Another Look
at
Solid Scintillator

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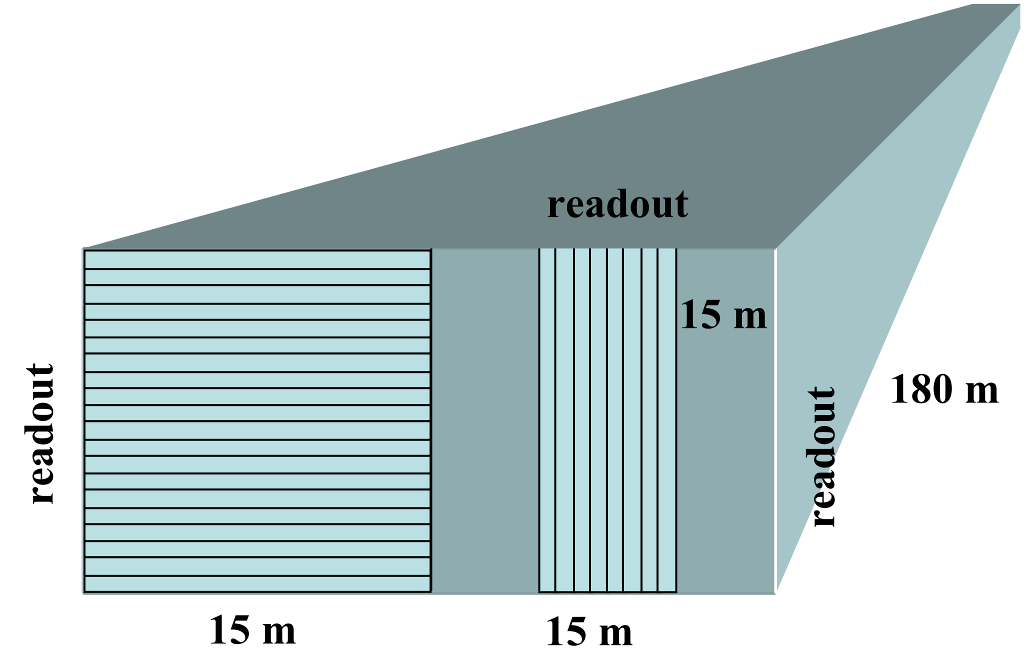
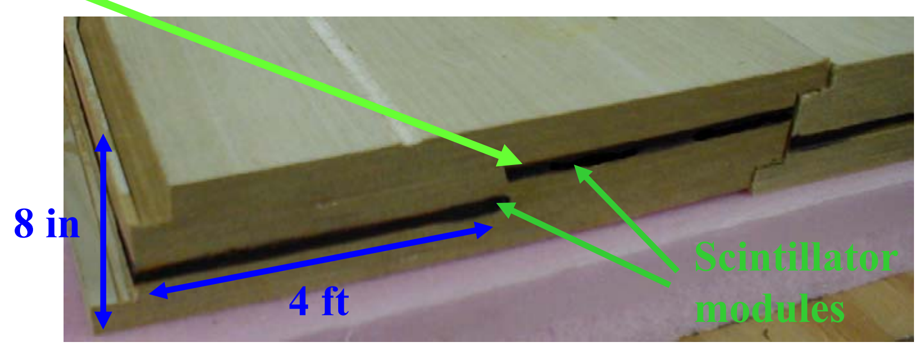
May 15, 2004

Last fall's base designs for Liquid and Solid Scintillator were nearly identical:



Fill the slots with liquid modules or solid modules



Scintillator Photon Economics

- **LIQUID**
- **.95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt**
- **10.6 pe @ 15 m with 1.2 mm fiber with MINOS scintillator and APD (1.4x spectrum, 8x QE at peak)**
- **42.5 pe @ 15 m with 1.2 mm fiber U loop, APD with MINOS scintillator**
- **28 pe @ 15 m with 0.8 mm fiber U loop, APD with MINOS scintillator**
- **42 pe @ 15 m with 0.8 mm fiber U, APD with liquid scintillator (3 cm x 4 cm cell** *gives more photons produced and more advantageous geometry*, **1.5x)**
- **?**

- **SOLID**
- **.95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt**
- **10.6 pe @ 15 m with 1.2 mm fiber with MINOS scintillator and APD (1.4x spectrum, 8x QE at peak)**
- **42.5 pe @ 15 m with 1.2 mm fiber U loop, APD with MINOS scintillator**
- **28 pe @ 15 m with 0.8 mm fiber U Loop, APD with MINOS scintillator**
- **Out of options?**

Cost Comparison in Proposal

WBS		RPC : X and Y readout	RPC : X or Y Readout	Solid Scintillator	Liquid Scintillator
2.0	Far Detector				
2.1	Absorber	12.6	12.6	13.3	12.1
2.2	Active Detector	57.0	50.7	78.2	36.5
2.3	FEE, Trigger and DAQ	8.3	4.5	6.1	5.0
2.4	Shipping & Customs	2.2	2.2	3.0	1.0
2.5	Installation	2.6	2.6	5.8	4.7
	Detector Sub-total	**82.7**	**72.6**	**106.4**	**59.3**

