DNP LRPC Presentation

Nuclear Physics Brief Committee:

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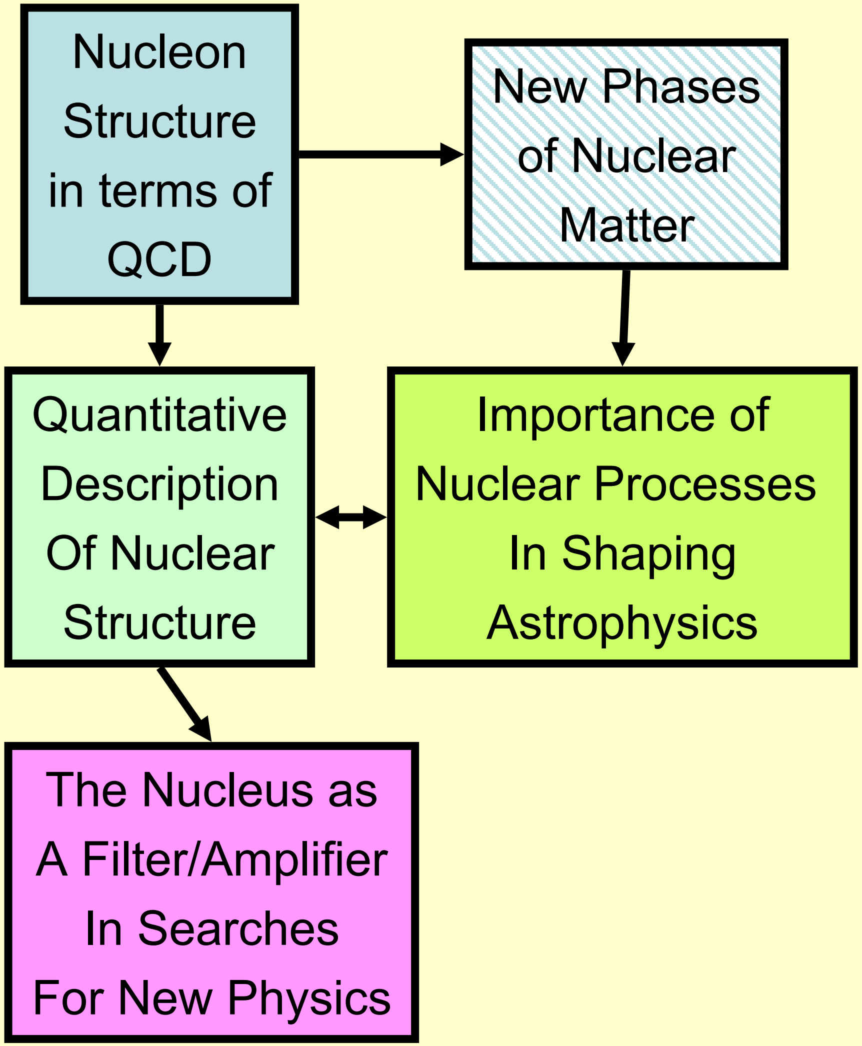
Nuclear Physics is driven by fundamental investigations on the origin, evolution and structure of strongly interacting matter.

- A far-reaching mission that requires a *balanced program* of experimental and theoretical effort.
- Broad international consensus on the key questions of significance to the broader community.



1. Can we understand hadron structure and interactions in terms of QCD?

It is well-known that nucleons are composite particles made up of quarks and gluons, but we have only partial answers from high-energy physics to questions such as how the quarks are distributed in the nucleon and how they move.

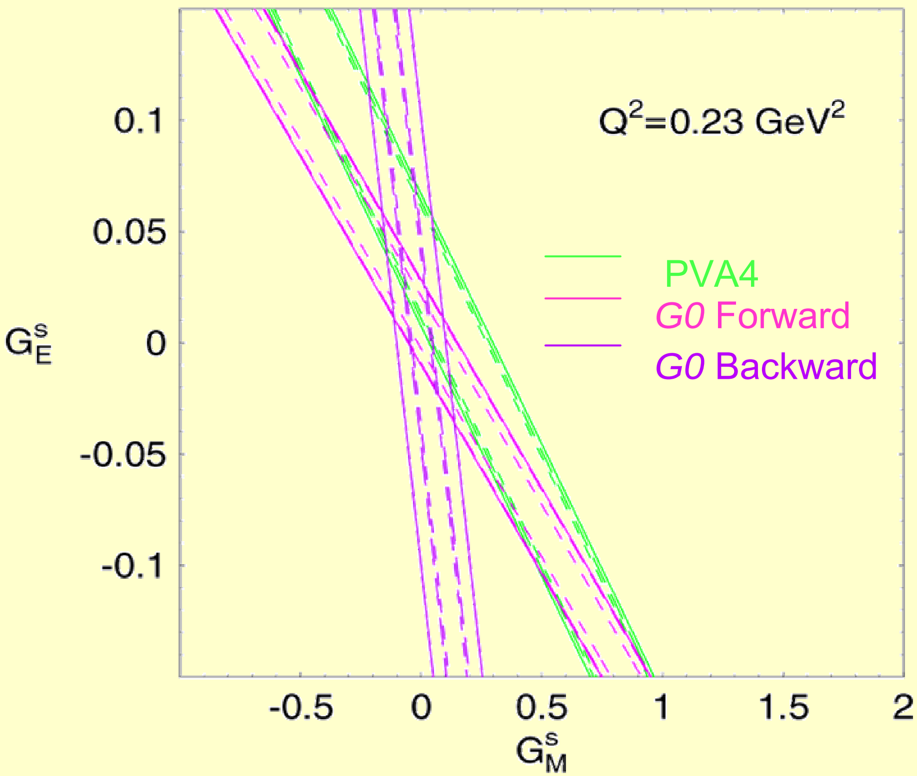
- The 2004 Nobel Prize was awarded for the discovery of asymptotic freedom within the context of perturbative QCD, **but QCD remains unsolved in the confinement regime**.
- One of the central problems of modern physics remains the connection of the observed properties of the hadrons to the underlying theoretical framework of QCD.

Can the properties of the nucleon, such as mass, spin, polarizabilities, charge and current distributions, be reproduced quantitatively in the framework of QCD?

- Following a long tradition of Canadian leadership in hadron physics at TRIUMF and SAL, the present program primarily utilizes electromagnetic probes at offshore facilities (JLab, MAMI, HIGS).
- Essential support from Canadian nuclear theory community.
  - → The chiral dynamics of QCD at low energy are exploited to produce specific predictions.
  - → Recent advances in Lattice QCD techniques allow new calculations to be performed in the light quark sector.
  - → Detailed radiative corrections calculations.
- Parts of this program are related to structure function studies at HERMES and ZEUS.

Example: G^0 Experiment at JLab

- Measurement of the weak form factors of the proton.
- Method: utilize the ~5ppm parity-violating asymmetry due to γ-Z^0 interference in *e-p* elastic scattering.
- Goal: determine the strange quark contribution to the structure of the proton.
- Forward angle run completed.
- Backward angle run will take most of 2006.
- Experiment relied heavily upon technical and infrastructure support of TRIUMF.



"Best" Lattice QCD calculation provided by Canadian group.

----- stat
– – – stat + sys
—— stat + sys + model

Resonance Studies at MAMI and JLab

Study low-lying baryonic states at low to moderate momentum transfer to gain insight into QCD-based models of hadron dynamics.

e.g. Electromagnetic multipoles of "Roper" $P_{11}(1440)$ are difficult to reconcile with standard quark picture. Are there significant gluonic or di-quark wave function components?

Selected studies:

$$\boxed{\vec{\gamma} p \to \pi^0 \gamma' p}$$

Obtain first measurement of $\Delta^+(1232)$ magnetic moment via detection of de-excitation γ' and π^0.

$$\boxed{\vec{\gamma} p \to \eta \gamma' p}$$

Planned measurement to obtain the $S_{11}^+(1535)$ magnetic moment using the same technique.

$$\boxed{\vec{\gamma}_v p \to \vec{\Delta}, \vec{N}^* \to \vec{p} \pi^0}$$

Study excitation of Δ and Roper resonances via EM multipole analysis.

Planned measurement of Roper form factor.

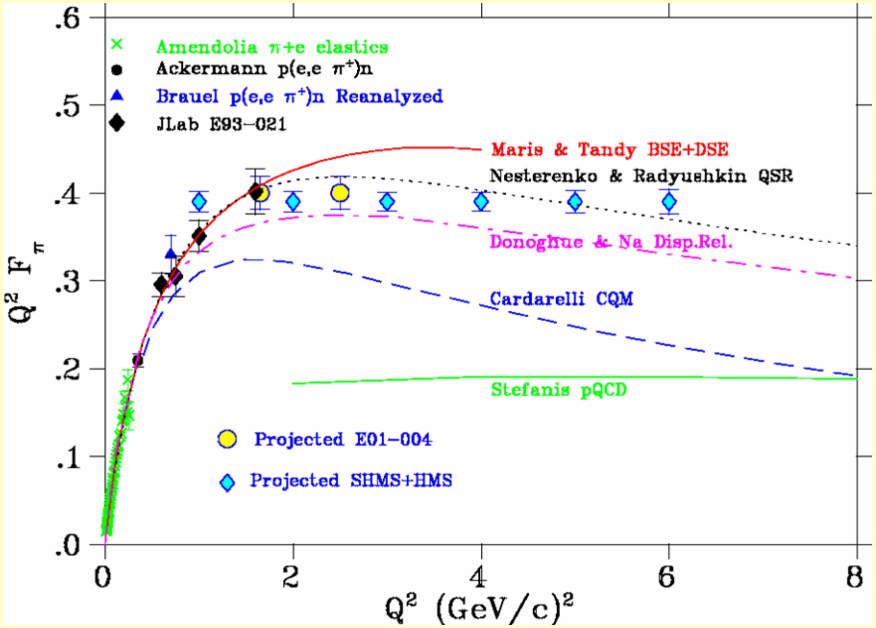
Long term: JLab 12 GeV Upgrade in ~2012

- Higher energy electron beam increases available photon flux and allows access to a larger range of Q^2.
- New opportunities to explore QCD properties in the transition region between confinement and asymptotic freedom regimes will be opened.

Example:

Measurement of the Pion form factor at high Q^2.

→Investigate transition to pQCD.



GlueX (IPP project at JLab) has related physics goals (QCD in confinement regime).

2. *What is the structure of nuclear matter?*

A central goal of nuclear physics is to explain the properties of nuclei and nuclear matter.

It is best to approach this task in steps :

→ Basic equations of QCD.

→ Effective field theories.

→ Inter-nucleon interactions and few-body systems.

→ Various treatments of nuclear structure, ranging from exact treatments such as Green's function Monte Carlo, to the shell model, and density functional theory.

While there has been significant progress toward this goal, experiments are required to guide the development of theory.

