Measuring full ^{48}Ca weak charge density

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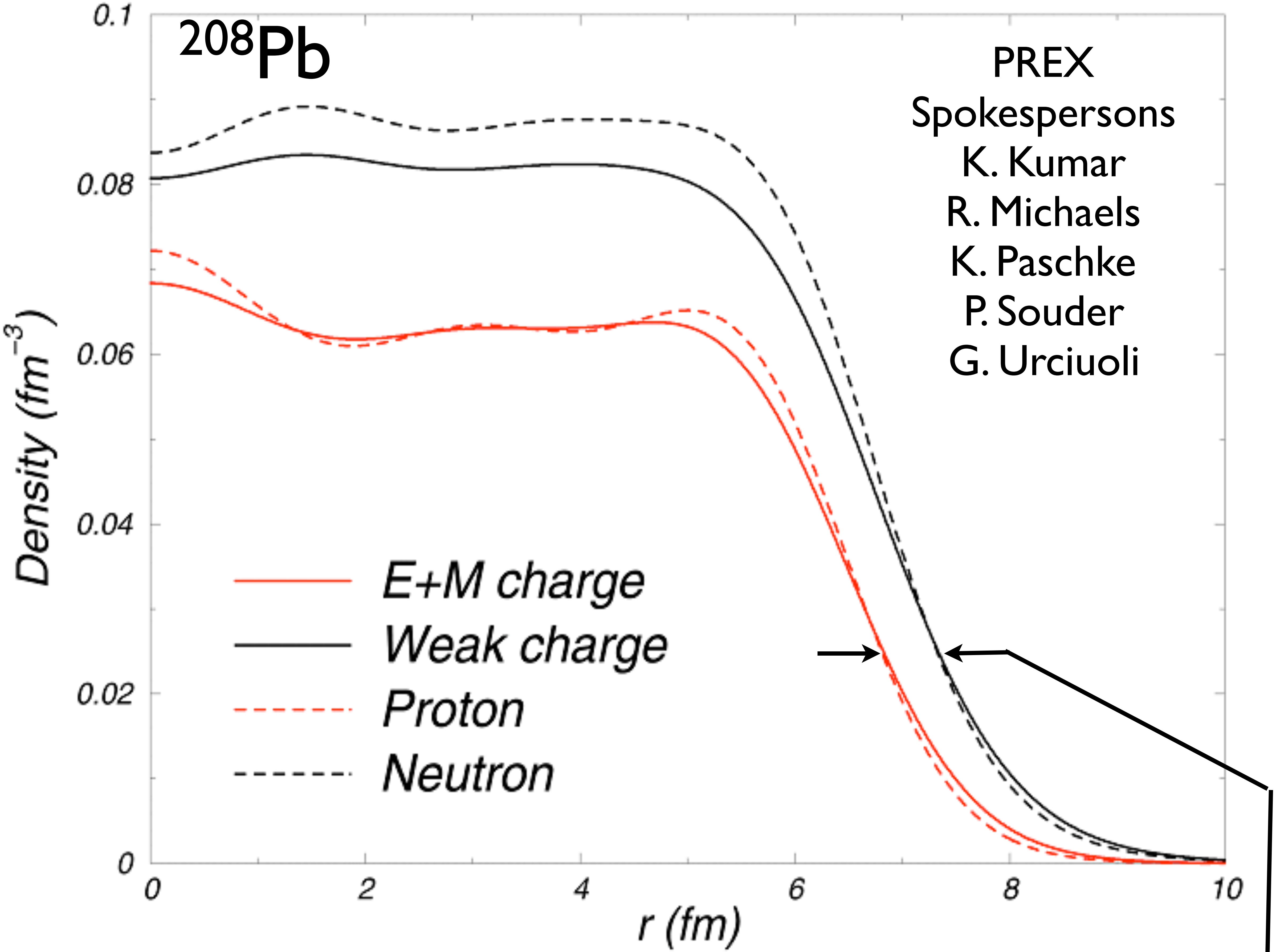
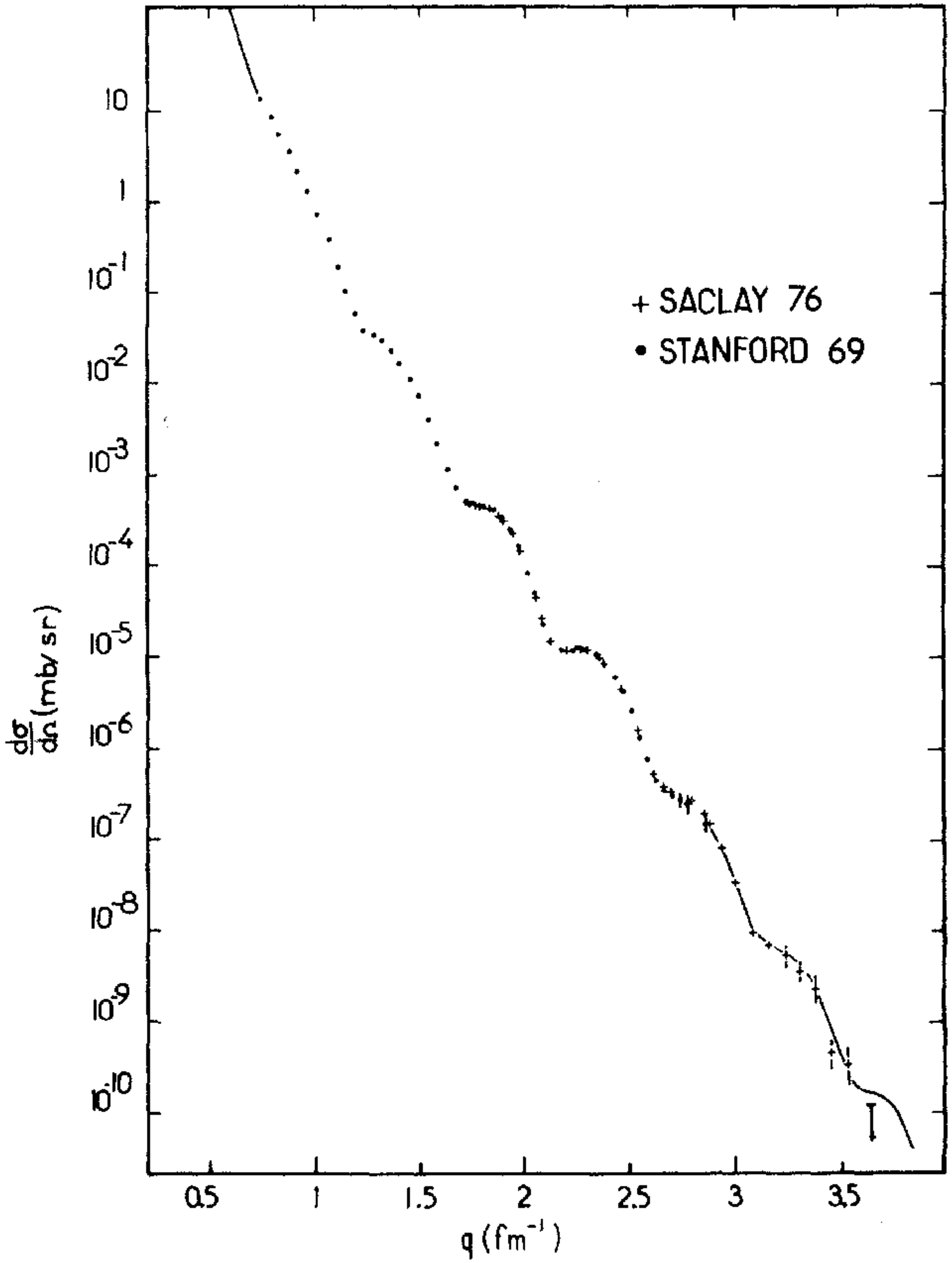


