Beta-Decay Weak Interaction Studies in the Era of the LHC

Towards a measurement of the beta energy spectrum in ^{6}He decay

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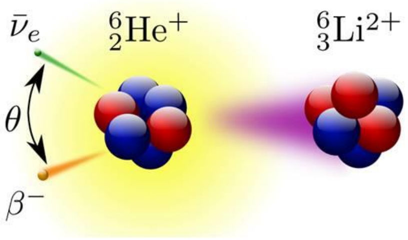
Scope and Outline

• Review the motivations for measurements of the shape of the beta particle energy spectrum in GT transitions.

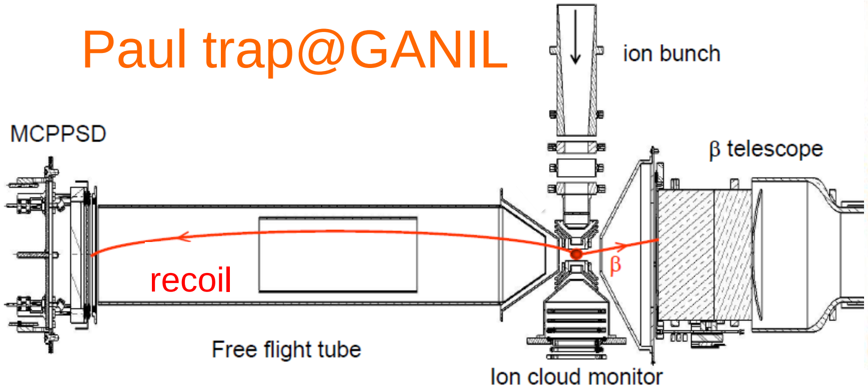
• Discuss new techniques using implanted ^{6}He ions inside active detectors.

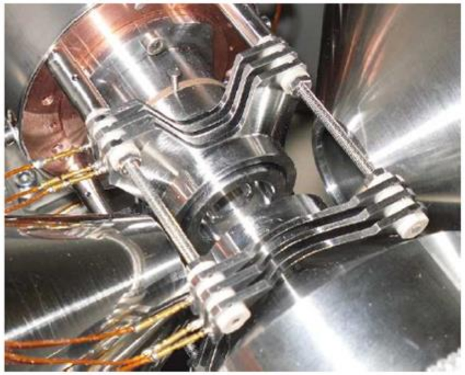
1. Motivations
2. Previous measurements in ^{6}He
3. Experimental difficulties
4. An experiment using fragmented radioactive beams
5. Data analysis and simulations
6. Summary and Outlook

Motivation: *a* in ^{6}He decay

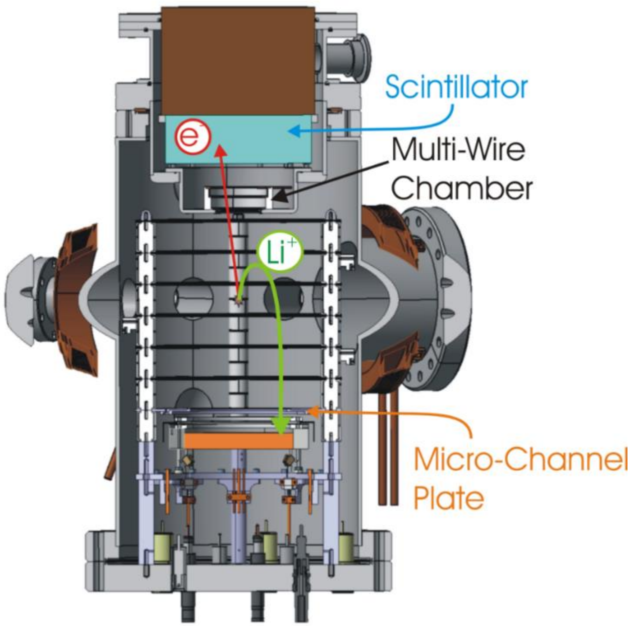


Paul trap@GANIL





MOT@CENPA



EIBT@WI

EIBT@LBNL

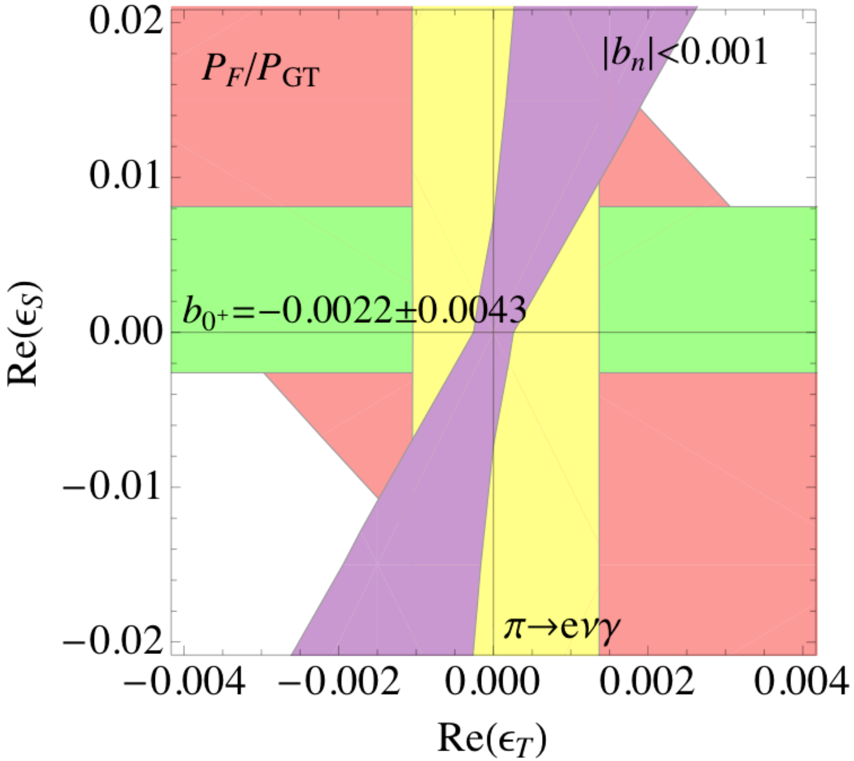
Experiments require an accurate description of beta spectrum within SM.

