EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE

CERN - PS DIVISION

PS/ PA/ Note 96-39

DESIGN OF T9 (ATLAS/CMS) FOR EHNL

L. Durieu, O. Ferrando

Geneva, Switzerland
6 December 1996

I. Constraints, design and needs of T9 line.

1. General Considerations.

The new version of T9 line has been adapted to satisfy geometrical and optical constraints requested for the tests of ATLAS/CMS experiments. The structure of the line is similar to the one defined in EHNL5 document (ref.1), some changes in optical elements position being done to fulfil the geometrical compatibility with T10 line. The line is designed to provide the users with non-separated secondary particles, positive or negative polarity . The beam momentum attained is 15 GeV/c .

2. Geometrical and optical design

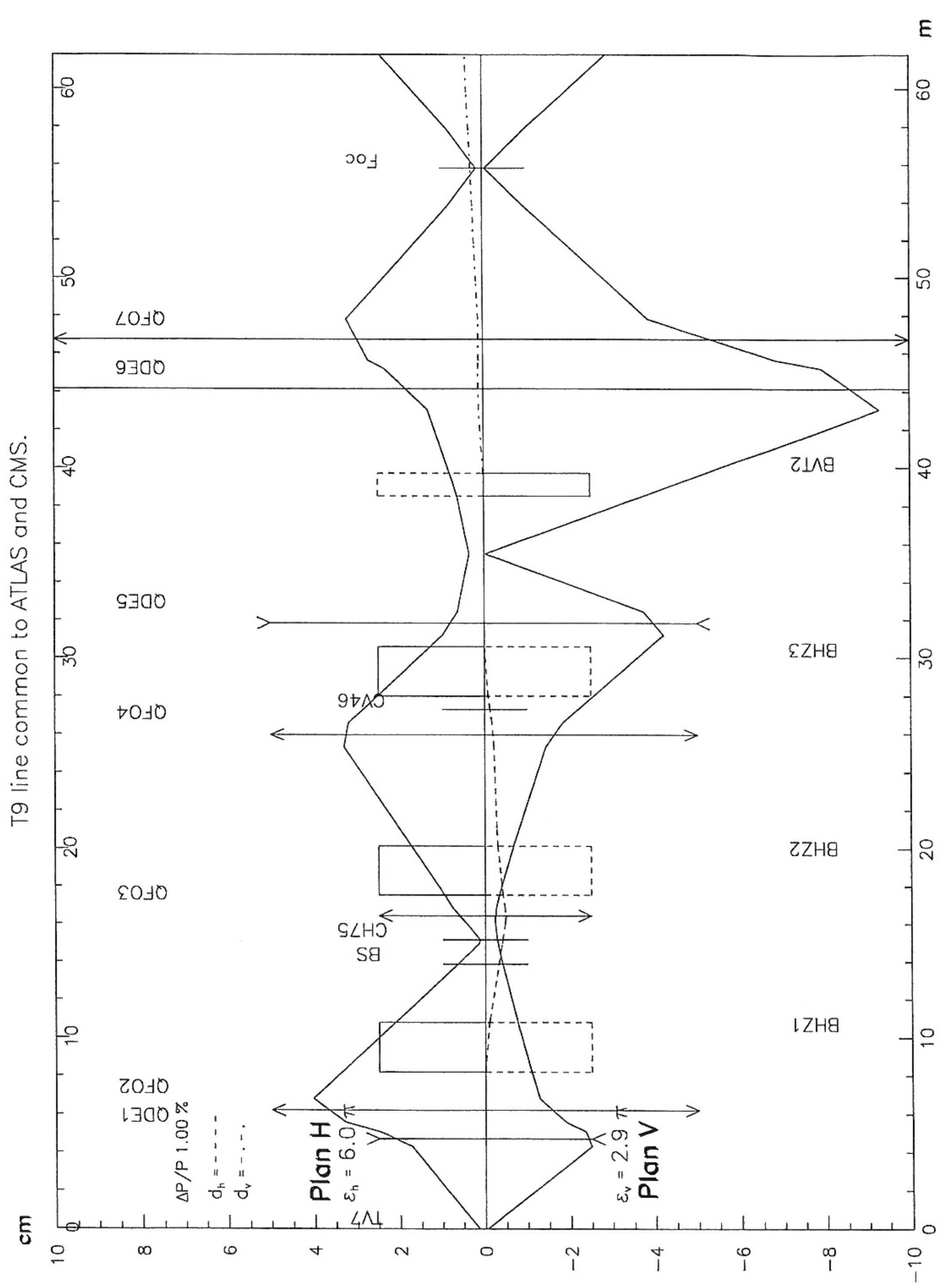
The line consists of three focusing functions over three separate stages (see Fig. 1.) :

- **momentum analysis** :
  the first stage including quadrupoles QDE1, QFO2 and bending magnet BHZ01 performs the momentum analysis at a variable-aperture horizontal collimator CH75 (momentum slit).
- **momentum recombination** :
  the second stage including bending magnets BHZ02, BHZ03 and quadrupoles QF04, QDE5 performs the momentum recombination by the use of " field lens " QFO3 and determines an intermediate focus.
- **final focus** :
  the third stage with QDE6 and QFO7 quadrupoles refocuses the beam in the experimental area. The final focus may be moved along the area by changing the currents in the last quadrupole doublet.

