Intense Beams Experiment (IBEX)
Ion trap for accelerator physics

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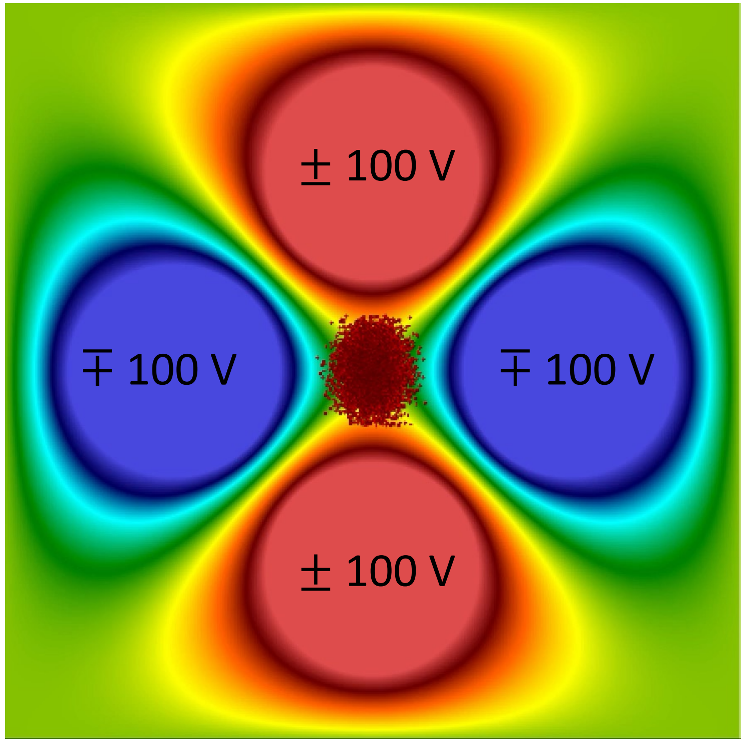
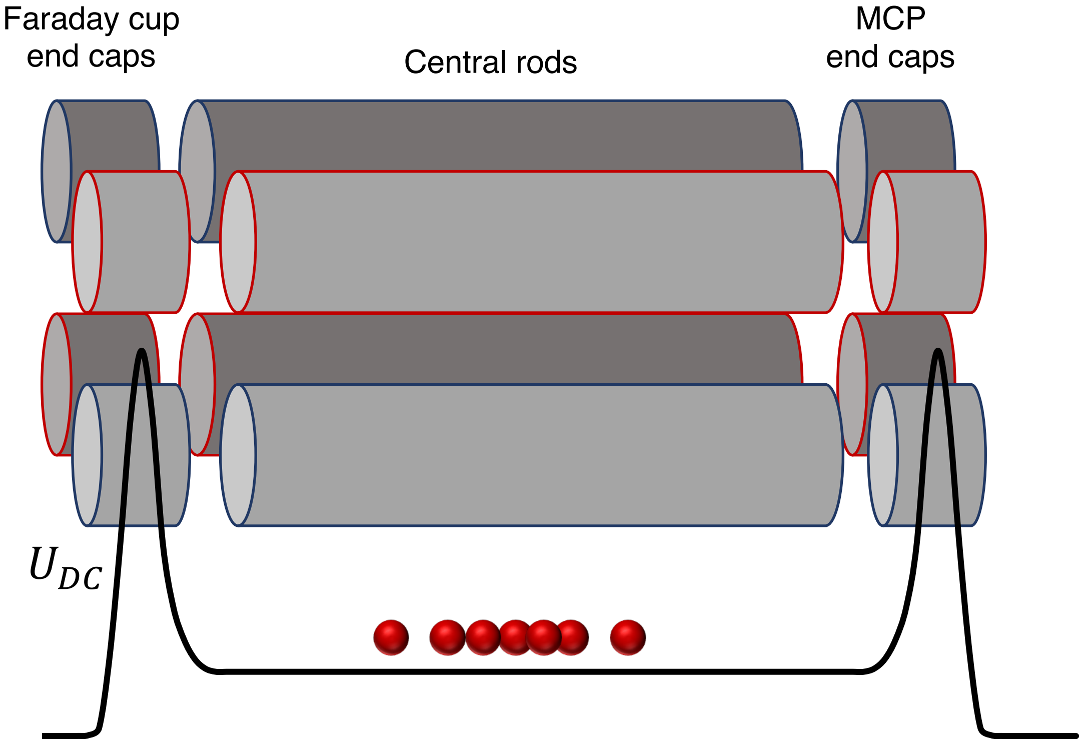
Ion Trap Meeting

Using Paul Traps to study Accelerator physics

Transverse confinement



Longitudinal confinement



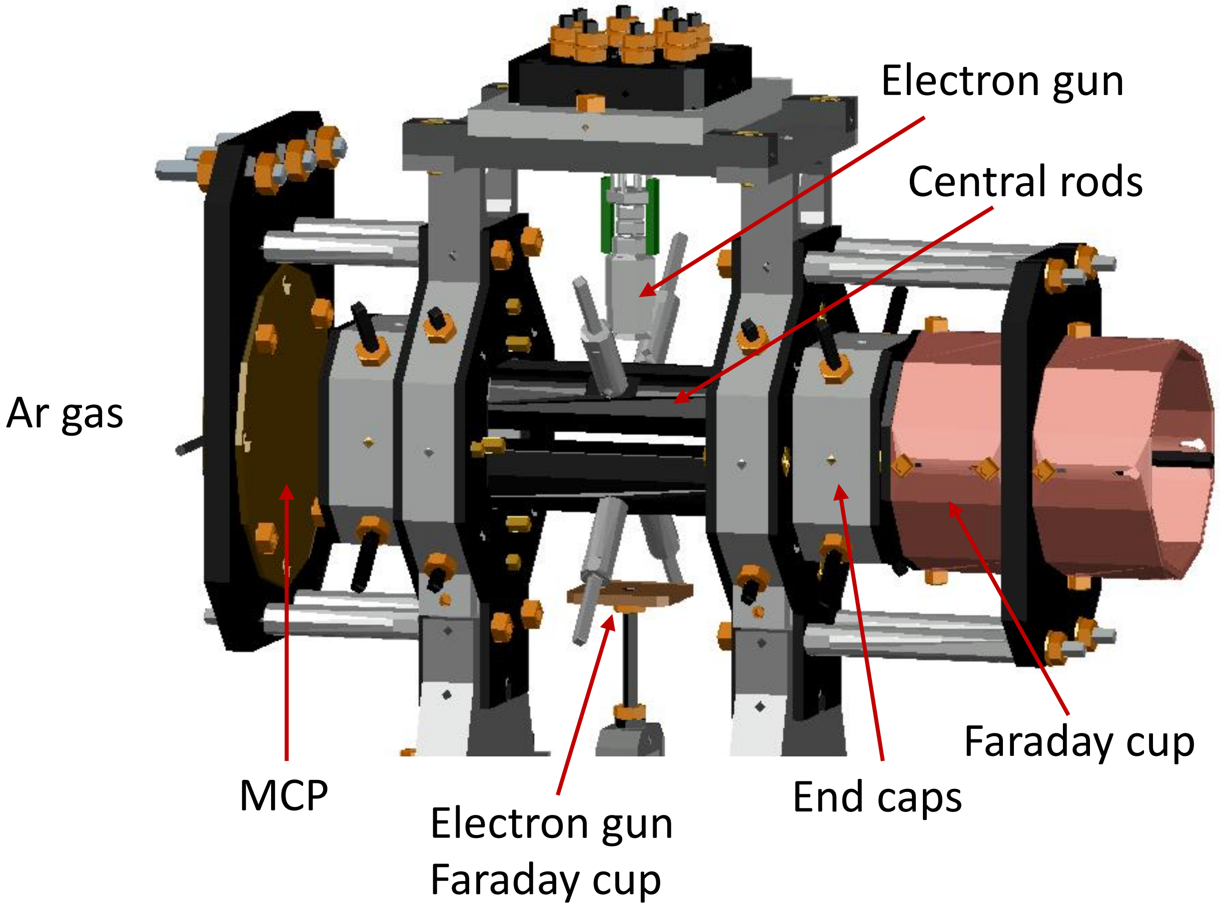
$$H_{\text{paul}} = \frac{(p_x^2 + p_y^2)}{2} + \frac{1}{2}K_{\text{p}}(\tau)(x^2 - y^2) + \frac{q}{mc^2}(\phi_{\text{sc}}) \qquad K_{\text{p}}(\tau) = \frac{2qV_Q(\tau)}{mc^2 r_0^2}$$

Why study accelerator physics in a Paul trap?

