



WBS 2.6.3

Readout Infrastructure

Craig Dukes
University of Virginia

CD-3b DOE Review of NO_vA
July 21-23, 2009



Organization

1. Power Distribution System (PDS) (Dukes)
2. APD Thermoelectric Cooler Cooling System (see Mualem talk)

- WBS Items {
- 2.6.3.1 Low voltage power supplies/racks
 - 2.6.3.2 High voltage power supplies
 - 2.6.3.3 Power cables/cable trays
 - 2.6.3.4 Power distribution boxes (PDBs)
 - 2.6.3.5 Cooling
 - 2.6.3.6 Shipping

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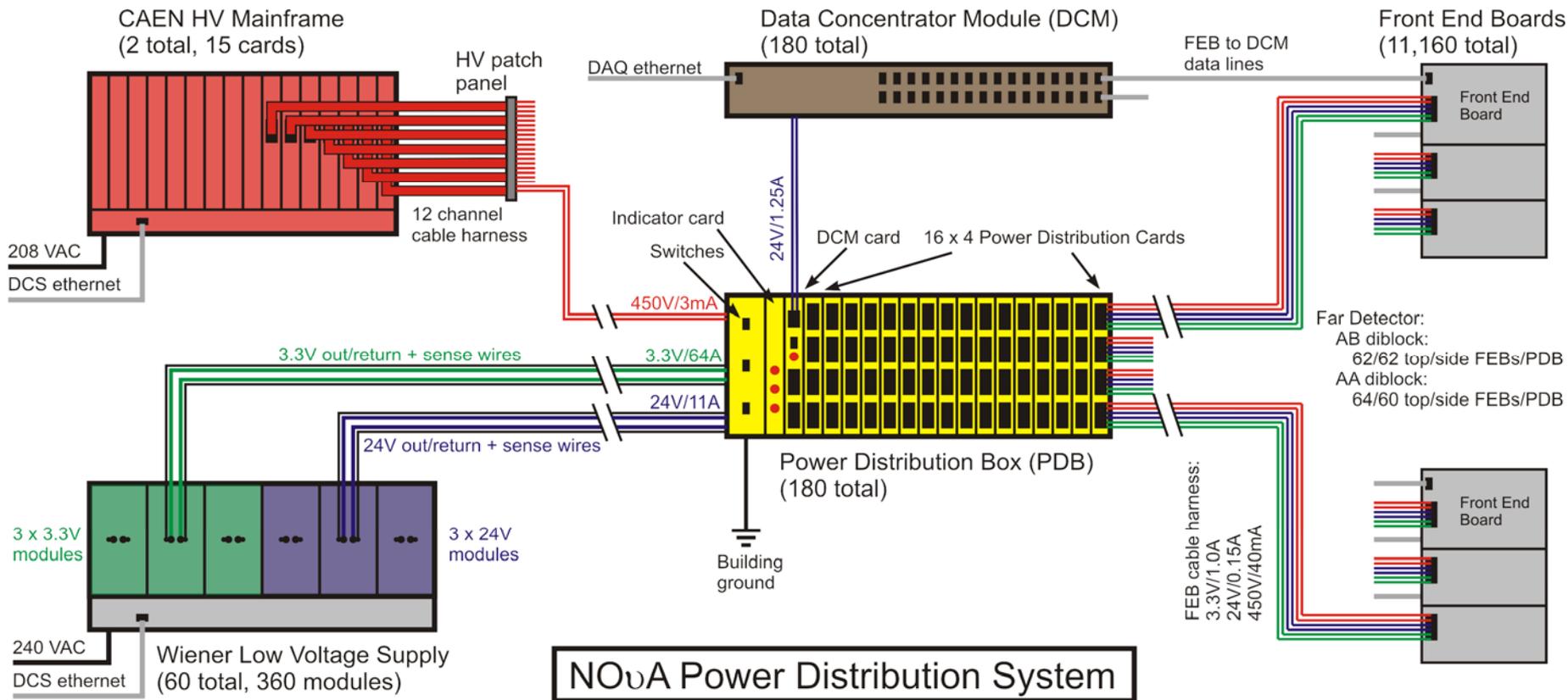


Power Distribution System

- Feeds electrical power to:
 - The Avalanche Photodiodes (APDs)
 - The Thermoelectric Coolers (TECs)
 - The Front End Boards (FEBs)
 - The Data Concentrator Modules (DCMs)
- Requirements
 - Low noise (3.3V + 450V)
 - Remote control and monitoring
 - Floating power supplies
 - Remote sensing for LV supplies
 - Reliable operation over 10+ years



Power Distribution System Layout



| Detector | CAEN | Wieners | PDBs | FEBs |
|----------|------|---------|------|--------|
| FD | 2 | 60 | 180 | 11,160 |
| IPND/ND | 1 | 4 | 10 | 497 |



PDS Power Requirements

| Power Delivered per Power Distribution Box | | | | | |
|--|-----------------|------------|--------------|---------------|-------------|
| Item | Nominal Voltage | Current | Max Channels | Total Current | Total Power |
| FEB | 3.3 V | 1.00 A | 64 | 64 A | 260 W |
| TEC | 24 V | 0.15 A | 64 | 10 A | 230 W |
| DCM | 24 V | 1.25 A | 1 | 1.25 A | 30 W |
| Timing | 24 V | 1.04 A | 1/24 | 1 A | 24 W |
| APD | 450 V | 50 μ A | 64 | 3.2 mA | 1.44 W |

Provided by DCS

| Total Far Detector Power | | |
|--------------------------|--------------|---------------|
| | Delivered | Total |
| 3.3 V | 47 kW | 64 kW |
| 24 V | 47 kW | 56 kW |
| Total: | 94 kW | 120 kW |



