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DESIGN OF A TAGGED PHOTON BEAM (CONTINUED): FITTING INTO THE PROTON LAB

Thomas Nash

National Accelerator Laboratory

May 25, 1972

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

ABSTRACT

We describe the status of the design of the tagged photon facility at NAL as of the end of May, 1972. A series of modifications has been made to the design reported earlier by a working group of physicists interested in the facility. The front end of the beam has been redesigned to include the primary beam dump and target within a single shielded target box. The first set of bending magnets have been moved into East Enclosure 1. The beam has been made more completely achromatic at the final focus and its acceptance increased slightly. Focussing criteria in the second stage to meet the requirements of Experiment 25 have been determined. The use of sextupoles to reduce second order terms has been analyzed. The effect of these changes (particularly the first) on beam contamination has been carefully studied and it is concluded that the beam will not be hurt by them.

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I. INTRODUCTION

This note updates the design of a tagged photon beam at NAL which was published by a working group representing all proposed NAL experiments which require a tagged photon beam.[1,2] Major and minor modifications of the beam design of the working group report were necessary in three areas. Two of these involved restrictions imposed by the facilities of the Proton Laboratory. The third and most minor area of modification was required to meet the experimental requirements on beam size for Experiment 25.

In the following, we will discuss these modifications and outline the NAL design of the beam as it stands at this point in time. Details of the beam, a schematic drawing and parameter list, may be found in Fig. 1.

II. THE TARGET BOX AND THE PROTON DUMP

Handling of radioactive targets in P-East will follow a basic philosophy that has been worked out for the Proton Laboratory. Targets, dumps and portions of the beam front ends for all P-East experiments will sit on movable drawers that slide in and out of a 40-foot long,

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heavily shielded target box. These drawers may be removed without exposing personnel to radiation by sliding them into a shielded coffin like transporter which can remove one drawer at a time. The system has been designed by Dave Eartly.

The three experiments will be accomodated by use of a splitting magnet located about 80-feet upstream of the targets. When either experiment 87 or 100 are running the proton beam will be bent 6.4 mrad east. When the tagged photon beam is in operation the protons will be bent 6.4 mrad west. The 12.8 mrad split corresponds to about a foot separation in the region of the targets. Fig. 2 is a preliminary design drawing showing the location of elements for the three experiments within the target box. Fig. 3 shows schematically a side view of the front end of the tagged photon beam.

In the original designs of the tagged photon beam it was assumed that the proton beam dump would be located beyond the first quads and that, other than the radiator and the walls of the sweeping magnets, there would be no scattering sources between the primary target and the quads. Location of the dump so far from the target causes a number of serious radiation problems. These include the shielding and handling of an intense 500-GeV proton beam crossing through the thin roofed Proton East Enclosure (EE1) as well as the difficulties associated with having a second hot handling location in the east area of the Proton Lab. For these reasons, unless the future success of the tagged photon beam facility is seriously endangered, the proton dump should be located as close as possible to the primary target and be contained within the target box. We have considered in some detail the effect of this new design of the beam front end and conclude from these considerations that the beam will not be compromised if certain precautions are taken. Summarized below are the results of these calculations. Details are available if requested.

a) Muon Flux at the Experimental Area.

The vertical bending of the sweeping magnets splits the muon distribution into two separated lobes. The magnets dump the positive proton beam down so that positive muons are found in the lower lobe and negative muons in the upper lobe. The degree of splitting is, of course, determined by the strength of the dumping magnets, and the more splitting the cleaner the experimental area which is located between the lobes, 1000 feet downstream. The bending power of the dumping magnets is about 450 kg-ft. Because of the space limitations within the target box this is about 40% lower than in the earlier designs of this facility. It is therefore an obvious worry that the muon fluxes at the experimental area will be higher than before.

