TeVNet: Methods and Results

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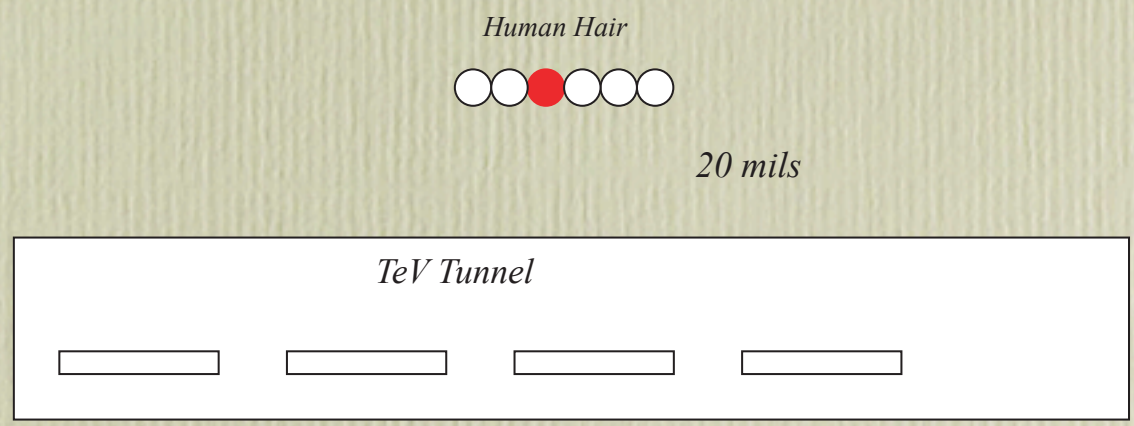
What is the Problem?

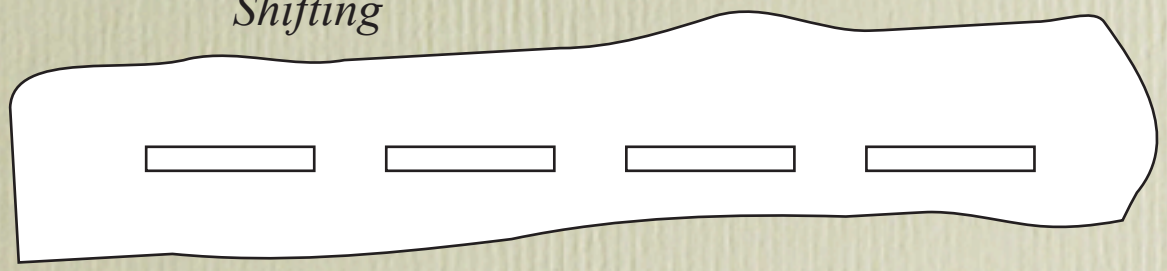
- Want location of TeV Magnets to 20 mils:



6.28 km
= 247,243,600 mils

- Relative to What?

TeV Tunnel After Years of Settling, Cracking, Shifting

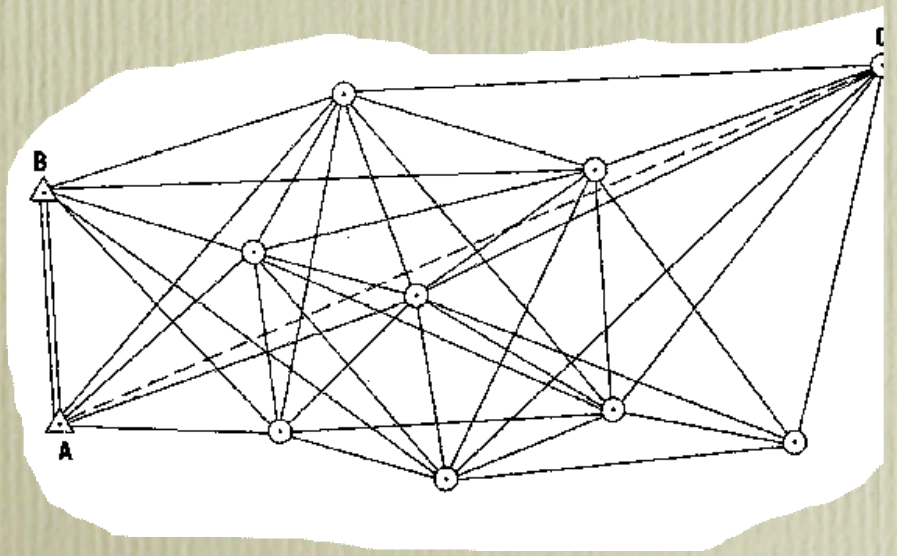


What Have We Done Until Now?

- Originally shot 210 “Murphy Lines” from Gazebo, five magnets/ line
- Each line good to < 5mm, but angles uncertain
- Set up “Murphy Brass” in floor

Old-Fashioned Hard Work

- Traditional Survey Techniques:
  - Triangulation
  - Trilateration Networks: get sides from “mekometer”



Sager Greenwood

(don’t lean on tripod!)

What Are Problems with Trilateration?

