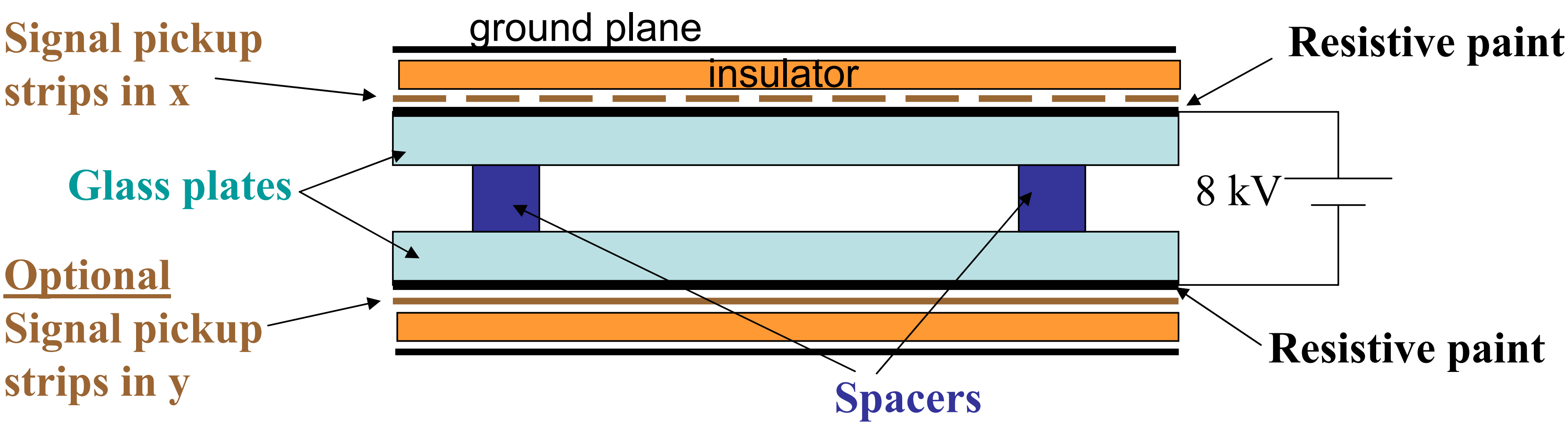
Off-Axis Detector with RPCs
(Resistive Plate Chambers)
John Cooper, Fermilab

- We have an alternate RPC design for the detector
  - It is by no means a final design
  - Plenty of room for new collaborators to help design a better version
  - I believe "better" means
    "cheaper, but with adequate performance to accomplish the physics goals"
  - This is a fact of life when you talk about building 50 kilotons of anything
    - If it's too expensive we won't get to build it at all, or
    - We will have to wait additional years to accumulate the funds to build it
    - I would be happy to trade years of waiting for a less than perfect but adequate detector

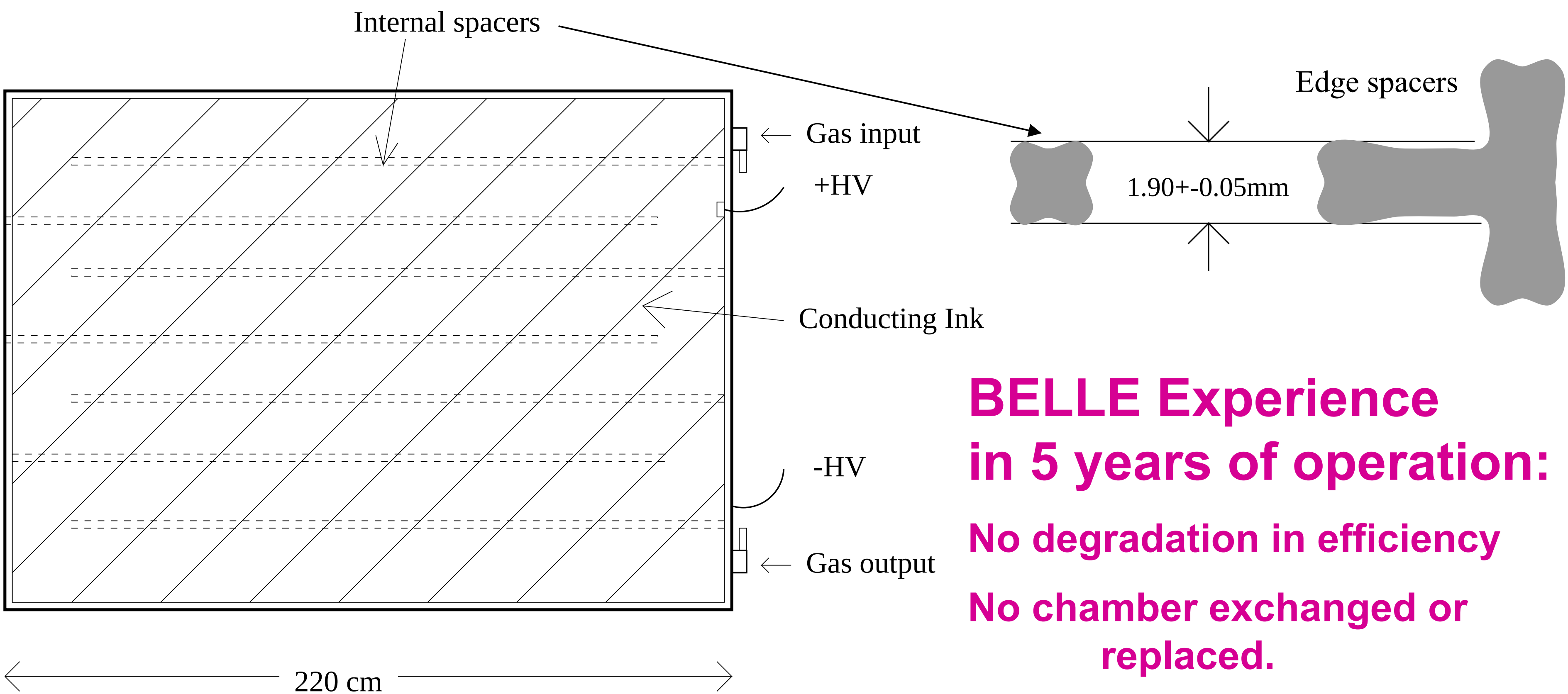
- This talk describes the current RPC version
- Then suggests avenues of R&D to make it cheaper

The basic RPC unit

- Glass RPCs are our design baseline
  - This is a conservative choice based on the successful BELLE experience with their barrel and endcap muon systems
    - BELLE has 5,000 m^2 of such chambers
    - BELLE has operated them without problems for 5 years



BELLE design detail – a very simple device



BELLE Experience in 5 years of operation:

No degradation in efficiency

No chamber exchanged or replaced.

