Lil' a with laser trapped ^{6}He

Peter Müller

^{6}He Collaboration

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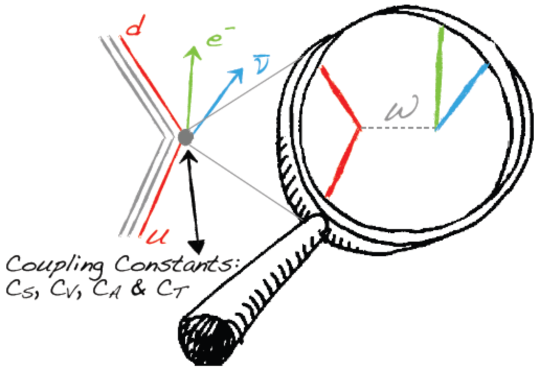
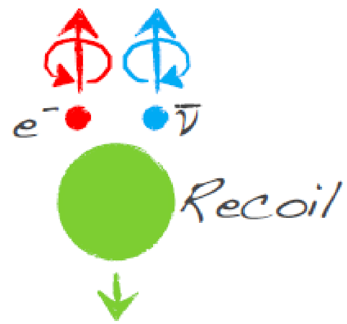
*$ **PM DOE Early Career Research Grant**, DOE CENPA, LPC $*

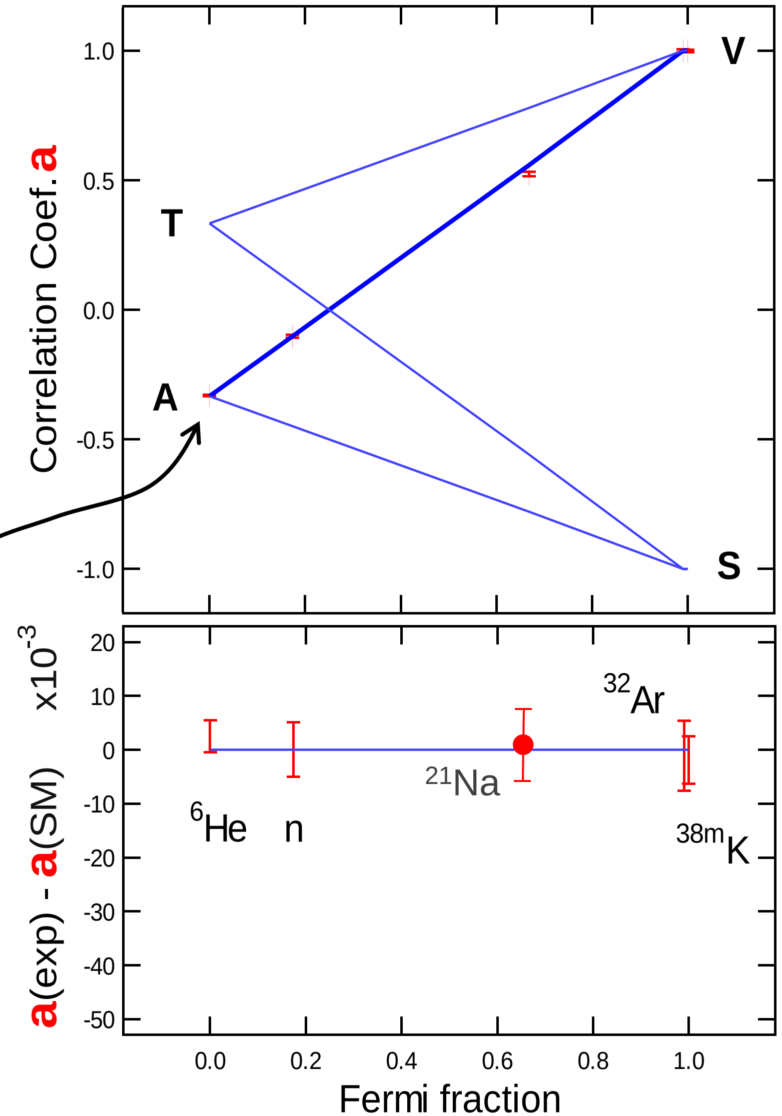
PhD, Postdoc

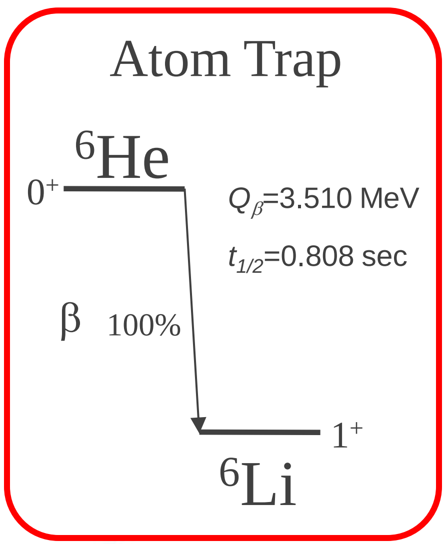
Weak Interaction Studies: *β–ν Angular Correlations*

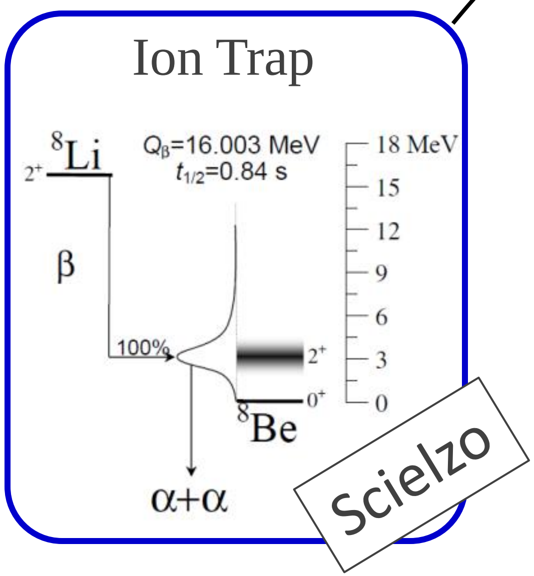




$$N(E_\beta,\theta_{\beta\nu}) \propto 1 + a\frac{p_\beta}{E_\beta}\cos(\theta_{\beta\nu}) + b\frac{m}{E_\beta}$$

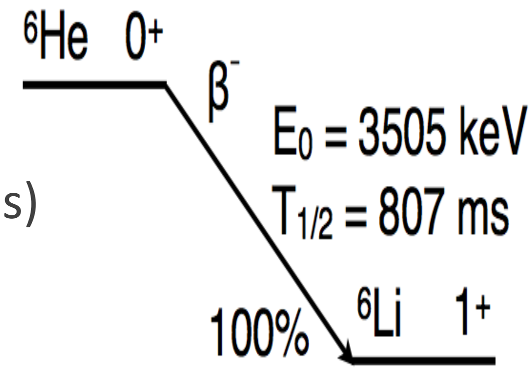






The Case for ^{6}He

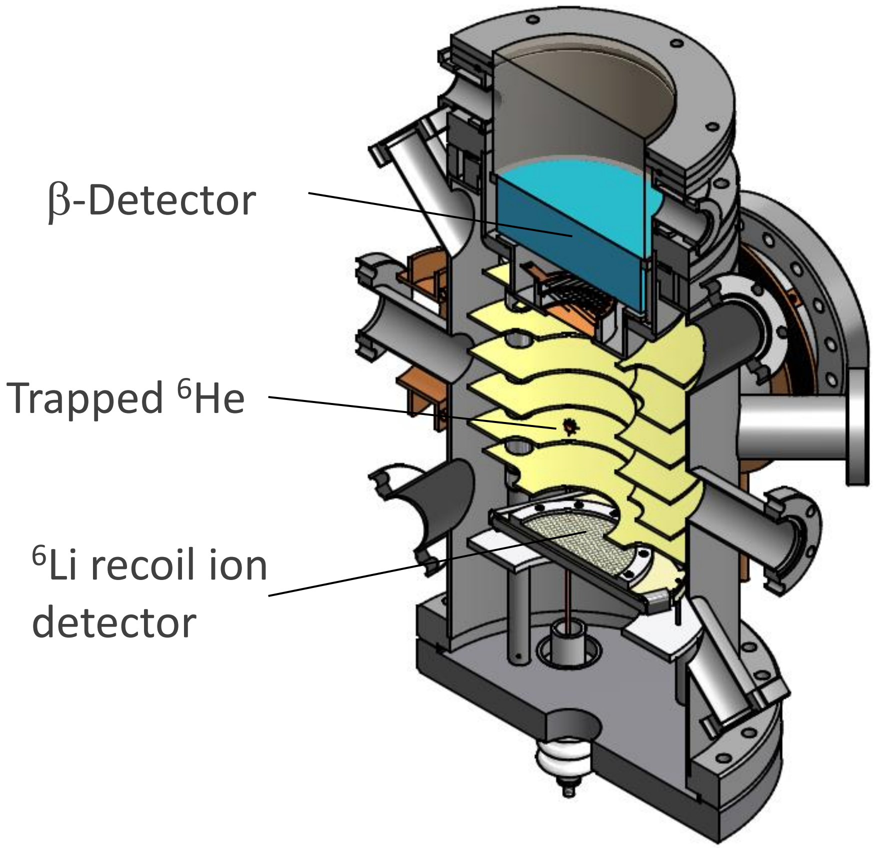
- β^- decay, pure Gamow-Teller decay to g.s. ^{6}Li
- Suitable half-life and Q-value
- Produced and transferred with high yield (noble gas)
- Simple nuclear and atomic structure
- Small branch of ~10^{-6} for ^{6}He → α+d



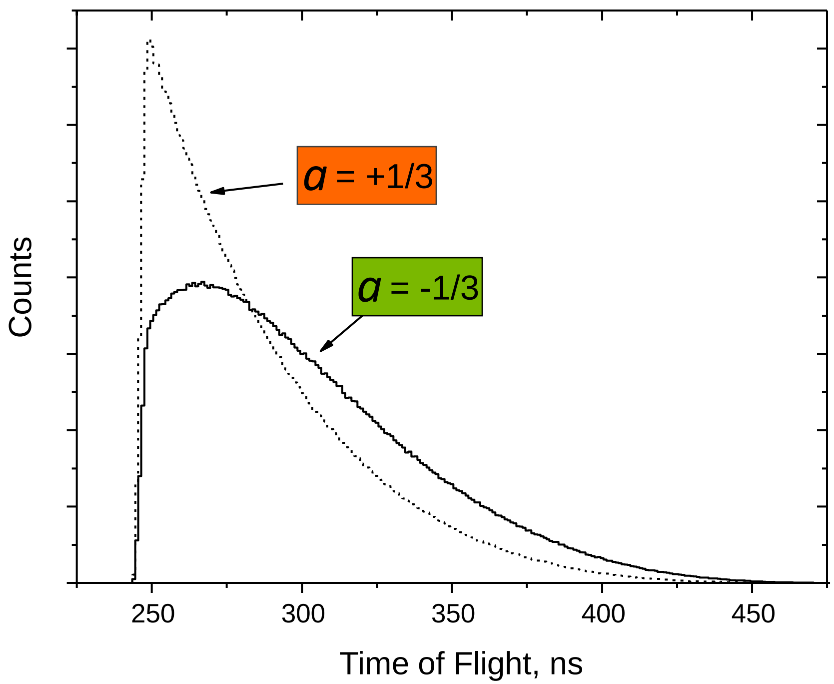
Current experiments searching for tensor cpl. in β decay

Parent	Observable	Group/Lab	Technique
n	b	Nab/SNS	Mag. Spect.
n	b	UCNb/LANL	4π detector
^{6}He	a	LPC+/GANIL	Paul trap
^{6}He	a	ANL+/CENPA	MOT
^{6}He	a	WIS/Soreq	Electrostatic
^{8}Li	$g \approx 3a_{GT}$	ANL	Paul trap

Beta-Decay Study with Laser Trapped ^{6}He



Recoil time-of-flight spectrum (MC simulation)



