High Power Proton Diagnostics

Andreas Jansson

European Spallation Source

Seville, Spain, 2011-11-11

EUROPEAN SPALLATION SOURCE

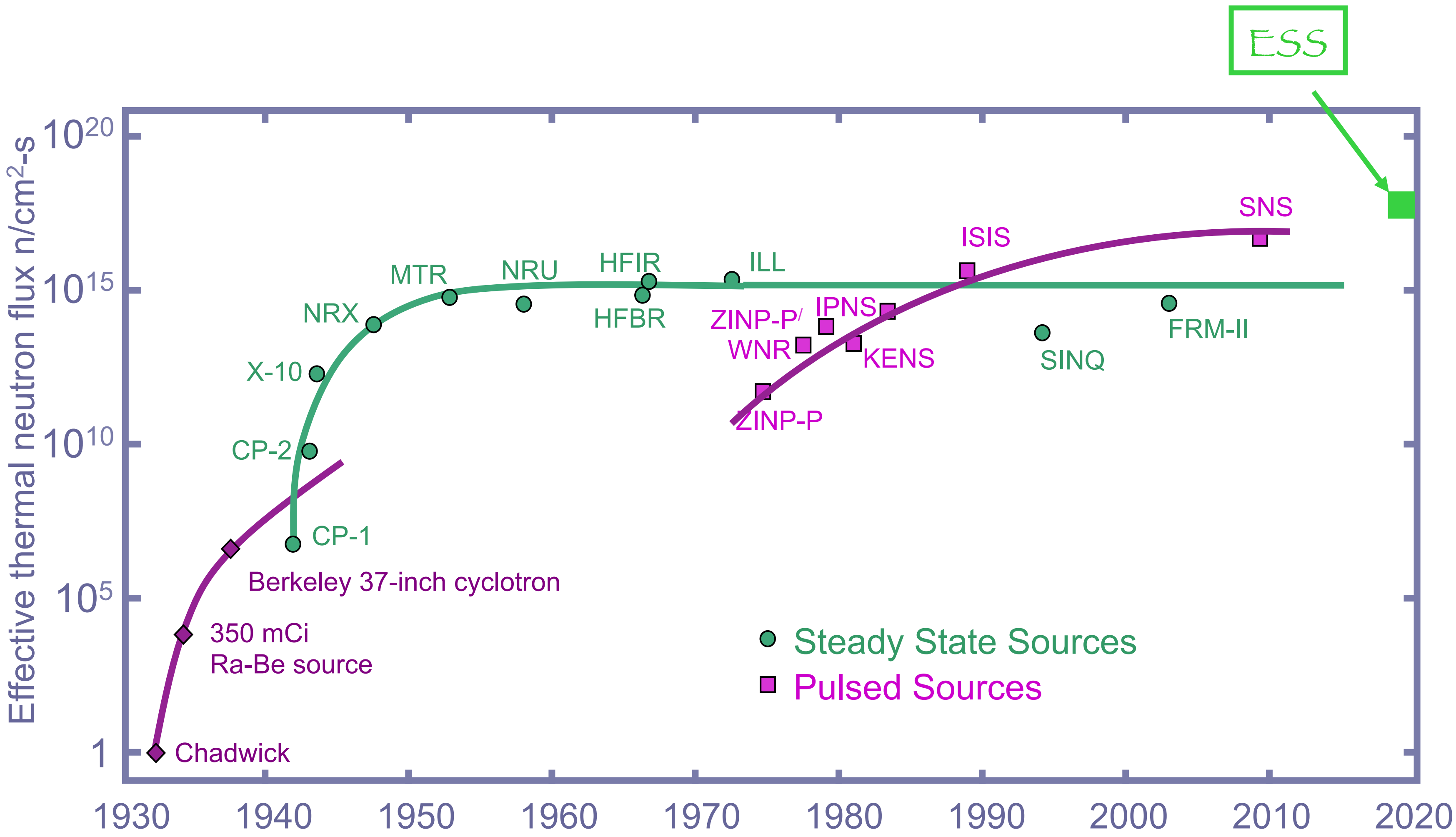
Outline

- Brief intro to ESS - a high power proton linac
  - Talk will focus mainly on linac diagnostics
- Beam loss for protons vs H-
- High power hadron diagnostics challenges
  - Position, phase, current & loss
- Specific issues with high power protons (a opposed to H-)
  - Transverse & longitudinal profile/halo

What is ESS?

