Tomography Example from NOvA

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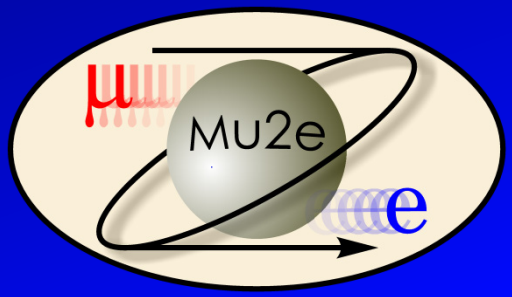
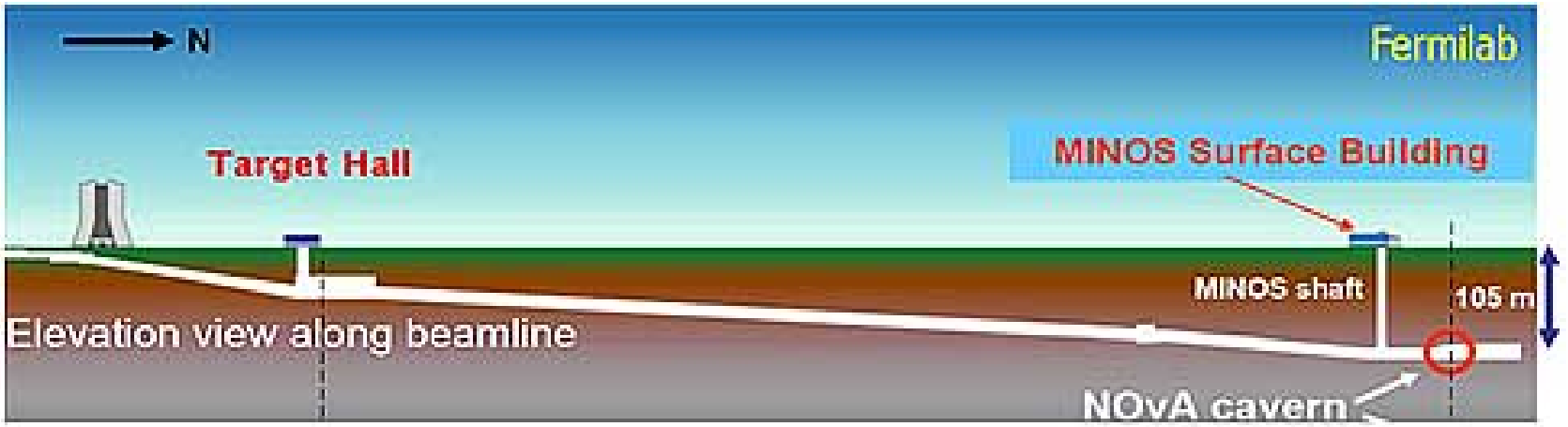
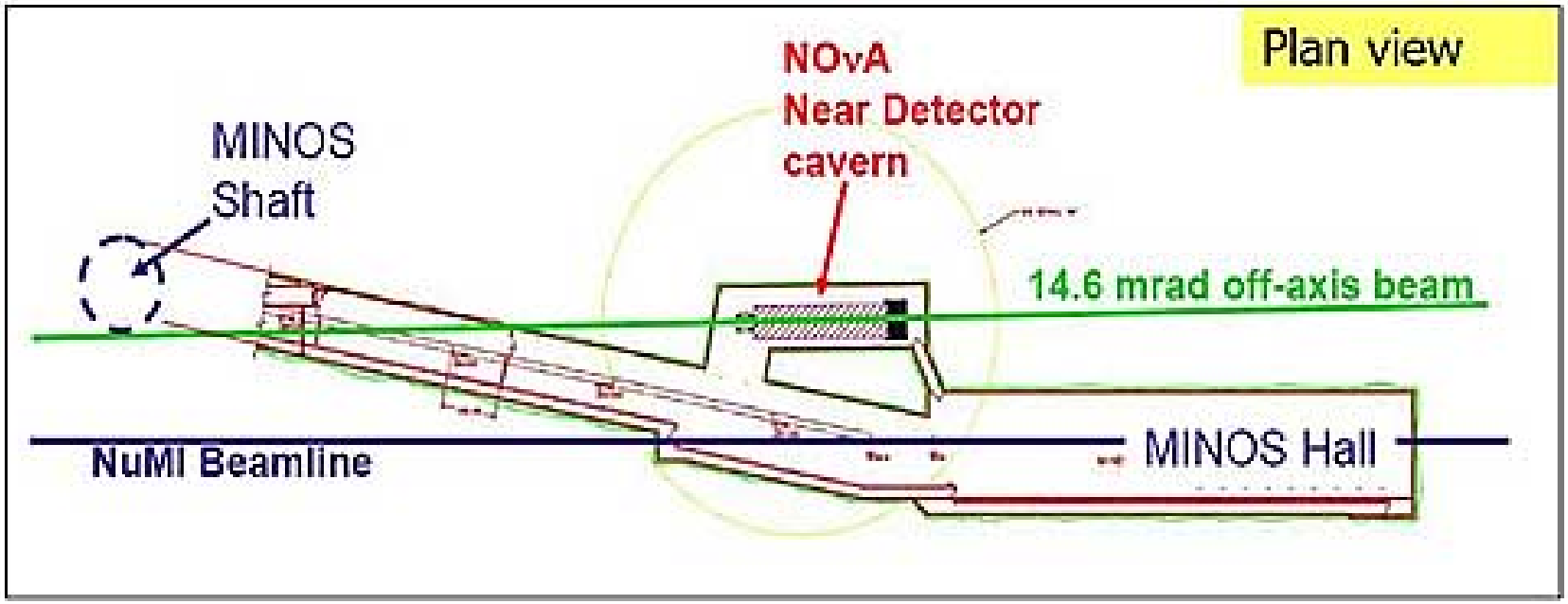
for the CRV Group