Key questions for experiments to address:

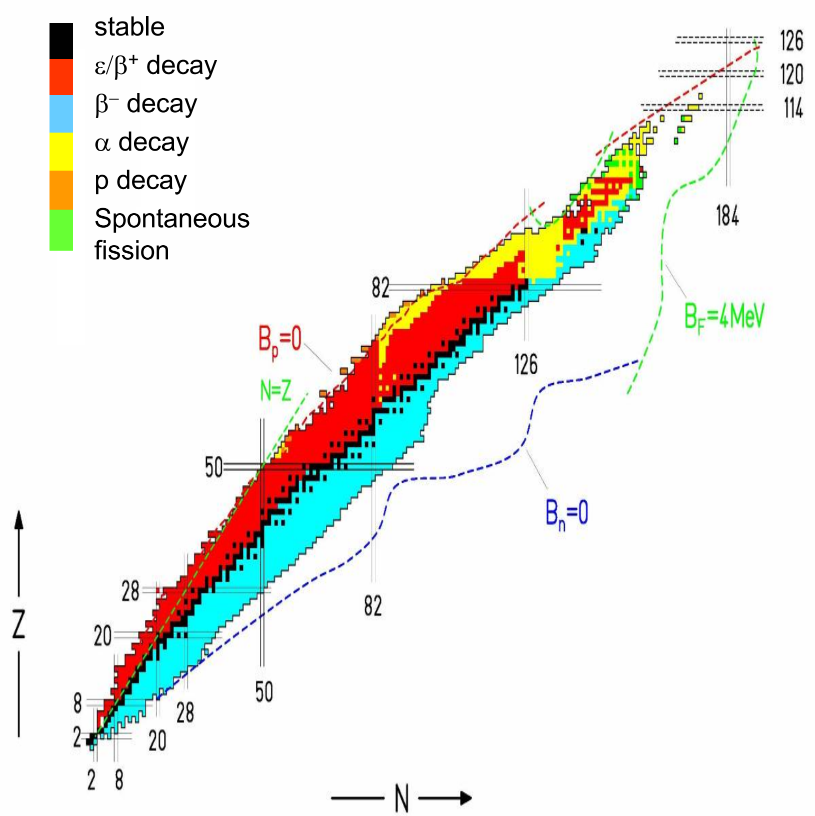
→ What are the limits of nuclear existence?

→ How are nuclei "built" from the underlying nucleon-nucleon interaction?

→ How do the properties of nuclei evolve with N/Z?

→ How do simple, regular patterns emerge from complex, many-body systems?

Radioactive beam facilities allow the advance from a 1-D picture where only *A* (mass number) varies, to a 2-D picture where both *(Z,N)* vary over a wide range.

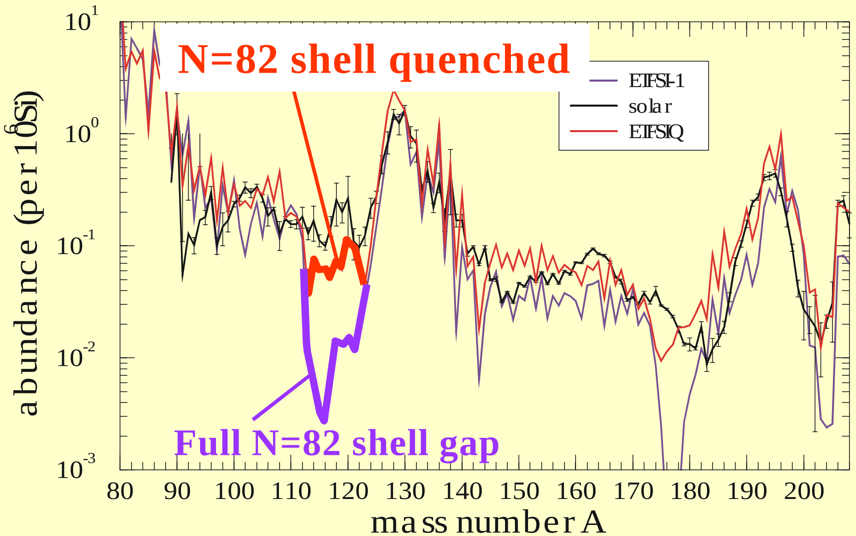


e.g. The limits of nuclear existence are not known, especially for nuclei on the neutron-rich side of the line of stability.

Studies at radioactive beam facilities that investigate the properties of nuclei off stability are expected to provide the missing links to our present understanding.

At present, and for the coming decade, the ISAC facility at TRIUMF is **the world leader** in radioactive on-line beam technology, and Canadians have a unique opportunity to make substantive contributions to the field.

Sometimes, clues about nuclear structure far from the line of stability come from astrophysics.

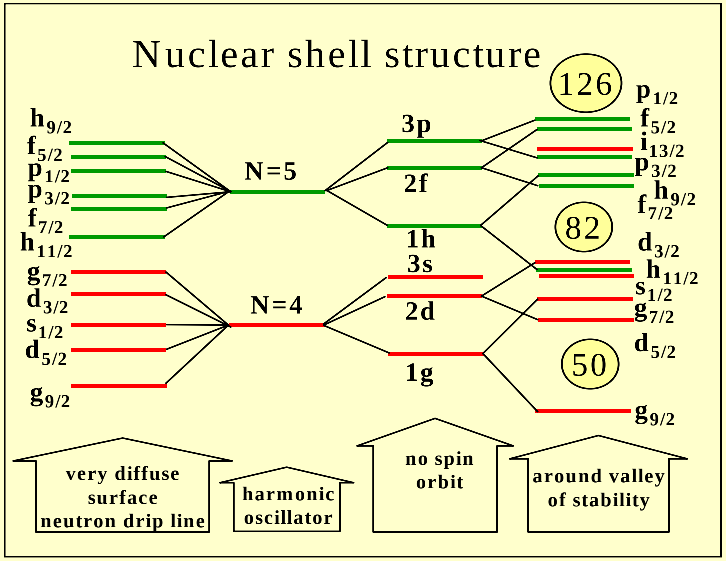


← Nuclear abundances near A=120 and comparison with rapid neutron capture (*r*-)process calculations under two different assumptions of the N=82 shell structure.

The inferred quenching of the N=82 shell far from the line of stability. →

This modification of shell structure was called for from astrophysics before any evidence from nuclear shell structure studies was found.

NOT YET CONFIRMED!



Nuclear structure and astrophysics are strongly interconnected.

There is considerable uncertainty in predicting nuclear properties away from the line of stability.

Canadians will investigate the location of *p,n* shells, limits of stability, via:

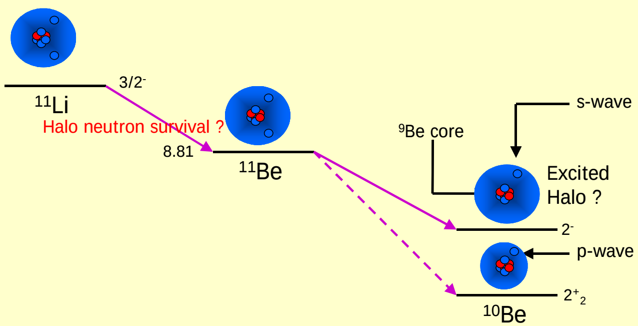
- accurate and precise nuclear mass measurements far from stability:
  - → Canadian Penning Trap (CPT) at Argonne.
  - → TITAN ion trap at ISAC.
- β-decay, Coulomb excitation, single-nucleon transfer reaction studies using:
  - → 8π and TIGRESS γ-ray spectrometers, EMMA recoil separator at ISAC.
- Nuclear radius measurements using laser spectroscopy.

Another question relates to how the properties of nuclei evolve as a function of *n/p* asymmetry.

New, sometimes unexpected phenomena appear in very neutron-rich nuclei.

Light-mass nuclei with an excess of neutrons can form `halo' systems.

- ^{11}Li first discovered example of a halo nucleus.



^{11}Li (3*p* and 8*n*) is nearly the size of ^{208}Pb.

Its outer halo consists mainly of 2 weakly-bound neutrons.

→ an example of an isolated "nucleon Cooper pair".

→ strongly-correlated state with similarities to electron Cooper pairs in superconductivity.

A key question is whether the halo survives not only the β-decay to ^{11}Be, but also the neutron emission to ^{10}Be.

Canadian and international collaborations have been taking advantage of ISAC's uniquely large ^{11}Li production to do complementary studies using the 8π spectrometer and laser spectroscopy.

Studies of haloes and neutron skins are planned at ISAC, ISAC-II using 8π, TIGRESS and EMMA.

Studies of collective behavior in nuclei

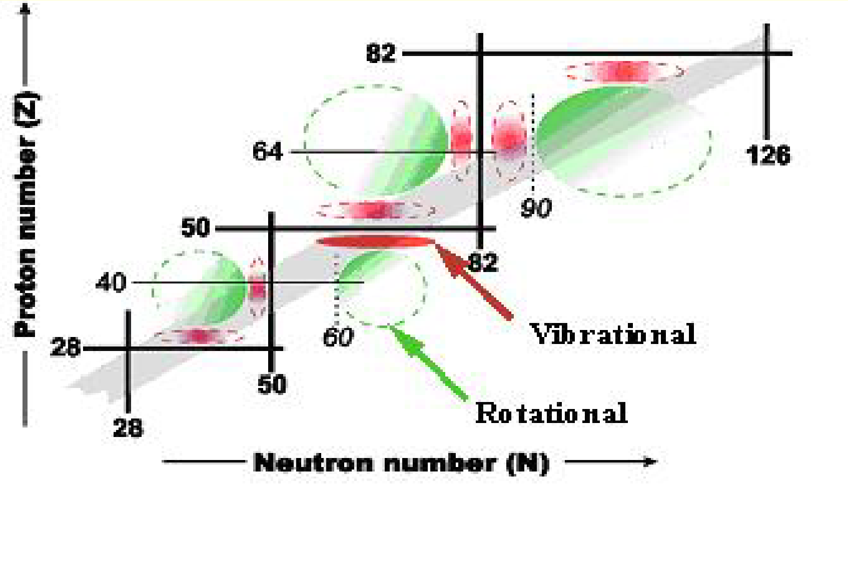
In complex systems, simple patterns sometimes emerge, reflecting underlying symmetries in the Hamiltonian.

Nuclei organize into different shapes and can possess surface vibrational modes.

- *e.g.* A rapid transition occurs from *spherical-vibrational* to *well- deformed rotational* for isotopes near N=90 along the line of stability.
  – May indicate a quantum phase transition in the shape degree of freedom.

Studies of rapid changes in structure associated with coherent wave function effects are planned with 8π and TIGRESS+EMMA.

Canadians have a long history of world-leading research in this area; tools like the 8π, TIGRESS, and EMMA ensure they remain at the forefront.



Research Vision

- In the past 5 years, the ISAC user community has developed a set of high quality instrumentation.
- Users now need to exploit it and interpret the results so that the next set of questions can be developed.
- Currently planned studies:
  - Program to study nuclear shell closure:
    - Investigation of changes in nuclear shell structure in neutron-rich nuclei, e.g. heavy magnesium, calcium, germanium, cadmium, etc.
  - Program to study nuclear collectivity:
    - Quantum phase transitions, saturation effects, etc.
  - Program to study halo nuclei:
    - ISAC1,2 have world's greatest intensity of ^{11}Li.
    - Extension to heavier systems and neutron-skin effects.

The comprehensive and complementary approach afforded by ISAC's capabilities is the secret to its success.

3. *What is the role of nuclei in shaping the evolution of the universe?*

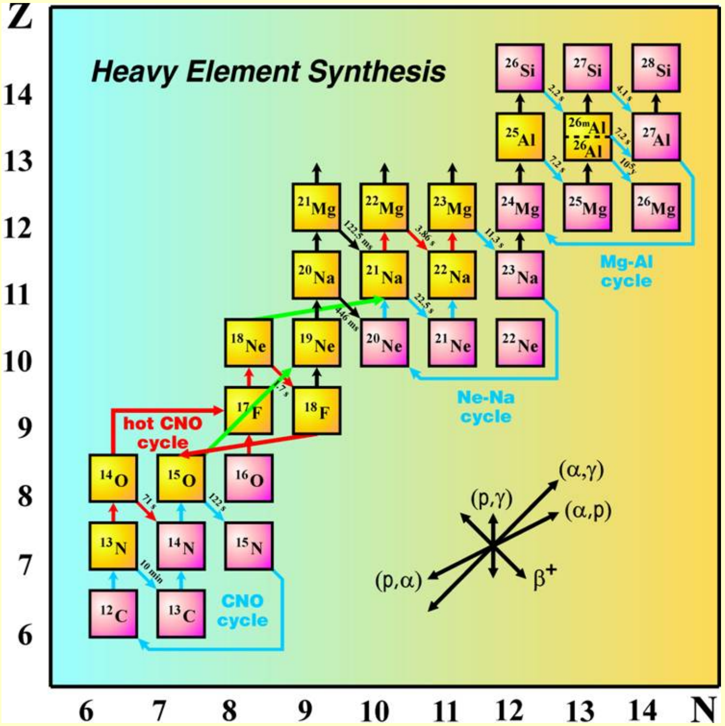
The nucleosynthesis that occurred during the cooling immediately following the Big Bang gave rise to primordial abundances of H, He, and Li.

