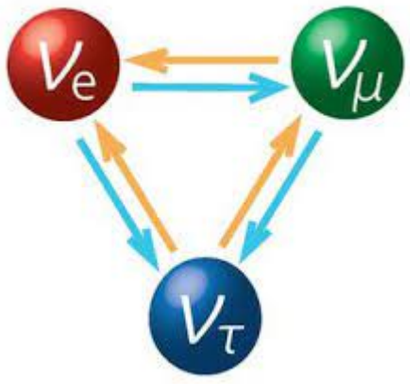


Neutrino physics

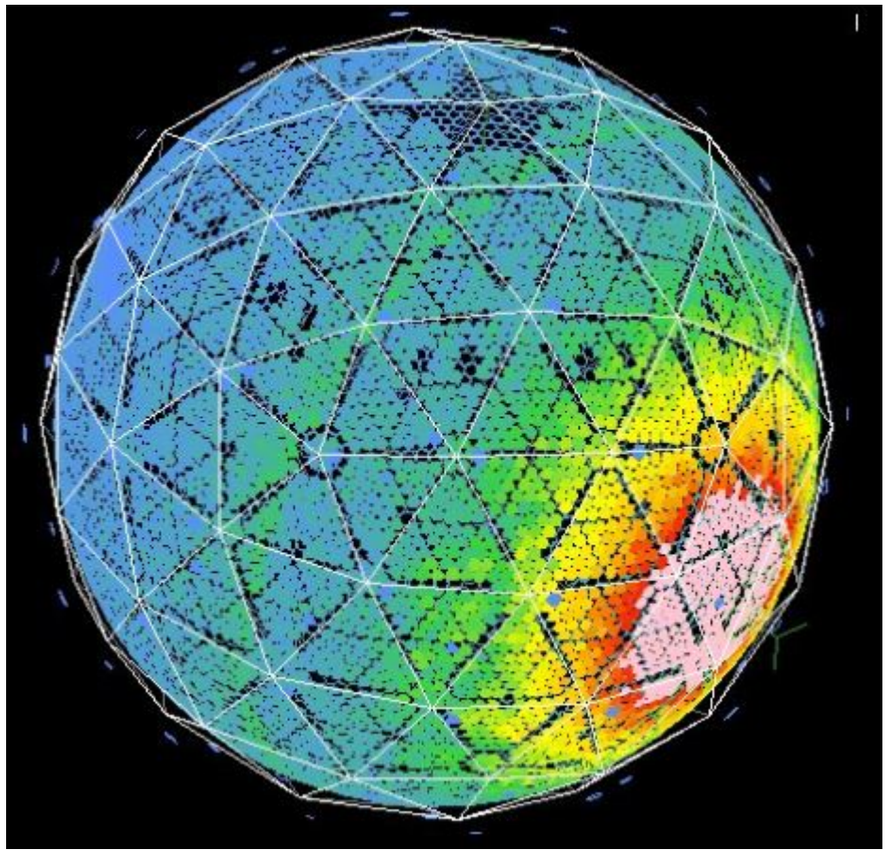
at the University of Sussex

Simon Peeters, on behalf of the neutrino group
EPP group meeting 2021.10.12

Summary

- A very brief overview of the field today
- How Sussex fits in
- What we have done over the last year and where we are going
  - SNO+
  - JSNS^2
  - SBND
  - NOvA
  - DUNE
  - Medical detectors

Only time for a very quick overview!

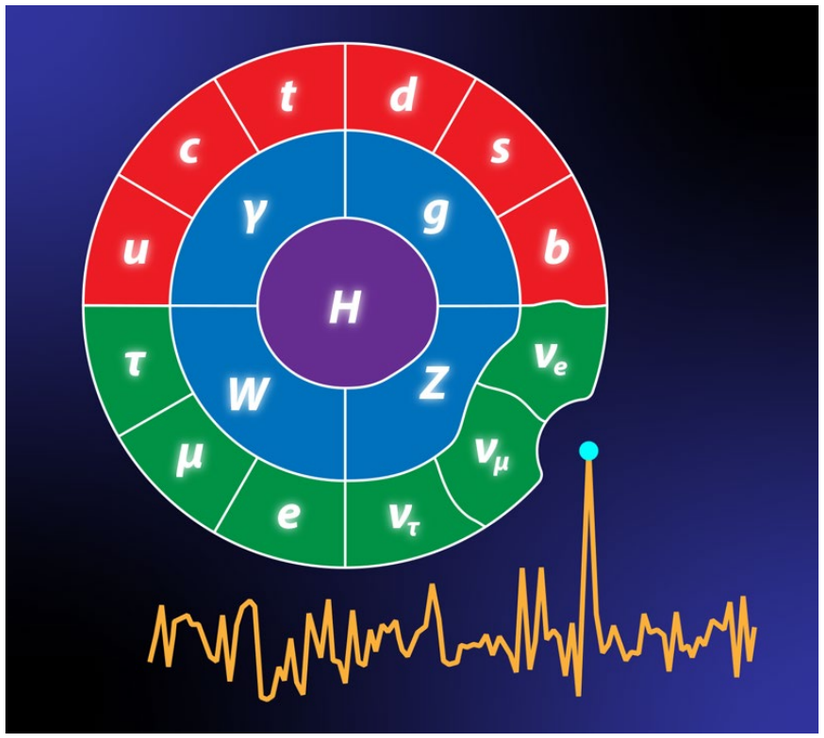


Neutrinos

Today's key questions

- Are neutrinos Majorana fermions?

- What is the neutrino mass hierarchy?



https://physics.aps.org/articles/v13/79

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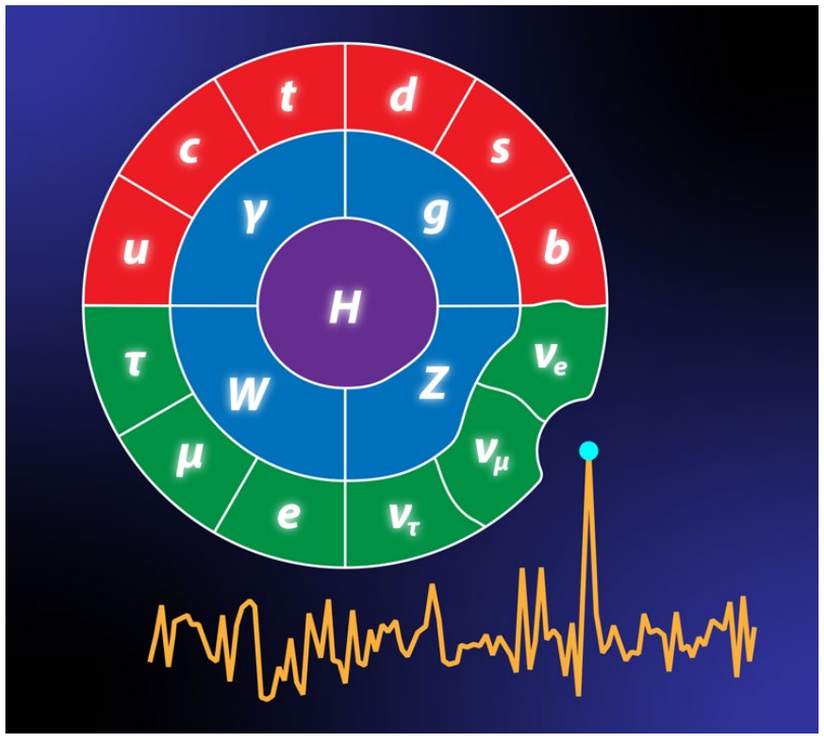

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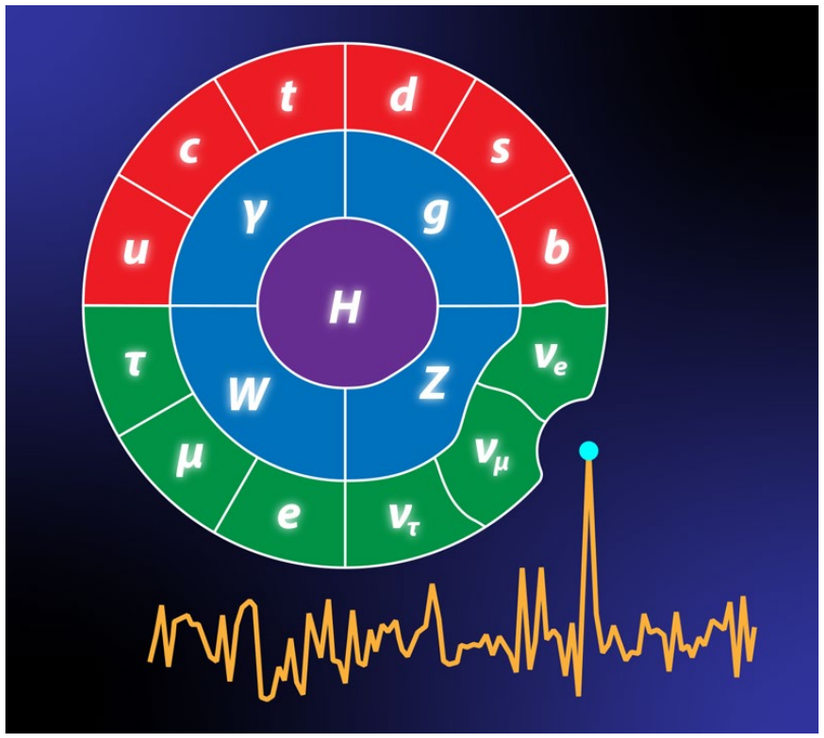
  NOvA, DUNE



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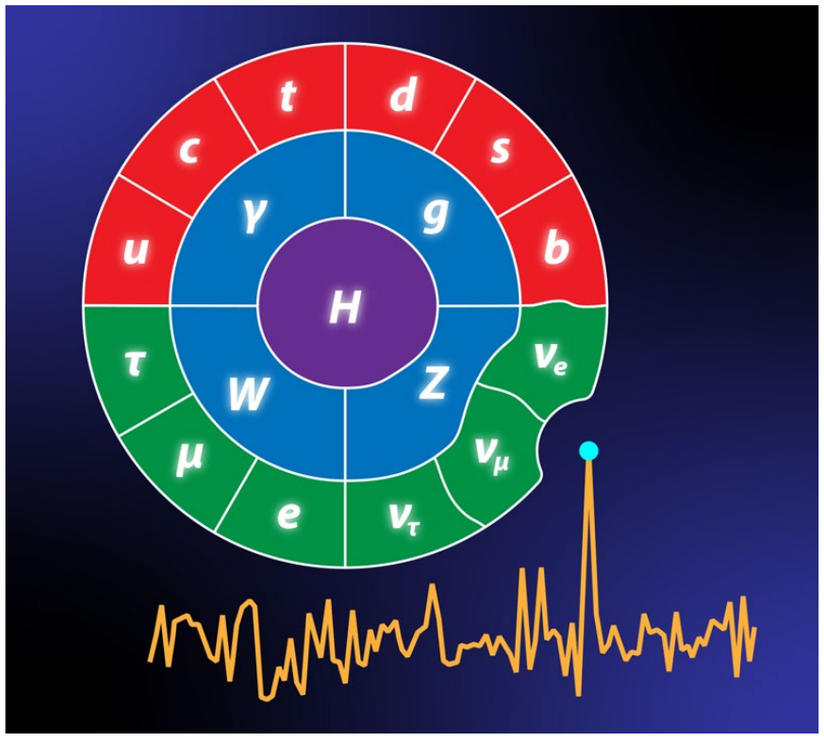

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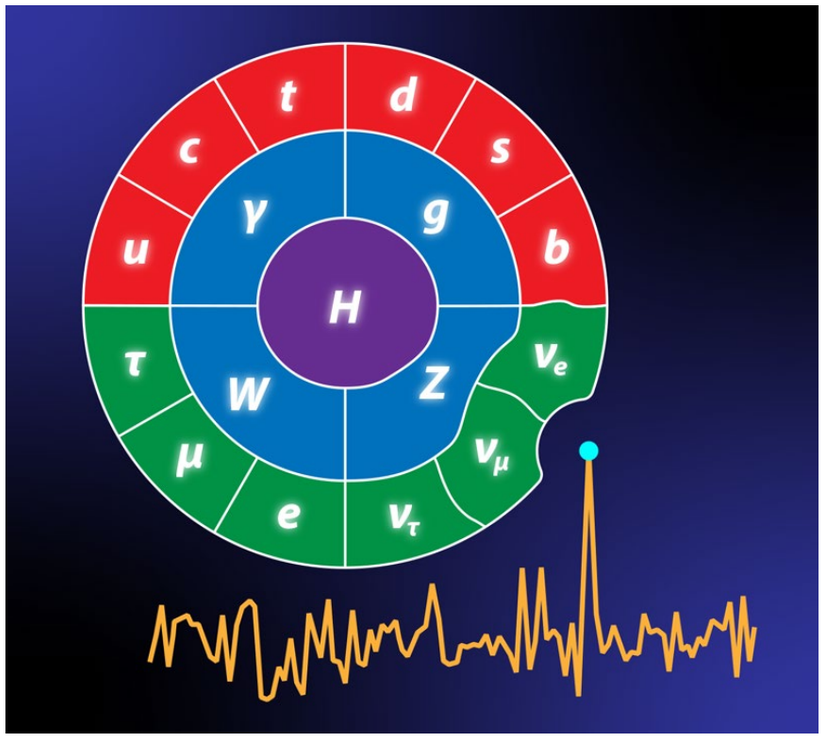

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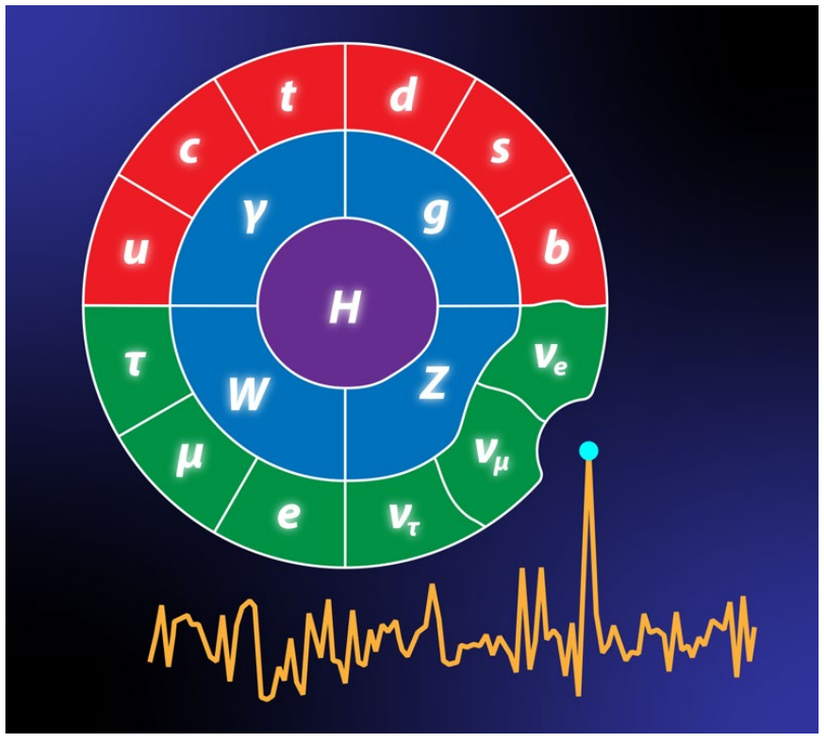

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  NOvA, DUNE

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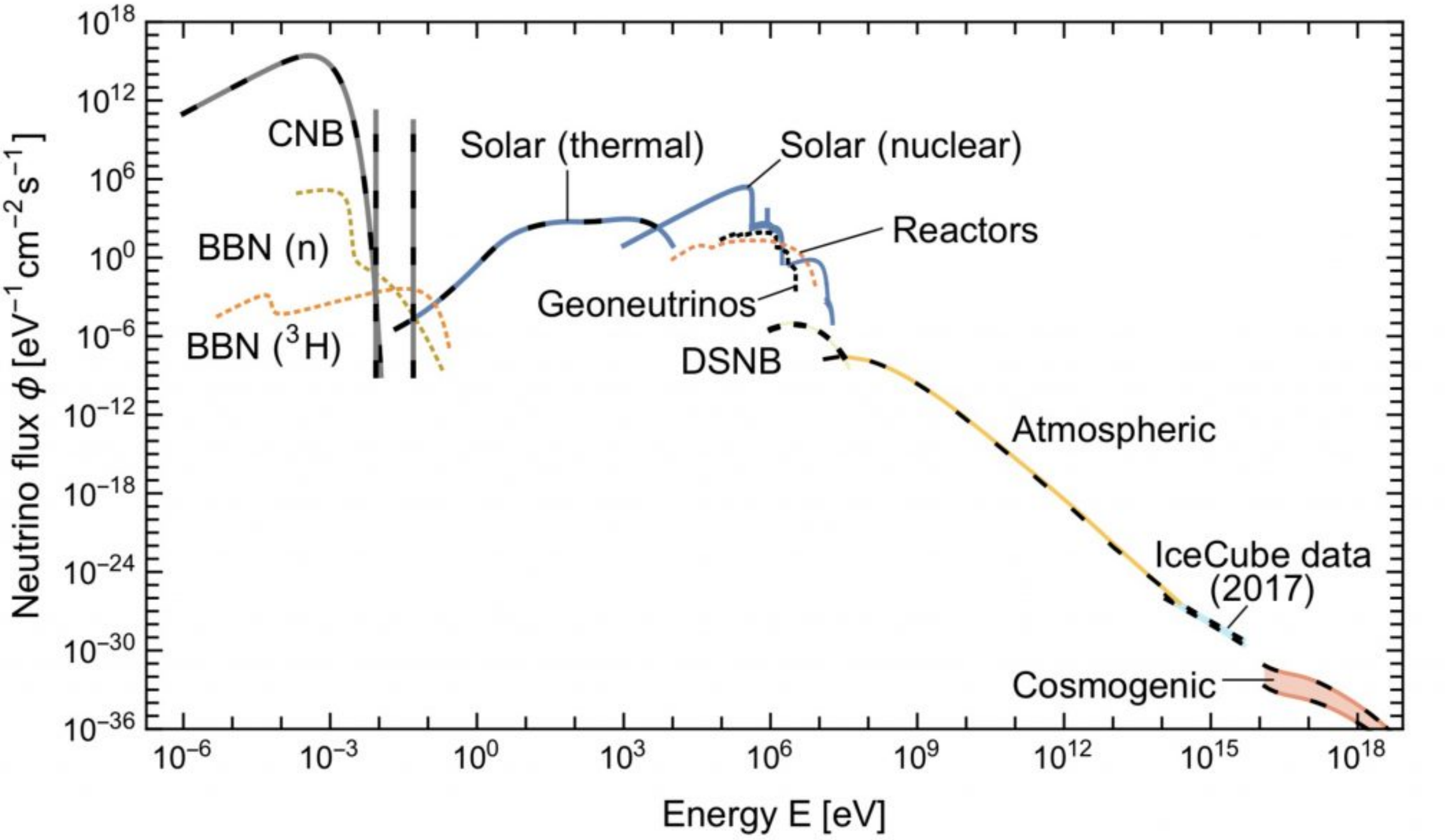
  JSNS^2, SBND

