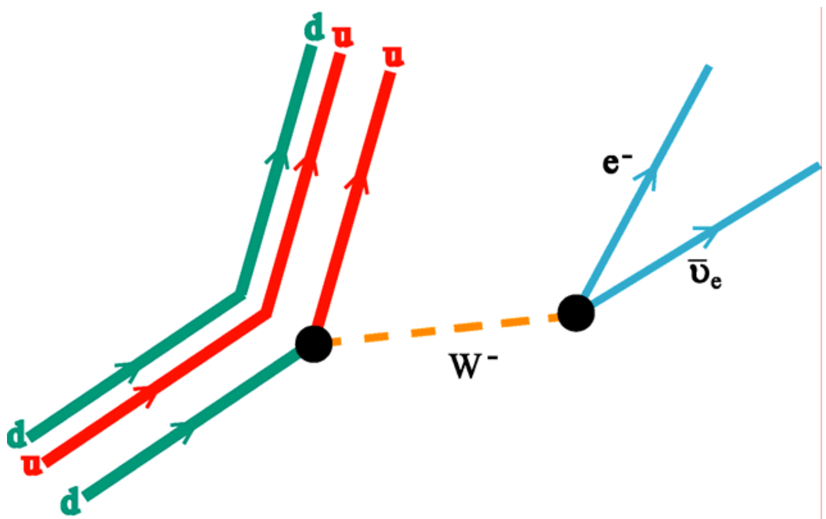
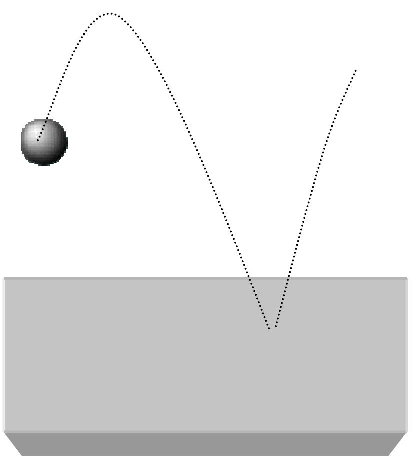
Overview of the UCNA Experiment





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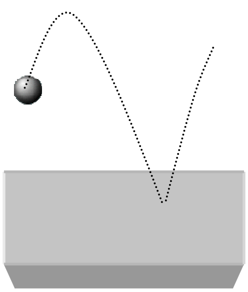


Outline

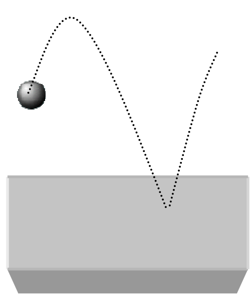
- Motivation (a few observations)
- Experimental approach
- Progress highlights

  April 2004 Source test

  Guides

  Polarization and spin-flipping

  Detector development
- UCNA schedule and new projects



Why Study Neutron Decay

"Clean" extraction of fundamental charged current parameters

All neutron β-decay observables are a function of three form-factors, two of which are specified in the standard model (there are two more which are negligible for our purposes):

$f^V,\ f^{WM}$ Specified by CVC

f^A Must be determined by experiment

Therefore typically two measurements must be performed on the neutron to extract standard model parameters…{lifetime, β-asymmetry, ν-asymmetry, β-ν correl.,etc…}
For example:

Neutron lifetime & Neutron β-asymmetry
+ μ lifetime
+ masses of p, n, e^-, and μ ⇒ G_F, V_{ud}, f^A

+ Weak decay rates for K, B mesons ⇒ Unitarity test of CKM
→supersymmetry

V_{us} remeasured/analyzed by E825, KTeV and KLOE and Vcd by Cleo-C

Neutron lifetime & Neutron β-asymmetry ⇒ L/R symmetric models

Neutron β-asymmetry energy dependence ⇒ f^{WM}
→CVC, SCC and the induced tensor ff

“Loops” are “in”

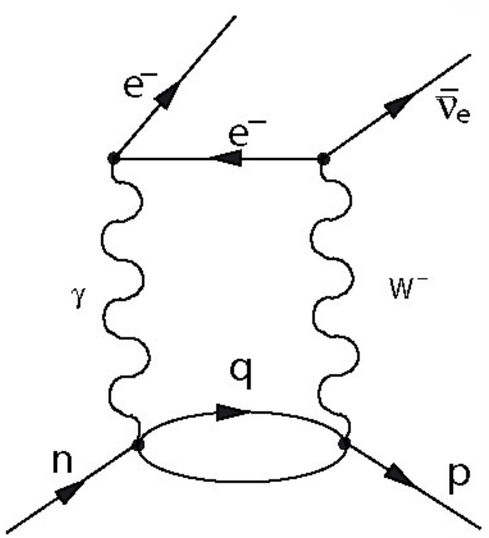
- Dominant theoretical uncertainty in extracting V_{ud} comes from hadronic loops

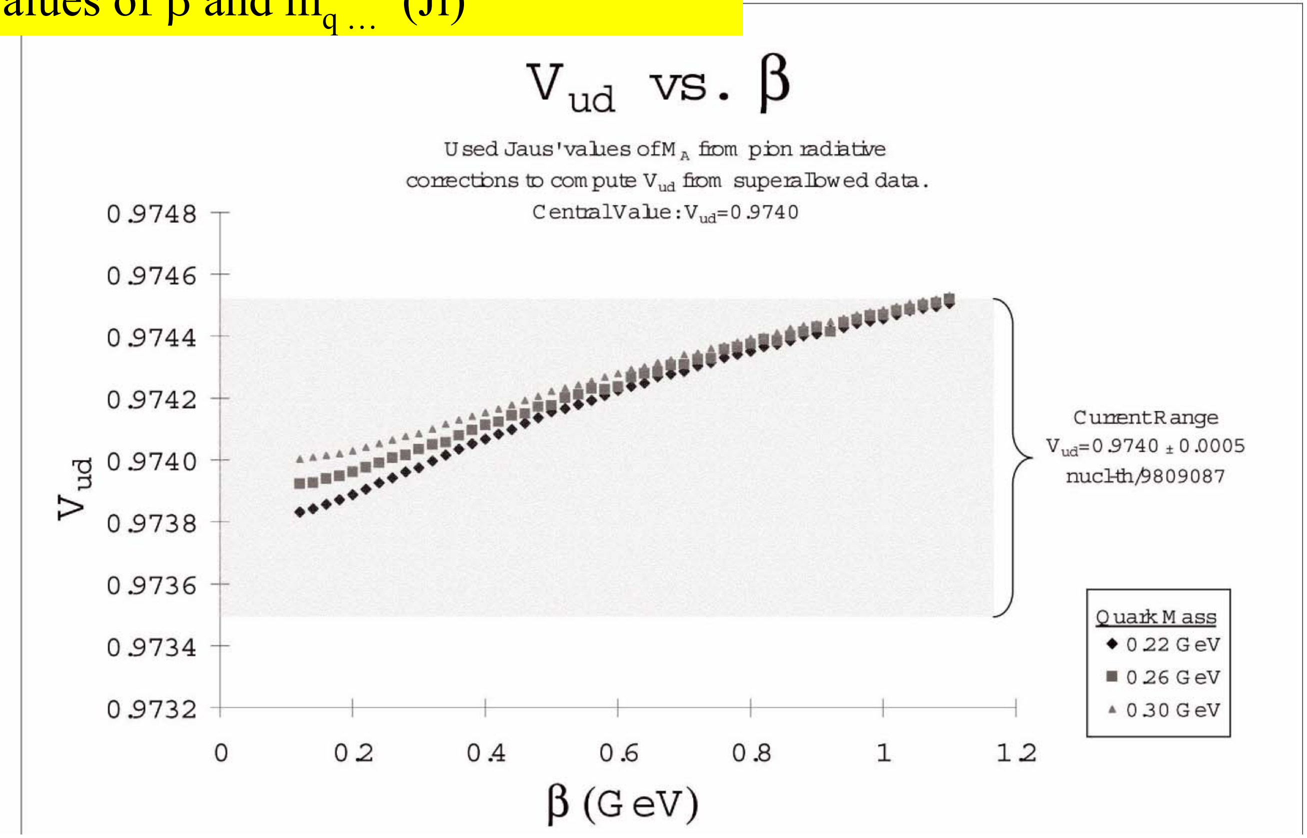
Sirlin, Rev. Mod. Phys. **50**, p. 573 (1978).

