TRIUMF

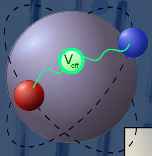
Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

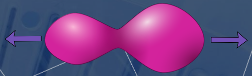
FRIB Day 1:
Nuclear Structure Theory

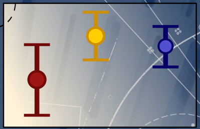
Ragnar Stroberg

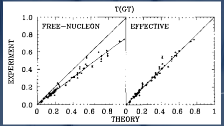
TRIUMF & Reed College

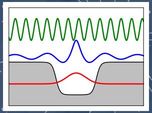
FRIB Day 1 Science Workshop
Low-Energy Community Meeting
Argonne National Laboratory
August 2, 2017

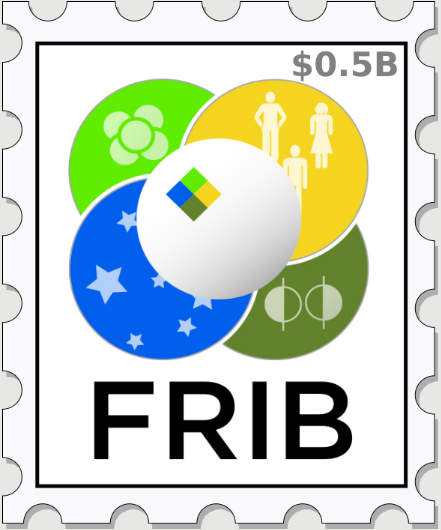






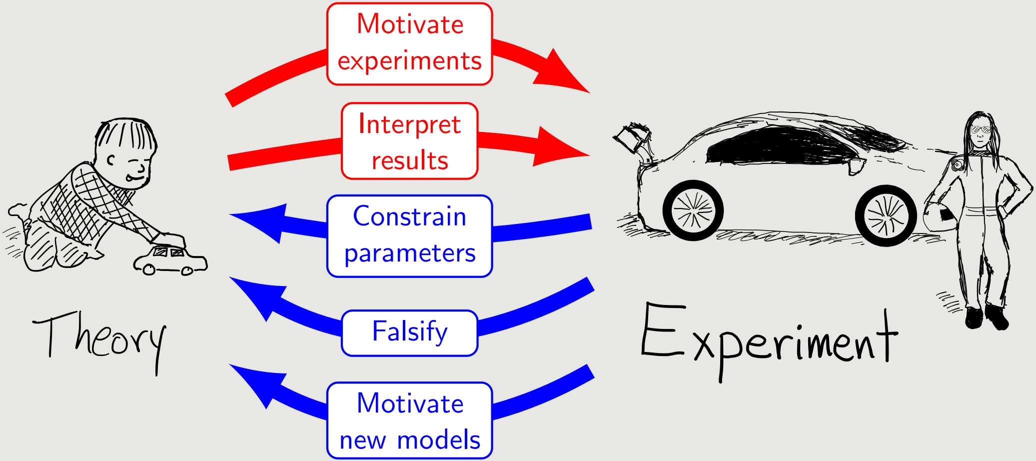


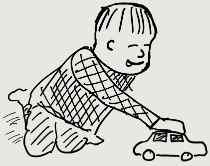




How can we avoid "femtoscale philately"?

How science works





Theory

Motivate experiments

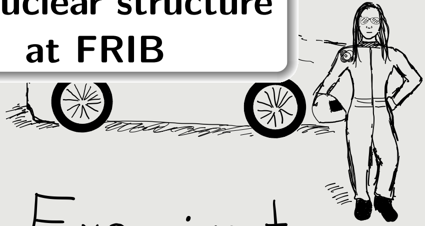
Interpret results

Constrain parameters

Falsify

Motivate new models

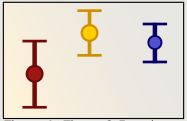
Theory priorities for nuclear structure at FRIB

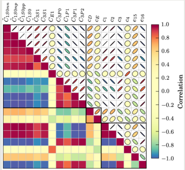


Experiment

Quantified theoretical uncertainties

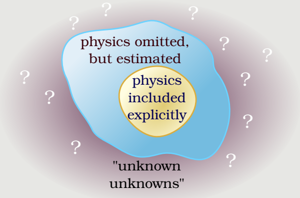
"Does my model agree with the data?"