Atom trap properties

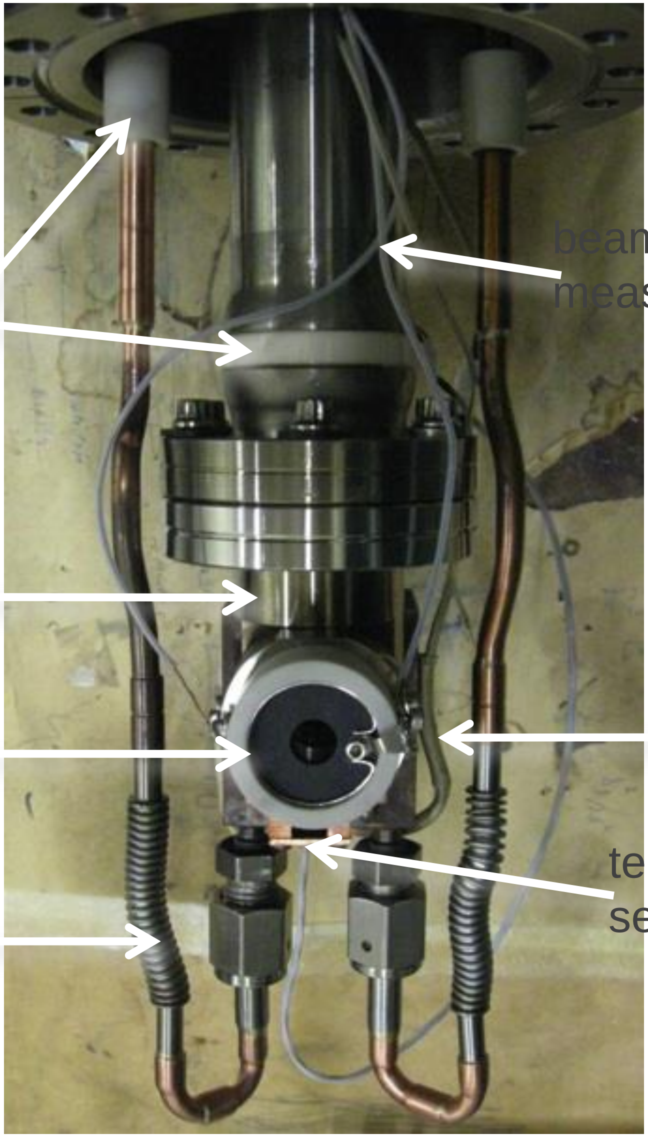
- Highly selective capture
- No RF fields or space charge
- Low temperature sample (<mK)
- Tight spatial confinement (< 100μm)

- ~5x10^9 ^{6}He/s production yield
- trapping rate ~1x10^3 ^{6}He/s
- ~0.1% statistics in ~8 weeks beam time

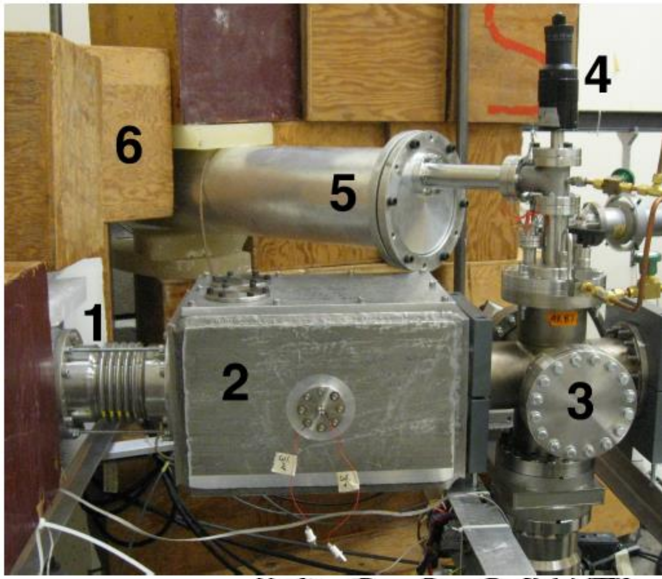
Production of ^{6}He @ CENPA

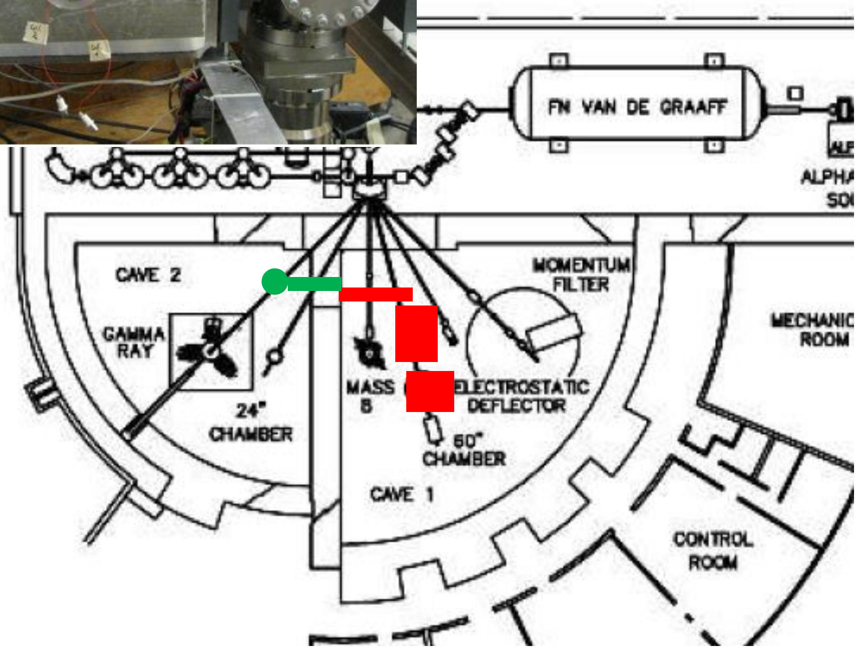
David Zumwalt

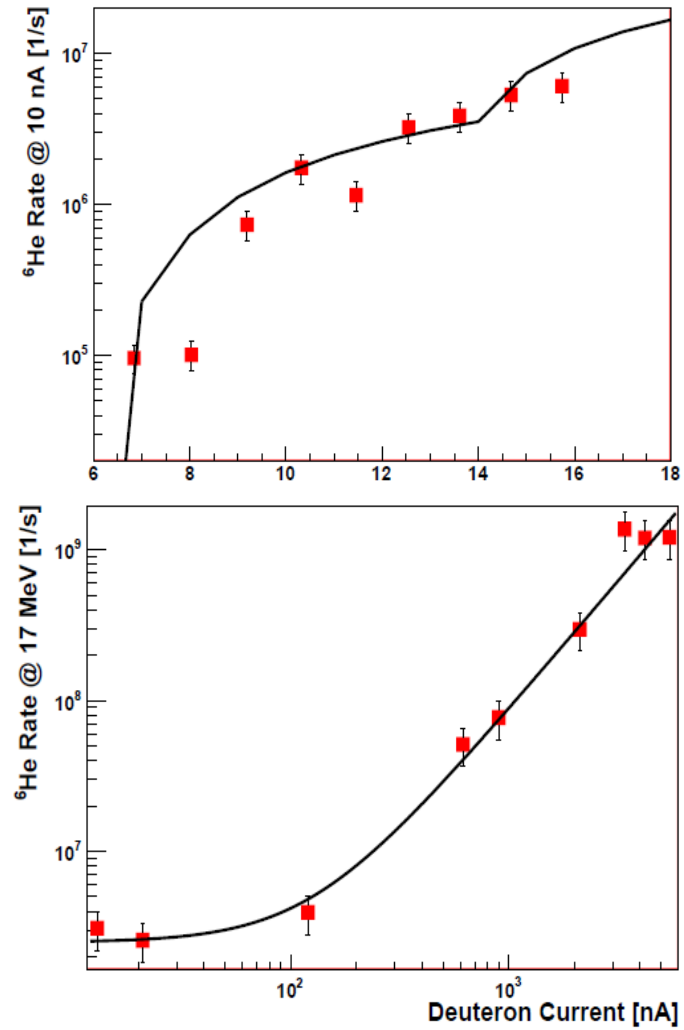
- ^{6}He produced using the ^{7}Li(d,^{3}He)^{6}He reaction on molten lithium
- Deuteron currents up to 10 µA @ 18 MeV using tandem Van de Graaff accelerator at CENPA/UW
- ^{6}He extracted to vacuum and transported to low background environment



^{6}He Production and Transfer

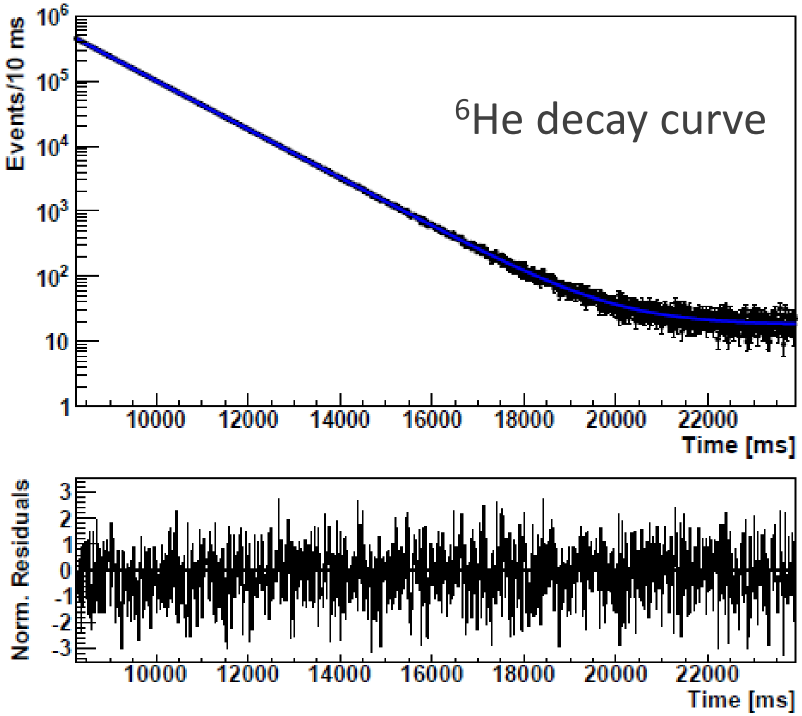


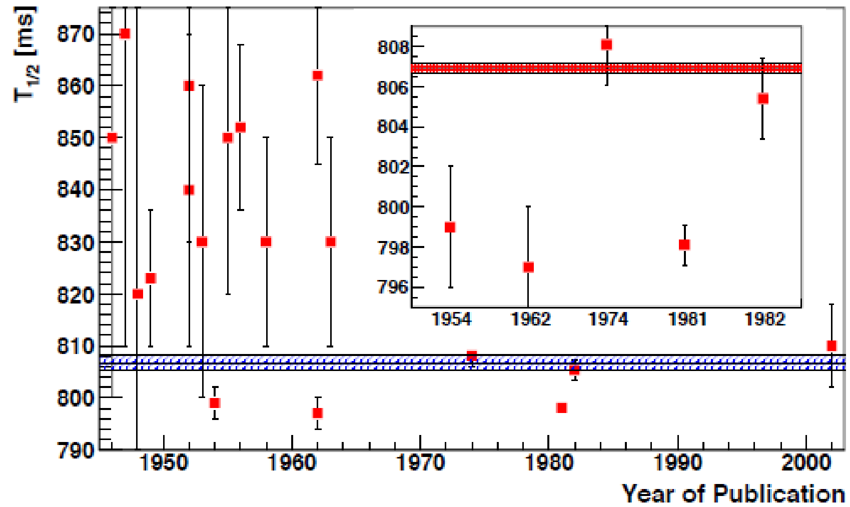




A. Knecht *et al.*, NIM A **660**, 43 (2011)

Precision ^{6}He Lifetime





^{6}He half-life

$$806.89 \pm 0.11_{\mathrm{stat}} \,{}^{+0.23}_{-0.19}\,\mathrm{syst}$$

ft-value

$$804.65(57)\ \mathrm{s}$$

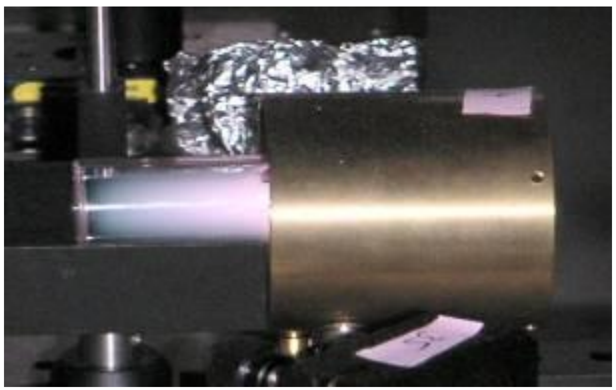
Source	Shift [ms]	Uncertainty [ms]
Deadtime correction	-	0.037
^{6}He Diffusion	0	$< {}^{+0.12/0.22}_{-0}$
Gain shift	-0.19	0.19
^{8}Li contamination	0	$< {}^{+0}_{-0.007}$
Background	0.046	0.004
Data correction	0	< 0.01
Deadtime drift	0	0.009
Afterpulsing	0	< 0.003
Clock accuracy	0.006	0.011
Total	-0.14	${}^{+0.23}_{-0.19}$ / ${}^{+0.29}_{-0.19}$

