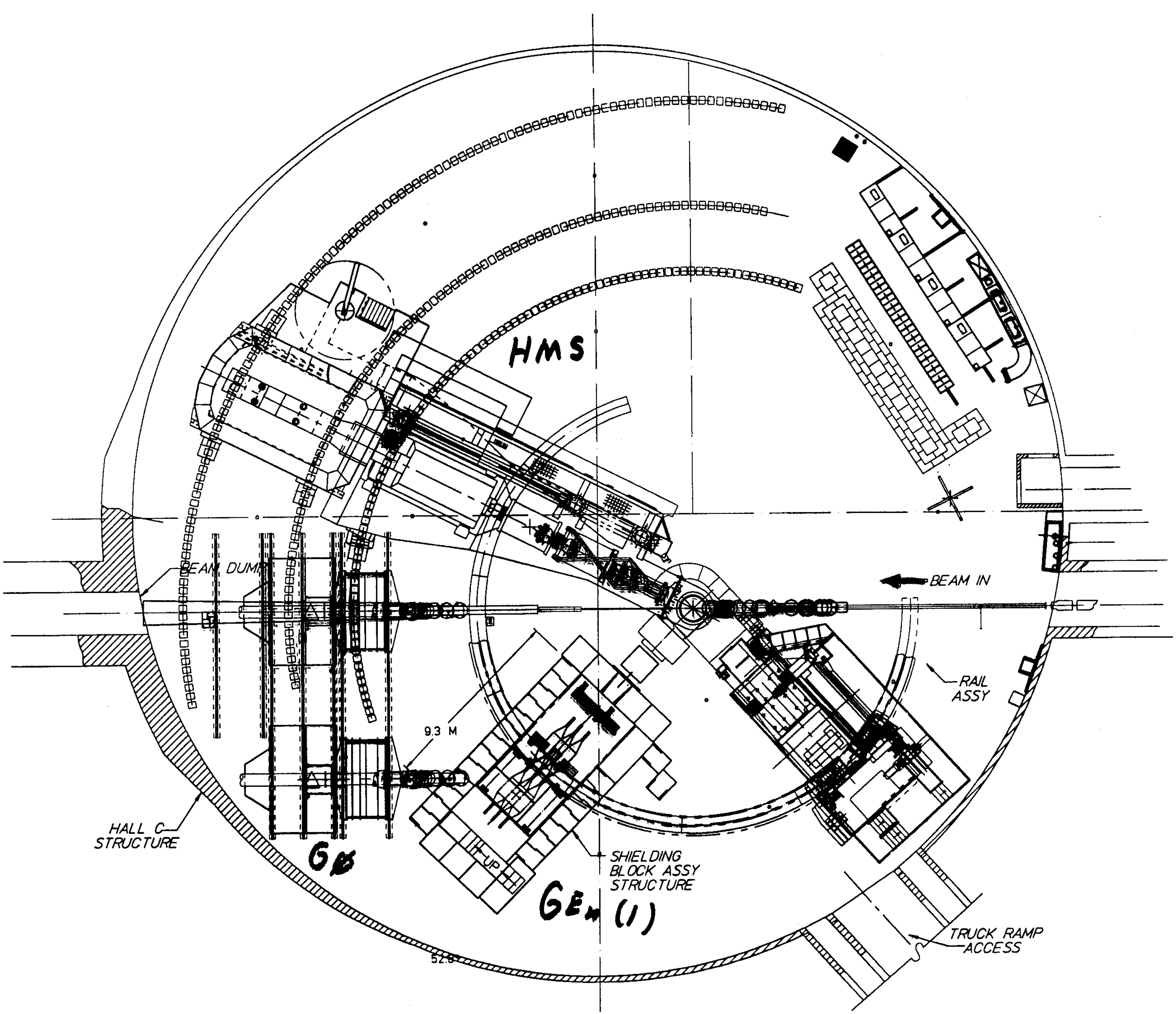
THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY

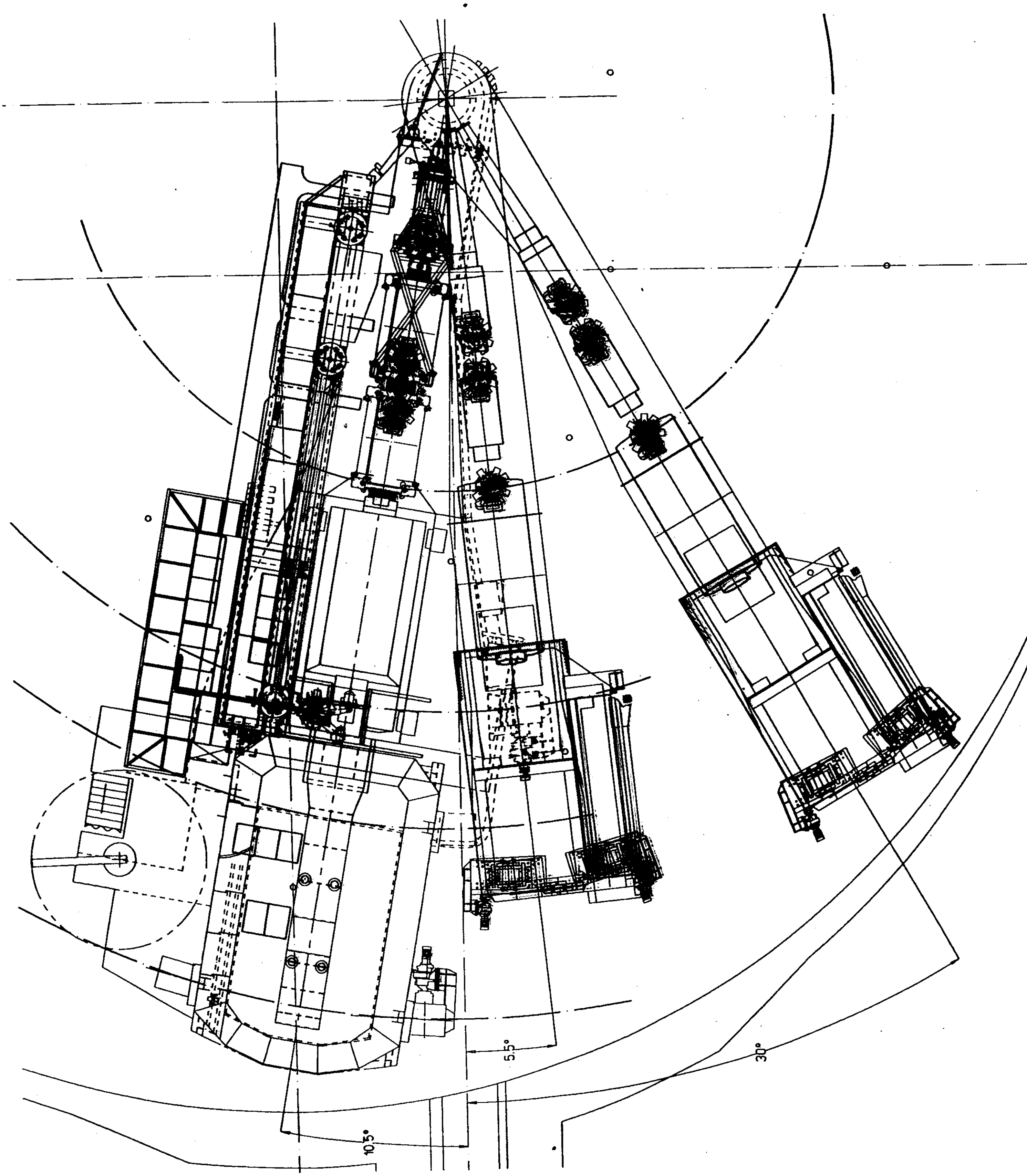
12000 Jefferson Avenue
Newport News, Virginia 23606

