Difference of measured proton and He3 EDMs: reduced systematics test of T-reversal Invariance

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2 Outline

Simultaneous counter-circulating, frozen spin proton beams in MDM comparator ring PTR

Proposed proton EDM Prototype, COSY, Juelich, Germany

Distortion-free, Quadrupole-free, Doubly-magic, Two-way Toroidal Optics

Proposed proton, He3 EDM difference measurement at BNL

Cancellation of proton/He3 systematic Error

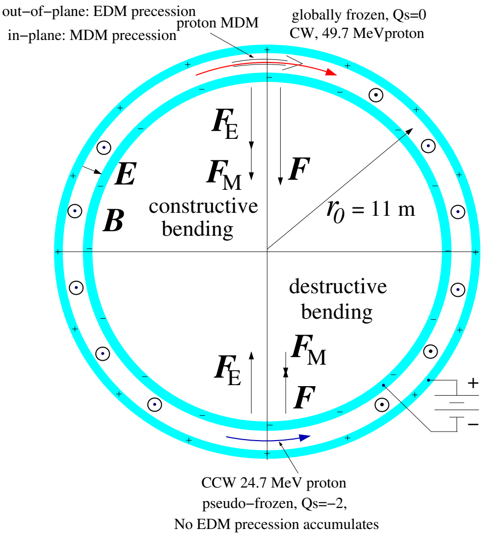
Gyroscopic Phase-locked CW/CCW Reversal

Counting Statistics

Systematic Error

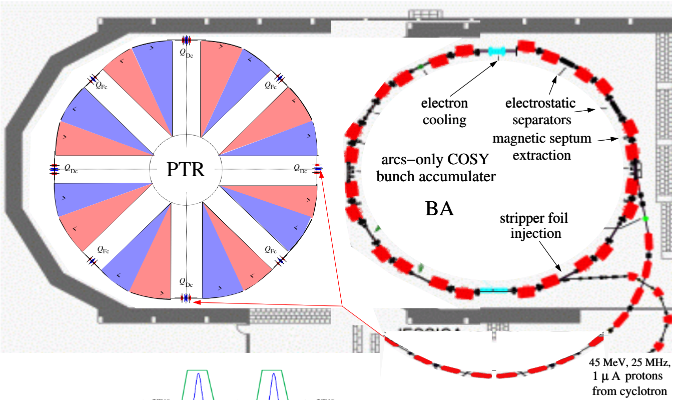
Extra material

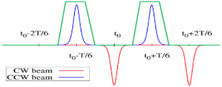
Simultaneous counter−circulating, frozen spin proton beams in MDM comparator ring PTR



- The EDM signature is “out-of-plane” precession of the MDM

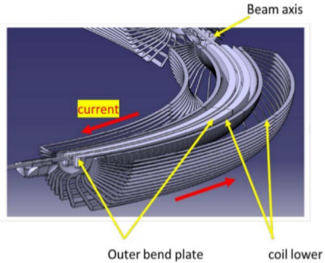
Proposed proton EDM Prototype; COSY, Juelich, Germany





- Stripper foil injection from cyclotron, bunch acccumulation and rebunching occurs in BA
- Polarized bunch pairs are transferred to PTR in successive injection cycles

PTR



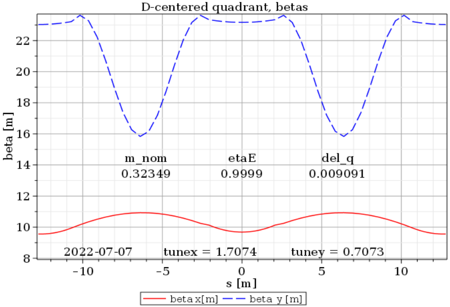
Toroidal two–way frozen spin storage ring
CW: 49.7 MeV "magic", Qs=0, protons, EDM signal
CCW 24.7 MeV pseudo–frozen, Qs=–2, no EDM signal

Table 1. PTR and COSY-arcs-only bunch accumulator (BA) parameters.

file name	variable name	unit	BA COSY-arcs-only	PTR
circumference	circum	m	102.250	102.250
bend radius	r0	m		11.0
E field., 30 MeV proton.	E	MV/m		5.370
long straight length	llsnom	m		4.142
totol available straight	16×llsh	m		32
electrodes/quadrant				4
bend/electrode	Thetah	radian		$2\pi/16$
electrode length	Leh	m		4.32
PTR stored p's no BA				0.6×10^7
COSY-arcs-only BA			0.6×10^{11}	0.6×10^{11}
min/max horizontal beta	β_x	m		9.60/10.83
min/max vertical beta	β_y	m		16.6/24.8
horizontal tune	Q_x			1.726
vertical tune	Q_y			0.673

