A Feasibility Study on a Neutrino Source Based on a Muon Storage Ring

General Considerations for a Muon Storage Ring Sited at Fermilab

David Finley

Outline: Choices for 50 GeV MuSR

- Ring Choices
  - Use a racetrack shaped storage ring
  - Use a limit of 6 Tesla magnetic fields in the arcs

- Site Specific Choices
  - Aim at a detector on the West coast
  - Stay above the sandstone water table and stay below the surface of the site
  - Look at Fermilab and Federal radiation rules

- Civil Construction Choices
  - Show space for "near detectors" at the top and bottom of the ring

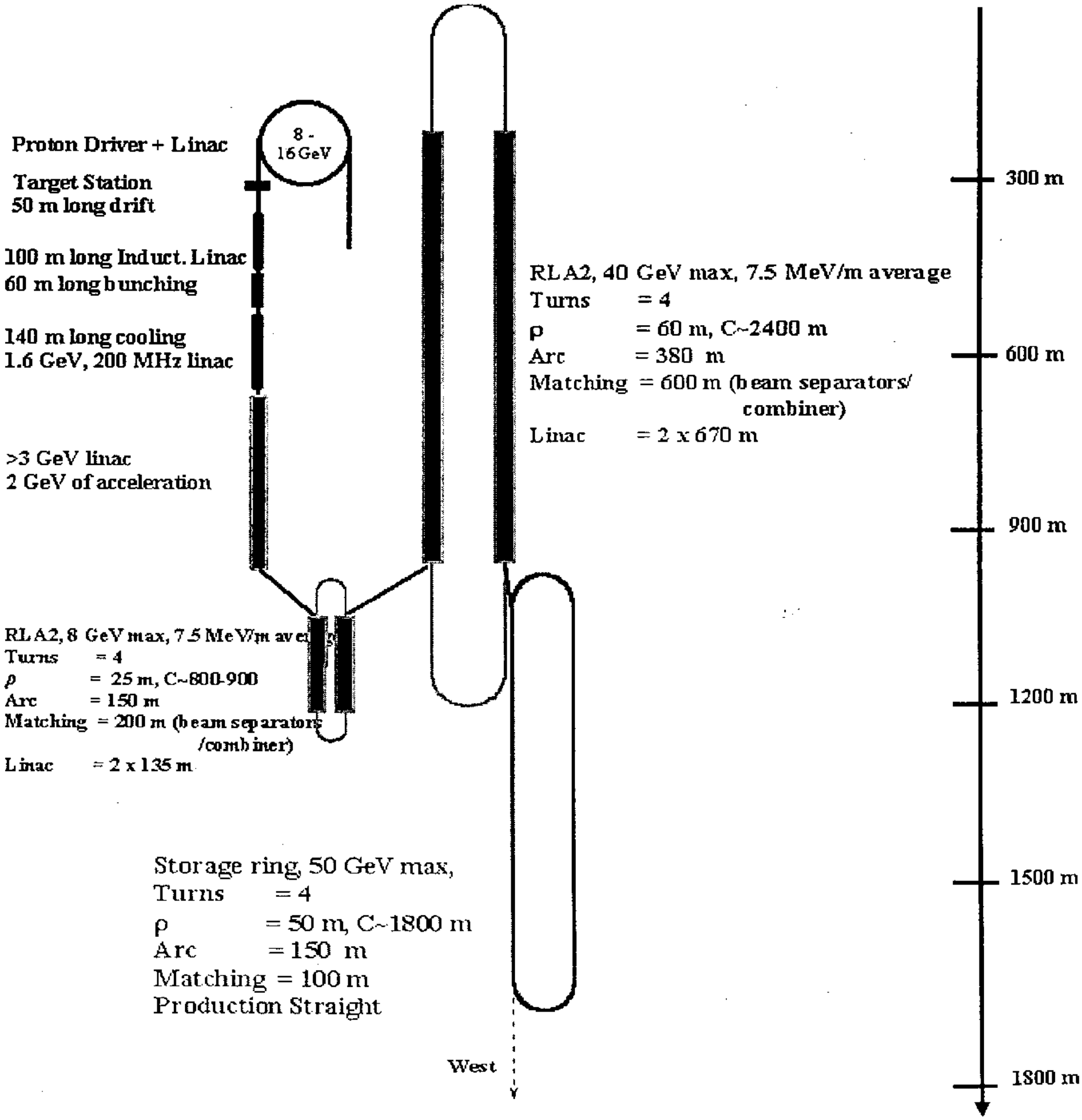
Parameter Choices for Study

Parameters for the Neutrino Source		
- Energy of the ring	**GeV**	**50**
- Number of muons decaying in straight section		**$2x10^{20}$/y**
- no polarization		
- capability to switch between μ^+ and μ^-		
- Fermilab to SLAC / LBNL		

- Basic Calculation
  - If
    - 1/3 of the muons decay in the straight section
    - 10 protons for 1 μ into the storage ring
    - $2x10^7$ sec (versus $1x10^7$) in a year
  - Then
    - $2x10^{13}$ proton on target per pulse @ 16 GeV and 15 Hz
    - $2x10^{12}$ μ per pulse to be accelerated and injected into the ring
  - Longer bunch in proton driver (1 nsec --> 3 nsec)
  - Ring tilt is 13 degrees (22%)
  - Maximize straight section / circumference

Footprint for a 50 GeV Neutrino Source

- Infrastructure is very close together ...



