Diagnostics for intense heavy ion beams in the HIF-VNL*

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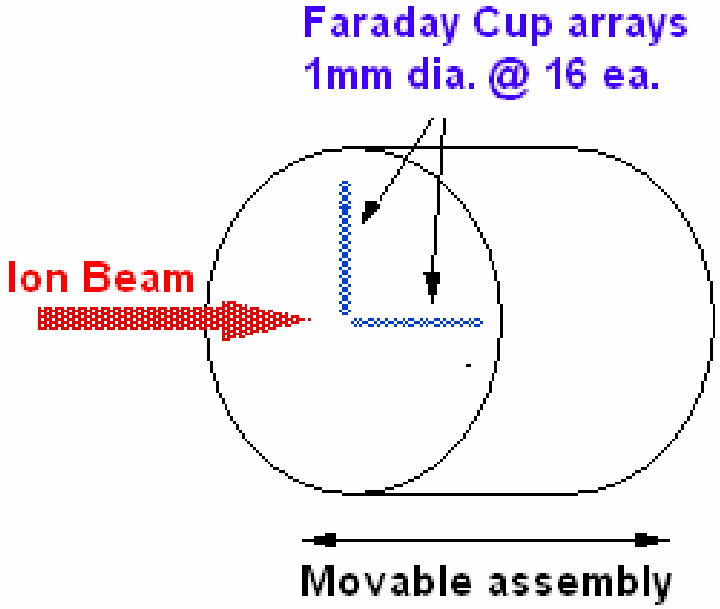
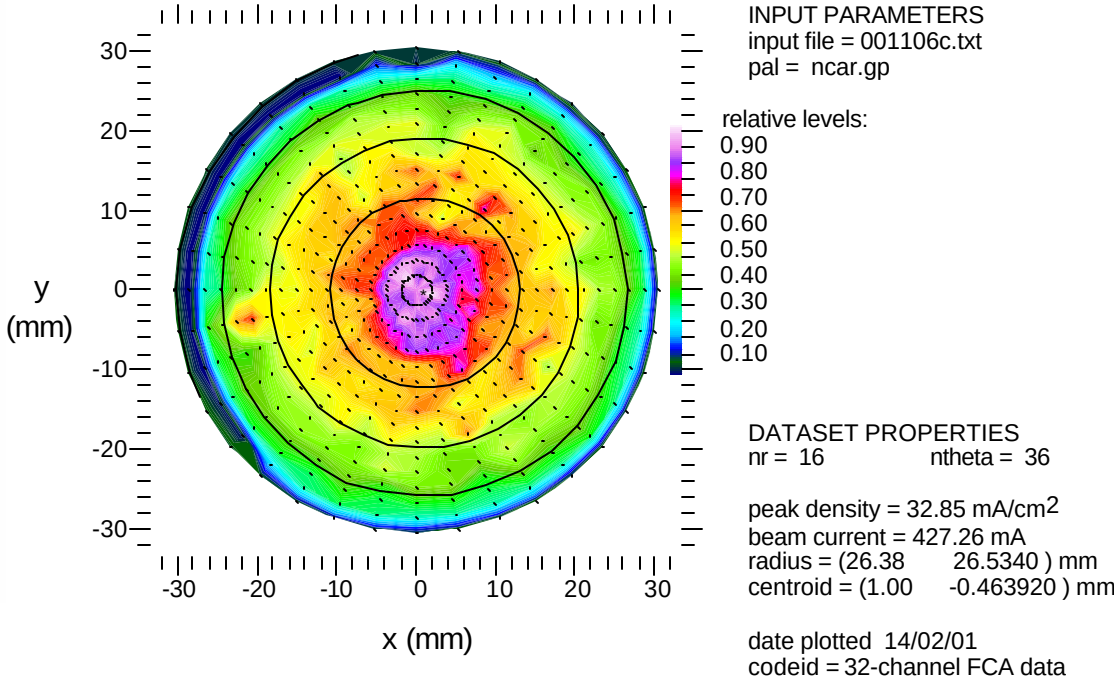
Introduction

- HIF-VNL experimental beams are K^+, Cs^+, Ar^+, 50 keV to 2 MeV, <1 to >100 mA/cm^2, 4-20 ms pulse length.
- Diagnostic access is limited by high longitudinal occupancy in beam transport lines.
- High quality diagnostics are necessary because of nonlinear, collective effects in intense beams, and to interface with simulations.
- Diagnostics grouped into three categories:
  - Intercepting – Faraday cups, slit scanner, kapton and optical imagers, electrostatic energy analyzer
  - Passive nonintercepting – magnetic, capacitive pickups, secondary particle diagnostics
  - Active nonintercepting – electron beam probe, space charge waves

Multiple Faraday cup array has been used to measure beam current density profile in 2 MV Injector (now HCX) diode.



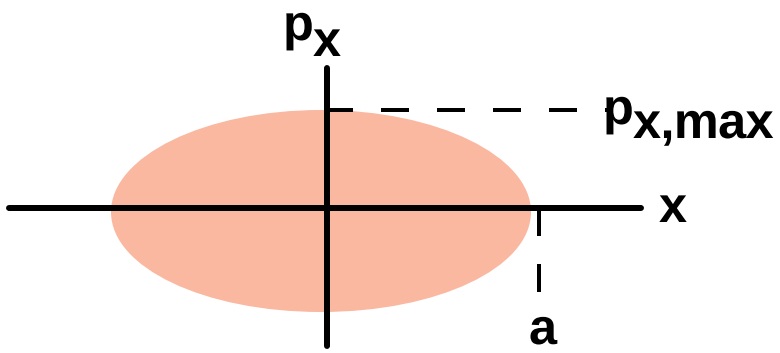


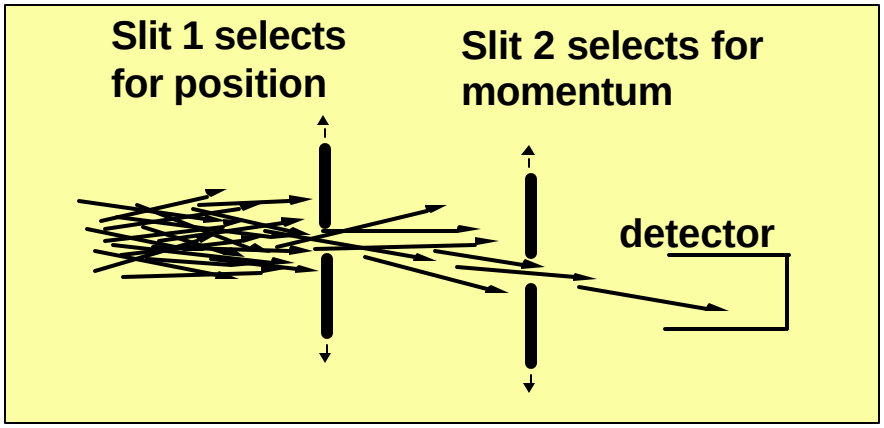
Rotatable assembly of 32 miniature Faraday cups inserted in the diode region