The dispersion control is made with the field lens Horizontal dispersion is suppressed at the exit of quadrupole QDE5. The deflection angle of BHZ01 is 72 mrad while BHZ02 and BHZ03 deflects the beam by 61.1 mrad.

A vertical collimator CV46 is placed between quadrupoles QF04 and QDE5 to improve its efficiency. Taking into account the quite large energy of the primary particles beam , thickness of the shielding wall is 4.40 m.

FIGURE 1   First order topics for the T9 line (nominal focus)



3. Needed magnetic resources and power supplies

As in T10 line, all quadrupoles and magnets on the present line are recovered, while magnet BHZ03 and quadrupoles QFO4 , QDE5 are to be added. Details are showed in Table 1.

M-name	Magnet	I max	P max (KW)	Flow (l/min)
QDE1	Q75	593	42	30
QFO2	Q120A	602	67	48
BHZ01	MNP23	1343	415	299
QFO3	Q75	302	11	8
BHZ02	MCB	383	25	18
QFO4	Q100	184	7	5
BHZ03	MCB	382	25	18
QDE5	Q100	332	19	13
BVT02	M105	427	38	27
QDE6	Q221	646	88	63
QFO7	Q222	618	80	58
TOTAL			817	590

Table 1 . Magnets, powers and required water flow.

The quoted power takes into account the DC resistance of the magnet at a mean coil temperature of 35° Celsius. It neglects wiring losses and efficiency of the power converters. The water flow is given for a 20° Celsius temperature rise (~36 m^3/h).

4. Monitoring devices

The line has to be equipped with standard detectors in order to facilitate its setting-up or to provide beam diagnostic during operation. The list required includes the following elements:

- MWPC or equivalent devices at line end and at the experimental focus to control relative intensity, profile of the beam and centering on the target.
- MWPC or equivalent devices at the intermediate focus in order to assure an observation point for beam control. Aperture of MWPC should step from 2 - 6 mm depending on its location on the beam axis.
- Computer data acquisition is also requested to improved efficiency of the line.

5. Line vacuum

The line is expected to be under crude vacuum (<10 Pa, there is not strong argument to go much below this value) from the upstream face of QDE01 up to the downstream face of BVT02. This will ensure minimal multiple scattering in air and vacuum windows.

Table 2. Geometry of the new T9 line, version 5.1

```
Reported by TRANPLT/SRV program   [std units: L(m), S(m), Field(kG)]          Run at  18.09.43   22/11/96
 Initial coord. at Sx=Sy=Sz=0, Ax=pi/2, Ay=0, Az=-pi/2
 Bend coord. given at Xing point of straight lines
 Angle to the left or to the up side is >0
 Z axis stands as the altitude
 Program version 1.1 - any complain to JYH (CERN)
 Start Ax,Ay,Az (radians)=       1.7981     -.2273     -1.5408
```

Name	dS1	S.lgth	S.x	S.y	S.z	B.pos	Length	Field	deg	rad
_TV7	.000	.000	2076.407	2182.183	1.326	.000				
*QDE1	4.700	4.700	2080.984	2181.124	1.467	4.700	.780	-9.6425		
*QFO2	1.500	6.200	2082.445	2180.786	1.512	6.200	1.240	10.9462		
>BHZ1	3.301	9.501	2085.659	2180.043	1.611	9.500	2.600	13.8557	4.1253	.0720
_BS	4.371	13.871	2089.976	2179.367	1.742	13.870				
_CH75	1.292	15.164	2091.252	2179.167	1.781	15.162				
*QFO3	1.266	16.430	2092.502	2178.971	1.819	16.428	.780	4.9651		
>BHZ2	2.409	18.839	2094.881	2178.599	1.891	18.837	2.600	11.7555	3.5000	.0611
*QFO4	7.123	25.962	2101.969	2177.929	2.105	25.960	1.240	4.7260		
_CV46	1.330	27.292	2103.293	2177.804	2.145	27.290				
>BHZ3	2.010	29.302	2105.293	2177.615	2.205	29.300	2.600	11.7550	3.4998	.0611
*QDE5	2.520	31.823	2107.811	2177.532	2.281	31.820	1.240	-8.4457		
>BVT2	7.310	39.133	2115.114	2177.291	2.500	39.130	1.180	12.7207	-1.7189	-.0300
*QDE6	5.000	44.133	2120.111	2177.125	2.500	44.130	2.160	-9.1596		
*QFO7	2.600	46.733	2122.709	2177.039	2.500	46.730	2.160	9.0230		
_Foc	9.080	55.813	2131.785	2176.739	2.500	55.810				
_ENDP	6.000	61.813	2137.782	2176.540	2.500	61.810				

```
 Final Ax,Ay,Az (radians)=       1.6039     -.0331     -1.5708

BHZ1   H    72    mrad left
BHZ2   H    61.1  mrad left
```

