

Search for the electron electric dipole moment

- electron EDM and new physics
- how to detect an EDM
- the previous and current generation of e-EDM searches
- our approach: electron EDM in PbO*

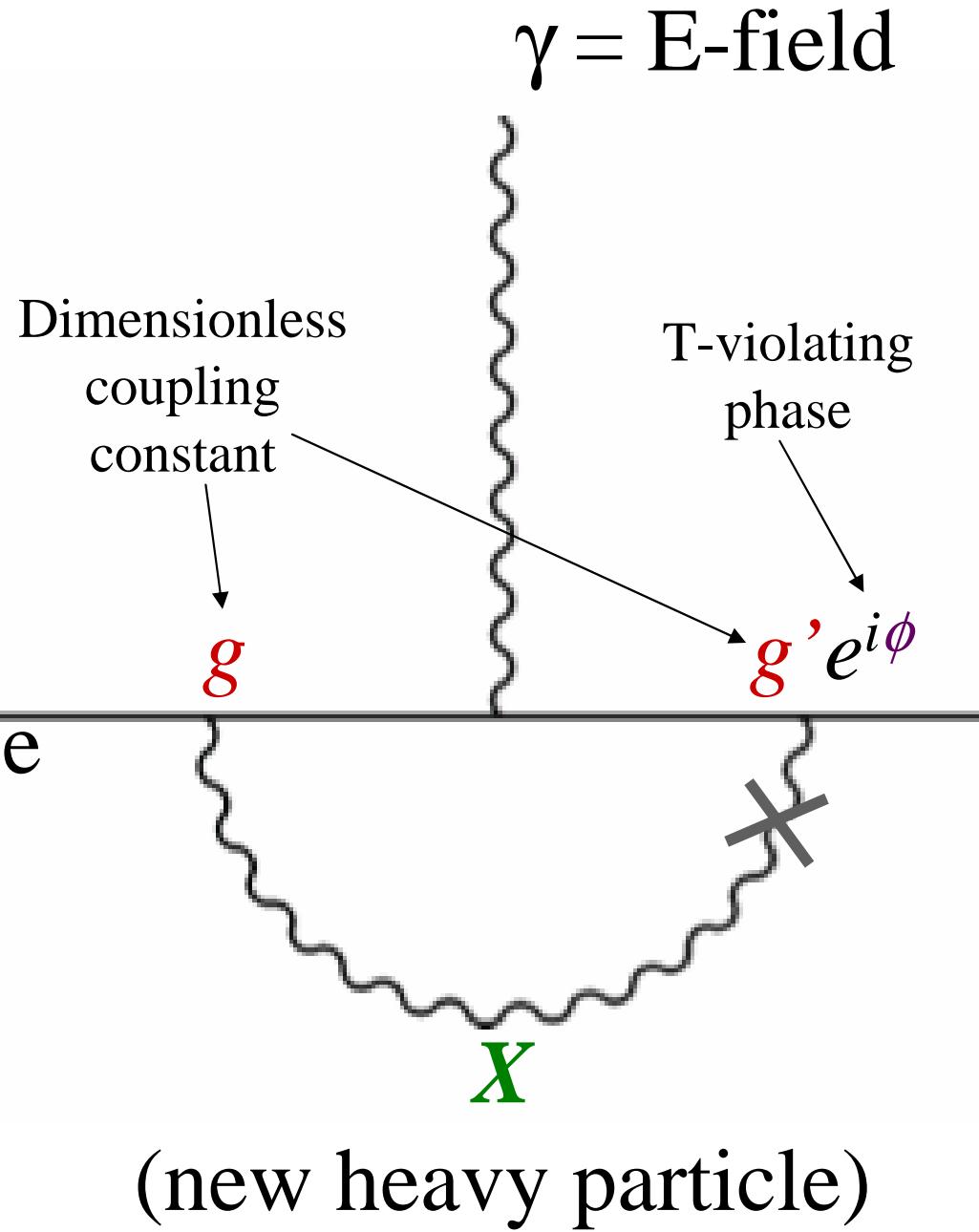


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Virtual exotic particles can generate EDMs



