Penta-Quark 2003 Workshop
Jefferson Lab, Newport News, Virginia 23606
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On the possibility of producing and measuring the spin and parity of the Θ^+ using slow extraction beam at AGS / BNL

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Two – Body Reactions

$$k^{+}\,\mathrm{d} \rightarrow \Theta^{+}\;\mathrm{p}$$

$$k^{+}\,\mathrm{p} \rightarrow \Theta^{+}\;\pi^{+}$$

$$\pi^{-}\,p \rightarrow \Theta^{+}\;\mathrm{k}^{-}$$

Why these Two – Body Reactions ?

Large production cross sections relative to these for electromagnetic processes.

W. Liu and C.M. Ko : ~1 mb

Photoproduction: less than 100 nb

$1:10^4$

The current world data base: **~ 200 events.**

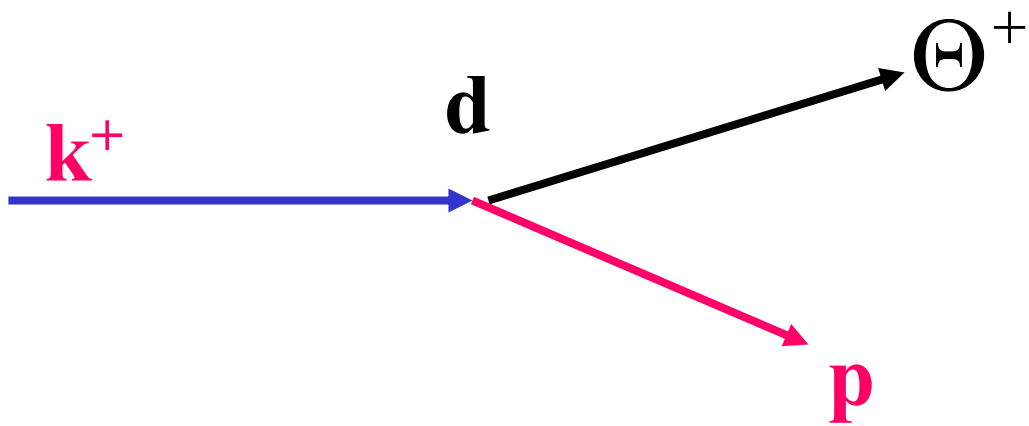
CLASS / TJNAF new approved proposal: **800 events / 400 Hr.**

Hall A , to be proposed : **100 events / day .**

At BNL 1 mb production yield: **hundreds of events per hour.**

Why these Two – Body Reactions (cont.) ?

A measurement of a single particle momentum (pion or proton) determines the mass of the theta.

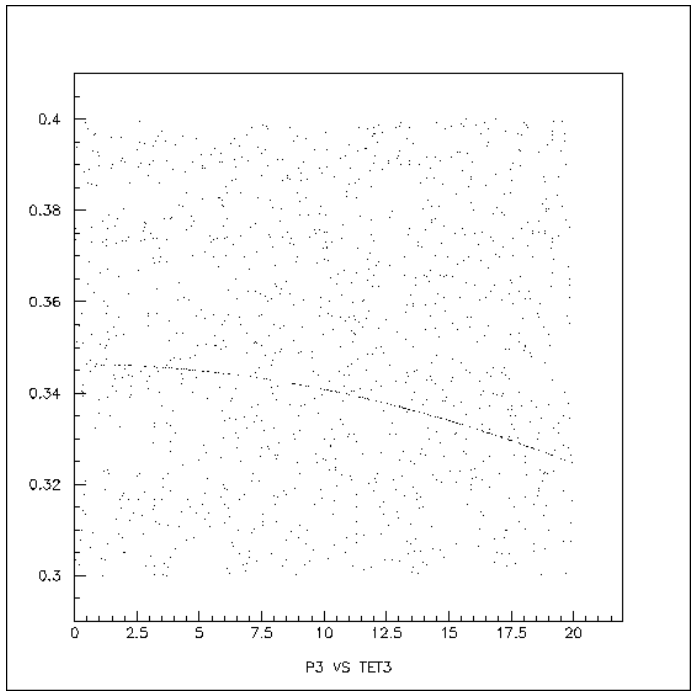


$$k^+ \, \mathrm{d} \rightarrow \Theta^+ \; \mathrm{p}$$

Why these Two – Body Reactions (cont.) ?

A clear signal due to the two – body kinematical correlation between the production angle and momentum.

The proton momentum [GeV/c]



The proton detection angle [deg.]

Simulation with:

1 mb $k^+ \, d \rightarrow \Theta^+ \, p$

30 mb $k^+ \, d \rightarrow k^+ \, n \, p$

$P_k = 450$ MeV/c

Why these Two – Body Reactions (cont) ?

The parity and spin of the theta can be determined by the angular distribution of the outgoing detected particle.

$$k^+ \, \mathrm{d} \rightarrow \Theta^+ \, \mathrm{p}$$

Intrinsic parity: - + + (?) +

$\Delta L = \mathrm{I_f} - \mathrm{I_i}$ Must be odd if the initial and final states have opposite parity.

$$\Delta L = 1, 3, 5 \ldots.$$

$$k^+ \, \mathrm{d} \rightarrow \Theta^+ \, \mathrm{p}$$

Spin: 0 1 1/2 (?) 1/2

1 $\frac{1}{2} + \frac{1}{2} = 1, 0$

$$\boxed{\theta^+ = \frac{1}{2}^+ \Rightarrow \Delta L = 1}$$

$$k^+ \, p \rightarrow \Theta^+ \quad \pi^+$$

Intrinsic parity: - + + (?) -

$\Delta L = I_f - I_i$ Must be even if the initial and final states have same parity.

$$\Delta L = 0, 2, 4 \ldots.$$

$$k^+ \, p \rightarrow \Theta^+ \quad \pi^+$$

Spin: 0 1/2 1/2 (?) 0

1/2 1/2

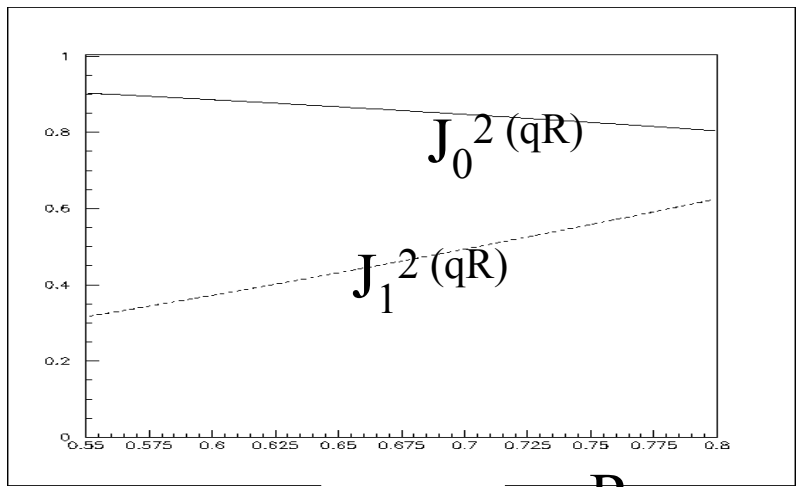
$$\boxed{\theta^+ = 1/2^{\,+} \Rightarrow \Delta L = 0}$$

Why these Two – Body Reactions (cont) ?

$\Delta L = I_f - I_i$ determined the angular distribution.

The parity and spin of the theta can be determined by the angular distribution of the outgoing detected particle.

Plane wave approximation



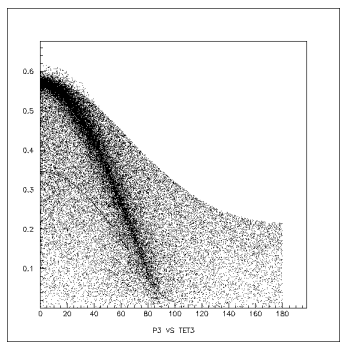
qR

R=1fm

What incident momentum to choose?

	threshold [MeV/c]	Threshold for extra pion production (k n π x) [MeV/c]
$k^+ d \rightarrow \Theta^+ p$	400	460
$k^+ p \rightarrow \Theta^+ \pi^+$	760	820
$\pi^- p \rightarrow \Theta^+ k^-$	1720	1790

At 600 MeV/c the θ's are produced at rest.



Maximize the production cross section.

Allow separation from QE events.