- **Fast measurement times** ($1\ s \sim 1{,}000{,}000$ periodic cells).
- **Large parameter space:**
  - Can easily create various different lattice types.
  - Can easily change the intensity ($\Delta Q \sim 10^{-5} - 0.1$).

- **Low energy** ions – will not damage components when lost.
- **Dispersion-** and **chromaticity- free** environment.
- **Cost effective** when compared to building an accelerator.

IBEX: Old Trap


Electron gun

Central rods

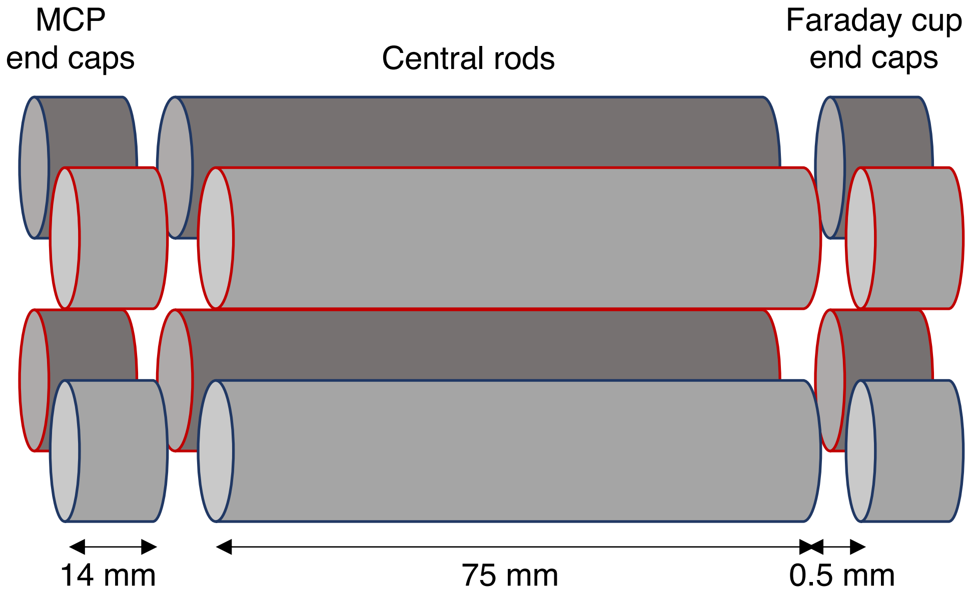
Ar gas

MCP

Electron gun
Faraday cup

End caps

Faraday cup


MCP
end caps

Central rods

