Chapter I. Constraints, design and needs of the new T7 line.

Section 1: General and vicinity constraints.

The new T7 shall fit the geometry as defined in EHNL5 document (ref. 1.), with adequate optical characteristics and geometrical spacing with respect to the DIRAC (T8) line. It is desirable to reuse the presently available magnets and power supplies as far as practical.

This T7 line will be mainly dedicated to tests of the LHC LHC-B experiment, the maximum available momentum will be 10 GeV/c.

The design should guarantee good and reproducible beam quality at the experimental focus, within its expected useable range. The optical design is an adaptation of the classical double monochromator scheme, with its known favourable quality/complexity ratio. Its proper optimisation is, however, far from trivial, but the work investment is concentrated at design time, with comparative ease of operation however, once the line have been properly commissioned.

Section 2: geometry and momentum adaptation.

It is now necessary to switch between T7 and T8 instead of just giving beam on the south target as done in the past. The switching element, for the physical separation, is the new F61S.BHZ2 laminated magnet of MCB type. This magnet deflects the beam by 39 mrad to the right when feeding the ZT7 target and let it pass directly for the DIRAC line (T8). The optics itself, in particular a full set of quadrupoles has also to be changed in a quasi PPM mode in order to give the proper set of optical parameters for each mode of beam operation.

The nominal beam height is 1.28 m above ground as now; a vertical correction magnet is included which will allow for small vertical steering in the experimental area.

Section 3: optical design.

This line has the dispersion magnets imbedded in the optics, this couples focusing and dispersion control meaning that all five quadrupoles are needed in a full matching, which was done for the nominal focus. Thereafter the last focus is modified using only the last doublet. It has been verified that the residual dispersion in doing so is small enough to be safely neglected.

Optical conditions are set as follows : for the intermediate focus : horizontal in the mid plane of the momentum slit, vertical close to the principal object plane of the field lens QFO03 (diverging plane) for minimum sensitivity. The final focus is set at the nominal experimental location for both planes. The exact intermediate V focus location along with the field lens strength allow full compensation of the dispersion beyond BHZ2. Doublet polarity is chosen to avoid aperture limit in the comparatively small gap of BHZ1.

The resulting geometry, once all matching and cross checks are done, can be found in Table 2. The nominal optics (first order) is shown on fig. 1.

Section 4: needed magnetic resources and power supplies.

All the magnets (except for BHZ1), quadrupoles and their associated power supplies are recovered from the present line and reused under conditions quite similar than now. Power dissipation are very similar than at present. Details can be found in Table 3.

Two magnets presently used are freed (one M200SP with 110 mm gap and one M200SP with 140 mm gap); all others are reused as well as the ancillary equipment such as the collimators. The beam stopper is replaced by a shorter one with some adaptation of the safety procedure.

M-name	Magnet	I max	P max (kW)	Flow (l/min)
BHZ1	Mcb[b]	396	27	19
QDE1	Q606[a]	788	223	160
QFO2	Q607[a]	788	224	160
BVT2	MDX100[a]	~80		
QFO3	Q123[a]	421	34	24
QFO4	Q141[a]	654	86	62
BHZ2	MC208[a]	709	181	130
QDE5	Q125[a]	545	60	43
Total			**835**	**600**

Table 1. Magnets, power and required water flow.

a/ magnet and power supply already exist in the present T7 line, no change required

b/ the magnet type only is defined, a new magnet and a power supply should be installed

Remark : the quoted power takes into account the DC resistance of the magnet at a mean coil temperature of 35 Celsius. It neglect wiring losses and efficiency of the power converters. The water flow is given for a 20 Celsius temperature rise (~36 m^3/h); it may be lower if a higher temperature rise is acceptable.

Section 5: ancillary equipment.

- Momentum collimator : same as now at almost the same location, in the target area.
- Vertical and horizontal acceptance collimators are kept, their locations being exchanged to insure better optical location.
- Beam stopper : will be changed and placed in the target area between the first doublet and the field lens. This location being now free.
- Shielding: moved downstream between field lens and second doublet..

Section 6: monitoring devices.

The effective devices installed have still to be discussed with the beam diagnostics group for availability, feasibility and performances; our wish list is however quite clear :

- MWPC or equivalent devices at line end and at the vicinity of experimental focus. Resolution in the order of 2 or 4 mm seems adequate.
- Some kind of intensity measurement would be very useful. It should reflect the effective intensity delivered to the experiment and impose minimal degradation of the beam quality. Its location and type is open to discussion.

