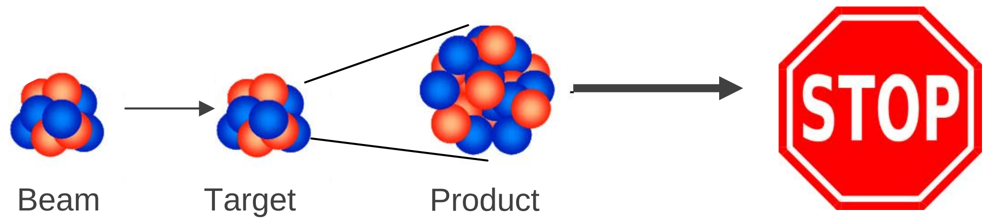
Physics with stopped beams



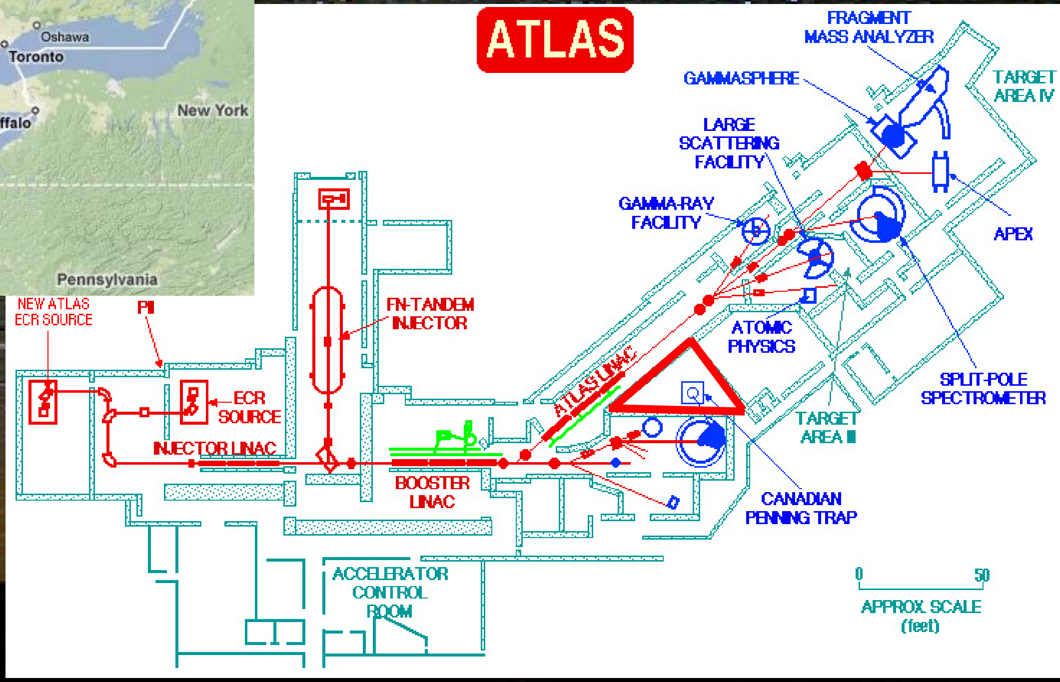
Jason Clark

ATLAS 25th Anniversary Celebration

October 22, 2010

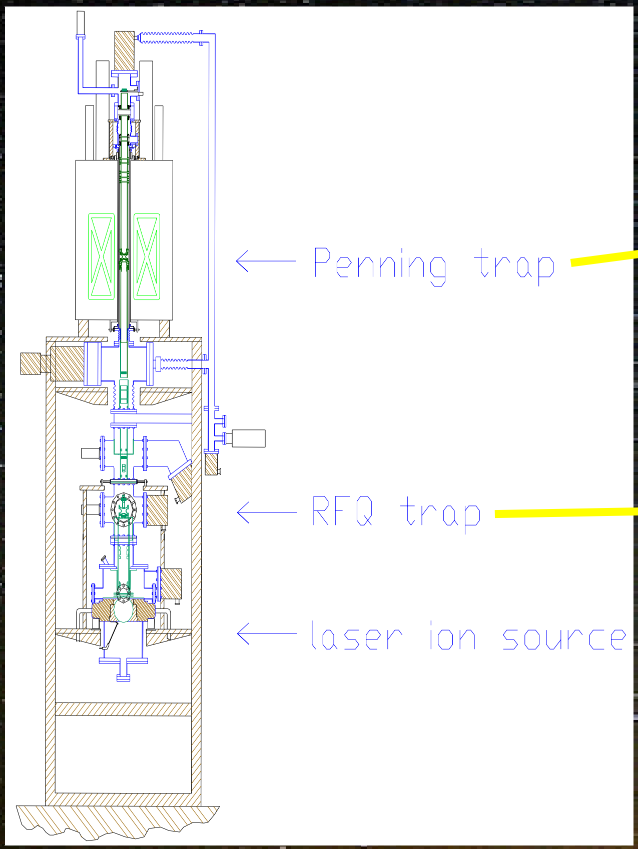
The first move of the Canadian Penning Trap (CPT) mass spectrometer

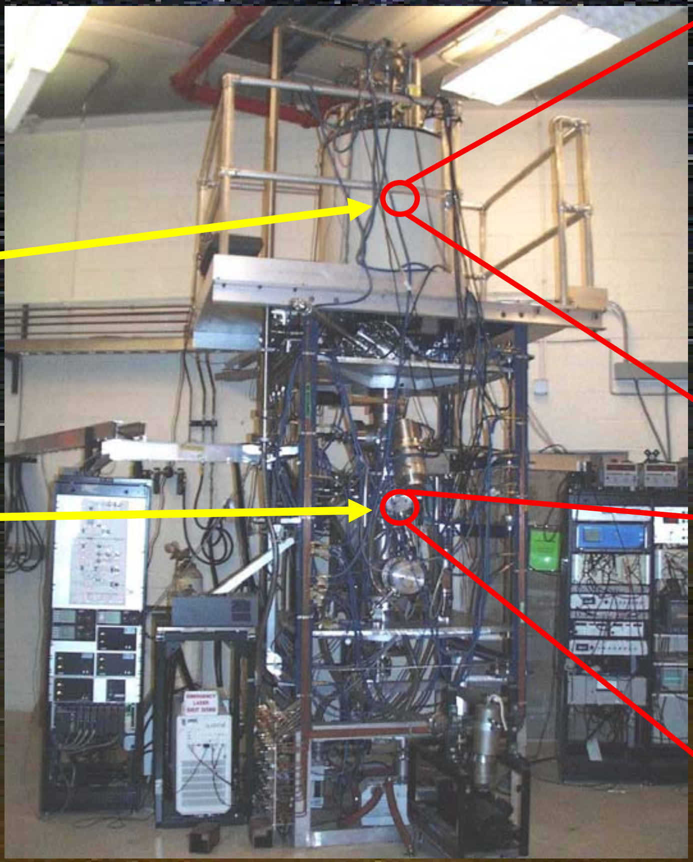
Constructed at Chalk River Labs, Ontario, Canada



