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Measurement of Beam Halo in FT61S for the DIRAC Experiment.

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1. Introduction.

The DIRAC experiment which has requested time on the PS machine would normally be placed on a new line on the south branch serving the East Hall. This experiment is expected to be sensitive to particles outside the beam core in the vertical plane (halo).

It is thus necessary to measure the beam density distribution in the vertical direction down to low densities, far from the core, under optical conditions similar to what is expected in the vicinity of the sensitive parts of the experiment.

The absolute maximum tolerable limit of the halo intensity is now defined to be $4*10^7$ p per spill in the coordinate detector (Sci-Fi, see Ref. 1.). It is located 2 m downstream of the target, with a lower edge 67 mm above beam, and a useful size of 10 cm by 10 cm. Low density is required in order to avoid pile-up and reduction in efficiency.

2. Previous measurements.

A first measurement was done with RPL type devices in 1993 (Ref. 2), for the horizontal distribution. Another attempt was made in June 1994, this time in the vertical plane, using first a scintillator (unsuccessful due to excessive noise and counting rate) then RPL type devices once more. The results of the second test were discussed with the experiment before the 1995 Cogne meeting, but not published (see Annex A).

These results, although useful, were not sufficient to be conclusive for the experiment people.

3. Set-up for this measurement.

Location : near MTV10 in the primary area serving the East Hall, along the south branch.

- The beam axis was changed with ZT7.BHZ01 in order to get maximum clearance with respect to walls and secondary line material to reduce, as far as possible, unwanted secondaries.
- Upstream of the copper target, the primary beam interacted with 0.6 mm equivalent Al (vacuum window and Secondary Emission Chamber) and 7 m of air.
- Downstream of the copper target, the beam had to pass through 12 m of air before being absorbed in the beam dump (iron wall).

Optics : as close as possible to DIRAC focusing conditions using available elements in the line. Identity is not possible as the DIRAC line proposed model can not be fully simulated in the available line. In the first part of the line, two sets of optics have been devised :

1. Normal transfer trough splitter, as expected under data taking conditions.
2. Modified optics in the splitter to reduce the number of particles scattered along the edges, used to confirm splitter generation of the halo (reduced vertical size, centered beam).

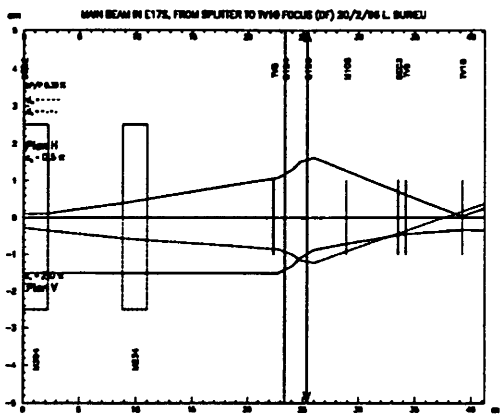

Fig. 1. Main beam to TV10, optics DF.

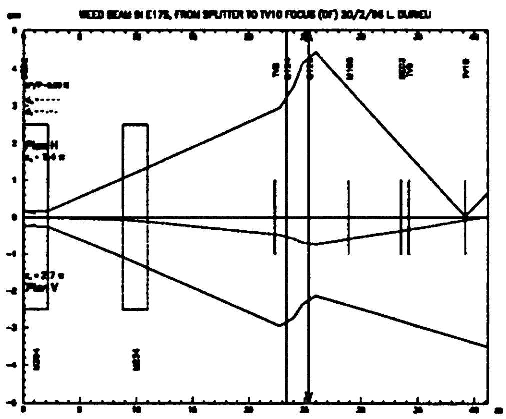

Fig. 2. Halo from splitter to TV10, optics DF.

4. Measuring devices.

1. Exposure of Al foils to the primary beam to get a bidimensional profile using activation (both Na^{24} and F^{18} were traced). This has only been done for the optics with splitter due to lack of time. This measure is sensitive to the particle gas in the area, in particular to secondaries generated in air or back scattered from the beam dump.
2. Telescope made with two scintillators of 1 by 1 cm spaced 5 cm, looking at the secondary particles emitted at right angle by the interaction of the beam with a thick copper target (moveable in the vertical plane to scan the primary beam density). The telescope was placed one meter under the beam axis and shielded with lead blocks to reduce the incidentals coming from other directions.
3. One scintillator located between FT61.QFO07 and FT61.QDE08, outside the beam pipe, used to monitor possible beam losses and global noise level.