Section 7: line vacuum.

The line is expected to be under crude vacuum (< 10 Pa) from the upstream face of QFO1 up to the downstream face of QFO5. This will ensure minimal multiple scattering in air and vacuum windows.

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Reported by TRANPLT/SRV program   [std units: L(m), S(m), Field(kG)]          Run at  09.51.05   14/06/97
Initial coord. at Sx=Sy=Sz=0, Ax=pi/2, Ay=0, Az=-pi/2
Bend coord. given at Xing point of straight lines
Z axis stands as the altitude
Program version 1.2 - J-Y.Hemery (CERN)
```

Start Ax,Ay,Az (radians)=			1.8981	-.3273	-1.5708					
Name	dS1	S.lgth	S.x	S.y	S.z	B.pos	Length	Field	deg	rad
----	-----	--------	------	-------	-------	-------	-------	------	------	------
_TV2	.000	.000	2086.740	2177.874	1.280	.000				
>BHZ1	4.001	4.001	2090.529	2176.588	1.280	4.000	2.600	-12.0596	-5.3858	-.0940
*QFO1	3.151	7.152	2093.404	2175.300	1.280	7.150	1.620	8.3942		
_CH1	1.425	8.577	2094.705	2174.717	1.280	8.575				
*QDE2	1.375	9.952	2095.960	2174.155	1.280	9.950	1.620	-8.3954		
_CV1	1.660	11.612	2097.475	2173.476	1.280	11.610				
_STP1	3.500	15.112	2100.669	2172.044	1.280	15.110				
_CH2	1.150	16.262	2101.719	2171.574	1.280	16.260				
