BNL-101599-2014-TECH

RHIC/PG/56;BNL-101599-2013-IR

Internal Fixed Targets For RHIC Foils, Wires And Gas Jets

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May 1984

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U.S. Department of Energy

USDOE Office of Science (SC)

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INTERNAL FIXED TARGETS
FOR RHIC
FOILS, WIRES AND GAS JETS

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Fixed Targets (Gas Jet, Foil or Wire) 4/30/84

We can write the reaction rate $R = \frac{\rho \tau N_A}{A.W_i} I \sigma$ where ρ = target density [g/cm^3], τ = target thickness [cm], N_A is Avogadro's #, A.W. is the gram atomic weight and I is the number of beam particles [sec^{-1}], that is,

$$L_{effective} = \frac{\rho \tau N_A}{A.W.} I \qquad \text{effective fixed target luminosity.}$$

a) Foil target Take a 5 $\mu g/cm^2$ ^{12}C foil. This will self support (standard thin stripper foil for a tandem).

$$L_{eff} = \frac{5\ 10^{-6} \frac{g}{cm^2}\ 6\ 10^{23}}{12\ g/mole}\ 57 \times 10^9 \times 78.197\ 10^3/sec$$
$$= 1.1\ 10^{33}\ cm^{-2}\ sec^{-1}$$

for the canonical gold beam. Realities of supporting such a foil mean it intercepts the entire beam. Take $\sigma = \pi (R_1 + R_2)^2 = \pi\, 1.25^2 (12^{1/3} + 197^{1/3})^2\ fm^2$
$= 3.23$ barns

Then $R = L_{eff}\, \sigma = 3.55 \times 10^9$ /second, or the beam lasts 16 seconds! (Well, that is really a e^{-1} time, but you get the idea!)

b) Gas or Metal Jet Take a 1 nanogram/cm^2 jet of (say) copper. Assume it intercepts the entire beam. Make a metal jet so the stuff does not pollute our laboriously achieved high vacuum.

$$L_{eff} = \frac{10^{-9}\ g/cm^2\ 6.02\ 10^{23}}{63\ g/mole}\ 57 \times 10^9 \times 78,197/sec \qquad \text{(gold again)}$$
$$= 4.3 \times 10^{28}\ cm^{-2}\ sec^{-1}$$

$\sigma_R = 4.7$ barns. Then $R = L_{eff}\, \sigma = 2.0\ 10^5$/sec, or a 1/e time of 78.3 hours. This is fine.

c) Wire Target   Take a 10μ diameter wire (the thinnest I have played with) of copper. Assume the beam emittances, H & V, are 20π mm mrad (normalized, 95%). The density of Cu is 8.9 g/cm³. Then $\sigma_{H,V} = \sqrt{\frac{\epsilon_N \beta^*}{6\pi\beta\gamma}} = 0.88$ mm, using $\beta^* = 25$ m (I want a large, diffuse beam, so take a modest β^*.) and 100 GeV/A ($\gamma = 108.4$)

If we put this wire in the center of the beam, and place it vertically, then it sees the peak density in the horizontal plane and the whole density in the vertical plane. The spatial density in the vertical plane can then be ignored and the particle density given by (x = horizontal)

$$57 \times 10^9 \times 78{,}197/\text{sec} \times \left(\frac{1}{\sqrt{2\pi}\,\sigma} e^{-x^2/2\sigma^2}\right), \quad \sigma = 0.88\text{ mm}$$

with the wire spanning 10μ in x. Then one intercepts a fraction of the beam

$$f = \frac{1}{\sqrt{2\pi}\,\sigma} \underbrace{e^{-0^2/2\sigma^2}}_{1} \cdot 10 \cdot 10^{-3}\text{mm} = 0.00453$$

giving $I_{effective} = I_0 f$, $I_0 = 57 \times 10^9 \times 78{,}197/\text{sec}$

Thus $$L_{eff_{0\sigma}} = \frac{8.9\text{ g/cm}^2 \times 10 \times 10^{-4}\text{cm} \times 6.02\ 10^{23}}{63\text{ g/mole}} \times I_0 f$$

$$= 1.7\ 10^{33}\text{ cm}^{-2}\text{ s}^{-1}$$ which is too large.

