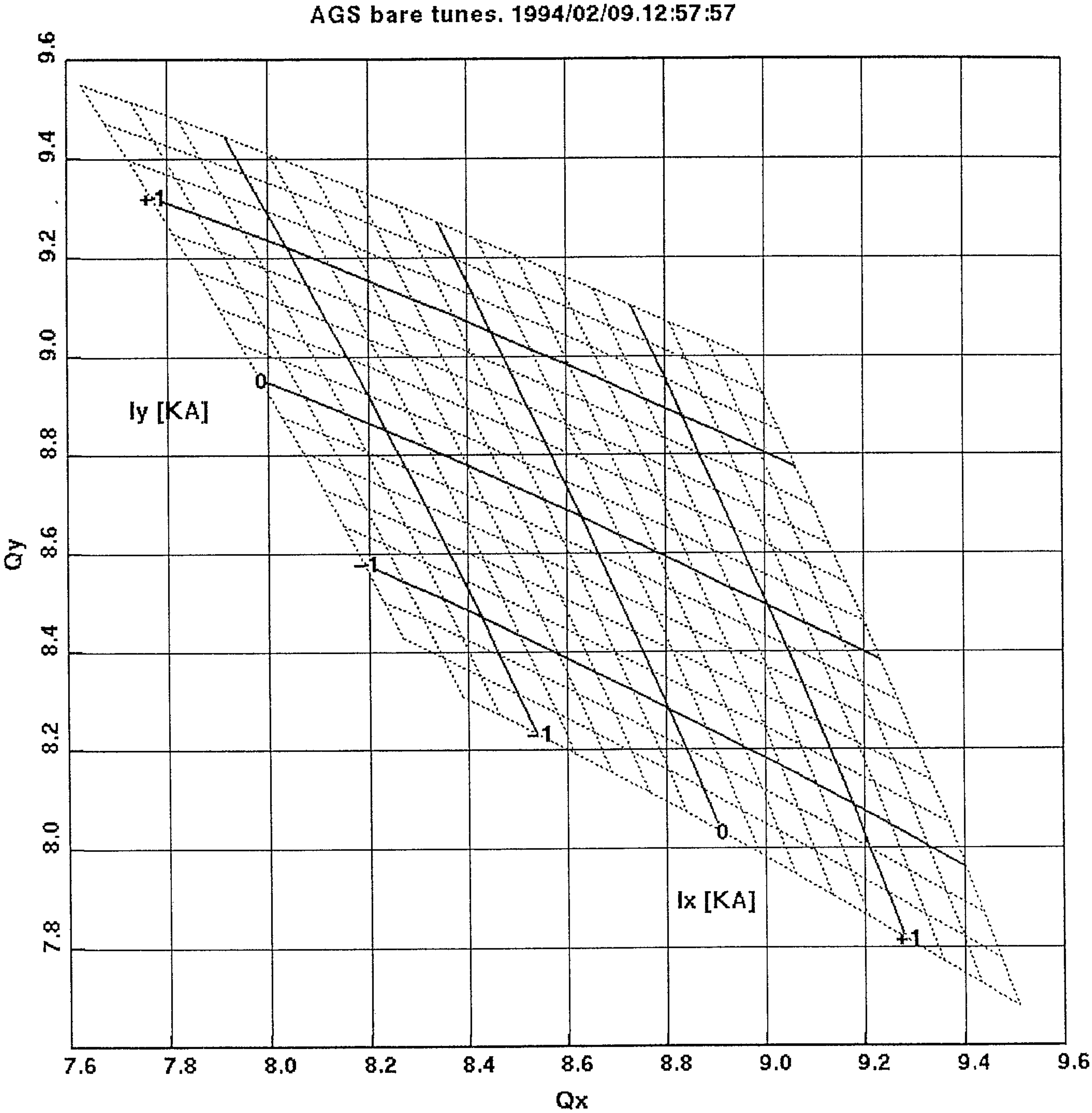

Fig.15. AGS. Chart of HF Quadrupole Currents vs. Tunes. Protons 32 GeV/c.

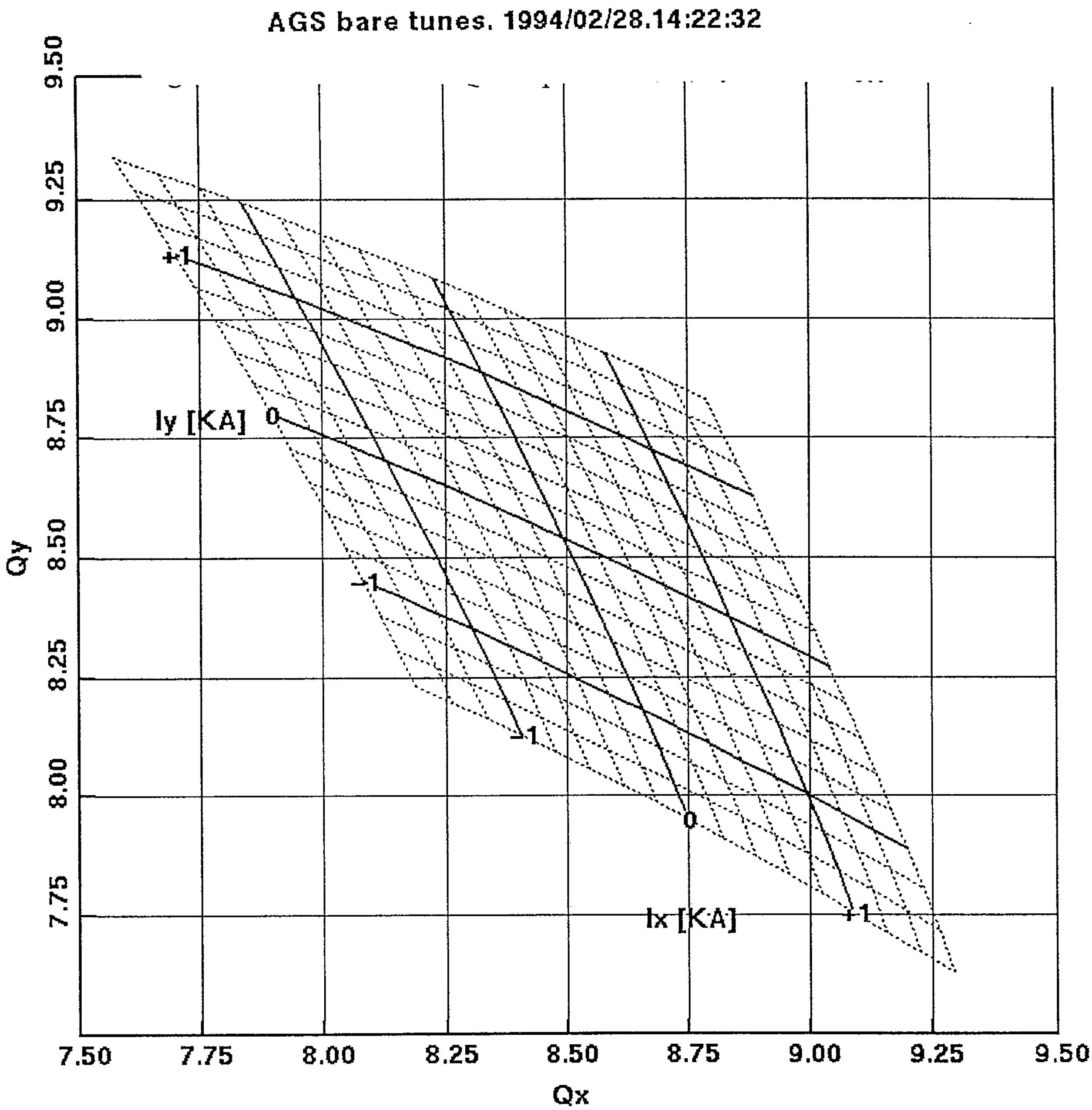

Fig.16. AGS. Chart of HF Quadrupole Currents vs. Chromaticity. Protons 15 GeV/c.

