

NOMAD Collaboration

NOMAD Note #72

## NOMAD by Numbers

Version 1.00

Compiled By

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# 1 Coordinate System

The convention for the coordinate system is:  $z$  is the beam direction (ignoring the 42.53 mrad tilt of the beam in the vertical direction),  $y$  is vertical (down to up), and  $x$  is horizontal (from counting room to the gas hut). In other words, the  $x$ - $z$  plane is parallel with the surface of the floor of the hall. The Magnetic field points in the positive  $x$  direction. The coordinates  $u$  and  $v$  are  $-5^\circ$  and  $+5^\circ$  from  $y$ , respectively.

The origin is defined to be at the inner edge of the basket at the incoming beam side and by the support axis of the basket.

# 2 The Veto

**Description :** The veto consists of 53 scintillators organized into 9 banks. The slabs of scintillator are made out of NE110 and they come in two sizes (long and short). In order to diminish dead-time, counters 1 to 3 of bank 1 and counters 6 to 8 of bank 3 are not included in the veto "OR" that forms the  $\bar{V}$  signal.

**Dimensions :**

- Size of long scintillator : 2.1 cm x 21.2 cm x 300.0 cm
- Size of short scintillator : 2.1 cm x 21.2 cm x 210.0 cm
- Total veto transverse area : 26.995 m<sup>2</sup>
- Maximum extent in  $x$  and  $y$  (total veto) : 535.4 cm x 502.0 cm
- Active veto area : 23.642 m<sup>2</sup>
- Maximum extent in  $x$  and  $y$  (active veto) : 413.0 cm x 502.0 cm
- Bank characteristics (see figure 1 for clarification):

**Bank 1 :** 8 long vertical slabs

- (i) Centre position ( $x, y, z$ ): 185.7 cm, 78.7 cm, -83.15 cm
- (ii) Width and height ( $\Delta x, \Delta y$ ): 164.0 cm, 300.0 cm

**Bank 2 :** 8 long vertical slabs divided in two sections, a and b.

- (i) Centre position ( $x, y, z$ ):
  - Bank 2a : 66.8 cm, 78.7 cm, -83.15 cm
  - Bank 2b : -66.8 cm, 78.7 cm, -83.15 cm
- (ii) Width and height ( $\Delta x, \Delta y$ ):
  - Bank 2a : 75.8 cm, 300.0 cm

Bank 2b : 75.8 cm, 300.0 cm

**Bank 3** : 8 long vertical slabs

(i) Centre position (x,y,z): -185.7 cm, 78.7 cm, -83.15 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 164.0 cm, 300.0 cm

**Bank 4** : 6 short vertical slabs

(i) Centre position (x,y,z): 206.1 cm, -150.2 cm, -254.95 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 123.2 cm, 210.0 cm

**Bank 5** : 6 short vertical slabs

(i) Centre position (x,y,z): -206.1 cm, -150.2 cm, -254.95 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 123.2 cm, 210.0 cm

**Bank 6 (counters 1 and 2)** : 2 long horizontal slabs

(i) Centre position (x,y,z): 0.0 cm, 21.6 cm, -86.9 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 300.0 cm, 43.2 cm

**Bank 6 (counters 3 to 8) and bank 7** : 8 long horizontal slabs

(i) Centre position (x,y,z): 0.0 cm, -191.45 cm, -99.62 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 300.0 cm, 163.7 cm

(iii) Rotation around x-axis:  $-10^\circ$

**Bank 8** : 4 long vertical slabs

(i) Centre position (x,y,z): 0.0 cm, -58.8 cm, -267.55 cm

(ii) Width and height ( $\Delta x, \Delta y$ ): 82.4 cm, 300.0 cm

**Bank 9** : 3 short vertical slabs with single ended read-out

(i) Bank 9,#1 centre position (x,y,z): 20.3 cm, 173.7 cm, -81.65 cm

(ii) Bank 9,#2 centre position (x,y,z): 0.0 cm, 179.7 cm, -88.6 cm

(iii) Bank 9,#3 centre position (x,y,z): -20.3 cm, 173.7 cm, -81.65 cm

**Readout** : Most scintillators have double-ended read-out through wedge shaped light-guides that feed into Philips XP2020 photomultipliers. These are then mean-timed, forming one signal per counter that is fed onto a TDC channel. The three scintillators in bank 9 are single-ended and only have read-out from the top.