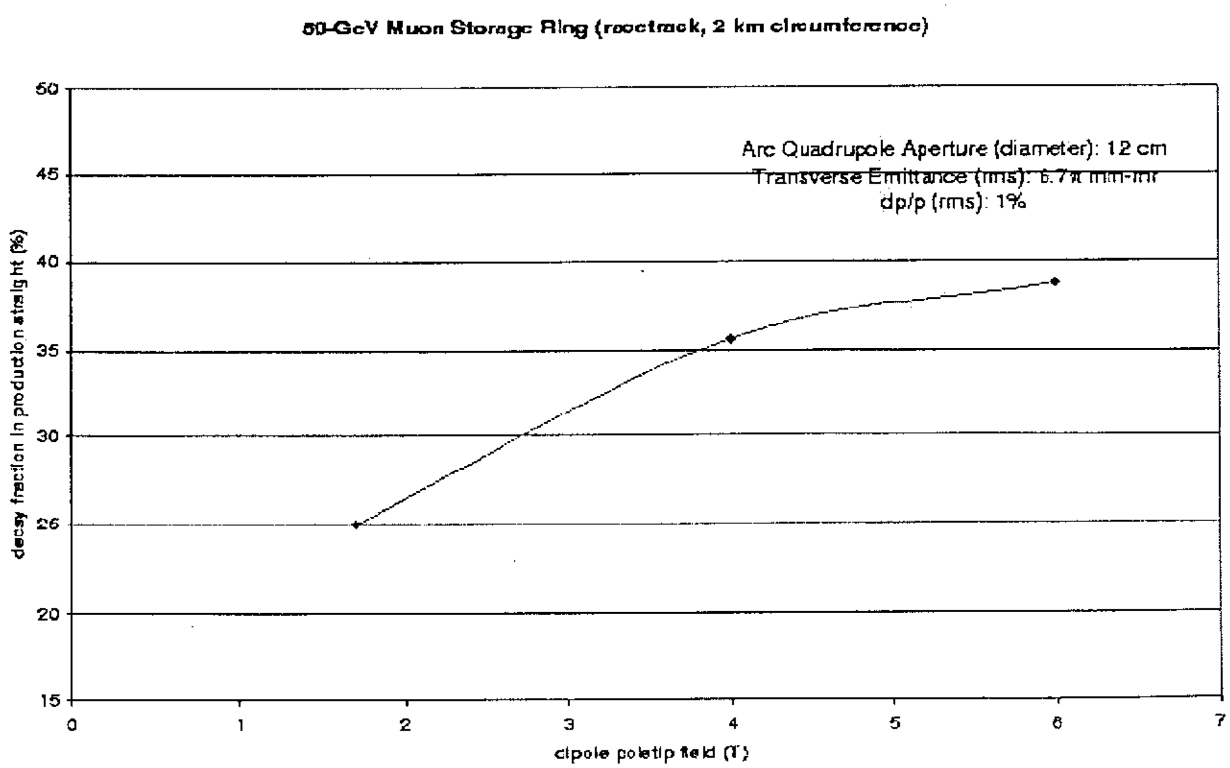
Ring Choices - 1

- Use a racetrack shaped storage ring
  - Simplest shape … to start with.
  - Maximizes number of muons decaying towards the west coast (see Rule)
  - Emittances (given in Table)
  - 50 GeV muon beam divergence is to be less than 0.2 mrad
  - Inject in downward straight section … to start with. This compromise with the neutrino beam going to the west coast is made in order to keep the injection line simple.

Optimization of the Storage Ring

- Rule: The cheapest way to produce muons decaying in the straight section is to make the straight sections as long as possible compared to the circumference.

- Efficiency = straight section / circumference
- = Length of straight / ($2\pi\rho$ + 2 x Length of straight)

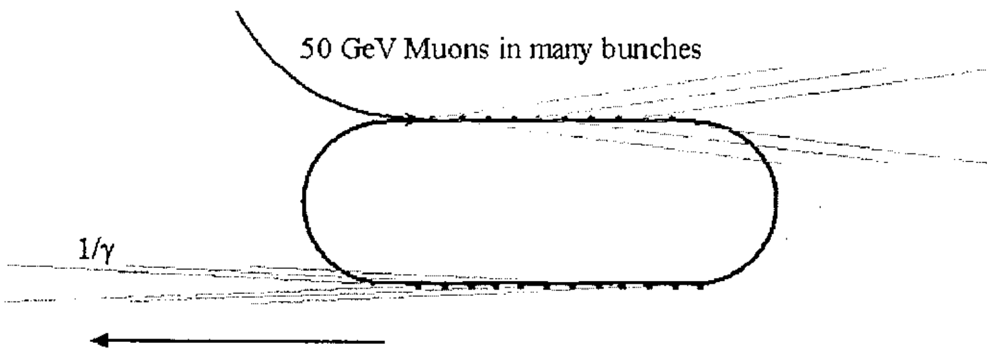


B (Tesla)

A Neutrino Source

- First experiment based on an intense muon source
  - small emittance not necessary because divergence is dominated by decay kinematics
  - recognized by S. Geer

Muon Storage Ring as a Neutrino Source



Parameters for the Muon Storage Ring		
Energy	GeV	50
decay ratio	%	>40
inv. Emittance	m*rad	**0.0032**
β in straight	m	160
N_μ/pulse	10^{12}	6
typical decay angle of μ = $1/\gamma$	mrad	2.0
Beam angle $(\sqrt{\varepsilon/\beta_0}) = (\sqrt{\varepsilon}\,\gamma)$	mrad	0.2
Lifetime $c*\gamma*\tau$	m	3×10^5

$\gamma = (1-\alpha^2)/\beta$

Ring Choices - 2

- Use a limit of 6 Tesla magnetic fields in the arcs
  - Does not push this technology for additional muon decays
  - Must handle electrons from muon decays

Large Acceptance 50-GeV Muon Storage Ring for Neutrino Production: Lattice Design, CJ2.0 *

C. Johnstone, † FNAL, Batavia, IL 60510

Table 1: Muon Storage Ring Design Parameters and Constraints

Storage Ring Geometry		racetrack
Storage Ring Energy	GeV	50
Vertical Descent Limit	m	≈183
Declination Angle	deg	≈13
Cross-sectional profile	m	813
ϵ_{rms} (normalized)	mm-rad	3.2π
dp/p (rms)	%	1
maximum poletip field	T	6.0
arc cell phase advance	deg	90

Table 2: Parameters of the large-momentum acceptance arc cells for a 50-GeV muon storage ring

General: tungsten shield thickness	cm	1.0
beam-stay clear	cm	1.0
intermagnet spacing	m	0.75
Dipoles:		
dipole length	m	2.4
dipole bend	rad	0.0859
dipole field	T	6.0
beam size (6σ, max), WxH	cm	8.0x5.3
dipole full aperture**, WxH	cm	12x9.3
sagitta	cm	2.67
Quadrupoles:		
quadrupole length	m	1
arc quadrupole strength	m^{-2}	.31
arc quadrupole poletip field	T	3.6
beam size (6σ), WxH		
F quad	cm	9.2x2.6
D quad	cm	4.2x6.2
arc quadrupole bore**	cm	14
Sextupoles (overlay on quad field)		
horiz. sextupole strength	m^{-2}	0.64
vert. sextupole strength	m^{-2}	1.26
horiz. sextupole poletip field	T	.52
vert. sextupole poletip field	T	1.03
Arc FODO cell parameters:		
cell length	m	9.8
cell phase advance	deg	90
β_{max}	m	16.2
$D_x(max)$	m	1.3
total number arc cells		31