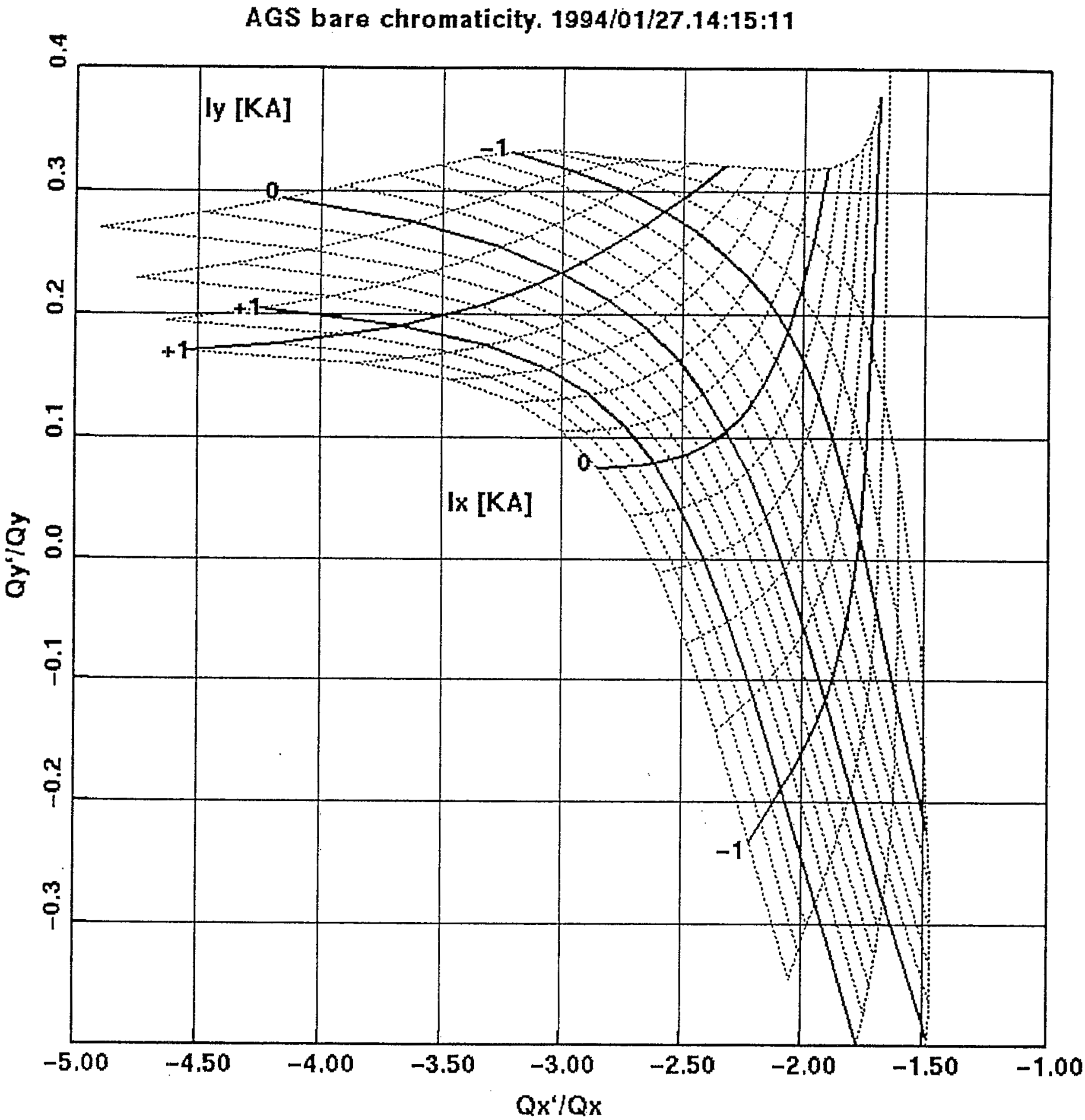

Fig.17. AGS. Chart of HF Quadrupole Currents vs. Chromaticity. Protons 20 GeV/c.

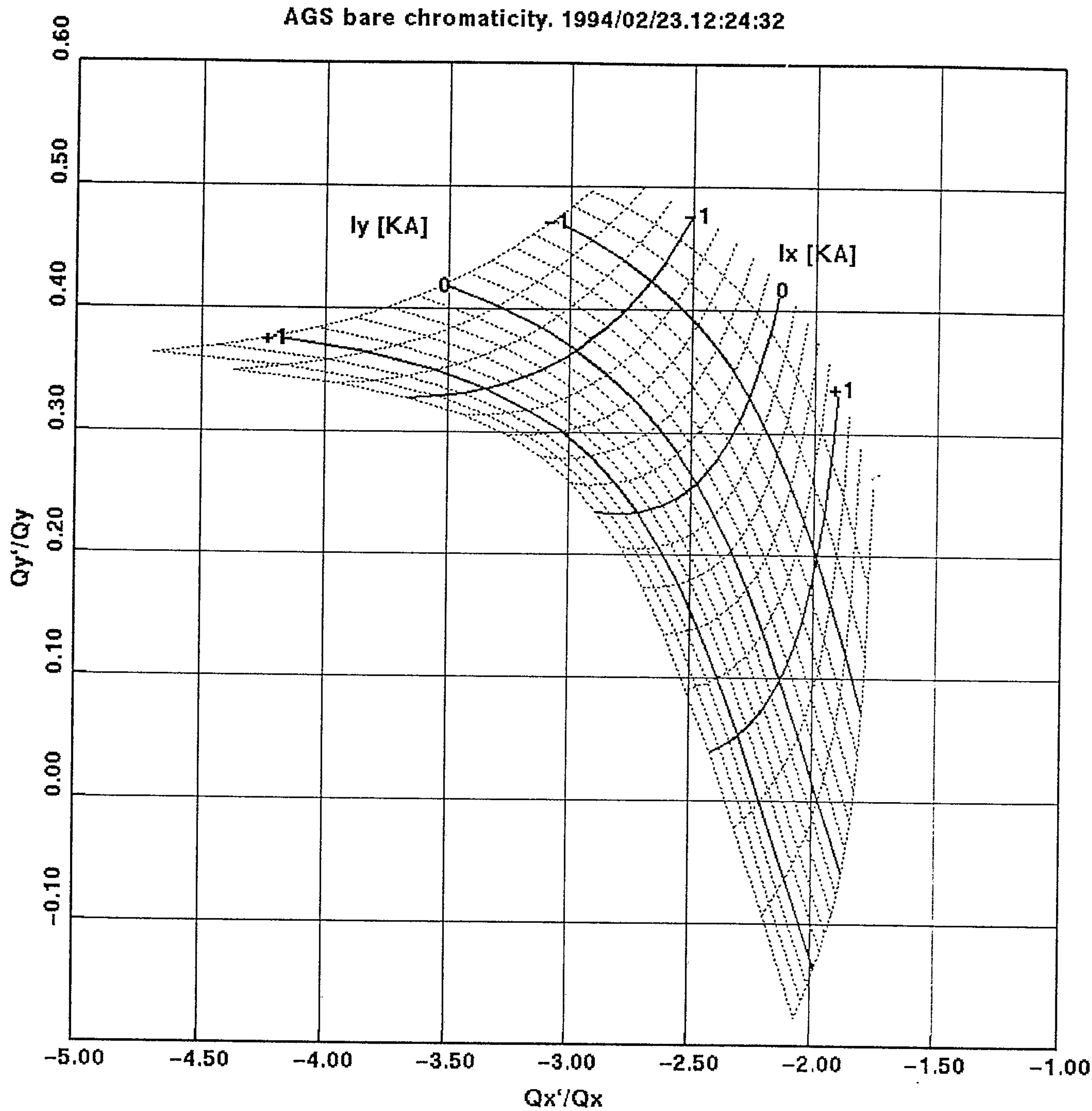

Fig.18. AGS. Chart of HF Quadrupole Currents vs. Chromaticity. Protons 25 GeV/c.