- PREX measures how much neutrons stick out past protons (neutron skin).

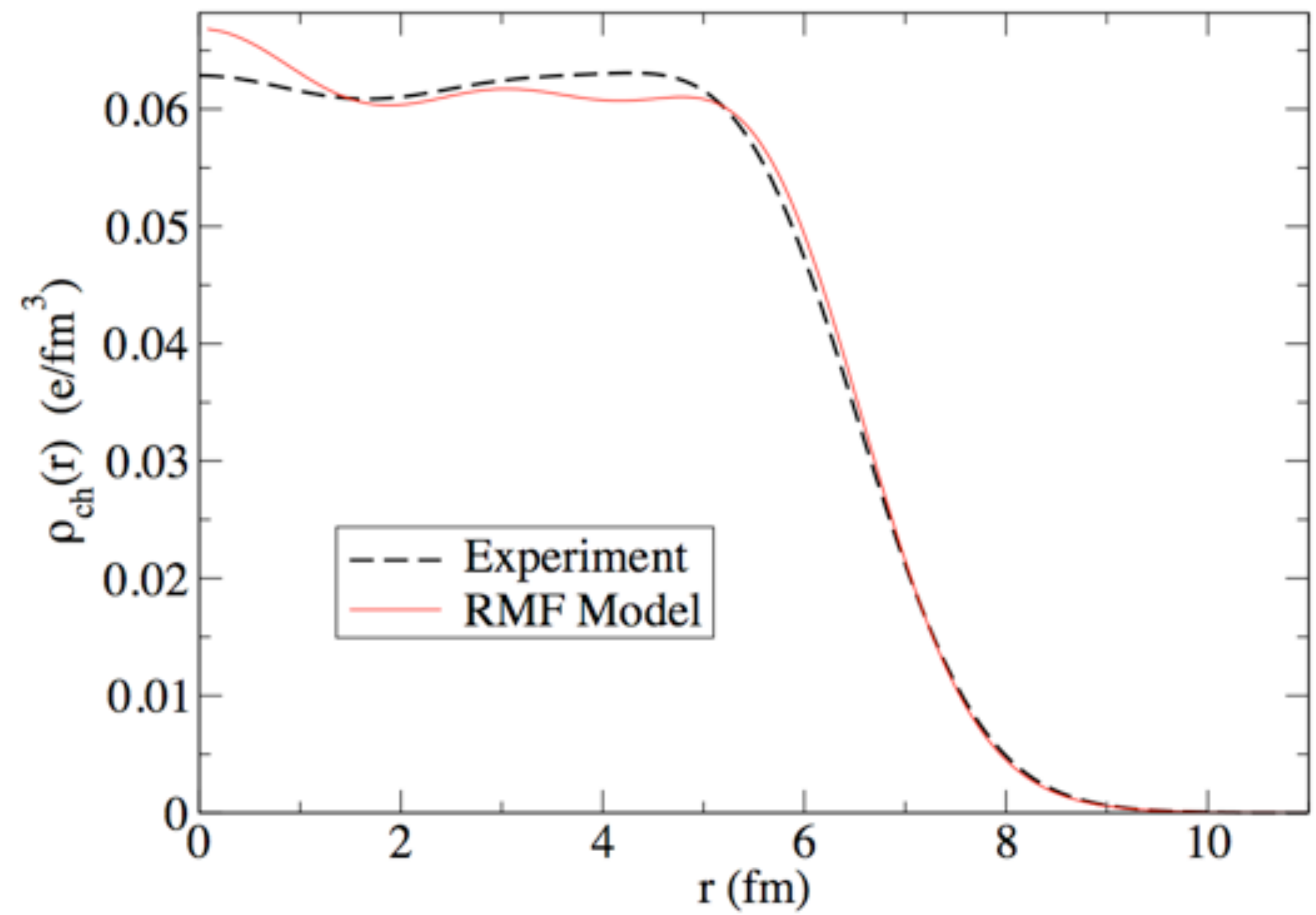
Why not just measure a 2nd Q^2 point? Or 1,2…∞!

- Model dependent Fermi function, Helm,… densities are so 1970s.
- We already know charge density, and to first approx, neutron surface thickness is same as proton.
- The experimental elastic charge density IS our picture of the atomic nucleus and has had a tremendous impact.

Charge Density of ^{208}Pb, accurately measured in elastic electron scattering.



Cross section measured over 12 orders of magnitude.



