

Improved Event Reconstruction and Spectrum Analysis using PROSPECT Antineutrino Data

Christian Roca Catala - X.13.2021

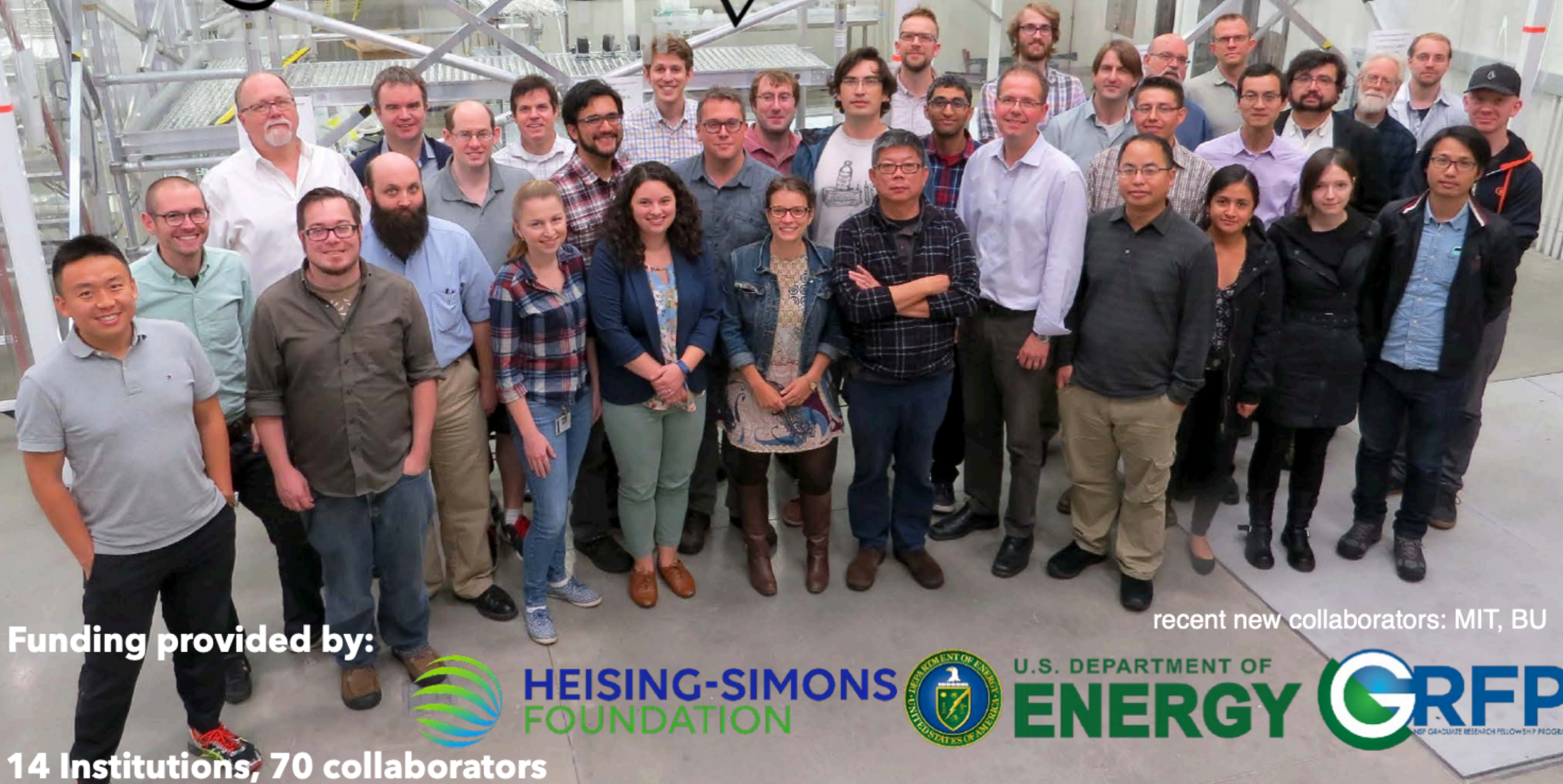
On behalf of the PROSPECT collaboration



LLNL-PRES-XXXXX

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PROSPECT

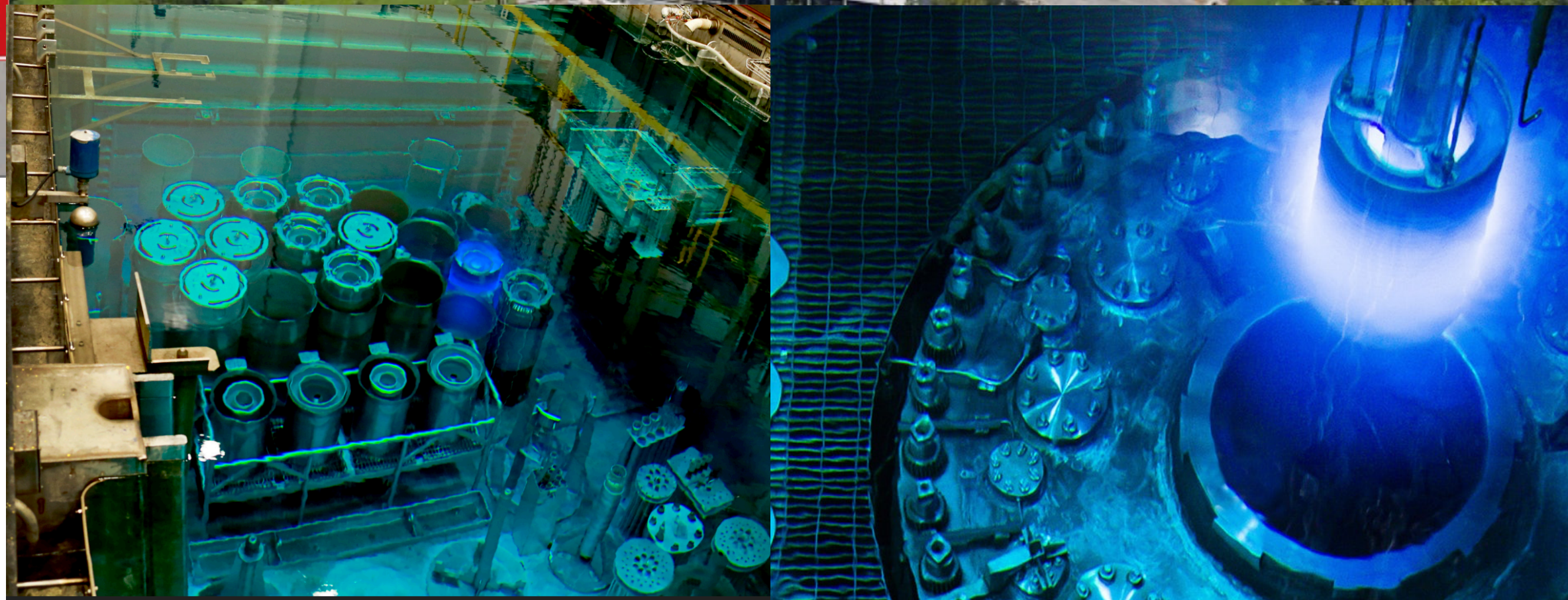
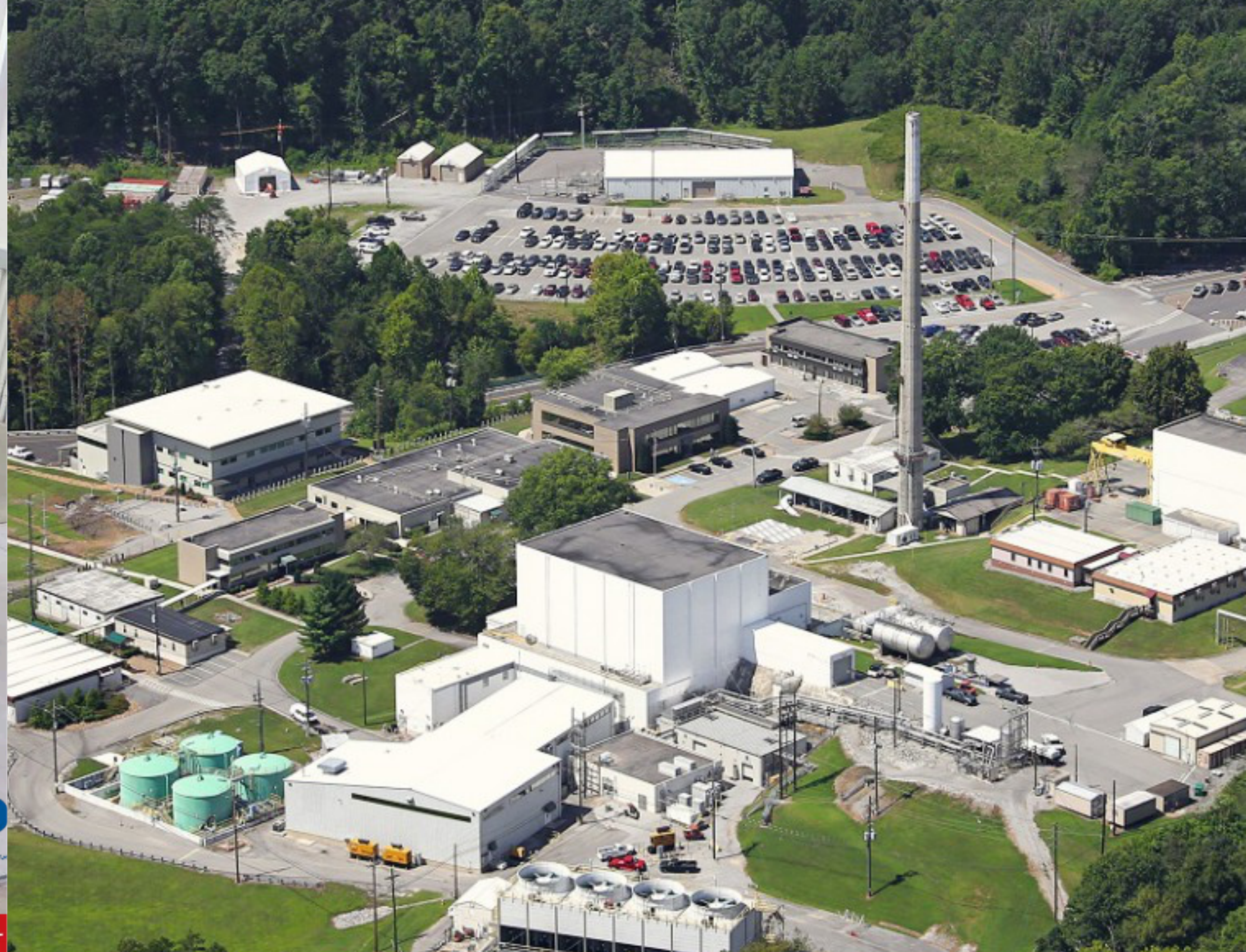


