Overview of Braidwood Reactor Experiment

E. Blucher, Chicago

- Introduction to Braidwood site
- General strategy and layout of experiment
- Underground construction estimate
- Plans

Midwest θ_{13} Collaboration

ANL: Maury Goodman, Vic Guarino, David Reyna

Chicago: Erin Abouzaid, Kelby Anderson, Ed Blucher, Jim Pilcher, Matt Worcester

Columbia: Janet Conrad, Jon Link, Mike Shaevitz

FNAL: Larry Bartoszek, Dave Finley, Hans Jostlein, Chris Laughton, Ray Stefanski

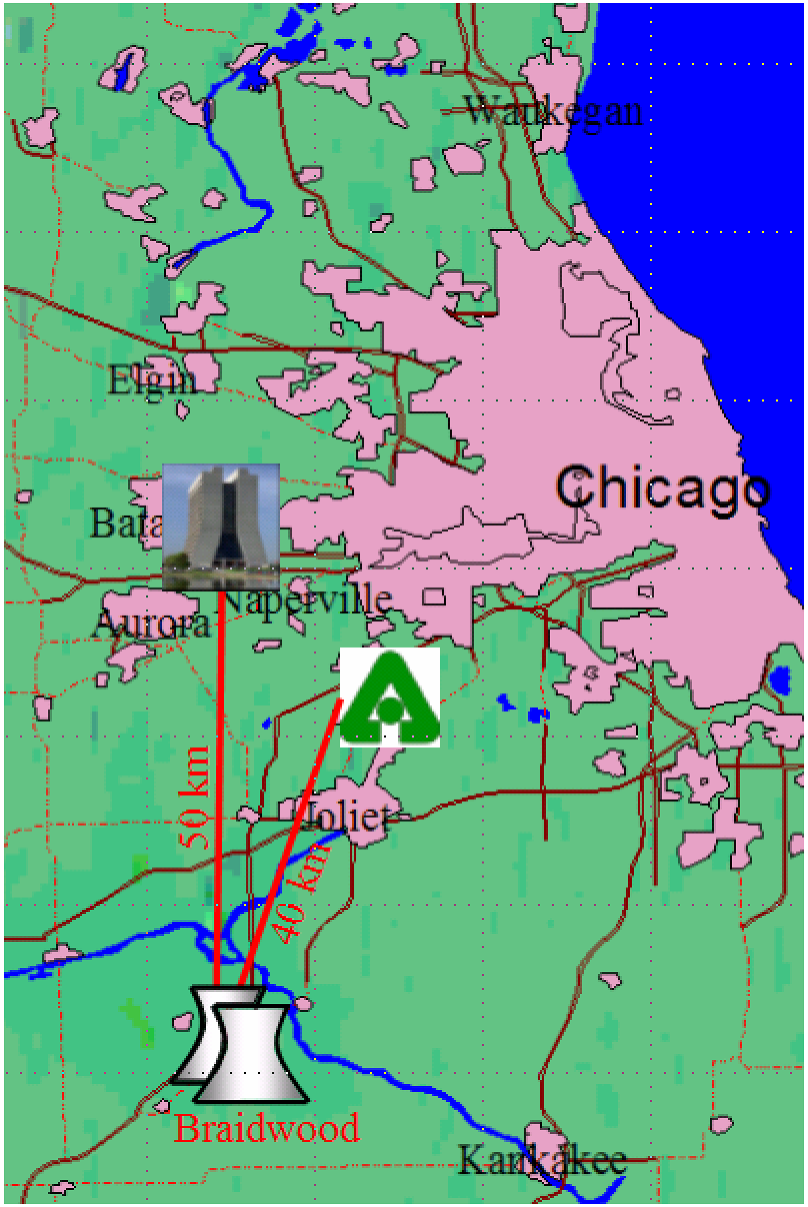
Kansas: Tim Bolton, Noel Stanton

Michigan: Byron Roe

Oxford: Steve Biller, Nick Jelley

Pittsburgh: Donna Naples, Vittorio Paolone

Texas: Josh Klein



•We considered several sites in Illinois (Braidwood, Byron, Lasalle) and Kansas (Wolf Creek).

•We have focused on the Braidwood site managed by Exelon Nuclear.

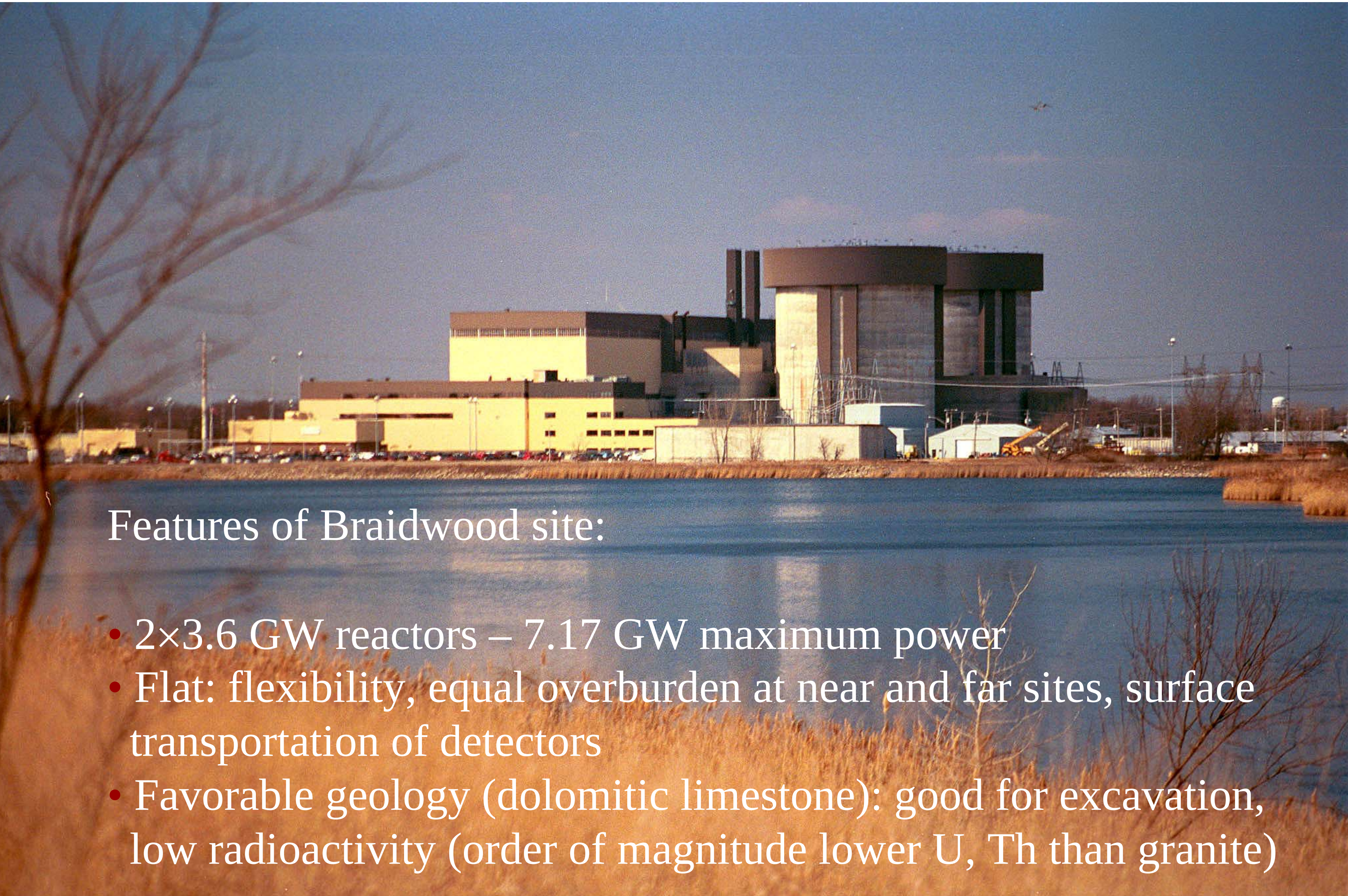
Braidwood:

•2×3.6 GW reactors – 7.17 GW (thermal) maximum power

•Efficient operation: 90% capacity factor over last several years.