We have checked to see how serious this problem becomes by running the same Monte Carlo program that was used before[3] to estimate the muon fluxes taking into account the field and shielding of the new front end. The results confirm that the splitting of the lobes is somewhat reduced but muon fluxes at the experiments even with 10^{13} 500-GeV protons incident/sec are still two or more orders of magnitude below the most stringent requirement of 10^4 muons/m^2 sec.

Since more π^+ are produced than π^- the lower lobe will be more intense than the upper. It is therefore obviously prudent to have the tagging system bend up rather than down.

To protect against the eventuality that these calculations turn out to have been optimistic, we will take the precaution of leaving space to locate "muon spoiler" magnets between the target box and the standard radiator location 75 feet from the target. With these the effective splitting power of the front end with respect to muons can be raised to their former value.

Even though the dump is located nearer the target, muons emanating from this source are still less of a problem than those coming from the target. This results from the facts that less than half as many protons interact in the dump, the protons are heading 9-10 mrad down and away from the beam line, and relatively more pions interact in the dump before they decay than do in the target.

b) The Dump as a Source of Beam Contamination

With the dump located inside the target box, the radiator (at its standard location 75 feet from the target) now follows instead of precedes the dump. One must consider, therefore, how serious a source of hadronic contamination the dump is, both in terms of particles multiply scattering through the dump material and in terms of particles bouncing down the walls of the collimator that passes the photon beam through the dump.

Between 20 and 25 interaction lengths of dump material will be contained within the target box. Additional material will be added following the target box to make at least 30 interaction lengths. About 20 feet of collimators used by the untagged photon beam (Exp. 87) can be shifted to this beam between the target box and radiator to add more shielding. However, it is possible that this material would have an adverse effect on the muon flux at the experimental area by scattering muons out of the lobes into the experiment. The Monte Carlo calculation indicates that this most likely will not be a significant effect. At any rate, assuming 30 interaction lengths the attenuation of hadrons is $e^{-30} \simeq 10^{-13}$, so that even with 10^{13} 500-GeV protons and a 50-GeV beam we cannot expect more than a few hadrons to go all the way through the dump not considering even whether they head for the beam.

The likelihood of a hadron produced in the dump (about 2.5" below the photon beam) rescattering in the walls of the dump collimator and coming out headed for the beam is very low. Two scatters are required and if the particle is not to go through many interaction lengths of material the scattering angle is very large. For example, if the path in the dump is 1 interaction length, the production angle is of the order of 200 mrad. At 100-GeV, $P_{\perp} \simeq$ 20-GeV/c for both scatters. Everything that is presently known about hadronic scattering indicates that cross sections fall very rapidly for large $P_{\perp}$. More detailed arguments using the Hagedorn Ranft model or the experimentally measured $P_{\perp}$ distribution show that the hadronic contamination from sources of this type is indeed low.

Even though any contamination we can think of resulting from locating the radiator behind the dump is very small, at relatively little expense we can provide an alternate location for the radiator in front of the dump. A remote target handler will be located 28-feet from the target immediately after the sweeping magnets. If the contamination turns out to be serious after all, we will have the option of changing the topology of the beam front end with very little effort.

The shorter distance between target and radiator has both advantages and disadvantages. Shortening this distance has the effect of shrinking both the pion and electron apparent spot sizes (see Ref. 1). This will make the spot size at the experimental area smaller, a significant advantage from the standpoint of Experiment 25. It will also strongly reduce any beam losses in second stage magnets which might lead to worrisome halo problems. On the other hand, it will be a little harder to collimate and discriminate against pions to reduce the π/e ratio. TRANSPORT and Monte Carlo calculations indicate that this will amount to a 15% worsening of the π/e ratio.

