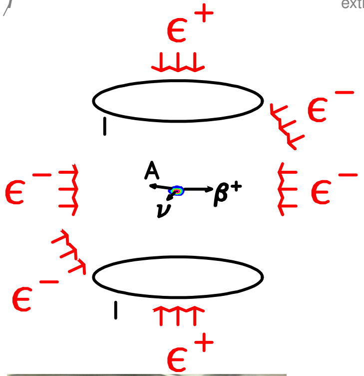
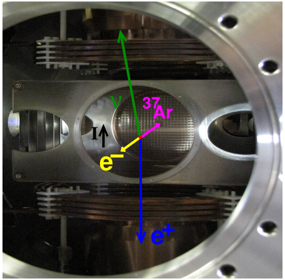
Fun Sym with Atom Traps

- Parity *P* symmetry

  How to test *P* symmetry experimentally

  Only left-handed ν so far: how do we know?
- $\not P$ with TRIUMF Neutral Atom trap for β decay
- $\not P$ in Francium atoms
- How atom traps work
- $\not T$ experiments *so much time, so little to do*





TRIUMF
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J. McNeil (UBC)
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University of Waterloo H. Gallop

Texas A&M University
D. Melconian

University of Manitoba
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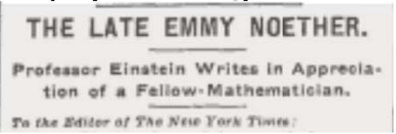
G. Gwinner
T. Hucko
A. Sharma
L. Xie

Symmetries: Continuous vs Discrete

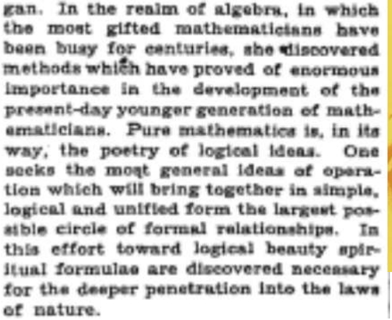
- **Noether's theorem (1915):**

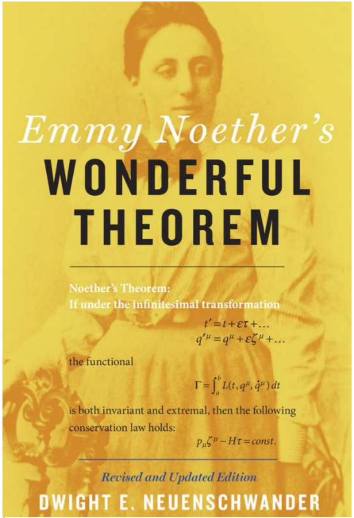
Continuous symmetry	→	Conserved quantity
Time-translational invariance	→	Energy
Space-translational invariance	→	Momentum
Rotational invariance	→	Angular momentum
(Laplace-Runge-Lenz vector)	→	name?


THE LATE EMMY NOETHER.

Professor Einstein Writes in Apprecia-
tion of a Fellow-Mathematician.

To the Editor of The New York Times:


gan. In the realm of algebra, in which the most gifted mathematicians have been busy for centuries, she discovered methods which have proved of enormous importance in the development of the present-day younger generation of mathematicians. Pure mathematics is, in its way, the poetry of logical ideas. One seeks the most general ideas of operation which will bring together in simple, logical and unified form the largest possible circle of formal relationships. In this effort toward logical beauty spiritual formulae are discovered necessary for the deeper penetration into the laws of nature.



In Ted Chiang's "Story of Your Life" aliens think in terms of the action, not position and momentum [Movie "Arrival"]

- **Discrete symmetries in quantum mechanics: Parity, Time reversal →**

Historical Ideas about P, T breaking

- Wigner considered implications of P, T symmetry conservation in atomic spectra 1926-28. Showed $\langle T\psi_i, T\psi_f\rangle = \langle\psi_f, \psi_i\rangle^*$

"In quantum theory, invariance principles permit even further reaching conclusions than in classical mechanics." (D. Gross, Physics Today 48 46 (1995))

- Weyl 1931 considered C, P, T and CPT in "Maxwell-Dirac theory": C $\Rightarrow$ Dirac eq. negative energy states had to have same mass as the e^- plato.stanford.edu
- From "CP Violation Without Strangeness" Khriplovich and Lamoreaux:

1949 Dirac "I do not believe there is any need for physical laws to be invariant under reflections in space and time although the exact laws of nature so far known do have this invariance."

Apr 1956 Asimov "The Dead Past" ν travels backwards in time

- Oct 1956 Lee and Yang proposed $\not{P}$ in weak decays to fix the θ-τ puzzle
- Feynman gives Ramsey 50:1 odds $\not{P}$ would not be observable
  Ramsey experiment starting at ORNL gets derailed by fission experiments...
  it's OK, Ramsey won 1989 Nobel for his fringes
- 1957 3 simultaneous experimental measurements of $\not{P}$ $\rightarrow$

Parity (From A. Zee "Fearful Symmetry")

As of 1956, we thought all interactions respected parity

Parity operator

$\boldsymbol{P}\,\psi(\vec{r}) \rightarrow \pm\,\psi(-\vec{r})$

P  $=$ 

1957:

$\tau - \theta$ Puzzle

+ μ decay

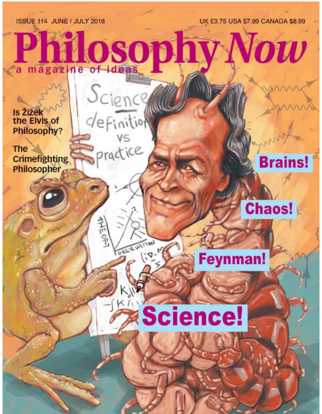
+ ^{60}Co decay $\Rightarrow$

P  $\neq$ 

Mirrors are not really reversing x,y,z and are kinda confusing

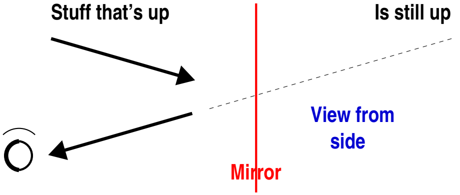
Plato's 'mirror problem':

