Deuteron Polarimetry in the Dedicated Muon EDM Experiment

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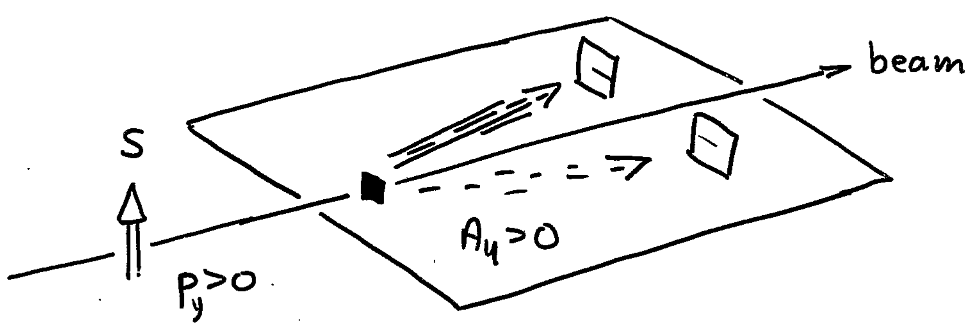
Master equation:

- spherical tensor: $\sigma(\theta,\varphi) = \sigma_{unp}(\theta)\left[1 + 2\, it_{11}\; iT_{11}(\theta)\cos\varphi \ldots\right]$

polarization   analyzing power

- Cartesian: $\sigma(\theta,\varphi) = \sigma_{unp}(\theta)\left[1 + \frac{3}{2} p_y A_y + \ldots\right]$



Why a deuteron beam? (thanks to Bill Morse)

The "ideal" test beam would check $\vec{B}$ and $\vec{E}$ near their operating point for muons.

$$\vec{\omega} = -\frac{e}{m}\left[a\vec{B} + \left(\frac{1}{\gamma^2-1} - a\right)\frac{\vec{\beta}\times\vec{E}}{c}\right] \rightarrow 0$$

For $a \ll \frac{1}{\gamma^2-1}$, the ratio of fields is

$$\frac{E}{Bc} \approx \frac{ap}{m}\left[1+\frac{p^2}{m^2}\right]^{1/2}$$

	a	m(MeV)	$10^6 \frac{a}{m}$	p(MeV/c)	$10^3 \frac{E}{Bc}$	B(T)	ω_s
μ	0.001166	105	11.1	518	28.9	0.233	2.3
p	1.793	938	1900				
d	-0.143	1876	7.6	389	30.3	0.218	14

design for $\gamma^2 = 5$

choose 40 MeV deuterons

These values are close enough to check operating fields.

Factor of ~100 between deuteron and muon a helps to suppress any contribution from EDM in deuteron.

