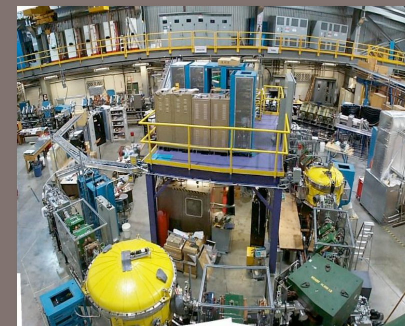
TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

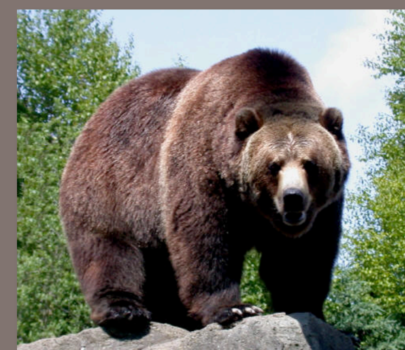


Changing the Questions

TRIUMF

May 18, 2010

Byron K. Jennings | TRIUMF



TRIUMF

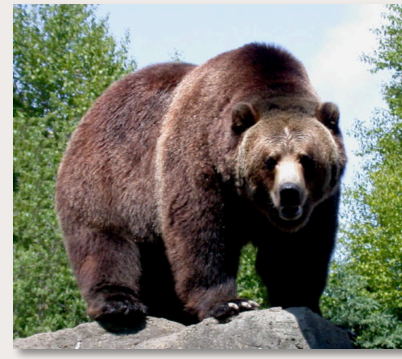
Outline

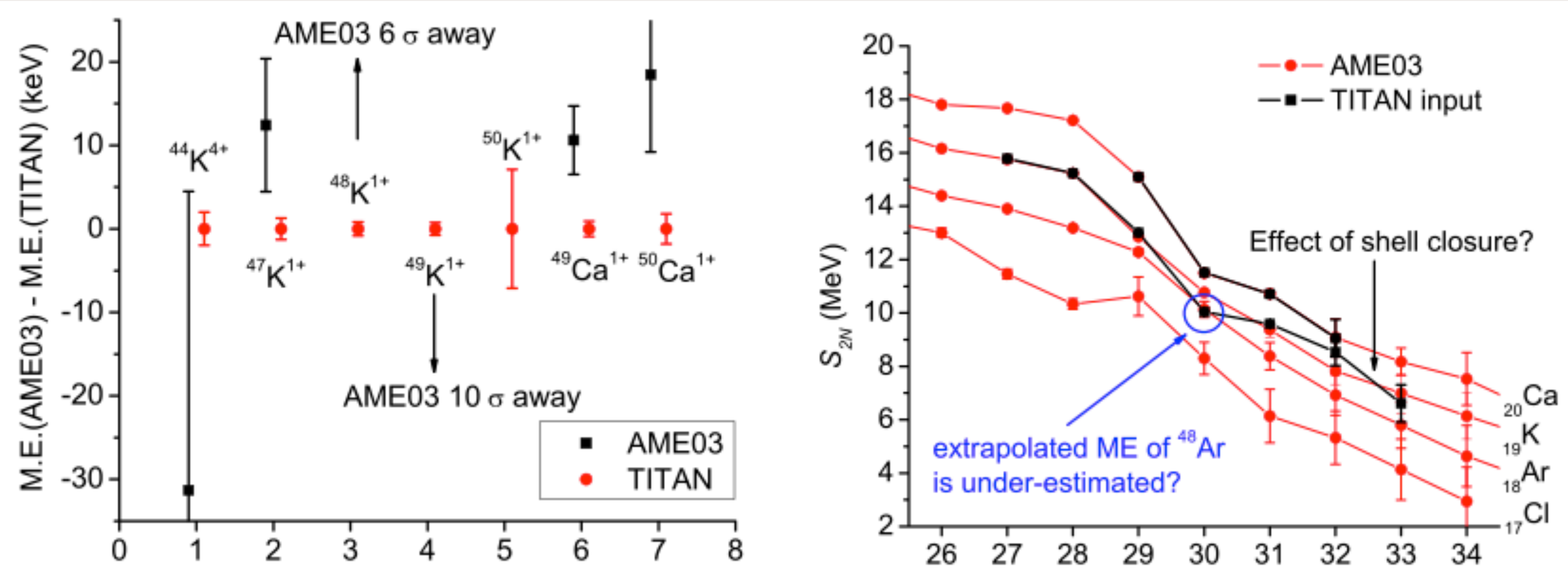
- The Vision
  - Changing the questions.
    - Not just answering them.
    - Not just doing better than others.
- Clarifying the Vision
  - Changing the science questions.
    - The last 15 years in nuclear physics.
- Achieving the Vision
  - Changing the administrative questions.
    - Single-minded emphasis on increasing science impact.

The Vision

- Define ourselves (TRIUMF) in terms of our science impact.
  - Not in terms of how we compare to others.

➢ Outrun the grizzly!





