The Fermilab HINS Test Facility and Beam Measurements of the Ion Source and 325 MHZ RFQ

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Fermilab

DITANET High Intensity Proton Diagnostics Workshop

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MDB (HINS) Test Facility

The Meson Detector Building (MDB) Test Facility (formerly known as HINS – High Intensity Neutrino Source) ultimately comprises:

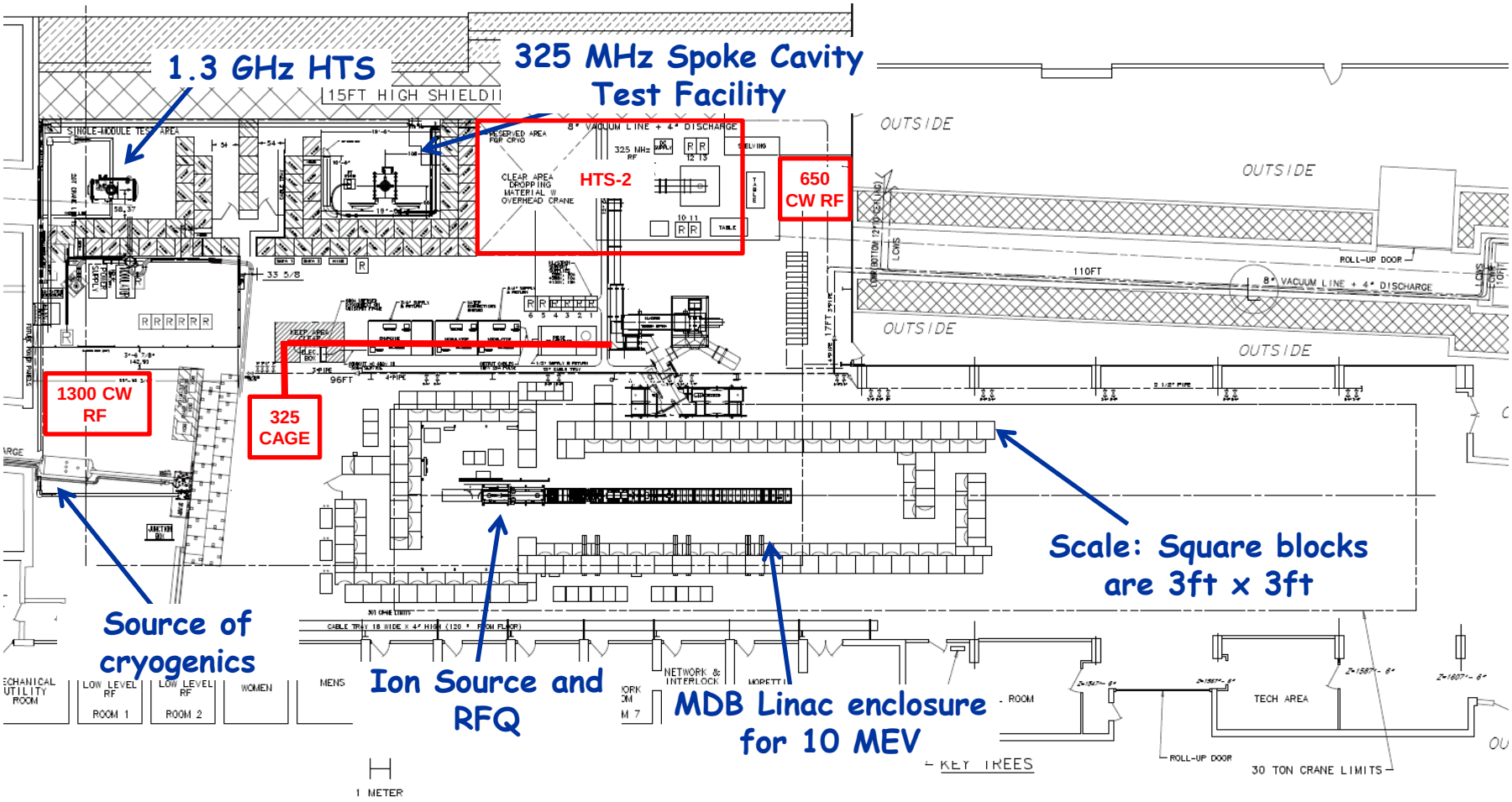
- A shielded beam line enclosure with first proton, then H^-, pulsed 1% duty factor, 3 millisecond beam up to 10MeV
  - For Project X 325 MHz superconducting spoke cavity beam tests
  - For Project X chopper tests
  - For Project X H^- beam instrumentation development
- Shielded enclosures and RF power systems for testing individual, jacketed 1.3 GHz, 650 MHz, and 325 MHz superconducting RF cavities (no beam)
  - For ILC
  - For Project X

Project X - Fermilab's proposed superconducting RF, multi-MW, multi-GeV CW proton/H- linac for the Intensity Frontier.

Brief History of Meson Detector Building (HINS) Test Facility

- This thrust began in 2006 with initiation of the High Intensity Neutrino Source (HINS) program to demonstrate technology applications new to the low-energy front-end of a pulsed, high-intensity proton/H^- Linac
- The plan *was* to construct a ten's of MeV Linac to demonstrate:
  - Beam acceleration using spoke-type superconducting RF (SRF) cavity structures starting at a beam energy of 10 MeV
  - High power RF vector modulators controlling multiple RF cavities driven by a single high power klystron for acceleration of a non-relativistic beam
  - Control of beam halo and emittance growth by the use of solenoid focusing optics
  - Fast, 325 MHz bunch-by-bunch, beam chopping
- Now plan is to demonstrate:
  - *High power RF vector modulators controlling multiple RF cavities driven by a single high power klystron for acceleration of a non-relativistic beam*
  - ***Test facility for beam diagnostics and fast chopper***

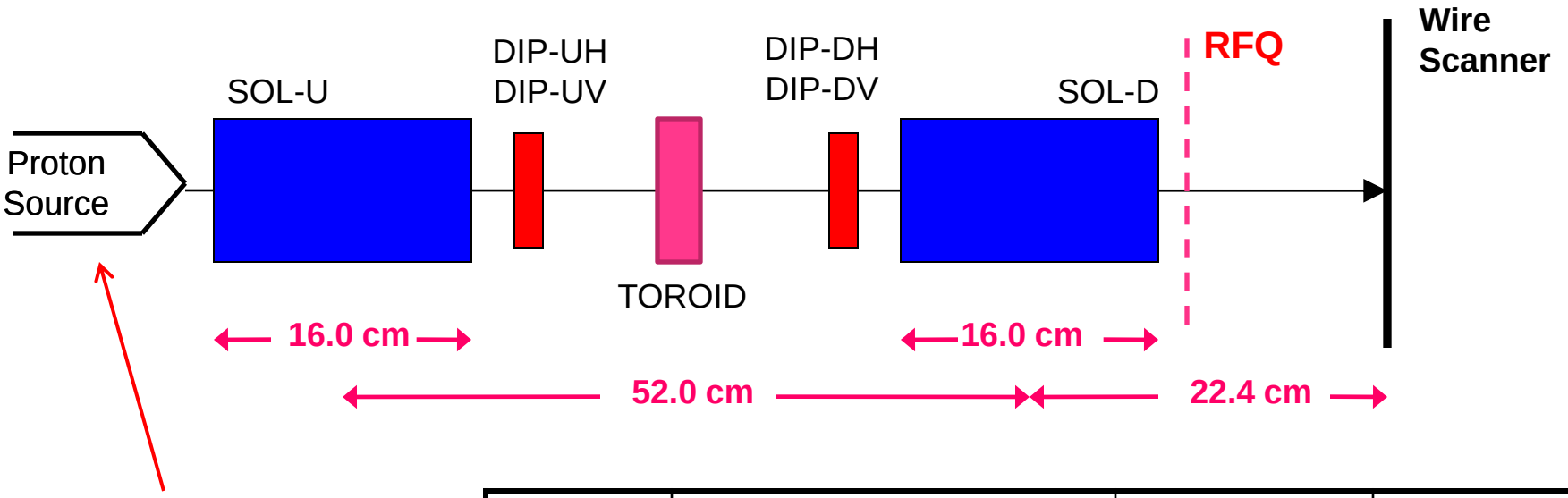
MDB Test Facility Layout



HINS Beam Parameters

	Proposed	Actual	
Particle	H+ then H-	H+ then H-	
Nominal Bunch Frequency/Spacing	325 3.1	325 3.1	MHz nsec
Pulse Length	3 @ 2.5 Hz 1 @ 10 Hz	1 @ 0.2 Hz 0.1 @ 1 Hz	msec
Average Pulse Current	~ 20 (source)	~ 20 (H, 2H+, 3H+) ~8 (RFQ - H)	mA
Pulse Rep. Rate	2.5/10	0.2/1	Hz
Beam Energy	Up to 10	2.5 to 3.0	MeV

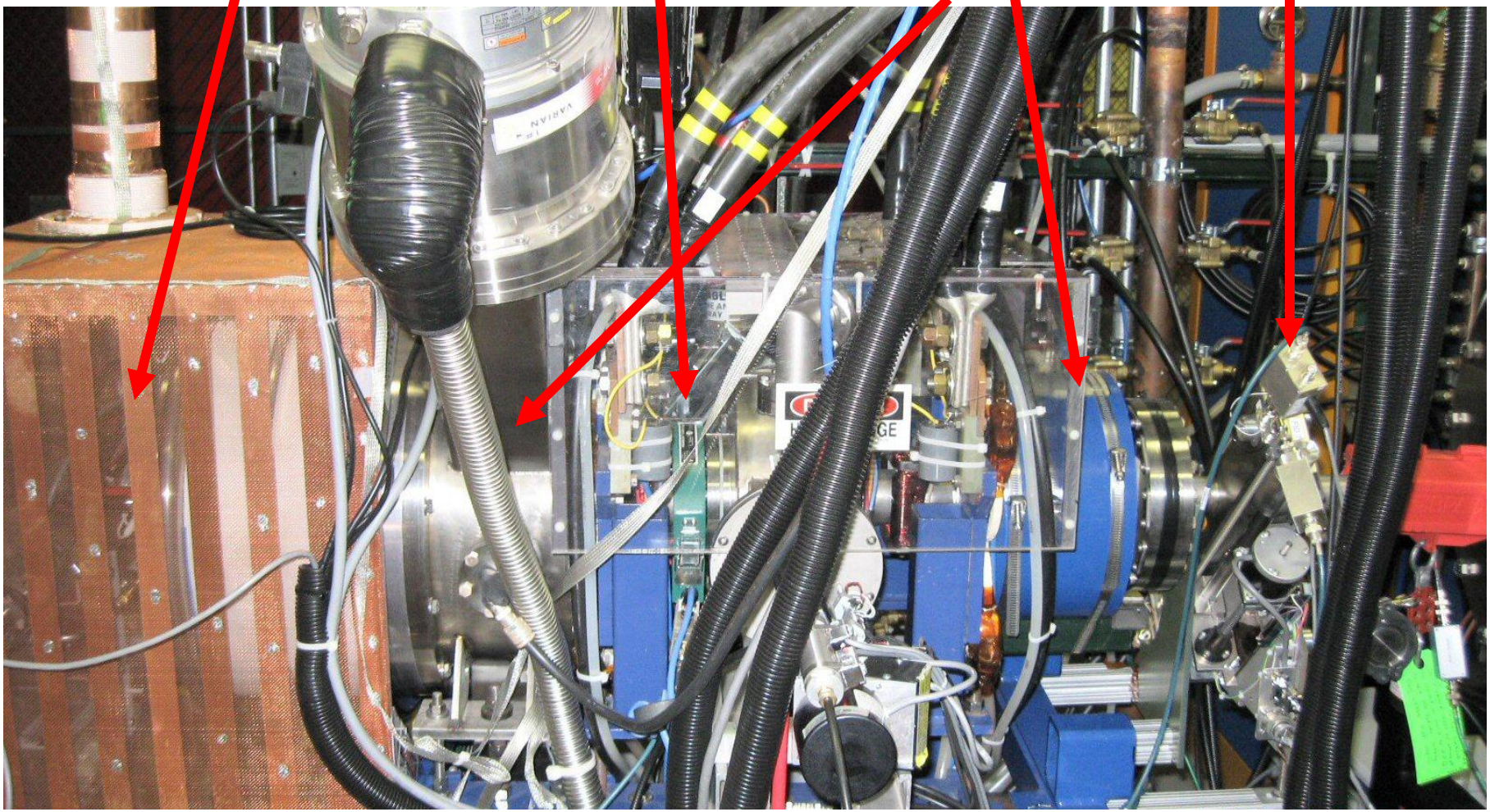
HINS Proton Source and LEBT



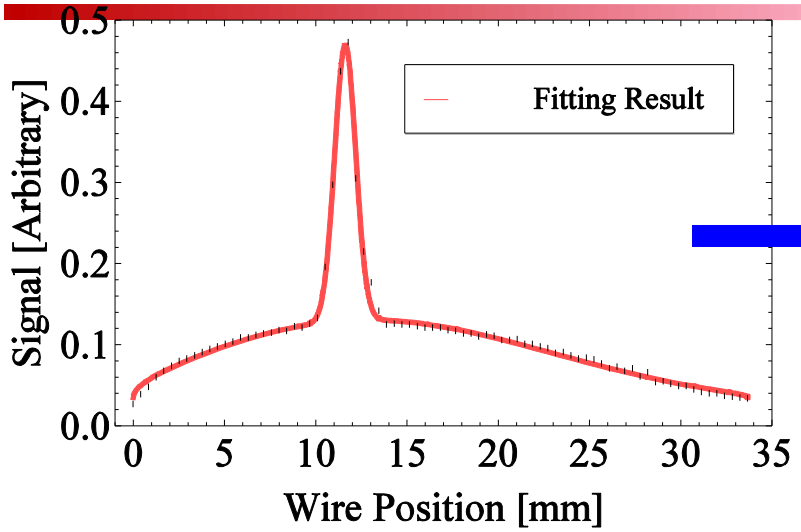
Duo-plasmatron Proton Source	
Energy	50 keV
Peak Current	> 20 mA
Pulse	3 msec
Rep. rate	2.5 Hz

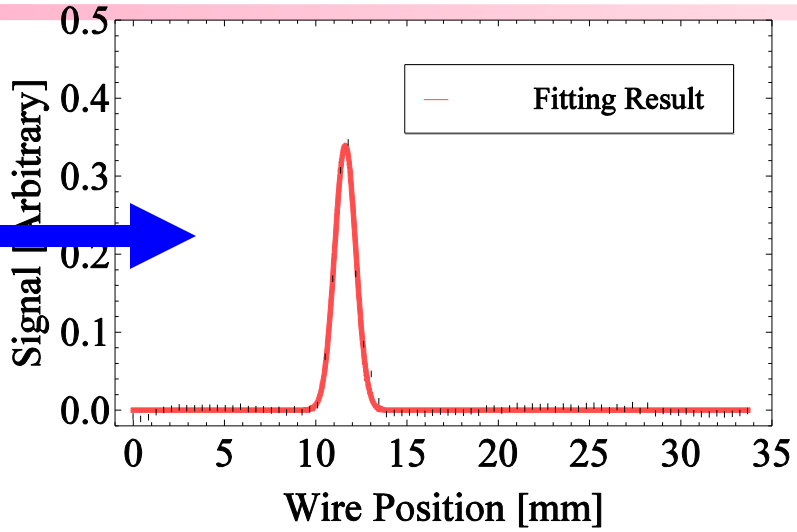
	Name	Current [Amp]	B [Gauss]
SOL-U	Upstream solenoid	850	7900
SOL-D	Downstream solenoid	850	7900
DIP-UH	Upstream horizontal dipole	3	100
DIP-UV	Upstream vertical dipole	3	100
DIP-DH	Downstream horizontal dipole	3	100
DIP-DV	Downstream vertical dipole	3	100

