Measurements of Electron-Proton Coincidences with UCN and the Neutrino Asymmetry B

"UCNB" Collaboration

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Research Opportunities with UCN in the U.S.

Santa Fe November 6-7, 2009

Neutrino asymmetry B

$$W\, dE_e d\Omega_e d\Omega_\nu \propto p_e E_e (E_0 - E_e)^2 dE_e d\Omega_e d\Omega_\nu$$
$$\times \left[1 + a \frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b \frac{m_e}{E_e} + \left\langle \frac{\vec{J}_n}{J_n} \right\rangle \cdot \left(A \frac{\vec{p}_e}{E_e} + B \frac{\vec{p}_\nu}{E_\nu} + D \frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} \right) \right]$$

Neutrino Asymmetry B

PDG Value : B = 0.9807 ± 0.0030

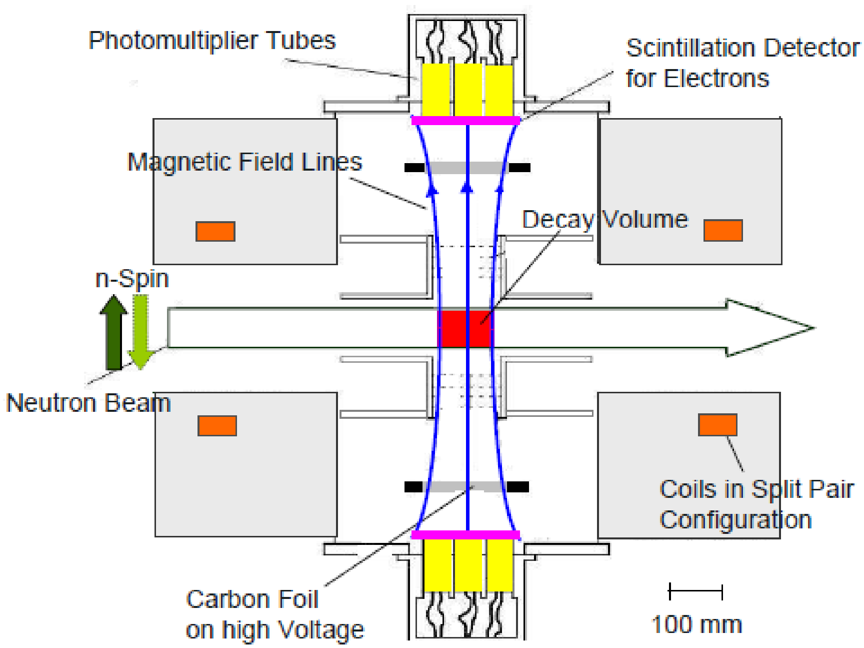
$$B = 2 \frac{\lambda^2 - \lambda}{1 + 3\lambda^2}$$

$\lambda = g_A / g_V$

- Less sensitive to λ than A
  - But require consistency !
- Historically, constraints on L-R models
  - $M(W_R) > 290$ GeV/c^2
- With improvements, search for new physics
  - MSSM parameter space (see S. Tulin talk)

Prior measurements of B

VALUE	DOCUMENT ID		TECN	COMMENT	P =
0.9807±0.0030 OUR AVERAGE					
0.9802±0.0034±0.0036	SCHUMANN	07	CNTR	Cold *n*, polarized	0.997(1)
0.967 ±0.006 ±0.010	KREUZ	05	CNTR	Cold *n*, polarized	0.987(5)
0.9801±0.0046	SEREBROV	98	CNTR	Cold *n*, polarized	0.975(3)
0.9894±0.0083	KUZNETSOV	95	CNTR	Cold *n*, polarized	0.669(2)
1.00 ±0.05	CHRISTENSEN	70	CNTR	Cold *n*, polarized	0.87(3)
0.995 ±0.034	EROZOLIM...	70c	CNTR	Cold *n*, polarized	0.74(1)



PERKEO IIB

M. Schumann et al., PRL 99, 191803 (2007); and Ph.D. Thesis

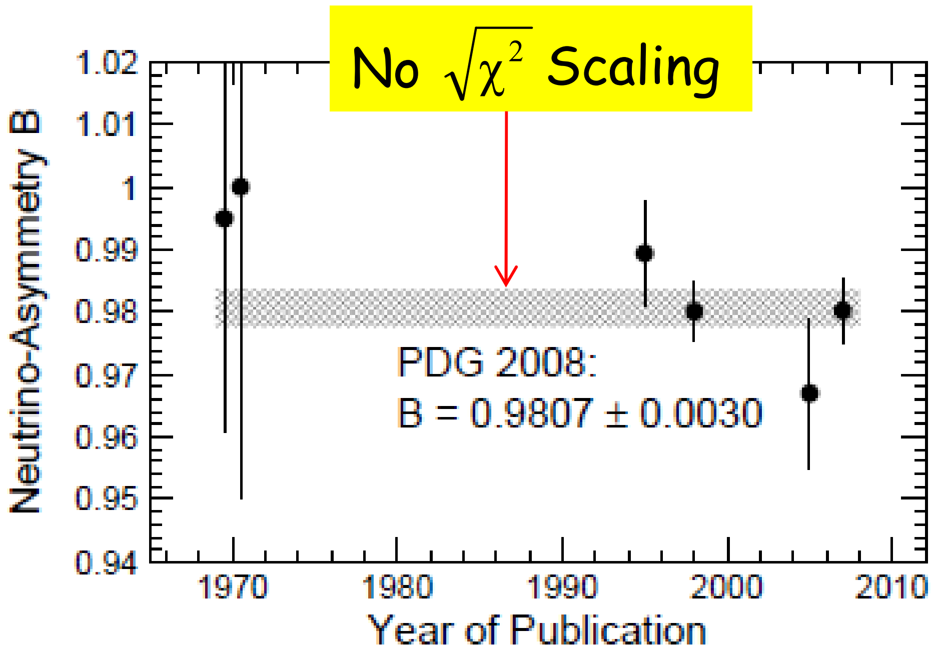
$$B_{\exp}(E_e) = \frac{N^{--}(E_e) - N^{++}(E_e)}{N^{--}(E_e) + N^{++}(E_e)}$$

