Nonlinear Integrable Optics at the University of Maryland

ASTA Users Meeting
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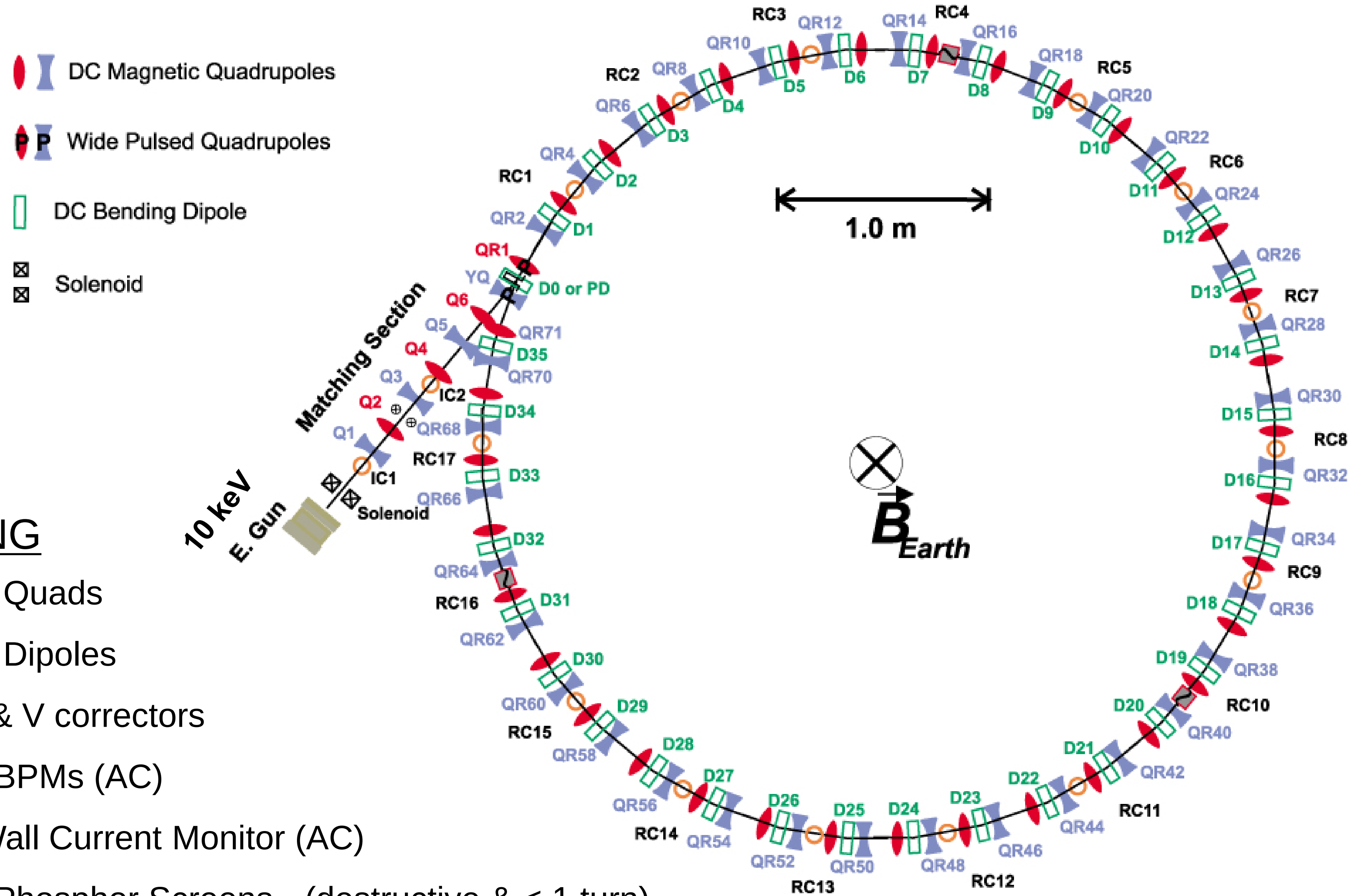
Presentation Outline

Goal: Demonstrate nonlinear lattice in the presence of space charge.

- UMER Facility
- Relevance to IOTA
- Proposed Program at UMER
  - Simulation Program
    - WARP PIC code – space charge effects!
  - Experimental Program
    - Ring modification
      - Feasibility study with elegant
    - Magnet Design
    - Diagnostic capabilities
- Conclusions

