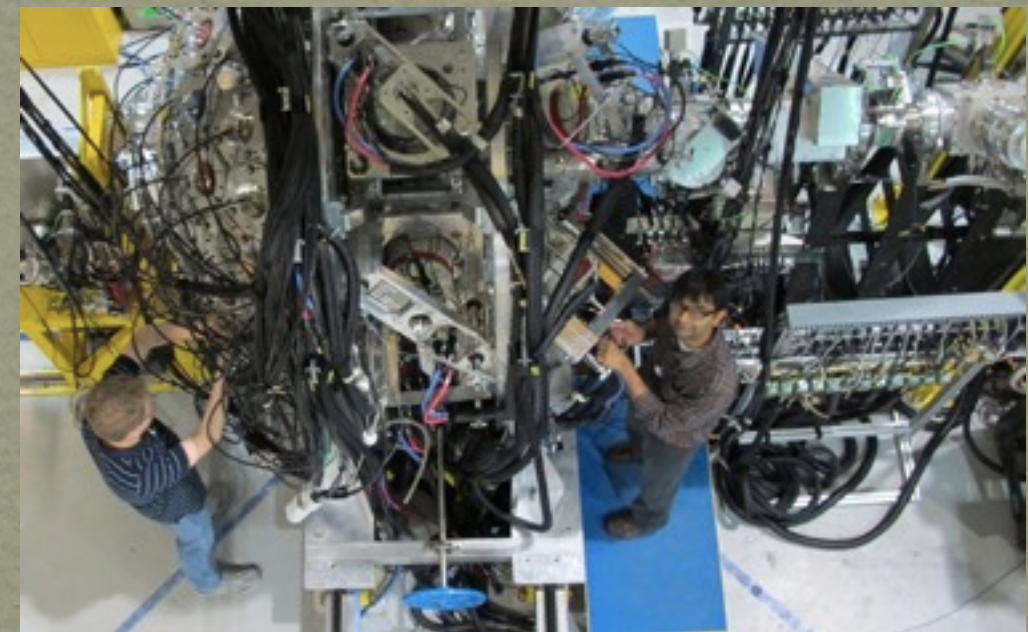
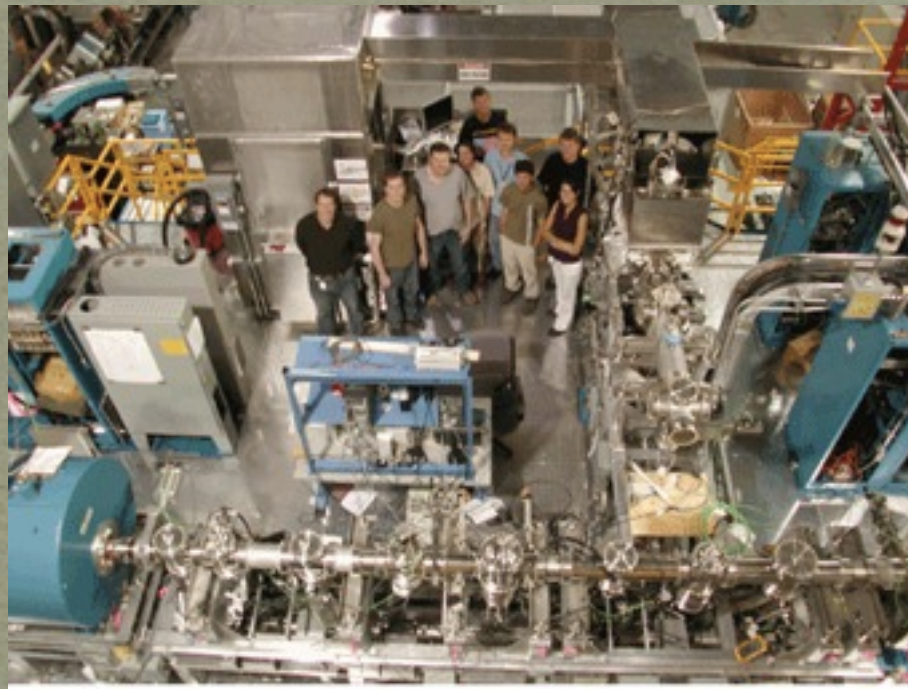


# RI-BEAM GRADUATE STUDIES AND RESEARCH OPPORTUNITIES IN CANADA



R. KANUNGO  
Saint Mary's University, Halifax



# State of Nuclear Physics in Canada

The State of Science and Technology in Canada -

*Council of Canadian Academies report : 2012*

“One of the 9 sub-fields of research in which Canada leads the world in scientific impact”

## **Nuclear and Particle Physics**



# State of Nuclear Physics in Canada

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## Nuclear and Particle Physics

### Subatomic Physics

*Particle Physics*

IPP

(Institute of Particle Physics)

*Nuclear Physics*

CINP

(Canadian Institute of Nuclear Physics)

*Institutional members*

McGill Univ.  
*C. Gale*  
Mount Alison Univ.  
*D. Hornidge*  
Saint Mary's Univ.  
*A.J. Sarty*  
TRIUMF  
*R. Kruecken*  
Univ. of Guelph  
*P.E. Garrett*  
Univ. of Manitoba  
*K. Sharma*  
Univ. of Regina  
*Z. Papandreou*  
Univ. of Winnipeg  
*J. Martin*

*Board of Directors*

President  
*R. Kanungo*  
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Members  
*J. Barrette*  
*J. Dilling*  
*D. Hornidge*  
*J. Martin*

Executive  
Director  
*G. Huber*

Graduate Student and Postdocs :  
Associate members of CINP.



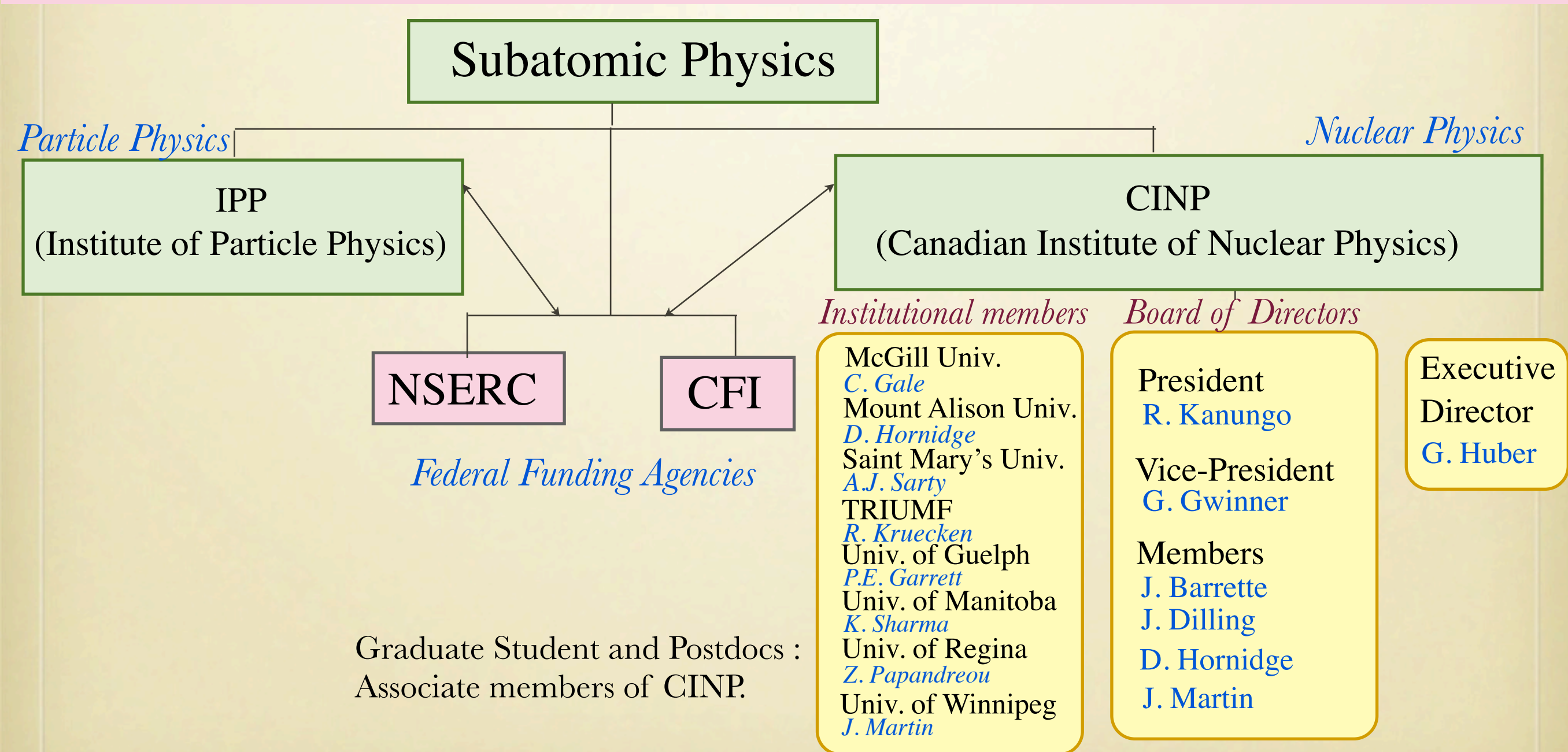
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## Nuclear and Particle Physics





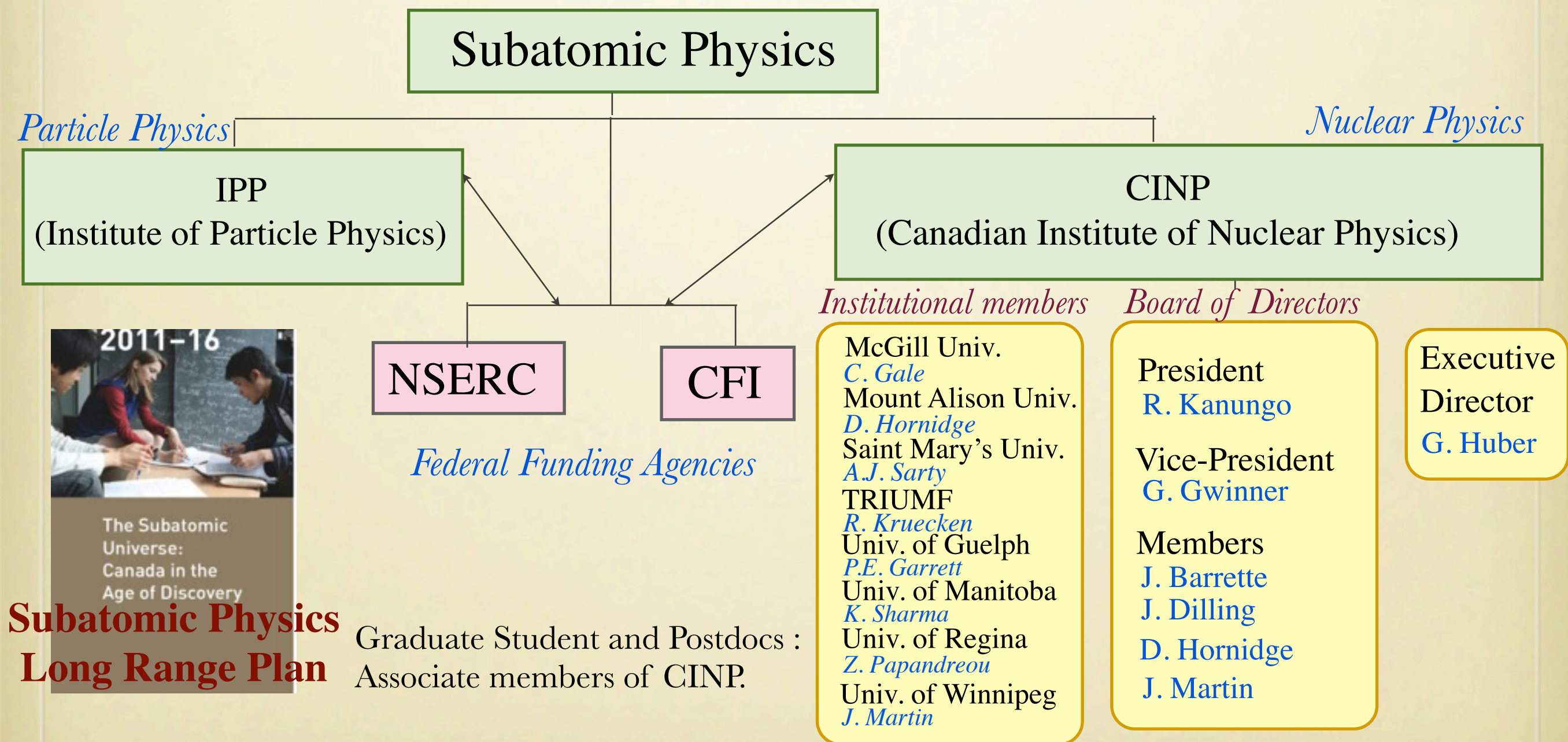
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## Nuclear and Particle Physics



# Graduate Study and Research in Canada

## Graduate Program

- M.Sc. program with thesis : 2 years
- Ph.D. program with thesis : ~4 years
- M.Sc.+Ph.D. combined program with one thesis : 5-6 years  
*Subject to academic performance in first 2 years*

