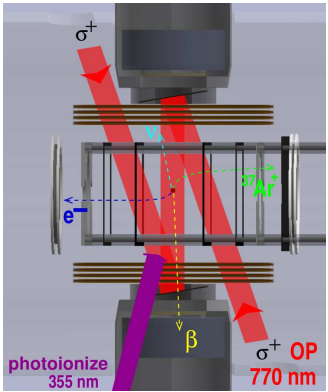
S1188 Spin-polarized ^{37}K β^+ Decay with TRINAT



$p_{^{37}Ar}$ from TOF and MCP position, uniform $\vec{E}$ (β^+ or e^- TOF trigger)

β^+ detection for A_β

- Update Motivation
  - High-energy physics progress
  - 2nd-class currents: unique contribution from nuclear β decay
  - Competition in β decay
- Experimental improvements, projected uncertainty budgets:
  - Spin Polarization (common)
  - A_{recoil}
  - A_β
- Status, Request, TRINAT plans

TRIumf Neutral Atom Trap collaboration:

P. Shidling
A. Ozmetin (Ft)
D. Melconian

A. Gorelov
J.A. Behr
M.R. Pearson
Undergrad
A. Afanassieva

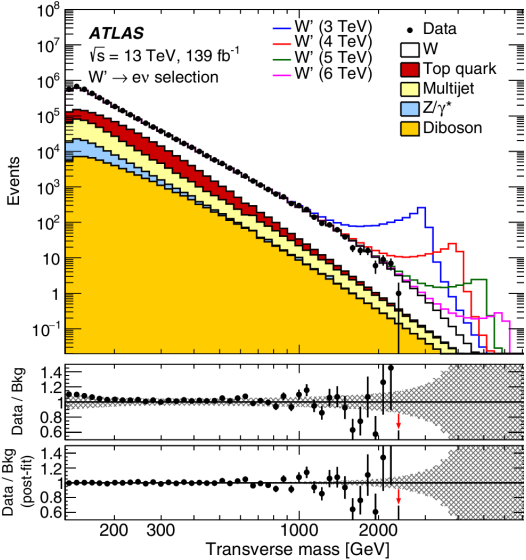
J. McNeil

UNIVERSITY OF MANITOBA

M. Anholm
G. Gwinner

Supported by NSERC, NRC through TRIUMF, DOE
M. Anholm will finish Ph.D. analyzing $A_\beta[E_\beta]$
J. McNeil will do requested A_{recoil} for his Ph.D.

Quasi-direct limits from high-energy colliders: update

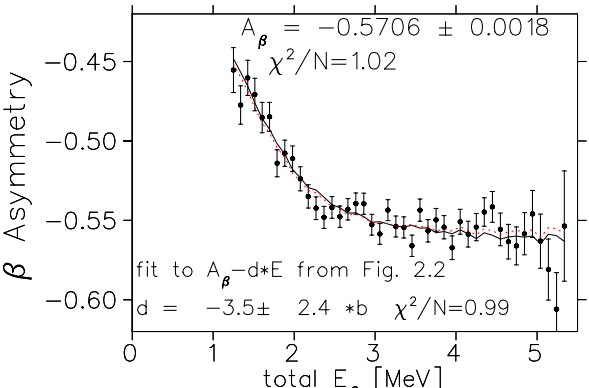


LHC13 $\sigma[p + p \to e + \text{missing } p_\perp]$ is related to $n \to p + e + \nu$ by EFT (to scale the momentum transfer dependence, etc.) see Gonzalez-Alonso, Naviliat-Cuncic, Severijns, Prog Par Nuc Phys 104 165 (2019):

← 13 TeV data:
ATLAS expected 3, saw 2
Phys Rev D 100 052013 2019
CMS expected 2.5 events, saw 2 JHEP06 128 2018

LHC won't say more until ∼ 2025
Experiments should now show complementary discovery potential

2nd-class currents: unconstrained by $pp \rightarrow e + p_\perp$



"2nd-class" weak interactions violate g-parity (charge symmetry) when quarks are combined by QCD into nucleons.