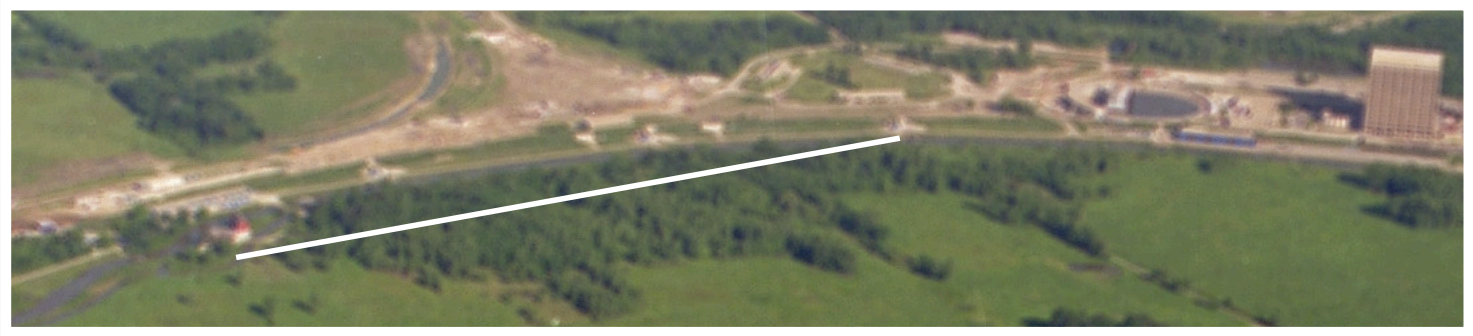
- Hard, Time-Consuming
- Requires Closure: lots of checks, lots of loops
- In TeV Tunnel, Essentially Following a Straight Line for 6.2 km
- Hard to Keep “random walk” errors down

So Just Trilaterate the TeV

- Do it Aboveground
- Now Can Get Path and Shape with Direct, Checked Measurements
- Easily (!) Drop Results into Tunnel – a whole other problem, more later

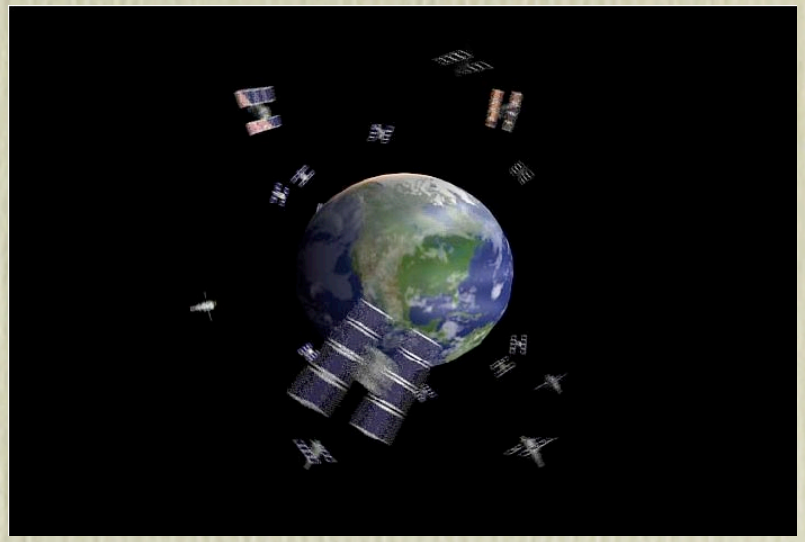
What Are Some Problems?

- (and just *some* problems)
- Need Heights since Earth Curves
  - and maybe plane of ring isn't as flat as we think!
- There's stuff in the way: *e.g.* near F-O

