FROST

Forest **o**f **S**cintillating **T**ubes
for Detecting Reactor Neutrino Directions
Motivated by need to resolve
clandestine reactors and
details of reactor cores

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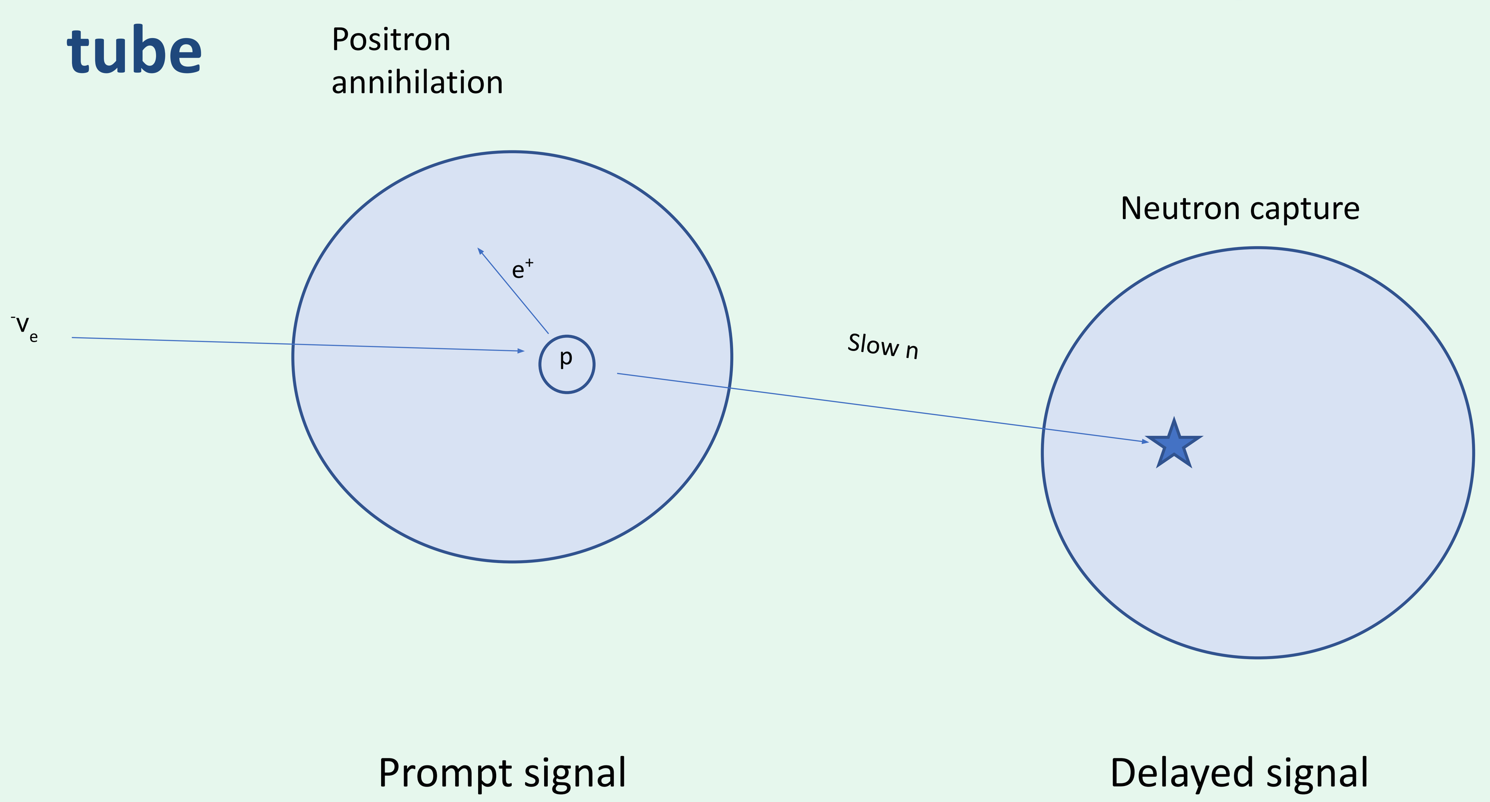
NIST-like deployment scenario:
$20MW_{Th}$ reactor power, 10m standoff, assuming 10% overall detection efficiency, and ~4T target mass)

Predicted live-time for this resolution is less than 24 hours!

