Recent Developments at the NSCL Small Isochronous Ring

NSCL/MSU

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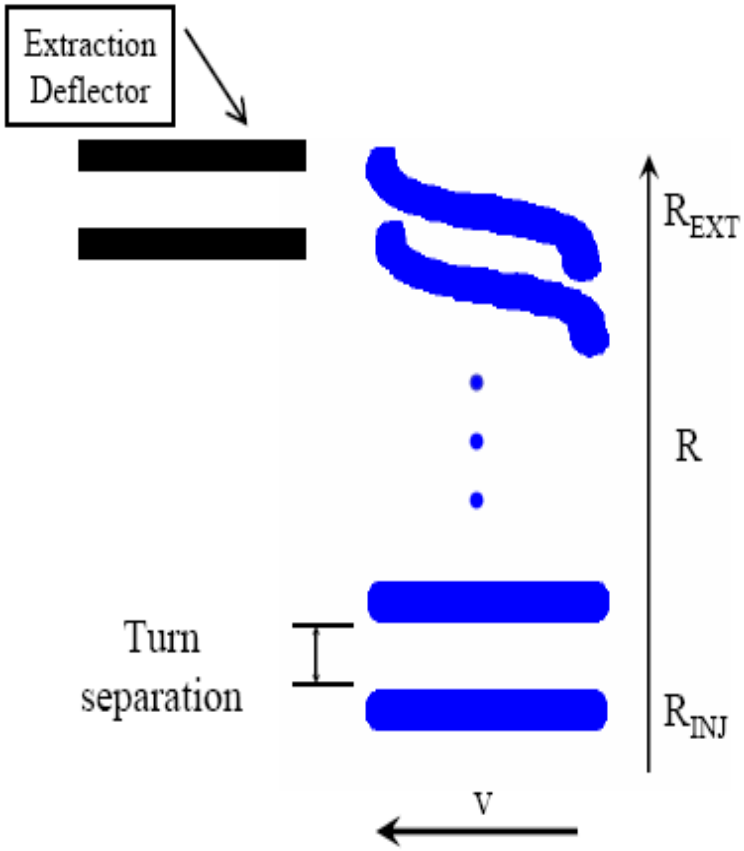
Main Topics

- Brief Introduction to Small Isochronous Ring (SIR)
- Beam Instability
- Design of Energy Analyzer
- Energy Spread Measurement

Space Charge Effects



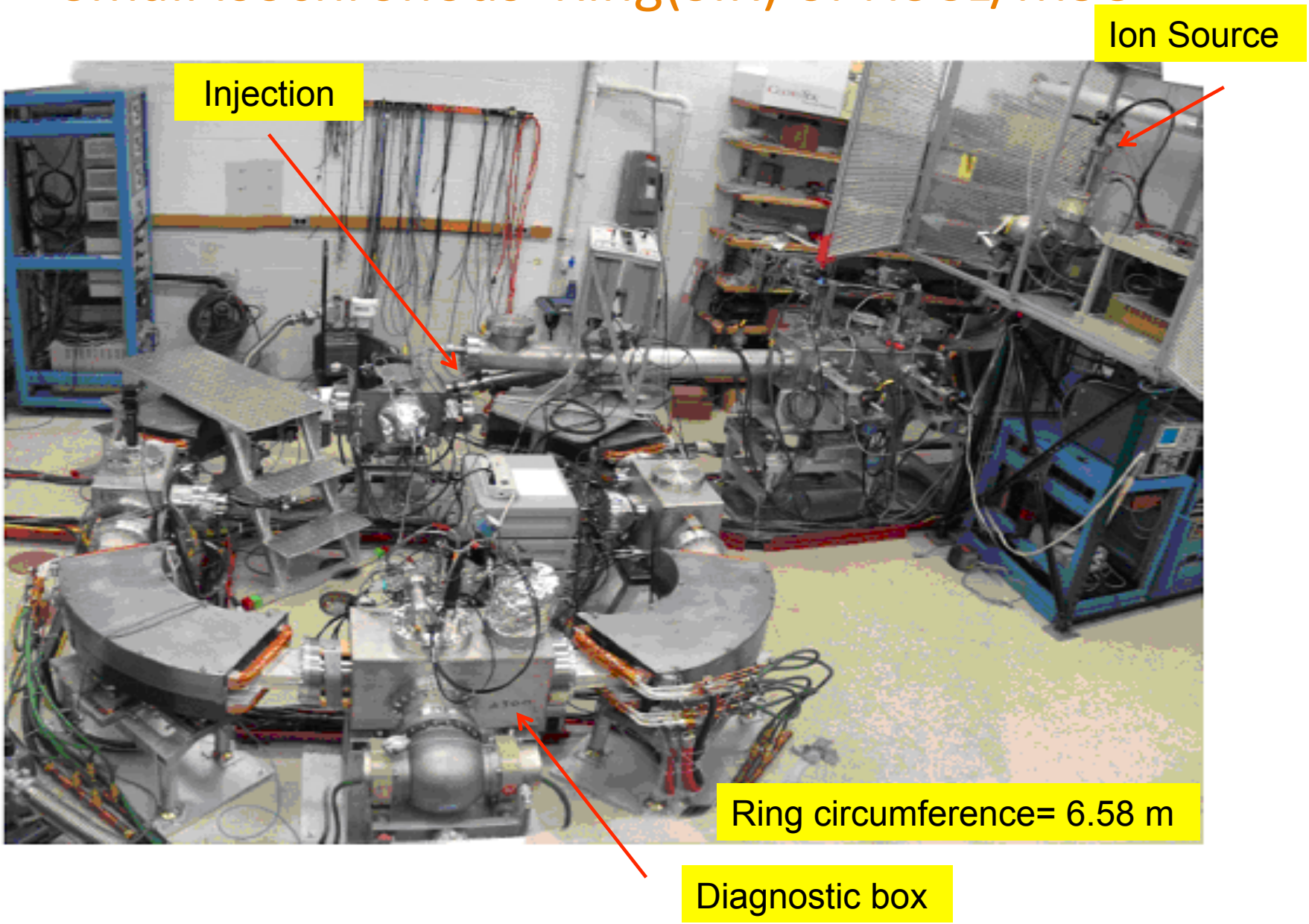
- Why are we interested in space charge forces in isochronous accelerators?

