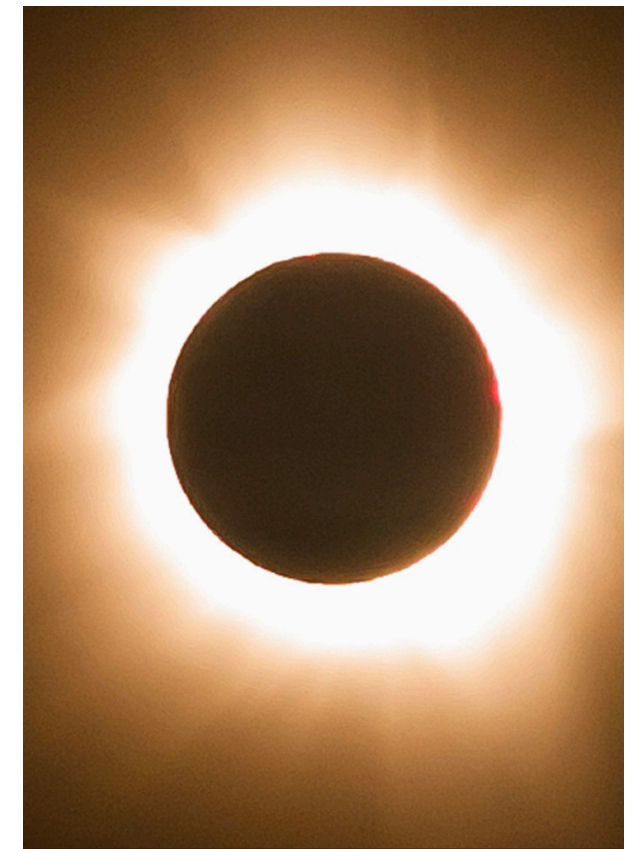
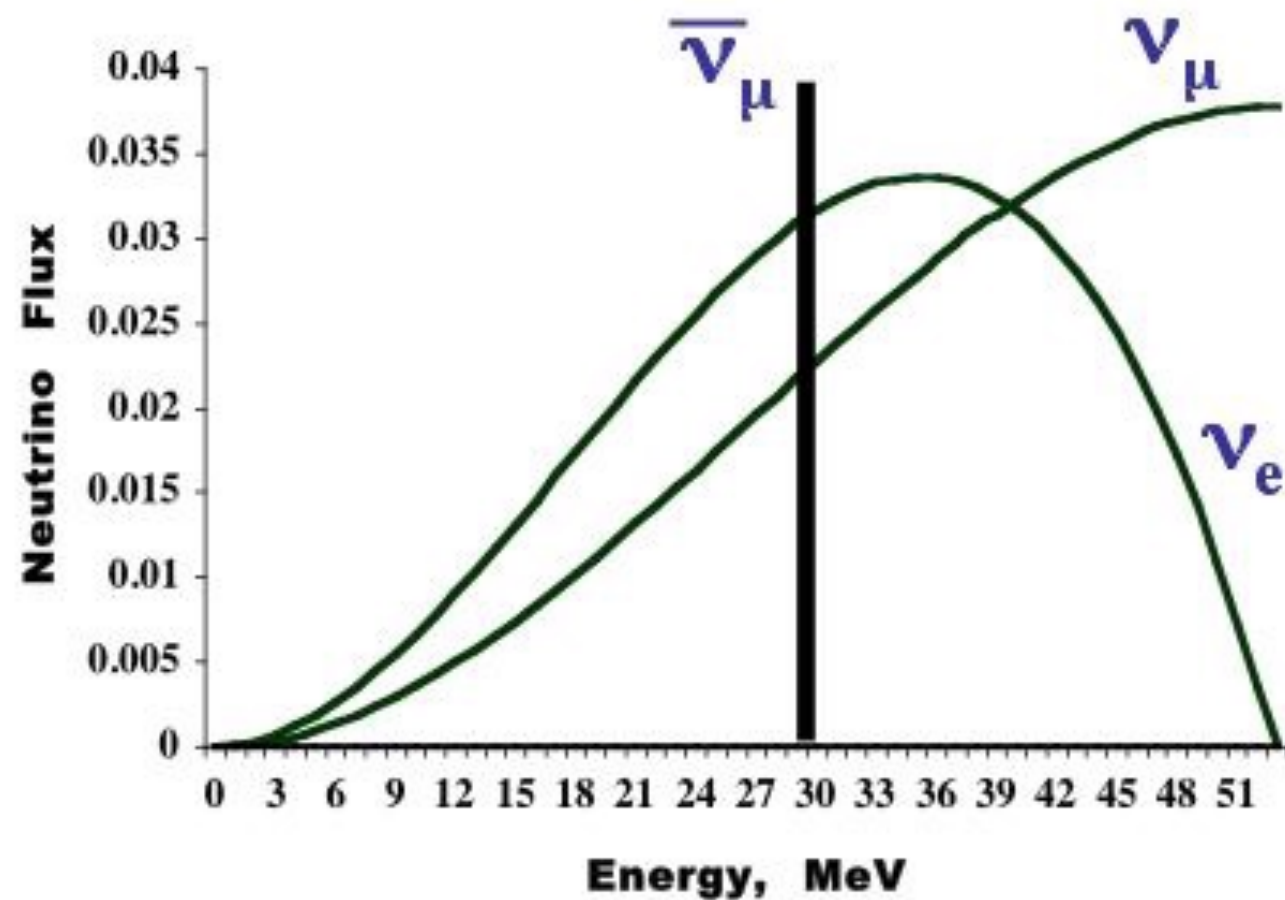
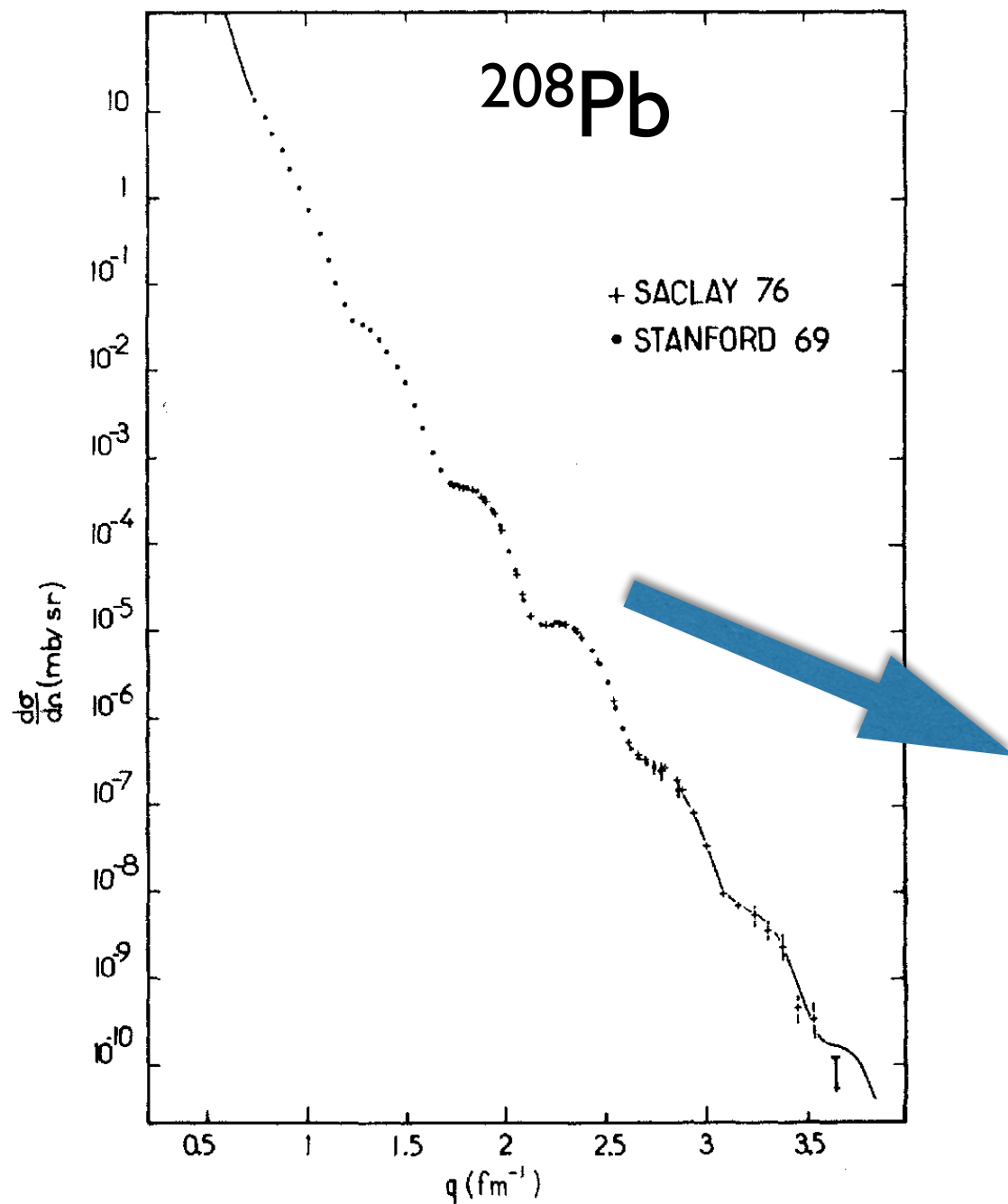


