SNO/SNO+ UK Calibration Experience

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18/12/13

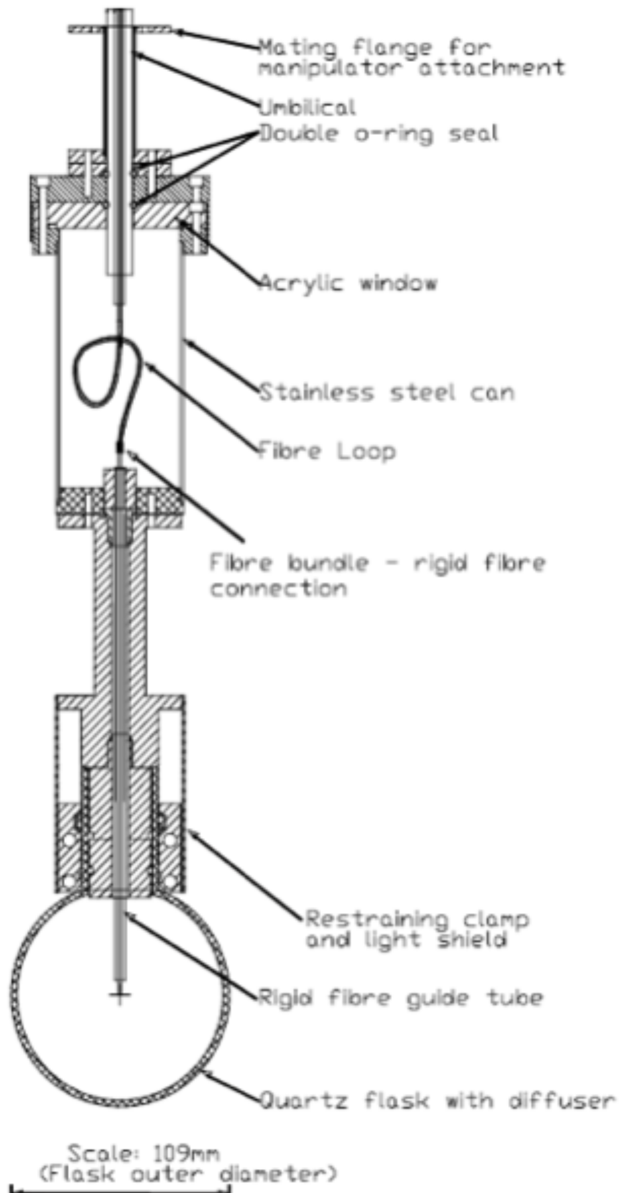
Contents

- Deployed Optical Sources
- Embedded Optical Fibres
  - PMT Calibrations
  - Optical Analysis
- Radioactive sources
  - ^{16}N, ^{8}Li, pT
- Materials cleanliness and safety

SNO and SNO+: Laserball

- Deployed, isotropic optical source.
- Quartz flask, silicone gel + diffusing glass spheres
- Nitrogen Dye laser (337,369,385,420,505,619nm)
- ND filters to adjust intensity
- Flexible umbilical of optical fibres
- Challenges
  - Source isotropy
  - Intensity variations between pulses
  - Exact location of source
  - Contamination during deployment

B.A. Moffat, et al
NIM A554 (2005) pp. 255-265



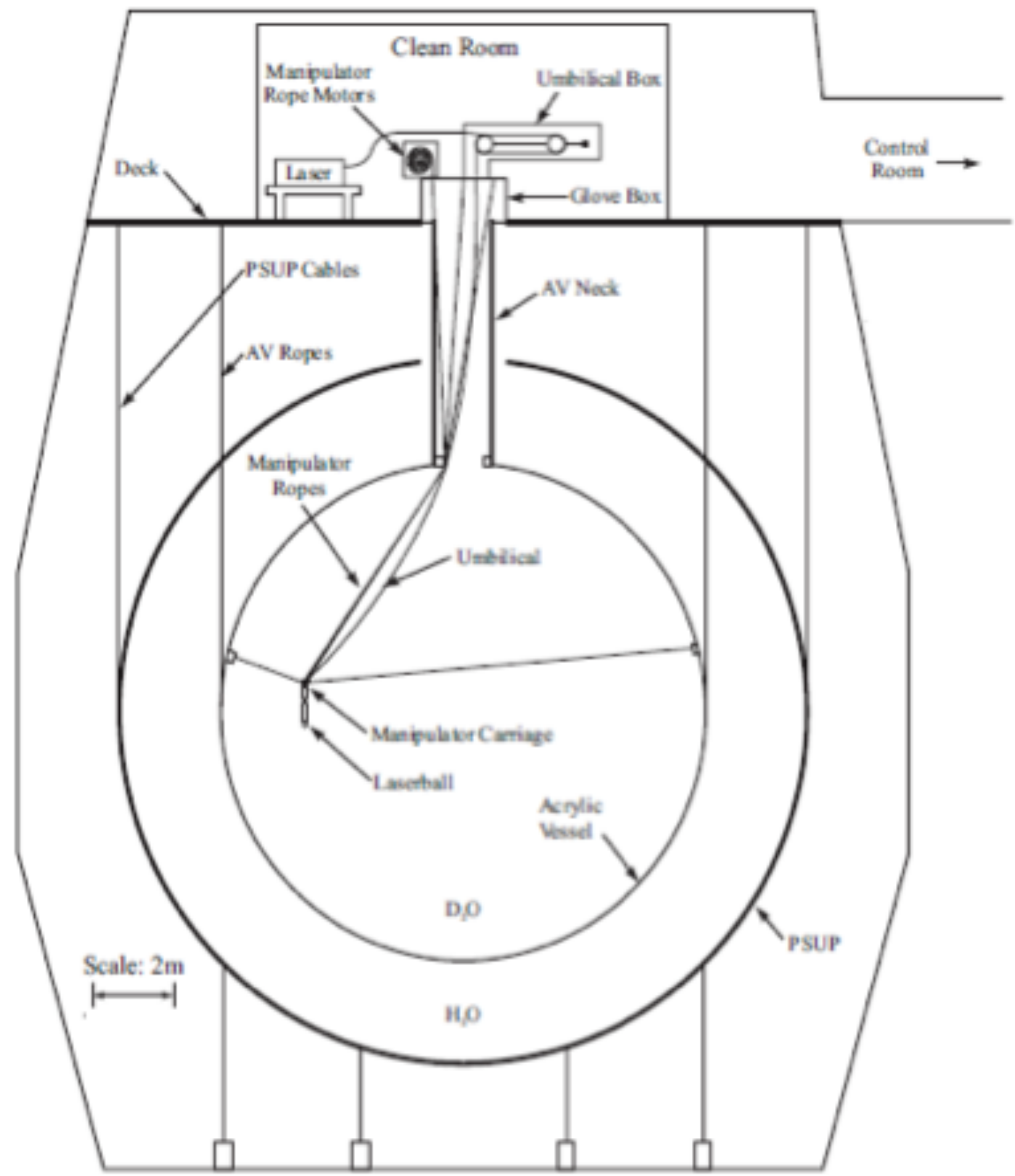
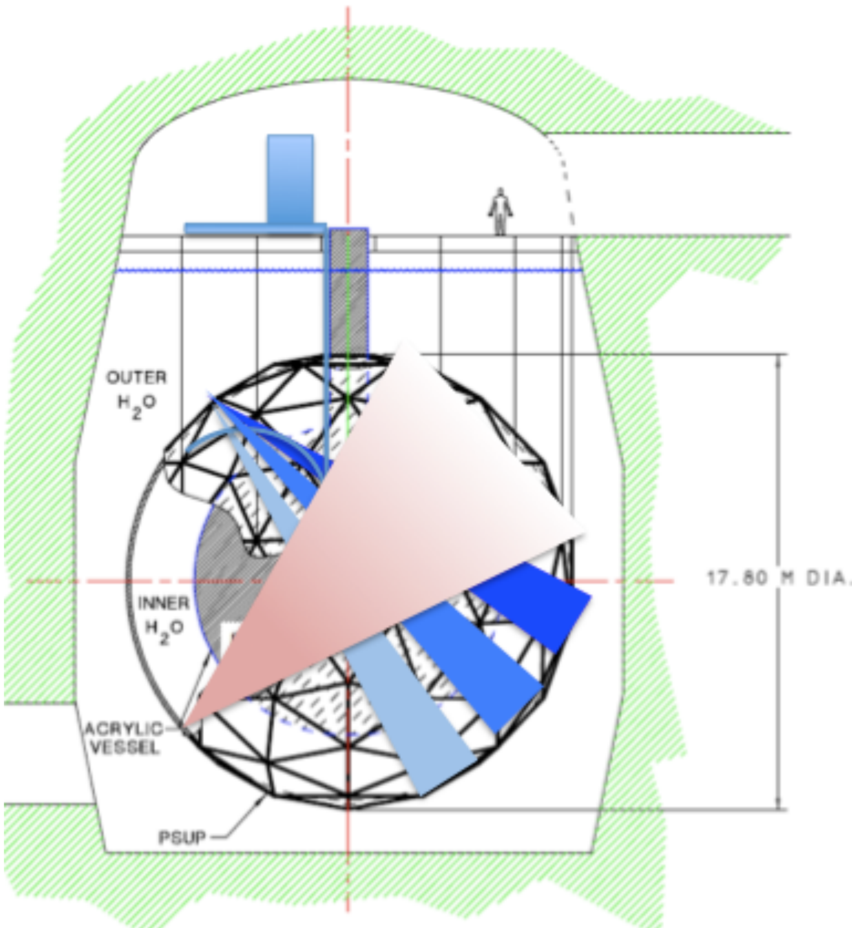