*QFO3	1.300	17.562	2102.905	2171.042	1.280	17.560	1.160	7.9426		
*QDE4	4.870	22.432	2107.349	2169.051	1.280	22.430	1.160	-9.7805		
>BHZ2	2.381	24.813	2109.522	2168.077	1.280	24.810	2.160	-13.8985	-5.1566	-.0900
*QFO5	2.381	27.193	2111.598	2166.912	1.280	27.190	1.160	7.4486		
_foc	10.260	37.453	2120.546	2161.892	1.280	37.450				
_ENDP	2.500	39.953	2122.726	2160.669	1.280	39.950				
Final Ax,Ay,Az (radians)=			2.0821	-.5113	-1.5708					

Ligne T7 pour LHC-B, EHNL5-N. Version 5.4 14/06/97 "

Table 2. Geometry of the new T7 line, version 5.4

Required power, kW								Line total	at -4m	at +4m
Momentum	ZT7.BHZ1	ZT7.QFO1	ZT7.QDE2	ZT7.QFO3	ZT7.QDE4	ZT7.BHZ2	ZT7.QFO5			
1.00	0.25	2.21	2.21	0.32	0.48	1.77	0.28	7.52	7.75	7.43
1.50	0.56	4.98	4.98	0.72	1.09	3.97	0.63	16.93	17.44	16.72
2.00	1.00	8.85	8.86	1.27	1.93	7.05	1.12	30.09	30.99	29.72
2.50	1.56	13.84	13.84	1.99	3.02	11.01	1.75	47.00	48.42	46.43
3.00	2.24	19.93	19.94	2.87	4.35	15.83	2.52	67.68	69.73	66.84
3.50	3.04	27.14	27.15	3.91	5.94	21.51	3.43	92.12	94.92	90.98
4.00	3.96	35.46	35.47	5.11	7.78	28.05	4.49	120.32	124.00	118.83
4.50	5.00	44.90	44.91	6.48	9.88	35.45	5.69	152.32	157.01	150.41
5.00	6.17	55.46	55.47	8.02	12.27	43.71	7.04	188.13	193.99	185.77
