Beam Injection and Matching in the University of Maryland Electron Ring (UMER)

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Outline

1. Overview of the University of Maryland Electron Ring (UMER)
2. Beam matching in UMER
3. Computer **simulation** of beam matching for:
   - low current beam (0.55mA)
   - more intense beam (23mA)
   - Test under different injection schemes
4. **Single and Multi-turn Experiments** with low and high current beam
5. Conclusion

Summary of the work

AIM: To inject and transport electron beam in the University of Maryland Electron Ring (UMER) over several turns

ACCOMPLISHMENT:

- Multi-turn transport of 0.55mA Beam and 23mA Beam

ACKNOWLEDGMENT:

"Injecting/Matching an electron beam is a collaborative effort ".

- Prof. Patrick O'Shea
- Dr. Bernal, Prof. Kishek, Dr. Sutter, Bryan Quinn, Dr. Walter, Dr. Godlove , Dr. Haber
- Diktys , Bai , Chris

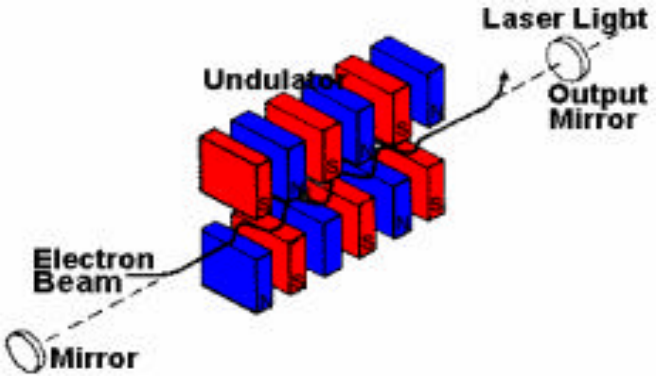
Accelerator-based light sources need Intense Beams

- To see something small, we need light of wavelength that is still smaller
  - Biology
  - Nanoscience

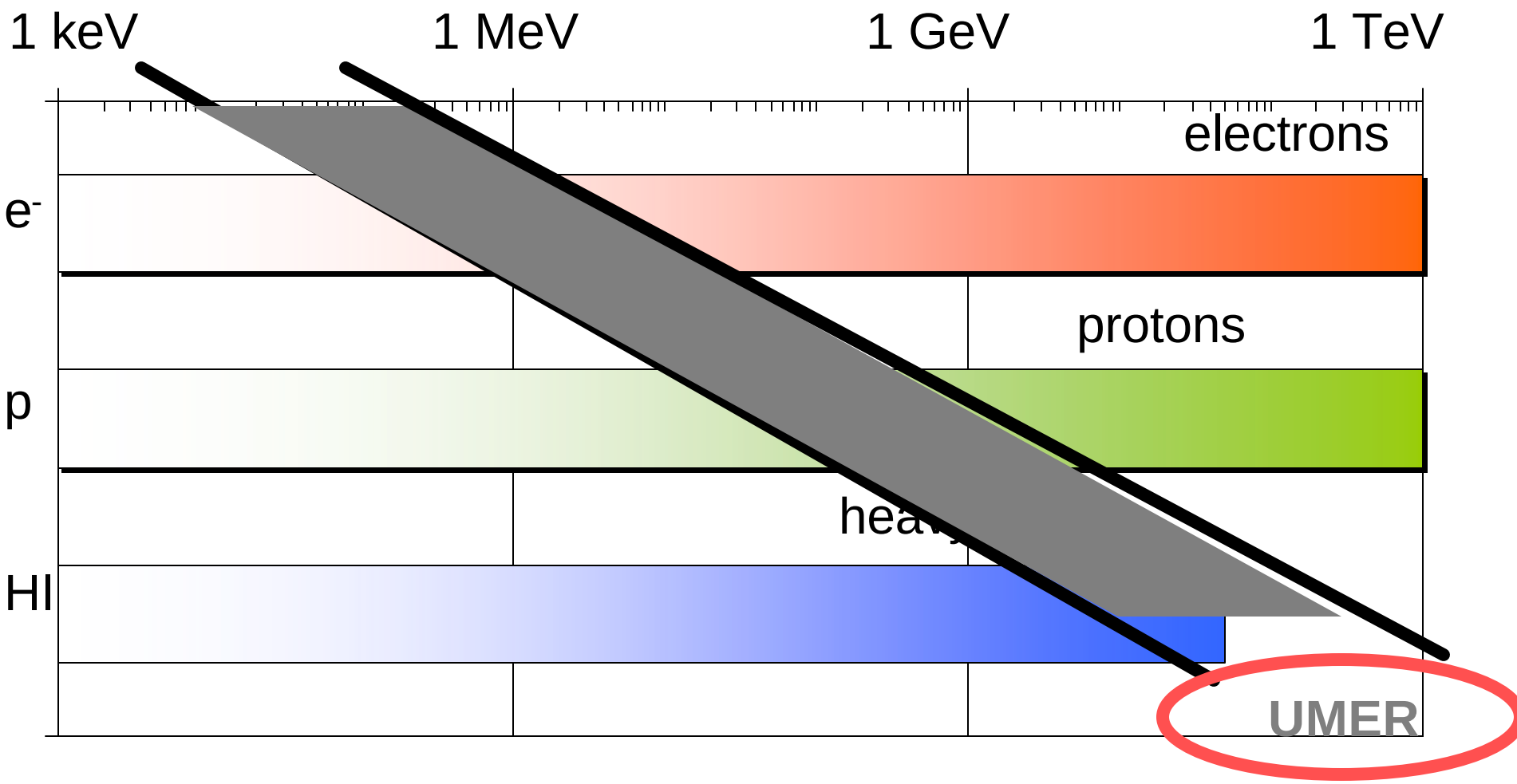
DNA
~2.5 nm diameter

Carbon nanotube
~1.3 nm diameter

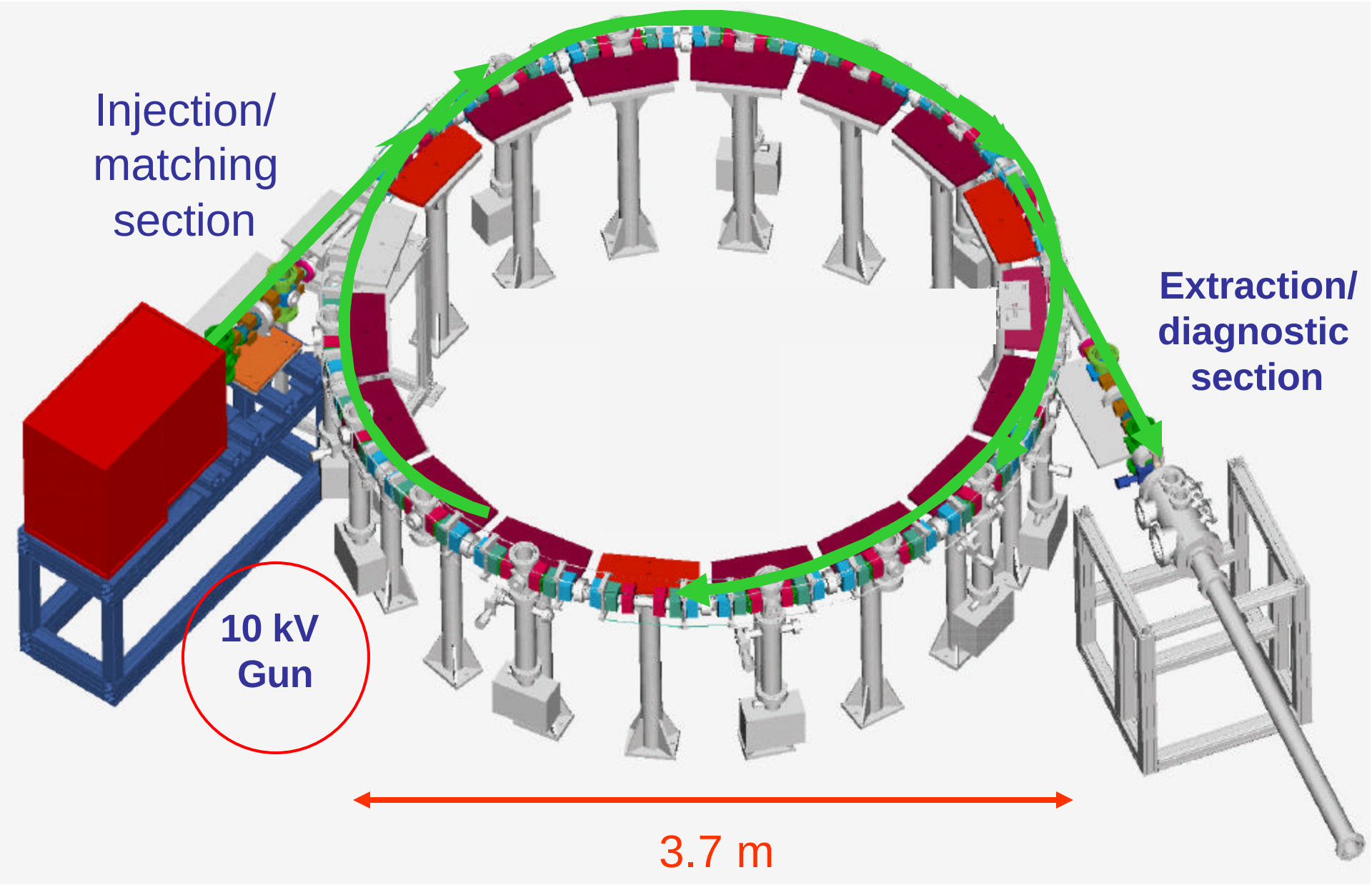
- Accelerator based light source
  - Change “color” (frequency) : Tunable
  - Blow things up! Super-Microscopes
  - e.g. Free Electron Laser