The way forward:

- Effective (field) theories with reliable power counting
- Evaluate uncertainty due to parameter fitting (this can also be done in phenomenology)
- Many-body uncertainty: what is perturbative?
- ✓ Extrapolate to IR convergence



Connection to experiment:

- Theory uncertainty is mandatory for a meaningful comparison

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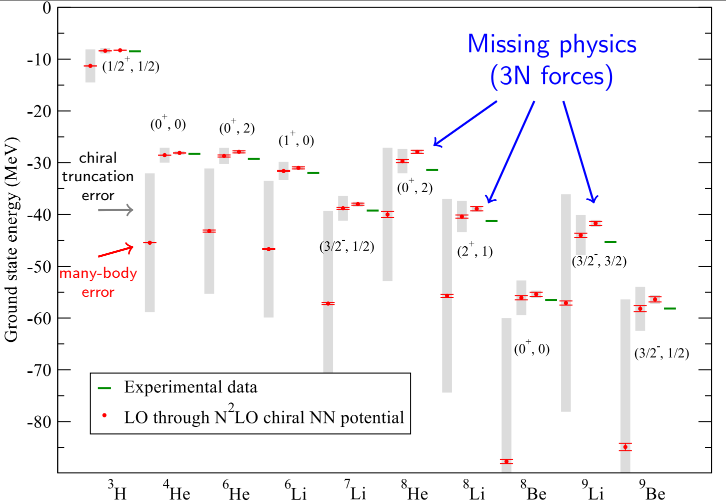
Furnstahl, More, and Papenbrock 2014; Carlsson et al. 2016; Dyhdalo, Bogner, and Furnstahl 2017; Nogga, Timmermans, and VanKolck 2005; Epelbaum and Meißner 2013...; LENPIC figure courtesy James Vary



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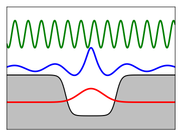
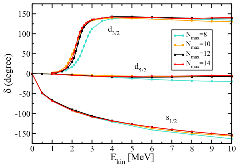
Priorities for FRIB theory

A consistent framework for bound states, resonances, and reactions





The way forward:

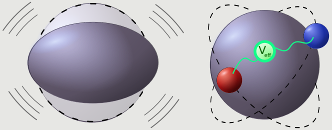
- ◷ Ab initio methods in the Berggren basis
- ◷ Consistently transform operators
- ◷ Ab initio optical model potentials
- ✓ Extend NCSM to continuum (limited to p shell)
- ✓ Clusters, α-α scattering with lattice-EFT

Connection to experiment:

- More meaningful interpretation of transfer/knockout reaction data
- Dripline physics (what can we learn?)
- Halo physics (what can we learn?)
- Elastic scattering can help constrain phenomenological optical potentials

Rotureau et al. 2017; Vorabbi, Finelli, and Giusti 2016; Navrátil et al. 2016; Mahzoon et al. 2014; Freer et al. 2017; Lee 2017. . .

Consistent treatment of collective and single-particle degrees of freedom



The way forward:

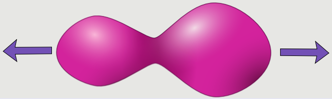
- ✓ Employ large shell model spaces
- Find efficient truncation schemes (e.g. symplectic symmetry)
- Connect DFT with microscopic methods

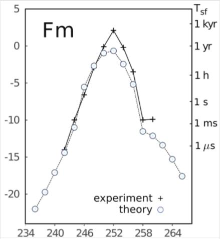
Connection to Experiment:

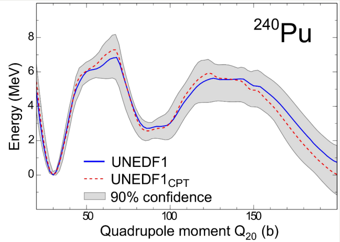
- Shape coexistence
- Shell evolution
- How can theory utilize new information?

