BNL - FNAL - LBNL - SLAC

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Advanced Instrumentation Proposals

A. Ratti

L. Doolittle

R. Connolly

+ many others

Presented at the DoE review of LARP/LAUC

Berkeley

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Overview

We present two separate proposals in support of linac4 construction

- LLRF controllers
- Non intercepting beam diagnostics

Both benefit from successful recent experience with SNS linac

Collaborative effort of several US labs with direct participation of CERN

Describe technical approach and proposals

Linac 4 and Linac upgrade projects

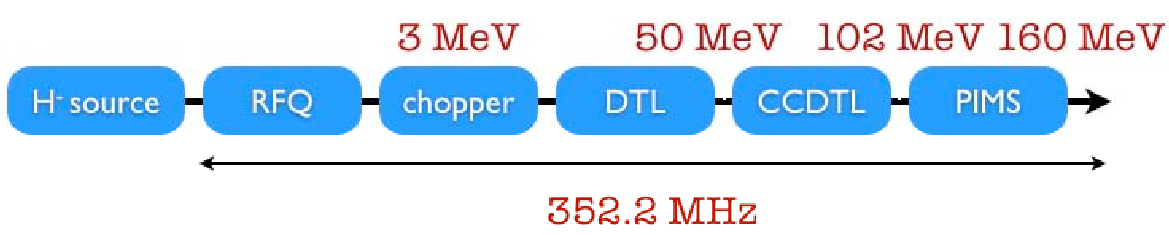
CERN linac upgrades have begun with linac4, now under construction

- 0.4 - 1.2ms, 2 Hz pulses
- 40 mA H^-

Next planned phase is to extend to a superconducting linac up to 4/5 GeV

Technologies and components very similar to the SNS, Project X

Leverage experience in the US to contribute advanced technologies to CERN



RF Controllers - Technology Evolution

Recent evolution in FPGA technologies have enabled the next generation RF controllers

- Low latency enable fully digital system in a single FPGA

Chips always become faster, cheaper, better

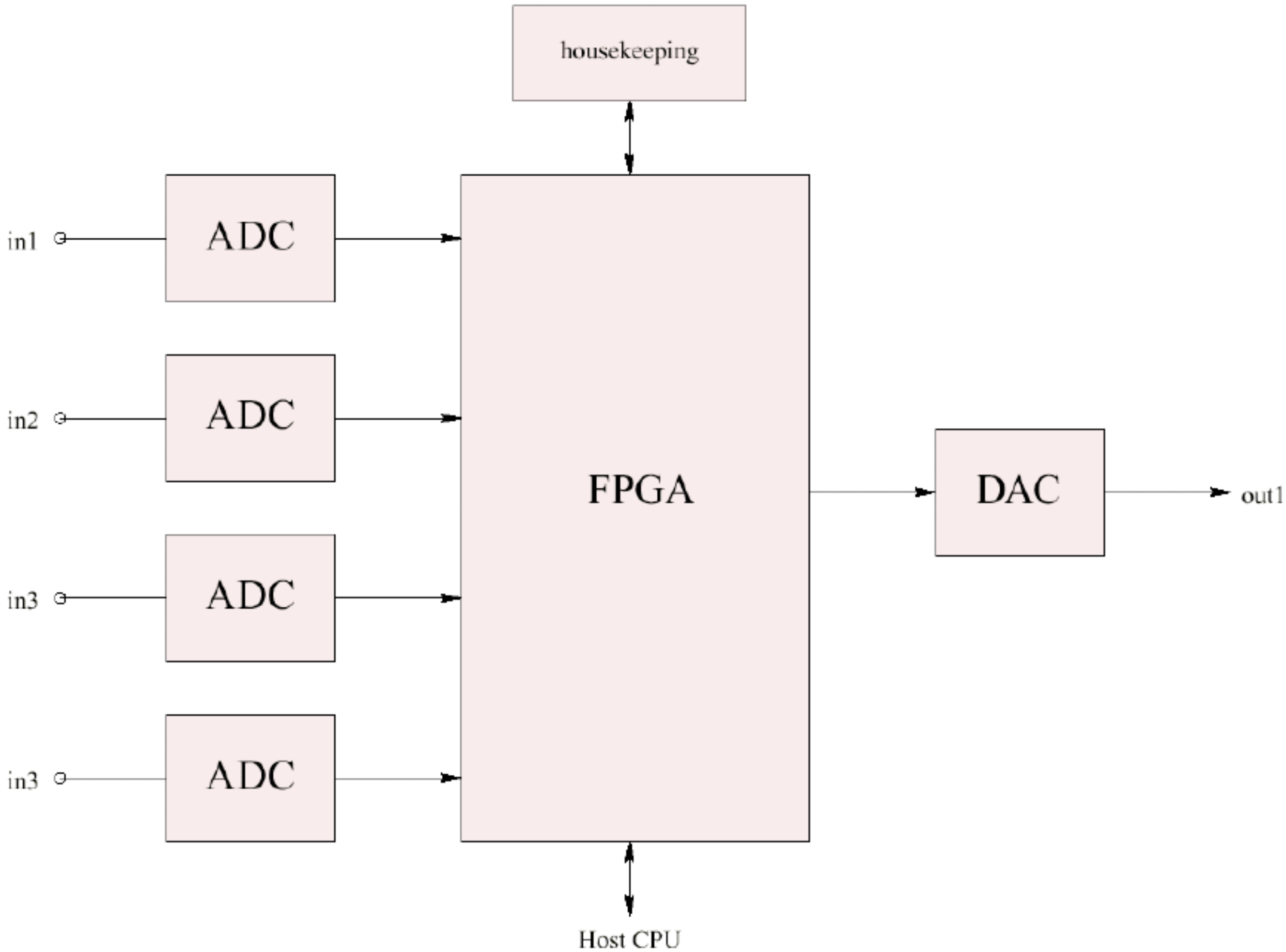
FPGAs are improving regularly

Faster ADCs and DAC with more resolution

- Better resolution allows for more dynamic range
- Faster processing helps reducing noise floors

But the next generation accelerators are more demanding

Purposely Familiar Diagram



The SNS Experience

LBNL led the collaboration that resulted in the RF controller for the SNS linac

- L. Doolittle (LBNL) - lead engineer

Hardware designed by LANL in collaboration with LBNL

- Production at SNS

SNS also provided RF reference distribution system and software integration with significant contributions from other labs