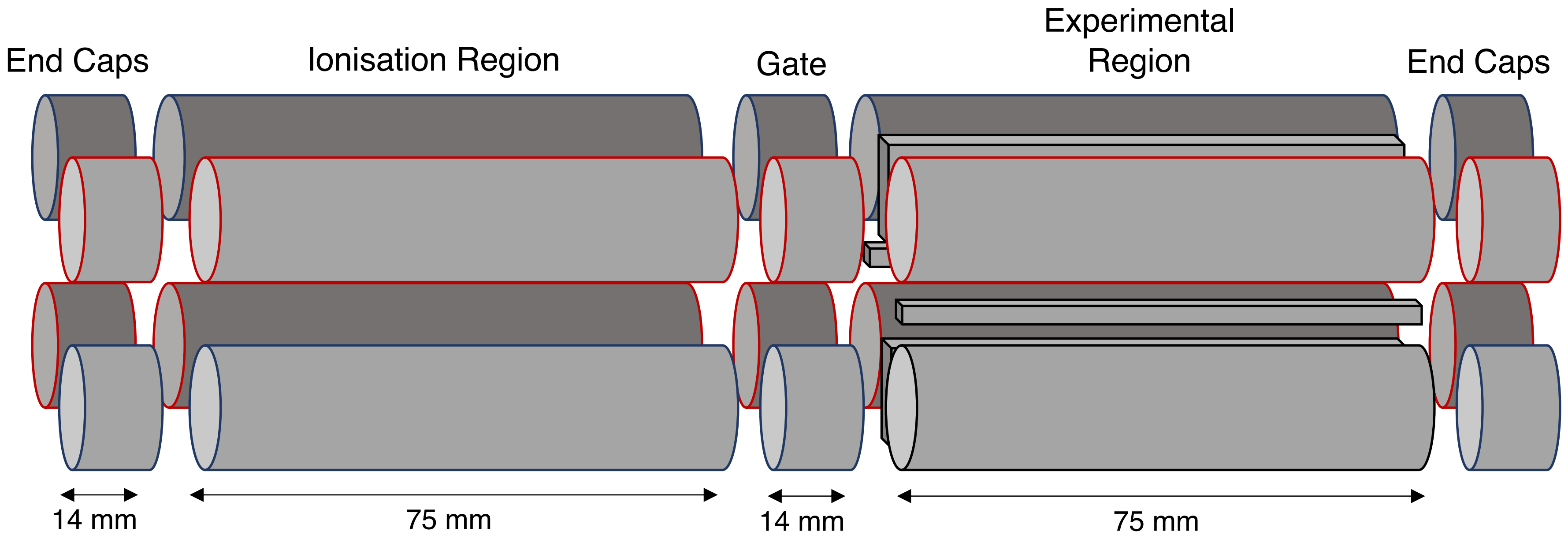
Faraday cup
end caps

14 mm

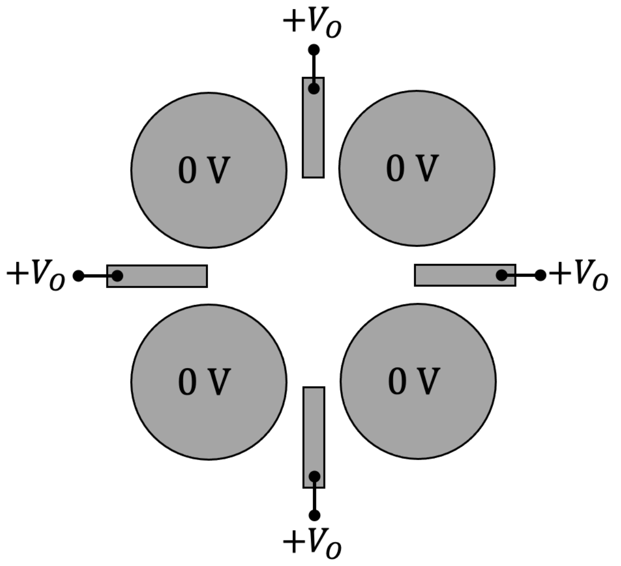
75 mm

0.5 mm

Nonlinear upgrade to IBEX

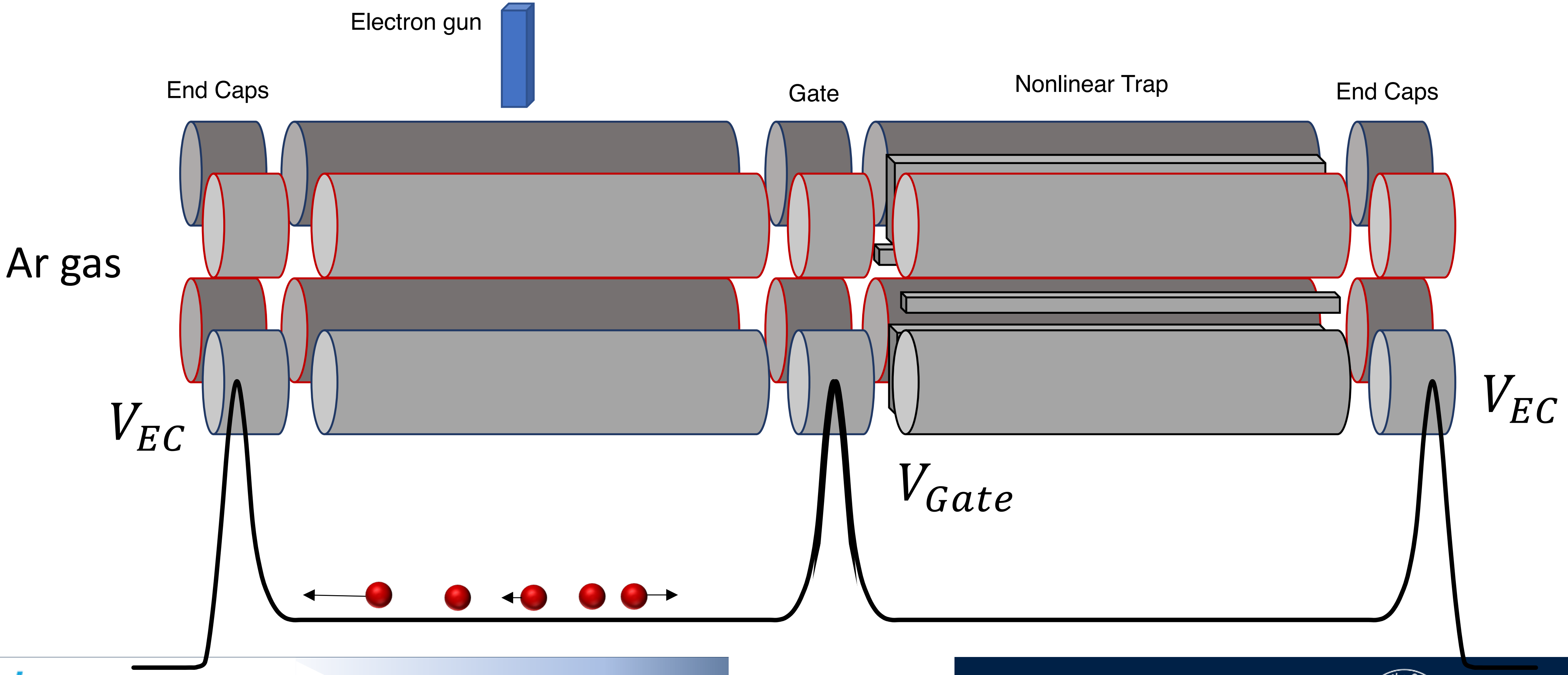


Octupole field

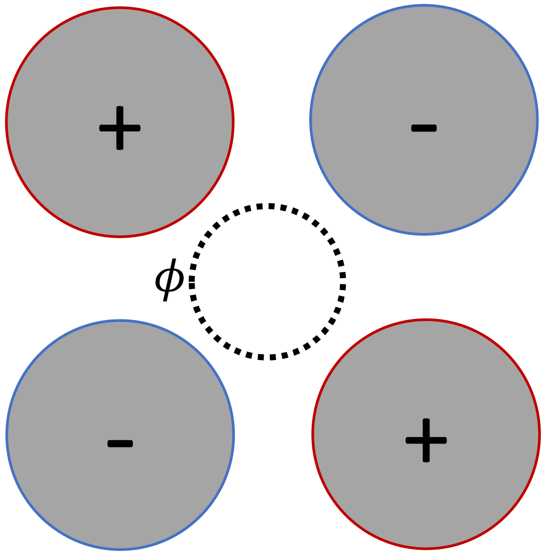


FUKUSHIMA, K., & OKAMOTO, H. (2015). Design Study of a Multipole Ion Trap for Beam Physics Applications. *Plasma and Fusion Research*, *10*(0), 1401081–1401081.

Trap operation

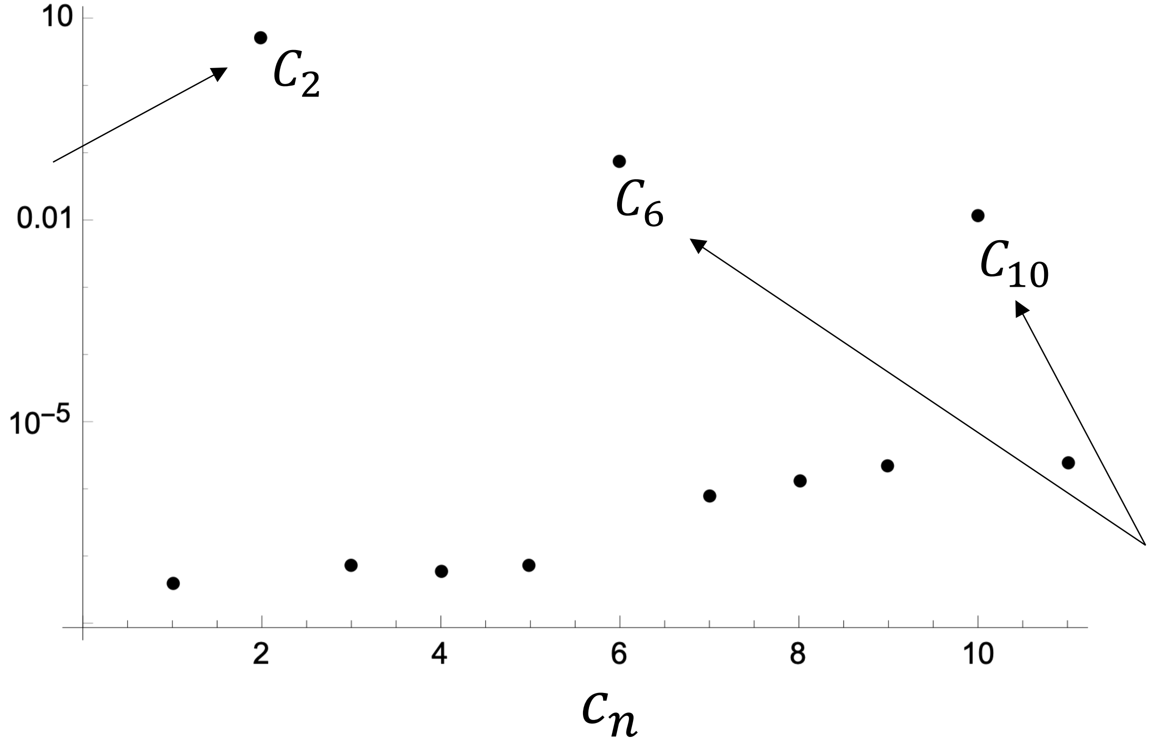


Quadrupole field decomposition



$$\phi(r,\theta) = \sum_{n=1}^{\infty} c_n\left(\frac{r}{r_0}\right)^n \cos(n\theta).$$