Caurier et al. 2005; Drut, Furnstahl, and Platter 2010; Shimizu et al. 2017; Draayer et al. 2015...

Predictive theory of nuclear fission







The way forward:

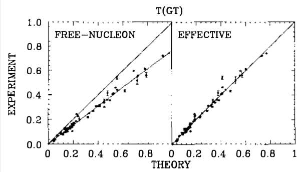
- ✓ (Time-dependent) Density functional theory
- ✓* Evaluate uncertainties
- Understand dissipation (coupling of intrinsic and collective motion)
- Connect DFT with microscopic methods

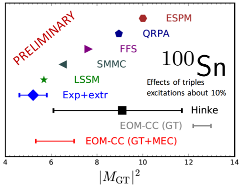
Connection to Experiment:

- Deformation properties of neutron-rich nuclei can help fix DFT parameters
- Confrontation with experiment can motivate new EDF parameterizations

McDonnell et al. 2015; Kortelainen et al. 2014. . . ; figures courtesy N. Schunck

Understand quenching of g_A





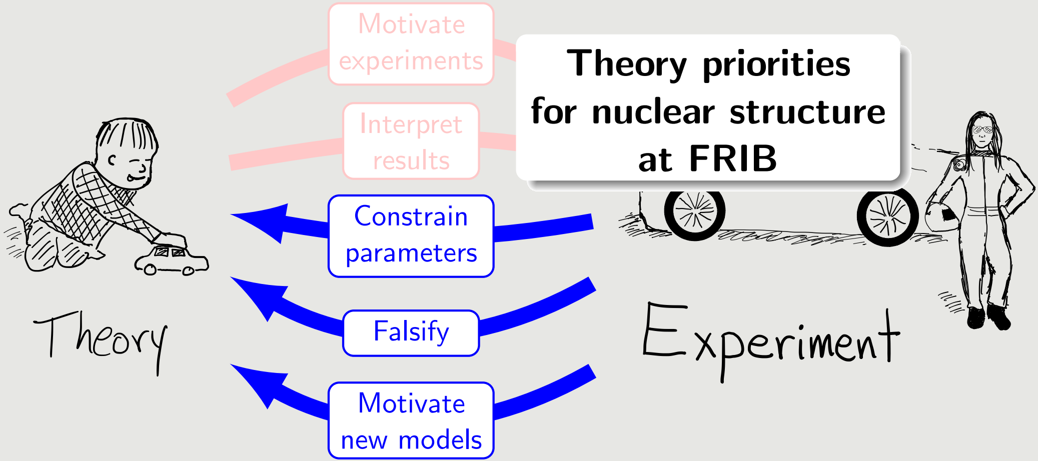
The way forward:

- ✓ Consistent treatment of interaction and transition operator
- Include 2b currents from chiral EFT
- Evaluate uncertainties

Connection to Experiment:

- High importance for neutrinoless $\beta\beta$ decay searches
- Need precision measurements of large GT matrix elements
- Values for closed-shell nuclei will be particularly helpful
- Examples: ^{34}Si, ^{48}Ni, ^{100}Sn

Brown and Wildenthal 1988; Hinke et al. 2012; Menéndez, Gazit, and Schwenk 2011; Ekström et al. 2015; Parzuchowski et al. 2017...; ^{100}Sn figure courtesy G. Hagen