- At least four groups actively pursuing improvements in this situation:

Marciano and Sirlin, Ramsey-Musolf *et al.*, Gudkov *et al.*, and Ji

Ex: light front quark model reproduces full range of Sirlin radiative corrections for n beta-decay when model parameters range over *all* possible values of β and m_q … (Ji)

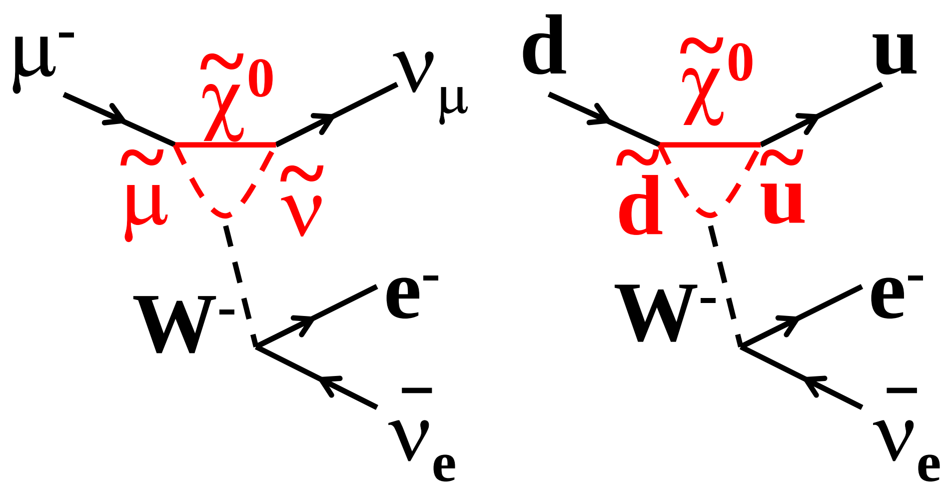




More loops!

Supersymmetry

Sensitive to loop corrections
β-decay sensitive to differences in squark/slepton couplings

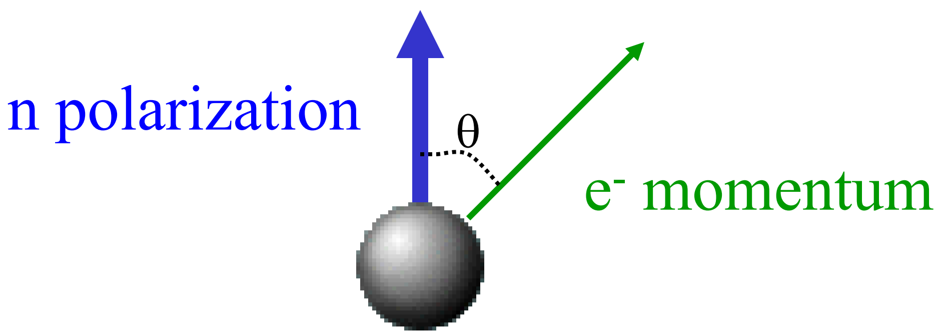


Kurylov and Ramsey-Musolf PRL88(2001)076007

Summary of Scientific Motivation

- Previous measurements only consistent at the level of roughly 1.2%
- Measurements of the beta-asymmetry provide a clean determination of fundamental parameters in the electroweak standard model
- Various extensions to the standard model are constrained by measurements of the beta-asymmetry (including super-symmetry, left-right symmetric models, a charged Higgs sector and second class currents)
- Although KTeV, E865 and KLOE are now reporting roughly consistent values for V_{us} in better agreement with CKM unitarity, there are also 2 new form factor calculations and the possibility of significantly improved data (from the KLOE collaboration), reducing existing uncertainties in V_{us} and setting the stage for improved confrontation between theory and experiment -- "jury is still out" (private communication: W. Marciano, Sept. 2004).

Beta-Asymmetry



$$R = R_o(1 + (v/c)\, P\, A(E)\cos\theta)$$

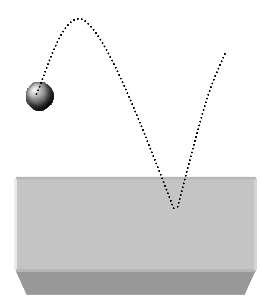
β-asymmetry = A(E) in angular distribution of e^-

To leading order:

$$A = -2\frac{-G_A G_V + G_A^2}{G_V^2 + 3G_A^2}, \qquad t_n = \frac{\text{constant}}{G_V^2 + 3G_A^2}$$

$$G_V = G_F V_{ud} f^V, \qquad G_A = G_F V_{ud} f^A$$

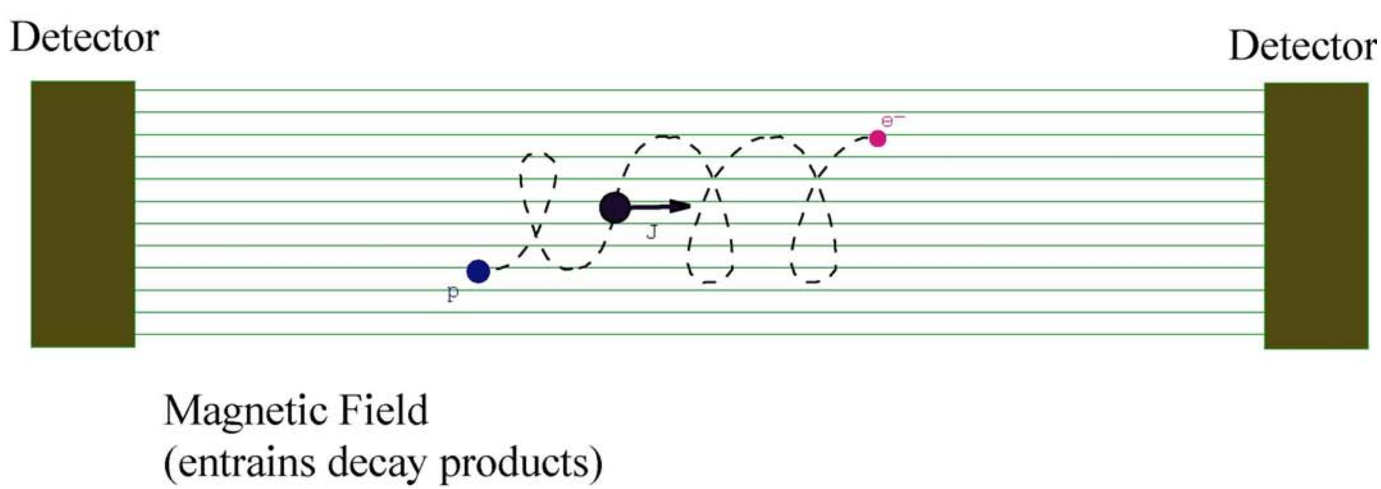
$$f^V = 1\ (\text{CVC}), \qquad f^A \cong 1.25\ (\text{expt})$$



Theoretical corrections: RC = 2.40±.08 %, leading recoil order terms ~ 1%/MeV

How to Measure a Beta-Asymmetry

β directional distribution: $1 + P\frac{v}{c}A(E)\cos\theta$
(polarized neutrons)



$$A(E) \propto \frac{N_+ - N_-}{N_+ + N_-}$$

We must determine P (the average neutron polarization), v and E (the β velocity and energy) and cosθ