Motivation: b in ^{6}He decay

- Sensitivity of searches for NP

Constraints from weak decays

ONC and M. Gonzalez-Alonso, Ann. Phys. (Berlin) **525** (2013) 600

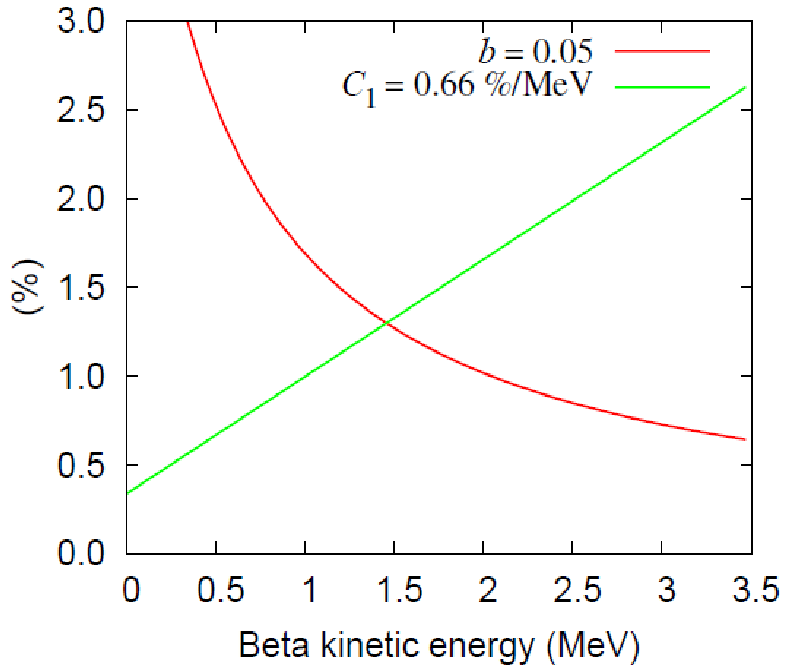


- Competitive limits as compared with projected LHC, requires a precision level $\Delta b < 10^{-3}$.

Motivation: WM in ^{6}He decay

• The contribution of the weak magnetism form factor to the linear term of the shape factor in the beta energy spectrum is estimated to produce a slope +0.66 %/MeV (1).

• This corresponds to the average slope (with opposite sign) of a Fierz term for b~0.05.



• Any attempt to reach $\Delta b < 0.05$ should then first see the effect of IWC, if strong CVC holds.

(1) F. Calaprice and B.R. Holstein, NPA **273** (1976) 301

2. Previous measurements in ^{6}He

Previous measurements of beta spectrum

The only "publication"

The Beta-Spectrum of He^6†

C. S. Wu, B. M. Rustad, V. Perez-Mendez, and L. Lidofsky
Columbia University, New York, New York
(Received August 5, 1952)

Magnetic spectrometer; extract end-point energy

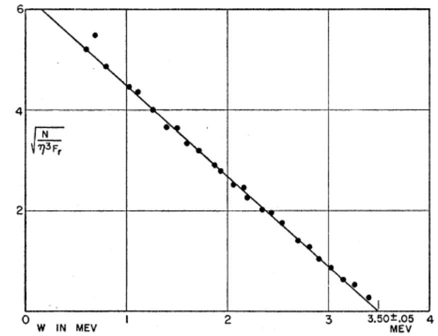


Fig. 2. Kurie plot of He^6 beta-spectrum.

B.M. Rustad and S.L. Ruby, PR **97** (1955) 991

Plastic scintillator (control spectrum); conclude weak interaction is dominated by Tensor

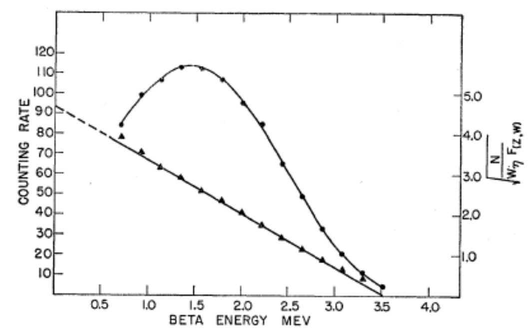


Fig. 3. He^6 beta spectrum measured with the stilbene scintillation spectrometer. The Kurie plot of the spectrum is linear and the end-point is in agreement with the value 3.50±0.05 Mev reported by Wu *et al.* (see reference 8). The slight deviations at the ends of the spectrum are attributable to the resolution width of the spectrometer.

A. Schwarzschild, PhD thesis, Univ. Columbia, New York, 1957 (unpublished)

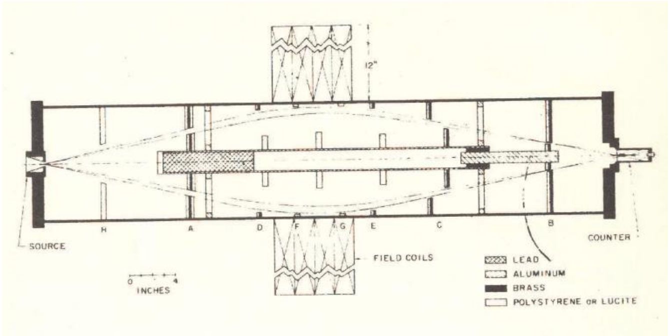
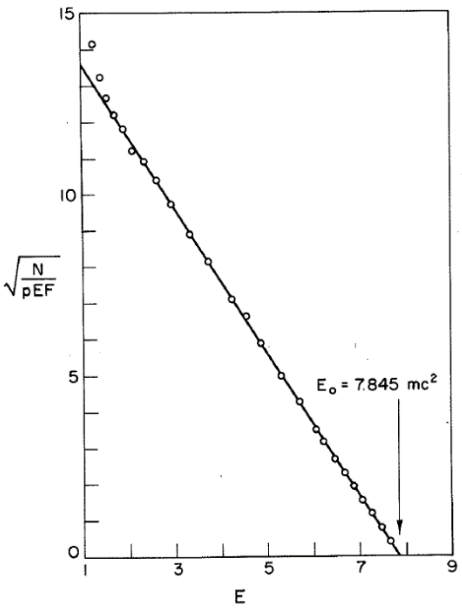