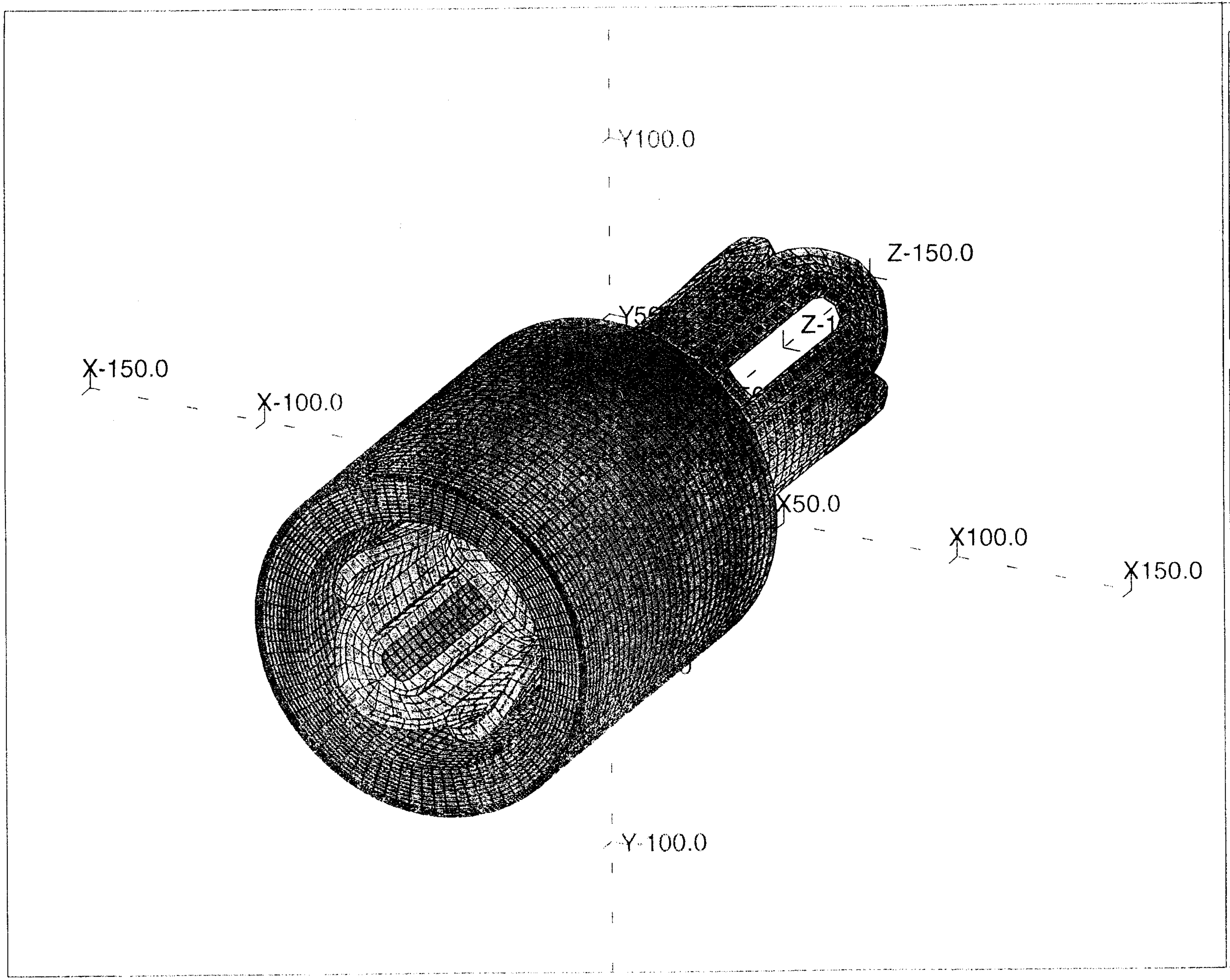
SHMS

D. Mack



HALL C -- PLAN VIEW


5.5°
30°
10.5°



UNITS

Length	: cm
Magn Flux Den	: gau
Magnetic field	: oers
Magn Scalar Pot	: oers
Magn Vector Pot	: gau
Elec Flux Den	: C cr
Electric field	: V cr
Conductivity	: S cr
Current density	: A cr
Power	: W
Force	: N
Energy	: J

PROBLEM DA
hms-q1\shms-q1-\
TOSCA
Magnetostatic
Non-linear materia
Simulation No 1 o
50250 elements
141670 nodes
Nodal fields

LOCAL COOR

Xlocal	= 0.0
Ylocal	= 0.0
Zlocal	= 0.0
Theta	= 0.0
Phi	= 0.0
Psi	= 0.0

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OPER.
Post-Processor

Evolution of Hall C into a High Q^2 Hall

New "Core" Equipment Required

- **"Basic" Super HMS Design Parameters**

  - ~12GeV momentum capability.
  - ~5.5° minimum laboratory angle (HMS at 10.5°).
  - ~25° maximum laboratory angle (HMS max. ~85°).
  - 1.5 to 3 msr acceptance.
  - Bending angle of ~18°.
  - Flexible detector package similar to present designs.

- **"Typical" Coincidence Setup with 12GeV/c Beam**

  - Super HMS (max. 25°) replaces HMS (max. 85°)
    HMS (max. 85°) replaces SOS (max.140°)

Super HMS

D. J. Mack
TJNAF
January 13, 2000

- Motivation
- Design Constraints
- Preliminary:

  Drawing

  Design Specifications

  Detector Package

A Critical Review of Spectrometer Requirements

Original mission of hall C:

- Flexible, general purpose hall to support a broad research program
- High luminosity
- Single-arm and coincidence experiments
- High Q^2 inclusive scattering
- photo-disintegration measurements
- $(e, e'p)$
- Hypernuclear physics
- electro-weak physics
- out-of-plane measurements

To address such a program, two general purpose spectrometers were built:

HMS	SOS
• High Momentum (7.4 GeV)	• Low Momentum (1.8 GeV)
• Long flight path (23.2 m)	• Short flight path (7.3 m)
• Few 10^{-4} $\delta p/p$	• 10^{-3} $\delta p/p$
• large solid angle	• Large solid angle
• Electron or hadron arm	• Hadron or electron arm
• Good PID	• Excellent PID
	• Out-of-plane capability

Hall C designed with room for specialized spectrometers/detectors to be mounted.

D. Potterveld

Motivation for the Super HMS-Lite

Existing Hall C spectrometers:

HMS

$$P_{max} = 7.6 \text{ GeV/c}$$
$$\Delta P \simeq 20\%$$
$$dp/p \simeq 10^{-3}$$
$$\Theta_{min} \leq 10.5 \text{ deg}$$
$$\Delta\Omega \simeq 6 msr$$

SOS

$$P_{max} = 1.8 \text{ GeV/c (significantly saturating)}$$
$$\Delta P \simeq 40\%$$
$$dp/p \simeq 10^{-3}$$
$$\Theta_{min} \leq 12.5 \text{ deg}$$
$$\Delta\Omega \simeq 6 msr$$

#1. Now that JLab can routinely produce beam energies greater than 4 GeV, the low SOS P_{max} reduces the utility of Hall C. The HMS could use a new friend.

