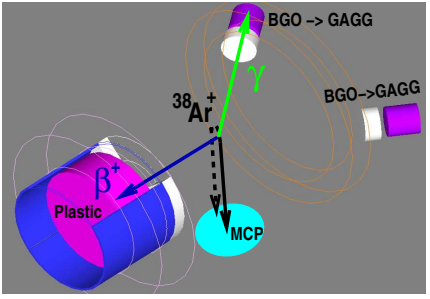
Progress: S1603 Time-reversal violation in radiative β decay

- **Update: Motivation for this type of $\not{T}$**
- **Update: our test of our experimental method (symbiotic with ^{92}Rb β-ν correlation)**
- **Reassure Beam Delivery that the target chemists know why the ^{37,38m}K was better**
- **Summary and future shift plan wrt S1188**



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A. Gorelov
J.A. Behr
J. McNeil
M. Khoo (UG)

TEXAS A&M UNIVERSITY
D. Melconian

UNIVERSITY OF MANITOBA
M. Anholm
G. Gwinner

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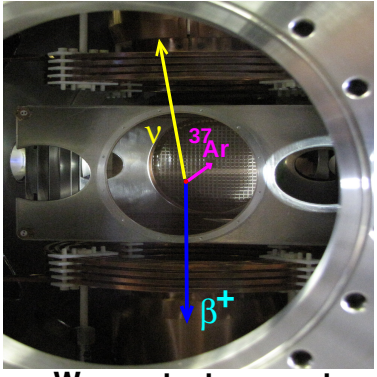
3-momentum $\not{T}$ correlation: Our example

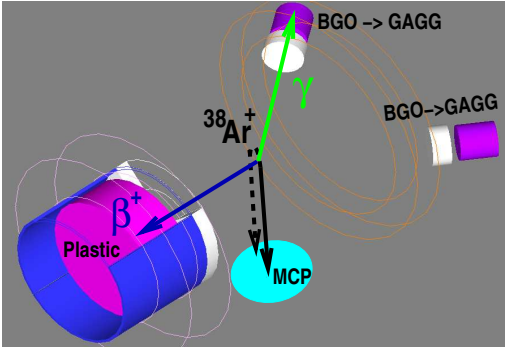
When t → -t :

$\vec{r} \rightarrow \vec{r}$ $\quad \vec{p} \sim \frac{d\vec{r}}{dt} \rightarrow -\vec{p}$



$$\vec{p_\nu} \cdot \vec{p_\beta} \times \vec{p_\gamma} = -\vec{p}_{\text{recoil}} \cdot \vec{p_\beta} \times \vec{p_\gamma}$$

$$\xrightarrow{t \rightarrow -t} \vec{p}_{\text{recoil}} \cdot \vec{p_\beta} \times \vec{p_\gamma}$$



- We can test symmetry of apparatus with coincident pairs
- Not exact: outgoing particles interact → 'final-state' fake $\not{T}$

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Motivation review

• Once P was found to be maximally broken, many spin-dependent T-odd observables were proposed and measured to be $\lesssim 10^{-3}$ like

$$D\hat{J}\cdot\frac{\vec{p}_\beta}{E_\beta}\times\frac{\vec{p}_\nu}{E_\beta}\quad R\vec{\sigma}_\beta\cdot\hat{\mathbf{J}}\times\frac{\vec{\mathbf{p}}_\beta}{E_\beta}$$

• In contrast, our type of $\not{T}$ needs 3 independent momenta. E.g. proposed $\not{T}$ in $\pi^\pm\to e^\pm\nu e^+e^-$ [Flagg Phys Rev 178 2387 (1969)] was never done:

• Our exp. would be unique to 1st generation of particles

Harvey Hill Hill PRL 99 261601 (2007);

EFT with SM interactions combined in the nucleon: goal was extra γ production by medium-energy ν's

QCD Weak E&M

$$\mathcal{L}=\frac{-4c_5}{m_{\text{nucleon}}{}^2}\frac{eG_FV_{ud}}{\sqrt{2}}\epsilon^{\sigma\mu\nu\rho}\bar{\mathbf{p}}\gamma_\sigma\mathbf{n}\bar{\psi}_{eL}\gamma_\mu\psi_{\nu L}F_{\nu\rho}$$

Gardner, He PRD 2013: looked for contributions to radiative n decay. Noticed QCD antisymmetry led to a scalar triple product of momenta ☺:

$$|\mathcal{M}_{c5}|^2\propto\frac{Im(c_5g_V)}{M^2}\frac{E_e}{p_ek}(\vec{p_e}\times\vec{k_\gamma})\cdot\vec{p_\nu}$$

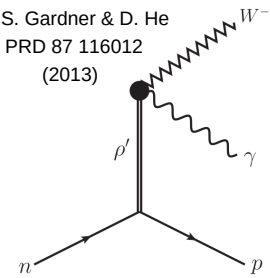
Needs non-SM QCD-like physics, scale $M\sim$ 10's of MeV

Gardner further considered explicit models with new particles weakly coupled to SM, strongly interacting among themselves →

Though $\vec{p_\nu} \cdot \vec{p_\beta} \times \vec{p_\gamma}$ doesn't involve spin, EDM's indirectly constrain:

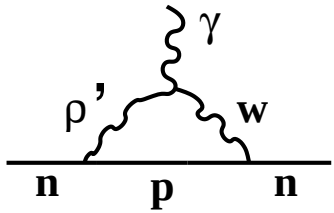
Some *TRV* $\gamma\beta\nu$ interactions, e.g. :

S. Gardner & D. He
PRD 87 116012
(2013)



make neutron EDM at "1-loop" order

(D. McKeen, private comm):



"Naive Dimensional Analysis" $c_5 \frac{e^2 G_F M_W^3}{16\pi^2 m_{\rho'}^2}$ **suggests nEDM larger than experiment by** $\sim 10^8$.