If the wire sits at $x = 4\sigma_H$ from the center, $f = \frac{1}{\sqrt{2\pi}\,\sigma} e^{-(4\sigma)^2/2\sigma^2} = 1.52\ 10^{-6}$

and $L_{eff_{4\sigma}} = 5.8 \times 10^{29}\text{ cm}^{-2}\text{s}^{-1}$ Acceptable

At $x = 5\sigma$, $L_{eff_{5\sigma}} = 6.4 \times 10^{27}\text{ cm}^{-2}\text{s}^{-1}$. (If beam is really still gaussian at $x = 5\sigma$!)

Conclusions

a) Use a metalvapor jet of 1 nanogram/cm^2
(ie. 9.5×10^{12} atoms/cm^2 for Copper) intercepting the whole beam.

b) Use a wire of 25μ diameter (1 mil) or less
placed on the periphery of the beam, (or if one wants it centered, consider decreasing the number of bunches or the ions/bunch by a factor 10^4 !). Vibrate or rotate wire for less L_{eff}.

c) Forget about foil targets.

d) You will have luminosities (effective) of $10^{28} - 10^{29}$ $cm^{-2}s^{-1}$

e) Metal vapor jet is to be prefered over gas because of the large pumping Speed needed to clear out gas.
Consider: A supersonic jet at 1000 miles/hour = 44,704 cm/sec of area 1cm x 1mm and density 10^{-8} g/cm^3 (a nanogram/cm^2 for 1mm thick) puts 4.26×10^{17} atoms/sec into the beam line (for a copper jet)
The beampipe is 383384 cm long by 3 cm radius, for a volume of 1.08×10^7 cm^3. At 10^{-11} torr of H_2 (warm) there are 7.05×10^5 atoms/cm^3, or 7.61×10^{12} atoms in the entire beamline.
Then 1 second operation of a jet raises the atom density by $\frac{4.26 \times 10^{17}}{7.61 \times 10^{12}} =$ 56,000 ! if no pumping were added.

(∴ use metal, which condenses when it hits a wall)

Multiple Scattering in a Gas/Metal Vapor Jet

Take 30 GeV/A ^{197}Au hitting a gold vapor jet, where

p = 30.917 GeV/c/A, or total momentum = 6090.6 GeV/c

Multiple coulomb scattering angle is given by

$$\theta_{plane}^{rms} = Z_{projectile} \frac{15\ MeV/c}{p_{\substack{TOTAL\\proj}}\ \beta_{proj}} \sqrt{\frac{\delta_x}{L_R}} \text{ radians, where}$$

δ_x = target thickness in g/cm² and L_R = target radiation length in gm/cm². $Z_{proj} = 79$, $p_{\substack{TOTAL\\proj}} = 6090600$ MeV/c, $L_R = 6.5$ g/cm² for gold and we take $\delta_x = 10^{-9}$ g/cm², as before.

The emittance growth per pass is

$$\Delta\varepsilon = \beta(\theta_{plane}^{rms})^2 \text{, so for } n \text{ passes it is } n(\Delta\varepsilon)$$

In 10 hours the beam makes $10 \cdot 3600 \cdot 78197$/sec passes = 2.82×10^9 passes.

Then $$\Delta\varepsilon_{10\ hours} = 2.82\ 10^9\ (1\text{ meter}) \left[79 \cdot \frac{15\ MeV/c}{6090600\ MeV/c} \sqrt{\frac{10^{-9}\ g/cm^2}{6.5\ g/cm^2}} \cdot \frac{10^3\ mrad}{rad}\right]^2$$

$$= 0.016 * \beta\ (\text{in meters})\ \text{mm-mrad}$$

So even for $\beta = 60$ m (max. arc value), we get only 1 mm mrad emittance growth. We focus to $\beta \leq 7$ m at the target, so there is only ~ 0.1 mm mrad growth.

∴ Not A Problem.

Kinematics, Gold at 30 GeV/A, 100 GeV/A incident on fixed target

$y_{Target} = 0$ both cases y projectile $= 4.1964$ 30 GeV/A $\sqrt{s} = 7.705$
5.3793 100 GeV/A $\sqrt{s} = 13.776$

$y = \frac{1}{2} \ln \frac{E + p_{\parallel}}{E - p_{\parallel}}$

∴ midrapidity (90° cm) = 2.0982 30 GeV/A
2.6896 100 GeV/A

Experiments want especially to be able to cover the central 2 units of rapidity.

