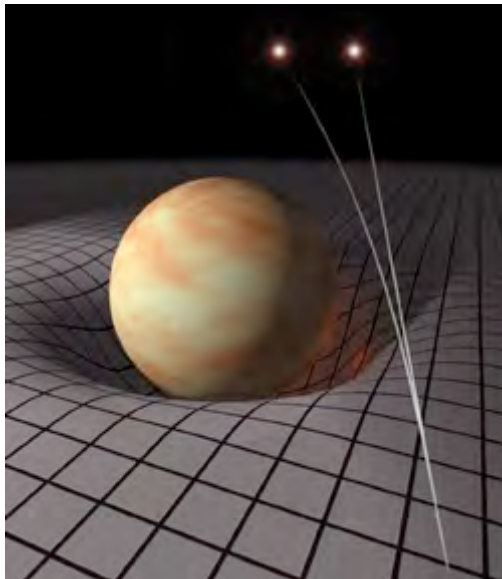


Torsion Balance Search for Lorentz-invariance, Dark Energy and Dark Matter

Claire Cramer
AAPT Meeting
5 January, 2007

Why search for violations of Lorentz-invariance?

General Relativity



the Standard Model

Standard Model of FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model is a theory of particle physics that describes the interactions of elementary particles. It is based on the principles of quantum field theory and special relativity.

FERMIONS				matter constituents			
Leptons spin = 1/2				Quarks spin = 1/2			
Flavor	Mass (GeV/c ²)	Electric charge	Spin	Flavor	Approx. Mass (GeV/c ²)	Electric charge	Spin
e^- electron	$< 2 \times 10^{-6}$	0	1/2	u up	4×10^{-6}	2/3	1/2
ν_e neutrino	$< 2 \times 10^{-6}$	-1	1/2	d down	7×10^{-6}	-1/3	1/2
μ^- muon	$< 3 \times 10^{-4}$	0	1/2	c charm	1.5	2/3	1/2
τ^- tau	1.784	-1	1/2	s strange	0.15	-1/3	1/2
				t top (not yet observed)	> 89	2/3	1/2
				b bottom	4.7	-1/3	1/2

Structure within the Atom

BOSONS				force carriers			
Unified Electroweak spin = 1				Strong or color spin = 1			
Flavor	Mass (GeV/c ²)	Electric charge	Spin	Flavor	Mass (GeV/c ²)	Electric charge	Spin
γ photon	0	0	1	g gluon	0	0	1
W ⁻	80.6	-1	1				
W ⁺	80.6	+1	1				
Z ⁰	91.16	0	1				

PROPERTIES OF THE INTERACTIONS

Sample Fermionic Hadrons	Properties	Interaction				Sample Bosonic Hadrons	
		Gravitational	Weak	Electromagnetic (Electroweak)	Strong	Residual	
n neutron	udd	1	0	0	1	1	
p proton	uud	1	0	1	1	1	
Λ baryon	uds	1	0	0	1	1	
Σ^0 baryon	uds	1	0	0	1	1	
π^+ meson	u \bar{d}	1	0	1	1	0	
π^0 meson	u \bar{u} or d \bar{d}	1	0	0	1	0	
π^- meson	d \bar{u}	1	0	0	1	0	
K^+ meson	u \bar{s}	1	0	0	1	0	
K^0 meson	d \bar{s} or s \bar{d}	1	0	0	1	0	
K^- meson	s \bar{u}	1	0	0	1	0	
η meson	u \bar{u} or d \bar{d} or s \bar{s}	1	0	0	1	0	
ω meson	u \bar{u} or d \bar{d} or s \bar{s}	1	0	0	1	0	
ρ meson	u \bar{u} or d \bar{d} or s \bar{s}	1	0	0	1	0	
Δ baryon	uuu or uud or udu or udu	1	0	0	1	0	
Σ^+ baryon	uud	1	0	0	1	0	
Σ^0 baryon	uds	1	0	0	1	0	
Σ^- baryon	dds	1	0	0	1	0	
Λ baryon	uds	1	0	0	1	0	
Ξ^0 baryon	uds	1	0	0	1	0	
Ξ^- baryon	dds	1	0	0	1	0	
Ω^- baryon	sss	1	0	0	1	0	

Contemporary Physics Education Project

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GR + SM = Lorentz-symmetry breaking???

What about Dark Energy and Dark Matter?