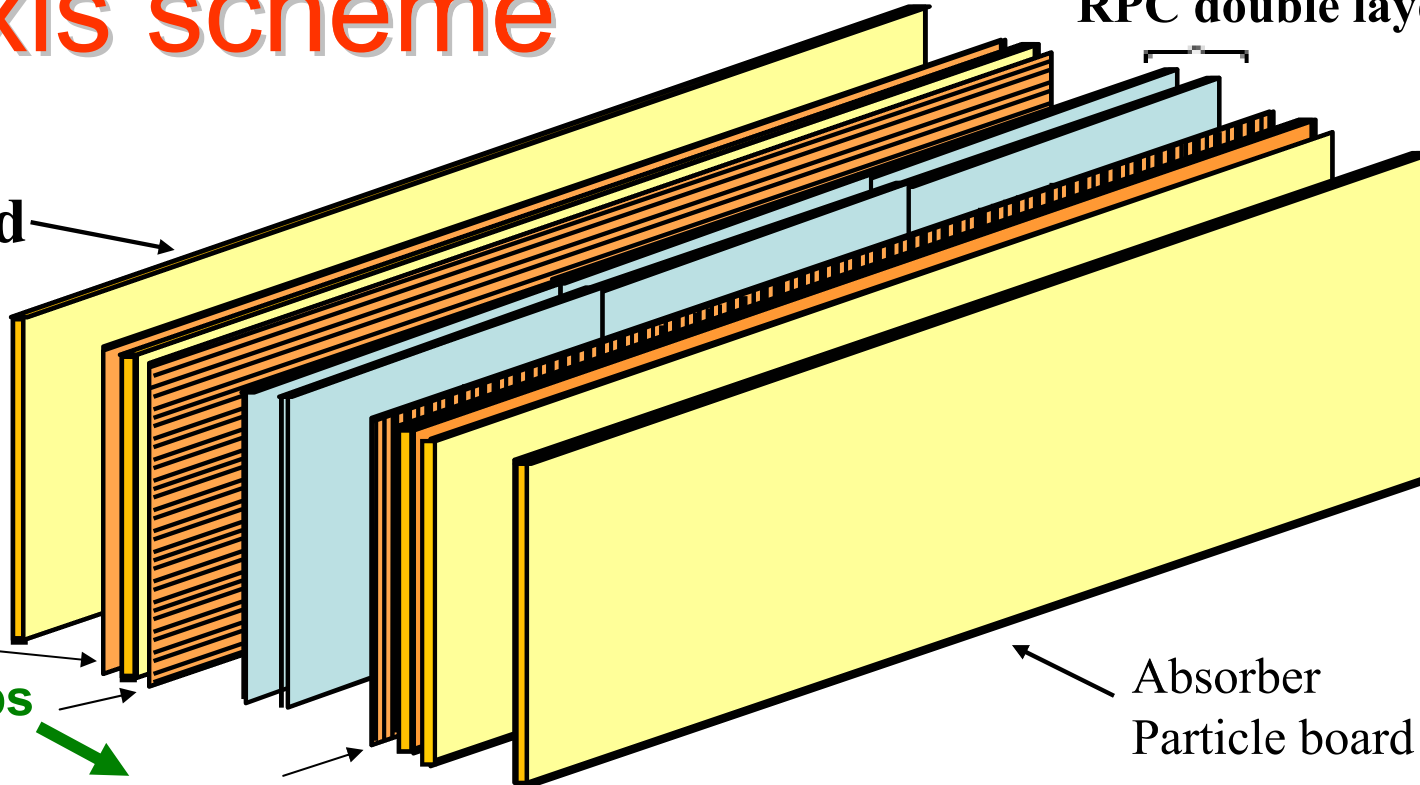
Two large sheets of float glass, 2 mm thick, 10^{12} Ωcm resistivity

Noryl spacers every 10 cm, Epoxy 3M 2216

India ink (30%black + 70%white), of order 1 MΩ per square

Gas connectors, Gas: 30% Argon, 62% HFC-134A tetrafluoroethane, 8% Butane, (not flammable)

Off-Axis scheme



Absorber
Particle board
8 ft x 28 ft
"magic" max size
From industry,
1 inch thick
0.7 gm/cc

Ground plane

Horizontal strips
About 4 cm wide,
17 micron Cu foil
on Particle Board
64 channels

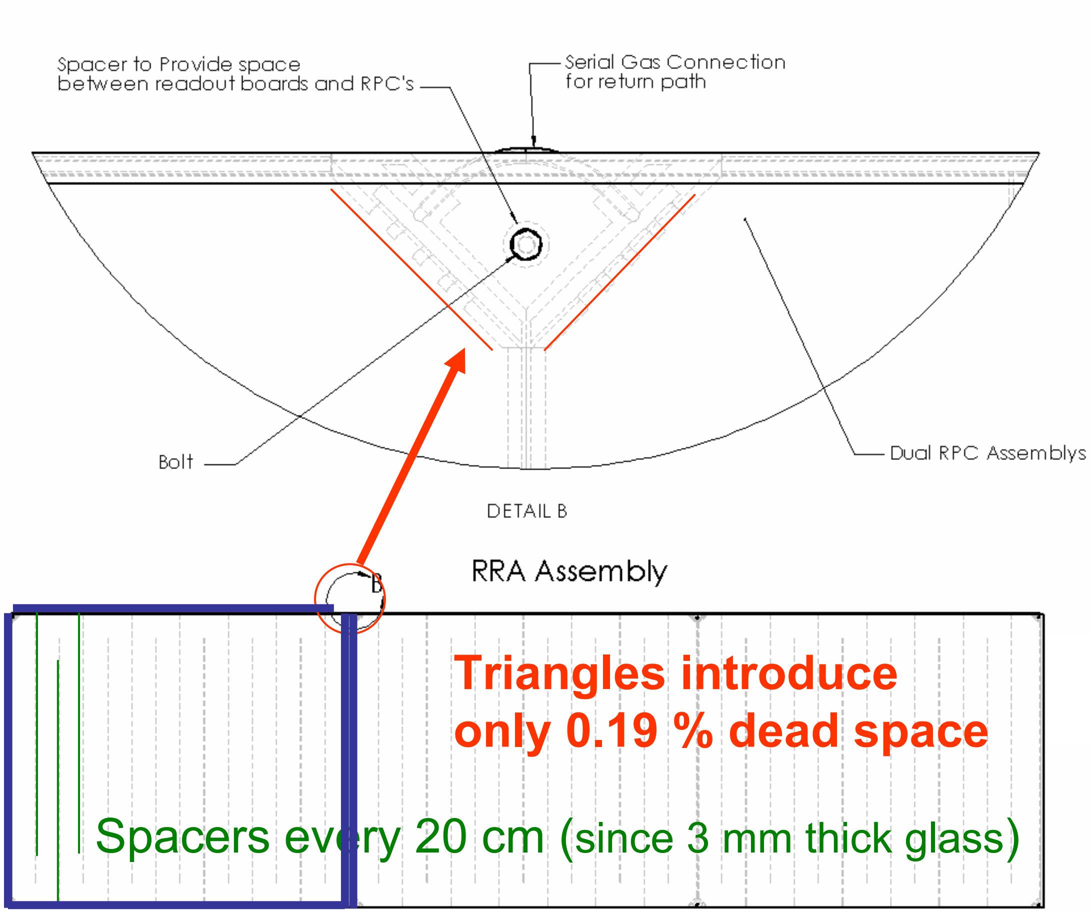
Vertical strips,
About 4 cm wide,
Cu on Particle Board
3 x 64 = 192 channels

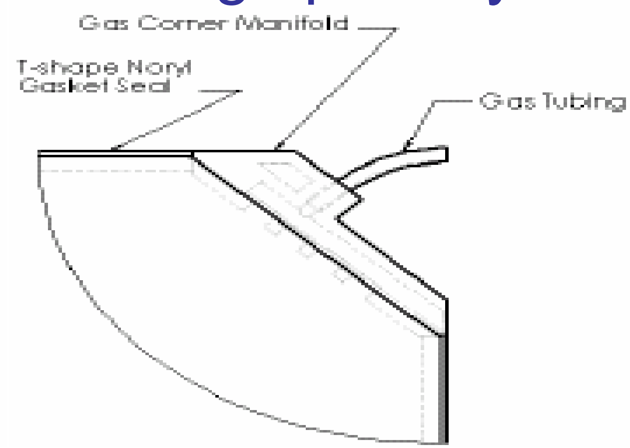
If BOTH strips, called XANDY
If one per layer, XORY
(and half the electronics)

- 6 separate chambers, each 2.84m by 2.43m, 3mm thick glass (vs. BELLE 2mm)
- Arranged in two layers to get full efficiency (offset dead spacer areas)
- Call this unit an "**RRA**" , **R**PC **R**eadout board **A**ssembly
- 4 layers of glass, 2 layers of strips on Particle Board, ground plane on opposite side, assorted resistive paint and insulating layers
- 2 more outside Particle Boards for protection

Gas plumbing details on the RRA

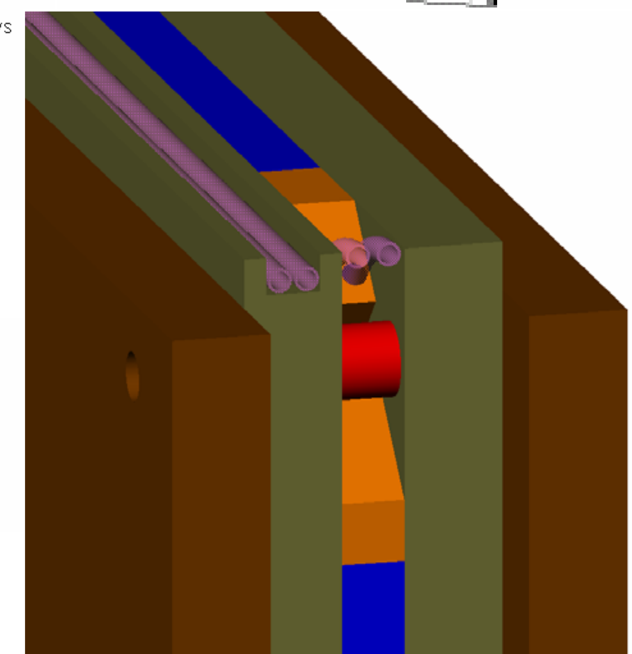
triangular cutout on glass corners for gas manifold,
recirculating gas system with 1 volume change per day





