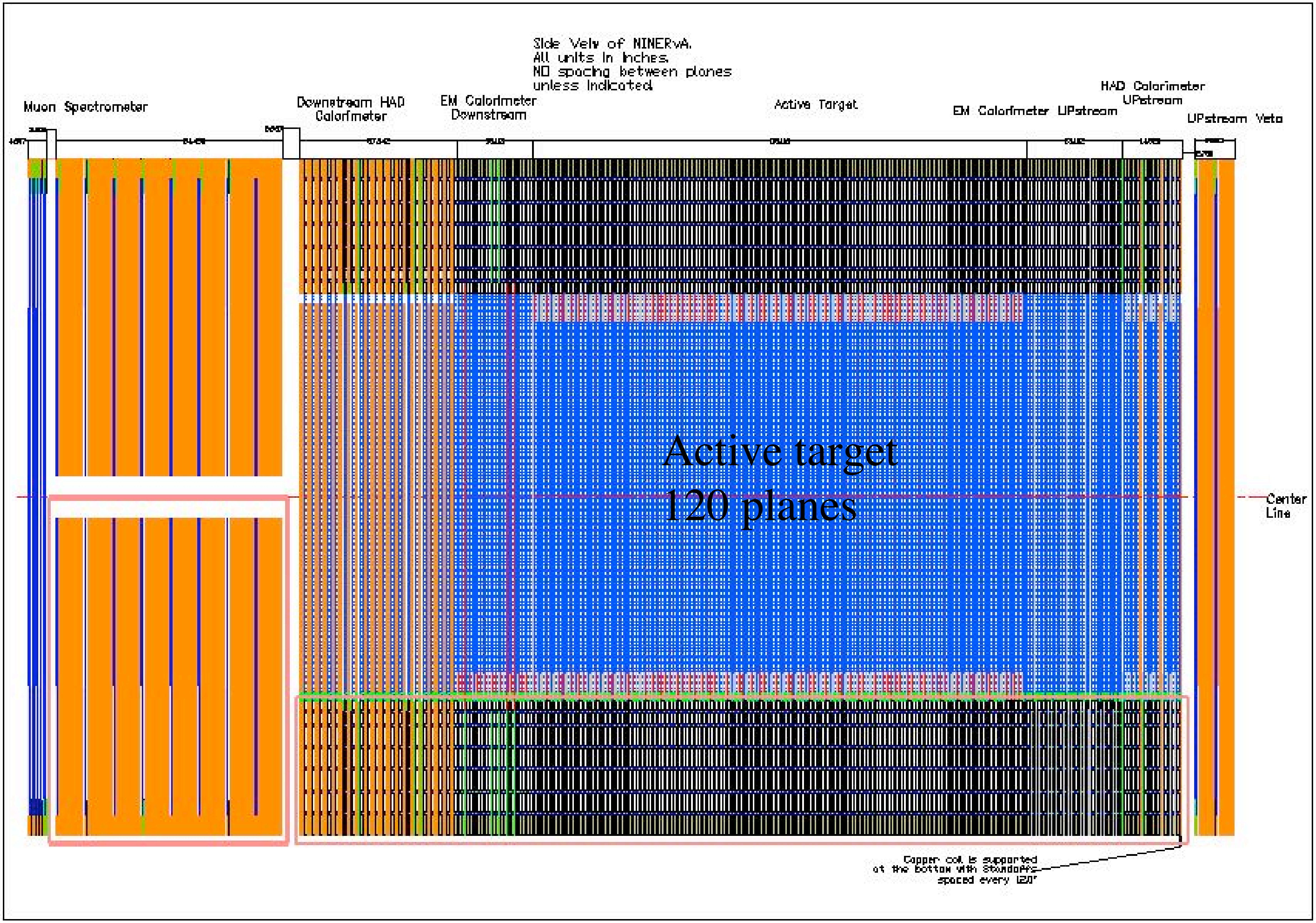
Hexagonal Design for MINERvA A. Bodek- Assembly procedure 11/22/03 and Cost Estimate

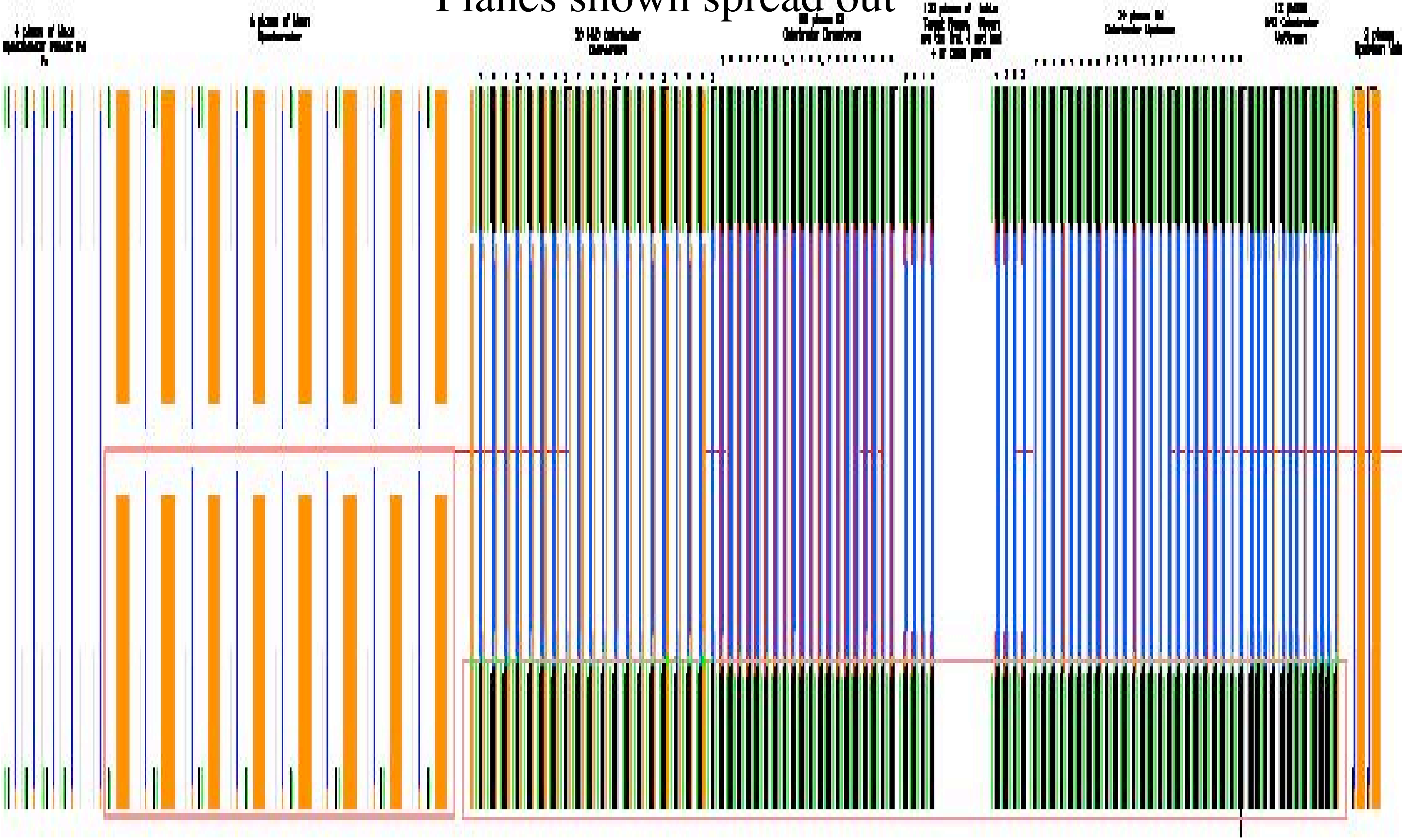
Use figures from http://www.pas.rochester.edu/~teng/
Click on MINERvA/ click on : acwebpublish.htm

(1) Define: Superplane or Supermodule. 4 planes together XUXV.
(2) Define a single plane as one of these.
(3) Start with Parts list and Assembly procedure. Constrain all work to be completed in one year (6 months for 120 planes of active target and barrel).
(4) This defines space considerations and number of techs.
(5) Use Active Target+Plus barrel calorimeter (120 planes) as a benchmark for construction.
(6) For now, multiply by 2 to get total assembly time (to account for hadron calorimeter, muon spectrometer and upstream vetos
(later refine costs more exaclty for those)

ASSUMING NO SPACE BETWEEN PLANES



Planes shown spread out



Slide 4: Start with rough gestmimate then refine as we define detailed procedure:

Take a plane with 128 active bars in the inner plus +6 X 8 (outer/barrel) detector = 128 + 48 = 172 bars

Assume: 6 8-channel connectors for barrel and 8 16- channel connectors (4 for left side and 4 for right side).

Assume that one needs 2 people to lift bars and install in place and route to connector. Assume average of 12 bars per hour (about 5 min a bar) for two people.

172 bars/12 = 14 hours. So with 7 hours a day, one gets one plane per 2 days. Assume that we have 2 tables in parallel, so we have 2 planes per two days (with 4 people). This takes 120 days, or six months with 4 techs (plus one tech to help prepare the next table and assembly supermodules.

120 planes = 120x172 = 20,640 channels.

Slide 5: Estimate of rest of detector.

If active detector 120 planes take 6 months with 5 techs for 20K channels.

Assume that the other 15K channels plus prototyping (for muon absorber, hadron calorimeter etc,. takes another six months,

Get 5 techs for one year for assembly of all supermodules.