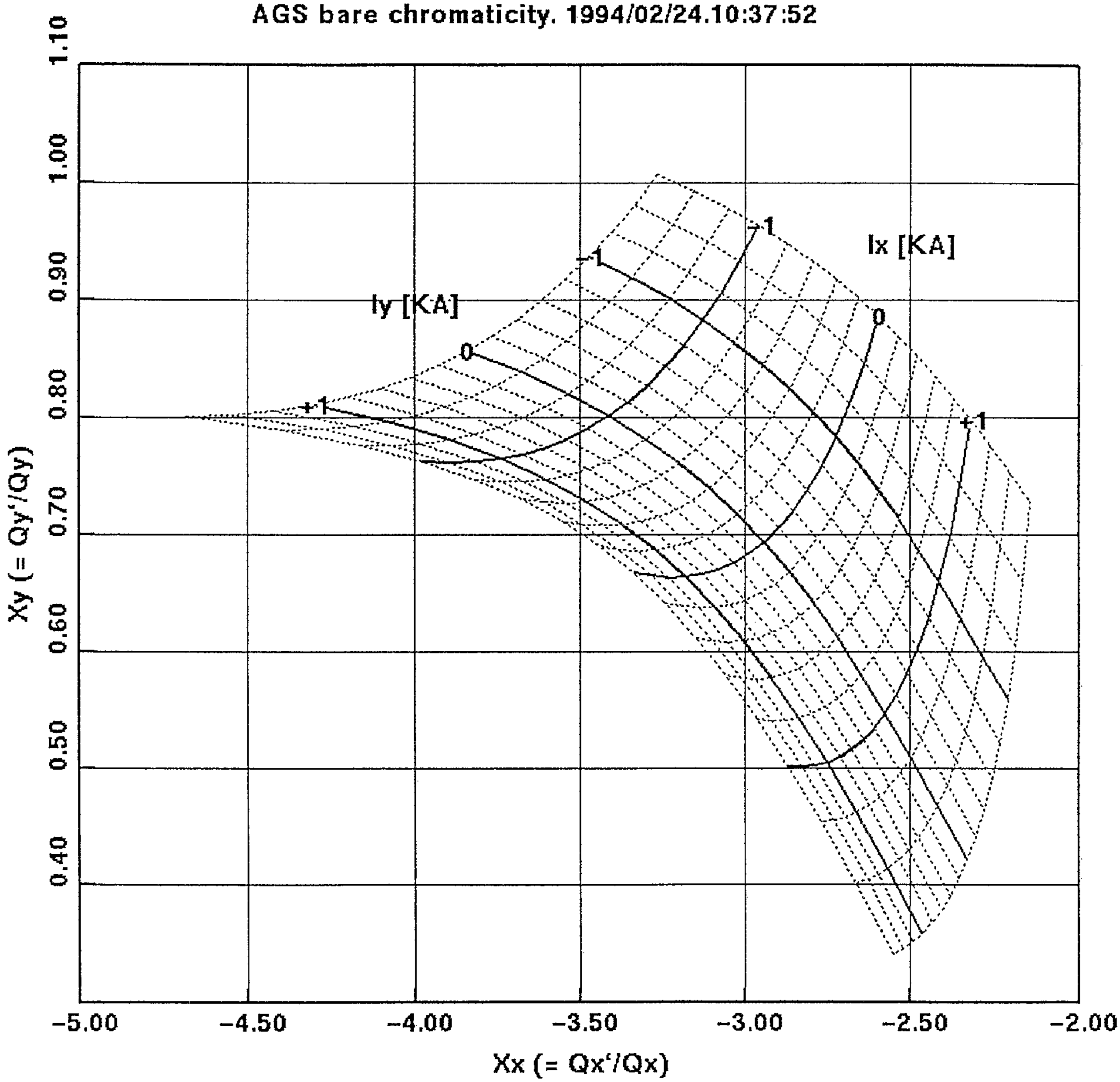

Fig.19. AGS. Chart of HF Quadrupole Currents vs. Chromaticity. Protons 29 GeV/c.

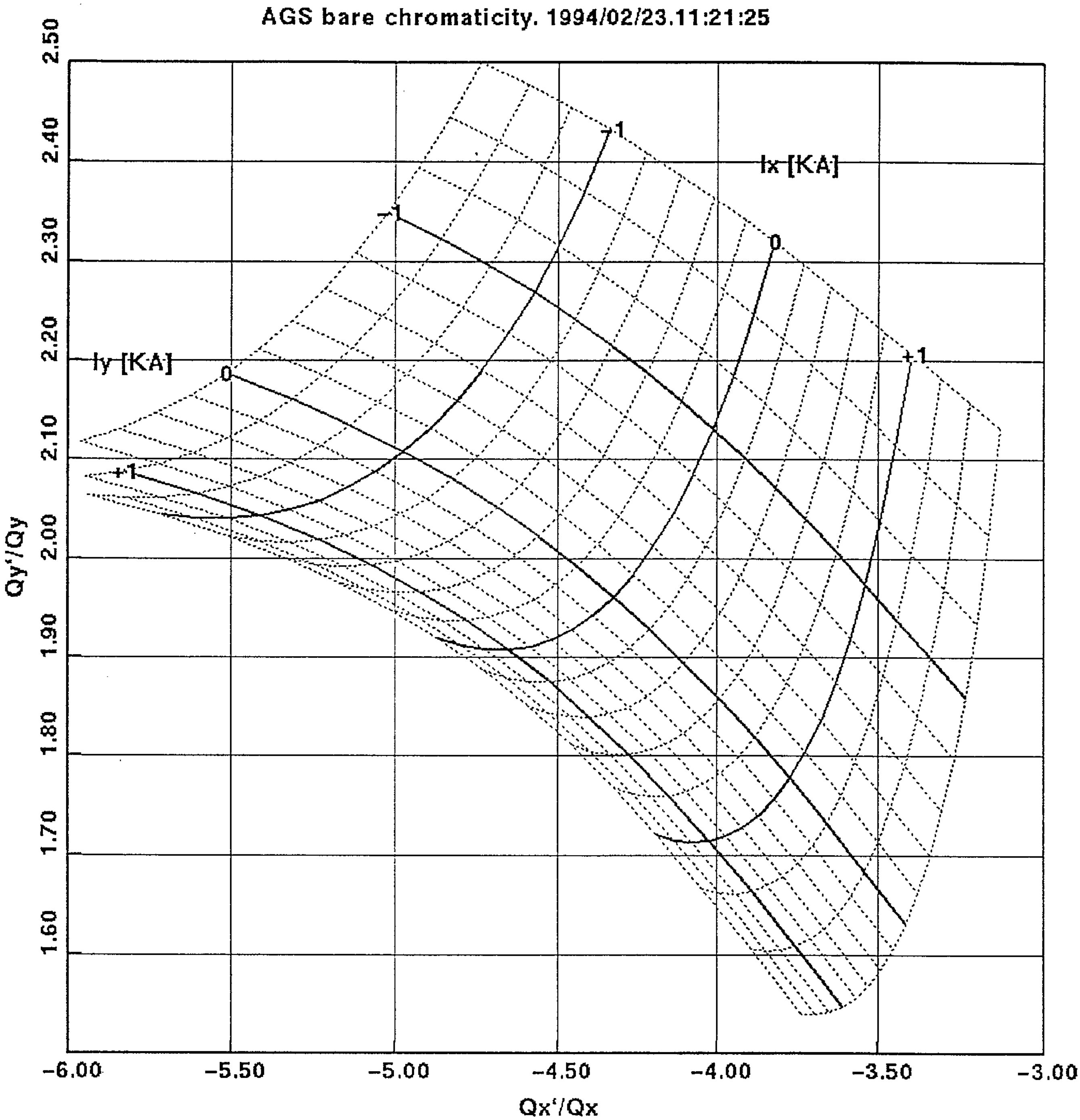

Fig.20. AGS. Chart of HF Quadrupole Currents vs. Chromaticity. Protons 32 GeV/c.

