Nuclear Physics

Parallel Session Convener Report

Chris Ruiz & Barry Davids

Physical Sciences Division

2020-08-21

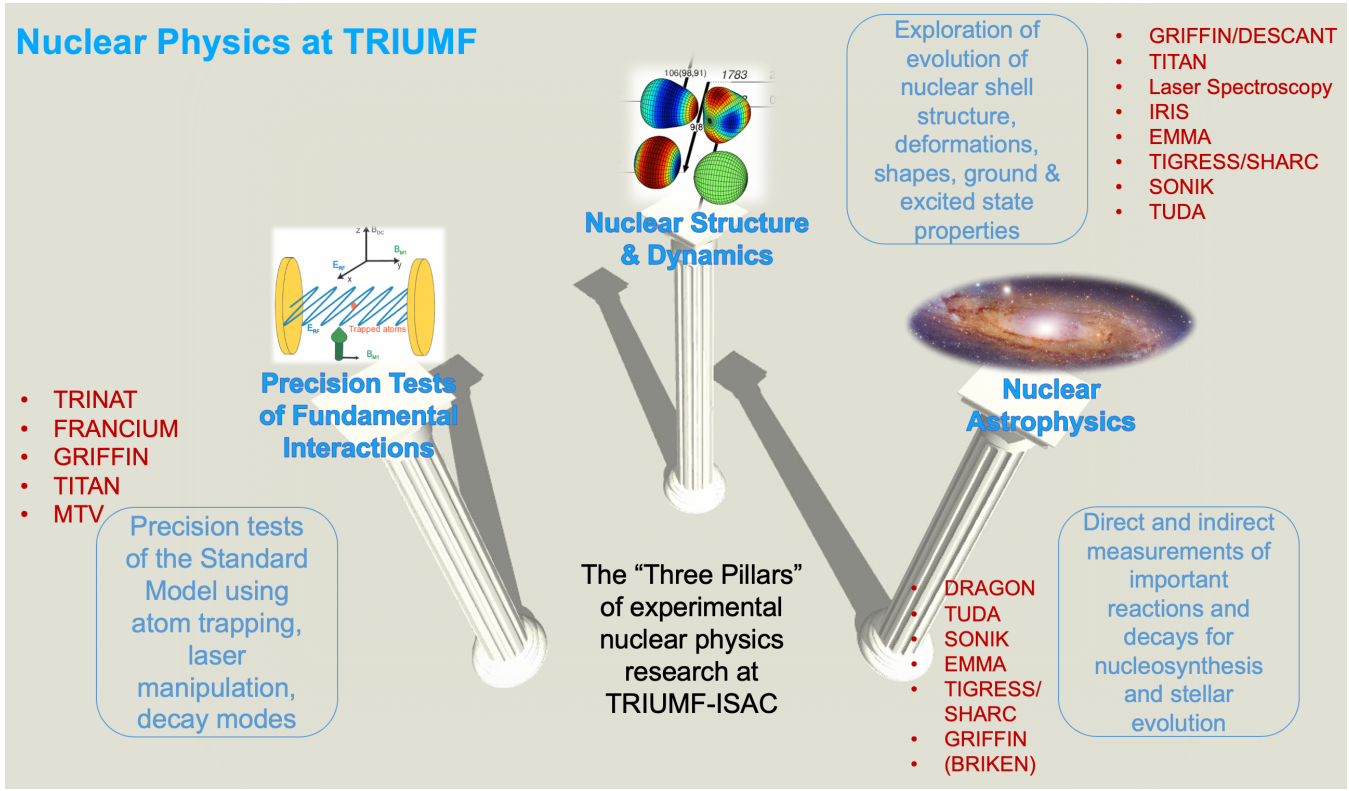
Discovery, accelerated

Nuclear Physics During the Week Recap

Nuclear Physics from ISAC to ARIEL

(Ania Kwiatkowski)

- *State-of-the art* facilities covering a broad range of measurements towards “three pillars”: Nuclear Structure, Nuclear Astro, Fundamental-Symmetries
- ARIEL+CANREB brings:
  - (a) new (clean) beams near *r*-process path and within *i*-process path
  - (b) 3x beam-time allowing more frequent, longer experiments
  - (c) 3 simultaneous RIBs
  - (d) CANREB beams for A>30 also for astro
- Beatrice Franke also covered 5-year-plan Fundamental Symmetries



Nuclear Physics During the Week Recap

Exploring Major Nuclear Structure Issues with Rare Isotopes

(Jason Holt)

Towards a first-principles picture of atomic nuclei (Chiral EFT)

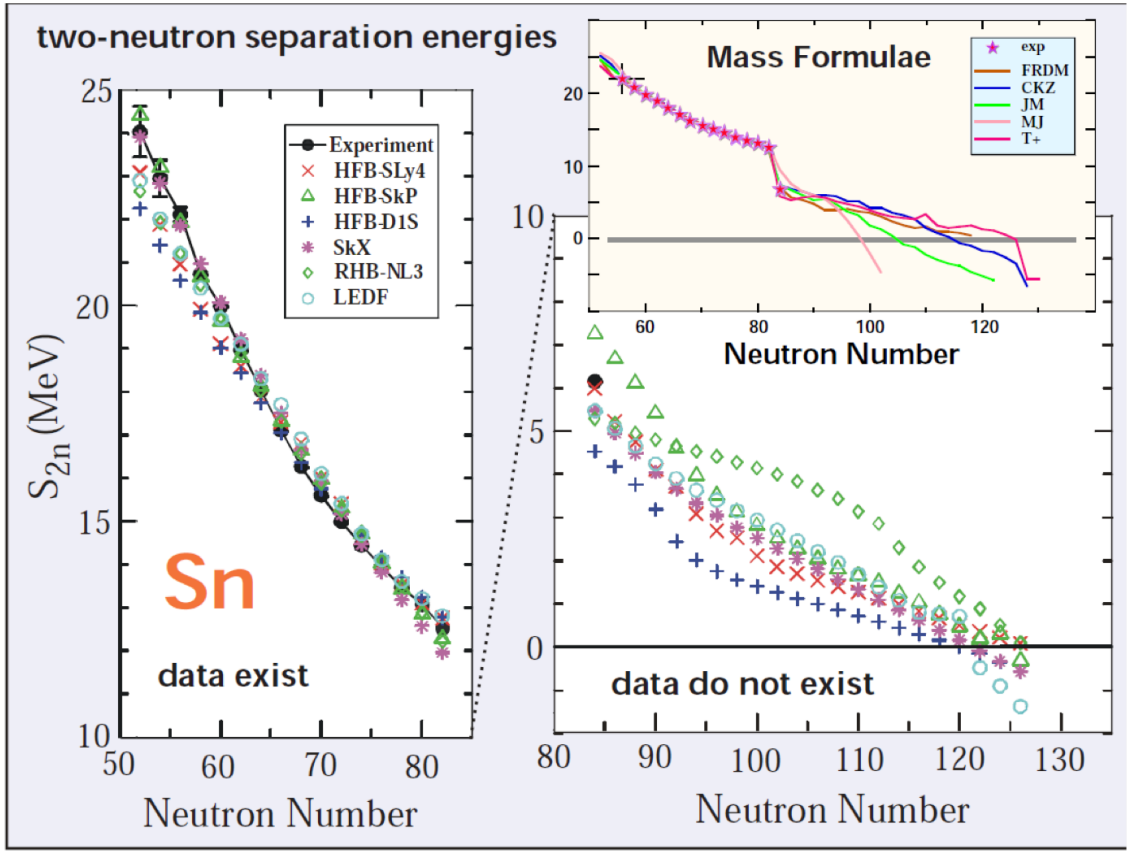
- How do theory & exp inform & improve each other?
- → Need to continually expand region data!
- e.g. charge radii across isotopic chains, B(E2) in *sd*-shell, GT decays, G.S. masses, dripline predictions, etc

