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H^- Diagnostics Studies

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Outline

- Principle and technical approach
- The need at linac4 and other facilities
- Laser technology
- APL profile monitors
- Emittance measurements
- Experiments and studies
- Proposed collaboration

Introduction

- Laser neutralization based diagnostics have been studied since the 1970es (LANL)
- Their role increased with the growth of SRF systems to overcome shortcomings of solid (carbon…) wires
- “Operational” at SNS since day 1
  - Mostly when resident experts are available
- Several H^- linacs are interested and could get involved
  - Project X
  - SNS
  - CERN linac 4
- Linac4 direct need
  - Characterize emittance growth in the long transfer line to the PS booster

Laser Neutralization of H^-

First ionization potential for H^- ions is 0.75eV

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

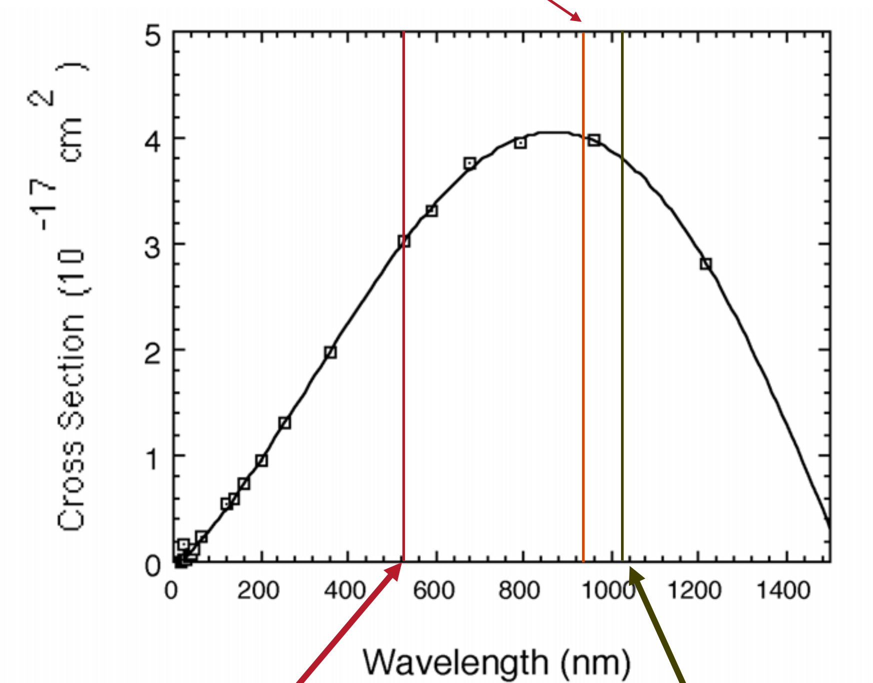
Laser can be used to mark a portion of beam by neutralization

Non interceptive approach has many advantages

Laser bean can be switched to support multiple stations

Laser neutralization cross section

Wavelength in 160 MeV frame



Wavelength in 1 GeV beam frame.

Lab frame laser wavelength

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.