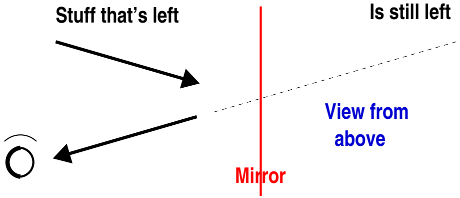
"Mirror, Mirror"
T. Wilkinson,
PhilNow 114 (2016)



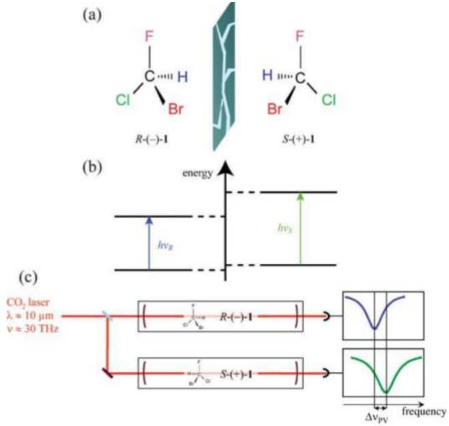
Plato: Why do mirrors reverse L-R but not U-D?
JB: You gotta look at this diagram. See,
Up stuff stays Up, and Left stuff stays Left.
Nothing's actually reversing.
I'd say your interpretation of 'left' is not quite right ☺
Plato: 'explains what I'm missing, but still too abstract for JB'

JB thinks Plato and other philosophy is critical to humans, but there's not much deep about mirrors.





Molecule binding energy depends on handedness

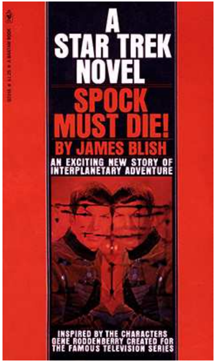


Letokhov, Difference of energy-levels of left and right molecules due to weak interactions. Phys Lett A (1975) 53 275

Darquie et al. CHIRALITY 22 870 (2010) Progress Toward the 1st Observation of $\not{P}$ in Chiral Molecules by High-Resolution Laser Spec

- **Very small $\sim 10^{-16}$ to 10^{-14} energy shifts.**

Astrobiology 18 (2018) Selection of Amino Acid Chirality via ν Interactions with ^{14}N in $\vec{E} \times \vec{B}$ Fields
M.A. Famiano, R. N. Boyd...



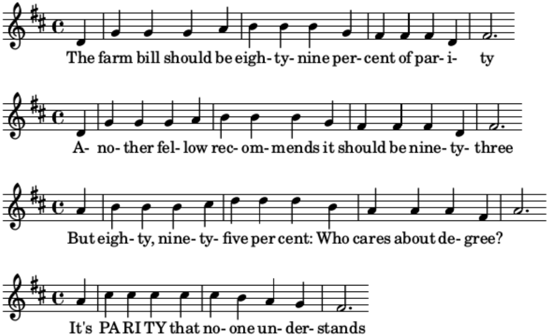
mirrorSpock synthesized wrong-handed amino acids to eat

mirrorSpock was loyal to the Klingons

Parity: influences? 1956 Broadway Musical Lil' Abner

20 minutes by public transit

Timeless Lyrics: Gene de Paul, music Johnny Mercer

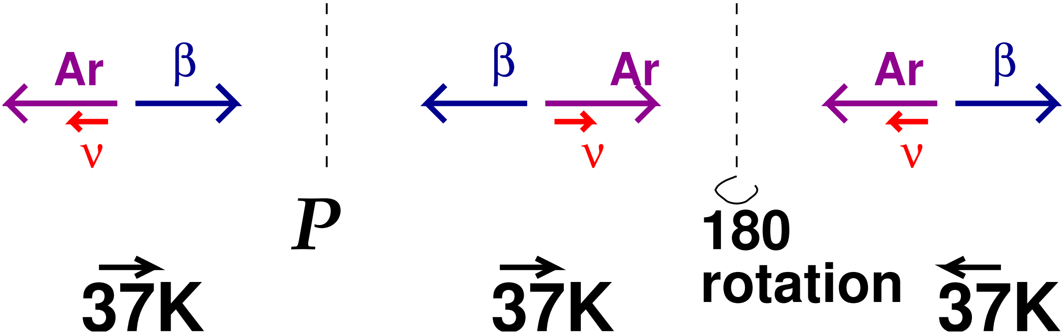


Lee and Yang, theory of parity violation published Oct 1956;
Opening night Lil' Abner Nov '56 (any free rehearsals?);
β experiment Wu et al. Jan '57; μ Garwin et al. Jan '57
(Mom, an admin asst at Columbia, thinks this is unrelated)
Theory won Nobel; experiment, music did not ☹

Decays: Parity Operation can be simulated by Spin Flip

Under Parity operation *P*:

$\vec{\mathbf{r}} \rightarrow -\vec{\mathbf{r}}$ $\quad$ $\vec{\mathbf{p}} \sim \frac{d\vec{\mathbf{r}}}{dt} \rightarrow -\vec{\mathbf{p}}$ $\quad$ $\vec{\mathbf{J}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}} \rightarrow +\vec{\mathbf{J}}$



⇒ A spin flip corresponds exactly to *P* reversal

Decays don't exactly test *T*-reversal symmetry

One experimental discovery of parity violation

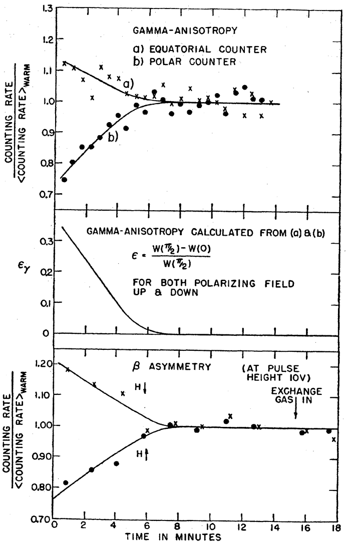
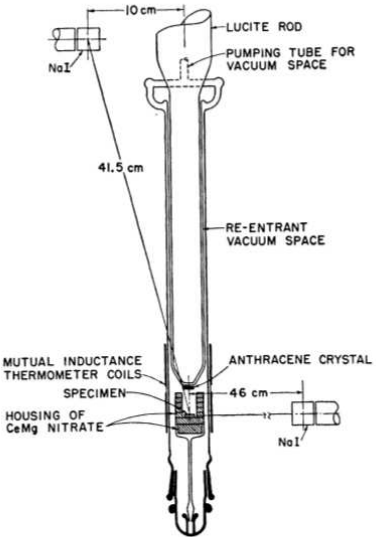


FIG. 2. Gamma anisotropy and beta asymmetry for polarizing field pointing up and pointing down.