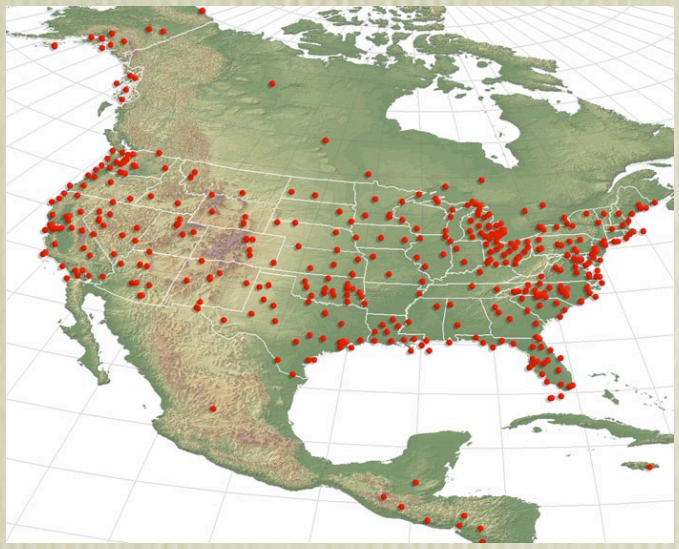


Use GPS

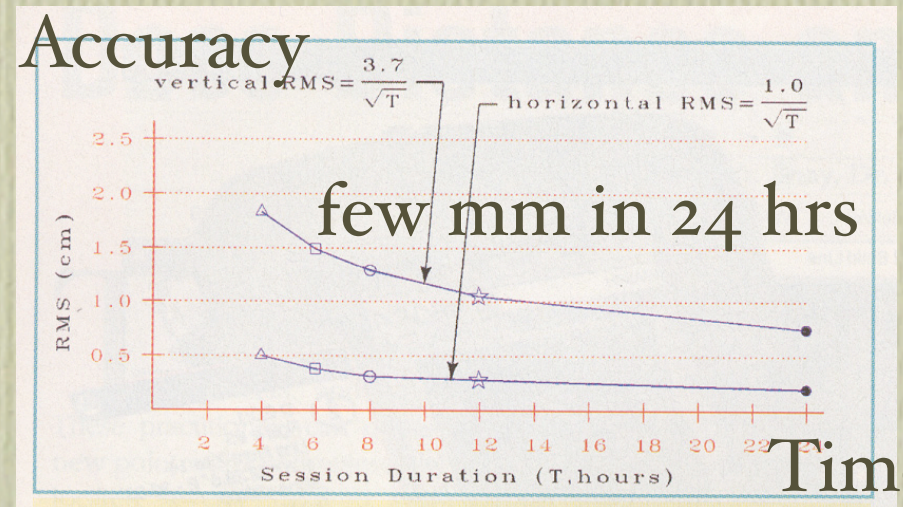
- Can Get near 1 mm differential
  - strengthens measurements and sees around trees!



- Tie into US HARN



How Well Does GPS Do?



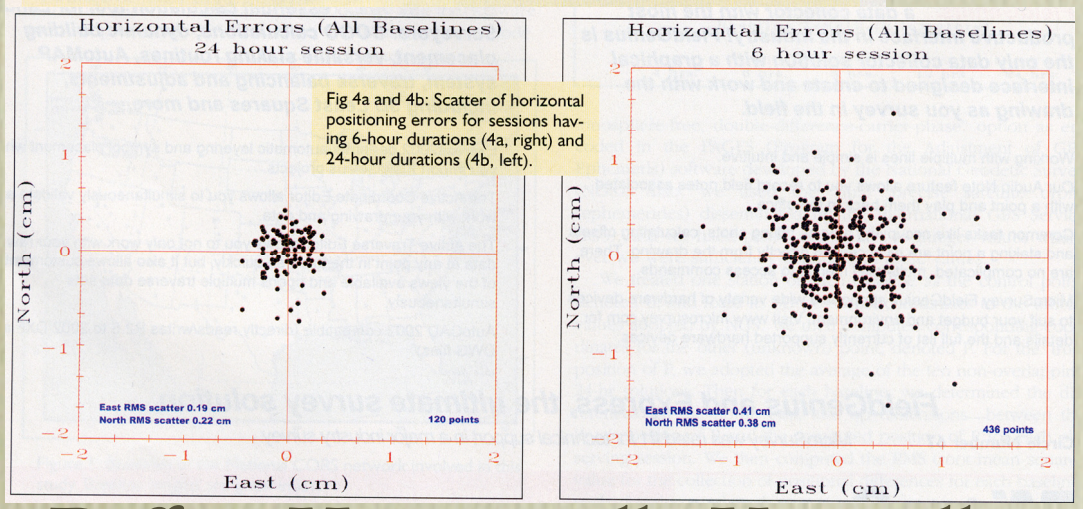


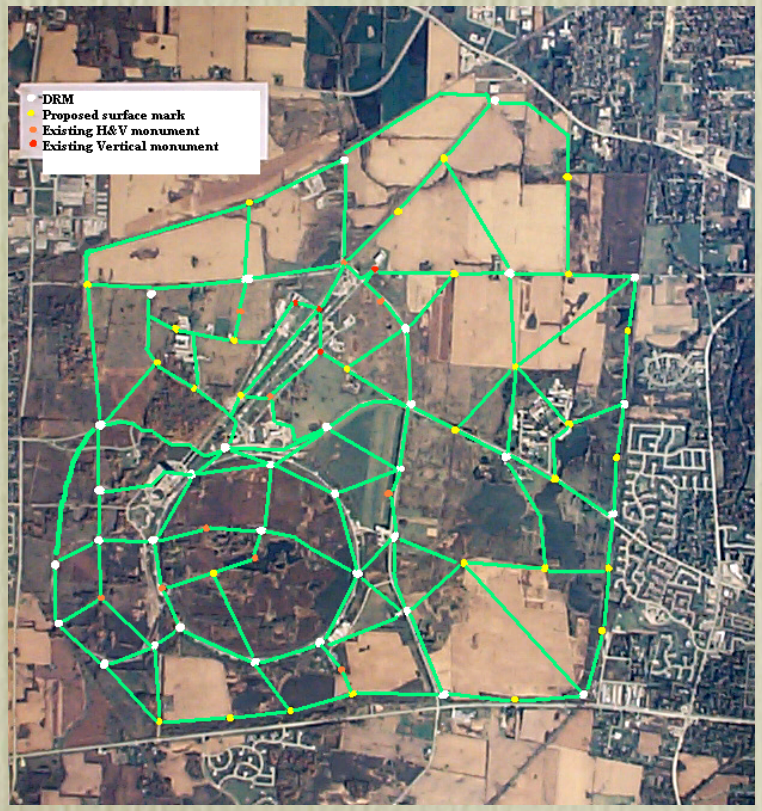
Fig 4a and 4b: Scatter of horizontal positioning errors for sessions having 6-hour durations (4a, right) and 24-hour durations (4b, left).