October 28, 2019



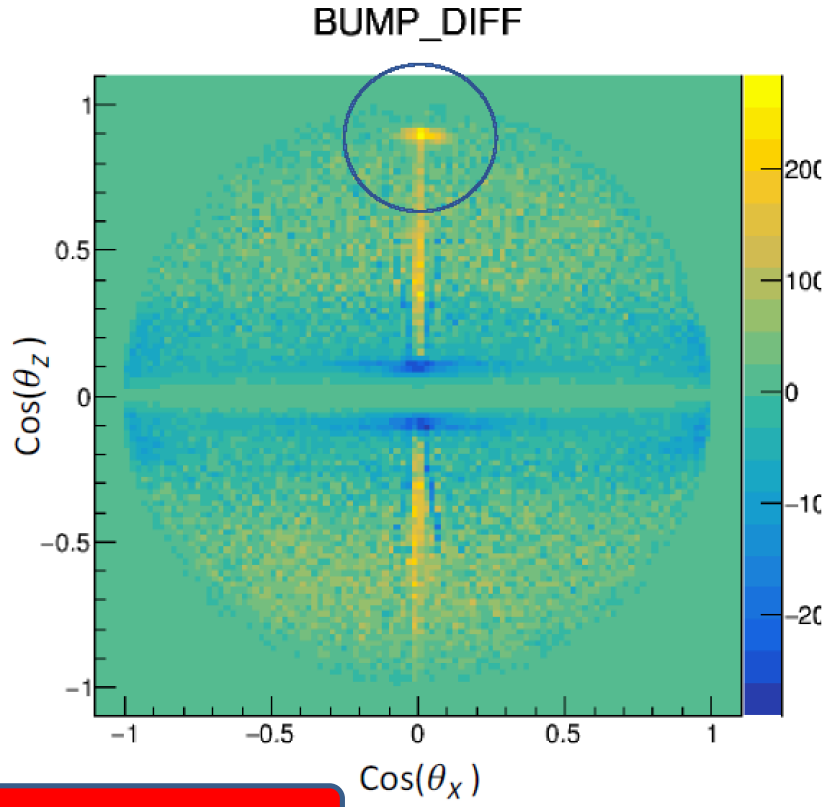
NOvA Near Detector is Being Used for Tomography

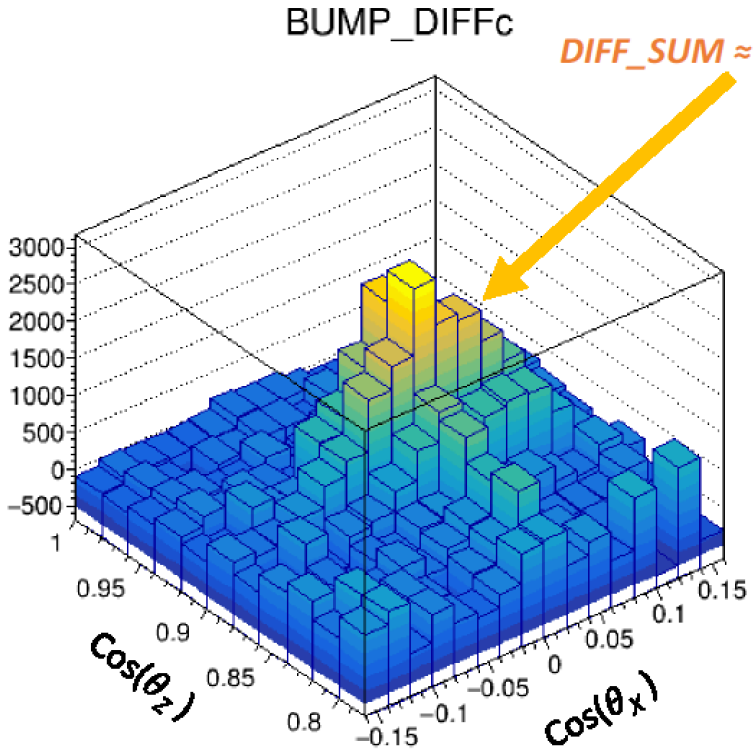




A Bump was Found in Muon Flux

BUMP MAGNITUDE: ➔ ***amount of excessive tracks in the Bump ?***





Total tracks:
164 x10^6
in 2015"B"
excess
is
1.9 x10^{-4}

(0.02 %)

