SBND and JUNO updates

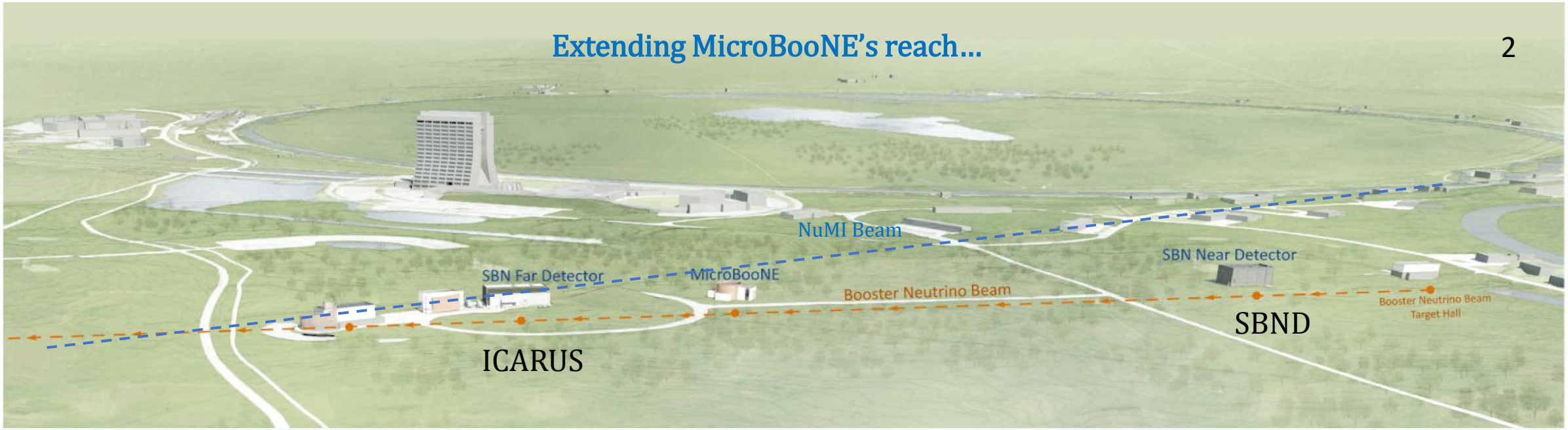
John Plows

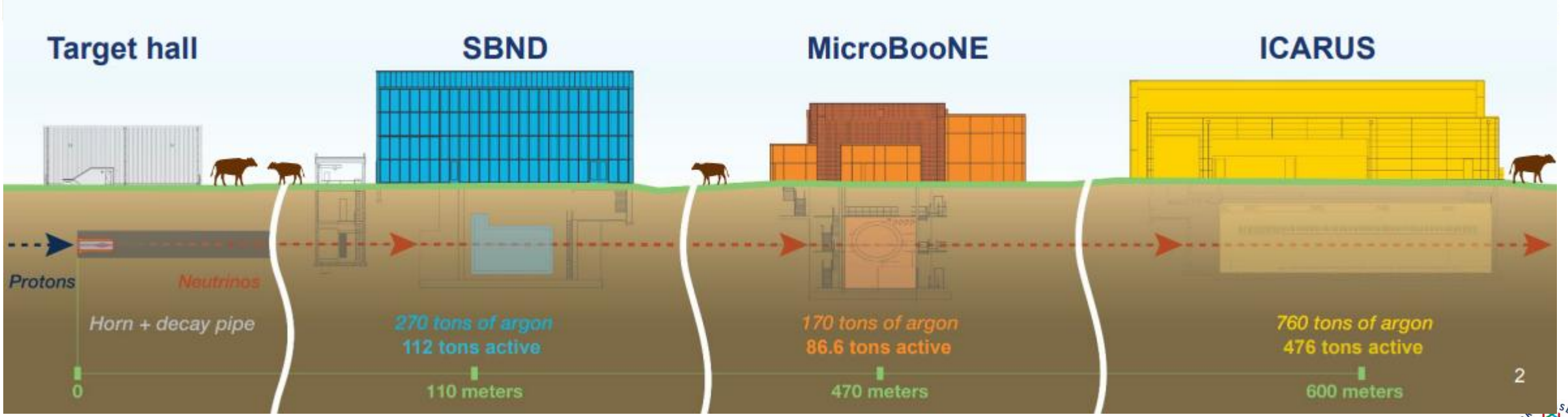
HEP Annual Meeting

22/May/2025

UNIVERSITY OF LIVERPOOL

Extending MicroBooNE's reach…





The SBN programme has 3 main physics goals:

1. Accept or rule out **definitively** the **short-baseline anomalies**
2. Precisely measure **neutrino-argon interactions** in preparation for next-generation long-baseline experiments (**DUNE**)
3. Search for exotic signatures **beyond the Standard Model**
4. Characterise the **performance of LAr** detectors for DUNE

Liverpool at SBND

Academics:

- Costas Andreopoulos (IB)
- Christos Touramanis
- Kostas Mavrokoridis

Research staff:

- David Payne
- John Plows
- Also many thanks to Marco Roda for his previous work on SBND!

PhD students:

- Beth Slater (**finishing soon**)

Making **key contributions** in:

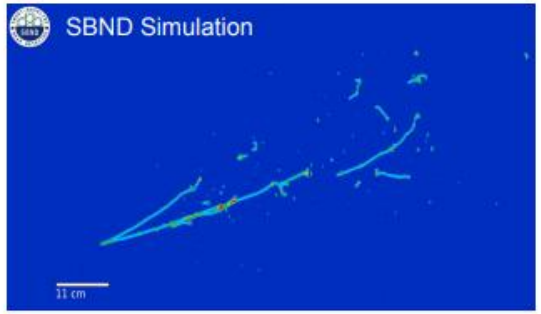
- Oscillation analyses (VALOR group -- Costas, Beth, John)
- Systematics frameworks (John)
- Flux and BSM simulations (John)
- Expert detector operations (David, Beth, John)

BSM signatures in SBND

R. Jones, Status of SBND, ICHEP 2022

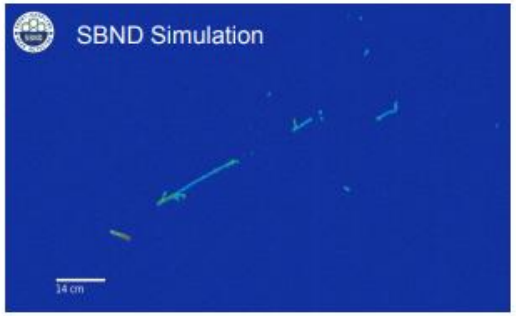
✓ = realisation of LLP

Dark Neutrinos



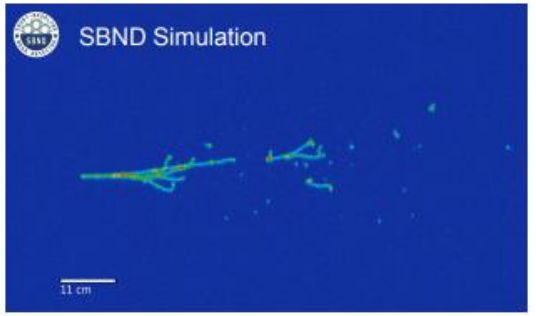
e^+e^- pair with or w/o hadronic activity

Transition Magnetic Moment



Photon shower and hadronic activity

Axion-like Particles ✓



High-energy e^+e^- or $\mu^+\mu^-$

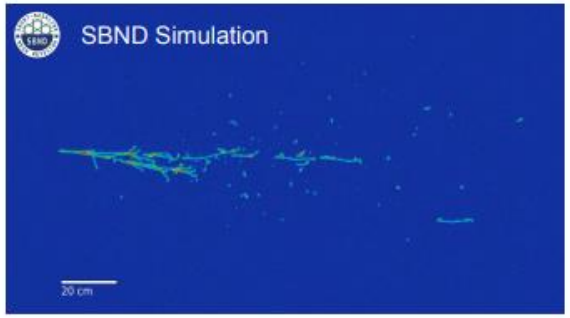
Example signatures and event displays for various BSM scenarios

Not an exhaustive list

Some diagram credit: Pedro Machado

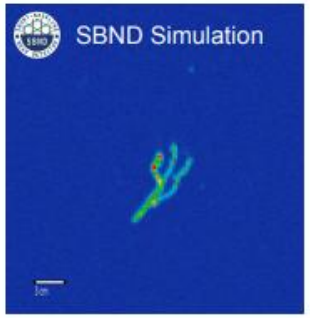
Slide credit: Marco Del Tutto

Heavy Neutral Leptons ✓



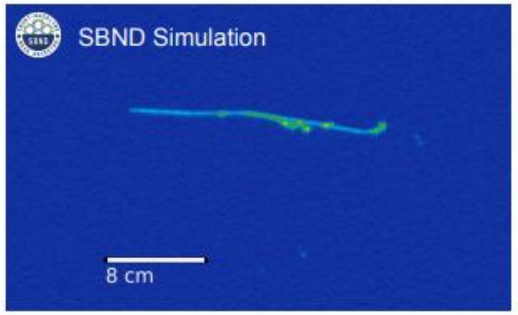
e^+e^-, $\mu^+\mu^-$ or $\mu\pi$

Higgs Portal Scalar ✓



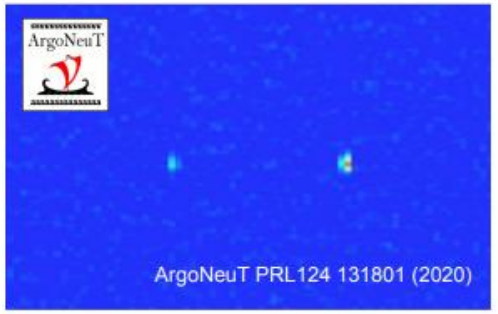
e^+e^- or $\mu^+\mu^-$, no hadronic activity