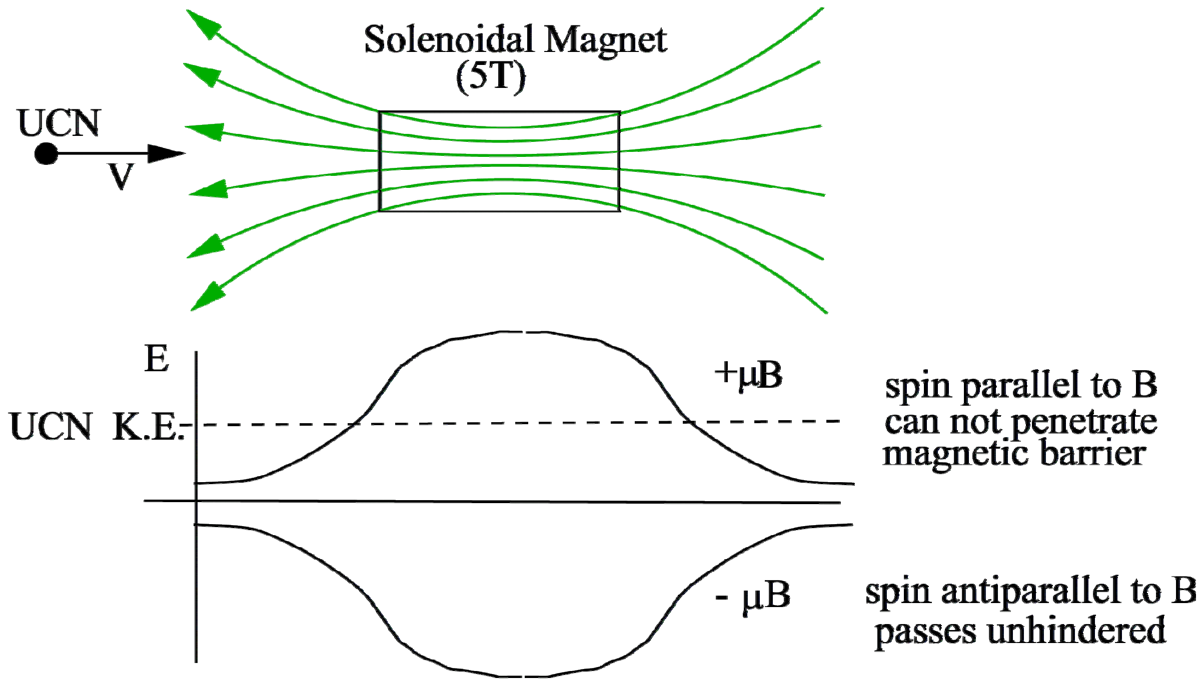
N_+,N_-,v and E: Signals from the detector arrays → singles backgrounds subtraction critical

cosθ: use magnetic fields to capture all decay products → $\cos\theta = \pm\ 1/2$ (with small corrections)

P: polarize UCN, limit depolarization and measure depolarized UCN fraction

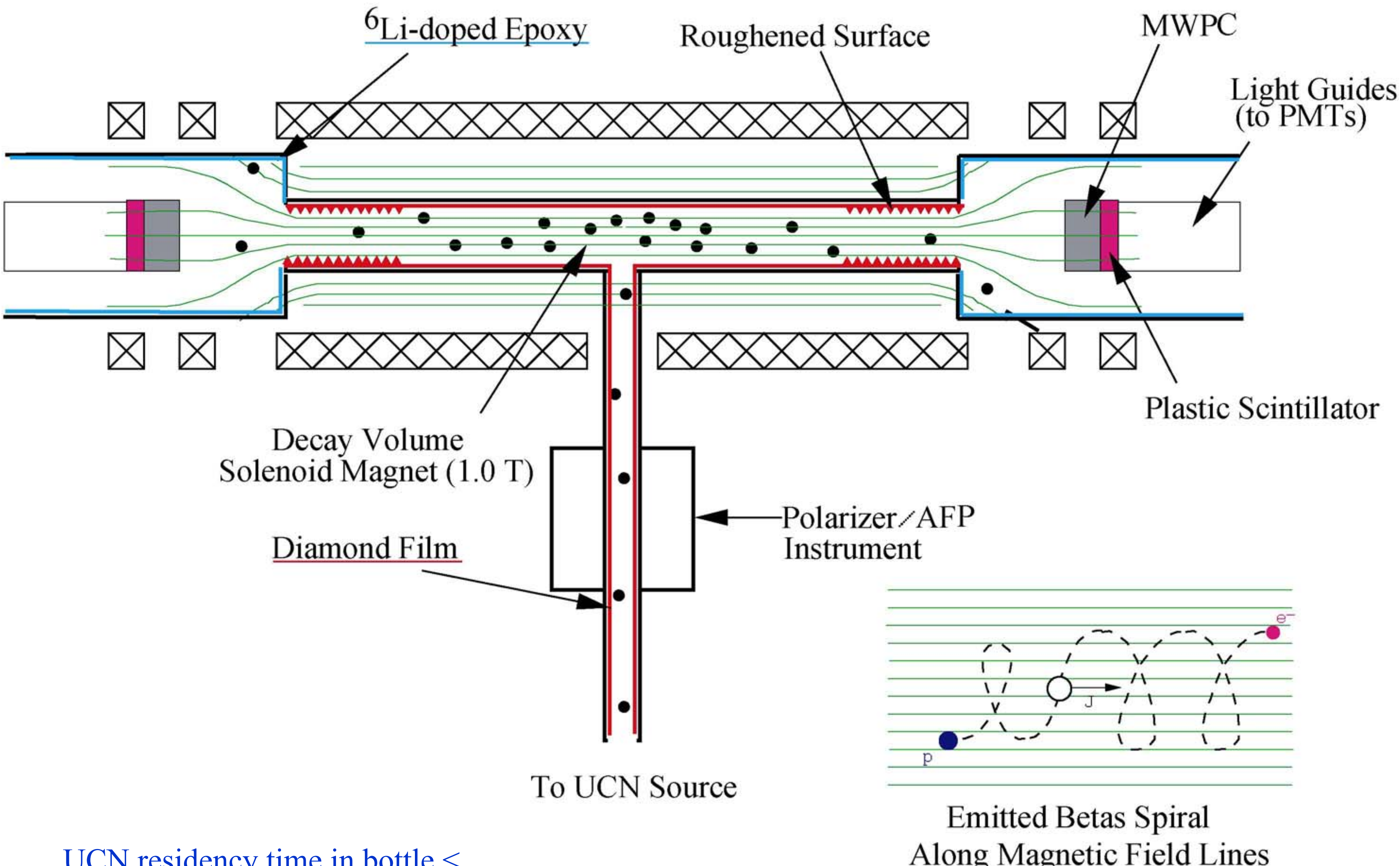
Advantages of using UCN for Beta-Asymmetry measurement

UCN can be essentially 100 percent polarized



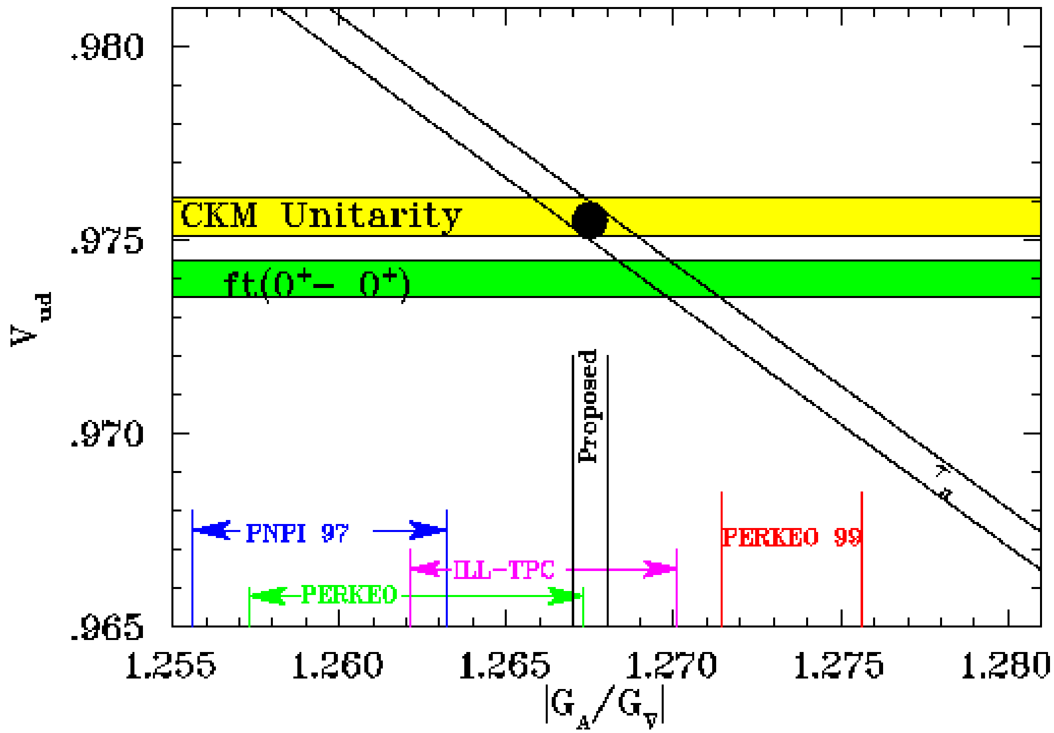
(note: neutron magnetic moment is negative)