Wu, Ambler, Hayward, Hopper, Hobson, PR 105 1413 Feb '57

Dilution Refrigerator to spin-polarize

^{60}Co $\rightarrow$ ^{60}Ni + β^- + $\bar{\nu}$

$$W[\theta] = 1 + PA\hat{I} \cdot \frac{\vec{p}_\beta}{E_\beta}$$

$$= 1 + A\frac{v}{c}\cos[\theta]$$

$A_{\beta-} \approx -1.0$

Followup:

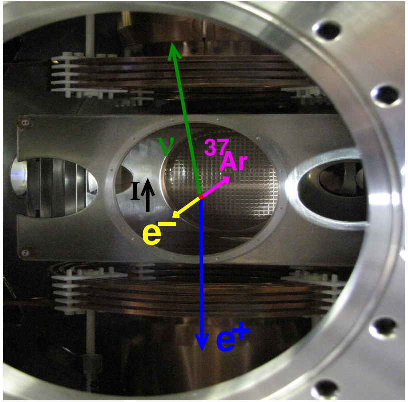
^{58}Co $\rightarrow$ ^{58}Fe + β^+ + ν

$A_{\beta+} > 0$

CP conserved?

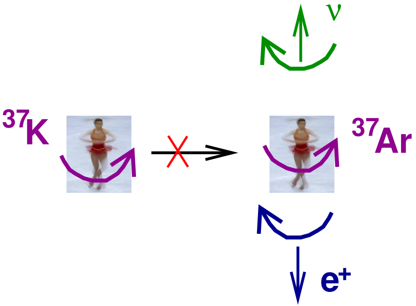
You said you were going to talk about the ν helicity

a different isospin mirror-decay spin-polarized observable



- 10,000 atoms trapped
- P measured in-situ on ^{37}K by atomic method
- ion + shakeoff e$^-$ for A_{recoil}

Isobaric mirror decay has helicity-driven null

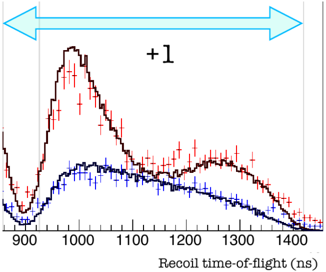


$$W(\theta,P) \approx 1 + a_{pol} \cos(\theta_{\beta\nu})$$

with $a_{pol} = (A_\beta - B_\nu)P - a_{\beta\nu} + 2c/3$

$= 1$ or 0, indep of $\frac{M_{GT}}{M_F}$

2014 polarized β-recoil



a_{pol} is an elegant observable, but we may always be statistics-limited– we push upgrades of singles A_β and A_{recoil}

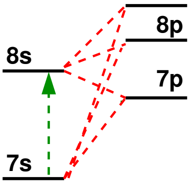
The neutron community checks this combination of observables for consistency

Mostovoi+Frank Pis'ma Zh. Eksp. Teor. Fiz. 24 45 (1976)

University of Manitoba

FrPNC: Recent results

TRIUMF



Weak interaction mixes

s, p

Claude & Marie-Anne Bouchiat
Used in Cs by Wieman. In Fr:

$$|A_{7s\to 8s}|^2 = |E1_{\rm Stark} + E1_{\rm PNC} + \overset{\text{in PBC}}{M1}|^2$$

$$\approx |E1_{\rm stark}|^2 + 2E1_{\rm Stark}E1_{\rm PNC}$$

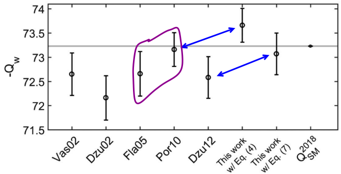
$E1_{\rm PNC} \sim 10^{-9}$ of an allowed $E1$ transition amplitude

By picking an E field one can make the asymmetry $\sim 10^{-3}$

Measurement of $|M1|^2$ with PBC $\sim 10^{-13}$ of an allowed $|E1|^2$

T.Hucko, A.Sharma, Kalita, Orozco, Gorelov, Gwinner...

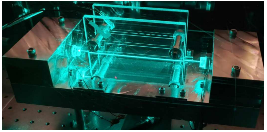
Toh Damitz Tanner Johnson Elliott PRL 2019



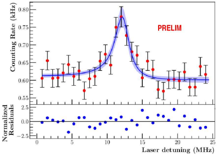
Cs: $E1_{PNC} \xrightarrow{\text{theory}} Q_W$ disagrees $\sim 1.5\ \sigma$
Cs: Asym $\longrightarrow E1_{PNC}$ using measured $M1/\beta$ differs from using other observables

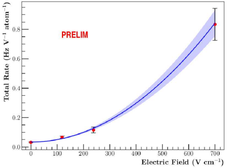
- 8% accuracy differentiates between calculations (theory - exp. ~10% in Cs, only other M1 measured)
- Interference (without PBC) will measure $M1/\beta$ better (Goal 2022)
  $M1$ Fr/Cs ≈ 3, so goal is $M1/\beta$ to deterministic accuracy