Towards a HERENT Neutrino Eclipse



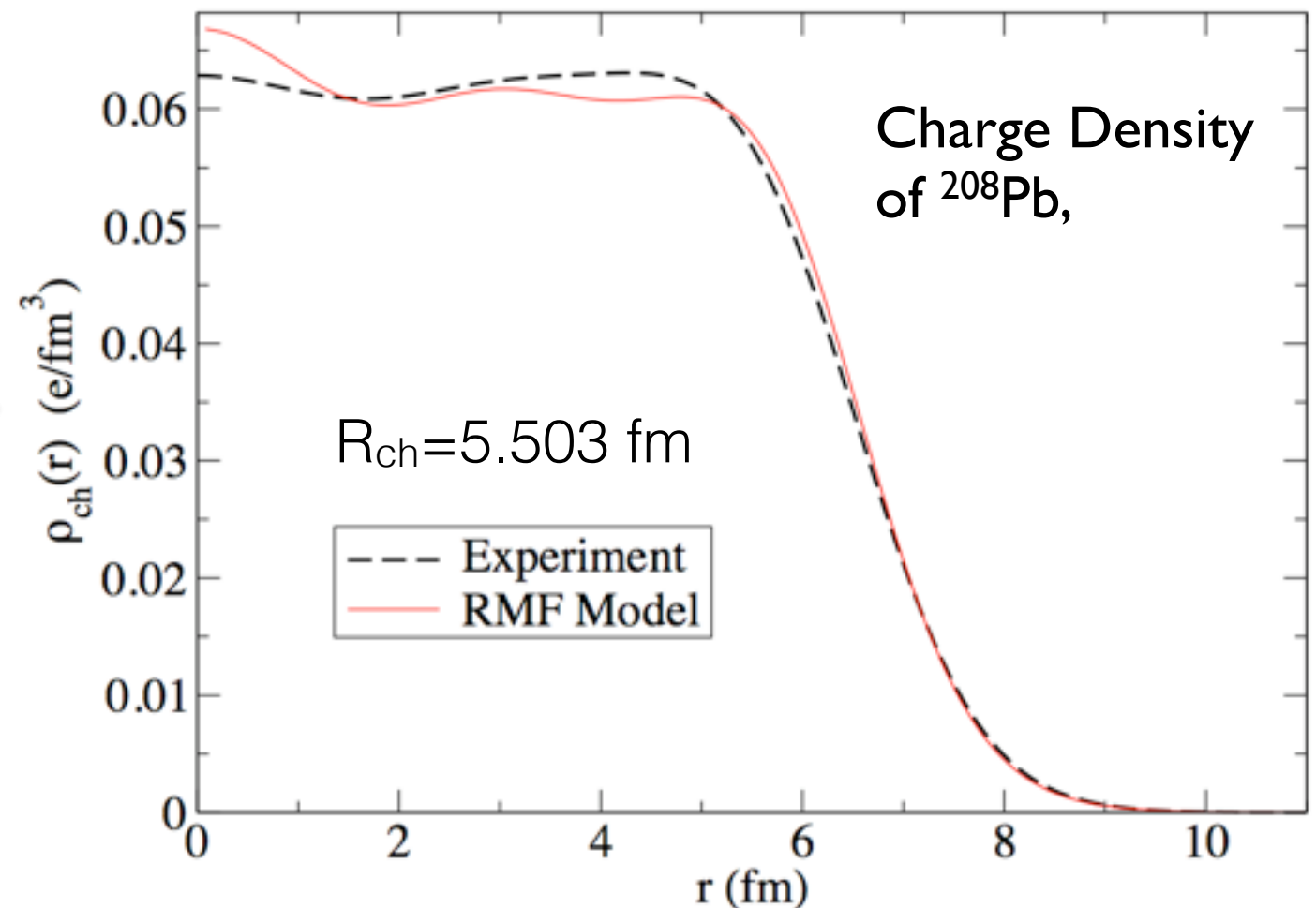
Chuck Horowitz, Indiana U., NuEclipse, Knoxville, TN, Aug. 2017

We live in a coherent (E+M) world



Cross section measured over 12 orders of magnitude.

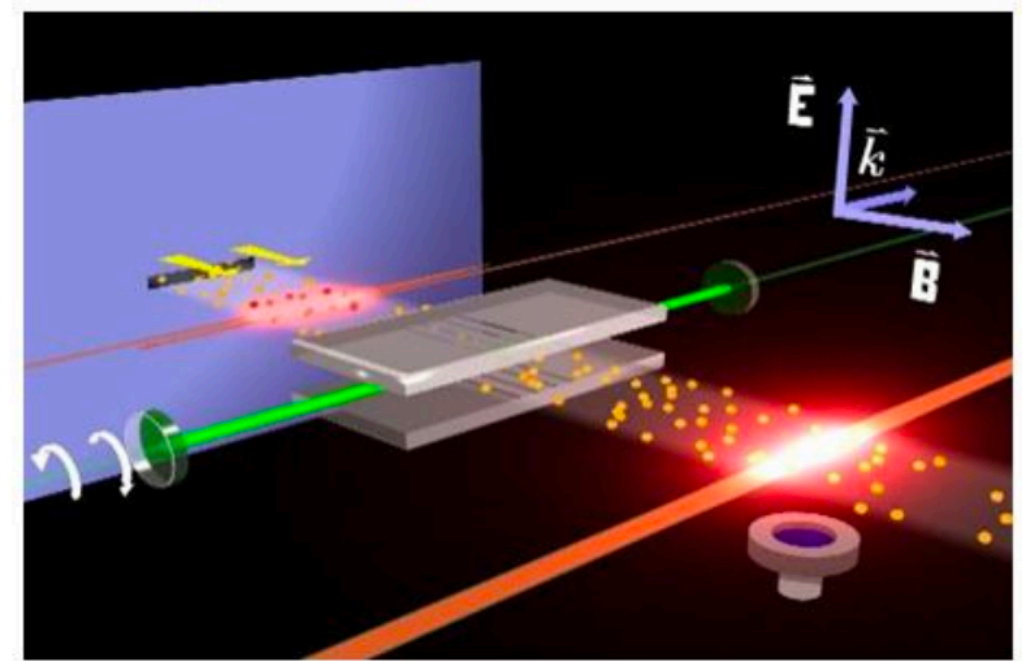
Often dominated by coherent charge form factor describing elastic scattering from all Z protons in a nucleus.