Fig. 1. Overview of the SNO calibration source deployment system. The laserball and its associated umbilical cable are also shown.

New laserball for SNO+

SNO+ : ELLIE

External LED/Laser Light Injection Entity

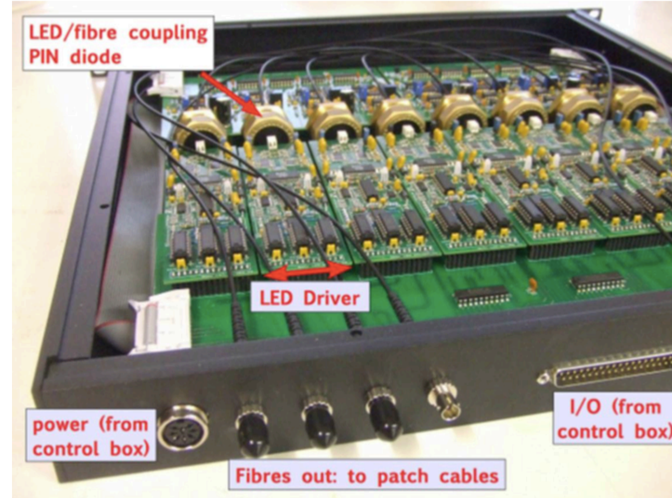


TELLIE – Timing calibration (LED)

SMELLIE – Scattering Module (laser)

AMELLIE – Attenuation Monitoring (LED)

TELLIE



- 91 nodes
- 14.5° (20% peak Intensity)
  - All PMTs illuminated by >1 beam
- 505nm LED coupled to plastic optical fibres
- Pulses ~1.8ns rise-time, 6.6ns fall time
- Dedicated TELLIE runs (kHz) or embedded in data stream (~10Hz).
  - Main purpose: PMT timing calibration
  - Also test PMT mapping, rope position (shadowing) AV position (reflections)

SMELLIE

- 4 sub ns pulsed diode lasers
  - 375, 407, 446 & 495nm
- Bespoke laser switching unit
- Internal monitoring system
- 5x14 mechanical-relay Optical Fibre Switch
- 12 quartz optical fibres, 4 mounting points, 3 directions (0,10°,20°)
- GRIN lens collimation ~7 degree ~top-hat opening angle
  - Main purpose: Scattering measurement
  - Also test reflections, trigger timing effects?

AMELLIE

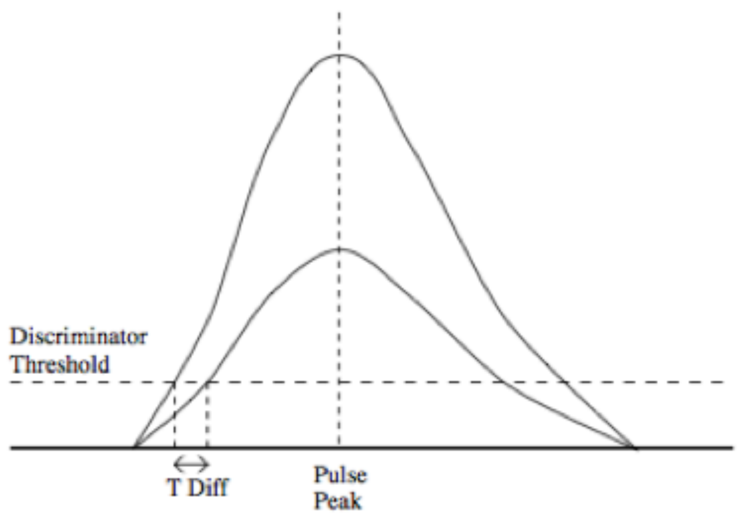
- Similar setup to TELLIE but use quartz fibres and range of wavelength LEDs (exact wavelengths to be decided)
- *4 injection positions, 2 angles per position*
- *Wavelengths: 400, 520nm*

- Uniform emission of LEDs allows attenuation to be monitored over time.