Power buildup cavity
UHV
$Q \approx 4{,}000$



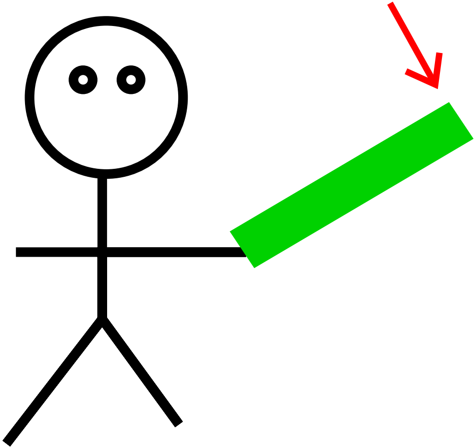
T. Hucko, ACOT 2021





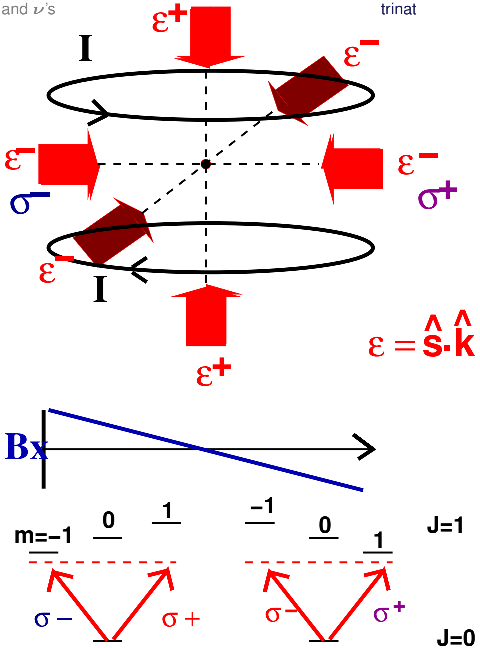
""Light sabers would make atom traps easy" (H. Norton)

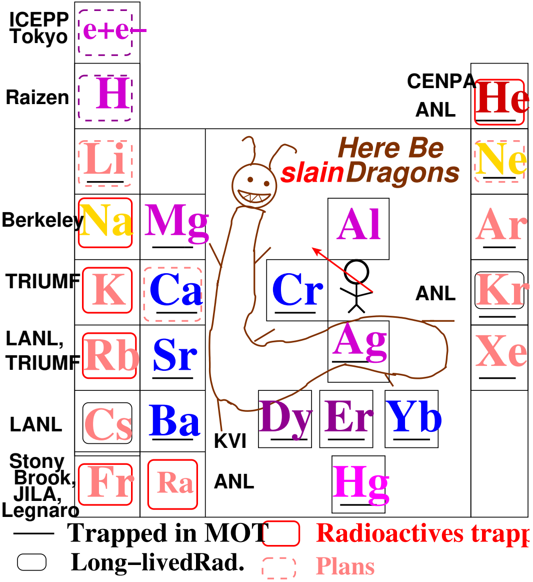
$$\vec{\nabla} \cdot \vec{S} \neq 0$$



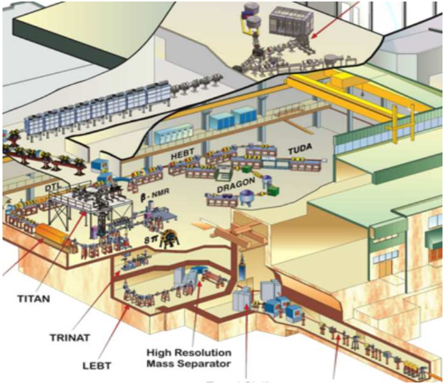
But light sabers violate Poynting's theorem

Magneto-optical trap: damped HO



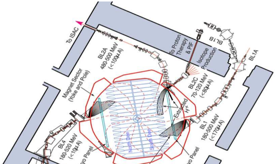


TRIumf Neutral Atom trap at ISAC

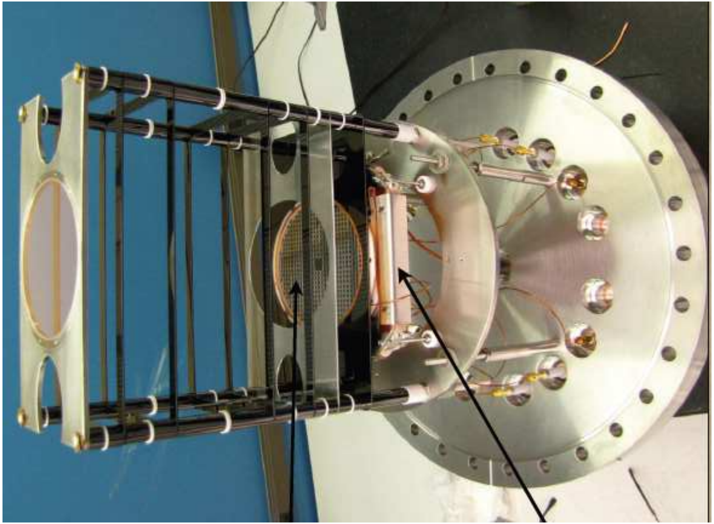


^{37}K 8x10^7/s TiC target 1750^{o}C 70 μA protons

main TRIUMF cyclotron
'world's largest'
500 MeV H$^-$ (0.5 Tesla)



ion MCP assembly



14 inch CF flange

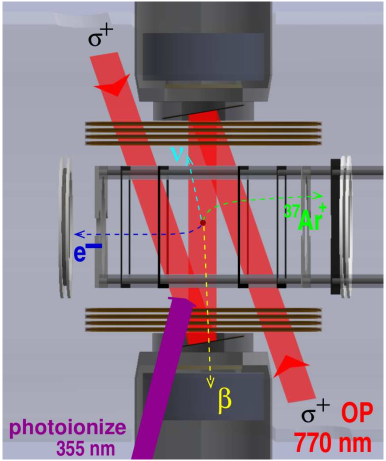
Electrostatic field

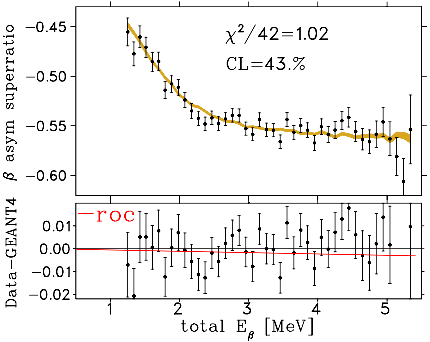
delay-line anode for position info

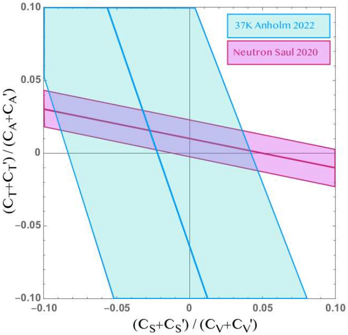
no stray wires

Low-Z (glassy carbon, titanium) to minimize β^+ scattering

β^+ asymmetry trinat ^{37}K







Fenker et al. Phys Rev Lett 120, 062502 (2018)