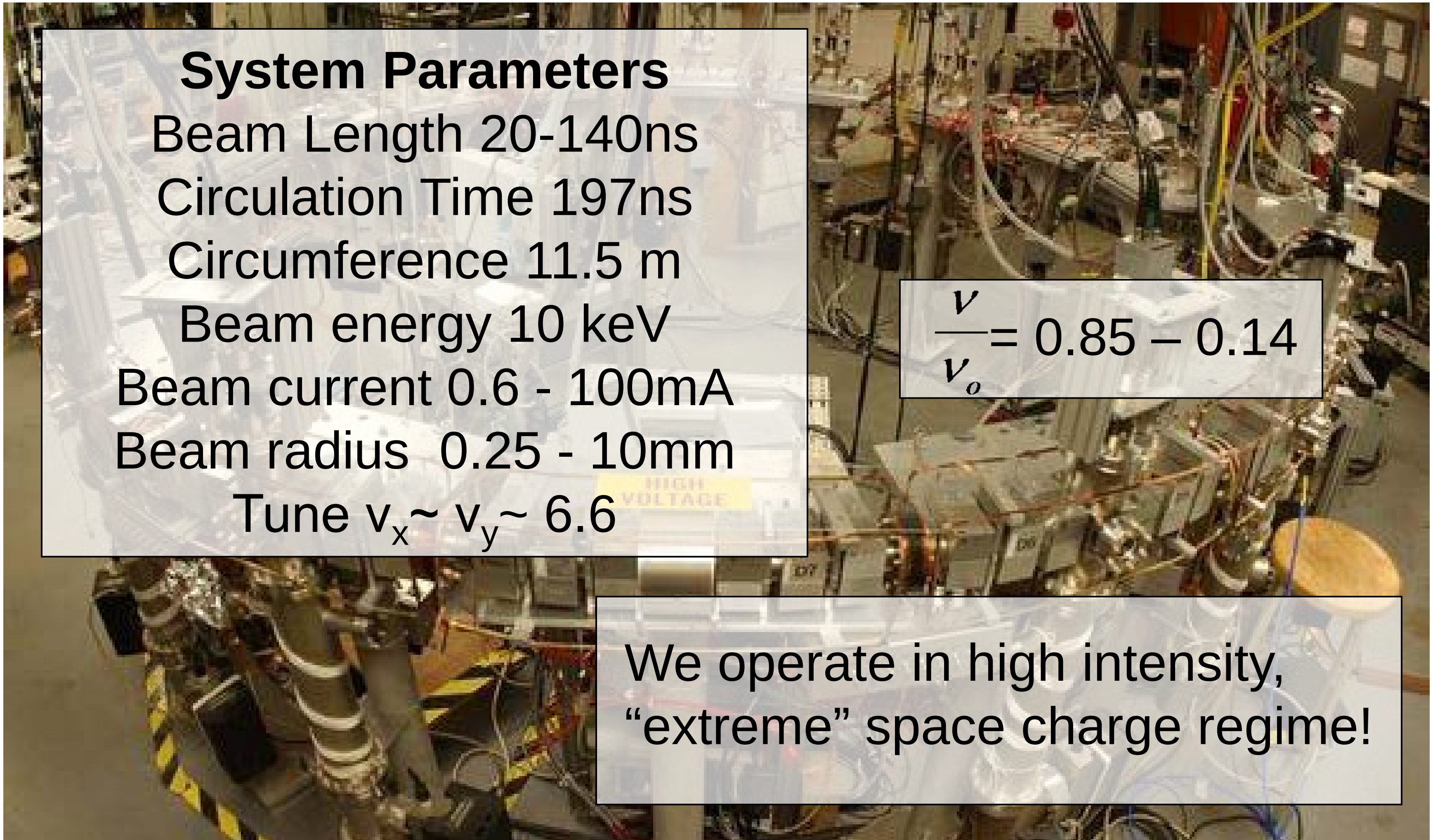
UMER Overview



RING

- 72 Quads
- 36 Dipoles
- H & V correctors
-14 BPMs (AC)
-1 Wall Current Monitor (AC)
-14 Phosphor Screens (destructive & < 1 turn)

UMER Overview



System Parameters

Beam Length 20-140ns

Circulation Time 197ns

Circumference 11.5 m

Beam energy 10 keV

Beam current 0.6 - 100mA

Beam radius 0.25 - 10mm

Tune $v_x \sim v_y \sim 6.6$

$$\frac{\nu}{\nu_o} = 0.85 - 0.14$$

We operate in high intensity, “extreme” space charge regime!

Current UMER Projects

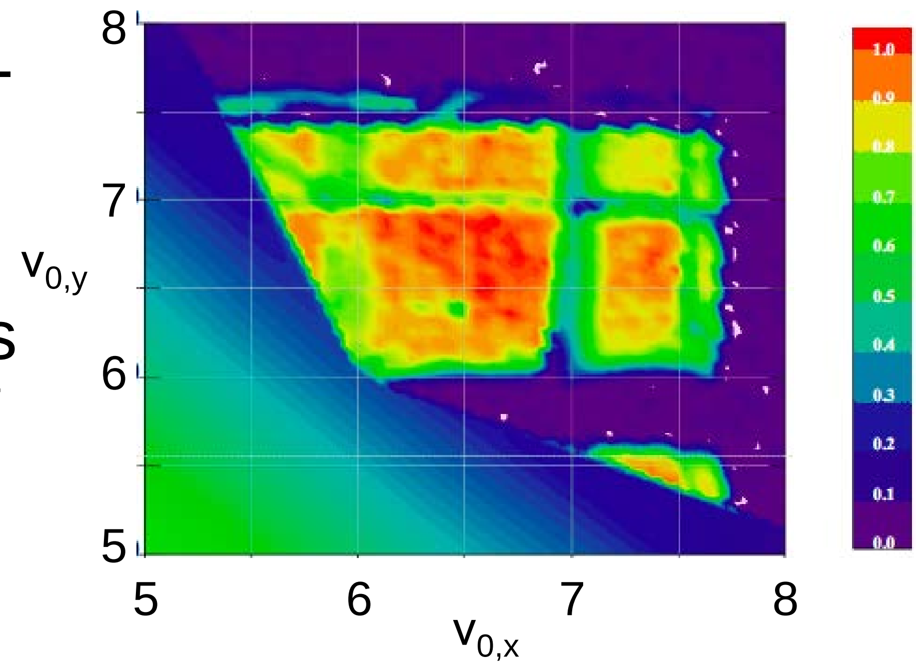
- Halo Formation
- Soliton waves in dense electron beam/ longitudinal space charge effects
- Space-charge driven resonances
- Multi-stream instability
- Machine Improvement
  - Magnet development
  - Extraction section designs
  - Response Matrix
- Diagnostic development

R. A. Kishek et. al, Nucl. Instrum. Methods Phys. Rev. A, 2013

Nonlinear Integrable Optics and UMER

- UMER experiences beam loss from linear and space-charge driven resonances
- NIO theory is compelling for single particle dynamics (Danilov and Nagaitsev, Phys. Rev. ST Accel. Beams, 2010)
    - Space charge?
    - UMER flexibility → ideal testing ground for NIO with intense beams