**aperture = beam size + liner thickness + beam-stay-clear

Table 3: Parameters of the high-beta cells for neutrino production in a 50-GeV muon storage ring

drift length	m	65.8
quadrupole length	m	3
quadrupole strength	m^{-2}	0.0019
quadrupole poletip field	T	0.05
quadrupole bore	cm	33
total cell length	m	137.6
cell phase advance	deg	≈ 22
β_{max}	m	436.0
rms divergence	mr	0.20
number of high-beta cells		5

Table 4: Parameters of cells in return straight of 50-GeV muon storage ring

cell length	m	50.78
quadrupole length	m	1
quadrupole strength	m^{-2}	0.056
quadrupole poletip field	T	0.84
quadrupole bore	cm	18
cell phase advance	deg	90
β_{max}	m	86.3
rms divergence	mr	0.73
number of cells		12

Table 5: Storage Ring Parameters at 50-GeV

Circumference	m	1752.8
Neutrino decay fraction		39.2%
Production region:		
matching and dispersion suppression	m	44.1
High-β FODO straight	m	688
$\beta_{xmax}/\beta_{ymax}$	m	435/484
$\nu_x/\nu y$		13.63/13.31
natural chromaticity		-23.9/-23.9

* Work supported by the U.S. Department of Energy under contract No. DE-AC02-76HO3000

† email: cjj@fnal.gov

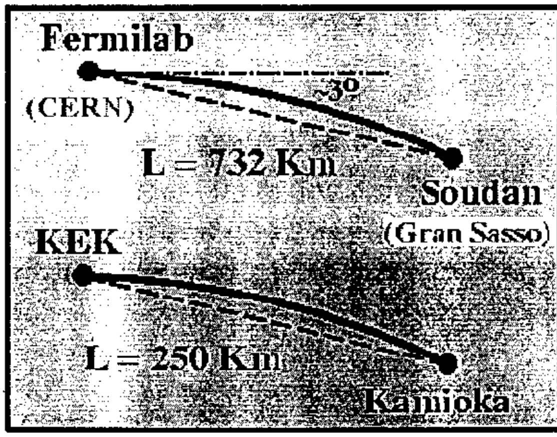
Site Specific Choices

- Aim at a detector on the West coast
  - 13 degree slope in straight section
- Stay above the sandstone water table and stay below the surface of the site
  - 680 foot vertical drop
- 13 degrees and 680 feet (minus 80 feet) give
  - The "profile" of 813 meters
- Look at Fermilab and Federal radiation rules
  - 10 mrem / year and 100 mrem / year
  - determines distances from site boundary

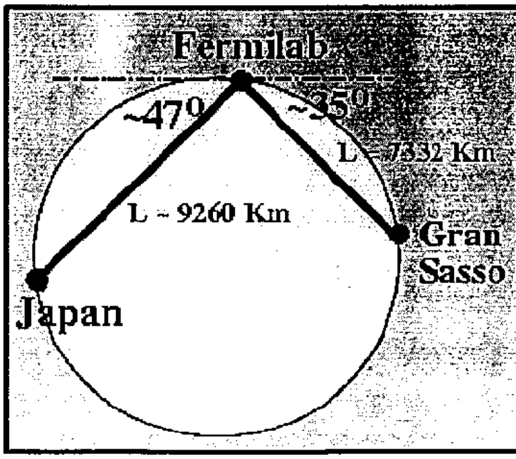
L/E and Other Physics Guidance

- Purity of the beam: μ^+/μ^- -> $e^{+/-}\nu_e/\nu_\mu$
- Kinematics from decay well known
- Polarization -> oscillation of ν_e component

	L (km)	Dip (Deg.)	Heading (Deg.)
FNAL -> Soudan	732	3	336
FNAL -> Gran Sasso	7332	35	50
FNAL -> Kamioka	9263	47	325

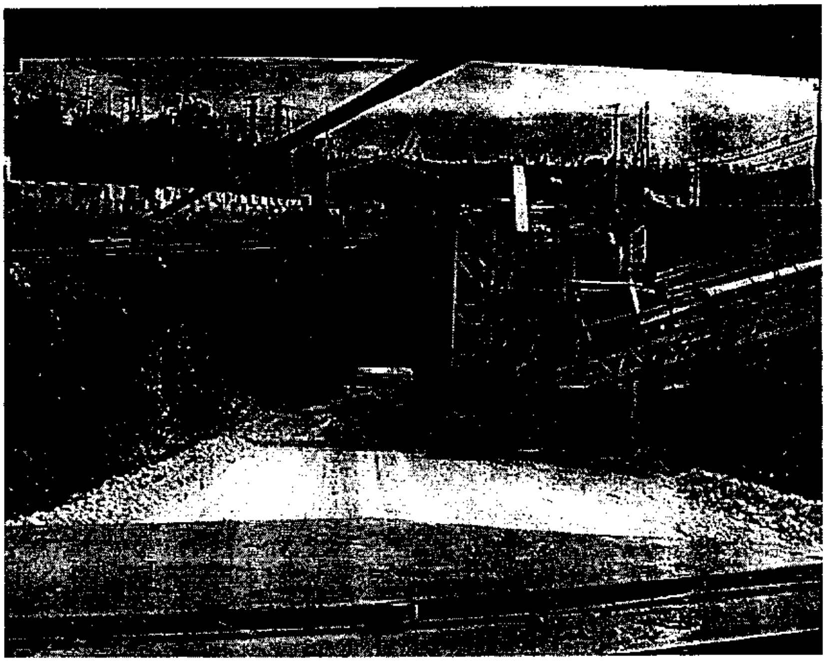


E_ν (GeV)	L/E (Km/GeV)	
	FNAL–Soudan	KEK–Kam.
10	73.2	25.0
20	36.6	12.5
30	24.4	8.3
40	18.3	6.3
50	14.6	5.0