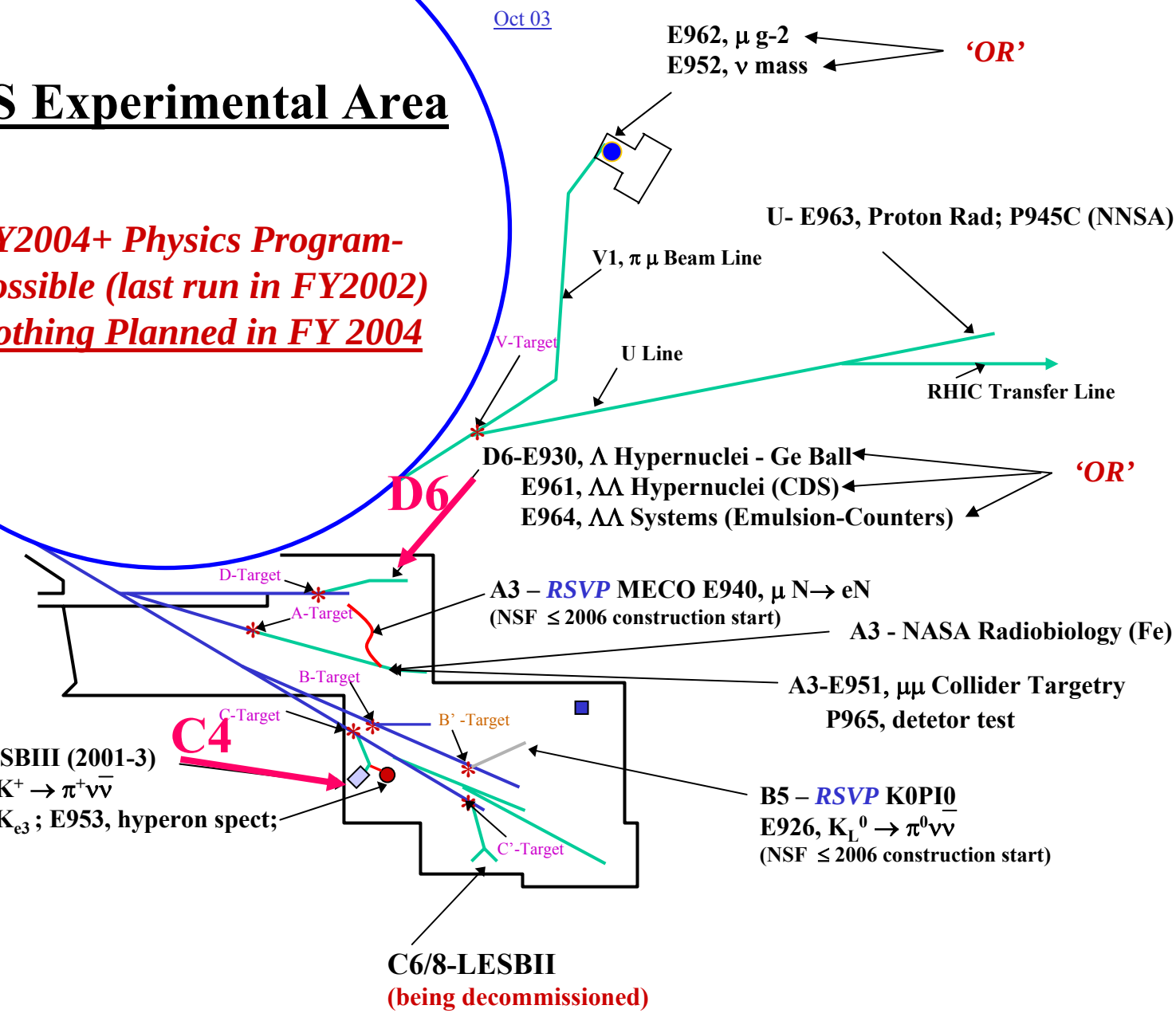
Enough energy to the outgoing particles.

Angular distribution range sensitive to the theta quantum numbers.

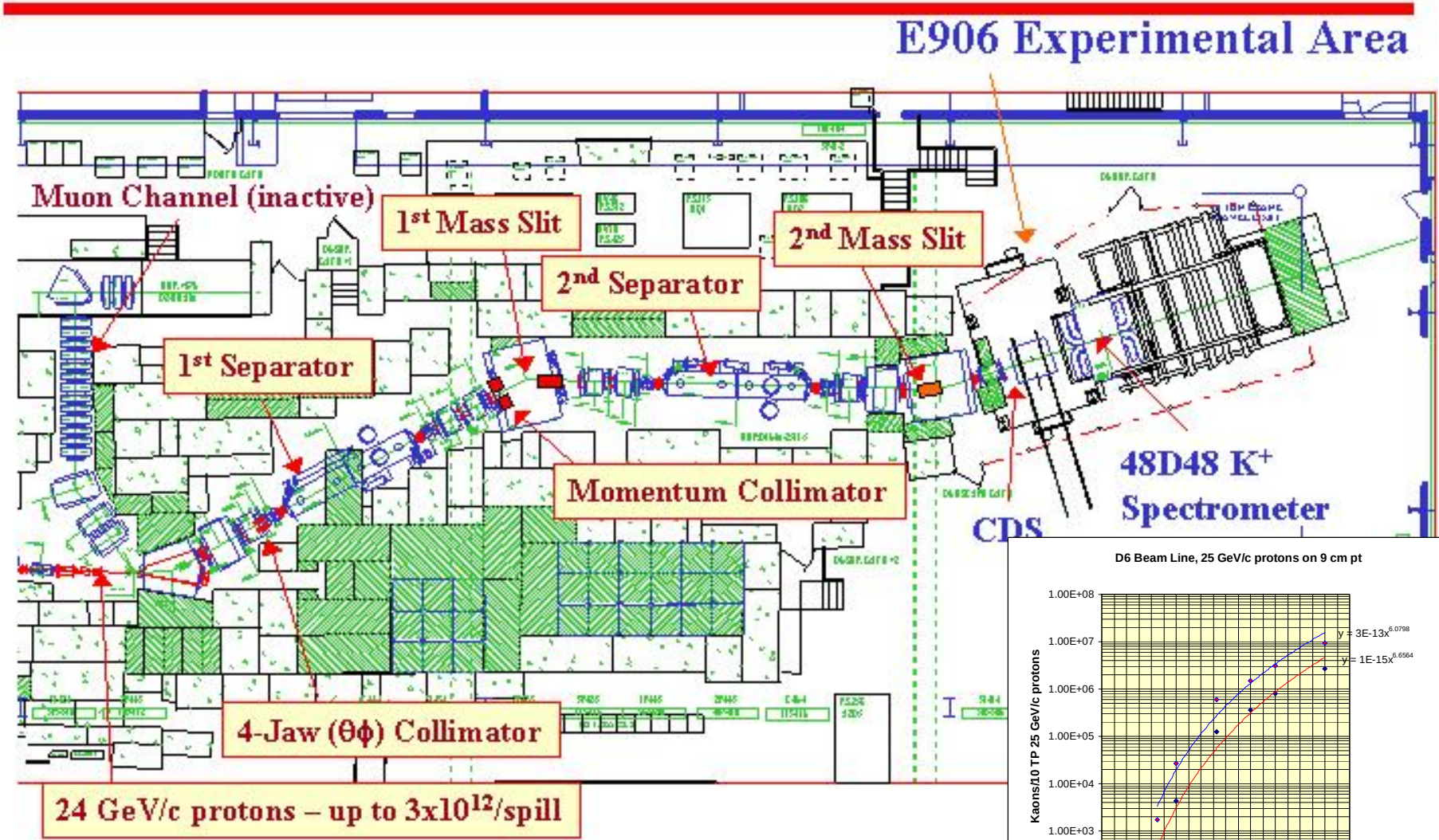
AGS Experimental Area

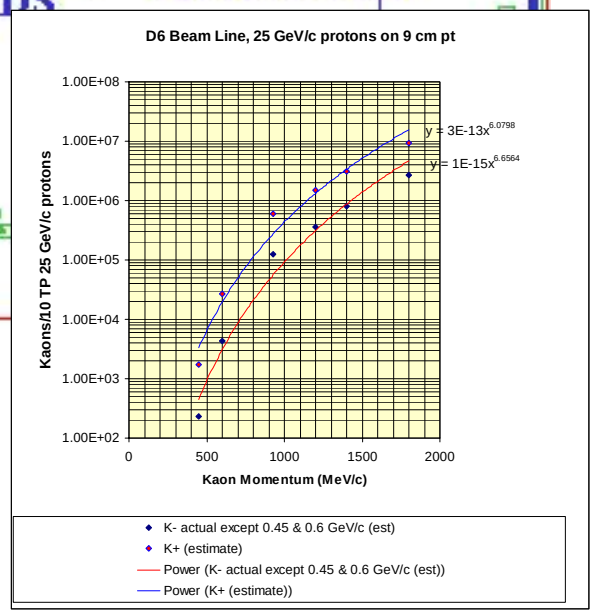
Oct 03

FY2004+ Physics Program-
Possible (last run in FY2002)
Nothing Planned in FY 2004