Braidwood site

Braidwood site



Features of Braidwood site:

- 2×3.6 GW reactors – 7.17 GW maximum power
- Flat: flexibility, equal overburden at near and far sites, surface transportation of detectors
- Favorable geology (dolomitic limestone): good for excavation, low radioactivity (order of magnitude lower U, Th than granite)

Physics Goals of Experiment

I. $\sin^2 2\theta_{13} \sim 0.01$: If $\sin^2 2\theta_{13} < 0.01$, it will be difficult for long-baseline "superbeam" experiments to investigate mass hierarchy and CP violation. Reactor experiment with sensitivity of 0.01 will indicate scale of future experiments needed to make progress.

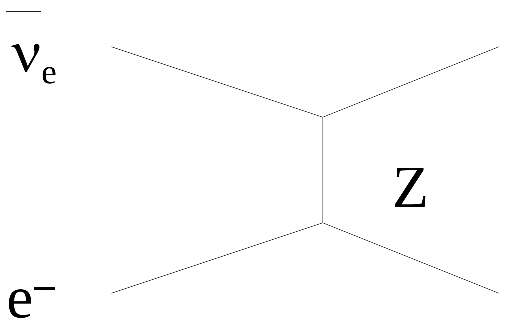
If $\sin^2 2\theta_{13}$ is relatively large (e.g. observable by Double Chooz), a precision measurement of θ_{13} will be useful in combination with accelerator experiments to resolve the θ_{23} degeneracy, and to provide early indications of CP violation, mass hierarchy.

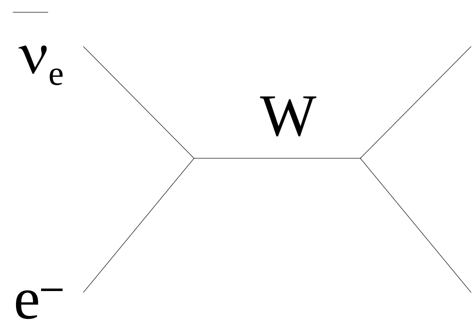
II. $\sin^2\theta_W$: If possible, maintain design that will allow measurement of $\sin^2\theta_W$ using antineutrino-electron elastic scattering in near detector. Ideally, near detector should be close to reactor, deep, and have the same overburden as far detector (to allow measurement of environmental backgrounds using far detector).

Weak Mixing Angle

Early studies indicate that a measurement of $\sin^2\theta_W$ with precision comparable to NuTeV could be performed using $\bar{\nu}_e - e^-$ scattering (normalized with inverse β decay).

(Conrad, Link, Shaevitz, hep-ex/0403048)





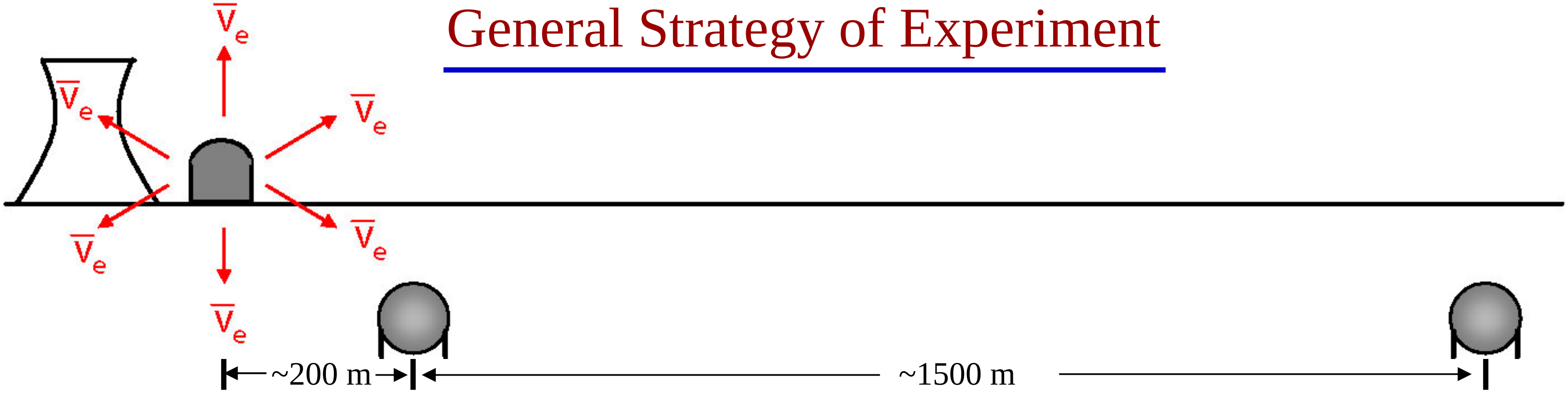
$$\frac{d\sigma}{dT} = \frac{G^2 m}{2\pi} \left\{ (C_V + C_A)^2 + (C_V - C_A)^2 \left(1 - \frac{T}{E}\right)^2 + (C_A^2 - C_V^2)\, m \frac{T}{E^2} \right\}$$

$C_V = ½ + 2 \sin^2 \theta_W$

$C_A = ½$

T = electron KE energy
E = neutrino energy
m= mass of electron
This assumes μ_ν=0

General Strategy of Experiment



- 1 near detector and 2 (or more) far detectors
- 6.5 m diameter spherical detectors with 3 zones (Gd-loaded scint.)
- 25-50+ ton fid. mass per detector, depending on required buffer regions
- Significant information from both rate and energy spectrum
- Movable detectors with surface transport for cross-calibration; vertical shaft access to detector halls
- Full detector construction above ground
- Near and far detectors at same depth of 450 mwe (contingent on bore holes)
- Near detector at ~200 m security perimeter (L~270 m); far detectors at ~1700 m

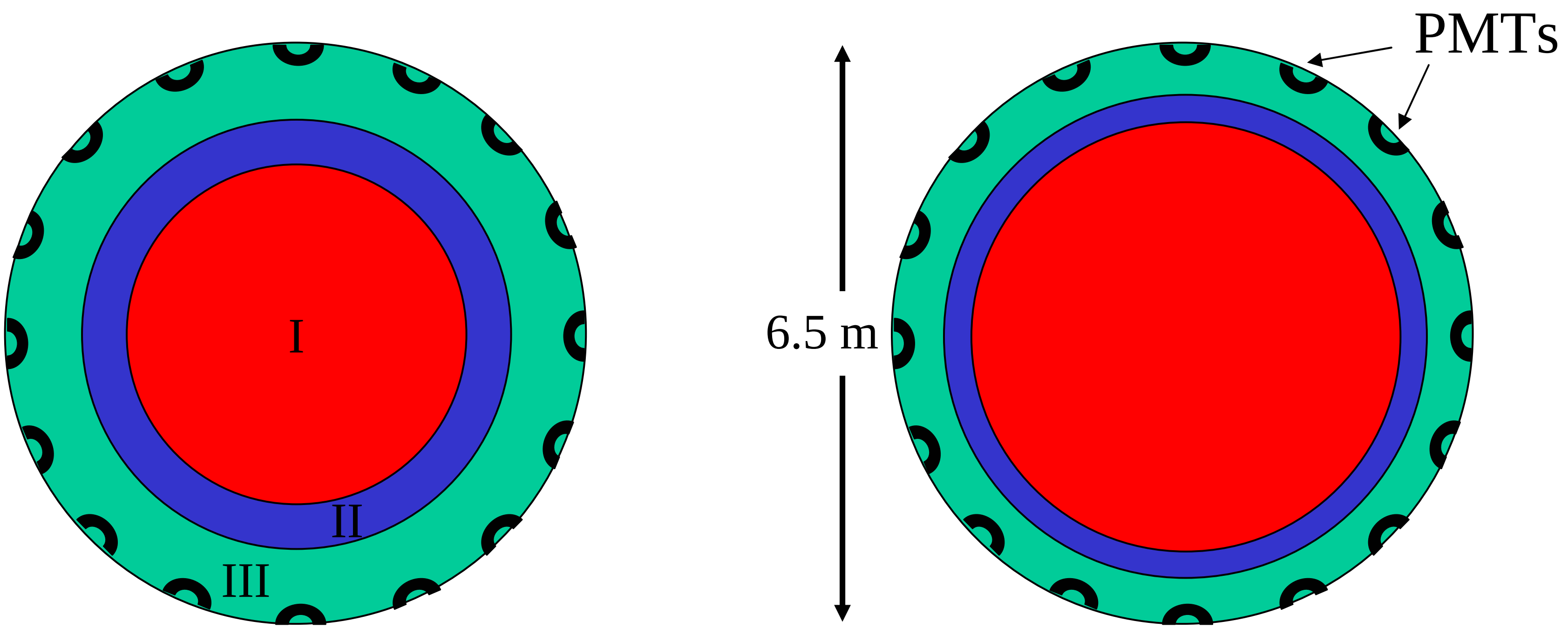
3-zone Gd-based Detector

I. Gd-loaded liquid scintillator

II. γ catcher: liquid scintillator (no Gd)

III. Non-scintillating buffer

Two examples:



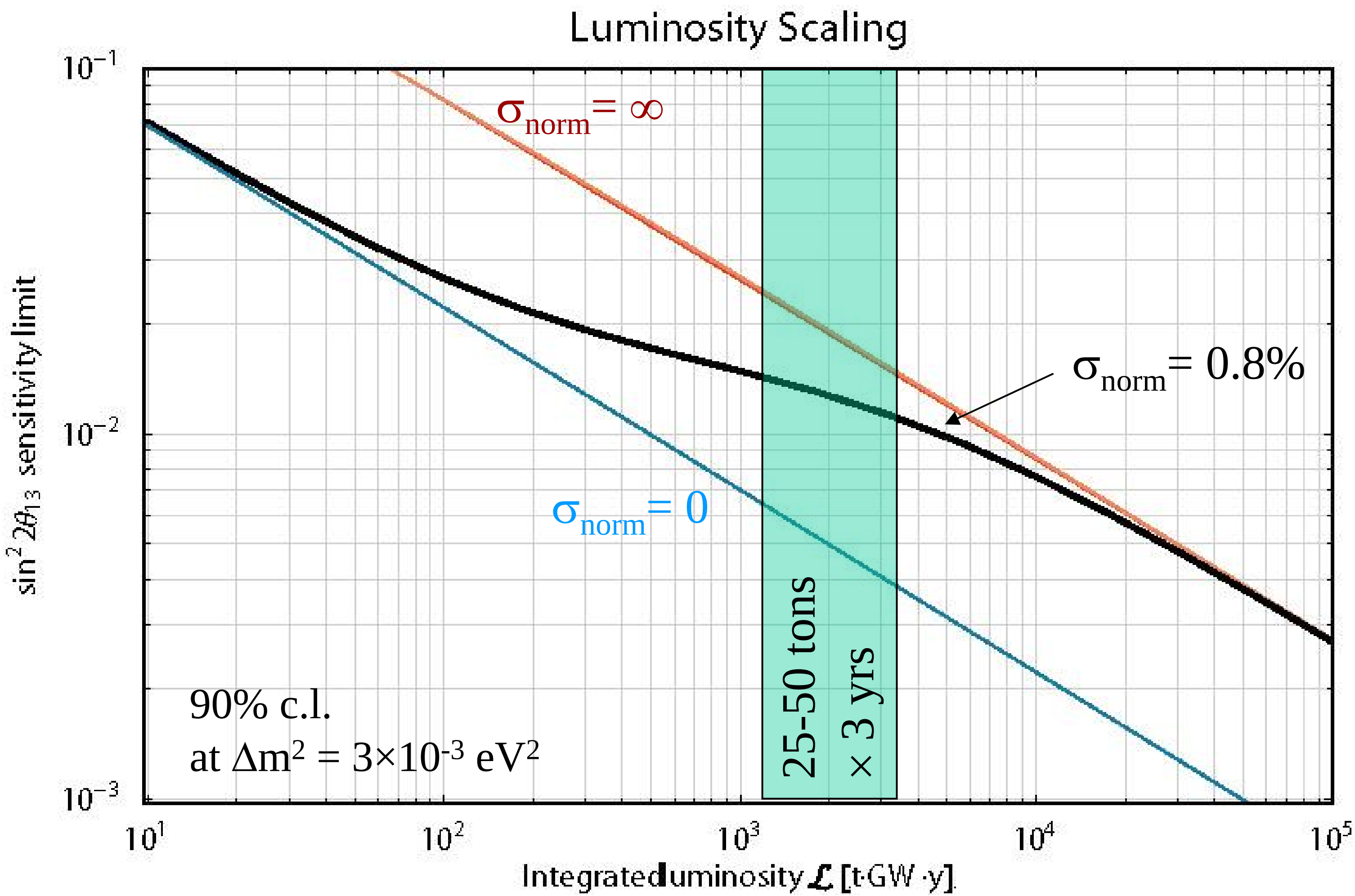
I.	R=1.9 m, m=25 tons
II.	R=2.4 m
III.	R=3.25 m

I.	R=2.4 m, m=50 tons
II.	R=2.7 m
III.	R=3.25 m

Total detector mass ~150 tons

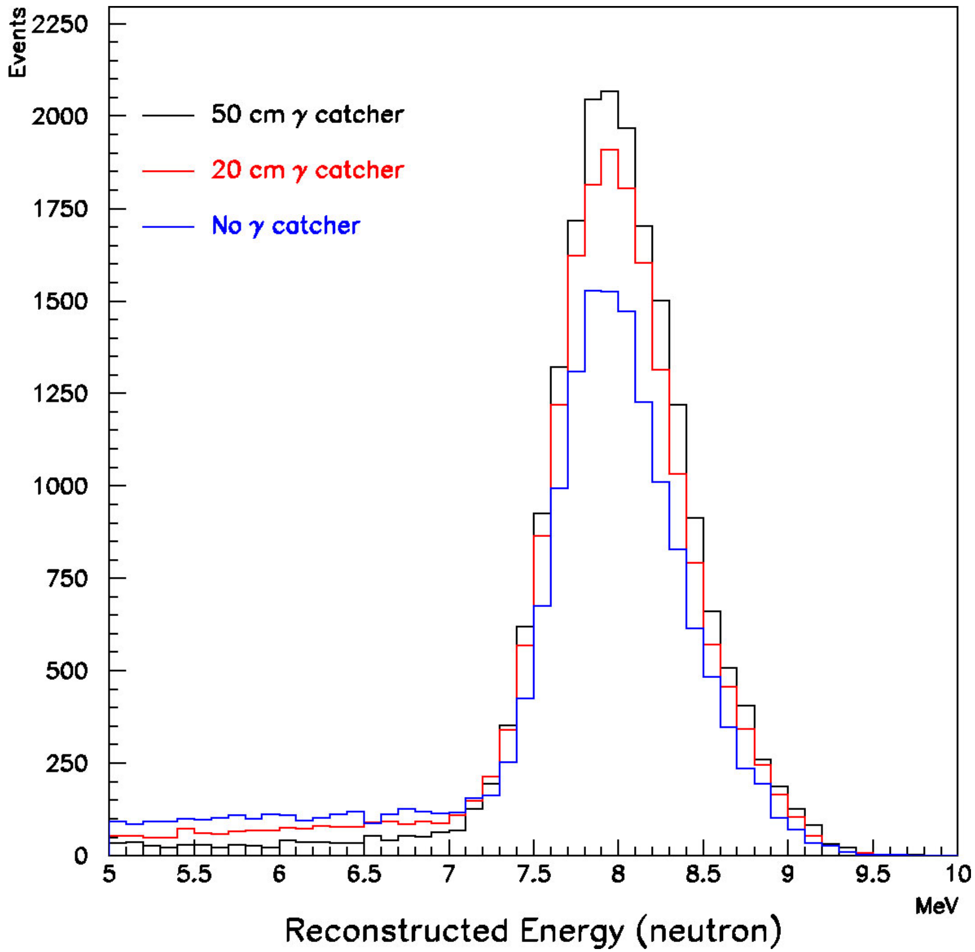
Sensitivity Using Rate and Energy Spectrum

(Huber *et al.* hep-ph/0303232)