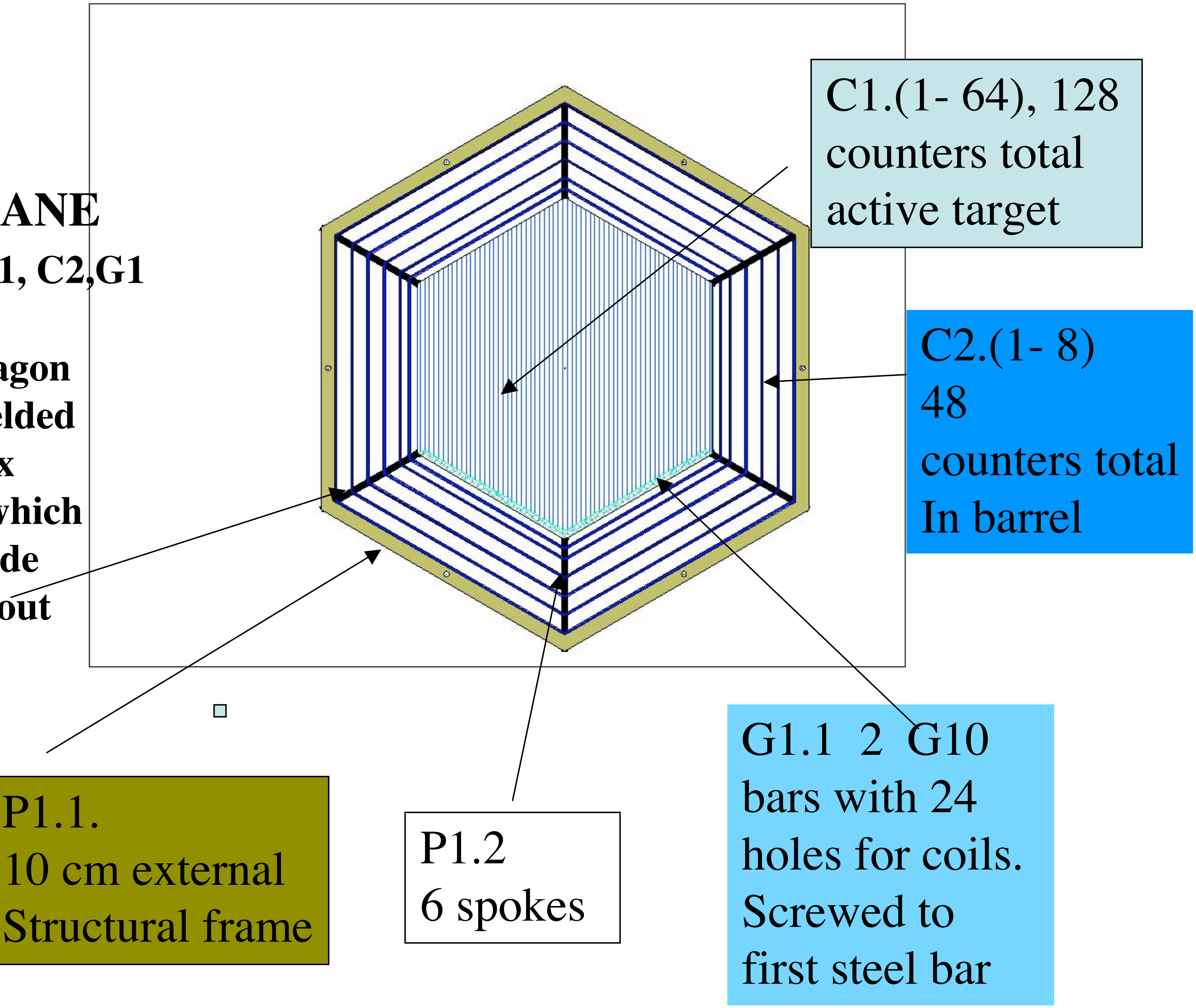
At $75K per tech per year (including benefits, overhead) times 5. This is about $375K.

We get 5 tech for one year total.

Now we see if our estimate of 5 techs for 6 months for 120 planes, with two parallel setup tables is reasonable if we go through all the details.

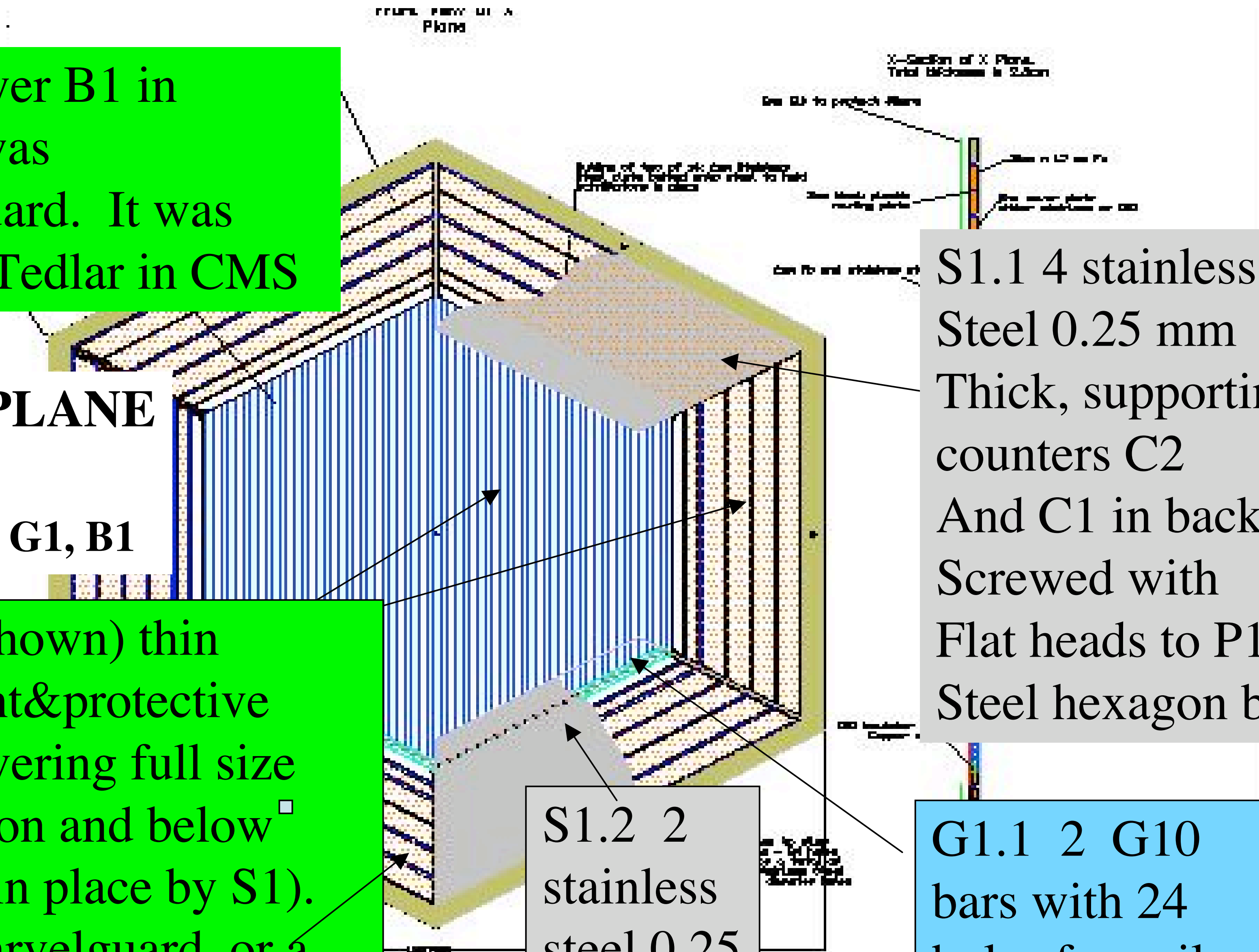
Slide 6: PLANE Parts P1, C1, C2,G1

P1. Steel hexagon frame. All welded together to six steel spokes which are 1.7 cm wide (thickness about 1 cm)



Note: Layer B1 in NuTeV was Marvelguard. It was Tyvek + Tedlar in CMS

Slide 7: PLANE Back Parts S1, G1, B1



S1.1 4 stainless Steel 0.25 mm Thick, supporting counters C2 And C1 in back. Screwed with Flat heads to P1 Steel hexagon bars

B1 (not shown) thin Light tight&protective Layer covering full size Of hexagon and below S1 (held in place by S1). Either marvelguard, or a Layer of Tyvek-white house wrap and Tedlar on outside (black plastic)