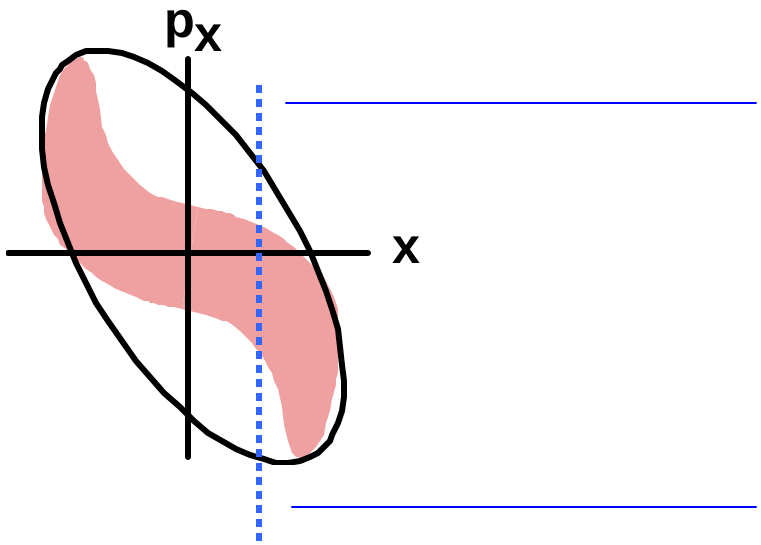
Measured beam current density profile obtained from the Faraday cup array

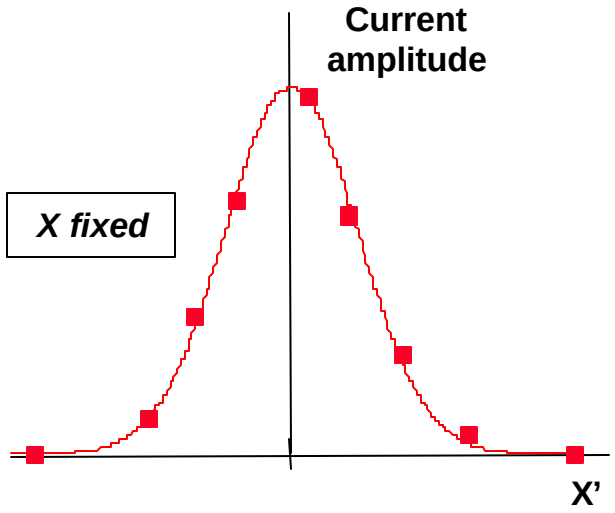
Emittance slit scanner measures 2-D transverse emittance.

Two-dimensional emittance is determined by the distribution of particles in the (x-x') or (y-y') space ($x'=p_x/p_z$).



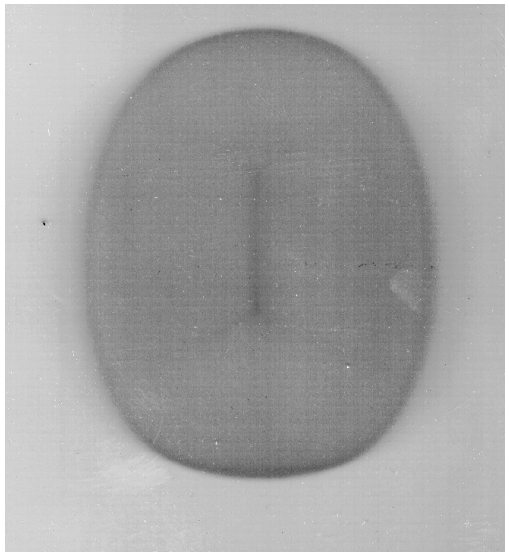






Beam imaging with kapton film and ceramic scintillator.

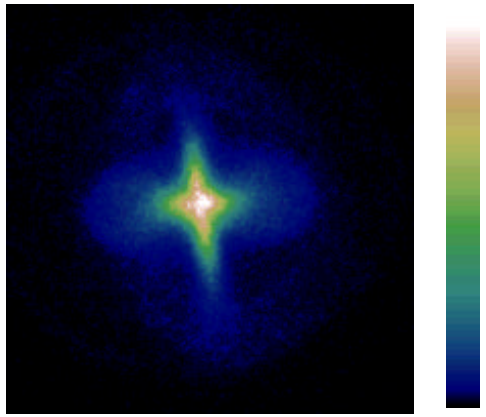
- **Kapton: Heavy-ion beam pulse damages bonds in exposed kapton film – image on the film represents the time-integrated beam pulse. Bieniosek et.al. Rev. Sci. Instrum. 73, 2867 (2002).**



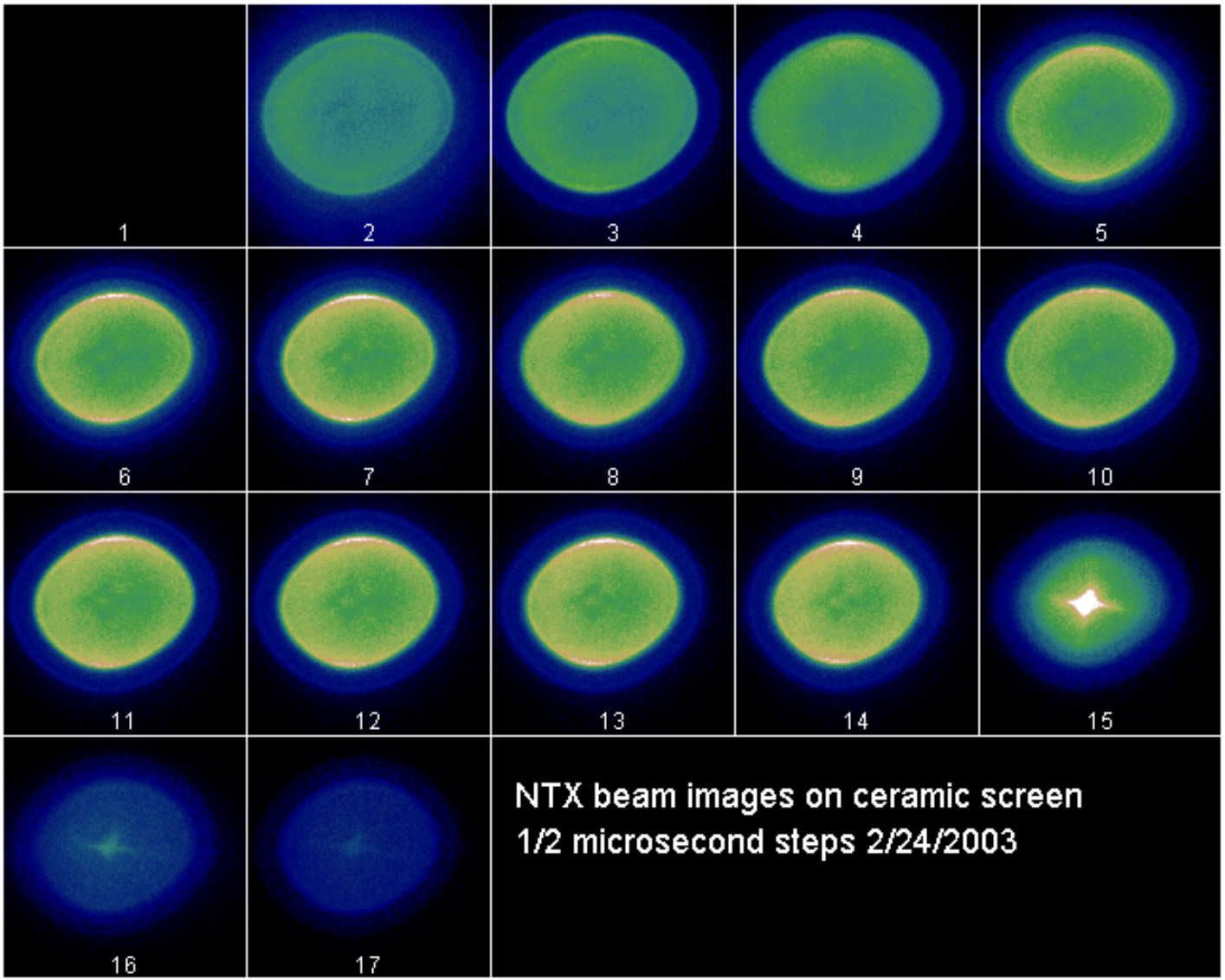
- **Optical techniques:**

  Ceramic (sintered alumina) scintillators are used as the sensing element in a beam imager.

