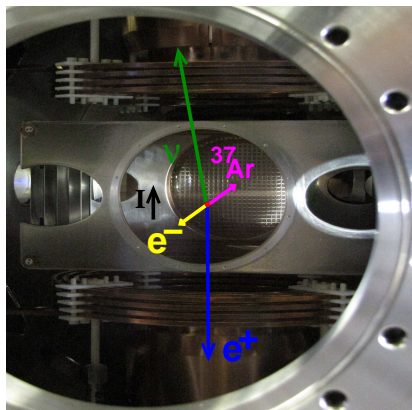


S1070 Upgrade of ^{38m}K β - ν correlation

Gorelov 2005 PRL is the best measurement now, and we need much care to plan to make it better

- **Motivation update**
Theory+Phenomenology
from other experiments
Other β - ν experiments
- **Experiment status**
- **Beam request**
included original E1070
talk slides



Pure Fermi β - ν correlation

- $0^+ \rightarrow 0^+$ pure Fermi β decay has tiny and well-understood higher-order corrections— the standard model prediction is cleaner than for the neutron

The lepton helicity argument for $a=1$ —

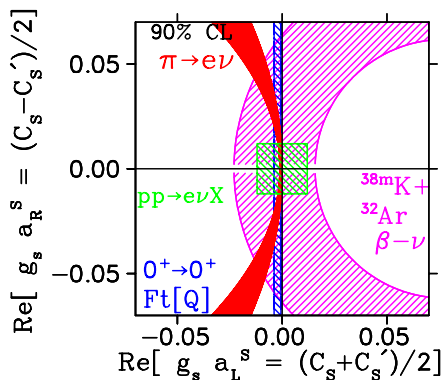
lepton and antilepton can't be emitted back-to-back because they carry off spin 1—
does not depend on isospin mixing.

Radiative correction (real photon emission) is 2×10^{-3} , calculable to few percent of its value

Recoil-order corrections start at 1×10^{-4} .

No nuclear structure-dependent corrections until 2nd-forbidden transitions, down by at least 1×10^{-6}

Constraints on scalar interactions



- The best constraints on scalars coupling to ν with standard helicity are from the superallowed Ft values.

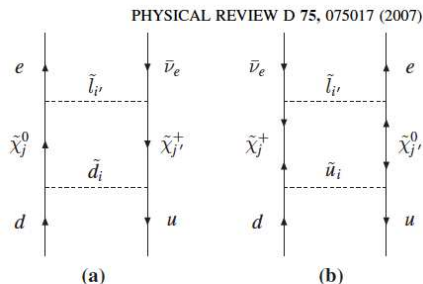
One goal of S1077 is to achieve similar sensitivity within one experiment

- LHC constraints ($p p \rightarrow e \nu X$ Cirigliano et al.) have improved on scalars coupling to wrong-handed ν

$\pi \rightarrow e \nu$ will have more accuracy from TRIUMF and PSI soon.

dodges for EFT in both cases, e.g. by lighter bosons with weaker coupling strength.

Theory: SUSY contributions to β decay



SUSY can produce up to 0.001 changes in nuclear β decay observables.
Not direct exchange of leptoquarks
but higher-order 'box' diagram with two particles exchanged at once.

FIG. 2. Feynman diagrams relative to supersymmetric contributions giving rise to anomalous amplitudes in β decay processes.

This corner of SUSY is hard to constrain and hard to eliminate. Profumo et al. considered \tilde{d} , \tilde{u} masses 1-10 times the lightest SUSY particle mass, not actually using Tevatron constraints. Some such masses are ruled out by LHC but a full reanalysis would have to be done.

Other Experiments: β - ν correlation in other traps

Two ion traps working on ^{35}Ar , a mixed F-GT with a small GT contribution

Usually interpreted as another superallowed Ft measurement, but if take V_{ud} from elsewhere and include an isospin mixing calculation, then are sensitive to scalar interaction

Caen's LPC trap at GANIL: taken data with statistical error 0.002, systematics under analysis [G. Ban et al. Annalen der Physik 525 576 (2013)]

WITCH 1st proof of principle (S. Van Gorp, thesis)