[approx.]
of TOTAL FLUX

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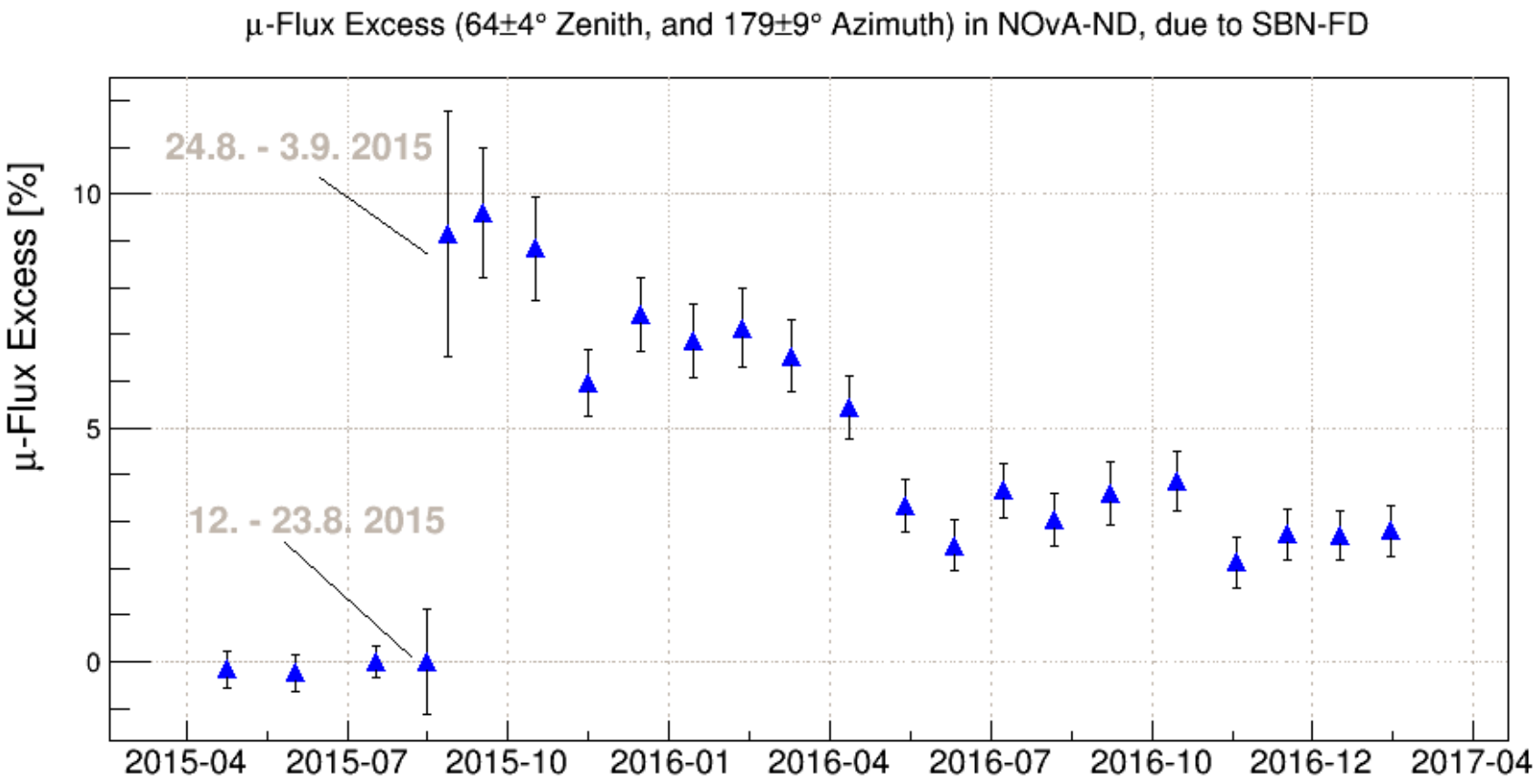
BUMP_Excess: ***3% - 15% of μ-Flux*** *in narrow angular region: 64 ± 4°, 179 ± 8°.*