Concept:
Prompt measurement of neutrino direction from Inverse Beta Decay

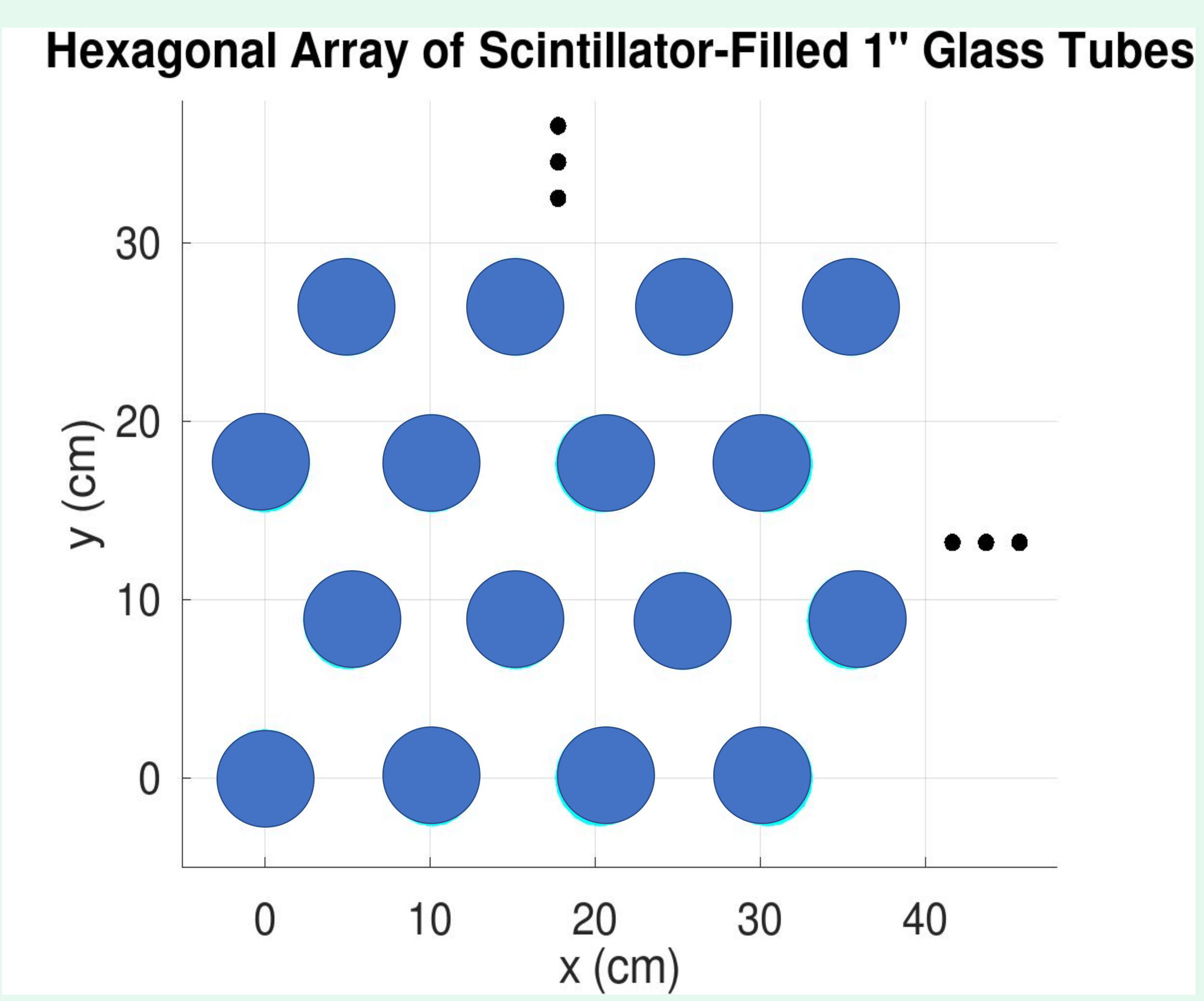
- Reactors make huge numbers of electron anti-neutrinos $\bar{\nu}_e$
- IBD: $\bar{\nu}_e + p \rightarrow e^+ + n$
- Positron e^+ gets neutrino kinetic energy, neutron gets momentum (direction)
- Neutron loses direction in successive collisions, soon doing random walk:
 must capture *n* before scatters much (unlike Double Chooz)
- Insight: neutrino target scintillator material in small diameter tube so neutron escapes proton-heavy region (scintillator) before losing direction
- Use glass tube (mostly SiO2) to avoid neutron scatters
- **Previous IBD detectors have had little or no direction resolution**

IBD event with neutron captured in neighbor tube



- **Measure capture distance and location relative to initial IBD. Neutron speed ~c/10,000!**
- **511 KeV gammas from positron annihilation travel at c and usually go long distance**

Top view of hexagonal tube lattice used in MC



Tubes may be 2.5 cm diameter and 10m long, spacing ~10 cm.