Power, Kw												Line total
Momentum	QDE1	QFO2	BHZ01	QFO3	BHZ02	QFO4	BHZ03	QDE5	BVT02	QDE6	QFO7	
1	0.18	0.23	1.83	0.05	0.10	0.03	0.10	0.08	0.15	0.33	0.31	3.40
2	0.71	0.92	7.33	0.19	0.42	0.12	0.42	0.33	0.61	1.31	1.23	13.59
3	1.61	2.06	16.50	0.43	0.94	0.27	0.94	0.74	1.37	2.95	2.77	30.58
4	2.87	3.66	29.34	0.76	1.66	0.48	1.66	1.31	2.42	5.26	4.93	54.36
5	4.52	5.71	45.86	1.19	2.59	0.75	2.59	2.04	3.75	8.24	7.72	84.96
6	6.56	8.21	66.05	1.71	3.72	1.09	3.72	2.94	5.35	11.91	11.16	122.41
7	8.99	11.19	89.93	2.34	5.05	1.48	5.05	3.99	7.22	16.28	15.25	166.79
8	11.83	14.66	117.50	3.06	6.59	1.93	6.59	5.20	9.39	21.40	20.04	218.19
9	15.07	18.68	148.78	3.89	8.34	2.44	8.34	6.58	11.86	27.31	25.55	276.82
10	18.70	23.32	183.76	4.82	10.30	3.01	10.30	8.13	14.68	34.08	31.85	342.93
11	22.70	28.72	222.46	5.85	12.51	3.63	12.51	9.84	17.91	41.81	39.01	416.96
12	27.05	35.10	264.89	6.99	15.00	4.32	15.00	11.74	21.66	50.66	47.16	499.59
13	31.75	42.88	311.06	8.24	17.81	5.07	17.81	13.84	26.08	60.89	56.50	591.94
14	36.80	52.86	360.99	9.59	21.04	5.87	21.04	16.15	31.44	72.94	67.35	696.09
15	42.21	66.96	414.69	11.05	24.87	6.74	24.87	18.72	38.22	87.69	80.28	816.29

Table 3. Computed power in magnets function of momentum for the nominal focus

Momentum		QDE1	QFO2	BHZ01	QFO3	BHZ02	QFO4	BHZ03	QDE5	BVT02	QDE6	QFO7
1		38.44	35.25	89.28	19.82	24.8	12.3	24.8	21.98	27.1	39.48	38.24
2		76.98	70.45	178.56	39.66	49.57	24.6	49.57	43.94	54.08	79	76.5
3		115.71	105.58	267.86	59.52	74.28	36.89	74.28	65.87	80.84	118.57	114.82
4		154.72	140.64	357.18	79.43	98.92	49.17	98.92	87.76	107.33	158.24	153.22
5		194.06	175.66	446.52	99.39	123.48	61.44	123.48	109.61	133.55	198.07	191.77
6		233.75	210.71	535.89	119.41	147.97	73.7	147.97	131.42	159.56	238.11	230.5
7		273.75	245.92	625.31	139.51	172.42	85.95	172.42	153.19	185.46	278.47	269.51
8		314	281.49	714.76	159.7	196.89	98.18	196.89	174.96	211.41	319.25	308.9
9		354.37	317.72	804.27	179.97	221.44	110.4	221.44	196.75	237.63	360.64	348.81
10		394.72	355.02	893.84	200.33	246.2	122.6	246.2	218.62	264.39	402.85	389.42
11		434.91	394	983.47	220.79	271.32	134.8	271.32	240.61	292.06	446.21	431
12		474.81	435.61	1073.17	241.34	297.03	146.98	297.03	262.81	321.16	491.18	473.91
13		514.39	481.46	1162.94	261.97	323.68	159.17	323.68	285.32	352.41	538.49	518.72
14		553.74	534.56	1252.81	282.67	351.83	171.35	351.83	308.26	386.94	589.36	566.32
15		593.09	601.6	1342.76	303.43	382.49	183.53	382.49	331.81	426.6	646.21	618.29

Table 4. Computed currents (A) for the nominal focus, function of the momentum

Momentum	QDE1	QFO7	QDE1	QFO7	QDE1	QFO7	QDE1	QFO7	QDE1	QFO7
	nominal foc	nominal foc	+2.5 m	+2.5m	+5 m	+5m	+7.5 m	+7.5m	+10 m	+10 m
1	39.48	38.23	36.42	34.06	35.25	31.82	34.36	30.25	33.67	29.09
2	79	76.49	72.87	68.13	70.52	63.66	68.75	60.51	67.36	58.2
3	118.57	114.81	109.36	102.24	105.83	95.53	103.17	90.79	101.09	87.32
4	158.24	153.21	145.93	136.42	141.21	127.45	137.66	121.12	134.87	116.48
5	198.07	191.75	182.62	170.68	176.7	159.44	172.23	151.5	168.74	145.7
6	238.11	230.48	219.46	205.07	212.32	191.53	206.94	181.98	202.74	174.99
7	278.47	269.49	256.53	239.64	248.15	223.76	241.83	212.56	236.9	204.37
8	319.25	308.87	293.91	274.44	284.24	256.16	276.96	243.28	271.28	233.88
9	360.64	348.77	331.71	309.55	320.7	288.8	312.42	274.2	305.96	263.56
10	402.85	389.38	370.06	345.07	357.63	321.74	348.3	305.36	341.03	293.44
11	446.21	430.95	409.17	381.13	395.21	355.07	384.76	336.84	376.62	323.58
12	491.18	473.86	449.31	417.92	433.65	388.92	421.96	368.72	412.88	354.06
13	538.49	518.66	490.84	455.65	473.24	423.44	460.17	401.11	450.04	384.96
14	589.36	566.25	534.36	494.68	514.44	458.82	499.74	434.16	488.41	416.4
15	646.21	618.21	580.79	535.5	557.9	495.36	541.21	468.06	528.42	448.53

Table 5. Computed currents (A) in the last doublet, function of momentum and distance from the nominal focus

II Precomputed behaviour of the T9 line.

