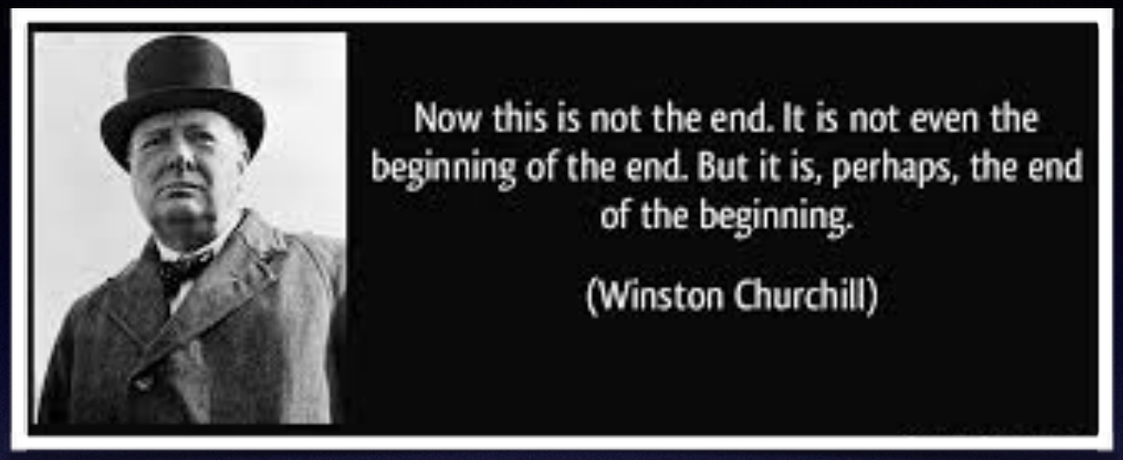
The End of the Beginning

Jorge Piekarewicz - Florida State University



Neutron Skins of Nuclei:
From Laboratory to Stars

May 4-7, 2015

Mainz Institute for Theoretical Physics

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

The Beginning of the End
May 17-27, 2016

Thank you all for Coming!

NSKINS-2015

la Repubblica
SABATO 7 MAGGIO 2016
MILANO XV

Società
SPETTACOLI CULTURA SPORT

Check in Check out

Xavier Roca Maza. Il liceo scientifico a Barcellona, poi un lavoro da elettricista, infine l'università e il trasloco a Milano

<SEGUE DALLA PRIMA DI MILANO
SANDRA BONZI

PER FORTUNA Xavier non solo conosce anche la lingua di noi comuni esseri mortali, ma è pure dotato di una buona dose di santa pazienza. Come potrebbe altrimenti studiare per anni e anni sempre e solo la struttura del nucleo? Non si annoia? «Assolutamente no! La materia è talmente complessa che non c'è la possibilità di stancarsi — risponde sorridendo — E l conferma il fatto che è dal pr mo decennio del XX secol da quando cioè fu scoperta struttura interna all'atom che siamo in molti a studia lo, senza annoiarci».

Tocca crederci. Anche per ché lui Fisica se l'è proprio ar data a cercare. Terminato il l ceo scientifico, infatti, aveva iniziato a lavorare. «Era inizia to come lavoretto estivo — ricorda — Un'azienda di materiali elettrici, niente di che. Se non che ci avevo preso velocemente gusto ad avere la mia indipendenza economica. Dopo quattro anni — però — l'idea che la mia vita fosse tutta lì mi ha spinto a rispolverare il mio antico interesse per il funzionamento delle cose e mi sono iscritto a Fisica». Pura passione perché — come dice sorridendo — «fisica si studia solo per devozione. Non si sceglie certo per i soldi».

E adesso, eccolo qui. Dal 2010 presso il dipartimento di Fisica dell'università Statale di Milano. «Prima con una borsa di studio dell'Istituto Nazionale di fisica nucleare, da due anni ricercatore a tempo determinato — spiega — Mi occupo di fisica teorica delle interazioni fondamentali, conduco le esercitazioni di elettromagnetismo». Direttamente da Barcellona. Cervellino in entrata. Perché? Dubito che in Italia i ricercatori abbiano vita più facile che in Spagna. Infatti. La precarietà come destino. Ma — siccome anche i fisici hanno un cuore — lui qui ci è arrivato per amore che, nel suo caso, prende il nome di Benedetta, di Roma ma conosciuta a Barcellona mentre lui sta facendo il dottorato e lei il suo post dottorato. Fisica, pure lei. Questione di elettroni, immagino. «Quando Benedetta ha trovato lavoro in Italia ho deciso di seguirla». Peccato che lei lo trovi prima a Torino e poi a Roma, mentre lui finisce in via Celoria. «Per due anni ho fatto il pendolare Torino-Milano, per altri due ho diviso le mie settimane tra qui e Roma. Poi, finalmente, anche Benedetta ha trovato lavoro a Milano, presso il Center for Genomic Science dell'Istituto Italiano di Tecnologia e da un paio di anni ci possiamo godere la città». Qui si muove rigorosamente in bici («Milano sarebbe una città perfetta per le due ruote se solo ci fossero più piste ciclabili e meno rotaie del tram», fa lunghe passeggiate a parco Lambro e se proprio deve usare l'auto, utilizza «l'ottimo servizio di carsharing». «Qui sto bene: questa è una città che funziona, è vivace, giovane e c'è la possibilità di trovare lavoro di ottimo livello — racconta — Peccato il cielo sia spesso così grigio».

Nessuna nostalgia di Barcellona? «Ovviamente mi mancano familiari e amici, la luce e un clima che non conosce veramente l'inverno. Ma qui ho trovato un gruppo con il quale lavoro molto bene». Possiamo considerarti dei nostri? «Chi può dirlo? — risponde con lo sguardo di chi ha quotidianamente a che fare con relatività spazio-temporale — Per me, ma forse non solo, non è il luogo il criterio prioritario della scelta: conta l'amore e il lavoro». Insomma, va' dove ti porta il cuore (e il protone).

IL CUORE
In Spagna ho conosciuto Benedetta, anche lei fisica, e l'ho seguita a Torino e poi a Roma

IL LAVORO
Alla base c'è una pura passione perché questa materia si studia solo per devozione, non per i soldi

IN AULA
Xavier è ricercatore a tempo determinato e si occupa di fisica teorica delle interazioni fondamentali

Va' dove ti porta il protone

In laboratorio serve il cervello ma il fisico ha anche un cuore

Just before NSKINS-2016

Why is this Meeting Different from any other Meeting?

Neutron Skins of Nuclei

Dear Colleague:

We are planning a two-week program at Mainz during the May 17-27, 2016 period that will gather the stakeholders interested in the determination of the neutron skins of nuclei (e.g., Ca and Pb) and their impact on the density dependence of the symmetry energy. As you may have heard, a successful one-week workshop aimed at defining the goals and expectations for the upcoming two-week program took place in Mainz in May, 2015.

Although various meetings of this sort have already been organized, it is the primary goal of the workshop to establish quantitatively the strengths and limitations of the various experimental techniques. This requires a detailed analysis of the systematic errors. Moreover, given that in most instances theory must be used to connect the measured experimental observable to the neutron skin, it also essential to quantify the statistical and systematic errors associated with the given theory. Finally, we aim to design a suite of experiments and the precision required to determine neutron skins in a manner that will provide meaningful constraints on the density dependence of the symmetry energy — and ultimately on astrophysical observables. Thus, our interest for you to present your results and actively shape the success of the program.

Given that the Mainz Institute for Theoretical Physics (MITP) limits the number of participants to the program, we urge you to apply as soon as possible by visiting the program webpage at: https://indico.mitp.uni-mainz.de/conferenceDisplay.py?confId=47. There, you will be able to find material of relevance to the program — which will be constantly updated — including some of the slides from the May, 2015 meeting.

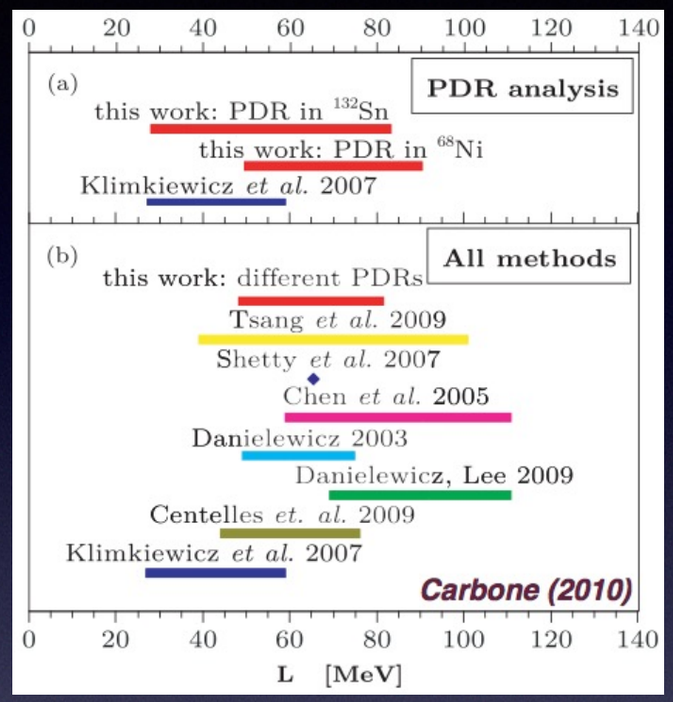
Kindest Regards

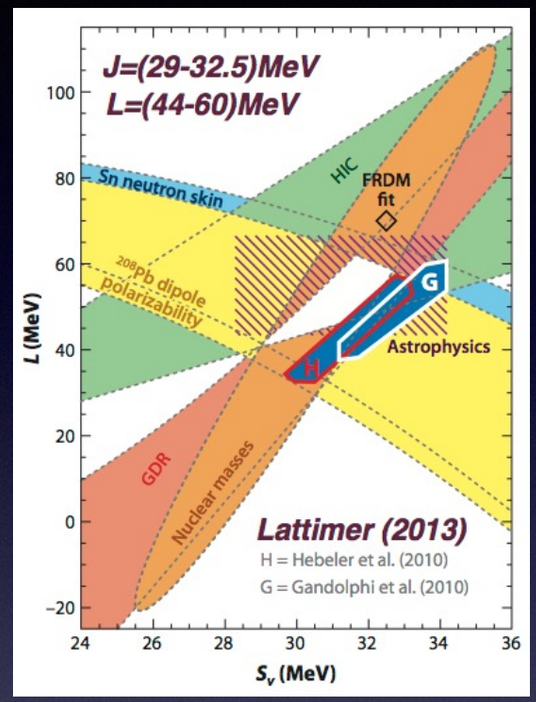
Chuck Horowitz, Jorge Piekarewicz, Concettina Sfienti, and Mark Vanderhaeghen