Thus for 30 GeV, consider pions and protons travelling at $p_{\perp} = .20$, .40, 1.0, 2.0 and 5.0 GeV/c and having rapidity of 2.0982 ± 1.
We can write also $y = \ln \frac{E + p_{\parallel}}{m_{\perp}}$ where transverse mass $m_{\perp} \equiv \sqrt{m^2 + p_{\perp}^2}$.
Then $p_{\parallel} = m_{\perp} \sinh y$, and $E = m_{\perp} \cosh y$, and $\theta_{lab} = \tan^{-1} \frac{p_{\perp}}{p_{\parallel}}$

Pions (30 GeV/A fixed target) $m_0 = 0.14$ GeV/c²

$p_{\perp}$	$m_{\perp}$	y	$p_{\parallel}$	E	θ_{lab}
0.2	.2441	1.0982	.3253	.407	31.6°
0.4	.424	1.0982	.565	.706	35.3°
1.0	1.010	1.0982	1.346	1.683	36.6°
2.0	2.005	1.0982	2.672	3.341	36.8°
5.0	5.002	1.0982	6.666	8.334	36.9°
10.0	10.001	1.0982	13.328	16.663	36.9°
0.2	.244	3.0982	2.698	2.709	4.24°
0.4	.424	3.0982	4.688	4.707	4.88°
1.0	1.010	3.0982	11.167	11.216	5.12°
2.0	2.005	3.0982	22.168	22.259	5.16°
5.0	5.002	3.0982	55.304	55.530	5.17°
10.0	10.001	3.0982	110.576	111.027	5.17°

Pions (30 GeV/A fixed target) (cont)

$p_\perp$	$m_\perp$	y	$p_\parallel$	E	θ_{lab}
0.2	.244	2.0982	.480	1.009	11.5°
0.4	.424	2.0982	1.702	1.754	13.2°
1.0	1.010	2.0982	4.055	4.179	13.9°
2.0	2.005	2.0982	8.049	8.295	14.0°
5.0	5.002	2.0982	20.080	20.694	14.0°
10.0	10.001	2.0982	40.148	41.375	14.0°

Protons (30 GeV/A fixed target) $m_0 = .9383$ GeV/c^2

$p_\perp$	$m_\perp$	y	$p_\parallel$	E	θ_{lab}
0.2	.959	1.0982	1.278	1.598	8.89°
0.4	1.020	1.0982	1.359	1.699	16.4°
1.0	1.371	1.0982	1.827	2.284	28.7°
2.0	2.209	1.0982	2.944	3.680	34.2°
5.0	5.087	1.0982	6.779	8.476	36.4°
10.0	10.044	1.0982	13.385	16.734	36.8°
0.2	.959	3.0982	10.603	10.646	1.08°
0.4	1.020	3.0982	11.278	11.324	2.03°
1.0	1.371	3.0982	15.158	15.220	3.77°
2.0	2.209	3.0982	24.424	24.523	4.68°
5.0	5.087	3.0982	56.244	56.474	5.08°
10.0	10.044	3.0982	111.051	111.504	5.15°
0.2	.959	2.0982	3.850	3.968	2.97°
0.4	1.020	2.0982	4.095	4.220	5.58°
1.0	1.371	2.0982	5.504	5.672	10.3°
2.0	2.209	2.0982	8.868	9.139	12.7°
5.0	5.087	2.0982	20.421	21.045	13.4°
10.0	10.044	2.0982	40.321	41.553	13.9°