Light Dark Matter ✓



Electron scattering

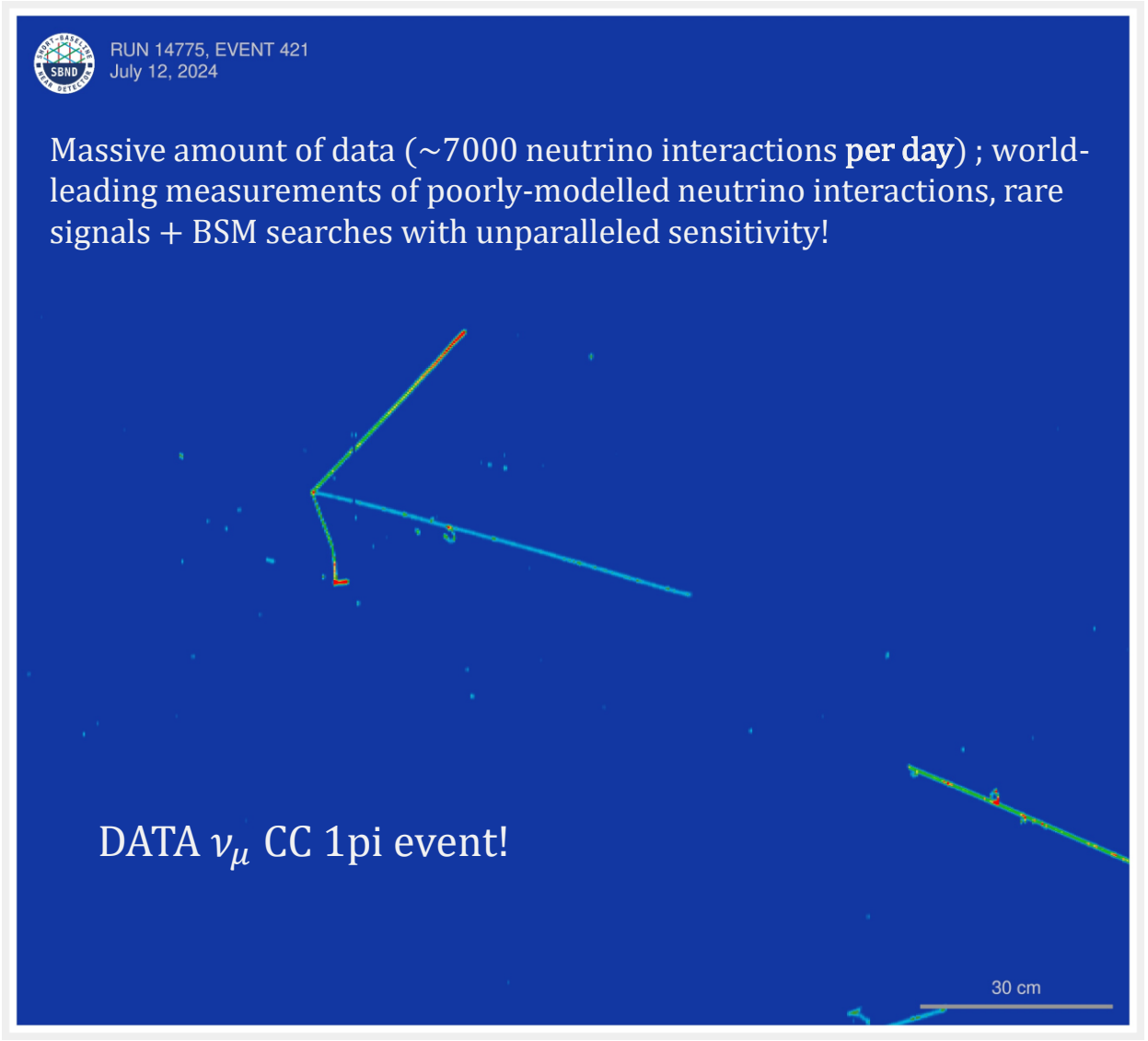
Millicharged Particles ✓



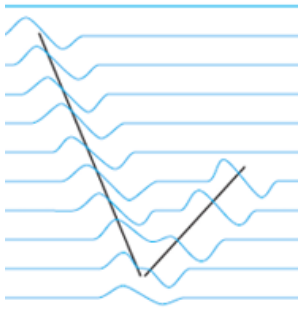
Blips/faint tracks

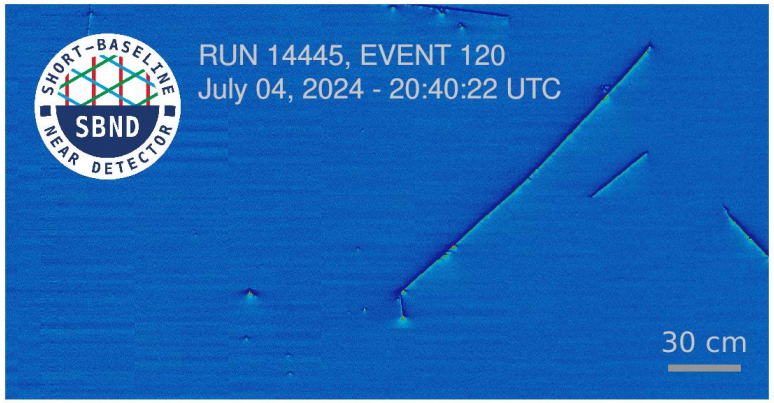
SBND Data!

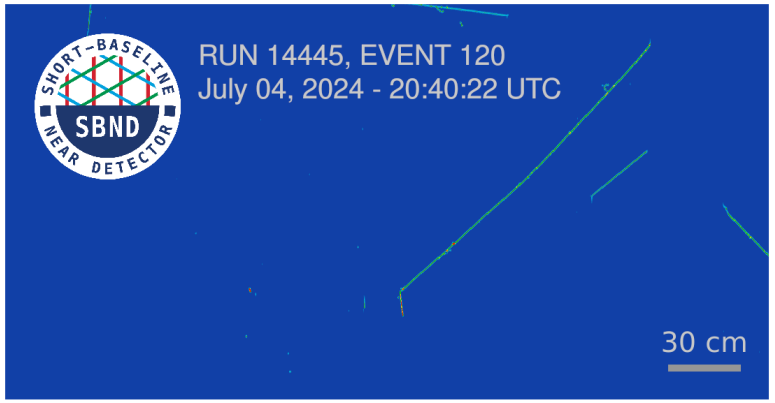
- SBND started taking BNB data Summer 2024 (May-July) then again from end August onwards
  - Keepup is split between FermiGrid (FNAL) and Polaris (ANL)
  - Temporarily paused keepup processing due to disk size constraints **but** have ~1e20 POT already



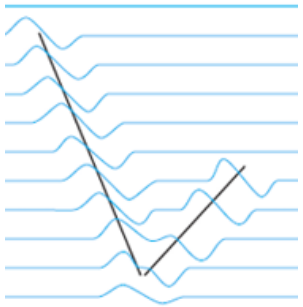
[Induction] Plane 0

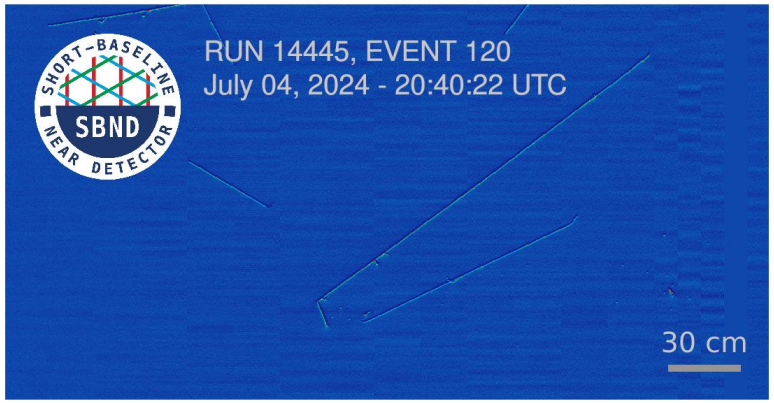


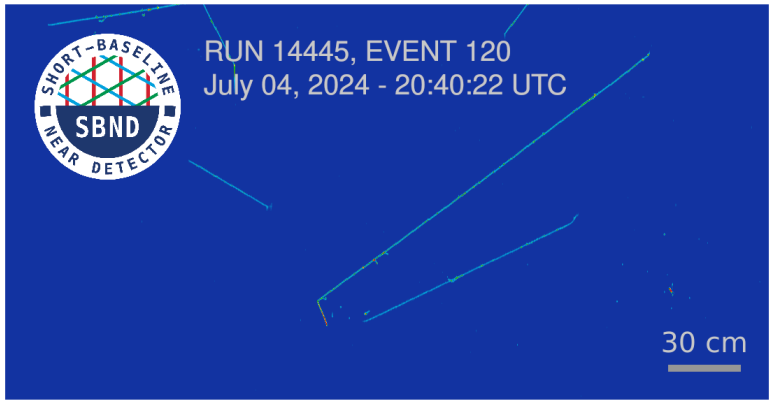




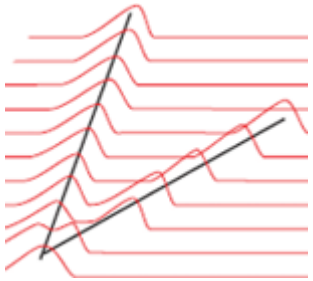
[Induction] Plane 1

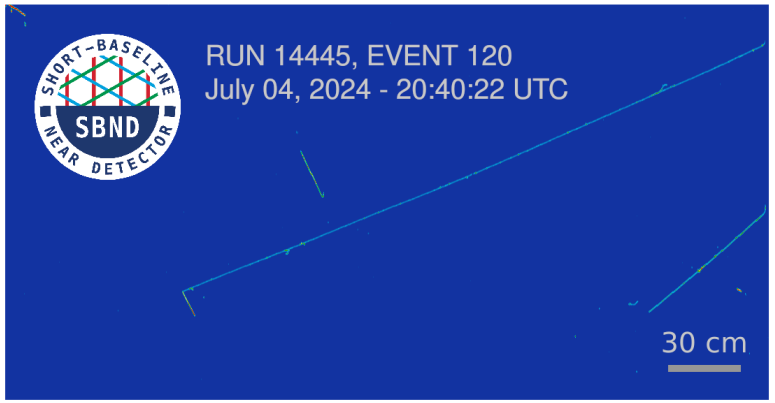






[Collection] Plane 2





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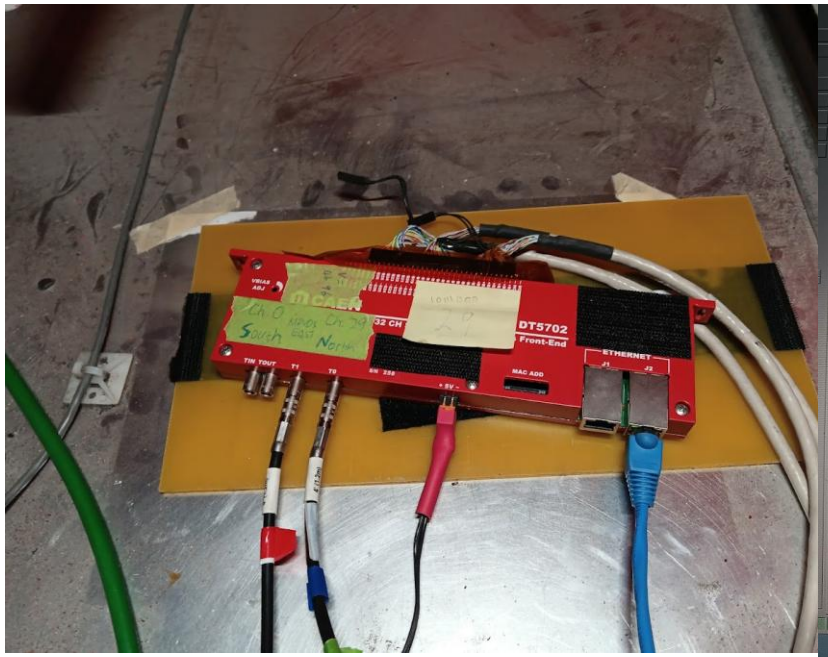
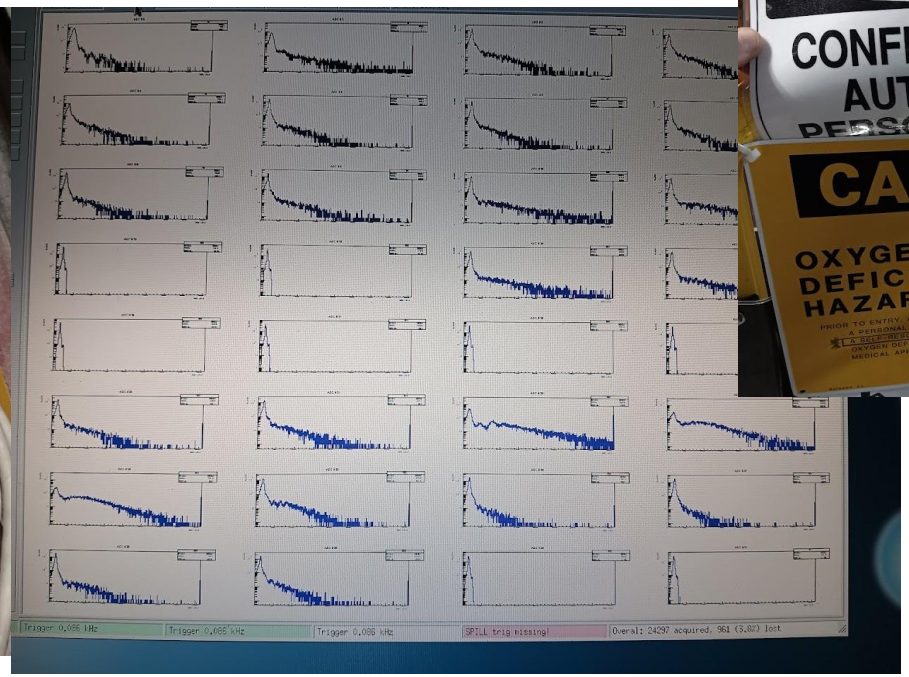
Commissioning