We're also not sure what the universe is made of:

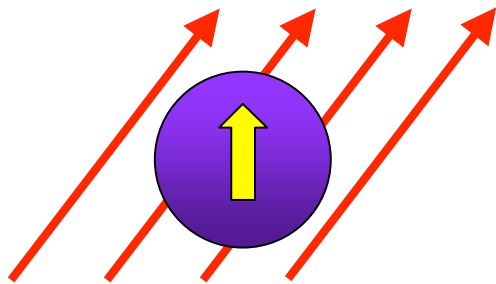


96% new particles and fields that mediate forces we may be able to measure in the laboratory

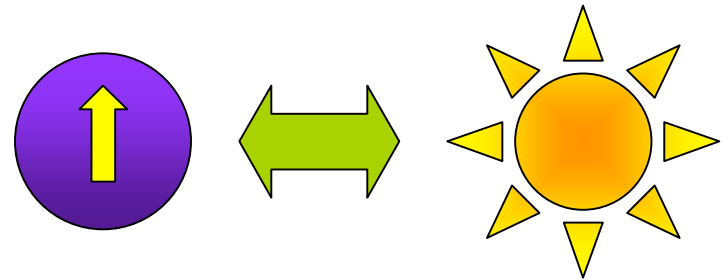
Spin-dependent forces

spin is a property of all fundamental particles

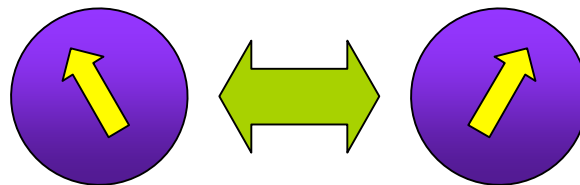
theories of quantum gravity, dark energy and dark matter predict forces between a particle's spin and:



a background field
fixed in space



sources of unpolarized matter



another particle's spin

Torsion balances

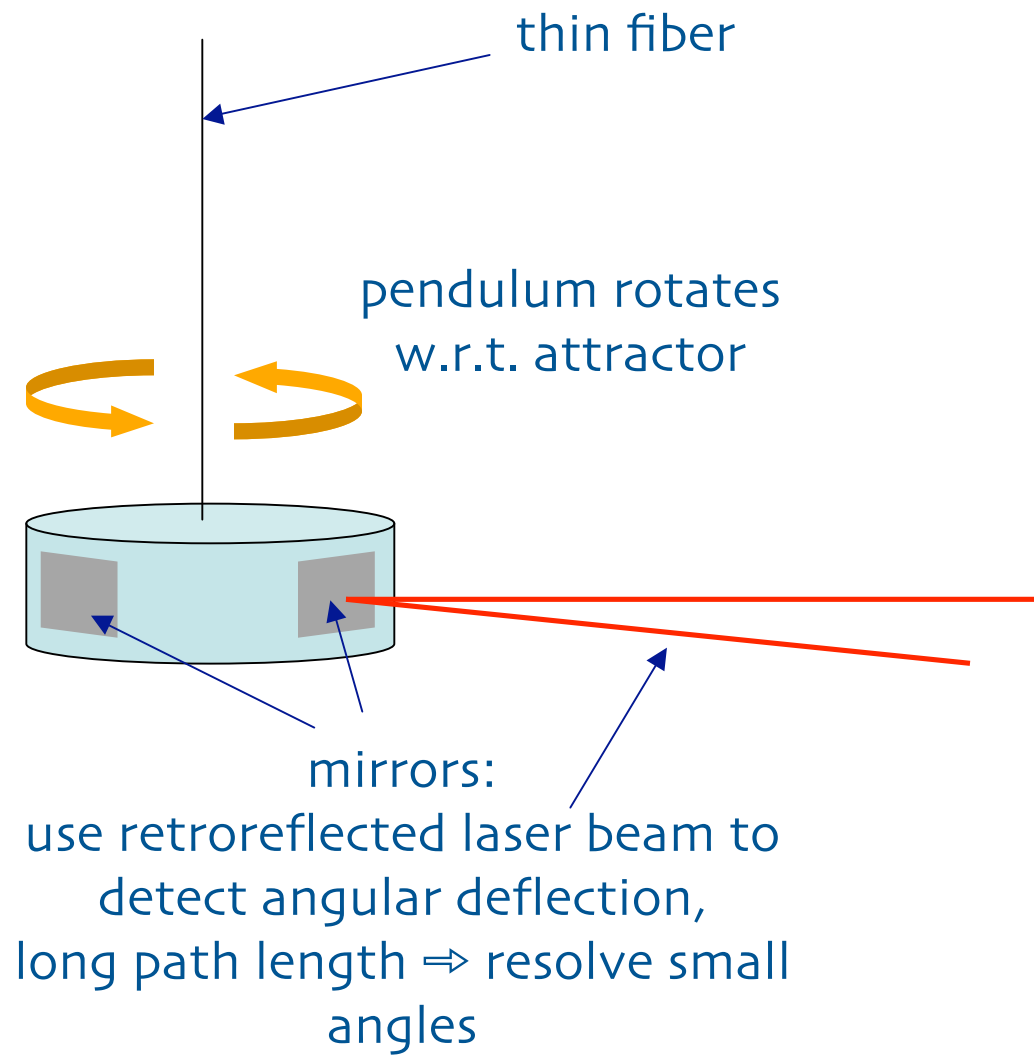
Coulomb's torsion
balance:

A high precision
measurement of forces
coupled to electrons in
1871



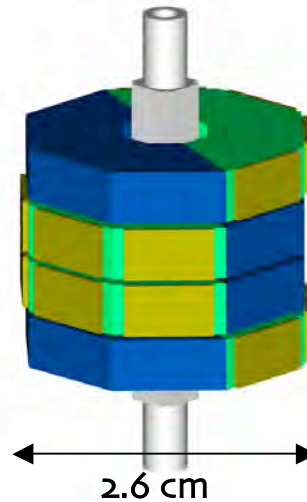
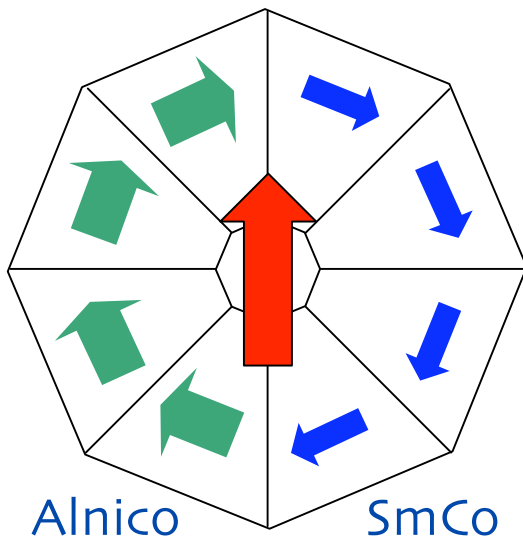
How they work:

attractor:
a background field, a
distant mass, something
we made ...

