Current Status and Future Plans For Better Understanding Reactor Neutrino Emissions

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December 4

Map Of Reactor Experiments/Efforts

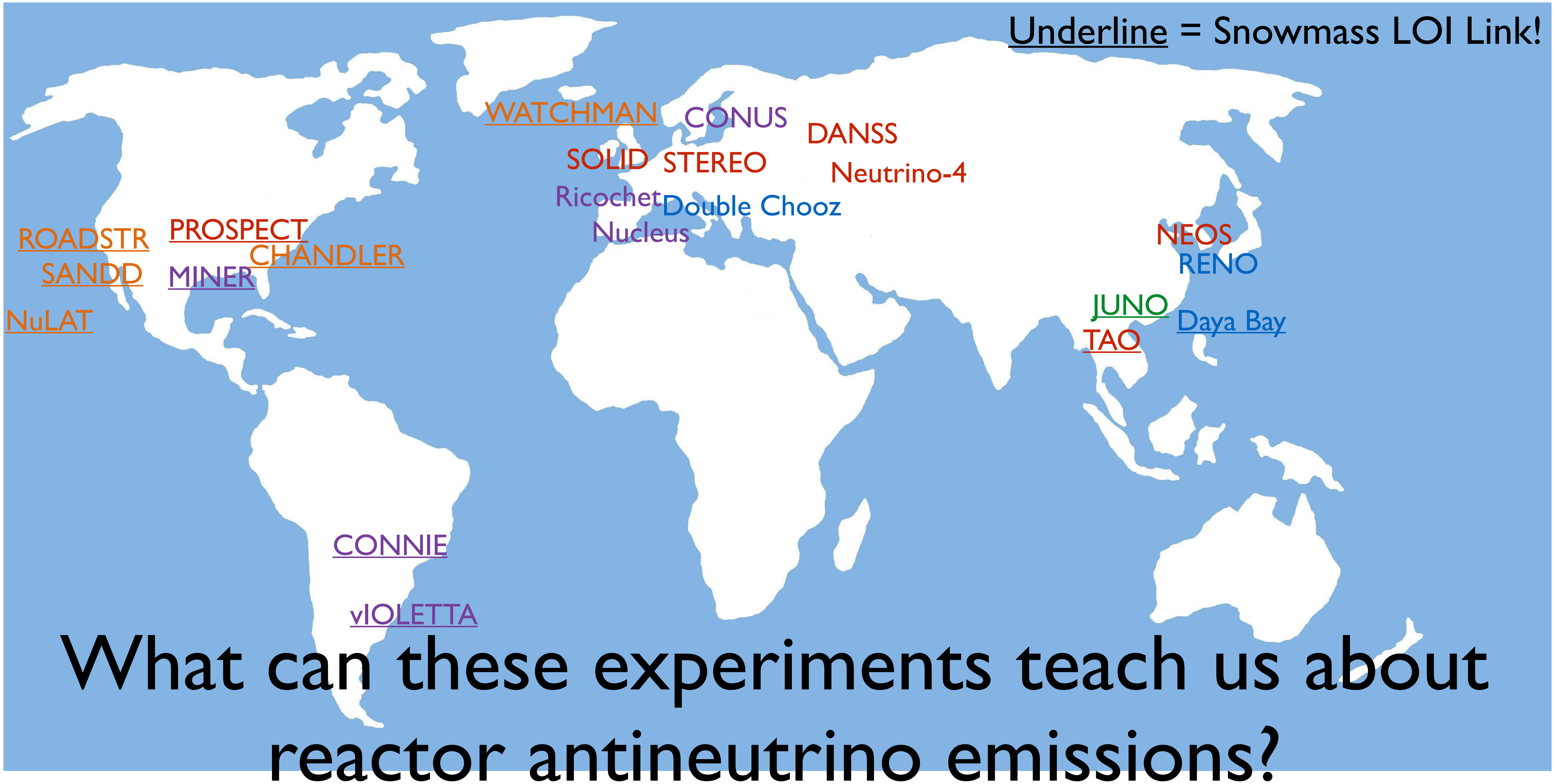
Theta13

Long-Baseline

Short-Baseline

Applications-focused

CEvNS



What can these experiments teach us about reactor antineutrino emissions?

Talk Organization

- Focus on our knowledge of reactor antineutrino emissions: their absolute fluxes and spectra
  - All the other neutrino physics we can learn is of course great — For NF01, NF02, NF03, blahblah…
  - But that's not in my sights today: today is NF07 and NF09!

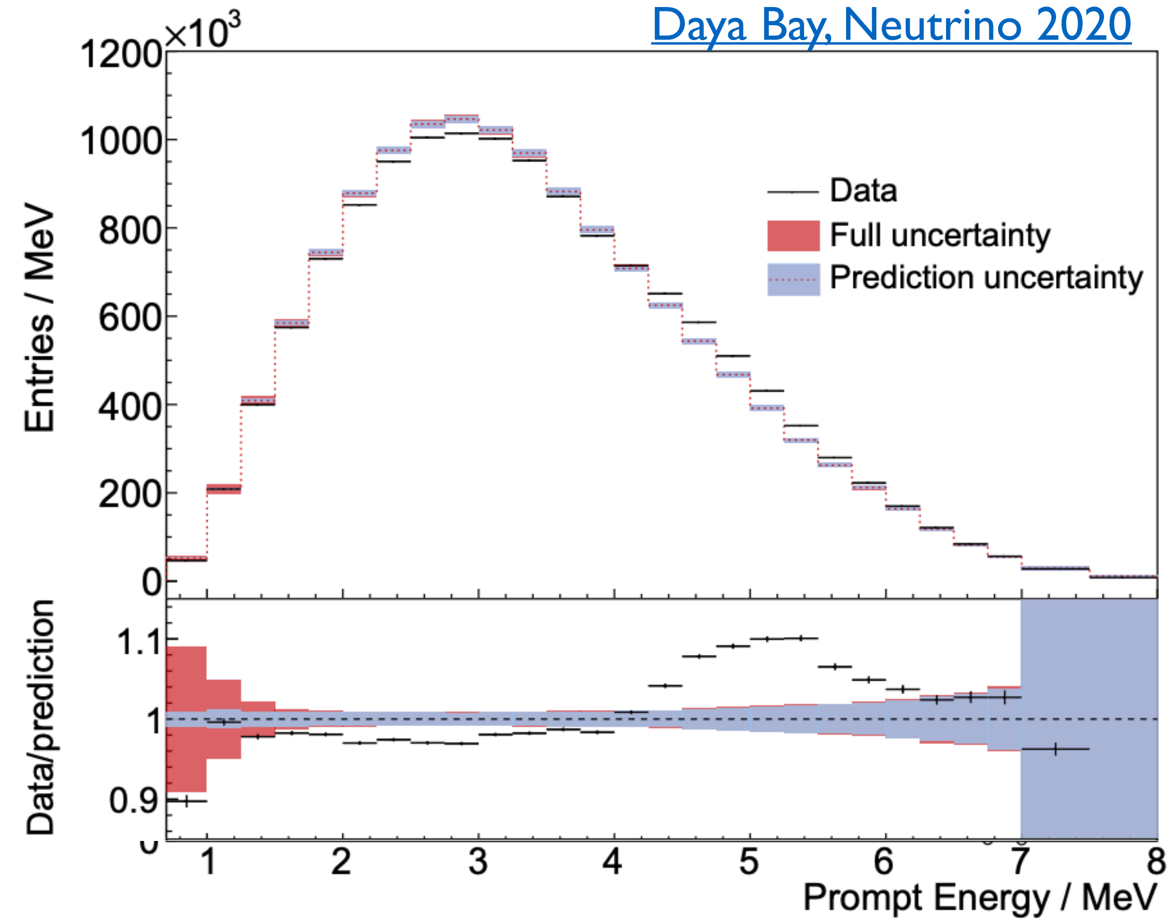
- What we DO KNOW from current experiments
- What we DO NOT KNOW
- What we COULD LEARN in the future from current and future reactor antineutrino experiments

What We <u>DO</u> Know

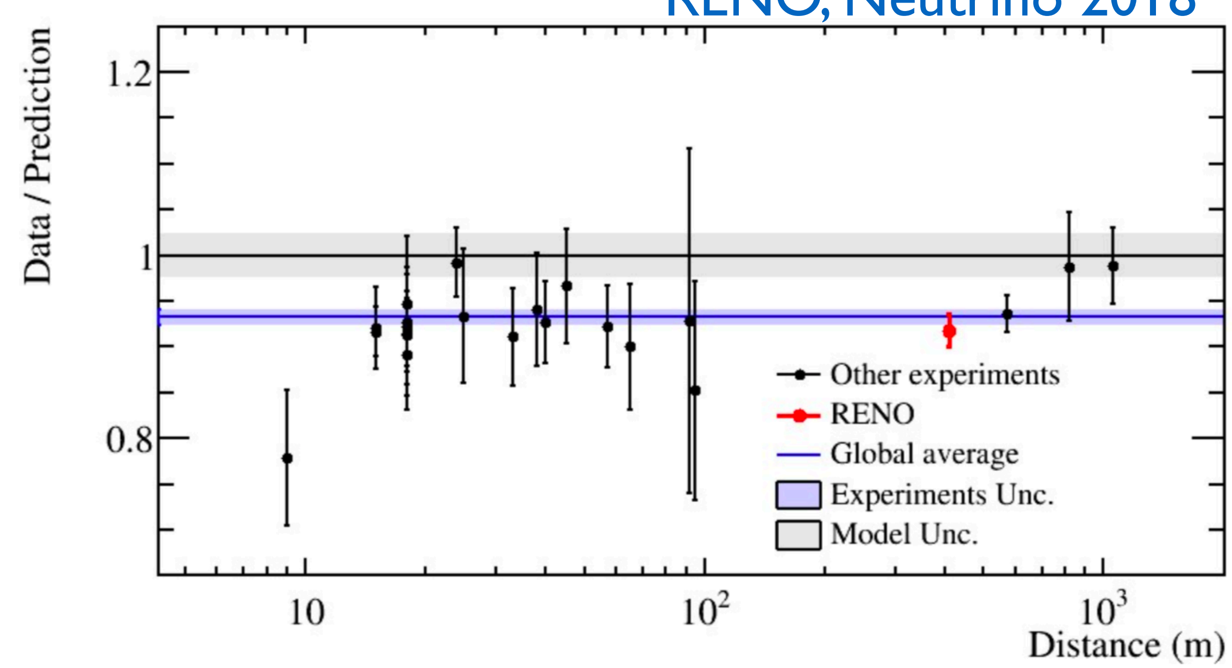
Gains: LEU Measurements

- θ_{13} experiments have completely changed the Rx spectrum game
  - Due to both massive statistics AND excellent detector response and characterization
  - We now know the LEU spectrum is poorly predicted by both conversion and summation predictions
- They have also confirmed the reality of the 'reactor anomaly' with 'modern' technologies
  - We now know that measured fluxes are indeed lower than both predictions for LEU experiments
  - Not totally sure if this deficit is a significant one, though: models may be too biased or uncertain…

Daya Bay, Neutrino 2020



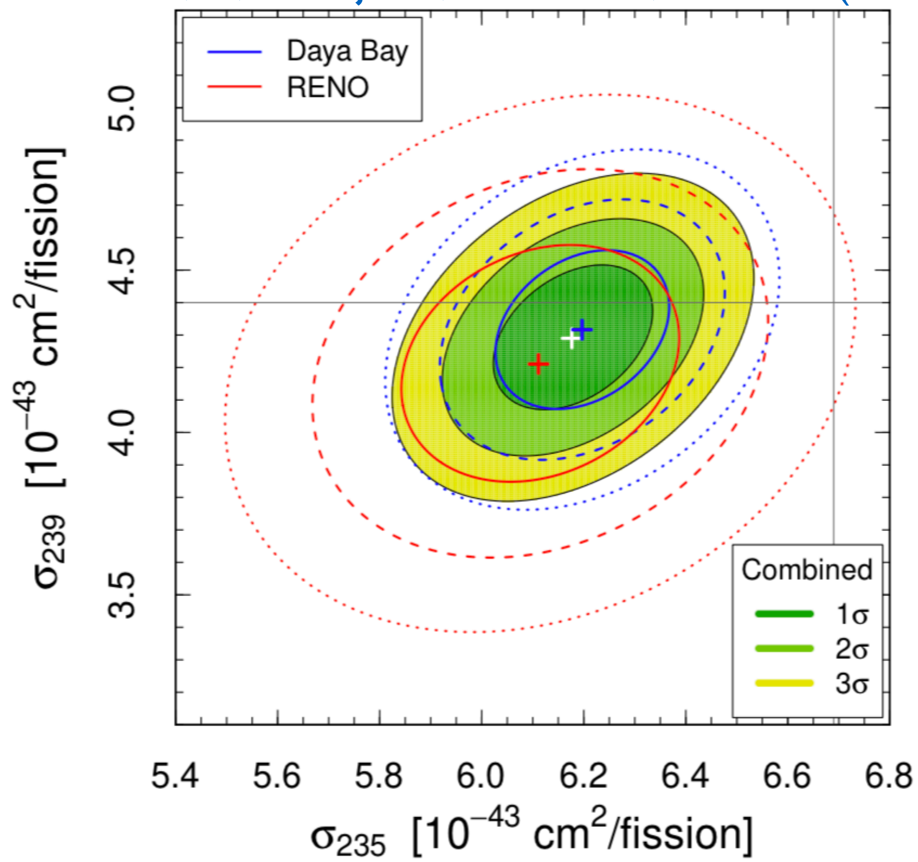
RENO, Neutrino 2018

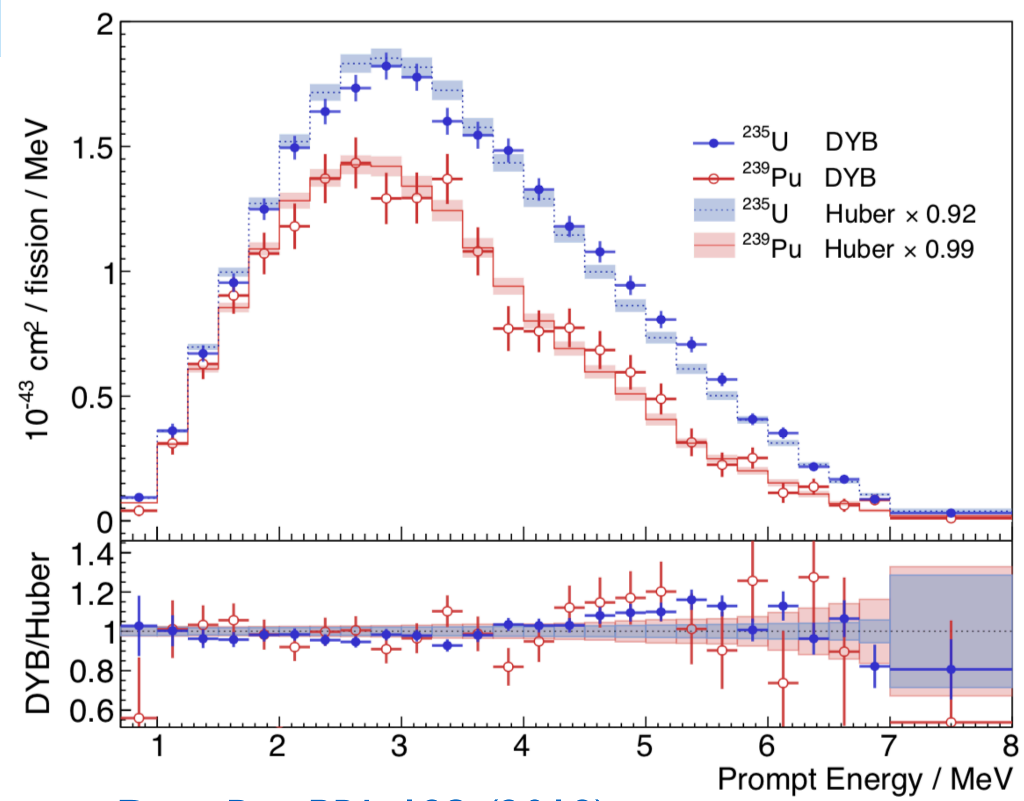


Gains: LEU Evolution Measurements

- New flux AND spectrum knowledge derived from 'evolution' results at θ_{13} experiments
- Have directly measured isotopic flux for dominant fission isotopes
  - Assuming no oscillations, conversion model appears to over-predict fluxes from U235.
  - We know summation models do not exhibit this same issue. Conversion model problem?!
- Have directly measured isotopic spectra of dominant fission isotopes
  - With LEU data alone, we know U235 predictions, specifically, are bad.
  - Not enough LEU statistics to know if Pu239 is similarly poorly predicted.

Giunti, Li, Littlejohn, Surukuchi, PRD 99 (2019)



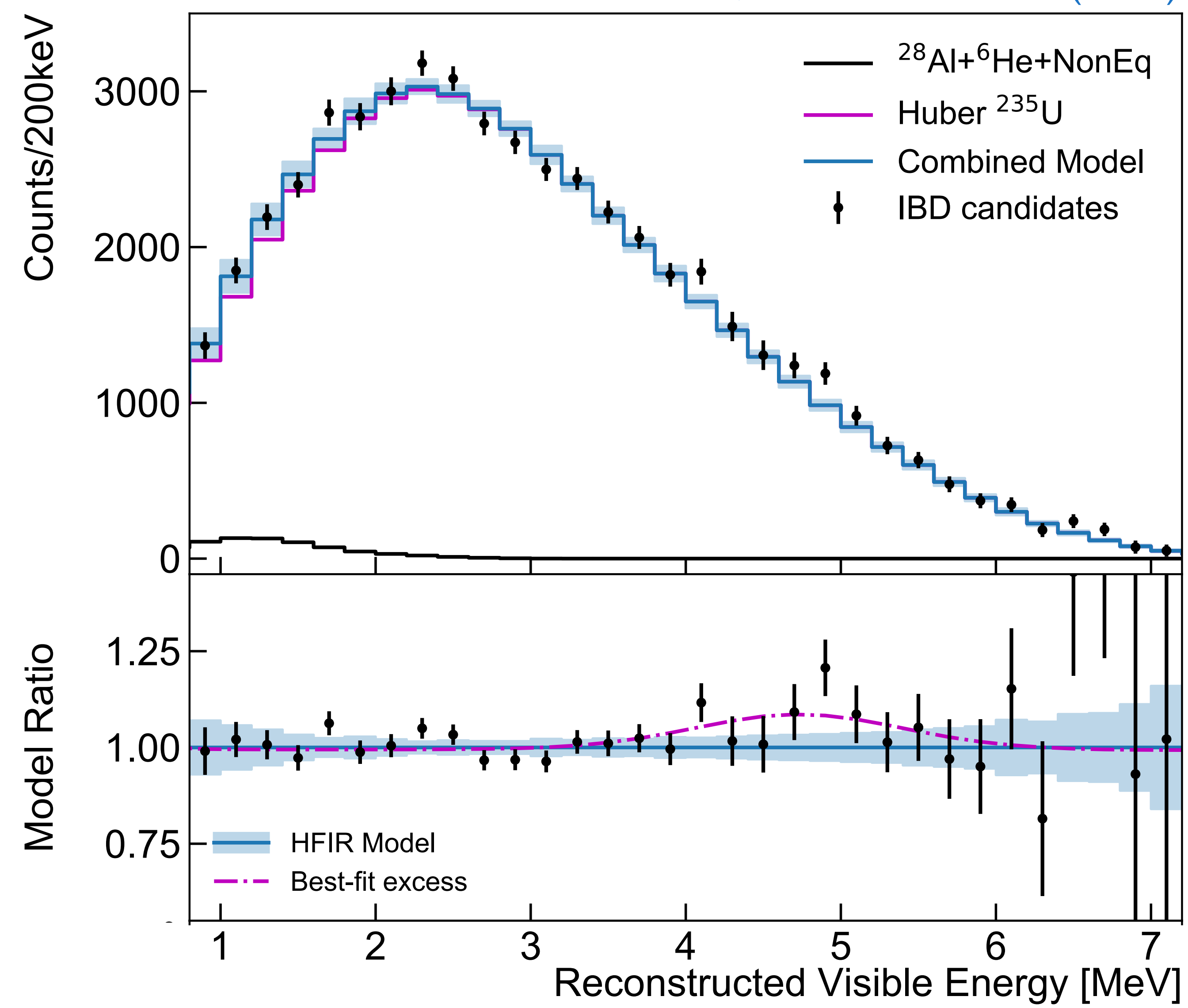


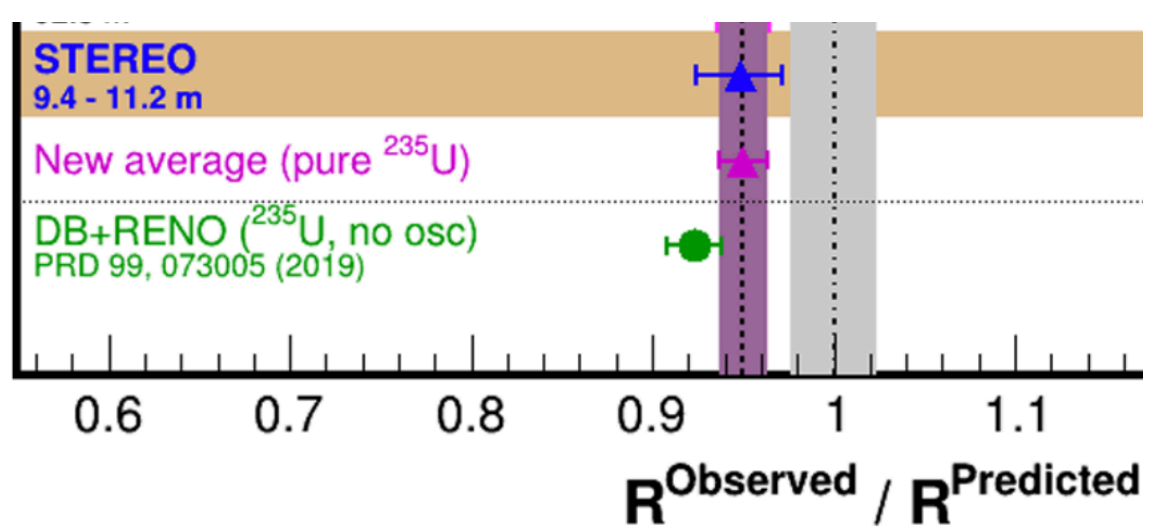
Daya Bay, PRL 123 (2019)

Gains: HEU Measurements

- HEU core measurements further illustrate our picture of isotopic emissions
- PROSPECT and STEREO both have reported HEU spectrum measurements
  - '5-7 MeV bump' from HEU is the same size as from LEU: indicates Pu239 and U235 predictions are 'equally bad'
- STEREO has confirmed the reality of the 'flux anomaly' at HEU experiments with 'modern' technology
  - We know HEU experiments see a 'deficit' like LEU experiments.

PROSPECT, arXiv:2006.11210 (2020)





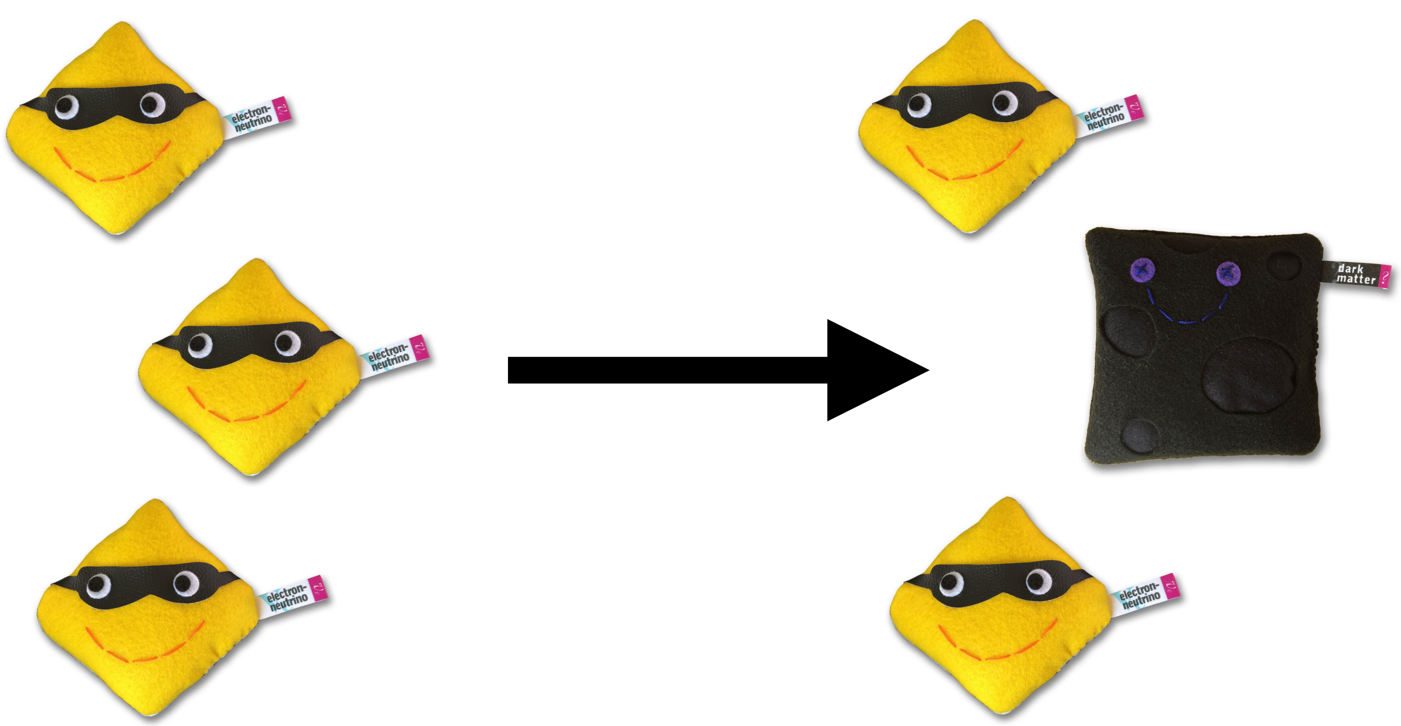
STEREO, arXiv:2004.04075 (2020)