- Finalising Cosmic Ray Tagger commissioning
  - Added repurposed MINOS modules to CRT Bottom wall → increased cosmic coverage
- David (our Ops lead) & CRT team have put together a plan to use BNB summer shutdown for testing
  - This is a huge amount of work from all CRT team!
  - Lots of test runs ahead 🧪





Other operations updates

- We've been taking large amounts of control room (Beth Slater + I) and expert (Beth [Trigger], Dave [CRT], I [DQM]) shifts
  - U Liverpool currently maintains the following authors
  - Shift points assigned to Liverpool were:
    - 88 (Jan-Jun 2024)
    - 118 (Jul-Dec 2024)
    - 108 (Jan-Jun 2025)
  - At 10 points per CR shift and 3 per expert shift
  - Quotas will hopefully be lowered

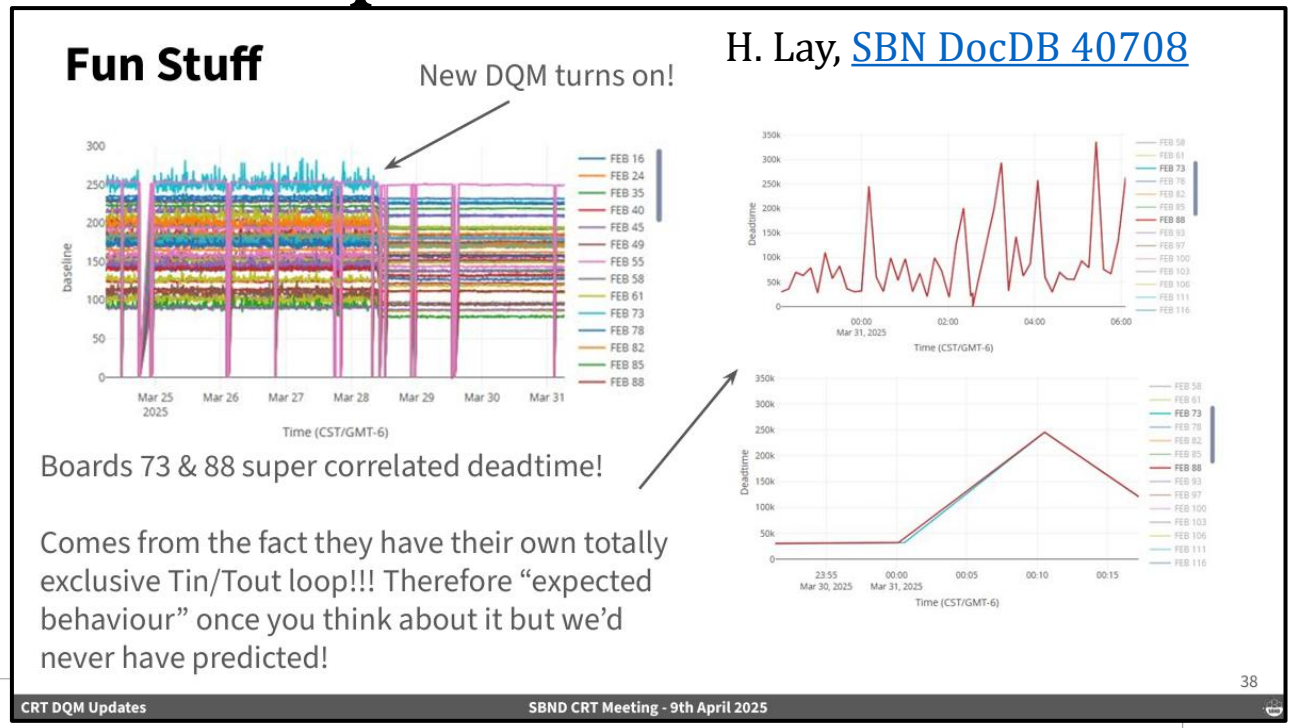
Username	Name	Disabled	Inactive	Author	Shifter	Status	Skills
costas	Costas Andreopoulos			author	shifter		
kostasm	Kostas Mavrokoridis			author	shifter		
mccauley	Neil McCauley	disabled	inactive	author			
djpayne	David Payne			author	shifter		
kplows	Komninos John Plows			author	shifter		DQM
bslater2	Beth Slater			author	shifter		

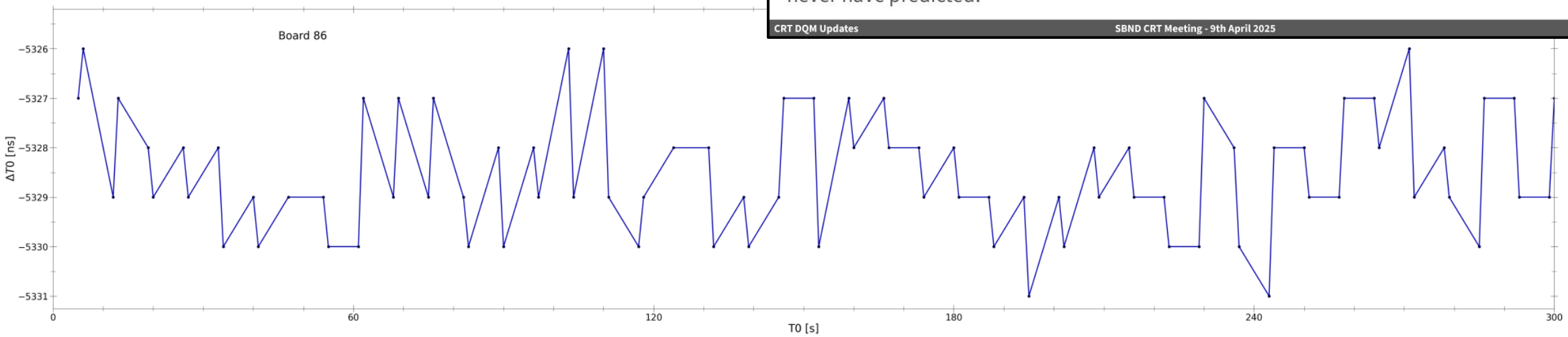
- **SBND shifters need to sign up for ECL account**(FNAL computing account required)
  - https://dbweb8.fnal.gov:8443/ECL/sbnd/E/index
  - Shifts can be remote
- One has to fill out a shift preferences form every ~6 months (look out for emails by SBND shift coordinator)
  - CR split by weekday (Mon-Thu) and weekend (Fri-Sun), Night (06:00-14:00 UK) / Day (14:00 - 22:00) / Swing (22:00 - 06:00) ; expert is in weekly blocks 24/7
- Best way to test connections for remote CR shifts: **shadow shift** (sign up on ECL, no points)
  - I also wrote up a "cheat sheet" with detailed instructions re. remote connections

Other operations updates

- **Data quality**: We monitor our data for features that might require intervention from subsystem experts
  - Example: spotted (potential cable?) delay by 5.3 µs on CRT board 86
  - Supported by common SBN-wide backend (for decoding data fragments) + Flask frontend