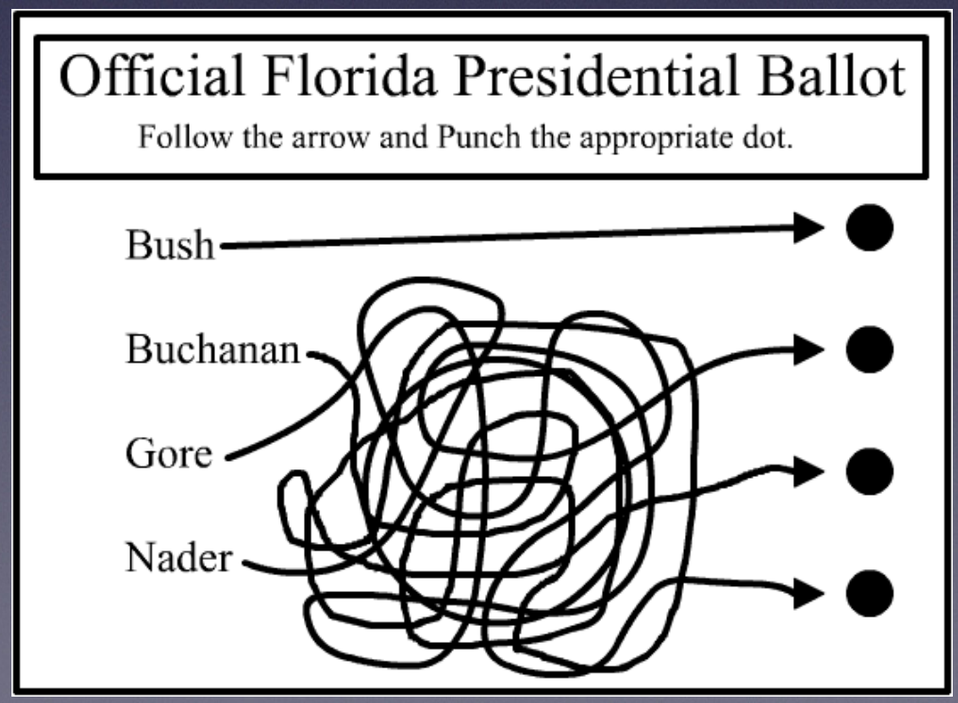
From Measurable Observables to the Neutron Skin

- What is actually measured?
  Cross section, asymmetry, spin observables, …
- How is the measured observable connected to the neutron skin?
- What are the assumptions implicit in making this connection?
  Impulse approximation, off-shell ambiguities, distortion effects, …
- How sensitive is the extraction of the neutron radius/skin to these assumptions?
- Quantitative assessment of both statistical and systematic errors

All observables are equal, but some observables are more equal than others … Pedigree!







Theory Informing Experiment

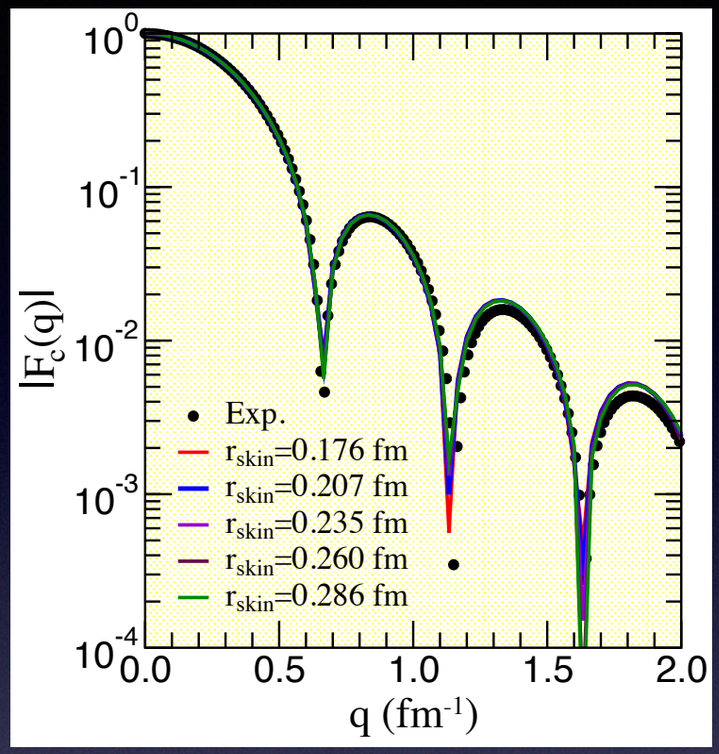
- Quantitative assessment of both statistical and systematic errors; theory must provide error bars!
  Uncertainty quantification and covariance analysis (theoretical errors & correlations)

- Precision required in the determination of the neutron radius/skin?
  - As precisely as “humanly possible” - fundamental nuclear structure property
  - To strongly impact Astrophysics?
  - What astrophysical observables to benchmark?

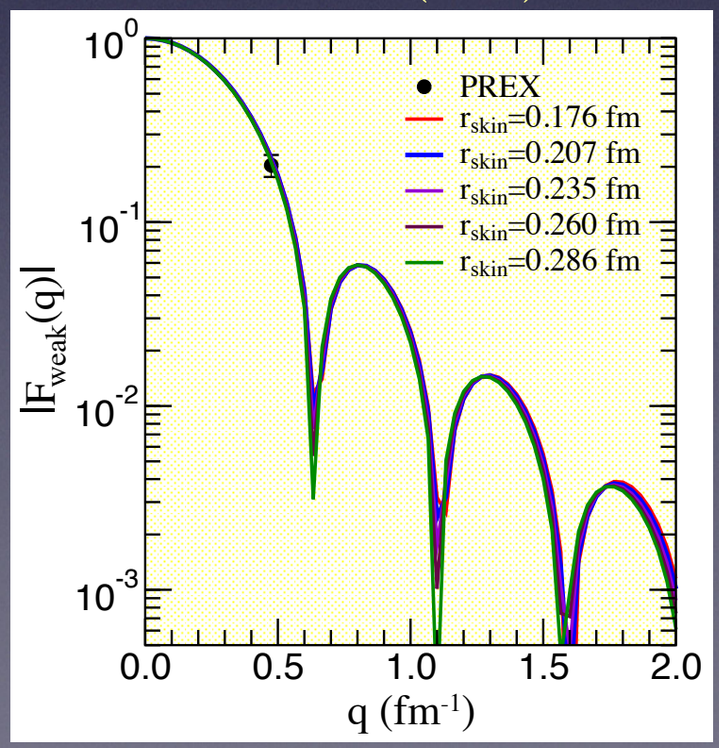
- Is there a need for a systematic study over “many” nuclei?
  PREX, CREX, SREX, ZREX, …

- Is there a need for more than one Q-square point?
  Radius and diffuseness … the whole form factor?