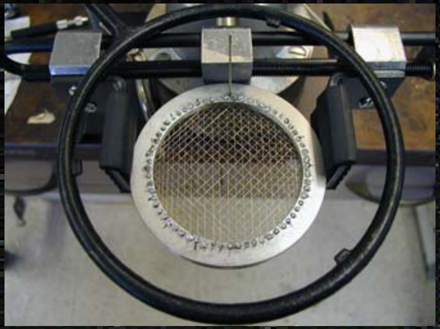
Moved to the ATLAS facility in 1997

The early days of the CPT at ATLAS

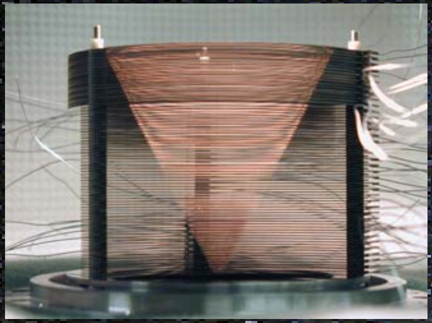




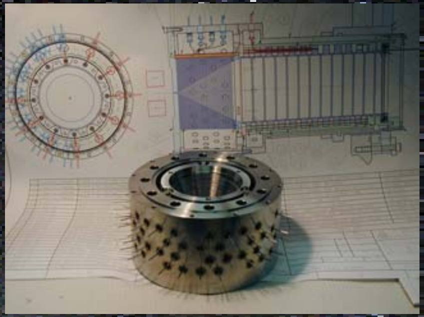
Gas Catcher Development



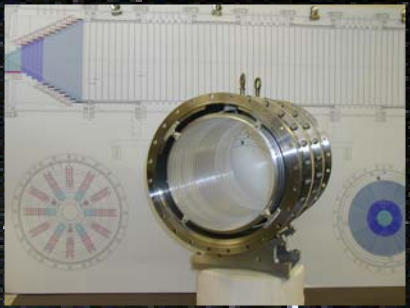
Window



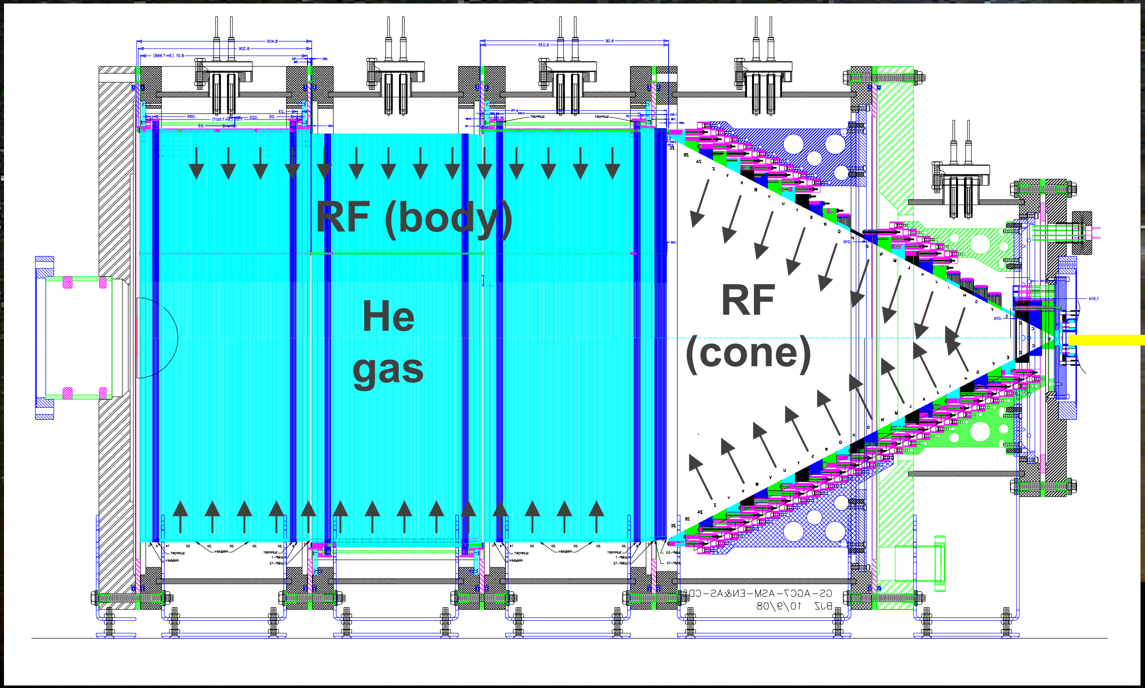
Cone



Cone

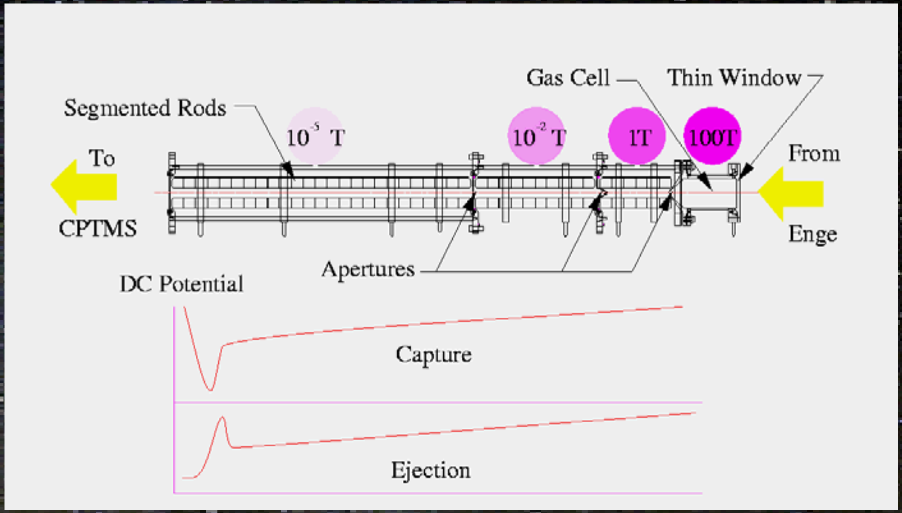


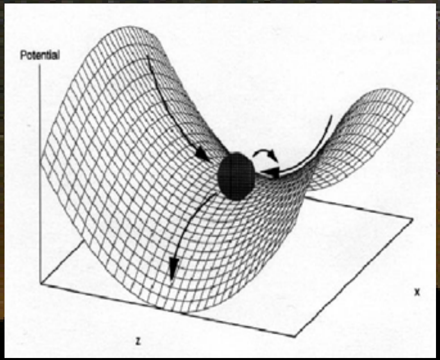
Body

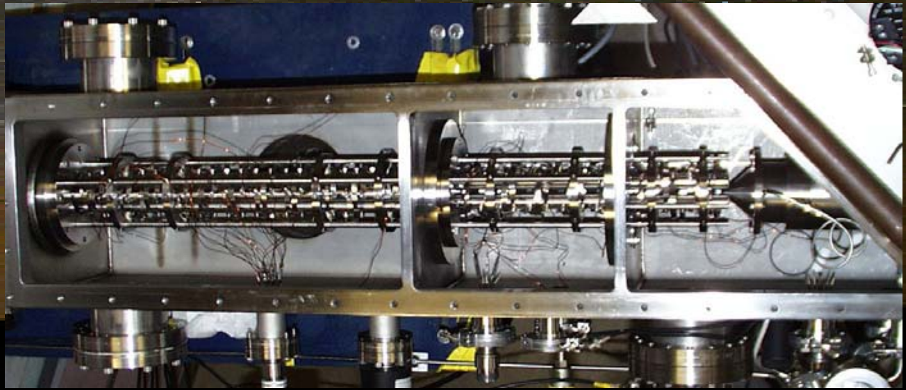


Ion guide / buncher

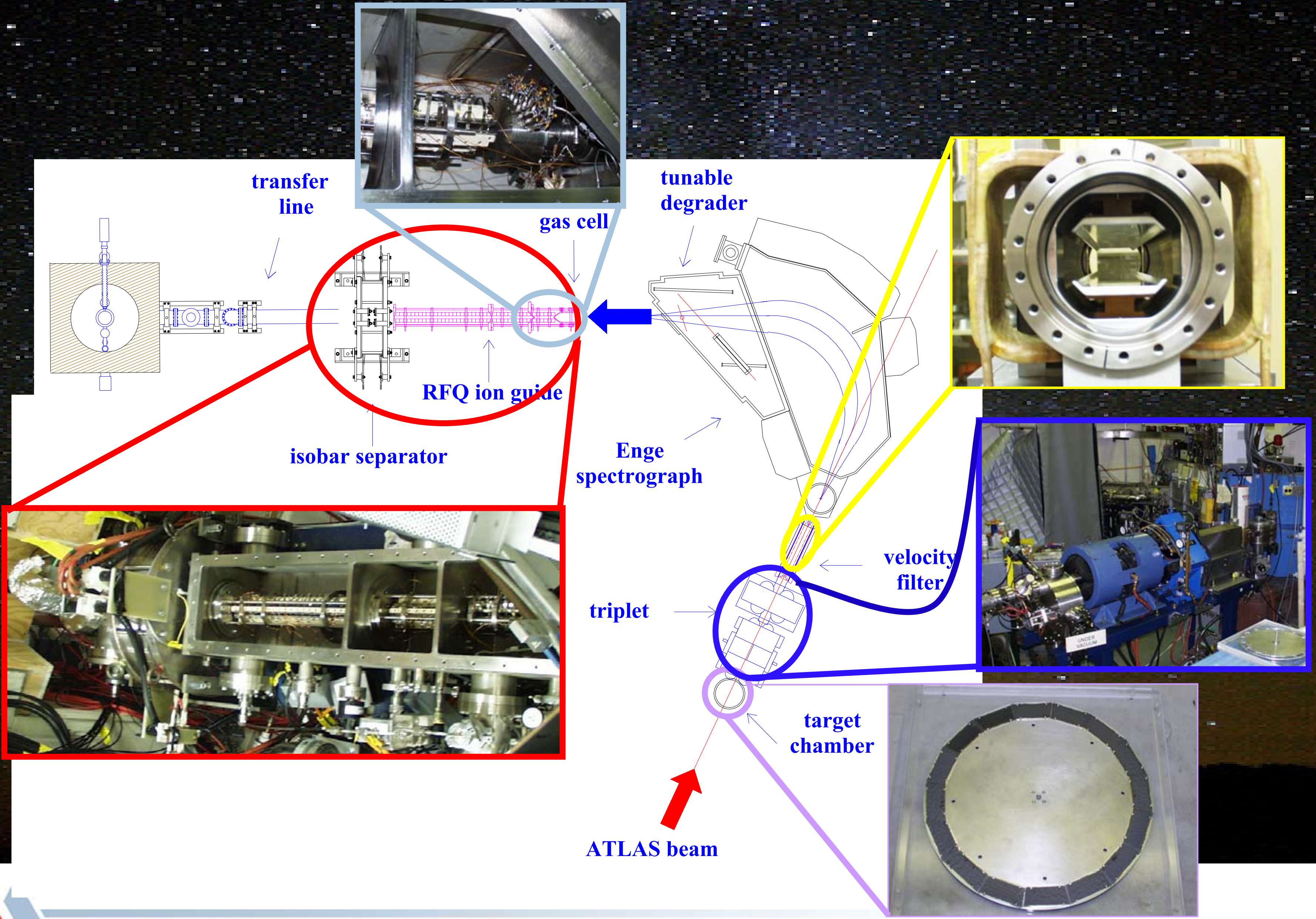
- Ion cooler divided by apertures into 3 sections
- Permits a differentially pumped system to remove the He gas used to stop the ions in the gas catcher
- RFQ ion guide can be used in a mass selective mode
- linear trap at the end of the RFQ ion guide transforms the continous beam into a bunched beam







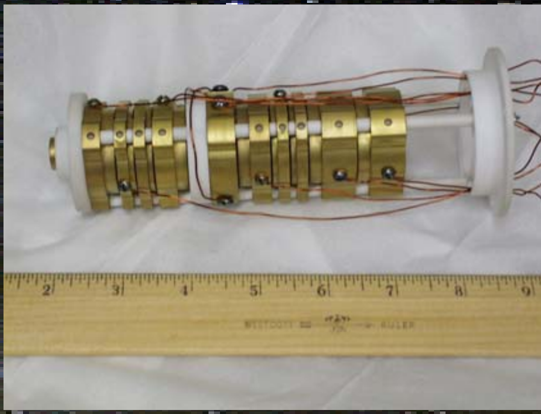
Transfer of online reaction products to the CPT



‘Old’ isobar separator

Initial problem: too many contaminant molecular ions

Constructed gas-filled cylindrical Penning trap

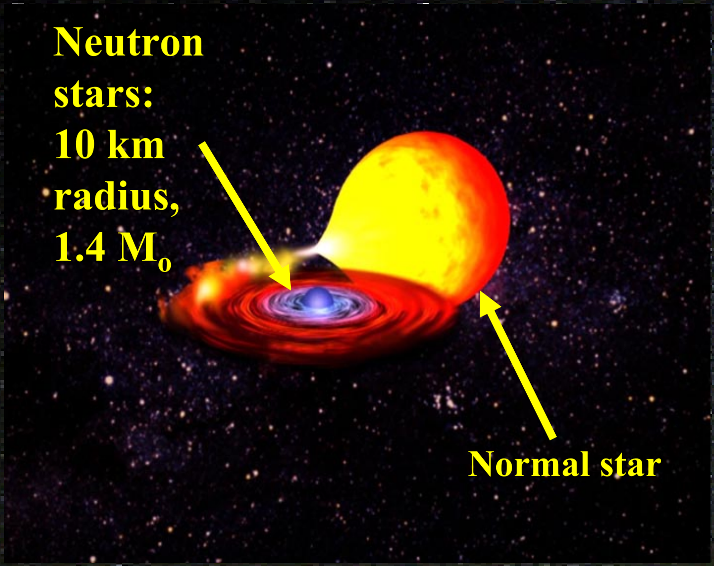


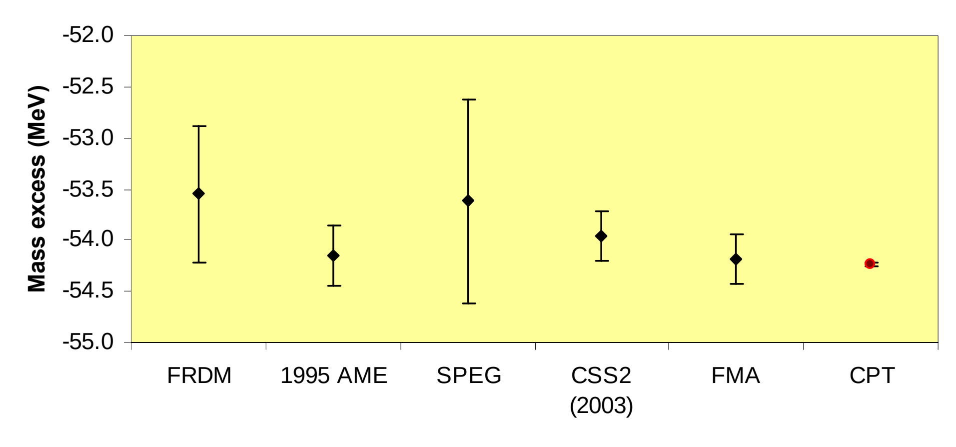
Used to suppress contamination

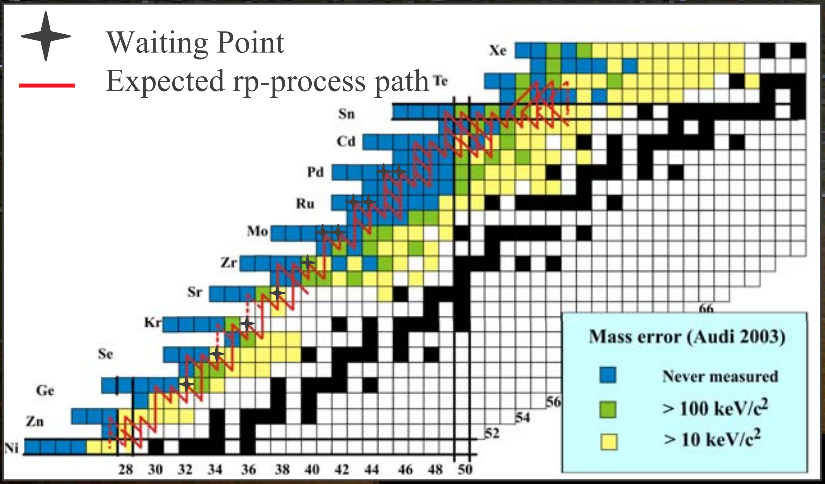
R ~ 1000 for A ~ 100

We initially had some debugging to do!