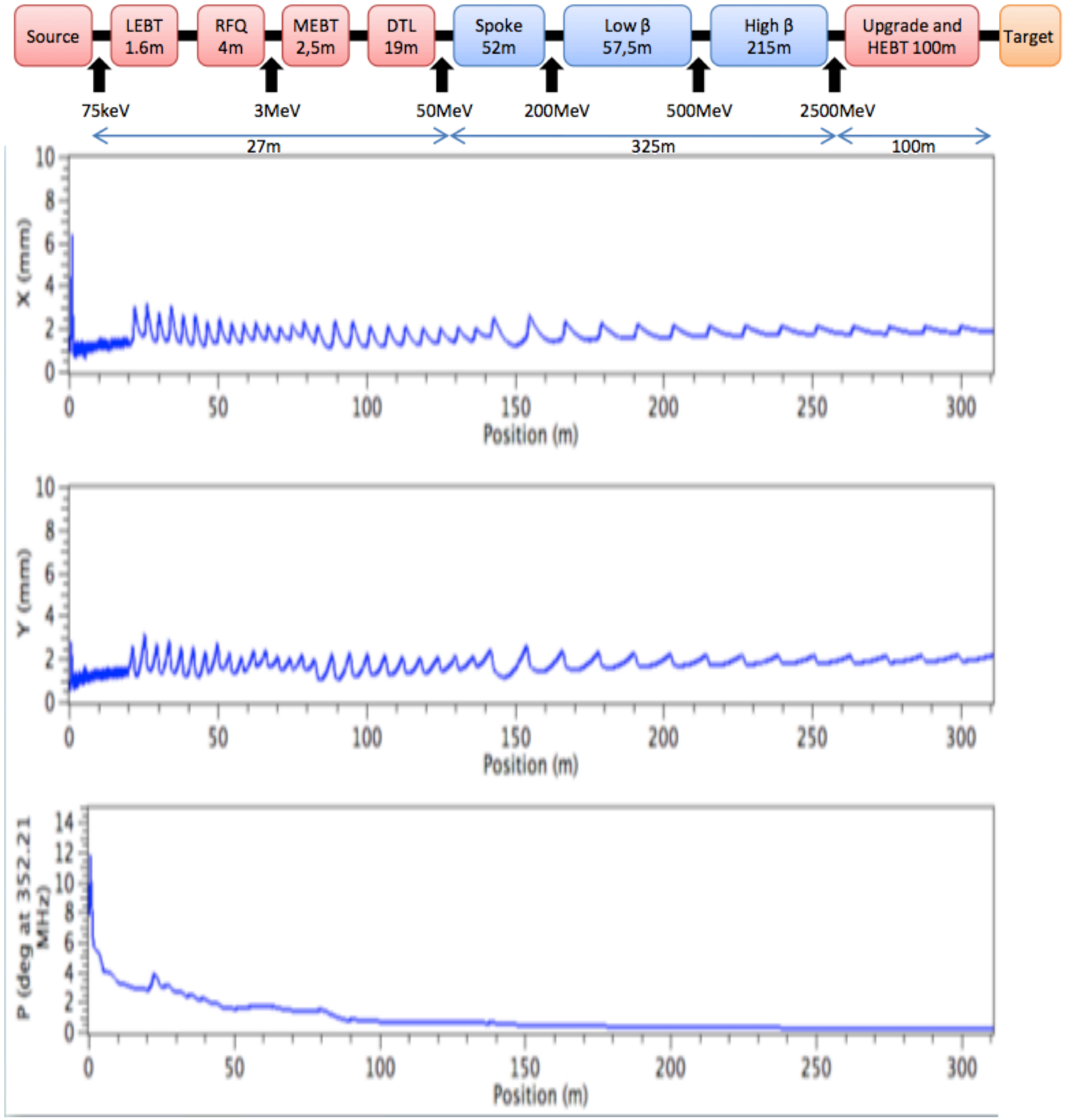
- ESS is a long pulse spallation neutron source based a 5MW superconducting proton linac.
  - Will be built in Lund, Sweden.
  - Partnership of 17 (and counting) European countries
  - “Neutrons before the decade is out”
- Besides becoming the worlds most powerful neutron source, it also aims to be the worlds first sustainable (large scale) research facility.

Evolution of the performance of neutron sources



(Updated from *Neutron Scattering*, K. Skold and D. L. Price, eds., Academic Press, 1986)

ESS Beam Parameters



Average Beam Power
5 MW

Beam Pulse Current:
50 mA (60mA from source)