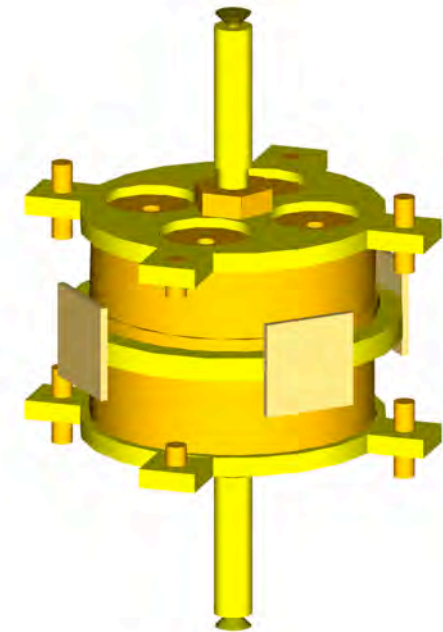


The spin pendulum

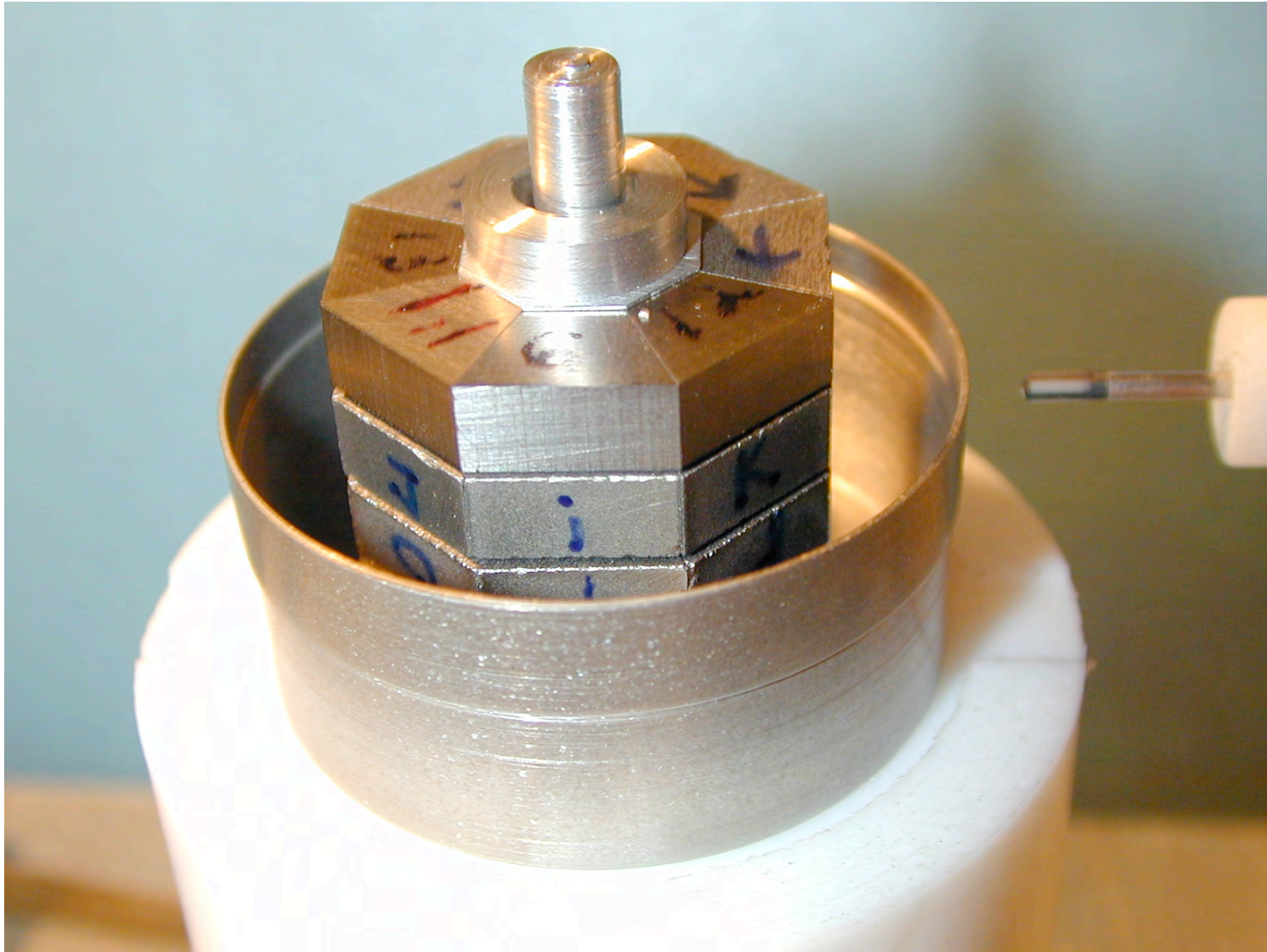
- large net electron spin
- negligible external magnetic field