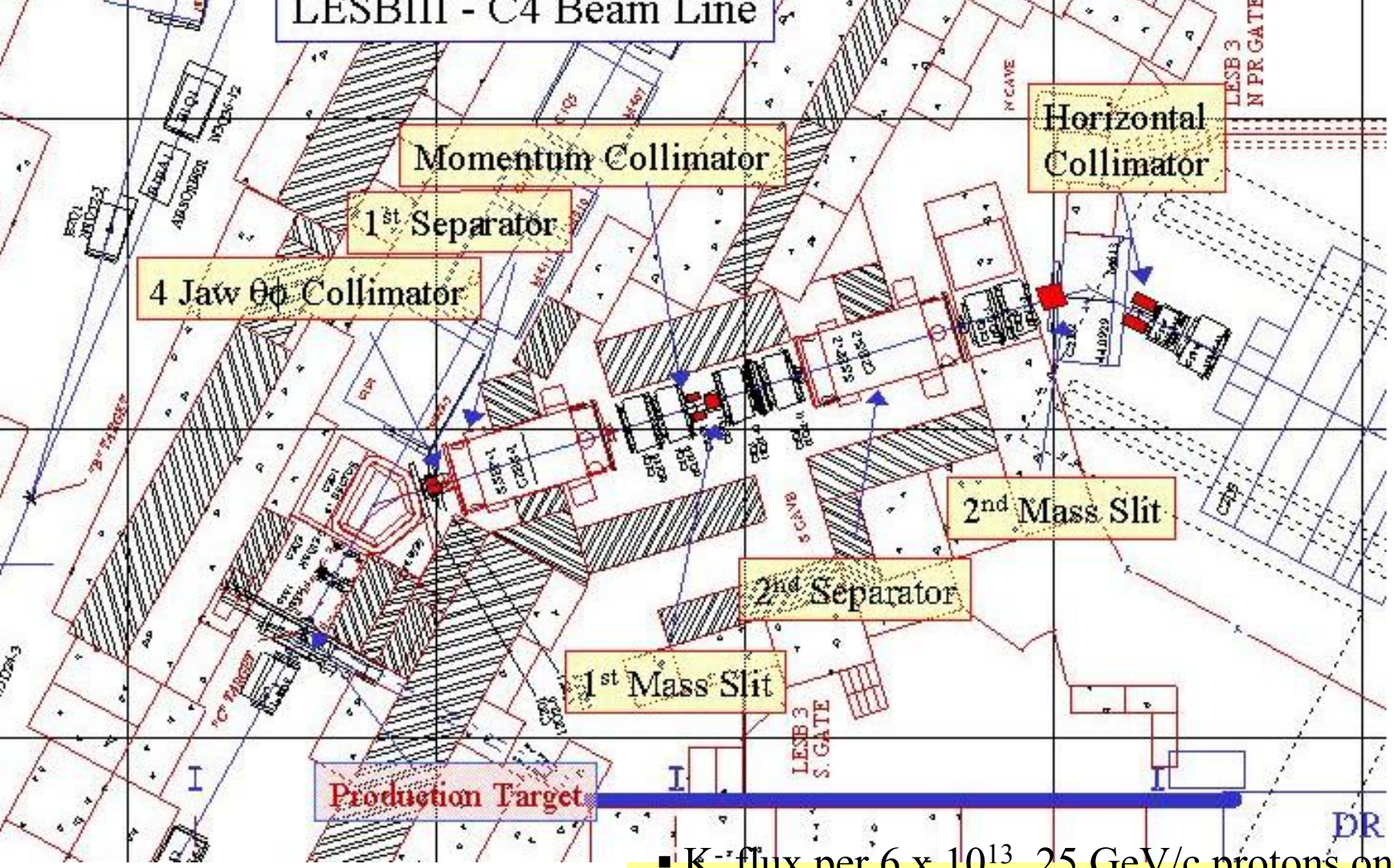


D6 Beam Line and Experimental Area





- Maximum Momentum:1900 MeV/c
  2 Stage Separation, 3rd order optics, special collimators
  Length: 31.6 meters



- Maximum Momentum: 830 MeV/c

2 Stage Separation, 3rd order optics, special collimators

Length: 19.6 meters

- K^- flux per 6 x 10^{13}, 25 GeV/c protons on 6 cm Pt target

Particle	Momentum	Flux
• K^+	800 MeV/c	3.0 x 10^7
• K^+	stopping	6.0 x 10^6

Summary:

We propose a "second generation" experiment that can provide a strong signal of the theta and information on the spin and parity of the state.

Large production cross sections relative to these for electromagnetic processes.

A measurement of a single particle momentum (pion or proton) determines the mass of the theta.

A **clear signal** due to the two – body kinematical correlation between the production angle and momentum.

The **parity and spin of the theta can be determined** by the angular distribution of the outgoing detected particle.

AGS/BNL is a natural place to exploit the Θ^+

- ✓ Beam lines and target are available
- ✓ A spectrometer is available for the D6 beam line, one could be configured for the LESBIII beam line
- ✓ No major equipment development is necessary
- ✓ As far as equipment and manpower is concern, these measurements can be done in early 2004 in the D6 beam line, some work required to be able to use LESBIII

- ❑ ***Problem:***
  - ➢ **to get BNL / DOE to support an AGS fixed target experiment**
  - ➢ **Anticipated budget problems are severe in FY 2004. There are 11 AGS fixed target NP and HEP experiments on the books with little hope of running**

Only an exceptional strong support from a large community for a measurement with a very compelling physics potential might lead to positive response

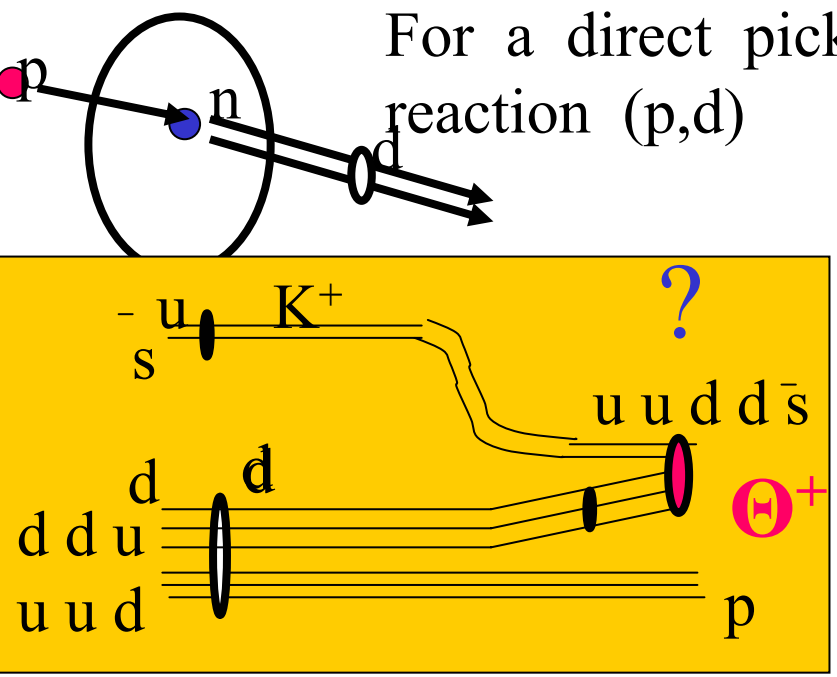
The end

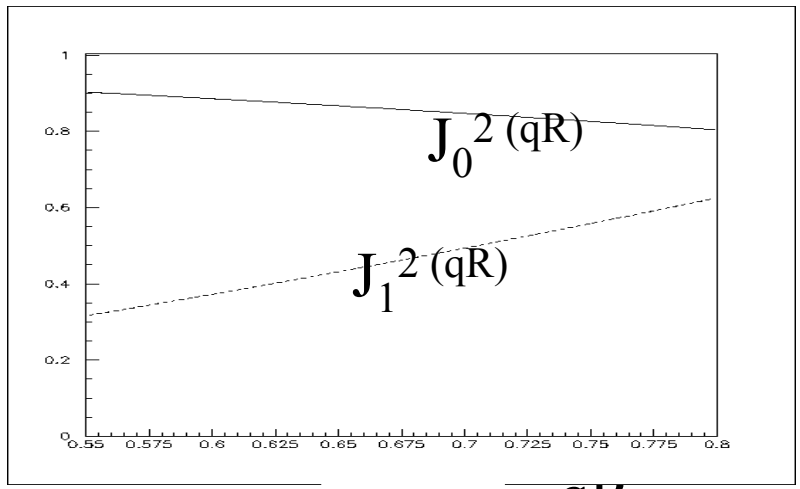
Why these Two – Body Reactions (cont) ?

$\Delta L = I_f - I_i$ determined the angular distribution.