Other neutrino physics



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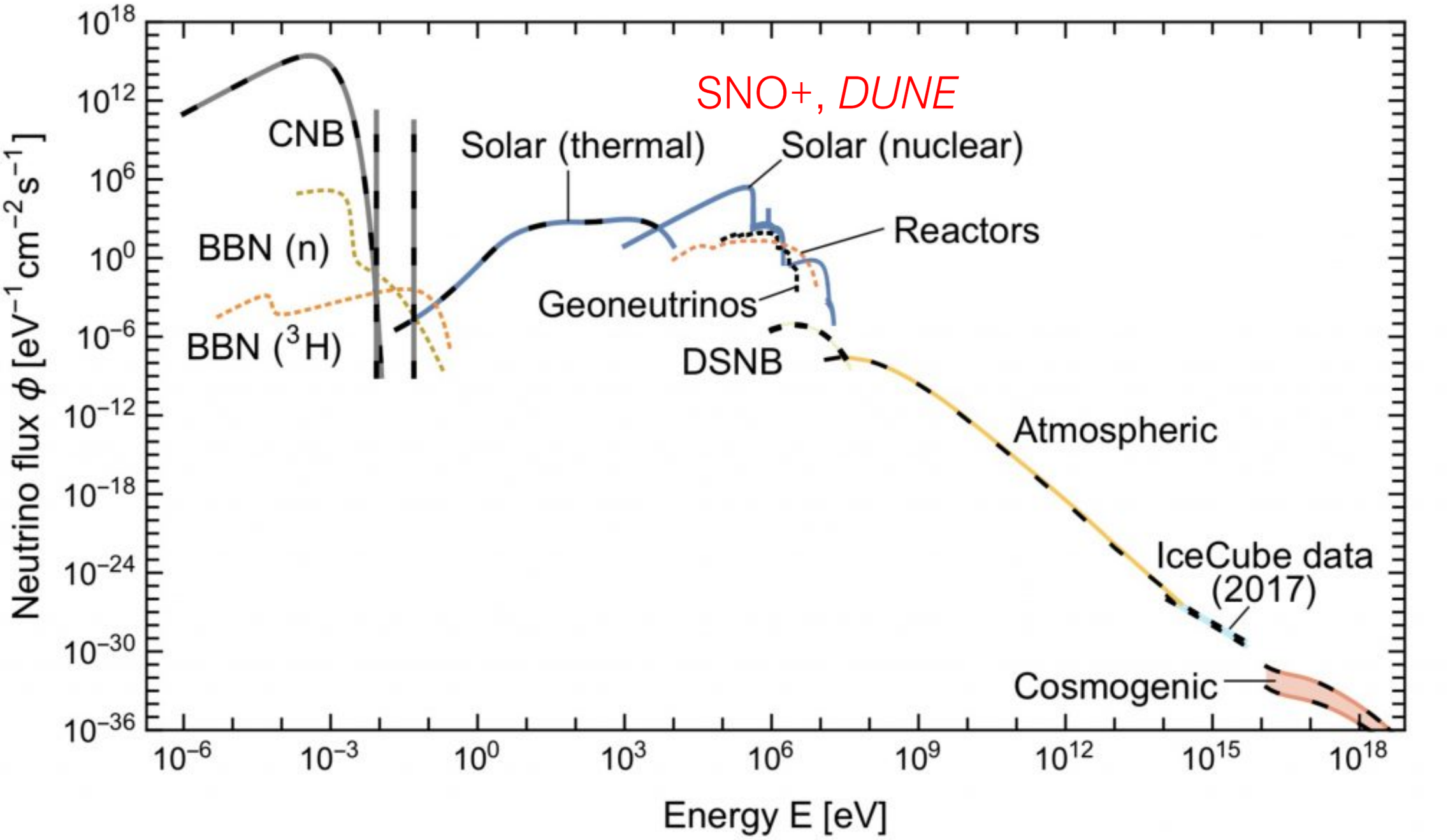

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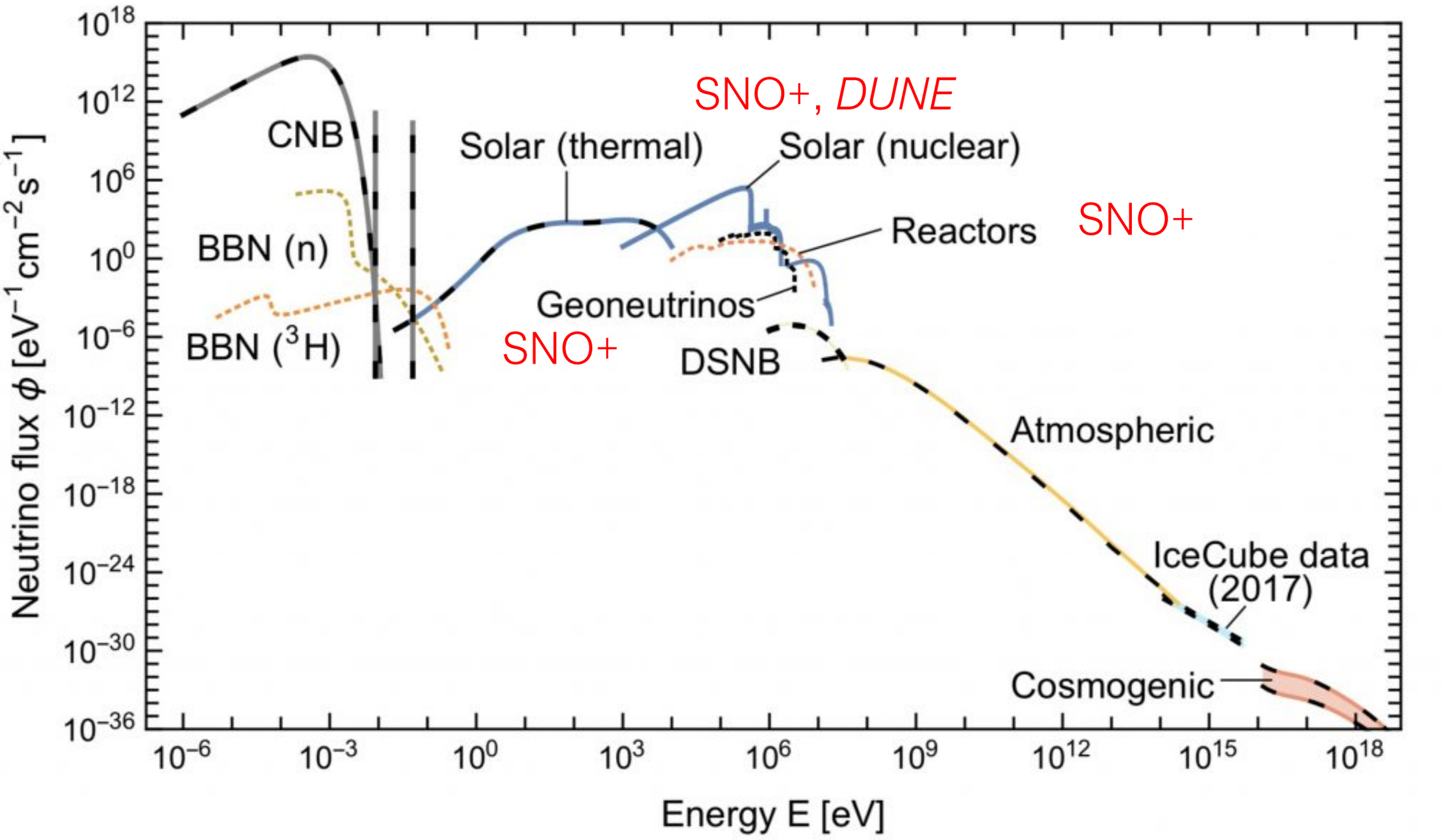

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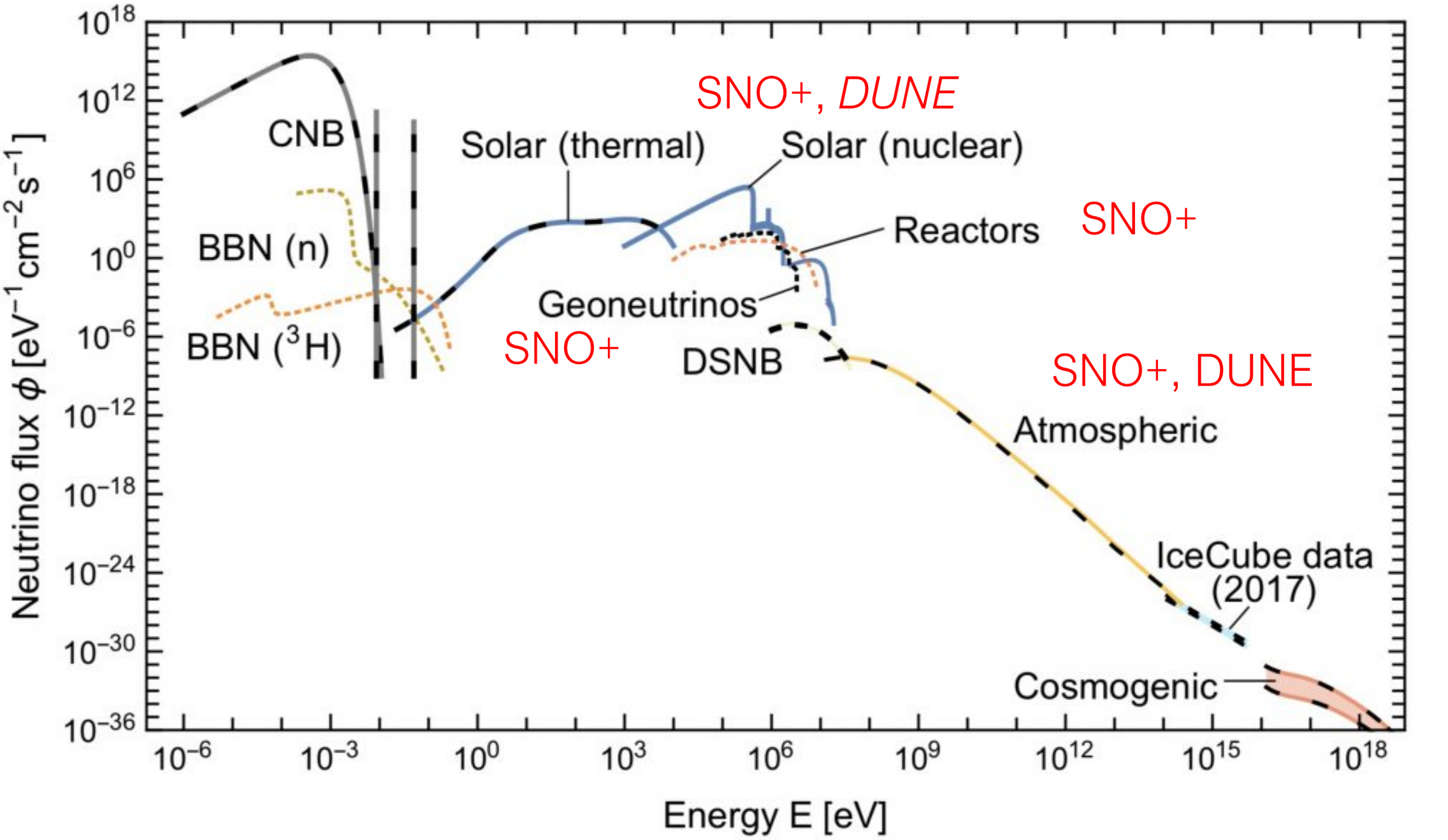
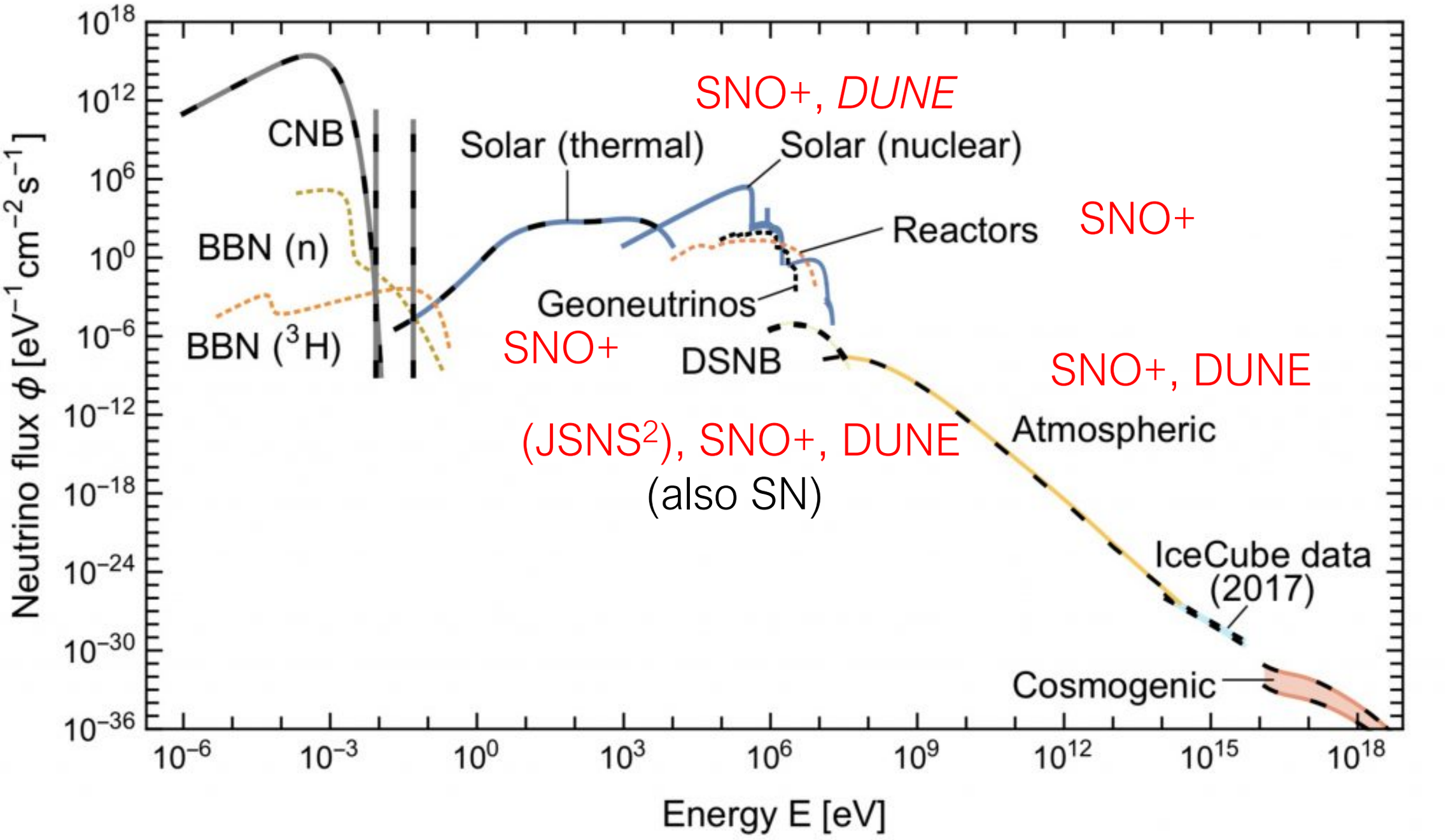
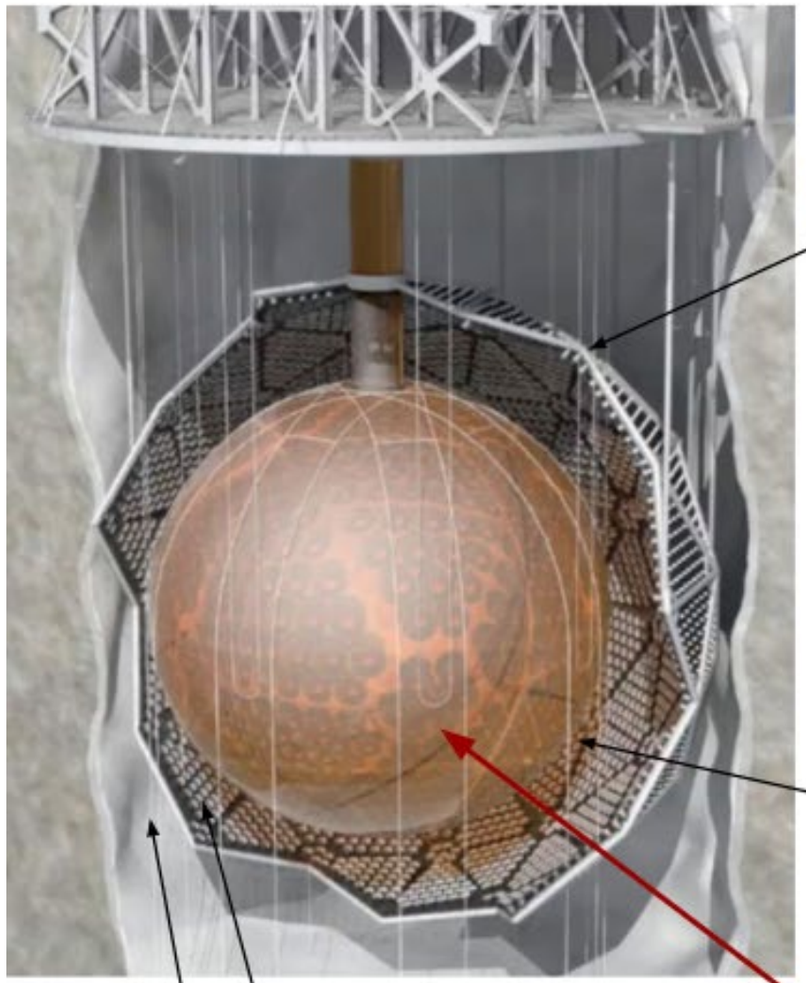


Other neutrino physics



2070 m rock overburden

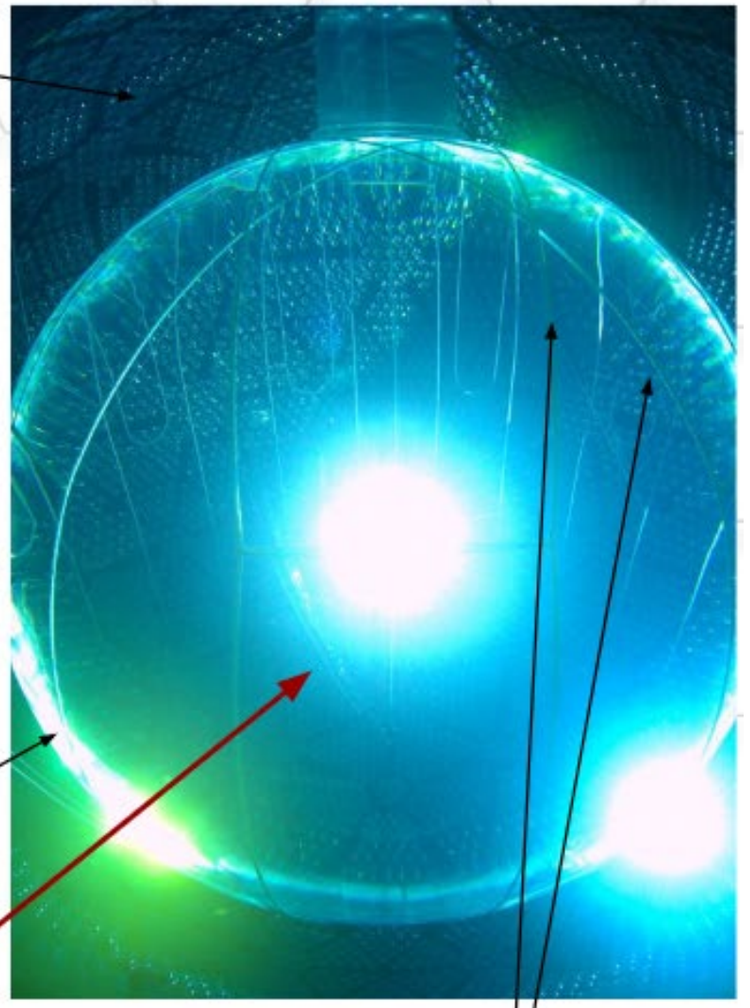


~9300 photomultiplier tubes (PMTs)

PMT support structure (18m diameter)

The SNO+ Experiment

Multi-purpose neutrino detector in Sudbury, Canada



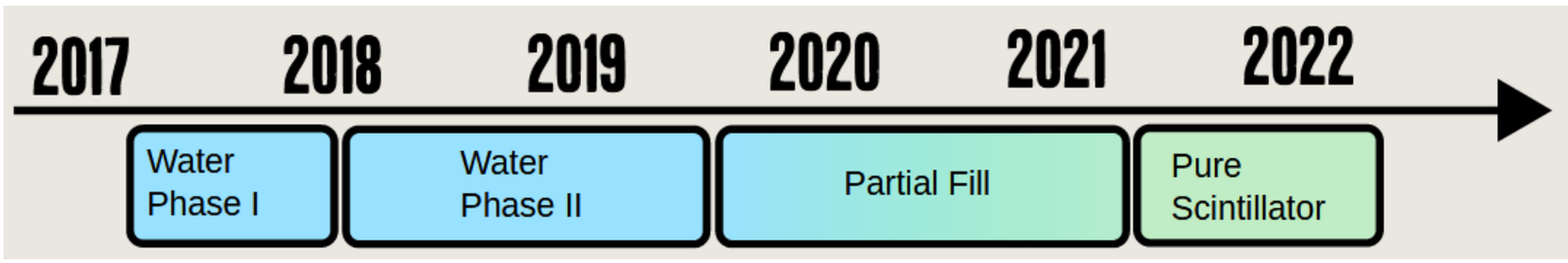
Acrylic vessel (12 m diameter)

5 kt ultra-pure water shielding

Target

905 t ultra-pure water - finished 2019
780 t liquid scintillator (LS) - full, ongoing fluor loading
4 t of natural Te loaded to the LS - loading starts 2022

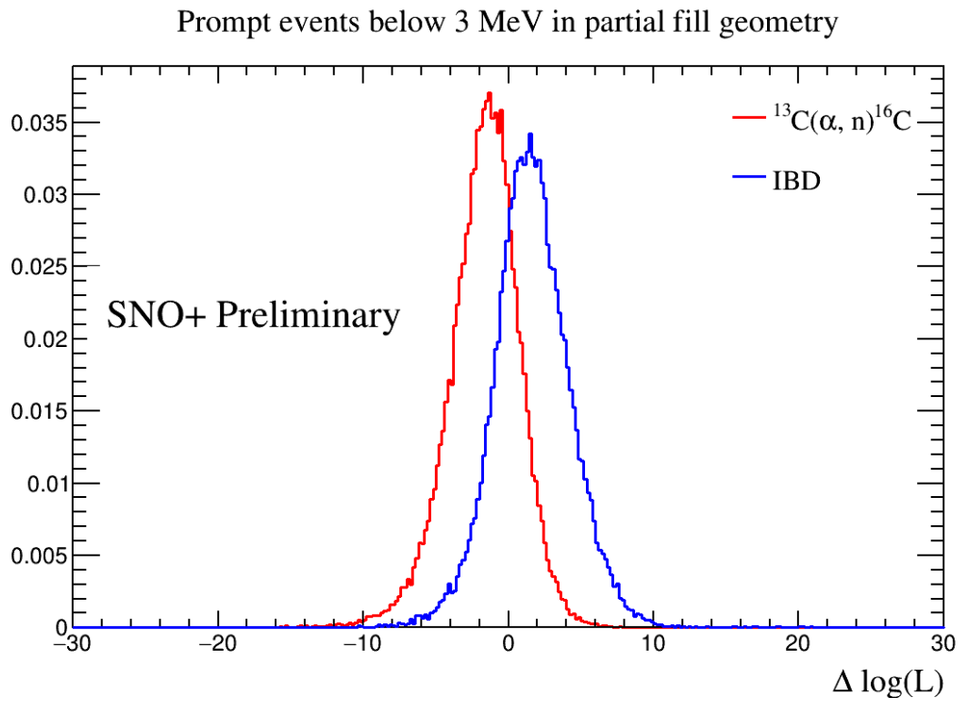
Hold up and hold down ropes



SNO+ Physics

<u>Reactor anti-neutrino oscillation</u>
(Charlie, James, Thiago, Lisa)

- Charlie (final year PhD) has developed an event classifier to discriminate between the IBD prompt event and its main background, alpha capture on ^{13}C followed by neutron capture. He is currently studying its impact on the sensitivity of the anti-nu analysis.