Fig. 6. Thin lens spectrometer

Some citations of Schwarzschild's thesis

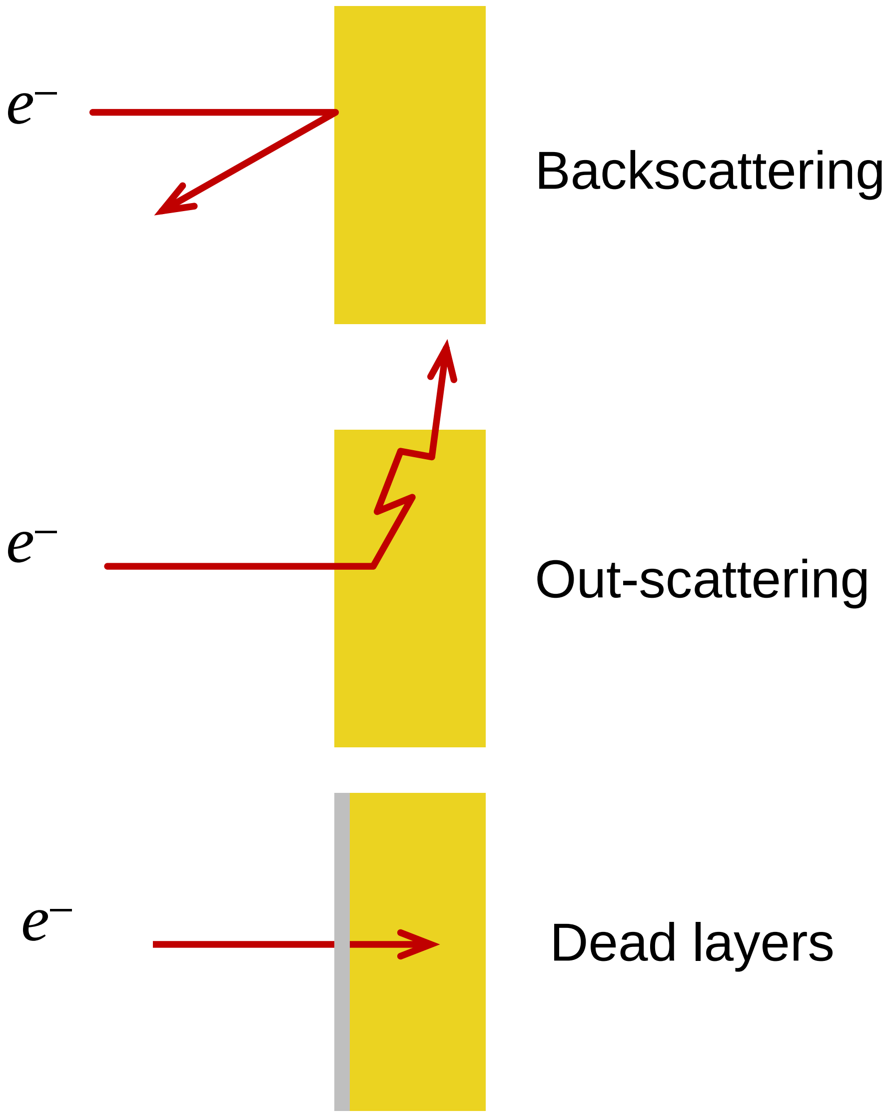
1. M. Morita, Prog. Theo. Phys. **26** (1963); p.36
2. H. Daniel, Rev. Mod. Phys. **40** (1968) 659; p.667
3. M. Morita, *Beta decay and muon capture*, 1973, p.32



• Schwarzschild thesis (unpublished) has been cited several times to set some early constraints on exotic couplings but the document is now hard/impossible to find...

3. Experimental difficulties

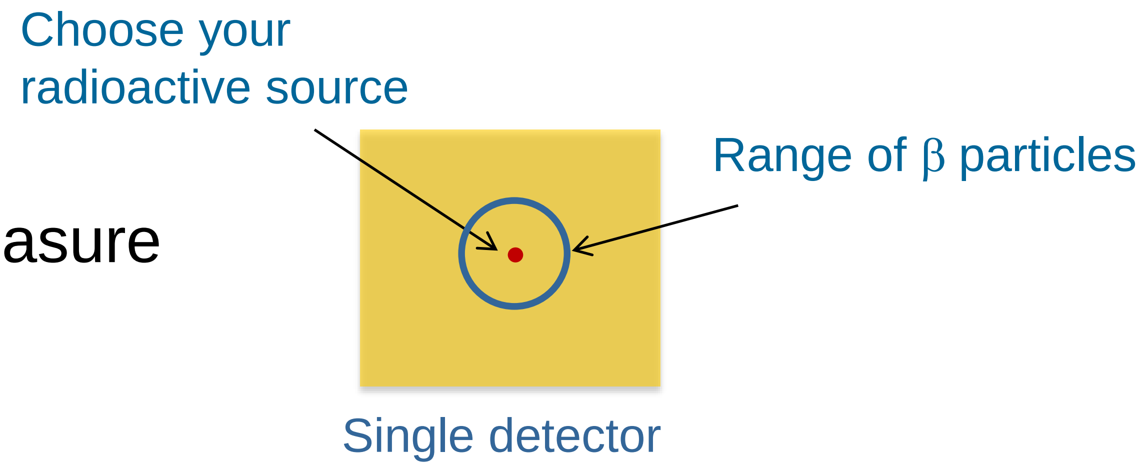
Some known instrumental difficulties



- Any partial energy deposition in the detector will result in distortions of the energy spectrum.
- Backscattering effects increase at lower energies

General principle (calorimetry)

A textbook setup to measure the spectrum shape

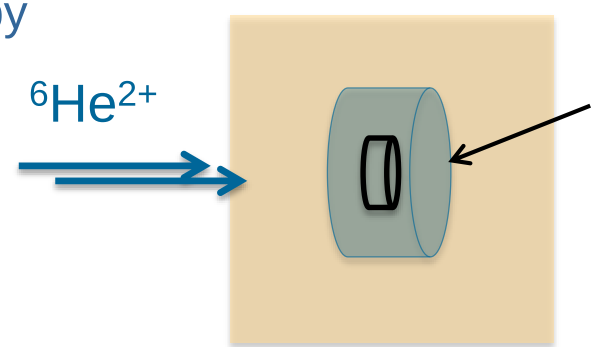


- Well localized and clean source
- 4π solid angle and 100% detection efficiency
- Detection of β particles without backscattering, out-scattering, or energy loss in dead-layers.

How close can we get to such conditions with radioactive implanted ions produced by fragmentation?