Detector Optimization

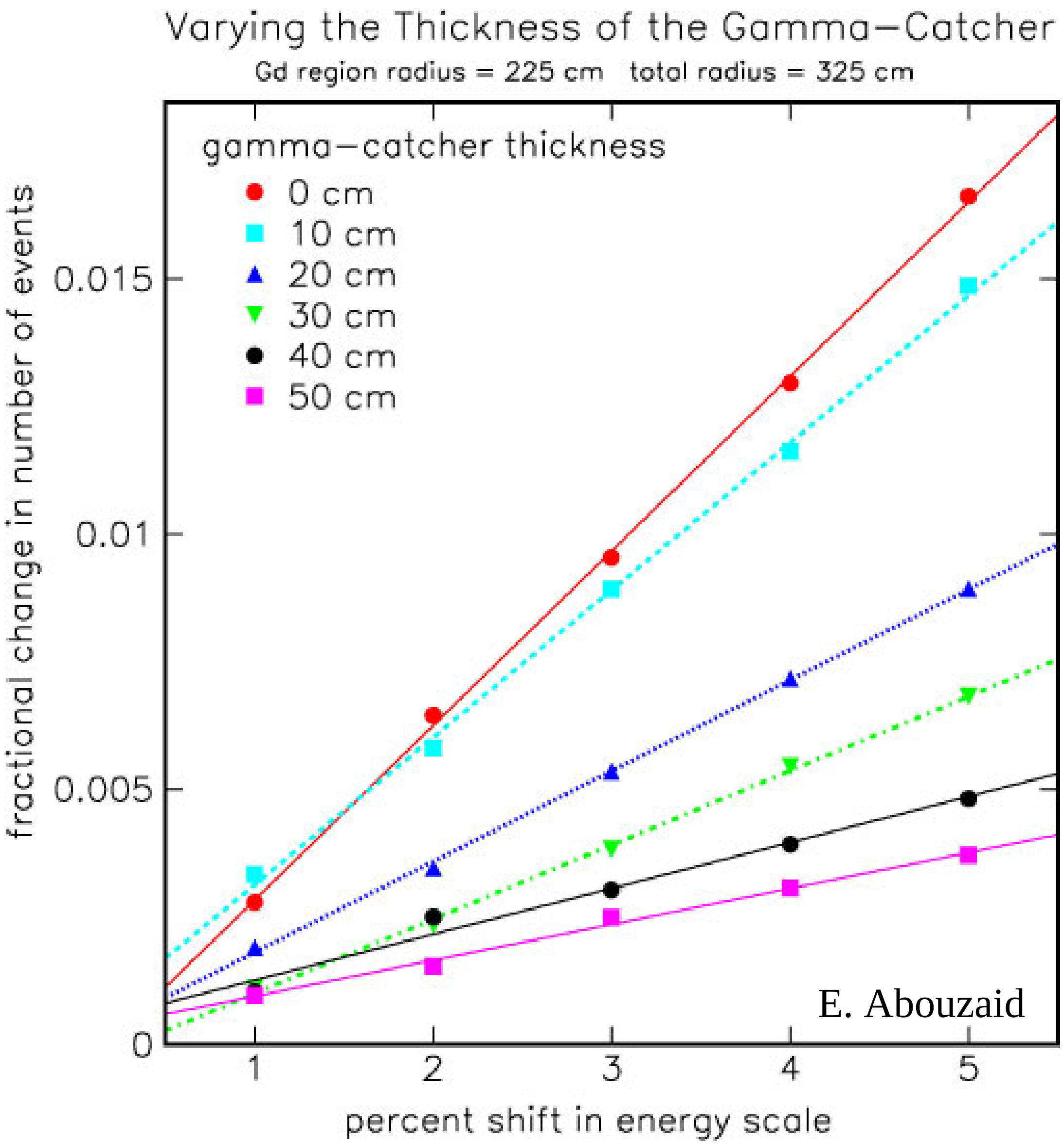
We've developed a hit-level Monte Carlo for initial design studies. In parallel, studies with modified SNO MC (Oxford) and a Geant-4 based detector model.



Currently studying detector optimization:

- required buffer thicknesses
- active and passive shielding

How thick a γ catcher is required (if any)?



Energy requirements:

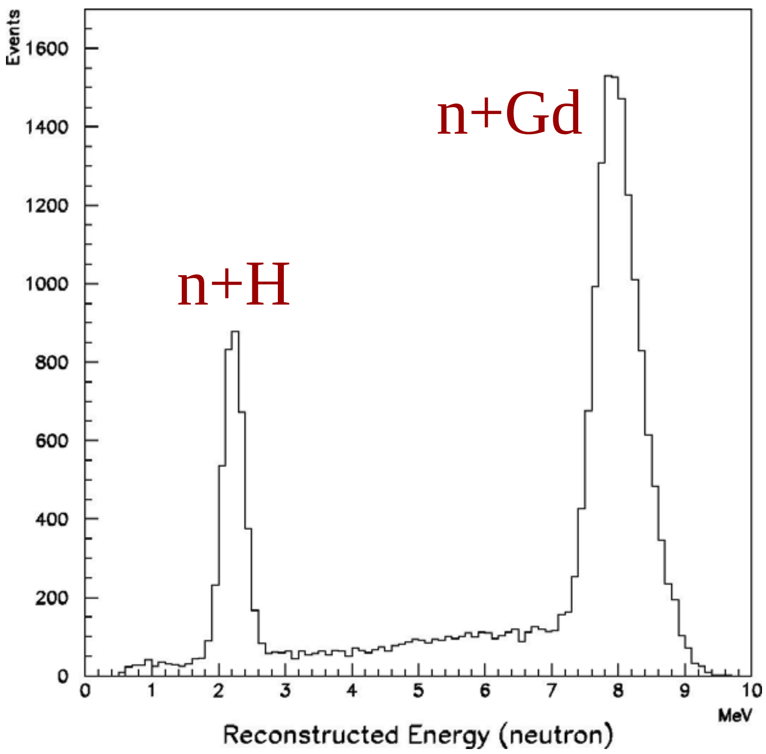
$E_{e+} > 0.5$ MeV

$E_n > 6$ MeV

Relative Acceptance Strategy

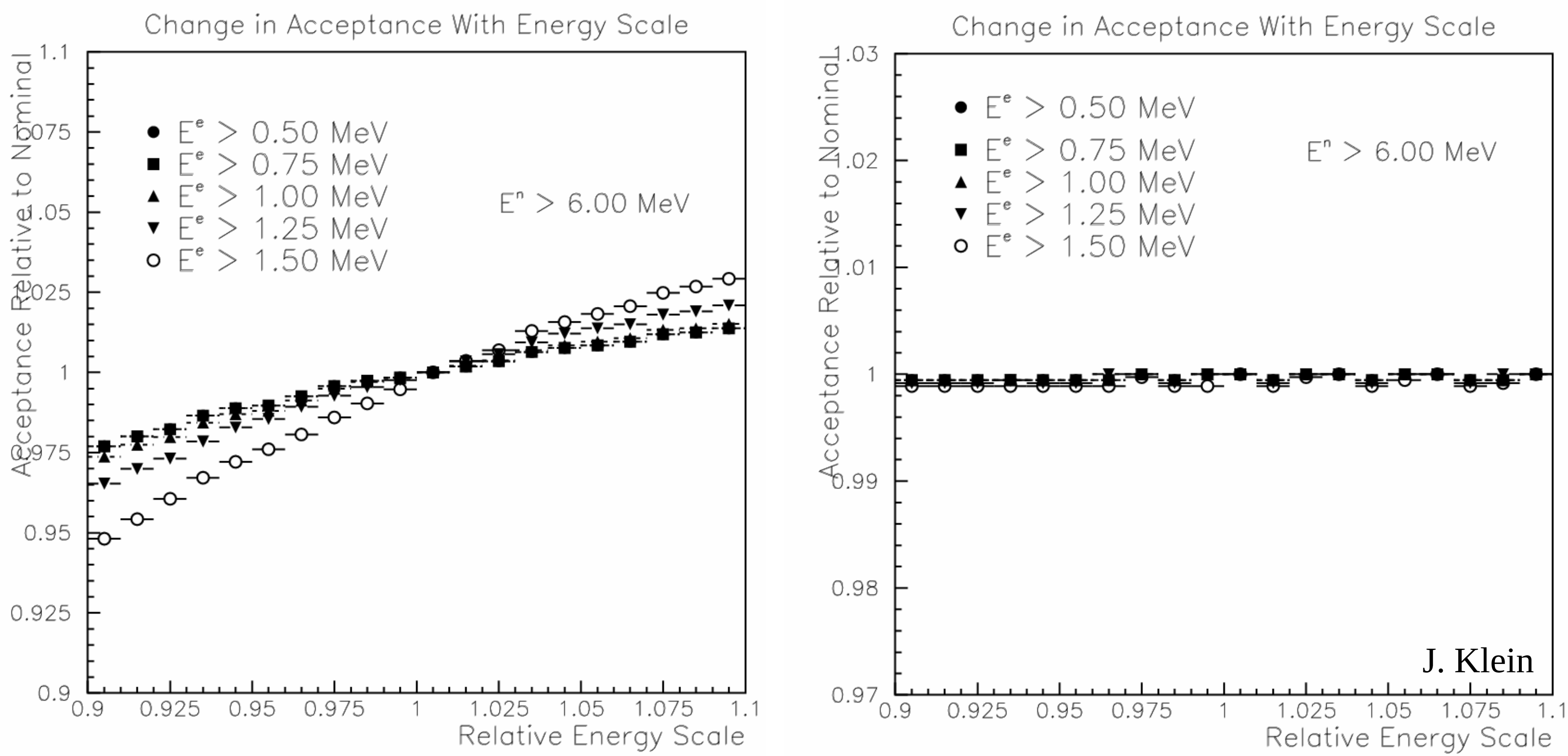
• Establish relative acceptances as well as possible without detector movement – careful detector construction, radioactive sources, reactor ν interactions, cosmics, etc.