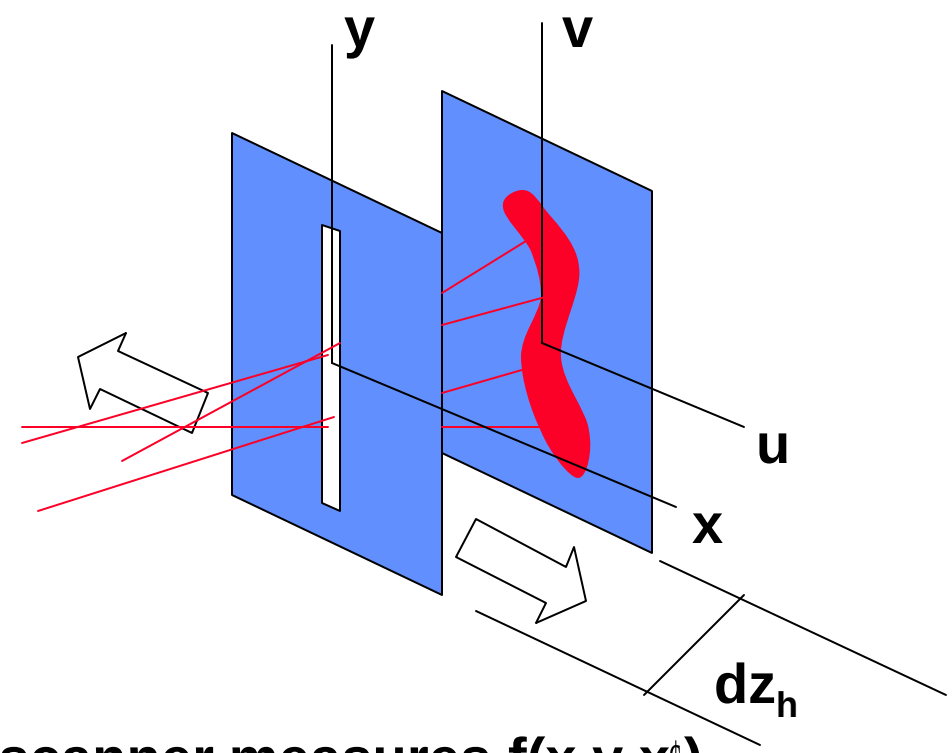
  For long life, full intensity beam must be attenuated by slits, pepper-pot.



Time evolution of the beam pulse is measured by time-gated CCD camera.



Optical slit diagnostic yields a 3-D projection of the 4-D transverse phase space.

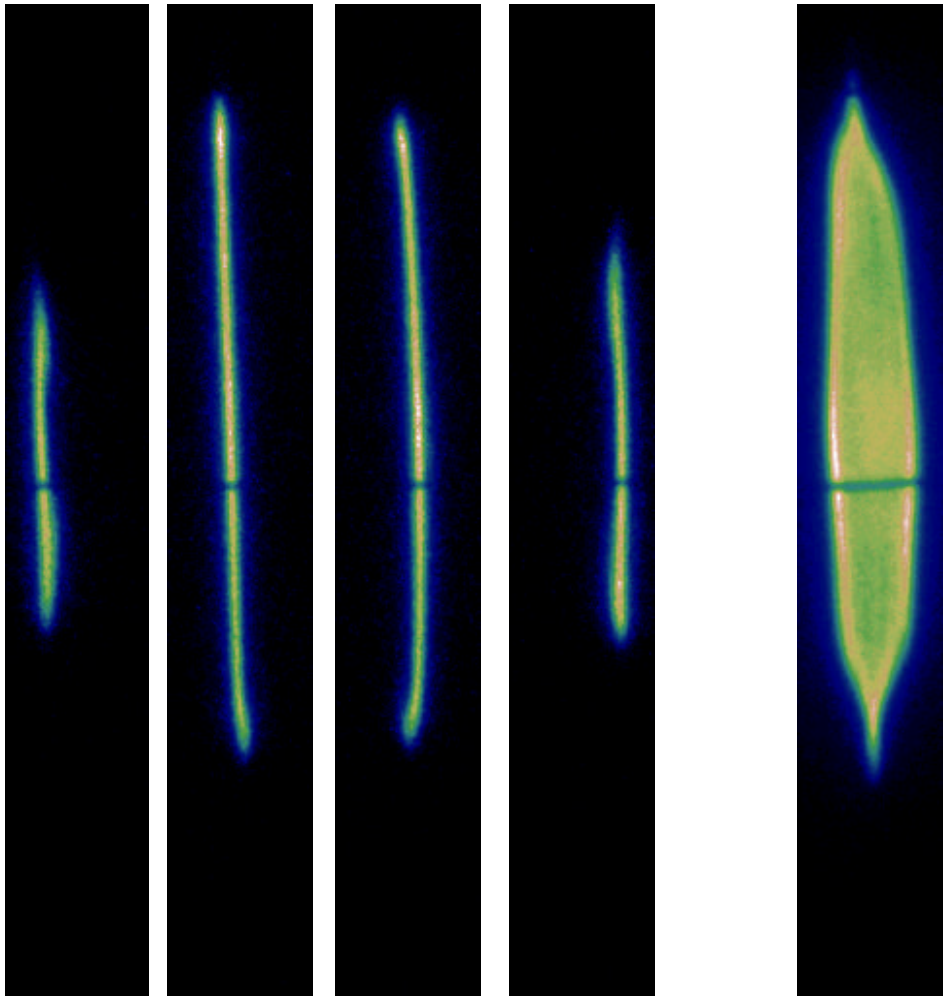


- This scanner measures f(x,y,x¢)
- It contains such information as the (y,y¢) distribution as a function of x, or averaged over all x
- It can be gated in time
- View from front or back

Transverse beam structure is measured by taking a series of images of the beam through the slit at various horizontal locations.

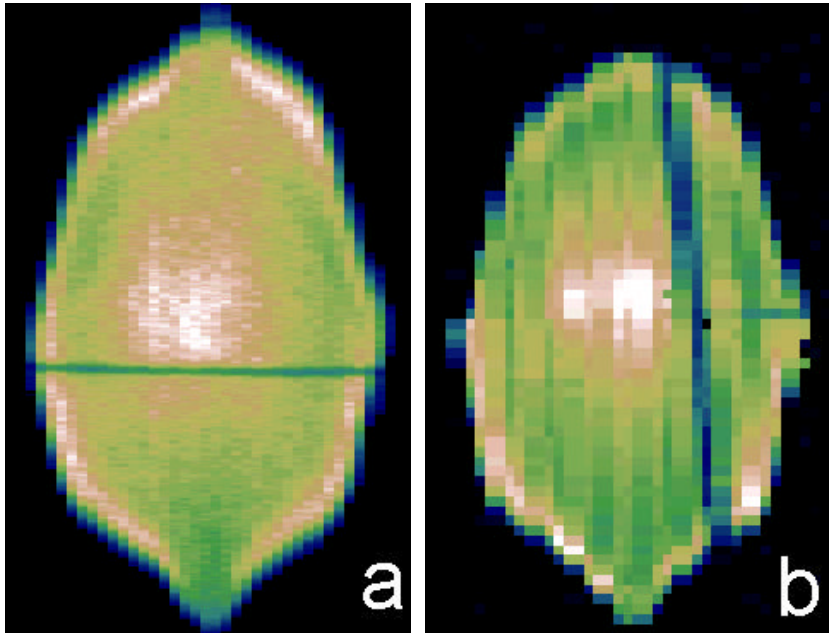
(a) Representative images of the beam through a vertically-oriented slit.

