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1 General Requirements

1.1 The description of the study

Within the collaboration as well as in the involved laboratories (BNL, CERN, FNAL, LBNL) the necessity of doing a feasibility study has been understood. This will be useful to understand the main technical challenges, as well as the cost drivers in this facility. Such a study will also be used to define and launch the necessary R&D program to fulfill these tasks. The goal of the study is to develop a preliminary layout of a Muon storage ring used as a neutrino source. The neutrino beam from the straight section is pointing towards a laboratory at the West Coast (distance approximately 2700 kilometers) and therefore has to be build at an angle of 13 degrees. A second experiment will be assumed for a very short baseline on top of the site. The storage ring energy should operate at 50 GeV and the number of muon decays required for the experiment is $2x10^{20}$ per year. Further, the study should give a description of the major subsystem of this facility, starting with the proton driver up to the storage ring. The goal is to investigate technical feasibility, cost, schedule and the accompanying R&D program if this would be considered as a possible major facility at the lab. The time frame is end of March 2000, when this document is going to be delivered.

1.2 Number of Protons per cycle

The final number of protons on target which are required for the first neutrino source layout is difficult to calculate because of the uncertainty in the efficiency of the different subsystems. As mentioned in the document describing the storage ring, $2x10^{20}$ muons per straight section per year are required, which translates into $2x10^{12}$ muons per booster cycle assuming that 1/3 of the muons decay in the straight. This calculation is based on the fact that $2x10^{7}$ seconds define the operational year. This is optimistic but for a dedicated facility certainly possible, if compared to other pulsed machines. E.g. the fixed target program at Fermilab (average up time 73 % for the first 14 weeks of operation in 1999) or the SLC (Stanford Linear accelerator, average up time 52% averaged over one year in ‘98/’99). With the standard assumption, that 0.1 muon pro proton can be captured and finally accelerated, $2x10^{13}$ protons are required on target. This number can change as further calculations show that subsystem can not deliver this kind of yield. An additional 25 % safety factor will make this a typical muon collider type driver bunch. The goal therefore should be to produce $2.5x10^{13}$ protons on target.

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2 THE PROTON DRIVER

2.1 Proton Driver Goals

The Proton driver will have to deliver the high energy protons to the pion production target. At this point in time it is very difficult to define the beam pulse exactly. Nevertheless it will be done to our best knowledge keeping a number of assumption in mind. Certainly the ultimate beam power should be not less than 4 MW which should be included in the consideration for civil engineering etc. Given the total number of muons required and the efficiencies of the subsystems, this will determine the number of protons on target which finally have to be achieved. In the present overall layout, for the phase rotation an induction linac is necessary, which will phase rotate the beam. Because of the limitation in repetition rate of this device, it is necessary to have all the pions/muons come from the target at the same time and therefore necessary, to have all the protons on target at the same time as well. Recombination of bunches in front of the target is one of the promising method to do that. Whether 2 or 4 bunches and the appropriate number of beamlines and kickers is the optimum remains to be determined. Simultaneously the option of firing the induction linac more often (2-4 times per booster cycle) will be investigated by the group investigating the induction linac. A compromising option, where the bunches are extracted out of the booster on different revolutions (spacing would than be a few microsec) should be kept in mind as well. Still, the induction linac would have to pulse within a very short period of time.

From our present studies we know, that achieving a bunch length of 1 nsec seems to be very difficult and requires significant effort and cost. Keeping in mind, that these ultra-short bunches seem to be required only in order to produce polarized beams, one can go up to a bunch length of ~ 3 nsec (both are rms numbers), because polarization will not be considered for this report. I would like to understand the difference between these two designs in terms of accelerator physics and cost. For the neutrino source study one would like to see a design which fits the neutrino source requirements only. For this reason one could consider lower energy proton drivers with higher charge per pulse as well.

3 THE TARGET

3.1 General description

The goal for the target study group is the investigation of a multi-megawatt target for a Neutrino source. While the ultimate goal is to target approximately 4 MW of proton beam (15 Hz, 16 GeV, 10^{14} protons) in the target area, smaller values (1-2 MW) might be considered earlier in time. While the 4 MW goal should define the facility requirement as well as civil construction and shielding, remote handling, radioactive water system etc., the present system layout should be done for a 1 –1.5 MW target.