Far Detector Di-block Layout

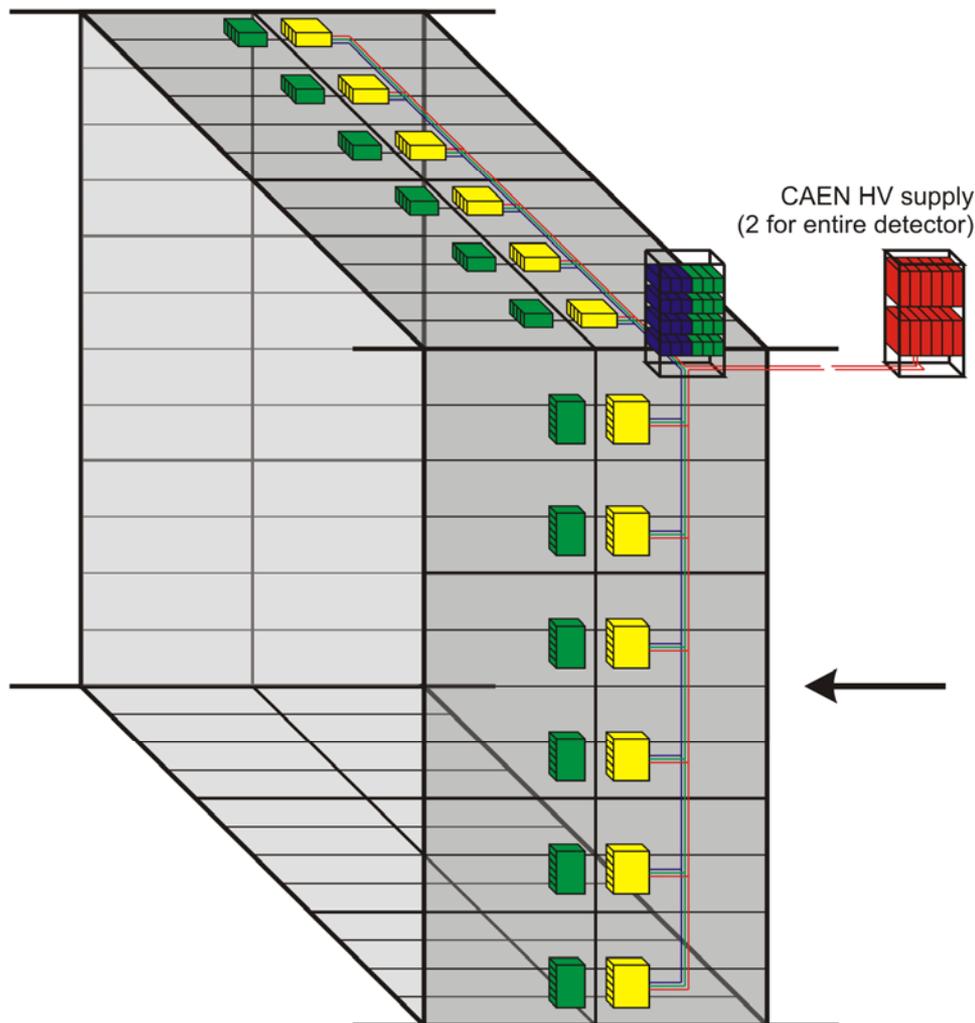
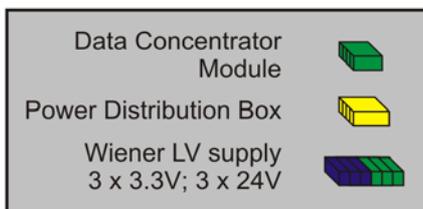
Layout of Power Distribution System NOVA Far Detector

AB di-block:

| | Planes | FEBs | PDBs | FEBs/PDB |
|----|--------|-------------|------|----------|
| V: | 31 | 12x31 = 372 | 6 | 62 |
| H: | 31 | 12x31 = 372 | 6 | 62 |

AA di-block:

| | Planes | FEBs | PDBs | FEBs/PDB |
|----|--------|-------------|------|----------|
| V: | 32 | 12x32 = 384 | 6 | 64 |
| H: | 30 | 12x30 = 360 | 6 | 60 |





Far Detector Di-block Layout

NOvA Far Detector Electronics Layout

Craig Dukes
12-Jun-09

14 kT Detector

| | | | |
|---------------|-----|---------------|---------|
| Modules/Plane | | Blocks: | 30 |
| Vert | Hor | Planes: | 930 |
| 12 | 12 | Modules: | 11,160 |
| | | Cells/module: | 32 |
| | | Cells: | 357,120 |

"A" block:

| | |
|---|---|
| v | v |
| h | h |

 "B" block:

| | |
|---|---|
| h | h |
| v | v |

 Other:

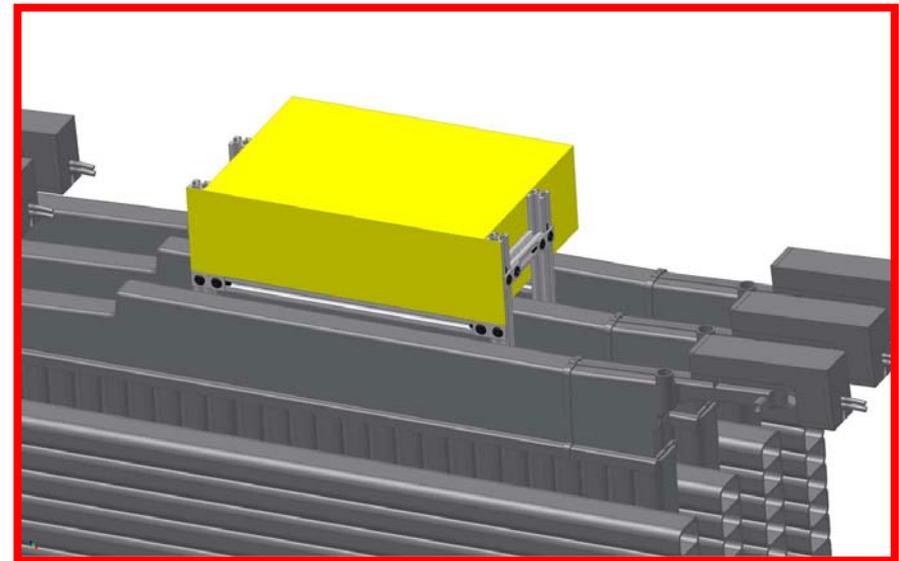
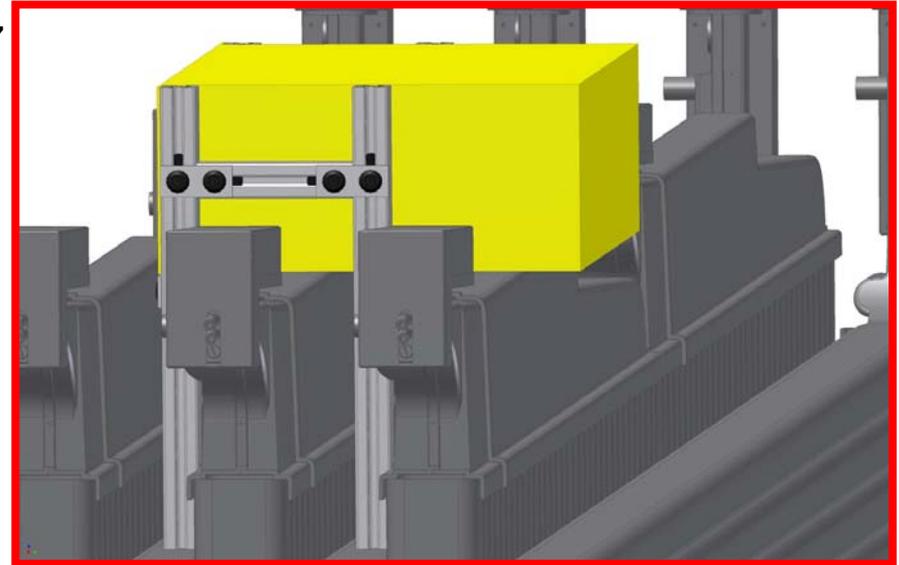
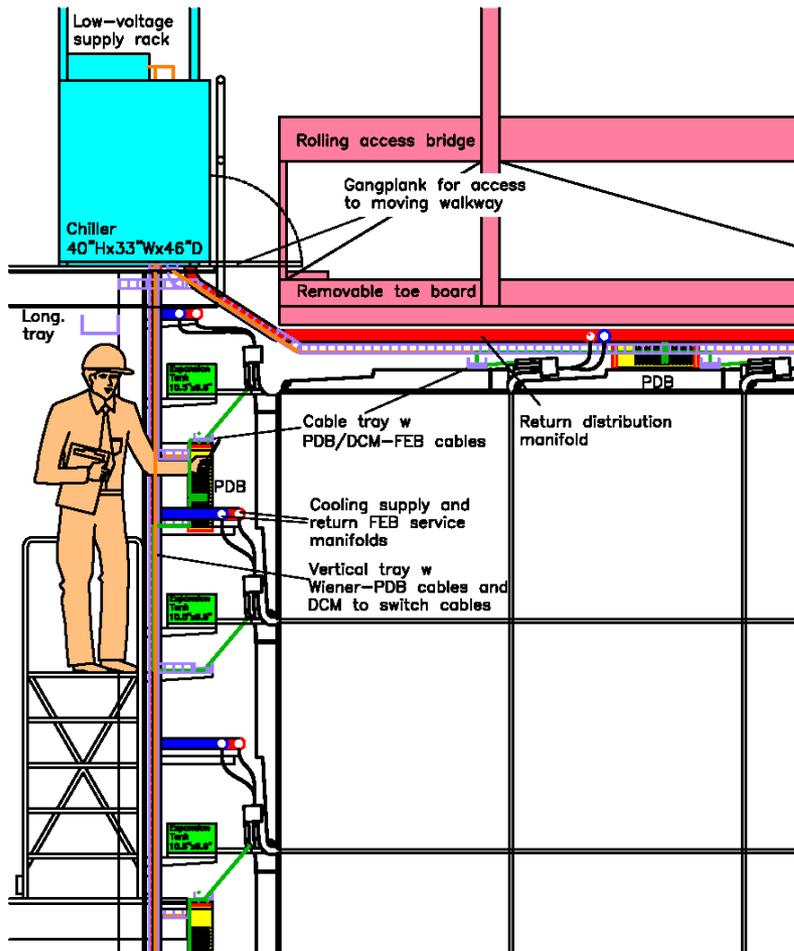
| | |
|---|---|
| v | v |
|---|---|