Precession due to θ between $\vec{B}$ and $\vec{\beta}\times\vec{E}$ goes as

$$\omega_s = \frac{\mu\theta E}{c\beta\gamma^2}$$

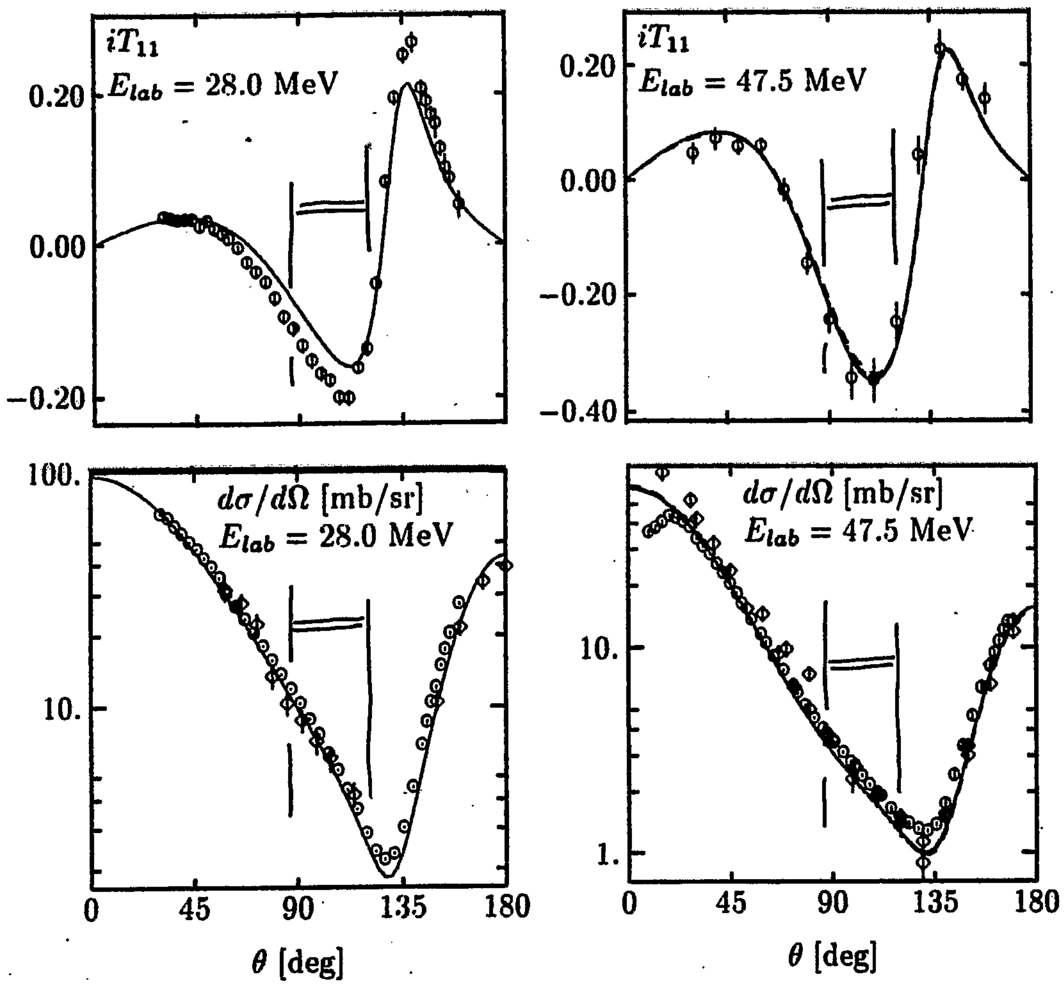
For $\theta \sim 10^{-8}$, deuteron is 6 times more sensitive

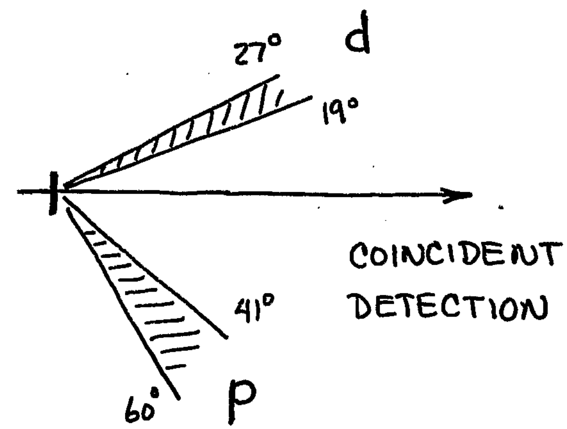
d + p

proposed angle range: $\theta_{cm} = 84° - 120°$

$\theta_{lab}(d) = 19° - 27°$ $\quad\theta_{lab}(p) = 41° - 60°$

$\langle \sigma \rangle = 15.7$ mb
$\langle \sigma \, iT_{11} \rangle = -3.5$ mb
$\langle iT_{11} \rangle = -0.22$
$\langle A_y \rangle = -0.25$