3.2 Technical description and parameters

The target itself is a more complex device and more detailed descriptions can be found in various Muon Collider reports. The only target coming somewhat close in terms of specifications is the presently designed SNS target, which on the other hand has a much larger volume. The details of the target geometry, the target material, and the decision to start with a solid or liquid target, has to be part of this study. The target is embedded in a high field magnet (may be as large as 20 Tesla) and followed by a strong magnetic field channel, where the field tapers down from 20 Tesla to 1.5-5 Tesla (dependant on the cost optimum). While for the cooling and the acceleration a multi-bunch beam is considered, on target one bunch (or a few) can only be allowed per booster cycle. This as a matter of fact is very similar compared to what has been discussed so far for the Muon Collider. The reason is an induction linac following later on in the chain of accelerators, which would have to produce as many pulses as there are bunches per booster cycle on target.

The final number of protons on target which are required for the the first neutrino source layout is difficult to calculate because of the uncertainty in efficiency of the different subsystems. As mentioned in the document describing the storage ring, $2x10^{20}$ muons per year per straight section are required, which translates into $2x10^{12}$ muons per booster cycle. With the standard assumption, that 0.1 muon pro proton can be captured and finally accelerated, $2x10^{13}$ protons are required on target per booster cycle. This number can change as further calculations show that subsystem can not deliver this kind of yield. An additional 25 % safety factor will make this a typical muon collider type driver bunch. The goal therefore should be to produce $2.5x10^{13}$ protons on target in a single bunch with an rms bunch length as long as 3 nsec.

For the target itself, this corresponds so far to a 1- 1.5 MW primary beam on target. As mentioned before, this is significantly smaller than for the muon collider and comes even close to the type of target being used for NuMI (compare NuMI design report, Version 1.0, Oct 1998 Fermilab). Also one should keep in mind that because of inefficiencies of certain subsystems, which we might find later as the study goes on the requirement to increase this might arise. Different target materials (low Z etc) should be reconsidered to ease the first step. Given the Fermilab Proton Driver energy of 16 GeV, the difference in the pion production rate for high Z compared to low Z material is according to recent calculations (MUCOOL note 61) only 40-50 % or so, while the energy deposited goes down by a factor of almost 5 with the same primary beam power. Therefore it seems preferable to work with a e.g. a graphite target, which in addition has the capability of much higher operating temperatures. Additional information is available because of recent developments and tests with a graphite target developed for NuMI (Neutrinos at the Main Injector). This target is designed for an intensity of 3×10^{13} protons per pulse at 120 GeV which is almost seven times the energy deposited per pulse as compared to the Neutrino source target. On the other hand the target has to deal with a primary beam power of 400 kW (only) as compared to 1.0-1.5 MW.

3.3 Tasks

The remaining critical questions are:

1. What exactly is the difference in yield between low Z and high Z?
2. How does the transverse phase space compare between low Z and high Z?
3. How can we cool the target without sacrificing the yield ?
4. How can we achieve a focal length, with 1 ½ interaction length of graphite (=60 cm) and the given beam parameters from the proton driver ($\gamma\varepsilon$=200 π mm mrad)?

3.4 Involvement of other laboratories

Oak Ridge National Laboratory has, due to the recent experience with the target design for the Neutron Spallation Source, the know how for designing a target station for the Neutrino Source. Together with the work being done on design of high power targets, this part of the study should make fast progress for a complete design. The NuMI target at Fermi Lab will be the basis for this design and the people involved in that design will contribute their experience.

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4 INDUCTION LINAC

4.1 General Description

In the present scenario, an induction linac is used to phase rotate the muon beam after leaving a drift section of approximately 100 to 150 meters. This drift section is described in more detail in a later part of the overall document where the different solenoid channels are described. It is only used to develop a correlation between energy and momentum in the longitudinal phase space of the muon beam. For given energy spread of the beam the drift velocity of the individual muons are different and after a given distance the lower energy particles are behind the higher energy particles. Therefore the position in the beam is correlated to a certain energy, which enables phase rotation, e.g. application of a time dependant voltage to reduce the energy spread, accepting that the bunch is longer afterwards. An induction linac would be suitable to do the phase rotation, because the muon bunch length is of the order of 160 nsec (50 meters, or more) which is a very typical pulse length for an induction linac.

4.2 Goals

The features of the induction linac which is required in order to phase rotate the beam are described in mote detail in another paper (V. Balbakov, MUCOOL Note Nr 59). A few very special requirements though are specific to this application and will be mentioned here.