(b) Sum of the slit images in a horizontal scan across the beam.



(a) (b)

Comparison of image of the HCX beam intensity profile referred to the slit plane based on (a) optical and (b) mechanical crossed-slit measurements. The scale is 3.0 x 4.68 cm.



Optical (31 beam pulses)

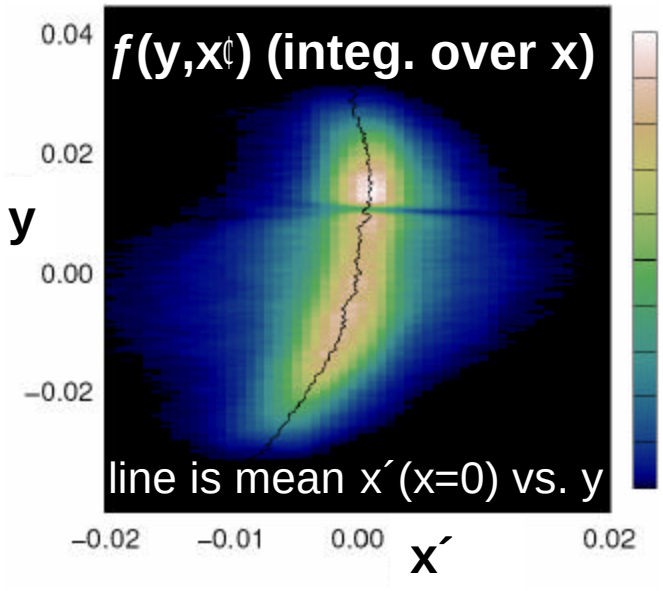
Crossed-slit (4096 beam pulses)

Comparison between measured 2-RMS beam size and 4-RMS emittances shows good agreement:

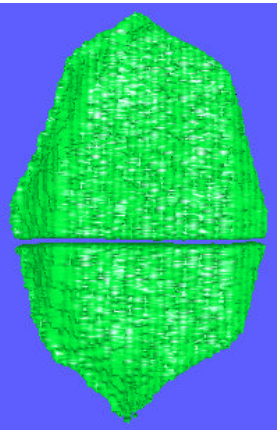
	Double-slit	Optical
a	12.3 mm	12.1 mm
b	20.9 mm	20.4 mm
a´	-37.9 mrad	-35.8 mrad
b´	43.3 mrad	41.6 mrad
e_x	67 p mm mrad	76 p mm mrad
e_y	64 p mm mrad	71 p mm mrad

(The faint band in the images comes from a bridge in the slit.)

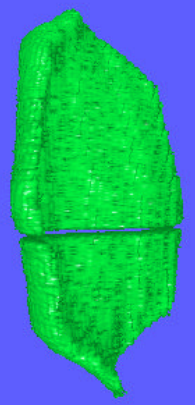
The optical slit diagnostic on HCX yields unprecedented information about the beam distribution