These elastic charge densities **are** our picture of the atomic nucleus!

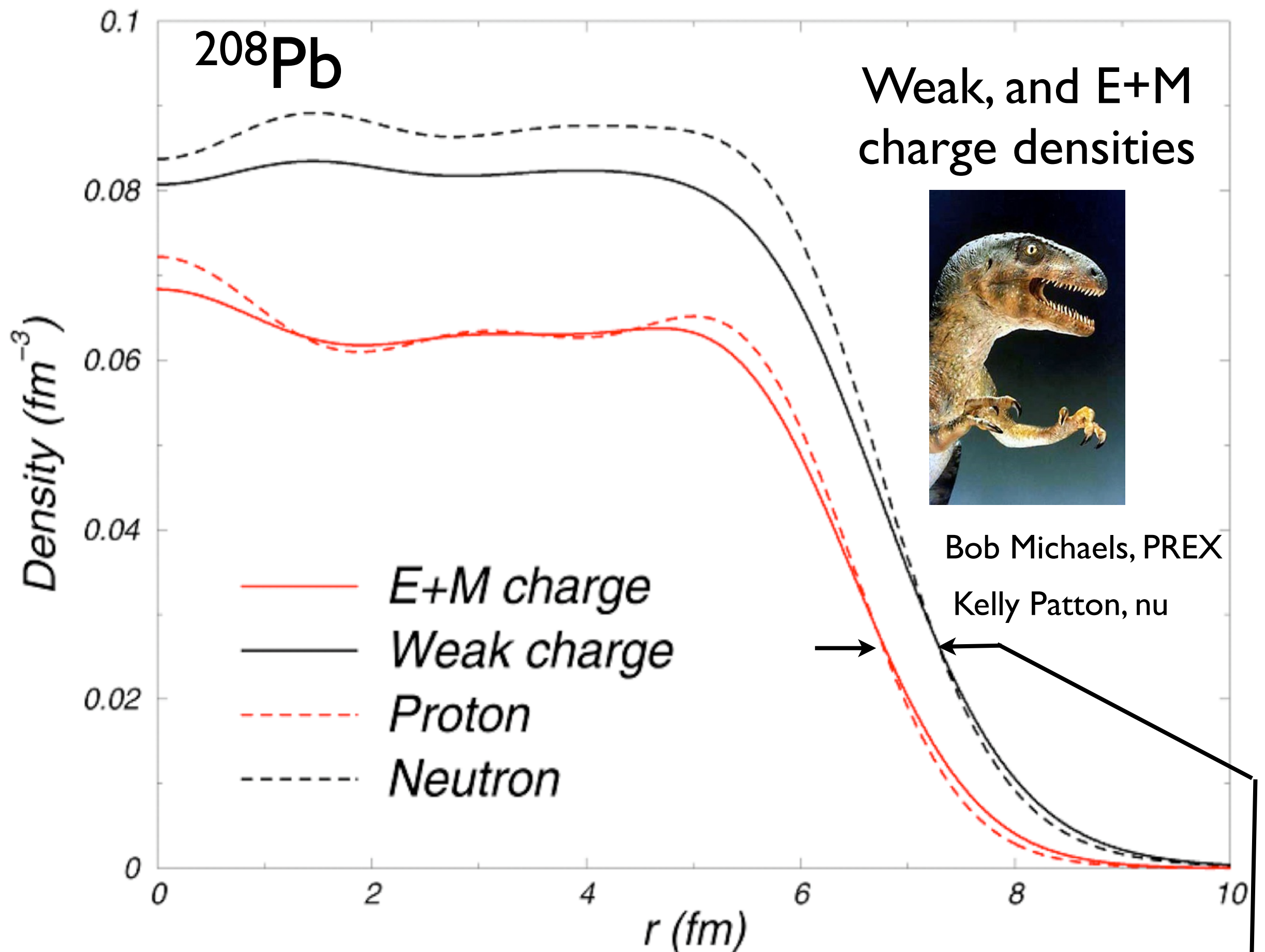
There is an exciting coherent (weak) world for neutral particles

- Weak charge of neutron
(big) $Q_W^n = -1$ and proton
(small) $Q_W^p = 1 - 4\sin^2\Theta_W \approx 0.05$
- Weak charge of Cs
measured with atomic
parity: $Q_W^{\text{inferred}} = -73.16(29)_{\text{expt}} (20)_{\text{theory}}$
- Weak form factor of ^{208}Pb
from parity violating
electron scattering (PREX)
 $F_W(q=0.475 \text{ fm}^{-1})=0.204\pm0.028$



Cs atomic parity exp.

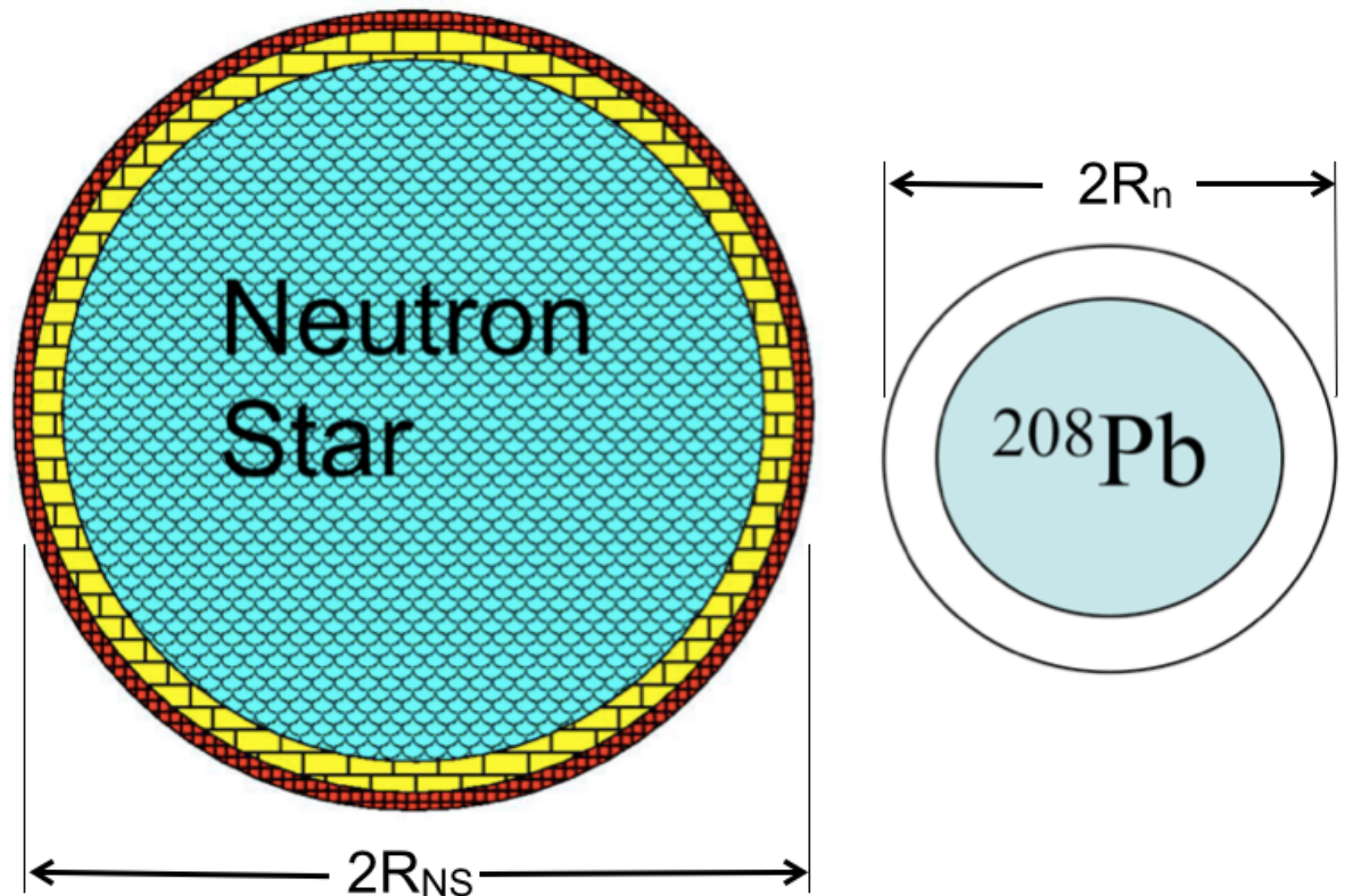
—> $R_W=5.83 \pm 0.18 \text{ fm}$
compared to $R_{\text{ch}}=5.50 \text{ fm}$
R. Michaels will discuss
PREX II and CREX (^{48}Ca)