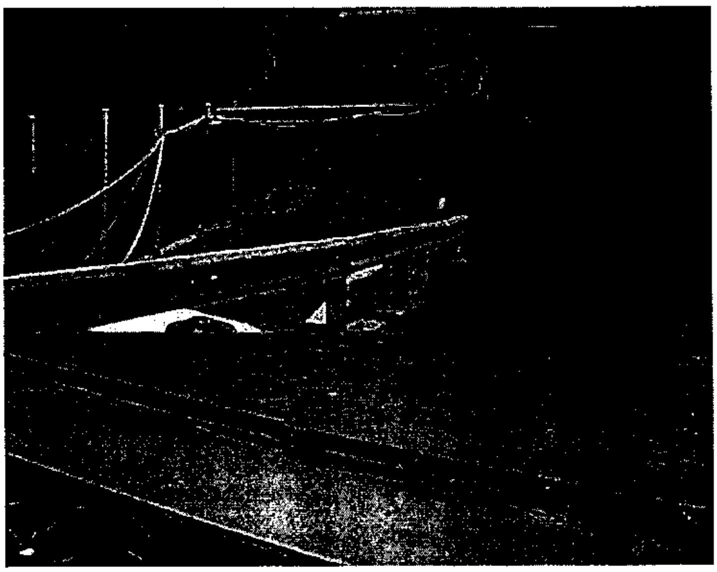


E_ν (GeV)	L/E (Km/GeV)	
	Gran S.	Japan
10	~733	~926
20	~367	~463
30	~244	~309
40	~183	~232
50	~145	~185

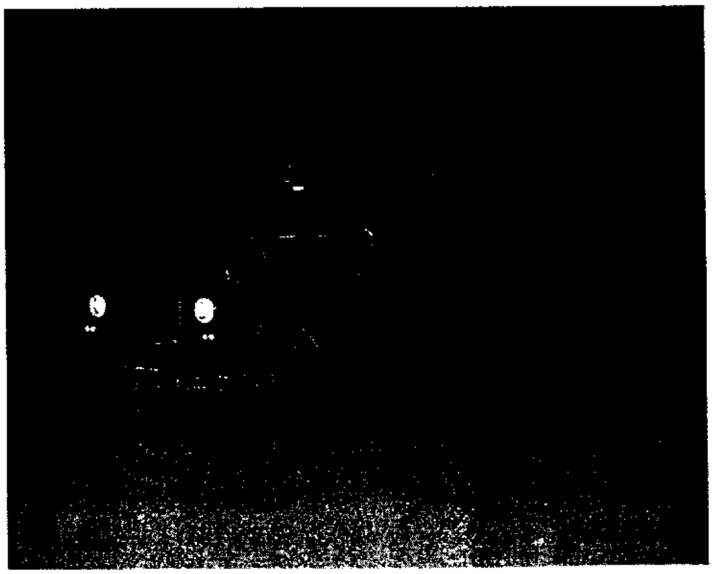
How Steep is 22%?



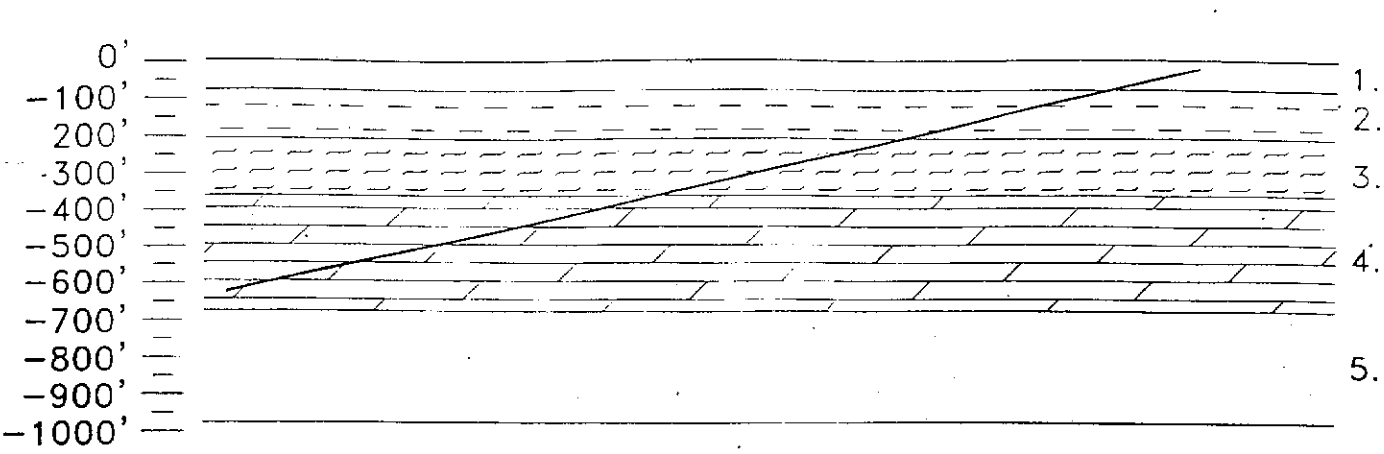
- 17 % into a quarry
- there is water !
- incremental cost small compared making more ν
- extend the ring up to the surface



Further down the ramp



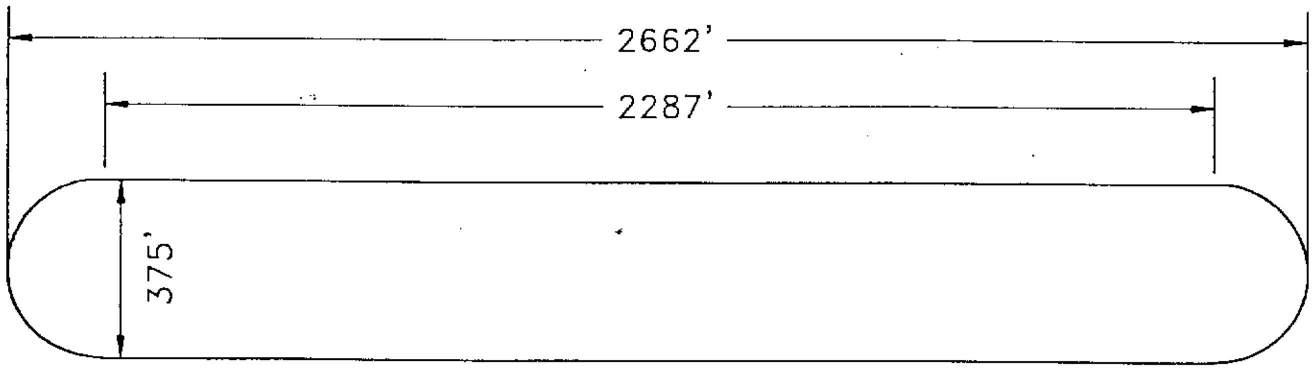
Use vehicles



GEOLOGY DETAIL

1"=100'-0"