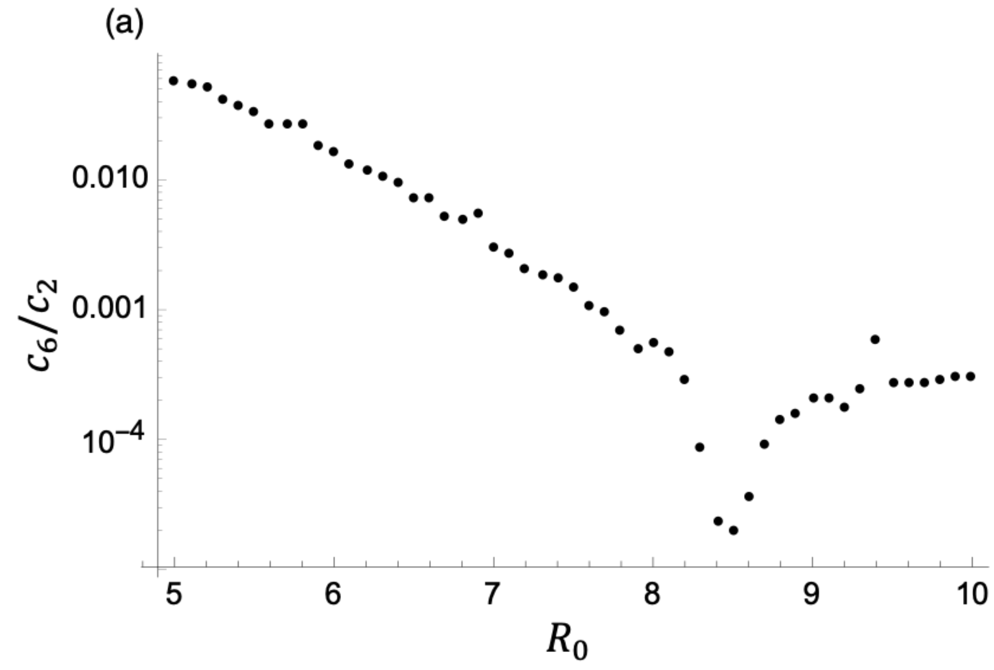
Quadrupole component



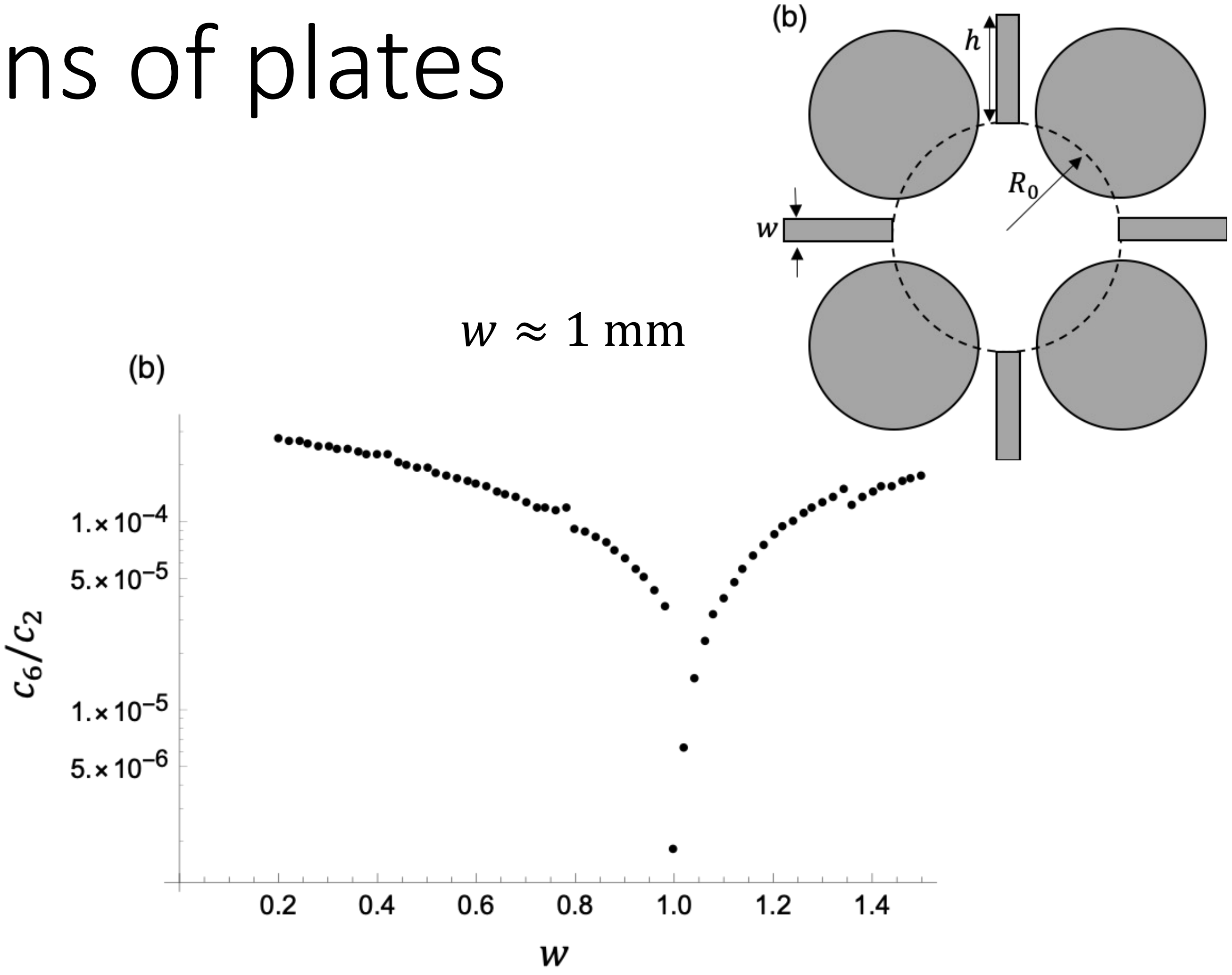
Unwanted nonlinearities

Optimising dimensions of plates

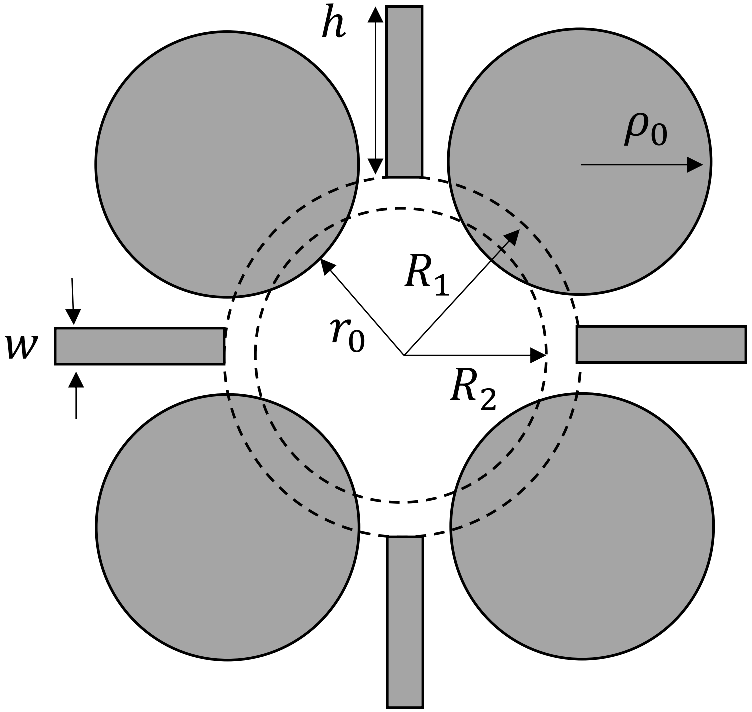
$R_0 = 8.5\ \mathrm{mm}$



$w \approx 1\ \mathrm{mm}$



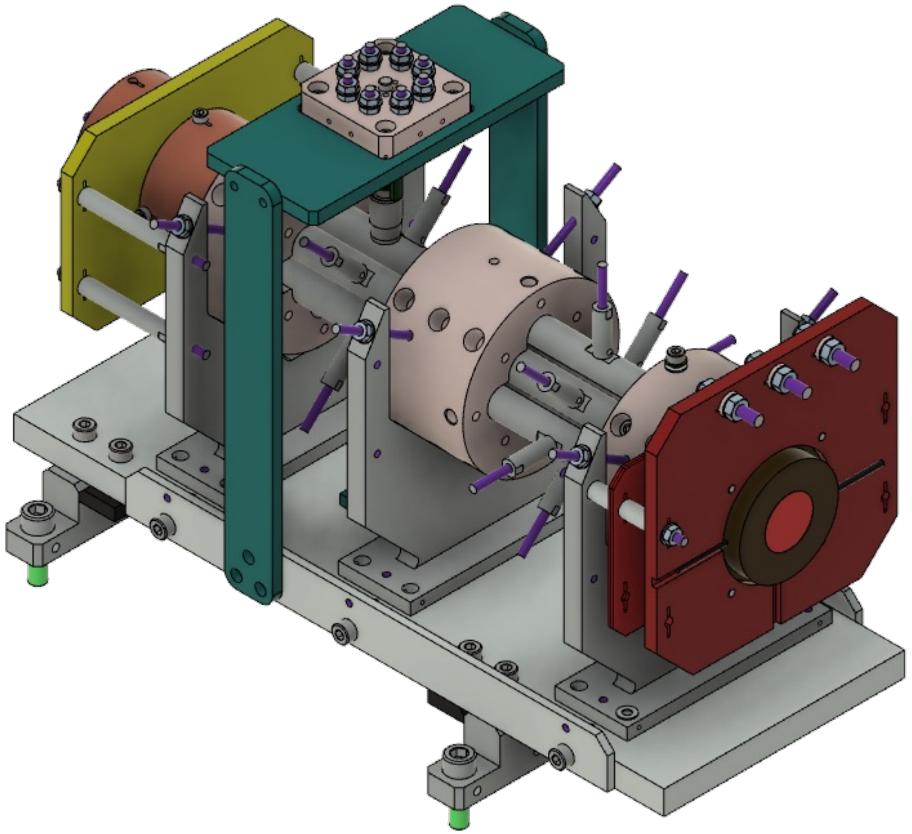
