

# S1188 Spin-polarized $^{37}\text{K}$ $\beta^+$ decay with TRINAT

## • Status:

$^{37}\text{K}$   $A_\beta = -0.5706 \pm 0.0018$  [Fenker DNP16]

S.M.  $A_\beta = -0.5715 \pm 0.0007$

The most accurate  $A_\beta$  measurement

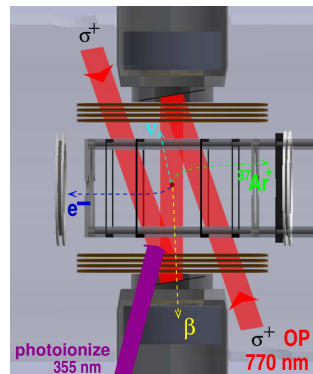
High-accuracy polarization measurement,  
continuous in situ probe

## • Improvements to $A_\beta$

Phenomenology implications

## • New observable $A_{\text{recoil}}$ in same geometry

## • Shift request



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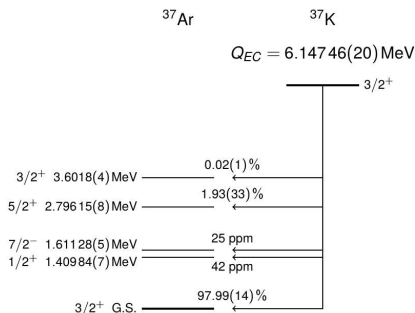


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# $^{37}\text{K}$ isobaric mirror decay



**DFT for isospin mixing has improved its functional in this region**

**Using weighted average for  $\delta_C$  would  $\rightarrow$**

$$\rho = 0.5774 \pm 0.0022$$

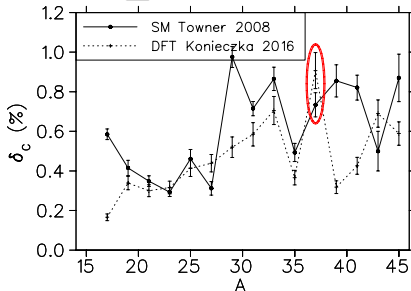
**1st-order recoil-order corrections from E&M moments by CVC**

**(One small 2nd-order axial current term depends on nuclear structure)**

**$Ft$  (Shidling 2014)  $\rightarrow$**

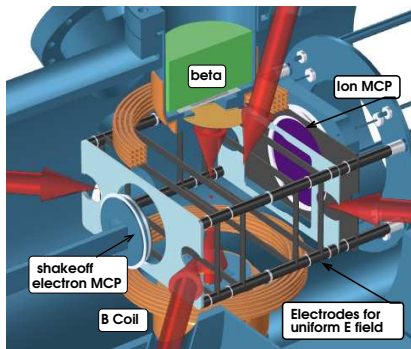
$$\rho = C_A M_{GT} / C_V M_F$$

$$= 0.5768 \pm 0.0021$$

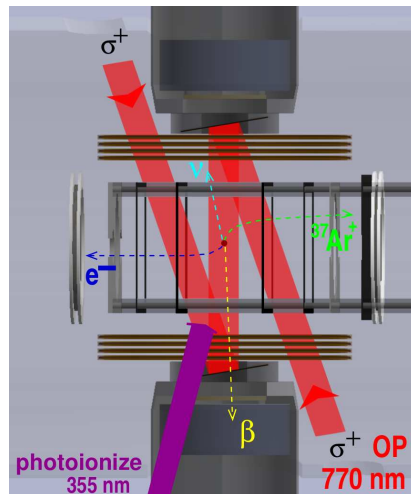




# $^{37}\text{K}$ decay geometry



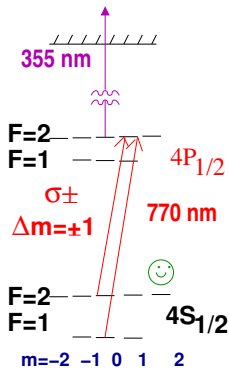
- $\beta$ , recoil nucleus
- shakeoff  $e^-$  for TOF trigger



