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Title:

Commissioning Results from the Low-Energy Demonstration Accelerator (LEDA) Radio-Frequency Quadrupole (RFQ)

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and
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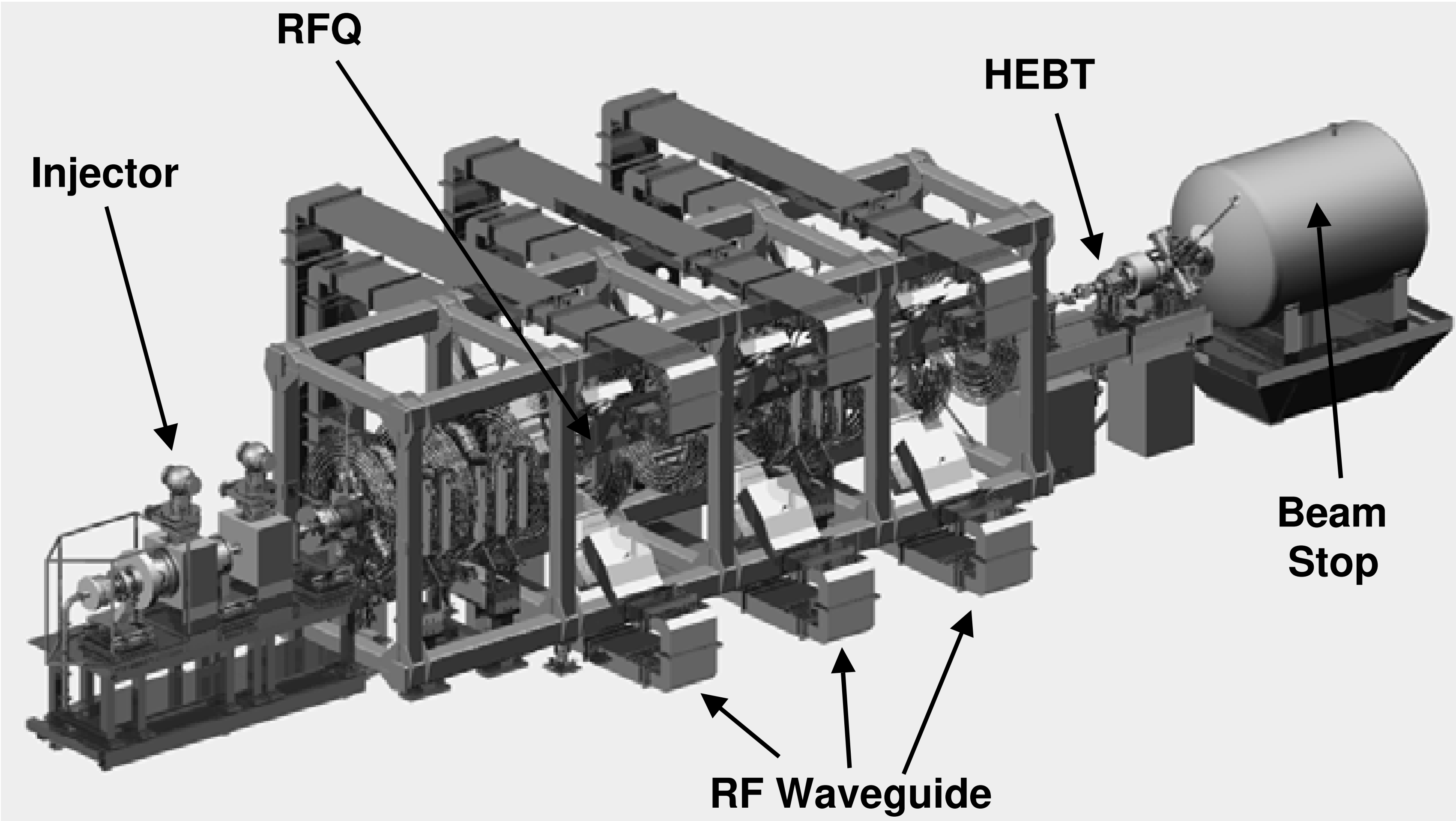
Abstract

- The LEDA RFQ is a 100% duty factor (CW) linac that delivers >100 mA of 6.7 MeV H^+ beam with ≈94% RFQ transmission
- It has been operated for >30 hr cumulative for RFQ output beam currents ≥100 mA CW and for >70 hr cumulative for ≥90 mA CW
- At ≥100 μsec into ≥90 mA beam pulses the RFQ transmission abruptly drops below the PARMTEQM prediction
- Raising the rf field level to 105-110% of design restores the RFQ transmission to the 100% rf field prediction
- Preliminary analysis of the quadrupole-magnet-scan emittance measurements indicates the RFQ output beam rms emittance $\varepsilon_x \approx 0.25\ \pi$ mm mrad (normalized), within the experimental error of the PARMTEQM-predicted value of 0.23 π mm mrad

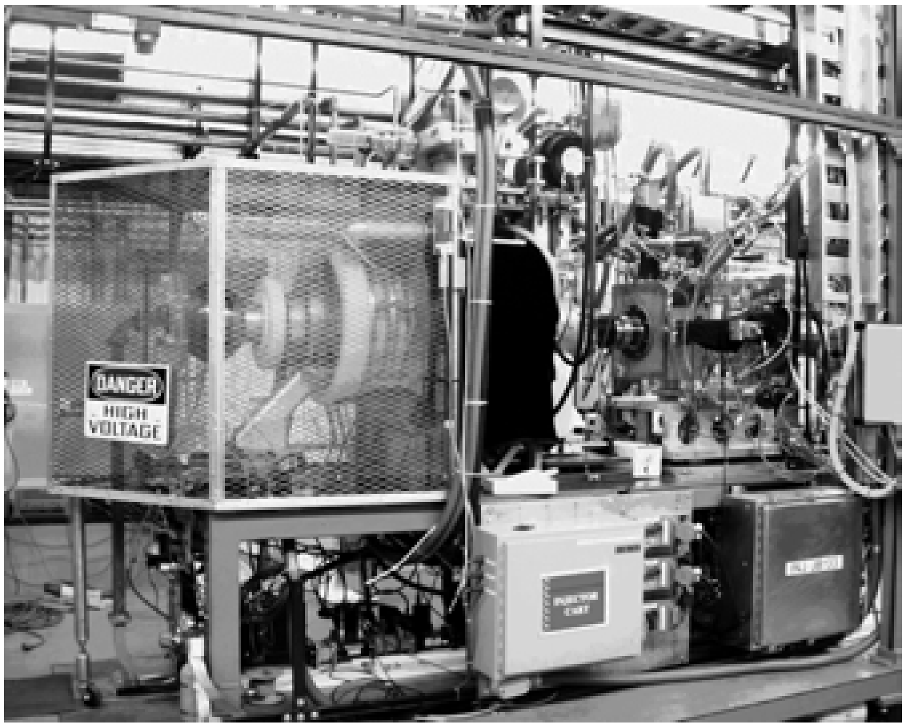
LEDA is a Test Bed to Demonstrate Components to be Used in the Front End of an APT Plant

- Components already demonstrated include
  - 75-keV, 110-mA proton injector
  - 6.7-MeV, 100-mA RFQ
  - 350-MHz rf system, including the LLRF
  - Simple HEBT transport and 670-kW beamstop
  - Beam diagnostics
- Components to be demonstrated in the future
  - 11-m-long FODO channel to measure beam halo
  - 7.28-MeV CCDTL