M. Brodeur

TRIUMF

TRIUMF's Mission Statement

TRIUMF is Canada's national laboratory for particle and nuclear physics. It is owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada with building capital funds provided by the Government of British Columbia. Its mission is:

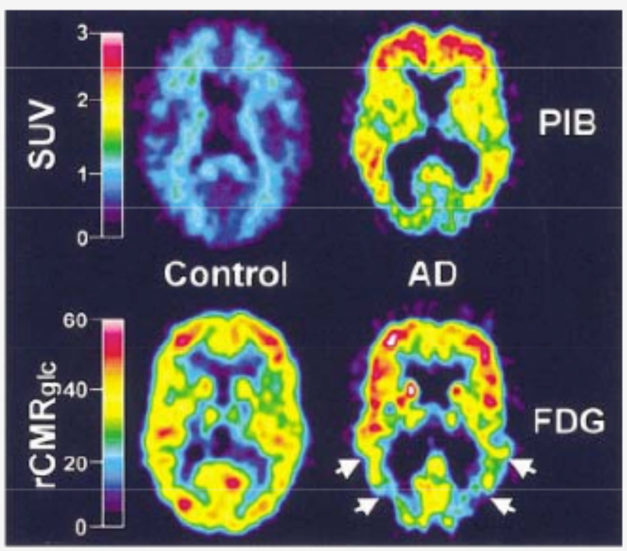
- To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science;
- To act as Canada's steward for the advancement of particle accelerators and detection technologies; and
- To transfer knowledge, train highly skilled personnel, and commercialize research for the economic, social, environmental, and health benefit of all Canadians.

Three Imperatives

- Strong local science program.
  - To strengthen the research community support.
- Strong ties to the universities.
  - To strengthen the university community support.
- Strong benefits to society.
  - To strengthen tax payer and government support.

Science!

- A strong science program underpins:
  - The mission statement
  - The three imperatives
- Science: The goose that lays the golden egg.



Klunk *et al.*, Ann. Neurol. 2004; 55: 306-19

NRC CNRC

From Discovery to Innovation...

Science at work for Canada

NATIONAL RESEARCH COUNCIL CANADA

NEWS RELEASE

Emerging Technologies Thrive in Canada

Canada's Government recognizes D-Pace as a Canadian Innovation Leader

For immediate release

September 16, 2009, Nelson, B.C. – Mr. Colin Mayes, Member of Parliament for Okanagan-Shuswap, on behalf of the Honourable Gary Goodyear, Minister of State (Science and Technology), today recognized Dehnel - Particle Accelerator Components and Engineering, Inc. (D-Pace) as a Canadian Innovation Leader for researching, developing, supplying and commercializing products and services for the international commercial accelerator industry, linking scientific research to commercialization, jobs, and economic growth.

TRIUMF's Mission Statement

TRIUMF is Canada's national laboratory for particle and nuclear physics. It is owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada with building capital funds provided by the Government of British Columbia. Its mission is:

- To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science;
- To act as Canada's steward for the advancement of particle accelerators and detection technologies; and
- To transfer knowledge, train highly skilled personnel, and commercialize research for the economic, social, environmental, and health benefit of all Canadians.

TRIUMF

The Vision

- To make discoveries that address the most compelling questions in particle physics, nuclear physics, nuclear medicine, and materials science
  - The most compelling questions?
    - Platonic ideals?
  - Change the questions!
    - Not just in science but in running the division.
- ➢ To make discoveries that change the field!
  - Change our understanding of the universe.
  - Change the questions.
  - Change the paradigm (if you are a fan of Kuhn).

Nuclear Physics
How the Questions Changed.

- The nucleon-nucleon potential:
  - The old model: Meson exchange.
  - The new model: Effective field theory.
- Theoretically Driven
  - Renormalization group and related techniques
  - Systematic suppression of virtual high-momentum states
  - Relation to experimental program not immediately obvious.
  - Bogner, Furnstahl, Schwenk, arXiv:0912.3688[nucl-th]

➢ Question changing.

A General Principle

- At low momentum the high momentum properties of a model are not probed.
  - Can replace “true” behavior with something simpler.
    - Must preserve low momentum properties.
  - Essential for progress in science
    - Do not need explicit string degrees of freedom.
    - Do not need explicit QCD degrees of freedom.
- Renormalization group
  - Peter Lapage

The Problem

- The problem:
  - Start with an N-N potential that fits the two-body data and derive nuclear properties
    - Caveat: Role of many-body forces.
- Other approaches to nuclear physics:
  - Collective models
    - Use macroscopic degrees of freedom.
      - For example: John Wood's TRIUMF lectures, P. Garrett's work on vibrational nuclei.
  - Direct calculation from QCD.
    - Constituent quark or quark-meson coupling model
    - Lattice QCD

TRIUMF

The N-N Potential

- Relation to QCD.

QCD ➡ N-N potential ➡ Nuclear Physics

- N-N potential decouples nuclear physics from QCD.
  - Nucleon degrees of freedom:
    - Not quarks and gluons,
    - Not collective degrees of freedom.
  - Potentials are not observables,
    - Hence N-N potential not unique

TRIUMF

The N-N Potential

- Formally: Start with QCD
  - Integrate out quark and gluon degrees of freedom.
    - Nucleons are emergent.
  - Derive N-N potential.
- Practically: Start with symmetries of true model:
  - Write most general form.
  - Determine parameters phenomenologically
    - Compare with those calculated from QCD
  - Renormalization group simplifies short distance behavior.

The N-N Potential
Two Approaches

- Meson exchange (goes back to Yukawa)
  - Very successful (Reid, Stony Brook, Paris, Bonn, Argonne).
  - Dispersion relations: unitarity, crossing symmetry, analyticity.
  - Meson couplings determined phenomenologically.
    - Phenomenological short range components (Argonne).
  - Many-body forces not well controlled.
  - Contains high momentum components.
- Effective field theory
  - Chiral symmetry.
  - Low momentum expansion, expansion coefficients.
  - Errors controlled.
  - Only low momentum components.
    - Precursors: Volkov, Minnesota forces.