Compare with *ab-initio* calculations of $|M_{GT}|$ to obtain g_A in nuclear medium

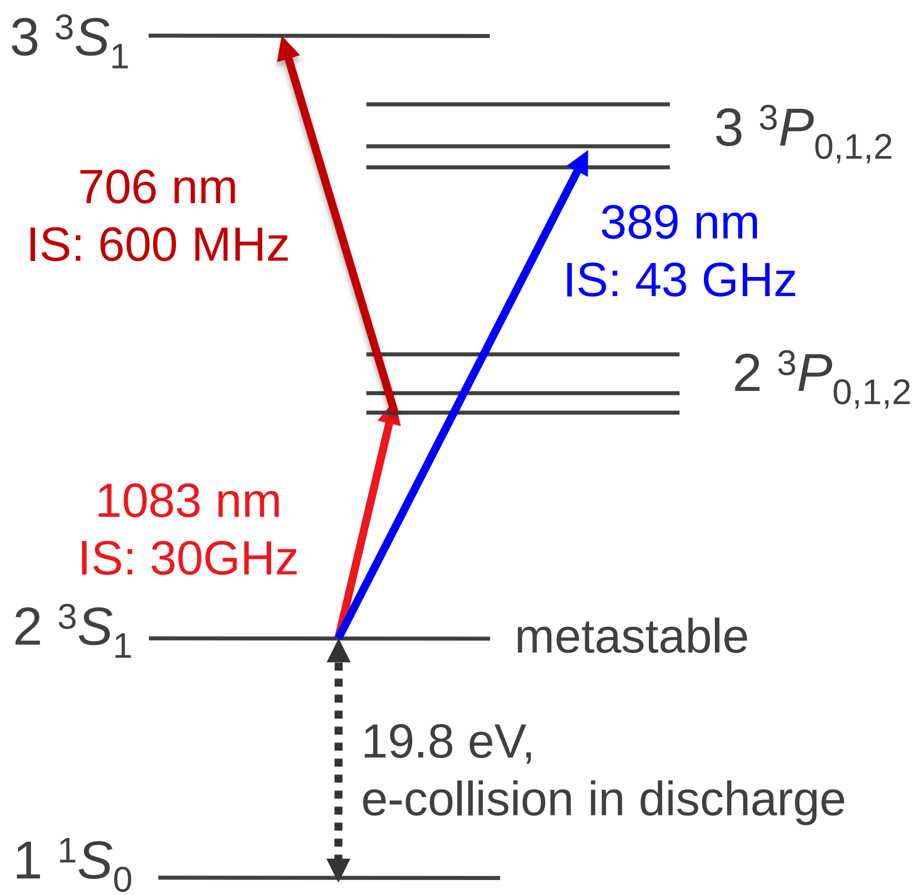
A. Knecht *et al.*, PRL **108**, 122502 (2012)
A. Knecht *et al.*, PRC **86**, 035506 (2012)