Flux Suddenly Increased



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Bump Points to ICARUS

Origin of the Bump: Excavation of Soil @ SBN-FD

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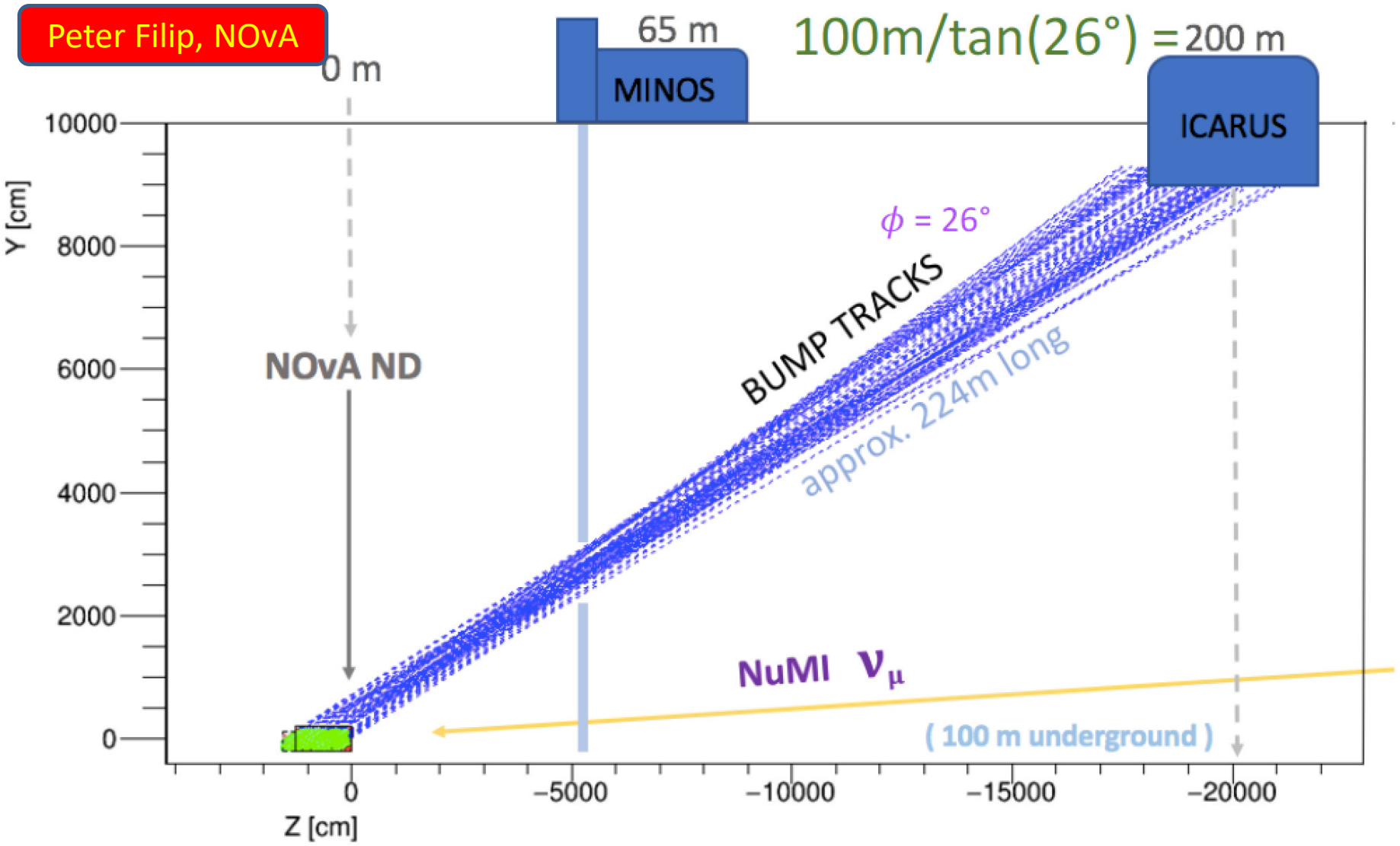
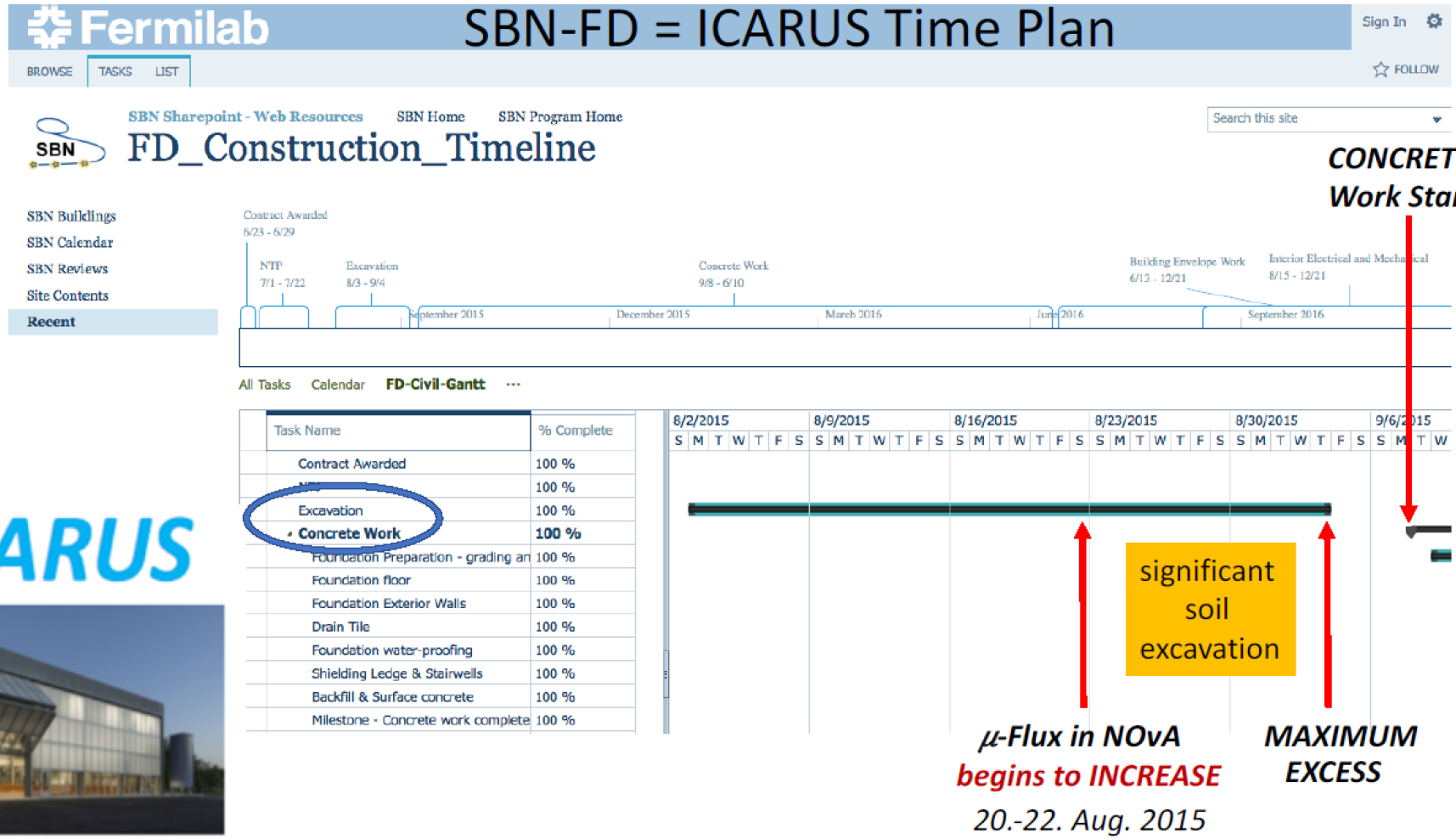