What We <u>DO NOT</u> Know

… or should try to understand better with neutrinos, at least

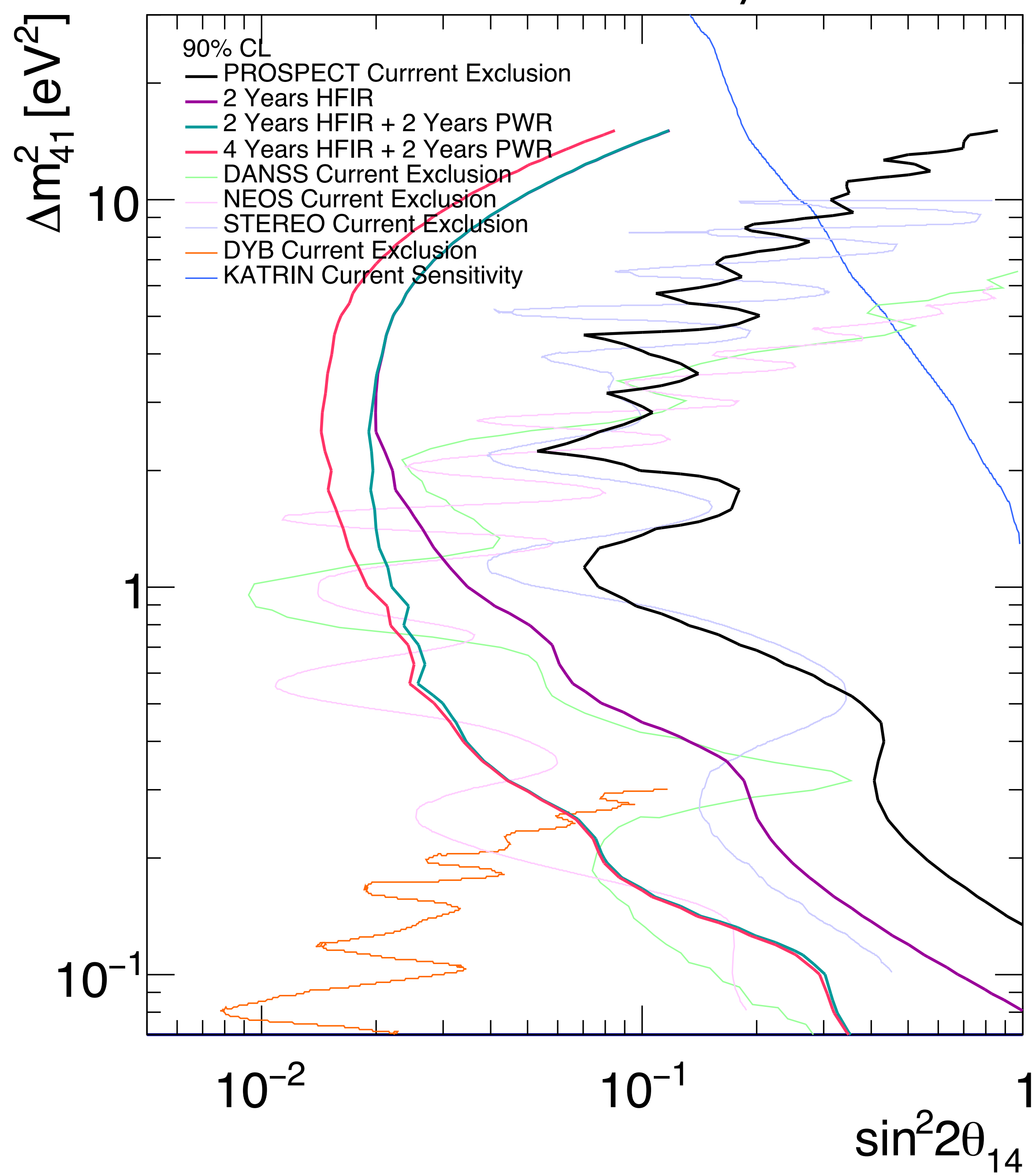
Not Known 1: Sterile Oscillations

- Don't know what 'true' emission is due to possible impacts of sterile neutrino oscillations during propagation
  - Can try to tease this out with L+E measurements
  - Oh yeah… this is also REALLY interesting physics on its own (Hello NF02)!



example: 33% disappearance

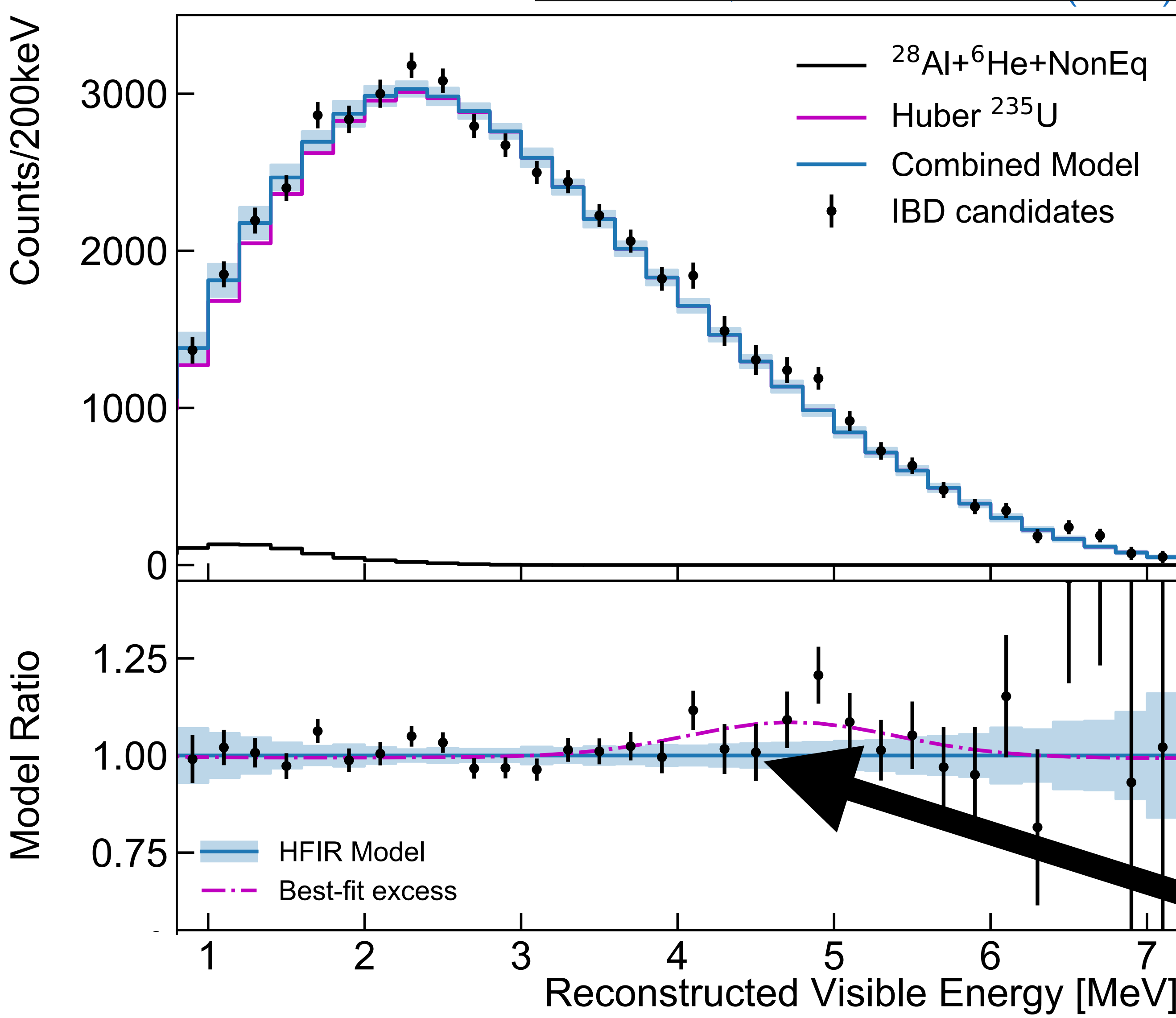
Courtesy of PROSPECT

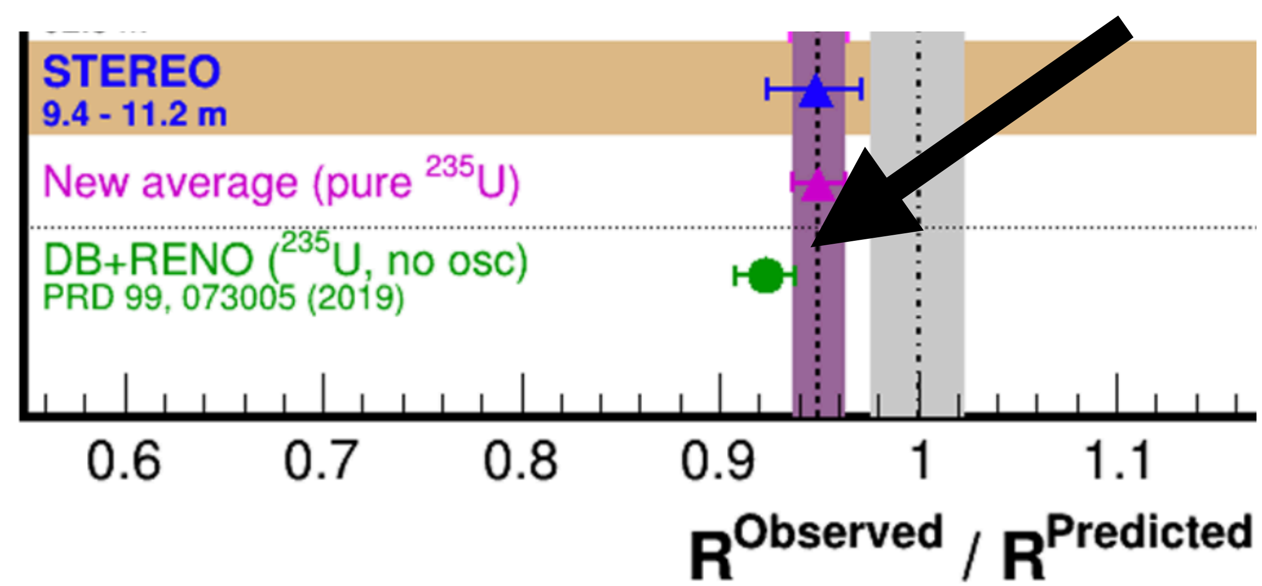


Not Known 2: Isotopic Precision Issues

- HEU statistics are still rather low: <100k total IBDs
- Slight conflict between DYB- and HEU-reported U-235 fluxes
  - ~3% offset; perhaps there's some physics underlying this that can be resolved?

[PROSPECT, arXiv:2006.11210 (2020)](#)





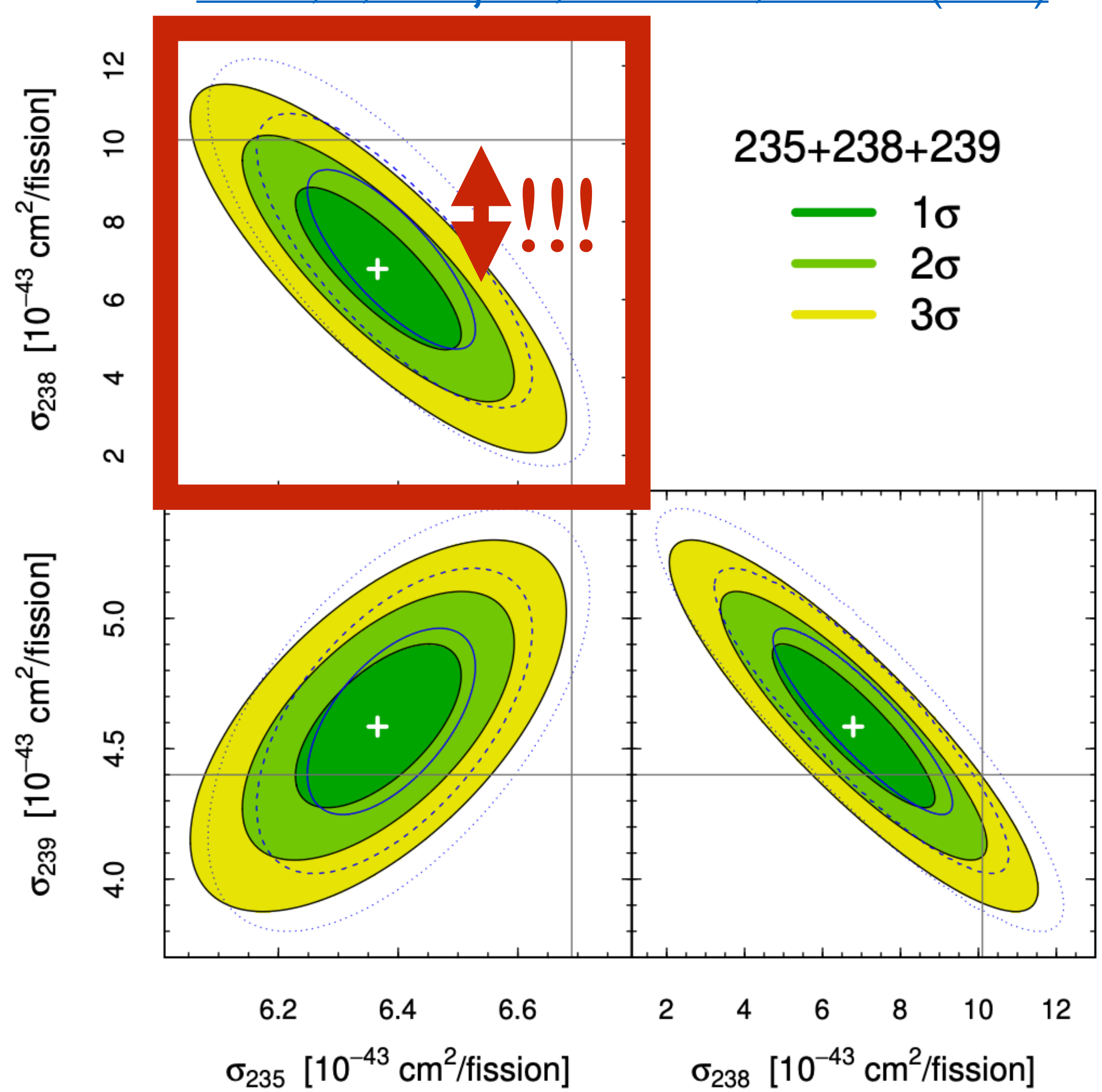
[STEREO, arXiv:2004.04075 (2020)](#)

Shrink these?

Not Known 3: Sub-Dominant Fission Isotopes

- All our findings of U235, Pu239 fluxes and spectra say practically nothing about other isotopes: U238, Pu241, Pu240
- Only tidbit we have from global flux fits doesn't look great…
  - HEU pins U235 flux;
    DYB evolution pins 239 flux;
    HEU-LEU offset pins 238 flux.
  - If there are no oscillations, summation models seem to WAY OVER-PREDICT the U238 flux — by ~30%!
- How can we learn more about emissions from these isotopes?
  - If we want to understand emissions from <u>advanced reactors</u>, this knowledge is pretty important!

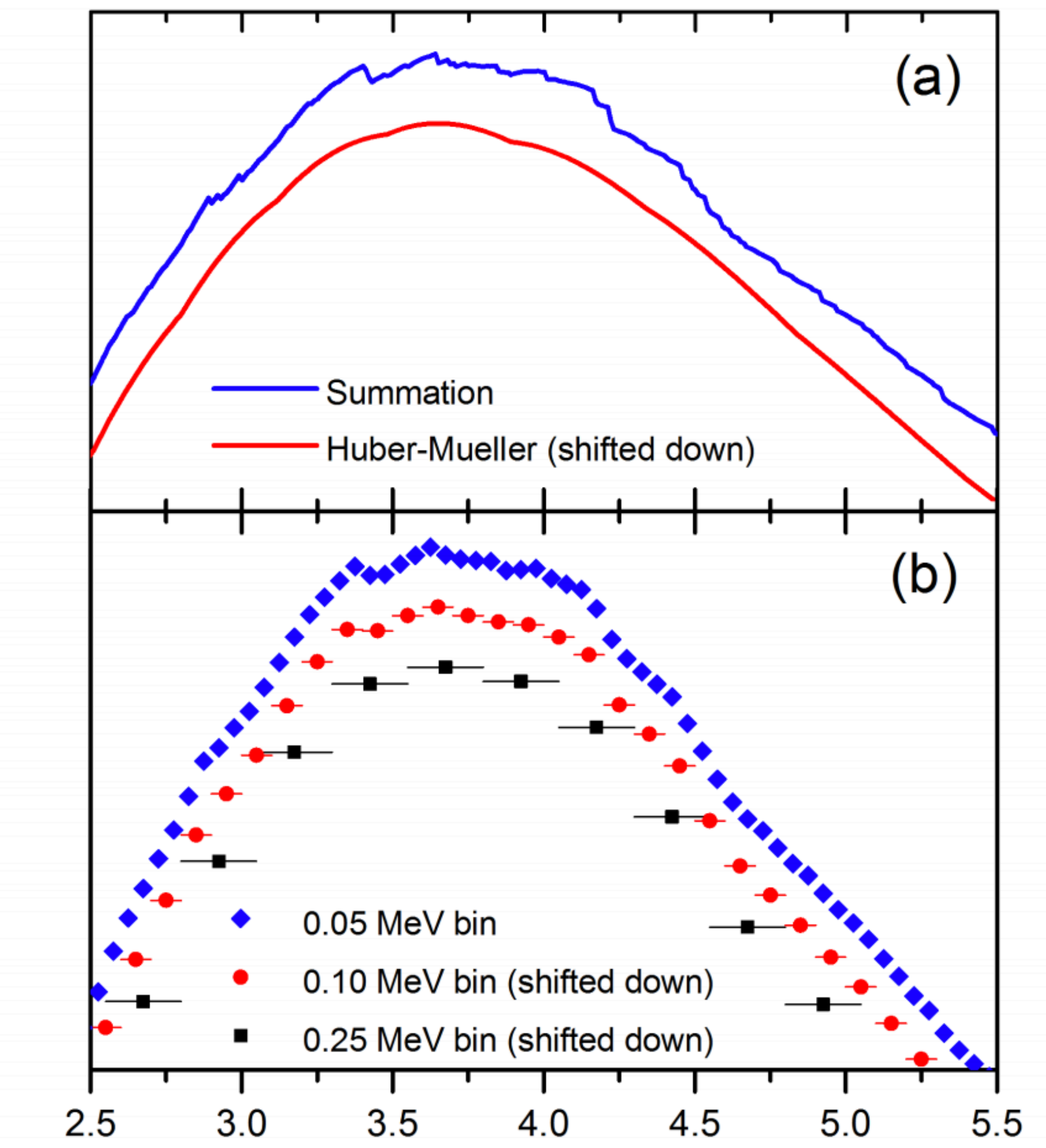
Giunti, Li, Littlejohn, Surukuchi, PRD 99 (2019)



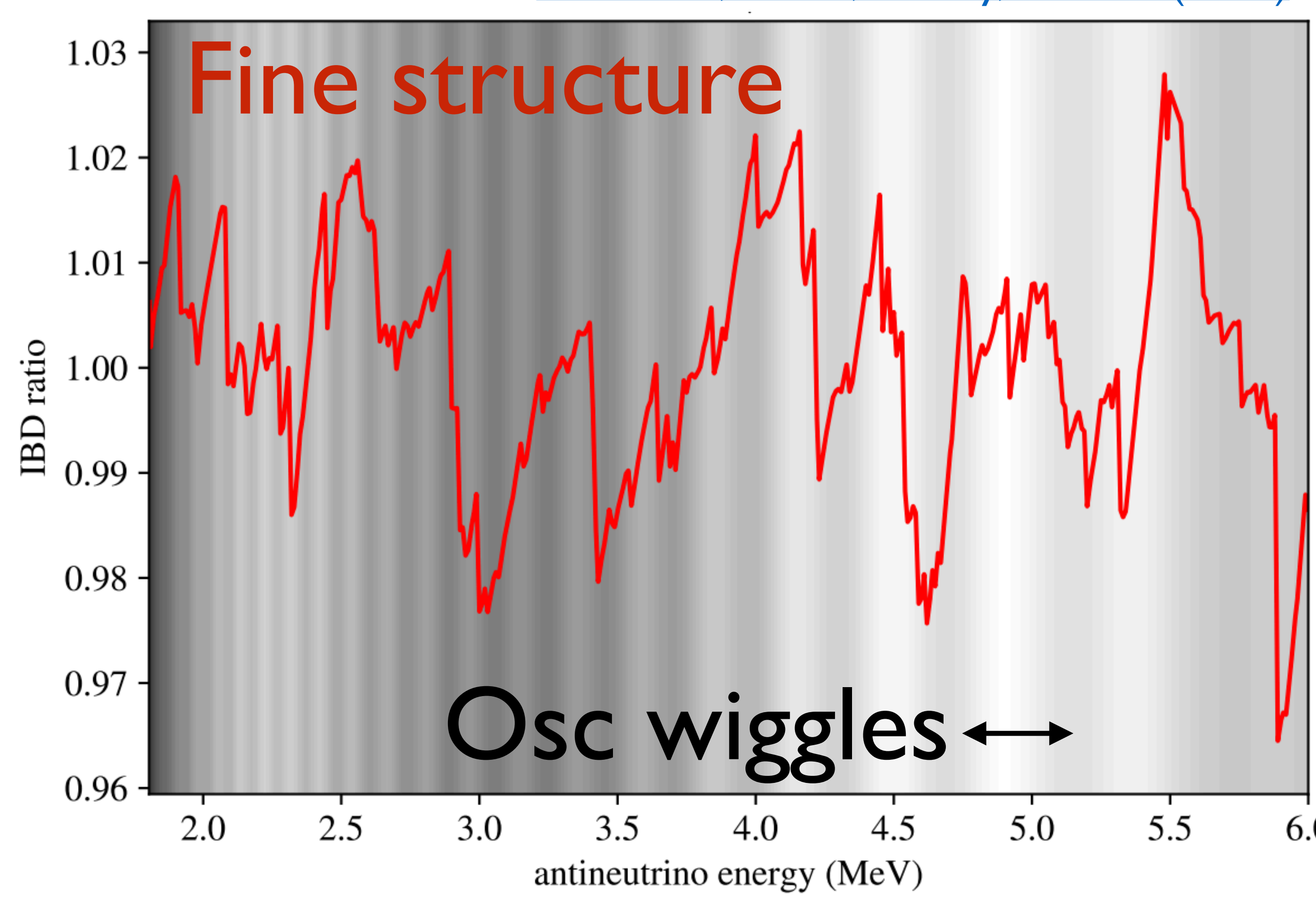
Not Known 4: Fine Structure

- What is it? It's never been precisely directly measured
  - Matters for SM osc: would hate to screw up mass hierarchy because of this
  - Matters for nuclear data: direct spectroscopy of rare fission products

Sonzogni, Nico, McCutchan, PRC 98 (2018)



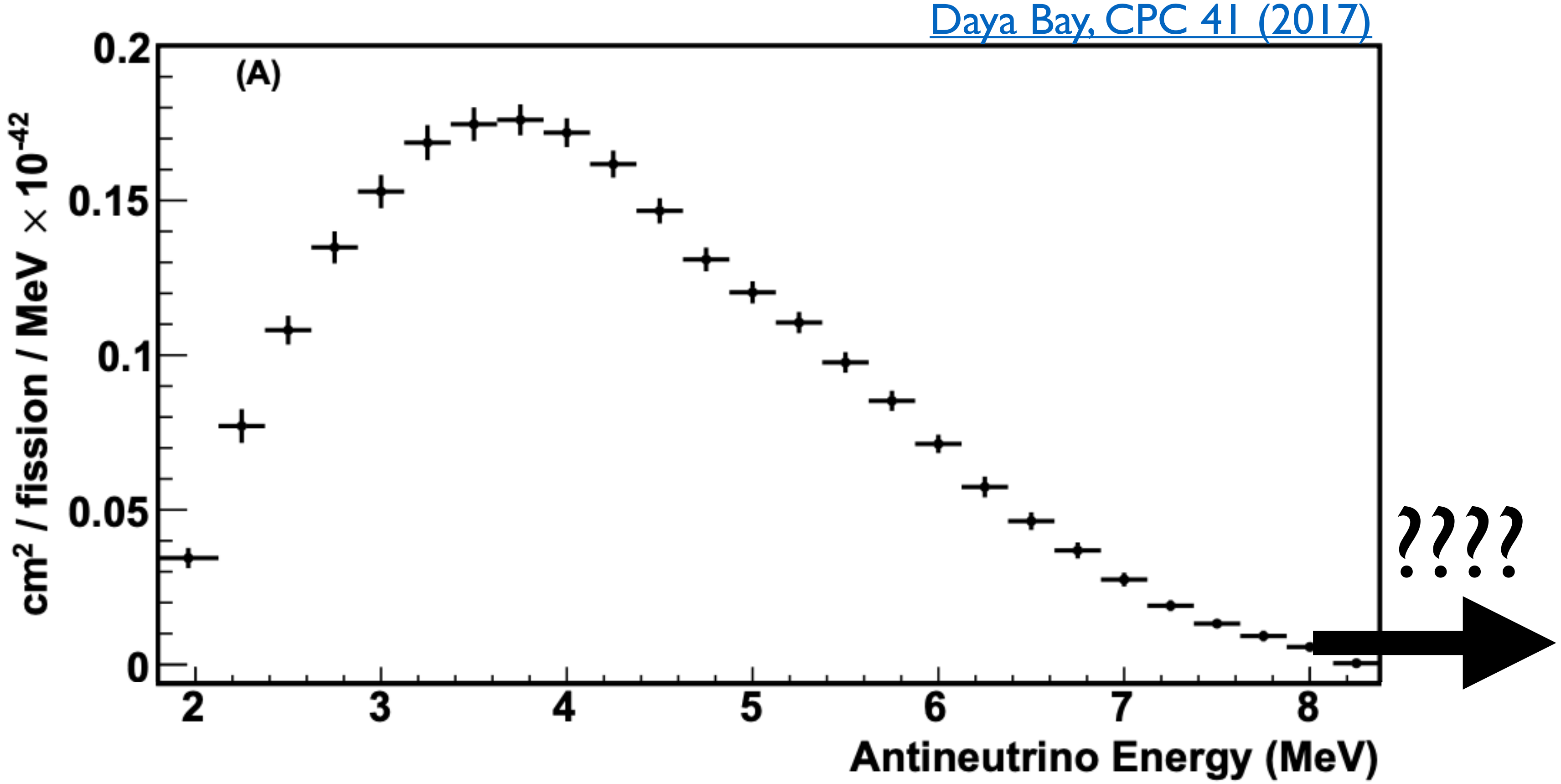
Danielson, Hanes, Garvey, PRD 99 (2019)



Not Known 5: High-Energy Flux

- What is it? It hasn't been reported in a precise way >8 MeV
  - Vogel-Engel, summation predictions are ALL likely to be WAY off in this energy regime — possibly even >>10% off! No Huber prediction here.
- If summation predictions are not great in this regime, then nuclear data is not great in this regime.