All other chemical elements in the universe were produced as a result of nuclear reactions in stars, or during supernova explosions, etc.

Many fundamental questions remain open:

- → *The origin of the elements.*
- → *The mechanism of core-collapse supernovae.*
- → *The structure and cooling of neutron stars.*
- → *The origin, propagation, and interaction of the highest-energy cosmic rays.*
- → *The nature of galactic and extragalactic γ-ray sources.*

Reactions relevant to stellar evolution



Two different processes lead to the conversion of hydrogen to helium:

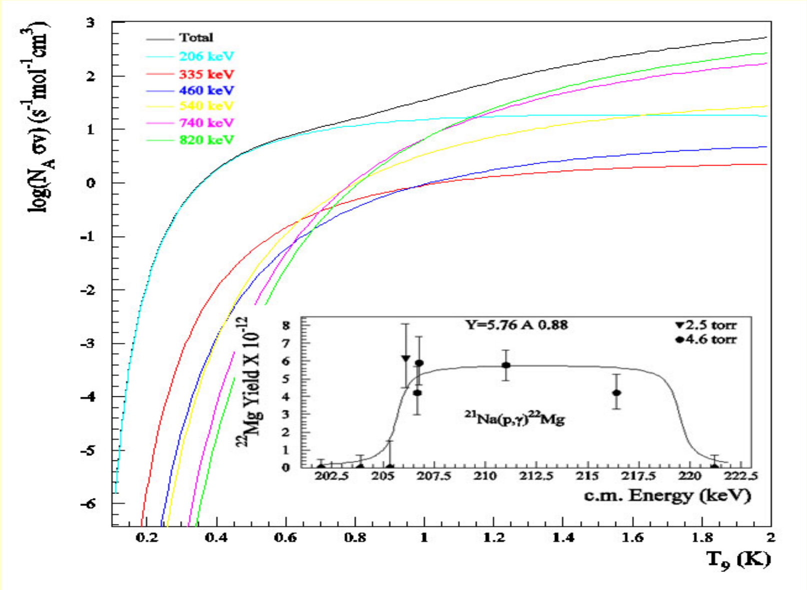
a) *p-p* chain, utilizing only protons.

b) CNO cycle, which requires a ^{12}C nucleus as a catalyst.

Heavier nuclei are produced via the hot CNO, Ne-Na, and Mg-Al cycles.

To date, DRAGON has measured the key $^{21}Na(p,\gamma)^{22}Mg$ reaction.

Other relevant reactions will be measured by DRAGON and TUDA as beams are developed.



Linkages to γ-ray Astronomy

γ-ray observing satellites have observed γ from ^{26}Al, ^{44}Ti decay, but not ^{22}Na.

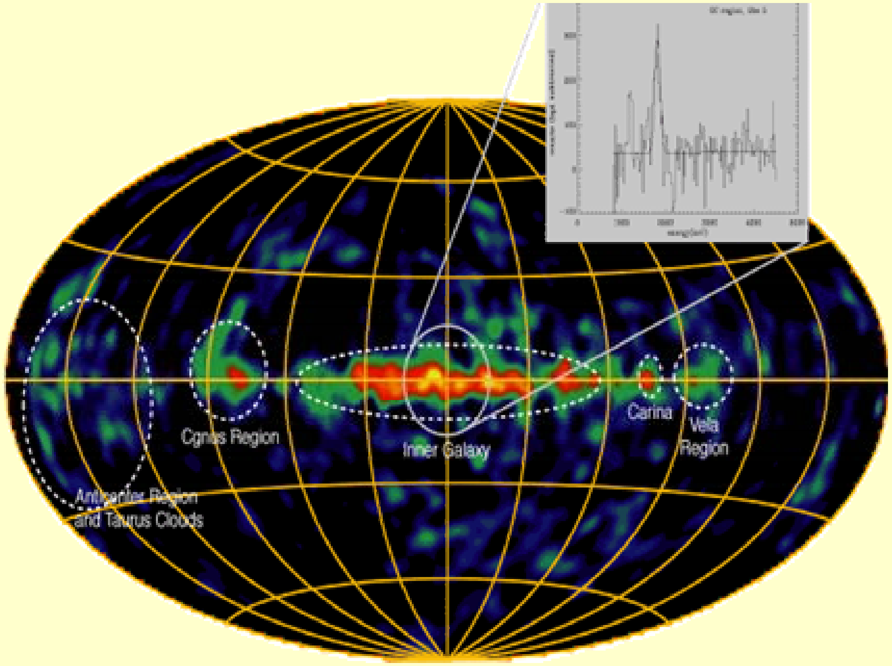
Contradicts reaction network models that produce ^{22}Na in sufficient quantity to have been observed.

The $^{22}Na(p,\gamma)^{23}Mg$ reaction will be studied by a Canadian and US collaboration using ISAC-produced ^{22}Na.

^{44}Ti is of great astrophysical significance.

→Observed directly in SN1987A light curve.

→Its key production rate $^{40}Ca(\alpha,\gamma)^{44}Ti$ is unknown and will be studied with DRAGON.



Long Term Goals

- A key question is to understand the transition from the CNO cycle to Ne-Na cycle in stellar environments.
  - Does the Ne-Na cycle occur only in Novae or also in older stars? (i.e. what temperature is needed to initiate the Ne-Na cycle?)
  - Properties of ^{18,19}Ne nuclei key to this question.
  - Where is the ^{22}Na produced by Neon-Sodium Novae?
    - ^{21}Na(p,γ)^{22}Na completed by DRAGON.
    - ^{22}Na(p,γ)^{23}Na planned by ISAC/Seattle collaboration.

- Reactions important for supernova explosions, ^{12}C+^{12}C fusion and ^{8}Li(α,n) reactions, will be studied with TACTIC.

- Observed ^{26}Al is primarily confined to the galactic plane.
  - Is ^{26}Al produced in Novae or Supernovae?
    - ^{26}Al(p,γ) completed at TRIUMF.
    - ^{25}Al(p,γ) to be done after ^{25}Al beam is developed.

These are only examples of the many reactions that must be studied to understand stellar evolution and nucleosynthesis

4. What physics lies beyond the standard model?

Studies of fundamental symmetries via very precise low and intermediate-energy experiments have been part of nuclear physics since its inception.

Complementary to direct probes by high energy physicists since precision lower-energy experiments probe mass scales and parameter spaces not otherwise accessible.

Recent experimental developments allow Canadian physicists a unique opportunity to contribute:

1) Development of efficient atom trapping techniques.
2) Availability of intense beams of exotic nuclear species from which one can exploit more discriminating selectivity.

This ISAC program is augmented with other precision measurements at TRIUMF, JLab, LANSCE, CERN and J-PARC.

A new generation of high-precision experiments

- Weak interaction studies in atomic systems and in electron scattering.
  - Complementary to future discoveries at LHC and elsewhere.
    - probe couplings of any new LHC-discovered particles to electrons.
    - continue to search for new physics at the multi-TeV scale.
    - narrow predictions on Higgs mass.

- Precision measurements of the properties of the neutron, atoms, and mesons may uncover the presence of new time-asymmetric forces which could explain the observed matter/anti-matter asymmetry of the universe.

- Clarification of the nature of the identified neutrino oscillation via studies of rare processes, such as neutrinoless double beta decay.

Weak Interaction Symmetry Tests

What we know about Electroweak Interactions:

- Unification: $SU(2)_L \otimes U(1)_Y$
- Only spin-1 vector exchange bosons.
- Only left-handed ν, parity is maximally violated, only V-A couplings.

What we can test:

1) Are there spin-0 scalar bosons?
   - β-ν angular correlation studies using ^{38m}K and TRINAT neutral atom trap [PRL **94**(2005)142501].
   - Proposed 0.1% measurement of $\pi^+ \rightarrow e^+ \nu_e$ branching ratio at TRIUMF probes lepto-quarks in the 200 TeV region.
2) Right handed ν, V+A couplings?
   - TWIST polarized μ-decay experiment at TRIUMF.
   - Neutral alkali atoms (^{38m}K, ^{37}K, ^{80}Rb) in TRINAT.

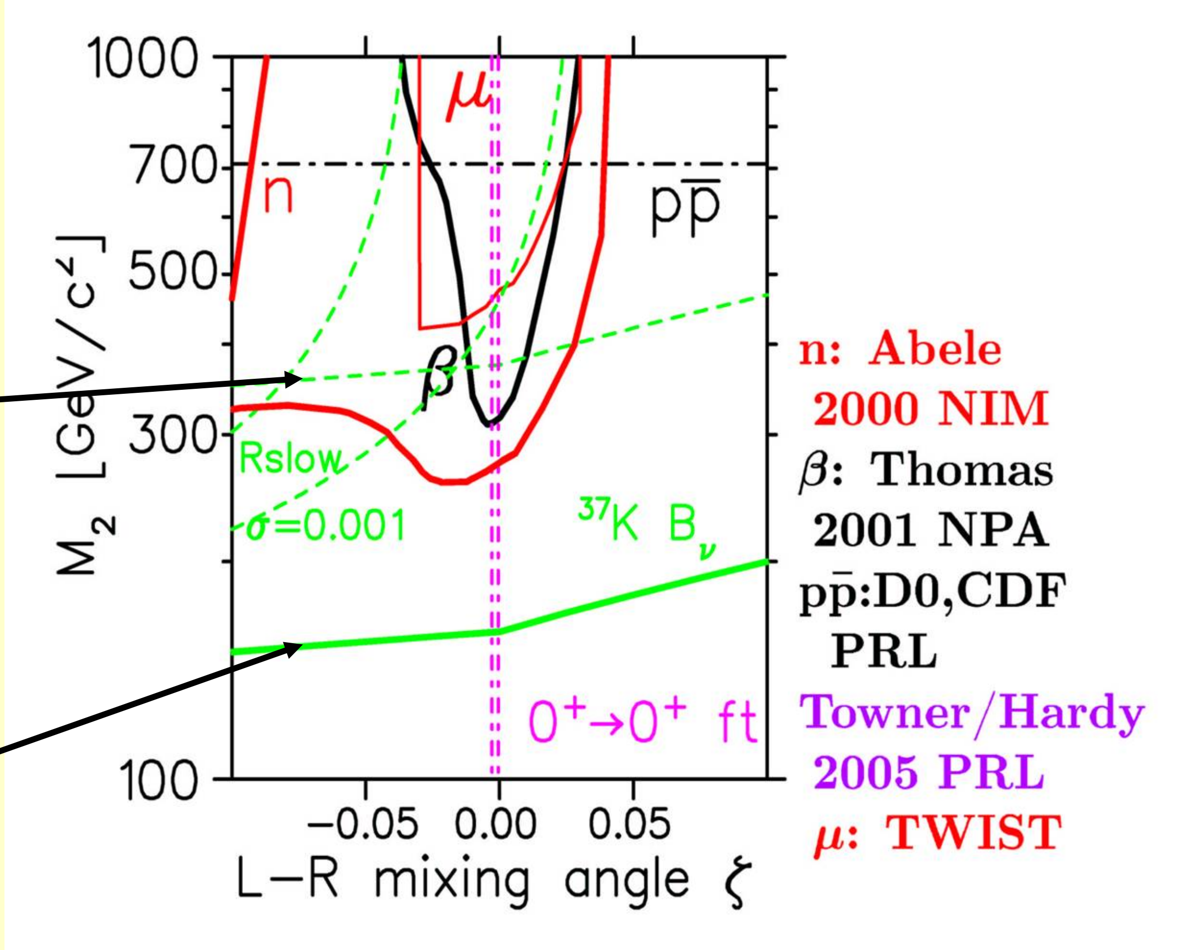
     → Polarized observables with $\sigma \approx 0.1\%$ needed.
3) Tensor interactions?
   - β-ν correlation studies at TRINAT using new polarization technique.