In this chapter are resumed the values of the expected T9 line parameters . Intensity of various particle species will be identical as presently as the source itself is unmodified, data can be found in Ref.. 2.

Characteristics of the beam T9.

Maximum design momentum		15 Gev/c
Distance from target to reference focus		55.81 m
Beam height		2.5 m
Production angle from target[1]	H	0 mrad
	V	0 mrad
Angular acceptance H (in QF02)		4.015 mrad
Angular acceptance V (in QDE1)		5.78 mrad
Horizontal magnification at momentum slit		0.83
Momentum slit displacement		4 mm for 1% Δp/p
Theoretical momentum resolution		0.24%

Optical characteristics at reference focus (minimum Δp/p, multiple scattering not included).

Dispersion (1% Δp/p)	H	0 mm/ 0 mrad (first order calc.)
	V	2.8 mm/ 0.20 mrad
Magnification from target	H	1
	V	1.2

Beam intensity and structure.

Intensity of various particle species will be almost identical as presently as the source itself is unmodified, data can be found in Ref. 2 (given for $2 \cdot 10^{11}$ at 24 GeV/c on standard target and 4 mm half width of the momentum slit).

The standard beam on target comes from the slow extraction of a PS coasting beam with a spill time around 350 ms. The target and the line are transparent to the impinging time structure down to the ns level.

Line tuning.

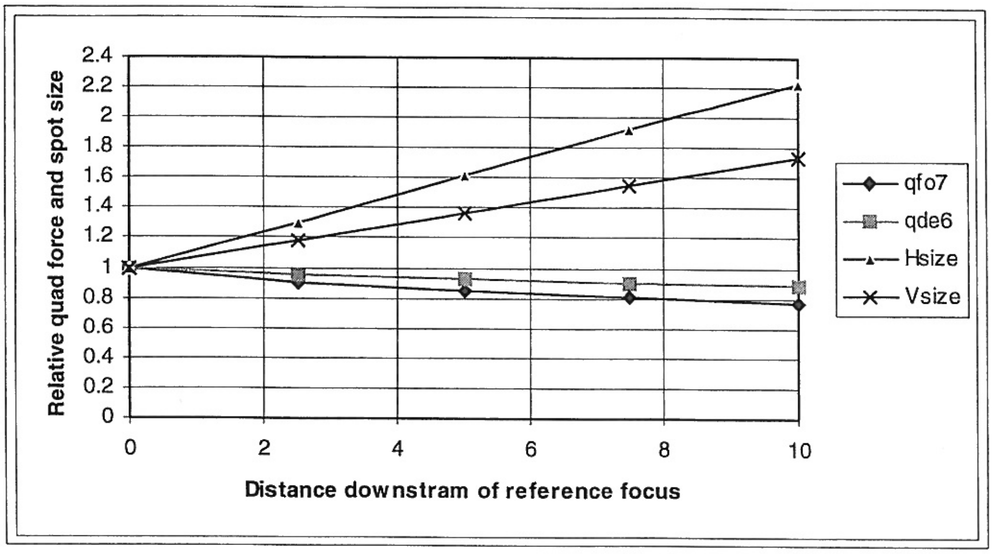
It can be done with the help of the Tables 3, 4 and 5 given in the previous pages. By convention, magnets are wired such that all polarities are the same as the selected particle species (i.e. all positive currents for protons). Final beam focusing and steering can be done with the last three magnets (QDE6, QF07, BVT02).

Final Focusing.

Table 4. should be used to move the focus point along the line. Distances are relative to the nominal focus which is marked in the zone. The tuning of the last doublet and the expected beam behaviour (spot sizes at focus) is graphically illustrated below.

[1] It should be noted that the target is at 30 mrad from splitter magnet position in the vertical plane and 0 mrad in the horizontal plane (see ref. 2 pag.25)

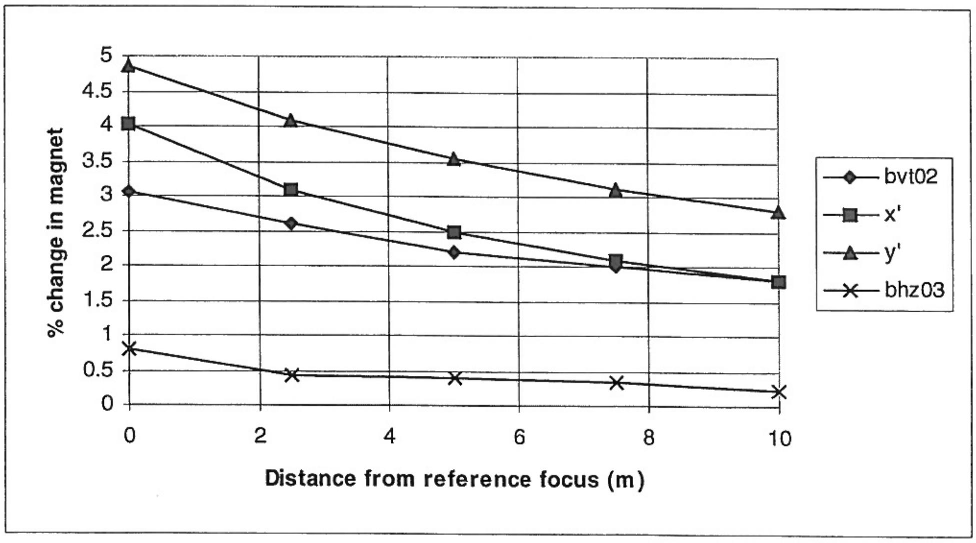
Variation of quadrupoles and spot sizes
When changing the focus location



H and V steering.