Beta-decay measurements performed with UCNs produced at a spallation source may have an order of magnitude or more improvement in backgrounds (targets: > 100 Hz decay rate, <0.5 Hz total background rate)



UCN residency time in bottle <
5s to limit depolarization…

Status of Previous Experiments



Re-evaluation of V_{us} (?),

Shift towards agreement *and* reduce uncertainties in Unitarity range

Experiment		A (Beta-Asymmetry)	Systematic Corrections P	Background	Other
PERKEO	1986	-0.1146 ± 0.0019	2.6%	3%	Mirror: 12%
PNPI	1991	-0.1116 ± 0.0014	27%	small	
ILL-TPC	1995	-0.1160 ± 0.0015	1.9%	3%	Sld ang:15%
PERKEO II	1997	-0.1189 ± 0.0012	1.5%	1.6% (15% "env")	
PNPI* (revised)	1998	-0.1135 ± 0.0014	~27% (adj.)	small	
PERKEO II	2000	-0.1189 ± 0.0007	1.1%	0.5% (15% "env")	

& detector characterization, usually minor correction until now, is growing increasingly important!

Systematic Uncertainty Budget

Original Goal: measure A to precision of 0.2% or better

for a decay rate of 116 Hz in our bottle

requires 45 days of beam time + 45 days to explore systematics

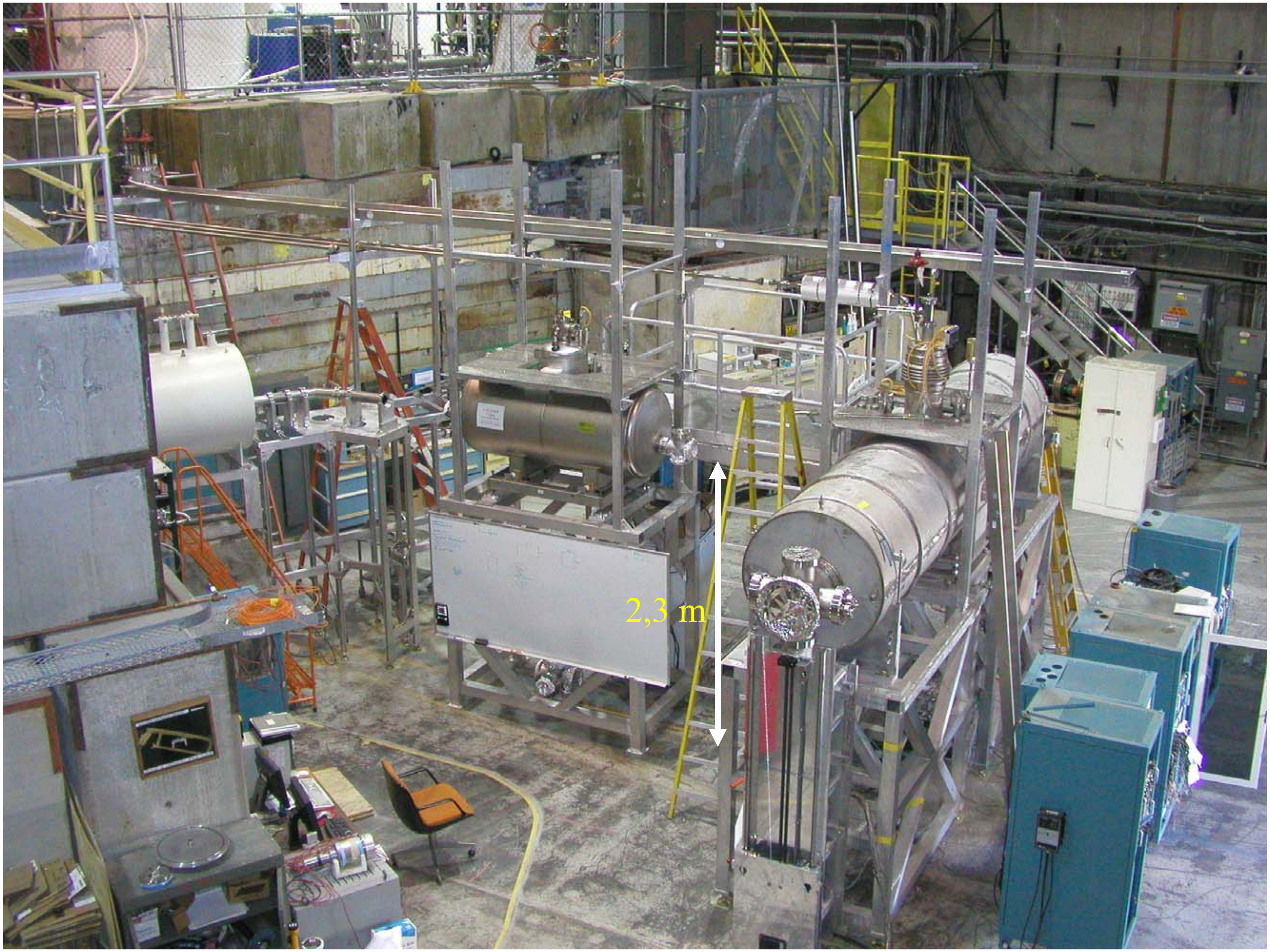
Dominant systematic corrections

Systematic Effect	Size of correction	Uncertainty
UCN Pol/spin-flip eff.	1×10^{-3}	1×10^{-4}
Wall depolarization	9×10^{-4}	1×10^{-4}
Backscattering	2×10^{-3}	4×10^{-4}
Field non-uniformity	7×10^{-4}	7×10^{-5}
Detector response	3×10^{-4}	3×10^{-4}
Detector linearity	6×10^{-5}	6×10^{-5}
Total background	.5 Hz	.1 Hz
Total	2.5×10^{-3}	1.0×10^{-3}