A_β[experiment]= -0.5707 $\pm$ 0.0019

A_β[theory] = -0.5706 $\pm$ 0.0007

$A_\beta[E_\beta]$ also constrains new physics

Anholm thesis 2022

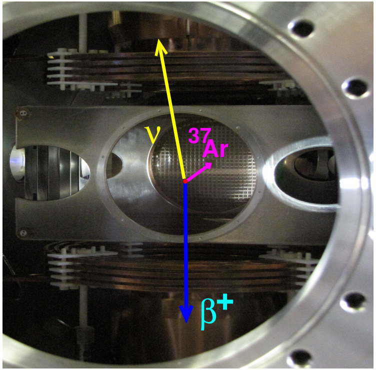
b_{Fierz} = 0.033 $\pm$ 0.084(stat) $\pm$ 0.039(syst)

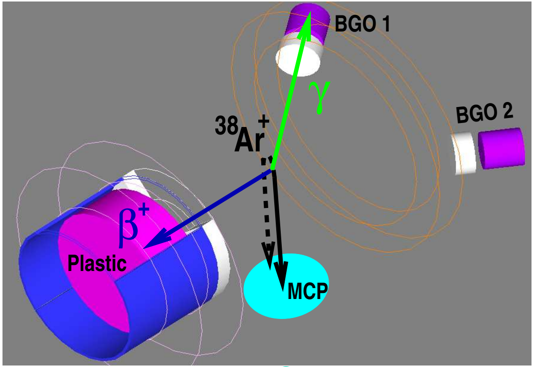
TRIUMF $\not T$ correlation of 3 of 4 momenta

$\mathbf{t} \rightarrow \mathbf{-t} \Rightarrow \vec{\mathbf{p}} \propto \frac{d\vec{r}}{dt} \rightarrow \mathbf{-\vec{p}}$

but $\vec{p}_{\rm recoil} \cdot \vec{p}_\beta \times \vec{p}_\nu \equiv 0$ ☹

$\vec{p}_\nu \cdot \vec{p}_\beta \times \vec{p}_\gamma = -\vec{p}_{\rm recoil} \cdot \vec{p}_\beta \times \vec{p}_\gamma \xrightarrow{t \rightarrow -t} \vec{p}_{\rm recoil} \cdot \vec{p}_\beta \times \vec{p}_\gamma$





- We can test symmetry of apparatus with coincident pairs ☺
- Not exact. Outgoing particles interact $\rightarrow$ fake $\not T$

EDM in a fundamental particle breaks T: this is exact

Landau, Nucl. Phys. 3 (1957) p. 127

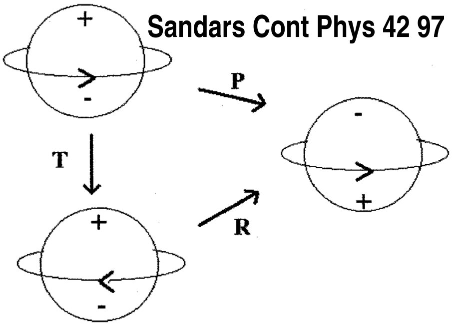
Electric Dipole moment $\vec{d} = \sum q_i \vec{r}_i$

Since the angular momentum is the only vector in the problem, $\vec{d} = a\vec{J}$

Under T, $\vec{J} \stackrel{t\rightarrow -t}{\rightarrow} -\vec{J} \quad \vec{d} \stackrel{t\rightarrow -t}{\rightarrow} +\vec{d}$

If the physics is invariant under T, this is a contradiction, $\Rightarrow a = 0$

Sandars Cont Phys 42 97



[• The other logical possibility: there are 2 states, with opposite sign of the EDM, and T just formally changes one state to the other.
For most fundamental particles, we know there aren't 2 states
Why do we know the electron doesn't have 2 states?
E.g. some polar molecules have a dipole moment listed in tables, which produces degenerate states and does not break T ...]

$\not{T}$ is related to $\not{CP}$ by the "CPT Theorem"

"All local Lorentz invariant QFT's are invariant under CPT"
Schwinger Phys Rev 82 914 (1951)
Lüders, Pauli, Bell 1954

- **Gravity $\rightarrow$ not flat:**

K meson experiments Adler PhysLettB 364 (1995) 239 test $\not{CPT}$ to within 1000x expected from quantum gravity

- **Strings not 'local'**

Proofs still pursued $\rightarrow$

Studies in History and Philosophy of Modern Physics 45 (2014) 46–65
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Studies in History and Philosophy of Modern Physics
journal homepage: www.elsevier.com/locate/shpsb

On the CPT theorem

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Discrete symmetries
Spacetime symmetries

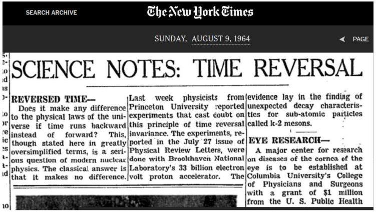
ABSTRACT
We provide a careful development and rigorous proof of the CPT theorem within the framework of mainstream (Lagrangian) quantum field theory. This is in contrast to the usual rigorous proofs in purely axiomatic frameworks, and non-rigorous proof-sketches in the mainstream approach. We construct the CPT transformation for a general field directly, without appealing to the enumerative classification of representations, and in a manner that is clearly related to the requirements of our proof. Our approach applies equally in Minkowski spacetimes of any dimension at least three, and is in principle neutral between classical and quantum field theories: the quantum CPT theorem has a natural classical analogue. The key mathematical tool is that of complexification; this tool is central to the existing axiomatic proofs, but plays no overt role in the usual mainstream approaches to CPT.