Firmware by LBNL

Important to integrate the system at the home lab from the beginning

- Hardware and firmware maintenance

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Systems Firmware

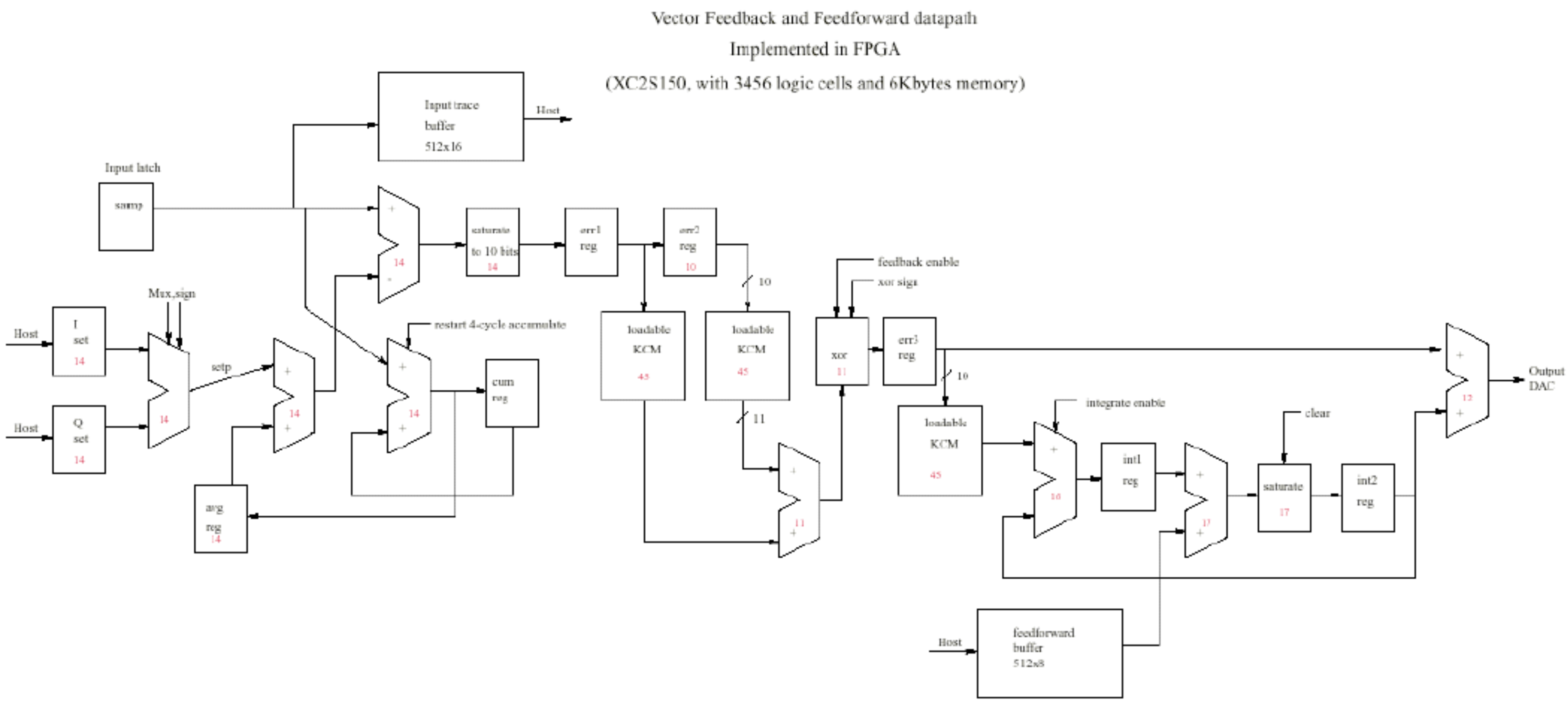
Firmware is the heart of the system
- Most of the value is obtained through firmware
  - provided good hardware is available
- Can be shared among the community

Verliog is the current language
- Some legacy VHDL used in earlier versions
- More compact and intuitive

Modular and transportable
- if well written!!

Always hard to convince management that the hard work STARTS with the completion of the digital card

SNS FPGA programming path



Firmware Development

LBNL's firmware developed for SNS and now under evolution for other linac applications

Many advanced features to fully exploit digital technology

- Adaptive feed forward
  - beam loading compensation
- Pulse to pulse calibration
  - errors are removed with a calibration pulse before each beam pulse
- Resonance hunting and cavity warmup
- SC cavity control in pulsed mode
  - Lorentz force detuning and microphonics control

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SNS Firmware Organization

	FE / RFQ	DTL	CCL	SCL	Linac Operations
Feedback Control of Amp. & Ph. - ±0.5%, ±0.5Deg	X	X	X	X	X
Setpoint Curve	--	X	X	X	X
Scalar Setpoints	X	X	X	X	X
Feed Forward	--	X	X	X	X
Adaptive Feed Forward	--	--	--	X	X
Adjustable PID Parameters	X	X	X	X	X
Resonance Hunting	X	X	X	X	X
Cavity Warmup	X	X	X	NA	X
NC Resonance Control	X	X	X	NA	X
SC Resonance Control	NA	NA	NA	X	X
History Buffers	X	X	X	X	X
High Power Protec	X	X	X	X	X
Cavity Arc Detection	X	X	X	X	X
Cavity Quench Detection	NA	NA	NA	X	X
Consecutive Fault Detection	X	X	X	X	X