ICARUS Construction Schedule

https://web.fnal.gov/collaboration/sbn_sharepoint/Lists/FD_Construction/FDCivilGantt.aspx



ICARUS

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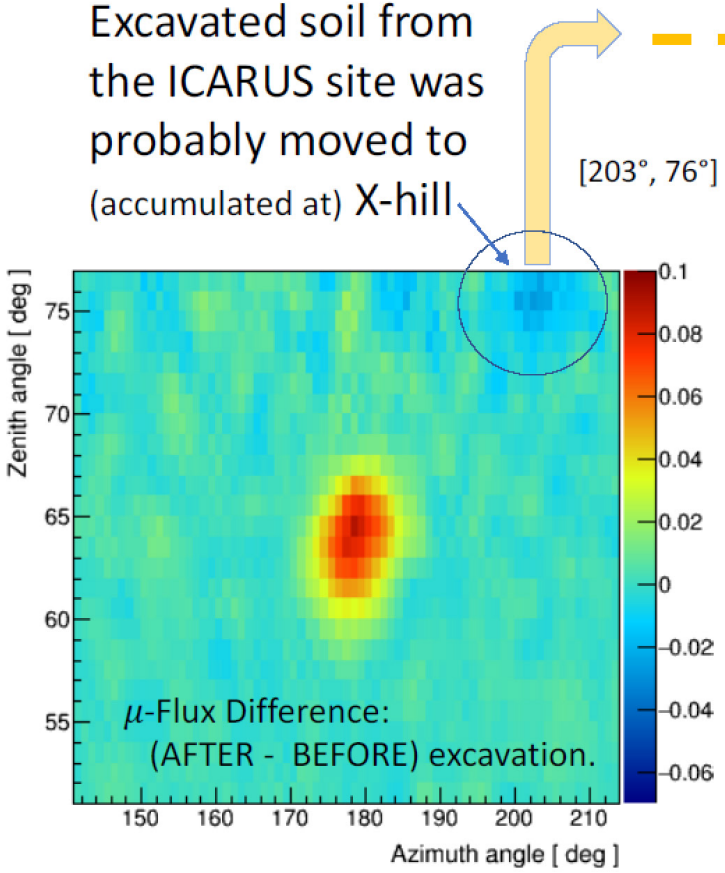
Found a Deficit as Well

New Observation:

Excavated soil from the ICARUS site was probably moved to (accumulated at) X-hill



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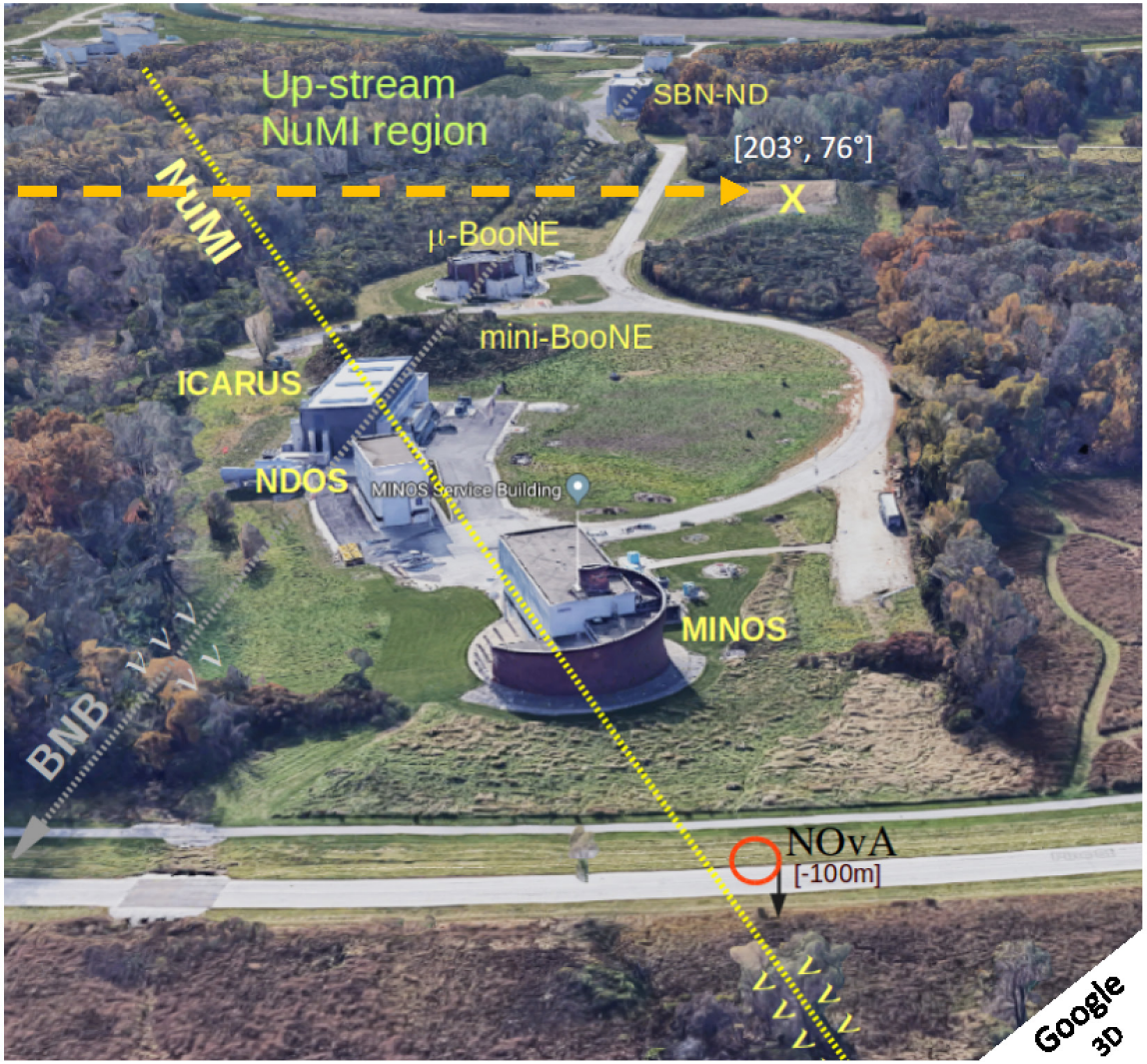
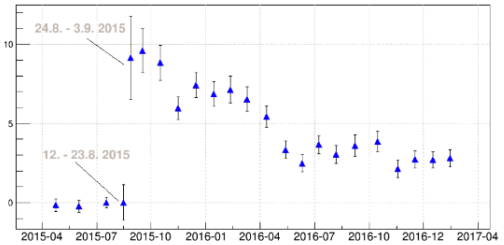