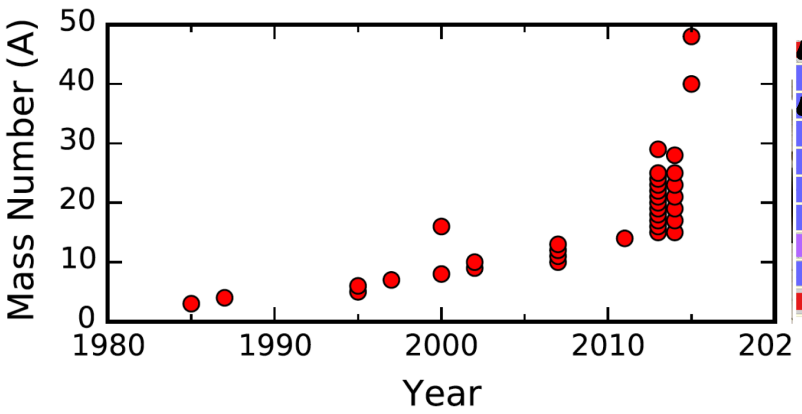
Explosion in limits of ab initio theory

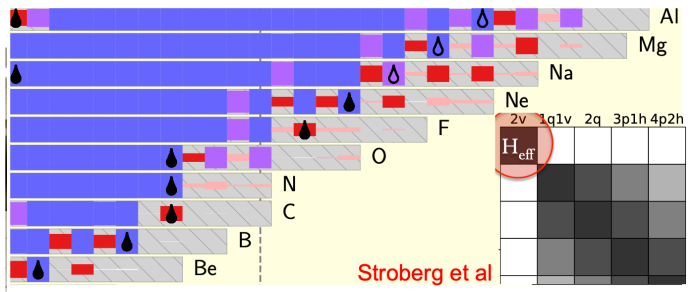
- G.s. energy calcs up to ^{132}Sn with new matrix storage truncation (even ^{208}Pb)
- Neutron skin thickness vs g.s. mass constrains n-star EOS.

Data, data, data! still needed far from stability

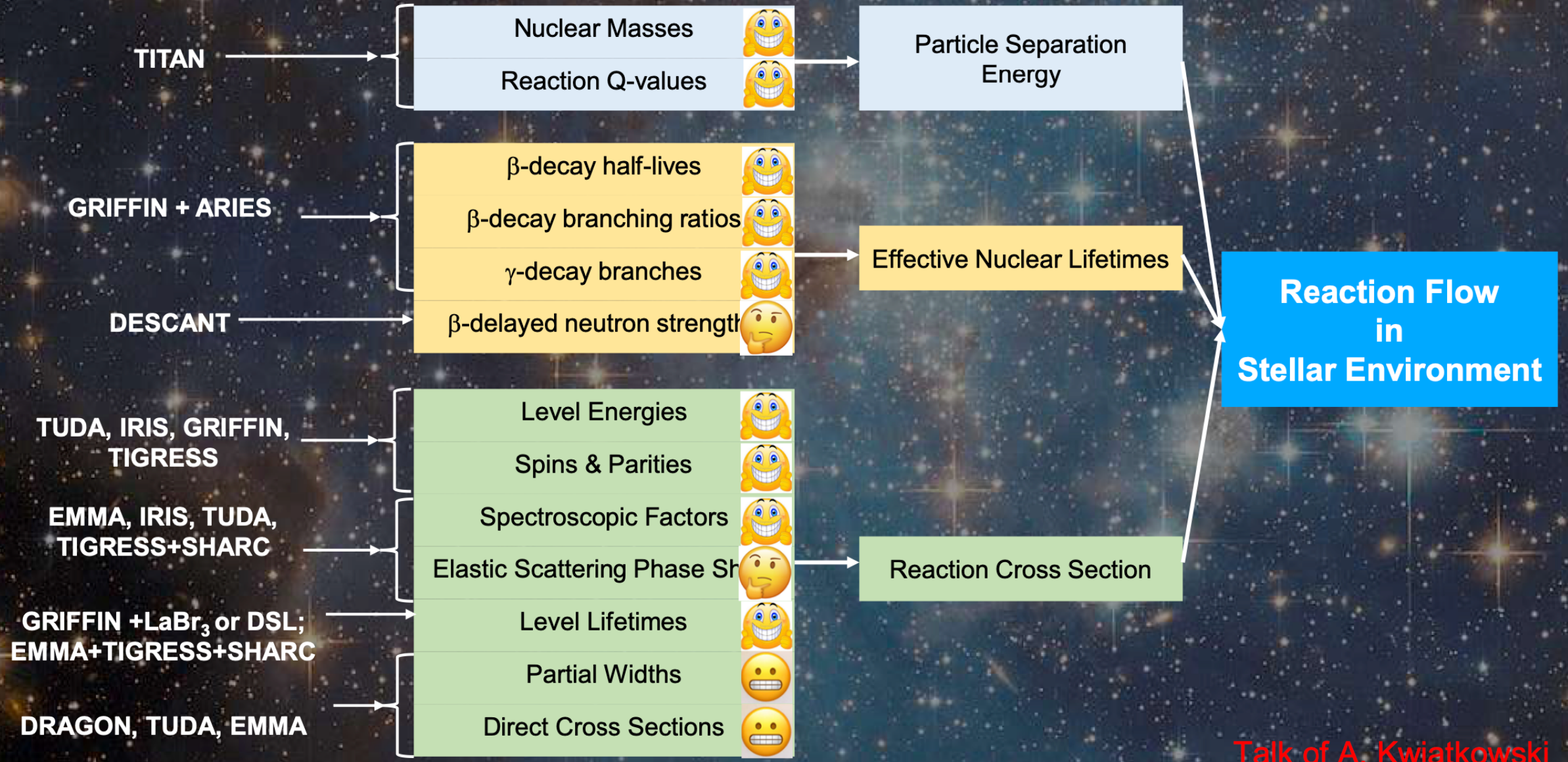
→ ISAC/ARIEL Good match with theory calculable observables (see next slide)







TRIUMF's nuclear astrophysics program in the era of multi-messenger astronomy



Talk of A. Kwiatkowski

Nuclear Physics During the Week Recap

Search for New Physics with Atoms & Molecules

(Marianna Safronova)

- Atomic PV e.g. trapped Francium
- EDM experiments (TeV scale SUSY *must* have EDMs)
  - → Need heavy atom, or molecule with heavy atom
- Atomic clocks → fund. physics e.g. variation of fundamental constants, equivalence principle tests, Lorentz invariance, DM
- → Ultracold highly-charged ions for atomic clock (e.g. Cf)
  → need supply of such isotopes
- → Nuclear clocks e.g. ^{229m}Th would offer exceptional sensitivity
- Nuclear parity violating effects in light nuclei are calculable by TRIUMF theory group, enabling extraction of poorly known S.M. prediction → laser-cooling triatomic molecules
- Non-linear King plot sensitivity to new physics → win further uniquely by 3x in an isotopic chain of radioactives.