Became $ 65 M

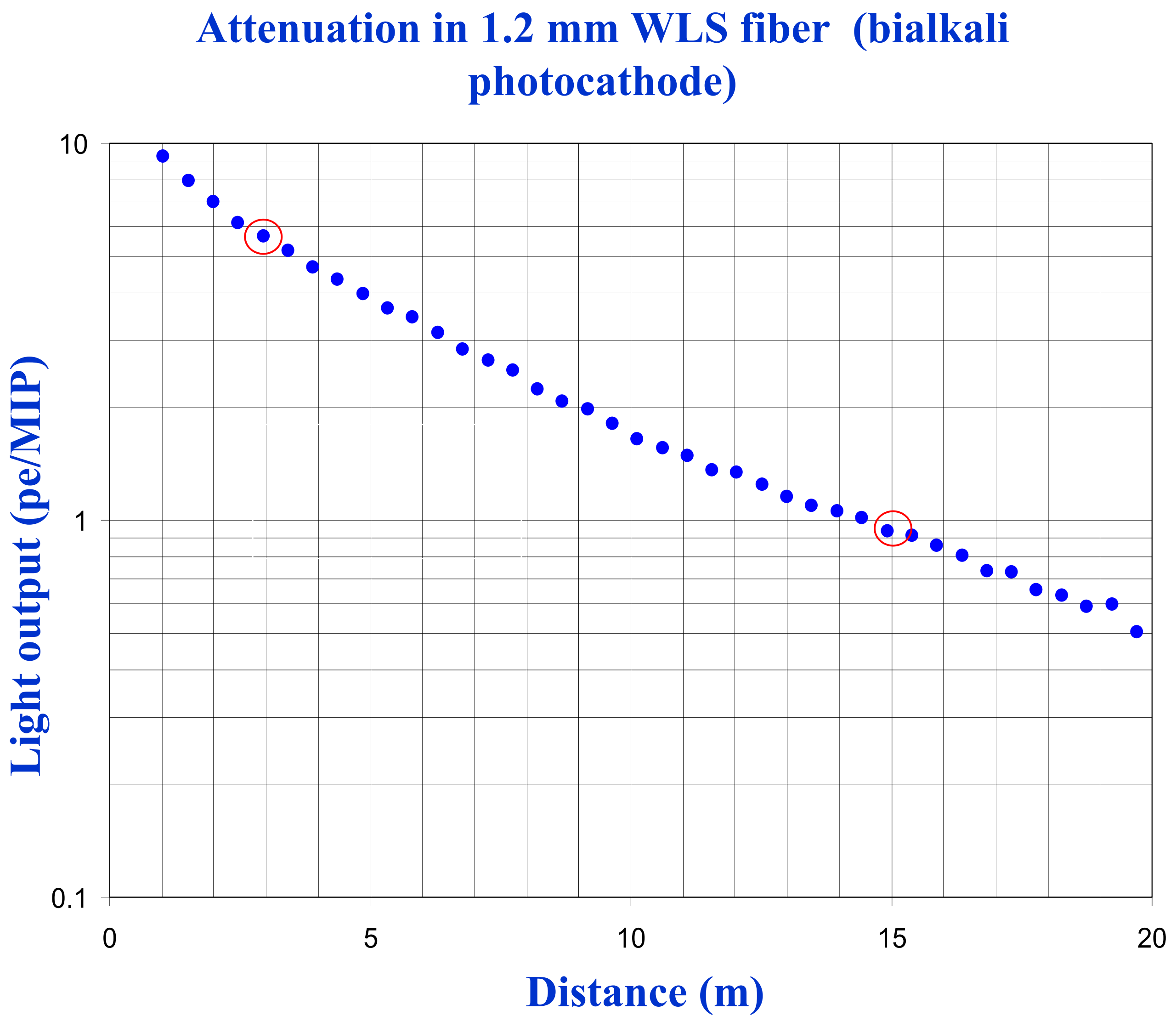
Delta of $ 47 M

With Contingency… multiplier of about 2.3 → $ 108 M

- **This seemed out of bounds, so we put it to one side last year**
- **Is there any way to reduce the cost?**