- Number of long scintillators : 38
- Number of short scintillators : 15
- Number of photomultiplier tubes : 103
- Number of TDC channels : 53

**Performance :**

- Efficiency : typically 96.5-97.5%
- Time resolution : .3 ns
- Dead-time due to veto : typically 3%

### **3 The Magnet**

**Description :** Recycled UA1 Magnet. Aluminium dipole magnet with iron flux return (in the shape of [ ] known as C's).

**Dimensions Coil :**

- Inner Size in z : 709.6 cm
- Inner Size in y : 353.6 cm
- Inner Size in x : 350.0 cm
- Thickness : 23 cm
- Weight :  $\sim 20$  tons
- Average Density :  $2.36 \text{ g/cm}^3$
- Radiation Length :  $3.2 X_0$
- Interaction Length :  $0.7 \lambda$

**Dimensions C's :**

- Number of C's : 8
- Inner Crosssection of C's : 352.0 cm x 403.4 cm
- Thickness of C's : 52.8 cm
- Average density of C's :  $5.67 \text{ g/cm}^3$

**Performance :**

- Average Field : 0.4 Tesla @ 5713 Amps
- Field Homogeneity :  $\sim 2\%$  (at center) to  $\sim 10\%$  (near edge)

## 4 The Drift Chambers

**Description :** The NOMAD drift chambers are to be numbered 1 thru 49, with #1 being the upstream most. There are 11 modules of 4 chambers each forming the Target region. There are 5 chambers positioned in the TRD region as well (see TRD section). Each chamber consists of three planes of sense wires at  $-5^\circ$ ,  $+5^\circ$ ,  $0^\circ$  with respect to the magnetic field which correspond to  $u$ ,  $v$ , and  $y$  respectively. Four walls of Aramid fiber honeycomb covered with Kevlar-epoxy layers sandwich the wire planes. The separation between anode wires is 6.4 cm with a cathode wire between each pair of anodes. Field shaping is provided by 3 mm wide aluminum strips, with 1 mm separation, glued to the chamber walls. The gas is an ethane-argon mixture with 60% ethane and 40% argon.

To help eliminate up-down ambiguity, the chambers are offset by  $\pm 1.6$  cm in  $y$ . The chambers are moved alternatively  $+1.6$  cm (up) or  $-1.6$  cm (down).

### Specifications for Drift Chambers :

- $x$  range :  $-150.0 \text{ cm} \leq x \leq 150.0 \text{ cm}$
- $y$  range :  $-150.0 \text{ cm} \leq y \leq 150.0 \text{ cm}$
- $z$  range :  $0.0 \text{ cm} \leq z \leq 400.0 \text{ cm}$
- covered  $x$  range :  $-135.0 \text{ cm} \leq x \leq 135.0 \text{ cm}$
- covered  $y$  range :  $-130.0 \text{ cm} \leq y \leq 130.0 \text{ cm}$
- covered  $z$  range :  $0.0 \text{ cm} \leq z \leq 400.0 \text{ cm}$
- fiducial tonnage : 2.57 tons
- Number of Wires in  $y$  : 44
- Number of Wires in  $u$  and  $v$  : 41
- Wire Spacing : 6.4 cm
- Wire Length : 300.0 cm
- Honeycomb and Mylar Thickness : 1.6 cm
- Drift Gap Width : 0.8 cm
- Drift Medium : 60% ethane, 40% argon
- Radiation Lengths per chamber :  $.02 X_0$

**Readout :** 1 TDC channel per wire.

**Performance :**

- Position Resolution in x :  $\sim 1500 \mu\text{m}$  per chamber
- Position Resolution in y :  $\sim 250 \mu\text{m}$  per plane

## 5 The Trigger

**Description :** The Trigger consists of two planes of Scintillator counters before and after the TRD region. Each plane is divided into two half planes consisting of 14 horizontal counters read out on one side only. The light guides of the horizontal counters are covered by 2 vertical counters in order to increase the fiducial area.

