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

Richard Talman
Laboratory for Elementary-Particle Physics
Cornell University, Ithaca, NY, US,

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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

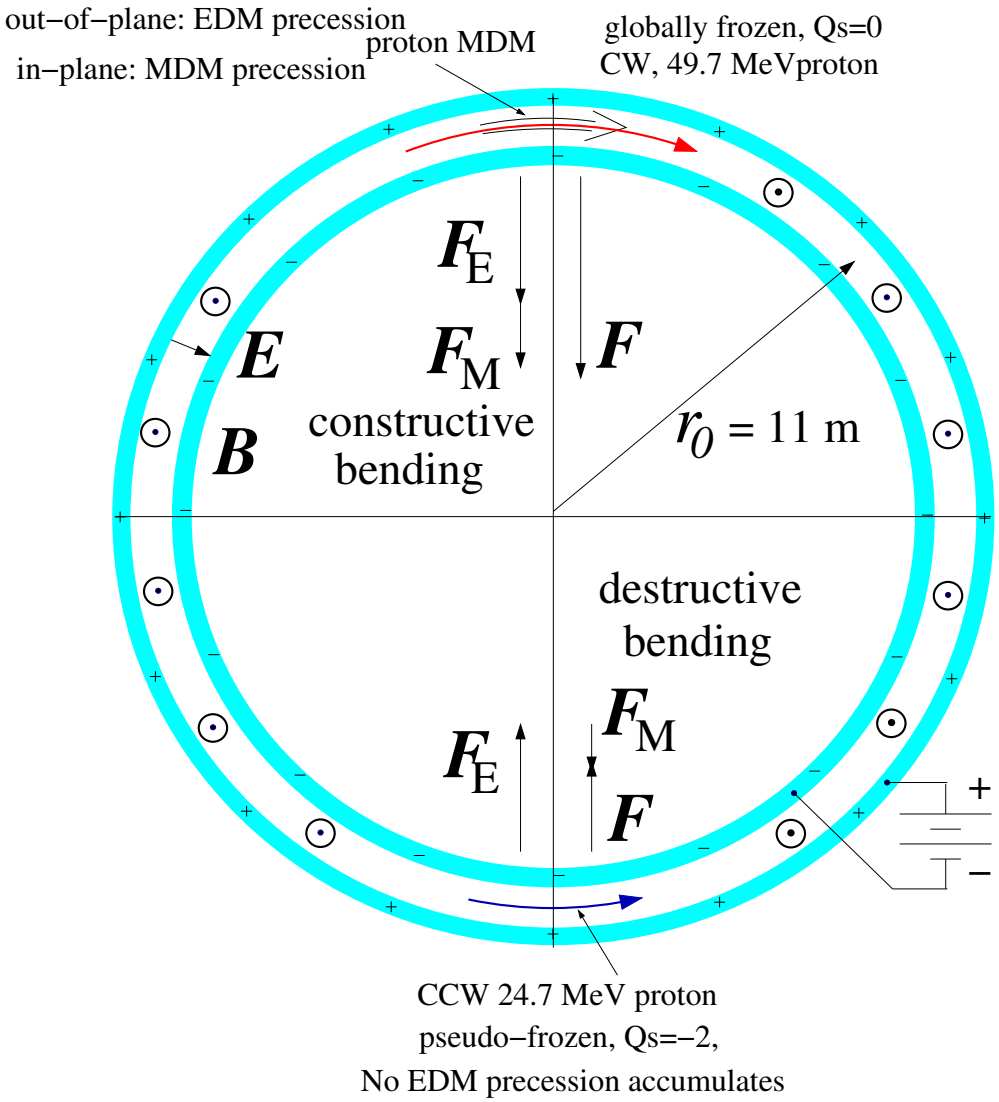
