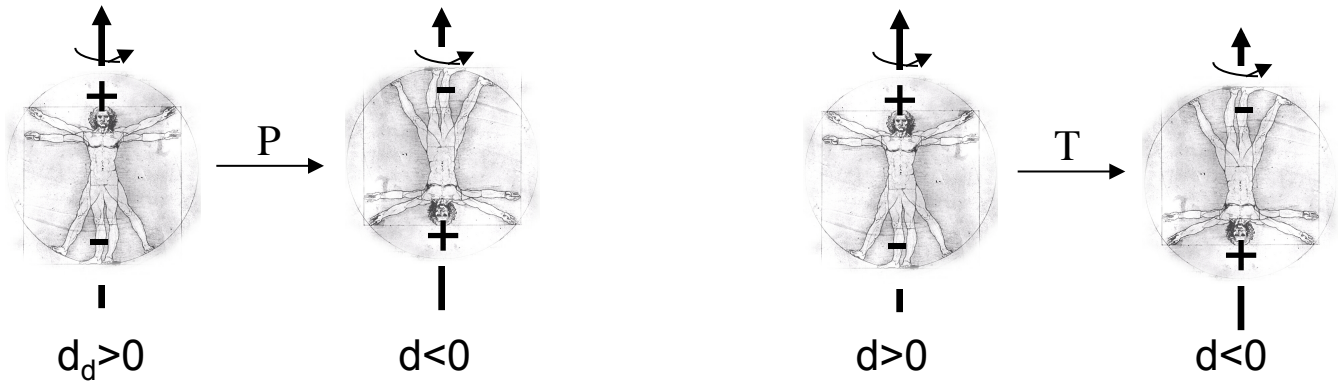
EDM prospects at Project X: From the tabletop into the fire



Tim Chupp

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A Sensitive Storage Ring Proton EDM experiment at FNAL

GARDNER, SusanTheory of EDMs

BLUM, Kfir EDM LHC EDM

NOLEN, JerryA concept for intense yields of Rn, Fr, and Ra isotopes at Project X

DIETRICH, MatthewSearch for the EDM of Ra-225

CHUPP, Tim Discussion: Fundamental Symmetries and EDM Prospects at Project X

+ *Lattice talks on calculating EDM*

EDM Motivations

Undiscovered – Most sensitive experiment

Statistics Rate (neutron, polarized protons, molecules, rare atoms, light)

Sensitivity (Schiff theorem, enhancements)

Systematics (leakage currents, geom. phases, etc.)