isosurface where $f(x,y,x') = 30\%$ of peak

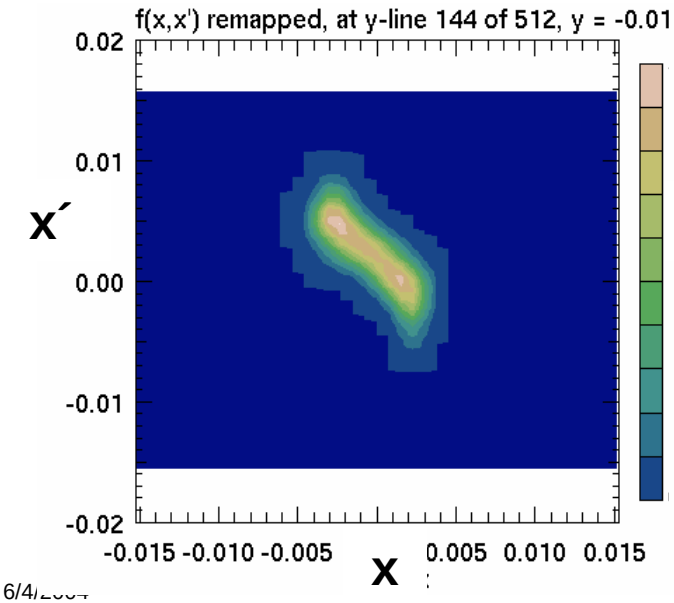


face-on (xy) view

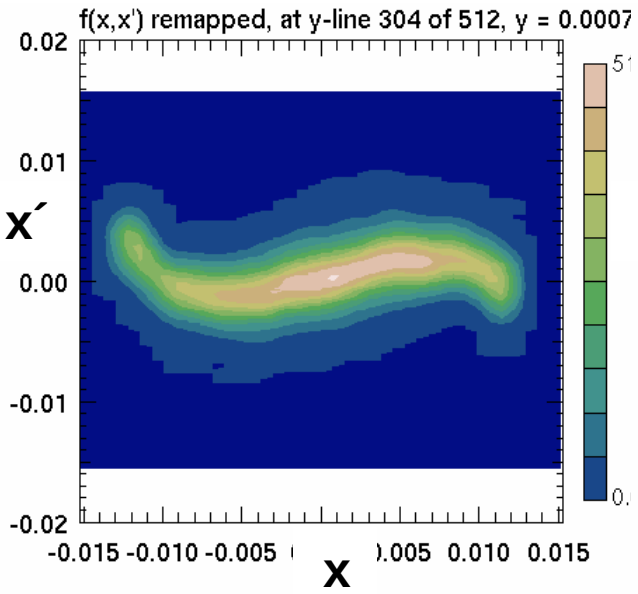


rotated to right

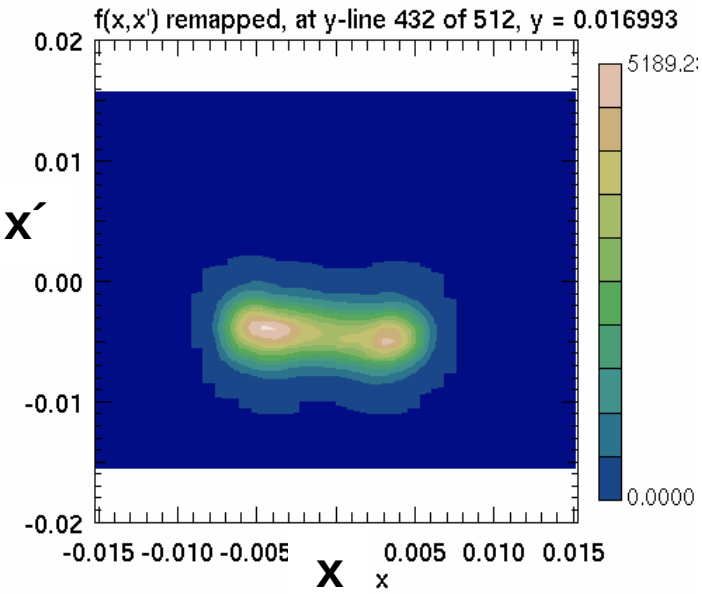
$f(x,-19.5mm,x')$



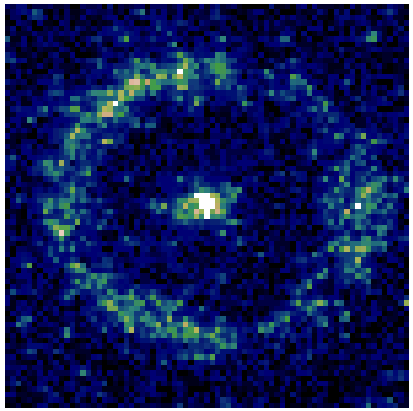
$f(x,0.8mm,x')$

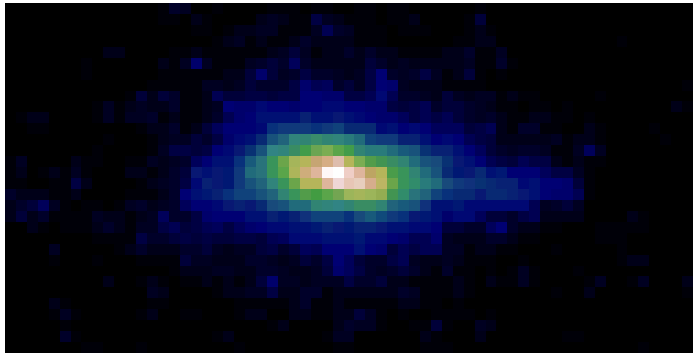


$f(x,17.0mm,x')$



Images of the beam downstream of pinholes provide information about beam particle distribution in x´ – y´ space. Data from NTX also show a ring in x´ – y´ space.





NTX: 23.08 x 23.08 mrad

HCX: 52. 8 x 26.4 mrad

Quantitative interpretation of optical signals should take into account limitations of scintillator.

***Scintillators are damaged by ion beams, and sensitive to electrons.**

*** Turn on <50 ns, turn off complicated <1 ms.**

***Light emission from surface gas cloud can affect the image.**

Image on scintillator

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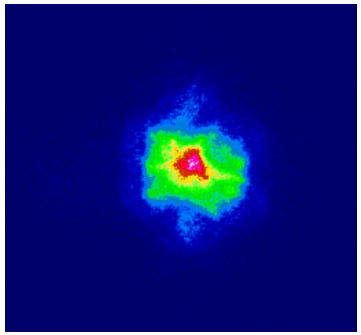

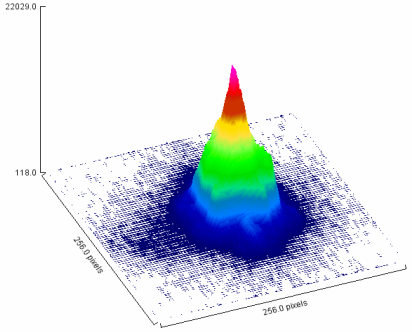

Image on hole plate

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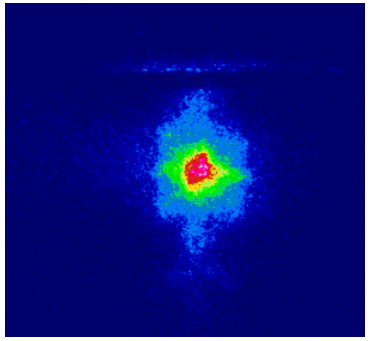
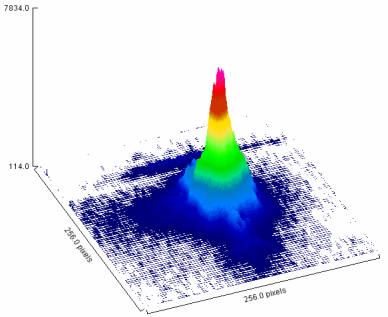
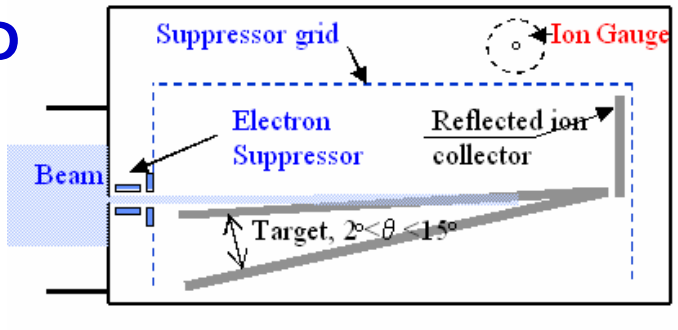


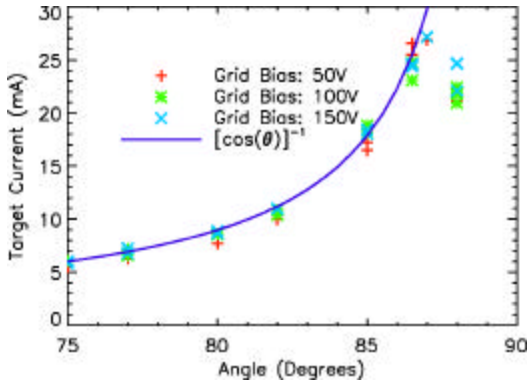


Hole plate

Gas-Electron Source Diagnostic (GESD) and gridded probes measure gas desorption and secondary electron and ion emission.

GESD



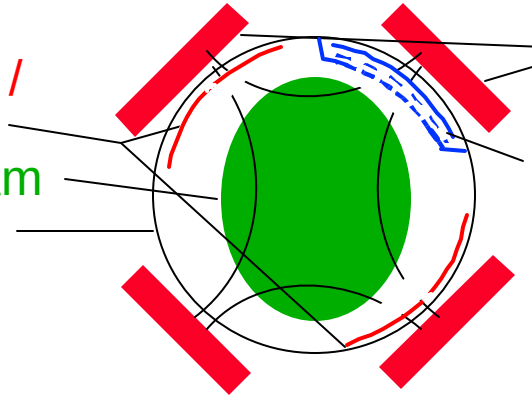


Magnetic quadrupole focusing

Capacitive probes / collectors

Beam

Beam pipe



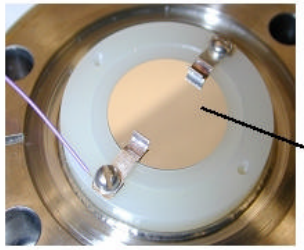
Magnet coils

Gridded energy analyzer in a quadrupole magnet bore measures secondary ion or electron energy.