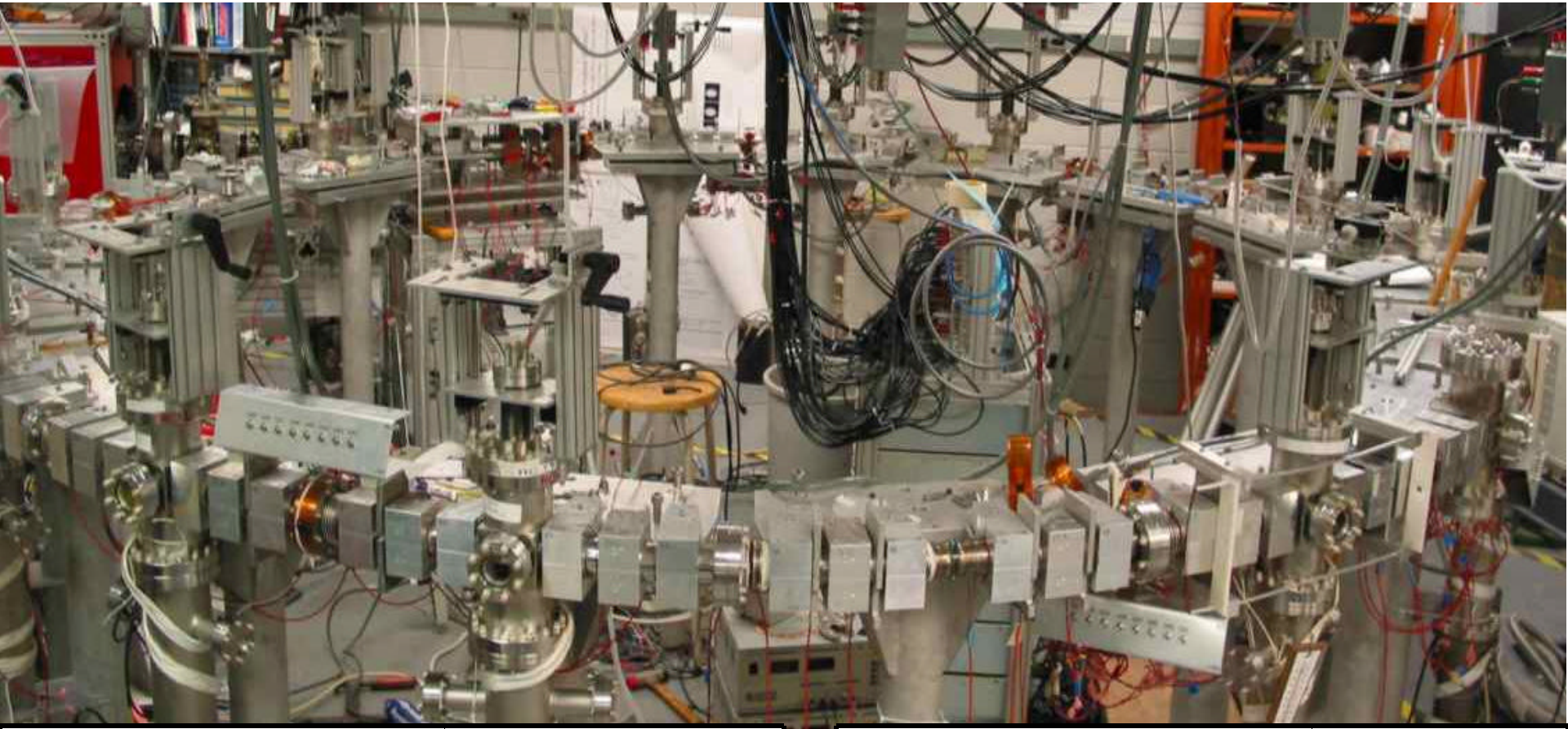
University of Maryland Electron Ring (UMER) a low-cost model of *HIGH INTENSITY* accelerators



UMER Operation



The University of Maryland Electron Ring



Energy	10 keV
Energy Spread	20 eV
Current Range	0.6-100 mA
rms Emittance (normalised)	0.2-3 μm

Circulation time	200 ns
Pulse length	20-100 ns
Zero-Current Tune	7.6
Depressed Tune	1.5 – 6.5

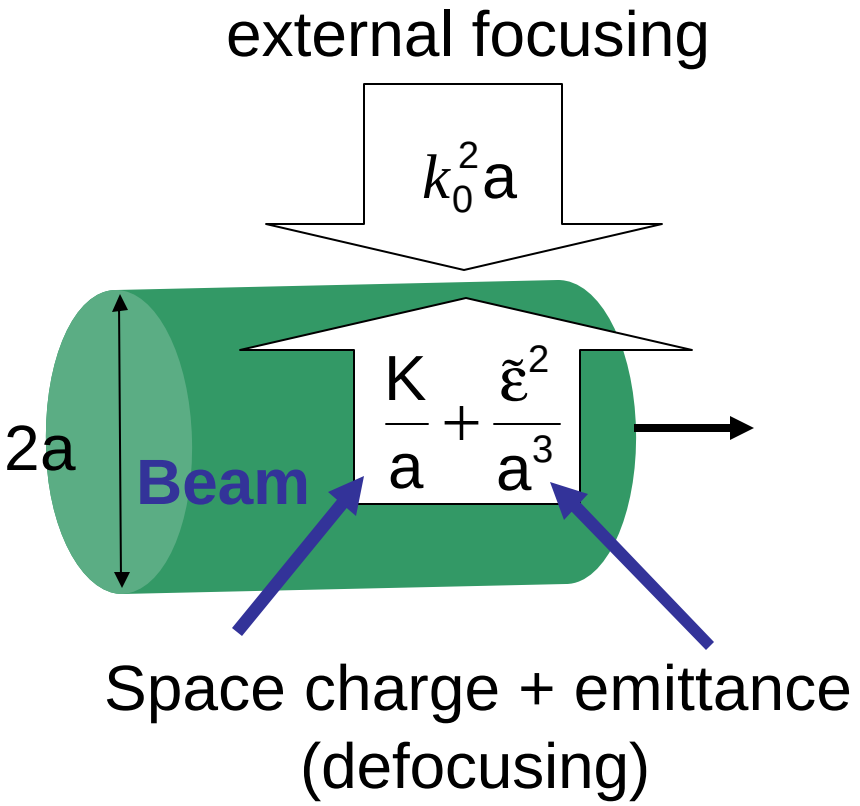
Matching a beam

Matched Beam envelope force balance equation:

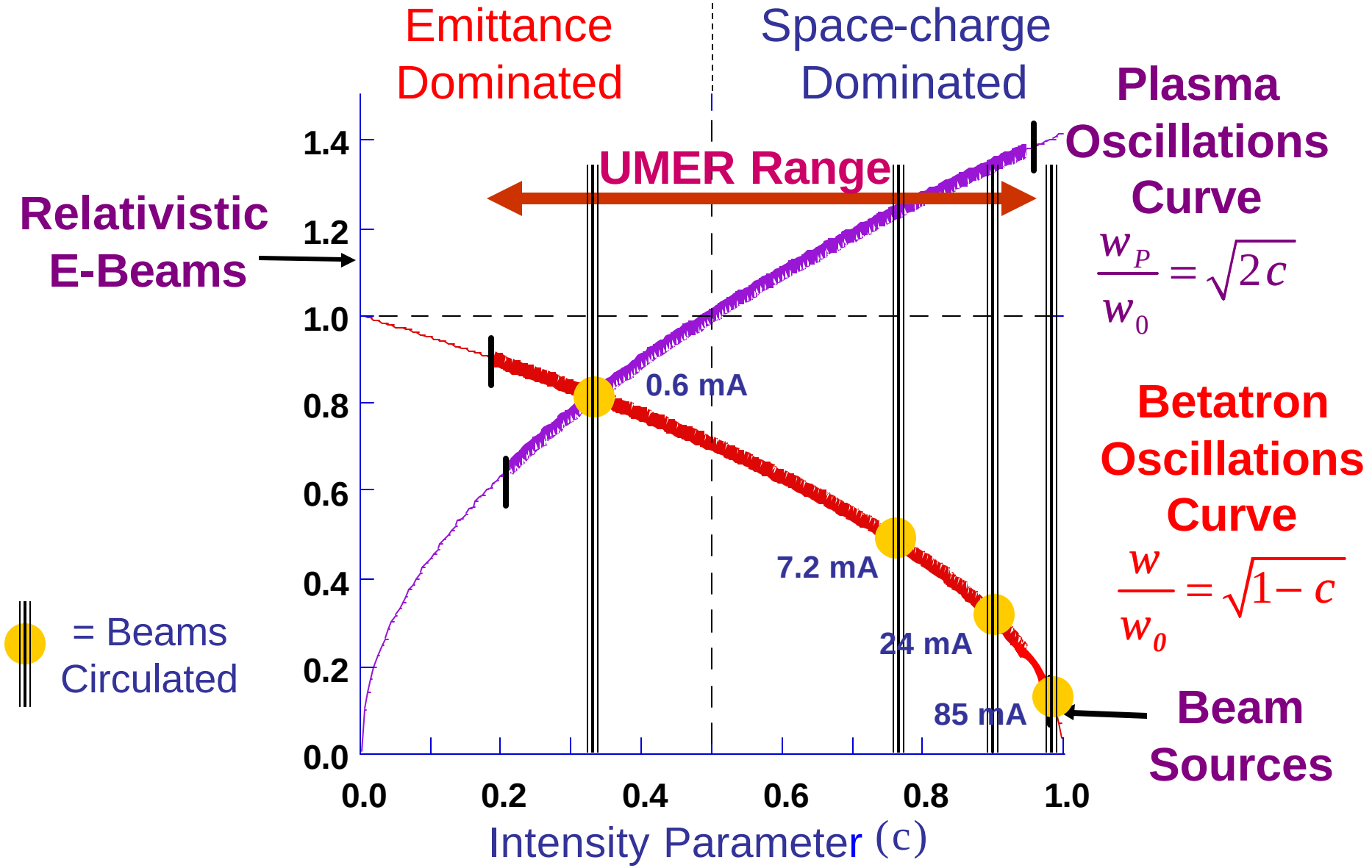
$$k_0^2 a = \frac{K}{a} + \frac{\tilde{\varepsilon}^2}{a^3}$$

$$c \equiv \frac{K}{k_o^2 a^2} = \frac{\text{space charge force}}{\text{external focusing force}}$$

0 £ c £ 1



UMER Operating Points –
LOW ENERGY,HIGH CURRENT electron beam



Why do we need a matched beam?