- Longitudinal space charge forces increase energy spread

- Adjacent turns overlap, reducing the turn separation at extraction, increasing losses

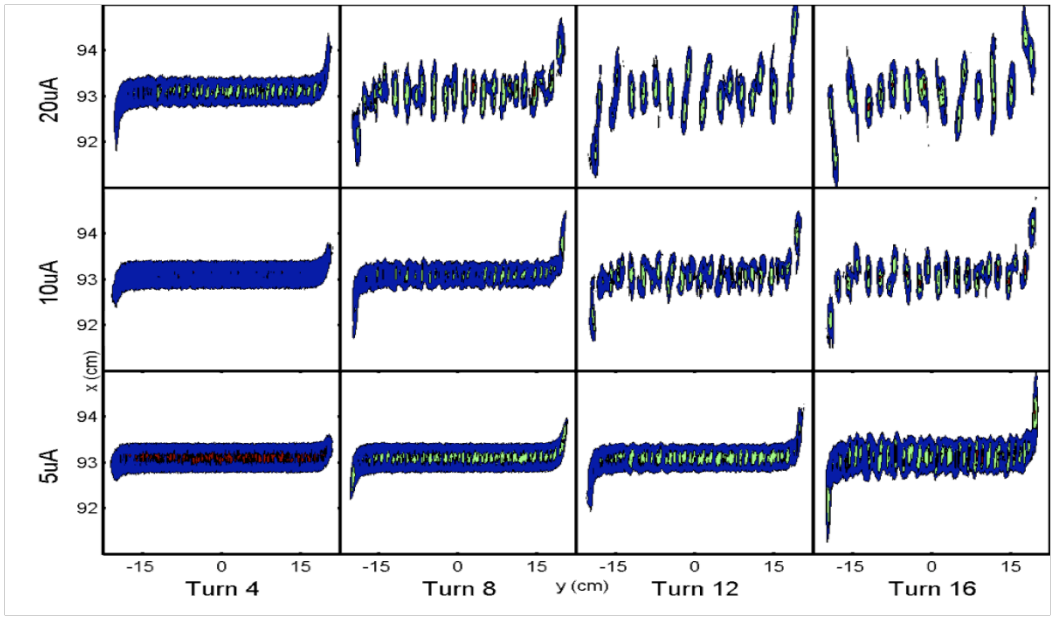
The Small Isochronous Ring was started as a PhD dissertation work by E. Pozdeyev and J. A. Rodriguez to study space charge effects in Isochronous accelerators.

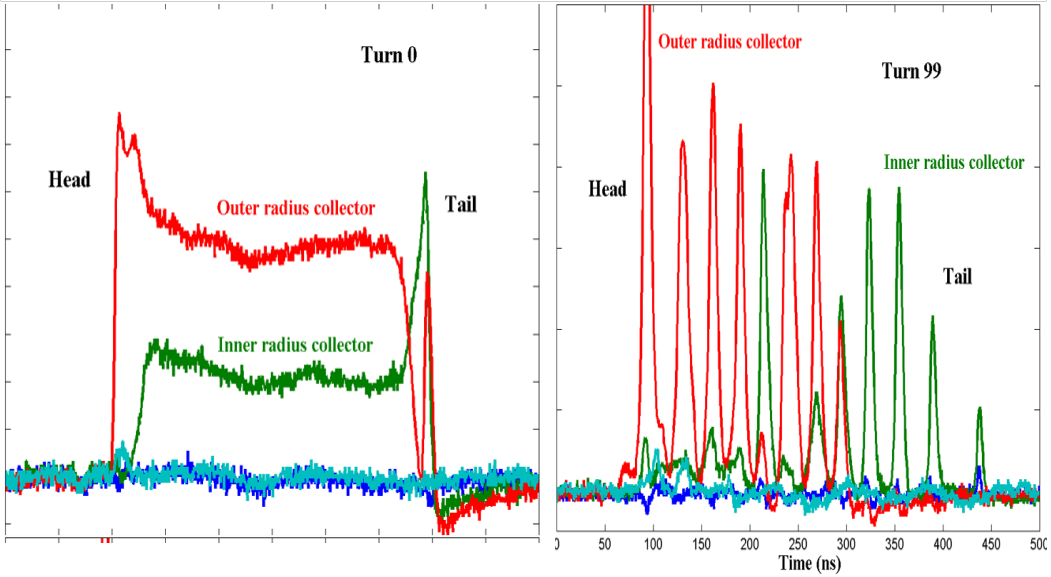
Small Isochronous Ring(SIR) of NSCL/MSU



Beam Instability of SIR

30 cm





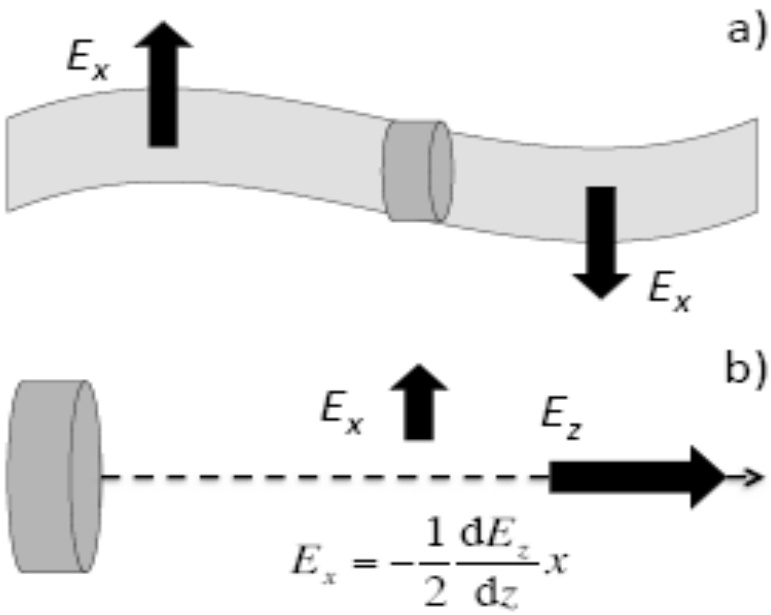
Simulations of beam breakup by CYCO [1] shows the onset of the instability and its dependence on the beam current.

Experimental results obtained at SIR showing the breakup of the beam[2]

[1]E.Pozdeyev, Ph.D thesis, Michigan State University(2003)

[2] J.A.Rodriguez, Ph.D thesis, Michigan State University(2004)

Beam Instability of SIR[1]



- Initial charge modulation induces energy modulation, then radius oscillation.
- The dispersion function changes and so does the slip factor.
- Working point is raised above transition, then instability takes place
- Growth rate of instability is proportional to Beam current I_0 instead of $I_0^{1/2}$

[1] E. Pozdeyev et al. FR5RFP036 of this conference and PRSTAB to be published.