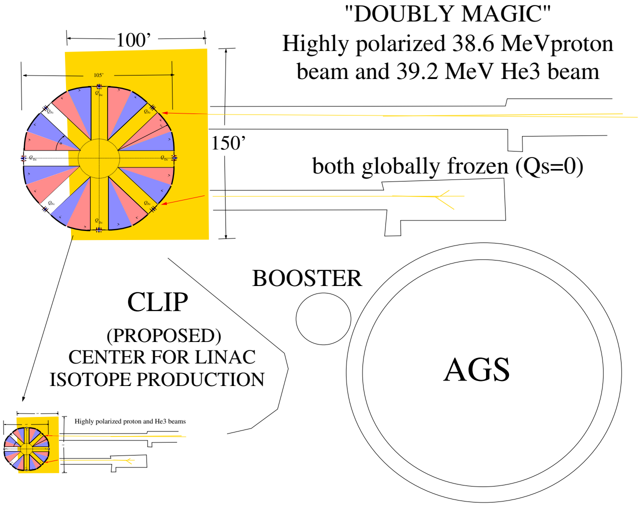
- **Left:** Two-way, toroidal, thick-lens, "MDM Comparator" storage ring
- **Right:** Parameters of EDM prototype PTR.

Distortion–free, Quadrupole–free, Doubly–magic, Two–way Tororoidal Optics



- Electric/magnetic superimposed, "MDM comparator" optics
- Astigmatically-corrected, thick lens, toroidal optics
- Nearly identical forward and backward optics: vertical exact, horizontal perturbative
- Running on sum resonance (equal fractional tunes), all spin decoherence modes canceled; long SCT
- "No quads" allowed, (except for trimming)

Proposed proton, He3 EDM difference measurement at BNL



The dominant systematic error cancels in the difference EDM[proton] – EDM[He3]

8 Cancellation of proton/He3 systematic error

- EDM signature: out-of-plane MDM precession
- Dominant systematic error: radial magnetic field error acting on MDM mimics electric field acting on MDM
- For the proton-He3 combination, measure $\Delta =$ EDM[proton]-EDM[He3]
- Systematic error cancels.
- Non-zero Δ implies BSM physics

9 Gyroscopic Phase-locked CW/CCW Reversal

- Reversing CW/CCW requires reversing the magnetic field
- Setting, reversing, and resetting magnetic field with frequency domain accuracy relies only on MDMs acting as magneto sensing gyroscopes
- This avoids need for (unachievably precise) magnetic field measurement
- while allowing systematic error reduction averaging over CW/CCW reversal

Counting Statistics

Run length = nominal week = 2x10^5 seconds

$\sigma_{stat} = +/- 10^{-29}$ e cm, in all cases

i.e. counting statistics error can "always" be neglected for runs of one week or longer

11 Systematic Error

run sequencing	consecutive	concurrent	concurrent	Δ
	singly magic	singly magic	doubly magic	p-He3
	$\pm\sigma_{\text{syst.}}$	$\pm\sigma_{\text{syst.}}$	$\pm\sigma_{\text{syst.}}$	difference
	e cm	e cm	e cm	e cm
single run	10^{-26}	10^{-27}	10^{-28}	
polarization reversal	0.5×10^{-26}	0.5×10^{-27}	0.5×10^{-28}	
CW/CCW reversal	10^{-27}	10^{-28}	10^{-29}	$< 10^{-29}$

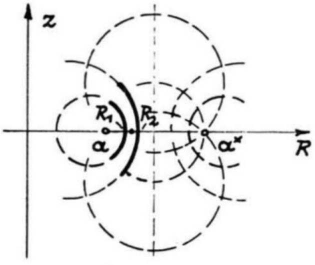
12 Extra material

THANKS FOR YOUR ATTENTION

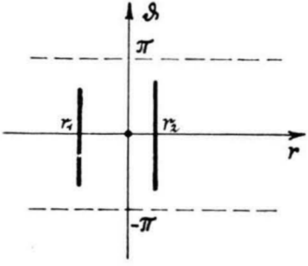
13 Koop menu of counter-circulating nuclear options

Nuclei	m, GeV/c^2	J	μ	a
p	0.938272	1/2	2.792847351	1.792847
d	1.8756123	1	0.8574376	-0.142988
Li6	5.601518	1	0.8220473	-0.182058
Li7	6.533833	3/2	3.2564268	1.519638
He3	2.808391	1/2	-2.12762485	-4.191437
C13	12.10948	1/2	0.7024118	0.510906

14 Albrecht conformal mapping derivation of toroidal optics

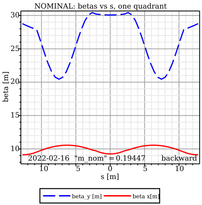


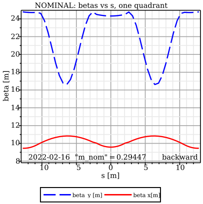
ζ-Ebene

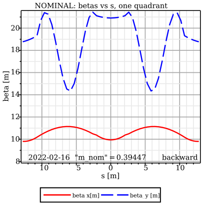


w-Ebene

15 "No quadrupole" optics; quads off in center figure







16 Forward (top) and backward (bottom) p, p optics