Development of a laser emittance meter

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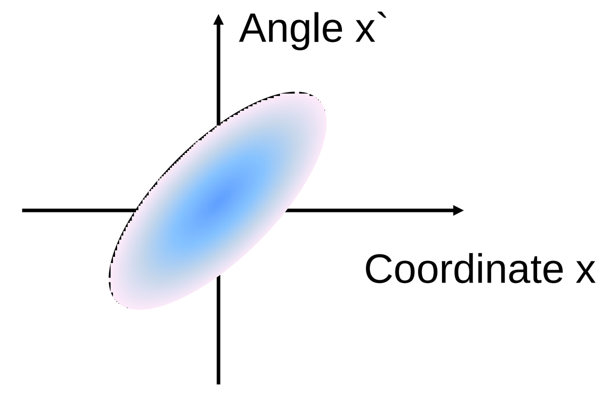
Motivation

The transverse emittance is one of the most important beam parameter at any particle accelerator. It tells about the particles distribution in phase space (**position** vs. **angle**).
In the low energy part of LINAC4 the emittance is measured with the so called slit&grid technique where the parameters are obtained by a slit which scans through the beam. At higher energies, this technique has major limitations. The most important one is that due to the increased beam energy the slit needs to be very thick (> 100mm) to stop the particles. This is one of the reasons why the new concept of a **laser emittance meter** becomes attractive.
Furthermore a laser emittance meter is a **non-destructive** method of measurement which means that the beam can still be used while the emittance is measured. Also the spacial resolution and SNR is supposed to be higher.

Emittance of a particle beam



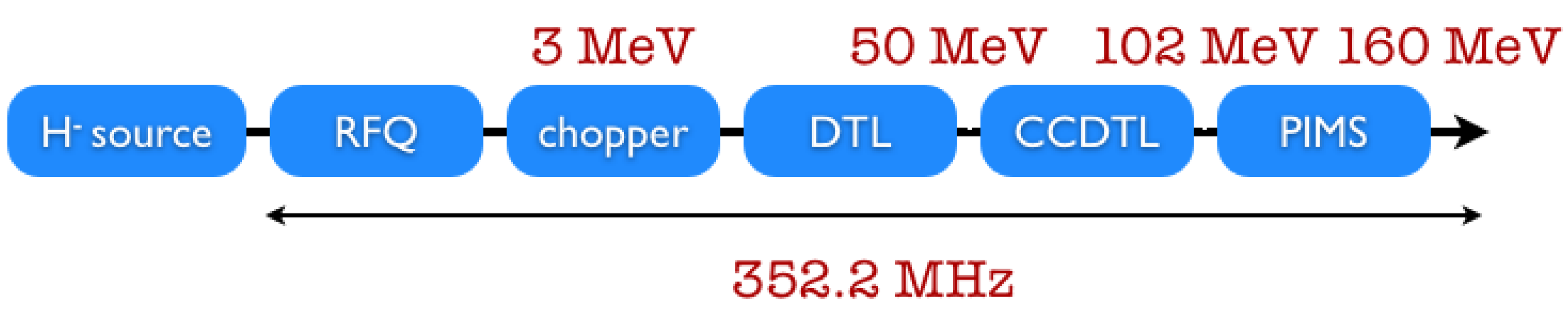
LINAC4

The LINAC4 is going to replace the LINAC2 which is the **first linear acceleration stage** downstream the particle source. After further acceleration these particles will be used for the LHC experiments.