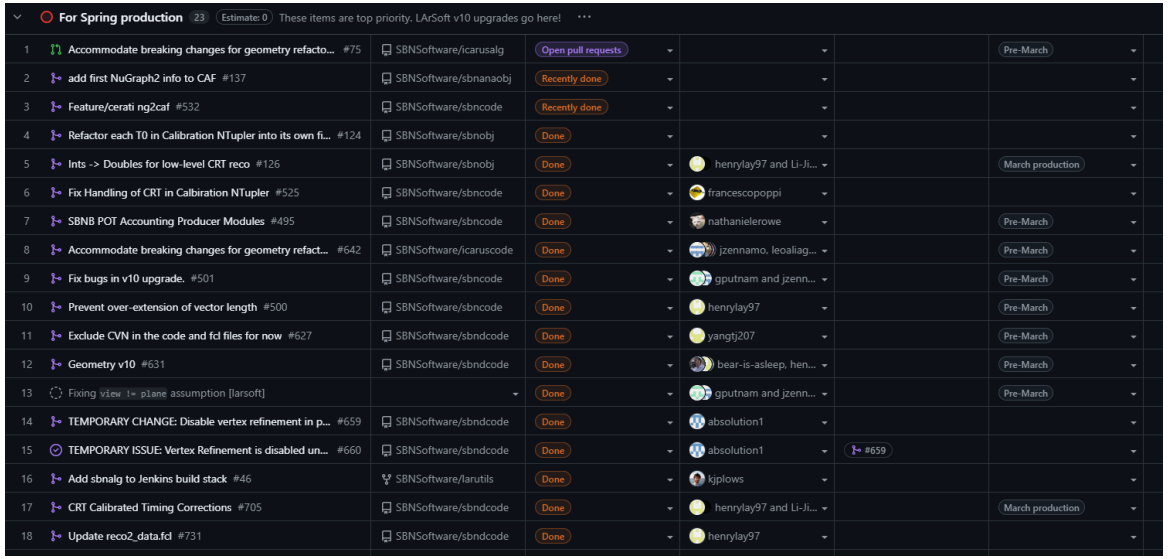
H. Lay, SBN DocDB 40708

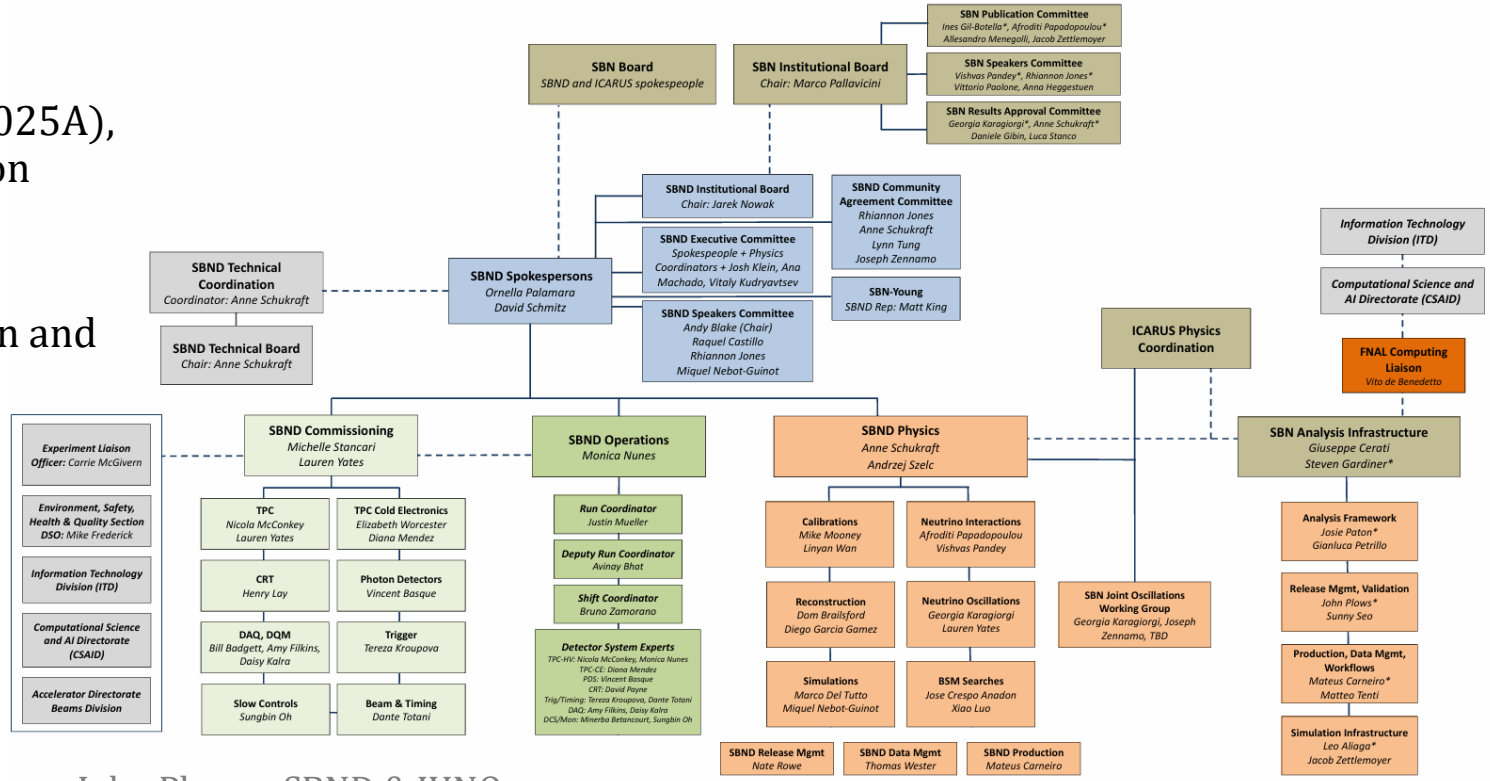




Other operations updates

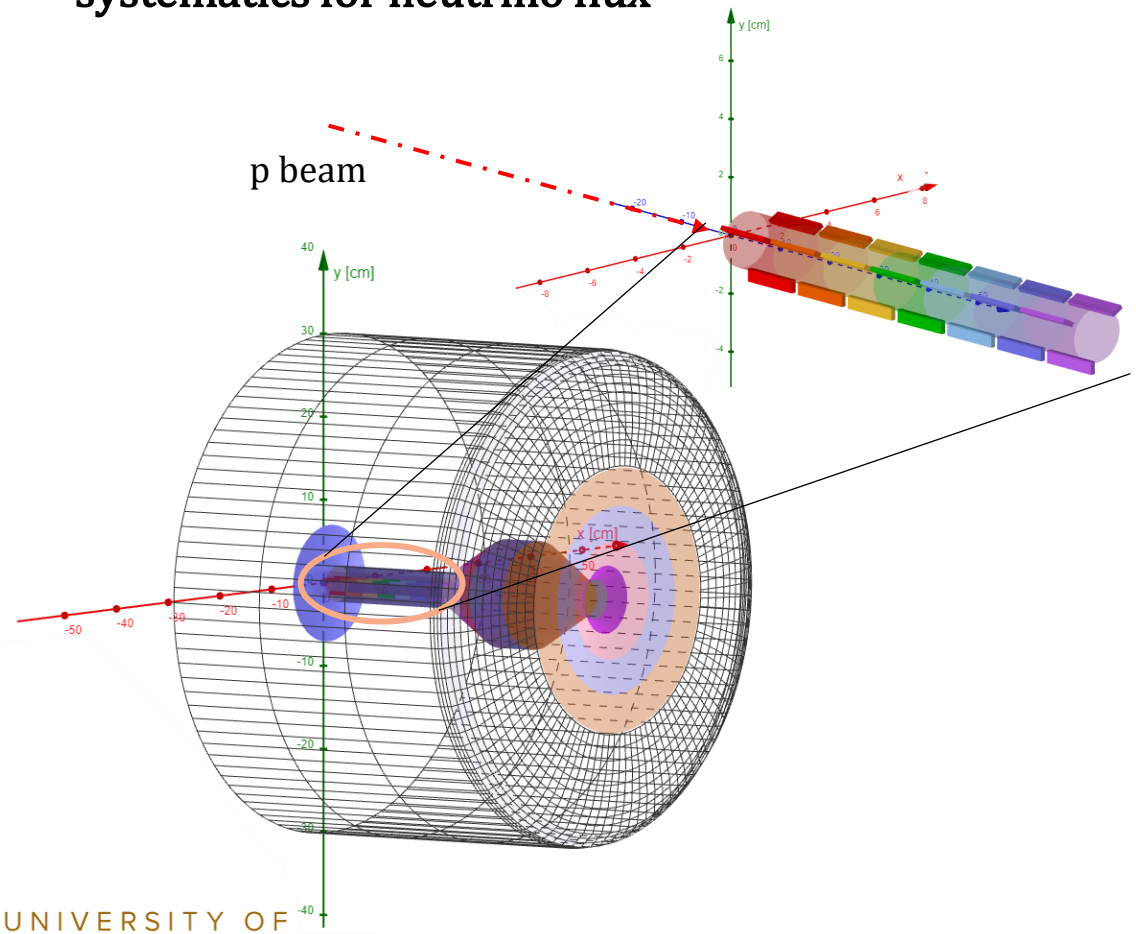
- **SBN Releases + Production:**
  - **SBN is moving into its Spring production campaign**
  - This requires coordinated effort from SBND and ICARUS for release coordination
  - SBN software is hierarchical:
    - LArSoft → SBNSoftware
    - larsoft (+ other repos) → sbncode, sbnalg, … → sbndcode
  - Validated our production campaign (MCP2025A), now running **full campaign** with emphasis on detector model systematics
  - Next productions will emphasise interaction and flux systematics

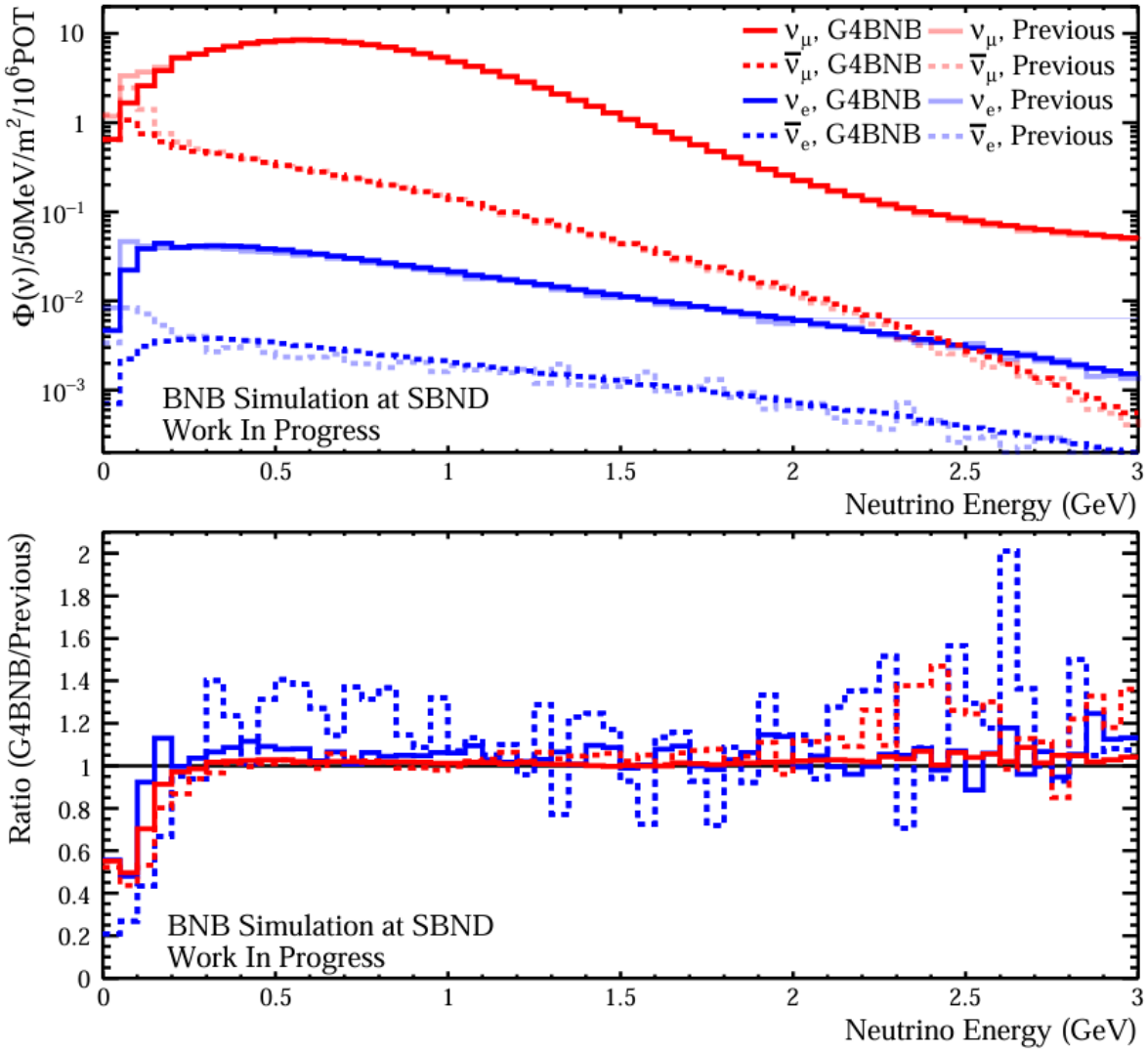




G4BNB

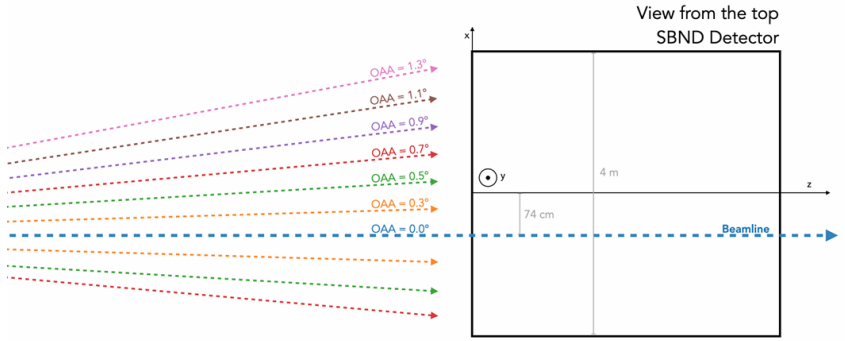
- SBN flux simulation originally derives from miniBooNE simulation
  - We constrain the simulation to use the same p-Be interaction cross-section
  - Validating our new G4 simulation to use robust flux drivers, **providing detailed systematics for neutrino flux**