- PREX measures how much neutrons stick out past protons (neutron skin).

Radii of ^{208}Pb and Neutron Stars

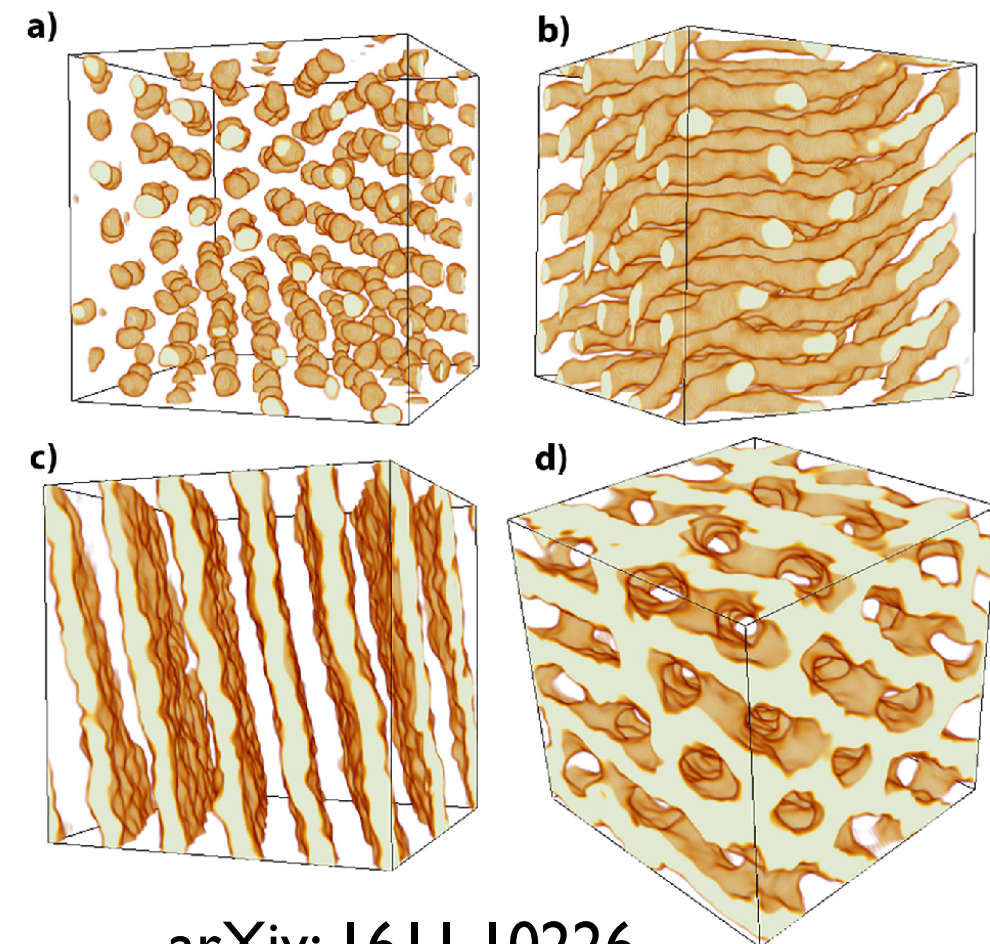
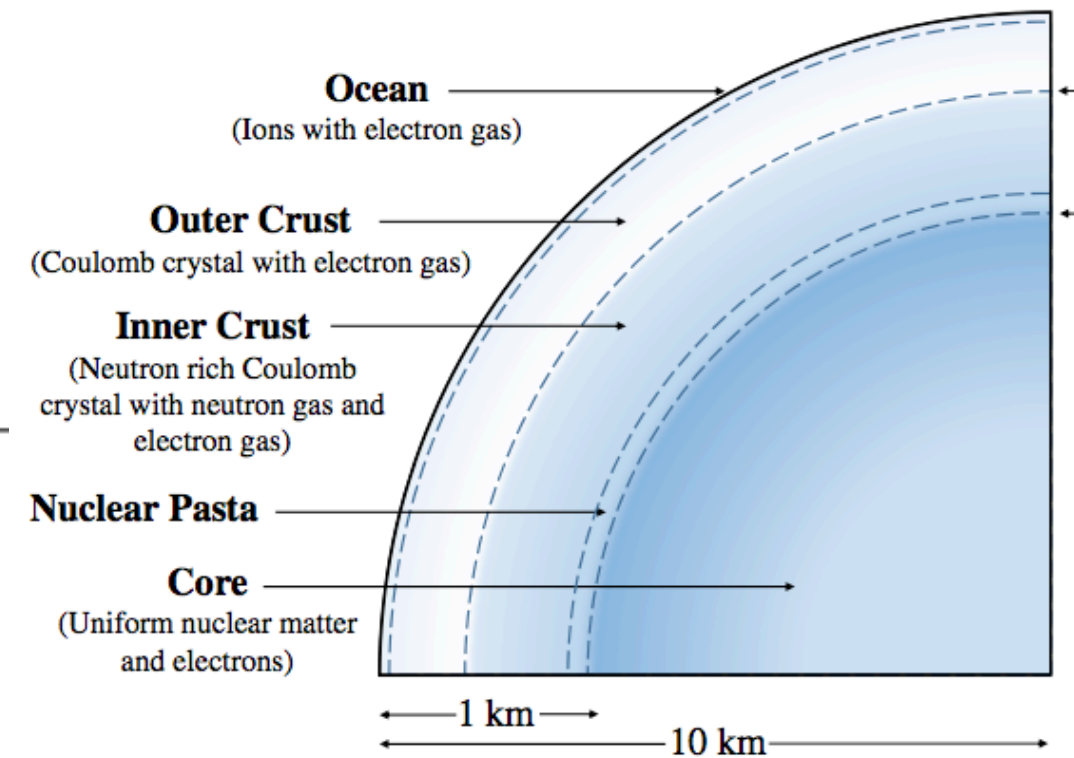
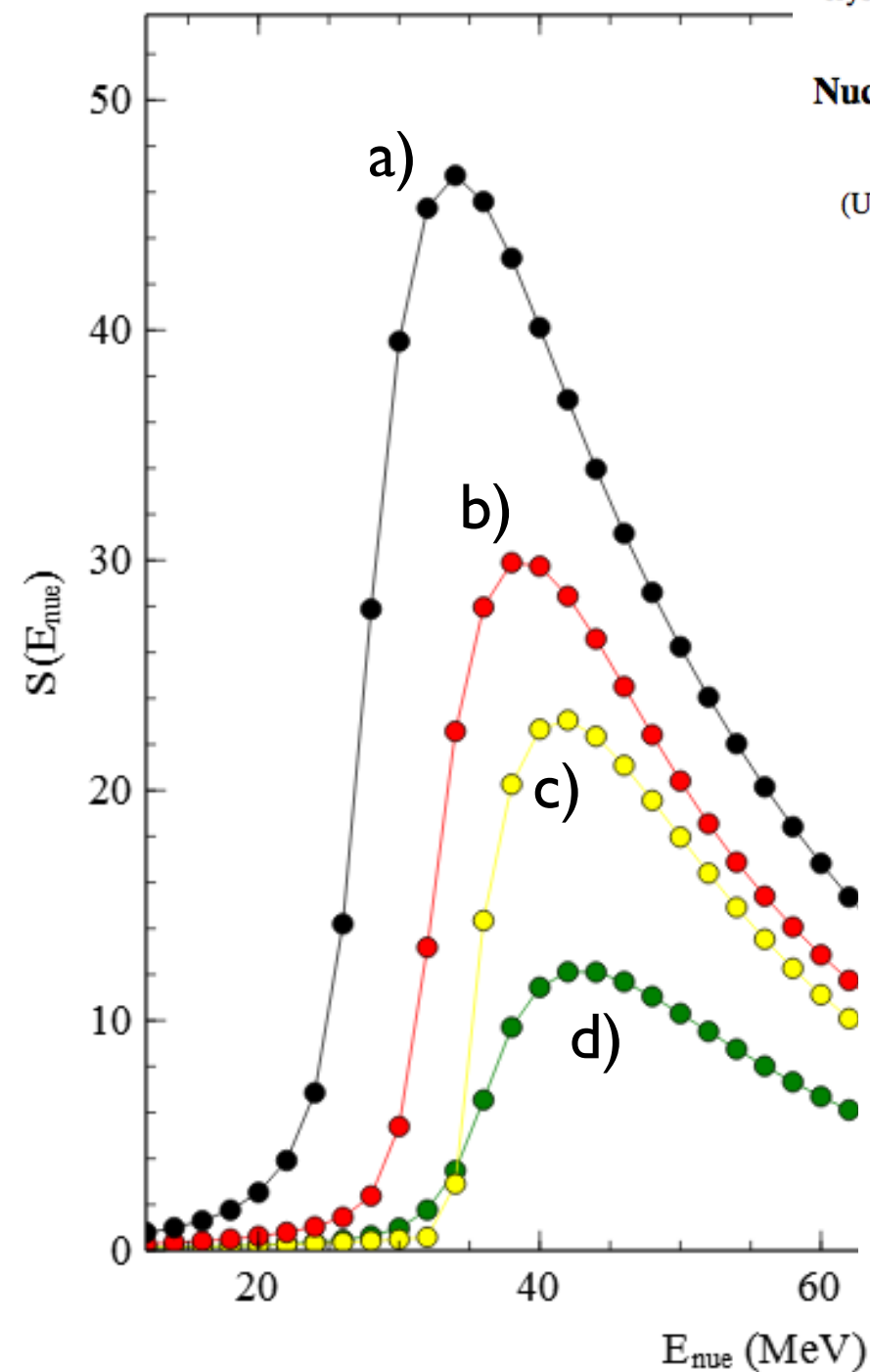
- Pressure of neutron matter pushes neutrons out against surface tension $\Rightarrow R_n - R_p$ of ^{208}Pb correlated with P of neutron matter.
- Radius of a neutron star also depends on P of neutron matter.
- Measurement of nuclear weak radius in laboratory has important implications for the structure of neutron stars.