4. Experiment using fragmented radioactive beams

Implementation and questions

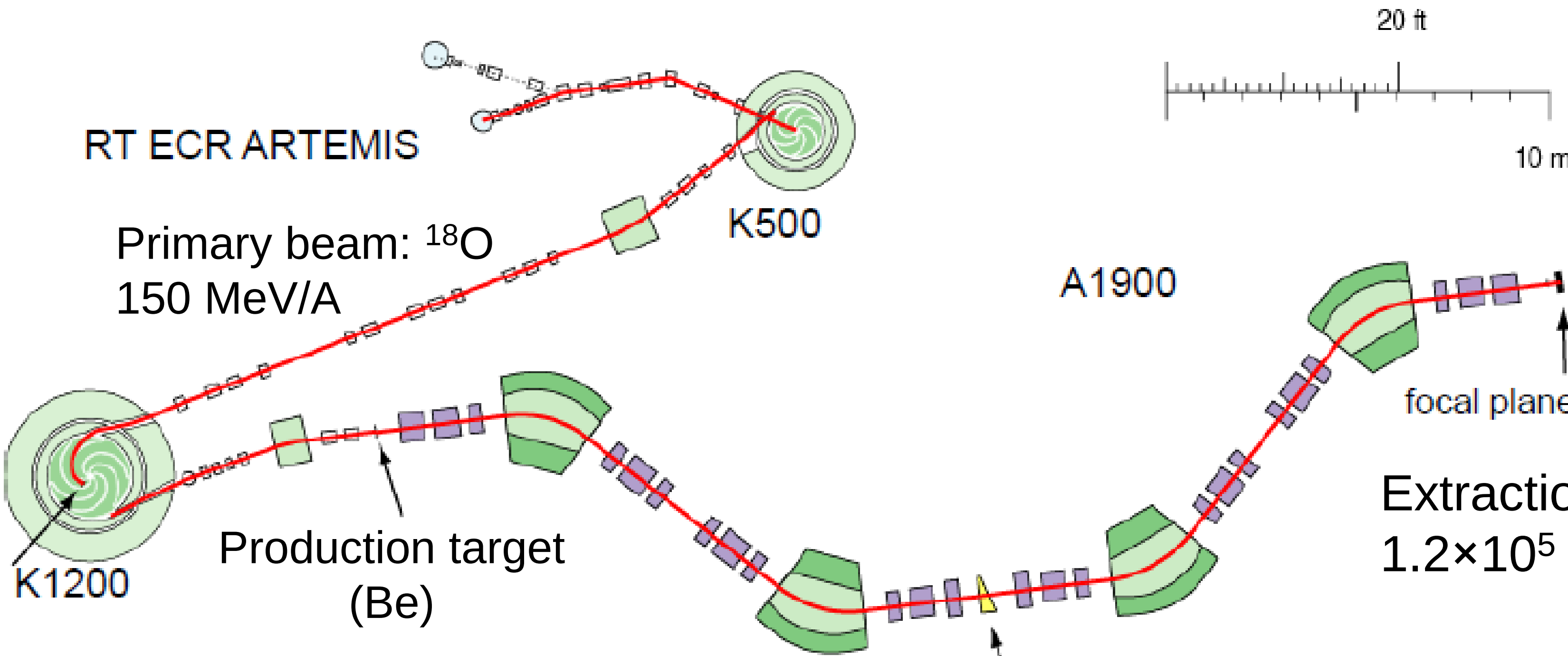


1. Are the "cocktail beams" produced by fragmentation sufficiently pure for such a measurement? LISE++ separation calculation OK, but not reliable below 10^{-2} level.

2. What are the ion induced backgrounds in detectors during implantation? R.Ronningen: PHITS Radiation transport calculation for implantation in CsI(Na), NaI(Tl), Ge, CH_2 and follow decays products: OK. To what level is this reliable?

3. Can the implanted ions produce damages in the detectors (light output changes)? Many studies for doses 10^{13} or larger but no sensitivities for “low” doses 10^{7}-10^{8}.

NSCL Coupled Cyclotron Facility

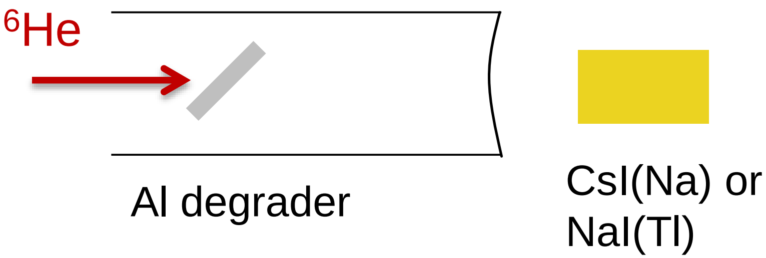


Extraction:
1.2×10^{5} $^{6}He/s$

- $\Delta p/p$ = 1%
- $\Delta x \times \Delta y$ = 1.5×2 mm^2

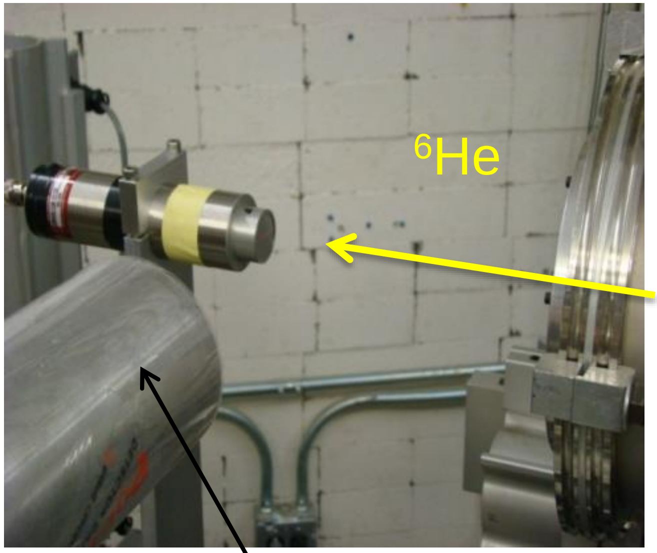
- No traces of ^{8}Li or ^{9}Li contamination

Experimental setup



- Implant ^{6}He ions "deep enough" in the detector.
- The range of 3.5 MeV electrons in CsI is 6 mm.
- Requires 40-50 MeV/A ions

- CsI(Na) (2"×2"×5")
- NaI(Tl) (Ø3"×3")
- 2 small CsI(Na) and NaI(Tl) detectors (Ø1"×1")

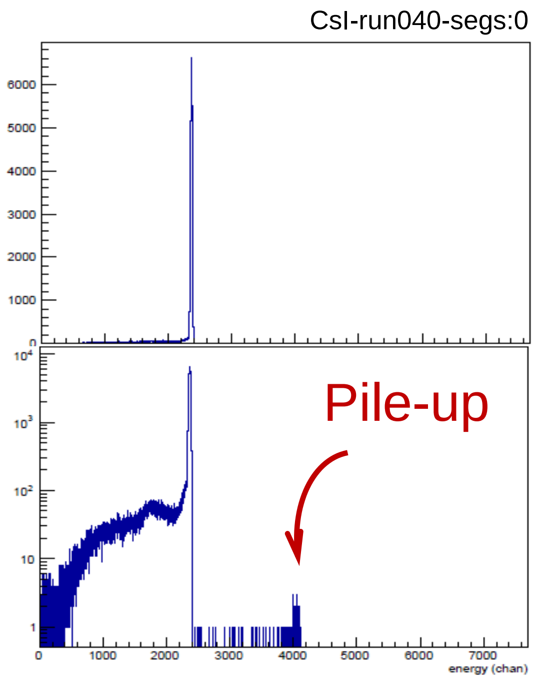


- 46 MeV/nucleon after degrader

γ detectors for background identification

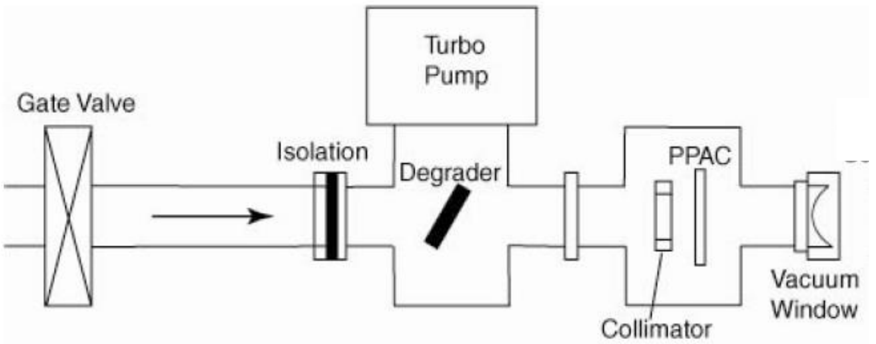
Beam purity and slowing down

Beam energy at implantation detector
(operating the detector at lower gain)