1. The beam is to be confined inside a pipe
2. To reduce beam-quality degradation (emittance growth) due to mismatch
3. Prevent mismatch envelope oscillations
4. Minimize Halos

In UMER:

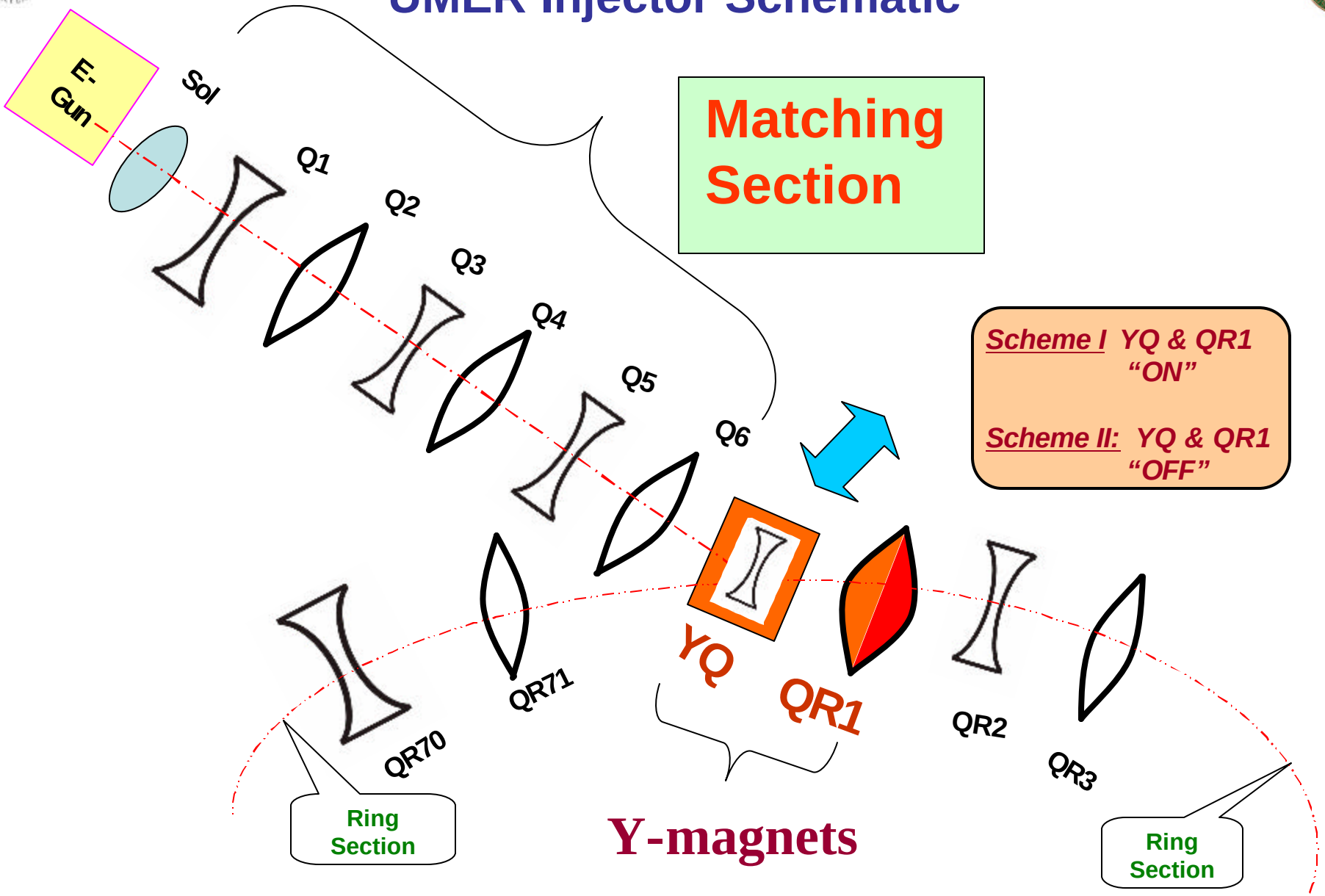
To maximize current transport and multi-turn operation around the ring.

Conditions of Mismatch

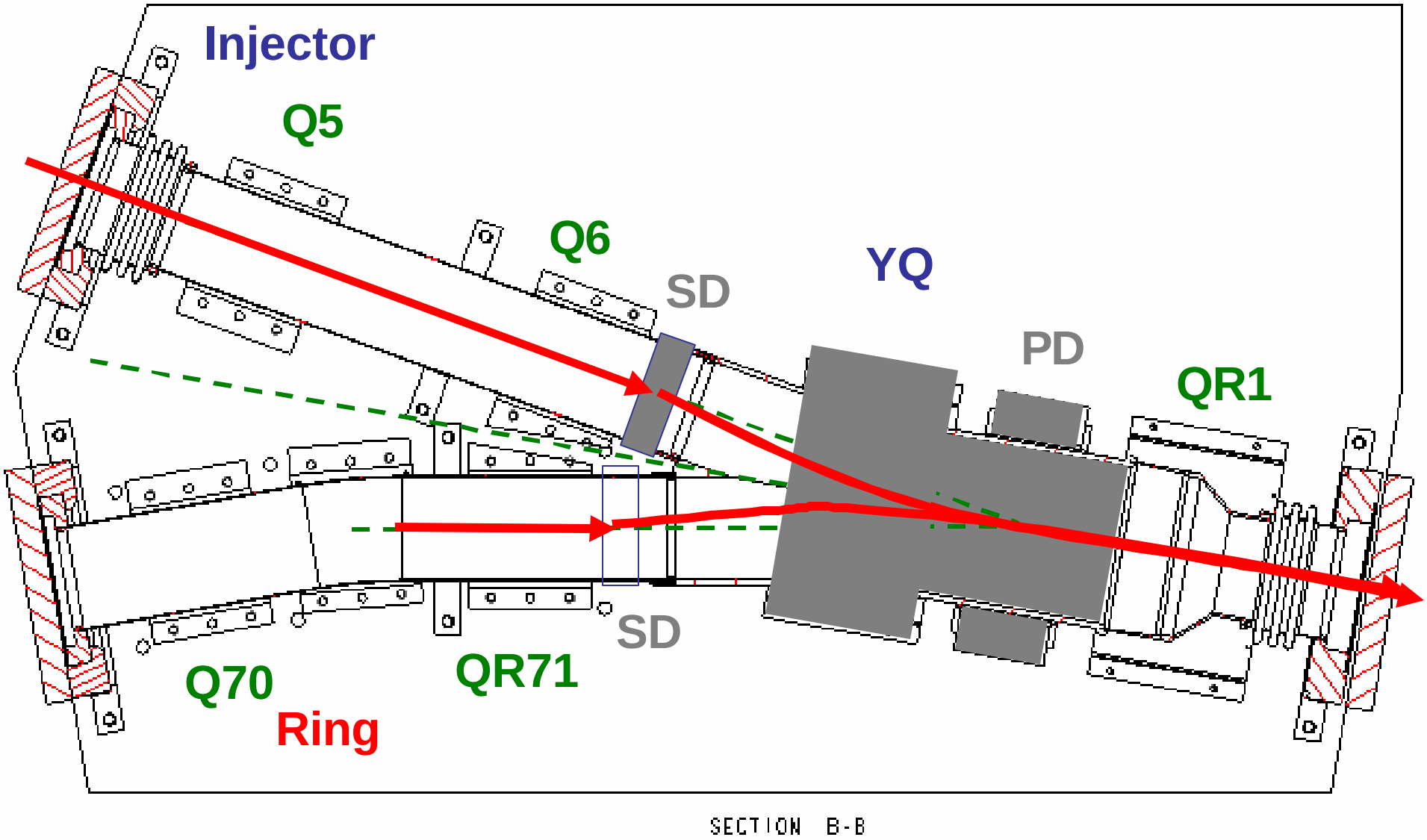
- Beam Transport : Beam mismatch due to external focusing , a function of the lattice optics

- Collective effects :Space Charge Effects due to the particle distribution $\Rightarrow$ Internal