recent new collaborators: MIT, BU

Funding provided by:



14 Institutions, 70 collaborators

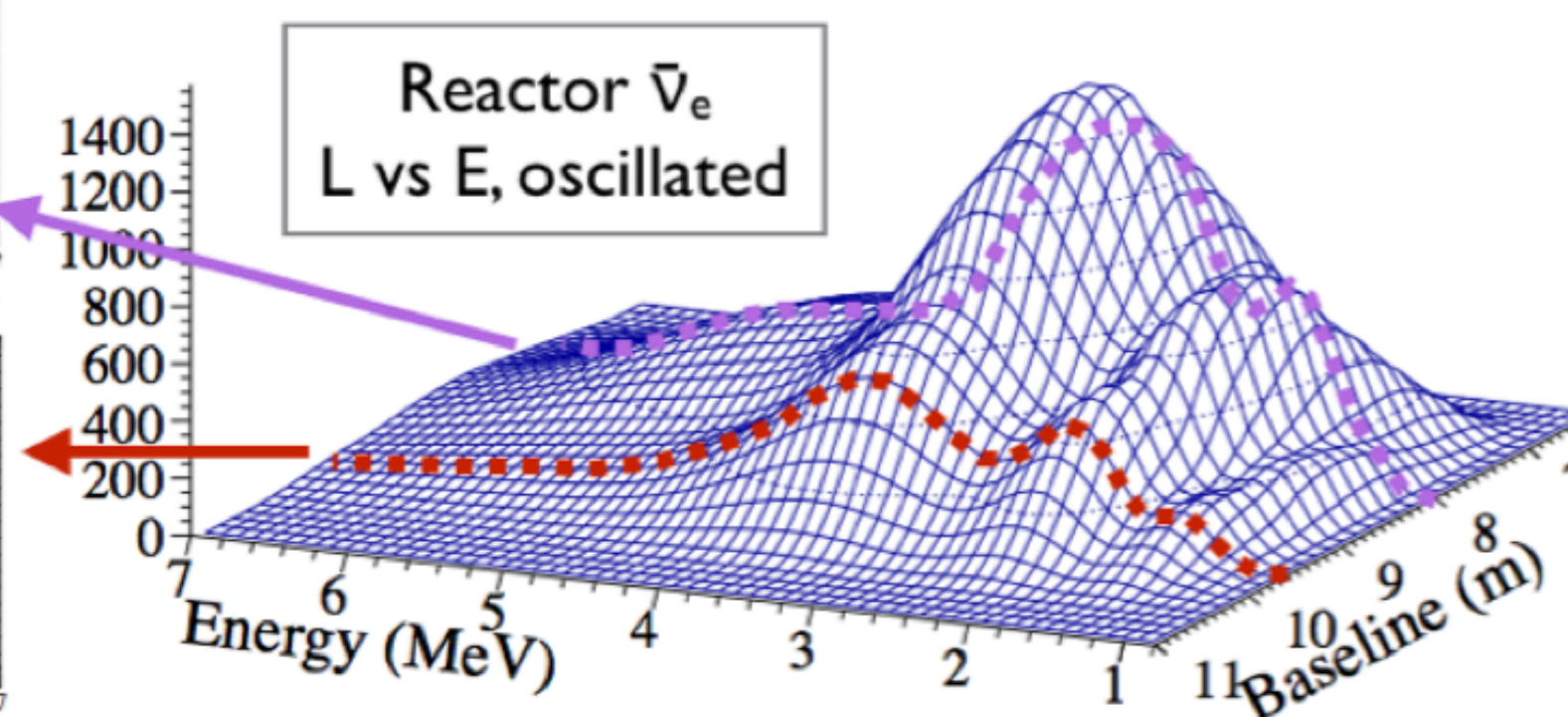