5. Results from April 95 measurements.

5.1. Results of Al irradiation.

A square aluminium foil of 10 cm edge was exposed during 5 hours to the proton beam, the splitter cutting the beam in two parts of very similar intensity. The foil was fixed such that the beam hit in its center and was finely focused at MTV10, 40 cm upstream. TRANSPORT estimated beam sizes were 1.65 mm V and 0.4 mm H (r.m.s. value) neglecting dispersion and second order effects.

The foil was then cut in 100 pieces of 1 cm by 1 cm and individually measured for induced radioactivity, after some cooling time. A report giving the raw results is available (see Ref. 3).

The data was then fitted to a set of two gaussian functions with pedestal by a specially written MATHCAD worksheet. The very crude spatial resolution can not distinguish between the r.m.s extend and the amplitude for the beam spot which is too small; however the subtended area stays valid. It was also done with a program made to fit a gaussian on bin (difference of erf function), giving :

		beam		halo	
	Pedestal	σ (mm)	Area	σ (mm)	Area
2 major bins	240/cm	1.98	486400	15.2	11540
all bins	1077/cm	2.02	489400	16.1	23620
TURTLE	-	1.65	-	16.5	-

The empty entries in the TURTLE prevision reflects the ability of this program to give the beam sizes and transmission for a given source; it is not able to generate these sources.

We find a very similar result than with the previous irradiation, consistent with a halo generated by multiple scattering by the splitter edge. GEANT simulations let us expect a fraction of 3 to 7% of the transmitted beam, source located close to the beginning of the splitter, longitudinally spread along its edge. The momentum loss is small, order of 0.1% and the scattered particles will be channeled normally. The measured dimension of 16 mm is also coherent with the 0.7 mrad and 2 mm (r.m.s.) once modified by the optics.

Important remark : the halo distribution is later taken as gaussian. The multiple scattering distribution is only approximately so, meaning that the distribution tails will be higher; however no quantitative estimate exists far from the core (see Ref. 4, pages 1253..).

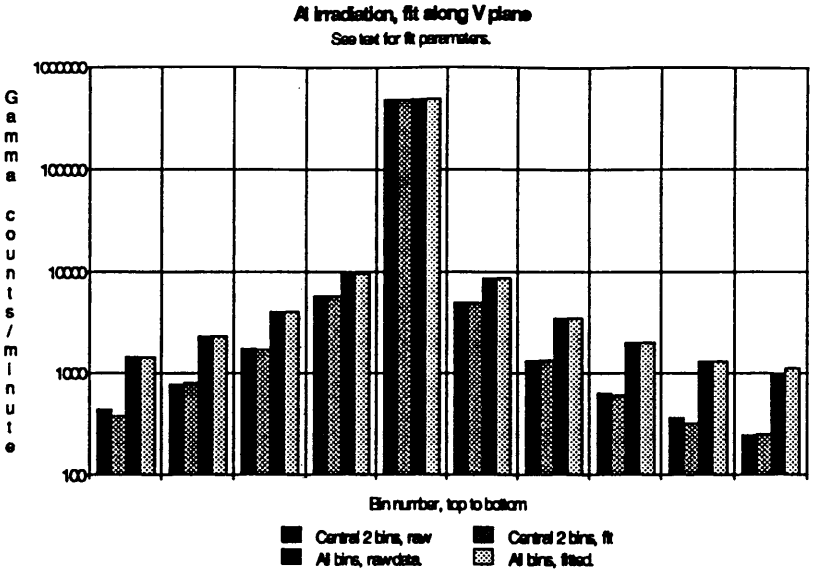

Fig. 3. Fit of irradiation of Al, F^{18} γ activity.