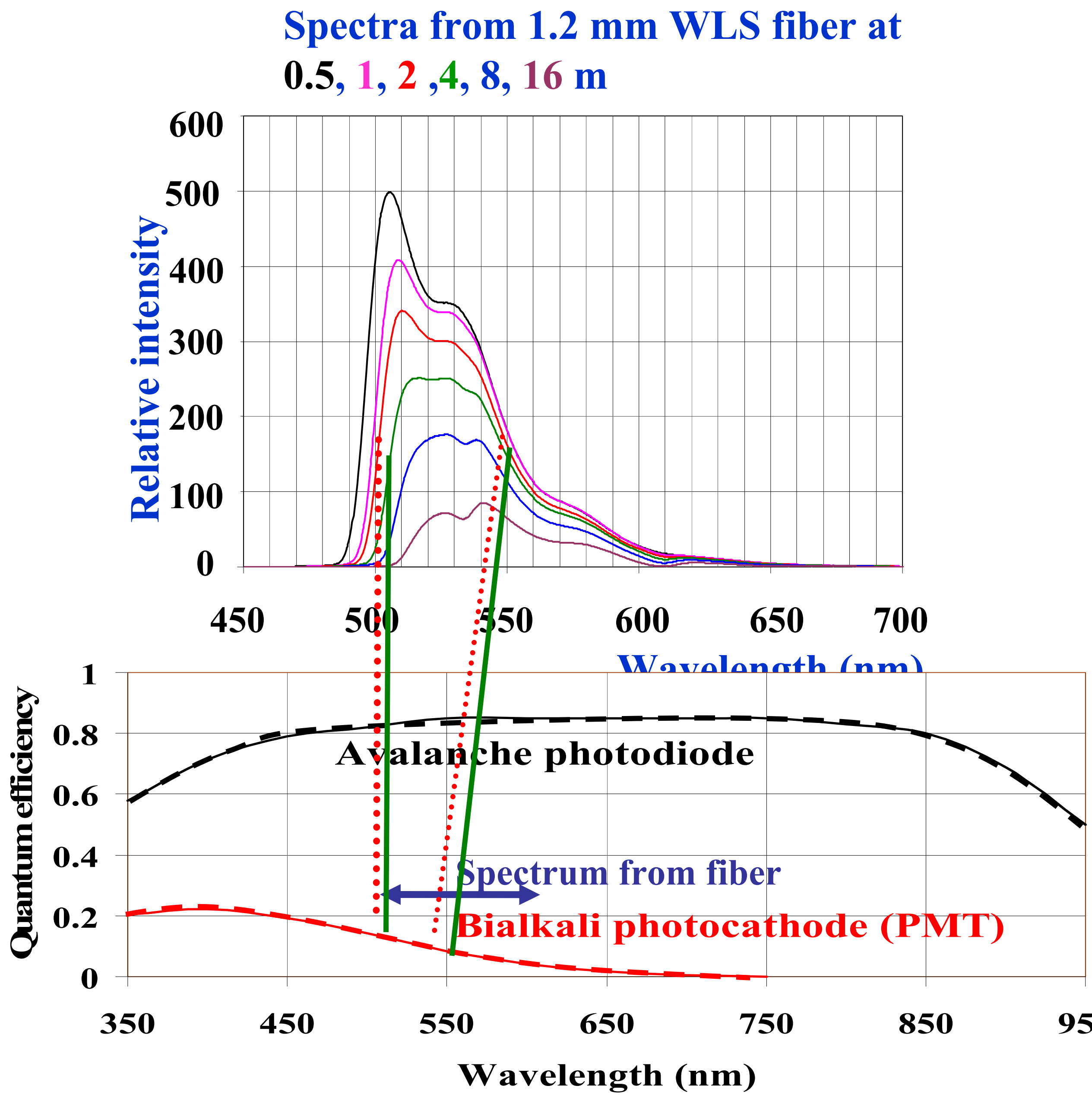
A different scheme – try going shorter

- .95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
- 5.8 pe/mip @ 3 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
    - 6.5 pe @ 2.4 m



A different scheme – shorter but still use APDs

- .95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
- 5.8 pe/mip @ 3 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
  - 6.5 pe @ 2.4 m
- 42 pe @ 3 m with 1.2 mm fiber, APD with MINOS scintillator (factor of 7.2 QE at 525 nm)
  - 47 pe @ 2.4 m
  - (probably underestimated due to high wavelength tails)



A different scheme – shorter, APD, use single fiber but mirror the end, and change to 0.9 mm diameter fiber

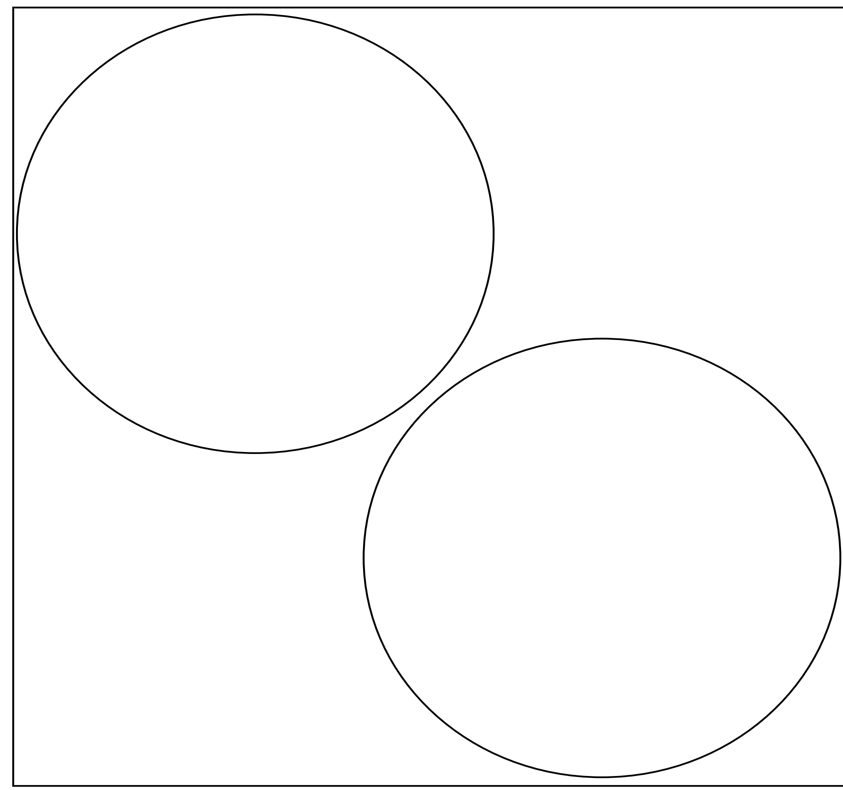
- .95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
- 5.8 pe/mip @ 3 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
  - 6.5 pe @ 2.4 m
- 42 pe @ 3 m with 1.2 mm fiber, APD with MINOS scintillator (factor of 7.2 QE at 525 nm)
  - 47 pe @ 2.4 m
- 80 pe @ 3 m with 1.2 mm fiber and mirrored end with 90% efficiency, APD with MINOS scintillator
  - 89 pe @ 2.4 m
- 54 pe @ 3 m with 0.9 mm fiber and mirrored end, APD with MINOS 1cm scintillator (factor of 0,67)
  - 60 pe @ 2.4 m

WLS Fibre Multiclad. Diamater in mm	Unit Price in US $ per Meter	Light Output Compared to 1.2mm Fibre	Light Output for U shape fibre (3.55±0.35) NuMI-L-414
0.4	0.15	0.21	0.75
0.5	0.22	0.29	1.03
0.6	0.31	0.38	1.35
0.7	0.43	0.47	1.67
0.8	0.56	0.57	2.02
0.9	0.70	**0.67**	2.38
1.0	0.76	0.77	
1.1	0.92	0.89	
1.2	1.08	1.00	

A different scheme – shorter, APD, use single fiber with mirrored end, change to 0.9 mm fiber connect to 3 m clear fiber and APD pixel

- .95 pe/mip @ 15 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
- 5.8 pe/mip @ 3 m with 1.2 mm fiber with MINOS scintillator (1 cm) and pmt
  - 6.5 pe @ 2.4 m
- 42 pe @ 3 m with 1.2 mm fiber, APD with MINOS scintillator (factor of 7.2 QE at 525 nm)
  - 47 pe @ 2.4 m
- 80 pe @ 3 m with 1.2 mm fiber and mirrored end, APD with MINOS scintillator (mirrored eff 90%)
  - 89 pe @ 2.4 m
- 54 pe @ 3 m with 0.9 mm fiber and mirrored end, APD with MINOS 1cm scintillator (factor of 0,67)
  - 60 pe @ 2.4 m
- 37 pe @ 3m + 3m of 0.9 mm clear fiber, mirrored end, APD, MINOS 1 cm scintillator (factor of 0.69)
  - 41 pe @ 2.4 m