Importance of Energy Spread

- Energy spread is key to the long-term beam distribution and instability
- Particle distribution function[1]

$$f=f_0(\varepsilon,t)+f_1(\varepsilon,\theta,t)=f_0(\varepsilon,t)+\mathrm{Re}\left[\sum_{n\neq 0} h_n(\varepsilon,t)e^{i(n\theta-\Omega_n t)}\right]$$

Where $\varepsilon = E-E_0$ is energy shift

Ω_n is only a function of energy shift ε by dispersion relation

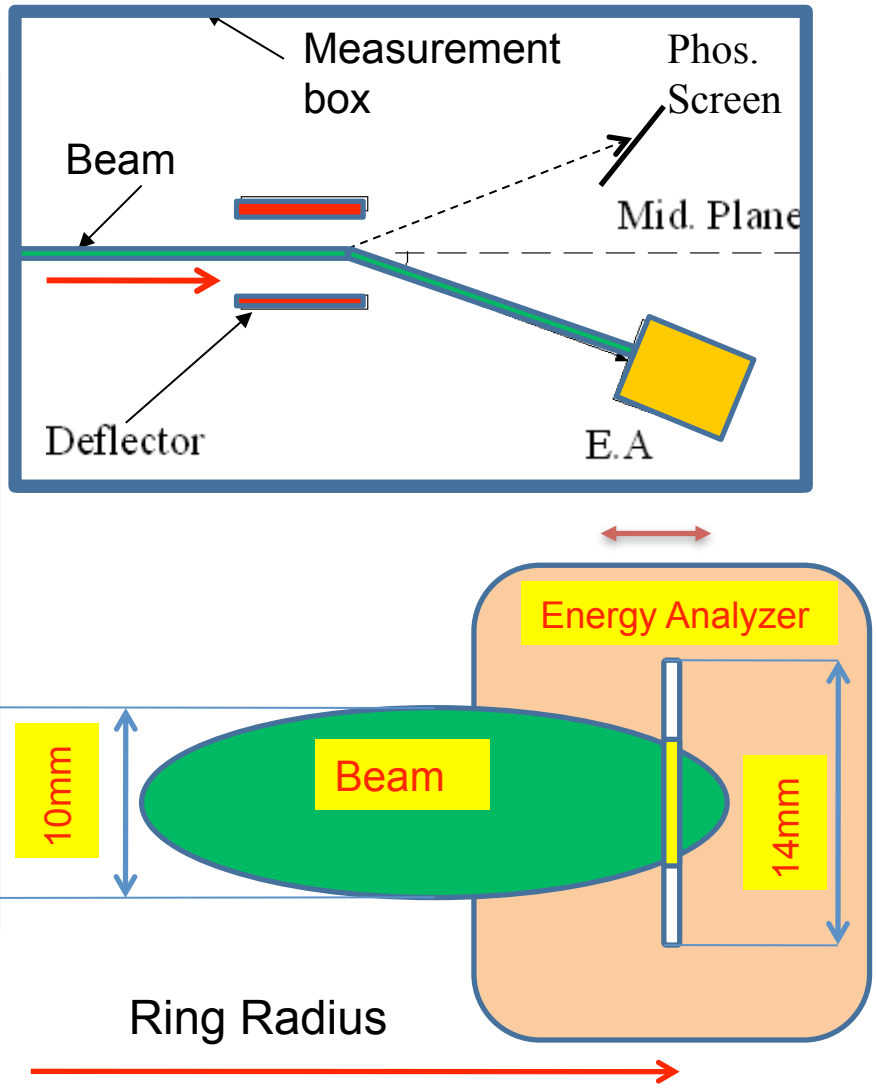
[1]Yongho Chin et al. *Physics Review D* , Volume 28 Number 9 (1983)

Design Parameters of Energy Analyzer for SIR

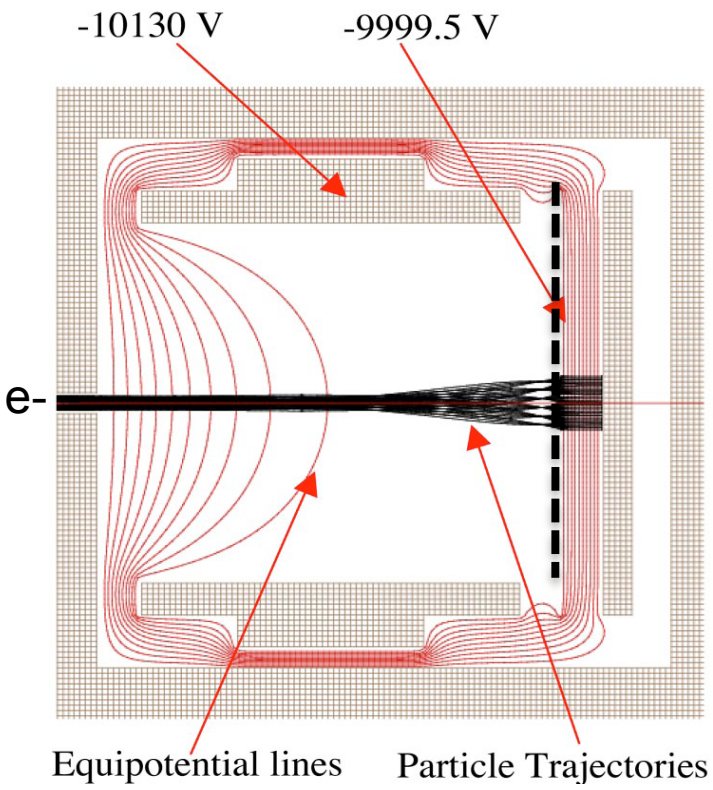
- Ions : H_2+
- Beam Energy: 20 keV
- Beam Current: 10-30 uA
- Energy change (SC)/turn: 7-8eV
- Beam Radius: 5mm
- Half Disp. Angle: < 5mrad
- Entrance Slit : 14×1mm
- Restriction of Space:

  L<80mm,H<70mm,W<80mm

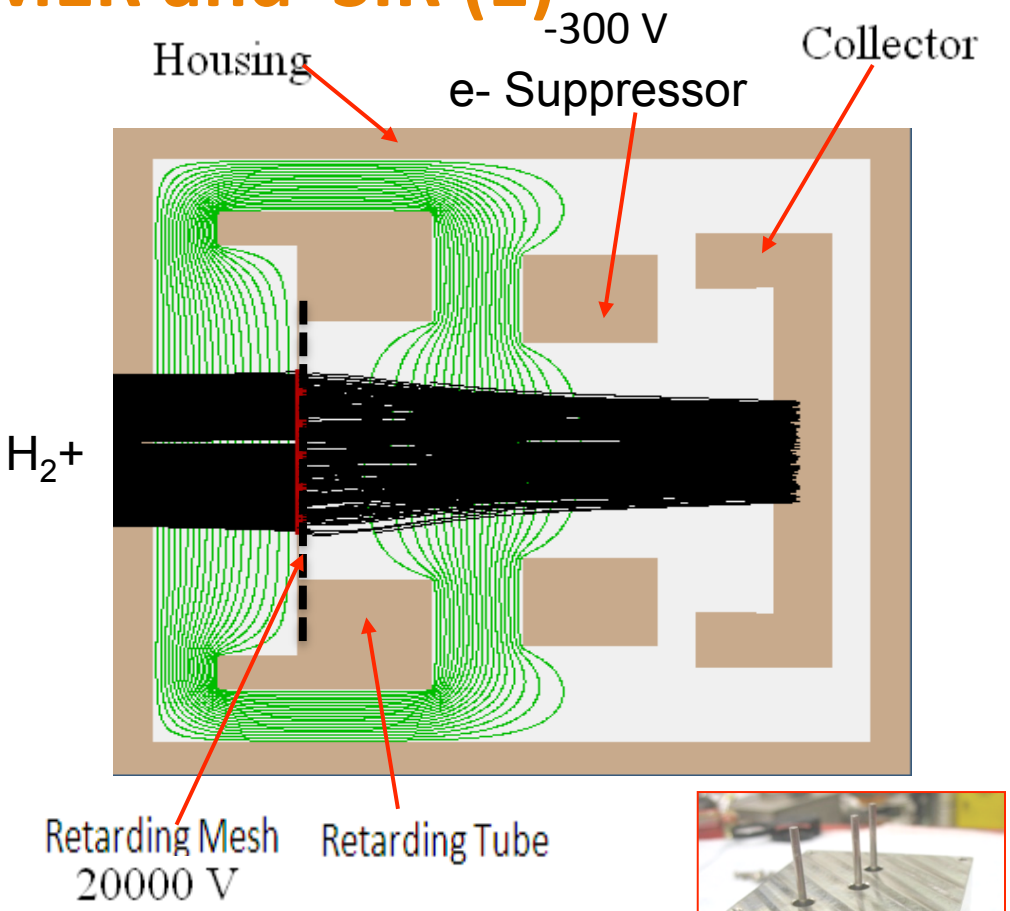
  The Analyzer should be movable along ring radius.



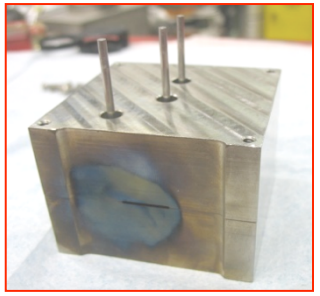
Comparison of Analyzers Between UMER and SIR (1)



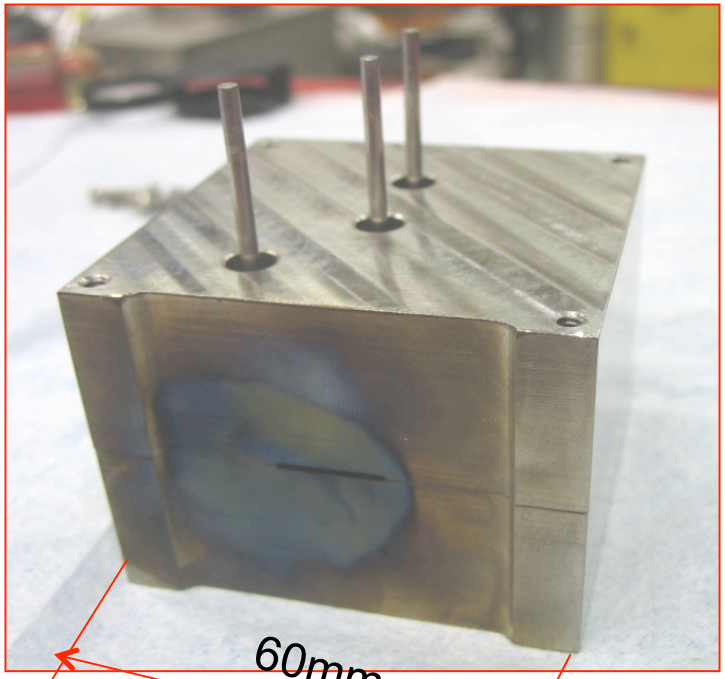
UMER Analyzer[1]
(U. of Maryland)