Neutron star is 18 orders of magnitude larger than Pb nucleus but has same neutrons, strong interactions, and equation of state.

Coherent neutrino-pasta scattering in supernovae

- Large neutrino-nucleus elastic cross section first traps neutrinos in SN. Maintains lepton pressure support and can prevent collapse to a black hole.
- Neutrino-pasta coherent scattering, described by static structure factor $S(q)$, could impact late time neutrino signal.

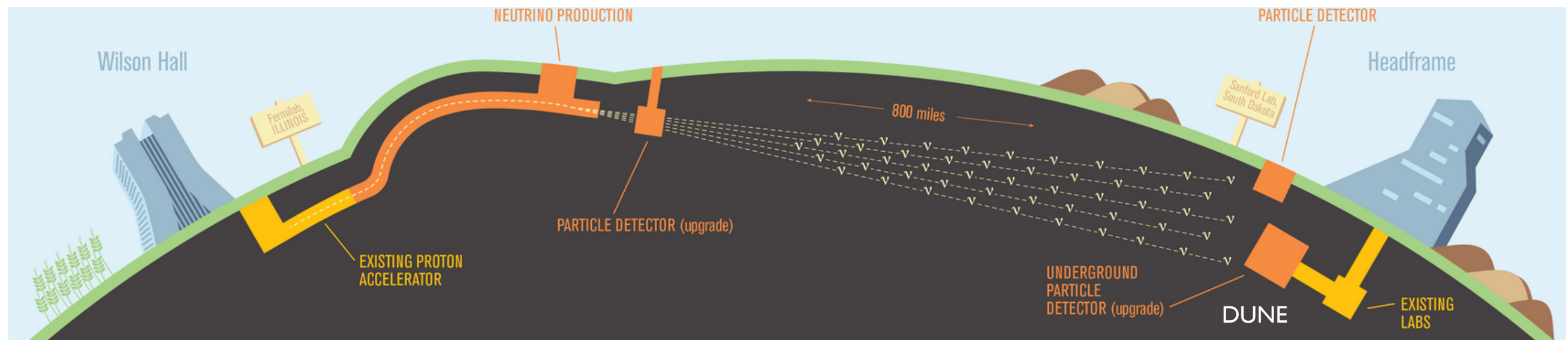
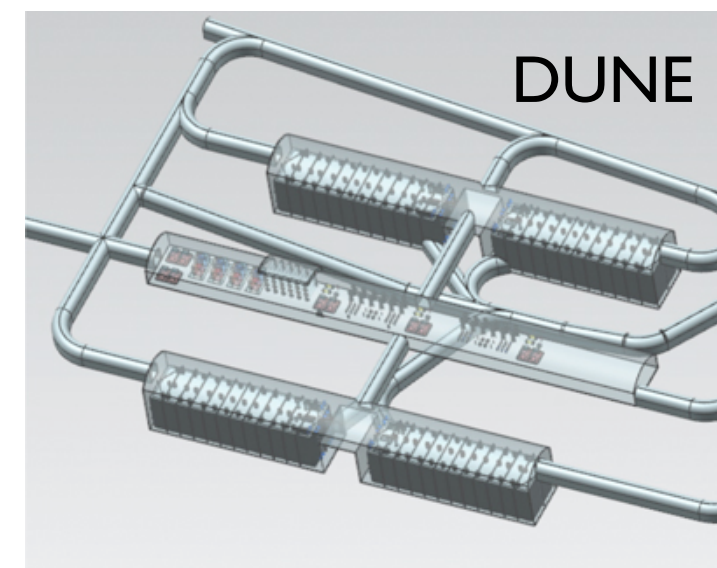
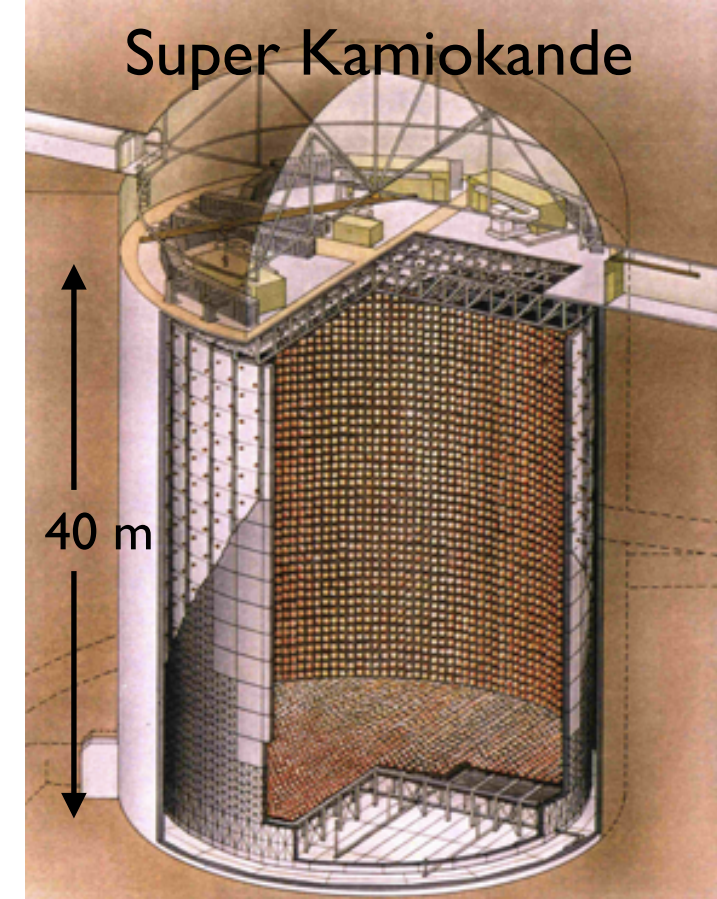