Meson-Exchange
The Hard Core

- Strong repulsive core
  - ω(782) boson exchange.
  - S-wave phase shift starts attractive and goes repulsive.
    - Repulsion present for any approximately local potential.
  - Makes nuclear many-body calculations difficult.
    - Disconnect between N-N potential and nuclear phenomenology.
  - Strong short range and tensor correlations
    - Reduced spectroscopic strength at low energies.

TRIUMF

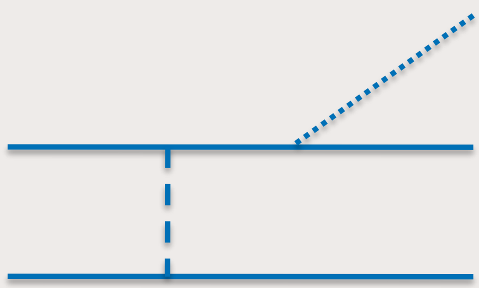
Meson-Exchange
Compelling Questions

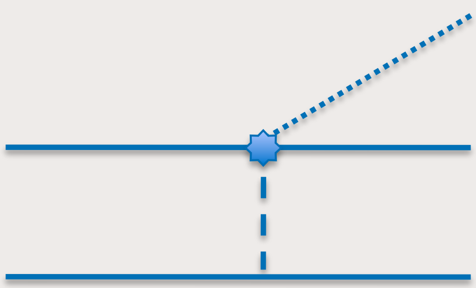
- What is the off-shell behavior of the N-N potential?
  - N-N bremsstrahlung (TRIUMF)
- What are the values of coupling constants?
  - Strong vs weak ρ couping
  - What is the nucleon form factor?
- How to evaluate many-body forces?
  - Tucson-Melbourne potential
- How do you treat a hard potential in a many-body system?
  - What are the values of spectroscopic factors?

TRIUMF

Off-Shell Properties

- Nuclear calculations depend on them.
  - How to determine?
- Polarized proton-proton bremsstrahlung
  - Kitching, P.; Hutcheon, D. A.; Michaelian, K.; Abegg, R.; Coombes, G. H.; Dawson, W. K.; Fielding, H.; Gaillard, G.; Green, P.; Greeniaus, L. G.; Hugi, M.; Miller, C. A.; Neilson, G. C.; Olsen, W. C.; Stevenson, N. R.; Wesick, J.; Fearing, H. W.; Workman, R. L.
  - Physical Review Letters, Volume 57, Issue 19, November 10, 1986, pp. 2363-2366
- The Off-Shell Nucleon-Nucleon Amplitude: Why it is Unmeasurable in Nucleon-Nucleon Bremsstrahlung
  - H.W. Fearing, Phys. Rev. Lett. 81, 758–761 (1998)

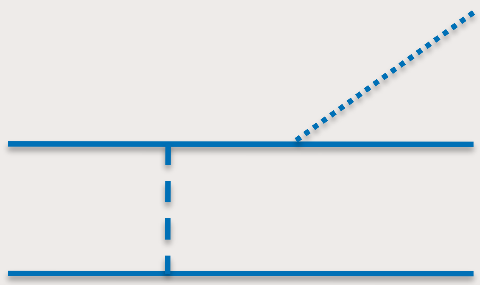




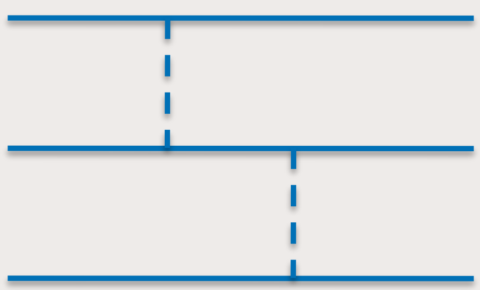
Meson-Exchange
Compelling Questions

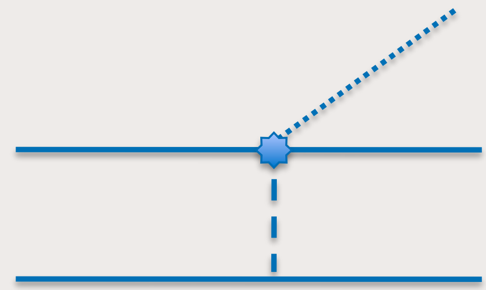
- What is the off-shell behavior of the N-N potential?
  - N-N bremsstrahlung (TRIUMF)
- What are the values of coupling constants?
  - Strong vs weak ρ couping
  - What is the nucleon form factor?
- How to evaluate many-body forces?
  - Tucson-Melbourne potential
- How do you treat a hard potential in a many-body system?
  - What are the values of spectroscopic factors?