LEDA Consists of an Injector, 6.7-MeV RFQ, HEBT, and Beamstop

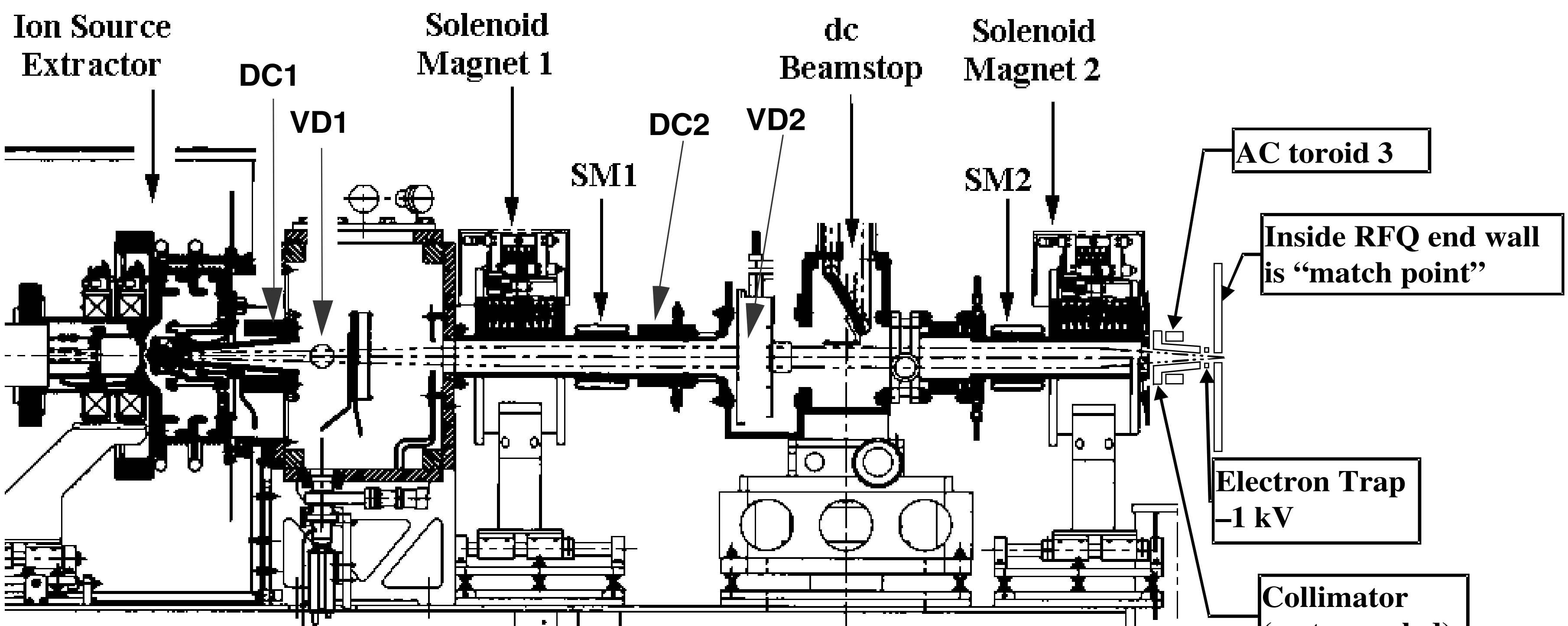


The injector matches a dc 75-keV, 110-mA proton beam into the LEDA RFQ

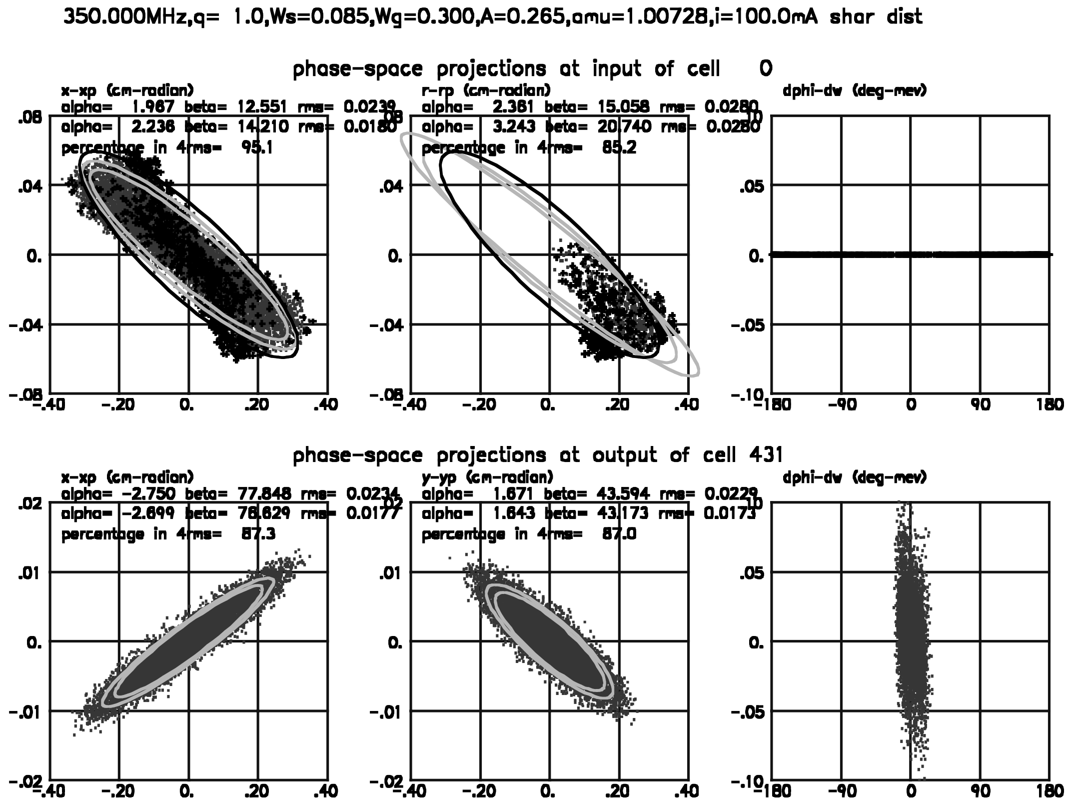


- **Key injector components**
  - **2.45-GHz microwave ion source**
  - **single-gap extractor**
  - **dual magnetic solenoid, gas-neutralized LEBT**
- **Key ion source parameters**
  - **800-1200 W of 2.45-GHz microwave power**
  - **85% ≤ proton fraction ≤ 95%**
- **Key injector beam parameters**
  - **proton current ≥110 mA at 75-keV**
  - **emittance <0.2 π mm-mrad (normalized)**

The LEDA injector beam diagnostics are used to characterize the RFQ input beam.

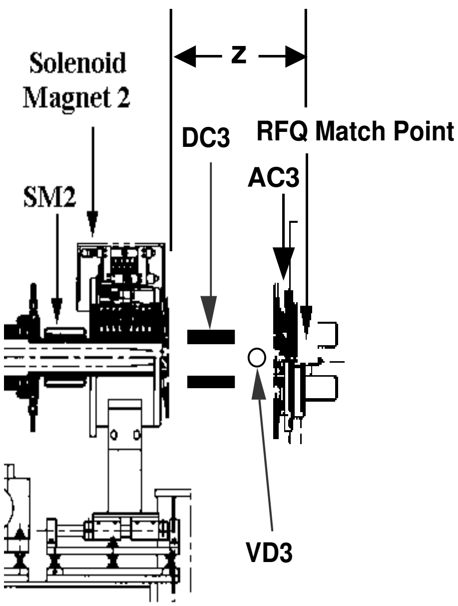


PARMTEQM calculates the RFQ output emittance is 0.232 π mm mrad for the 100-mA H^+ beam.



PARMTEQM-calculated RFQ input (top) and output (bottom) phase space for 100 mA input current). The 5000-particle input beam is derived from the SCHAR-calculated file for the 100-mA beam. PARMTEQM calculates the RFQ transmission is 92.2% for the 100-mA H^+ beam.