arXiv: 1611.10226

Semiclassical MD simulation with 50,000 nucleons

Detecting Supernova Neutrinos

- SN radiate the gravitational binding energy of a neutron star, $0.2 M_{\text{sun}} c^2$, as 10^{58} neutrinos in ~ 10 s
- Historic detection of ~ 20 neutrinos from SN 1987A
- Expect several thousand events from next galactic SN in Super Kamiokande: 32 kilotons of H_2O + phototubes. **Good antineutrino detector.**
- Deep Underground Neutrino Experiment (DUNE) in South Dakota plans 40 kilotons of liquid Ar to study oscillations of Fermilab neutrinos. **Good neutrino detector.**
- Hyper Kamiokande is possible very large version of SuperK. Expect 100,000 events. Good for late times.

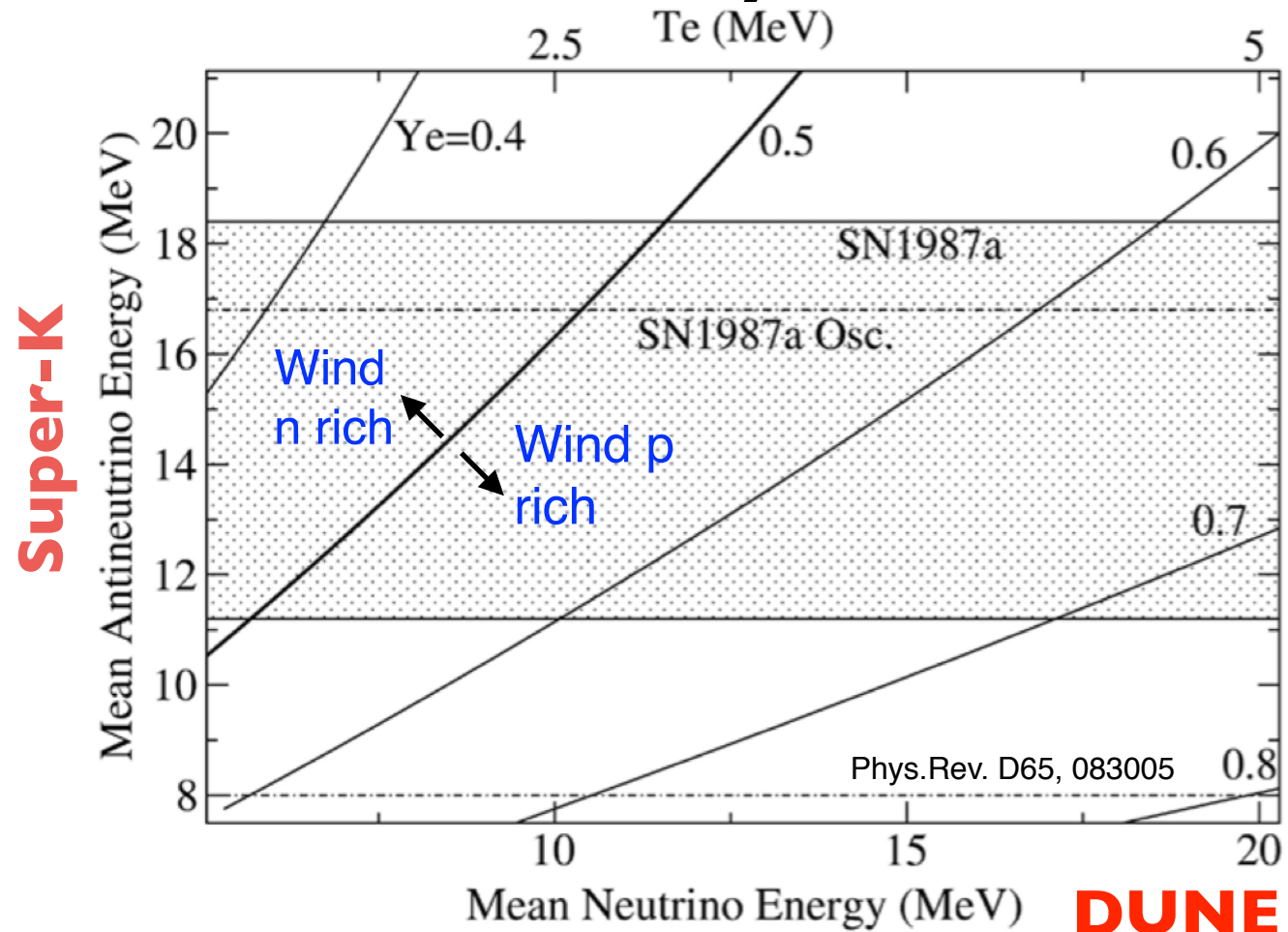


SN neutrinos and r-process nucleosynthesis

- Possible site of r-process (makes Au, Pt, U,...) is the neutrino driven wind in SN.
- Ratio of neutrons to protons in wind set by capture rates that depend on neutrino and anti-neutrino energies.



- Measure difference in average energy of **antineutrinos** and **neutrinos**. If large, wind will be neutron rich. If it is small, wind will be proton rich and likely a problem for r-process.
- Composition (Y_e) of wind depends on anti-neutrino energy (Y-axis) [results from ~20 SNI 987A events shown] and energy of neutrinos (X-axis). Energy of neutrinos, not yet measured, depends on properties of n rich gas (nu-sphere).



Need to calibrate DUNE by measuring charged current Ar cross section. Can do at SNS.