1. High gradient is desirable in order to provide the phase rotation over a short distance because of the finite decay time of the muons. More total voltage will on the other hand allow to phase rotate a larger fraction of the muon beam.
2. A voltage swing from $-V_{max}$ to $+V_{max}$ is necessary (without flat top operation) in order to make optimum use of the applicable voltage (stored energy in the cores) for the phase rotation.
3. A large aperture beam channel for the muon beam because of the large emittance beam coming from the source. At least 60 cm free aperture for the beam is required.
4. SC magnets (1.25-3.0 T) integrated into the induction linac to focus the muon beam through the linac are necessary.
5. Multiple pulse per cycle (eg. 4 pulses within 2 μsec) are desirable although a large number of pulses per booster cycle might be excluded for practical reasons.

Multiple bunch operation from the proton source, and sending these bunches directly to the target, will require multiple pulses from the induction linac per booster cycle. Apart from the general question of feasibility of an induction linac for this type of application, this is the most critical issue which has to be resolved as soon as possible. Certainly it would be desirable to have the capability of multiple bunch operation, at least in a later stage. If only single bunch / single pulse operation is possible, a specific solution has to be found in the proton driver to generate and accelerate a single bunch or before the target to recombine bunches before they hit the target. From the technical point of view, complexity and cost of these solutions have to be compared with multiple pulsing of the induction linac.

4.3 Optimization Criteria for the Parameters of an Induction Linac

In principle two different scenarios are of interest. The first one is investigated at Fermi (V. Balbekhov et al) while the second one is referred to as the baseline design (B. Palmer, Mucool Note 46). Either the induction linac is used after the previously mentioned drift section behind the target with approximately ±100 MV or more in order to phase rotate the beam. In the second scenario the induction linac is used in combination with an rf phase rotation (low frequency rf cavities behind the target) and the so called mini cooling where the transverse emittance is reduced by approximately a factor of 3. In this case the required voltage from the induction linac reduces to ±100 MV. For both cases the general optimization criteria apply.

Comparing both scenarios in more detail, the first one has the advantage of having a single system only required to perform the phase rotation, but at generally higher average kinetic energy (280 MeV or so) and with a larger integrated voltage required. The average total momentum of the muon beam in the second case is approximately 190 MeV/c. The factor of 3 in transverse emittance reduction for the second scenario in combination with a given longitudinal focusing field will make a difference in the required aperture . Or, to give a different description, for a given aperture in the induction linac channel the magnetic field on axis could be a factor of two (0.7 from transverse emittance and 0.6 from average momentum) lower in this case.

Comparing the different requirements for the total voltage used in the phase rotation (see chapter before), the required average gradient is the approximately the same for both scenarios. The difference in γ is approximately 70 %, which means that the decay length is different by 70 % too. While the first scenario needs at least twice the voltage as compared to the second scenario, this difference in γ leads the same gradient requirement for both cases in order to have the same decay loss. Therefore the study does not have to distinguish between these two cases. In general the design should ask for a cost(=length) optimized induction linac versus decay loss in the beam, assuming that ±100 MV total voltage is required. From this linac we can scale two a slightly shorter or longer linac for whatever the final layout will look like.

4.4 Tasks

Induction linacs are not commonly used yet and only a few have been build and operated over a significant period of time. Certainly none has been build with a total voltage of ±100 MV or more and a gradient of 1 MV/m. Before a study can be launched, investigating the technical details of such an induction linac, a number of aspects have to be clarified beforehand. General issues like:

1. General technical feasibility for this kind of application
2. The estimated total power consumption of such a linac
3. The (very rough) investment cost
4. Whether such a device could reliably operate for 3×10^8 pulses per year
5. Whether the cores of the induction linac can operate in a comparatively high magnetic field environment (~ 0.5 T or so) without saturation and sacrificing the performance (dc magnetic field parallel to winding layer of cores).

I preliminary conclusion should be made about 4 weeks from now (Nov. 1st 1999) in order to go ahead with the second part. By then also the question of one or more bunches on target should be more clear concerning other solutions then multiple pulses in the linac. More specific tasks for further studies will be defined then.