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## Graduate Fellowships

- **NSERC grants of individual faculty members** ~ \$20,000 - 25,000/yr  
*International and Canadian students*  
Process : Contact the faculty member typically in November-December  
Application deadlines typically in January-February. Term starts from September.  
*For Ph.D. there is more flexibility to accept students starting in January or May*
- **NSERC - Vanier Canada graduate scholarships** \$50,000/yr for 3 years  
*International and Canadian students*  
Few selected few scholarships  
University quota based. Pre-selection done by the university. (*contact by May-June*)  
<http://www.vanier.gc.ca/>  
Institutional nomination deadline for the 2015-2016 competition: **November 4, 2015**
- **NSERC - PGS-D and CGS-D** ~ \$21,000 - 35,000/yr  
*Canadian students*



# TRIUMF - Canada's National Laboratory @ Vancouver



Owned & operated  
by a consortium of  
**19** universities

- 12 MEMBERS
- 7 ASSOCIATE MEMBERS

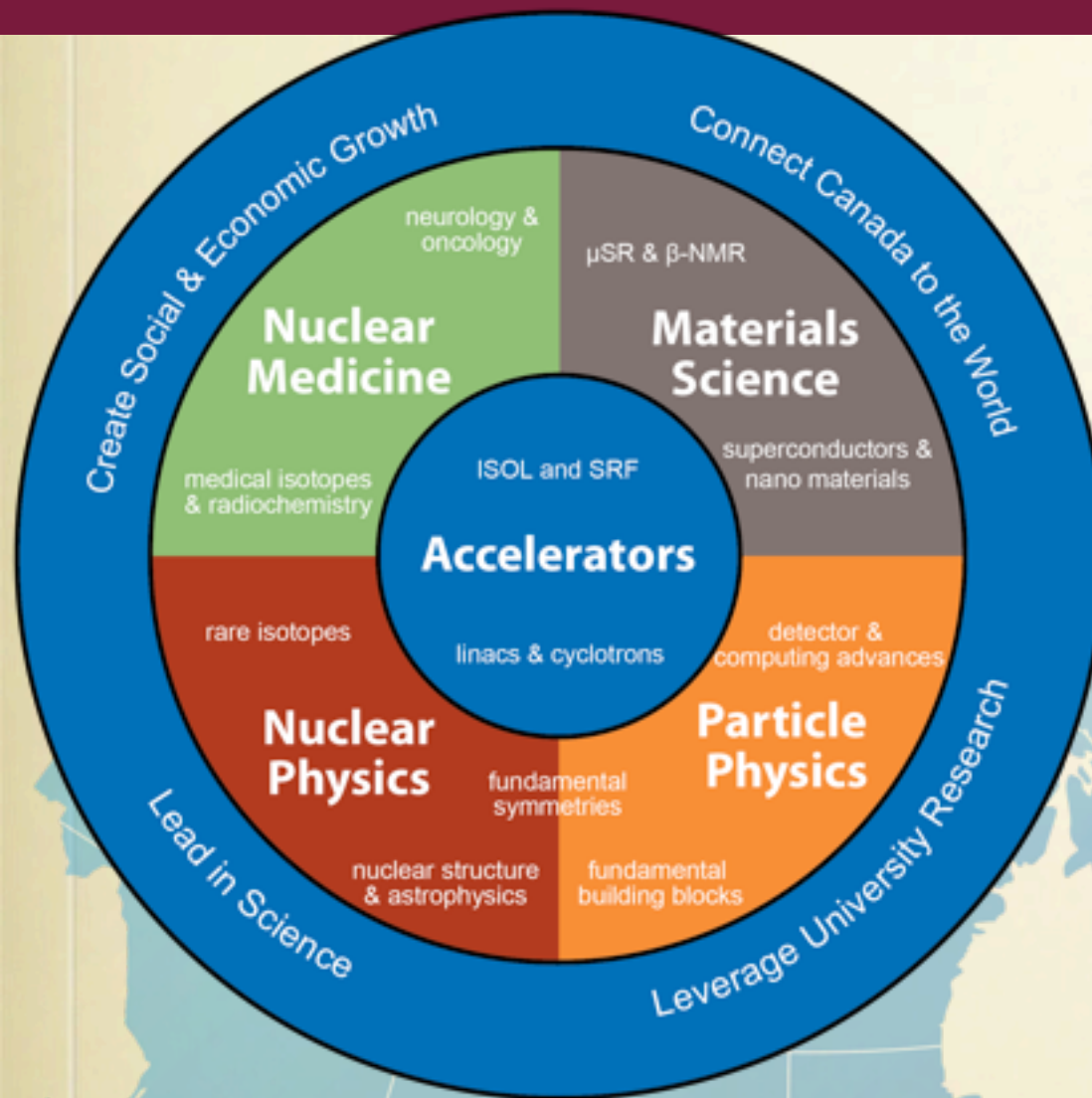


Courtesy : TRIUMF





# TRIUMF - Canada's National Laboratory @ Vancouver



## TRIUMF Accelerators:

- 520 MeV, 350 $\mu$ A, H<sup>-</sup> cyclotron
- 4 medical isotopes cyclotrons (TR13, CP42, TR30x2)
- ISAC 50kW ISOL facility
  - RFQ,  $3 \leq A/q < 30$
  - DTL,  $A/q \leq 7$ , 0.1-1.8 MeV/u
  - 40 MV Heavy Ion SRF Linac
- ARIEL e-linac (10mA, 50 MeV)

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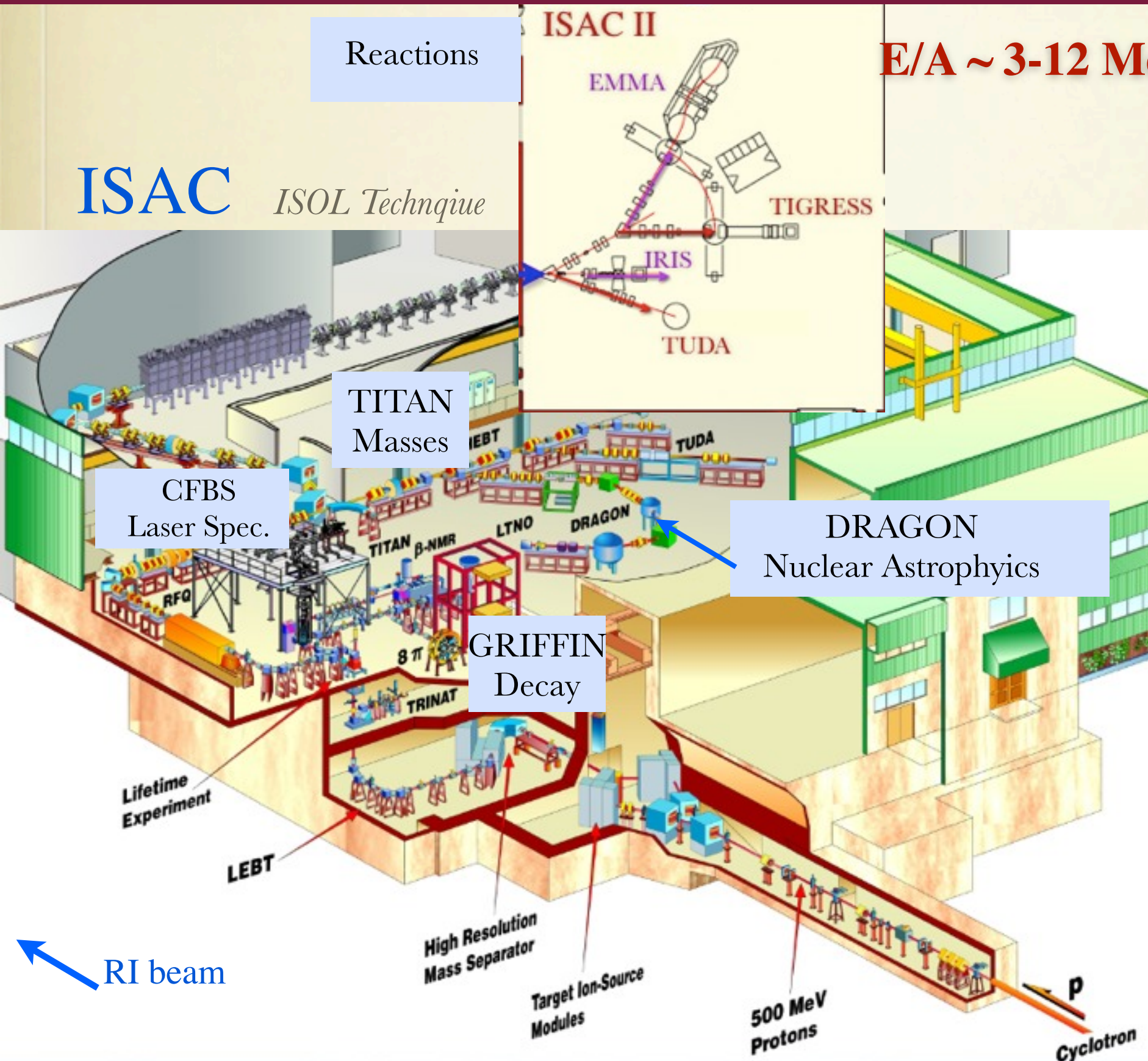
Courtesy : TRIUMF





# RI- Beam Facility in Canada

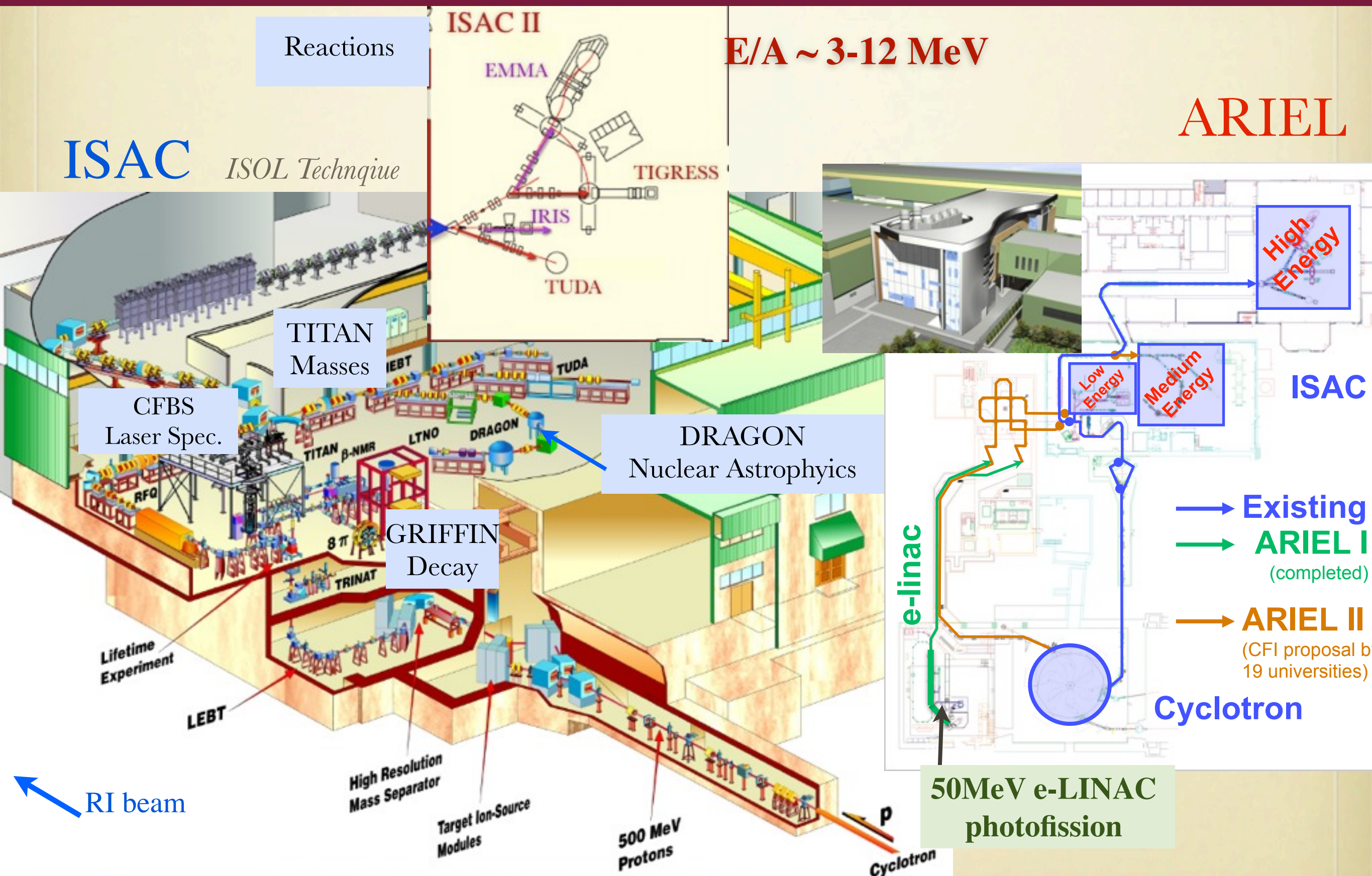
Highest power ISOL facility





# RI- Beam Facility in Canada

Highest power ISOL facility





## Facilities @ ISAC

### ■ Nuclear Structure and Reactions

- Exploring halo and skin nuclei
- Evolution of shell structure
- *Ab initio* theory and three-nucleon force

### ■ Nuclear Astrophysics

- r-process in neutron-rich nuclei
- rp-process in proton-rich nuclei
- H, He burning and hot CNO cycle