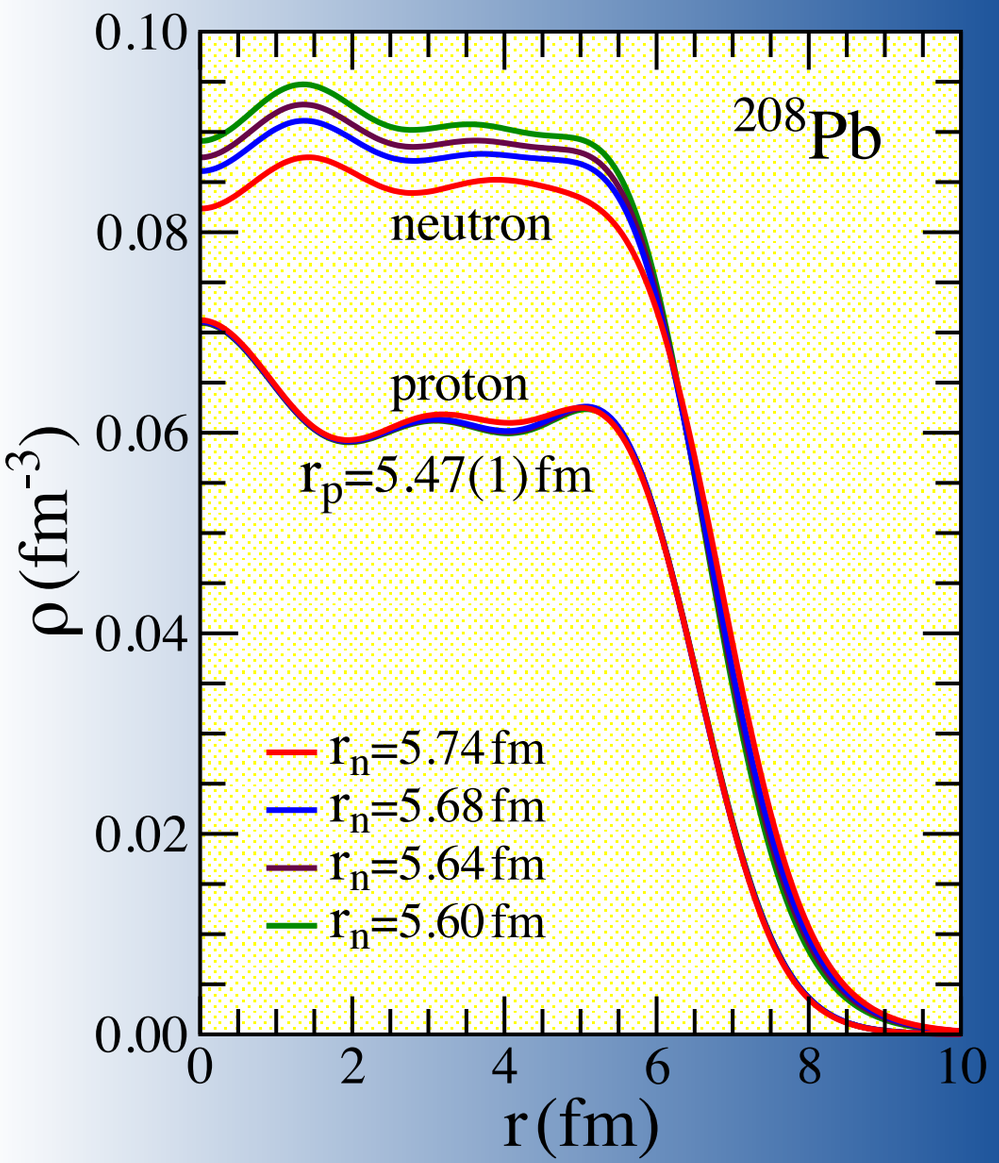
$R_{ch} = 5.5012(13)\ \mathrm{fm}$

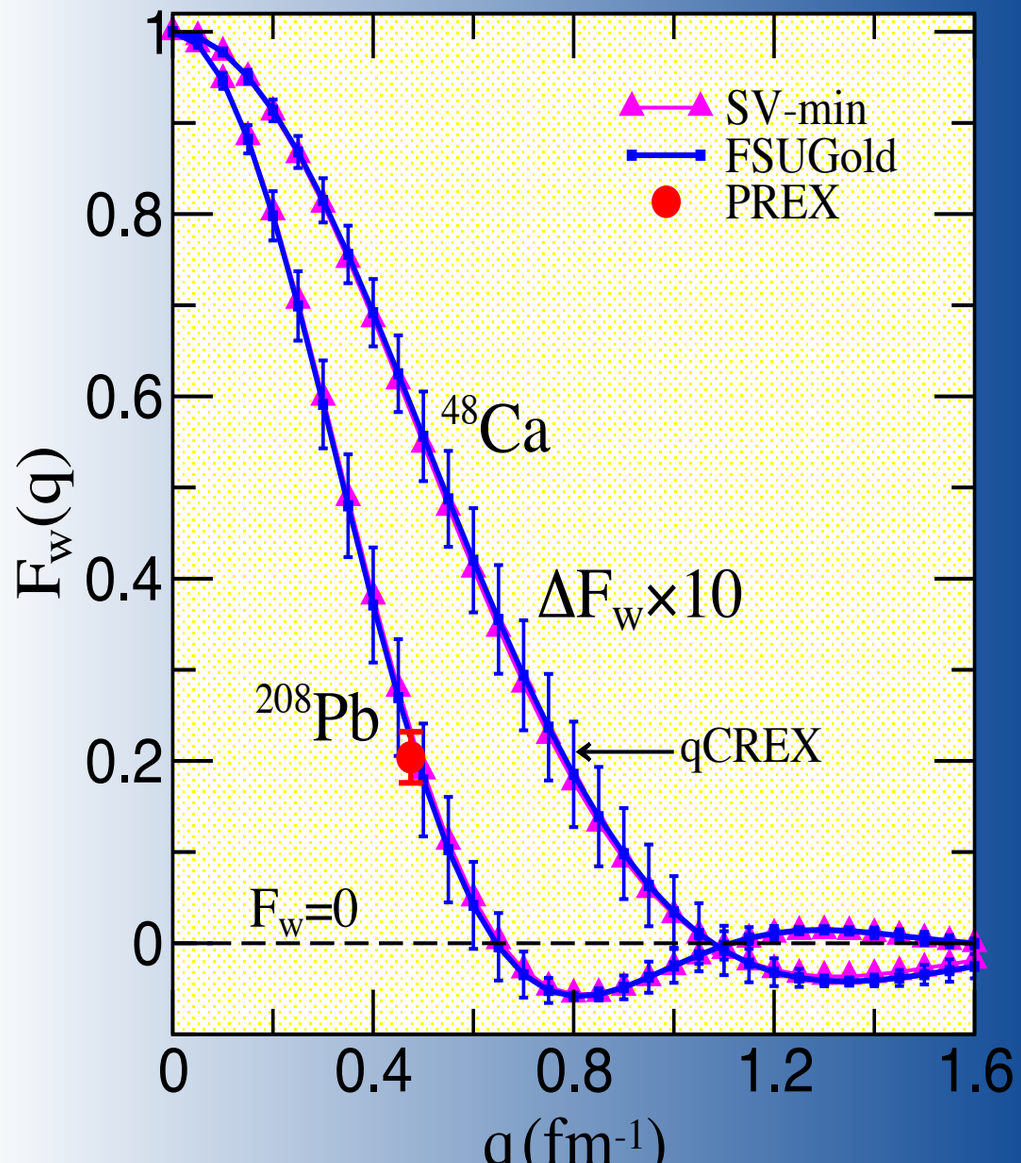


$R_{wk} = 5.826(181)\ \mathrm{fm}$



Uncertainty Quantification





Need both; Systematic and Statistical Theoretical Errors

Nuclear Structure, Error Bars, and Correlations: Statistical

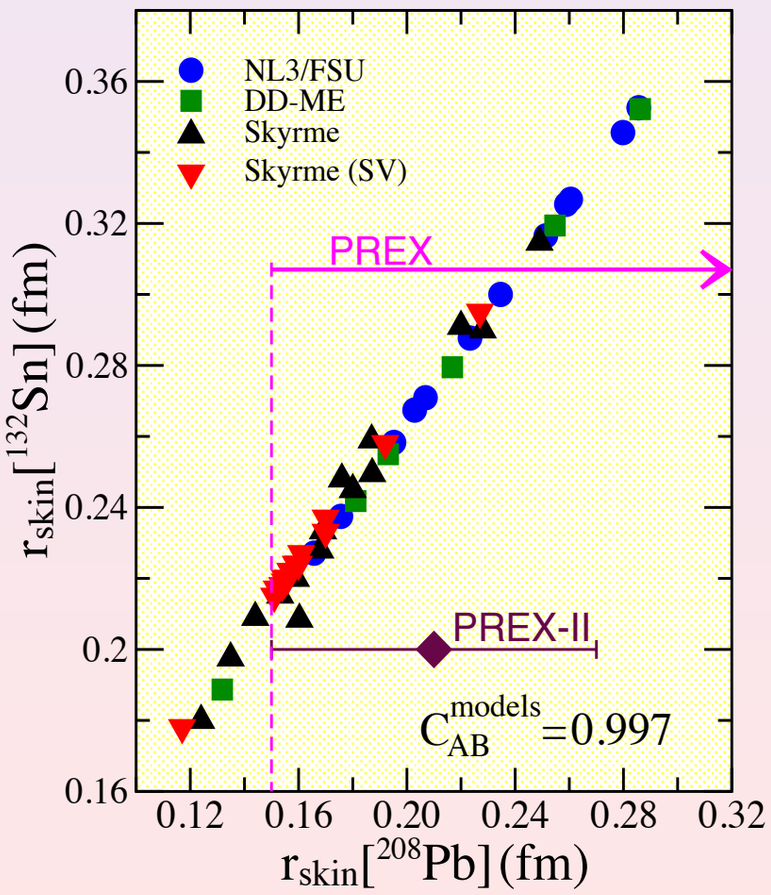
Reinhard-Nazarewicz, PRC81 (2010) 051303(R) Fattoyev-Piekarewicz, PRC86 (2012) 015802; PRC84 (2011) 064302