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Linac 4 Parameters

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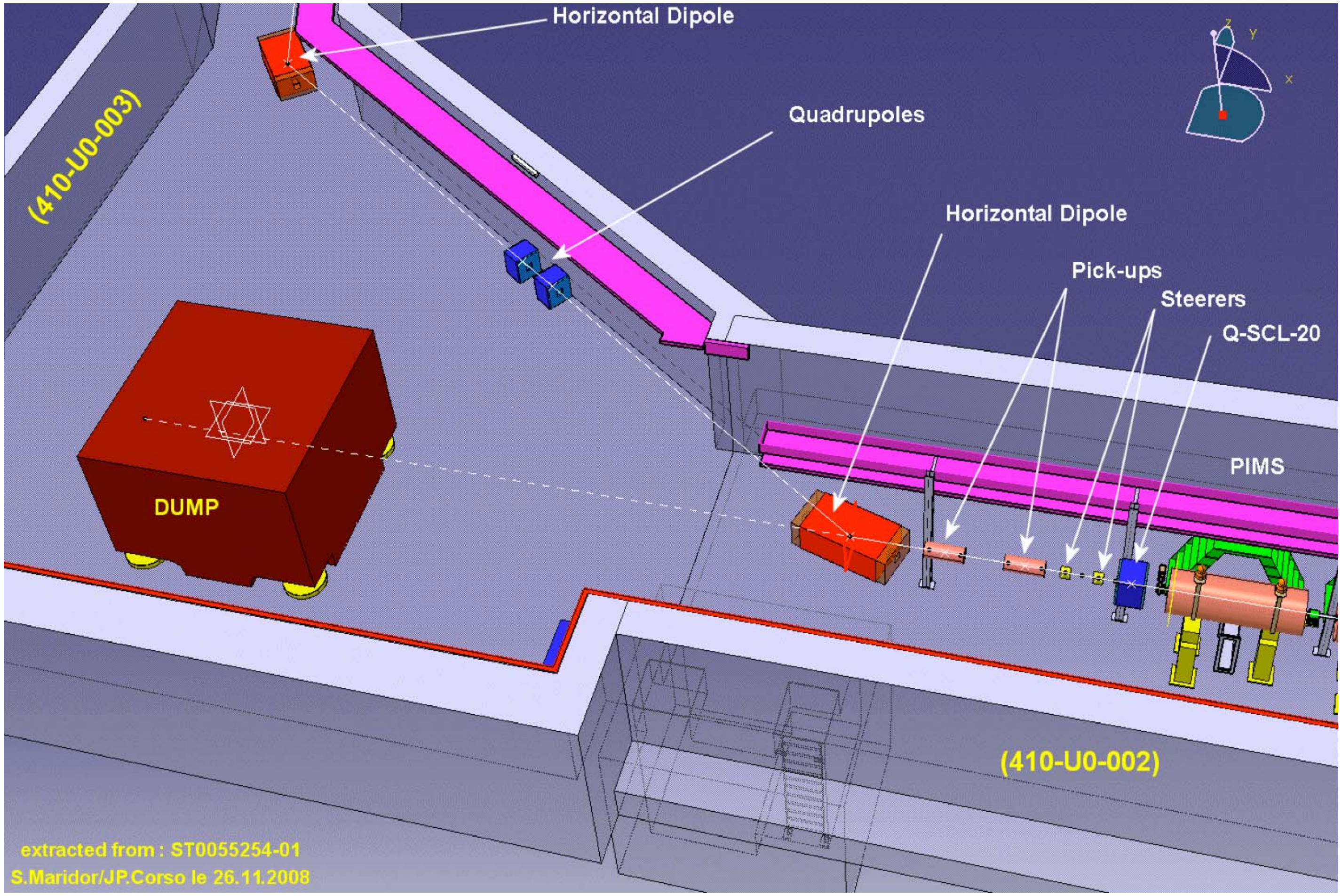
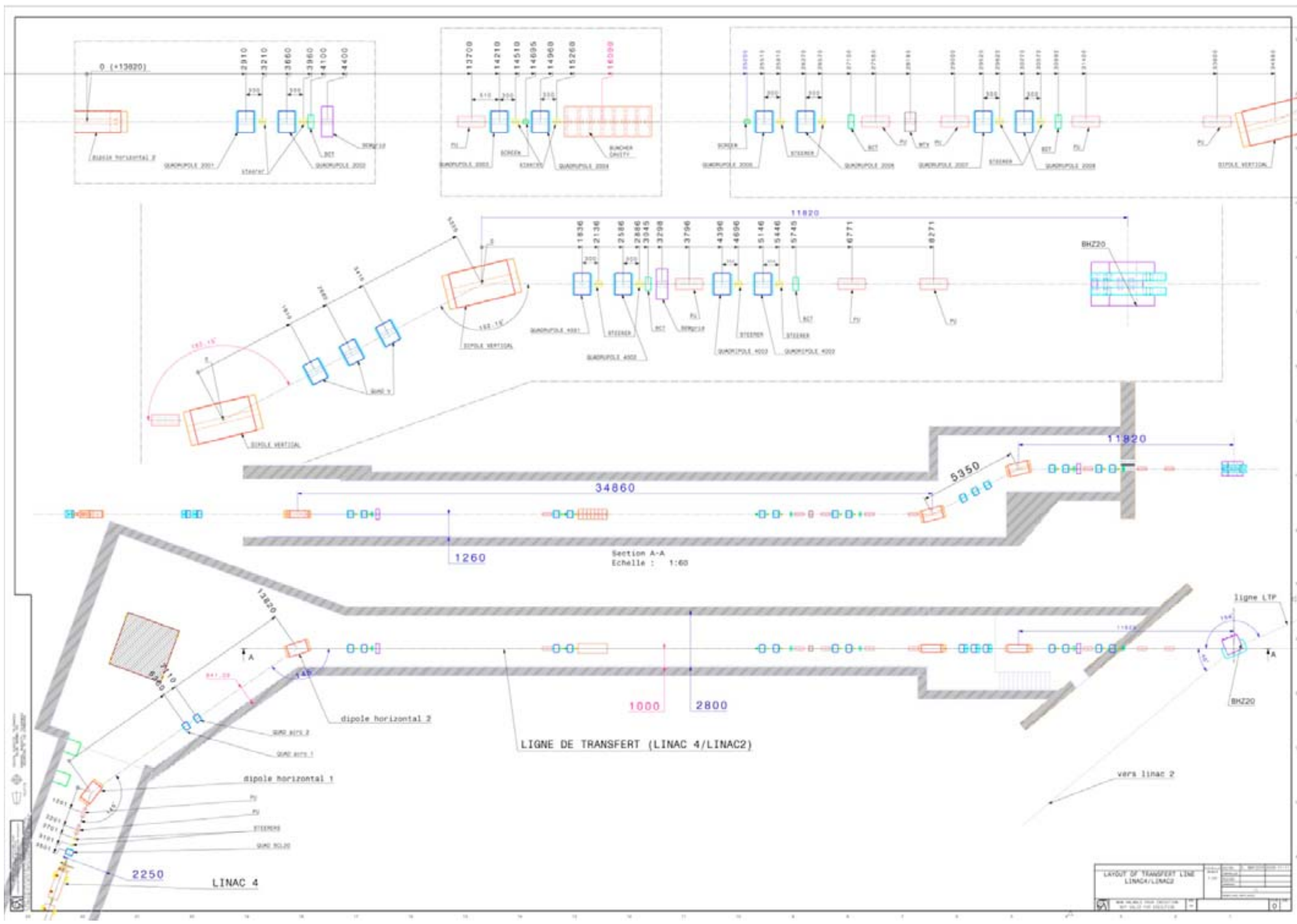
LINAC4	Value	Units
Ion Species	H-	
Output energy	160	MeV
Bunch frequency	352.2	MHz
Repetition rate (max)	2	Hz
Beam pulse length	400	μs
Number of particles / bunch	1.14	E9
Number of particles / pulse	1.00	E14
Linac current	40	mA
Max beam power	5.1	kW (at 2 Hz)
Transverse normalized emittances (rms)	0.33	π mm-mrad
Transverse beam sizes (rms)	1 to 4	mm
Beam velocity, β=v/c	0.52	