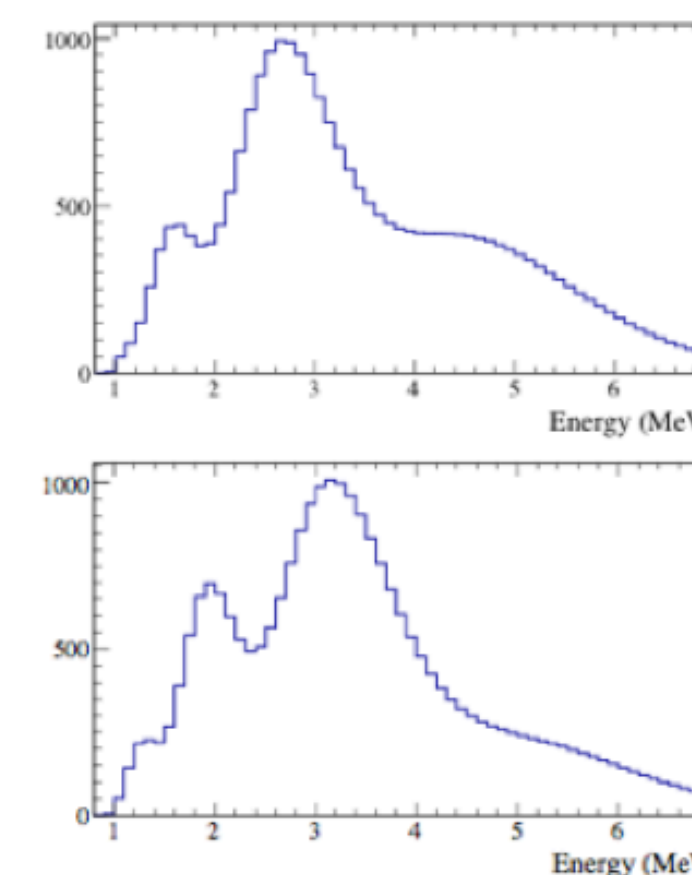
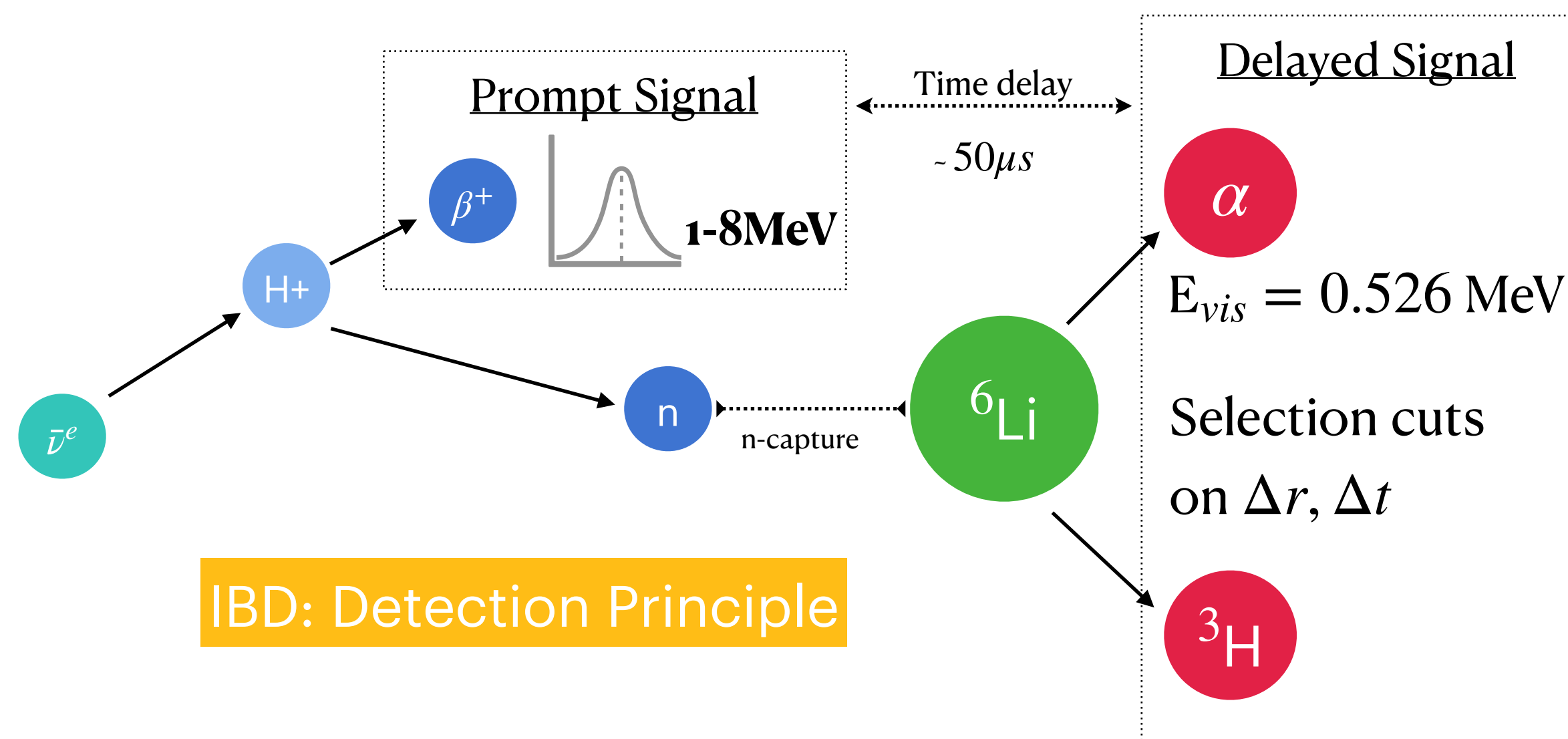
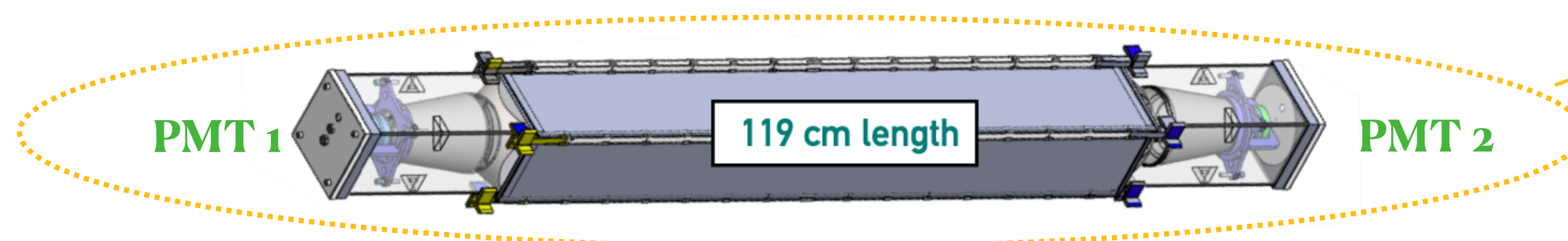
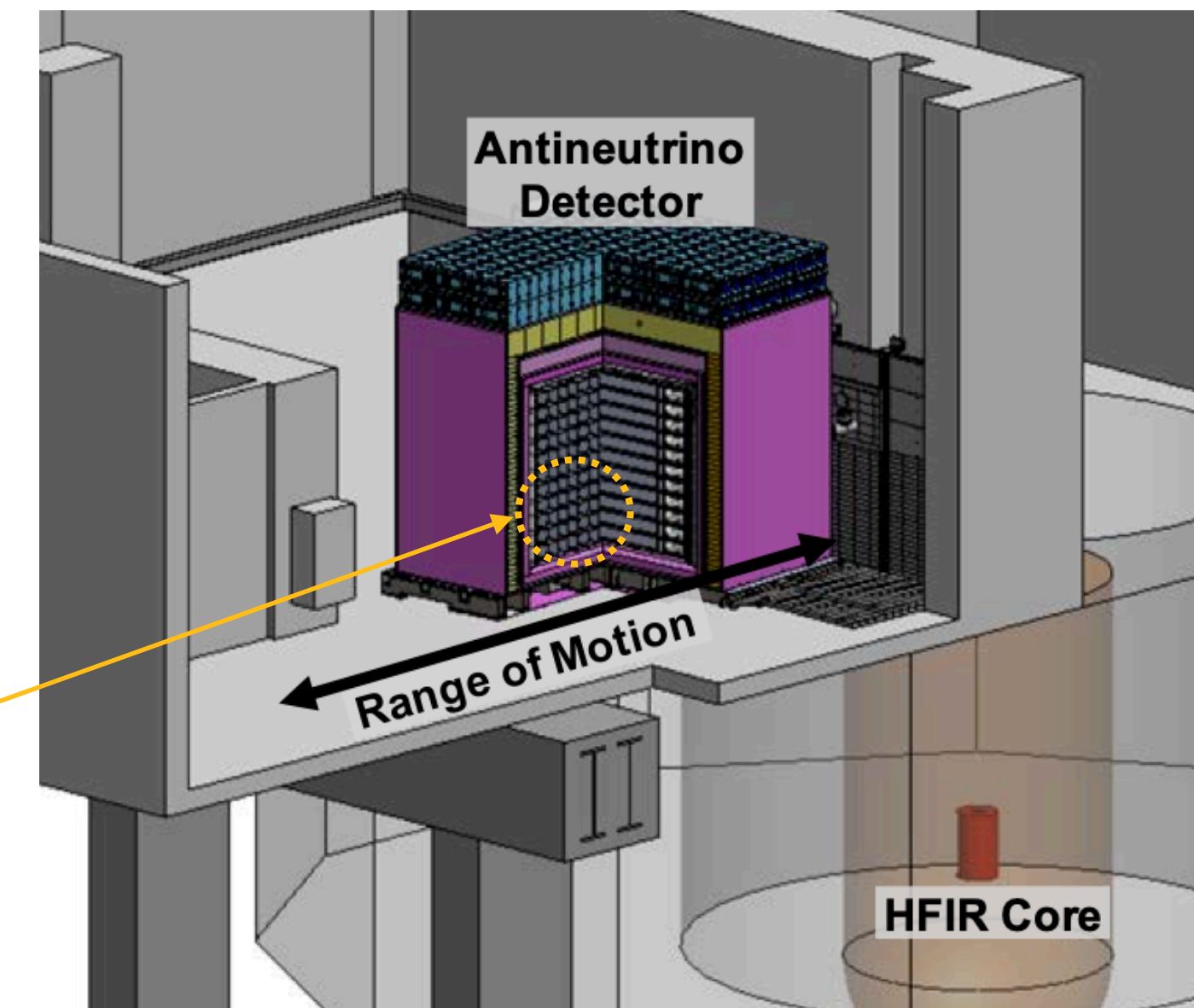