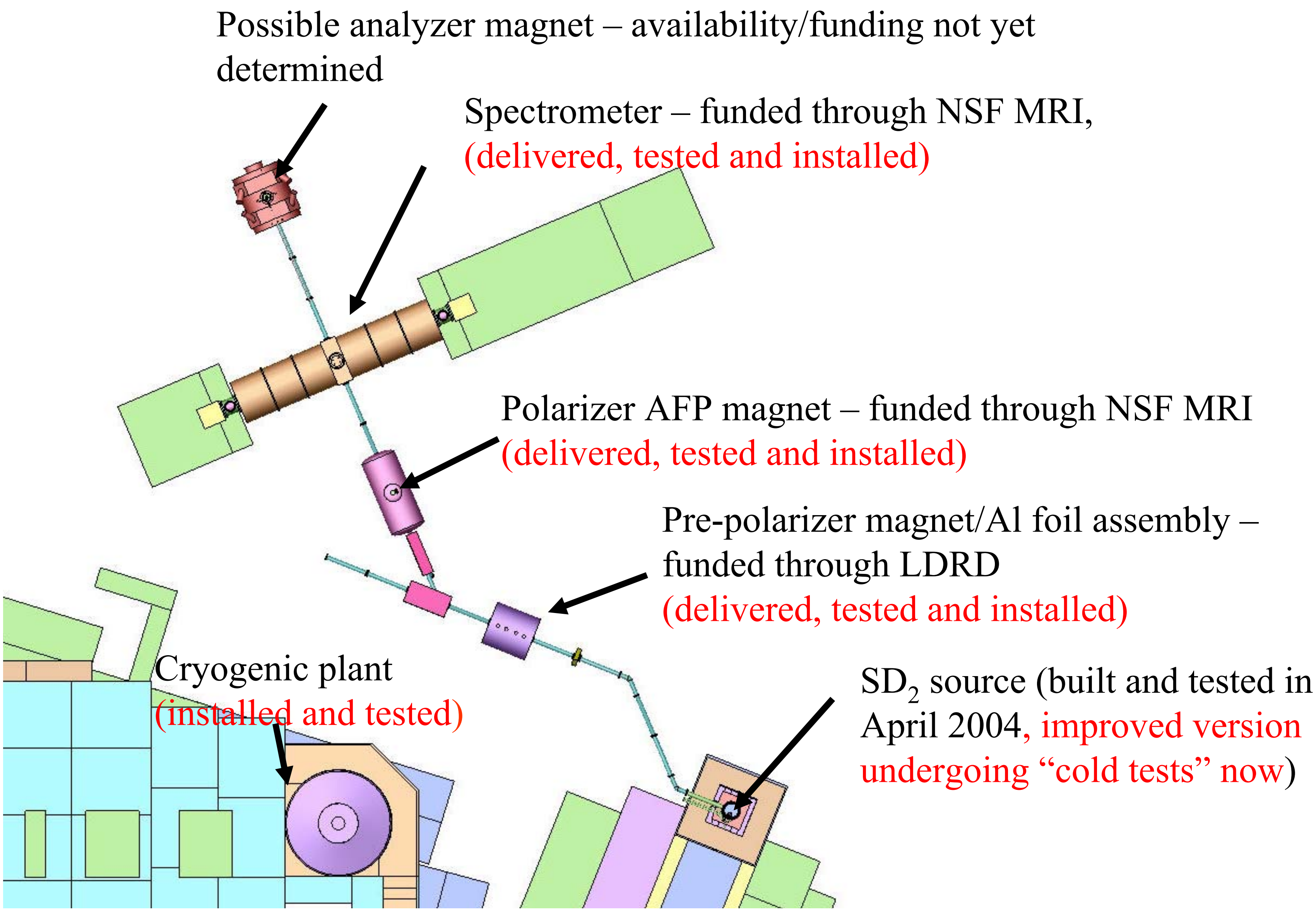
Leading corrections roughly order of mag smaller than prev experiments

Need *in situ* measurement with UCN!

It’s essentially built!



Major-System Status:

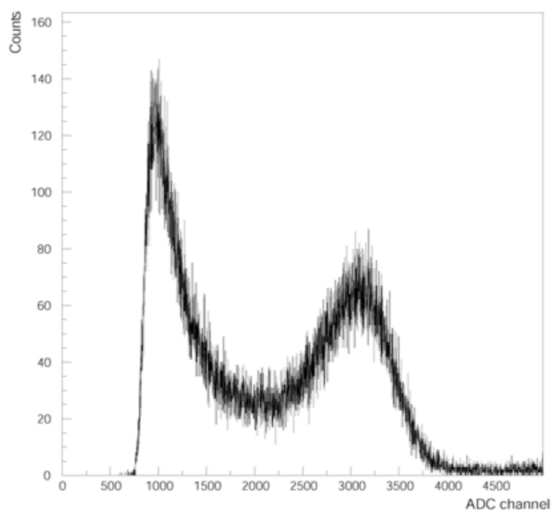


April 2004 Tests of the Area B Source

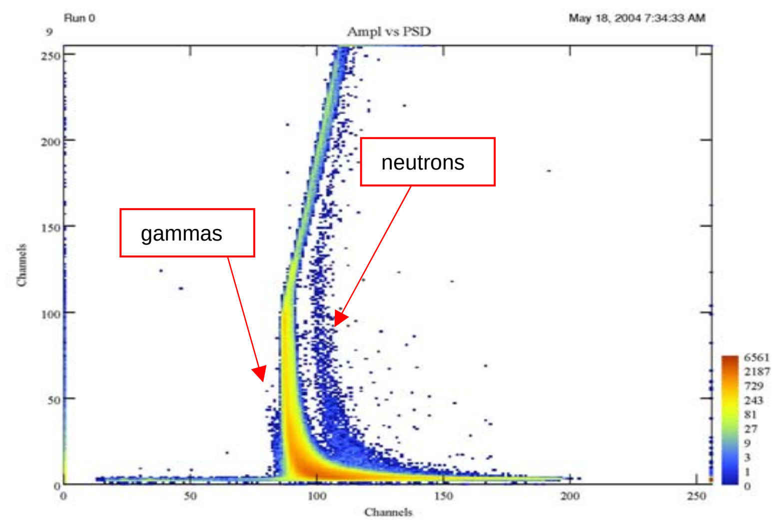
UCN PRODUCTION → see source talk (still project more than adequate UCN density to meet our goal of 116 dps)

AMBIENT BACKGROUNDS → extremely low (as we expected)

- Measured ambient backgrounds in beta-detectors consistent with being dominated entirely by cosmic-ray muons (beam-generated backgrounds in the energy range of interest are negligible with a 1ms cut around the time beam is on target) when full current directed on target



^{113}Sn spectrum taken in Area B



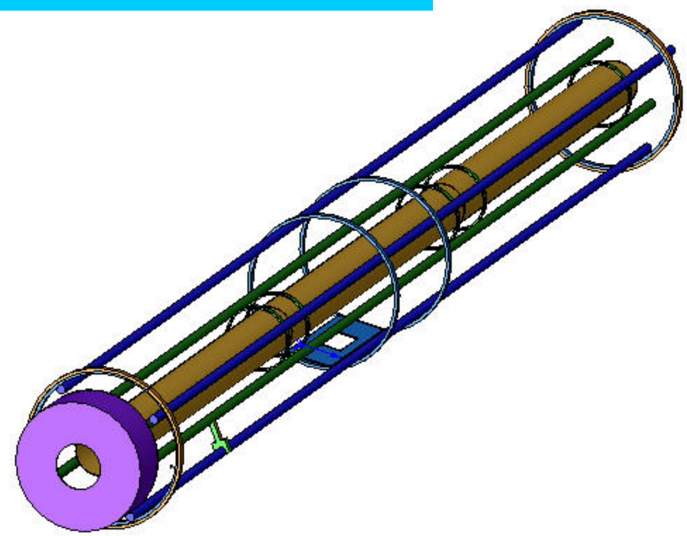
Beam-generated neutron and gamma spectrum

- Beam-produced fast neutron and gamma backgrounds also independently evaluated and found to be negligible outside of a 1ms window when beam is on target

