A Novel Nuclear Recoil Calibration in the LUX Detector Using a D-D Neutron Generator

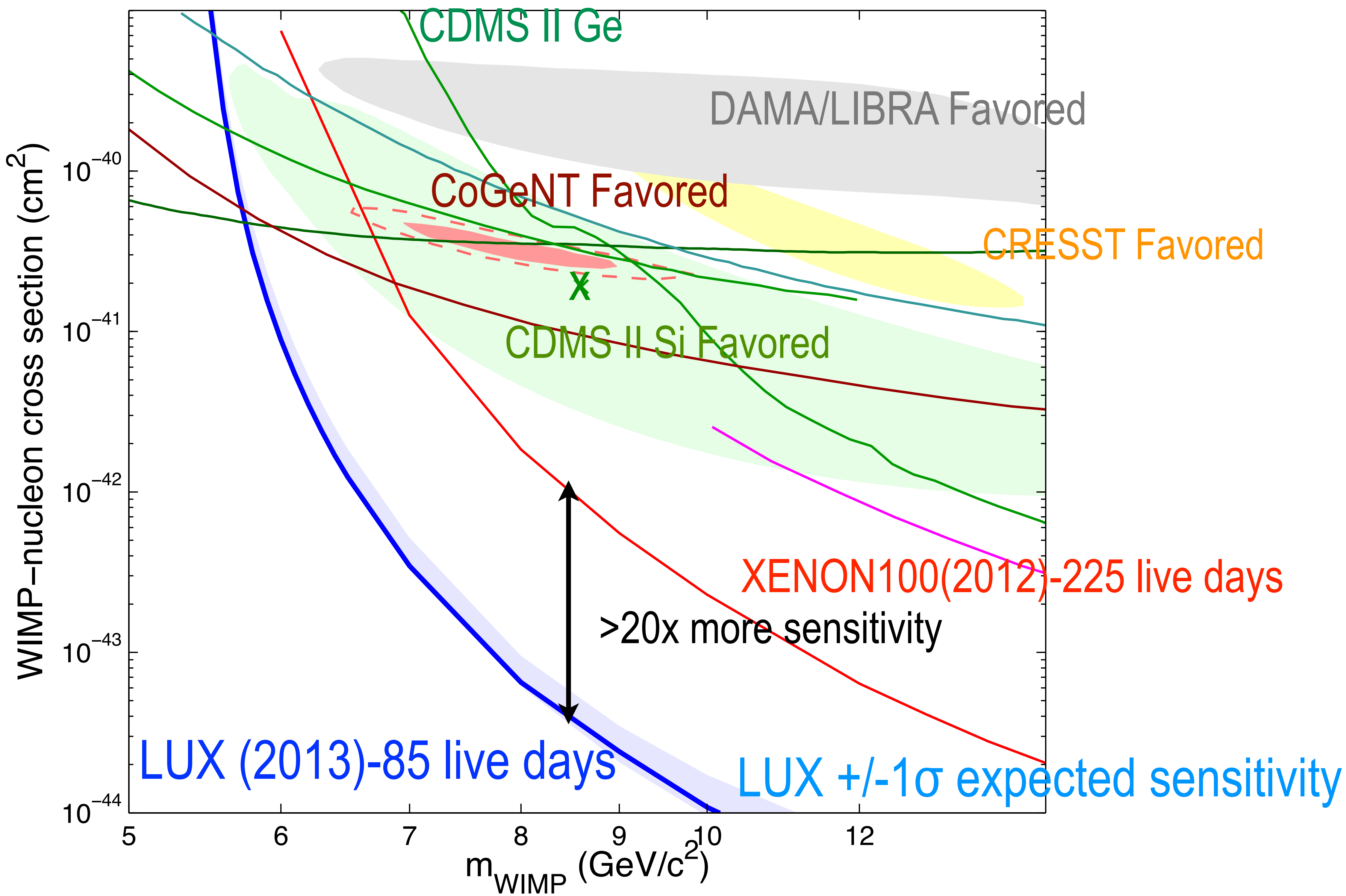
James Verbus
Brown University

April APS Meeting

April 12th, 2015

BROWN

Low Mass WIMPs - Fully Excluded by LUX

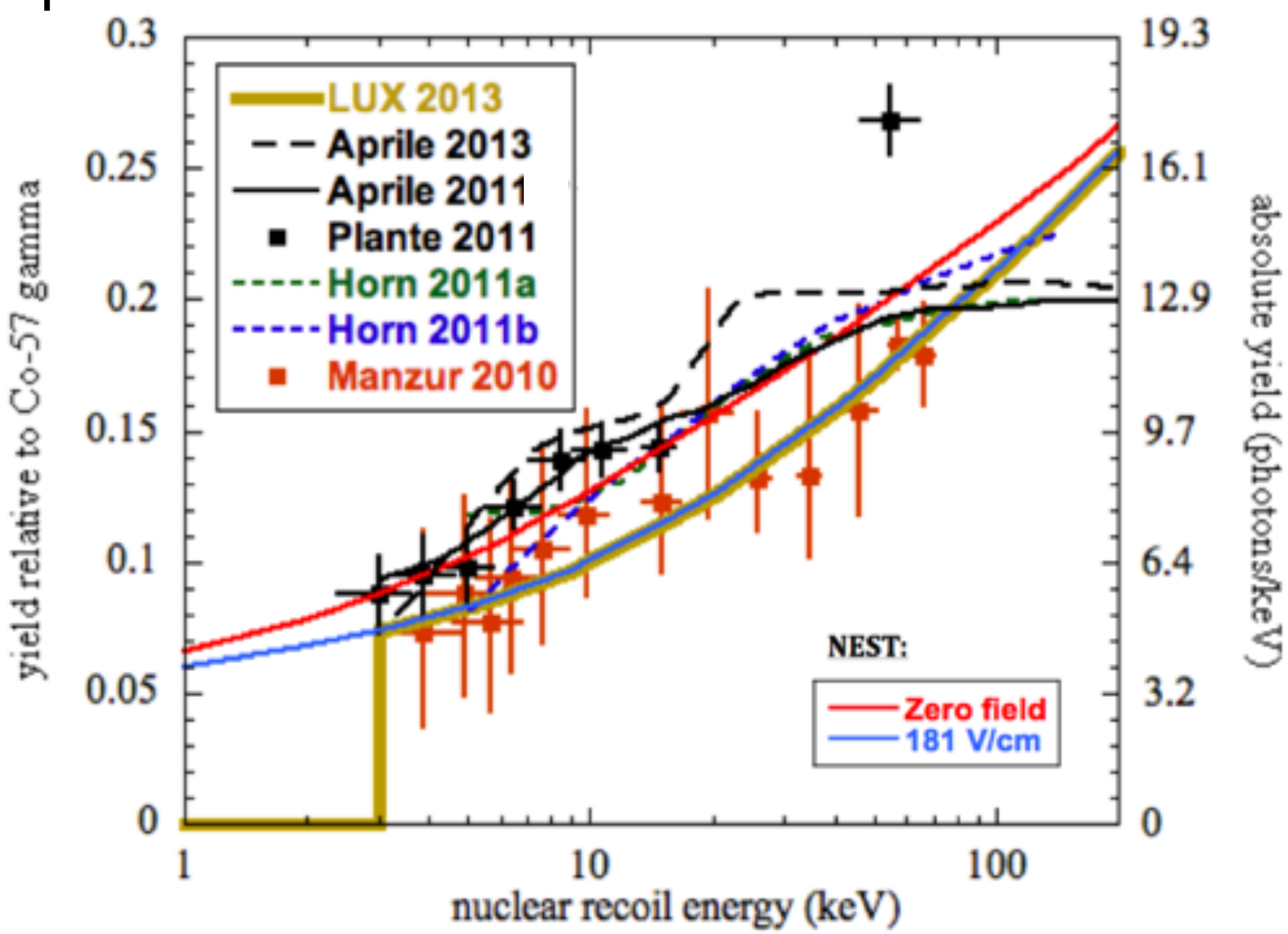


Conservative Light and Charge Yields Assumed for LUX 2014 PRL

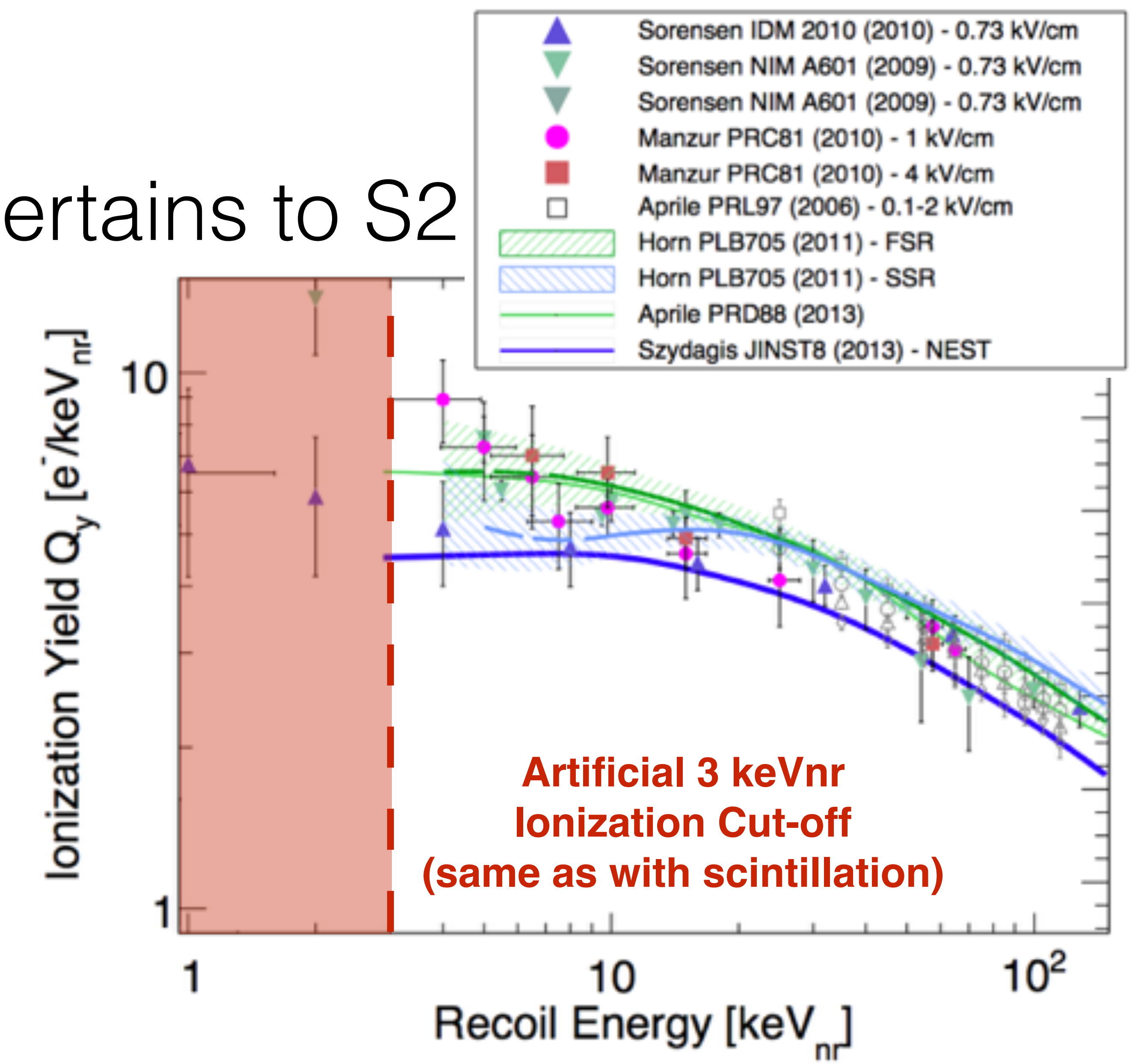
- Modeled Using Noble Element Simulation Technique (NEST)
  - Szydagis et al., arxiv:1106.1613
- NEST based on canon of existing experimental data.
- Artificial cutoff in light and charge yields assumed below 3 keVnr, to be conservative.
- Includes predicted electric field quenching of light signal, to 77-82% of the zero field light yield