Off-Shell Properties

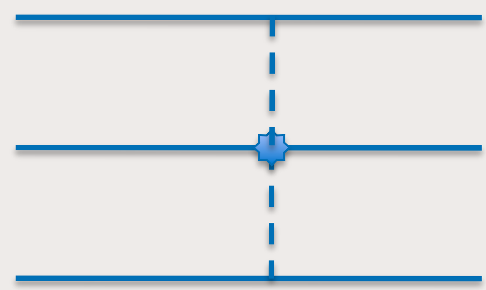


Iterated
two-body





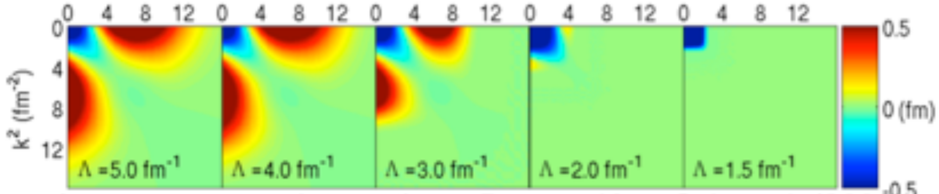
Three-body



Effective Field Theory

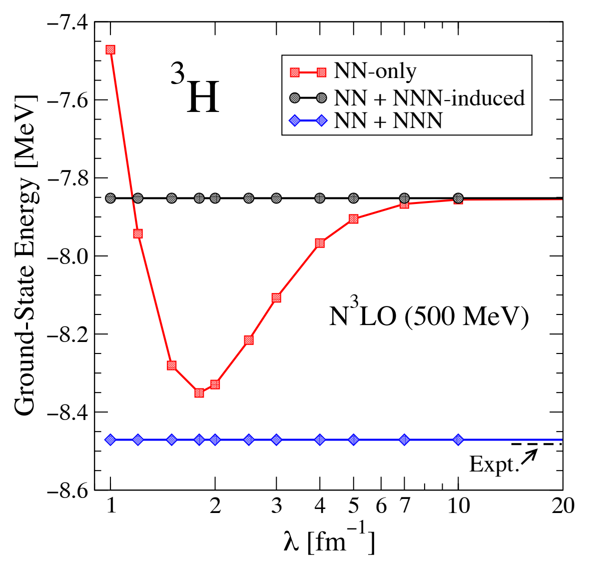
Use to Calculate Nuclear Properties

Evolution of 2N forces: phase-shift equivalent

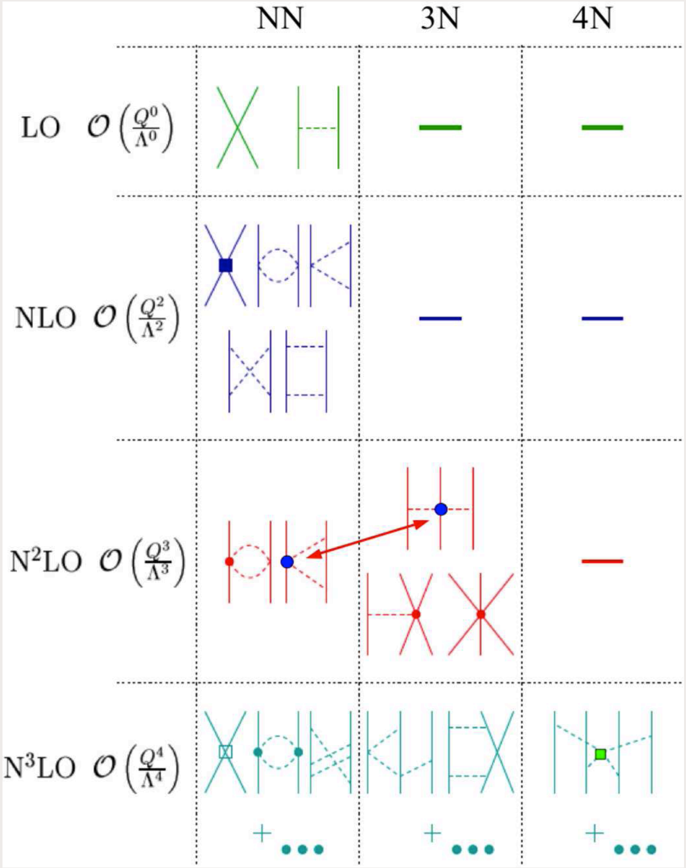


Low-momentum interactions: Bogner, Kuo, Schwenk (2003)
need smaller basis

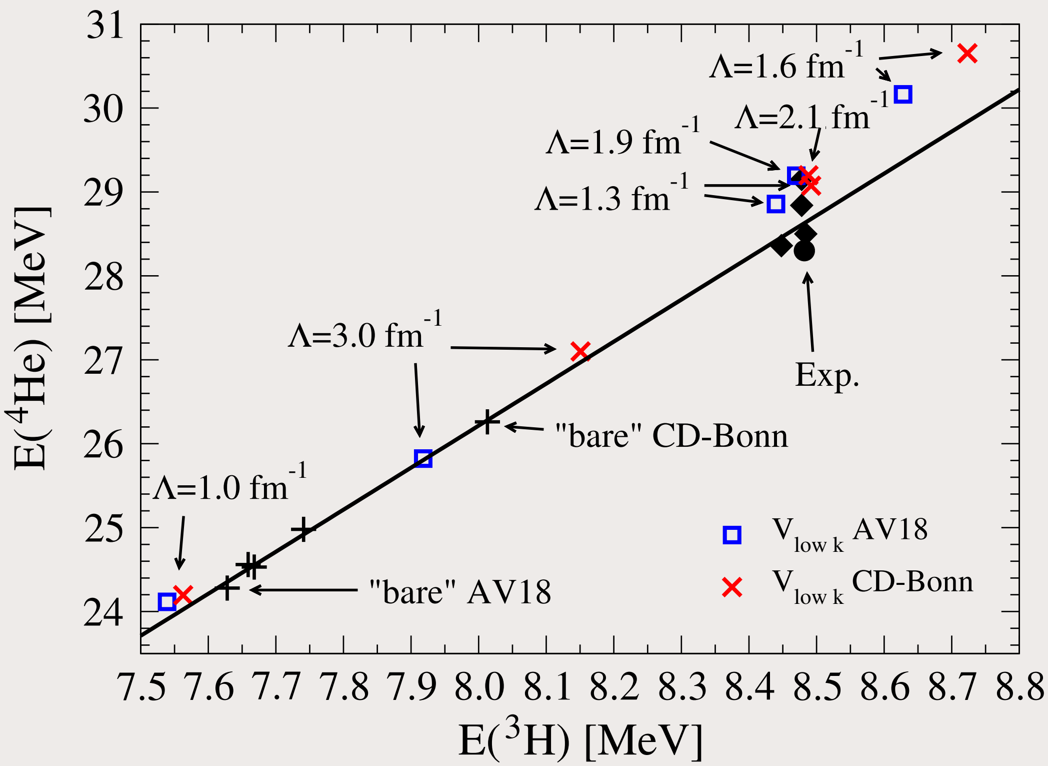
Can evolve 3N forces consistently:
Jurgenson, Navratil, Furnstahl (2009)