Beam Lifetime Plot, 6.0 mA



color bar = % survival after 10 turns

R. A. Kishek et. al, Nucl. Instr. Meth. Phys. Rev. A, 2013

Proposal Framework

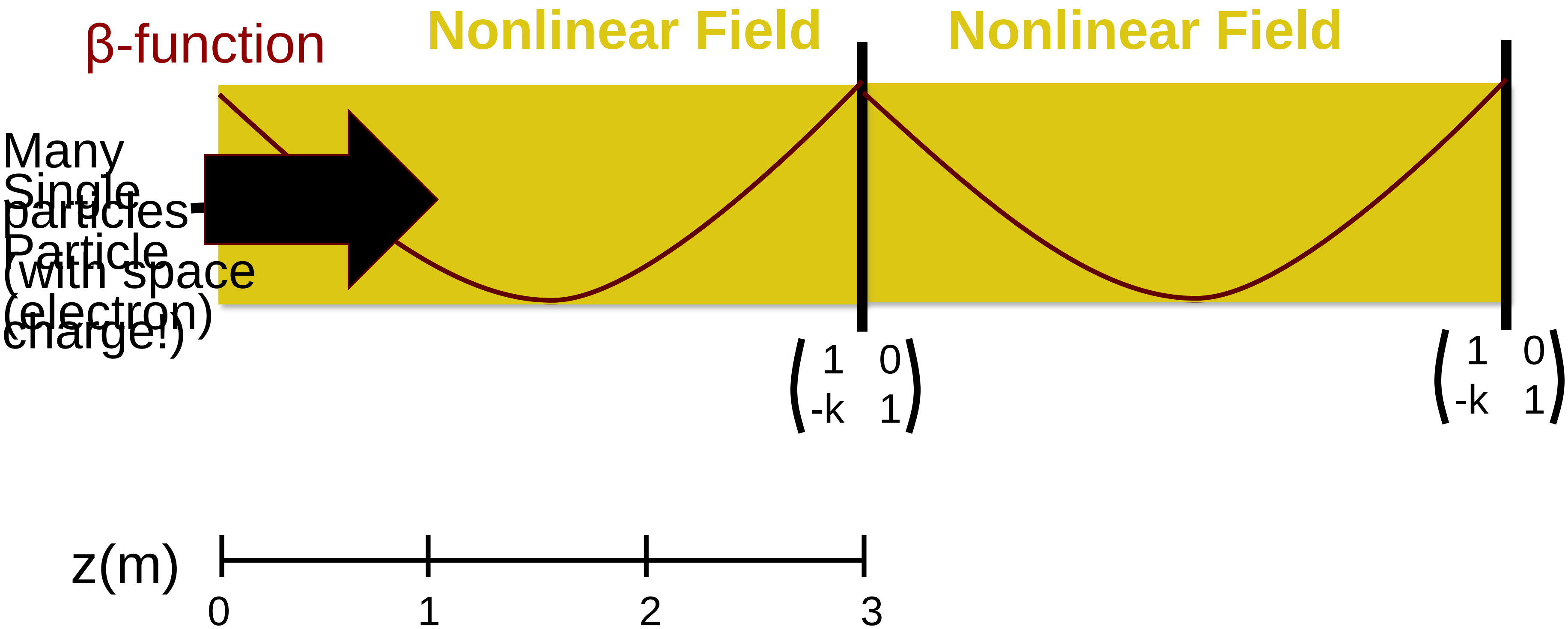
We aim to support and complement the research in nonlinear integrable optics at the IOTA ring in ASTA

UMD can contribute on 2 fronts:

- Simulation:
  - Apply group expertise to simulate IOTA ring with WARP PIC code (space charge dynamics)
- Experimental:
  - Modification of ring lattice to run NIO experiment
    - New magnet design, refined diagnostics
  - Goals:
    - map lattice phase space
    - halo suppression
    - beam loss near resonance

Preliminary WARP Simulation of IOTA Ring

- Currently developing a basic WARP model of the IOTA lattice:

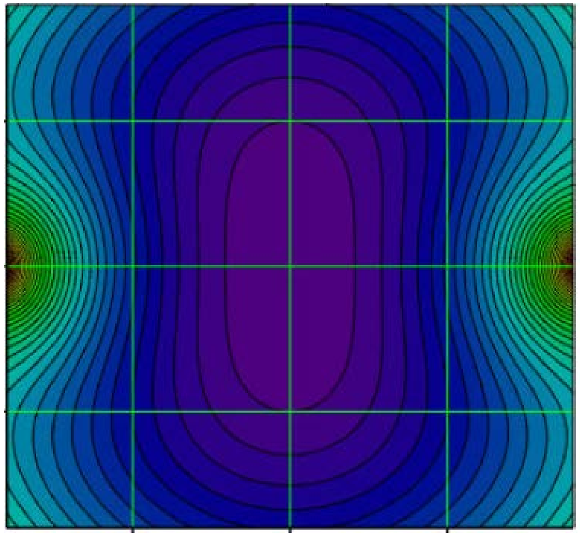


Preliminary WARP Simulation of IOTA Ring

$$U(x,y) = -\frac{t}{c^2}\,\mathrm{Im}\left[(x+iy)^2 + \frac{2}{3c^2}(x+iy)^4 + \frac{8}{15c^4}(x+iy)^6 + \ldots\right]$$