**Dimensions :**

- Transverse Area :  $286.0 \text{ cm} \times 286.0 \text{ cm}$
- Size of Horizontal Counters :  $124.0 \text{ cm} \times 19.9 \text{ cm} \times .5 \text{ cm}$
- Size of Vertical Counters :  $130.0 \text{ cm} \times 19.9 \text{ cm} \times .5 \text{ cm}$
- Position of Plane 1 :  $408.3 \text{ cm}$
- Position of Plane 2 :  $569.3 \text{ cm}$

**Performance :**

- Single Counter Efficiency :  $\sim 98\%$
- CC Trigger Efficiency ( from MC ) :  $\sim 98\%$
- NC Trigger Efficiency ( from MC ) :  $\sim 83\%$

**Trigger :**

- During nu-spill :  $\bar{V} \times T_1 \times T_2$
- During flat top :  $V \times T_1 \times T_2$

## 6 The Transition Radiation Detector

**Description :** The transition radiation detector (TRD) has 9 radiators, 9 straw tube planes and 5 drift chambers. A module of TRD is a radiator followed by a plane of straw tubes. The drift chambers are placed after the modules #2, #4, #6, #8, and #9. The radiators themselves are made of 315 foils,  $15 \mu\text{m}$  thick with  $250 \mu\text{m}$  gas gap between foils. This gap is filled with nitrogen

gas to prevent contamination from moisture and oxygen. A straw tube plane has 176 tubes per plane oriented vertically. The tubes are 3.0 m long made of 25  $\mu\text{m}$  thick aluminized-Mylar tube, with an internal diameter of 1.6 cm. The sense wire is a 50  $\mu\text{m}$  diameter tungsten wire. The tube is filled with 80% xenon and 20% methane. Consecutive planes are staggered to cover the dead area caused by the walls and space between tubes.

Overall, the TRD gives an  $e/\pi$  rejection factor of  $10^3$ .

#### **Specifications for Radiator :**

- Position of first Module : 412.3 cm
- Overall Dimensions : 3.0 m  $\times$  3.0 m  $\times$  0.8 m
- Number of Radiators : 9
- Number of Foils per Radiator : 315
- Foil Material : Polypropylene
- Foil Thickness : 515  $\mu\text{m}$
- Gap between foils : 250  $\mu\text{m}$
- Foil Gap Medium : Nitrogen Gas
- Radiation Length of Radiator: .033  $X_0$

#### **Specifications for Straw Tubes :**

- Number of Straw Tube Planes : 9
- Number of Tubes per Plane : 176
- Length of Tube : 3.0 m
- Inside Diameter of Tube : 1.6 cm
- Diameter of Wire : 50  $\mu\text{m}$
- Wire Material : Tungsten
- Tube Medium : 80% xenon, 20% methane
- Tube Wall Thickness : 25  $\mu\text{m}$
- Tube Wall Material : aluminized-Mylar

**Specifications for Drift Chambers : See Drift Chamber Section**

## 7 The Preshower

**Description :** The NOMAD Preshower consists of two lead-antimony (4% Sb by weight) sheets hanging on either side of a 2.0 mm thick Al sheet, followed by two planes of 290 proportional tubes (horizontal and vertical) of which 286 are active in the horizontal direction and 288 are active in the vertical direction. The gas is .20-.80 Argon-CO<sub>2</sub>.

### Dimensions :

- Transverse Size : 292.1 cm x 290.1 cm
- Cross-sectional Size of tubes : 1.0 cm x 1.0 cm, internal size .9X.9 mm<sup>2</sup>
- Length of Horizontal tubes : 291.1 cm
- Length of Vertical tubes : 288.7 cm
- Transverse Size of Lead Sheet : 288.0 cm x 288.0 cm
- Thickness of Each of Two Lead Sheets : 0.45 cm
- Front Face of Lead Position : 575.8 cm
- Radiation Length : 1.6 X<sub>0</sub>
- Interaction Length : 0.05  $\lambda$

**Readout :** 288 + 286 ADC channels

### Performance :

## 8 The Electro magnetic Calorimeter

**Description :** The NOMAD EM calorimeter consists of 875 (35 rows of 25 towers) TF1-000 rectangular lead glass blocks, each equipped with 3-inch Hamamatsu phototetrodes of type R2186. The phototetrodes are coupled to the the block with a tilt of 45° with respect to the magnetic field direction and the axis of the block. Each block is monitored by two LEDs on opposite corners of the slanted face of the tower. The calibration was done in November 1993 and moved to NOMAD assuming that the LED signals remain the same.