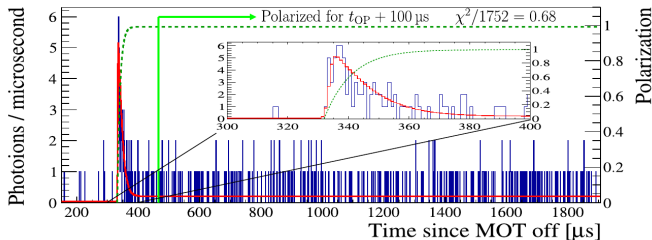
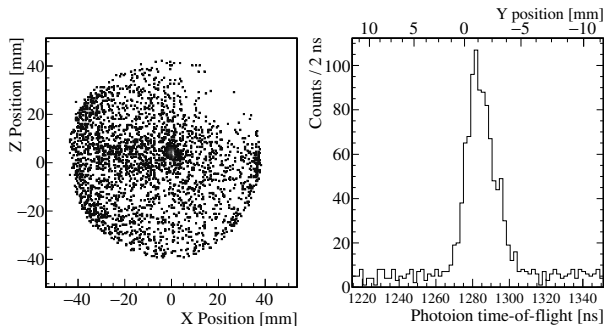
June 2014 data at reduced  $\mathbf{E}$  field for  $A_\beta$

The decay pattern shown on the right is helicity-forbidden if the  $\nu$  goes straight up, independent of Gamow-Teller/Fermi ratio.

# TRIUMF Optical pumping and probing $^{37}\text{K}$



- Photoionize  
 $\sim 1\%$
- continuous  
*in situ* probe





# Polarization Improvements



SYST  $\times 10^{-4}$

$\Delta P$

$\Delta T$

$\sigma^-$   $\sigma^+$   $\sigma^-$   $\sigma^+$

Initial  $T$

3 3 10 8

Global fit v. ave

2 2 7 6

$S_3^{\text{out}}$  Uncertainty

1 2 11 5

Cloud temp

2 0.5 3 2

Binning

1 1 4 3

$B_z$  Uncertainty

0.5 3 2 7

Initial  $P$

0.1 0.1 0.4 0.4

Require  $\mathcal{I}_+ = \mathcal{I}_-$

0.1 0.1 0.1 0.2

Total SYSTEMATIC

5 5 17 14

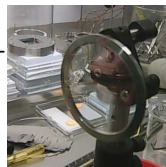
STATISTICS

7 6 21 17

B. Fenker New J. Phys **18** 073028  
2016

$P(\sigma^+) = +0.9913(8)$   $T(\sigma^+) = -0.9770(22)$

$P(\sigma^-) = -0.9912(9)$   $T(\sigma^-) = -0.9761(27)$



• pellicle mirrors:  
less  $\beta^+$  scattering

• define  $T$  by OP

• trim B gradients

• improve  $S_3$  flipping  
and gradients

• add flipping of  $B_z$

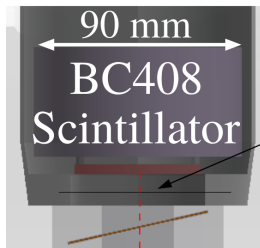
• higher-power  
photoionizing laser

• gentler RAC-MOT

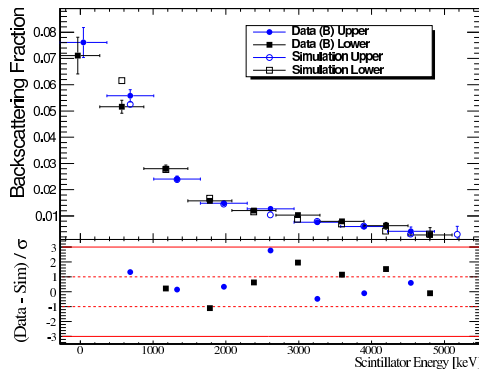
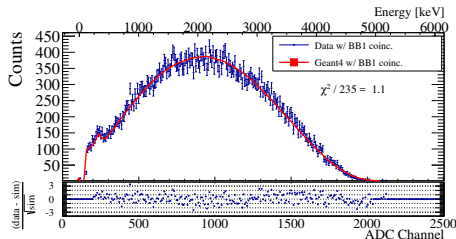
• Uncertainty  $\propto$   
(1-P)



# $\beta^+$ Spectra



- 300  $\mu\text{m}$  DSSSD + plastic scintillator
- linear calibration uses 511 keV Compton edge and  $E_\beta$  endpoint
- Backscatter from scint ( $> 1$  DSSSD pixel fires) agrees with GEANT4 to  $\sim 10\%$  over  $E_{\beta+}$  range of interest (in preparation)