"Induced tensor" $d \approx 0$ in isobaric mirror decay.

- **"To provide for 2nd-class currents it would be necessary... to introduce 2 pairs of quarks and to suppose that each is a doublet under strong interactions..." Holstein and Treiman, PRD 13 3059 (1976)**

↑ A strongly interacting dark sector?

Complementary to other nuclear β decay (Sumikama PRC 2011) in models with two strong-interaction couplings, where 2nd-class currents change with nucleus (Wilkinson EPJA 2000)

BABAR set best 3rd-generation constraints PRL 2009 $\tau^- \rightarrow \omega\pi^-\nu_\tau$

Nuclear and neutron β decay progress

Some highlights from INT workshop Nov 2019

V_{ud} radiative corrections, including as a function of E_β, heighten interest

PERKEO III has made a large advance in neutron A_β, along with a Fierz term measurement.

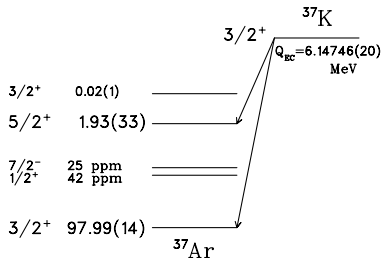
aSPECT disagrees in neutron a_β by 2.8 σ with PERKEO III

ANL ^8Li, ^8B β decay in a Paul trap continues to make progress

New techniques to measure the β energy spectrum to search for the Fierz term including implantation in detectors (Naviliat-Cuncic) and cyclotron resonance microwave emission (Garcia U.W.).

WISArD: WITCH magnet, β-delayed proton decay of ^{32}Ar, proton energy shift with β^+. Test run arXiv:1906.05135. Uses catcher foil, so backscattering...

^{37}K: TAMU *Ft* progress: theory status



$\mathcal{F}t$ (Shidling PRC 2014) = 4576 ± 8 s

Ozmetin et al. TAMU

Branch to 5/2$^+$ improved

→ PRELIM 4585±4 s

∼0.0005 for V_{ud} from A_{recoil} becomes possible

CVC ⇒ most important corrections:

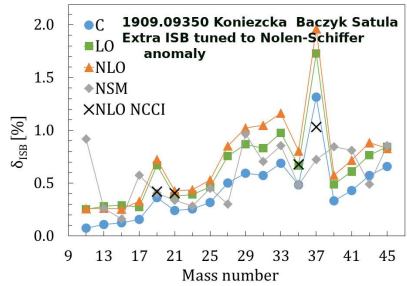
$\mu \Rightarrow b_{WM}$ (small for $\pi d_{3/2}$)

Induced tensor $d_1 \approx 0$ for isobaric mirror

$Q \Rightarrow$ largest 2nd-order recoil + Coulomb + finite-size ⇒

$\Delta A_\beta \approx -0.0028\ (E_\beta/E_0)$ Holstein RMP 1975

Our deduced V_{ud} from ^{37}K A_β agrees with Hayen Severijns arXiv 1906.09870 using Behrens and Bühring formalism



DFT with extra isospin breaking tuned to fix Nolen-Schiffer differs from Towner 2008 in ^{35}Ar, ^{37}K

Stroberg,Holt are applying in-medium similarity renormalization group

TRIUMF

Polarization=0.991(1) → projected 0.9960(5)

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Source	ΔP [$\times 10^{-4}$] σ^-	σ^+	ΔT [$\times 10^{-4}$] σ^-	σ^+	ΔP σ^-
SYSTEMATICS					**PROJ**
Initial T	3	3	10	8	2
Global fit v. ave	2	2	7	6	1
S_3^{out} Uncertainty	1	2	11	5	0
Cloud temp	2	0.5	3	2	1
Binning	1	1	4	3	0
B_z Uncertainty	0.5	3	2	7	0.5
Initial P	0.1	0.1	0.4	0.4	0.1
Require $\mathcal{I}_+ = \mathcal{I}_-$	0.1	0.1	0.1	0.2	0
Total Systematic	5	5	17	14	2.5
STATISTICS	7	6	21	17	4