Cross-section: Dimensions

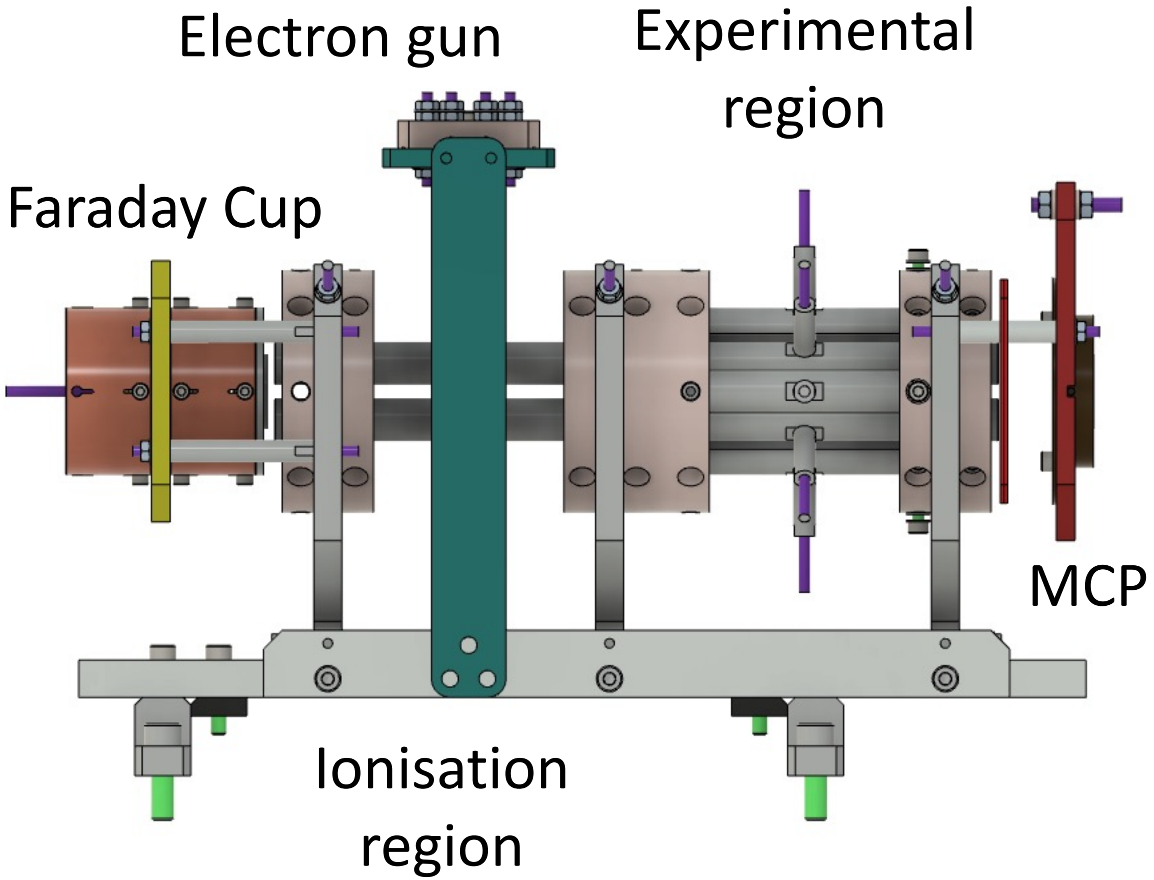


Two possible positions for the plates: Inscribed radius of 8.5 mm & 7.4 mm

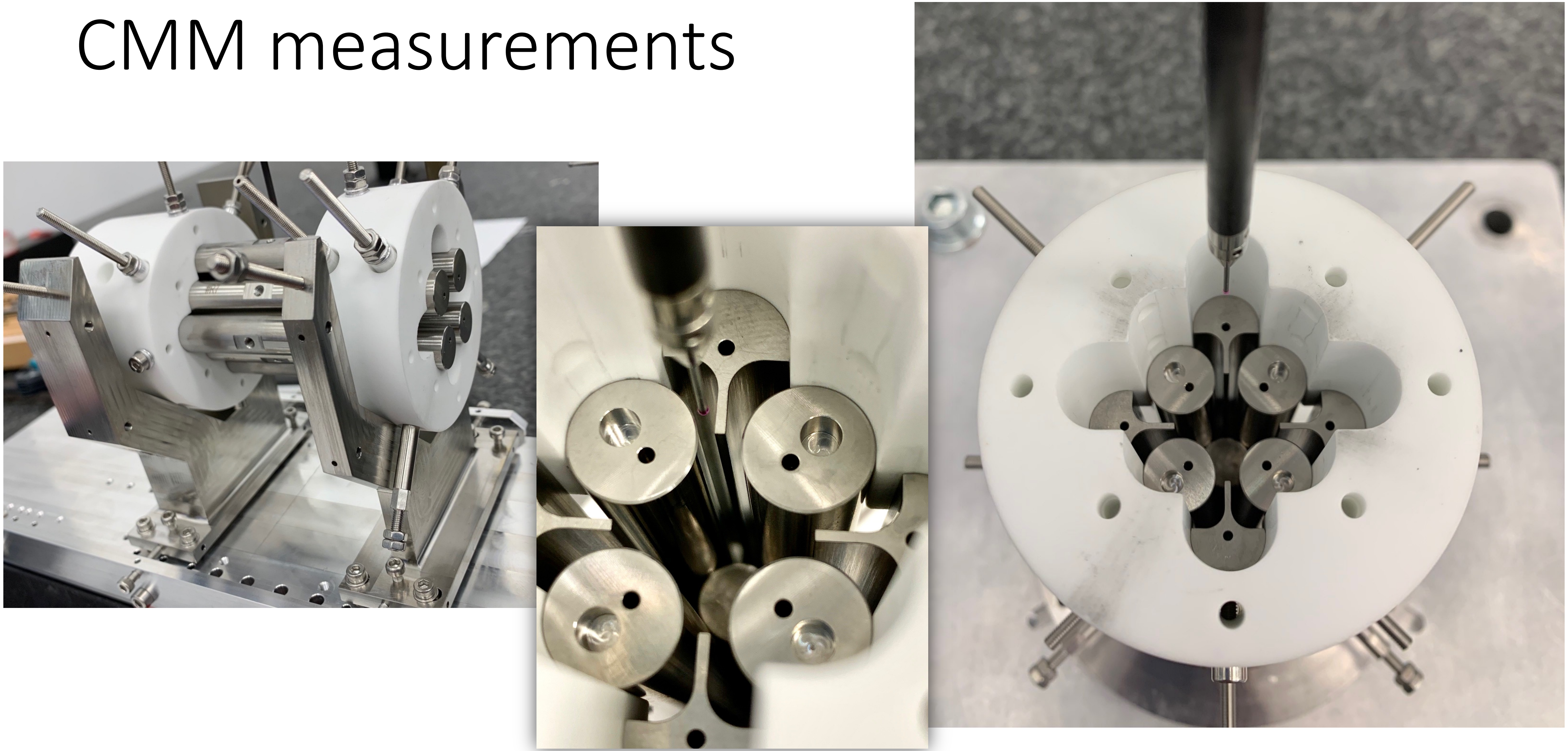
$r_0 = 5$ mm
$\rho_0 = 5.75$ mm
$R_1 = 8.5$ mm
$R_2 = 7.4$ mm
$w = 1$ mm
$h = 6$ mm