Horizontal and vertical displacement of the beam are made by BHZ03 and BVT02 magnets. The expected sensitivities are illustrated in the table below (% change of current in magnet for 10mm move).

Current selected changes for 10 mm displacement
at the focus plane



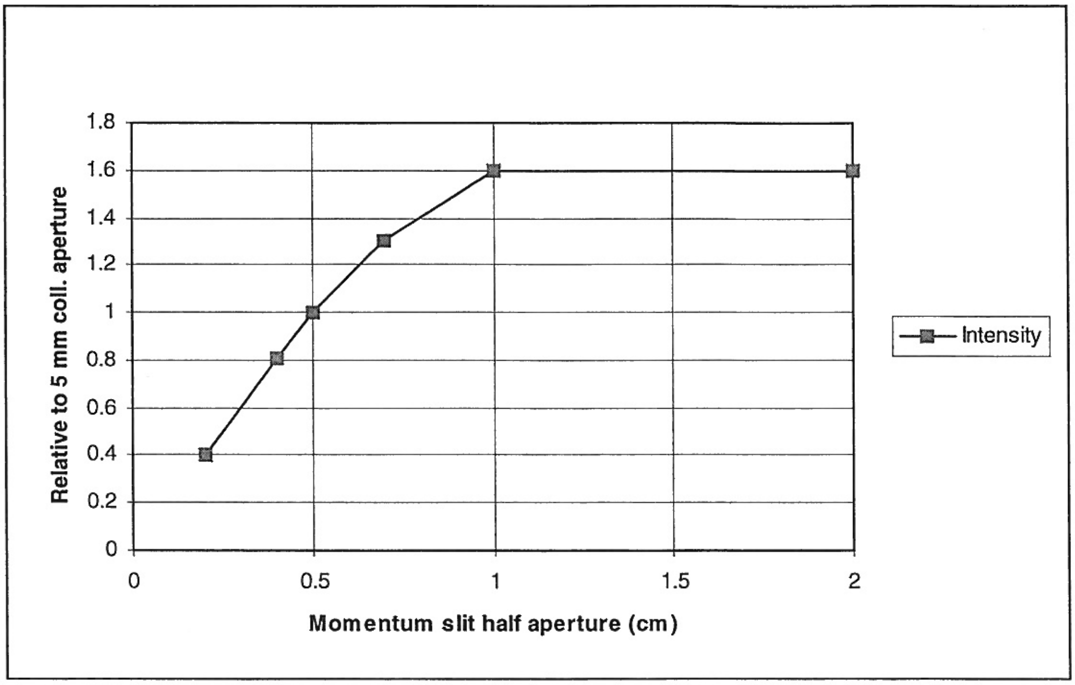
Collimators effects (intensity and momentum spread tuning).

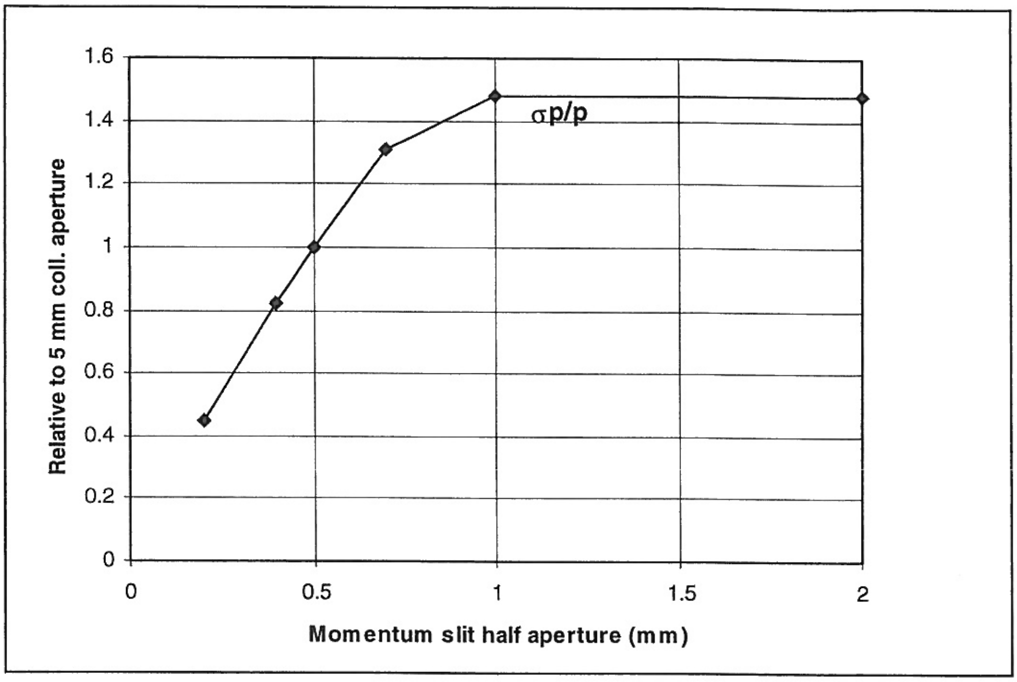
The following graphs show the effects of collimators CH75 and CV46 . Values are obtained by TURTLE runs and each point has a statistic uncertainty of 2 to 4% due to finite sample size. Reference points for the collimators are :

- 5 mm half-width for the momentum slit ($\sigma_p/p \sim 0.4\%$)
- Vertical acceptance collimator fully open (> 20 mm for each jaw).