### ■ Fundamental Symmetries in nature

- Parity Non Conservation (APNC) in Francium
- Unitarity of CKM matrix
- Electric dipole moment (Rn)

### ■ ■ ■ Gamma, Neutron Spectroscopy

Beta decay @ GRIFFIN

Beta Delayed neutron @ DESCANT

Coulomb excitation @ TIGRESS

Lifetime @ TIP-TIGRESS

### ■ ■ Reaction Spectroscopy

Transfer, Elastic and Inelastic Scattering @ IRIS, TIGRESS, EMMA

Radiative Capture @ DRAGON

### ■ ■ ■ Traps

Mass @ TITAN Ion Trap

APNC @ FrPNC Laser Trapping

### ■ Laser Spectroscopy

EM moments, Charge Radii @ CFBS

### ■ ■ Nuclear Theory (details in Sonia Bacca's talk)

No core shell model

Coupled Cluster

Shell model

EM interactions



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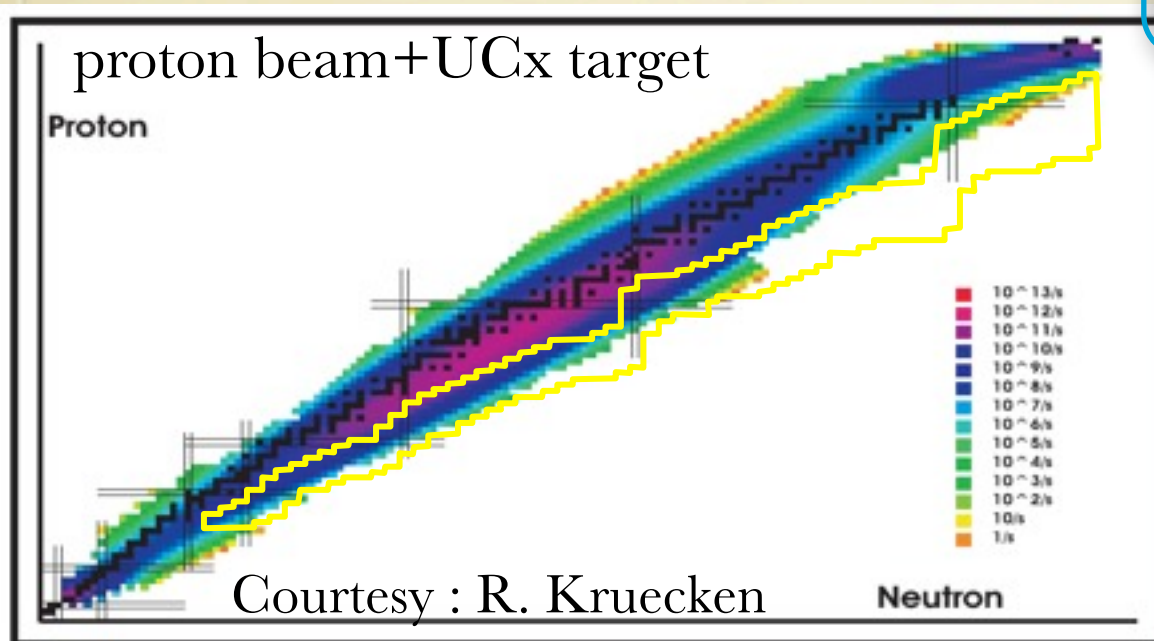
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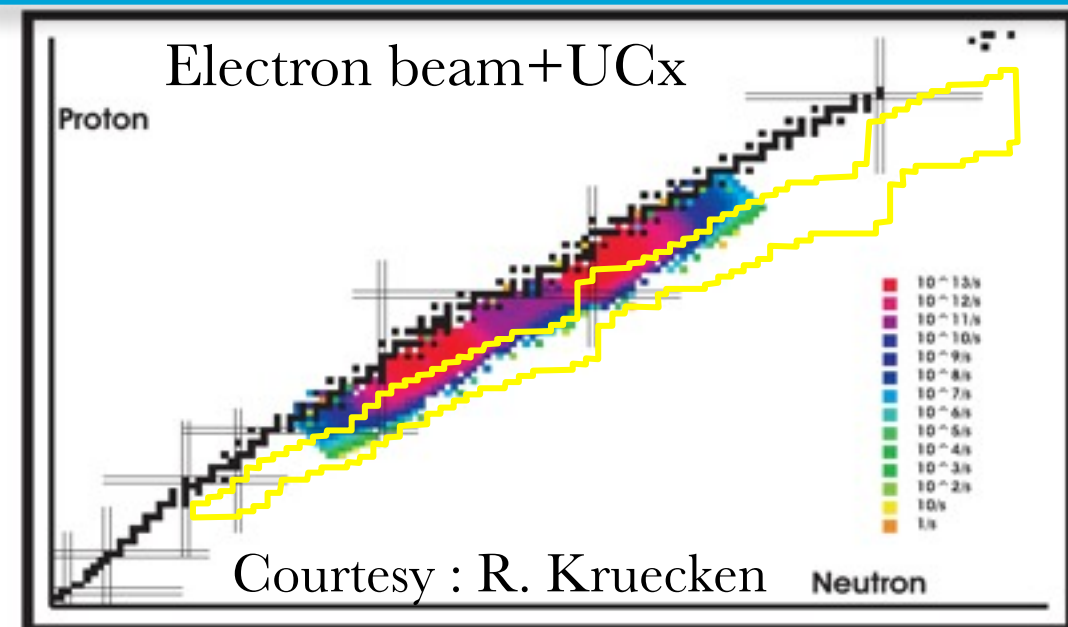
Shell model

EM interactions



Courtesy : R. Kruecken

Figure 7: Production yield in target assuming a 10  $\mu$ A proton beam onto a 25 g/cm<sup>2</sup> UC<sub>x</sub> target using FLUKA.

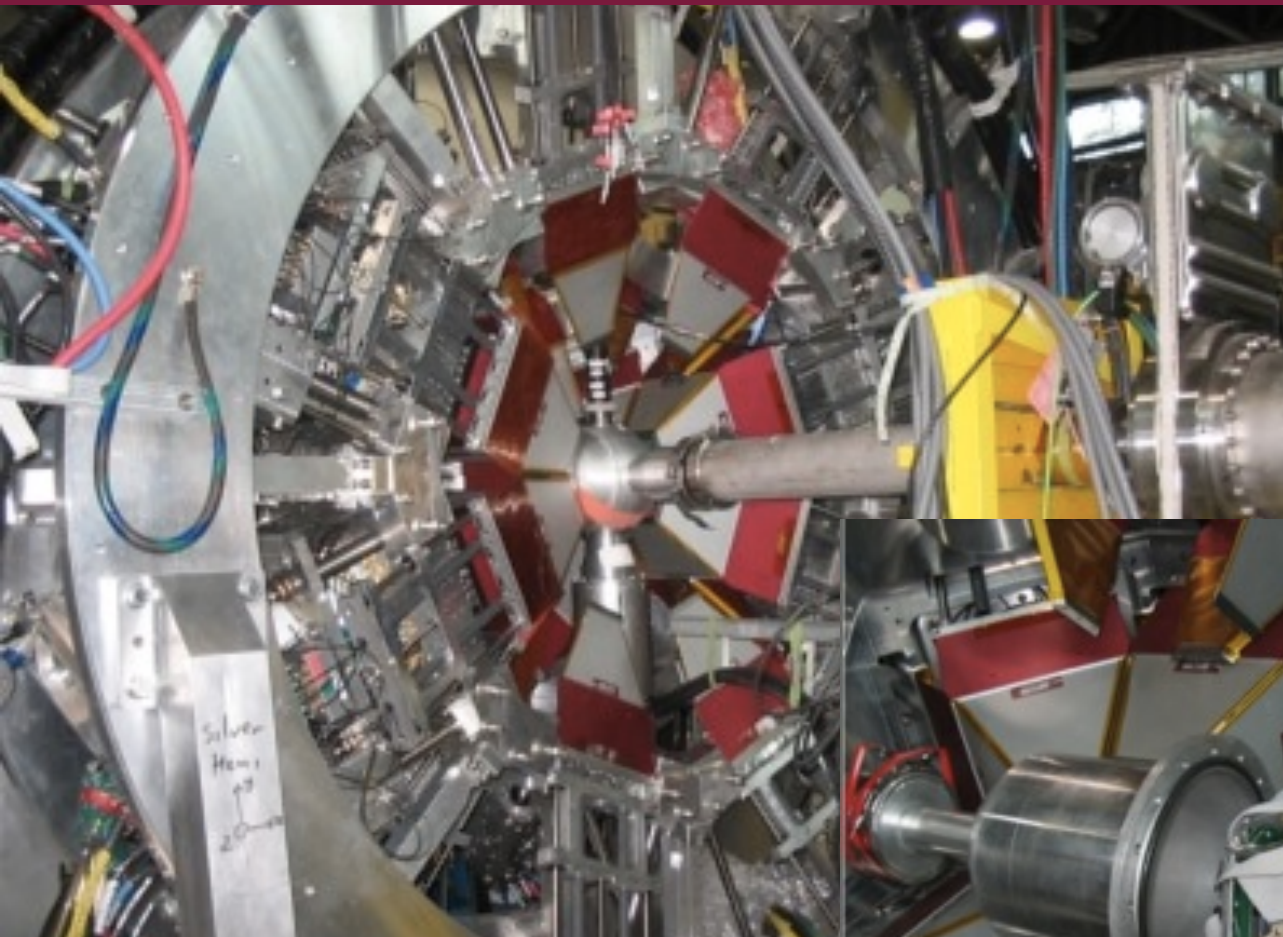


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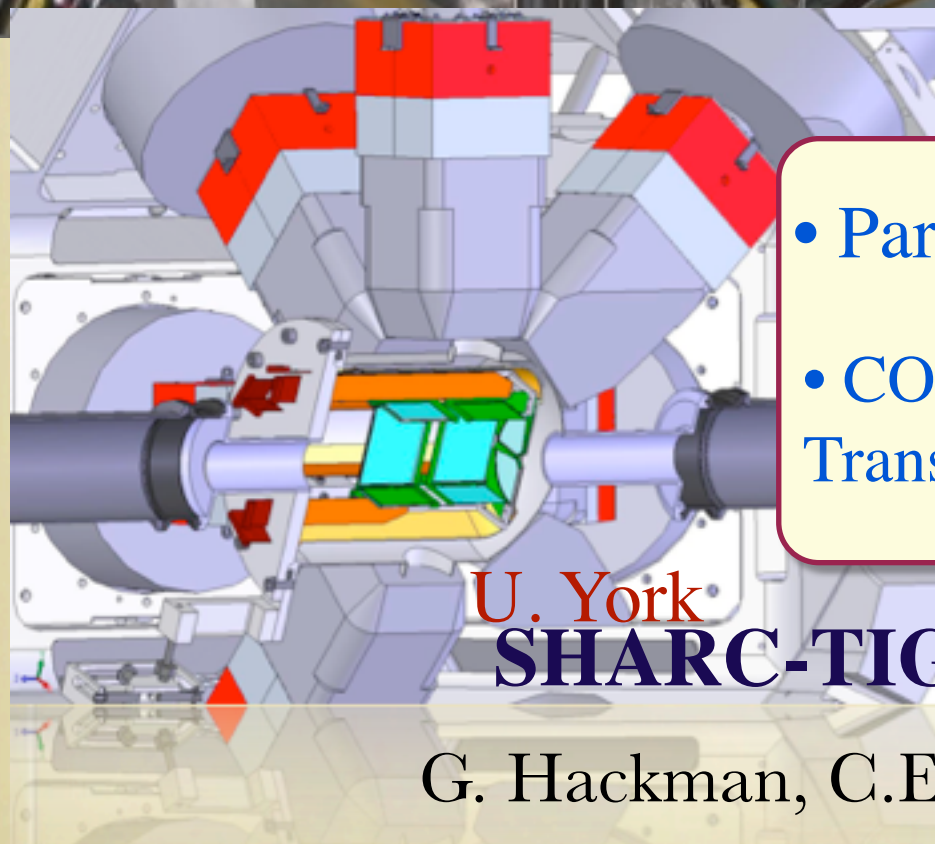
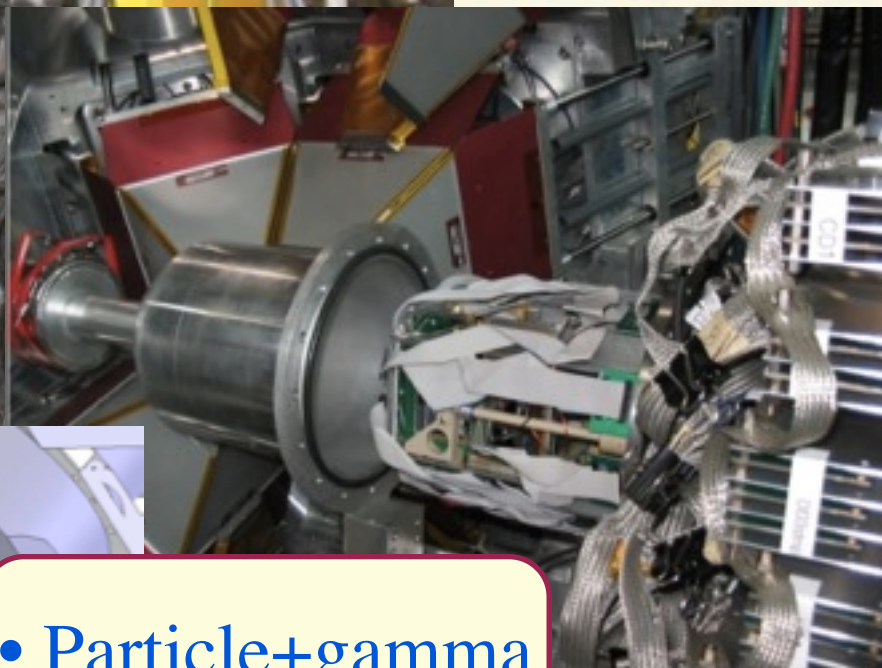
Figure 8: Production in target assuming  $4.6 \times 10^{13}$  photo-fission induced into a 15 g/cm<sup>2</sup> UC<sub>x</sub> target.