“natural” assumptions

$$gg'/\hbar c \approx \alpha$$

$$\sin(\phi) \sim 1$$

$$m_X \sim 100 \text{ GeV}$$

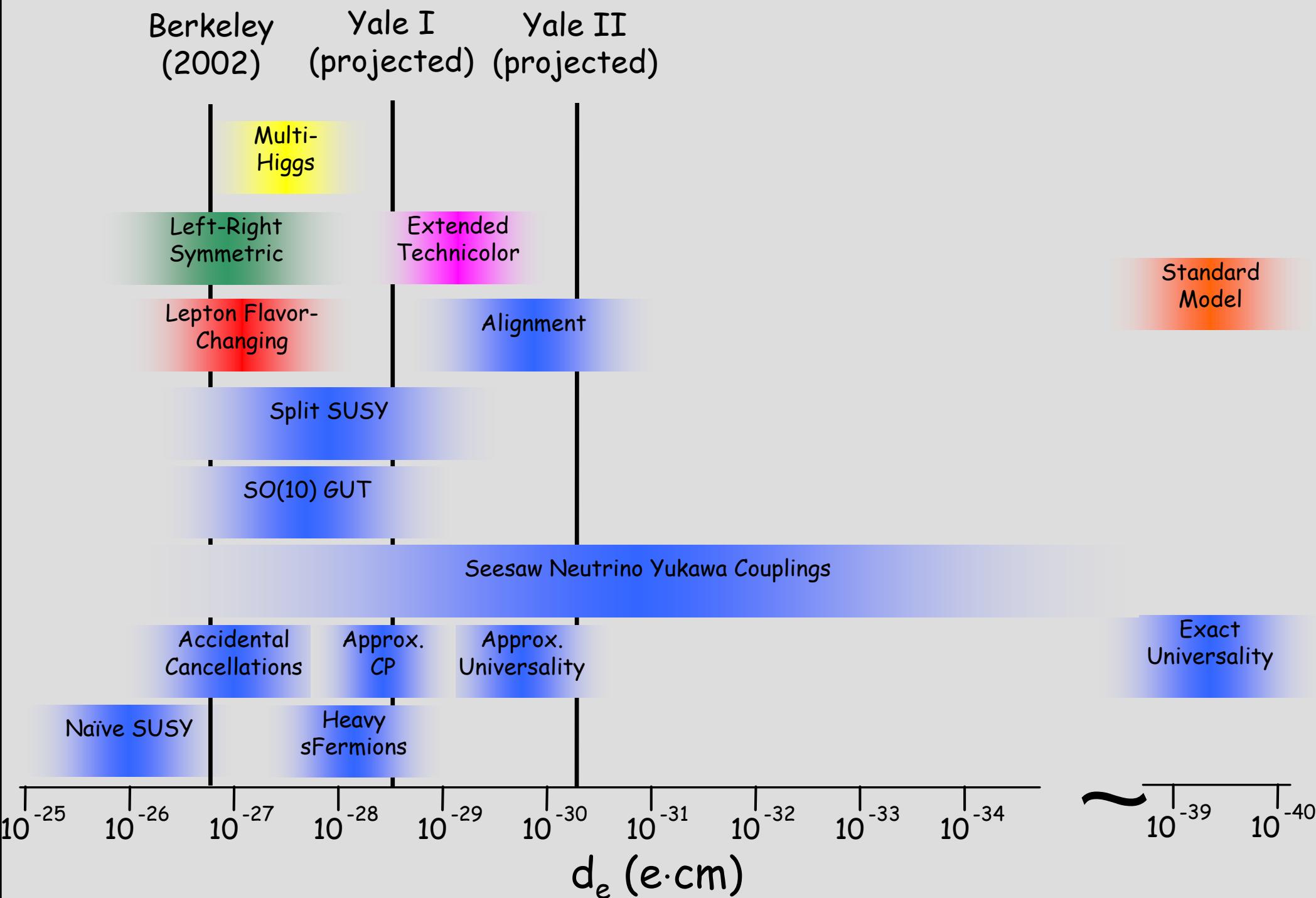


typical e-EDM d_e

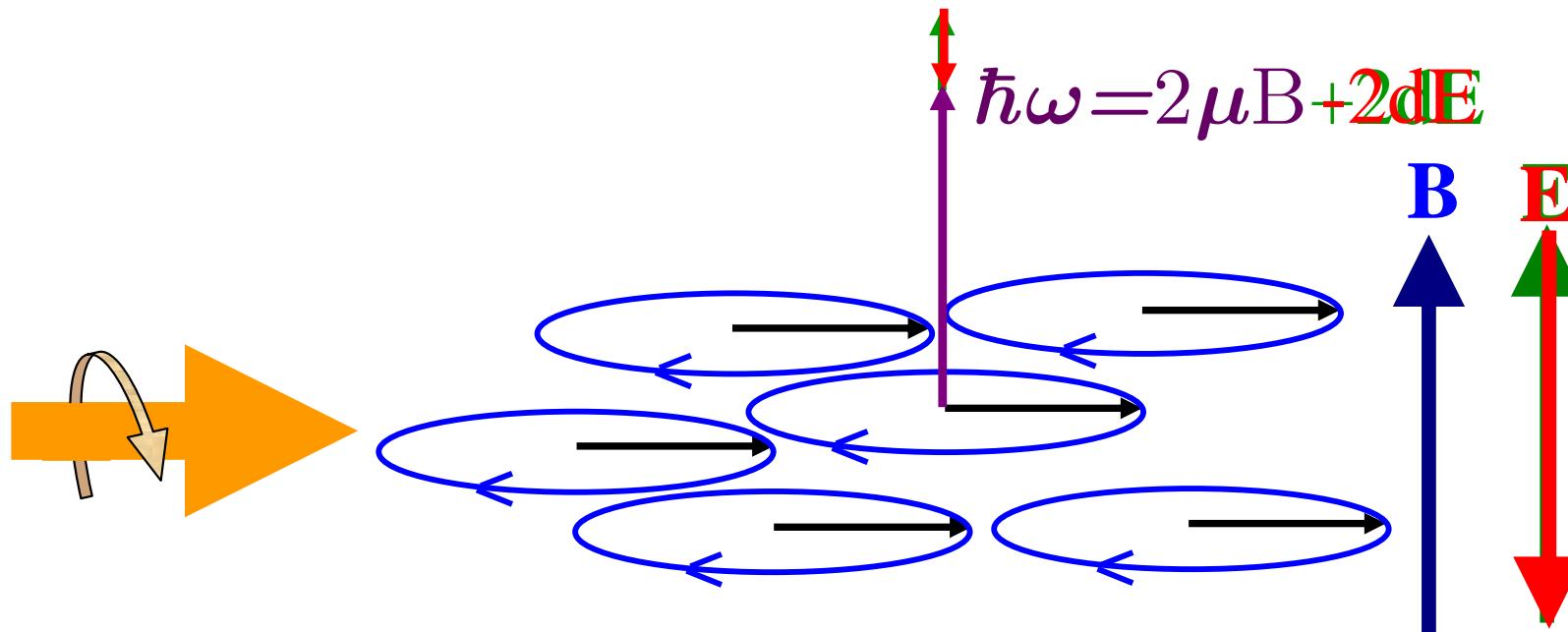
$$\sim \mu_B \cdot (\alpha/\pi)^N (m_e/m_X)^2 \sin\phi$$

$d_e \approx 100-1x$
current limit!
(1 vs. 2 loops)

Searching for new physics with the electron EDM



General method to detect an EDM



Energy level picture:

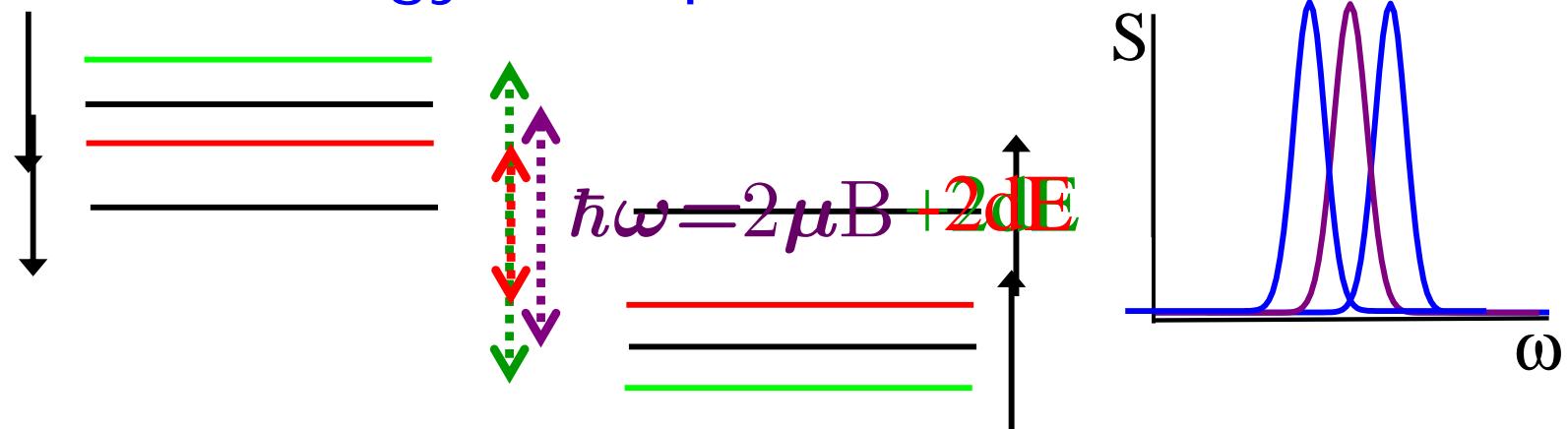
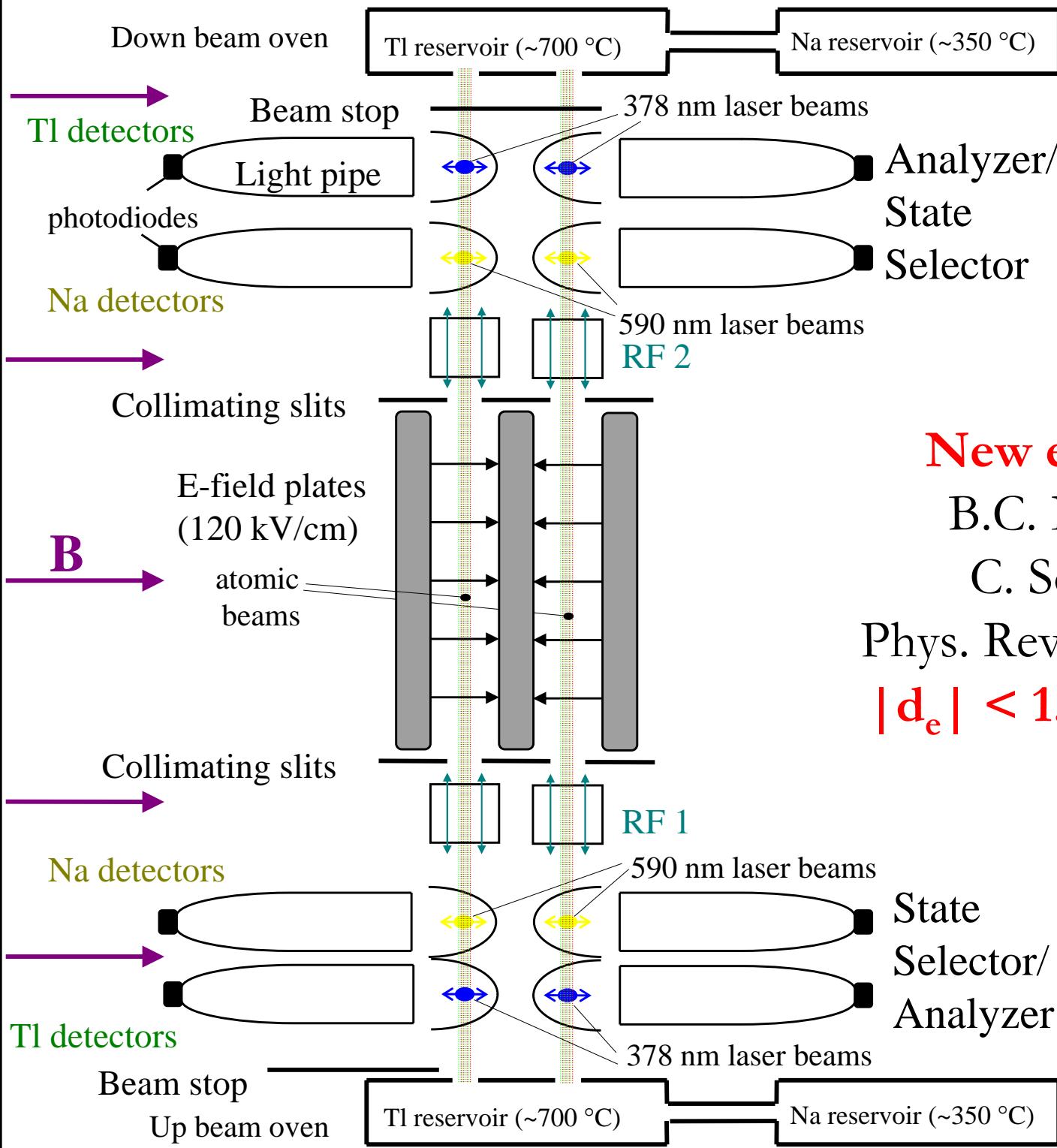


Figure of merit:
$$\frac{\text{shift}}{\text{resolution}} = \frac{dE}{(1/\tau_{coh})(S/N)^{-1}} \propto E \cdot \tau_{coh} \cdot \sqrt{N \cdot T_{\text{int}}}$$



- Thermal beam of atomic Tl ($Z=81$)
- Efficient laser/rf spin

New electron EDM limit:

B.C. Regan, E. Commins,
C. Schmidt, D. DeMille

Phys. Rev. Lett. **88**, 071805 (2002)

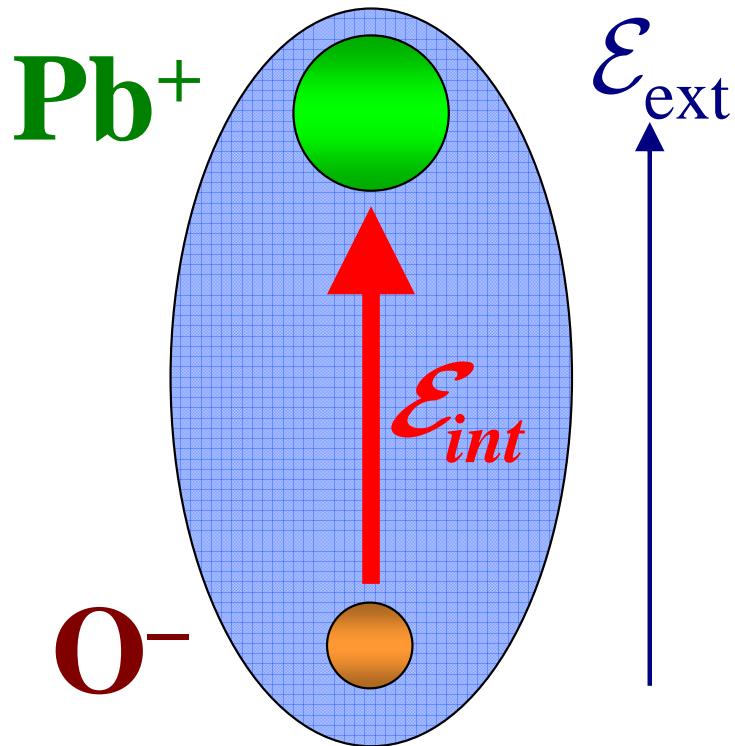
$$|d_e| < 1.6 \times 10^{-27} \text{ e}\cdot\text{cm} \text{ (90% c.l.)}$$

systematic effects from
 $B_{\text{motional}} = \mathcal{E} \times \mathbf{v}/c$
(but: complex procedure to null residuals)