Engineering drawings for the upgrade

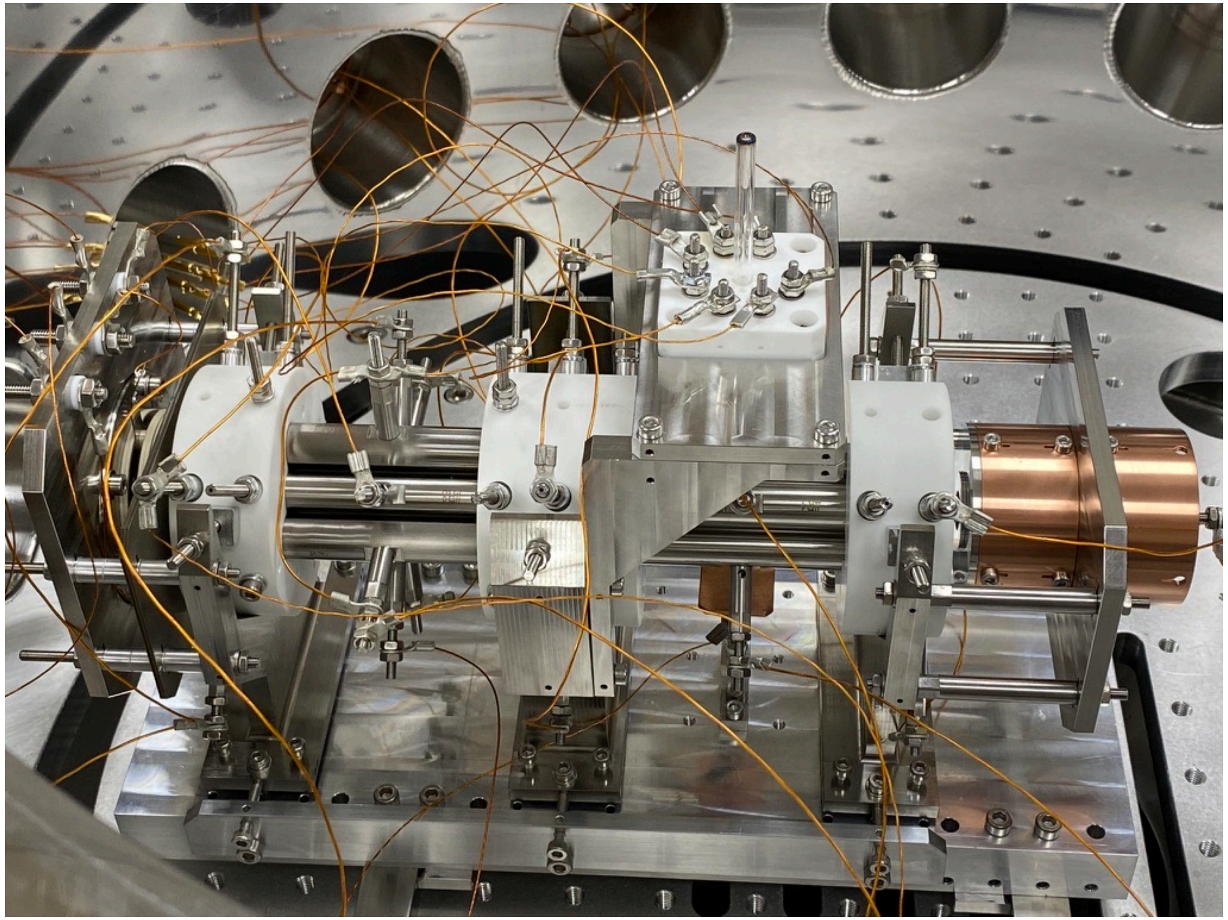


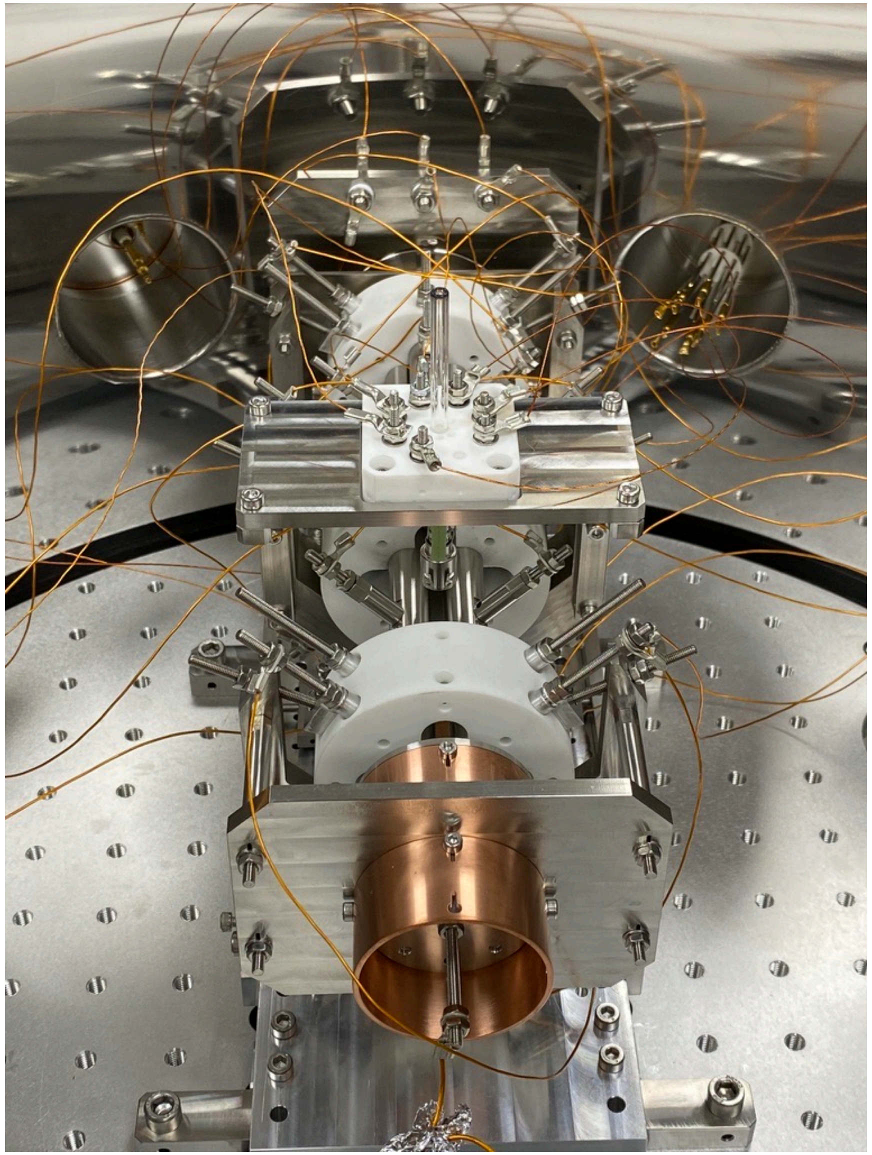


CMM measurements

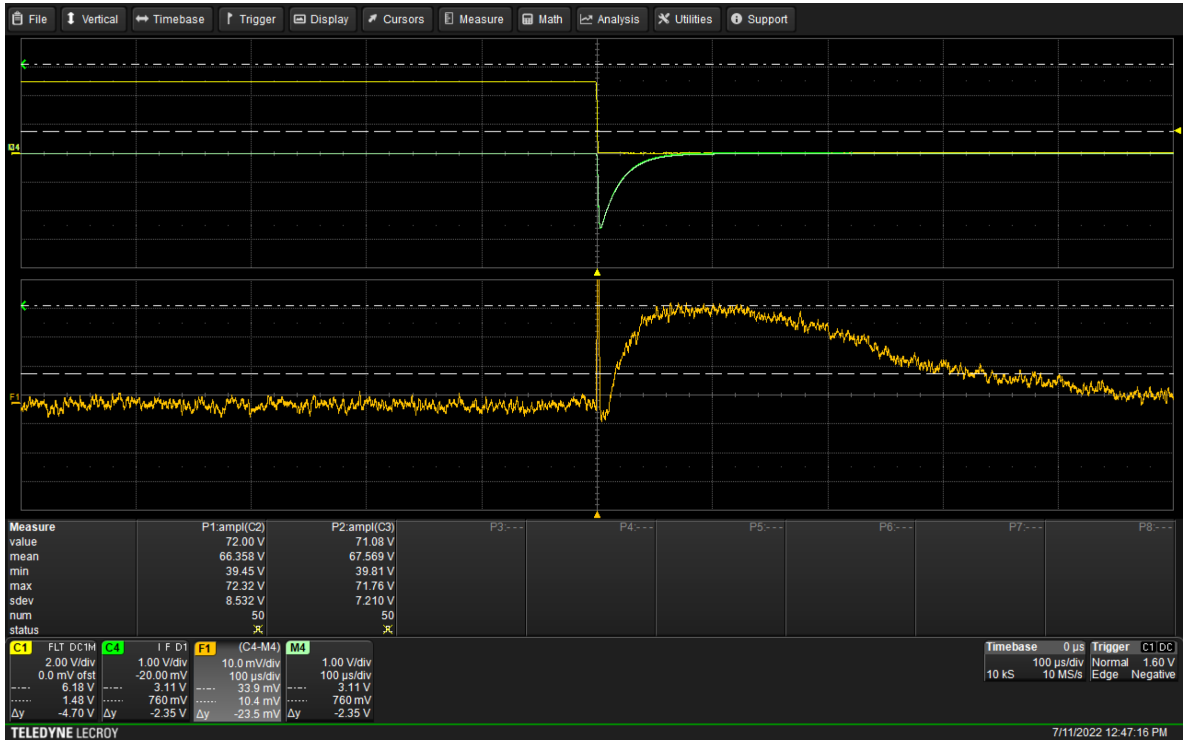


IBEX 2.0!





First ions trapped in June!