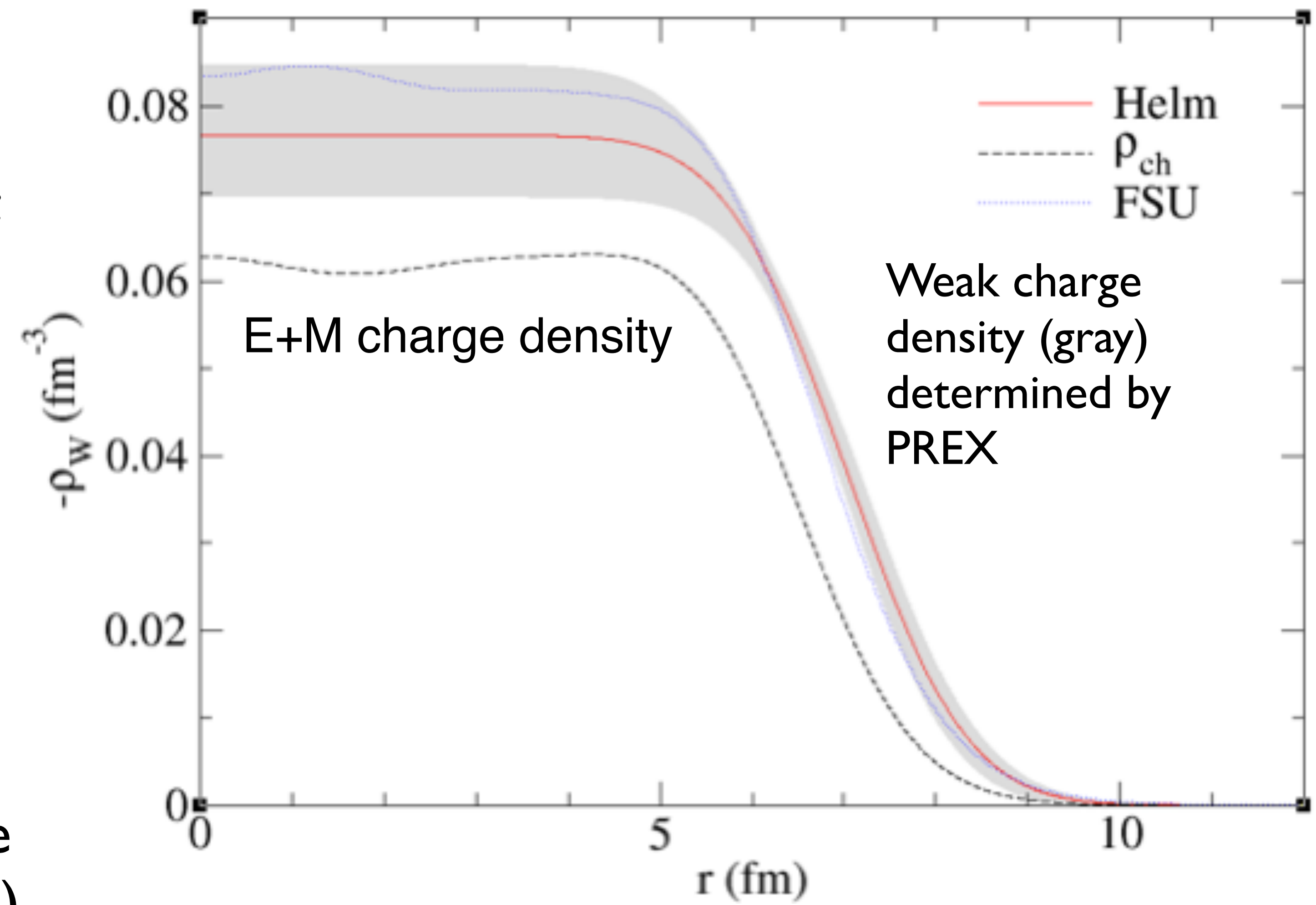
These elastic charge densities ***are*** our picture of the atomic nucleus!

Charge Density

- Shell oscillations are observed but often smaller than in theoretical models.
- Detailed knowledge of surface thickness for charge density.
- Charge density in interior of ^{208}Pb observed flat —> our most detailed knowledge of nuclear saturation. Saturation density n_0=0.16 fm^{-3} extrapolated from rho_ch(r=0) in 208Pb! Nontrivial because neutron density is not equal to charge density.
- To determine rho_ch(r=0) need

PREX results from 2010 run

- 1.05 GeV electrons elastically scattering at ~5 deg. from ^{208}Pb
- **A_{PV} = 0.657 ± 0.060(stat) ± 0.014(sym) ppm**
- Weak form factor at q=0.475 fm^{-1}:
  $F_W(q)$ = 0.204 ± 0.028
- Radius of weak charge distr.
  R_W = 5.83 ± 0.18 fm
- Compare to charge radius R_{ch}=5.503 fm --> weak skin:
  $R_W - R_{ch}$ = 0.32 ± 0.18 ± 0.03 fm
- First observation that weak charge density more extended than (E+M) charge density --> weak skin.
- Unfold nucleon ff--> neutron skin:
  $R_n - R_p = 0.33^{+0.16}_{-0.18}$ fm
- Phys Rev Let. **108**, 112502 (2012), Phys. Rev. C **85**, 032501(R) (2012)