Triangles introduce only 0.19 % dead space

Spacers every 20 cm (since 3 mm thick glass)

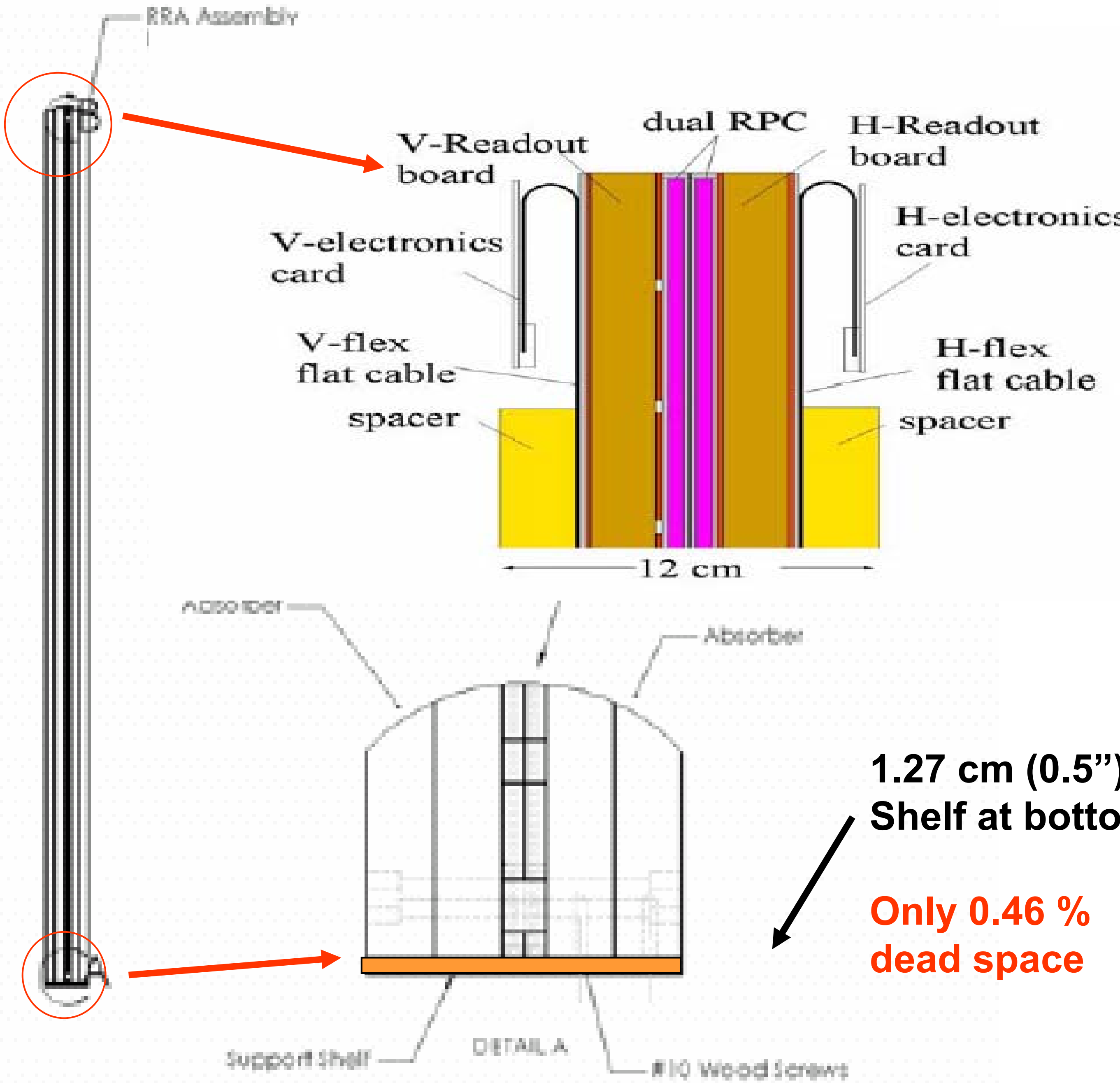


Gas flow spacers introduce a 0.92% dead space

(but can offset in the two layers, so count as 0.0 %)

Edge spacers introduce 0.84 % dead space

RRA End View

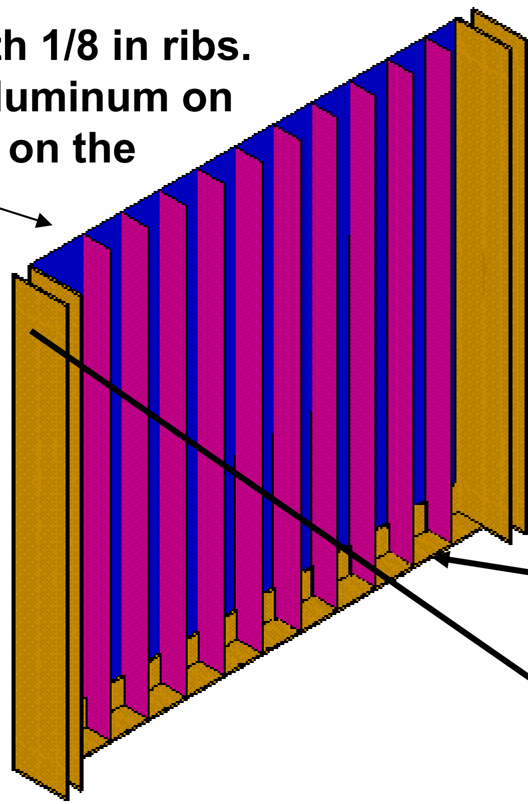


1.27 cm (0.5") Shelf at bottom

Only 0.46 % dead space

Next, assemble 12 RRCs into a module called a "Toaster"

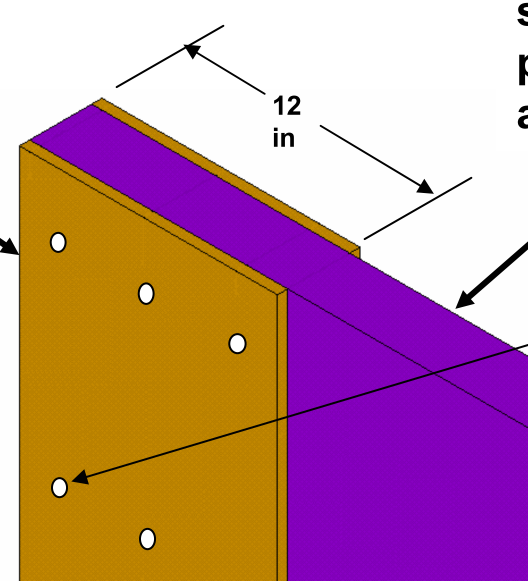
1/8 in. skin with 1/8 in ribs. Endframe is aluminum on one end, steel on the other end



Structural angle "shelf" for RPC and absorber support.
aluminum endwall uses L 6 x 6 x 1/2
Steel end is 3/8

Composite particle board corner post formed by sandwiching 3 inch of absorber between two 1/2 inch thick aluminum plates