# $A_\beta$ + Uncertainties



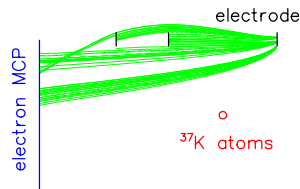
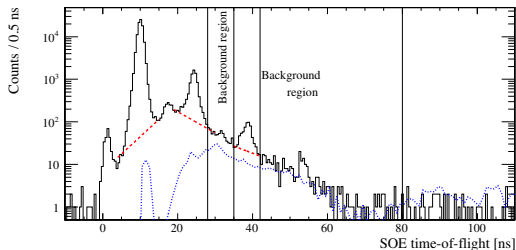
Source $\times 10^{-4}$ [ $\dagger$ : $\beta$ scattering]	$\Delta A_\beta$
Background (Correction 1.0013)	7
Trap Position	4
Trap <b>Sail velocity</b>	<b>5</b>
Trap Temperature & width	1
<b>BB1 Radius<math>^\dagger</math></b>	<b>4</b>
BB1 Energy agreement	2
BB1 threshold	1
Scintillator threshold	0.3
GEANT4 physics list $^\dagger$	4
Shakeoff electron t.o.f. region	3
SiC mirror thickness $^\dagger$	1
Be window thickness $^\dagger$	0.9
Scintillator or summed $^\dagger$	1
Scintillator calibration	0.1
Total systematics	12
<b>Statistics</b>	<b>13</b>
Polarization	5
Total uncertainty	18

**Background** see next slide

- **New trap control system and faster CMOS camera  $\rightarrow$  smaller cloud temp. and size. Will try 405nm cooling.**
- **Pellicles  $\rightarrow$  less  $\beta^+$  scattering.**
- **Properly tapered collimators**
- **better ion MCP: better-known photoions**

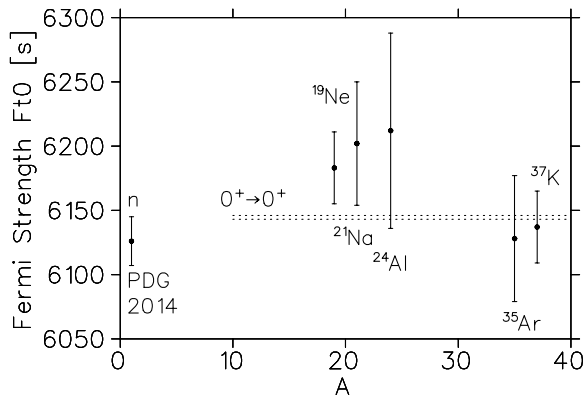


# Background



- $\beta$  telescope and shakeoff  $e^-$  coincidence remove most decays not from the trap cloud. Remainder is our largest uncertainty.
- Conservatively assume polarized between 0 and 100%.
- These will be removed by MCP position info when we increase to design  $\mathbf{E}$  field




 $V_{ud}$ 


- CVC hypothesis can be assumed only where we can test it

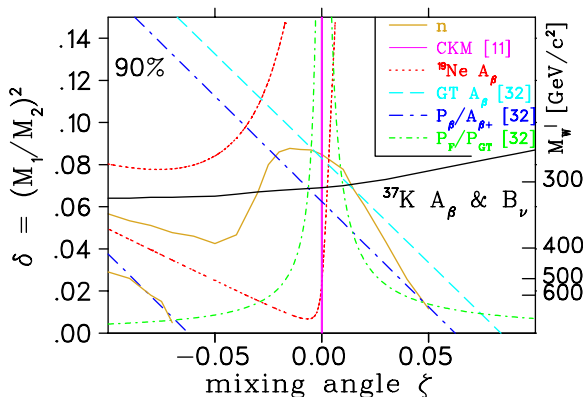
**CVC tests constrain SM physics in addition to isospin mixing.**  
**E.g. Salam Nature 1974:**  
 phase transitions at very high B fields could drive  $\theta_{\text{Cabibbo}} \rightarrow 0$   
 Hardy Towner PLB 1975 applied to the  $^{35}\text{Ar}$   $A_\beta$  controversy.



# Right-handed vector currents



Standard model W exchange produces left-handed  $\nu$  and right-handed  $\beta^+$  (“V-A”)



**$^{19}\text{Ne } A_\beta$**   
**disagrees SM**  
**(worse after DNP**  
**2016)**

**$^{37}\text{K}$  constraint**  
**complementary**

**$\zeta = 0$ :**  
 **$W_R M > 310 \text{ GeV}$**   
 **$(\approx P_\beta/A_\beta \text{ } ^{12}\text{N}$**   
**Thomas 2001 )**