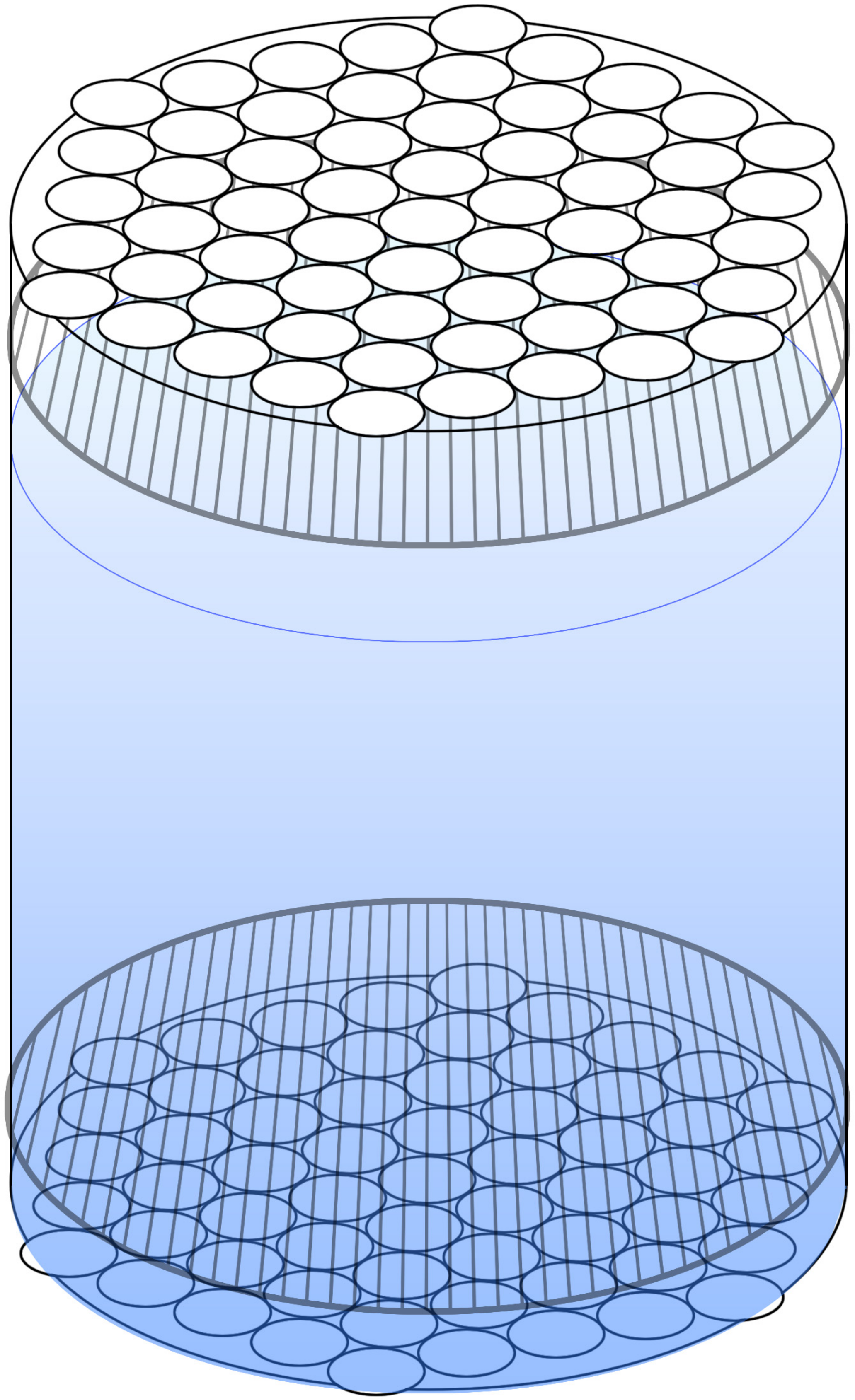
- **Conservative threshold used in LUX 2014 PRL Dark Matter Result arXiv:1310.8214v2**

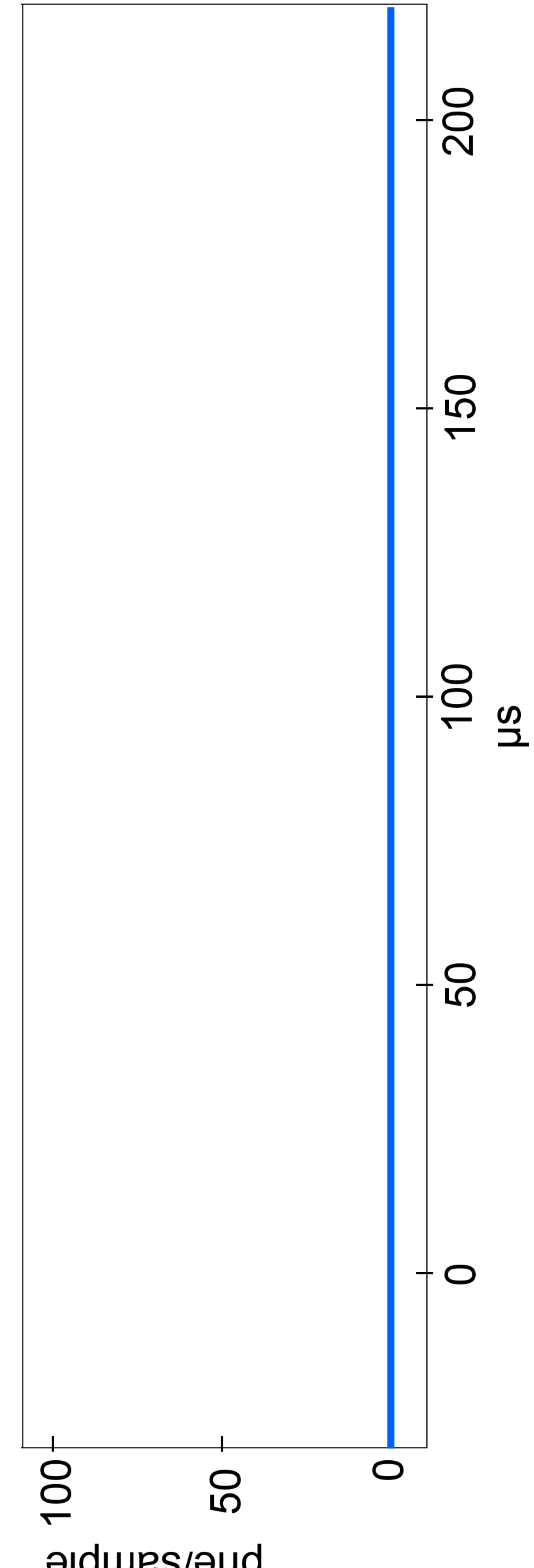
pertains to S1



pertains to S2

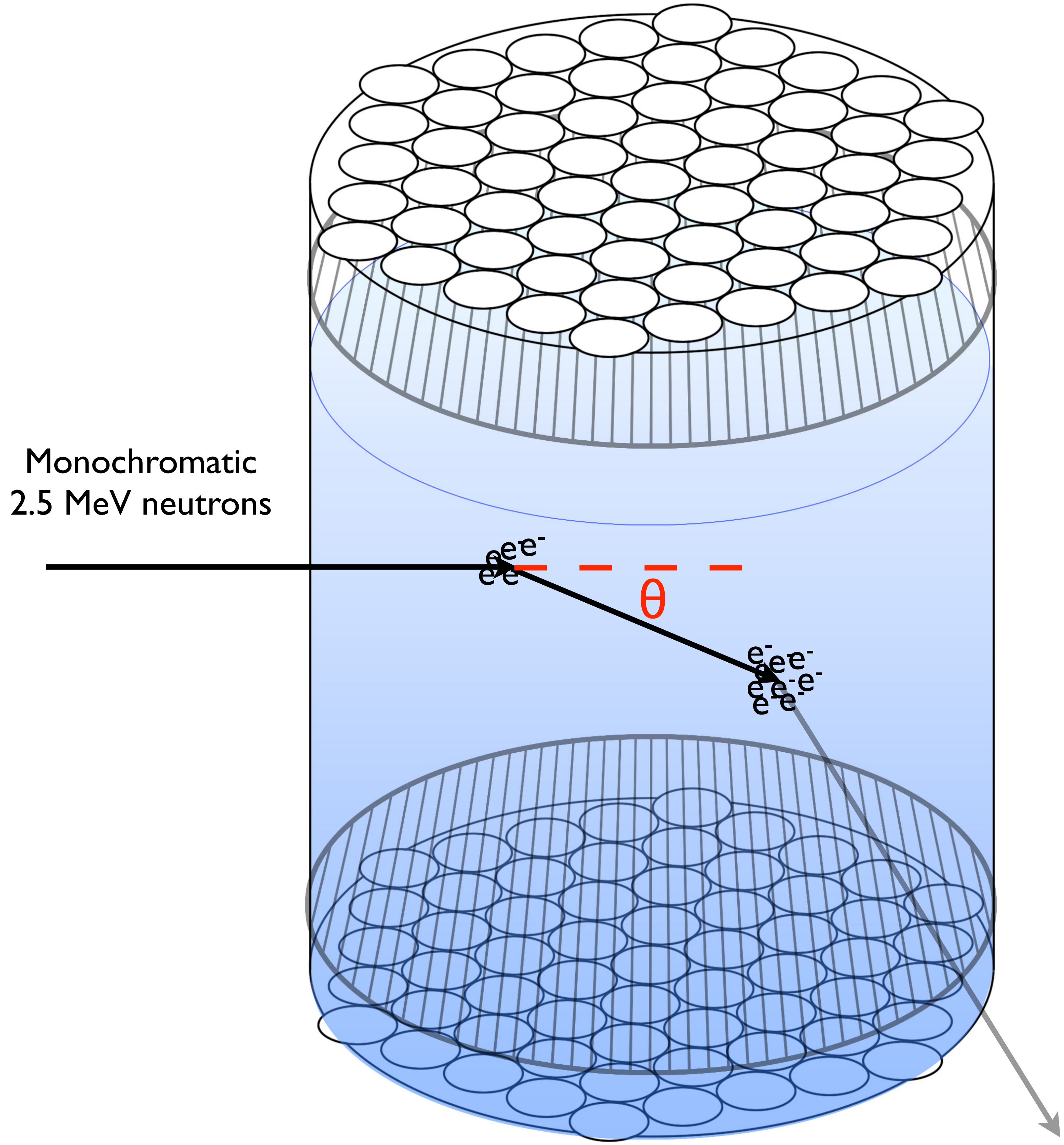


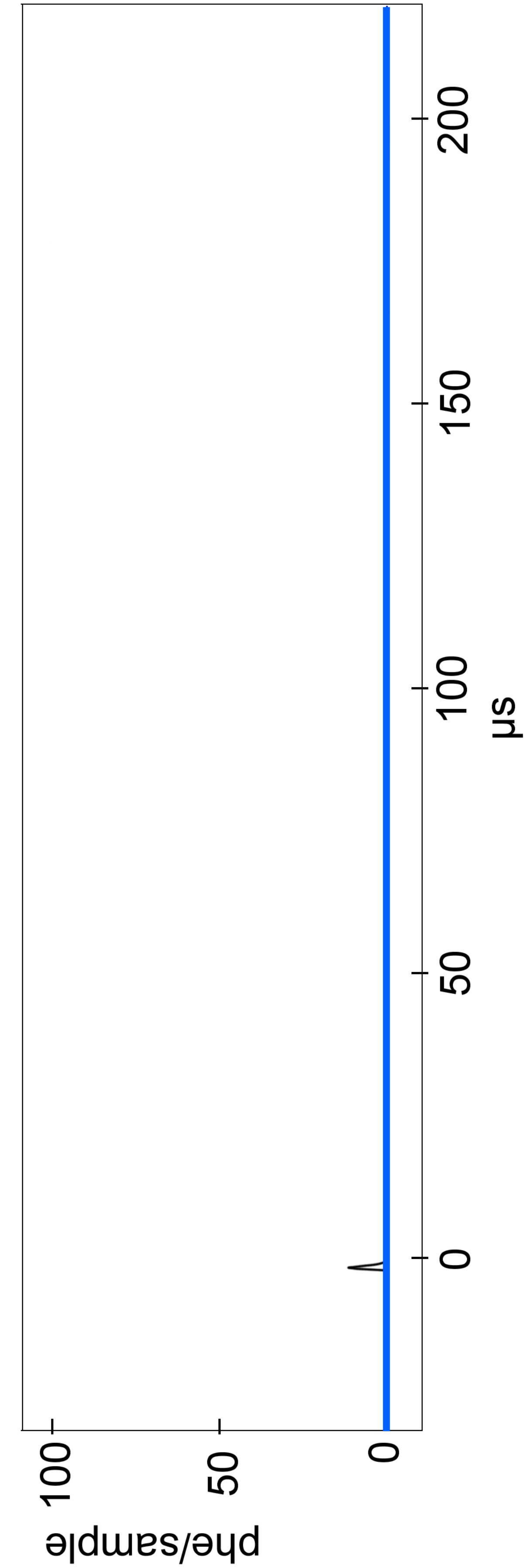




$$E_r = E_n \frac{4 m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1 - \cos\theta}{2}$$

Samuel Chan, Carlos Faham for the LUX Collaboration





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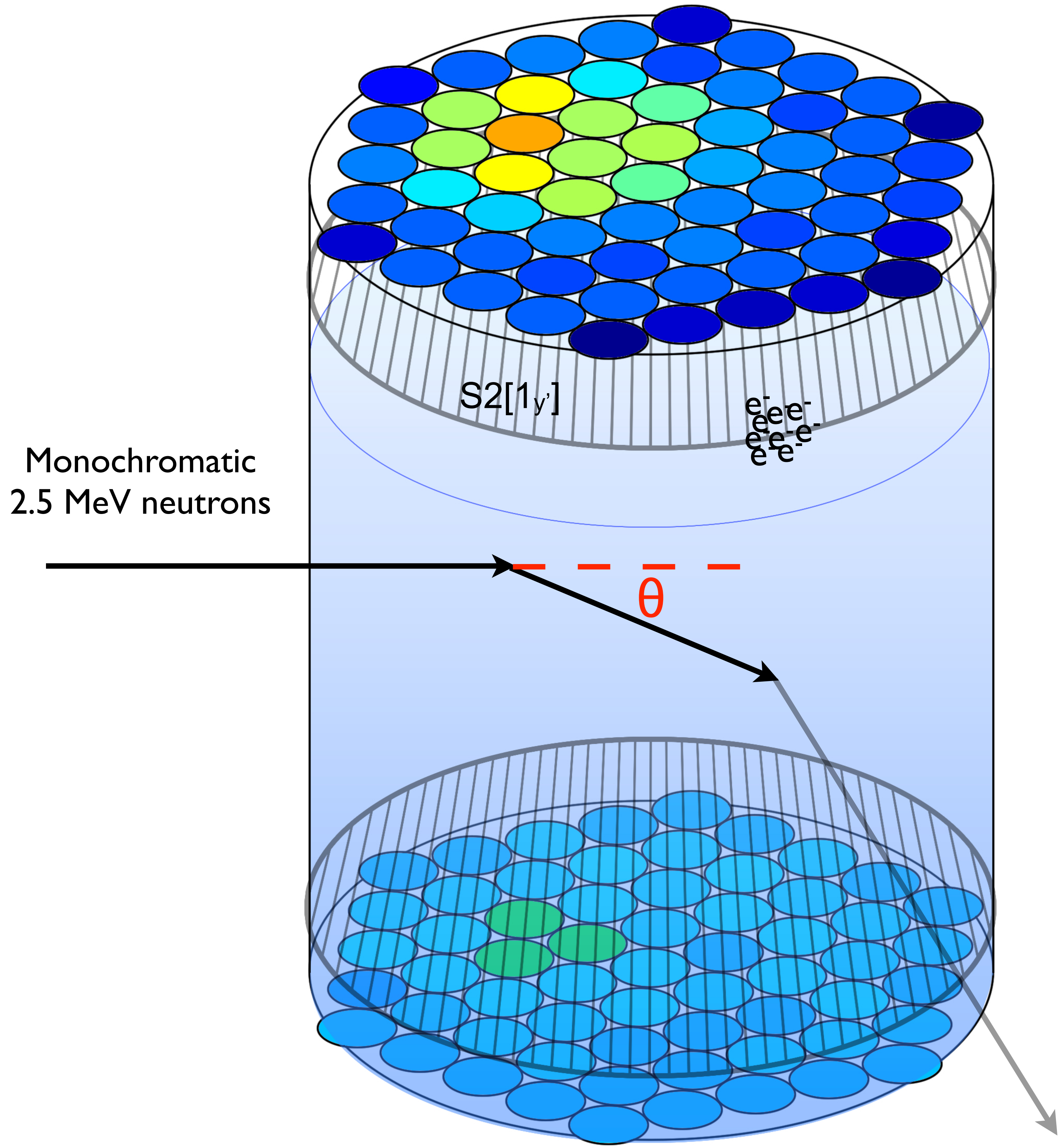