Differs Horizontally, Vertically: Angle of Satellites

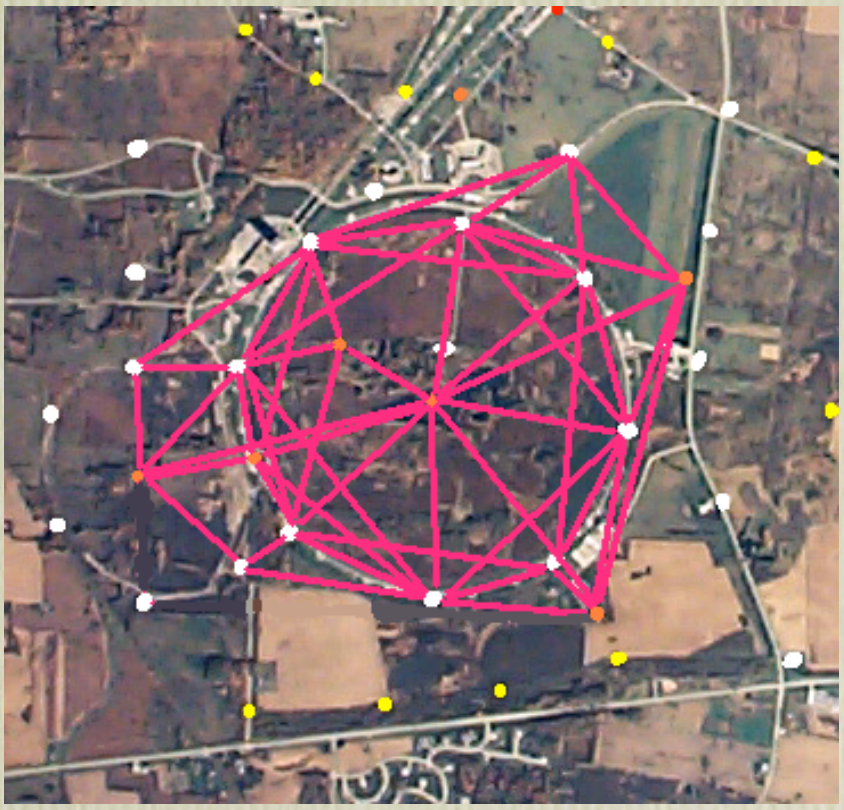
- Requires Long Observation Times
- Many Man-Hours & Repeated Measurements
- Have to Wait for >4 satellites with proper observational geometry

GPS Site Networks

Vertical Network



Horizontal Network



Deep Rod Monuments

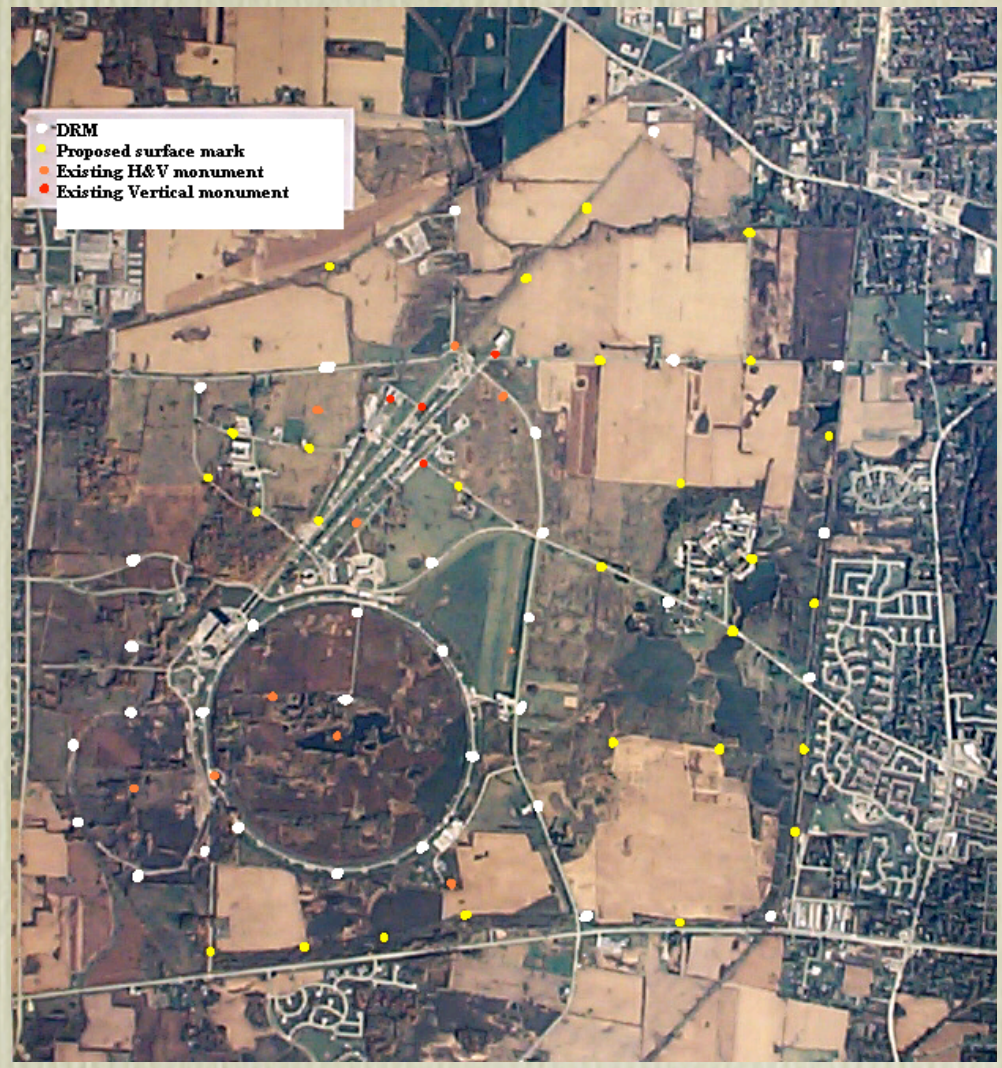
- Standard Method of Setting Reference Heights
- Drive Rod into Ground to “Refusal” – won’t vary with season
- Now Have Stable Reference Height