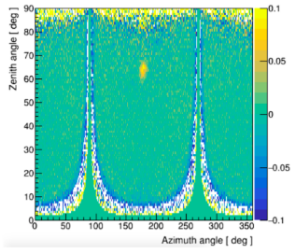
Is There a North-South Difference

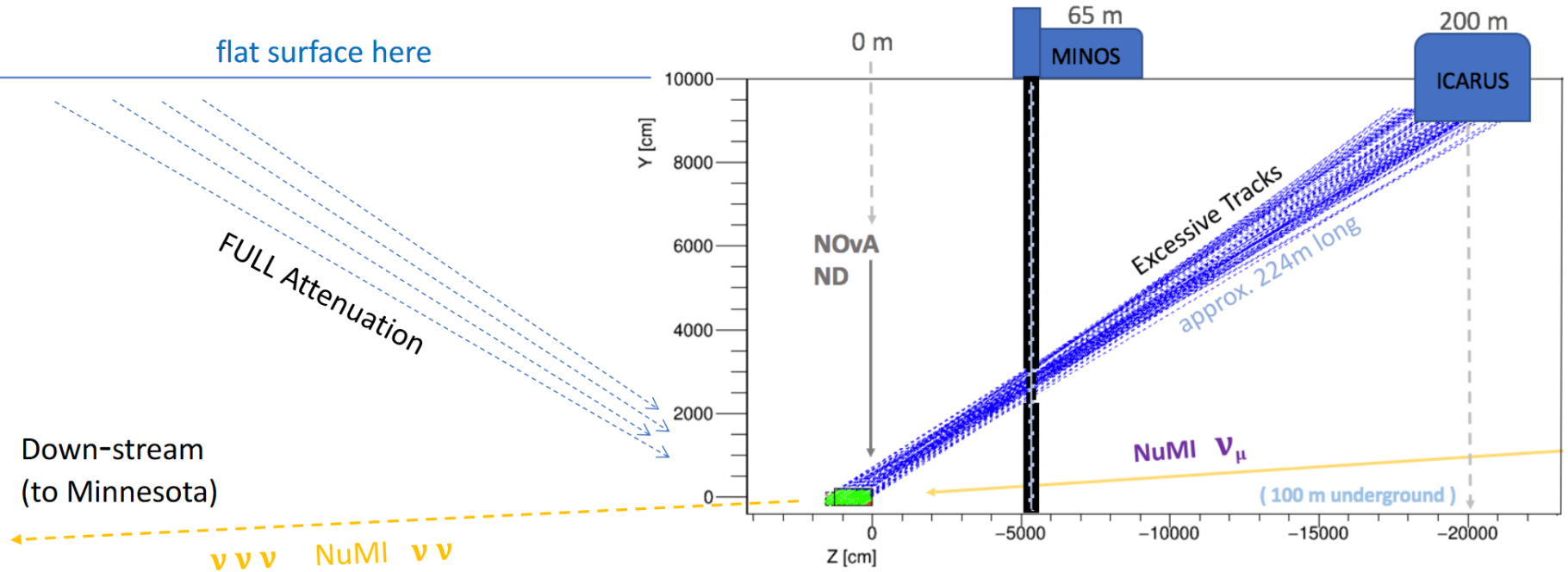
ICARUS Excess: observed via "TIME" Difference

NOW: observed using N/S

⇒ Up – Down-stream Diff.