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5 MINI COOLING

5.1 General description

As the pion beam comes out of the decay channel, the transverse emittance of the beam is of the order of $\gamma\varepsilon=2.0\text{x}10^{-2}\ \pi$ m rad. In either of the two schemes investigated presently this emittance should be reduced as well as the average energy of the muons in order to:

- reduce the transverse momentum
- decrease the energy for adiabatic capture
- shorten the drift channel where the correlation between energy and momentum develops

5.2 Goals

The goal in this stage is to achieve a transverse emittance of $\gamma\varepsilon=0.9\ \text{x}10^{-2}$ π m rad before the 100 meter long drift channel will be entered. This cooling stage is approximately 3.5 meters long and will reduce the kinetic energy by approximately 100 MeV. The physical size of the beam in a 1.5 Tesla longitudinal magnetic field will still be of the order of 50 cm in diameter. The absorber, embedded in the magnetic field, will therefore have to be larger than that and the inner Bore of the solenoids is probably around 0.8-1.0 meter. The larmor period is of the order of 6 m in the 1.25 T channel which of the order of the absorber length. For the same reason like in the main cooling channel the longitudinal direction of the magnetic field will probably have to change in this stage, which is one of the open questions which should be addressed immediately.

5.3 Tasks

The matching for the muon beam into this specific cooling section as well as out of the section has to be investigated. Both is strongly coupled to the questions whether the longitudinal direction of the magnetic field has to be changed or not. A geometric layout of the comparatively large and long cooling cell is necessary.

6 THE ADIABATIC CAPTURE SECTION

6.1 The RF Capture of the Beam after Phase Rotation

The rf capture of the muon beam coming out of the phase rotation is one of the most critical steps in getting the highest possible number of muons into the storage ring. Different methods of capture have been proposed and are presently under investigation. The muon beam as it leaves the induction linac and has still a considerable energy spread with most of the muons within $\Delta E/E < 10$ %. Adiabatic capture usually requires a much smaller energy spread and slowly ramps up the voltage as bunches form in the bucket going down the linac. This will take about 100 meters of rf structure with gradients between 1-5 MeV/m. A more aggressive bunching scenario requires less length and higher gradients but will naturally come out with a larger energy spread because the muons start rotating in longitudinal phase space.
It is this stage in the whole neutrino factory scenario which is most critical for the overall efficiency of the capture and cooling channel, because the number of muons accepted will strongly depend on how well the beam coming out of the induction linac can be matched into the capture and from there, with a small enough energy spread, into the cooling channel. It is most critical, because the cooling channel has a finite energy acceptance which will, once being too large exceeded, not cool any more.
Together with the induction linac, this stage makes it possible to avoid the very low frequency rf channel (< 50 MHz) so far required for muon cooling in the muon collider scenario. By phase rotating the beam into a long (~150 nsec) beam pulse followed by re-bunching, it is only the combination of longitudinal magnetic focussing field and the required aperture in the cavity which determines the choice of frequency. At the presently foreseen field of 1.25 –2 Tesla the choice would therefore be, to use 175-200 MHz cavities.

6.2 Goal

The capture section should at least bunch 60 % of the total beam current coming from the phase rotation of the induction linac into 175-200 MHz buckets with an energy spread of less than $\Delta E/E_{rms} = 9$ %. The muon beam should transversely as well as longitudinally match into the cooling channel. In addition, it should be investigated whether or not the muon beam develops a correlation between transverse position (radius) and longitudinal momentum (p_z) which is required to minimize beam loss later on the cooling channel. This as a matter of fact is a special preparation of the muon beam in order to counteract the non isochronicity of the solenoid transport channel.

6.3 Technical description and Parameters

The solenoid channel in the capture section consists of standard solenoids with a magnetic field on axis of 1.25 – 2 Tesla. The solenoids have to be large enough to embed the accelerating 175-200 MHz cavities inside. The magnetic field direction can be unipolar and does not have to change. The solenoids will have to have a warm bore in order to allow for the normal conducting cavities inside which will have considerable heat dissipation . The accelerating rf structures will be the same as the ones used in the cooling channel but because of the lower gradient (1-5 MeV) will no require as much rf peak power per unit length.

6.4 Task

The design of the capture section includes the full simulation of the beam coming out of the phase rotation from the induction linac into the cooling section. The emphasize will be on the combined effort (induction linac + capture) to produce a small energy spread beam with maximum capture efficiency and transmission.