Pulse length:
2.86 ms

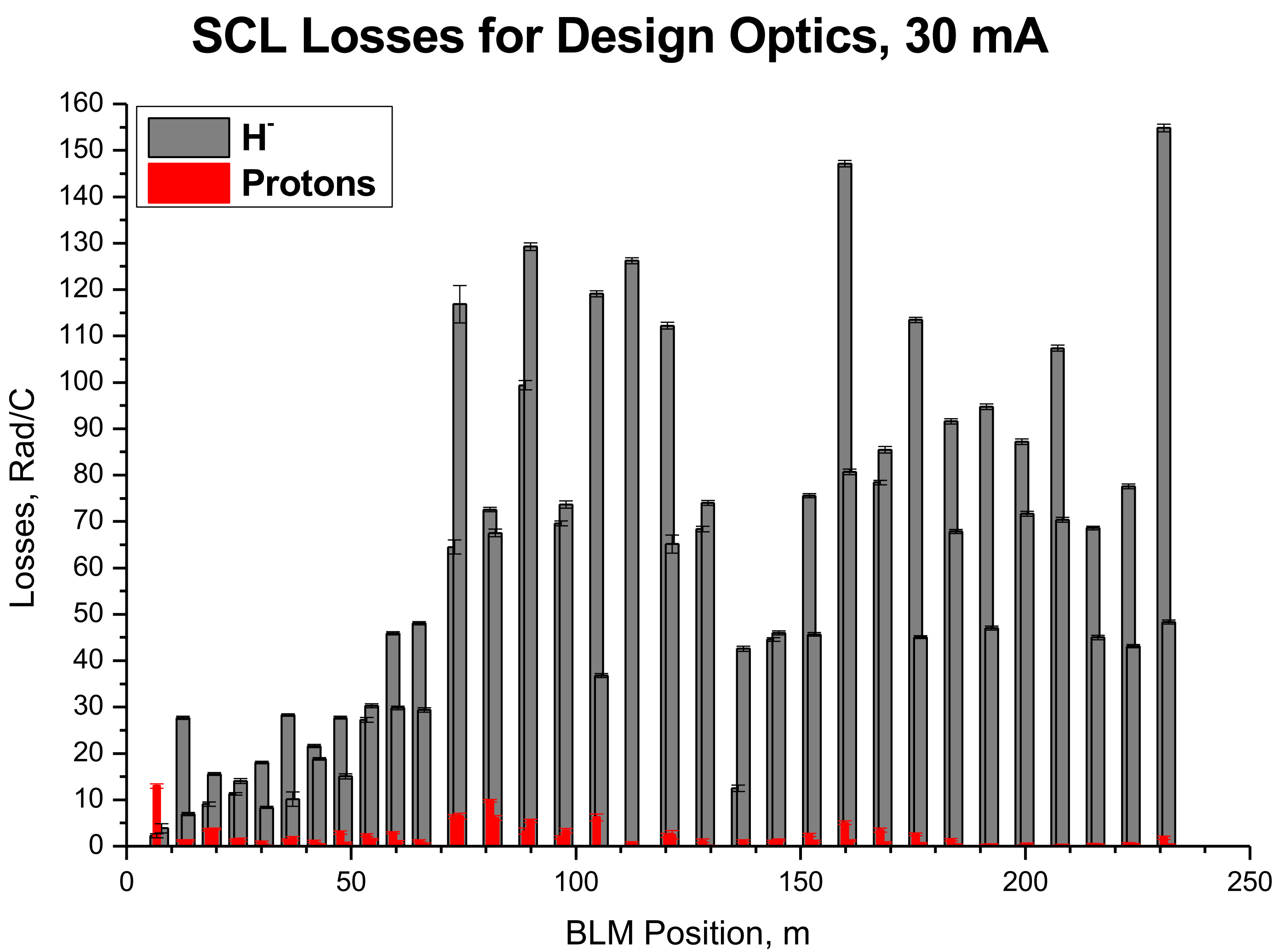
Bunch repetition rate:
352 MHz

Bunch charge:
140 pC

Bunch length (r.m.s.):
10-40 ps

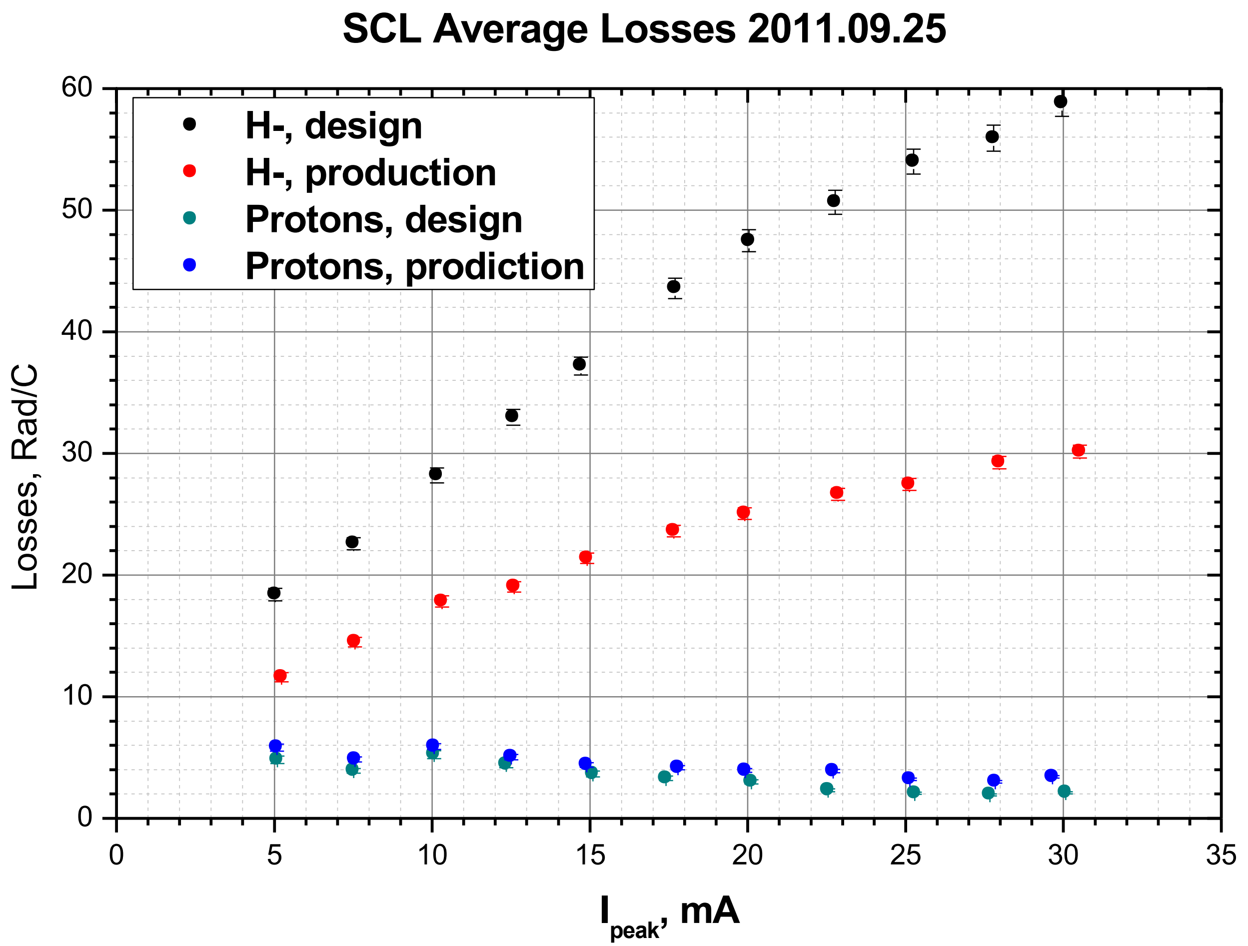
Beam size (r.m.s.):
1-3 mm

SNS Proton vs H- losses



A. Shilshlo et al, SNS

SNS Losses vs beam current



A. Shilshlo et al, SNS

General high power hadron issues

- Beam loss
  - beam can do significant damage, so
    - fast response (~ few us) needed
    - blind spots must be avoided
- Beam Current
  - Differential current may need to trigger abort
- Beam position
  - Large excursions may need to trigger abort
- Beam phase
  - Non-relativistic beam, need to measure time-of-arrival for cavity phasing (linacs)