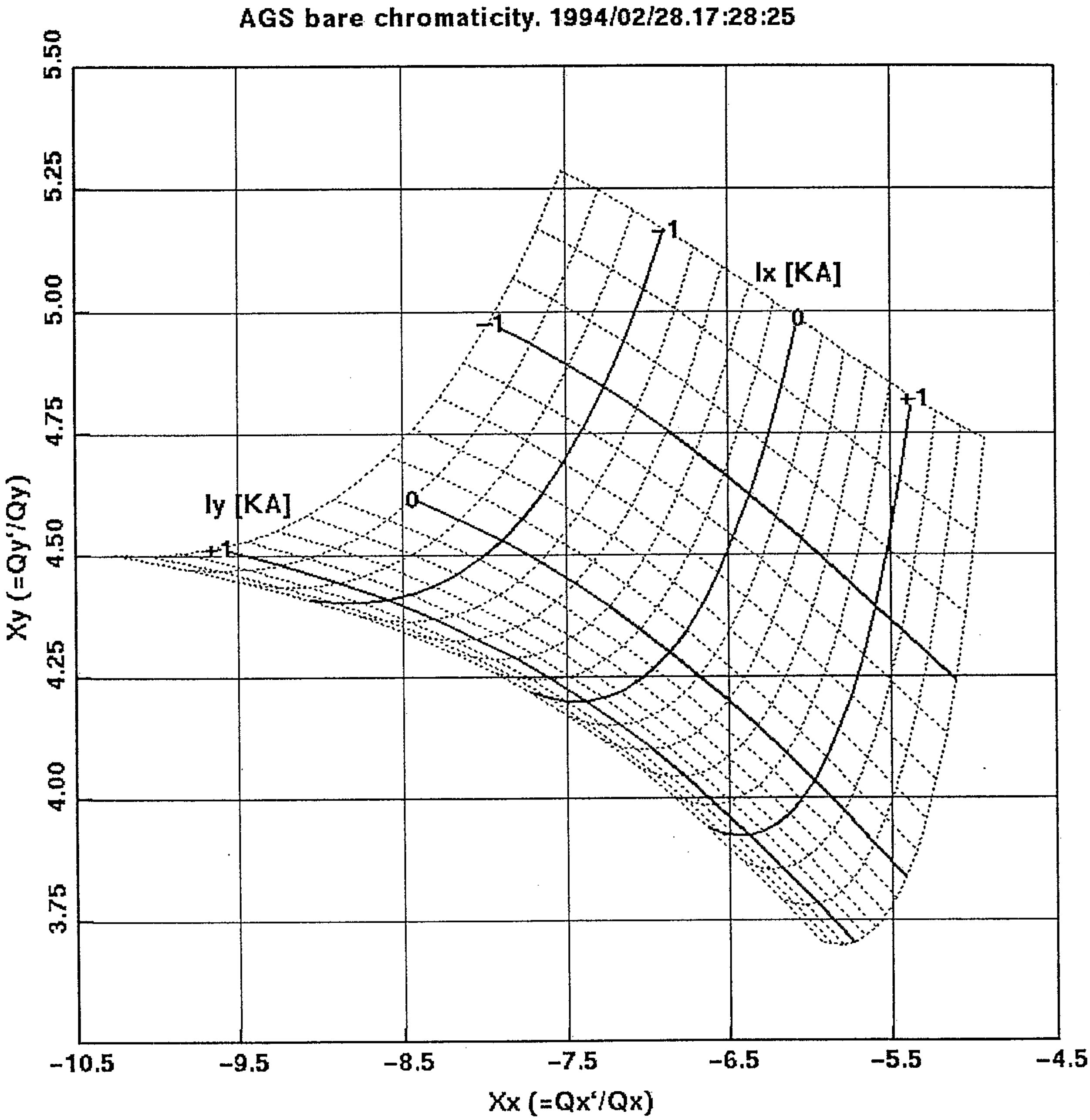

Fig.21. AGS. Chart of Tune Differences vs. HF Quadrupole Currents. Protons 15 GeV/c. Reference values for I_x=I_y=0 (see fig. 1) are: Q_x=8.72007, Q_y=8.77242.

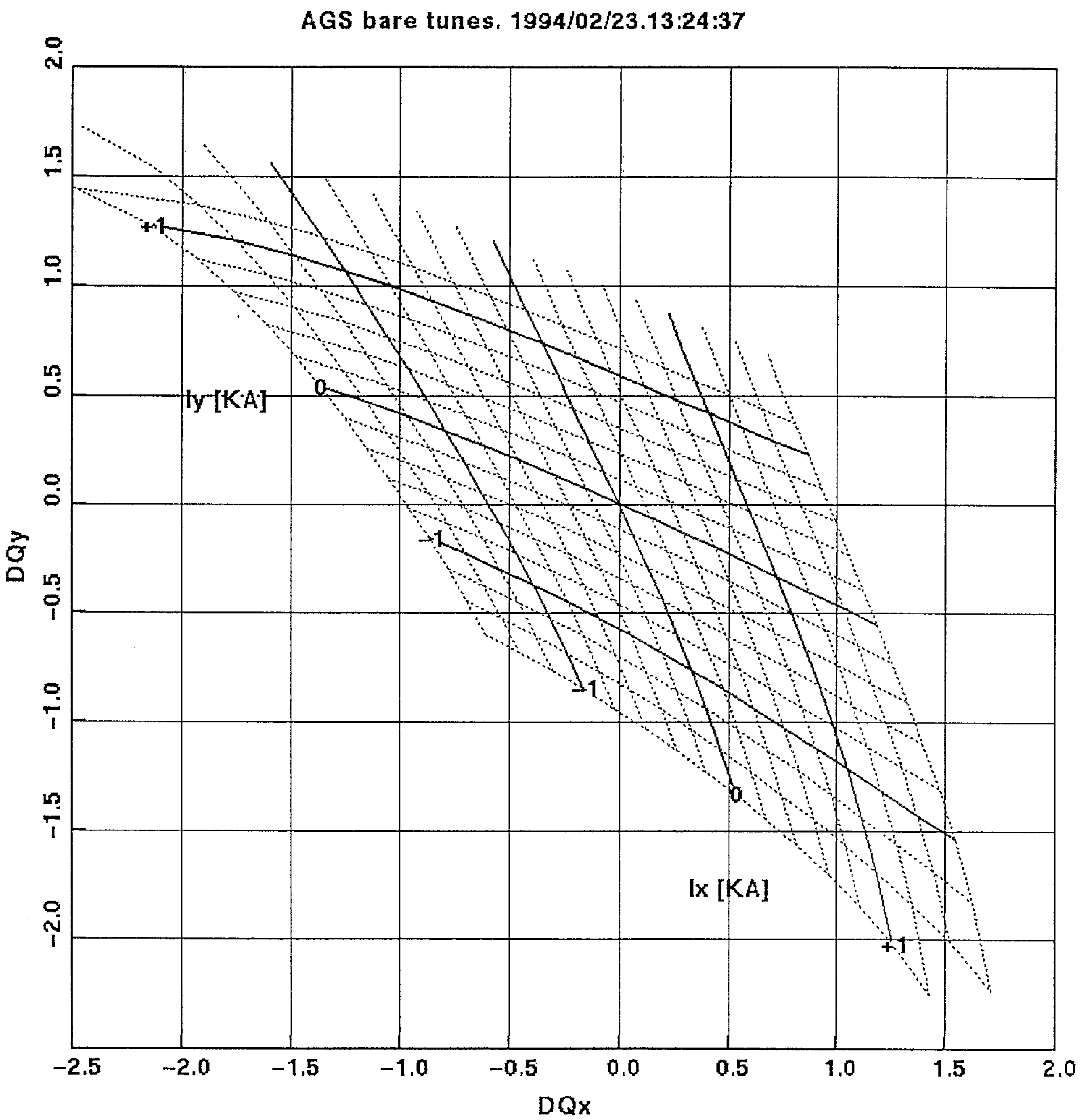

Fig.22. AGS. Chart of Tune Differences vs. HF Quadrupole Currents. Protons 20 GeV/c. Reference values for I_x=I_y=0 (see fig. 2) are: Q_x=8.71350, Q_y=8.76270.