5.50	7.46	67.14	67.16	9.73	14.95	52.83	8.54	227.81	235.00	224.91
6.00	8.88	79.94	79.97	11.63	17.95	62.83	10.20	271.41	280.13	267.92
6.50	10.43	93.88	93.91	13.72	21.32	73.74	12.02	319.02	329.51	314.86
7.00	12.13	108.96	108.99	16.02	25.10	85.58	14.01	370.77	383.32	365.84
7.50	13.98	125.17	125.20	18.54	29.37	98.41	16.18	426.84	441.84	421.02
8.00	16.02	142.52	142.56	21.30	34.24	112.28	18.55	487.47	505.45	480.61
8.50	18.26	161.03	161.07	24.33	39.90	127.30	21.13	553.02	574.75	544.90
9.00	20.76	180.68	180.74	27.67	46.64	143.58	23.95	624.03	650.81	614.34
9.50	23.60	201.51	201.57	31.38	55.05	161.31	27.04	701.45	735.73	689.63
10.00	26.90	223.49	223.56	35.53	66.44	180.76	30.44	787.12	835.35	771.99

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

Chapter II : precomputed behaviour of the T7 line.

This chapter presents what is to be expected from the modified T7 line. Some of the values may change slightly during implementation and will have to be confirmed at commissioning time.

Characteristics of the beam T7.

Maximum design momentum		10.0 GeV/c
Length at reference focus[1]		37.45 m
Beam height		1.28 m
Production angle from target	H	0 mrad
	V	0 mrad
	total	0 mrad
Horizontal angular acceptance[2] (in QFO1)		13.8 mrad