Patient undergrads lead most of these improvements

0.25 mm SiC-backed mirrors → pellicles for less β^+ scattering

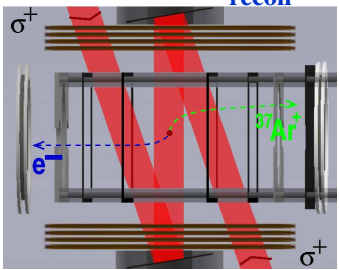
Stern Family of National Photocolor

70nm Au + 4μ Kapton 5λ flatness

- **PCTFE viewport seals**
- **Lower-frequency AC-MOT**
- **Double OP power: fight Larmor precession**
- **Better spin flips TnLC**
- **3x more photoionizing light**
- **Uncertainty $\propto (1 - P)$**

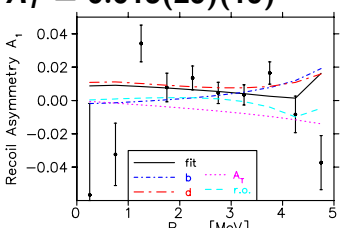
TRIUMF

$A_{recoil} \propto A_\beta + B_\nu$ in ^{37}K decay

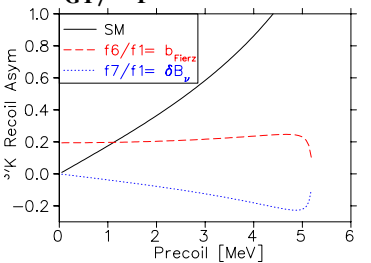


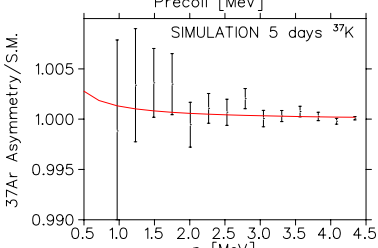
see ^{80}Rb Pitcairn PRC09

$A_T = 0.015(29)(19)$

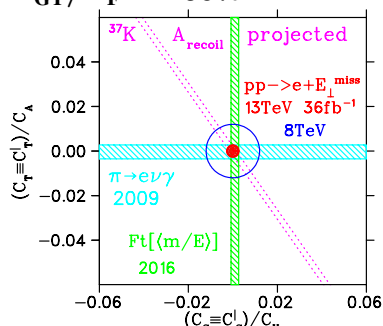


$A_{recoil}[p_{recoil}]$ independent of M_{GT}/M_F





Discovery potential, assuming known M_{GT}/M_F 90%



Completed upgrade to 1 kV/cm, fine-tuning polarization: plan to be ready in October 2020.

Scattered β's

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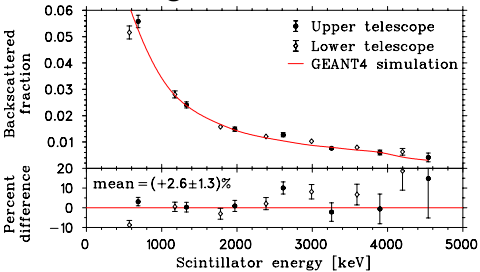
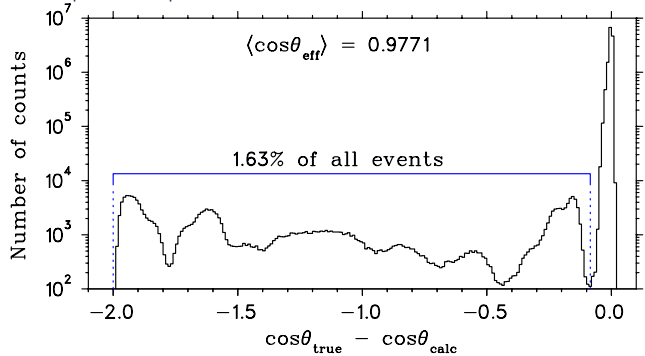
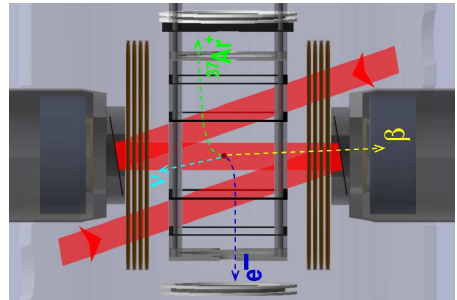
We can reduce the backscattering from SS collimator by lowering Z. We consider Cesic (carbon fiber reinforced silicon carbide ceramic) and covering the Cu coils