Measure	P1:ampl(C2)	P2:ampl(C3)	P3:- - -	P4:- - -	P5:- - -	P6:- - -	P7:- - -	P8:- - -
value	72.00 V	71.08 V						
mean	66.358 V	67.569 V						
min	39.45 V	39.81 V						
max	72.32 V	71.76 V						
sdev	8.532 V	7.210 V						
num	50	50						
status	⌘	⌘						

C1 FLT DC1M	C4 I F D1	F1 (C4-M4)	M4
2.00 V/div	1.00 V/div	10.0 mV/div	1.00 V/div
0.0 mV ofst	-20.00 mV	100 µs/div	100 µs/div
‐·‐·‐ 6.18 V	‐·‐·‐ 3.11 V	‐·‐·‐ 33.9 mV	‐·‐·‐ 3.11 V
······ 1.48 V	······ 760 mV	······ 10.4 mV	······ 760 mV
Δy -4.70 V	Δy -2.35 V	Δy -23.5 mV	Δy -2.35 V

Timebase	0 µs	Trigger	C1 DC
	100 µs/div	Normal	1.60 V
10 kS	10 MS/s	Edge	Negative

TELEDYNE LECROY

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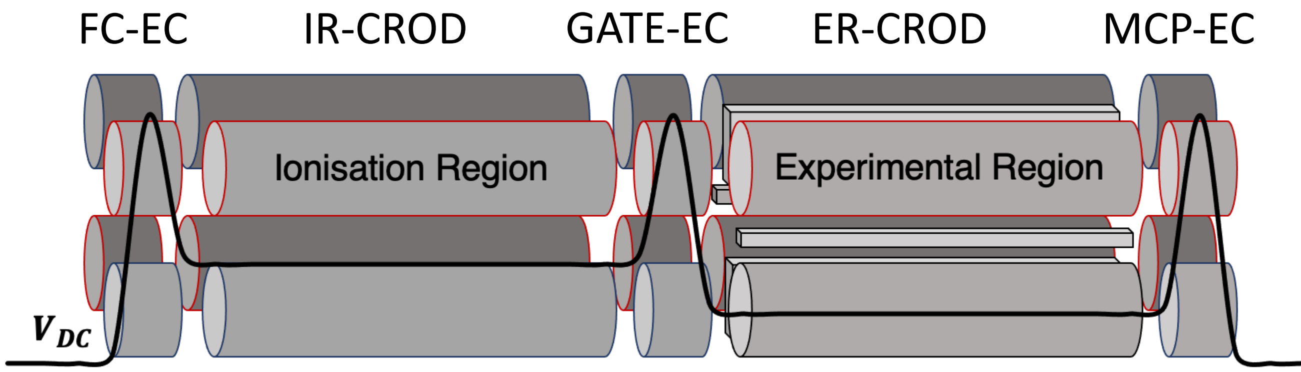
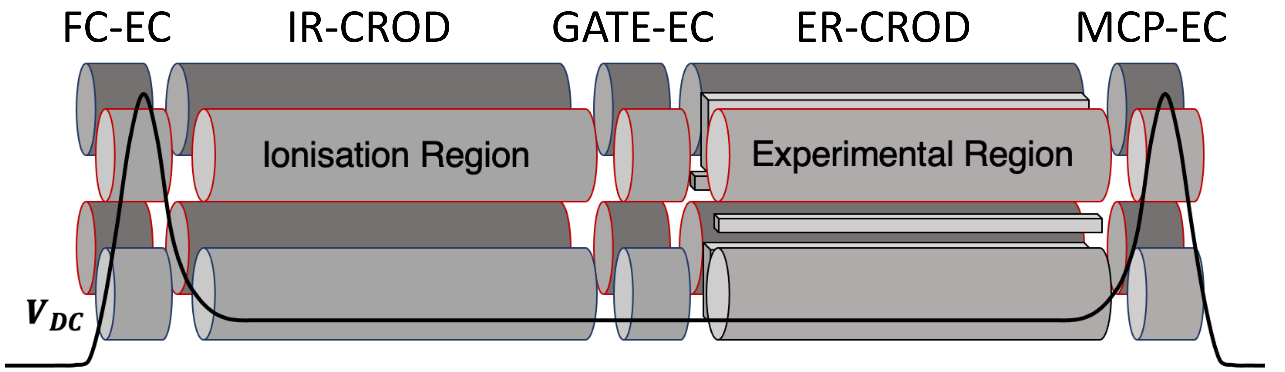
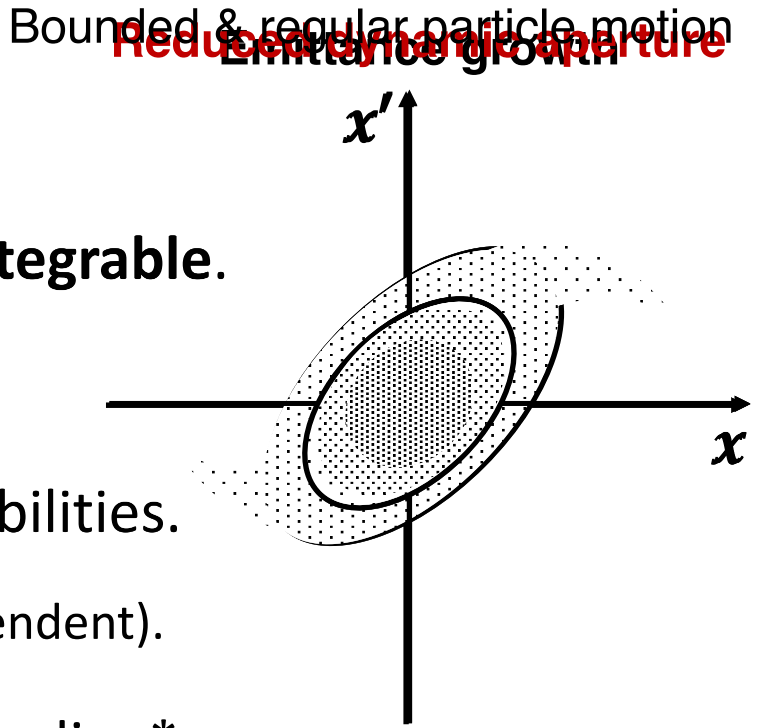




Back up slides

Quasi-Integrable Optics



- In an ideal accelerator (linear components) the motion is **integrable**.
- Linear accelerators are susceptible to resonances.
- Use nonlinear components (i.e. octupoles) to dampen instabilities.
  - However, now the system is **non-integrable** (no longer time-independent).
- Can make a quasi-integrable system with correct octupole scaling*:

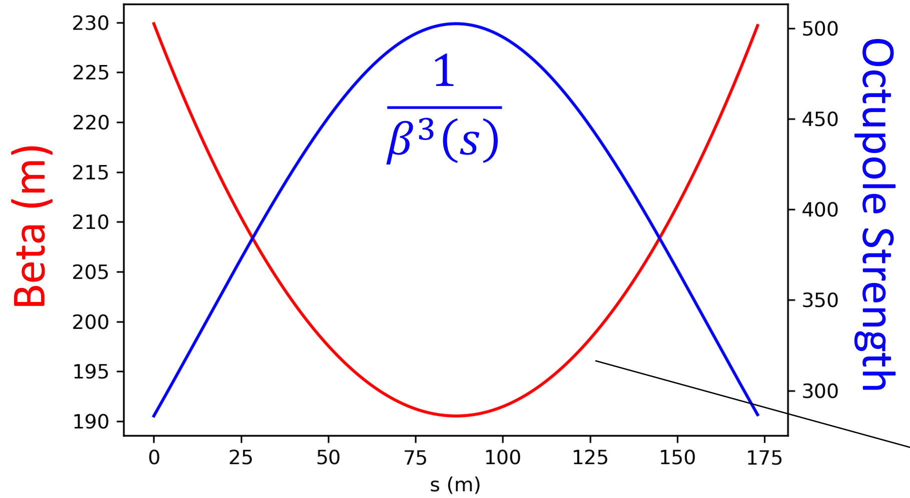
$$H_N = \frac{p_{xN}^2 + p_{yN}^2}{2} + \frac{x_N^2 + y_N^2}{2} + U(x_N, y_N),$$

$$\boxed{U\left(x_N, y_N\right) = k_4\left(\frac{x_N^4}{4} + \frac{y_N^4}{4} - \frac{3x_N^2 y_N^2}{2}\right)}$$

*V. Danilov and S. Nagaitsev (2010)