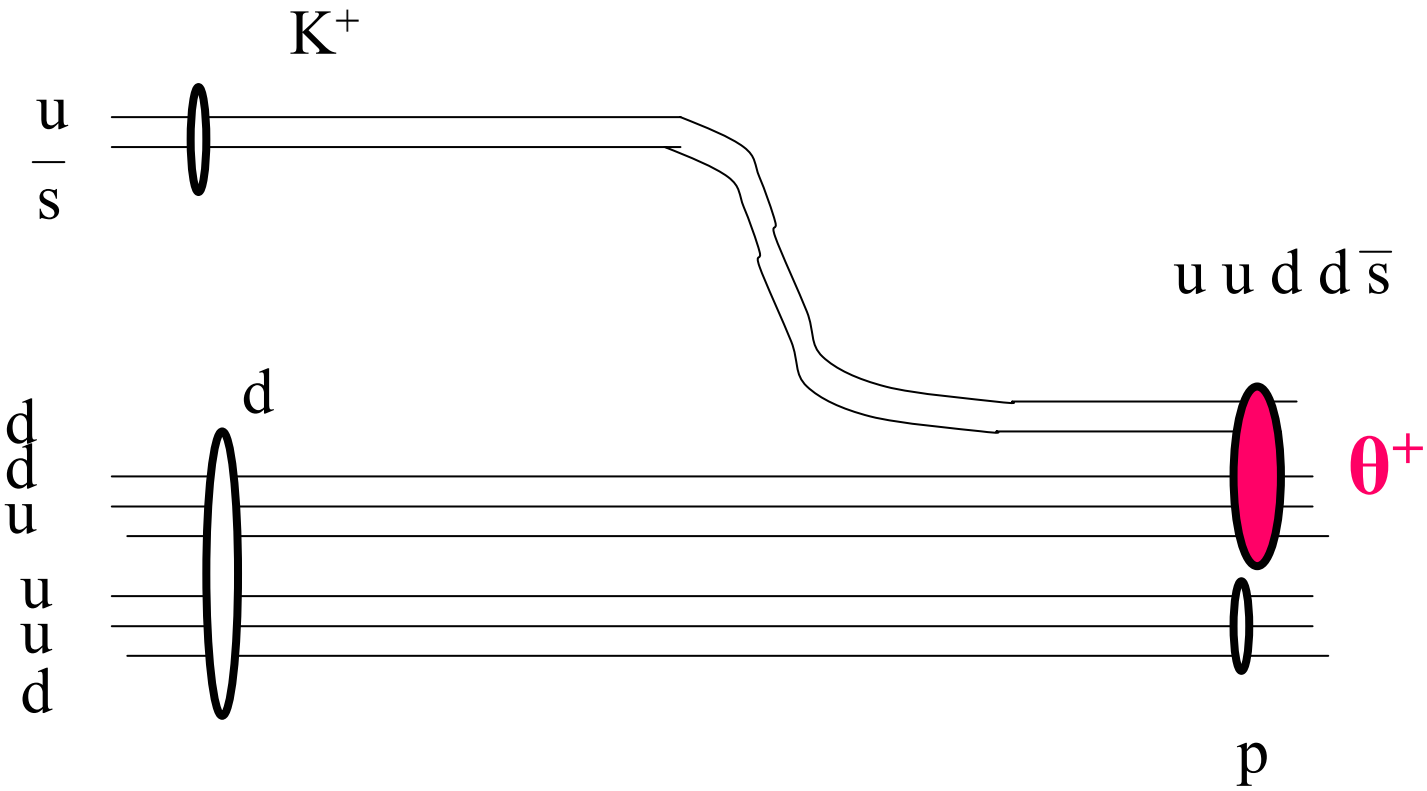
The parity and spin of the theta can be determined by the angular distribution of the outgoing detected particle.

For a direct pickup reaction (p,d)