7 ACCELERATION OF THE MUONS

7.1 General description

Acceleration of the muons from 0.1 GeV/c to 50 GeV/c is certainly one of the cost driving items of the facility because large scale low frequency rf systems are involved as well as large aperture magnets in the arcs. The large transverse emittance ($\gamma\varepsilon$=1.5x10^{-3} $\pi\cdot$m$\cdot$rad) requires a large aperture cavity and the large longitudinal emittance requires a low frequency and a high gradient. After leaving the cooling section the beam has to be recaptured longitudinally and accelerated to reduce the relative energy spread. This will most probably be done in a linac. From that point on recirculating linacs can be used to accelerate the beam in a more efficient way up to the final energy of 50 GeV.

7.2 Goal

In order to have a preliminary design ready in approximately six month, it is necessary to have a first layout from the beam dynamics point of view as soon as possible. The layout should include the optimization of the injection energy from the first linac with respect to the acceptance of the following re-circulating linacs (RLA's). For the RLA's an optimization of the number of turns versus the installed rf voltage is required and special attention will have to be given to the design of the arcs keeping in mind the large transverse emittance, the large energy-spread and the bunch length. Further on, a cost estimate based on the preliminary design should be developed. This cost and schedule estimate should include the fabrication and installation of the accelerating systems plus the necessary support facilities (cryo, modulator, klystron, low power rf).
An estimate of the cost and schedule for an R&D program necessary to develop the technology for these accelerating systems would be very useful as well.

7.3 Technical description and Parameters

At this point only the expected output parameters of a cooling channel can be defined. It will have to be proven that these parameters can be achieved with the foreseen cooling channel. Various cooling channels are under intense investigation right now and more results should be available soon. The table below gives most of the parameters necessary to start with. The gradients being assumed for the accelerating systems have to be defined. A reasonably optimistic assumption on the average accelerating gradient and the filling factor should be made.

Muon Parameter for Acceleration between
190 MeV/c – 50 GeV/c

Based on cooling assumption		
incoming norm.emittance $\varepsilon_{x,y}$	π mm rad	1.5
outgoing emittance at 50 GeV	π mm rad	3.2
energy spread at 50 GeV (95%)	%	+/- 2
incoming momentum	MeV/c	190
incoming norm. emittance ε_{long}	π mm	28
bunch length	mm	120
momentum spread (rms)	%	11
$\beta\ \gamma$ at start	~	2
pulse length	~	150 nsec
number of bunches in one pulse	~	30
number muons per pulse	10^{12}	2.5
repetition rate	Hz	15
acceleration I (linac)	GeV	1
RLA_1 + RLA_2	GeV	30

7.4 Tasks

The tasks of the study are summarized in the following list.

1. Technical feasibility of an accelerating system which accelerates the muon beam from approximately 190 MeV/c to 50 GeV/c. The definition and the combination of linacs and re-circulating linacs necessary to do so is up to the study.
2. A rough cost estimate good to within 30 percent should be part of the study. It is understood that this estimate is made according to everyone's best knowledge and with the final cost depending on a successful R&D program.
3. A rough schedule, which gives an estimate for the time required to a) fulfill the R&D and b) fabricate and install the accelerating systems
4. The definition of an R&D program necessary to support the construction of such a facility.

7.5 Involvement of other laboratories

So far CEBAF has been asked to develop a baseline scenario for the acceleration of the muons. Given the above parameters this scenario will give a first layout which will allow to make a technical layout as well. This technical layout should be discussed in a larger group of people (Cornell, CEBAF, TESLA, FERMI (H.Edwards) and may be CERN if we can find interest), because the different laboratories have expertise in different fields which all will be required to formulate a successful program.

8 THE STORAGE RING

8.1 General description

The present design study performed at Fermilab investigates the feasibility of a 50 GeV Muon storage ring.. The neutrino beams coming from the decaying muons in the straight section form a very well collimated neutrino beam. These neutrino beams will be used for medium length baseline experiment (Fermilab to SLAC distance which is 2700 km between source and detector). The neutrino source offers the possibility to make use of a newly developed intense muon source without the necessity of strong transverse and longitudinal cooling. Here the required cooling factor is in the range of 50 – 100 and the accelerating system would have to take this beam up to approximately 50 GeV. The physics prospects as well as the technical requirements make the neutrino source an attractive user of an intense muon beam.

8.2 Goals

For the study an agreement has been made to investigate a specific scenario which we will be used from now. The specified intensity is 2 x 10^{20} muons per year in the straight section of the ring. Polarization will not be considered for this study.