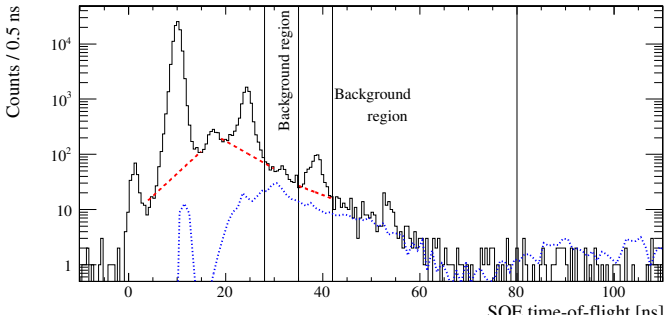


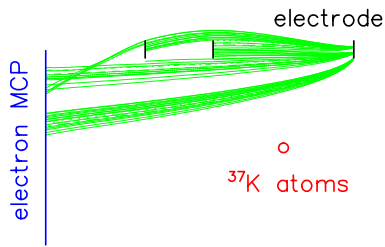
Extend to lower E_β, benchmark GEANT4 with higher statistics





Background in β - shakeoff e^- coincidence





- **2.8×10^{-3} of events in main peak are background from non-trapped atoms**
- **Conservatively assume polarized between 0 and 100%. $\rightarrow A_\beta \times (1.0014 \pm 0.0014)$**
- **These will be removed by MCP position info when we run at design *E* field 1 kV/cm**

A_β Systematics	$\Delta A_\beta \times 10^{-4}$	Proj
Background (Correction 1.0014 1.0000)	8	0
β scattering† (Correction 1.0234 1.01)	7	3
Trap Position (typ. $\leq \pm 20\mu$m)	4	2
Sail velocity (typ. $\leq \pm 30\mu$m/ms)	5	3
Temperature (typ. $\leq$ 0.2mK) & width	1	0.7
BB1 Radius† $15^{+3.5}_{-5.5}$ mm	4	4
Energy agreement ($3\sigma \leftrightarrow 5\sigma$)	2	2
threshold (60↔40 keV)	1	1
Scintillator threshold (0.4 ↔ 1.0 MeV)	0.3	0.3
Shakeoff electron t.o.f. region	3	1
SiC mirror thickness† ($\pm 6\mu$m)	1	0
Be window thickness† ($\pm 23\mu$m)	0.9	0.9
BB1 thickness† ($\pm 5\mu$m)	0.1	0.1
Scintillator or summed†	1	1
Scintillator calibration (± 0.4ch/keV)	0.1	0.1
Total systematics	12	7
Statistics	13	6
Polarization	5	2
Total uncertainty	18	8

^{37}K A_β Improvements

- **Minimize Background by sweeping away e^- with larger $\vec{E}$**
- **Reduce scattering by 2 with lower-Z materials Improve understanding**
- **Reduced energy threshold using pellicle mirrors**
- **Improve statistics**