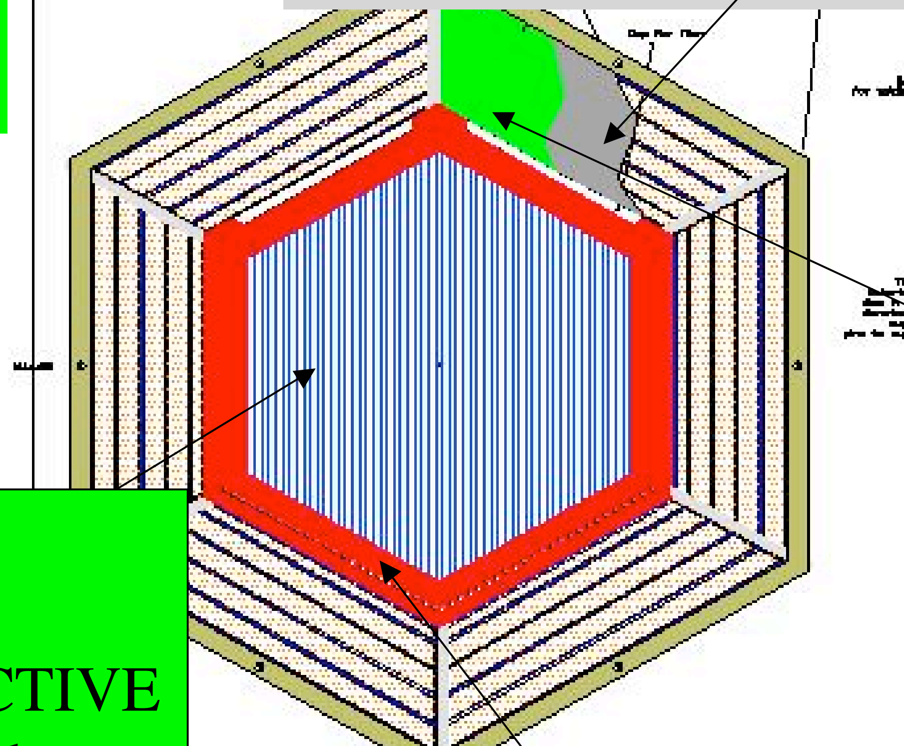
S1.2 2 stainless steel 0.25 mm with holes for coils

G1.1 2 G10 bars with 24 holes for coils. Screwed to first steel bar

Note: Layer B2 in NuTeV was Marvelguard. It was Tyvek + Tedlar in CMS

S2 6 {2-mm G10 or Al or stainless steel 0.25 mm } to protect Routing plate R1

Slide 8: PLANE Front Parts L1, R1,S2, B2

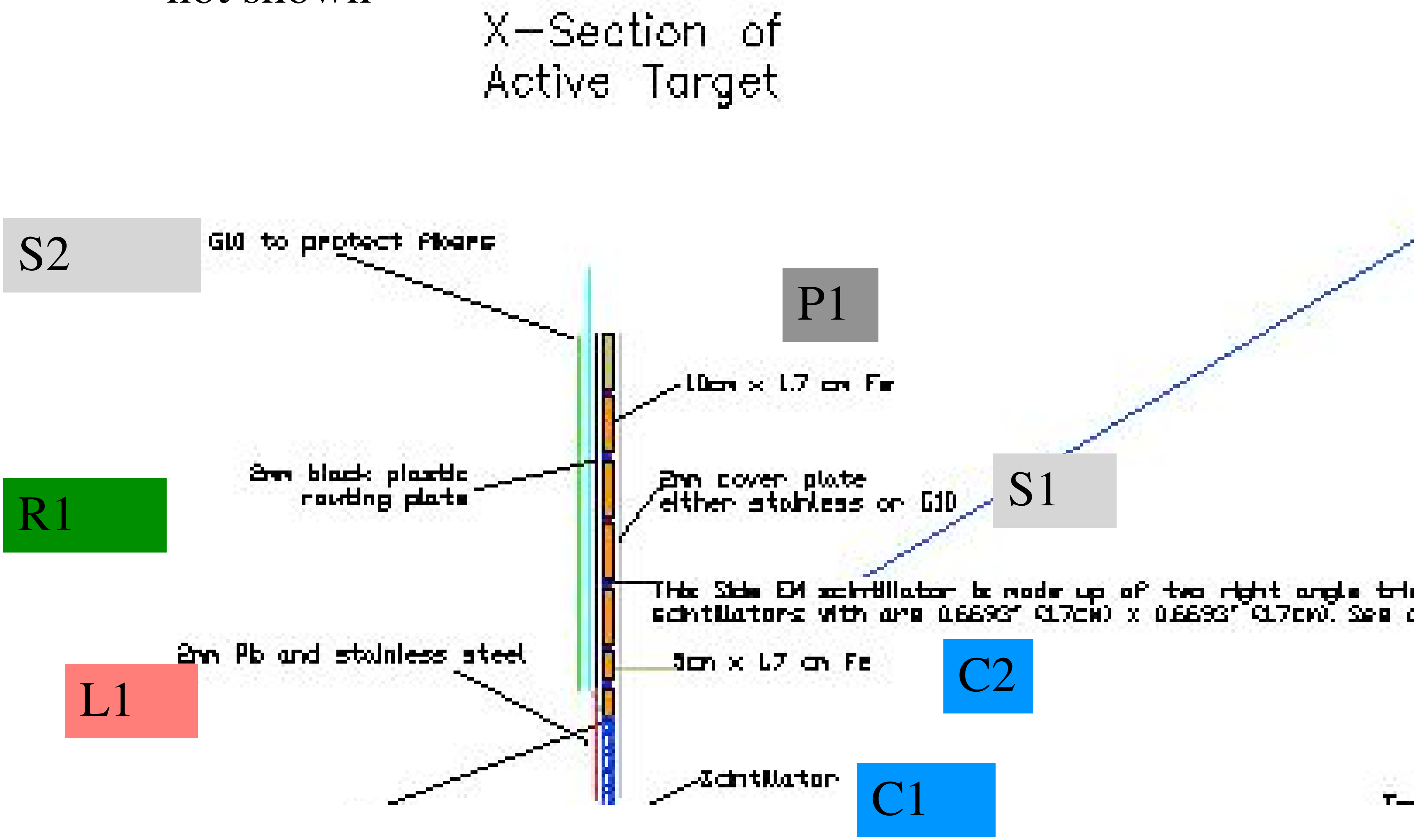


R1.(1-3) 6 Black plastic fiber routing plates. Top 2 are different from bottom 4

B2 (not shown) thin Light tight&protective Layer covering only ACTIVE layer of hexagon and below L1 (held in place by L1). Either marvelguard, or a Layer of Tyvek-white house wrap and Tedlar on outside (black plastic)

L1. 1.5 mm lead sandwhiched between 0.25 mm Stainless flat screwed to first steel bar

Slide 9: Note- thicknesses and materials need to be updated on drawing. B1 and B2 protective layers not shown



Slide 10: Step 1 P1->P1A: {P1 is the Steel Hexagon Frame, welded together to make a Hexagon. 8 Hexgaon bars welded together along six spokes to keep their separation from each other (a small dead area) (one per plane) - Function, Hadron calorimeter, barrel muon detector (magnetized).}.P1 units are stored vertically and can be moved and layed down without any backing, Have one P1 on table 1, and one P1 on table 2. Each day. Each table has a backing fixture on it for lifting final assembled plane later. The P1A (is P1 with backing) is constructed as follows.

(a) Start with P1 on table. Flat screw two 10 cm G1 bars with 24 holes each in them (G1 used for coil positioning)to bottom two inner sides of steel bars of hexagon.

(b) Put thin protective layer over B1 over entire hexagon.

(c) Flat screw six units of S1 (2 with holes which cover G1 bars and 4 without holes over rest of hexagon. P1A is now complete.

(d) Pick up P1A (which has the back side up) with crane and flip over so P1A back side is down.

Assume counters are extruded with white light tight skins and have Fibers in them. Already in assembly area.

Slide 11: Step 2 inserting counters: Subunit P1B

Assume R1 covers plates have connectors on them and fiber grooves.

(a) Put counters C2. (1-8) in each inter steel gaps in the barrel

(b) Repeat for all remaining 5 barrel sections of hexagon (two 2-man team working in parallel,

(c) Put Readout Cover Plates R1. (1.-6) over barrel sections and flat screw to steel bars in barrel.

(d) Run fibers from Barrel in groove of R1 readout plate and insert into the six 8-fiber connectors. Light tight with tape all areas.

(e) Start on one edge and put active counters C1 one at a time into the frame. And rout fiber in groove to each of the four 16-fiber connectors. Complete left half (64 counters) one team while second team does right half. Put tape over grooves to light tight and place fibers in place

(f) Put light&protective layer B2 over entire area of 128 active counters.

(g) Light tight all areas between layer B2 and cover plate R1

Slide 12: Step 3 putting on lead and final assembly: Subunit P1C

(a) Put epoxy into connectors to glue connectors to fibers. Plane should now be light tight.
(b) Put protective cover S2 over six Readout cover plates R1.(1-6)and flat screw to steel, Flat screws must be large to transfer force to steel bar. There are round washers in the holes R1 so that no pressure is put on the fibers and R1 if plate S2 is hit.
(b) Take lead sheet which backed by stainless steel on each side and put on the counters. Flat screw to steel bars.
(c) Wait for epoxy to cure overnight.

In parallel, plane 2 which cured the night before has connectors cut and polished with portable diamond unit.

(b) Move over to table 2 which has a plane from last night.
(a) Attach plane to backup lifting gig with bolts to steel frame
(b) Lift plane with crane, bring over to storage area. Remove backup lifting gig, and attach to Supermodule (XUXV) with bolts
(c) Assume that supermodule of 4 planes, with steel backing on the sides is 10 cm thick and can be lifted and transported vertically safely later.