→ Promising applications at ARIEL for new crossover regime of RIBs + atomic & molecular techniques towards precision measurements

Extraordinary progress in the control of atoms and ions

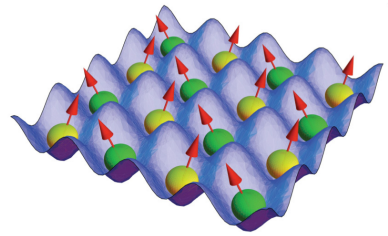
1997 Nobel Prize
Laser cooling and trapping

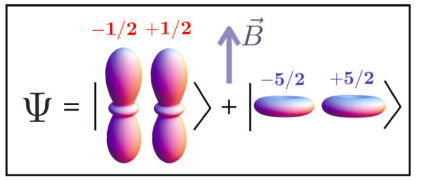
2001 Nobel Prize
Bose-Einstein Condensation

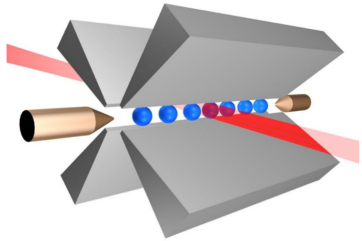
2005 Nobel Prize
Frequency combs

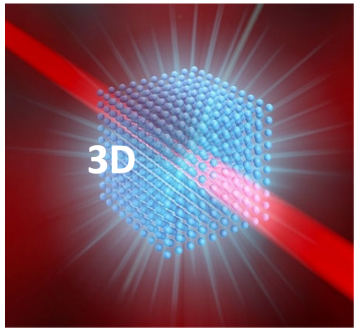
2012 Nobel prize
Quantum control

300K









pK

Atoms are now: **Ultracold** **Trapped** **Precisely controlled**

Sources of atomic and molecular EDMs

Paramagnetic atoms
Cs, Tl, **Fr** (eedm.info)
Molecules
YbF, ThO, HfF^+, ThF^+, **RaF**
YbOH, **RaOH**

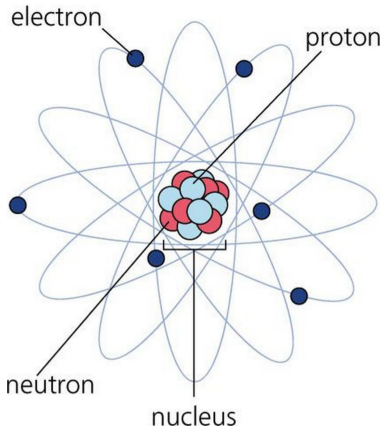
Ronald Fernando GARCIA RUIZ
Radioactive molecules as laboratories for fundamental physics (Friday)

Diamagnetic atoms
Hg, Xe, **Ra, Rn**
Molecules
TlF

Electron EDM

P, T – violating electron-nucleon interaction

Nucleon EDM



P, T – violating nucleon- nucleon interaction

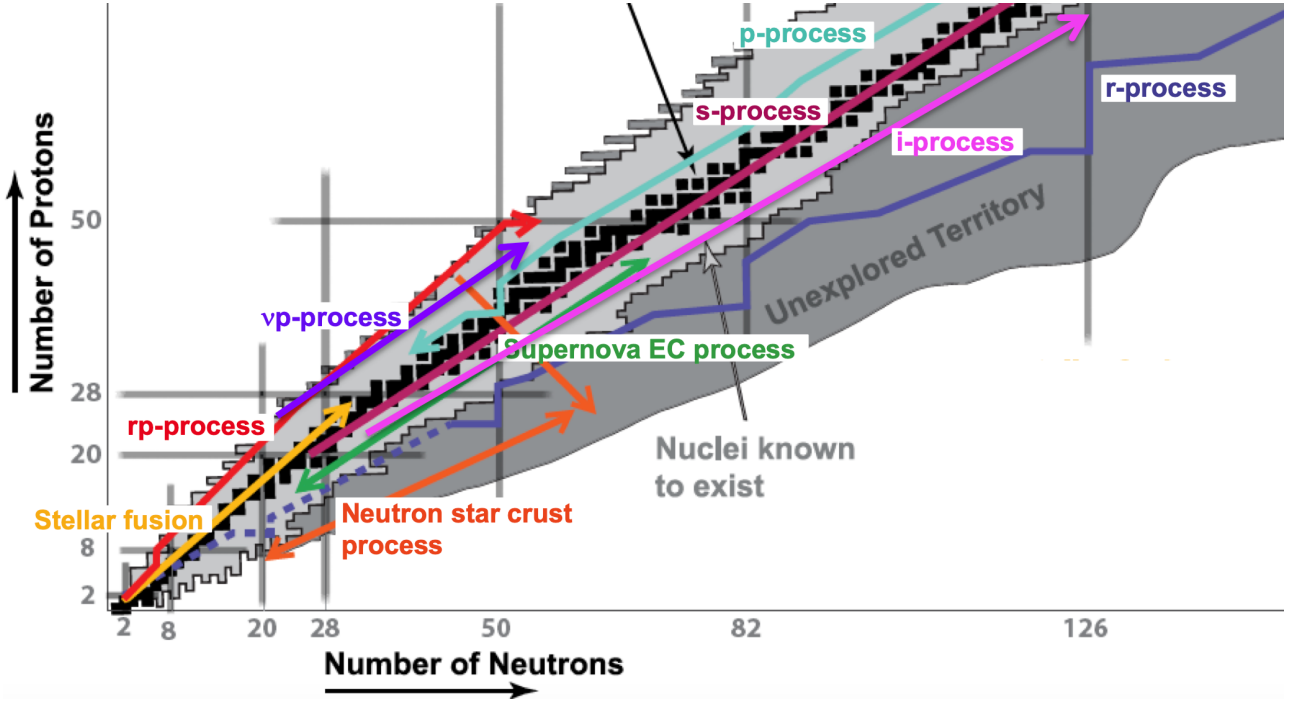
Need heavy atom or a molecule with a heavy atom for larger effect