Physics of average A_β

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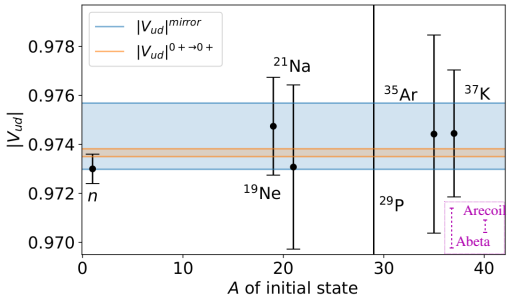
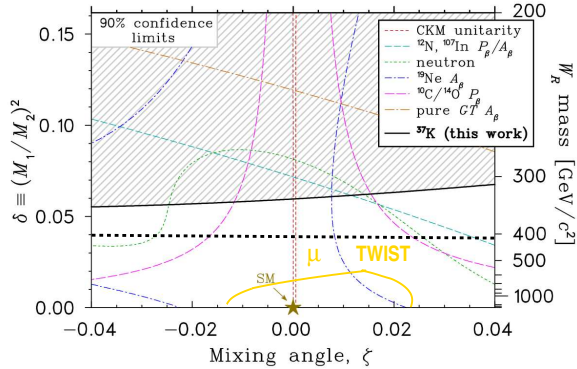
Deduced V_{ud} from mirror decays
Hayen and Severijns,
arXiv:1906.09870 (June 2019)
including G-T radiative correction



We project to reach 0.0005 accuracy, as good as any $0^+ \to 0^+$ except ^{26m}Al. Assumes 5% isospin breaking

as of Fenker et al. PRL 2018:



Right-handed V+A currents from nuclear and neutron β decay, in manifest left-right model
Projection for 3x better A_β

S1188 Request and TRINAT plans

We have used a few shifts to test apparatus: remaining 10 shifts expiring now.
We request to have 20 shifts total to:

- **measure $A_\beta[E_\beta]$ 3-5 x better. At same time:**
- **A_{recoil} with sensitivity to '4-fermion contact' interactions complementary to $\pi \to e\nu\gamma$, $\pi \to e\nu$, and LHC $p + p \to e + E_\perp$**

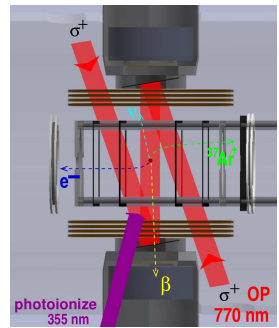
J. McNeil, UBC Ph.D. project

- **S1810 ^{92}Rb $0^- \to 0^+$ E_ν $a_{\beta\nu}$**

^{92}Rb was J. McNeil M.Sc.
Looking for a student for 2 more cases.

- **S1603 TRV $\beta\nu\gamma$ 3-momentum correlation**

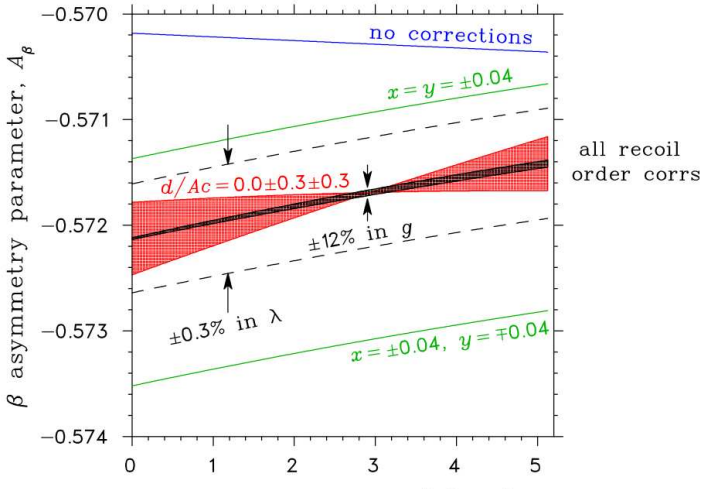
Proceeding with undergrad γ-ray development.
Recruiting a student.



^{37}K: recoil-order effects to 2nd order

from D. Melconian TRIUMF EEC 2008 proposal

g is the 2nd-order electric quadrupole moment weak analog; it is known better now



A_β (PRELIM: A_β [E_β]) agrees with S.M.