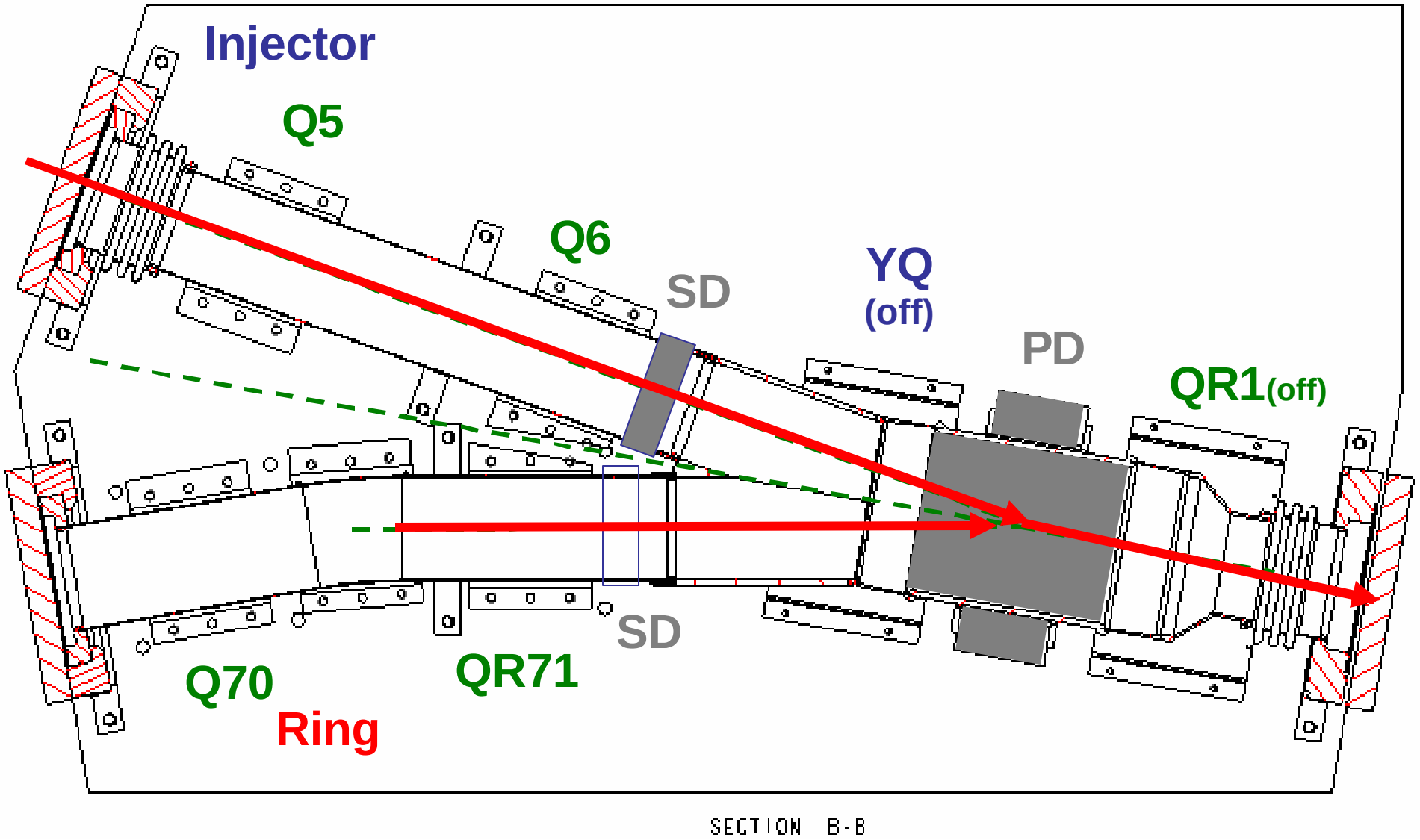
UMER Injector Schematic



Injection Y – Normal (Edge) Injection



Injection Y – Collins Injection



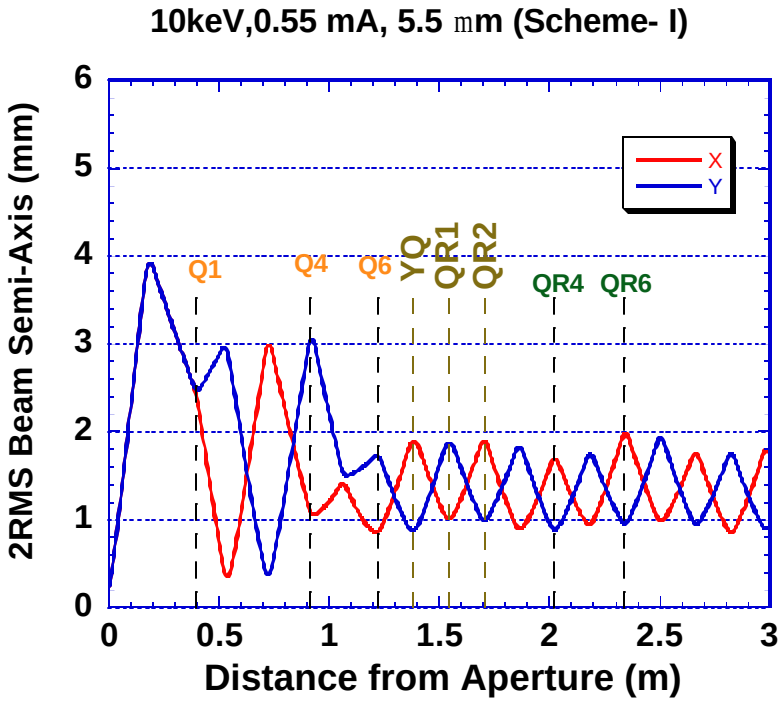
Classic Vs Collins Injection Scheme (Courtesy: Dr.Bernal and Dr.Sutter)

SCHEME	DIPOLE PEAK CURRENT ON INJECTION/RECIRCULATION	DIPOLE PEAK CURRENT ON CIRCULATION	PROS	CONS
CLASSIC (With Earth Field)	27.5 A[1]	14 A[1]	YQ Quad helps in bending	Injection angle and Matching are coupled Difficult centroid calculations
CLASSIC (Without Earth Field)	21 A[2]	21 A[2]	YQ Quad helps in bending	Injection angle and Matching are coupled Difficult centroid calculations
COLLINS (With Earth Field)	36-38 A[3]	20 A[4]	No injection angle through Y-Quads to control No distortion from injection quads	Large envelope excursion, so image force a problem. Therefore higher current beam cannot be contained Need circulation matching
COLLINS (Without Earth Field)	29A[4]	29 A [4]	Simpler centroid calculation No distortion from injection quads	Same as above with image effects reduced as there is no deflection from earth's magnetic field

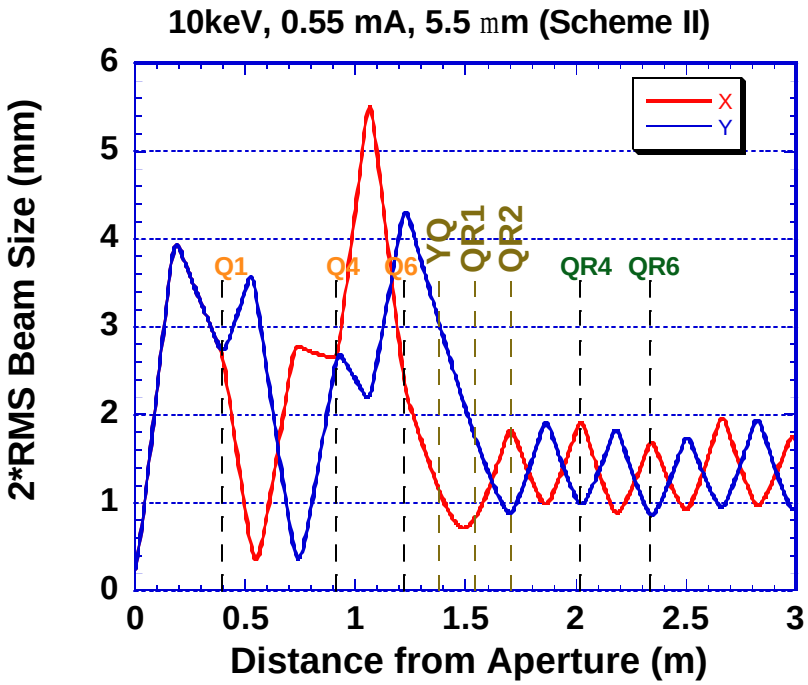
1 Experimental. 2.G.Bai's thesis and Hui Li's Thesis 3.Experimental 4.Calculated from simple model (which neglects steerers SD5 and SD6)

Matching of the 0.55mA Beam (Simulation- MENV*)

Scheme I



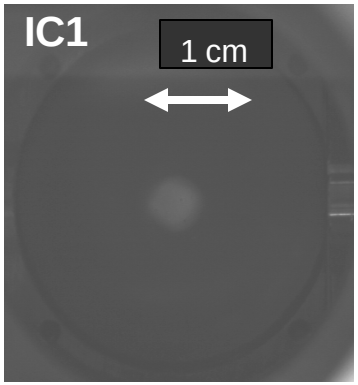
Scheme II

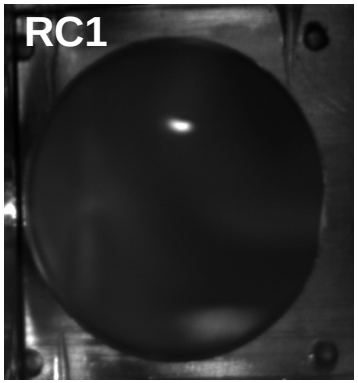


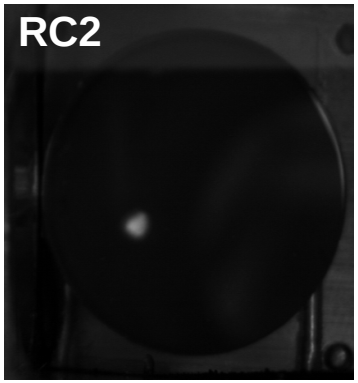
Pipe Radius = 2.5 cm

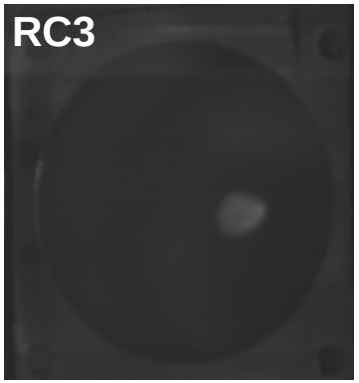
Courtesy: H. Li

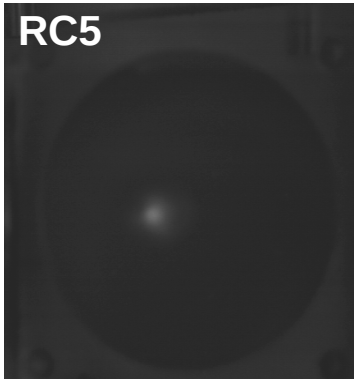
Jan. 19th, 2006 UMER EXPERIMENT: PENCIL BEAM TRANSPORT WITH REGULAR (EDGE) INJECTION (Bernal, Charles)