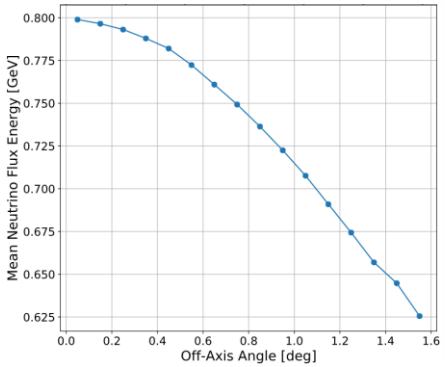


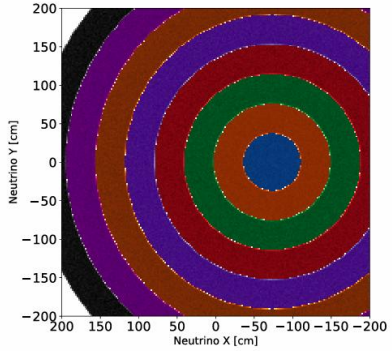


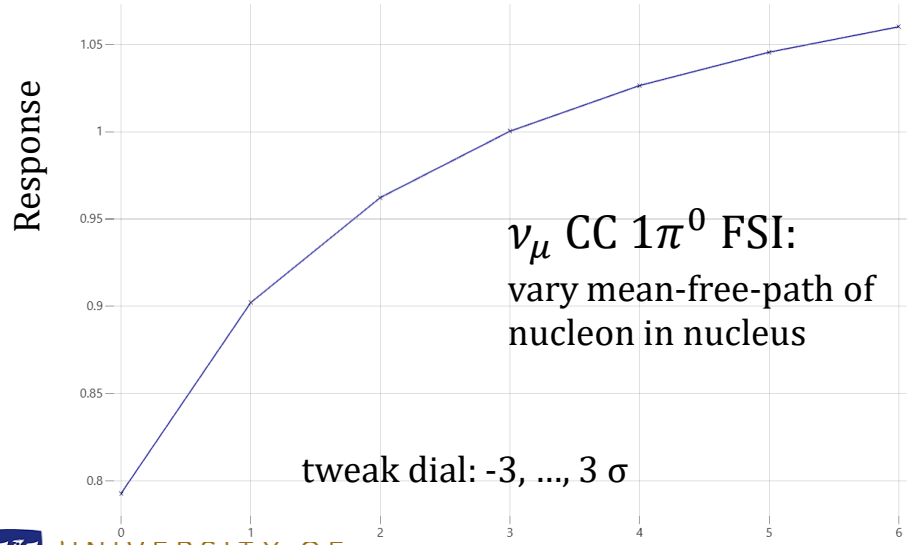
VALOR-SBN + simulation effort

- Carrying out joint fit using SBND-PRISM (off-axis slices of detector which see different neutrino fluxes)
- Have been updating our recent sensitivities to use the "MicroBooNE CC0π tune" in GENIE (*Phys. Rev. D* **105** (2022) 072001)
  - Beth's also producing mock data for near and far detector → useful characterisation of effects that can confound sterile neutrino signals!
- We're also developing the full systematics framework to include correlated systematic uncertainties
  - 128 (cross-section x flux) systematic parameters
  - Many interaction modes
    - → O(1000) individual response functions!
- Carrying out cross-checks with other SBN fitter groups



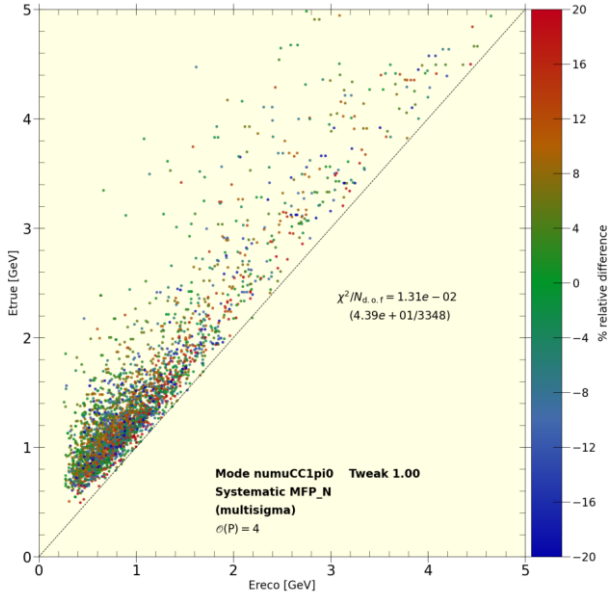


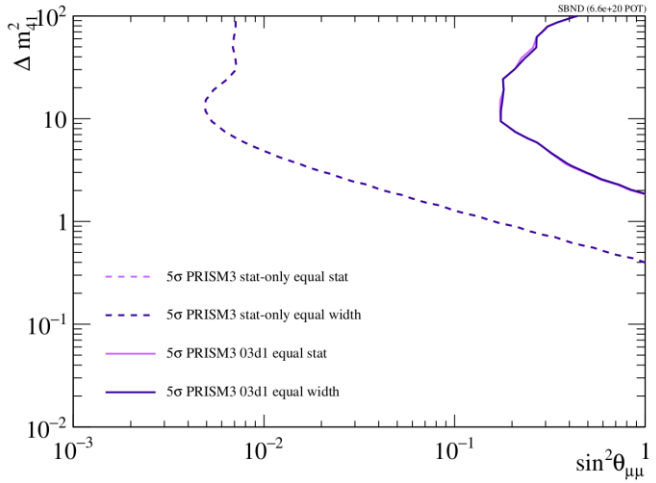




ν_μ CC $1\pi^0$ FSI:
vary mean-free-path of nucleon in nucleus

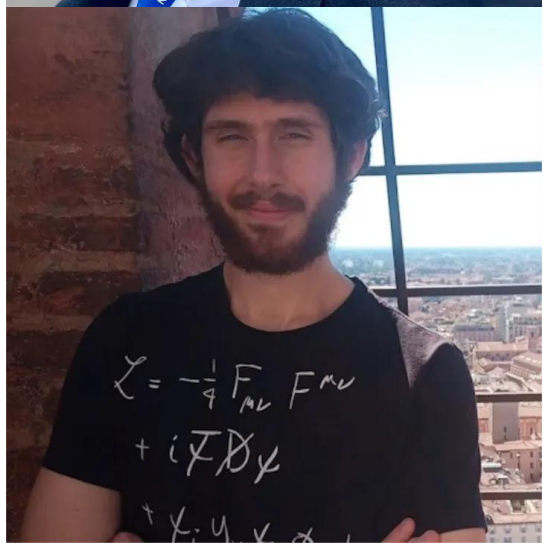
tweak dial: -3, ..., 3 σ





It's been a great year and we're looking forward to another excellent one!

Huge **thanks** to everyone for helping get awesome physics out of SBND 😄



JUNO (Jiangmen Underground Neutrino Observatory)

A massive (20 kton) liquid scintillator detector (the **largest ever built**) with **extreme radiopurity and energy resolution**.
700 m underground, 53 km away from the Taishan and Yangjiang nuclear power plants **in south China**, near Hong Kong.

An observatory with **uniquely rich physics program**

- **reactor** neutrinos,
- **solar** neutrinos,
- **atmospheric** neutrinos,
- **geo-**neutrinos,
- diffuse **supernova** background neutrinos,
- nucleon decay
- dark sector searches

Main science goal: **Determination of the neutrino mass ordering (NMO) by 2030**

Liverpool is a new member of the JUNO Collaboration - one of only two UK groups (w/ Warwick)

JUNO work at Liverpool

- ML-based **neutrino event reconstruction** and classification
- **Physics simulations** - Liverpool-led **GENIE**: http://www.genie-mc.org
- **Analysis frameworks** - Liverpool-led **VALOR**: https://valor-fit.github.io
- **Atmospheric neutrino** oscillation analysis
  - Aiming to **enhance JUNO NMO** sensitivity
- Other analysis topics under consideration
  - ***Dark sector** searches,*
  - *Tests of **quantum foundations***

Team Leader
*Prof. Costas **Andreopoulos***

PhD students:
- *Mr Liam **Jones***
- *Mr Yaoqi **Cao** (w/ Warwick)*
- *Mr. Ziou **He** (w/ Warwick)*
- *Mr Zekun **Yang** (expected to start 10/2025)*
- *Ms Qianying **Yu** (expected to start 10/2025)*

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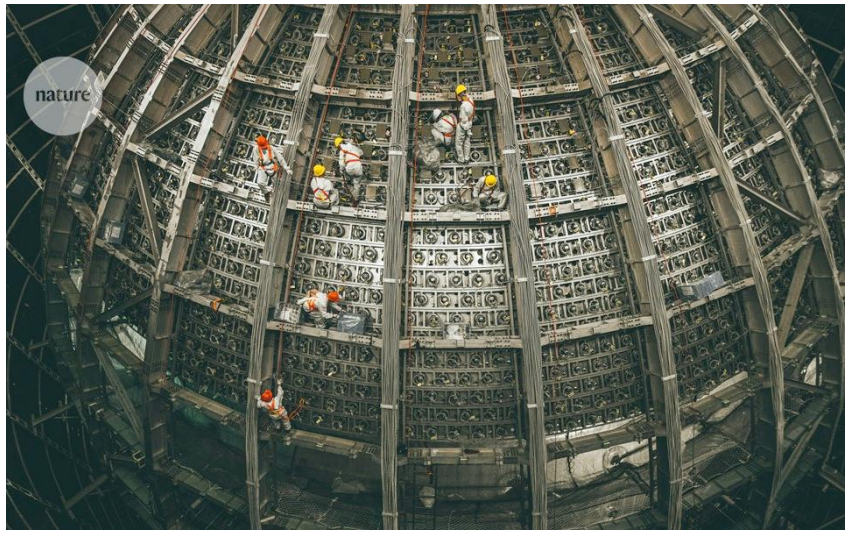
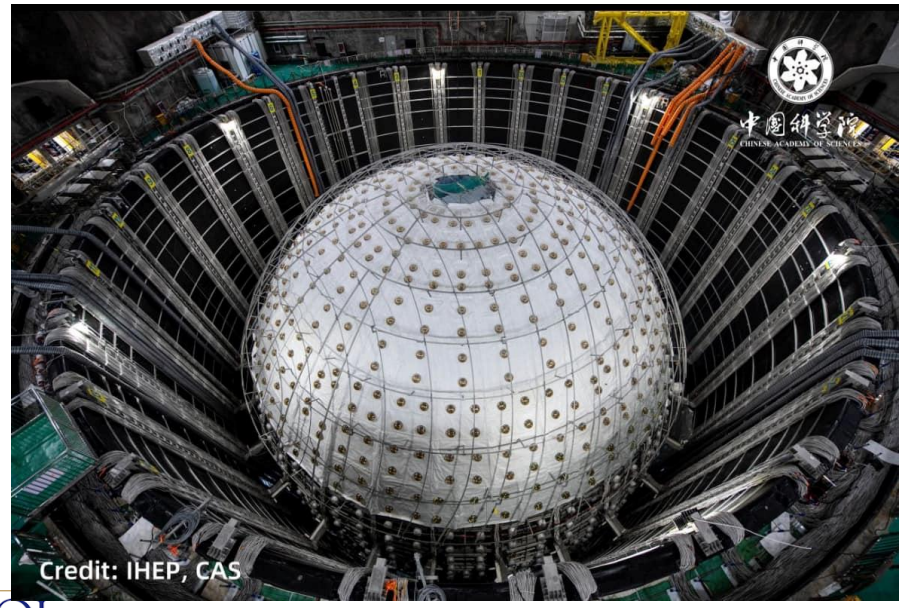
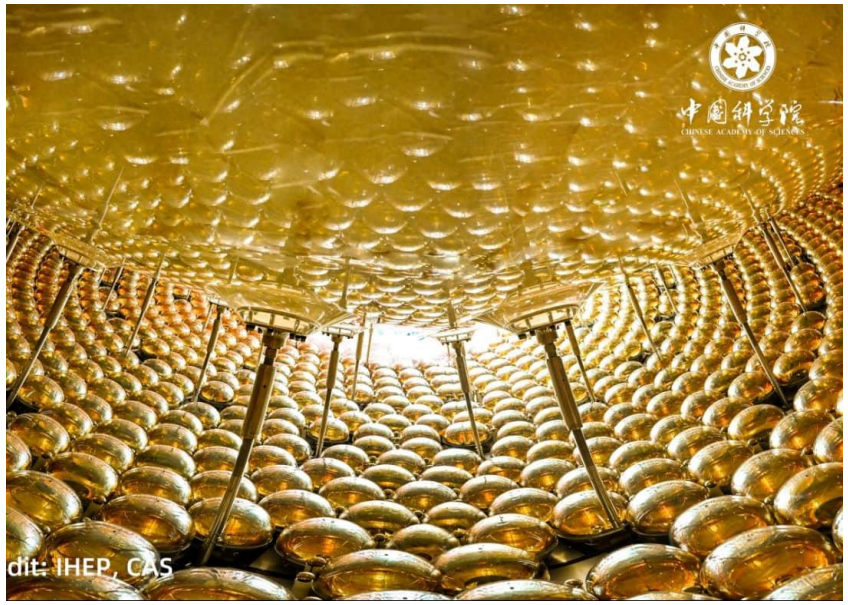
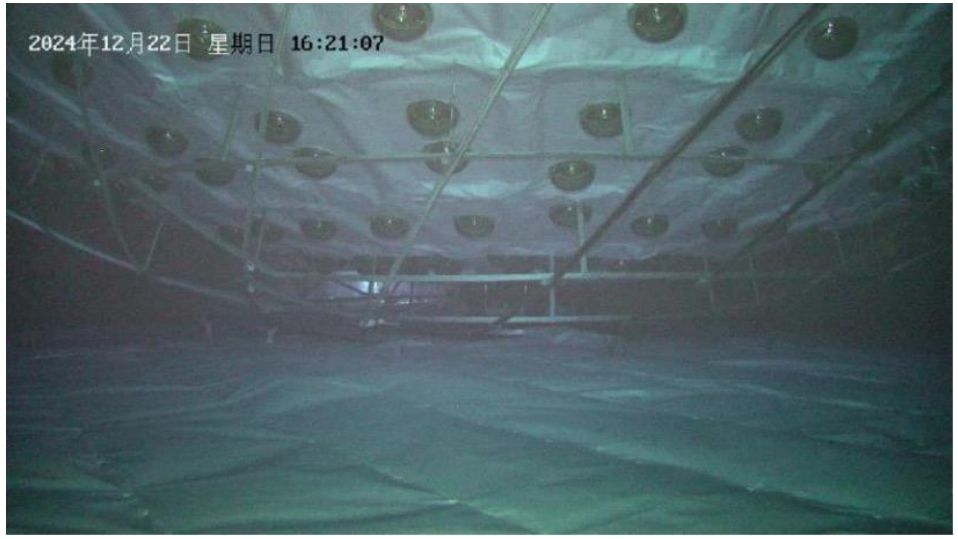
JUNO starts physics data taking in August 2025