Stainless steel rod driven to refusal

Poured in place concrete post

Site Monumentation

- White Dots: New DRM's
- Yellow New Surface Mark
- Orange Dots: Existing Horizontal & Vertical
- Red Dots: Existing Vertical



Where Are We?

- Now Have Direct Line-of-Sight Measurements and a Network Above Ground
- Use these Direct Shots instead of circling around inside tunnel
- But pay a price: must go from Outside Network into the TeV

Drop Into TeV

- Connect outside network to inside network
- GPS tower locations, drop a gravity line into TeV
- Constrains inside network

Inside the TeV

- System of floor plugs and wall mounts: Dijak bolts and tie rods

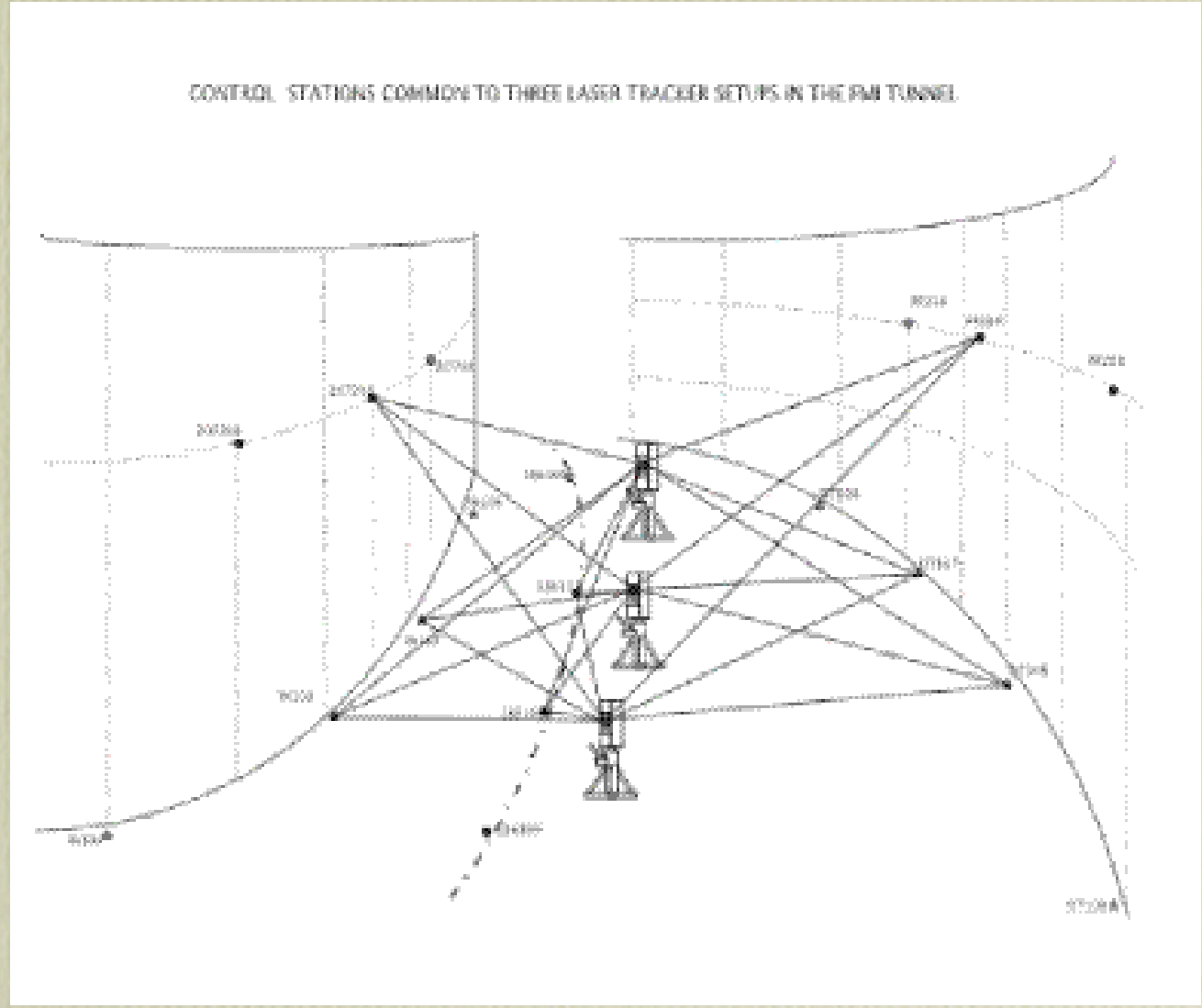
- Added many floor bolts to strengthen network (Karen Kephart. *et al.*)

