The Muon Storage Ring Design

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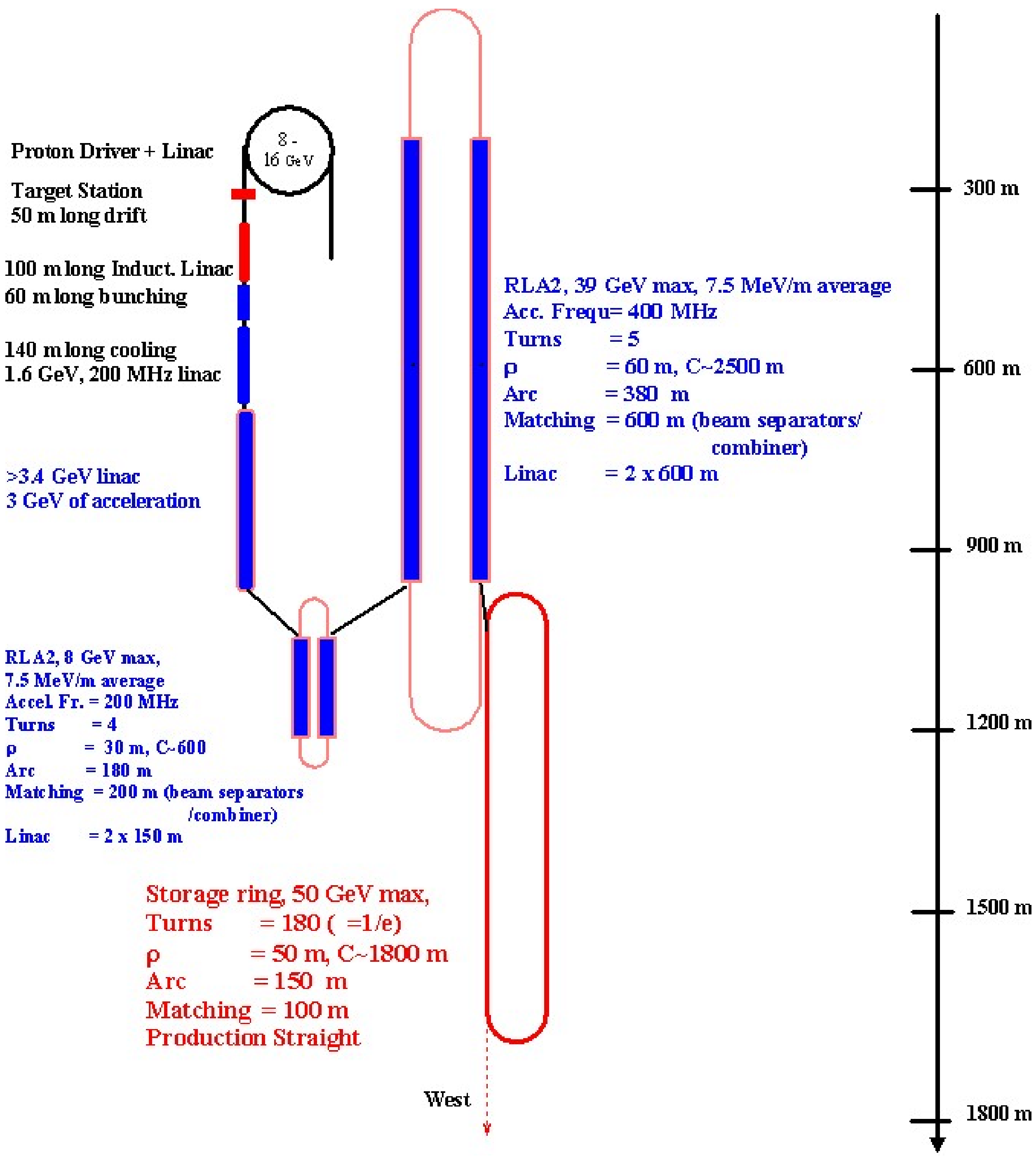
- Introduction
- Basic Parameters
- Tracking and Beam Stability
- Polarization
- Technical Feasibility
- Cost
- Further Work

Footprint for a 50 GeV Neutrino Source

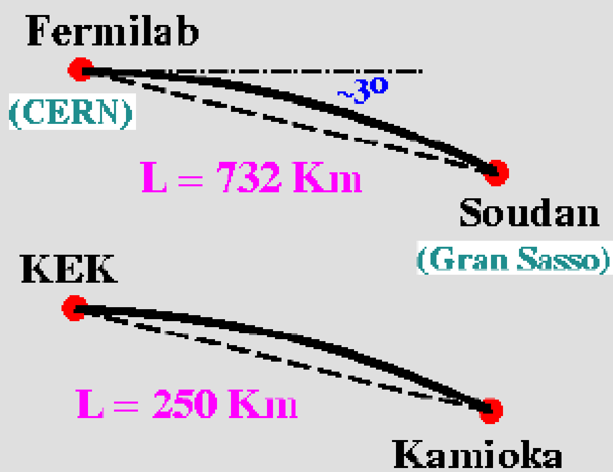
- ⇒ Direction of P beam on target defines layout
- Ring is not largest facility and comparatively conventional
- Racetrack “requires” injection into downward straight



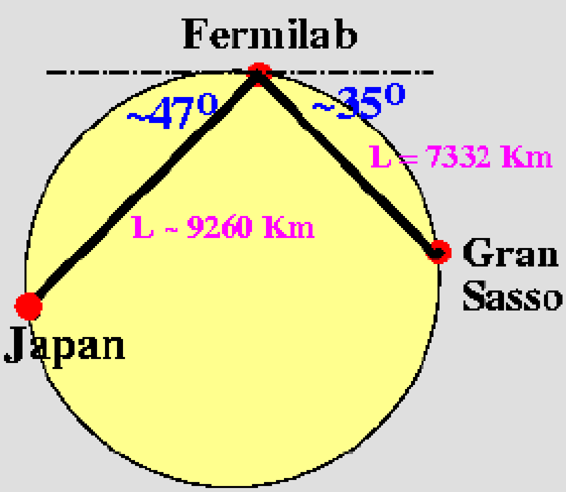
The Energy Choice, the Experiment and the Options

- Choice of baseline beam line angle are connected

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

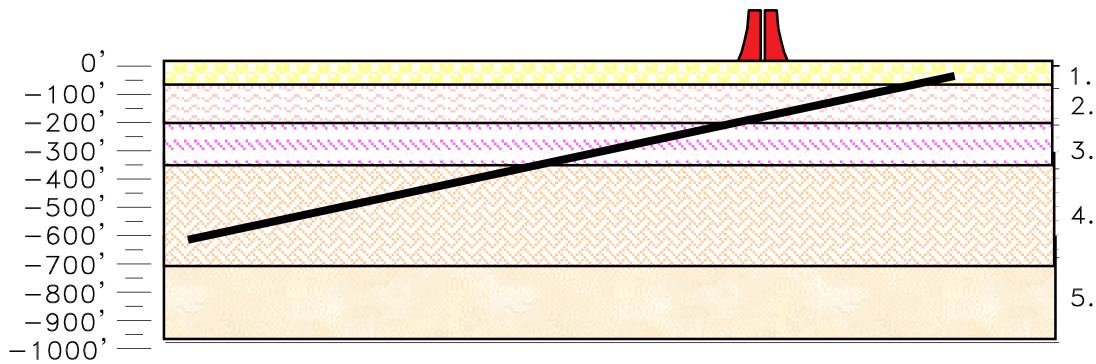


E_ν (GeV)	L/E (Km/GeV) FNAL–Soudan	KEK–Kam.
10	73.2	25.0
20	36.6	12.5
30	24.4	8.3
40	18.3	6.3
50	14.6	5.0



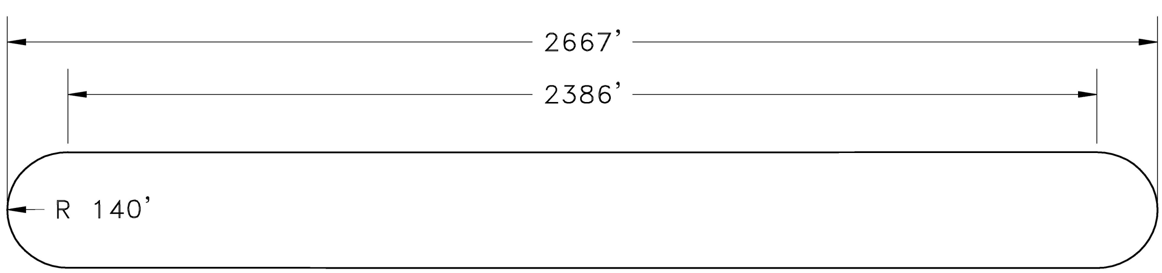
E_ν (GeV)	L/E (Km/GeV) Gran S.	Japan
10	~733	~926
20	~367	~463
30	~244	~309
40	~183	~232
50	~145	~185

What is Site Specific ?