In manifest left-right models, parity is partially restored by a heavy-mass W_R that couples to ν_R.

Many experiments have complementary exclusions of the W_R mass and its mixing angle with W_L.

TRINAT goals of 0.1% in B_ν and R_{slow}

Present TRINAT 3% B_ν 37K result.

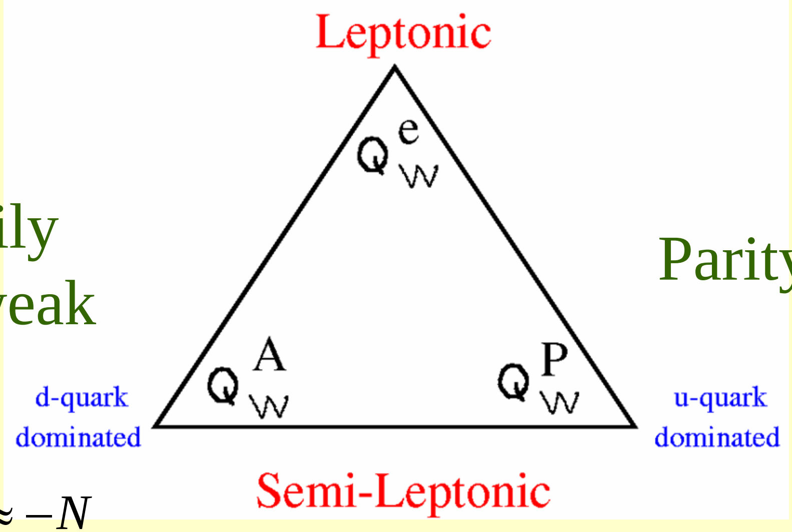


Weak charge "triad" (M. Ramsey-Musolf)

PV Möller scattering

$$\vec{e} + e \rightarrow e + e$$

$$Q_W^e \approx -(1 - 4\sin^2\theta_W)$$



Atomic PV: primarily sensitive to neutron weak charge

$$Q_W^A \approx -N + Z(1 - 4\sin^2\theta_W) \approx -N$$

Parity-violating *e*-*p* elastic scattering

$$\vec{e} + p \rightarrow e + p$$

$$Q_W^p \approx 1 - 4\sin^2\theta_W$$

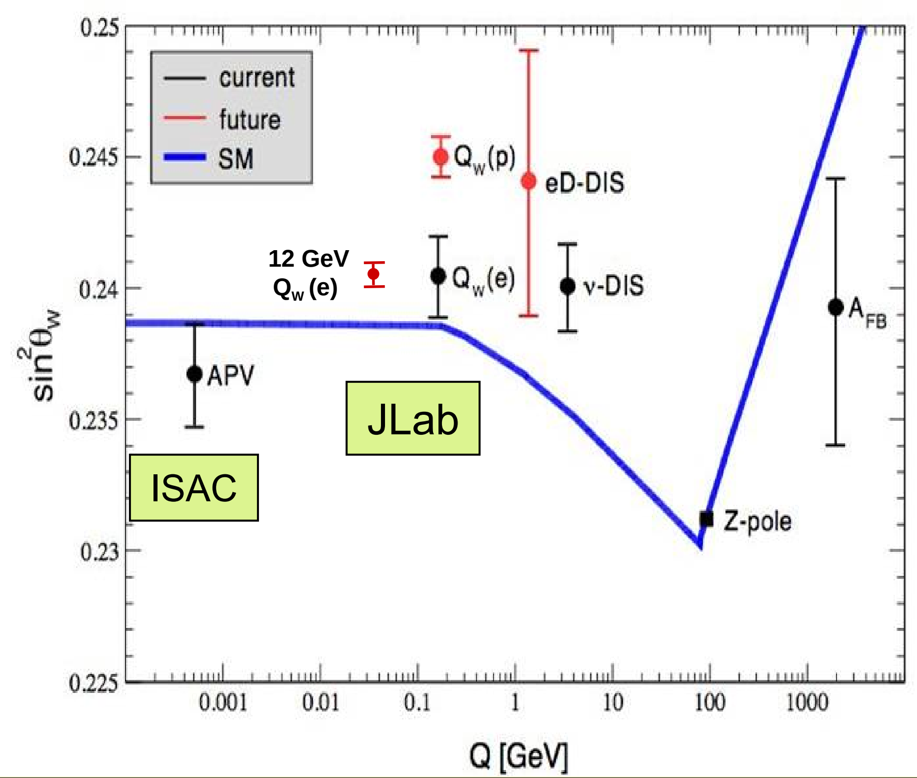
These three types of experiments are a complementary set for exploring new physics possibilities well below the Z^0 pole.

→ **Canadians play leading roles in all three**.

The Running of $\sin^2\theta_W$

Motivation: Search for new physics at the TeV scale

present:
"d-quark dominated": Cesium APV ($Q^A{}_W$): SM running verified at ~ 4σ level
"pure lepton": SLAC E158 ($Q^e{}_W$): SM running verified at ~ 6σ level



future:
"u-quark dominated" : Q_{weak} ($Q^p{}_W$) at JLab: test SM running ~10σ level.
"d-quark dominated": APV with ultra-cold Francium at ISAC.

→ Fr atomic theory understood to same level as Cs, but APV effect 20x larger.

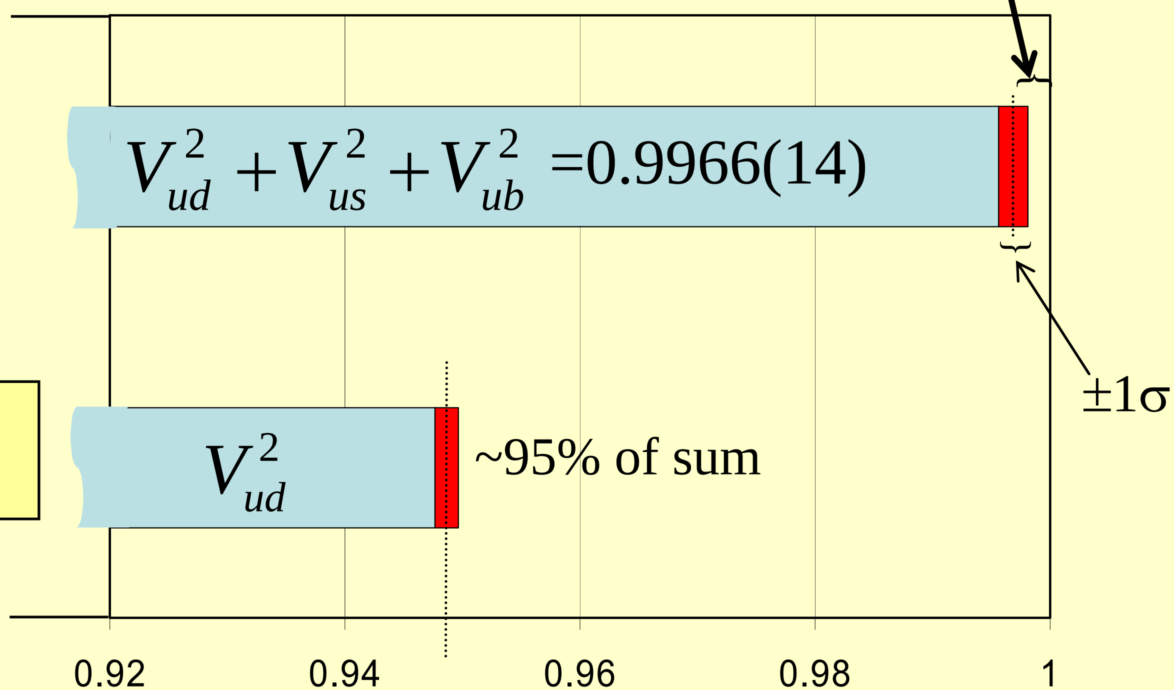
"pure lepton":12 GeV Möller ($Q^e{}_W$) at JLab: test SM running ~ 25σ level.

→ recent DOE review cited this experiment as having ``discovery potential''.

CKM Unitarity Tests

- Current tests of CKM matrix unitarity, using PDG values for matrix elements, show discrepancy at 2.3σ level.
- Attention has focused on value of V_{ud}, extracted from nuclear β decay, because the precision of V_{ud} determines the level of the precision of the unitarity test. (V_{us} *was* considered to be well-known, but recent experiments shed uncertainty.)
- Stringent tests of V_{ud}, and theoretical corrections that must be applied for its extraction, are being performed at TRIUMF-ISAC with 8π and TITAN.
- Complemented with ultra-cold neutron decay study at Los Alamos (LANSCE).

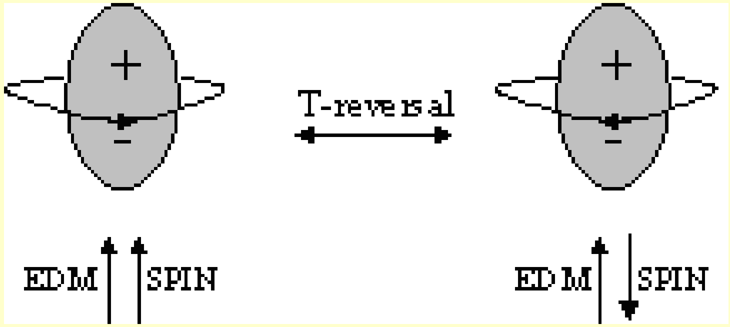
PDG values: different from Unitarity condition at 98% confidence level (2.3σ)



Contribution from nuclear physics

Note scale!