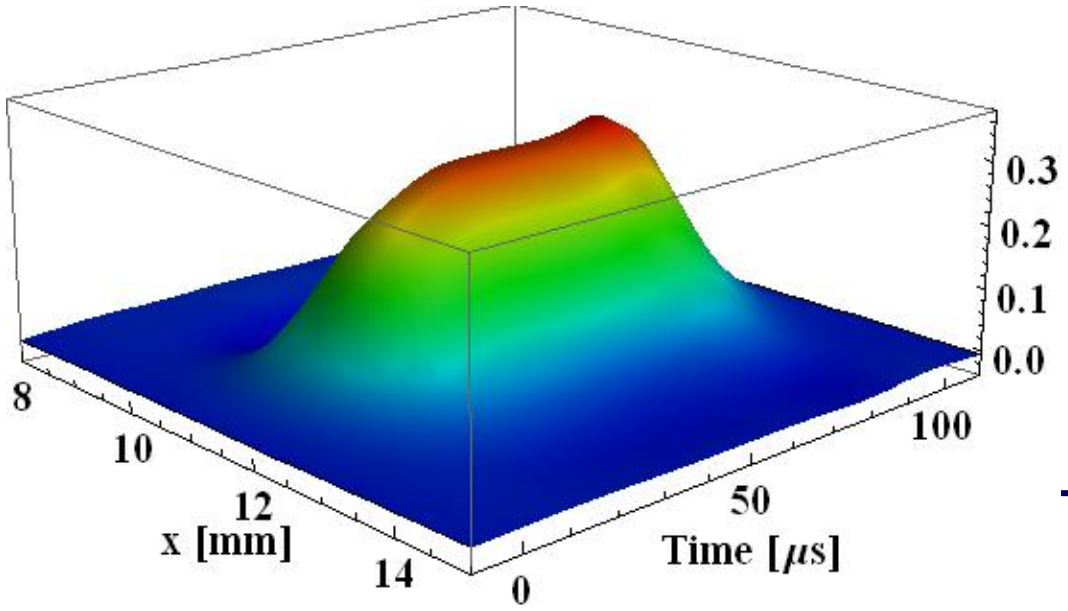
HINS LEBT Beam Measurement Setup



A Typical Wire Scan



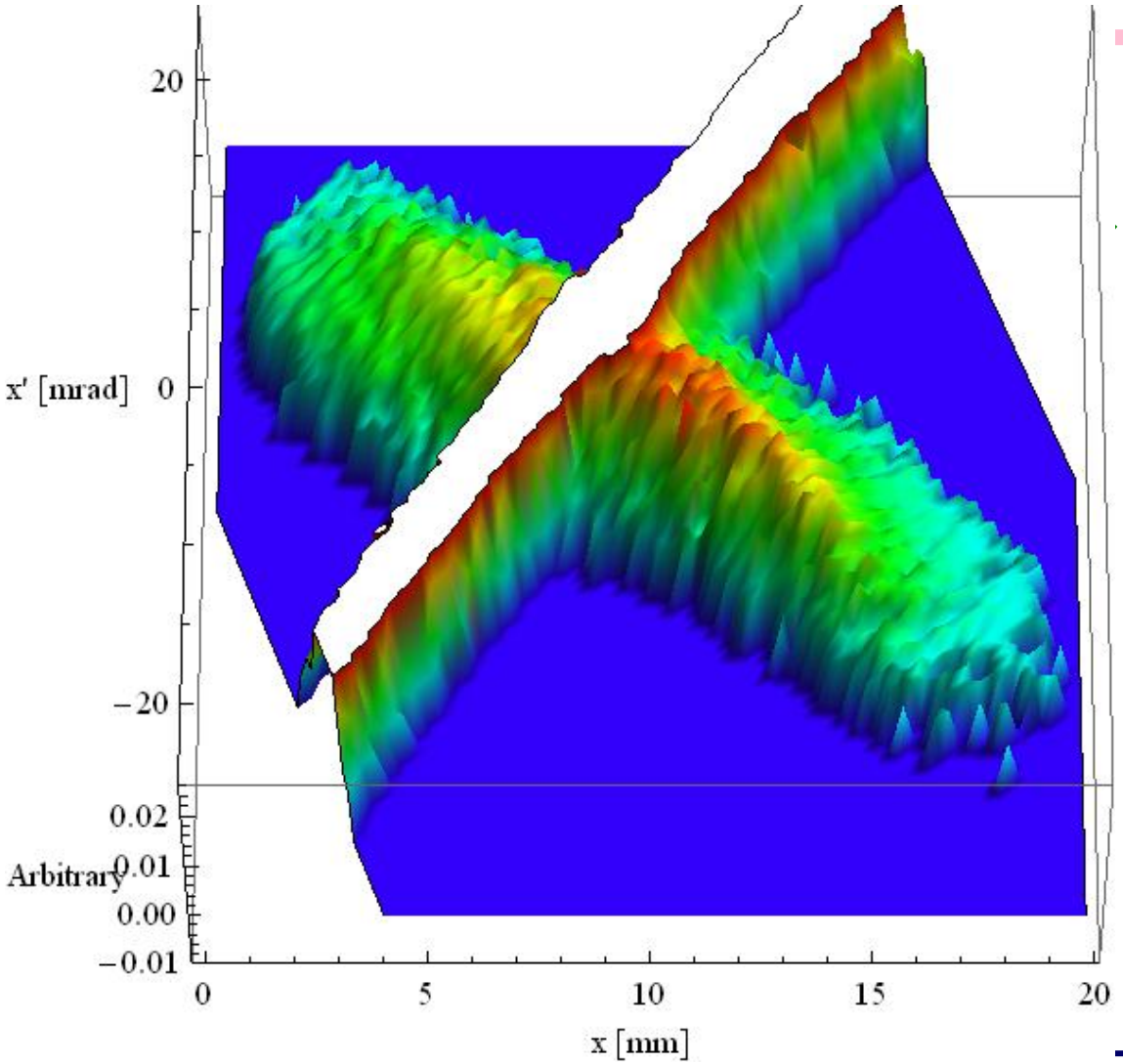




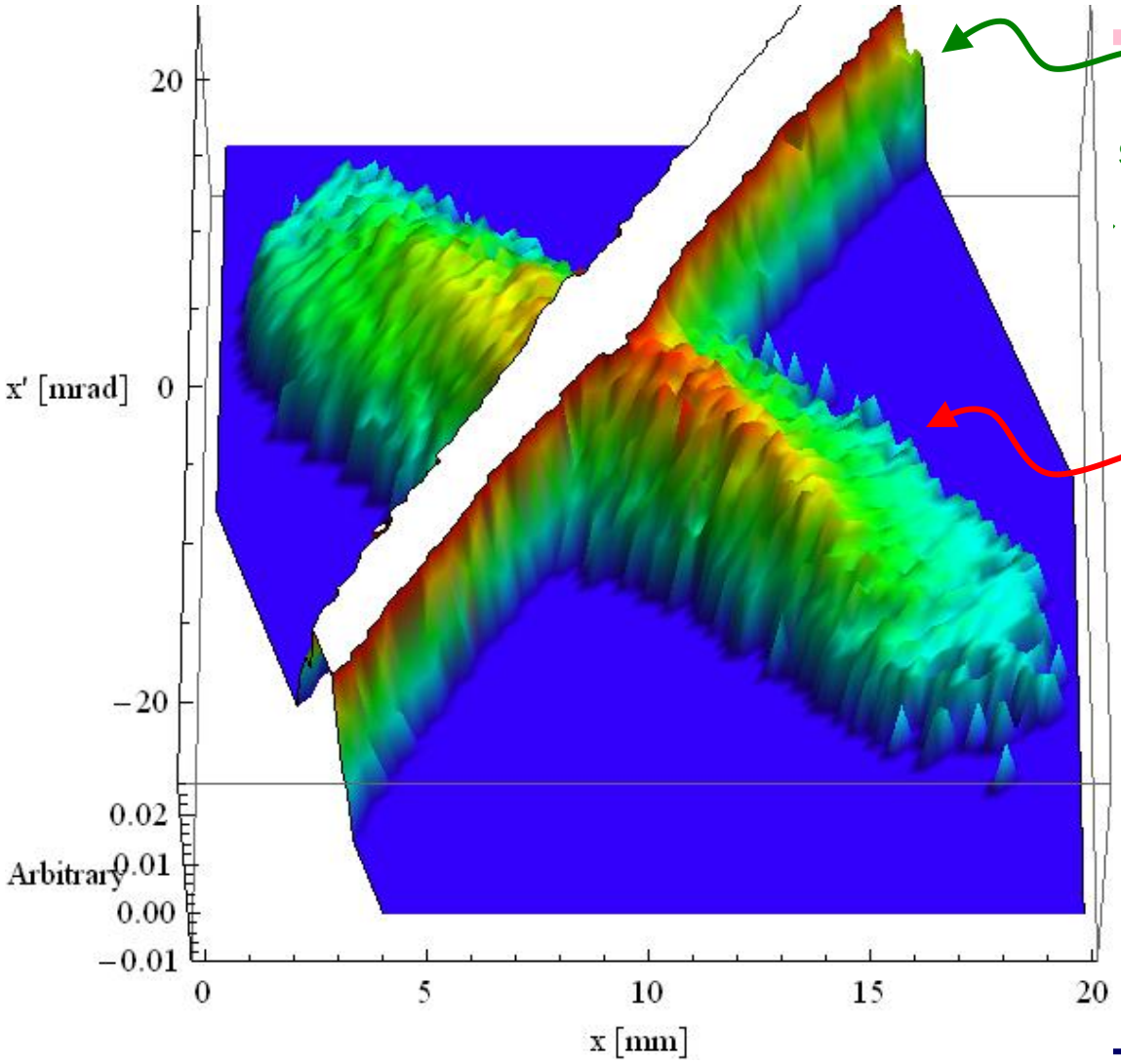
Signal with background subtracted.

The time structure of a 100 μs pulse. The flattop is about 50 μs.

Proton Source Slit-WS Emittance Measurement



Proton Source Slit-WS Emittance Measurement

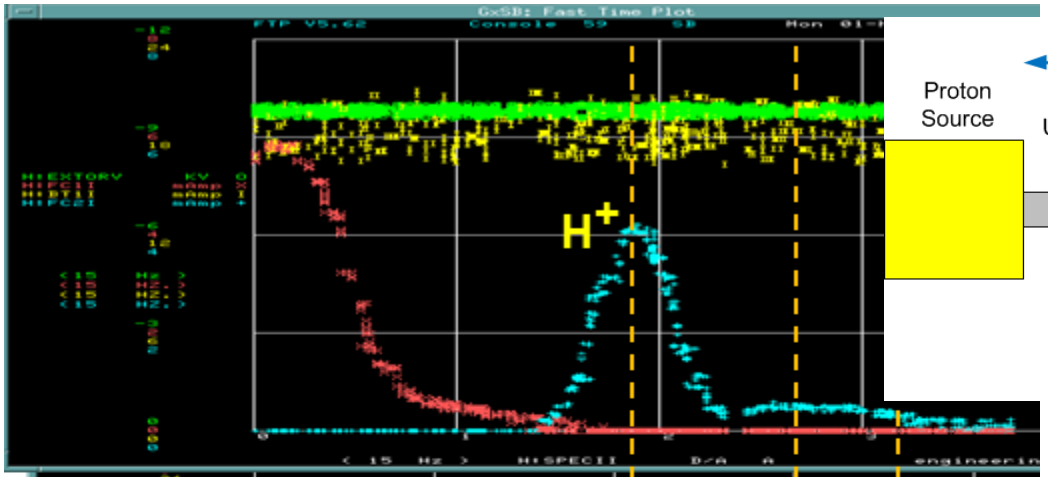


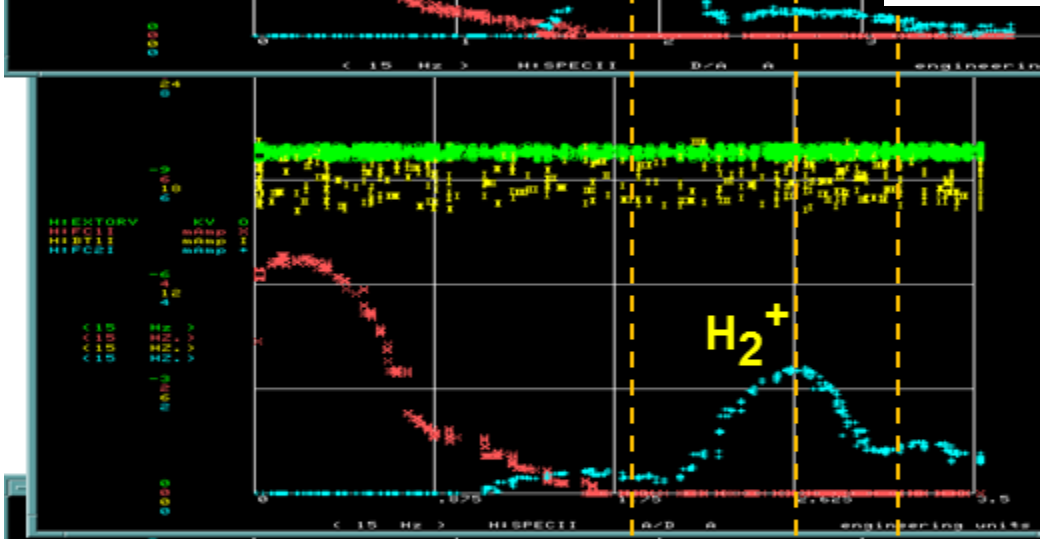
Other particle species fill the beam pipe

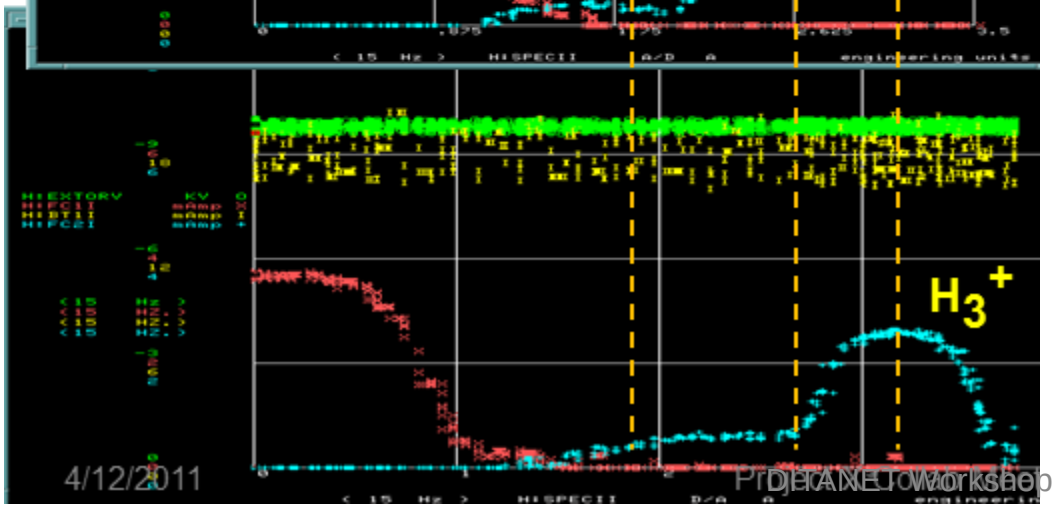
Proton

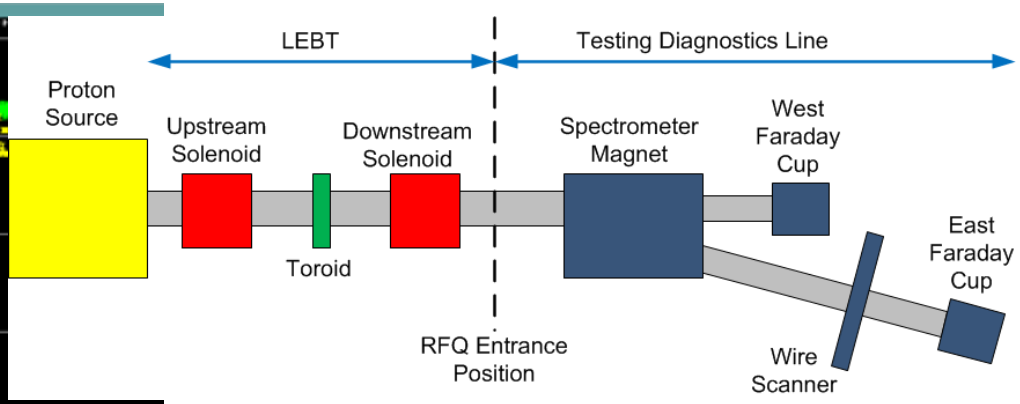
Slit motion

Background signal outweighs proton signal.