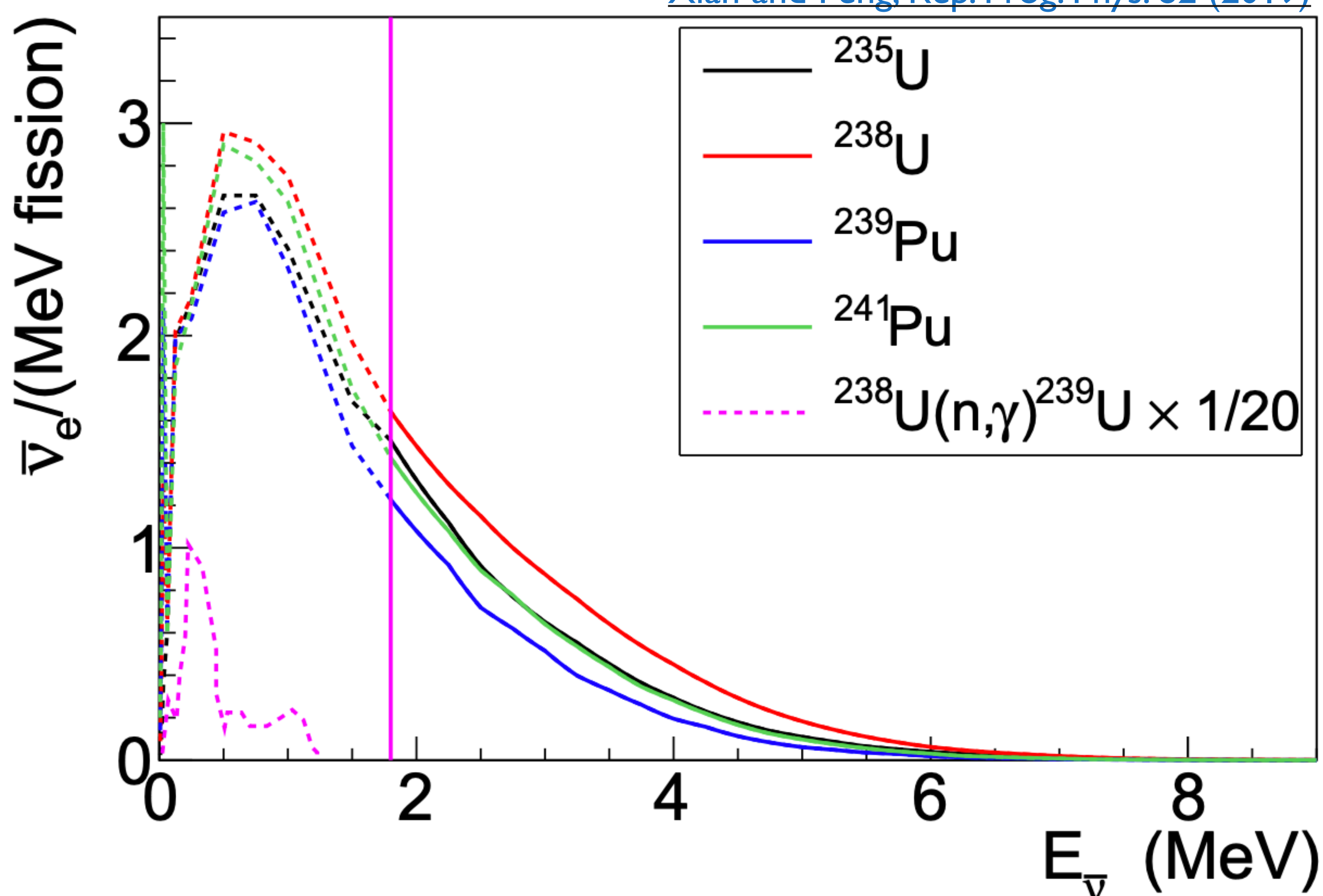
Daya Bay, CPC 41 (2017)



Not Known 6: <2 MeV Contributions

- What is the antineutrino content below the IBD threshold?
  - Contribution from low-energy portion of beta spectra, low-Q fission daughters, beta decays to highly excited states
  - Also non-fission sources: non-fuel as well as actinide beta decays
- IBDs cannot directly help here.
  - Indirectly by validating summation model improvements: 'if it's better at high-energy, it should be better at low-energy too…?'
  - Better: use new data from non-IBD detection channels to learn more

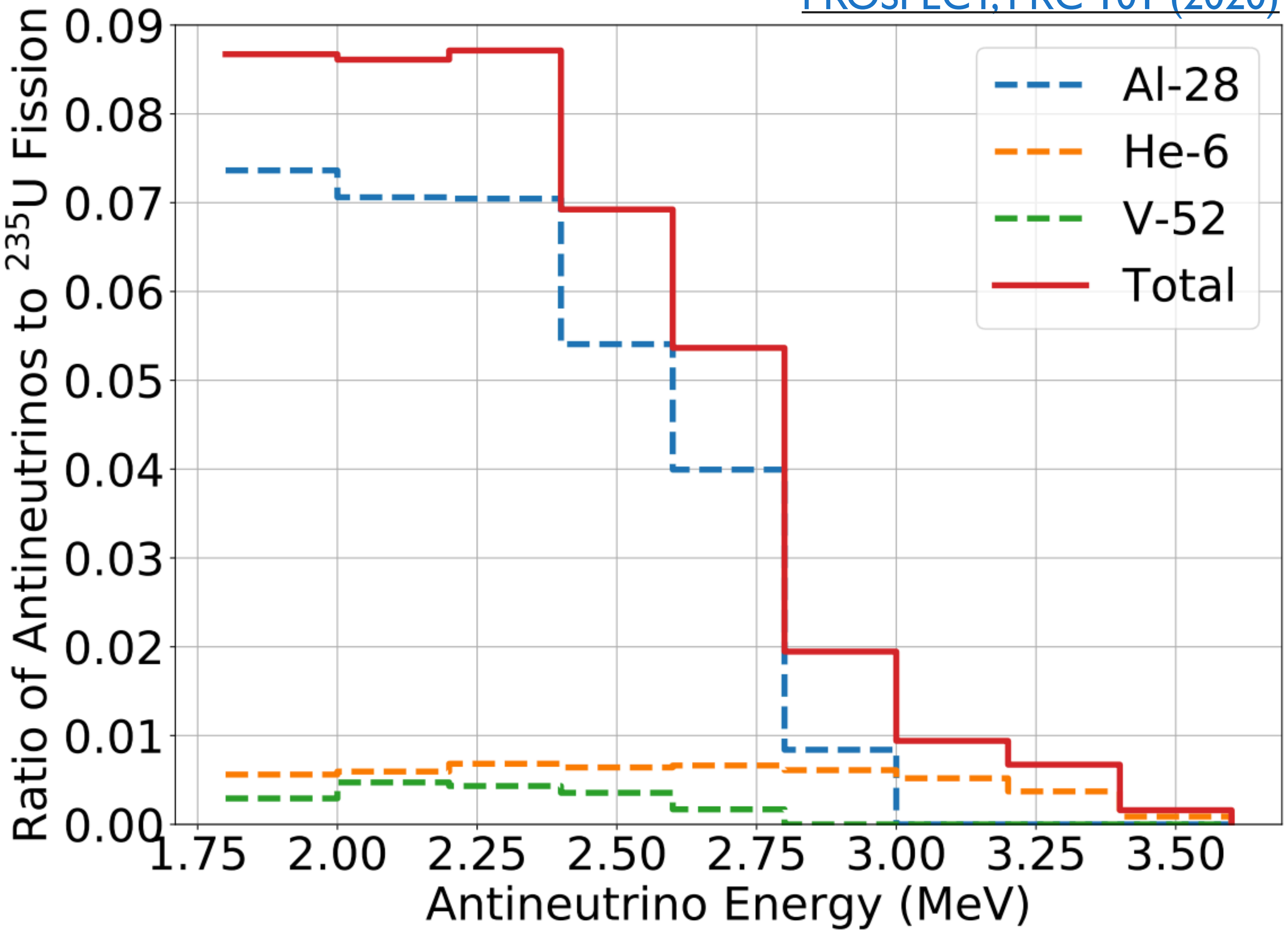
Xian and Peng, Rep. Prog. Phys. 82 (2019)



Not Known 7: Non-Fuel Contributions

- How large are non-fission antineutrino contributions?
  - Substantial issue for research reactors in particular, low energies (<3MeV)
  - For example: activation and beta decay of aluminum in HEU core structure
  - Must be predicted by non-neutrino-physicists (nuclear engineering folks) using non-neutrino Monte Carlo tools (like MCNP) A. Conant, PhD Thesis, Georgia Tech (2019)

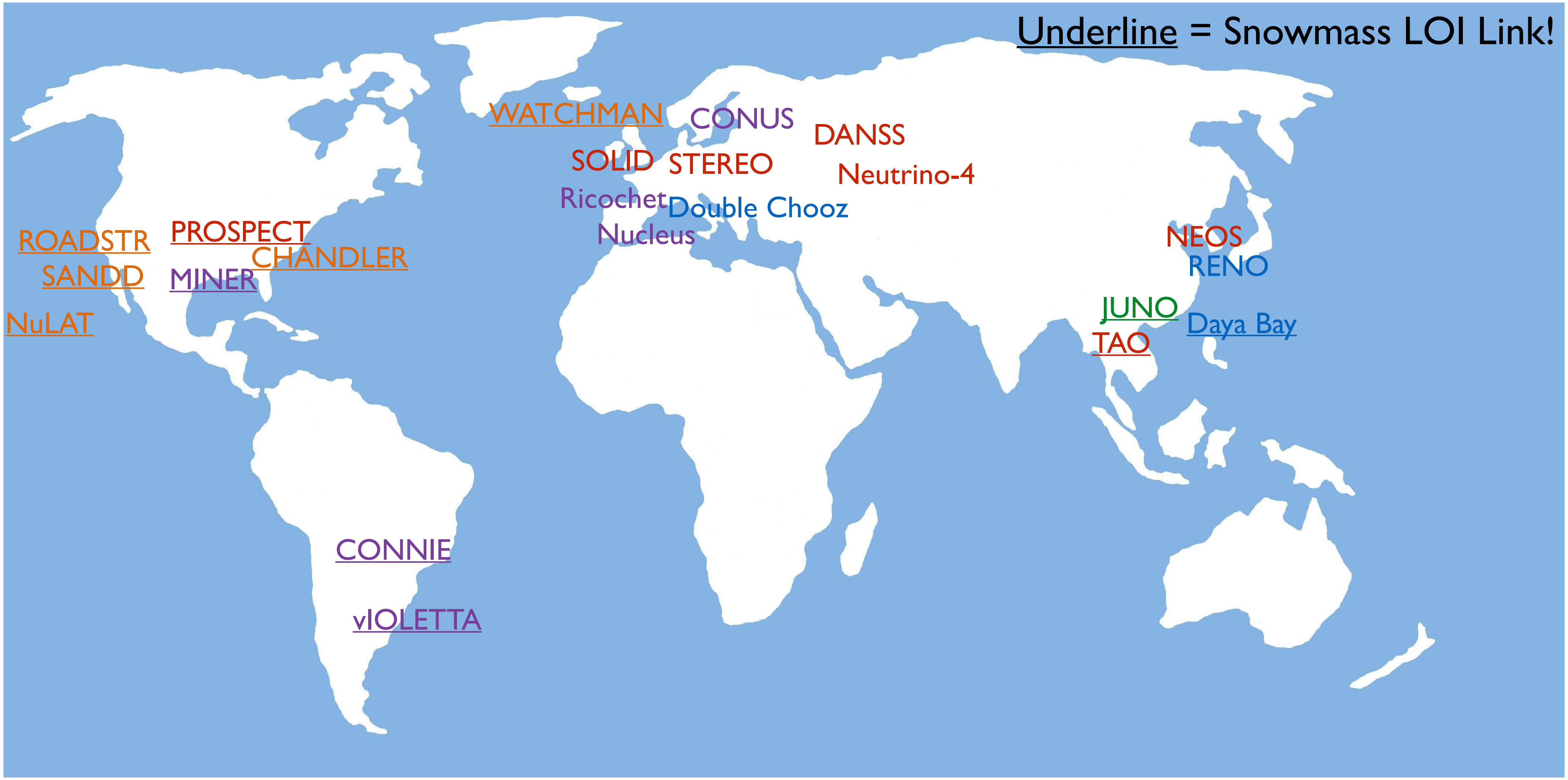
PROSPECT, PRC 101 (2020)



What We Could Learn In The Near Future

Reactor Speectrum/Flux Snowmass LOI

Improvement Areas:
1: Sterile Oscillations
2: Isotopic Precision
3: Sub-dominant isotopes
4: Fine structure
5: High-energy neutrinos
6: <2MeV contributions
7: Non-fuel contributions

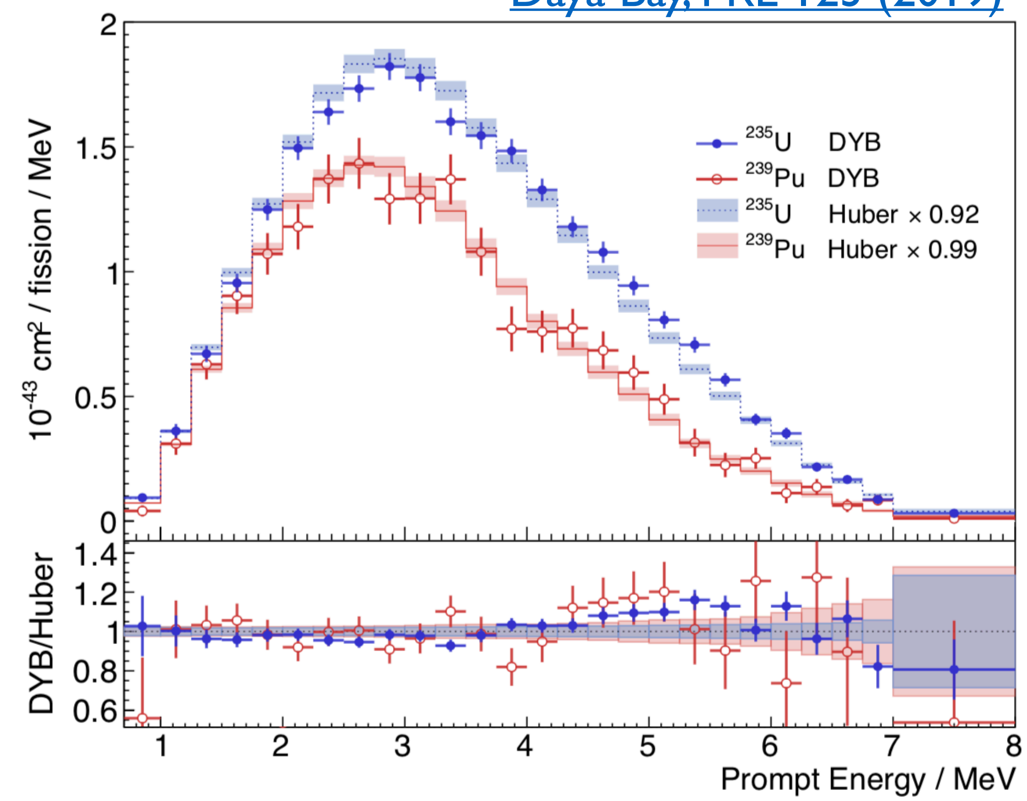


Future LEU Measurements

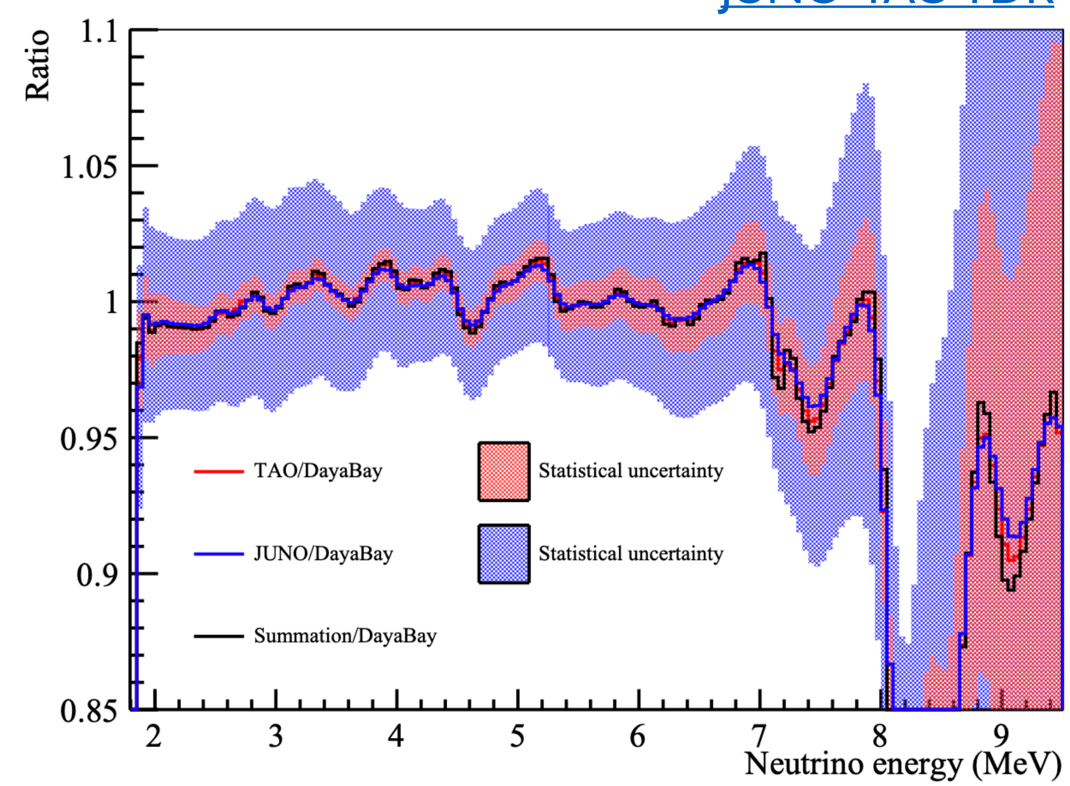
- Improved isotopic information coming in next few years from different LEU efforts:
  - **NEOS-II**: >1M stats from a single core, wider fission fraction range than DYB
  - Still need **DYB's** final 'evolution' measurement with >8M statistics; perhaps more with nH+nGd combo?
  - Other SBL experiments step up? **DANSS**?
- Within ~5 years: **JUNO-TAO**
  - 1% energy resolution will hopefully excellent probe of fine structure, also an interesting sterile oscillation probe

Improvement Areas:
1: Sterile Oscillations
2: Isotopic Precision
4: Fine structure
5: High-energy neutrinos

Daya Bay, PRL 123 (2019)



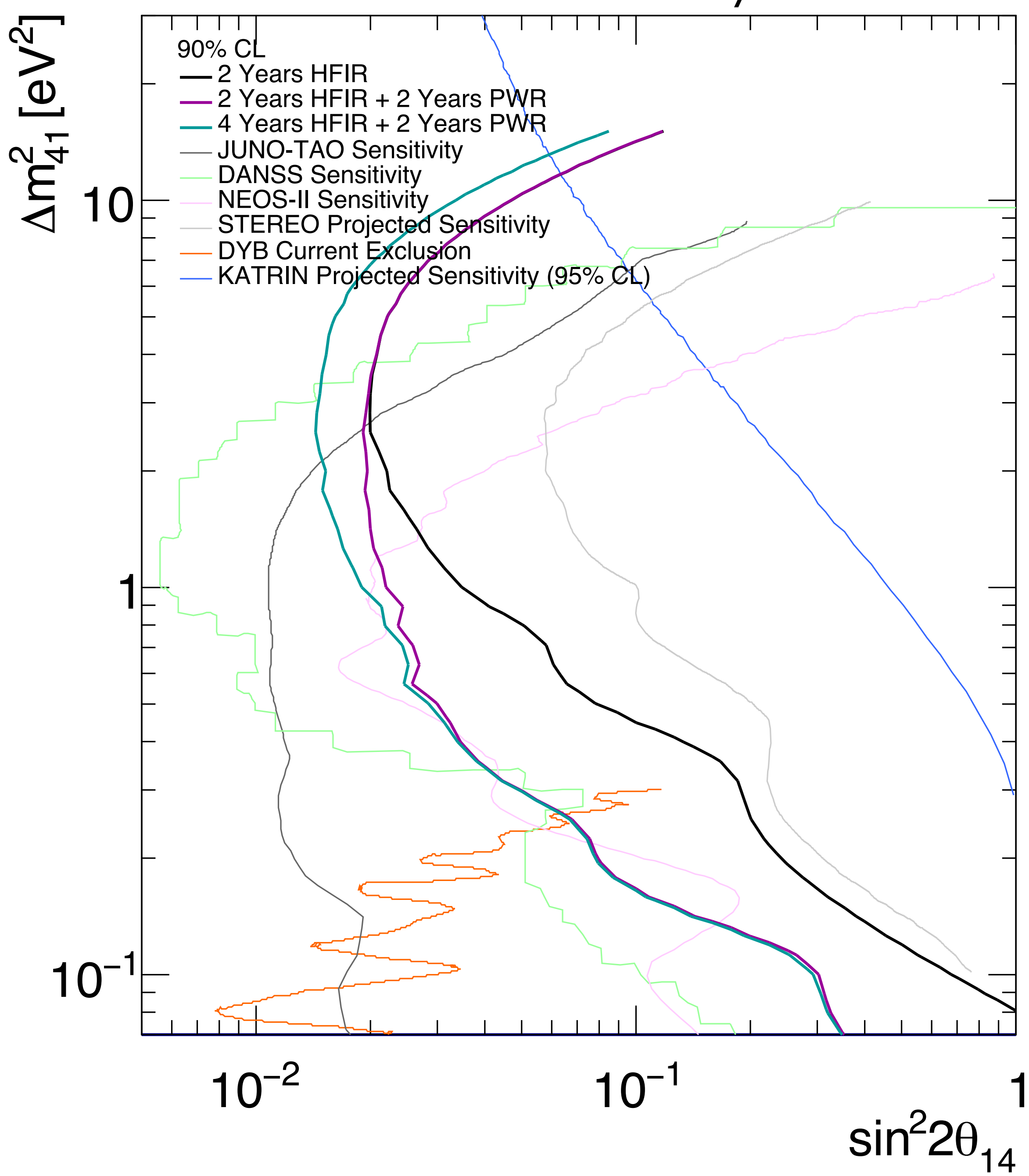
JUNO-TAO TDR



Future HEU Measurements

- **PROSPECT, STEREO** have 'final' datasets coming in the next year or so
  - More statistics, modest improvement in HEU flux, spectrum knowledge
- Major increase in HEU statistics with future **PROSPECT-2** HFIR deployment
  - Major improvement in both HEU flux+spectrum knowledge as well as oscillation sensitivity.
  - Will necessitate/produce further development of non-fuel contribution calculation infrastructure.
- Other SBL experiments step up too? Like **Solid**?

Courtesy of PROSPECT

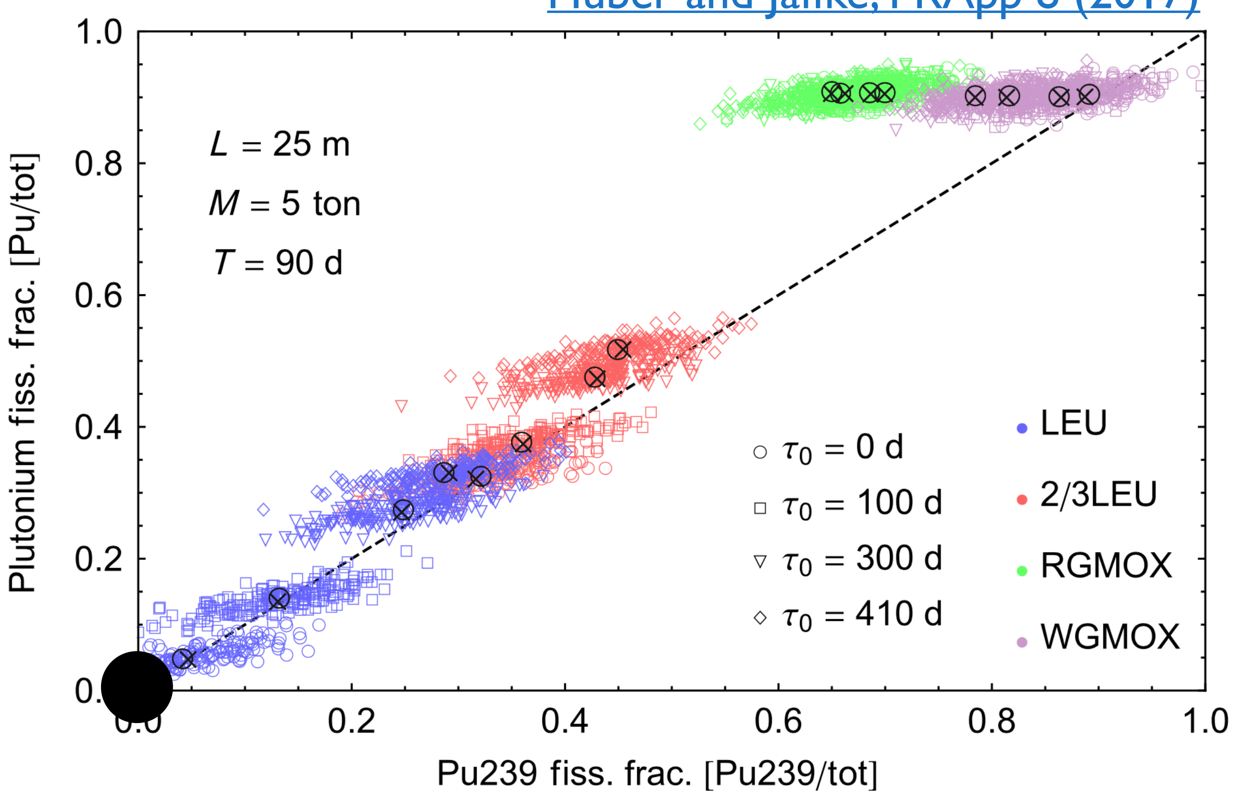


Improvement Areas:
1: Sterile Oscillations
2: Isotopic Precision
7: Non-fuel contributions

Future HEU+LEU Measurements

- Substantial benefits if HEU and LEU reactors can be measured with the same detector (or identical detectors)
  - Correlations improve ability to probe sub-dominant isotopes: like U238
  - **PROSPECT-2** to be designed with such a demonstration in mind
- Advanced reactor measurements offer similar benefits for probing sub-dominant isotopes.