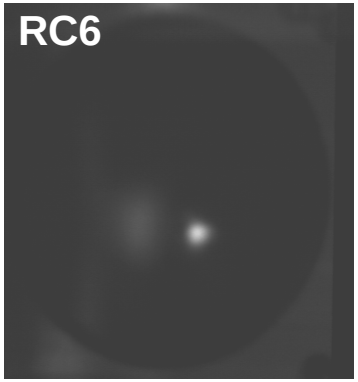


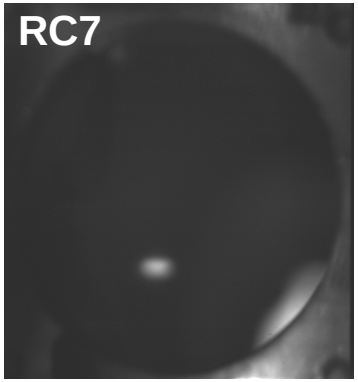


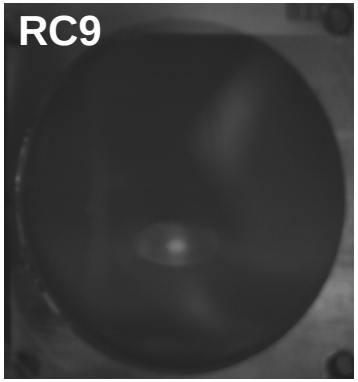


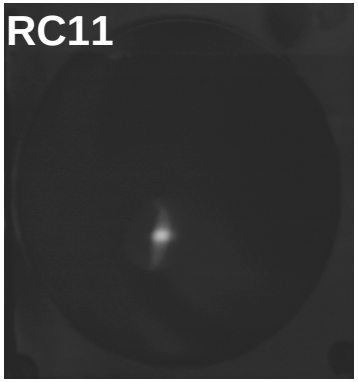


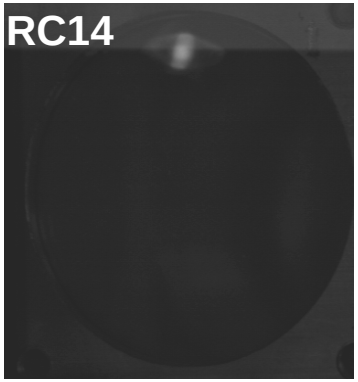


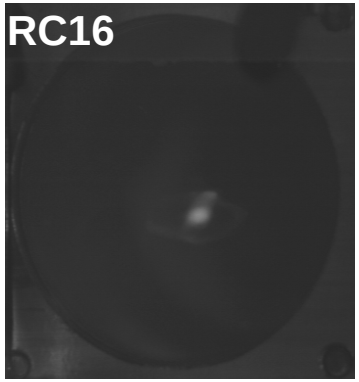




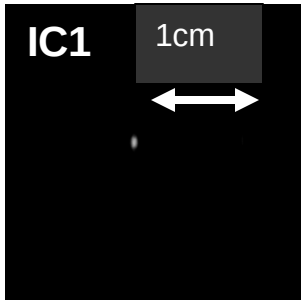


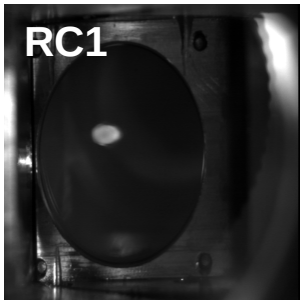


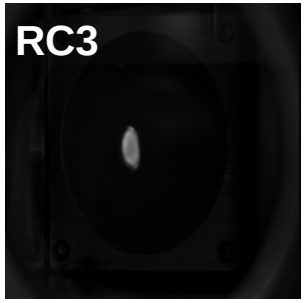


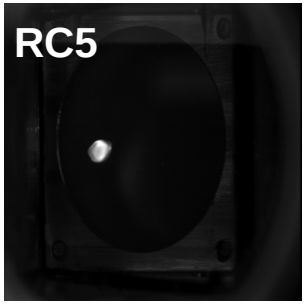


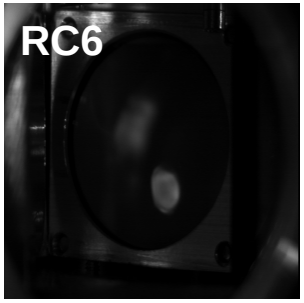
Jan.23, 2006 UMER EXPERIMENT: PENCIL BEAM TRANSPORT WITH COLLINS INJECTION (Bernal, Charles)