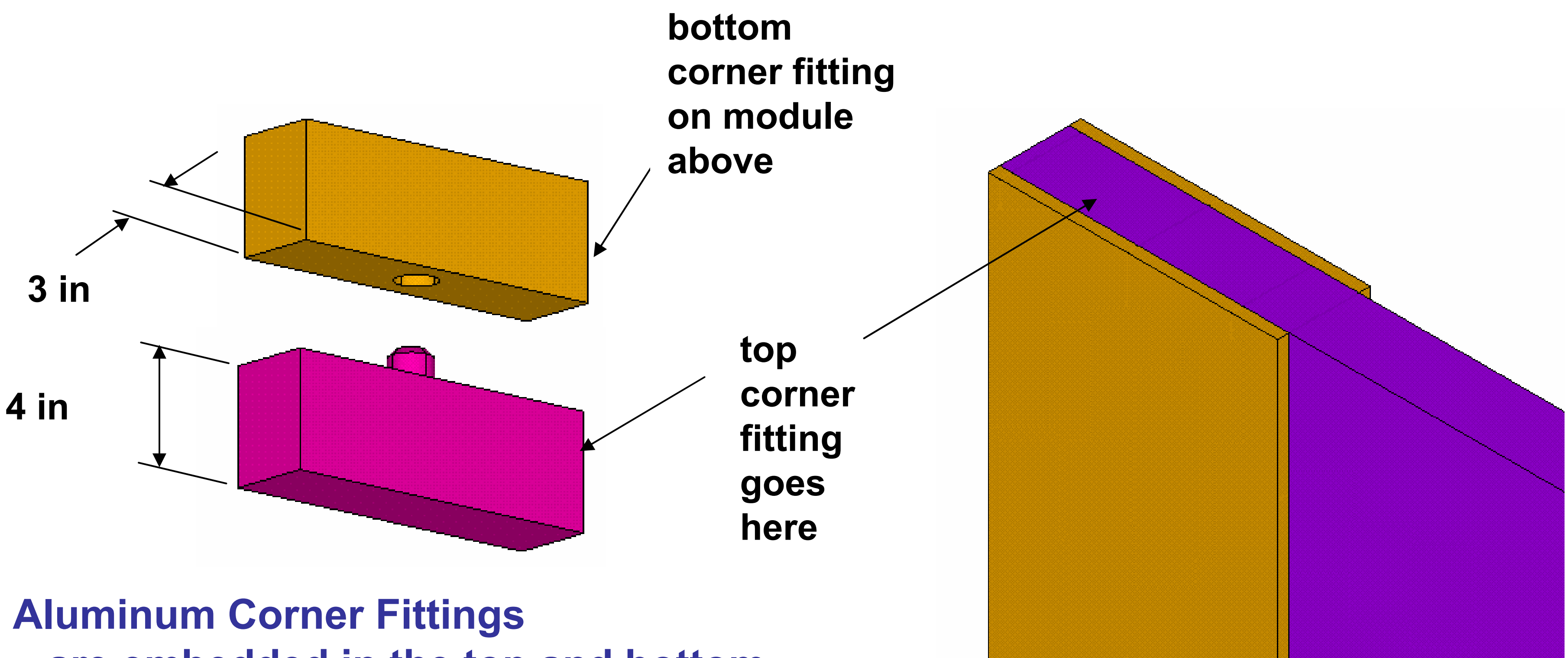
STRONG structural sidewall particle board absorber



8 rows of 5/8 in countersunk bolts, 3 bolts/row. Metal/particle board surfaces are also glued

Corner Posts inspired by ISO Shipping Containers bear the Toaster weight,
Particle Board is self-supporting between the 2 endwalls

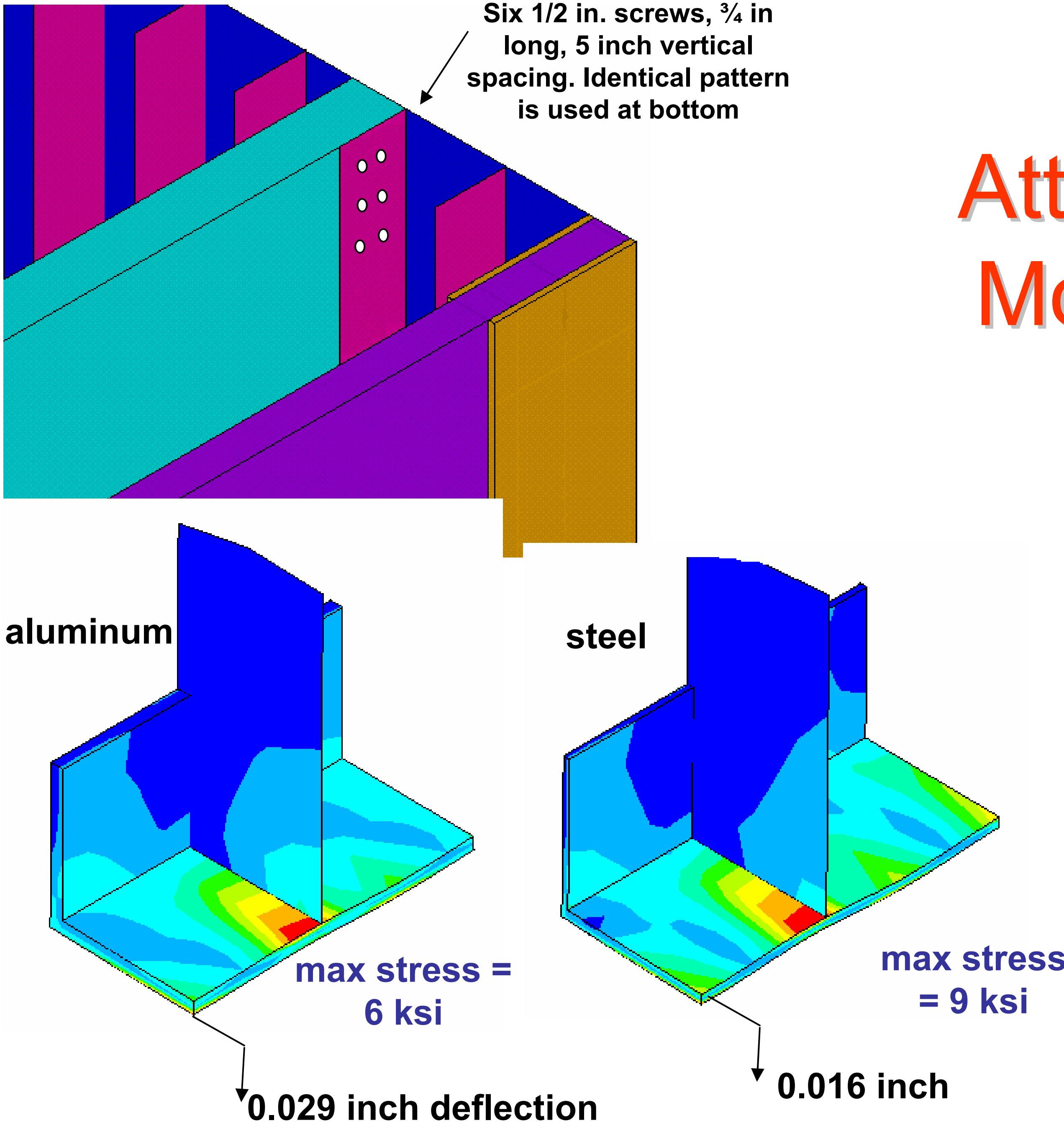
Embed Corner fittings on the posts to allow stacking of several modules



Aluminum Corner Fittings
are embedded in the top and bottom
4 inches of composite column
(can remove "nipple" for lifting fixture attach point)

Allow 0.5 inch clearance between particle boards in adjacent vertical stack
Only 0.46 % dead space