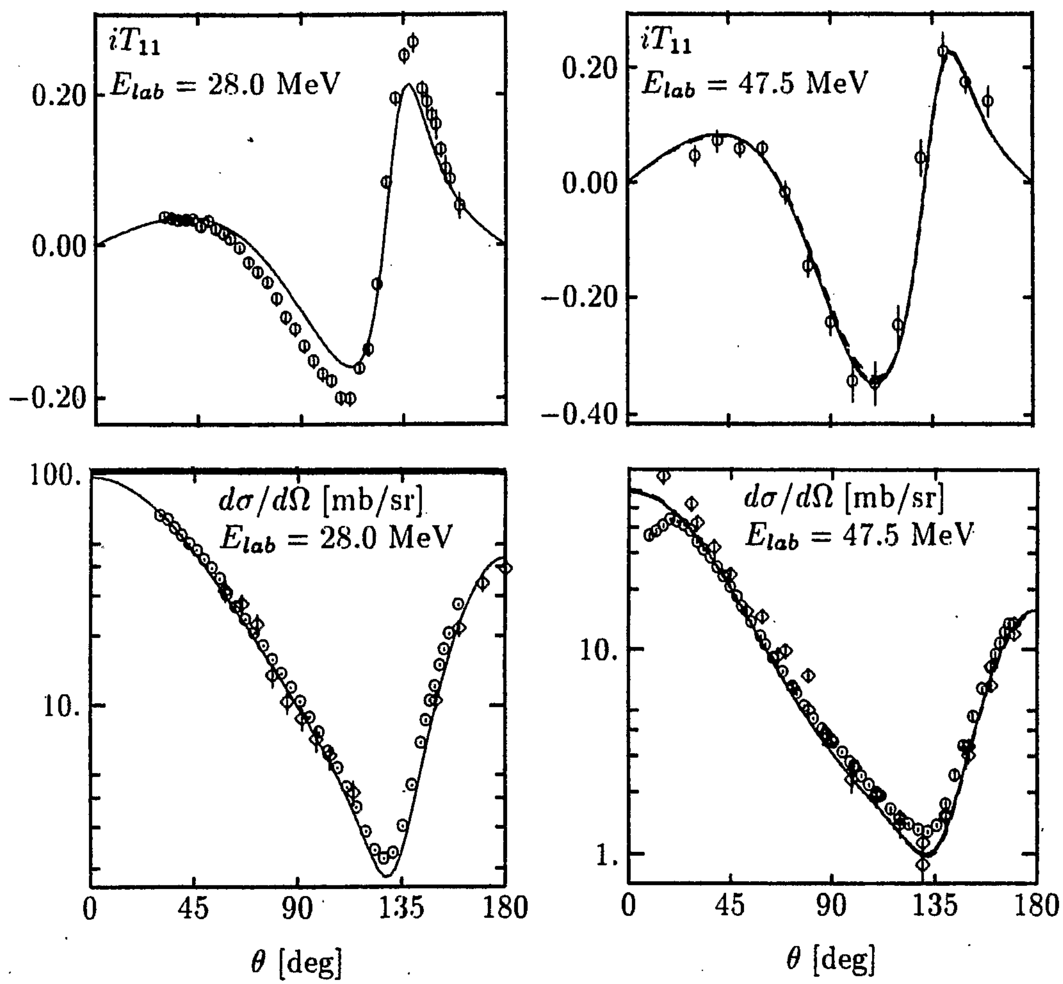


COINCIDENT DETECTION

Background: d+p → p+p+n

Information on
p, d angle
p, d energy
relative time-of-flight
can make clean separation.