Short-lived potassium yields May-June 2014

High-power TiC with finer-ground TiC

$1 \times 10^8/\text{sec}$ ^{37}K for 3 weeks

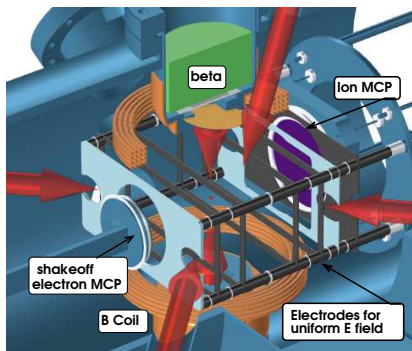
$70 \mu\text{A}$ not fully heating target

$100 \mu\text{A}$ produced 2x more; rotating beam to make target temperature more uniform should help

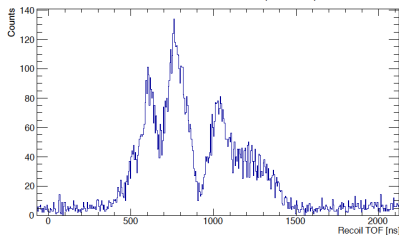
Same half-life as $^{38\text{m}}\text{K}$. Previous yields from TiC have been about the same

Trapped 10,000 atoms of ^{37}K , which extrapolates to the 5x rate for $^{38\text{m}}\text{K}$ that is in the original E1070 proposal

^{37}K spin-polarized experiment technical progress

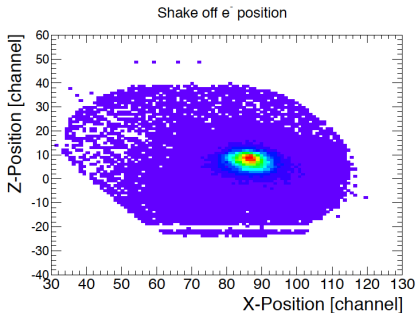


TOF w.r.t. scintillator (Run 423)

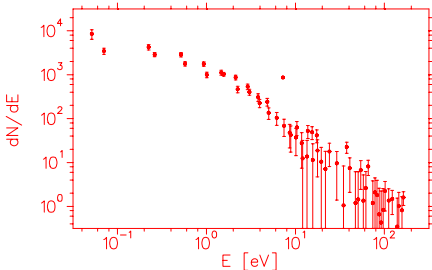
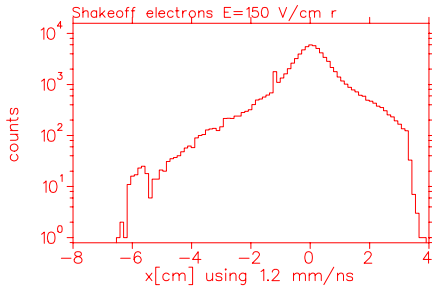


- A_β to few $\times 0.1\%$ for 2nd Ph.D. student, coincidence spin observables under analysis by other Ph.D. student.
- Spin polarization measured in-situ on ^{37}K by atomic method; prelim $\approx 99 \pm 0.004$
- Summary plan in S1188 proposal: now evaluate systematics to improve apparatus for better measurements.
- Position-sensitive electron detector shows shakeoff electrons contained \rightarrow

Shakeoff electrons ^{37}K

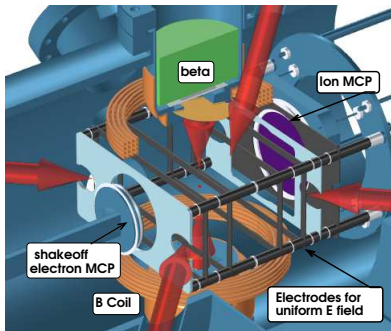


- Contained on position-sensitive MCP
- with quad B field off, get energy spectrum from radius dependence

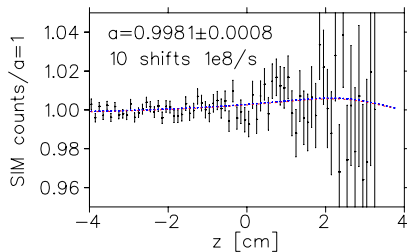
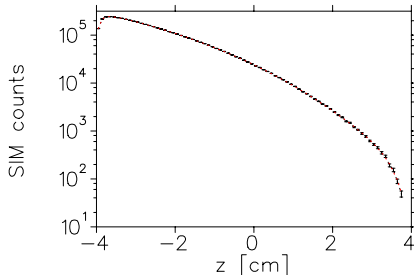