Huber and Jaffke, PRApp 8 (2017)



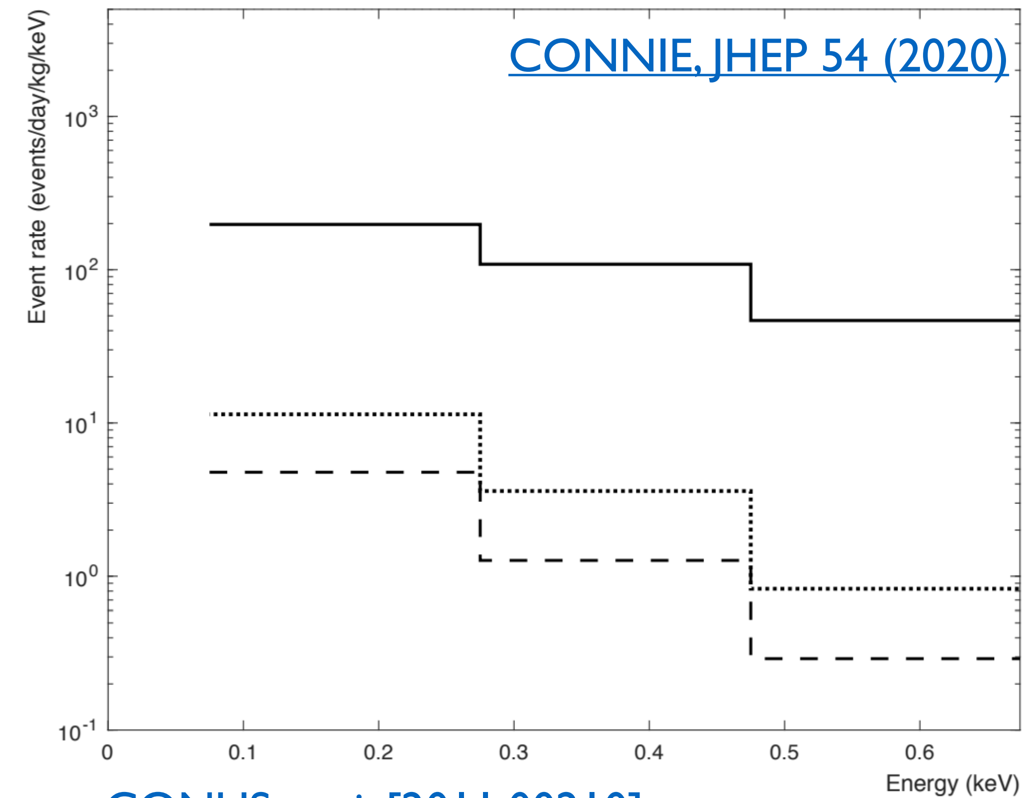
Gebre, Littlejohn, Surukuchi, PRD 97 (2018)

Case	Description	Precision on σ_i (%)		
		^{235}U	^{239}Pu	^{238}U
1	Daya Bay-like LEU	2.8	5.9	10.0
2	Daya Bay-like LEU + new HEU	1.3	5.3	9.2
3	Improved Daya Bay-like LEU + HEU	1.3	4.8	8.9
4	Short-Baseline LEU + HEU	1.2	3.7	8.8
5	Short-Baseline LEU + HEU, Correlated	1.5	3.8	6.7

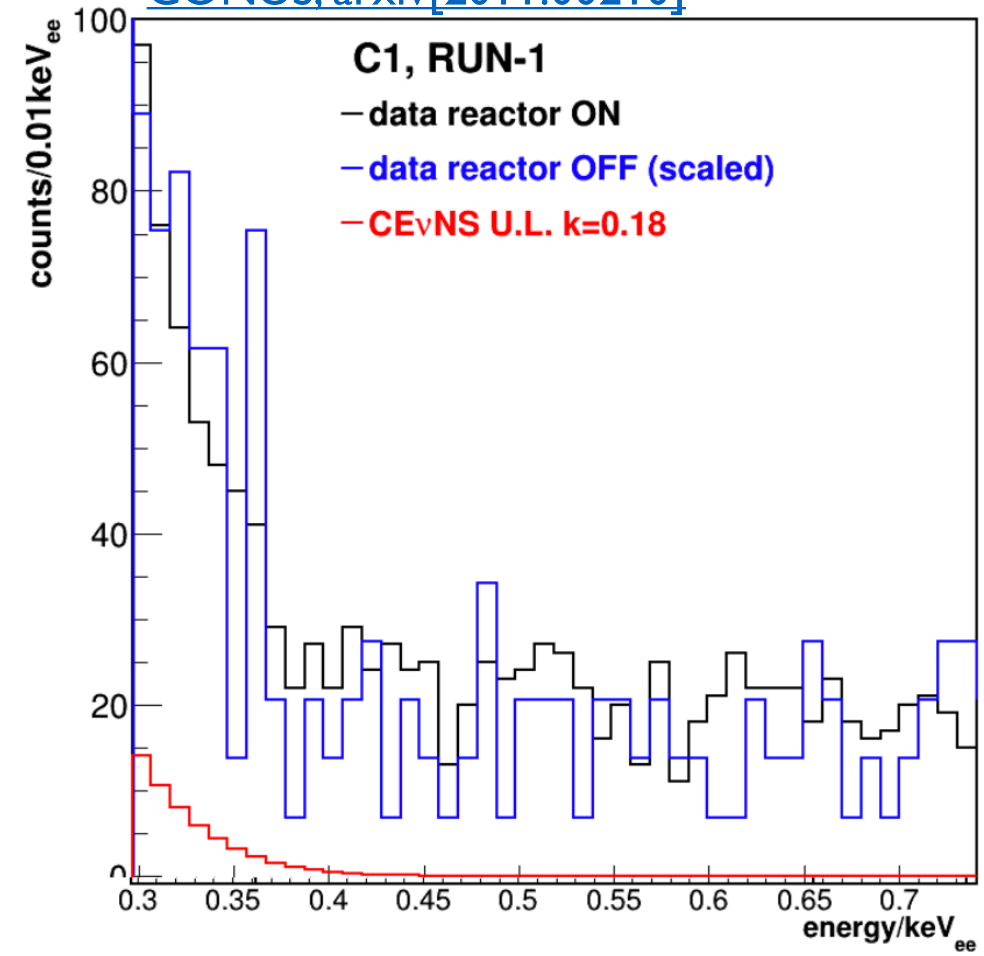
<u>Improvement Areas:</u>
1: Sterile Oscillations
2: Isotopic Precision
3: Sub-dominant isotopes

Reactor-Based CEvNS Measurements

- CEvNS does not have a 1.8 MeV threshold, like IBD!
  - Great way to probe low-energy neutrino emissions, and non-fuel contributions there
- Current CEvNS experiments are getting close to seeing reactor neutrinos.
  - **CONNIE** and **CONUS** backgrounds are within roughly an order of magnitude of CEvNS signal
  - Future generations of cryogenic detectors will substantially lower detection thresholds, and may enable use to probe this <1.8 MeV regime: **νIOLETA, NUCLEUS, Ricochet**



CONUS, arxiv[2011:00210]



Improvement Areas:
6: <2MeV contributions
7: Non-fuel contributions
EXTRA: BSM like wut!!!

Joint Analyses and Data Sharing

- Combined results of different experiments can be used to say more than that of the individual experiment by themselves.
  - **NEOS** sterile neutrino result is a perfect example. NEOS, Neutrino 2020 Talk
  - **PROSPECT** 'bump origin' results are another one. PROSPECT, arXiv:2006.11210 (2020)
- Results combination should be continued and facilitated!
  - Important part of this process: public data sharing
  - Can we establish a common community standard for RxNu datasets?
  - Critical, given that many **Theta13** experiments are close to winding down!

Improvement Areas:
1: Sterile Oscillations
2: Isotopic Precision
3: Sub-dominant isotopes
7: Non-fuel contributions

Joint Analysis Snowmass LOI

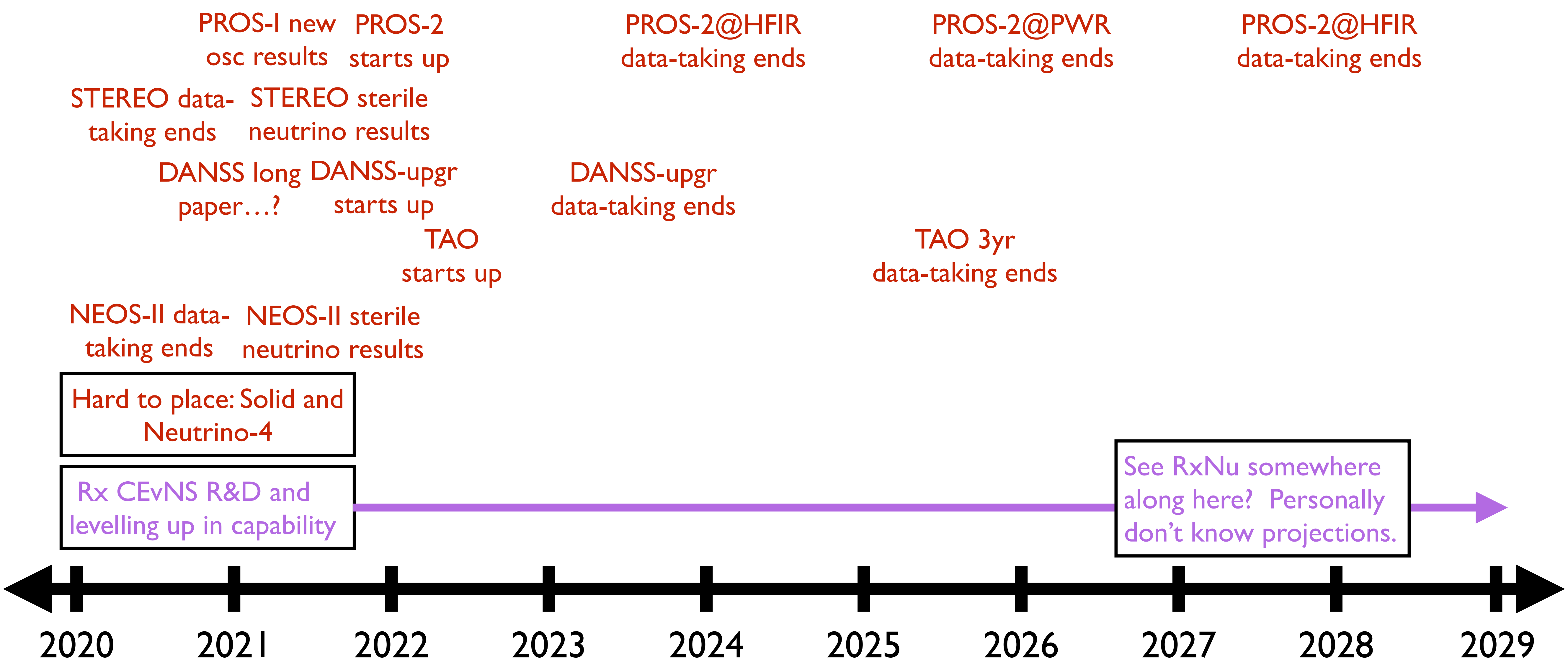
Data-Driven Predictions, Applications

- For particle physics and neutrino applications at reactors, can we just forego the theoretical predictions entirely?
- Given a declared reactor type and operational history:
  - Predict emanations based on existing **precision measurements**
  - Compare data-driven predictions to measurements from **applications-oriented neutrino detectors, like ROADSTR, CHANDLER, or SANDD**
- It's possible near-term **applications-oriented detectors** could also provide useful input to data-driven predictions
  - Dependent on deployment choices and realized detector capabilities

Improvement Areas:
2: Isotopic Precision
EXTRA: Applications Use-Case Demo!!!

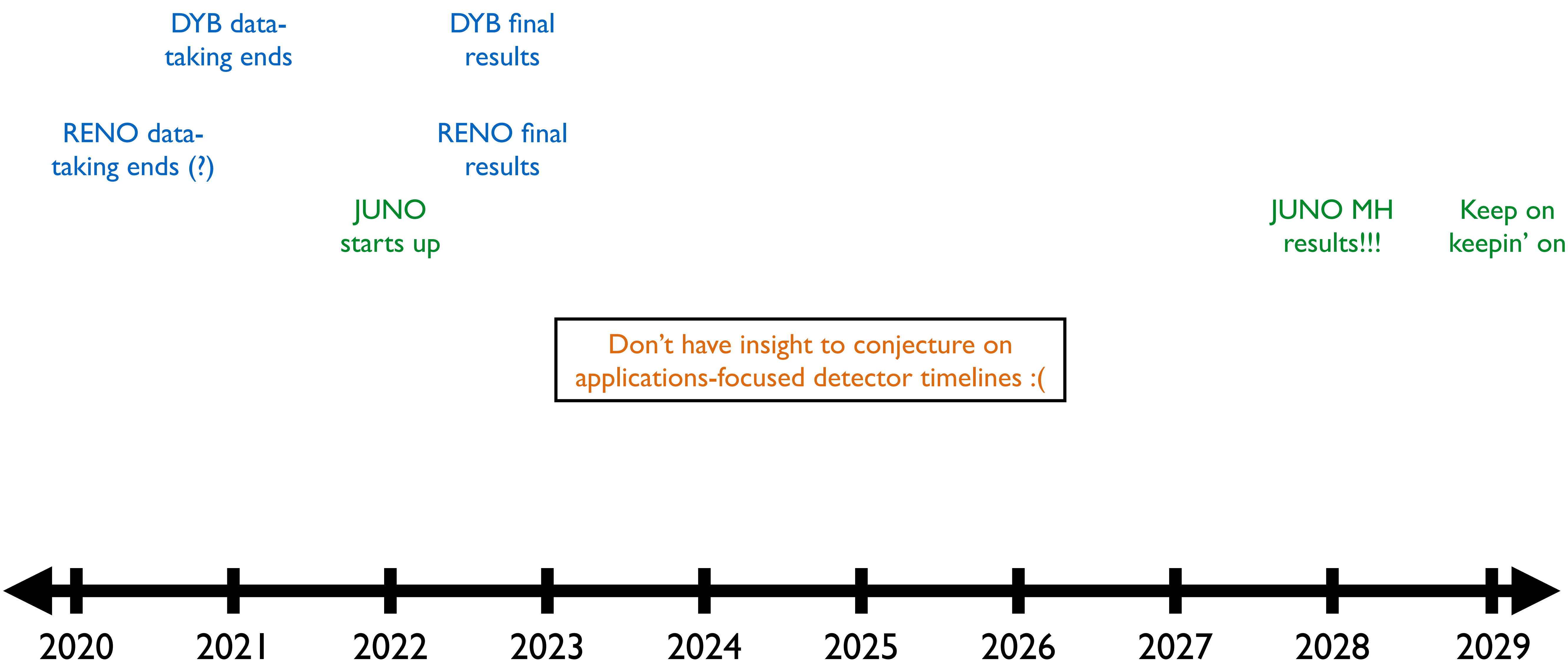
Reactor Applications Snowmass LOI

Lining Up Timelines: SBL, CEvNS



- Outcomes of this informal exercise:
  - Likely that SBL Rx experiments will run well into this decade
  - SBL field may clear out a bit as we approach the middle of the decade, although new efforts of course may arise…
  - Rx CEvNS will likely be an active/growing effort throughout the 2020s

Lining Up Timelines: Theta13, LBL



- Outcomes of this informal exercise:
  - Theta13 experiments are near complete, will be finished before mid-decade
  - JUNO will produce impactful reactor neutrino physics well into next decade
  -

Conclusions

- Since last Snowmass, a shocking level of progress has been made in better understanding reactor antineutrino emissions
- The current+future reactor antineutrino program will push us further towards developing a fully data-driven picture
- Seven needed areas of improvement can be addressed by five current/future reactor experiment types

  Theta13 Long-Baseline Short-Baseline

  Applications-focused CEvNS

Improvement Areas:
1: Sterile Oscillations
2: Isotopic Precision
3: Sub-dominant isotopes
4: Fine structure
5: High-energy neutrinos
6: <2MeV contributions
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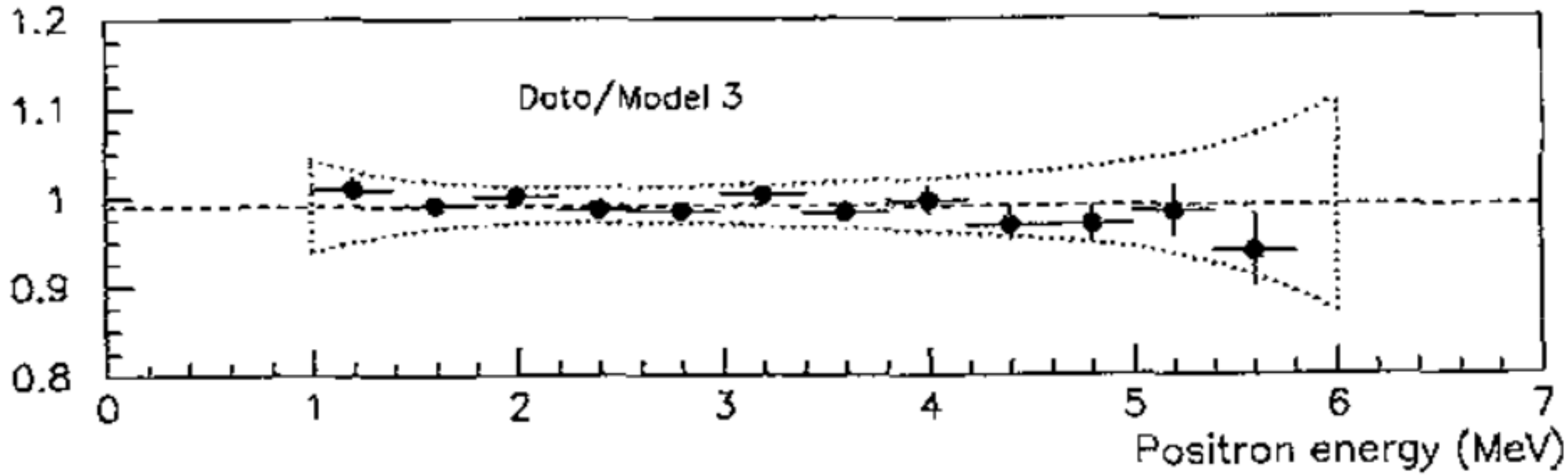
- We should expect this program to provide cutting-edge neutrino/applications physics knowledge and workforce training well into this decade and beyond.

Done.

Reactor Spectrum/Flux Measurements

- We have come a HUGE DISTANCE in 10 years…
- Best data/model comparison in existence in 2010 (Bugey-3)



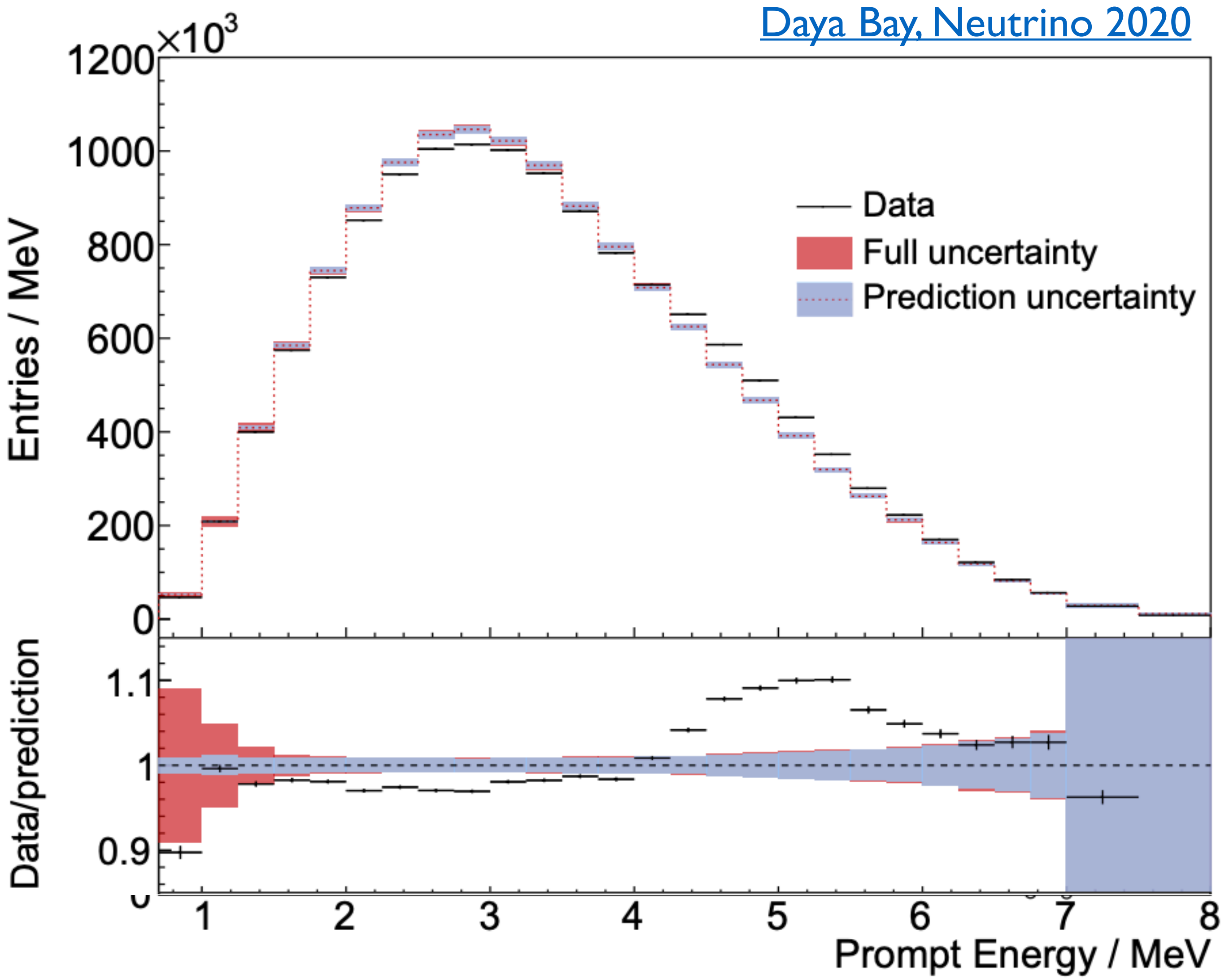
- State of our direct knowledge of emissions in 2010/2011:
  - Conversion-predicted LEU spectra look… pretty good.
  - Conversion-predicted LEU fluxes look… a bit too high.

Reactor Spectrum/Flux Measurements

- We have come a HUGE DISTANCE in 10 years…
- Data/model comparisons we have in hand in 2020:

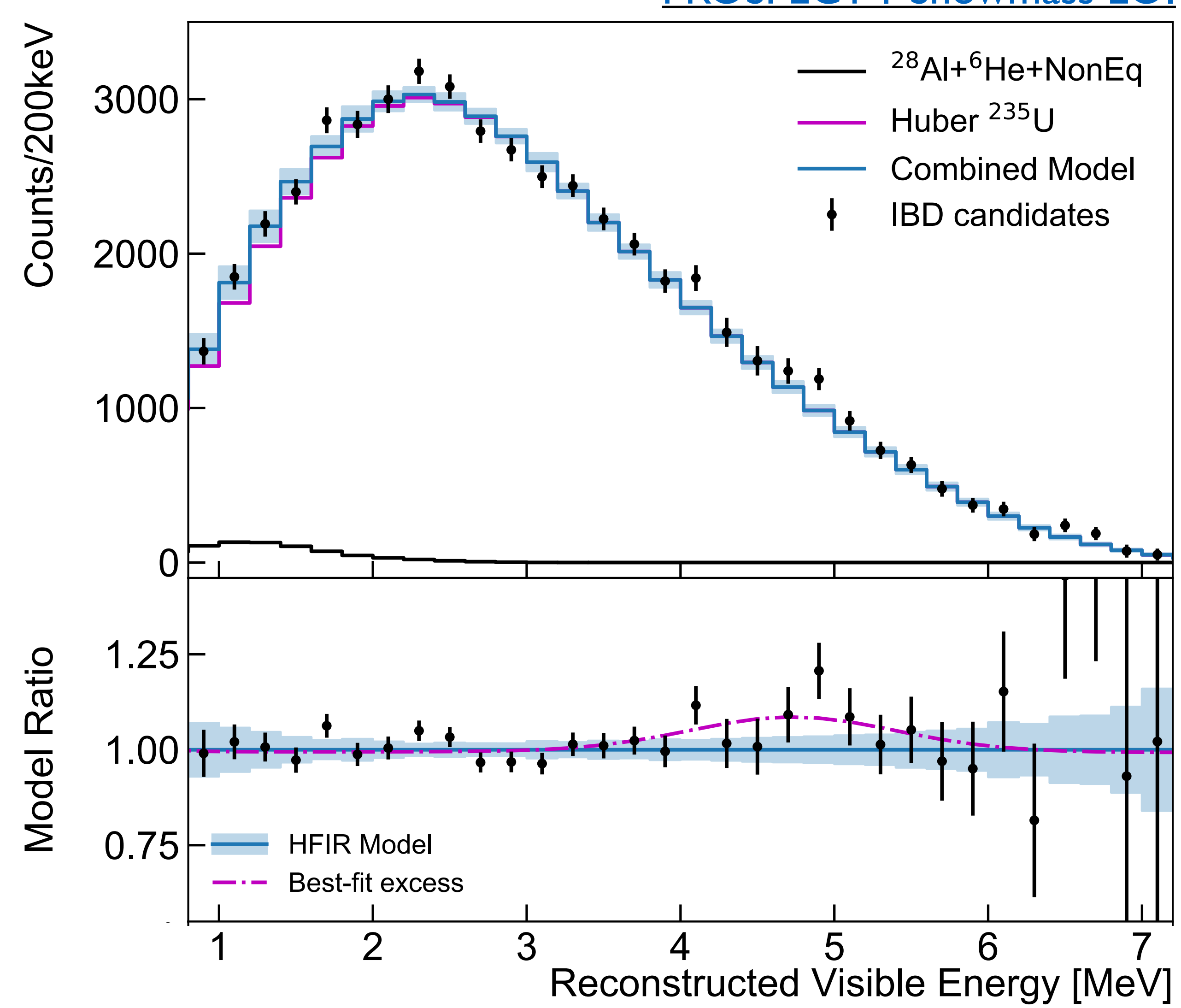
Low-enriched reactors!

Daya Bay, Neutrino 2020



Highly-enriched reactors!