| Superblock | Diblock | Block | Plane orientation | | Planes | | | Diblock planes | | FEBs per PDB | | FEBs per diblock | | PDBs per diblock | | |
|---------------------------|---------|-------|-------------------|---|------------|------------|------------|----------------|---------------|----------------|----------------|------------------|------------|------------------|-----|--|
| | | | F | L | Vert | Hor | Total | Vert | Hor | Vert | Hor | Vert | Hor | Vert | Hor | |
| 1 | 1 | 1 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 2 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 2 | 3 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 4 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 3 | 5 | v | v | 16 | 15 | 31 | 32 | 30 | 64 | 60 | 384 | 360 | 6 | 6 | |
| | | 6 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 4 | 7 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 8 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 5 | 9 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 10 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 6 | 11 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 12 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 7 | 13 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 14 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 8 | 15 | v | v | 16 | 15 | 31 | 32 | 30 | 64 | 60 | 384 | 360 | 6 | 6 | |
| | | 16 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 9 | 17 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 18 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 10 | 19 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 20 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 5 | 21 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 22 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 12 | 23 | v | v | 16 | 15 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 24 | h | h | 15 | 16 | 31 | | | | | | | | | |
| | 13 | 25 | v | v | 16 | 15 | 31 | 32 | 30 | 64 | 60 | 384 | 360 | 6 | 6 | |
| | | 26 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 6 | 27 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 28 | v | v | 16 | 15 | 31 | | | | | | | | | |
| | 15 | 29 | h | h | 15 | 16 | 31 | 31 | 31 | 62 | 62 | 372 | 372 | 6 | 6 | |
| | | 30 | v | v | 16 | 15 | 31 | | | | | | | | | |
| Plane total: | | | | | 468 | 462 | 930 | | | Vert | Hor | Total | | | | |
| Planes/superblock: | | | | | 78 | 77 | 155 | | | PDBs | 90 | 90 | 180 | | | |
| | | | | | | | | | FEBs | 5,616 | 5,544 | 11,160 | | | | |
| | | | | | | | | | Cells: | 179,712 | 177,408 | 357,120 | | | | |



Mounting the PDS on the Far Detector

- Detailed design of layout finished in 2007
- Final design of fixtures being done with FSAP and 3D CAD model



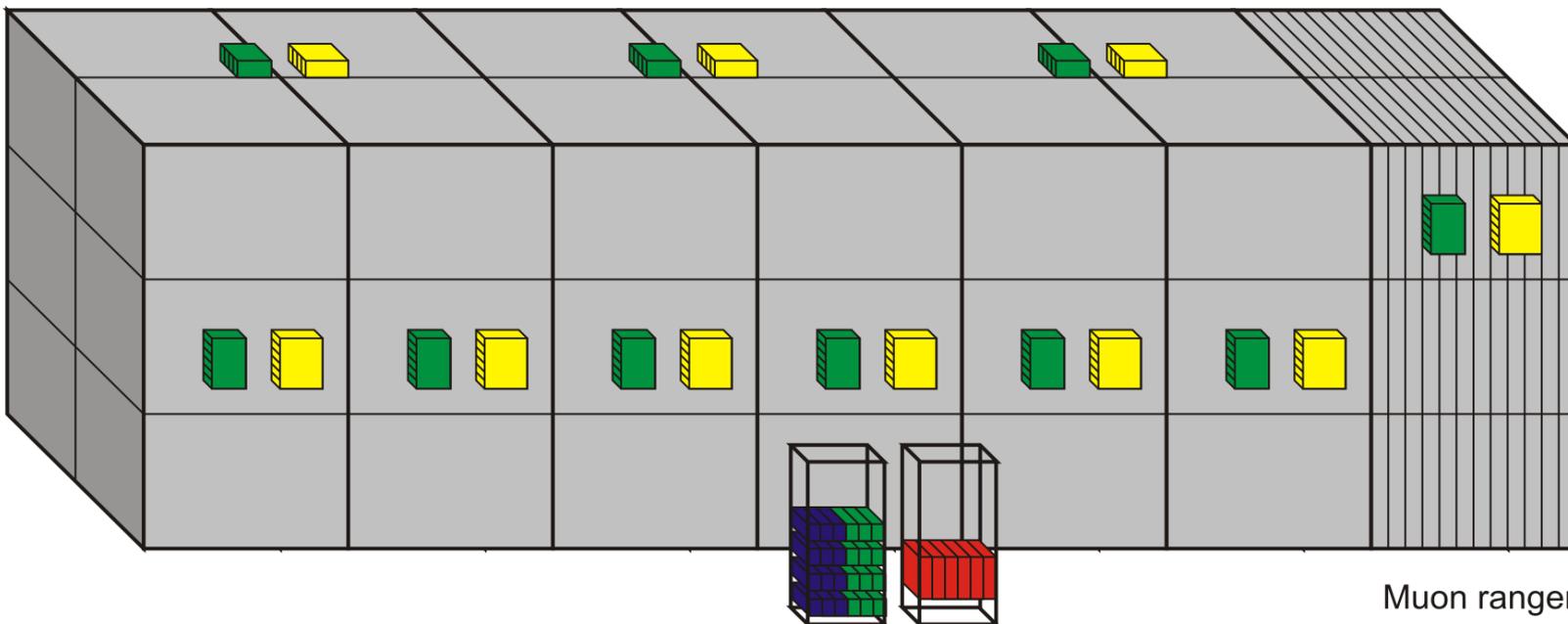
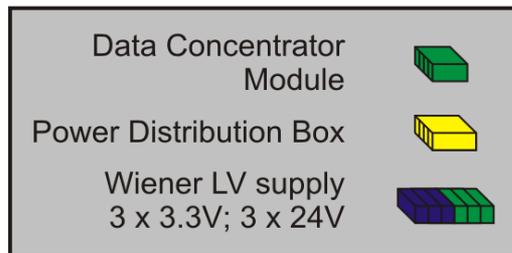