Gyroscopic Phase-locked CW/CCW Reversal

Counting Statistics

Systematic Error

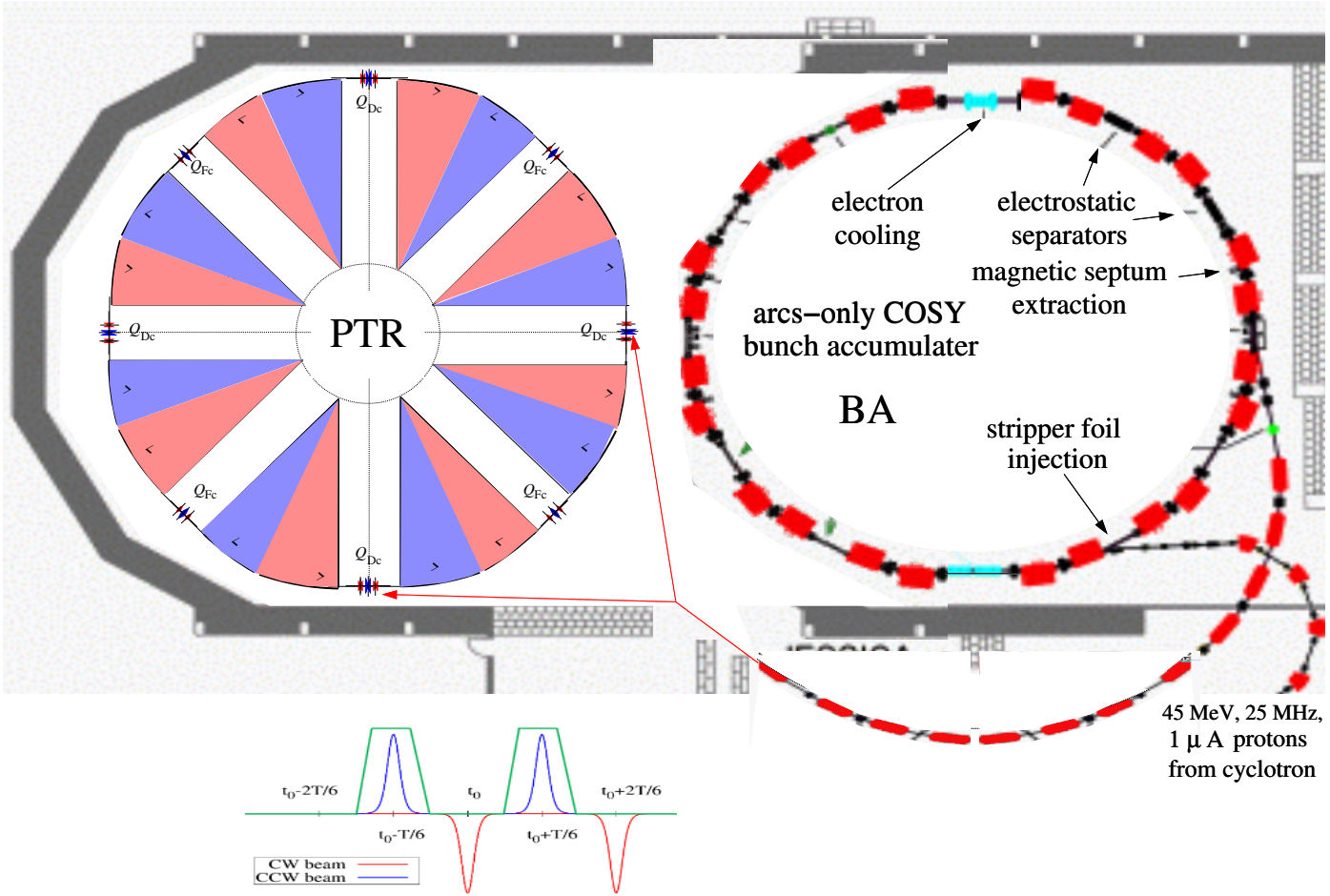
Extra material

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



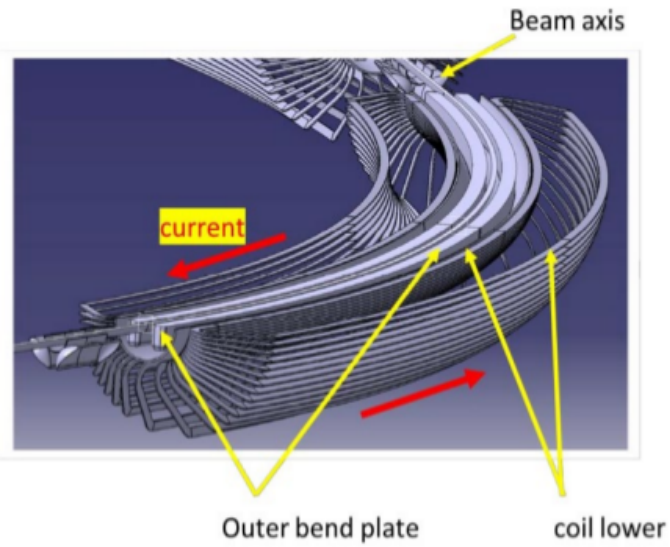
- The EDM signature is “out-of-plane” precession of the MDM