PV Neutron Density Experiments

- JLAB completed exp.: PREX R_n-R_p(^{208}Pb)=0.33+/-0.17 fm
- JLAB approved experiments:
  - PREX II improve statistics of PREX with goal of R_n-R_p for ^{208}Pb to +/- 0.06 fm
  - CREX measure R_n-R_p for ^{48}Ca to +/- 0.02 fm
- Possibility at Mainz or at Cornel:
  - A # of parity violating measurements of neutron densities are possible both with the existing machine and with Mesa.
  - "Super PREX" could take advantage of a large acceptance detector and the new intense MESA electron accelerator to measure R_n-R_p for ^{208}Pb to +/- 0.03 fm (half the error of PREXII). Very well motivated to maximize information on density dependence of symmetry energy and the pressure of neutron matter from laboratory exp.

CREX: ^{48}Ca

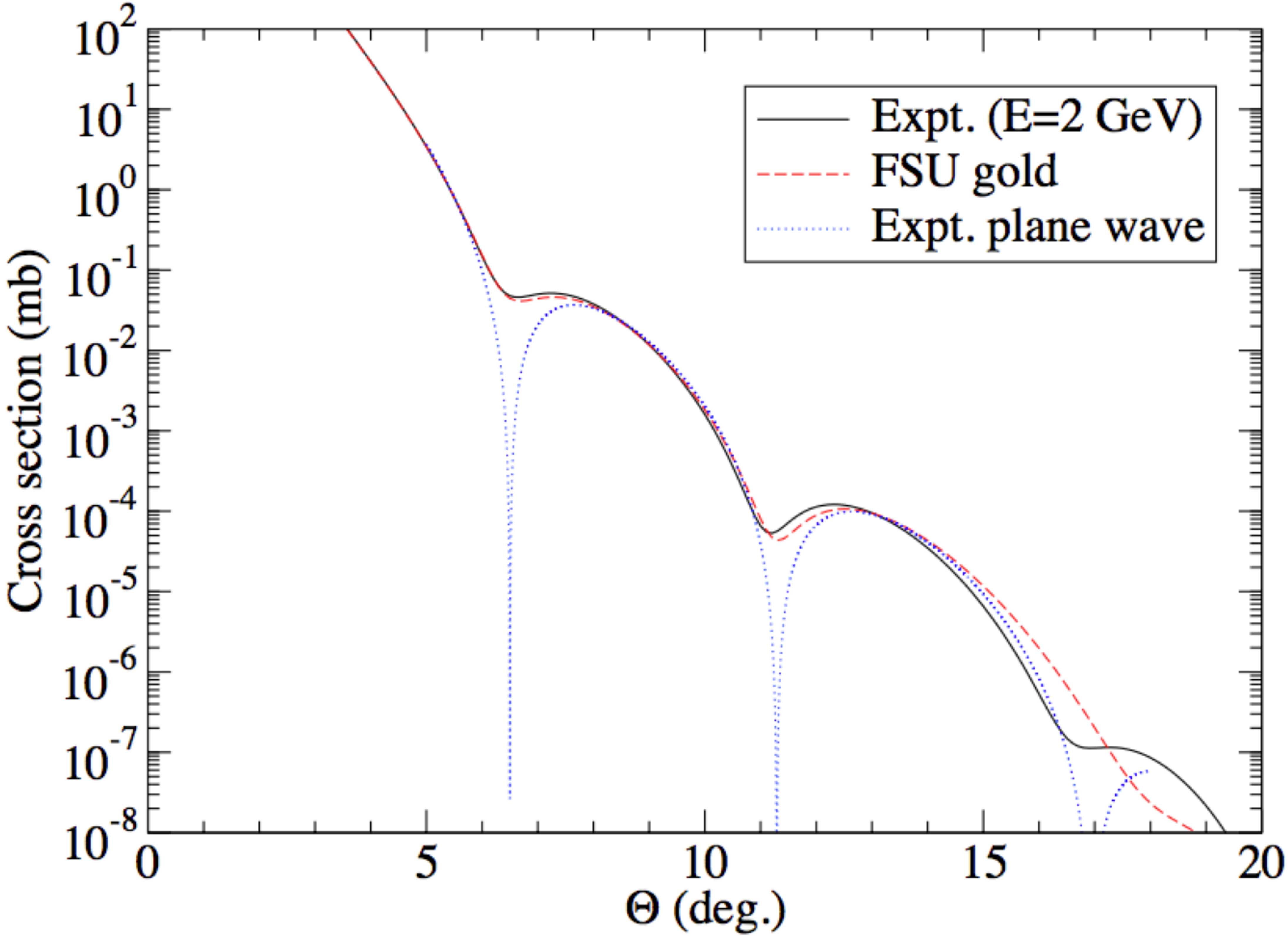
- Measuring the neutron radius for both ^{208}Pb (heavy) and ^{48}Ca (lighter) constrains both volume and surface isovector terms in energy functionals.
- ^{48}Ca is light enough that microscopic coupled cluster calculations are feasible to directly relate R_n to 2 and 3 nucleon forces (G. Hagen et al.). [These calculations should soon provide first microscopic double beta decay matrix element determination!]
- Indeed ^{48}Ca provides an important interface between density functionals, accurate for heavy nuclei, and more microscopic approaches.