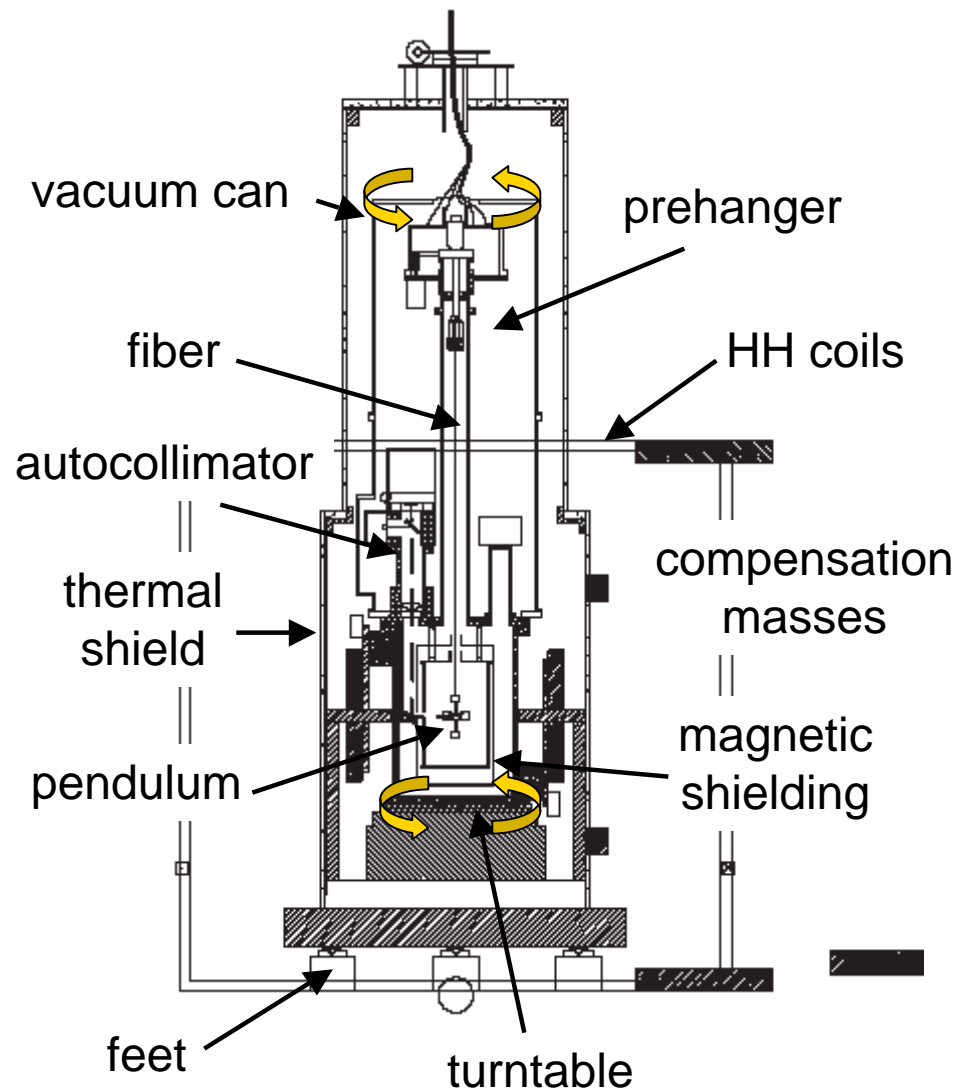
- gold-plated
- magnetically shielded
- 4 mirrors