HALL C - Completed Experiments

Title	Experiment	Spokesperson	Status	Graduate Students	Ph.D.'s Awarded
Energy Dependence of N Propagation in Nuclei in (e,e'p)	E-91-013	D. Geesaman	pub. (1), sub. (1)	2	2
Photodisintegration of the Deuteron at 1.5 - 4 GeV	E-89-012	R. J. Holt	published (2)	3	3
Inclusive Scattering from Nuclei at x > 1 and High Q2	E-89-008	B. Filippone	published	3	1
Electroproduction of Kaons and Light Hypernuclei	E-91-016 (A)	B. Zeidman	draft	4	1
L/T Separation in p(e,e'K+)	E-93-018	O. K. Baker	pub. (1), sub. (2)	3	3
Δ (1232) Form Factor at High Momentum Transfer	E-94-014	J. Napolitano	published (2)	2	2
T_{20} from D(e,e'd)	E-94-018	S. Kox/E. Beise	pub. (1), draft (1)	6	5
Charged Pion Form Factor	E-93-021	D. Mack	analysis	2	
Pion Electroproduction in 2D, 3He, and 4He	E-91-003	H. Jackson	analysis	2	
The Charge Form Factor of the Neutron	E-93-026 (A)	D. Day	analysis	2	
Two-Body Photodisintegration of Deuteron at High Energy	E-96-003	R. J. Holt	analysis	1	
Color Transparency	E-91-007	R. Milner	analysis	1	
Measurement of R = σ_L/σ_T in the Resonance Region	E-94-110	C. Keppel	analysis	1	
Correlated Spectral Function & (e,e'p) Reaction Mechanism	E097-006	I. Sick	analysis	1	
Electroproduction of Kaons and Light Hypernuclei	E-91-016 (B)	B. Zeidman	analysis	1	

Calendar 2000 Program

Title	Experiment	Spokesperson	Status
➡ Spin Dependence of ΛN Effective Interaction in P Shell	E-89-009	Hungerford / Tang	run 2000
Inclusive resonance σ for Parton-Hadron duality studies	E-97-010	C Keppel	run 2000
➡ The Electric and Magnetic Form Factors of the Neutron	E-93-038	Madey / Kowalski	run 2000

Upcoming Large Scale Exp's

Title	Experiment	Spokesperson	Status
➡ The Charge Form Factor of the Neutron	E-93-026 (B)	Day / Mitchel	run 2001
➡ G0 Parity Measurement	E-91-017	D. Beck	run 2002

8 published | 34 | 17

-new- DNP Dissertation Award
John Arrington
[illegible] thesis

3 submitted

Motivation for the Super HMS

Potential HMS-SHMS Physics Program:

color transparency in $A(e, e'p)A-1$

Δ and S_{11} transition form factors in $p(e, e'p)\pi^0, \eta$

F_π in $p(e, e'\pi^+)n$

tagged structure function studies in $p(e, e'\pi^\pm)X$ or $p(e, e'k^\pm)X$

factorization/duality studies in $p(e, e'\pi^\pm)X$ or $p(e, e'k^\pm)X$

... plus a potential single arm physics program in kinematic regimes inaccessible to the HMS:

$x_B \geq 1$ studies in $A(e, e')$

inclusive spin structure function studies in $\vec{p}, \vec{d}(e, e')X$

#2. At an upgraded 12 GeV JLab, the HMS-SHMS pair would make possible an exciting physics program potentially attractive to hundreds of users from around the world.

By re-using the Hall C and 7.6 GeV/c HMS infrastructure, we get a big bang for the buck.

Phased Approach to SHMS

I SHMS Lite $P_{max} = 6$ GeV/c

1 resistive dipole:

2.05 T by 3.2 m (eg, SLAC B202/B203)

2 superconducting quads

9.9 T/m by 2.0 m (new cos2θ design)

II SHMS $P_{max} = 12$ GeV/c

1 superconducting replacement dipole

3.75 T by 3.46 m

SHMS Design Criteria

Hard Constraints:

- must fit in hall (target to hall exit $\simeq$ 27 m with existing pivot)

Firm Assumptions:

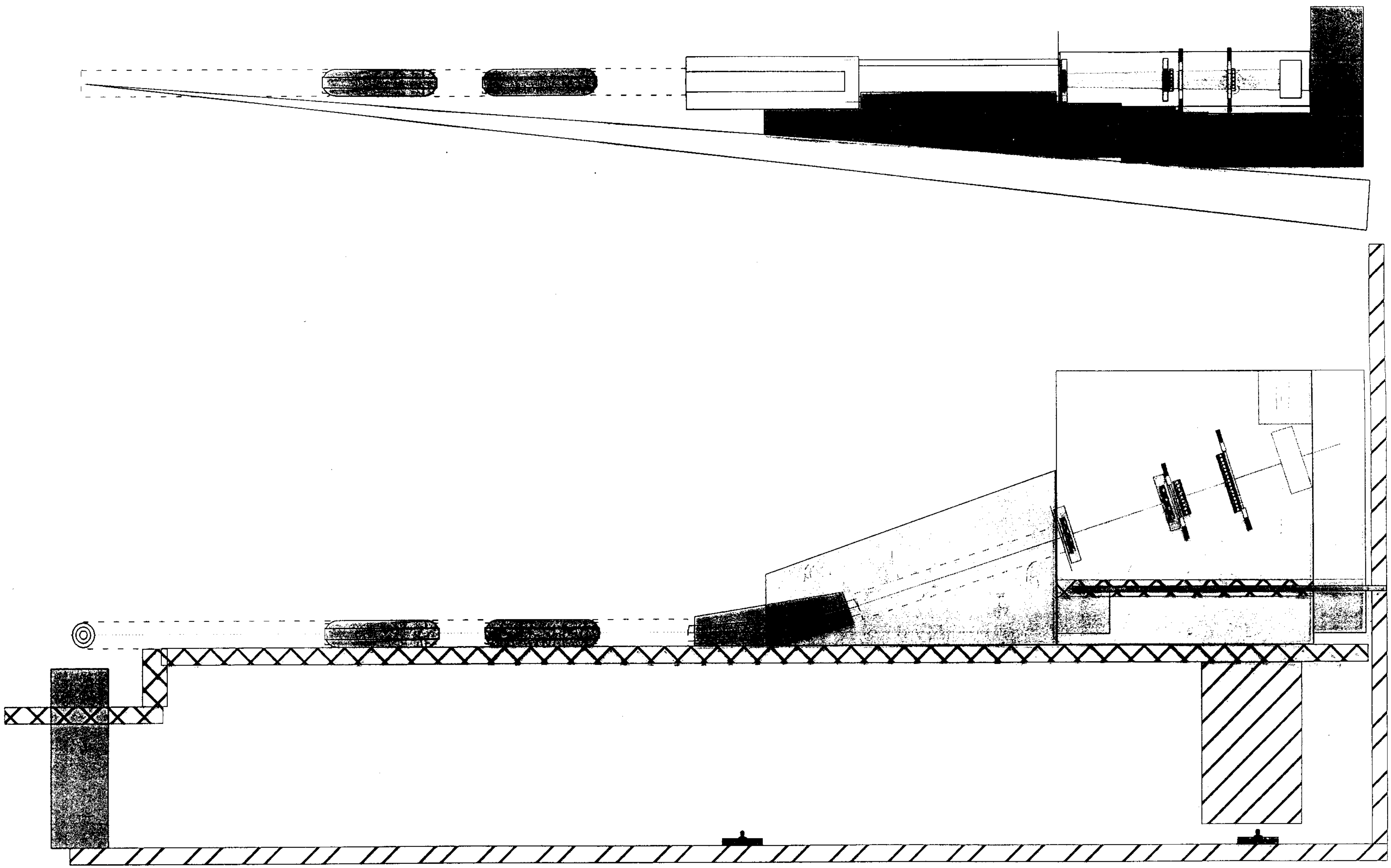
- $\simeq$ 12 GeV/c maximum momentum
- bend angle $\simeq 18°$
- $\simeq 5.5°$ minimum scattering angle (assume HMS is at 10.5°)
- maximum scattering angle $\geq 20°$
- $\Delta P \geq 10\%$
- $\Delta\Omega \geq 2$ msr
- moderate angle and momentum resolution
- serves as electron or hadron spectrometer: needs a flexible detector package capable of flexible e, π, k, p discrimination
- quadrupoles will be superconducting. SHMS-Lite and SHMS will use the same quadrupoles