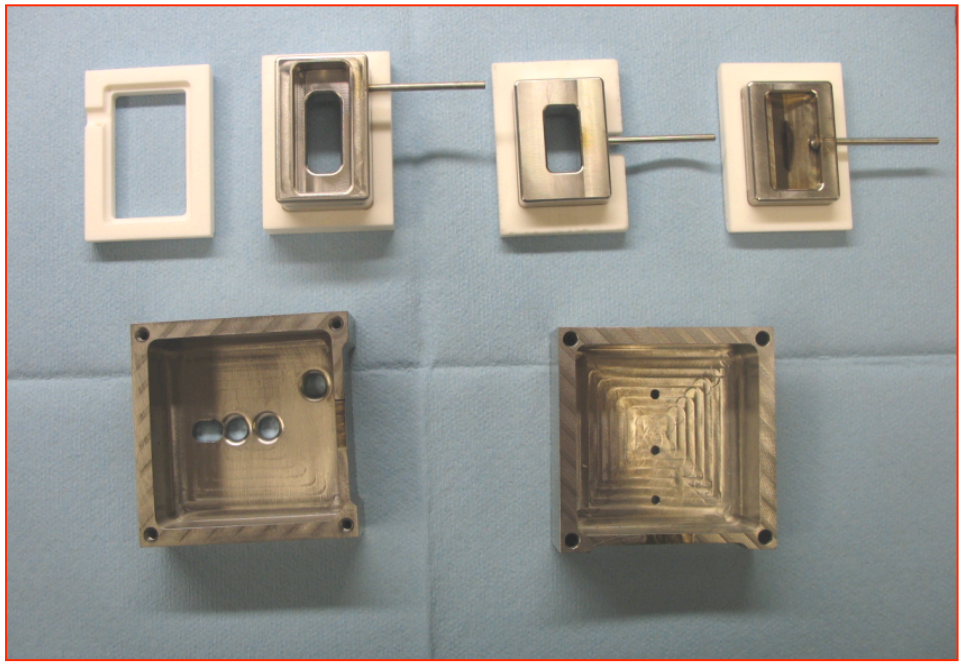


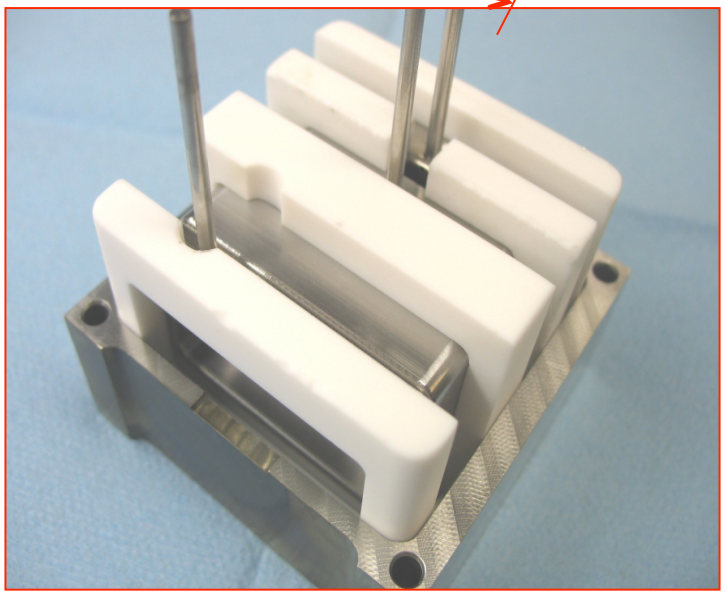
SIR Analyzer
(NSCL/MSU)

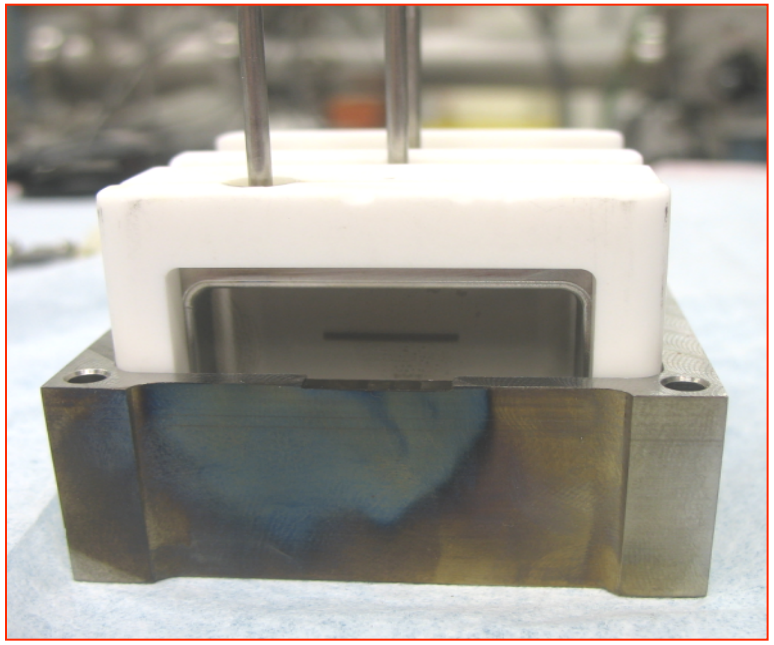


[1] Y.Cui,Y.Zou,et al. *Review of Scientific Instruments Volume* 75 Number 8 (2004)