Linac4 extraction and tuning dump



Linac4 transfer line layout



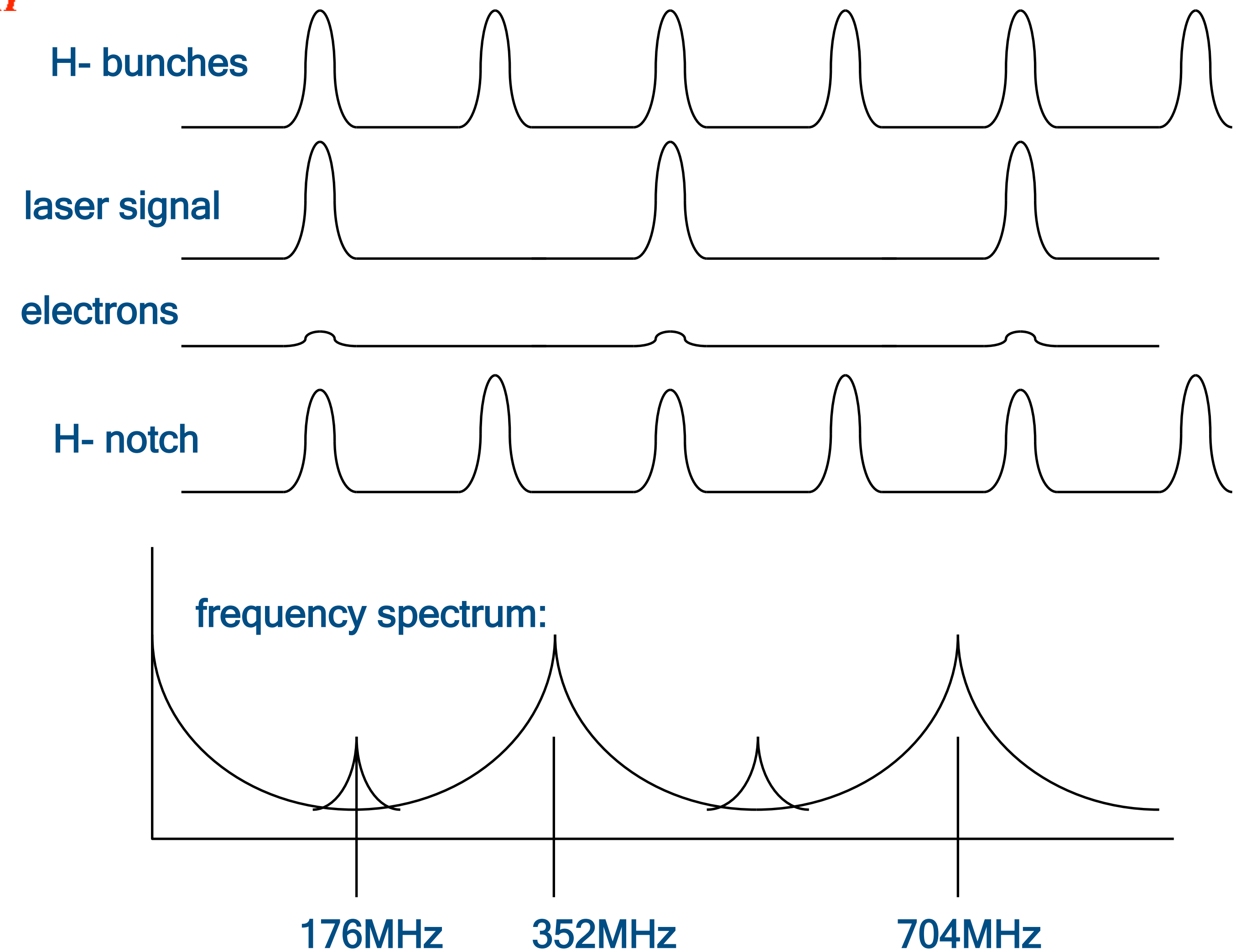
Laser Design Considerations

- Need to minimize required laser power for a given signal-to-noise ratio
  - Reduce Laser power
    - Lower cost, more reliable
    - Higher power lasers break more often
- Produce continuous train of pulses
  - Lower peak power reduces damage, enables fiber delivery
  - Continuous signal allows fast scans, even within 1ms pulse
- Possible fiber delivery of laser to diagnostic
  - Easier to maintain alignment
  - Laser can be far from radiation
  - One laser can be used for multiple stations