Vertical angular acceptance[2] (in QDE2)		5.3 mrad
solid angle acceptance[3]		230 μsr
Horizontal magnification at momentum slit		2.4
Momentum slit displacement		8.9 mm for 1% Δp/p
Theoretical momentum resolution[4]		0.27%

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

dispersion (/% Δp/p)	H	0 mm/ 0 mrad (first order full correction)
	V	0 mm/ 0 mrad (if no vertical displacement)
magnification from target	H	1.6
	V	1.7

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1 Reference focus is located 10.26 m downstream of the last magnet centre (QFO5)

2 The physical aperture limit is inside the first two quadrupoles, inner radius of 92 mm.

3 The aperture limit is an ellipse with semi-axis 80.4*30.7 (mm, H*V) at the entrance face of the first quadrupole, located 7.96m from the target plane.

4 For an effective production target of 2*2 mm^2.

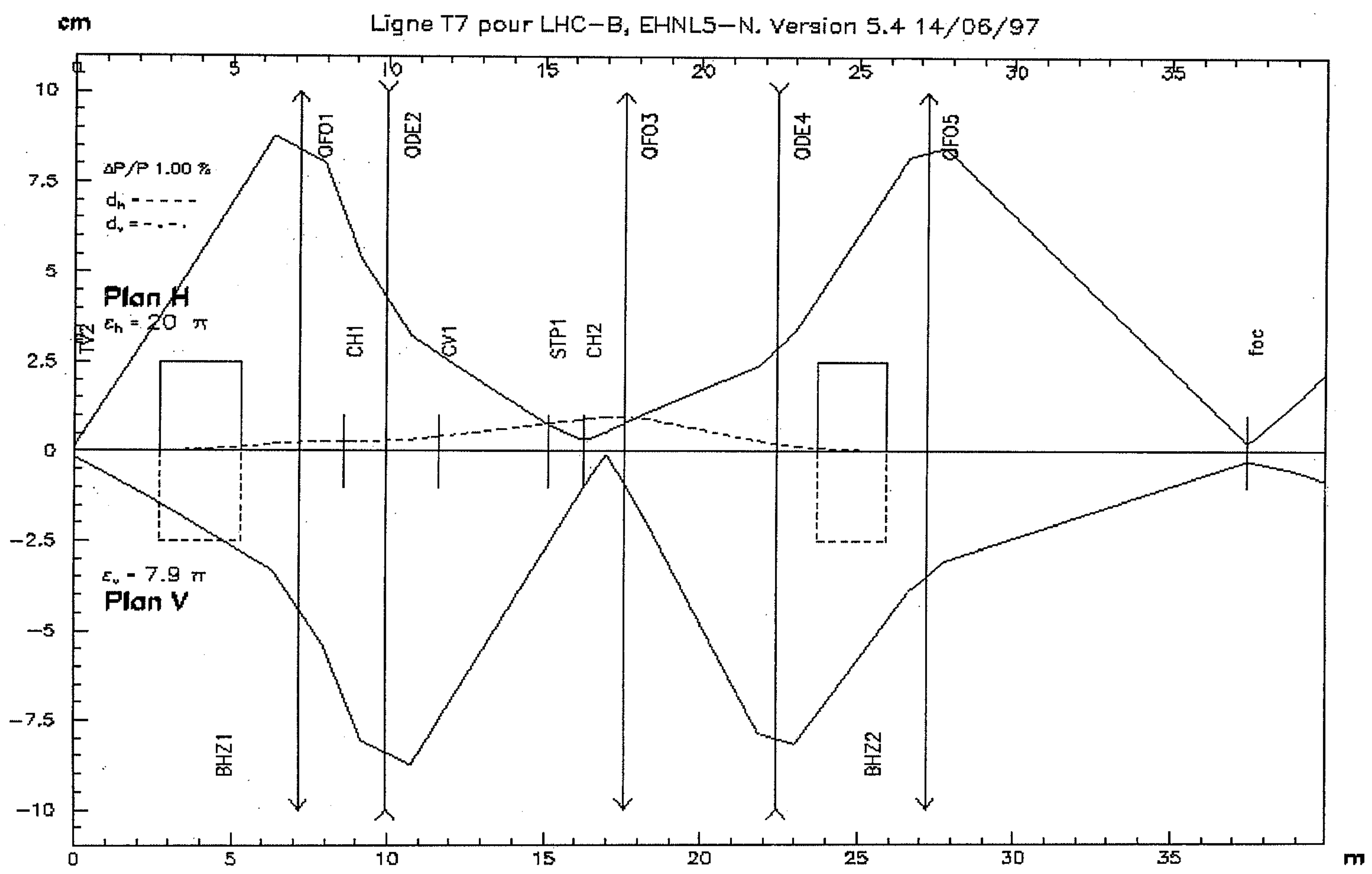


Fig 1. First order optics for the T7 line (nominal focus).

Momentum	ZT7.BHZ1	ZT7.QFO1	ZT7.QDE2	ZT7.QFO3	ZT7.QDE4	ZT7.BHZ2	ZT7.QFO5
					Nominal focus		Nominal focus
1.00	38.15	78.40	78.42	39.87	49.10	70.06	37.39
2.00	76.20	156.83	156.86	79.77	98.24	139.99	74.80
3.00	114.07	235.31	235.34	119.72	147.54	209.69	112.26