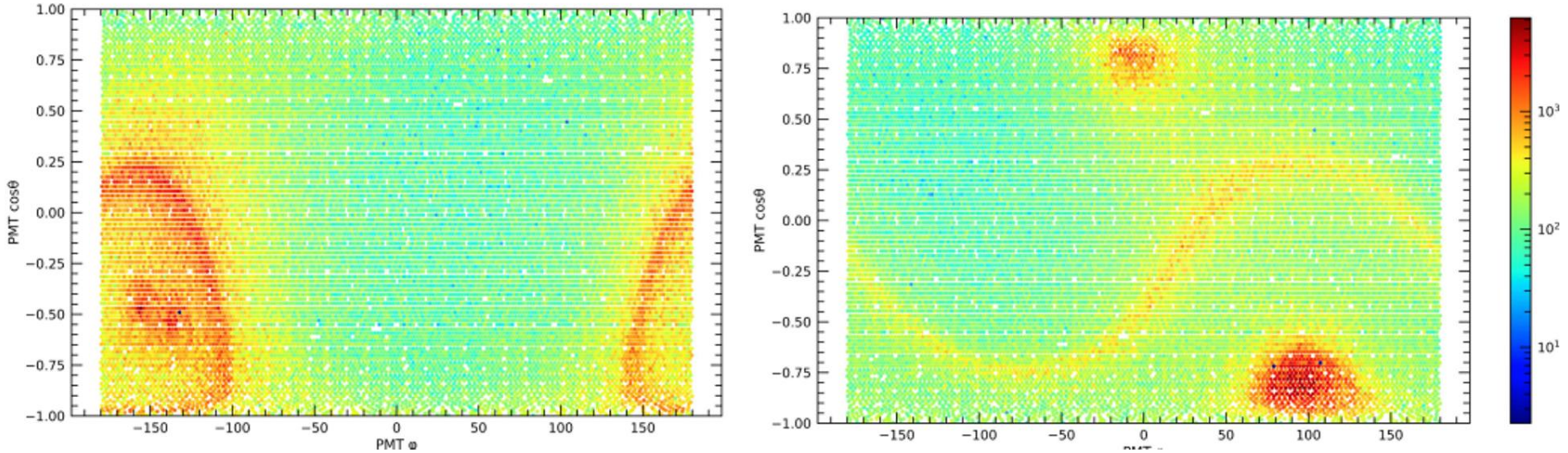


JUNO starts physics data taking in August 2025

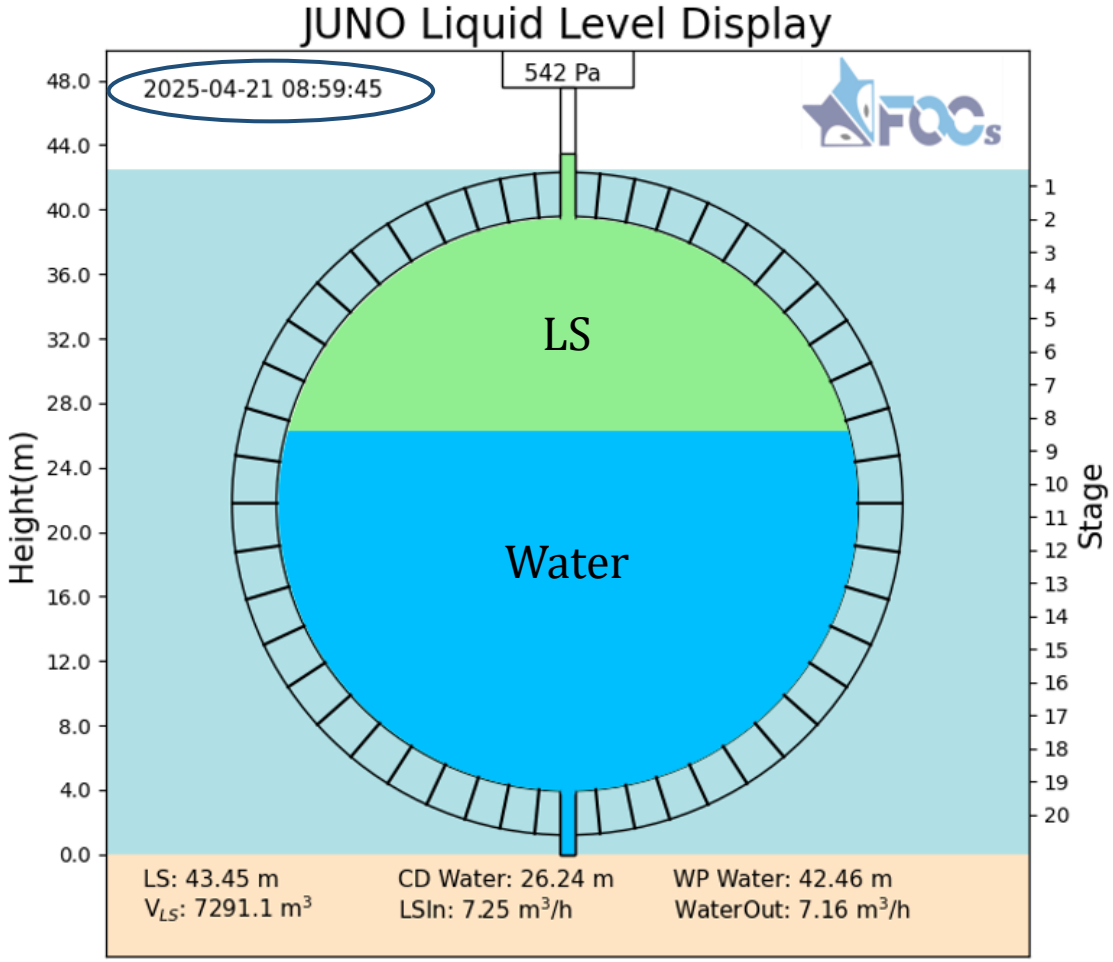


Filling with water
completed earlier this year

First muon events in water pool - PMTs work fine



JUNO starts physics data taking in August 2025



Replacing the water in the central detector (CD) **with** the JUNO **liquid scintillator** (LS) mix is in progress.

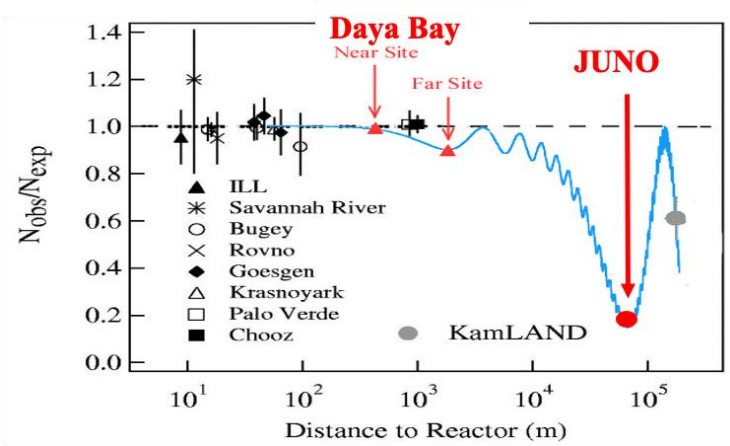
Comprehensive QC/QA program at every step of the LS production and frequent measurement for batches:

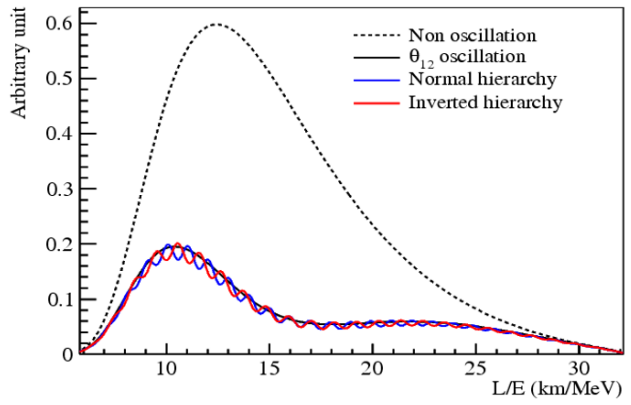
- UV-Vis for every batch
- Attenuation length for sampling batches, ~20m
- Radiopurity by ICP-MS every week:
  - U/Th <~ 1×10^{-16} g/g
- ^{222}Rn by test facility (OSIRIS):
  - ~ 0.5 mBq/m^3
- Radiopurity monitoring for N2 and water
- Leak control and checks

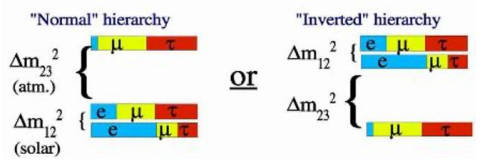
LS filling expected to be **completed** at the **end of July 2025**

JUNO has superb physics sensitivity

JUNO is using a novel technique that **exploits the interference between the solar and atmospheric oscillation** frequencies,





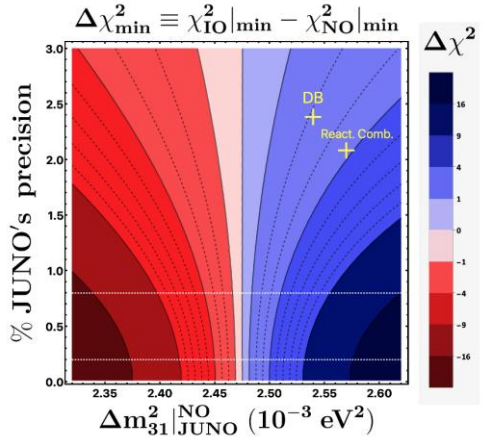


$$\Delta m^2_{31} = \Delta m^2_{32} + \Delta m^2_{21}$$
$$\text{NH}: |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|$$
$$\text{IH}: |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}|$$

$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$
$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$
$$P_{31} = \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})$$

	Central Value	PDG2020	100 days	6 years	20 years
Δm^2_{31} ($\times 10^{-3}$ eV^2)	2.5283	±0.034 (1.3%)	±0.021 (0.8%)	±0.0047 (0.2%)	±0.0029 (0.1%)
Δm^2_{21} ($\times 10^{-5}$ eV^2)	7.53	±0.18 (2.4%)	±0.074 (1.0%)	±0.024 (0.3%)	±0.017 (0.2%)
$\sin^2\theta_{12}$	0.307	±0.013 (4.2%)	±0.0058 (1.9%)	±0.0016 (0.5%)	±0.0010 (0.3%)
$\sin^2\theta_{13}$	0.0218	±0.0007 (3.2%)	±0.010 (47.9%)	±0.0026 (12.1%)	±0.0016 (7.3%)

$\sin^2 2\theta_{12}$, Δm^2_{21}, $|\Delta m^2_{32}|$, leading measurements in 100 days; precision <0.5% in 6 years



Combination for JUNO **atmospherics** and/or external data accelerator (NOvA, T2K) or atmospheric data enhances JUNO sensitivity.