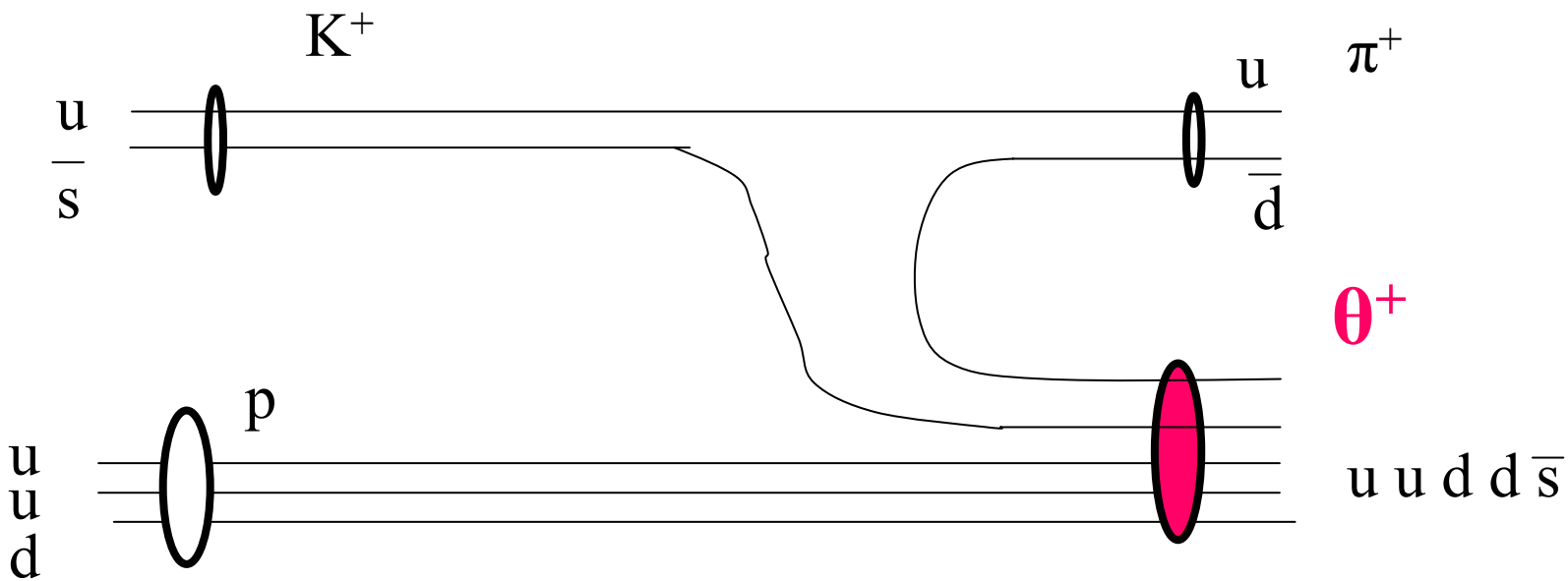


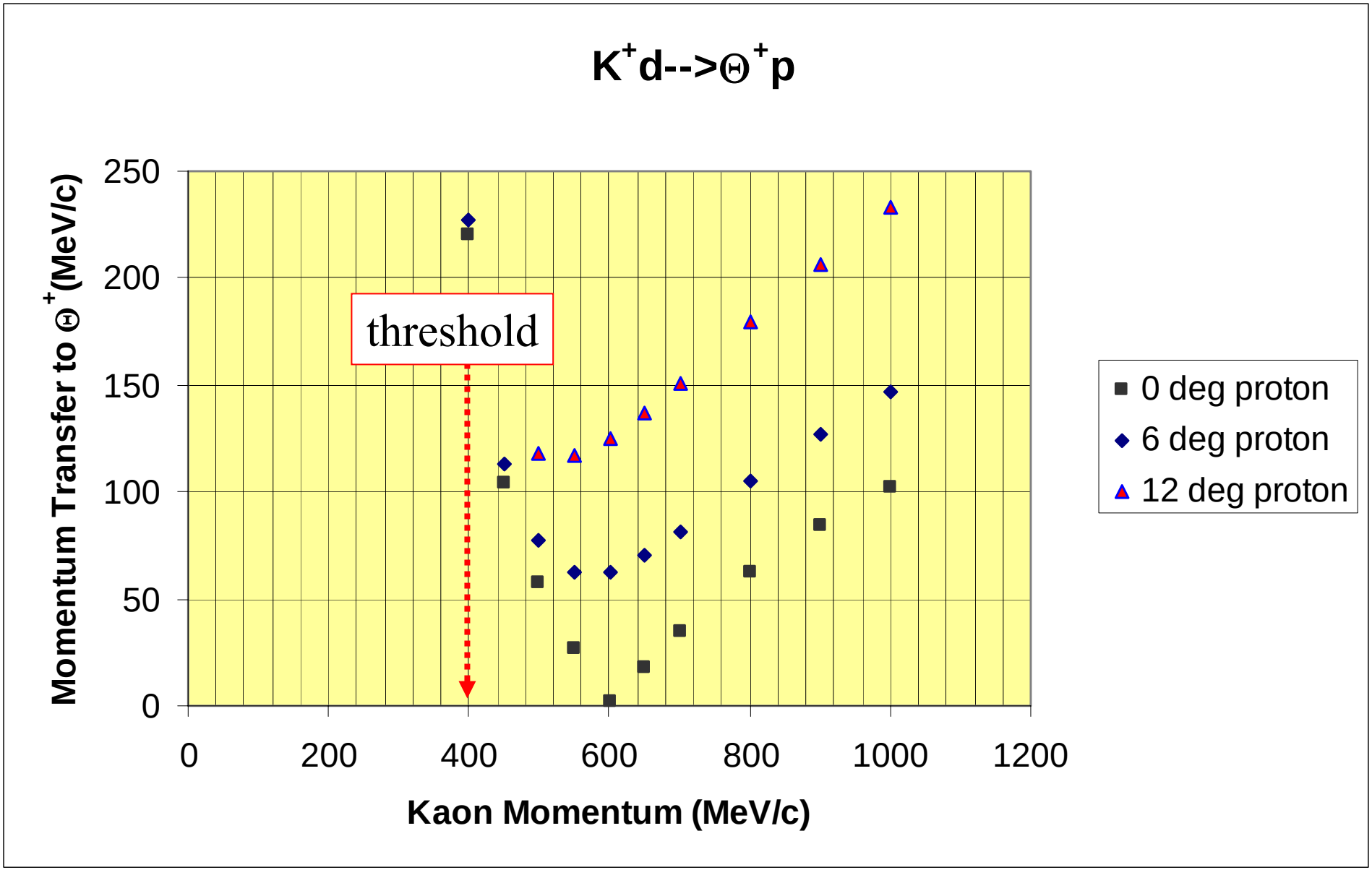


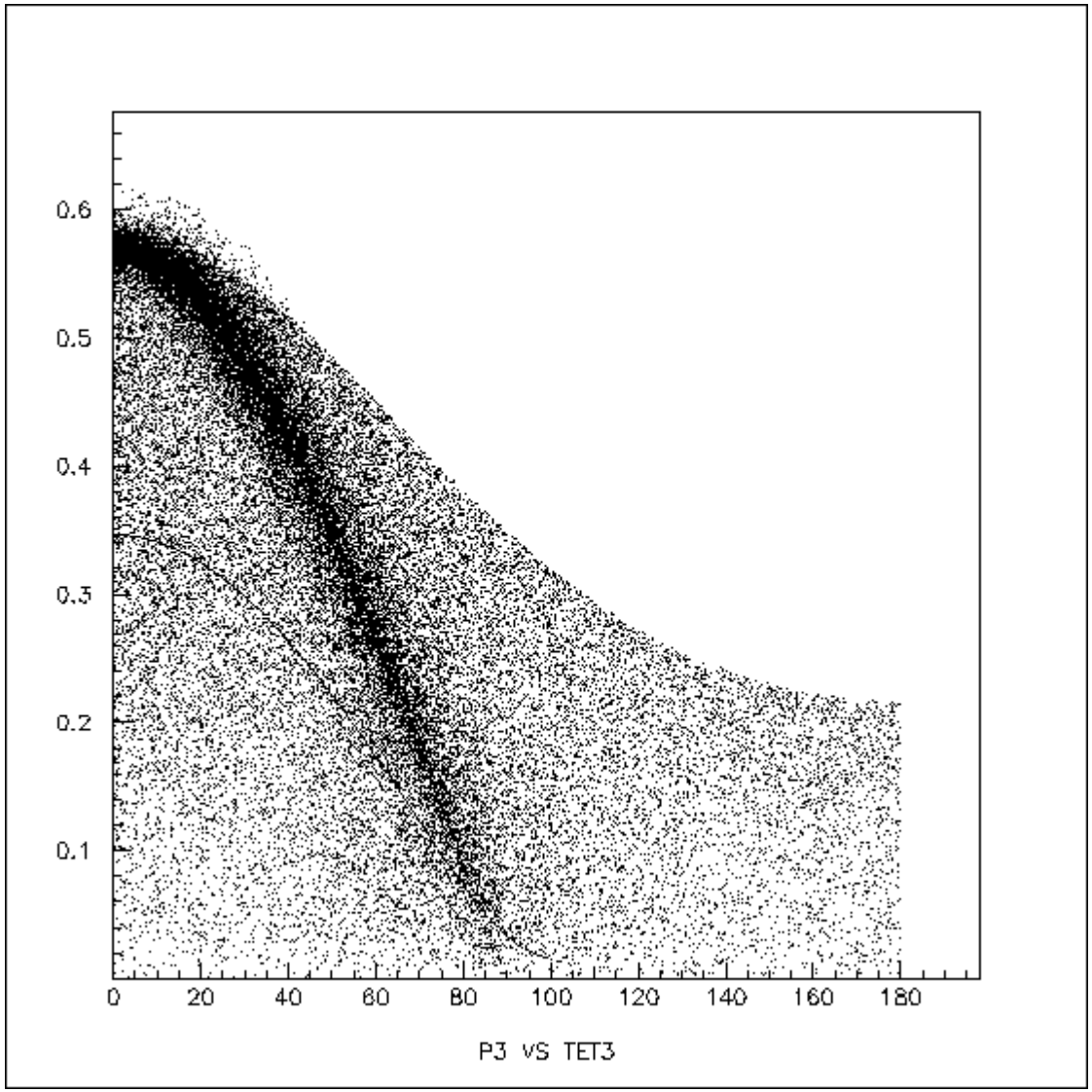
$$k^+ \, d \rightarrow \Theta^+ \; p$$