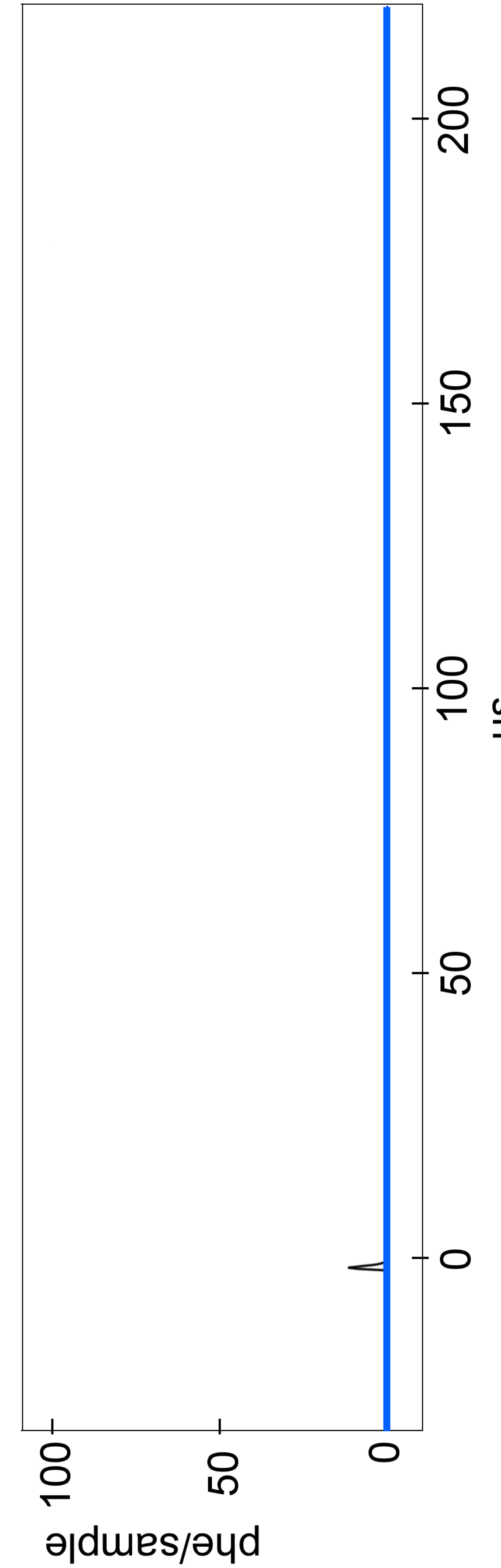

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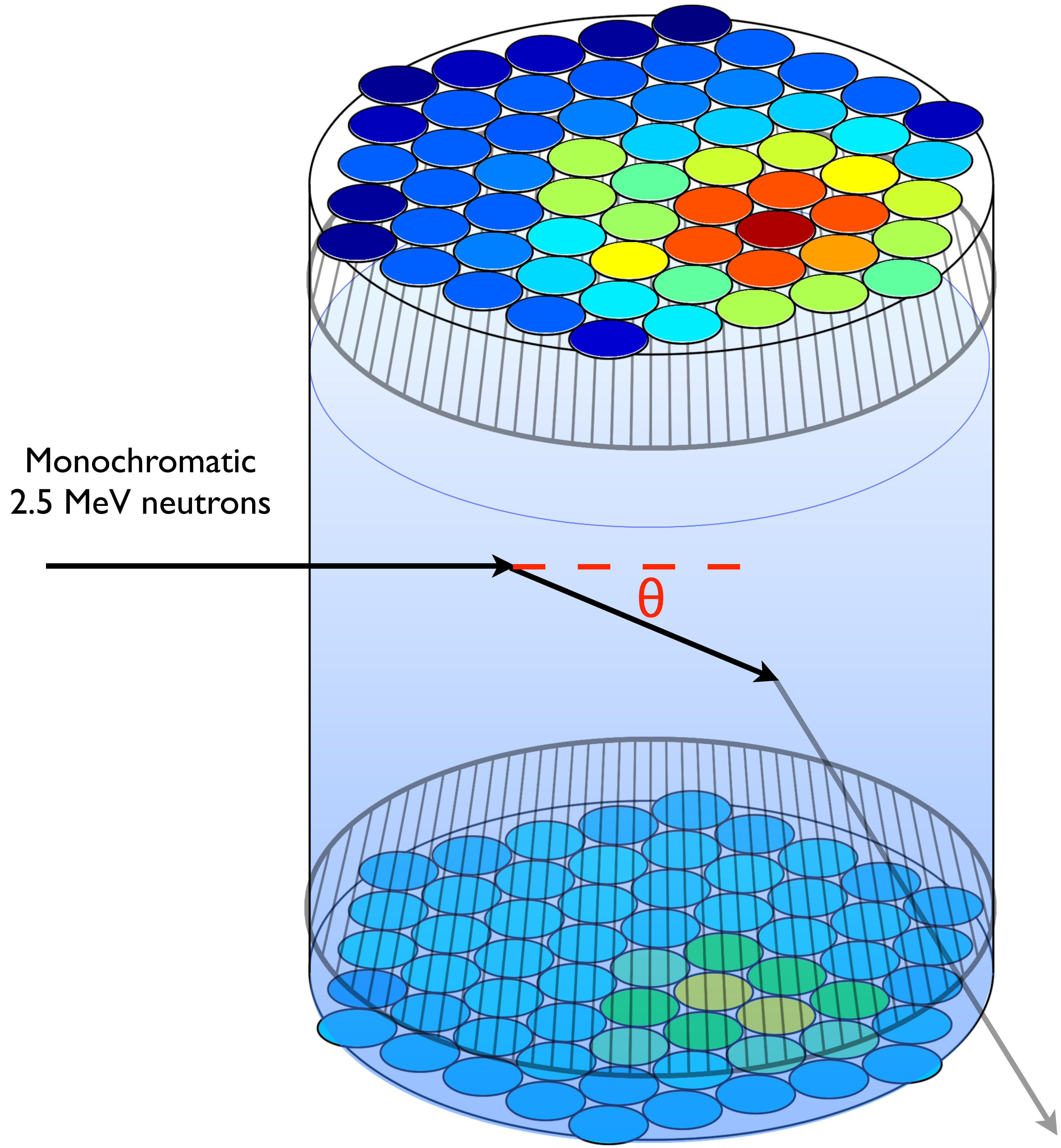

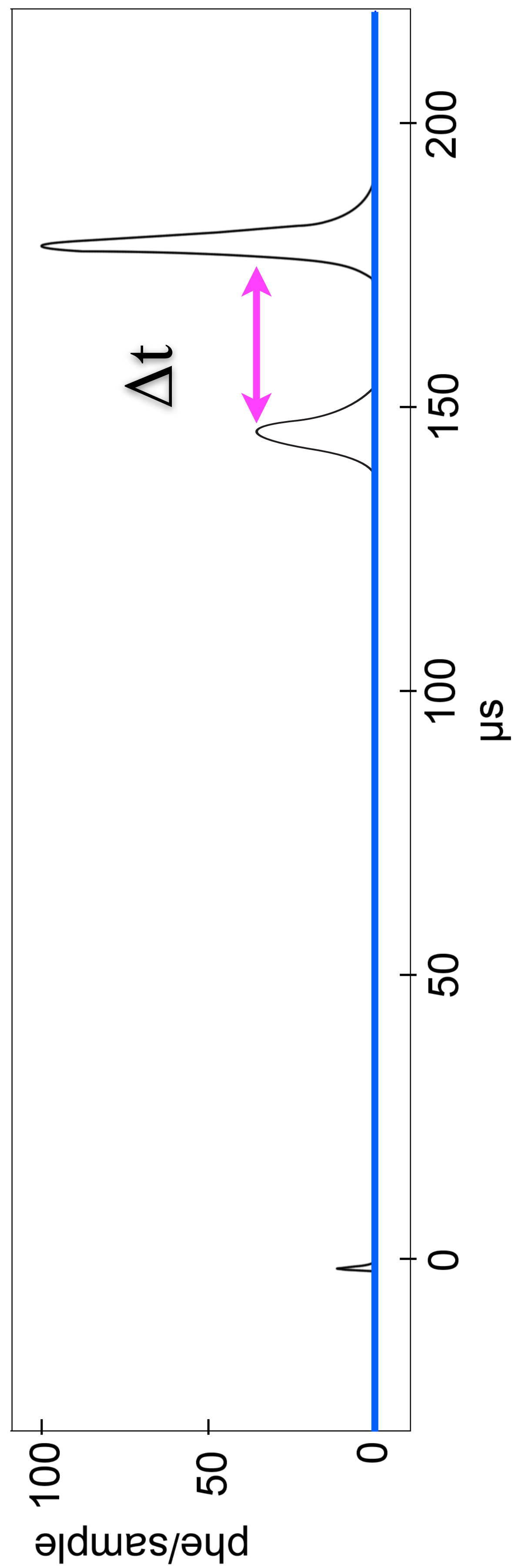

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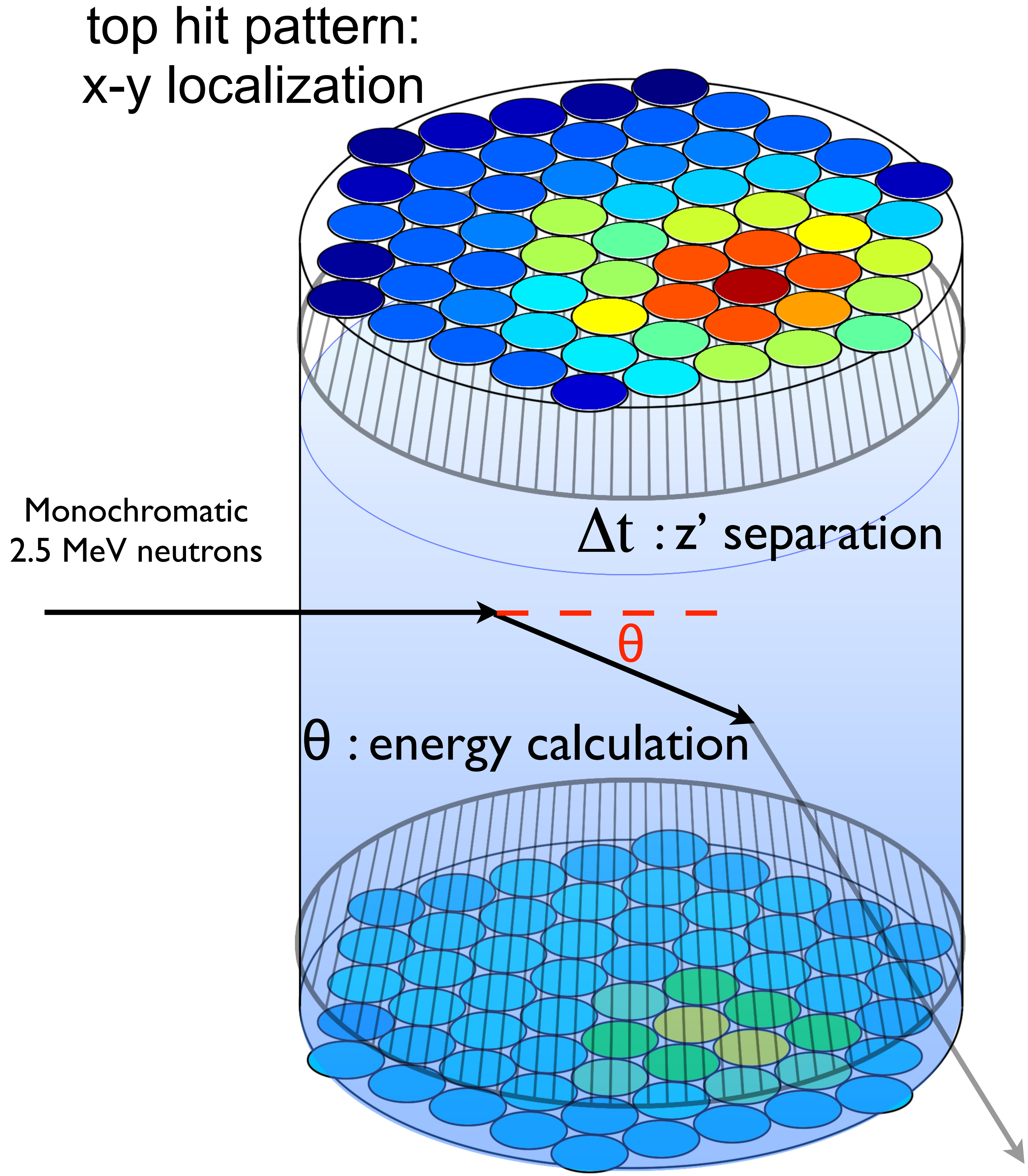