8.3 Geometric considerations

The baseline of 2700 km defines the tilt angle to be 13 degree. Given the angle at which the storage ring has to be build and accepting the assumption that the ring will be build between the bottom layer of the the Galena Platteville (see geologic boundary conditions at FERMI Lab) and the surface (50 feet less or so), the extension of the ring is substantial. In the present layout the straight is about 800 meters and the arc is approximately 140 meters (B_{dipole} 6 T; filling factor inlcuded in the arc length) which brings the decay ratio up to ~ 40 %. The geometry is more precisely given by the following scenario:

- 200 feet vertical drop for the MuSR
- 3 m distance from tunnel ceiling to tunnel floor
- 3 m shielding above tunnel ceiling to surface
- 17 m undisturbed bottom layer of Galena Platteville
- 10 feet For uncertainties on the above three numbers (10, 10 and 50).
- total available length ($2 \times \rho + L_{straight} = 813$ m) to protect the tunnel from the underlying aquifer

8.4 Technical description and parameters

While the use of sc magnets is preferable for a larger decay ratio in the straight sections, the use of normal conducting magnets brings the decay fraction down to 25% which is still significant. The use of super-conducting magnets presents a significant complication due to the large required aperture (-> stored energy) and due to the electrons (from muon decay), which will produce synchrotron radiation first and finally deposit their energy in the vacuum chamber and the cold mass of the magnet once they have been bent.

Based on 6.0 Tesla dipole field design		
incoming emittance	**π mm rad**	**3.2**
transv. acceptance (500 turns)	**π mm rad**	**>3.2**
physical acceptance	**π mm rad**	**3 σ**
energy acceptance (total)	%	**$\pm$ 2**
length of straight section	**m**	**~650**
β_average in decay straight	**m**	**~160**
β_average in inj. straight		**23**
decay angle at 50 GeV	**mrad**	**~2.0**
divergence in the straight	**mrad**	**~0.2**
% of muon decays in straight	**%**	**> 33/45**
injection bend (3 sept. + 15 kick)	**mrad**	**60 + 6**
circumference	**m**	**> 1550**

9 THE LARGE SUPPORT FACILITIES

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10 RF ACCELERATION IN THE COOLING CHANNEL

The rf system in the cooling channel is a 200 (175 MHz) high peak power rf system. This type of rf system will be used in the whole accelerator complex and has to drive normal conducting as well as sc cavities with very similar load characteristics, which is a very unusual application.

10.1 General Introduction

The ultimate requirements for the accelerating system of the cooling channel for the muon storage are not defined yet. For any of the investigated scenarios a cooling channel with a length of 140 meters is required. About every meter the muon beam has to be re-accelerated using a 175 (or 200) MHz cavity which has to operate at high gradient, typically around 12-15 MV/m. The peak power required to drive such a cavity is approximately 5 MW. The Q value is 60.000 and we need about three filling times to achieve the full gradient on axis. The design repetition rate is 15 Hz. These parameters define the duty cycle as well as the peak power per unit length.

10.2 Technical Description

The peak power requirement fits the power capability of the presently existing 5 MW Triodes which are used in the Fermilab linac gallery to drive the 200 MHz Alvarez structure. In order to provide enough peak power per unit length, a layout is required which provides 5 MW every meter over a length of roughly 100 meter. Because the details of the layout are not known more precisely, this is what should be laid out for the study. A gallery necessary to provide this peak power including all the supporting equipment (HV PS, modulators, capacitor banks, charging units etc) should be designed.

Reasonable optimistic assumptions on a power tube with higher peak power could be made (eg. max. 10 MW per tetrode). Also novel schemes in driving a series of triodes should be investigated (driving many triodes with one 5 / 10 MW triode etc).

The goal of the study is to investigate the technical feasibility and the cost of such an installation. Also a floor plan and estimates on the size of the support building, the operating cost and the necessary R&D should be made. The exact length of the cooling channel is not know yet, which will make it necessary to scale from the 100 meter long klystron gallery to be designed to whatever the required length finally is going to be.