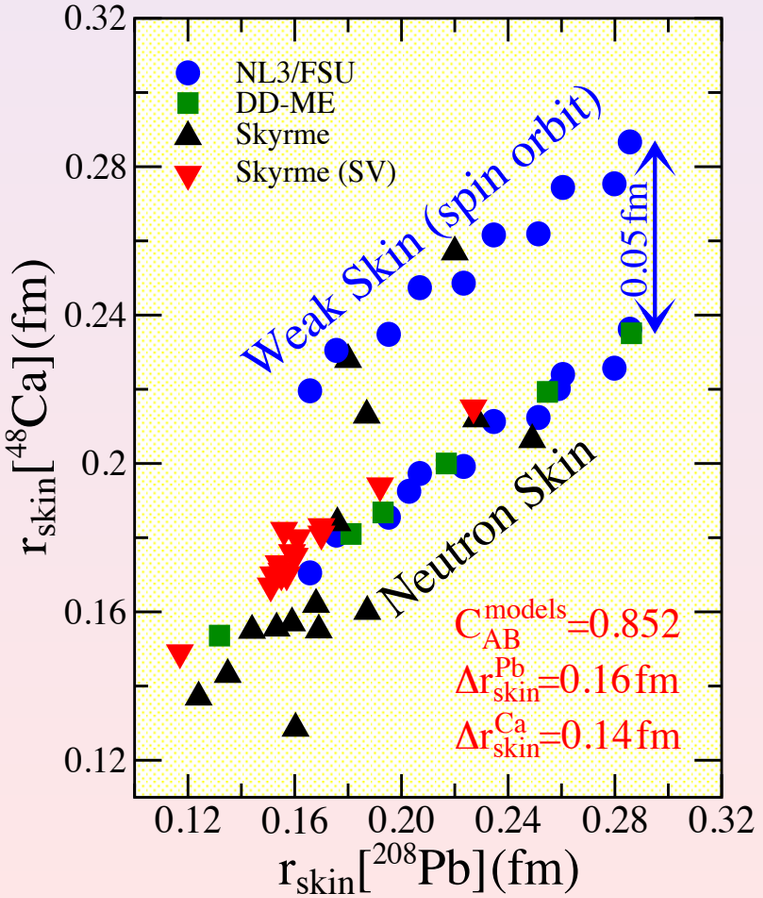
- Empirical constants determined from optimization of a quality measure

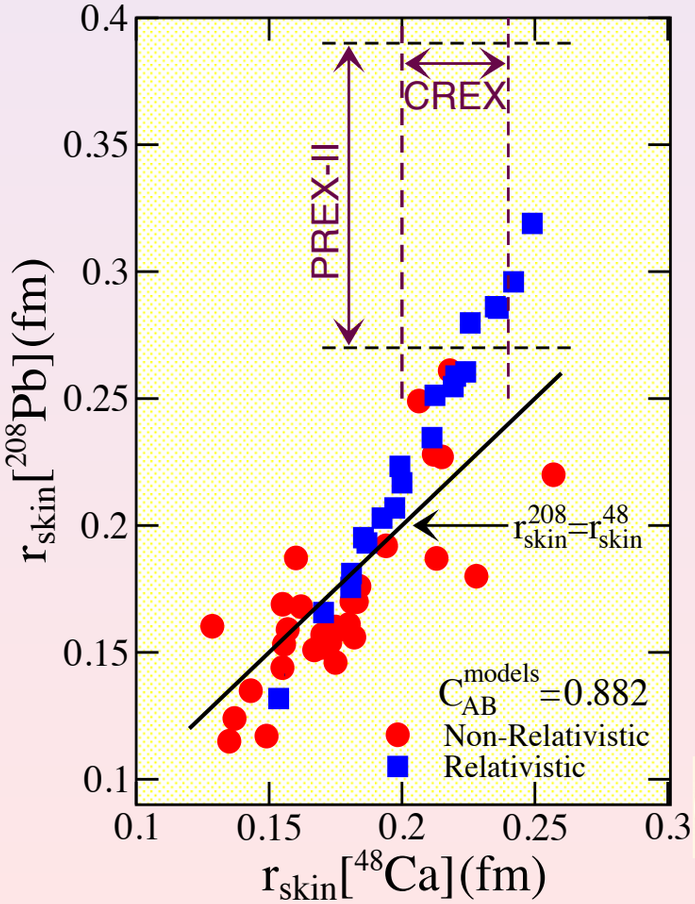
$$\chi^2(\mathbf{p}) = \sum_{n=1}^{N} \left(\frac{\mathcal{O}_n^{(\mathrm{th})}(\mathbf{p}) - \mathcal{O}_n^{(\mathrm{exp})}}{\Delta \mathcal{O}_n} \right)^2 = \chi^2(\mathbf{p}_0) + \mathbf{x}^T \hat{\Sigma}^{-1} \mathbf{x} + \ldots$$

- Predictions accompanied by meaningful theoretical errors
- Covariance analysis least biased approach to uncover correlations

$$\mathrm{Cov}(A,B) = \partial_i A \, \hat{\Sigma}_{ij} \, \partial_j B \; ; \qquad \mathrm{Corr}(A,B) = \frac{\mathrm{Cov}(A,B)}{\sqrt{\mathrm{Var}(A)\mathrm{Var}(B)}}$$