Electric Dipole Moment Measurements

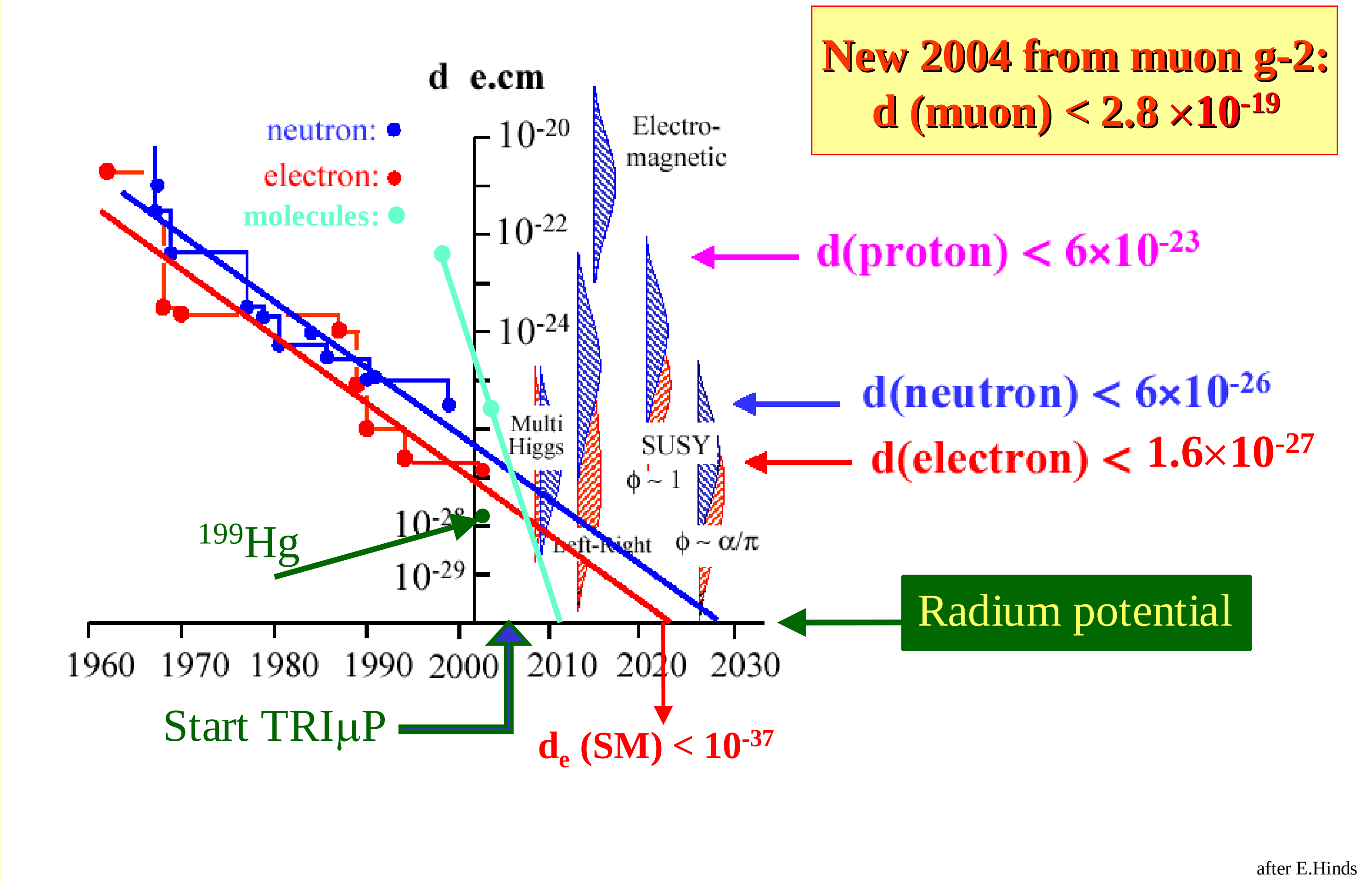


An electric dipole moment (EDM) changes sign under both parity and time reversal. For an elementary particle, atom, or molecule an EDM would represent explicit T and, hence CP, violation, distinct from the flavor-changing CP violation studied to date in the neutral *K* and *B* meson systems.

CP violation beyond that incorporated in the Standard Model (via the CKM matrix and θ_{QCD}) is required to account for the observed cosmic matter – antimatter asymmetry.

Proposed extensions to the Standard Model generically predict particle EDM's in the range of current experimental limits.

Some EDM Experiments compared



The current experimental limits are already placing restraints on the parameters of the various models.

Significant improvement over current EDM limits requires:

1. Advanced Technology

 e.g. ultra-cold neutrons in superfluid helium.

 → Experiment planned at Oak Ridge (SNS).

 → Possible experiment at TRIUMF under study.

2. Cases with enhanced sensitivity to the underlying CP violation

 e.g. octupole deformed nuclei.

^{223}Rn is predicted to be 600 times more sensitive than ^{199}Hg to an underlying CP-violating interaction!

→ The establishment of the predicted octupole deformation and determination of the parity-doublet energy differences requires detailed Rn-isotope spectroscopy to be performed with the 8π spectrometer.

→ Approved experiment using TIGRESS at ISAC depends on availability of intense Radon beams planned over next few years.

→ **Order of magnitude improvement on current best limit from ^{199}Hg expected.**

Long Term Roadmap

ISAC Program:

- Studies of the Weak Interaction via the ^{37}K program at TRINAT in progress, CKM matrix unitarity tests by TITAN and 8π collaborations. (Complemented with CPT at Argonne and *n* decay at LANSCE.)
- EDM of Radon by TIGRESS/TRINAT team in preparation.
  EDM of ultra-cold Fr under consideration.
- Fr Q^A_{weak} program is a longer-term development.
  - need to do Fr atomic physics.
  - need to do APV studies on a series of isotopes.

JLab Program:

- Q^p_{weak} test of $\sin^2\theta_w$ running in preparation.
- Q^e_{weak} experiment planned for JLab 12 GeV upgrade.

Mesons:

- Studies of μ,π decays at TRIUMF meson hall planned or in progress.
- T-odd K-decay study at J-PARC planned.

Anti-hydrogen: CPT test at CERN (ALPHA) in R&D stage.

Recommendation #1

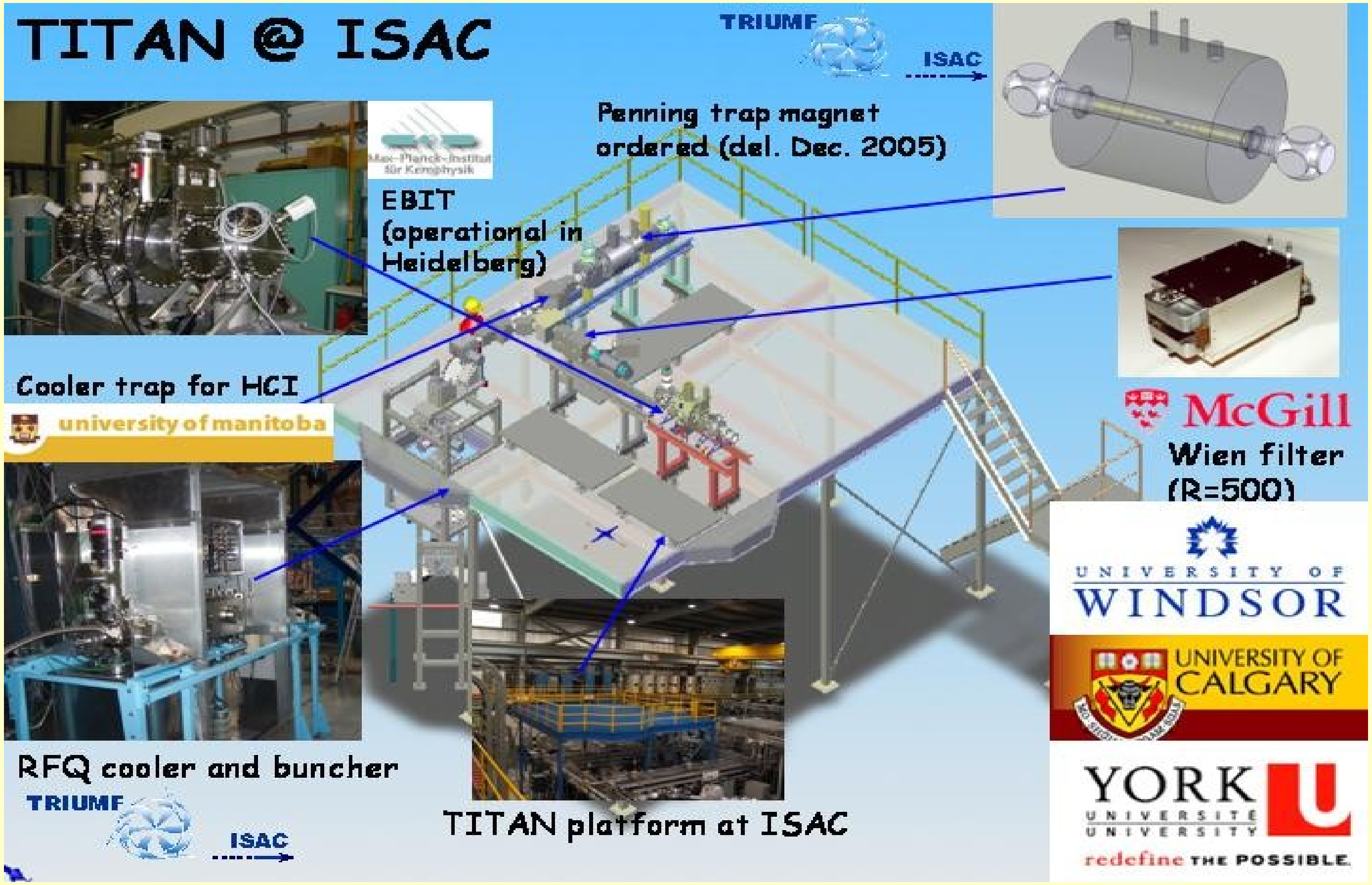
Maintain a broad-based program in nuclear physics in all funding scenarios.

- Canadian NP program is grouped around several high priority physics questions of broad significance and internationally recognized as each being of high priority.
- Canadians lead or make key contributions in a variety of initiatives, in both theory and experiment, in Canada and abroad.
- With significant advances occuring in multiple domains, it is clear that a broad-based nuclear physics program addressing these key questions must be maintained in all funding scenarios.

Physics driven innovation and instrumentation

The Canadian ISAC community has designed and built world-leading instruments:

<u>TITAN:</u> for mass measurements: addressing questions in nuclear structure, astrophysics, and weak interaction tests



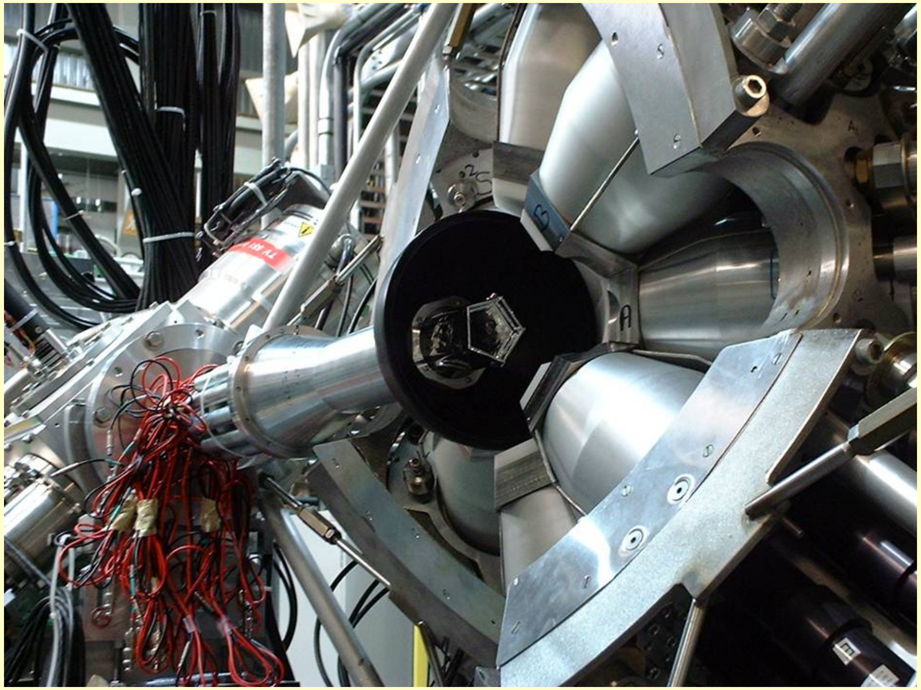
Coming online at ISAC 2006

Physics driven innovation and instrumentation

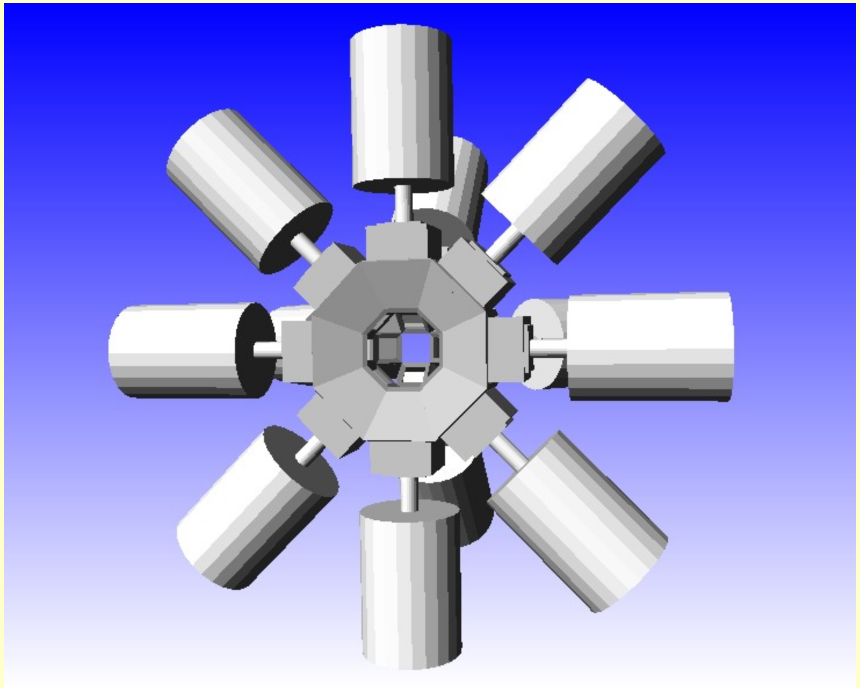
The Canadian ISAC community has designed and built world-leading instruments:

<u>8π and TIGRESS γ-ray spectrometers:</u> addressing questions in nuclear structure, astrophysics, and weak interaction and symmetry tests.