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)



CE 2.1 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"

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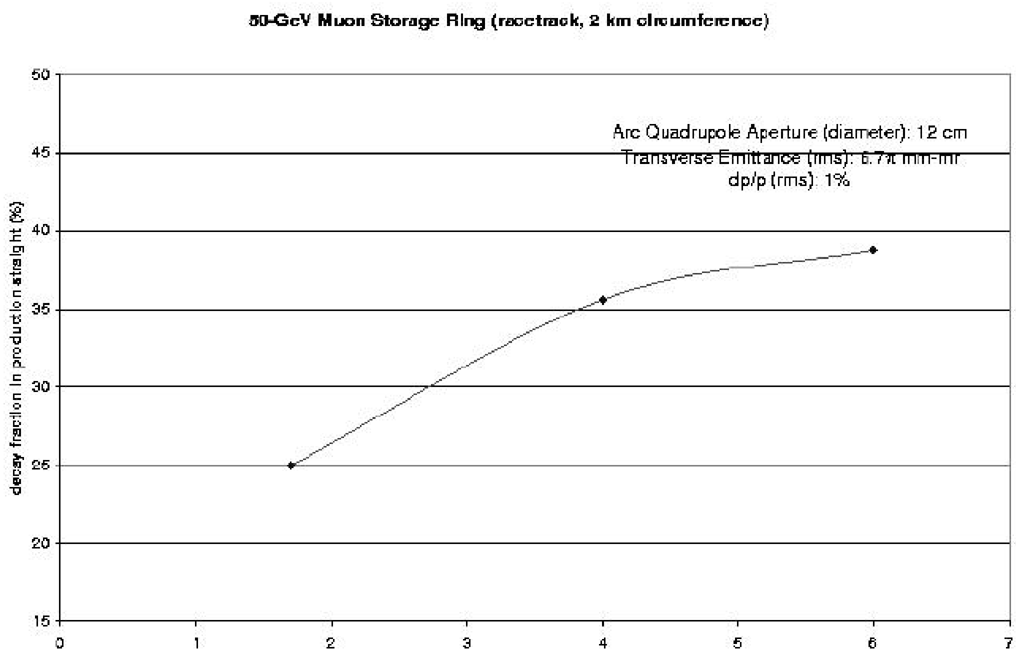
Optimization of the Storage Ring

- The cheapest way to produce neutrinos is to make the straight section as long as possible !

$$\eta = \frac{\text{Nr of } \mu \text{ decaying in straight section}}{\text{Nr of } \mu \text{ injected}}$$

L=length of straight

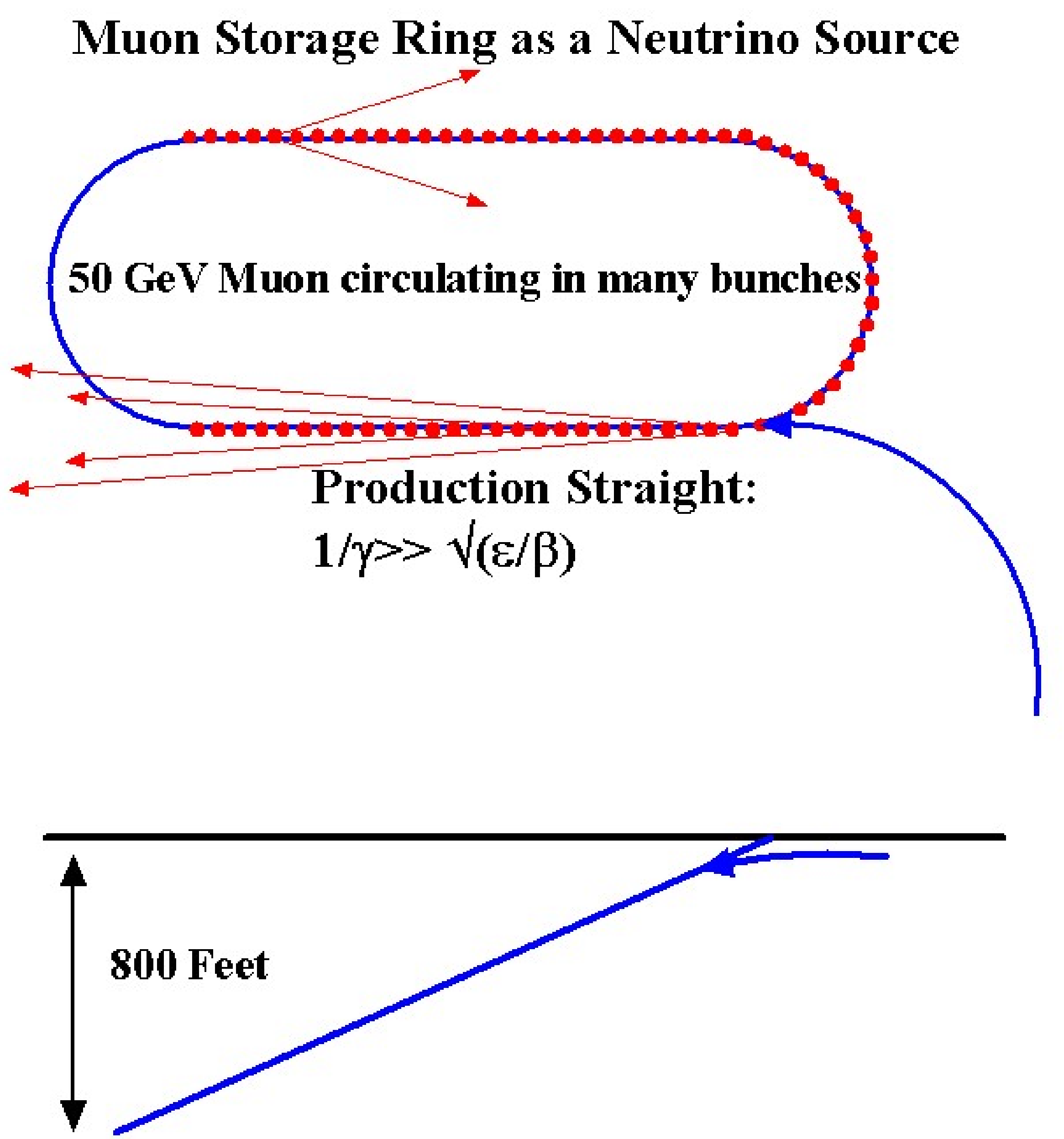
$$\eta = \frac{1}{2\,(1+\pi\,\rho\,/L)} = \frac{1}{2\,(1+0.2)}$$



B / Tesla

Conceptual Layout of the Muon Storage Ring

- Circumference larger than bunch train:
  - Easy injection (long rise, short fall time of kicker)
- Injection into downward straight:
  - Injection line is natural ⇒ very close to the surface