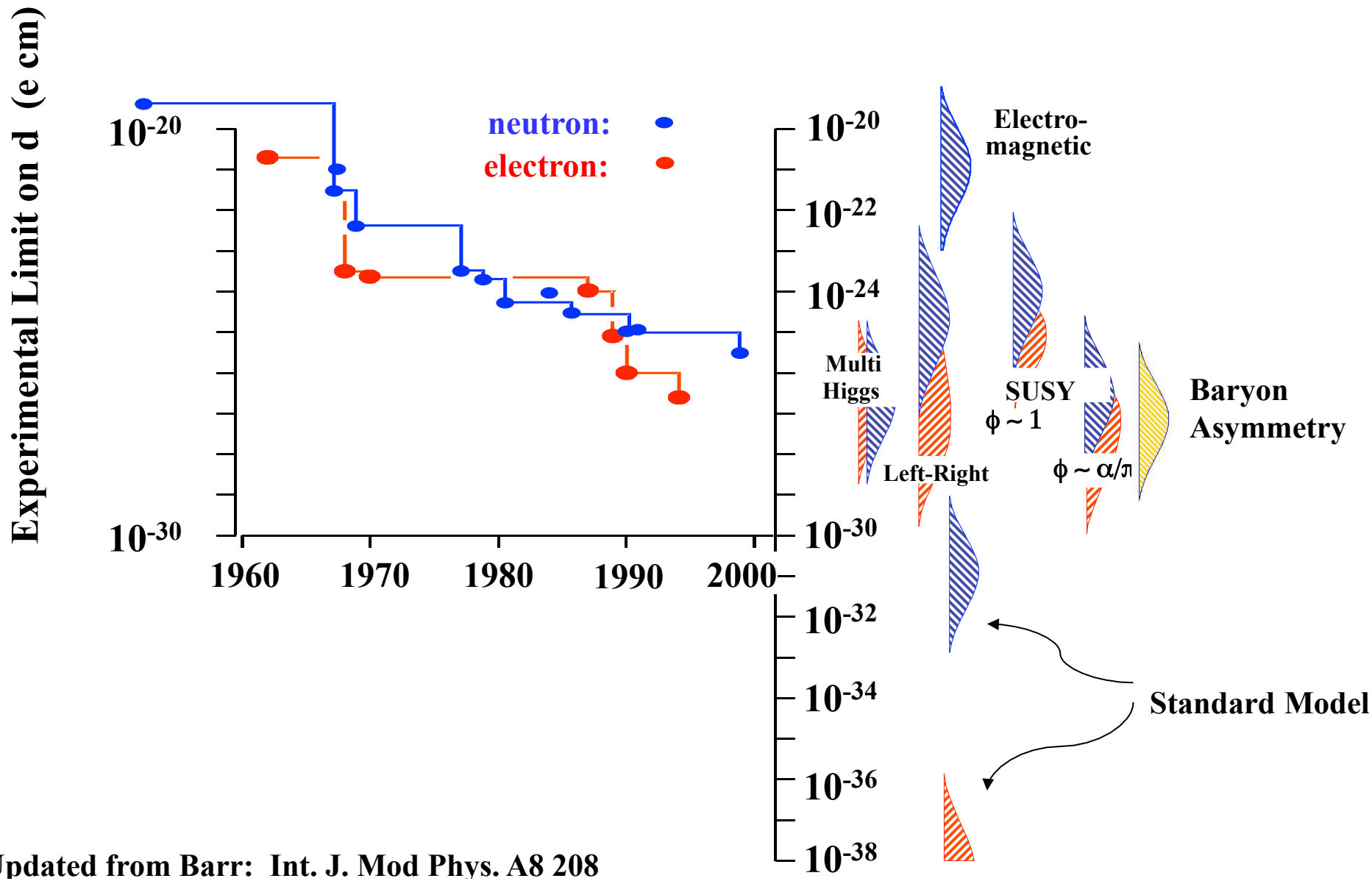
Study CP violation: mass scale

Complemtary experiments (separate θ_{QCD})

Study/Constrain NEW PHYSICS (beyond SM - CKM)