— Sam Hedges

SN simulations find too few neutrons for main or 3rd peak (Au, actinides) r-process. SN make lighter nuclei??

Instead site may be neutron star mergers. LIGO is measuring rate.

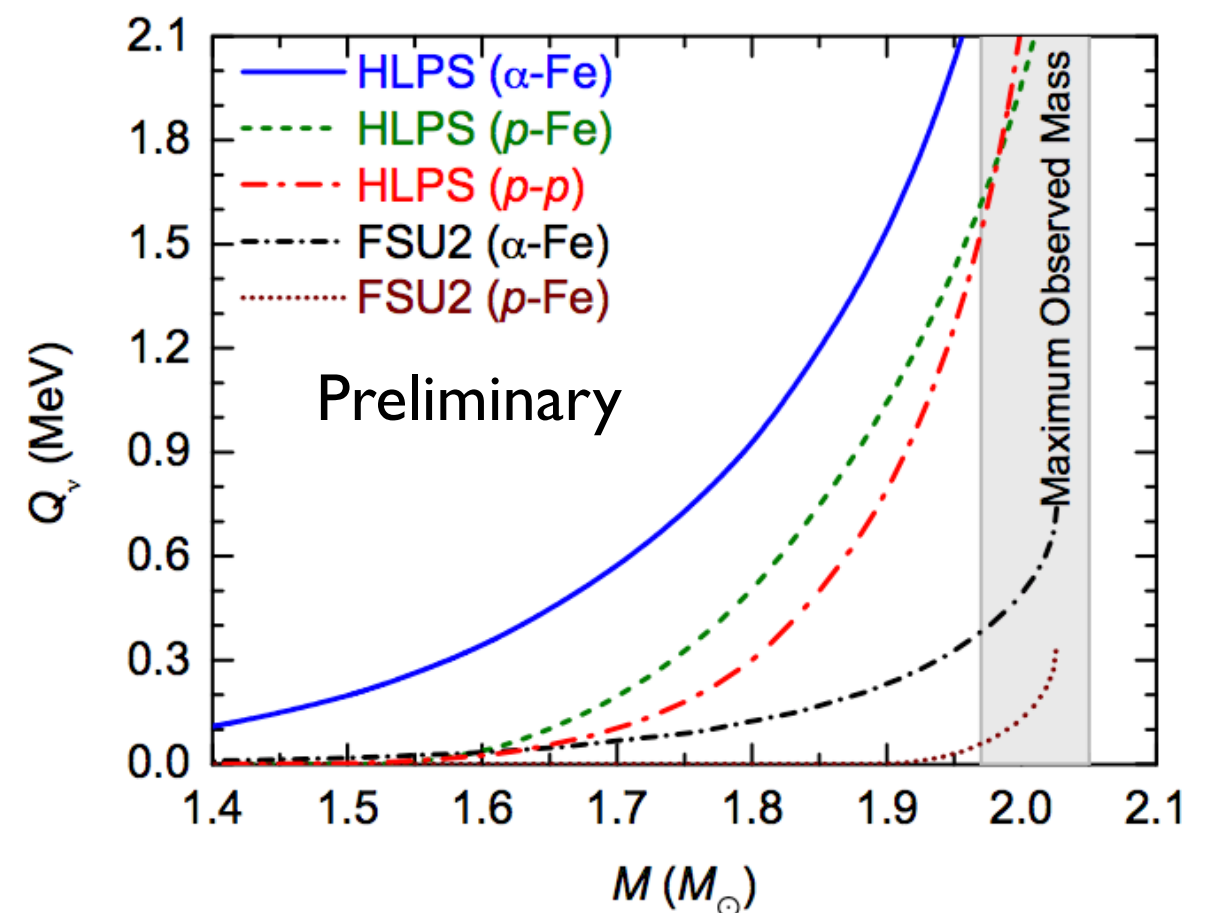
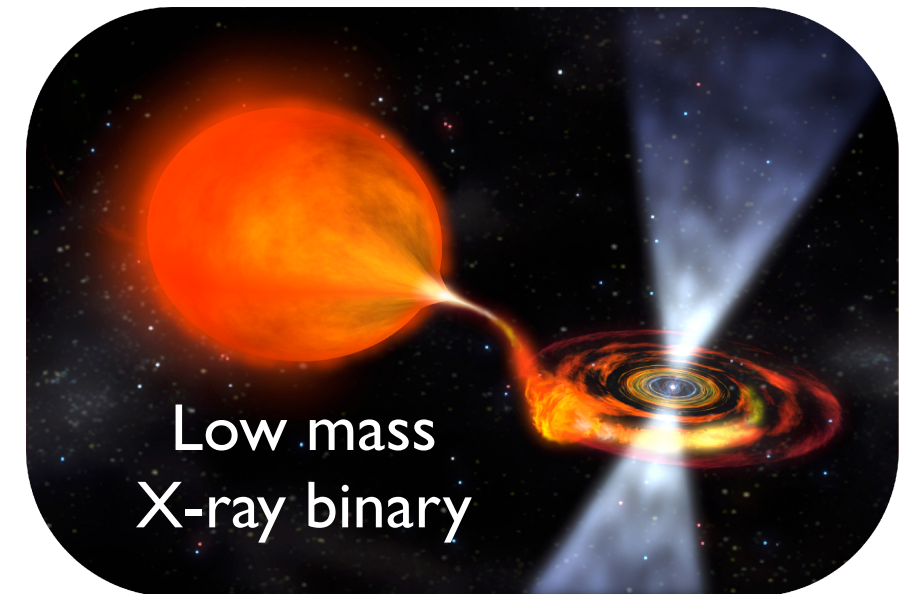
Neutral current detection via coherent nu-nucleus elastic scattering

- Important to have a good SN ν_x detector (neutral current) in addition to existing anti- ν_e (H_2O , liquid scint.) and ν_e (liquid Ar DUNE) detectors.
- One possibility is neutrino-nucleus elastic scattering in large dark matter detectors.
- Large coherent cross section $\sim N^2$, sensitive to all six ν flavors, all detector mass contributes (not just small H fraction) \longrightarrow very large yields:
- 10s of events per *TON* for SN at 10 kpc compared to 100s of events per *kiloton* for conventional detector.