Next, Attach RRC Modules to Ribs



Weld Stress and Angle Deflection in Endframes

Assembly order for 12 RRAs and 2 Sidewalls

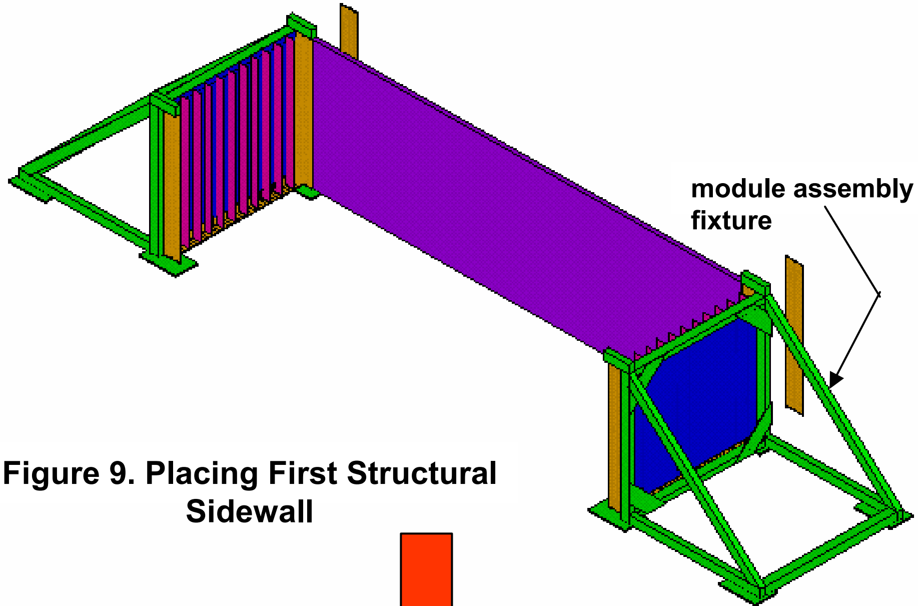


Figure 9. Placing First Structural Sidewall

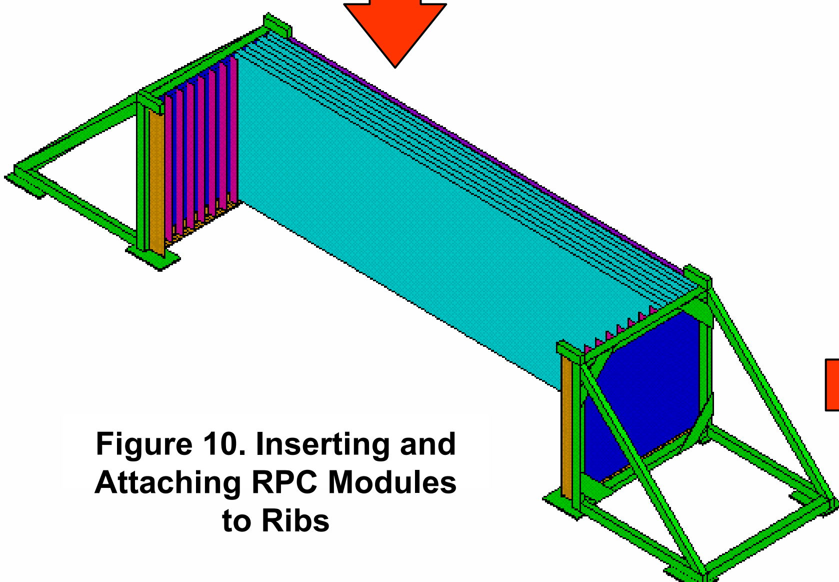


Figure 10. Inserting and Attaching RPC Modules to Ribs

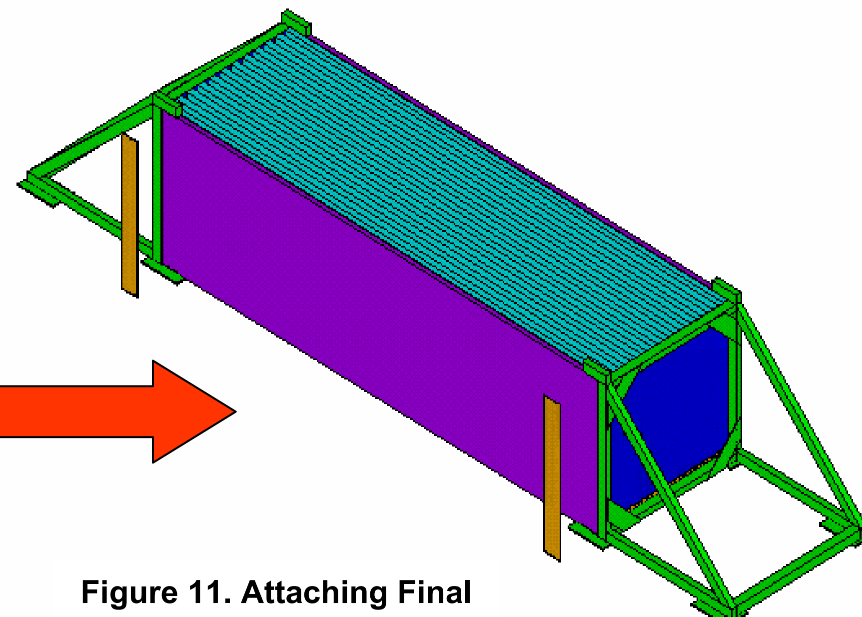
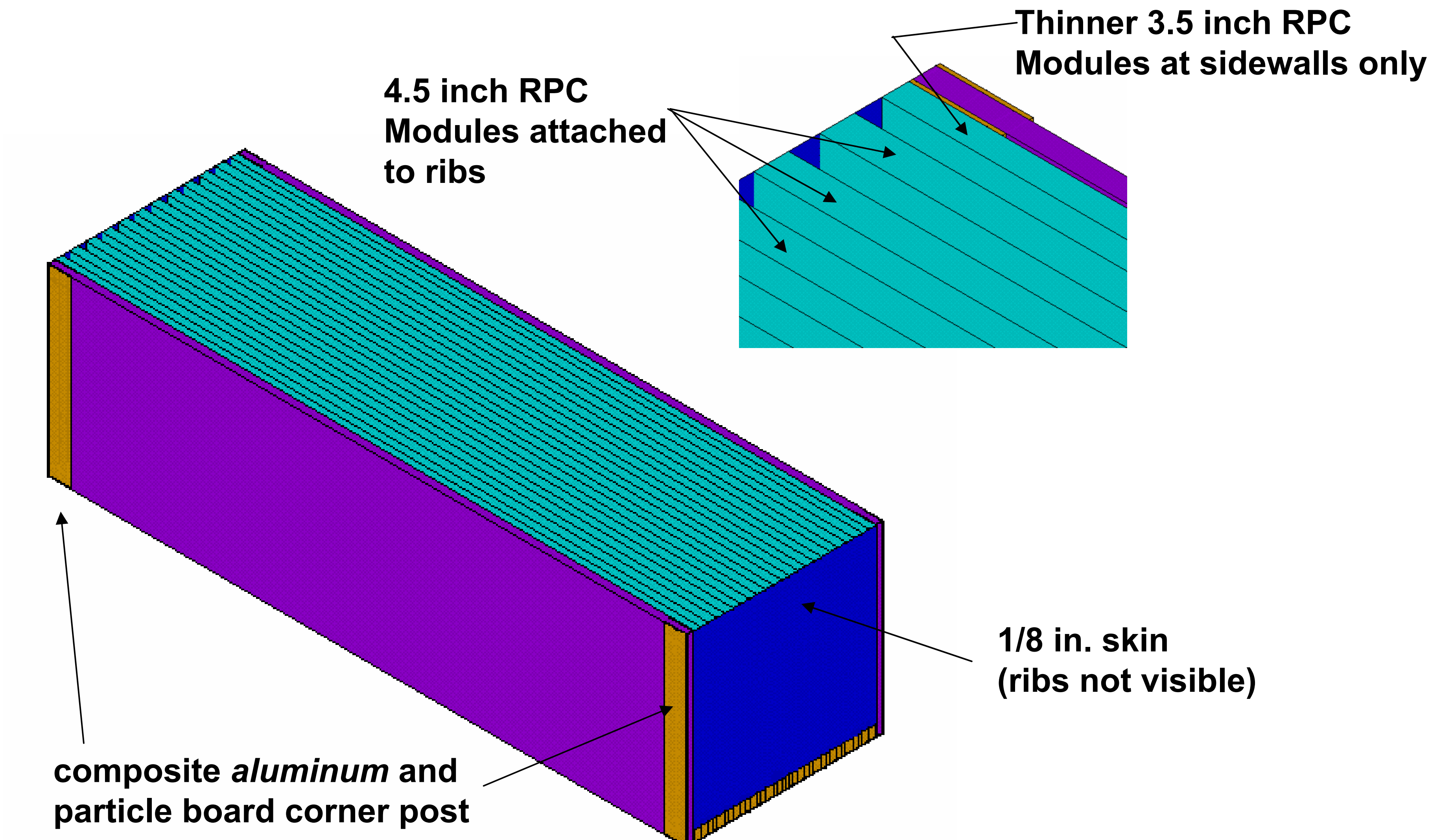
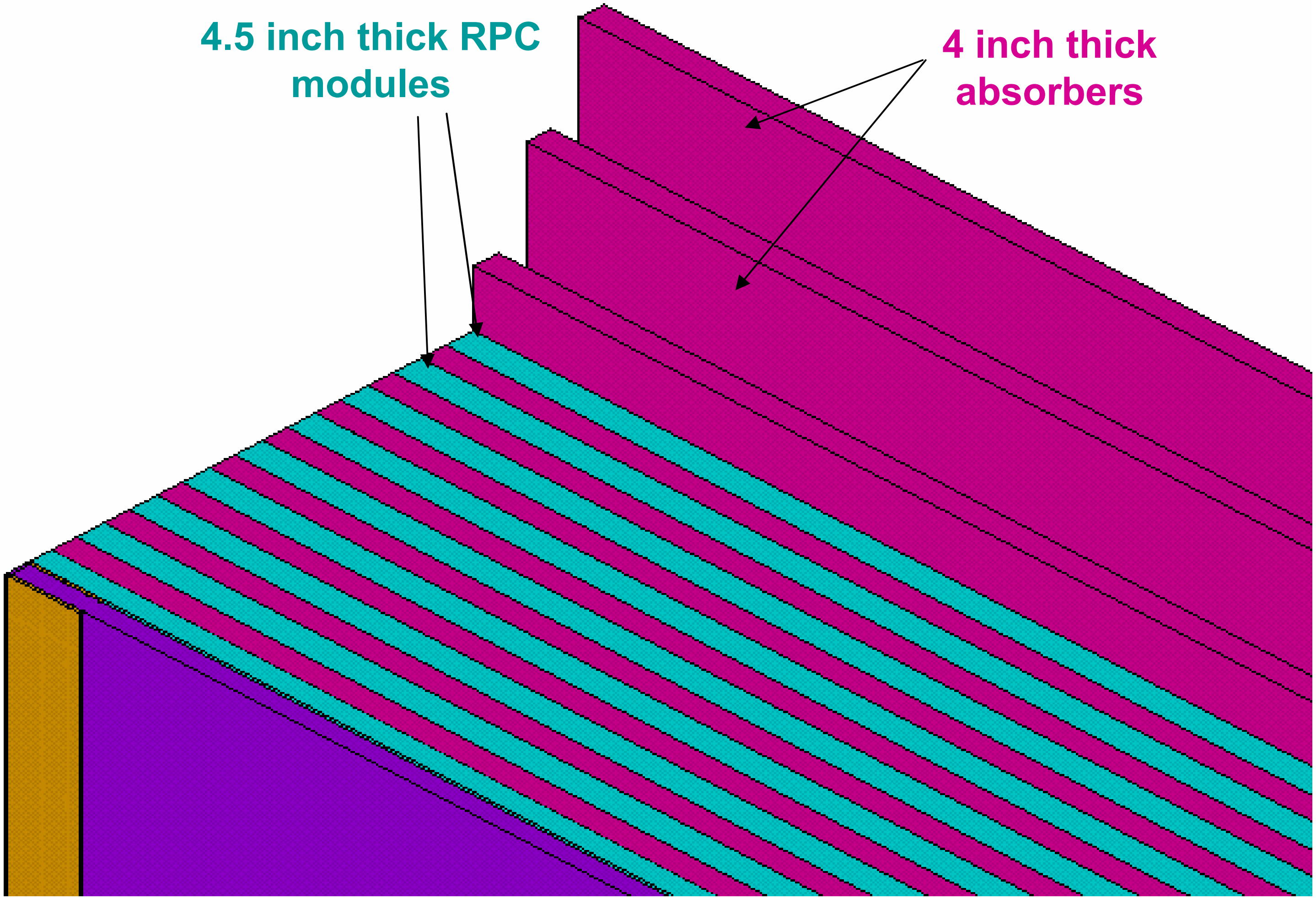