Motivate experiments
Interpret results
Constrain parameters
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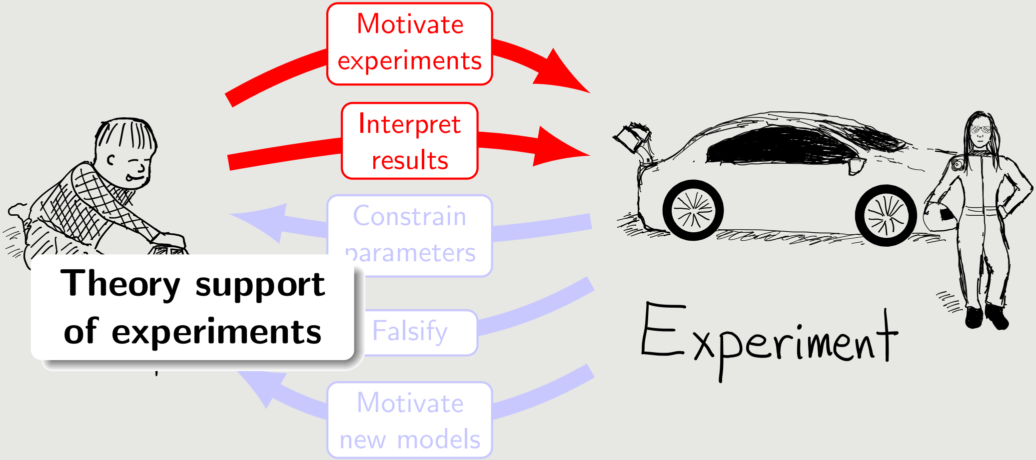
Theory priorities for nuclear structure at FRIB
Theory
Experiment


Motivate experiments
Interpret results
Constrain parameters
Falsify
Motivate new models
Theory support of experiments
Experiment

Are we prepared?

- Much of the theory needed for FRIB is identical to that needed for current experiments at NCSL, RIKEN, GANIL, etc.
- Are we happy with that theory?
- If not, these two tasks are indispensible
- Do we have the people power do to it?

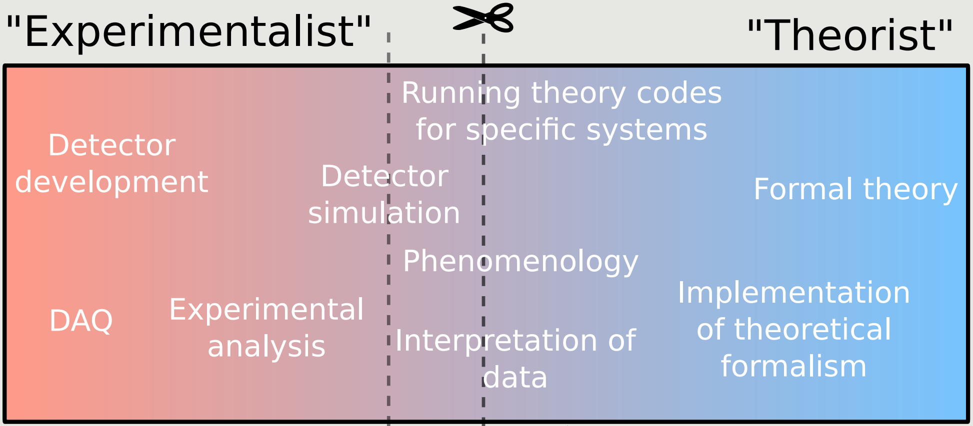
1) Uncertainties

- UQ for phenomenology?
- Parameter determination
- Chiral power counting
- Truncation of many-body problem
- Information content of observables

2) Unified structure and reactions

- Phenomenological optical potentials
- Ab initio optical potentials
- Consistent treatment of $a^\dagger$ operators
- Make truncations more systematic with, e.g. operator product expansion?

Job descriptions



Theorists should provide user-friendly codes. Experimentalists should learn to use them.

Particle physics

Nuclear physics

NNDC for theory?
(See e.g. MassExplorer)

Open questions:

- Where are the driplines?
- Where are the shell and sub-shell closures located? (model-dependent?)
- How does collectivity emerge? (model-dependent?)

- DFT, LSSM, ab initio IMSRG/SCGF/CC/NCSM/QMC can address these
- But without uncertainties, we have uncontrolled model dependence
- UQ is a major undertaking ⇒ paradigm shift in nuclear physics
- Achieving this in time for FRIB will require concerted effort

Thank you!

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