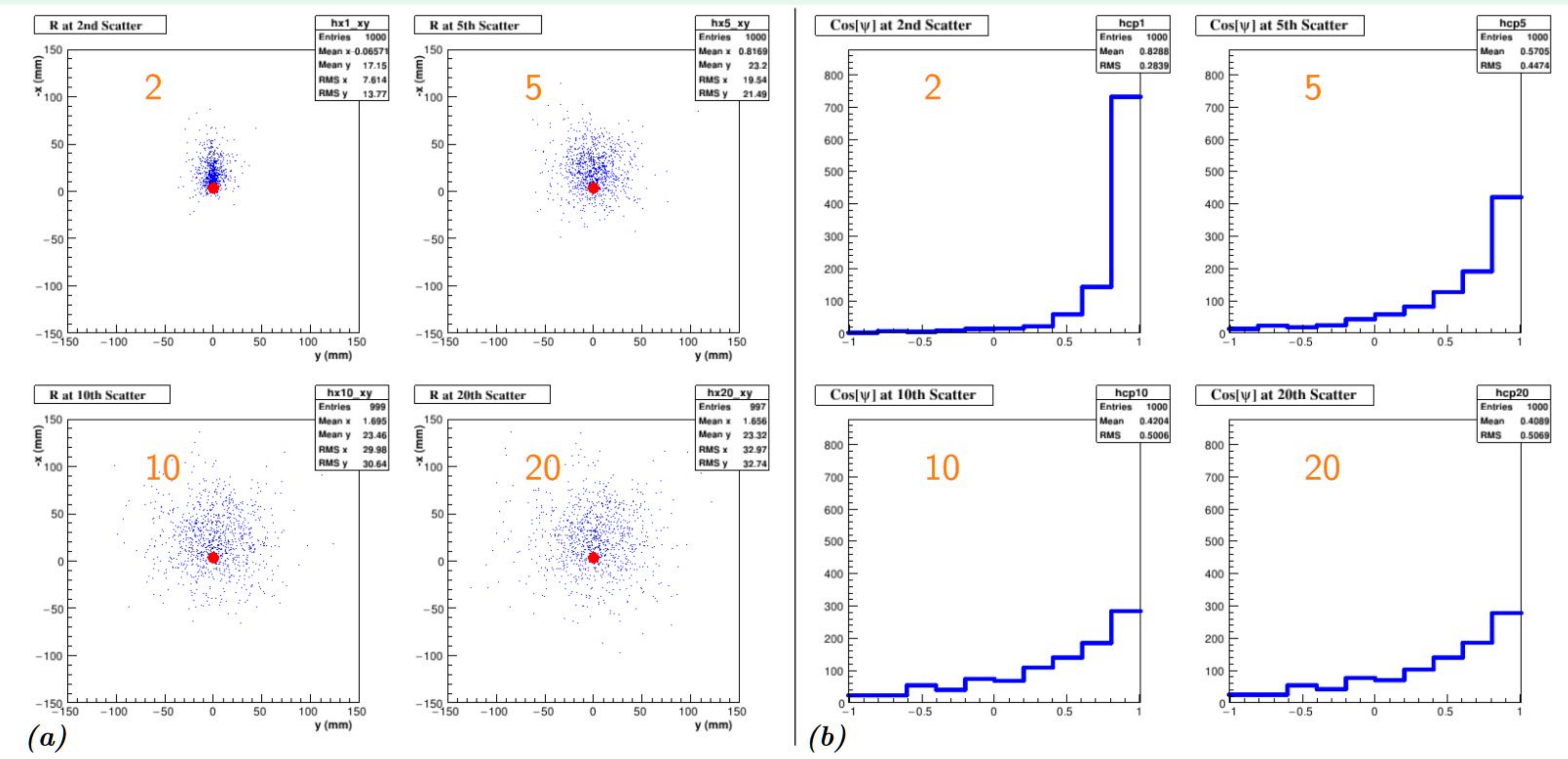
Dimensions need optimization.