Guide Development and Construction

PLD & ^{58}Ni

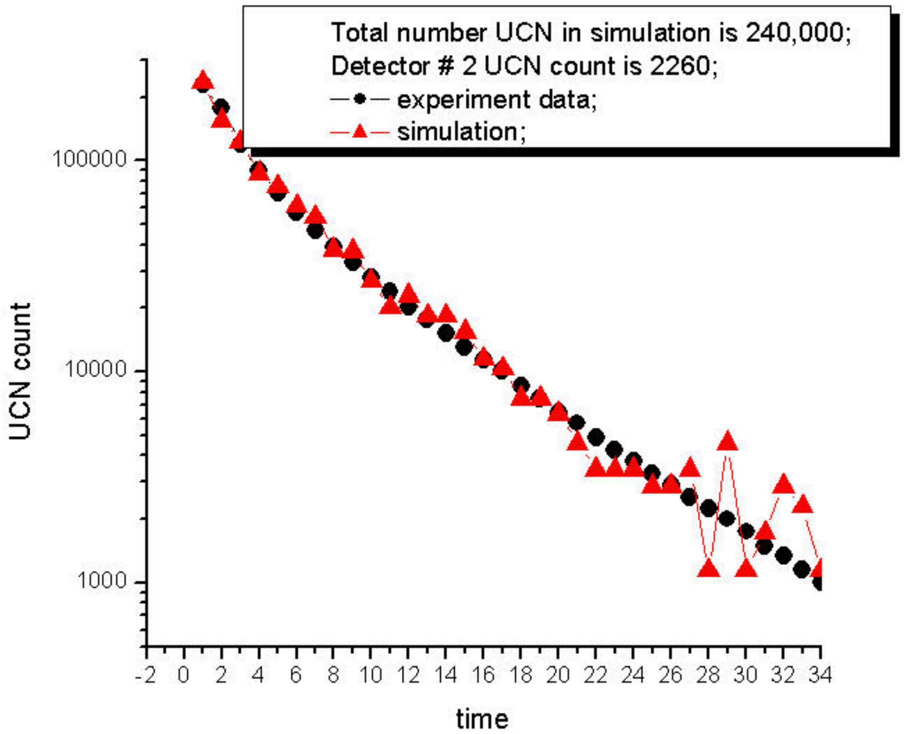
- PLD DLC coatings on quartz substrates provide > 99% specularity (now our standard)
- all guide tubes coated and delivered
- excimer laser to provide PLD coating
- e-beam to allow coating with Cu and Ni
- can coat 1m tubes and UCN source parts



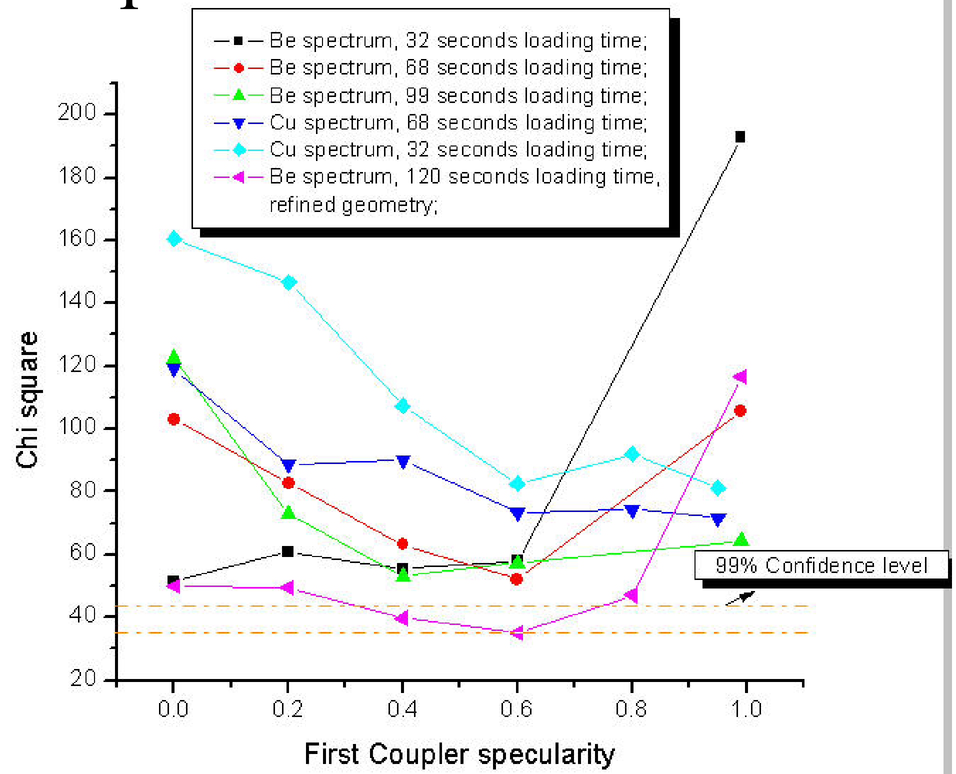
Decay Trap

- assembled and installed
- rail mounted to allow extraction from SCS
- Diffuse sections fabricated using diamond scribe on a conventional lathe
- will be biasable to +/- 10 kV (not implemented yet)

Understanding Guide Transport -- Simulations



Simulated signal in detector 2 after switcher state changes



Study of agreement (over 48 seconds) of simulated detector 2 signal and exptl data

We have steadily improving confidence that we have developed a superior guide technology and that it will perform as we expect in the UCNA experiment

UCN Polarization

Overall strategy:

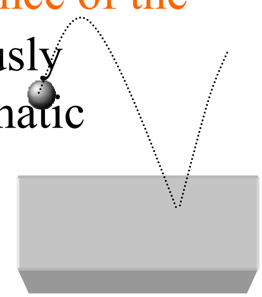
(1) Use high enough polarizing field to ensure complete rejection of wrong-spin UCN – established via Monte Carlo thus far

(2) Reduce all sources of depolarization to well below 0.1%

Utilize PLD diamond-like carbon films to ensure extremely low depolarization rates on guide walls

Utilize "Birdcage" resonator: rf-spin flipper with greater than 99.97% efficiency (from Monte Carlo and analytical ests)

(3) We also plan to monitor the polarization *in situ*, monitor the time dependence of the asymmetries during bottle loading and emptying periods, and simultaneously measure the proton asymmetry to quantitatively assess polarization systematic uncertainties…



Results of R&D at ILL

PLD has 3 times lower depolarization rate than best previously measured materials! (graphite and copper)

Depol. / bounce < 3 x 10^{-6}

AFP efficiency consistent with our expectations

AFP efficiency 99.6 ± .4%

Soldner reports better than 99.9% efficiency for CN using rf AFP technique (Sept., 2002)

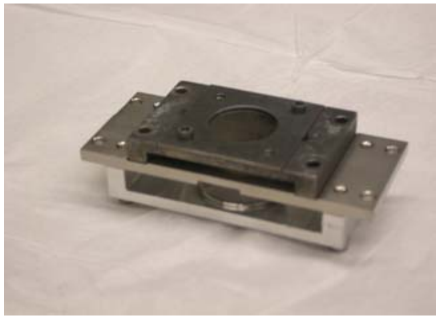
UCN Detectors and Absorbers

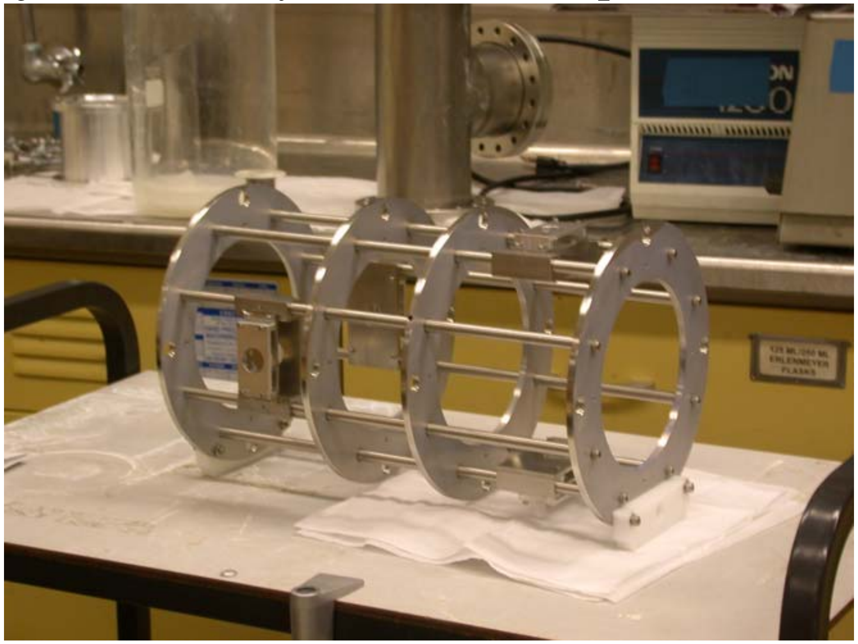
Detectors:

- General purpose, surface barrier detectors with converter foil (200 nm Ni foil with coatings on outer face)