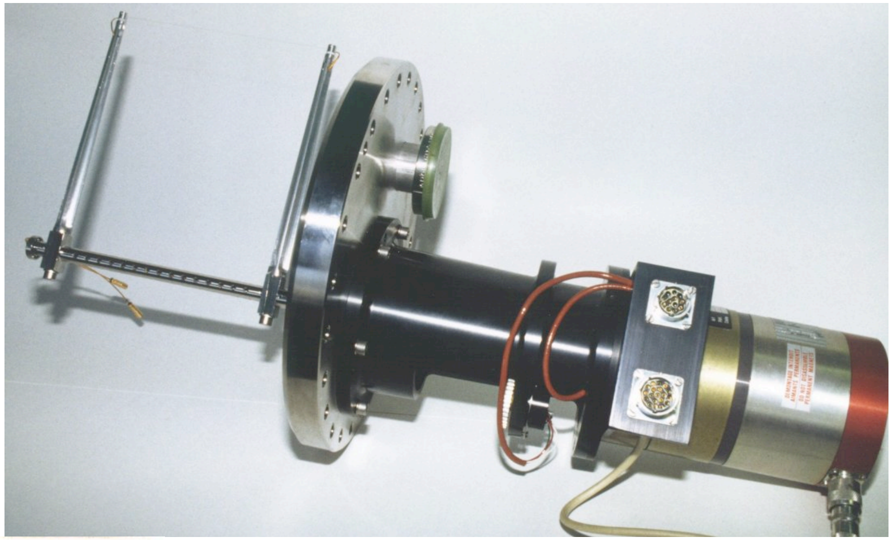
EUROPEAN SPALLATION SOURCE

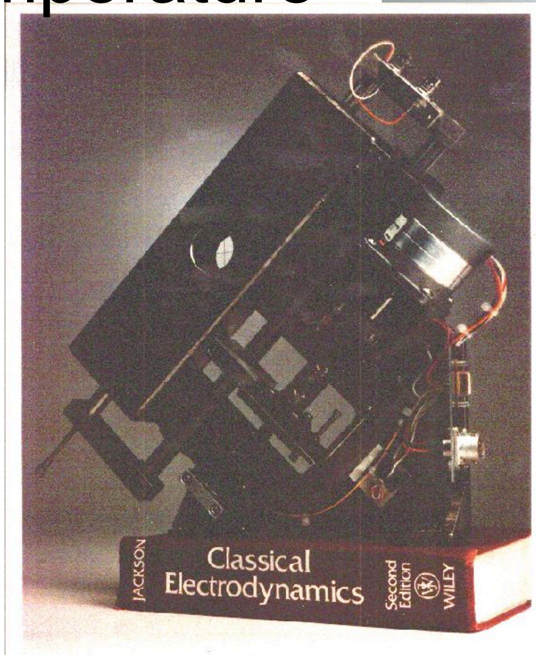
Specific High Power Proton Issues

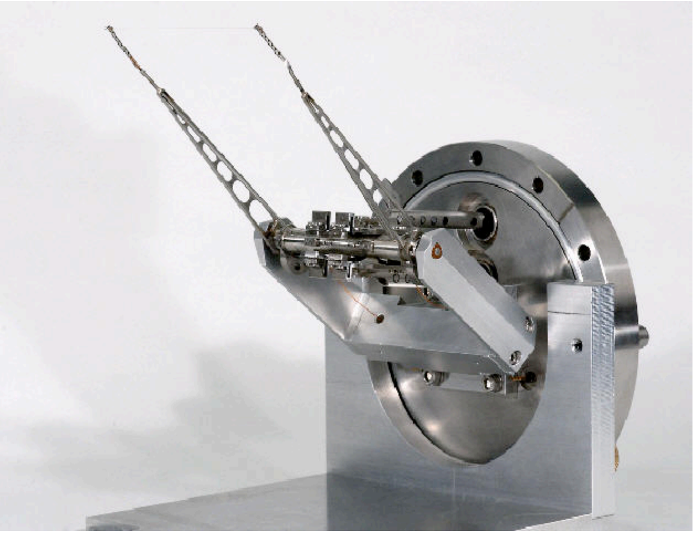
- Due to high power, non-invasive or minimally invasive diagnostics needed.
  - Since no electrons to remove, laser (photo-detachment) based diagnostics not an option.
  - Difficult to measure beam dimensions
    - Transverse profile
    - Longitudinal profile
- Some diagnostics may not be able to take full beam
  - Special short diagnostics pulse (~100us)

Wire Scanners

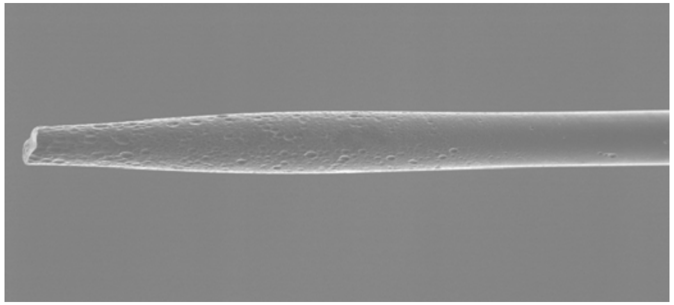
- Minimally invasive -> very thin wires.
- Wires down to 7 microns (carbon)
- Thermionic emission limits useful temperature range







Wire Damage



Carbon wire tested at LEDA
Los Alamos (M Plum et al)

- Wire may break, and need to be replaced
- Concerns about use of wire scanners close to SC cavities due to possible contamination from wire fragments.
- Tests at GANIL showed no effect of sublimating wires close to SC cavities, except from carbon (bad)
  - Spiral2 will use wire scanners in SC linac.

IPM

- Collects rest gas ions (or electrons) ionized by the beam.
- In the case of ions, space charge may be an issue.
- For electrons, need B-field.
- Microchannel plates age, and need to be replaced (break vacuum)

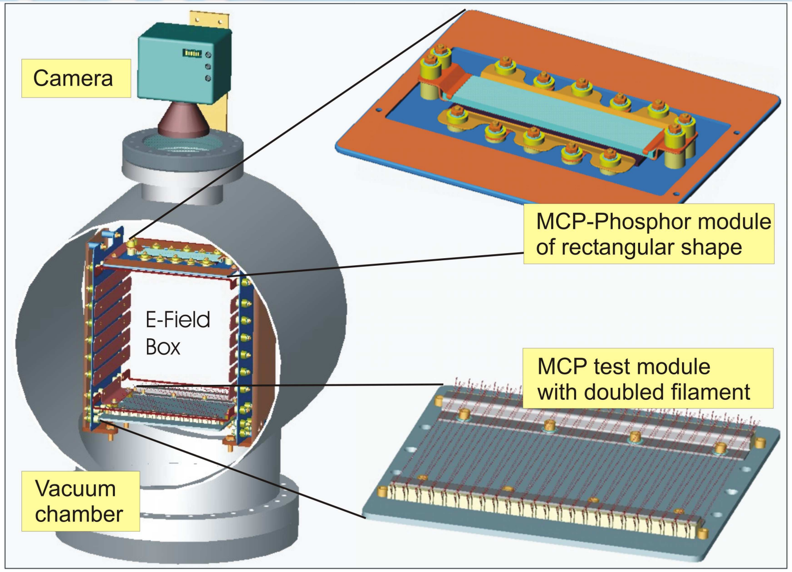
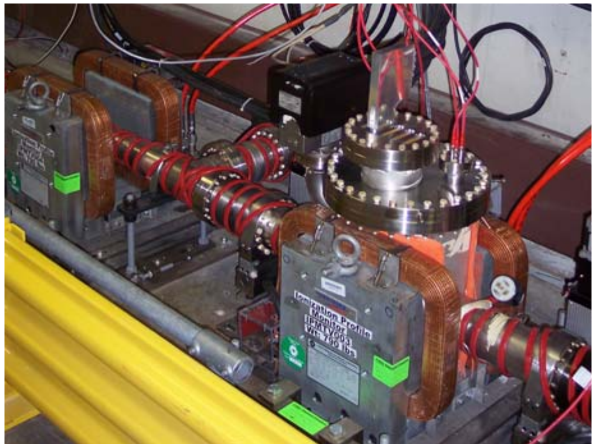
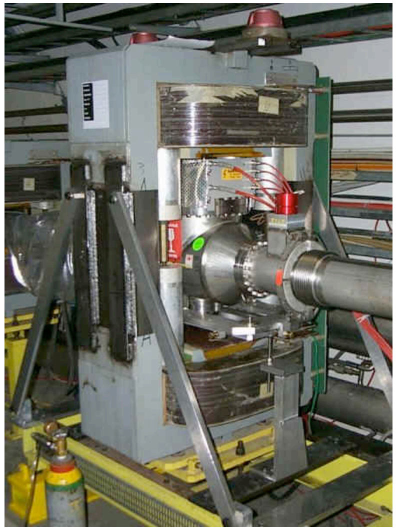