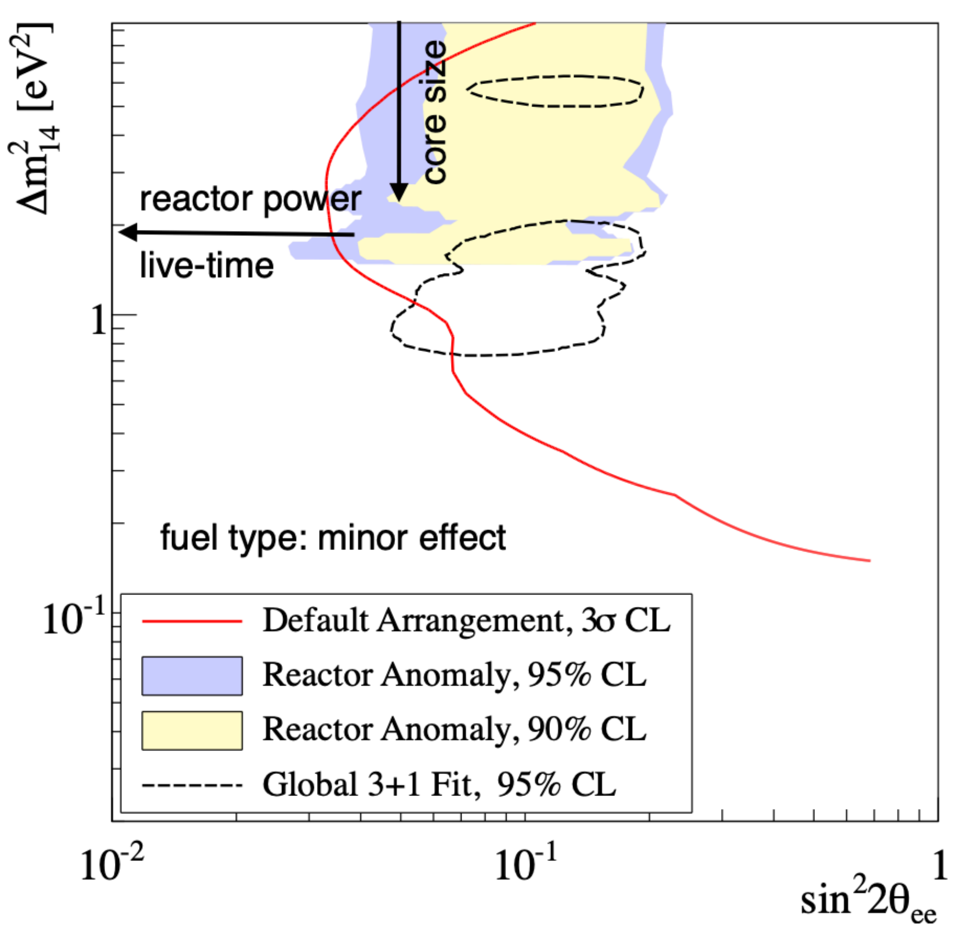
PROSPECT-I Snowmass LOI

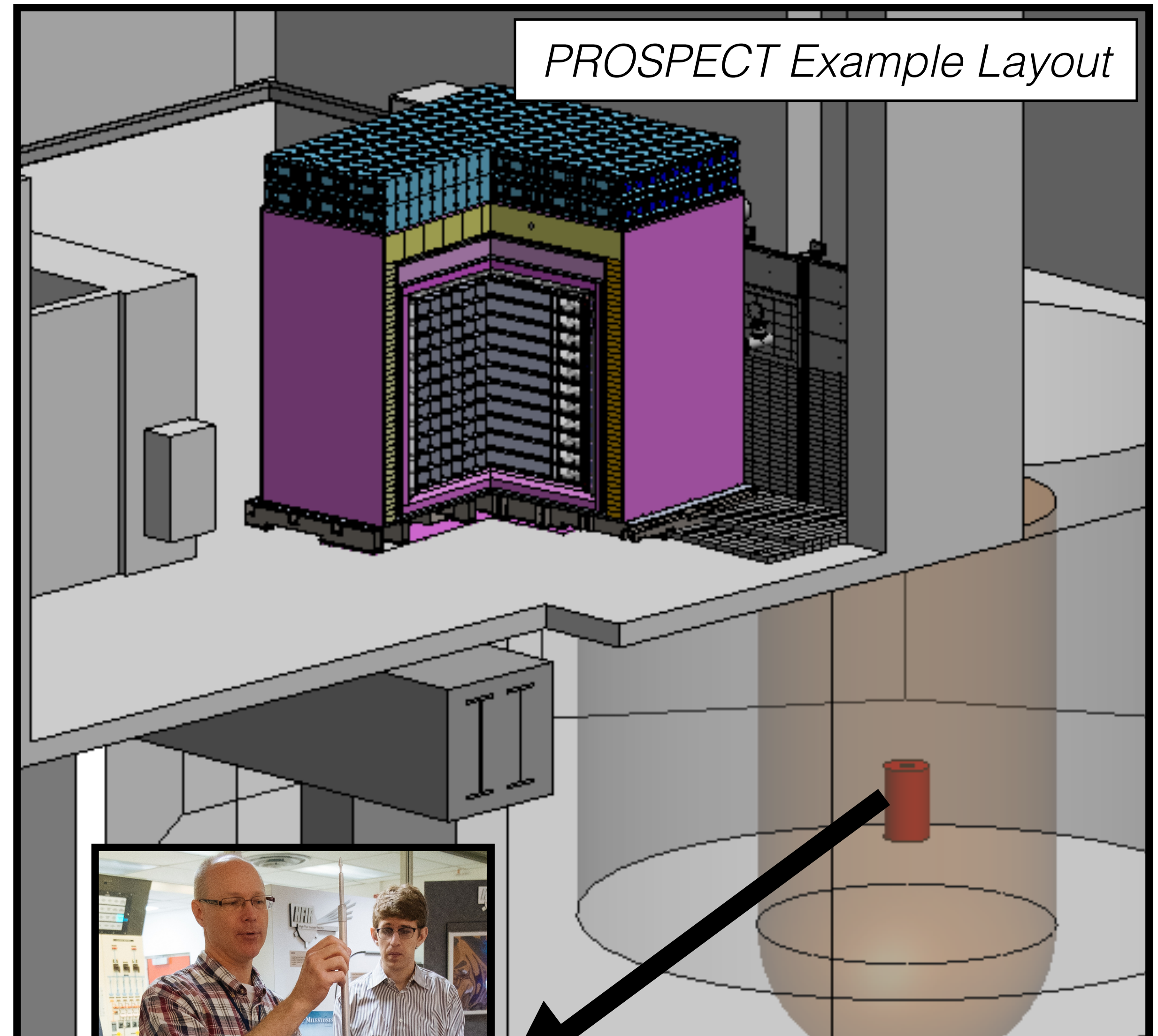


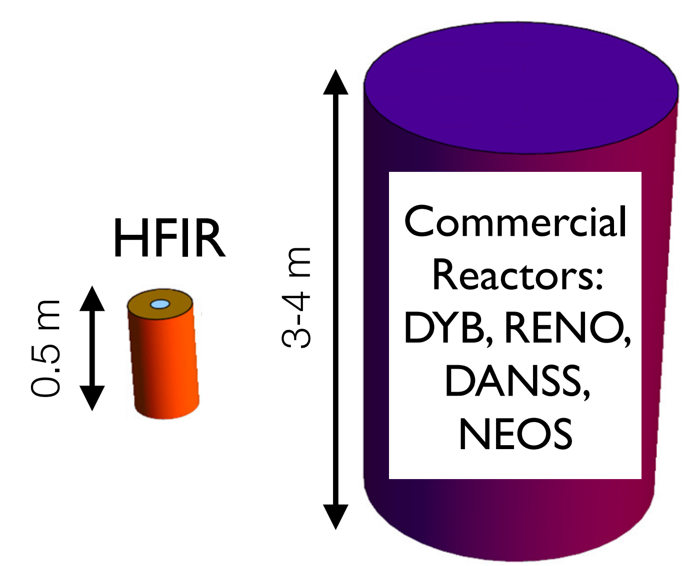
SBL Rx Experimental Parameters

- Useful experimental parameter variations to keep in mind:
  - Reactor power: very important
    - If not >1GW, better be very close to reactor
  - Reactor core size: very important
    - Above meter size, lose high mass splittings

Heeger, Littlejohn, Tobin, Mumm, PRD 87 (2013)



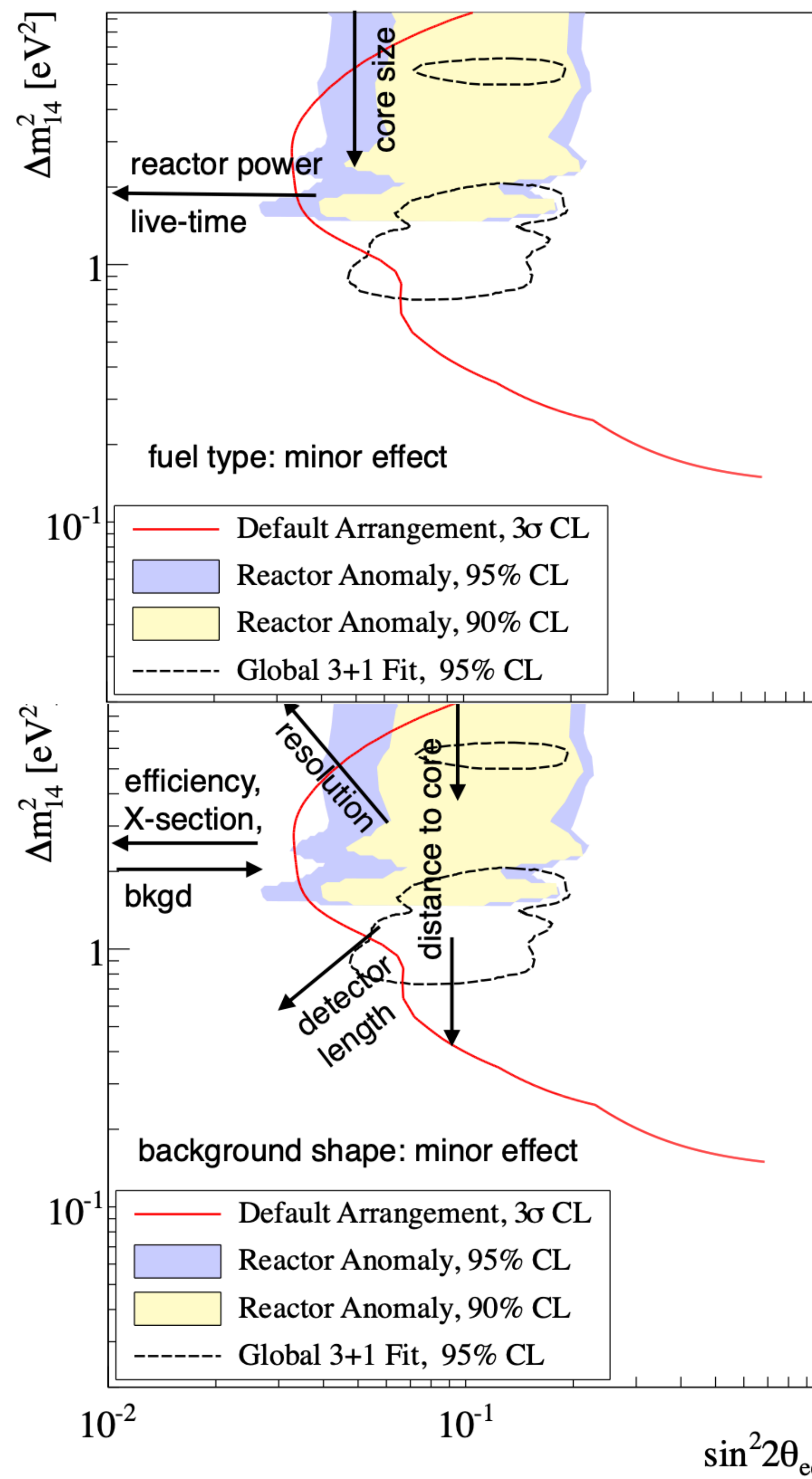




SBL Rx Experimental Parameters

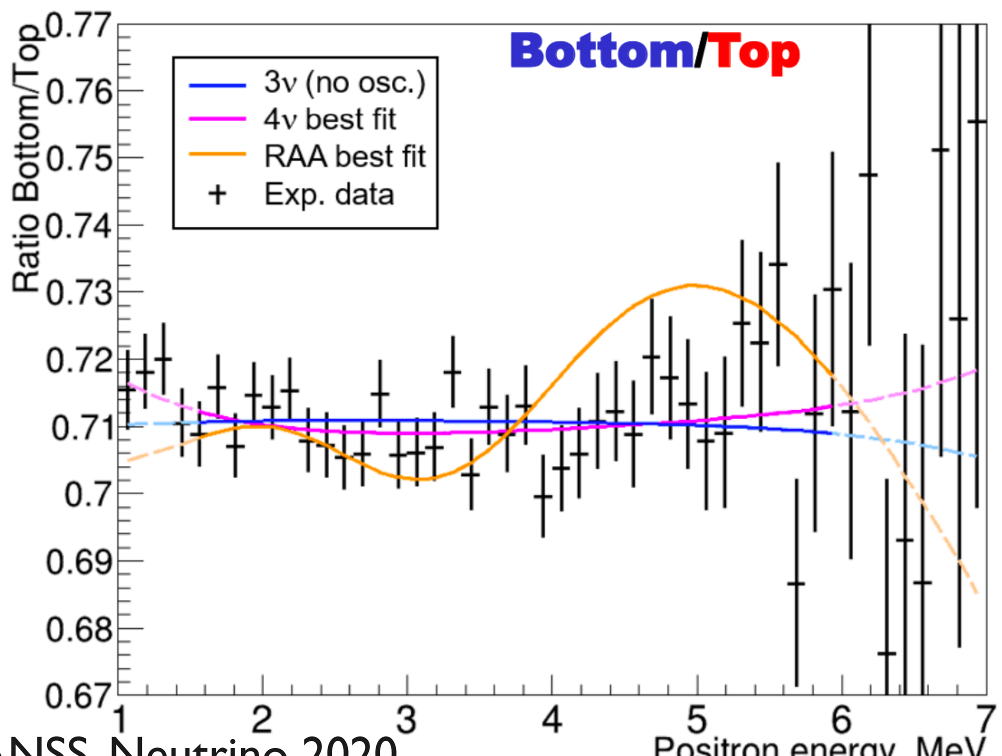
- Useful experimental parameter variations to keep in mind:
  - Reactor power: very important
    - If not >1GW, you'd better be very close to reactor
  - Reactor core size: very important
    - Above meter size, lose high mass splittings
  - Signal-to-background ratio: very important
    - Keep it close to 1:1, or better if possible
  - Reactor-detector baseline: important
    - Also: total baseline coverage of experiment (in meters)
  - Energy resolution: kind of important
    - Better than ~10-20% and you'll be fine
  - HEU versus LEU: not important
    - Flux/spectrum is similar from statistical point of view

Heeger, Littlejohn, Tobin, Mumm, PRD 87 (2013)

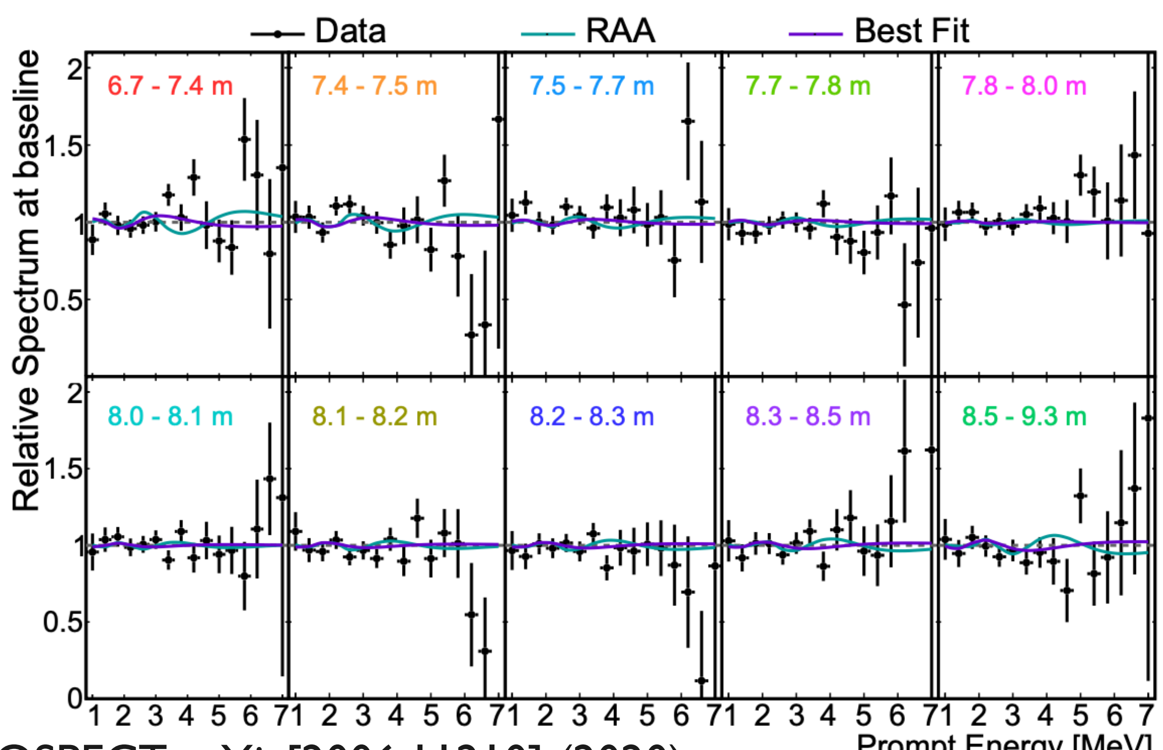


Analysis Choices

- Keep in mind variations in the information being used to generate sensitivity/exclusion contours
- The Gold Standard: 'single-experiment spectrum ratios'
  - Comparing spectra from the same detector in different locations (DANSS)
    - Of course, that detector's performance can drift, which is a small source of systematic error; backgrounds can vary with position too.
  - Compare spectra from different regions in a detector (PROSPECT, STEREO)
    - Of course, different regions may have differing response, so small systematics present there, too.



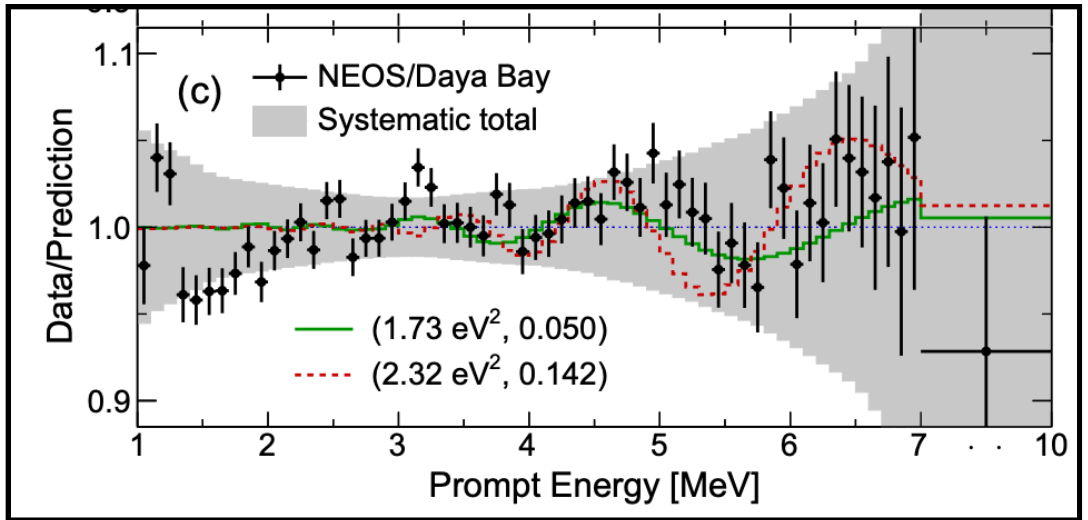
DANSS, Neutrino 2020



PROSPECT, arXiv[2006.11210] (2020)

Analysis Choices

- Keep in mind variations in the information being used to generate sensitivity/exclusion contours
- Varied use of absolute spectrum information
  - Compare measured spectrum to a reference spectrum (NEOS)
    - Necessary when you only have one accessible baseline in your experiment
    - Will require knowledge of absolute detector response and associated systematic uncertainty, which is almost certainly larger than those described on the previous page
    - Also requires consideration of possible differences in reactor fuel content and design
  - Use absolute spectrum to boost a result based on a ‘spectrum ratio’ (TAO)
    - Spectrum ratio helps at high Δm^2; absolute comparison to a model helps at low Δm^2
  - Approach seems fine, as long as you are conservative about the errors associated with your measurement and your model
    - Also must fully communicate this in a detailed way i.e. in publications.

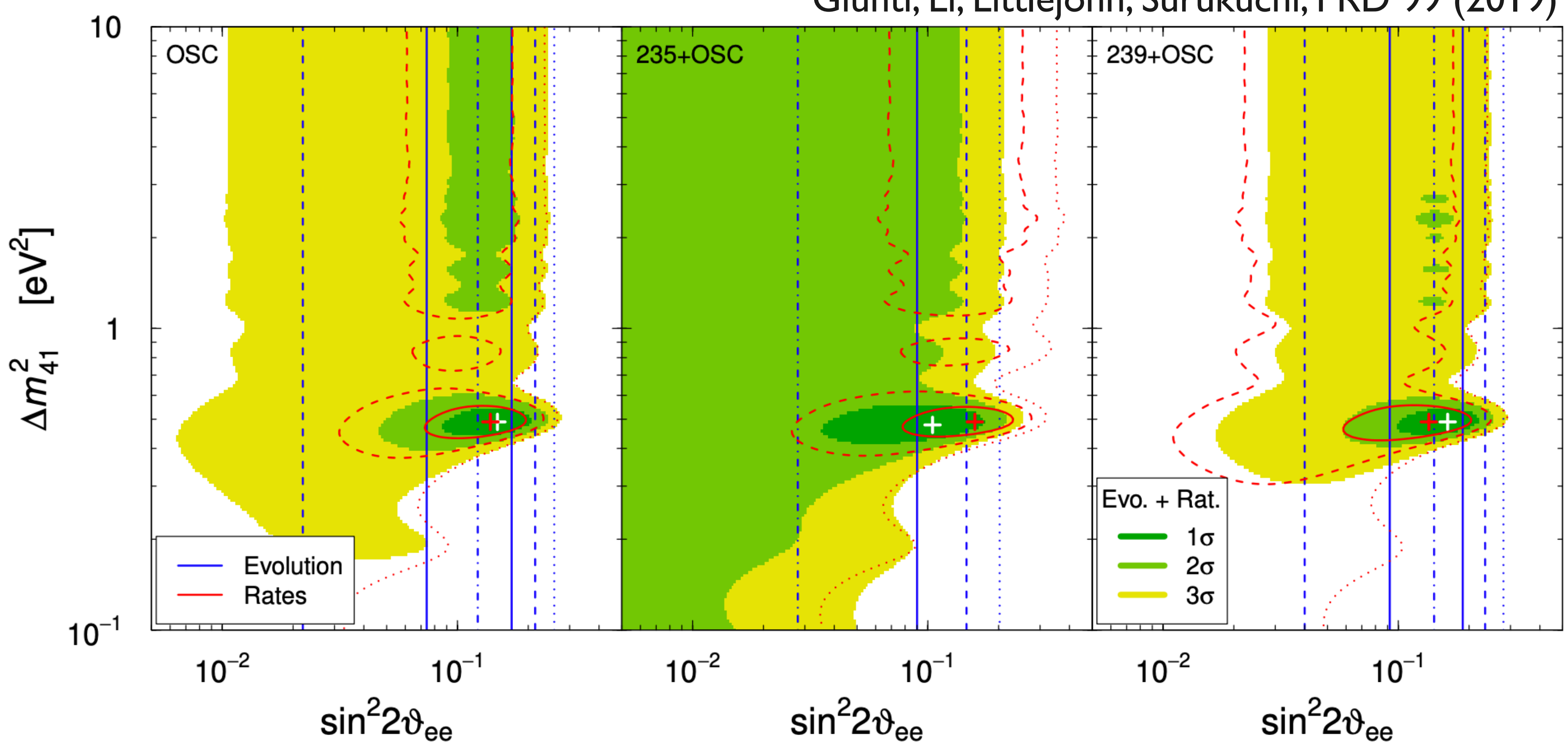


NEOS, Neutrino 2020 Talk

Analysis Choices

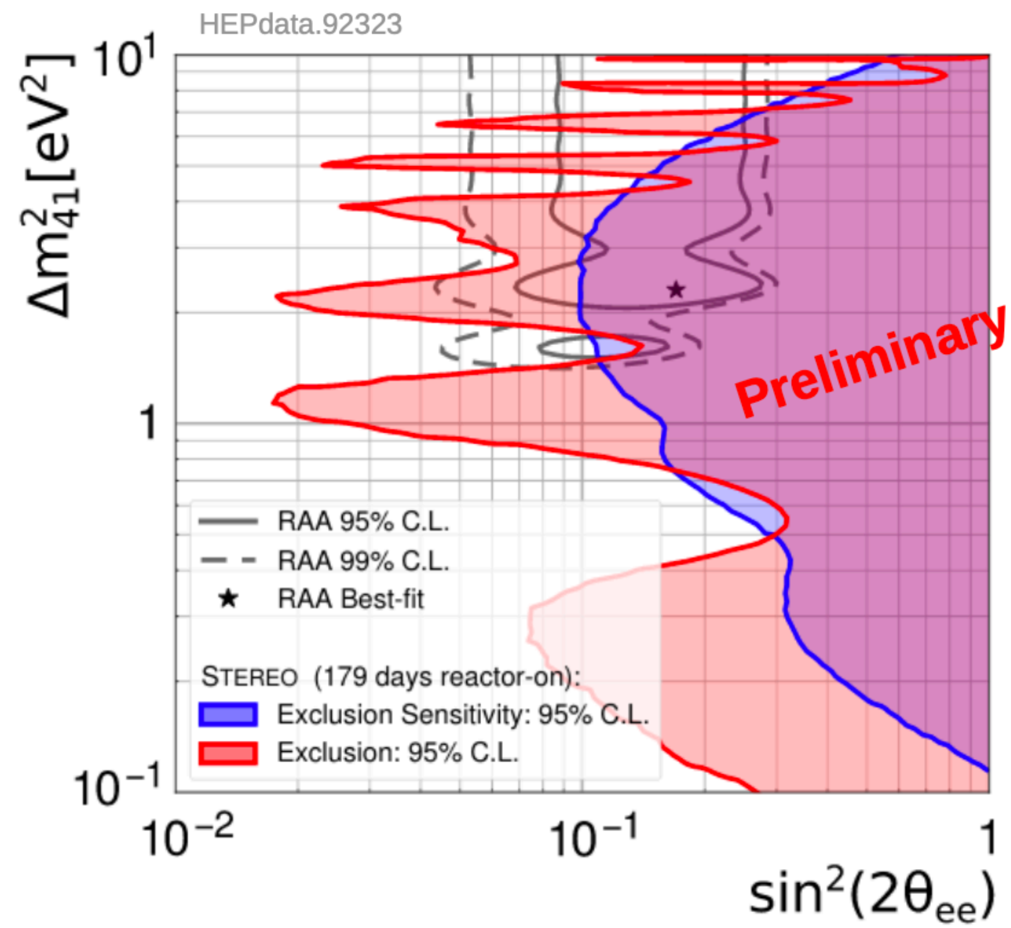
- Keep in mind variations in the information being used to generate sensitivity/exclusion contours
- Use of absolute rate information
  - Likely only helps experiments' contours 'look better' at very high Δm^2
  - We don't understand the absolute flux, or how it changes with fuel content!
  - <u>Experimenters: can we all agree to not use absolute rate information in our short-baseline reactor sensitivity/exclusion fits/contours…?</u>

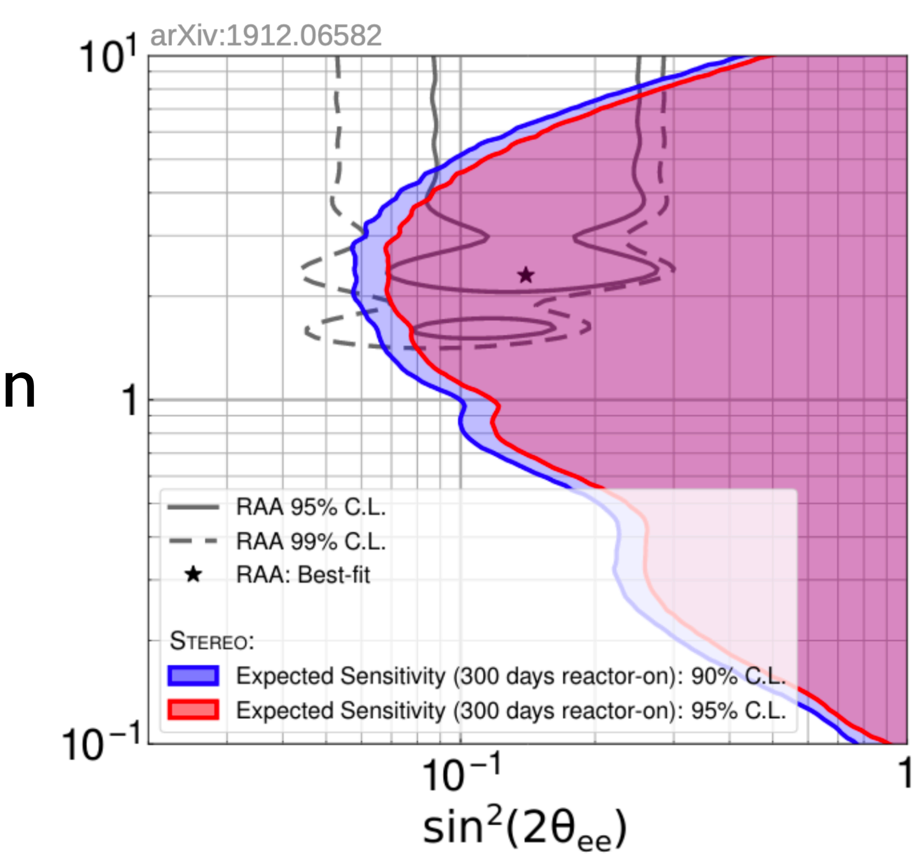
Giunti, Li, Littlejohn, Surukuchi, PRD 99 (2019)



STEREO

- Pros
  - Compact core: ~50cm diameter/height
  - Short baseline: 6-9 m baseline coverage
- Cons
  - Lower statistics: roughly 75k IBDs
  - Background is manageable, but non-negligible: S:B~1
- Sensitivity is very good
  - Particularly good at high mass splitting
  - Note: 'higher' chi2 for null-osc hypothesis; leads to 'big wiggles' and 'better-than-average' exclusion
- Will increase the size of its dataset by end of 2020
  - Not aware of any planned upgrade beyond that.