IPND/ND Layout

Layout of Power Distribution System NOvA Near Detector

- 6 blocks (4A + 2B)
- 1 muon catcher block
- 10 Data Concentrator Modules
- 10 Power Distribution Modules

V: 62,64 FEBs/PDB
H: 45,48 FEBs/PDB



Muon ranger



IPND/Near Detector Layout

NOvA Near Detector Electronics Layout

Craig Dukes

12-Jun-09

| Modules/Plane | | Normal blocks: | 6 |
|---------------|-----|----------------|--------|
| Vert | Hor | | |
| 2 | 3 | Total planes: | 199 |
| | | Modules: | 497 |
| | | Cells/module: | 32 |
| | | Cells: | 15,904 |

| | | |
|----------------|---|---|
| "A" block: | v | v |
| "B" block: | h | h |
| special block: | h | h |

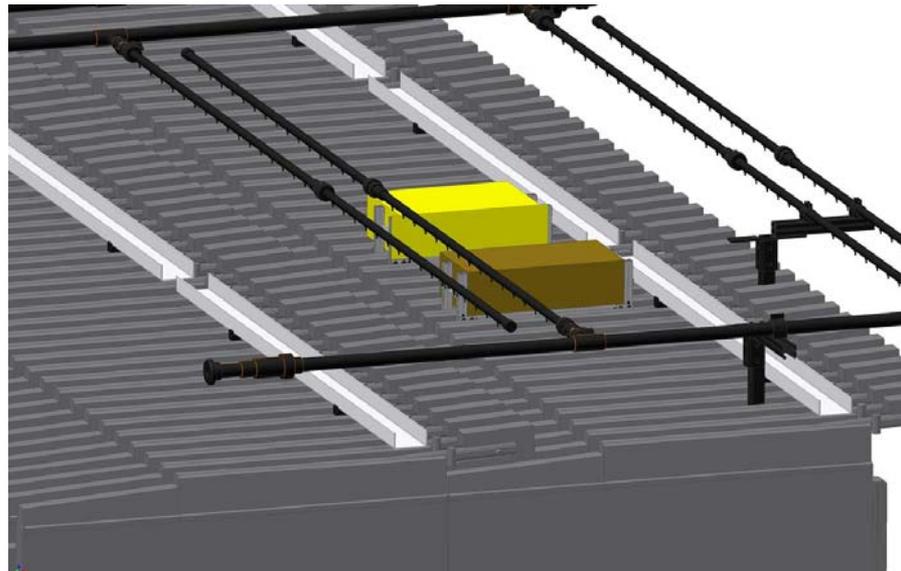
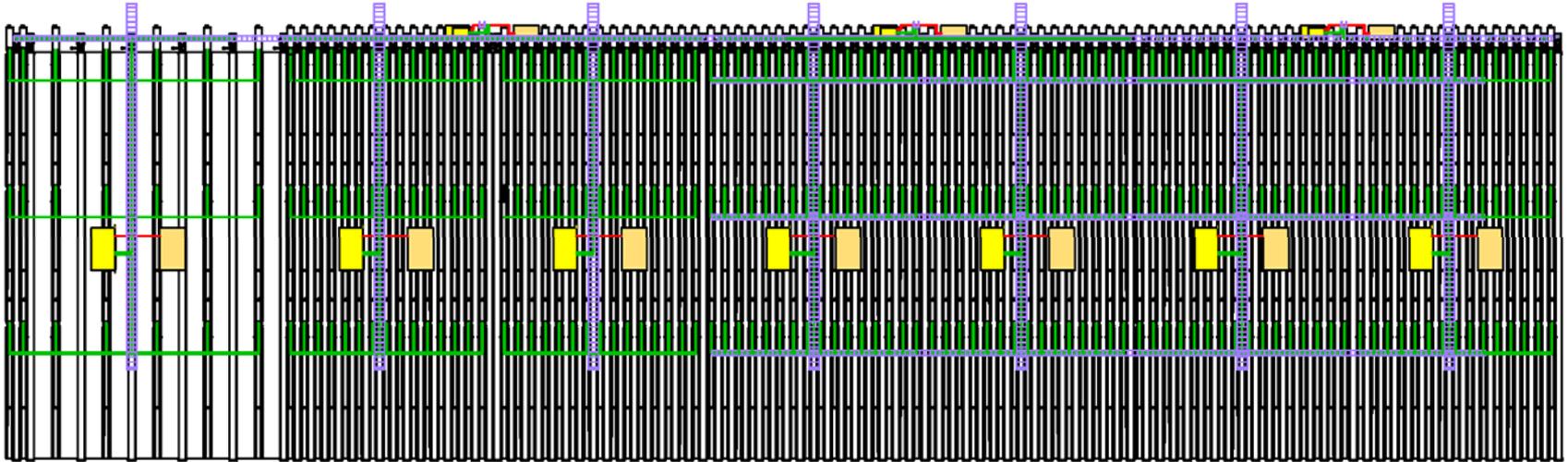
| Block | Plane orientation | | Planes | | | FEBs/PDB | | FEBs/block | | PDBs/block | |
|----------------------|-------------------|---|------------|-----------|------------|---------------------------|-----|---------------|--------------|------------|----------|
| | F | L | Vert | Hor | Total | Vert | Hor | Vert | Hor | Vert | Hor |
| 1 | v | v | 16 | 15 | 31 | 62 | 45 | 32 | 45 | 1 | 1 |
| 2 | h | h | 15 | 16 | 31 | 62 | 48 | 30 | 48 | 1 | 1 |
| 3 | v | v | 16 | 15 | 31 | 62 | 45 | 32 | 45 | 1 | 1 |
| 4 | h | h | 15 | 16 | 31 | 64 | 45 | 32 | 45 | 1 | 1 |
| 5 | v | v | 16 | 15 | 31 | 33 | 45 | 8 | 15 | 1 | 1 |
| 6 | v | v | 16 | 15 | 31 | 4 | 45 | 4 | 6 | 1 | 1 |
| 7 | h | h | 4 | 5 | 9 | | | | | | |
| 8 | v | h | 2 | 2 | 4 | | | | | | |
| Total planes: | | | 100 | 99 | 199 | Total: | | 200 | 297 | 3 | 6 |
| | | | | | | Total (V+H): | | 497 | | 10 | |
| | | | | | | Cell total: | | 6,400 | 9,504 | | |
| | | | | | | Total cells (V+H): | | 15,904 | | | |

Muon Catcher



Mounting the PDS on the IPND/ND

- Detailed 3D CAD design underway with all fittings

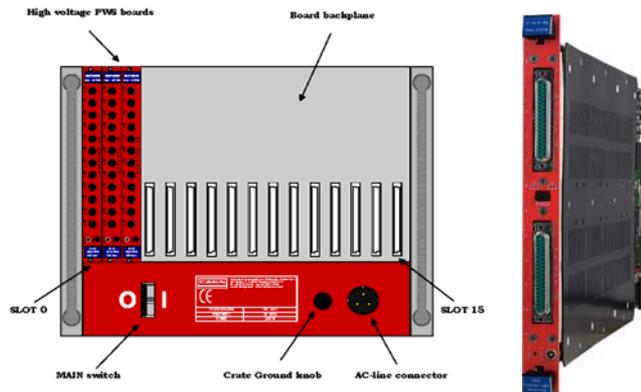




High Voltage Supply

| | CAEN SY1527LC | ISEG |
|----------------------|----------------------|---------------------------|
| Card type | A1511B | EHQ F605x-F |
| Channels/per card | 12 | 16 |
| Cards/crate | 12 | 10 |
| Voltage range | 0 – 500V | 0 – 500 V |
| Maximum current/ch | 10 mA | 15 mA |
| Floating | Yes | Yes |
| Ripple and noise | < 30 mVpp | < 5 mVpp |
| Voltage resolution | 100 mV (-0.5%) | 16 bit (20 mV) |
| Voltage set accuracy | $\pm 0.3\% \pm 0.5V$ | |
| Interface | OPC/CAENbus | SNMP/CAN-bus |
| Connector | DB-37 | 51 pin Redel |
| Input power | 100-230VAC | 95-220VAC |
| Other users | CDF, CMS | ATLAS, ALICE, LHCb, Panda |