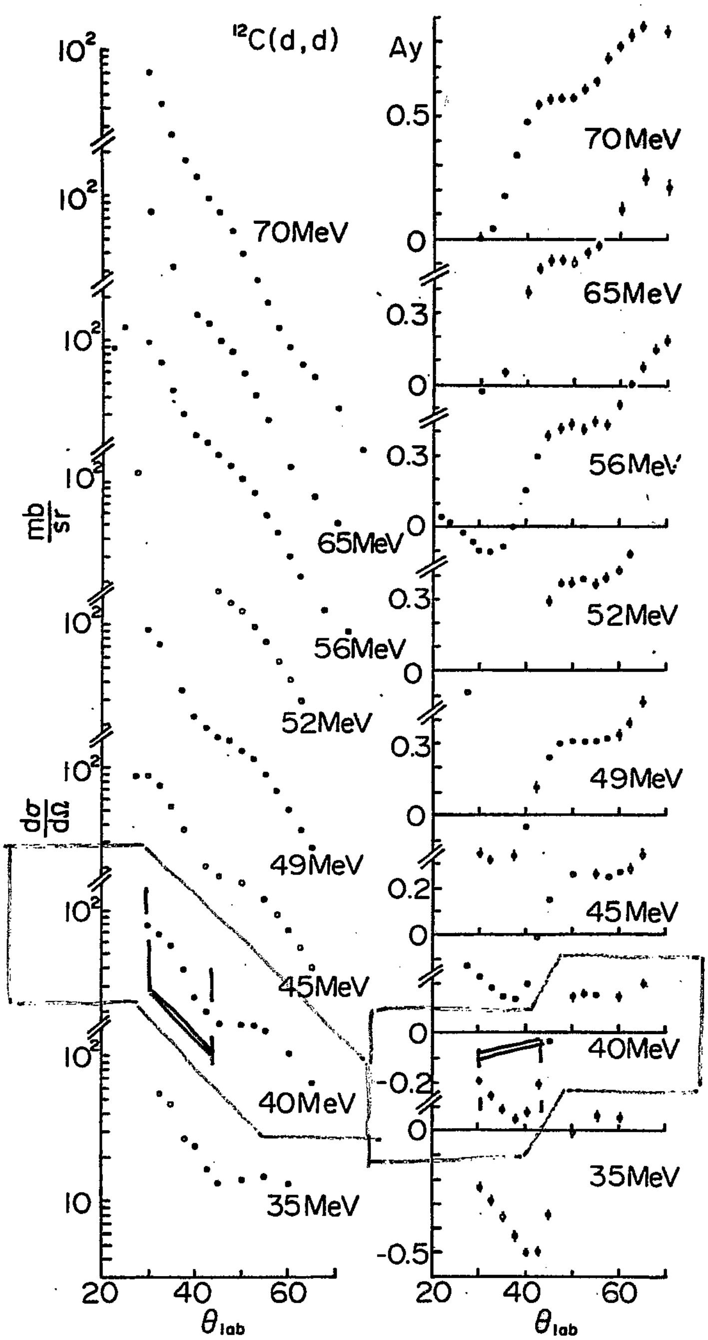
data from K. Hatanaka et al., Nucl. Phys. A426, 77 (1984) at 28 MeV and H. Witala et al., Few-Body Systems 15, 67 (1993). Faddeev calculations by W. Glöckle et al., Phys. Rep. 274, 107 (1996).



iT_{11}
$E_{lab} = 28.0$ MeV
iT_{11}
$E_{lab} = 47.5$ MeV
$d\sigma/d\Omega$ [mb/sr]
$E_{lab} = 28.0$ MeV
$d\sigma/d\Omega$ [mb/sr]
$E_{lab} = 47.5$ MeV
θ [deg]
θ [deg]

$d + {}^{12}C$

proposed angle range: $\Theta_{lab} = 30° - 43°$



$\langle\sigma\rangle = 37.9$ mb

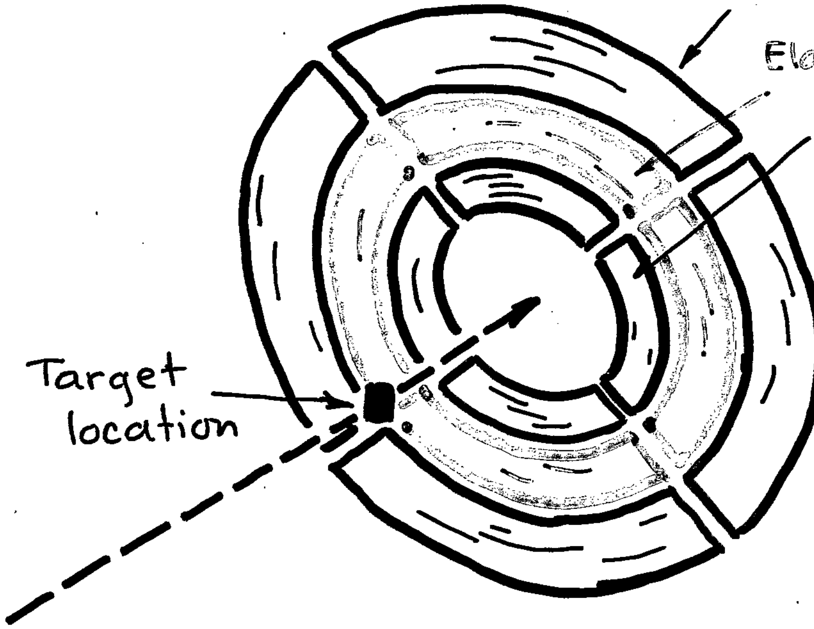
$\langle\sigma A_y\rangle = -10.7$ mb

$\langle A_y\rangle = -0.28$

The shape of $A_y(\Theta)$ follows trends driven by $\vec{L}\cdot\vec{S}$ interaction (optical model or semi-classical description). All inelastic states will follow the same trends.