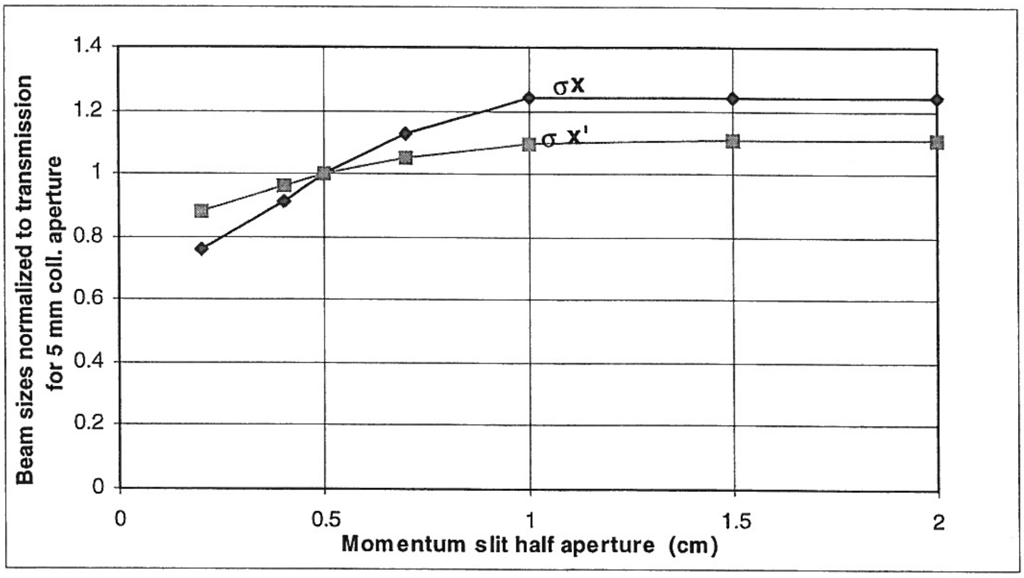
Collimators are supposed to be set symmetrical with respect to the beam axis.