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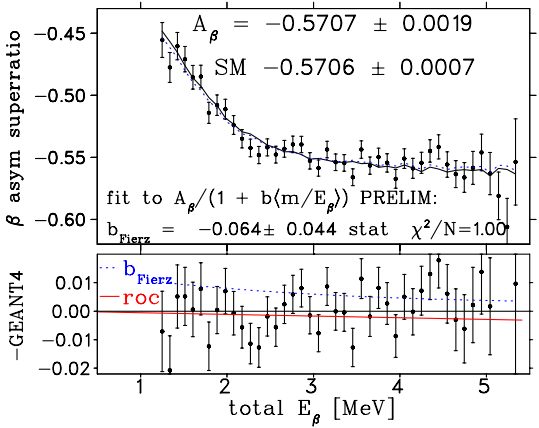
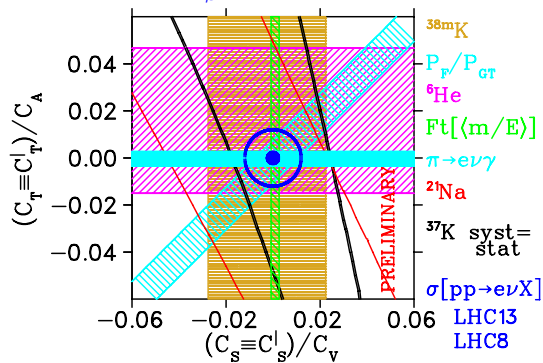


Nucleon, Lepton Currents making up Lagrangian (a scalar) can separately transform like *S*, *T*, *V*, *A*

1957 version of EFT.

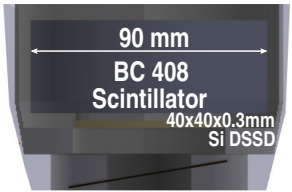
Fierz term $\propto \left\langle \frac{m_\beta}{E_\beta} \right\rangle$ ↓ floating this changes V_{ud}



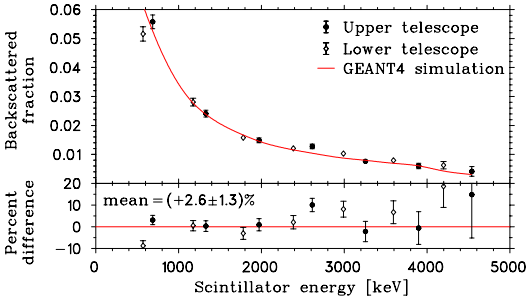
LHC13 $\sigma[p + p \to e\nu X]$ Naviliat-Cuncic Gonzalez-Alonso AnDP 2013 (Cirigliano et al JHEP 2013) and