A new generation of electron EDM searches

Group	System	Advantages	Projected gain
D. Weiss (Penn St.)	Trapped Cs	Long coherence	~100!
D. Heinzen (Texas)	Trapped Cs	Long coherence	~100!
H. Gould (LBL)	Cs fountain	Long coherence	?
L. Hunter (Amherst)	GdIG solid	Huge S/N	100?
S. Lamoreaux (LANL) C.-Y. Liu (Indiana)	GGG solid	Huge S/N	100?-100,000?
E. Hinds (Imperial)	YbF beam	Large Internal E	2-3
D. DeMille (Yale)	PbO* cell	Int.E+good S/N	30!-1,000?
E. Cornell (JILA)	trapped HBr ⁺	Int. E + long T	??
N. Shafer-Ray (Okla.)	trapped PbF	Int. E + long T	??

Amplifying the electric field \mathcal{E} with a polar molecule

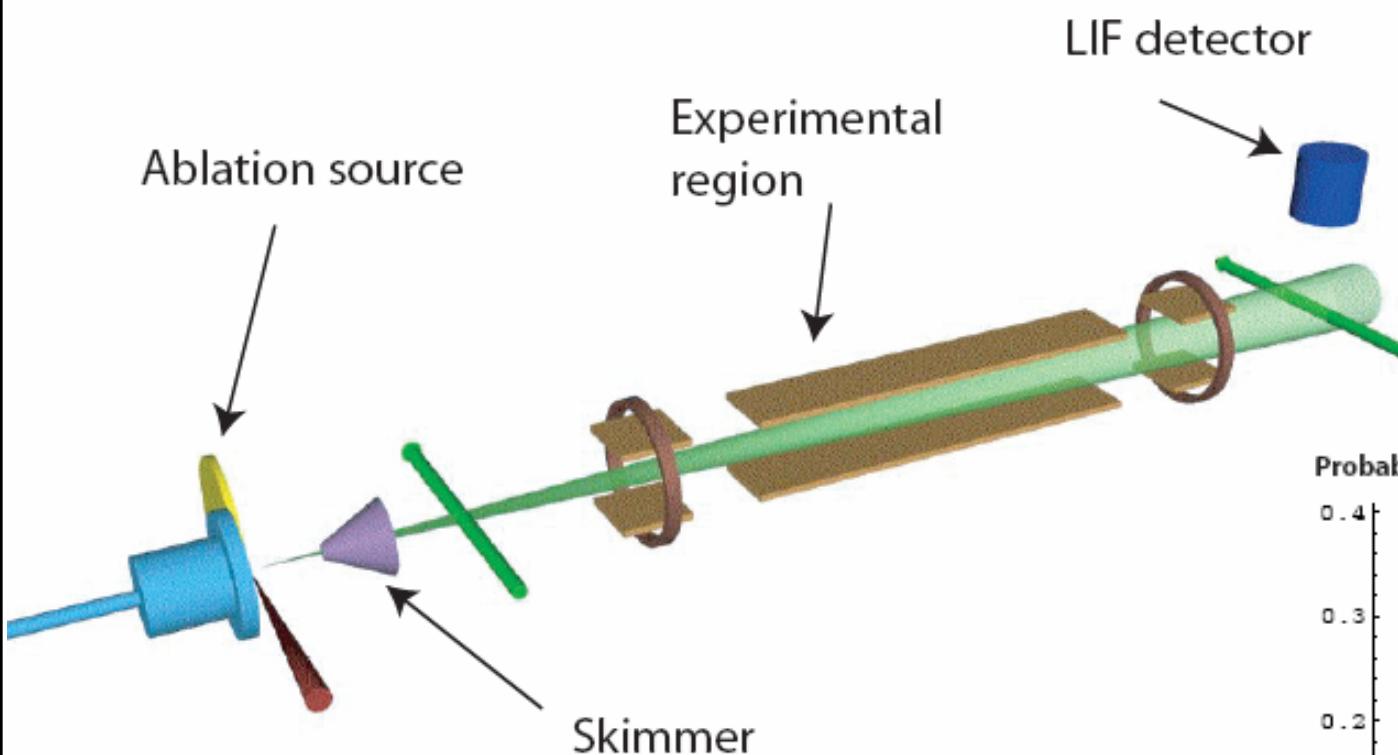


Complete electrical polarization
attainable with molecules subjects valence electrons to huge internal field
 $\mathcal{E}_{\text{int}} \sim 10^{11} \text{ V/cm}$
with modest polarizing field
 $\mathcal{E}_{\text{ext}} \sim 10\text{-}10,000 \text{ V/cm}$

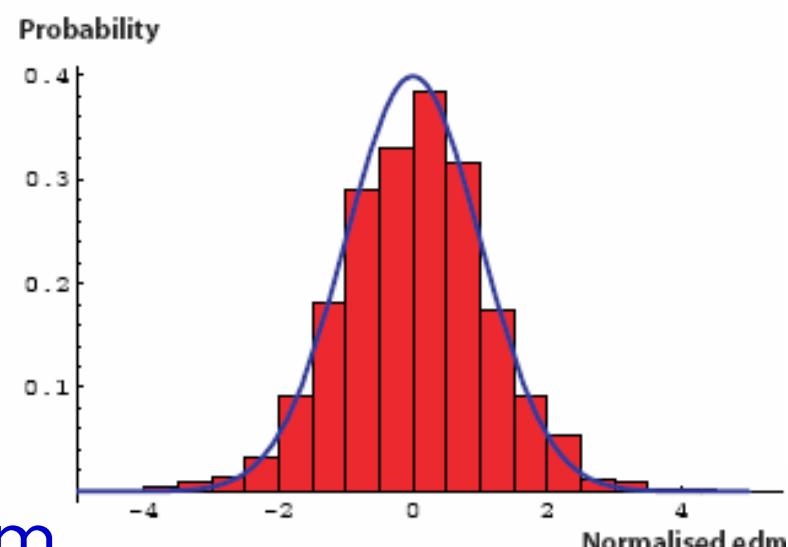
Explicit calculations indicate valence electron feels
 $\mathcal{E}_{\text{int}} \sim \alpha^2 Z^3 e / a_0^2 \sim 2.1 - 4.0 \times 10^{10} \text{ V/cm}$ in PbO^*

semiempirical: M. Kozlov & D.D., PRL **89**, 133001 (2002);
ab initio: Petrov, Titov, Isaev, Mosyagin, D.D., PRA **72**, 022505 (2005).