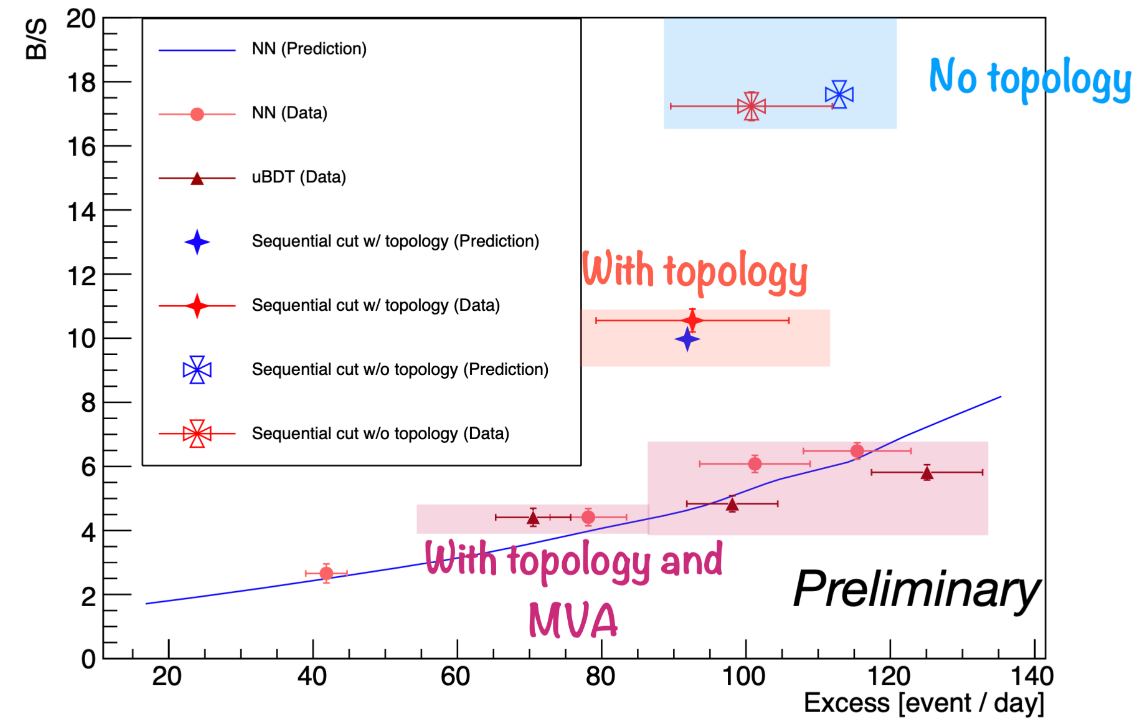


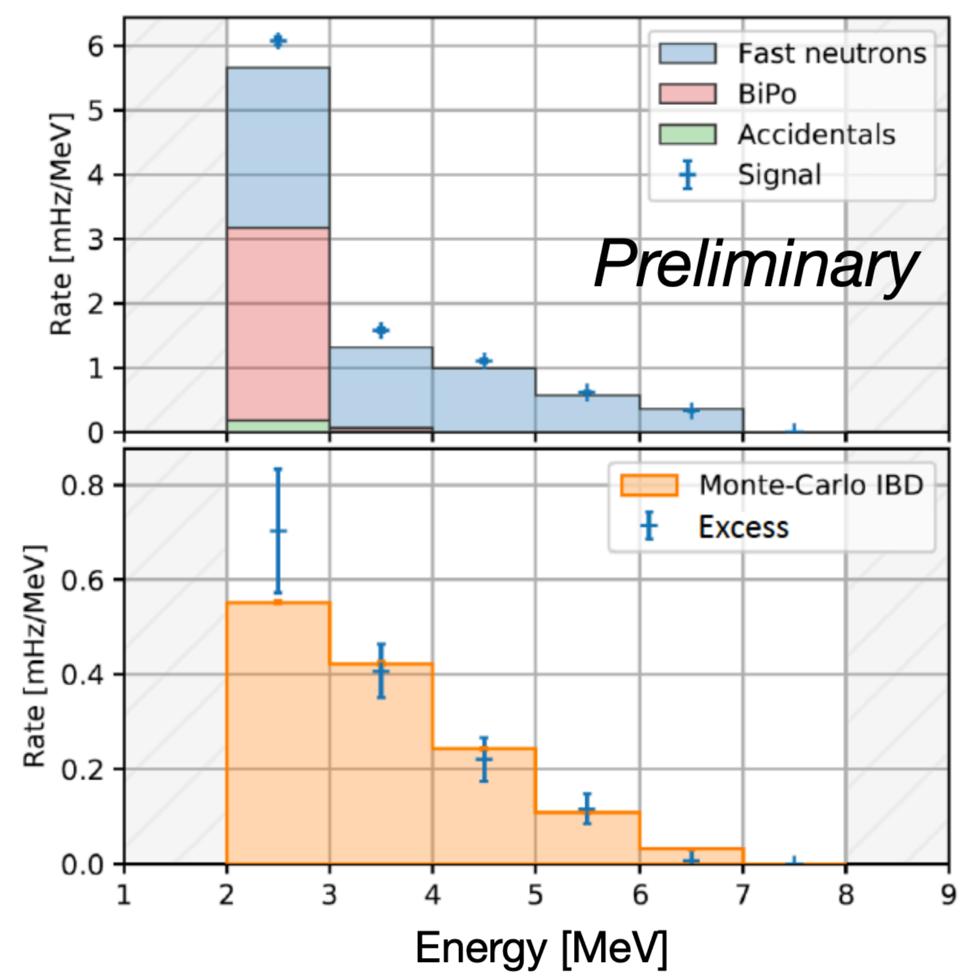


Solid

Solid, ICHEP 2020

- Pros
  - Compact core: ~50cm diameter/height
  - Short baseline: 6-9 m baseline coverage
- Cons
  - S:B is currently not great: somewhere between 1:4 and 1:10 at present?
- Haven't yet reported oscillation results
  - Unless S:B improves, it will be hard to field a competitive exclusion
  - Upgraded detector will lower threshold by 40%, and perhaps get to 1:1 S:B
  - Get 1000 IBD interactions/day, but unclear how long an upgraded run would last

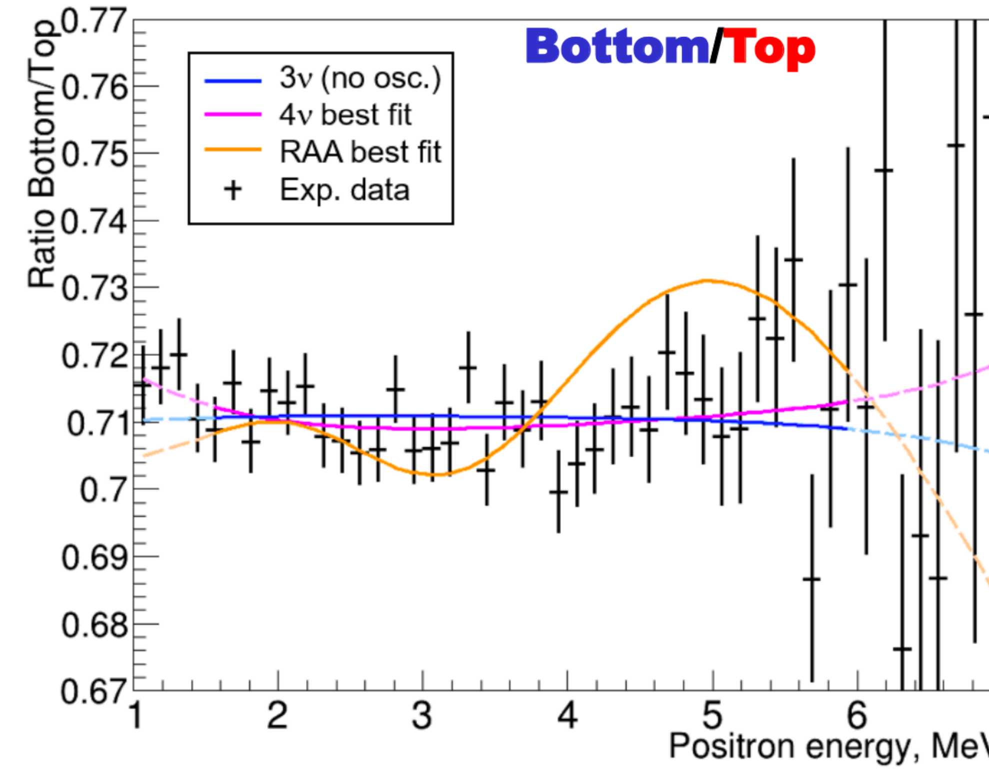


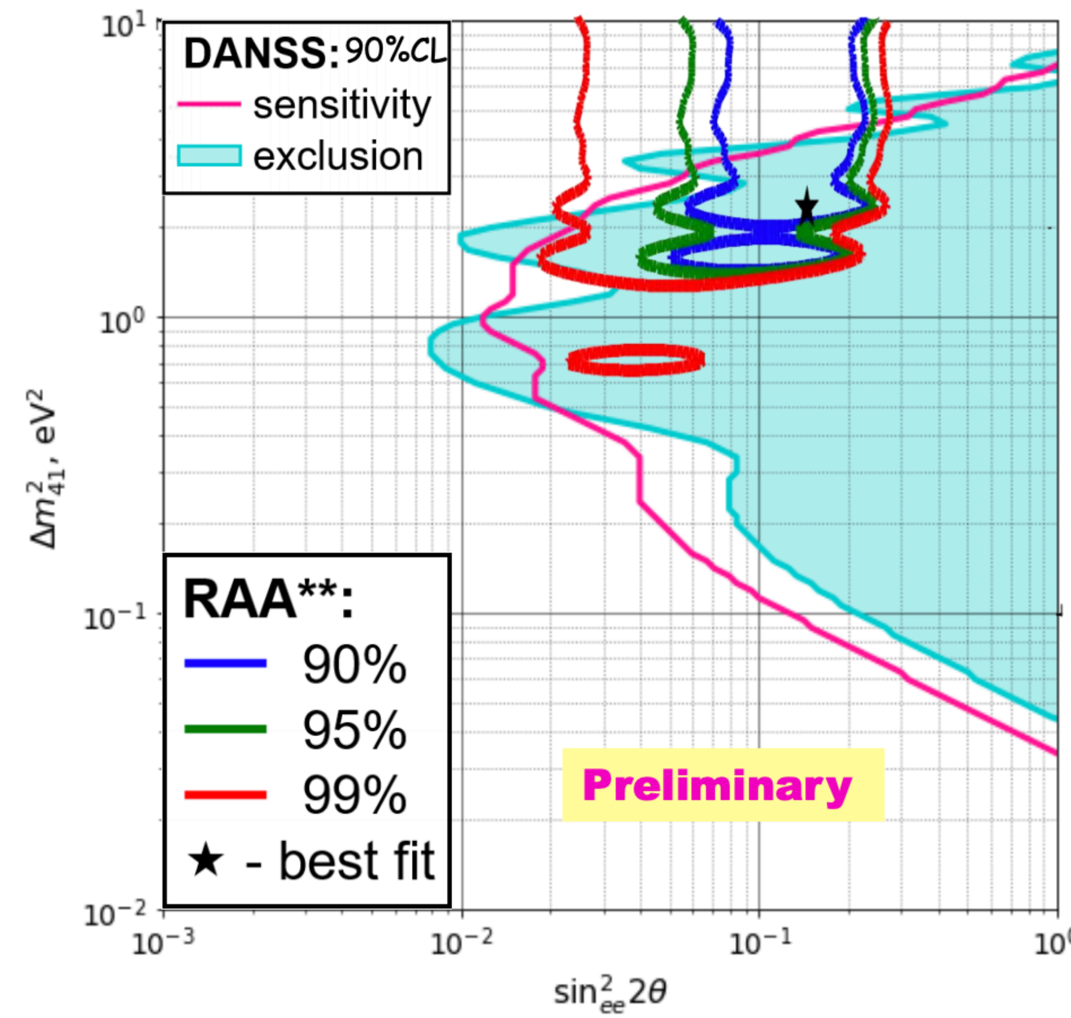


DANSS

DANSS, Neutrino 2020

- Pros
  - LEU data already in hand: 4M IBD events!
  - S:B is excellent due to high rate and having the reactor as overburden (!!!)
  - Situated well for systematics cancellation
  - Quite close: 10m closest distance
- Cons
  - Large reactor: >3m height
  - Broad energy resolution: ~35%
- Excellent demonstrated exclusion
  - Most precise limit of any SBL experiment (<1% precision!), but Δm^2 range more limited that other experiments
  - Detailed description of systematics in a long PRD publication would be valuable

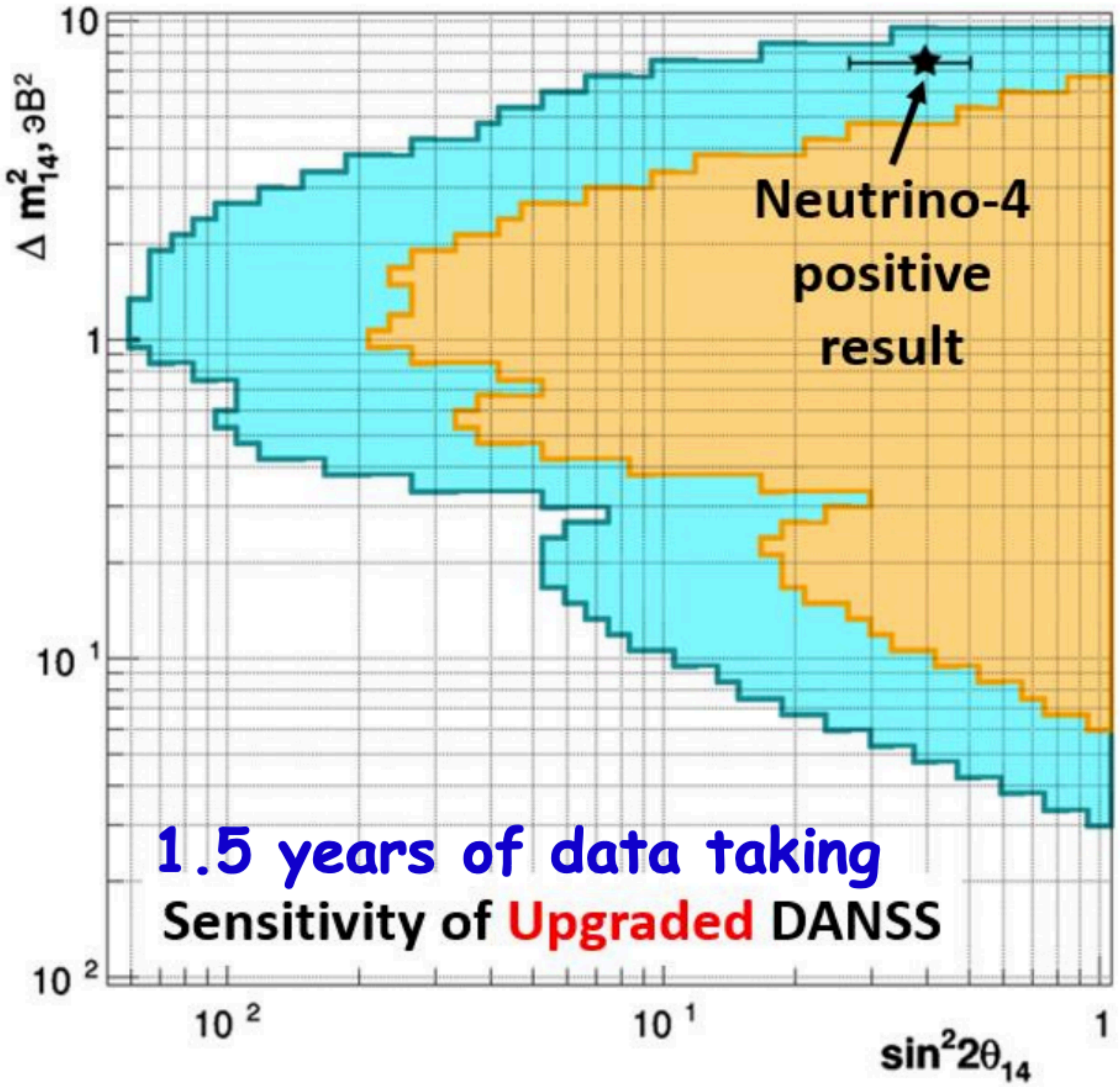




DANSS

- Pros
  - LEU data already in hand: 4M IBD events!
  - S:B is excellent due to high rate and having the reactor as overburden (!!!)
  - Situated well for systematics cancellation
  - Quite close: 10m closest distance
- Cons
  - Large reactor: >3m height
- Upgrade
  - Yellow: published PLB result; Blue: claimed upgrade sensitivity
  - With this high of statistics, systematics are increasingly important; reduced/improved systematics may provide more benefit than new data.
  - With increased importance of systematics, full description of those systematics becomes very crucial to assessing veracity of claimed exclusion/sensitivity.

DANSS, Neutrino 2020

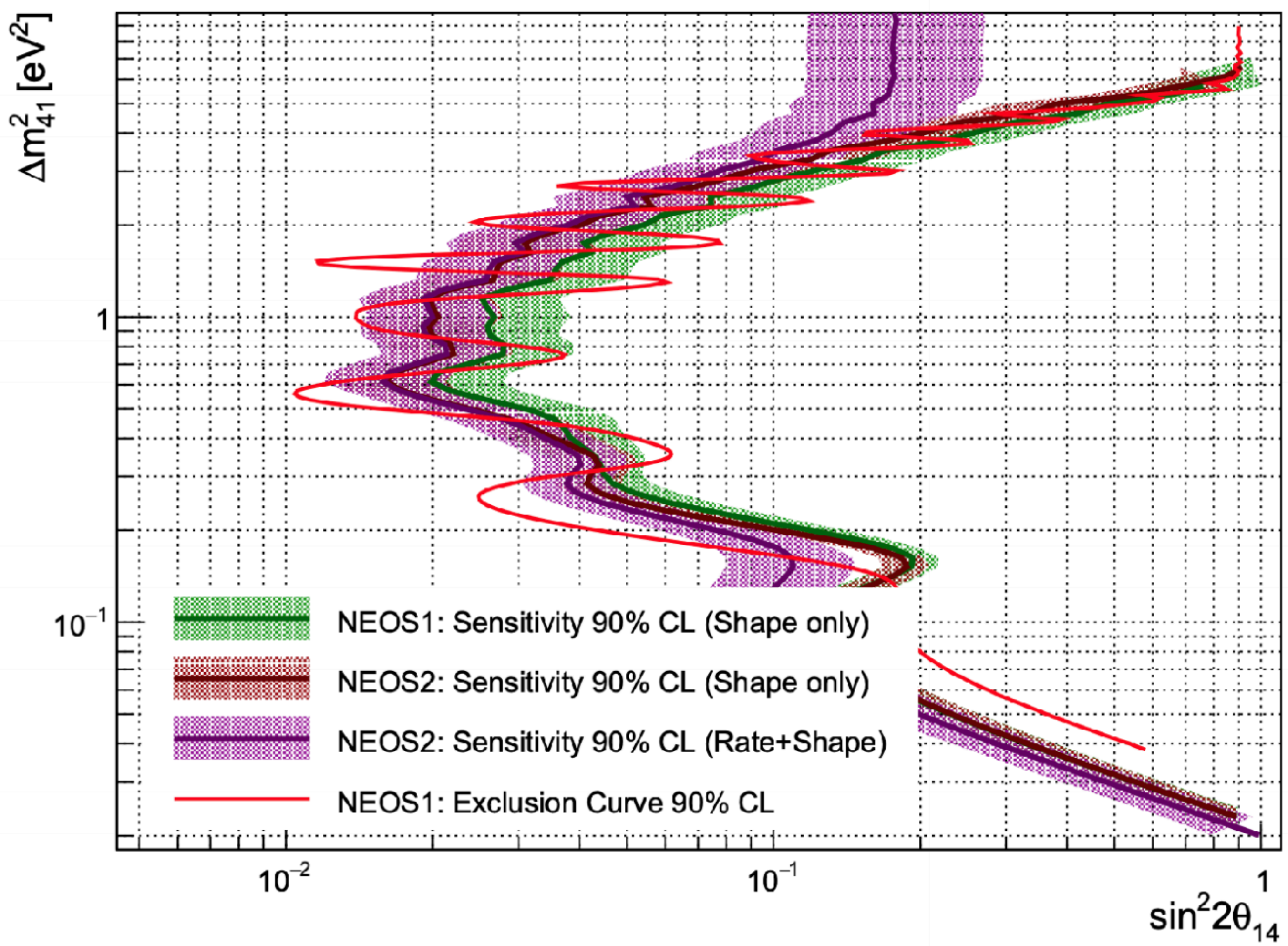


NEOS-II

NEOS, Neutrino 2020 Talk

- Pros:
  - LEU Data is in hand already: ~1.1M IBDs expected
    - Compare to NEOS-1: ~0.4M IBDs
  - S:B is excellent due to 20 mwe overburden: better than 10:1
- Cons:
  - Longer baseline: 24 meters
  - Larger reactor: >3m height, diameter
  - Systematics cancellation is 'indirect:' compare to DYB unfolded antineutrino spectrum
- Sensitivity will be ~25% better than NEOS-I
  - Only paying attention to 'shape-only' here…

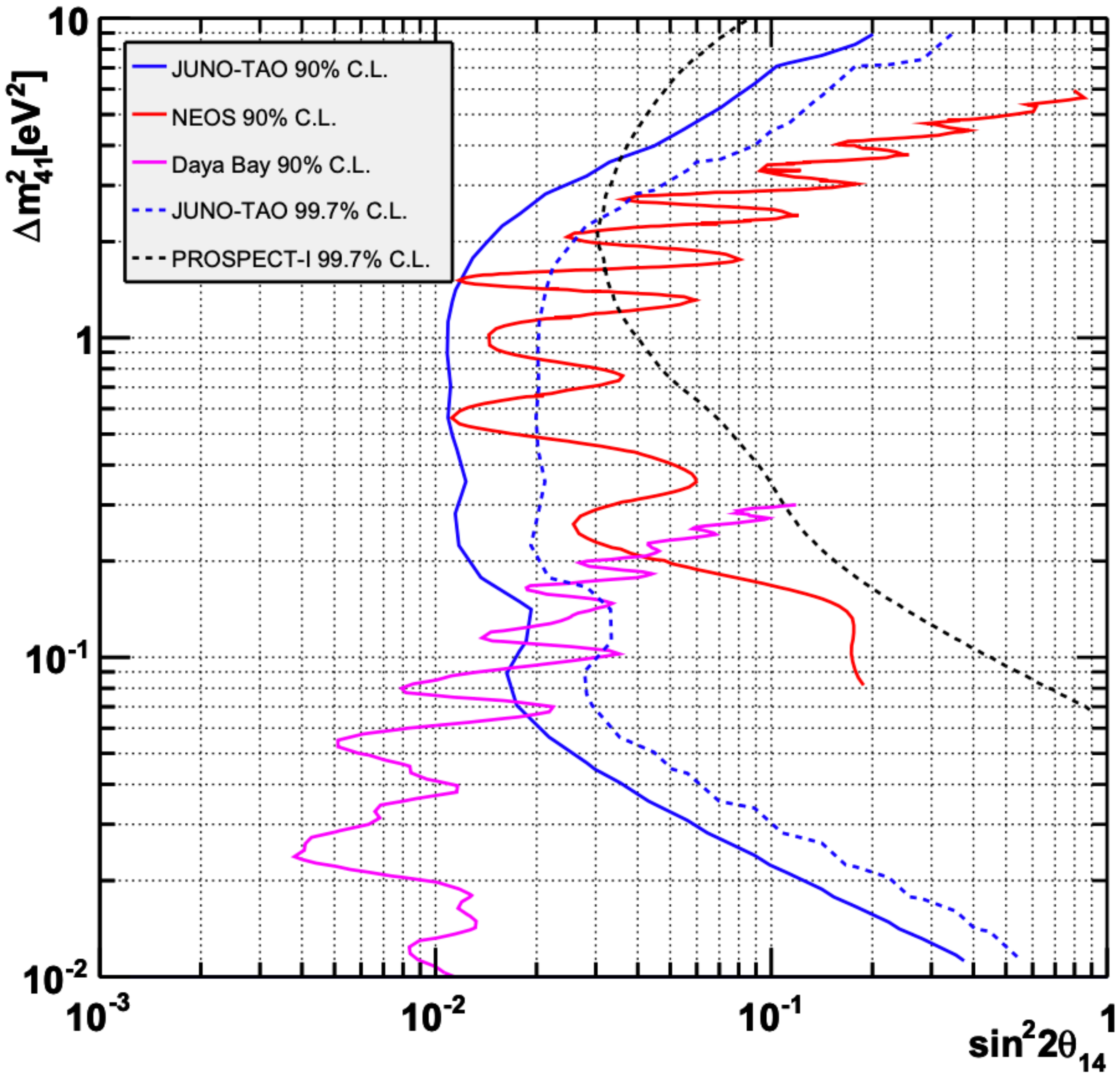
NEOS, AAP 2019 @ SYSU, China



JUNO-TAO

JUNO, arXiv:2005.08745 (2020)

- Pros:
  - 3 years running with 2000 events/day: ~1.75M IBD events
  - Excellent energy resolution: ~1%!
- Cons:
  - Longer baseline: ~32m
  - Larger reactor:
    >3m diameter, height
  - ~no overburden (like PROSPECT), but GdLS. TBD if S:B will be good
    - Assumed 10:1 S:B in sterile projections
- Claimed sensitivity is quite good
  - More stats than NEOS, so makes sense
  - Particularly at higher Δm^2
  - Note: contour includes 5% spectrum shape constraint; not sure about rate.



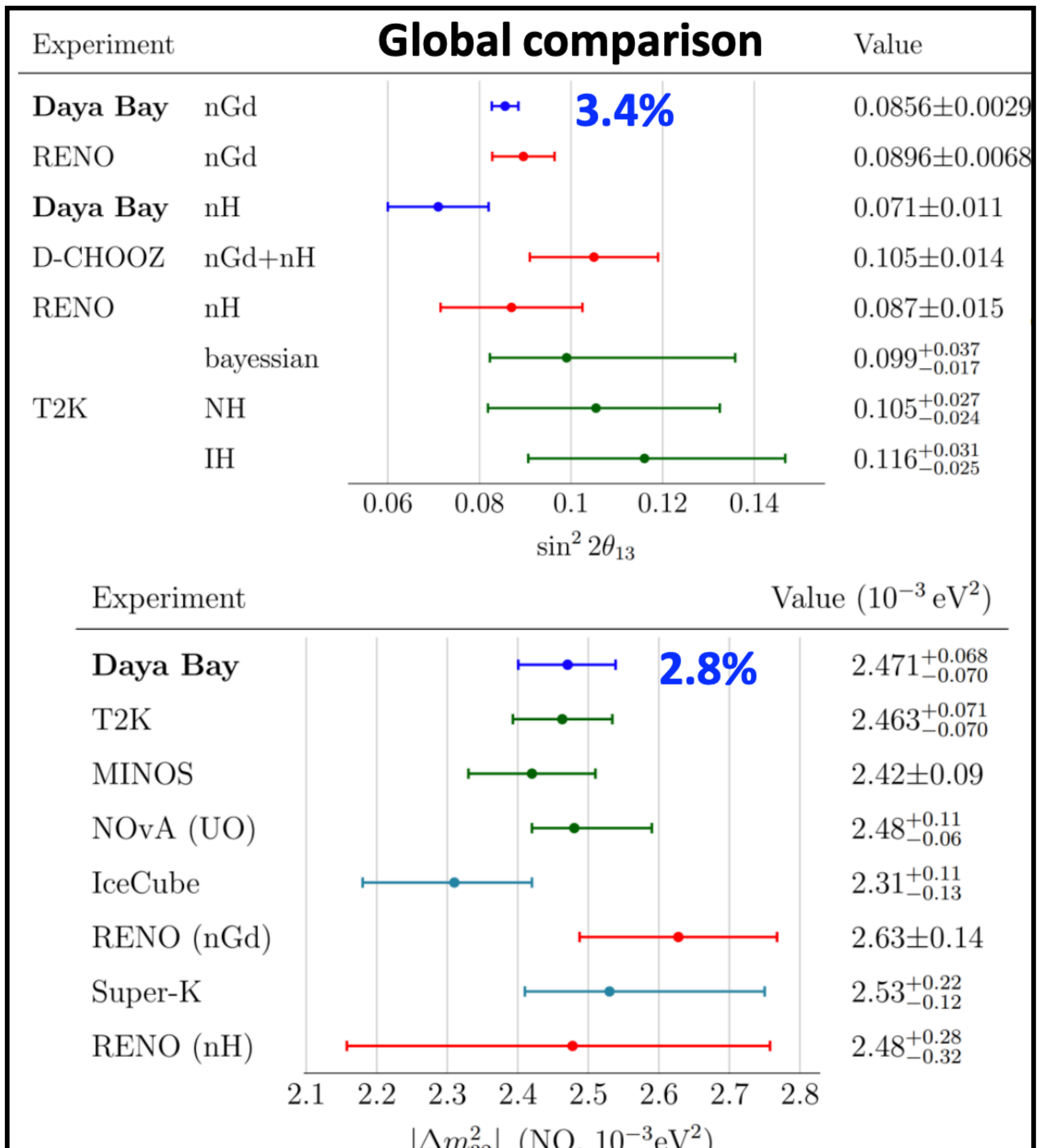
Neutrino-4

- Pros
  - Compact core: < 50cm diameter/height
  - Short and wide baseline coverage: 6-12 m baseline
  - Many years of data-taking at ~200 IBD detections/day; should have >100k IBD in the can?
- Cons
  - Claimed S:B of 0.5; not good, but not horrible either
- Has all the makings of a sensitivity on par with both STEREO and PROSPECT
  - Beyond this, it's difficult to say much more: https://arxiv.org/abs/2006.13147
  - Experiment will continue to take data for the foreseeable future, I think.