- James (2nd year) has developed a new algorithm to compute neutrino oscillation matter effects that is several times faster than the leading GLOBES software package, and which we will seek to submit for publication.

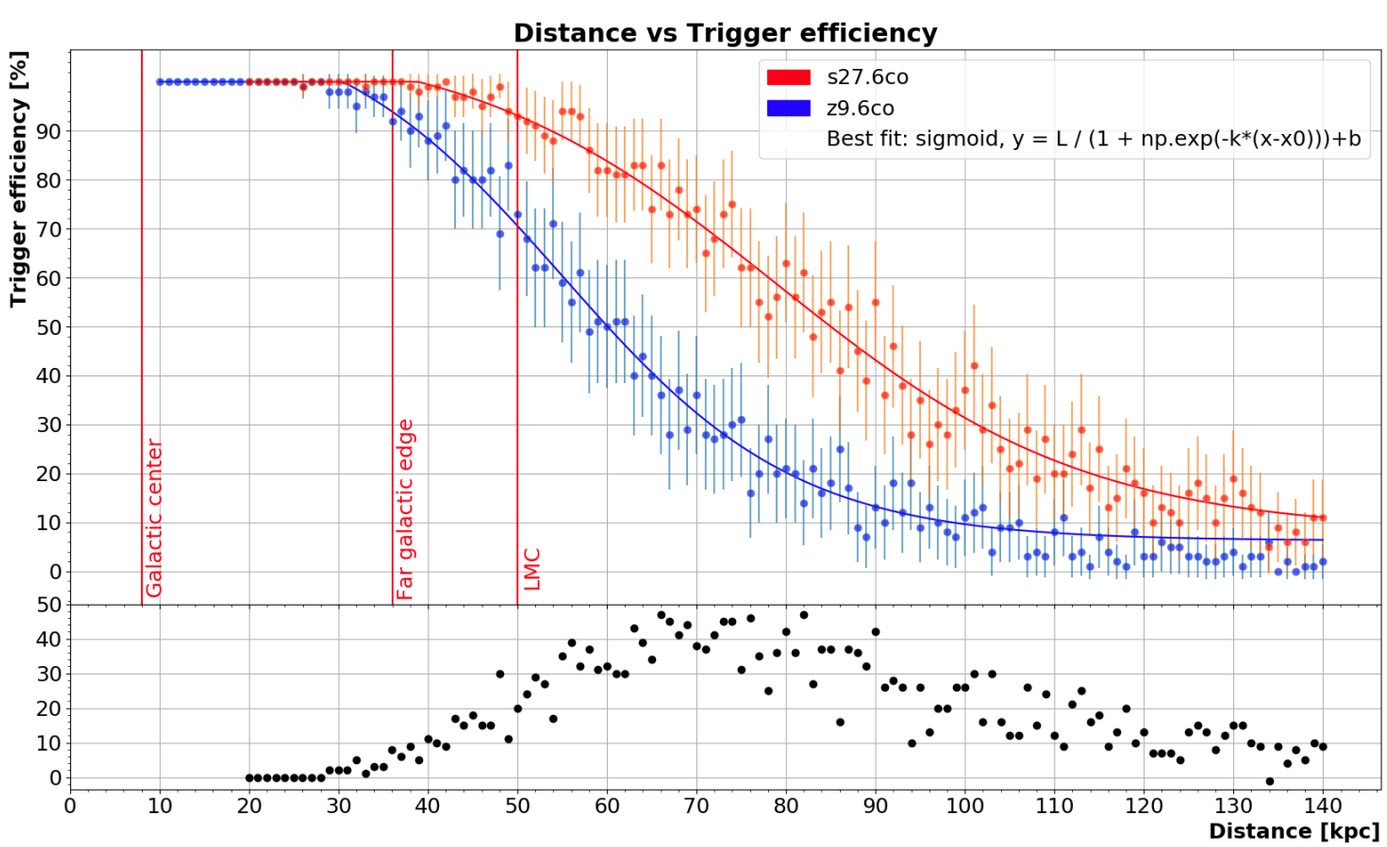
- Thiago, who joined SNO+ in the spring, is focusing on the IBD event selection, with a particular emphasis on assessing the removal of muons, an important source of background neutron events.

SNO+ Physics

Supernova neutrinos (Michal, Simon):

Michal, who has just submitted his thesis, and Simon have developed a complete supernova trigger system, including a burst trigger, monitoring web pages and an email alert system, which will be linked up with the global SNEWS supernova early-warning network.

His thesis includes a much updated assessment of the supernova sensitivity for SNO+ (including looking at black hole formation).



SNO+ Operations

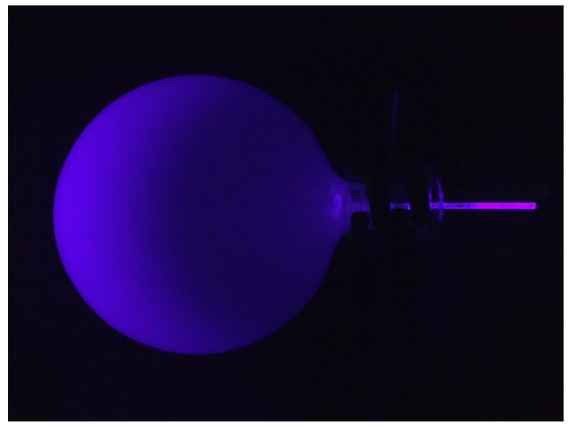
Calibration (Sammy, Michal, Simon, Charlie, James, Lisa)

Simon advises the SNO+ calibration group and is on the source committee (approval for source deployment).

Sussex is responsible for the development and operations of several of the experiment's optical calibration systems (TELLIE and AMELLIE, Laserball, UFO) for PMT calibration and attenuation monitoring of the detector medium.

Sammy is finalising the LB and UFO for imminent shipping to SNOLAB. He has recently taken over responsibility for the TELLIE PCA analysis from Michal, who will spend the next three months automating the analysis of TELLIE and start on automation of the operation of TELLIE + AMELLIE.

Charlie and James are developing the AMELLIE attenuation analysis and software.



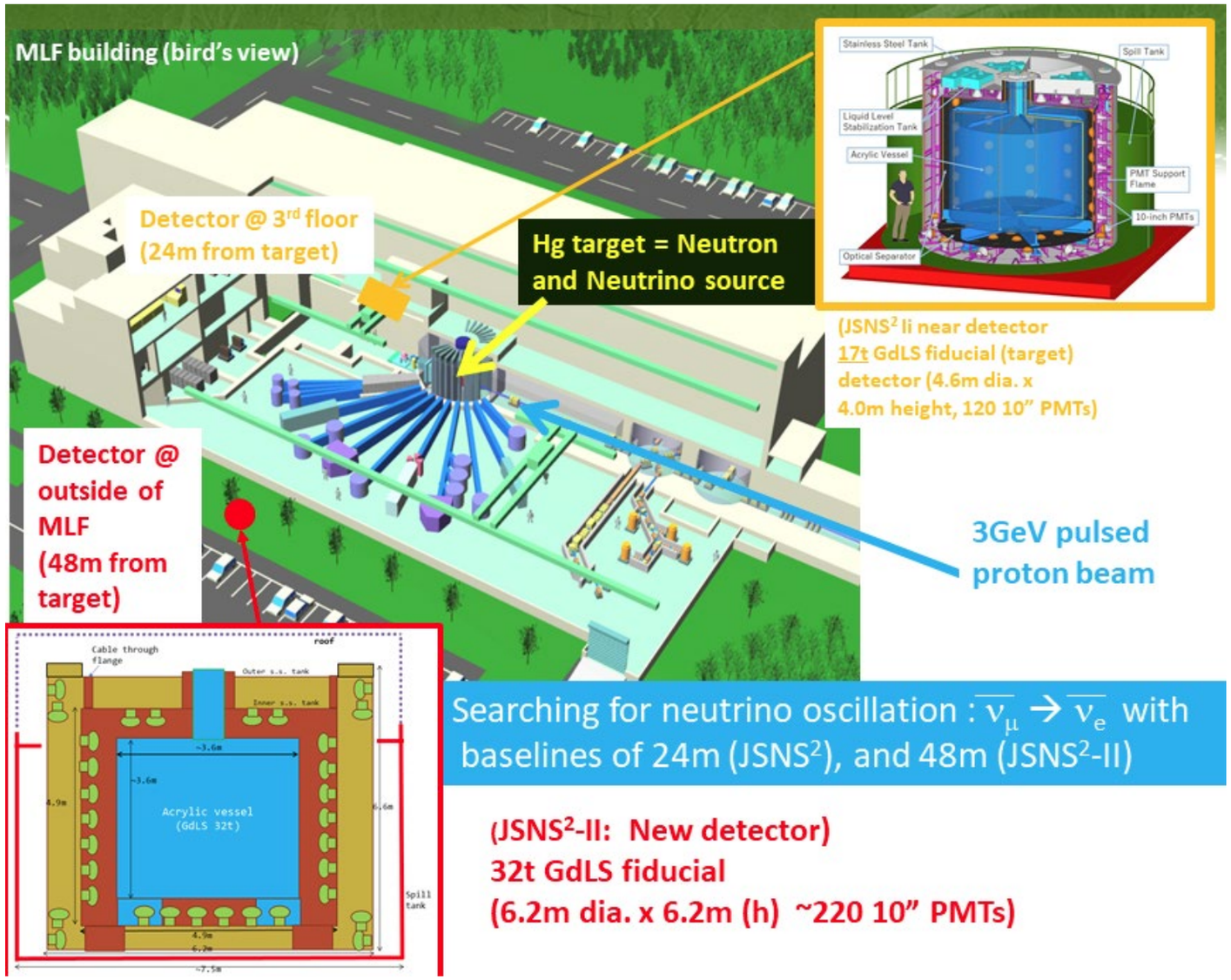
SNO+ Operations

Data quality and run selection (Charlie, James, Lisa):

Lisa co-convenes the Run Selection group, which is responsible for data quality checking. Charlie has developed several parts of the software framework, and James is continuing the automation of the production of run lists for physics analyses.

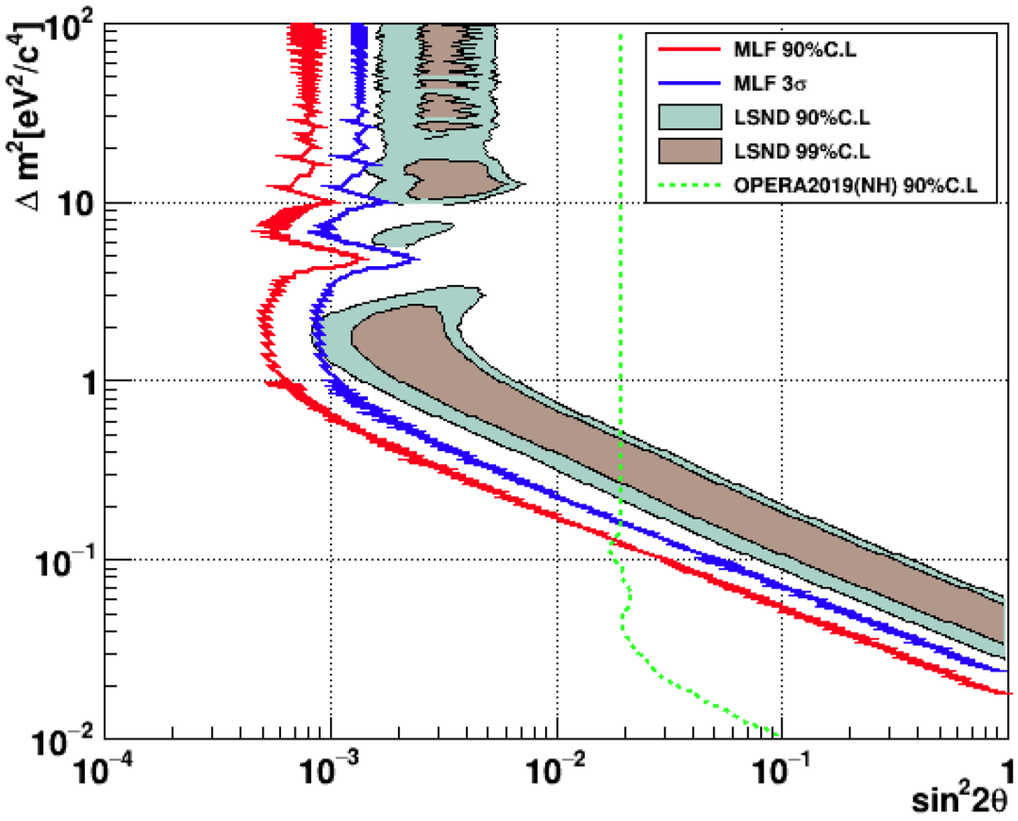
JSNS^2 I & II

(J-PARC, Japan)



Searching for neutrino oscillation : $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ with baselines of 24m (JSNS^2), and 48m (JSNS^2-II)

(JSNS^2-II: New detector)
32t GdLS fiducial
(6.2m dia. x 6.2m (h) ~220 10" PMTs)



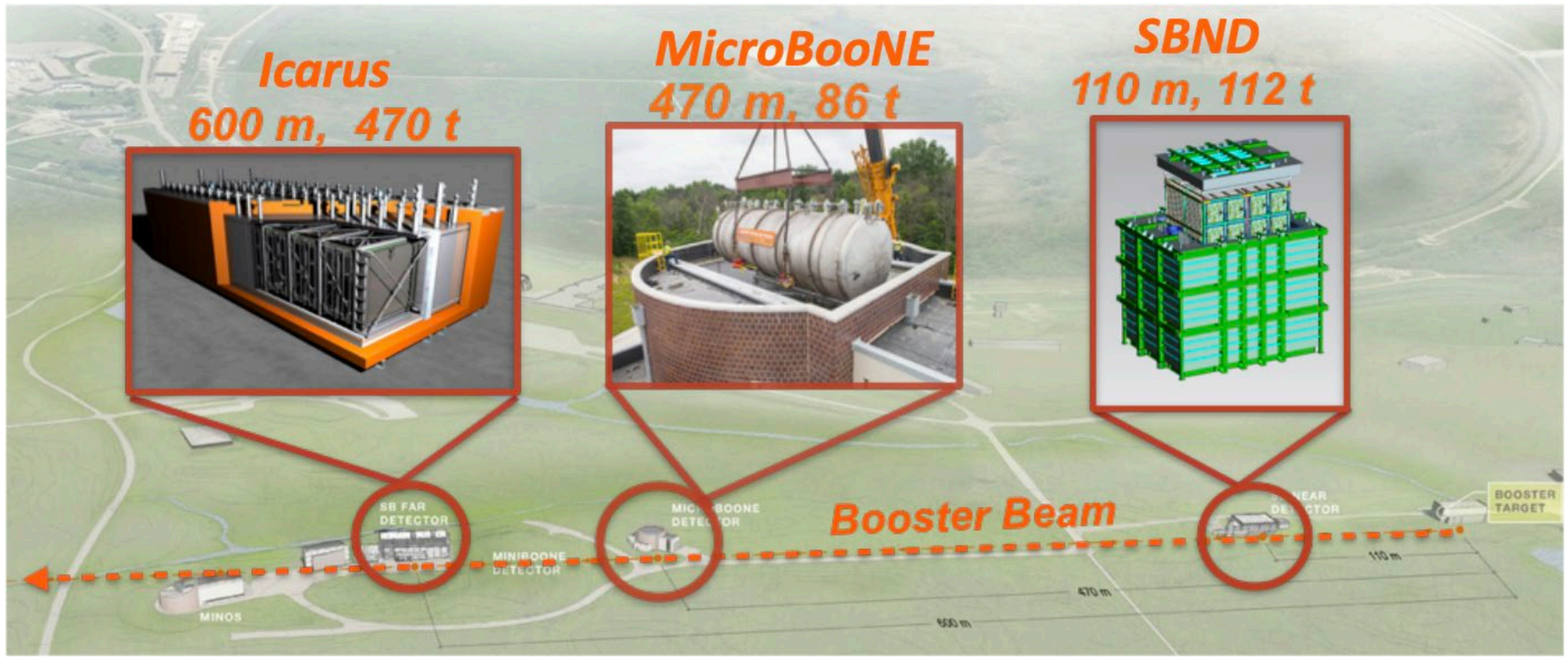
Sterile neutrino search

Simon (JSPS fellowship, involvement to Oct 22)

- Provided ultrafast calibration system to JSNS^2 I
- Providing second system for JSNS^2 II

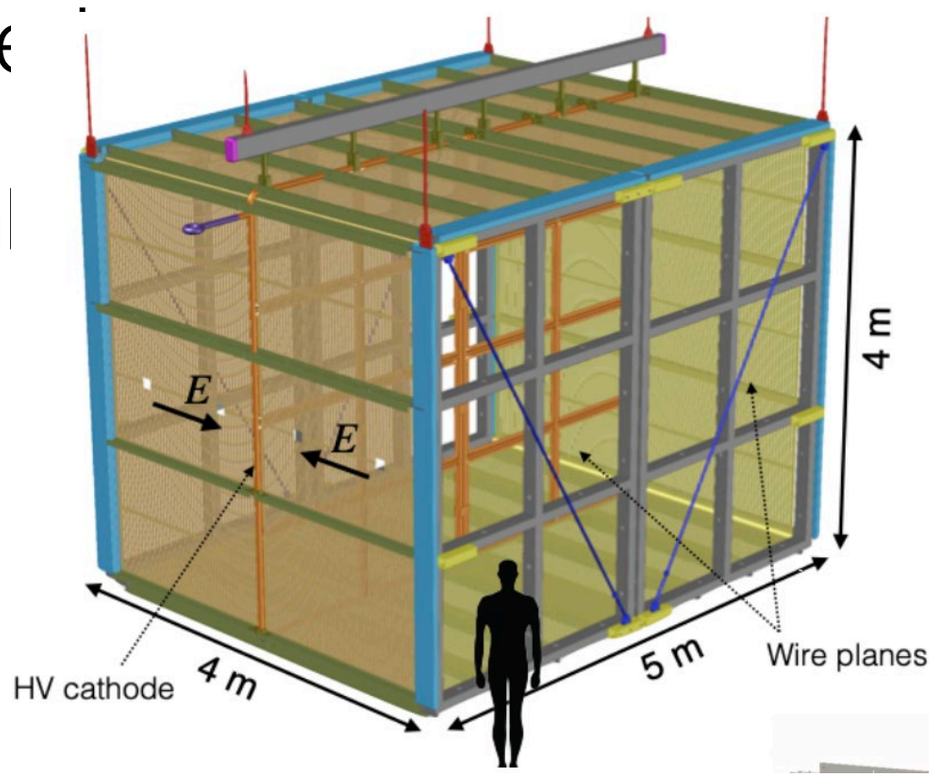
SBND experiment

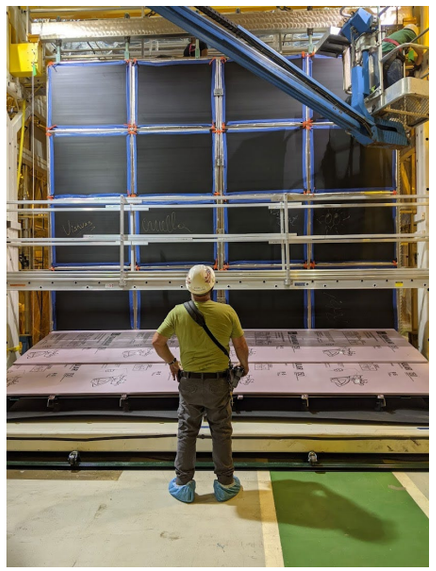
- Near detector of the LAr TPC Short Baseline Neutrino (SBN) program at Fermilab
  - Aims to nail down hints of anomalies in short baseline oscillation measurements seen in LSND, MiniBooNE, ...
  - Near detector is crucial to understand unoscillated neutrino flux, systematics