Applies directly to Linac4

Demonstrated Performance

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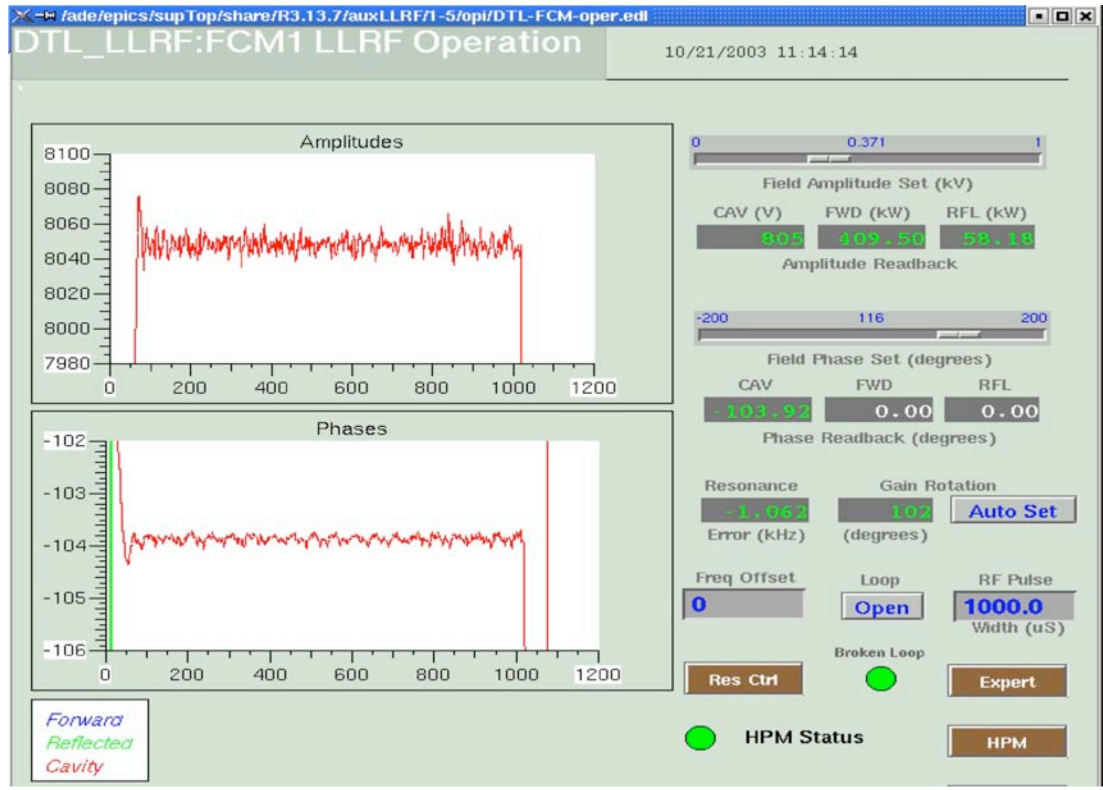
Operating reliably SNS since early commissioning in 2004

Good stability

- Better than 0.5%, 0.5 deg.

Large scale deployment

- 80+ stations



HW/SW Considerations

LBNL has an existing board (LLRF4)

- Used for firmware development and performance validation at LBL

Linac4 system will be built with CERN's hardware

- Possibly a simple modification of LHC boards
- LBNL's firmware will be integrated in CERN's hardware

CERN maintains full control over hardware and local software

- HW and SW are very site specific due to integration and maintenance

LAUC Proposal for CERN's linacs

LAUC

Provide modeling, simulations, firmware development

Contribute to conceptual design and implementation

Deliver, integrate and customize the proven firmware code set to linac4

Support detailed system design and dedicated hardware development (if needed)

Support/facilitate software integration

Possible collaboration of LBNL, SLAC, FNAL

CERN

Hardware development and production

Local installation, cabling, integration

Software integration in control system

Non Intercepting Diagnostics

Obvious advantages in accelerator operations

R. Connolly (BNL) one of leaders in the field of laser based diagnostics by H^- neutralization since the work done at LANL in the 80ies

Routinely used in the SNS for profile measurements

- Now expanding to emittance measurements

S. Assadi leads the SNS effort

Laser Neutralization of H^-

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First ionization potential for H^- ions is 0.75eV

Photons with λ<1500 nm can separate H^- ion into free electron and neutral H

Laser can be used to mark a portion of beam by neutralization

Measurements can be made
- on the neutral beam
- the removed electrons
- the reduced beam current
  - beam current transformer or BPM stripline

This method has been used at Los Alamos for transverse and longitudinal emittance measurements

Routinely used in SNS for measurement of transverse beam profiles

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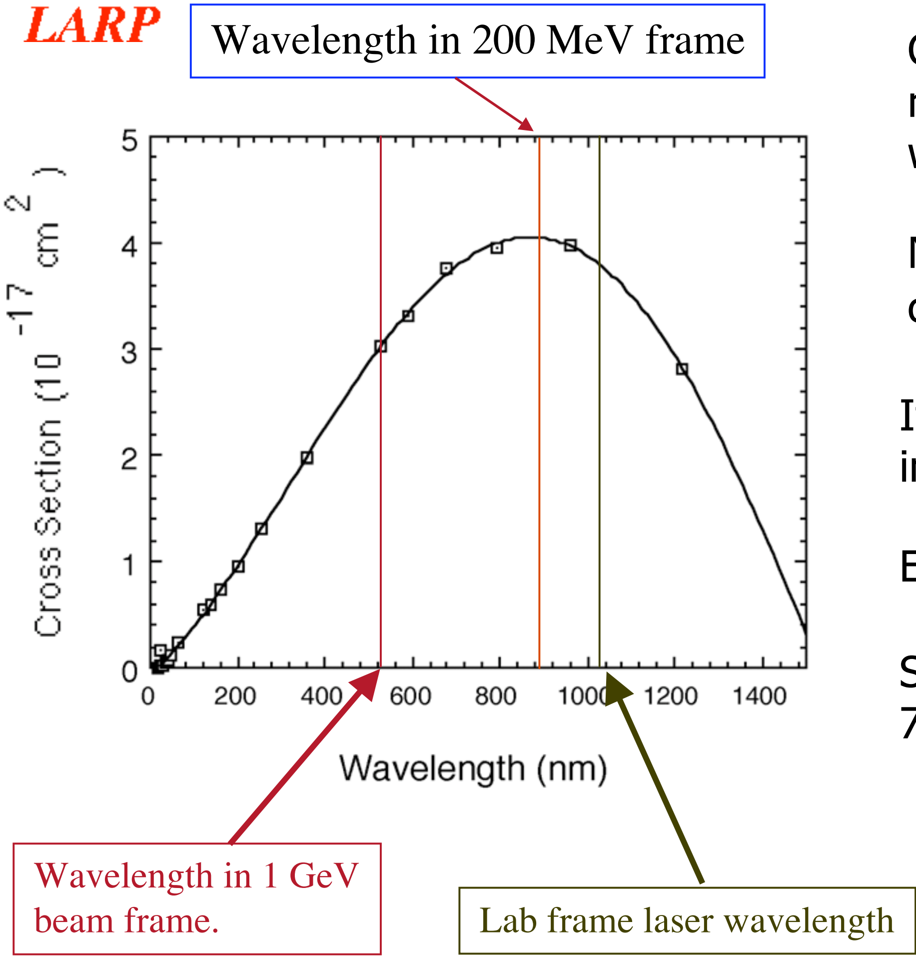
Laser neutralization cross section



Calculated cross section for H- photo-neutralization as a function of photon wavelength*

Nd:YAG laser has λ=1064nm where the cross section is about 90% of the maximum.