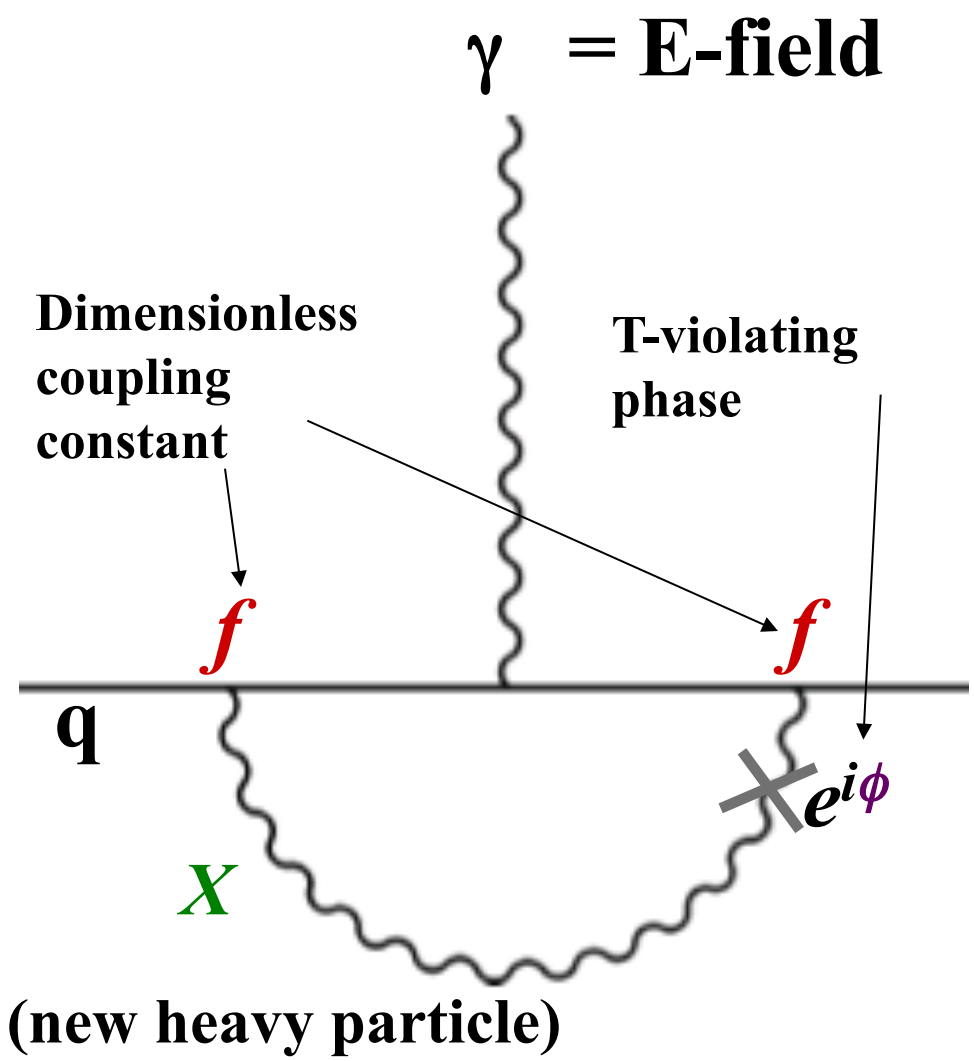
Cosmological Baryon Asymmetry

Sensitive Measurements: Neutron EDM



Updated from Barr: Int. J. Mod Phys. A8 208

EDMs probe TeV-scale physics



$$\mu \approx \frac{e\hbar}{2m} \qquad (\alpha = \frac{e^2}{\hbar c})$$

$$\frac{d}{\mu} \approx f^{2N}\left(\frac{m_q}{m_X}\right)^2 \sin\phi$$

≈ 1

$\approx \alpha$

$\approx 10^{-14}$

$d_n \sim 10^{-26}$ e-cm

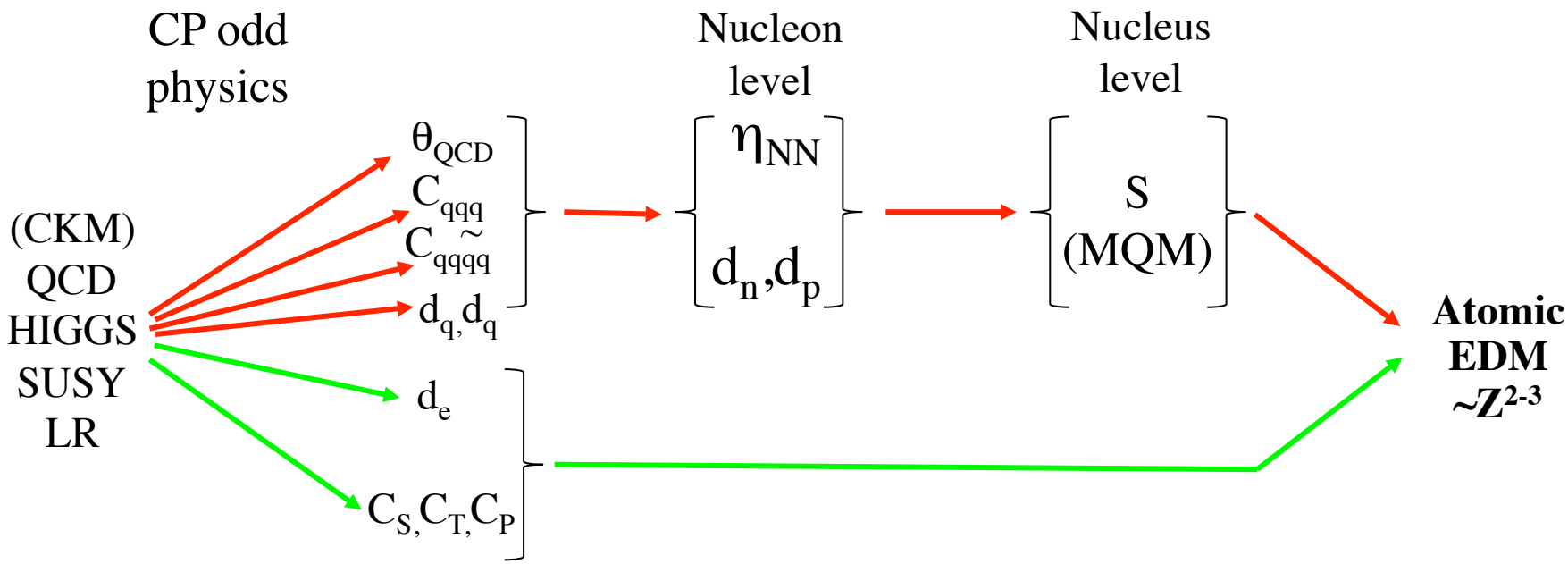
loops

$$m_X \approx m_q \sqrt{10^{14}\,\alpha^N}$$

~ 1 TeV (SUSY/DM scale)

Atomic EDMs

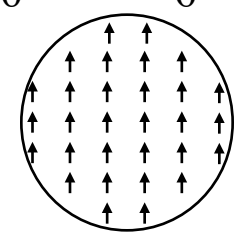
Particle Interactions Polarize Atoms



$$d_A = \kappa_S S(\theta_{QCD}, d_q) + (k_T C_T + k_S C_S) + \eta_e d_e$$

+higher nuclear moments (MQM)

$$\vec{S} = \frac{1}{10}\langle r^2 \vec{r}_p \rangle - \frac{1}{6} Z \langle r^2 \rangle \langle \vec{r}_p \rangle$$



$$\vec{E} \propto \vec{J}$$

Shiff Moment

Complimentarity

Upper Limits (only)

System	Primary Sensitivity	d ($e \cdot$ cm)
Cs	d_e, C_S	$(-1.8 \pm 6.9) \times 10^{-24}$
^{129}Xe	$\theta_{\rm QCD}$, $g_{\pi NN}$, C_T	$(\ 0.7 \pm 3.3) \times 10^{-27}$
Tl	d_e, C_S	$(-4.0 \pm 4.3) \times 10^{-25}$
TlF	$\theta_{\rm QCD}$, $g_{\pi NN}$, d_p, C_T	$(-1.7 \pm 2.9) \times 10^{-23}$
neutron	$\theta_{\rm QCD}$, quark-EDMs	$(\ 0.2 \pm 1.7) \times 10^{-26}$
muon	d_μ	$(\ 0.0 \pm 0.9) \times 10^{-19}$
^{199}Hg	$\theta_{\rm QCD}$, $g_{\pi NN}$, C_T	$(\ 0.5 \pm 1.5) \times 10^{-29}$
YbF	d_e, C_S	$(-2.4 \pm 5.8) \times 10^{-23}$

Table 1: Limits (90% C.L.) on phenomenological parameters of CP violation, including the most recent neutron EDM result[21] and evaluation of atomic sensitivities from reference [24].

Parameter	^{199}Hg limit[20]	Neutron limit[21]	Other limits	Theory Ref.
θ_{QCD}	1.5×10^{-10}	4.1×10^{-10}	-	[26]
down quark EDM	-	5×10^{-26} e-cm	-	[23]
color EDM	3×10^{-26} e-cm	-	-	[26]
$\epsilon_q^{\rm SUSY}$	2×10^{-3}	5×10^{-3}	-	[27]
$\epsilon_q^{\rm Higgs}$	$0.4/\tan\beta$*	-	$0.3/\tan\beta$ (Tl)[18]	[27]
$x^{\rm LR}$	1×10^{-3}	5×10^{-3}	-	[27]
C_T	1×10^{-8}	-	5×10^{-7} (TlF)[28]	[29]
C_S	3×10^{-7}	-	2×10^{-7} (Tl) [18]	[29]

*The ratio of masses of the two Higgs bosons in this theory is $\tan\beta$.