We have realized some good uses for this detector for ^{38}mK →

studying $^{38\text{m}}\text{K} \beta\text{-}\nu$ in ^{37}K geometry

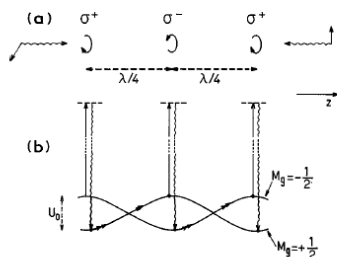


- e^- & β , e^- & ion, β -ion \rightarrow efficiencies (pairs/triplets)
- Position info \sim TOF in Gorelov 2005 \rightarrow
- Cloud size is critical for position resolution
- β -recoil + e^- -recoil



- Reconstruct $\theta_{\beta\text{-}\nu}$ \rightarrow 3x better sensitivity.

Sub-Doppler cooling of $l=0$ alkali



Cohen-Tannoudji Nobel lecture
“Lin \perp Lin” molasses.

Order of magnitude lower T
The textbook example has
never been done. Needs $l=0$
alkali.

A MOT does **NOT** use Lin \perp
Lin molasses.

FIG. 2. Sisyphus cooling. Laser configuration formed by two

$\sigma^+ \sigma^-$ molasses \rightarrow linear polarization rotation in space, needs
AC Stark shift dependence on m^2 . **No effect for $m=1/2$**

So we used Doppler-limited cooling in 38mK before, achieving
poor temperatures but tight 0.7 mm cloud with high power.

We have since achieved 0.25 mm ^{85}Rb like everyone else.

We want a) smaller cloud; b) less intensity to minimize dimers

1) Add optical pumping light for Lin \perp Lin molasses

2) Flip between trapping and Lin \perp Lin with the MOT beams

Collaboration

Current Members of Group

<u>Name</u>	<u>Institution</u>	<u>Status</u>	<u>% of research time</u>
J.A. Behr	TRIUMF	Research Scientist	100%
A. Gorelov	TRIUMF	PDF	100%
soon	UBC	Student (Graduate)	100%
D. Ashery	Tel Aviv University	Professor	20%
D.G. Melconian	Texas A&M University	Assistant Professor	10%
M. Anholm	UBC	Student (Graduate)	5%
Spencer Behling	Texas A&M	Student (PhD)	5%
Ben Fenker	Texas A&M	Student (PhD)	5%
G. Gwinner	University of Manitoba	Professor	5%
K.P. Jackson	TRIUMF	Senior Research	5%
M.R. Pearson	TRIUMF	Research Scientist	5%

Beamtime Request and Summary

6 shifts total of $^{38\text{m}}\text{K}$ using the ^{37}K geometry in the next year or so.

Breakdown:

- 2 shifts for $l=0$ alkali laser cooling:

- 1 can be with $l=0$ Rb

- 1 for adding extra $\text{Lin} \perp \text{Lin}$ from D1 light should be done on $^{38\text{m}}\text{K}$ itself.

Determines optics and chamber design constraints for final $^{38\text{m}}\text{K}$ experiment design

- 4 shifts for decay tests needing TiC target, interleave with ^{37}K

- tests of background suppression (e.g. atoms on hoops) with the shakeoff e^- coincidence

- efficiency calibration of ion MCP by double vs triple coincidences

- Dimers with high/low laser intensity

Backups from E1070 original proposal

E1070 Upgrade of $^{38\text{m}}\text{K}$ β - ν correlation

Trap \rightarrow β^+ -recoil coincidence \Rightarrow ν momentum
 Best general scalar Limits from β - ν correlation
 Gorelov et al. PRL April 2005

The theory interpretation is clean,
 so we should do it better

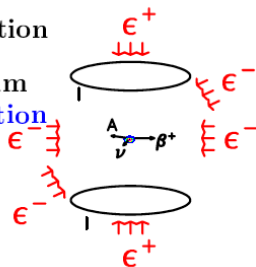
We propose a 3x better measurement of $\tilde{a} = a / (1 + bm/E)$
 and independent determination of a and b

Method I, II: Upgrade of present method with higher yields,
 trapping efficiencies, and detection efficiencies

Method III:

New Tool: recoil- atomic e^- coincidence

10-50 \times statistics, different systematics, simpler analysis



Scalar Hamiltonian in 'modern' chirality notation

$$H_S = [(C_S + C'_S)\bar{e}(1 - \gamma_5)\nu_e^{(L)} + (C_S - C'_S)\bar{e}(1 + \gamma_5)\nu_e^{(R)}]\bar{u}d$$

$$W[\theta_{\beta\nu}] = 1 + bm_{\beta}/\langle E_{\beta} \rangle + a v/c \cos[\theta_{\beta\nu}]$$

$$a = \frac{|C_V|^2 + |C'_V|^2 - |C_S|^2 - |C'_S|^2 + (\frac{\alpha Z m}{p}) 2 \text{Im}(C_S C_V^* + C'_S C_V'^*)}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}$$

Note the sensitivity to $\text{Im}(C_S + C'_S)$

$$b = \frac{-2\sqrt{1 - \alpha^2 Z^2} \text{Re}(C_S C_V^* + C'_S C_V'^*)}{|C_V|^2 + |C'_V|^2 + |C_S|^2 + |C'_S|^2}$$

$$a \approx 1 - (|C_S|^2 + |C'_S|^2)$$

$$b \approx -\text{Re}(C_S + C'_S)$$

Sources of Scalars: Are there any?

Charged Higgs: Required in SUSY

- 1st generation couplings unknown

⇒ most general limits on 1st generation couplings are from nuclear β decay

- Couplings in simplest MSSM:

like S.M. Higgs, couplings \propto masses: (Not so in less simple Higgs models (Langacker hep-ph/0503068))

(Herczeg, Prog. Part. Nucl. Phys. 46/2 413 (2001), Haber et al. Nucl.Phys.B 161 493 (1979))

$$C_S + C'_S \approx 2g_s \frac{m_e m_d}{m_H^2} \tan^2 \beta \leq 5 \times 10^{-6}$$

for $\tan \beta \leq 65$ and $m_H \geq 69$ GeV neglects squark family mixing

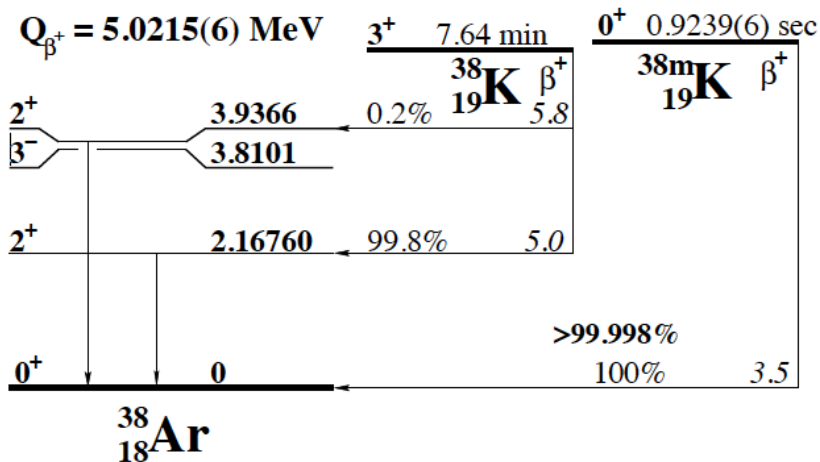
- R-parity violating sleptons

constrained by $\pi \rightarrow e\nu$, $C_S + C'_S$ can be $\sim -2 \times 10^{-3}$

- B. Campbell et al. NPB 709 419 (2005) limits from $\pi \rightarrow e\nu$

Other searches:

^{32}Ar Garcia/Adelberger; WITCH $^{35}\text{Ar}^+$ Leuven/ISOLDE; $^{14}\text{O}^+$ ANL; superallowed ft Q-value dependence