Figure 11. Attaching Final Structural Sidewall

And you have a 24 ton “Toaster” with empty slots



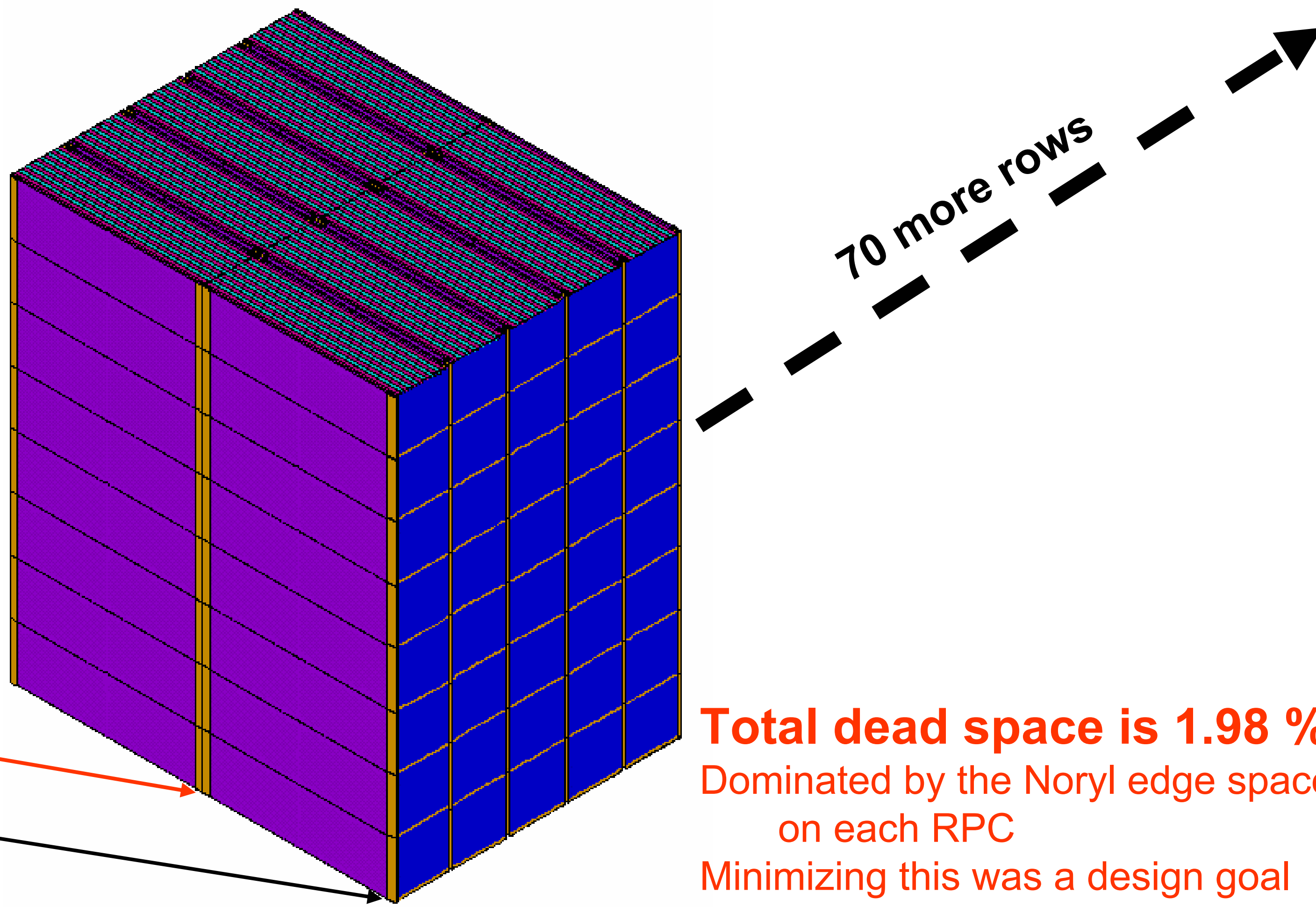
Fill it with Toast (at the Far Site) and you get a 44 ton assembly



All the non-structural particle board absorbers sit on the endwall ledges and are self supporting

Stack the full Toasters
2 wide, 8 high, 75 deep

1200 Toasters in all



aluminum endframes at the center crack,
Only 0.033% dead space

steel endframes to the outside (cheaper)