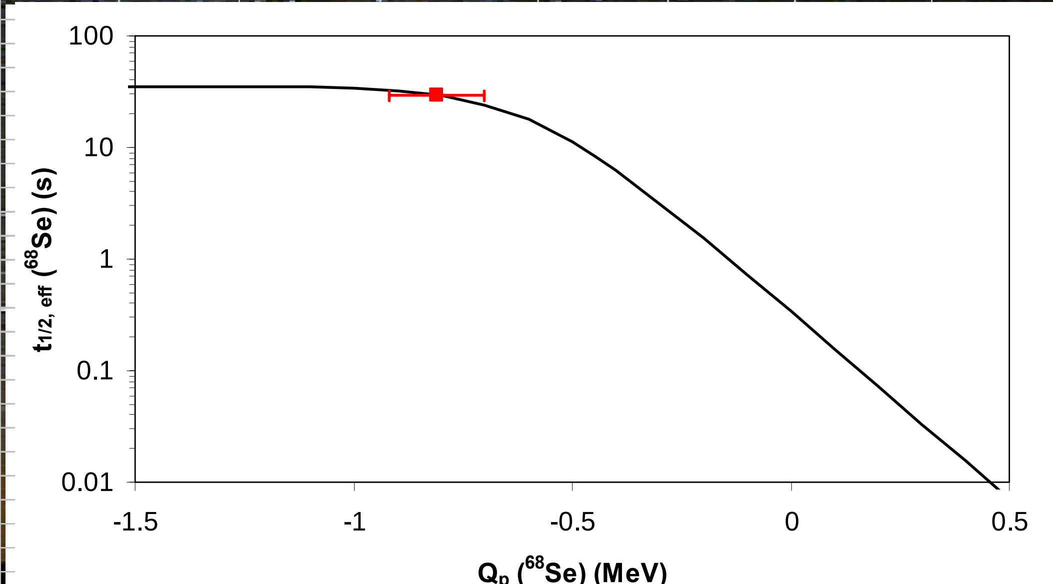
First online measurements with the CPT







G. Audi *et al.*, Nucl. Phys. A 729, 337 (2003).



Contribution of ^{68}Se to the timescale of the rp-process ~ 32 s at x-ray burst T~1.5 GK.

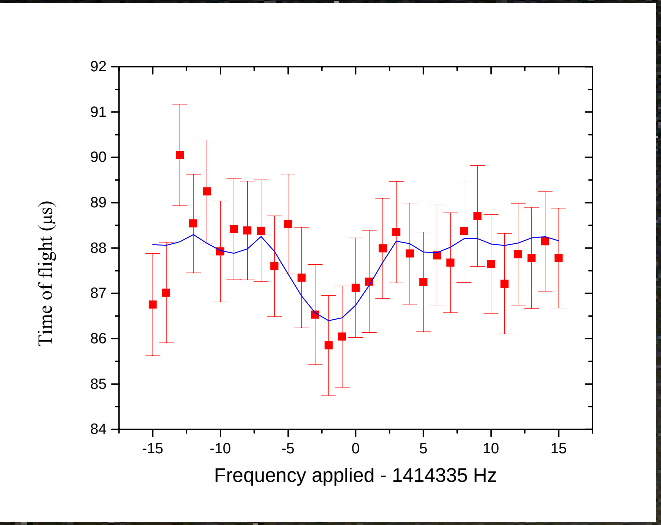
FRDM: P. Möller *et al.*, At. Data Nucl. Data Tables **59,** 185 (1995).
1995 AME: G. Audi and A.H. Wapstra, Nucl. Phys. **A595,** 409 (1995).
SPEG: G.F. Lima *et al.*, Phys. Rev. C **65,** 044618 (2002).
CSS2: M. Chartier *et al.*, J. Phys. G 31, S1771 (2005).
FMA: A Wöhr *et al.*, Nucl. Phys. **A742,** 349 (2004).
CPT: J.A. Clark *et al.*, Phys. Rev. Lett. **92,** 192501 (2004).
HF: B. A. Brown *et al.*, Phys. Rev. C **65,** 045802 (2002).

Mass measurement of the *rp*-process waiting-point nuclide ^{64}Ge

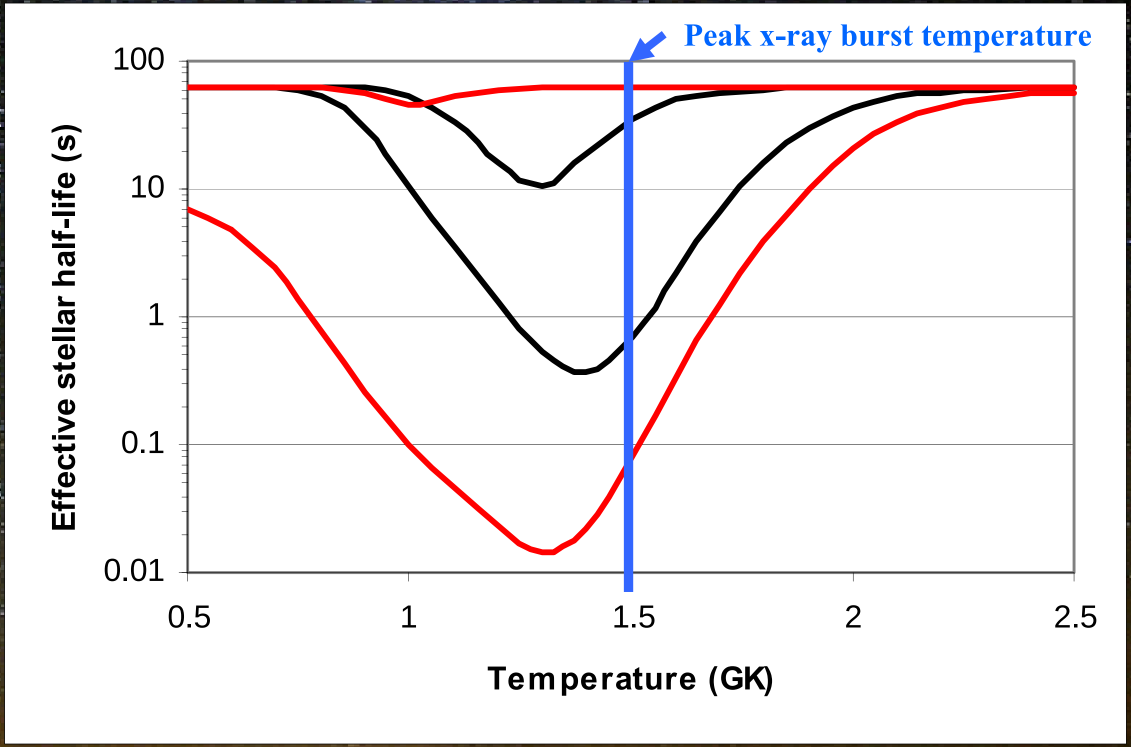
Network calculation:

- **considers (p,γ), (γ,p), and β decay**
- **solves differential equations for each x-ray burst T**

CPT @ ANL



ΔM = **-54344 (30)** keV



Red lines delineate the range allowed by the 1995 AME.
Black lines delineate the range allowed with CPT result.

CPT: J.A. Clark *et al.*, Phys. Rev.C **75,** 032801(R) (2007).

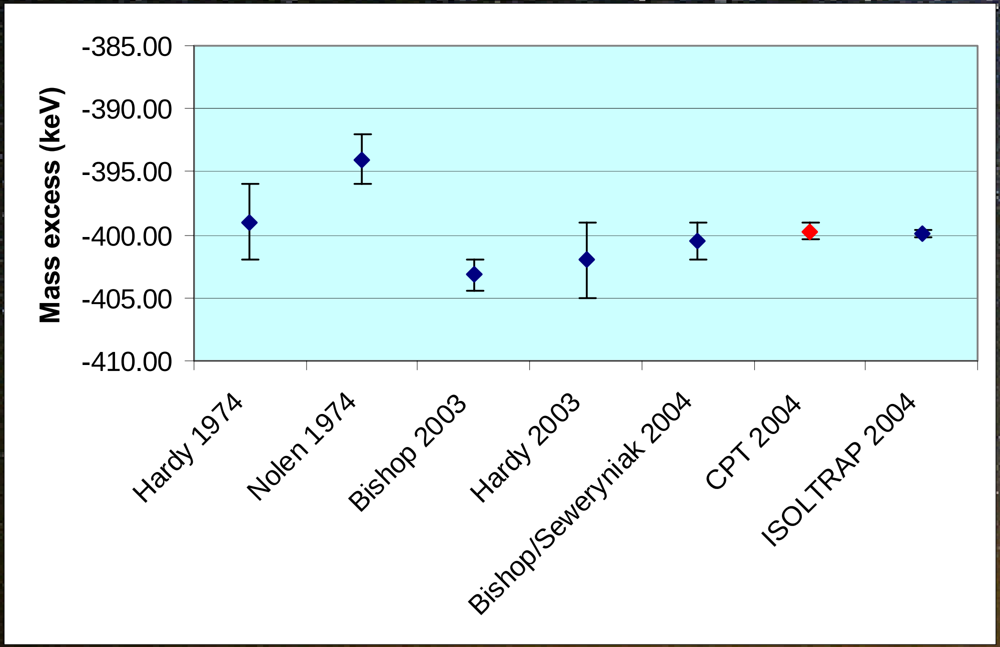
Gas purification and the mass of ^{22}Mg