- New approaches to converter foils: ^{10}B implanted in Vanadium evaporated on the outer face or ^{6}LiF evaporated on the outer face of 200 nm Ni foil substrates (to reflect UCN and improve efficiency)

- Detectors and absorbers mounted on adjustable rail system in field expansion area





Absorbers:

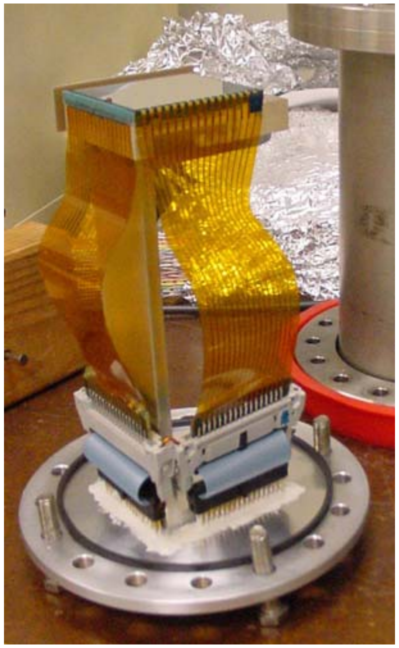
- Evaporated ^{6}LiF

- TPX plastic film

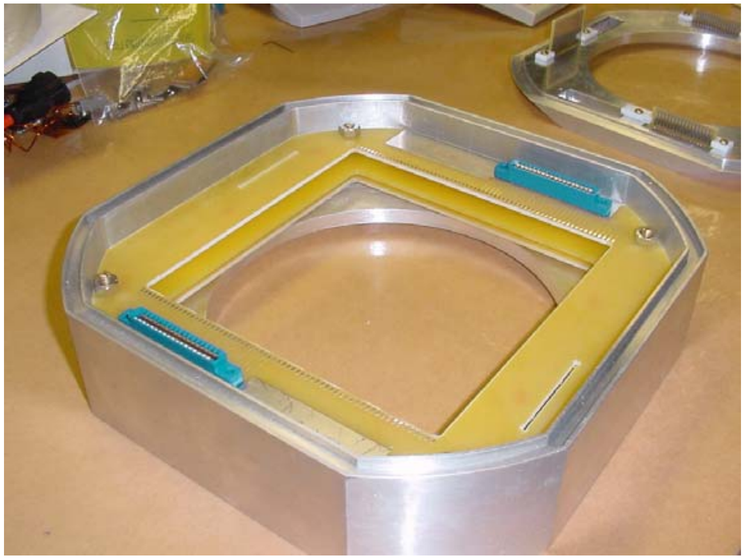
Detector Strategy

Because each detector system has a characteristic set of systematic corrections, we plan to ultimately use several different systems to characterize beta-decay in our spectrometer

- Use MWPC + plastic scintillator ← Initial measurements
  - minimize backscatter (low Z)
  - maximize efficiency for betas
  - avoid aperture corrections using position sens.
  - reduce backgrounds through coincidence req.
- Use silicon detector (possibly together with MWPC)
  - excellent spectroscopy for slope measurement
  - permits spectral anaylsis of some backgrounds
- Apply accelerating fields to detect protons (using thin films or Si -- low energy proton beam already constructed)