- Baseline design: CAEN SY1527LC/A1511B
- New ISEG (Wiener) HV supply available
- Both supplies being evaluated at Fermilab with help from Vince Pavlicek's group



Baseline design

Note: new FEB design has adjustable voltage regulation on it, allowing gains of FEBs to be matched





Low Voltage Supply

| | Wiener PL508 | CAEN SY8800 |
|--------------------|--------------------------------------|--|
| Pod type | 2-7V MEH 12-30V MEH | 2-7V, 7-16V, 20-28V prototypes |
| Channels/per pod | 1 | 1 |
| Pods/crate | 2-7V: 3, 12-30V: 3 | 2-7V: 2, 20-28V: 3 |
| Voltage range | 2-7V, 12-30V | 2-7V, 7-16V, 20-28V |
| Maximum current/ch | 2-7V: 115A 12-30V: 23A | 2-7V: 110A 7-16V: 23A 20-28V: 11A |
| Float isolation | ± 10 V | |
| Ripple and noise | < 3 mVpp | <5mVpp (@load) |
| Voltage resolution | 100 mV (-0.5%) | 20mV |
| Regulation | Static: < 25 mV Dynamic: < 100 mV | < 10mV 2-7V < 15mV 20-28V |
| Remote sense | < 10m, <100m | Length limited by 20% maximum drop of Vset |
| Interface | SNMP/CAN-bus | RS232/USB/CAN/ Ethernet (OPC) |
| Connector | Screw locks | Screw locks |
| Input power | ?-264VAC | 100-211VAC |
| Max. input current | 16A | 16A |
| Other users | CDF, CMS, D0 | Prototype @ FNAL |

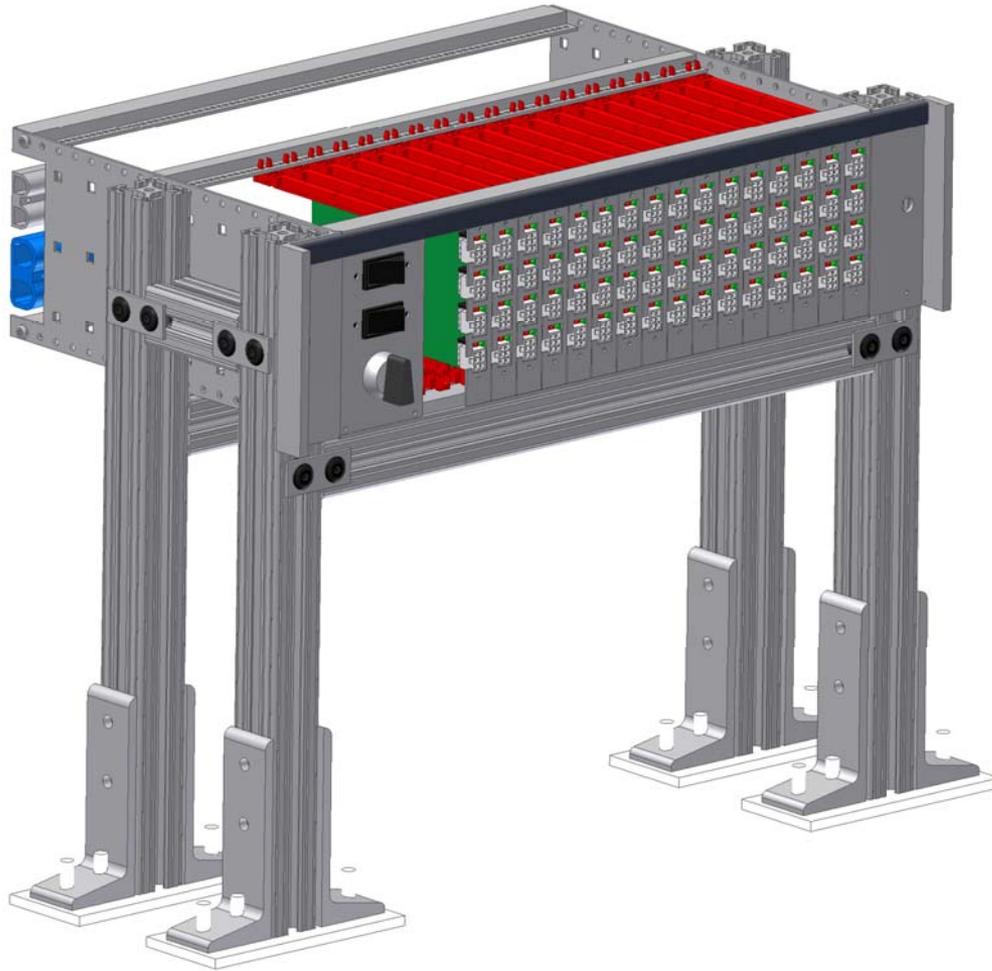
- Baseline design: Wiener PL508
- New CAEN LV supply available
- Both supplies being evaluated at Fermilab with help from Vince Pavlicek's group