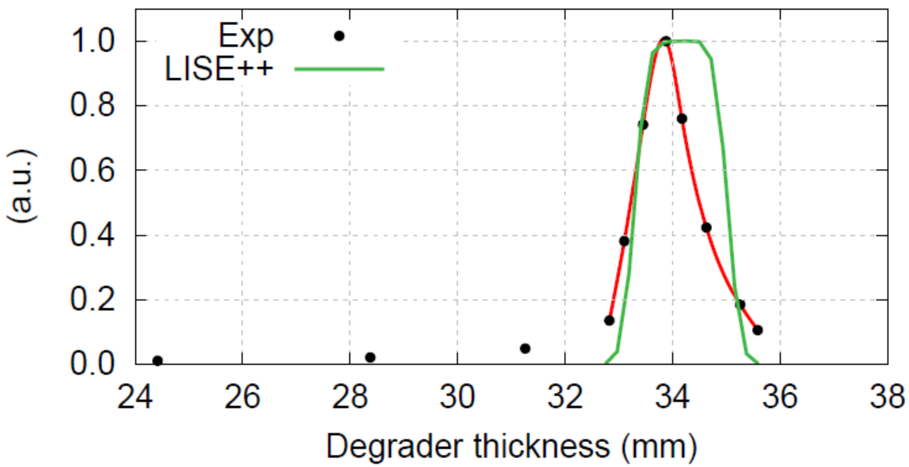


- No traces of ^{8}Li or ^{9}Li.
- Tail is due to induced reactions in the detector

Vary degrader thickness by rotation



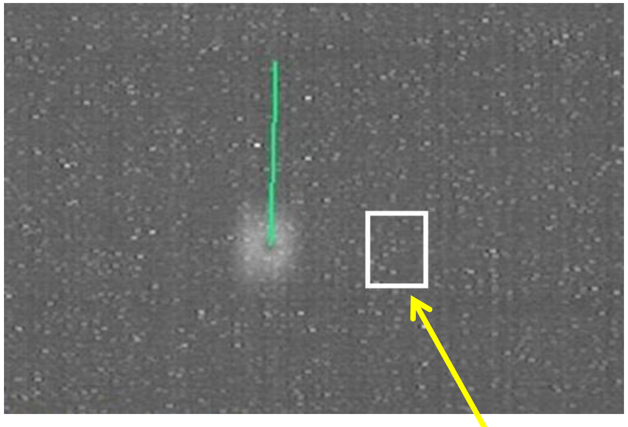
Range distribution in Al degrader



Beam spot size and implantation depth

Transverse dimension

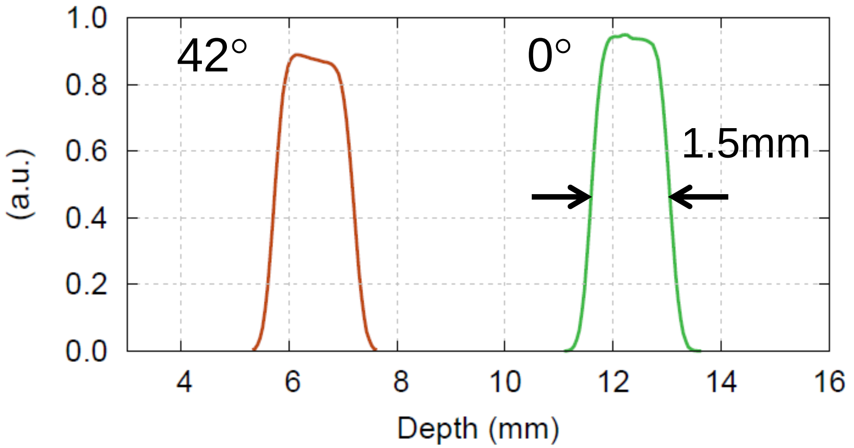
Spot image with high intensity pilot beam on "viewer"



Rectangle: 5x4 mm^2

Longitudinal dimension

Deduced implantation depth profile in CsI (LISE++/SRIM) vs degrader angle.



Diffusion of He in solids

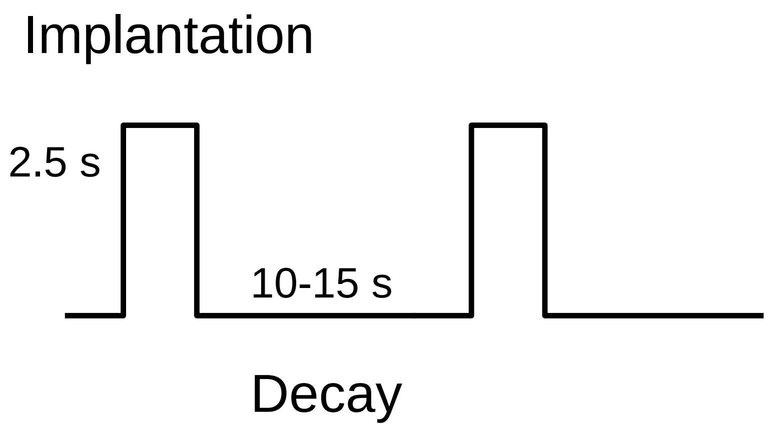
- Data of ^{6}He in graphite is available (SPIRAL1 target at GANIL) but extrapolation to lower temperatures is questionable.

- Diffusion coefficients of ^{4}He:

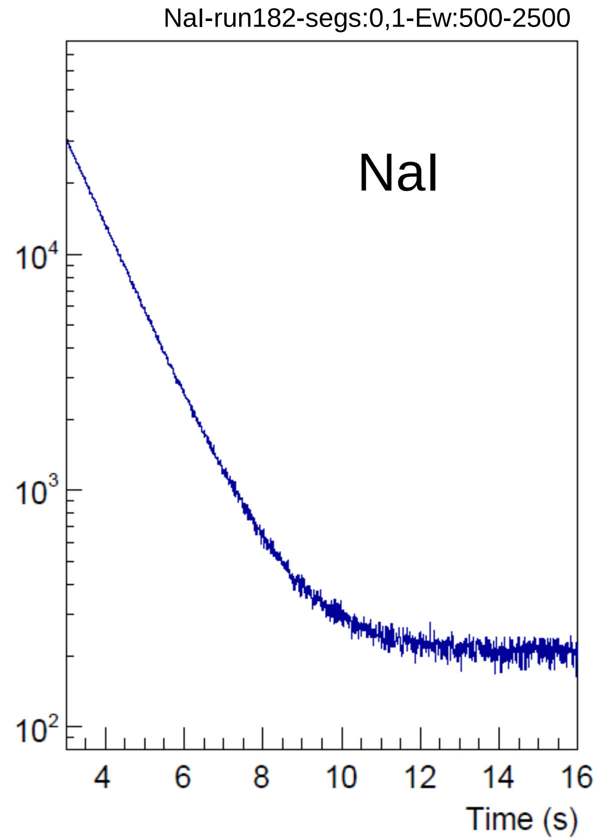
Material	Diffusion coeff. (cm^2/s)	Temp. (K)
SiO_2	$2.4\text{-}5.5 \times 10^{-10}$	293
NaCl	2.8×10^{-13}	369
Glass	4.4×10^{-8}	356

Within ~10 sec, the source "radius" would have increased by at most 10 μm.