Full ^{48}Ca weak charge density

- Measure A_{pv} at multiple q^2 points to determine the full radial form of the weak density. This is feasible for ^{48}Ca, really hard for ^{208}Pb.
- Expand in Fourier Bessel series:

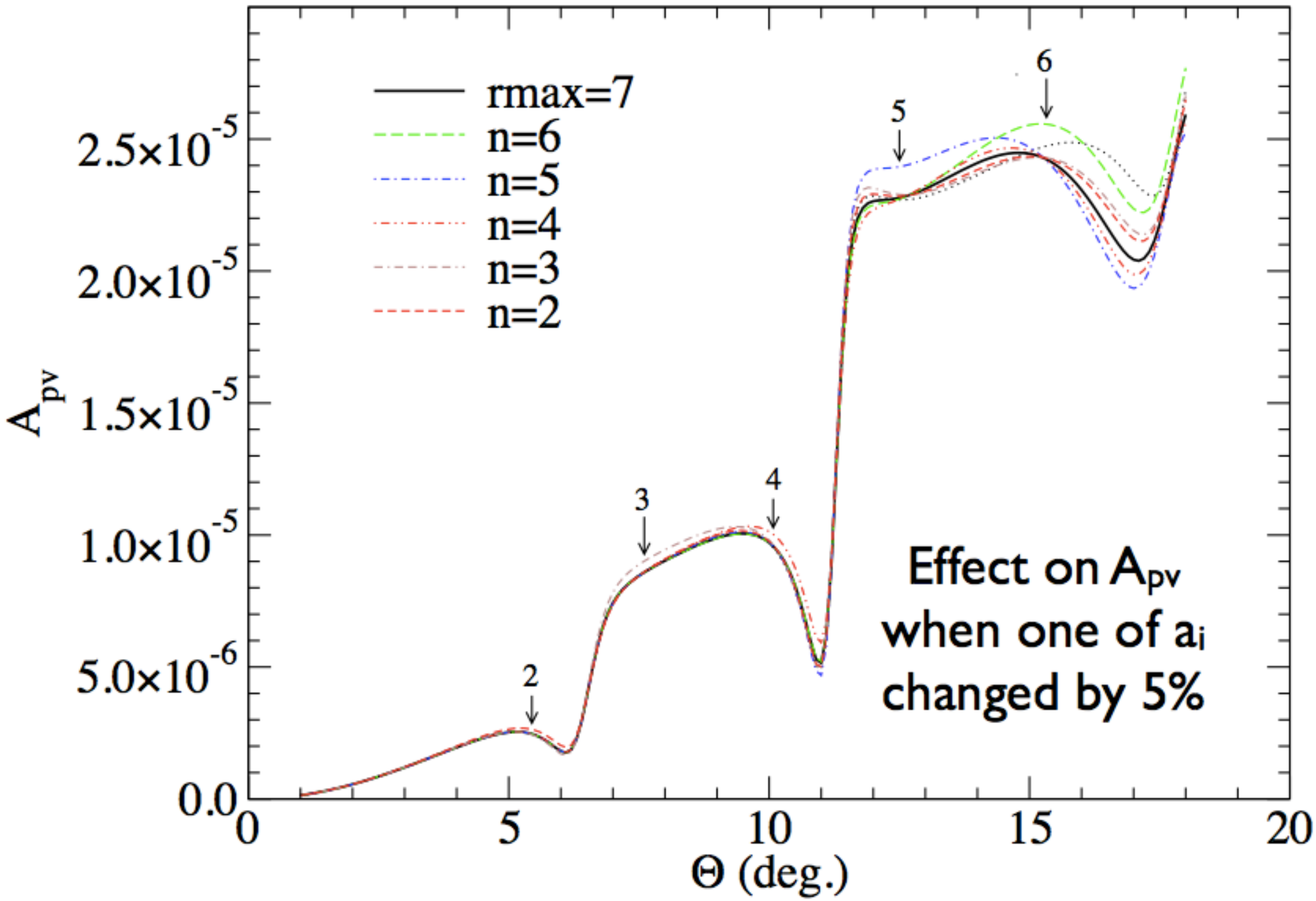
$$\rho_W(r) = \sum_{i=1}^{n_{max}} a_i j_0(q_i r)$$