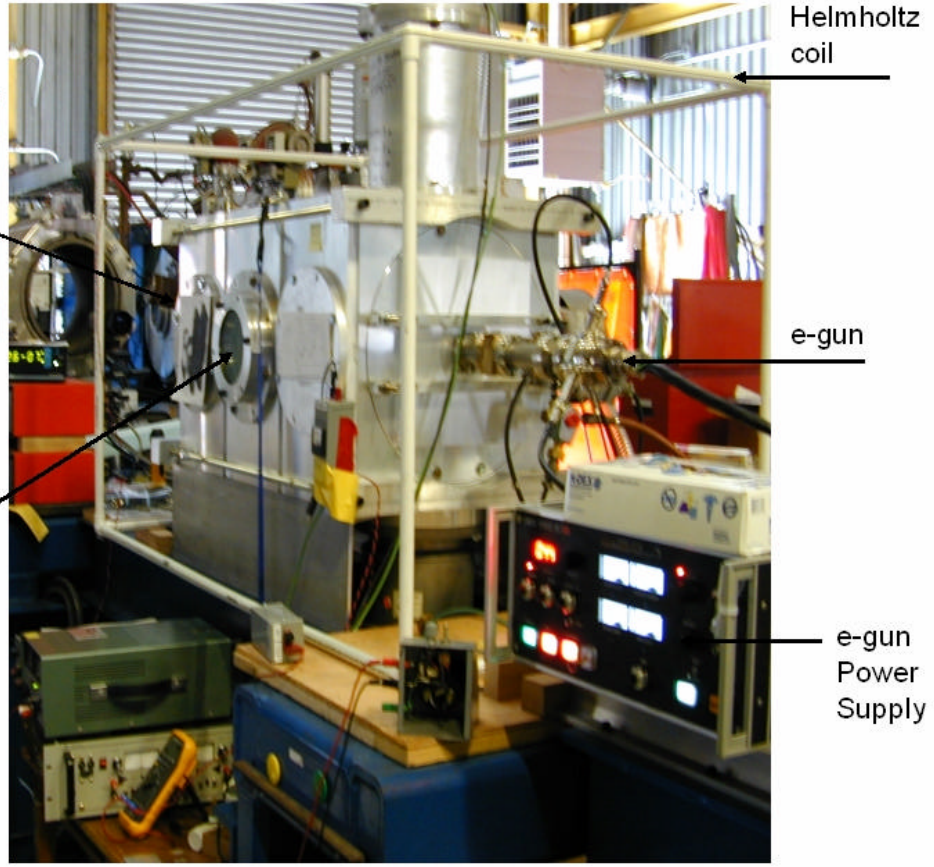
Related presentation: Experimental studies of electrons in a heavy ion beam, Molvik, et.al., Th.I-02.

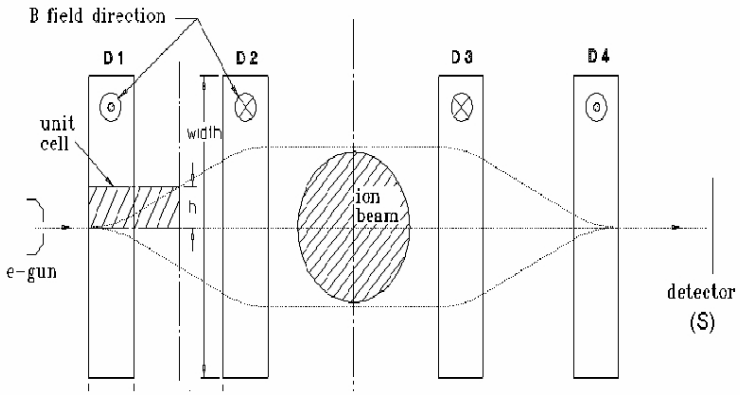
Non-intercepting beam profile diagnostic: electron beam probe measures space potential.

Electron beam is installed on NTX. Initial deflection data is reported at poster Th.P-28.

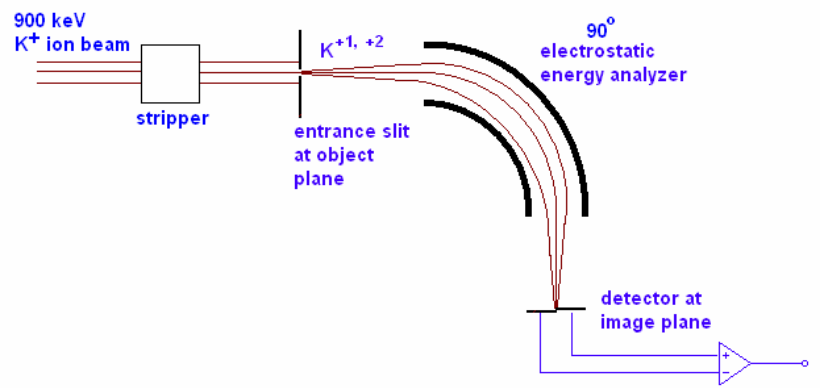


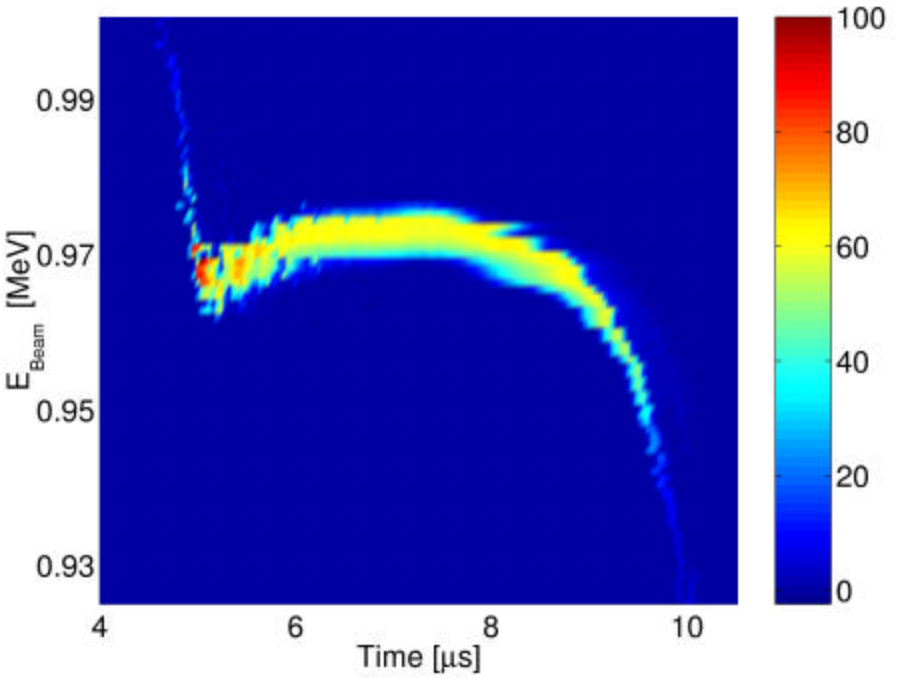
Al coated
YAP scintillator
assembly





Electrostatic energy analyzer (EEA) measures beam energy as a function of time.



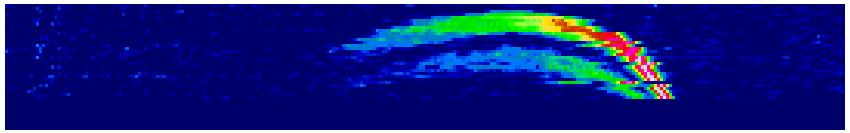


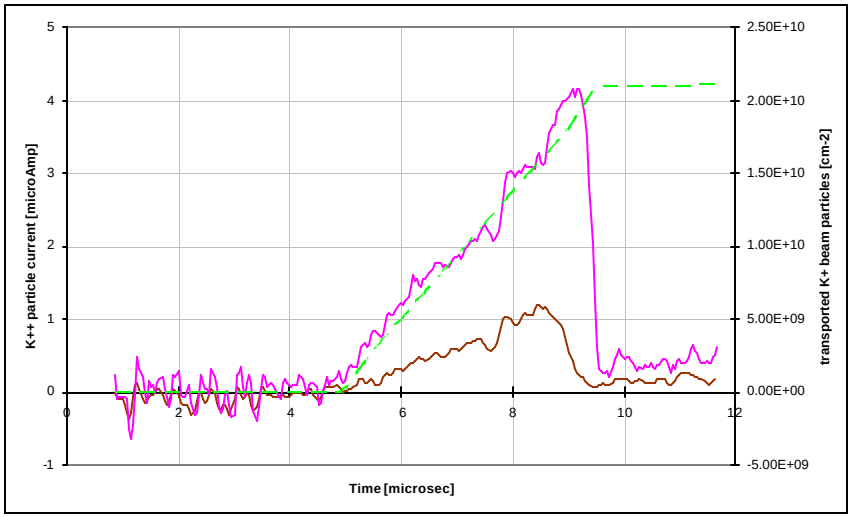
- **Applying a bias to the stripper - hole plate provides an absolute calibration of the EEA, referenced to ground, by varying the beam energy in a controlled manner.**