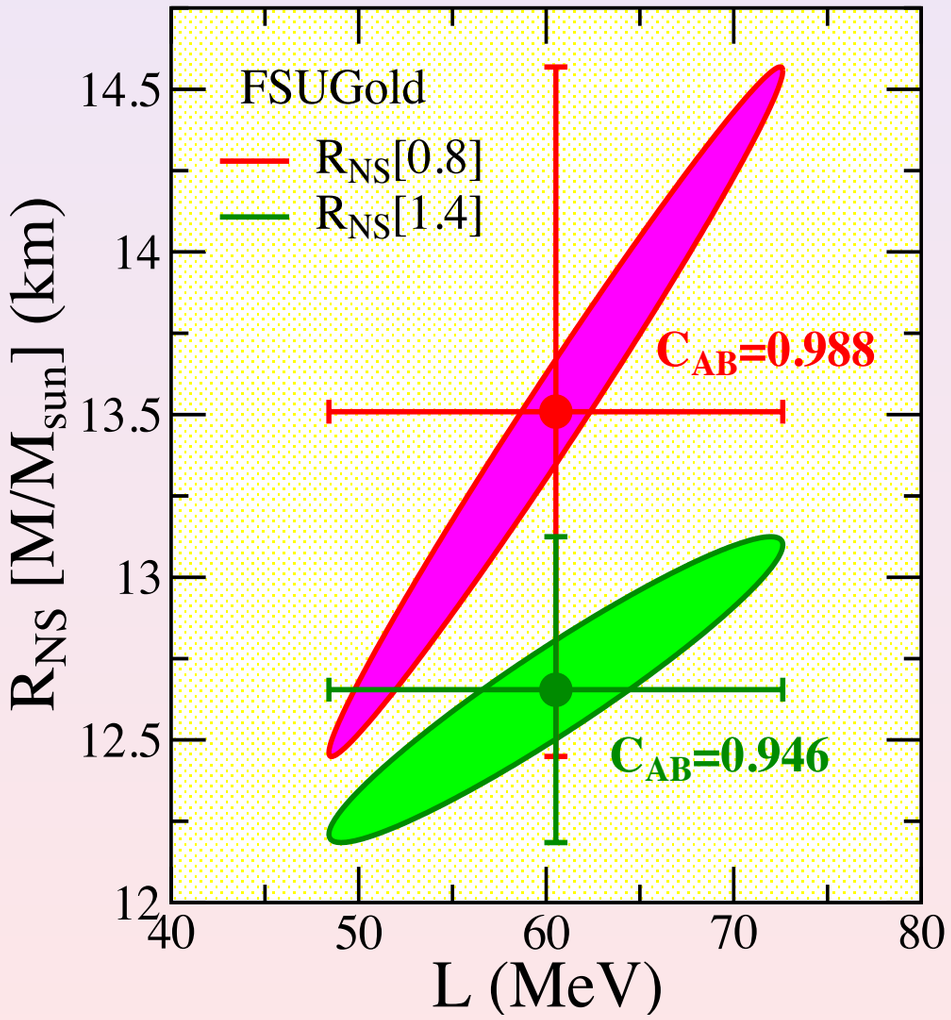


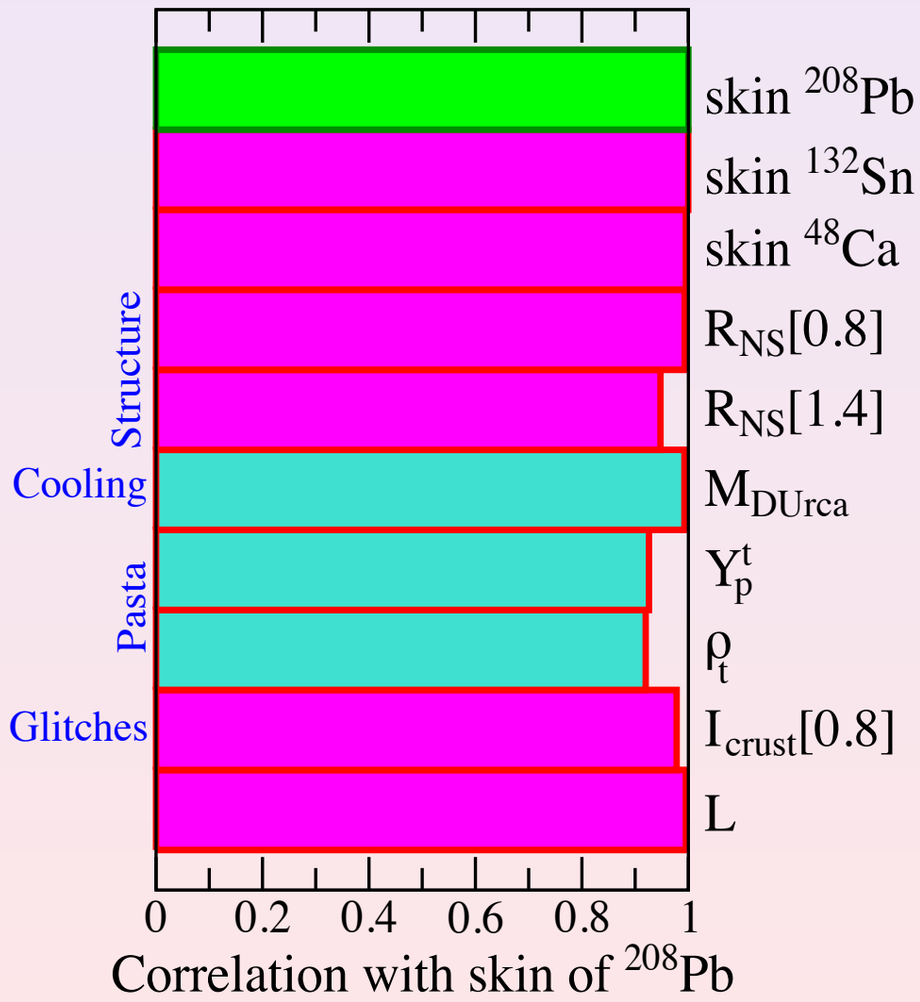




The Enormous Reach of the Neutron Skin: Covariance Analysis

- Neutron skin as proxy for neutron-star radii . . . and more!
- Calibration of nuclear functional from optimization of a quality measure
- New era: predictability typical – uncertainty quantification demanded
- Neutron skin strongly correlated to a myriad of neutron star properties:
  Radii, Enhanced Cooling, Moment of Inertia, . . .





A Path Forward in Uncertainty Quantification

ECT*

EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS
TRENTO, ITALY
Institutional Member of the ESF Expert Committee NuPECC

Castello di Trento ("Trint"), watercolour, 19,8 x 27,7, painted by A. Dürer on his way back from Venice (1495) — British Museum, London.

Information and Statistics in Nuclear Experiment and Theory ISNET-3

Trento, November 16-20, 2015

Main Topics

Estimation of statistical uncertainties of calculated quantities,
assessment of systematic errors,
validation and verification of extrapolations,
information content of observables with respect to current theoretical models,
statistical tools of nuclear theory and planning of future experiments,
Bayesian methods and computational techniques,
novel methods of optimization

Key Speakers

Anatoli Afanasjev (Mississippi State University, USA), Enrique Ruiz Arriola (University of Granada, Spain), Julia Bliss (Technical University of Darmstadt, Germany), Rick Casten (Yale University, USA), Gianluca Colo (University of Milan and INFN, Italy), Andreas Ekstrom (University of Tennessee, USA), Christian Forssen (Chalmers University of Technology, Sweden), Dick Furnstahl (Ohio State University, USA), Krzysztof Graczyk (University of Wroclaw, Poland), Tiia Haverinen (University of Jyväskylä, Finland), Dave Ireland (University of Glasgow, UK), Yannen Jaganathen (Michigan State University, USA), Markus Kortelainen (University of Jyvaskyla and Helsinki Institute of Physics, Finland), Amy Lovell (Michigan State University, USA), Rodrigo Navarro-Perez (Lawrence Livermore National Laboratory, USA), Witold Nazarewicz (Michigan State University, USA), Nils Paar (University of Basel, Switzerland), Alessandro Pastore (University of York, UK), Jorge Piekarewicz (Florida State University, USA), Scott Pratt (Michigan State University, USA), David Regnier (CEA Bruyères, France), Paul-Gerhard Reinhard (University of Erlangen, Germany), David Richards (Jefferson Laboratory, USA), Xavier Roca-Maza (University of Milan and INFN, Italy), Jan Ryckebusch (Ghent University, Belgium), Nicolas Schunck (Lawrence Livermore National Laboratory, USA), Achim Schwenk (TU Darmstadt), Paul Stevenson (University of Surrey, UK), Rebecca Surman (University of Notre Dame, USA), Bartlomiej Szpak (Insitute of Nuclear Physics PAN - Krakow), Sarah Wesolowski (Ohio State University, USA), Stefan Wild (Argonne National Laboratory, USA)

Organizers

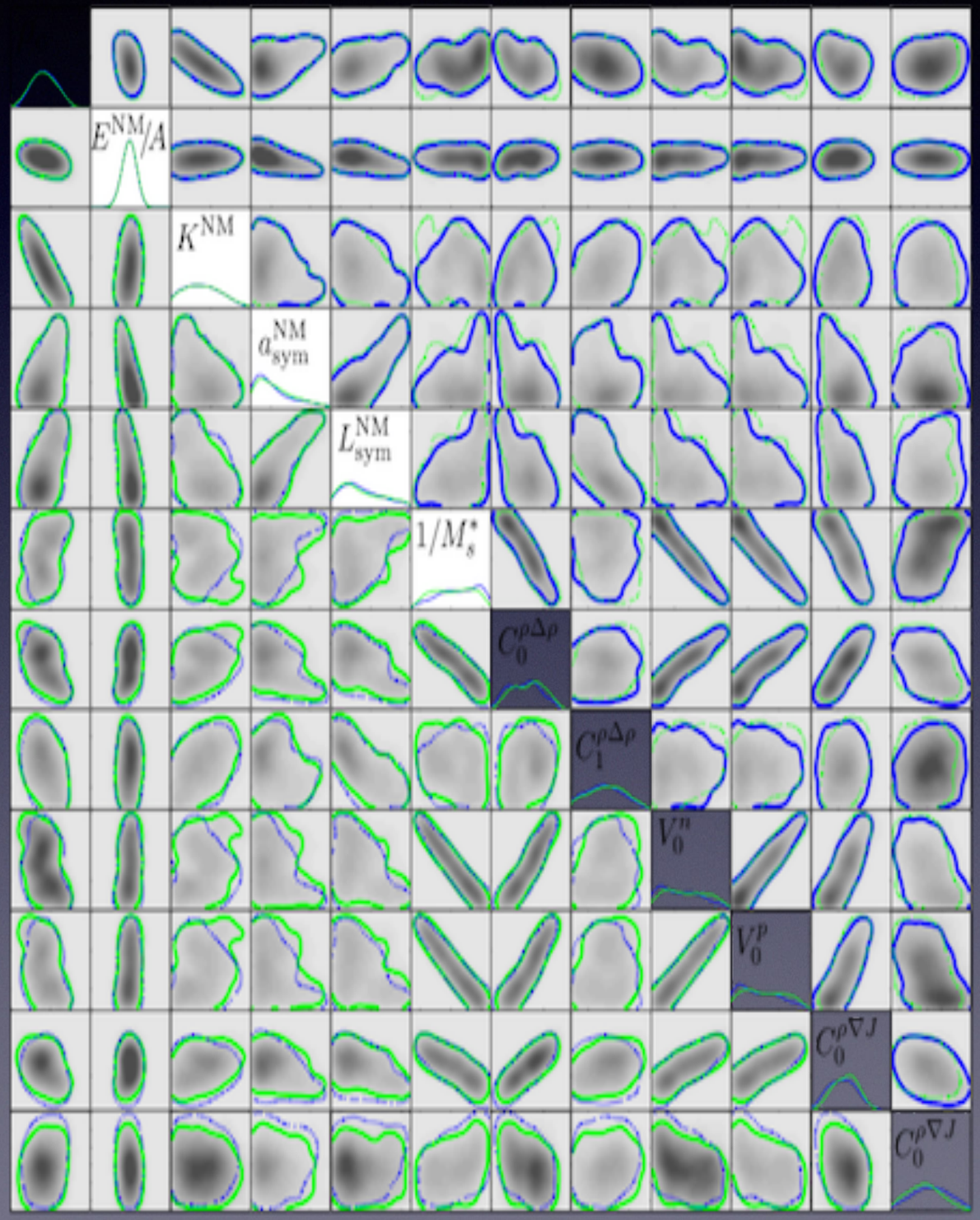
David Ireland (University of Glasgow)
Witold Nazarewicz (FRIB/NSCL - Michigan State University)
Bartlomiej Szpak (Insitute of Nuclear Physics PAN - Krakow)

Director of the ECT*: Professor Wolfram Weise (ECT*)

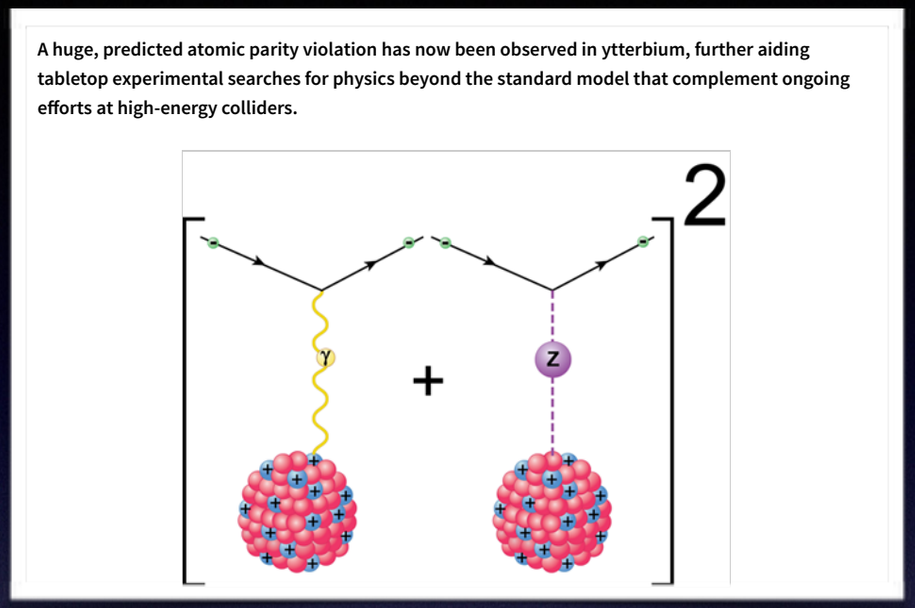
The ECT* is sponsored by the "Fondazione Bruno Kessler" in collaboration with the "Assessorato alla Cultura" (Provincia Autonoma di Trento), funding agencies of EU Member and Associated States and has the support of the Department of Physics of the University of Trento.