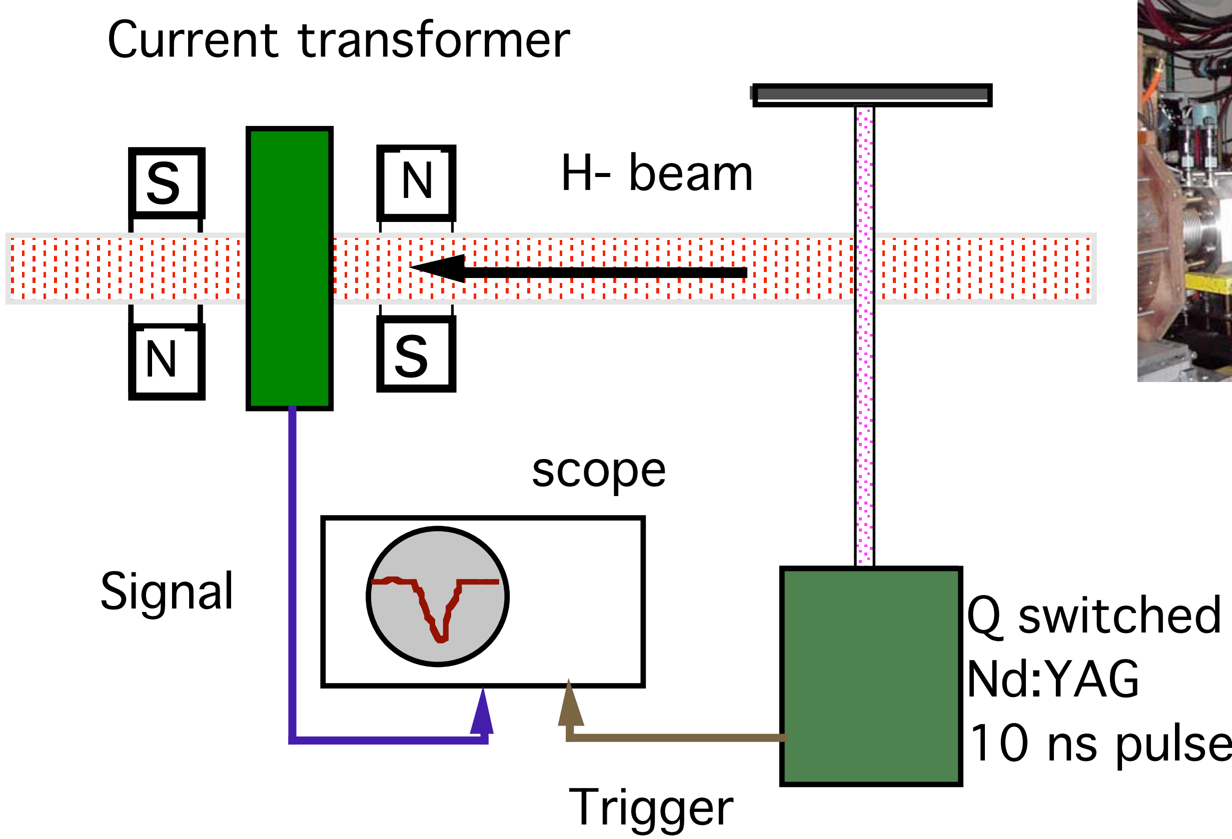
If laser beam crosses ion beam at angle q_L, in lab the center of mass energy is given by,

$E_{CM}=\gamma E_L[1-\beta\cos(\theta_L)]$

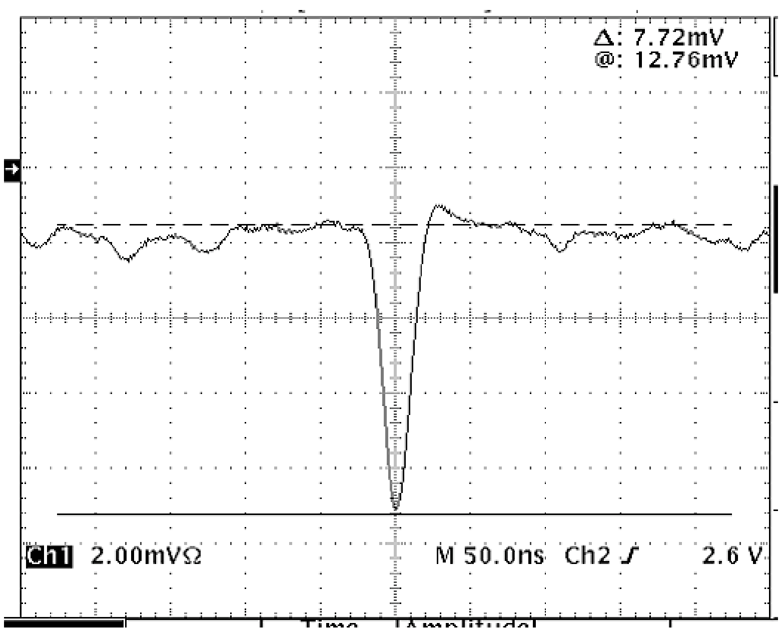
So Nd:YAG cross section at 1GeV is about 70% of low-energy cross section.

*J.T. Broad and W.P. Reinhardt, Phys. Rev. A14 (6) (1976) 2159.

Laser profile experiment on BNL linac



Scope trace of current notch



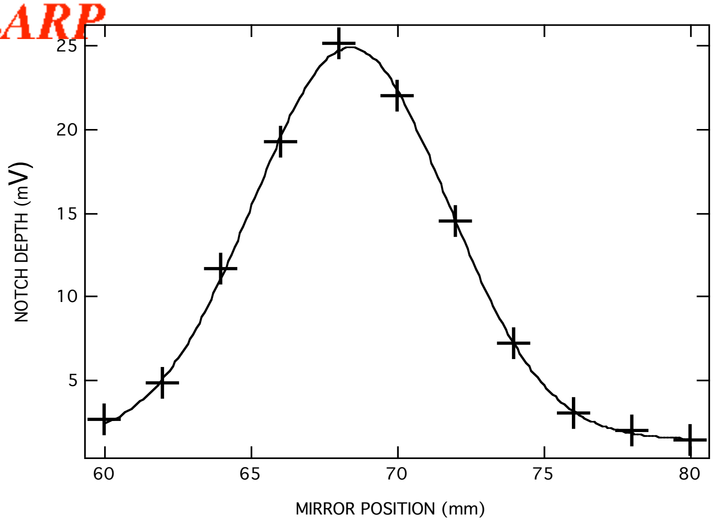
Oscilloscope trace of output of current transformer showing current notch created by laser