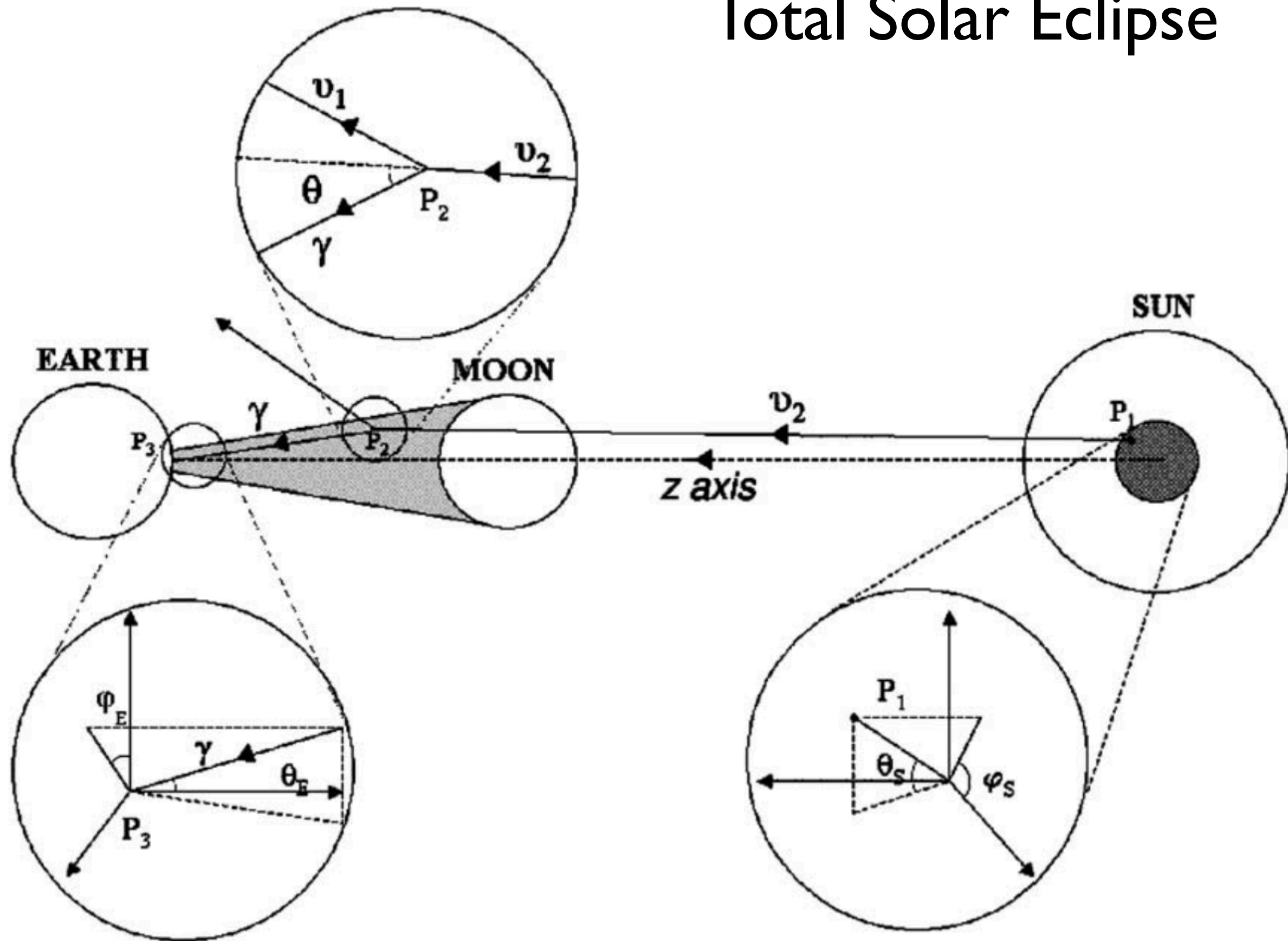
Shayne Reichard

SNS on a neutron star

- Nucleons accreting on a NS can produce some positive pions when they strike the surface.
- $\sim 1/2$ of decay at rest neutrinos will interact about 1 km deep and heat the inner crust.
- Heat will diffuse to surface in \sim year after accretion stops, delaying the cooling of crust.
- Heating Q in MeV per accreted nucleon can be significant for compact massive stars (HLPS EOS).
- F.J. Fattoyev, Edward F. Brown, Andrew Cumming, C. J. Horowitz, Bao-An Li, and Zidu Lin in progress.

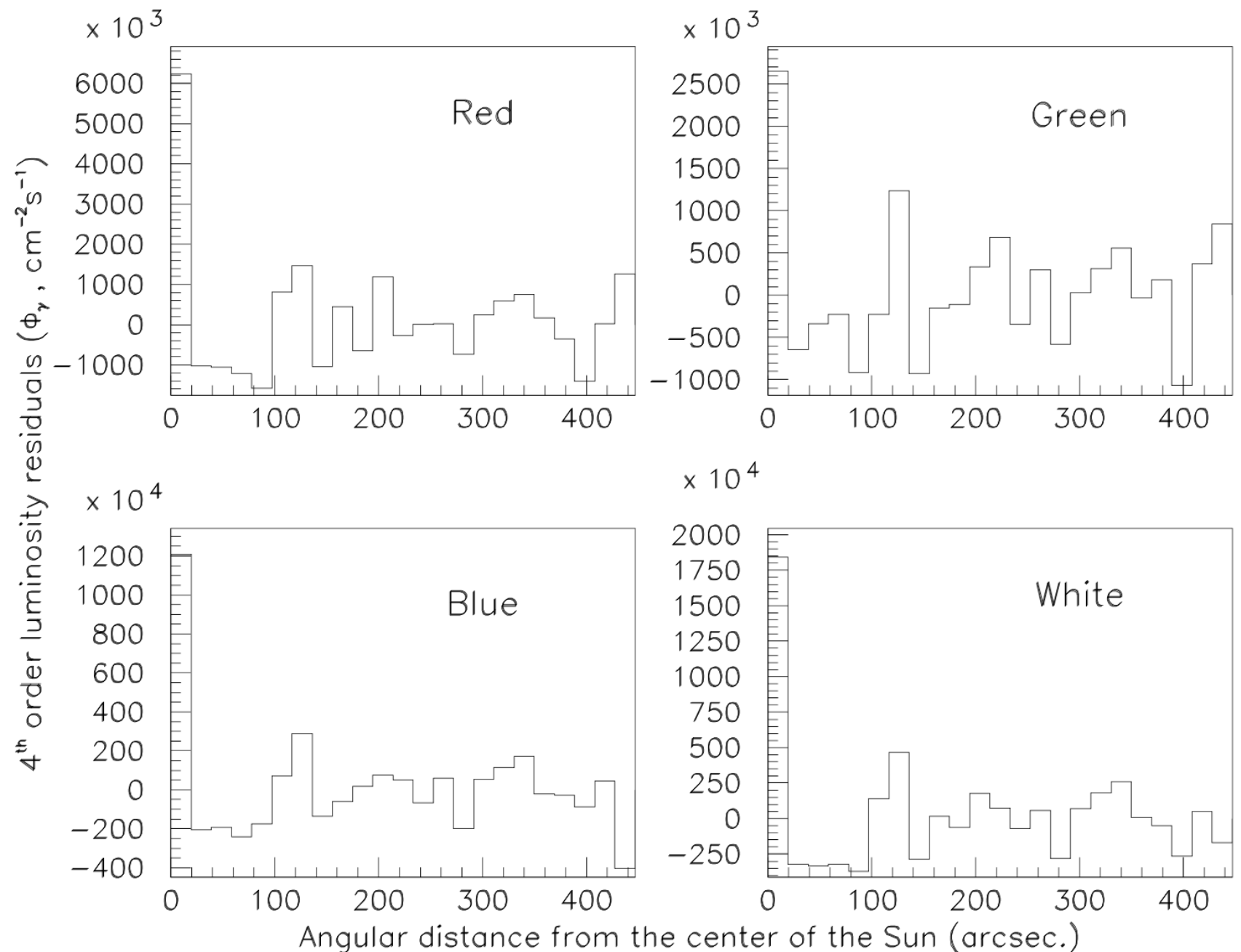


Total Solar Eclipse



Radiative neutrino decay during a solar eclipse

- Search for visible photons from radiative neutrino decays between moon and earth.
- G. Giacomelli and V. Popa, hep-ex/0110013 from 1999 eclipse.
- Background from earth shine.



[arXiv:hep-ex/0110013](https://arxiv.org/abs/hep-ex/0110013), [hep-ph/0309107](https://arxiv.org/abs/hep-ph/0309107)

Towards a Coherent Neutrino Eclipse

- PREX/ CREX: K. Kumar, P. Souder, R. Michaels, K. Paschke...
- MD simulations of nuclear pasta: **Matt Caplan, Zidu Lin**, Don Berry, Farrukh Fattoyev, Andre Schneider...
- Neutrino pasta scattering: Luke Roberts, Evan O'Connor, Tobias Fischer, W. Newton...



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