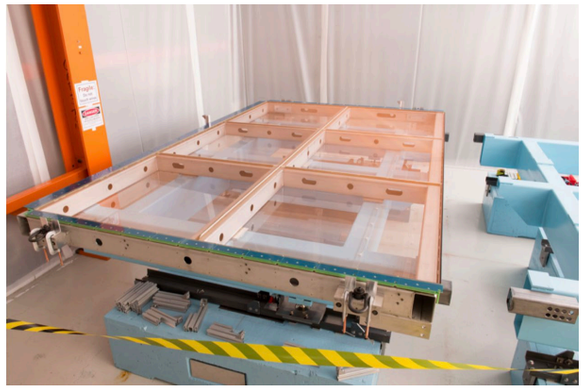
SBND construction

- Detector assembly is picking up spee
  - cathode plane and field cage assem
    plane mounting beginning
  - cryostat installation in November
- LAr filling to begin in late 2022





HV cathode

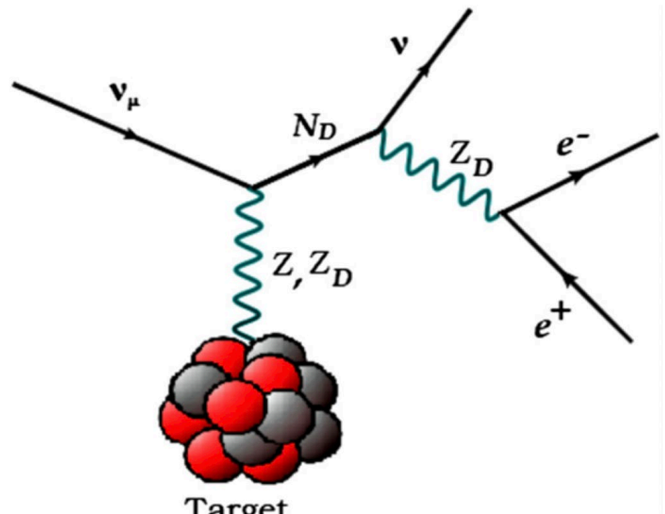


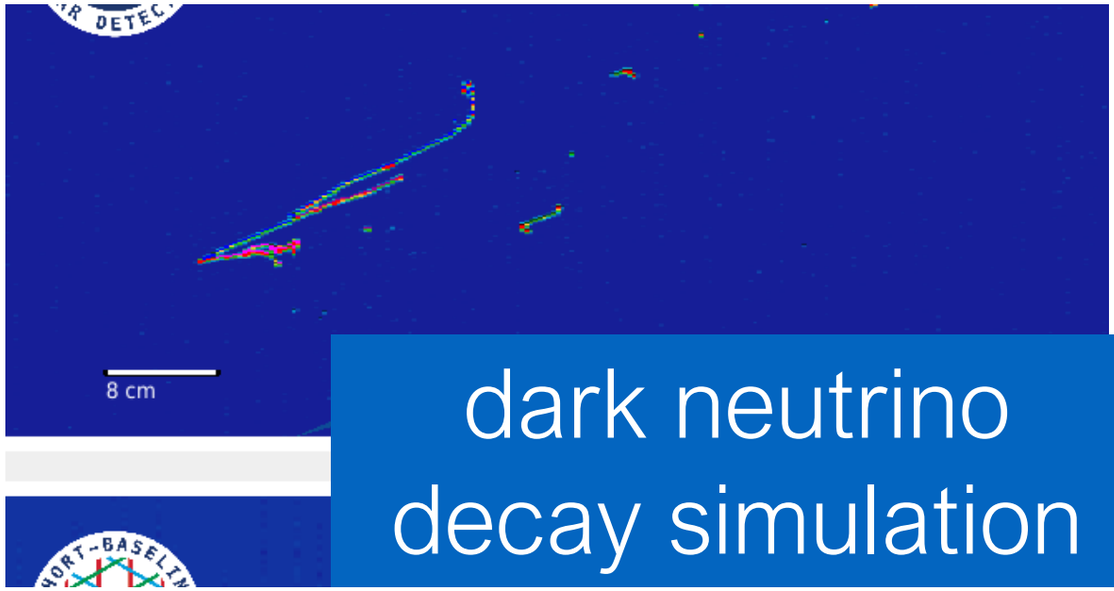
Wire plane

Outer frame for cryostat

Sussex contributions

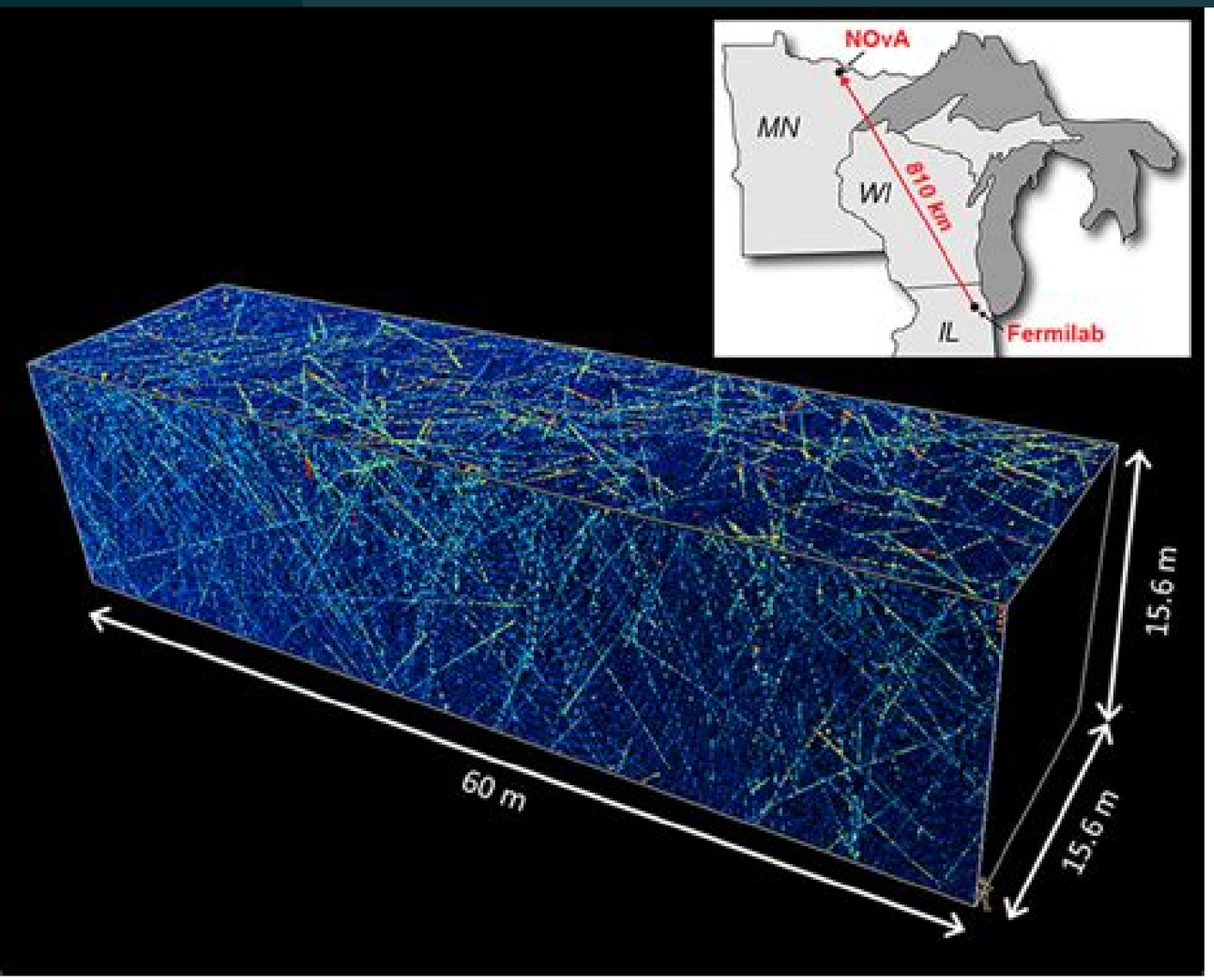
- Group leader: Clark Griffith
- PhD students:
  - Iker de Icaza Astiz
    (will submit thesis next month!)
    - software tools for matching TPC electric charge signals to light signals
    - dark neutrino analysis – BSM candidate to explain MiniBooNe low energy excess
  - Georgia Chisnall (3rd year)
    - low energy electron reconstruction – towards detector calibration and reconstruction of dark neutrino events
    - studying implementing a Michel electron trigger for detector commissioning data
  - Robert Darby (just started!)

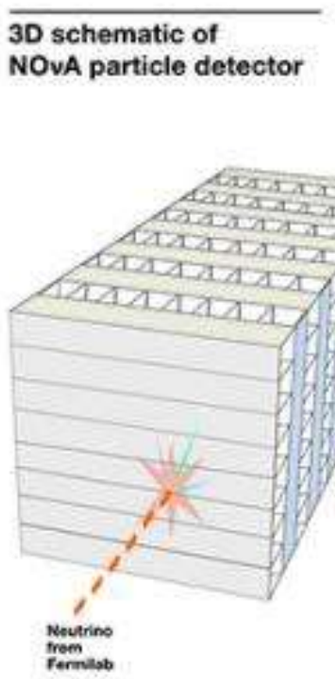


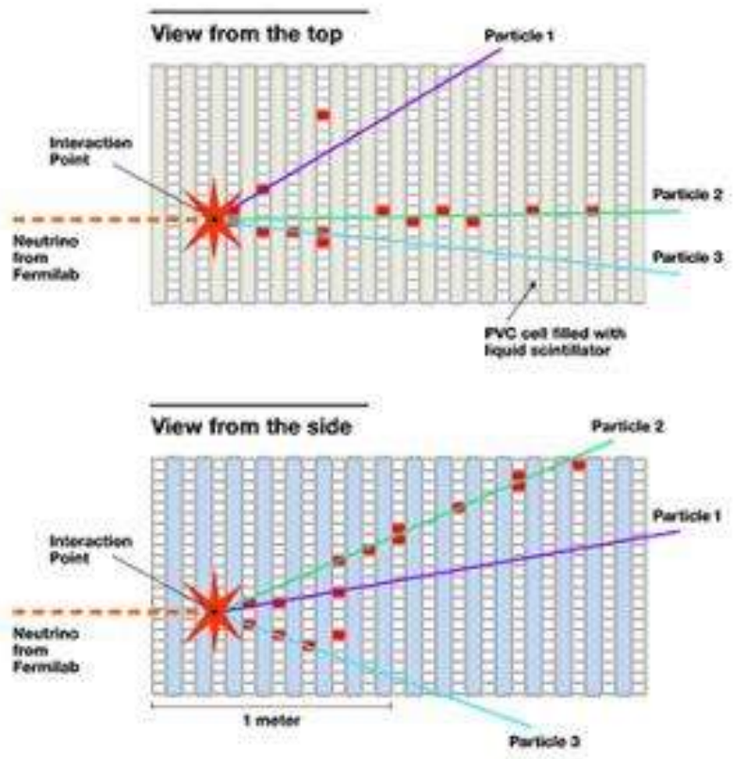


dark neutrino decay simulation

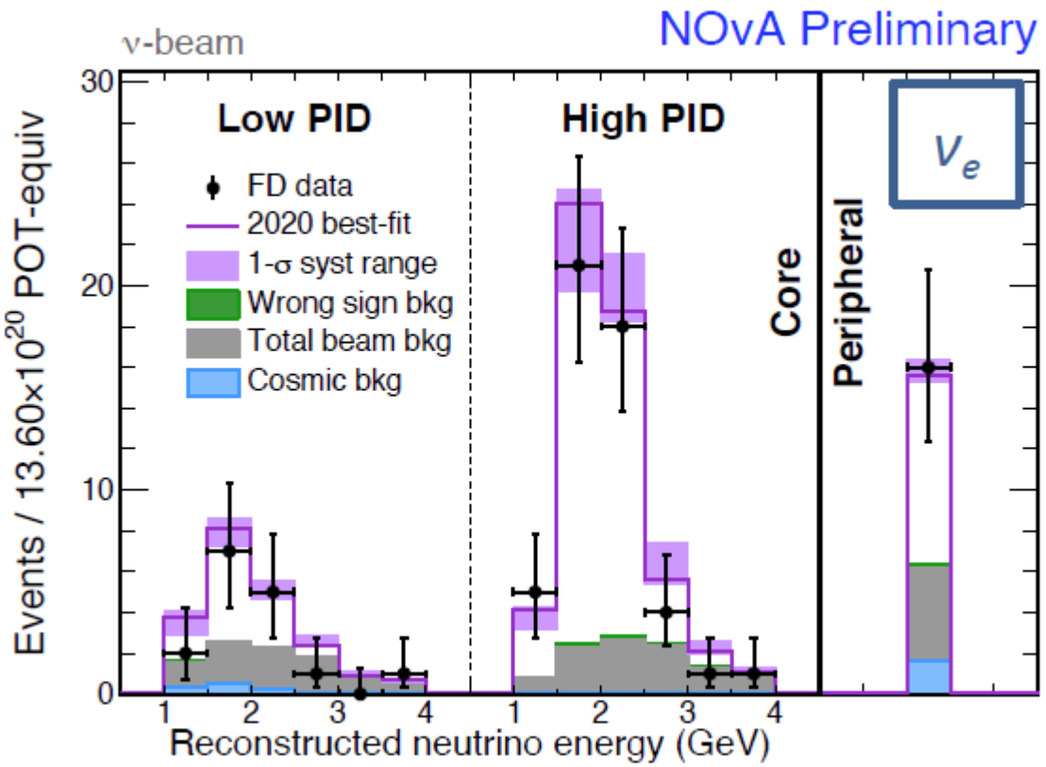
NOvA

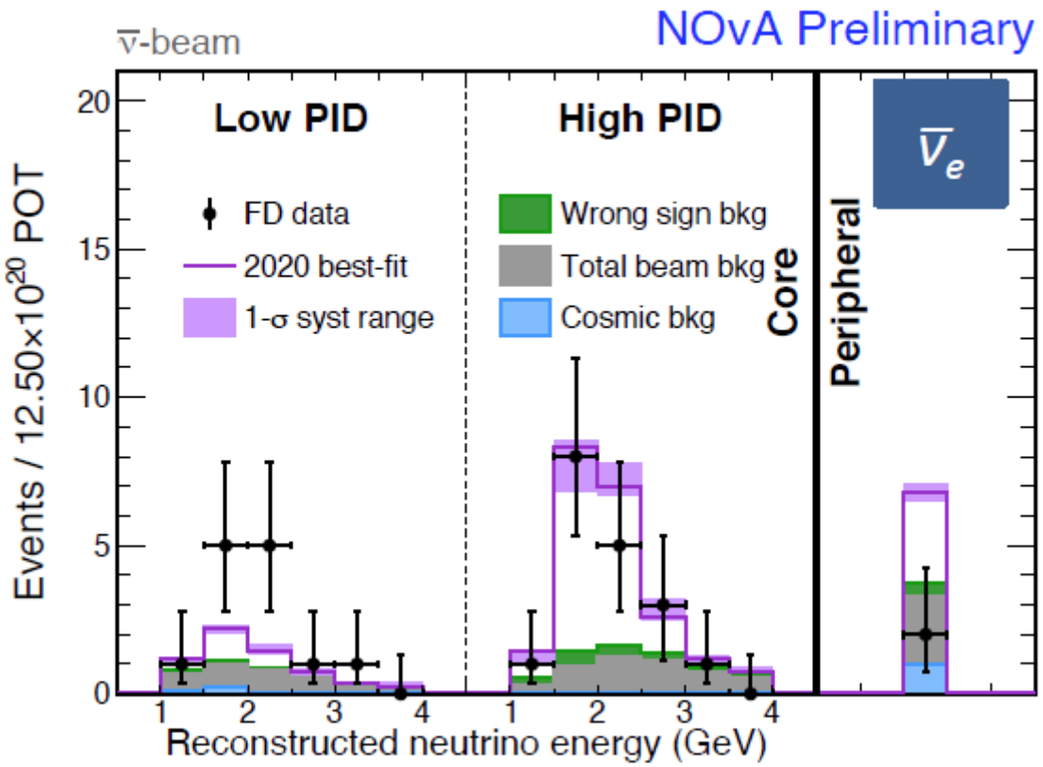

NOvA
MN
WI
IL
Fermilab
810 km
15.6 m
60 m
15.6 m


3D schematic of
NOvA particle detector
Neutrino
from
Fermilab


View from the top
Particle 1
Interaction
Point
Particle 2
Particle 3
Neutrino
from
Fermilab
PVC cell filled with
liquid scintillator
View from the side
Particle 2
Particle 1
Interaction
Point
Neutrino
from
Fermilab
1 meter
Particle 3

NOvA ν_e and $\bar{\nu}_e$ Data





Total Observed	82	Range
Total Prediction	85.8	52-110
Wrong-sign	1.0	0.6-1.7
Beam Bkgd.	22.7	
Cosmic Bkgd.	3.1	
Total Bkgd.	26.8	26-28

Total Observed	33	Range
Total Prediction	33.2	25-45
Wrong-sign	2.3	1.0-3.2
Beam Bkgd.	10.2	
Cosmic Bkgd.	1.6	
Total Bkgd.	14.0	13-15

>4σ evidence of $\bar{\nu}_e$ appearance

Best Fit

Normal hierarchy

$\Delta m^2_{32} = (2.41 \pm 0.07) \times 10^{-3}$ eV^2

$\sin^2\theta_{23} = 0.57^{+0.04}_{-0.03}$

$\delta = 0.82\pi$

See no strong asymmetry in the rates of appearance of ν_e and $\bar{\nu}_e$

Consistent with hierarchy-octant-δ combinations which include some "cancellation" of matter effect and CPv.