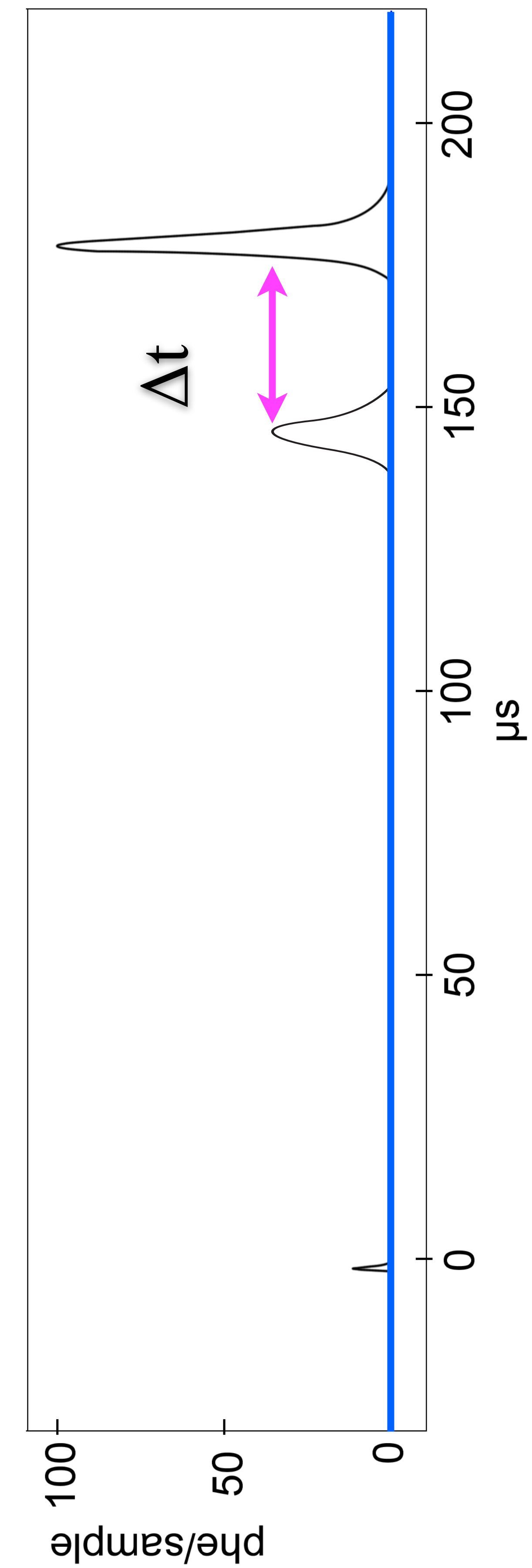

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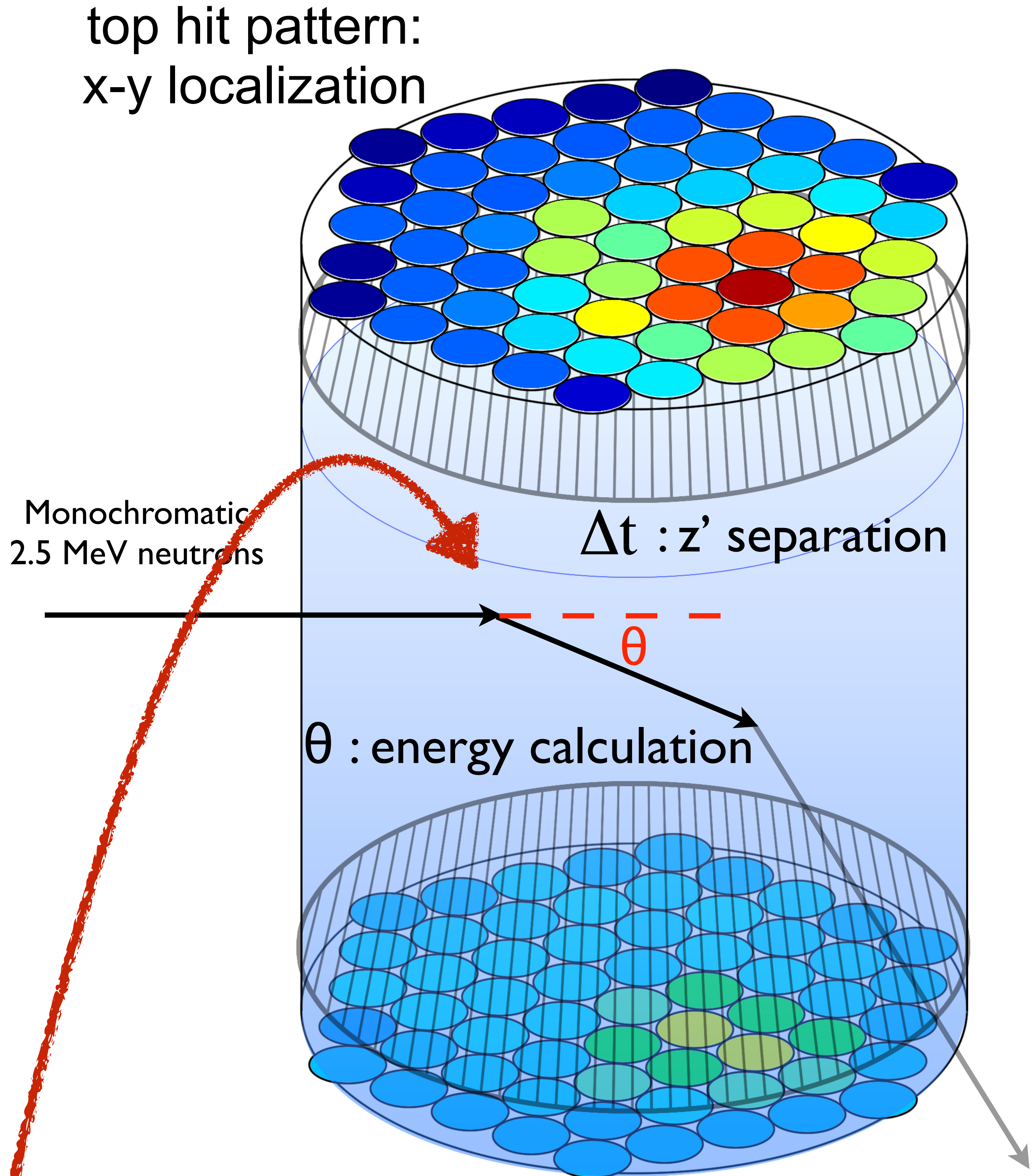

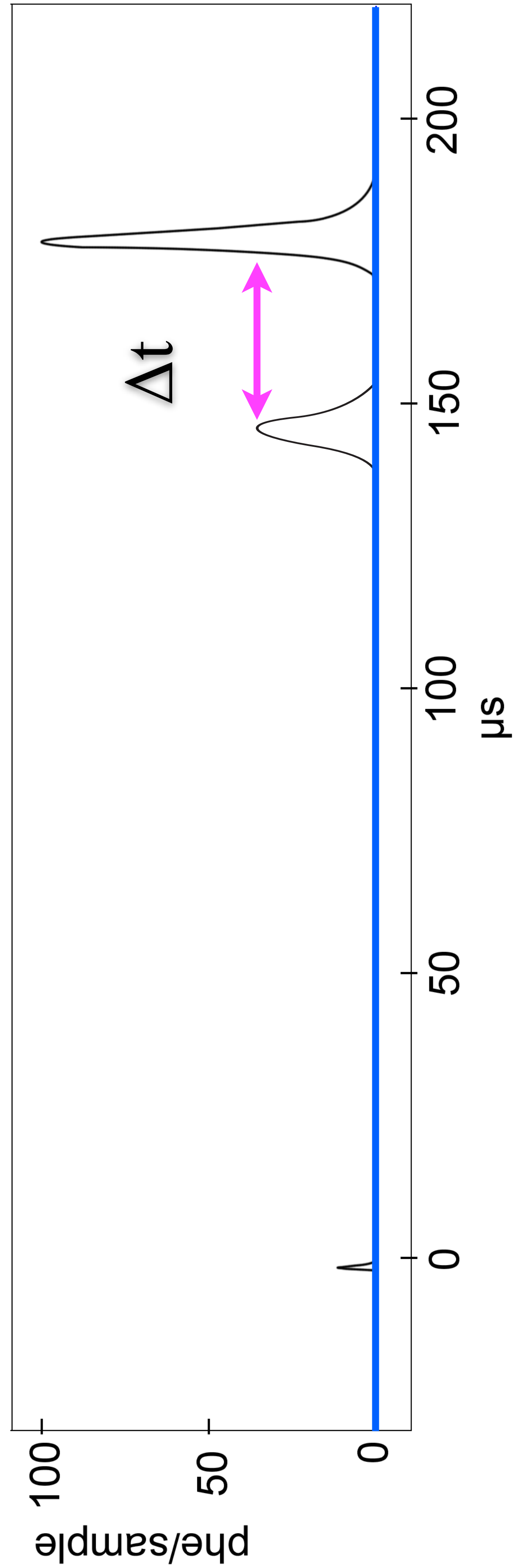

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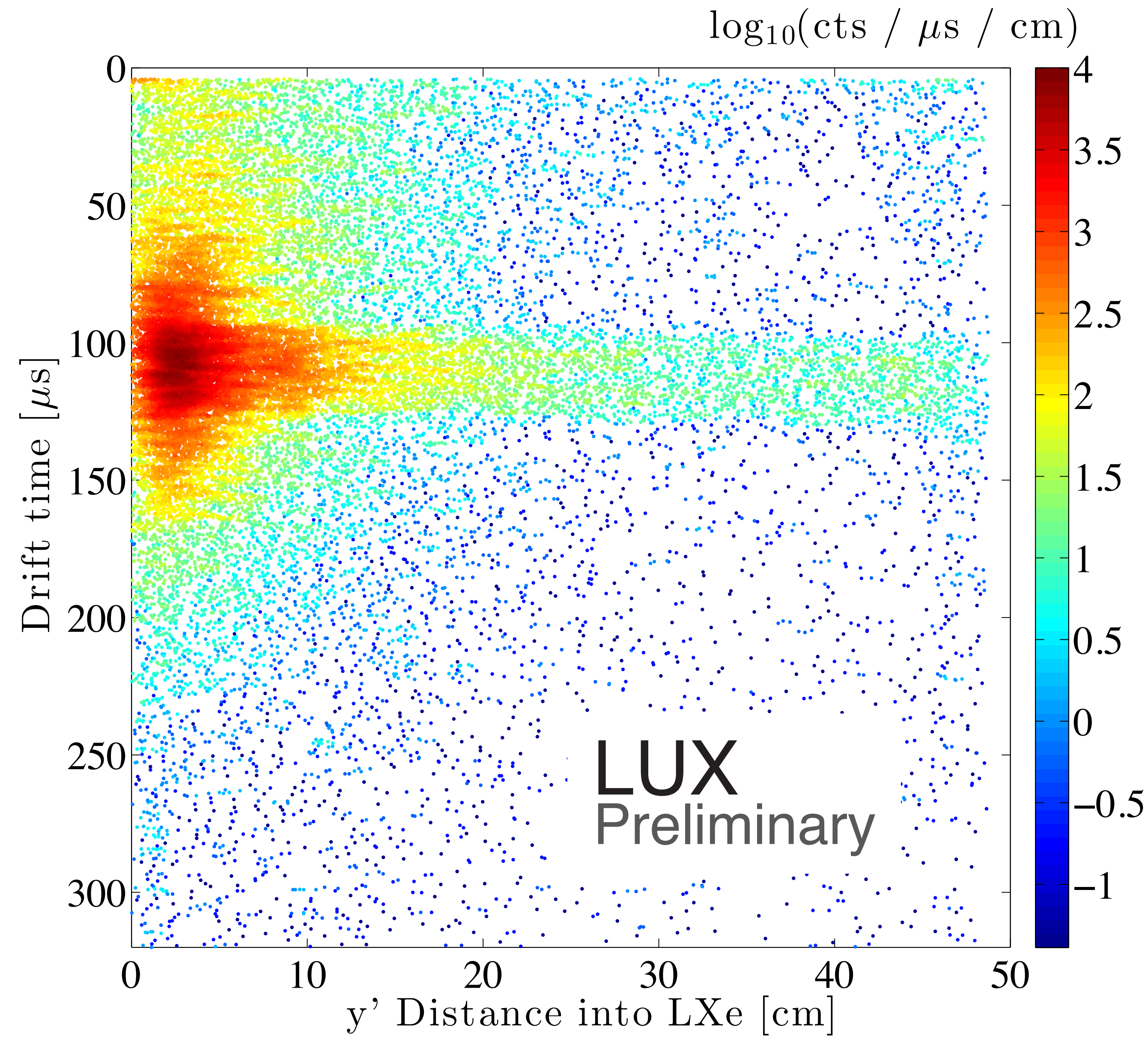
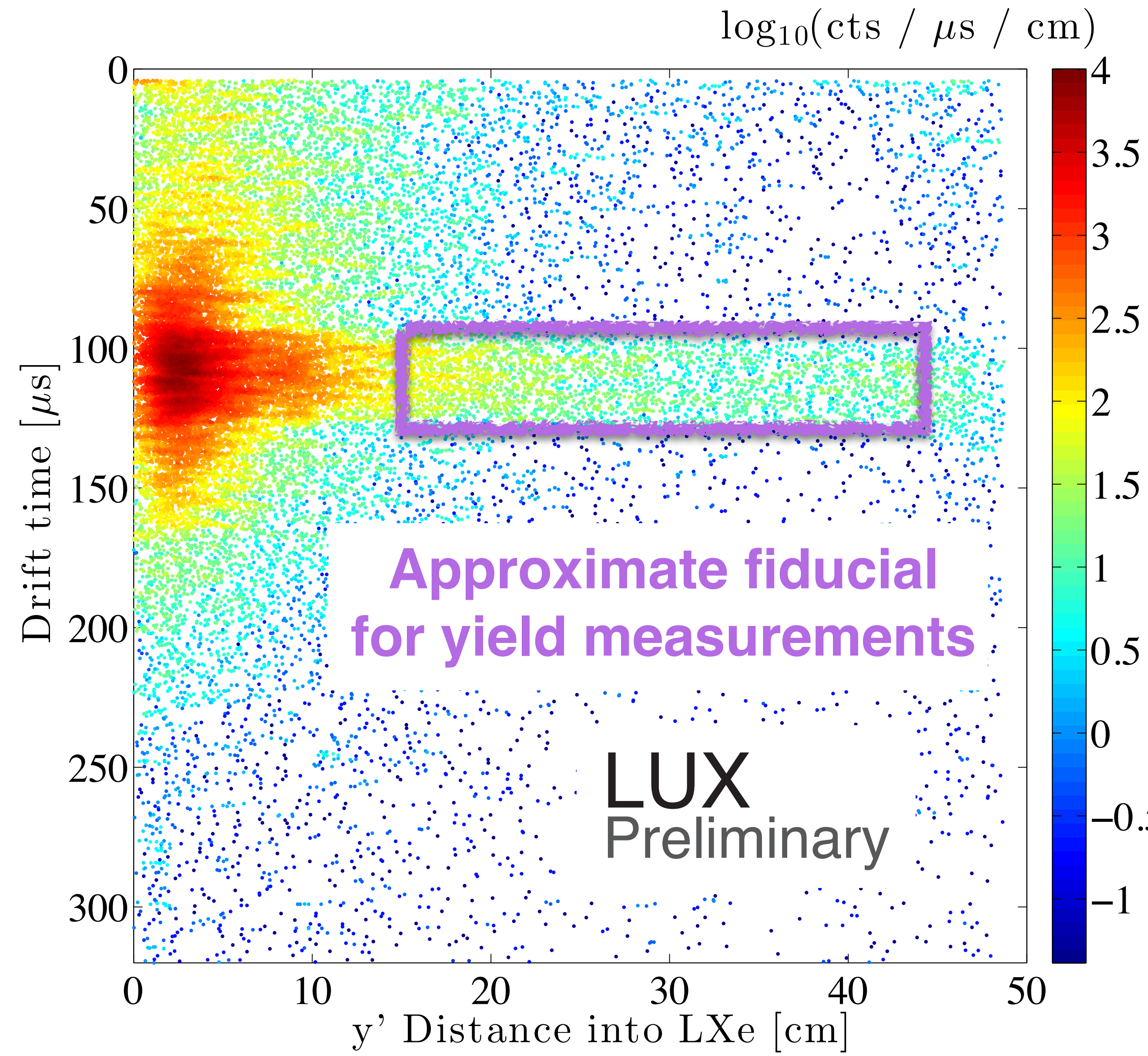
Neutron Conduit Installed in the LUX Water Tank