Measuring sequence



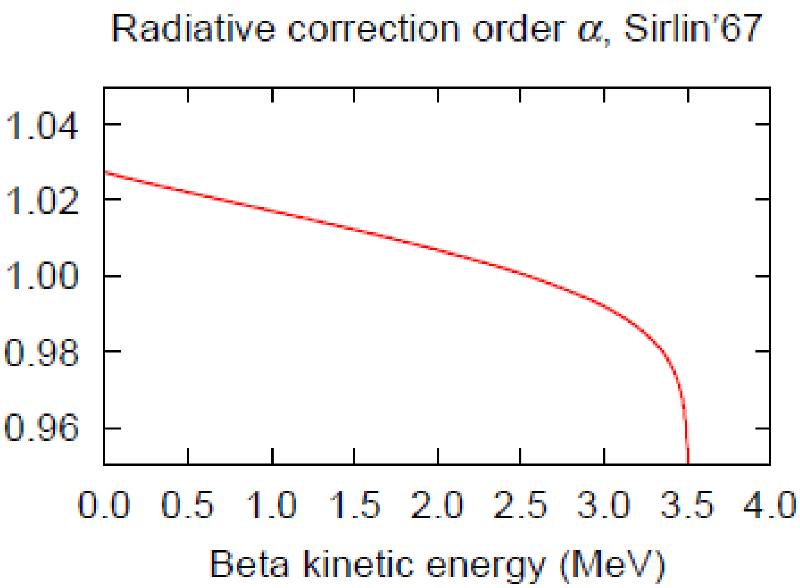
Decay spectrum



(Consistent with ^{6}He half-life and a single decay component)

5. Data analysis and simulations

Theoretical corrections to beta spectrum

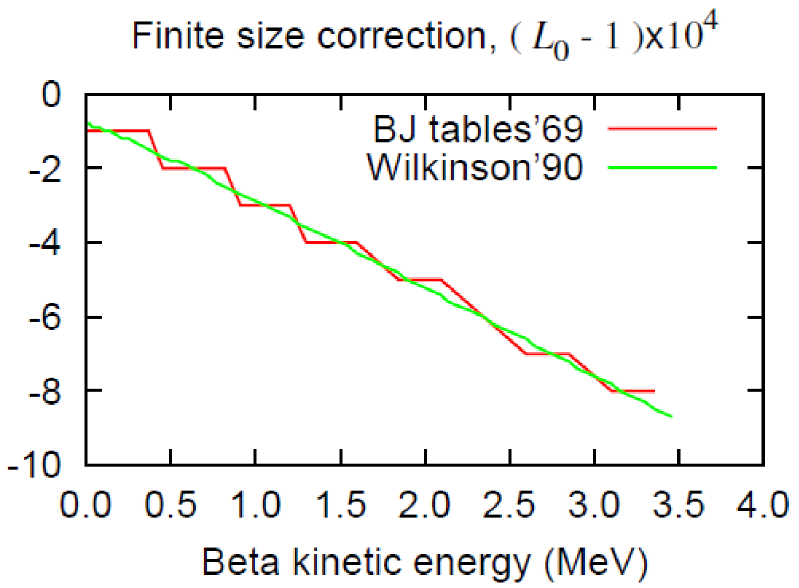


$$Z\alpha^2$$

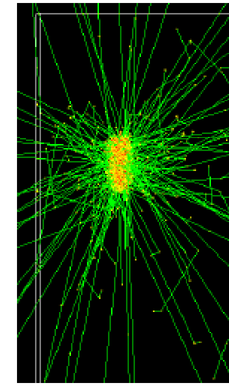
(Sirlin'87, not negligible)

$$Z^2\alpha^3$$

(could safely be neglected)

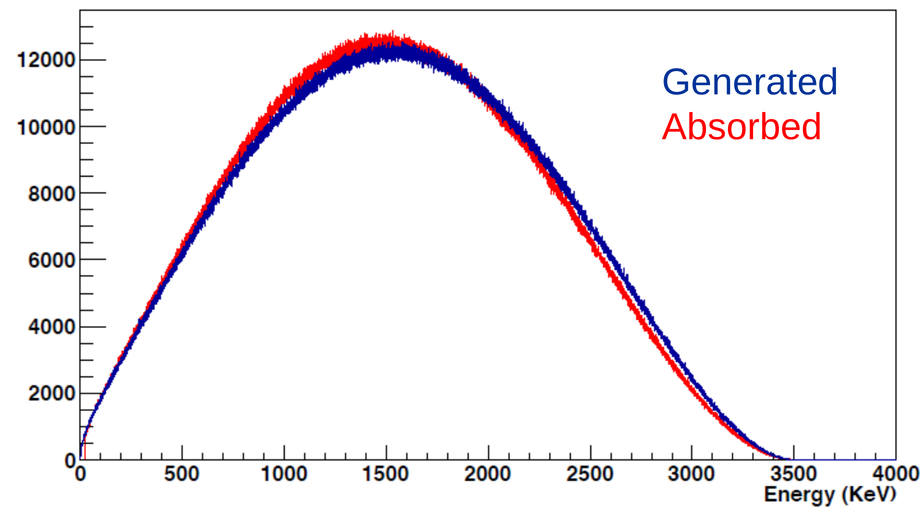


MC simulations



Calculate spectrum of the energy absorbed in the detector.
including the effect of escaping bremsstrahlung radiation.