Laser Design Considerations (2)

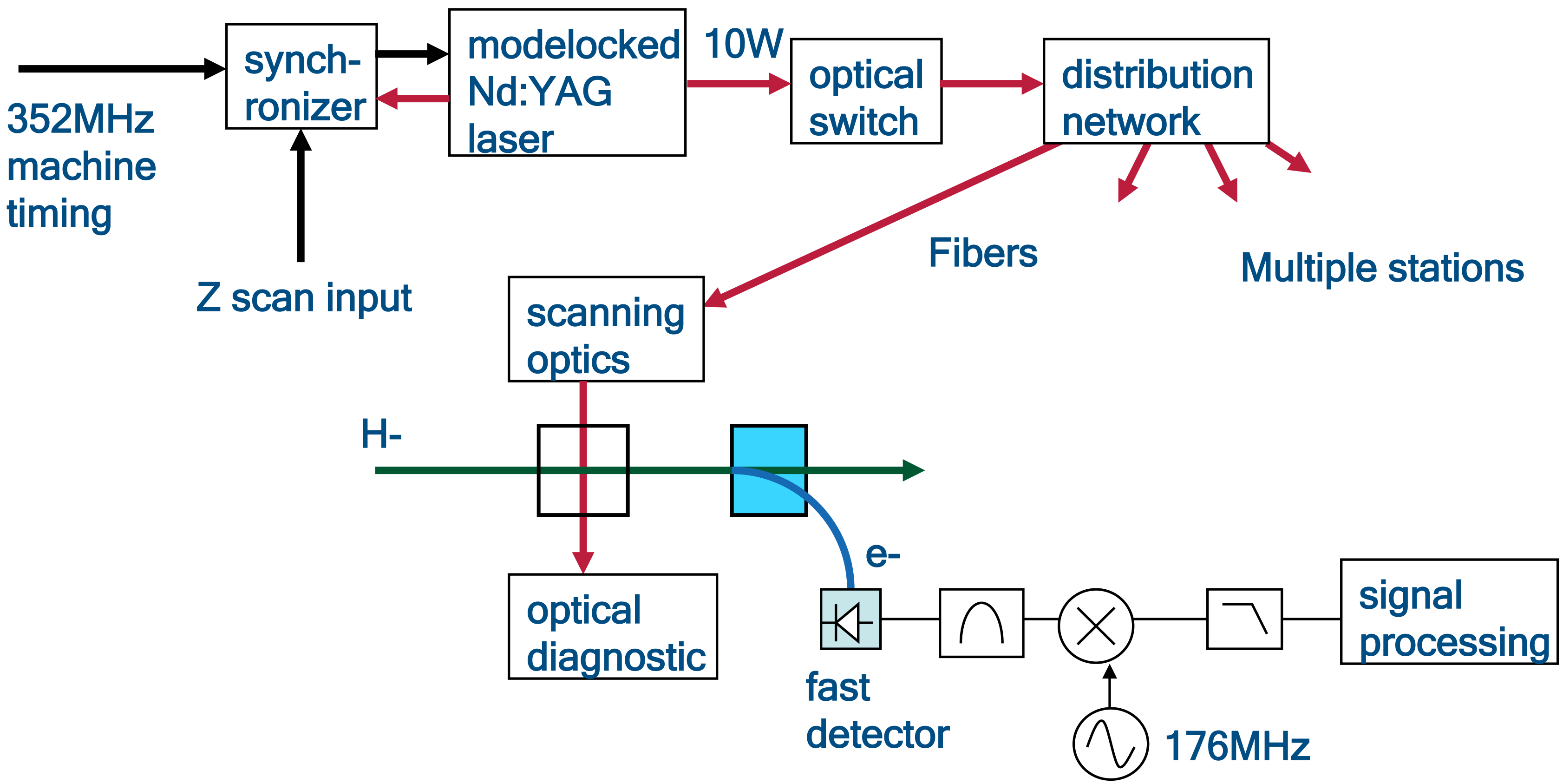
- Use synchronous detection to locate signal in low noise area
  - Modulation of signal can be simply a lower rep rate for laser
  - Demodulate signal at detector, filter out background signal
  - Detection can be via electrons or notches in H-
- Main question: what is the background signal?
  - Experiments with fast detectors are needed
  - Estimates of background signal, from gas stripping etc.