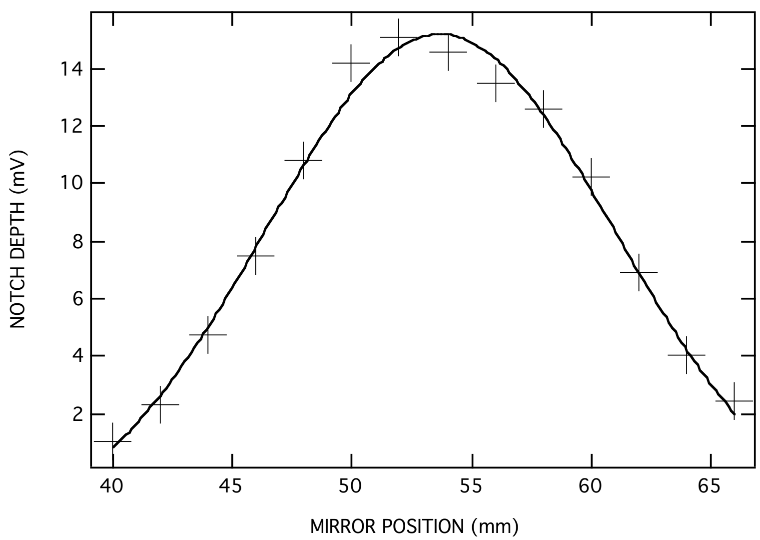
The signal is filtered with a 50 MHz low pass filter to remove the linac 200 MHz rf

Profile measurements were made by measuring the notch depth at each mirror position

S/N at beam center of 25dB. Signal to ~2.5 σ

Beam Profiles Measured on BNL linac





Horizontal (top) and vertical profiles of the BNL linac beam. Measurements were made after the RFQ with 750 keV beam

The markers are the data and the lines are gaussian fits

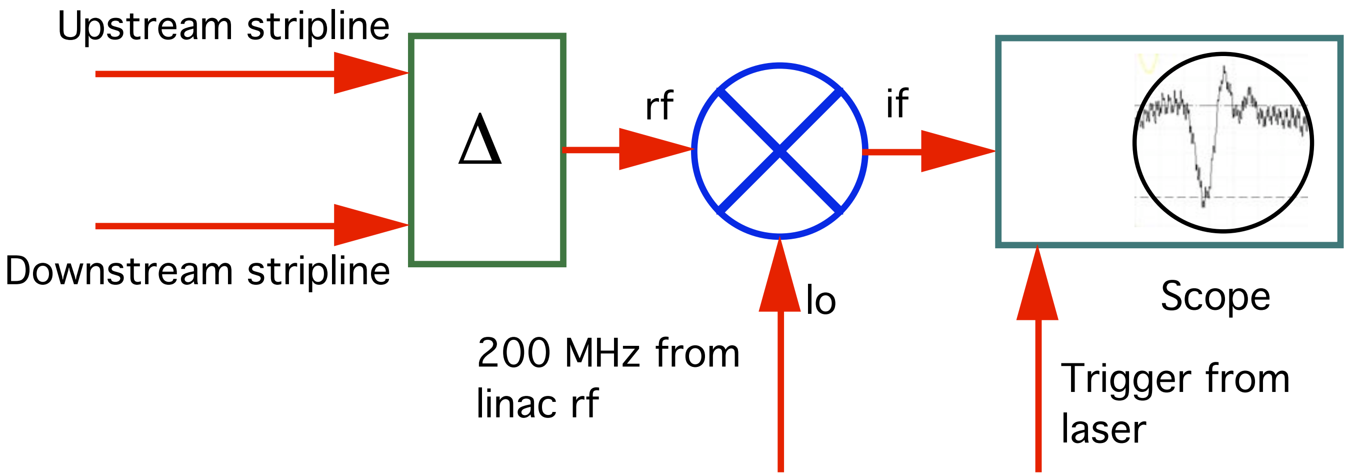
Widths of fits:

$$\sigma_x = 3.32 \pm 0.05 \text{ mm}$$

$$\sigma_y = 7.3 \pm 0.6 \text{ mm}$$

Each data point is from averaging 15 pulses

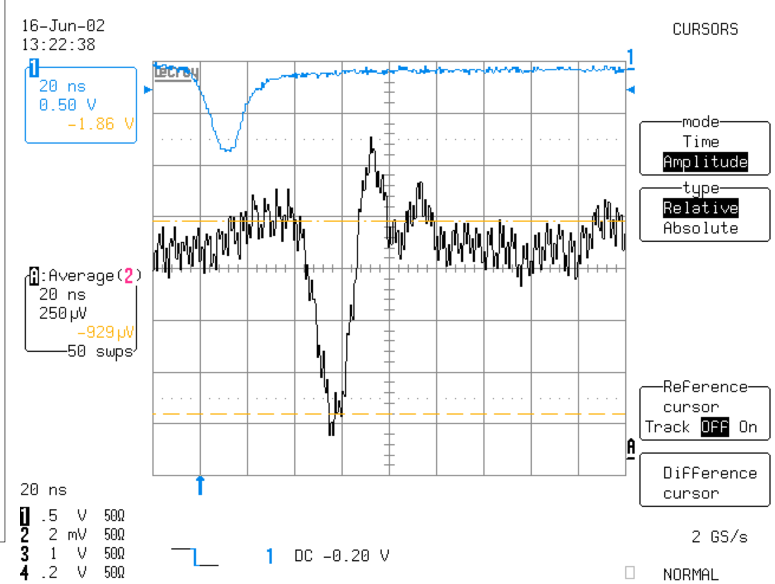
Stripline signal detection of current notch at 200 MeV



The signals from one upstream and one downstream stripline are subtracted and the difference signal is mixed With 200MHz from the linac rf to remove the carrier frequency. The mixer output is passed through a 50MHz low-pass filter.

We were 40m from the end of the linac so the 1% energy jitter became a ±70° phase jitter. This is the source of the rf on the scope trace.

The phase jitter would not be a problem with a detector located in the linac.