Old Presentation --Hexagonal Design for MINERvA
A. Bodek, Updated Nov. 14, 2003

1. Designed to be movable to off axis tunnel (less than 4.4 meter in transverse dimensions)

2. Designed to have X u X v segmentation

3. All fiber routing and mechanical design considerations understood

4. Have sufficient side magnetic field for full solid angle muon sign and momentum determination for off axis (low energy running) - For on axis, it helps to be in front of MINOS to improve resolution of high E forward muons

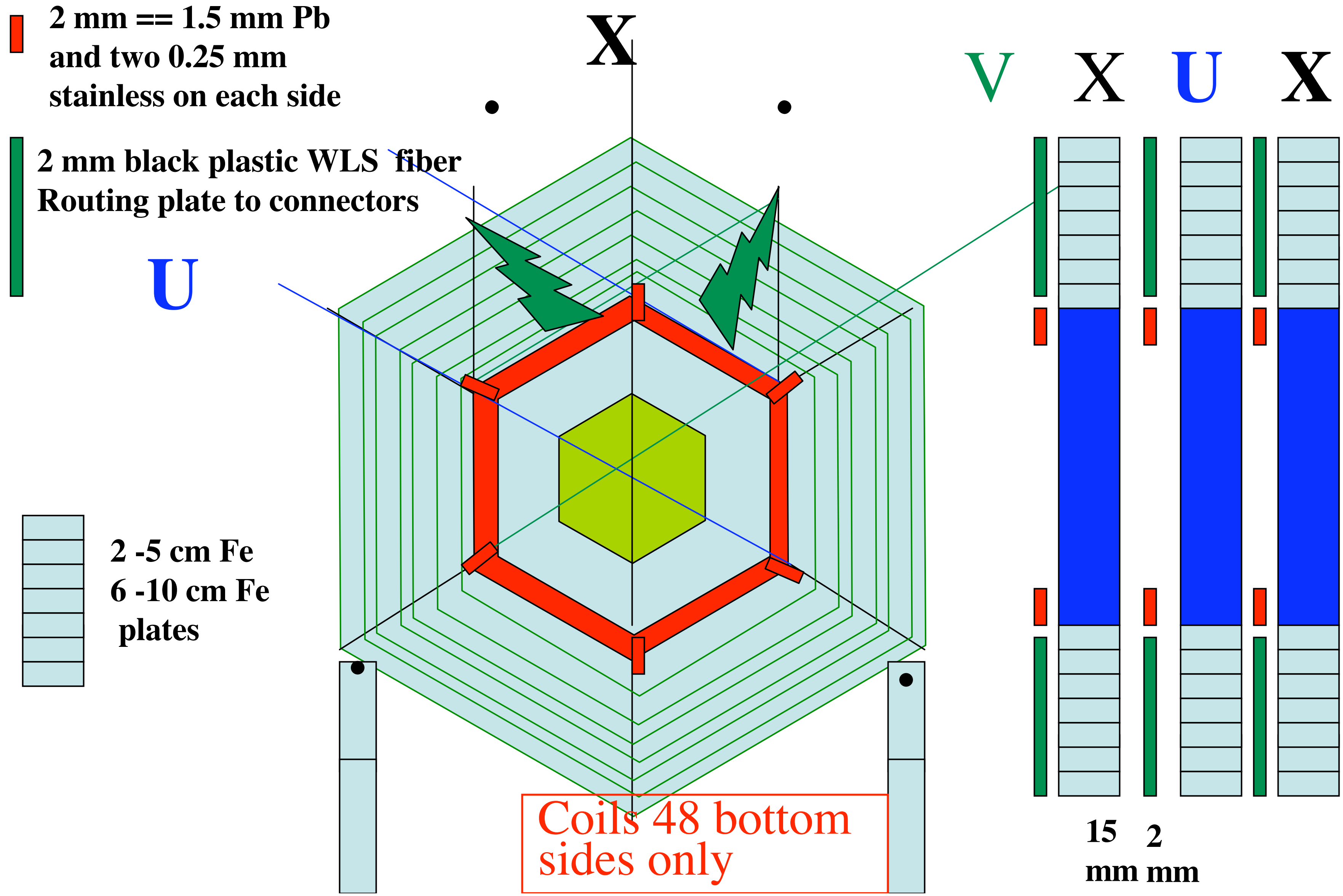
5. Excellent EM resolution, reasonable hadron resolution

OLD-Hexagonal Design file for MINERvA
A. Bodek, Nov. 14, 2003

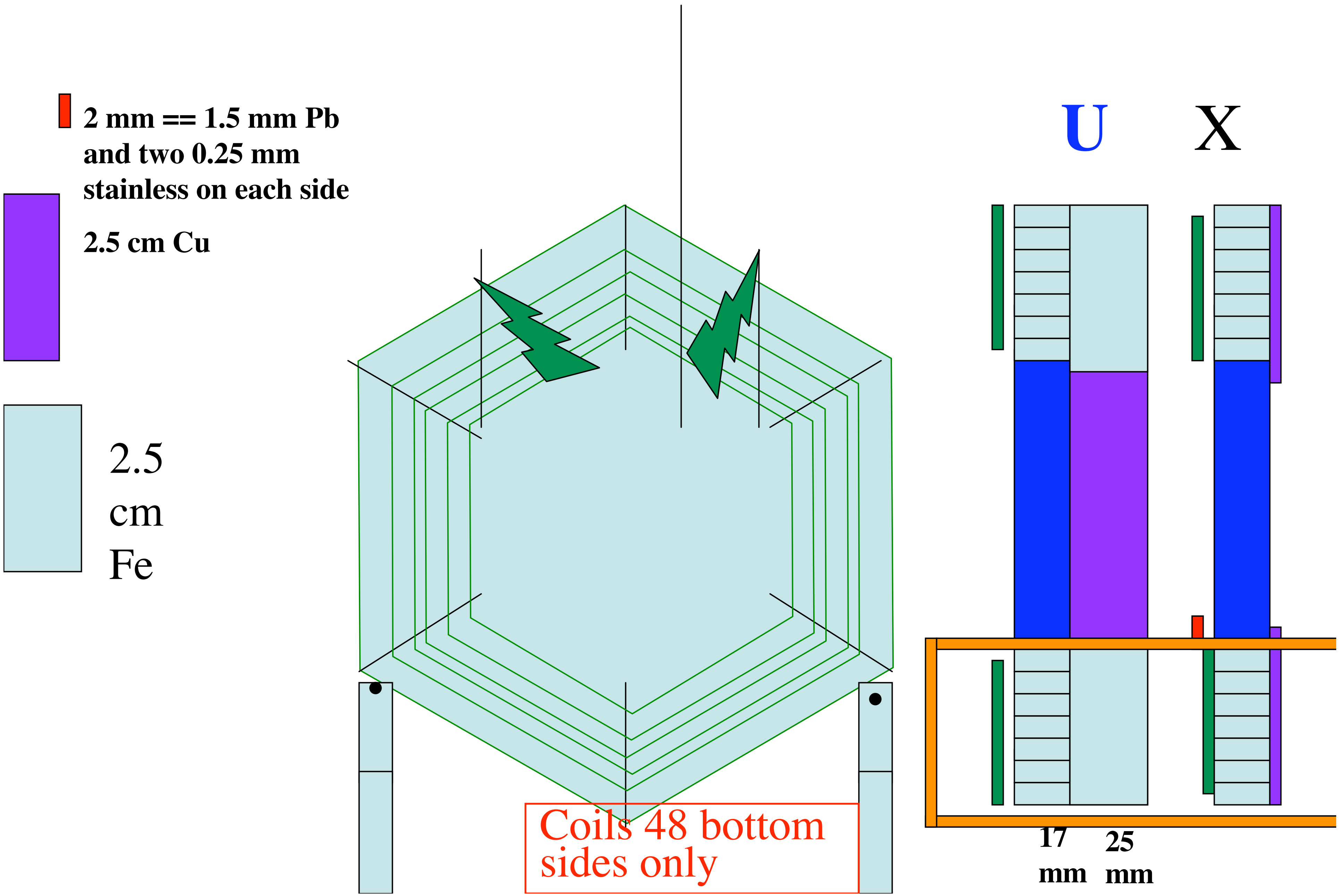
Things that still need to be done:

1. Optimize *upstream* Pb EM shower counter and Fe hadron calorimeter to serve a dual functio as Pb and Fe targets. Ask Nuclear Targets Subgroup to look into this
2. Optimize exact dimensions and segmentation (current design is pretty close. Ask simulation subgroup to look into this.

Minimize transverse to 4.1 meters to fit within 4.4 m tunnel . Run X-U-X-V-X-U planes at 60 degrees. Use x view to seed the track with 3 hits 120 planes of active 1.7 cm target. Total 1.5 m of Scintillator in Z