Atomic Energy Levels of Helium

He discharge

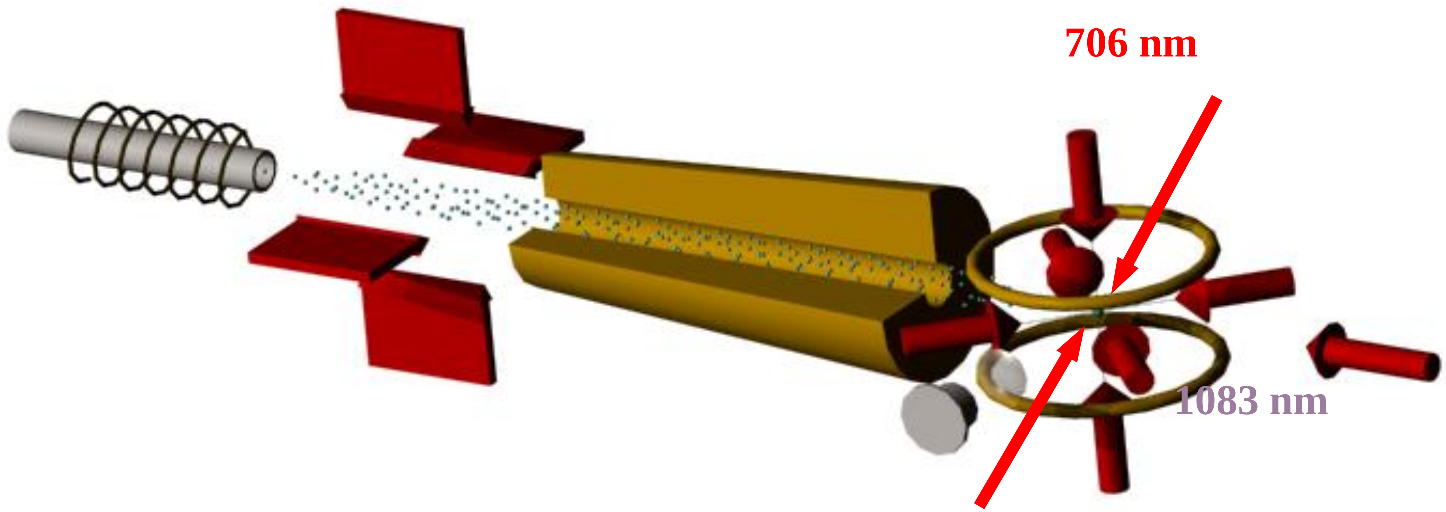


He energy level diagram



Atom Trapping of ^{6}He

Atom Trap Setup

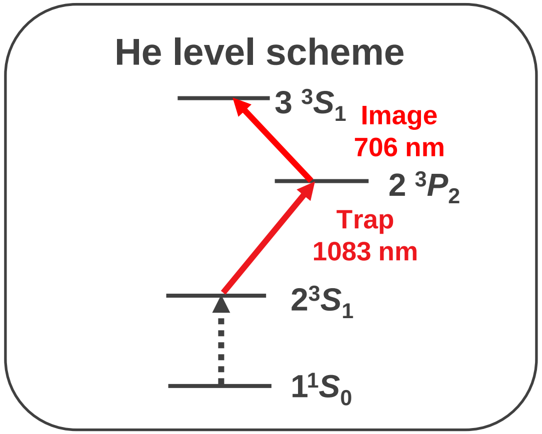


^{6}He Rates

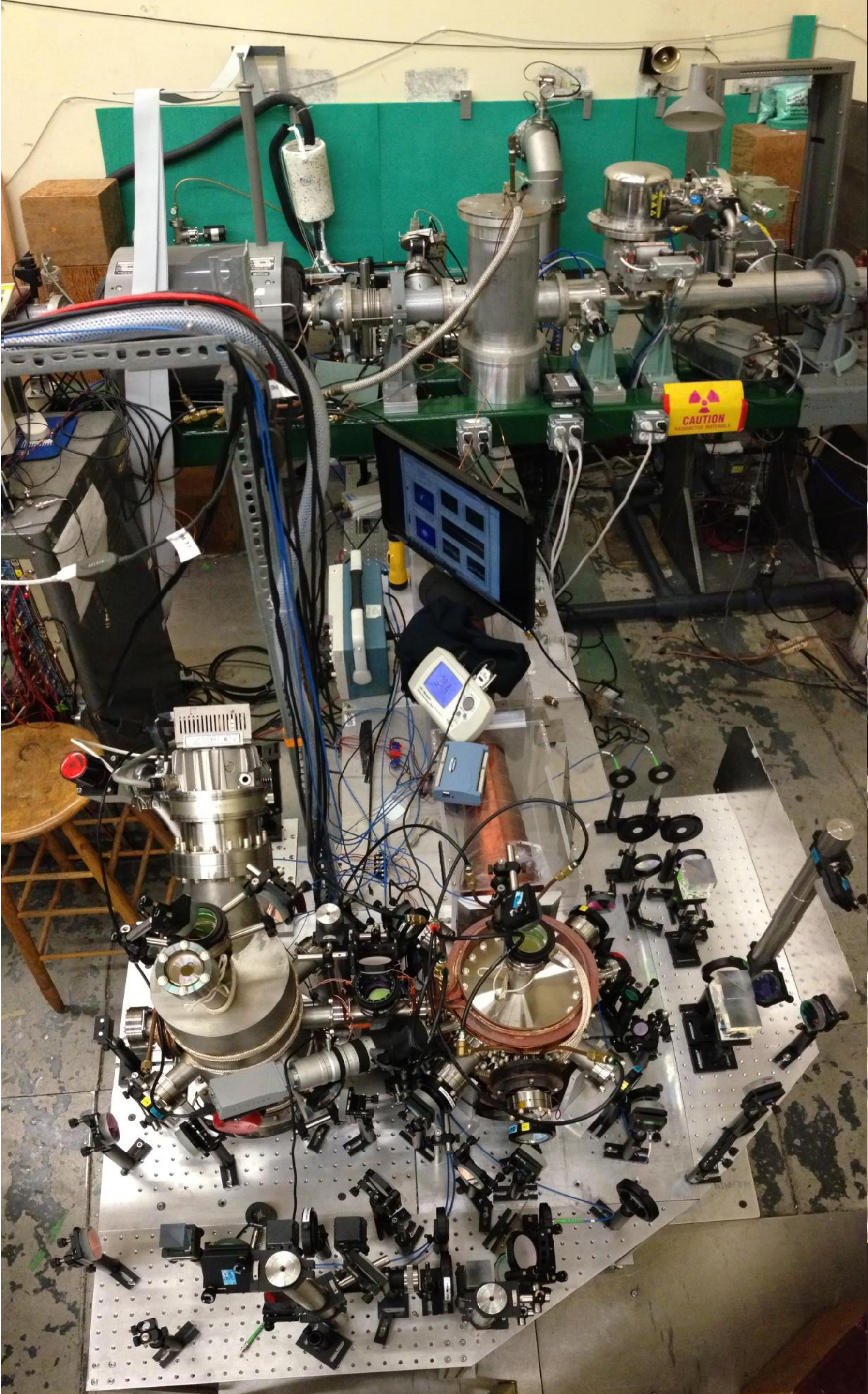
@ source 5×10^9 s^{-1}

Capt. efficiency = 2×10^{-7}

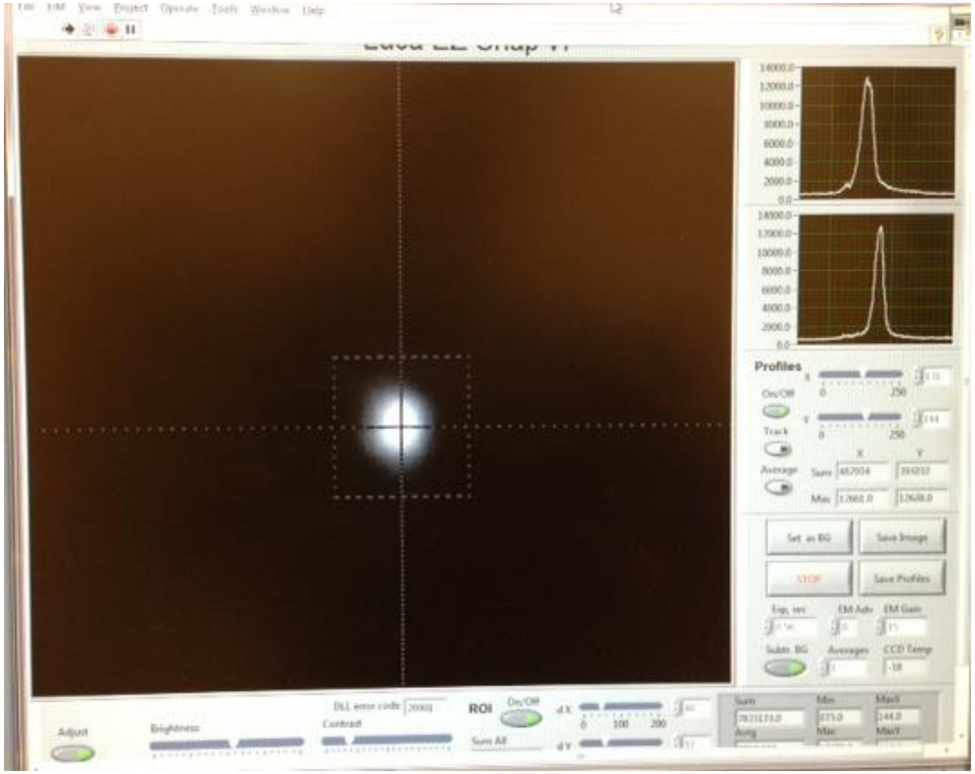
@ trap 1000 s^{-1}



Helium MOT Setup @ CENPA



MOT Imaging

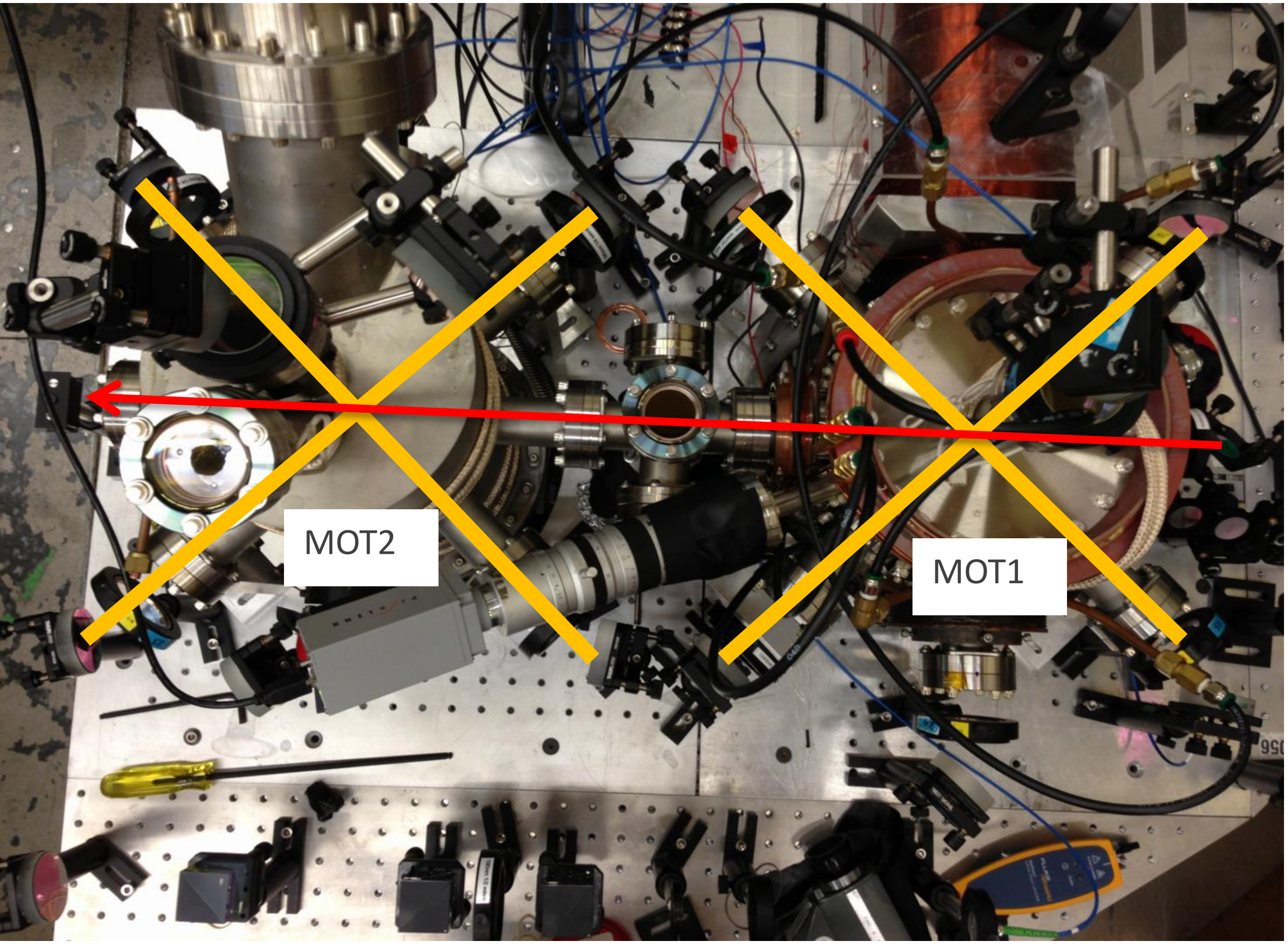


- On-line MOT imaging
- 2 cameras for x/y/z control
- Trap diameter

  < 200 μm
- Trap stability

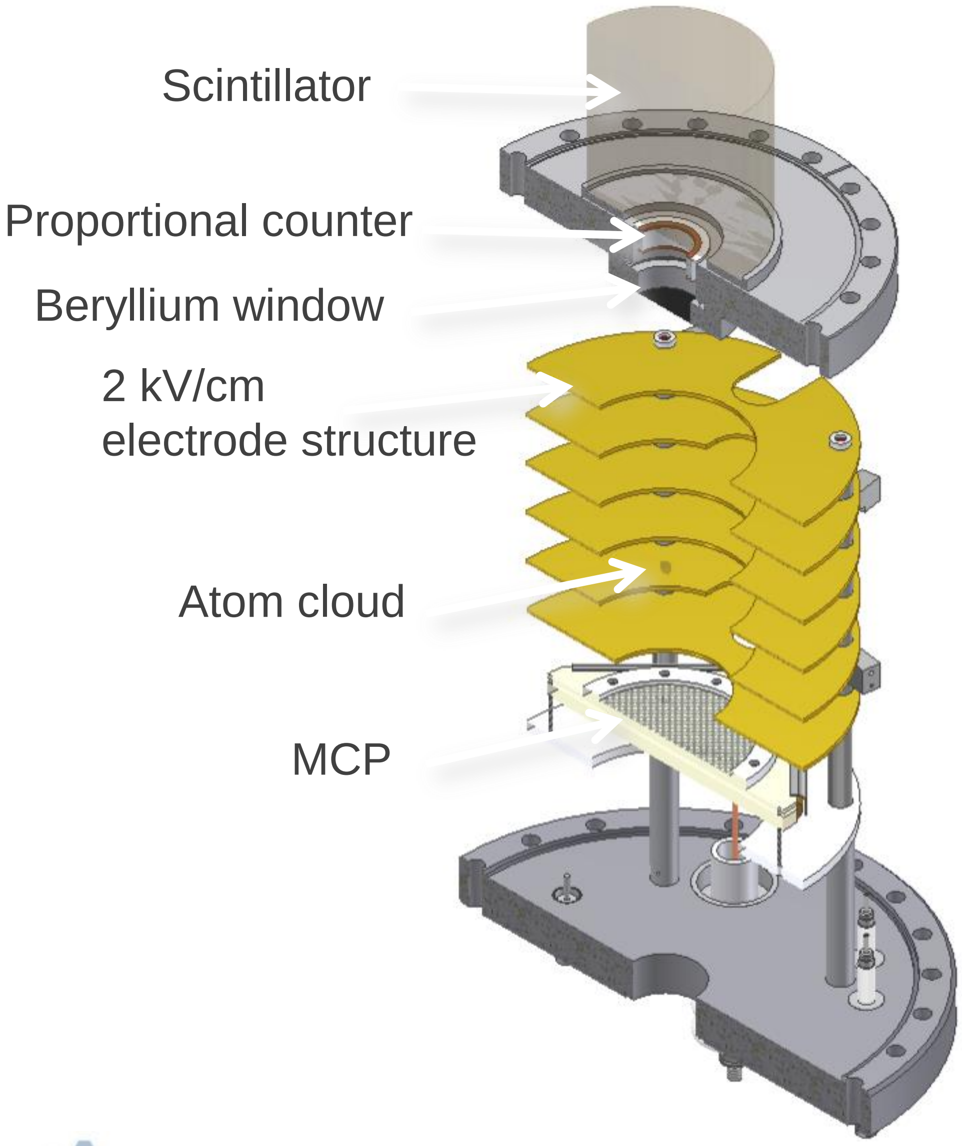
  < 10 μm *

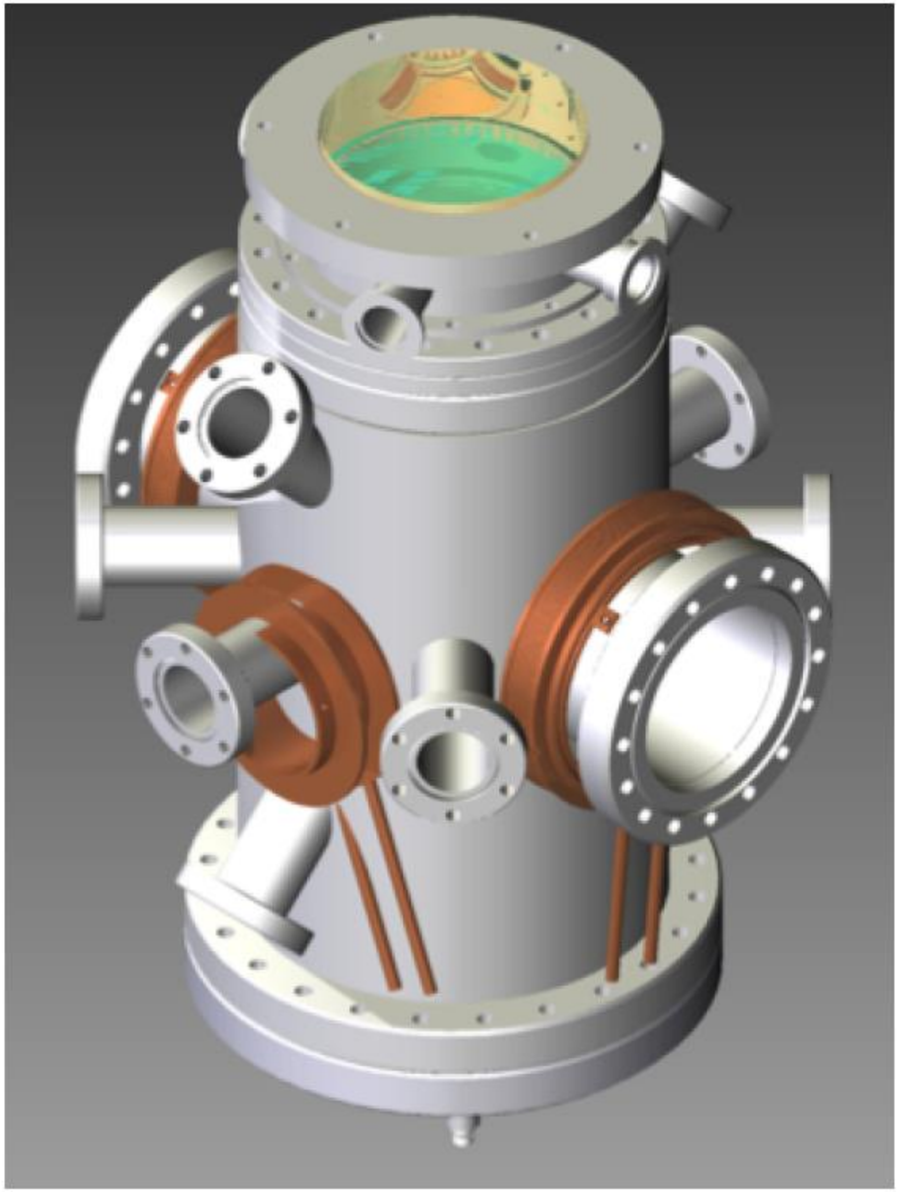
MOT to MOT transfer



- Reduce background from un-trapped ^{6}He through diff. pumping
- Separate MOT functions capture vs. detection
- Optical "push" beam
- Transverse cooling
- ~40% transfer in 15 ms