The LINAC4 will have the following key features:

- Increase of beam **brightness** by a factor of 2
- Output energy: **160MeV** instead 50MeV at LINAC2
- **H^- ions** instead of protons

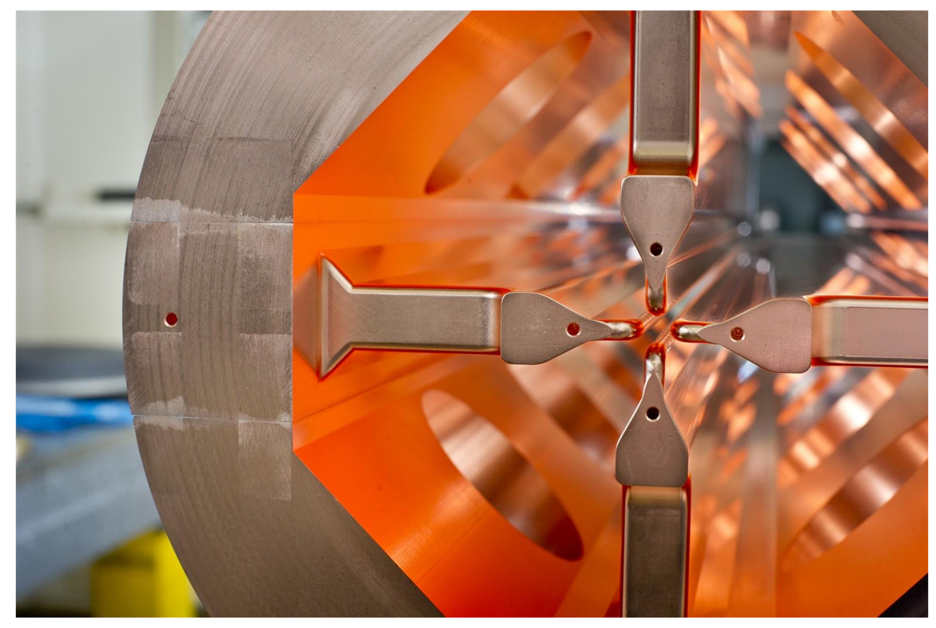
Scheme of LINAC4



Ref: cern.ch/linac4-project

RFQ: Radio Frequency Quadrupol
DTL: Drift Tube Linac
CCDTL: Cell-Coupled Drift Tube Linac
PIMS: Pi-Mode Structure