The High Flux Isotope Reactor - Oak Ridge

- Compact HEU core
- Pure U-235 fuel
- Research reactor ~ 85MW - 46% reactor up time

PROSPECT design

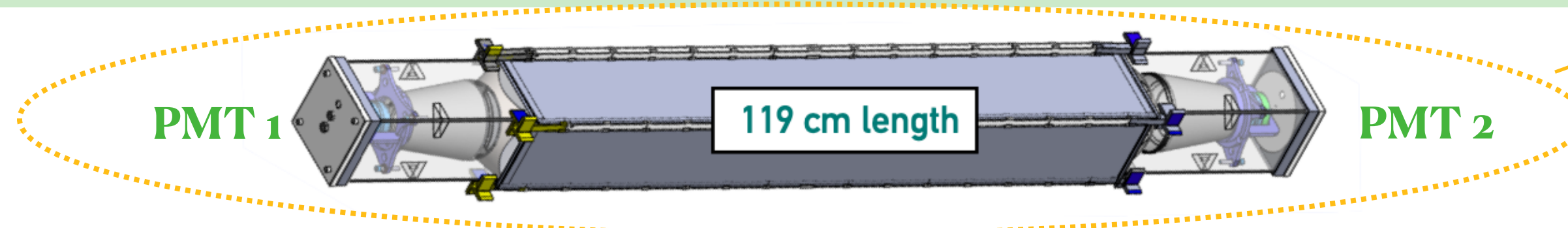
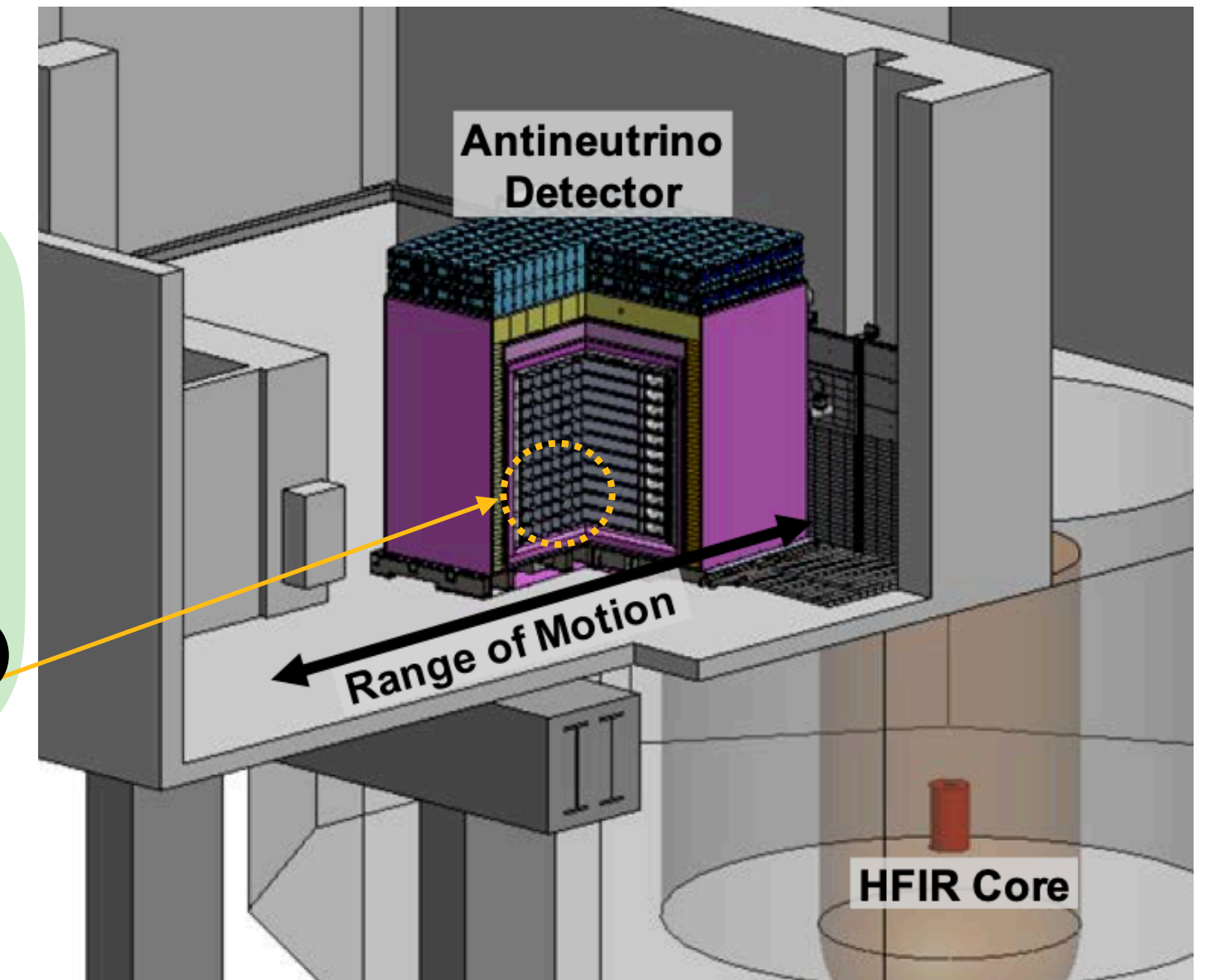
- **Liquid Scintillator** loaded to a mf of 0.08% ^6Li
- High-resolution **spectrum** at a range of **baselines (7-9 m)**
- 14x11 **Segmented** detector allows **topology selection** and **background rejection**
- **Double PMT** readout with light concentrators $\sim 5\% \sqrt{E}$ energy resolution



Search for relative spectral distortions within the detector volume

PROSPECT neutrino measurement

- Liquid Scintillator (LS) ingress in some of the PMT housings fatally affecting HV/signal dividing bases.
- The latest published results [PhysRevD.103.032001] only included IBDs from 97/154 segments w/ **Double Ended Event Reconstruction (DEER)**



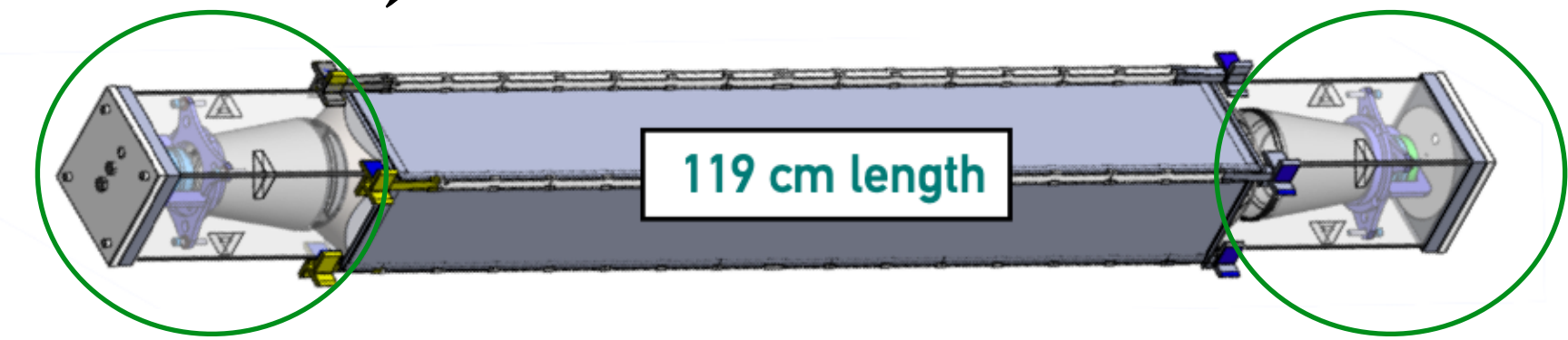
	Healthy	Monocular	Blind										
140	141	142	143	144	145	146	147	148	149	150	151	152	153
126	127	128	129	130	131	132	133	134	135	136	137	138	139
112	113	114	115	116	117	118	119	120	121	122	123	124	125
98	99	100	101	102	103	104	105	106	107	108	109	110	111
84	85	86	87	88	89	90	91	92	93	94	95	96	97
70	71	72	73	74	75	76	77	78	79	80	81	82	83
56	57	58	59	60	61	62	63	64	65	66	67	68	69
42	43	44	45	46	47	48	49	50	51	52	53	54	55
28	29	30	31	32	33	34	35	36	37	38	39	40	41
14	15	16	17	18	19	20	21	22	23	24	25	26	27
0	1	2	3	4	5	6	7	8	9	10	11	12	13

- 47 single ended segments were **excluded**
- Single Ended Event Reconstruction (SEER)** has been developed to improve the **IBD statistics**
- Data Splitting (DS)** into different **periods** would allow a more efficient and effective **active segment selection**.