Laser Tracker SMR

spherically mounted retroreflector

Move Along Tunnel

- Systematically Proceed through Tie-Rods,
- Floor Points,
- Magnets,
- (except where you can't like Bo, Co, Do)
- or JVolk in the way

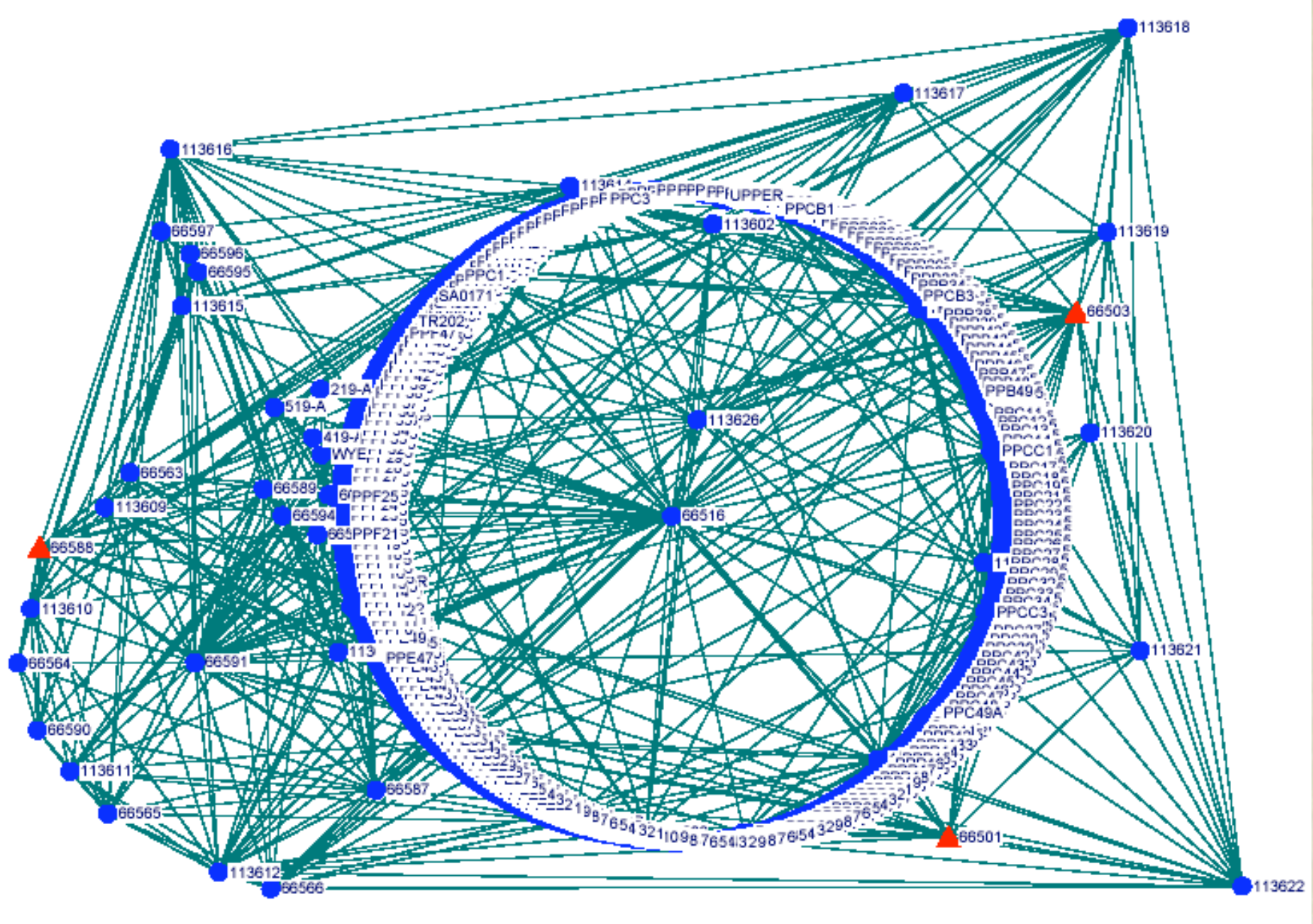


Elements in Analysis

- 482 LT Stations
- 69658 LT Observations
- 25498 LT Chords
- 612 GPS Baselines
- 141 Mekometer Distances
- 24 Gyro Azimuths
- 14 Vertical Drops
- 893 Tunnel Elevation Differences
- 86 Surface Elevation Differences
- 1824 Network Control Points