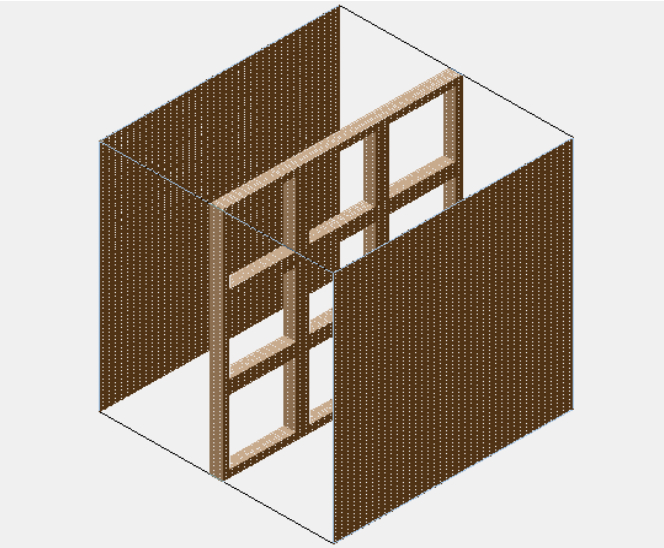

60mm

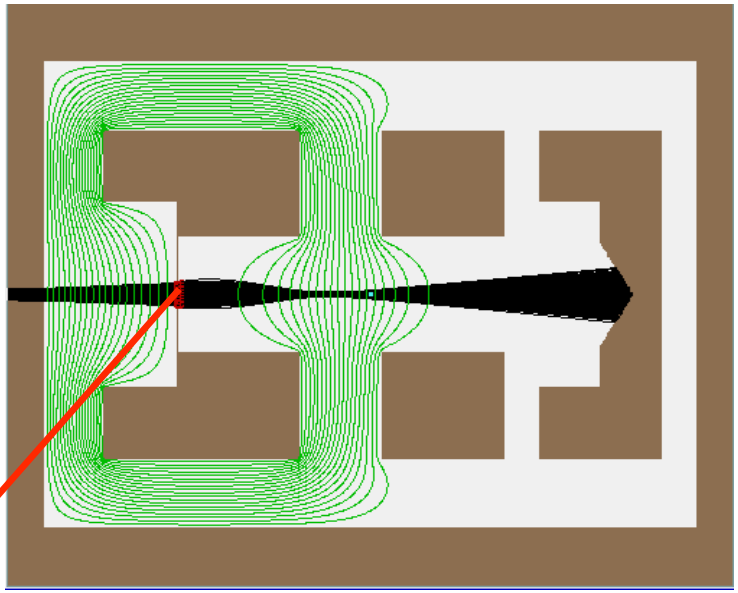


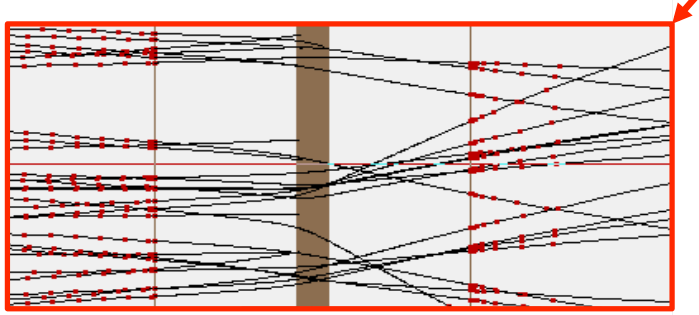




Field Model of Real Mesh (SIMION 8.0)





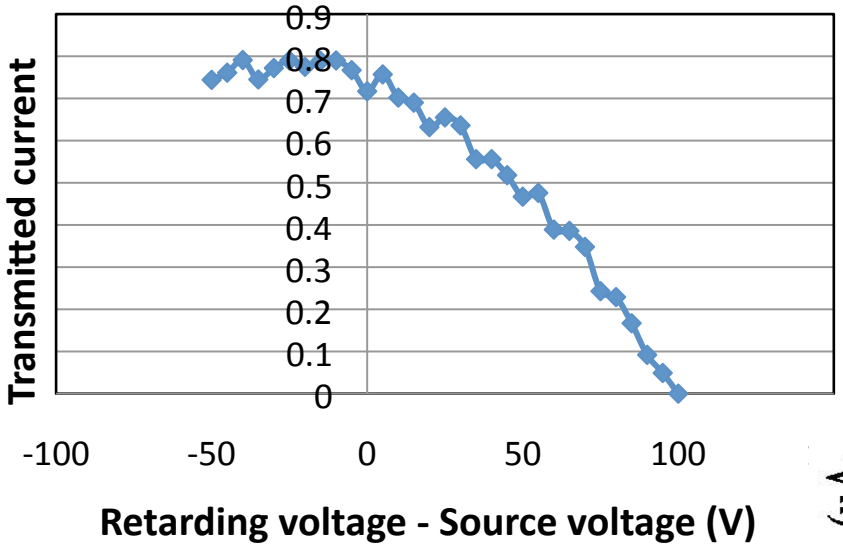


- The potential on the retarding plane is not uniform
- we set up a small piece of field model which can move along the retarding plane to represent the whole real mesh in simulation .

Performance of Analyzer with Coarse Grid

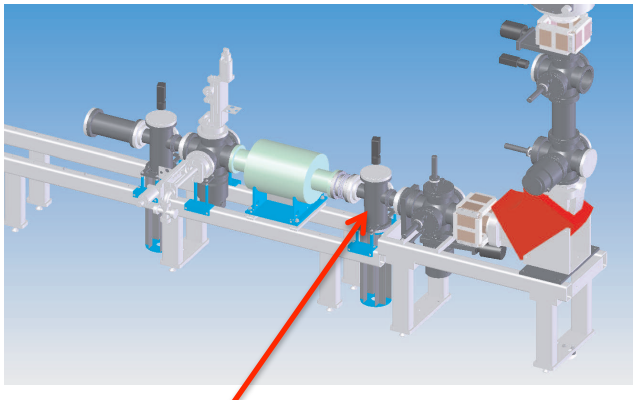
(Lines Per Inch(LPI)=100 Transmission Rate=72%)

SIMION simulation ΔE/E=5e-3

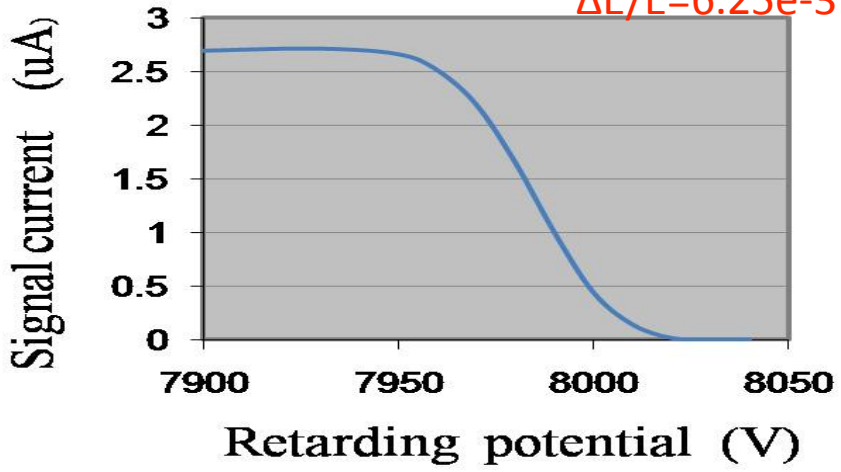


Retarding voltage=20 kV

ARTEMIS-B Ion Source[1]