Incomplete list of experiments

Neutron (10^{-28} ecm)

ILL/PNPI
ILL CryoEDM
PSI OILL – PSI nEDM
SNS nEDM
Munich nEDM
KEK/TRIUMF

Electron (10^{-30} ecm)

YbF - London
ThO – Harvard/Yale
WC – Michigan
Radium – KVI (NL)
Francium – LBL/TRIUMF
Solid state – Indiana/Yale/UBC

Storage Rings (10^{-29} ecm)

Proton/D/^{3}He - BNL/COSY (FNAL)
Muon (w g-2)

Schiff

Hg – Seattle
Xe – Japan, Munich, Michigan
Ra – ANL
Rn - TRIUMF

Notes on ^{199}Hg and YbF

- From Fortson and Heckel: improvement in ^{199}Hg
  - Noise (stat) limited by light-shift, B-field noise
  - Systematics limited by leakage currents
- Expect 10-50x improvement!

- For YbF
  - "Systematics are small and under control"
    - Short-term goal @ 67% c.l. of $d_e \sim 2\times10^{-28}$ e-cm
    - Buffer gas source: $6\text{x}10^{-29}$ e-cm or less

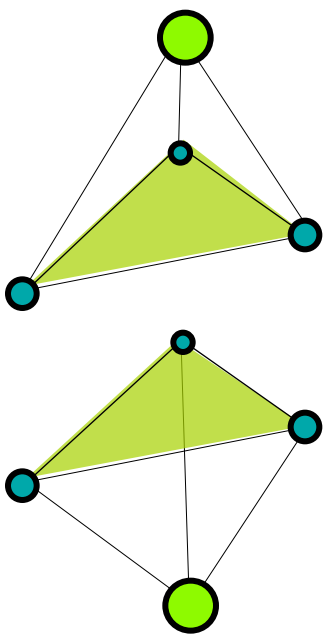
What can Project X do?

- Proton-EDM (storage ring)
- Rare-isotope (isol) source for Ra, Fr, Ra EDM
- UCN Source for neutron EDM

Octupole Enhancements

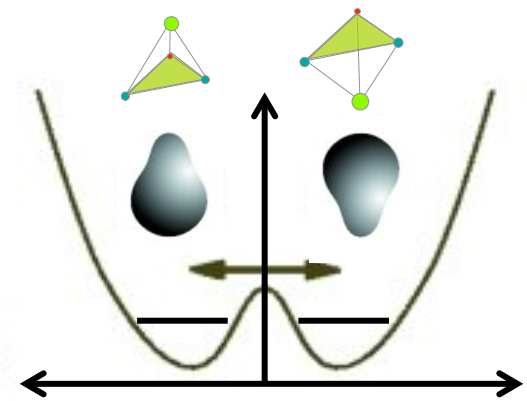
(see Feynman vol 3.)

NH_3

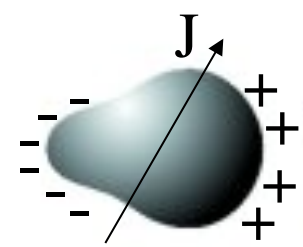


$|a\rangle$

$|b\rangle$



β_3

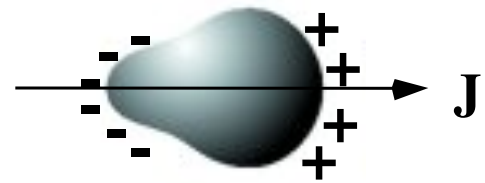


$$|\psi_\pm\rangle = \frac{1}{\sqrt{2}}\left(|a\rangle \pm |b\rangle \right) \qquad S \sim \frac{\langle + | \eta r^3 \cos\theta | - \rangle}{E_+ - E_-} \sim \frac{\eta \beta_2 \beta^2{}_3 Z A^{2/3} r_0{}^3}{E_+ - E_-}$$

Nuclei with Octupole Deformation/Vibration

(Haxton & Henley; Auerbach, Flambaum, Spevak; Engel et al., Hayes & Friar, etc.)

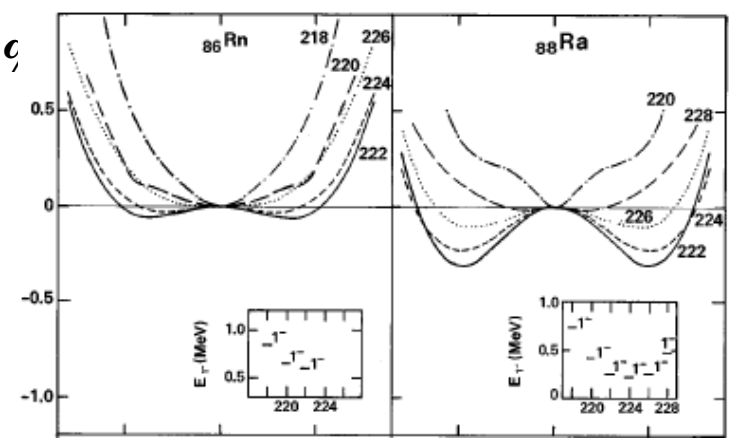
$$S \sim \frac{\langle +|\eta r^3 \cos\theta|- \rangle}{E_+ - E_-} \sim \frac{\eta \beta_2 \beta^2{}_3 Z A^{2/3} r_0{}^3}{E_+ - E_-}$$



$\eta_{qq} = 3.75 \times 10^{-4}$

	^{223}Rn	^{223}Ra	^{225}Ra	^{223}Fr	^{129}Xe	^{199}Hg
$t_{1/2}$	23.2 m	11.4 d	14.9 d	22 m		
I	7/2	3/2	1/2	3/2	1/2	1/2
ΔE th (keV)	37*	170	47	75		
ΔE exp (keV)	-	50.2	55.2	160.5		
$10^{11} S$ (e-fm^3)	375	150	115	185	0.6	-0.75
$10^{28} d_A$ (e-cm)	1250	1250	940	1050	0.3	2.1