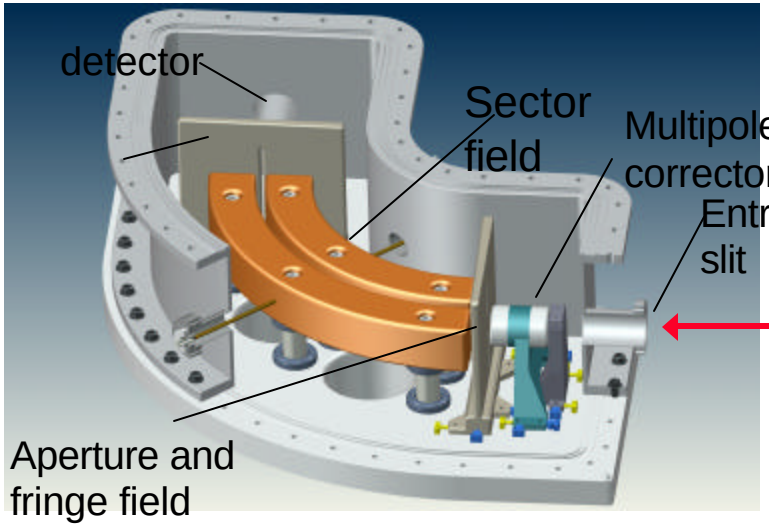
- **Beam energy distribution from EEA used to measure charge exchange rate in gas source at STS-100 (Poster Th.P-12).**

Energy distribution in HCX beam pulse (Presentation W.I-07).

Electrostatic energy analyzer measures gas cloud density at wall, and an improved energy analyzer is being designed.



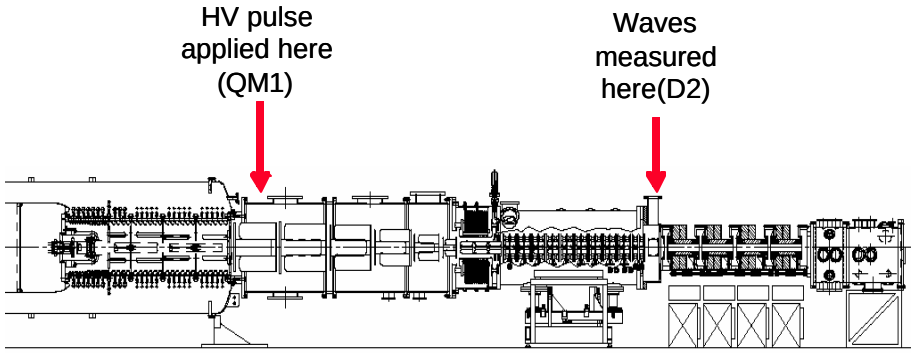




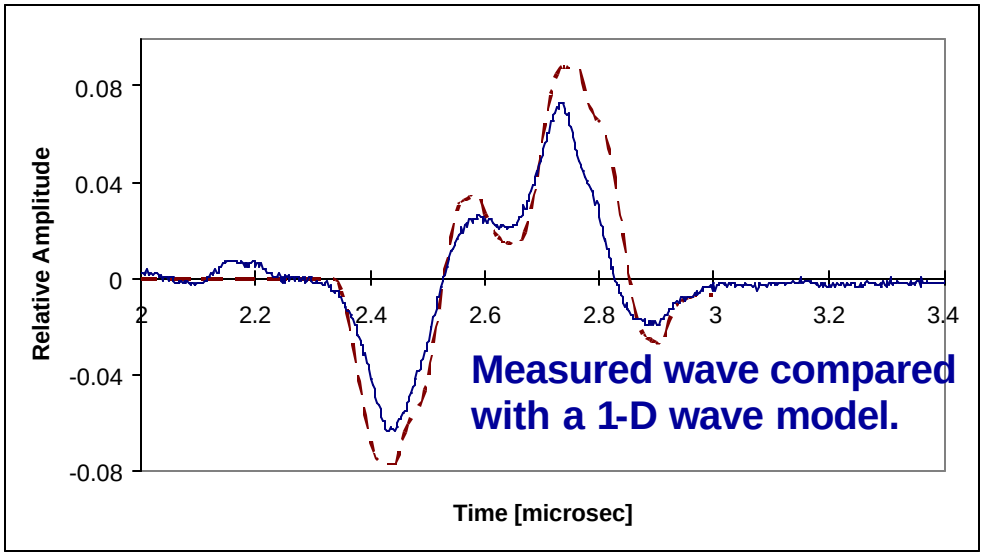
+2 ions created at hole plate and analyzer entrance slit provide an independent measure of gas cloud density at the wall.

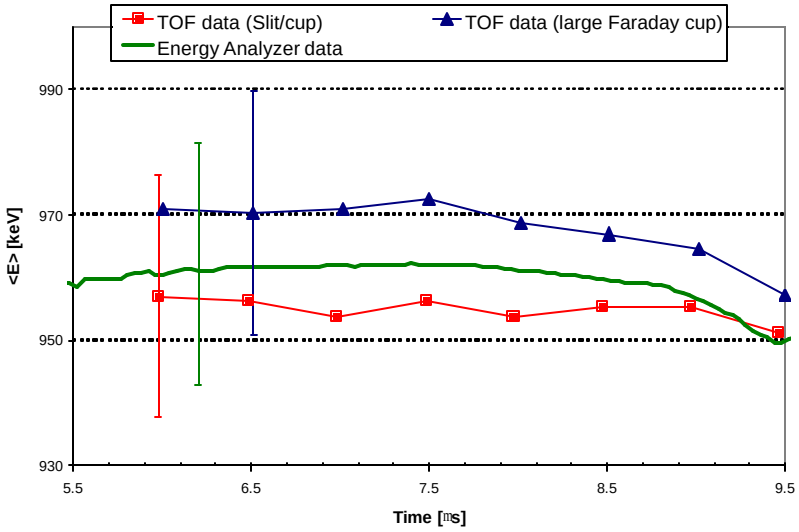
A new analyzer is being designed for improved energy resolution in planned experiments, e.g. NDC/HEDP.

Space-charge waves on HCX are used to measure beam energy by time of flight (TOF).



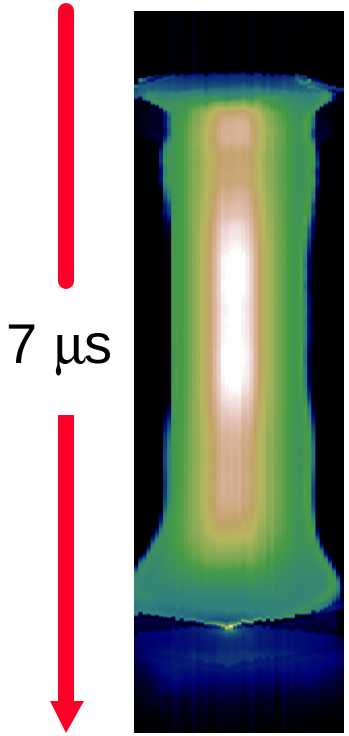
Waves applied by a fast pulse to quadrupole QM1.