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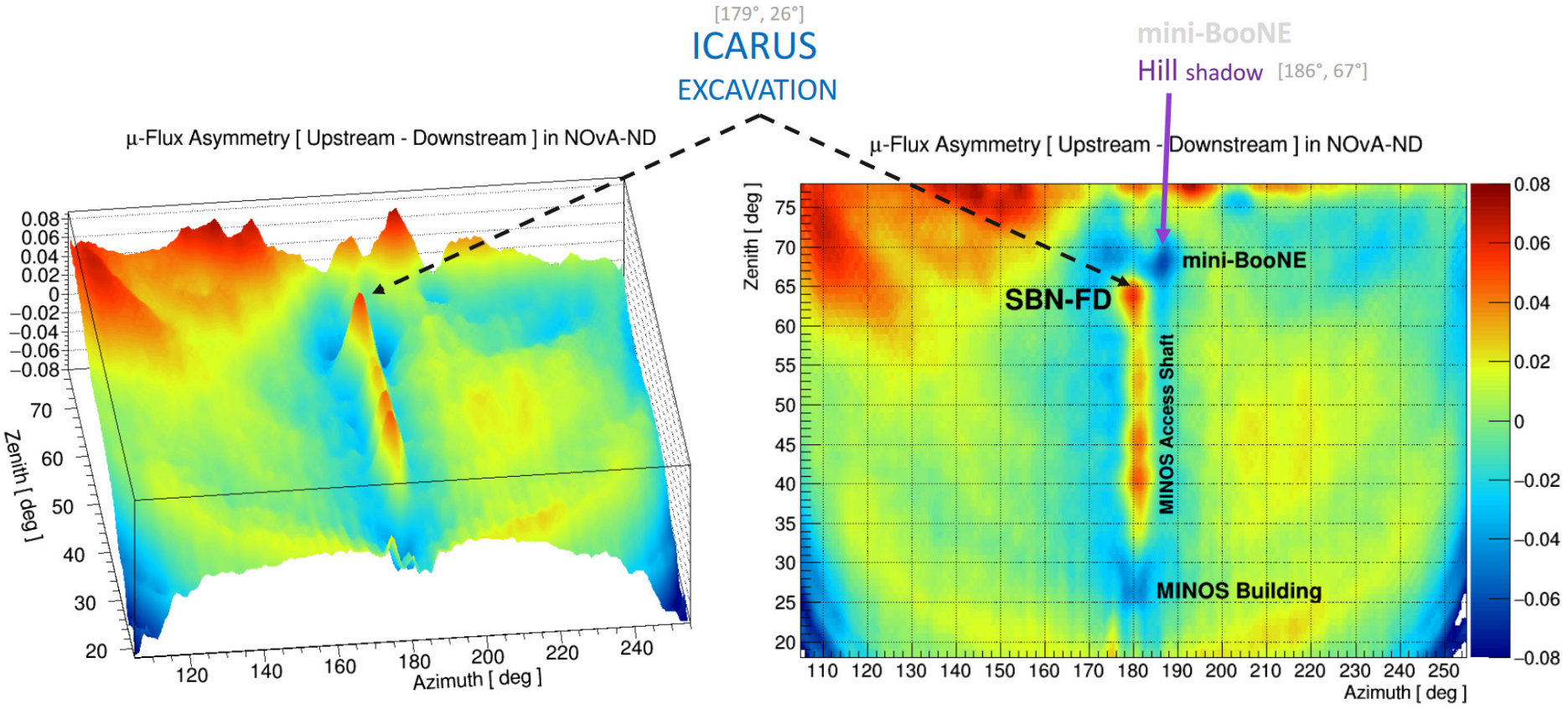
North-South Difference

Here: muon-Radiography DATA from NOvA ND



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North-South Difference

Normalized μ-Flux Subtraction

muon-Flux:

DETECTOR Acceptance

$$F(\theta,\phi) = F_o \cdot G(\theta) \cdot K(\theta,\phi) \cdot A(\theta,\phi)$$

μ-Flux

TIME FACTOR ACCUMULATION

$[\cos(\theta)]^k$ zenith dependence

ATTENUATION "KERNEL" GEOLOGY + CONSTRUCTIONs

Up-stream ↔ Down-stream (SUBTRACTION)

$$\frac{F(\theta,\phi) - F(\theta,\phi+\pi)}{F(\theta,\phi) + F(\theta,\phi+\pi)}$$