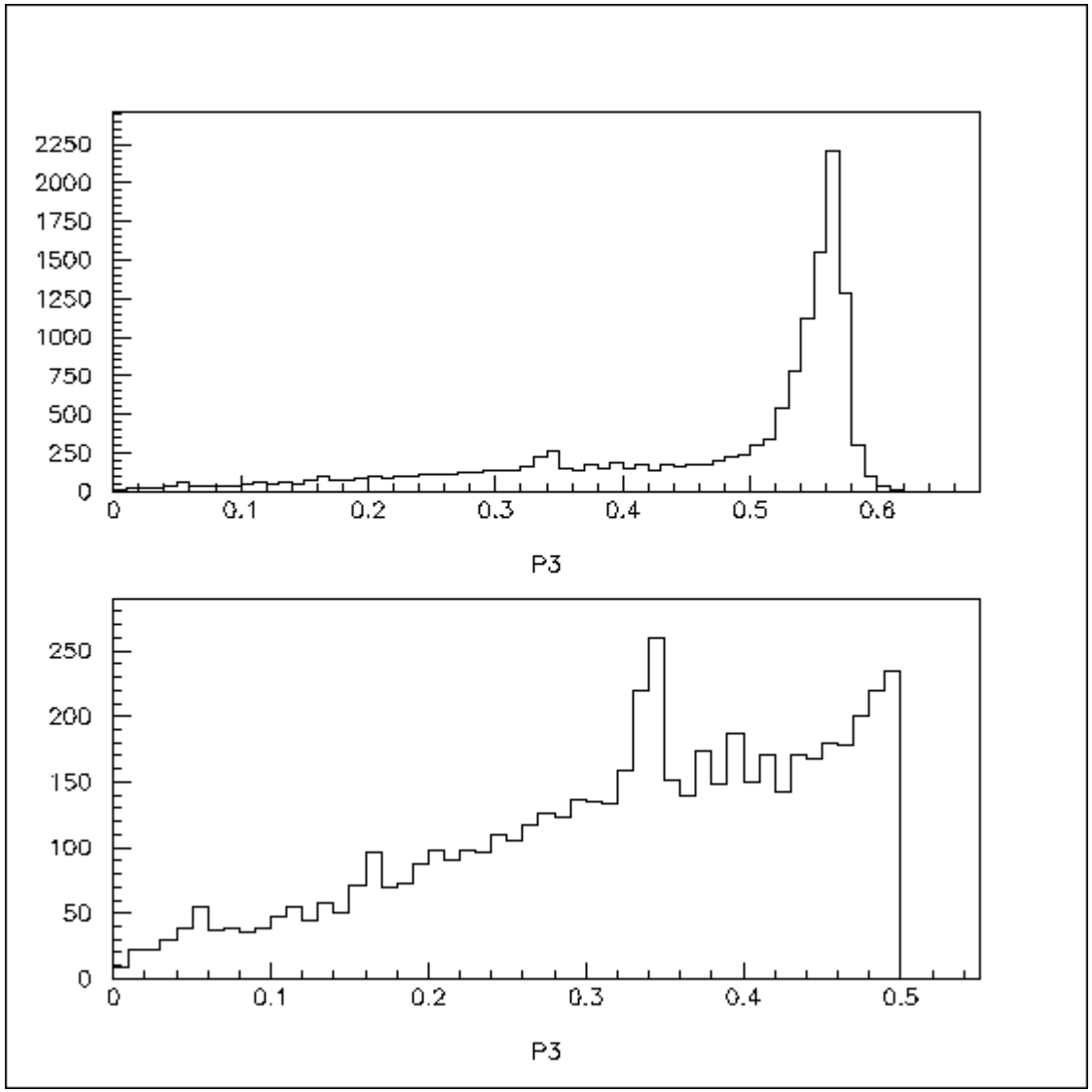


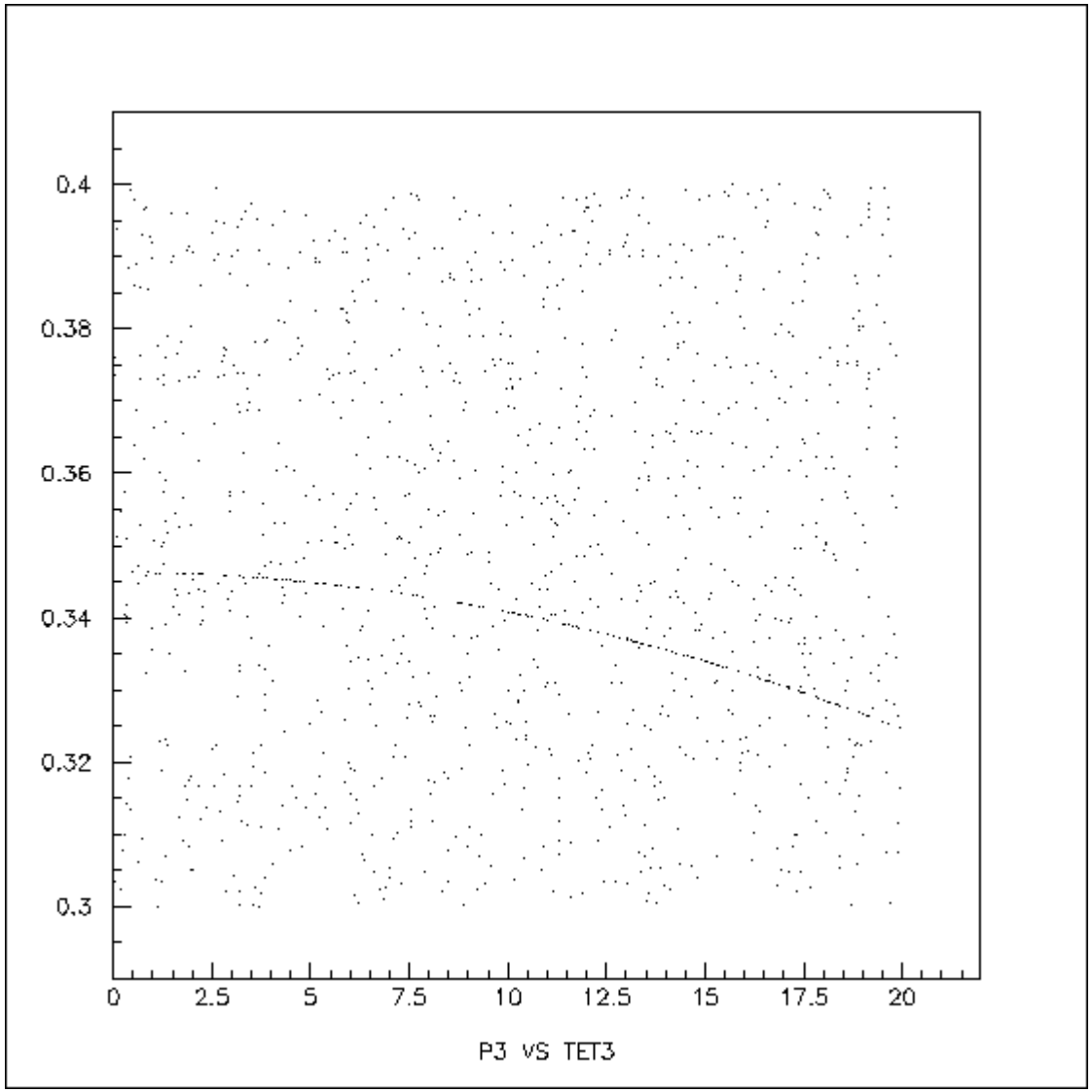
$$k^+ \, p \rightarrow \Theta^+ \; \pi^+$$