The 8π is in full operation



TIGRESS coming on-line 2006-2009

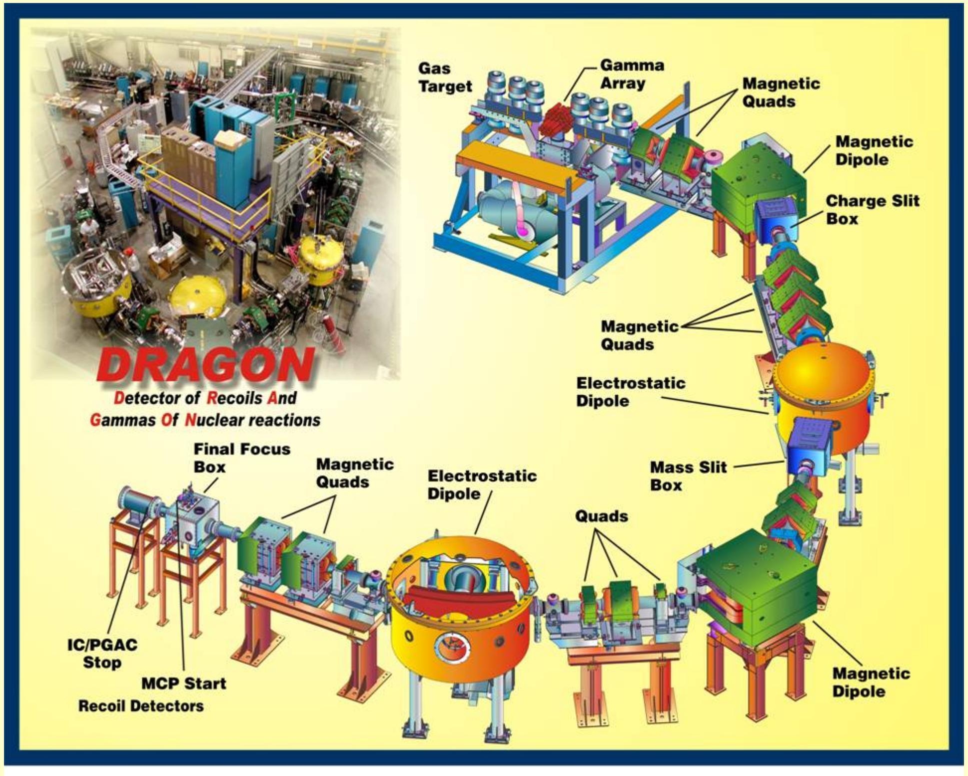


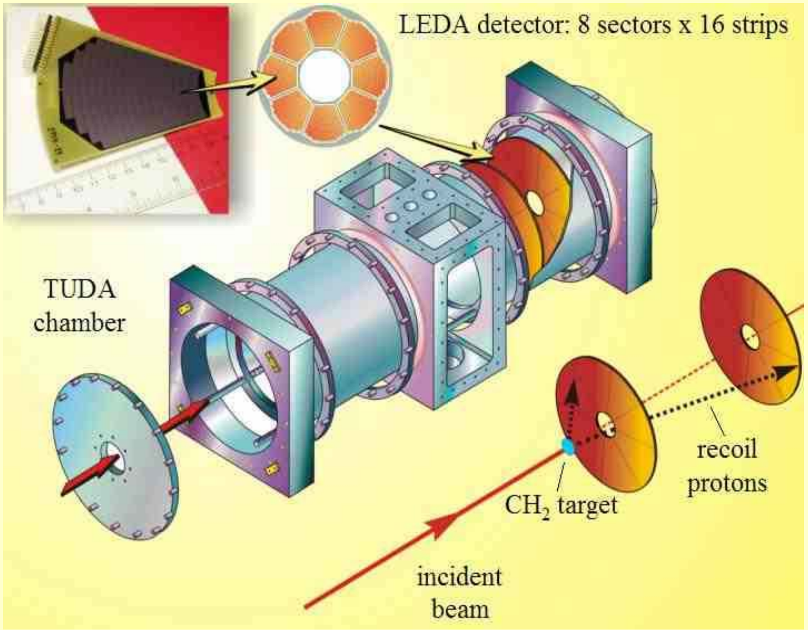
Physics driven innovation and instrumentation

The Canadian ISAC community has designed and built world-leading instruments:

<u>DRAGON and TUDA facilities:</u> addressing questions in nuclear astrophysics

DRAGON and TUDA are in full operation at TRIUMF-ISAC



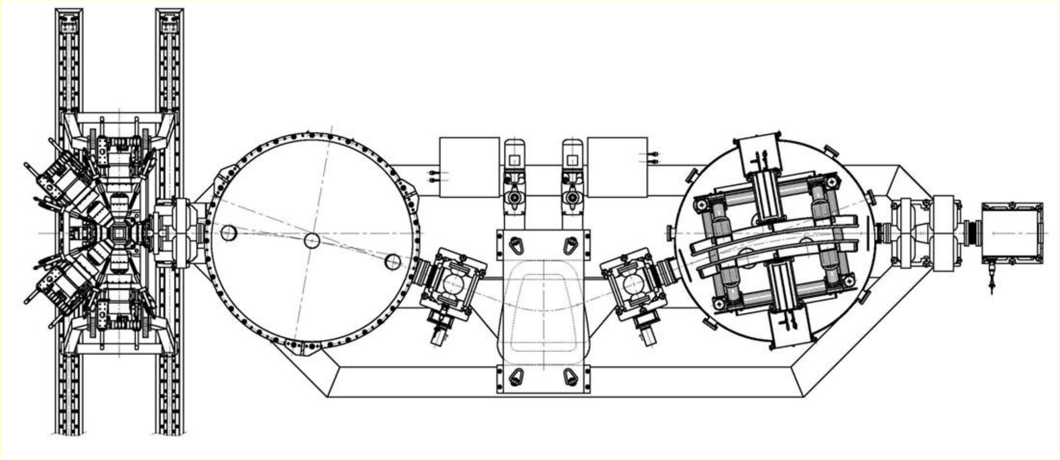


Vision for instrumentation

To perform the science, and remain world-leading, the ISAC community envisions as high-priority the following 3 instruments:

EMMA – $2M proposal to NSERC Fall 2005.

A *world-leading* recoil separator to enable experiments in nuclear structure and astrophysics that cannot be performed any other way.

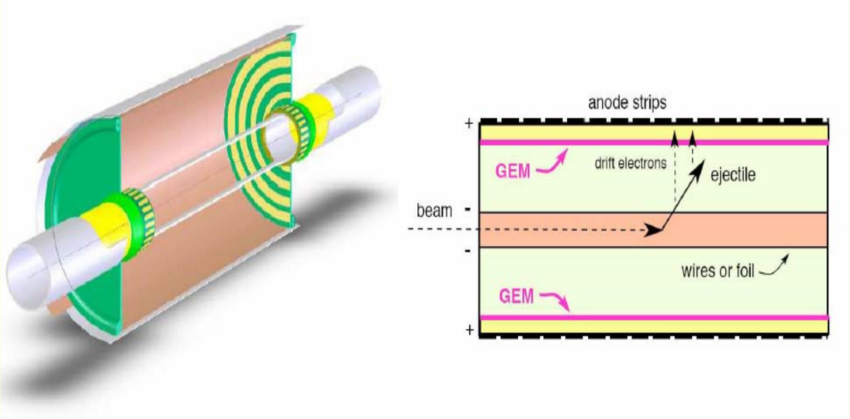


EMMA = #1 priority for new capital equipment for nuclear physics

Vision for instrumentation

<u>TACTIC</u> – \$163k proposal to NSERC Fall 2005.

A new cylindrical time-projection chamber to enable a new class of nuclear astrophysics experiments.



<u>8π Ge upgrade</u> – \$3M proposal to NSERC in 2011.

The 8π is world-class, but the drive to extremes will require an order of magnitude increase in γ-ray detection efficiency. This can be achieved with an upgrade of Ge detectors. These detectors will be optimized for β-decay studies, and will have a different geometry than the TIGRESS detectors.

Recommendation #2

Complete and exploit the new facilities at ISAC and ISAC-2.

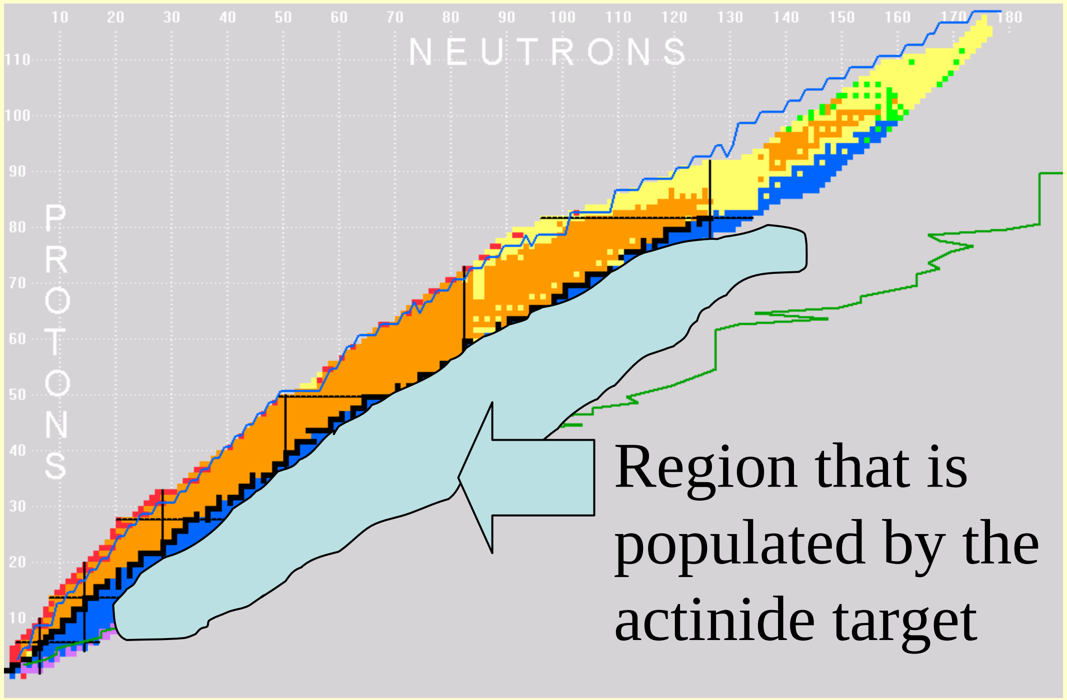
- A large investment has been made by Canada in the ISAC, ISAC-2 infrastructure.
- To allow the maximum physics impact to be made from these investments, significant SAP envelope funds are required to complete the experimental equipment and provide necessary operating funds.