Source Species

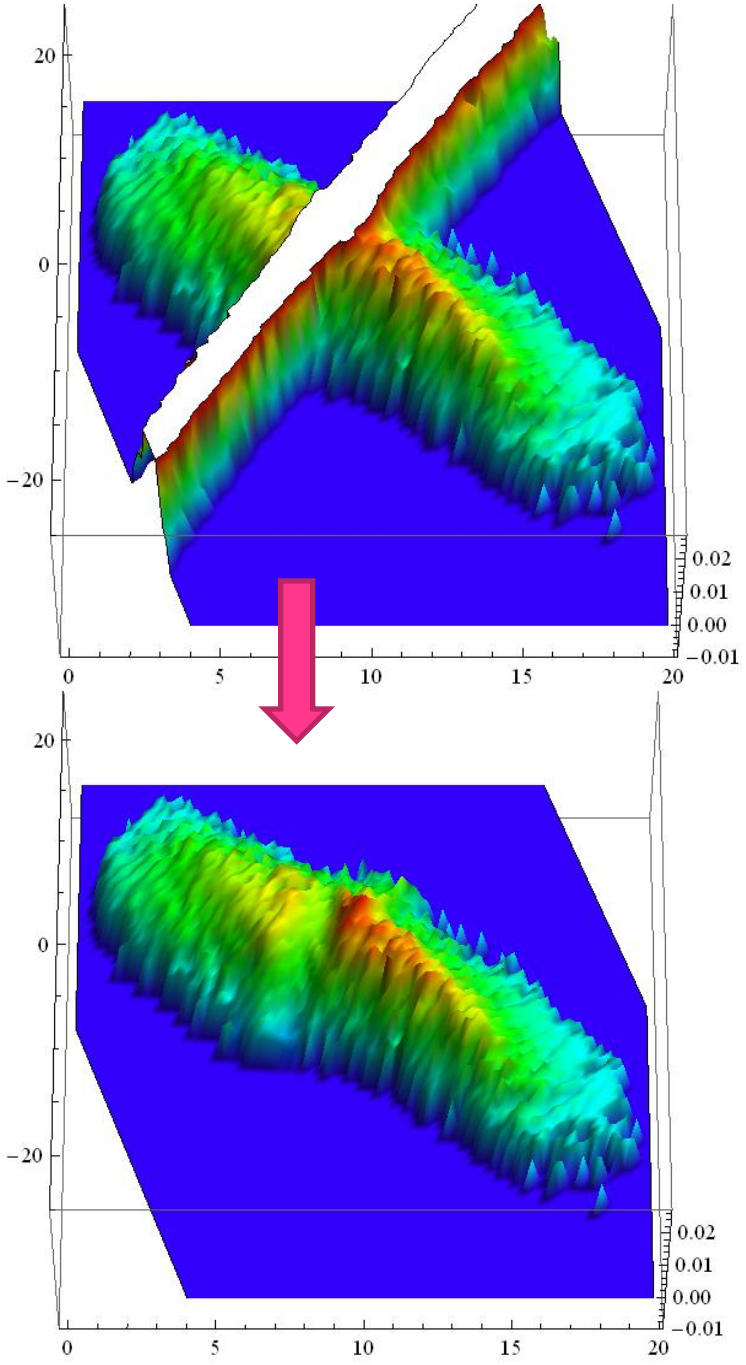
Green – Source Extractor Voltage
Yellow – LEBT Toroid Current
Red – Straight ahead Faraday Cup
Blue – Spectrometer Faraday Cup (bend)

- Downstream solenoid optimized for each species
- Upstream solenoid fixed at 470 A

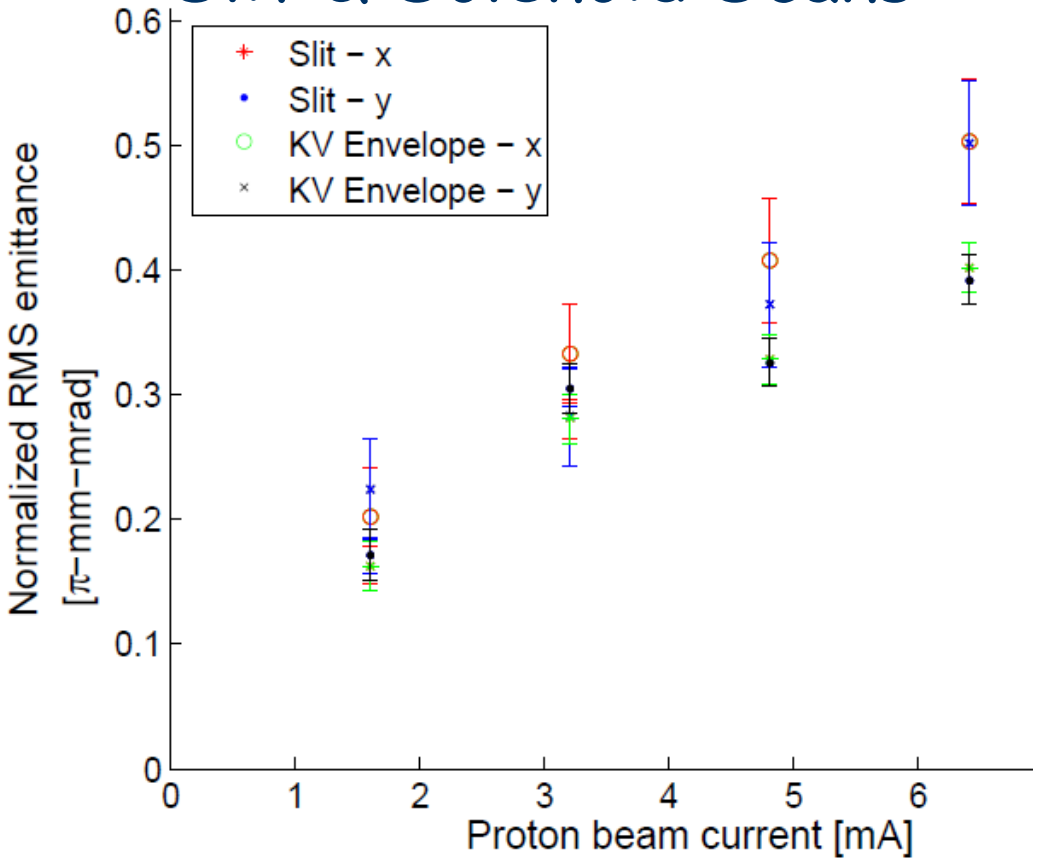
~ 40% Protons
~ 30% H2+
~ 30% H3+

- ***As measured by LEBT toroid***

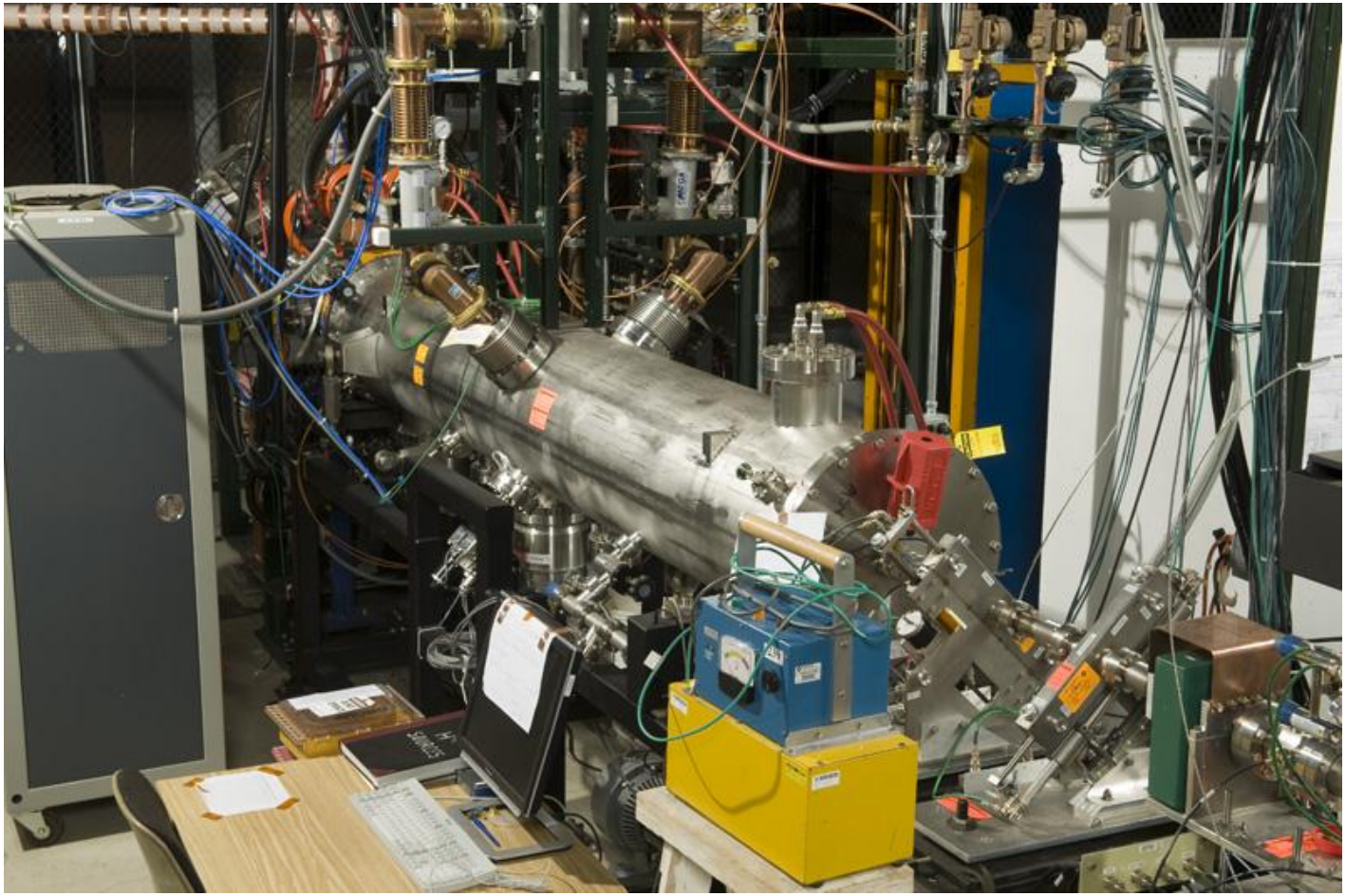
Phase Space Signal Cleaning



Source Emittance Slit & Solenoid Scans



MDB Test Facility
325 MHz Pulsed RFQ

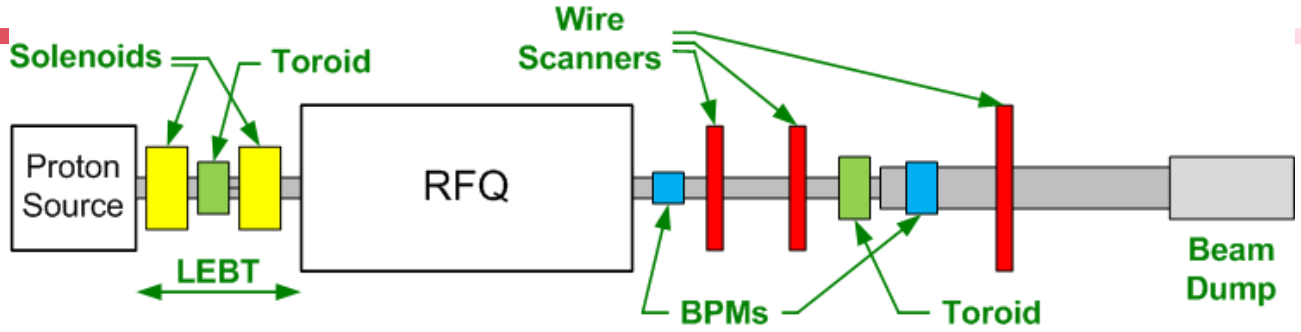


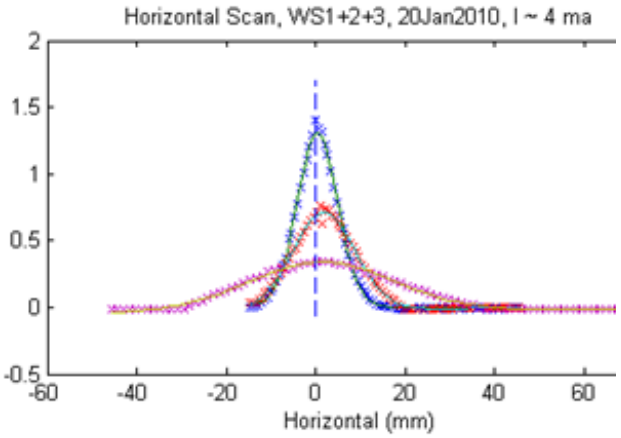
Initial RFQ Beam Measurements

RFQ design:

- 2.5 Mev
- 325 MHz
- Peak power up to 450 KW
- 1 ms pulses at 10 Hz

RFQ suffered from detuning problems and water leaks → 50 μs pulses at 1 Hz





Profile Sigmas and Integrals ; I ~ 4 mA

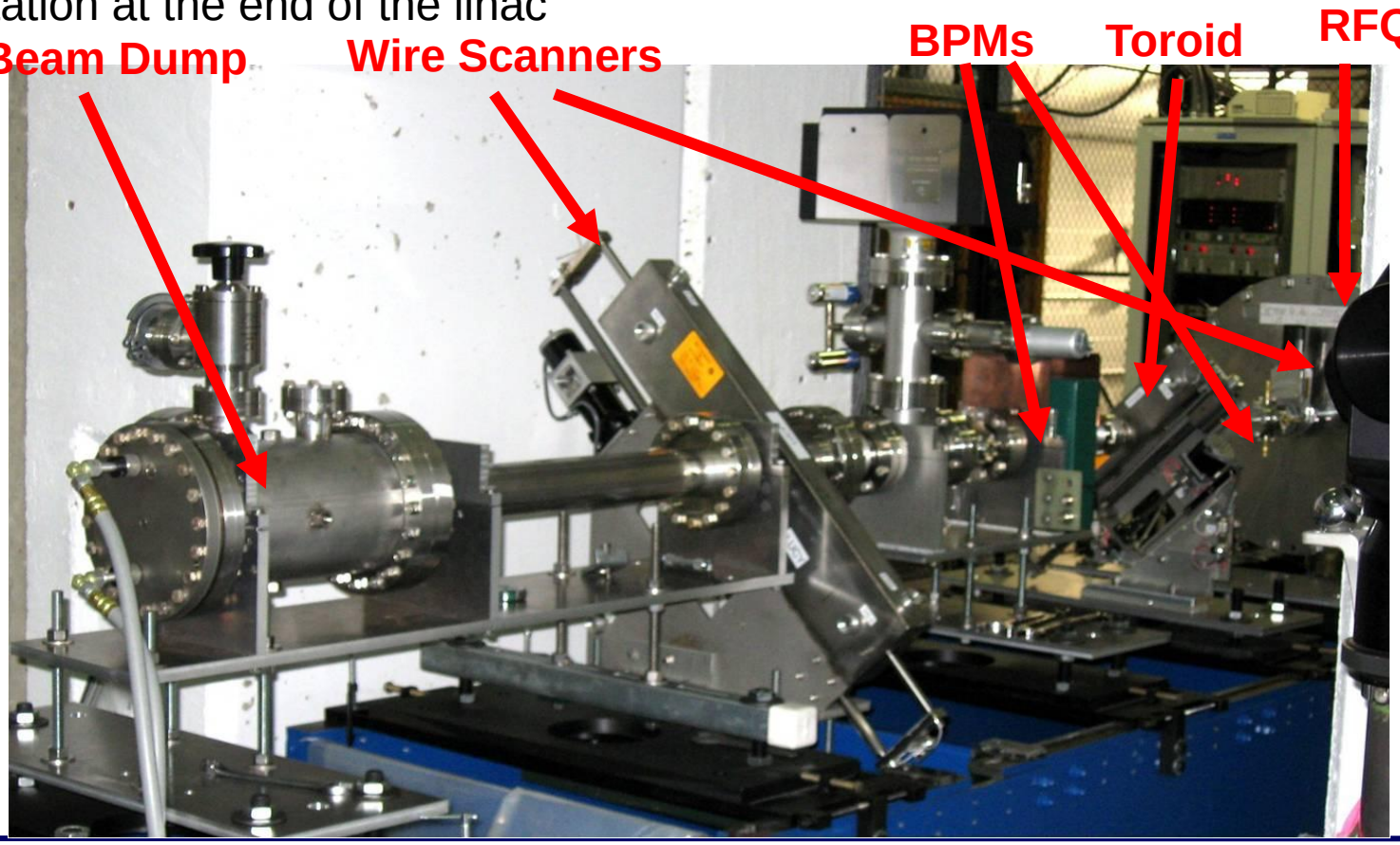
Sigmas	Horizontal	Vertical	Diagonal
Scanner 1	4.5 mm	4.2 mm	4.3 mm
Scanner 2	7.0 mm	6.8 mm	6.2 mm
Scanner 3	16.2 mm	13.2 mm	13.4 mm

Integrals	Horizontal	Vertical	Diagonal
Scanner 1	14.8 V*mm	14.9 V*mm	14.7 V*mm
Scanner 2	11.8 V*mm	10.5 V*mm	10.2 V*mm
Scanner 3	11.6 V*mm	10.1 V*mm	10.7 V*mm

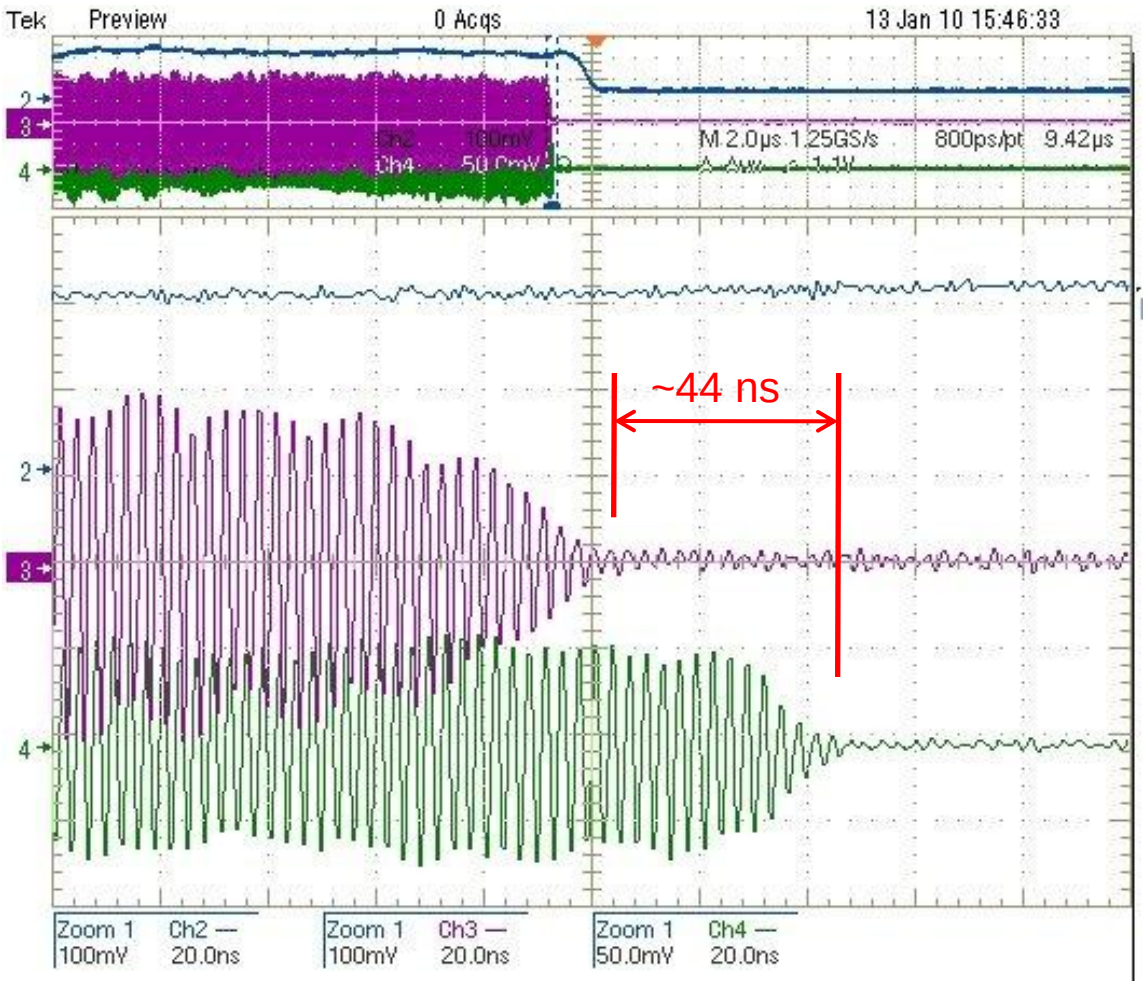
Beam loss after first wire scanner → need focusing

Initial RFQ Beam Diagnostics

The HINS linac was equipped with a reconfigurable, movable diagnostics station at the end of the linac



RFQ Energy Measurement by Time of Flight



Signals from toroid and two BPM buttons, all downstream of the RFQ

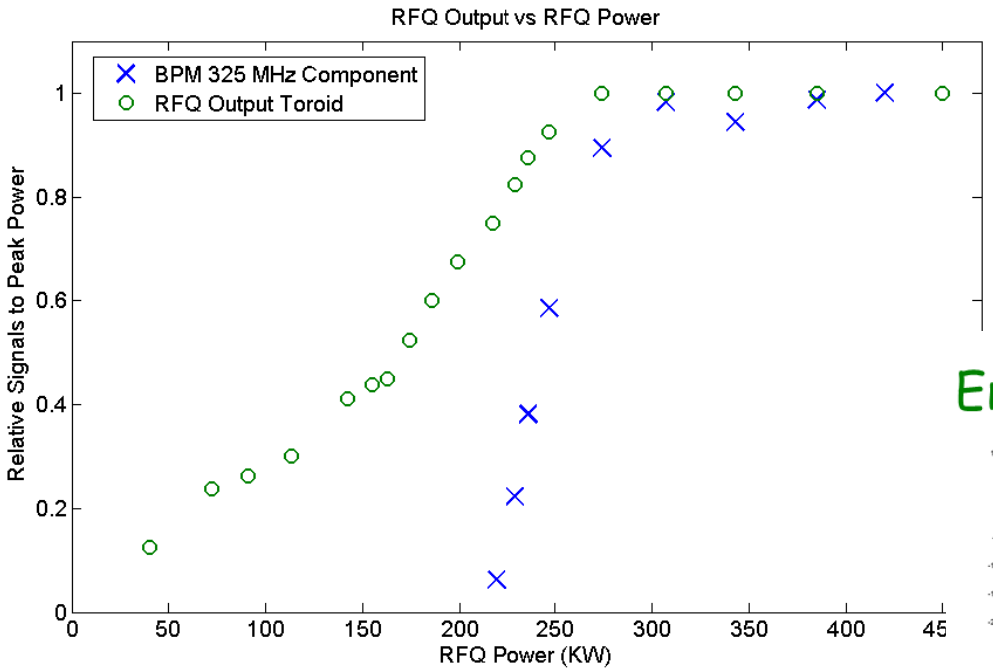
Upper display: 2 µsec/div

Lower display: 20 nsec/div

Lower display shows the 44 ns delay expected for transit of 2.5 MeV beam between the BPM two buttons separated by 0.96 meters

Beam current is about 3 mA

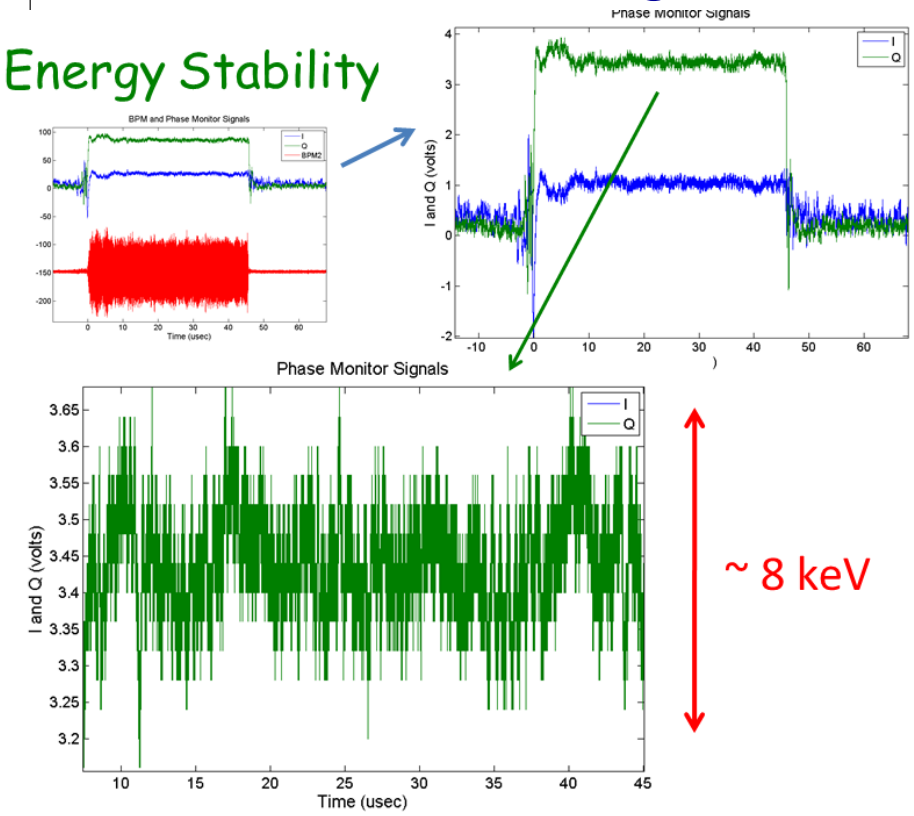
RFQ Stability



Relative RFQ output beam vs. RF Power

Phase variation from time-of-flight

Energy Stability



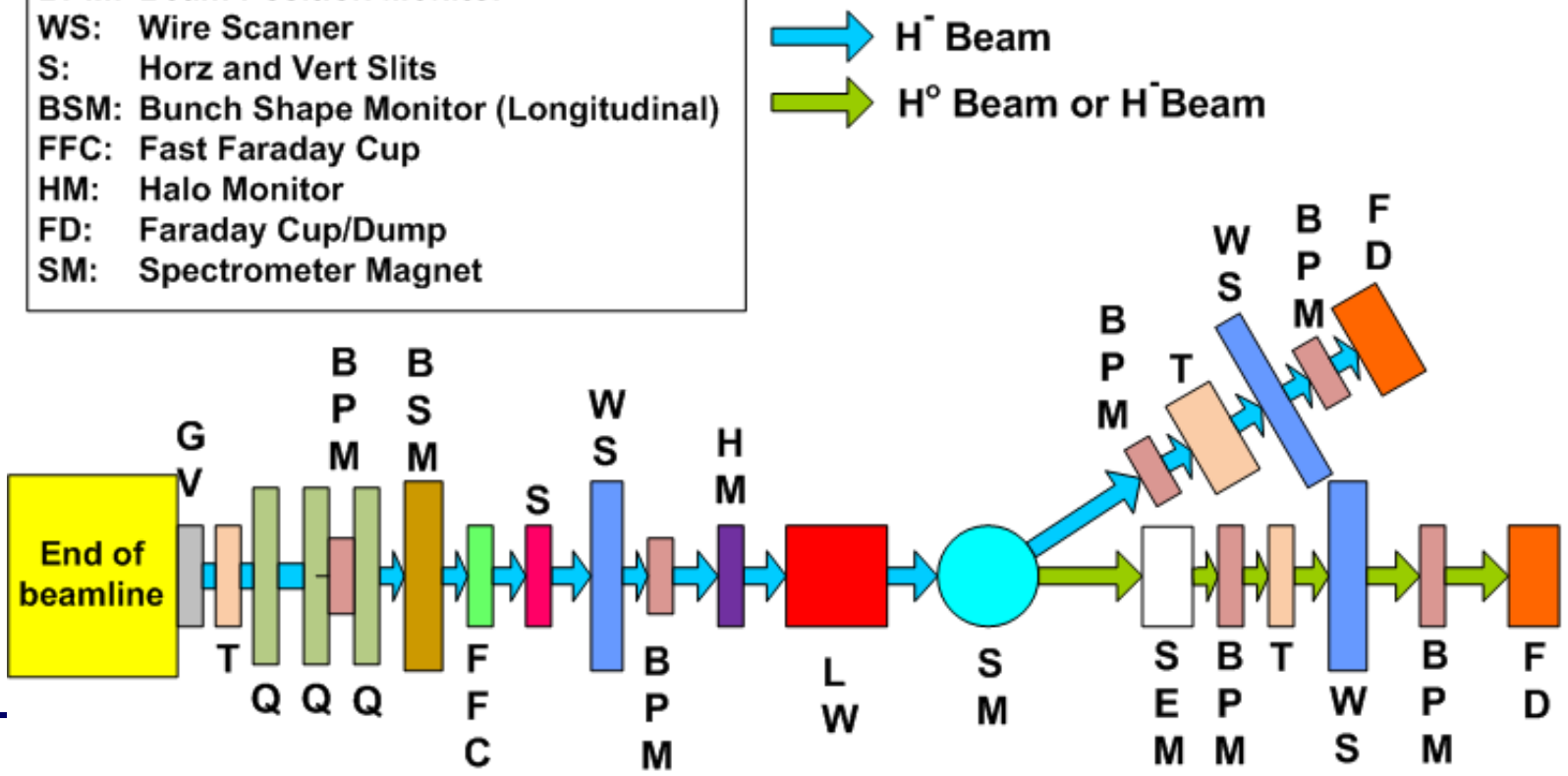
Next Iteration of RFQ Beam Measurements

- Initial measurements suffered from RFQ water leak problems
  - RFQ limited to 50 μsec pulses
  - RFQ has been repaired and reinstalled at the Meson test facility
- Initial RFQ measurements suffered many issues
  - No transverse focusing → Quadrupoles added
  - No longitudinal measurements → FFC and BSM
  - No transverse emittance measurements → Quad-Wire, Slit-Wire
  - Energy measurement was not precise → Spectrometer magnet
  - RFQ efficiency not accurately measured → Toroid at RFQ output
- New diagnostics line has been install
  - Reconfigurable, movable
  - ***Space available for R&D projects***