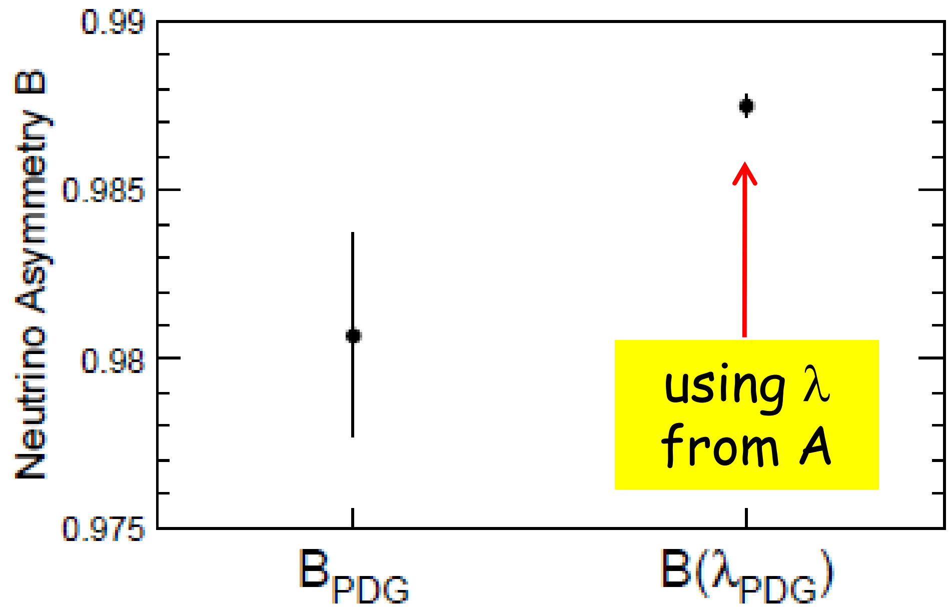
$B_{exp}(E_e)$ related to B via integration of W over the hemispheres

A and B consistency

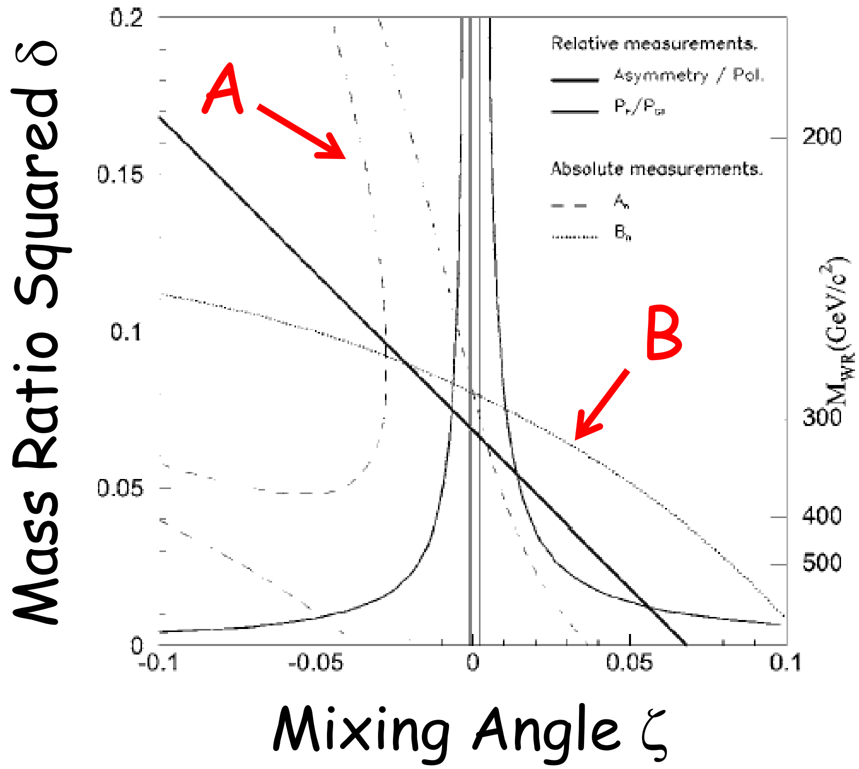
$$A = -2\frac{\lambda^2 + \lambda}{1 + 3\lambda^2} \longleftrightarrow B = 2\frac{\lambda^2 - \lambda}{1 + 3\lambda^2}$$

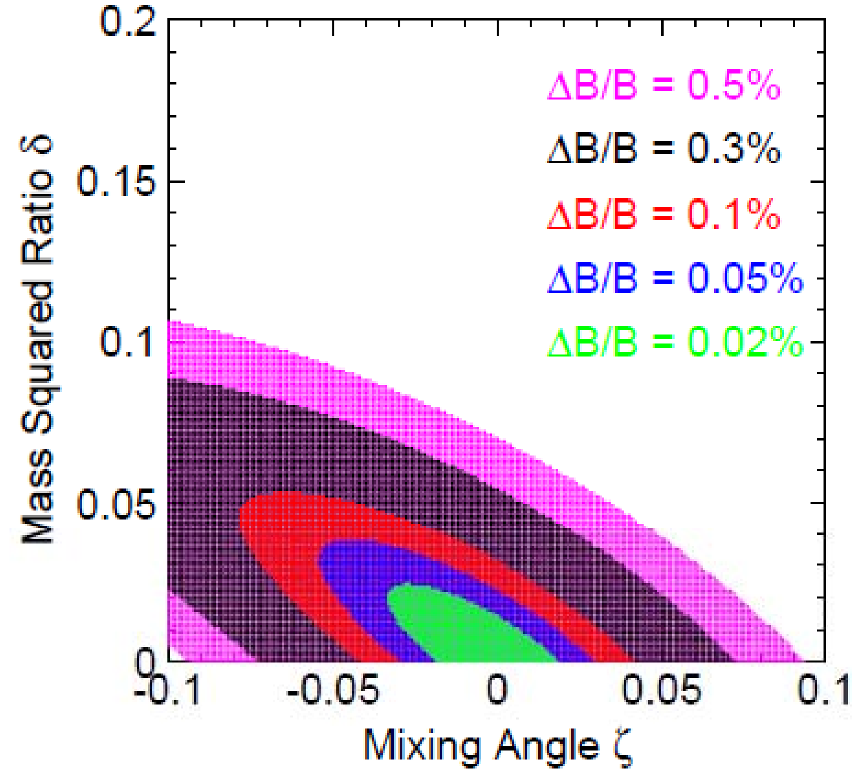
Or: B = 1 + A − a





Constraints on L-R models





N. Severijns, M. Beck, and O. Naviliat-Cuncic, RMP 78, 991 (2006)

[Using PDG 2004 data for A and B within context of manifest L-R symmetric model.]