We have investigated sources of contamination with the radiator at 28-feet. The neutron induced pion rate is the same as before. A new factor is the possibility that protons and pions of both charges produced at certain angles may be swept away from the dump by the sweeping magnets and into the radiator where they may rescatter into the beam. The scattering angles involved here are $\gtrsim$ 10 mrad (the dumping angle) so that $P_{\perp}$ is not as large as in the case we considered earlier. Making use of the experimental $P_\perp$ distribution (assumed valid out to at least 2-GeV/c) and the Hagedorn Ranft production distributions of hadrons in the primary target, we have been able to do a hand calculation integrating over the production angle. Taking into account a Monte Carlo calculation that shows that the beam rejects (to better than 100 to 1) rays with apparent source locations greater than .25 inches, we find that in the worst case (500-GeV protons, 50-GeV beam) the pions resulting from this cause are $< 10^{-6}$ of the expected e^- yield.

In sum, a target handler for the radiator at 28-feet will be a valuable flexibility to include inside the target box.

c) Primary Target Hadrons That Interact in the Walls of the Dump Collimator.

The problem of charged pions swept into the walls of the collimator by the sweeping magnets is very similar to that considered earlier. The result of detailed calculation is that the contribution from this source to the pion component of the beam is also safely less than 10^{-6} of the electron intensity.

Potentially more serious are neutrons interacting in the collimator walls and producing π^- just as in the radiator. The resulting pion intensities are equal or larger than those from the radiator until one takes into account the fact that the resulting pions appear to come from a source outside the acceptance of the beam. If all obstructions are kept outside a region where scatters toward the beam appear to come from sources small enough to be accepted, this effect is reduced by at least 100. Using the Monte Carlo and TRANSPORT determinations of the beam source and angular acceptance at the 1% level we have determined the following envelope which will be obstruction free:

$$|y| < .25 + 5 \times 10^{-4} \text{ z inches}$$

$$|x| < .4 + 1.3 \times 10^{-3} \text{ z inches}$$

Here z is the distance from the target, x is the horizontal coordinate, and y the vertical.

Even outside this limit all surfaces will be lined with a smooth short interaction length material. The smoothness prevents particles from striking a source long enough to produce many secondaries and not long enough to attenuate the secondaries.

In conclusion, it appears that with reasonable care and flexibility this beam will not be hurt by the new front end design. In some cases there will be benefit.

III. MODIFICATIONS TO THE BEAM OPTICS: MOVING THE BENDING MAGNETS

The location of the primary target for the tagged photon beam is determined by the location of the shielded target box which in turn is located near the center of the Proton East Target Hall in order to provide a long enough lever arm to focus and split the external proton beam. The target location in turn determines where the photon beam transport magnets will be. In particular, the bank of bending magnets in the first stage of the working group design would lie in a no-man's land between the end of East Enclosure 1 and the not-yet-constructed pit for Experiment 87 (EE4). These magnets were positioned in the optics as they were because their vertical aperture (1.5-in) limits the beam acceptance. The preceding quadrupole doublet focusses the beam so that as one moves back towards the quads the beam size increases.

The series of bending magnets is now placed inside EE1. See Fig. 1. In order to maintain the beam acceptance, special bending magnets with 2.25-inch gaps will be used. The design of these magnets by Dave Eartly is essentially a modification of the standard 5-1.5-120 dipoles. Two additional coils are added to compensate for the wider gaps.

The bending power is set to obtain essentially the same dispersion at F1 (0.70-inch/%) as in the earlier designs. Five 5-2.25-120 magnets are used with field 13.03 kG at 300-GeV.

The cluster of magnets and collimators around the first focus fit in the northwest corner of the Experiment 87 pit (EE4). Thus with the new bending magnet locations only one new enclosure will be required for this facility. Starting 717-feet from the target a single long thin enclosure will contain the last quadrupole doublet and bending magnets, the tagging system and the experimental area. The first 138-feet of this enclosure is 5-feet wide. This is followed for the next 90-feet by a 10-foot wide area to house the tagging system. Finally, a 130-foot long, 12-foot wide, section is the experimental area that meets the requirements of Experiment 25.