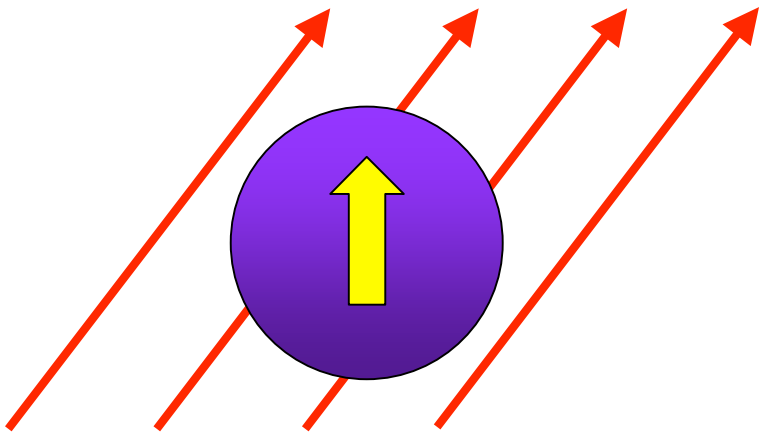
- more spins
- greater symmetry



The torsion balance apparatus



Recent Results: limits on a background field



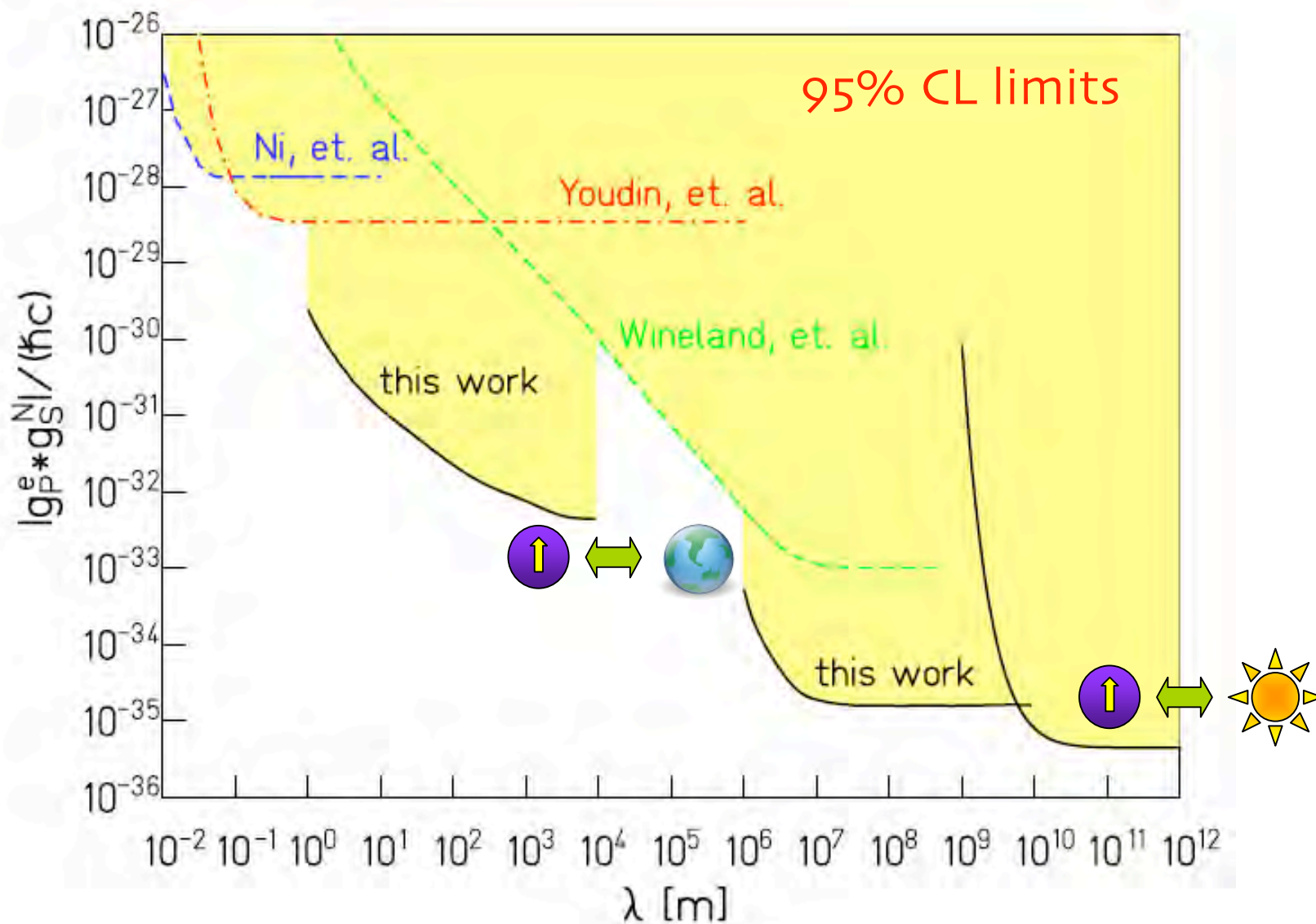
$$|b_{\perp}| = (1.8 \pm 2.5) \times 10^{-22} \text{ eV}$$

$$b_z = (-29 \pm 39) \times 10^{-22} \text{ eV}$$

expect to see effects of new physics at:

$$(m_e/m_{Pl})m_e \sim 10^{-17} \text{ eV}$$

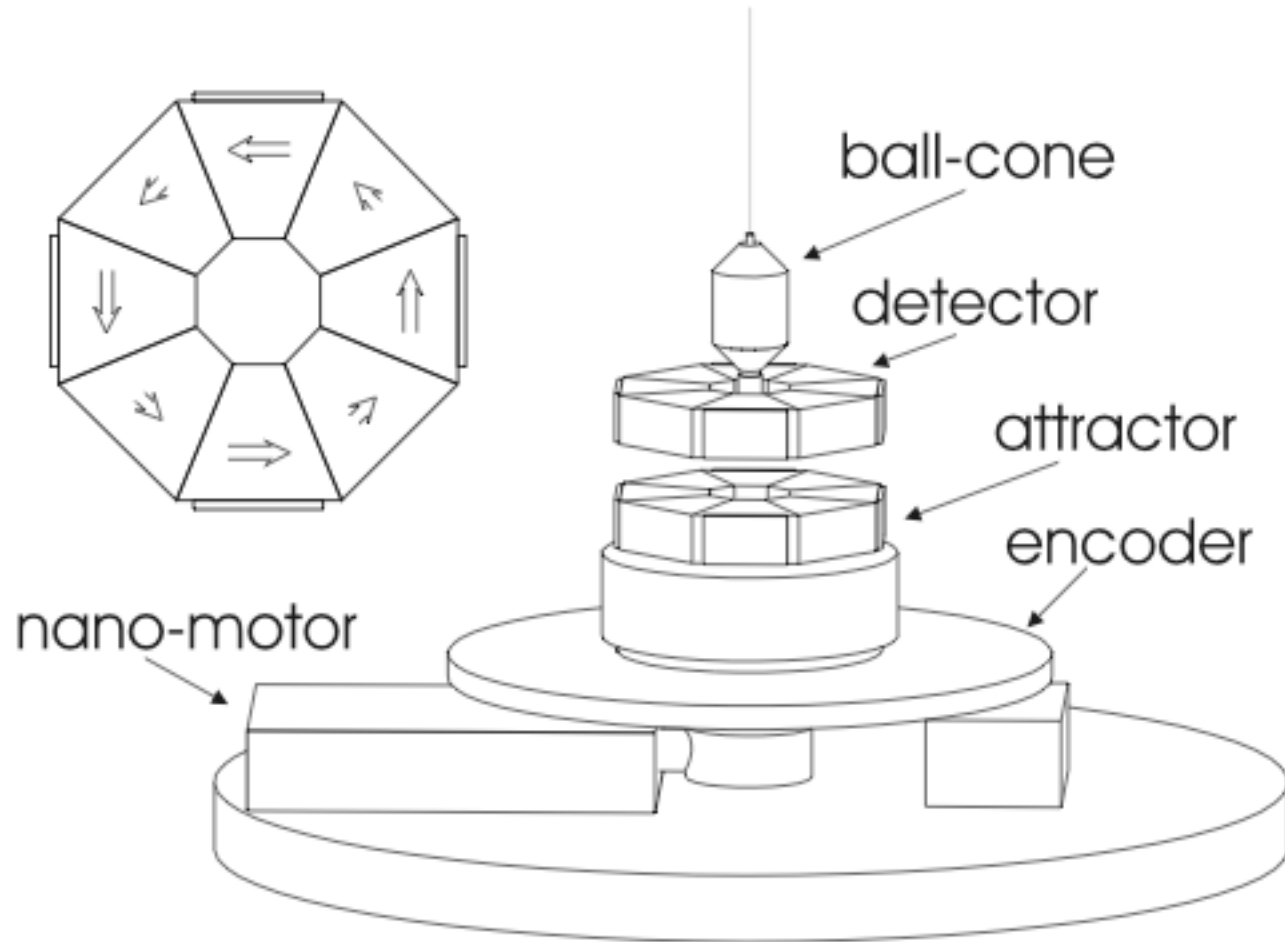
More Recent Results:



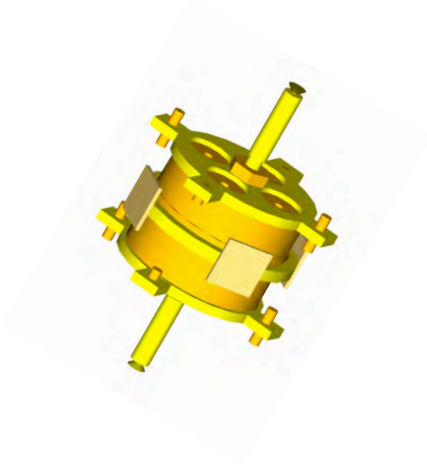
Torsion balance + spin sources



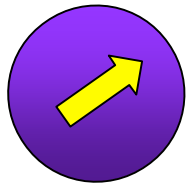
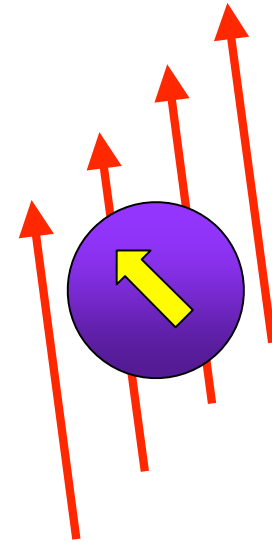
New torsion pendulum



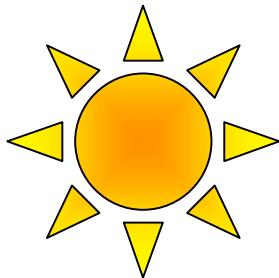
Thanks to . . .