For local organization please contact: Gianmaria Ziglio - ECT* Secretariat - Villa Tambosi - Strada delle Tabarelle 286 - 38123 Villazzano (Trento) - Italy
Tel.:(+39-0461) 314721 Fax:(+39-0461) 314750, E-mail: **ect@ectstar.eu** or visit **http://www.ectstar.eu**

INT Program INT-16-2a
Bayesian Methods in Nuclear Physics
June 13 - July 8, 2016



Electroweak Measurements



PV elastic e-scattering

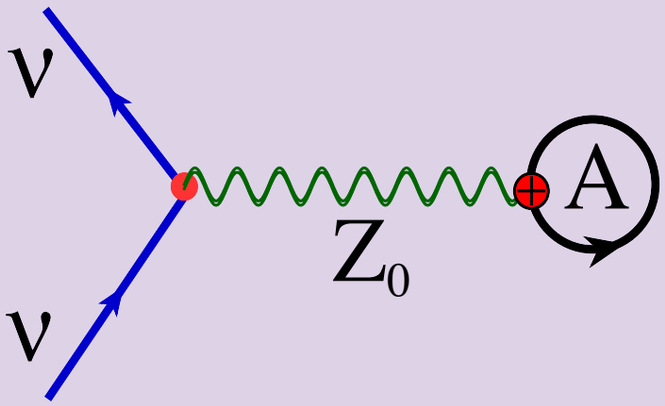
Atomic PV
measured in long-chains
(e.g., Yb) to eliminate
uncertainties in atomic theory

Enormously Clean …
Extraordinarily Expensive!

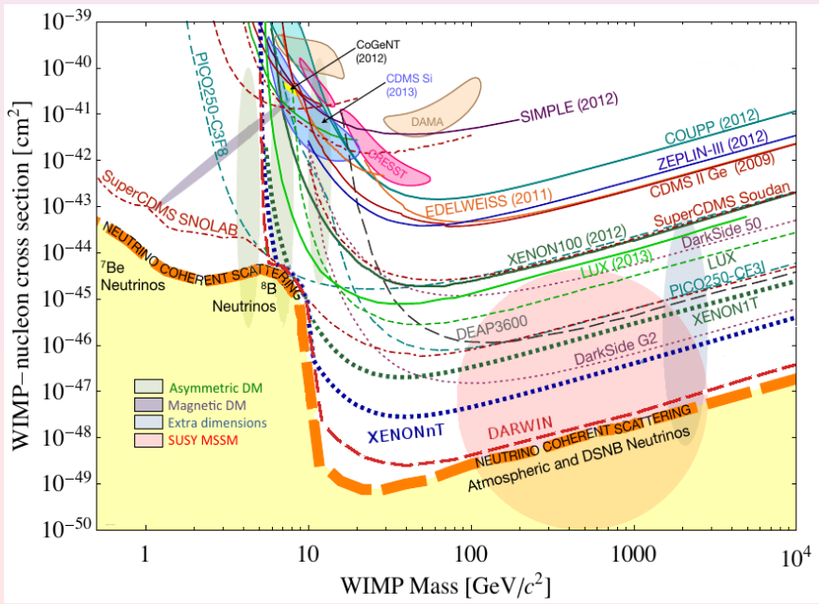
- Weak FF determined in a model independent way (exactly as the Charge FF)
- Very strongly coupled to nSkin …
- "Mild" model dependence going from FF to nSkin (Theory Homework)
- Measuring the FF at two (or more) points (Experiment/Theory Homework)
- Measuring the FF in several nuclei? (Experiment/Theory Homework)
- Understanding dispersive corrections (Theory Homework)

From Dark Matter to Neutron Stars

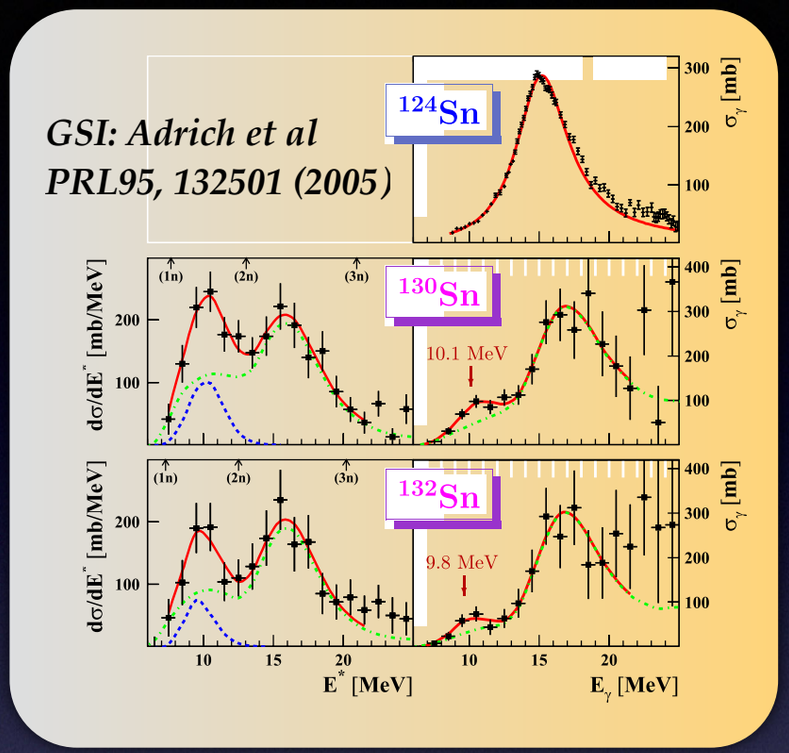
- Coherent elastic ν-Nucleus scattering has never been observed!
- Predicted shortly after the discovery of weak neutral currents
- Enormously challenging; must detect exceedingly slow recoils
- CEvNS (*pronounced "7s"*) are backgrounds for DM searches
- CEvNS is coherent ("large") as it scales $\sim N^2$
- "Piggybacking" on the enormous progress in dark-matter searches

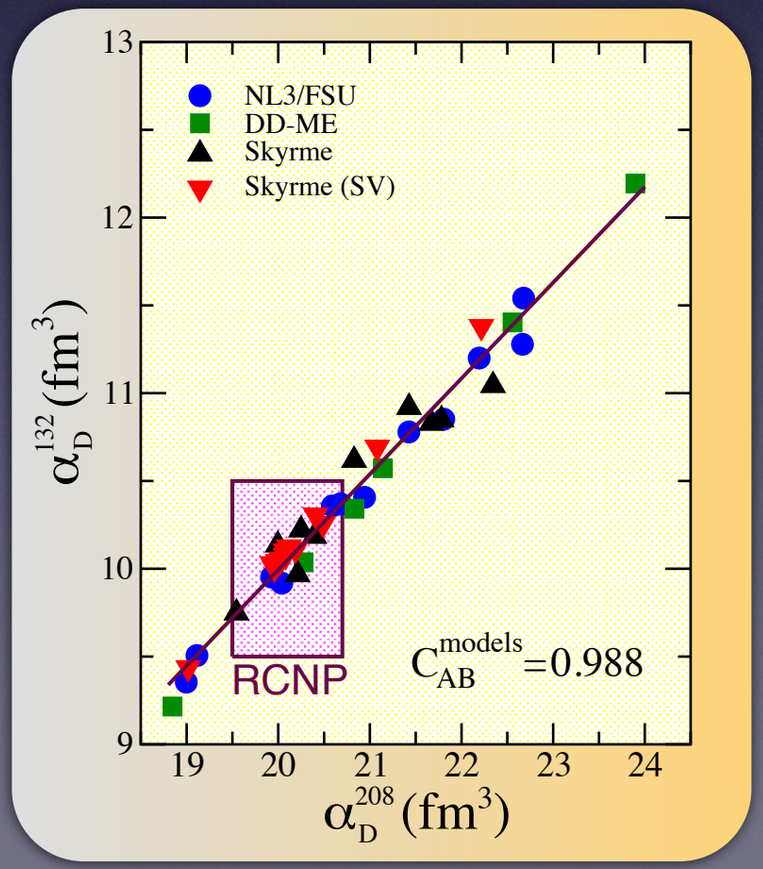


Coherent Elastic ν-Nucleus Scattering at the Spallation Neutron Source (ORNL) may become possible in the "not-so-distant" future



Electric Dipole Polarizability





Enormous progress in sight …

- High quality data on a variety of nuclei at RCNP & GSI, such as Pb, Sn-isotopes, Ni, Ca…
  (Experiment Homework)

- K,J, L, … are not experimental observables!
  Extract K by reproducing data on GMR
  Extract L by reproducing data on GDR
  (Theory Homework)

One single compelling theoretical picture!