Adelphi DD108 Neutron Generator Installed Outside LUX Water Tank



- Neutron generator/beam pipe assembly aligned 16 cm below liquid level in LUX active region to maximize usable single / double scatters
- Beam leveled to ~1 degree
- 107.2 live hours of neutron tube data used for analysis

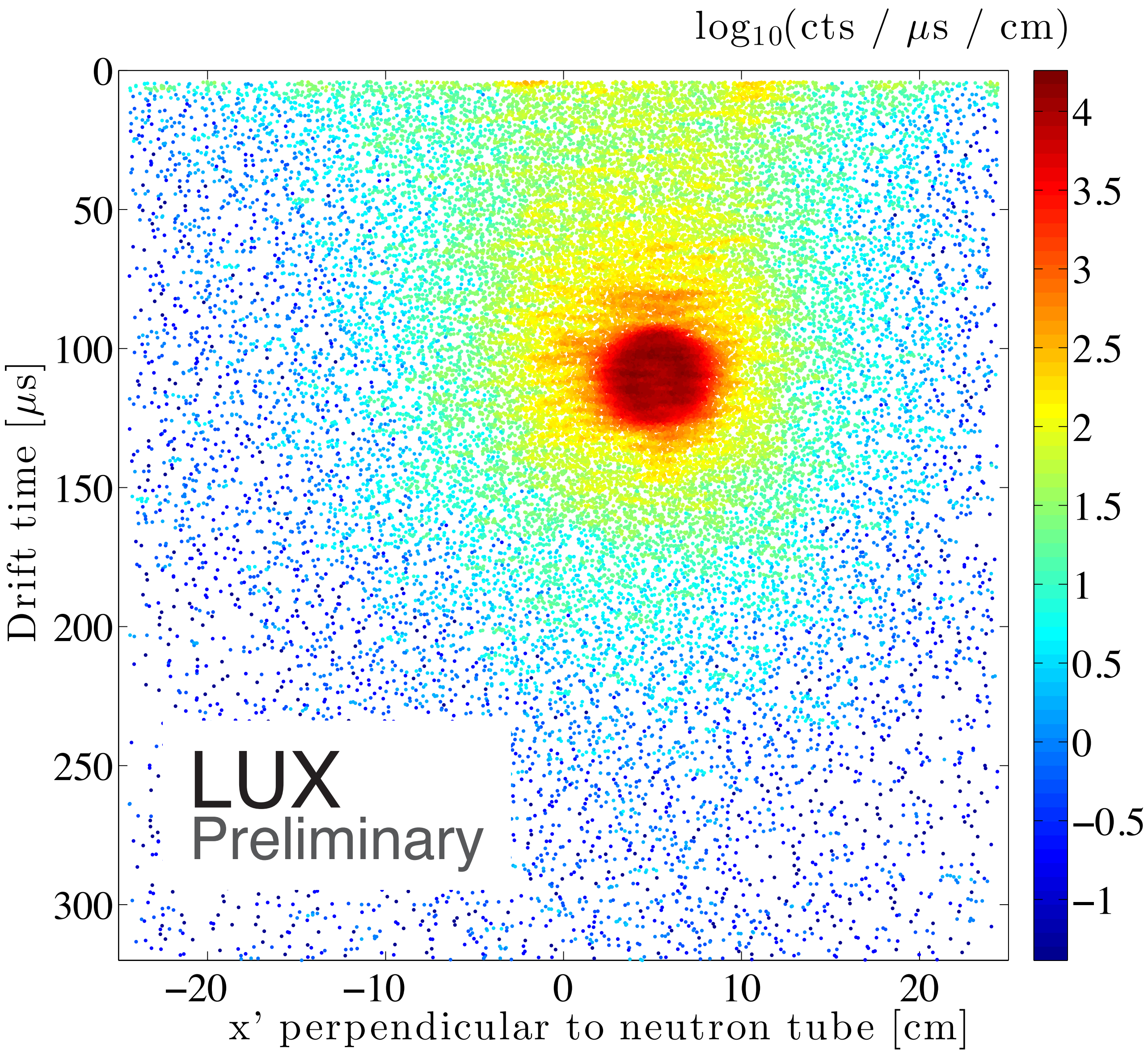
Adelphi DD108 Neutron Generator Installed Outside LUX Water Tank



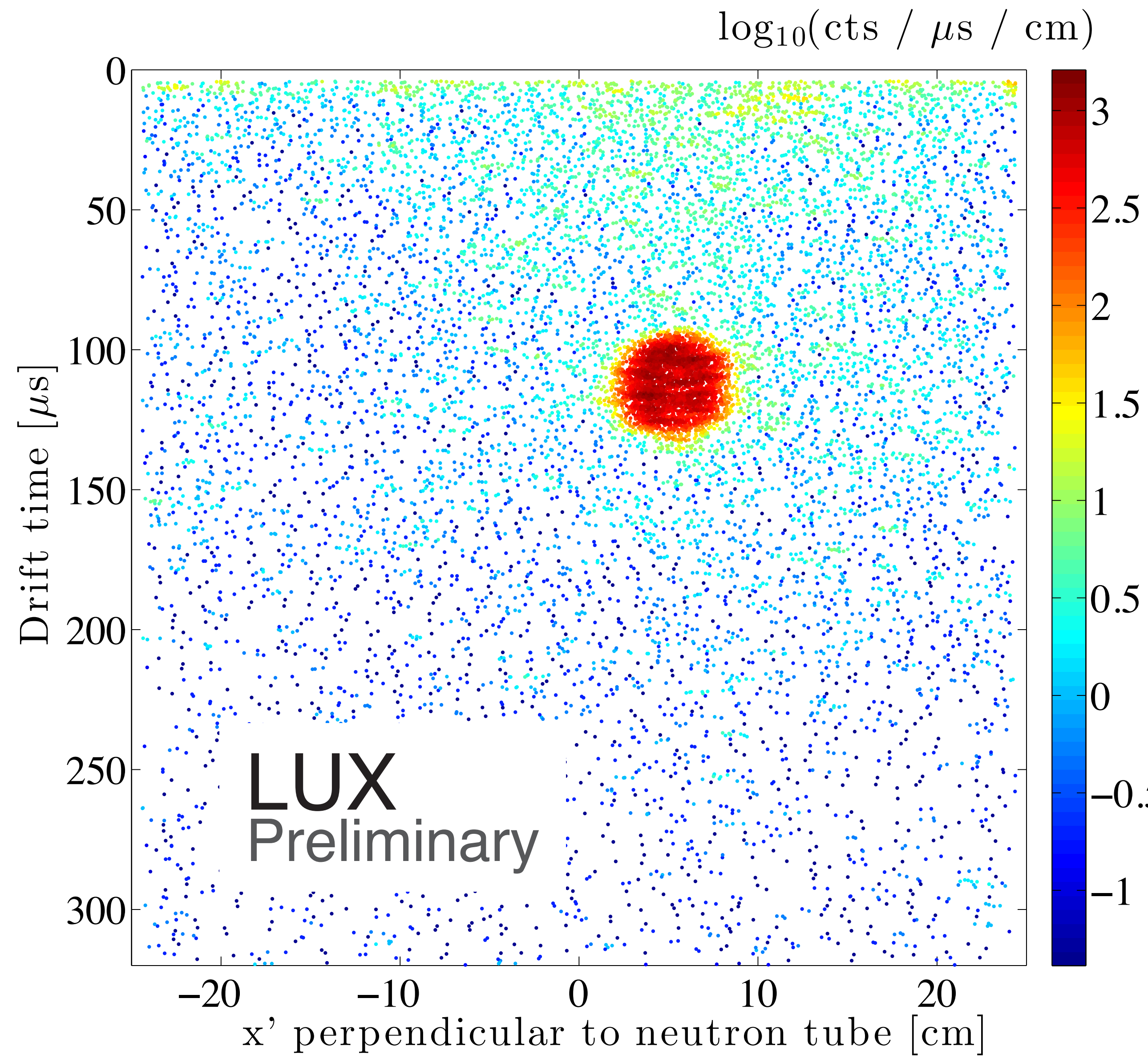
- This cut eliminates shine from passive materials and ensures 95% of neutrons in beam sample have energy within 4% of 2.45 MeV
- The mean energy of neutrons produced at 90° by the DD108 was measured to be 2.45 ± 0.05 MeV at Brown University

Beam Projection in Active Region (x')

- Accepting all events along y'. The shine from scatters in passive detector materials is visible.



- After application of y' > 15 cm beam purity cut. This cut eliminates shine from passive materials and ensures 95% of neutrons in beam sample have energy within 4% of 2.45 MeV.

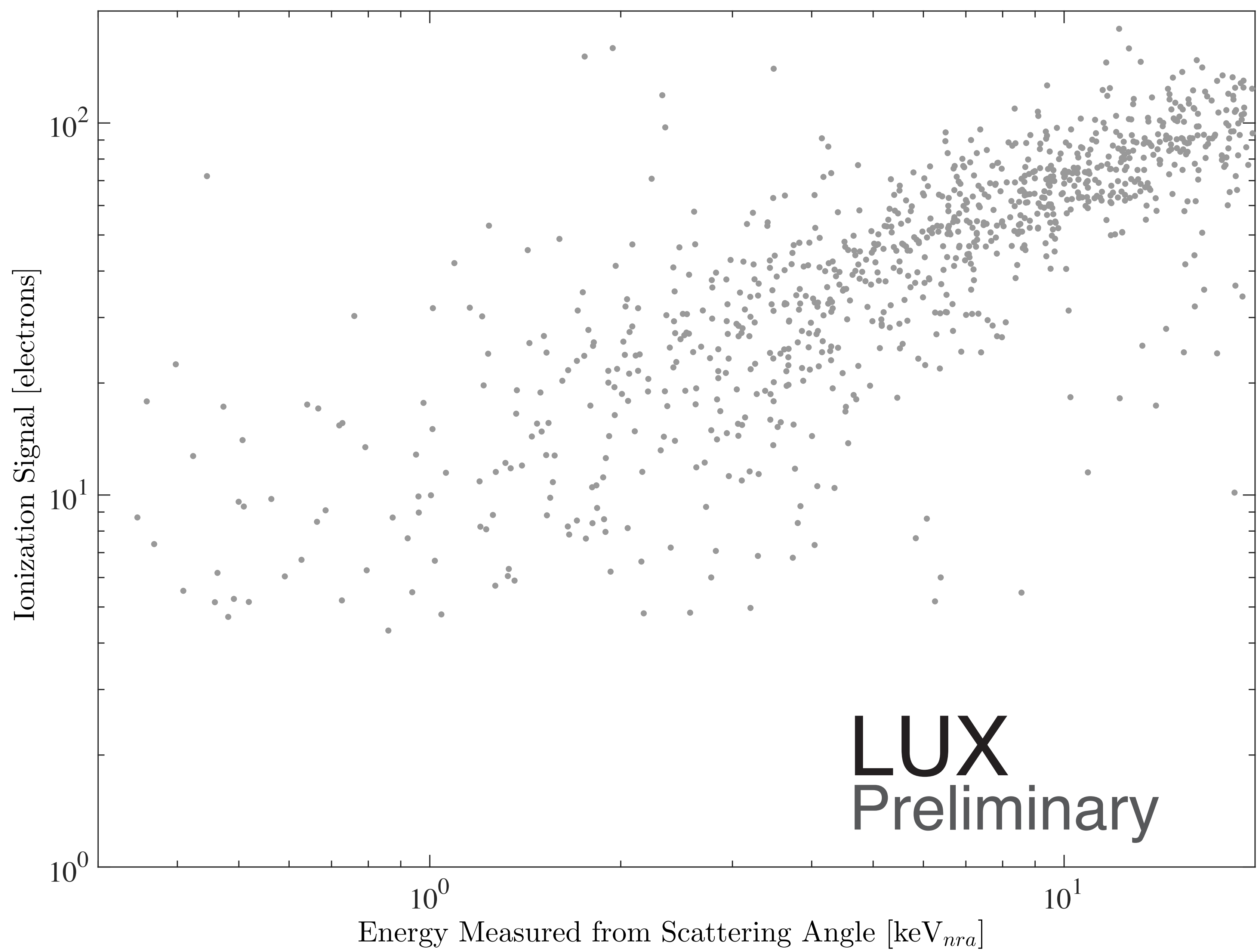


Observed Ionization Signal

- Event Selection Cuts
  - Event Identification
    - Select double scatters
    - Determine vertex ordering via scattering geometry only
  - Neutron Beam Energy Purity
    - Enforced via position of scatters along beam line / depth into active LXe
    - After geometry cut, 95% of neutrons have energy within 4% of 2.45 MeV
  - Data Quality
    - Ensure quiet detector conditions
    - Ensure properly reconstructed events
- Cuts are flat for S2[1_y] (first scatter along beam direction) in energy region of interest