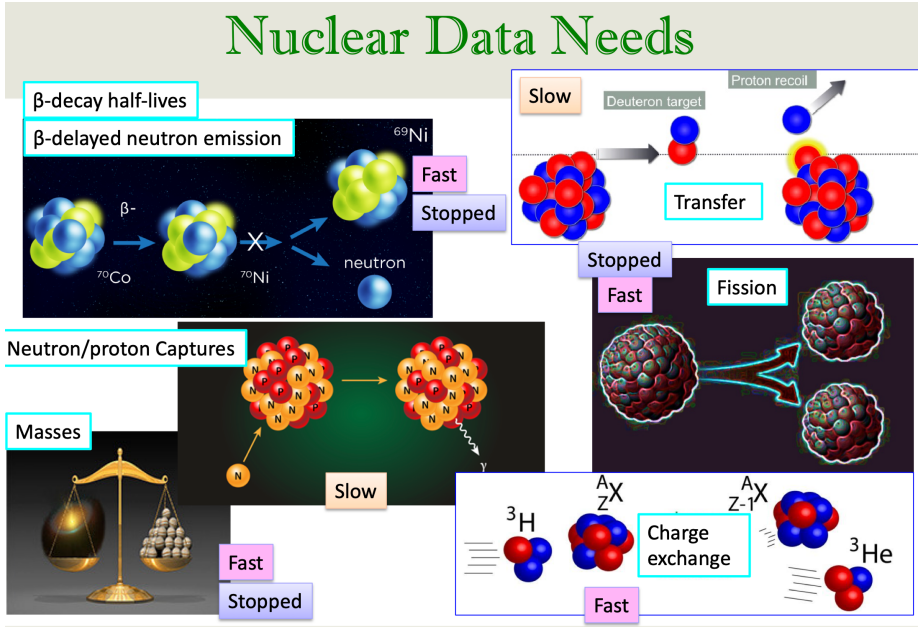
Nuclear Physics During the Week Recap

Laboratory Nuclear Astrophysics

(Artemis Spyrou)

- **Multi-Messenger Era**: Now have many observables through multiple wavelength γ, ν, G-waves, grains etc
- ∃ sophisticated 3D models: mixing; almost every stellar scenario seen or postulated; state-of-the art codes such as MESA/NuGrid; more community access
- Theory insufficient, Exp insufficient – each filling in blanks for the other → Need *targeted* nuclear data
- Variety of nuclear observable begets different experimental techniques --> ISAC (ARIEL) has significant coverage of them
- Fragmentation vs ISOL facilities
  - Complementarity: ISOL more limited in elements, but access to high intensity beams → different class of experiments
- Some overlap of beams = good! We want experiments/data VALIDATED
- Some smaller detectors can move lab-to-lab, no point duplicating, some collaboration needed, unless beam time needs prohibitive → then duplicate
- Larger facilities (e.g. TITAN, GRIFFIN, DRAGON, EMMA, TIGRESS, SECAR) don't move → need to be located at each lab
- Difficulty of (n,γ) discussed → huge effort in indirect experiments → perfect case for direct measurements (storage ring)





Low-Energy Quantum Sensing Methods with Rare-Isotopes at ISAC (Kyle Leach)

Tunnel Junctions

$E \rightarrow \Delta Q$ (electrons)

low (E_{max} < 10 keV)

$\sim[2\Delta_{sc}E]^{1/2}$

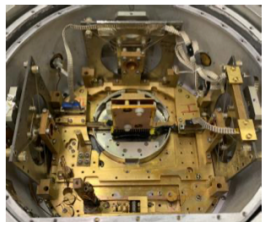
~0.2 - 20 eV FWHM

<10,000 cts/s

High, > 1000 Ω

FET at room T

<0.5 K (ADR)



Microcalorimeters

$E \rightarrow \Delta T$ (phonons)

high (E_{max} < MeV)

$\sim[k_B T^2 C_{abs}]^{1/2}$

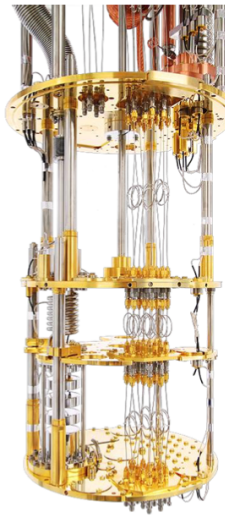
~1 - 5 eV FWHM

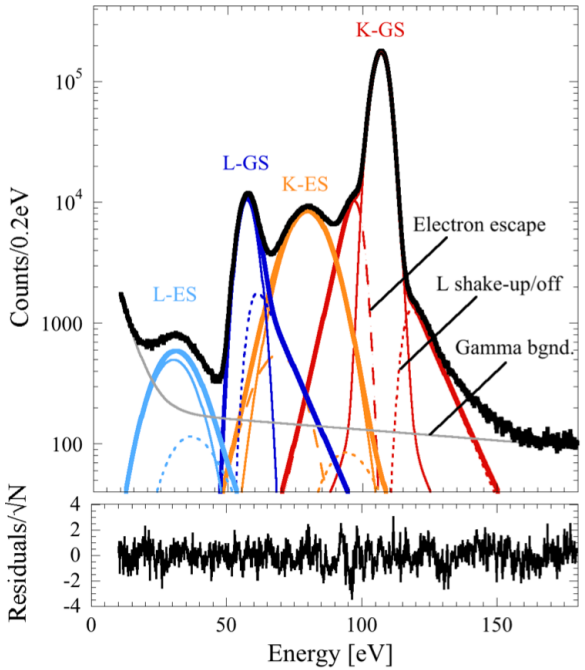
~10-100 cts/s

Low, < 0.1 Ω

SQUID at 4 K

<0.1 K (Dil Fridge)