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



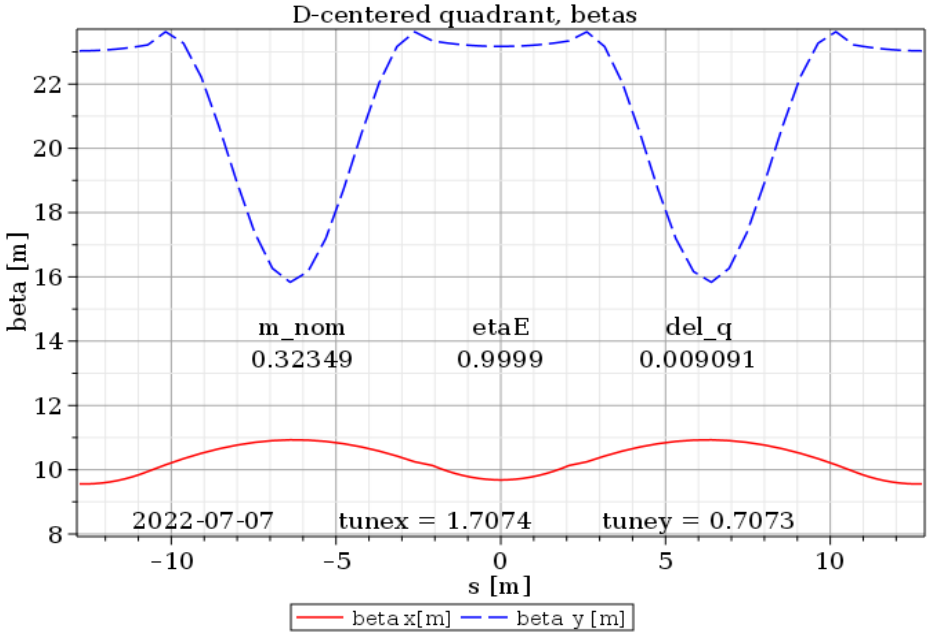
Toroidal two−way frozen spin storage ring
CW: 49.7 MeV "magic", Qs=0, protons, EDM signal
CCW 24.7 MeV pseudo−frozen, Qs=−2, no EDM signal

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.