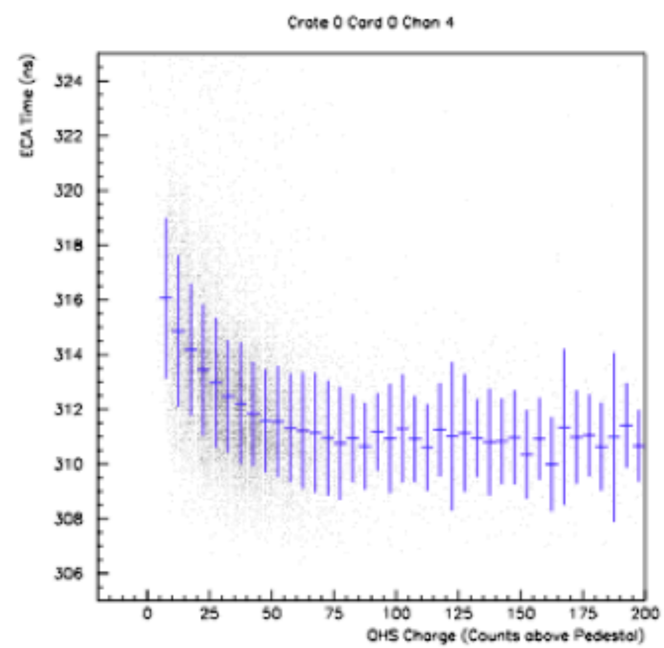
PMT Calibrations: PCA

Aims:

- remove time offsets between PMTs (arising from eg. Cable delays)
- Correct for discriminator 'walk' effect.
- Characterise PMT charge spectrum



Small pulses take longer to cross the discriminator threshold with respect to
f the peak than large pulses.



J. Cameron, PhD thesis, Oxford, 2001

Figure 3.2: An example of discriminator walk. It shows ECA time ag
for data collected from an external asynchronously triggered laserbal
card 0, channel 4. The blue crosses are a profile histogram of the data
bars showing the RMS spread. The size of the walk is about 5 ns.

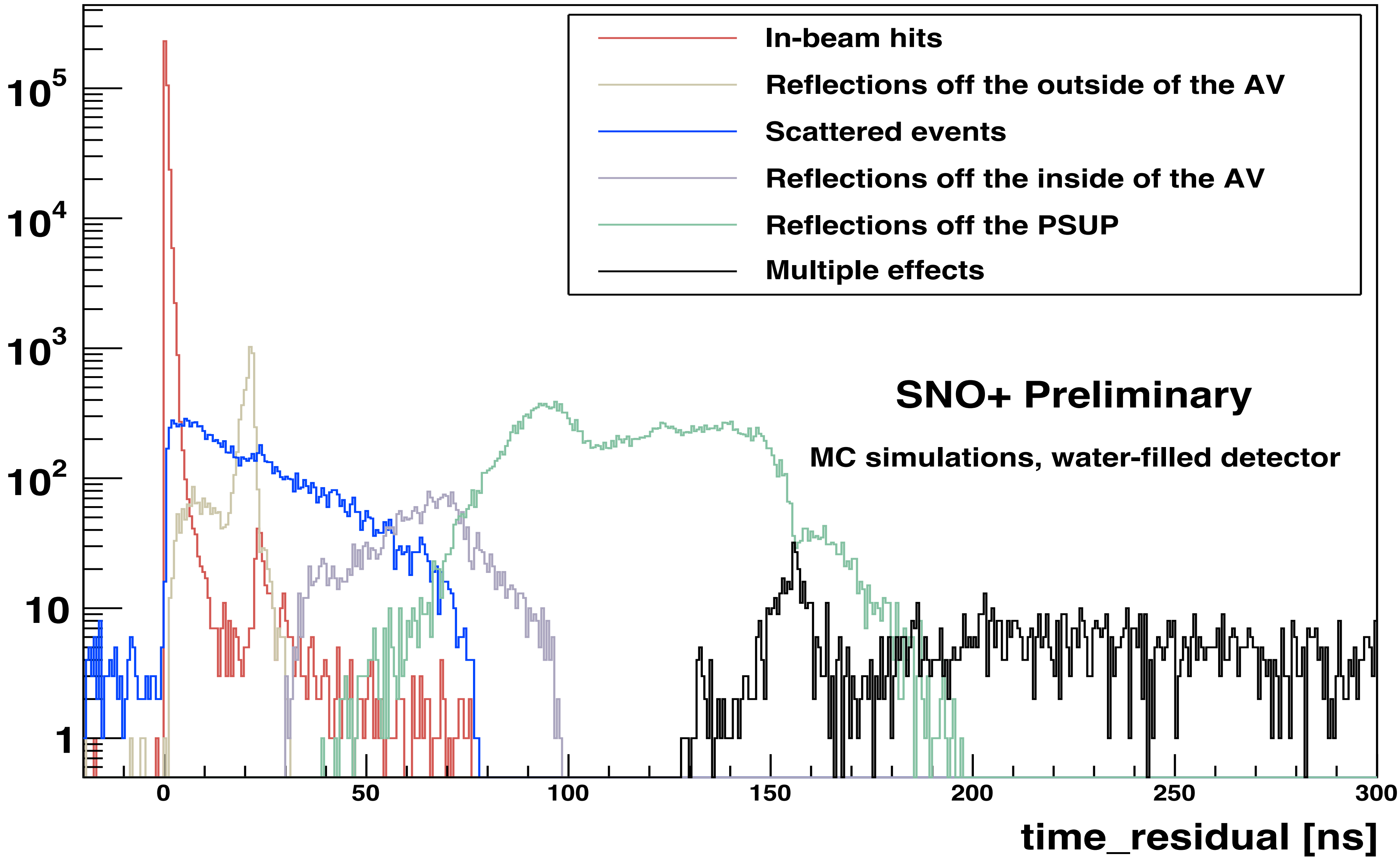
PCA considerations

- Central laserball
  - We correct all hits for transit time from source, but uncertainties in deployed source position
  - Multiple points to account for rope shadowing

- TELLIE
  - Different driver for each fibre. Different delays relative to trigger
  - Derive differences using peak times from PMT that sees 2 fibres.

SMELLIE Analysis

- Select PMT hits in angle and time.
  - >95% purity, >60% efficiency for scattering in water
- Different lasers:
  - sensitivity to Rayleigh λ^4 dependence
  - Absorption/reemission
- 0, 10°, 20°:
  - different pathlengths through acrylic and water to break correlations
- Scale scattering in MC to match data


In-beam hits
Reflections off the outside of the AV
Scattered events
Reflections off the inside of the AV
Reflections off the PSUP
Multiple effects
SNO+ Preliminary
MC simulations, water-filled detector
10^5
10^4
10^3
10^2
10
1
0
50
100
150
200
250
300
time_residual [ns]

Optical Analysis (OCA)

- Observable:
  - PMT integrated occupancy as a function of laserball position (~30 positions)
- Parameters:
  - Media attenuations, PMT angular response, laserball distribution
- Method:
  - Multi-parameter fit to all positions occupancy data
  - Separate fit at each wavelength
  - Source position crucial input
  - Interpolate measured parameters between wavelengths
  - Subtract scattering from total attenuation