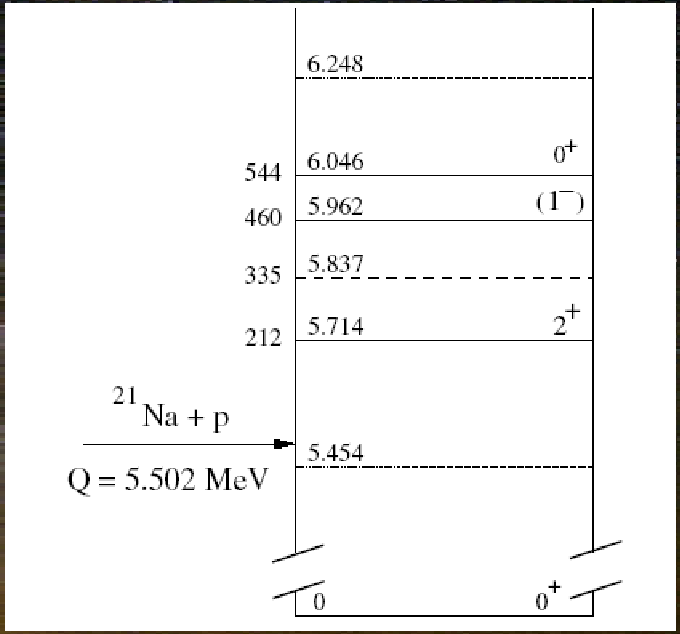
Motivation: • test the unitarity of the CKM matrix

• uncertainty in the ^{21}Na(p,γ) rate in novae

Problem: 'Purified' He gas contained ^{22}Ne which overwhelmed ^{22}Mg yield

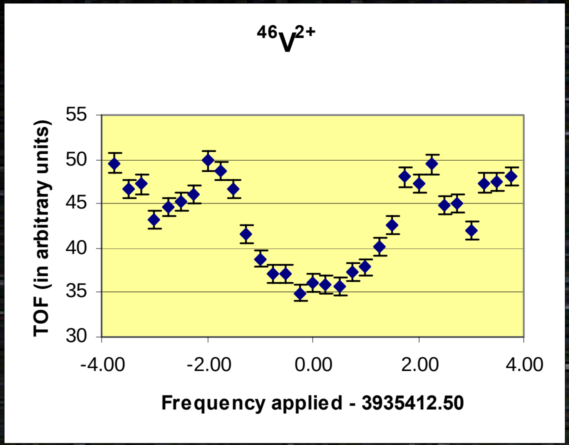
Solution: Build a 'Ne trap': a cryogenically cooled charcoal trap

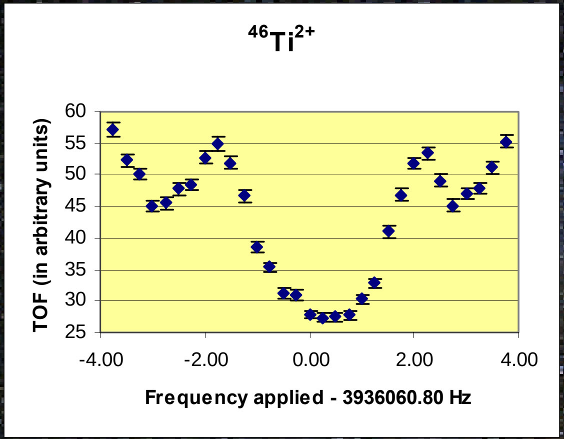




Hardy 1974: J. C. Hardy *et al.*, Phys. Rev. C **9**, 252 (1974).
Nolen 1974: J. A. Nolen *et al.*, Nucl. Instrum. Methods **115**, 189 (1974).
Bishop 2003: S. Bishop *et al.*, Phys. Rev. Lett. **90**, 162501 (2003).
Hardy 2003: J.C. Hardy *et al.*, Phys. Rev. Lett. **91**, 082501 (2003).
Seweryniak 2004: D. Seweryniak *et al.*, Phys. Rev. Lett. **94,** 032501 (2005).
CPT 2004: G. Savard *et al.*, Phys. Rev. C **70**, 042501(R) (2004).
ISOLTRAP 2004: M. Mukherjee *et al.*, Phys. Rev. Lett. **93**, 150801 (2004).

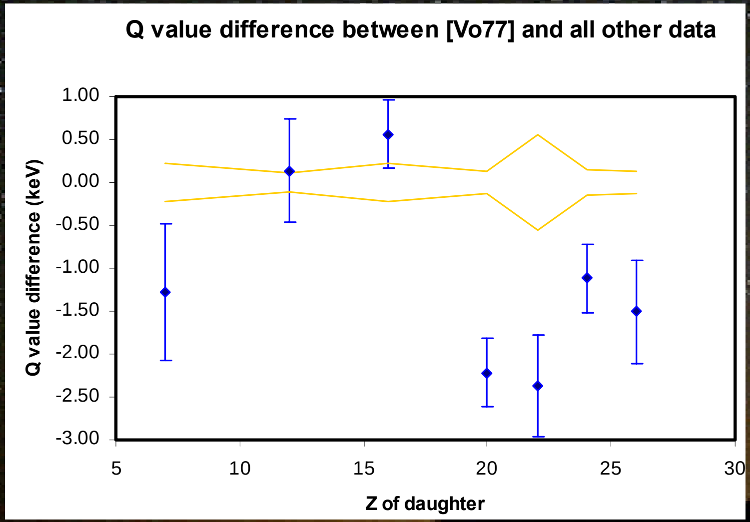
High precision measurements: tests of the CKM matrix unitarity



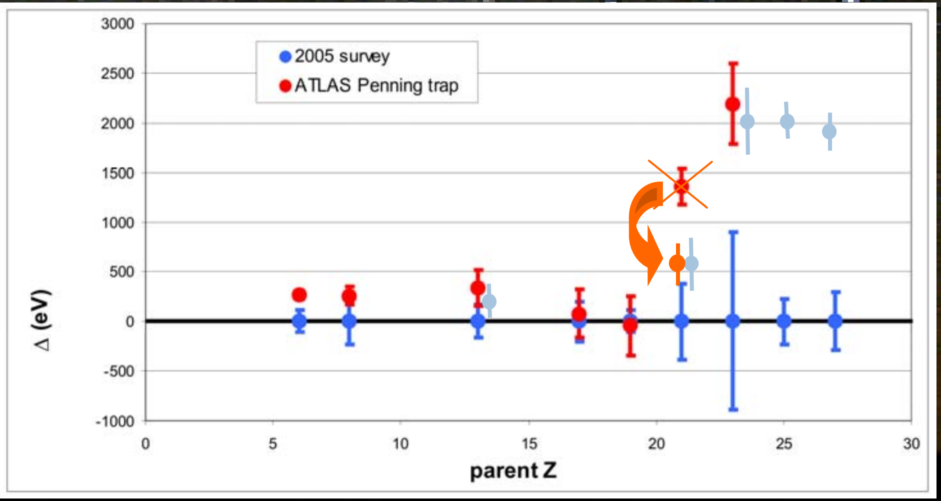


G. Savard *et al.*, Phys. Rev. Lett. **95**, 102501 (2005).

- As of 2004, ^{46}V had largest Q-value uncertainty of the 9 most precise superallowed $0^+ \rightarrow 0^+$ cases
- First measurement of doubly-charged ion in Penning trap
- Found large deviations between [Vo77] and other results
- 7 of the 9 precise cases have now been studied by the CPT

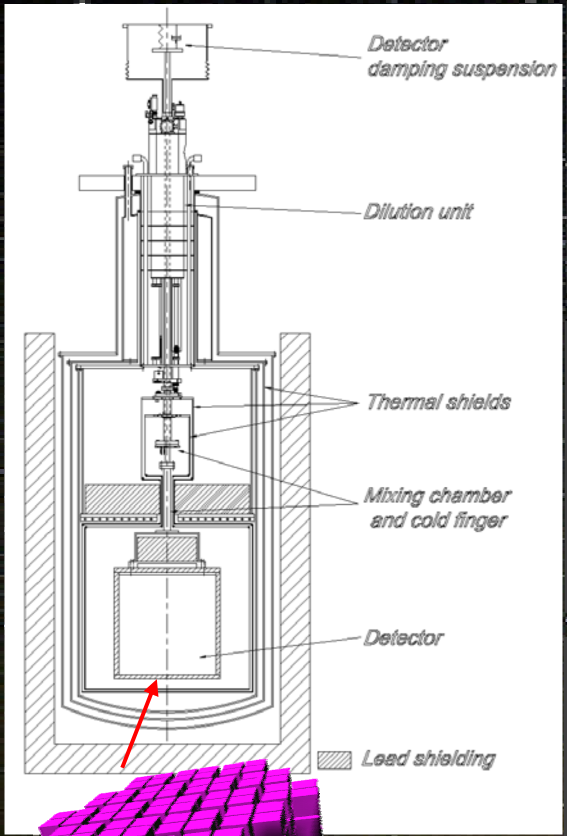


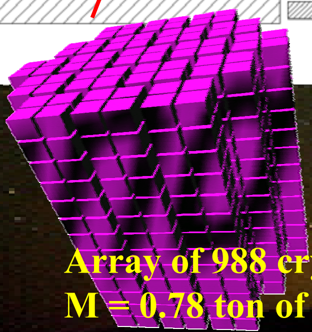
[Vo77] H. Vonach *et al.*, Nucl. Phys. **A278**, 189 (1977).



Double-beta decay of Tellurium

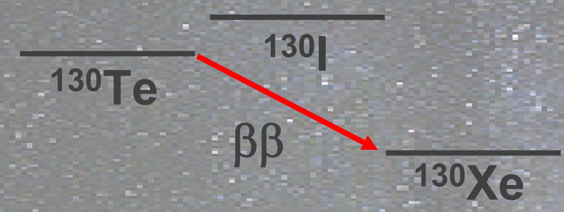
CUORE





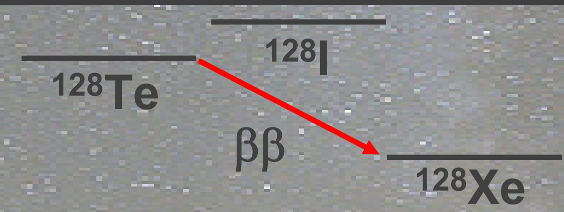
Array of 988 crystals:
M = 0.78 ton of TeO_2

Three isotopes of Te can undergo double-beta decay:



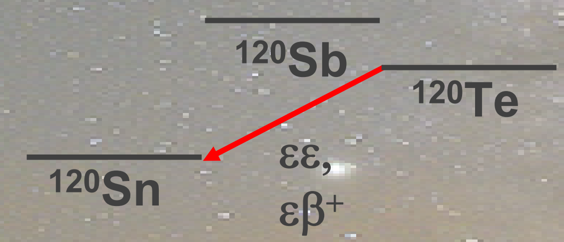
Isotope of primary interest for CUORICINO and CUORE experiments

$Q_{\beta\beta}$ = 2527.1(2.1) keV Abundance: 33.8%



Although abundant, small Q-value means double beta decay rate much smaller than ^{130}Te