Pions (100 GeV/A, fixed target) $m_0 = 0.14$ GeV/c^2

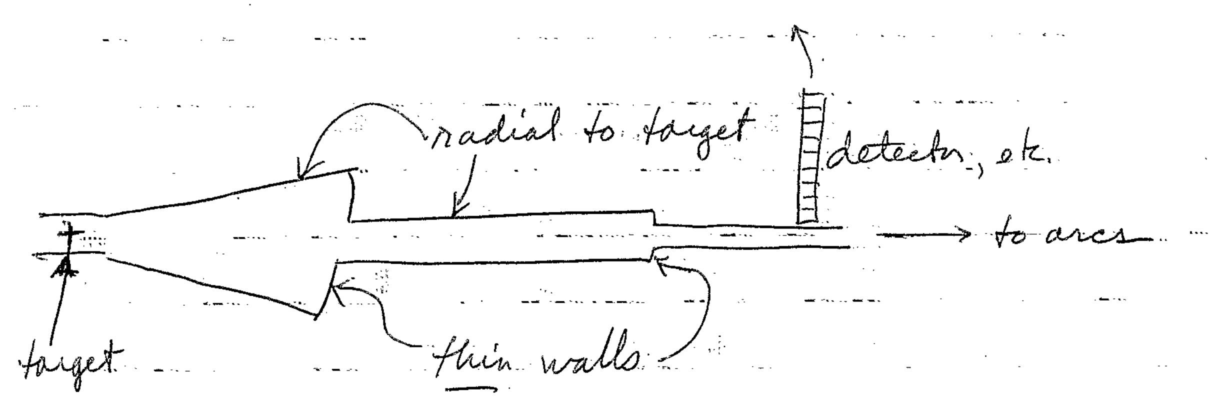
$p_\perp$	$m_\perp$	y	$p_\parallel$	E	θ_{lab}
0.2	.244	1.6896	.638	.683	17.4°
0.4	.424	"	1.109	1.187	19.8°
1.0	1.010	"	2.643	2.829	20.7°
2.0	2.005	"	5.246	5.616	20.9°
5.0	5.002	"	13.087	14.010	20.9°
10.0	10.001	"	26.166	28.012	20.9°
0.2	.244	2.6896	1.788	1.805	6.38°
0.4	.424	"	3.107	3.136	7.27°
1.0	1.010	"	7.402	7.471	7.69°
2.0	2.005	"	14.695	14.831	7.75°
5.0	5.002	"	36.659	36.999	7.77°
10.0	10.001	"	73.297	73.976	7.77°
0.2	.244	3.6896	4.880	4.886	2.35°
0.4	.424	"	8.481	8.492	2.70°
1.0	1.010	"	20.202	20.227	2.83°
2.0	2.005	"	40.104	40.154	2.85°
5.0	5.002	"	100.050	100.175	2.86°
10.0	10.001	"	200.089	200.289	2.86°