For example:



• Check relative acceptances by cross-calibrating detectors at near detector location: surface movement of detectors

No calibration | Calibration from n+Gd peak



Uses 10k events in far detector and assumes perfect linearity

Movable detectors

•Relatively flat terrain allows “inexpensive” movement of detectors on surface.

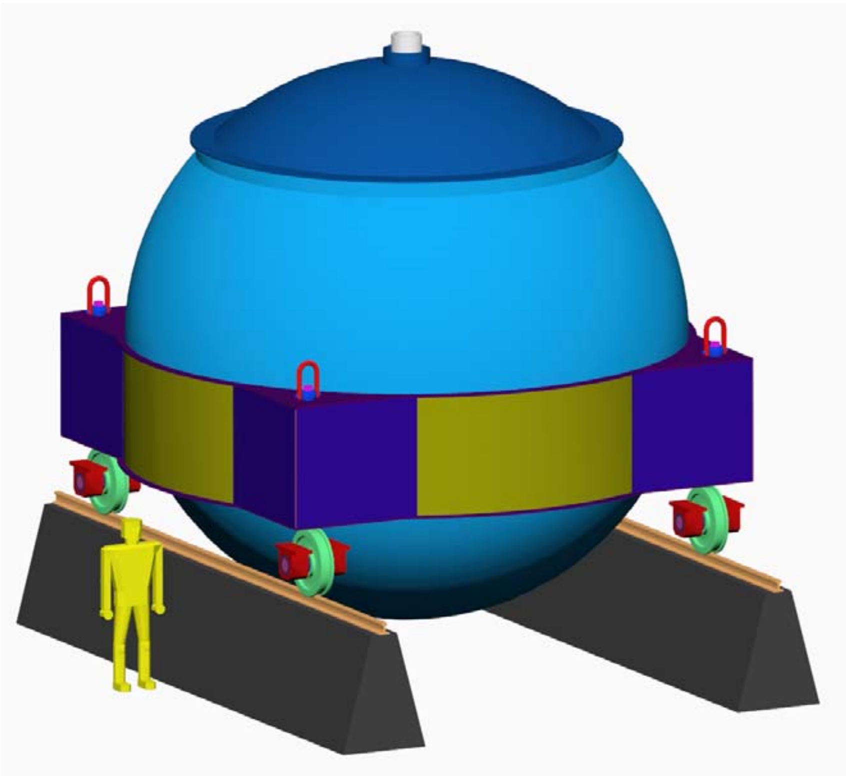
•Many crane or gantry options with adequate capacity

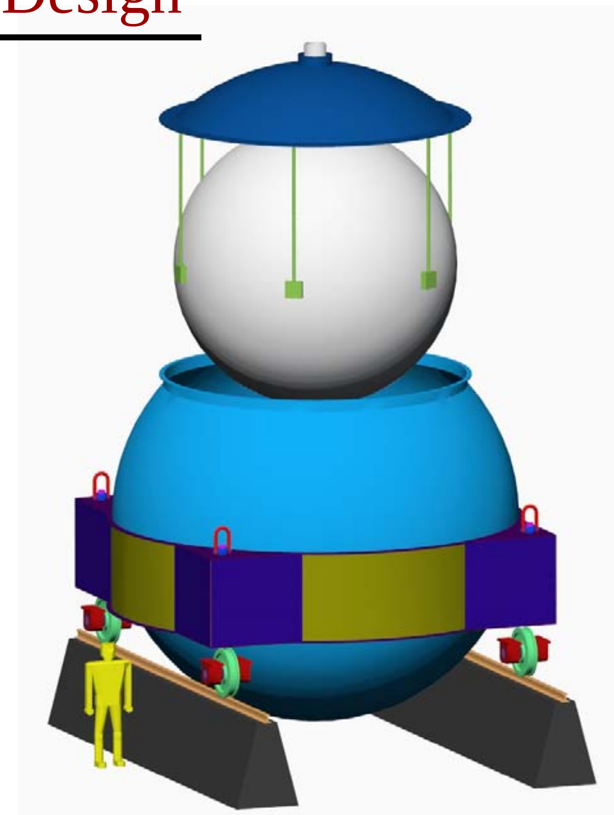
E.g., 750-ton capacity crawler crane performing test lift of 750 tons

•Surface movement either with multi-axle “truck” on gravel road or with surface rail system (depends on acceptable stresses)

Transport and handling of 200 ton drilling equipment using gantry and self-propelled platform trailor designed by ALE Lastra.

Conceptual Mechanical Design





Design issues:

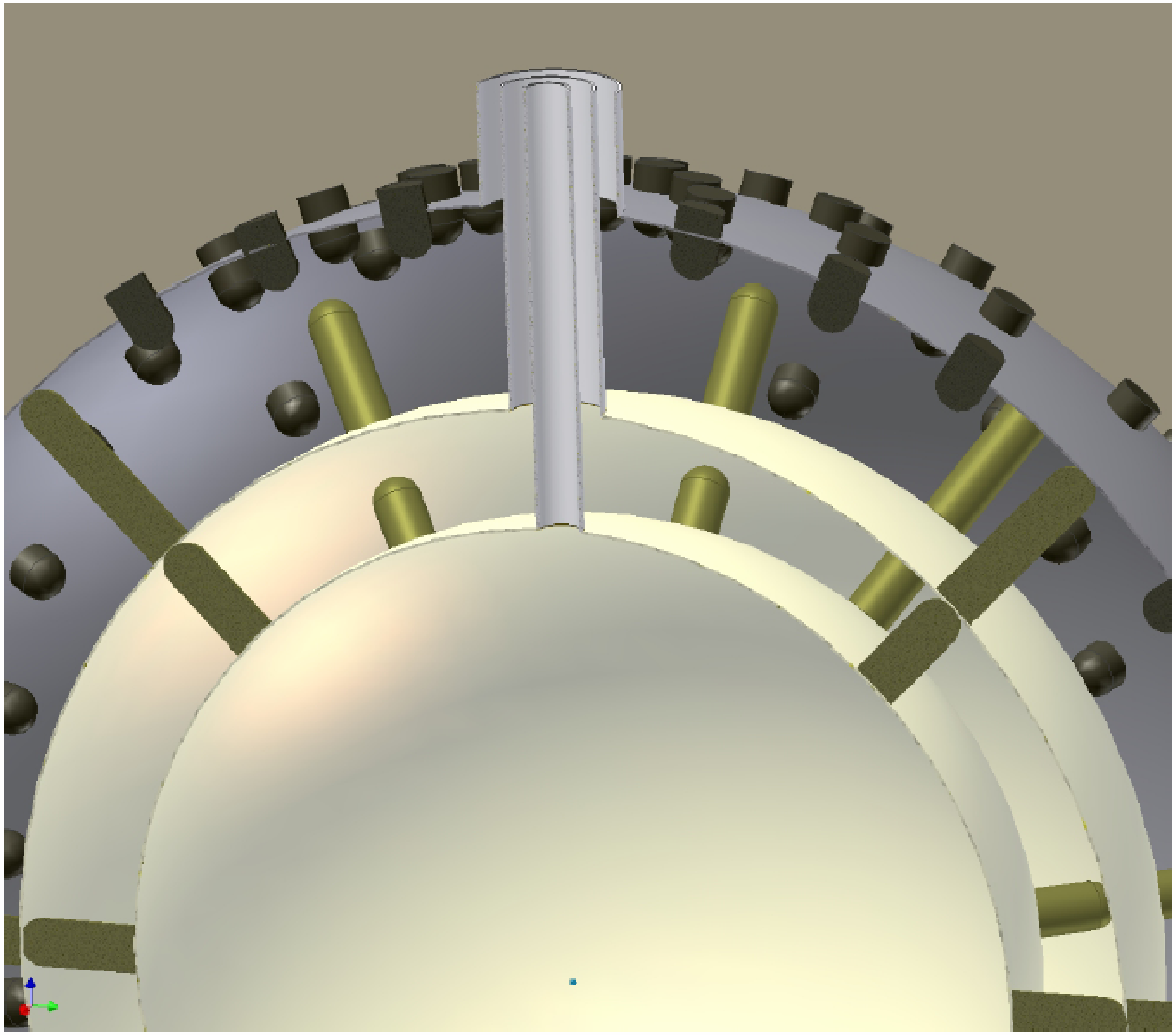
- Support for concentric acrylic vessels
- Integration of source calibration system with vessel support
- Integration of detector design with surface movement (i.e., what is maximum safe instantaneous acceleration?)
- Engineering of active and passive veto system

Support of Concentric Acrylic Spheres

Example:

- Multiple <1" diameter spacers

- Assumes simultaneous filling of all volumes to maintain neutral buoyancy.



V. Guarino

Underground Construction Estimate

- A detailed estimate of cost and schedule for underground construction at the Braidwood site was performed by Hilton and Associates, Inc. (tunnel cost estimating consultants).

- Complete estimate of costs associated with underground facility; includes all civil construction, underground outfitting (pumps, elevators, ventilation, etc.); even includes cost associated with decommissioning shafts at end of experiment.

- Does not include permanent surface buildings or detectors.

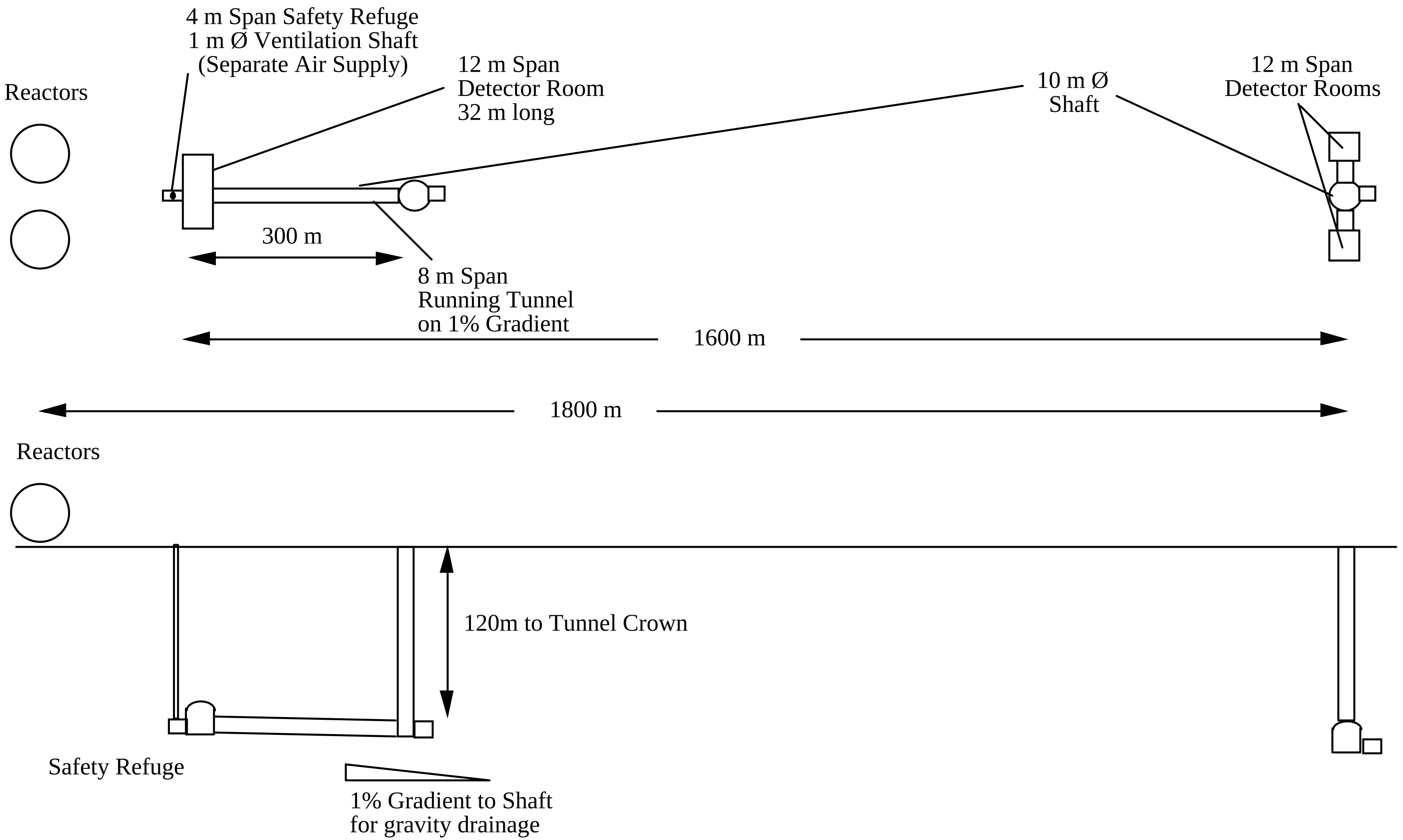
- Components of cost separated in enough detail to allow scaling of costs with changes in design.