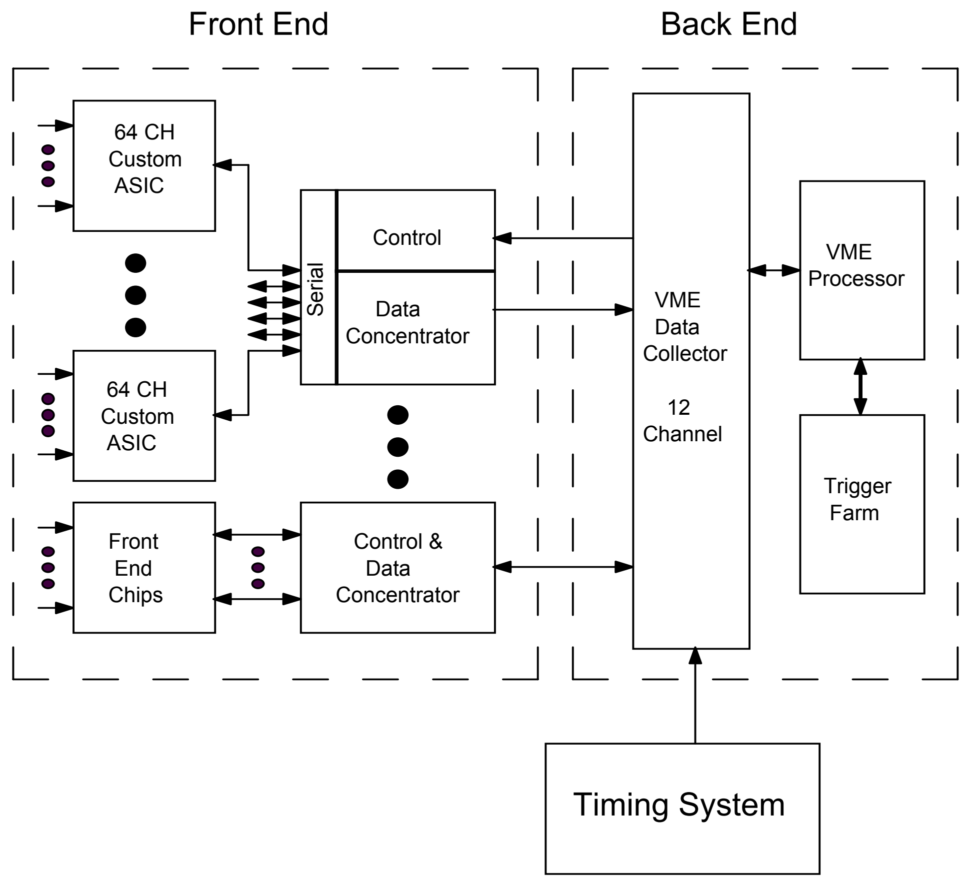
Total dead space is 1.98 %,
Dominated by the Noryl edge spacers on each RPC
Minimizing this was a design goal

HV System sits on the outside edge of the RRAs

- Cockroft-Walton HV supplies with current readback
- Implementation for Neutrino Detector
  - 6 C-W supplies mounted on one PC-board
  - One PC-board services 6 RPCs in a double layer
  - Each C-W generates up to + 4,500 V and – 4,500 V
  - Serial control via CANbus
    - CANbus node serves the 12 C-W boards on a module
    - Multiplexed DAC and ADC reside on CANbus node
- One serial cable and one low voltage cable are all that is needed to provide HV and monitor current to a module

Electronics is all on the outside edge

- **System Overview**
  - Discriminate Hits from Detector
  - Timestamp Hits in Front End
  - Store Timestamps in Local Buffers
  - Read Buffers Periodically
  - Use Back End Trigger Processor to Reconstruct Hits



➢ *Trigger-less* – Like MINOS

➢ Similar to a Parallel Development for the Linear Collider

  ➢ Custom ASIC design at Fermilab in collaboration with Argonne LC

➢ Primary Goal: Cheap Electronics, 1 Bit Dynamic Range

So I hope you are convinced that we have a complete RPC design for costing and simulation purposes

- As you will hear, this design seems to be more expensive than the basic scintillator design
  - Many parts to build and assemble
    - More parts implies more cost
    - but does give each institution a part of the detector to build

- Is this the final word?
- NO, many options remain to be investigated

Some options are simple, not too controversial

- **Change the gas system from copper to some plastic tubing impervious to water?**
  - BELLE had an initial problem with water vapor through polyflow
  - PVDF tubing may work
- **Combine the HV and gas systems for each of the two RPC layers in an RRA**
  - Lose ability to control separately,
  - but these chambers are robust, so why have the unused extra control?
- **Simplify the gas system manifold?**
  - Remove scintered metal strainer and flow restrictor (0.25 mm I.D.) per triplet of RPCs – lose perfectly balanced flow to all RPCs
- **Reduce gas flow, don't recirculate?**
  - We have 1 volume change per day, BELLE did per 2 days
  - Maybe can flow at 0.1 – 0.2 per day in **pulsed flow** with a long output tube open to atmosphere? (OK, this one is pretty controversial)

Some options are more ambitious

- **Drop double RPC layer**
  - Single layer is 93-94 % efficient including dead area from spacers
  - Compensate by operating RPCs in avalanche mode instead of streamer mode
    - Increases efficiency per layer to 98-99 %, so one layer may be enough
    - Signals are 100 times smaller
      - » 200 mV into 100 ohm → 2 mV into 100 ohm
  - Avalanche Electronics design is in common with US LC hadron calorimeter groups (Jose Repond at ANL, Ray Yarema at Fermilab) so we can test this

  - Alternate scheme, drop double layer, stay in streamer mode, but add 5% more layers to compensate for 5% drop in efficiency

- **Replace the Copper strips with Aluminum Strips already laminated** ($0.15 + $0.30/sq ft → $0.20 or less)
  - The original scheme used Johns-Manville AP Foil-Faced polyisocynurate foam sheathing or DOW THERMAX
    - foam board plus a kraft paper / aluminum laminate (another std building material)
  - Could not find an reliable cheap way to attach cables to Aluminum strips
    - Could we deliberately do a **capacitive coupled connection**, using a controlled thickness spacer with copper tape overlay at the ends of strips?

Some options are more radical

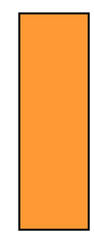
- The present design was a compromise between RPC enthusiasts in favor of monolithic structures (like the liquid scintillator) and modular structures using intermodal shipping containers
  - We compromised so that “a solution” could be written up by our small group of 4 physicists and 6 engineers on a deadline of last September
- In retrospect we all agree we compromised on a solution that has the world’s most expensive custom container, a container so large that we can’t fill it and transport it on US Interstate highways.
  - This is why we build a toaster but add the toast at the far site
  - Committee design of an elephant resulted in a <u>white</u> elephant?
- So we are again separately pursuing the monolith & container solutions
  - Each seeking a lower cost with adequate performance
  - We still meet together every week

RPCs in a **monolithic** design – Options

- **Overall the monolithic design, completely assembled at the far site may be cheaper**
  - At least the assembly should be as cheap as the very similar Liquid Scintillator assembly

- **This can reduce the number of vertical strip readout channels by 50%**

8 foot high vertical strips become 28 ft
(or even 56 ft high?)



8 vertical strip channels become 2 channels
(or even 1 channel?)

RPCs in a **shipping container** design -- Options

- **1200 custom 28 ft long modules replaced with 2400 standard 20 ft steel shipping containers**
  - $ 3500 custom module becomes $1000(used) or $1500(new) container
    - Readily available throughout the U.S. (trade imbalance)
- **Full modules can be built and tested at many sites**
  - Nice for collaboration, but have to watch transportation costs

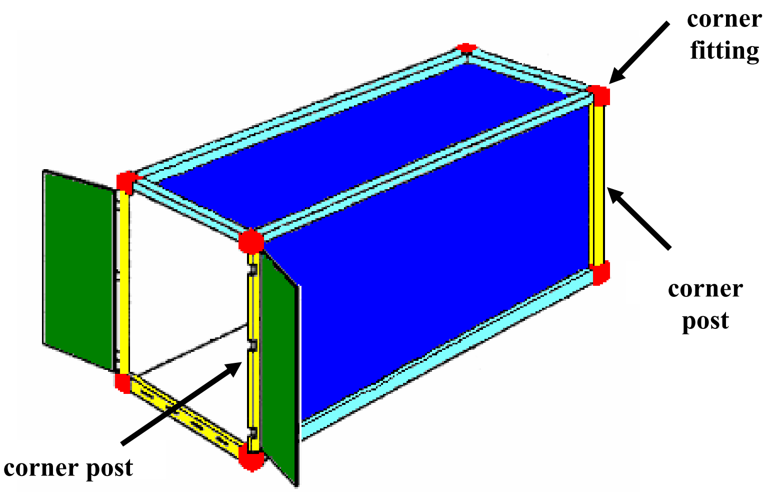


Figure 1. ISO Series 1 Shipping Container

Use the corner fittings to lift the containers with a crane

More on RPCs in Containers

- **A steel container does not need to rely on the strength of particle board absorber since the container has a fully supported floor**
  - **Price of particle board is $ 0.13 per pound and we need $ 12.4 M of it**
    - Radiation length is 53.6 cm, density is 0.65 gm/cc
  - **An alternate material is Drywall or Sheetrock**
    - This is Gypsum, $Ca\ SO_4\ \ 2H_2O$, Calcium Sulfate Dihydrate
    - US annual output is 38,000 kilotons, Cost is about **$ 0.05 per pound**
    - Radiation length is 37.9 cm, density is 0.68 gm/cc
  - **Another alternate is Cellular Foam Concrete**
    - This is Portland cement, sand, water, and "shaving cream"
      - 50% Tricalcium Silicate, 25% Dicalcium Silicate, 10% Tricalcium Aluminate, 10%Tetracalcium Aluminoferrite, all hydrated, 5% gypsum,
    - Not common in the US, invented in Europe, US price about **$ 0.10 per lb**
    - Radiation length can be made at 47 cm, density of 0.7 gm/cc with sand : portland cement at 3.5 : 1, i.e "structural sand"
    - Pour in place, labor savings?