data from S. Kato and ...
NIM A238, 453 (1985)

CONCEPTUAL DETECTOR SPECIFICATIONS



Partition into 4 azimuthal sections gives information on horizontal and vertical transverse polarization components.

d+p separation requires:
- fast timing coincidence
- sensitivity to d+p kinematics
- pulse height / timing background reduction

→ scintillator array segmented in θ_{lab}.

d+C detection
- counters to get total energy
- recoil detectors may help

→ can also be scintillator

Horizontal: $\frac{E}{B}$ errors

Vertical: θ between $\vec{B}$ and $\vec{\beta} \times \vec{E}$

Both asymmetries grow with time. So it is not necessary to remove all offset errors.

NOTE: Largest deuteron vector polarization also carries tensor polarization (pure m=1 or −1 state). Rotation of spin axis away from $\hat{z}$ produces $\cos 2\phi$ "asymmetry" that may be used as a consistency check.

Targets, rates, etc....

- Loss of polarization due to momentum spread in beam:

$$\Delta\theta_{prec} = 4\pi \frac{\Delta p}{p} \gamma(\mu-1) N \longrightarrow 1 \quad \text{(useless)}$$

turns

If collimation can give $\frac{\Delta p}{p} \sim 10^{-5}$, then $N \sim 6\times10^4$

Orbit period = 0.73 μs, holding time $\tau \sim 40$ ms

- Assume polarimeter target is uniformly distributed, thickness must not slow it to the point where it is lost from the ring.

$\Delta E \sim 250$ keV on $E_d = 40$ MeV

So: $N_T < 5\times10^{16}$ /cm² for H_2 (thick jet)

$< 8\times10^{15}$ /cm² for C

Ribbon from RHIC CNI pol. $\sim 10^{13}$/cm²

Rates: H_2 84K /s C 17K /s

Run electronics into scalers.

- Goal is to detect a deflection of $\theta = 0.20 \pm 0.05$ mrad.

Take:
- Vector/tensor beam with $p = 0.85$.
- $\langle A_y \rangle = -0.25$
- Asymmetry $\epsilon = \frac{3}{2} p \langle A_y \rangle \theta = 6.4 \pm 1.6 \times 10^{-5}$
- Events needed: $C = \frac{1}{(d\epsilon)^2} = 4\times10^9$

Assuming 4 time bins, machine duty cycle
- Total rate $\sim 5\times10^5$/s $\Longrightarrow$ need 6 days

- How to improve? $\epsilon \propto \tau$ but events $\propto 1/\tau^2$.
You want longer τ, thinner targets.

ISSUE: Hydrogen target is about one mono-layer, so slowing of beam becomes important because

- change of β destroys cancellation of spin precession
- slowing alters height of equilibrium orbit, introducing time-dependent asymmetries.

What about fibers or droplets?

- Must assume deuteron that hits is lost, so beam intensity decays exponentially. While the events seen scales as t (target size), scaling still requires long stores and favors small t.

CARBON $\dfrac{\text{events}}{\text{store}} = \begin{cases} 10^7\ t(\text{cm}) & \text{fiber} \\ 7\times10^6\ t(\text{cm}) & \text{sphere} \end{cases}$

Here, a 40 ms lifetime gives rates above 2×10^6/s, more than we can handle. (diameter ~ 0.1 mm)

$\Downarrow$

NOTE: It may be worth considering oil (CH_2) droplets, as both H and C asymmetries become available.

Present techniques limit sizes so that lifetimes are < 10 ms for a round fiber (Also true for them to remove deuteron from beam using normal pipe with no away-side collimator.)

NOW IT'S TIME TO GET TO WORK!

In February, 2001, IUCF put its first "m=1" polarized deuteron beam into the Cooler storage ring and measured the polarization. The ring can run 40-MeV deuterons. Small 'trim' solenoids can be used to distort the stable spin orbit at levels comparable to what would be seen here. But, this equipment will be available for less than 2 more years under present plans!