- $q_i=\pi i/R_{max}$, $j_0(x)=\sin(x)/x$, $n_{max}=6$, $R_{max}=7$ fm.



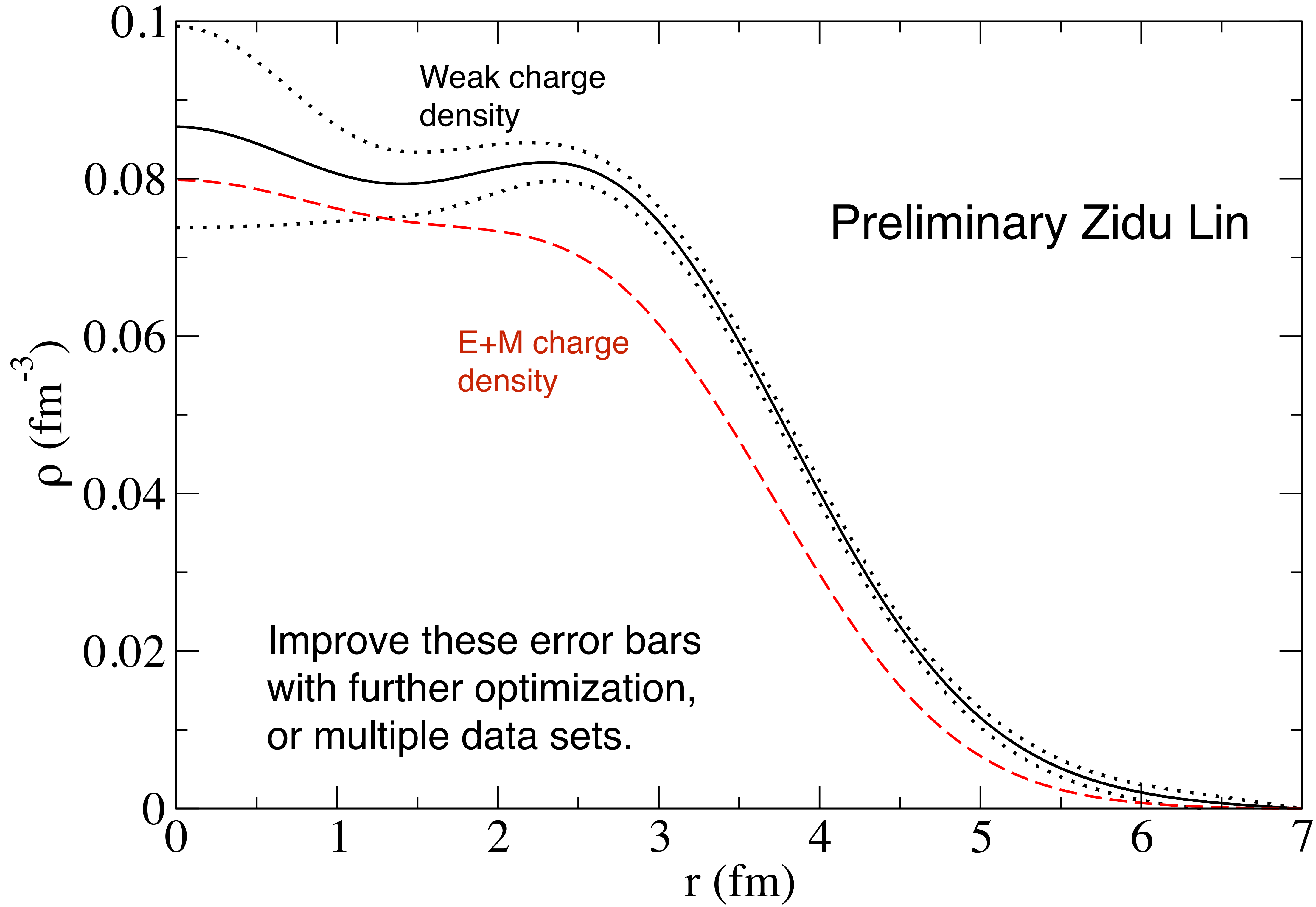
Expt. (E=2 GeV)
FSU gold
Expt. plane wave
Cross section (mb)
Θ (deg.)
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
0
5
10
15
20