Advanced HINS Diagnostics Line

T:	Toroid
GV:	Gate Value
Q:	Quadrupole
LW:	Laser Wire
SEM:	Secondary Emission Monitor
BPM:	Beam Position Monitor
WS:	Wire Scanner
S:	Horz and Vert Slits
BSM:	Bunch Shape Monitor (Longitudinal)
FFC:	Fast Faraday Cup
HM:	Halo Monitor
FD:	Faraday Cup/Dump
SM:	Spectrometer Magnet

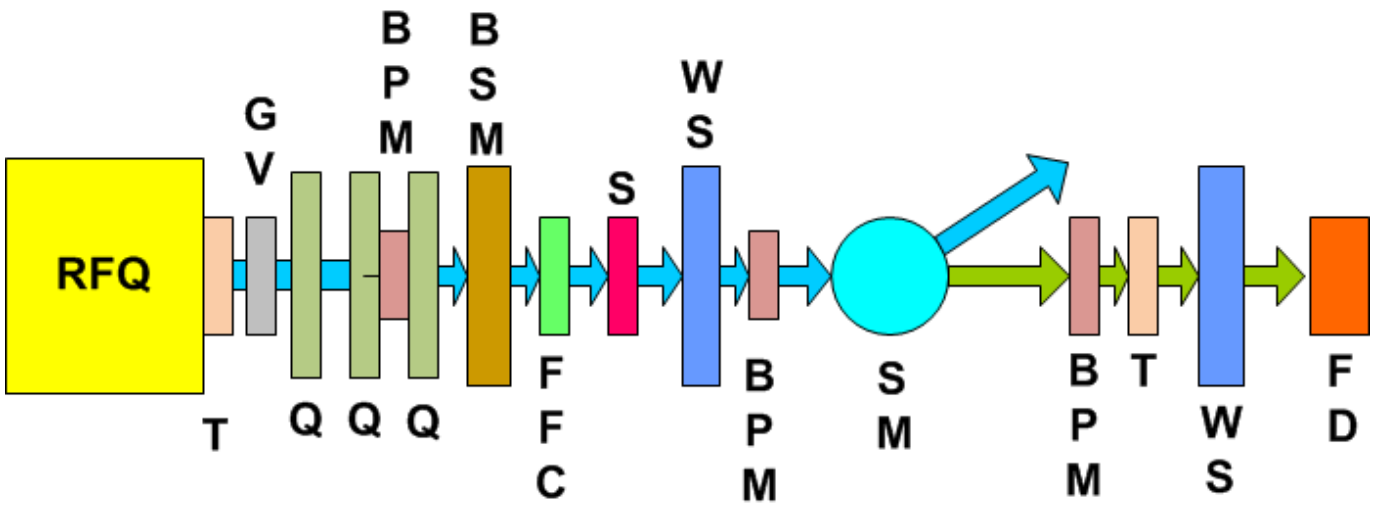
Advanced HINS Diagnostics Line
V 1.0
May 19, 2010



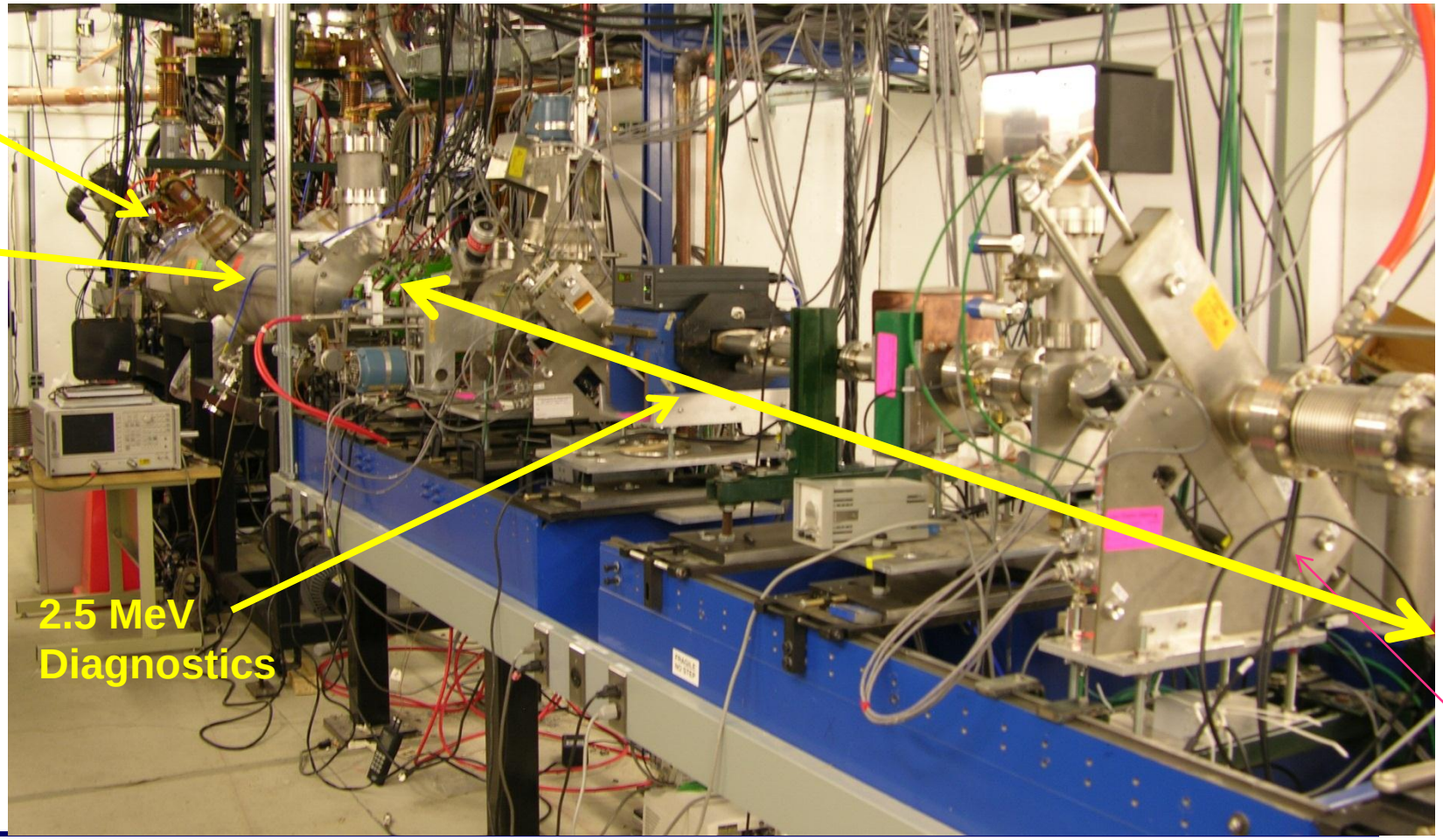
Advanced HINS Diagnostics Line

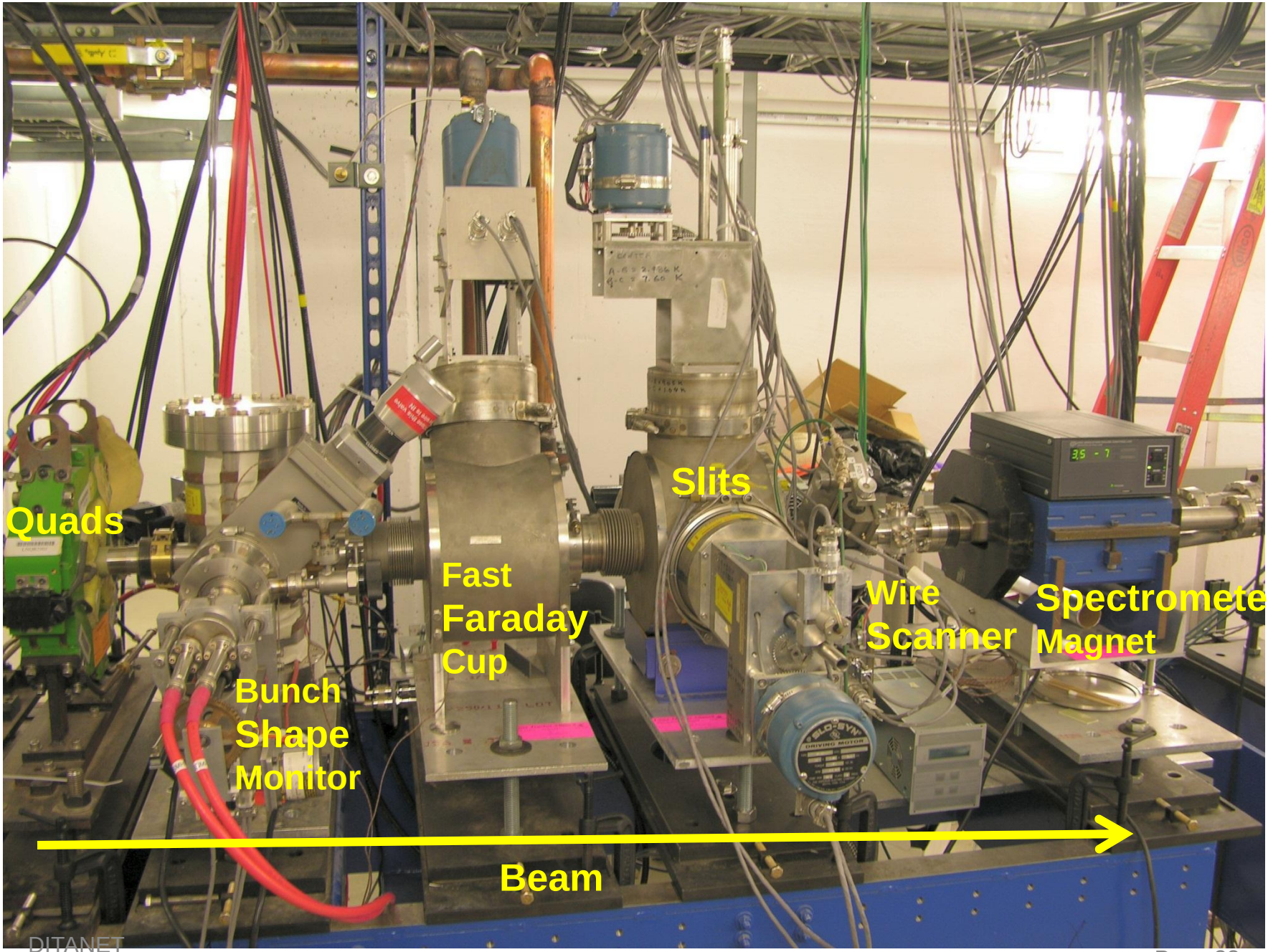
T:	Toroid
GV:	Gate Value
Q:	Quadrupole
BPM:	Beam Position Monitor
WS:	Wire Scanner
S:	Horz and Vert Slits
BSM:	Bunch Shape Monitor (Longitudinal)
FFC:	Fast Faraday Cup
FD:	Faraday Cup/Dump
SM:	Spectrometer Magnet

RFQ Beam Diagnostics April 2011

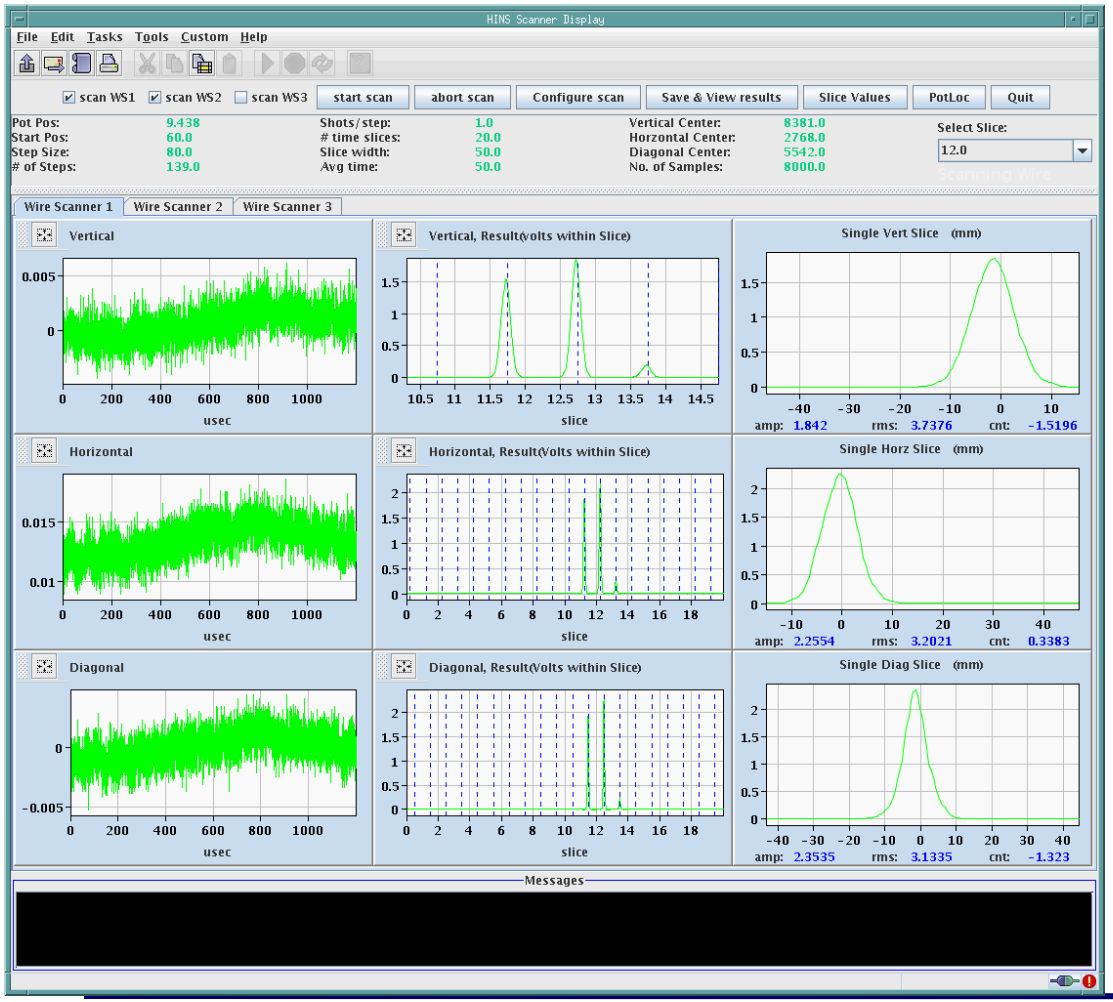


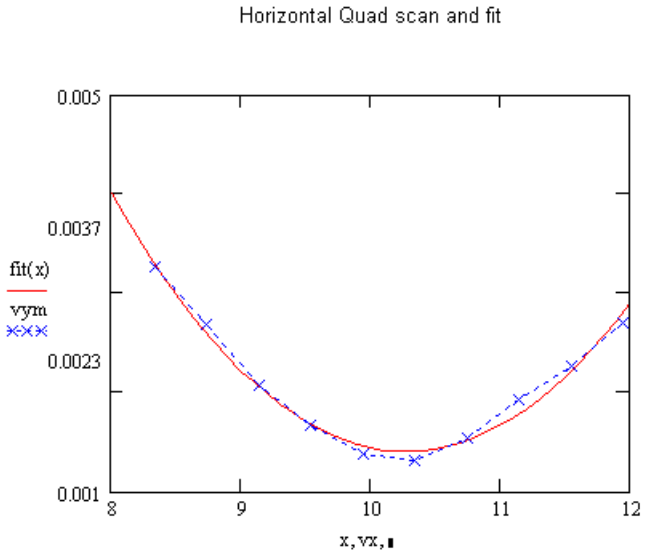
HINS Beamline




Quads
Bunch
Shape
Monitor
Fast
Faraday
Cup
Slits
Wire
Scanner
Spectrometer
Magnet
Beam