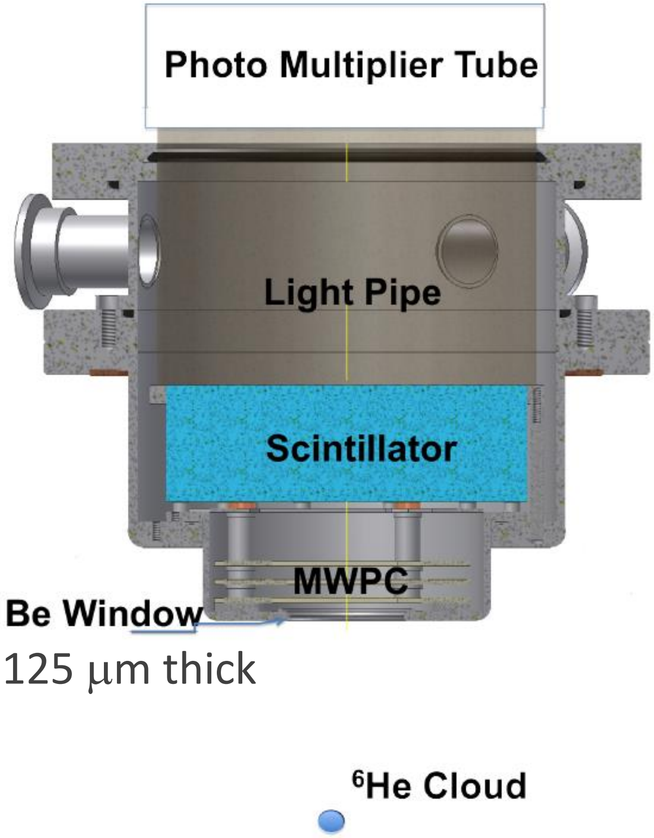
Beta and Recoil Ion Detectors

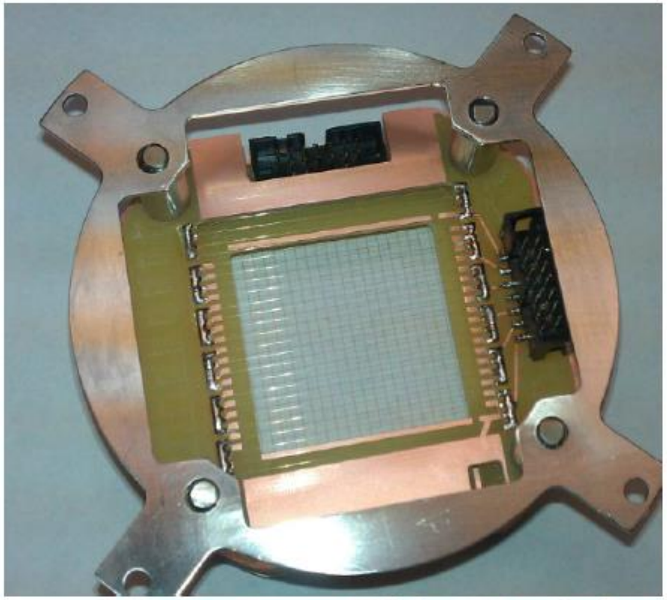


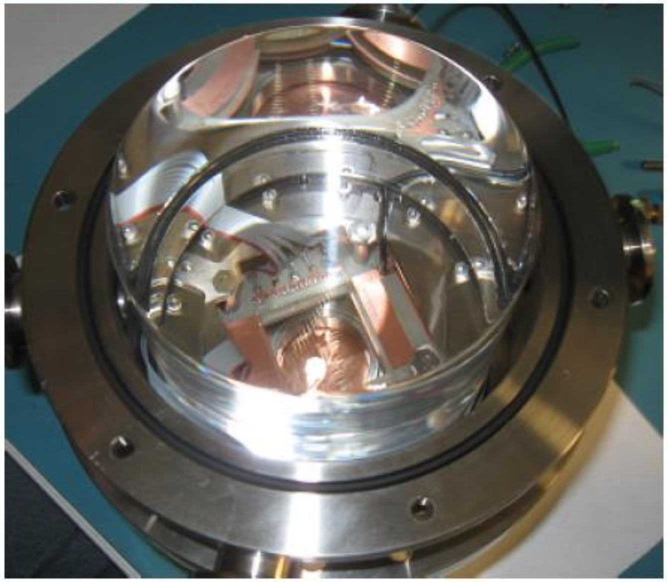


Beta Detector System

Ran Hong

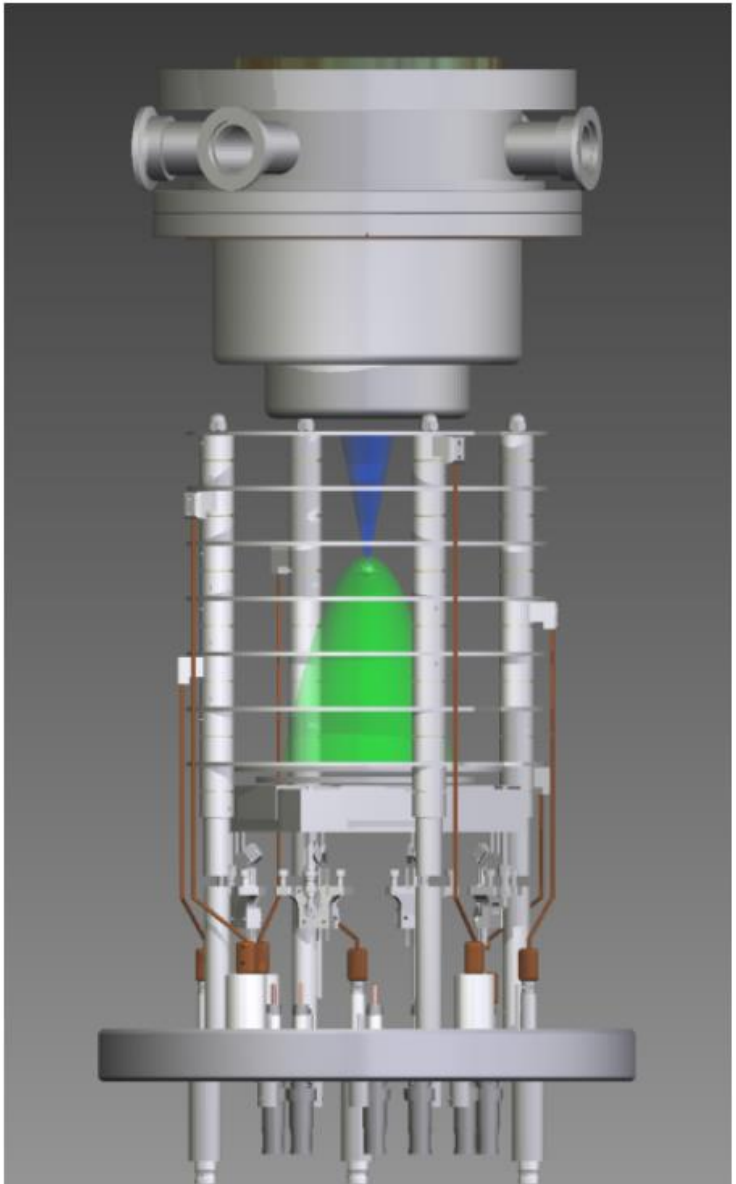




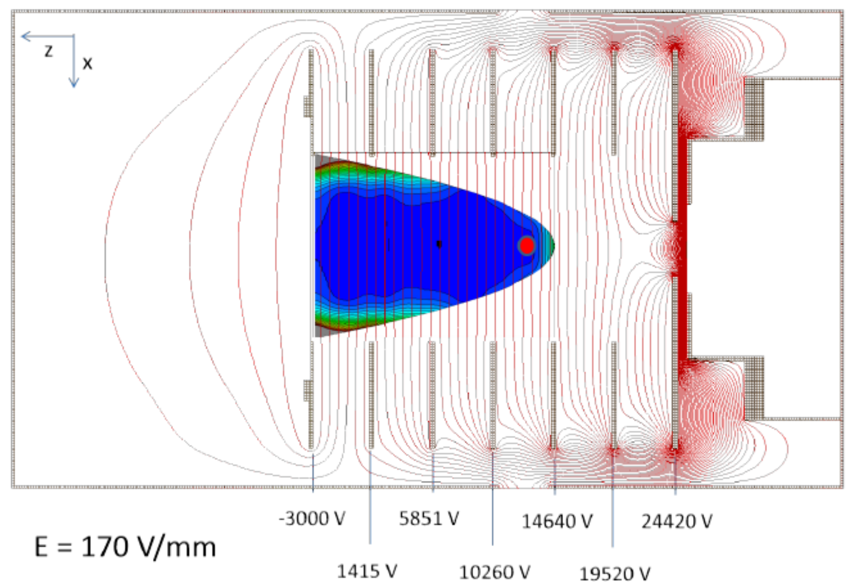


Electrode System

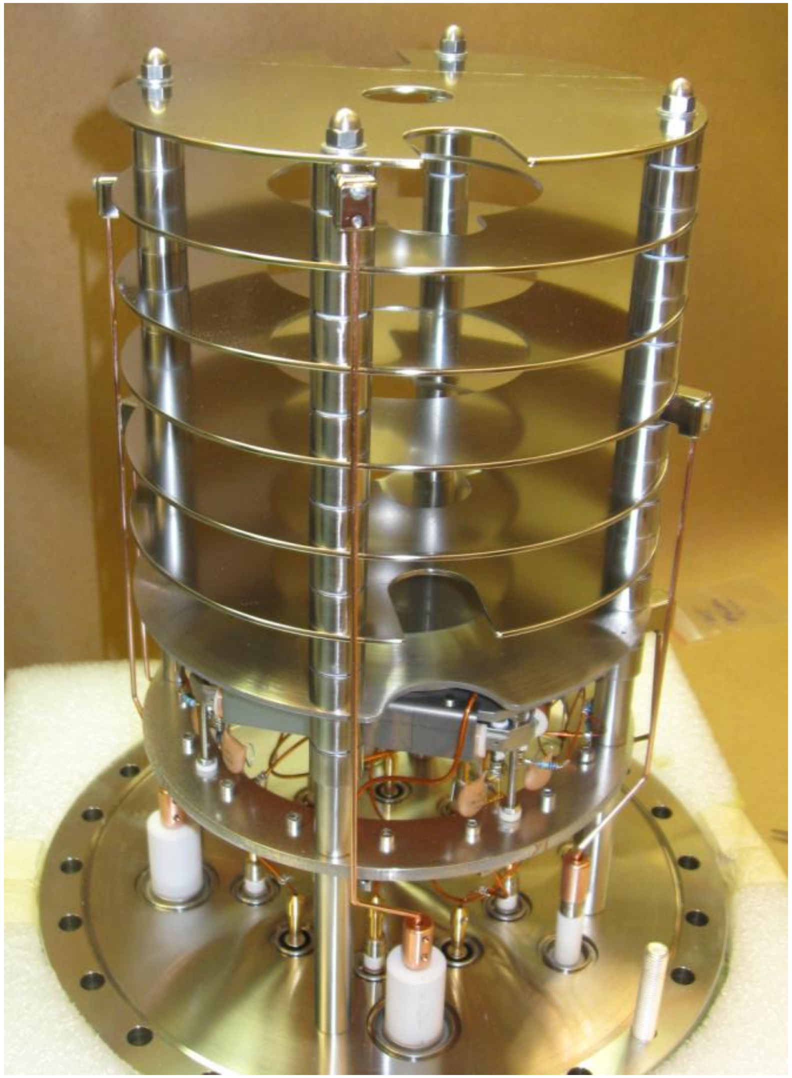
Yelena Bagdasarova

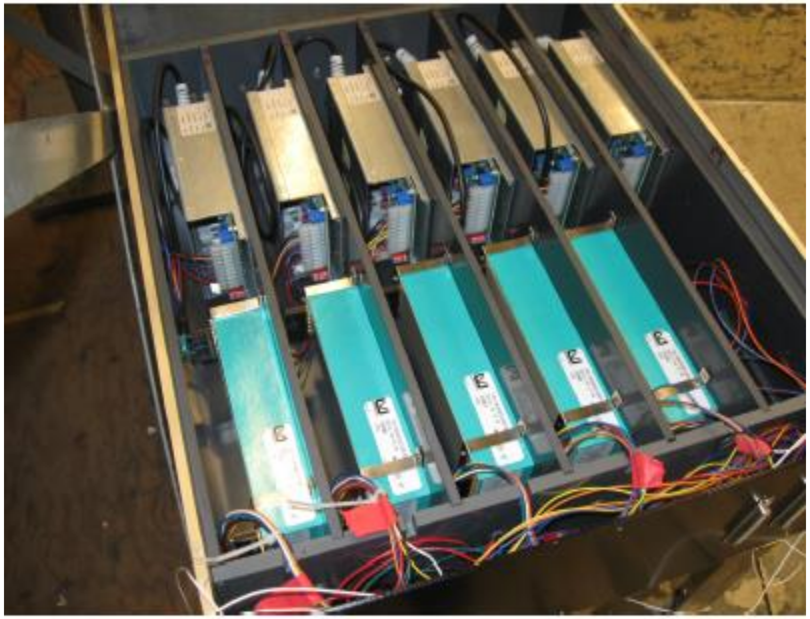


- Deflect recoil ions (1.4 keV max.) onto 8 cm dia. MCP
- Variable, uniform electric field with 0.05% relative stability and accuracy
- 1.5 – 2.0 kV/cm -> 80 – 99% coll. eff.