1. GLACIAL TILL – AQUIFER
2. SILURIAN GROUP – AQUIFER (PRIMARILY DOLOMITE)
3. MAQUOKETA GROUP – AQUIFER (PRIMARILY SHALE)
4. GALENA / PLATTEVILLE GROUP – AQUATARD (PRIMARILY DOLOMITE)
5. ANCEL GROUP – AQUIFER (PRIMARILY SANDSTONE)



39.8% = (ONE STRAIGHT SECTION/PERIMETER)*100

CJ 2.0 LATTICE PLAN

N.T.S.

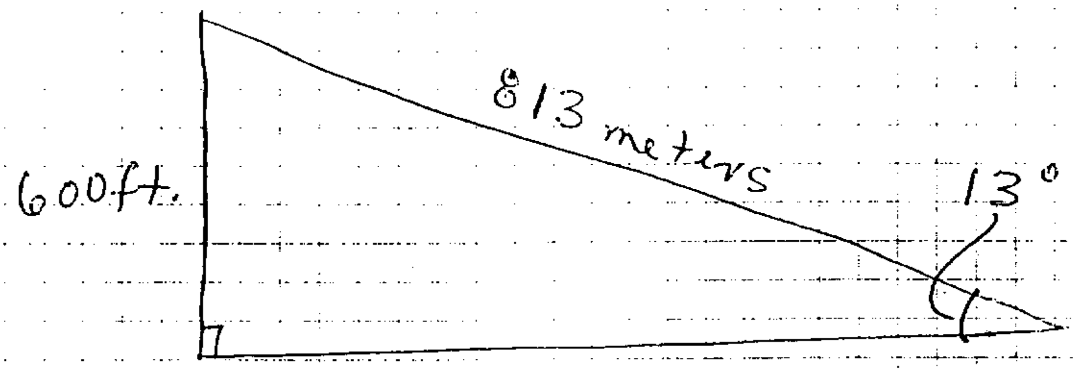
ORIENTATION:

NAME	AZIMUTH (DEG–MIN–SEC)	VERT. ANGLE (DEG–MIN–SEC)
PALO ALTO CA.	271–20'–42.27"	–13–09'–26.99"

MuSR
CTE 9-NOV-99

6 OCT 99

MuSR Profile

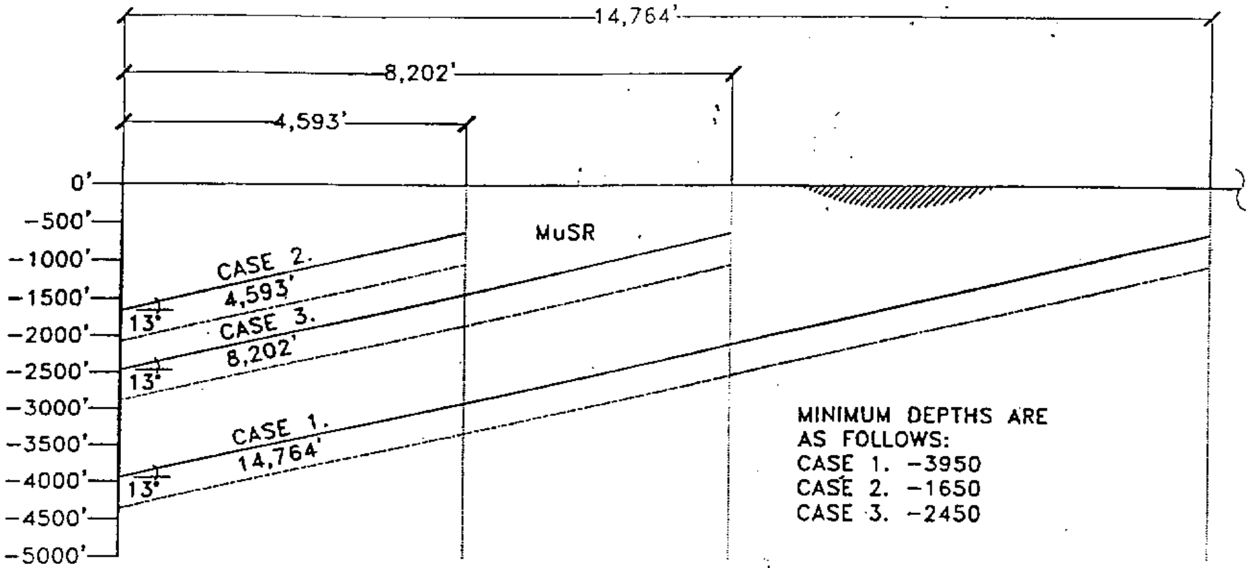


600 feet Ring vertical drop.
10 feet Tunnel ceiling to floor
10 feet Shielding above ring
50 feet Undisturbed bottom layer of Galena Platteville
10 feet For uncertainties in above three numbers