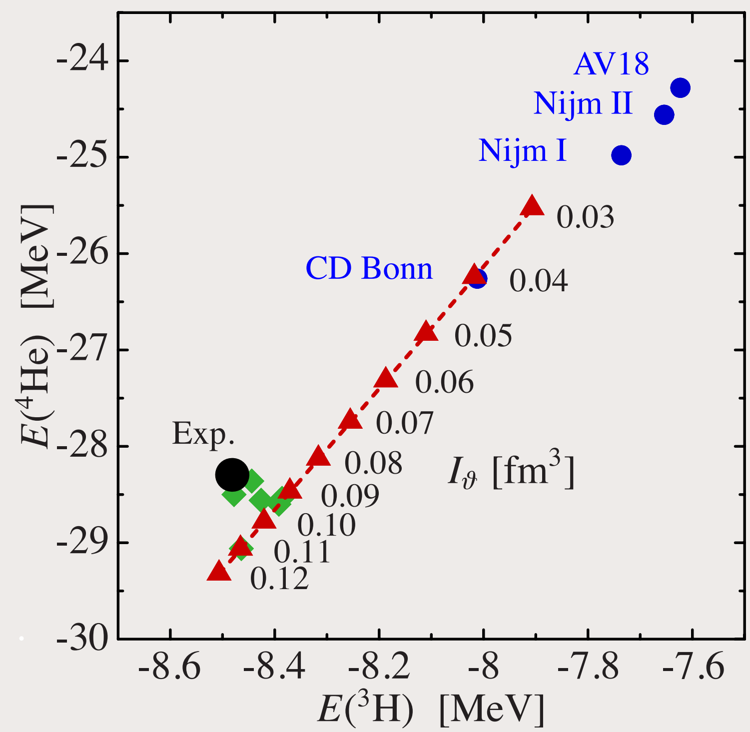
Power Law Diagrams



The Three-Body Force



Vlow k



Unitary Correlation Operator Method

TRIUMF

Effective Field Theory

- Choose degrees of freedom that are appropriate for the problem.
  - Nucleons for doing low-energy nuclear physics.
- Choose cutoffs that are appropriate for the problem.
  - The order of 2 inverse Fermi.
- Meson-exchange model not so much wrong but rather inconvenient.
  - Much of the problems and controversies in the past related to dealing with the high momentum components in an ad hoc manner (EELL effect in pion scattering, Dirac phenomenology).

➢ Nature abhors high momenta (not a vacuum).

Meson-Exchange
Compelling Questions

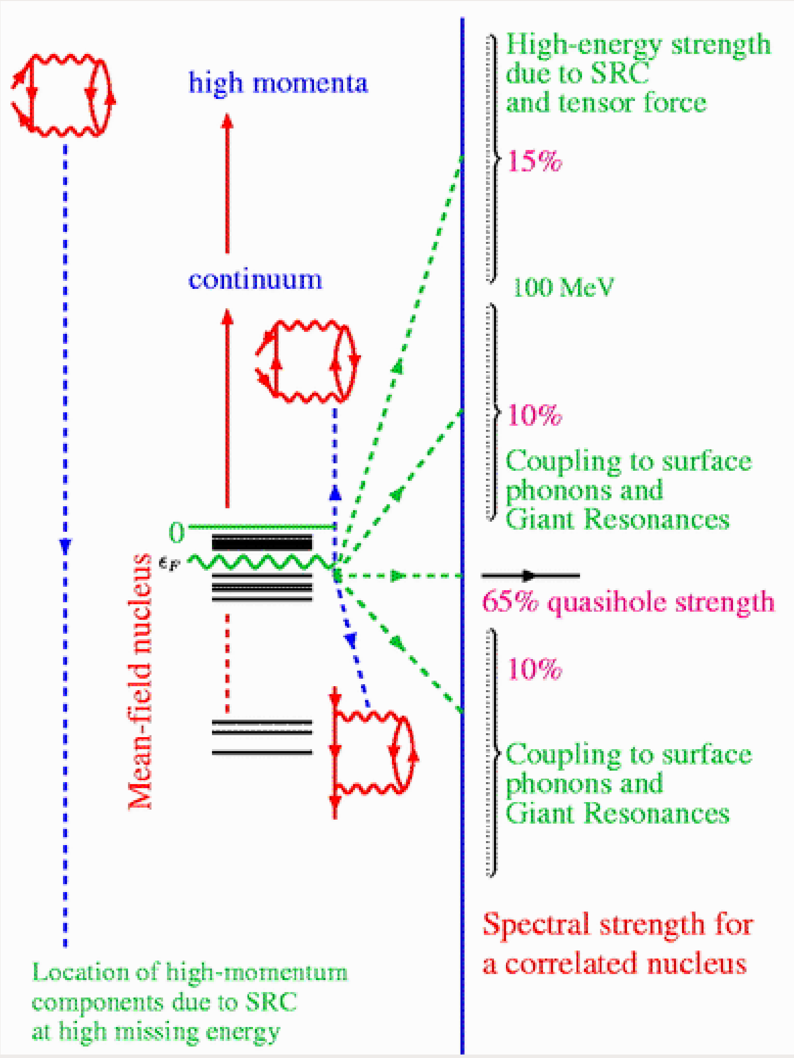
- What is the off-shell behavior of the N-N potential?
  - N-N bremsstrahlung (TRIUMF)
- What are the values of coupling constants?
  - Strong vs weak ρ couping
  - What is the nucleon form factor?
- How to evaluate many-body forces?
  - Tucson-Melbourne potential
- How do you treat a hard potential in a many-body system?
  - What are the values of spectroscopic factors?