- Impedance matching between theory and experiment; e.g., quasi-D contribution
  (Experiment/Theory Homework)

- Measure the full dynamic response to learn about FF
  (Experiment Homework)

$$S(q,\omega)$$

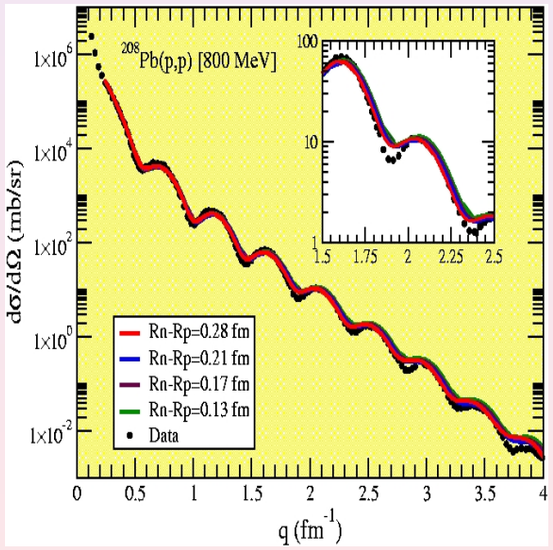
Coherent Elastic Pion and Proton Scattering

PREX-II and CREX as Anchors for FRIB Physics

"One of the main science drivers of FRIB is the study of nuclei with neutron skins 3-4 times thicker than is currently possible. FRIB will provide rare isotopes to explore the properties of halos and skins. JLab uses parity violation to measure the neutron radius of stable lead and calcium nuclei. Studies of neutron skins at JLab and FRIB will help pin down the behavior of nuclear matter at densities below twice typical nuclear density" 2013 Subcommittee Report to NSAC

The Traditional Approach: Proton-Nucleus Scattering

- FRIB will scatter protons from radioactive nuclei in inverse kinematics
- Large and uncontrolled uncertainties in the reaction mechanism
- Enormous ambiguities yield an energy dependent neutron skin
- FRIB must use PREX-II and CREX as calibrating anchors!



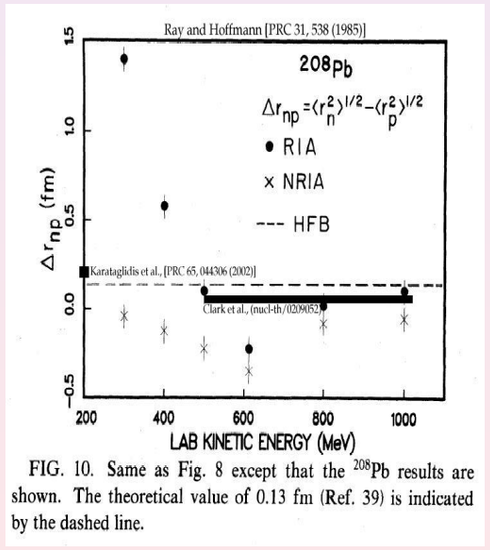
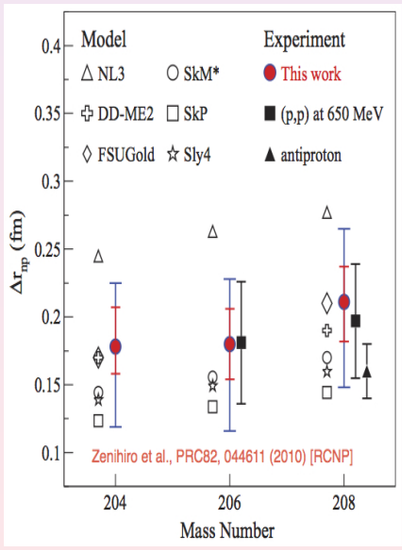


FIG. 10. Same as Fig. 8 except that the ^{208}Pb results are shown. The theoretical value of 0.13 fm (Ref. 39) is indicated by the dashed line.



Uncontrolled Uncertainties

- Impulse Approximation
- Off-shell Ambiguities
- Distortion Effects
- . . .

Potentially very useful observables
Difficult Experiment/Theory Homework.
Very large skins of unstable neutron-rich nuclei a critical new direction!

$$\mathcal{M}_{PWIA} \sim A_1(s,t)\rho_T(Q)/Q \approx A_1(s,t)\rho_V(Q)$$

What else ?

Extra Credit Homework and Planning

- What worked in 2015; what did not?
- Deliverables for May 2016?
- Breadth vs Depth for May 2016?
- Goals for two weeks in May 2016?
- . . .

So Far!

PHYSICAL REVIEW C **92**, 014313 (2015)

Full weak-charge density distribution of ^{48}Ca from parity-violating electron scattering

Z. Lin and C. J. Horowitz
Center for the Exploration of Energy and Matter and Department of Physics, Indiana University, Bloomington, Indiana 47405, USA
(Received 25 May 2015; published 20 July 2015)

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **92**, 031305(R) (2015)

Dipole polarizability of ^{120}Sn and nuclear energy density functionals

T. Hashimoto,[1,*] A. M. Krumbholz,[2] P.-G. Reinhard,[3] A. Tamii,[1] P. von Neumann-Cosel,[2,†] T. Adachi,[4] N. Aoi,[1] C. A. Bertulani,[5] H. Fujita,[1] Y. Fujita,[1] E. Ganioğlu,[6] K. Hatanaka,[1] E. Ideguchi,[1] C. Iwamoto,[1] T. Kawabata,[7] N. T. Khai,[8] A. Krugmann,[2] D. Martin,[2] H. Matsubara,[9] K. Miki,[1] R. Neveling,[10] H. Okamura,[1] H. J. Ong,[1] I. Poltoratska,[2] V. Yu. Ponomarev,[2] A. Richter,[2] H. Sakaguchi,[1] Y. Shimbara,[11] Y. Shimizu,[12] J. Simonis,[2] F. D. Smit,[10] G. Süsoy,[6] T. Suzuki,[1] J. H. Thies,[13] M. Yosoi,[1] and J. Zenihiro[12]

ARTICLES
PUBLISHED ONLINE: 2 NOVEMBER 2015 | DOI: 10.1038/NPHYS3529
nature physics

Neutron and weak-charge distributions of the ^{48}Ca nucleus

G. Hagen[1,2]*, A. Ekström[1,2], C. Forssén[1,2,3], G. R. Jansen[1,2], W. Nazarewicz[1,4,5], T. Papenbrock[1,2], K. A. Wendt[1,2], S. Bacca[6,7], N. Barnea[8], B. Carlsson[3], C. Drischler[9,10], K. Hebeler[9,10], M. Hjorth-Jensen[4,11], M. Miorelli[6,12], G. Orlandini[13,14], A. Schwenk[9,10] and J. Simonis[9,10]

PHYSICAL REVIEW C **92**, 064304 (2015)

Neutron skin thickness from the measured electric dipole polarizability in ^{68}Ni, ^{120}Sn, and ^{208}Pb

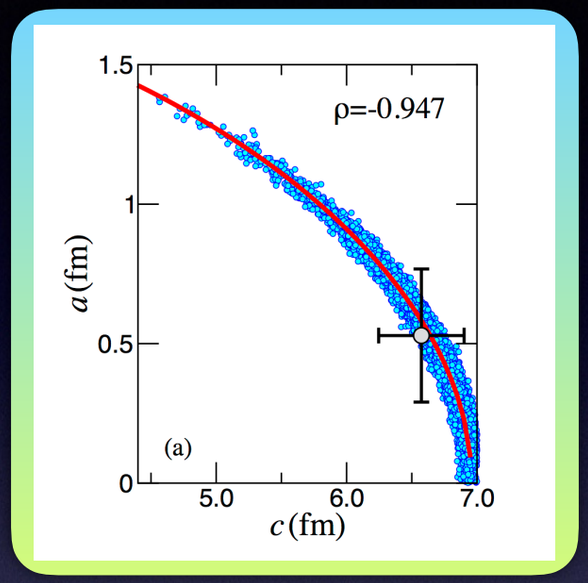
X. Roca-Maza,[1,*] X. Viñas,[2] M. Centelles,[2] B. K. Agrawal,[3] G. Colò,[1] N. Paar,[4,5] J. Piekarewicz,[6] and D. Vretenar[5]

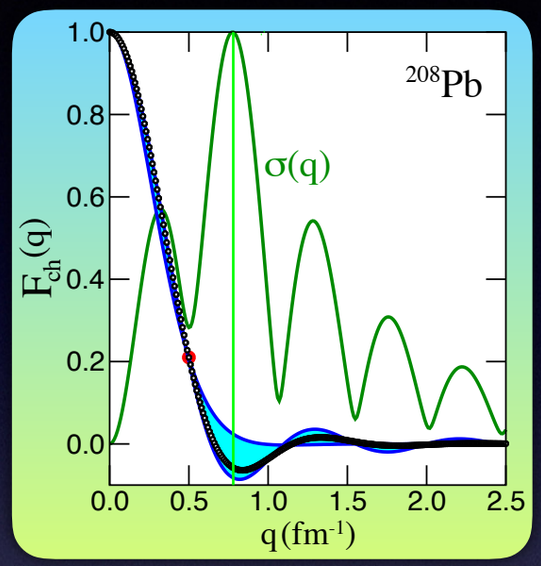
The power of two: Assessing the impact of a second measurement of the weak-charge form factor of ^{208}Pb