$Q_{\beta\beta}$ = 867.5(1.1) keV Abundance: 31.8%

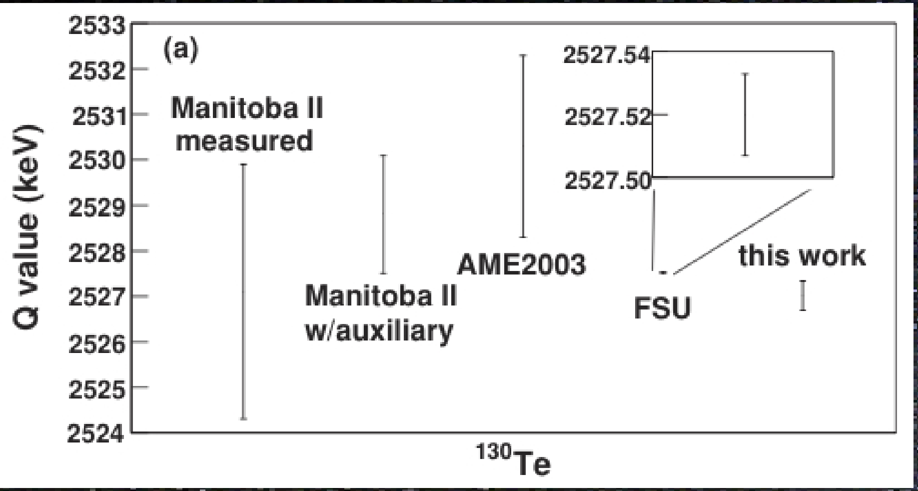


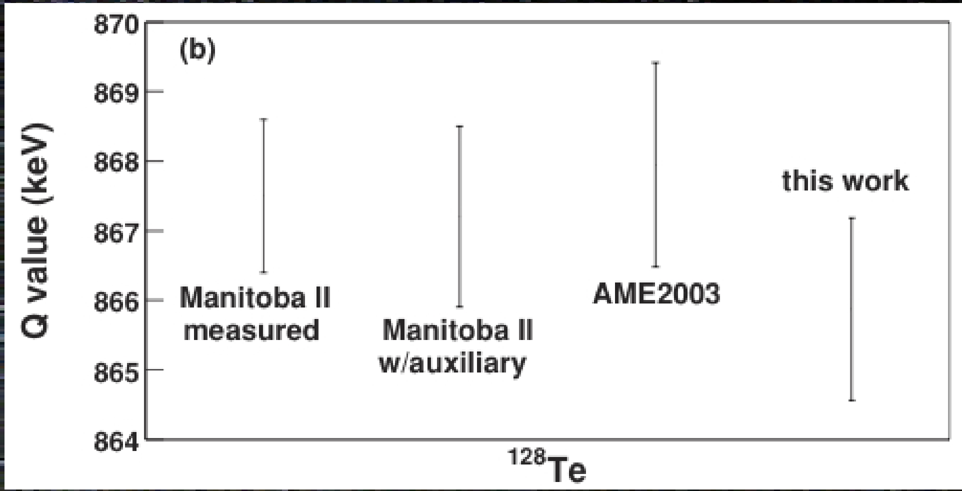
Low abundance but can place best limits on electron capture and electron capture/positron processes

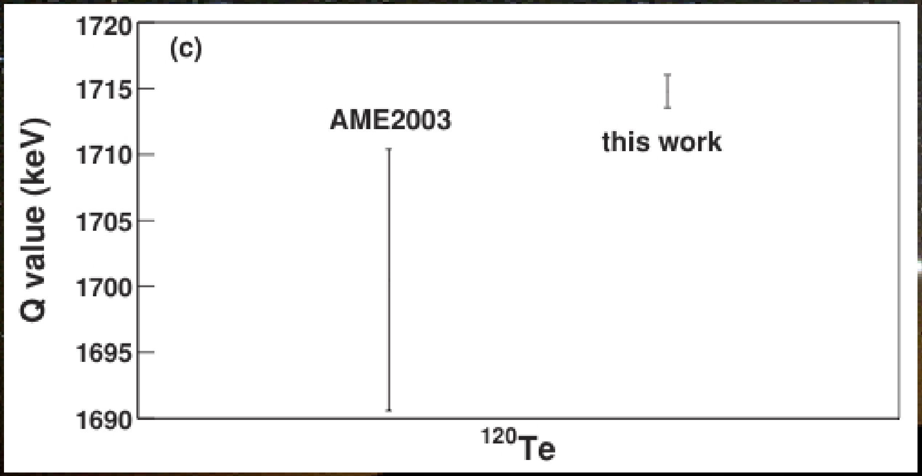
$Q_{\beta\beta}$ = 1700.5(9.9) keV Abundance: 0.1%

- Need accurate decay Q-values to know where to look
  - 1σ resolution of CUORE detectors is 2-3 keV at 2500 keV

Te Q-value measurements with the CPT

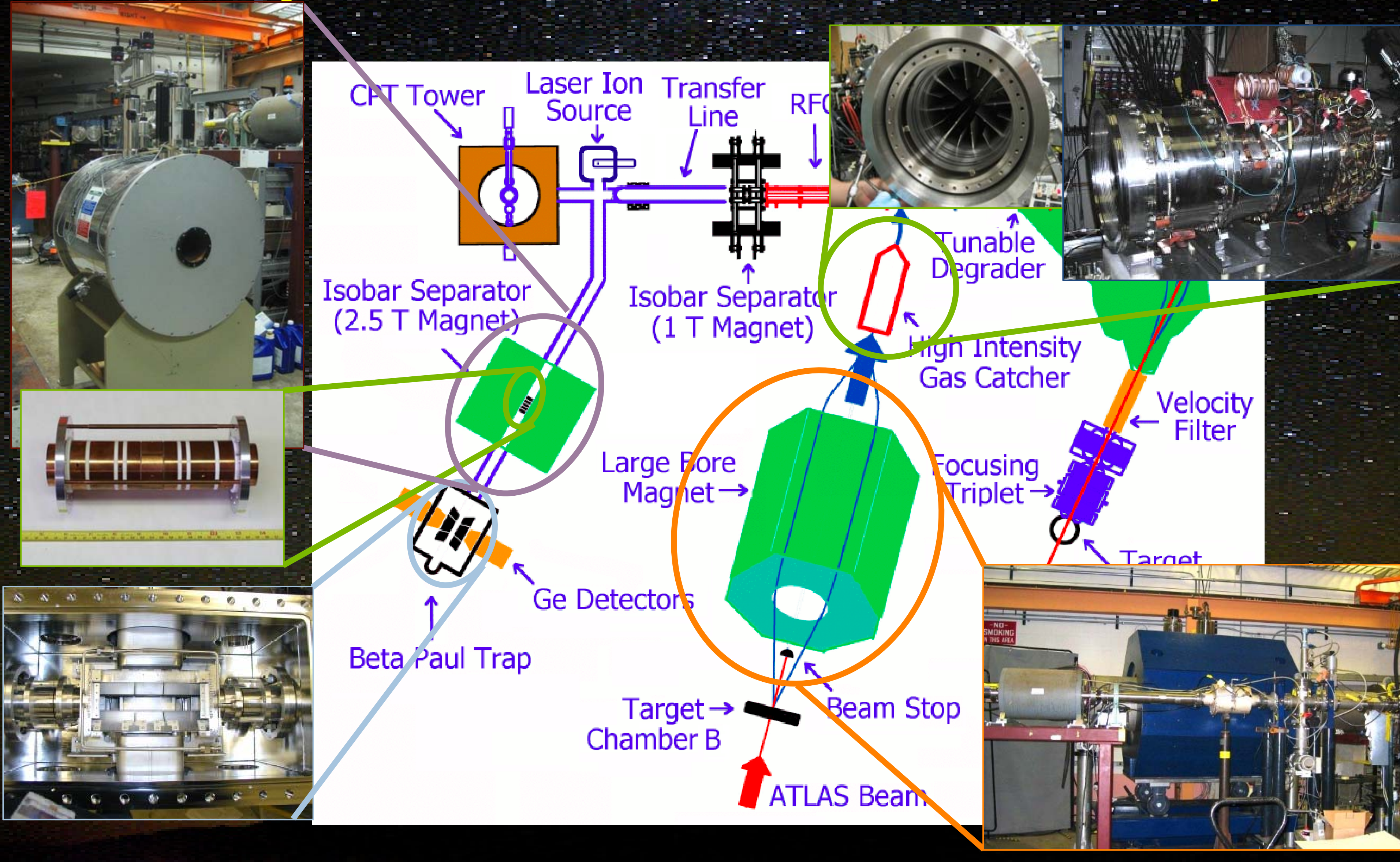




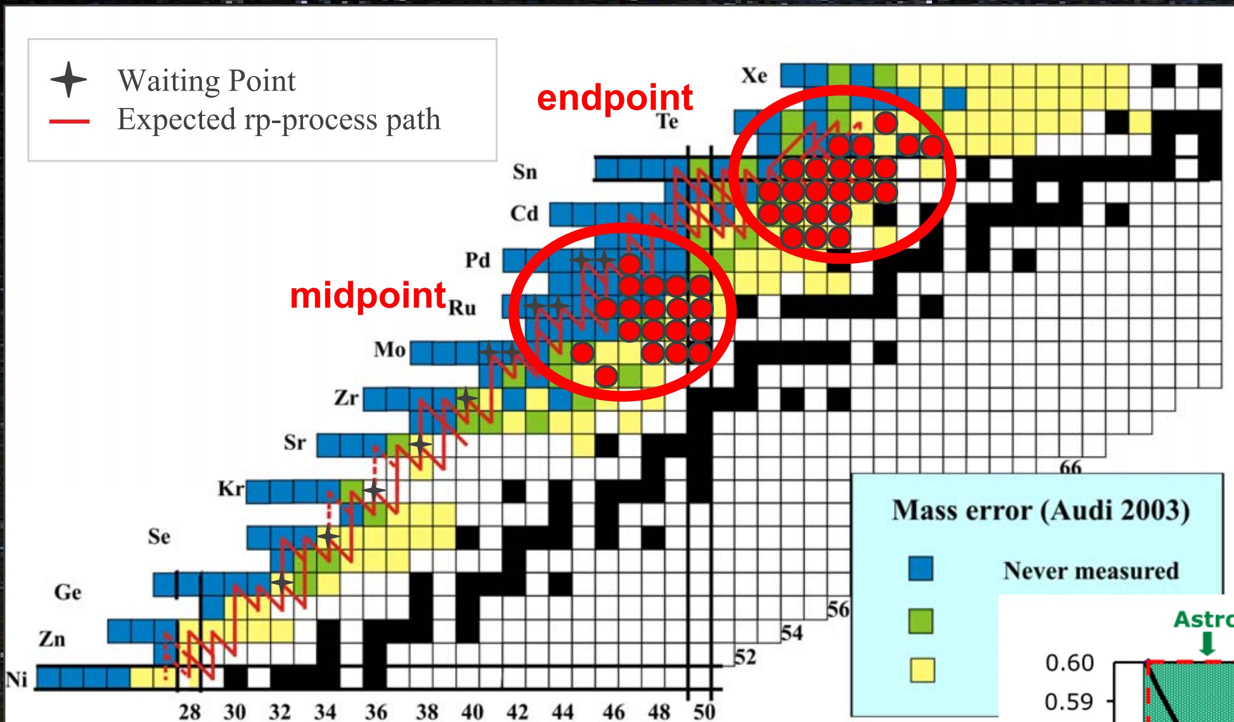


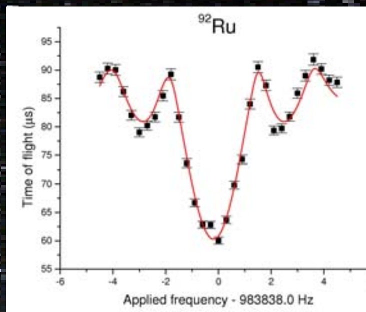
- Now the uncertainty in the Q values are well within the detector resolution!
- Results determine where $0\nu\beta\beta$ signatures would lie within background lines (from ^{214}Bi for example)