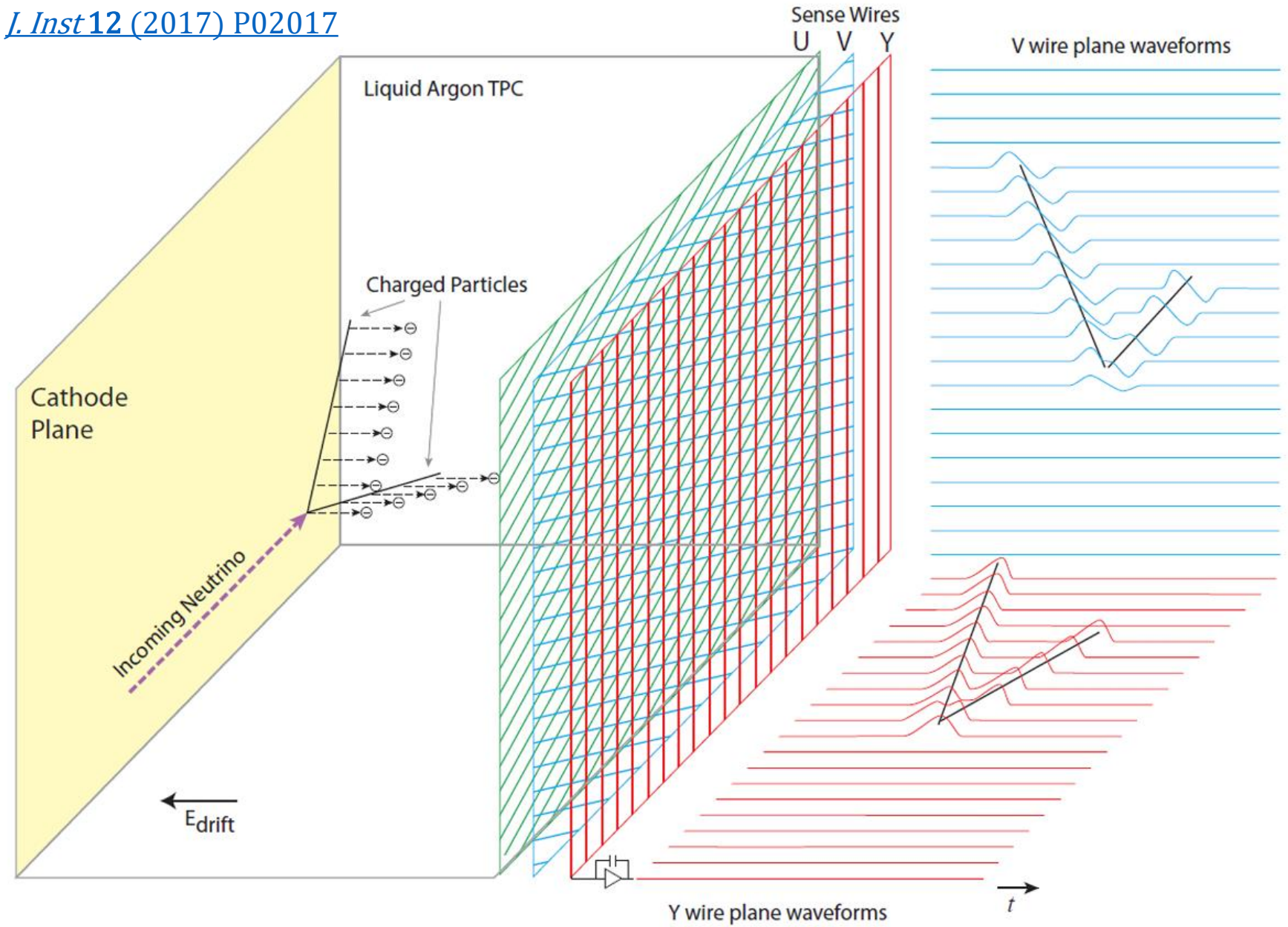
~3σ NMO determination with only ~1 year of data is a distinct possibility.

https://arxiv.org/pdf/2404.08733

Exciting times for JUNO just ahead; Stay tuned

Backup

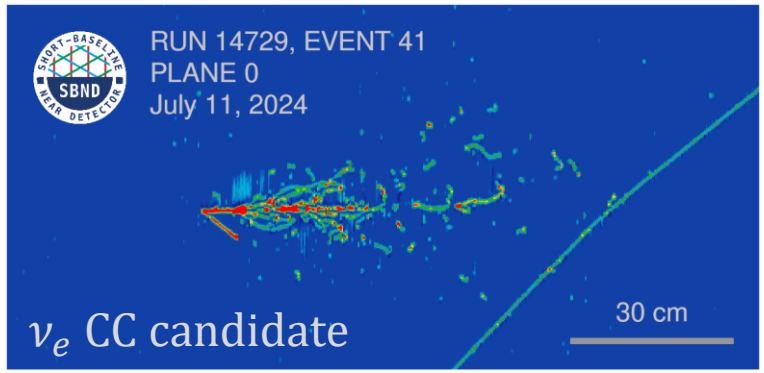
J. Inst **12** (2017) P02017

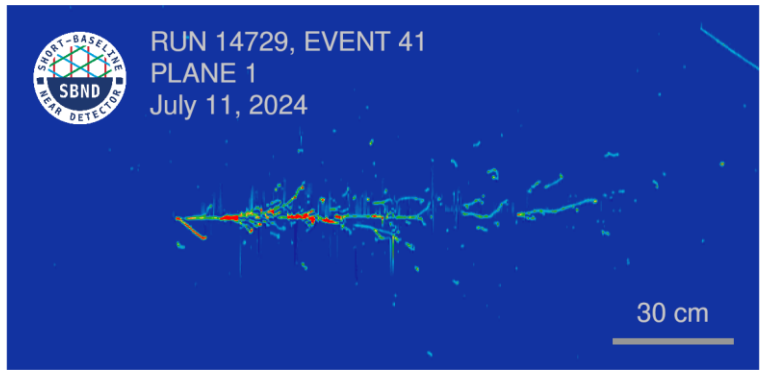


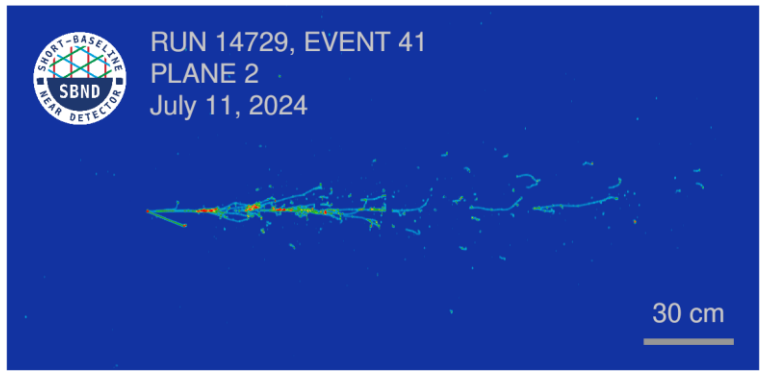
U and V ("induction") planes produce bipolar waveforms from electron drift

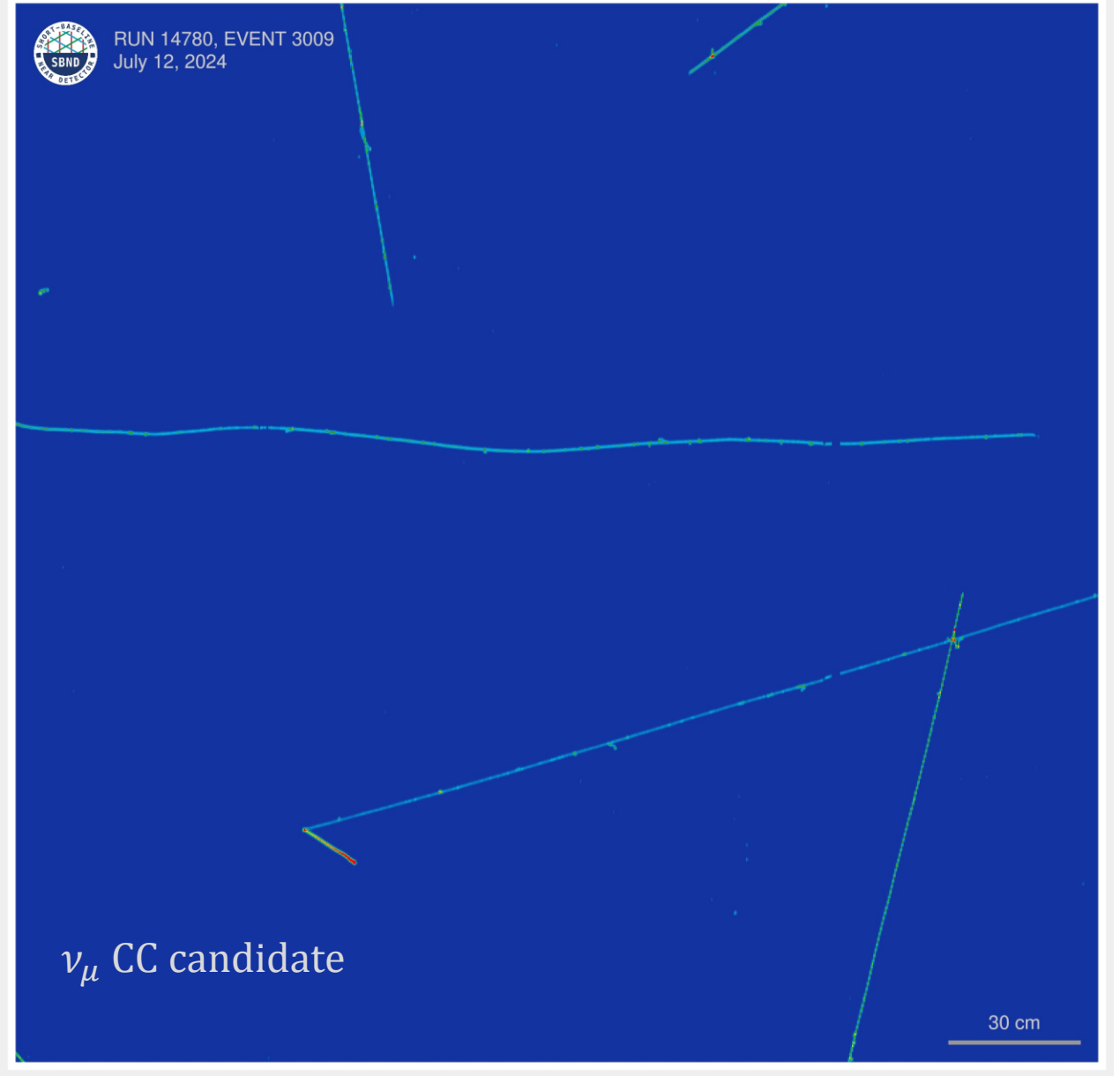
Y ("collection") plane produces unipolar waveforms from accumulated charge on anode