When citing this paper, please use the full journal title *Studies in History and Philosophy of Modern Physics*

Assuming CPT, $\not{CP} \Leftrightarrow \not{T}$ in most physics theories
The matter excess then motivates $\not{T}$ searches

$\not{T}$, $\not{CP}$, and everything

$\not{CP}$ discovery in $K\bar{K}$ got a paragraph in NY Times


SEARCH ARCHIVE The New York Times

SUNDAY, AUGUST 9, 1964 PAGE

SCIENCE NOTES: TIME REVERSAL

REVERSED TIME— Does it make any difference to the physical laws of the universe if time runs backward instead of forward? This, though stated here in greatly oversimplified terms, is a serious question of modern nuclear physics. The classical answer is that it makes no difference.

Last week physicists from Princeton University reported experiments that cast doubt on this principle of time reversal invariance. The experiments, reported in the July 27 issue of Physical Review Letters, were done with Brookhaven National Laboratory's 33 billion electron volt proton accelerator. The evidence lay in the finding of unexpected decay characteristics for sub-atomic particles called k-2 mesons.

EYE RESEARCH— A major center for research on diseases of the cornea of the eye is to be established at the Columbia University's College of Physicians and Surgeons with a grant of $1 million from the U. S. Public Health

'It's never been tested... a theoretical relationship between time and antimatter' Spock, 1966

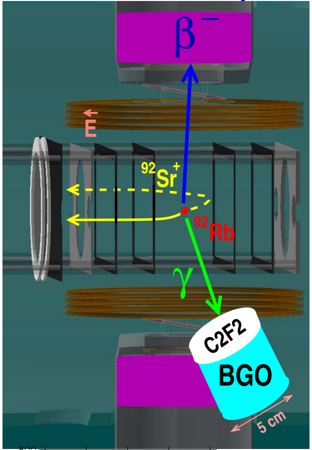
Sending the Enterprise back in time 3 days must have needed $\not{CP}$ well beyond Standard Model ☺

Sakharov immediately laid out ways to use $\not{CP}$ at early times to generate the excess of matter observed in the universe ("everything"), but the known amount makes about a billion times less matter than we see

Evidence for $\not{CP}$ in accelerator ν's may make more T2K Nature 580 339 (2020)

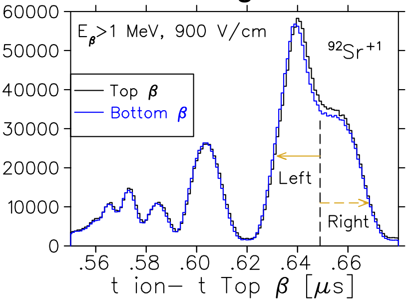
$\not{CPT}$ can also do it (Dolgov Phys Rep 222 309 (1992) also mentions Dine-Affleck topological defects)

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



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

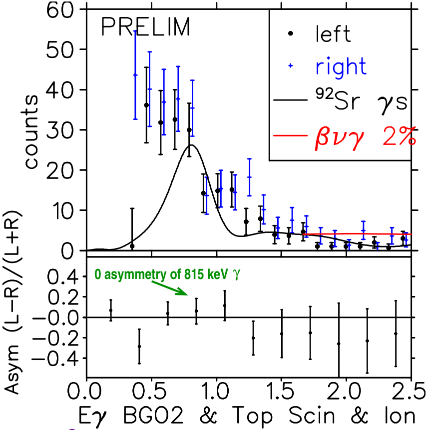
'left' vs. 'right':

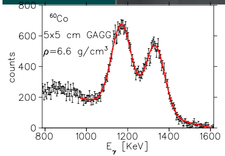


(other γ detector sees background from upstream)

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

'left' vs. 'right':





BGO $\rightarrow$ 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 $\sim$ 0.05 to 0.10 asymmetries of few percent branches

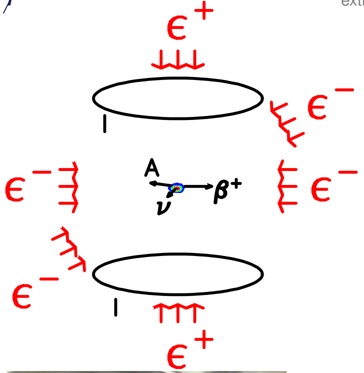
Fun Sym with Atom Traps

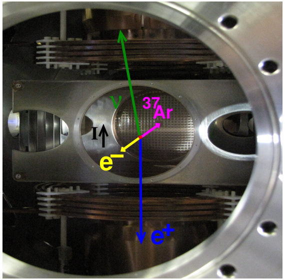
Truth loves its limits, for there it meets the beautiful
Rabindranath Tagore, "Fireflies"

- **Parity *P* symmetry**

  How to test *P* symmetry experimentally

  Only left-handed ν so far: how do we know?
- **$\not{P}$ with TRIUMF Neutral Atom trap for β decay**
- **$\not{P}$ in Francium atoms**
- **How atom traps work**
- **$\not{T}$ experiments**





Preview: Weak interaction breaks parity: Consequences?

'Pulsar kicks'