Momentum slit aperture effects
on intensity and momentum spread

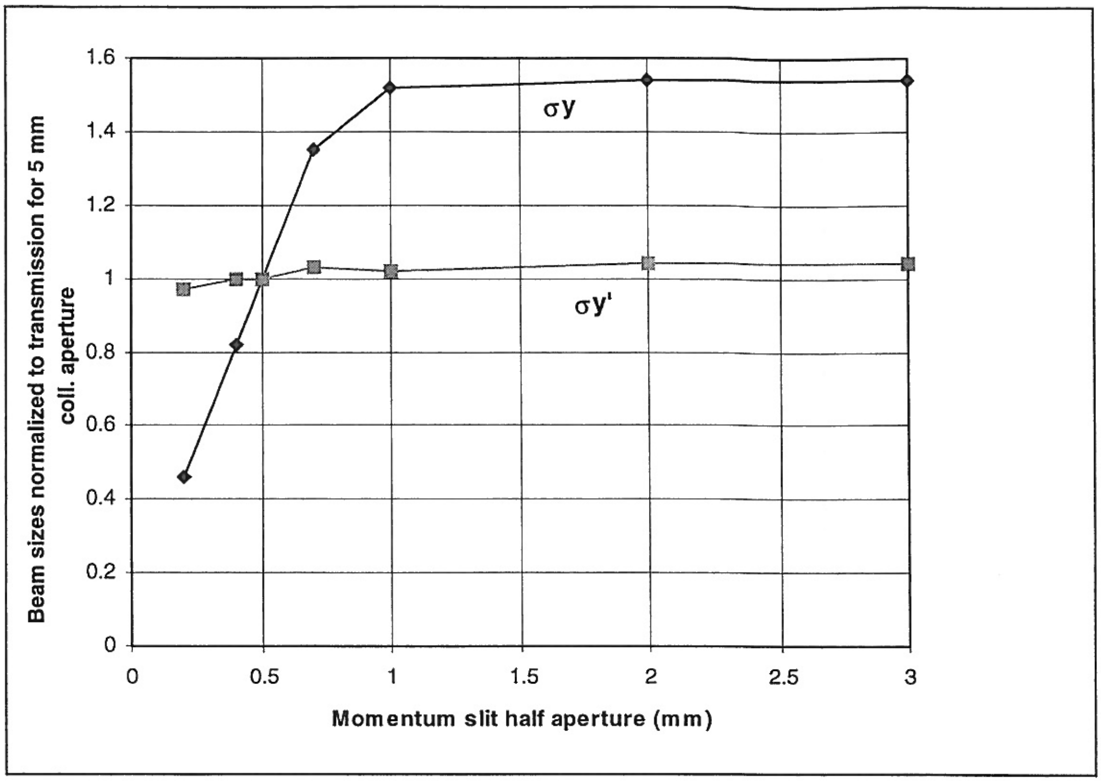




Momentum slit aperture effects
On beam at reference focus

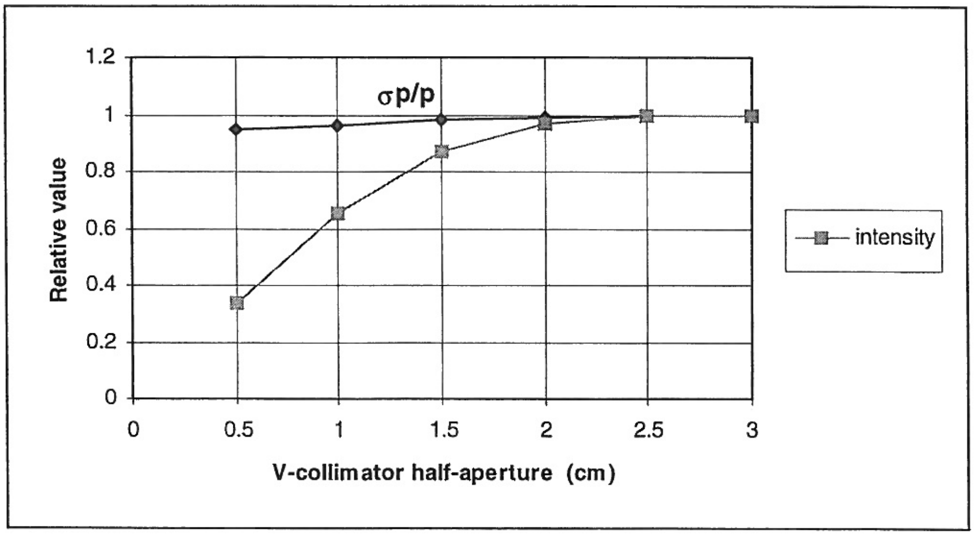


How to read the above graph : let's open the collimator to 1 cm, at this aperture the dimension σ_x of the beam will be 1.25 times the dimension σ_o at 0.5 cm collimator aperture.

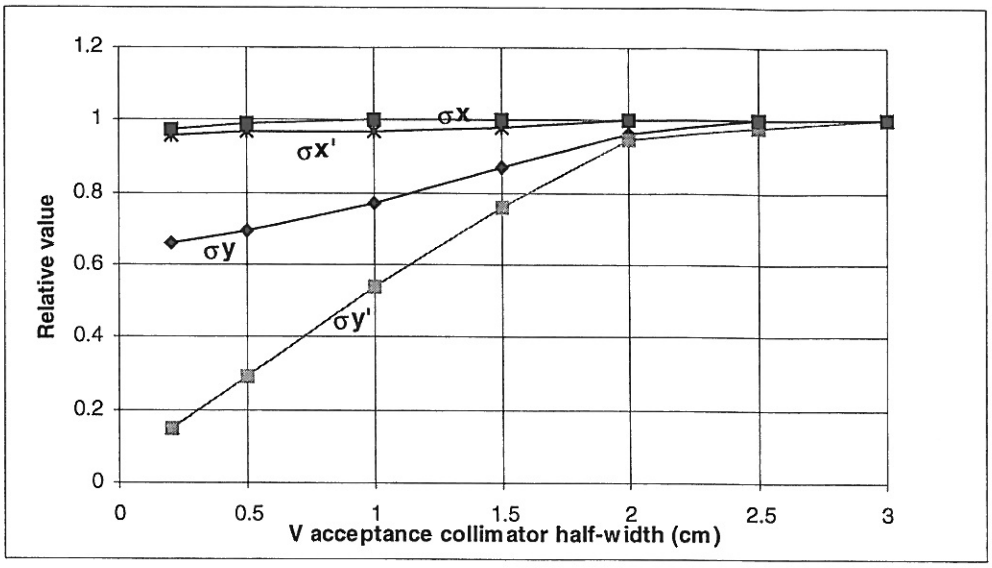


Observed changes in spot sizes are namely due to optics chromatism and not to the small residual dispersion at the focus. The effects in the V plane (y,y′) are insignificant. The drop in H divergence is caused by the finite length of the slit.

<u>Effects of V acceptance collimator</u>
on intensity and sigma p



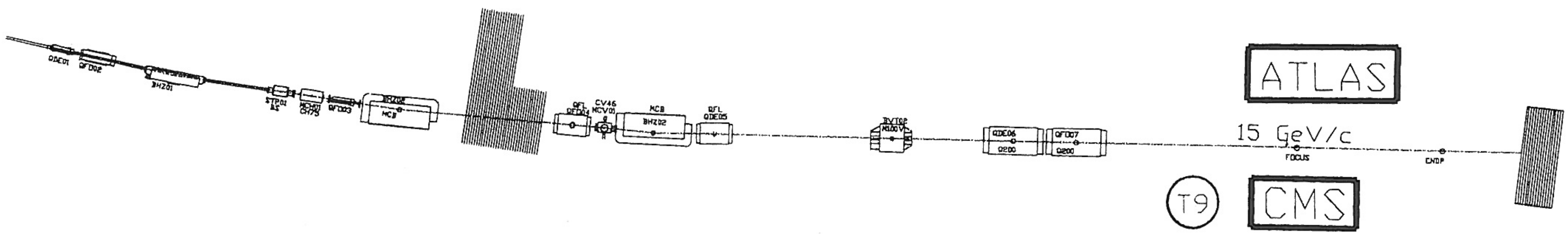
Effects of V acceptance collimator
on beam at reference focus