Baseline design



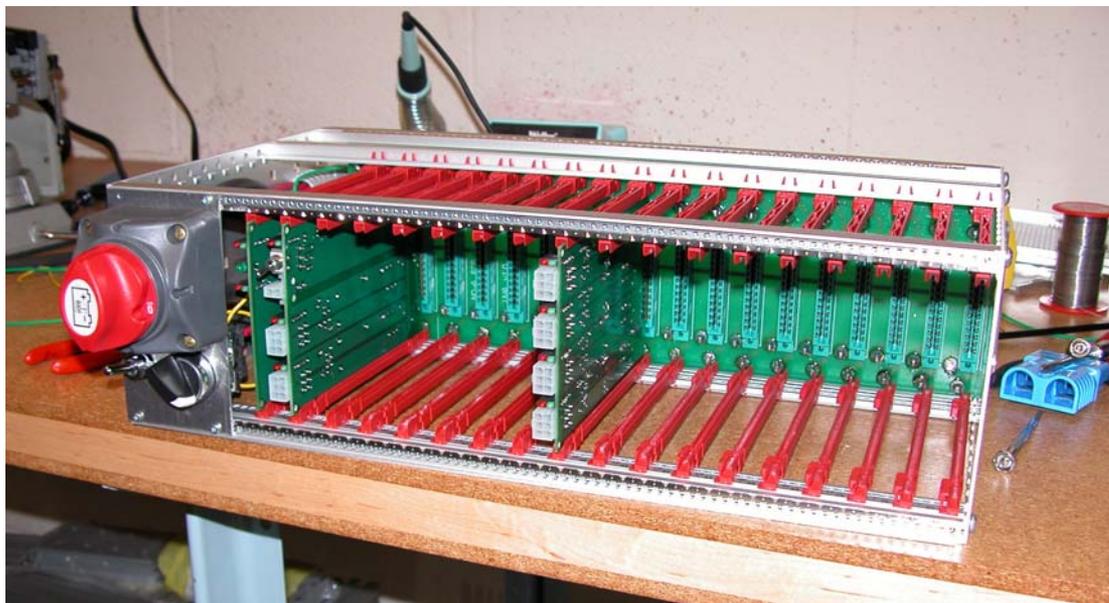
Power Distribution Box



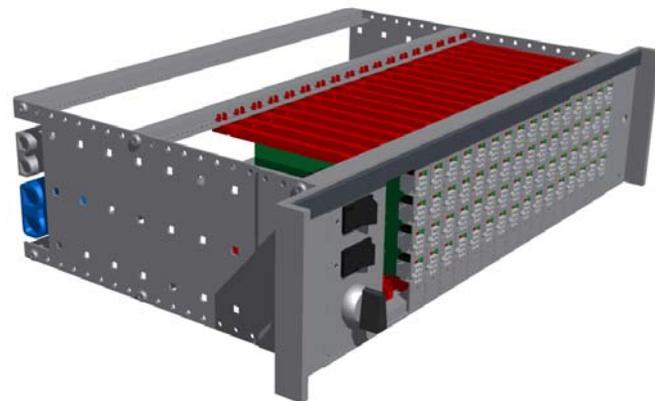
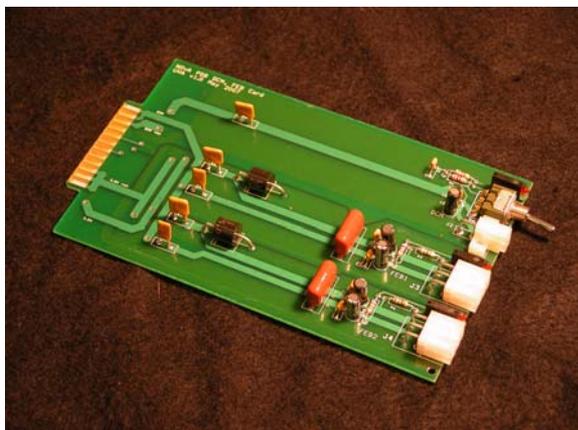
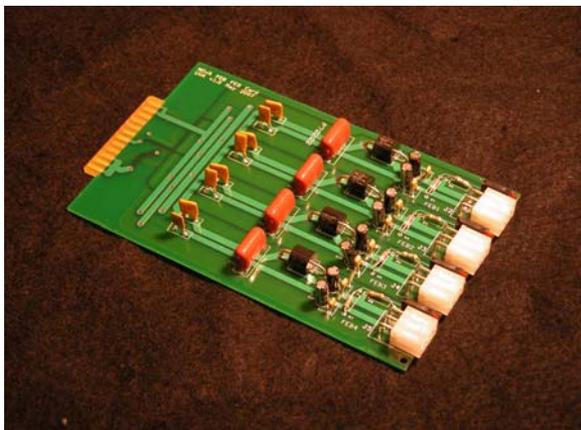
- Fans out 3.3V, 24V, and 450V to up to 64 FEB boards, and 24V to 1 DCM
- 3U crate
- $16 \times 4 + 2 = 66$ FEB channels (2 spares)
- LED indicators for crate 3.3V, 24V, and 450V power
- LED indicators for card 3.3V and 24V power
- Front panel on/off switches
- Fused with TVS for 3.3V lines
- Note: FEBs have voltage regulators
- Reference to ground
- Designed and built at UVA
- FD: 180
- ND: 10
- IPND: 6



Prototype PDB Fabricated

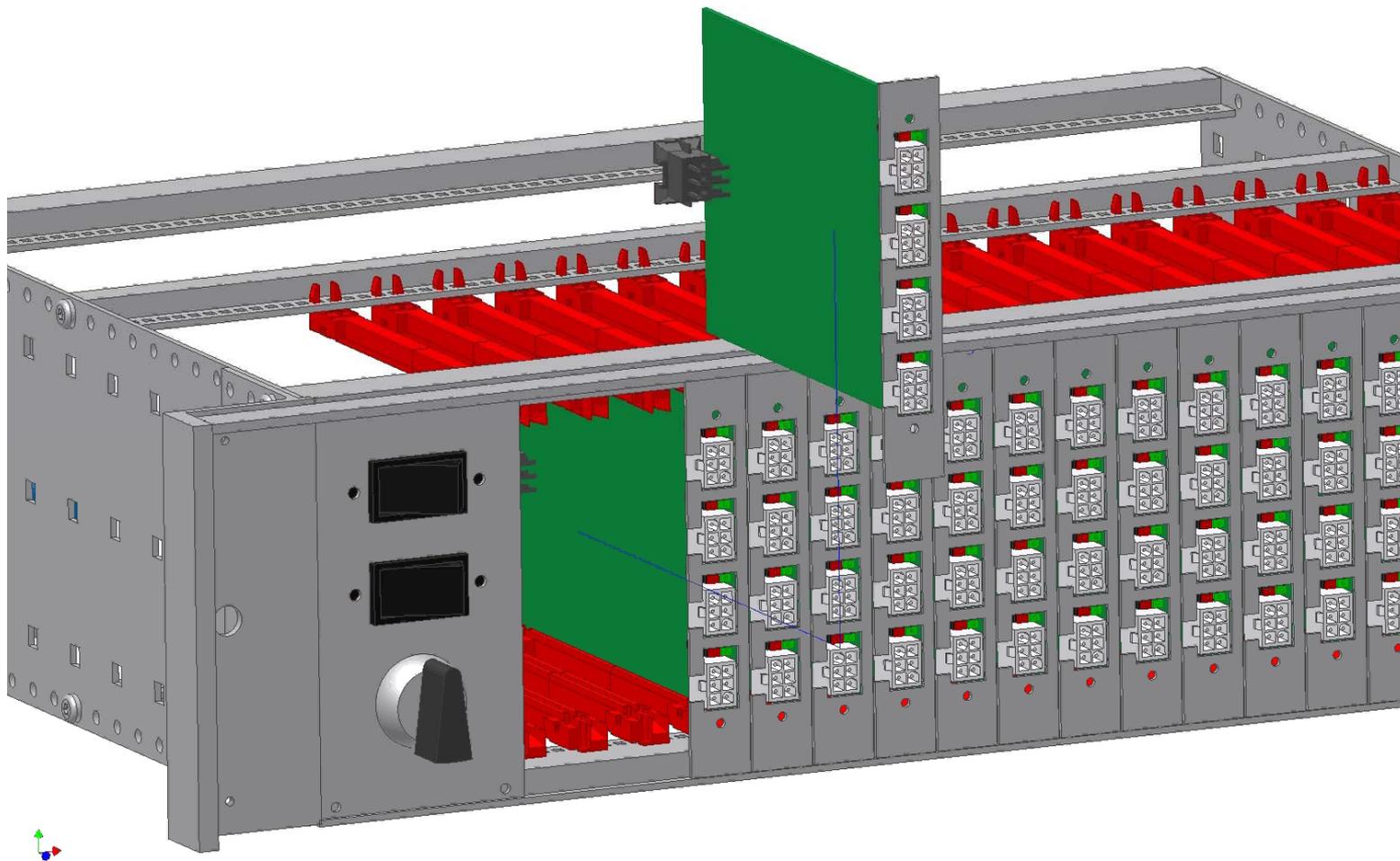


- Works according to specifications
- Preliminary safety review in March, 2009 at Fermilab with Steve Chappa
- Minor redesign in progress in response to safety review
 - New design will have extra 3.3V and 24V current capacity
 - Current limiter added for 450V
 - Backplane header changed