Less Firm Assumptions:

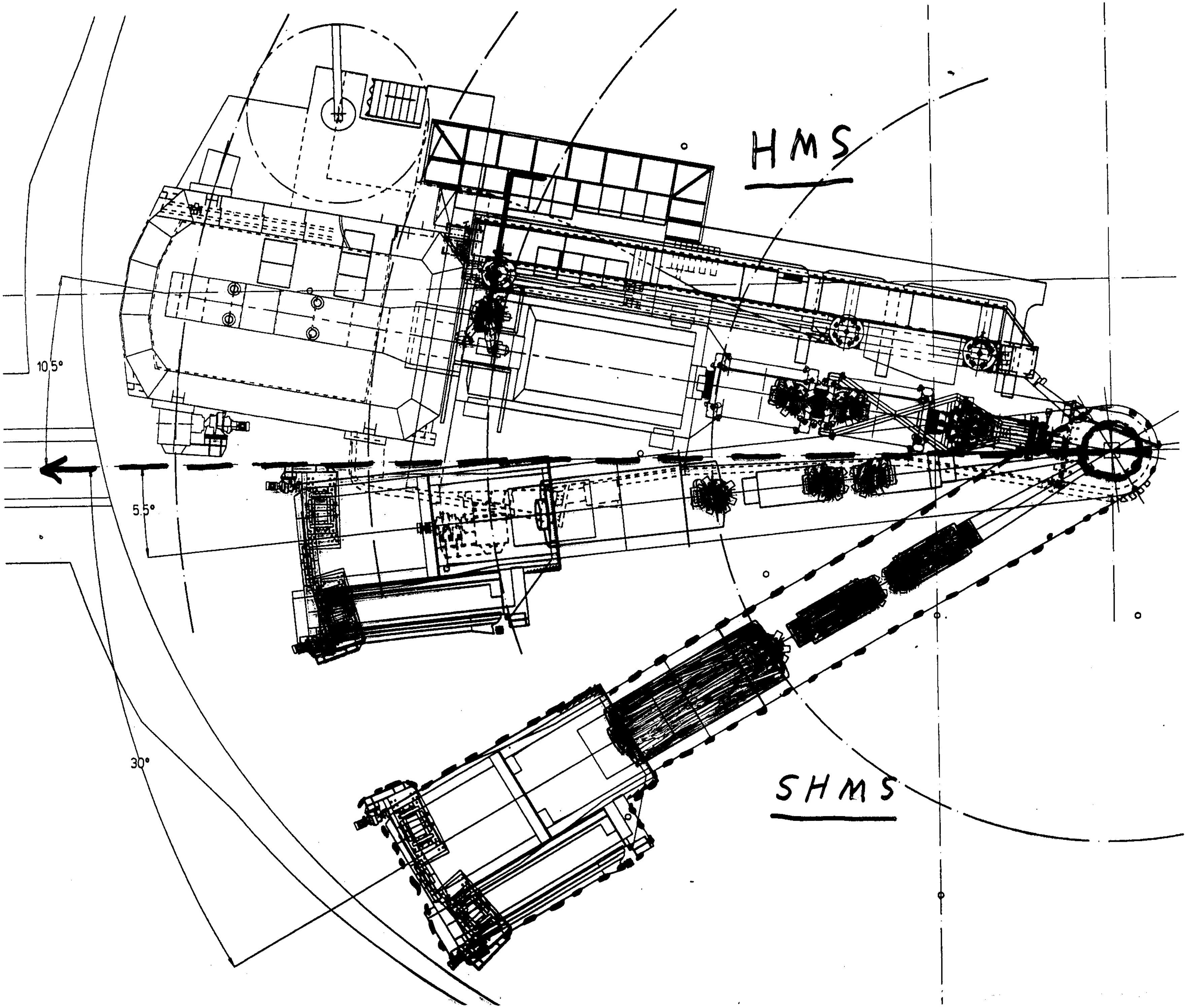
- assume point-to-point transverse focus (easy to commission, easy to tell when you're screwing up)

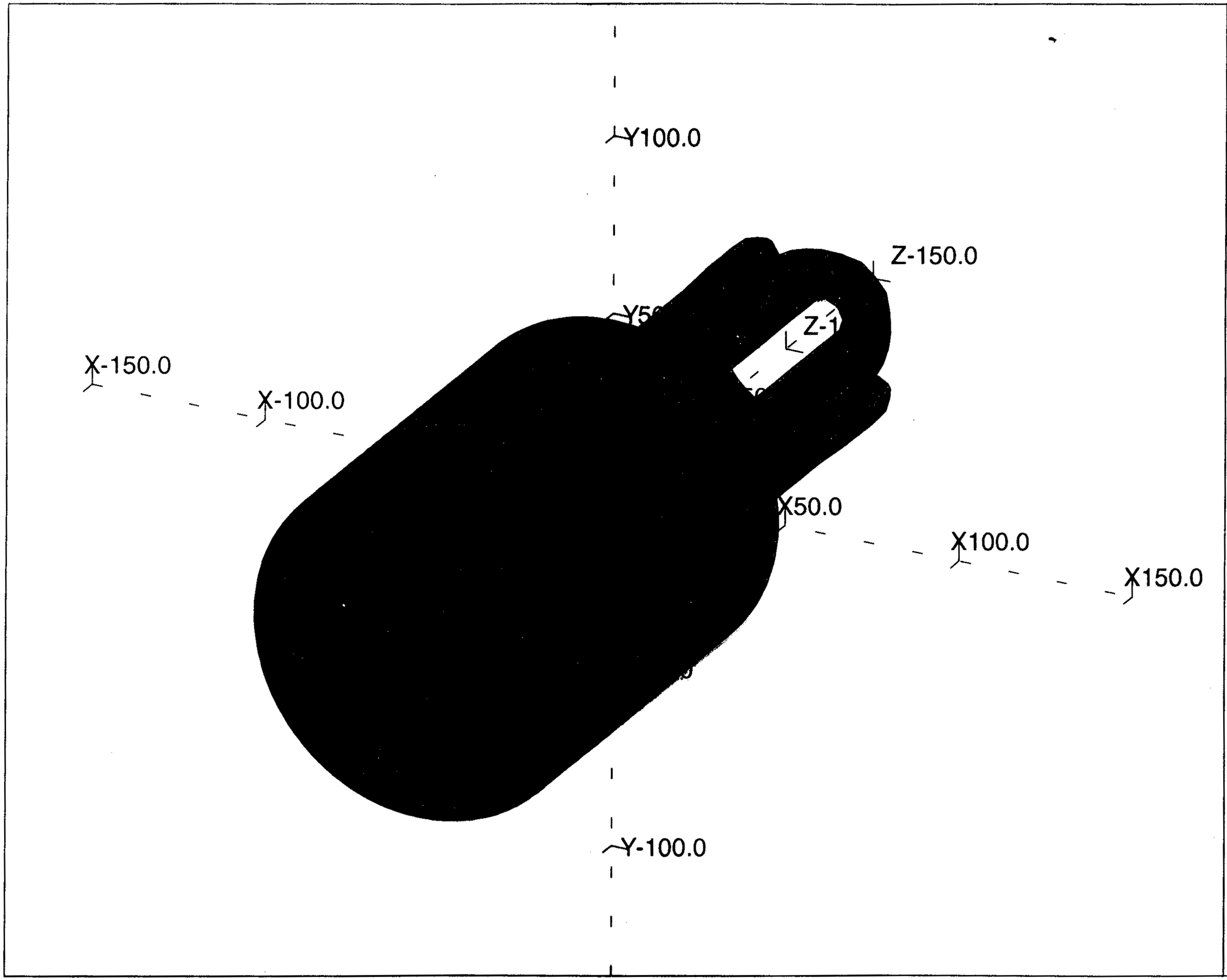
Making SHMS-Lite Happen

- **Users** – during calendar 2000 develop physics program for ~6GeV beam using SHMS-Lite + HMS.
  - Develop of scale 3 outstanding proposals
- **Users + Jlab** – define and obtain commitments from user community to build the detector package components.
  - New components
  - Explore recycling SOS systems
- **Jlab** – during calendar 2000 develop technical proposal for a SHMS-Lite which is straightforwardly upgradable to ~12GeV via a new superconducting dipole.
  - Support structure & shield house
  - 2 "slim width" superconducting quads.
  - Use 1 "surplus" resistive dipole (SLAC ESA 20GeV dipole or equiv.)
- **Early Calendar 2001** – submit proposals and technical design to Jlab management & PAC.