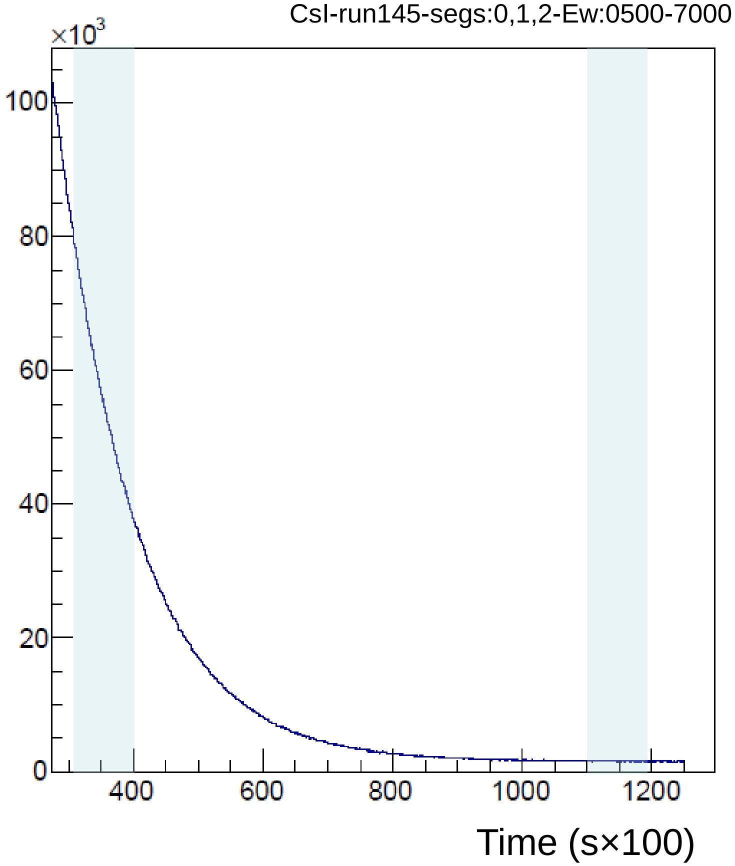
- G4 EM packages
  - Standard
  - Livermore
  - Penelope
- EGSnrc
  - Imp-0
  - Imp-1



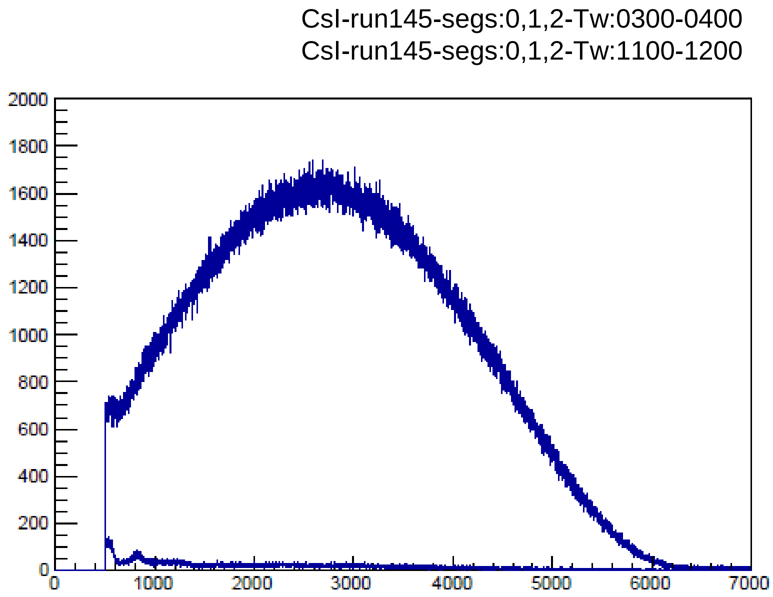
X. Huyan

- So far, the differences in the comparison between codes/ packages/ implementations have been observed to be < 5×10^{-4} /MeV.

Background subtraction



IN SINGLES !!!

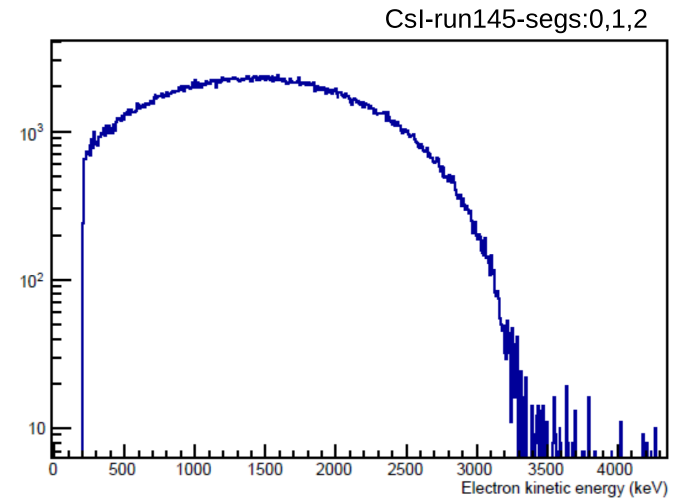


Different time windows offer independent analysis with different S/B ratios.

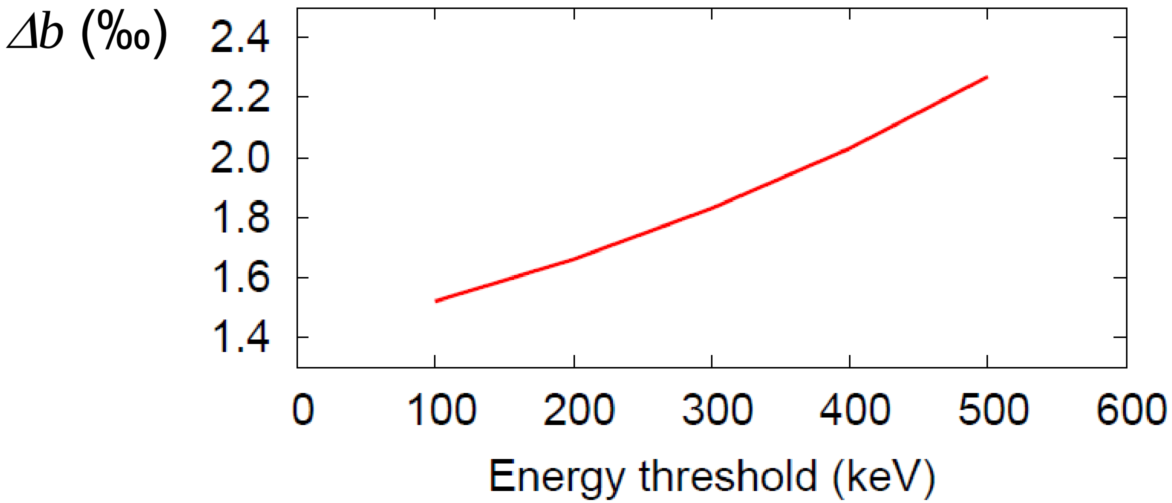
Statistics and sensitivity

- 1 h run ≈ 2×10^6 net events
- ~20 runs with CsI(Na) [1 day]
- ~20 runs with NaI(Tl) [1 day]

- Collected about 10^8 events



Sensitivity



Statistics is not a problem!

Instrumental effects

Compare results obtained from two independent measurement using different implantation detectors.