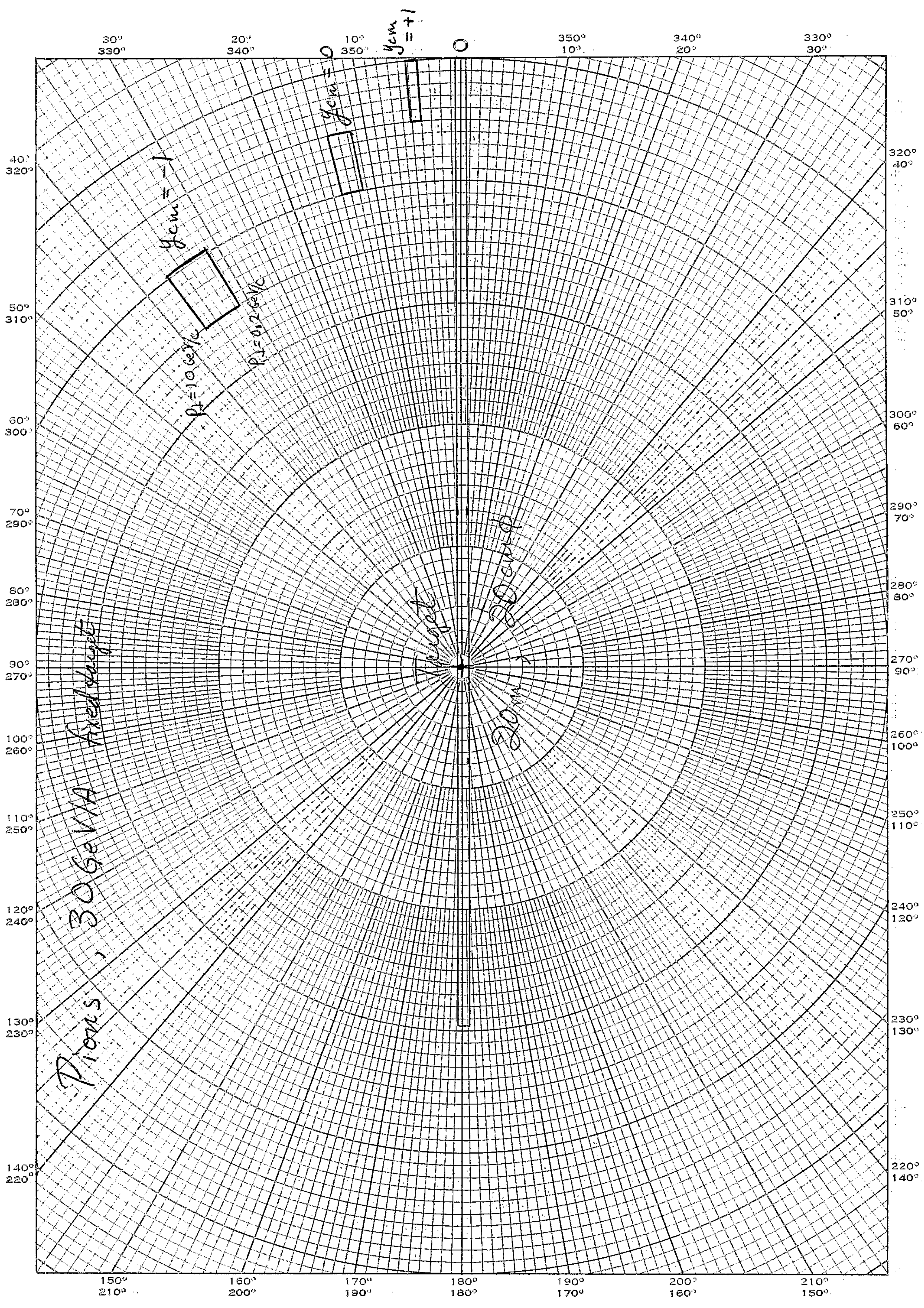
Protons (100 GeV/A, fixed target) $m_0 = 0.9383\ \mathrm{GeV}/c^2$

$p_\perp$	$m_\perp$	y	$p_\parallel$	E	θ_{lab}
0.2	.959	1.6896	2.509	2.686	4.56°
0.4	1.020	"	2.669	2.857	8.52°
1.0	1.371	"	3.587	3.840	15.6°
2.0	2.209	"	5.780	6.188	19.1°
5.0	5.087	"	13.309	14.248	20.6°
10.0	10.044	"	26.279	28.133	20.8°
0.2	.959	2.6896	7.028	7.093	1.63°
0.4	1.020	"	7.476	7.545	3.06°
1.0	1.371	"	10.048	10.141	5.68°
2.0	2.209	"	16.190	16.340	7.04°
5.0	5.087	"	37.282	37.627	7.64°
10.0	10.044	"	73.612	74.294	7.74°
0.2	.959	3.6896	19.182 ~~38.364~~	19.206 ~~[illegible]~~	0.597° ~~[illegible]~~
0.4	1.020	"	20.402	20.427	1.12°
1.0	1.371	"	27.423	27.457	2.09°
2.0	2.209	"	44.184	44.239	2.59°
5.0	5.087	"	101.750	101.877	2.81°
10.0	10.044	"	200.899	201.150	2.86°