IGR J11014–6103 v= 0.01 c

Fuller PRD 2003

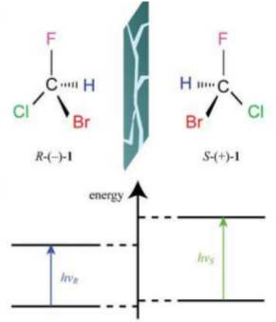
Forced $p + e^- \rightarrow n + \nu$

$W(\theta) = 1 + \frac{\langle m_I \rangle}{I} A_\nu \cos(\theta_{\hat{I}})$

B field polarizes p's

Need ν_e to include 10^{-8} admixture of $m_\nu \sim$ keV

Earthling's amino acids are all left-handed



Letokhov PLA'75

Darquie CHIRALITY 2010

$\Delta E \sim 10^{14-16}$eV

Not Enough for left-handed bugs to win, so →

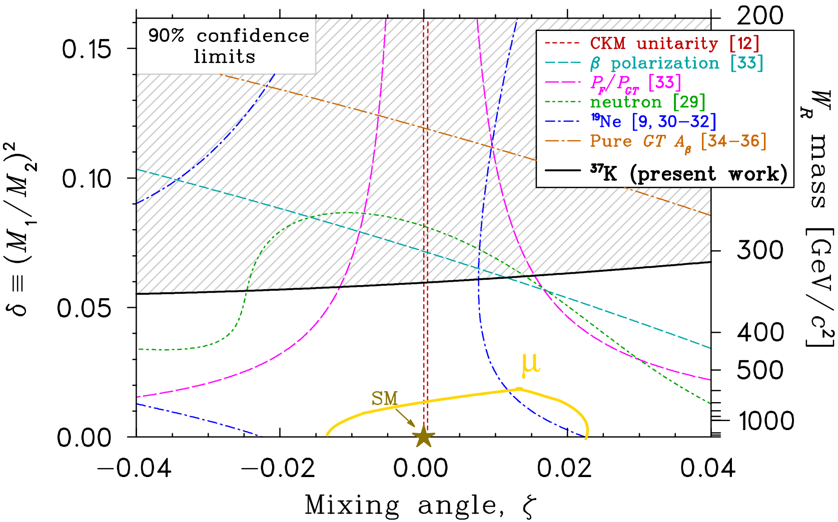
Spin-polarized SN ν's could preferentially zap wrong-handed amino acids

Finding the right environment for spin-polarized amino acids? e.g. :

Astrobiology 18 (2018) Selection of Amino Acid Chirality via ν Interactions with ^{14}N in $\vec{E} \times \vec{B}$ Fields M.A. Famiano, R.N. Boyd

(TRIUMF EEC 90's)...

Still no wrong-handed ν's



Extra W' with heavier mass, couples to wrong-handed ν_R

We can evade TWIST limits by assuming the muon ν_R is heavy

LHC $M'_W > 3.7$ TeV 90%

TRIUMF

The nucleon: a special place for γ's

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 ↓

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

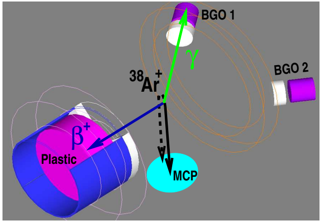
Gardner, He PRD 2013: looked for contributions to radiative n decay. Noticed QCD antisymmetry led to a scalar triple product of momenta ☺:

$$|\mathcal{M}_{c5}|^2 \propto \frac{Im(c_5 g_V)}{M^2}\frac{E_e}{p_e k}(\vec{p_e}\times\vec{k_\gamma})\cdot\vec{p_\nu}$$

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

Particles strongly interacting with themselves
but weakly interacting with us
are also possible dark matter candidates

See the 'SIMP miracle' Hochberg et al. arXiv:1402.5143



UNIVERSITY OF MANITOBA

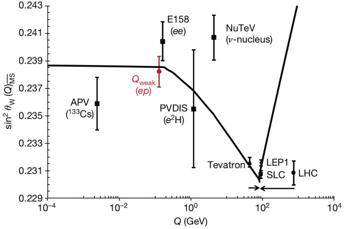
FrPNC Discovery potential: Weak neutral current

TRIUMF

Best prediction of SM: weak neutral current
$\leftarrow$ Seen 1973 by Gargamelle in ν scattering

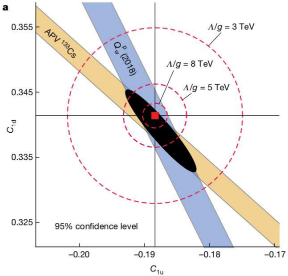
- **Could have been 1st measured in ^{18}F γ asymmetry (CSULA, INFN, Mainz, Queens) but isovector/isoscalar $\propto \sin^2(\theta_W)/N_c$**

Manitoba @ TRIUMF Fr trap: 10^6 atoms $\Rightarrow < 1\%$ stats in < 1 day



Androic Nature 2018 (Qweak)

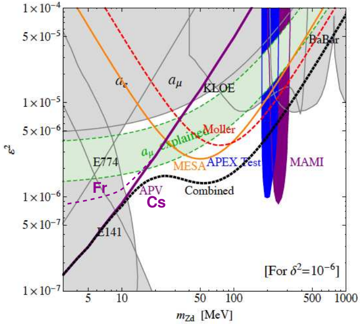
(Recent M_W CDF Science 376 170 2022 would move APV prediction 1 σ down 2204.11991v3)



Sensitivity to new bosons at mass scale 5 to 8 TeV

- **Fr/Cs$\propto$(rel)$Z^2/N \approx 20$ FrPNC goal: exceed Cs**

lower-mass Z' Davoudiasl PRL 109 031802 2012



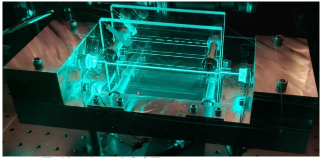
q_{Cs} = 2.4 MeV/c, q_{Fr} = 10 MeV/c $\Rightarrow$ different sensitivity to $m_{Z'} \sim$ MeV

An example of university-driven precision measurement, backed by NSERC using TRIUMF-ISAC unique isotope delivery, patiently producing physics

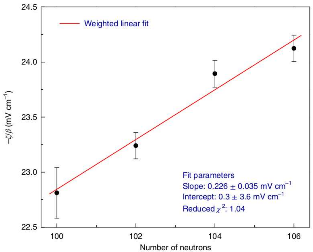
University of Manitoba

FrPNC: goals and needs

TRIUMF



T. Hucko, ACOT 2021



Antypas Budker Nat Phys 15 120 2019

- Atomic parity-violating signal 2024
- Competitive electron-quark neutral weak coupling 2025+
- Nuclear anapole also extracted 2025+ (parity-violating E&M moment induced by nucleon-nucleon weak interaction). Only measured in ^{133}Cs, ^{205,207}Tl : more cases needed
- Needs: Maximum yield and long beamtimes $^{208-213}$Fr to beat down systematic uncertainties
- Further needs: $^{220-226}$Fr would provide greater lever arm to test SM dependence on N, in competition with Yb $\sim$1% atomic PNC measurements $\rightarrow$