5.2. Results from the telescope measurement.

Great care was taken to properly calibrate the telescope, by finding the plateau, checking for accidentals and adjustment of the time window. Every measurement was repeated five times, normalized with respect to SEC3, accidentals measured with the time window and removed.

With the normal optics, splitter in beam, the fit gives similar results than the Al irradiation, namely beam/halo content is ~50. It seems interesting that the mean value of the halo is above the main beam. The apparent asymmetry of the main distribution can be explained by the splitter cut if the angle was not zero on the Cu target.

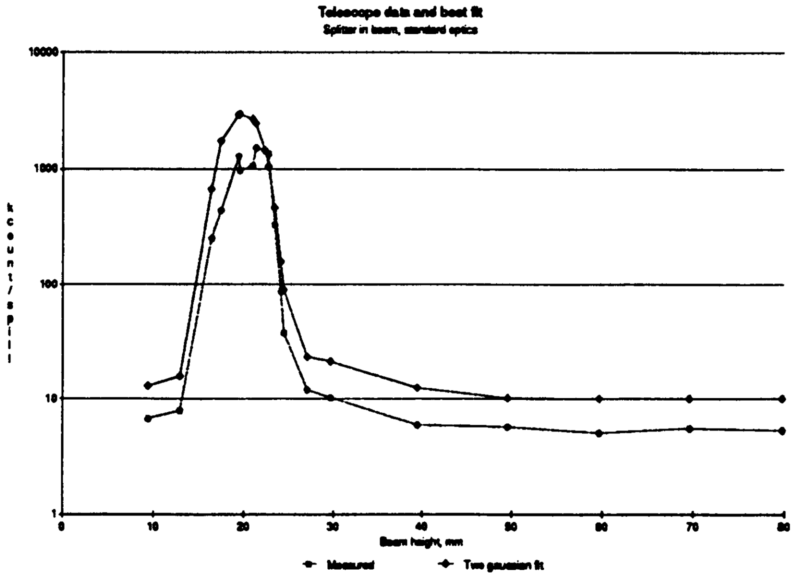

Fig. 4. Two gaussian fit, standard optics.

The fitted curve has been multiplied by two to improve readability. Some points at high intensity were given reduced weight, because of telescope saturation (just starting). It is interesting to note that gaussian distribution are not centered at the same location (halo is above main beam) which was to be expected if the halo comes from particles scattered by the splitter edge.

	beam				halo		
	Pedestal	σ (mm)	mean	Area	σ (mm)	mean	Area
Coincidences	5.05	1.08	19.76	1500	8.14	24.1	30

Another measurement has been done by displacing the beam between the splitter edge, giving a symmetrical cut. The estimated halo/beam was expected to be down by a factor 2 or 3. In this case, we suffered from the telescope saturation due to the increase of the transmitted beam. This has gone as far as reducing the readings when the beam hit directly the copper plate. Unfortunately, there was not enough time left to correct for this effect without loosing any references for comparison.

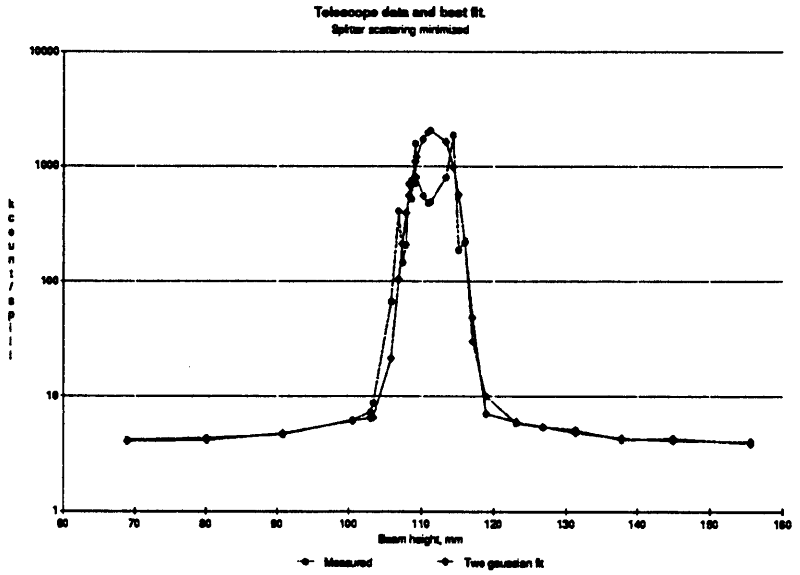

Fig. 5. Two gaussian fit, reduced splitter scattering.