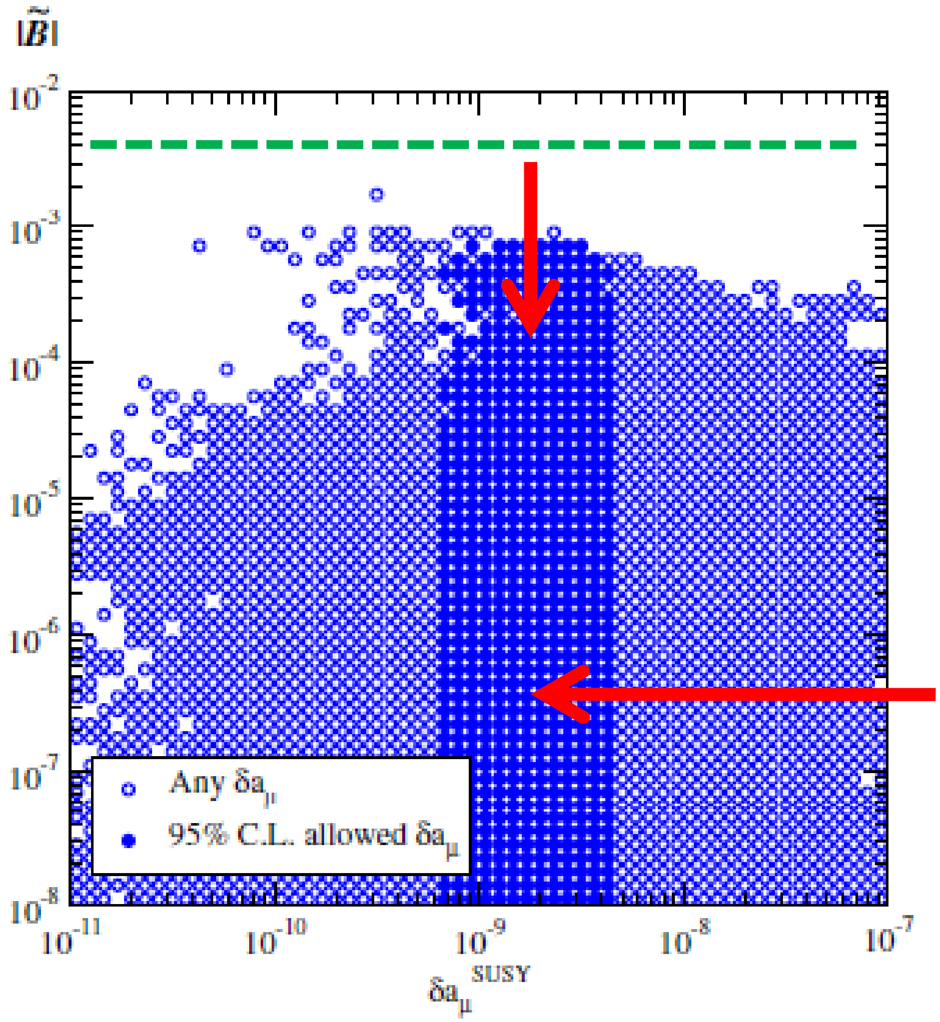
TWIST Collaboration

$M(W_R) > 420\ GeV/c^2$

A. Gaponenko et al., PRD 71, 071101(R) (2005).

MSSM parameter space

S. Profumo, M.J. Ramsey-Musolf, and S. Tulin, PRD 75, 075017 (2007).

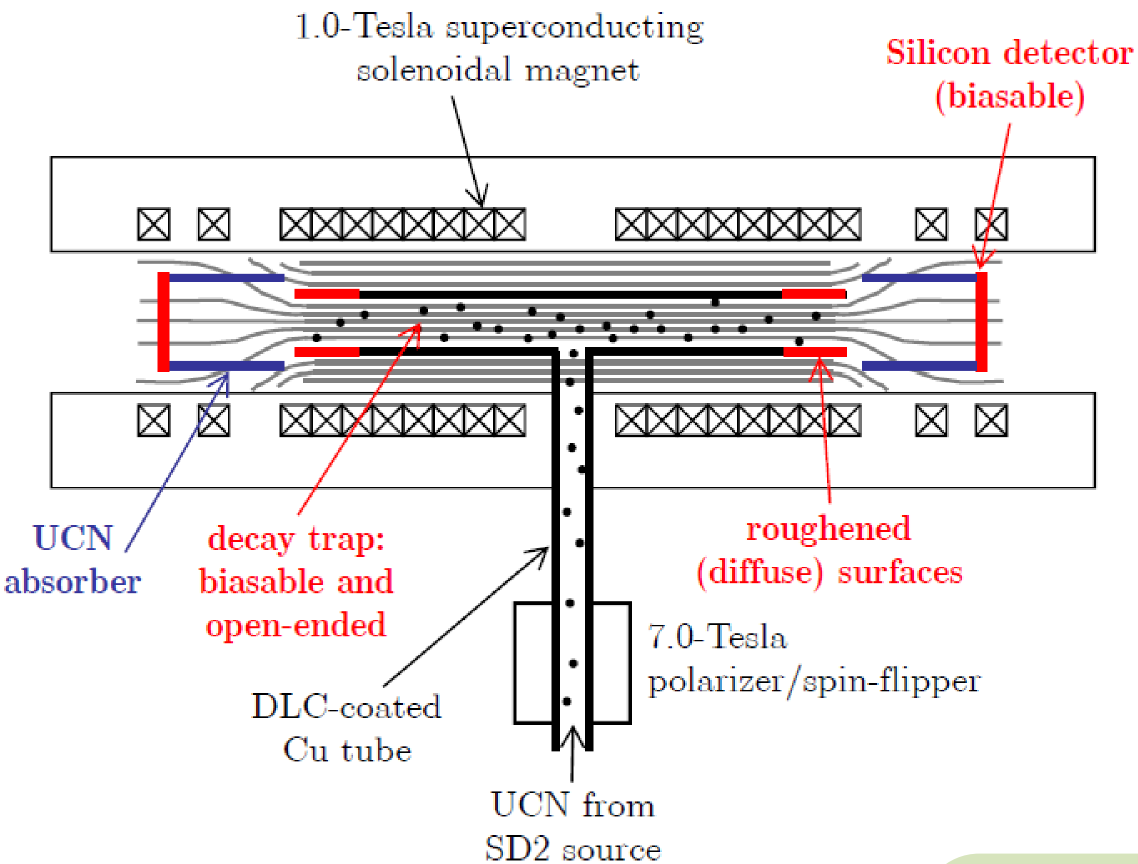


Current 0.3% precision on B

Model choices consistent with muon (g – 2)

The "UCNB" concept

[W.S. Wilburn et al., submitted to Rev. Mex. Fis.]