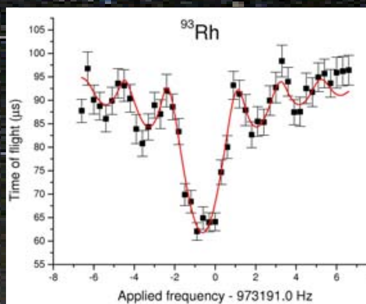
Extending the reach with the CPT and other ion traps

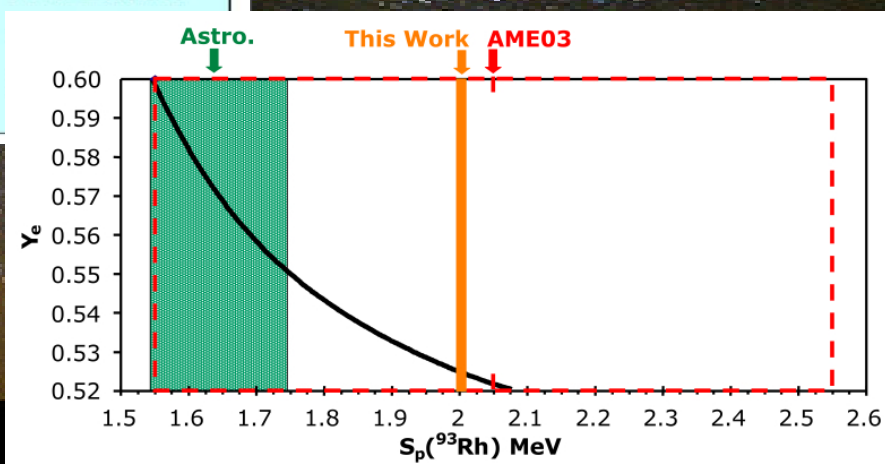


Measurements along the *rp*- and *νp*-process path





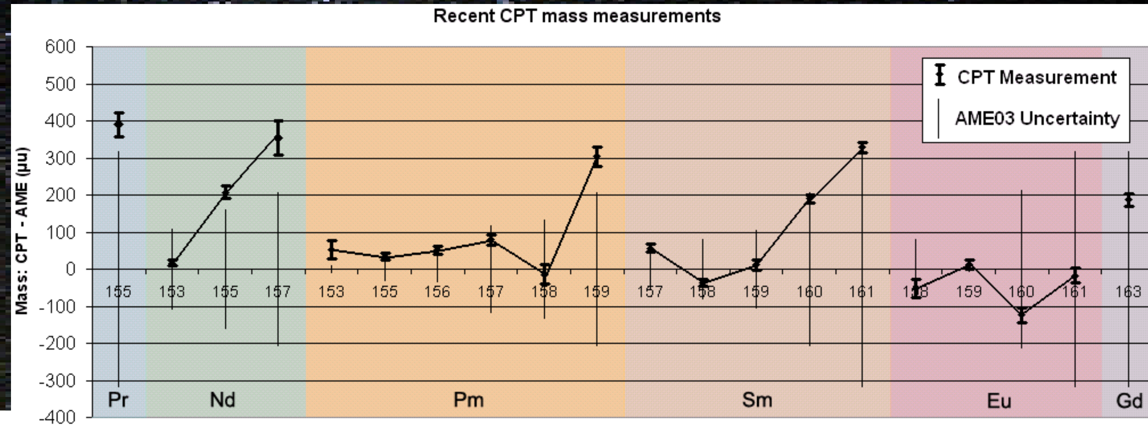




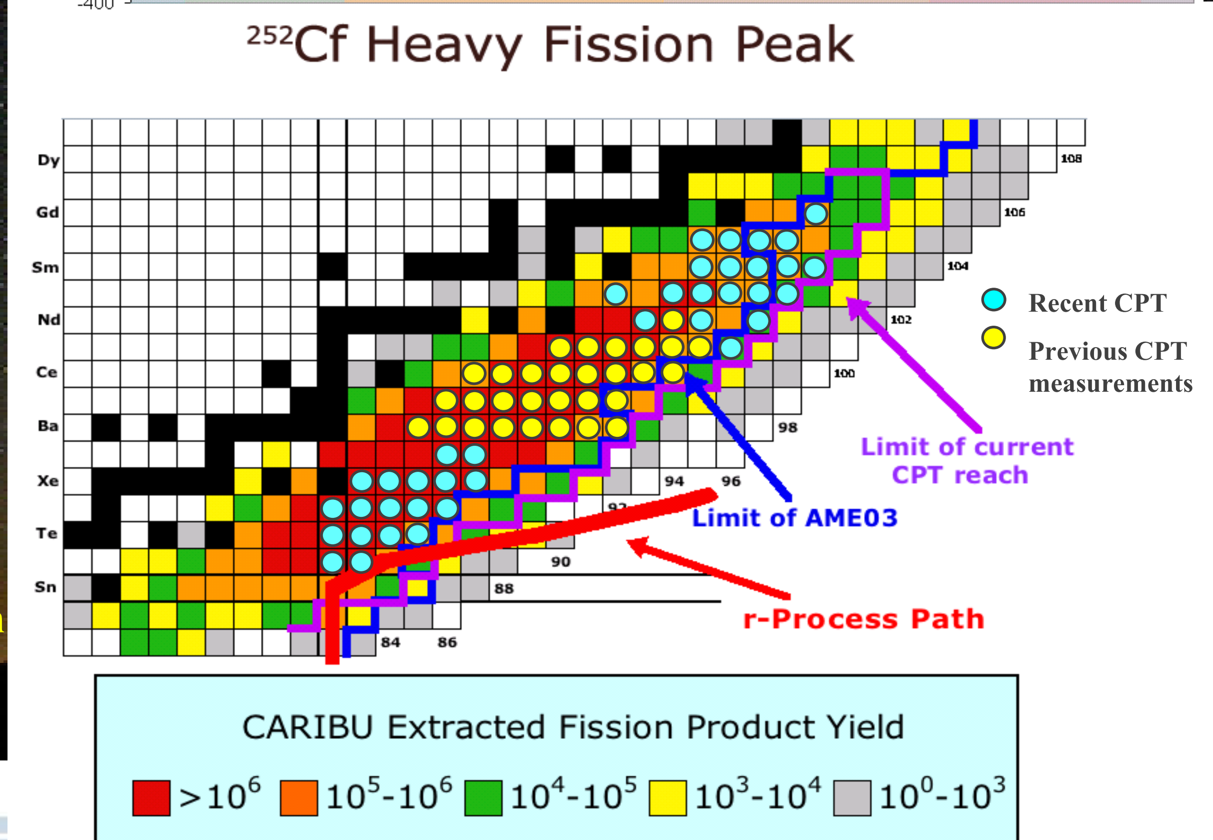
- More than 40 proton-rich nuclides measured over the past few years
- Most masses were determined to better than 10 keV/c^2
- ^{92}Mo/^{94}Mo abundance ratio sensitive to $S_p(^{93}Rh)$ in particular supernova model … or not?

J. Fallis *et al.*, Phys. Rev. C **78**, 022801(R), (2008)

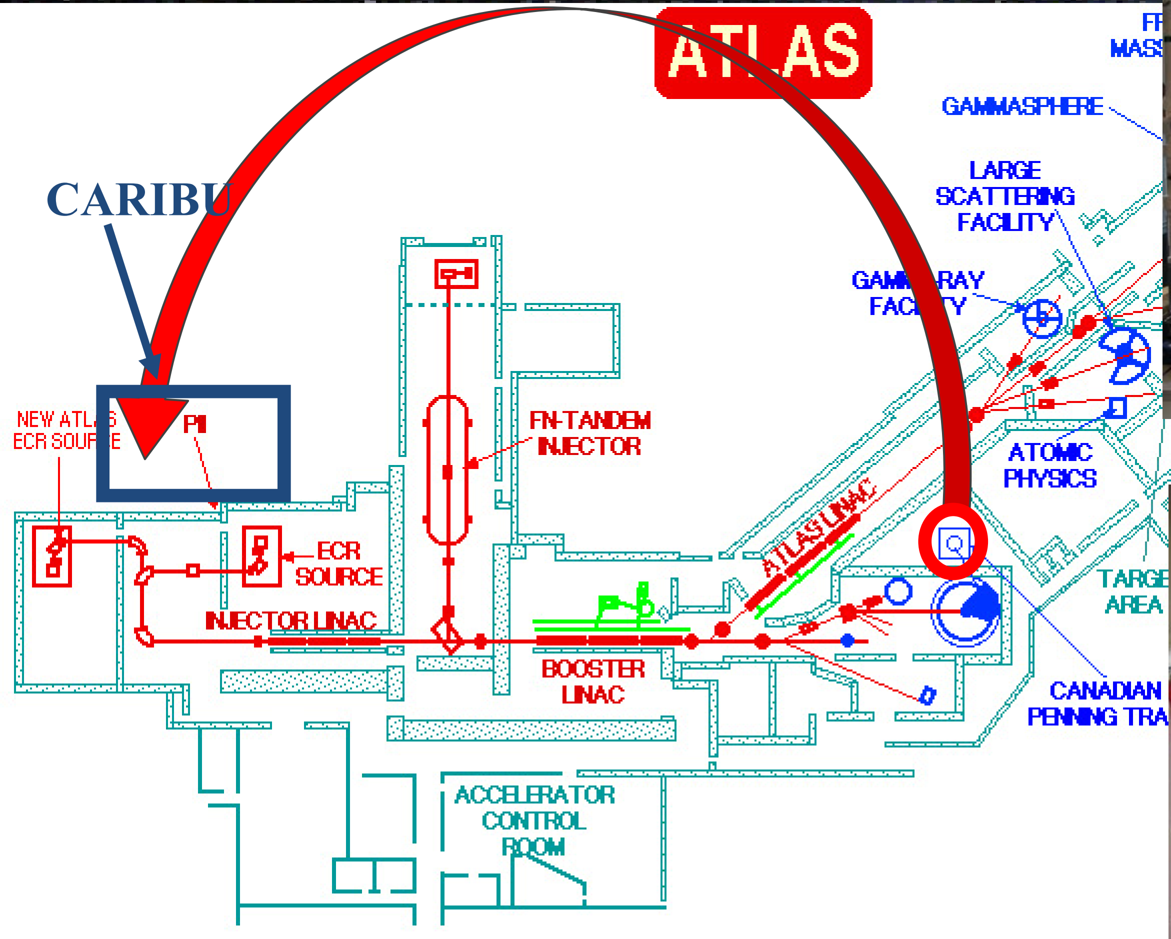
Measurements of neutron-rich nuclides from ^{252}Cf