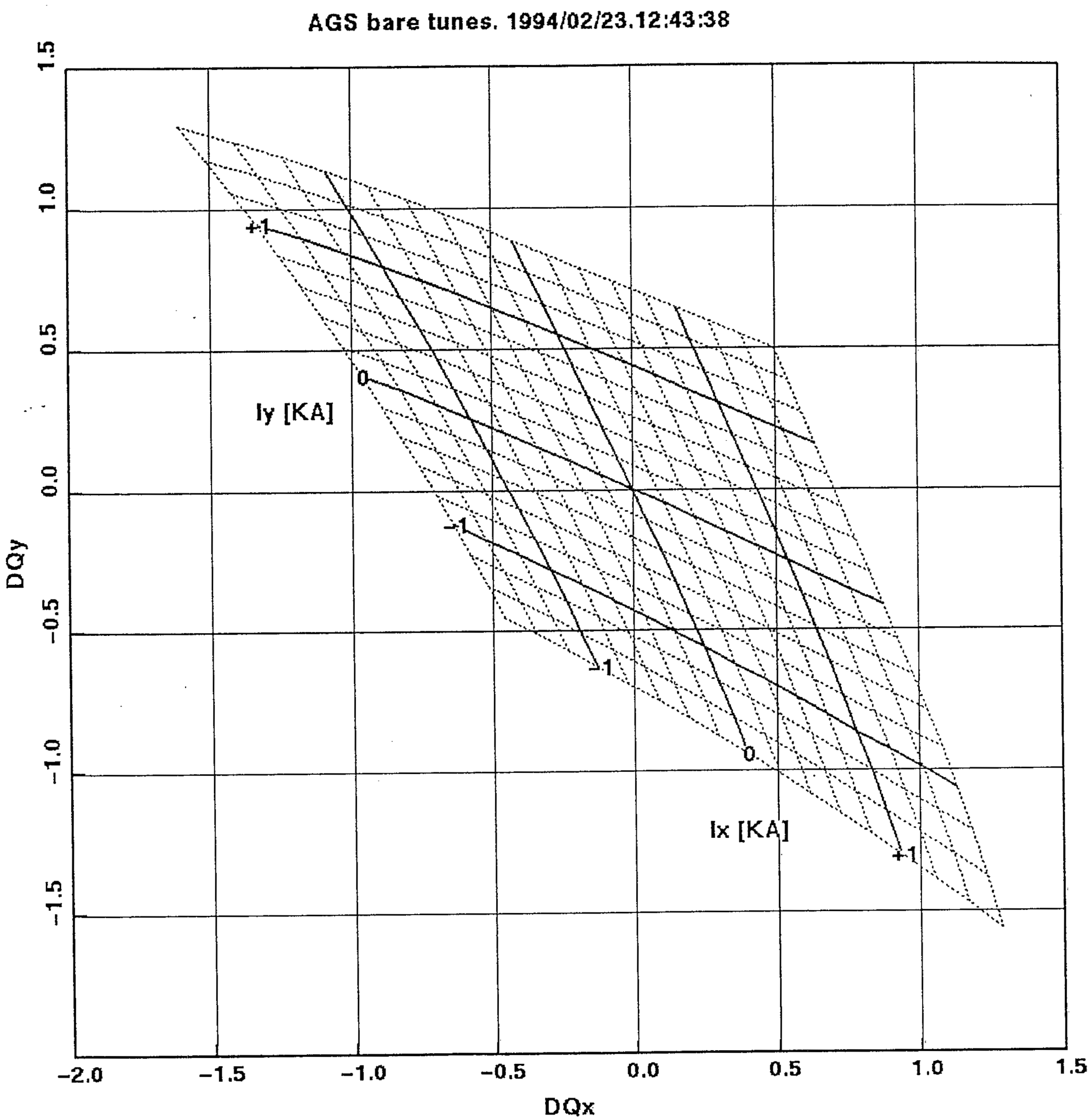

Fig.23. AGS. Chart of Tune Differences vs. HF Quadrupole Currents. Protons 25 GeV/c. Reference values for $I_x = I_y = 0$ (see fig. 3) are: $Q_x = 8.69195$ $Q_y = 8.73368$.

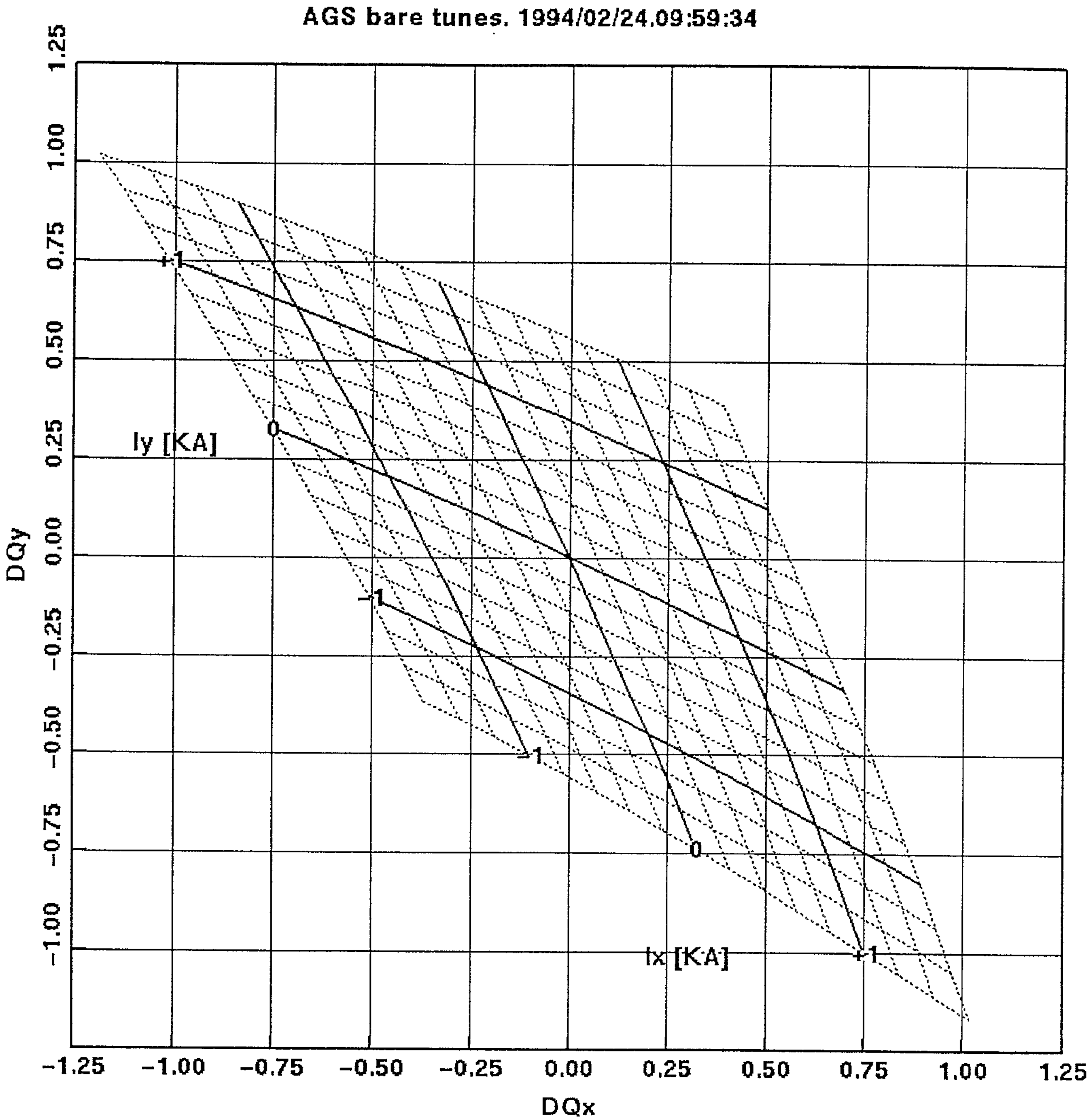

Fig.24. AGS. Chart of Tune Differences vs. HF Quadrupole Currents. Protons 29 GeV/c.
Reference values for I_x=I_y=0 (see fig. 4) are: Q_x=8.63262, Q_y=8.67035.