H. Fenker


HMS
SHMS
10.5°
5.5°
30°



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Magn Scalar Pot	: oers
Magn Vector Pot	: gau
Elec Flux Den	: C cr
Electric field	: V cr
Conductivity	: S cr
Current density	: A cr
Power	: W
Force	: N
Energy	: J

PROBLEM DA
hms-q1\shms-q1-\
TOSCA
Magnetostatic
Non-linear materia
Simulation No 1 o
50250 elements
141670 nodes
Nodal fields

LOCAL COOR

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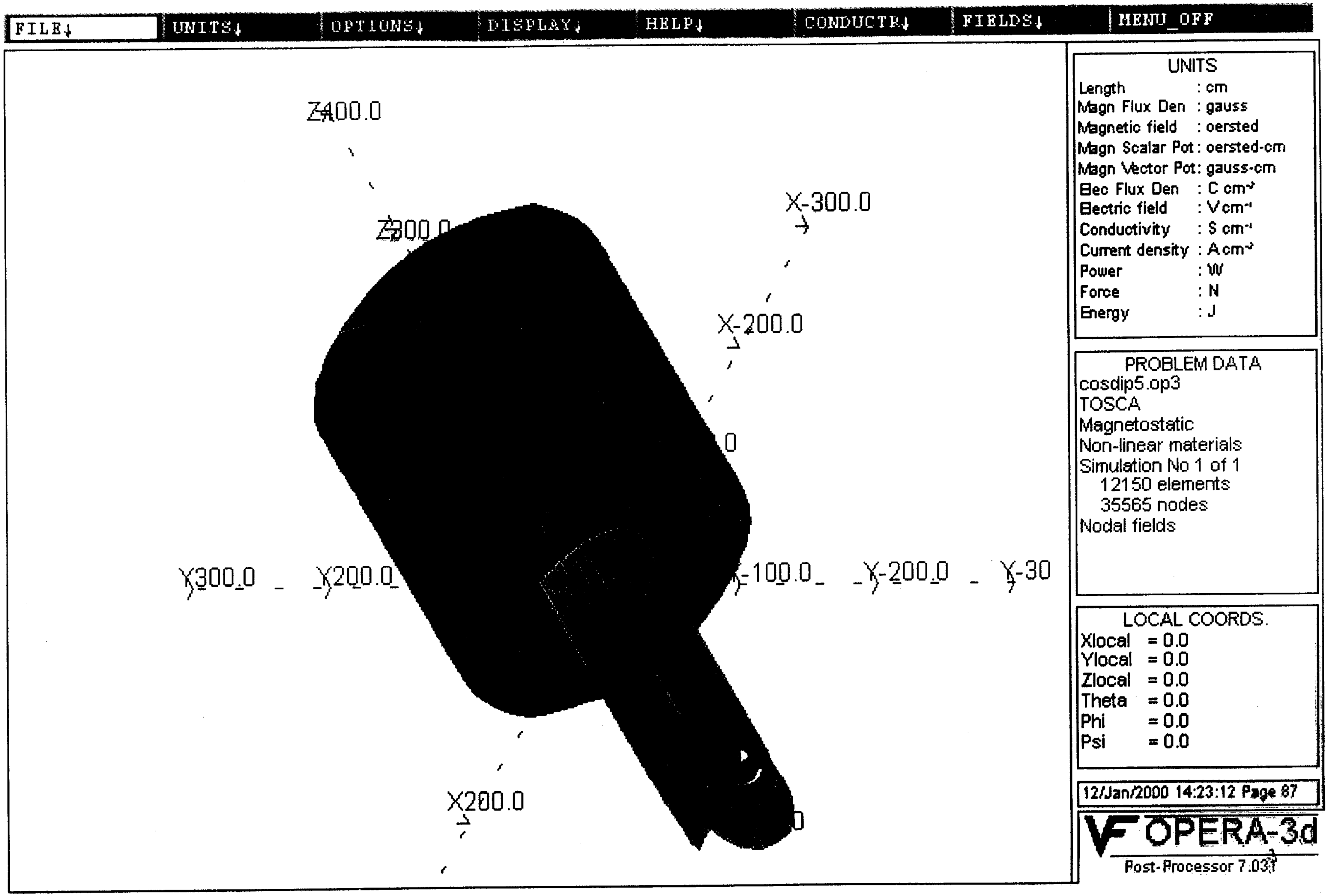
OPER.
Post-Processor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Magn Scalar Pot : oersted-cm
Magn Vector Pot : gauss-cm
Elec Flux Den : C cm⁻²
Electric field : V cm⁻¹
Conductivity : S cm⁻¹
Current density : A cm⁻²
Power : W
Force : N
Energy : J
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TOSCA
Magnetostatic
Non-linear materials
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Nodal fields
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12/Jan/2000 14:23:12 Page 87
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Z300.0
X-300.0
X-200.0
Y300.0
Y200.0
Y-100.0
Y-200.0
Y-30
X200.0

SHMS Base Design

Characteristic	SHMS	SHMS "lite"*
Configuration	QQD	QQD
P_{max} (GeV/c)	12	6
Solid Angle (msr)	1.7-3.0	1.7-3.0
In-plane (mr)	13	13
Out-of-plane (mr)	42	42
Minimum Scattering Angle (deg)	5.5	5.5
Bend Angle (deg)	18.9	18.3
D (cm/%)	1.852	1.765
D/M (cm/%)	3.12	3.12
Acceptance (%)	±10	±10
Focal Plane Angle (deg)	4.69	5.07
Resolution:		
Momentum	10^{-3}	10^{-3}
In-plane angle (mr)	0.9	0.9
Out-of-plane angle (mr)	3.0	3.0
Dipole Power (MW)	0.3	0.7

* Uses SLAC B203 dipole (or equiv.)

SHMS performance requirements:

Horizontal angle setting

MIN	5.5
MAX	30
ACCURACY	?

(fast remote changes required)