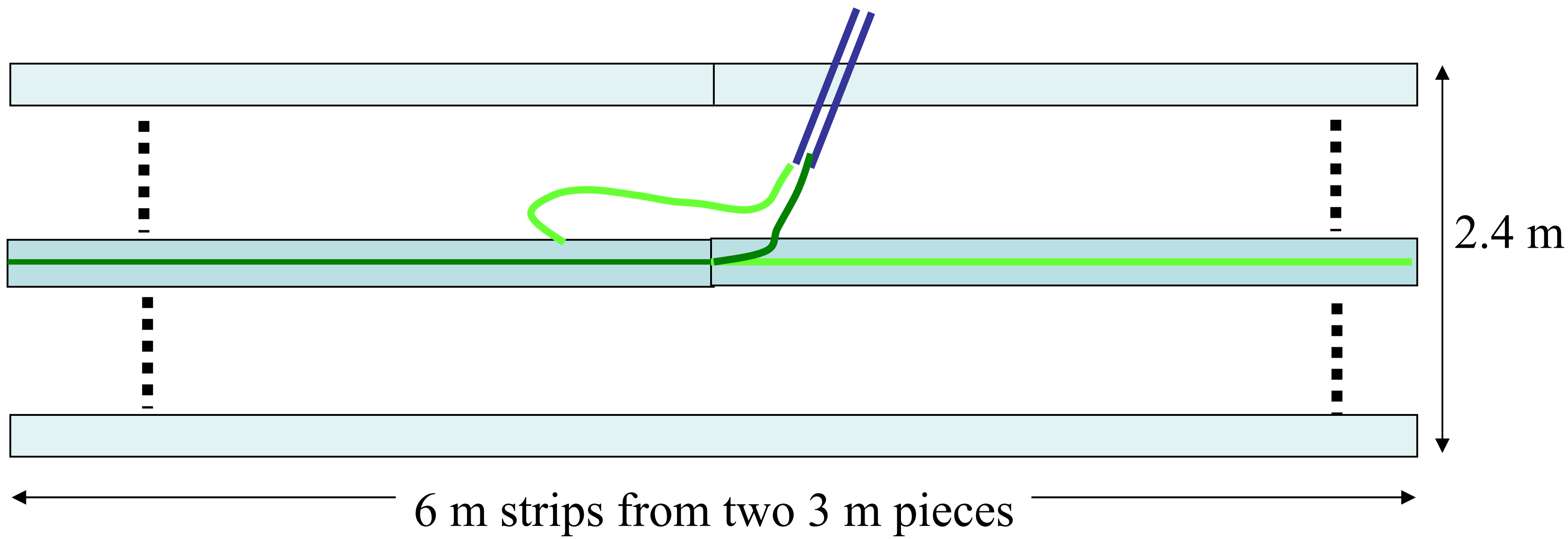
2 (0.9 mm) on a 1.6 mm square pixel



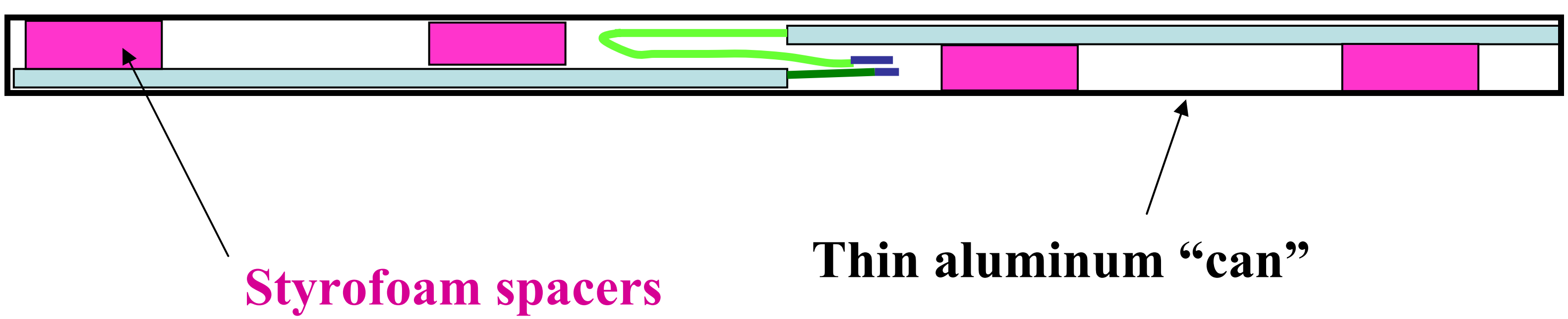
Assume 8m attenuation length for 0.9 mm clear fiber (DZero)