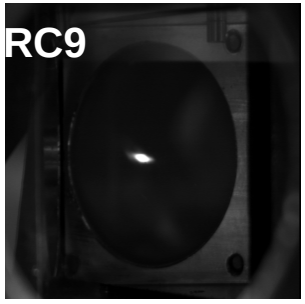


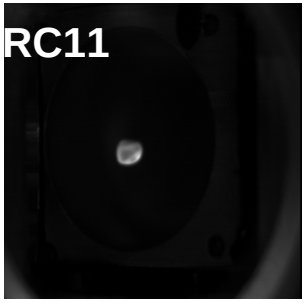


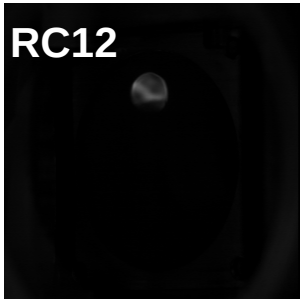


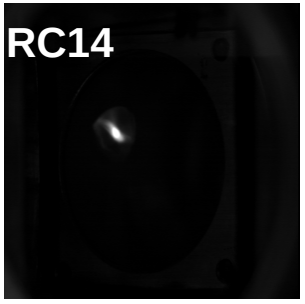


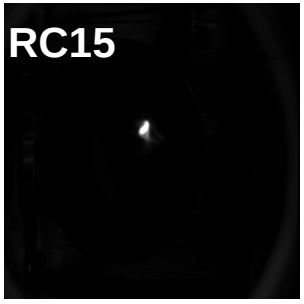






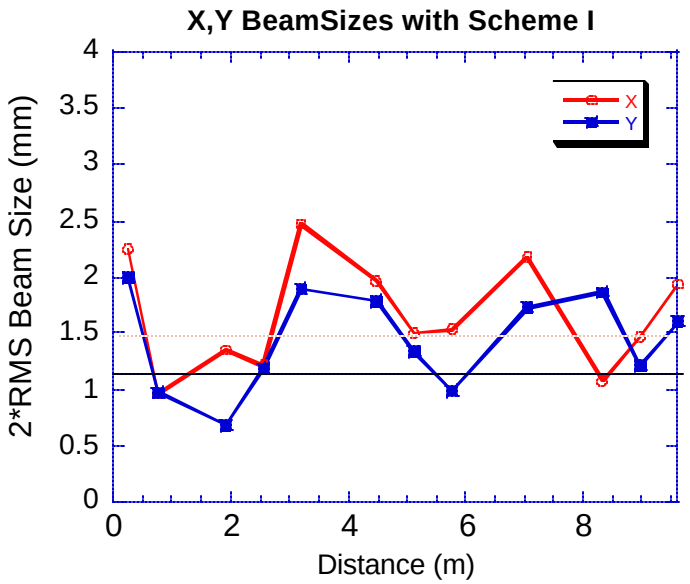




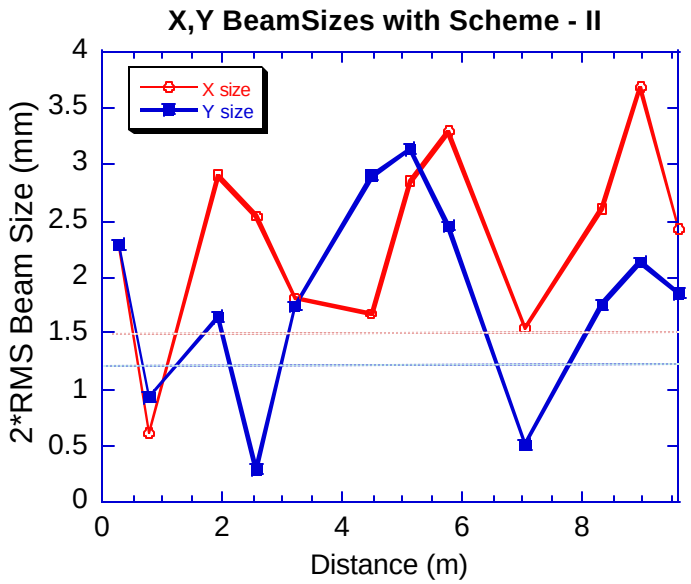


Experimental Result for 0.55mA Beam

Scheme I

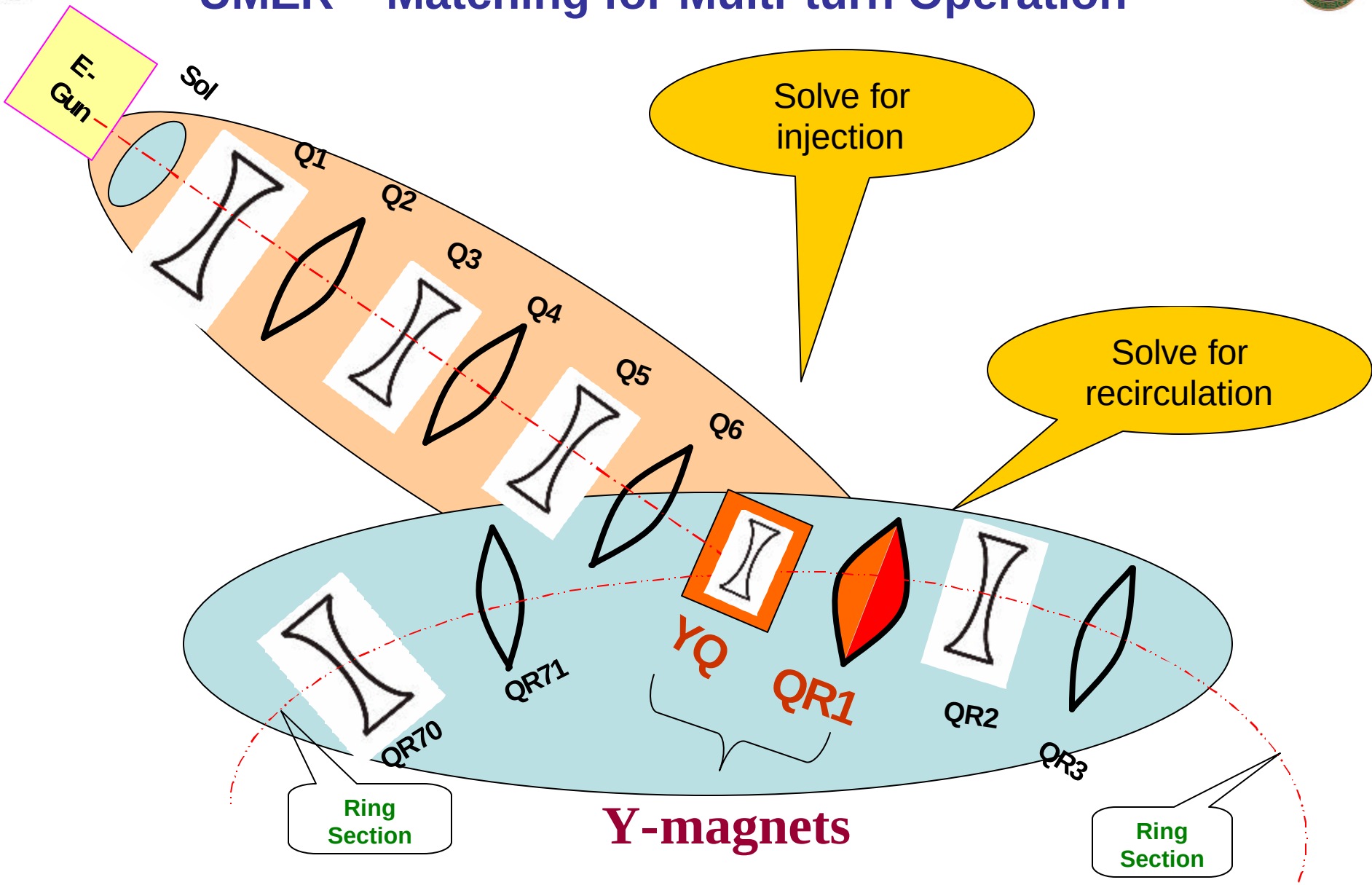


Scheme II

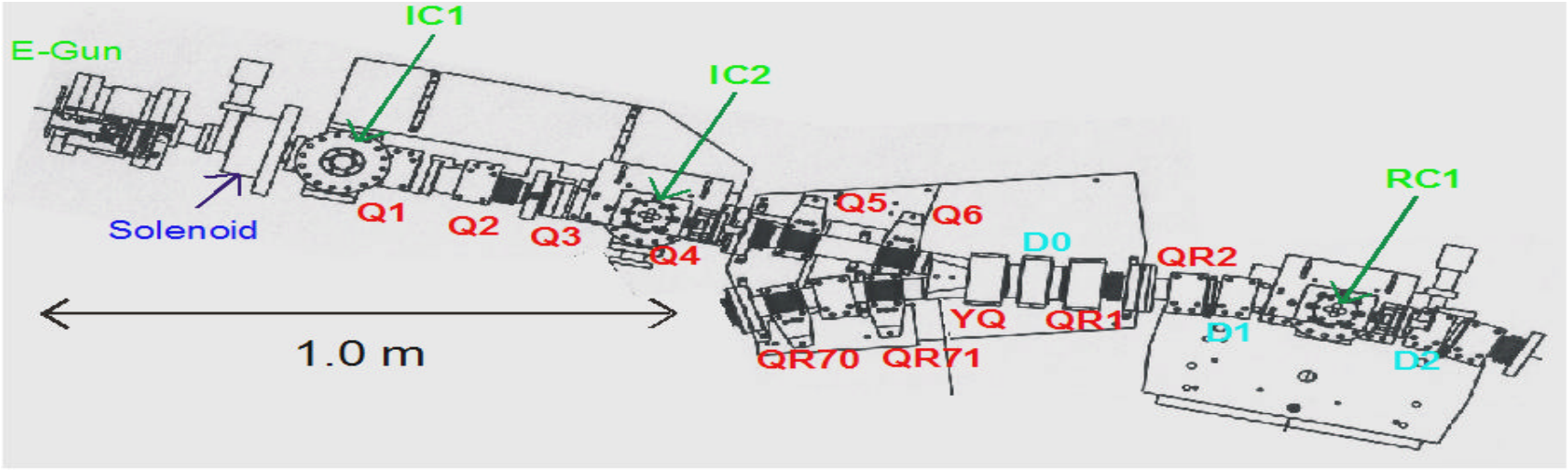


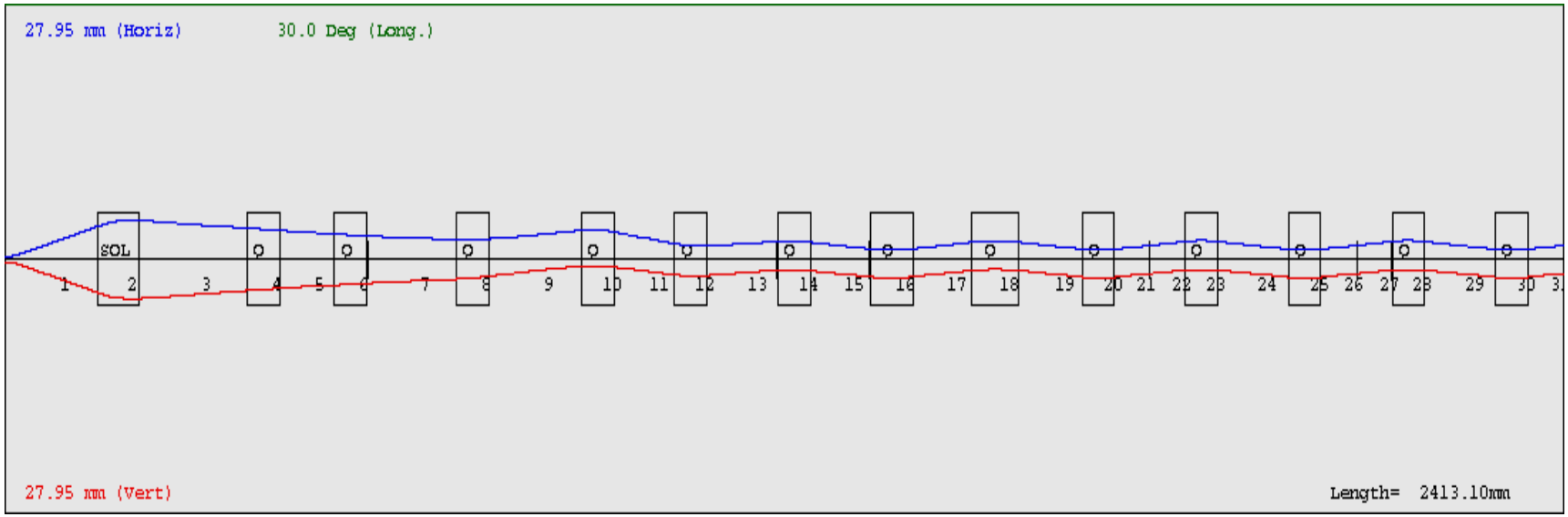
Scheme I is better than Scheme II

UMER – Matching for Multi-turn Operation

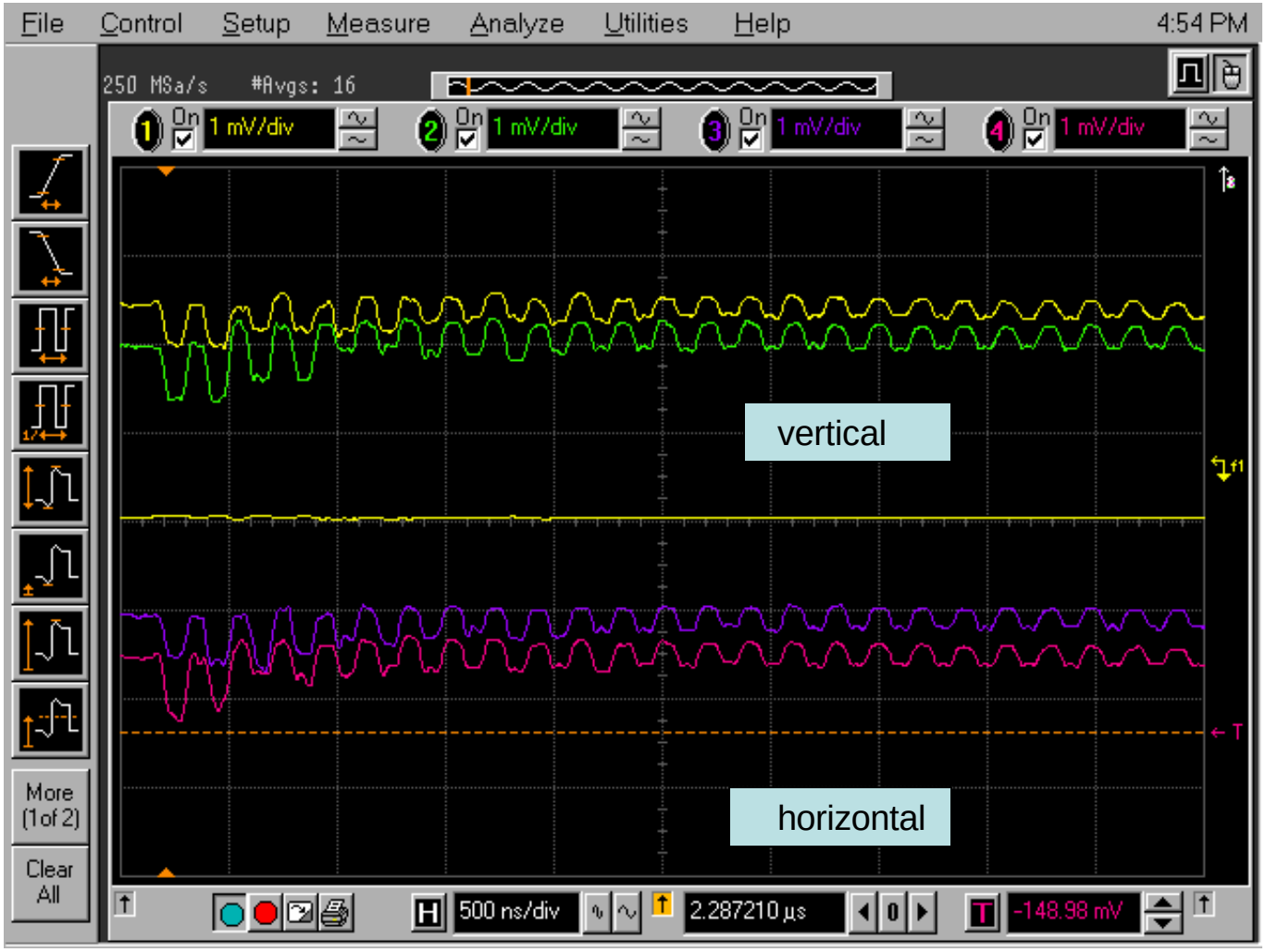


Matching for Multi-Turn – Low current Beam



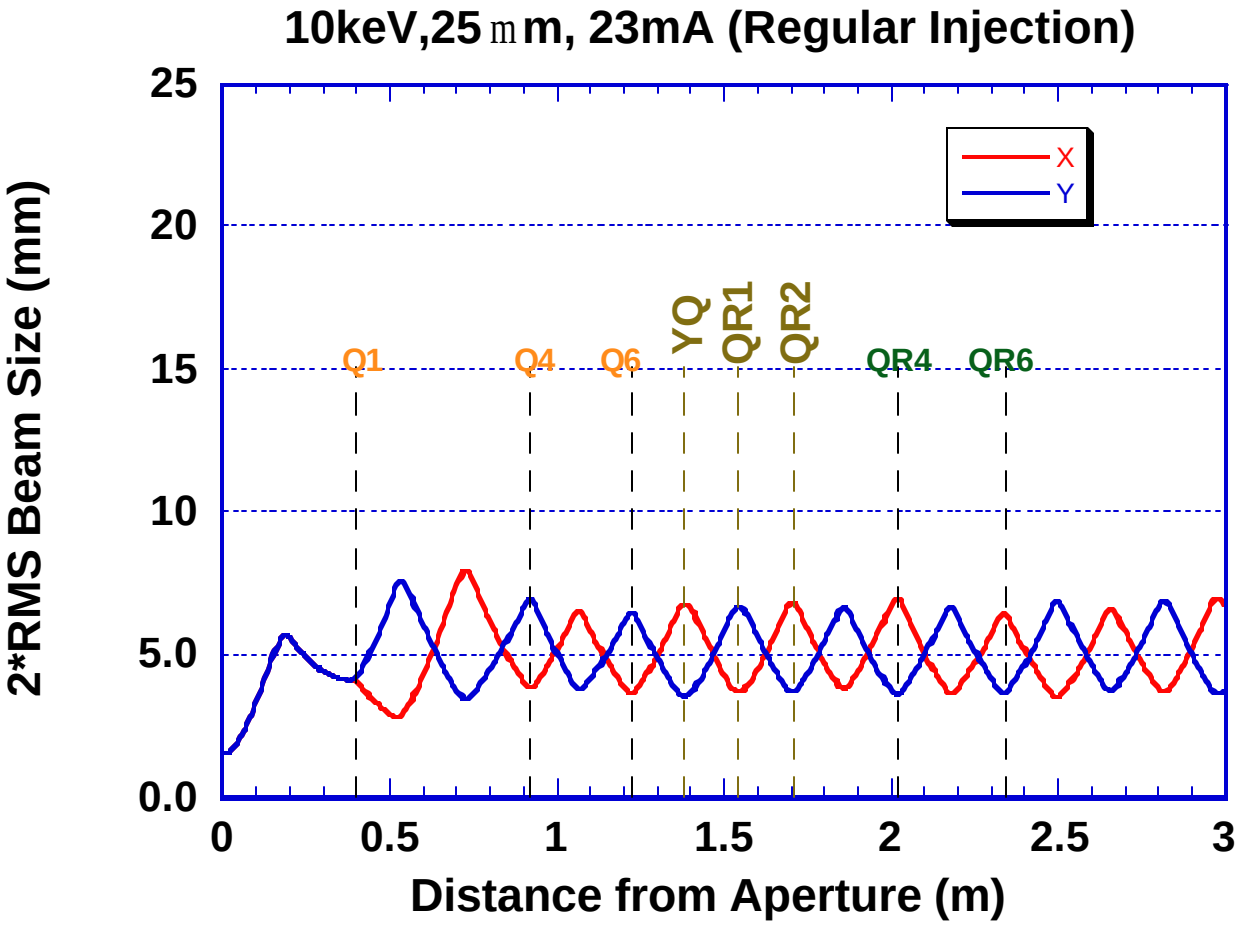


Multi-Turn Experiment of low current beam

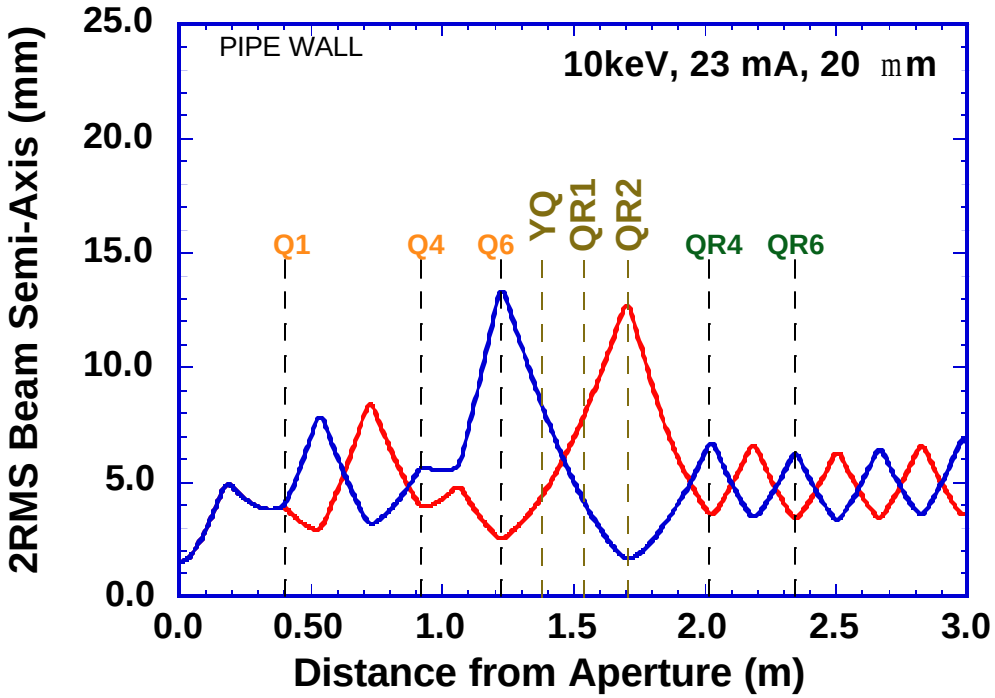


Oscilloscope output from the capacitive beam pickup (BPM)

Matching Calculations for 23mA beam (Scheme I)



Matching Calculations for 23mA beam (Scheme II)



Empirical matching