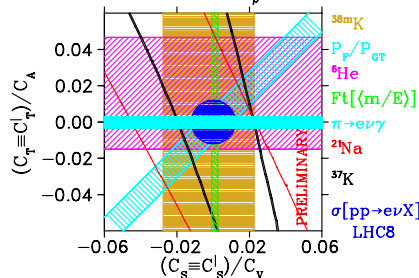
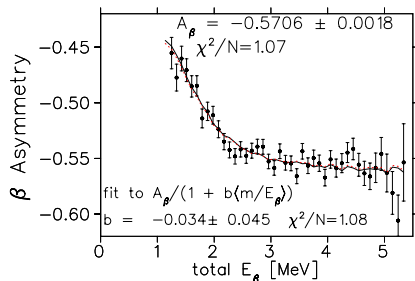
**Non-manifest:**

**Nuclear  $\beta$  decay average  $g_R \lesssim 6.7$  at 4 TeV**

**For  $M'_W < 70 \text{ GeV}$ , nuclear  $\beta$  decay constrains  $V_{ud R}$**   
**(Severijns Naviliat-Cuncic ARNPS 2011)**

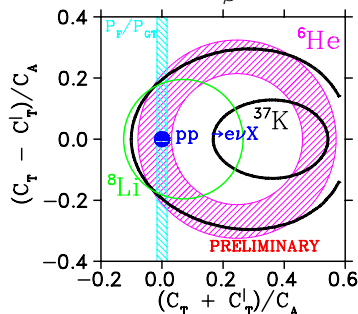


# $A_\beta [E_\beta]$ agrees with S.M.



**Nucleon, Lepton Currents making up Lagrangian (a scalar) can separately transform like  $S, T, V, A$  1957 version of EFT.**

**Fierz term  $\propto \langle \frac{m_\beta}{E_\beta} \rangle$**

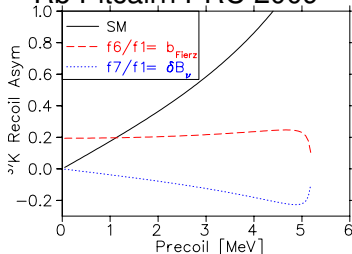


Specific models: spin-1 leptoquarks make  $S$  and  $T$ ;  
 MSUSY sums over particles to make combination of  $S, T$

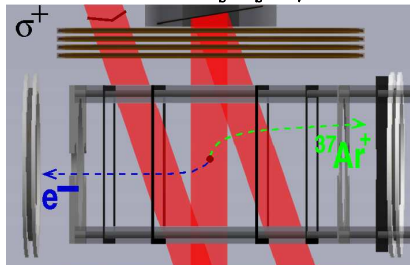
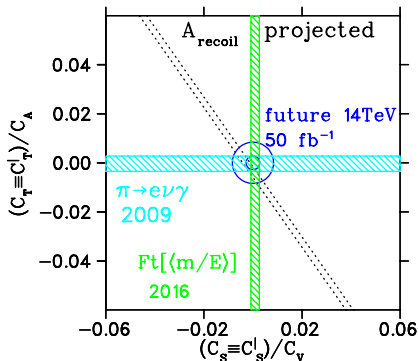
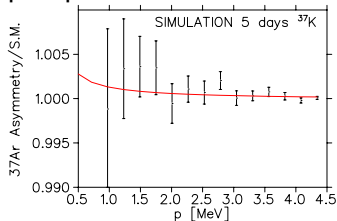


$$A_{\text{recoil}} \propto A_\beta + B_\nu$$

Technique demonstrated in  
 $^{80}\text{Rb}$  Pitcairn PRC 2009



Ave  $A_{\text{recoil}}$  depends on  $\rho$ ;  
 $\rho$  dependence doesn't

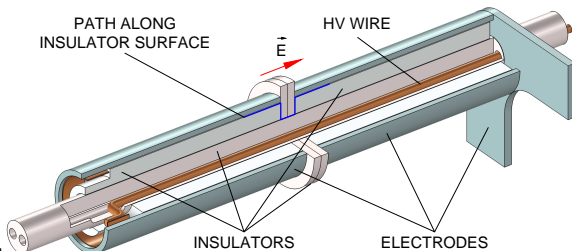




## E field status

**Nested insulators: E no longer falls across dielectric surfaces**

- Argon conditioning
- 1.2 kV/cm reached
- Improved ion MCP mount (as in Hong et al. NIM Seattle-Argonne) in progress
- More compact shakeoff  $e^-$  MCP and wedge-and-strip readout to allow simultaneous ion and  $e^-$  detection.



- Remove  $A_\beta$  background
- Adds  $A_{\text{recoil}}$
- All detectors together for trap diagnostics and for  $\rho$ -independent  $\beta$ -recoil observable



# Summary and request S1188



High polarization accuracy  $99.13 \pm 0.09\%$   $\rightarrow$  program of polarized correlations.