Changes made in the LEBT during RFQ commissioning.

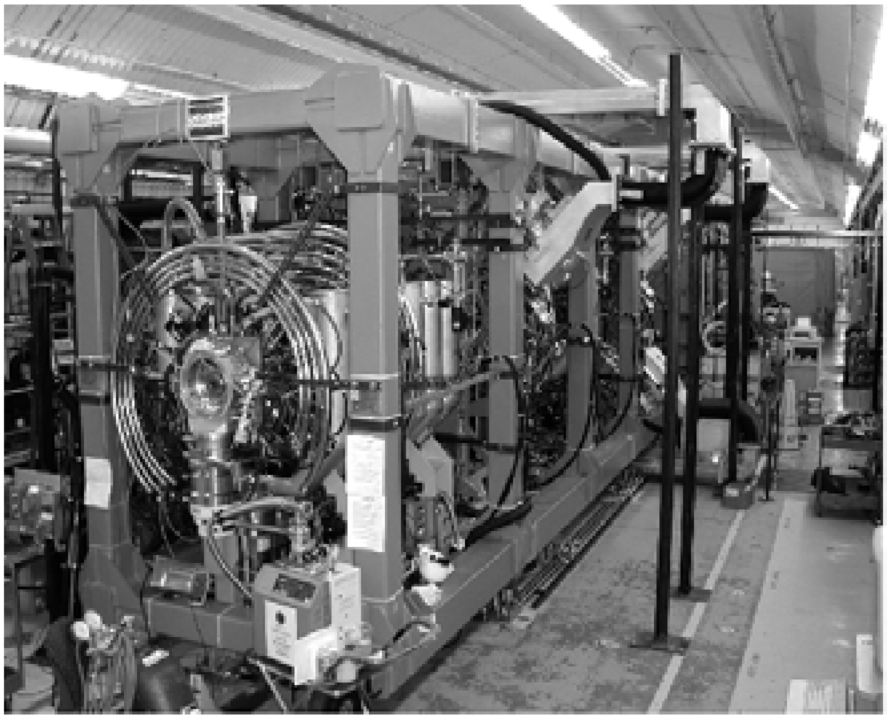
- **The shape of the iron core in the first solenoid was changed to lower the lens aberrations**
- 

  - **The distance z between the second solenoid lens and the RFQ entrance was shortened to increase the beam convergence angle into the RFQ**
  - **An electron trap was placed just in front of the RFQ to minimize the space-charge-induced beam expansion in front of the RFQ**
- **Lloyd Young discussed these changes in his 1999 Physics of High-Brightness Beams paper**

We measured the RFQ performance using triode and tetrode extraction geometries.

- **PBGUNS predicts that, for the same emitter, extractor, and gap dimensions the triode will produce larger currents and lower divergence**
- **RFQ measurements confirm this prediction <u>but</u>**
  - **The injector spark-down rate is higher with the triode than with the tetrode**
  - **RFQ rf fault recovery is faster with the tetrode, with little or no operator intervention**
- **The tetrode extraction system was used for the measurements presented here**

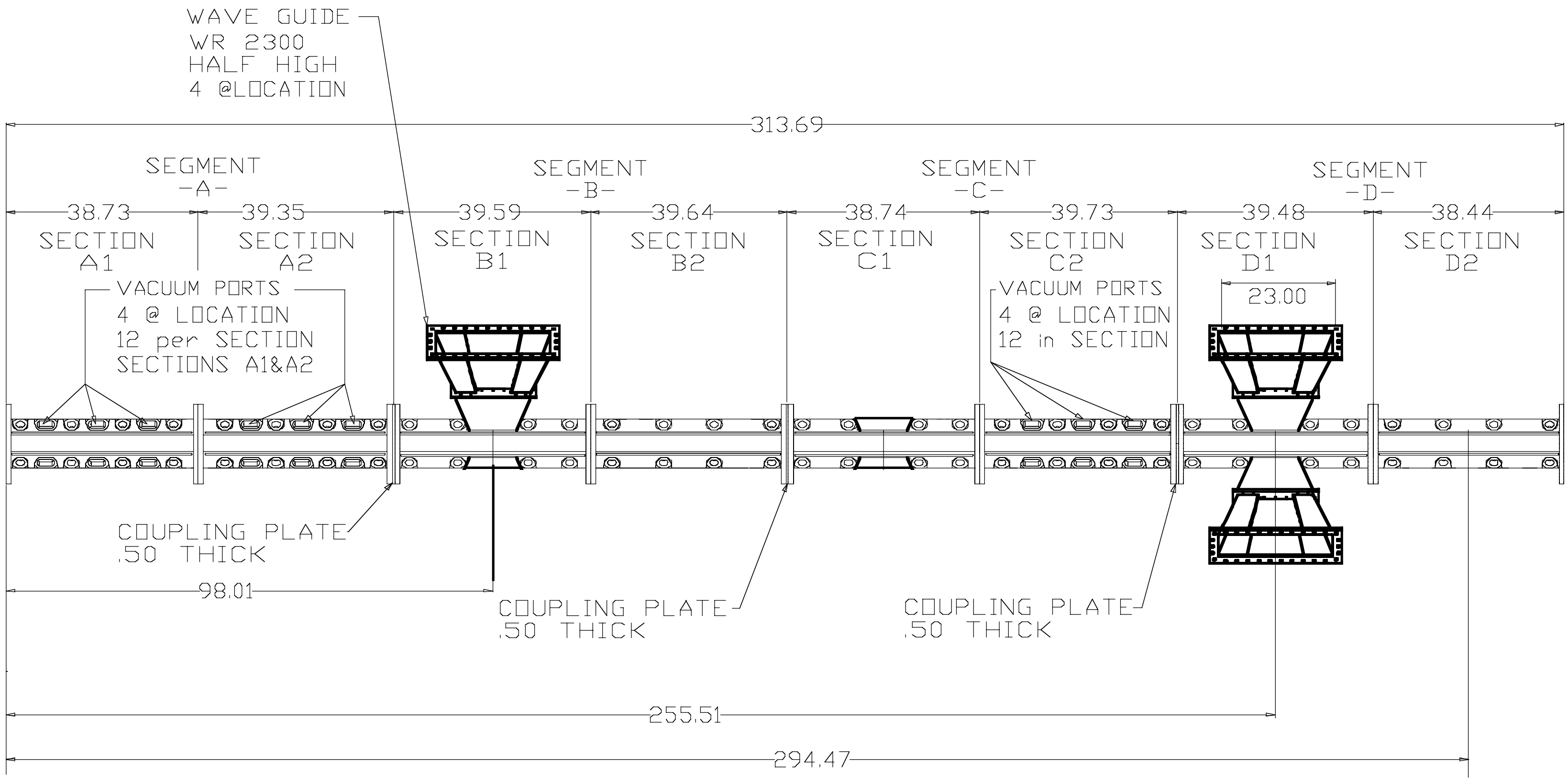
The 350-MHz RFQ accelerates 100 mA of protons to 6.7 MeV.



LEDA RFQ with the injector rolled back.