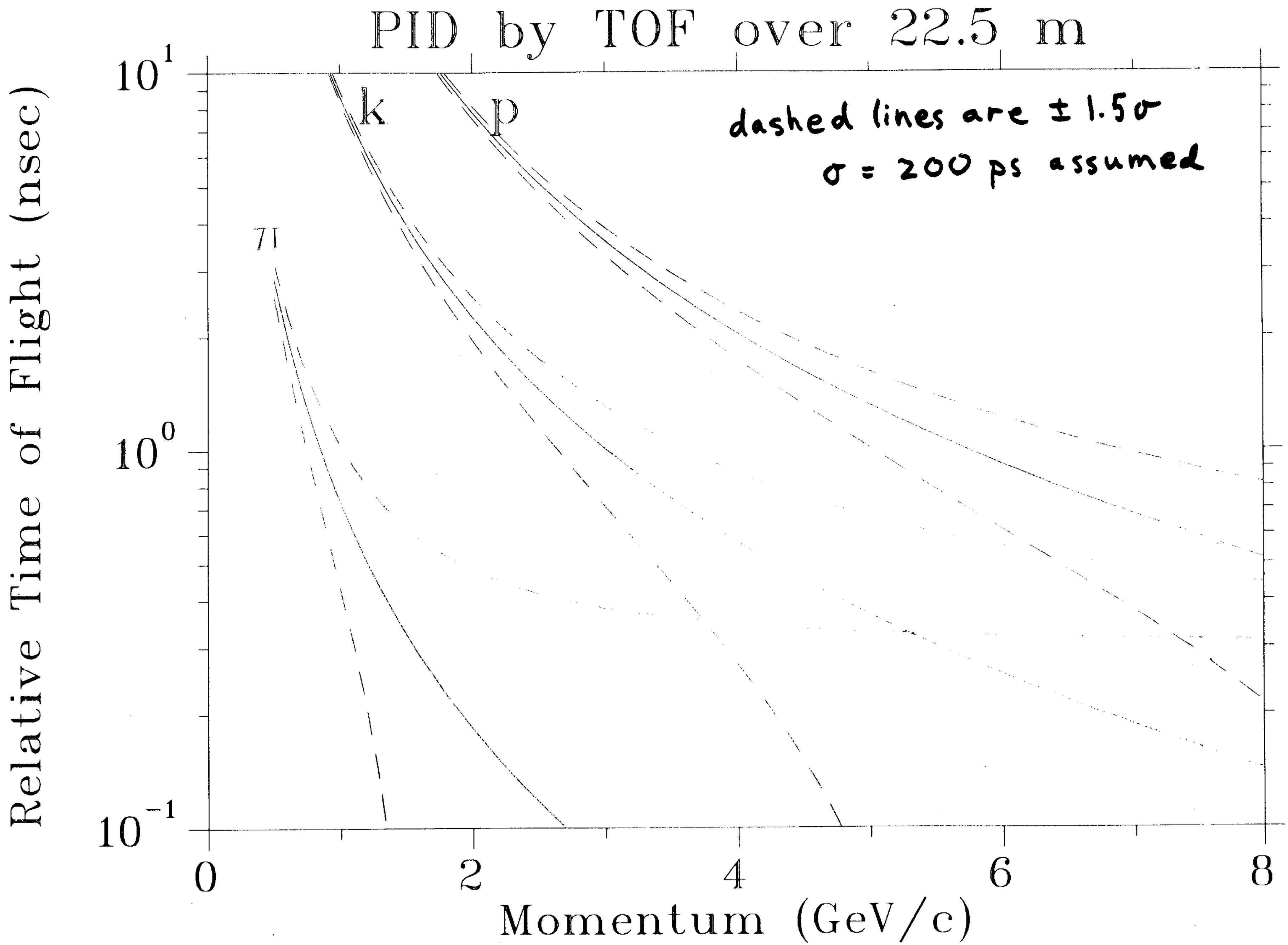
H angle acceptance:	+/- 45 mr
H angle resolution:	1 mr
V angle acceptance:	+/- 45 mr
V angle resolution:	1 mr
V/H aspect ratio:	2:1
Solid angle (pt tgt)	~2 msr

Momentum setting

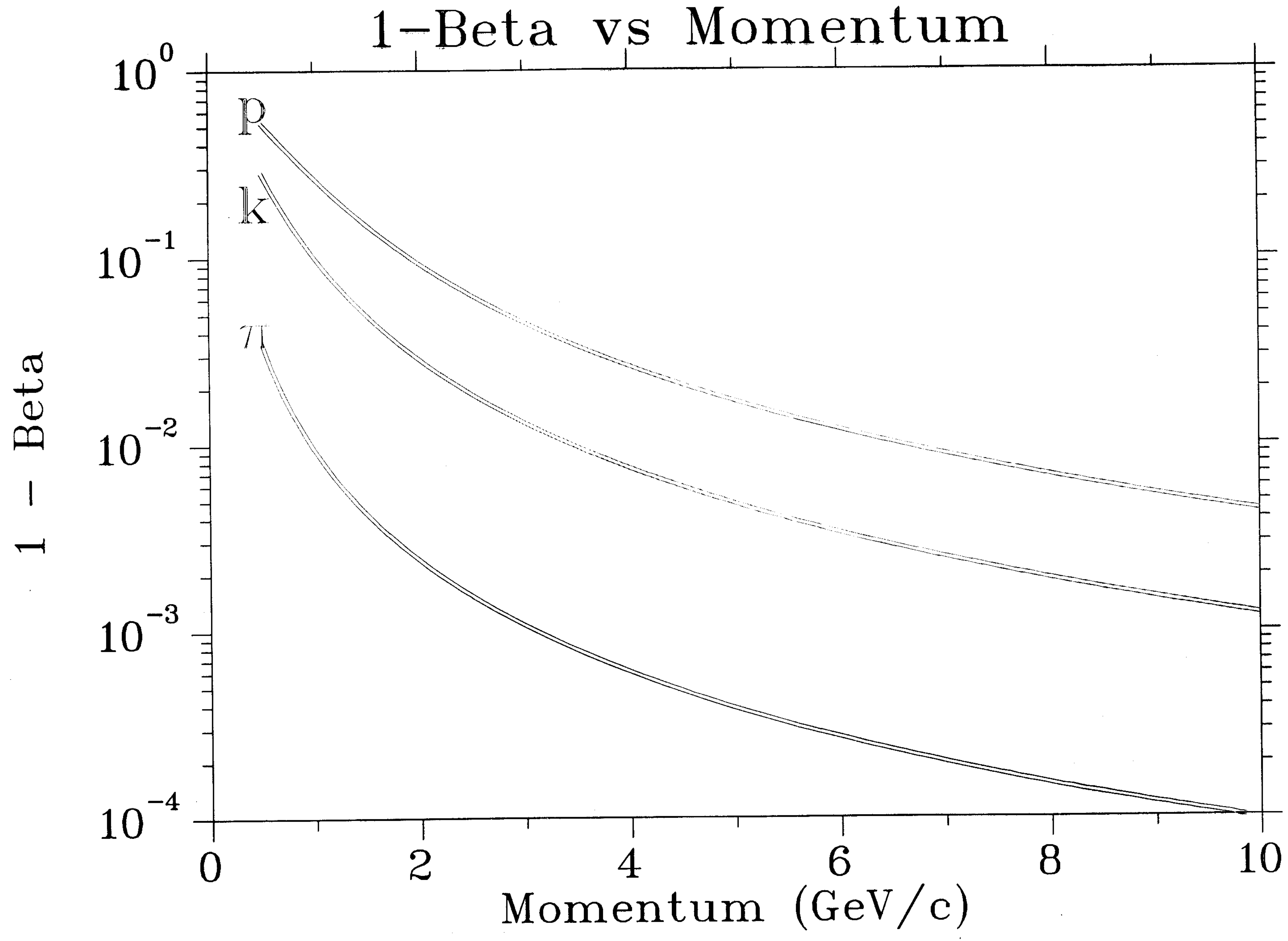
MIN	1.0 GeV
MAX	6 (12)
ACCURACY	10E-3
REPEATABILITY	10E-4

(fast remote changes required)