Basic Idea: Detect e-p coincidences

e: "start" (prompt)

p: "slow" (~ μs – ms)

UCNB Observables

Neutron Polarization

Electron and Proton Directions

Electron Energy

First-Pass Goal: 0.1% on B

UCNA → UCNB

Replace MWPC/Scintillator detector with Silicon detectors

- S. Wilburn's LDRD-developed Si detectors

Windowless decay trap

- Roughened surfaces at ends to increase UCN storage time

Electric field configuration (~30 kV)

- Biasable decay trap and/or detectors

(Prior to) Field-expansion region

- UCN absorbers

Potential advantage of UCNB

Degree of polarization expected

$$B_{\exp}(E_e) = \frac{4P}{3} \times \begin{cases} \dfrac{A\beta(2r-3)+B(3-r^2)}{8-4r+a\beta(r^2-2)} & [r<1] \\ \dfrac{-A\beta+2Br}{4r-a\beta} & [r \geq 1] \end{cases}$$

$$r = \frac{\beta(E_e+m_e)}{(E_0-E_e)}$$

UCNA 2008: No measured depolarization, 0.2% statistics

Future: Push measurement of depolarized fraction to < 0.1% level, with 20% uncertainty → δB ~ 0.02%

UCNB: Open-ended decay trap, shorter storage time
→ Smaller depolarization (in principle) than UCNA

Silicon detectors

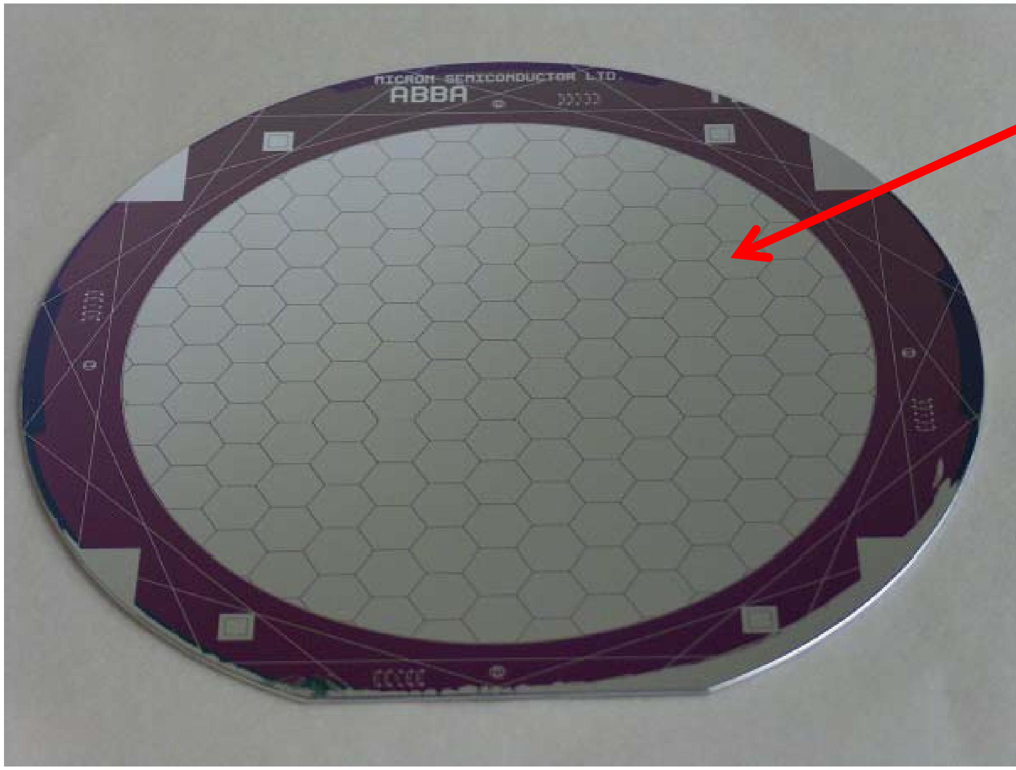
W.S. Wilburn et al. (LANL)

<u>Requirements</u>

- Detect electrons up to ~800 keV (1.7-mm)
  - 2-mm thick now in hand at LANL
  - Energy resolution ~ few keV
  - Timing ~ few ns ("start", e-backscattering)
- Detect protons ~ 30 keV
  - Entrance window ~ 100 nm Si (< 10 keV T_p)
- High efficiency, Hermetic
  - 15-cm diameter, single wafer of Si

Silicon detectors

W.S. Wilburn et al. (LANL)



127 hexagonal 70 mm^2 pixels

0.5, 1.0, 1.5, and 2.0-mm detectors now in hand

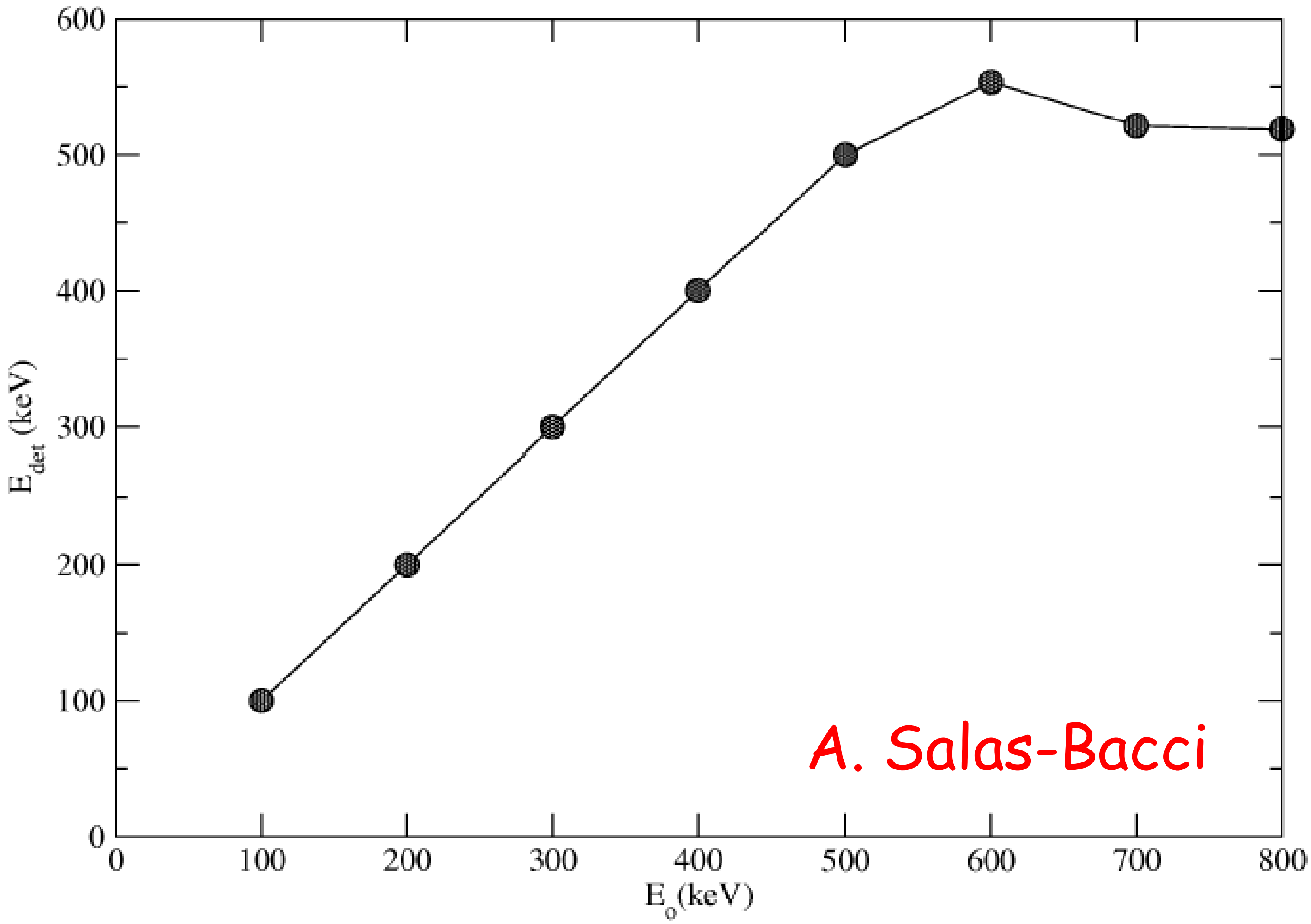
Dead-layer appears reasonable (via rotation studies)