RFQ for LINAC4



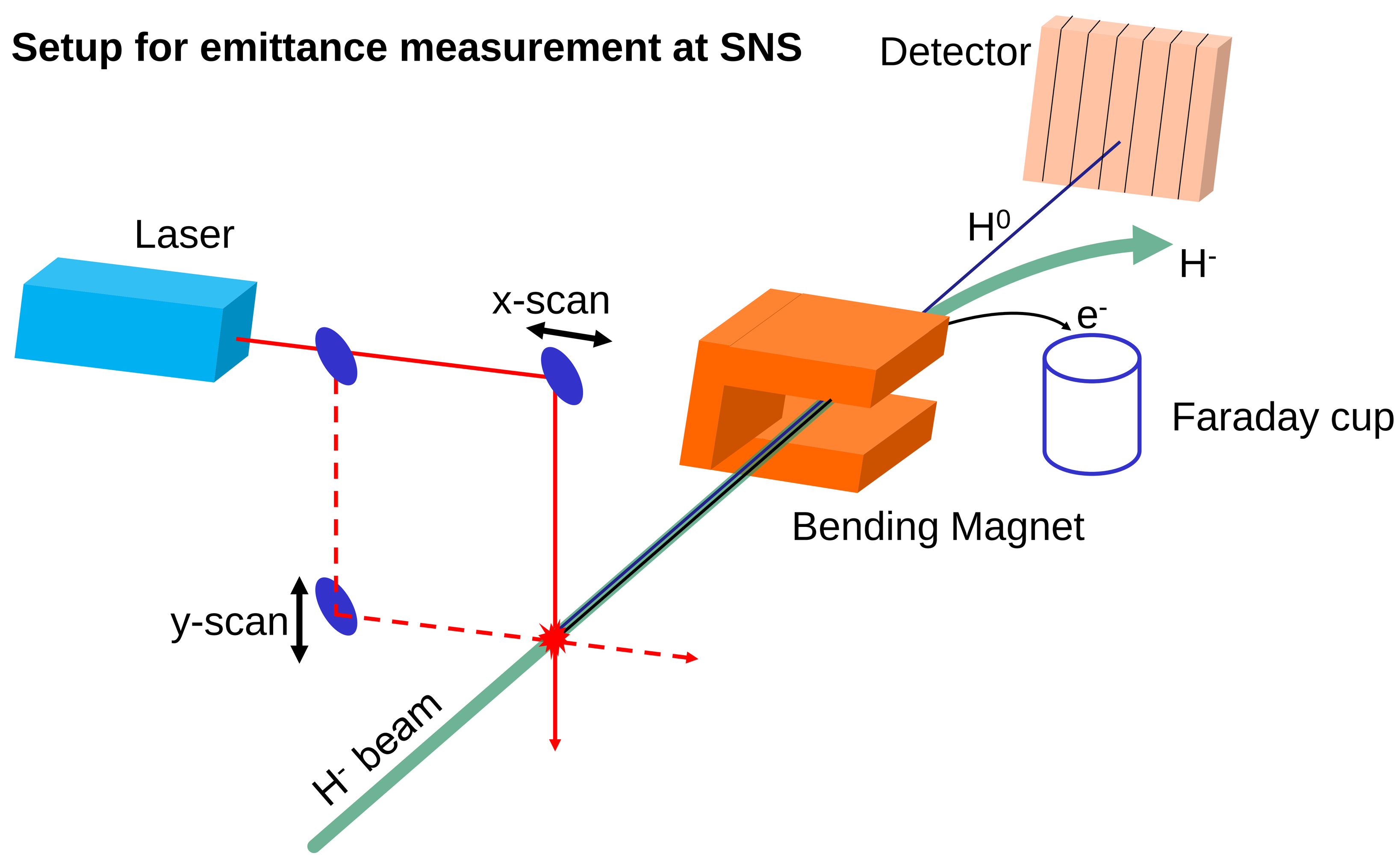
Ref: cern.ch

The designated position for the laser emittance meter is at the end of the LINAC4 where the H^- ions are at 160 MeV.

Basic concept and previous developments

The basic concept of a laser emittance meter is shown at the outline to the right. It shows the setup for emittance measurement which is running at SNS (Spallation Neutron Source) in the USA.
The first important component is a **Nd-YAG laser** in the mJ range. Through motorized mirrors the laser can be scanned through the beam vertical or horizontal. The laser interacts with the beam by **neutralizing H^- ions**.
The following **bending magnet** can separate the different beam particles. The untouched H^- ions are deflected to further accelerator stages.
The stripped electrons which were generated by the laser are stronger deflected than the H^- ions due to their much lower mass and can be measured in a faraday cup. This signal is proportional to the H^- beam intensity at the laser position.
The H^0 atoms are not deflected and can be received by a detector with spacial resolution perpendicular to the laser direction. The spacial distribution at this detector is now proportional to the angle distribution of the H^- beam.
By scanning the beam in x- and y-direction through the H^- beam we can reconstruct the transverse emittance.