Property	NaI(Tl)	CsI(Na)	Effect
Signal decay time	230 ns	630 ns	Pile-up
Average *Z*	32	54	Bremsstrahlung
Composition	Na, I	Cs, I	Induced reactions

…analysis in progress

Summary…

• Hadronic contributions (WM) should manifest on the way to a precision measurement of b, at the level of about b=0.05. This provides a sensitive test of any technique for a measurement of b with higher sensitivity.

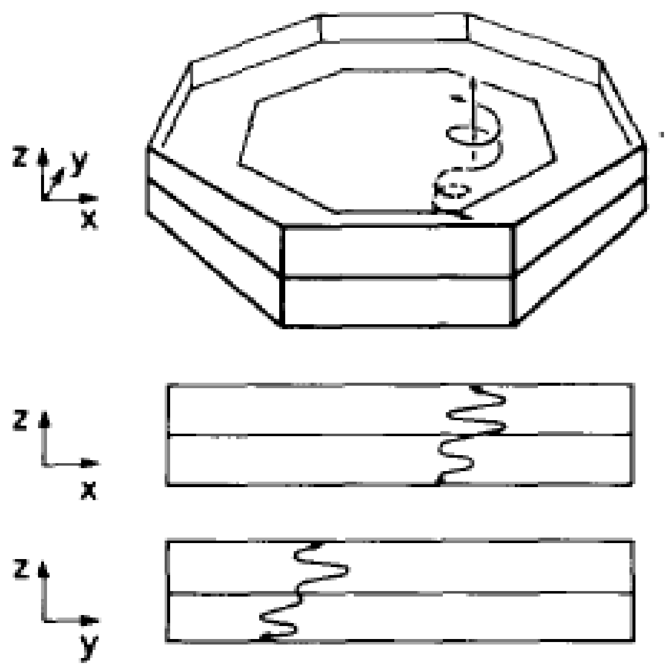
• We have explored a technique using implanted ions from fragmentation reactions at NSCL and have performed a high statistics measurement of the ^{6}He beta energy spectrum.

• No optimization has been made so far (detector size-ambient background-bremsstrahlung-external shield…). The first shot indicates that beam induced activation is ~3 times smaller than ambient background.

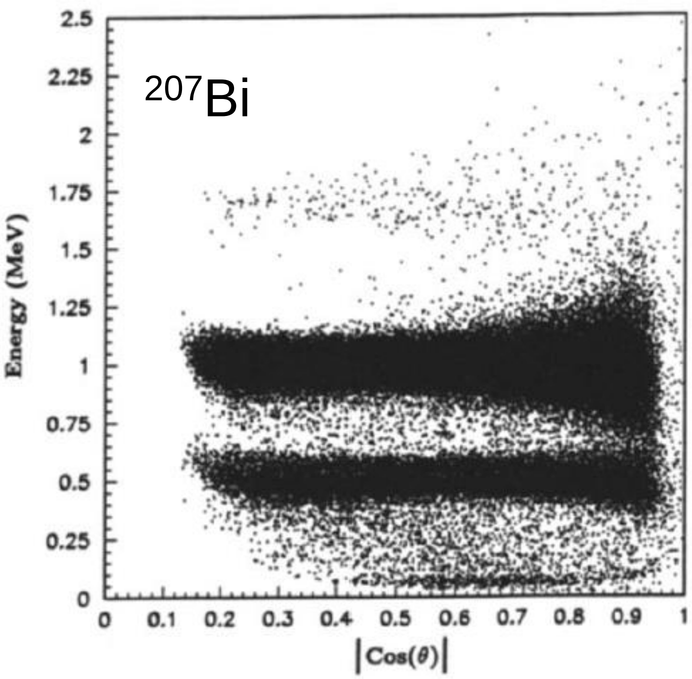
Outlook

• Backscattering effects can be eliminated by implantation in active detectors. Can we also reduce Bremsstrahlung effects?

S.R. Elliot et al., NIMA **273** (1988) 226

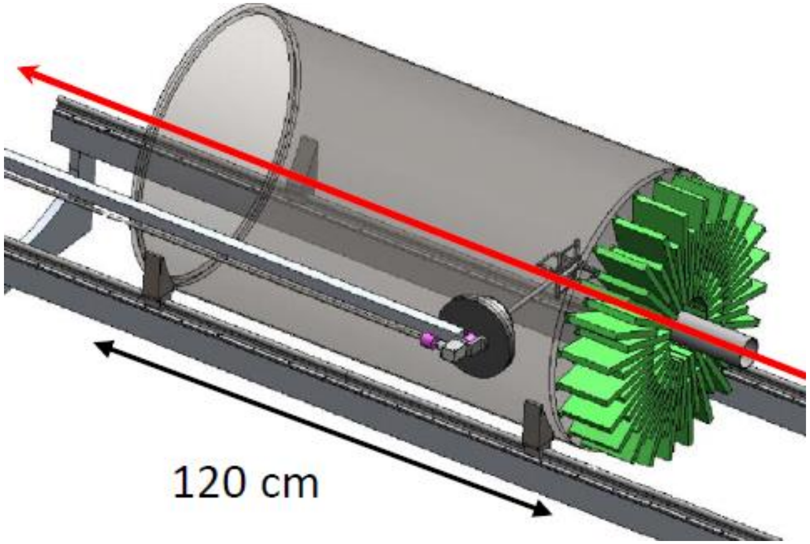


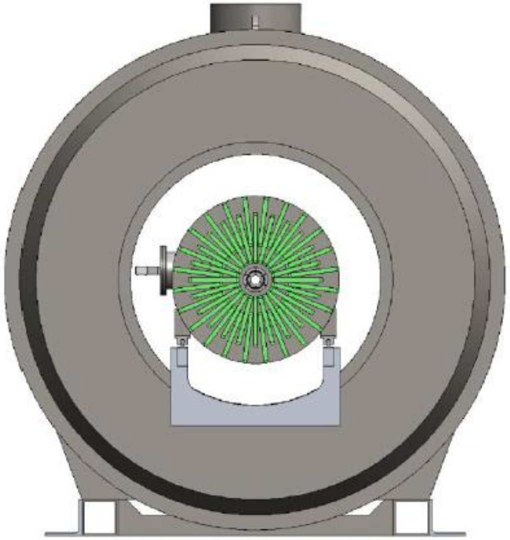
M.K. Moe et al., PPNP **32** (1994) 247



Outlook

(AT-TPC, NSCL, W. Mittig et al.)





10X better position resolution in all 3 dimensions.

Test response and track reconstruction with ^{207}Bi source located inside the TPC.

People and institutions

V. Bader[1], D. Bazin[1], S. Beceiro-Novo[1], M. Bowry[1], W. Buhro[1], A. Gade[1], M. Hughes[1], X. Huyan[1], S. Liddick[1], K. Minamisono[1], O. Naviliat-Cuncic[1], S. Noji[1], S. Paulauskas[1], A. Simon[1], P. Voytas[2], D. Weisshaar[1]

[1] *NSCL/Michigan State University, MI, USA*
[2] *Wittenberg University, OH, USA*