Every other bunch is hit, for ~1ms



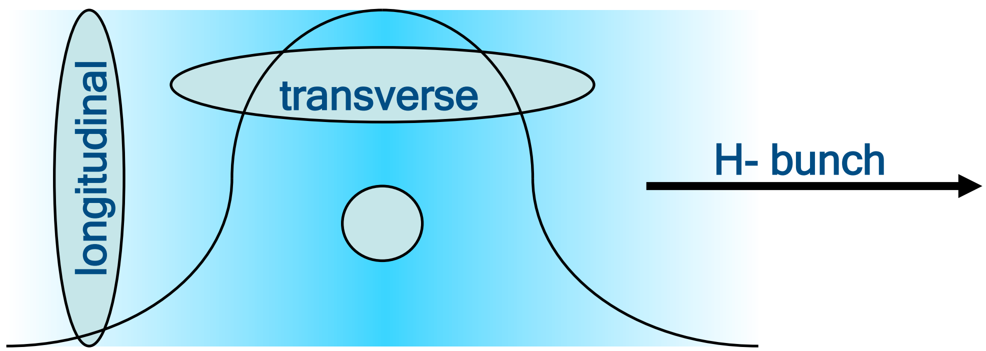
- Laser rep rate can be made to sit at lowest noise area, once it's found

Block diagram of scanning system



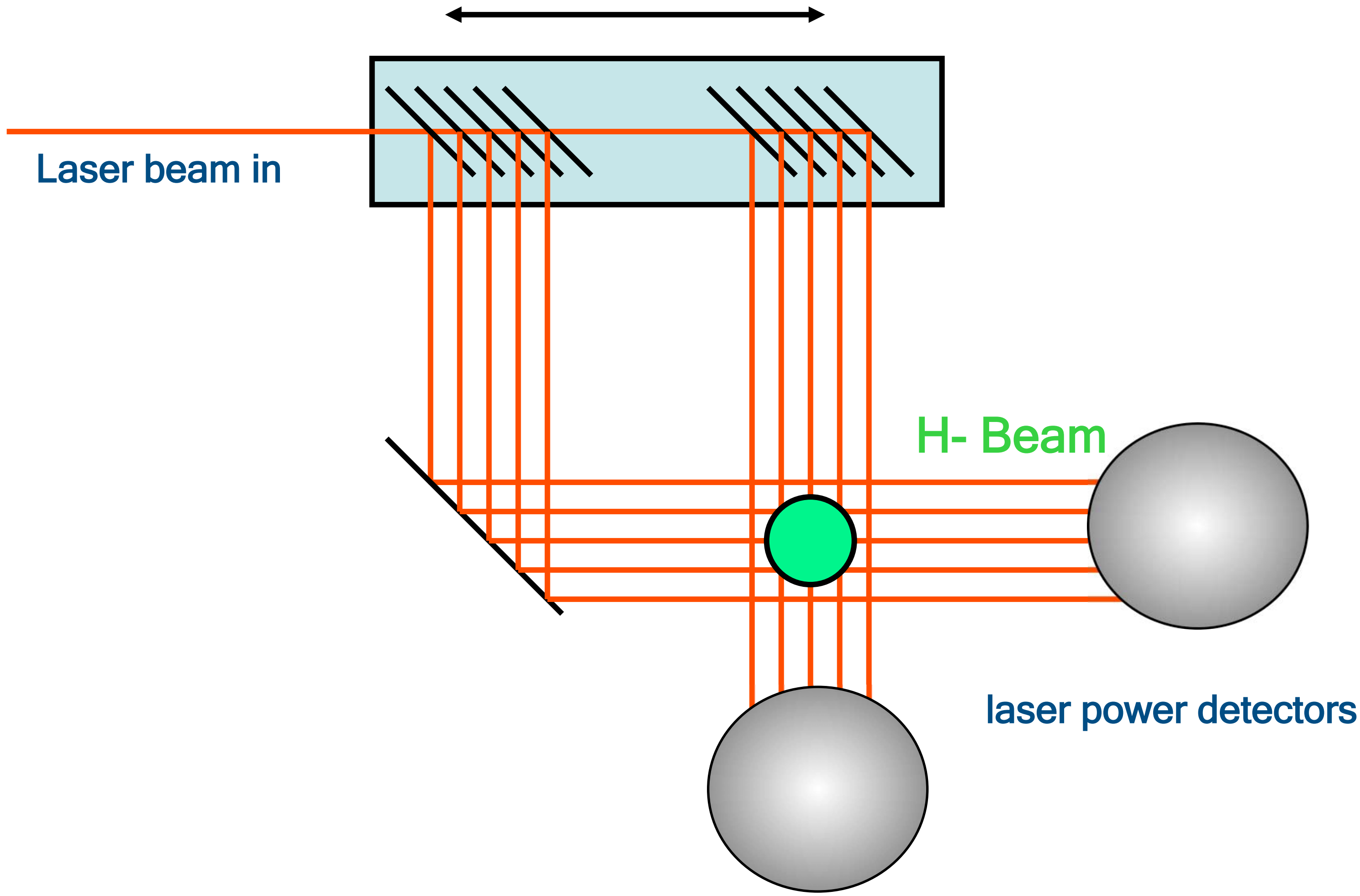
- Signal analysis is analog, digital or combination
- Longitudinal scanning is done by adjusting synchronizer