4.00	151.77	313.85	313.90	159.83	197.20	279.14	149.83
5.00	189.40	392.49	392.55	200.23	247.66	348.43	187.62
6.00	227.18	471.24	471.31	241.16	299.61	417.78	225.80
7.00	265.54	550.14	550.22	283.00	354.24	487.57	264.64
8.00	305.18	629.20	629.29	326.31	413.77	558.48	304.53
9.00	347.45	708.45	708.56	371.96	482.92	631.54	346.04
10.00	395.47	787.92	788.04	421.47	576.36	708.59	390.11

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

Momentum	ZT7.QDE4	ZT7.QFO5	ZT7.QDE4	ZT7.QFO5	ZT7.QDE4	ZT7.QFO5	ZT7.QDE4	ZT7.QFO5	ZT7.QDE4	ZT7.QFO5
	-4 m		-2 m		nominal focus		+2 m		+4 m	
1.00	51.62	47.71	50.18	41.29	49.1	37.39	48.26	34.77	47.59	32.89
2.00	103.29	95.46	100.4	82.6	98.24	74.8	96.57	69.56	95.22	65.8
3.00	155.15	143.34	150.79	123.98	147.54	112.26	145.01	104.39	142.99	98.73
4.00	207.47	191.55	201.59	165.53	197.2	149.83	193.8	139.29	191.07	131.73
5.00	260.8	240.45	253.27	207.44	247.66	187.62	243.31	174.36	239.84	164.85
6.00	316.06	290.64	306.61	249.98	299.61	225.8	294.19	209.71	289.88	198.19
7.00	374.89	343.12	362.99	293.59	354.24	264.64	347.52	245.51	342.19	231.89
8.00	440.54	399.68	425	338.97	413.77	304.53	405.23	282.04	398.51	266.12
9.00	521.18	463.92	498.58	387.24	482.92	346.04	471.32	319.67	462.36	301.18