Figure 6: Schematic sketch of an IPM.

P. Forck et al, GSI



Tevatron IPM



CERN SPS IPM

Gas Fluorescence

- Measures light emitted by atoms/molecules excited by the beam.
- Cross sections much lower than for ionization
- Light emitted isotropically, collected in limited solid angle.
- Simple (viewport and camera)

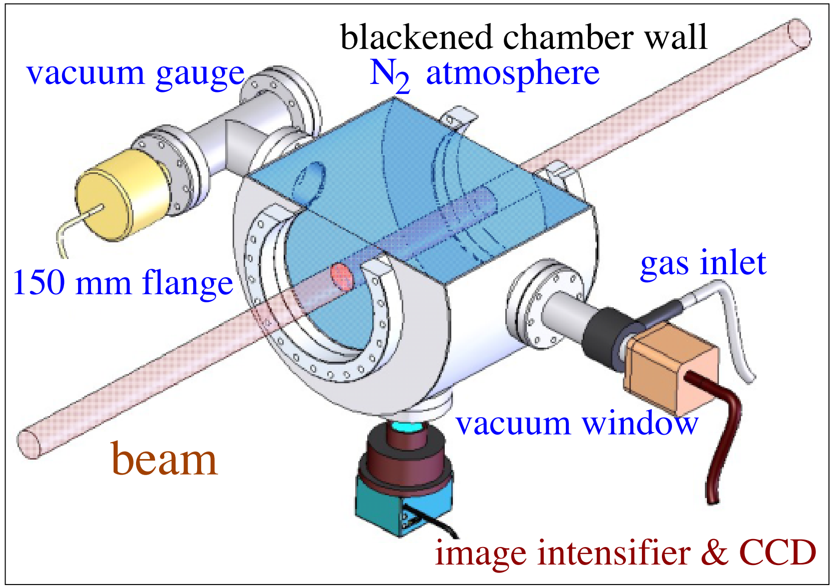
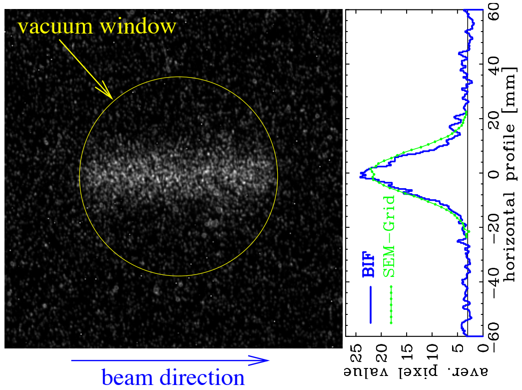


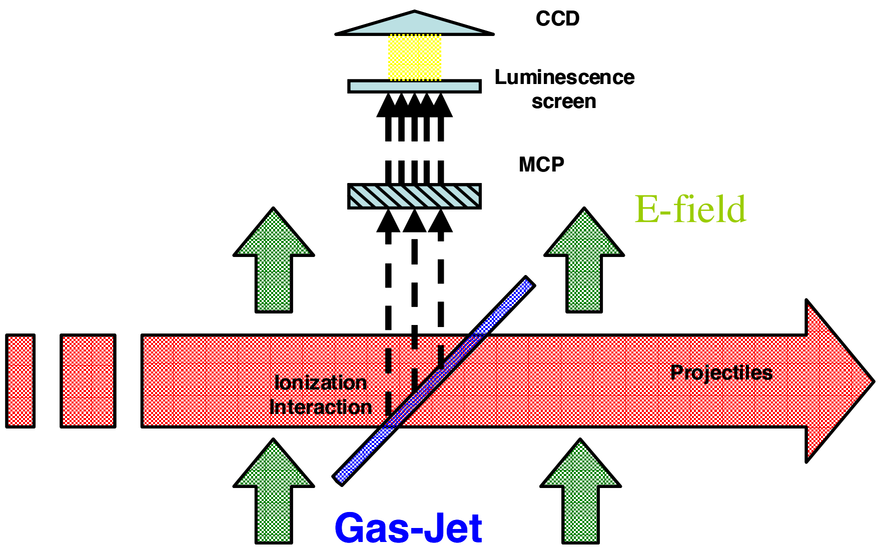
Figure 1: Scheme of a BIF-Monitor.