Sussex leadership

→ Physics analysis coordinator

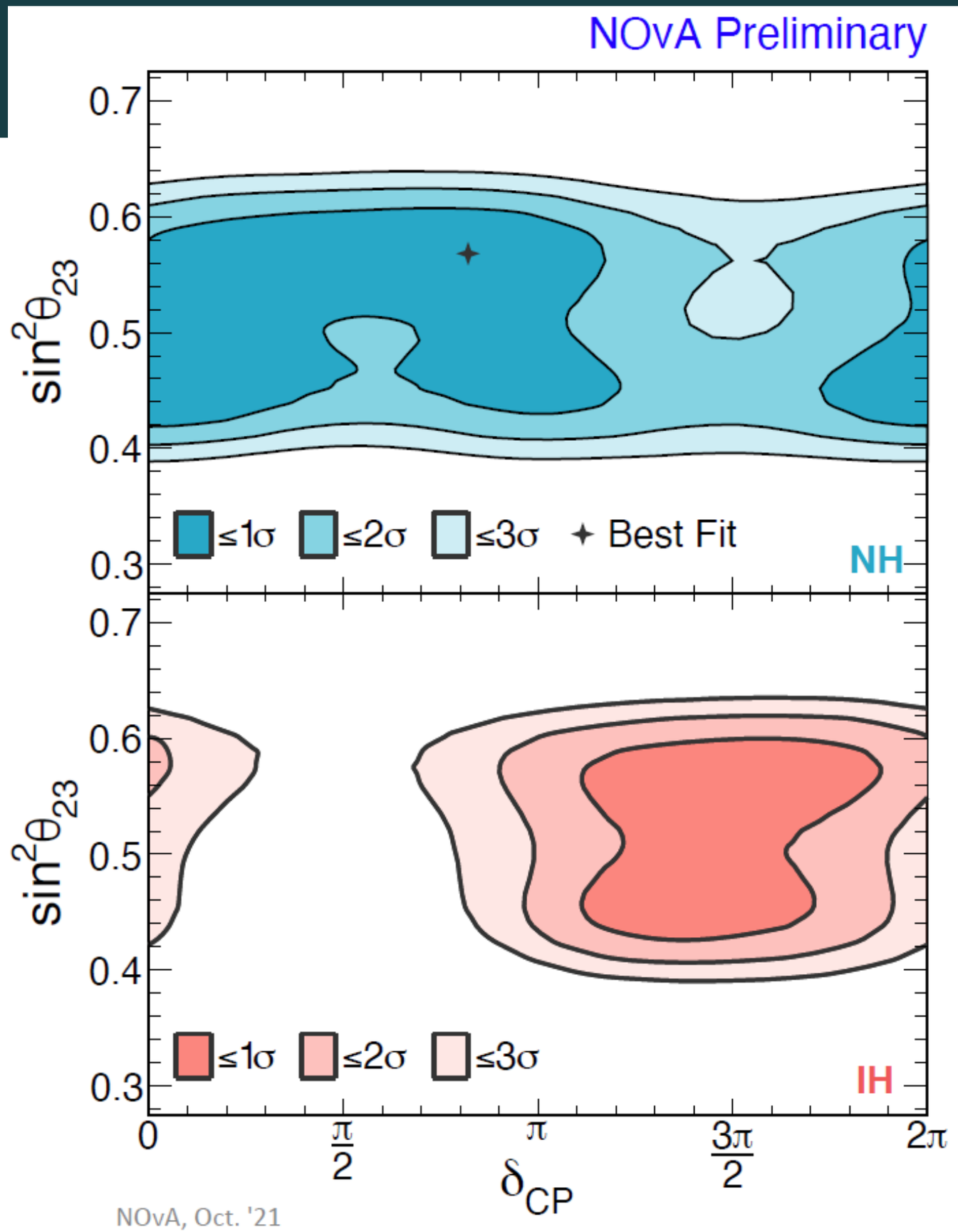
→ Reconstruction convenor

→ Test-beam run coordinator

→ Software release manager

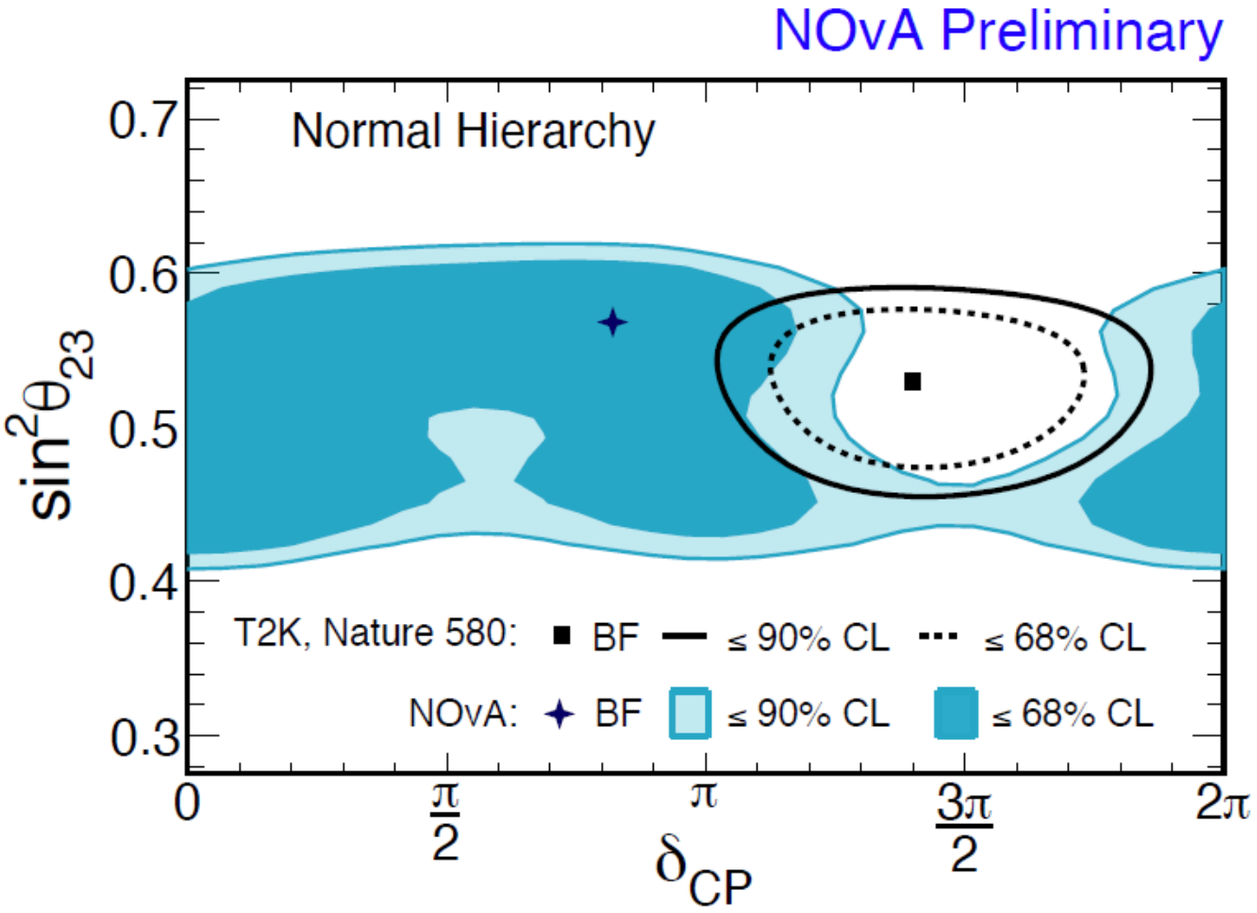
New UK group: **QMUL**, joins Sussex and UCL

STFC provided vital postdoc support in 2019 consolidated grant



Comparison with T2K

- Tension with T2K's preferred region
- Quantifying consistency requires a joint fit of the data from the two experiments, which is already in the works



- UK NOvA and T2K groups heavily involved
- Sussex provides a member of cross-experiment senior leadership team (from NOvA)

NOvA will run to 2025 or beyond (>2.5x more data to come)

Other NOvA activities

Production & Computing (Josh & Lily & Brett & Yibing)

Josh Porter is the NOvA release manager
Lily completed her term as Production convener last Autumn, now gives just a little time for tackling complex technical issues that just won't behave. Brett and Yibing completed their terms as Production shifters in the last year, having contributed to the understanding of production issues particularly related to calibration samples.

Reconstruction & Deep Learning (Lily & Brett)

Lily is joint convenor of the Reco&DL group on NOvA, where the main focuses are on using Convolutional Visual Networks to improve particle ID in NOvA, and gaining insight into the uncertainties associated with using DL techniques (including the use of adversarial networks for generator comparisons and detector effects). Brett (final year PhD) is training event-level classification and regression networks to (a) improve the reconstructed neutrino energy resolution and (b) win back neutrino events lost by over-zealous containment cuts, in the NOvA Far Detector.

Neutrino Magnetic Moment (Robert & Lily & Jeff)

Robert (2nd year) is doing a sensitivity study for the measurement of the contribution to the muon-neutrino-on-electron scattering cross section in the Near Detector, which is a study of interest to several groups on NOvA and DUNE.

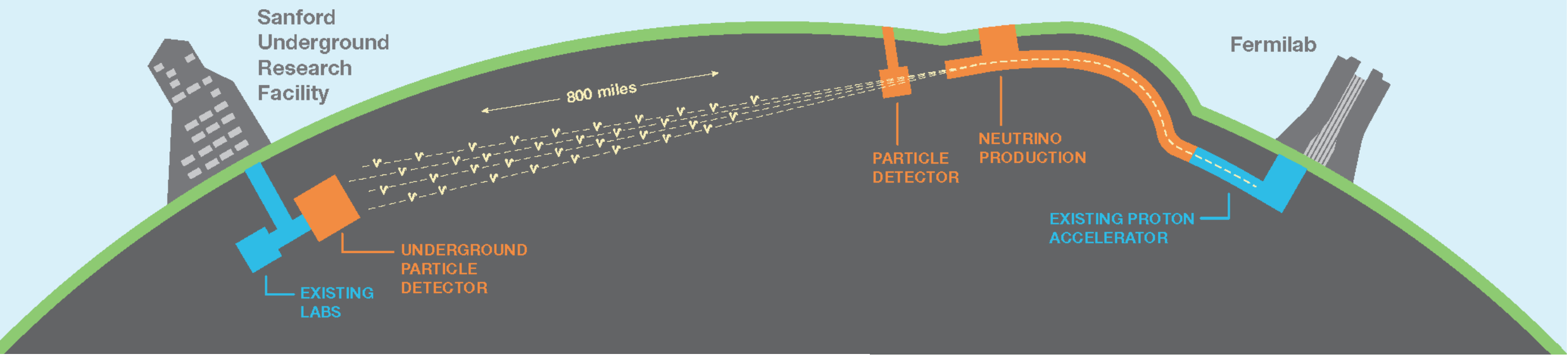
Testbeam (Lily & Robert)

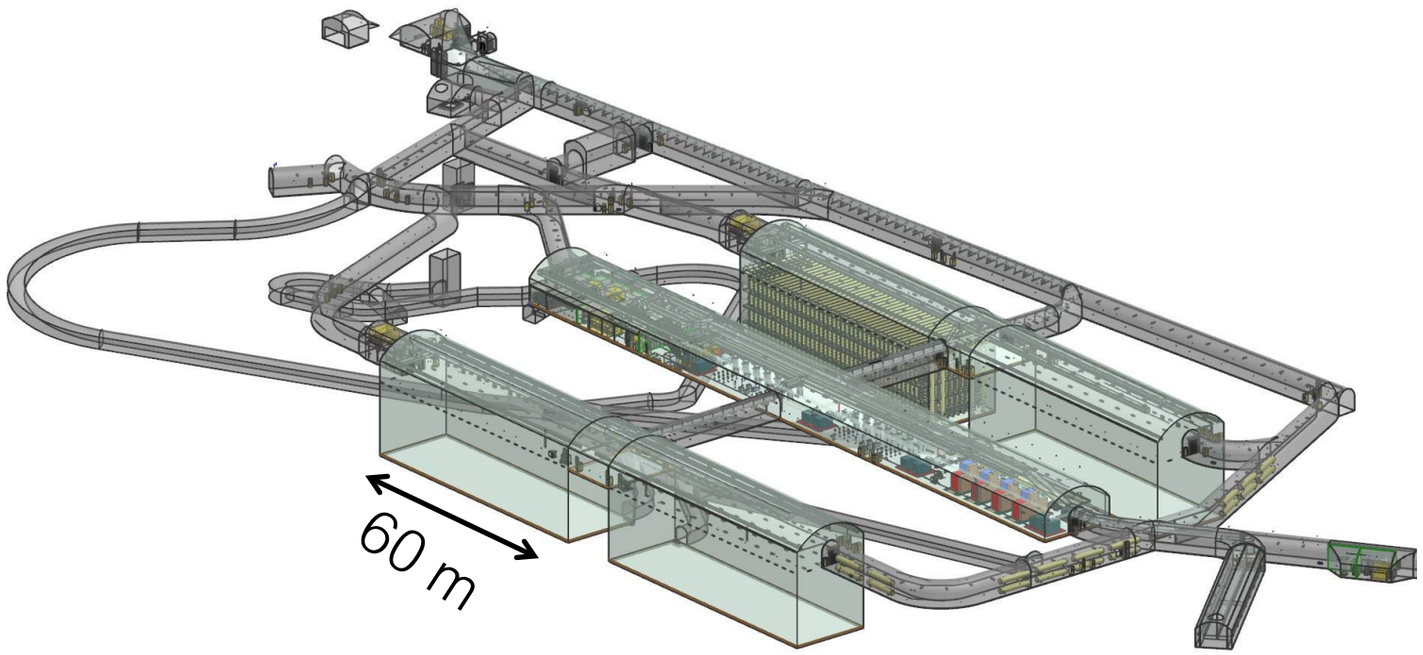
Lily and Robert are heading to Fermilab after Christmas. Lily will be taking on the role of testbeam Run Coordinator for the final NOvA testbeam run for 6 months. Robert will be involved in both testbeam ops (probably as calibration expert) and analysis (probably using tb data to improve reconstruction and particle ID as a joint effort with Reco&DL).

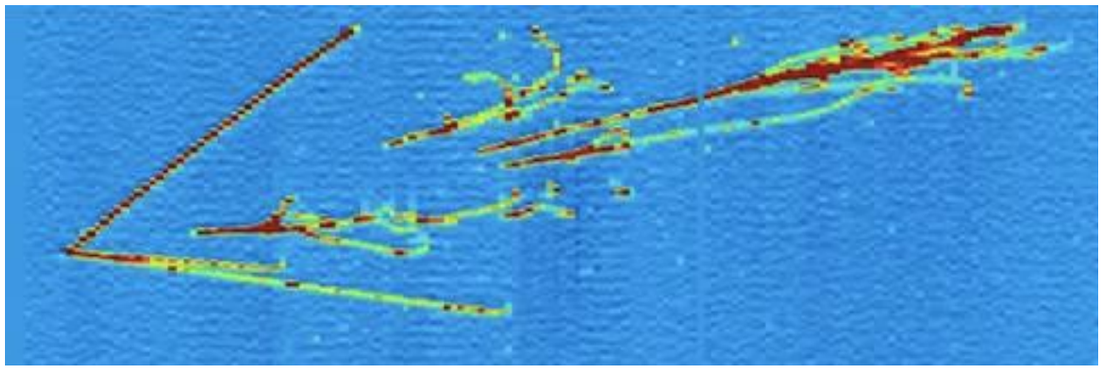
NOvA/DUNE PDRA advertised

UNIVERSITY OF SUSSEX

DUNE







DUNE outreach

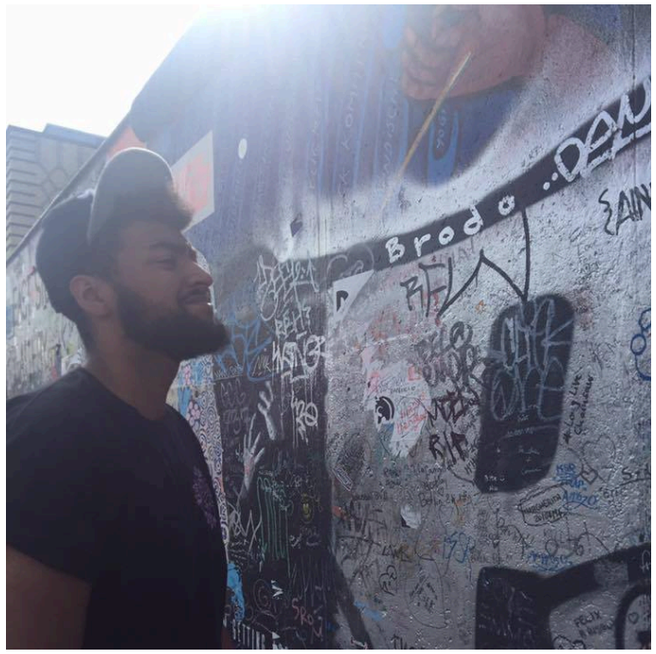
The amount of data DUNE will handle is equivalent to streaming 400 HD movies per second for one detector, or 1,600 for the four detectors each second. That is almost 60 billions movies per year! We can only store twelve millions movies per year, so we need to sift through this data 'live' and select the information we want to keep, that is 1 out of 5,000 movies!

Kate Shaw is organising a Sussex DUNE movie,
in co-operation with the DUNE outreach team.

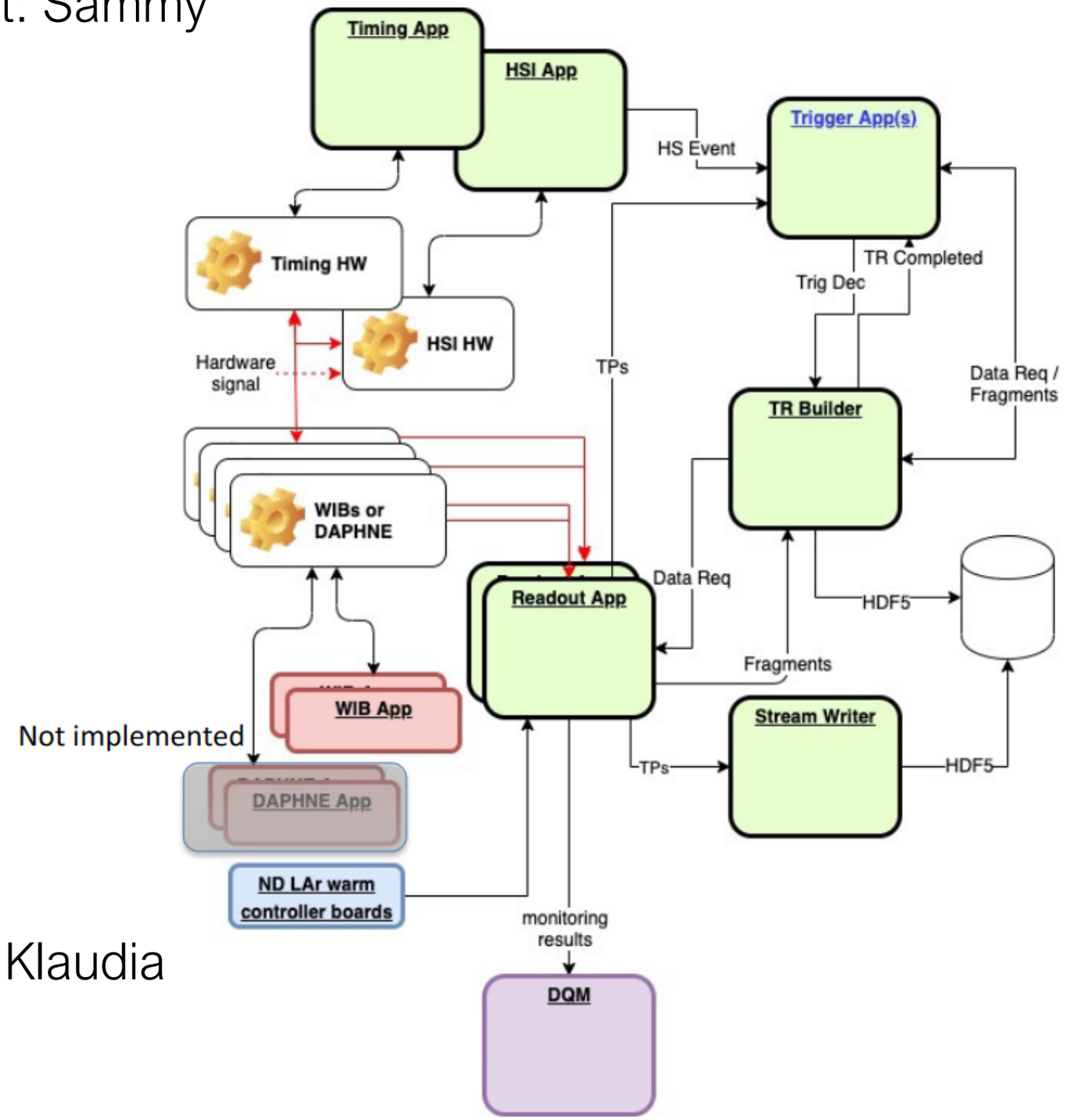
DUNE DAQ

UK project manager: Simon
Control, Configuration, and Management: Sammy

Antony Earle is implementing trigger primitive finding, testing it, and deploying it at ProtoDUNE-I and II.