Recommendation #3

Further development of the TRIUMF experimental capabilities.

- Many high priority aspects of the ISAC nuclear physics program depend on the continued development of these capabilities.
- This is of relevance to the TRIUMF 5 year plan, not GSC-19, but provided so LRPC members appreciate that these items are not decoupled.

Actinide Radioisotope Production Target



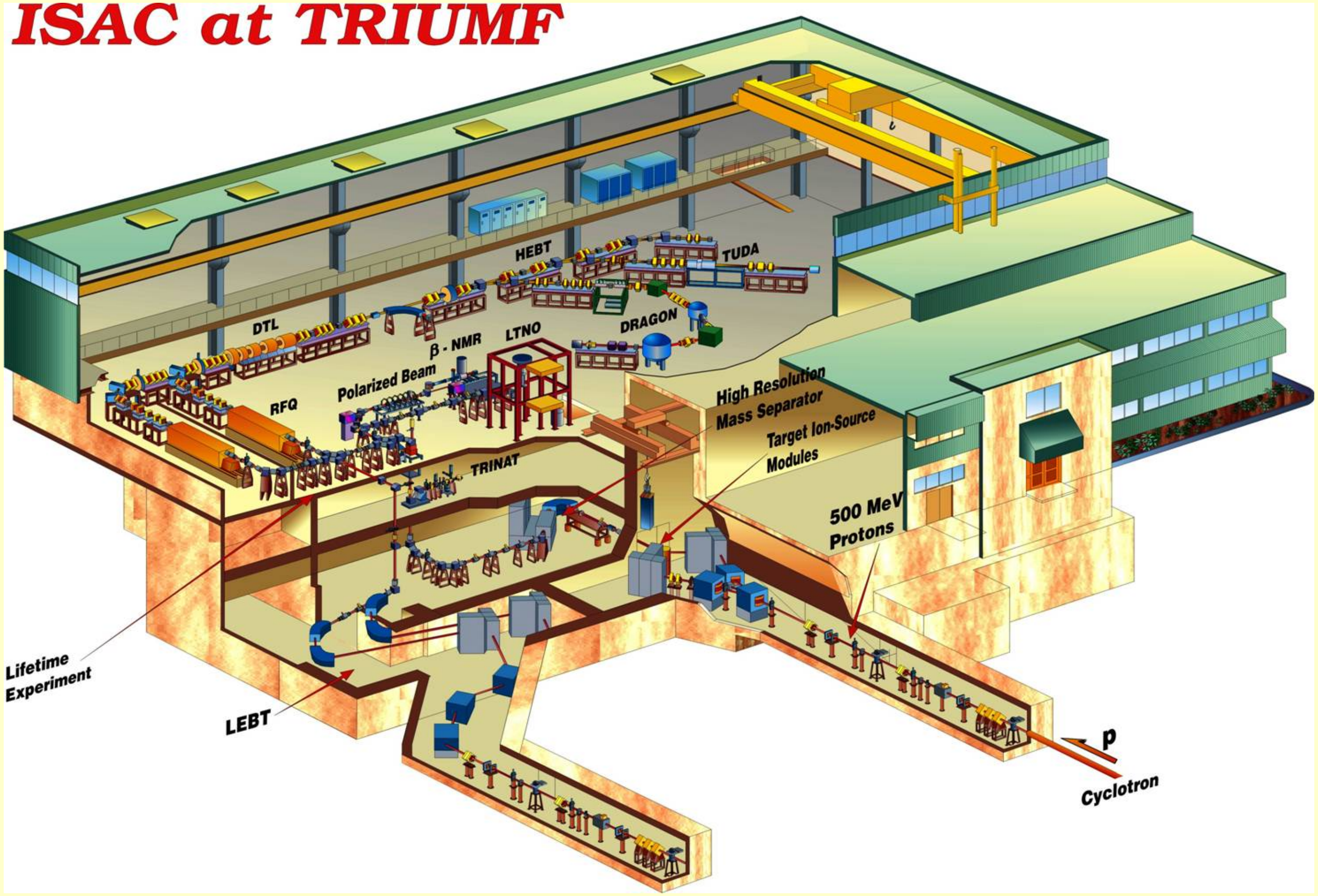
Necessary for the production of heavy isotopes urgently needed by ‘flagship’ experiments (Fr, Rn).

The production of neutron-rich nuclei (for the r-process in nuclear astrophysics) will either only be possible or strongly enhanced with the actinide target.

The actinide target is recognized by the TRIUMF User Group as the project with the highest priority at ISAC.

<u>Second high flux beamline:</u> an intense program of ion-source and target development is required over the next several years if ISAC is to realize its full potential.

→ will greatly improve the efficiency at which this development can proceed.



Recommendation #4

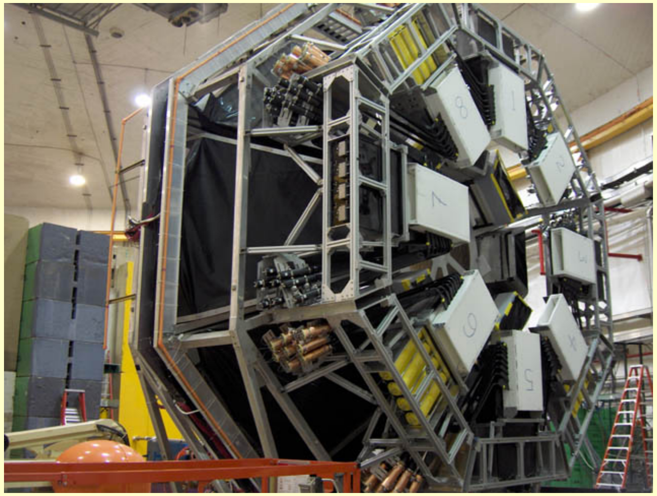
Opportunities for significant Canadian impact in offshore nuclear physics research should be fully exploited.

- Canadians have distinguished themselves by making a number of high impact contributions to hadron physics studies, fundamental symmetry tests, and moderate-energy tests of the Standard Model.
- Historically, the impact to investment ratio of this research has been very favorable.
- The culmination of this effort requires significant funding, as well as the continuation and strengthening of TRIUMF's role as a national support base for research at subatomic facilities outside of Canada.

TRIUMF's role in supporting offshore projects

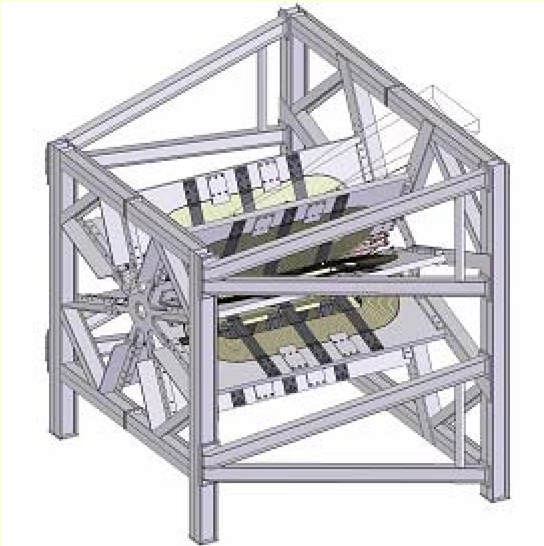
Infrastructure and technical expertise at TRIUMF crucial to success of high-profile experiments offshore.

e.g. the G^0 and Q_{weak} experiments at JLab.



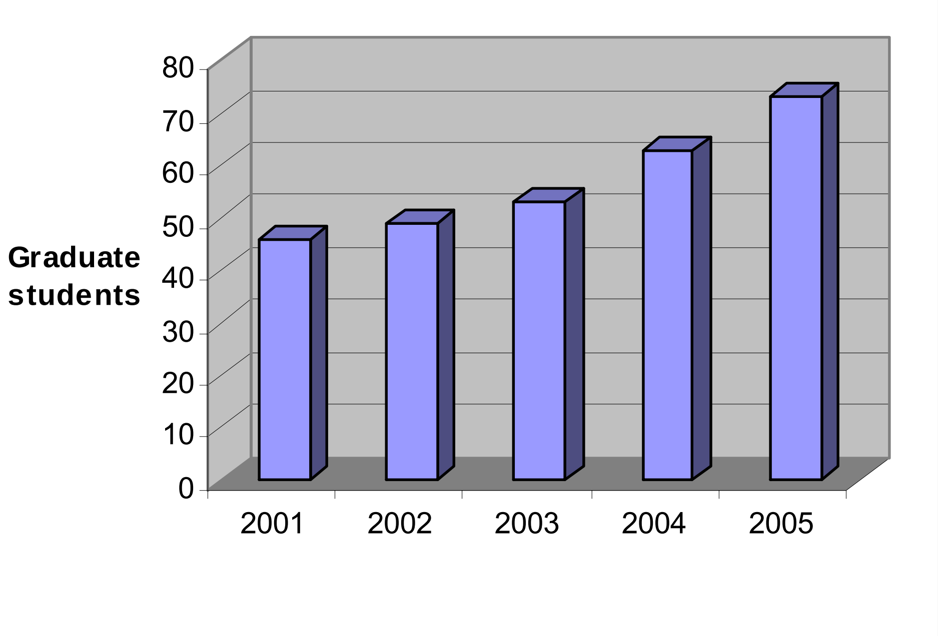
- G^0 projects completed at TRIUMF:
  - Development and production of PMT bases for the focal plane scintillators.
  - Beam monitors using PARITY electronics.
  - Design and construction of the Magnetic Field Verification device .
  - Design and construction of the Cryostat Exit Detectors (CED).
  - Design and construction of the Aerogel Cerenkov counters and their electronics .
  - Design and construction of the "Mini-Ferris Wheel" support structure for the new back-angle detectors (CED & Cerenkovs).

- Present and future Q_{weak} projects at TRIUMF:
  - Management of the design and construction of the toroidal magnet (QTOR).
  - Electronics for the main Quartz Cerenkov detector.
  - Electronics for the Hall C Compton polarimeter.
  - Quartz scanner detector.



Nuclear Physics Demographics

Graduate students in Nuclear Physics

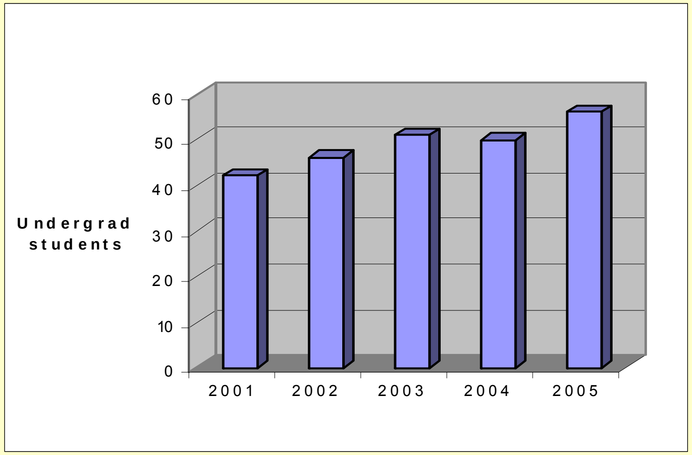


Increase of 63 % (45 – 73 students) over the last 5 years. Graduate students represent the attractiveness of the field, both intellectual and as a future perspective as a profession.