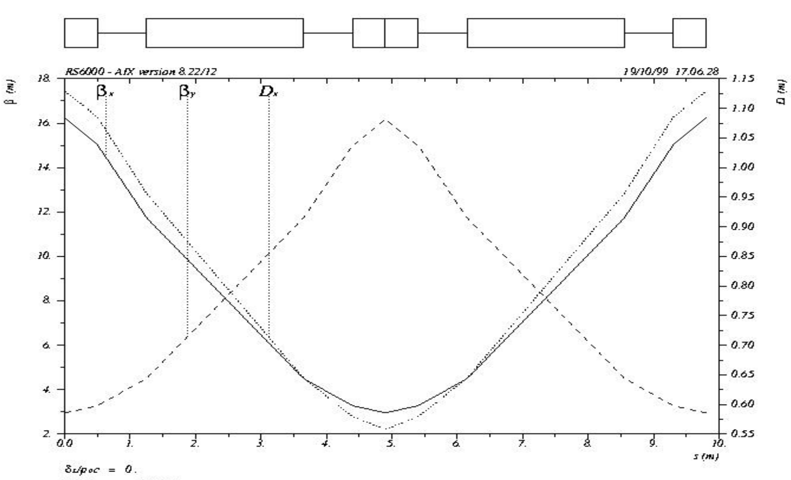


Storage Ring Parameters

Parameters for the Muon Storage Ring		
Energy	GeV	50
decay ratio	%	38
Designed for inv. Emittance	m*rad	**0.0032**
Cooling designed for inv. Emitt.	m*rad	**0.0016**
Momentum Acceptance	% (rms)	1
β in straight	m	~400
N_μ/pulse	10^{12}	~2
typical decay angle of $\mu = 1/\gamma$	mrad	2.0
Beam angle $(\sqrt{\varepsilon}/\beta_o) = (\sqrt{\varepsilon\,\gamma_\beta})$	mrad	0.2
Lifetime $c*\gamma*\tau$	m	$3\text{x}10^5$

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

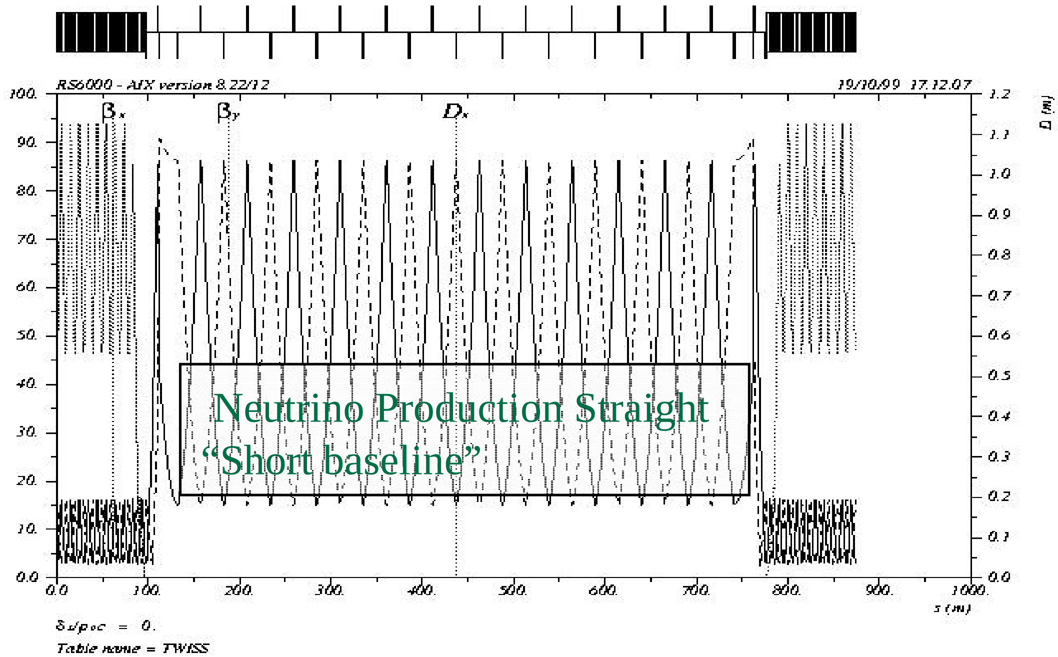
General		
Tungsten shield thickness	cm	1.0
Beam-stay-clear	cm	1.0
Inter magnet spacing	m	0.75
Dipoles		
Dipole length	m	2.4
Dipole bend	rad	0.0859
Dipole field	T	6.0
Beam size (6σ) WxH	cm	8.0x5.3
Dipole full aperture, WxH	cm	12x9.3
Sagitta	cm	2.67
Quadrupoles		
Quadrupole length	m	1.0
Quadrupole strength	m-2	0.31
Quadrupole poletip field	T	3.6
Beam size (6σ) WxH:		
F quad	cm	9.2x2.6
D quad	cm	4.2x6.2
Quadrupole bore	cm	14
Sextupoles (overlay on quad field)		
Horiz. Sextupole strength	m-3	0.64
Vert. Sextupole strength	m-3	1.26
Horiz. Sextupole field	T	0.52
Vert. Sextupole field	T	1.03
Arc FODO cell parameters		
Cell length	m	9.8
Cell phase advance	deg	90
β(max)	m	16.2
Dx(max)	m	1.3
Total number of arc cells		31