Setup for emittance measurement at SNS



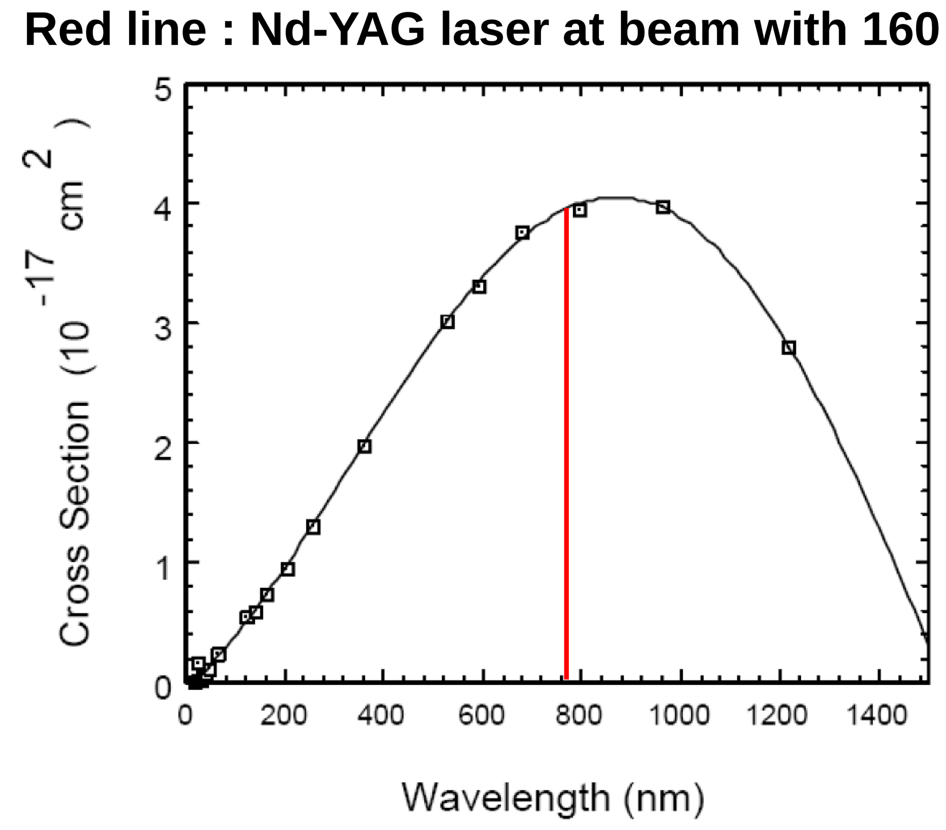
Tasks and Challenges

The first major task will be the **modeling and simulation** of the interaction of the particle beam with the laser. Important parameters for this simulation are laser parameters like wavelength and power as well as the shape of the laser beam. Therefore the selection of required **optical components** must be executed simultaneously.
At the right graph we see the photo neutralization efficiency as a function of the laser wavelength in the beam frame.

Furthermore also the **background** plays an important role. It is the limiting factor for the signal to noise ratio. Several effects can generate background particles:
- Blackbody radiation
- Magnetic field stripping
- Residual gas stripping

For the LINAC4 the **residual gas stripping** is expected to play the most important role. The principle is shown at the sketch below:

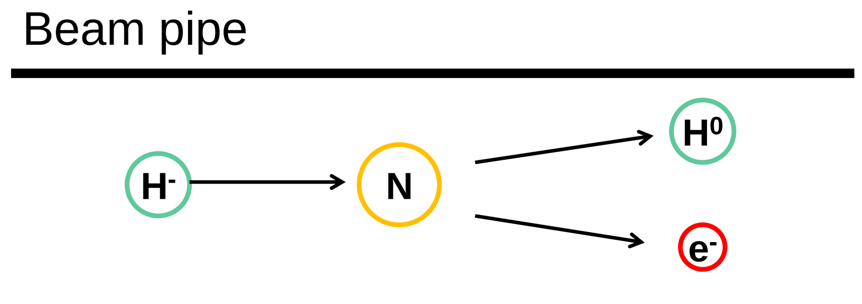
Photo neutralization efficiency
Red line : Nd-YAG laser at beam with 160 MeV



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

Residual gas stripping principle

Beam pipe



Furthermore the most suitable **type of detector** must be determined. There are several options. While wire-scanners and SEM-grids (Secondary Emission Monitor) are classically used, solid-state (e.g. Si or diamond) detectors can potentially be preferable in terms of resolution, accuracy and radiation hardness.

Another challenge is the **timing link** between the laser and the beam. Together with an envisaged real time monitoring there are strong requirements on the photon detectors, the IT and control systems.

The final aim is to design a **prototype setup** and test it directly on LINAC4.

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