Preamps based on KATRIN design being developed in collaboration with the University of Washington

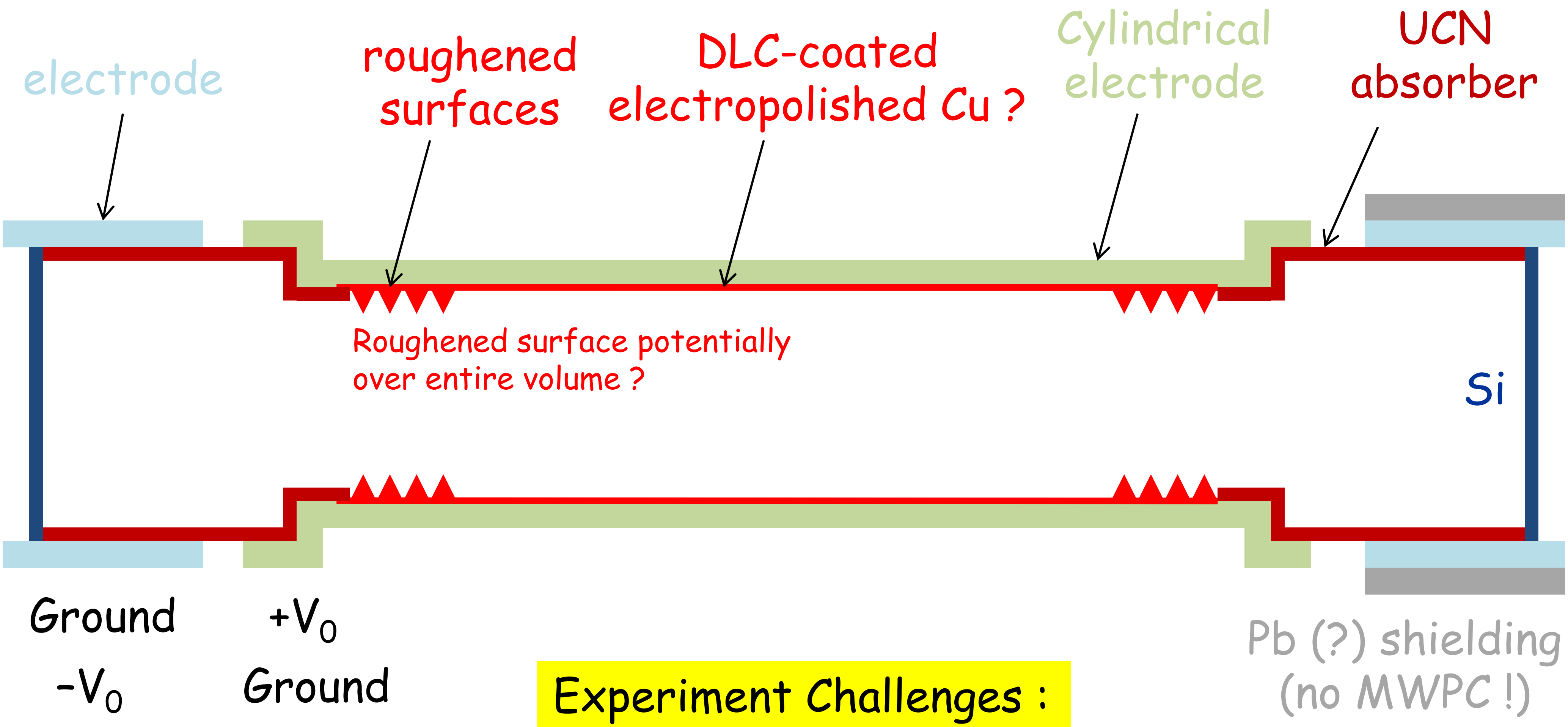
Silicon detectors

W.S. Wilburn et al. (LANL)

Energy deposition in 1.0-mm Si detector (PENELOPE) :