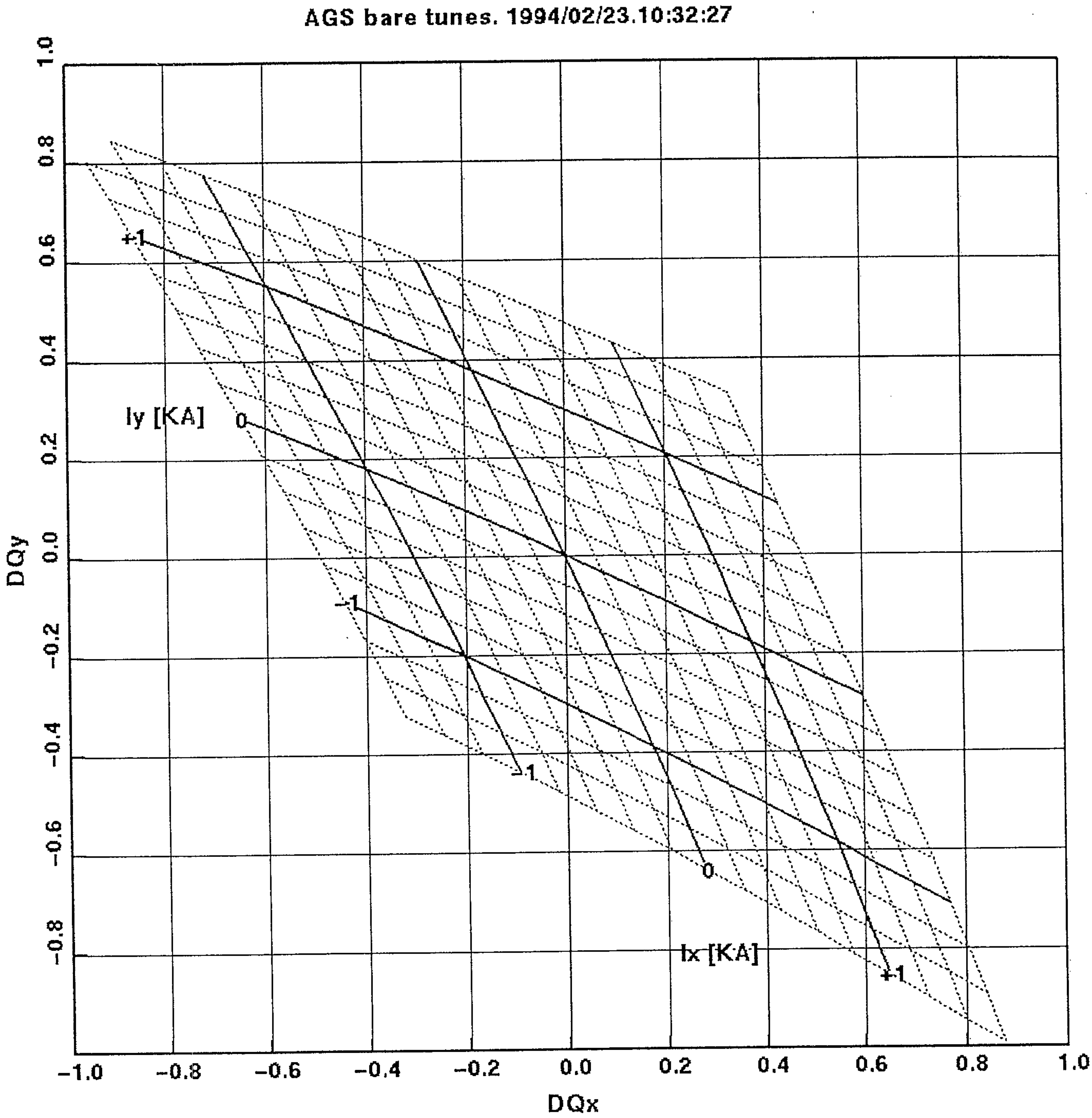

Fig.25. AGS. Chart of Tune Differences vs. HF Quadrupole Currents. Protons 32 GeV/c. Reference values for I_x=I_y=0 (see fig. 5) are: Q_x=8.49678, Q_y=8.53693.

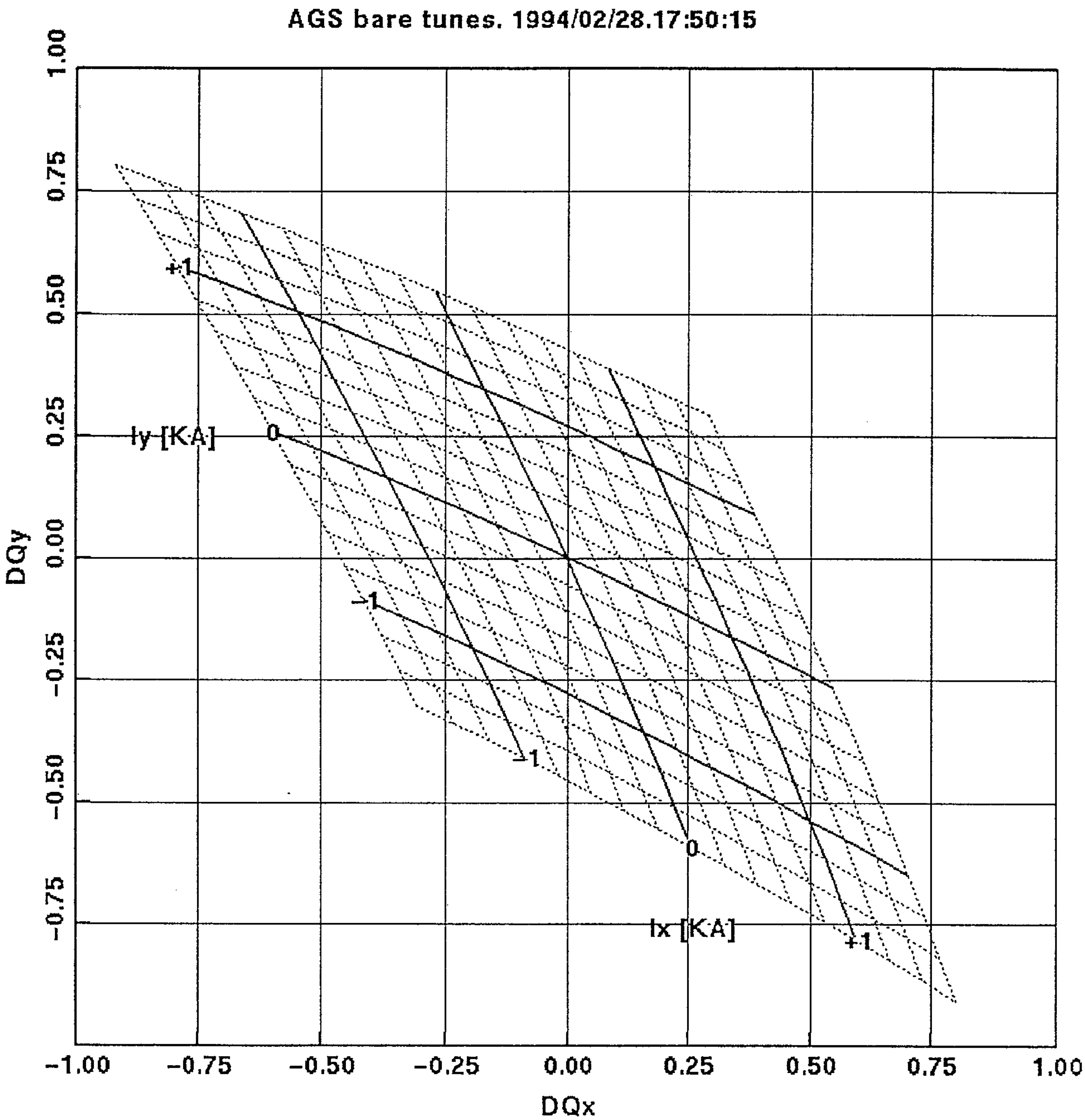

Fig.26. AGS. Chart of Chrom. Differences vs. HFQ Currents. Protons 15 GeV/c. Reference values for I_x=I_y=0 (see fig. 6) are: ξ_x=-2.31145, ξ_y=0.105530.