	beam				halo		
	Pedestal	σ (mm)	mean	Area	σ (mm)	mean	Area
Coincidences	3.96	1.35	111.69	2210	12.03	111.44	18.6

The fit was quite difficult because of telescope saturation, however the results are in the expected direction : reduction of halo/main ratio, same mean value for both beams. The change in sigmas is caused by the altered optic and is also coherent with expectations.

6. Estimation of halo transmission in DIRAC Sci-Fi.

6.1. Halo is part of the main beam.

Assuming the pedestal is purely generated by the noisy primary area environment and will not exist at all in the DIRAC set-up.

Assuming the beam halo has the same optical functions than the main beam at the DIRAC focus and the expected beam expansion between focus and the coordinate detector, we find at the detector : (under observed halo size and intensity, supposed gaussian)

halo/beam	:	4.9%
σ halo	:	9.8 mm (estimated, V magnification)
minimum distance	:	67 mm (6.87 σ)
beam above 67 mm	:	less than $1.5*10^7$ for $2*10^{11}$ incident protons (75 ppm)

However, if the pedestal is transported under the same conditions, the fraction of beam population hitting the Sci-Fi detector rises to 2% (two orders of magnitude too high!).

6.2. Halo originates from the splitter edge.

In this case, we can take advantage of the different optical functions to get rid of most of the halo. Figures refer to the initially proposed DIRAC optics and should be taken as illustrative only. The real DIRAC optics is under study in the framework of the EHNL project and is not available at the time of writing. Hints and conclusions will be included in the optimization process.

The required spot size, nominal, is 3mm*2mm at 2 σ (H*V). The halo coming from the splitter is naturally collimated in the first quadrupole of the line, upstream of the bending and will thus be truncated in spatial extension. This halo is found to be diverging and fairly big at the Sci-Fi location.

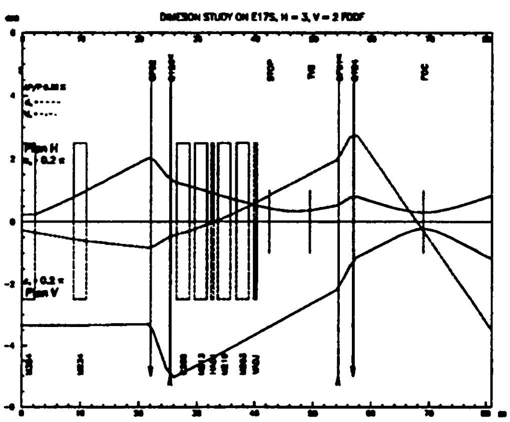

Fig. 6. Main beam optics for DIRAC.

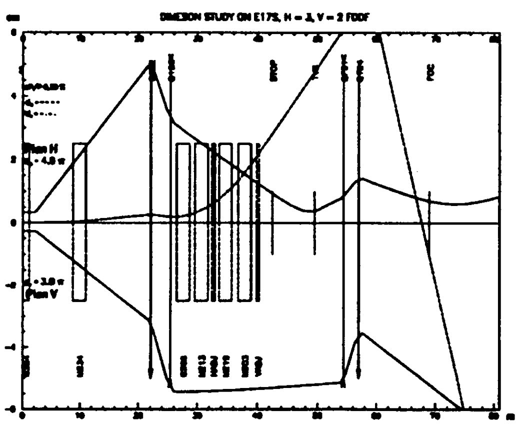

Fig. 7. Halo from splitter in standard optics.

Aperture limitations of 46 mm radius exist in all quadrupoles. Those in the first doublet effectively act as collimators for the halo originating from the splitter edge.