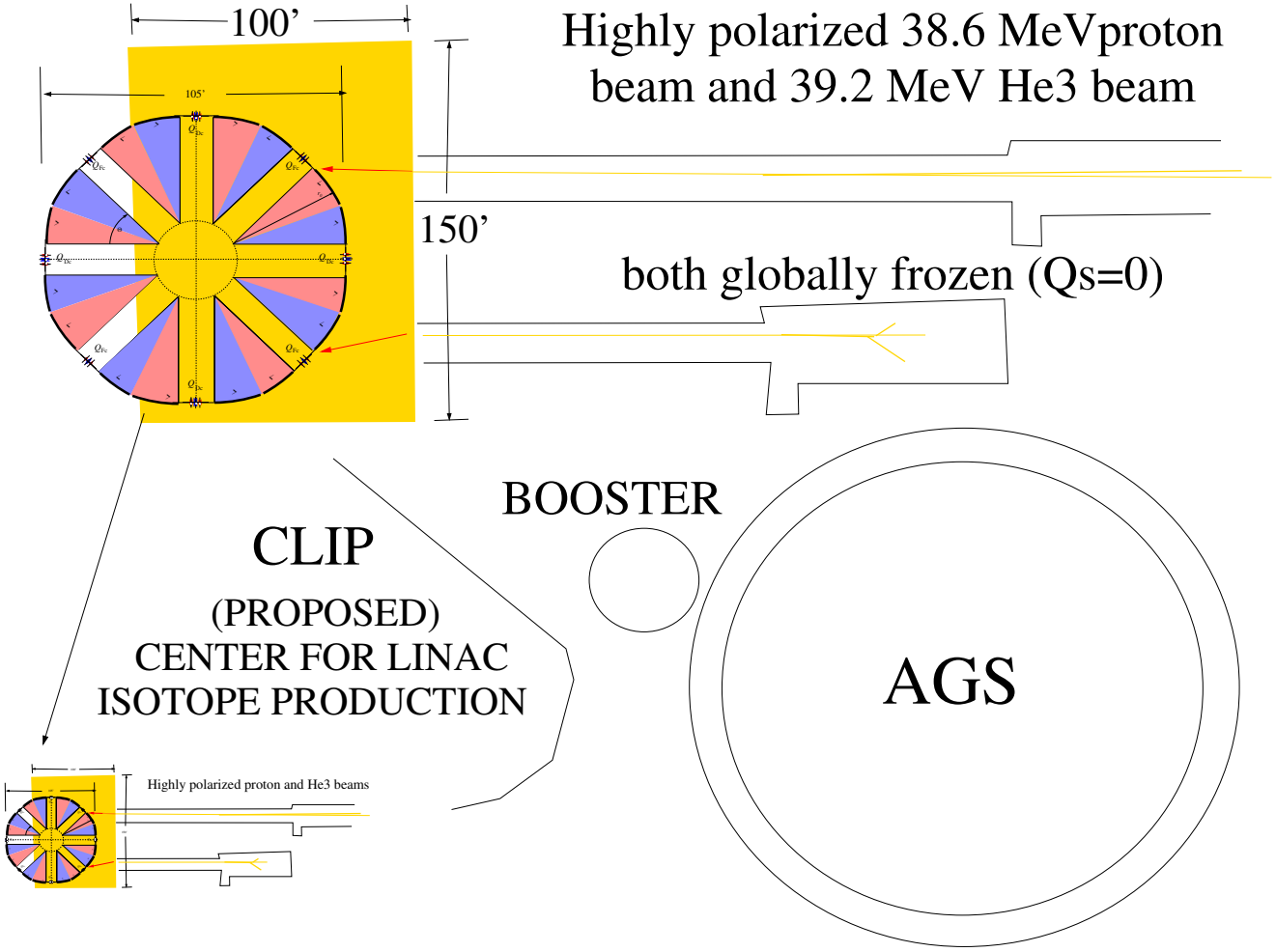
Distortion–free, Quadrupole–free, Doubly–magic, Two–way Tororoidal Optics