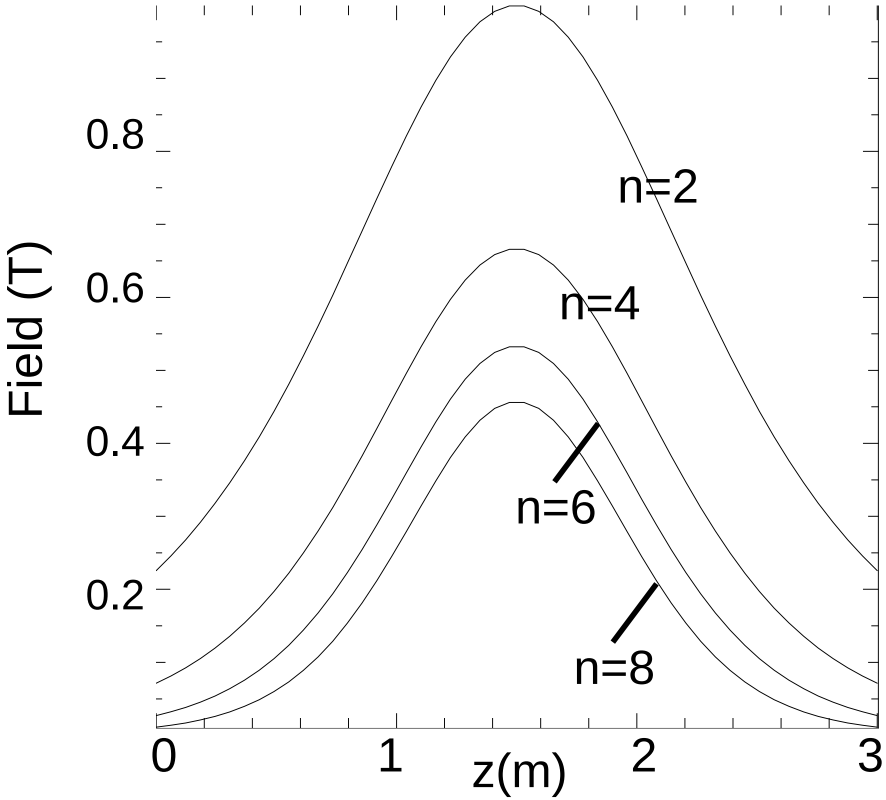
Valishev et. al, Fermilab Conf. 2011

Nonlinear Potential U(x,y)



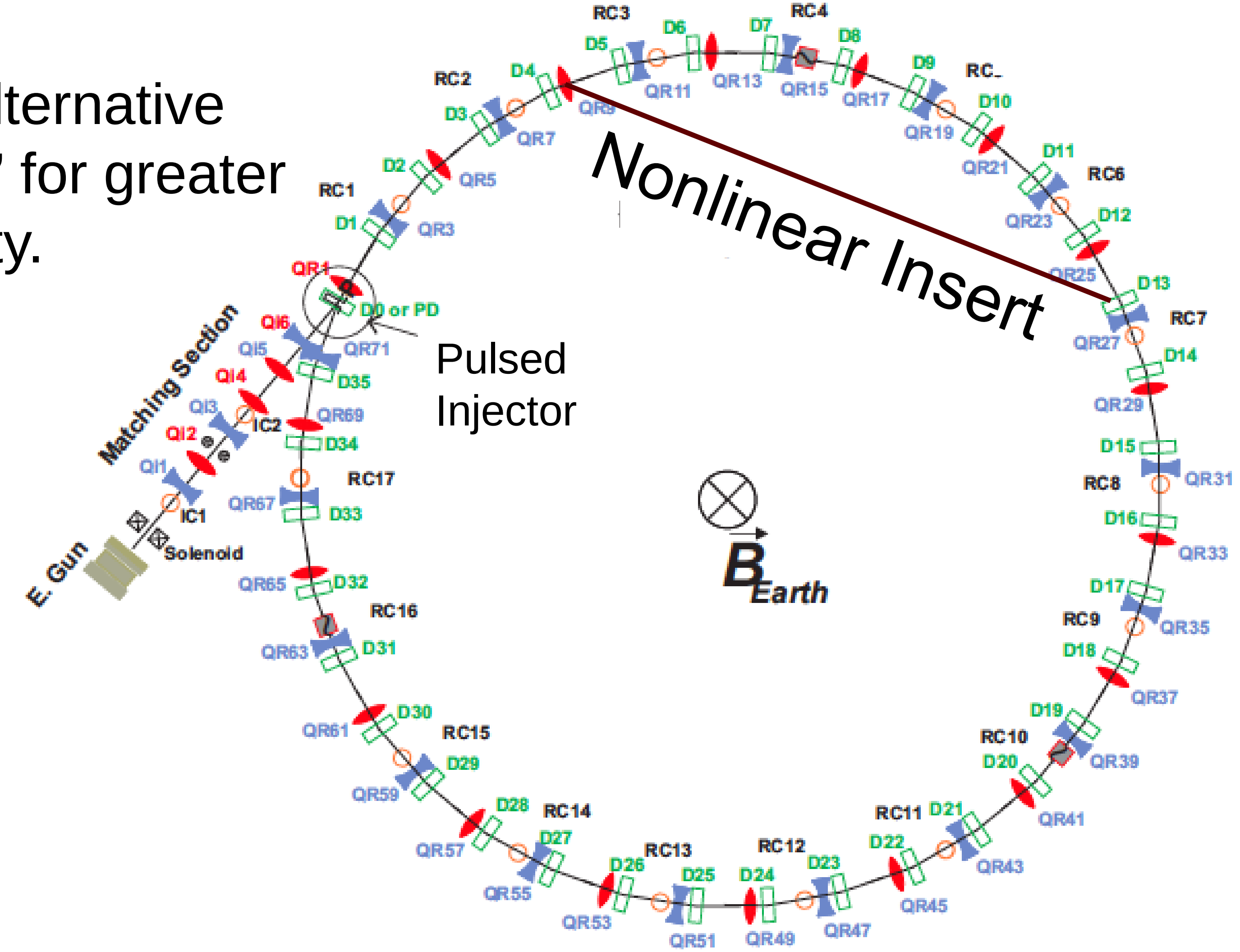
Nagaitsev et. al, Fermilab Conf. 2010

WARP Multipole Element



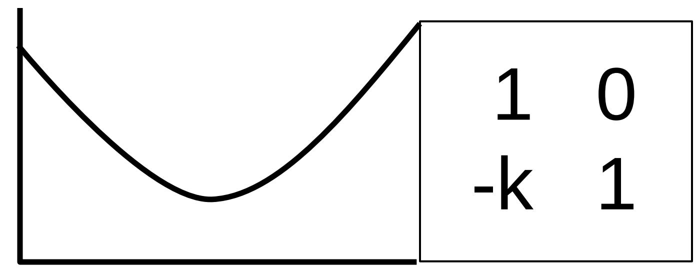
Experimental NIO Program at UMER

Use “Alternative Lattice” for greater flexibility.