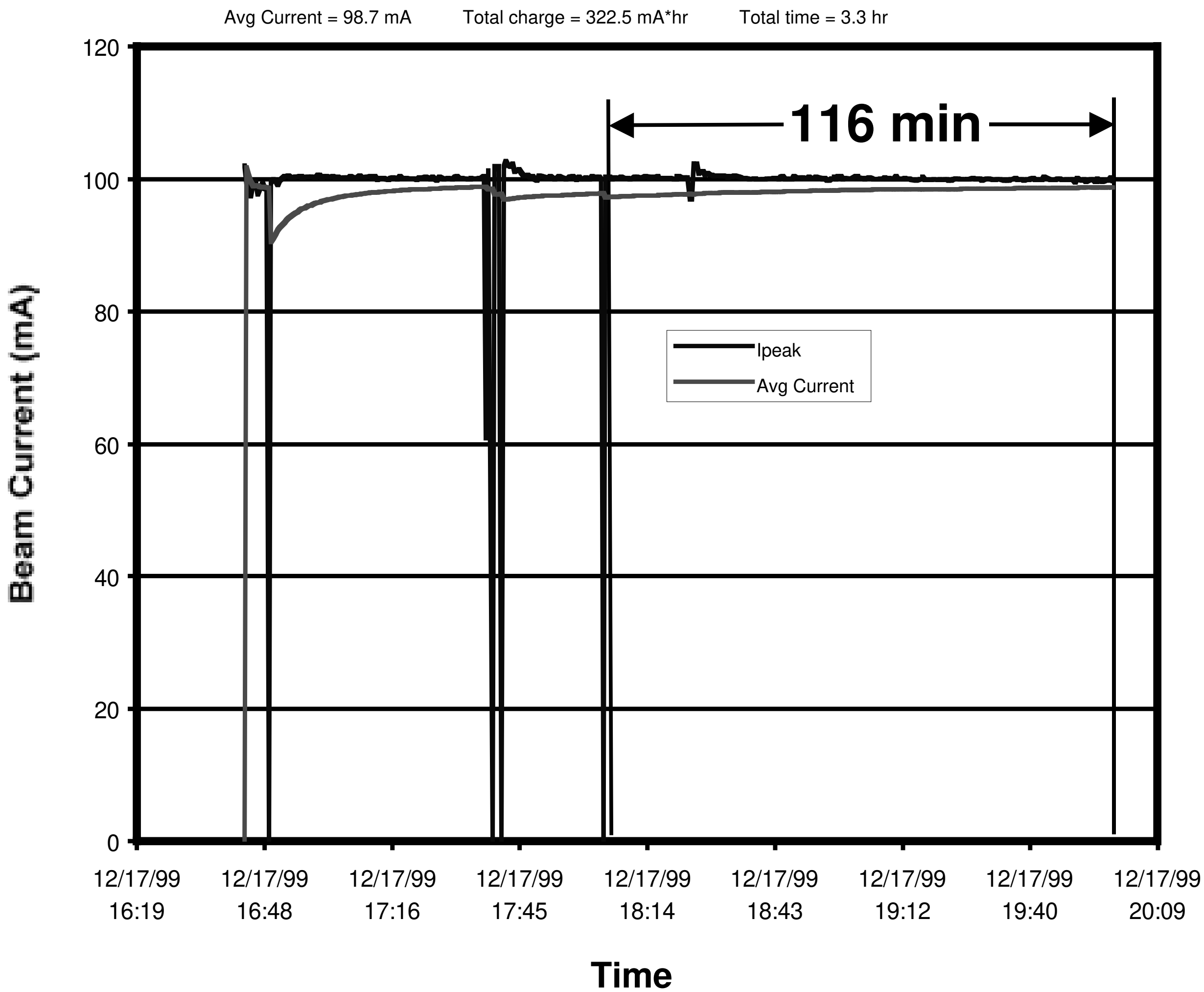
- Key RFQ components
  - vanes, vacuum vessel, and support structure
  - resonance-control cooling system
  - RF power feeds
  - vacuum system
- Key RFQ parameters
  - structure power - 1.5 MW average
  - RF feeds - 6 waveguide irises
  - cavity vacuum pumping - 3600 T-*l*/s
  - cooling water - ~1300 gpm at 50° F
- 6.7-MeV, 100-mA RFQ output beam
  - power - 670 kW CW
  - rms trans. normalized emittance - 0.22 π mm mrad
  - long. emittance - 0.174 deg-MeV

LEDA RFQ Configuration

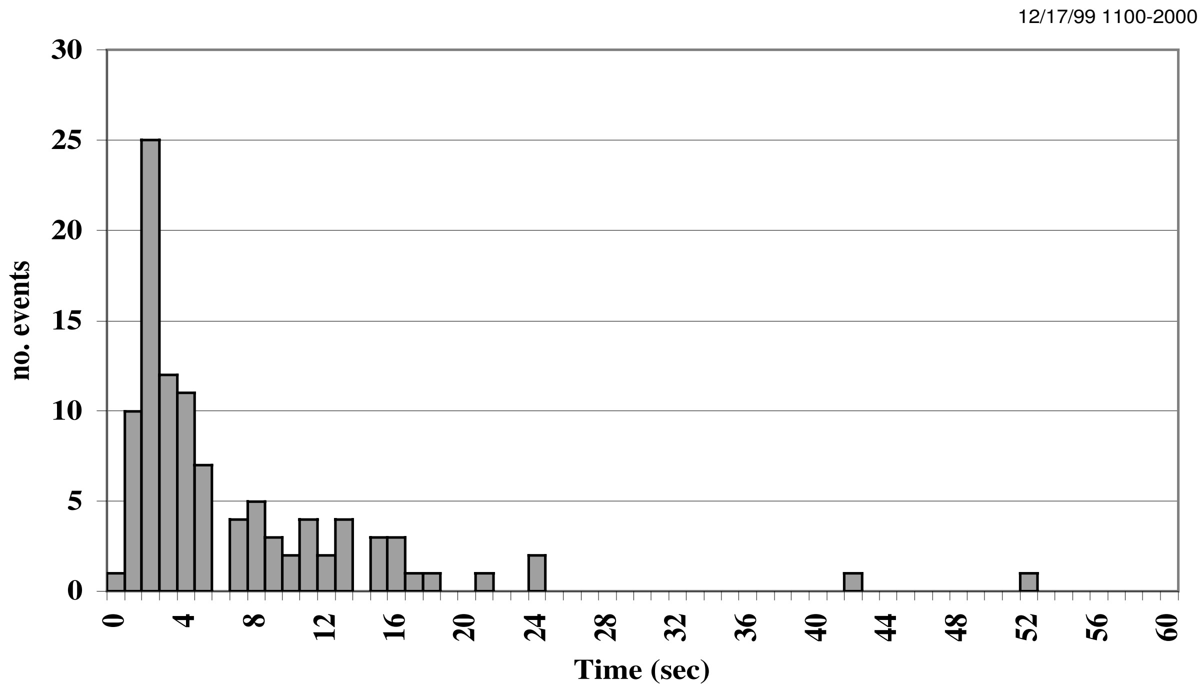


- **Two rf waveguide feeds on Section B1 and four on Section D1 are used to power the RFQ**

The LEDA RFQ has run a 100-mA, CW beam for 116 min uninterrupted.