J. Piekarewicz,[1,*] A. Linero,[2,†] P. Giuliani,[1,‡] and E. Chicken[2,§]
[1] *Department of Physics, Florida State University, Tallahassee, FL 32306*
[2] *Department of Statistics, Florida State University, Tallahassee, FL 32306*
(Dated: April 27, 2016)

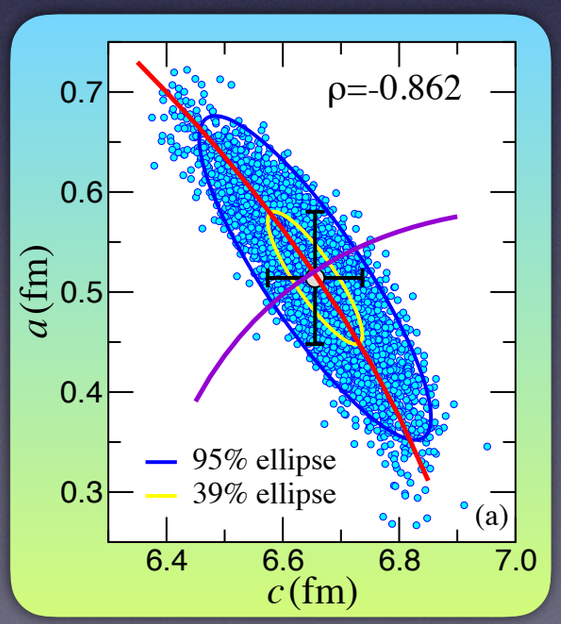
The power of two: Assessing the impact of a second measurement of the weak-charge form factor of ^{208}Pb

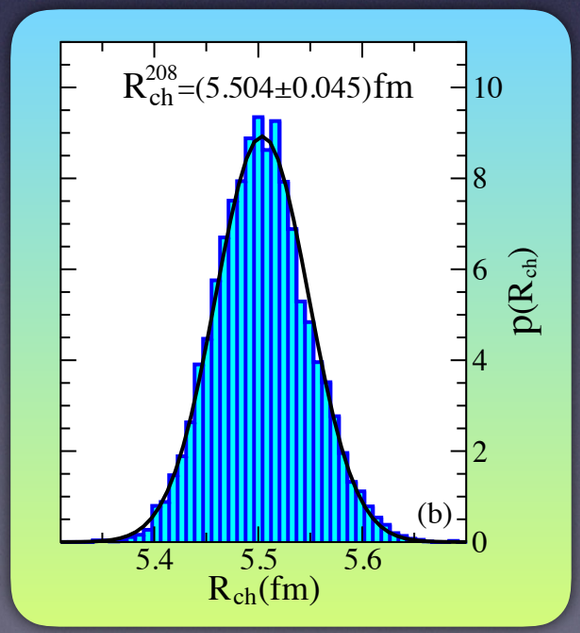
One Point: PREX/PREX-II/SPREX





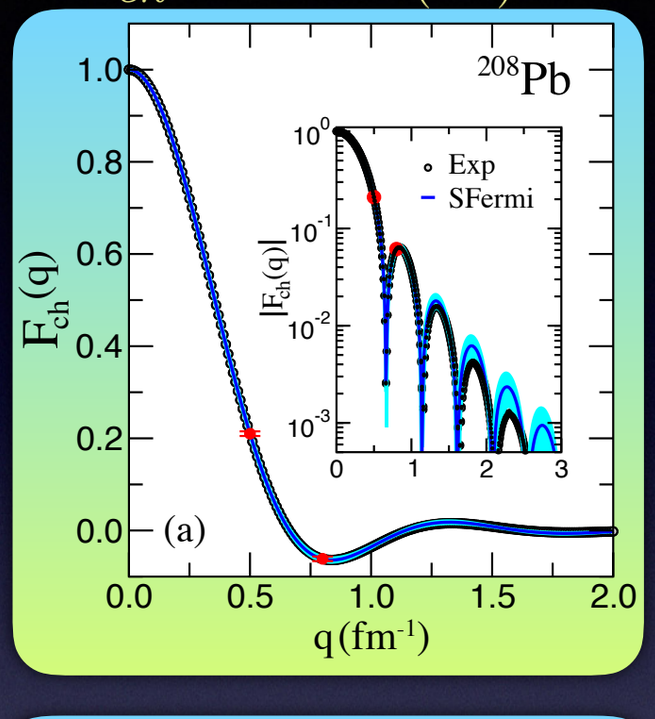
Two Points: Hyper-PREX

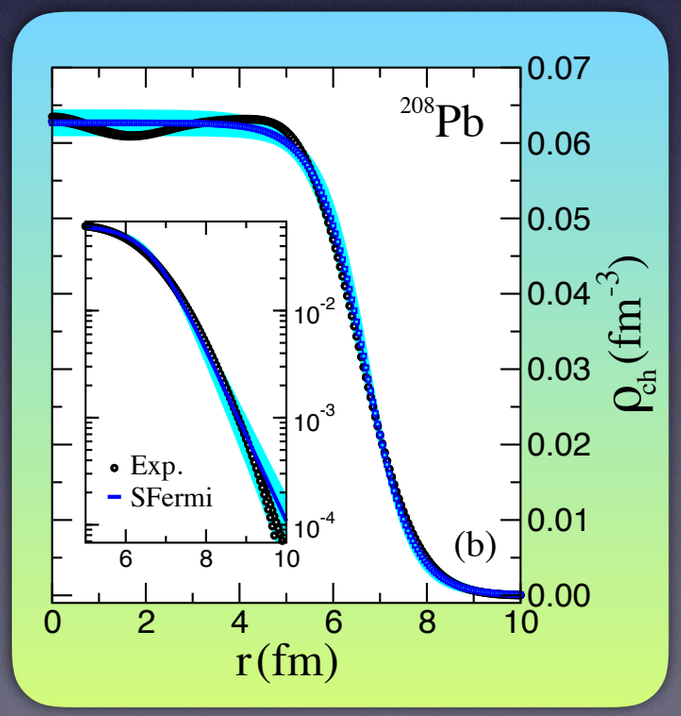




„Symmetrized" Fermi function

$R_{ch} = 5.5012(13)$ fm



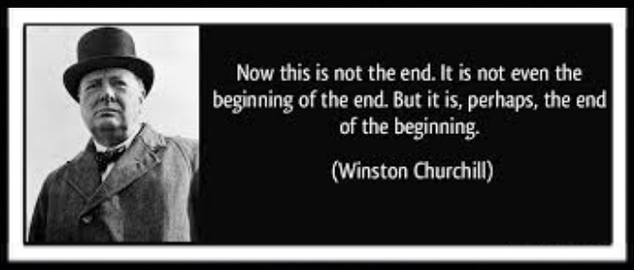


Charge FF as a proxy for weak FF

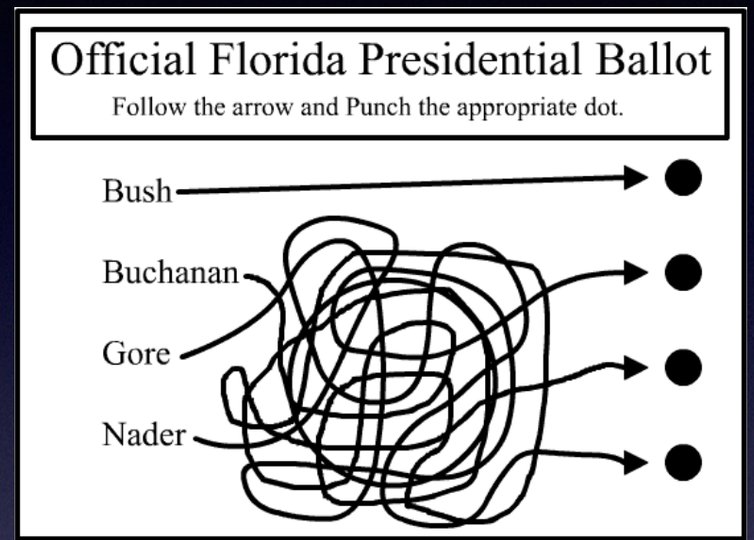
$$F_{\rm SF}(q) = \frac{3}{qc\Big((qc)^2 + (\pi q a)^2\Big)}\left(\frac{\pi q a}{\sinh(\pi q a)}\right)\left[\frac{\pi q a}{\tanh(\pi q a)}\sin(qc) - qc\cos(qc)\right] \rightarrow \frac{\cos(qc+\delta)}{qc}e^{-\pi q a}$$

- The End of the Beginning: MITP, May 4-7, 2015
- The Beginning of the End: MITP, May 17-27, 2016
- The End: Sometime around the beginning of 2017

Culminating with a Topical Review in JPG



- What is actually measured?
  Cross section, asymmetry, spin observables, …
- How is the measured observable connected to the neutron skin?
- What are the assumptions implicit in making this connection?
  Impulse approximation, off-shell ambiguities, distortion effects
- How sensitive is the extraction of the neutron radius/skin to these assumptions?
- Quantitative assessment of both statistical and systematic errors



Let's untangle the knots!

Mainz Institute for Theoretical Physics

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Our gratitude to MITP and all of you for coming;
let's have a fun and productive meeting!