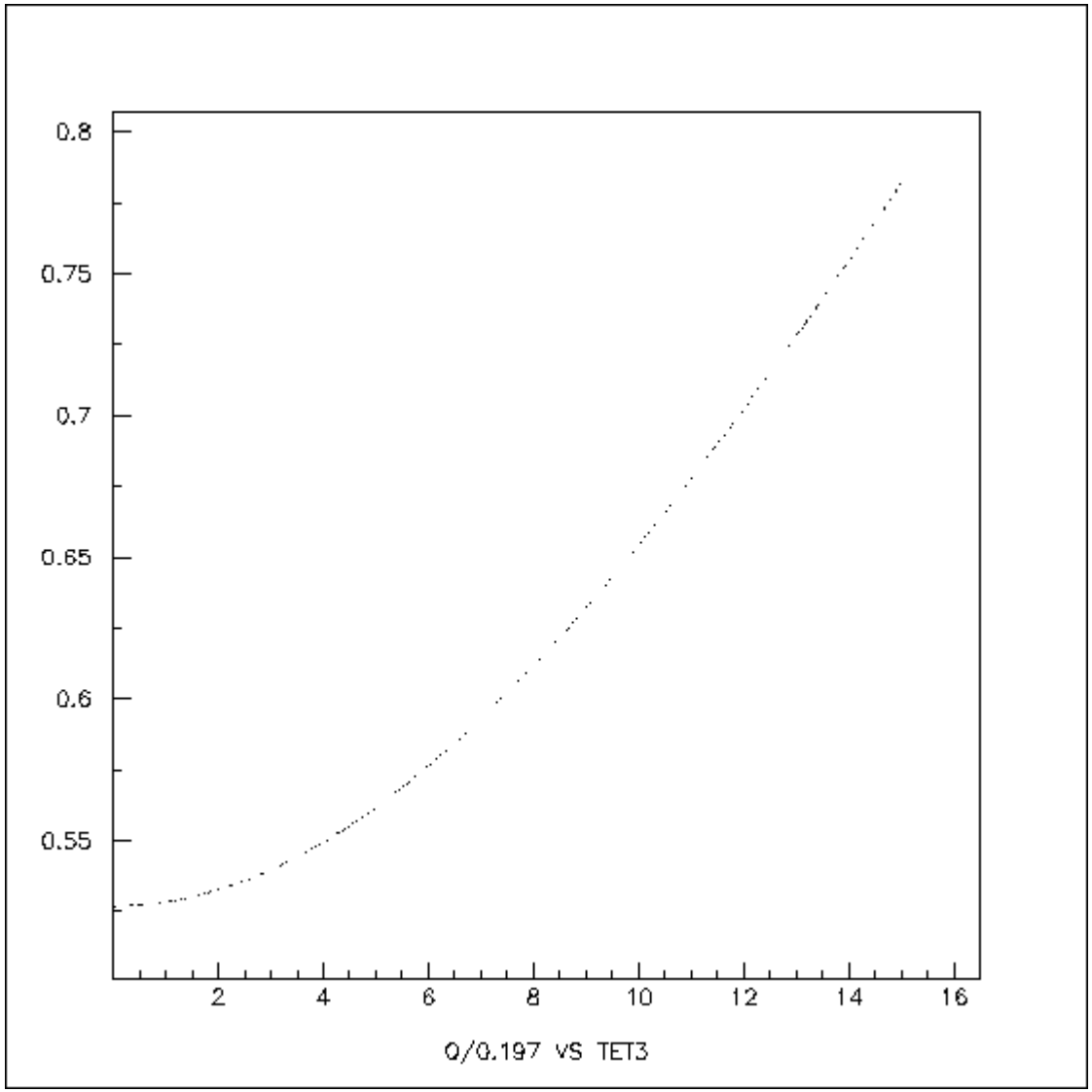


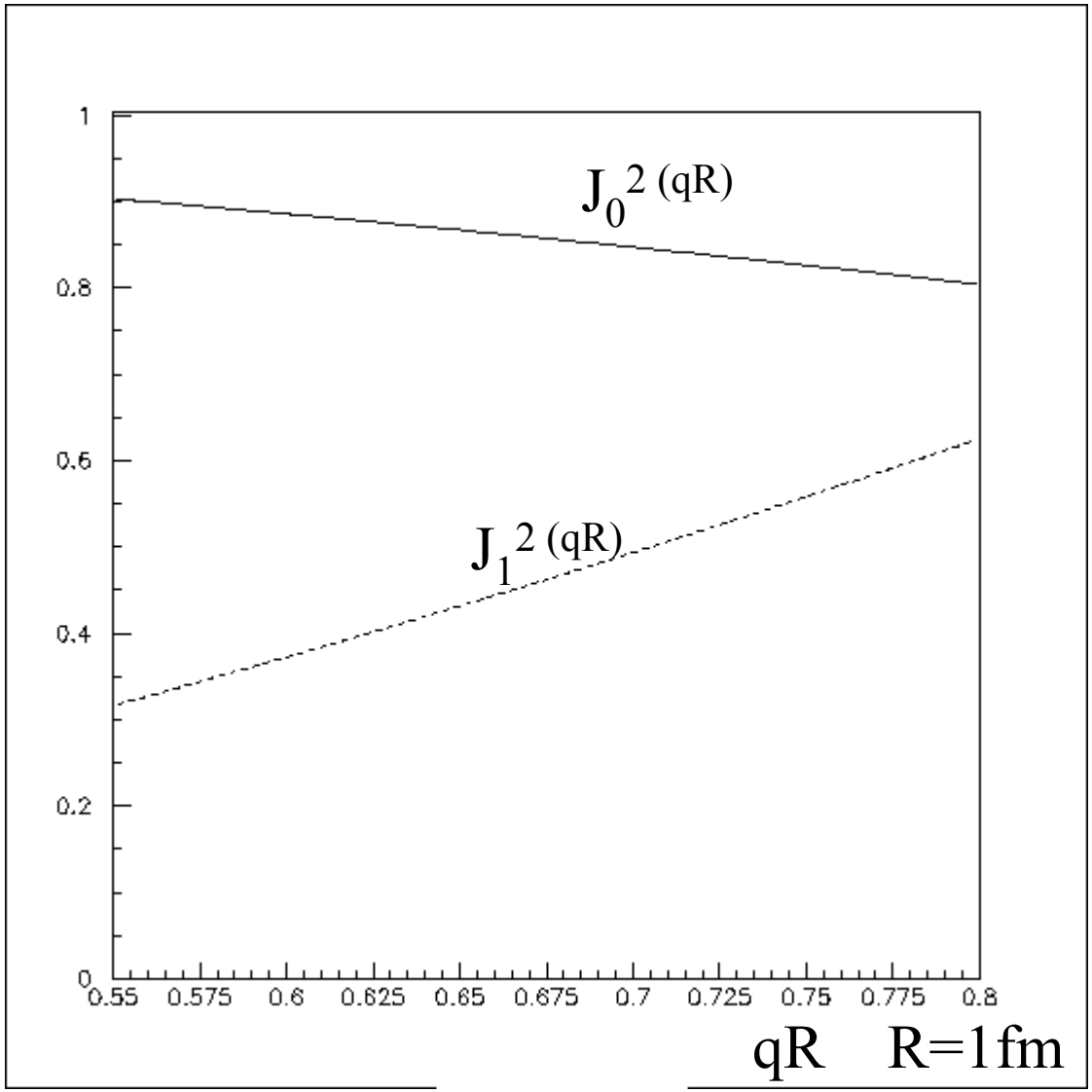

K+d-->Θ+p
Momentum Transfer to Θ+(MeV/c)
250
200
150
100
50
0
0
200
400
600
800
1000
1200
Kaon Momentum (MeV/c)
threshold
0 deg proton
6 deg proton
12 deg proton

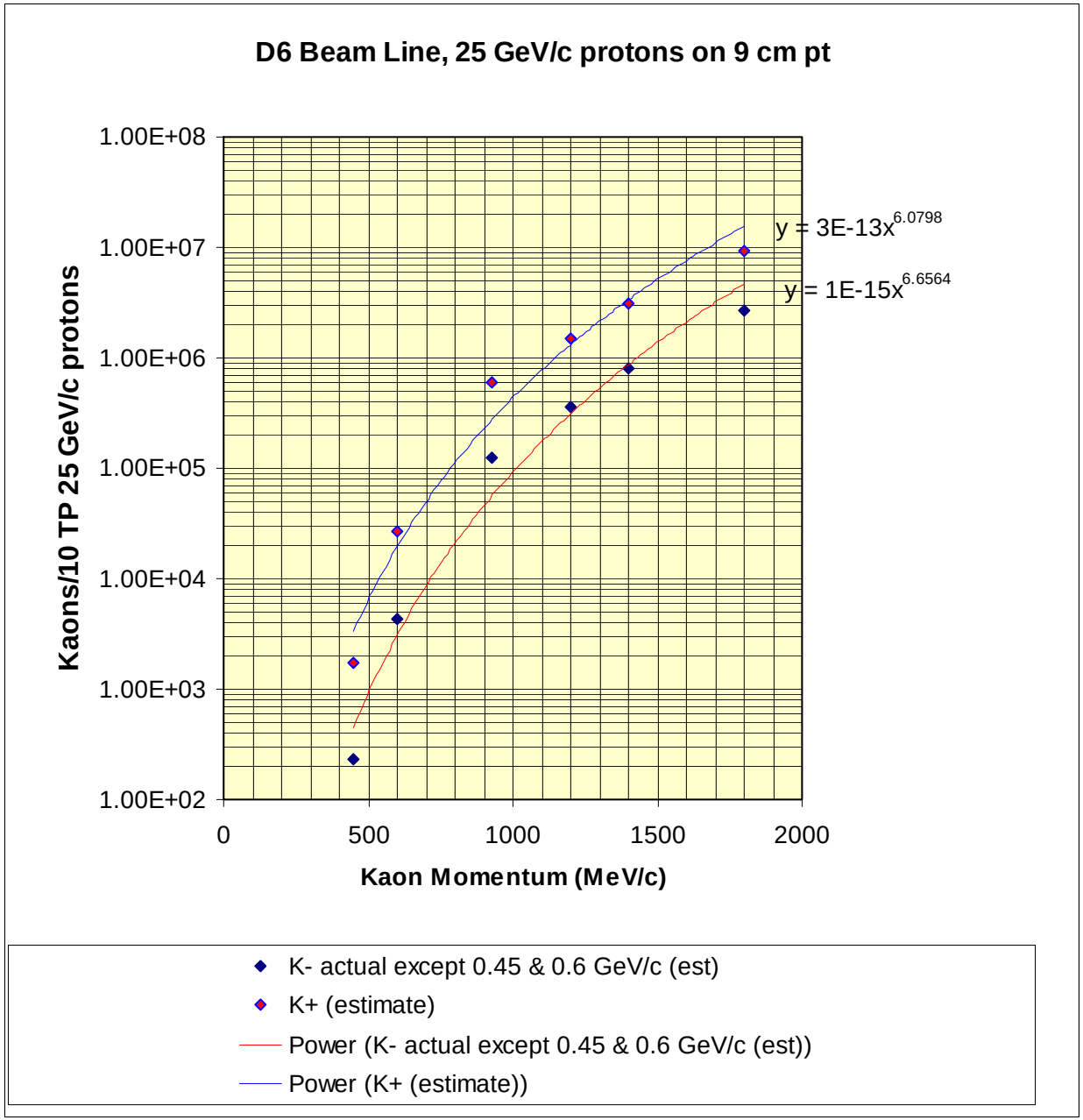

0.6
0.5
0.4
0.3
0.2
0.1
0
20
40
60
80
100
120
140
160
180
P3 VS TET3


2250
2000
1750
1500
1250
1000
750
500
250
0
0
0.1
0.2
0.3
0.4
0.5
0.6
P3
250
200
150
100
50
0
0
0.1
0.2
0.3
0.4
0.5
P3


0.4
0.38
0.36
0.34
0.32
0.3
0
2.5
5
7.5
10
12.5
15
17.5
20
P3 VS TET3


0.8
0.75
0.7
0.65
0.6
0.55
2
4
6
8
10
12
14
16
Q/0.197 VS TET3


1
0.8
0.6
0.4
0.2
0
0.55
0.575
0.6
0.625
0.65
0.675
0.7
0.725
0.75
0.775
0.8
J_0^2 (qR)
J_1^2 (qR)
qR R=1fm


D6 Beam Line, 25 GeV/c protons on 9 cm pt
Kaons/10 TP 25 GeV/c protons
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
0
500
1000
1500
2000
Kaon Momentum (MeV/c)
y = 3E-13x^6.0798
y = 1E-15x^6.6564
K- actual except 0.45 & 0.6 GeV/c (est)
K+ (estimate)
Power (K- actual except 0.45 & 0.6 GeV/c (est))
Power (K+ (estimate))

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Large production cross sections relative to these for electromagnetic processes.