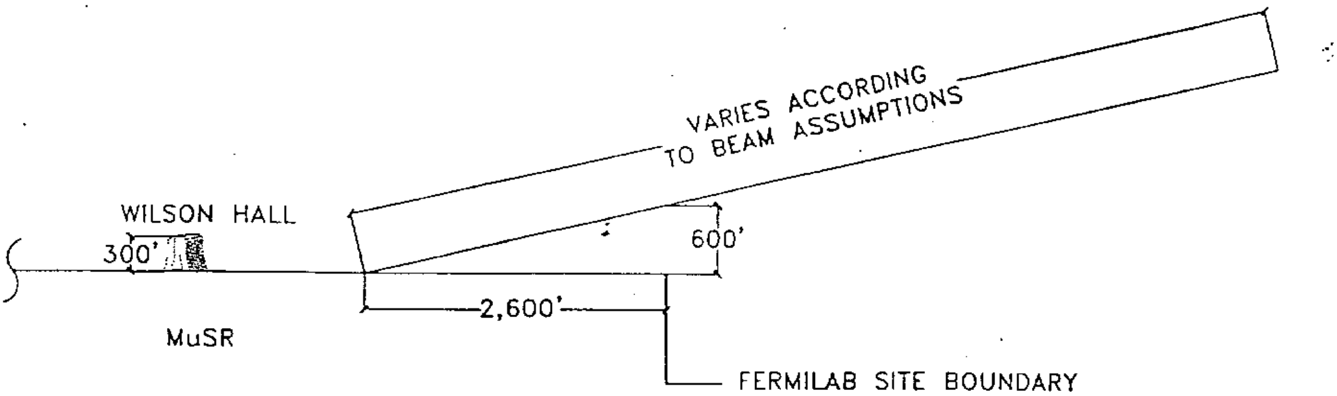
680 feet Surface to Bottom of Galena Platteville