OCA considerations

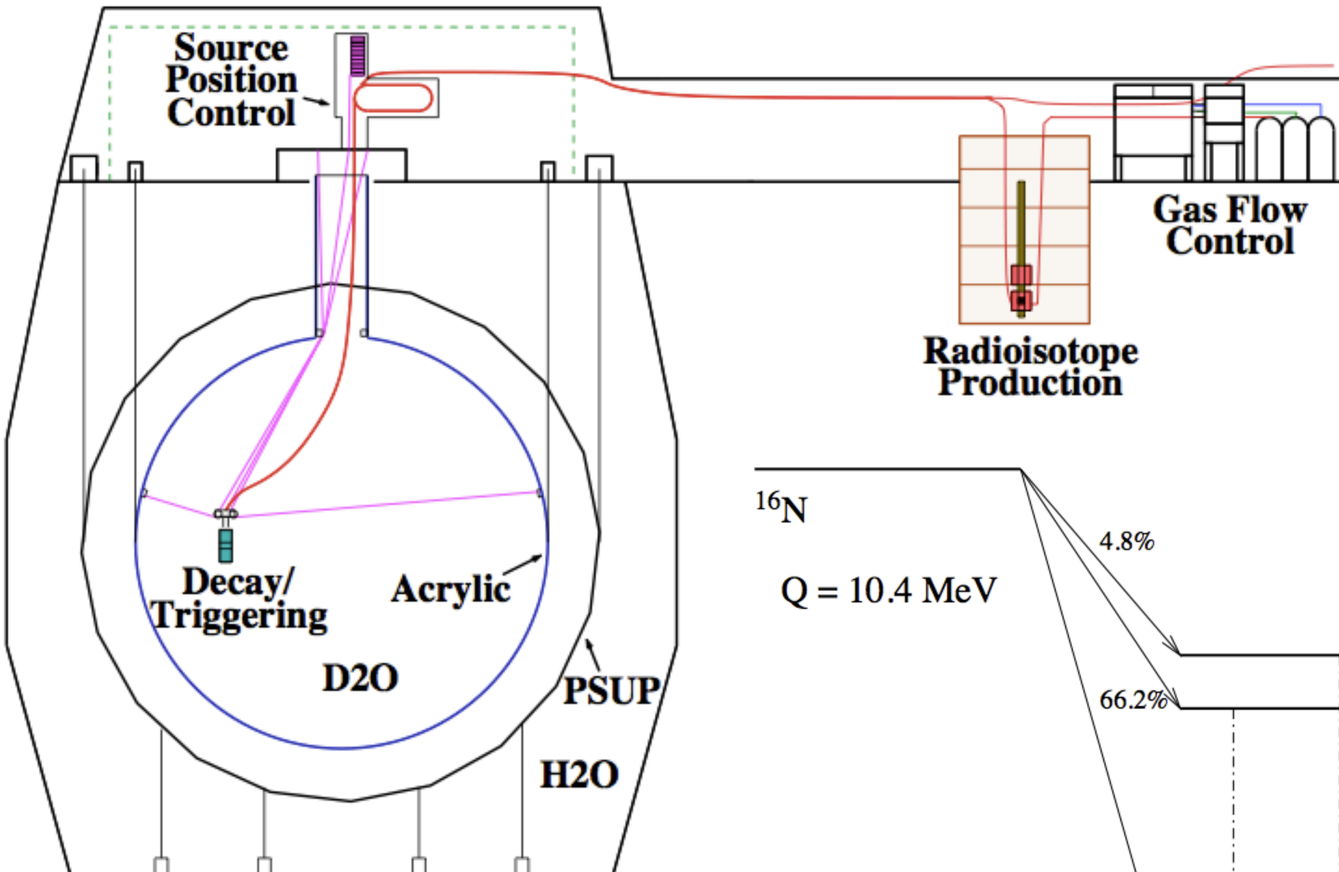
- Time consuming calibration
  - 30 positions × 6 wavelengths × ~15 minutes
- But need to monitor optics over time
  - Concentrator degradation
- Uncertainty from source position in SNO, improve for SNO+
  - Cameras
  - LED on deployment mechanism
- Rope shadowing complicates things

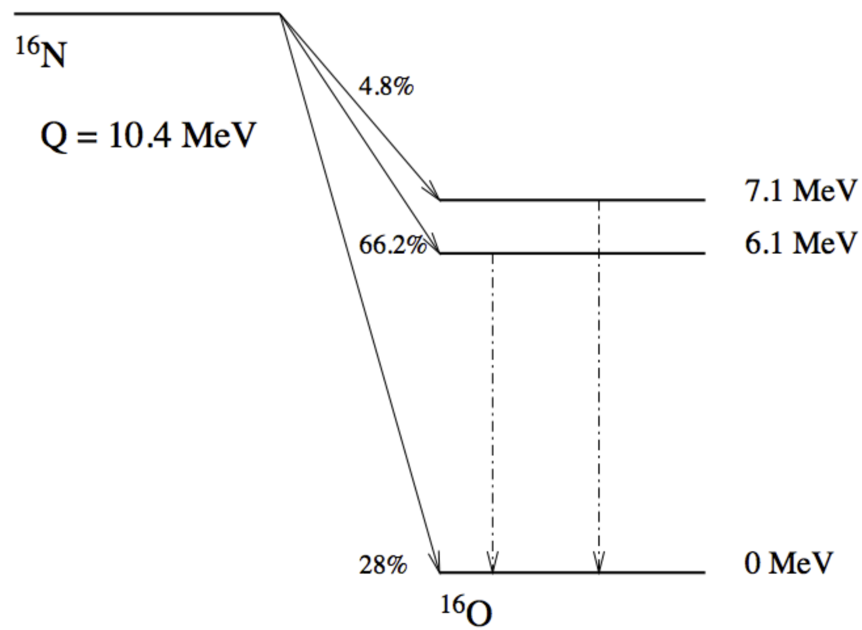
Radioactive sources

Calibration source	Details	Calibration
Pulsed nitrogen laser ("laserball")	337, 369, 385, 420, 505, 619 nm	Optical & timing calibration
^{16}N	6.13-MeV γ rays	Energy & reconstruction
^{8}Li	β spectrum	Energy & reconstruction
^{252}Cf	Neutrons	Neutron response
Am-Be	Neutrons	Neutron response
^{3}H$(p,\gamma)^{4}$He ("pT")	19.8-MeV γ rays	Energy linearity
Encapsulated U, Th	$\beta-\gamma$	Backgrounds
Dissolved Rn spike	$\beta-\gamma$	Backgrounds
In situ ^{24}Na activation	$\beta-\gamma$	Backgrounds