More on RPCs in Containers

- **Standard ISO containers introduce a new problem**
  - there is 20 cm high dead space or “crack” at the bottom of the container for fork lift pockets and the container floor and another dead space at the door end of the container
    - So 2 % dead area → 1.9 +7.6 + 2.6 % = 12.1 % dead area
  - **Can software for a “Tracking” Calorimeter keep track of where each track passes through such cracks and compensate?**

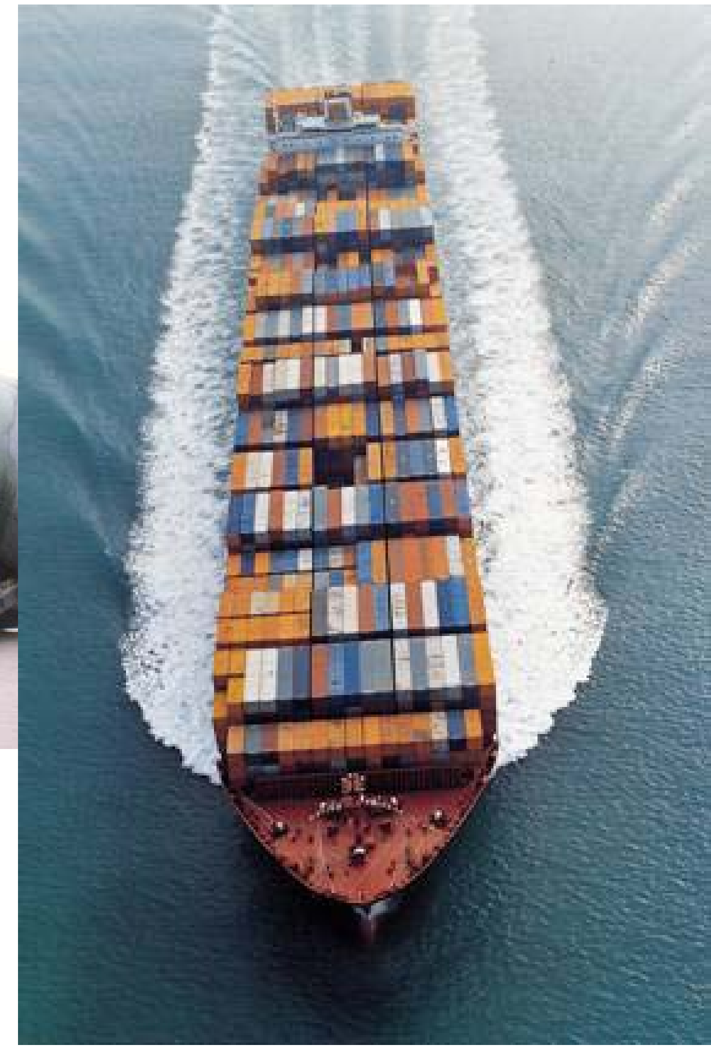
- **ISO containers at the US Interstate weight limit can stack as high as 11 on 1** (31 m or 100 ft high)
  - The detector building appears to be significantly cheaper (at equal volume) if higher but with a smaller area footprint

- **A Containerized Detector is mobile**
  - We may not know the optimum site early?
  - We may want to move to a different site after seeing a signal?

20 ft on a truck chassis

20 ft in a C-130

Double Stack Rail car



7,500 TEU Ship

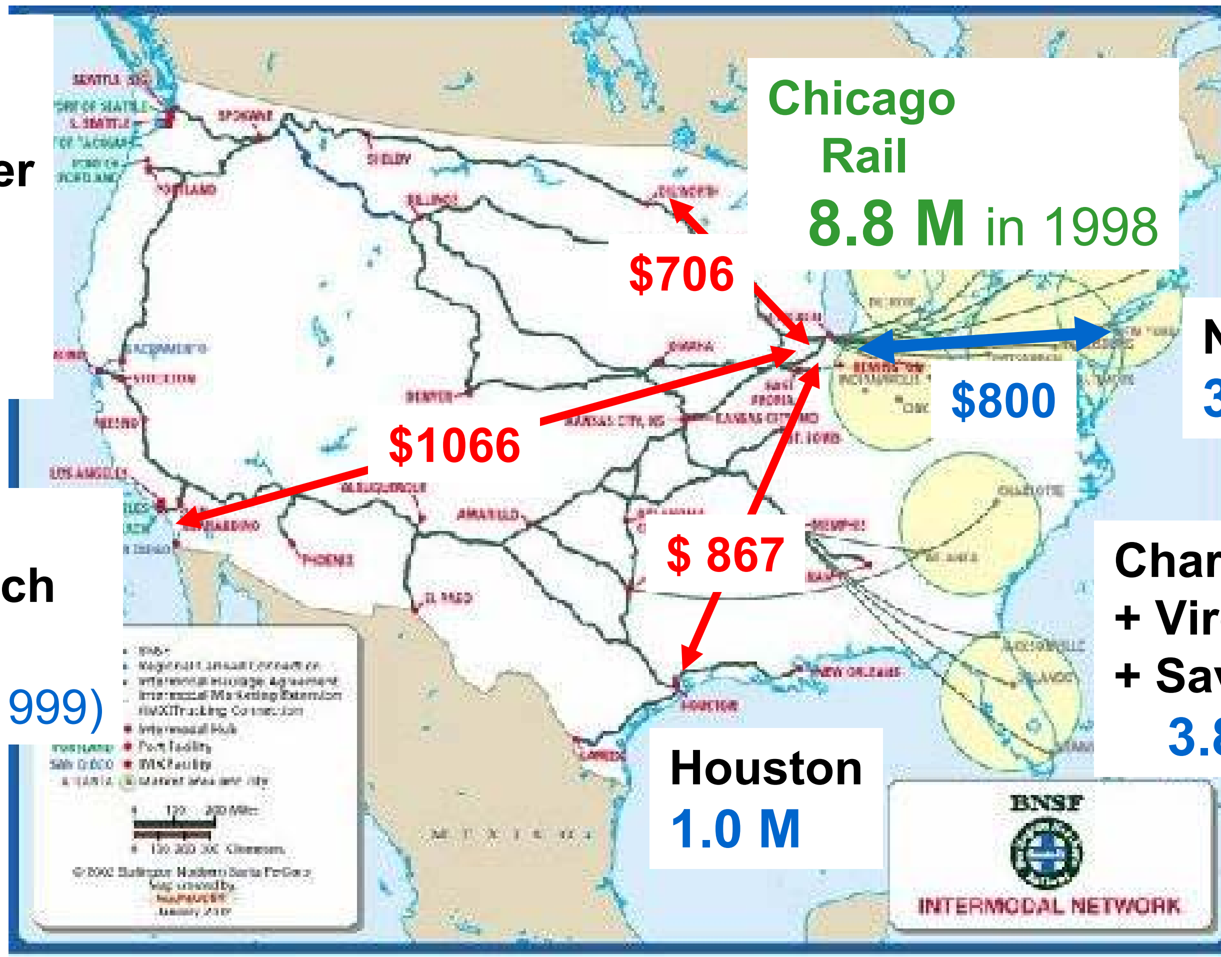
Intermodal Landbridge by Rail

& the cost to ship a 20-foot container

WEST ⟷ **EAST**

Burlington Northern Santa Fe or Union Pacific | CSX or Norfolk Southern

Costs from BNSF website



Seattle + Tacoma + Vancouver
3.7 M TEU in 2002

Chicago Rail
8.8 M in 1998

$706

$1066

$800

$ 867

NY, NJ
3.3 M

LA + Long Beach
9.6 M
(8.2 M in 1999)

Charleston + Virginia + Savanna
3.8 M

Houston
1.0 M

I think this explains why the cost of containers is fairly uniform across the US