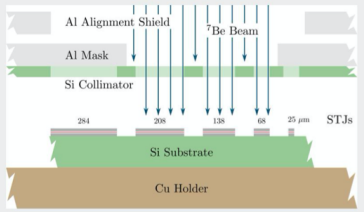




S. Fretwell *et al.*, Phys. Rev. Lett. **125**, 032701 (2020)

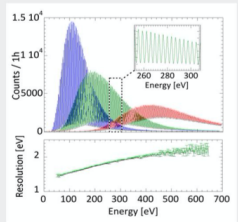
The BeEST Experimental Concept

Implanted ^{7}Be Sample



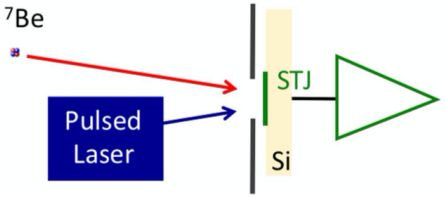
Simultaneous Laser Calibration

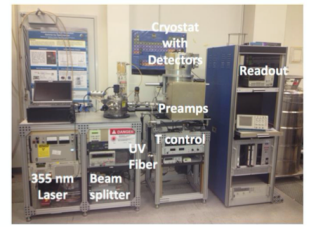
Provides energy calibration to <0.01 eV



TRIUMF

THE BeEST



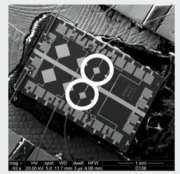


Lawrence Livermore National Laboratory

Ta-Based STJ Detectors

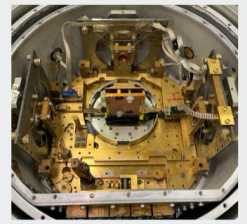
"Test" chips with 10 pixels of 5 sizes

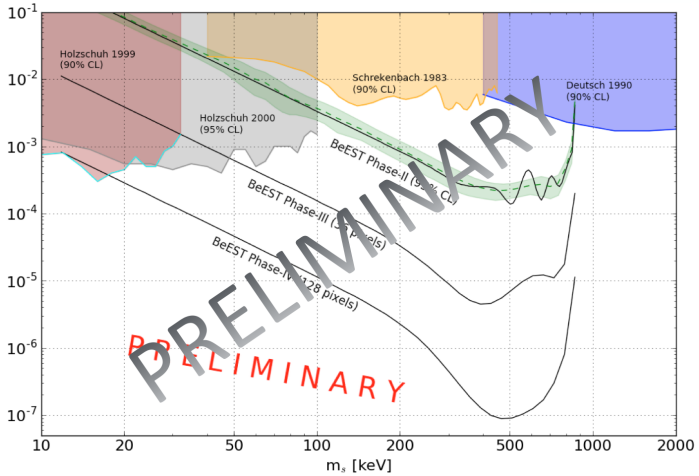
Phase-I

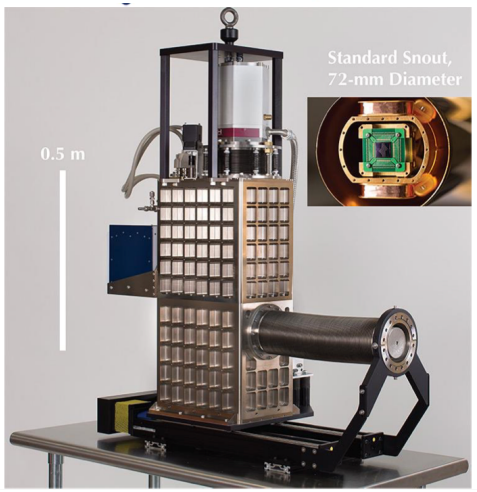


Phase-II

Cooled to 100 mK in an adiabatic demagnetization refrigerator (ADR)







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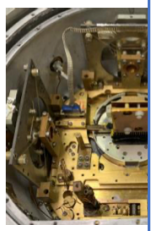

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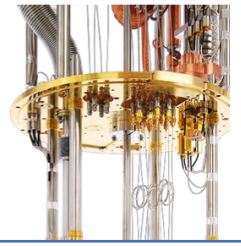
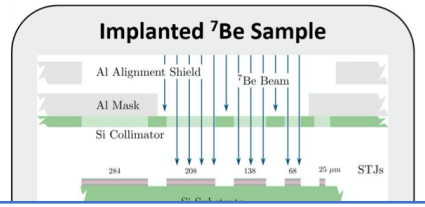
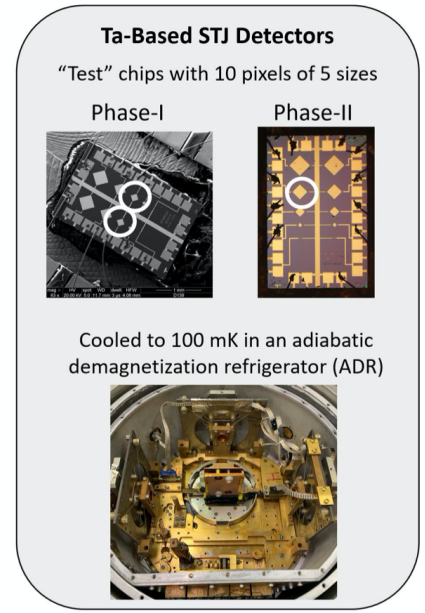


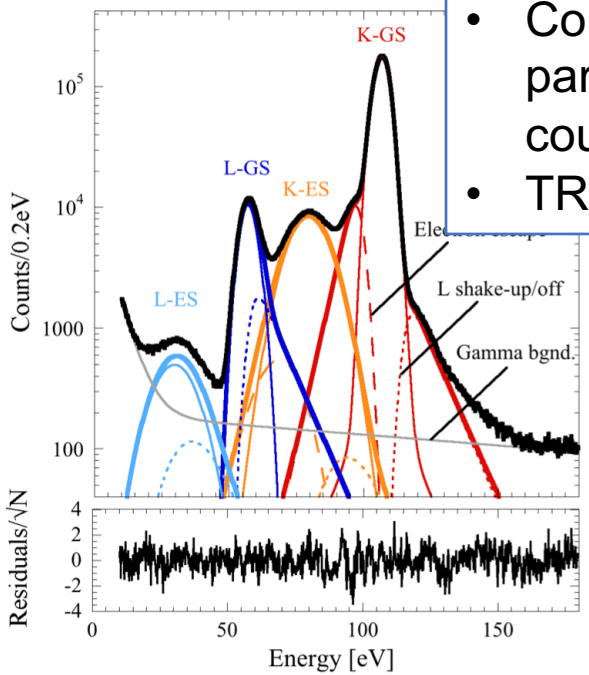


TRIUMF

^{7}Be



- Novel quantum sensing detectors opening new doors in low E nuclear physics → nuclear recoil experiments with unprecedented resolution & sensitivity
- Commercial units now available → beamline ready!
- Could we operate such device at ARIEL (through University partnership) → short-lived radioisotope studies, implantation, couple with trap etc
- TRIUMF as Canadian knowledge hub for these



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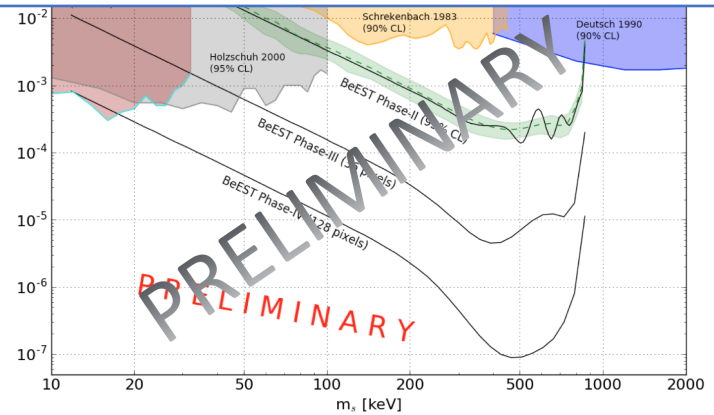
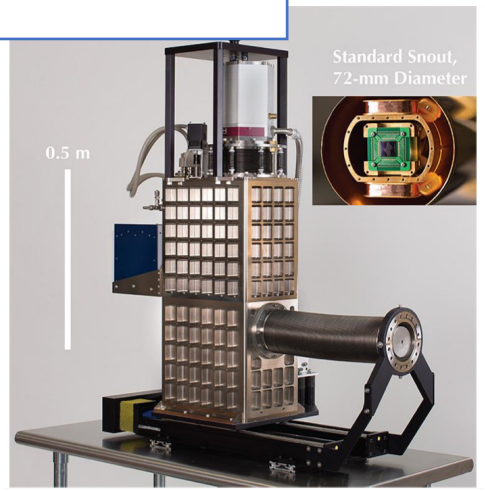
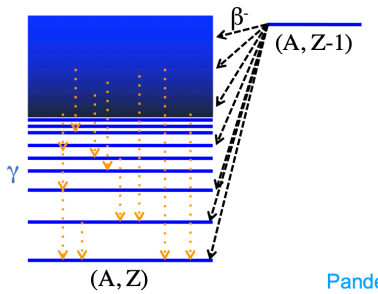