### Dimensions :

- Transverse Size : 280.0 cm x 277.0 cm
- Transverse Size of Block : 11.2 cm x 7.9 cm



- Block Length : 49.4 cm
- Front Face Position : 582.3 cm
- Weight :  $\sim 20$  Tons
- photoelectrons/GeV (B off) :  $\sim 1200$
- photoelectrons/GeV (B on) :  $\sim 950$
- Minimum Ionizing Signal : 0.55 GeV
- GeV/ADC count :  $\sim 0.025$  GeV
- Radiation Length :  $19.8 X_0$
- Interaction Length :  $1.6 \lambda$

**Readout** : 875 channels Peak sensing ADC 96 TDC Channels

**Performance** : Energy Resolution  $\sigma/E = 0.0085 + 0.03/\sqrt{E(GeV)}$

## 9 The Hadronic Calorimeter

**Description** : The NOMAD HAD calorimeter is a sampling calorimeter downstream from the EM calorimeter and the magnet coil in the slotted iron. It consists of 11 steel planes and scintillator counters. Each active plane contains 18 counters. There are two notches in counters 8 and 11 (counting from the bottom up) to provided for bolts which hold up the cradle.

**Dimensions** :

- Transverse Area : 360.0 cm x 350.0 cm
- Thickness of iron plane : 4.9 cm
- Length of a Counter : 360.0 cm
- Thickness of Counter : 1.0 cm
- Height of Standard Counter : 18.3 cm
- Height of Counter 7 & 8 : 21.9 cm
- Height of Counter 9 : 10.6 cm
- Height of Counter 10 : 13.6 cm
- Position of Front Face : 710.6 cm
- Interaction Length :  $3.2 \lambda$

**Readout** : 36 ADC and TDC channels

**Performance :** Energy Resolution  $\sigma/E \sim 1.2/\sqrt{E(\text{GeV})}$

**Installation :** 4 Modules in September. The whole HCAL before April 95

## 10 The Muon Chambers

**Description :** The NOMAD Muon Chambers are 5 Modules salvaged from the UA1 muon system. Each Module consists of 2 Chambers (one oriented horizontally and one vertically). Each Chamber consists of 48 long tubes oriented along the length of the Chamber and 73 short tubes oriented along the width with anode wire centrally positioned. The tubes are stacked in two rows one behind the other offset by half a tube. Modules 1-4 are oriented vertically and Module 5 is oriented horizontally. Modules 1, 2 and 5 are located in front of an iron absorber wall. Modules 3 and 4 are located behind the wall. The gas is Argon:Ethane, 40:60.

**Dimensions :**

- Transverse Size of Chamber : 375.0 cm x 555.0 cm
- Length of Long Tube : 555.0 cm
- Length of Short Tube : 375.0 cm
- Transverse size of Tube : 14.9 cm x 4.4 cm
- Position of Module 1 x,y,z : -172.5 cm, -135.0 cm, 907.3 cm
- Position of Module 2 x,y,z : 172.5 cm, -135.0 cm, 945.3 cm
- Position of Module 3 x,y,z : -172.5 cm, 0.0 cm, 1144.3 cm
- Position of Module 4 x,y,z : 172.5 cm, 0.0 cm, 1182.3 cm
- Position of Module 5 x,y,z : 0.0 cm, 363.0 cm, 926.3 cm
- Thickness of Iron Wall : 80.0 cm
- Transverse Area of Wall : 720.0 cm x 640.0 cm

**Readout :**

**Performance :** Resolution .25 mm for 0° track, .50 mm for 40° track

## 11 The Dummy Target

**Description :** The dummy target consists of two Blocks of polyethelene placed in upstream of the Drift Chamber Modules to compensate for the loss in fiducial mass due to lack of active target.