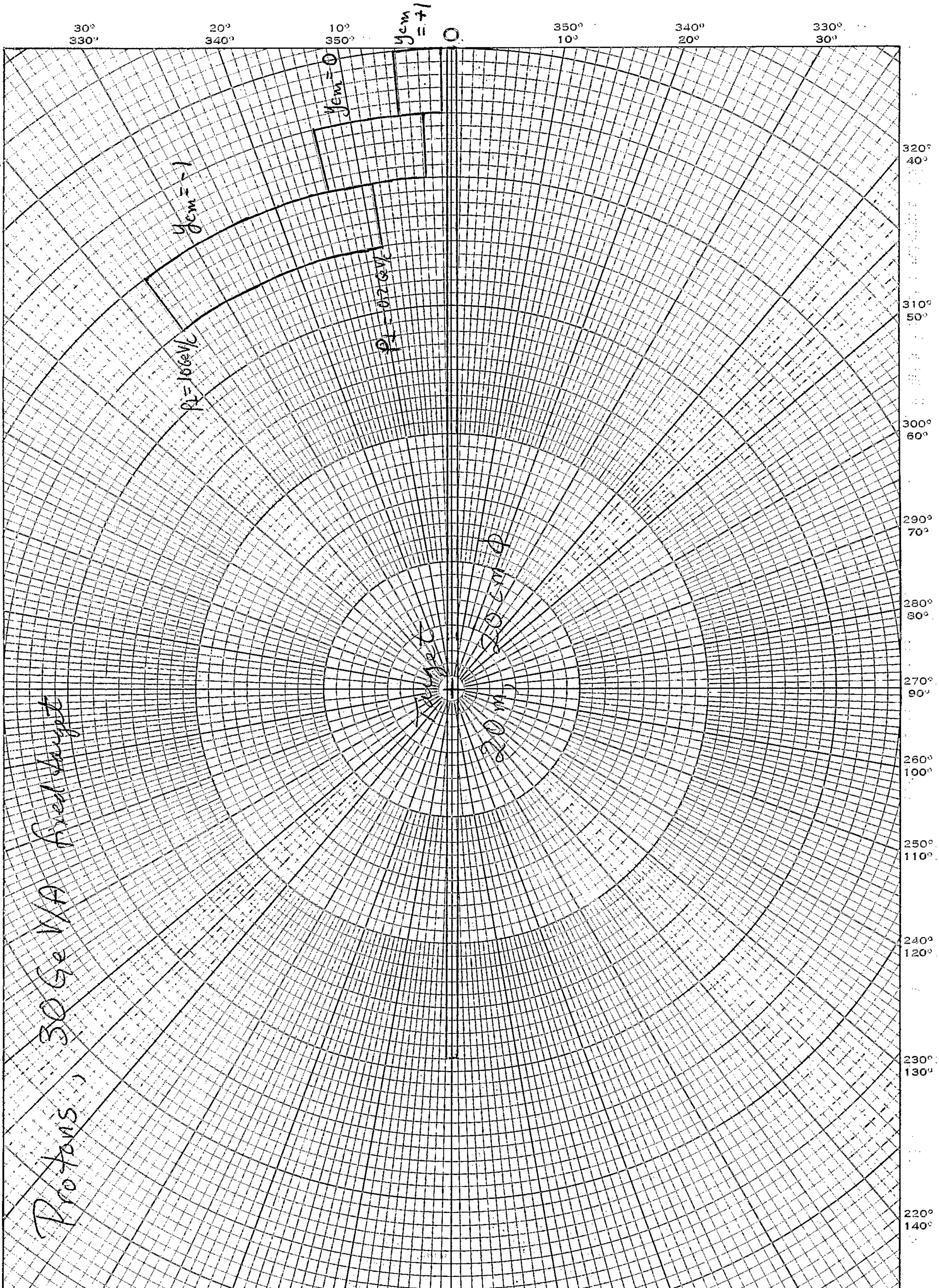
Attached graphs show the range of angular positions of pions and protons emitted at $y_{center\,of\,mass} = -1, 0$ and $+1$ for collisions at 30 and 100 GeV/A. The inner and outer angular positions correspond to $p_\perp = 0.2$ and 10.0 GeV/c, respectively. The radial positions are just for drawing convenience, though for the $y_{cm} = +1$ group they can be used to get an idea of the target to detector distances needed to be a given distance from the beam pipe. The thin rectangular box shows a 20 m pipe, 20 cm in diameter (which is much larger than an expected beam pipe) with the target 7½ m from the upstream end. Then a detector 11½ m away (the position of the $y_{cm} = +1$ box) could be ≥10 cm from the beam axis with its active area.