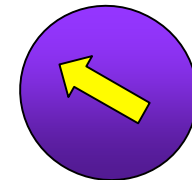
Blayne Heckel
Eric Adelberger
Jens Gundlach



Stephan Schlamming
Erik Swanson

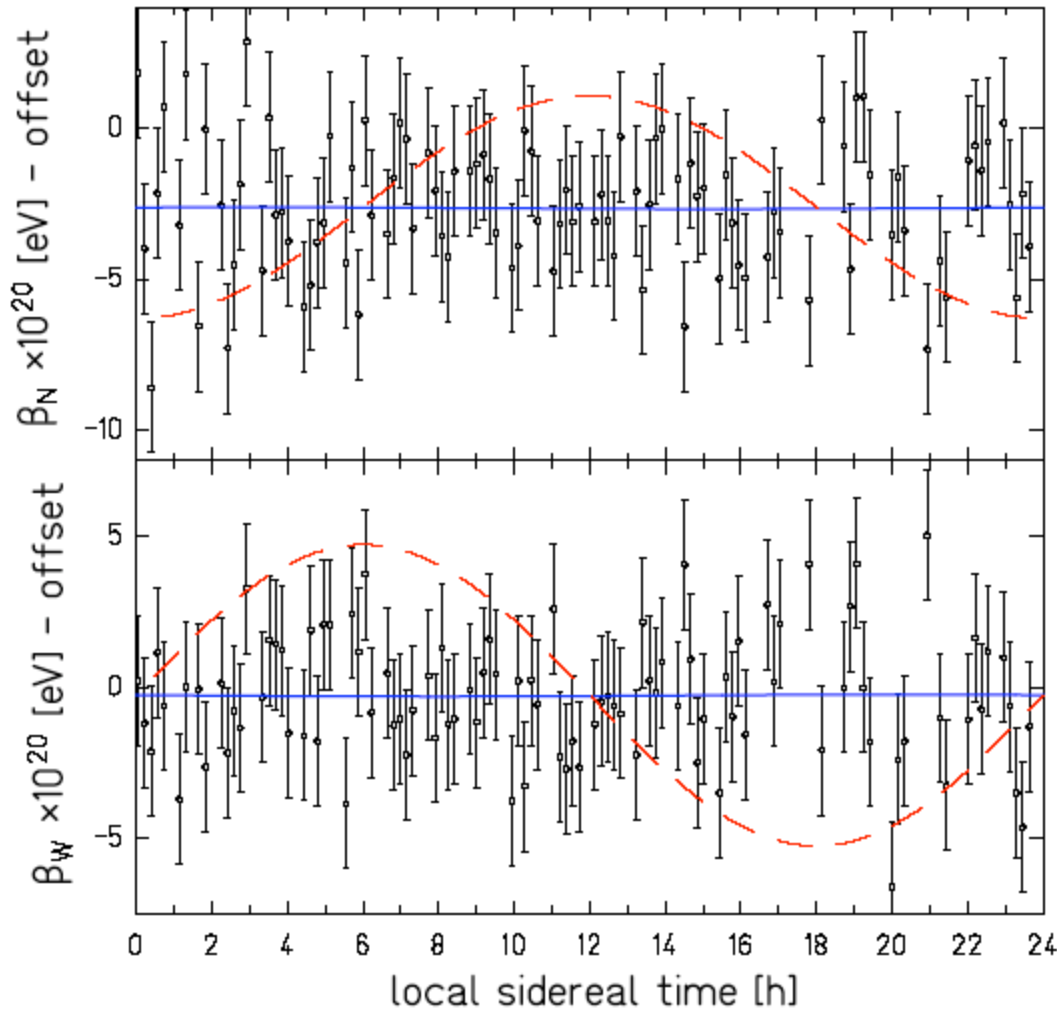


Ted Cook
William Terrano





Typical Data



hypothetical
 $b_x = 5 \times 10^{-20} \text{ eV}$
($b_y, b_z = 0$)

best sidereal fit:
 $b_x = (-0.2 \pm 1.9) \times 10^{-21} \text{ eV}$
 $b_y = (-0.1 \pm 1.9) \times 10^{-21} \text{ eV}$