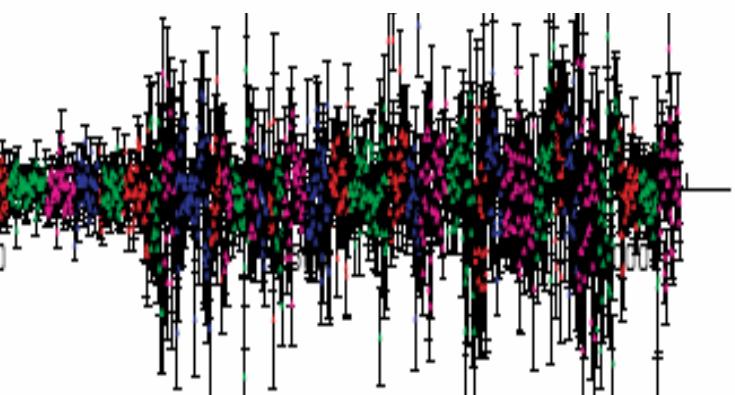
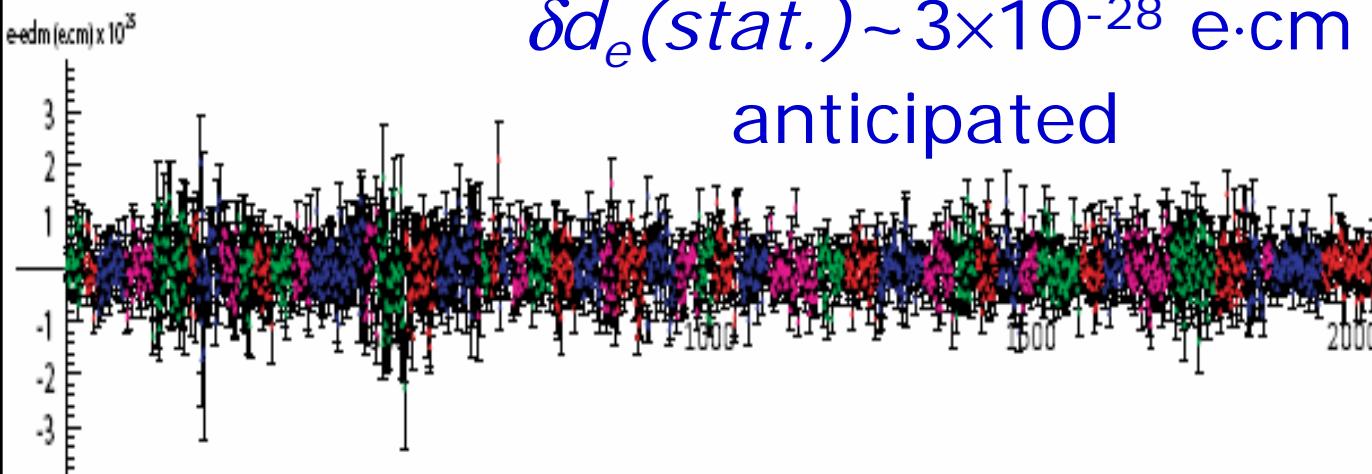
YbF beam experiment (Hinds/Sauer, Imperial College)



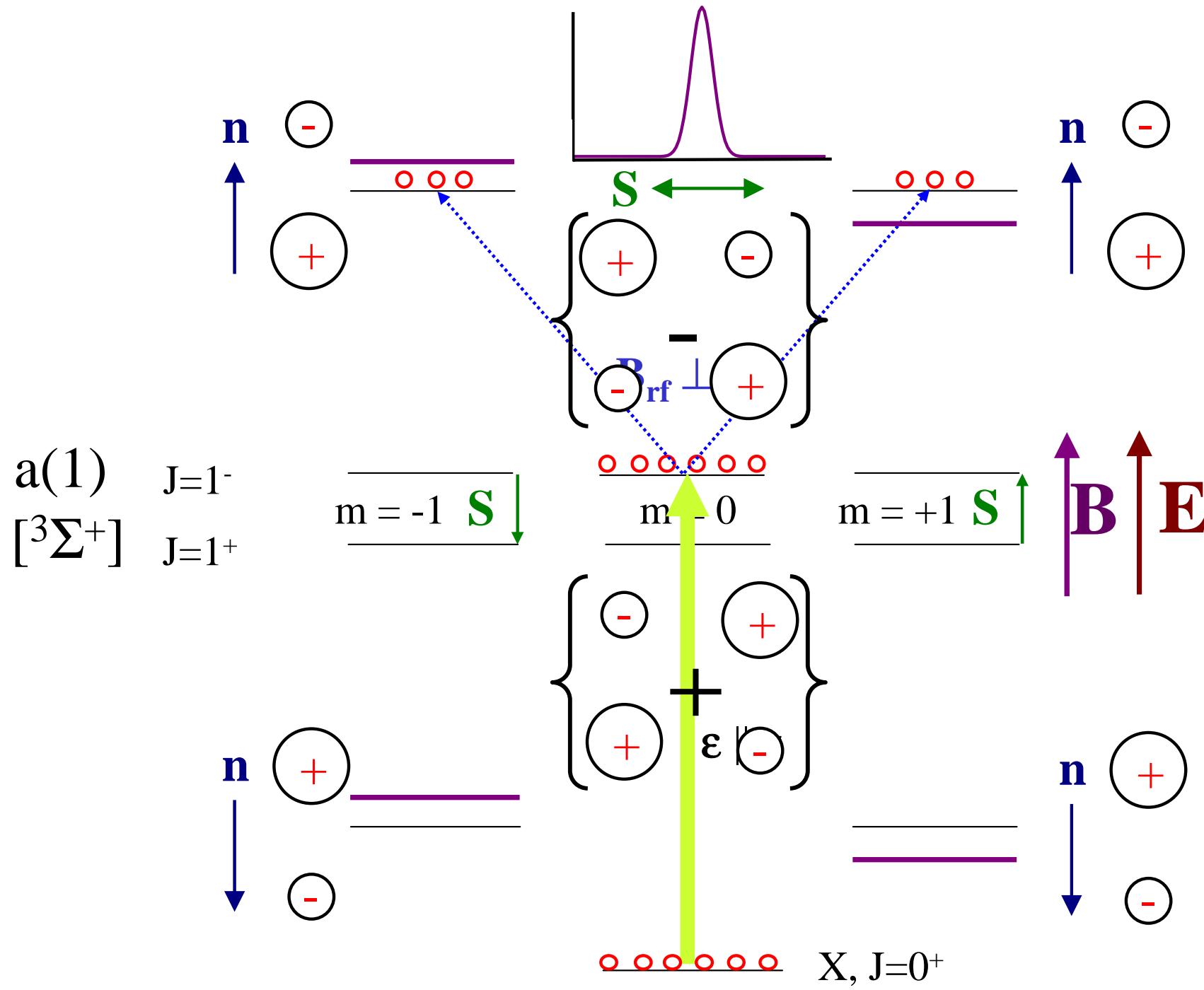
Improved statistics
w/new beam
source vs. 2002



taking data now:
 $\delta d_e(\text{stat.}) \sim 3 \times 10^{-28} \text{ e}\cdot\text{cm}$
anticipated