M.R. Dragowsky, et al
NIM A481 (2002) pp. 284-296

^{16}N

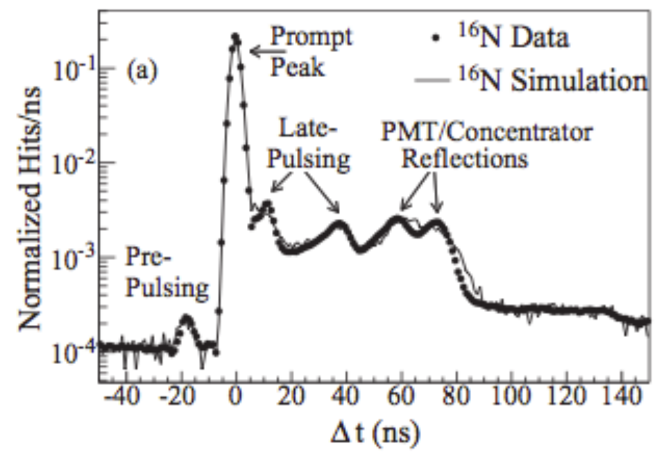


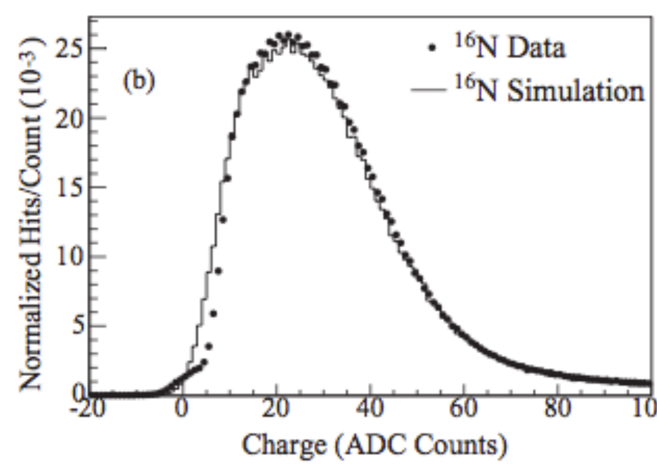


^{16}N Analysis

- 6.13MeV ϒ
  - compton scatter e^{-}s
  - T_{eff} distribution around 5MeV

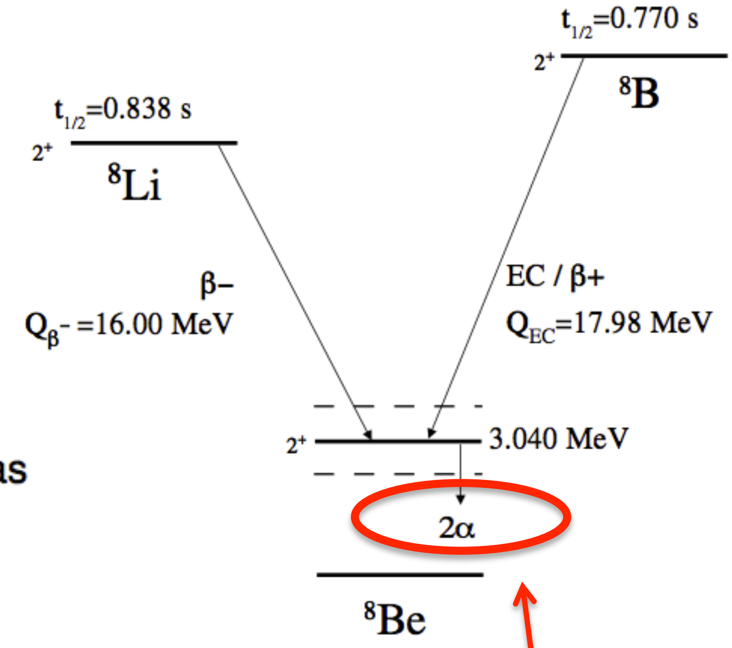
- Tune global collection efficiency
- Tests of optical model.
- Determine reconstruction systematics (position and energy)