Concept for $1m^3$ for prototype array

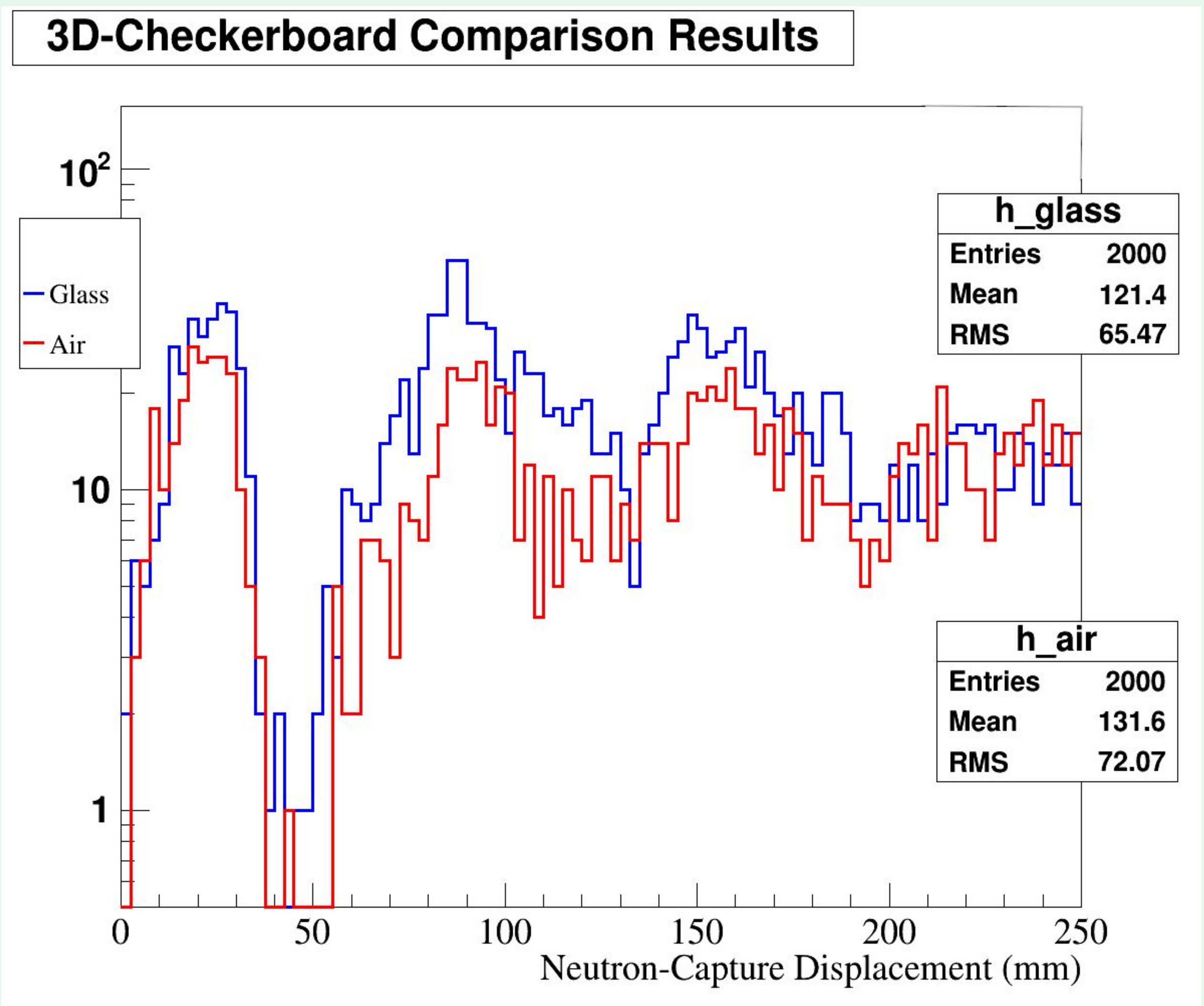
and $10m^3$ array for detection at mid ranges (~10-20km)

Neutron Direction versus number of scatters

- **Neutrons "forget" initial direction after only a few scatters**
- **Double Chooz measured after dozens**