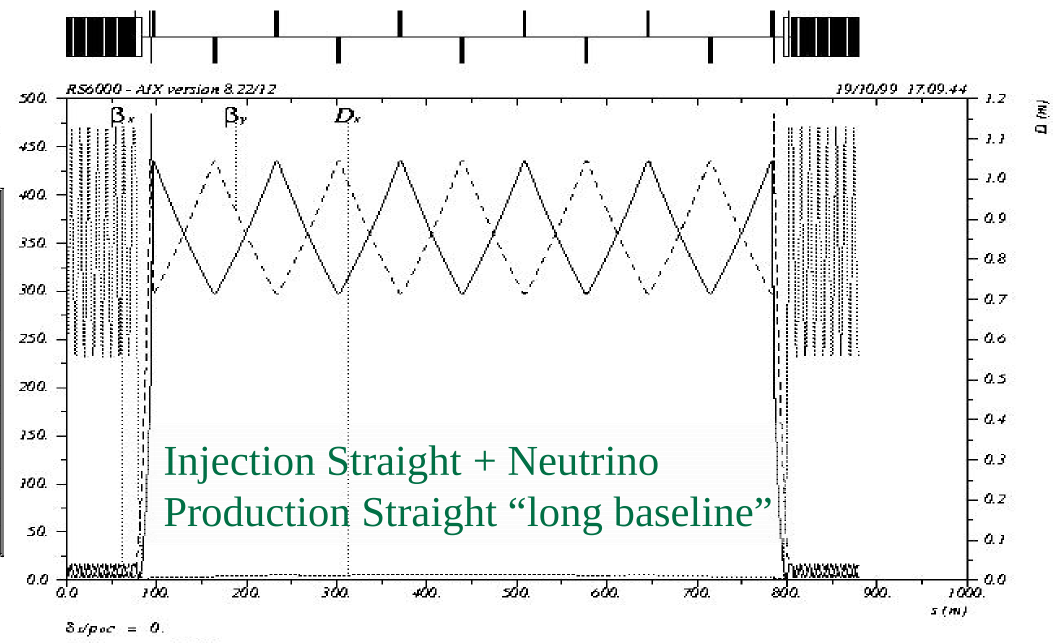
β function for one arc cell

A Storage Ring for 2 Experiments

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

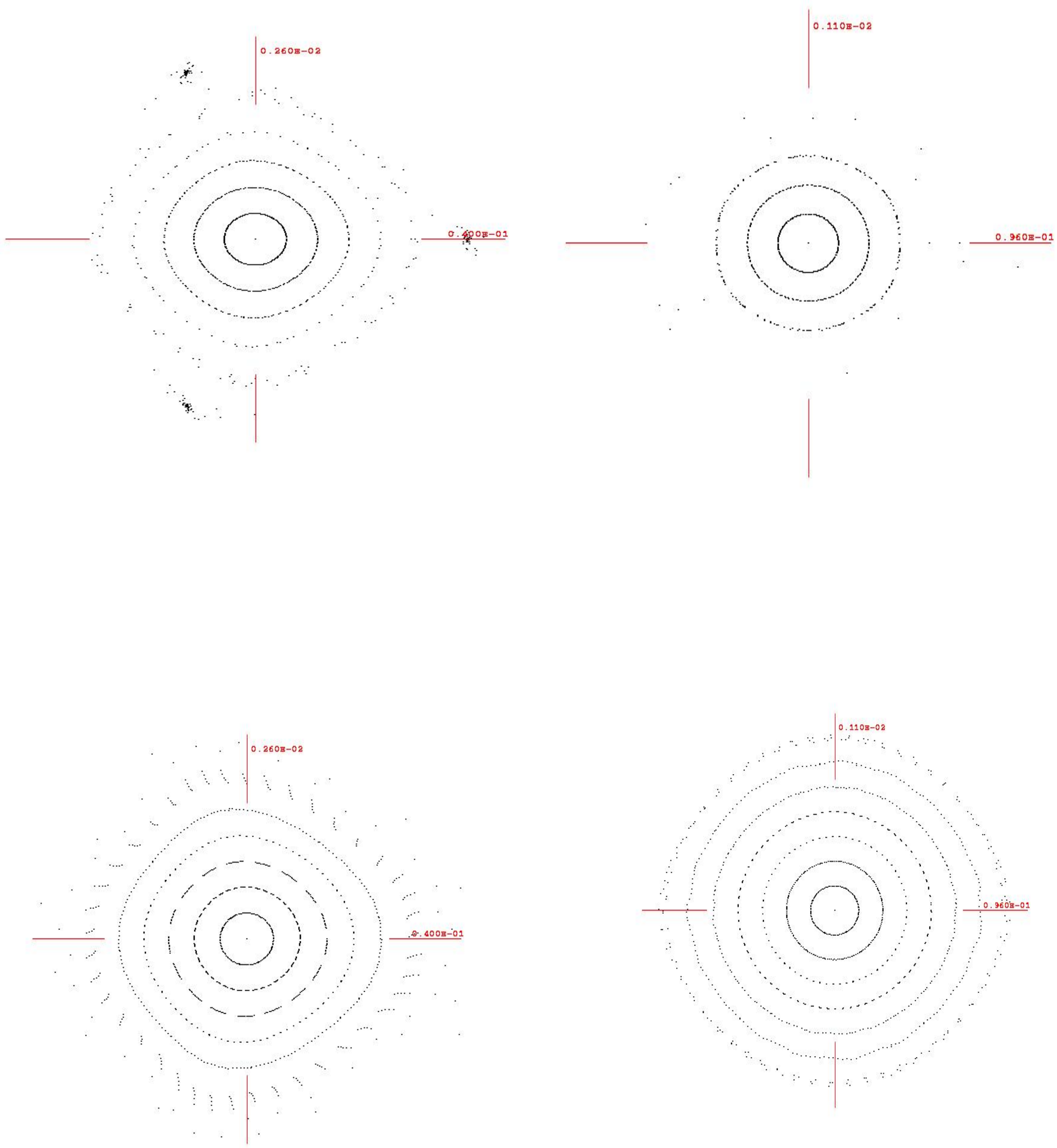


Cell length	m	137.6
Quadrupole length	m	3
Quadrupole strength	m-2	0.0019
Quadrupole poletip field	T	0.05
Quadrupole bore	cm	33
Cell phase advance	deg	≈22
β(max)	m	436.0
rms divergence	mr	0.20
Number of cells		5



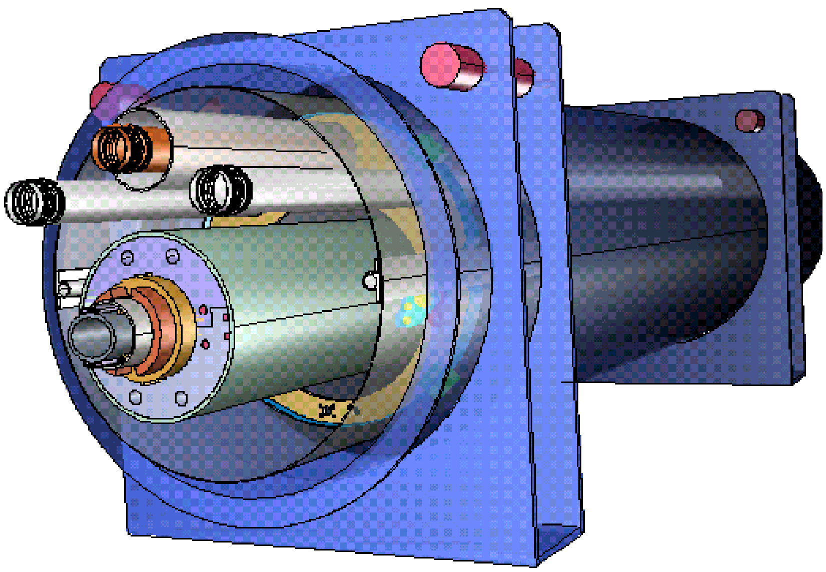
Tracking

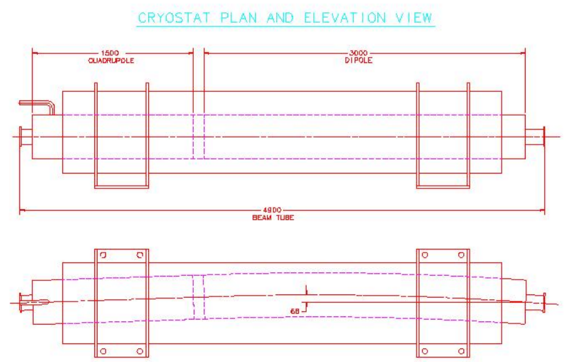
Top: Horizontal (left) and vertical (right) accepted phase space plots obtained by 9th order tracking including chromatic correction sextupoles and quadrupole fringe fields. Tracking is plotted in steps of 0.5 σ for an normalized emittance (rms) of 3200 π mm-mr. Bottom: Same as top plots but with quadrupole fringe fields in the matching sections to the production straight turned off.

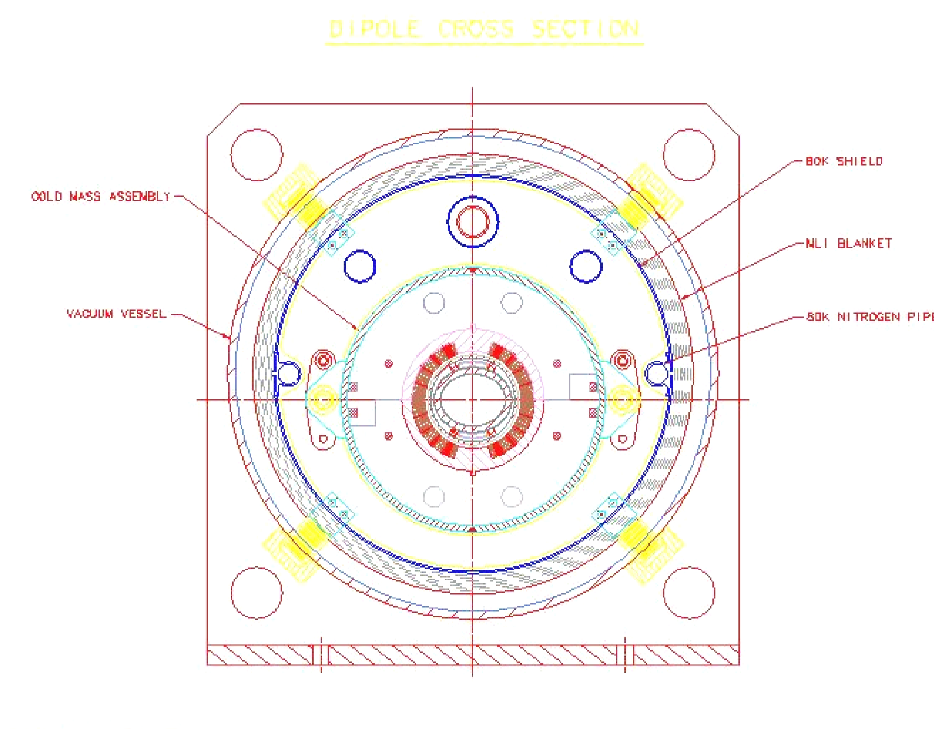


SC Large Bore Magnets

- Low field quality helps reduce price although large aperture
- 7 Watts/m into LHe due to electrons from Muon decay
- 1 cm tungsten (liner instead of 3 cm)