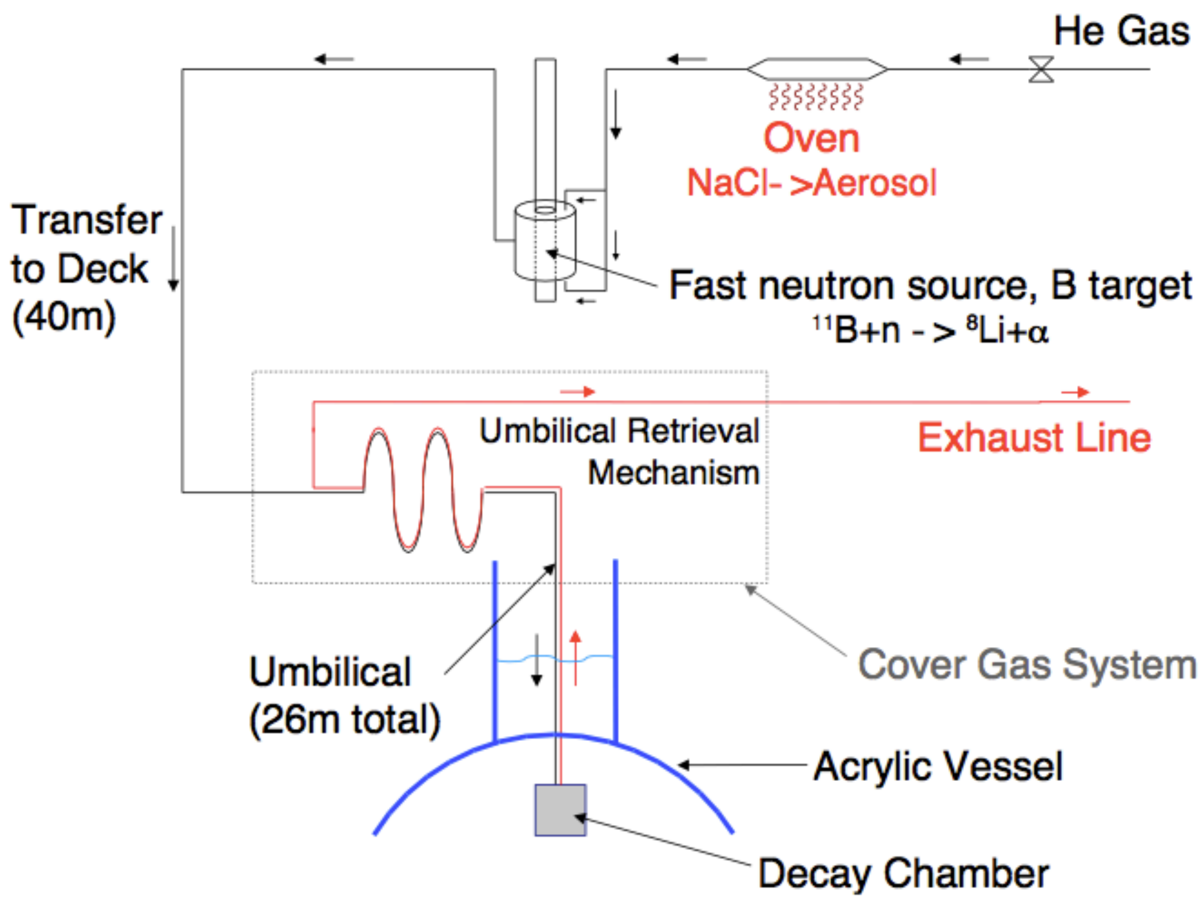




N. Tagg et. al.
NIM A489 (2002) pp. 92-102
Preprint: nucl-ex/0202024

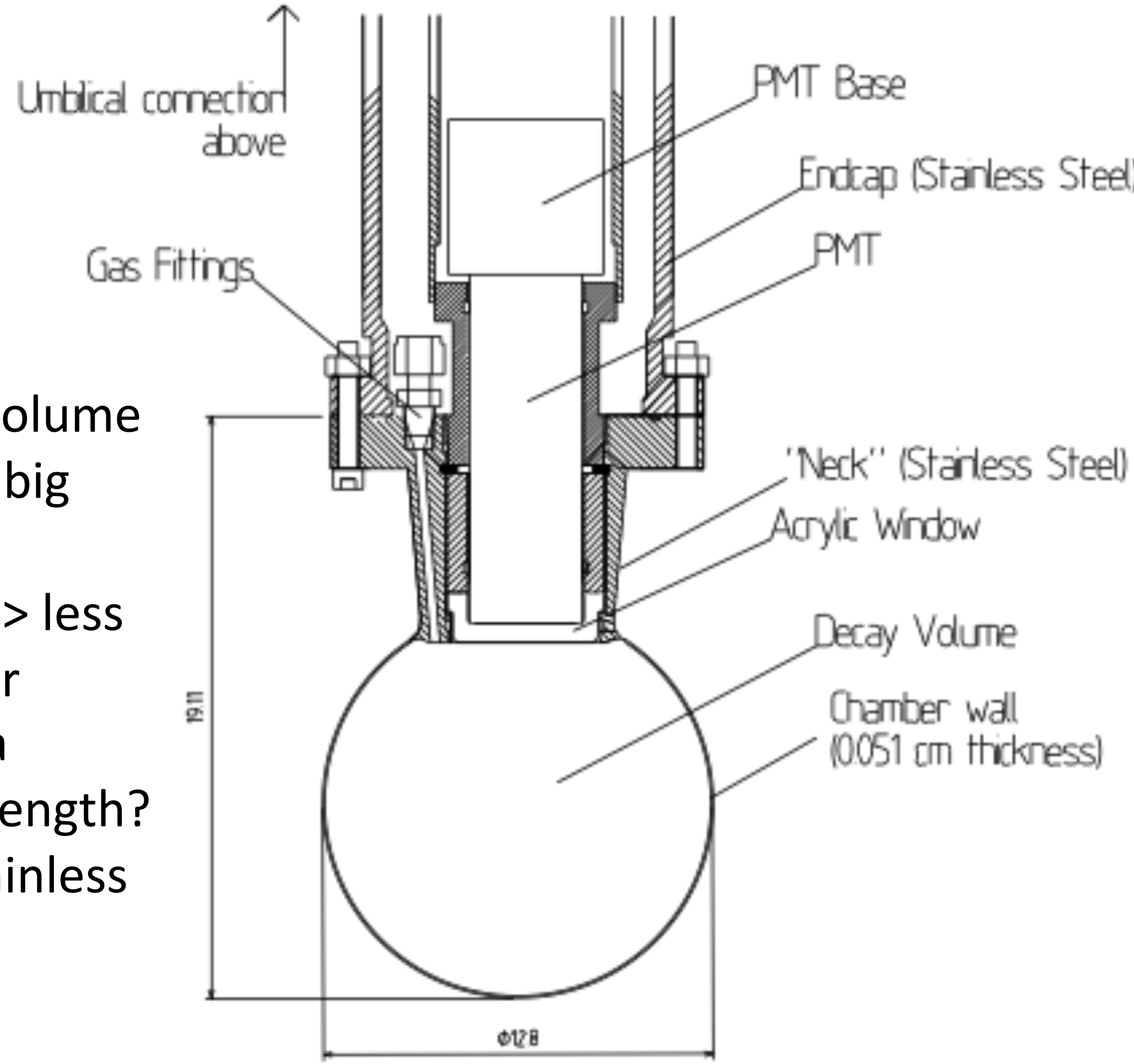
^{8}Li



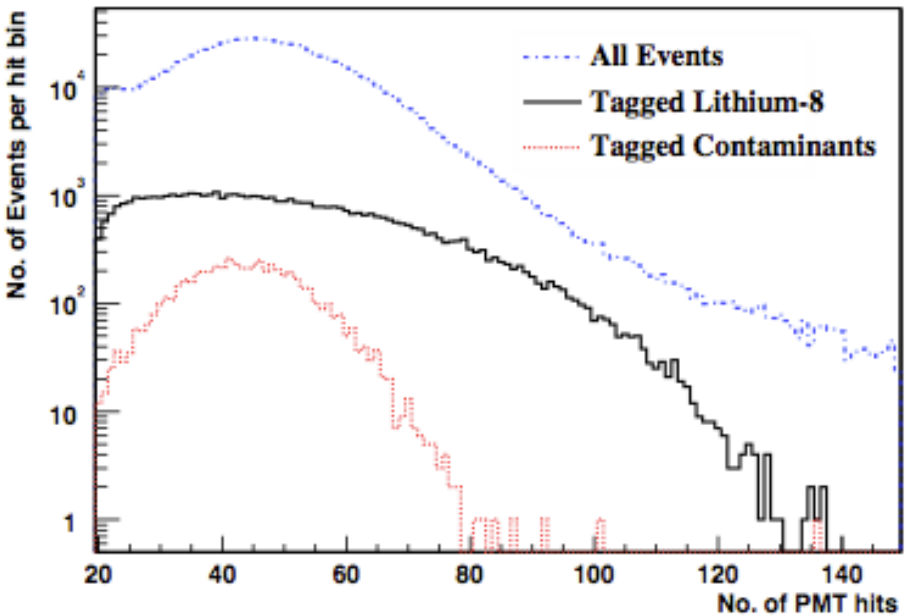


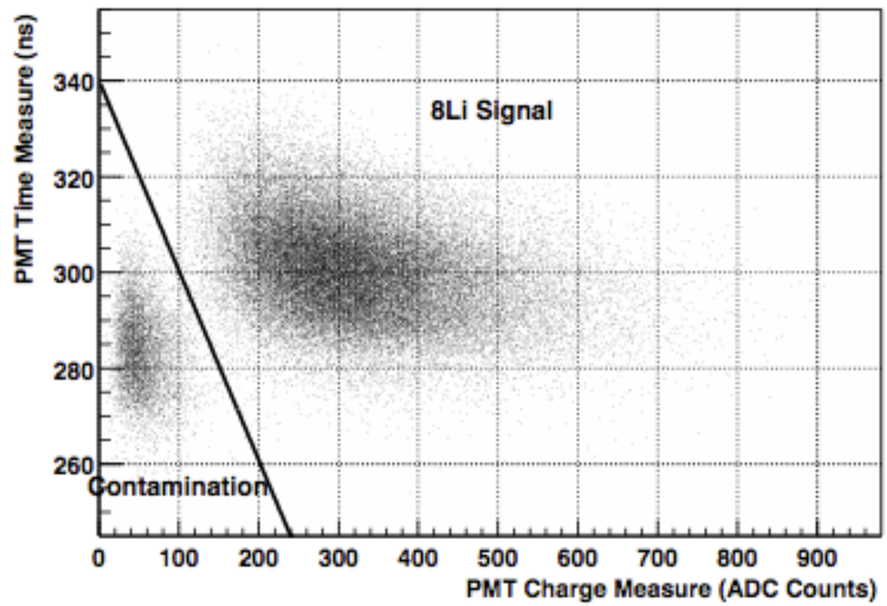
Tagged source
Scintillation in
He transport gas