Spectroscopic Factors
The Definition

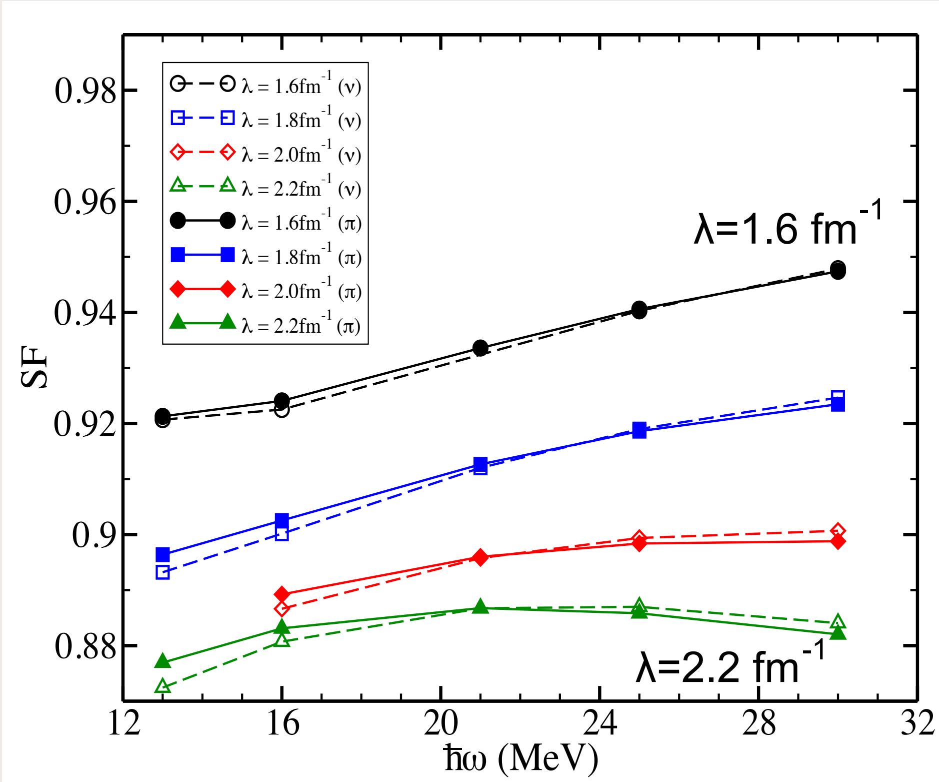
- Provides insight useful to a wide range of physics problems.
  - Atomic physics, nuclear physics
- Measures the change to the many-body wave-function when a particle is added or removed.
  - Spectroscopic amplitude (one-body overlap function).
    - $\phi(r) = \langle \Psi_{A-1} | a(r) | \psi_A \rangle$.
  - Spectroscopic factor:
    - $S = \int dr \, |\phi(r)|^2$.

Spectroscopic Factors

Meson Exchange



W. H. Dickhoff, C. Barbieri, Prog.Part.Nucl.Phys. 52 (2004) 377-496



Ø. Jensen, G. Hagen, T. Papenbrock, D. J. Dean, J. S. Vaagen, arXiv:1004.2611v1 [nucl-th]

Spectroscopic Factors
The Mathematics

^{7}Be(p,γ)^{8}B

$$\sigma \propto |\langle\psi_A^n|\mathcal{F}|\psi_A^{n'}\rangle|^2$$

$$\mathcal{F} = \int dr\, dr'\; a^\dagger(r)a(r')F(r,r')$$

$$\langle\psi_A^n|\mathcal{F}|\psi_A^{n'}\rangle = \int dr\, dr'\; F(r,r')\langle\psi_A^n|a^\dagger(r)a(r')|\psi_A^{n'}\rangle$$

$$\langle\psi_A^n|a^\dagger(r)a(r')|\psi_A^{n'}\rangle = \sum_m \langle\psi_A^n|a^\dagger(r)|\Psi_{A-1}^m\rangle\langle\Psi_{A-1}^m|a(r')|\psi_A^{n'}\rangle$$

$$= \sum_m \phi_m^{*n}(r)\phi_m^{n'}(r')$$

$$\langle\psi_A^n|a^\dagger(r)a(r')|\psi_A^{n'}\rangle \Longrightarrow \phi_0^{*n}(r)\phi_0^{n'}(r')$$

$$\sigma \propto |\int dr\phi_0^{*n}(r)\exp(i\vec{k}\cdot\vec{r})\phi_0^{n'}(r)|^2$$