Electrode, MCP and HV Supply

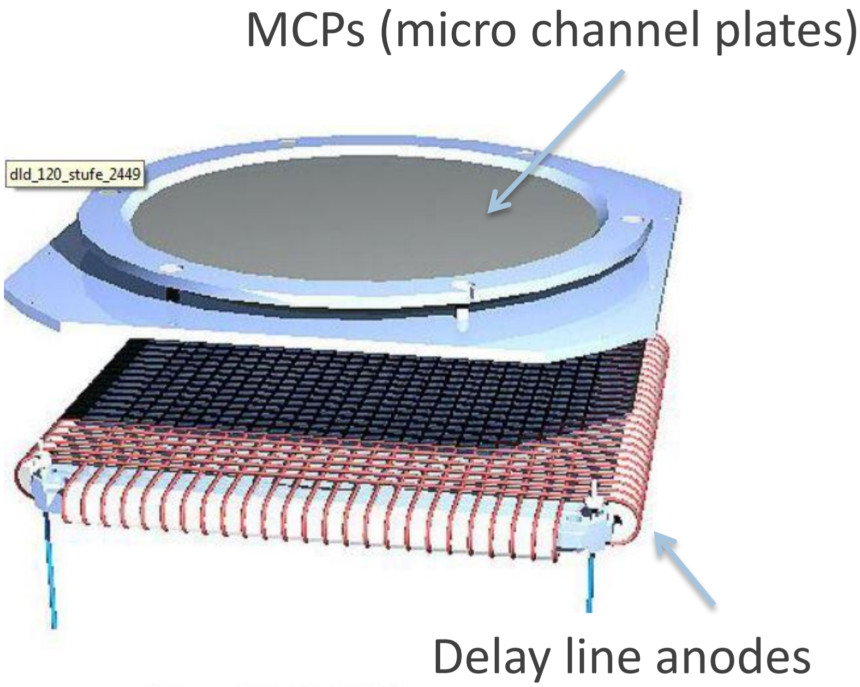




- Stacked HV supplies
- Control each electrode separately
- Enable variable field geometries

Recoil Ion Detector

Xavier Flechard, Etienne Liennard

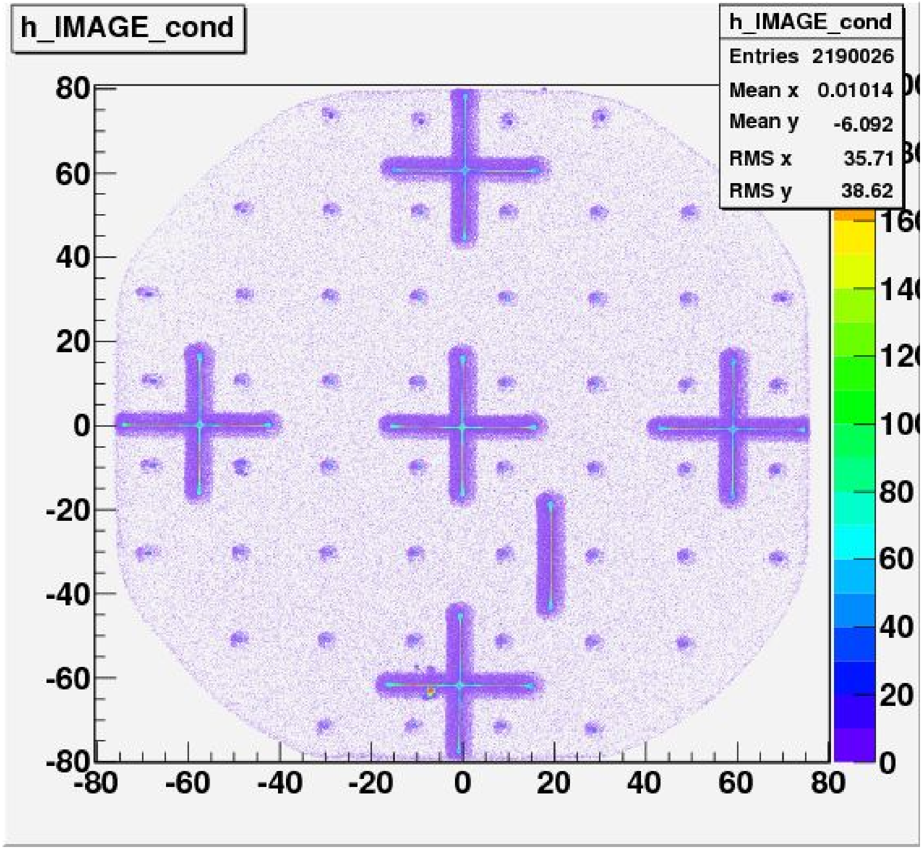


Digital readout of signals, FPGA processing
(LPC FASTER DAQ system)

On test flange with calibration mask

Recoil Ion Detector

Position calibration
with mask, Na^+ beam

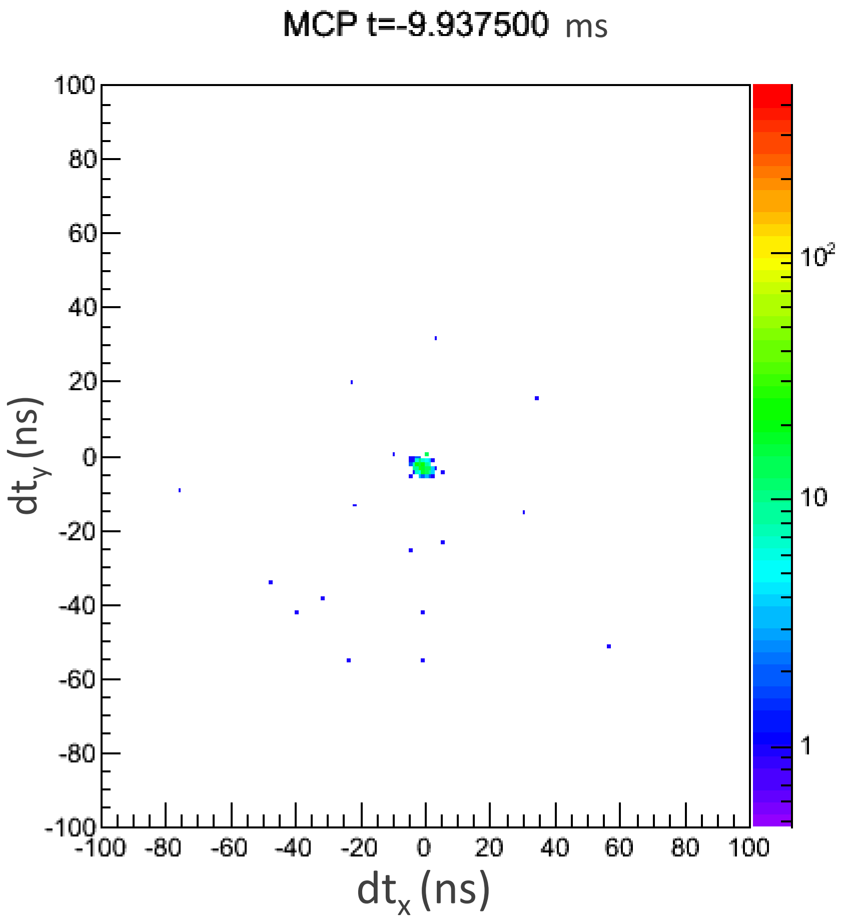


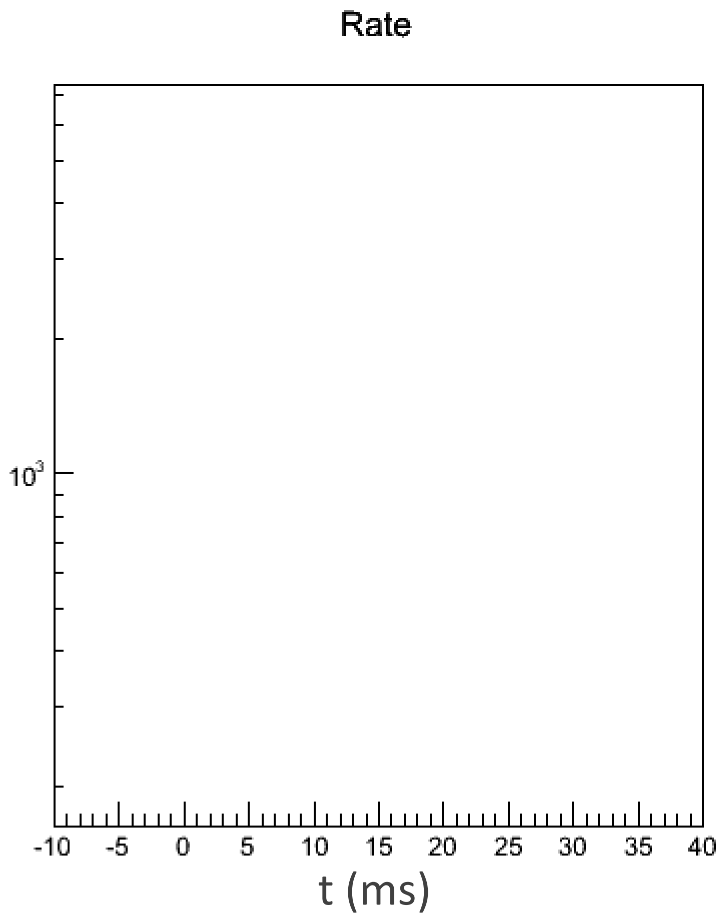
- DAQ system for beta and recoil detectors works
- MCP efficiency 52 % (70%)
- MCP uniformity 95.5 – 99.8%
- Timing resolution ~100 ps
- Position resolution ~100 μm
- Position reconstruction ~ ***1 mm***

Need to do

- In situ calibration with ^6He BG
- Timing calibration with ^4He Photo-ions (337 nm pulsed N_2 laser)