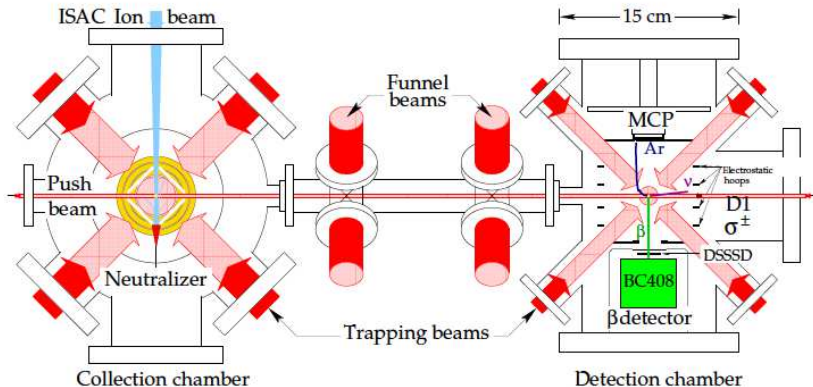


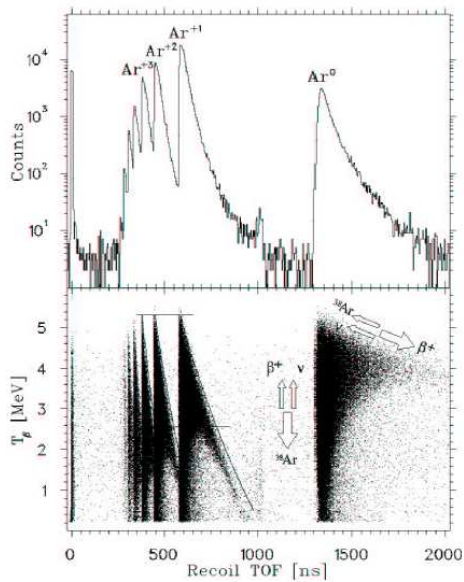
Excited-state branch known to be negligible

(Ground state makes a background in β singles:
we can deal with this better)

TRIUMF's Neutral Atom Trap

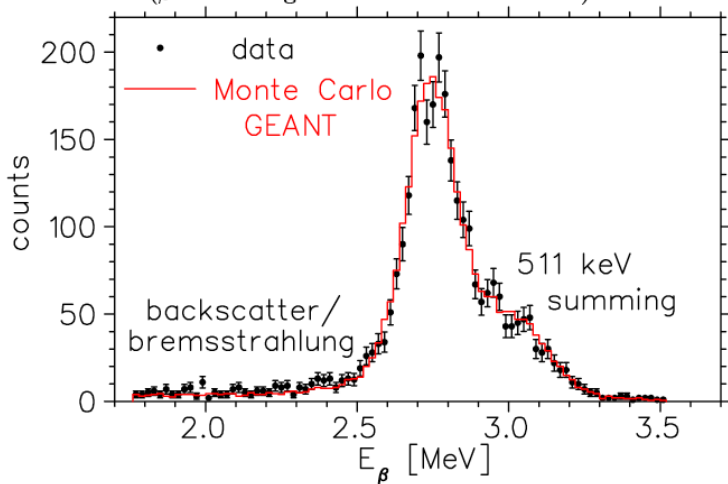
- Isotope/Isomer selective
- Evade 1000x untrapped atom background by \rightarrow 2nd MOT
- 75% transfer (must avoid backgrounds!); 10^{-3} capture
- 0.7 mm cloud for β -Ar⁺ \rightarrow ν momentum \rightarrow β - ν correlation



Method I,II: β -recoil coincidences Raw data

In-situ calibrations

E_β detector response for “monoenergetic” β 's from kinematics of other observables (β -recoil angle and recoil momentum)



Methods I and II agree:

I: recoil TOF [T_β],

$$T_\beta > 2.6 \text{ MeV}$$

C.L. of total fit is 52%

II: Angular distribution
determined from other
observables (except E_β).

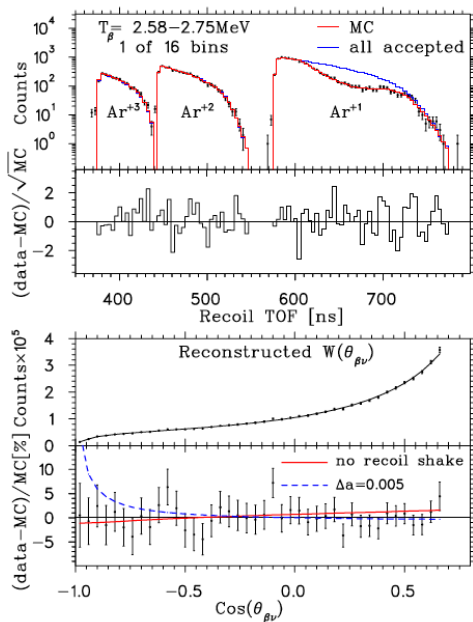
Can simultaneously fit
 E_{recoil} -dependent shakeoff

$$\bar{a} = 0.9981 \pm 0.0030(\text{stat}) \\ \pm 0.0037(\text{syst})$$

(Adelberger ^{32}Ar PRL 1999

$$\bar{a} = 0.9989 \pm 0.0052(\text{stat}) \\ \pm 0.0039(\text{syst})$$

still being re-evaluated)