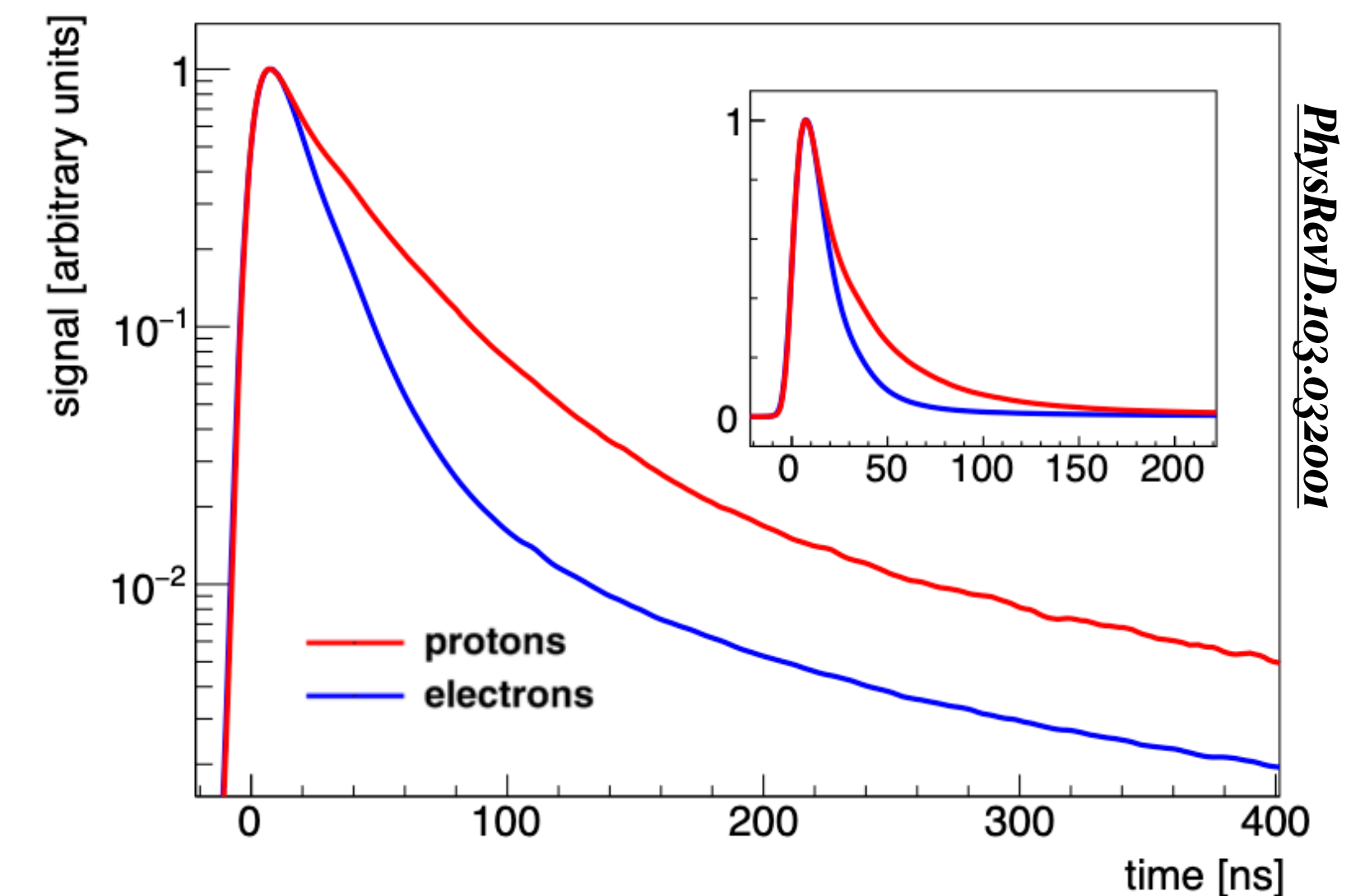
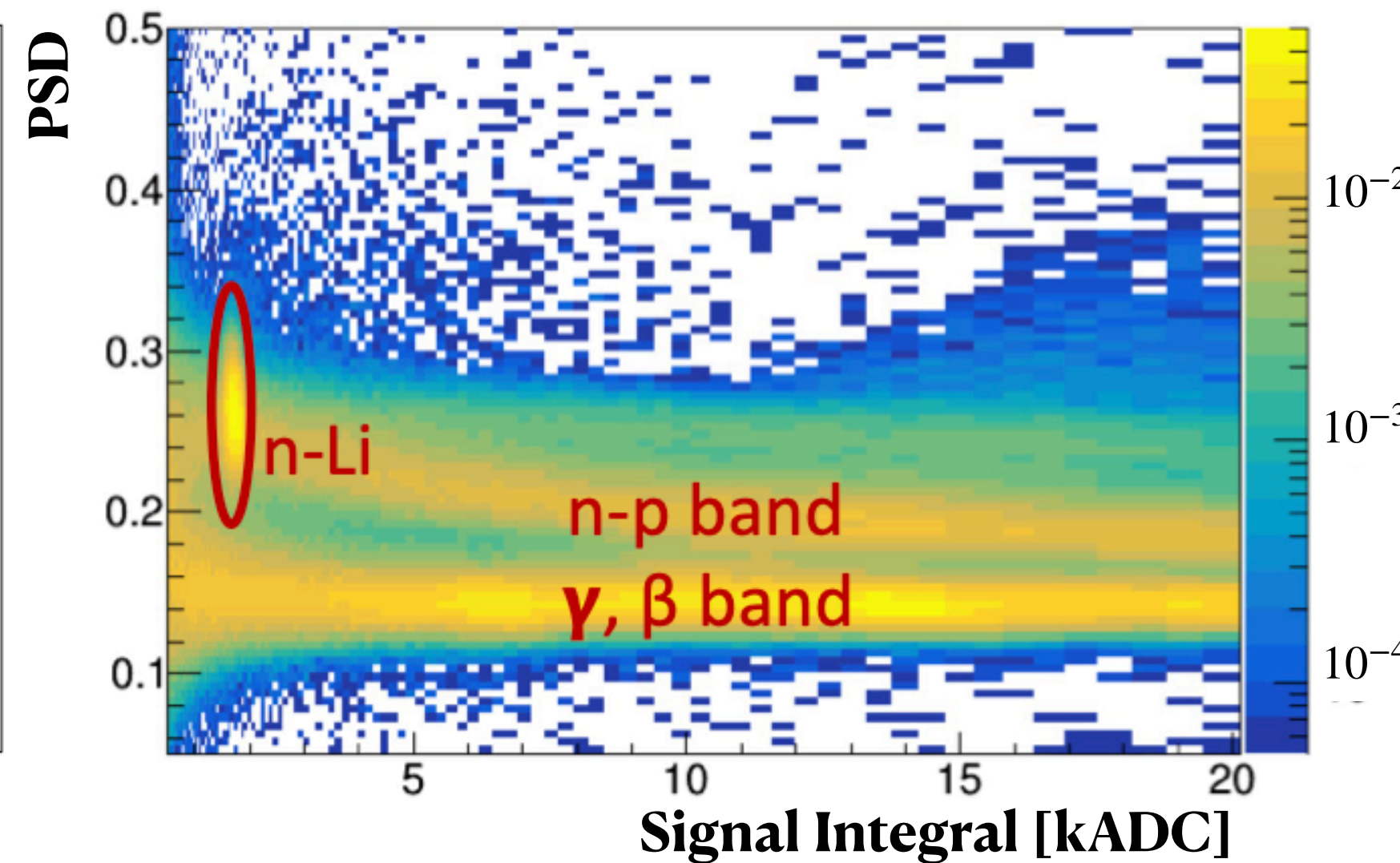
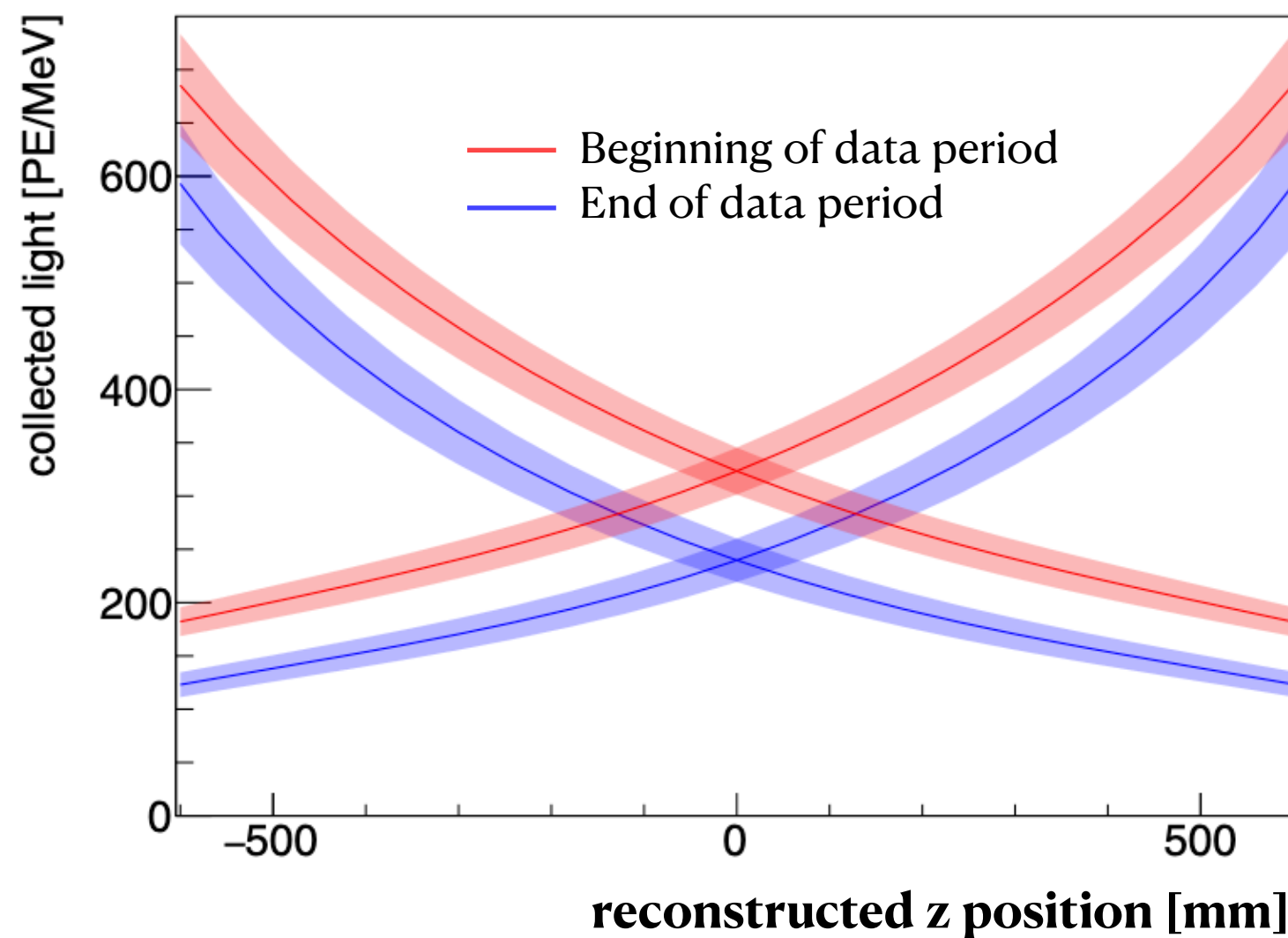
LS ingress increased over time