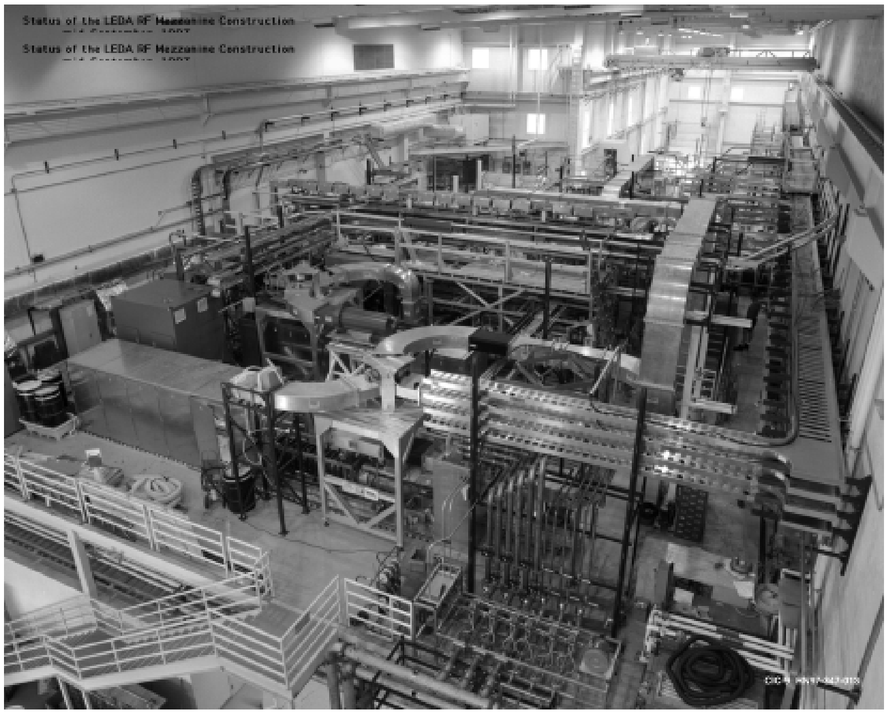


During the 116 minute run most of the beam interruptions were 1-6 sec in duration.



- The bulk of these trips were injector sparks that recovered quickly and automatically. LLRF frequency lock was not lost.

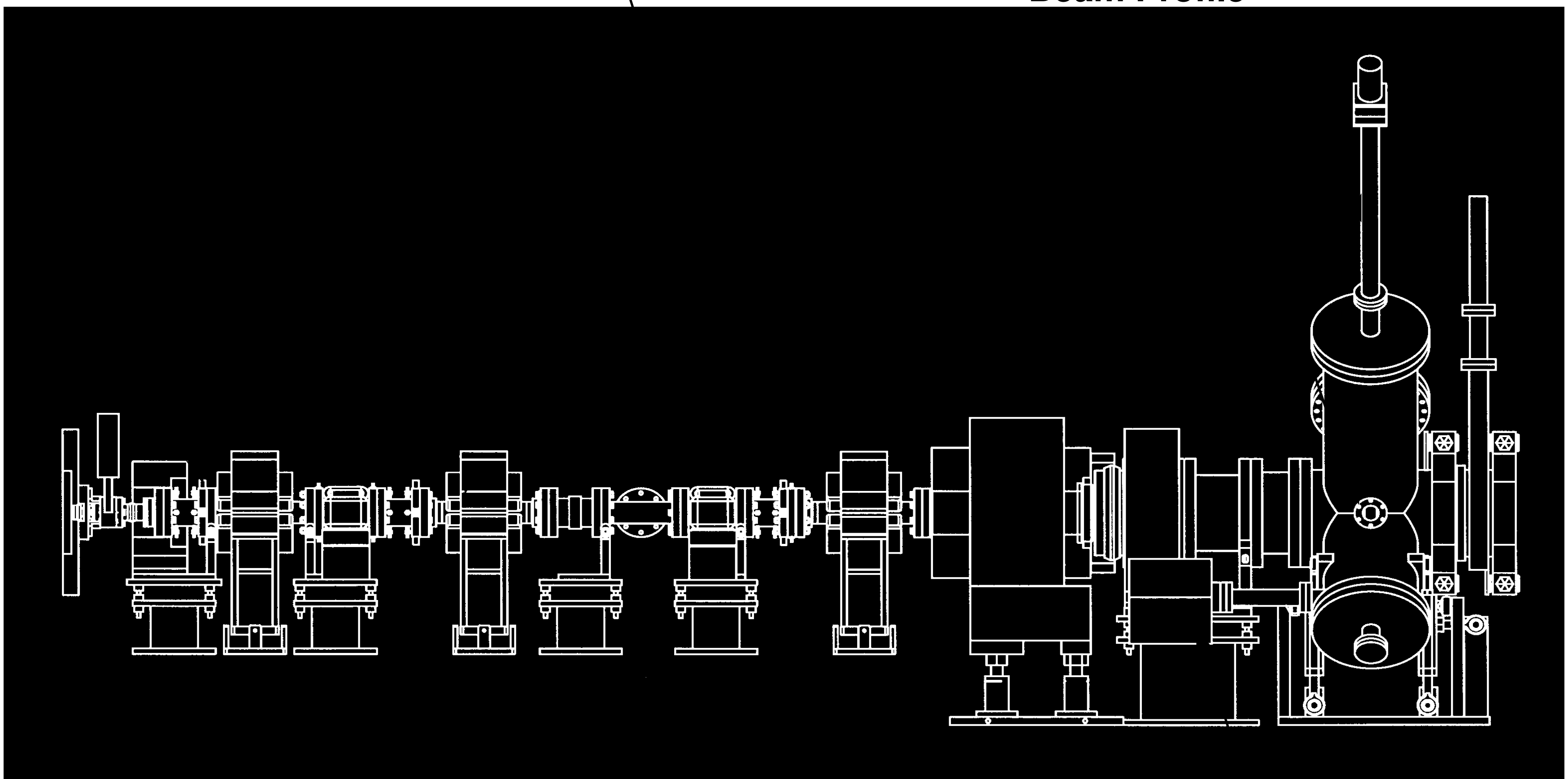
The High-Power RF System Converts 13.2-kV ac Site Power to 350- and 700-MHz RF Power



High-Power RF System equipment installed on the mezzanine

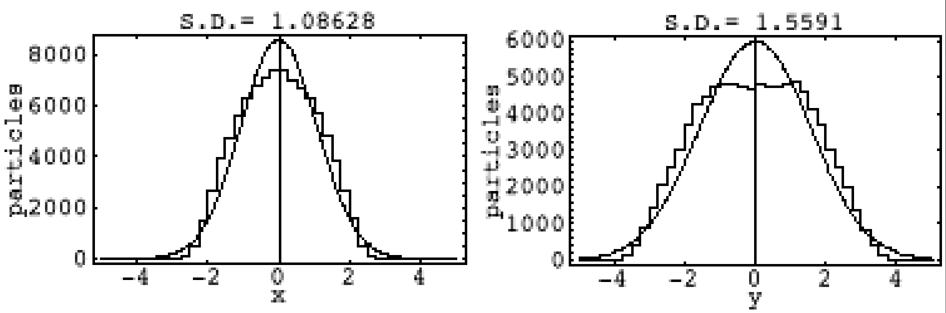
- **Key HPRF system components**
  - Klystrons, HVPS, circulators, switches, loads, and crowbars
  - Fault protection
  - RF waveguide
- **Key HPRF system features**
  - 350-MHz klystrons drive RFQ
  - 700-MHz klystrons drive CCDTL
  - Full-power collectors on klystrons
  - Testing advanced IGBT HVPS
- **Key HPRF system parameters**
  - Each of 6 rf windows operates at ≤360 kW, tested to ≥900 kW
  - Three 350-MHz systems deliver up to 2.4 MW to RFQ
  - One 700-MHz systems delivers up to 0.8 MW to CCDTL

Layout of HEBT Beamline Optics and Diagnostics.



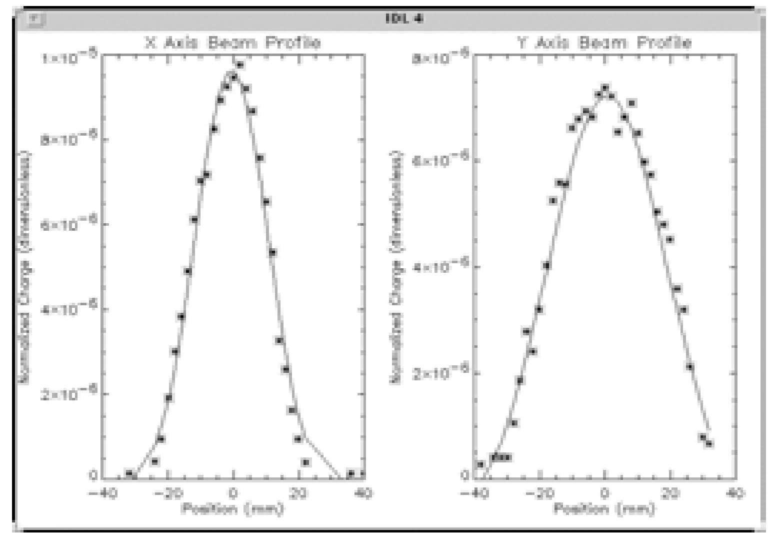
The HEBT is tuned to adjust the measured beam profiles to the design profiles.