The changes in the first stage of the beam propagated a number of changes in the last stage that have led to some improvement in beam quality and acceptance. In the earlier design there was some chromatic aberration at the final focus. Moving the first set of bending magnets made this a much more serious effect. By adding a dipole to the one already in the region just following F1, it was possible to raise the bending power at this point sufficiently to cancel chromatic aberration completely at the final focus. The first focus and subsequent field lens was moved up 11-feet so that the extra dipole would fit into the corner of the Experiment 87 pit. This in turn necessitated moving the second stage quadrupole doublet which was starting to cut into the acceptance. This doublet was moved up 25-feet so that it is now less of a limit on the acceptance than before, and the final focus was moved up shortening the nominal beam length by 14-feet to 995-feet. The result of this juggling of beam elements is a truly achromatic beam with about a 20% increase in acceptance as calculated by Monte Carlo. Losses in the last stage and the π/e ratio are essentially as before.

IV. MODIFICATIONS TO THE BEAM OPTICS: EXPERIMENT 25 CONFIGURATION

In order to be able to successfully veto the electromagnetic component in the measurement of the total hadronic photoproduction cross-section, it is necessary to maintain a beam spot of less than 1-inch diameter over a distance of 120-feet from the experimental target. For this experiment the target will be located at 950-feet which is 90-feet from the tagging target. The last quadrupole doublet is tuned to about 5% lower field by the condition of minimizing the beam spot from 950-feet to 1075-feet. The actual spot size is strongly dependent on the apparent source size at the primary target. This depends on the beam energy (lower energy means more multiple scattering in the radiator and a larger source) and the radiator location and thickness. At 100-GeV and a .5 r.l. Pb radiator located at 75-feet, second order calculations indicate that 90 - 95% of the beam falls within the required 1-inch diameter. With the radiator at 28-feet virtually the whole beam meets the requirement. The small fraction of the beam which is outside 1-inch (mostly in the horizontal direction at 1075-feet) will be eliminated by limiting the width of the tagging target and by use of a veto shower counter as an active collimator just before the target.

V. MODIFICATIONS TO THE BEAM OPTICS: POSSIBLE USE OF SEXTUPOLES

We can improve the π/e background ratio $\sim$ 15% by using one sextupole to reduce second order effects and minimize the vertical beam size at F1. A vertical collimator is located at F1 and the tighter it can be set around the electron spot the more of the pion halo will be eliminated. A 30-inch long by 4-inch diameter sextupole can be located at the beginning of EE4 (the Experiment 87 pit), a location which is sufficiently far from the focus and in a region of sufficiently large dispersion to be effective. A pole tip field strength of 5.6 kG and a location 404-feet from the target will reduce the vertical beam size at F1 from 0.226 to 0.188-inch. This 17% improvement will only be worthwhile if the pion background turns out to be a serious problem for a future experiment. The configuration has the effect of increasing the spot slightly at the experimental area, so that it will most likely not be used for the first experiment.

An attempt was made to use sextupoles to help reduce the spot size over the length of the first experiment. The sextupole in the first stage was used along with two in the last stage (located in the middle of and immediately following the quadrupole doublet). Because the effect of the sextupoles goes in opposite directions for the various second order terms, it was not possible to significantly improve the minimum spot at the experiment.

VI. ACKNOWLEDGMENTS

Dave Eartly has been responsible for designing the target box and the modified bending magnets. C. Halliwell assisted with the Monte Carlo calculation of the muon flux. I thank D. Carey, J. D. Prentice and A. L. Read for useful discussions.

References

1. C. Halliwell, P. J. Biggs, W. Busza, M. Chen, T. Nash, F. Murphy, G. Luxton, and J. D. Prentice, Design of a Tagged Photon-Electron Facility for NAL, Nuclear Instr. and Methods (to be published). NAL FN-241

2. C. Halliwell, P. J. Biggs, M. Chen, T. Nash, F. Murphy, G. Luxton and J. D. Prentice, Report of the Working Group on a Tagged Photon-Electron Beam Facility for NAL, NAL FN-240, 1972.