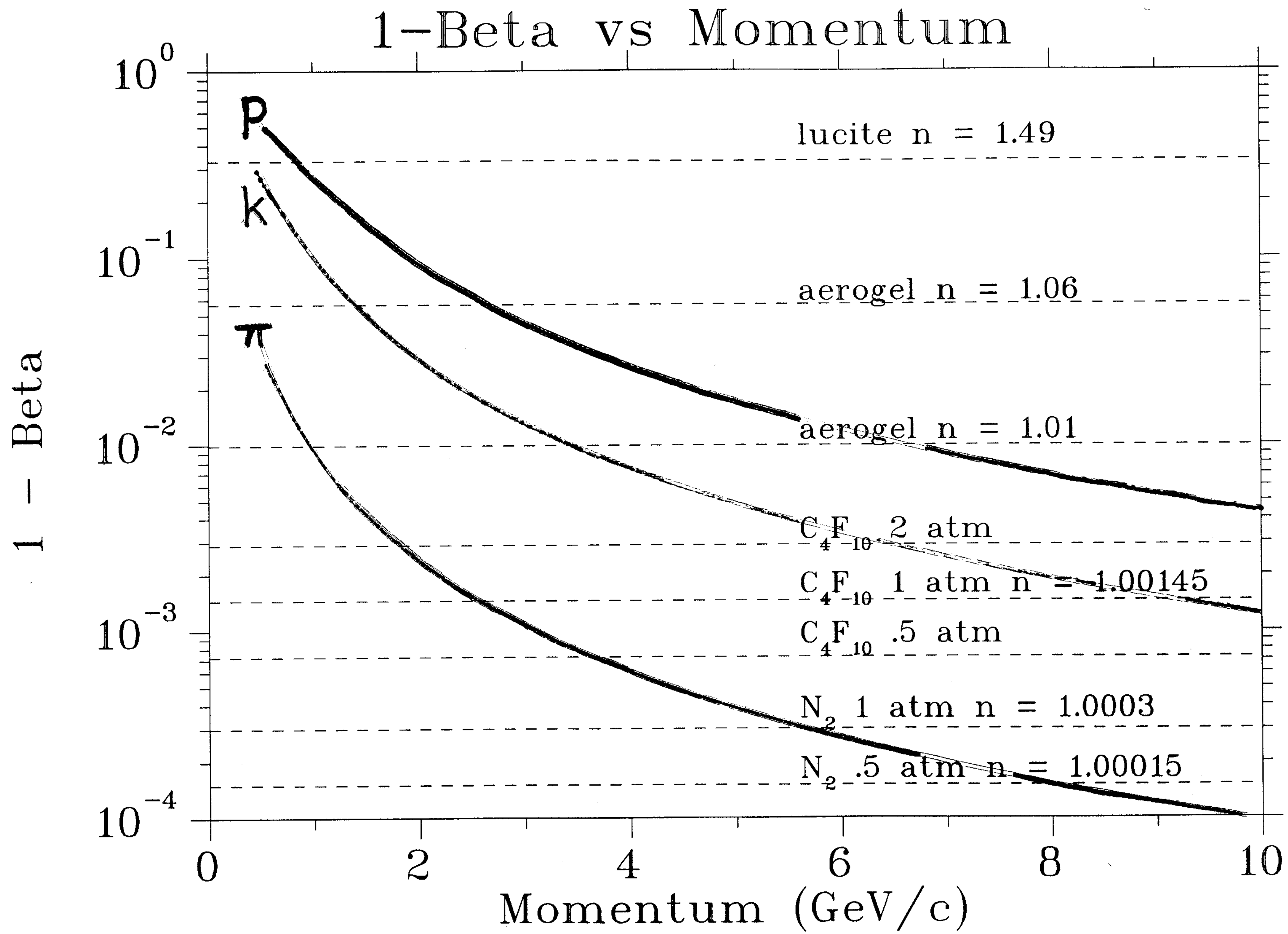
P bite:	20 %
P resolution:	10E-3
Target length:	12 cm (what angle?)
Vertex resolution:	5 mm (what angle?)
Particle ID:	e/pi, pi/X, k/p



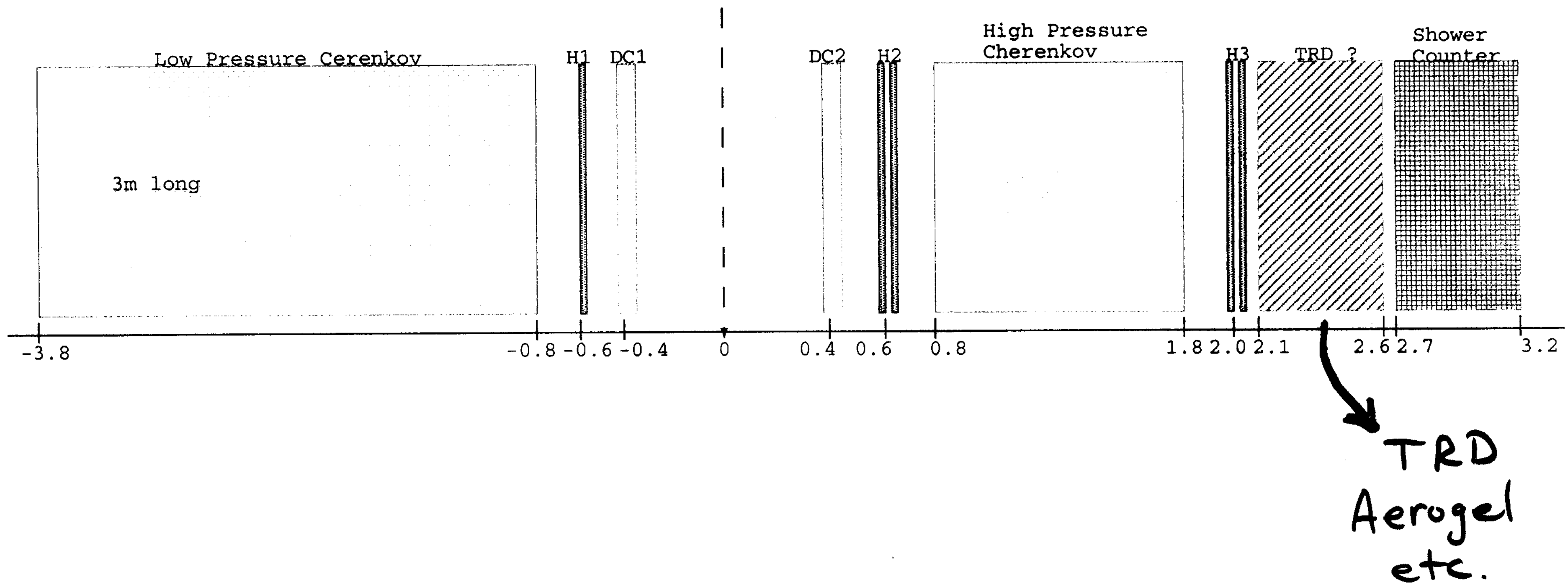
PID by TOF over 22.5 m
dashed lines are ± 1.5σ
σ = 200 ps assumed
π
k
p
Relative Time of Flight (nsec)
Momentum (GeV/c)
10^1
10^0
10^-1
0
2
4
6
8



1-Beta vs Momentum
1 - Beta
Momentum (GeV/c)
p
k
π
0
2
4
6
8
10
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}



1-Beta vs Momentum
P
K
π
lucite n = 1.49
aerogel n = 1.06
aerogel n = 1.01
C4F10 2 atm
C4F10 1 atm n = 1.00145
C4F10 .5 atm
N2 1 atm n = 1.0003
N2 .5 atm n = 1.00015
1 - Beta
10^0
10^-1
10^-2
10^-3
10^-4
0
2
4
6
8
10
Momentum (GeV/c)


Low Pressure Cerenkov
3m long
H1
DC1
DC2
H2
High Pressure
Cherenkov
H3
TRD ?
Shower
Counter
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-0.8
-0.6
-0.4
0
0.4
0.6
0.8
1.8
2.0
2.1
2.6
2.7
3.2
TRD
Aerogel
etc.

M. Boswell

Summary

We believe SHMS-HMS would provide flexible apparatus attractive to many experimental collaborations.

A phased approach appears most appropriate:

I SHMS-Lite 6 GeV/c

proposals and technical design to be submitted to JLab management early 2001.