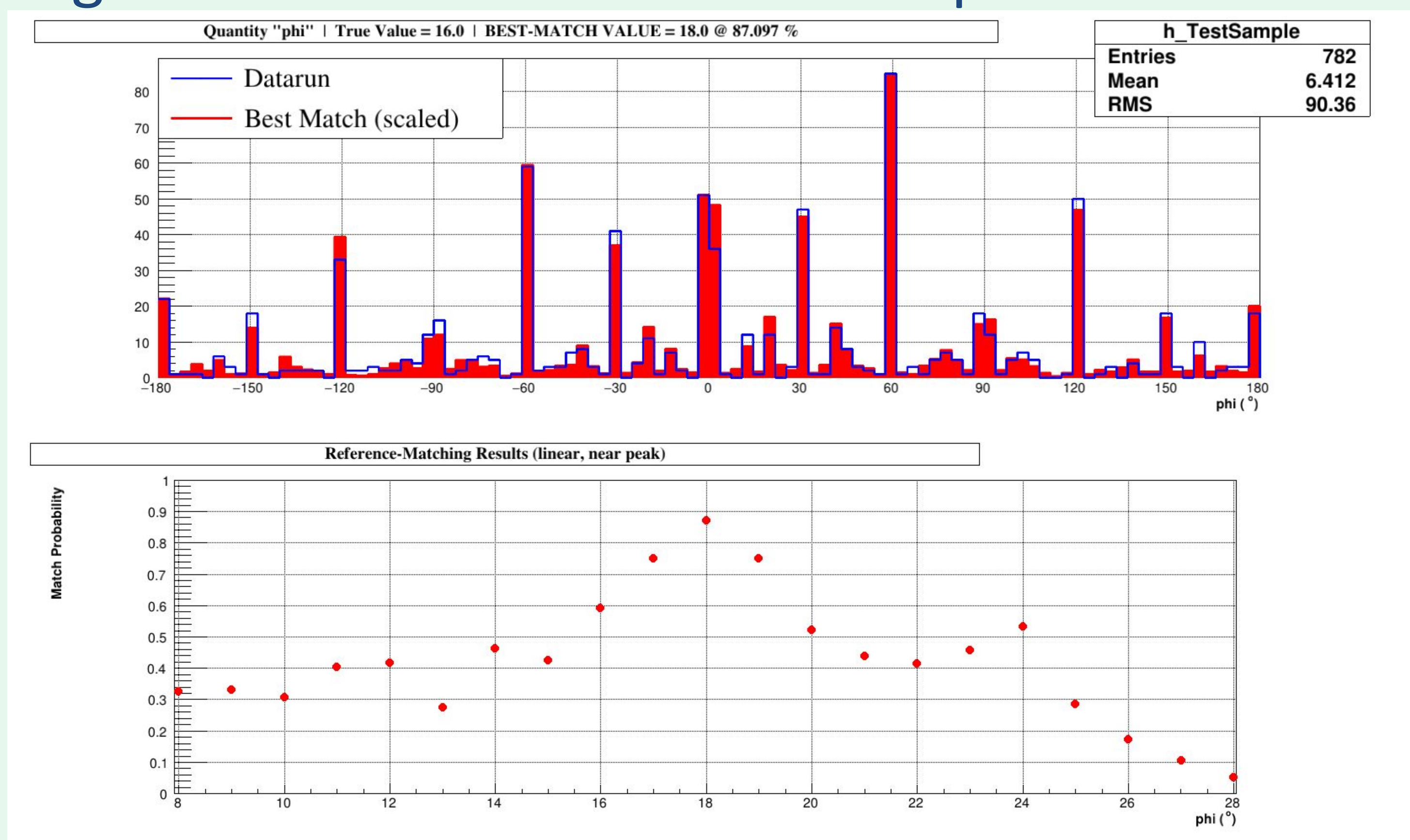


Neutron transmission through Glass



Why we use glass tubes to contain scintillator:
Fig. on left shows that even 5 cm of glass only slightly degrades neutron capture location (due to lack of free protons). Neutrons from IBD usually escape tubes with little or no angular scattering.