Build scintillator modules

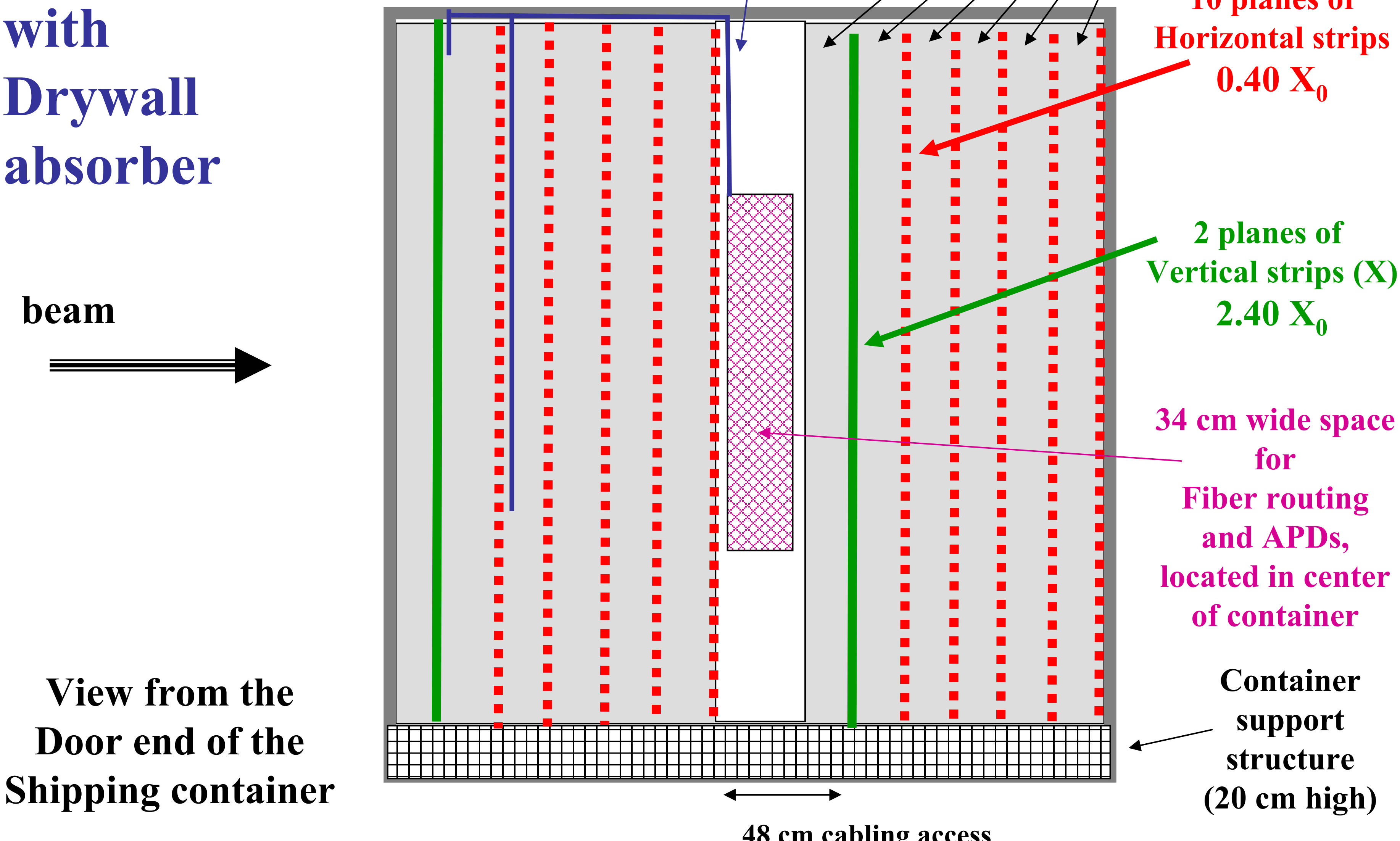
Beam View, **2 stacks of 60 strips to get a 2.4 m by 6.0 meter module**



Top View

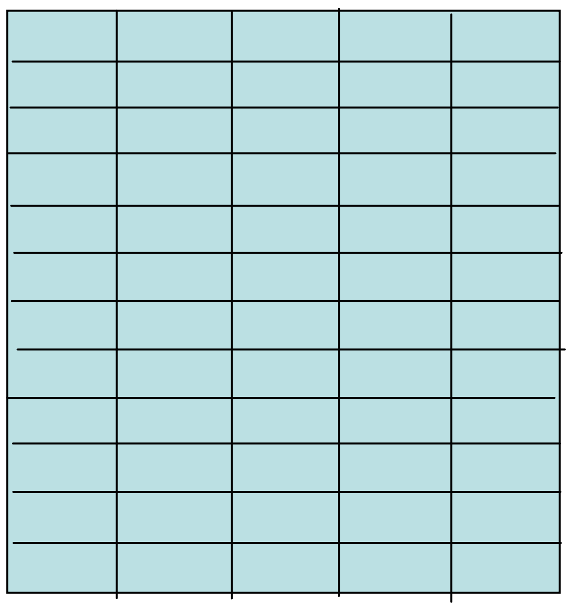


Put modules into Shipping Containers with Drywall absorber



Stack the Containers 5 wide by 12 high

Solid Scintillator in Containers



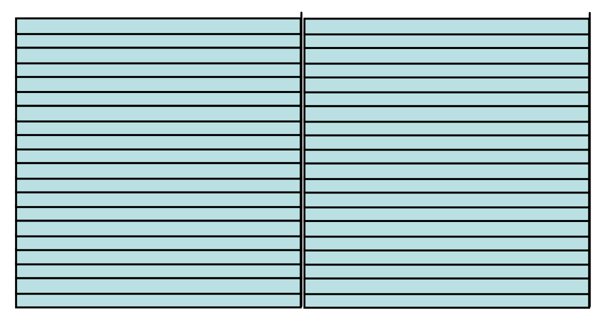
31 m

30 m

(46 layers deep, 113 m long)

50 kT + 6 kT containers

Liquid Scintillator Baseline



15 m

15 m 15 m

(180 m long)

Call it "MOSS"

- **MObile Solid Scintillator**
    - As in "a rolling stone gathers no ____"