The increase in students seems to be coupled in time to the start of ISAC.

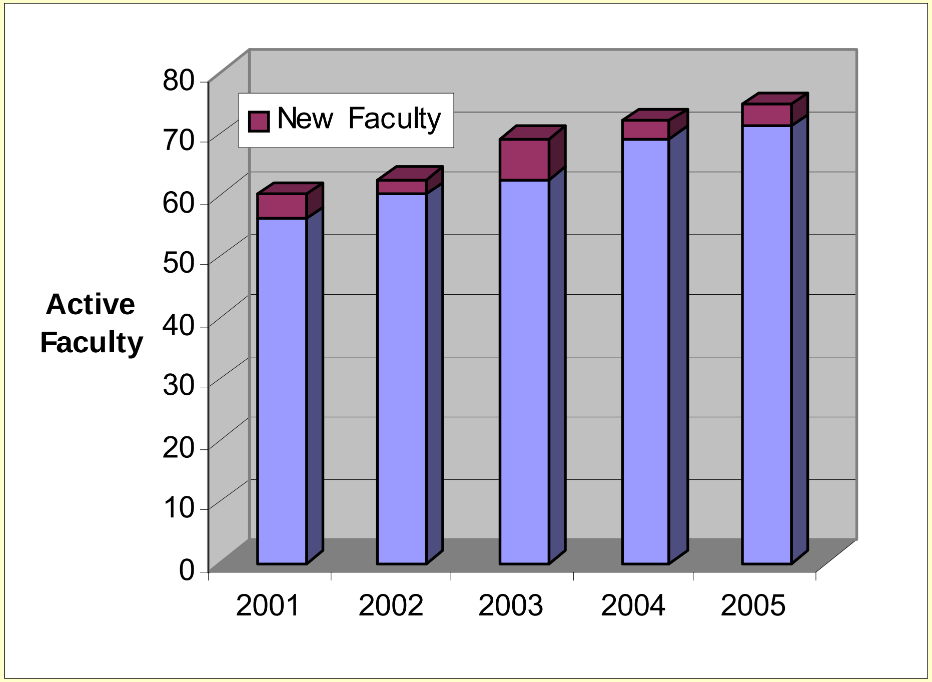
Undergrad students in Nuclear Physics

Increase by 33 % over last 5 years. Less rapid; nuclear physics always considered as attractive discipline in undergrad curriculum, that can be applied in many other fields.



Nuclear Physics Demographics

Faculty in Nuclear Physics



The trend towards new hires is not yet in saturation; comparable fields have ~ 5-7 faculty member per department. In Nuclear Physics the average is 3.25.
BUT: Mismatch between Theory and Experiment.

Presently 75 faculty (including post retirement), who are actively involved in theoretical or experimental nuclear physics.

Increase of 33%; 19 new hires in the field of Nuclear Physics over the last 5 years.

Recognized at universities, that Nuclear Physics is in demand in the overall curriculum **and** provides new opportunities for significant Canadian contributions.

Most new hires in ISAC related research.

Modern Nuclear Physics allows for interdisciplinary approach, which is attractive both to universities and students.

Funding Scenarios

- There has been significant growth in the NP community in the last 5 years.
- There is little doubt that operating and capital funds must grow in coming years in order to support the breadth and dynamism of the research being conducted.
- The +100% scenario will allow the capital projects envisioned by the ISAC community to proceed without delay.
- Significant contributions to offshore efforts such as the 12 GeV Möller experiment will be made.

Budget Summary Tables

- Grouped by key areas
- Four-year averaged capital used for “snapshots” at 5 and 10 years from now
- “Now” represents funds either held or being applied for in this competition year

+100% scenario	Operating Funds/yr			Capital			
$K/yr	Now	At 5 years	At 10 years	06	07	08	09
ISAC SubTotal	$2,399	$3,820	$4,246	$2,255	$3,013	$2,340	$1,890
JLab/Mainz/HIGS SubTotal	$652	$875	$1,008	$150	$150	$0	$500
Other SubTotal	$360	$1,190	$830	$385	$100	$300	$300
Totals	**$3,411**	**$5,885**	**$6,084**	**$2,790**	**$3,263**	**$2,640**	**$2,690**
New Initiatives		**$1,500**	**$4,000**		**Capital Average**		**$2,846**
Capital Average +Operating +New Initiatives	**$6,257**	**$10,231**	**$12,930**				
Status Quo **$6,257**							
Change in expenditure	**N/A**	**64%**	**107%**				

New initiatives in +100% scenario

- At year 10, up to $4M/year could be made available for new initiatives which are only now being imagined.
- Given the present growth of the community, many of these initiatives will be led by potential new hires.
- Possibilities:
  - Additional initiatives at the JLab 12 GeV upgrade.
  - Fundamental Neutron Physics, such as the neutron EDM at Oak Ridge (SNS), or possibly in Canada.
  - High Intensity Source for rare μ decay studies.
  - Future SNOLab experiments of relevance to Nuclear Physics.
  - Canadian participation in 25 GeV electron-light ion collider.

Status quo and -20% scenarios

All NP projects were prioritized by our committee:

- **Very High:** a new initiative which must proceed in all possible funding scenarios.
- **High:** A priority item whose funding would be preserved to the greatest extent possible in the -20% scenario.
- **Medium:** A worthwhile project in the 0% scenario, but at risk of losing funding in the -20% scenario.
- **Low:** A poorly motivated project. We have excluded these from further discussion. They are often eliminated at the Program Committee level.

In these difficult scenarios, we endeavored to preserve the NP scientific output to the greatest extent possible.

- Nonetheless, many opportunities would be lost.

  e.g. Canada would not realize the full potential of its investment in ISAC, ISAC-2.
- There would be little or no room for new initiatives.
- In the -20% scenario, the number of HQP’s would be adversely affected.

Status quo	Operating Funds/yr			Capital			
$K/year	Now	At 5 yrs	At 10 yrs	06	07	08	09
ISAC Subtotal	$2,399	$2,710	$2,710	$2,255	$3,013	$2,340	$1,890
Jlab/Mainz/HIGS Subtotal	$652	$652	$652	$150	$150	$0	$500
Other Subtotal	$360	$1,085	$725	$385	$100	$300	$300
Totals	**$3,411**	**$4,447**	**$4,087**	**$2,790**	**$3,263**	**$2,640**	**$2,690**
Capital Average +Operating	**$6,257**	**$7,293**	**$6,933**		**Capital Average**		**$2,846**
Status Quo **$6,257**							
Change in expenditure	**0%**	**17%**	**11%**				

-20% scenario	Operating Funds/yr			Capital			
$K/yr	Now	At 5 yrs	At 10 yrs	06	07	08	09
ISAC Subtotal	$2,399	$2,276	$2,276	$2,100	$2,863	$2,100	$0
Jlab/Mainz/HIGS Subtotal	$652	$595	$595	$150	$150	$0	$500
Other Subtotal	$360	$575	$325	$385	$0	$200	$200
Totals	**$3,411**	**$3,446**	**$3,196**	**$2,635**	**$3,013**	**$2,300**	**$700**
Capital Average +Operating	**$5,573**	**$5,608**	**$5,358**		**Capital Average**		**$2,162**
Status Quo **$6,257**							
Change in expenditure	**N/A**	**-10%**	**-14%**				

DNP

Division of Nuclear Physics

+100% scenario	Priority	Operating Funds/yr			Priority	Capital			
		Now	in 5 yrs	In 10 yrs		06	07	08	09
ISAC									
TITAN	high	$320	$460	$550	medium				$250
CPT	high	$200	$224	$250					
TRINAT/UMan/SB	high	$280	$500	$500					
-laser spectroscopy	medium		$200	$200					
8pi/TIGRESS	very high	$1,000	$1,400	$1,600	committed	$1,900	$1,800	$1,100	
complete TIGRESS					medium				$1,500
8pi upgrade					high				
EMMA	high	$60	$200	$220	very high	$100	$1,000	$1,000	
TUDA	medium	$74	$190	$190	medium	$100	$100	$200	$100
TACTIC	high	$65	$126	$126	high	$100	$63		
TACTIC upgrade					medium				
DRAGON	high	$230	$360	$450					
HERACLES	medium	$170	$160	$160	medium	$55	$50	$40	onward

+100% scenario	Priority	Operating Funds/yr			Priority	Capital			
		Now	In 5 yrs	In 10 yrs		06	07	08	09
Jlab/Mainz/HIGS									
G0	high	$210							
Qweak	high	$210	$400		high	$150	$150		
12 GeV Moller	high		$150	$550	high				$500
Hadronic	high	$175	$250	$360					
HIGS	medium	$57	$75	$98					

+100% scenario	Priority	Operating Funds/yr			Priority	Capital			
		Now	In 5 yrs	In 10 yrs		06	07	08	09
Other									
n beta decay	high	$10	$80						
NPDgamma	medium	$25	$80						
pienu	high		$200		high	$200			
K-decay	medium		$400	$400	medium		$100	onward	
Alpha	high	$325	$430	$430	high	$185		$200	$200

Status quo	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
ISAC									
TITAN	high	$320	$320	$320	medium				$250
CPT	high	$200	$200	$200					
TRINAT/UMan/SB	high	$280	$280	$280					
-laser spectroscopy	medium		$200	$200					
8pi/TIGRESS	very high	$1,000	$1,000	$1,000	committed	$1,900	$1,800	$1,100	
complete TIGRESS					medium				$1,500
8pi upgrade					high				
EMMA	high	$60	$120	$120	very high	$100	$1,000	$1,000	
TUDA	medium	$74	$74	$74	medium	$100	$100	$200	$100
TACTIC	high	$65	$126	$126	high	$100	$63		
TACTIC upgrade					medium				
DRAGON	high	$230	$230	$230					
HERACLES	medium	$170	$160	$160	medium	$55	$50	$40	$40

Status quo	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
Jlab/Mainz/HIGS									
G0	high	$210							
Qweak	high	$210	$270		high	$150	$150		
12 GeV Moller	high		$150	$420	high				$500
Hadronic	high	$175	$175	$175					
HIGS	medium	$57	$57	$57					

Status quo	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
Other									
n beta decay	high	$10	$80						
NPDgamma	medium	$25	$80						
pienu	high		$200		high	$200			
K-decay	medium		$400	$400	medium		$100	$100	$100
Alpha	high	$325	$325	$325	high	$185		$200	$200

-20% scenario	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
ISAC									
TITAN	high	$320	$320	$320					
CPT	high	$200	$200	$200					
TRINAT/UMan/SB	high	$280	$280	$280					
8pi/TIGRESS	very high	$1,000	$1,000	$1,000	committed	$1,900	$1,800	$1,100	
8pi upgrade					high				
EMMA	high	$60	$120	$120	very high	$100	$1,000	$1,000	
TUDA	medium	$74	$0	$0					
TACTIC	high	$65	$126	$126	high	$100	$63		
TACTIC upgrade					medium				
DRAGON	high	$230	$230	$230					
HERACLES	medium	$170	$0	$0					

-20% scenario	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
Jlab/Mainz/HIGS									
G0	high	$210							
Qweak	high	$210	$270		high	$150	$150		
12 GeV Moller	high		$150	$420	high				$500
Hadronic	high	$175	$175	$175					
HIGS	medium	$57	$0	$0					

-20% scenario	Priority	Operating			Priority	Capital			
		Now	5yr	10yr		06	07	08	09
Other									
n beta decay	high	$10	$50						
NPDgamma	medium	$25	$0						
pienu	high		$200		high	$200			
Alpha	high	$325	$325	$325	high	$185		$200	$200