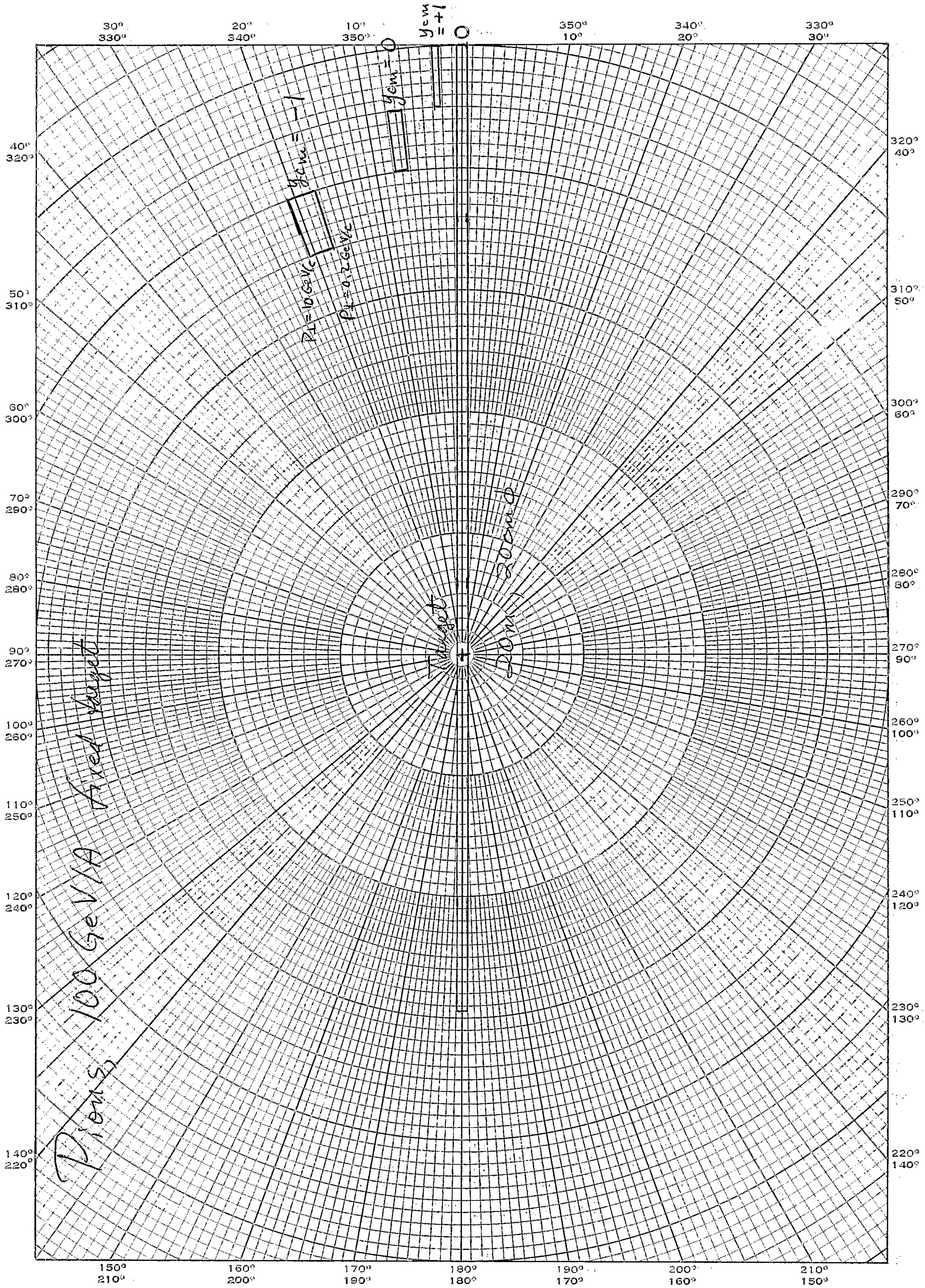
In reality, beam pipes would look like:



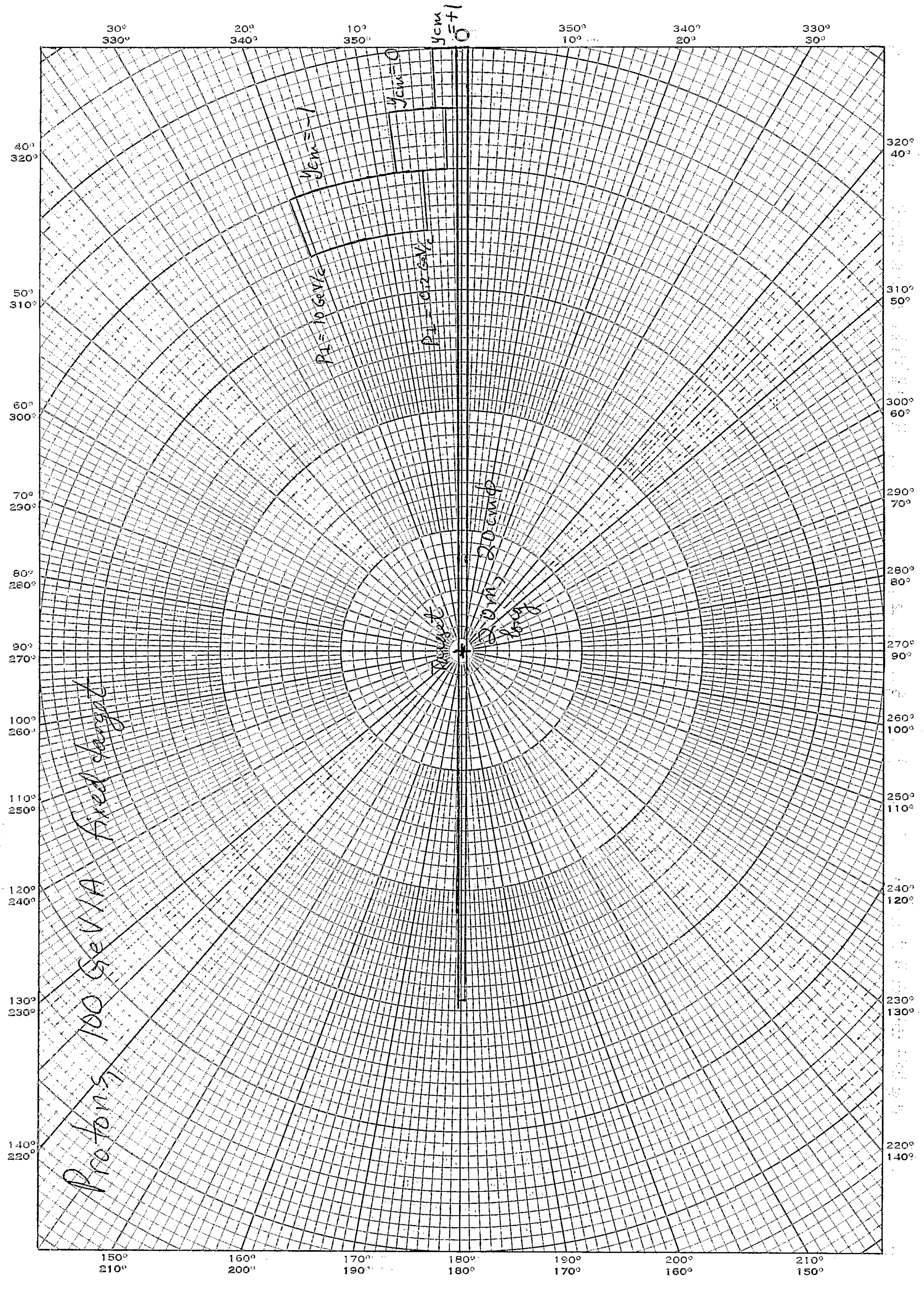


0
$y_{cm} = +1$
$y_{cm} = 0$
$y_{cm} = -1$
$p_\perp = 1.0$ GeV/c
$p_\perp = 0.2$ GeV/c
Target
20 cm
20 cm
Pions, 30 GeV/A Fixed target


$y_{cm} = +1$
$y_{cm} = 0$
$y_{cm} = -1$
$p_\perp = 0.2$ GeV/c
$p_\perp = 1.0$ GeV/c
0
Target
20 m
20 cm Φ
Protons, 30 GeV/A fixed target



Dions 100 GeV/A Fixed target
Target
200m
$y_{cm} = +1$
$y_{cm} = 0$
$y_{cm} = -1$
$p_\perp = 1.0$ GeV/c
$p_\perp = 0.2$ GeV/c



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