10.00	654.25	545.42	604.95	440.44	576.36	390.11	557.1	358.95	543.01	337.45

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

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 2.10^{11} p at 24 GeV/c on standard target and 7 mm half width of the momentum slit). Extrapolation to higher momentum has to be guessed at this time.

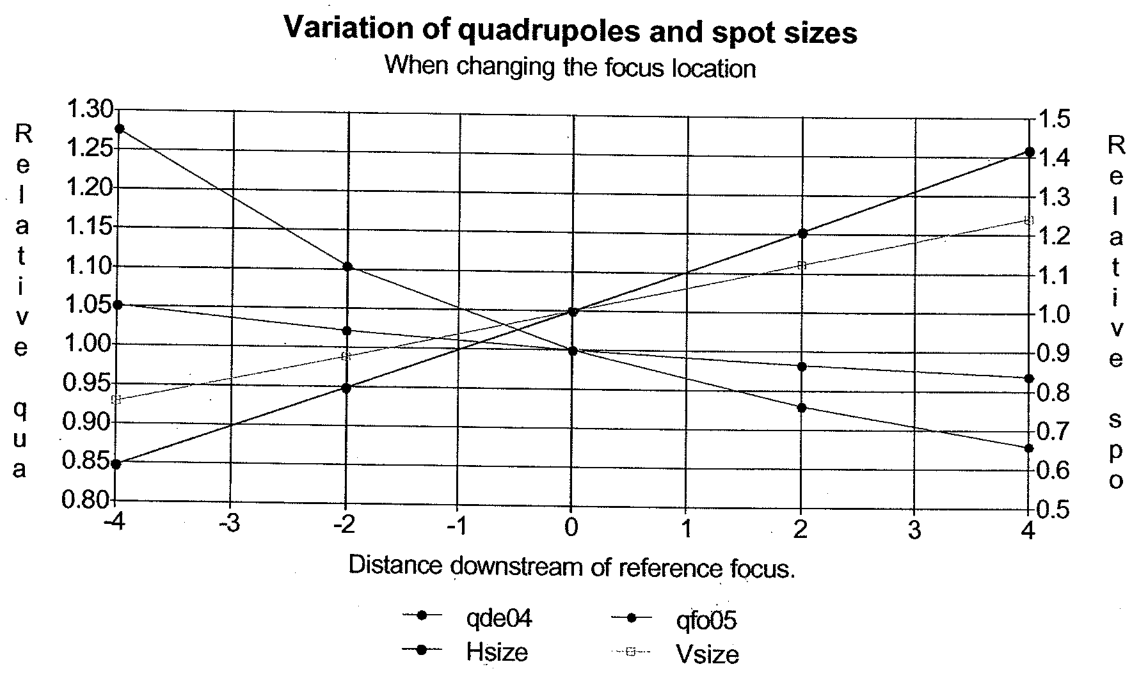
The standard beam on target comes from the slow extraction of a PS coasting beam with a spill time around 350 ms. The target and the line are transparent to the impinging time structure down to the ns level.

Line tuning.

It can be done with the help of tables 4 and 5. 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 four magnets (BHZ03, QFO04, QDE05 and BVT02). The first part is dedicated to momentum analysis and playing with it is strongly discouraged as the resulting optical behaviour will be less than ideal.

Focusing.

Table 5 should be used to move the longitudinal location of the focus, both foci H and V are in the same plane. Distances refer 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; note that quadrupolar forces change as shown, not their currents which are non linear in the high momentum range.