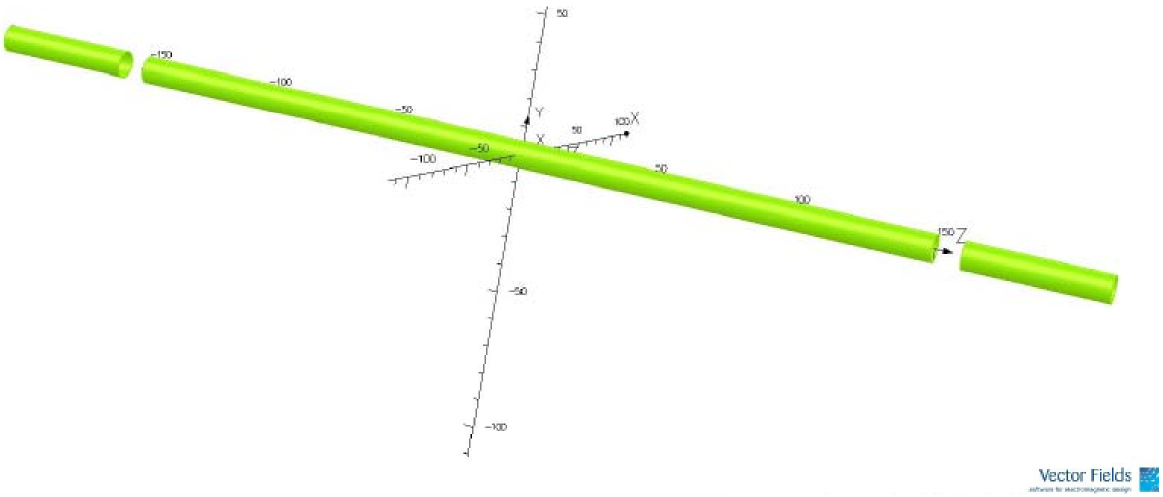


Decay trap and electrode structure



Experiment Challenges :
- Roughened surfaces
- Electrode structure

Electric field configuration

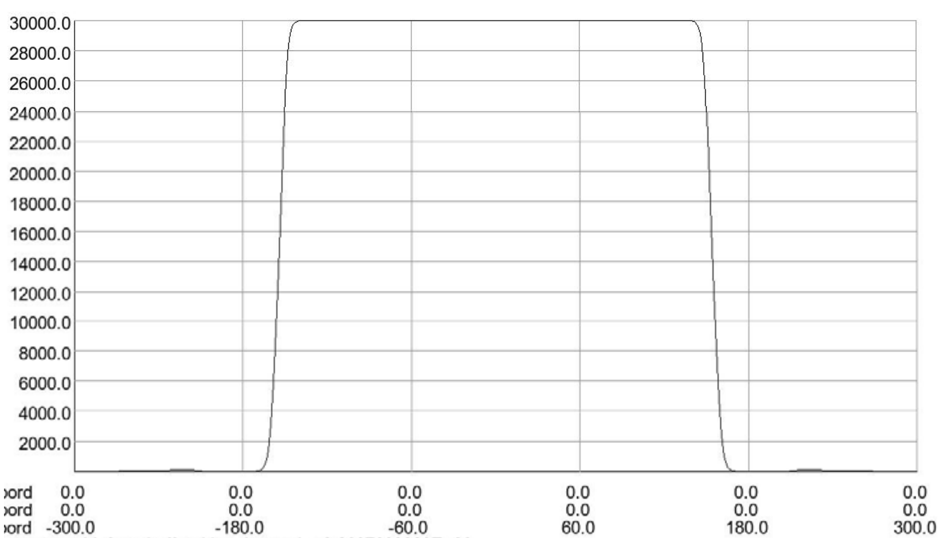


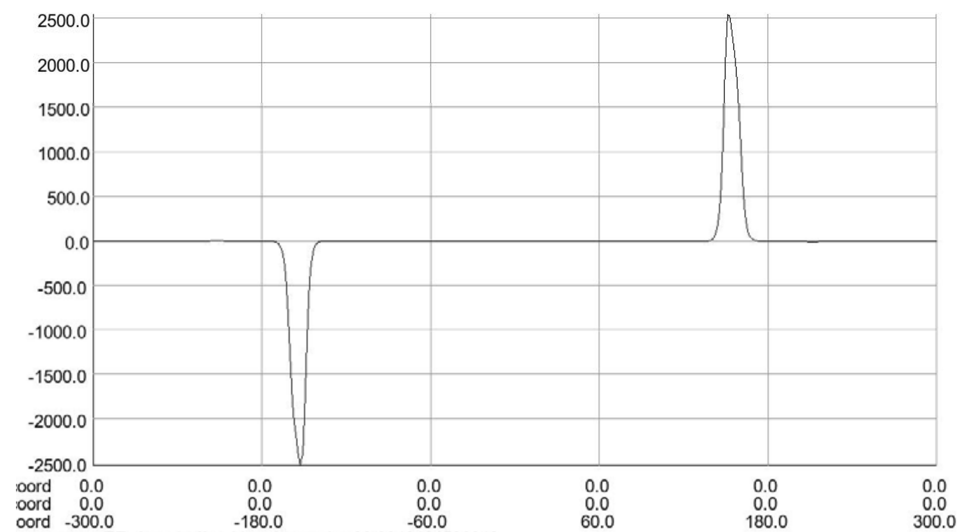
Exploratory E-field calc's

NCSU: Relax3D

UK: TOSCA

(Very) Simple Model: Adequate uniformity with decay volume electrode extending into field-expansion region





Electric field uniformity

UCNB Goal: Measure proton momentum direction

Thus, require uniform (as possible) E = 0 in decay (drift) volume

Potential fluctuations ("patch effects") on the surface of the decay volume electrode problematic

- Reflections for very low longitudinal velocities
- Distortions to longitudinal spectrum (thresholds ?)
- Work functions of Cu *do* vary for different crystallographic faces

Estimate that potential uniform to ~few mV sufficient

- Distance from surface to decay volume (averaged over entire decay volume) ~ large

Proton TOF spectrum can be used as a test/monitor of E field fluctuations

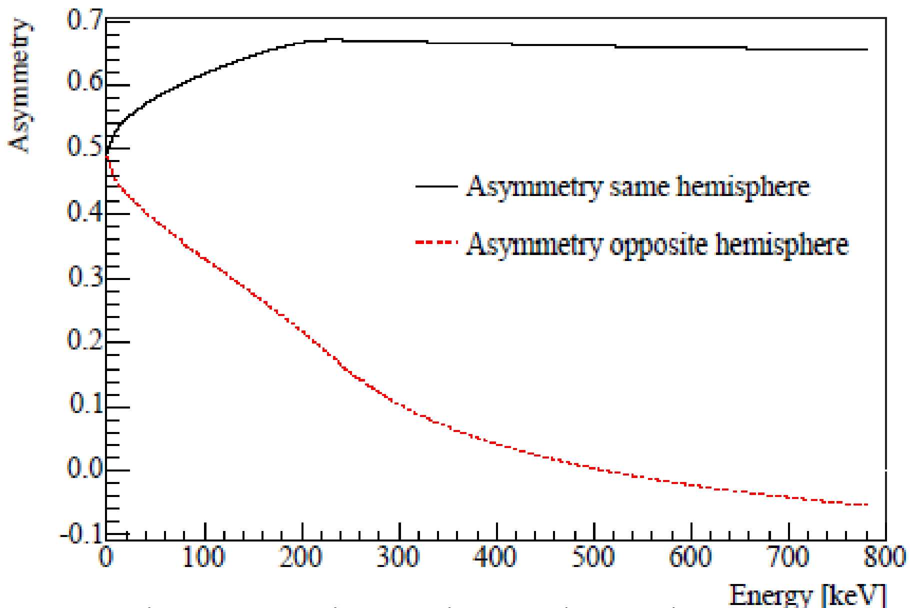
Possible e-p coincidence asymmetries

Symmetric Configuration

Both detectors sensitive to both particles

$$B_{\exp}(E_e) = \frac{N^{--}(E_e) - N^{++}(E_e)}{N^{--}(E_e) + N^{++}(E_e)}$$

[Would actually use "super-ratio" technique]