Design Profiles



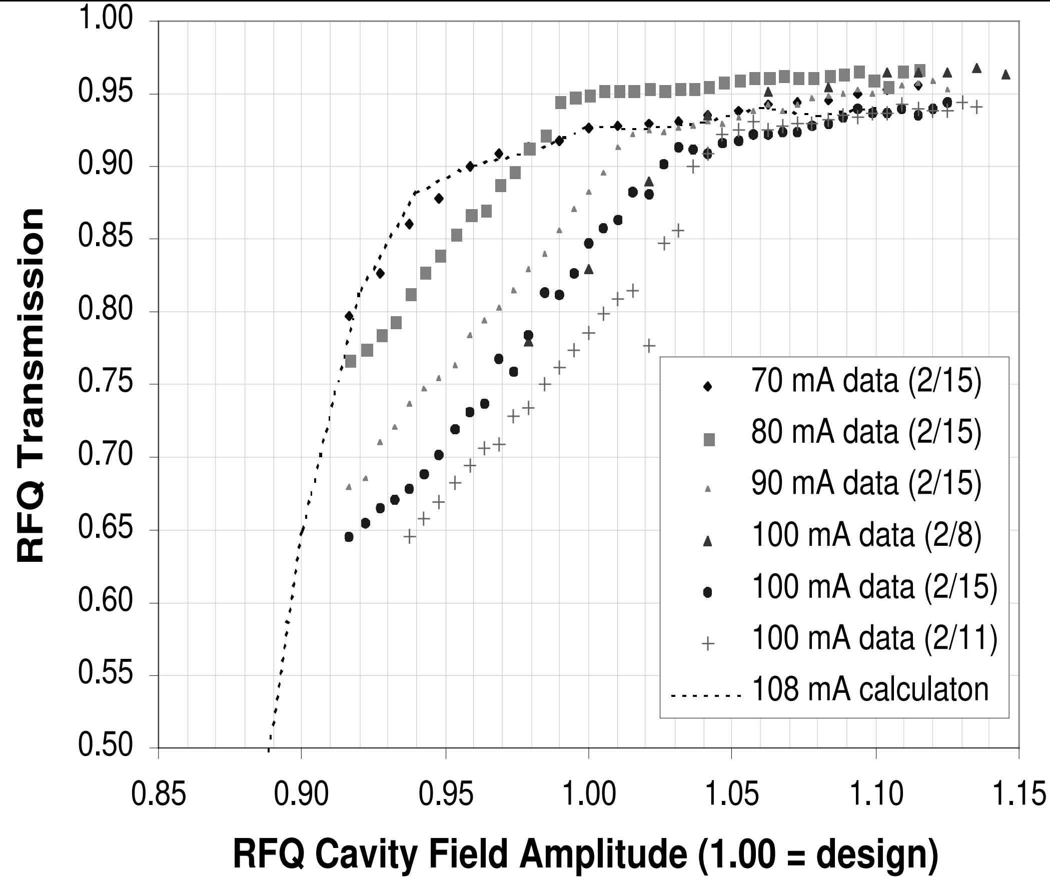
- The above LINAC (3D) profiles are at the wire scanner
- These profiles are for the nominal HEBT beam tune
- The x and y widths are 10.8 and 15.7 mm, respectively

Measured Profiles



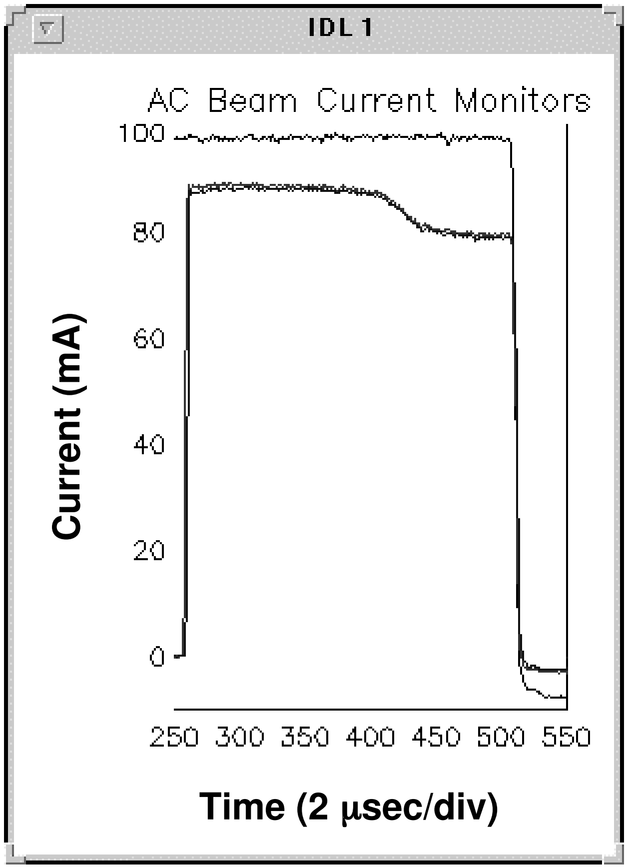
- The above measured profiles are for a 85-mA, 5-Hz, 100-μsec pulsed beam
- The displayed widths are 9.1 and 13.9 mm in x and y, respectively

RFQ Transmission vs RFQ Cavity Field Amplitude for 1.5-msec Long Beam Pulses



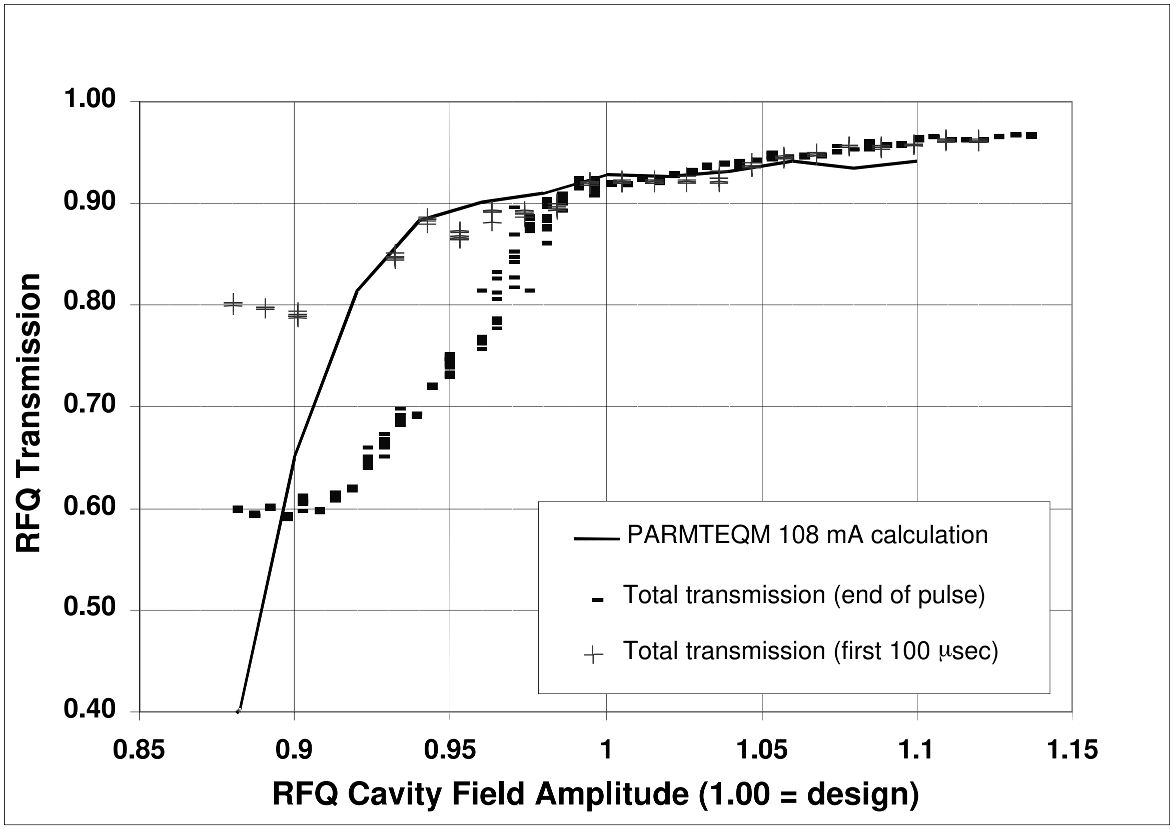
For currents ≥90 mA, raising the rf-field level to 1.05-1.10 of design increases the RFQ transmission to the PARMTEQM prediction.