Feasibility Studies with Elegant

- Need to meet requirements of T-matrix + drift with existing lattice
  - At least 28 quadrupoles available for optimization
- Alternate lattice solution in Elegant (FODO)
  - Strategy: solution for matching section to join alt. lattice solution to drift.
  - How many quadrupoles? Not sure, no solution yet!



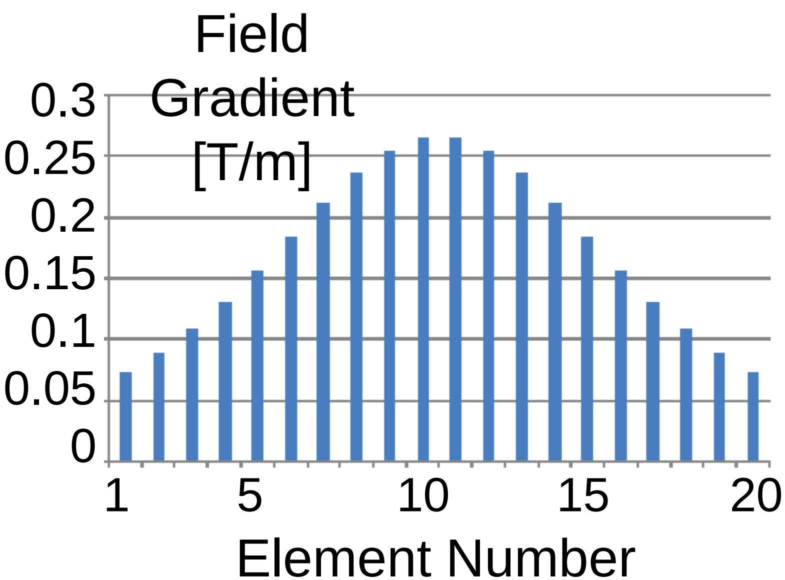
β in drift   T-insert

- Equivalent to thin lens kick
- Phase advance π
- $\beta_x = \beta_y$ in nonlinear insert
- Achromatic
- Tunable for multiple working points

Valishev et. al, Fermilab Conf. 2011

Nonlinear Magnet Design at UMER

IOTA magnets: constant variation along z

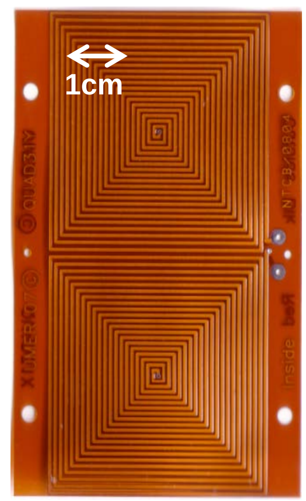


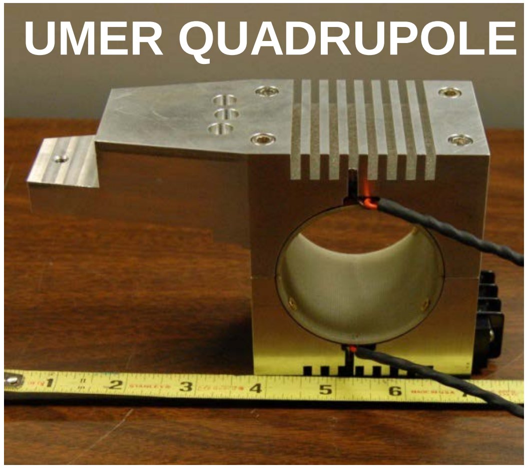
Quadrupole component in nonlinear IOTA magnet.