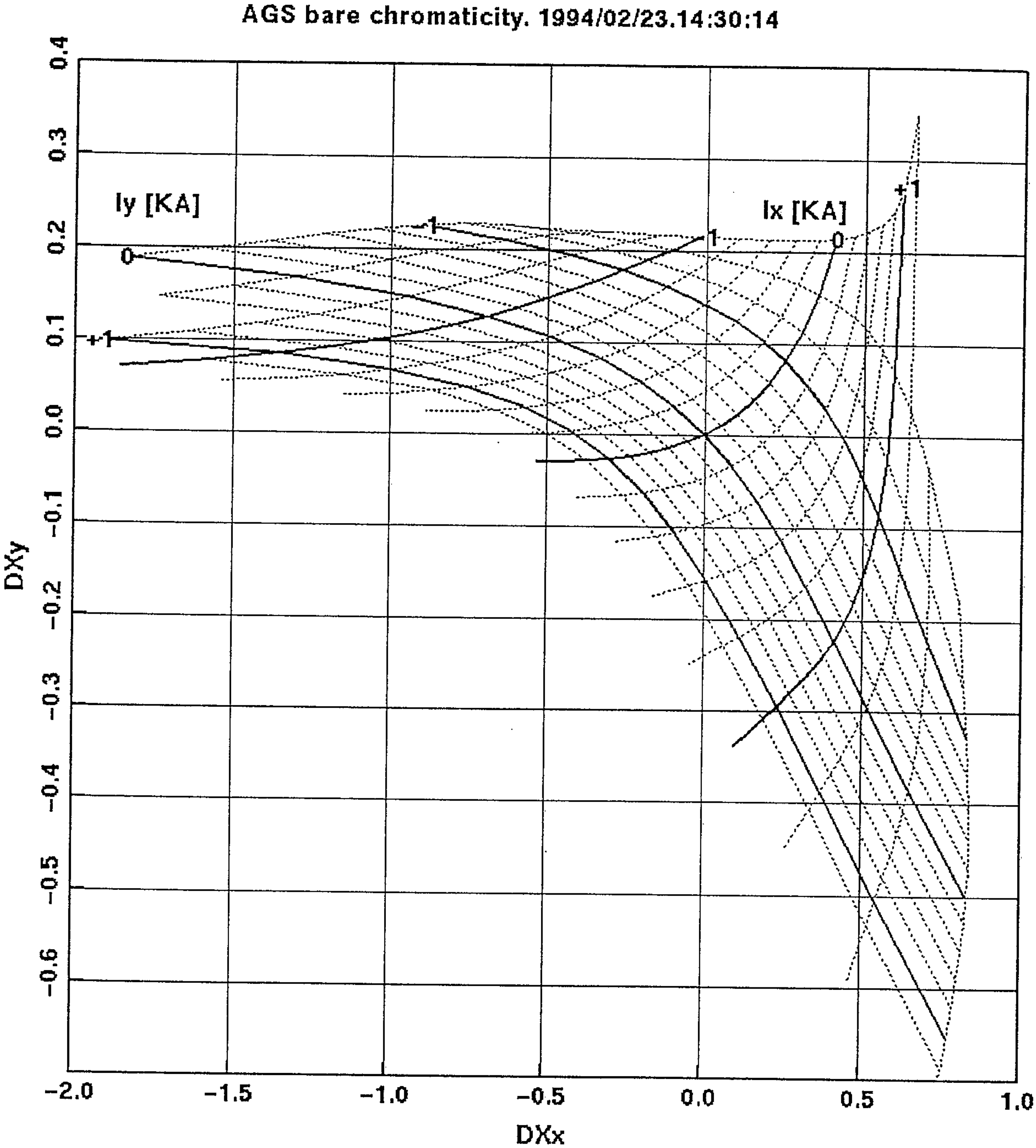

Fig.27. AGS. Chart of Chrom. Differences vs. HFQ Currents. Protons 20 GeV/c. Reference values for I_x=I_y=0 (see fig. 7) are: ξ_x=-2.47450, ξ_y=0.258700.

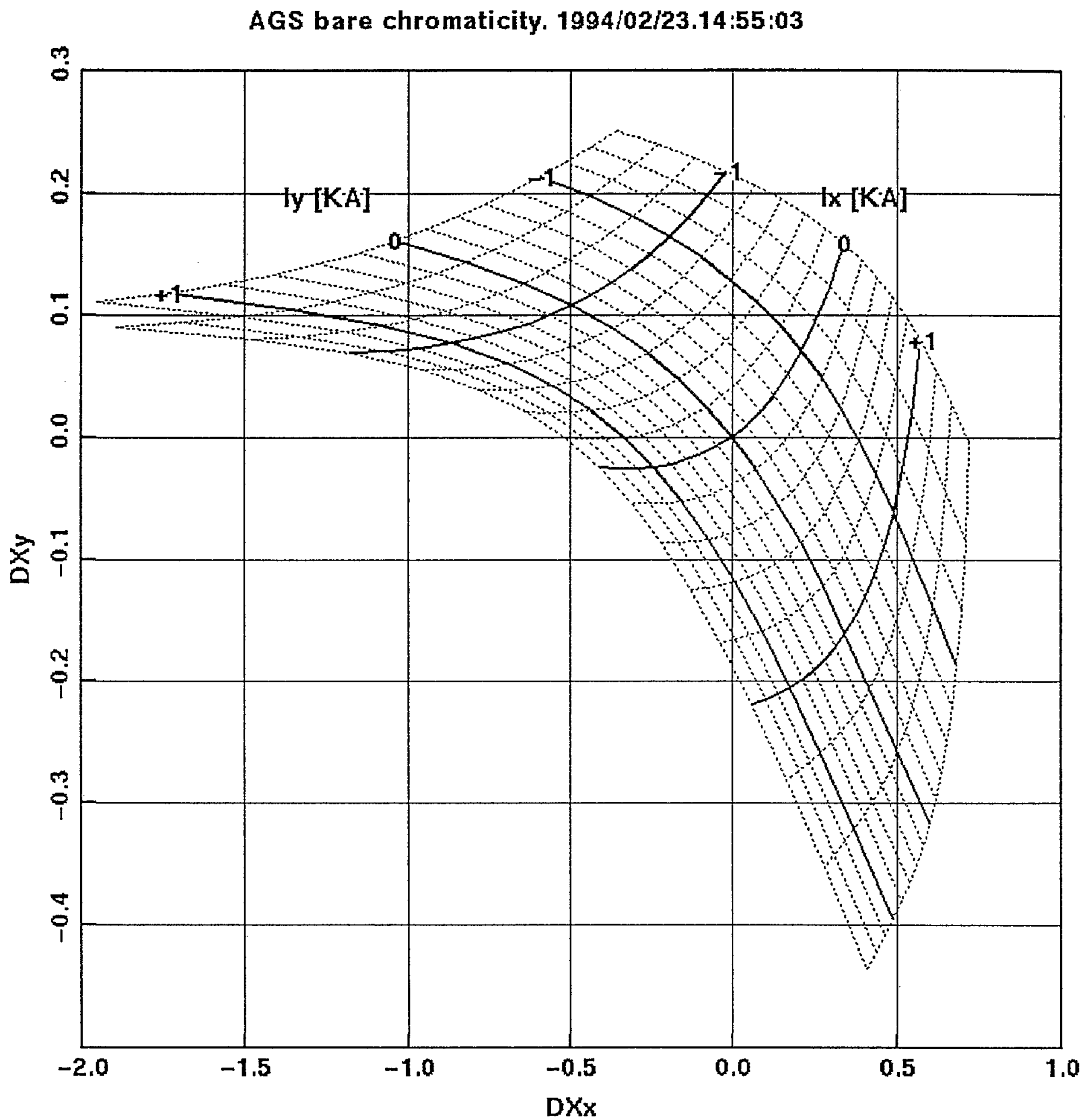

Fig.28. AGS. Chart of Chrom. Differences vs. HFQ Currents. Protons 25 GeV/c.
Reference values for I_x=I_y=0 (see fig. 8) are: ξ_x=-2.94135, ξ_y=0.692810.