New PDB Design





Power Cables

- All cables “tray cable”
- Oil resistant jackets

| | Type | Size (AWG) | Cond. | Length (m) | | | | Different Lengths | # Cables |
|---------------------|---------|-------------|-------|------------|------|------|--------|-------------------|----------|
| | | | | Min. | Max. | Ave. | Total | | |
| Power Supply to PDB | 3.3V | 2 | 1 | 2.6 | 16.0 | 9.3 | 3,350 | 12 | 180 |
| | 24 V | 10 | 2 | 2.4 | 15.9 | 9.2 | 1,657 | 12 | 180 |
| | Sense | 22 | 2 | 2.4 | 15.9 | 9.3 | 3,332 | 12 | 360 |
| | 450 V | 22 | 2 | 7.2 | 50.2 | 27.6 | 2,723 | 48 | 180 |
| PDB to FEB/DCM | PDB-FEB | 18 | 6 | 0.7 | 3.8 | 2.3 | 25,498 | 64 | 12,036 |
| | PDB-DCM | 18 | 2 | 1.0 | 1.0 | 1.0 | 180 | 1 | 198 |
| | Ground | 6, 1/0, 3/0 | 1 | 2.0 | 15.0 | | | 4 | 232 |



Power Cable Safety

Power supply to PDB cables can handle full current capacity of power supplies.

| Conditions | | | | |
|------------------------|---------------------------------------|--------|---------|----------|
| | Copper Temperature | | 75°C | 167°F |
| | Ambient Temperature | | 30°C | 86°F |
| SIZE in AWG, MCM | AMPERES | | | |
| | Number of conductors bundled together | | | |
| | 1 to 3 | 4 to 6 | 7 to 24 | 25 to 42 |
| 30 | 1.6 | 1.4 | 1.2 | 1.1 |
| 28 | 2.4 | 2.2 | 2 | 1.7 |
| 26 | 3.2 | 3 | 2.7 | 2.3 |
| 24 | 4.8 | 4.3 | 3.8 | 3.2 |
| 22 | 6.4 | 5.8 | 5 | 4.3 |
| 20 | 8 | 7 | 6 | 5 |
| 18 | 12 | 11 | 9 | 8 |
| 16 | 15 | 14 | 12 | 10 |
| 14 | 20 | 16 | 14 | 12 |
| 12 | 25 | 20 | 18 | 15 |
| 10 | 35 | 28 | 25 | 21 |
| 8 | 50 | 40 | 35 | 30 |
| 6 | 65 | 52 | 46 | 39 |
| 4 | 85 | 68 | 60 | 51 |
| 2 | 115 | 92 | 81 | 69 |
| 1 | 130 | 104 | 91 | 78 |

PDB-FEB
4A max
→

Wiener-FEB
24V: 23A max
→

Wiener-FEB
3.3V: 110A max
→



Power Budget and Voltage Drops

| Diblock Power Budget | | | |
|----------------------|-------|-------|---------|
| | 3.3V | 24V | Total |
| Total | 4,267 | 3,759 | 8,026 W |
| Output | 3,121 | 3,143 | 6,264 W |
| LVS | 1,146 | 617 | 1,762 W |
| Cables | 511 | 73 | 584 W |
| PDB/DCMs | 112 | 379 | 491 W |
| FEB/TECs | 2,455 | 2,678 | 5,134 W |

| NOVA Far Detector Diblock Power Budget | | | | | |
|--|--------|-------|---------|----------------|----------|
| Input Parameters | | | | LVS parameters | |
| FEB | TEC | DCM | APD | 4.2 V eff. | 77% |
| 3.3 | 24.0 | 24.0 | 450.0 | 24.8 V eff. | 89% |
| 1 channel | 1.00 | 0.15 | 1.25 | supply eff. | 95% |
| Channels | 62 | 62 | 1 | LVS voltage: | 240 V |
| able sizes | PS-PDB | | PDB-FEB | LVS current: | 16 A |
| 3.3V | 24 V | sense | FEB | LVS max. out: | 3009.6 W |
| 2 | 10 | 22 | 18 | LVS max. in: | 3840 W |
| | | | | power factor: | 0.997 |

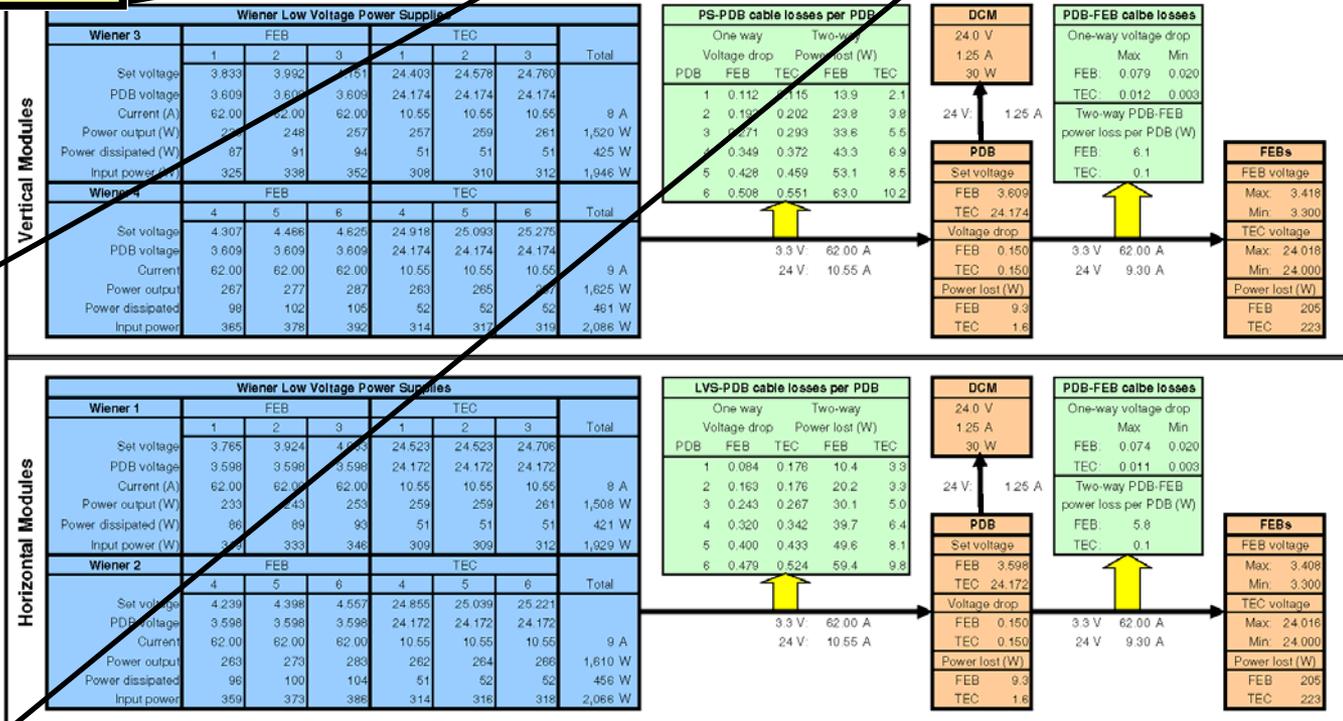
| Type AB diblock | | | Set Voltage Range | | |
|-----------------|-------|-------|-------------------|---------------------|---------------|
| Total | 4,267 | 3,759 | 8,026 W | Max | Min |
| Output | 3,121 | 3,143 | 6,264 W | FEB | 4.6 V 3.8 V |
| LVS | 1,146 | 617 | 1,762 W | TEC | 25.3 V 24.4 V |
| Cables | 511 | 73 | 584 W | Wiener Power Budget | |
| PDB/DCMs | 112 | 379 | 491 W | Max: | 2,086 W |
| FEB/TECs | 2,455 | 2,678 | 5,134 W | Min: | 1,829 W |