1 NOV 99: Chris Erickson uses 13° 9' 26.99" for the dip angle to SLAC.

WEST BOUNDARY CONSTRAINTS



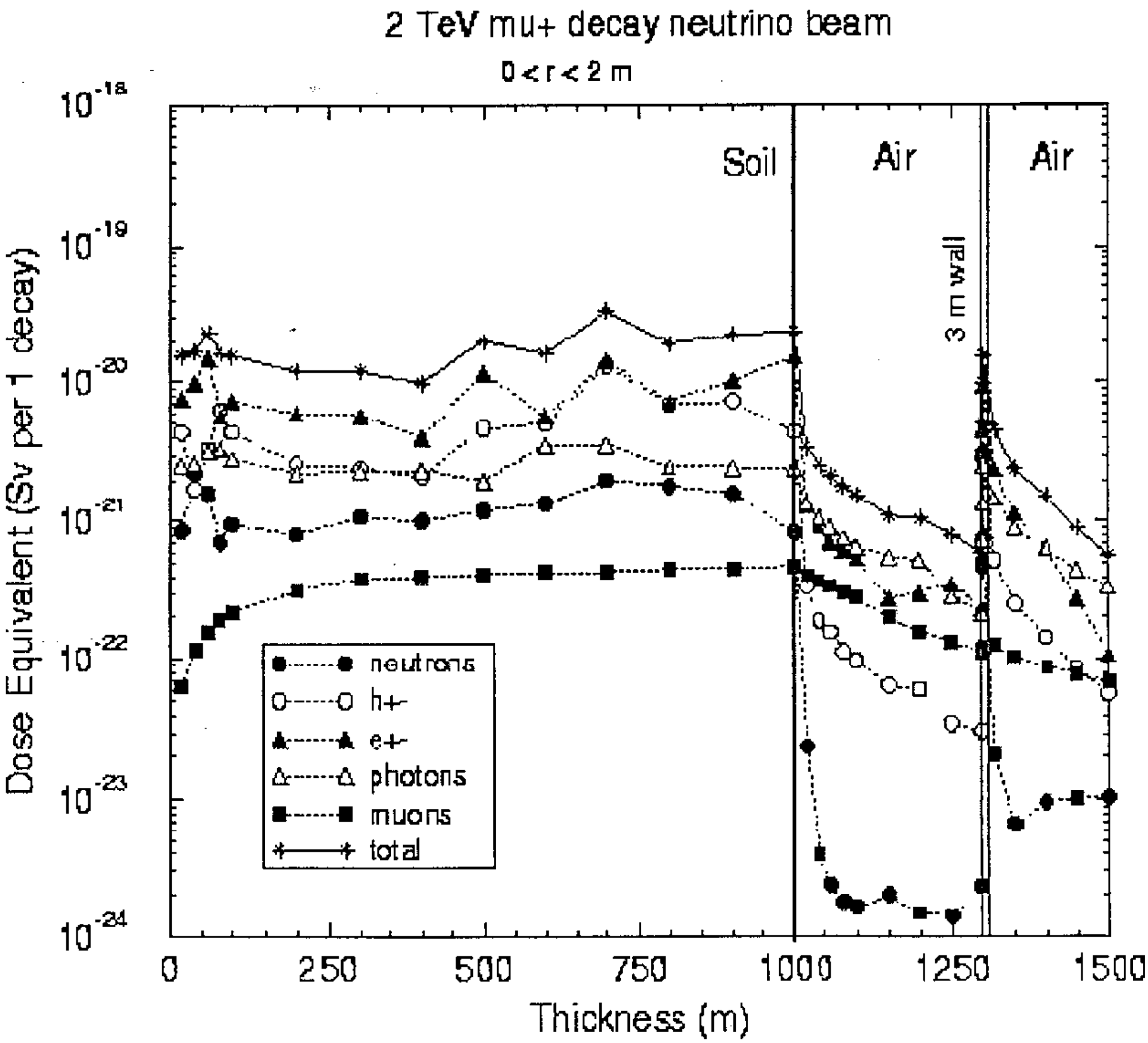
EAST BOUNDARY CONSTRAINTS

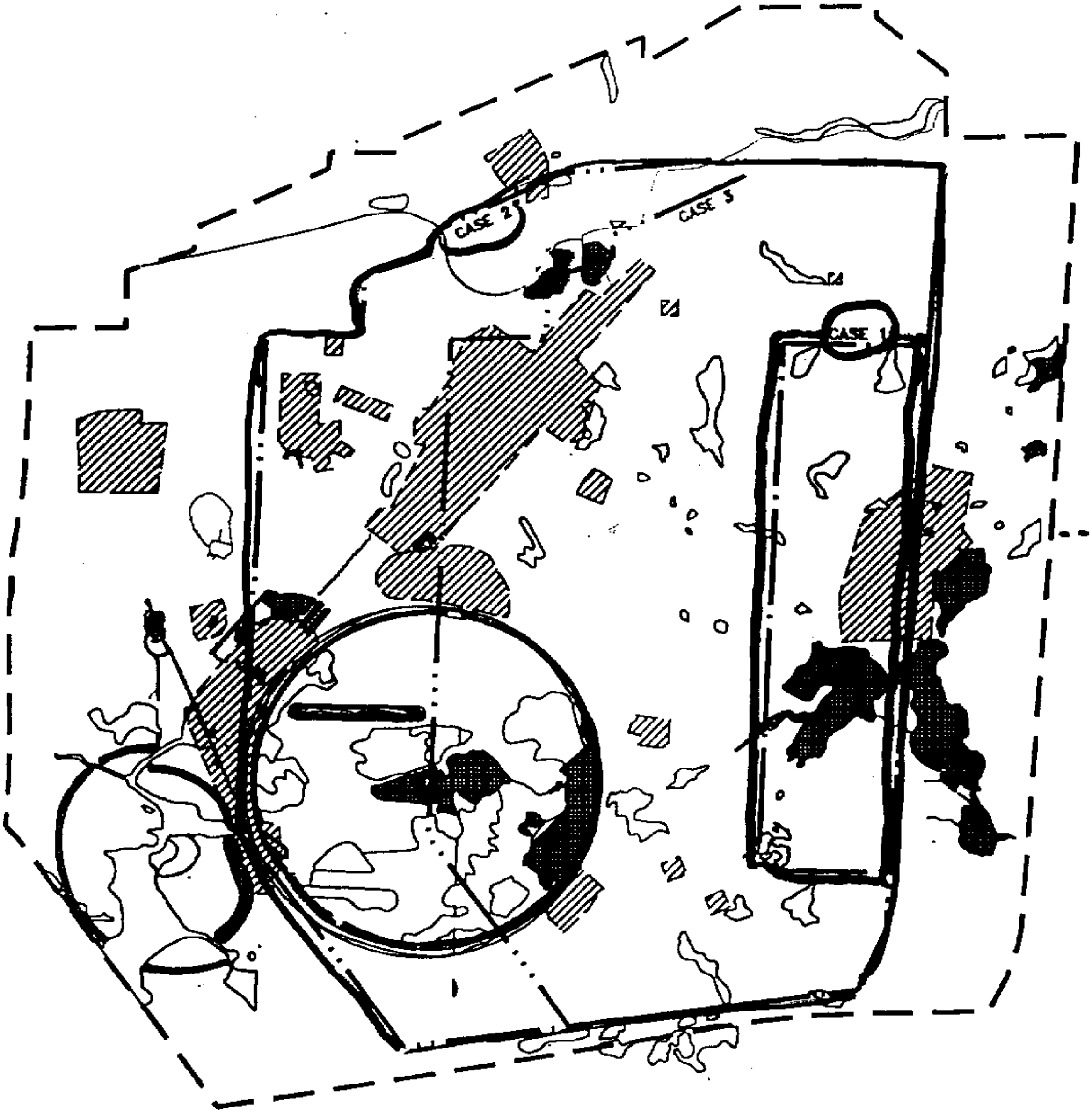


LIMITS:	mrem/year	CONTROL CYL.	
CASE 1. 50GeV	10	4.5KM	RADIUS=4.0M
CASE 2. 50GeV	100	1.4KM	RADIUS=1.2M
CASE 3. 30GeV	10	2.5KM	RADIUS=5.0M

MuSR
CTE 1-NOV-99

Upgoing Neutrino Radiation II





LEGEND:

LIMITS CASE 1.

LIMITS CASE 2.

LIMITS CASE 3.

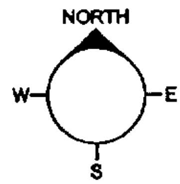
SITE BOUNDARY

LOCATION LIMITS

WETLAND LIMITS

LOCATION HATCH

WETLAND HATCH



LIMITS:		mrem/year		CONTROL CYL.
CASE 1.	50GeV	10	4.5KM	RADIUS=4.0M
CASE 2.	50GeV	100	1.4KM	RADIUS=1.2M
CASE 3.	30GeV	10	2.5KM	RADIUS=5.0M