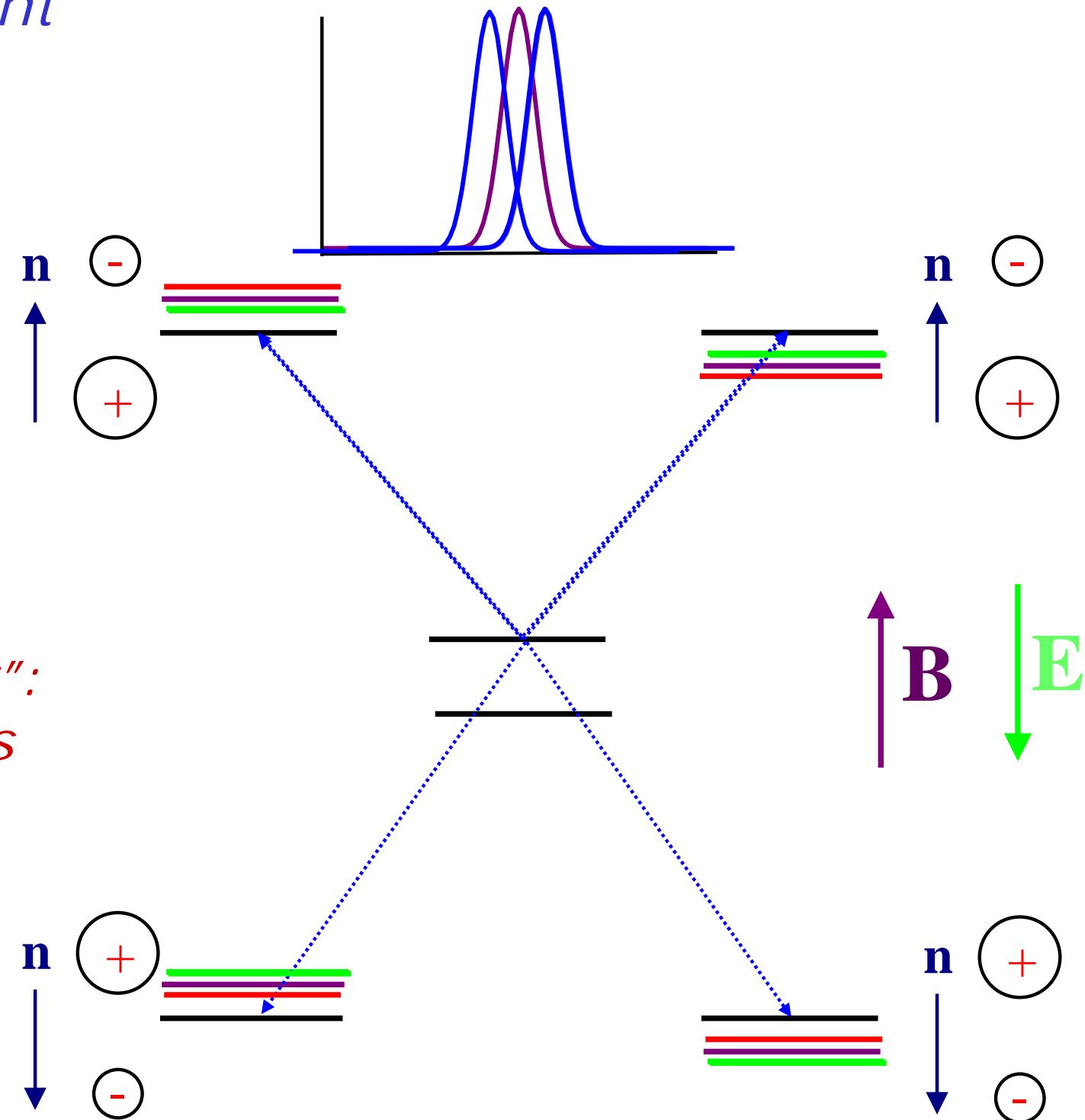
Spin alignment & molecular polarization in PbO (no EDM)