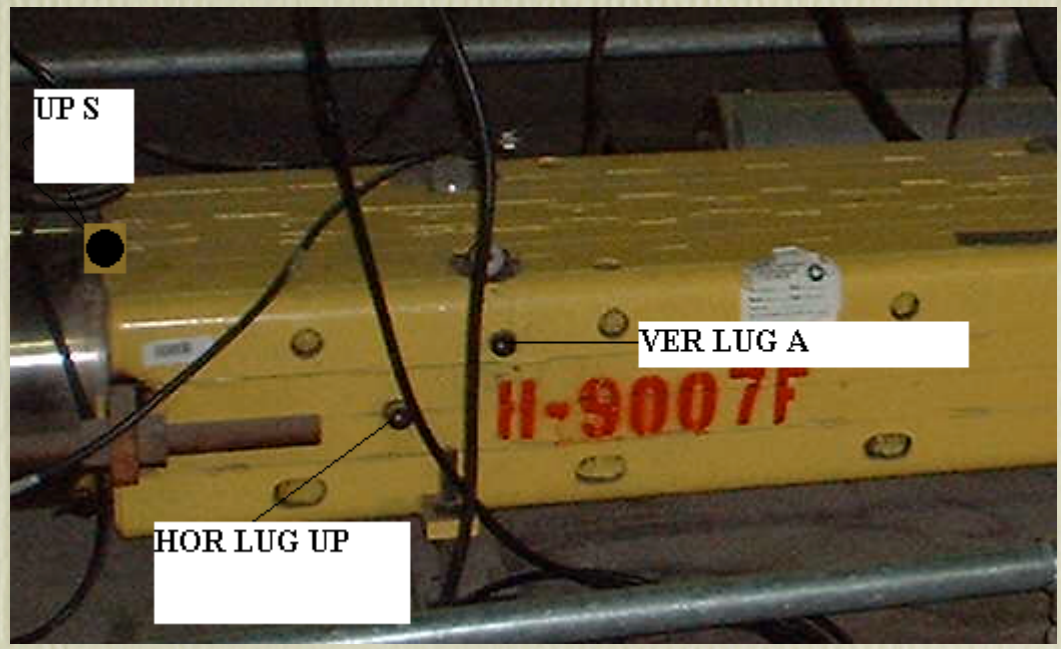
  - 7 months of planning
  - 200 field-crew weeks
    - 6 PPD Helpers
    - 3 Contractors
    - 14 Staff-Months of Analysis