Grey Points - Individual double scatter events

Double Scatter (S1, 2xS2s > 50 phe)



Ionization Signal Absolutely Measured below 1 keV_{nra} in LUX

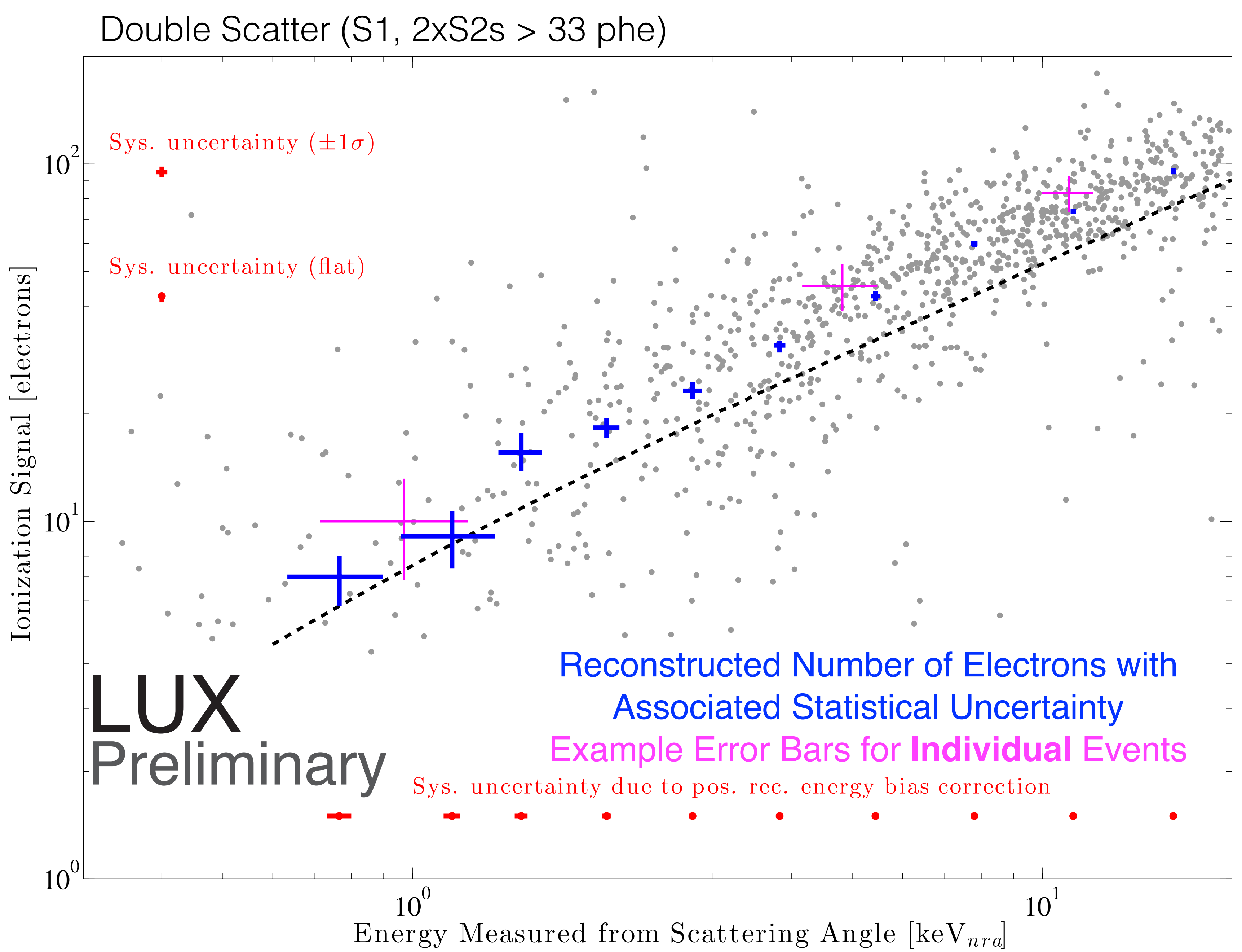
- Reconstruct number of electrons at interaction site by matching ionization signal model with observed event distribution using extended maximum-likelihood
- Red systematic error bar shows common scaling factor uncertainty. Dominated by uncertainty in electron extraction efficiency.
- Lowest event energy included for analysis is 0.3 keV_{nra}.

Grey Points - Individual double scatter events

Magenta Crosses - Error bars for individual event from best 10% from each bin

Blue Crosses - Reconstructed number of electrons at interaction site accounting for threshold effects in signal analysis

Black Dashed Line - Szydagis et al. (NEST v1.0) Predicted Ionization Signal at 180 V/cm



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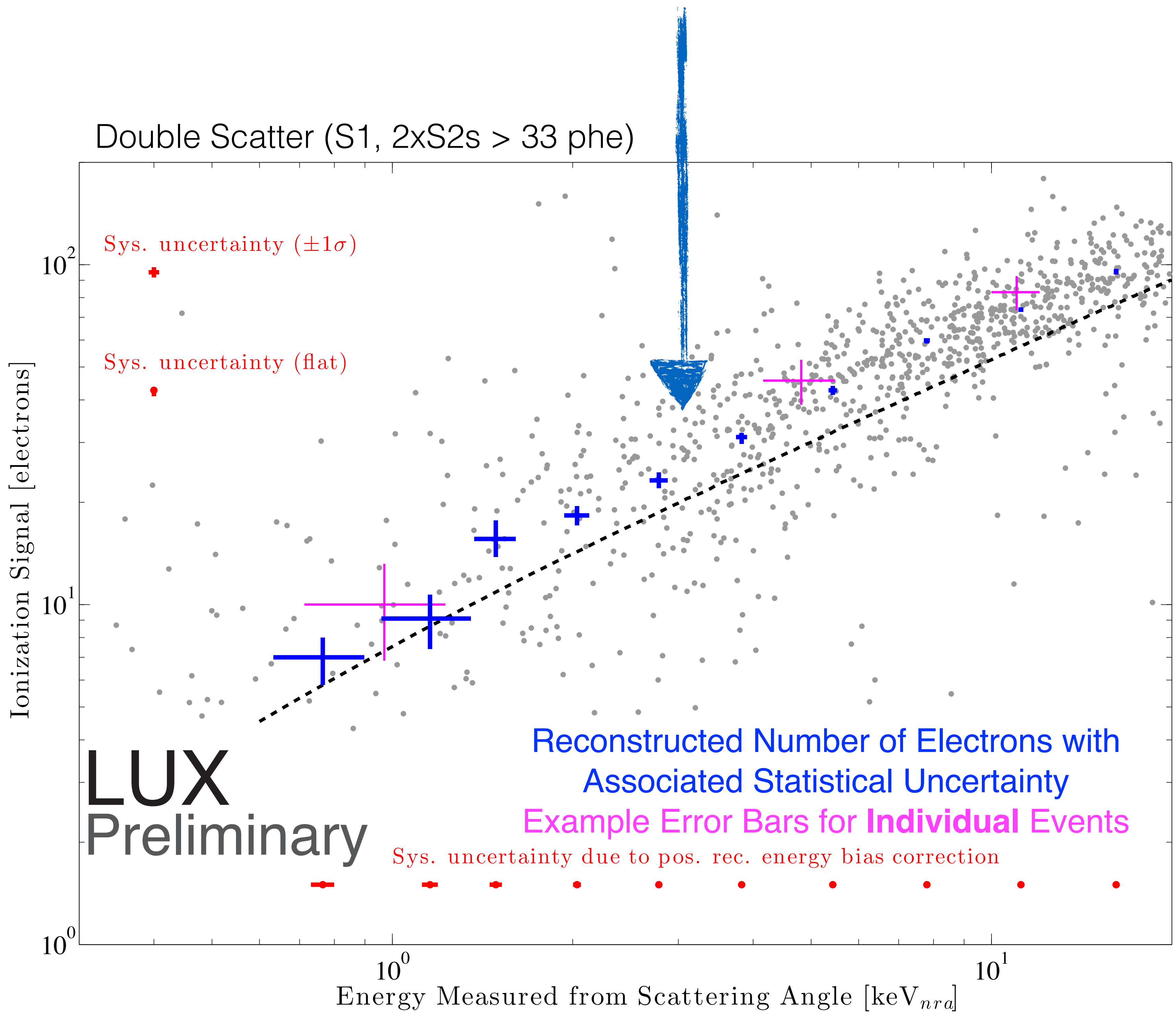
LUX 2014 PRL Conservative Threshold Cut-Off



Ionization Yield Absolutely Measured below 1 keV$_{nra}$ in LUX

- Red error bars show systematic uncertainties
  - (1σ) bar dominated by statistical uncertainty in electron extraction efficiency
  - (flat) bar accounts for detector parameter uncertainties and variations during the run
  - Pos. Rec. bias correction error bars compensate for modest Eddington bias due to position reconstruction uncertainties

Blue Crosses - LUX Measured Qy; 180 V/cm (absolute energy scale)

Green Crosses - Manzur 2010; 1 kV/cm (absolute energy scale)

Orange Crosses - Manzur 2010; 4 kV/cm (absolute energy scale)

Purple Band - Z3 Horn Combined FSR/SSR; 3.6 kV/cm (energy scale from best fit MC)

Teal Lines - Sorensen IDM 2010; 0.73 kV/cm (energy scale from best fit MC)