Ref: Dzuba PRA66, 012111 (2002) - Uncertainties of 50%
***Based on Woods-Saxon Potential**
† Nilsson Potential Prediction is 137 keV



NOTES:
Ocutpole Enhancements
Engel et al. agree with Flambaum et al.
Even octupole vibrations enhance S (Engel, Flambaum& Zelevinsky)

Radon-EDM Experiment

TRIUMF E929

Spokesmen: Timothy Chupp & Carl Svensson

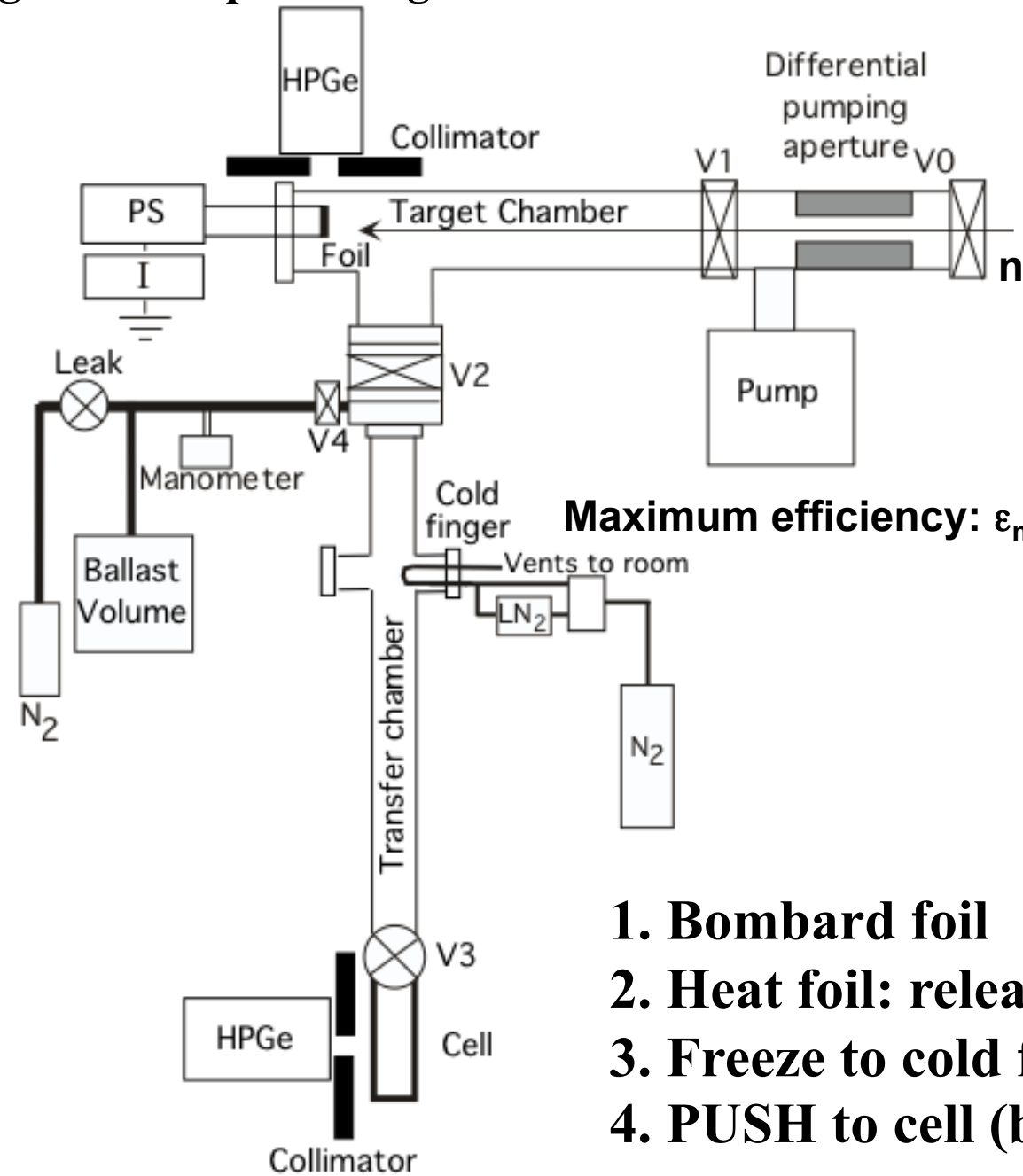
E-929 Collaboration (Guelph, Michigan, SFU, TRIUMF)