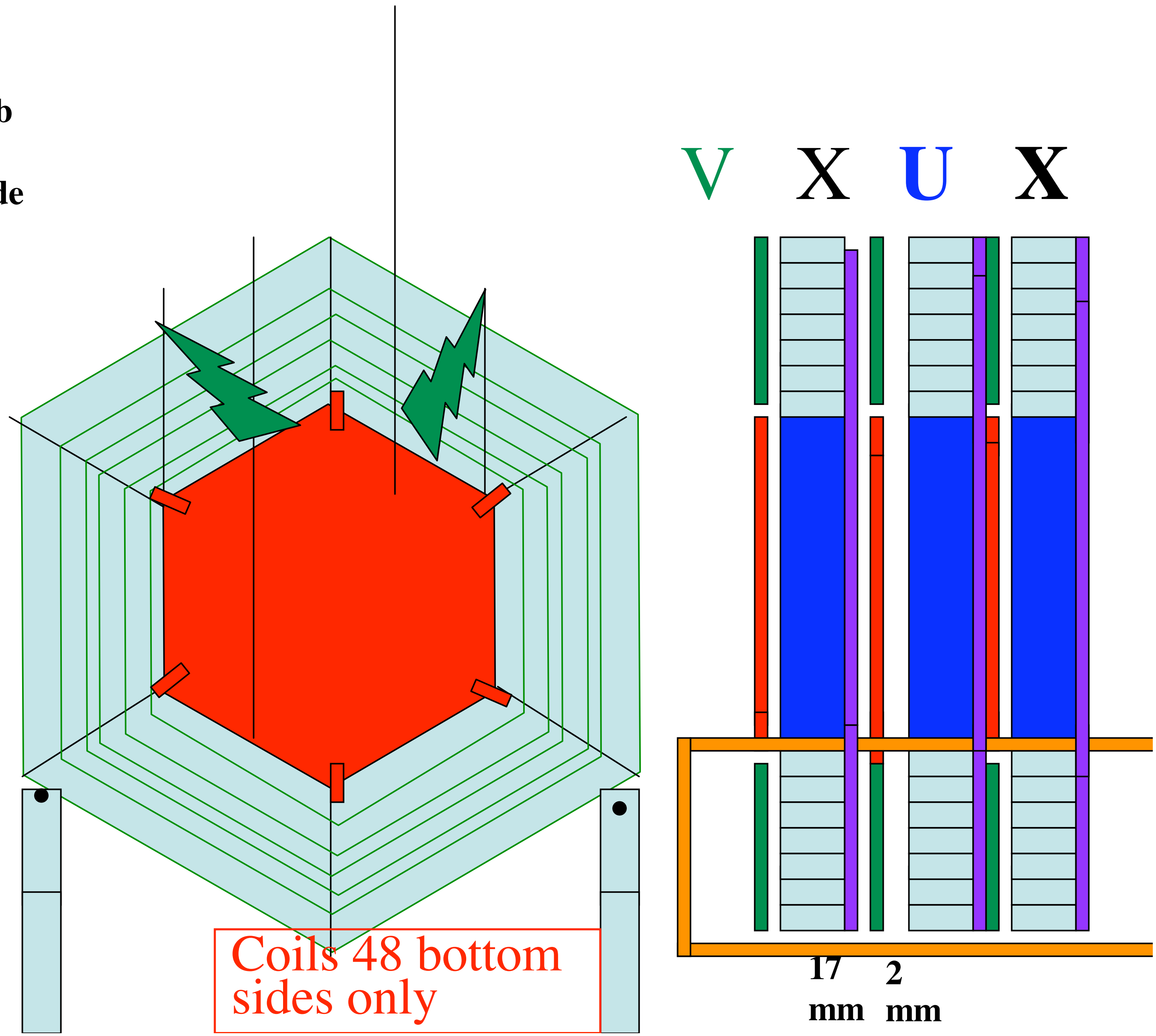
20 planes of HAD calorimeter downstream to fit within 4.4 m tunnel .



20 planes of EM calorimeter downstream to fit within 4.4 m tunnel .

2 mm == 1.5 mm Pb and two 0.25 mm stainless on each side

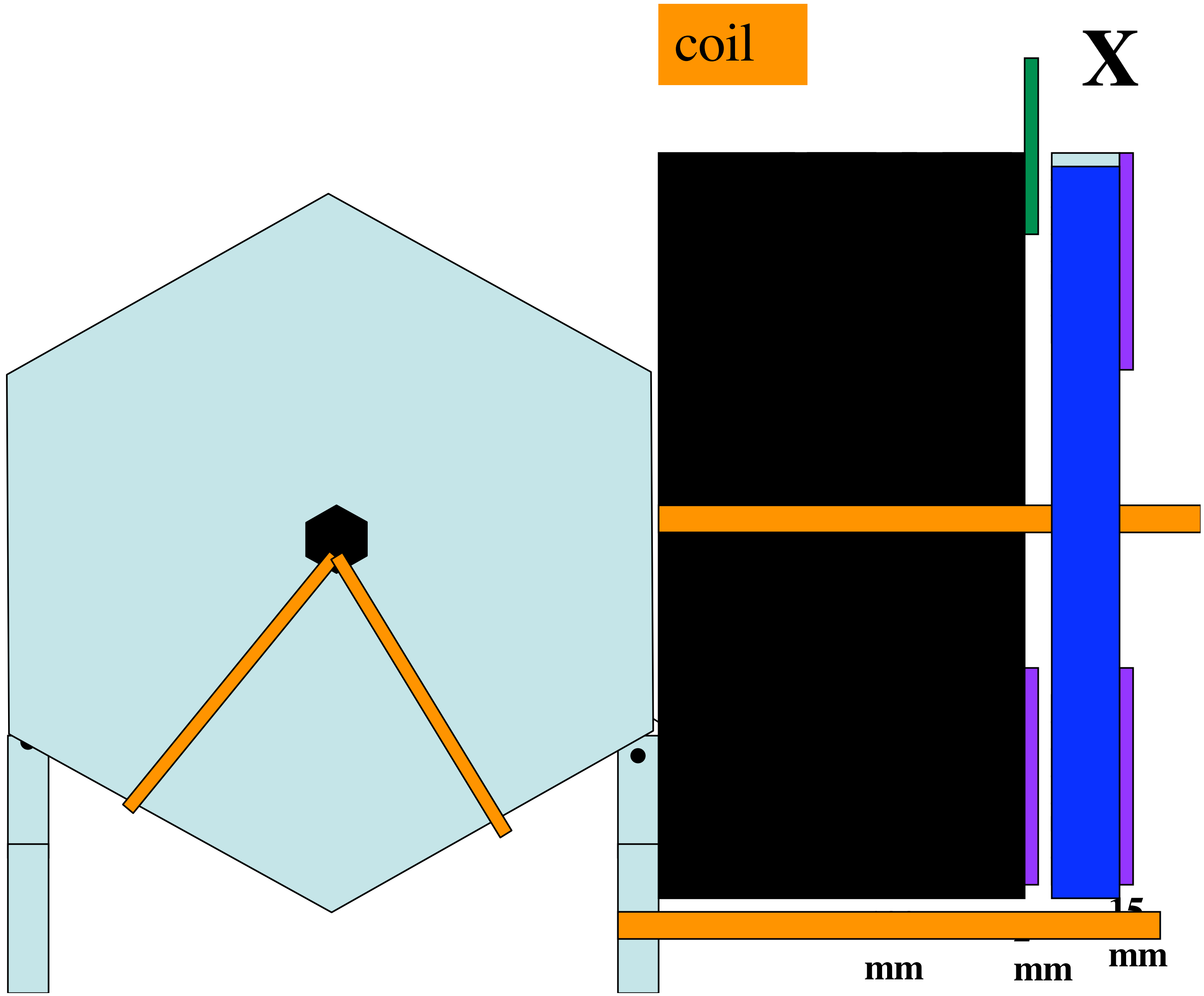
0.5 mm stainless to keep counters in place bolted to the steel barrel.

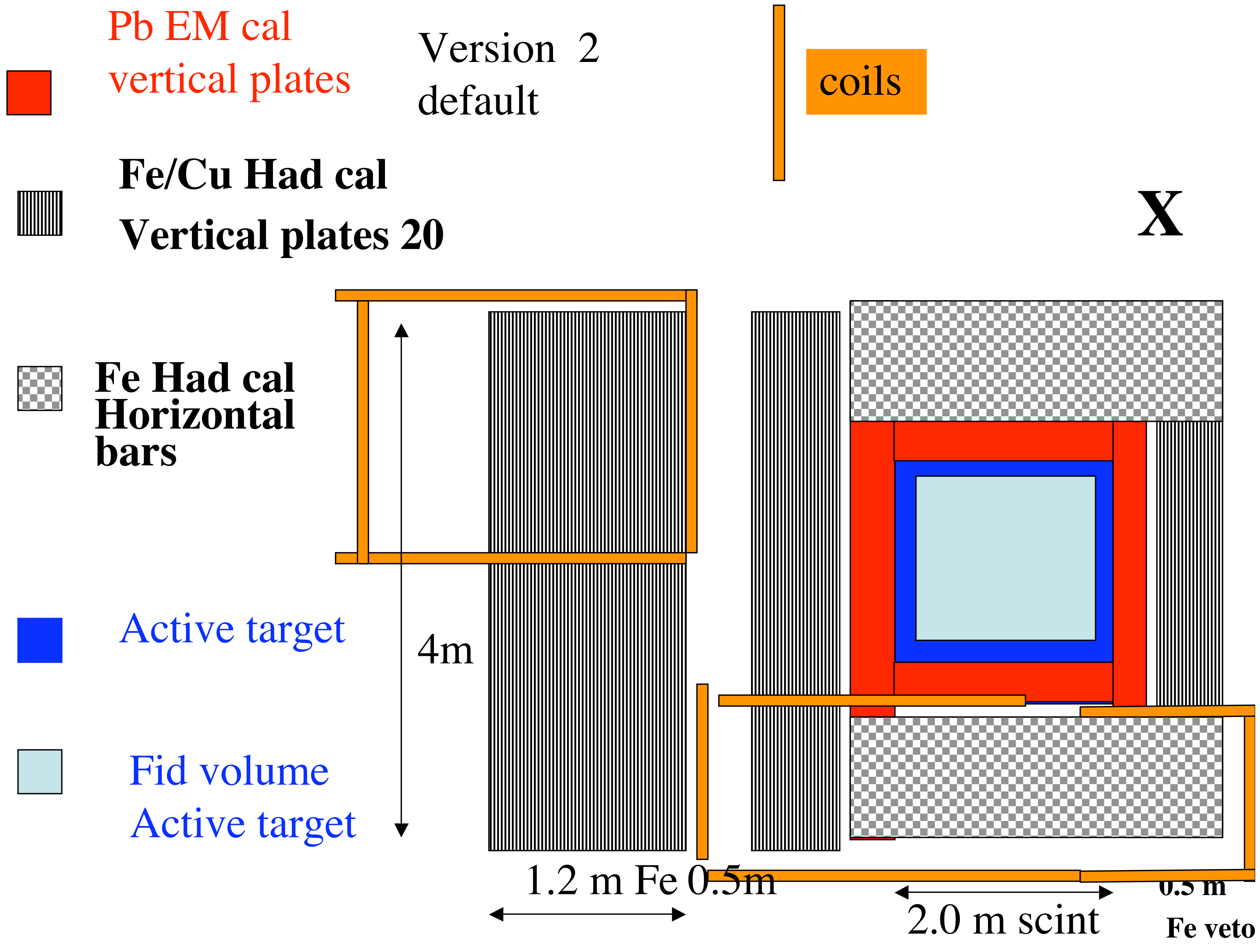


20 planes hadron calorimeter (spaced by 2.5 cm of Cu/FE) downstream followed by 8 planes of muon spectrometer (spaced by 15 cm Fe)