Trigger primitive verification and testing: Klaudia



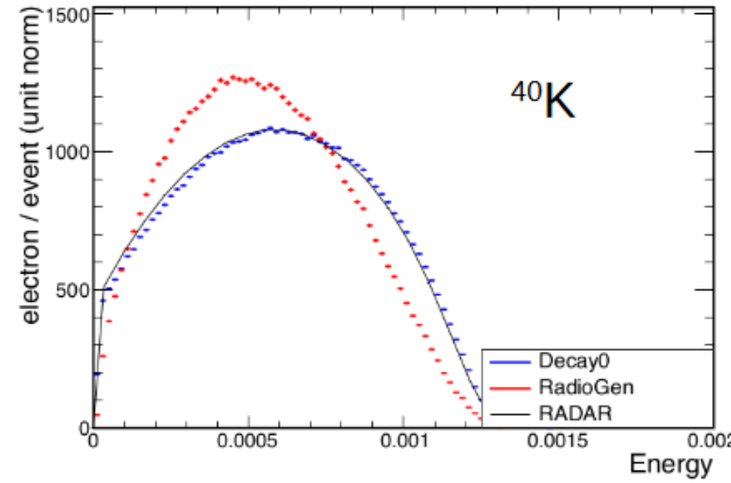
DUNE Background Task Force

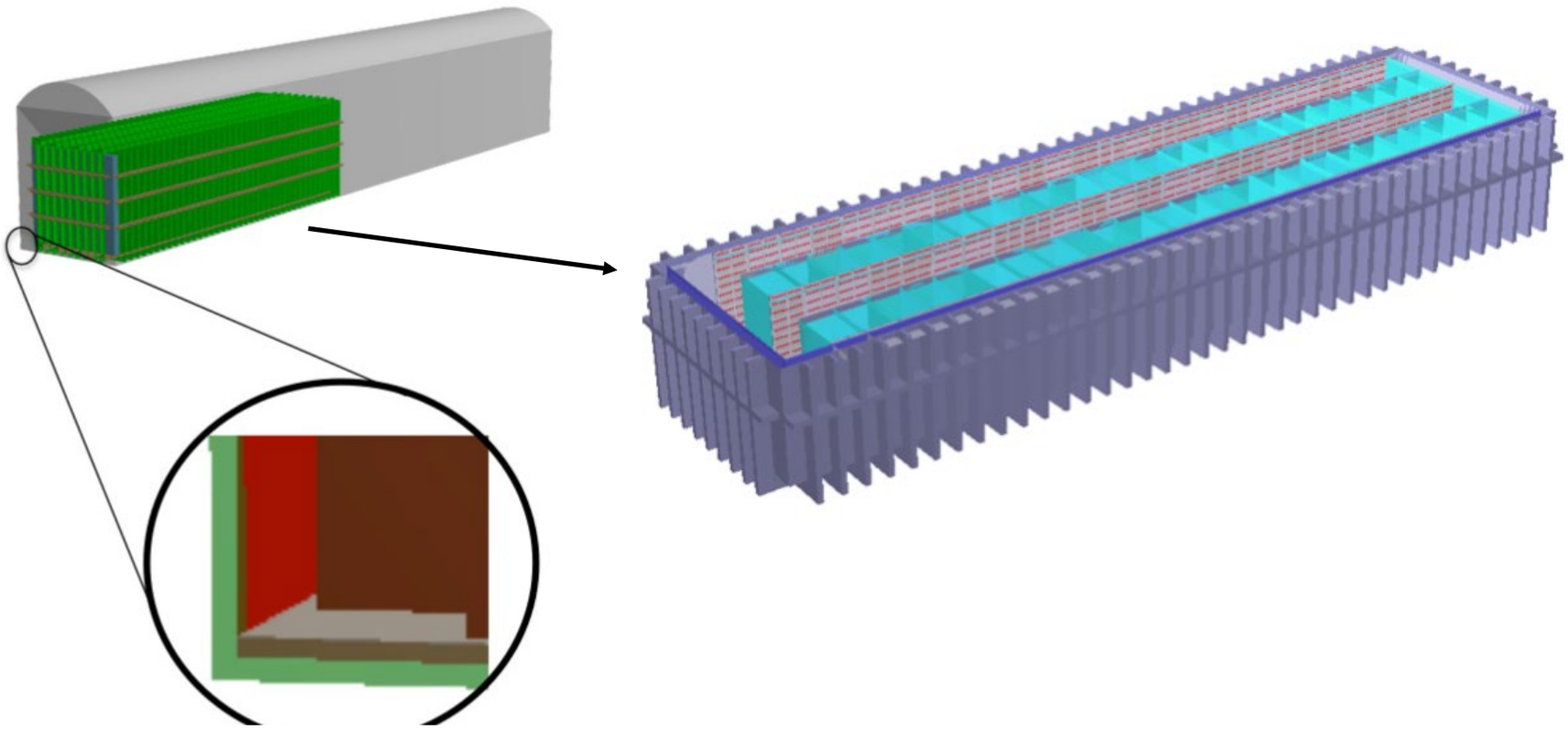
<u>Low-energy backgrounds (Simon international co-coordinator)</u>
Delivered new, detailed background model

Noise (~~Pierre~~): analysed and implemented correlated noise from ProtoDUNE-I into simulation

Decay0 (~~Pierre~~, Sammy): implemented improved background simulation

Neutrons (Aran): detailed calculation of the neutron flux
(and had to fully implement one module in a cavern in simulation)





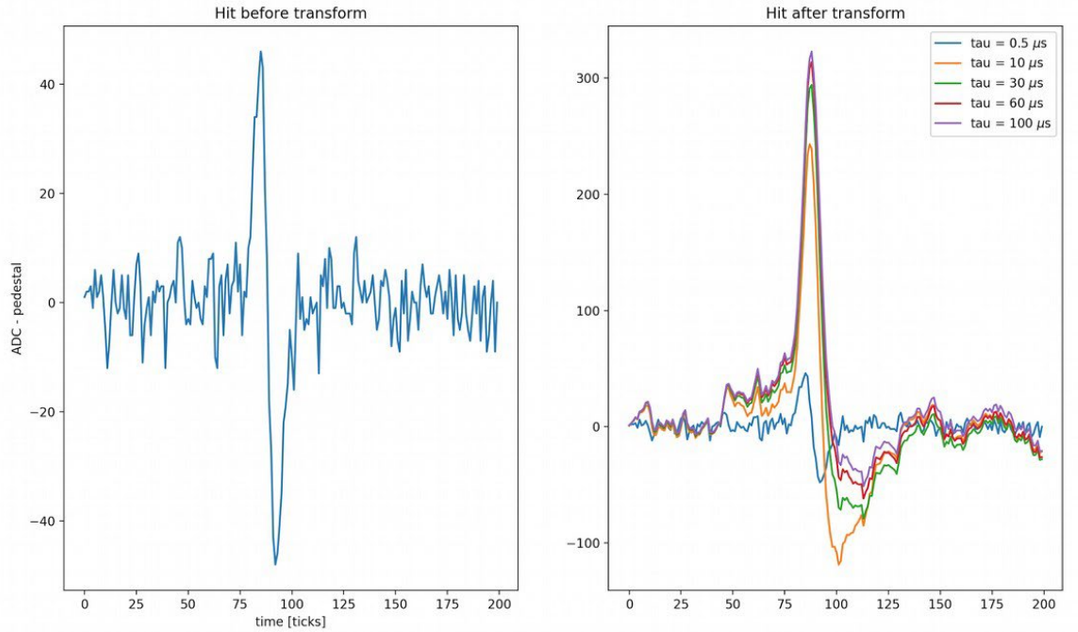
DUNE DAQ Physics Performance

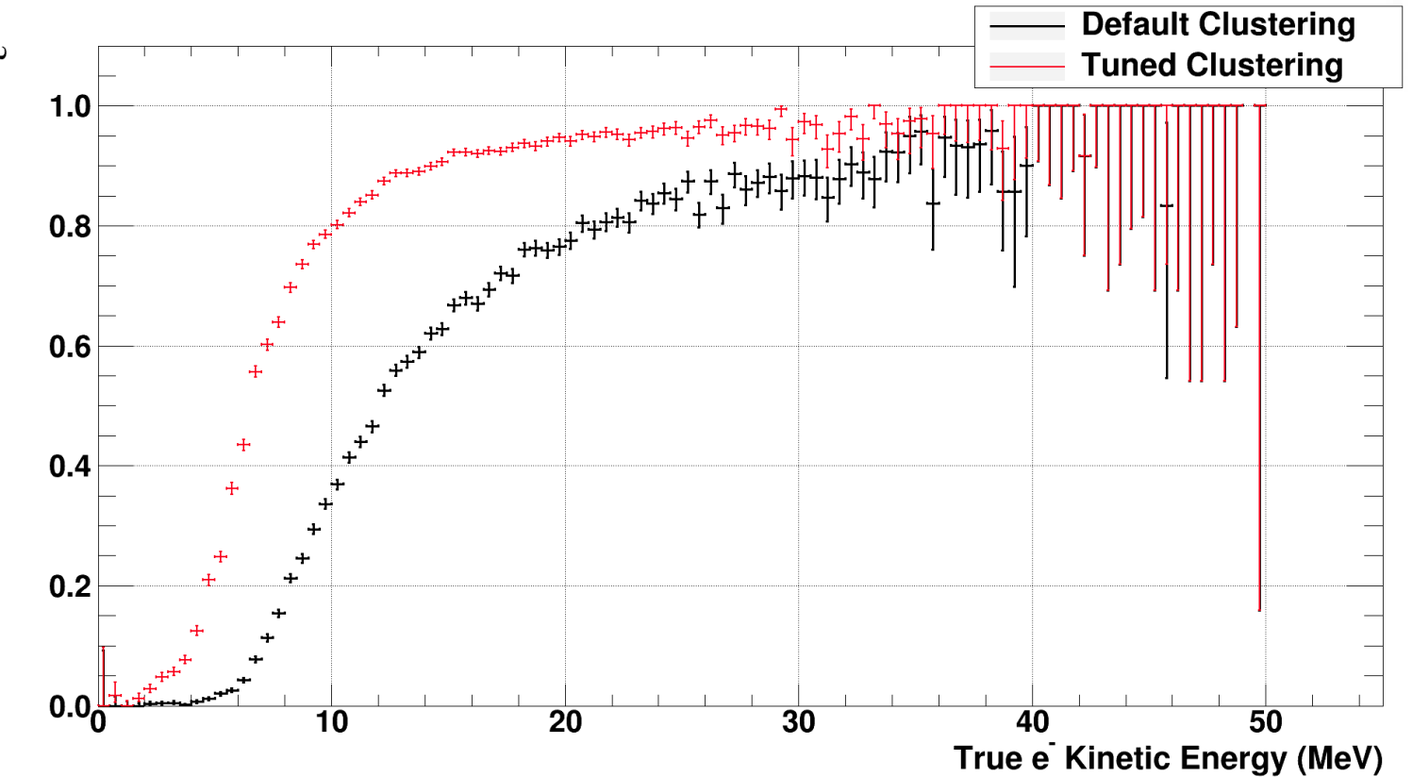
UK Physics Performance work package manager: Thiago
Implemented induction hit wire finding: Aran

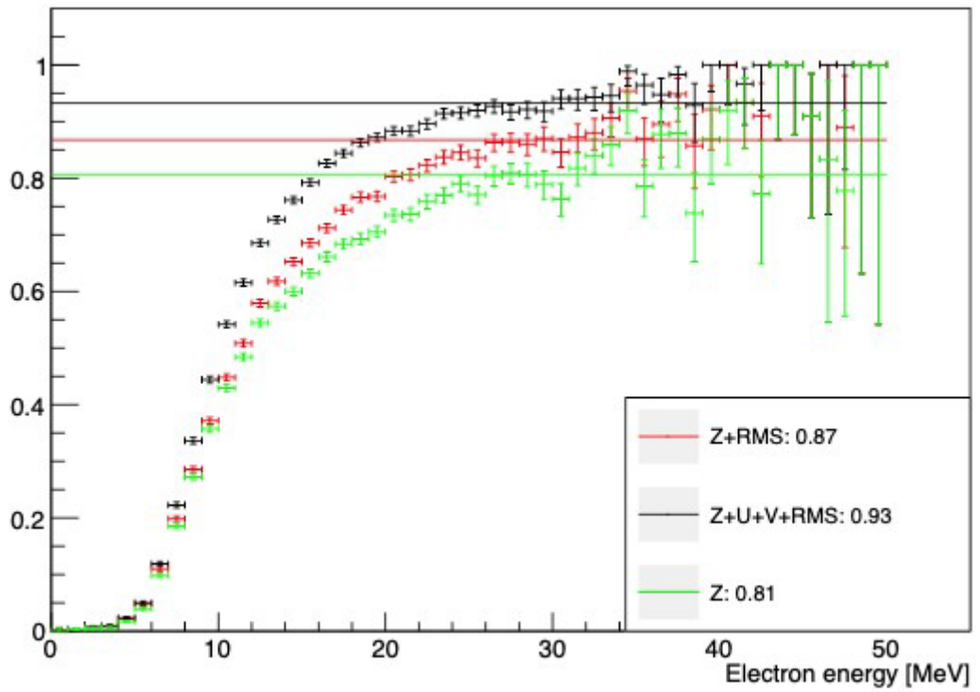
Low energies challenging but important:

- Supernova physics (core physics program!)
- Solar neutrino physics
- DSNB

Starting work on second (different design) module



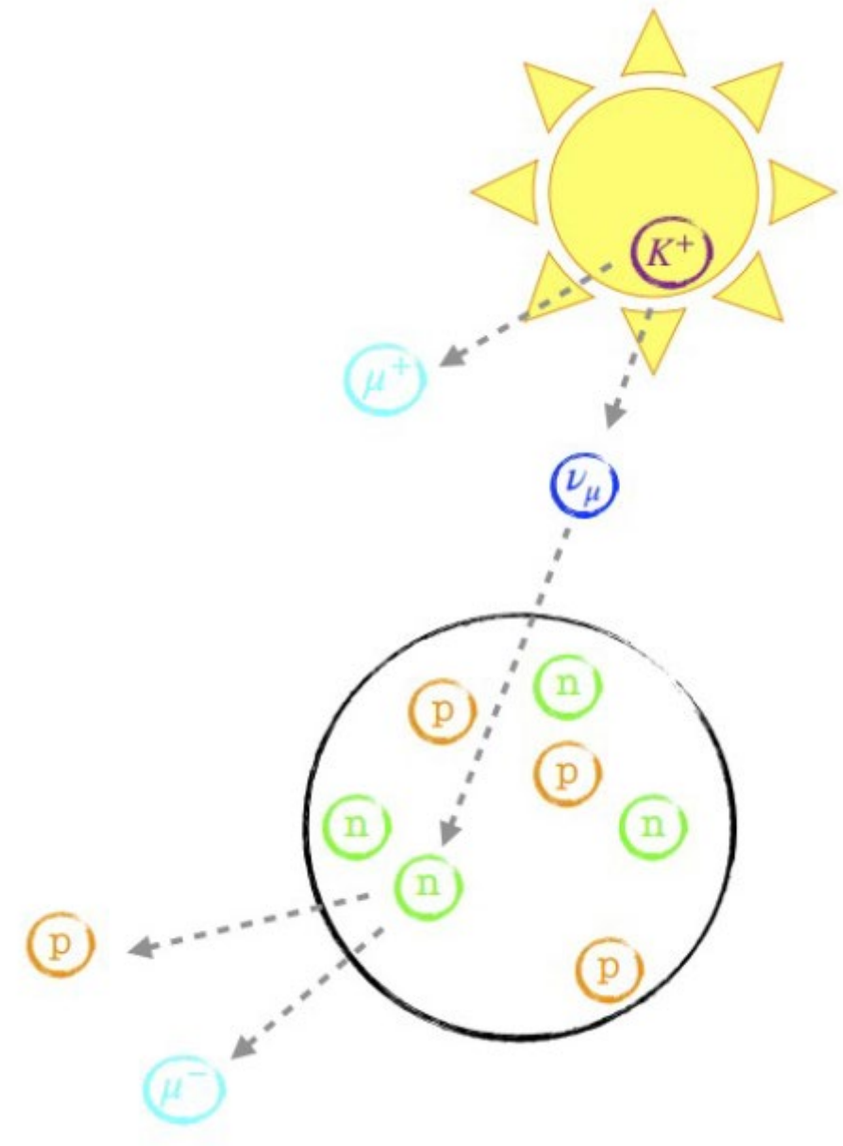




Neutrinos from DM in the Sun

Klaudia

- Clear signal,
  with atmospheric neutrino backgroun
- Improvements with better
  (“low-energy”) electron reconstructio

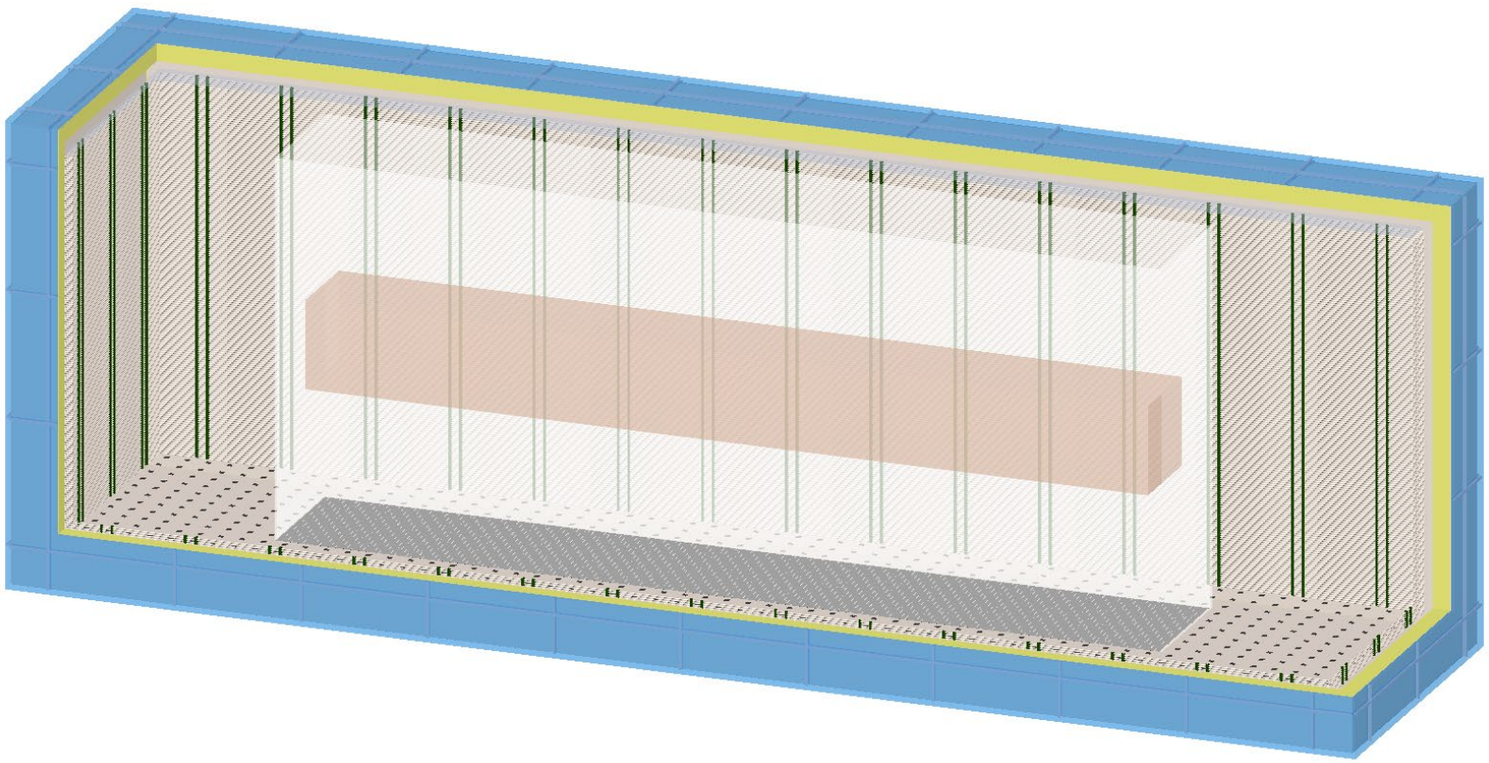


SNOWMASS

SNOWMASS ultralow background module proposal

Extent the physics goals

- Solar neutrino measurements
- Neutrinoless double-beta decay search
- WIMP Dark Matter search
- Supernovae detection
- Supernovae Coherent nu-Nuclear elastic scattering (CEvNS) “glow”

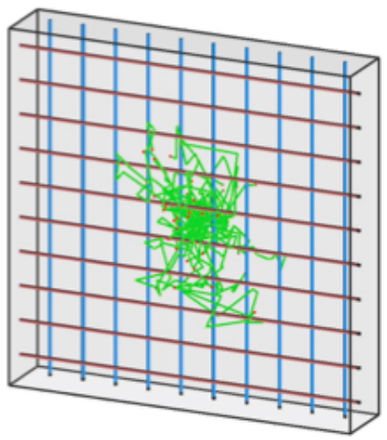


Opaque scintillator R&D

Jeff Hartnell, Joshua Porter

Medical Applications of Opaque Scintillator Radiation Detectors

Simulations



Simulations written in Geant4 that allow for detailed investigation into the behaviour of light and radiation in an opaque scintillator detector.