^{4}He trap diagnostics with MCP

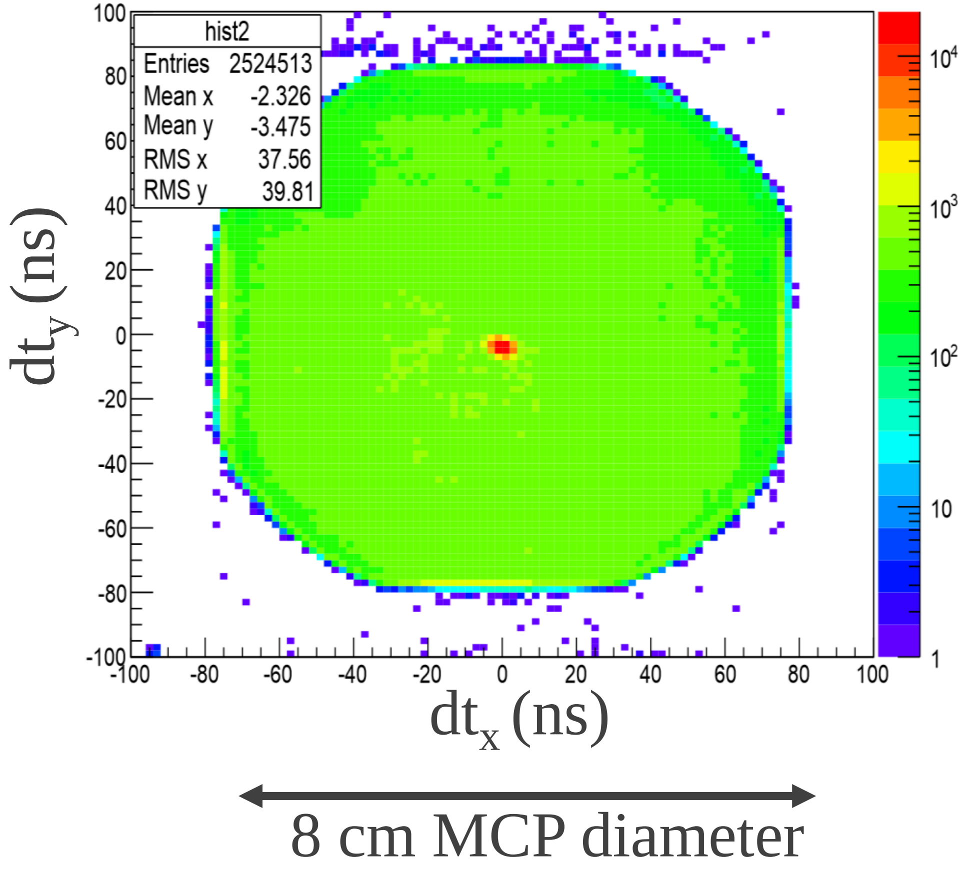




He* + X -> He + X^+ + e^-

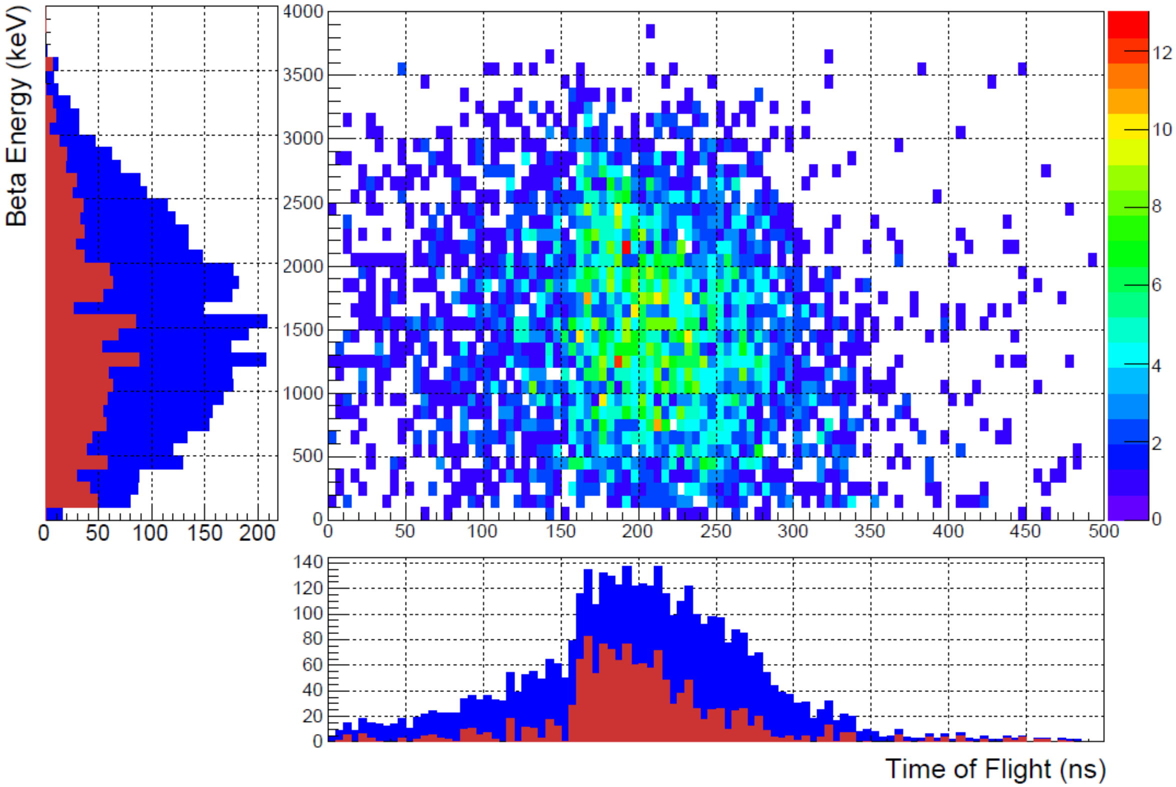
He* + He* -> He + He^+ + e^-

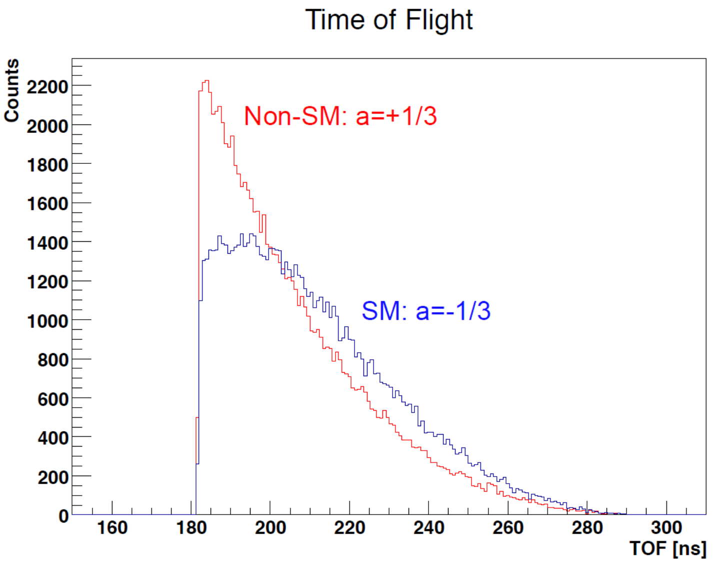
MCP Image of Trapped ^{6}He



Results: First coincidences

- 75 ^{6}He/s in MOT 2
- ~0.15 Hz trapped ^{6}He
- ~0.15 Hz background (untrapped ^{6}He)





Systematic Uncertainties

- Detailed MC simulation
- Geant4 for beta tracking and detector response
- COMSOL for E-field calculation, recoil ion tracking

	$\partial a/\partial x$	$(\partial a/\partial x)/a$	1% goal	0.1% goal	notes
Z-Position	<-3e-4 /0.1mm	<0.1%/0.1mm	δz = 1 mm	δt = 100 μm	
Timing (res)	-7e-4/1ns	0.2%/1ns	$\delta\sigma$ = 5.0 ns	$\delta\sigma$ = 500 ps	
MCP: radius cut	-0.02 /mm	6.5%/mm	δr = 150 μm	δr = 15 μm	r=37 mm βThresh = 200 keV
MCP: position	1.5e-3 / mm	0.3%/mm	δpos = 3 mm	δpos = 0.3 mm	offset in x-y plane
Beta threshold	2e-4/ 10 keV	0.065%/ 10 keV	δTh = 150 keV	δTh = 15 keV	r=37 mm βThresh = 200 keV
E-Field Stability	1e-4/V	0.03%/V	δV = 30 V	δV = 3 V	
Untrapped Decays	-0.003 / 1% of background	-1% / 1% of background			

Outlook

Short term

- Install recirculating discharge source and guide beam
- Aim for initial ~1% statistics (300k coincidences)
  - 1 Hz coincidence rate, ~ 1 week
- Compare with numerical simulations

Medium term

- Upgrade trap / detector
  - Improve discharge, recirculation, trap and transfer efficiency
  - Multilayer MWPC for tracking
- High statistics (0.1%) runs
  - 10 Hz coincidence rate, ~ 8 weeks

Longer term

- Lil’ b at 10^{-3}: beta spectrometer (PxR, CRES, traps, …)
- Lil’ a at 10^{-4}: shake-off electrons, dipole traps, large MCPs, …

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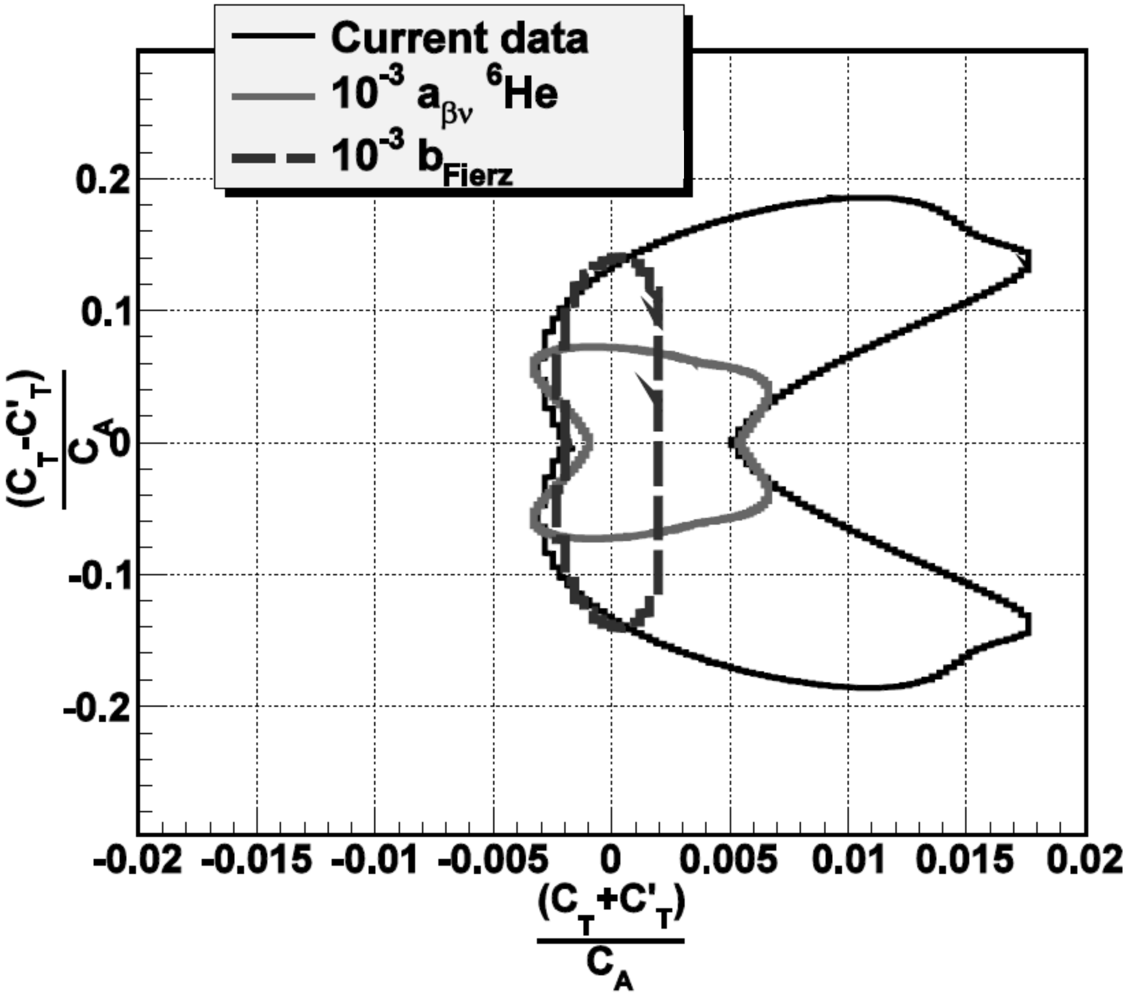
PhD, Postdoc