| Pod Power Budget | | FEB | | TEC | | Average | |
|------------------|-------|-------|-------|-------|-------|---------|-------|
| | Max | Min | | Max | Min | FEB | TEC |
| Total power | 392 W | 319 W | 319 W | 319 W | 308 W | 356 W | 313 W |
| Power output | 287 W | 233 W | 277 W | 257 W | 260 W | 262 W | 262 W |

Craig Dukes
12-Jun-09

| Detector Total | |
|----------------|--------|
| Total | 120 kW |
| Output | 94 kW |

| Set Voltage Range | | |
|-------------------|--------|--------|
| | Max | Min |
| FEB: | 4.6 V | 3.8 V |
| TEC: | 25.3 V | 24.4 V |

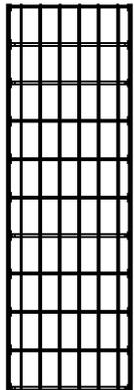




Cable Trays

| | |
|-------|---------------------|
| 2"x2" | 1,977 m 6,485 ft |
| 2"x4" | 1,657 m 5,435 ft |
| 4"x8" | 70 m 229 ft |

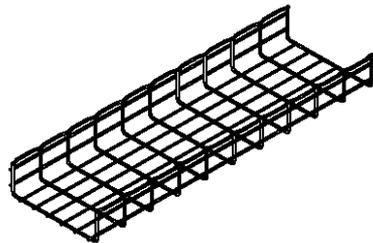
- PDB-FEB cables (6 conductor, 18AWG) in wire trays
- PS-PDB high-current cables in conduit
- Mounting fixtures final design underway



TOP



FRONT

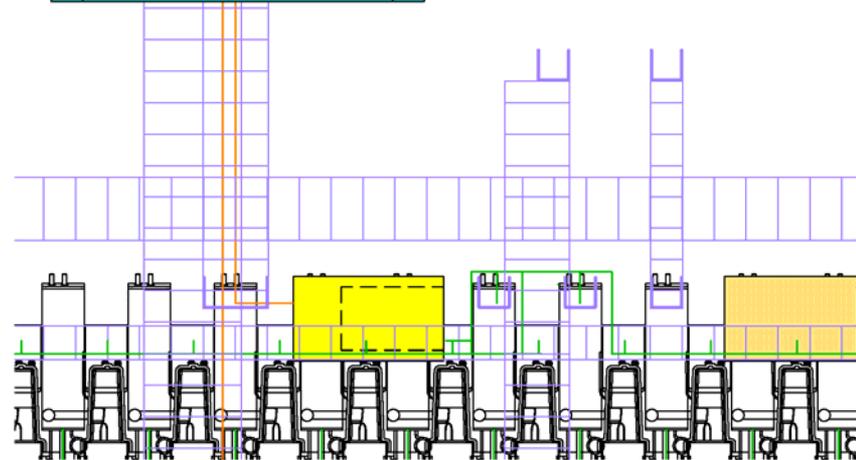
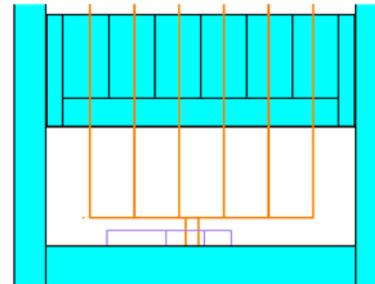


ISOMETRIC



SIDE

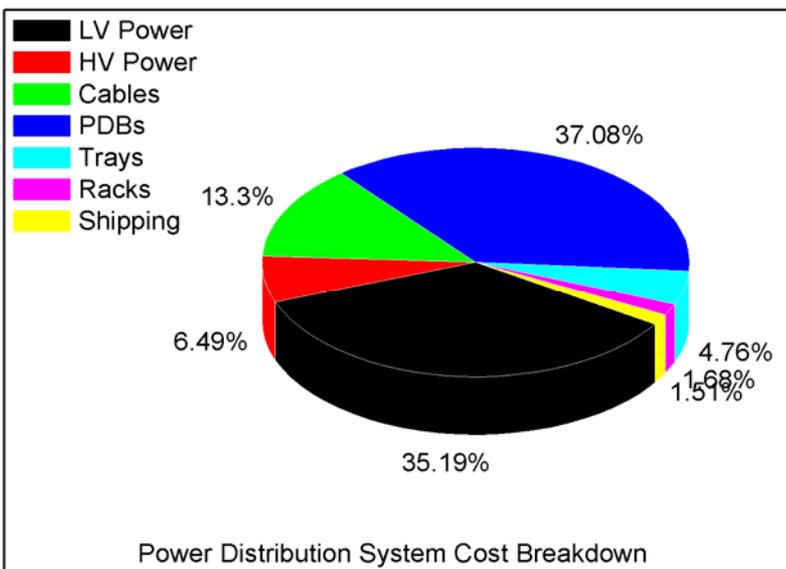
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Fax: WW!





Costs (ND+FD)

| Item | M&S | Labor | Contingency | Total |
|-----------------------|-----------------|---------------|-------------|-----------------|
| Low voltage supplies | \$542K | \$6K | 25% | \$682K |
| High voltage supplies | \$104K | \$1K | 15% | \$120K |
| Power cables | \$205K | \$47K | 32% | \$334K |
| PDBs | \$370K | \$68K | 21% | \$529K |
| PDS shipping | \$21K | \$3K | 15% | \$28K |
| Total: | \$1,242K | \$124K | 24% | \$1,693K |





Procurement

- Power Distribution System
 - Power supplies to be bought and shipped to Virginia to be tested.
 - Baseline design is for cables to be cut, terminated and tested at Virginia. Contacting vendors to off-load termination and testing.
 - Power Distribution Boxes will be fabricated and tested at Virginia.
 - Cable trays and relay racks will be delivered directly to the Far Detector site and FNAL.

Installation in WBS 2.9.4



Schedule

- **Lots of float: no critical-path items!**
- Power Distribution System
 - Fabrication of PDBs:
 - Need 215, including spares. Make and test 1/day with 1 tech
 - 200 days/1 tech
 - Fabrication of cables:
 - Dominated by 12,000 PDB-FEB cables
 - Baseline is to fabricate cables at Virginia
 - 1 student: cut, terminate, pack 5 cables/h: 80 days/4 undergrads
 - Exploring having vendors fabricate cable harnesses
 - UVa HEP building has enough storage for complete system → will deliver to detector in 3 shipments