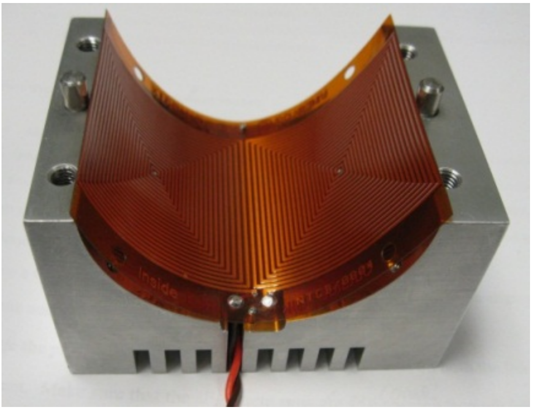
Valishev et. al, Fermilab Conf. 2011

Standard UMER magnets

$$\cos n\theta$$



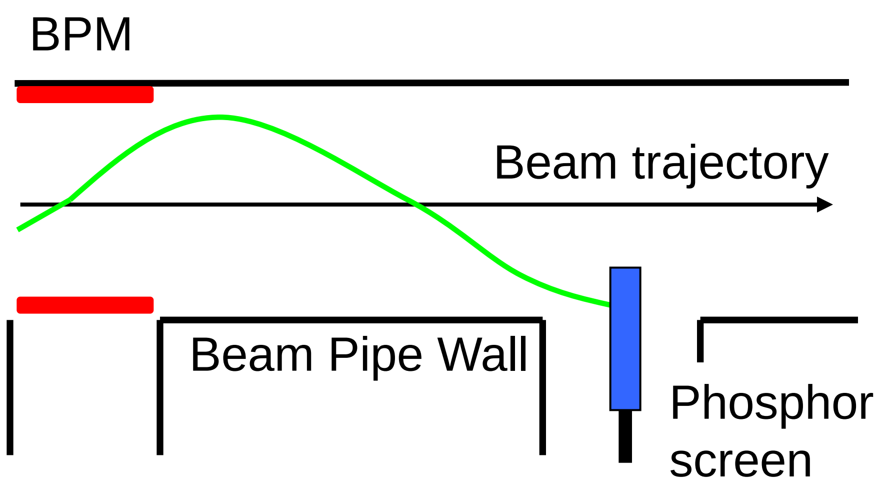


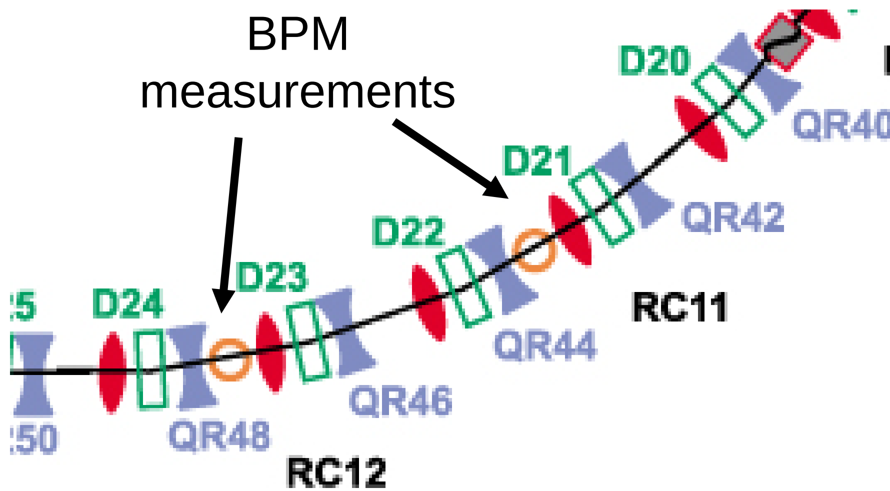


W.W. Zhang, et al, Phys. Rev. ST Accel. Beams, 2000
S. Bernal, et al, Phys. Rev. ST Accel. Beams, 2006

Diagnostic Approach to NIO Experiments

- BPM's
- Wall current monitor
- Multi-turn 3D imaging "knock-out"
- 3-step phase space sampling with Elegant
- Single-turn fast kicker (30 ns)
- Proof of principle demonstration complete
- Needs improvement: BPM signal-to-noise
- Distributed around ring





Conclusions

- Goal: Develop a research program in cooperation with IOTA efforts
  - Support eventual IOTA upgrade to ion beam with increased space effects
- UMER facility ideal for space charge NIO experiment
  - Low budget
  - Many modes of operation (easily vary intensity, lattice parameters)
  - Space-charge dominated regime
- Short term Goals:
  - Demonstrate experiment feasibility with Elegant
  - Use WARP model to predict NIO lattice performance in presence of space charge

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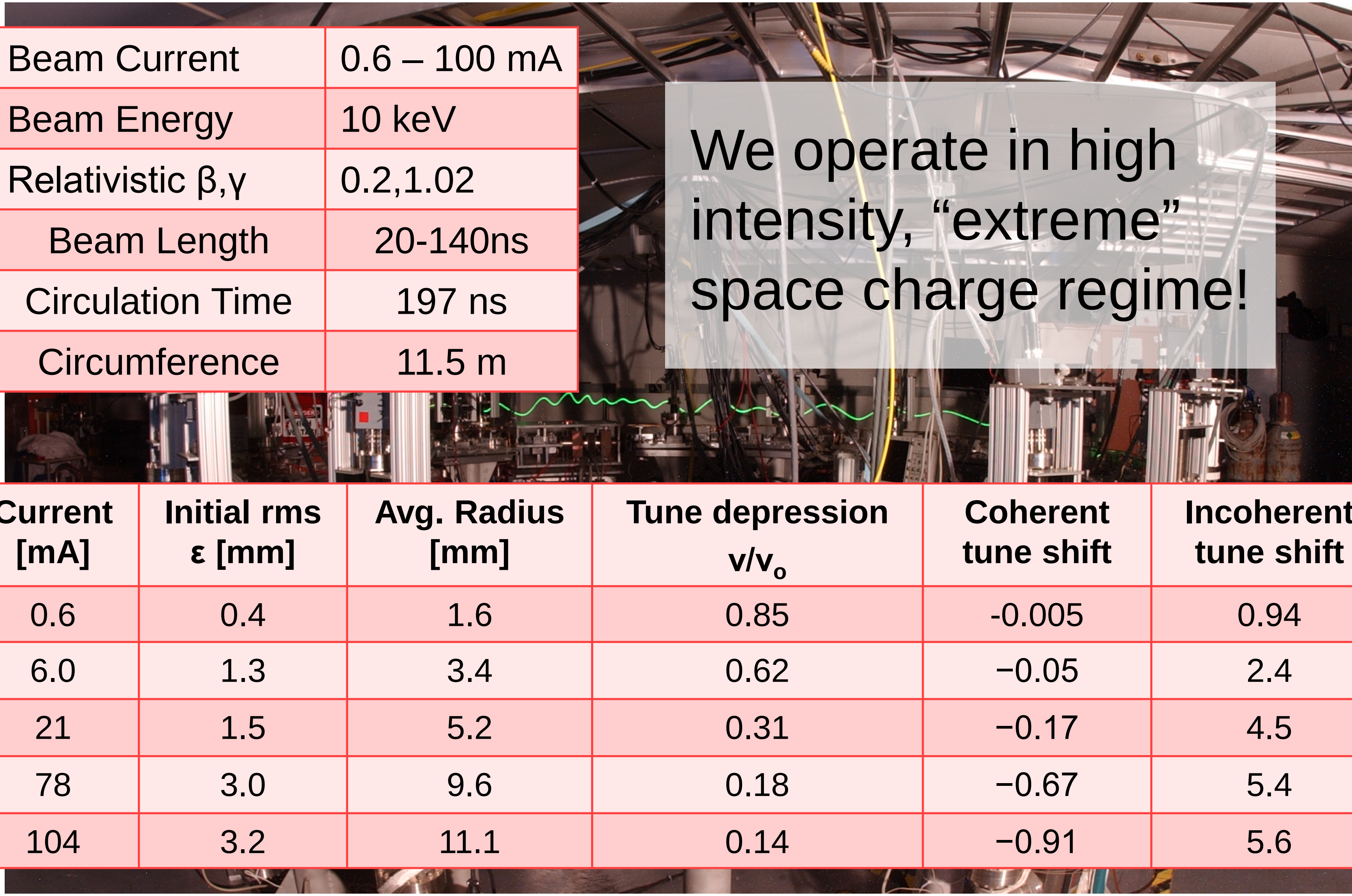
Thank you!