3. D. Therriot and K. Lee, private communication.

NATIONAL ACCELERATOR LABORATORY
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TAGGED PHOTON BEAM P2 (PHASE I)

PARAMETER SUMMARY – BEAM DIAGRAM – COORDINATES

30 MAY 1972

PHYSICIST RESPONSIBLE
T. NASH A.L. READ

PRODUCTION TARGET				
Material		Beryllium		
Width		±0.06 in.		
Height		±0.06 in.		
Length (Variable)		35 – 45 cm		
PRODUCTION RADIATOR				
Material		Lead		
Location (Variable)		28 ft.	75 ft	
Width		2.5 cm	7.5 cm	
Height		1.3 cm	3.8 cm	
Length (Variable)		0.0 – 0.6 cm		
PRODUCTION ANGLE				
	θ_p	0.0 – 5.0 mr		
	θ_v	0.0 – 5.0 mr		
	θ_h	0.0 mr		
ENERGY RANGE				
Minimum	E_o min	20 GeV/c		
Maximum	E_o max	300 GeV/c		
ACCEPTANCE				
Solid Angle	$\Delta\Omega$	2.0 μst		
Horizontal Angle	$\Delta\theta_h$	±1.30 mr		
Vertical Angle	$\Delta\theta_v$	±0.48 mr		
Momentum	$\Delta p/p$	±2.2%		
Horizontal Source Size	Δx	±.065 in		
Vertical Source Size	Δy	±.065 in		
PROPERTIES AT DISPERSED FOCUS				
Dispersion	$\frac{\Delta x}{\Delta p/p}$	0.695 in/%		
Momentum Resolution	$\delta p/p$	±0.86%		
Vertical Source Resolution	δy	±0.033 in		
PROPERTIES AT EXPERIMENT (See Note 2)				
Distance from Be Target		950 ft	1000 ft	1075 ft
Horizontal Beam Size	Δx	±0.52 in	±0.49 in	±0.54 in
Vertical Beam Size	Δy	±0.32 in	±0.34 in	±0.49 in
Horiz. Displacement from EPB Axis		20.0 ft	22.2 ft	25.7 ft
Nominal Beam Length		950 ft		
Horizontal Dispersion	$\Delta\theta_h$	0.29 mrad		
Vertical Dispersion	$\Delta\theta_v$	0.30 mrad		