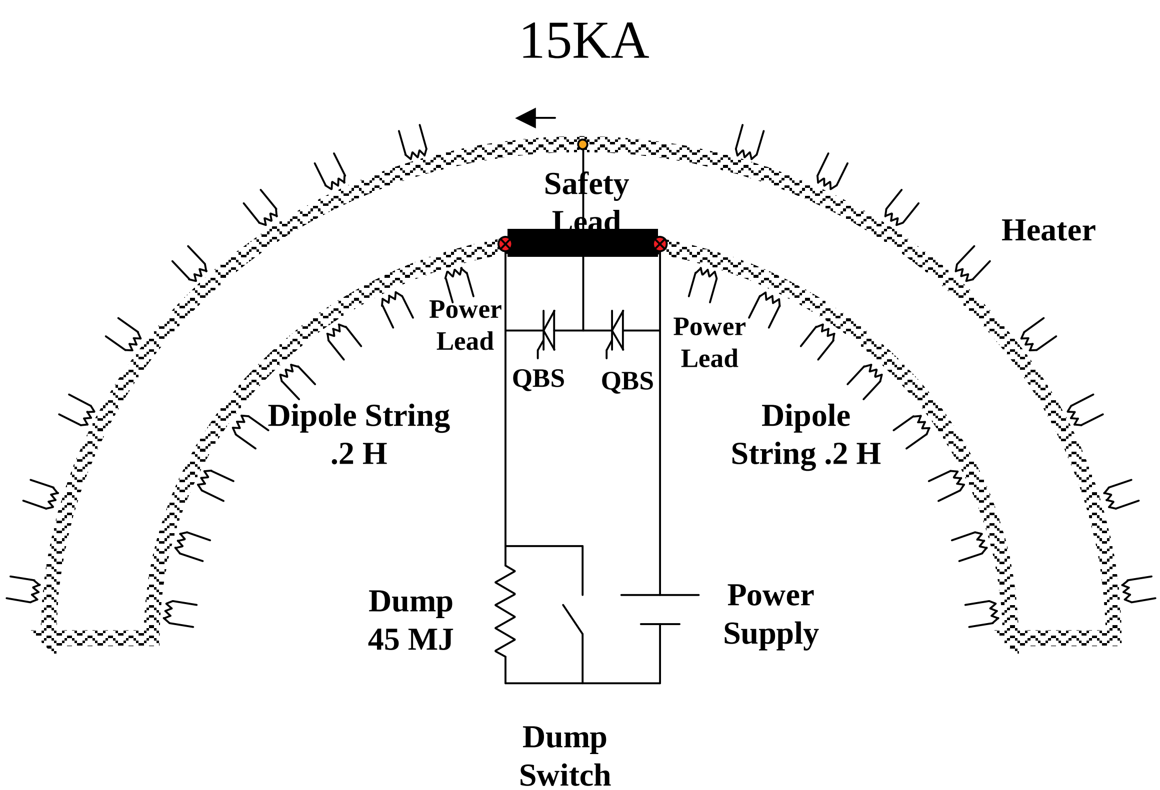






Cryo

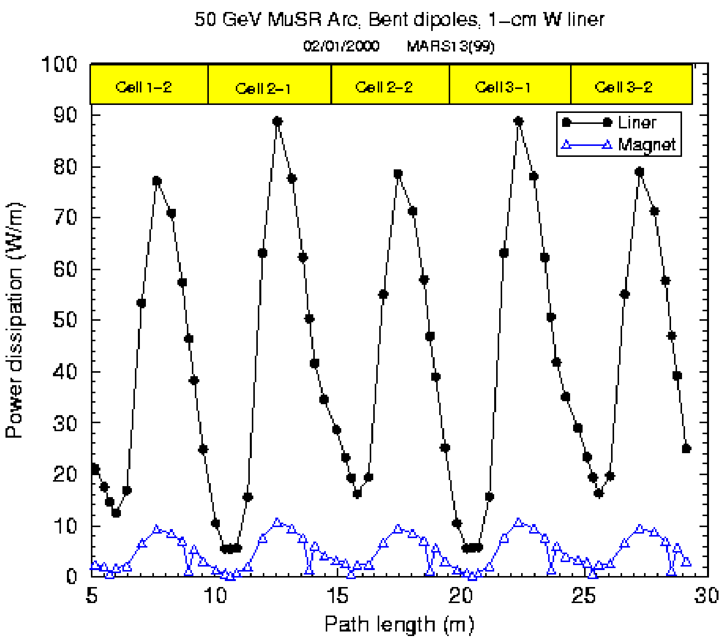
- Part of Lab wide facility with approximately 80 kW @ 4.5 K
- Loads for ring (@2x10^7 sec and 2x10^{20})
  - Static load ~ 3 W per cryostat
  - Dynamic load ~ 15 W cryostat

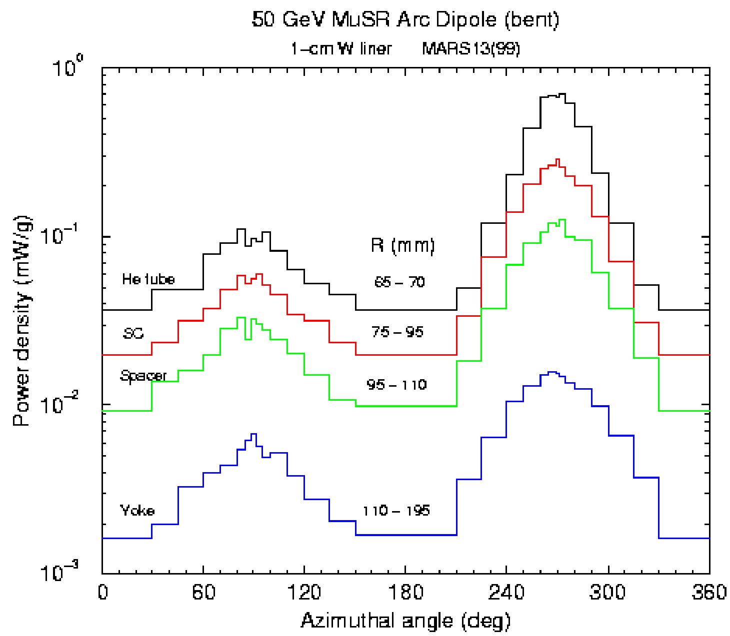


- Simple quench protection system
- Somewhat complicated LHe flux due to 10 m height difference in arc
- Plant upstairs but liquifier is 800 ft below, same with PS + support
  - Drop of 800 ft is too much for pumping LHe
  - Shielding is comparatively easy

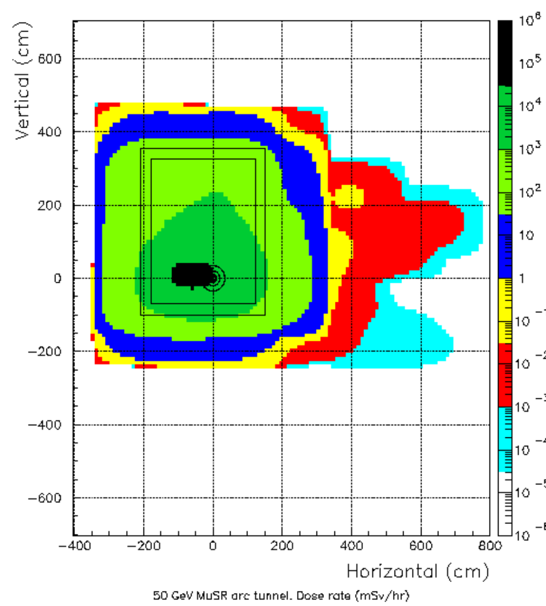
Decay Electrons

- Beam power
  - 240 kW muon beam → 80 kW deposition due to electrons
  - long racetrack → helps: 22 % decays in arcs
  - ~ 50 Watt/m in arcs + 1 cm tungsten shielding ~ 7 W/m into LHe