Plan: finish upgrades of present geometry [Aug 2017], beamtime measuring  $A_\beta$ ,  $A_{\text{recoil}}$ , and the  $\rho$ -insensitive  $\beta$ -recoil coincidence.

Future possibilities: replacing the  $e^-$  MCP by a  $\beta$  detector, optimized geometry for  $B_\nu$ . This geometry may be compatible with S1077  $^{38}\text{mK}$   $\beta$ - $\nu$  correlation.

**Shift Request:** We have 6 shifts now for S1188. We would use these for development.

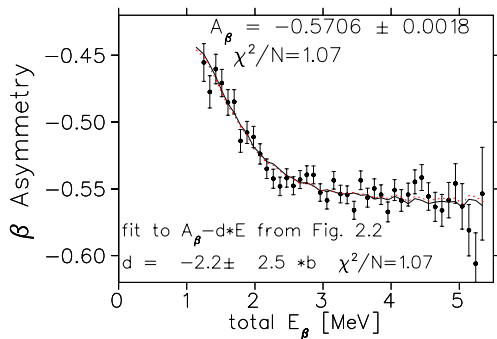
**We request an additional 20 shifts for  $A_\beta$  and  $A_{\text{recoil}}$  geometry measurement.**

Our projected result would be a decrease in the uncertainty on  $A_\beta$  by a factor of 3, enabling better sensitivity than the existing LHC information to  $S$ ,  $T$ .

The higher-statistics observable  $A_{\text{recoil}}$  would be complementary to projected LHC 14 TeV sensitivity.



## 2nd-class currents



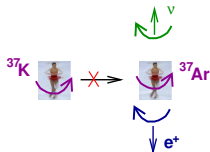
2nd-class currents violated isospin symmetry.

'induced tensor'  $d$  is predicted zero in isobaric mirror decay.

although the limit on  $d$  is not competitive yet, there are models where 2nd-class currents change with system where this result is complementary



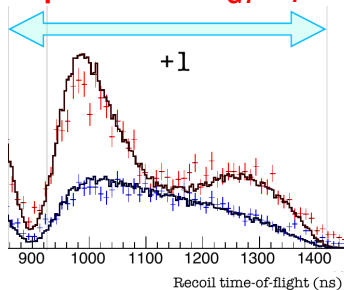
# Helicity-driven null in mirror decay



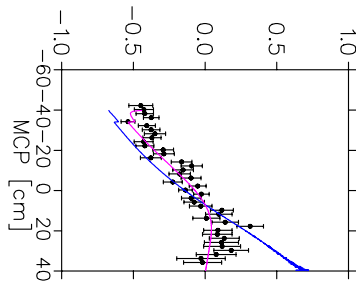
$$W(\theta_{\beta\nu i}) \approx 1 + \mathcal{A}_{\beta\nu i} \cos(\theta_{\beta\nu i})$$

$$\mathcal{A}_{\beta\nu i} = \frac{a + PB - 2cT/3}{1 + PA}$$

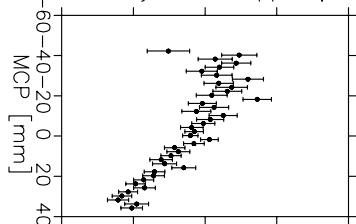
For  $P=-1$ ,  $\mathcal{A}_{\beta\nu i}=1$ ,  
independent of  $M_{GT}/M_F$



ion asym with lower  $\beta$



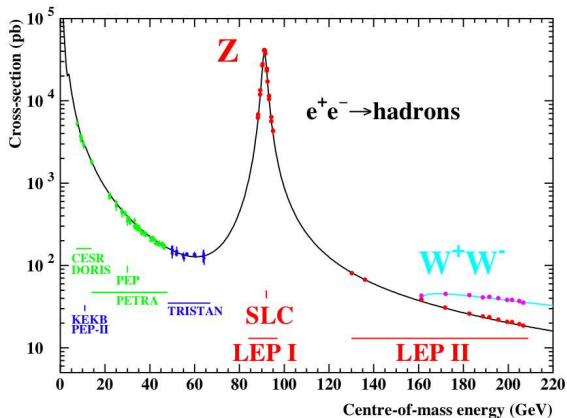
ion asym with upper  $\beta$



2014 data under analysis



# Weakly-coupled $W'$ still has electric charge



Does  $\sigma e^+ + e^- \rightarrow W^+ + W^-$  double for  $W'$ ?

Depends on the cut for  $W$ : typically this cut (explicitly listed in PDG) excludes low-mass  $W$  because of serious background