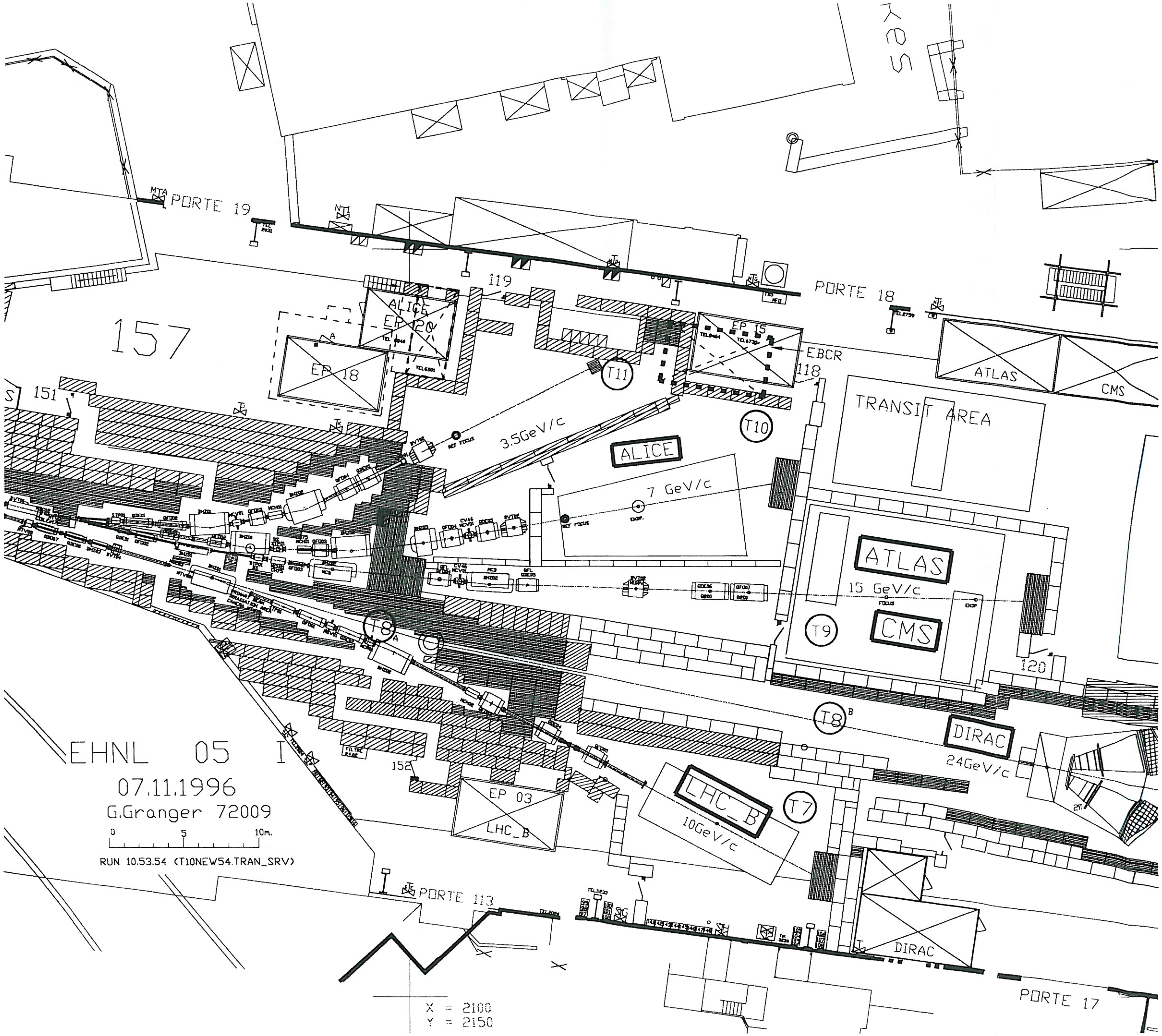
References:

1. EHNL_5 Proposal for the Beam & Areas for Tests and Experiments in the East Hall. PS/PA/Note 96-28. J.Y. Hemery

2. Secondary Beams for Tests in the PS East Experimental Area. PS/PA Note 93-21. Edited by D.J. Simon, revised by L. Durieu.



ATLAS
15 GeV/c
CMS
T9
FOCUS
ENDP
QDE01
QFD02
BHZ01
MCB
BHZ02
QFL
QDE05
CV46
MCV01
QDE06
QFD07
Q200


PORTE 19
PORTE 18
PORTE 113
PORTE 17
157
119
118
151
152
120
ALICE
EP 20
EP 18
EP 15
EBCR
T11
T10
3.5GeV/c
ALICE
7 GeV/c
ATLAS
CMS
TRANSIT AREA
ATLAS
15 GeV/c
T9
CMS
T8
T8
DIRAC
24GeV/c
LHC_B
10GeV/c
T7
EP 03
LHC_B
DIRAC
EHNL 05 I
07.11.1996
G.Granger 72009
0 5 10m.
RUN 10.53.54 (T10NEW54.TRAN_SRV)
X = 2100
Y = 2150