M. Schumann, Ph.D. Thesis (2007),
F. Gluck et al., NPA 593, 125 (1995)

$$\sigma_B = \frac{2.6}{\sqrt{N}}$$

[$0 < E_e < 782$ keV]

$\delta B/B \sim 0.1\% \rightarrow N \sim 1 \times 10^7$

[for restricted E_e window]

Possible e-p coincidence asymmetries

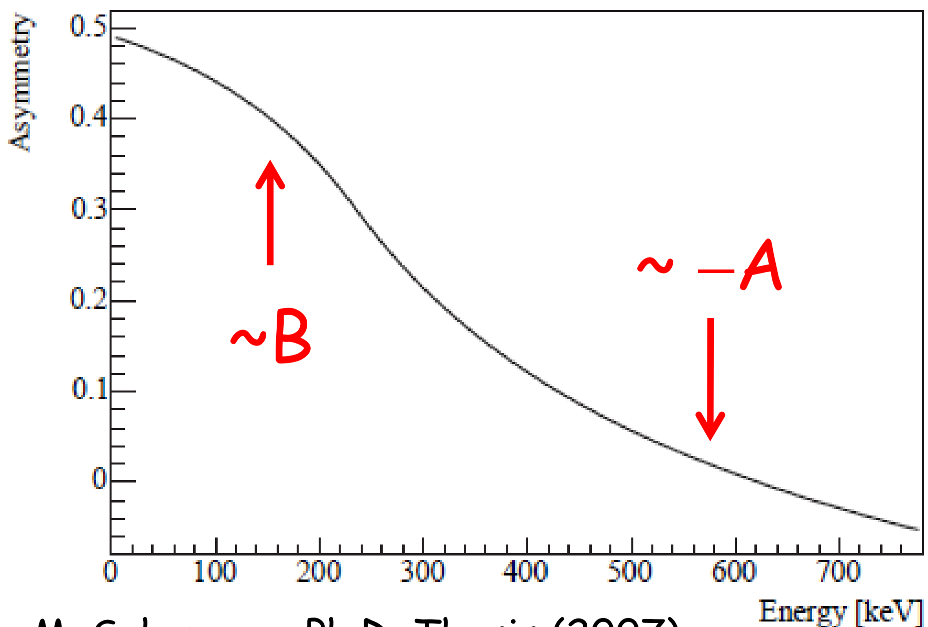
Symmetric Configuration

Both detectors sensitive to both particles

Proton Asymmetry vs. Energy:

$$C_{\exp}(E_e) = \frac{\rho^{\uparrow}(E_e) - \rho^{\downarrow}(E_e)}{\rho^{\uparrow}(E_e) + \rho^{\downarrow}(E_e)}$$

Integrate out electron direction



M. Schumann, Ph.D. Thesis (2007),
F. Gluck et al., NPA 593, 125 (1995)

Possible e-p coincidence asymmetries

Asymmetric Configuration

Proposed by A. Young and S. Hoedl (2003)

- One detector sensitive to protons
- Both detectors sensitive to electrons (measure E_e)

Can still form "super-ratio" with respect to spin-flip

- Still eliminates rate and detector efficiencies to first order
- Way to avoid Penning trapping of the electrons
- But less sensitive to B

$$\sigma_B \sim \frac{5.4}{\sqrt{N}}$$

$\delta B/B \sim 0.1\% \rightarrow N \sim 3 \times 10^7$

Running times

PRELIMINARY estimate of running times for 0.1% on B

Assuming 10 Hz e-p coincidence rates

Configuration	N	Weeks*
Symmetric	$\sim 1 \times 10^7$	~2
Asymmetric	$\sim 3 \times 10^7$	~6

* Assumes 2.5 days = 60 hours of 100% duty-factor β-decay running per week at 10 Hz

Error budget

VERY PRELIMINARY error budget for 0.1% measurement of B

	Dominant Errors and Unc.		
	Correction	Uncertainty	
Statistical	n/a	<0.05%	
Polarization	<0.1%	0.02%	UCNA experience
β Backscattering	0.3%	0.06%	Higher backscattering for Si, but no foils !
β Energy Calibration, Linearity and Resp. Fun.	0.1%	<0.01%	Projected/Expected silicon detector linearity
Proton Backscattering	0.07%	<0.01%	Probability ~ 7×10^{-4} [J. Nico et al. (2005)]
Missed Coincidences	0.1%	<0.03%	1 ms window [S. Hoedl Ph.D. Thesis (2003)]
Accidental Coincidences	-0.1%	<0.01%	Rate ~ 10/s, ~1 ms window [Hoedl (2003)]
Mirroring Effects in B Field Expansion Reg.	-0.04%	0.02%	UCN absorbers to suppress decays in field-expansion region
Total	<0.6%	0.09%	

Summary of "UCNB" concept

UCNB First-Pass Goal:

- With minor modifications to UCNA infrastructure 0.1% measurement of B appears to be feasible
- UCN-based measurement offers potential for small uncertainty in neutron polarization
- With decay rates ~10/s, 0.1% statistics possible via different methods in ~2 months of running time

At 0.1%, potential to start probing MSSM parameter space consistent with muon $(g-2)$ anomaly

Improve neutron-based constraints on L-R models

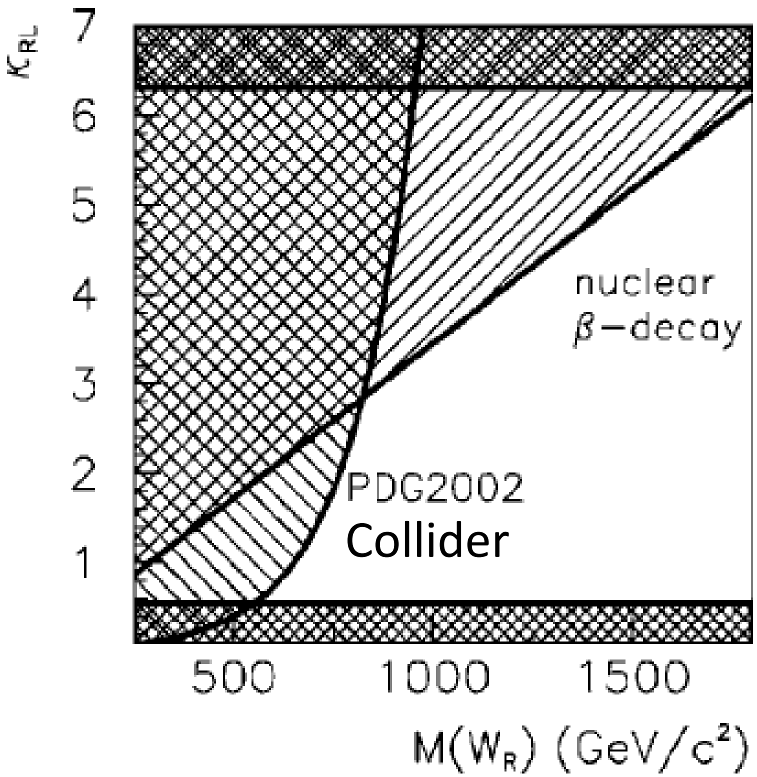
Test of consistency of SM description of β-decay