^{48}Ca at 2 GeV



Effect on A_{pv} when one of a_i changed by 5%

Example statistical error at JLAB: 60 days for all five q^2



Optimizations

- Choose R_{max} beyond which rho_W=0
- Choose $q_{max}=\pi\ i_{max}/R_{max}$
- Choose energy and angle and run times for each of the q_i points. Much time at last point!
- Look for highest solid angle detector with good energy resolution.
- Minimize stat error in some quantity such as weak density at origin.
- One constraint: total weak charge.

q_i fm^{-1}	E GeV	$\frac{d\sigma}{d\Omega}$ mb	A_{pv} ppm	T days	a_i fm^{-3}	$\Delta a_i/a_i$ %
0.45					0.0752	1.1
0.90	2.06	2.44	2.54	5	0.0468	5.9
1.35	3.09	1.07×10^{-1}	8.31	7	-0.0438	7.6
1.80	4	2.9×10^{-3}	9.92	10	-0.0147	27
2.24	4	4.05×10^{-4}	22.5	15	0.0161	29
2.69	4	9.7×10^{-6}	36.5	23	0.0066	90

Beam Energy

- Want q_{max} ~ 2.7 fm^{-1} to resolve internal weak charge density in ^{48}Ca.
- Need beam energy of order **E_{lab} ~ q_{max} ~ 500 MeV.**
- Measure q_{max} at about 60 degrees in Lab.
- MESA at Mainz is too low energy 150-200 MeV.

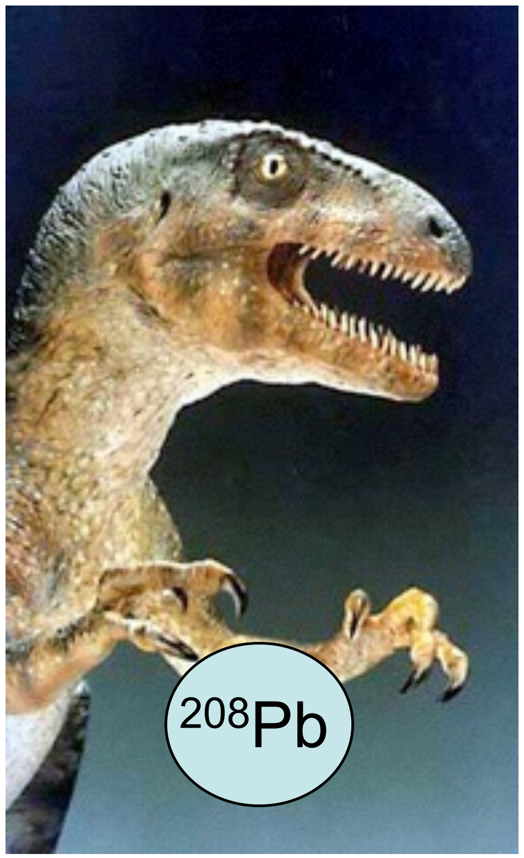
Systematic errors at high Q^2

- Very different from low Q^2 experiments.
- Low cross section and large stat error.
- Normalization errors very small
- Helicity correlated beam properties may not be a problem since A_{pv} is large and poorly determined.
- Backgrounds and energy resolution likely important issues!

Full ^{48}Ca weak charge density

- Would provide **text book picture of where neutrons and protons are in a nucleus**.
- Learn about shell oscillations of neutrons, saturation density of nuclear matter, neutron skin thickness, surface thickness of the neutrons…
- We expect central baryon density in ^{208}Pb to be approximately constant but we only know what the proton density is.
- Compare to new microscopic calculations of the neutron density in ^{48}Ca based on chiral effective field theory two and three nucleon interactions.

Weak form factors and neutron rich matter



- PREX uses parity violating electron scattering to measure the neutron radius of ^{208}Pb —> determines pressure of n rich matter.
- Complimentary to astronomical observations of neutron matter with photons, neutrinos and gravitational waves.
- Can measure not just radius but full model independent weak form factor.

- Collaborators: D. Berry, S. Ban, J. Piekarewicz, R. Michaels, K. Kumar, P. Souder, Students: Z. Lin, M. Caplan…
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