The H^+ beam current abruptly drops ≈300 μsec into the pulse for currents >90 mA and RFQ field levels ≤ design.



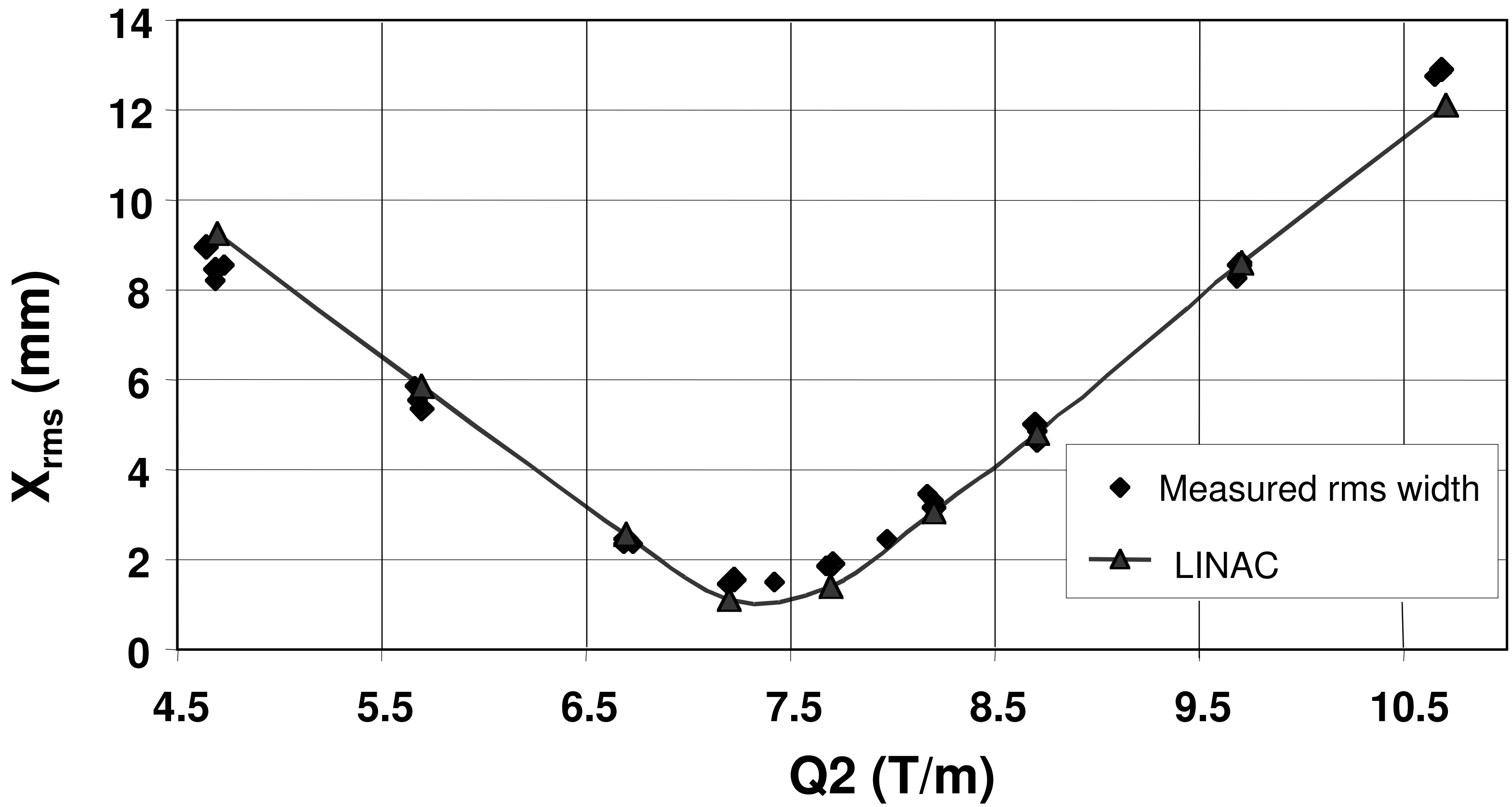
- For 105 mA injected into the RFQ (black)
- the RFQ output beam current (red) drops from 90 mA to 83 mA and the HEBT output current (blue) drops from 90 mA to 82 mA »300 msec into the 500 msec long beam pulse
- The rf field level is ~90% of the design field level for this measurement.
- Raising the rf field level to 1.05-1.10 of design eliminates this effect

RFQ Transmission vs RFQ Cavity Field Amplitude at the Start and End of 500-μsec Long, 90-mA Beam Pulses