Beam Coord. Z Cent(ft)	Beam Coord. X Cent(ft)	NAL Coord. X Cent(ft)	NAL Coord. Y Cent(ft)	Position Code	Element Code	B(KG) Pole Tip	I(amp)	P(KW)
0.00	0.00	0.00	0.00	P2T1	EPB Target			
28.00	0.00	27.8	-2.92	P2T2A	Alternate Radiator			
34.5	0.00	34.3	-3.60	P2C0	Fixed Collimator 11'			
75.0	0.00	74.6	-7.82	P2T2	Radiator			
101.00	0.00	100.45	-10.53	P2Q1	Quad. 3Q120	-5.809		
112.00	0.00	111.39	-11.68	P2Q2	Quad. 3Q120	-5.809		
128.00	0.00	127.30	-13.35	P2Q3	Quad. 3Q120	4.940		
139.00	0.00	138.24	-14.50	P2Q4	Quad. 3Q120	4.940		
187.5	0.00	186.48	-19.55	P2C1	Hor. Coll. 18" Lead			
196.00	0.01	194.93	-20.43	P2B1	Bend 5-2.25-120	13.03		
207.00	0.05	205.88	-21.54	P2B2	Bend 5-2.25-120	13.03		
218.00	0.14	216.83	-22.60	P2B3	Bend 5-2.25-120	13.03		
229.00	0.27	227.78	-23.61	P2B4	Bend 5-2.25-120	13.03		
240.00	0.45	238.74	-24.59	P2B5	Bend 5-2.25-120	13.03		
				P2P1	Beam Pipe (12" nom.)			
405.21	3.72	403.40	-38.56	P2V1	Vert. Vern. 6-4-30			
504.69	5.69	502.54	-46.98	P2V2	Vert. Vern. 6-4-30			
506.94	5.73	504.78	-47.17	P2M1	Profile Monitor			
508.94	5.77	506.78	-47.34	P2C1	Horiz. & Vert. Col. 24" Lead			
515.94	5.91	513.75	-47.93	P2Q5	Quad. 3Q120	-3.430		
526.94	6.14	524.71	-48.85	P2B6	Bend 5-1.5-120	11.77		
537.94	6.40	535.67	-49.74	P2B7	Bend 5-1.5-120	11.77		
				P2P2	Beam Pipe (12" nom.)			
724.12	11.42	721.36	-64.17	P2V3	Vert. Vern. 6-4-30			
727.62	11.52	724.85	-64.44	P2V4	Horiz. Vern. 6-4-30			
734.87	11.71	732.08	-65.00	P2Q6	Quad. 3Q120	4.289		
745.86	12.01	743.05	-65.85	P2Q7	Quad. 3Q120	4.289		
761.86	12.44	759.00	-67.09	P2Q8	Quad. 3Q120	-4.305		
772.85	12.74	769.97	-67.94	P2Q9	Quad. 3Q120	-4.305		
794.84	13.34	791.90	-69.63	P2B8	Bend 5-1.5-120	12.284		
805.84	13.68	802.87	-70.44	P2B9	Bend 5-1.5-120	12.284		
816.83	14.06	813.84	-71.21	P2B10	Bend 5-1.5-120	12.284		
827.82	14.48	824.82	-71.94	P2B11	Bend 5-1.5-120	12.284		
838.81	14.93	835.80	-72.63	P2B12	Bend 5-1.5-120	12.284		
858.79	15.84	855.76	-73.82	P2M2	Profile Monitor			
859.79	15.88	856.76	-73.88	P2T3	Radiator Tag. Sys.			
869.36	16.32	868.98	-74.60	P2B13	C Mag. (Vert) Tag. Sys.			
876.24	16.63	877.77	-75.12	P2B14	C Mag. (Vert) Tag. Sys.			
882.73	16.92	886.05	-75.61	P2B15	C Mag. (Vert) Tag. Sys.			
949.70	19.97	971.56	-80.66	P2T4	Experimental Target			

NOTES:

1. Entire beam line including tagging system to be under 100 micron vacuum except at radiators and collimators.
2. All vacuum pipes after 510 ft to be 9 in diameter except within elements.
3. Beam parameters calculated assuming ±0.1 in "apparent source" size. This corresponds approximately to a 100 GeV e^- beam with a 0.5 r.l. Pb radiator at 75.0 ft.
4. Beam parameters calculated to second order.
5. Sweeping magnets, alternate radiator and dump shown on target box drawings. Details of tagging system on tagging system drawings.

Bend Point	Beam Coords. Z Cent. (ft)	Beam Coords. X Cent. (ft)	NAL Coords. X Cent. (ft)	NAL Coords. Y Cent. (ft)	Angle (mr)	Total Angle (mr)
3200	0.00	0.00	0.00	0.00	0.00	0.00
3210	218.00	0.14	216.83	-22.60	19.84	19.84
3220	532.44	6.27	530.19	-49.30	7.08	27.01
3230	816.83	14.06	813.84	-71.21	18.71	45.72