Beam shape options



- Longitudinal is short pulse, sampling entire cross-section
  - Must have narrow horizontal diameter as well as in time
- Two transverse options
  - short pulse with wide horizontal diameter, narrow vertical
  - long pulse with small or wide horizontal diameter, narrow vertical
- Longer pulse has smaller peak power for lower nonlinearity

A slow scanning option



- Alternate method is fast scanning mirrors on each axis

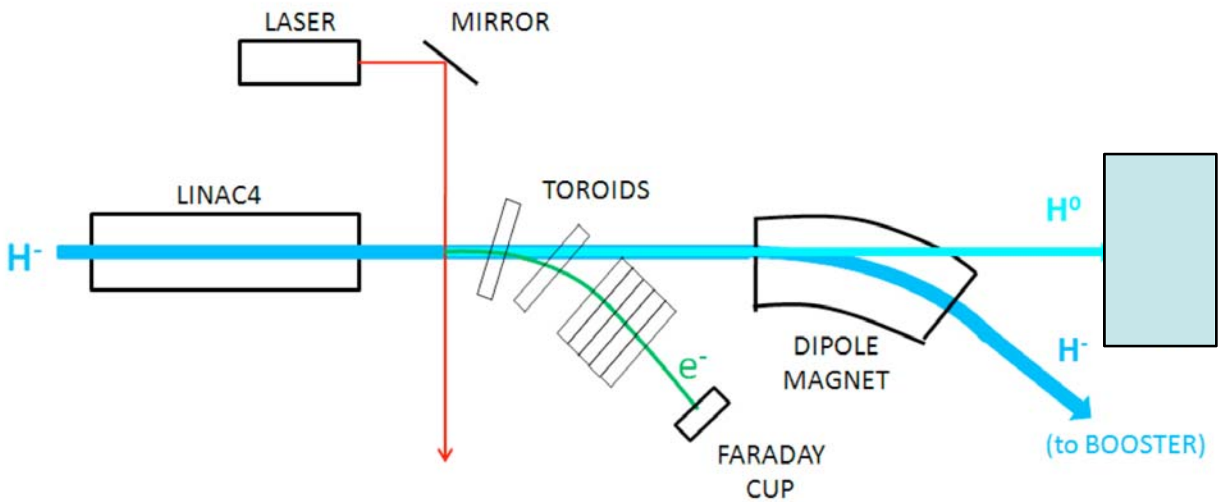
Profile Measurements and APUL

- Using the laser slit measurements can be made
  - on the neutral beam
  - the removed electrons
  - the reduced beam current
    - beam current transformer or BPM stripline
- Electron collection is the simplest approach
  - Suited for profile measurements
  - Harder to accomplish when measuring emittance
- APUL is proposing to build two transverse profile monitors
  - Can also be used to measure energy spread at the end of the linac
  - Basic laser without time resolution
    - Low risk and adequate

Emittance measurements

- Measuring Transverse Emittance is beyond the scope of APUL
  - New development, no existing system
  - R&D activity matches LARP's objectives
- Requires the use of a stable, short pulse laser
  - Additional Measurements are enabled by the same infrastructure
    - Time synched laser will allow longitudinal profiles
- Requires H_0 collection after a separator magnet
  - Use existing optics in the transfer line

Possible Setup in Linac4



H0 collector

Emittance measurements

Profile measurements

Laser Ionization

Photo detached ions

$$N_{PD} \ll N_{i,Volume}, \quad N_{PD} = \frac{I_b N_L}{\sqrt{2\pi} e \beta c} \frac{1-\beta\cos\theta}{\sin\theta} \frac{\sigma_d(E_{cm})}{\sqrt{2}\sigma_b}$$

- Where
  - σ_b = laser size
  - σ_d = photodetachment cross section
  - N_L = n. of photons in laser pulse
  - θ = Laser incident angle

- Laser optics can help maximizing efficiency
- Mode locked 1-10 MW low DF class laser are commercially available and should yield enough ionization for a good reading