Double End Event Reconstruction (DEER)

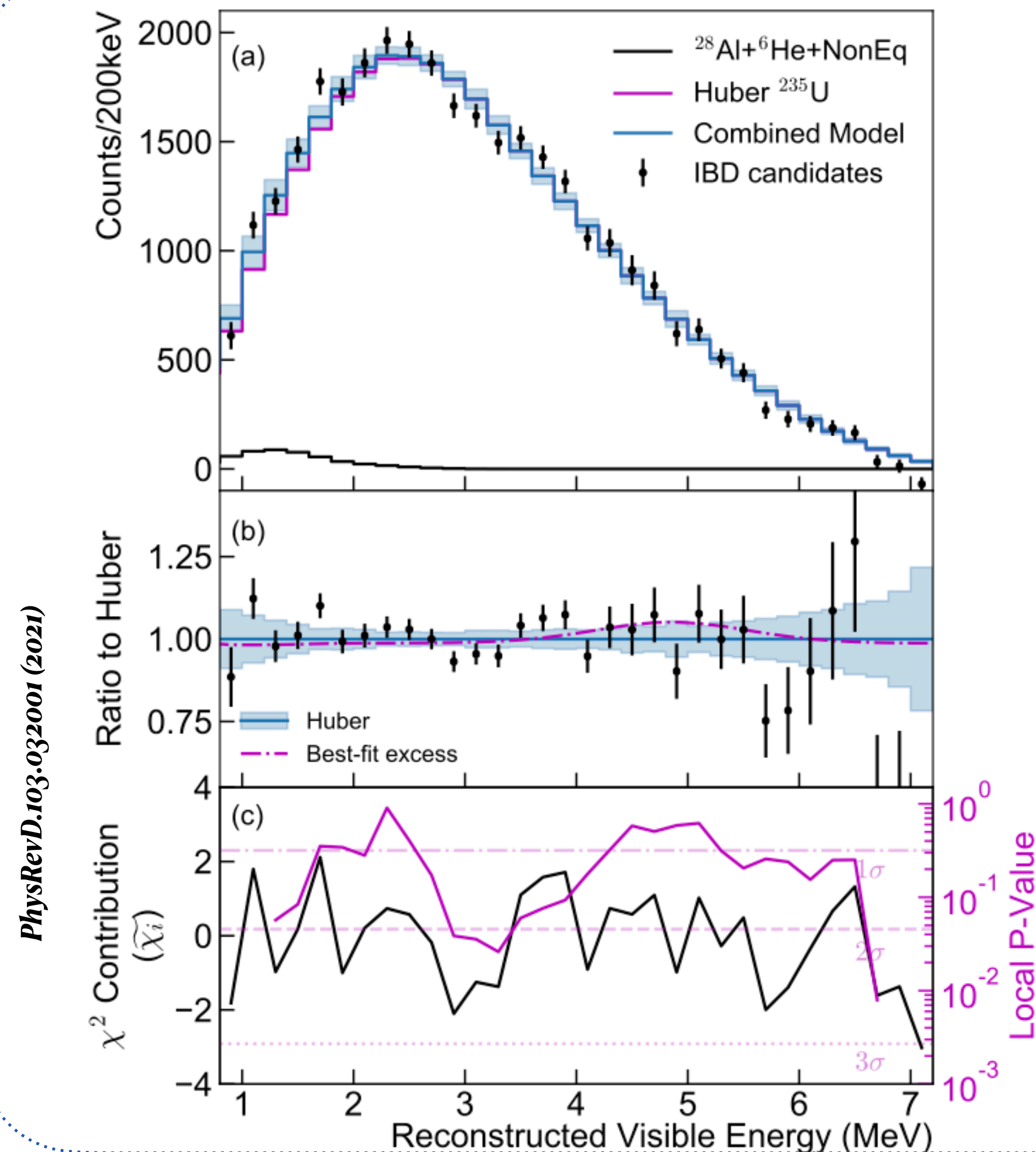
The standard route for event reconstruction in PROSPECT



- Rely on the **waveform** pair collected by **both PMTs** of a segment
- **Event position** along a segment (z-position) **reconstructed** with **timing** and **integral** difference on the pulse pair.
 - ➔ **Energy** reconstructed by pulse area with **position correction**.
- Pulse shape discriminations (**PSD**) are used to **distinguish** gamma/beta events from heavy particle **interactions** (n-Li captures and n-p recoils).
- **Pulses without** matching **pair** are **excluded** from calibrated data analysis.