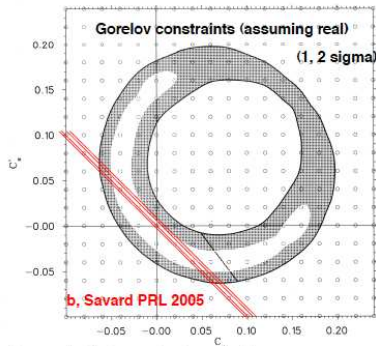
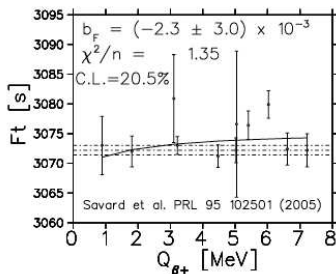


$^{38m}\text{K } \beta^+ - \nu$ Error Budget $a=0.9981 \pm 0.0030(\text{stat})$

Error	PRL	Future	
\vec{E} field/trap width :	0.17%	0.04%	Method I
E field nonuniformity	0.14%	0.03%	Planned Improvements:
β^+ backscattering bkgd	None	None	<ul style="list-style-type: none"> • Larger MCP • E_β calibration from interwoven background-free ^{37}K
E_{β^+} Detector Response:			
Lineshape tail/total	0.06%	0.03%	<ul style="list-style-type: none"> • $1/\sqrt{5}$ statistical error (conservative)
511 keV Compton sum	0.09%	0.04%	larger ISAC yields
Calibration, nonlinearity	0.17%	0.08%	more laser power
MCP Eff[E_{Ar^+}]	0.07%	0.03%	<ul style="list-style-type: none"> • Permanent mask on MCP for position info test
MCP Eff[θ]/XY position	0.08%	0.04%	
e^- shakeoff [E_{recoil}]	0.18%	0.08%	
Sum systematics	0.37%	0.14%	
Total error	0.48%	0.19%	

- Most systematic errors determined by statistics-limited data evaluation.
- Further improvements possible: use all kinematic information.

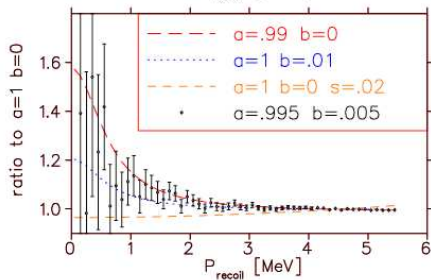
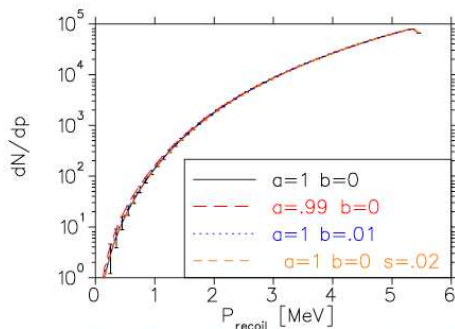
Constraints on scalars from 'Fierz interference term'



$b_f = -\text{Re}(C_S + C'_S)$, scalars that couple to left-handed ν only

$$W[\theta_{\beta\nu}] = 1 + b_F m_\beta / \langle E_\beta \rangle + a v/c \cos[\theta_{\beta\nu}] \quad a \approx 1 - |C_S|^2 + |C'_S|^2$$

- TRINAT present statistical error is 4x bigger
- Would improve systematics by using kinematic info for E_β at $E_\beta < Q/2$
- Would achieve similar accuracy within one β - ν experiment
- Goal: a window left open by $\pi \rightarrow e\nu$ for sleptons at 2×10^{-3}
 [Herczeg Prog. Part. Nucl. Phys. 46/2 413 (2001)]



SIMULATION

Recoil momentum spectrum
Sensitive to a (a , b highly correlated)

Can extract momentum dependence of shakeoff separately

From 10^6 events $\sigma_a = 0.001$
(3 hours)

Superallowed Q-dependence of b error 0.003: 1 shift

0.001 (sleptons) in 10 shifts

- In reality will run under many conditions like other precision experiments