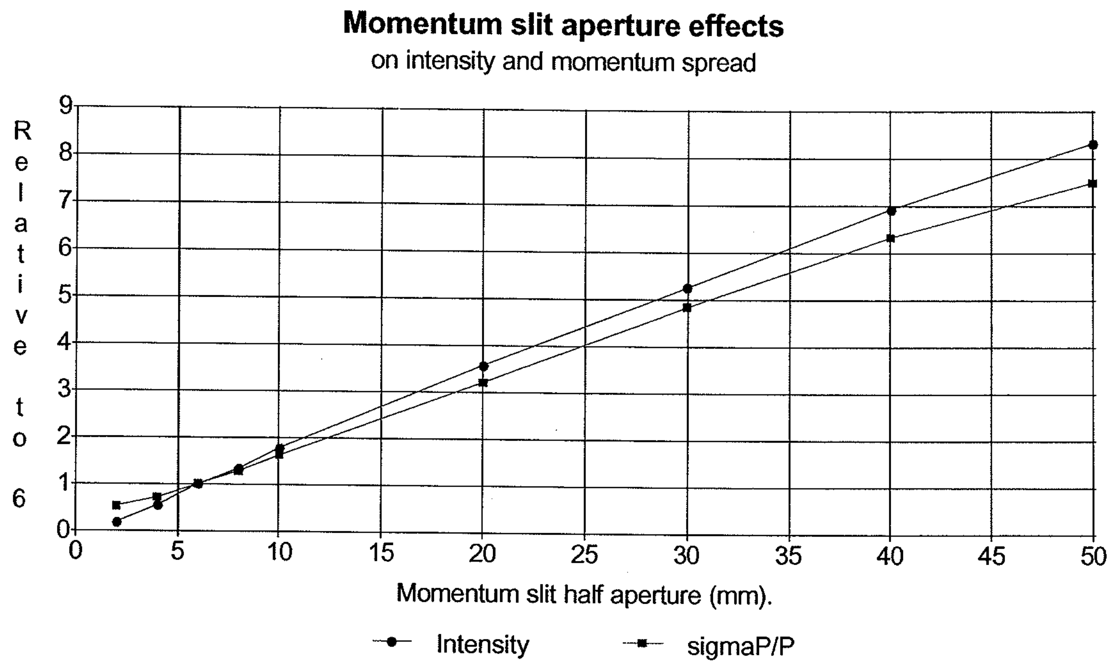
Collimators effects (intensity and momentum spread tuning).

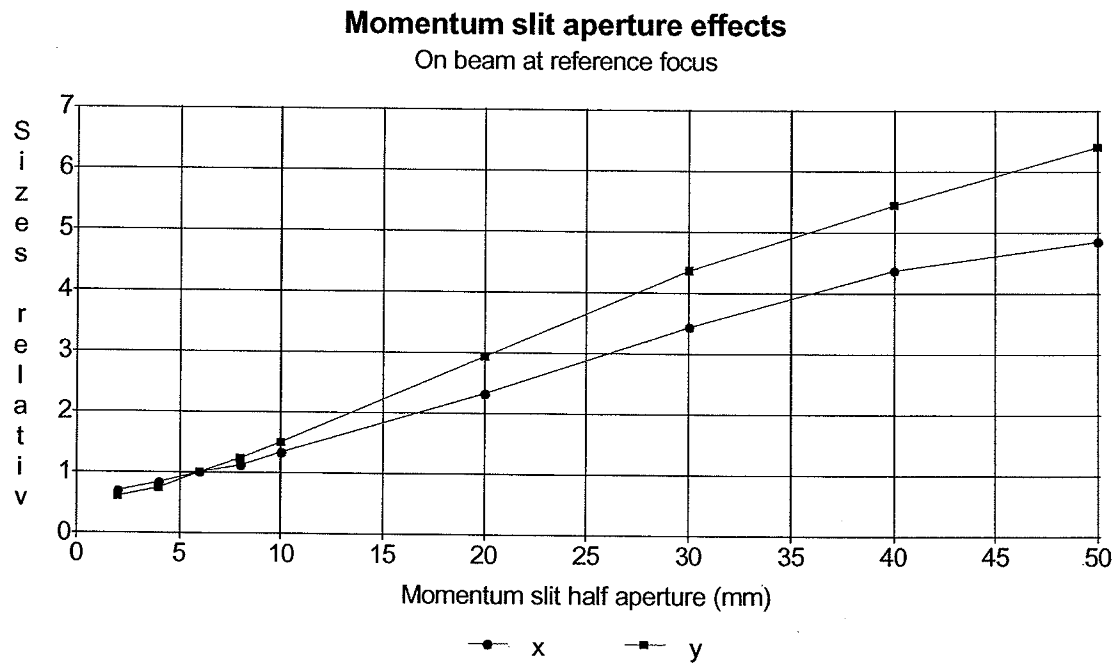
The following graphs are summaries from TURTLE runs; each point has a statistic uncertainty of 2 to 4% due the finite sample size. Reference points for the collimators are :

- 6 mm half-width for the momentum slit (σ_p/p ~0.45%).

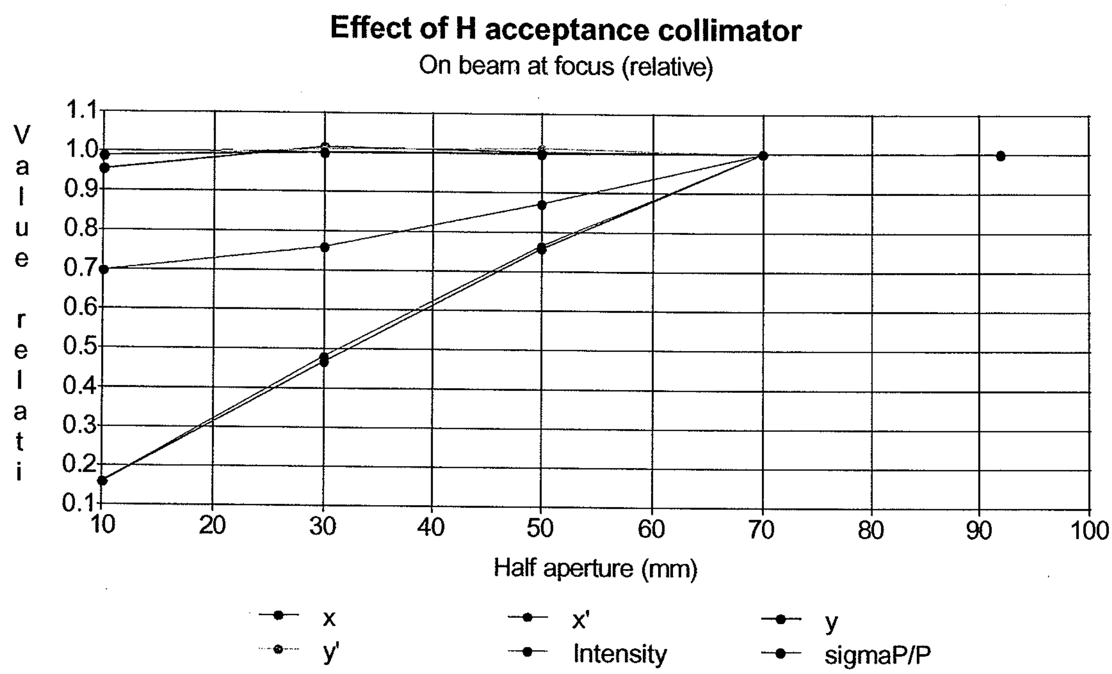
- Vertical acceptance collimator fully open (in this case > 70 mm for each jaw).

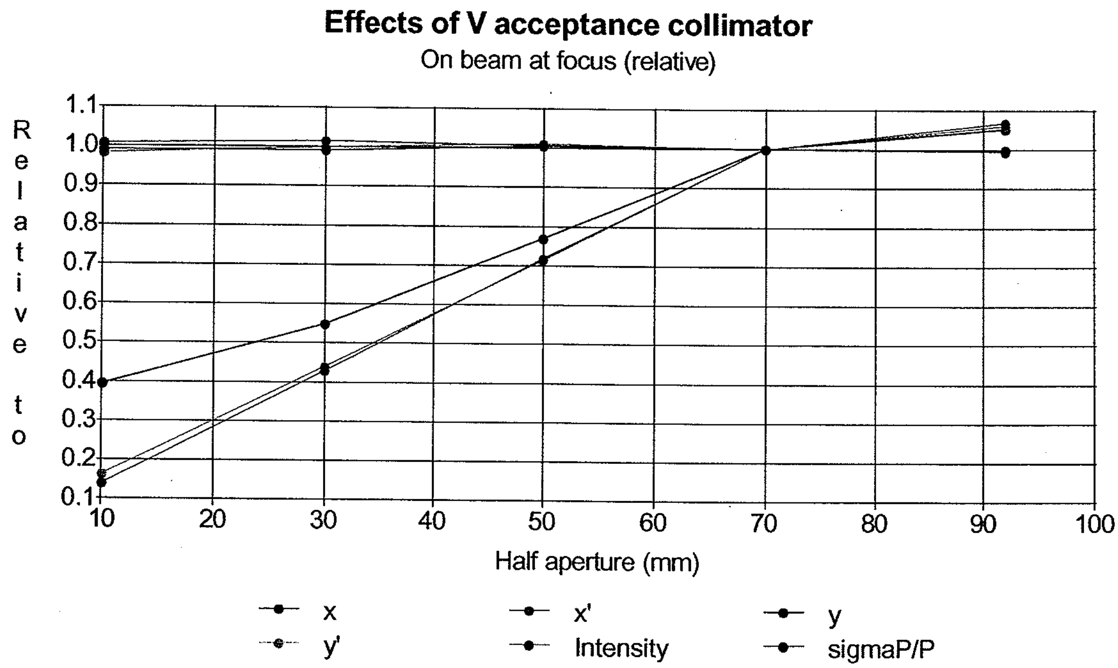
Collimators are supposed to be set symmetrical with respect to the beam axis as they should always be.





Observed changes in spot sizes are mainly due to optics chromatism and not to the small residual dispersion at the focus, although not insignificant in the V plane (y,y').





References:

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

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

T7 Beam Features

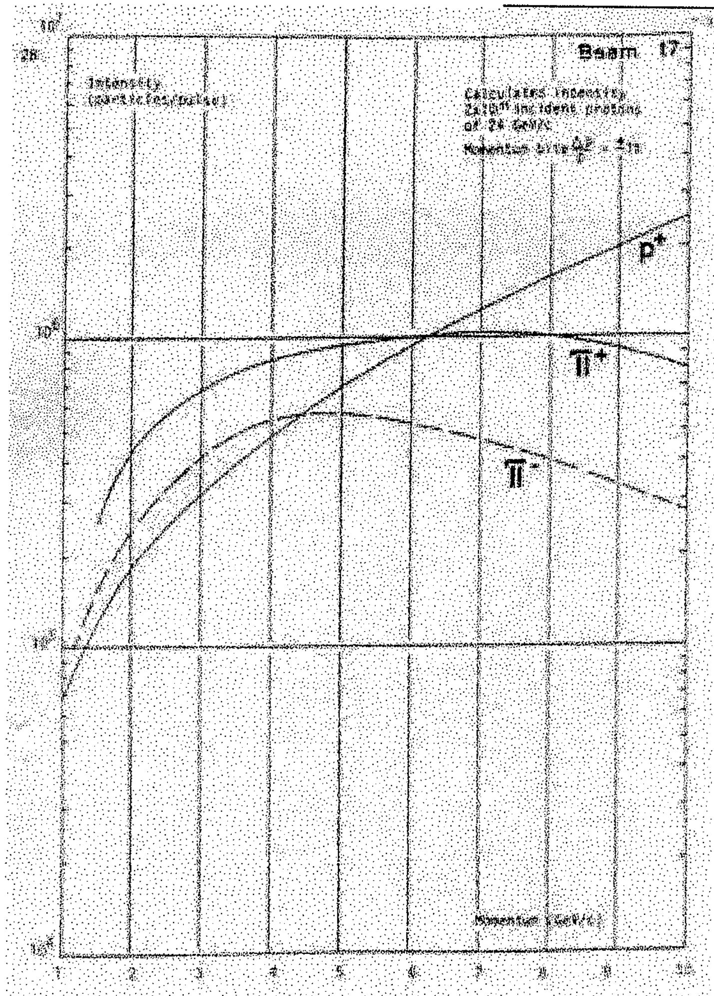


Fig. 13 Calculated intensity at the reference focus of t7.

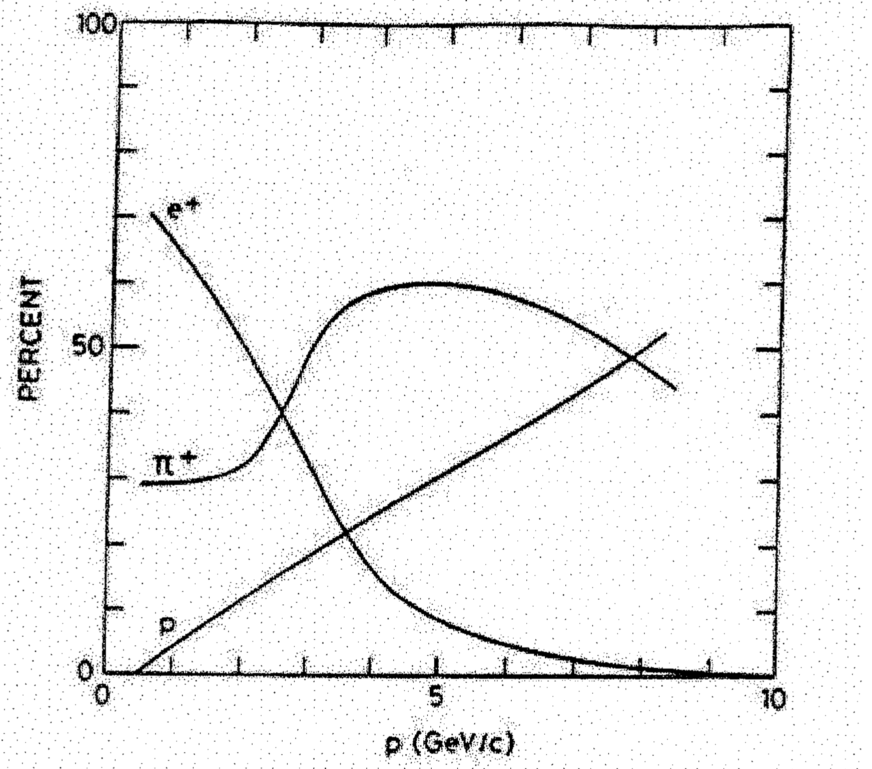


Fig. 14 Relative distribution of protons, pions and positrons in the t7-beam, as measured by PS188 (Ref. 6,7)