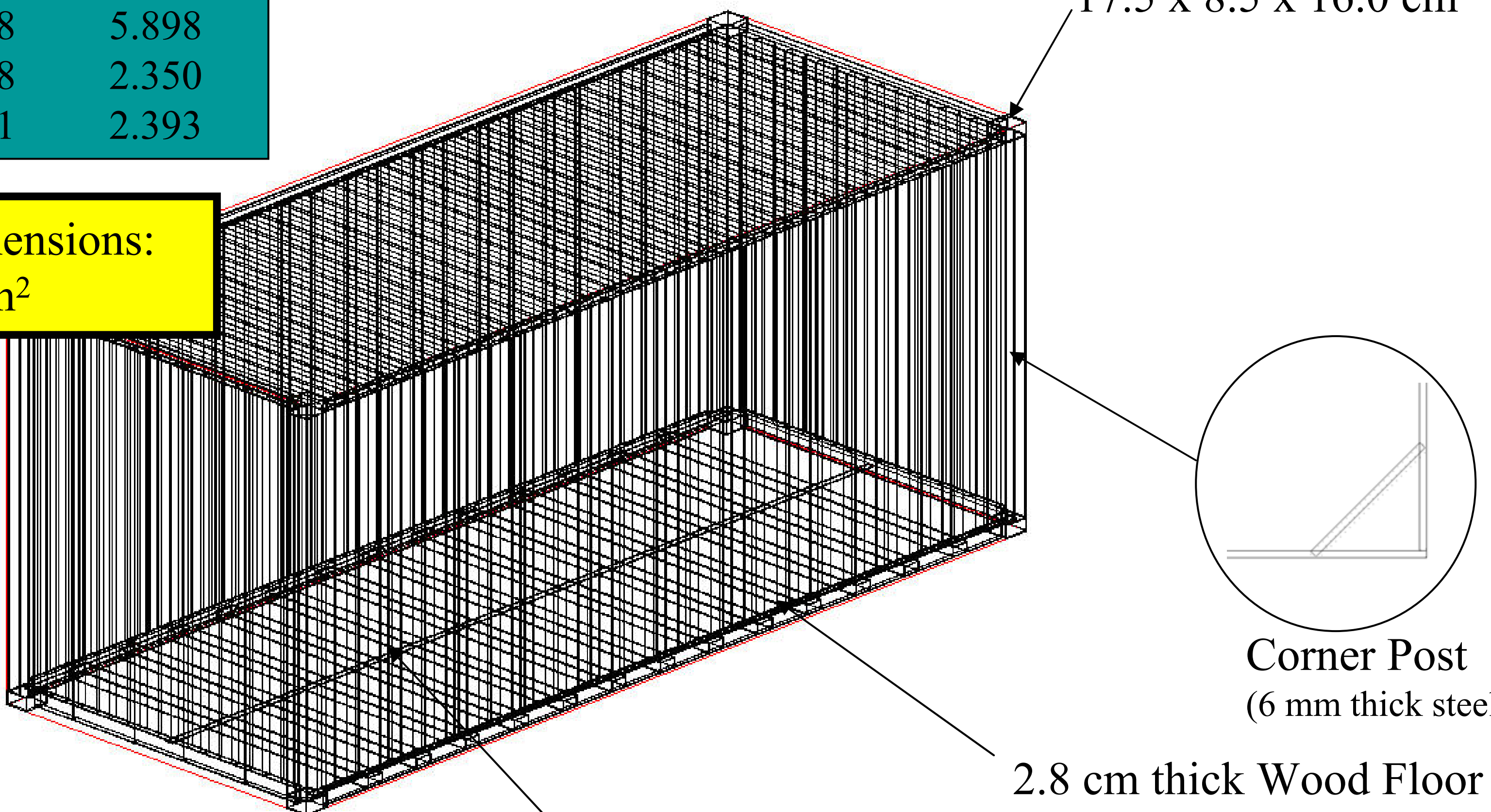
- **In a minute we can discuss the advantages of mobility, but in a nutshell they are**
    - **1. Quick final assembly in 10 months at a Far Site which can be determined as late as possible** (answers one PAC question)
    - **2. Future flexibility if the physics landscape changes – move half to a different baseline or different off-axis position for only the cost of a "half-building" (a dirt cheap $ 15 M new experiment) –** (answers another PAC question).

- **But first**
    - **What is the performance?**
    - **What is the cost?**

Recall Ron Ray's talk from July 2003
He had a full GEANT Implementation of a container

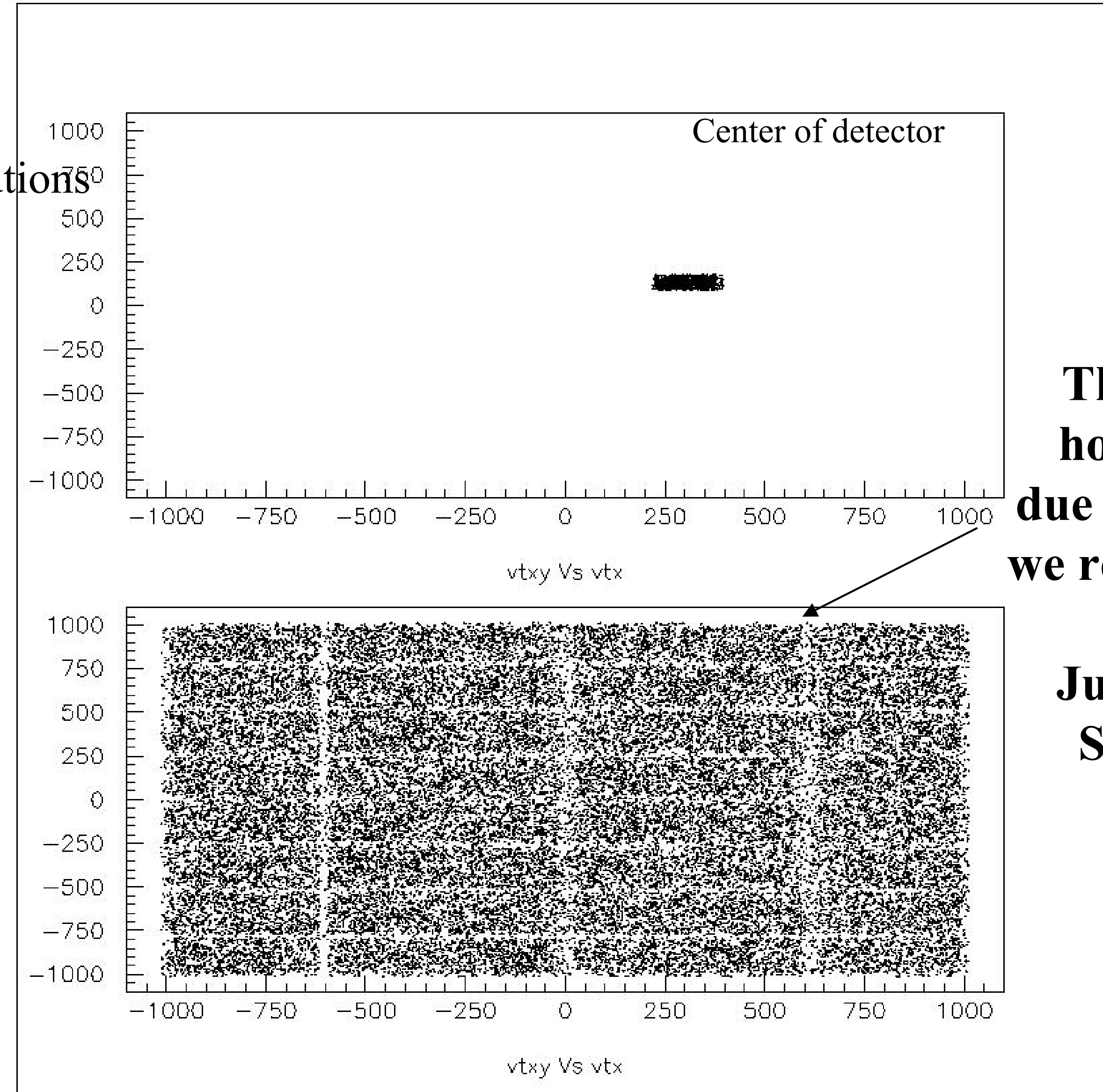
	O.D. (m)	I.D. (m)
Length	6.058	5.898
Width	2.438	2.350
Height	2.591	2.393