# TIGRESS- Gamma spectroscopy facility (Guelph-TRIUMF)



- 16 segmented Ge detectors



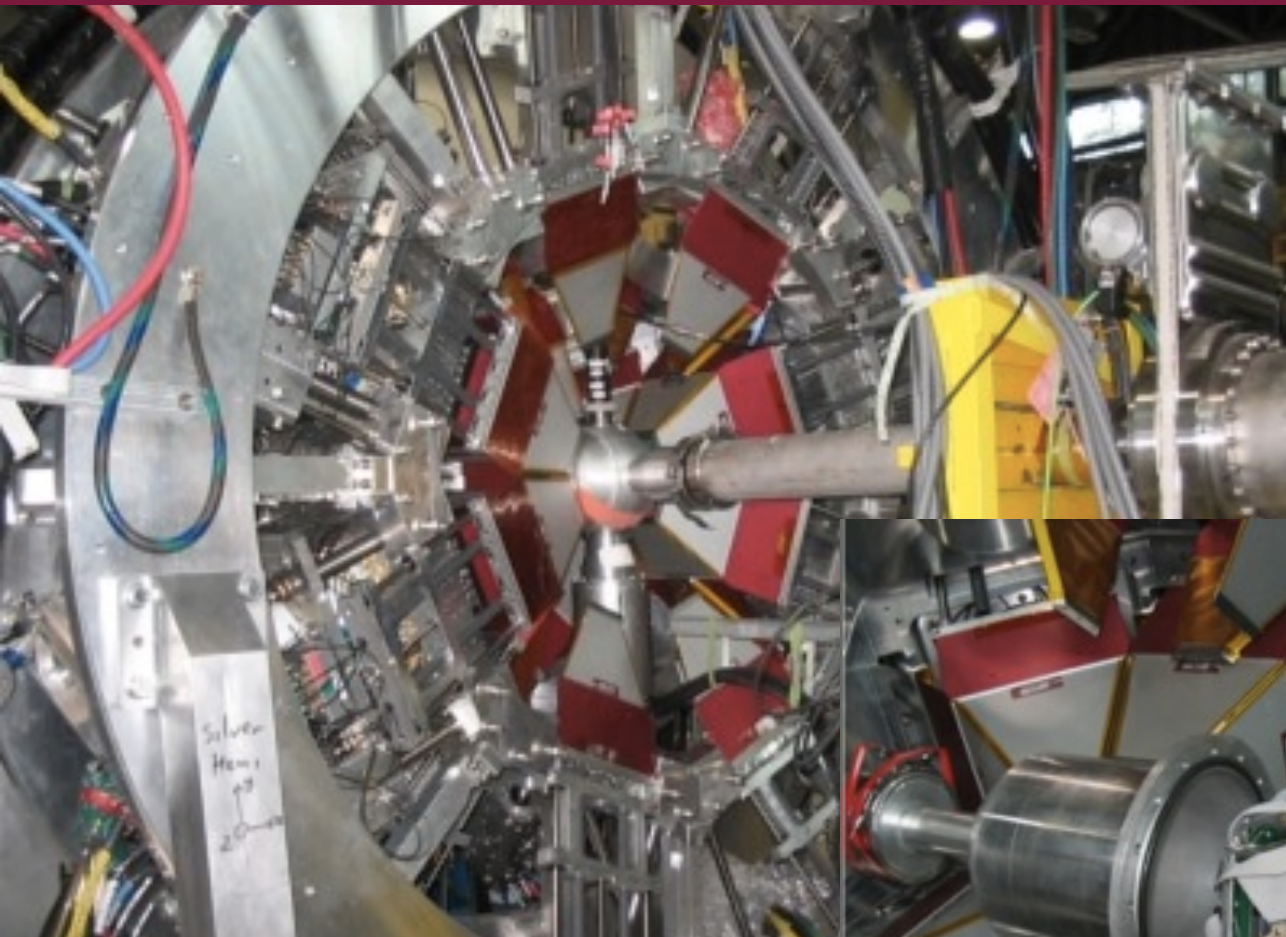
- Particle+gamma
- COULEX and Transfer

U. York  
**SHARC-TIGRESS**

G. Hackman, C.E. Svensson

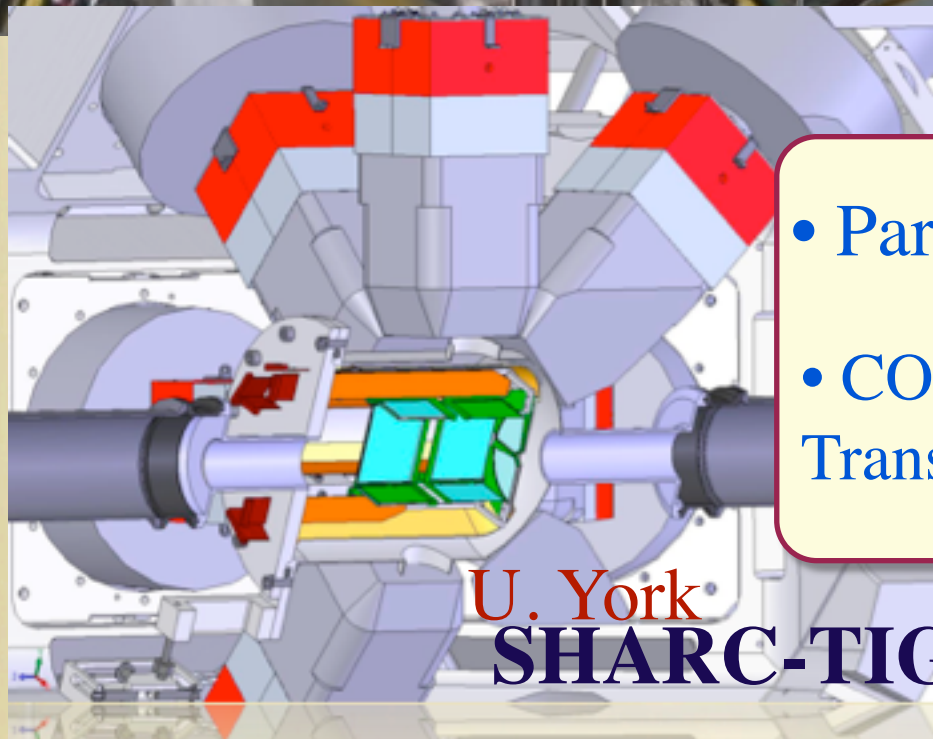
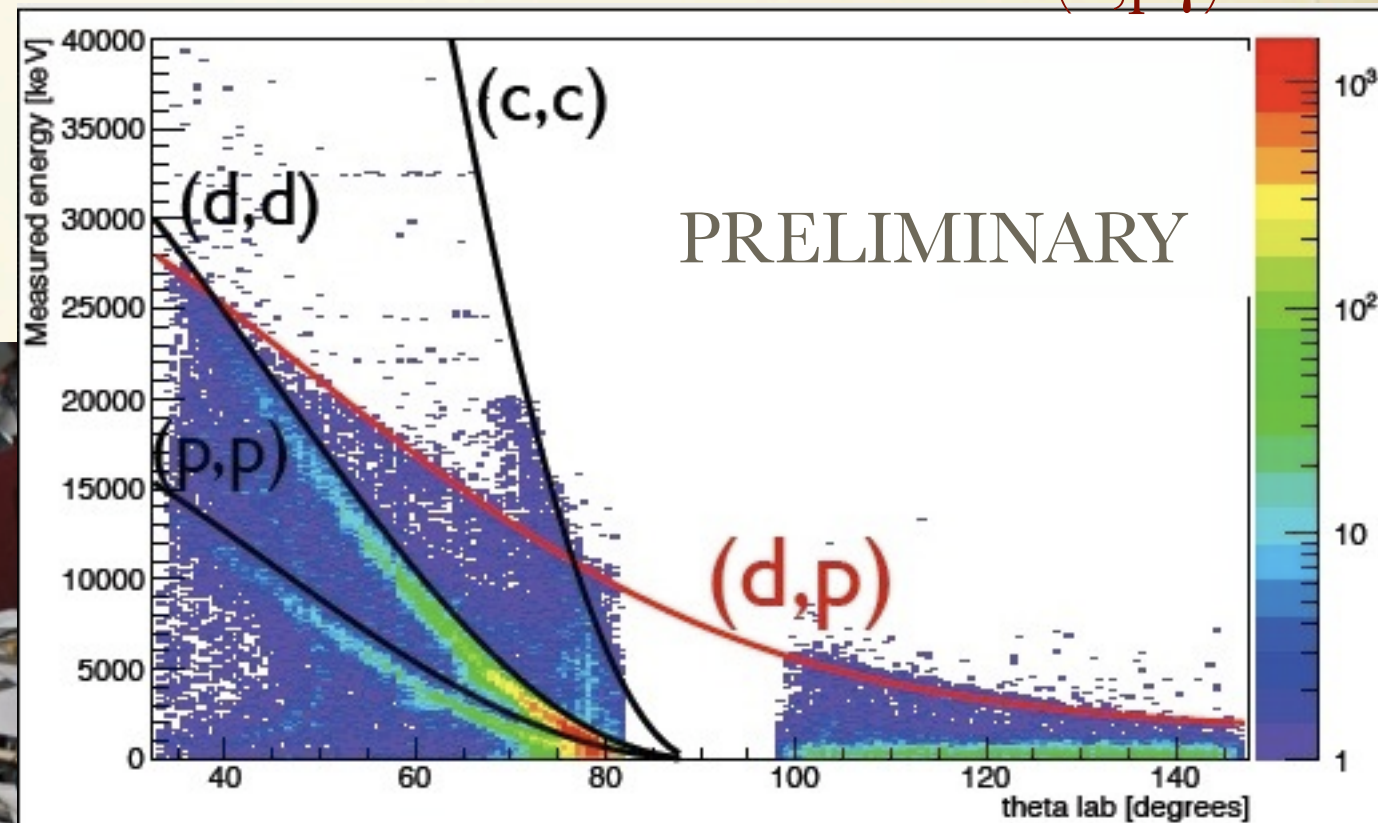


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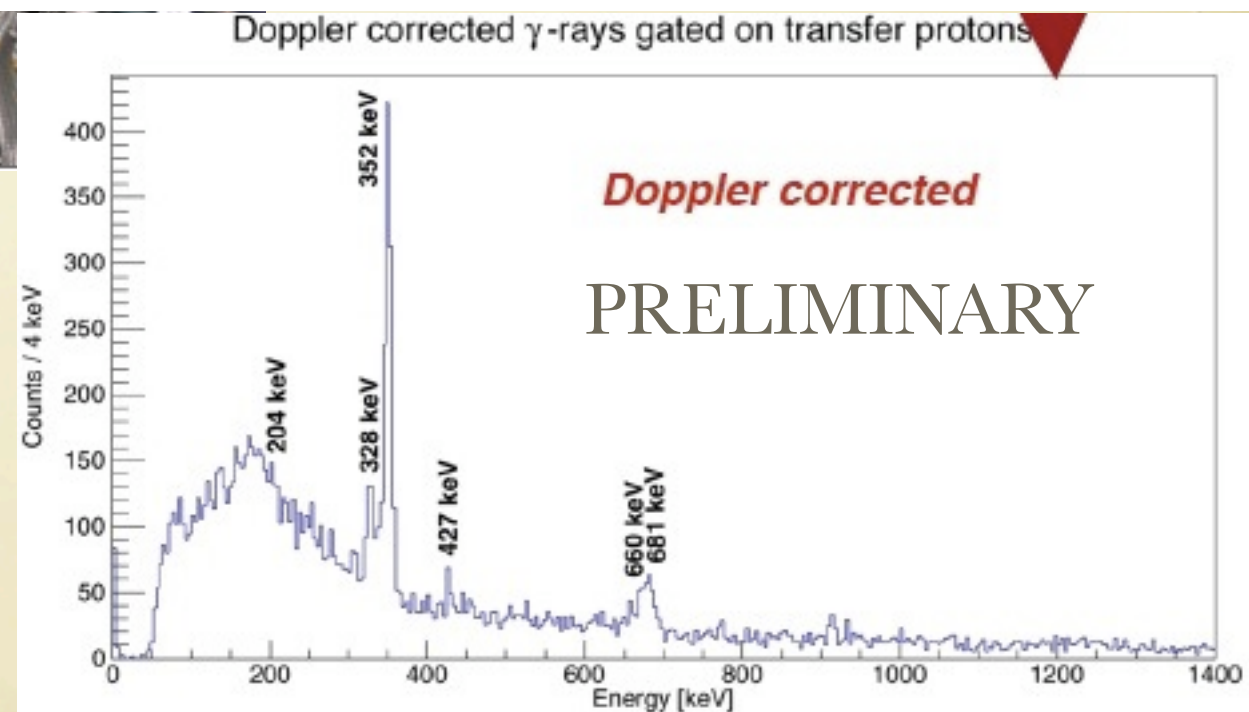
$^{94}\text{Sr}(d,p\gamma)^{95}\text{Sr}$