(SBND has two TPCs with the cathode in the middle)


RUN 14729, EVENT 41
PLANE 0
July 11, 2024
30 cm
ν_e CC candidate

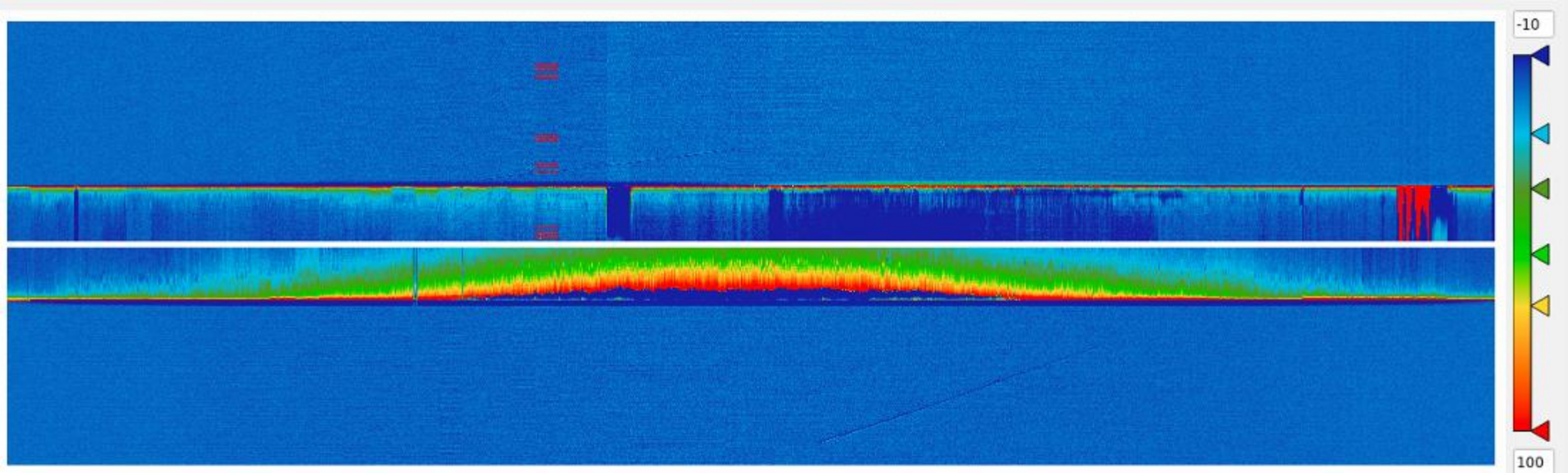

RUN 14729, EVENT 41
PLANE 1
July 11, 2024
30 cm

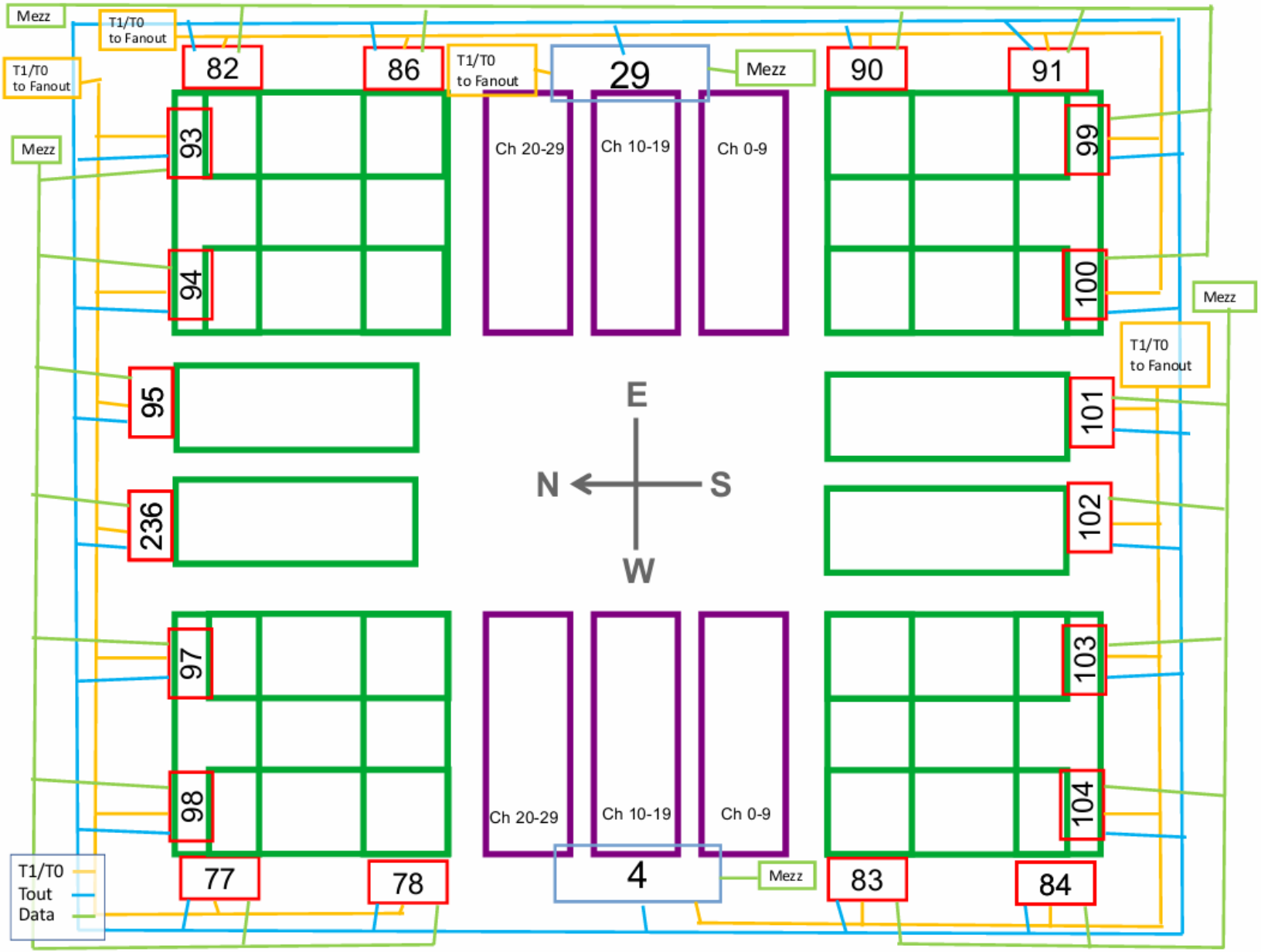

RUN 14729, EVENT 41
PLANE 2
July 11, 2024
30 cm


RUN 14780, EVENT 3009
July 12, 2024
30 cm
ν_μ CC candidate

Sunsets

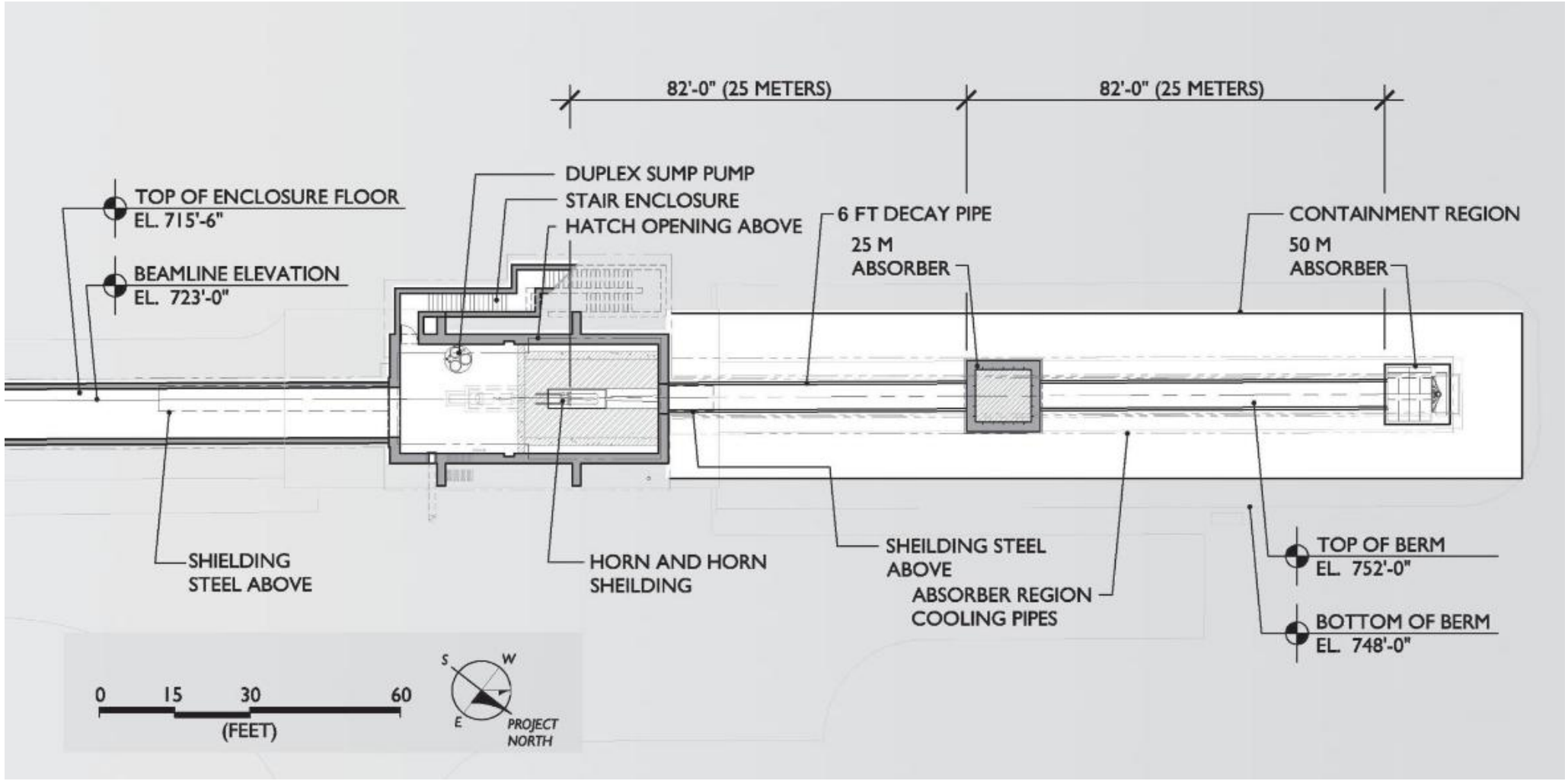
- An early feature of the detector showing characteristic “sunset” waveforms in the TPC
  - Believed to have been caused by an electrical short
  - Fixed during ramp-up - no sunsets have been observed since 35 kV (June 29, 2024)





CRT Bottom wall

(MINOS modules shown in purple)



[*Phys. Rev. D* **79** (2009) 072002]