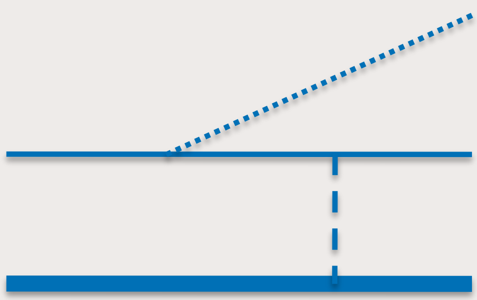
$$\sigma \propto S|\int dr\hat{\phi}_0^{*n}(r)\exp(i\vec{k}\cdot\vec{r})\phi_0^{n'}(r)|^2$$

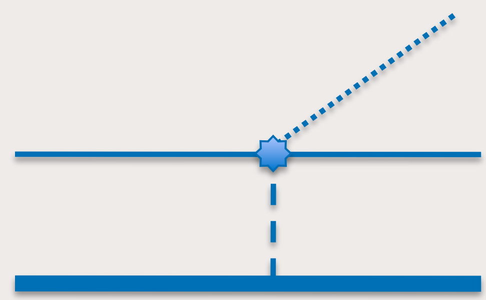
$F(r,r') \Longrightarrow \delta(r-r')\exp(i\vec{k}\cdot\vec{r})$
$|\psi_A^{n'}\rangle \Longrightarrow$ the p ^{7}Be scattering state.
$\langle\psi_A^n| \Longrightarrow$ ^{8}B final state.
$\langle\Psi_{A-1}^m| \Longrightarrow$ complete set of ^{7}Be states

$\phi_0^{*n}(r) = \langle\Psi_{A-1}^0|a(r)|\psi_A^n\rangle$ spectroscopic amplitude for the ^{8}B ground state.

$S_0 = \int dr\; |\phi_0^n(r)|^2$ spectroscopic factor

$\phi_0^{n'}(r') = \langle\Psi_{A-1}^0|a(r')|\psi_A^{n'}\rangle$ optical-model wave function for p ^{7}Be scattering state.

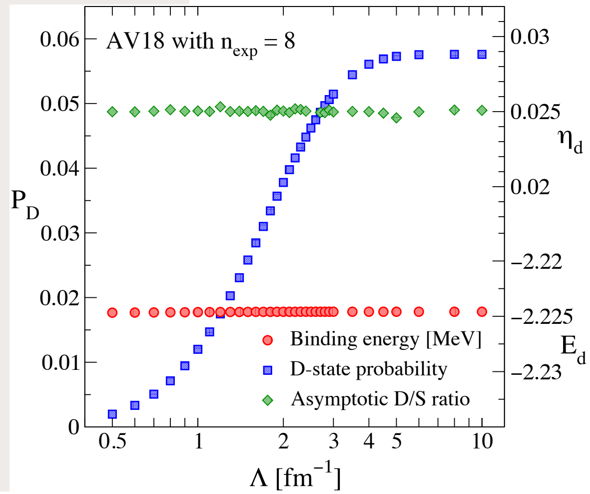




Spectroscopic Factors
Conclusions

- The spectroscopic factors are scale dependant.
- Shown to be unobservable 31 years ago.
  - Measurability of the deuteron *D* state probability, J.L. Friar, Phys. Rev. C 20, 325–330 (1979)
    - Deuteron d-state probability is a specific case of a spectroscopic factor.
  - Are Occupation Numbers Observable? R.J. Furnstahl, H-W. Hammer, Phys.Lett. B531 (2002) 203-208.
- Should look to asymptotic properties for observables:
  - Asymptotic s to d ratio for the deuteron,
  - Asymptotic normalization coefficient.

BFS, arXiv:0912.3688[nucl-th]



Meson-Exchange
Compelling Questions

- What is the off-shell behavior of the N-N potential?
  - N-N bremsstrahlung (TRIUMF)
- What are the values of coupling constants?
  - Strong vs weak ρ couping
  - What is the nucleon form factor?
- How to evaluate many-body forces?
  - Tucson-Melbourne potential
- How do you treat a hard potential in a many-body system?
  - What are the values of spectroscopic factors?

TRIUMF

Effective Field Theory
Compelling Questions

- What are the many-body forces and how do you characterize them?
- What are the low energy expansion coefficients and how to calculate them in QCD?
- How far can ab initio calculations go?
  - Few-body spectroscopy and reactions.
  - Intermediate-mass structure calculations.
  - Foundation for energy density functional.
  - Eventually derive collective Hamiltonian.

➢ Ab initio calculations make contact with observables.

The Vision

- Challenge to the ISAC user community and the theorists:
  - How can ISAC measurements:
    - Change the field?
    - Change our understanding?
    - Change the questions?
- What must TRIUMF do to help the user community?

The Vision

- Challenge to the TRIUMF community:
  – How can TRIUMF:
    - Change the field?
    - Change our understanding?
    - Change the questions?
- What must TRIUMF do to help the user community?

TRIUMF

The Science Division

- Science
  - ISAC Program
  - Molecular and Materials Science
  - Particle Physics
  - Theory
- Support
  - Computing
  - Detector Facilities

The Three Imperatives
Reprise

- Strong local science program.
  - To strengthen research community support.
- Strong ties to the universities.
  - To strengthen the university community support.
- Strong benefit to society.
  - To strengthen tax payer and government support.