- 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

"DOUBLY MAGIC"
Highly polarized 38.6 MeVproton
beam and 39.2 MeV He3 beam



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

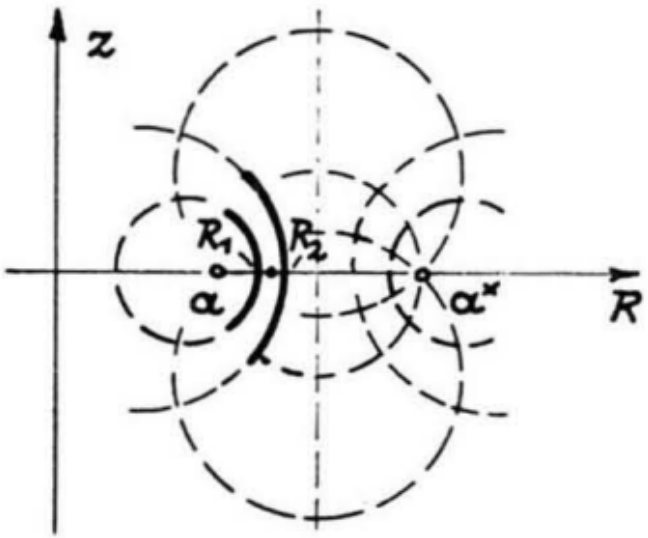
run sequencing	consecutive	concurrent	concurrent	Δ
	singly magic	singly magic	doubly magic	p-He3
	$\pm\sigma_{\text{syst.}}$	$\pm\sigma_{\text{syst.}}$	$\pm\sigma_{\text{syst.}}$	difference
	e cm	e cm	e cm	e cm
single run	10^{-26}	10^{-27}	10^{-28}	
polarization reversal	0.5×10^{-26}	0.5×10^{-27}	0.5×10^{-28}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

THANKS FOR YOUR ATTENTION

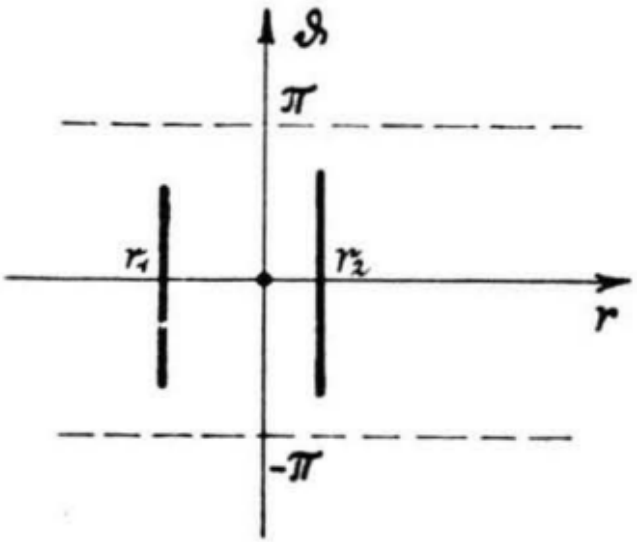
13 Koop menu of counter-circulating nuclear options