Neutrals Imaging

- Once the e- is stripped, we will collect H_0 after a separation magnet which is part of the transfer line

- H_0 collection can be done in several ways
  - Screen and camera
  - Stripline detector
  - RadHard Pixels

- System requirements are driven by 160 MeV energy of the beam
  - Spatial resolution is not an issue

- 10-16 channels, 8-12 bits readout

Backgrounds

- H- stripping happens naturally due to three effects
  - Ion Gas interaction
  - Black body radiation
  - Magnetic fields

- The calculated H0 flux is (for the given linac 4 parameters):
  - Thermal Photons (black body) - ~10^2/m or 500 in a 5m drift (or 8 10^{-17} C/pulse)
  - Ion gas – as much as 2 10^8 ions (or 86 pC)
  - Magnetic Fields – Negligible

- The expected contribution from gas stripping is dominant and can cause a substantial background level
  - Time gating is an option to reduce background levels during the measurement

Collaborative Effort

- CERN BE/BI is very involved
  - Transverse and Longitudinal Emittance Measurement in Hadron-(Pre-)Accelerators - CARE Workshop in Bad Kreuznach, Dec 2008
  - adweb.desy.de/mdi/CARE/Bad_Kreuznach/ABI_workshop_2008.htm

- US provides unique expertise and infrastructure
  - Technique developed in US
  - Operational at SNS, BNL
  - Laser expertise at LBL

- CERN will coordinate collaborative interest of European labs
- LBNL will coordinate collaboration in the US

Experimental Plan

FY09

- Feasibility study and system optimization

FY10

- System design and implementation

FY11

- Test at existing H- beam
  - SNS, BNL, HINS?
- System demonstration and benchmark performance

FY12

- Integrate with Linac4 measurement system
- Transfer to APUL-II or other separate construction project

Scope and Funding

Scope

- Using available laser sources, design, optimize and demonstrate feasibility and functionality of a system to be used in linac4

Funding

- Effort – 0.75 FTE/yr from FY10 to FY12
- Travel – $30k/yr
- Materials - $75k

"A successful task results in the transfer to a construction project, off the LARP books"