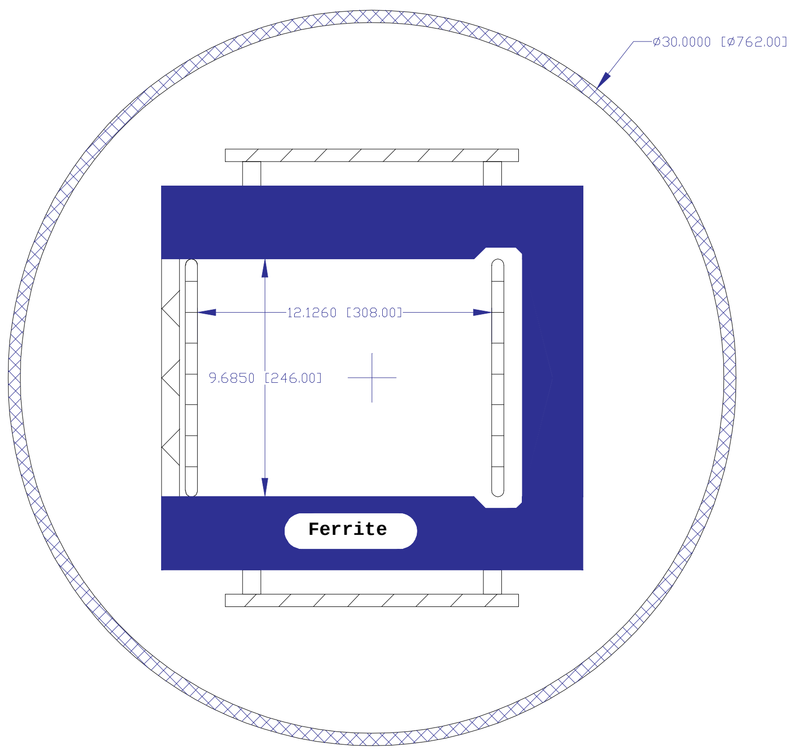


- Radiation in Tunnel
  - Mainly outward (7 m)
  - Inward ~ 3m is enough for unlimited occupancy



Injection

- Inject into downward straight
  - Large β-function
  - Fast fall time of kicker for on axis injection



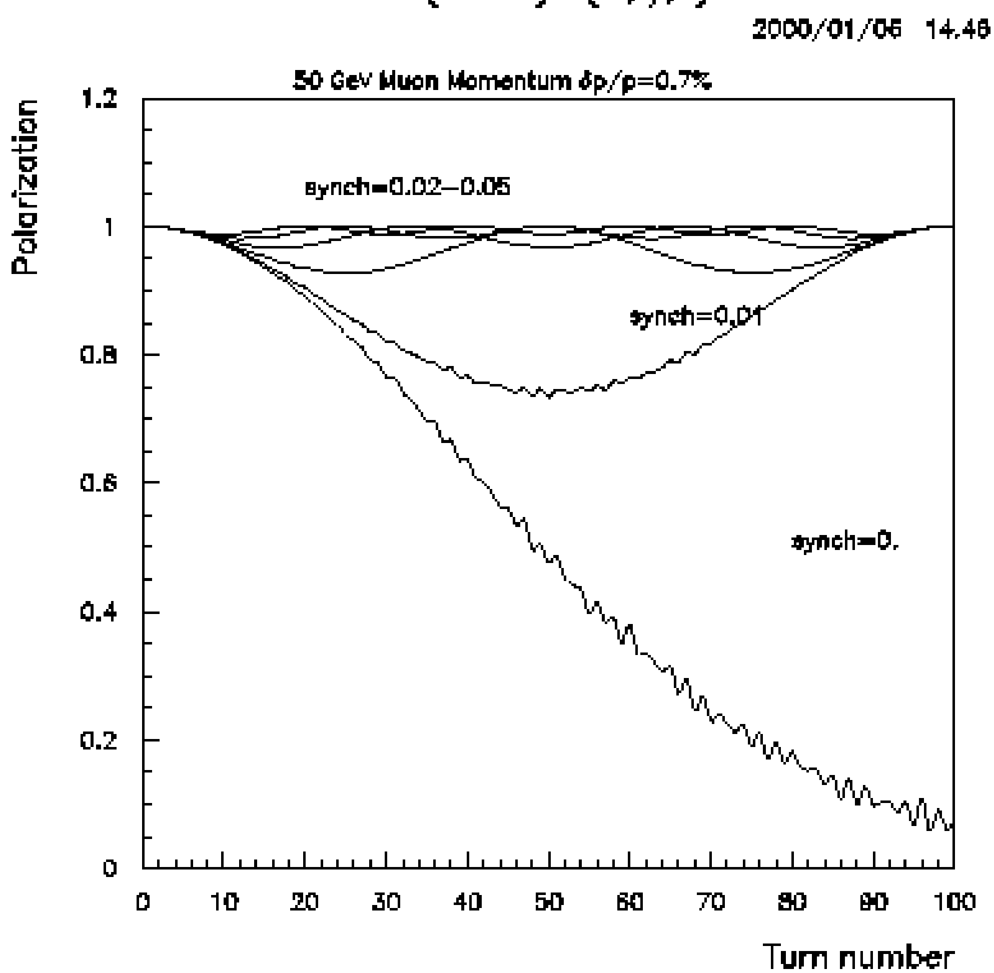
Type		Horizontal
Clear Gap WxH	mm	308x246
Integral BL	Tesla-meter	0.6
Field Flattop	μsec	2.0
Field Fall	μsec	4.0
Field Variation	%	10
Rep Rate	Hz	15
Length	m	25
Nr of Magnets		25

Polarization

- Needs RF installed
  - How much: depends on incoming dp/p
  - acceptable polarization swing

$$eV = \left(\frac{Q_s}{0.015}\right)\left(\frac{\delta p/p}{0.007}\right) 25 MV$$

$$rf\ frequency \approx \left(\frac{Q_s}{0.015}\right)\left(\frac{0.007}{\delta p/p}\right) 92 MHz$$



Is 22 % steep ?

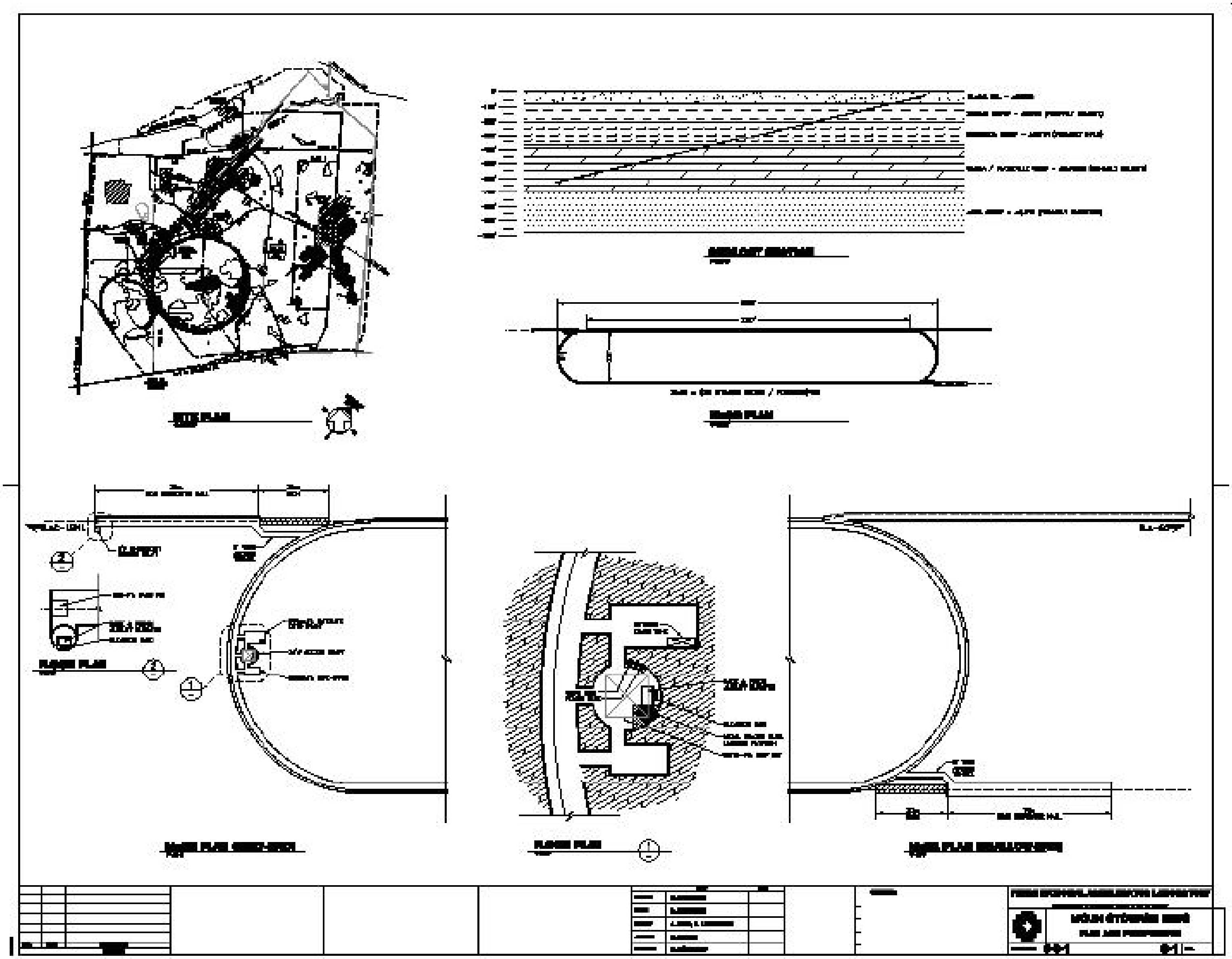
- •17 % into a quarry
- •there is water !
- •incremental cost small compared making more ν
- •extend the ring up to the surface