- Particle+gamma
- COULEX and Transfer

U. York  
**SHARC-TIGRESS**

G. Hackman, C.E. Svensson



S. Cruz (Ph.D. thesis), R. Kruecken, K. Wimmer, P. Bender

R. Kanungo







Ionization chamber

Silicon CsI(Tl)

Silicon

Scintillator

Beam

Windowless thin solid  $H_2/D_2$   
Higher reaction yield  
No C background

R.K.

world unique



# IRIS reaction spectroscopy facility (Saint Mary's-TRIUMF)



Ionization chamber

Silicon CsI(Tl)

S

Beam

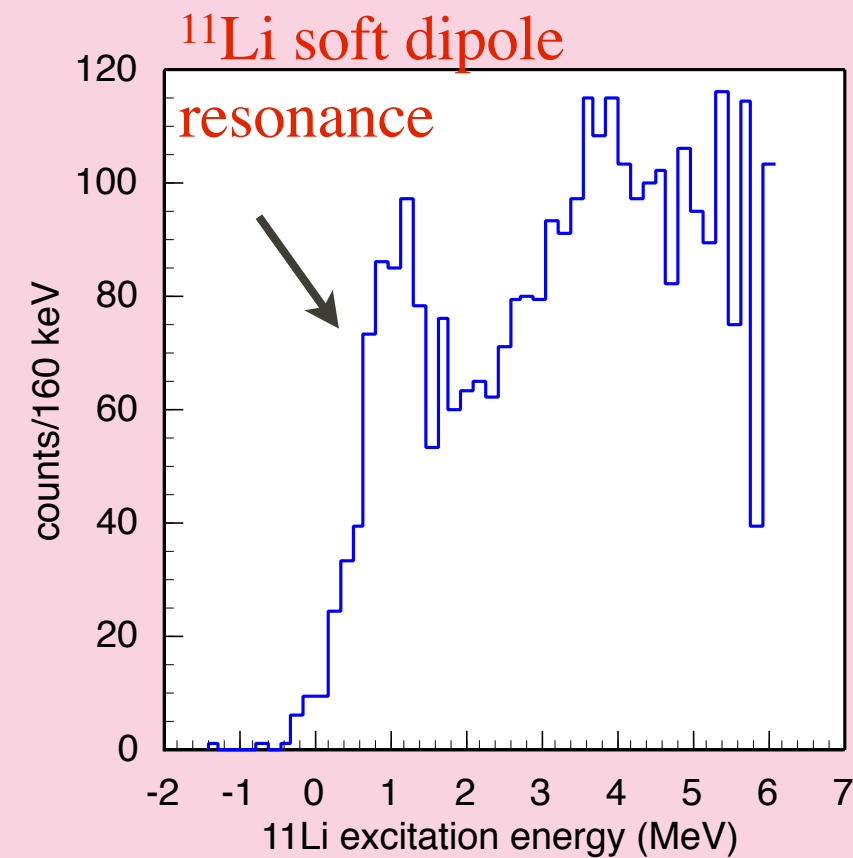
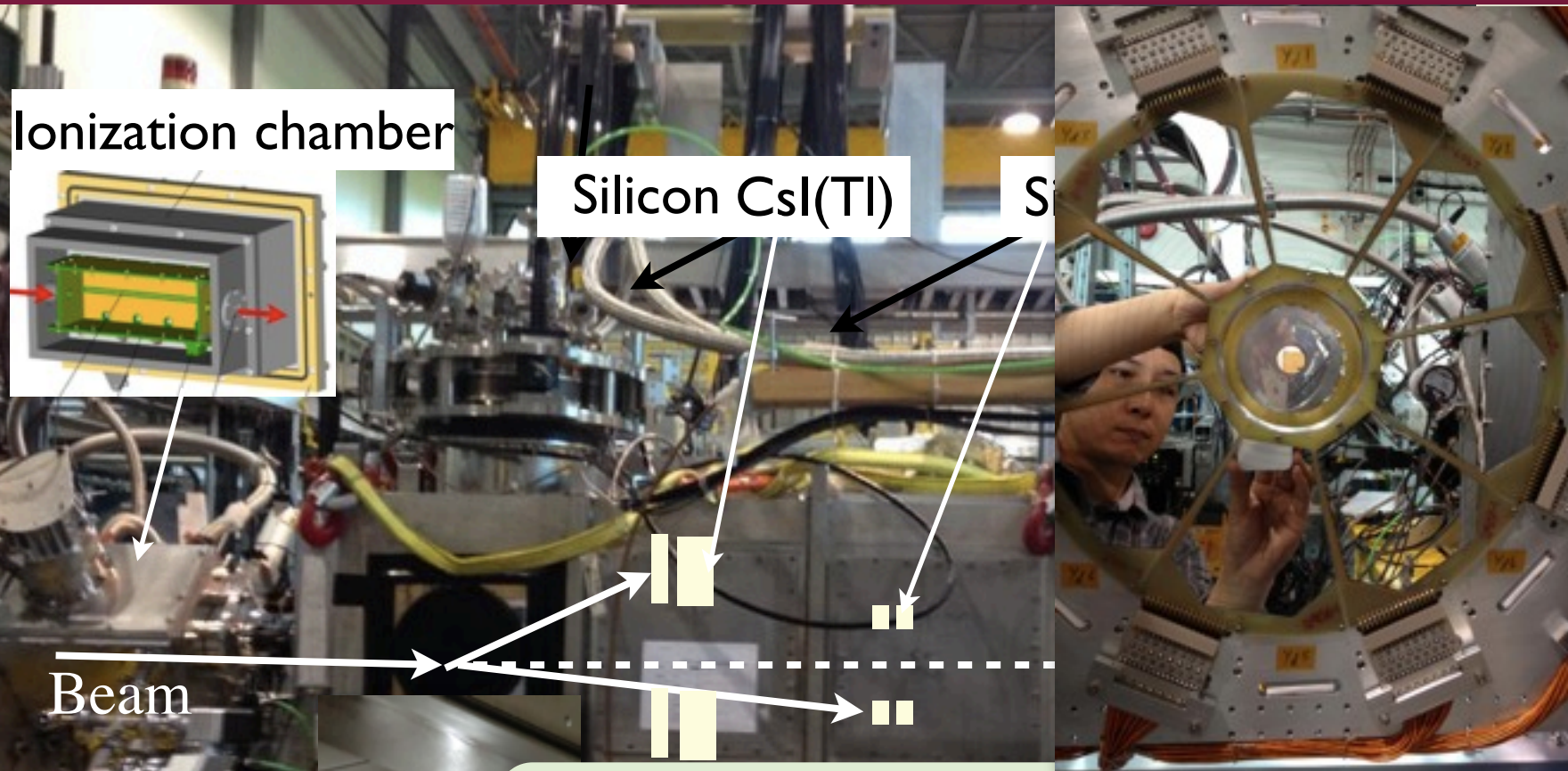
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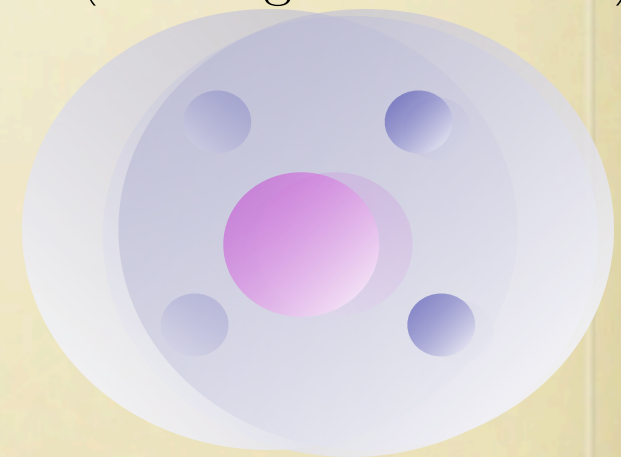


Windowless thin solid  $H_2/D_2$   
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R. Kanungo et al., PRL 114 (2015) 192502  
**J. Tanaka** (Ph.D. student)  
**M. Keefe** (Undergrad.. student)

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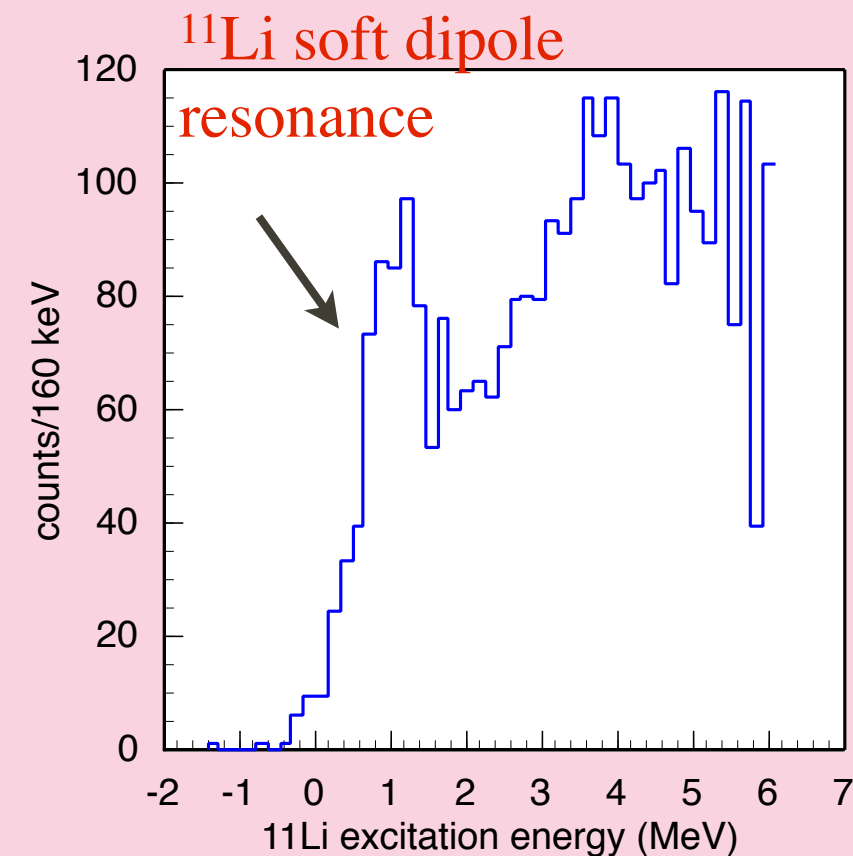
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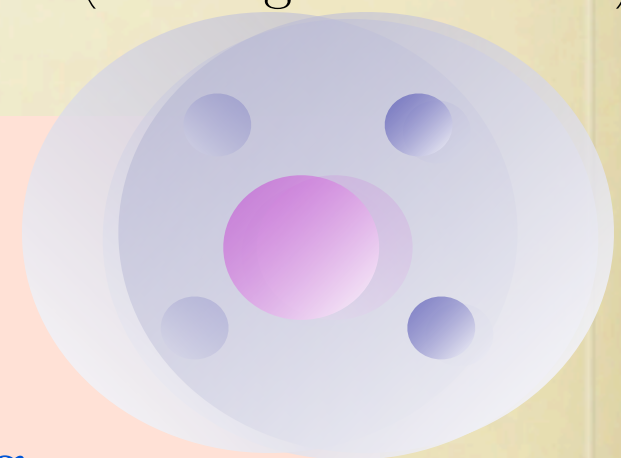
R.K.