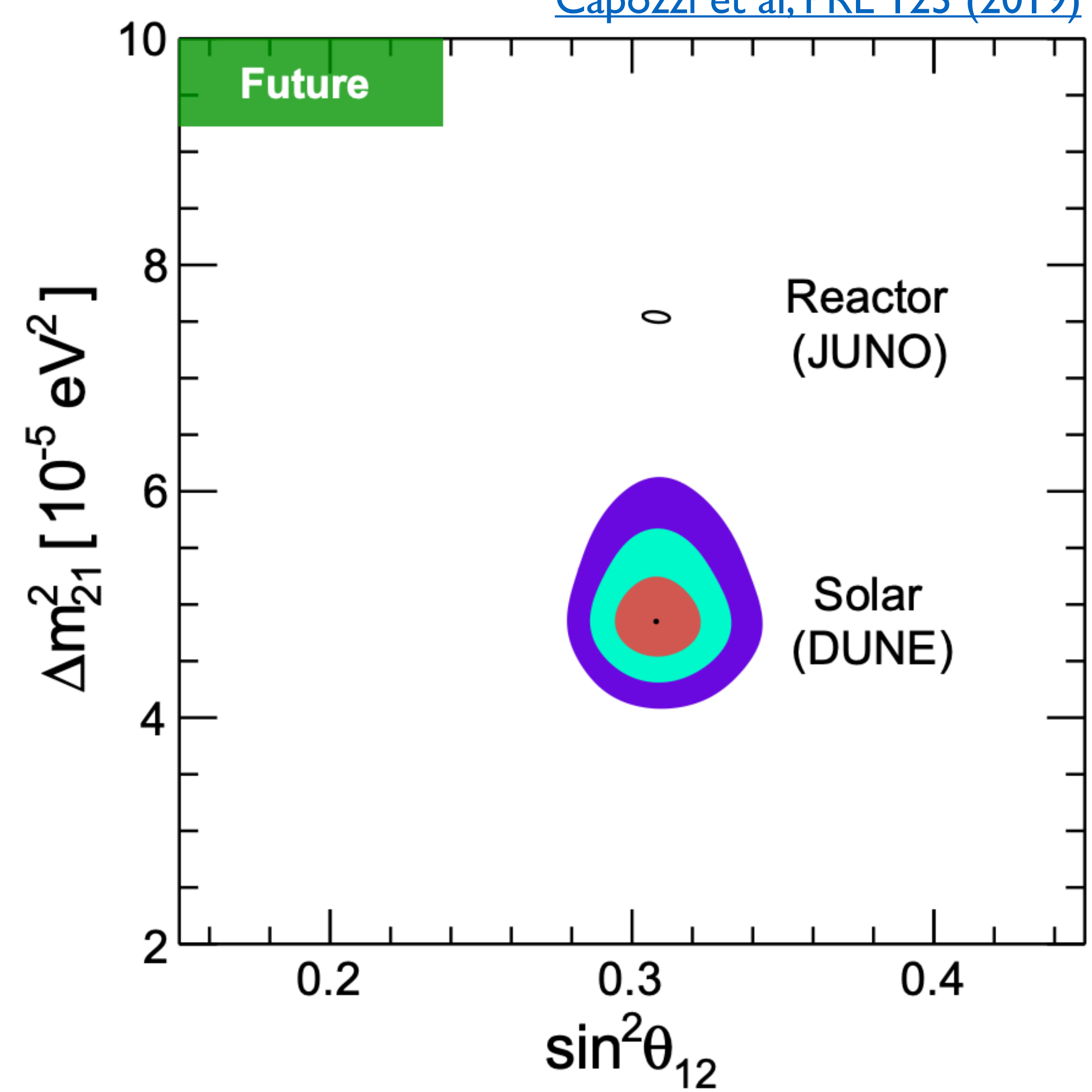
Standard Model Oscillation Experiments

- 10 years from now reactor nu measurements will hold best precision on <u>most</u> SM neutrino osc parameters!

Daya Bay Snowmass LOI

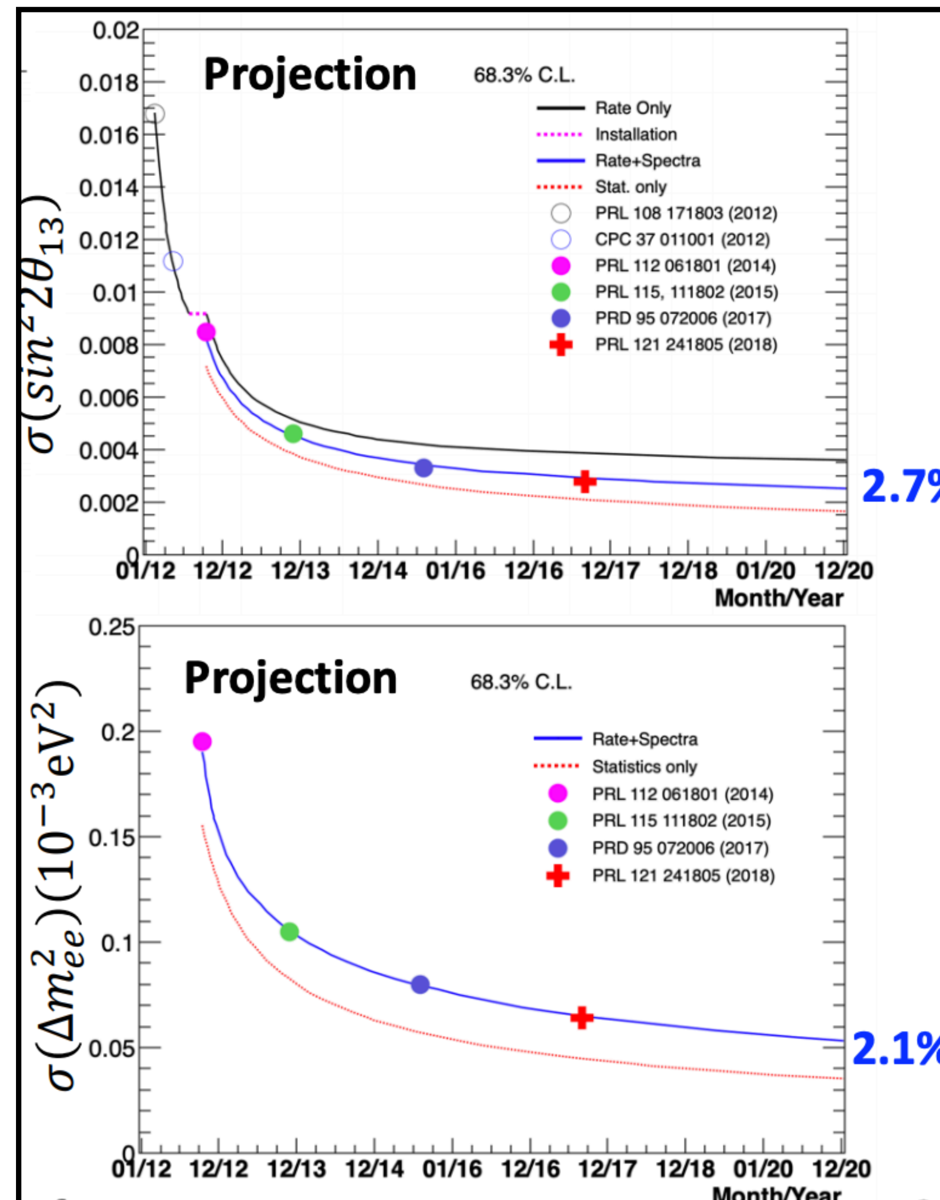


Capozzi et al, PRL 123 (2019)



θ_{13} Experiments

- θ13 experiments are complete or almost complete, with final results here, or in the next few years
  - Modest future improvements in osc precision can be expected: for example, DYB will improve from θ_{13} current 3.4% to ultimate ~2.7% precision
- Daya Bay will turn off in December 2020
  - Most recent analyses use data through late 2016: ~5 years' data used, ~4 years' data left to analyze
  - Final dataset results expected at Neutrino 2022
- Double Chooz is done
  - Full experimental dataset published in Nature
- RENO is done (?)
  - Most recent θ_{13} results at Neutrino 2020 use data thru Feb. 2020; not sure if more exists

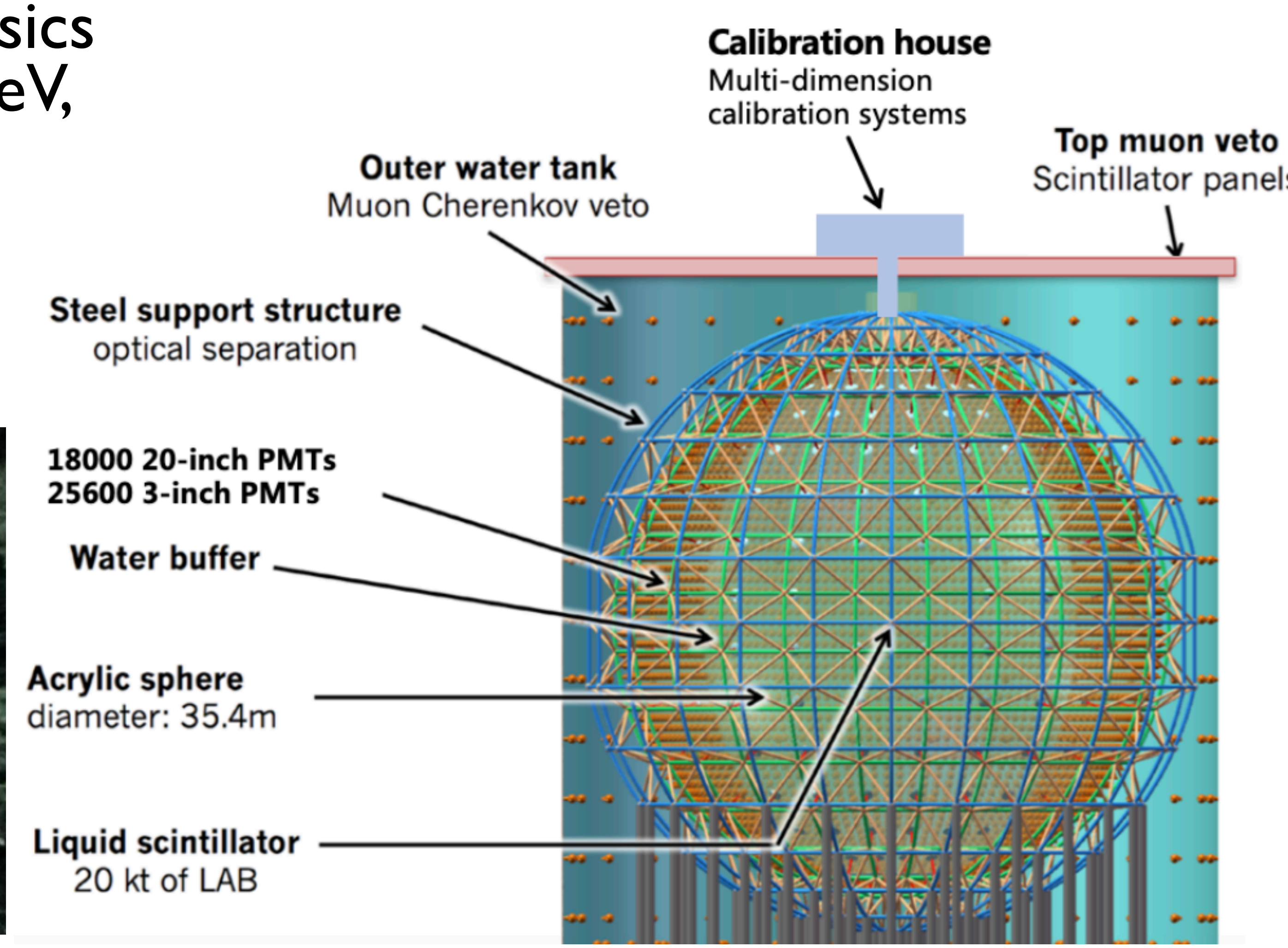


Daya Bay, Neutrino 2020

Mass Hierarchy: JUNO

JUNO Snowmass LOI

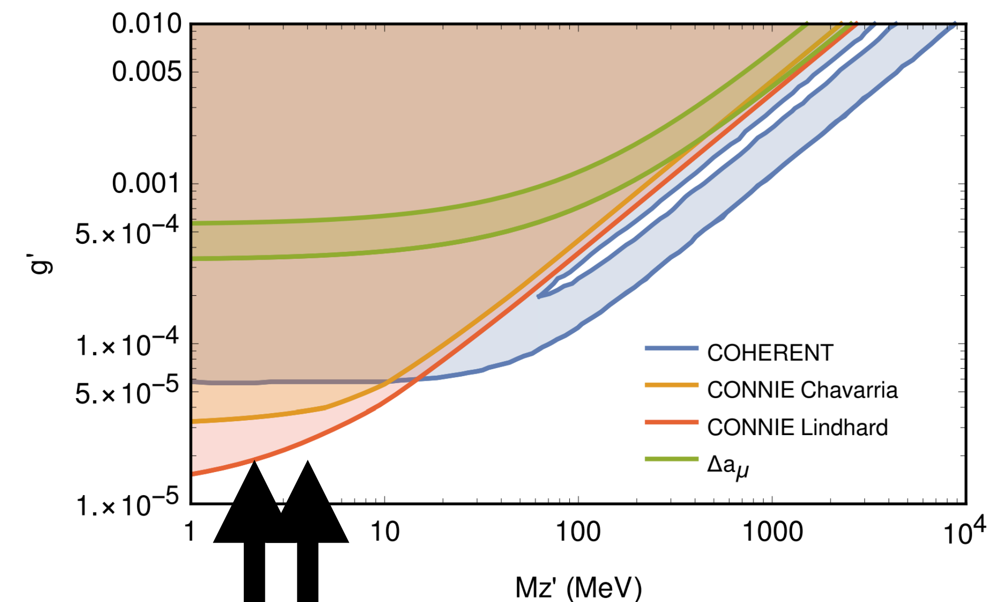
- JUNO will start data-taking in 2022
  - 3σ on mass hierarchy in ~6 years (2028)
  - Solar, geo, supernova, atm neutrino goals have 10-year quoted timelines (2032)
- Optimistically: we should think of JUNO like SuperK. Hopefully it will just run… forever.
  - DO NOT under-estimate the physics one can do with 20kT, 1200 PE/MeV, and ~ns timing precision!!!!
  - So we will NEVER stop doing reactor experiments :)



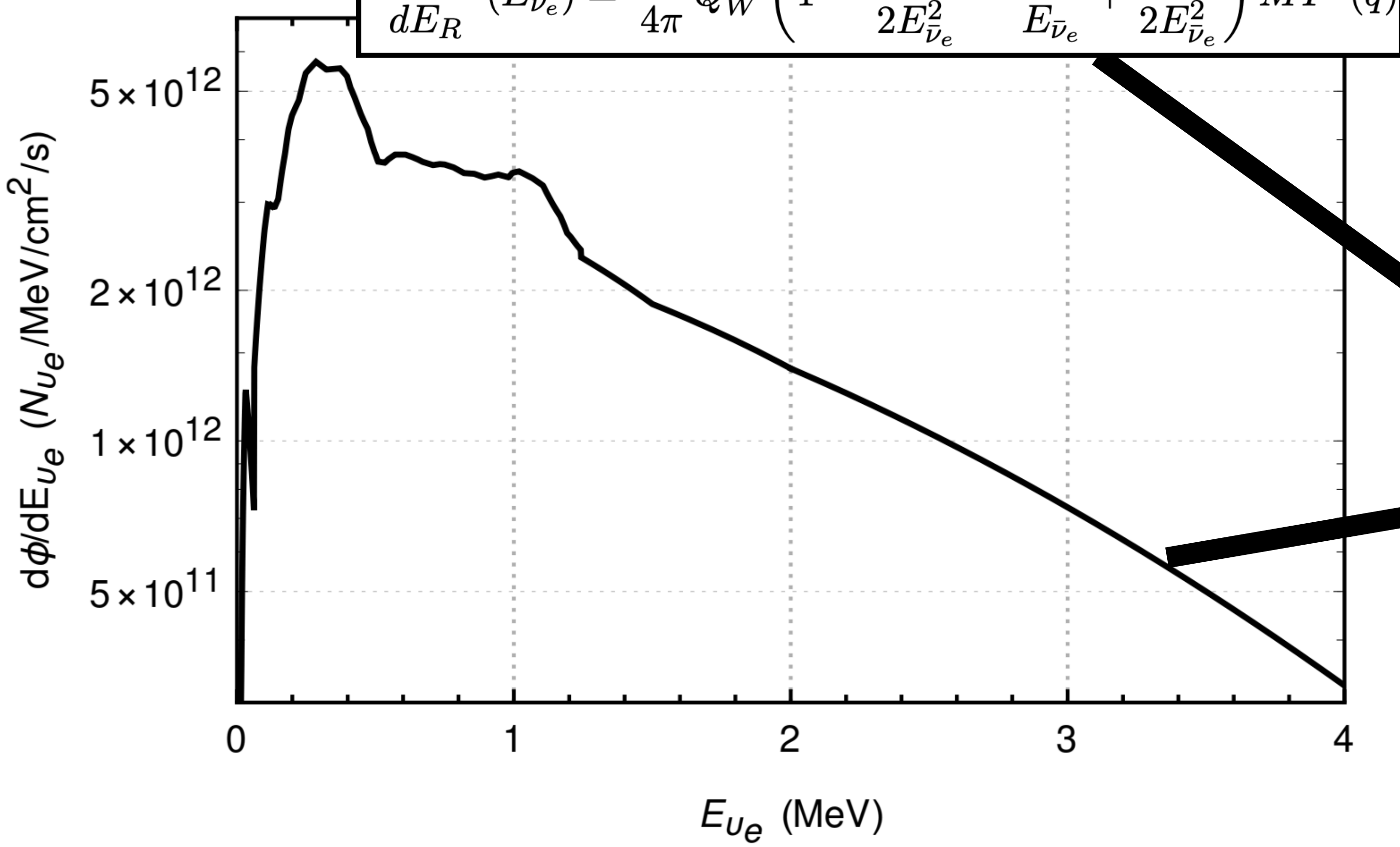
How To Do BSM with Reactor CEvNS

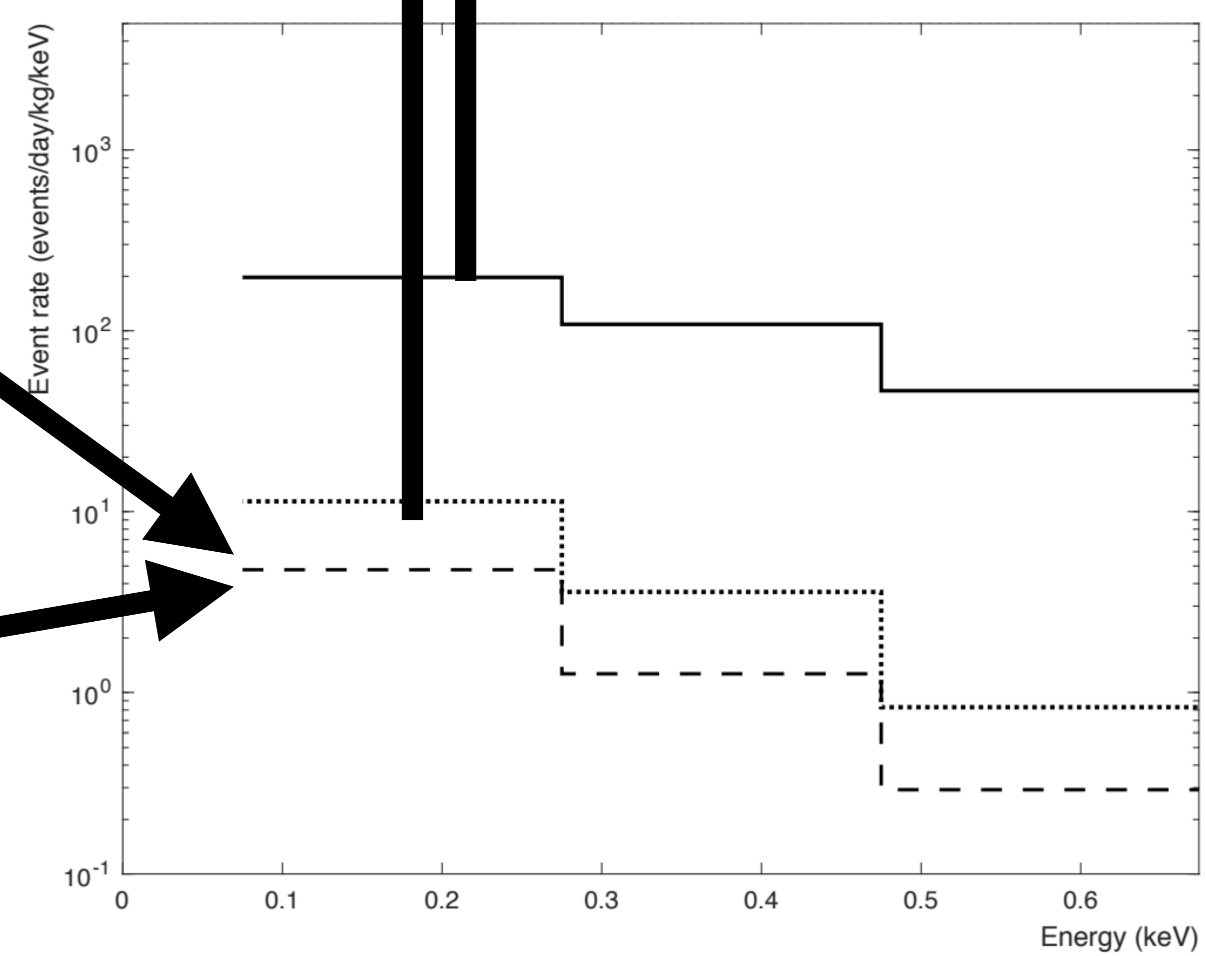
- Predict your reactor antineutrino flux times SM cross-section
- Measure it with a CEvNS detector
- Set limits on deviations from that SM prediction
- Key input: reactor antineutrino flux!

CONNIE, JHEP 54 (2020)



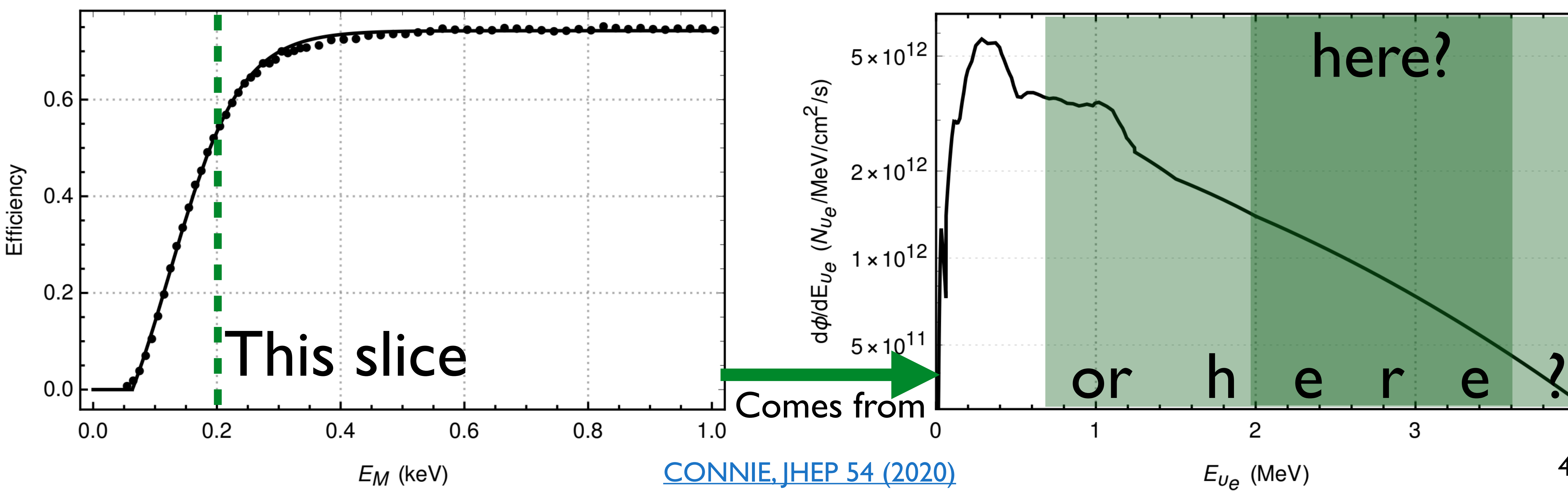
$$\frac{d\sigma_{SM}}{dE_R}(E_{\bar{\nu}_e}) = \frac{G_F^2}{4\pi} Q_W^2 \left(1 - \frac{M E_R}{2E_{\bar{\nu}_e}^2} - \frac{E_R}{E_{\bar{\nu}_e}} + \frac{E_R^2}{2E_{\bar{\nu}_e}^2}\right) M F^2(q)$$





An Important Consideration: E_{nu} to E_{meas}

- **How does neutrino energy map to measured recoil energy?**
  - "How much of the E_m spectrum above 0.2 keV arises from (E_{nu}) above 2 MeV?"
  - I'm sure there's a well-defined answer here, I'm just unlearned on the topic
- This determines a lot about what flux uncertainties matter!
  - If there's a tight correlation, the >8MeV flux uncertainties may matter a lot to CONUS or CONNIE, and can be greatly helped by IBD measurements!
  - If there's a very loose correlation, then the <2 MeV flux uncertainties are likely very important, in which case IBD measurements likely can't help much.