CMS 2018 JHEP06 128: 2.5 events expected, 2 seen

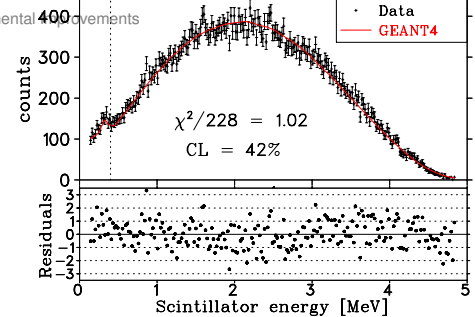
β^+ asymmetry ^{37}K data

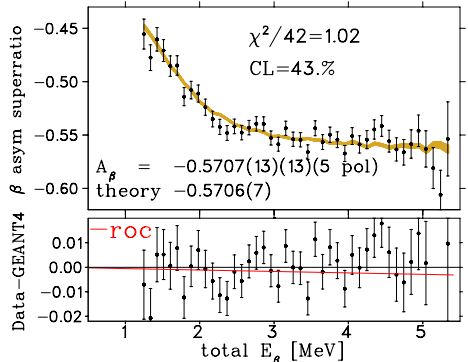


DSSD rejects BC408 backscatter



- **Backscatter from scint agrees to ≈5% over $E_{\beta+}$ range of interest**





Optical pumping and probing ^{37}K

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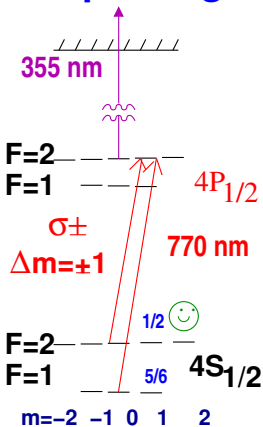
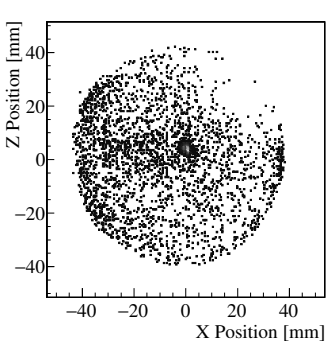
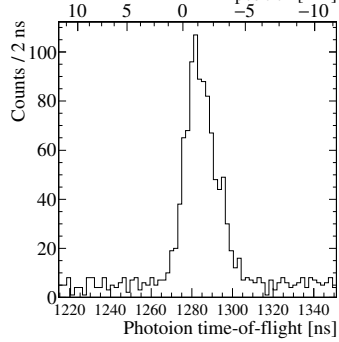
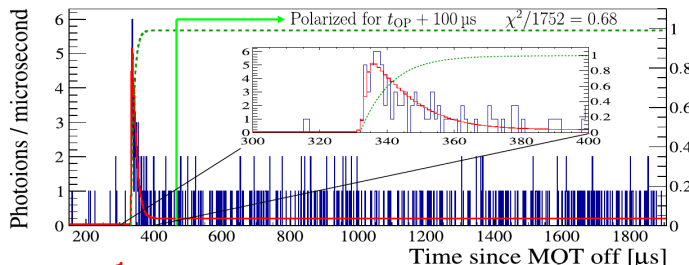


1 of 10 data sets







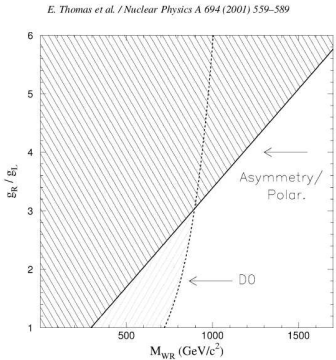
Photoionize 1% *in situ* **probe**

P_+=+0.9913(8) P_-=–0.9912(9)

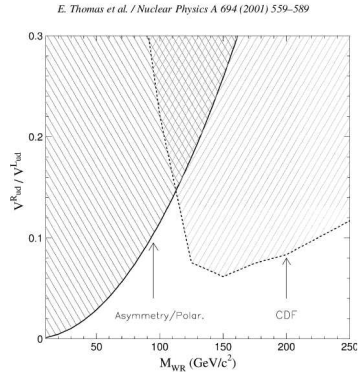
Fenker NJP 2016

$P \approx 1 - \frac{1}{3}(\text{tail}/\text{peak})$ unpumped atoms $P \sim \frac{2}{3}$ already

‘Non-manifest’ Left-Right models



$g_R > g_L$:
^{37}K $\Rightarrow g_R \lesssim 7.7$ at 4 TeV
(or $g_R < 4$, at 2 TeV but
LHC7 2 TeV ‘bump’ had
$g \sim 0.5$)



$V^R_{ud} < V^L_{ud}$
For $M'_W < 70$ GeV,
nuclear β decay
constrains V^R_{ud}

TRIUMF Ions backscatter

- **SRIM: $\sim$ 5% 10 keV Ar backscatter from nichrome**
  the $\vec{E}$ field will re-collect ions
- **F. Meyer et al. Phys. Scr. T92 182 (2001) experiment suggests $\sim$ 10% remain ionized.**

So $\sim$ 0.1% of the ions could trigger events significantly later. Study by multiple hits?