TRIUMF

Canada's National Laboratory for Particle and Nuclear Physics

Funding: NSF-Focus Center, DOE, NRC (TRIUMF), NSERC

Collecting rare isotope noble gases

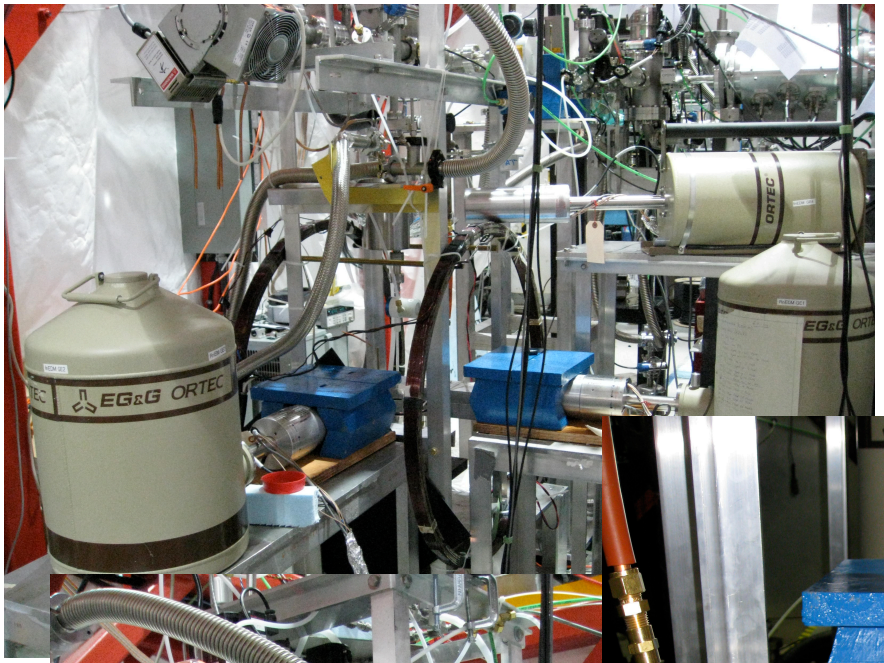


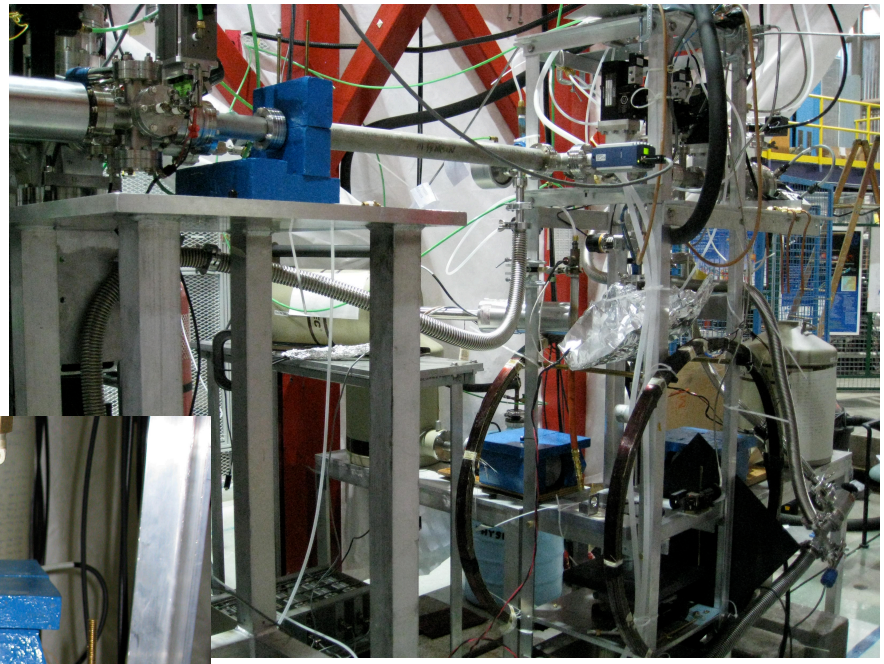
^{123}Cs (30 keV)