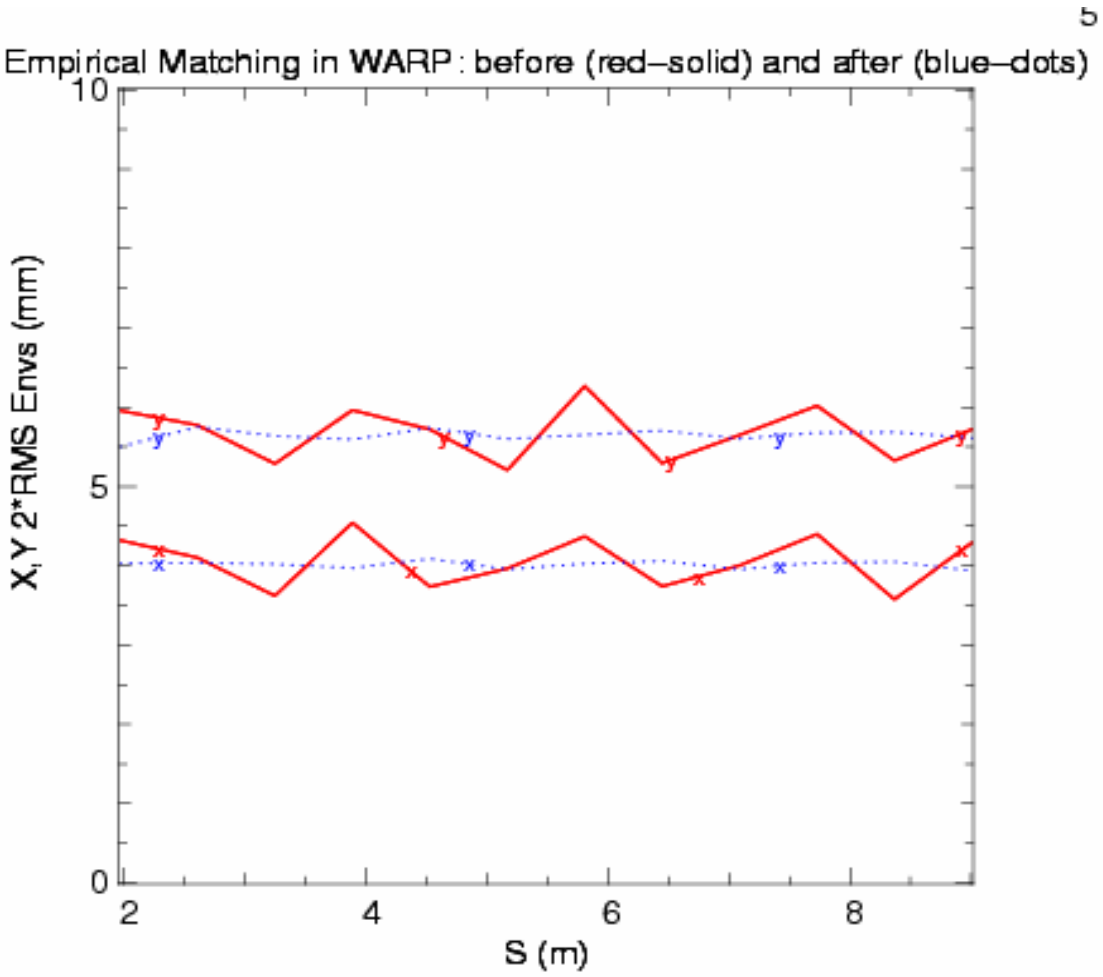
- Uncertainty in beam parameters (Current, Emittance, Initial Slope)
- $R_{xij} = \partial X_i / \partial I_j, R_{yij} = \partial Y_i / \partial I_j$ changes in Xi, Yi with respect to the current change in the quadrupole j.

$$\begin{pmatrix} X_1 \\ Y_1 \\ X_2 \\ Y_2 \\ \dots \\ X_n \\ Y_n \end{pmatrix} = \begin{bmatrix} R_{x11} & R_{x12} & R_{x13} & R_{x14} & 1 & 0 \\ R_{y11} & R_{y12} & R_{y13} & R_{y14} & 0 & 1 \\ R_{x21} & R_{x22} & R_{x23} & R_{x24} & 1 & 0 \\ R_{y21} & R_{y22} & R_{y23} & R_{y24} & 0 & 1 \\ \dots & \dots & \dots & \dots & \dots & \dots \\ R_{xm1} & R_{xm2} & R_{xm3} & R_{xm4} & 1 & 0 \\ R_{ym1} & R_{ym2} & R_{ym3} & R_{ym4} & 0 & 1 \end{bmatrix} \begin{pmatrix} \Delta I_1 \\ \Delta I_2 \\ \Delta I_3 \\ \Delta I_4 \\ X_m \\ Y_m \end{pmatrix}$$

E R U

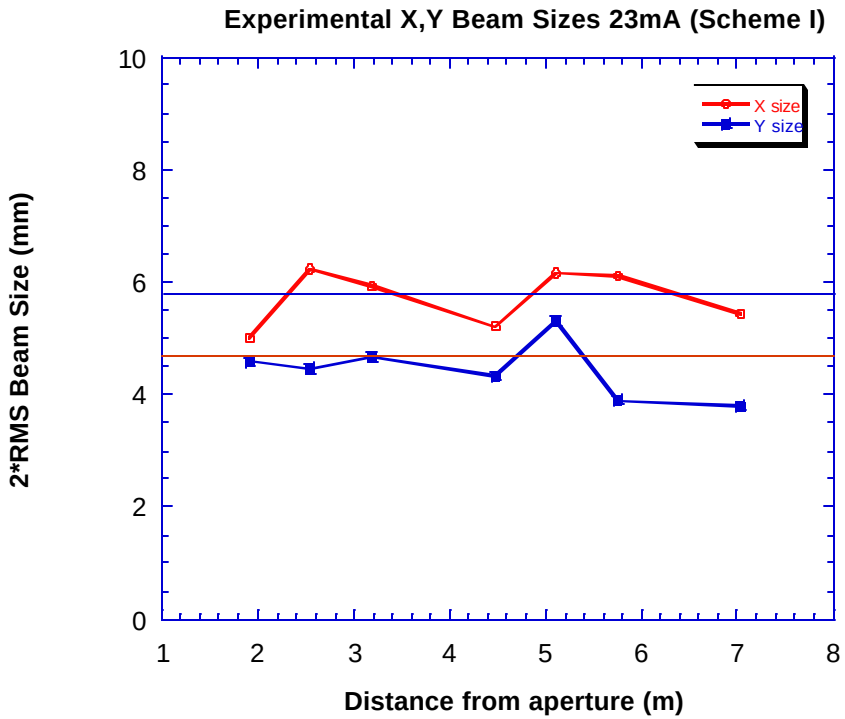
$$U = (R^T R)^{-1} R^T E$$

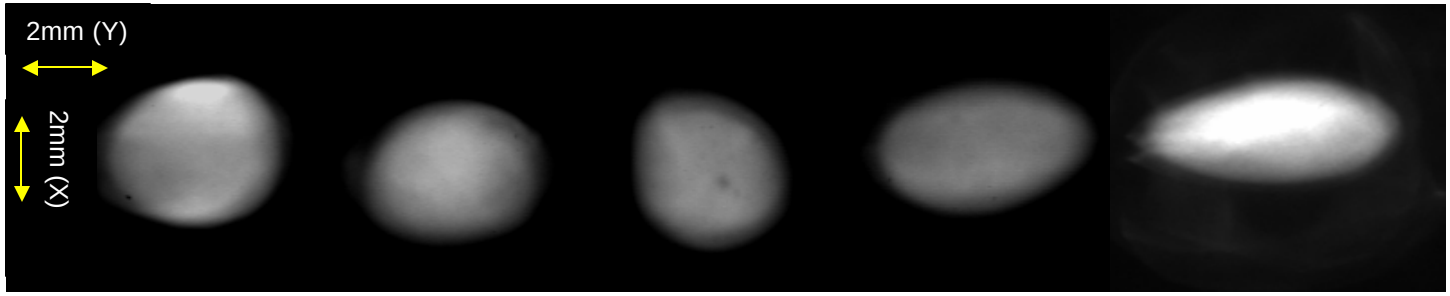
Empirical matching of 23mA Beam (WARP)