Published spectral studies



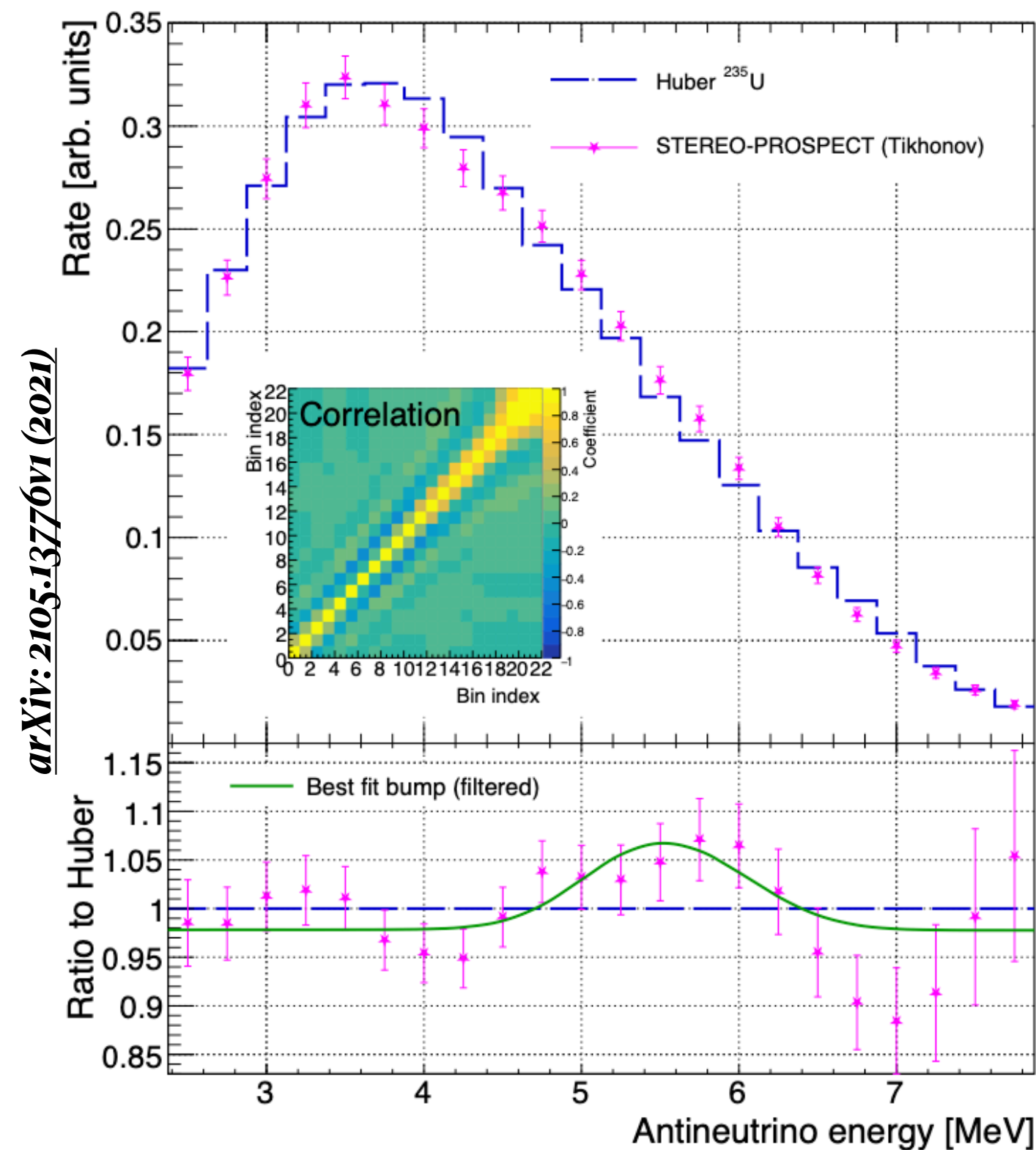
PROSPECT's solo analysis

- Using **DEER** events **only** ~ **50500 IBD** events
- **Comparison** to **HFIR** prediction (inc. reactor corrections) using **H-M** model.
- **Pure U235** spectrum shape.
- **Comparison** performed in **prompt E space** including gaussian **excess** in the **4-6MeV** area.
- Shape analysis agreement with H-M model ($\chi^2/\text{ndf} = 30.79/31$)
- Both **no-U235-bump** / **all-U235-bump** disfavored at the **2.2 / 2.4 σ** C.L.