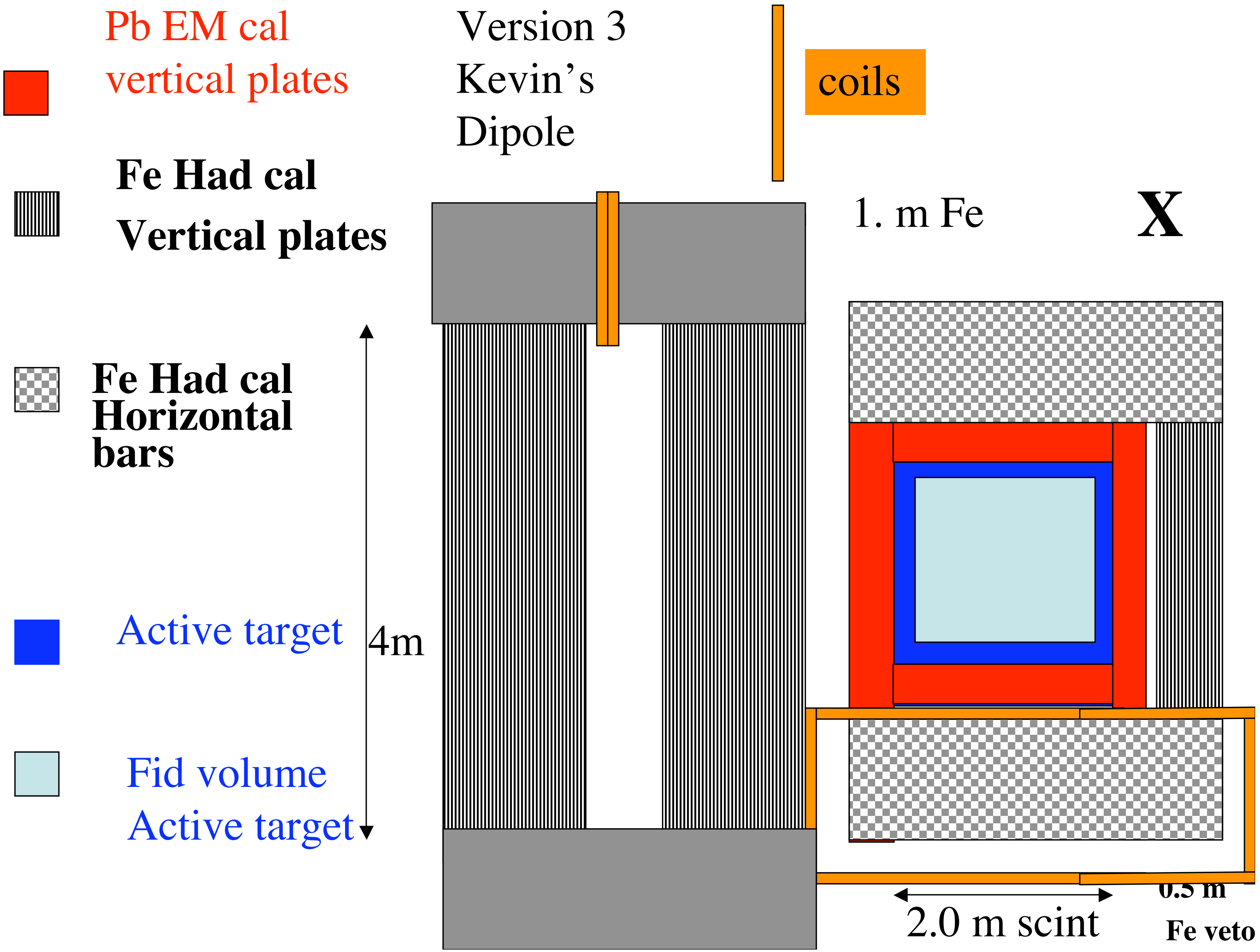
20 cm of Cu/Fe veto upstream

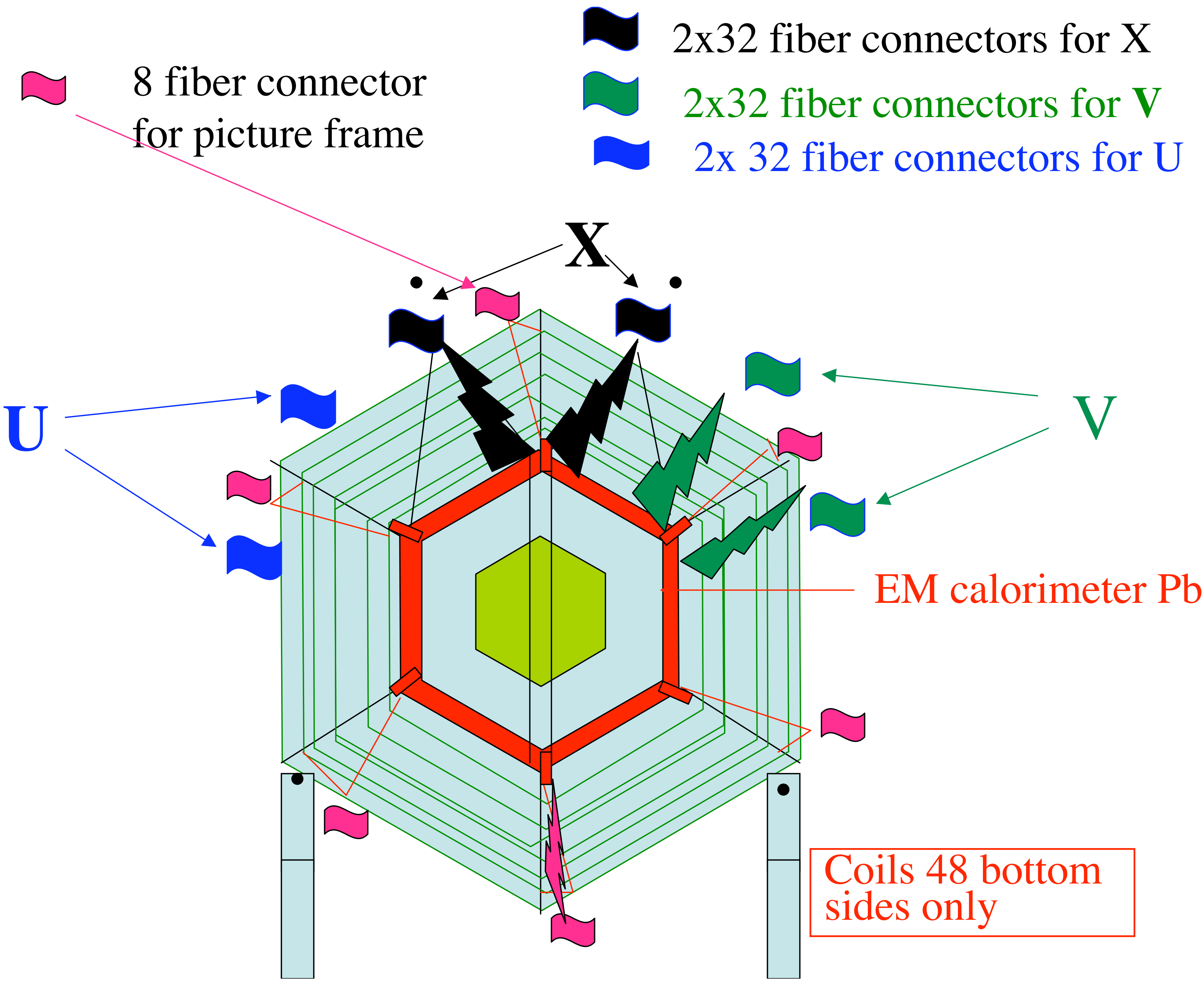
Same as hadron calorimger but not magnetized





Pb EM cal
vertical plates
Version 2
default
coils
Fe/Cu Had cal
Vertical plates 20
X
Fe Had cal
Horizontal
bars
Active target
4m
Fid volume
Active target
1.2 m Fe 0.5m
0.5 m
2.0 m scint
Fe veto


Pb EM cal
vertical plates
Version 3
Kevin's
Dipole
coils
Fe Had cal
Vertical plates
1. m Fe
X
Fe Had cal
Horizontal
bars
Active target
4m
Fid volume
Active target
0.5 m
2.0 m scint
Fe veto



2x32 fiber connectors for X
8 fiber connector
for picture frame
2x32 fiber connectors for V
2x 32 fiber connectors for U
X
U
V
EM calorimeter Pb
Coils 48 bottom
sides only