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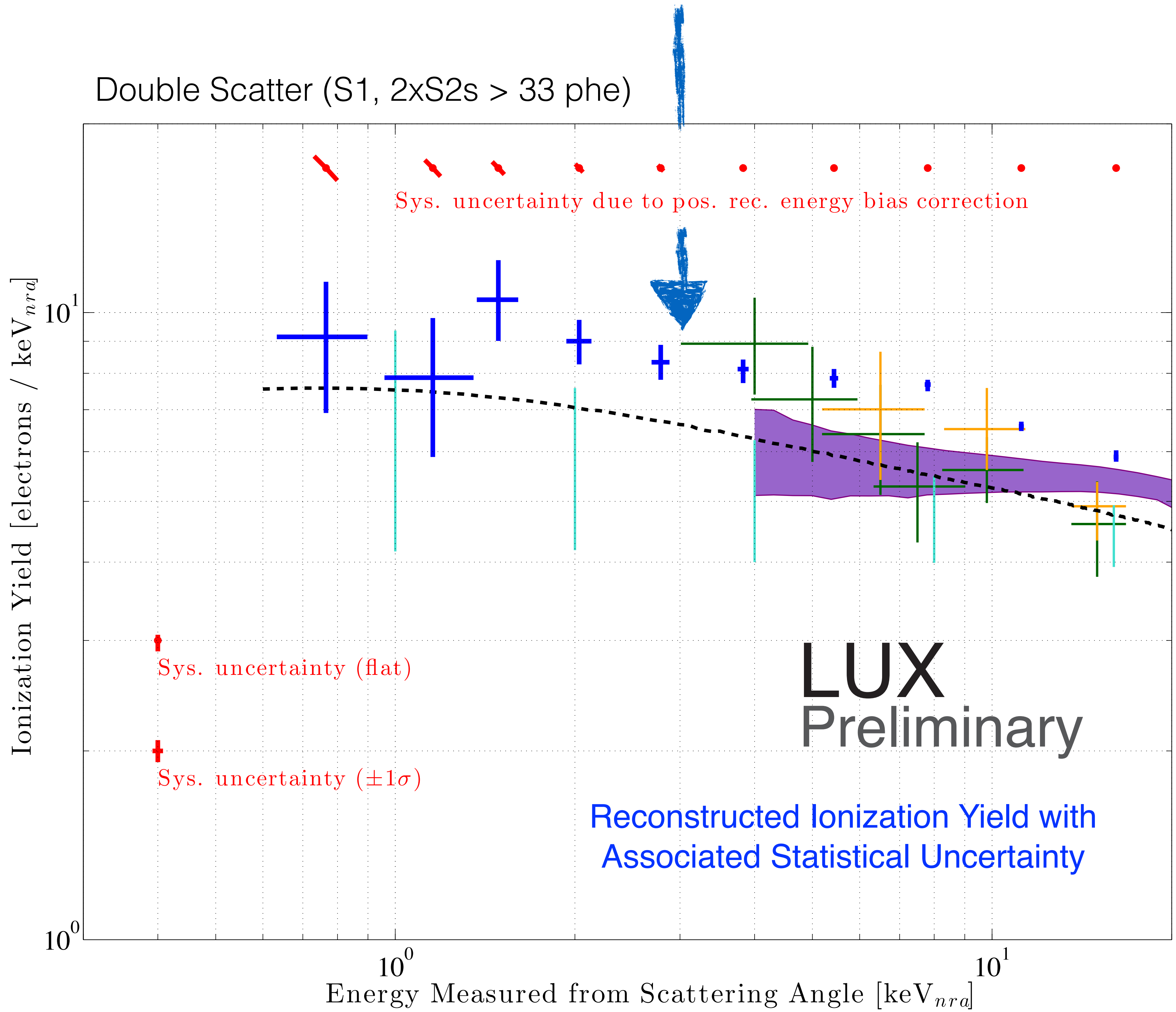
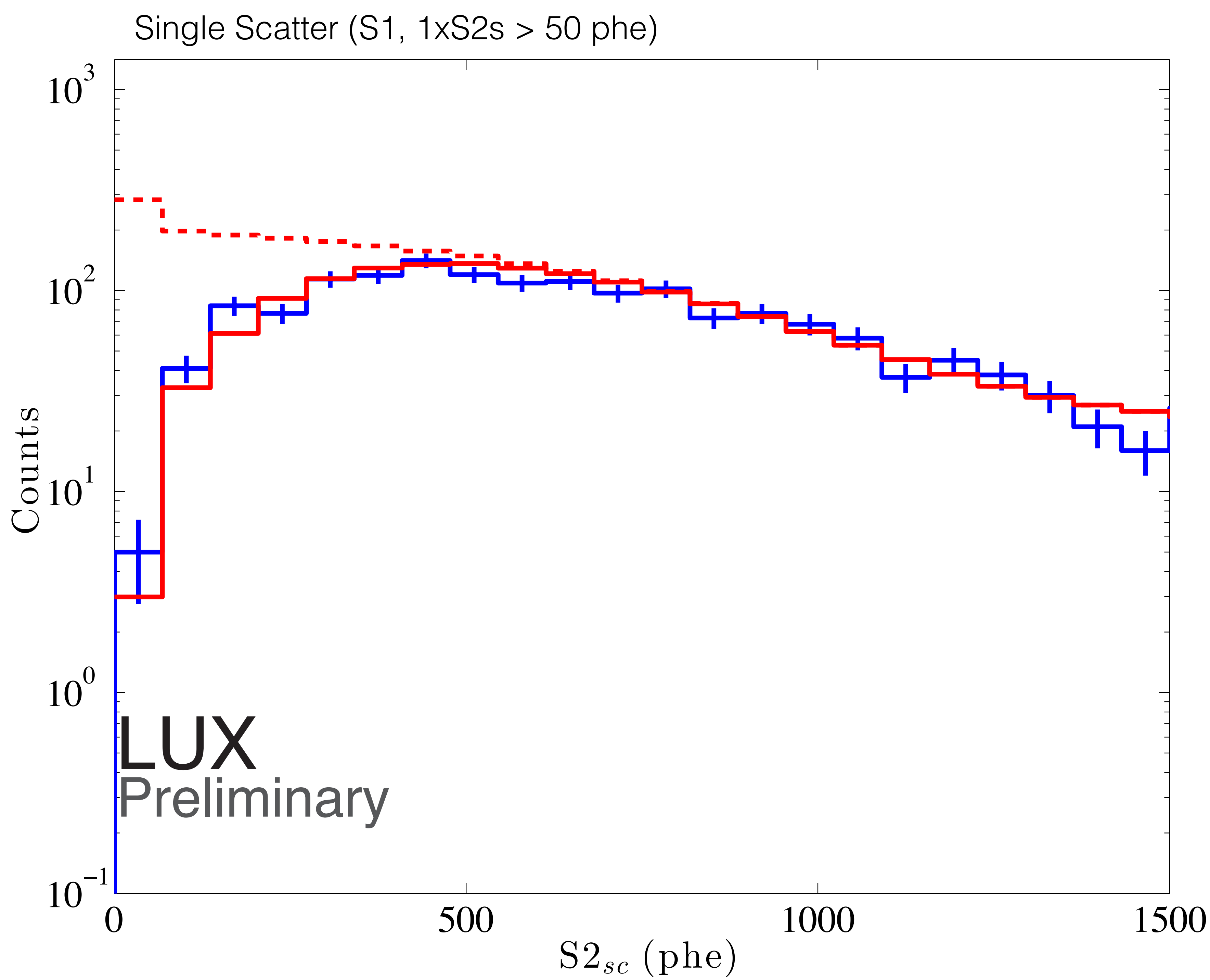


Measuring the Scintillation Yield

- Use **single scatters** with suitable selection criteria
- MC using measured LUX D-D charge yield to simulate expected single scatter energy spectrum with LUX threshold, purity, electron extraction, energy resolution effects applied
- Simulation uses JENDL-4.0 angular scattering cross-sections with isotope selection determined based upon natural abundance and total elastic cross-sections
- L_y measurement range is 0-900 phe $S2_{sc}$ using bins of 100 phe
    - Simulation event distribution is normalized outside of L_y measurement range using 900 < $S2_{sc}$ < 1500 phe



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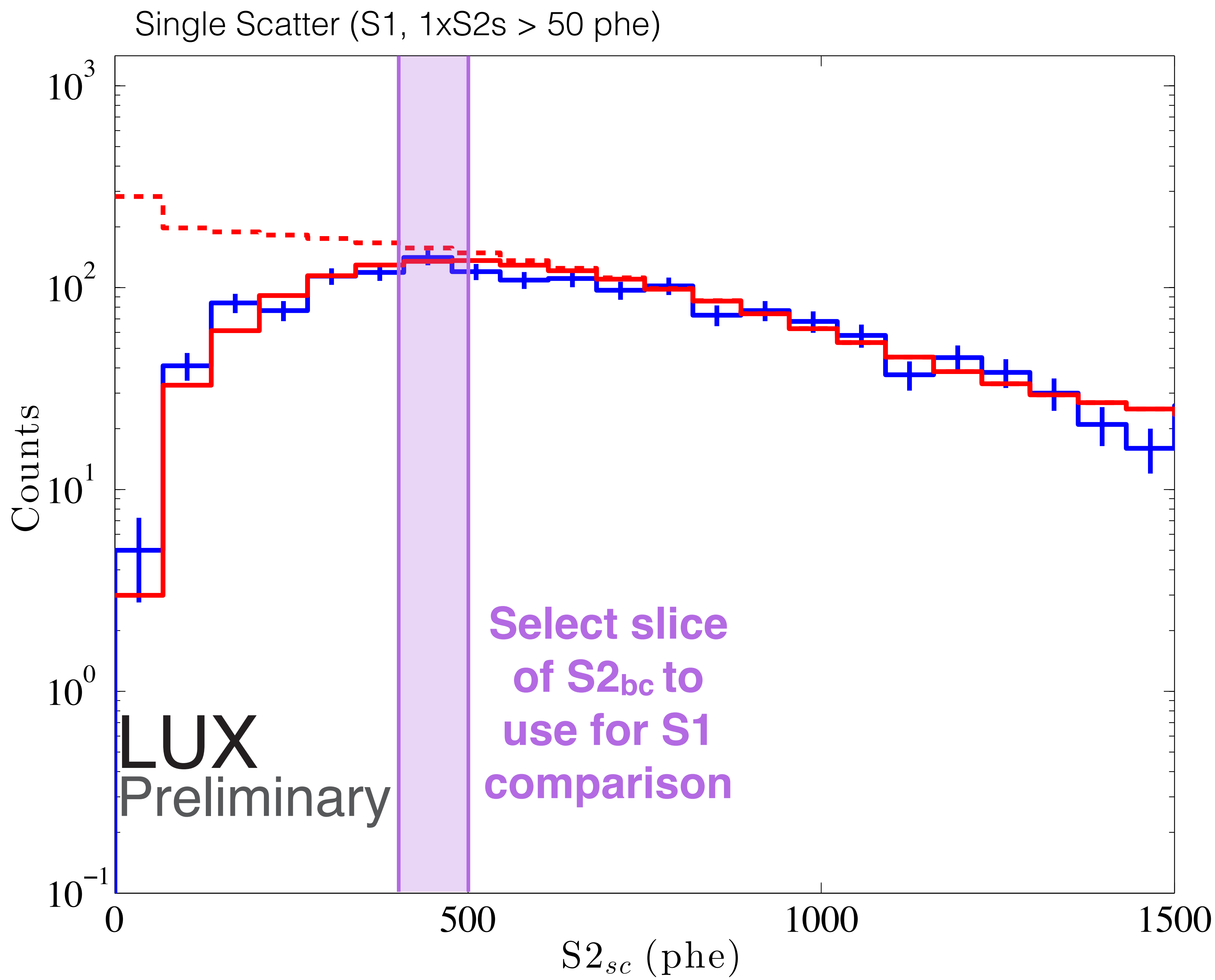

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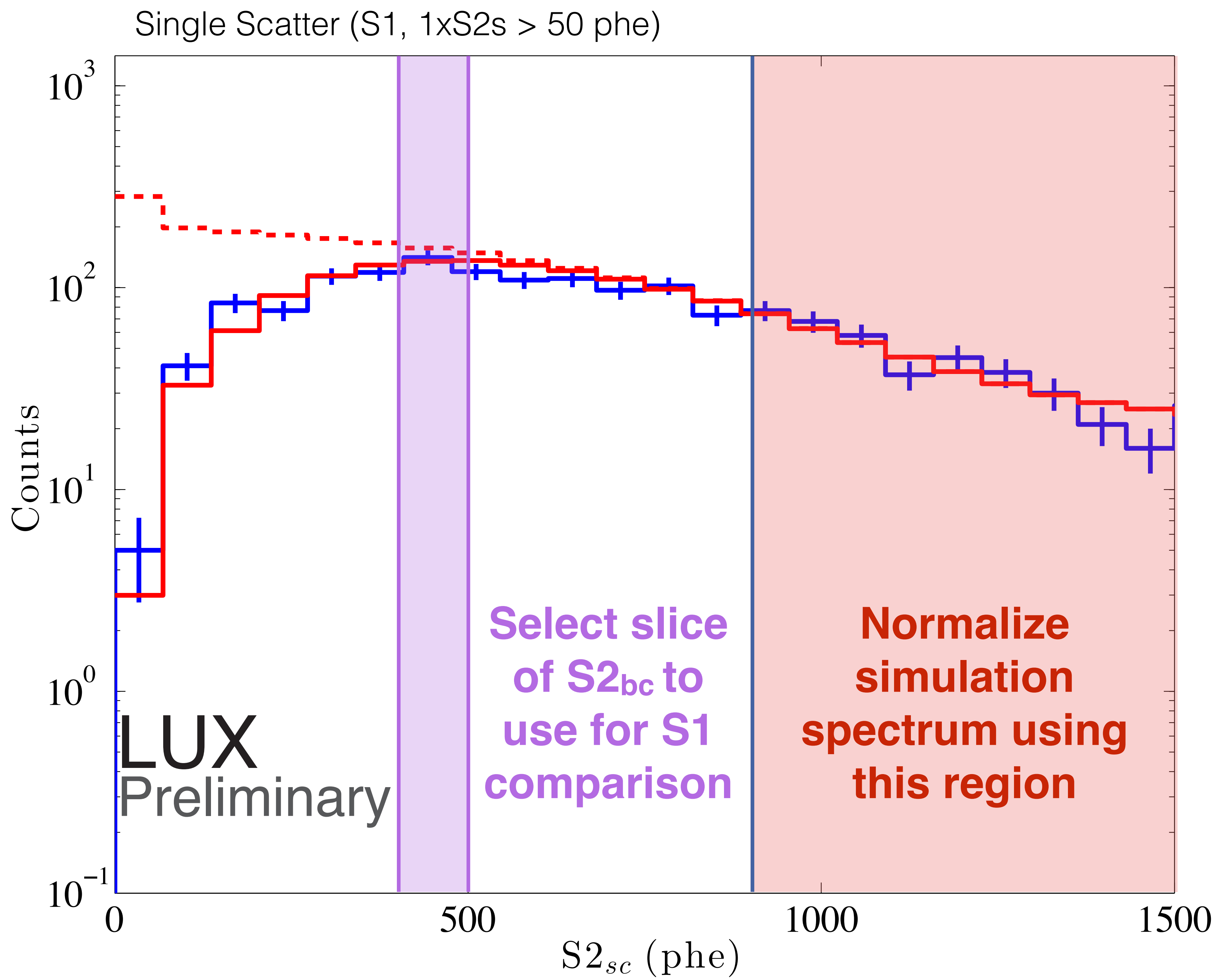
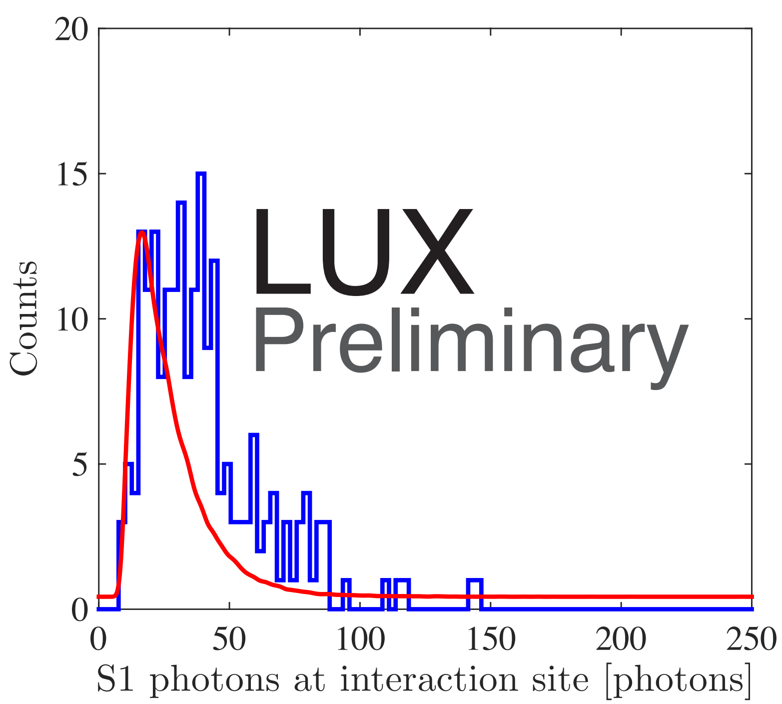