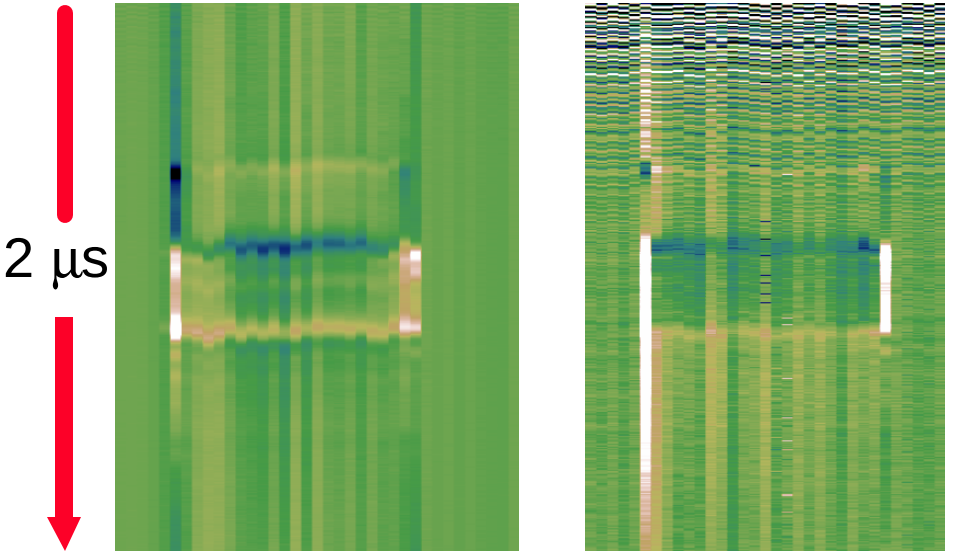


TOF data agree with energy analyzer data; HCX beam energy ~ 970 keV.

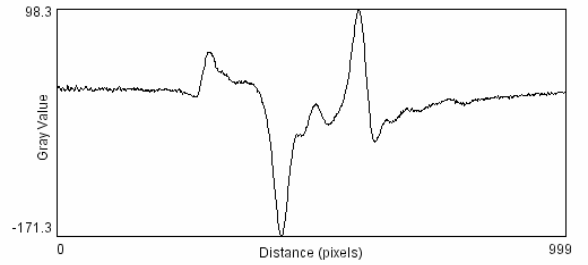
Waves show complicated structure in a cross section of the beam.



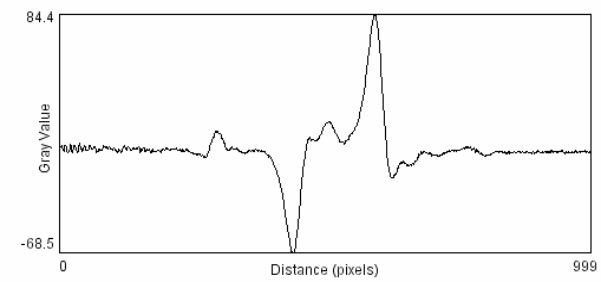
Horizontal slit profile + cross slit profile of wave @ matching section



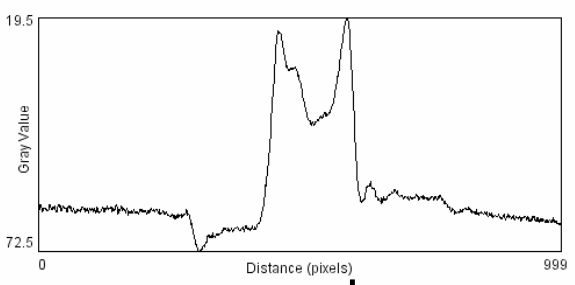
time structure of portions of the beam



entire beam



core



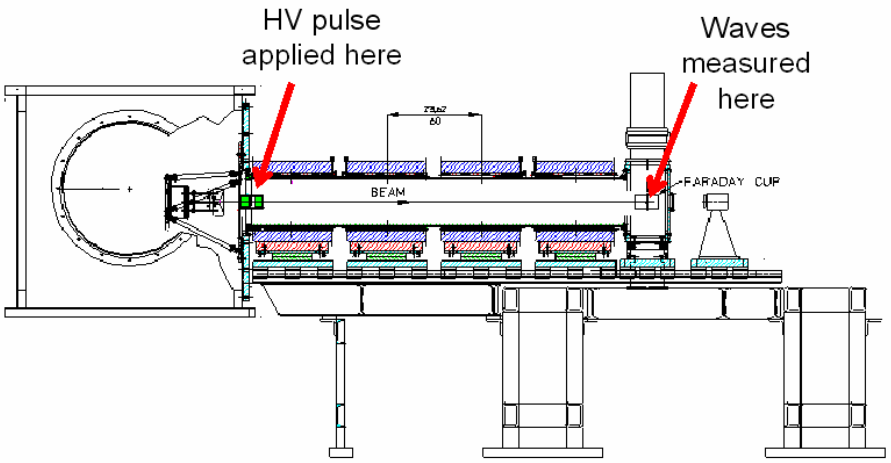
edge

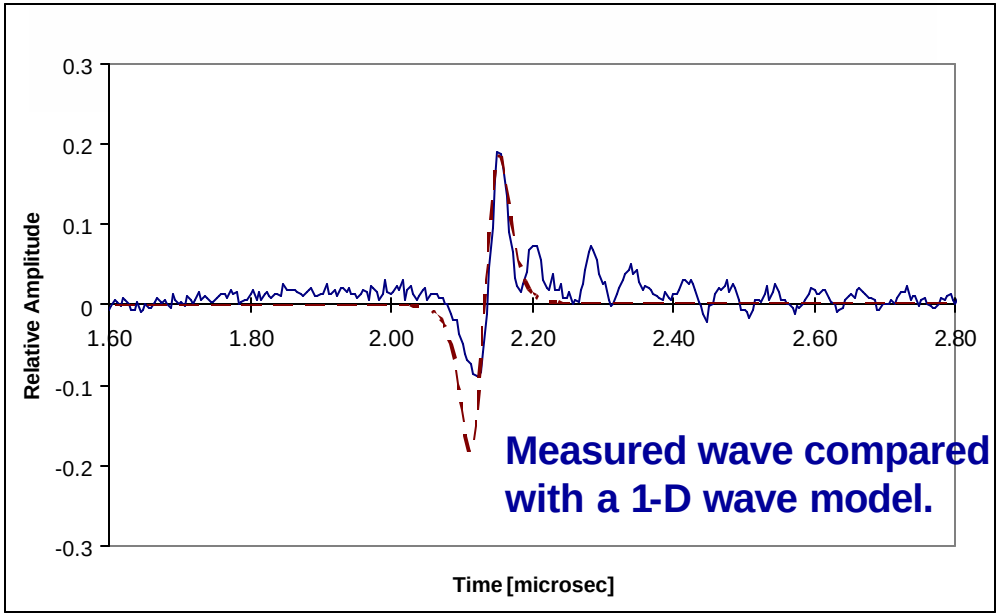
Space charge waves on NTX also measure beam energy by time of flight.

Waves applied by a fast pulse to aperture upstream of quadrupole magnets.

TOF yields a beam energy 3-5% lower than voltage dividers on NTX Marx.

More information on TOF and other results from space charge wave studies: Poster Th.P-21.





Conclusions.

- Optical diagnostic techniques provide detailed information on 4-D particle distributions. Further work is required in image processing, etc.
- Recent developments include new nonintercepting diagnostics.
- New electrostatic energy analyzer will improve energy resolution to provide 6 dimensional beam distribution information.
- Diagnostic development is continuing, with view toward advanced diagnostics for next-generation machines, especially diagnostics that are non-perturbing and that can be fielded in a compact configuration.