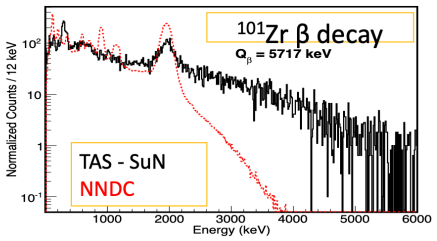


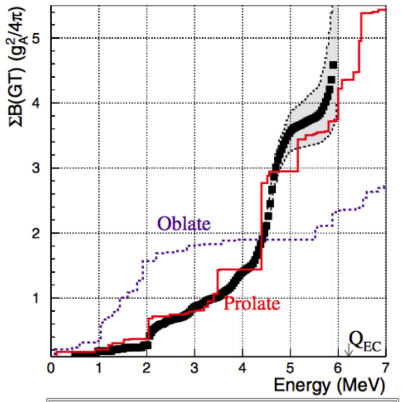
A total absorption spectrometer for ISAC (Dennis Muecher)

Beta-decay strength measurements: Structure, Astrophysics…



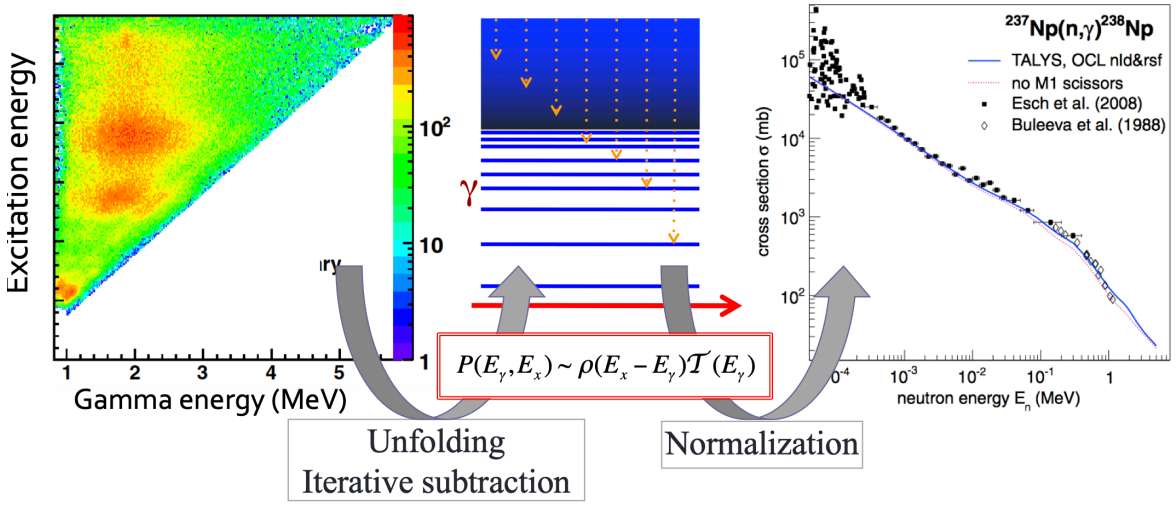
Pandemonium effect





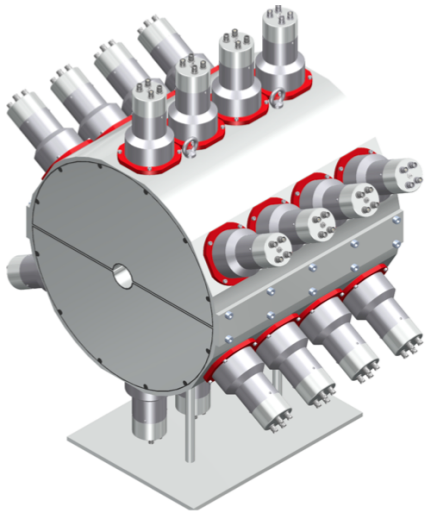
E. Nacher, *et al., Phys. Rev. Lett. 92 (2004) 232501.*

Oslo Method



T.G. Tornyi, M. Guttormsen,et al., PRC2014

- Detection of multiple decay products
- Higher efficiency for high γ energies
- β-decay GT strength
- Constrain (n,γ) via β-Oslo method
- TRIUMF advantage: cleaner beams than fragmentation facilities



SuN, NSCL

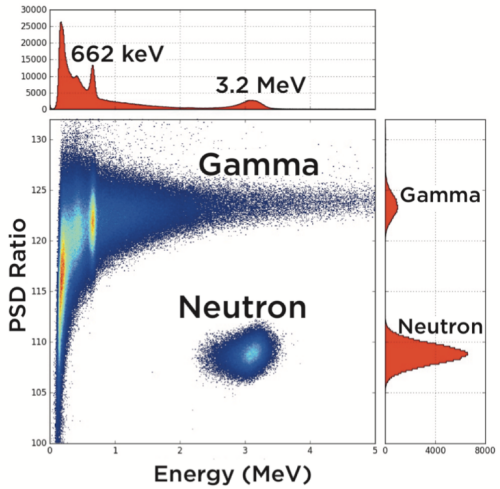
Wishlist for a dedicated ISAC-TAS:

- Basic design similar to existing TAS devices (SuN, MTAS)
- Tape system critical (we have experience with this at TRIUMF)
- new: neutron identification, e.g. NaI(Tl+Li) crystals
- new: suppression of β-decay electrons:
  - Permanent magnetic inside the bore?
  - External magnetic field?
  - Extra, inner, detector layer?
- new: Phototubes → SiPMs

Next steps:

- Input from ISAC community: other potential uses for such a device?
- Level-0 design study, cost estimate ($2.5M?)
- Gate-0 review
- …

SAINT-GOBAIN



Future neutron detection capabilities at TRIUMF for nuclear astrophysics and structure (Greg Christian)

- Science motivation is energy-sensitive (TOF) *n*-detection 1-10 MeV range for:
  - (d,n) [(p,γ) surrogate], direct e.g. (α,n)
    → Structure & astrophysics

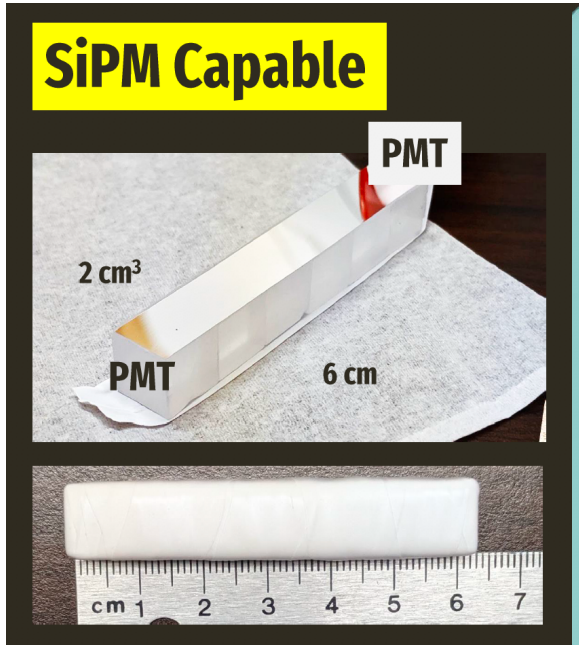
P-terphenyl (solid organic scintillator):