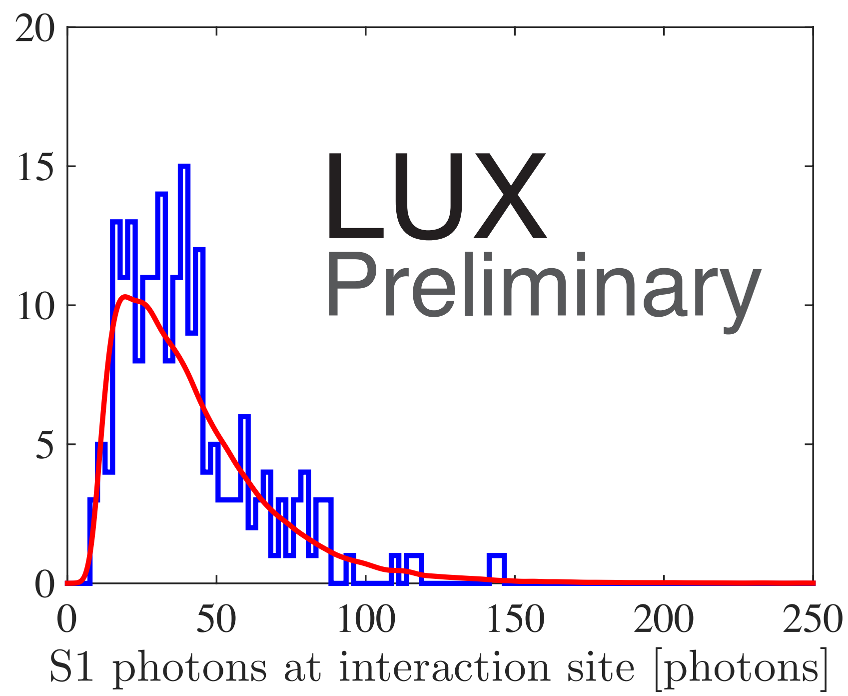
$S1_c$ Spectrum from 400-500 $S2_{sc}$

- Parameter α used to scale input energy to simulated S1 spectrum for fixed slice in $S2_{sc}$ (absolutely calibrated by LUX D-D Q_y)
- For each fixed $S2_{sc}$ bin, determine percent deviation from model L_y determined by optimizing α via unbinned maximum likelihood comparison between data and simulation S1 spectra
  - Both absolute number of events and spectrum shape incorporated into optimization

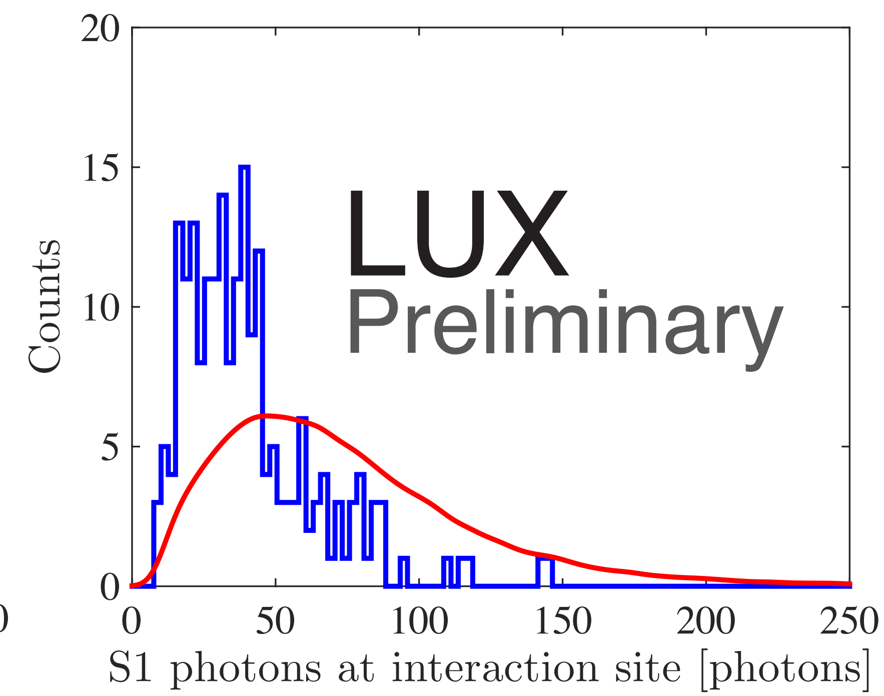
α = 0.5



α = 0.92



α = 1.5



L_{eff} Measured in LUX Using Absolute Energy Scale

- LUX L_y values reported at 180 V/cm
- X error bars representative of error on mean of population in bin
- Energy scale defined using LUX measured Qy
- Method can be extended below existing 1.2 keV_{nrS2} point
- ^{32m}Kr light yield at 32.1 keV measured to be 45.7 ± 3.13 photons/keV using same D-D beam fiducial

Blue Crosses - LUX Measured L_y; reported at 180 V/cm (absolute energy scale)

Green Crosses - Manzur 2010; 0 V/cm (absolute energy scale)

Purple Band - Horn Combined Zeplin III FSR/SSR; 3.6 kV/cm, rescaled to 0 V/cm (energy scale from best fit MC)

Orange Crosses - Plante 2011; 0 V/cm (absolute energy scale)

Grey Crosses - Aprile 2009 (absolute energy scale)

Black Dashed Line - Szydagis et al. (NEST) Predicted Scintillation Yield at 181 V/cm

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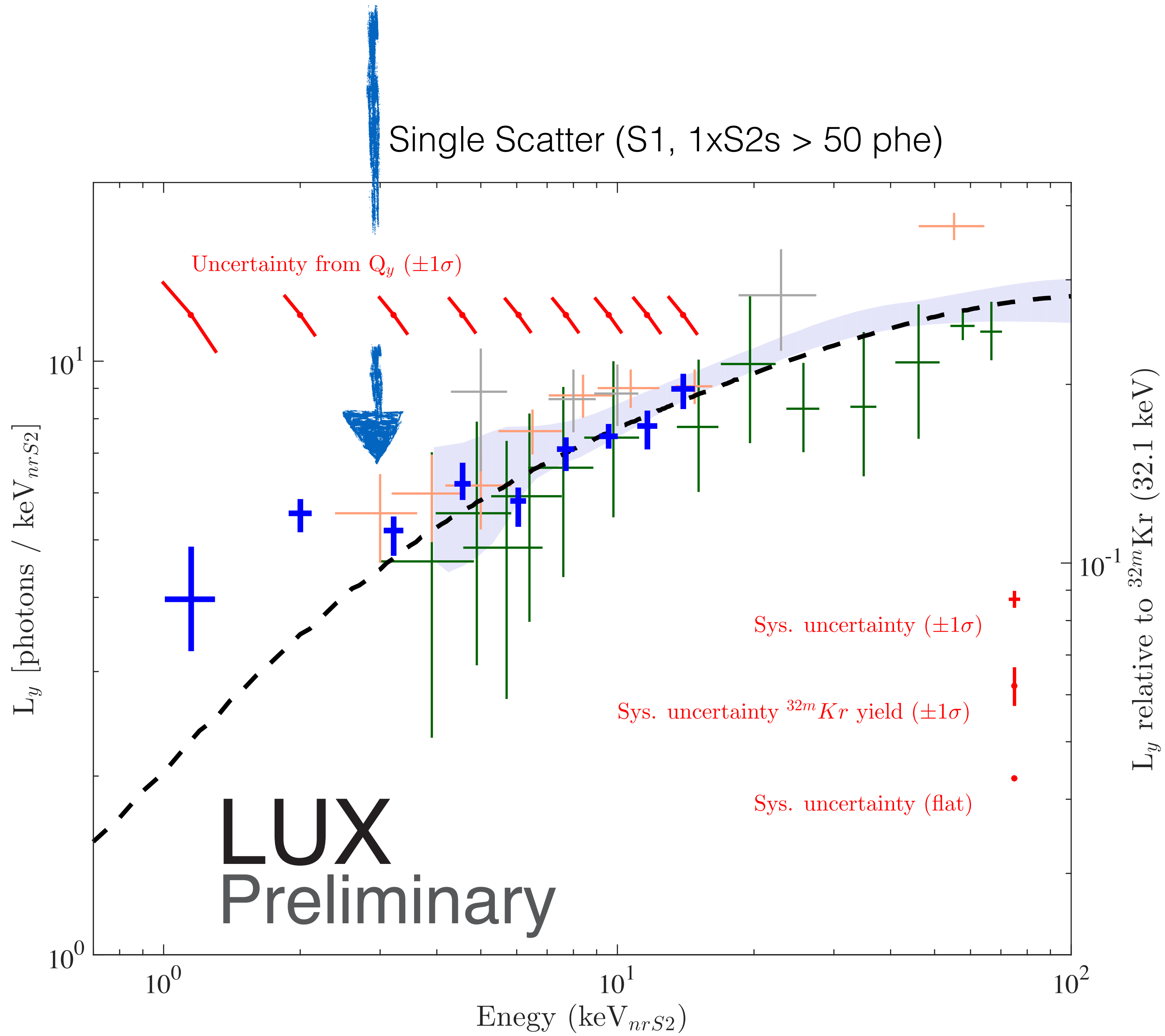
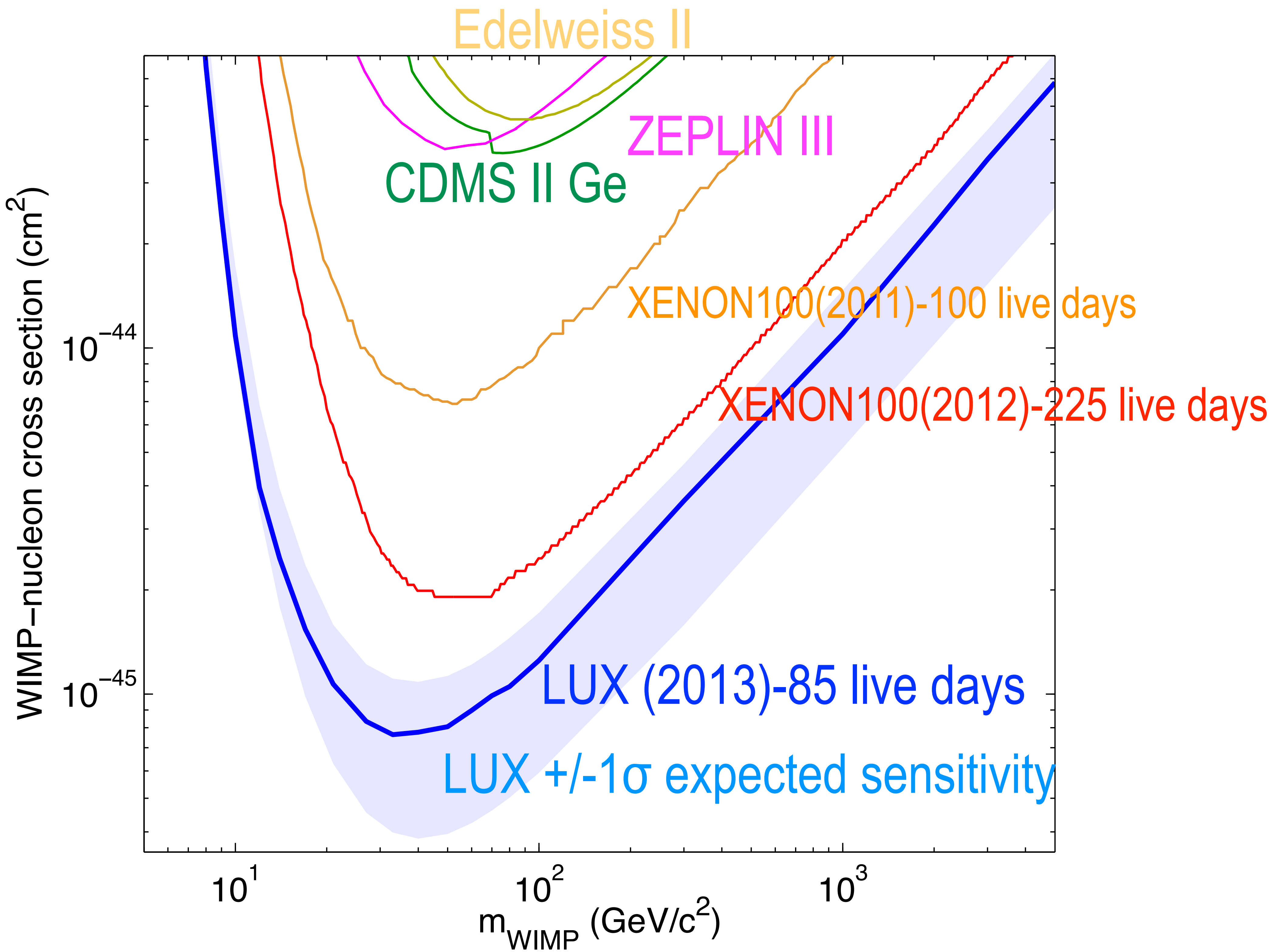


Conclusions

- Novel LUX absolute nuclear recoil calibration performed using mono-energetic D-D neutrons in-situ
    - Clear confirmation of the response used in the first LUX WIMP search analysis with an order of magnitude improvement in calibration uncertainties
    - The existing WIMP analysis only assumed a detector response at and above 3 keVnr
    - D-D neutron calibration technique allows us to calibrate detector response in region well below this, and so further improve LUX sensitivity to low mass WIMPs
- Coming soon
    - LUX paper on D-D results
    - NEST fit to D-D light and charge yields

Extra slides

Spin-Independent Sensitivity



Projected LUX 300 day WIMP Search Run

- LUX 300 day run is underway
  - Extending sensitivity by another factor 5
  - Even though LUX sees no WIMP-like events in the current run, it is still quite possible to discover a signal when extending the reach
  - LUX does not exclude LUX
- WIMPs remain our favored quarry
- LZ 20x increase in target mass
  - If approved plans to be deployed in Davis Lab in 2016+