CONNIE, JHEP 54 (2020)

Isotopic Origins: A Broader View

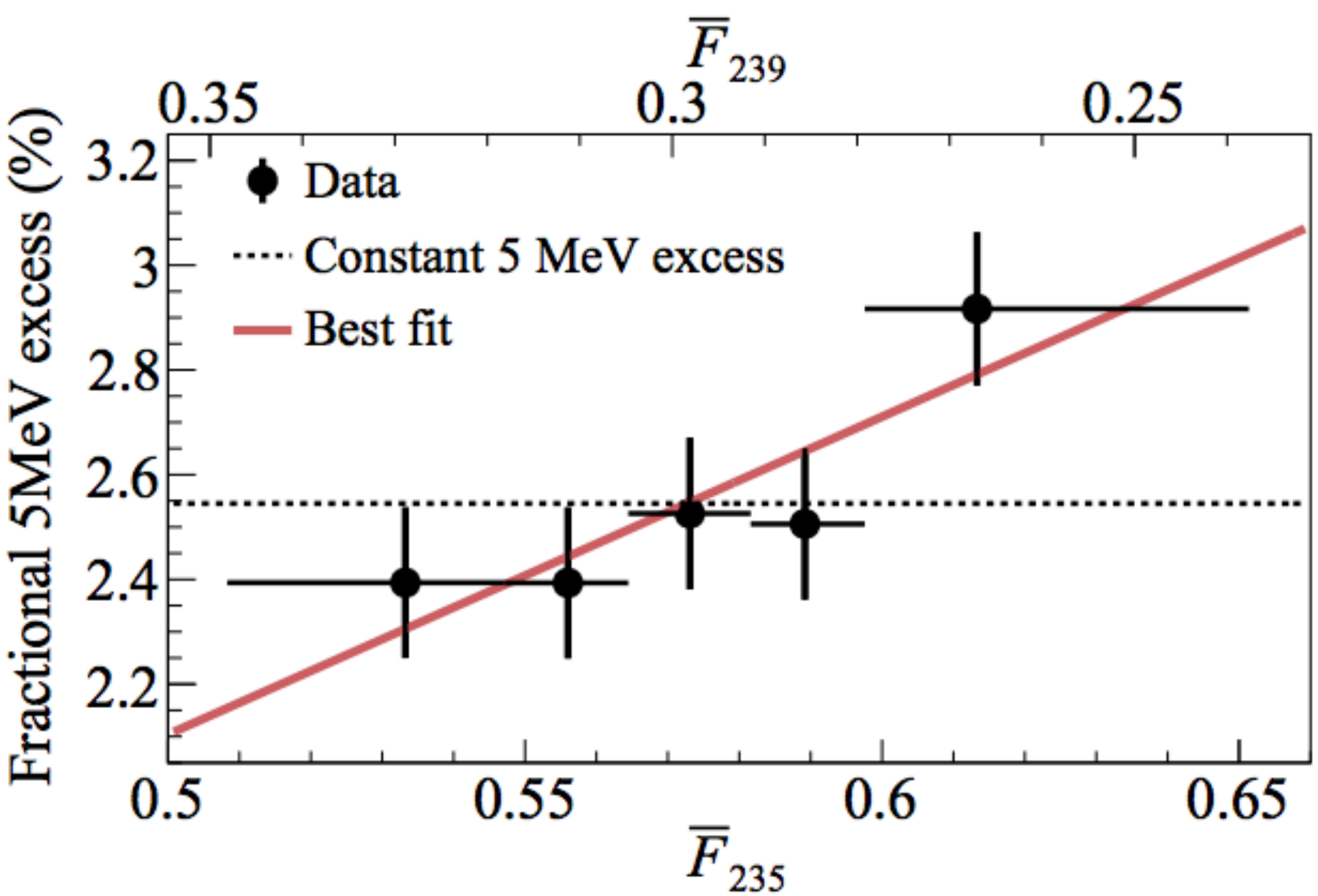
- Our simplified Q: 'Which isotopes produce the bump?'
- Experiments weighing in so far (my over-simplified summary…)

Experiment	~Only 235 (~No 239 bump)	Common origin	No 235 bump (~Pu only)	
Daya Bay	**OK**	**OK**	**NO**	Daya Bay, PRL 123 (2019)
RENO	**OK**	**NO**	**NO**	RENO, PRL 122 (2019)
PROSPECT	**NO**	**OK**	**NO**	PROSPECT, arXiv:2006.11210 (2020)
STEREO	**OK**	**OK**	**NO**	STEREO, arXiv:2010.01876 (2020)

- Most likely hypothesis: a common isotopic origin
  - Yields for different fission isotopes extensively overlap! X. Ma, et al, arXiv:1807.09265 (2018)
- All $\bar{\nu}_e$ data are consistent with this scenario except RENO
  - WHY? Should RENO claims be re-examined?

Isotopic Origins: RENO

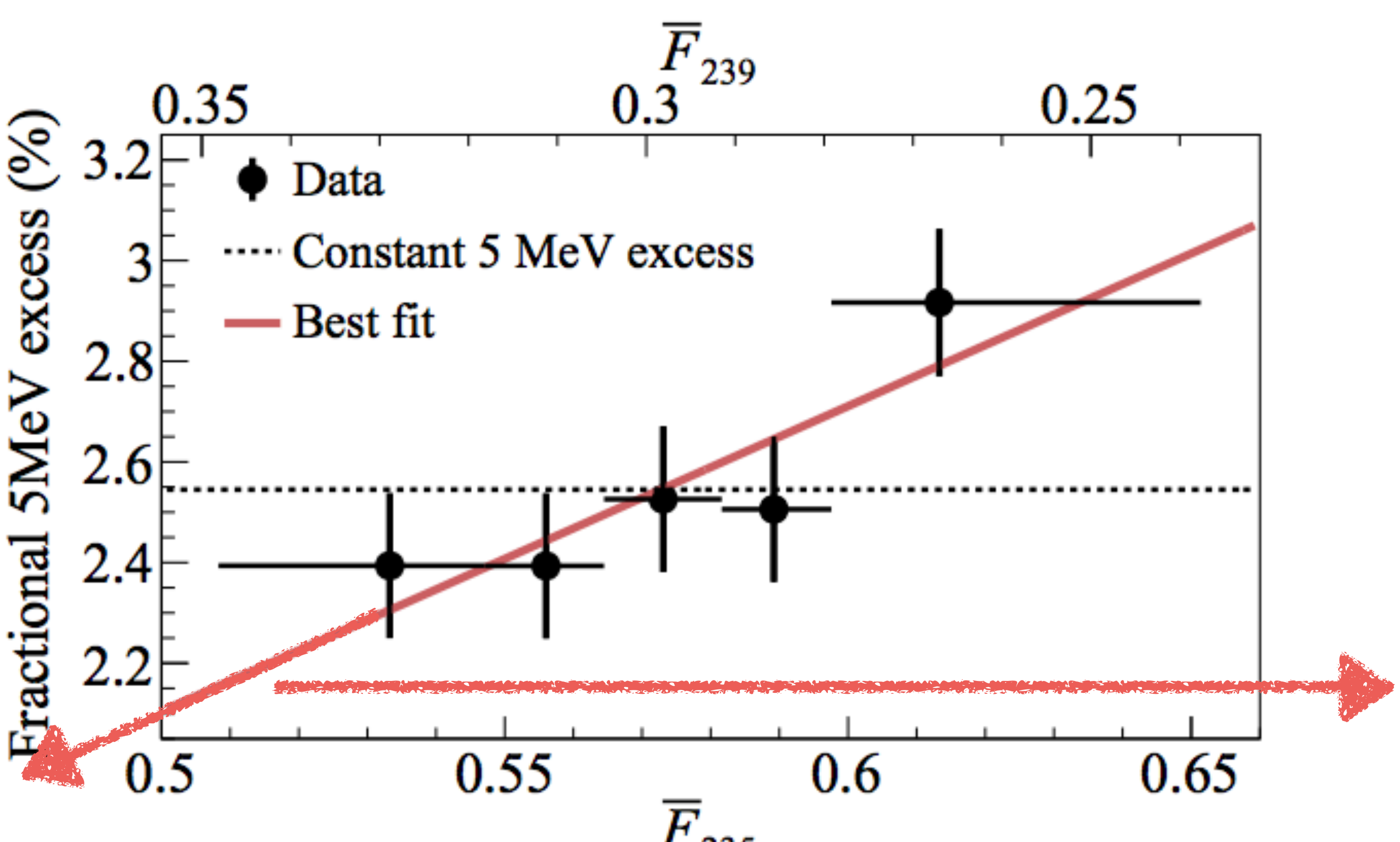
- RENO: does bump size change with fuel content?
  - Claim ~2.9σ indication of increasing bump size with increased ^{235}U burning
  - Newest arXiv posting increases this to 3.1σ RENO, arXiv:2010.14989 (2020)



RENO, arxiv[1806.00574].v1 (2018)

Isotopic Origins: RENO

- RENO: does bump size change with fuel content?
  - Claim ~2.9σ indication of increasing bump size with increased ^{235}U burning
  - Newest arXiv posting increases this to 3.1σ   RENO, arXiv:2010.14989 (2020)
- Another way of saying this: U235 has 'bigger bump' than Pu239
  - Actually, it's a 'bump' in 235, but a '**dip**' in Pu239!?



X-intercept (F_{235} = 0) is -0.55%!?

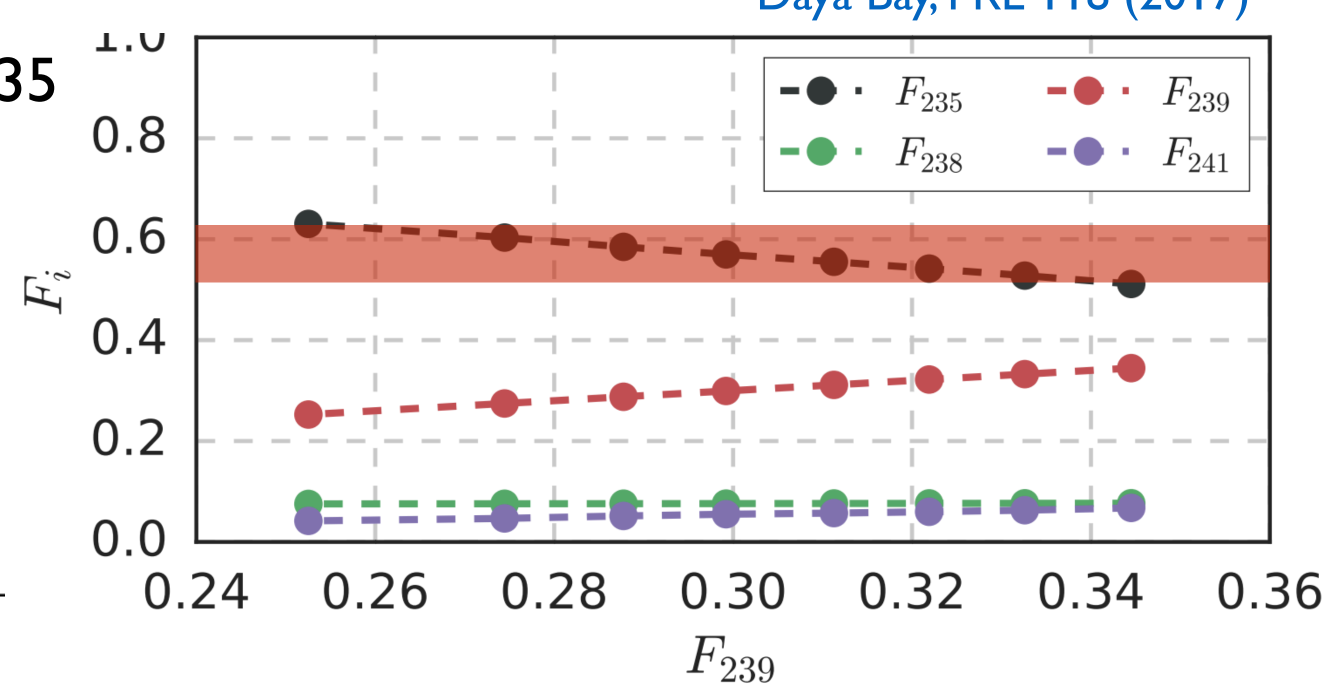
RENO, arxiv[1806.00574].v1 (2018)

Isotopic Origins: RENO

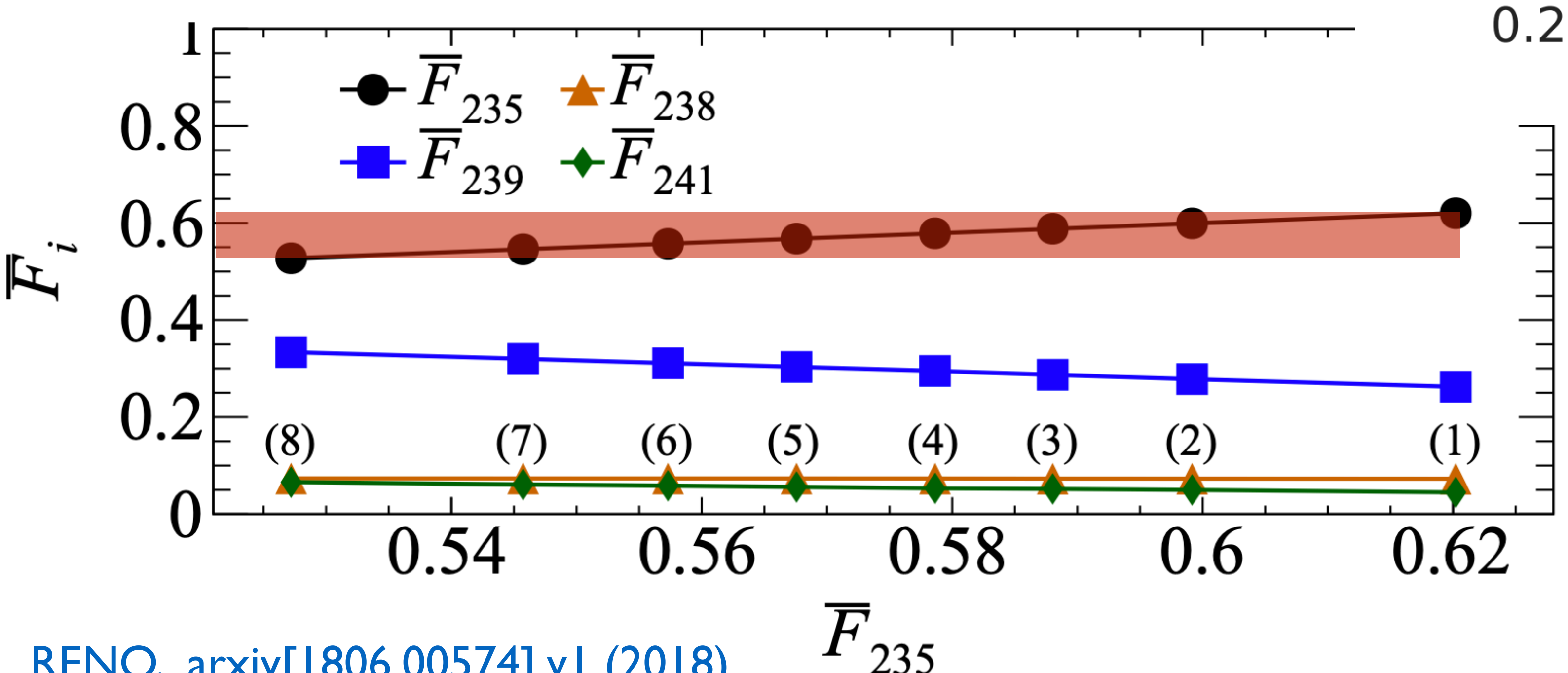
- Similar analysis at RENO: does bump change with fuel content?
  - Ask a meddling competitor:
    - Why does RENO have statistical capabilities to say something meaningful, <u>while DYB doesn't?</u> DYB statistics are **<u>>3x</u> <u>larger (!!!!)</u>**, and DYB samples slightly large range of fission fractions

Daya Bay, PRL 118 (2017)

Daya Bay: Change in binned U235 fission fraction of ~12%



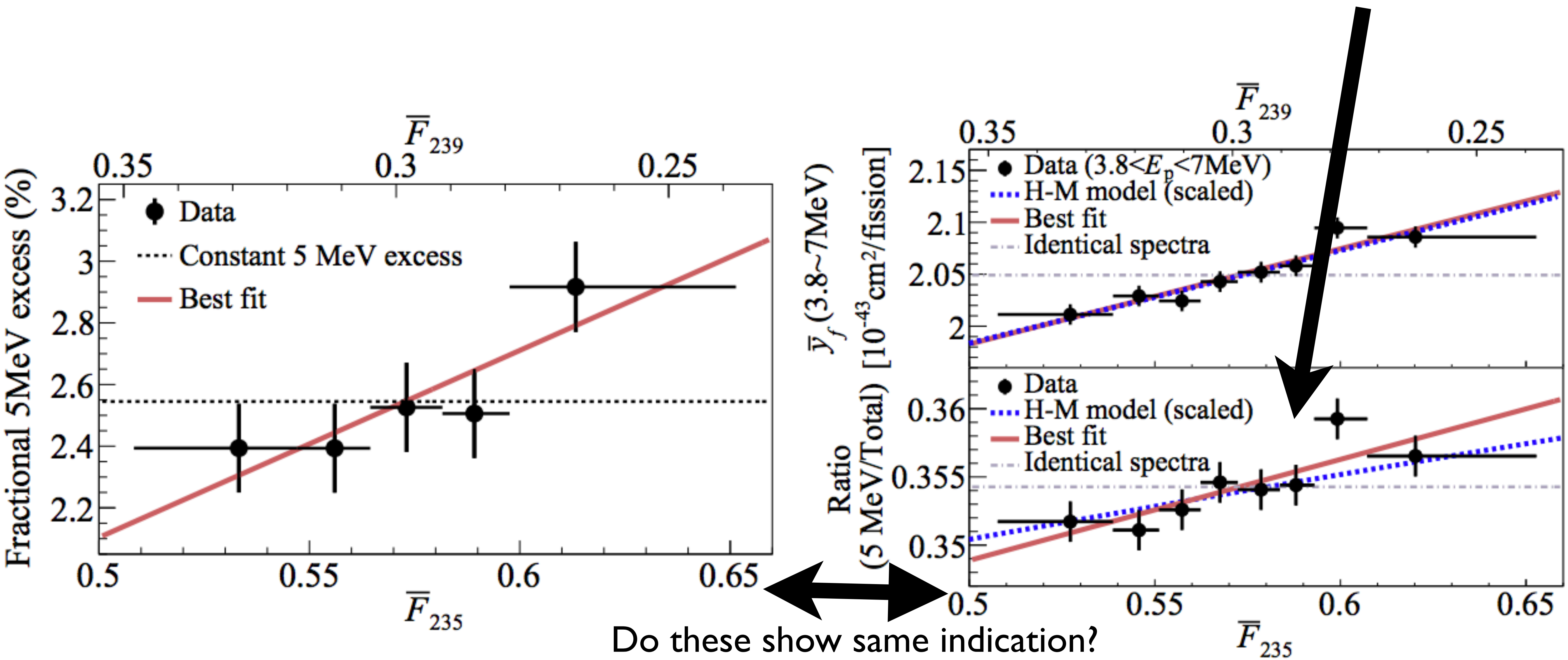
RENO: Change in binned U235 fission fraction of ~10%



RENO, arxiv[1806.00574].v1 (2018)

Isotopic Origins: RENO

- Similar analysis at RENO: does bump change with fuel content?
  - Ask a meddling competitor:
    - Why does RENO have statistical capabilities to say something meaningful, while DYB doesn't? DYB statistics are **>3x larger (!!!!)**, and DYB samples a larger range of fission fractions!
    - Similar metrics don't show similar indications (total 4-7 MeV contribution, for example)



Do these show same indication?
Seems not?

RENO, arxiv[1806.00574].v1 (2018)

Isotopic Origins: RENO

- Similar analysis at RENO: does bump change with fuel content?
  - Ask a meddling competitor:
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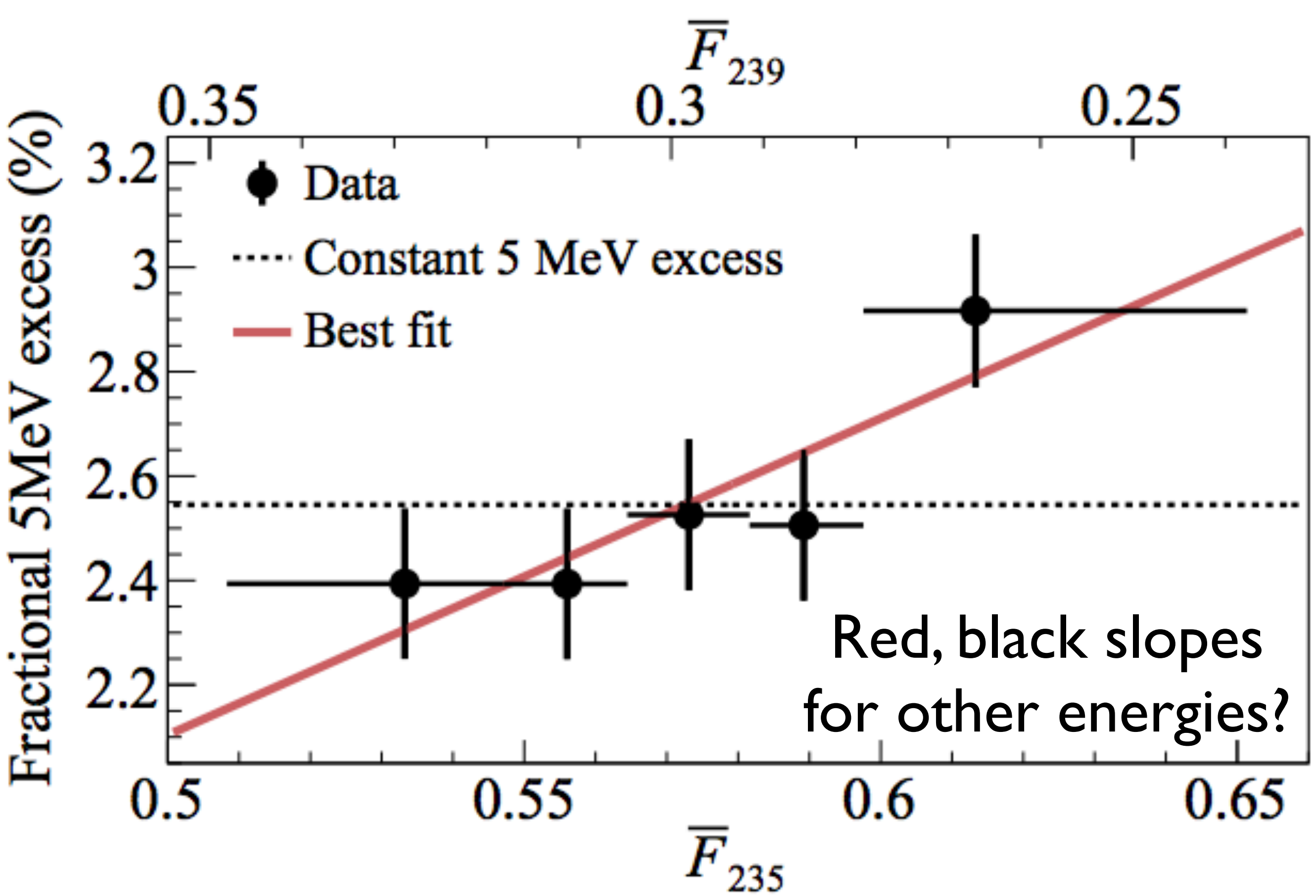
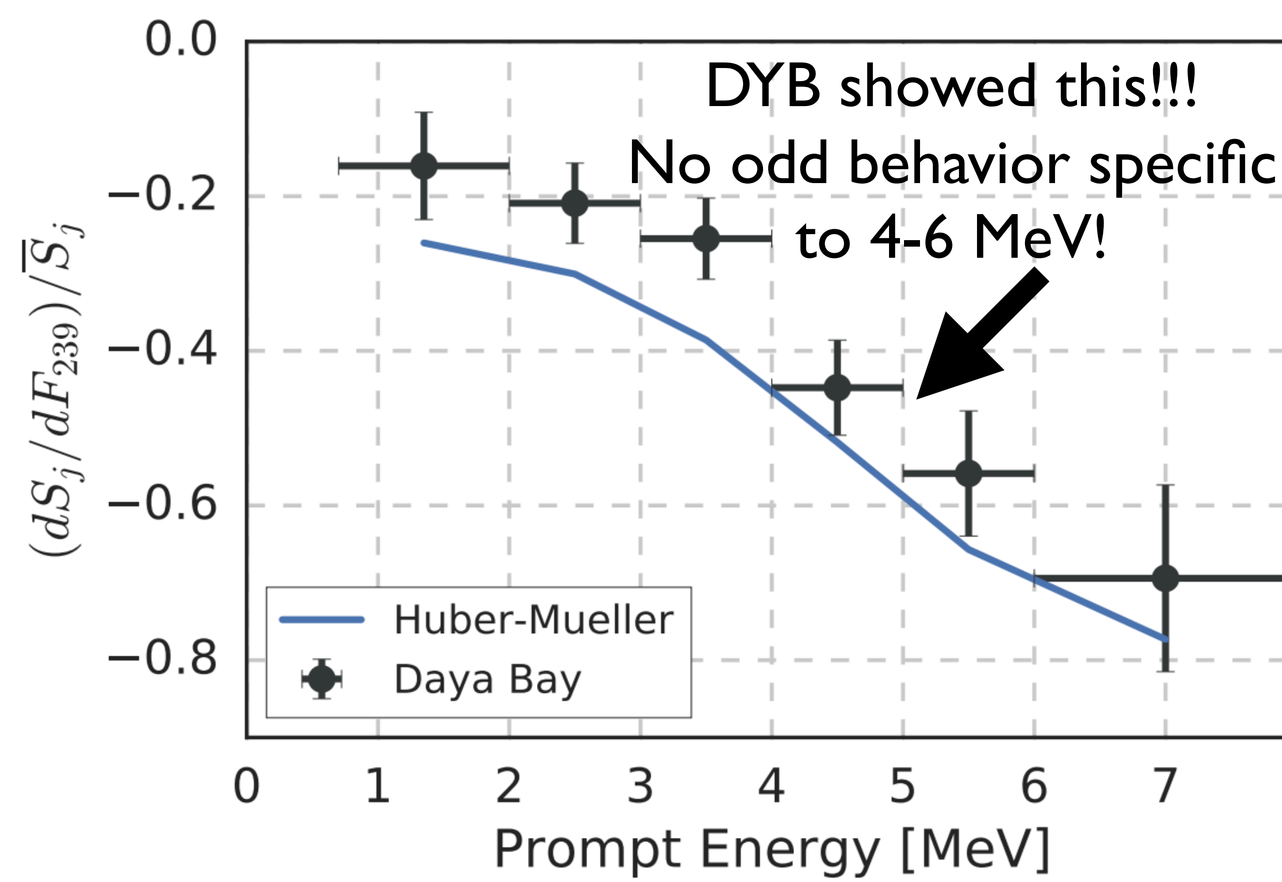
    - Similar metrics don't show similar indications (total 4-7 MeV contribution, for example)
    - What about behavior in other energy regions? Is 4-7 MeV region an outlier?





RENO, arxiv[1806.00574].v1 (2018)