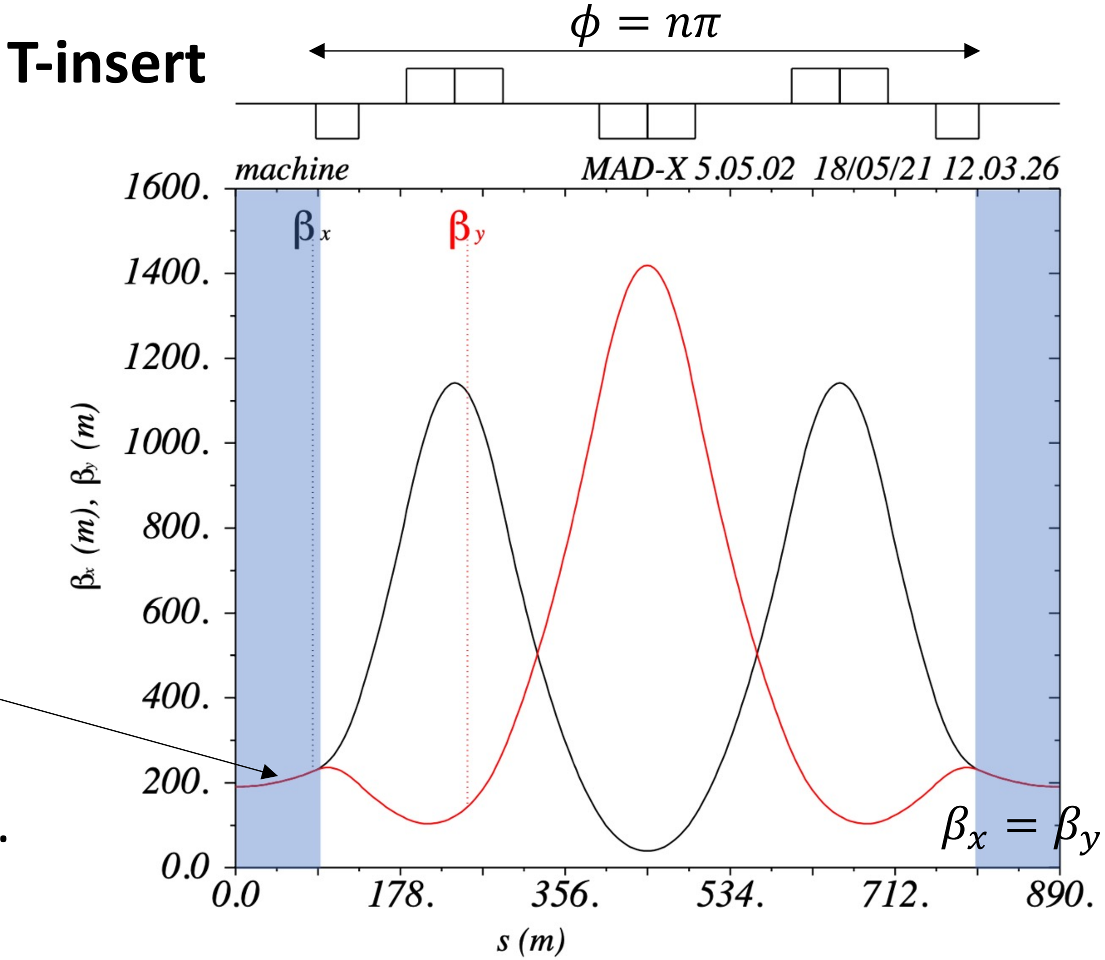
T-insert lattice for QIO

$$V(x,y,s) = \frac{k}{\beta(s)^3}\left(\frac{x^4}{4} + \frac{y^4}{4} - \frac{3x^2y^2}{2}\right)$$

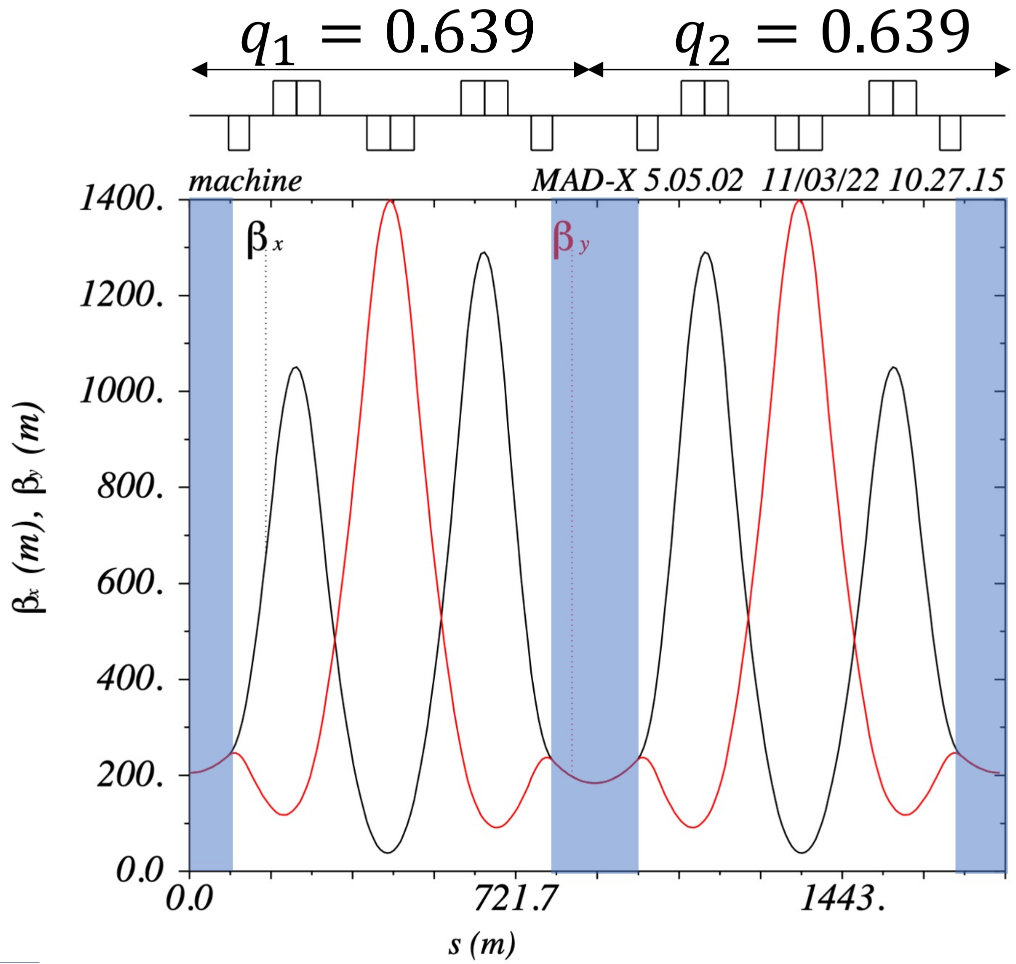


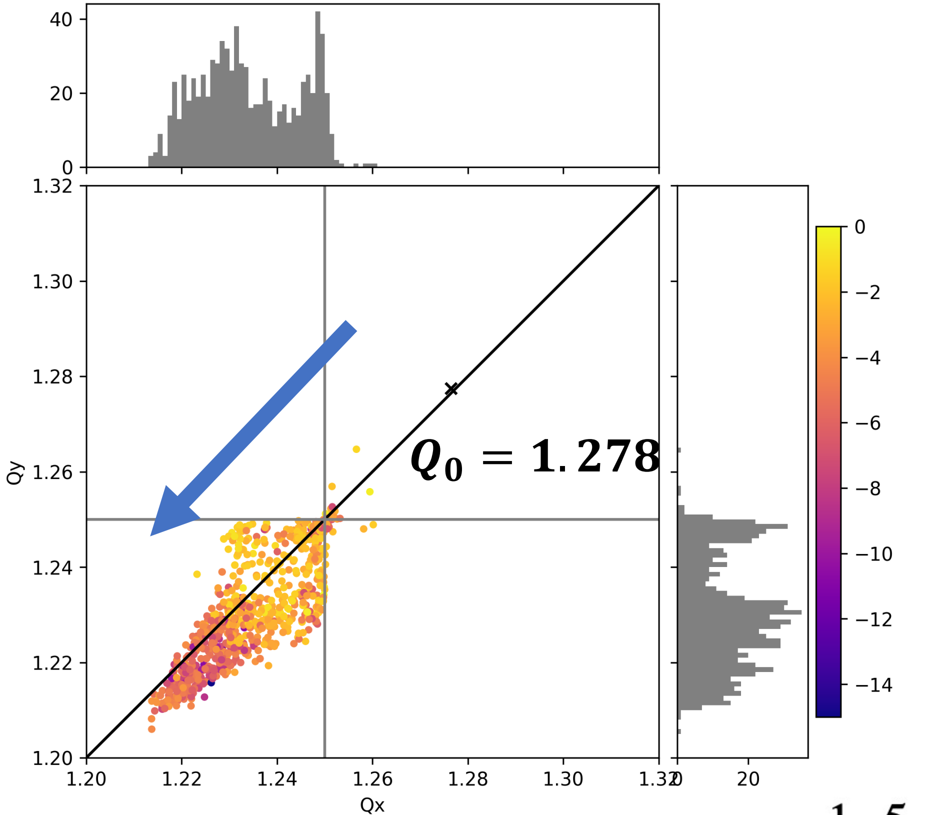
- Requires $n\pi$ phase advance and $\beta_x = \beta_y$ in drift.
- $1/\beta^3(s)$ octupole scaling makes H time-independent.

➢ (Quasi-) Integrable lattice which is robust to small perturbations.



T-insert to excite coherent resonance





$Q_0 = 1.278$

$$Q_0 + C_2 \Delta Q_{rms} = \frac{1}{2}\left(\frac{5}{2}\right)$$