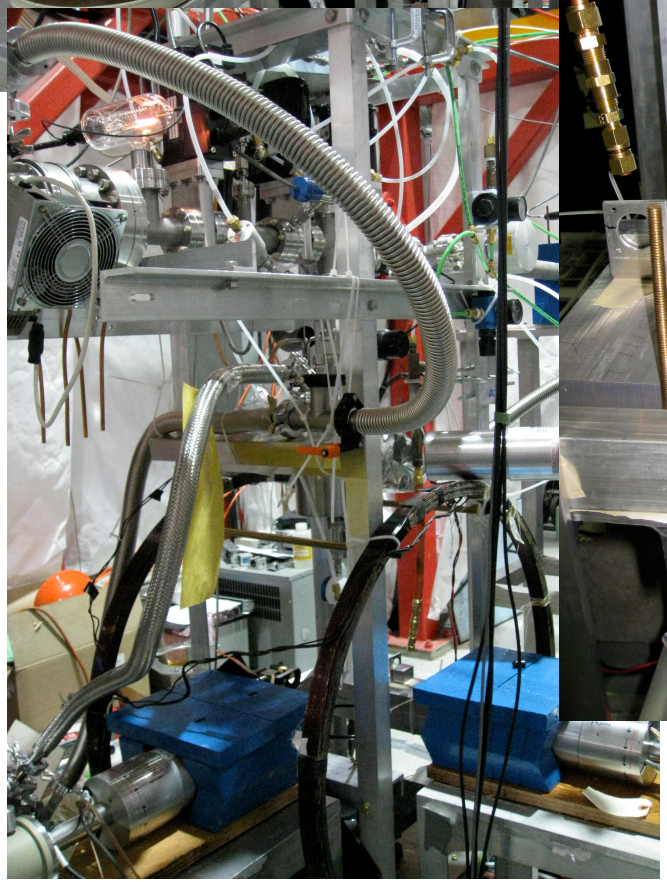
no radon at TRIUMF yet

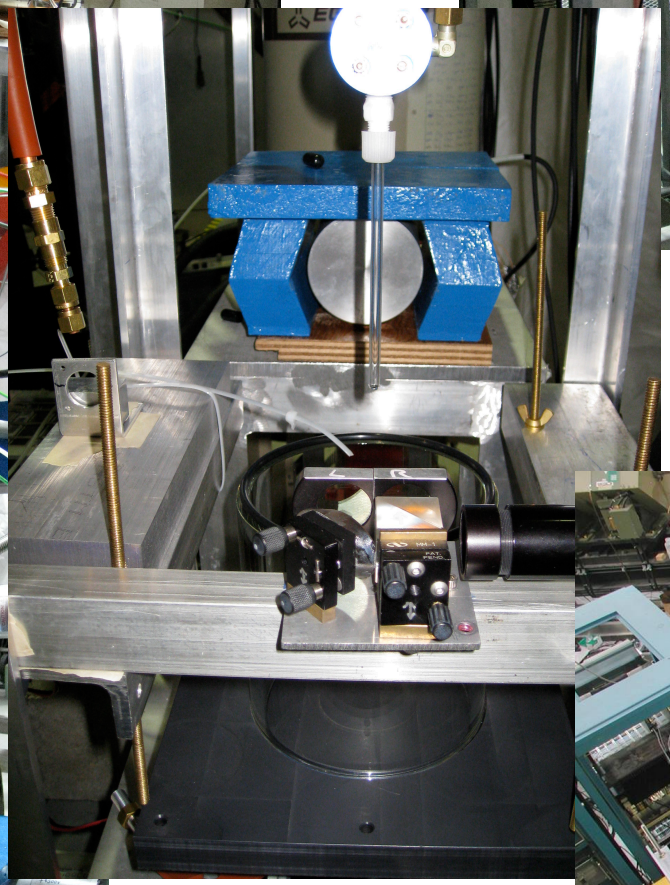
Maximum efficiency: ε_{max}=75%

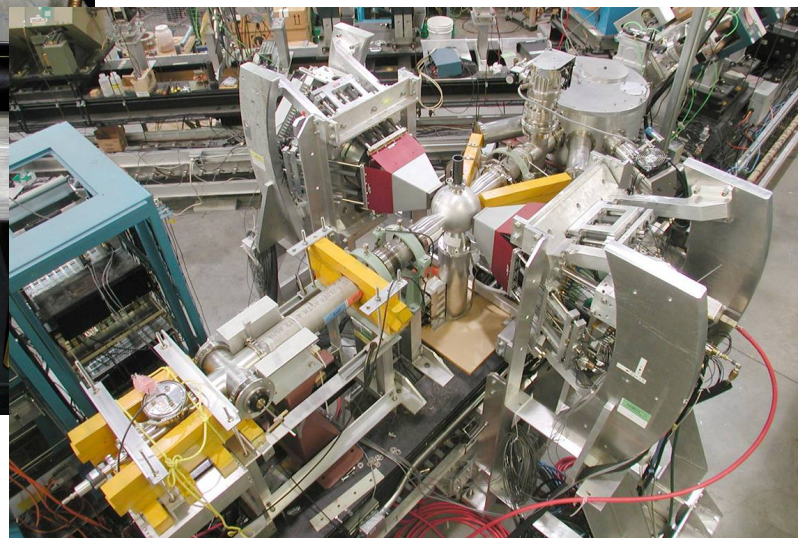
1. **Bombard foil**
2. **Heat foil: release to target chamber**
3. **Freeze to cold finger**
4. **PUSH to cell (buffer gas)**


EG&G ORTEC
ORTEC









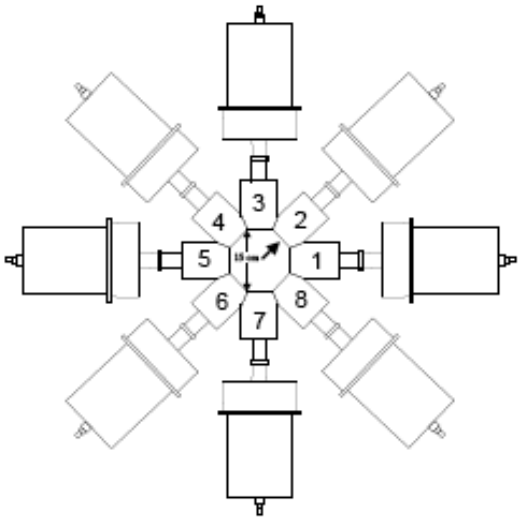
Techniques:

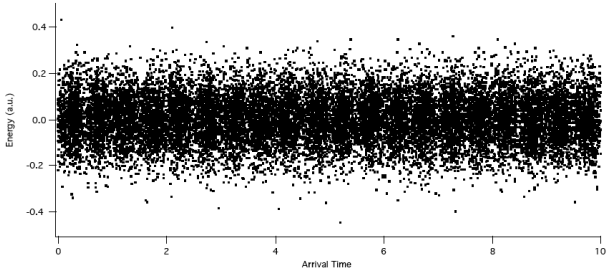
Produce rare ion radon beam

Collect in cell

Comagnetometer

Measure free precesion
(γ anisotropy/β asymmetry/laser)





$^{221/223}$Rn EDM projected sensitivity

Facility	Detection	S_d (100 d)
ISAC	γ anisotropy	2×10^{-26} e-cm
ISAC	β asymmetry	1×10^{-27} e-cm
FRIB	β asymmetry	2×10^{-28} e-cm