Further down the ramp

Use vehicles

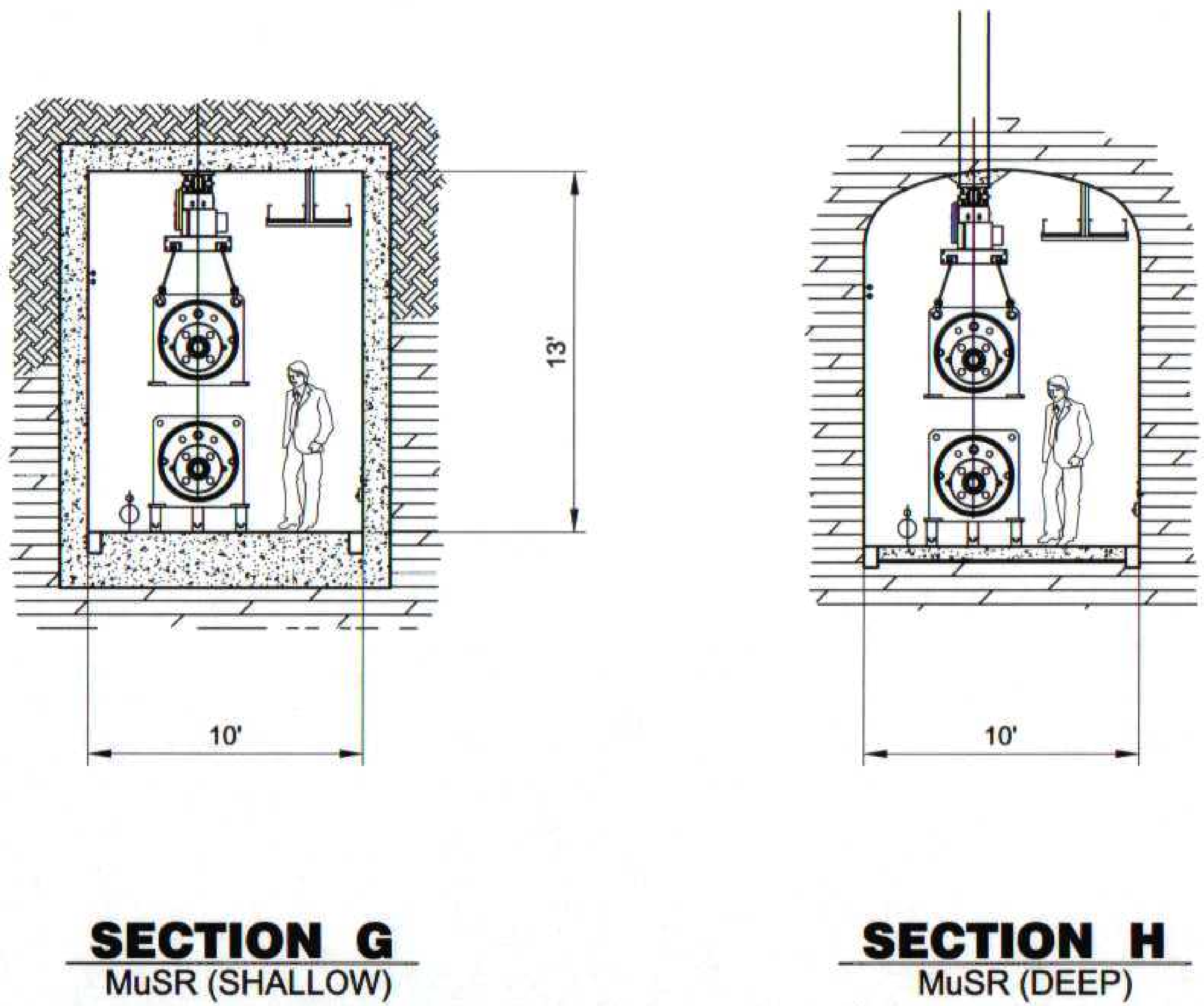
FESS

- Alcove at bottom end
- Near detector at bottom end
- Hall on surface
- Unlimited Access to bottom facility during operation

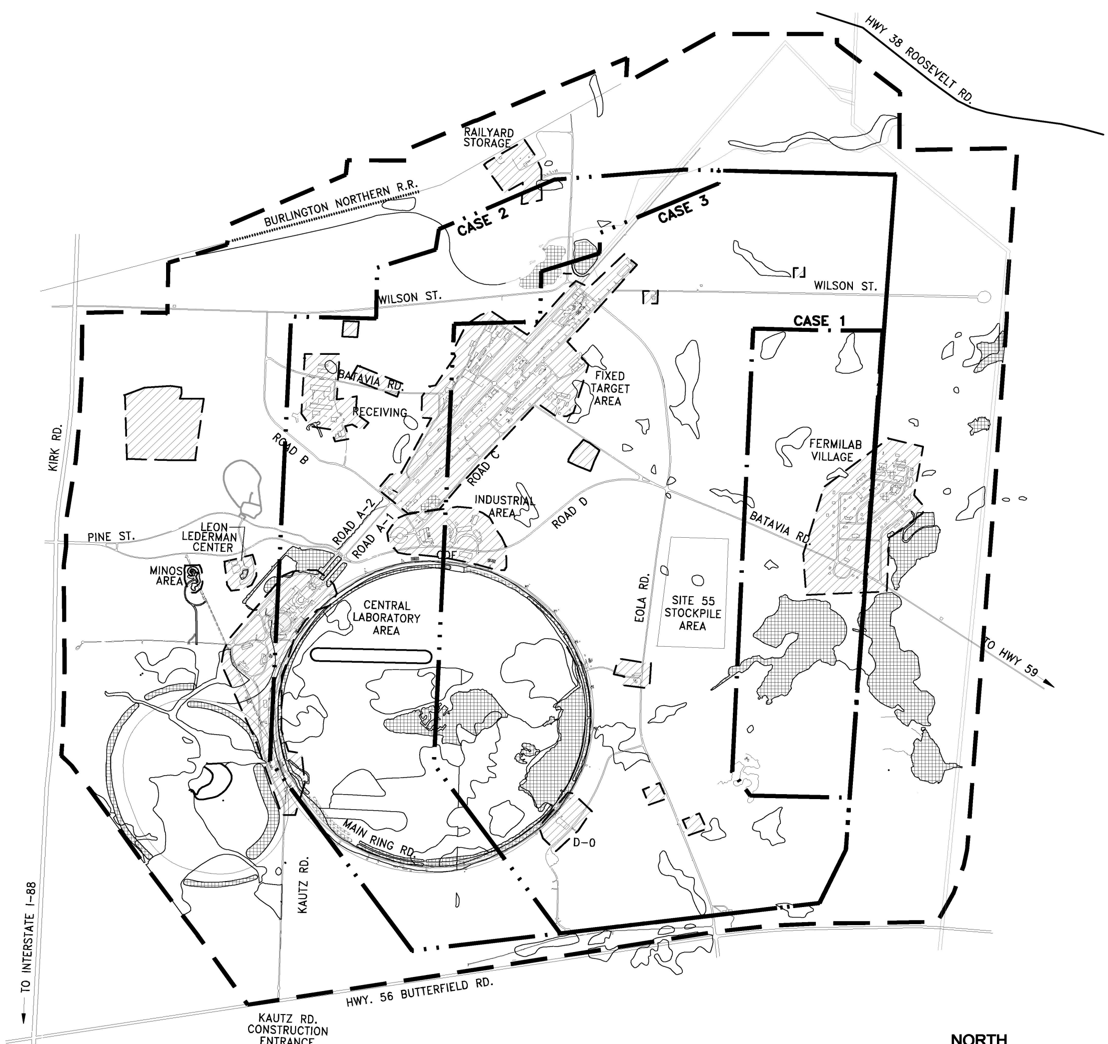


Civil Engineering for the Storage Ring

- Tunnel for very different environments



Radiation from the Neutrino Source @ FNAL



LEGEND:

- LIMITS CASE 1.
- LIMITS CASE 2.
- LIMITS CASE 3.
- SITE BOUNDARY
- LOCATION LIMITS
- WETLAND LIMITS
- LOCATION HATCH
- WETLAND HATCH

NORTH
W E
S

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

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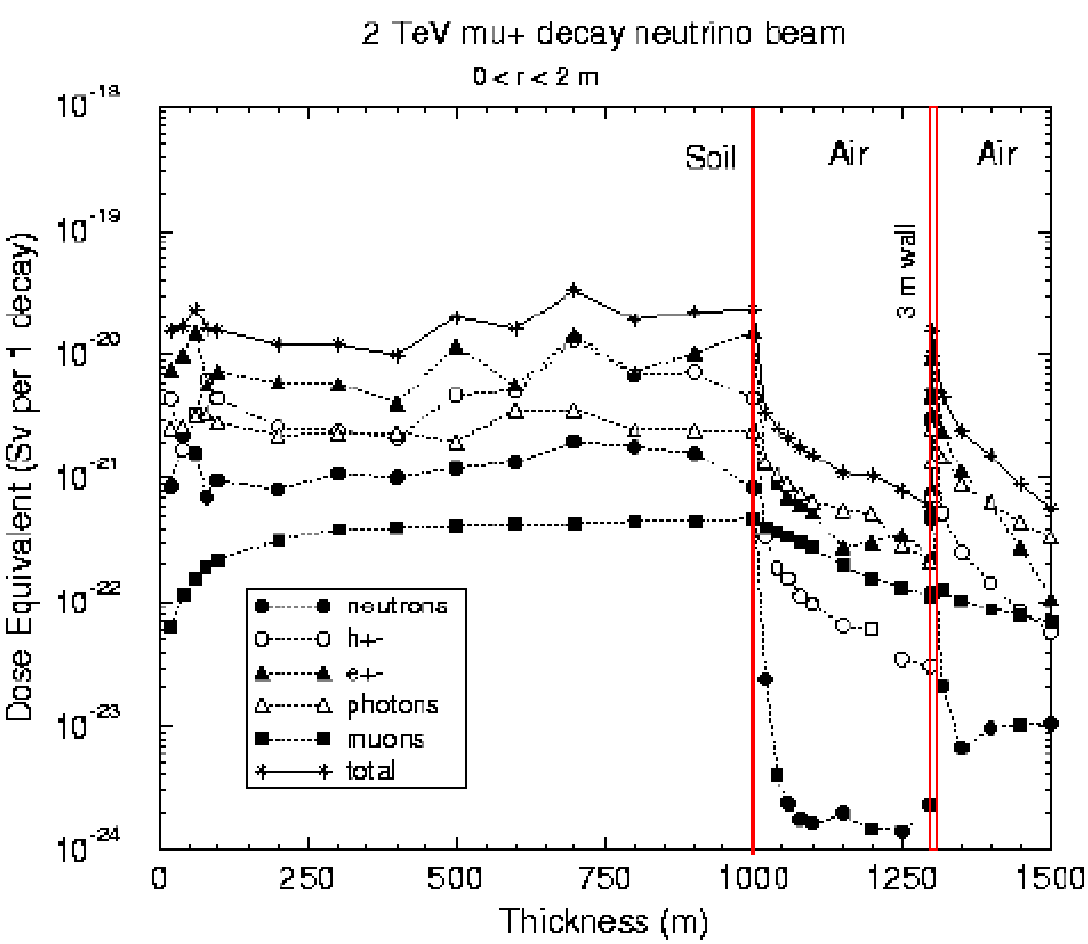
Neutrino Radiation from the μ Storage Ring: Max E_{μ} ?

- Neutrinos come up to surface: ϕ~13 deg (22%) μ-beam from the straight section pointing up

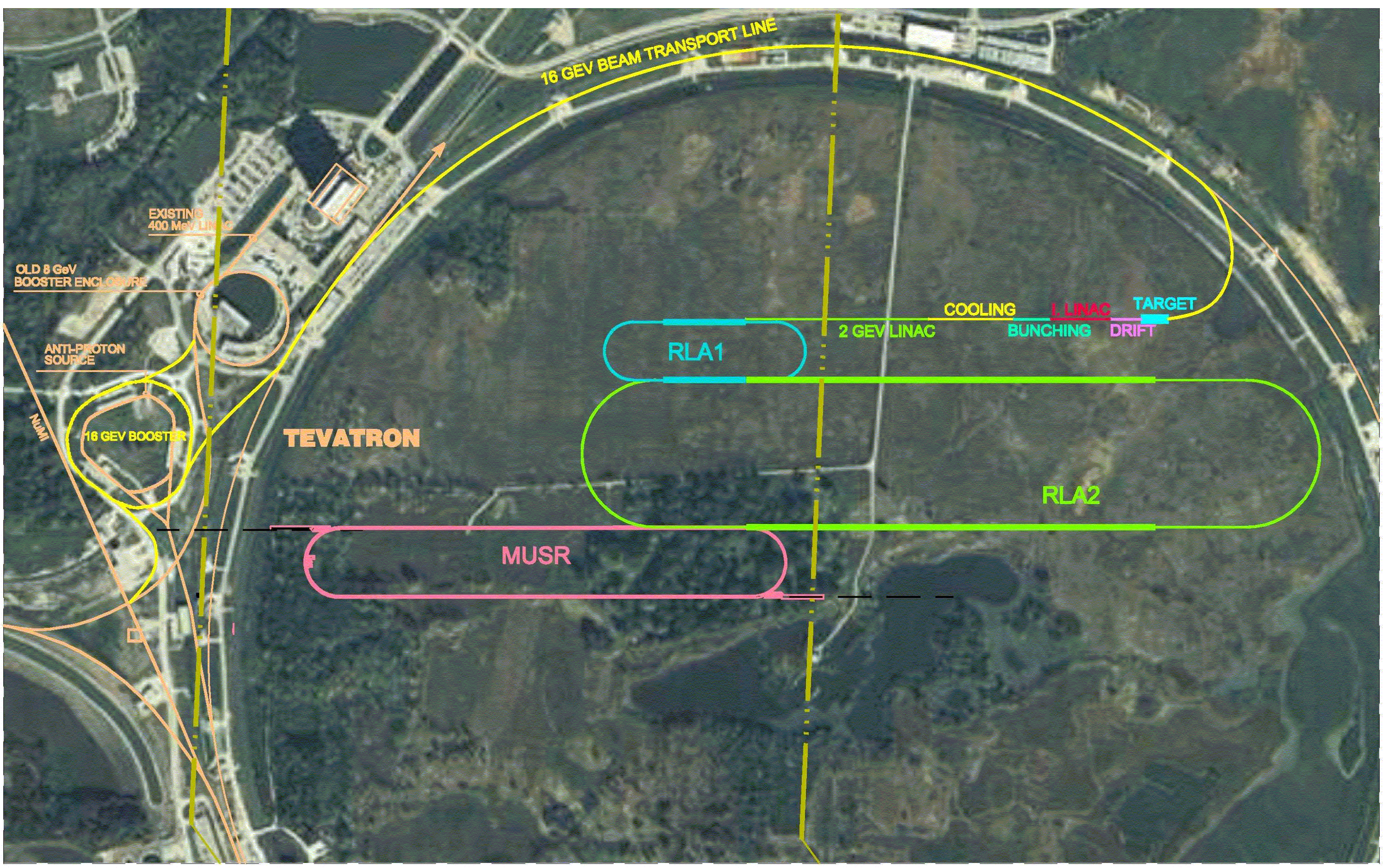


Fermi limit
0.1 mSv/year

Federal Limit
1.0 mSv/year

Layout on this Site

- Why ?
  - Worldwide Unique facility
  - Detector cost and Accelerator cost can be balanced
  - Long Term program ⇒can be staged
  - Fits under a site
  - Has a large NSF/University/Illinois State/Inter Lab. collab



Overall Cost

- Total