Beam profiles measured at 200 MeV

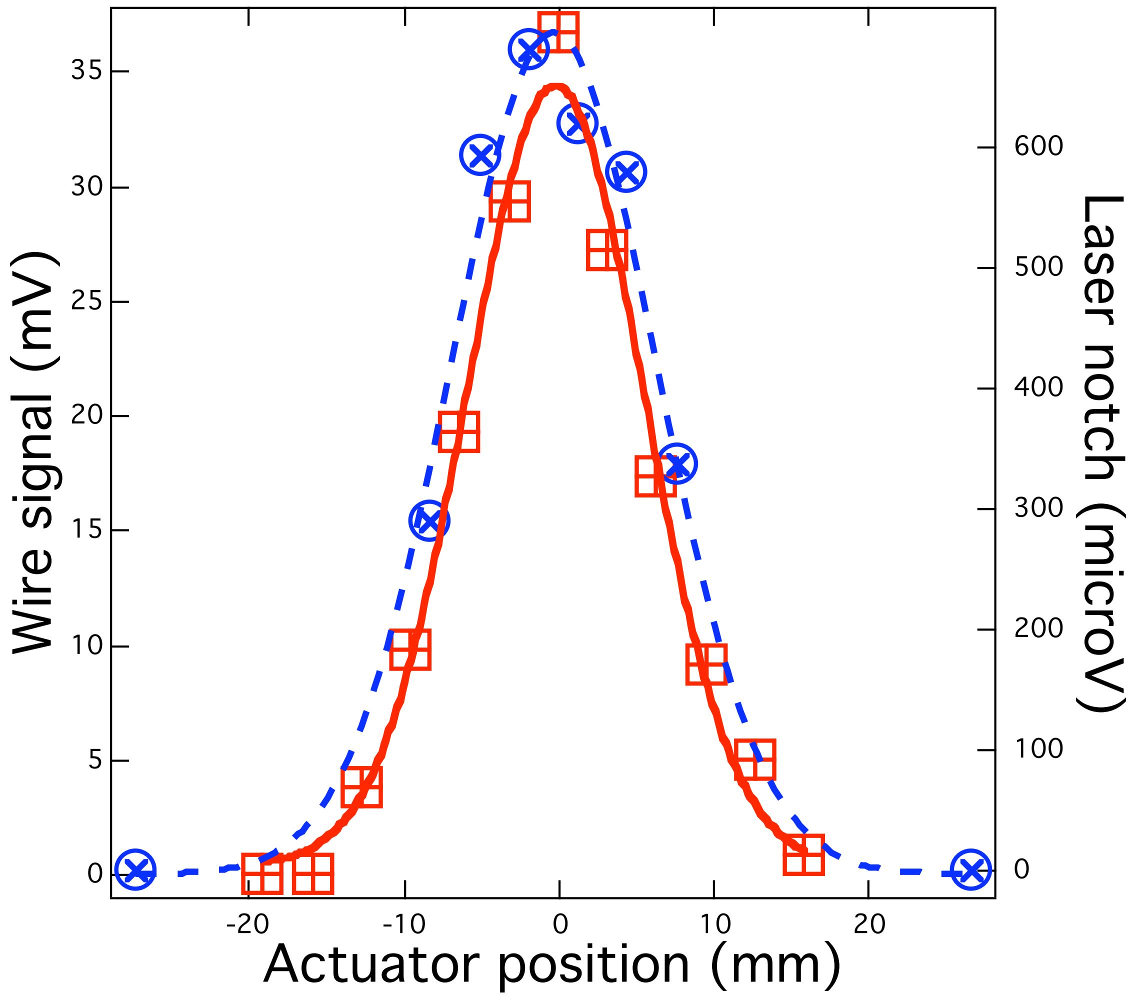
A carbon-wire beam scanner was also mounted in the laser chamber

Profiles were taken with both the wire scanner and the laser

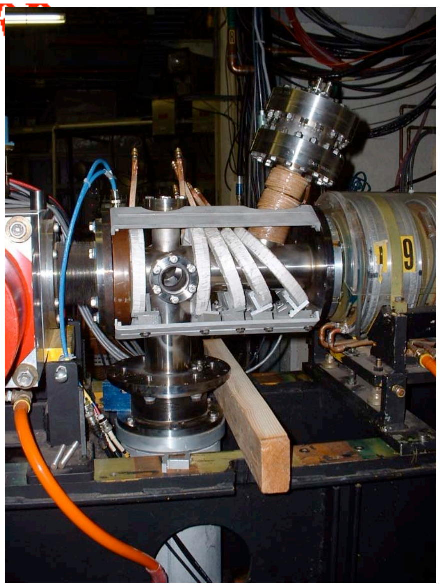
The laser profile is the blue, dotted curve. When the laser-beam width was deconvolved the measured widths are:

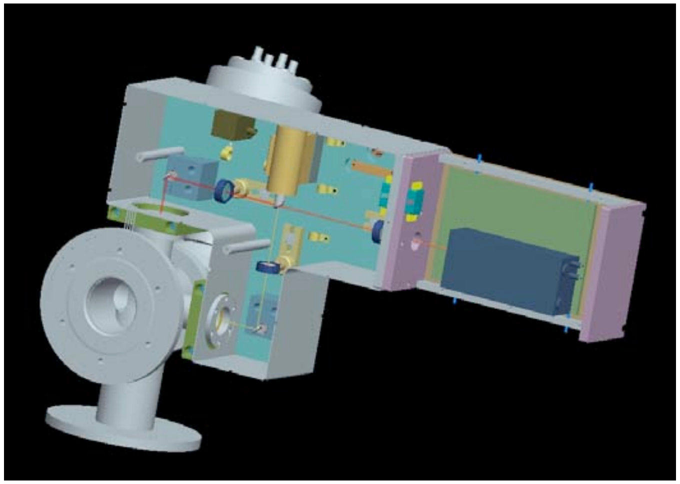
σ_{laser}=6.45±0.6 mm

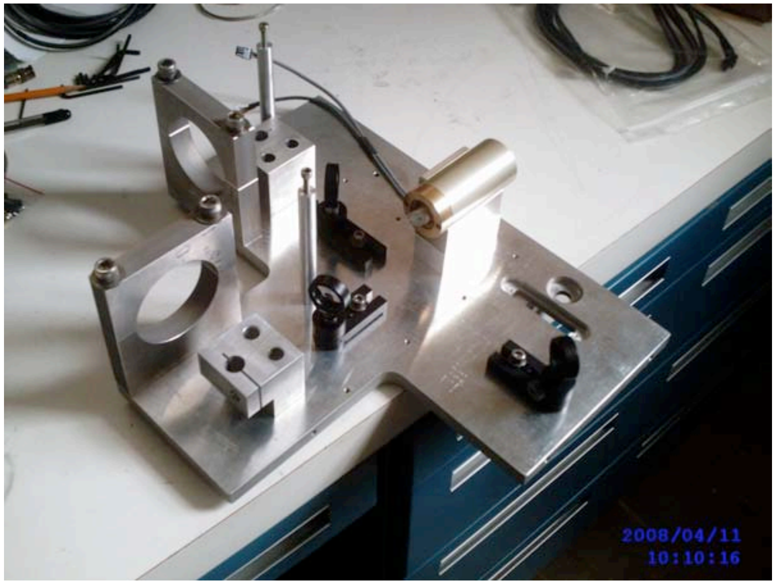
σ_{wire}=5.7±0.3 mm



Laser Profile Monitor for Project X at FNAL







At 750keV stripped electrons have to be channeled into detector with curved solenoidal magnet field provided by a series of coils.

At higher energies a downstream dipole is used (SNS).

Under development at BNL

Proposed system for CERN

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Detection of notch in beam current requires short, intense pulse

Measurements at BNL used 10 MW laser (200 mJ for 20 ns).

Detection of electrons requires far lower neutralization rate.

Electrons stripped from a 160MeV beam will be 87keV.
Si surface-barrier detector as a solid-state ionization chamber -> gain of 2.4×10^4

Proposed laser is solid-state, CW diode laser with fiber-optic output

Power 1-10W and λ= 975-980 nm

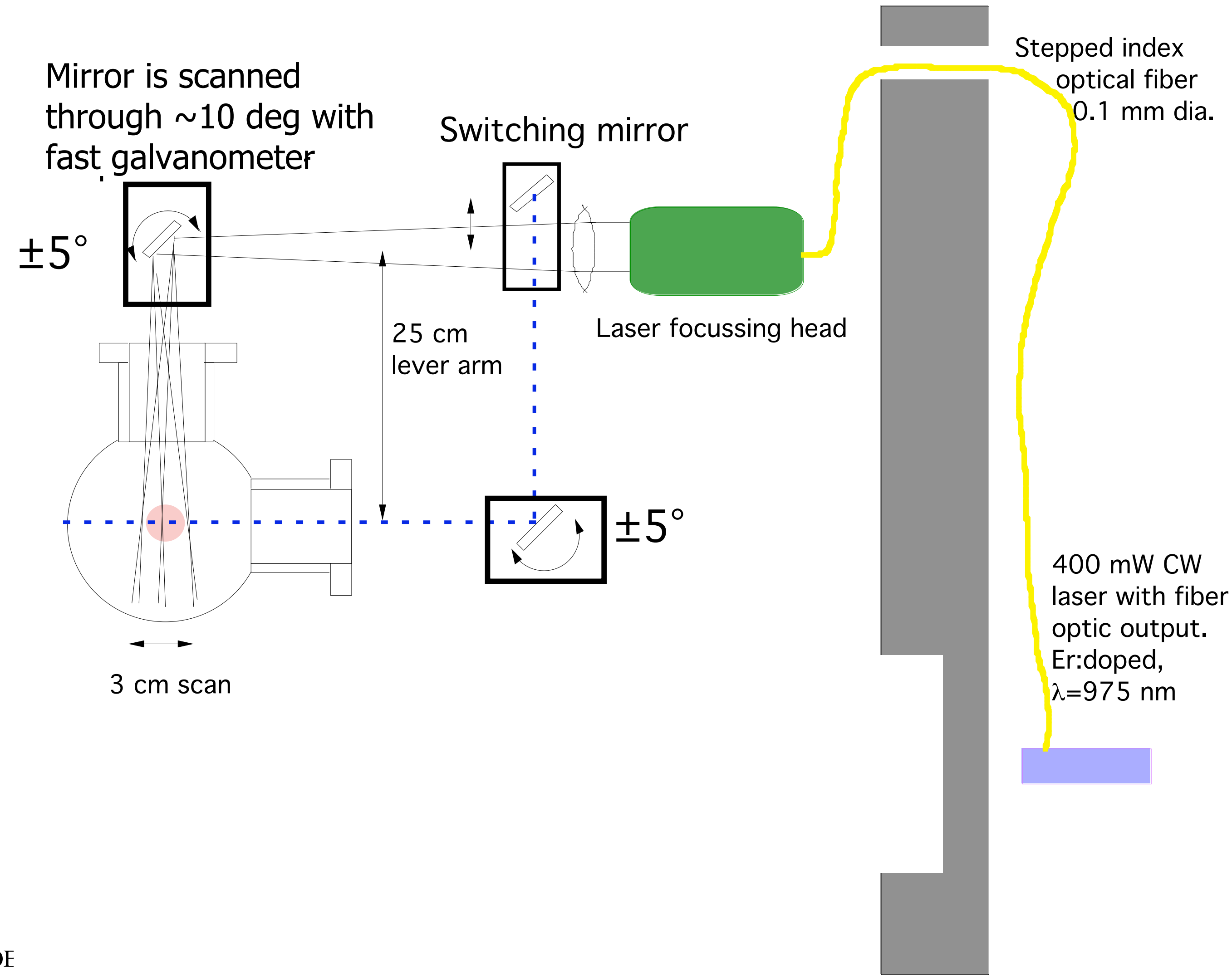
Good commercial availability for under $4k

With CW laser and electron collection we can scan with optical scanner and get full beam profile in one machine pulse (>300μs)