Transverse Emittance from Quadrupole Scans





the equation is sigma=.05452 - .01034k + 5.02791E-4k^2
setting the derivative to zero gives k0=10.283. Note this is the gradient at minimum

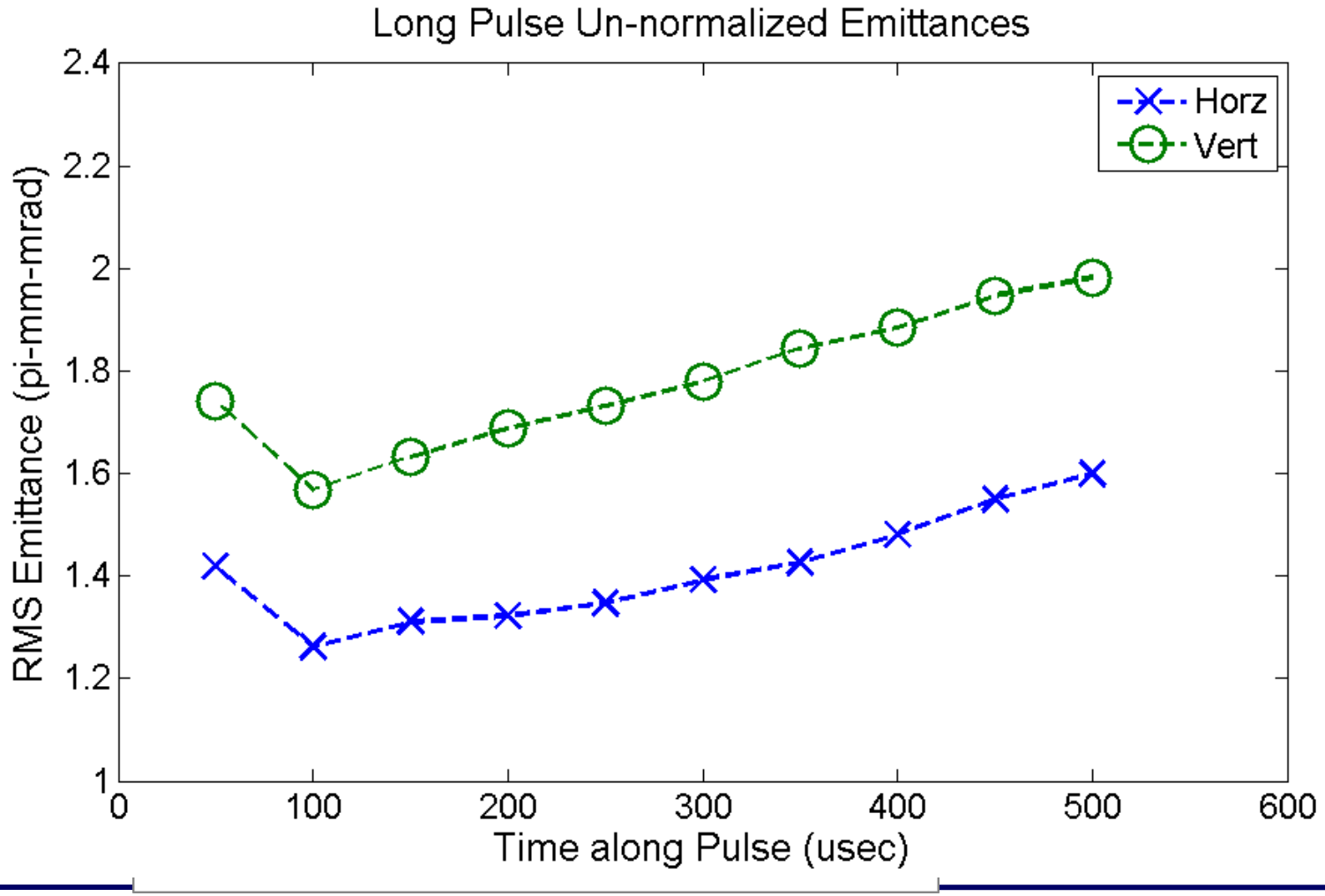
Unnormalized emittance

- 6 mA RFQ beam
- 100 usec pulses

H: 1.49 pi mm-mrad

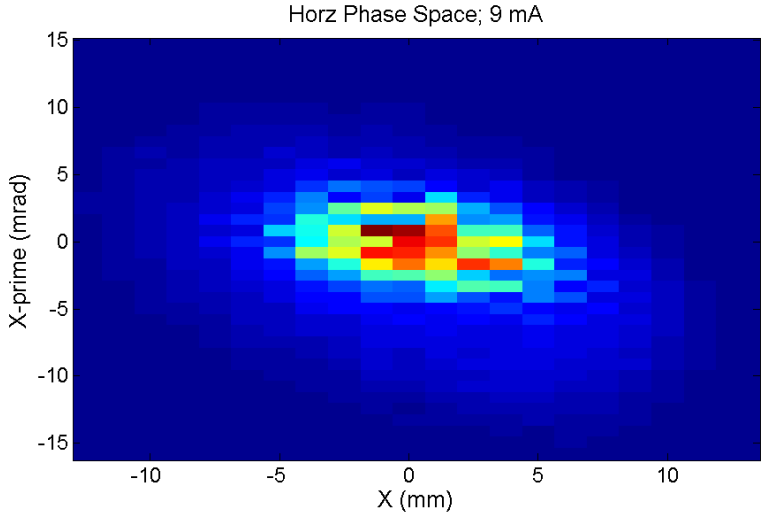
V: 1.88 pi mm-mrad

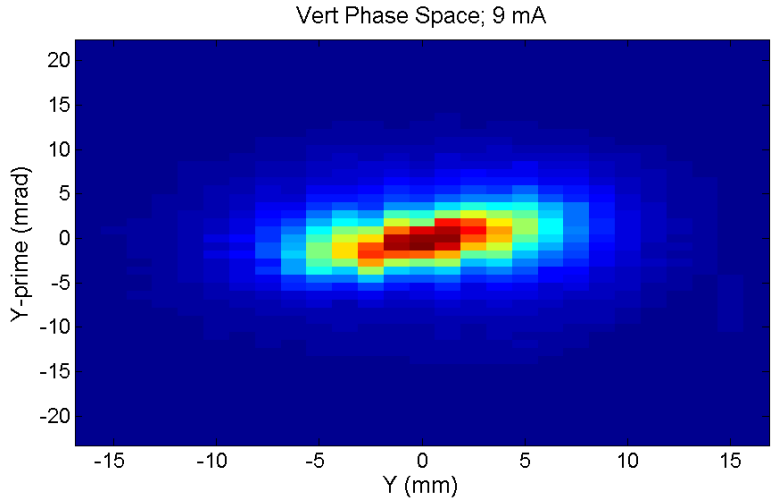
Un-normalized Emittance along 500 usec Pulse – Quad Scan

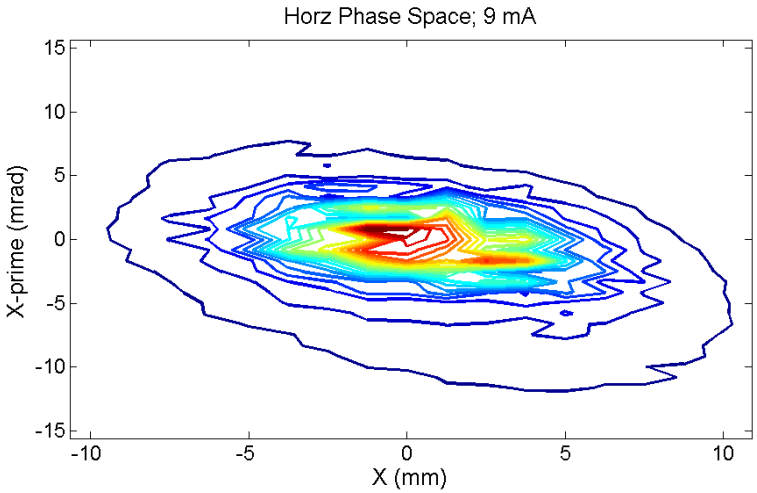


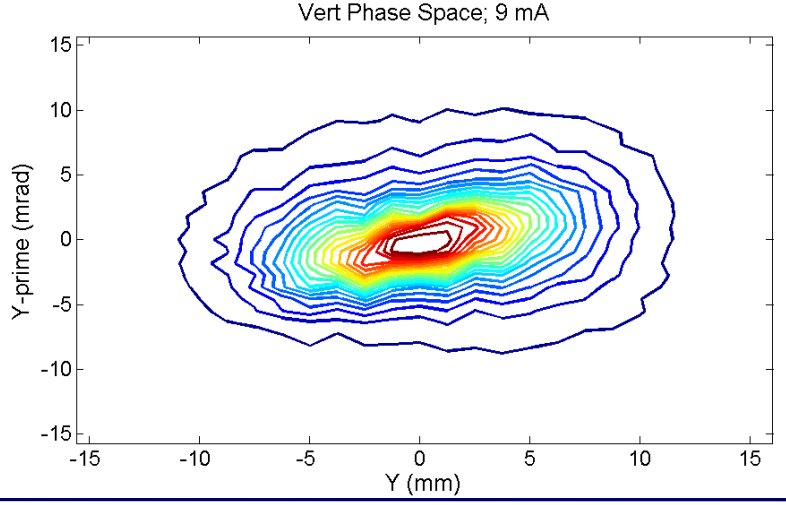
Phase Space Plots; 9 mA RFQ

HORIZONTAL



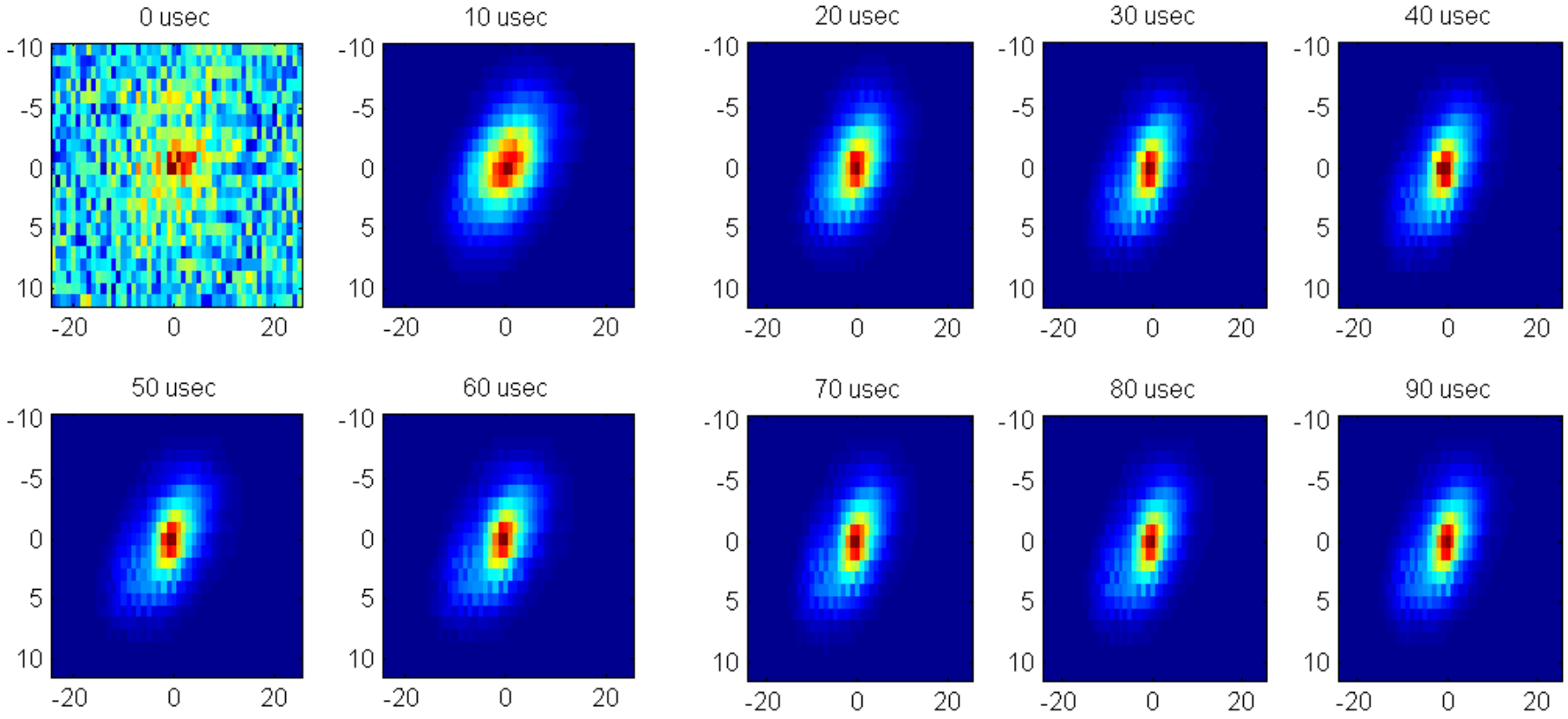






VERTICAL

Horizontal Phase Space along Pulse - *Preliminary*

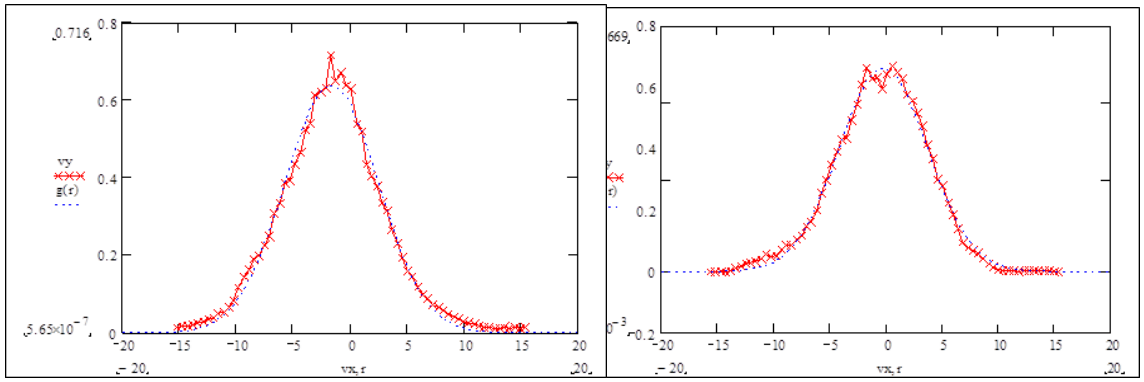


- X – X' along beam pulse; arbitrary units
- 6 mA beam

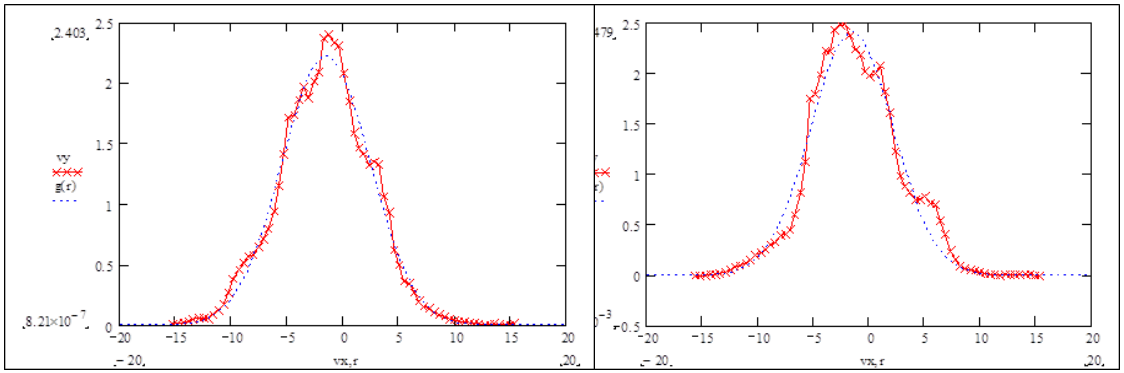
Odd Transverse Shape Effects

Vertical

Horizontal



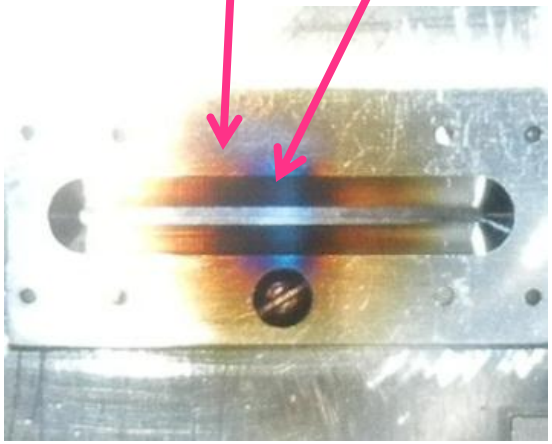
Front of pulse



Back of pulse

Halo?