- CPT has measured ~ 70 neutron-rich nuclides using prototype gas catcher delivery system over past few years
- Trends showing nuclei less bound with neutron excess
    - Changes location of dripline, astrophysical *r*-process path
- Goal: Measure ~ 100 neutron-rich masses with CARIBU which have never been previously measured

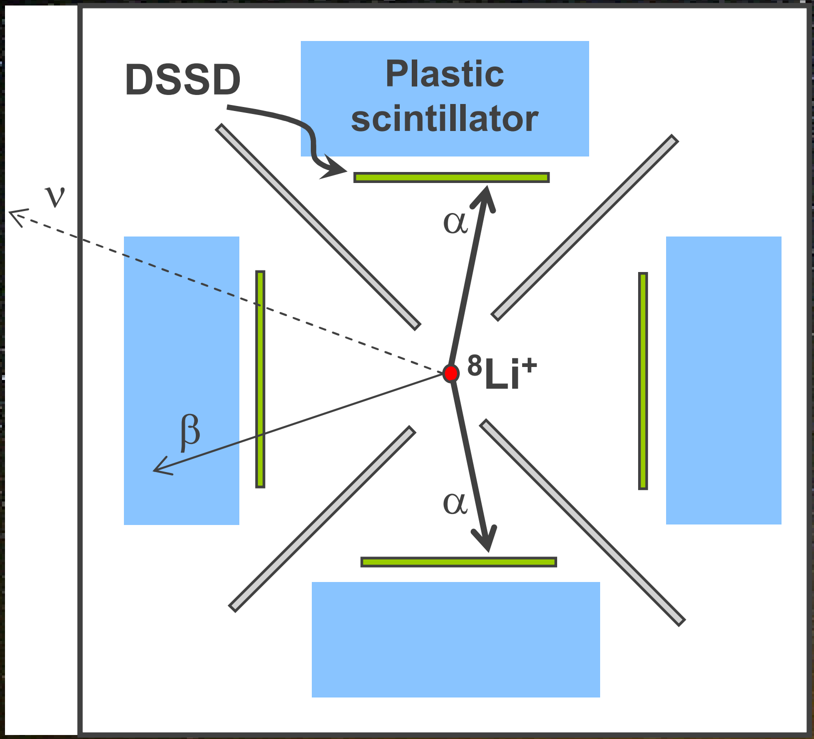


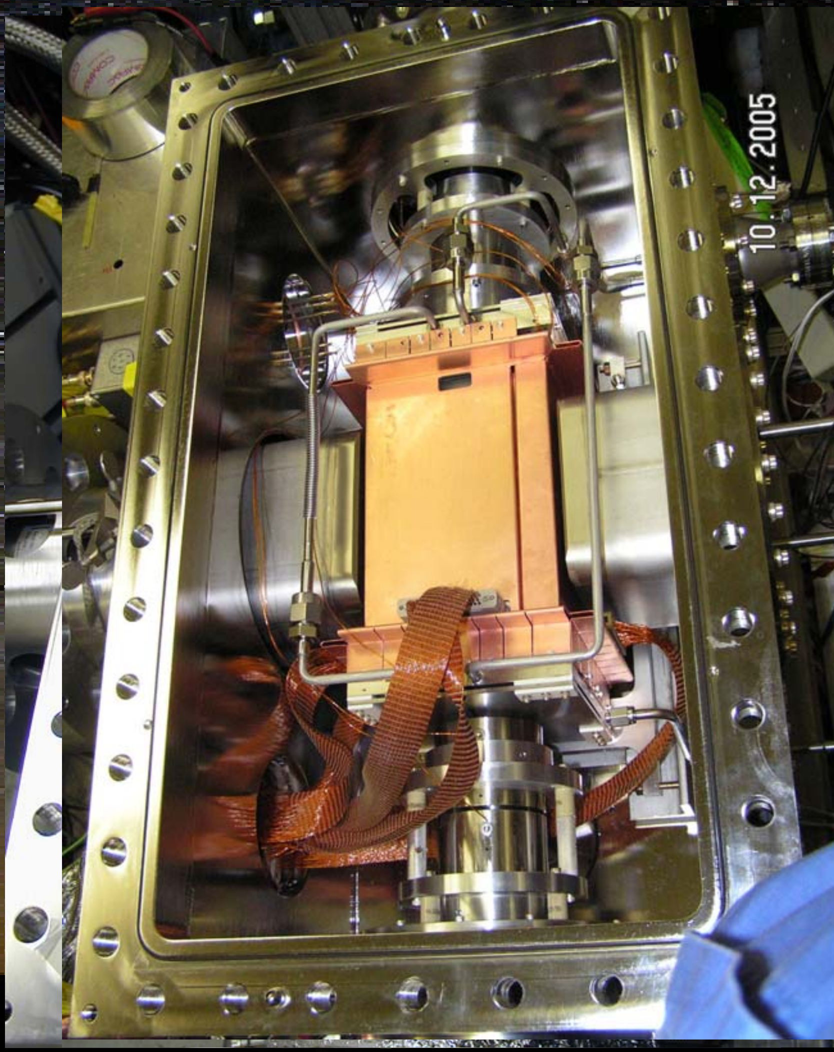
The second move: CPT to CARIBU



The Beta-decay Paul Trap (BPT)

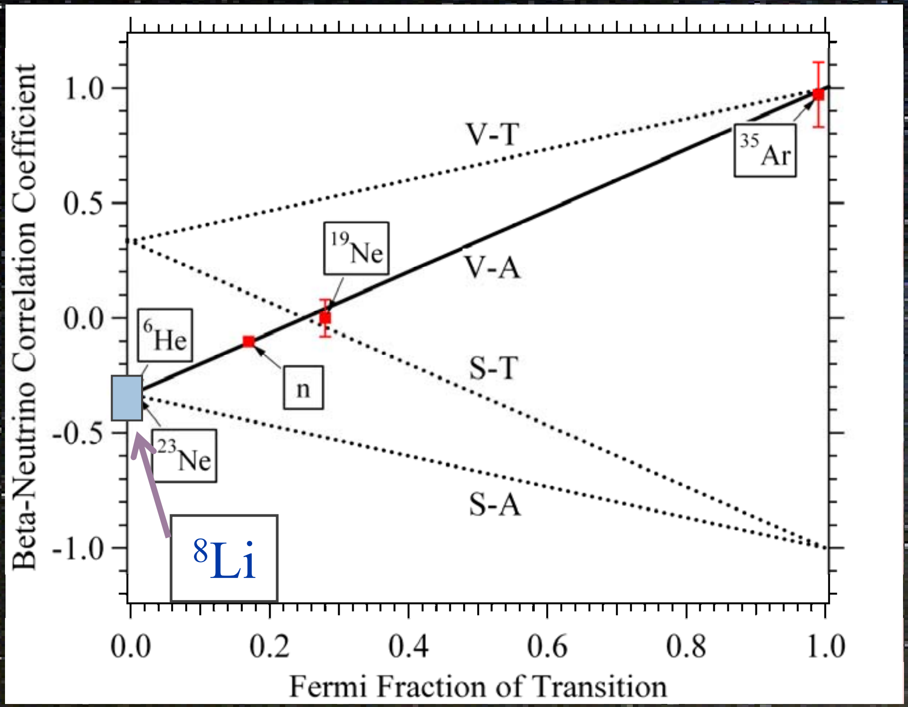
Open geometry trap used to detect decay products from ions at rest





Currently being used to study β – ν correlation in ^8Li decay

Beta-neutrino correlation in ^{8}Li



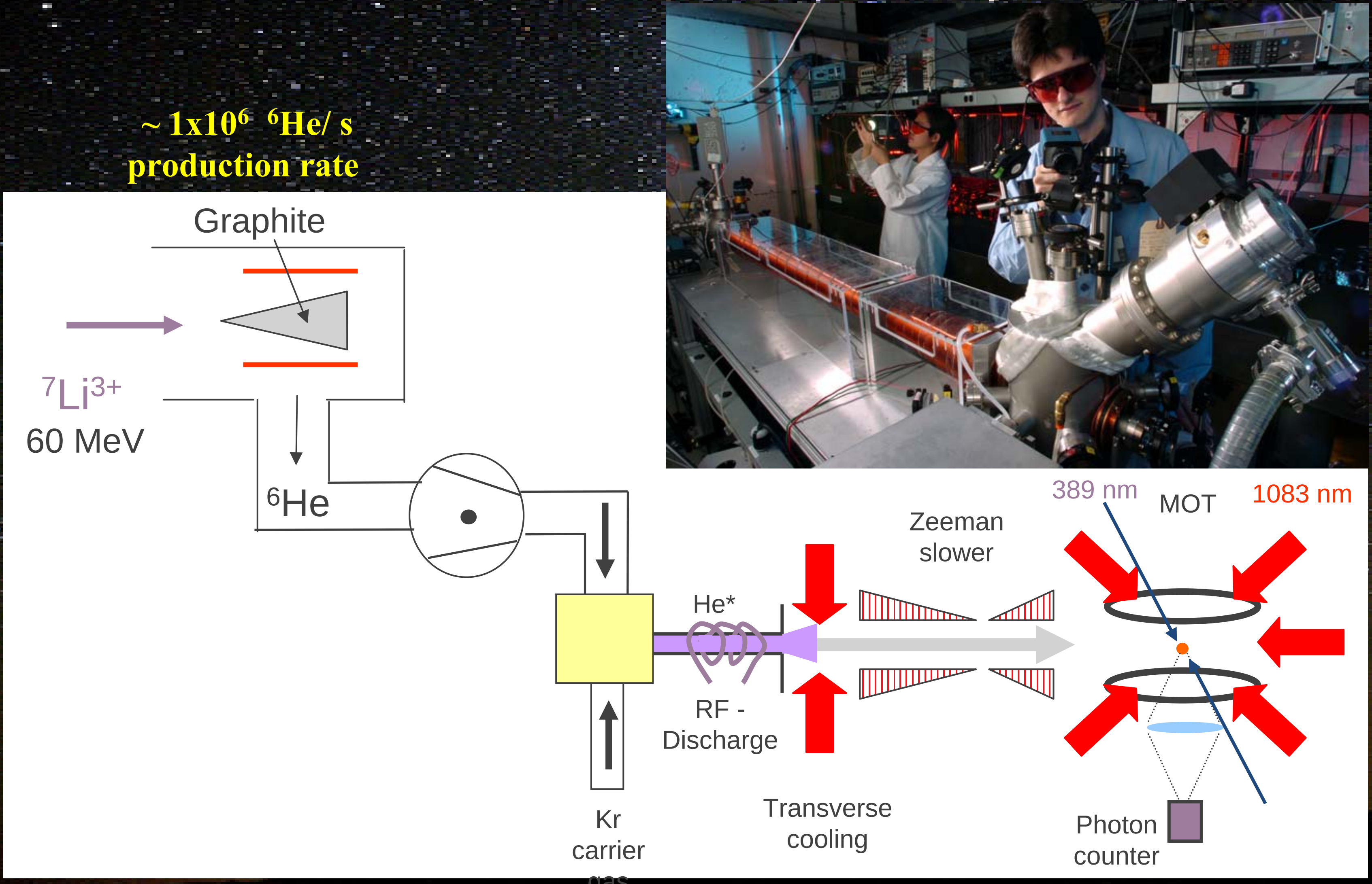
- measurements of the beta-neutrino correlation are conducted to search for scalar or tensor contributions from exotic weak bosons
- neutrino too difficult to detect; correlation must be inferred from nuclear recoil
- with BPT, β momentum/energy measured from plastic scintillator and DSSD
- ^{8}Be momentum/energy determined from alpha-particle breakup

$$^{8}Li \rightarrow {}^{8}Be^{*} + \beta^{-} + \nu$$
$$^{8}Be^{*} \rightarrow \alpha + \alpha$$