- Excellent PSD for n/γ
- Bright, non-toxic or volatile
- 600 ps Δt

→ Pseudo Bar design underway, position sensitive

→ "Next generation n-detection"

→ Many applications at TRIUMF, improving reach of many facilities:

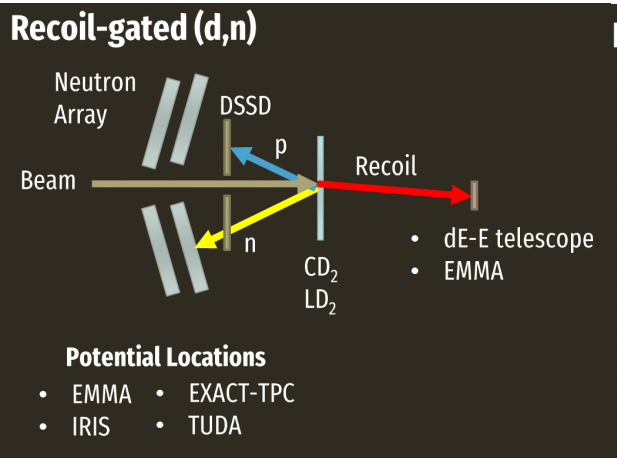


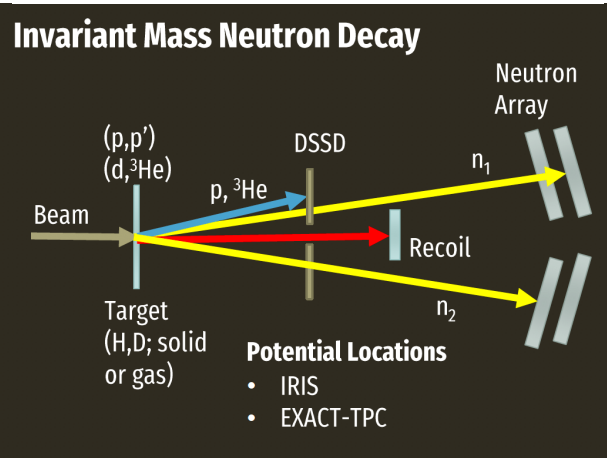
Center for Excellence in Low-Energy Nuclear Science

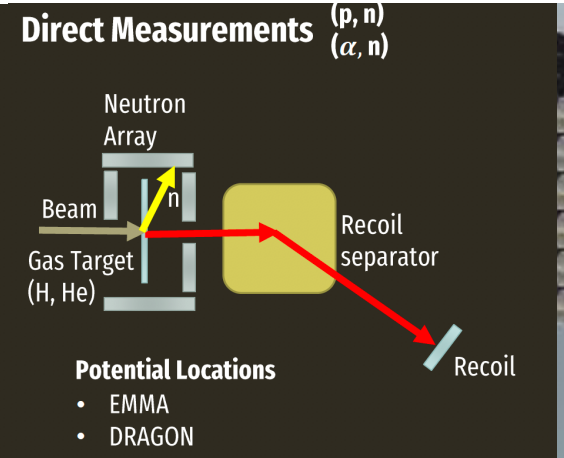
- **Major scientific thrust**: develop "next generation" neutron detectors for basic nuclear science.
- Specific focus on building a **position-sensitive p-Terphenyl array**.

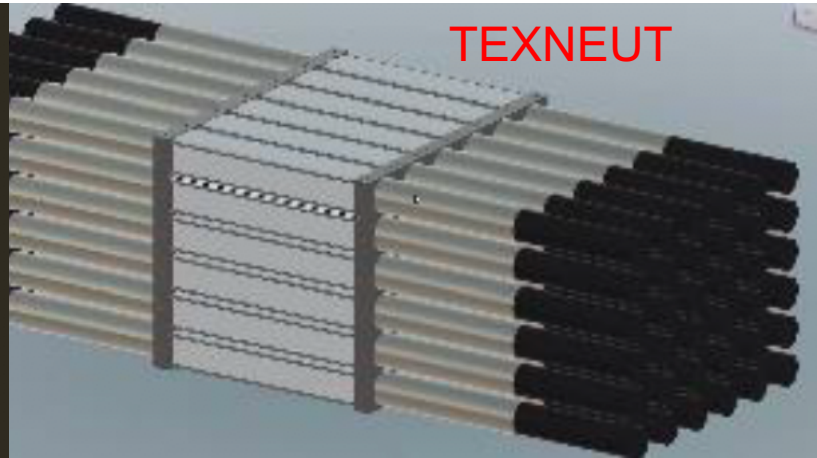
Project PIs

- L Sobotka (Wash. U)
- G. Rogachev (Texas A&M)
- G. Christian (Texas A&M → Saint Mary's)







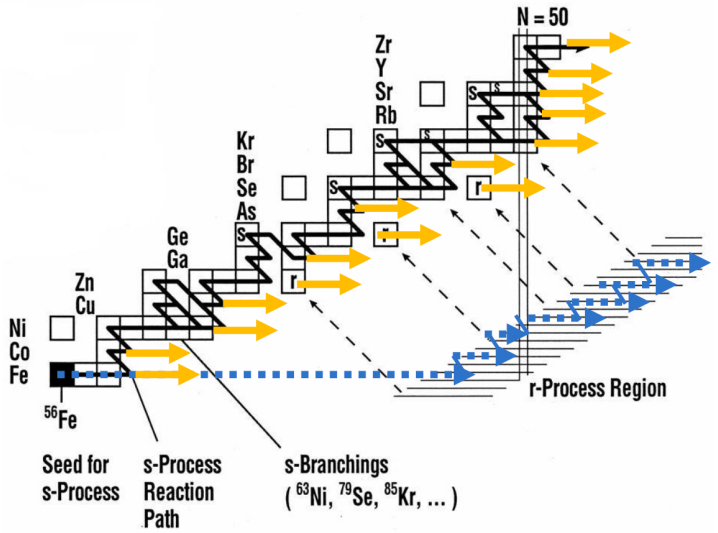


A low energy RIB storage ring for neutron capture (and more) (Iris Dillmann)

- Motivation for (n,γ) was clear (A. Spyrou)