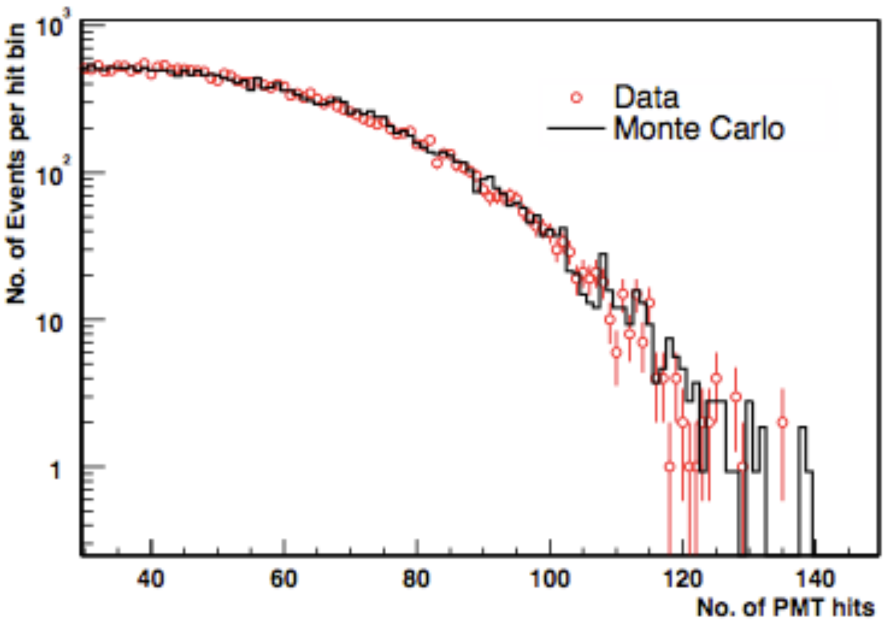
^8Li



Challenges:
- Maximise decay volume for source rate -> big source
- Longer umbilical -> less decays in chamber
- Thin shell for beta penetration -> strength?
- Reflections off stainless steel not well understood







- 92 ± 5 % tagging efficiency
- ^{16}N contamination successfully removed
- Achieved ~0.5Hz decay rate

Analysis:

- Energy and reconstruction systematics studies
- Signal sacrifice / data cleaning

A.W.P. Poon et al
NIM A452 (2000) pp. 15-129

pT $^{3}H(p,\Upsilon)^{4}He$

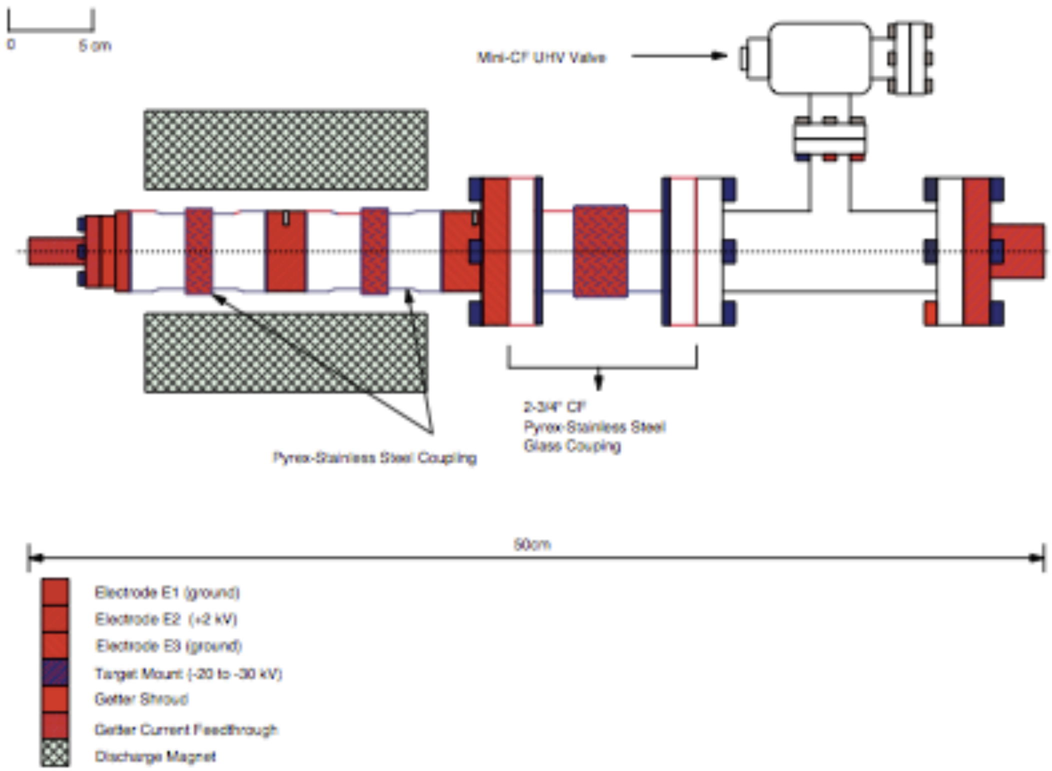


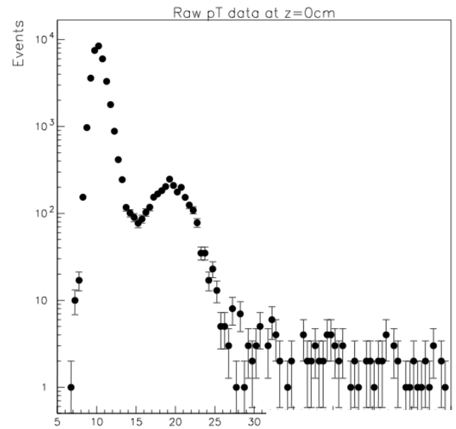
Fig. 1. Cross sectional drawing of the *pT* source.