W. Liu and C.M. Ko : ~1 mb

Photoproduction: less than 100 nb

$1:10^4$

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AGS performance

PROTON BEAM	FY96 SEB	FY97 SEB	FY97 FEB (g-2)	FY98/99 SEB	FY98/99 FEB (g-2)	FY2000 FEB (g-2)	FY2001 FEB (g-2)	FY2002 SEB
Beam Energy	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV	24 GeV
Peak Beam Intensity	62 x 10^{12} ppp	62 x 10^{12} ppp	46 x 10^{12} ppp	72 x 10^{12} ppp	58 x 10^{12} ppp	61 x 10^{12} ppp	63 x 10^{12} ppp	76 x 10^{12} ppp
Total protons accelerated	0.9 x 10^{20}	0.4 x 10^{20}	0.1 x 10^{20}	0.9 x 10^{20}	0.4 x 10^{20}	0.5 x 10^{20}	0.6 x 10^{20}	0.7 x 10^{20}
Spill Length/Cycle Time	1.6 sec/3.6 sec	1.6 sec/3.6 sec		2.8 sec/5.1 sec				2.4 sec/5.4 sec
-> Duty Cycle	44%	44%		55%				44%
Spill Structure Modulation (peak-average) /average	20%	20%		20%				20%
Average Availability /Best Week	76% / 92%	71% / 79%	58 % / 67 %	71% / 88%	55 % / 83 %	74 % / 87 %	83 % / 88 %	85 % / 97 %
HEAVY ION BEAM	**Au**	**Au**	**Fe (NASA)**	**Au**	**Fe (NASA)**	**Fe (NASA)**	**Fe (NASA)**	**Fe (NASA)**
Beam Energy /nucleon	11 / 4 / 2 GeV	11 / 8 / 6 GeV	1.0 / 0.6 GeV	11 GeV	1.0 / 0.6 GeV	1.0 GeV	1.0 GeV	1.0 GeV
Peak Beam Intensity	4 x 10^{8} Au/p	17 x 10^{8} Au/p	20 x 10^{8} Fe/p	9 x 10^{8} Au/bunch	36 x 10^{8} Fe/p	17 x 10^{8} Fe/p	80 x 10^{8} Fe/p	49 x 10^{8} Fe/p
Spill Length/Cycle Time	1.4 sec/3.6 sec	1.5 sec/4.0 sec		1.2 sec/3.0 sec		0.9 sec/3.3 sec	0.9 sec/3.3 sec	0.9 sec/3.3 sec
-> Duty Cycle	39%	38%		40 %		27%	27%	27%
Spill Structure Modulation (peak-average) /average	<20%	<20%		<20%		<20%	<20%	<20%
Average Availability	80%	82 %	96 %	81 %	90 %	90 %	97 %	84 %

Properties of D6 2GeV Beam Line

- Maximum Momentum:1900 MeV/c
- 2 Stage Separation, 3rd order optics, special collimators
- Length: 31.6 meters
- Particle flux* per 3 x 10^{13}, 25 GeV/c protons on 9 cm Pt target

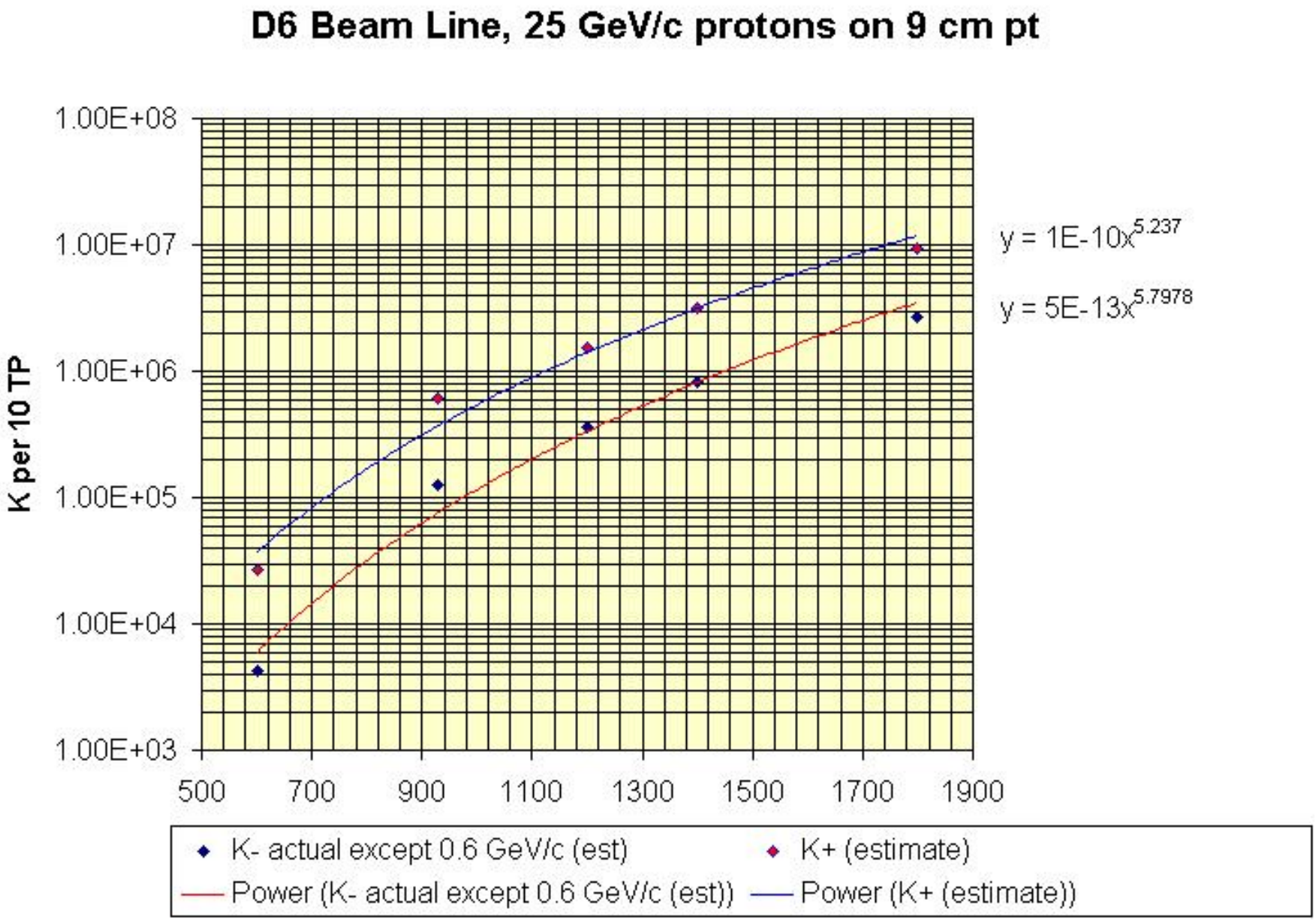
Particle	Momentum	Flux	Beam Purity
K^-	1800 MeV/c	8.0 x 10^6	36%
K^-	1800 MeV/c	3.0 x 10^6	70%
K^-	1200 MeV/c	1.1 x 10^6	94%
K^-	930 MeV/c	3.8 x 10^5	97%
p	1800 MeV/c	3.6 x 10^6	47%
p	1400 MeV/c	1.2 x 10^6	99%

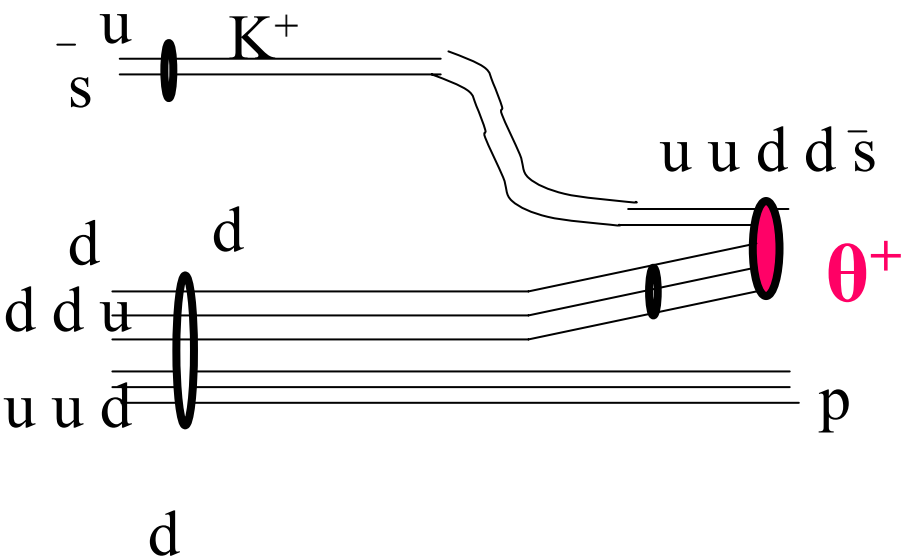
* Proton flux in D-line limited by beam loss considerations, up to 7.6 x 10^{13} protons/AGS cycle have been extracted.

Properties of C4 LESBIII Beam Line

- Maximum Momentum: 830 MeV/c
- 2 Stage Separation, 3rd order optics, special collimators
- Length: 19.6 meters
- K^- flux per 6 x 10^{13}, 25 GeV/c protons on 6 cm Pt target

Particle	Momentum	Flux	Beam Purity
• K^+	800 MeV/c	3.0 x 10^7	71%
• K^+	stopping	6.0 x 10^6	


D6 Beam Line, 25 GeV/c protons on 9 cm pt
K per 10 TP
1.00E+08
1.00E+07
1.00E+06
1.00E+05
1.00E+04
1.00E+03
500
700
900
1100
1300
1500
1700
1900
y = 1E-10x^5.237
y = 5E-13x^5.7978
K- actual except 0.6 GeV/c (est)
K+ (estimate)
Power (K- actual except 0.6 GeV/c (est))
Power (K+ (estimate))



For a direct pickup reaction (p,d)