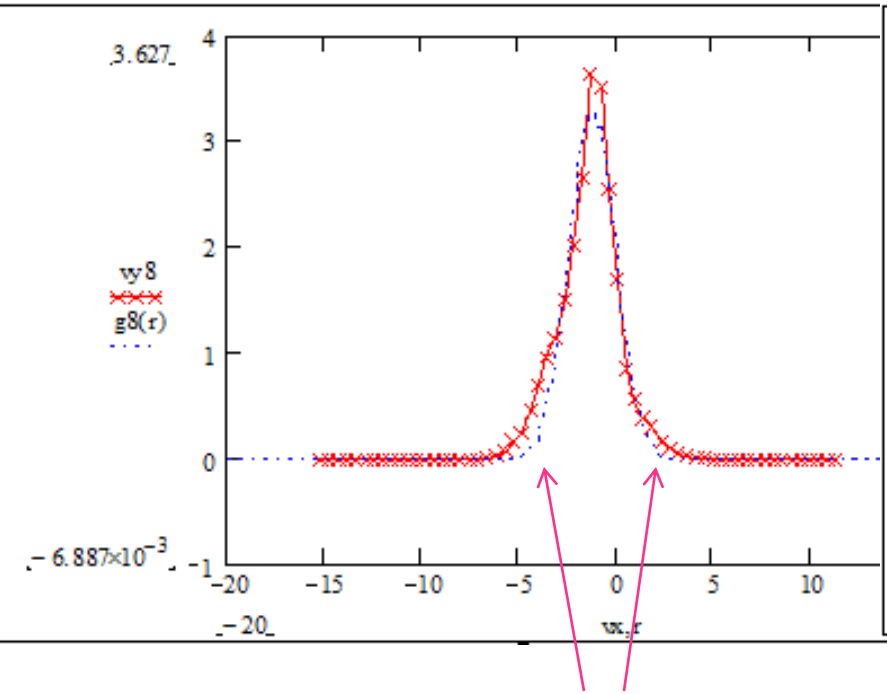
Main beam



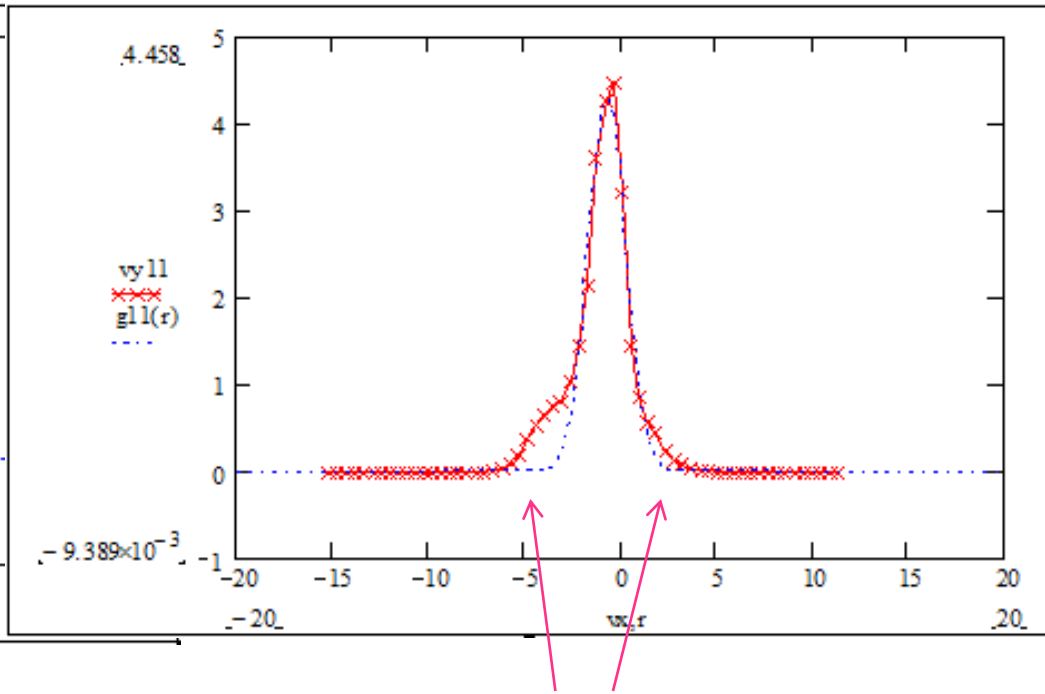
Horz Slit

Horz Shape at Minimum Focus at Wirescanner

Beginning of 100 usec pulse



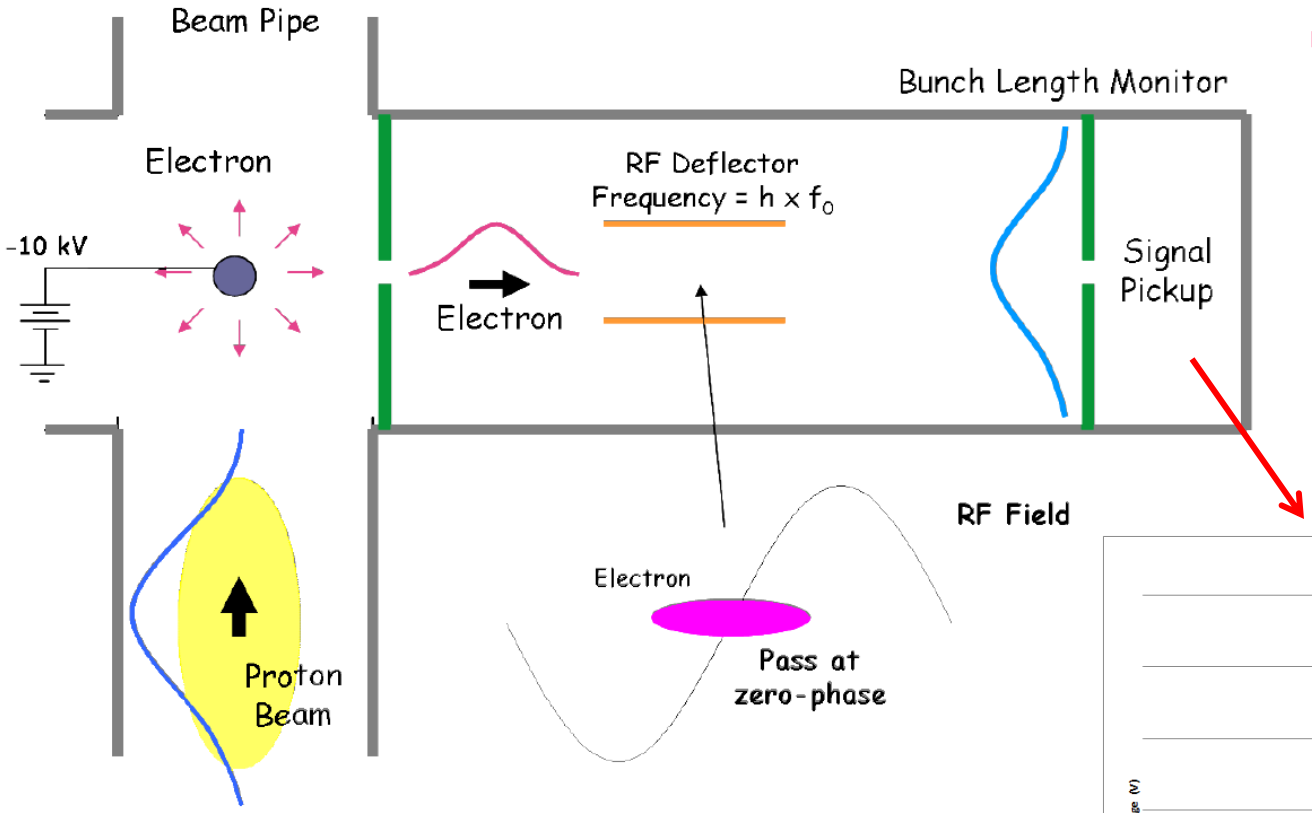
Middle of 100 usec pulse



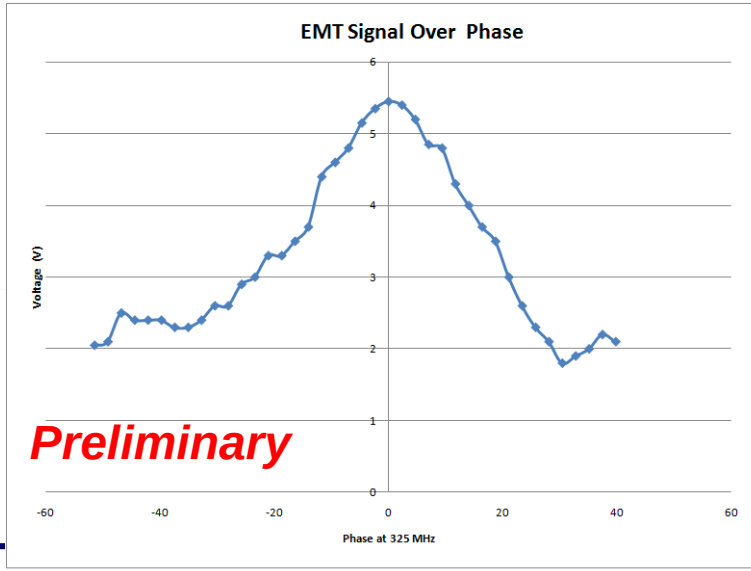
Background?

Background?

Longitudinal Bunch Shape Monitor



FWHM: (prelim)
~ 40^{O}@325 MHz
~ 340 ps

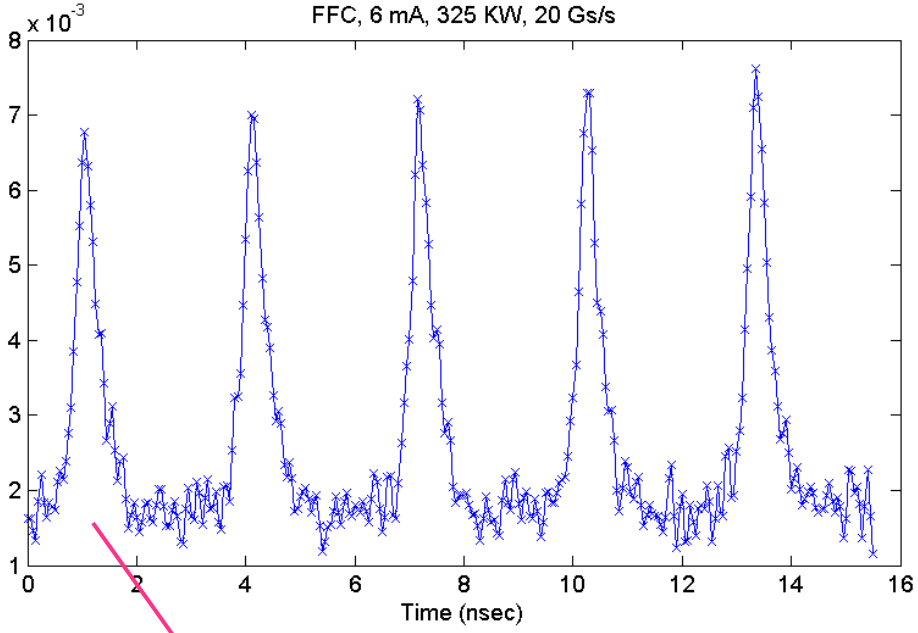


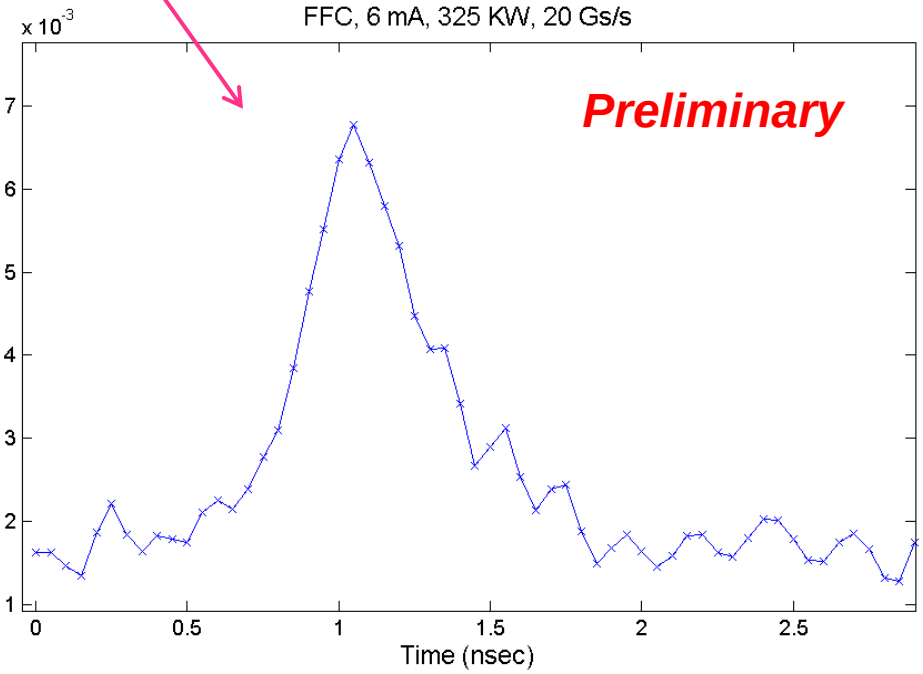
Translate time coordinate into space coordinate using RF deflector cavity

- like a streak camera

Systematics need to be understood for H- at low energy

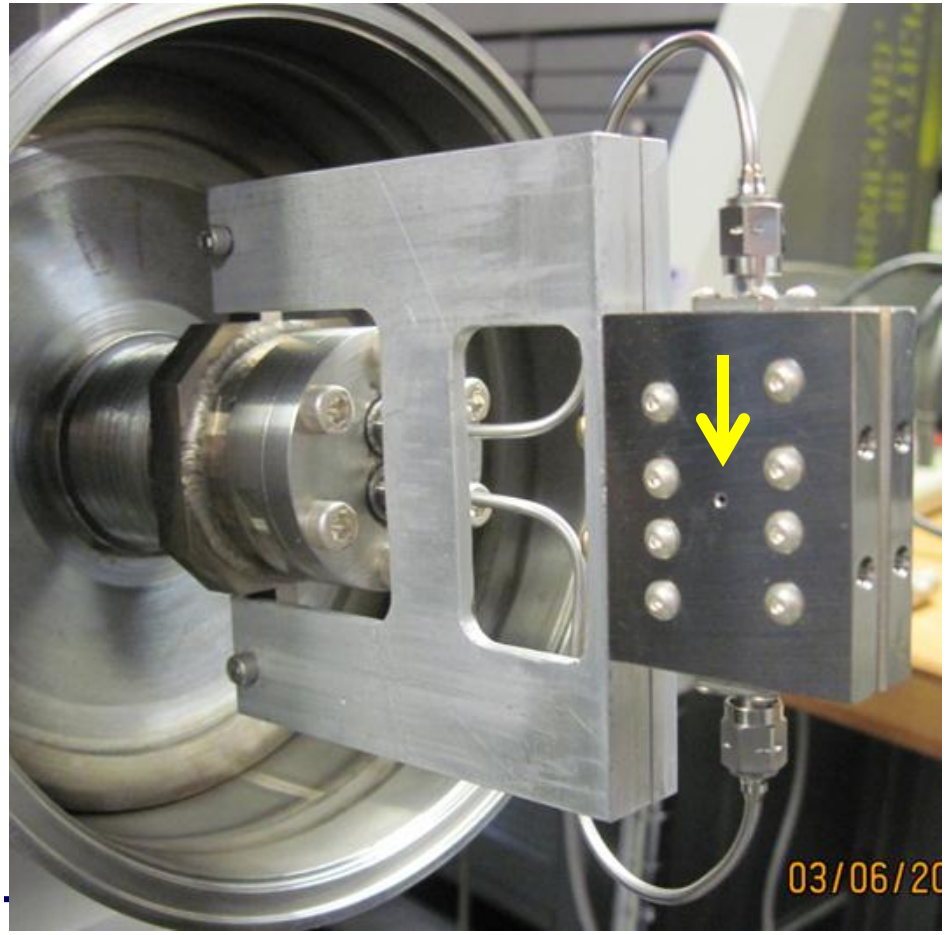
Longitudinal Bunch Shape – Fast Faraday Cup (SNS)