world unique



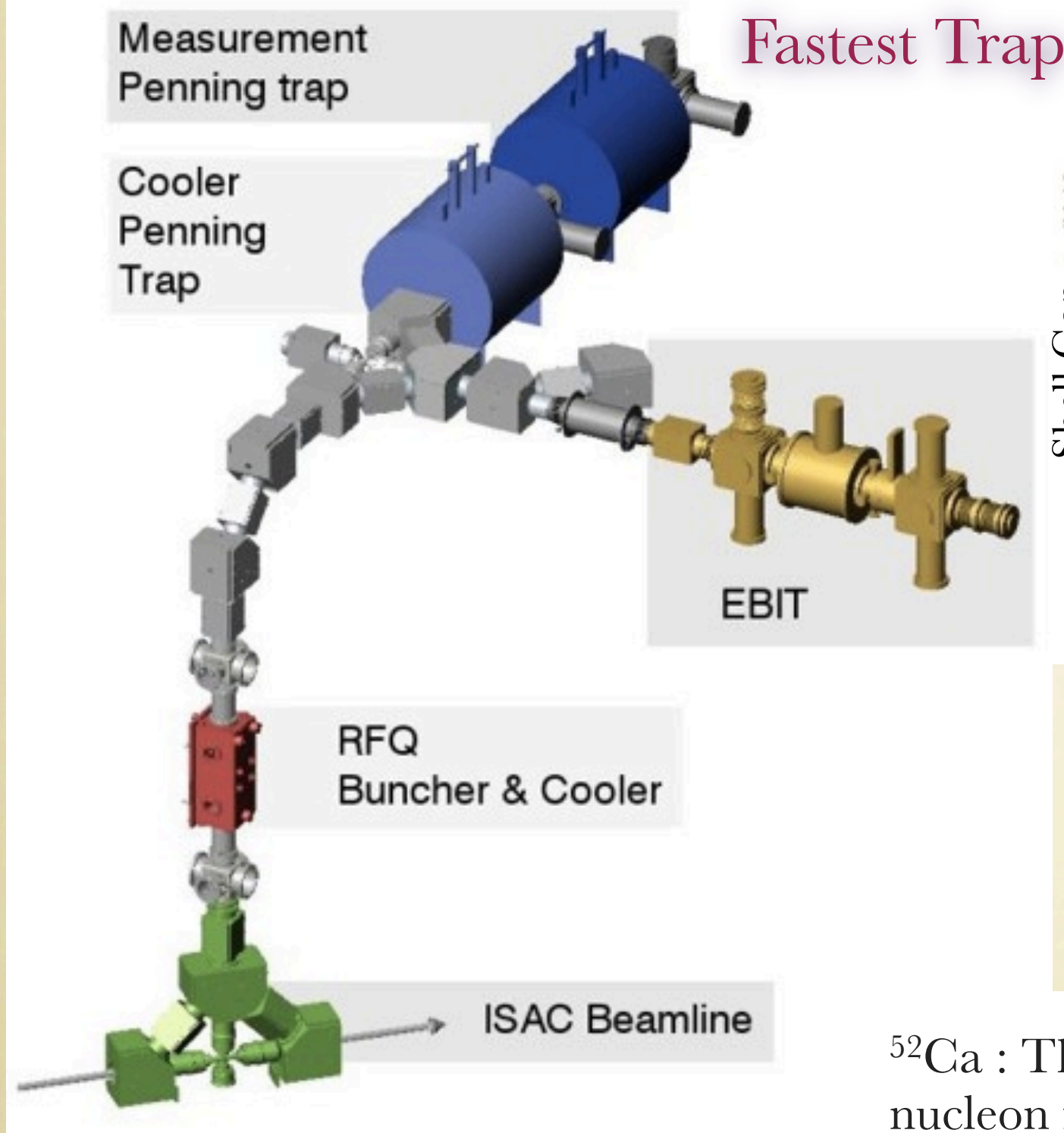
R. Kanungo et al., PRL 114 (2015) 192502  
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- Search for soft dipole resonances in neutron-rich nuclei
- Pairing interaction in neutron-rich nuclei
- Understanding 3N force through scattering
- Resonances and reaction rates for nuclear astrophysics