Angular distribution of neutron captures in FROST



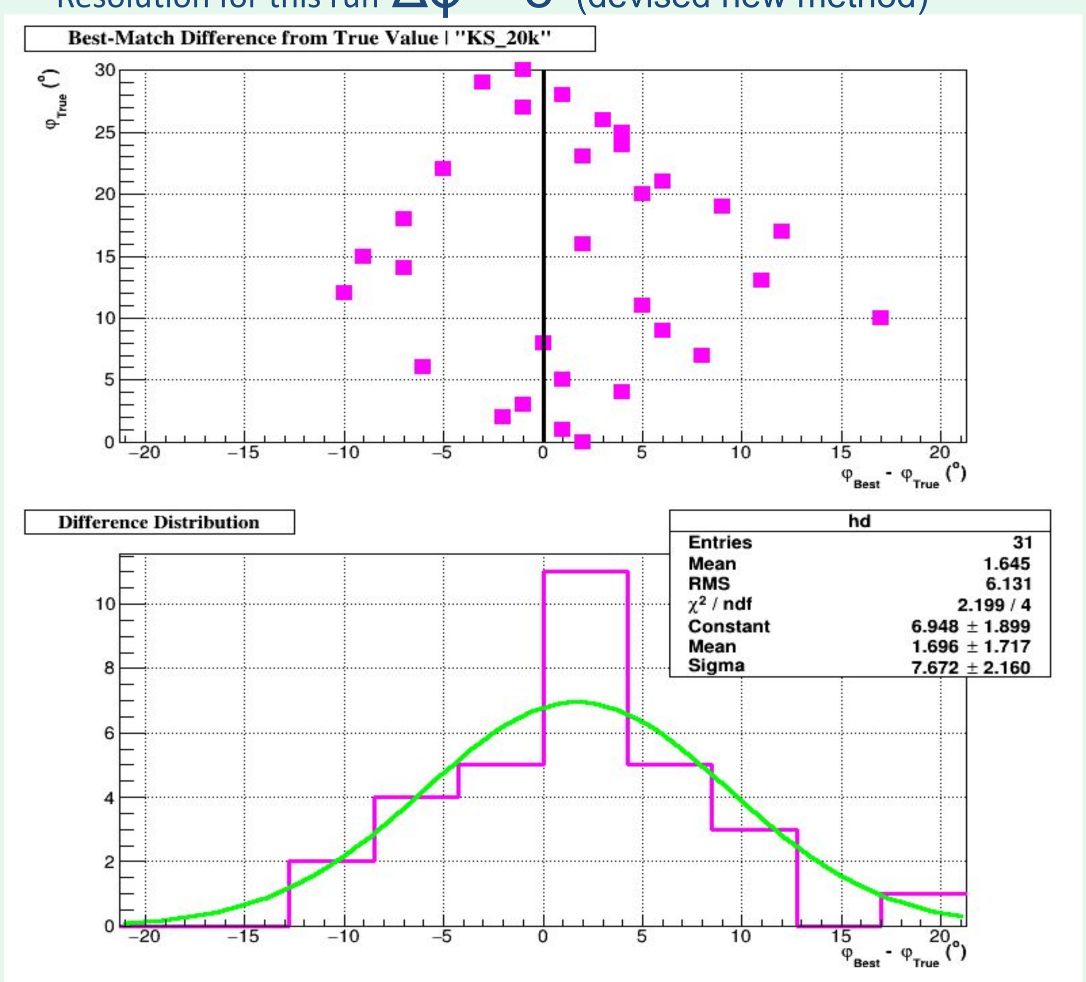
Reference Sets: 20 000 IBD events run @ each angle, ~80% captured --> ~16 000 recorded events each

"Experimental" Datasets: 1000 IBD events run @each angle, ~80% captured ~800 recorded events each, Resolution ~ 8°

Statistical Test Used: Kolmogorov-Smirnov

Angular resolution of FROST, via sequential fitting to test MC distributions

Resolution for this run $\Delta\varphi \sim 8°$ (devised new method)



Conclusions:
developing new method of observing IBD directions

- FROST array of scintillating tubes promises to do well at determining the azimuth of a reactor source of electron antineutrinos
- Applications for near-reactor studies and nuclear non-proliferation
- Test cells under active development at UH
- To do: design needs optimization of lattice geometry, sizes, spacing
- Many open questions of backgrounds, efficiency and resolution
- Tough hurdle: affordably making enough tubes with sufficient target volume to be practical… emphasis on tube scale (10m long?) and optical (SiPM) detectors at ends. We envision $10m^3$ array.
- Aiming for prototype trial at Fairport/Perry (Watchman) in several years.
- Tests and studies are underway, collaborations brewing in cooperation with LLNL, stay tuned.

National Nuclear Security Administration