Can modify key parameters of interest:

- Geometry
- Scintillator properties

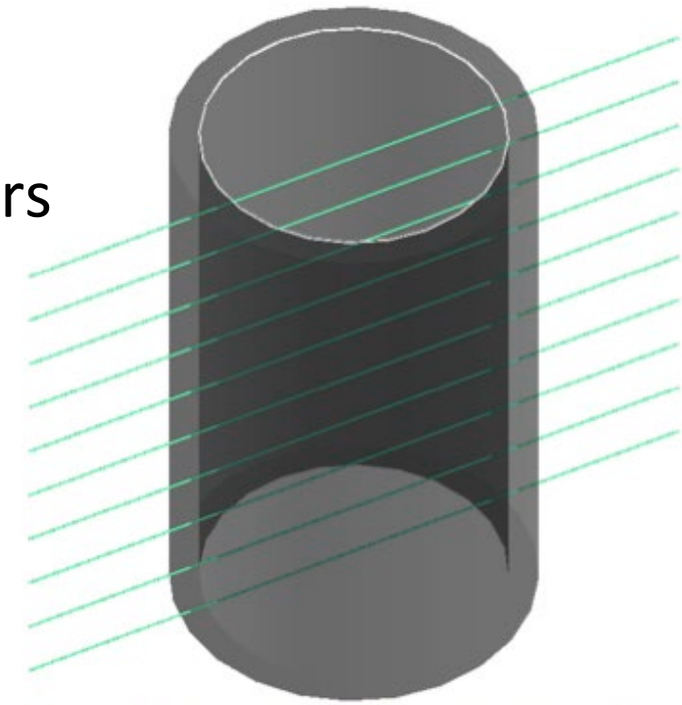
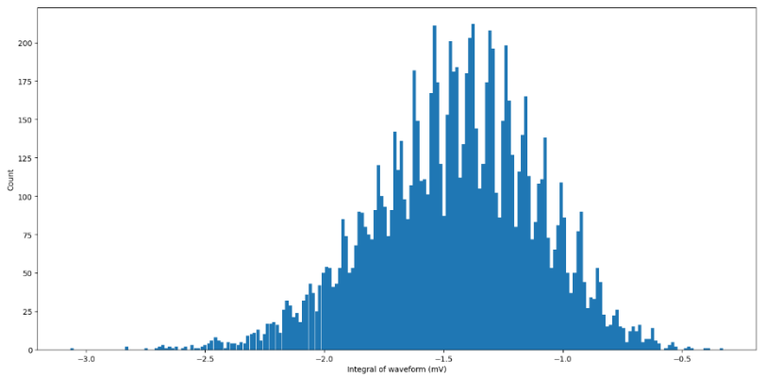
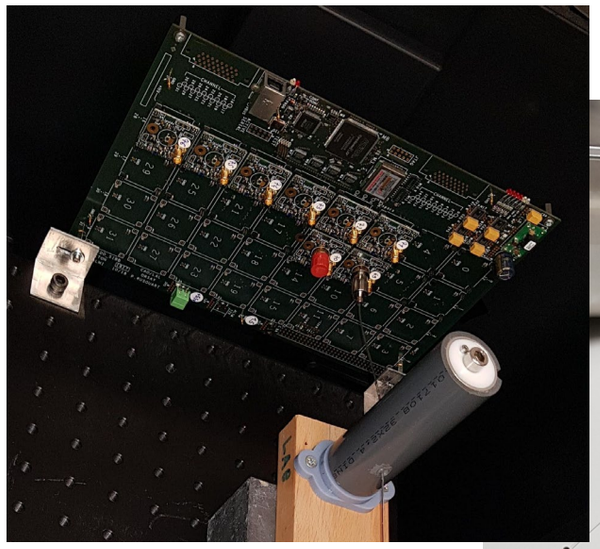
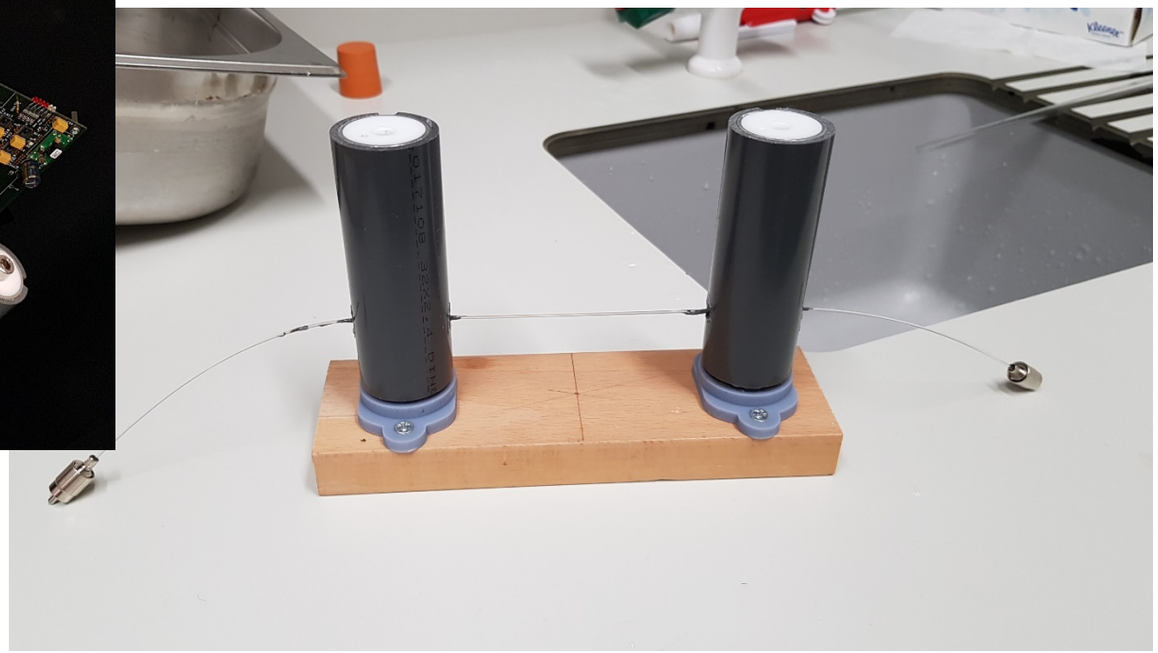


Figure 2 Schematic of the simple device that will be used to evaluate different opaque scintillators in the first half of the project.

Prototype + new electronics works!







Crystal scintillator R&D

Nicolò, Simon

Improve radiation detectors and luggage scanners

Provide a detailed MC,
determine releastic properties of new crystals
and relevant materials, different detectors.
Use this to improve systems

Neutrinos at Sussex

- Loads of fantastic activity with a very active and motivated team
  - *Exciting physics*
  - *Providing crucial contributions to the development and operation of experiments*

- Currently taking exiting data with NOvA, SNO+, JSNS^2
- Preparing for the next generation with SBND and DUNE
- Exiting spin-off with Opaque Scintillator R&D

backup

DUNE vs HyperK

Possible Experimental Strategies

EITHER:

- Keep L small (~200 km): so that matter effects are insignificant
  - First oscillation maximum:

$$\frac{\Delta m^2_{31} L}{4E} \sim \frac{\pi}{2} \Rightarrow E_\nu < 1\,\mathrm{GeV}$$

  - Want high flux at oscillation maximum

⇒ **Off-axis beam:** narrow range of neutrino energies

OR:

- Make L large (>1000 km): measure the matter effects (i.e., MH)
  - First oscillation maximum:

$$\frac{\Delta m^2_{31} L}{4E} \sim \frac{\pi}{2} \Rightarrow E_\nu > 2\,\mathrm{GeV}$$

  - **Unfold CPV from Matter Effects through E dependence**

⇒ **On-axis beam:** wide range of neutrino energies

Simple CAEN system to start

Thanks Iacopo!

Fibres


KURARAY WLS FIBER
Type O-2(100)MSJ
Cladding Multi
Size 1.0mmDia
Cross section RD
Quantity 3mX3Pcs
Lot No. 21071602-S
kuraray


KURARAY WLS FIBER
Type Y-8(100)MSJ
Cladding Multi
Size 1.0mmDia
Cross section RD
Quantity 3mX3pcs
Lot No. 21071601-S
kuraray


KURARAY WLS FIBER
Type R-3(100)MSJ
Cladding Multi
Size 1.0mmDia
Cross section RD
Quantity 3mX3pcs
Lot No. 21071603-S
kuraray

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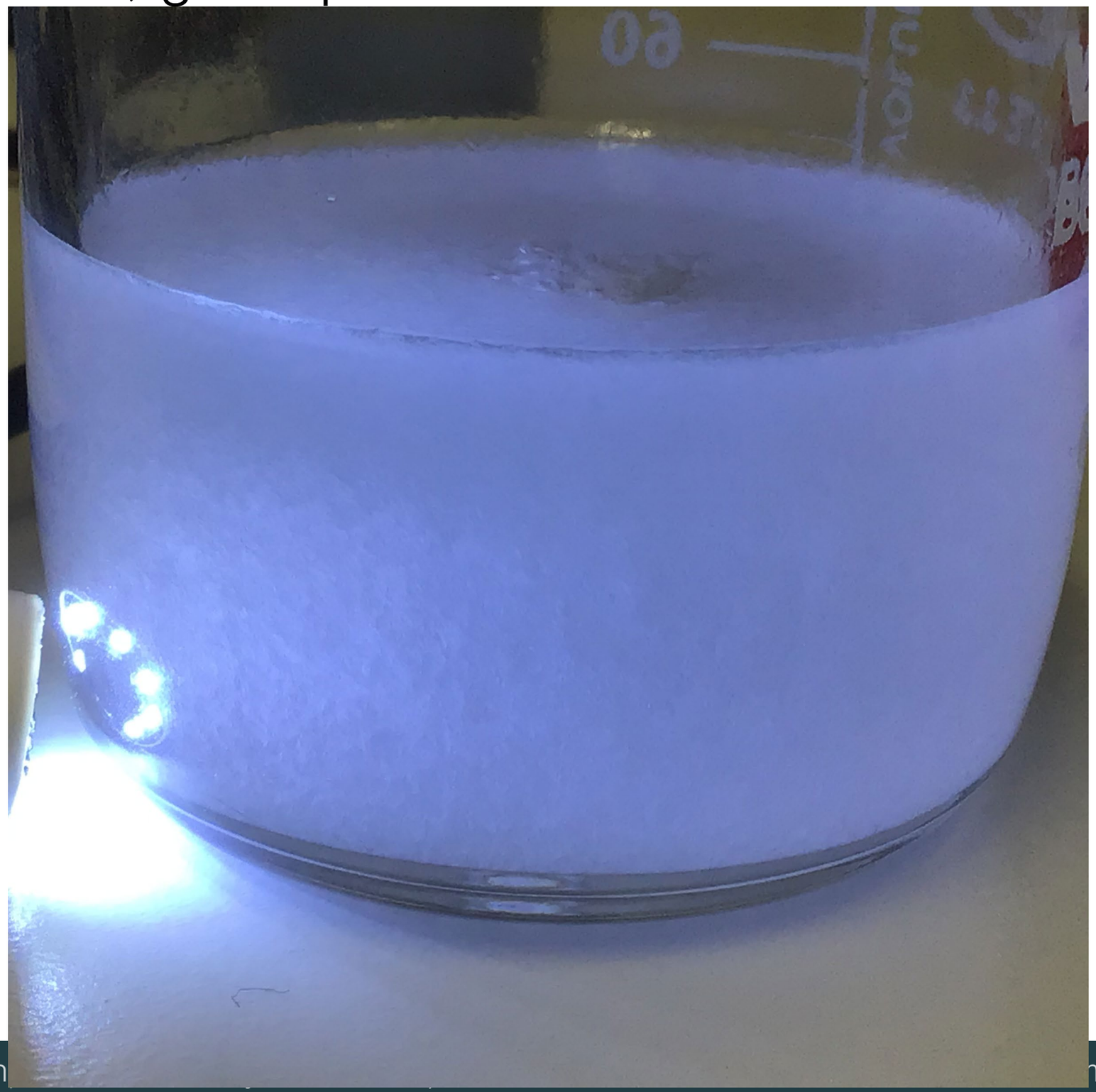
NoWASH: Opaque Scintillator

- Known to work, great place to start



Vessels

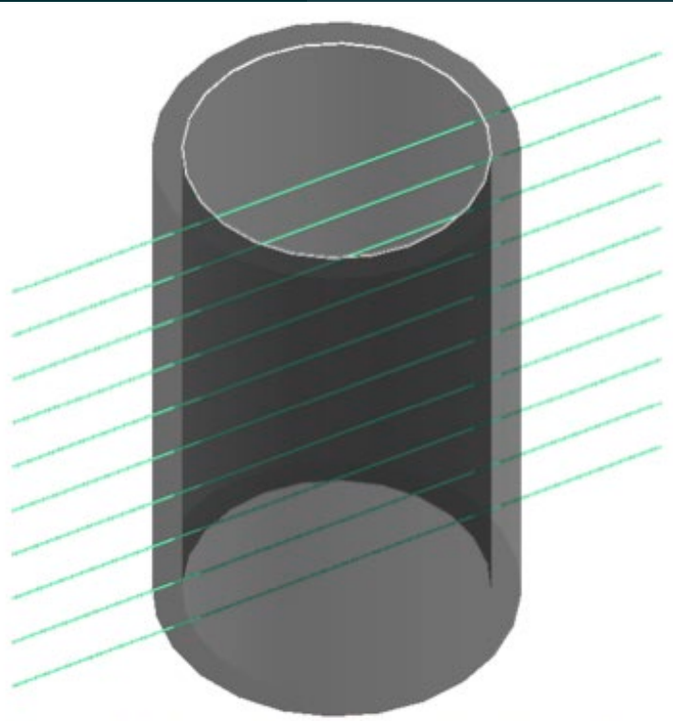


Figure 2 Schematic of the simple device that will be used to evaluate different opaque scintillators in the first half of the project.

Designed to be simple and in-expensive for rapid testing of lots of different opaque scintillators

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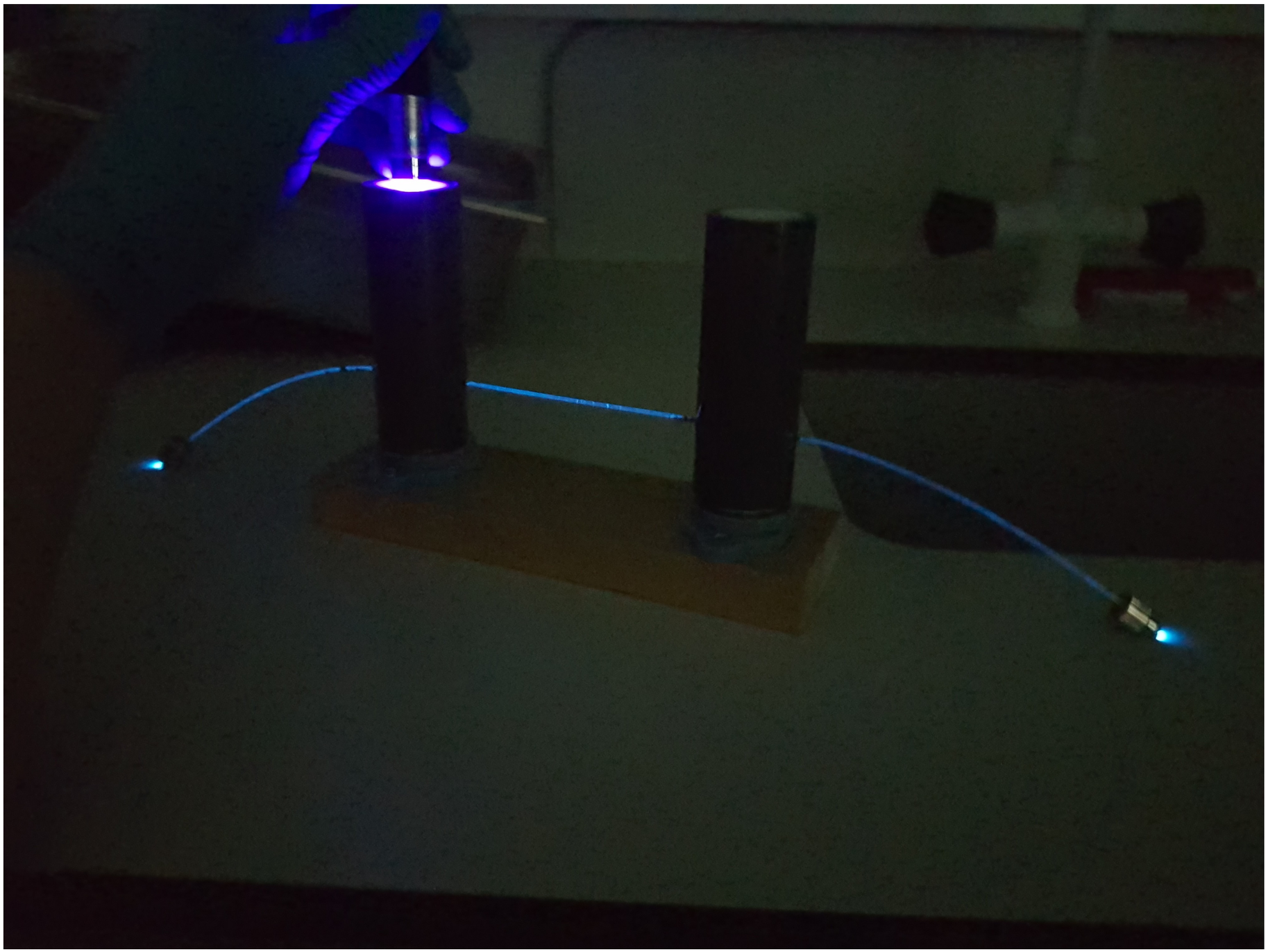
Demonstration of optical path



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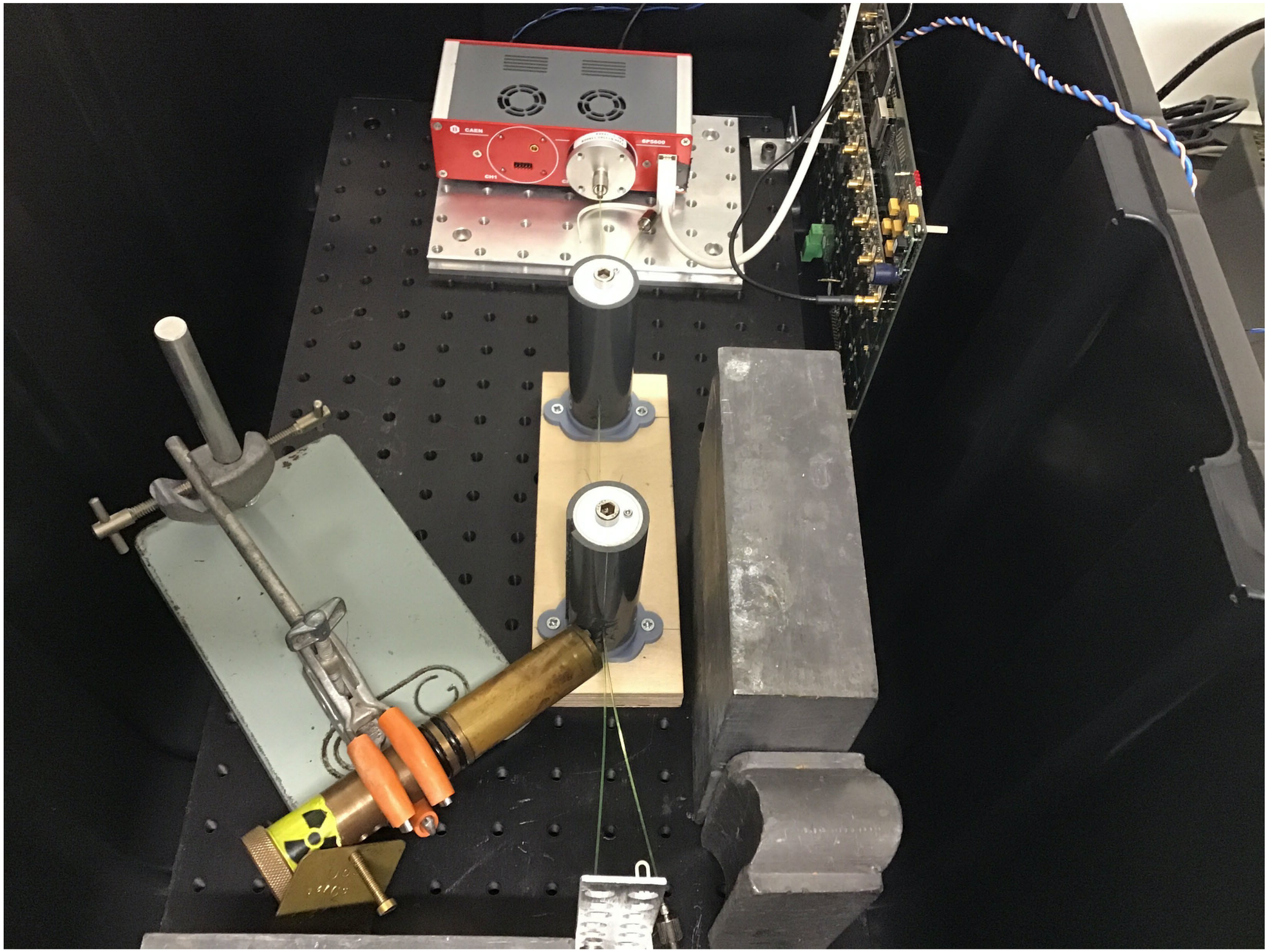
Darkbox, source, electronics, vessels