F. Becker et al, GSI

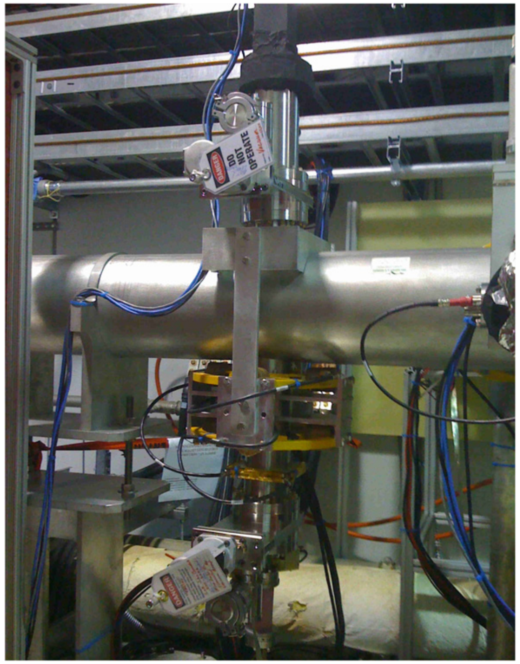
Gas Jet

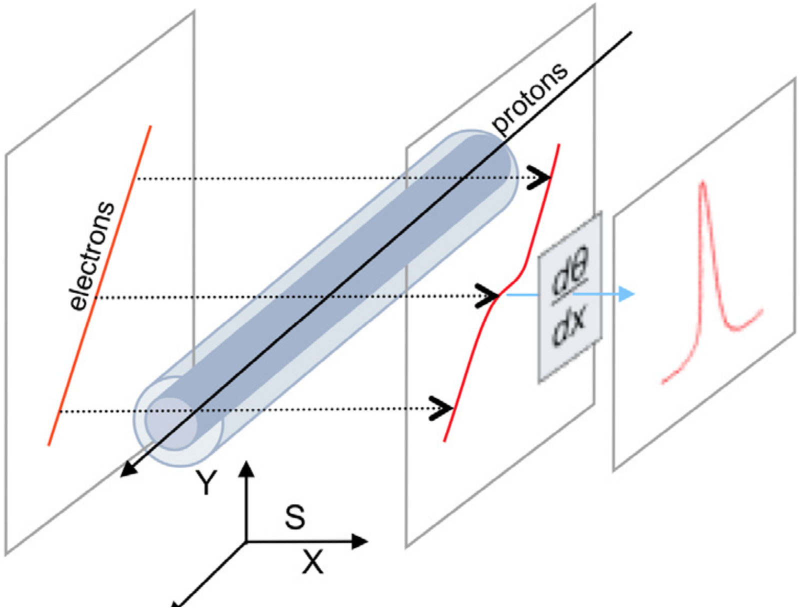
- If rest gas pressure not sufficient, may use gas jet to increase local pressure.



Kuehnel et al, EPAC08

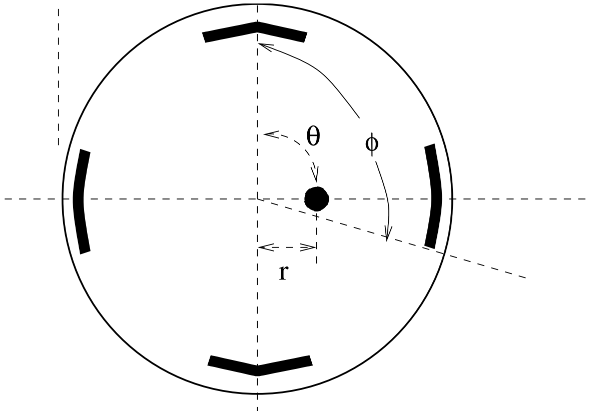
E-beam scanner/Profilometer





- Scan probe beam (ions or electrons) perpendicular to main beam, measure displacement and differentiate to get profile
- Slow ions average over many bunches, while electrons probe instantaneuos beam current.

Quadrupole Pick-up



$$A + B + C + D \propto I$$

$$A \quad - C \quad \propto x\, I$$

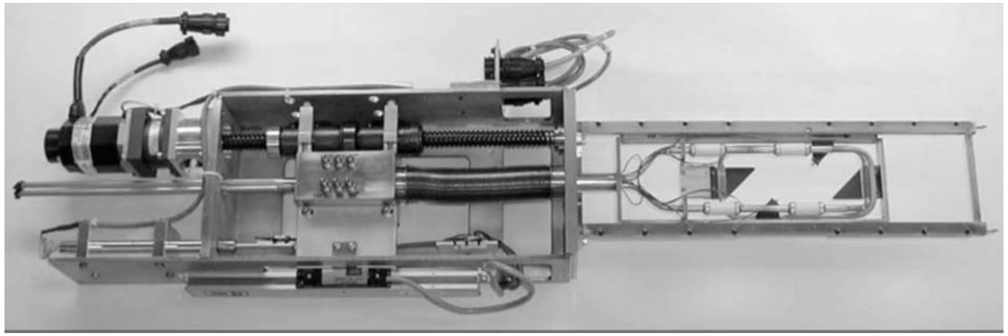
$$B \quad - D \propto y\, I$$

$$A - B + C - D \propto I(\sigma_x^2 - \sigma_y^2 + x^2 - y^2)$$

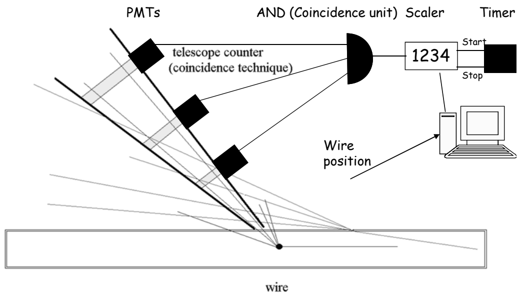
- Can be done with buttons, striplines, magnetic loops or cavities
- Very big difference between common mode and quadrupole mode signals
- Cavities and magnetic loops can be designed to suppress unwanted mode couplings
- Electrical offsets are important

Halo Diagnostics

- Options for halo measurements include instrumented scrapers, vibrating wires, and high dynamic range wire scanners
  - Interesting option is wire scanner with coincidence counting detector/ telescope



LEDA WS, LANL

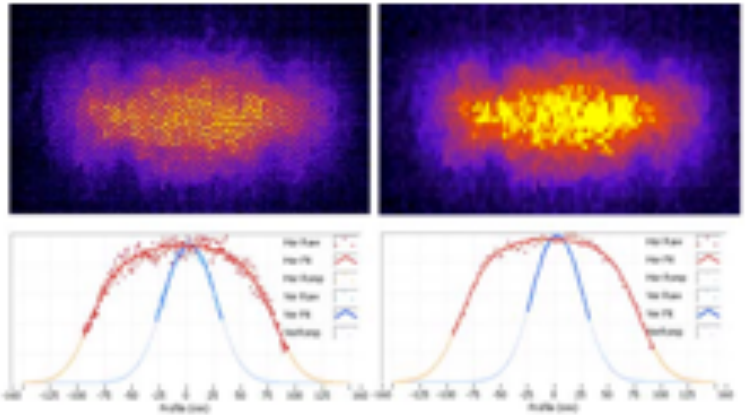


WS Telescope, eg ANL

Vibrating Wire, Bergoz

Target spot size

- Need to measure beam spot on target
- SNS use CrAl2O3 coated target.
  - Yield decreases approximately uniformly due to radiation effects, and stabilizes after some time.
- Fluorescence monitor (eg. Juelich)
- IPM (e.g. LiPAC)
- Wire temperature (e.g. PSI)