$Q \approx$ **13 MeV**
$t_{1/2}$ **= 0.808 sec**

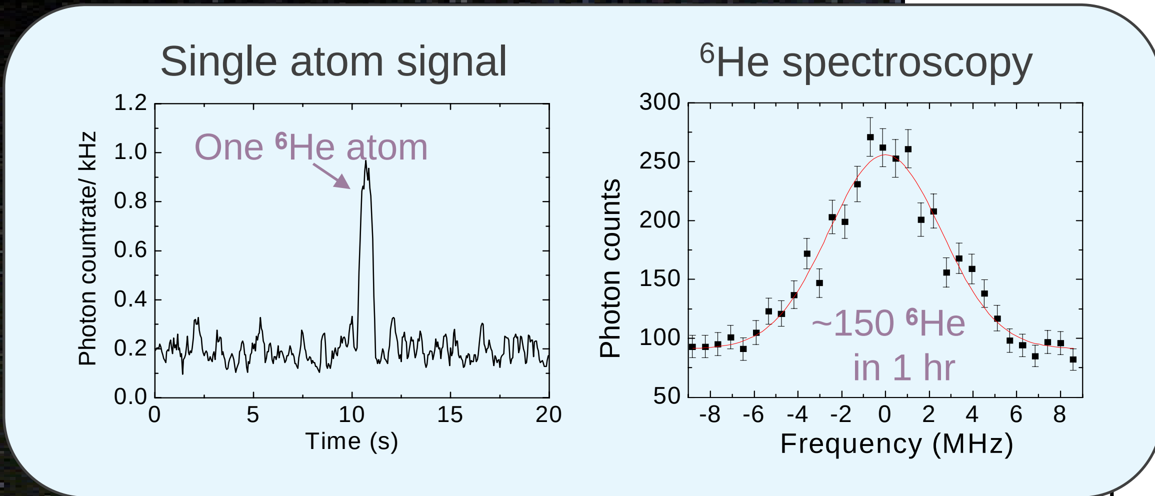
Atom trapping of ^{6}He at ATLAS

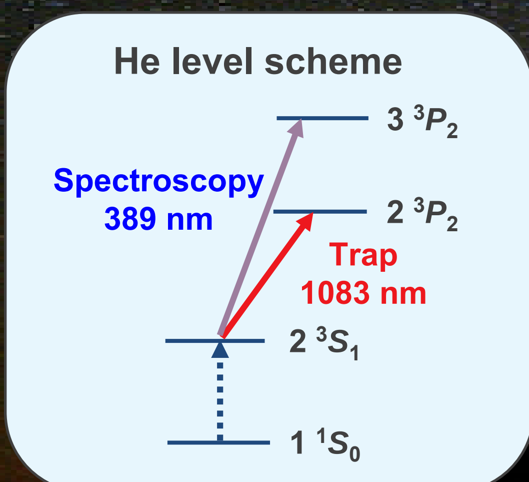
~ 1×10^{6} ^{6}He/ s
production rate

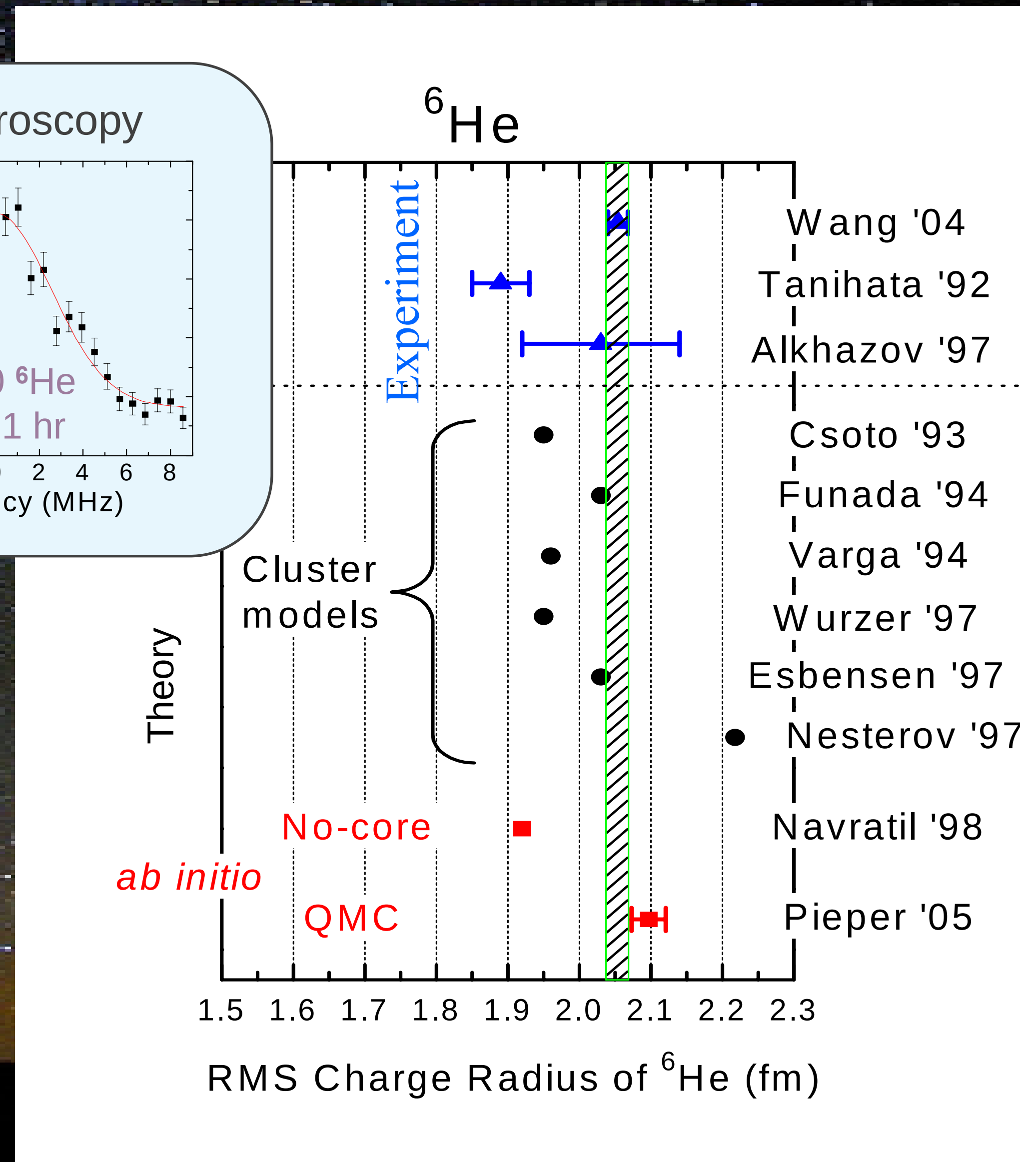


^{6}He
trapping
rate
~ 1 / min

Nuclear charge radius of ^{6}He



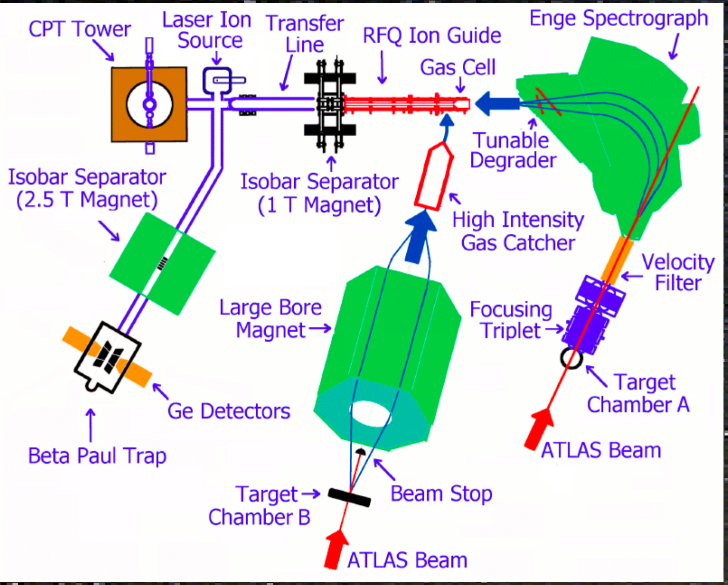




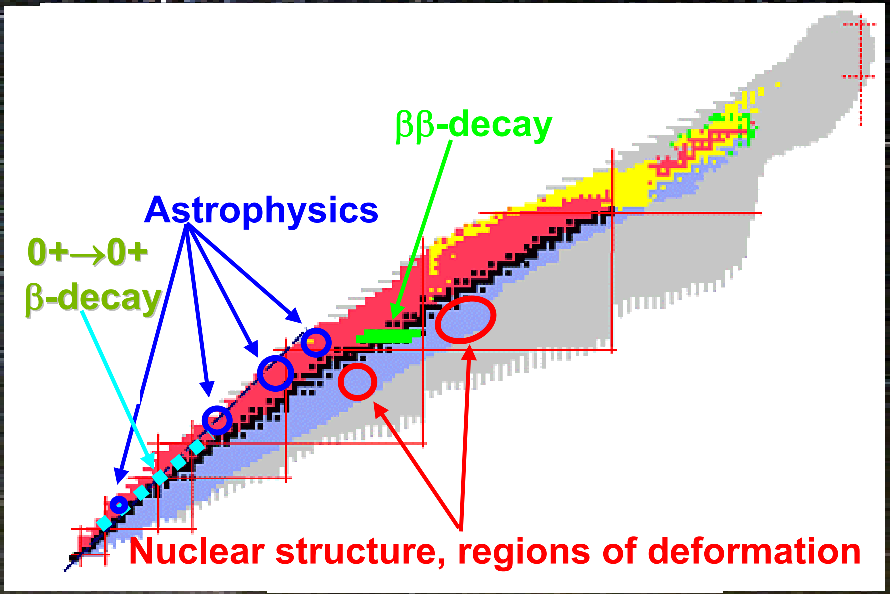
L.-B. Wang *et al.*, Phys. Rev. Lett. **93**, 142501 (2004)

Summary

Lots of development



Lots of interesting results



Past 25 years have been a lot of fun!

Looking forward to the next 25 years!

Cast of characters over the years…

34 undergraduate students

18 graduate students

16 postdocs

22 faculty/staff