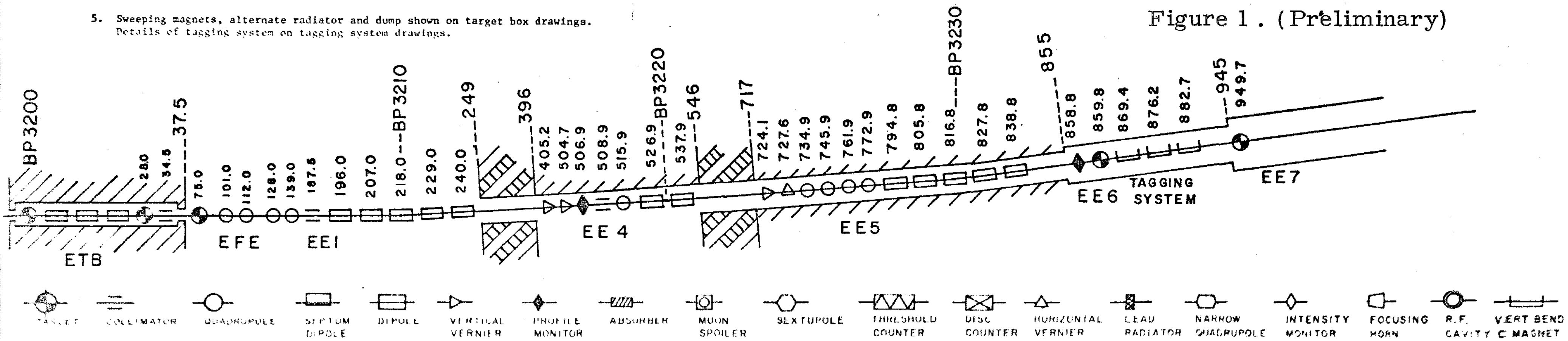

Figure 1. (Preliminary)