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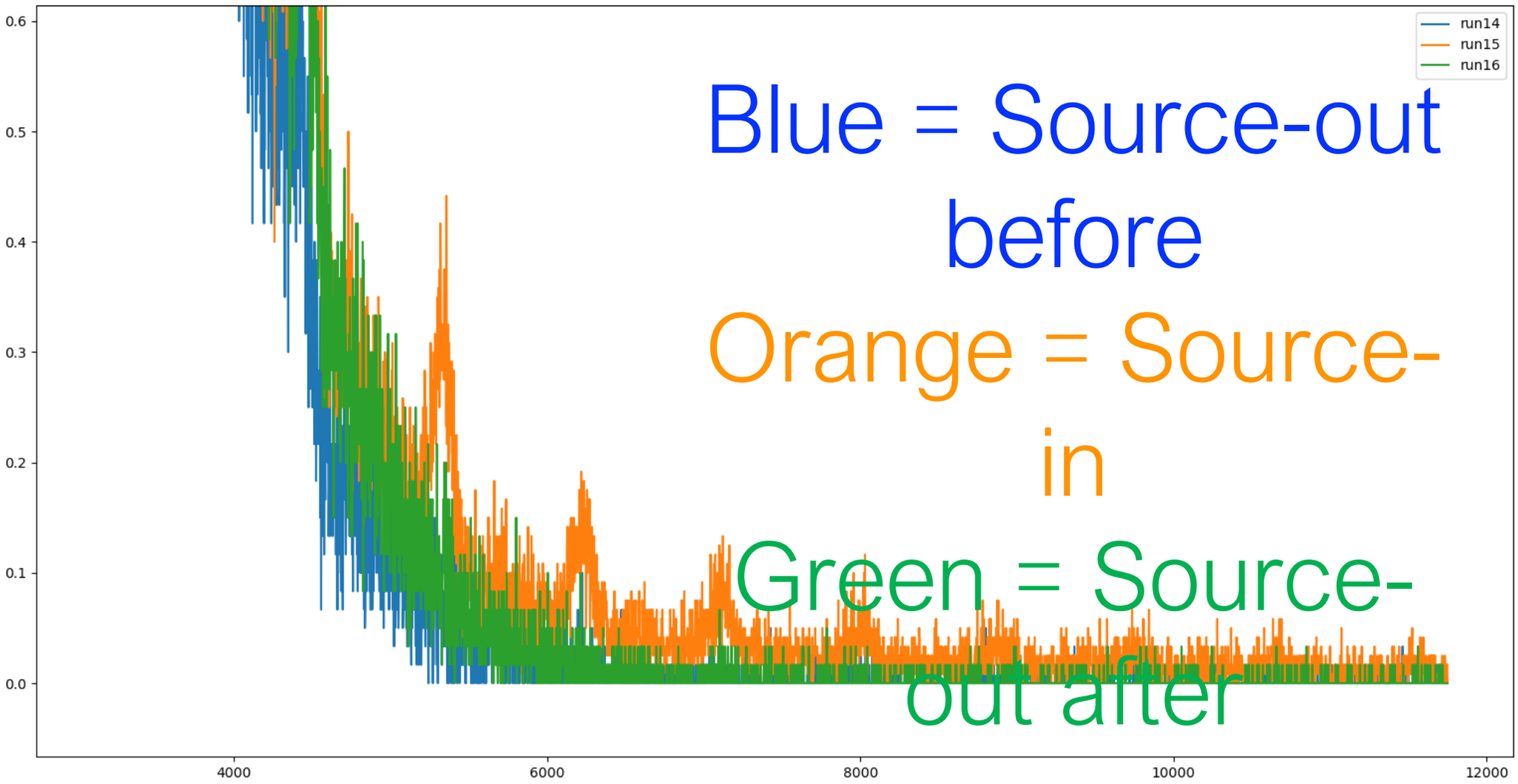
Milestone: first signal



Clear multi-photoelectron peaks

Established that we have a testing system

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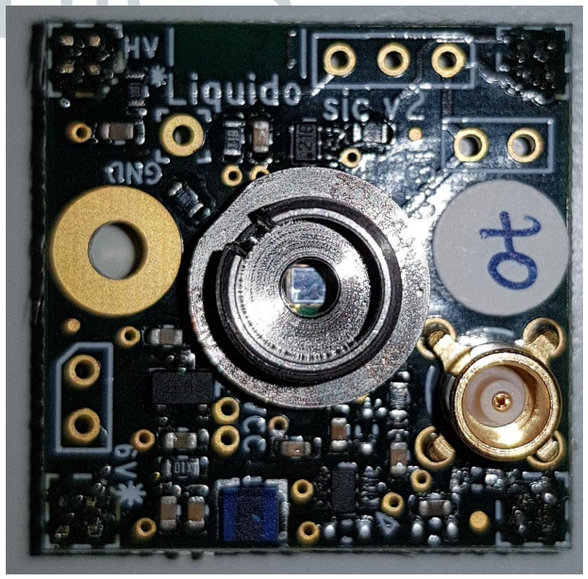
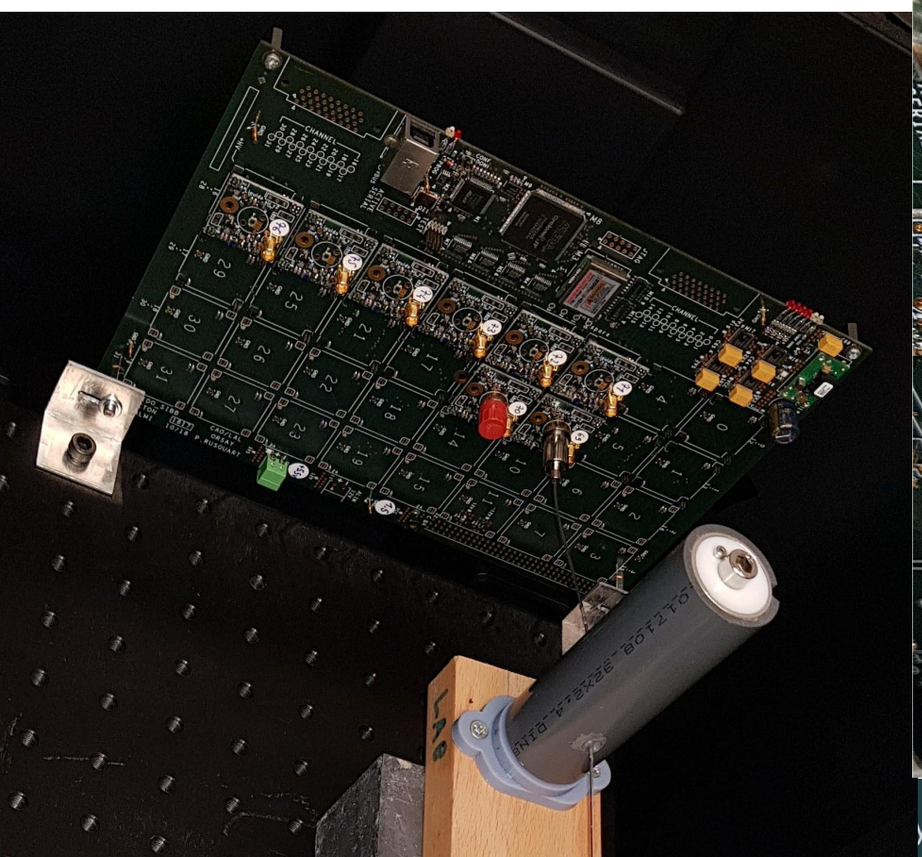
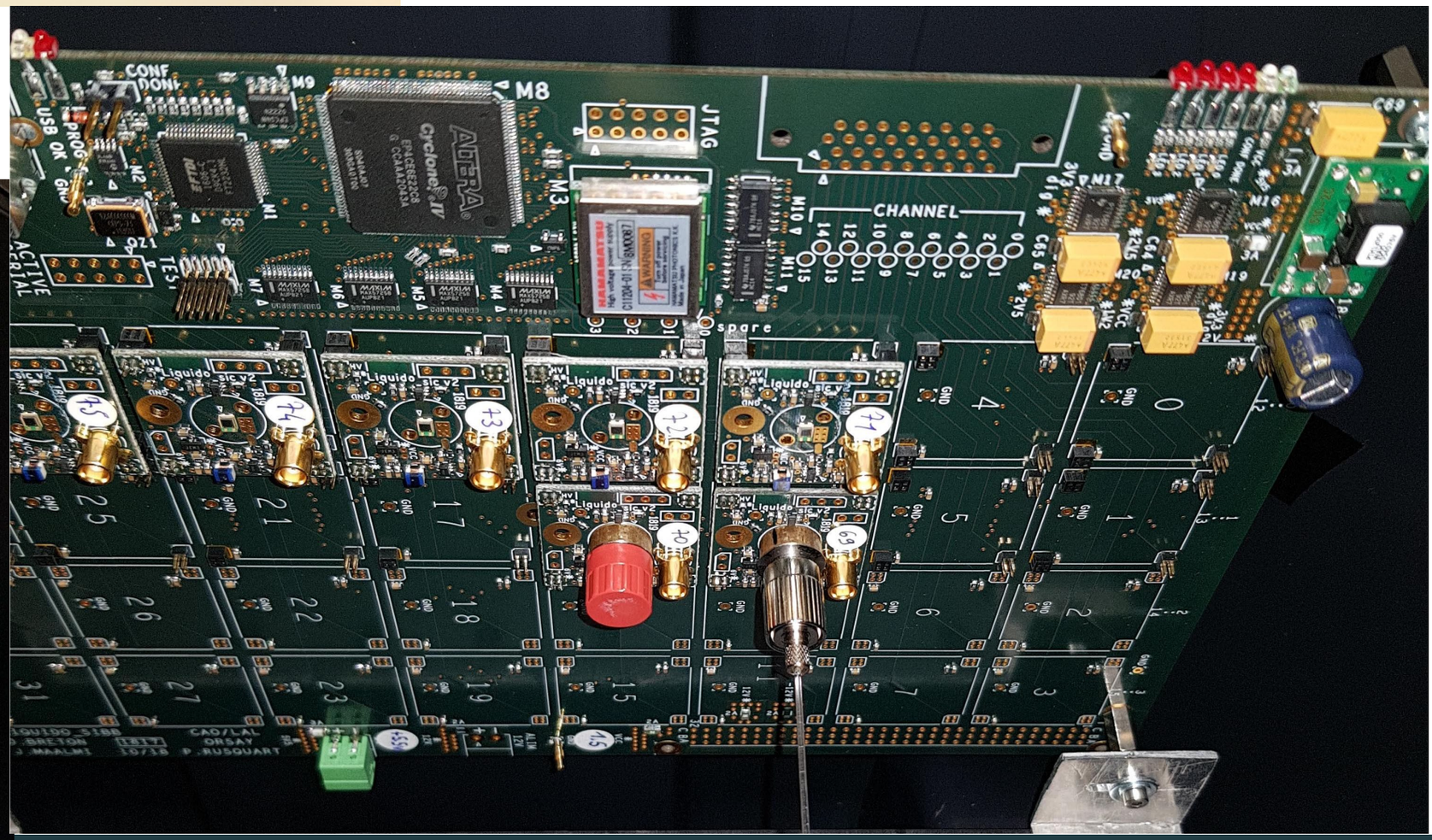
Next step on

electronics







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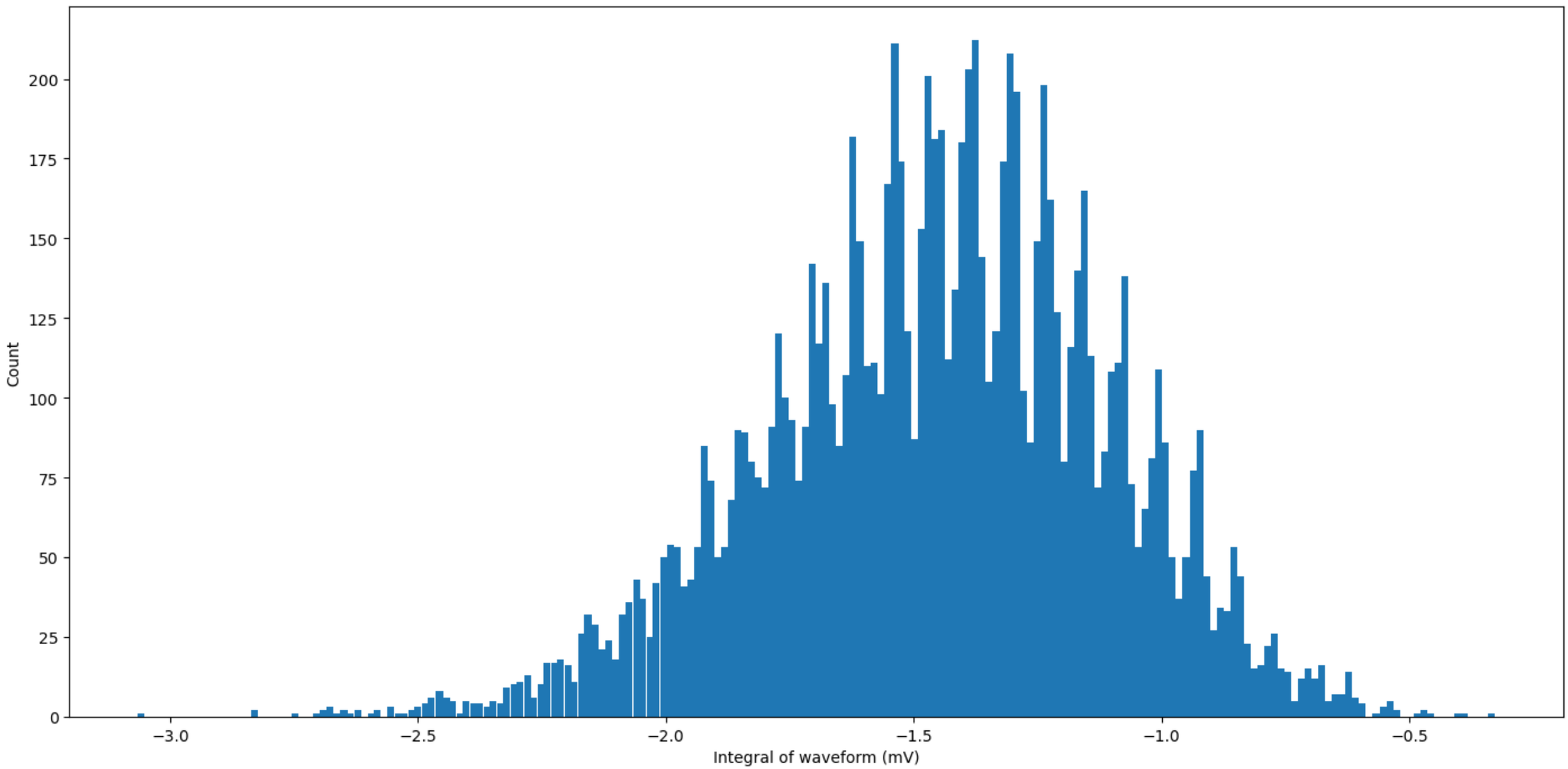
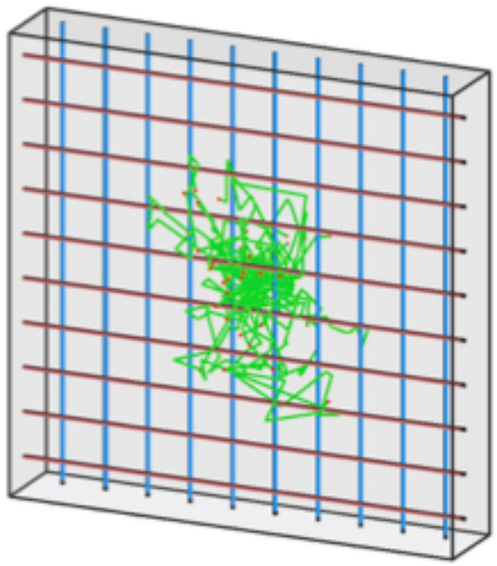
It’s working



Simulations



Simulations written in Geant4 that allow for detailed investigation into the behaviour of light and radiation in an opaque scintillator detector.

Can modify key parameters of interest:

- Geometry
- Scintillator properties

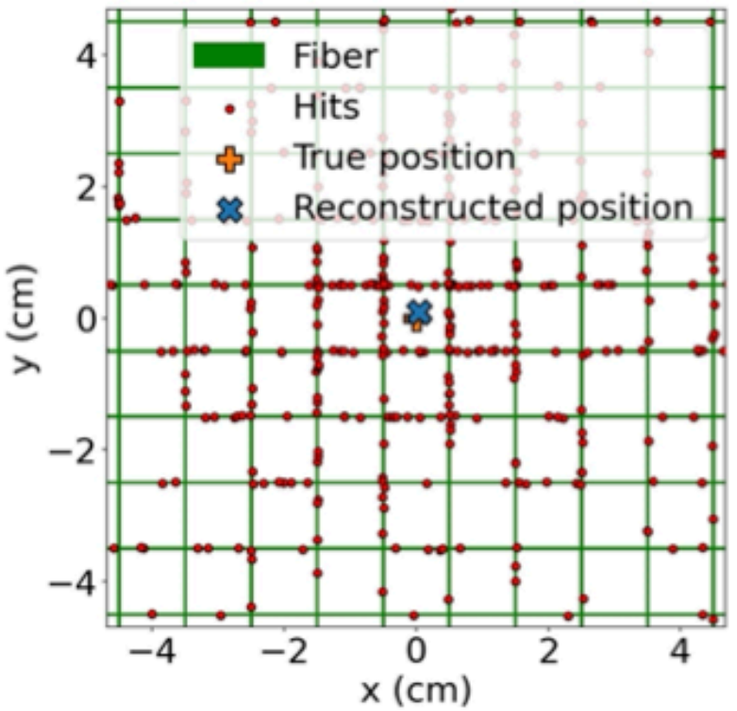
A simulated event

We get a set of photons hitting different fibers at different times.

Need to reconstruct event x, y position and time:

Position reconstruction:
Hit weighted average of fiber positions.

Time reconstruction:
Time of photon first hit.



Effect on resolution of detector parameters

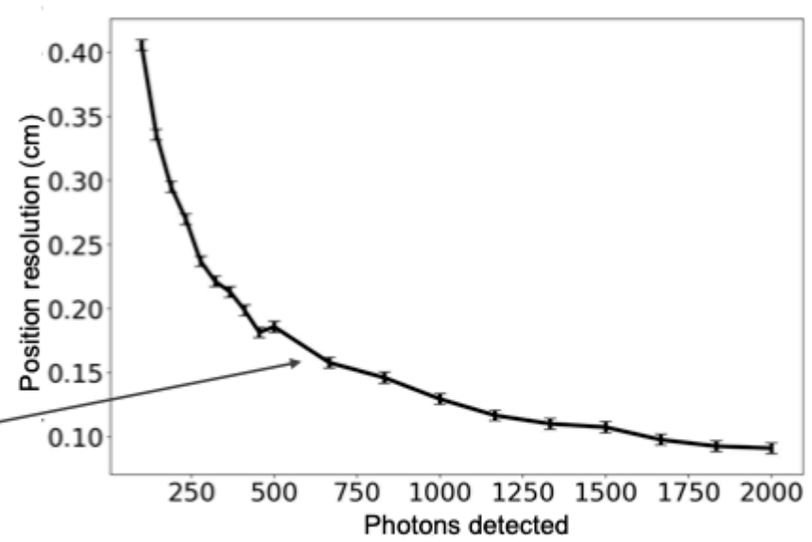
Absorption length: 5 m

Scattering length: 0.5 cm

Fiber pitch: 1 cm

Fiber diameter: 0.5 mm

Light yield: 600 photons detected/event



https://sites.google.com/view/stfccancerdiagnosis/home/workshops