Detector dimensions:
5.89 x 2.39 m^2



Ron compared events spread over a stack of containers to events in the center of one container (= no container)

Vertex Distributions



This had wider horizontal gaps due to "cell guides" we really don't need

Just stack them So they touch

Ron's results were for RPCs and Particle Board in containers

Results

	ν_e CC Container Center	ν_μ NC Container Center	Beam ν_e Container Center	ν_e CC Uniform Vertex	ν_μ NC Uniform vertex	Beam ν_e Uniform Vertex
Total Events (weighted)	50,530	99,842	5,571	202,150	397,224	21,196
Reconstruction Cuts	40,971	28,463	1,817	160,440	110,648	7,238
Total Hits between 30 - 100 (25 - 100)	33,956	9,419	1,149	138,141	45,648	4,783
Ave hits/plane ≥ 1.6 in each view	28,900	5,598	1,057	110,588	23,738	4,225
Track width < 8.5 cm^2 in each view	25,410	2,100	880	96,028	8,450	3,382
Frac of hits on track > 0.575 in each view	21,002	1,052	621	78,957	4,476	2,321
Number of hit planes bet 12 - 25 in each view	19,006	782	545	66,660	2,628	1,972
Hits on longest track bet 20 - 50 in each view	18,648	724	413	65,606	2,465	1,529
Efficiency	**0.369**	**0.007**	**0.074**	**0.324**	**0.006**	**0.072**
Number of Events (50 kt, 5 yr)	**246.8**	**48.1**	**34.2**	**216.7**	**41.3**	**33.3**
FOM		**27.2**			**25.1**	

Simulation Summary

- **Ron showed that container cracks cost about 2 units in FOM**
  - **Let me say it again: the loss in FOM is SMALL**
  - **The loss in ν_e efficiency was about 12%**
    - That's very close to the fractional size of the cracks in the study

- **At the same time (several simulation iterations ago), the RPCs were a few units of FOM worse than the Liquid Scintillator with PH – this scheme now includes PH**

- **So, while the work remains to be done, one might expect this SOLID scintillator version to get a FOM within a couple of units of the current Liquid solution**
  - The different X_0 sampling in the two views will need study

Some Cost Model details

- **All scintillator made at Fermilab or near Chicago**
  - Lab 5 NICADD can do all 4.9 kT in 6.1 years
  - Assume 4 year construction, so will need other vendors
- **All aluminum cans made at ANL or near Chicago**
- **All containers procured in Chicago**
- **Ship containers filled with Scintillator and Al cans**
  - To 11 university / laboratory factories, see next slide
- **Factories buy the drywall at local Home Depot / Lowe's /…**
  - Let the vendors bear that shipping cost
  - Require 660 4' x 8' sheets per container
- **Collect completed containers at Fermilab & ANL**
  - One-way truck shipping cost = round trip cost, so ship a completed container back every time a container with raw materials appears
  - Return container is over the U.S. road weight limit, requires permit
  - Exception is U. of Minn. – NEVER ship "south"
  - 4 year construction, building at FAR site need not be ready on day one
- **Finally ship all modules from Chicago to FAR site**
  - 10 months of shipping + assembly (16 containers / day)

Shipping permit story

- **You may recall the trucking permit cost to ship a RPC "toaster" was > $ 5,000**
  - That was for a 90,000 lb load
  - Tractor / trailer is 37,000 lb
  - Total was 127,000 lb
  - This high permit fee quoted by a transportation vendor led me astray

- **The real story is slightly different**
  - **These containers are 47,000 + 37,000 tractor/trailer = 84,000 lb**
  - **This is over the 80,000 lb limit**
  - **But permits in Illinois for up to 88,000 lb are only**
    - **$10 for the 1st 45 miles**
    - **$ 2.50 for every 45 miles thereafter**
    - **Have to use a six axle combination in a" 44/54 configuration"**
  - **Criterion is that the load "cannot be broken down"**
    - **IDOT says our "scientific material in a shipping container" would qualify**
    - **Have to check all other states**

44,000 lb on tandem drive

54,000 lb on tri-axle

These are called "routine permits" and US DOT says they are available in all states. (in Illinois different rates for 88, 100, 110, then through the roof for >120,000 lb)

One learns the strangest things

A Factory Model

				total			
Factory Positions:		**distance**	**round trip**	**permit**	**# modules**	**# crews at**	**total**
		(miles)	**ship cost**	**cost**	**built**	**each factory**	**shipping cost**
Fermilab	1	0	$ -	$ -	506	2.04	$ -
ANL	1	0	$ -	$ -	498	2.00	$ -
Ohio	1	350	$ 933	$ 29	123	0.50	$ 118,422
Michigan	1	250	$ 667	$ 24	123	0.50	$ 84,938
Indiana	1	175	$ 467	$ 20	248	1.00	$ 120,624
Boston	1	1000	$ 2,667	$ 66	123	0.50	$ 336,063
Virginia	1	870	$ 2,320	$ 58	123	0.50	$ 292,535
S. Carolina	1	800	$ 2,133	$ 54	123	0.50	$ 269,097
Texas	1	1090	$ 2,907	$ 71	123	0.50	$ 366,198
California	1	2050	$ 5,467	$ 124	123	0.50	$ 687,638
Minnesota	1	410	$ 1,093	$ -	620	2.50	$ 677,867
(no return from Minn. but still pay rd trip)					2733	11.00	**$ 2,953,383**
	11	TOTAL number of factories					
Finally will ship every container one-way to northern Minnesota (Except U of Minn), all overweight							
					MSU about equal direct or via Fermilab		
Ash River	from Chicago	625	$ 1,667	$ 45	2113		$ 3,615,518
	from Minn.	250	$ 667	$ 24	620		$ 428,144
							$ 4,043,662