TRIUMF

ISAC Program

- Contribution to imperatives:
  - Core of the onsite program
    - Essential for TRIUMF's health.
  - Interaction with universities
    - 14 Canadian Universities
  - Strong Highly Qualified Personnel (HQP)
- Current compelling question:
  - How do we maximize the science impact?
    - Optimum use of facilities.
    - Optimum beam development strategy.
    - Optimum use of manpower.

TRIUMF

ISAC Questions

- Previous questions:
  - How to build needed experimental facilities?
  - How to develop new beams?
- Current question: How to maximize science impact?
  - What is the optimum number of detector facilities?
  - What is the balance between developing new beams and exploiting current beams?
  - Evaluate programs not individual experiments?

➢ Hardnosed look at all aspects of the ISAC program to maximize science impact.

TRIUMF

Molecular and Materials Science

- Contribution to imperatives:
  - Onsite program
  - Strong university involvement
    - J. Brewer and the Brockhouse Metal.
    - 13 Canadian Universities
  - Practical applications
    - Battery research and green chemistry
- Current compelling questions:
  - How do we maximize the benefit from the increasing maturity of the field?
  - Can the MMS program carry more of the burden in justifying TRIUMF's funding?
    - How to increase visibility?

Particle Physics

- Contribution to imperatives:
  - Largely off-site.
  - Strong university connections.
    - Essential for TRIUMF's health
      - 10 Canadian Universities in ATLAS collaboration.
      - 6 Canadian Universities in T2K collaboration.
      - 14 Canadian Universities in off-site collaborations.
  - High visibility
    - Particularly ATLAS.
  - Other examples:
    - T2K, TWIST, PIENU, ALPHA,…

Particle Physics

- Contribution to imperatives:
  - Largely off-site.
  - Strong university connections.
    - Essential for TRIUMF’s health
  - High visibility
- Current compelling questions:
  - What is the next big project?
  - How to maintain and enhance detector development capability?
  - How important are the peripheral parts of the program?

TRIUMF

Theory

- Contribution to imperatives:
  - On-site,
  - HQP (very successful RA program),
  - Collaborations with 6 universities
- Group is being renewed.
  - Has now made the transition to the new TRIUMF direction.
    - Two new hires, one more on the way.

TRIUMF

Theory

- Contribution to imperatives.
  - Onsite, HQP, university collaborations
- Group is being renewed.
  - Has now made the transition to the new TRIUMF direction.
    - Two new hires, one more on the way.
- Current compelling questions:
  - How do we help the new members develop and take leadership roles?
  - How to increase the group’s visibility?
  - How to maintain or increase interaction with university community?

TRIUMF

Computing

- Contribution to imperatives:
  - Major part of TRIUMF infrastructure.
    - Indirect contribution to all imperatives.
- Recent major change made in how the group is run.
  - Following from a review last fall.
- Current compelling question:
  - How do we keep the current momentum going?
    - Outside consultants for Enterprise Resource Planning (ERP) software.

Detector Facility

- Contribution to imperatives:
  - Strong university connection:
    - TRIUMF's infrastructure role. (HERMES, BABAR, E787, ATLAS, Qweak, G0, SNO, T2K, DEAP, SNO+, EXO, Super B?).
  - Recent ISAC involvement.
- TRIUMF mission statement:
  - To act as Canada's steward for the advancement of particle accelerators and detection technologies;
- Current compelling question:
  - How do we maintain a strong detector capability?

Management Style

- Compelling question: How do we increase the science impact?
  - Team Work
    - Team 1: Senior Management
    - Team 2: The Science Division
      - Neither micromanagement nor abdication of responsibility.
    - Team 3: The user community
  - Resource allocation priorities set site wide
    - New project management procedures
      - Coherent use of resources.
      - Sharing of resources
      - Matrix management structure.

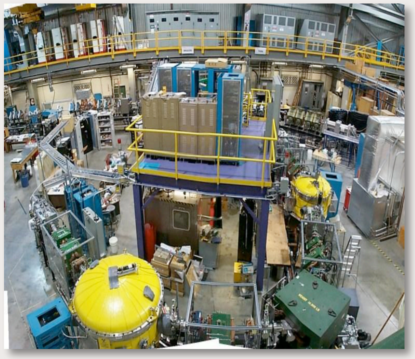
Conclusion

- Revolution in nuclear physics.
  - High momentum components tamed.
  - The questions changed.
- Maximize the science impact.
  - Change the field, our understanding and the questions:
    - That is the grizzly we are going to outrun.
  - Hardnosed review of ISAC.
  - Team work:
    - Across divisions, within the Science Division, and with the user community.
  - Site wide resource sharing and allocation.

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Thank you!
Merci!

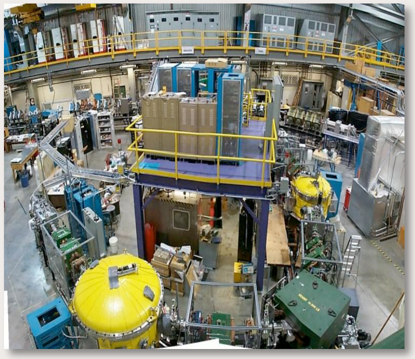


4004 Wesbrook Mall | Vancouver BC | Canada V6T 2A3 | Tel 604.222.1047 | Fax 604.222.1074 | www.triumf.ca

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics
Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

Thank you!
Merci!



4004 Wesbrook Mall | Vancouver BC | Canada V6T 2A3 | Tel 604.222.1047 | Fax 604.222.1074 | www.triumf.ca