Courtesy: Prof.Kishek

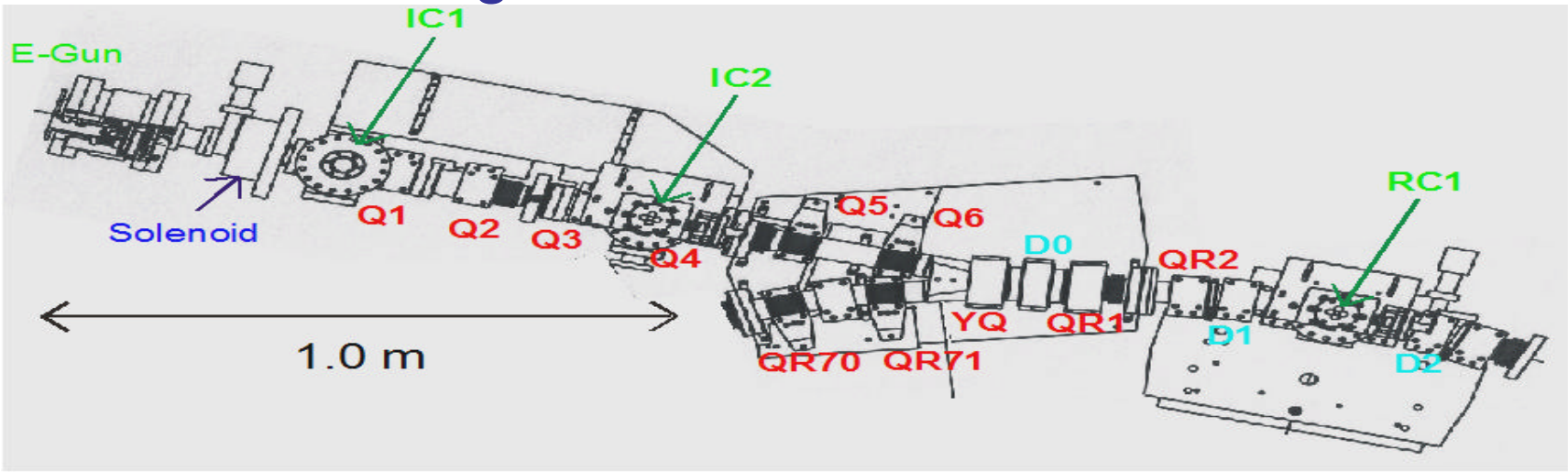
Experimental results of 23mA Beam (Single Turn)

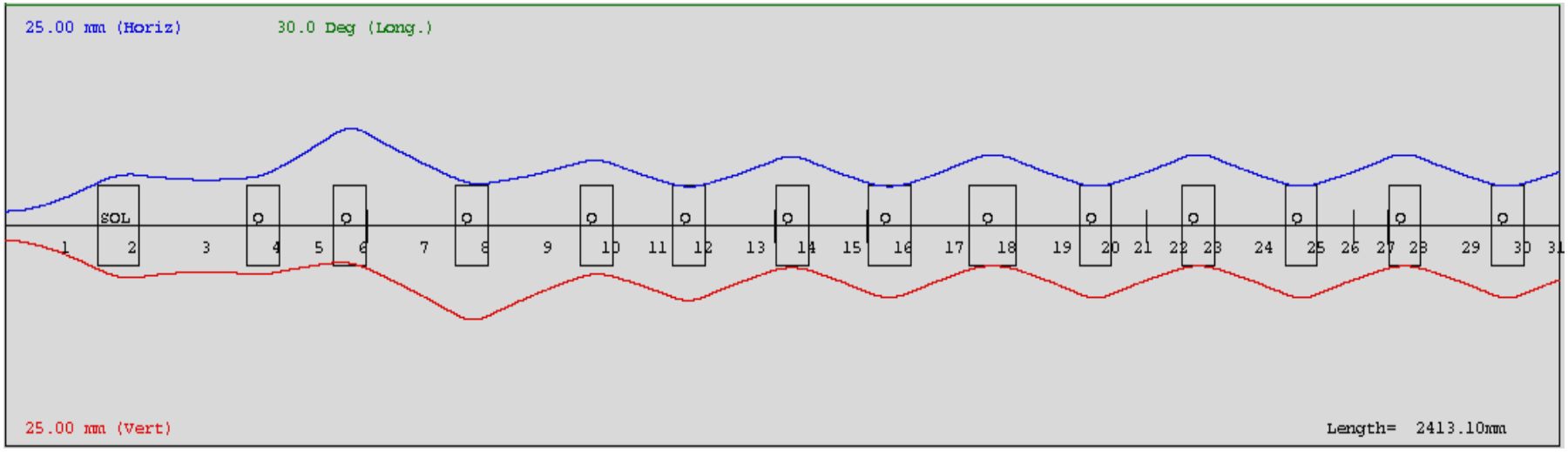




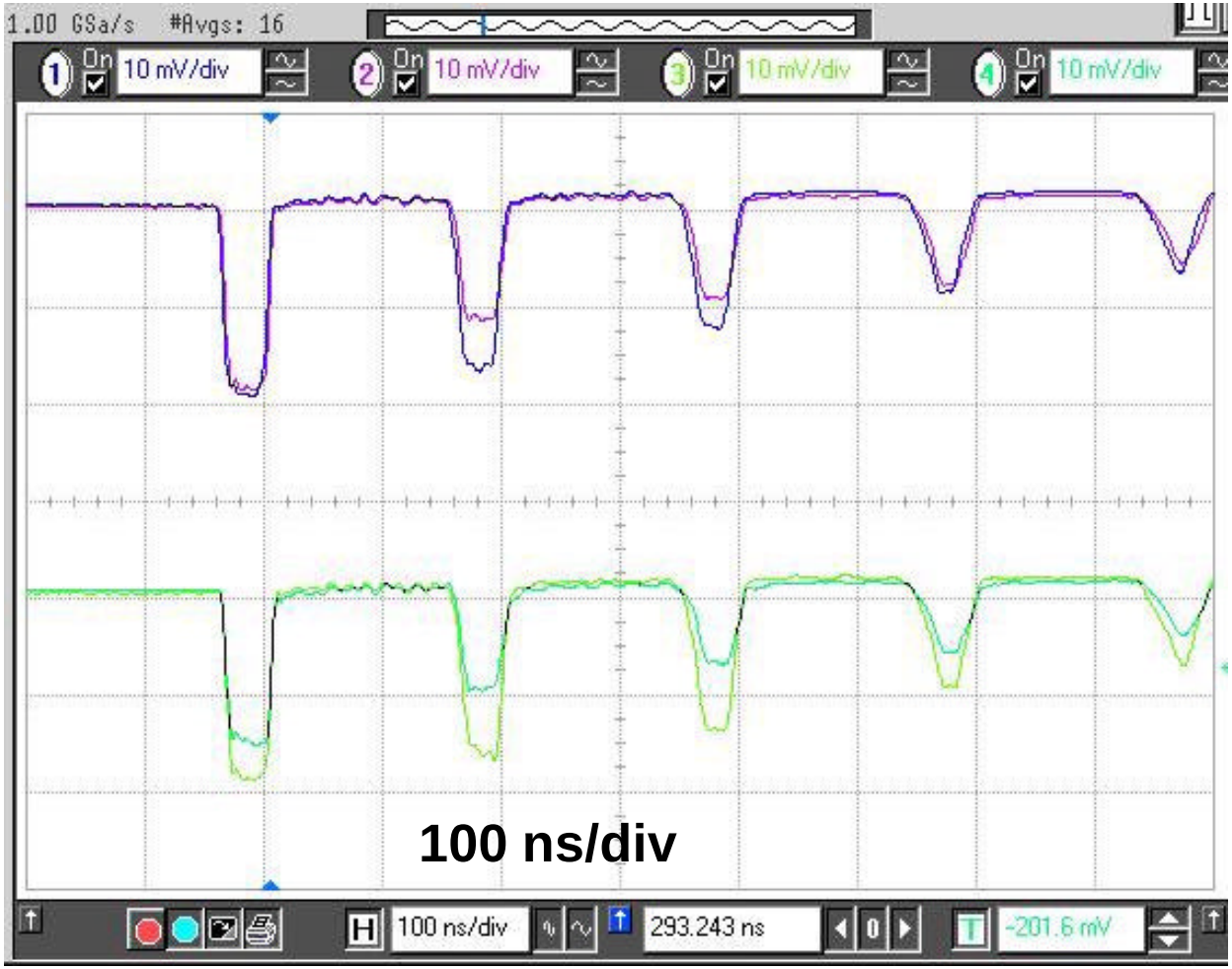
Z=1.91 m Z=3.19 m Z= 5.11 m Z=5.75 m Z=7.03m

Matching for Multi-Turn – 23mA Beam





Multi-Turn Experiment– High current beam



10 mv/div

horizontal

vertical

BPM signals

Conclusions

- Multi-turn (over 100) beam transport of low current (0.55mA) beam.
- Two schemes of injection have been investigated.
- Multi-turn operation of high current beam (23mA) has been achieved with current loss. Work in progress.

Thank You and thanks to ….