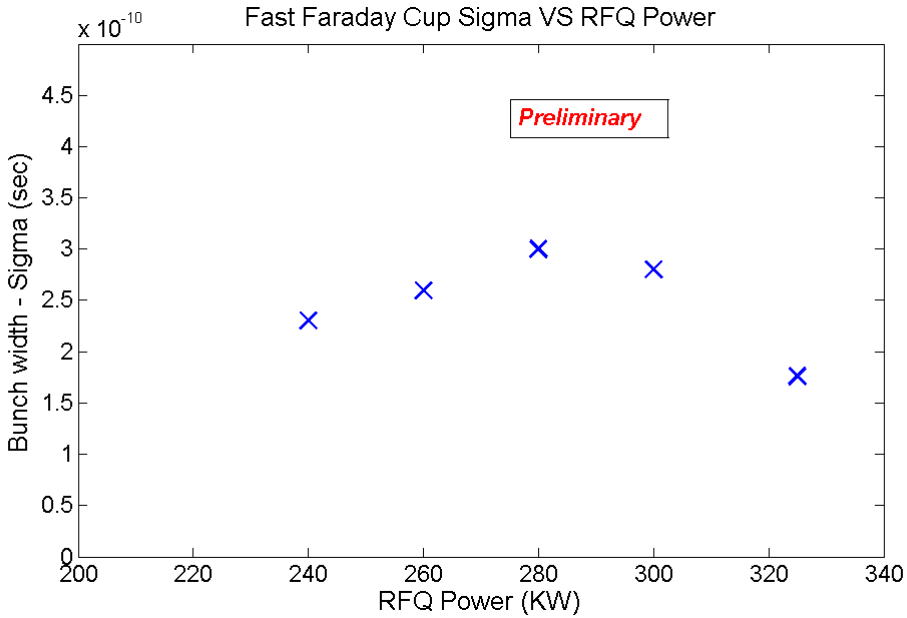
~ 20 GHz bandwidth

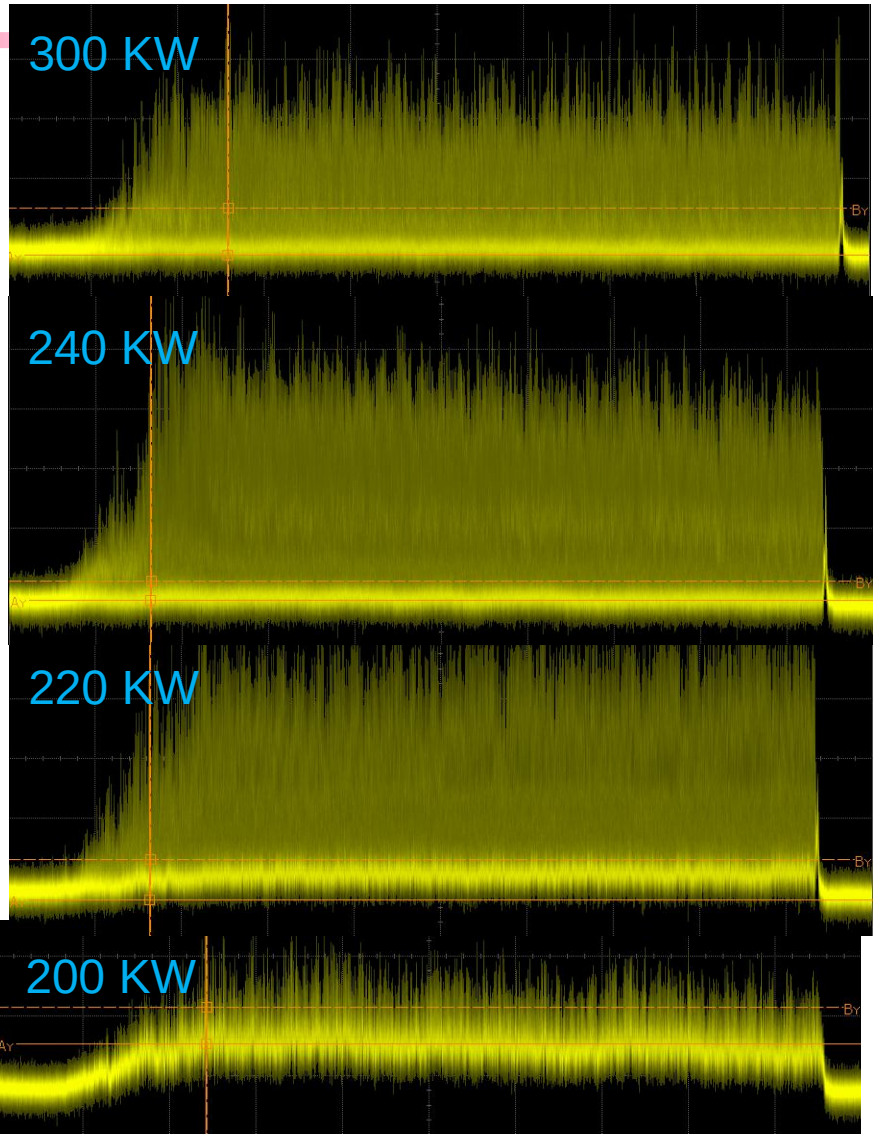
- Limited by signal cable



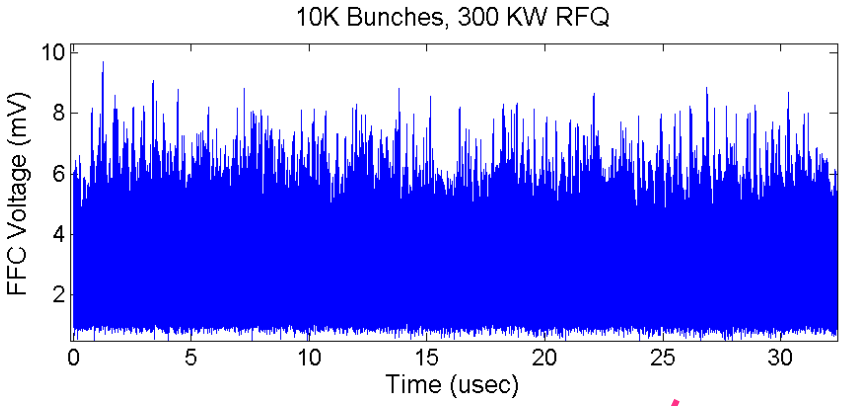
Longitudinal Shape VS RFQ Power

Feed fast Faraday Cup into high bandwidth scope (6 GHz ABW) to measure bunch shape.

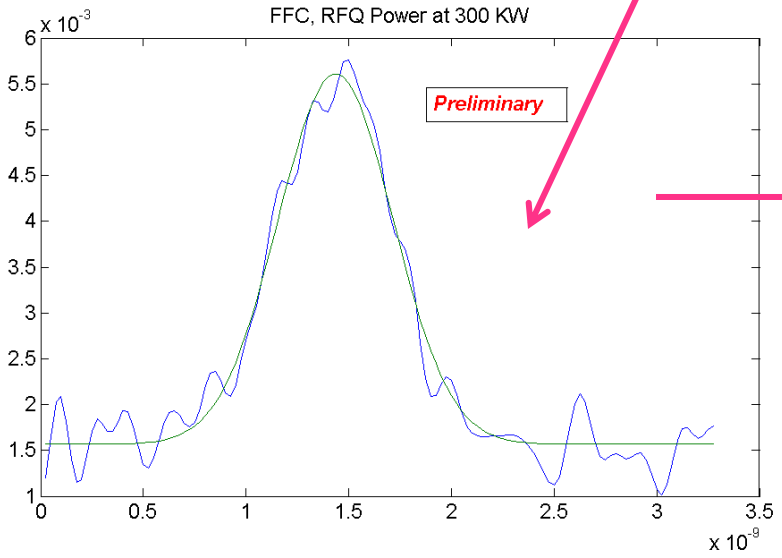


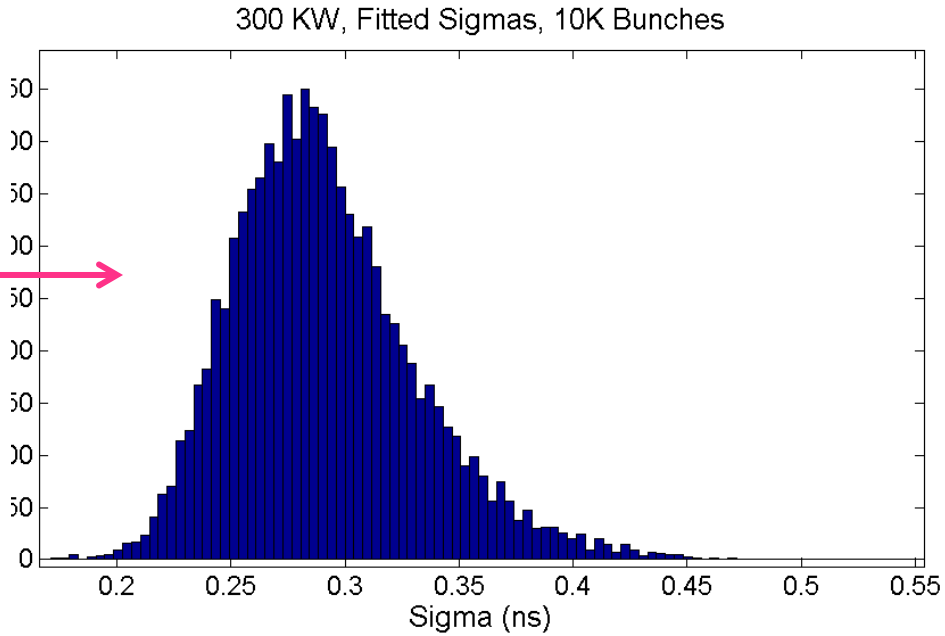


Bunch Shape Along Pulse



Fit individual bunches along pulse
- RFQ at 300 KW
- Histogram → ~ 0.28 ns sigma
- → 33 deg @ 325 MHz
- Need to deconvolve cable





Beam Diagnostic Projects for Project X

Transverse Diagnostics
- Laser Transverse Profile Monitor*
- Ionization Profile Monitors
- Electron Wire Transverse Profile Monitor – with SNS

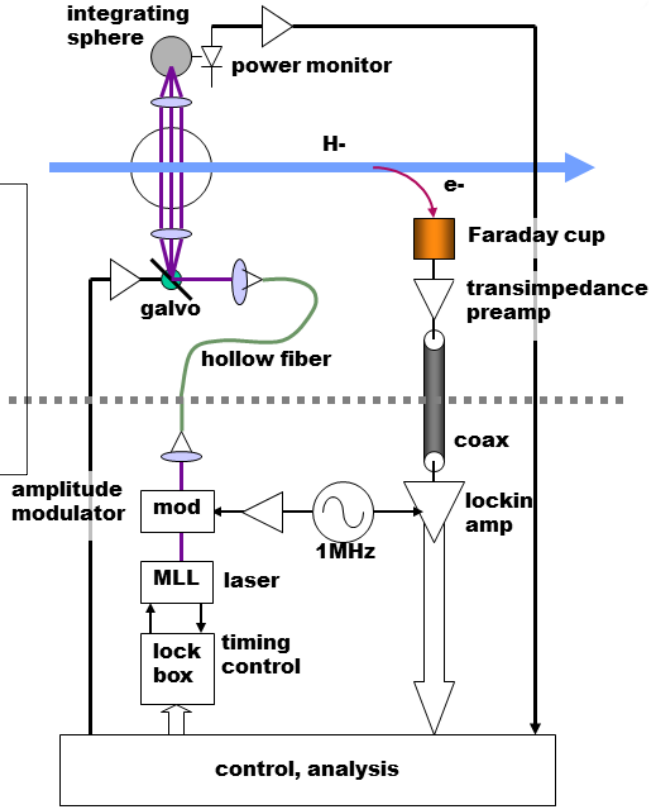
Longitudinal Diagnostics
- Wire Longitudinal Profile Monitor*
- Laser Longitudinal Profile Monitor* - with LBNL
- Broadband Faraday-cup – with SNS*

Halo Monitoring – transverse and longitudinal
- Vibrating wire* - *from Bergoz Instrumentation*
- Laser wire* - with LBNL

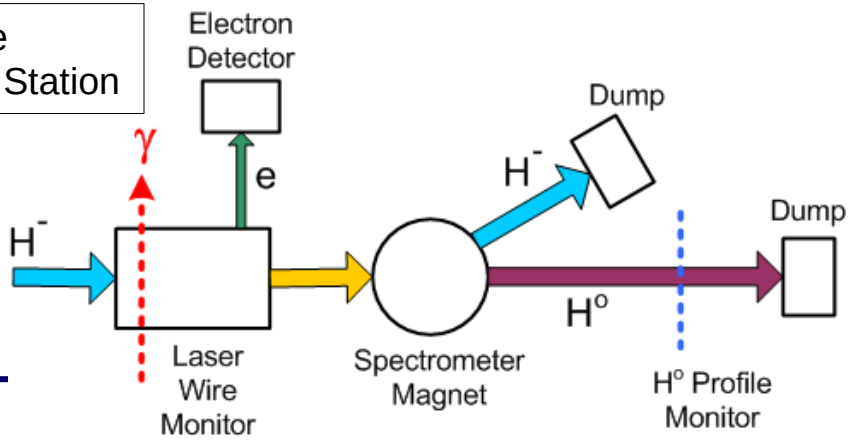
MEBT Emittance station
- Slit-collector*
- Laser Slit*

** Project X related instrumentation to be tested at HINS*

See R. Wilcox Poster TUPD53 "A Low-Power Laser Wire with Fiber Optic Distribution"



Laser Wire Emittance Station



Conclusion

- MDB Test Facility (HINS) has taken initial proton source and RFQ beam measurements
- RFQ has been repaired and reinstalled at MDB
- New diagnostics line has been installed
- RFQ Beam measurements have been made *– analysis proceeding*
- Six cavity being installed now – accelerator and buncher cavities for vector modulator test
  - Beam by early Sept
  - *H^- to be installed later this year*
- The MDB test facility HINS can play a role in Project X front-end testing
  - R&D for beam diagnostics and beam chopper
- ***Outside collaborators invited and encouraged to use MDB and HINS for diagnostic instrumentation R&D***

Sad Farewell – Sept 30, 2011

Tevatron Turnoff – 28 years as highest energy collider
Good Luck LHC

The End