Outside Network

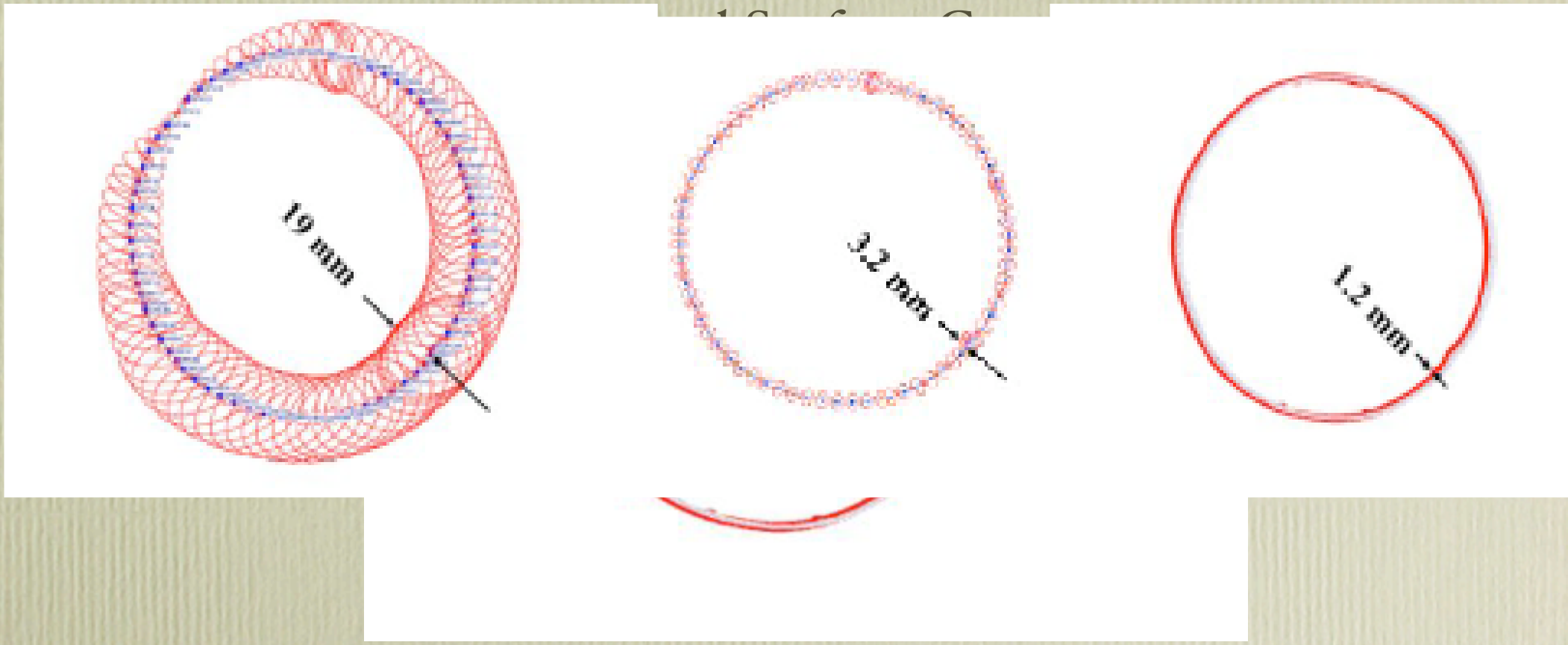


Now to Individual Magnets

- Put SMR fixture into lugs
- Use Laser Tracker to measure position
- Use Reference Geometry of Individual Magnet



How Does It All Fit Together?

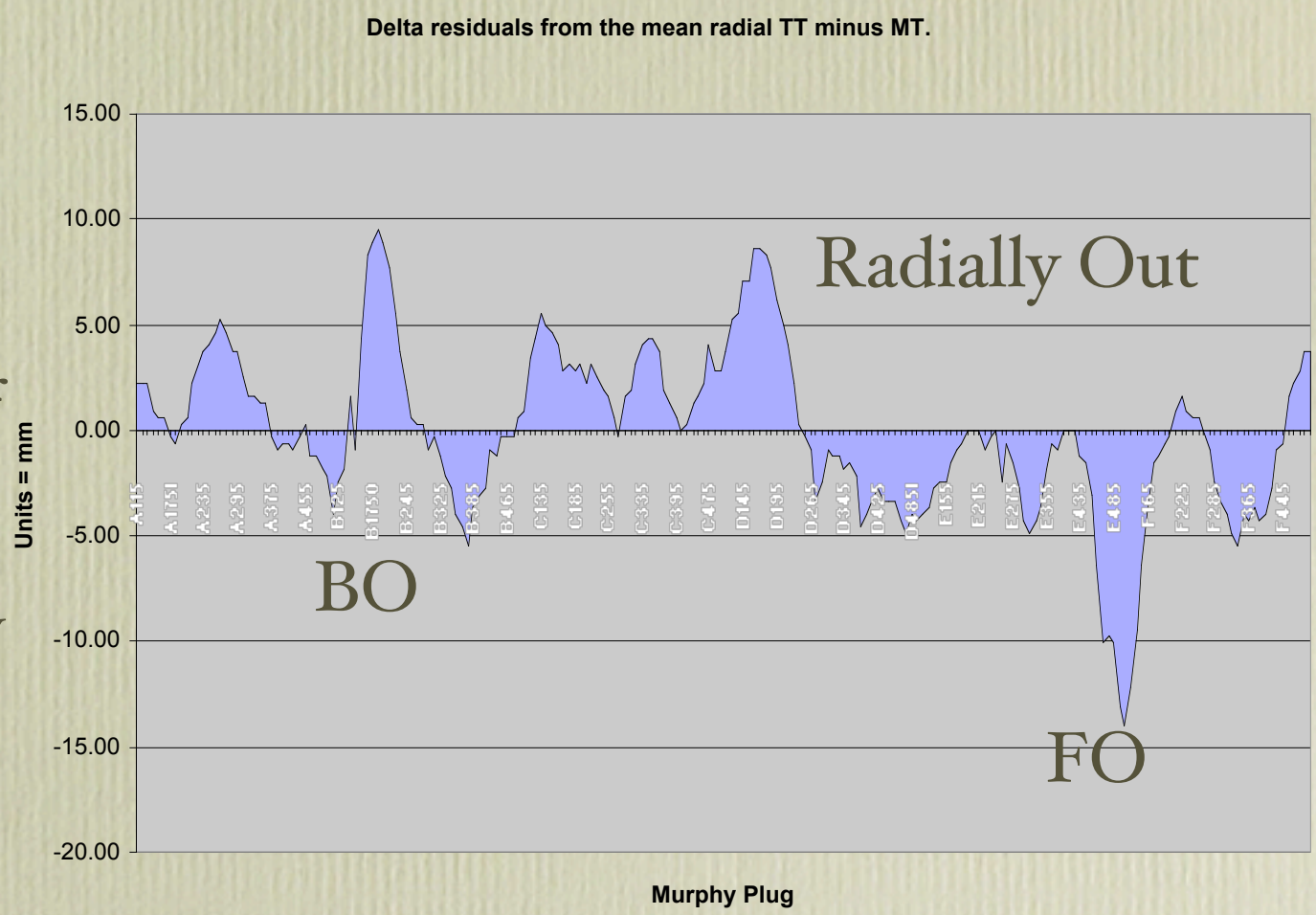


All together now

Constrained by Surface Network

Results on Murphy Lines

- Deviation of Murphy Plugs Horizontally



Conclusions

- TeVNet analysis essentially complete
- preparing group for major effort
- looking forward (?) to shutdown
- *Next Step: Joint Data Base*