The envelopes are drawn for the first intercepted particle. All particles inside are transported downstream. Particles at the border or outside are scattered and degraded in the Al vacuum pipe. Most will be lost or driven out of the momentum acceptance of the line and removed in the second doublet. The fraction of particles falling out of the acceptance is in the range of some 0.1% of total beam, all with significant angle; this ensures an efficient clean-up of the scattered fraction.

The dispersion trajectory has been drawn for 1.5% momentum loss corresponding to the traversal of 235 mm of Al. The energy loss is expected to at least that much. The shadow size at the Sci-Fi location is around 50 mm.

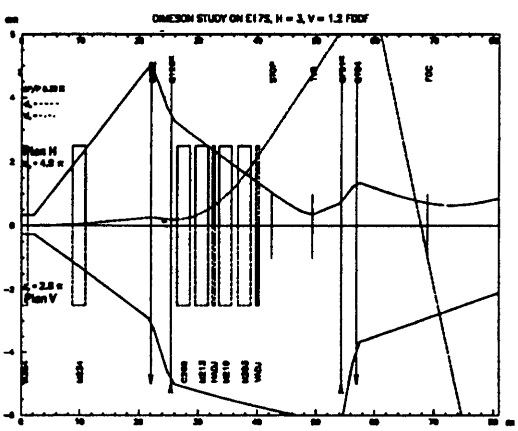

Fig. 8. Halo from splitter, vertical spot size 60%.

By alteration of the optics, it is possible to find a solution where the vertical envelope is smaller (converging or parallel) at the Sci-Fi detector. However part of the collimation is now done in the second doublet and may be more noisy. This is shown in the figure above.

Ref. 5 has been cited numerous times in collaboration mails or during discussion. Some of the described mechanisms can be used to advantage in the design of the DIRAC line, in conjunction with the others constraints. However the quoted figures should be majored for the Sci-Fi detector which is not a triple coincidence telescope but only one piece of it.

7. General conclusions.

- All results are coherent with a halo generated by the scattering of the main beam on the splitter edge. It holds approximately 2 % of the transmitted beam, with different vertical optical functions. This differences can be used to get rid of most of the halo in the downstream optics.
- The pedestal origin is not fully understood, GEANT simulation of scattered particles in air and back from the wall explains only one tenth of it. The pedestal seems however much lower in the

scintillator data. The mechanism is not the same, making difficult a definitive conclusion. Its far from the center contribution can be easily killed par properly located collimator device(s).

- Using tools like TRANSPORT and TURTLE, profile results, some optical changes, the amount of particles hitting the Sci-Fi detector can be changed by more than three orders of magnitude in the originally proposed optics. From totally unacceptable to well below requirements.
- As these changes are generated from relatively minor optics adjustments (about 5%), line tuning can be critical and data taking conditions must be expected to be unsatisfactory or unbearable from time to time. Some optimization during development time will be needed.
- The DIRAC required density for the halo are very stringent and quite atypical for a beam line. Understanding the source of this halo is only the first step needed in order to master it. The figure of 75 ppm of page 6 gives us some confidence that the goal can be met in the new optics. This is, however, not straightforward.

References.

[1] LIFETIME MEASUREMENT OF $\pi^+\pi^-$ ATOMS TO TEST LOW ENERGY QCD PREDICTIONS. Proposal to the SPSLC. CERN/SPSLC 95-1, SPSLC/P 284, December 15, 1994.

[2] DIRAC (I191) Preliminary Optics in the East Hall. PS/PA/Note 94-13.
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[3] Results of aluminium foil activation in the PS T7 beam. TIS-RP/JWN/jp (95-49).
J.W.N. Tuyn, G. Roubaud, J. Wolf.

[4] Physical Review D, Particles and Fields. 1 August 1994, Part 1. Review of Particles Properties.
Published by THE AMERICAN PHYSICAL SOCIETY.

[5] The Design and Performance of a Halo-Free Intense Extracted Proton Beam at Fermilab.
B. Cox and C.T. Murphy. Published in NUCLEAR INSTRUMENTS AND METHODS 136 (1976).

ANNEX A : results from 28 June 1994 vertical profile measurement.