MuSR

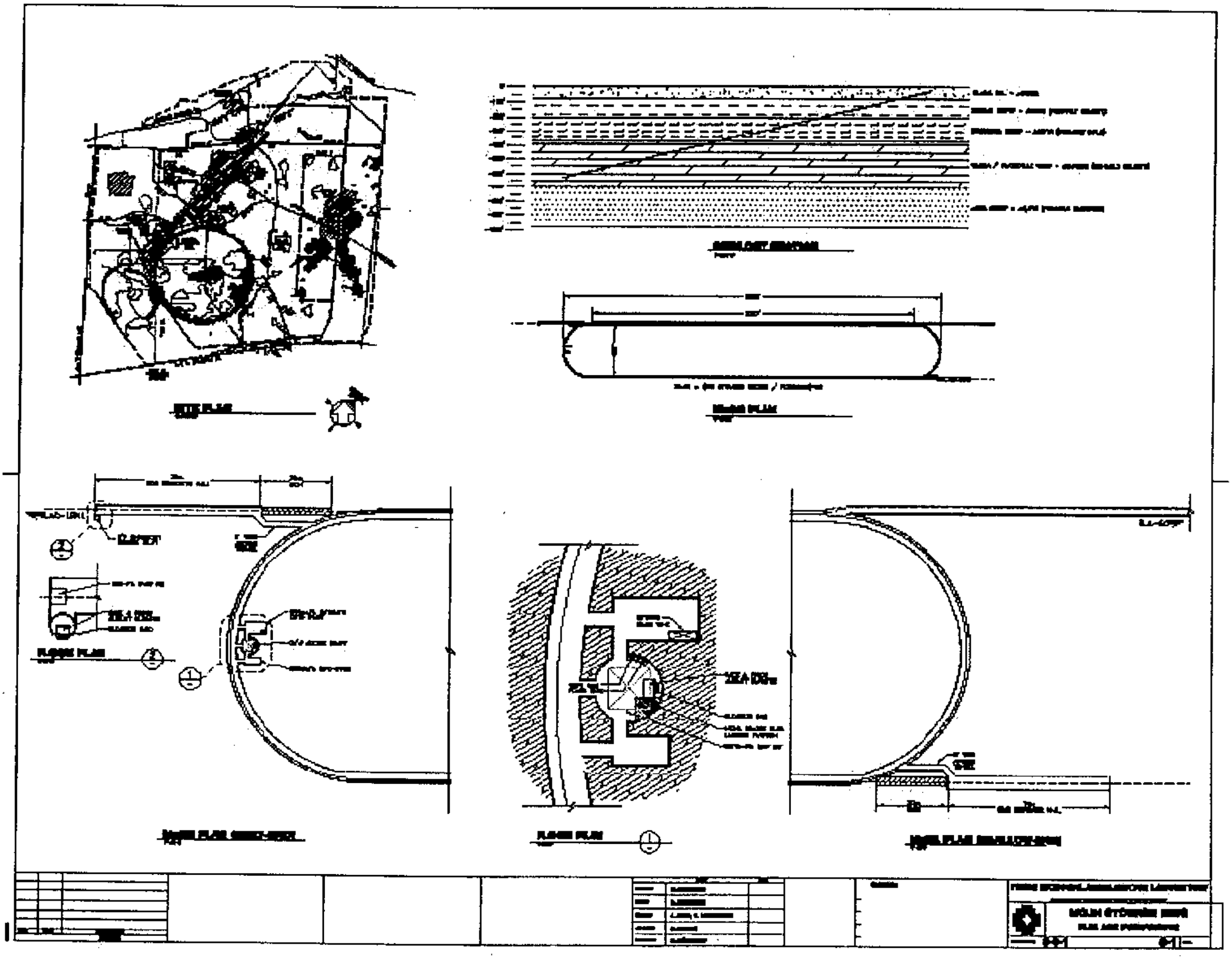
CTE 15-OCT-99

Civil Construction Choices

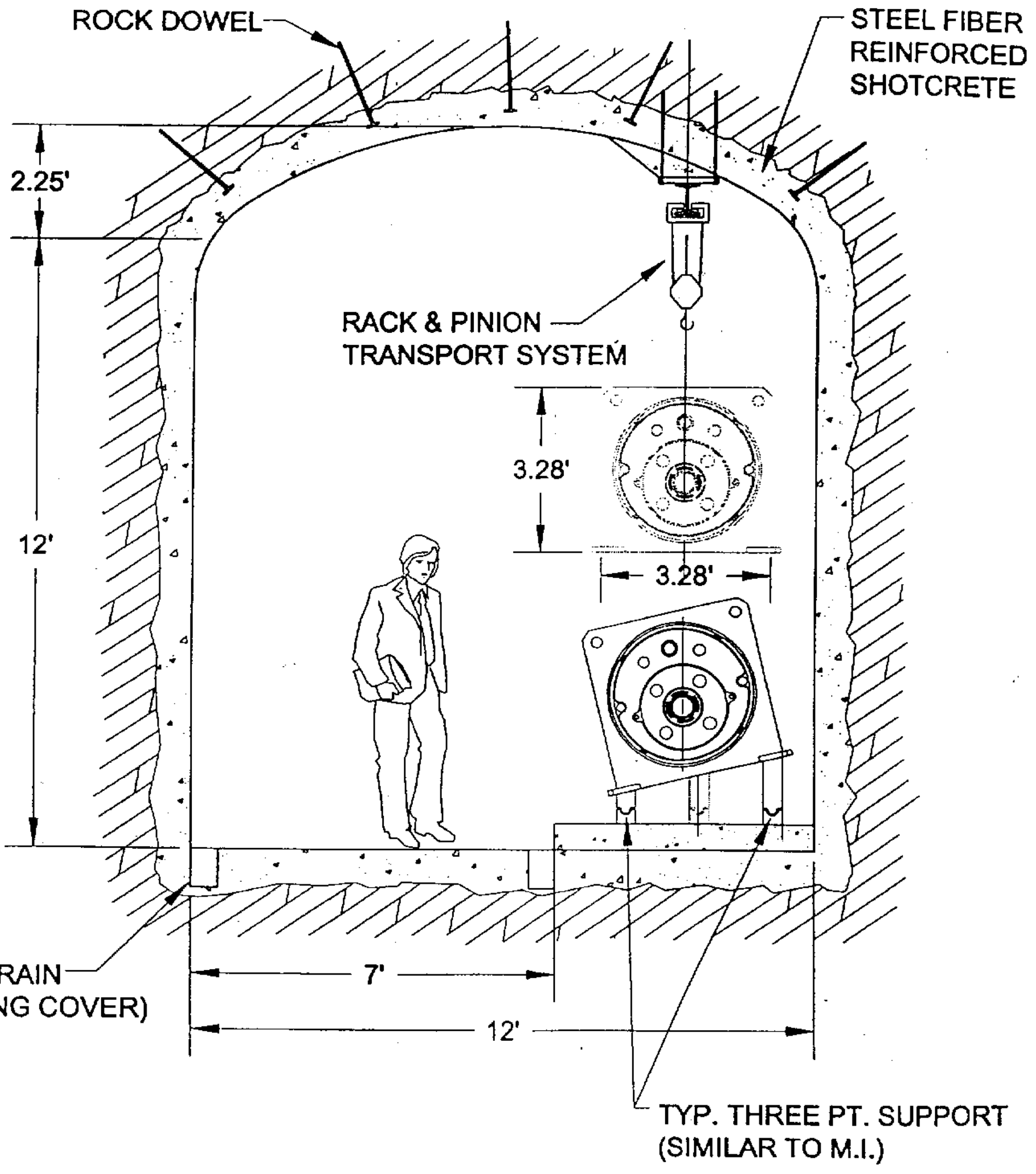
- Show space for "near detectors" at the top and bottom of the ring
  - Not developed so far, just indicated

- Also
  - Chose tunnel cross sections similar to previous construction (like NuMI)
  - Go as close to the surface as possible because it (very probably) costs less to let muons decay in the MuSR than it does to get more of them into the MuSR

Storage Ring Layout



TUNNEL CROSS-SECTION (ARC APEX)



CEILING GEOMETRY BASED ON NUMI DECAY TUNNEL SECTIONS (PROJ: 6-7-4)

MuSR
CTE 9-NOV-99

R&D for Storage Ring

- Since the 50 GeV storage ring is not a cost driver, the R&D should be aimed at reducing technical risk or increasing performance

  - Muon Beam Instrumentation (research)
    - What do the detectors need to know about the neutrino beam? See S. Geer list of "Required Precision" and "Flux Systematics"
    - What is needed to operate the (entire) facility?

  - Specification of magnet fields for "storage" of large emittance, 6D, not-linear beams (research)

  - (If / When needed) Preservation and Measurement of polarization (research)

  - When the appropriate time comes, development of engineering designs (development)