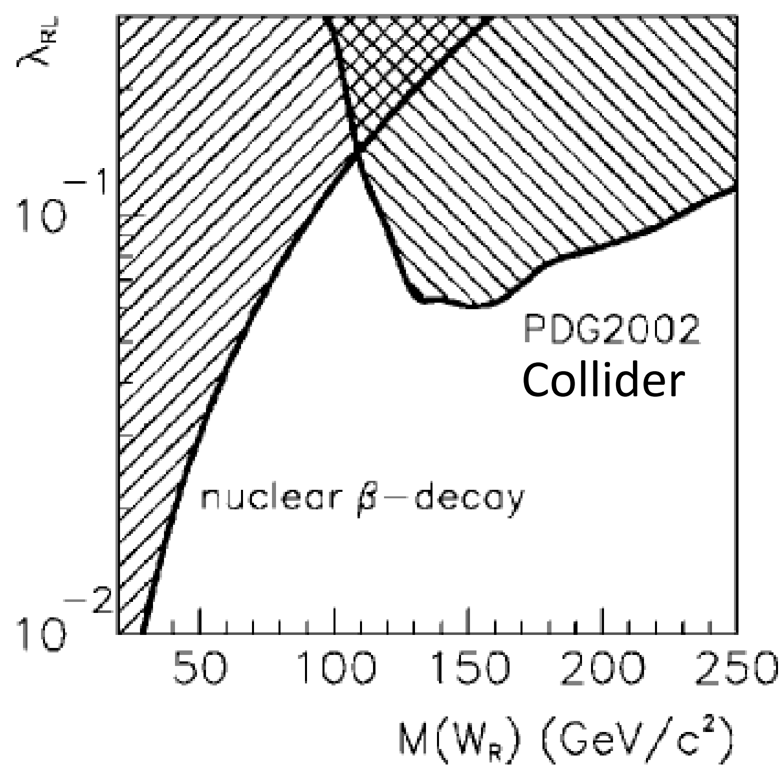
Backup slides

L-R models: Colliders vs. β-decay

In generalized L-R models :

N. Severijns, M. Beck, and O. Naviliat-Cuncic, RMP 78, 991 (2006)





$$\kappa_{RL} = g_R / g_L$$

$$\lambda_{RL} = |V_{ud}^R| / |V_{ud}^L|$$

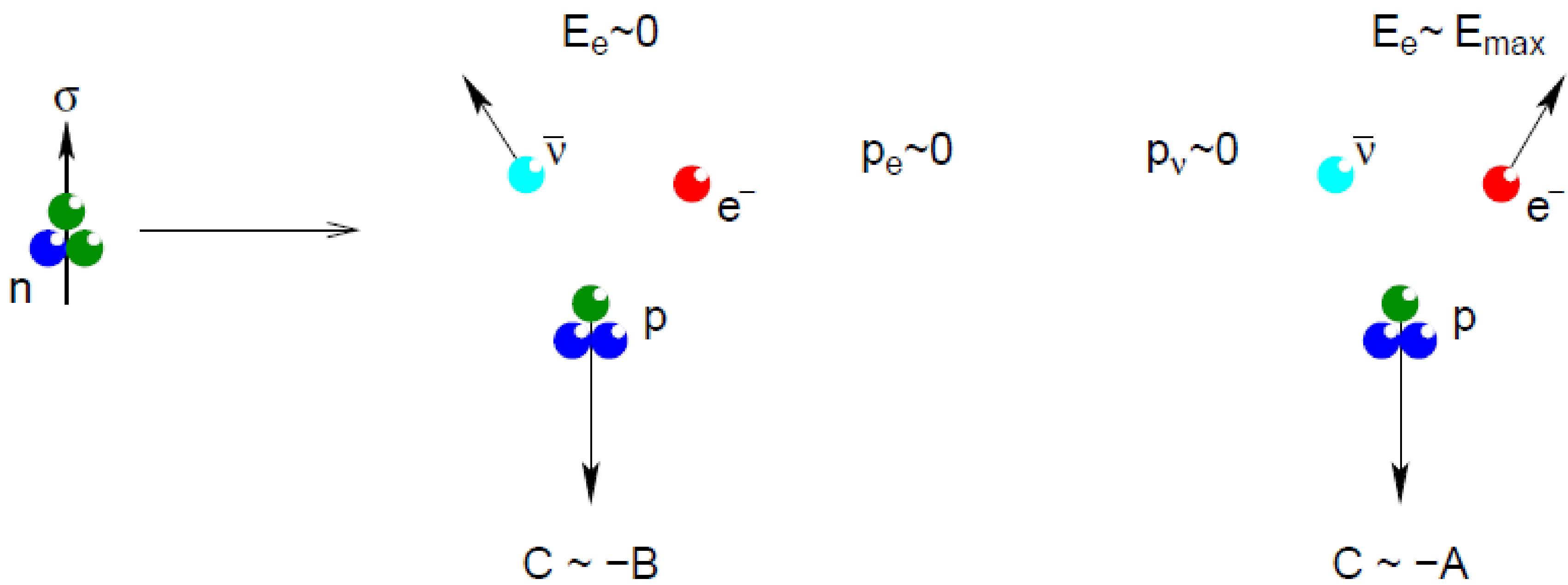
W.S. Wilburn DNP talk

Systematic Uncertainty Estimates

	abBA (Calculated)	UCNA (Actual)
Neutron Polarization	0.5×10^{-3}	1.3×10^{-3}
Res. Gas Scatt.	$< 0.5 \times 10^{-3}$	N/A
E-Field Inhomogeneity	$< 0.1 \times 10^{-3}$	N/A
B-Field Inhomogeneity	0.3×10^{-3}	0.5×10^{-3}
Detector Rate Effects	$< 0.1 \times 10^{-3}$	N/A

W.S. Wilburn DNP talk

Determination of Neutrino Asymmetry B from Proton Asymmetry C



Measure C as a function of E_e