Braidwood Site

Layout for underground construction estimate

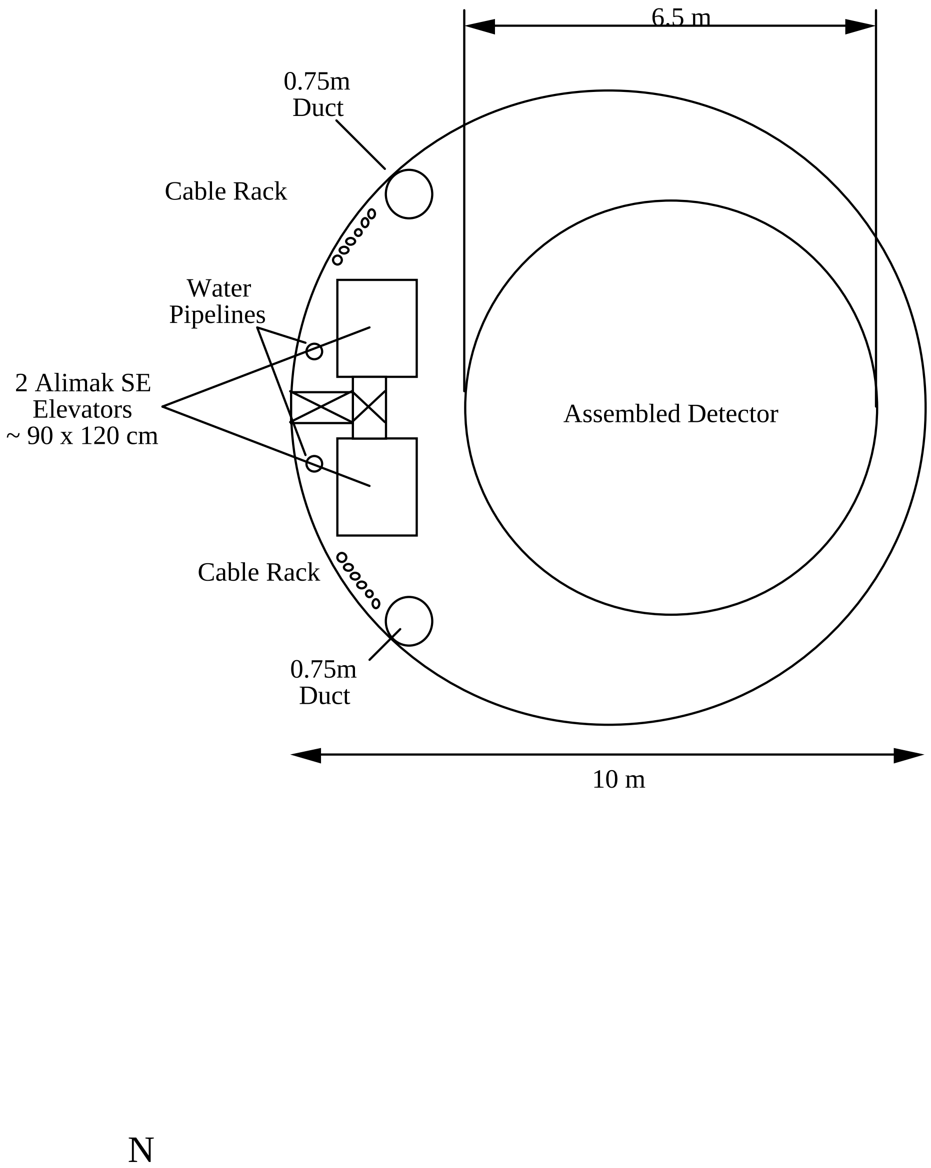
Layout for Underground Construction Estimate

TWO SHAFT LAYOUT (Forms Basis of Estimate)
(Schematic scope representation - shaft and tunnel layouts will be adjusted to match site constraints)

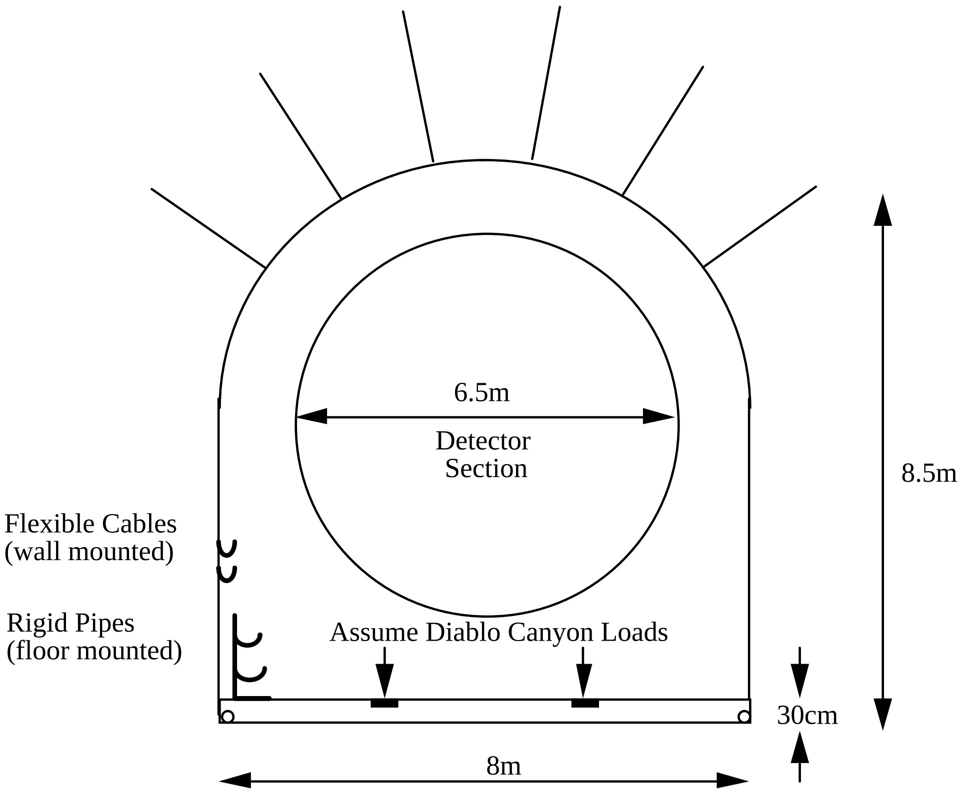


NOT TO SCALE

Near & Far Shaft Layouts

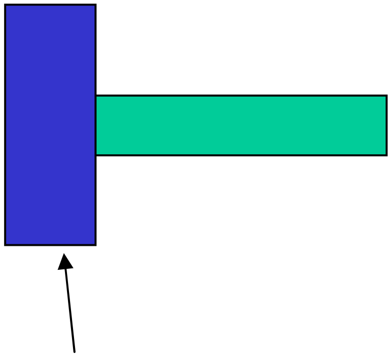


Tunnel cross section



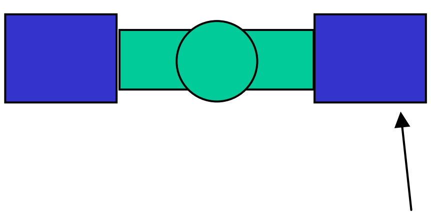
Detector Halls

Near hall:



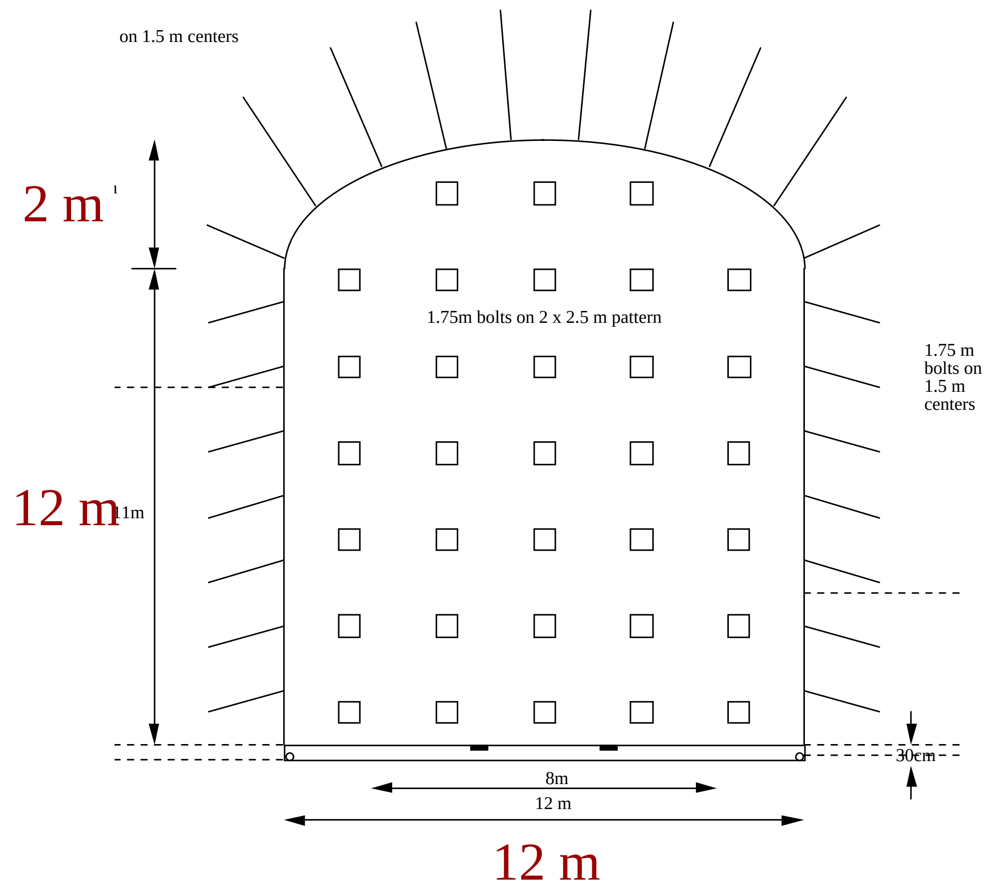
12 ×14 ×32 m

Far hall:

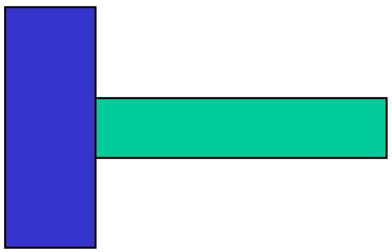


12 ×14 ×15 m

Detector hall cross section

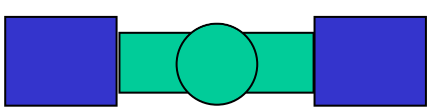


Near hall:



$12 \times 14 \times 32$ m

Far hall:

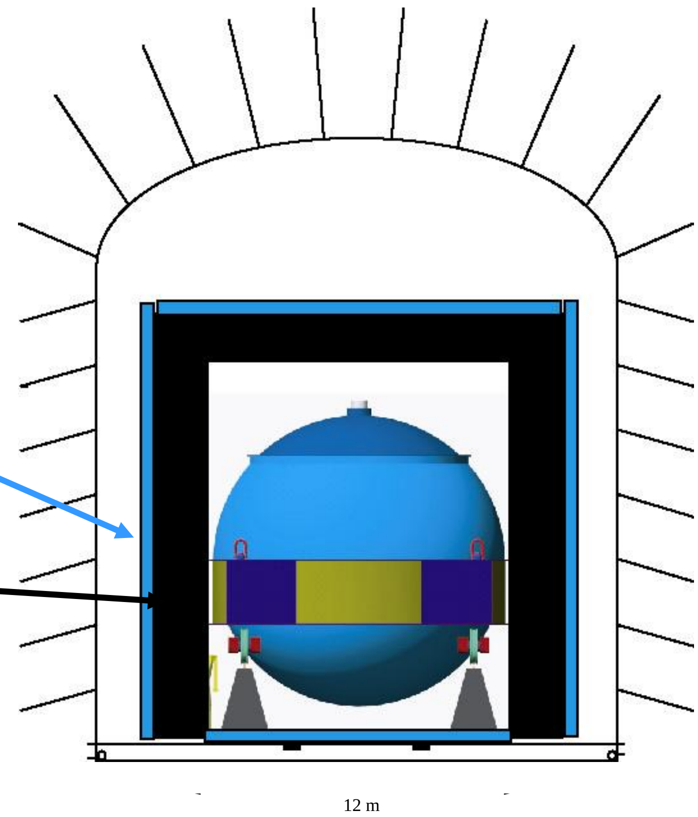


$12 \times 14 \times 15$ m

Detector hall will accommodate active and passive shielding

μ tracking

passive shielding



12 m

Layout used for underground construction estimate:
300 mwe, two shafts, different detector hall designs, 300m tunnel

Cost: \$35 million; Time: 39 months with sequential construction.

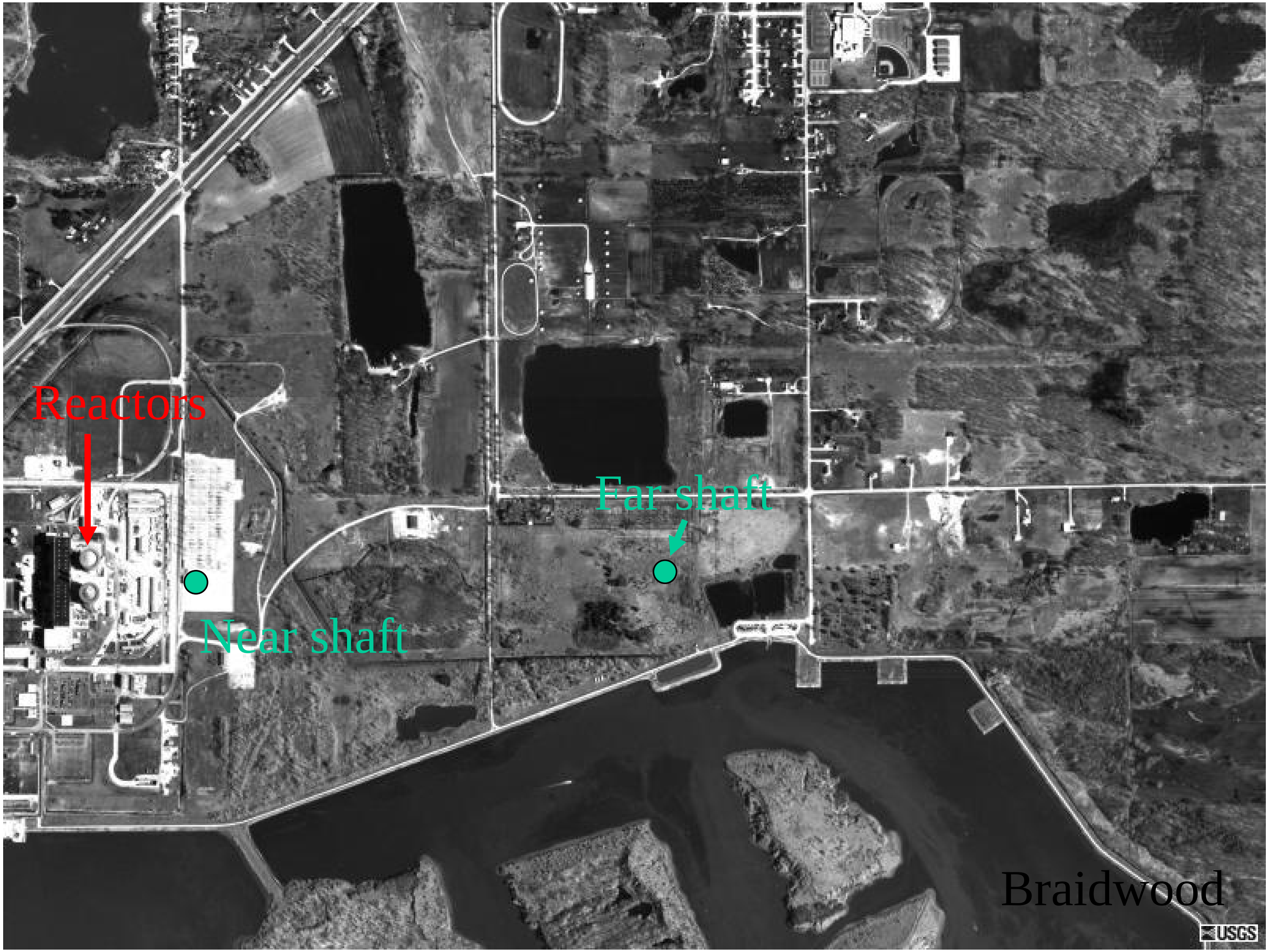
Revised layout:

• Increase depth to 450 mwe (160 m rock + 20 m soil) contingent on bore hole results

• Site near detector shaft to shorten or eliminate tunnel stub

•Cost: \$25-35 million
Time: ~36 months with sequential construction of near and far sites; < 2 years with simultaneous construction of sites.

Revised Layout




Near Site


Far Site

Conclusions

- Braidwood site appears very attractive
- High power reactor with cooperative management
- Can use vertical shafts to reach necessary depth
- Surface movement of detectors seems technically feasible.

Short-term Plans:

- Drill bore holes to full depth at both shaft positions: provides info about geology, radioactivity, density; will reduce contingency required for construction. (Bid proposal under review by Exelon, U. Chicago.)

  ⟹ Must decide on baseline for far detector bore hole
- Optimize detector design for acceptance uncertainty and background rejection (buffer regions, calibration system, active and passive shielding, etc.)
- Submit R&D proposal for support to prepare full proposal.

Compared to Double-Chooz

- Factor of ~3 better sensitivity to $\sin^2 2\theta_{13}$
- Large enough to have useful rate and shape information
- Optimized baseline
- Optimized depth
- Movable detectors to allow direct cross-check of calibration
- Multiple far detector modules for additional consistency checks