Published spectral studies

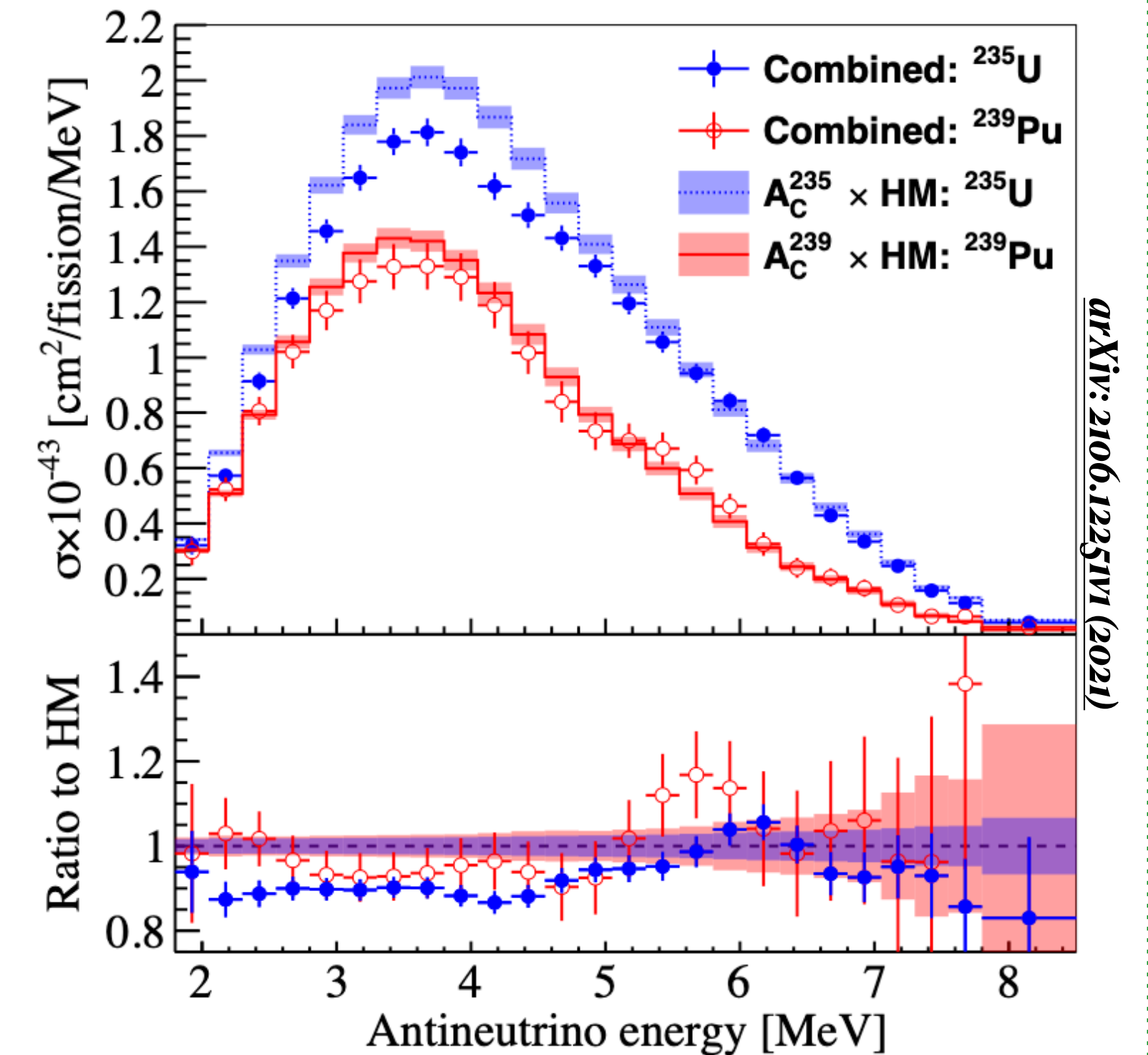
PROSPECT's combined analyses

PROSPECT + STEREO



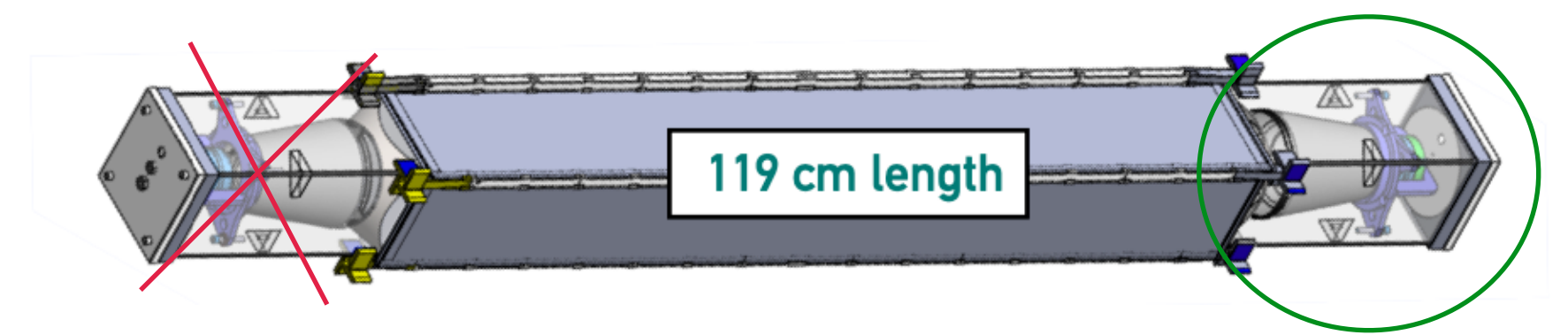
- **Comparison to H-M** performed in unfolded/**neutrino energy space**.
- Unfolding techniques: **Tikhonov regularization** and **WienerSVD**.
- Stronger **confirmation of excess** between 4-6 MeV area.
- **Improved uncertainty** of the **U235** spectral shape.
- **Proof of concept:** combining HEU/LEU experiments is possible and very positive.

PROSPECT + DAYA BAY



FK.00005: Precise Measurement of Reactor Antineutrino Spectra from Joint Analyses of PROSPECT, STEREO, and DAYA BAY

Single Ended Event Reconstruction (SEER)

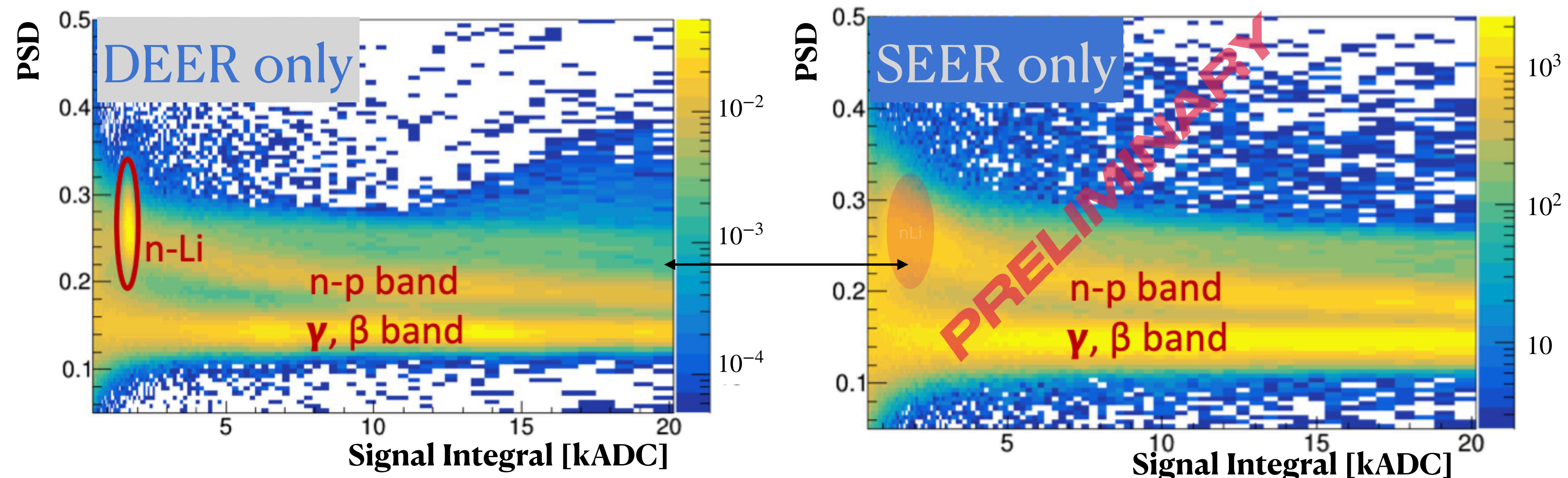


Position and energy reconstruction

- **SEER lacks** the ability to reconstruct **position** because of no counter part pulse comparison (**1 PMT** available).
- **Energy reconstruction** depends on position, therefore **not applicable** as IBD selection cut.

Particle Identification (PID)

- **PSD** capability with **single PMT** readout is applicable for **PID**
- **SEER PSD lacks** the ability to **distinguish n-Li capture** from n-p recoil events.
- **More active segments** from SEER+DEER allow for **better IBD selection** and bkg rejection.



Final Spectral Analysis: including SEER and Data Splitting (DS)

New event selection will allow PROSPECT to recompute its analysis with an updated dataset

LK.00008: Improved Inverse Beta Decay event selection and its impact on the PROSPECT oscillation analysis. (NEXT TALK IN THE SESSION!)

PROSPECT's solo spectral analysis

- Apply **SEER** + DEER to **event selection** to boost IBD statistics.
- Use **Data Splitting** to improve S:B and IBD statistics. Compute individual response matrices for each DS period
- **PROSPECT-only unfolding** of 5-fold prompt spectra from DS into **neutrino** space simultaneously.
- Leverage gained experience: use **WienerSVD** as unfolding technique.
- Timeline: end 2021/ early 2022

Final Spectral Analysis

PROSPECT's combined spectral analyses

- Expand DS **unfolding framework** for an arbitrary number of **experiments**.
- Easy-to-use tool to **combine** efforts across **collaborations**.
- Potential to provide **new benchmarks** for **U235 antineutrino spectrum**.
- Timeline: early/mid 2022

Generalized Combination

Available to any interested collaborator

Fixed Unfolded binning

Input Uniformity

PROSPECT's comparison framework

- Develop **comparison framework** to test hypothesis **beyond** vanilla **H-M**
- Use framework to **test uncertainties** in **ab initio** calculations.

Extended H-M model

+ virtual beta branches

Modified ab initio predictions

Conclusions and Outlook

Proven analyses and results

+50000 IBD signals and S:B = 1.4:1 using DEER and single dataset.

LS ingress in some PMT housings rendered them inoperable using DEER.

PROSPECT has collaborated with DB and STEREO to produce two separate joint analyses.

Joint analyses have improved uncertainties and overall understanding of U235 spectrum

New analysis

Using all possible data available through:

- SEER
- Data Splitting

Combined unfolding framework for multiple experiments on the road

PROSPECT's solo unfolded spectrum

Potential multi-collaboration combined unfolding

Comparison framework in the pipeline

FK.00005: Precise Measurement of Reactor Antineutrino Spectra from Joint Analyses of PROSPECT, STEREO, and DAYA BAY

FK.00006: PROSPECT-II: Physics goals with an upgraded precision reactor oscillation and spectrum neutrino experiment

FK.00007: Working towards and absolute reactor antineutrino flux measurement using PROSPECT-I Data

FK.00008: Reactor Background Measurement at HFIR in support of the PROSPECT-II experiment

LK.00006: PROSPECT-II calibration strategy

LK.00008: Improved Inverse Beta Decay event selection and its impact on the PROSPECT oscillation analysis