Si-microstrip Detector

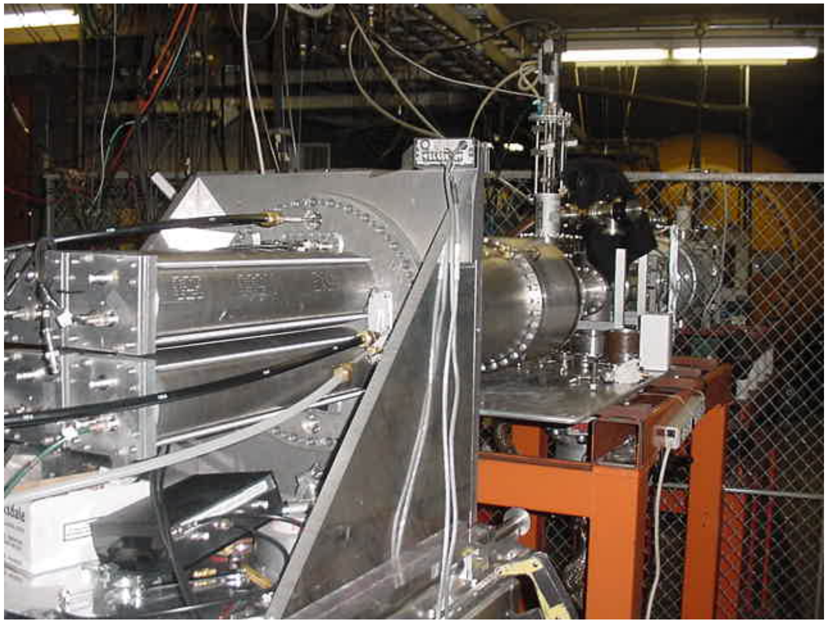


MWPC Detector

Scintillator Detector

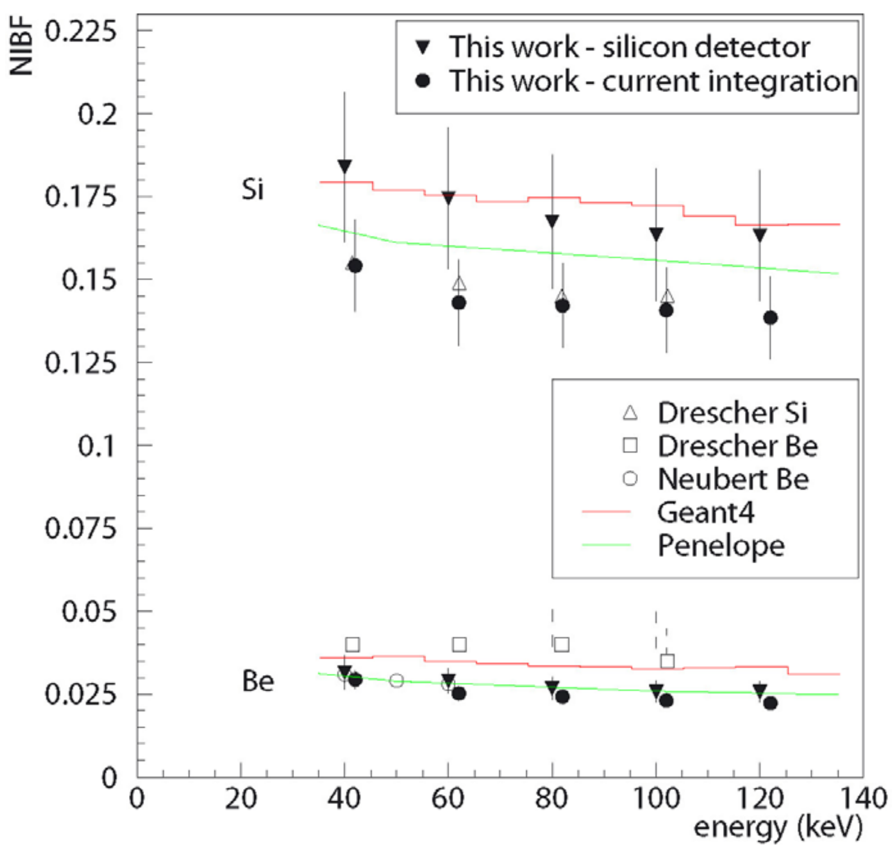
Beta-detectors

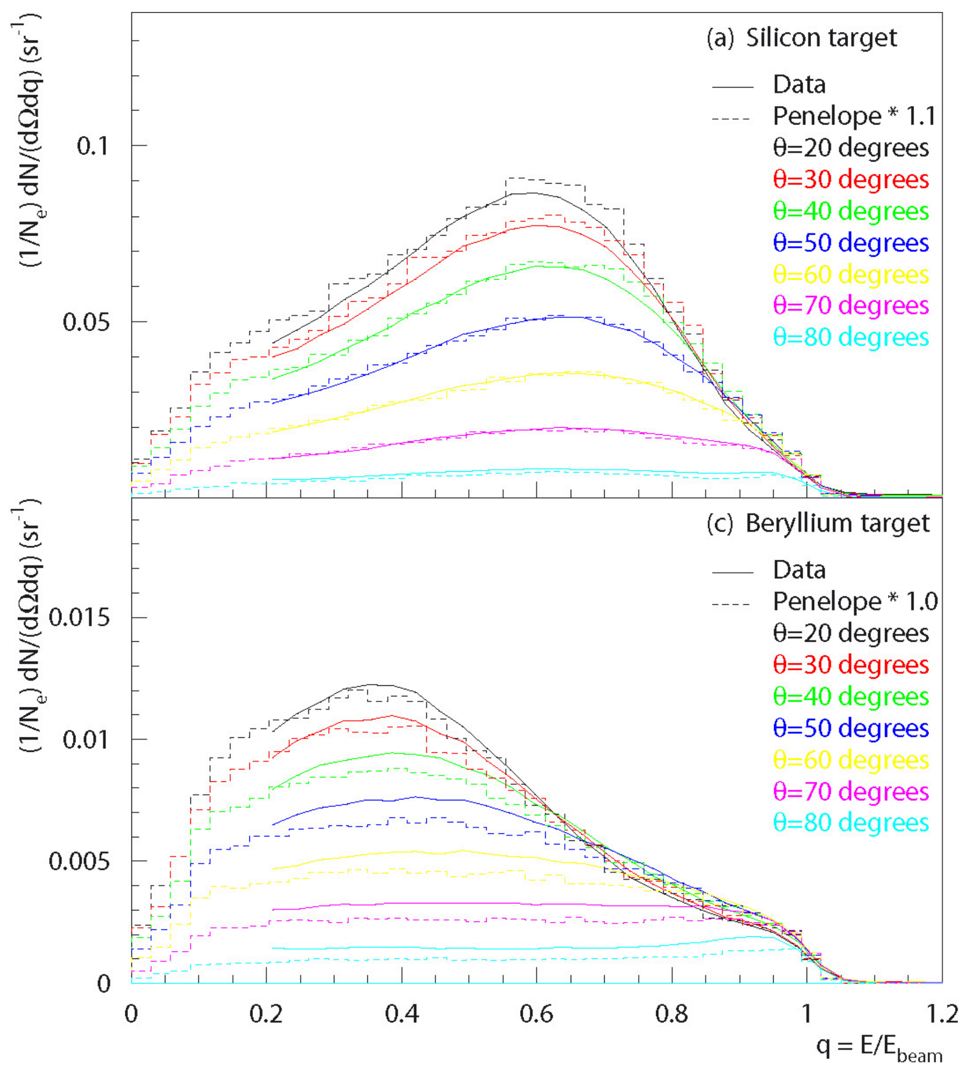
- Both Plastic scintillator and MWPC detectors are constructed, tested and installed in AREA B
- The beta-detector's response function has been thoroughly and carefully mapped from 20 keV to 120 keV using the Kellogg tunable electron beam -- first time such a program undertaken for a beta-asymmetry experiment
- A long-standing issue concerning the actual thickness of the dead-layer on plastic scintillator has been quantitatively investigated
- Noise, beam-generated backgrounds and backgrounds due to cosmic rays now measured for a full detector system in AREA B



Results of Detector R&D

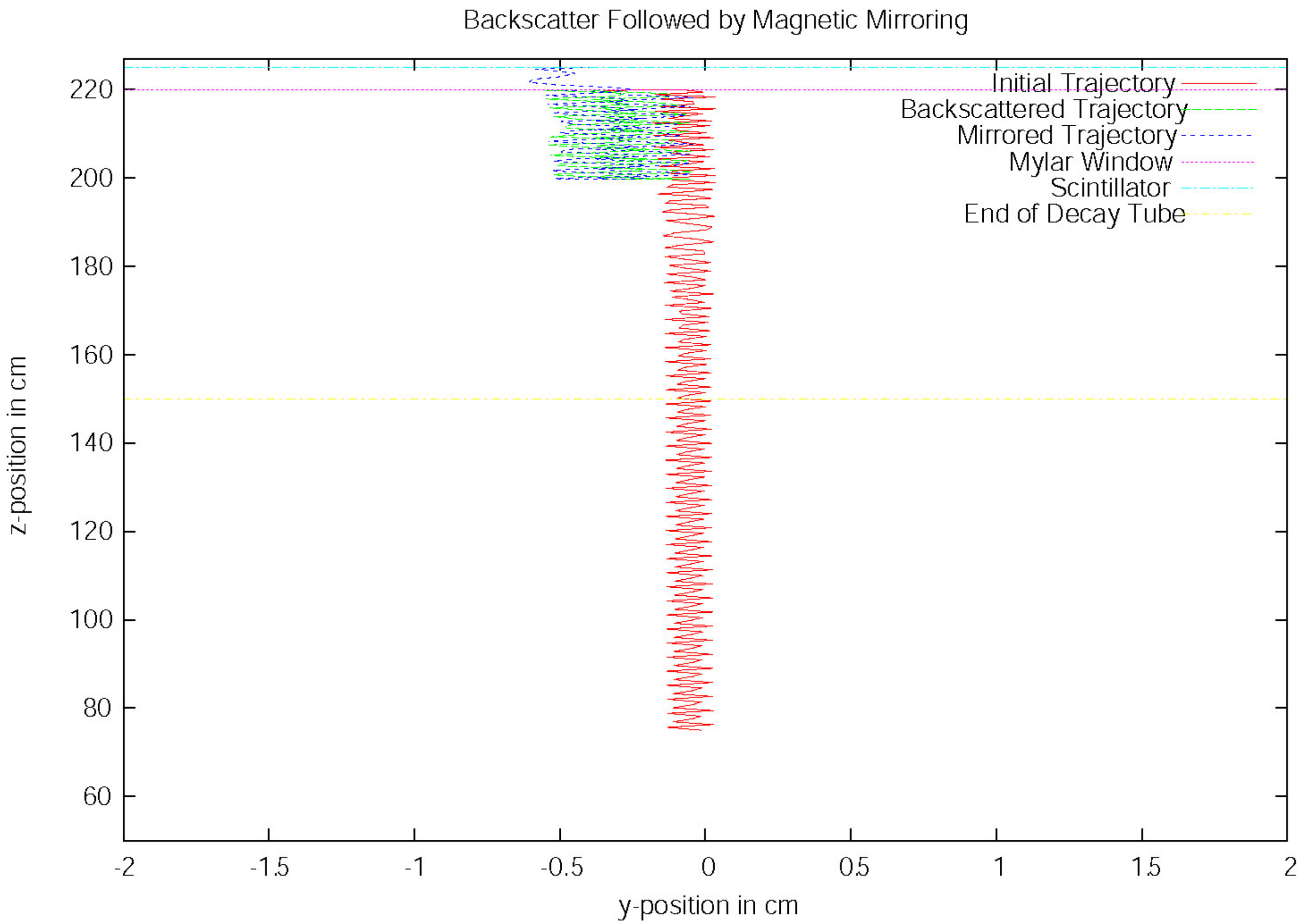
Conclusion: data and M.C. consistent at 15% level





New results for scintillator to be published soon!

An analysis goal was to develop two independent simulations of the beta signals in our detectors. One is the GEANT4 simulation, already developed, and the other is based on PENELOPE (see Seth Hoedl's thesis). The PENELOPE simulation required the development of a transport package in inhomogeneous fields which is now complete:



Conclusions for UCNA program

- Motivation for our measurements is strong
- We have either completed or made a great deal of progress on all aspects of the experiment. Essentially all construction is now complete.
- By the end of the planned run schedule for 2005, we hope to have an interesting, preliminary value for the beta-asymmetry!

New Physics Measurements Planned for the AREA B source

- Angular correlations involving measurements of both beta and proton recoils at UCNA (funded and ongoing)
- Neutron lifetime experiment (funded through LDRD, D. Bowman, spokesman)
- EDM test apparatus (funded through LDRD)
- Other fundamental studies (gravity, nnbar, etc…)
- Limited UCN source studies