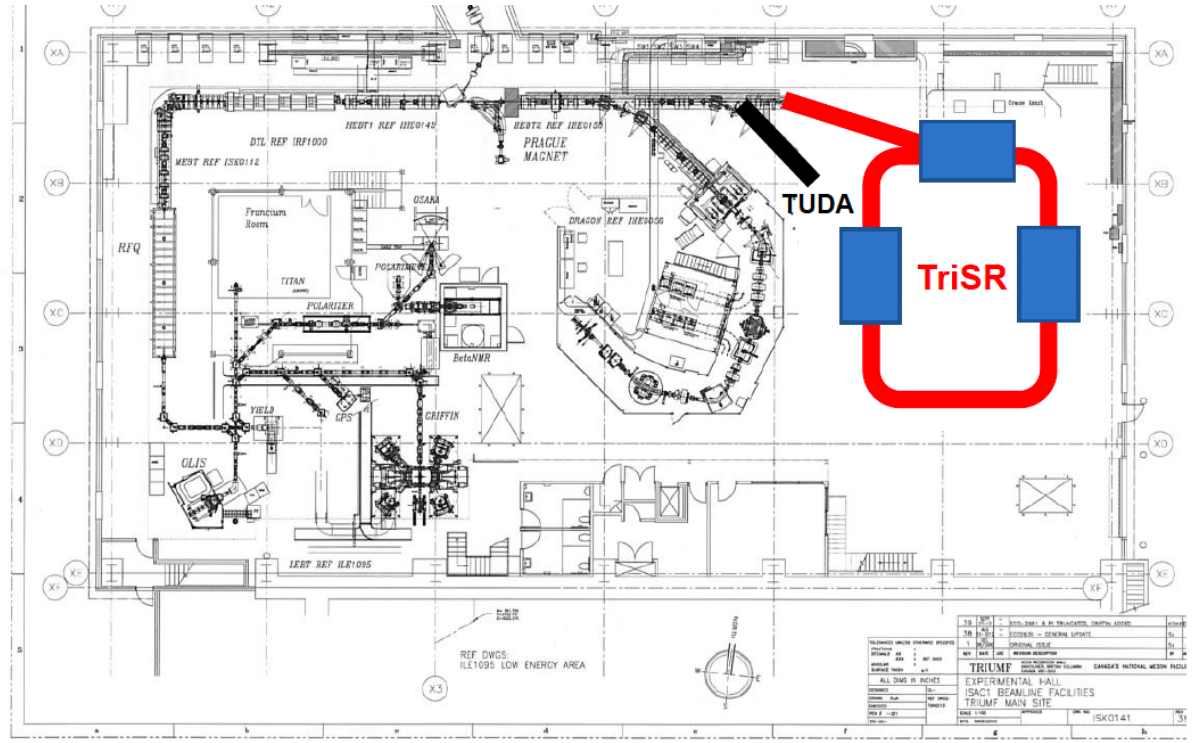
  → r-process, i-process.. Reaching n-star mergers etc… forefront of Nuclear Astrophysics right now
- Much effort & expense going into *indirect methods*
- A facility to *directly measure* (n,γ) on short-lived radioisotopes would be **unique, groundbreaking**

  → LE storage ring concept



Nuclear astrophysics

- Creation of elements heavier than iron: **slow** and **rapid** neutron capture process
- s-process: along stability (stable nuclei), E_n~ eV – 200 keV, **well investigated**
- r-process: very neutron-rich, E_n~ keV-MeV, not measured yet
- i-process: "intermediate" region, E_n~ eV- 200 keV, not measured yet directly



Within reach of TRIUMF expertise:

- Accelerators
- RIB production
- Radiative Capture in Inverse Kinematics community in Canada

✓

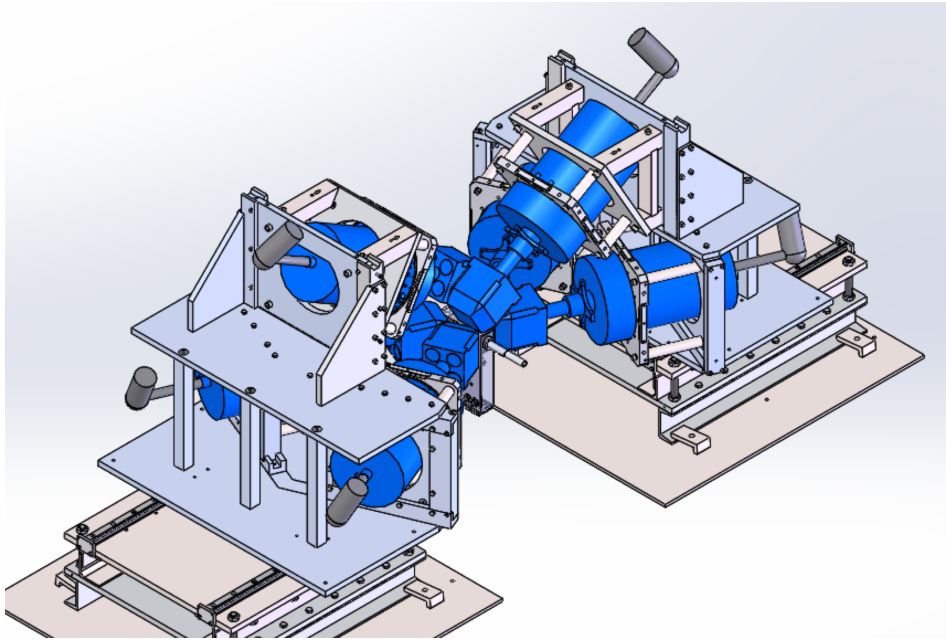
+ storage ring experts from Europe

Additional Project Upgrades (this 5YP +)

- 8pi clovers will be added to **TITAN Decay Spectroscopy** setup around EBIT for **NEEC and 2-γ decay**
- POLARIS, the CMMS extension to βNMR, will contain **polarized beam extension to GRIFFIN:** Compton Polarimetry

- **DRAGON**:
  - addition of **GRIFFIN clovers** for low-E direct capture experiments -> unprecedented precision/sensitivity even compared to stable beam experiments
  - $LaBr_3$ array for novel method of (p,gamma), (a,gamma) experiments x10 sensitivity

- **Active Target Time-Projection Chamber "EXACT":** particle tracking capability (Micromegas)
  - arrays of silicon and CsI(Tl) detectors
  - *p,d,t*,^{3,4}He targets
  - Reactions at low beam intensities, kinematically-complete, rare decay modes, resonance excitation functions
- **Regina Cube for Multiple Particles** (RCMP)
  - addition to GRIFFIN)
- **TiSTAR** Silicon Tracking Array (Guelph)
  - addition to TIGRESS



Keeping our facilities cutting edge
Reaching beyond our "pillars"
Collaboration, combining resources →
Maximize Science Output

Picked up from discussions

- ISAC/ARIEL is the driver for our science and will be for 20+ years
- Paramount to have development of new beams, reliability of systems
- Critical to keep experimental facilities evolving to stay competitive
- Facilities less like sunset experiments (e.g. TWIST) → More like Permanent capabilities continuously upgraded and improved

How to ensure ISAC/ARIEL Experimental Facilities are Cutting Edge?

Criteria: Science Case, Uniqueness, Competitiveness, Capability

- Maintain unique resources for scientific community
- Upgrades to maintain facilities as “one of the few best”
- Succession/replacement when facility can no longer meet the data needs of the scientific community (or our NSERC referees will tell us!)

We are coming out of our “silos”:

- Structure & Astro facilities/groups are now collaborating by combining detectors
- New detectors/techniques inspiring BSM experiments using nuclear & atomic techniques + applications in astrophysics
- Fundamental Symmetries nuclear overlap with atomic & particle communities
- Structure techniques (polarized gamma-spec) applications to Nuc Medicine

Competition / Complementarity:

- TRIUMF highest power ISOL facility – will have highest intensity of many beams
  → Complementarity with FRIB & other fragmentation facilities
- Need all the tools for discovery
- Where possible leverage collaboration to deploy detectors / resources across community where needed
  - E.g. AT-TPCs mature design, no expensive R&D needed – deploy duplicate designs for future

TRIUMF

Thank You
Merci

Discovery, accelerated