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11 SOLENOID CHANNEL MAGNETS

11.1 General Introduction

The decay channel for the Neutrino source as well as the drift channel for the present neutrino source general layout requires approximately 100 meter of solenoids with a magnetic field on axis of roughly 1.5-5 Tesla, dependant on the cost optimum. The inner diameter of these solenoids is determined by the transverse momentum of the incoming pion beam and the finally chosen magnetic field. An optimization of these two parameters with respect to cost should be part of the investigation.
The transverse momentum of the pions and muons drifting into the decay / drift channel is of the order of 300 MeV/c (average). In order to transport at least twice that momentum, the channel has to have an inner diameter of $D[m] = 4*3.334*P_{average}$ [GeV/c]/ B_z [T] . For example, with 3 Tesla on axis the inner diameter would have to be ~1.2 meter. On the other hand, the pion beam which leaves the target is adiabatically decompressed while the longitudinal magnetic field changes from 20 T at the target to 1.5-5 T in the decay channel. At the same time the transverse momentum is reduced by the square root of the field ratio (sqrt(20 T/3 T)=2.6) which means that the channel should have a diameter of ~0.45 m.
For the decay channel, the total length is approximately 40 meters (3 x τ_{pion}) . For the drift channel to develop the correlation of the beam, it is approximately 50-100 meter.

11.2 Technical Description

For the study different types of channels should be optimized:
1. **The Drift Channel:** A 50 meter long channel which has to transport the muon (with the parameters being described above. This channel is continuous and needs some correction coils and diagnostics included (penetrations in the cryostat). The magnetic field direction does not have to change, different from the cooling channel but can be uni-polar. The solenoids could also be build using a continuous cryostat without any warm cold transitions. The channel could have a cold bore if this is of any help. The inner diameter is dependent on the optimization (B*r^2 for acceptance versus B^2*r^2 for stored energy) between 60 and 40 cm with corresponding fields for 1.25 to 3 Tesla.
2. **The Decay Channel:** A 40 meter long channel with an average magnetic field on axis of about 1.5 Tesla and a diameter of approximately two meters. Here the cryostat is interrupted because it might have to have

cavities inside, so rf penetrations (and so on) will be necessary. It also will need a warm bore and of the order of 15-30 kW/m average power will have to be removed, which means that the cryostat needs significant heat shielding against the thermal load. Again the field can be unipolar.

3. **The Induction Linac Channel:** The third channel of interest is a sc solenoid channel which has to operate within an induction linac. This is the least defined technical component and the details will have to be worked out in close collaboration with the people working on the induction linac. Nevertheless, it is clear that the field is probably larger to reduce the inner diameter. A cost optimization has to include the cost of the induction linac (cores and core sizes) as well as the fact, that the cores will have to be shielded from the dc magnetic field. How to integrate this into the high voltage system and how and by how much to shield the DC field from the cores of the linac is an open question. These solenoids probably should have a warm bore (because of the HV gap every 20 cm or so). They can be unipolar. Iouri Terechkine (FNAL) has been working on a preliminary layout.

4. **The Cooling Channel:** The fourth channel is the actually channel in the cooling structure. Again about 100 meter of sc solenoid channel is required. Here the magnetic field strength is dictated by the cooling performance. The field on axis is more complex and will not be defined before sufficient simulation have been done. In order to give an impression: The field is kind of sinusoidal with a period of approximately 1.5-2 meters. The maximum field is +/- 5 Tesla and here the polarization (Bz on axis) changes, which has impact on the forces between the coils. The specification of this channel will not be given before being quite a bit into study. The aperture again is approximately 2 meters, determined by the outer diameter of the 175-200 MHz cavities embedded in the solenoid. Penetrations are every meter and a common cryostat seems to be difficult. A warm bore is necessary because a heat load of approximately 30 kW within the solenoids will exist. A good fraction of the engineering of the channel will most probably be done at Fermilab (E. Black, D. Kaplan, S. Geer) but the magnet part could be given to IHEP.

11.3 Goals

The goal for these channels is to develop a cost optimized first design. So far we assume that he channels will not be so much a technical challenge but much more a driven by cost optimization because of the large diameter, the large stored energy and the large amount of conductor being required. The freedom in designing most of these channel is considerable at this point in time and the real need is to develop some insight in what it means to build these large scale channels. A sketch of each of the channels with a principle layout would be very helpful, to learn about a reasonable module size, how to do the connections and the vacuum system, the current leads, the cryogenic and so on. If there a more critical R&D items they should be identified.

11.4 Tasks

Definition of the optimized diameter and magnetic field is certainly the highest priority item because this could have influence on the beam dynamics simulation going on. Further on the identified critical items should be explained and listed. In order to determine the rest of the infrastructure, the power supply requirements (voltage, current, inductance, quench protection (rudimentary design)) should be defined. For the cryogenics the expected heat load is of high interest. Definition of the super-conducting material proposed for construction would be interesting as well.