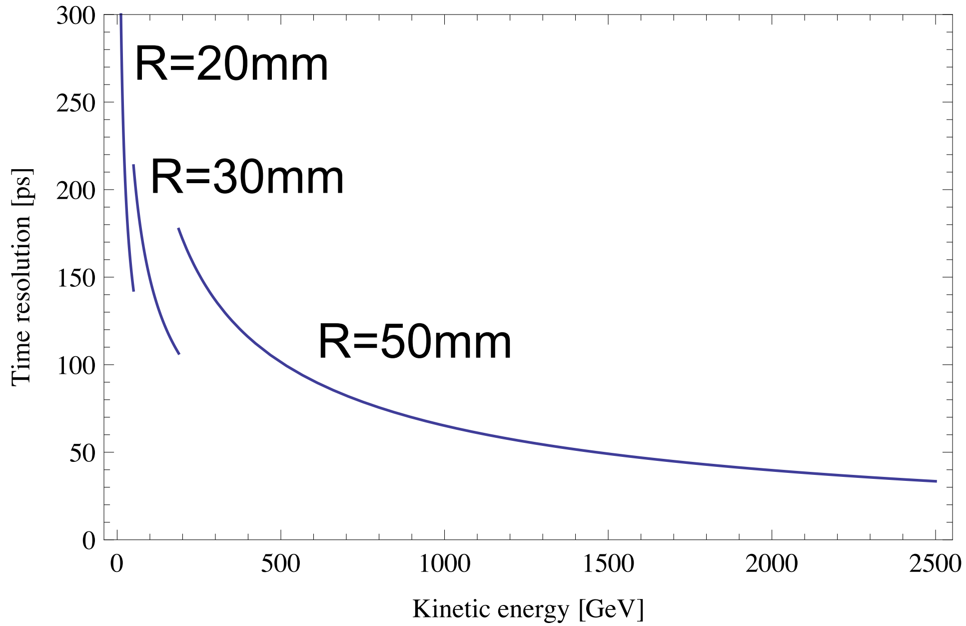


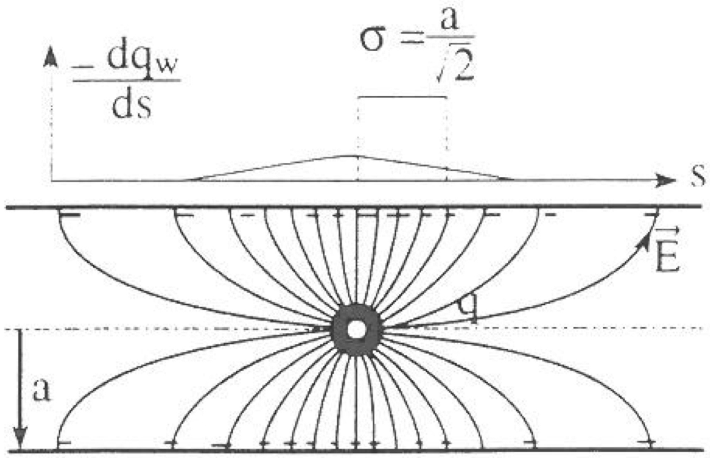
Target with Cr:Al2O3 coating

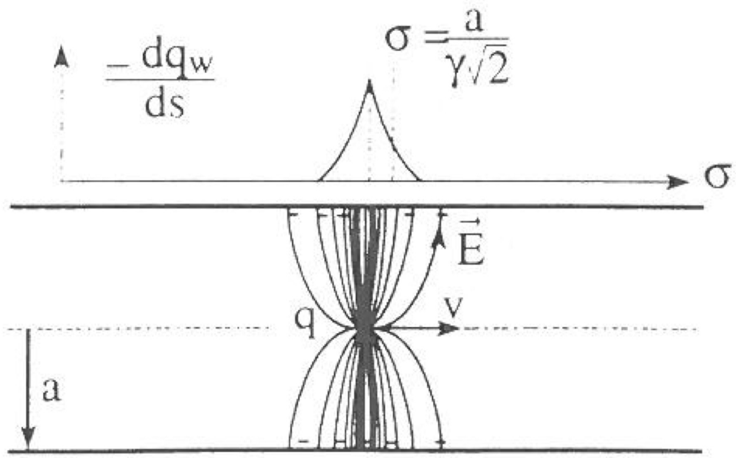
W. Blokland, BIW10

Bunch Shape Measurement

- At low beta, field is not transverse, and wall current not longer reflect beam pulse







Feshenko Bunch Shape Monitor

- The Feschenko monitor (first Faraday cup award) make use of secondary electrons from a wire in the tail of the beam distribution.
  - Very fast (ps) process
- A high bias voltage accelerate the electrons towards a slit, and an RF deflector turns time-of-arrival into position

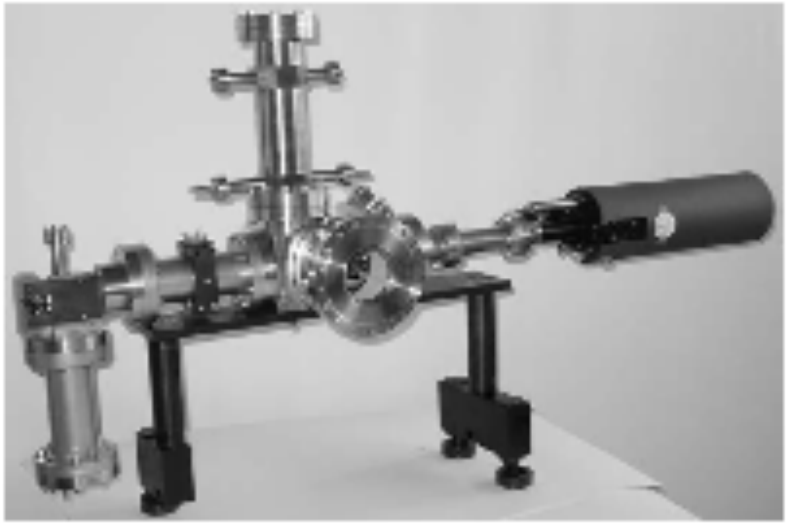
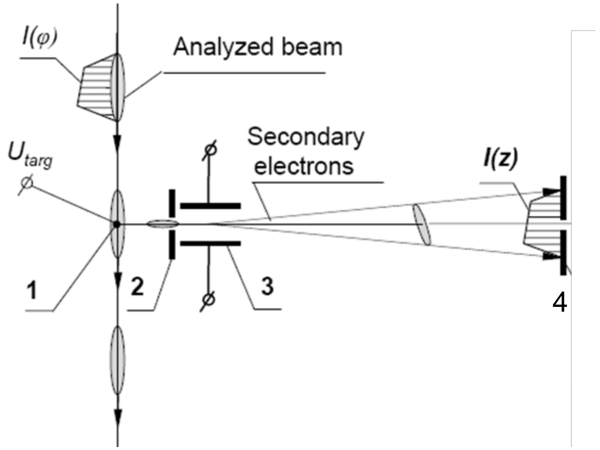