S2139LOI DeMille, Behr, Teigelhöfer would measure Fr_2 dimers in FrPNC trapping facility, to determine s-wave scattering and other properites for high-density Fr.
A full ^{223}FrAg EDM (nuclear $\not{T}$ Schiff moment) exp. needs to laser-cool Ag elsewhere

Measure ν helicity $\epsilon = \hat{s}_\nu \cdot \hat{k}_\nu$ directly: transfer $\hat{s}_\nu$ to γ circular polarization; boost $\vec{k}_\gamma$ by $\pm\vec{k}_\nu$

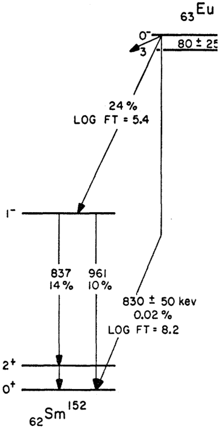
Goldhaber, Grodzins, Sunyar
Phys Rev 109 1015 (Dec 1957)

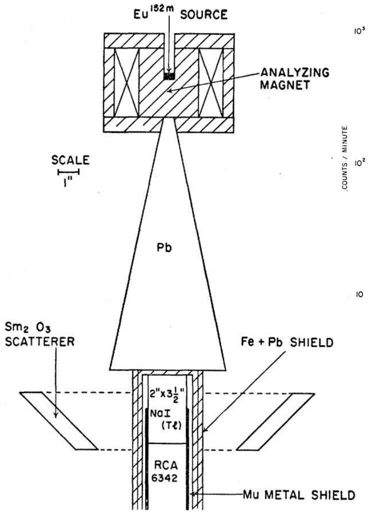
$$e^- + {}^{152\mathrm{m}}\mathrm{Eu} \rightarrow \nu + {}^{152}\mathrm{Sm}$$

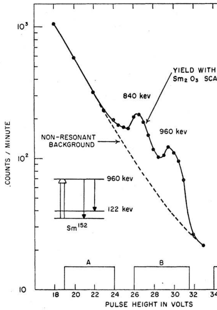
- **Upward-going ν populates $\langle I_z \rangle = 0, +1$ not -1**
- **So γ is circularly polarized– transmission through magnet depends on iron polarization: $\frac{N_+ - N_-}{N_+ + N_-}$=0.017±0.003**
- **Upward ν boosts γ momentum so it can be absorbed on-resonance**

$\Rightarrow$ ν helicity -1 $\pm$ 10%

(• $\bar{\nu}$ helicity $\sim$ +1
Palathingal PRL 524 24 '69)

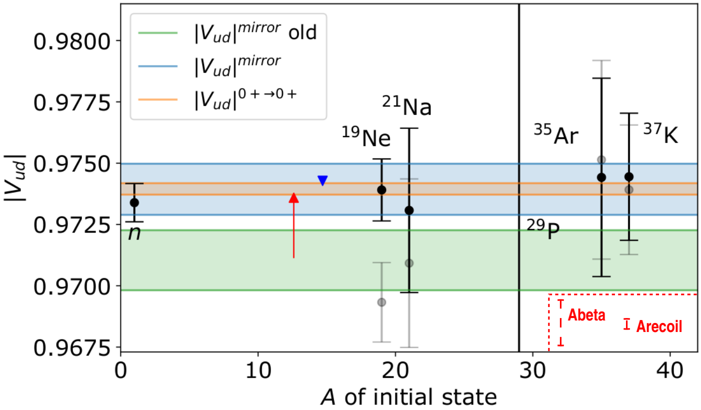






Surprisingly enough, this is the best direct measurement of ν helicity = $\hat{s}_\nu \cdot \hat{k}_\nu$

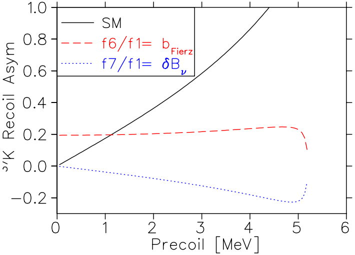
Mirror decays and V_{ud}



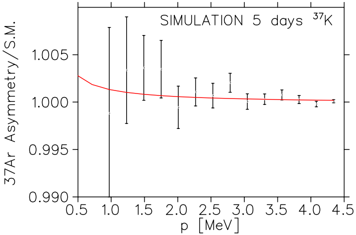
L. Hayen and A. Young arXiv 2009.11364

V_{ud} deduced from isobaric mirror decays highlighting the utility of making TRINAT ^{37}K result better our projections in red.

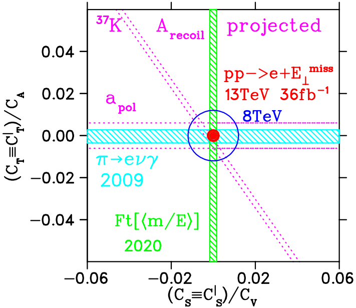
from TRINAT 2023 proposal



The recoil singles asymmetry as a function of recoil momentum from ^{37}K decay, showing the standard model prediction ('SM'), and the functional dependence of the standard model extensions from the Fierz interference term $\boldsymbol{b}$ ('f6') and changes in $\boldsymbol{\nu}$ asymmetry $\boldsymbol{\delta B}$ ('f7'): this demonstrates the large effects possible from $\boldsymbol{\delta B}$.



Simulation of 5 days of the ^{37}K recoil singles asymmetry with 10,000 atoms trapped, showing the momentum dependence of the simulated data divided by the standard model prediction.



90% limits from LHC $\boldsymbol{p}+\boldsymbol{p}\rightarrow \boldsymbol{e}^- + \boldsymbol{E}_\perp^{\mathbf{miss}}$ [?], $\boldsymbol{\pi}\rightarrow \boldsymbol{e\nu\gamma}$ [?], and $\mathbf{0}^+ \rightarrow \mathbf{0}^+$ decay $\boldsymbol{F}$t as a function of $\boldsymbol{E}_\beta$ [?]. Our projected limits from ^{37}K $\boldsymbol{A}_{\mathbf{recoil}}$ and $\boldsymbol{a}_{\mathbf{pol}}$ (magenta) would provide complementary sensitivity to BSM Lorentz structure.