Target

Basic design - rl of Fe is 1.76 cm and of Pb is 0.56 cm

Active Target **= transverse 2.15 meter (1.85m +0.3m) hexagon 64x2 planes 3.35 cm x 1.7 cm thick triangles (the 1.7 cm is to be optimized). Have 120 planes for a total of 2.0 meter of scintillator. 128x120 =15,360 active target channels.). All scintillator 1.85m x1.85m.**

Side EM alorimeter **Between planes, the outer 0.3 m of active target has washer of 2 mm thickness consisting of 1.5 mm pb (0,27 rl) +0.25x2= 0.5 mm stainless on both sides (total 1 mm of Fe or 0.06 rl. For a total of 0.33 rl. Since it is in the active target, it has X UX V readout. Therefore, inner 1.85 m is fully active and outer 0.3 cm is fully active except for photons. Readout for this is the same as active target, so there are no additional channels**

0.94 m Side Hadron Cal/Muon ID**. Magnetized steel /of Outer consisting of 2 5 cm Fe plates followed by 6 - 10 cm Fe plates, 8x2 (3. cm 1.7 cm right angle triangle scintillator) for a total thickness of 70 + 8x3= 94 cm with a 2.5 cm steel bars all around for shielding the last counter from background. Total number of channels. Is 6x8x2 = 96 - So have 96x100 = 9600 side readout channels. (each plane is 128+96 = 224 channels**

Downstream
Basic design - rl of Fe is 1.76 cm and of Pb is 0.56 cm

Downstream EM alorimeter **20 planes same as a standard plane, except for the fact that Pb absorber now covers the entire inner 2.15 meters. Same as in the target magnetizes the outside steel frame**

Downstream Hadron Calorimter/Muon absorber 20 planes same as dowstream EM calorimter , except for the fact that Pb absorbers are now replaced by 2.5 cm plates of Fe 4 m wide with a hole in the middle for another coil. If we do not have MINOS magnet downstream, then put another 10 planes of 15 cm plates.

Upstream Veto: same as downstream Downstream EM+ Hadron Calorimter/Muon absorber except for it being made of 8 Pb+ 4 Fe/Cu plane Needs to be optimized with MC to see how many backwards particles+energy

Total number of channels: 120 target planes x 224 = 26,880

Downstream EM calorimeter: 20 x 224 = 4480

Downstream Hadron calorimeter = 20 x N (=400 cm *3/3.35 = 240)

Upstream EM veto = 10x224 plus Upstream Fe Veto = 10x224,

plus downstream toroid 10x224

Resolutions Expected

SIMPLE FORMULAE FOR LIGHT YIELD CONSIDERATIONS IN THE DESIGN OF SCINTILLATOR FE AND SCINTILLATOR PB SAMPLING CALORIMETERS.
By Arie Bodek, Priscilla Auchincloss (Rochester U.). UR-1385
Published in Nucl.Instrum.Meth.A357:292-295,1995
On Web as http://doc.cern.ch/tmp/convert_SCAN-9502273.pdf

For Resolution of EM calorimters (with account made for thick scintillator) see: On the energy resolution of electromagnetic sampling calorimeters By J. Del Peso E. Ros Published in Nucl.Instrum.Meth.A276:456-467,1989

Better formulae for Resolutions: Note that the EM, Hadron energy resolutions for this detector can be prametrized as the following formulae: EM resolution (from Del Peso et al below) is:
Sigma/E EM in percent = 3.46% (t-absrober in rl)**0.67 /(t-scintillator in rl)**0.29

Combining information in the arrticles of Bodek and Auchincloss and Del Paso
Sigma/E HAD in percent = 87% (t-absorber in cm/10 cm)**0.67 /(t-scintillator in mm/25 mm)**0.29

EM calorimeter part has resolution of [**4%/Sqrt(Eem)]/costheta** for 1.5 mm plate Pb and 1.5 cm scintillator.
Hadron Calorimeter has resolution of [**64%/Sqrt(Ehad]/costheta** for 5 cm Fe sampling and 1.5 cm thick. For normal incidence to the plates costheta=1

Putting into the formula: costheta=0.7 for photons and hadrons at 45 degrees to the planes of the samples one gets : EM calorimter part has resolution of 4.5 %/Squrt(Eem) for 1.5 mm plate Pb (with 45 degrees incidence) and Hadron Calorimeter for 5 cm sampling has resolution of **70%/Sqrt(Ehad)** for 45 degree incidence.

3.46	0.670	0.290	SigmaZero	Alpha	Beta	costheta	
5.6	17.6	424	PbX0	FeX0	ScintX0		
1.5	0.5	15	thicknes-mm	thickness-mm	thickness-mm		1
0.26785714	0.02840909	0.03537736	t/X0	t/X0	t/X0		
0.29626623			Pb+Fe				
4.03620092			resolution%	EM			
			times sqrt(E)				
87	0.67	0.29	SigmaZero	Alpha	Beta		
	10	25		Fe	Scint		
	5	15		thickness cm	thickness mm		
	0.5	0.6		tfe/10	tscint/25		
0.5			Fe/10cm				
63.4111009			resolution%	Had			
			times sqrt(E)				

Resolutions Expected

Downstream

Hadron calorimeter 5 cm plates with 1.5 cm scintillator. 50 cm total followed by 10 15 cm plates for containment, Total 2 meters of Fe.

Haron energy resolution of 5 cm section:[**64%/Sqrt(Ehad]/costheta**

EM calorimeter 20 1/3 rl plates, total 6 rl. Followed by the hadron calorimter with 5 cm/1.76 = 2.8 rl sampling for containment.
[**4%/Sqrt(Eem)]/costheta** for 1.5 mm plate Pb and 1.5 cm scintillator.

Side EM planes in same direction as downstream EM so **4%/Sqrt(Eem)]/costheta**. Total thickness Is 6 rl/costheta

Side Had has 10 cm sampling so resolution is
0.87 / Sqrt [Ehad*sintheta} unless make plates thinner.

Case of magnetized Steel MINERVA

B-H Curve for steel can be found at http://www-fmi.fnal.gov/fmiinternal/MI_Notes_Pages/MI-0127.pdf which has been backed up to http://www.pas.rochester.edu/~bodek/minerva/MI-0127.pdf

Table 3 page 12 for Armco steel show that for H=10, B=10 Kgauss (B=1 T, or mu-1000). Pretty much around 1000 for lower H. However to get to saturated iron is hard. For H=30, B-15 and for H-60 B=20.5. So need a factor of 6 more current to go from B=10 Kgauss to B=20 Kgauss (below H=10 it is linear). Scaling from CCFR, which has B=1.6 T and L=4.8 meter and resolution of 10%. One gets momentum resolution (which will only be used for sign) of

Sigma = (16%/ B(Tesla) * Sqrt [4.8/L(meters)]   Pt kick = 2.4 GeV/c * (B/1.6 T) *(L meter/4.8m)

so for 1.2 iron at 1 T we get sigma of 16% times 2 or 32%. (PT KICK OF 0.44 GeV)
Factor of 2 Better if we use 2 T (see below) which requires factor of 10 more current Energy resolution from range is just how well you can determine range (the more scintillator sampling, the better range is determined).

What kind of current do we need.

Lab E has 4 coils. 12 turns 1200 amp each. total NI=48x1200 Amp Get 1.9 T at 1 foot and 1.55 T at the edge. 2.4 GeV Pt kick. However, it does not have quality magnet iron steel.

For a square rod going around Minerva of L=3.5x4 =14 meter so total path of magnetic field is 14 meters (most outer Design, inner path is L=3.5*2.15=7.5 meter
H = 4*Pi* (10-3) N I /L m in Orested**

Need to get H above 10, so running with 48 coils at between 300 and 500 Amps gives B=12 to 14 Kgauss (see spreadsheet).

2.5	3.96
3.5	4.95
4.1	5.95
5.5	6.94
6.0	7.94
8.0	8.93
9.9	9.93
10.4	10.17
10.8	10.42
11.3	10.64
11.3	10.91
12.8	11.16
13.8	11.40
14.3	11.65
14.9	11.89
15.9	12.14
16.5	12.39
17.4	12.63
18.0	12.88
19.0	13.12
20.5	13.37
21.5	13.62
23.0	13.86
24.0	14.11
25.0	14.35
26.5	14.60
28.6	14.84
29.9	15.09
32.8	15.33
35.4	15.58
38.2	15.82
[illegible]	[illegible]

Calculate on next slides for 2.15 and for 4 meter long bars what is H and B for several coil currents with 48 turns.

Get muon energy from ***both*** range and bend (sign) at low energies and ***only from bend*** at higher energies . So for on axis need muon MINOS downstream toroid to get resolutions bettern than 17%. Downstream we have 2m Fe (or 3 GeV range at zero degrees), side we have 0.7 GeV Fe, or 1 GeV range at 90 degrees.

			Res with 0.70 m Fe					
300	N	48	0.7			kick	kick	kick
			angle			90	45	30
H	B		90	45	30	Pt		
21	13.6		0.31	0.26	0.22	0.30	0.42	0.60
11	10.6		0.40	0.33	0.28	0.23	0.28	0.46
500	N	48						
H	B							
35	15.6		0.27	0.23	0.19	0.34	0.41	0.68
19	13.1		0.32	0.27	0.23	0.29	0.34	0.57
150	N	48						
H	B							
11	10.6		0.40	0.33	0.28	0.23	0.28	0.46
8	8.9		0.47	0.40	0.33	0.19	0.23	0.39

In forward direction we have 2 m or a factor of 1.6 better resolution (about 17% resol)

Armco Steel need 500 amps

At any angle, the Quasielastic muon has the highest possible energy for particles at that angle for a fixed Ezero.