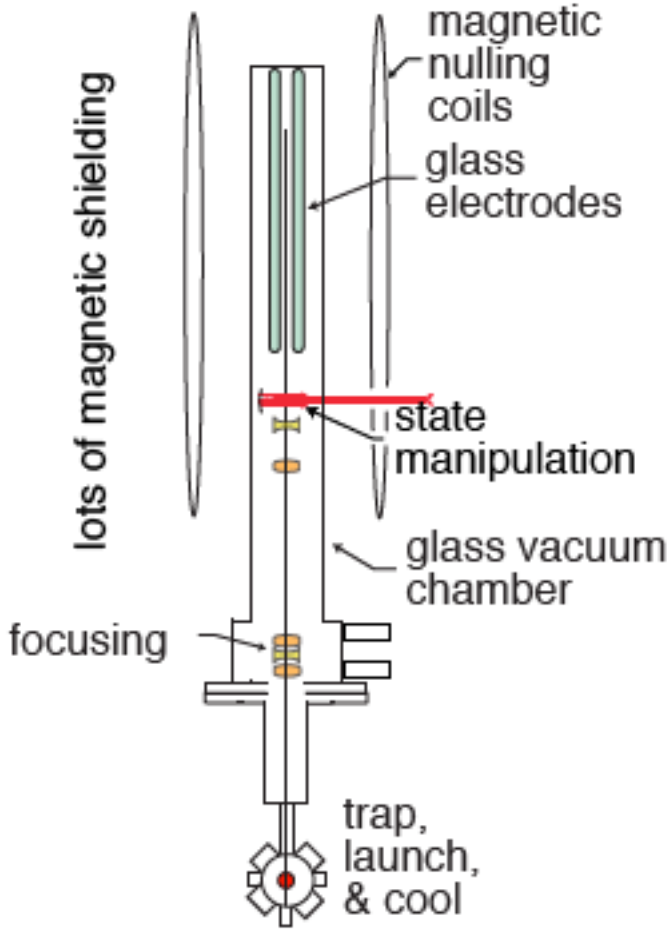
→ **~ 5×10^{-30} for ^{199}Hg**

Francium EDM

H. Gould – LBL (Berkeley)

η_e~ 900-1200

e-EDM fountain apparatus



Demonstration Cs Fountain e-EDM Experiment

J. M. Amini, C. T. Munger Jr. & H. Gould
http://arxiv.org/abs/physics/0602011

Jerry Nolen (atoms/s)

Radon 211: 10^{13} 219 10^{14} 223 10^{11}

Francium: 213 10^{13} 221 10^{14} 223 10^{12} (c.f. 2×10^{9})

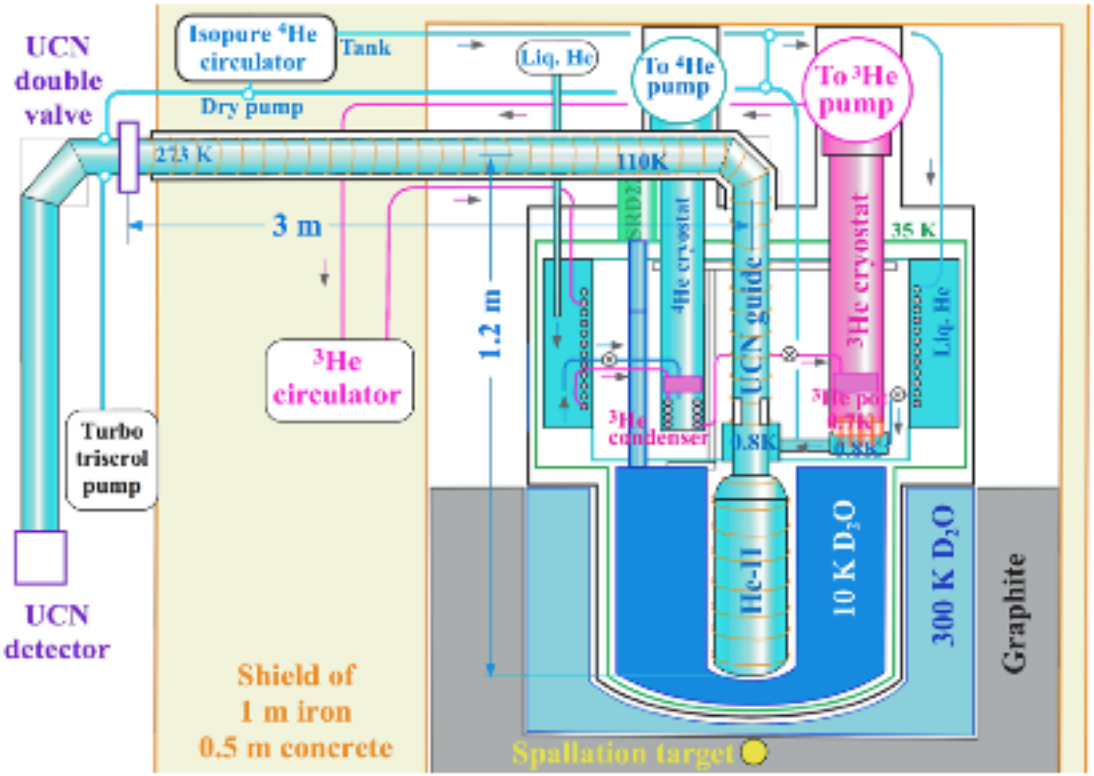
10 μA 500 MeV

Radium: 223 10^{13} 225 10^{13}

^{225}RaO: the best of both molecules and octupole

Neutrons

- Proposed TRIUMF/KEK neutron source



100's /cc - can this be scaled from 20 to 100 kW?

Discussion

EDMs: from the table top into the fire…..

How precise must theory be (enhancements, shielding)?

How do we couple the style and motivation into the realm of collider physics?

“EDM results have eliminated simple SUSY models years ago, but now LHC-CMS will get the credit…