Cost Summary

touched every cell of Gina's spreadsheet

WBS	Description	Base Cost	Base + OH & Cont.	Base Cost	Base + OH & Cont.	delta cost from Liq Scint total	
1.0	Near Detector	2,152,582	5,166,198	1,764,724	4,235,338	(930,860)	no support structure,
							no liquid handling,
2.0	Far Detector						easy install
2.1	Absorber	12,618,525	16,804,304	9,640,067	12,448,336	(4,355,968)	gypsum, but containers too
2.2	Active Detector	28,324,540	39,023,945	60,803,766	84,678,746	45,654,801	solid, more assembly
2.3	FEE, Trigger and DAQ	6,375,205	10,945,290	22,338,955	37,825,343	26,880,052	more channels
2.4	Shipping&Customs Charges	5,421,343	7,860,947	6,997,045	10,145,716	2,284,768	
2.5	Installation	11,789,067	20,520,401	2,026,937	3,534,030	(16,986,371)	simpler FAR install, less time
	Detector Sub-total	64,528,679	95,154,888	101,806,770	148,632,170	53,477,282	net delta cost for FAR
3.0	Building and Outfitting						
3.1	Building	16,634,800	27,105,127	14,595,100	23,781,593	(3,323,534)	shorter, taller building
3.2	Outfitting	4,745,748	9,776,240	1,805,148	3,718,604	(6,057,636)	no containment,
	Building & Outfitting Sub-total	21,380,548	36,881,367	16,400,248	27,500,197		no support structure
4.0	Active Shield	1,602,882	4,039,262	1,803,579	4,545,019	505,757	shorter, taller detector,
							but solid costs more
5.0	Project Management	3,935,000	6,024,780	3,935,000	6,024,780	-	assumed identical
TPC	**Total Project Cost**	**93,599,690**	**147,266,495**	**125,710,321**	**190,937,504**	43,671,009	**(down from 108,000,000)**
					15,609,400	Note cost of a "Half-Building" + outfitting	

So solid scintillator can be had for about what the RPCs would be -- but it's more robust, no gas, no glass

Advantages of MOSS

- **Do not have to invest in a \$ 30 M building with 1st year \$**
  - Could even wait until last 10 months + construction time (12 mo. ?)
    - Answers the PAC question "How long can we wait to choose the optimum site?"
    - Could build a half-building early, build the rest late
  - Contrast to Liquid Scintillator
    - We can't proceed without the building
    - We could run into environmental permit problems due to the liquid
- **MOSS is mobile**
  - It is easy to move a fraction of it elsewhere
    - Requires only the cost of a new building and some transportation – small rigging labor
    - Answers the PAC questions about two detectors
  - Contrast with Liquid Scintillator
    - Hard to believe we could move it for less than the cost of another 50 kT?
  - **MOSS would permit a cheap second experiment at a different spot**
    - Different baseline (could keep same L/E, Wisconsin or Canada) or
    - Different off-axis angle
      - for asymmetry optimization, or ultimately with a Proton Driver at the 2nd maximum
      - The \$ 150 – 200 M detector "sunk costs" will not be wasted
      - In a Proton Driver era, MOSS can even move cross country or be a part of a larger detector

More on why we would want MOSS

- **There is an undercurrent to questions –**
  "What can we do that is unique if..."
  - i.e. if T2K does it earlier, or a Reactor Group, or Aliens from Mars
  - This will be our LHC-b, and it won't go away – we need **multiple** counters right now and I'm not sure complementarity will be enough
  - **BTeV Stage 1 approval finally turned on their ability to make one measurement absolutely for sure better than any known competition no matter what the schedule(s).**
- **Another undercurrent is , "The field might just end up confused by the NOvA and T2K measurements."**
  - We need to stomp on this one:
    - If we disagree with T2K, it most likely means someone did NOT measure ZERO !
    - So this is a GOOD thing!
- DOE-speak now talks about project "off-ramps" = graceful ways to exit a project
  - We can always stop building containers full of scintillator, just stop the extruder, stop going to Home Depot,…
  - But we should emphasize that NOvA has "**on-ramps**" if the physics focus changes
  - NOvA has "**bypasses**", e.g. if MINOS sees a signal already, leap to ____

More Solid reasons for MOSS

- **About an hour ago the RPC enthusiasts admitted that their numbers are small and that RPCs should go on the back burner**
  - I believe there are way more enthusiasts for SOLID scintillator
    - Cost is the only reason most RPC people looked at RPCs to start with
  - I only know a few people who have used Liquid Scintillator in an experiment and ever want to touch it again
- **MOSS allows universities to participate in construction**
  - Both DOE and NSF support groups who are building detectors
  - You can't write this down in a proposal, but it is a factor.
  - It is a factor that should attract collaborators and with our projected cost, we need to have a much larger group
- **We can't ignore these issues, we have to look at the schemes and reach a consensus**

I would like for us to say to the PAC / Lab:

- "Your questions in the April meeting have prompted us to return to a scheme we first wrote down in our LOI in 2003 and mentioned again in our Proposal submitted in March, 2004 – that is, the possible use of intermodal shipping containers as the base structure of the detector. This gives several advantages"…. list on previous slides
  - This is the dance: They ask "what if", we answer with a concept to study and resolve by the end of the year. We have to dance.

- We should push the idea that we have demonstrated TWO technologies that can do the basic proposed physics measurement. Two more (TASD, MOSS) have come up that may give the detector better "legs" for other measurements. Collider eμ

- Meanwhile, we want Stage 1 **NOW** because our field is totally screwed up -- the number of hurdles to jump over (Stage 1, P5, CD0, CD1, CD2, CD3, EIR (BTev 3/7 in 4 yrs)) implies years of jumping before we can start construction. **We are asking to start the hurdle marathon**. There are off-ramps galore, but a real scientific opportunity as well.