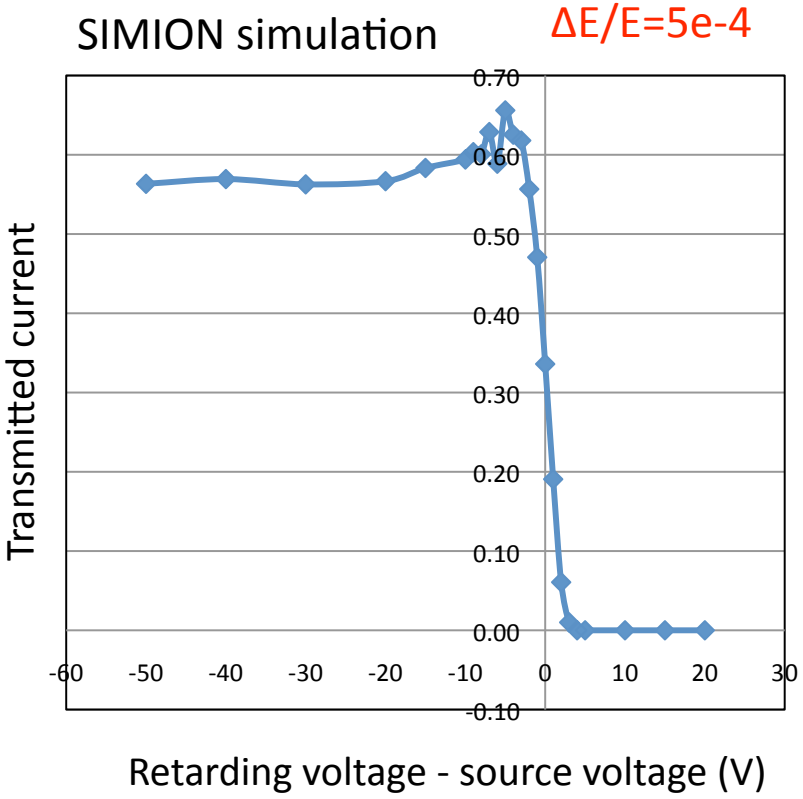


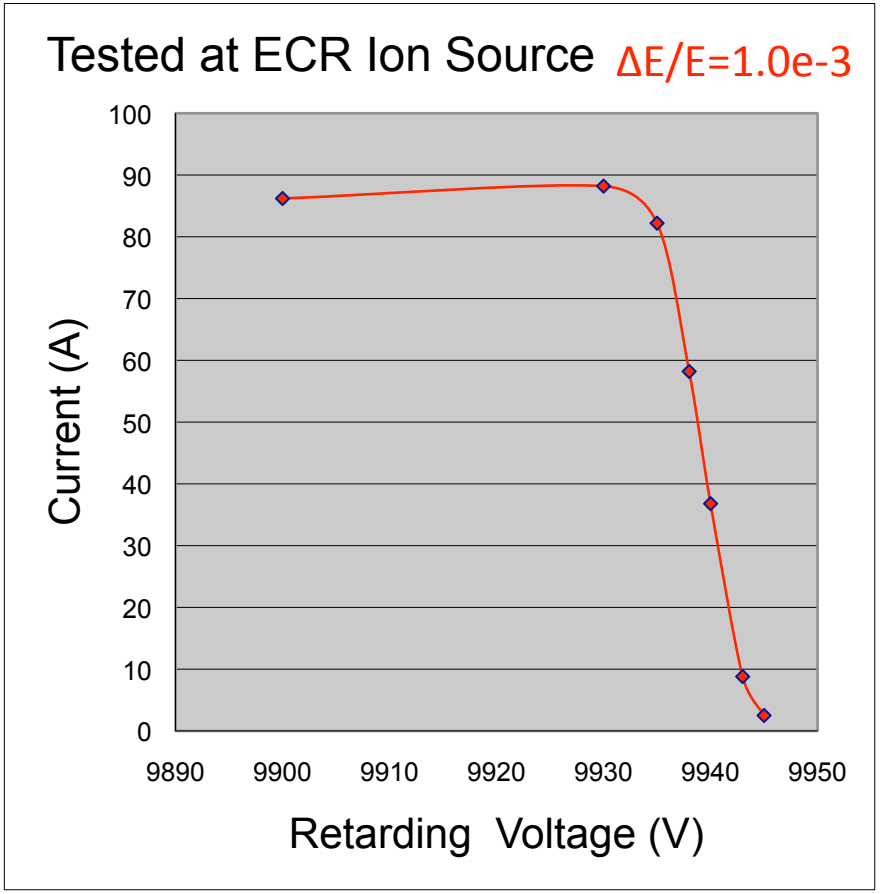
ΔE/E=6.25e-3



[1] G.Machicoane et. al *Rev. Sci. Instrum.* 77, 03A322 (2006)

Performance of Analyzer with Fine Mesh (LPI=1000,Transmission rate=50%)



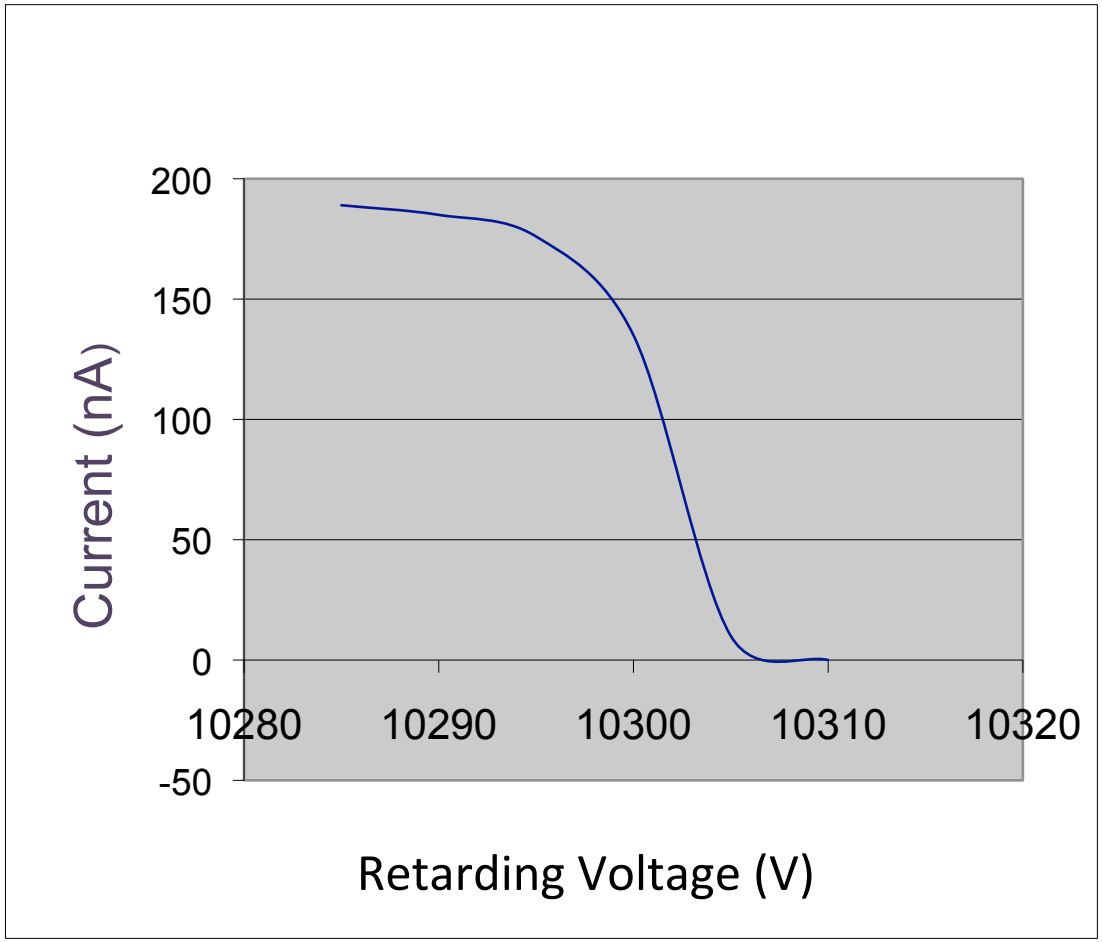


Retarding voltage=20 kV

Performance of Analyzer Tested at SIR

(DC beam, LPI =1000)

Δ E/E=1.3 e-3



- Work in progress
- Preliminary results with DC beam.
- Noise issues have to be worked out to work with pulsed beam.