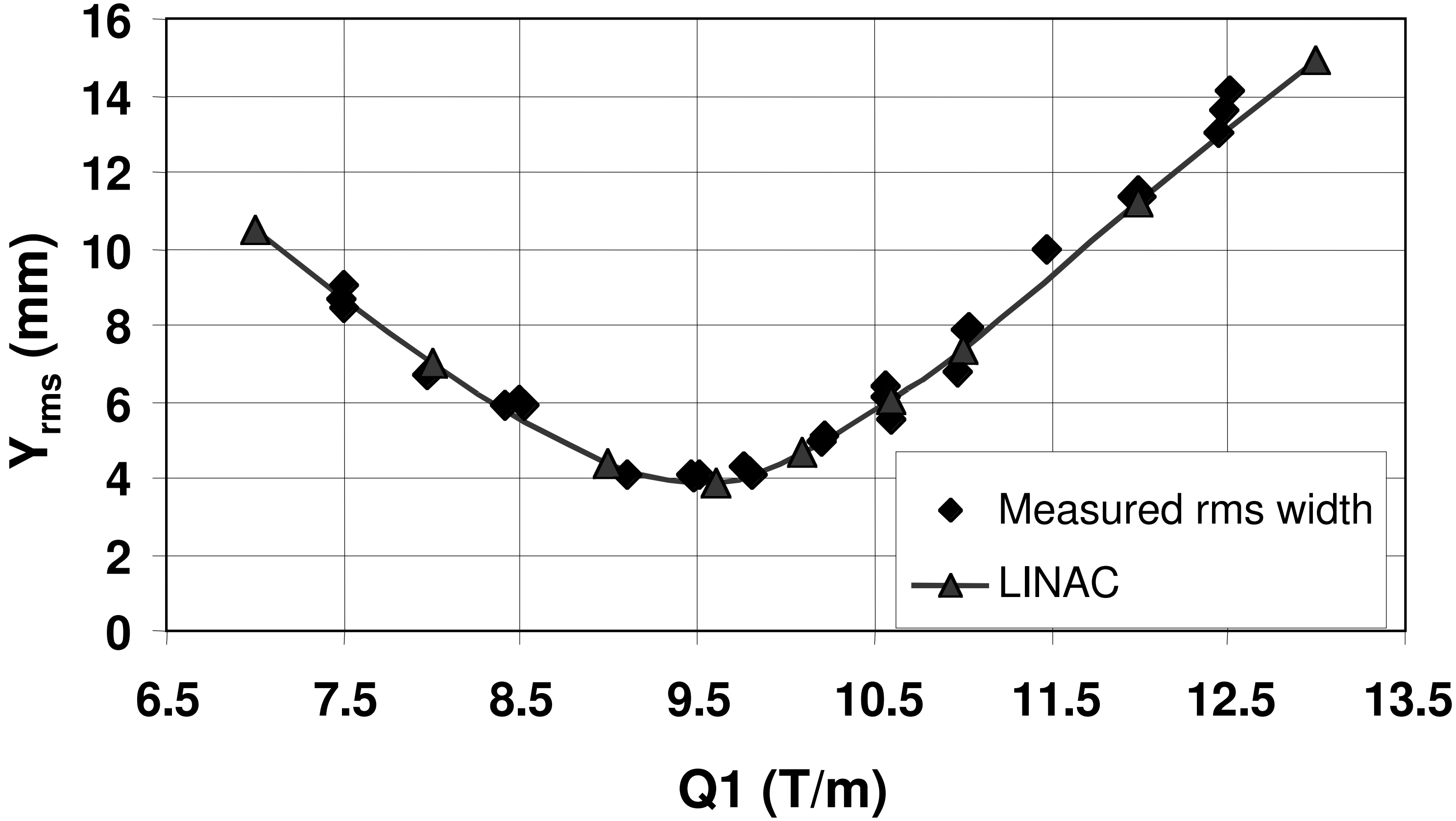
The total transmission at the start of the 90-mA pulse agrees with the PARMTEQM prediction for a 108-mA output beam.

X Quad Scans Analyzed with LINAC



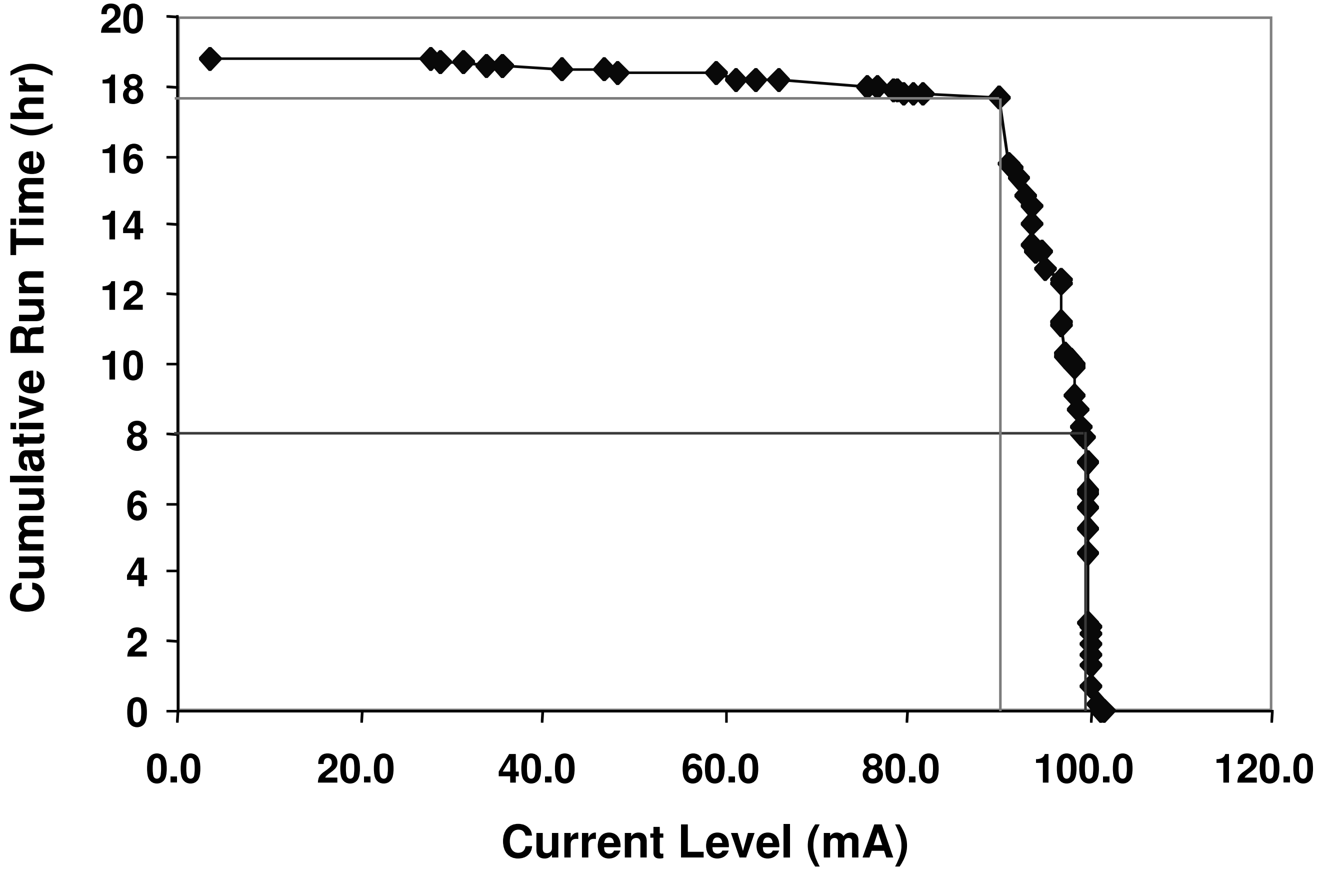
- The rms normalized emittance is 0.25 π mm mrad in this LINAC model of the HEBT transport for the 93-mA beam
- The other Twiss parameters are α = 1.8 and β = 36 cm
- The estimated experimental error in ε_x is +10% / -50%

Y Quad Scans Analyzed with LINAC



- The rms normalized emittance is 0.31 π mm mrad in this LINAC model of the HEBT transport for the 93-mA beam
- The other Twiss parameters are α = -2.5 and β = 90 cm
- The estimated experimental error in ε_y is +10% / -50%

The LEDA RFQ has >30 cumulative hr of operation with CW output currents ≥100 mA.



- **The data shown above (8 hr >100 mA, 17 hr >90 mA) is for 12/17-12/22/99**
- **To date there are >30 cumulative hr of operation with CW output currents >100 mA and >70 cumulative hr of operation with CW output currents >90 mA**

Summary

- 100 mA of RFQ CW output current has been achieved for an uninterrupted run of 116 min, with automatic fault recovery.
- High RFQ beam transmission, ≈94%, has been achieved.
- Overall RFQ accelerator system performance is better with the injector tetrode extraction system than with the triode.
- For output beam currents >90 mA the RFQ transmission agrees with the PARMTEQM prediction provided the rf field level is increased to 1.05-1.10 of the design field.
- Preliminary analysis of the RFQ output beam emittance measurements indicates the rms normalized emittance $\varepsilon_x \approx 0.25\ \pi$ mm mrad, within the experimental error of the PARMTEQM-predicted value of $0.23\ \pi$ mm mrad.