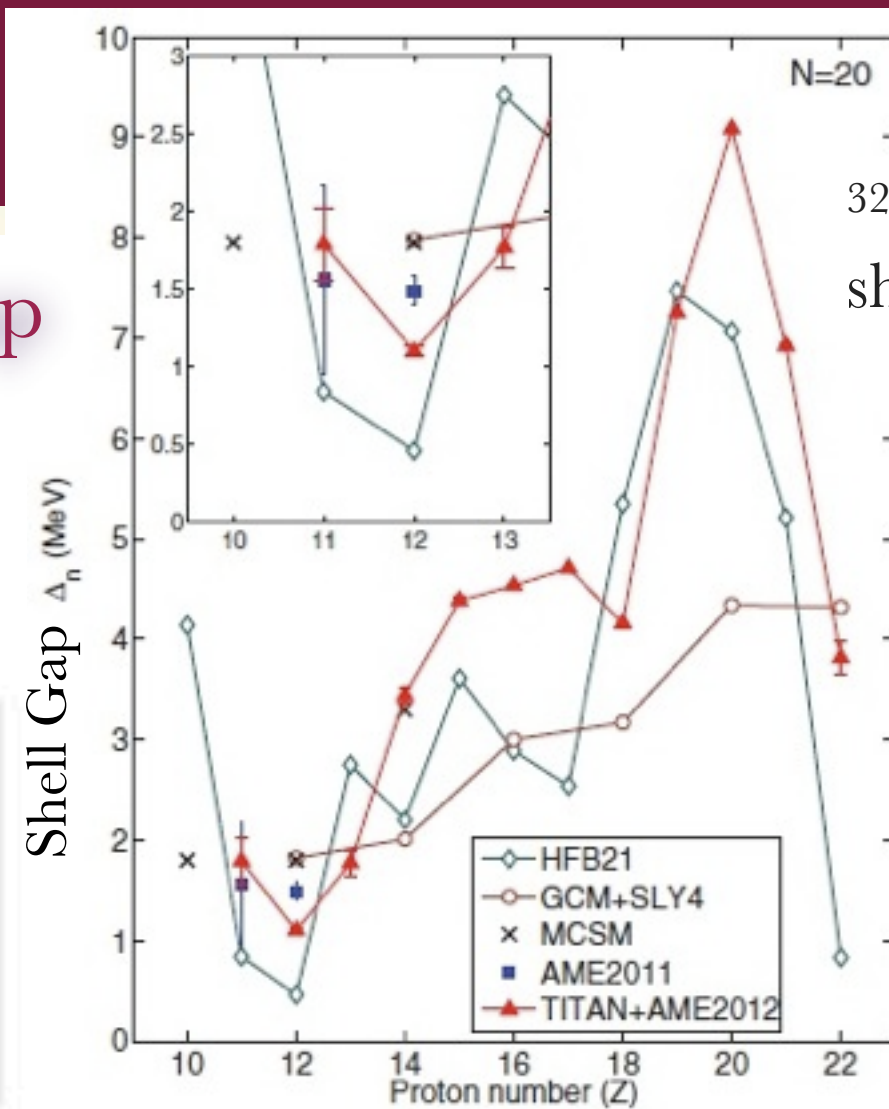




# TITAN Ion Trap (TRIUMF)

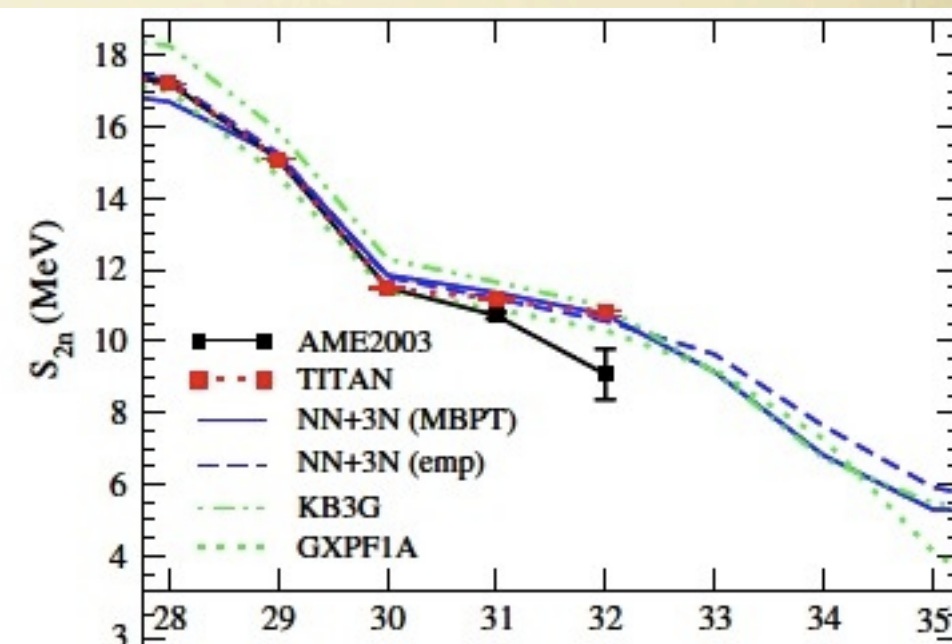


J. Dilling



A. Chaudhuri et al., PRC 88 (2013) 054317

$^{52}\text{Ca}$  : Three nucleon force effect

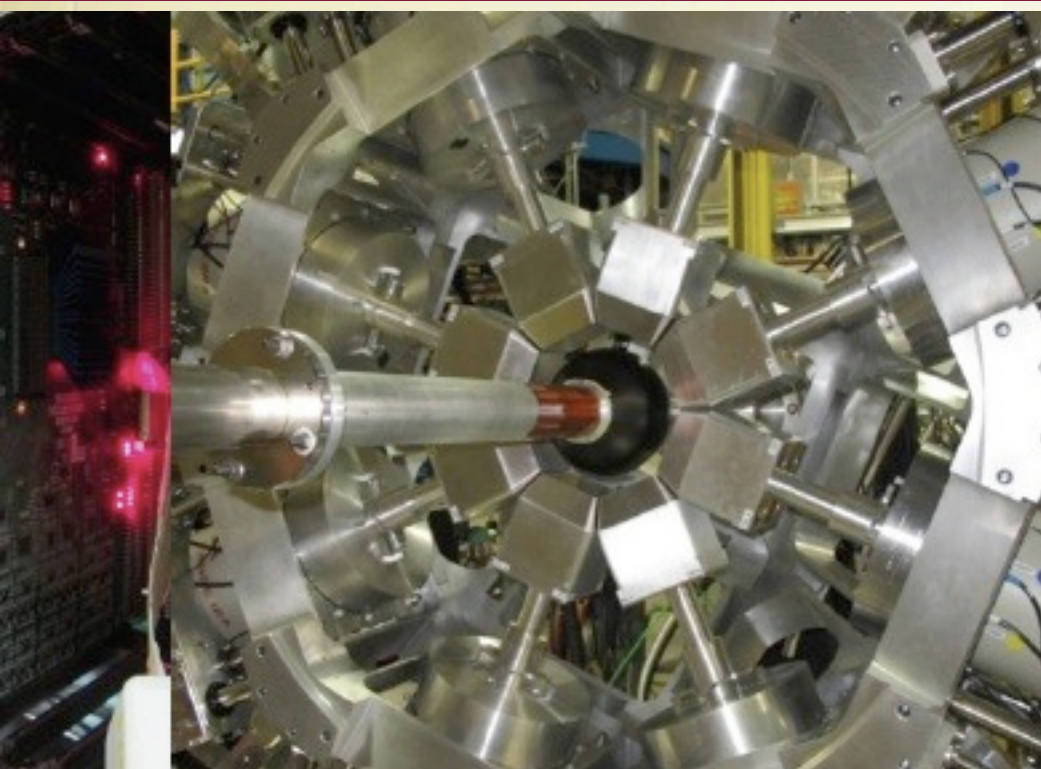


A.T. Gallant et al., PRL 109 (2012) 032506

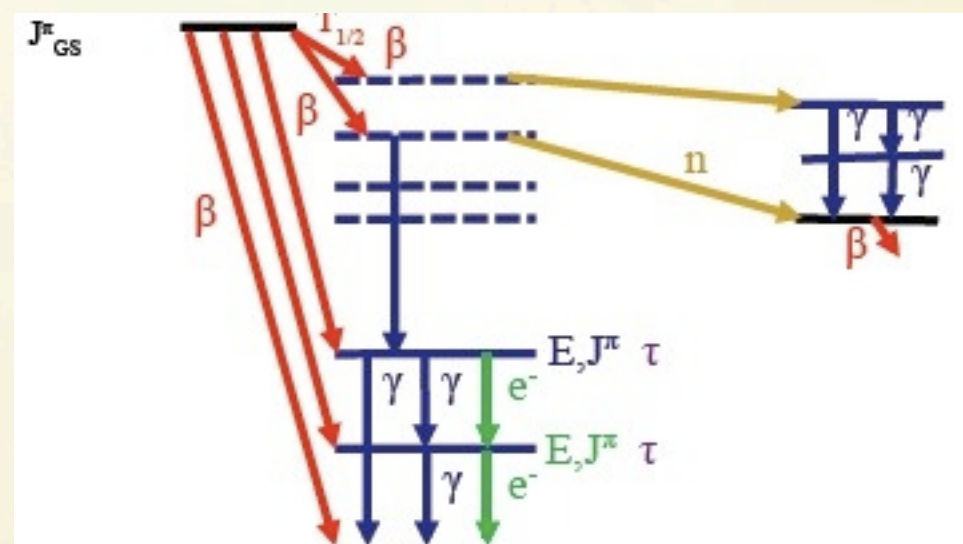




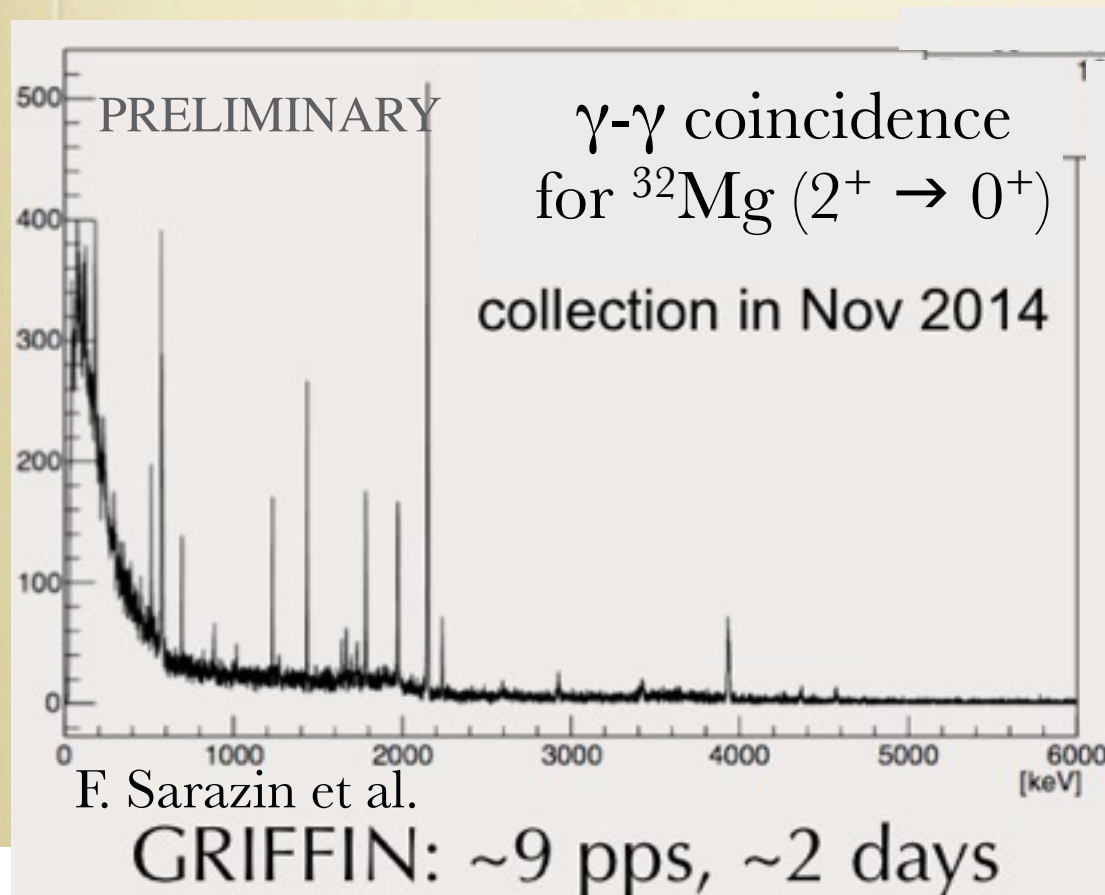
# GRIFFIN & DESCANT Decay spectroscopy facility (Guelph-TRIUMF)



- 16 HpGe clover detectors
- Scintillator, Si(Li) Detectors

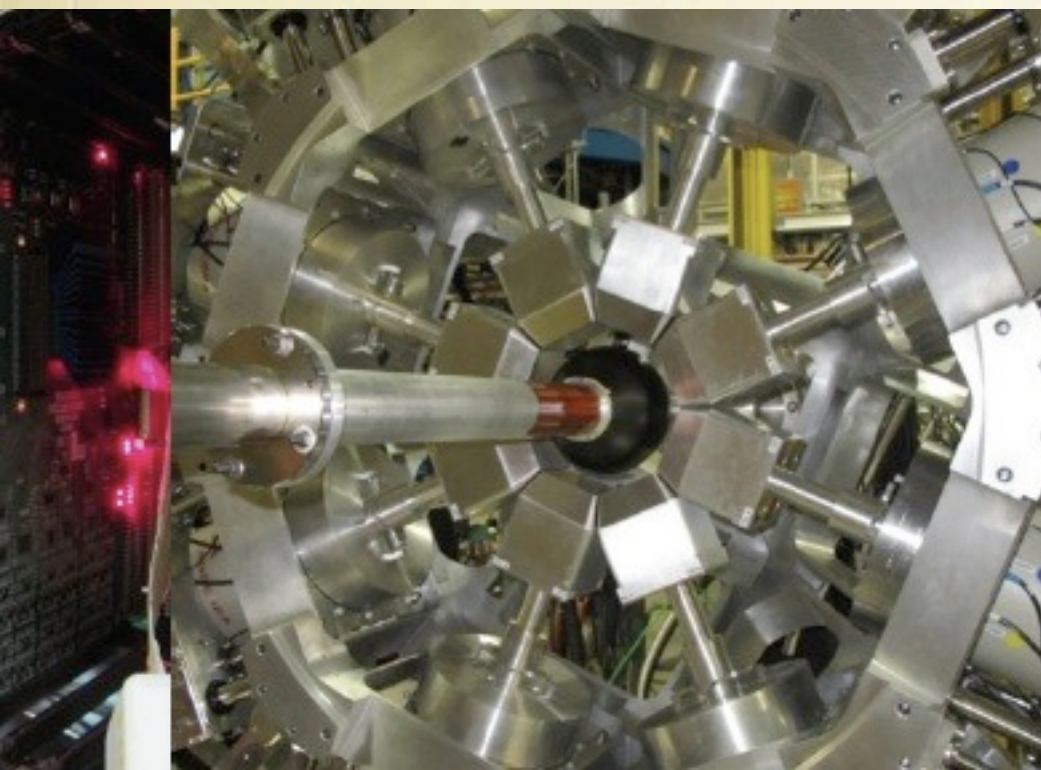


A.B. Garnsworthy, C.E. Svensson

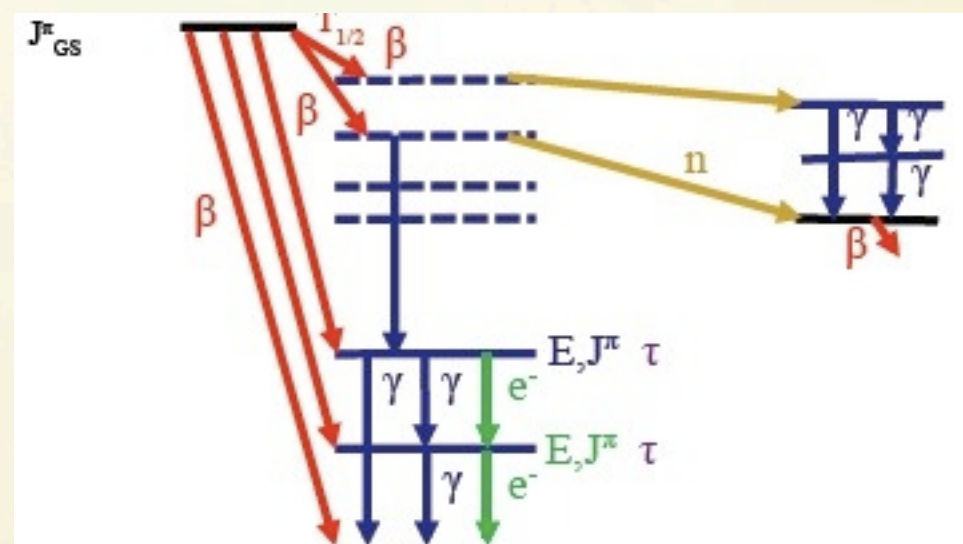




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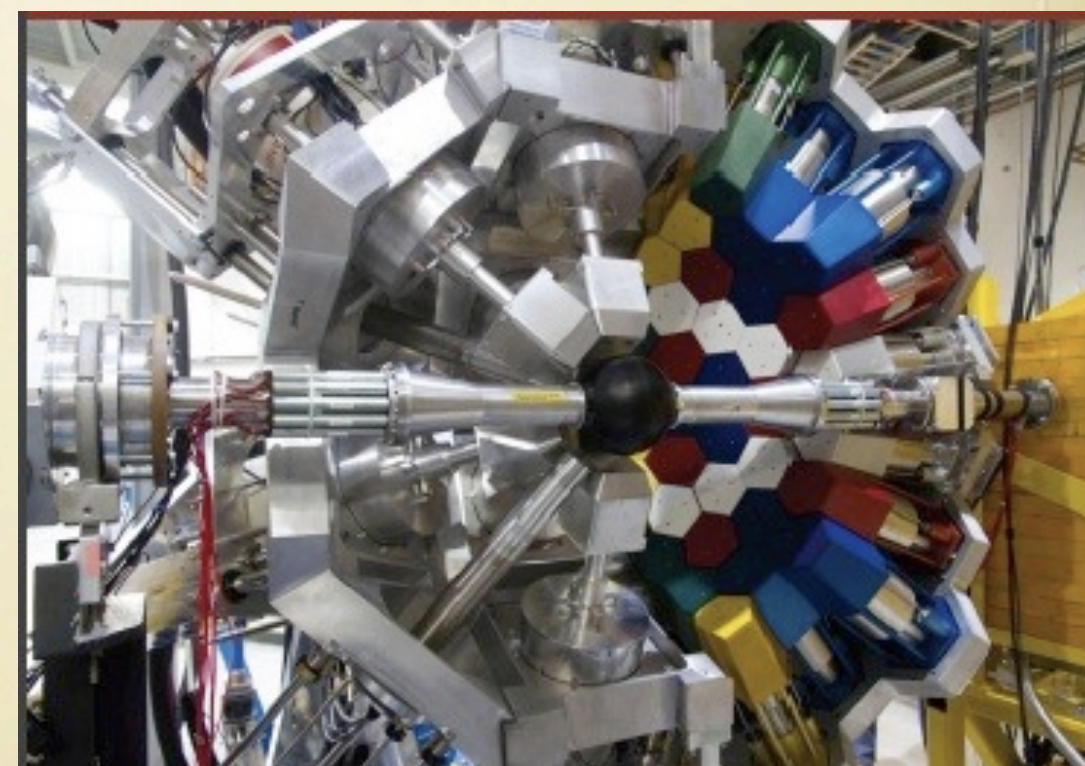


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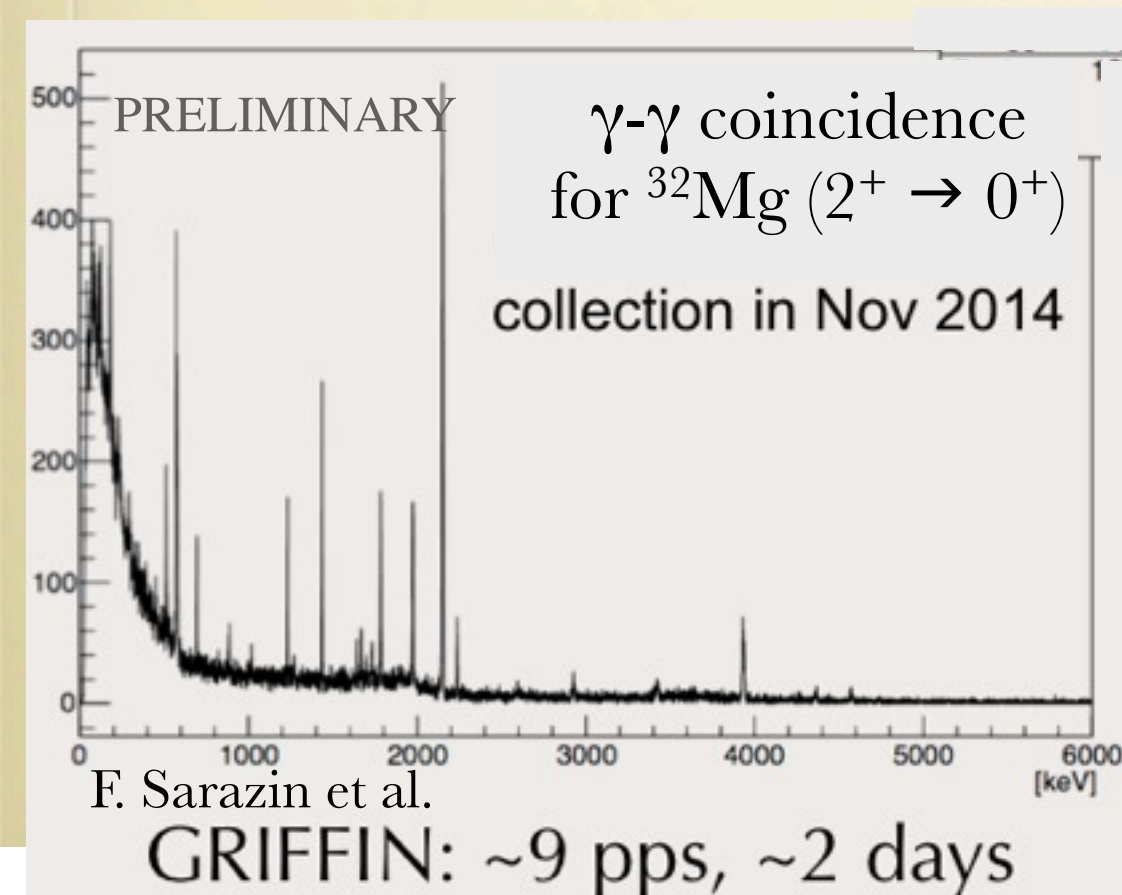