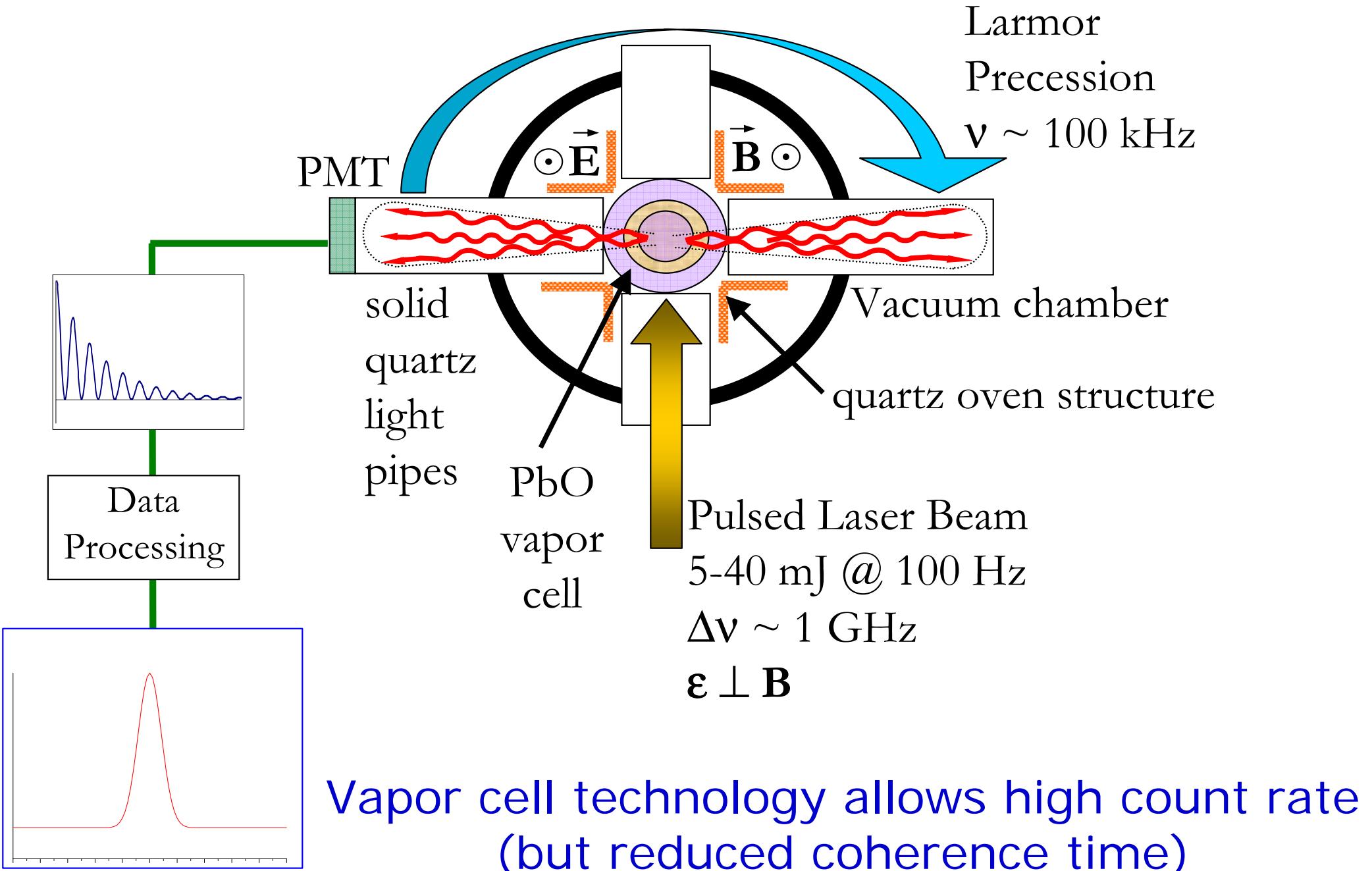
*EDM measurement in PbO**

Novel state
structure
allows extra
reversal of
EDM signal

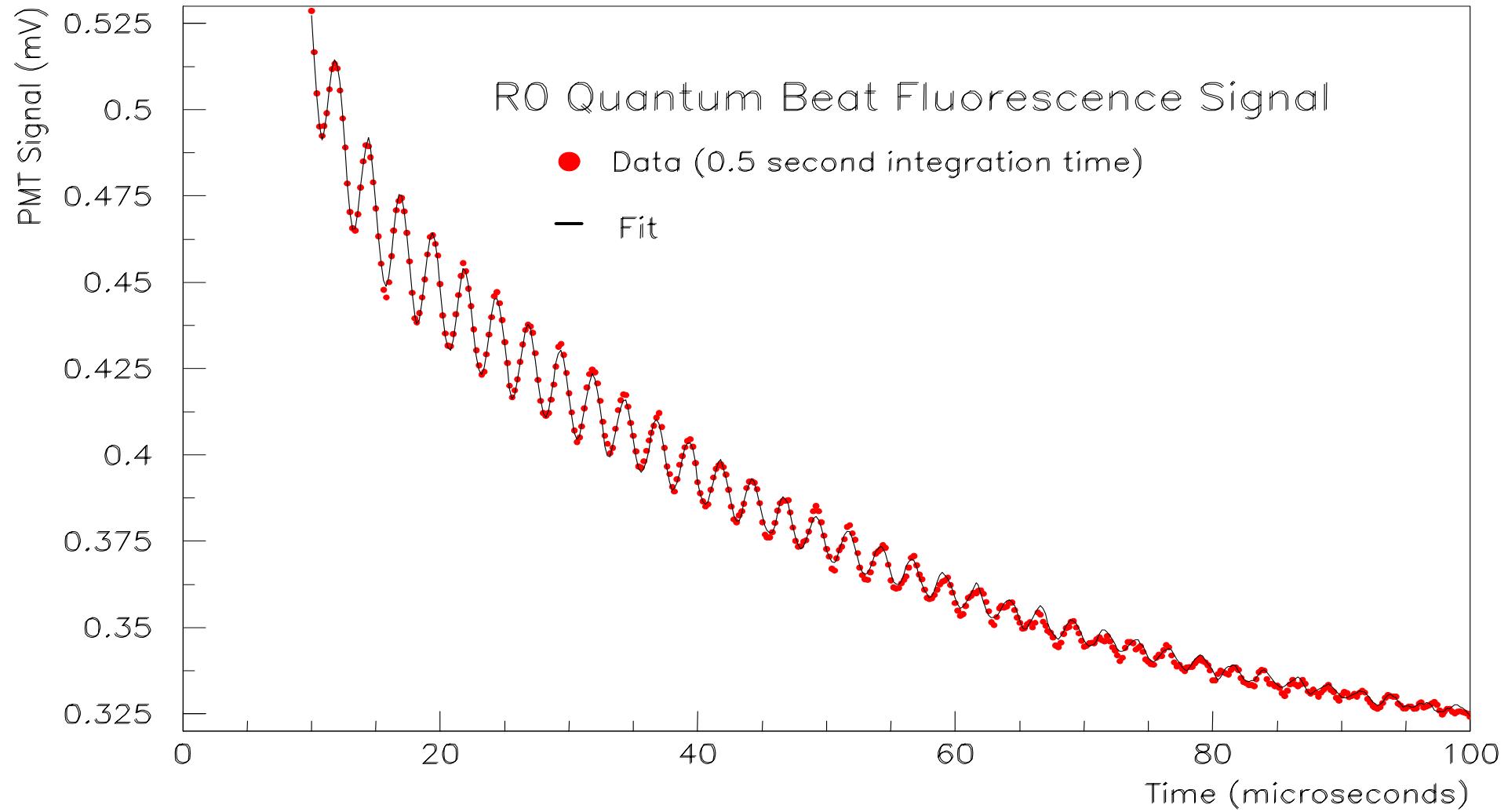
*"Internal
co-magnetometer":
most systematics
cancel in
comparison!*



Present Experimental Setup (top view)



Zeeman quantum beats in PbO



Excellent fit to Monte Carlo w/PbO motion, known lifetime
Shot noise-limited S/N in frequency extraction
(Laser-induced spin alignment only here)