II SHMS 12 GeV/c

Thanks to the Team

C. Yan
P. Brindza
R. Ent
H. Fenker
D. Potterveld
R. Carlini

Limiting factors

- Central angle: limited by approach to beamline and approach to hall C wall
- H angle acceptance: Limited by bore of first quad and dipole gap
- V angle acceptance: Limited by bore of second quad (and/or dipole vertical aperture)
- Q1 max field gradient: 8.4 T/m, $\Rightarrow$ Pmax = 11 GeV (2.1 T field)
- V/H aspect ratio conflicts with experiments.

Can vertical acceptance be increased?

- Increase diameter of second quad and dipole vertical extent. (small gain)
- Third quad: QQQD spectrometer, like HMS
- Try small quad between tgt and proposed 1st quad:
  - Q0: 15 cm radius, 1.2 m length
  - Rotated dipole polefaces
  - +/- 42 mr V, +/- 25 mr H
  - 12 GeV $\rightarrow$ Q0 = 2.52 T, Q1 = 3.00 T, Q2 = 1.32 T
  - Q1 limit of 8.4 T/m $\rightarrow$ P = 8.4 GeV
- Two tunes: high momentum (No Q0), Large solid angle (Q0 in)

SPECIFICATION:

Name:	B202/B203
Location:	SLAC Endstation A
Number:	2
Integral Bdl:	70 kG meter
Pole Gap:	14.8"
Pole width:	12.4"
Overall dimension:	45"x68"x147"
Max. current:	2700 A
Weight:	43 T
Cooling:	120 gpm
York type:	H
Coil style:	Window frame

OFFICIAL CONTROL TABLE

Name	B202	B203
Asse ID	PC20446	PC20448
Description	Bending Magnet	Bending Magnet
Location	061	061
Acquired	06/01/1968	06/01/1968
Cost	$99,871.11	$99,871.11
Documant ID	CEP3008	CEP3008
Inventory Date	07/31/97	07/31/97
Manufacturer	Westinghouse	Westinghouse
Profile ID	72043800	72043800

SLAC PROPERTY OFFICER

Karen Kruger
Karenk@slac.stanford.edu

Why a Cosine dipole and Cosine(2theta) quads?

*** Cold Iron Quads meet the fields but not the size**

Example HMS Q1 run at 160 % yields 9.5 T/m but
The quality is awful and there is 5 KG at the position of the beam
along the whole length !

Example HMS Q1 with a round yoke does not permit 5.5 Deg
But makes the Gradient
Cryostat mods to get 5.5 degrees are very extensive(costly)

Solution => cosine two theta quad with warm yoke

*** Conventional dipole with a SC coil a'La HMS**
2T and 6.4 M required

Too long to fit a good detector package in Hall C !
However 5.5 degrees can be reached
Magnet is huge = expensive ~ HMS dipole cost * inflation
Field quality 5 x 10(-4) drives size and cost
Conventional coils would be expensive to operate P >2MW

Solution : Cosine theta dipole , 4 T , 3.2 M eff length

SHMS-Q1 Cosine Theta Magnet

Jan 10 2000

Two cosine theta coils:
Inner radius of coil R1 = 0.25 m.
Outer radius of coil R2 = 0.28 m.
Length of coil Lc = 2.200 m

Iron Yoke:
Inner radius of yoke R1 = 0.350m
Outer radius of yoke R2 = 0.48 m.
Length of yoke Ly = 2.200 m.

Current density = 7.60E+07 A-T/m^2 (7,600 A-T/cm^2)
Two coils sectors. Angles: 0.0, 21.590, 26.075, and 33.635 degrees.
A1 = 40.6962 cm^2, A2 = 14.2502 cm^2, Total cross sectional area = 54.95 cm^2
NI/coil = 417.6 Kilo-Amps-turns /coil.
Total Amp turns = 1,670.4 Kilo-Amp-turns.

By(20,0,0) = 1.98028 Tesla
Integral By(20,0) dz = 1.994887 Telsa-meter
EFL = 2.0148 meters
Gradient = 9.9014 Tesla/meter

Central field harmonics at R=0.20 meters

n	B(n) Tesla	B(n)/B(2)
1	-3.81641E-08	-1.926E-08
2	1.98150E+00	1.000E+00
3	1.91741E-07	9.677E-08
4	1.41733E-07	7.153E-08
5	1.34818E-07	6.804E-08
6	-1.08674E-03	-5.484E-04
7	1.25426E-07	6.330E-08
8	1.49122E-07	7.526E-08
9	7.66044E-08	3.866E-08
10	-3.04790E-04	-1.538E-04
11	3.67379E-08	1.854E-08
12	3.07602E-08	1.552E-08
13	6.54856E-08	3.305E-08
14	-2.15531E-04	-1.088E-04
15	1.39397E-07	7.035E-08
16	1.92868E-07	9.733E-08
17	1.84404E-07	9.306E-08
18	-3.14639E-03	-1.588E-03
19	2.04710E-07	1.033E-07

Estimated weight of Magnet using 9 g/cc and a Volume of 1.16E+06 cc is 1.044E+07 grams (11.5 tons).

SHMS Dipole – Cosine Theta Magnet

4 sector SC cosine theta coils with warm iron yoke
good field is 80 % of coil inside radius ~ warm bore

warm bore radius 25 CM
inner coil radius 30 Cm
outer coil radius 34 Cm
Outer cryostat 49cm
Inner yoke radius 50 CM
Outer Yoke (eliptical) 110 cm vertical and 90 cm horizontal

current density 11,700 A/cm2
By(ooo) 3.75 T
Int BydL 13 T*M
Eff L 3.46 M
Bmax 4.1 T
dB/B < 4.7 x 10(-4) inside 20 cm
dB/B < 1x 10(-3) inside 25 Cm warm bore

Overall coil length/yoke length 4.2 M
Overall length ~ 5 M
Yoke weight 100 Tons (HMS dipole 500 Tons)
Coil weight ~ 16 tons (HMS dipole coil 20 Tons)

Coil sectors - degrees

1	0.00	-	26.97
2	28.89	-	43.62
3	40.4	-	59.50
4	69.45	-	74.87

" State of the art ca. 1980 "

Preliminary SHMS Specifications

Magnetic Elements (QQD):

- ~~HMS/Q1-type~~ Superconducting cos θ quadrupoles: maximum gradient ~~8.4~~ 9.9? T/m
- Resistive Dipole (SHMS-Lite): 2.05 Tesla by ~~3.148~~ 3.2 meters (eg, SLAC ESA B202)

  Superconducting Dipole (SHMS): 4. Tesla by 3.2 meters

Performance:

		SHMS-Lite	SHMS
	P_{max}	6 GeV/c	12 GeV/c
	ΔP	20% →	"
	dp/p	.1% (FWHM) →	"
	scattering angle range	5.5° to 25° →	"
± 13 – ± 17	xptar acceptance	±36 mrad or ±? mrad →	"
± 42 – ± 81	yptar acceptance	±13 mrad →	"
	xptar resolution	? mrad (FWHM) → 0.9	"
	yptar resolution	? mrad (FWHM) → 3.0	"
	ytarget range	±3.2 cm ~~±? cm →~~	"
1.7 – 4.3	solid angle	1.9 msr or ? msr →	"
	optical length	18.5 m →	"
	focal plane size	60 cm x 60 cm →	"
4.64 / 2.14	target to Q1 entrance	4.64 m or ~~3.64~~ 2.14 m →	"

Chen,
Can you supply or check any of the above numbers?
Dave

PID by TOF

Species to Separate	Acceptable Separation	Marginal Separation (3σ)
π - k	3 GeV/c	4 GeV/c
k - p	5 GeV/c	6 GeV/c

At very high momenta we will need supplemental particle identification. However, TOF thru the spectrometer with an electron time reference (basically our coincidence time) will always be essential for separating real and random coincidences.

The HMS path length is a bit longer (26m versus 22.5m for SHMS). Our conclusions still hold true.

LAYOUT OF PROPOSED SHMS