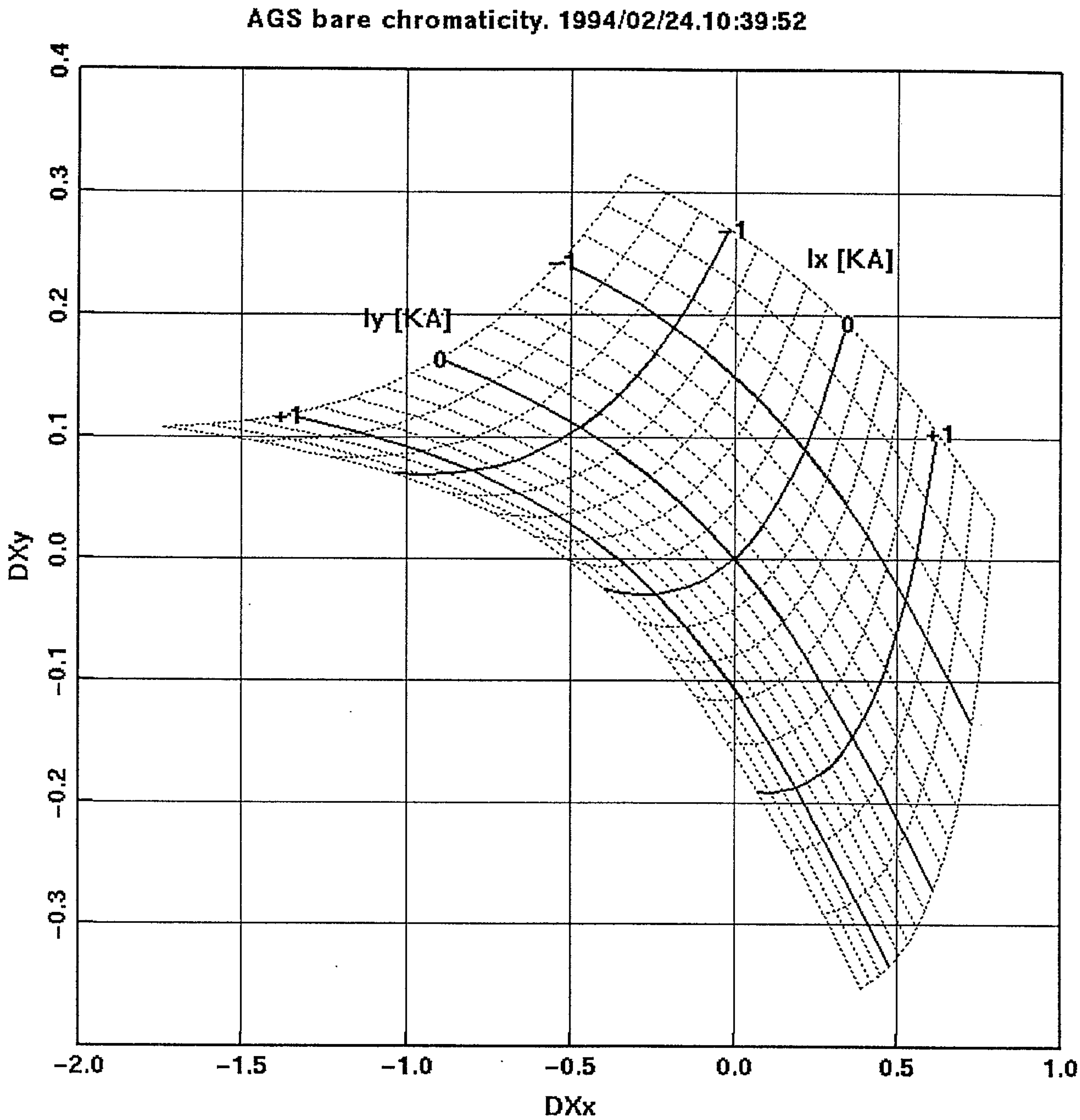

Fig.29. AGS. Chart of Chrom. Differences vs. HFQ Currents. Protons 29 GeV/c.
Reference values for I_x=I_y=0 (see fig. 9) are: ξ_x=-4.32175, ξ_y=1.96050.

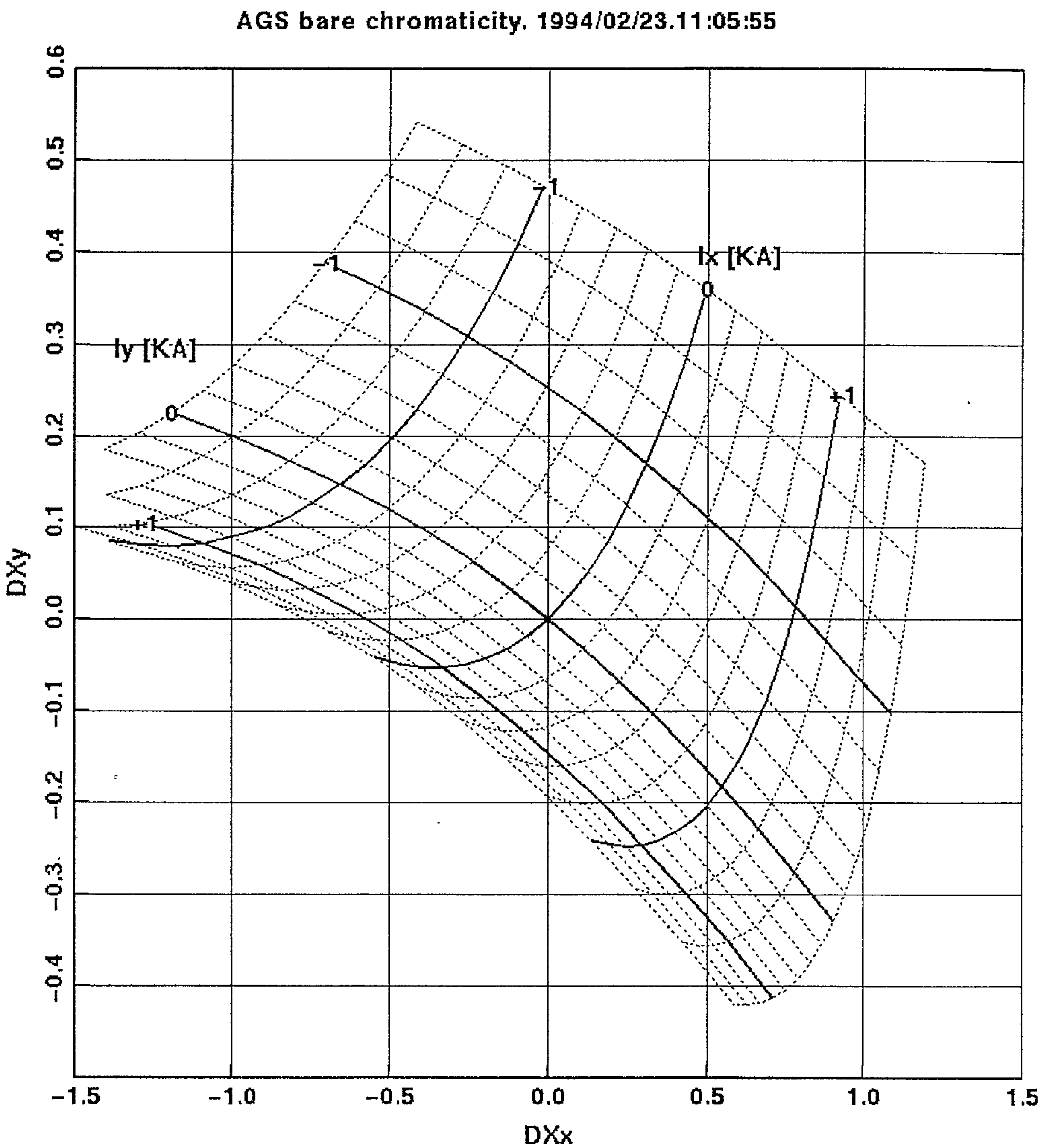

Fig.30. AGS. Chart of Chrom. Differences vs. HFQ Currents. Protons 32 GeV/c.
Reference values for I_x=I_y=0 (see fig. 10) are: ξ_x=-6.85840, ξ_y=4.29907