- 19.8MeV mono-energetic gamma
- Neutron backgrounds from: $^{2}H(t,n)^{4}He$, $^{3}H(d,n)^{4}He$, $^{3}H(t,nn)^{4}He$

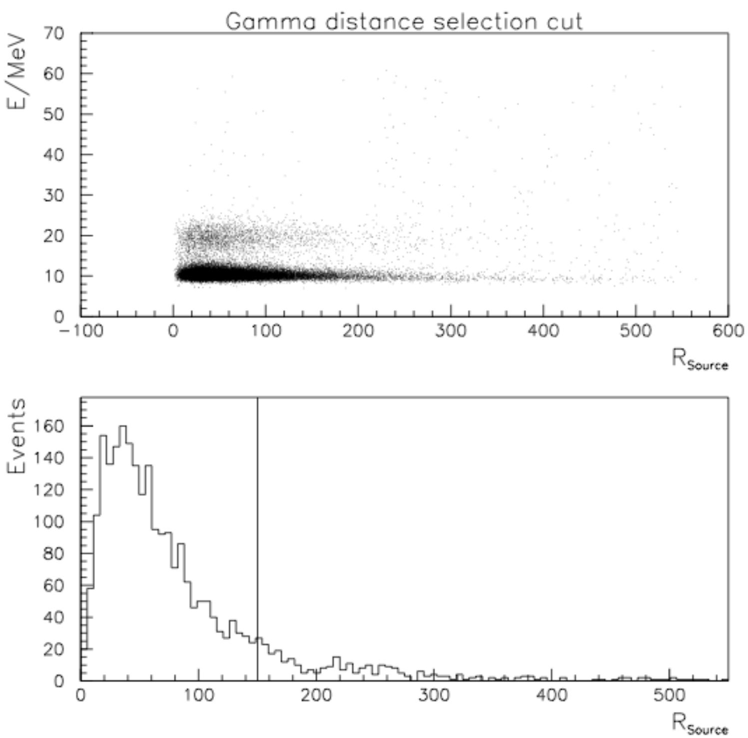
Gas discharge
Ion accelerator
ScandiumTritide target

- 60cm long, Stainless Steel cylinder

Backgrounds likely to reconstruct further from source



Compton electrons from 19.8MeV gammas point back to source



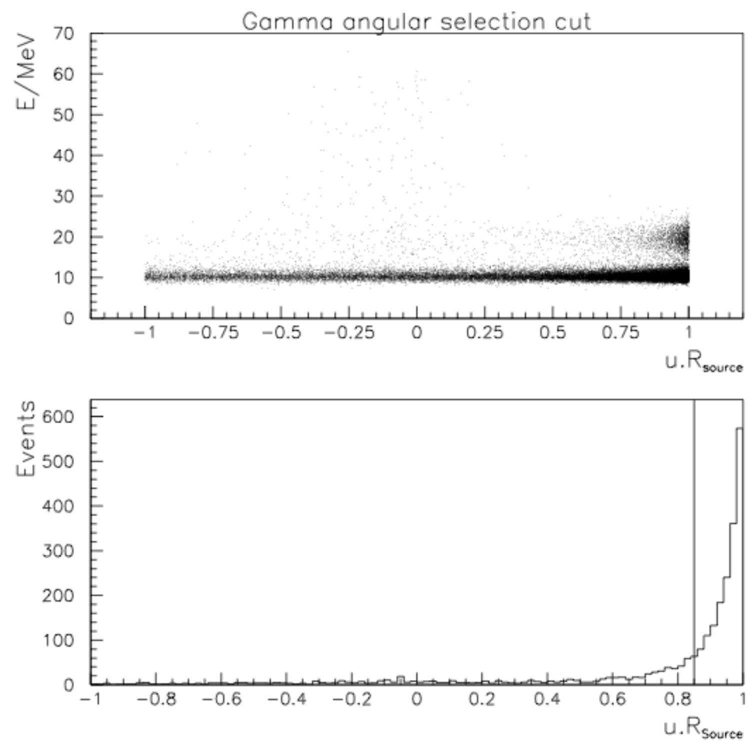
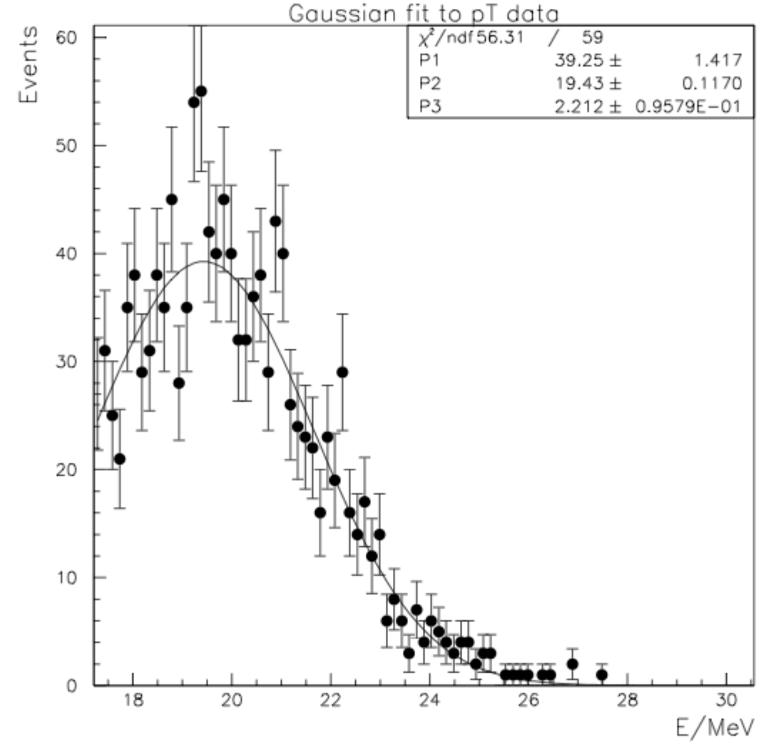


Figure 8.2: The distribution of the reconstructed distance from the source versus energy showing that the background events are more likely to reconstruct far from the source. Also shown is the placement of the cut at r=150cm.

Figure 8.3: The distribution of the cosine of angle between the event directi and the vector from the source to the event vertex versus energy. γ-raysfro the source are expected via Compton scattering to point along this vecto while the background contains no correlation. The cut is place at $cos(\theta)$ 0.85.

pT challenges & analysis



- Only deployed once
  - (single axis)
- Large source, difficult to operate
- Limited operational lifetime
- Time variation in output
- ‘partially’ remove contaminants with analysis cuts
- -> high energy point for energy scale
- Data:MC discrepancies at high radius

Materials Cleanliness

- SNO water: 10^{-14}g/g U, 10^{-15} g/g Th
- Leaching?
- Radon emanation
- Tape-lifts -> XRF
- Ge screening
  - Boulby Canberra model BE3830P built to custom ultra-low background specification with carbon fibre window for low energy acceptance
  - Resolution 0.45 keV at 5.9 keV; 0.72 keV at 122 keV; and 1.90 keV at 1332 keV.
  - sensitivity at the tens of parts per trillion (ppt) to uranium and thorium.

Other considerations: deployed sources

- Shadowing
- Simple geometry – ease of simulation
- Double encapsulation
- No sharp edges on sources
- No loose parts – screws etc
- Strength – pressure
- Radon ingress during source deployment