Acceptance Cancels-Out, due to ND **symmetry:**

$$A(\theta,\phi+\pi) = A(\theta,\phi)$$

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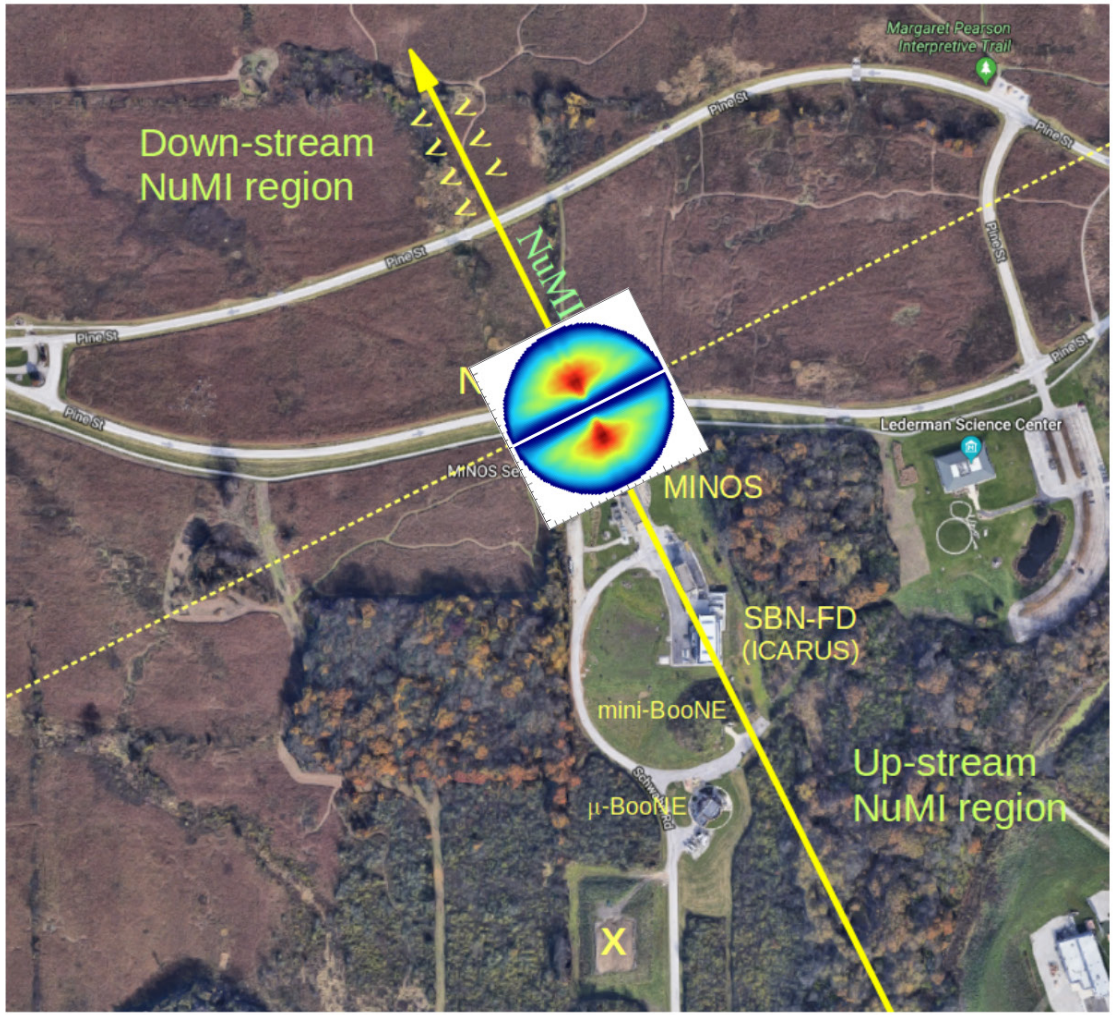
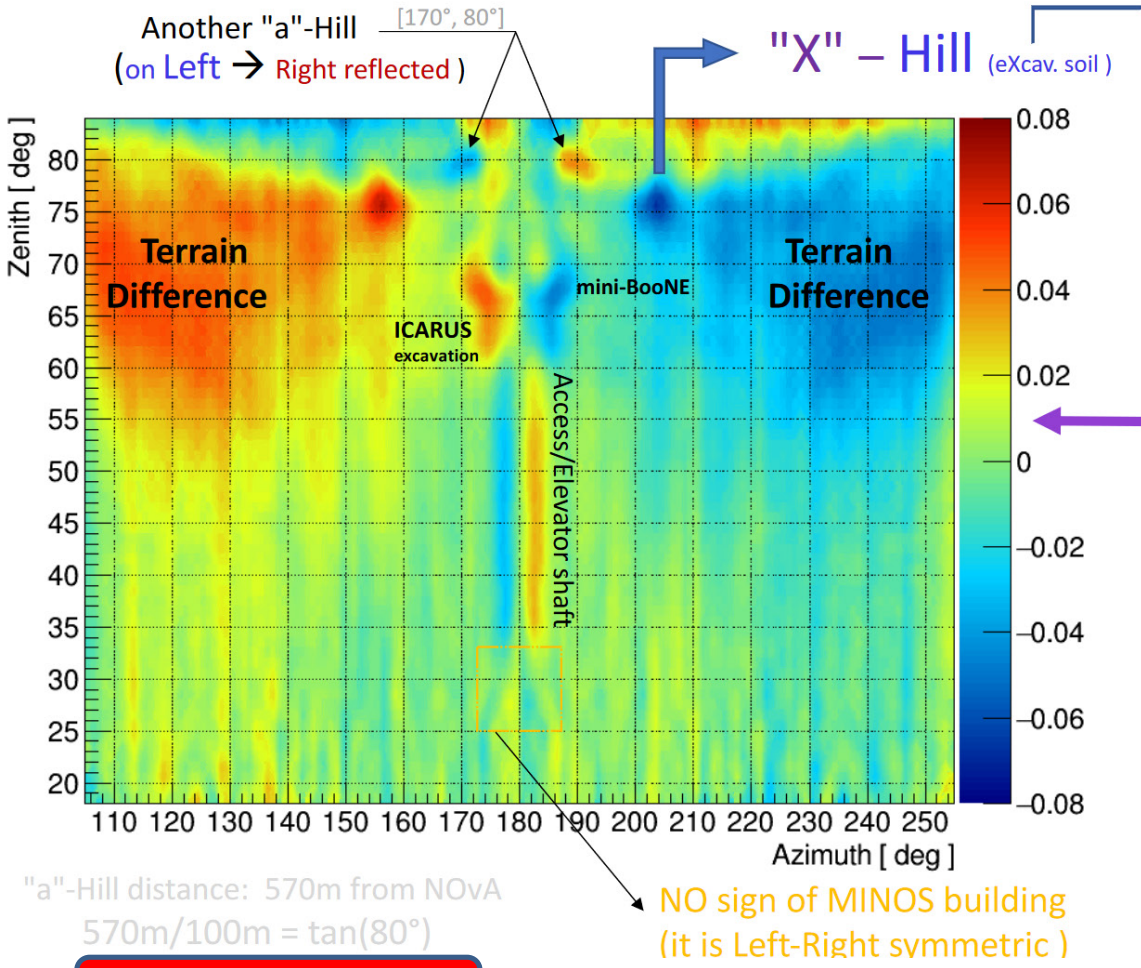
Satellite 2D view (google maps)



Left-Right Difference as Well

LEFT – RIGHT: UP-stream Attenuation Difference



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Comments

NOvA Near Detector is ~100 m underground, which removes low-energy muons

There is no East-West effect for high energy muons

We do not have this luxury for scanning the pyramid unless we can somehow eliminate low-energy muons

Eliminating low-energy muons (< 100 GeV) can be done using TRDs, which would mean a completely different design. Unfortunately, these are the muons we want!