UMER Facility

INSTITUTE FOR RESEARCH IN ELECTRONICS & APPLIED PHYSICS



Beam Current	0.6 – 100 mA
Beam Energy	10 keV
Relativistic β,γ	0.2,1.02
Beam Length	20-140ns
Circulation Time	197 ns
Circumference	11.5 m

We operate in high intensity, "extreme" space charge regime!

Current [mA]	Initial rms ε [mm]	Avg. Radius [mm]	Tune depression ν/ν_o	Coherent tune shift	Incoherent tune shift
0.6	0.4	1.6	0.85	-0.005	0.94
6.0	1.3	3.4	0.62	−0.05	2.4
21	1.5	5.2	0.31	−0.17	4.5
78	3.0	9.6	0.18	−0.67	5.4
104	3.2	11.1	0.14	−0.91	5.6

Experimental Program at UMER

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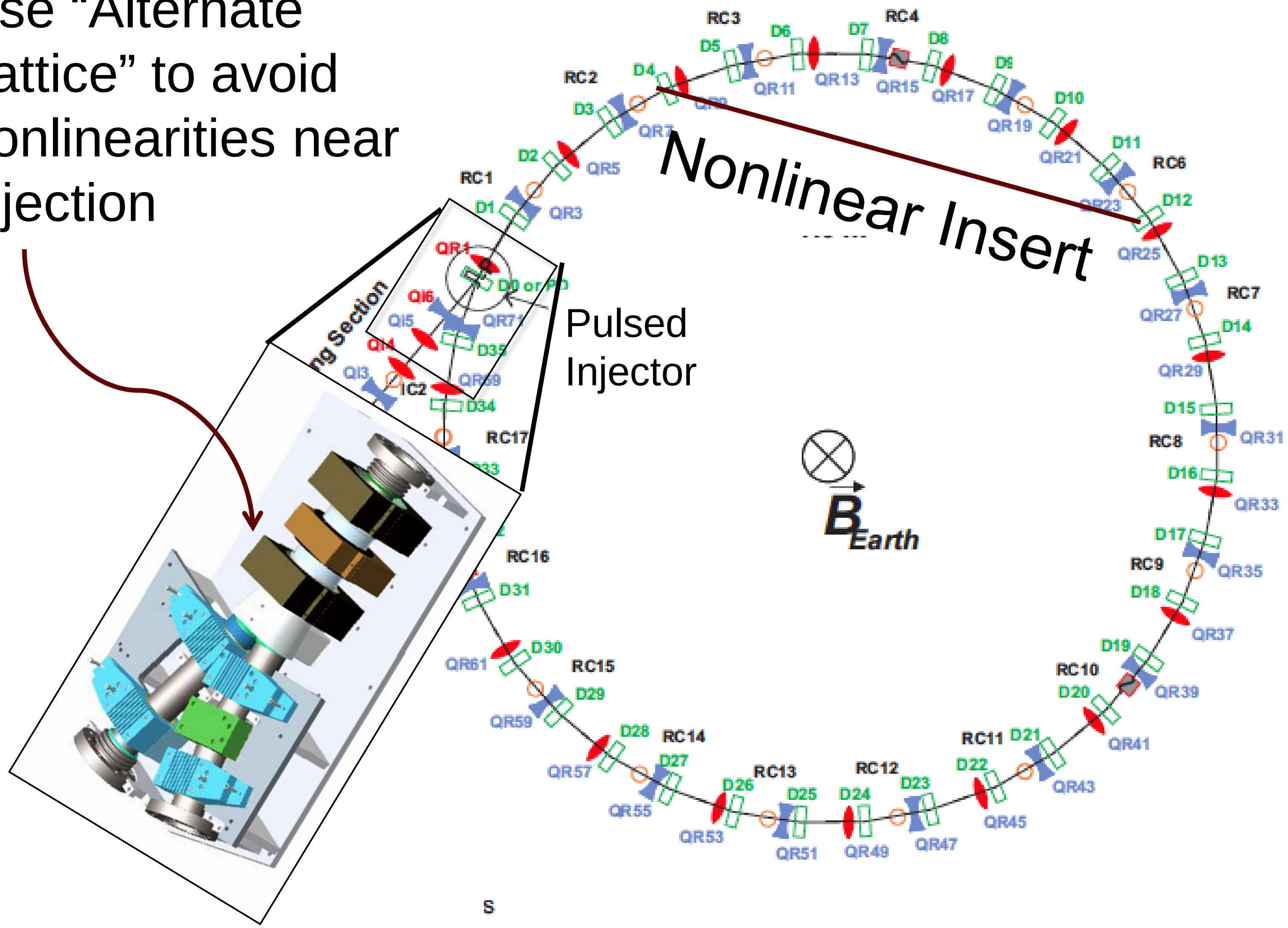
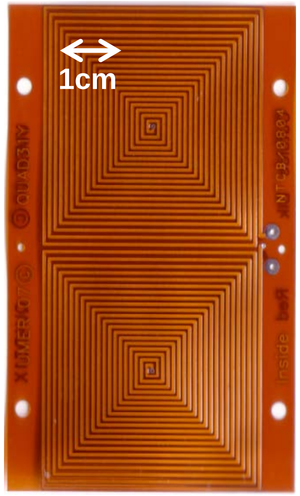
Use “Alternate Lattice” to avoid nonlinearities near injection