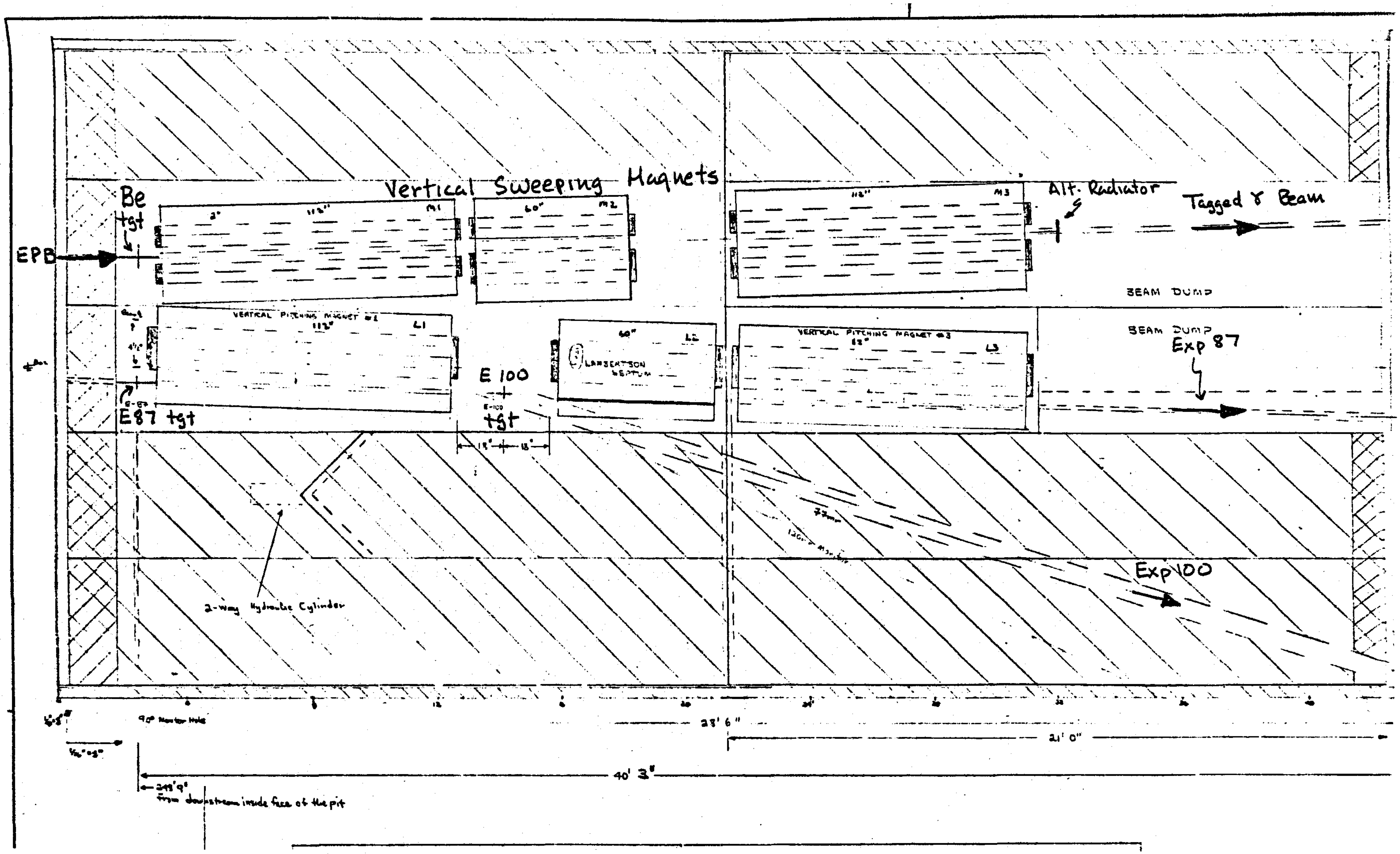

Figure 2. Design Sketch of Proton East Target Box (Top View)

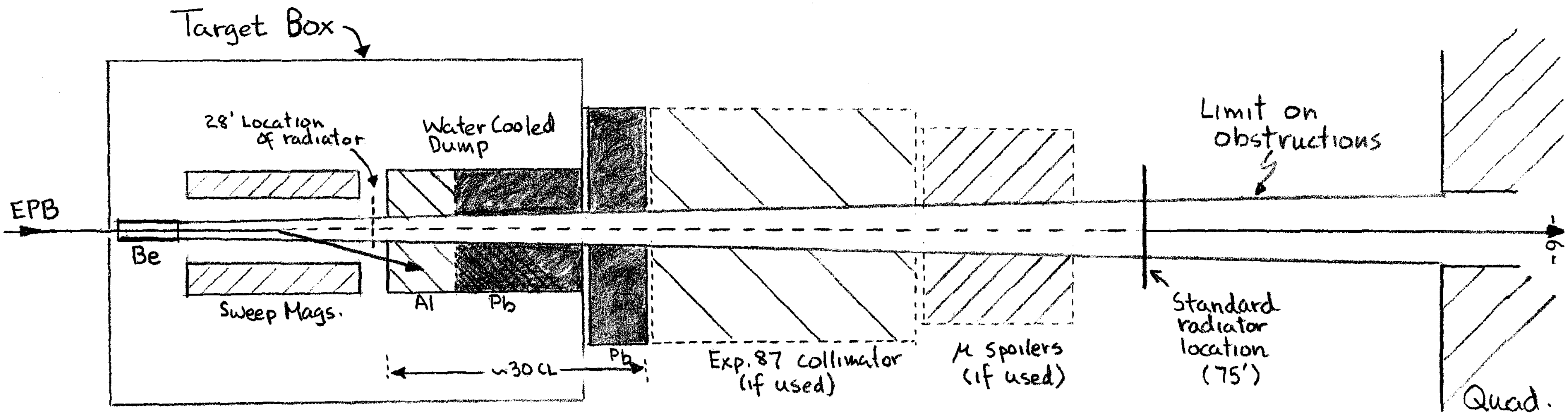

Figure 3. Side View of Tagged Photon Beam Front End (Schematic)