Measurement of the beam halo has been attempted with a simple scintillator placed in the primary beam path, moveable in the vertical direction. It was impossible to get any significant information due to count rate saturation, even far (>100 mm) from the beam core. A set of radiometer devices (RPL and alanine) was then exposed to the primary beam and measured. The results are given in the graph below (pitch is 5 mm in the vertical direction, no information in the horizontal plane).

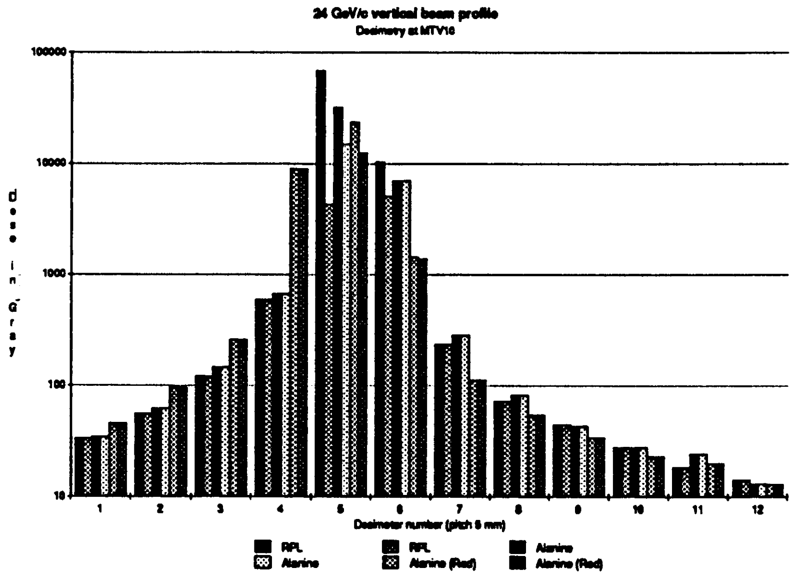

Fig. 9. RPL dose measurement.

The vertical scale is in Gray after a total exposure time of 3 hours. The dose is a compound of incident protons and any secondary scattered particles in the primary e17s area.

	beam			halo	
	Pedestal	σ (mm)	Area	σ (mm)	Area
mean of all	27/cm	1.49	27300	6.0	901
TURTLE	-	0.6+	-	5.6	-

The halo contains 3.3% of the main beam in irradiation effects. The pedestal value is the result of the fit mechanism; its real value is very small or nil as can be seen from the graph. The only valid conclusion here is that the beam and/or halo can not be simply described with gaussian distributions. TURTLE estimate of the main beam size does not include secondary effects. The match is quite good, taking into account the very limited spatial resolution of the RPL (5 mm).

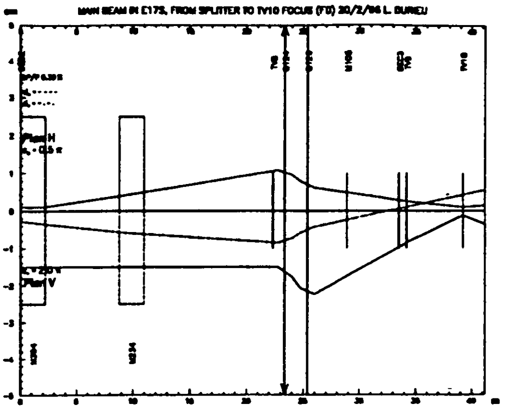

Fig. 10. Main beam to TV10, optics FD.

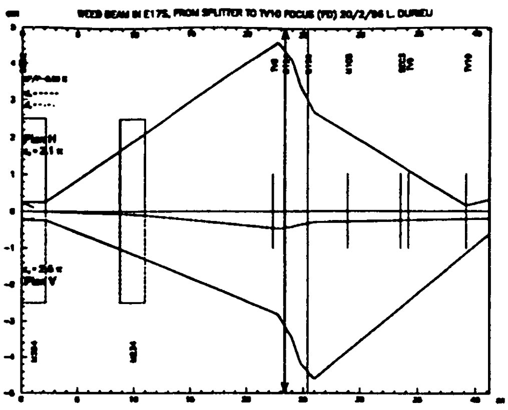

Fig. 11.Halo from splitter to TV10, optics FD.

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