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

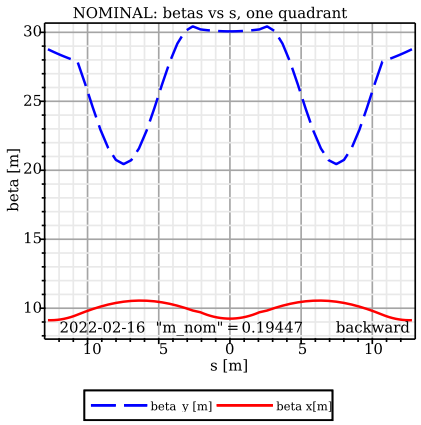


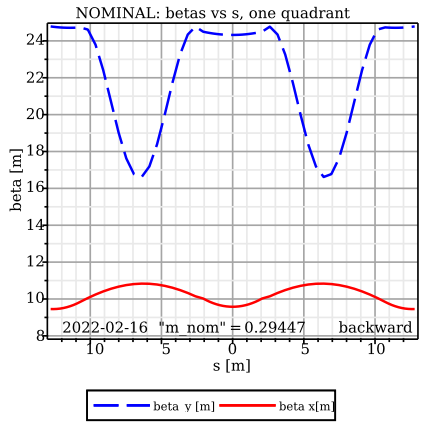
ζ-Ebene

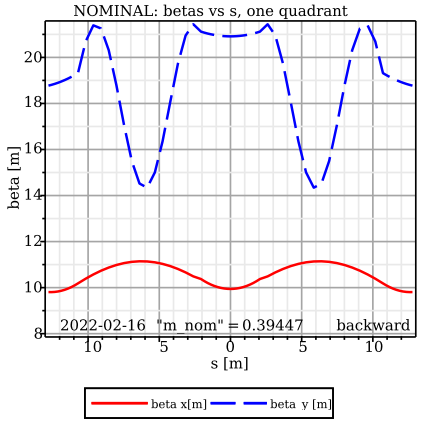
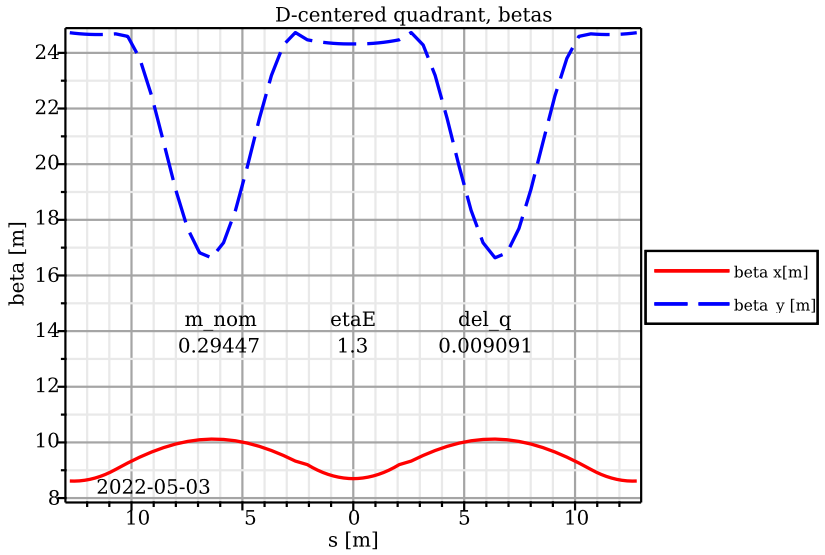
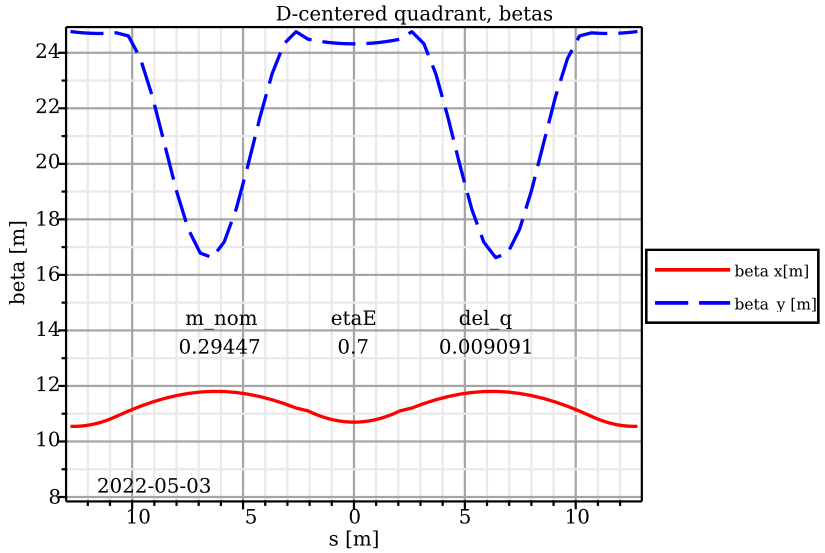


w-Ebene

15 “No quadrupole” optics; quads off in center figure







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