Future Work

- Improve Signal to Noise ratio for pulsed beam in SIR
- Measure energy spread of pulsed beam in SIR
- Solve Nonlinear Vlasov Equations numerically in which slip factor:

$$\eta = \eta_{s.c} + \eta_0 + \eta_1 \frac{\varepsilon}{\beta^2 E} + O(\varepsilon^2)$$

- Compare measurement results with analytical solution to explain the Growth Rate of Instability, Saturation of energy spread, etc.

Acknowledgement

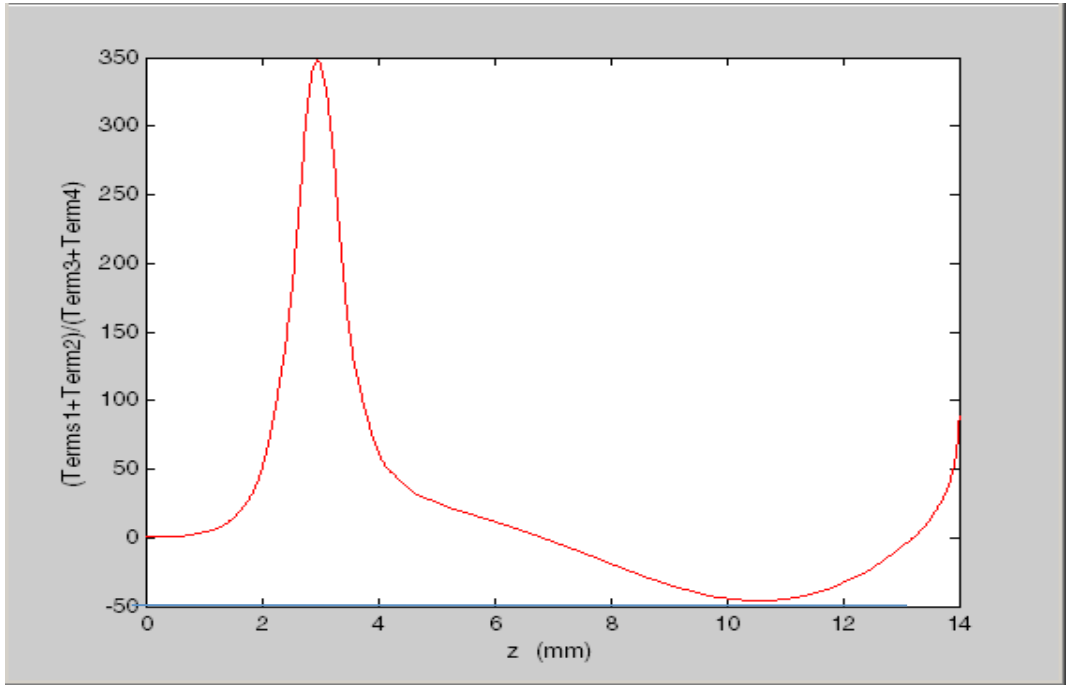
- Supervisor: Felix Marti
- E. Pozdeyev, Tom Wangler.
- John Oliva : Mechanical Design
- Guillaume Machicoane: Experiments
- Technician of NSCL Workshop
- Special thanks for generous help from colleagues of University of Maryland

Sheet Beam Envelope Equation[1]

$$X'' = -\left(\frac{\gamma'}{\gamma\beta^2}\right)X' - \left(\frac{\gamma''}{\gamma\beta^2}\right)X + K_x + \frac{\varepsilon_n^{\,2}}{\beta^2\gamma^2 X^3}$$

$$K_x = \frac{qJ}{2\varepsilon_0 m_0 (\gamma\beta c)^3}$$

(Term1+Term2)/(Term3/Term4) V.S distance



Typical beam parameters:

E_0=20050eV,

ε_0=1.0 π mm*mrad

I_0=20 uA

Xo=0.5mm

X'o=1.6 mrad

It shows that the change of beam current and emittance has little effects on resolution of analyzer during measurement

[1]Stanley Humphries, <*Charged Particle Beams*>,John Wiliey&Son,1990

Importance of Energy Spread

- Particle distribution function[1]

$f=f_0(\varepsilon,t)+f_1(\varepsilon,\theta,t)=f_0(\varepsilon,t)+\mathrm{Re}[\sum_{n\neq 0} h_n(\varepsilon,t)e^{i(n\theta-\Omega_n t)}]$

Where $\varepsilon = E-E_0$ is energy shift

- Dispersion relation[1]:

$$1-\frac{(e\omega_0)^2}{2\pi} iZ_n \int_{-\infty}^{\infty} \frac{\partial f_0(\varepsilon,t)/\partial\varepsilon}{\Omega_n - n(\omega_0 + k_0\varepsilon)} d\varepsilon = 0$$

$$k_0 = -\eta\frac{\omega_0}{\beta^2 E},\quad \eta = \eta_{s.c} + \eta_0 + \eta_1\frac{\varepsilon}{\beta^2 E} + O(\varepsilon^2)$$

Where Ω_n is only a function of energy shift ε

[1]Yongho Chin et al. *Physics Review D* , Volume 28 Number 9 (1983)

Comparison of Analyzers Between UMER and SIR(2)

	UMER	SIR
Extraction	Single pass	Variable Turn
Beam Species	e-	H_2+
e- Suppressor	No	Yes
Entrance Hole	1mm hole	14mm*1mm slit
Electrodes and Housing	Cylindrical	Rectangular
Working Mode	Static	Scanning
Beam Intensity	mA	nA