**Dimensions** • Size in X per block : 268. cm

- Size in Y per block : 300. cm
- Size in Z per block : 12.5 cm
- Distance between blocks : 1.5 cm
- Weight per block : 940 Kg

## 12 The Neutrino Beam

**Energy Spectrum :** low cut- 3 GeV, high 250-300 GeV ,

$$\nu_{\mu} : \langle E_{\nu_{\mu}} \rangle = 28 \text{ GeV},$$

$$\bar{\nu}_{\mu} : \langle E_{\bar{\nu}_{\mu}} \rangle = 28 \text{ GeV},$$

$$\nu_e : \langle E_{\nu_e} \rangle = 48 \text{ GeV},$$

$$\bar{\nu}_e : \langle E_{\bar{\nu}_e} \rangle = 40 \text{ GeV}$$

**Energy of Proton Beam :** 450 GeV

**Vertical Angle of Proton- and  $\nu$ -Beam :**  $42.5278 \text{ mrad} \equiv 2^{\circ} 26' 12''$

**Nominal BCT :**  $2.0 \cdot 10^{13}$  protons/burst, 2 spills per burst ( $1.3 \cdot 10^{13}$  and  $0.7 \cdot 10^{13}$ )

**Promised Total Protons on Target :**  $2.4 \cdot 10^{19}$  in two years

**Beam Cycle :**

- Cycle length: 14.4 s
- Length of first extraction : 5 ms
- Length of flat top : 2580 ms
- Length of second extraction : 4 ms

**Target :**

- 11 cylindrical rods of Beryllium (10 cm long, 3 mm diameter)

- The rods are collinear in the beam direction, with 9 cm gaps of helium between them.
- Total Length of Target : 2 meters
- Effective Length of Target 11x10 cm : 1.10 m of Be
- Interaction Length :  $2.7 \lambda$
- Protons non-interacting on Target: 6.7%

#### Horn :

- shape: cylinder with a cone-shaped hole
- length: 656 cm
- outer diameter: 42 cm
- large inner diameter: 14.0 cm
- small inner diameter: 0.8 cm
- Nominal Current: 100 kA
- maximum field: 5 Tesla
- Nominal Factor of focussing effect: 5

#### Reflector :

- shape: cylinder with a cone-shaped hole
- length: 654 cm
- outer diameter: 77.6 cm
- large inner diameter: 41.6 cm
- small inner diameter: 19.6 cm
- Nominal Current: 120 kA
- maximum field: 0.25 Tesla
- Nominal Factor of focusing effect: 2

#### Toroid :

- shape: toroidal (cylinder with cylindrical hole)
- length: 1000 cm
- outer diameter: 600 cm
- inner diameter: 200 cm
- Nominal Current: 3 kA

- maximum field: 0.72 Tesla

#### **Muon Pits :**

- Solid State Detectors (SSDs) used which measure the Muon Flux to determine the Neutrino Flux
- Number of Muon Pits equipped with SSD counters: 3
- Total Number of SSD counters : 51
- Number of fixed SSD counters in Pit 1: 15
- Number of fixed SSD counters in Pit 2: 10
- Number of fixed SSD counters in Pit 3: 6
- One calibration box with five SSD counters per Pit to calibrate the fixed counters
- One reference box with five SSD counters in one of the Pits (physically moved to calibrate the calibration box in each pit)
- Emulsion sheets exposed once per year to get absolute calibration
- Average Muon Flux measured by the central fixed SSD counters in Pit 1:  $450 * 10^{-8} \mu / (cm^2 * p)$
- Average Muon Flux measured by the central fixed SSD counters in Pit 2:  $120 * 10^{-8} \mu / (cm^2 * p)$
- Average Muon Flux measured by the central fixed SSD counters in Pit 3:  $24 * 10^{-8} \mu / (cm^2 * p)$

#### **Distances :**

- Target Center to Horn: 18.90 meters
- Horn to Reflector: 71.59 meters
- Target Center to Vacuum Decay Tunnel: 124.32 meters
- Length of 1st Decay Tunnel: 31.62 meters
- Length of 2nd Decay Tunnel: 258.19 meters
- Total Length of Vacuum Decay Tunnel: 289.81 meters
- Target Center to Dump: 414.13 meters
- Total Iron Shield: 185.0 meters
- Earth Shield: 44.0 meters
- Additional Iron Shield: 39.5 meters
- End of Earth Shield: 100.3 meters
- Target Center to front face of Nomad: 835.6276 meters

## 13 Disclaimer

This Living Document is neither exhaustive nor to be taken as Gospel. If additions are requested or mistakes found, please report them to the compilers (that's us the guys who wrote this thing).