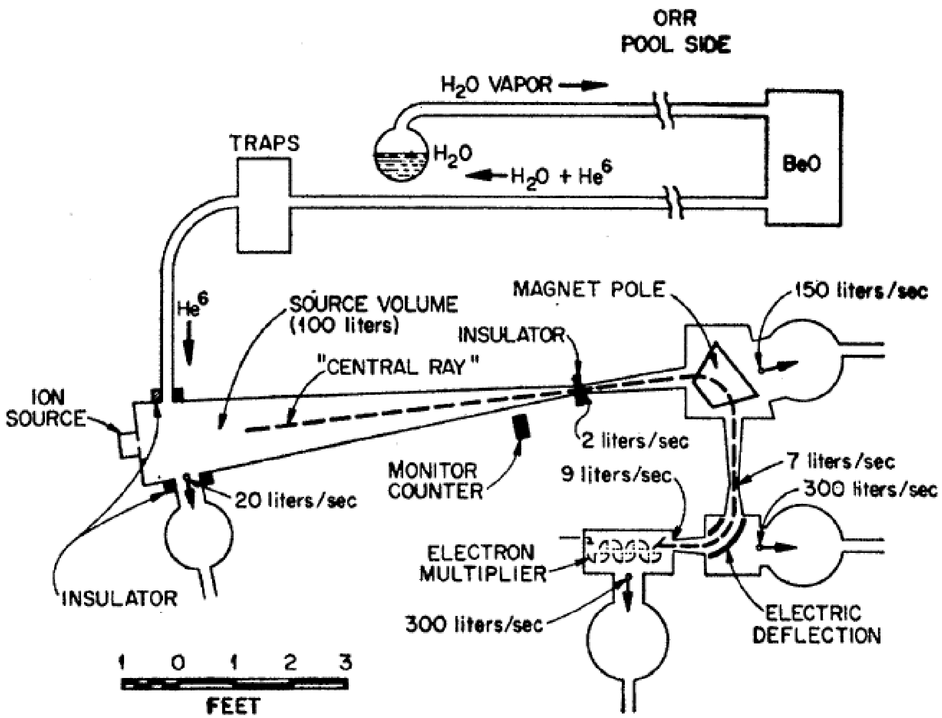
Limits with 0.1% ^{6}He Experiment

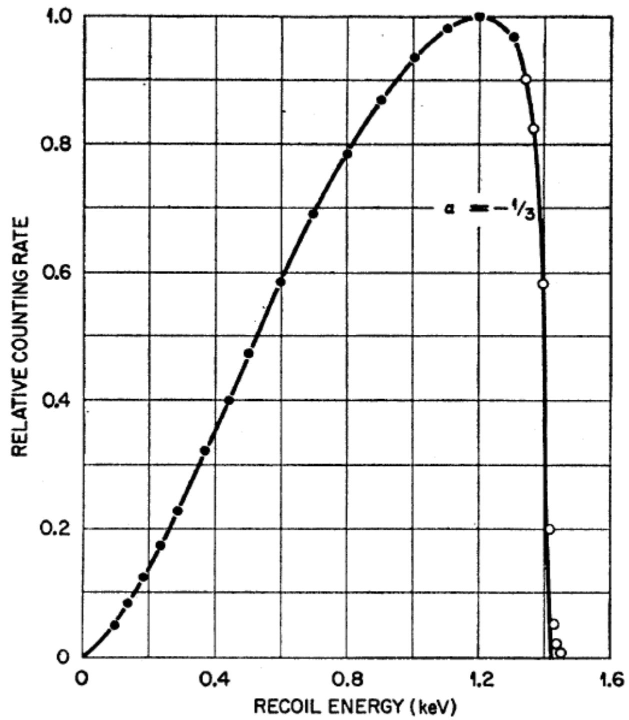


90% C.L.

The “Classic” ^{6}He Experiment

C.H. Johnson, F. Pleasonton, T.A. Carlson, Phys.Rev. 1963





Measure ^{6}Li recoil energy spectrum

a = - 0.3308(30)

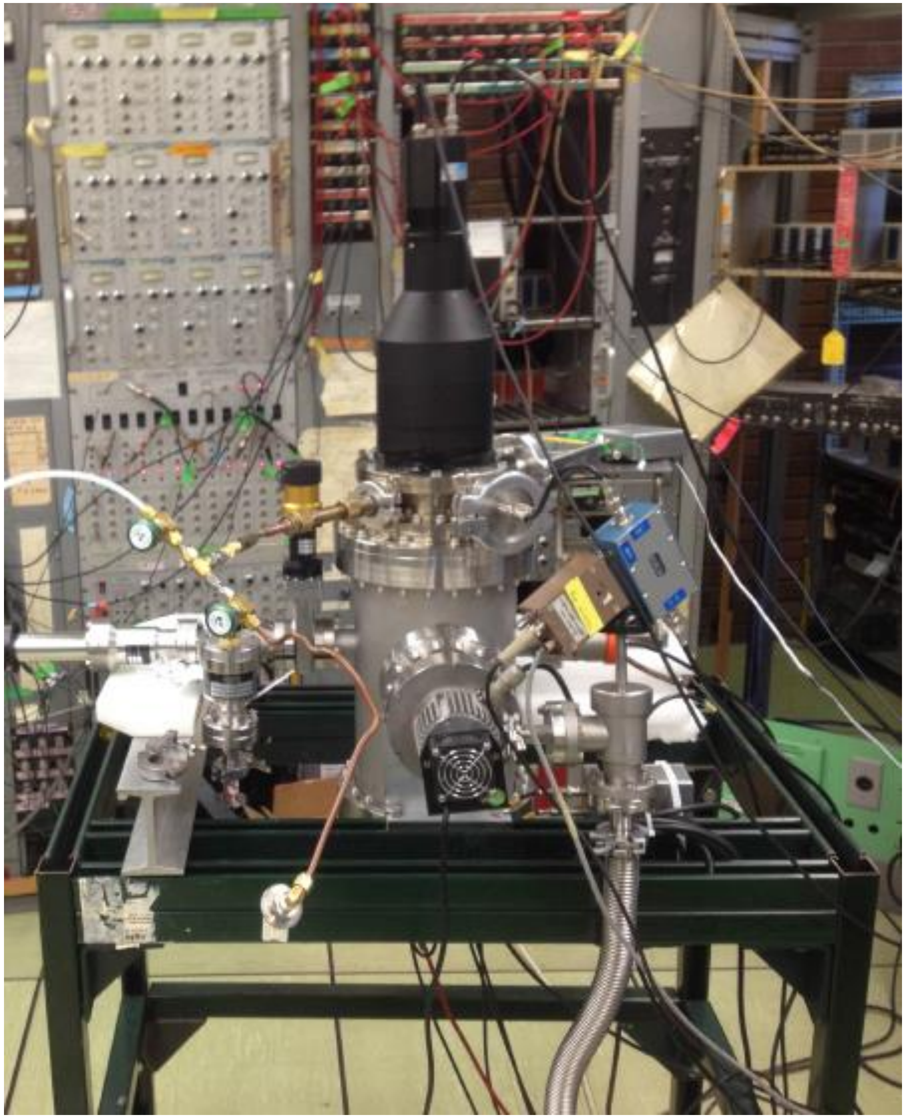
with radiative correction from F. Glueck, Nucl. Phys A, **628**, 493 (1998)

Systematic Uncertainty Estimates

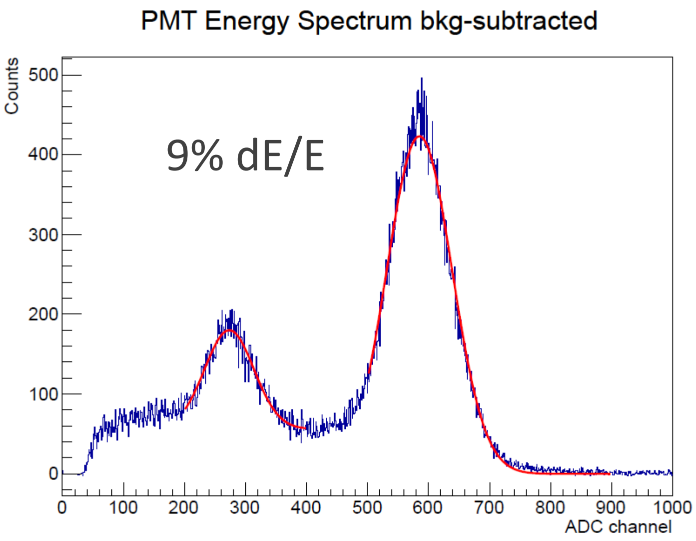
		$\delta a \times 10^{-3}$
Trap position stability	10 μm	0.15
Electric field stability	4×10^{-4}	0.15
MCP timing resolution	100 ps (200 ns)	0.15
MCP efficiency calibration	rel. 0.04%	
	30 μm	0.15
Beta detector calibration		0.30
		0.42 (0.13%)

- Need more detailed simulations on E-field distortions, beta detector response and beta backscattering
  - Calibration with ^{6}He background gas
  - Photoionization of ^{4}He
- Study different range for beta scattering parameters in GEANT4
  - Few % backscattering events, need to understand to rel. ~ 5%
  - Tracking in MWPC for fiducial cuts

Beta Detector System



Scintillator energy calibration, ^{207}Bi

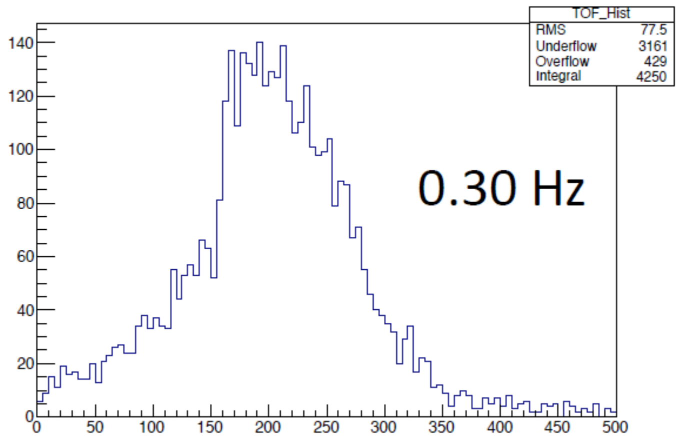


- MWPC 94% efficiency
- New double-layer frames for position resolution + angle under construction
- Be window leads to 150 keV loss + large angle straggling
- Explore other window materials

First coincidence signals

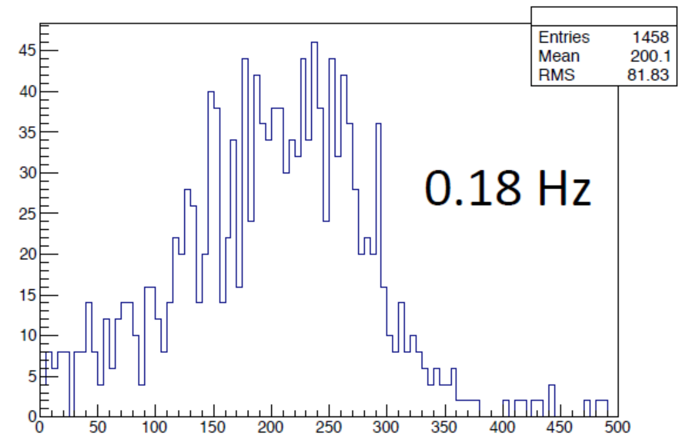
October 2013

Push Beam ON

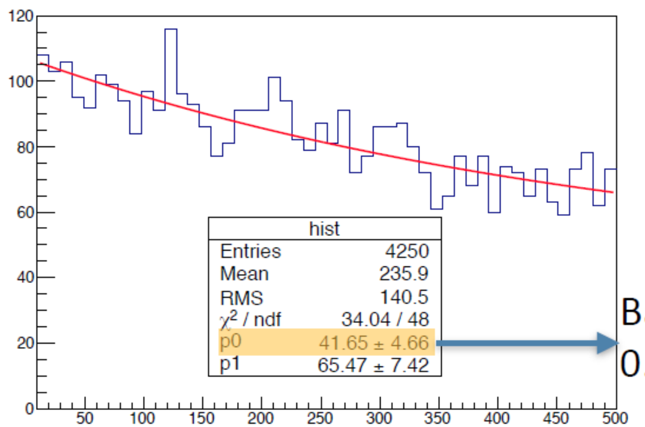


Recoil Time of Flight (ns)

Push Beam OFF

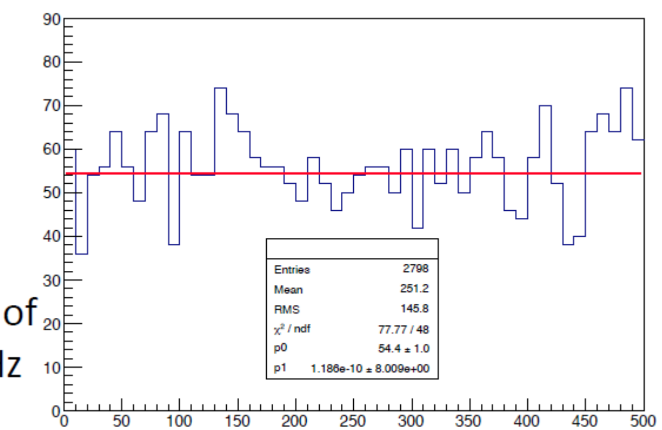


Recoil Time of Flight (ns)



Trap Lifetime (ns)

Background of 0.15 ± 0.02Hz



Trap Lifetime (ns)