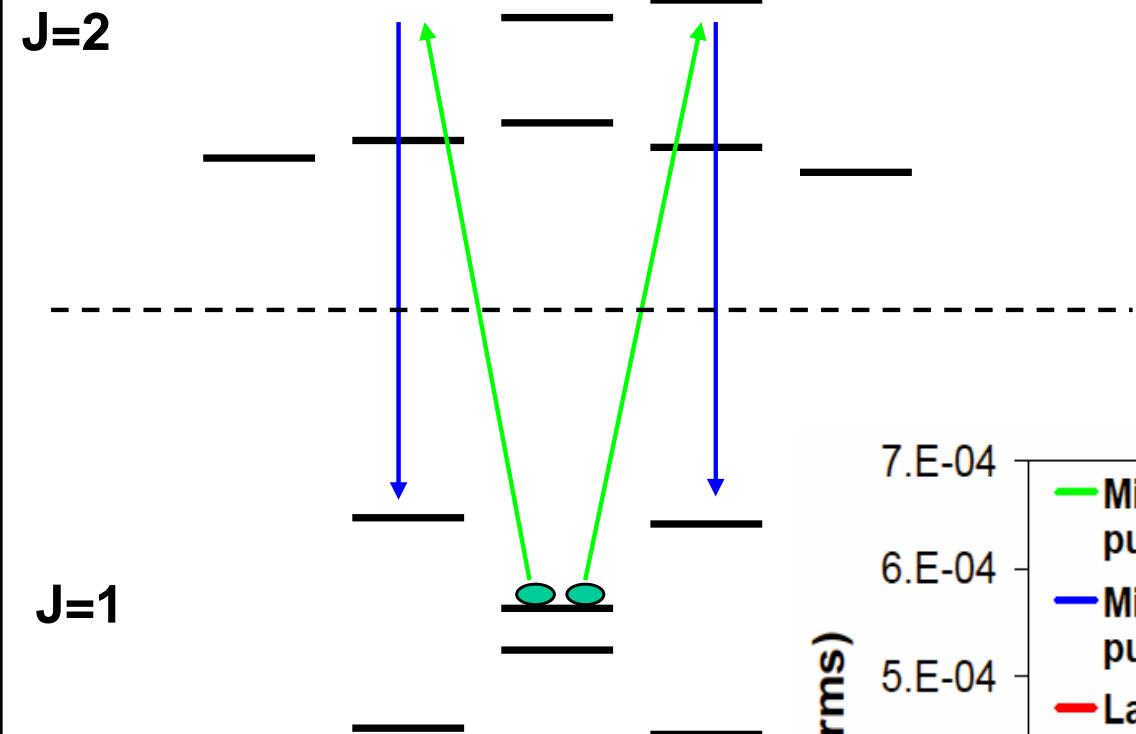
Current status: a proof of principle

[D. Kawall *et al.*, PRL 92, 133007 (2004)]

- PbO vapor cell technology in place
- Collisional cross-sections as expected \Rightarrow anticipated density OK
 - Signal sizes large, consistent with expectation; improvements under way should reach target count rate: $10^{11}/\text{s}$.
 - Shot-noise limited frequency measurement using quantum beats in fluorescence
 - g-factors of Ω -doublet states match precisely \Rightarrow co-magnetometer will be very effective
- E-fields of required size applied in cell; no apparent problems

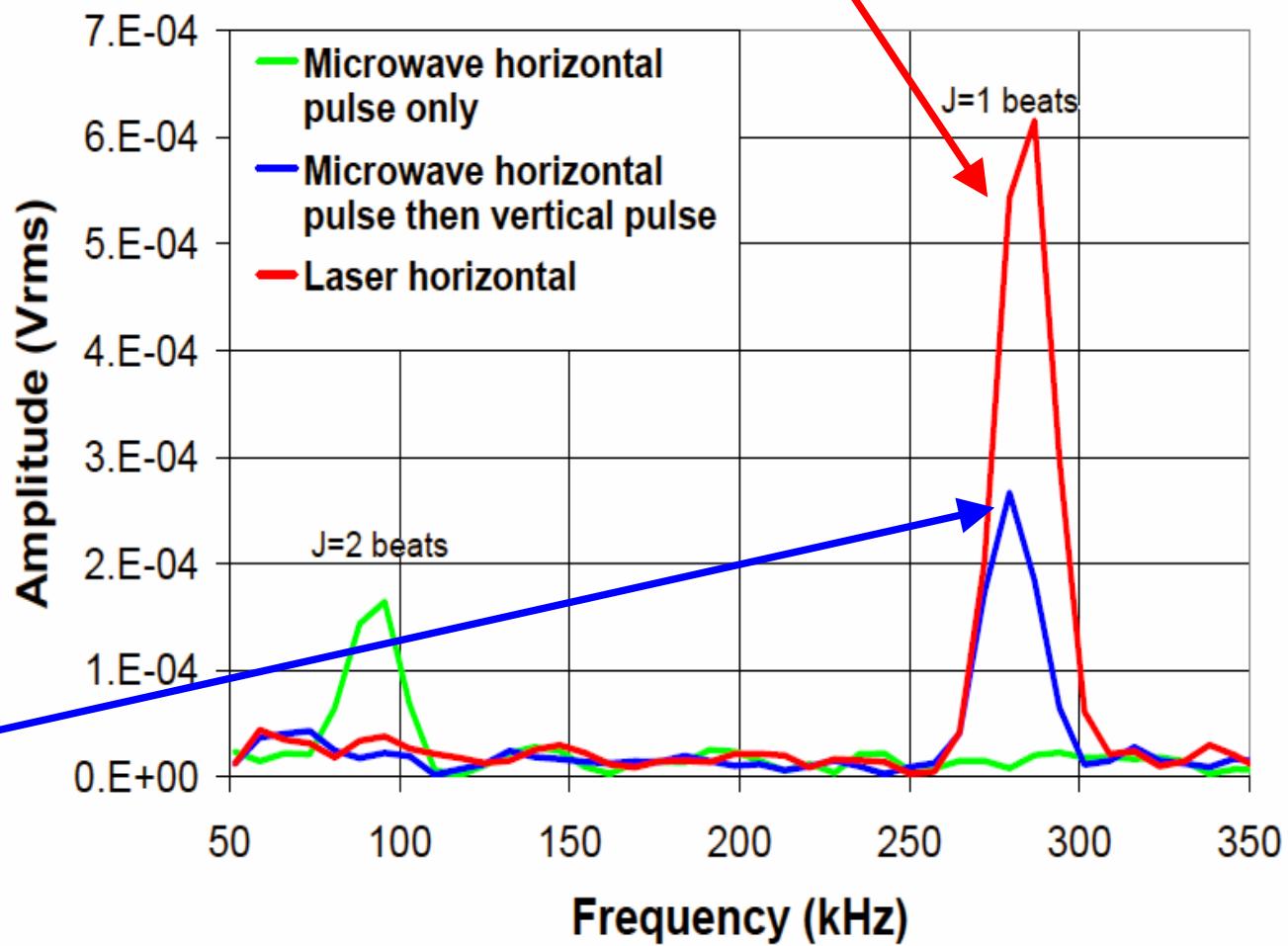
\Rightarrow *First useful EDM data ~late 2005;
 $\delta d_e \sim 3 \times 10^{-29} \text{ e}\cdot\text{cm}$ within ~2 years...?*

State preparation: microwave Raman excitation



laser-prepared superposition, as in proof-of-principle (no good for EDM)

laser + μ wave preparation, as needed for EDM



The PbO EDM group



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