- Neutron Array : DESCANT
- Deuterated Benzene Scintillators

A.B. Garnsworthy, C.E. Svensson



P.E. Garrett



ol, Pisa, Italy, July 20-24, 2015

R. Kanungo

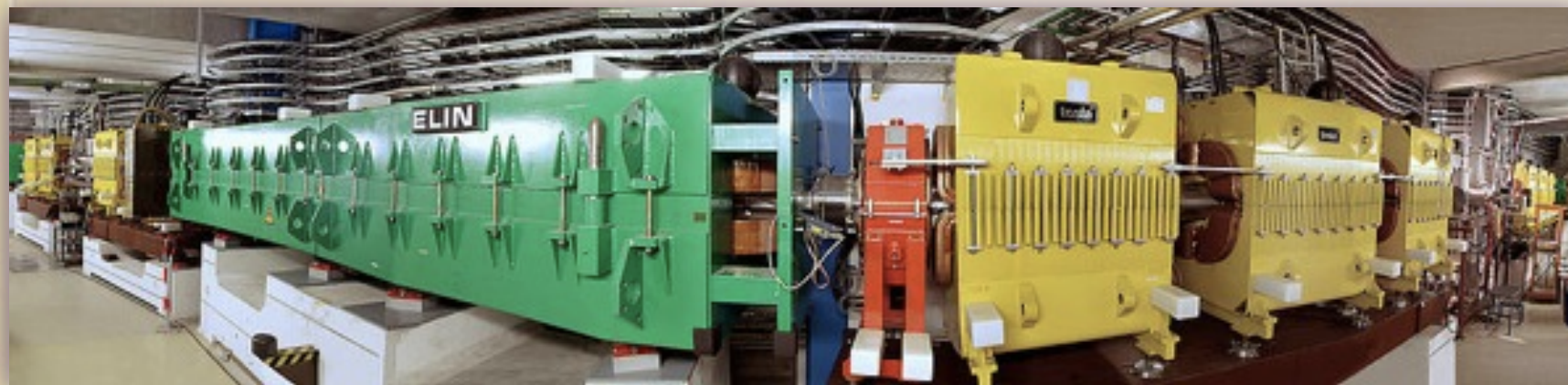


# Canadian RI beam research - offshore

**@ GSI ~ 1000 A MeV**

- Nuclear Radii R. Kanungo  
Equation of state of asymmetric nuclear matter  
Finding Halo and skin
- Nucleon Momentum Distribution R. Kanungo  
Evolution of shell structure
- Beta delayed Neutron spectroscopy I. Dillman  
r-process nucleosynthesis

Fragment Separator FRS @ GSI



In the future @ R<sup>3</sup>B and SuperFRS

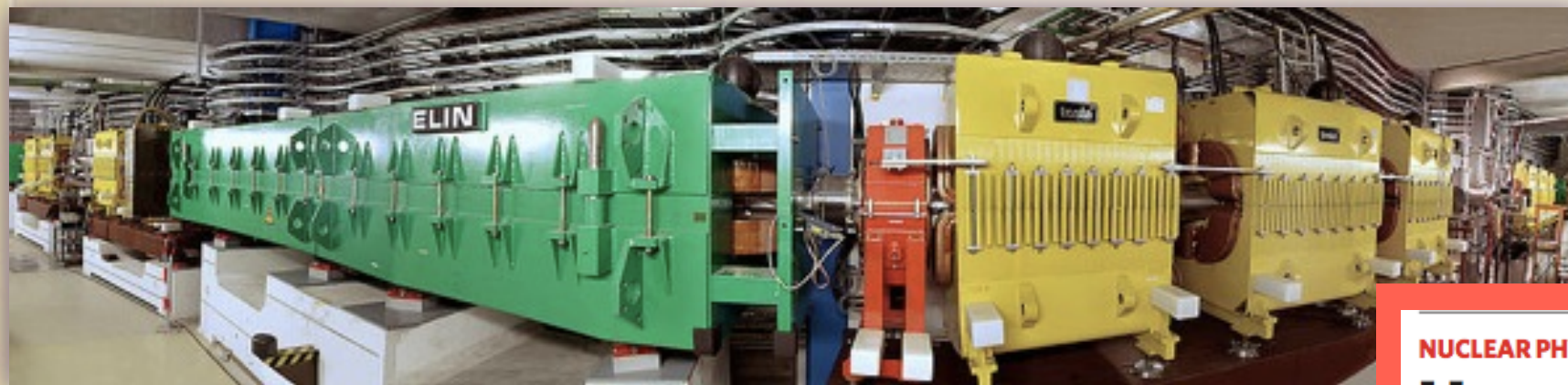


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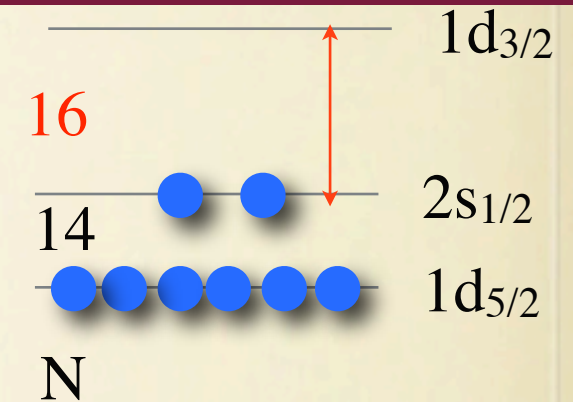
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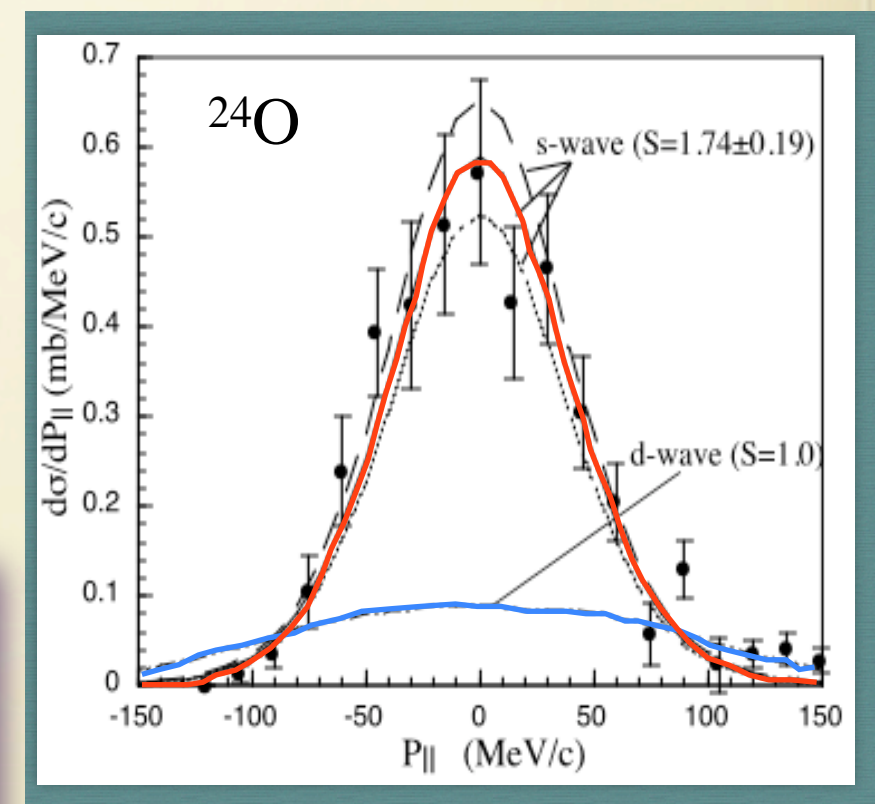
Fragment Separator FRS @ GSI



In the future @ R<sup>3</sup>B and SuperFRS



New magic number N=16



R. Kanungo et al., PRL 102 (2009) 152501

NUCLEAR PHYSICS New & Views : Nature 459 (2009) 1069

## Unexpected doubly magic nucleus

Robert V. F. Janssens

Nuclei with a 'magic' number of both protons and neutrons, dubbed doubly magic, are particularly stable. The oxygen isotope <sup>24</sup>O has been found to be one such nucleus — yet it lies just at the limit of stability.



# Canadian RI beam research - offshore

## @ RIKEN 200 - 340A MeV

- Beta delayed Gamma spectroscopy  
Evolution of shell structure R. Kruecken
- Beta delayed Neutron spectroscopy  
r-process nucleosynthesis I. Dillman
- Nucleon Momentum Distribution  
Evolution of shell structure R. Kanungo

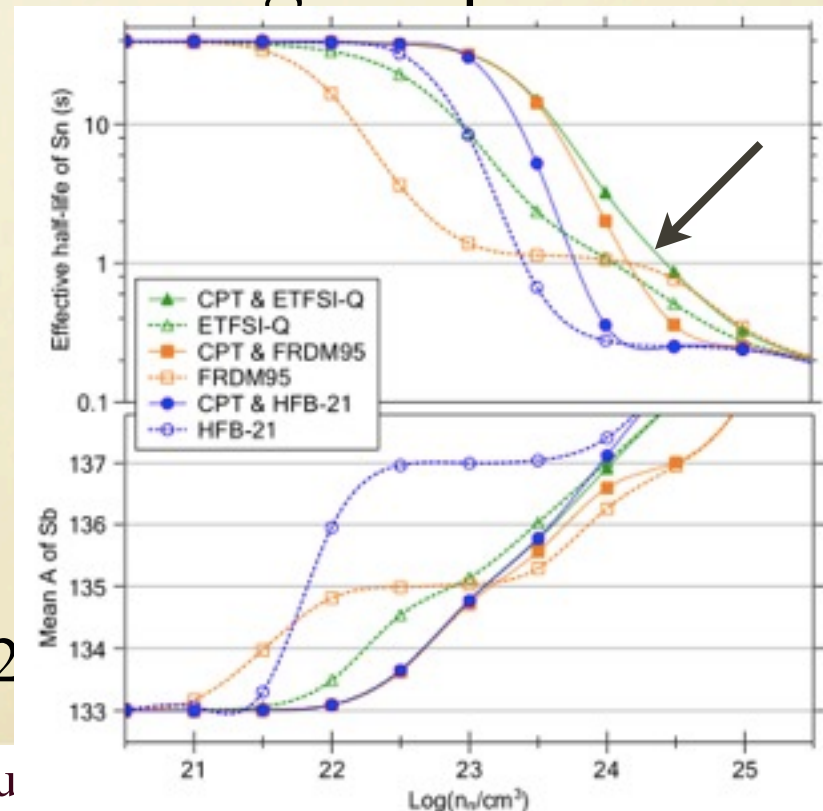
## @ ANL K. Sharma

- Mass measurements with Canadian Penning Trap



*Mass measurements of neutron-rich  
exotic nuclei on the r-process path*

V. Scheldt, et al., PRL 111 (2013) 061102



R. Kanungo



**RI beams are the eyes to see deep into the unknown neutron- and proton-rich corners of the universe.**

**New** generation facilities now under construction are waiting for **you**, the leaders of tomorrow, to reap their scientific benefits.

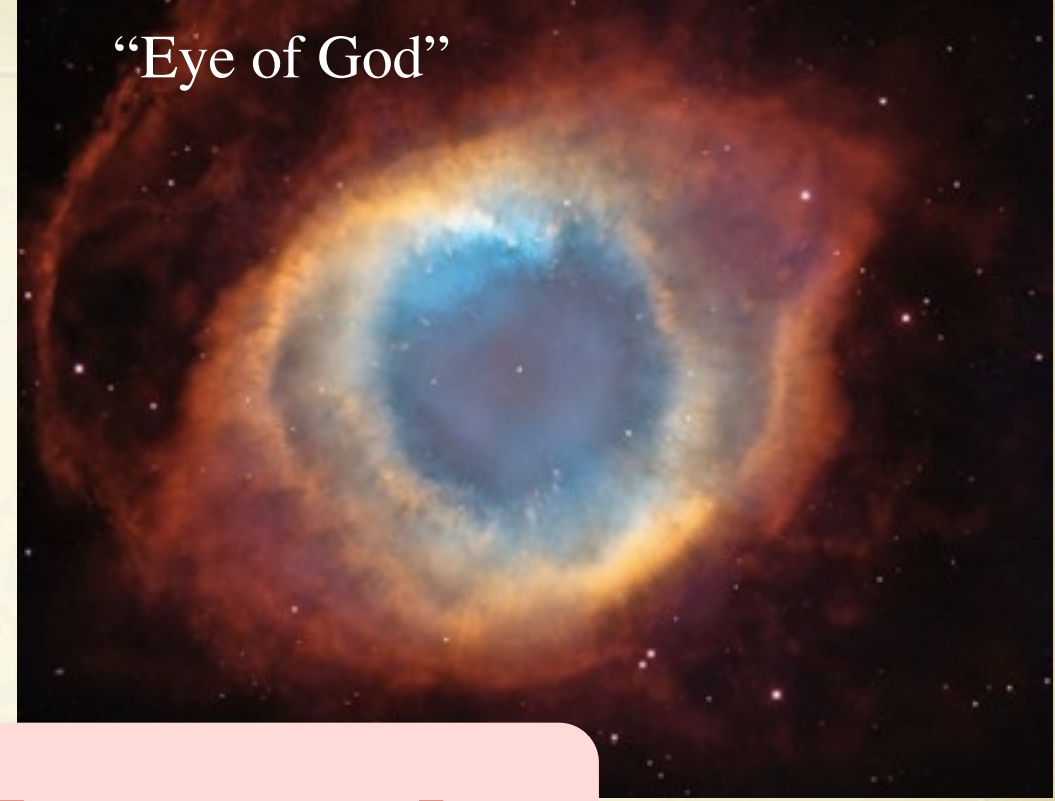


Helix Nebula, HST



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Helix Nebula, HST

**We welcome interested students to be  
a part of our exciting research in  
Canada**



Contact me : [ritu@triumf.ca](mailto:ritu@triumf.ca)



# Post Doctoral Fellowship

- Banting Post Doctoral Fellowship \$70,000 / year for 2 years

<http://banting.fellowships-bourses.gc.ca/home-accueil-eng.html>

International and Canadian students holding Ph.D. degree

Two Step selection:

University pre-selection made

University nominates and Banting committee makes final selection

- NSERC Grants of faculty members

Process : Contact the faculty members