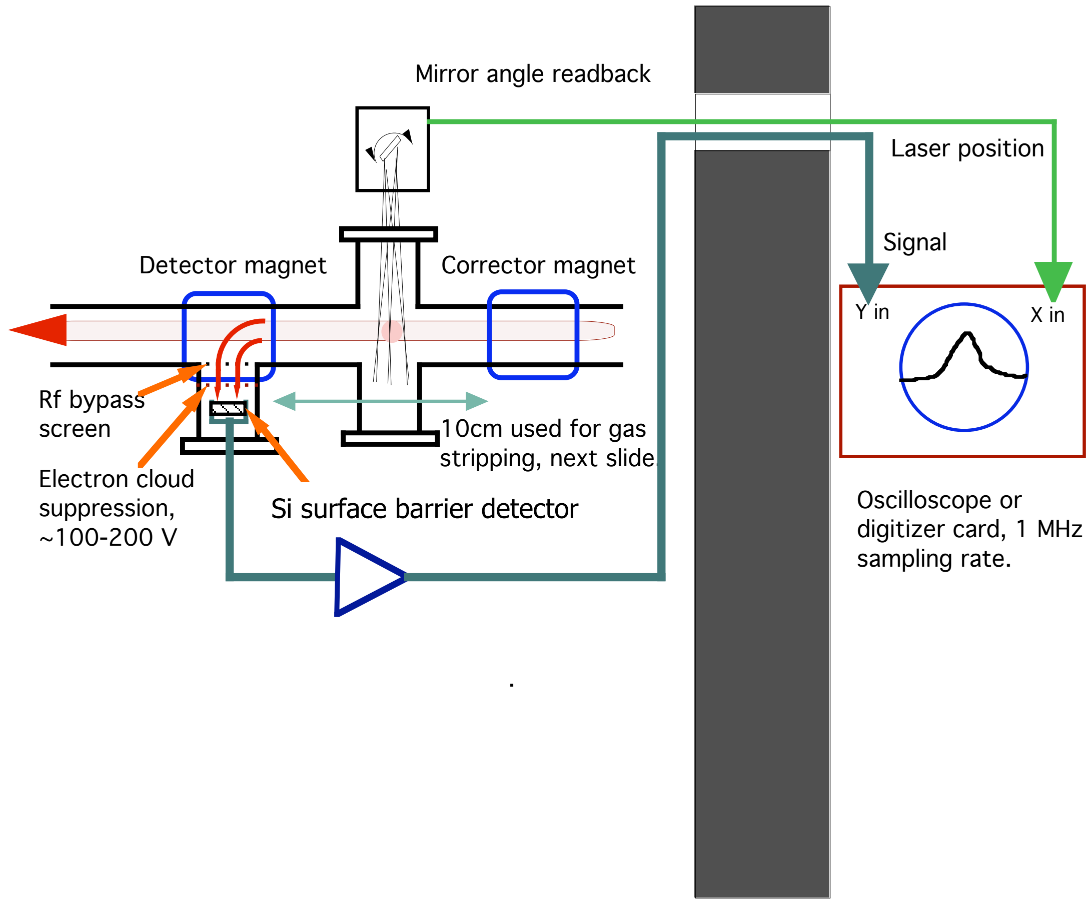
Electrons deflected into detector

- solenoidal magnetic field at low beam energies to keep electrons from being ejected by radial space-charge field OR
- dipole field

Transverse Scanning



System Readout

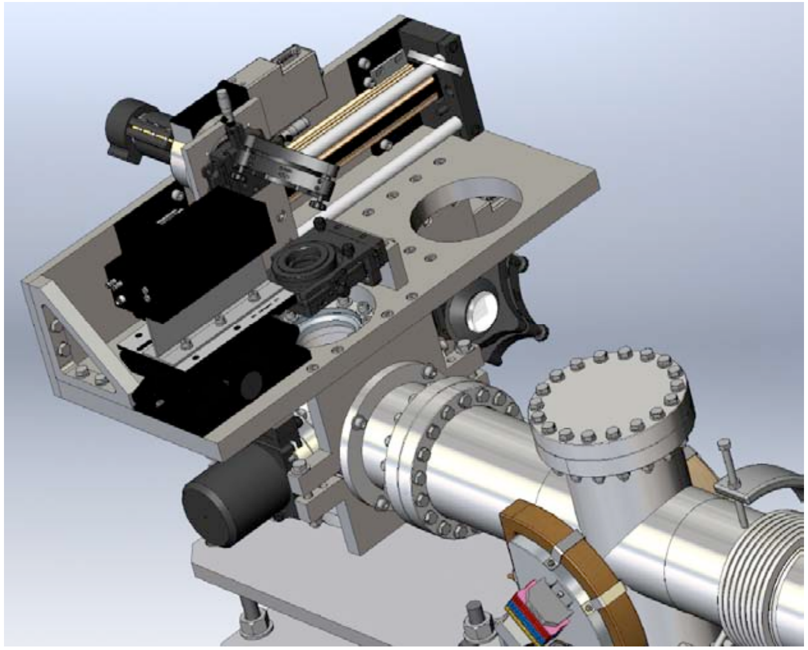


Extending to Emittance Measurements

Same laser setup can be used as a slit for emittance measurements

Drift/deflection region and a collector can complete the system
- Collector could be faraday cup, imaging camera, screen/foil…

Under development at SNS
- Detailed design done



Laser-based Diagnostics Summary

Transverse profiles of H- beams have been measured by laser photoneutralization using shoot-and-step technique with Q-switched laser

A CW laser beam can be swept through the ion beam in one machine pulse with commercial optical scanners

Electron collection with 1MHz electronics can give complete profiles in one machine pulse and emittances in few seconds

Microchannel plate amplification of electron signal at low beam energies or solid-state detection at higher energies reduces laser power requirement to 1-10W. Light is transported from laser to beamline over optical fiber

A scanning laser profile detector is being developed at BNL for FNAL

An emittance measurement system is being developed at SNS

LAUC Non-Intercepting Diagnostics Proposal

Design and build three integrated stations capable of measuring profiles and emittances

These are to be used in the transfer line from the linac4 to the PS Booster

CERN remains responsible for local cabling, integration coordination as well as control systems interfaces

LAUC contribution is a collaboration of US labs

- Possible involvement of BNL, FNAL, LBNL and SNS

Status and Schedule Considerations

Linac4 commissioning at the end of 2011

LAUC starting no earlier than FY10
-> about 2 years to complete

CERN requested to have a demo RF controller by 2009 and a prototype diagnostic system by 2010

Some funds will be needed in FY09 to support planning and an early start

Final deliverables by the end of FY11, support of beam commissioning and early operations in following FYs

CERN has established points of contact for both activities

Final design and deliverable schedule will be agreed upon with CERN in dedicated meetings

Conclusions

Propose two advanced technologies with direct impact on CERN's linac upgrades

Provide value to CERN by adding advanced systems, proven technologies

- Reduce risk by adopting existing solutions
- Easy path to planned additional upgrades with SC technology

Ideal match with core skills of US labs

- Both groups have been involved since the pioneering days
- Will be ready for detailed design and baseline in 2008

Collaborative effort among several US labs