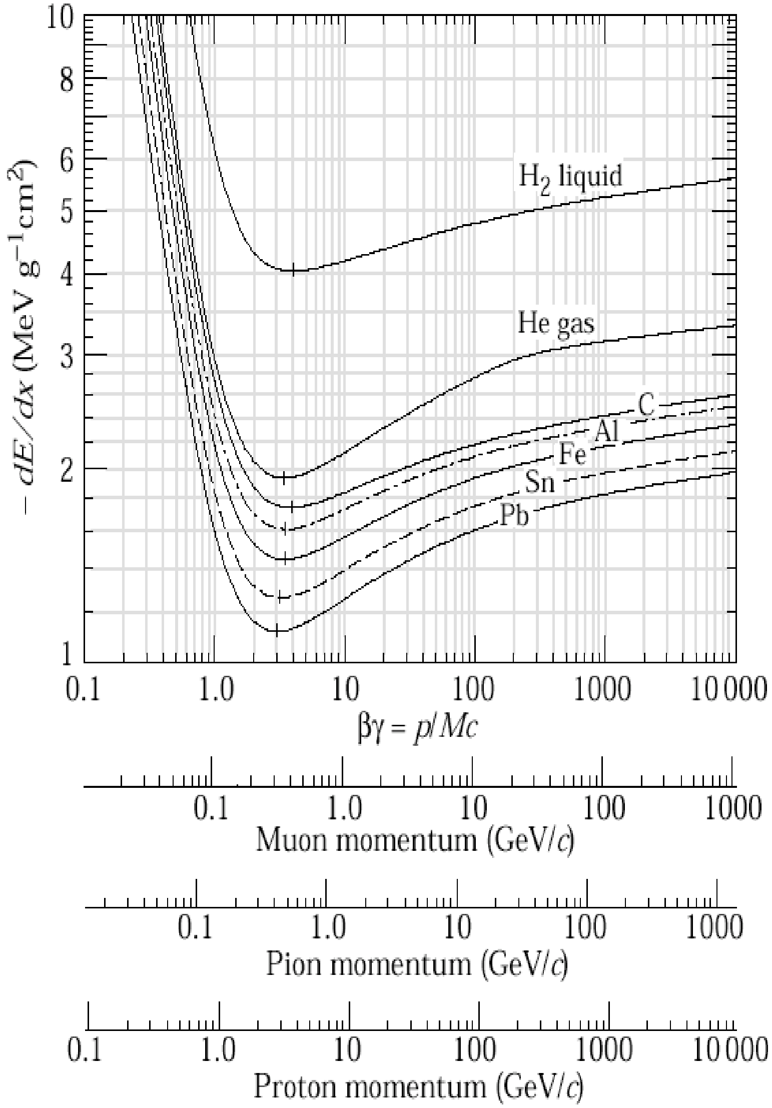
scintillator

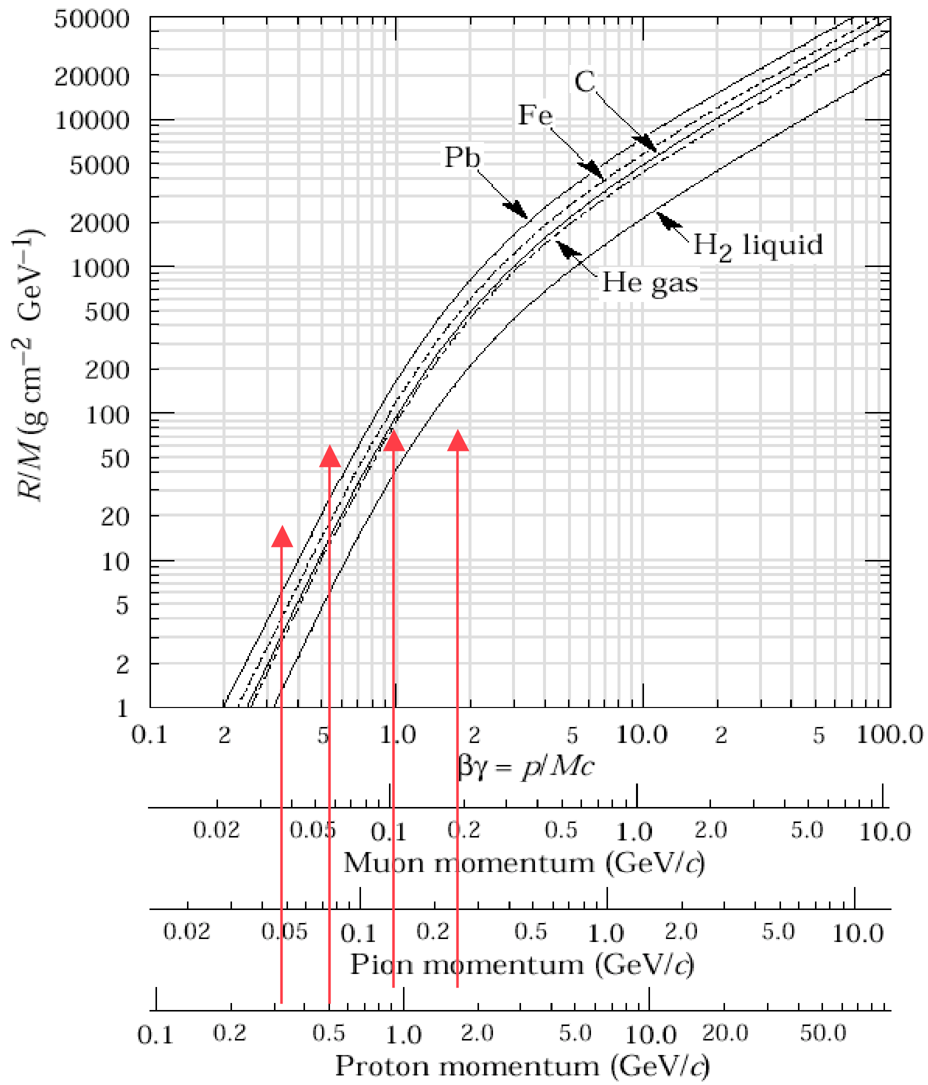
Theta	E'	range m	transverse	Q2
3 Gev Theta	E'	range m	PT of muon	Q2
0	3	14.3		0
15	2.71	12.9	0.7	0.6
30	2.10	10.0	1.1	1.7
45	1.55	7.4	1.1	2.7
60	1.15	5.5	1.0	3.5
90	0.71	3.4	0.7	4.3
135	0.46	2.2	0.3	4.8
180	0.41	1.9	0.0	4.9
10 Gev				
0	10.00	47.7		0.0
15	7.34	35.0	1.9	5.0
30	4.12	19.6	2.1	11.0
45	2.43	11.6	1.7	14.2
60	1.58	7.5	1.4	15.8
90	0.86	4.1	0.9	17.2
135	0.52	2.5	0.4	17.8
180	0.45	2.1	0.0	17.9

For muons at 90 degrees, the total range from the edge of the fiducial volume (1mx1m) includes the 42.5 cm of active target and the 30 cm picture-frame electromagnetic calorimeter and picture frame range detector (including 70 cm of Fe and 12 cm scintillator), Ignoring the Pb, this corresponds to a 42.5 cm + 30 cm +12cm = 85cm of scintillator and 70 cm of iron. For muons at 90 degrees this corresponds to a range of 250 MeV + +12 (Mev/cm)x70 = 1090 MeV which is sufficient to range out all particles at 90 degrees for E_0 of 3 GeV (maximum E' at 90 degrees of 710 MeV). Since the iron is magnetized, the particles bend forward so the effective absroption of the range is higher than 1.1 GeV

For muons at 45 degrees, the range of the picture-frame side absorber is increased by a factor of 1.414 (to 1.54 GeV), which ranges out a 45 degree quasielastic muon (E' = 1.52 GeV) for E_0 of 3 GeV. Therefore, even for neutrinos produced at the edge of the 1m x 1m active fiducial area, all quasielastic muons are contained. The fact that the muons bend forward adds another margin of safety.

Back of envelope estimates - needs to be done more quantitatively





For Q2=0.110 GeV2, q3=P=0.330 GeV

Proton kinetic energy = P**2/2M = 55 MeV

Range about 5 cm - Note nuclear binding about 30 MeV

0.5 GeV P = 15 cm of scintillator = 120 MeV energy

Versus 1 mip = 2 MeV/cm. Get 60 mips

Copy of Sept 4. 2003 Email

I have put Hexagonal design draft which can be put into on-axis or off- axis tunnel. File is at http://www.pas.rochester.edu/ ~bodek/ directory minerva file name hexagon-design.ppt

Concept is that EM calorimeter is like Tanakos idea of washers, but using Stainless steel clad Pb Plates. So it takes almost no room in Z. The hadron/muon calorimter is using the picture frame design, because any other design does not give much BxDL (formulae for resolutions are in the PPT file).

This design can be put as a default, and parameters varied and optimized. I have formulae that will calculate any muon resolution versus angle in the PPT file and hadron energy resolution and EM energy resolution below (and attached spreadsheet)

Please look at the design on this Web page. I will try to work on the file and update it. The exact resolutions are given in this Email (and attached spreadsheet) for EM and Hardron. I drew up a hexagon design in detail I also drew to scale.

Need about 27K channels. Also, as you will see, the detector is kind of square, so side detector only looks at particles greater than 45 degrees. We expect large angle and backward particles. I suggest that you look at 3 GeV neutrinos to see where particles go