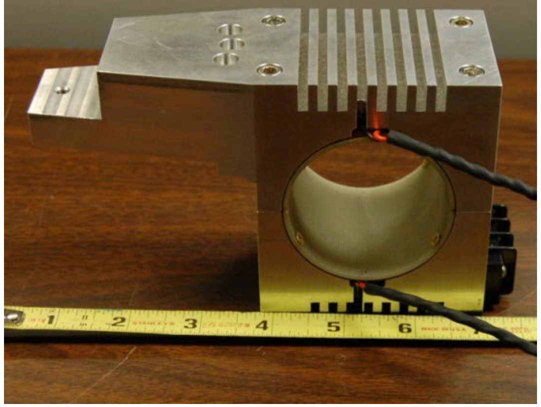
Magnet Design

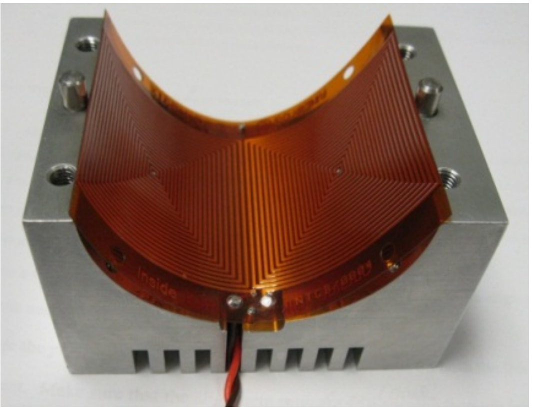
$\int K_z dz \propto \boldsymbol{\cos n\theta}$, *n*=order of multipole.

- High-tolerance design
- Design of any multipole or combination possible
- Low cost
- Variable strength and no hysteresis
- Almost any size or aspect ratio possible
- DC or pulsed operation
- Light but mechanically sound
- Stackable



UMER QUADRUPOLE





*W.W. Zhang, et al, Phys. Rev. ST Accel. Beams, 3, 122401 (2000).
S. Bernal, et al, Phys. Rev. ST Accel. Beams, 9, 064202 (2006).

Diagnostic Techniques:

Multi-turn 3-D 'Knock-Out' Diagnostic

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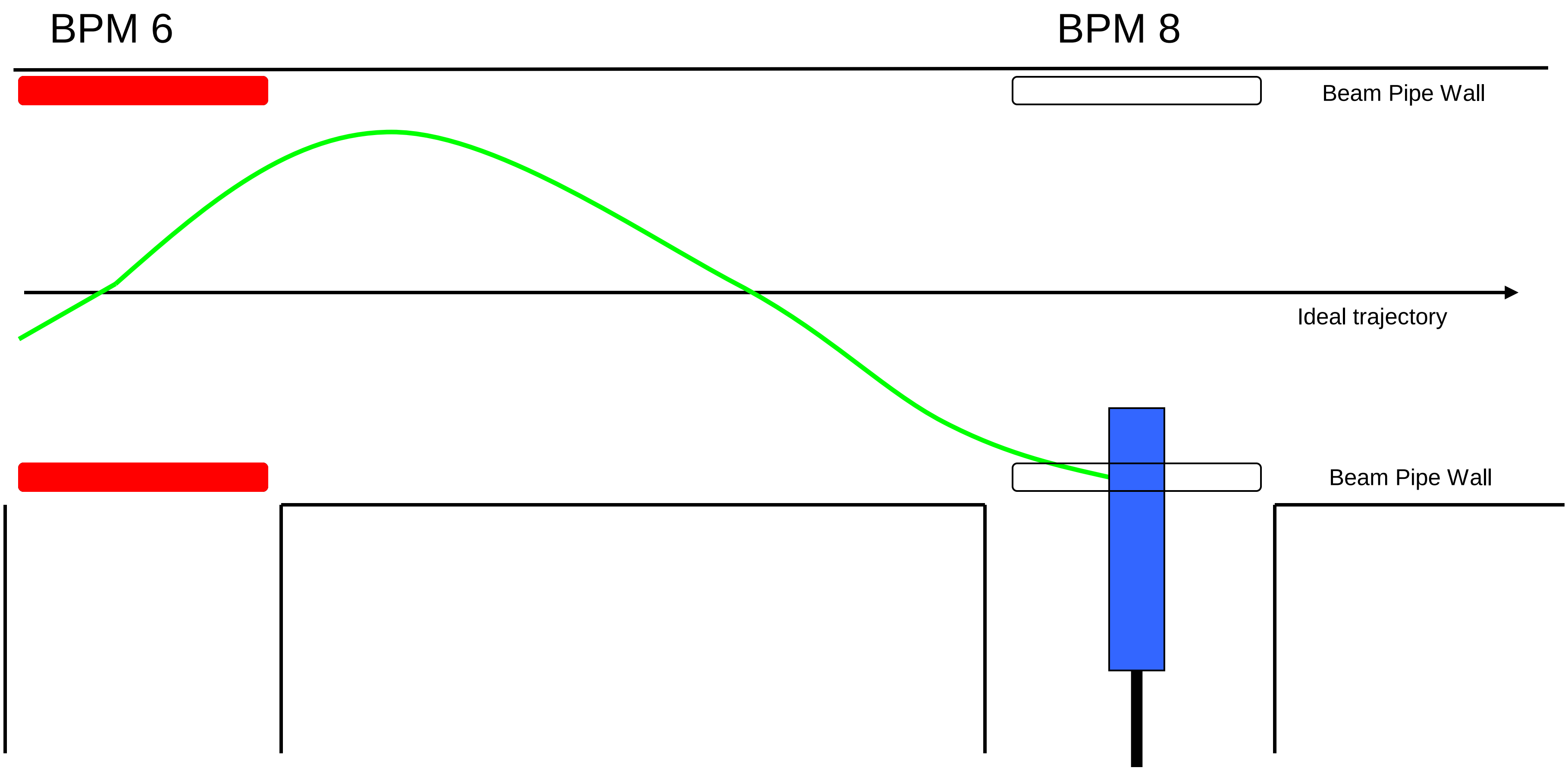

Measure halo and halo growth.

ZnO:Gd Fast Phosphor ~ 3 ns

Gated PIMAX II camera (3 ns)