$\rightarrow$ ***TRV*** $\beta\nu\gamma$ **from such interactions likely too tiny to measure** ☹

- **Other interactions (e.g. leptoquarks) need "2 loops" so generate comparatively tiny nEDM so are less constrained, could generate *TRV*** $\beta\nu\gamma$ **large enough to measure** ☺

Other constraints

- **Direct constraint from n** $\rightarrow$ **p** $\beta\nu\gamma$ **branch** $\propto |c_5|^2$

Bales PRL 2016: $3.4 \pm 0.2 \times 10^{-3}$ **(theory** 3.1×10^{-3}**)**

$\Rightarrow \frac{\mathrm{Im}(c_5)}{M^2} \leq 8 MeV^{-2} \Rightarrow$ ^{37}**K *TRV* asym can be** ~ 1 ☺

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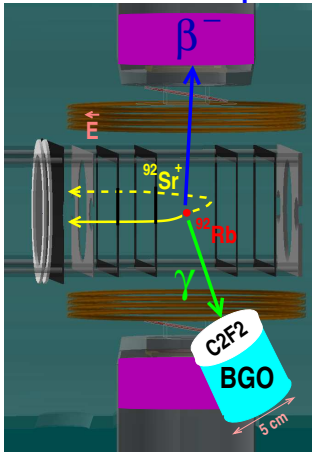
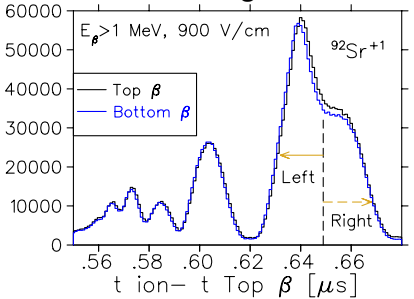
Test experiment in ^{92}Rb $0^- \rightarrow 0^+$ decay (no vector current) + BGO → GAGG



$\beta^- \cap {}^{92}Sr^+$

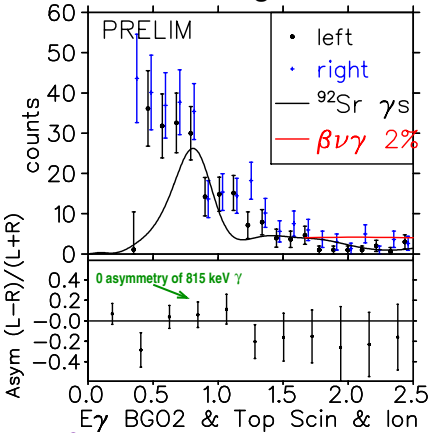
'left' vs. 'right':

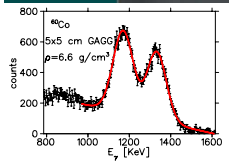


(other γ detector sees background from upstream)

$\beta^- \cap {}^{92}Sr^+ \cap \gamma$

'left' vs. 'right':





BGO → GAGG ($Ce:Gd_3Al_2Ga_3O_{12}$)

- better E_γ resolution and timing, ρ= 6.6 g/cm^3
- Good photopeak efficiency (55% at 1 MeV)
- not radioactive like LYSO

Sensitivity to ~ 0.05 to 0.10 asymmetries of few percent branches

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Readiness: beam

The beam readiness summary is correct: there was one TiC target that made $t_{1/2} \sim$ 1s yields $\sim 4\times$ larger than others

Details: Target chemists ground the TiC much finer, improving release time. This is labor-intensive (it wore out two mortal-and-pestles!), but the target chemists expect this to be reproducible.

We've been quoting this number for yields for S1188 as well, with the same minimum/ideal/maximum acceptance.

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S1603 can't run simultaneously with S1188

We've considered running S1603 first experiment at the same beamtime as our next ^{37}K spin-polarized S1188, but they are mutually incompatible (except for tests of both).

Issues include:

- **One GAGG (blocking one viewport) fits in S1188 geometry, but could produce scattering asymmetries for precision S1188**
- **Our simplest symmetric geometry for S1603 involves 2 γ detectors, blocking too many optical ports for S1188**
- **The γ-ray singles trigger is needed for *T*-even pairs to test apparatus symmetry, but disturbs efficiency of other triggers, critical for precision S1188**
- **Polarized on/off duty cycle is inefficient for S1603: residual MOT polarization and changing cloud size are systematics for S1603**

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S1603 $\not{T}$ in $\beta\nu\gamma$: Summary and shift request

Must have TiC target to make the isotopes that decay by the vector current i.e. Fermi operator, i.e. ^{37}K and/or ^{38m}K, to look for this mechanism for $\not{T}$.

We request as in the progress report:

Beyond the 3 shifts scheduled in August 2021, we project further test time will be done symbiotically with S1188 shifts– so we've dropped 3 test shifts from the new total:

- **We request 12 shifts dedicated to S1603 for the first TRV 3-momentum asymmetry, using either ^{37}K or ^{38m}K. We project sensitivity to 0.05 to 0.1 asymmetries for few percent branches.**
- **We expect to be ready for these shifts in Oct-Dec 2021 or in 2022.**