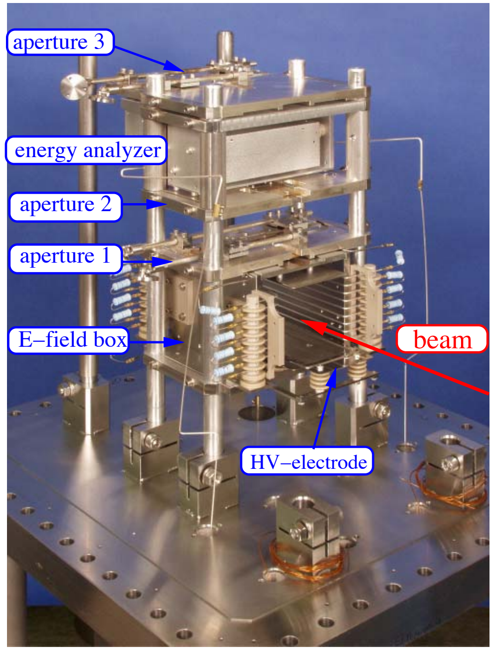
Figure 2: General view of BSM.

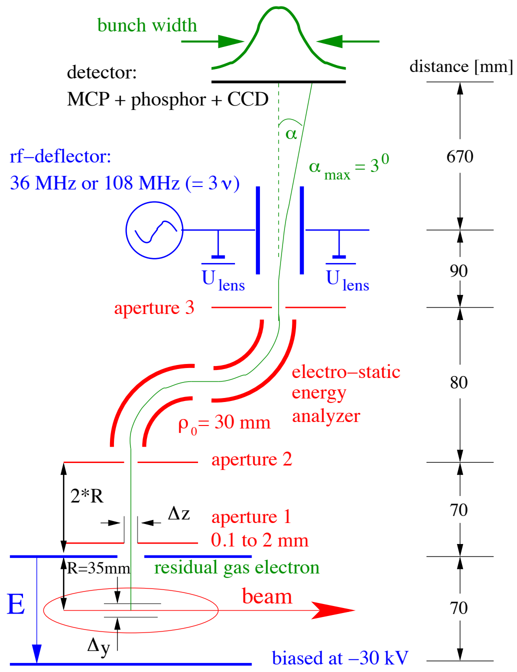


A. Feschenko, Bunch Shape Monitors using Low Energy Secondary Electrons, PAC'92

GSI (Forck) Variant

- The GSI variant uses ionization electrons instead of secondary electrons – no wire!
- Unresolved issues with background
- Space charge sensitive, since uniform electric field.

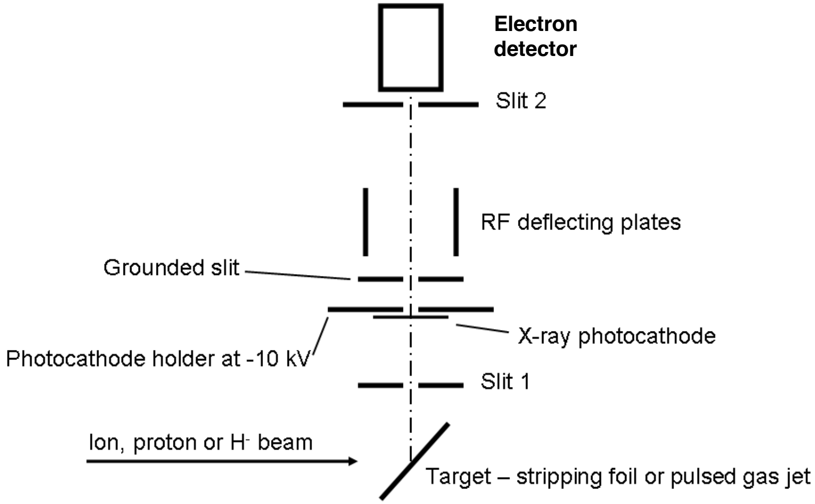


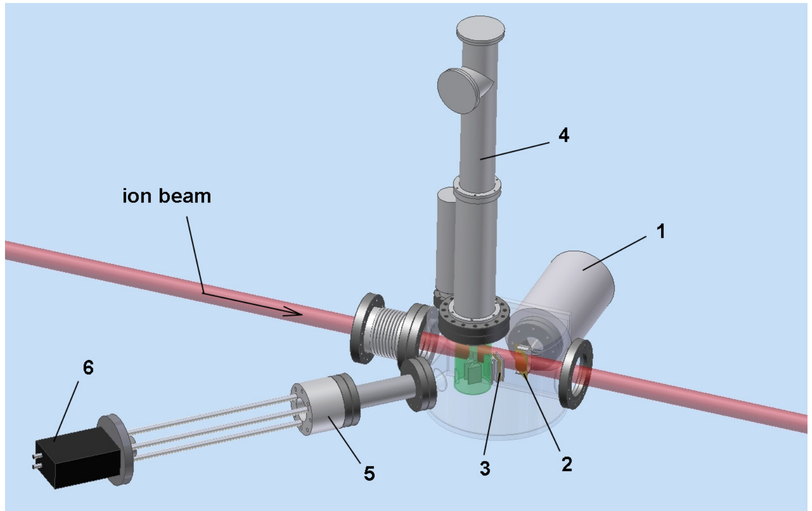


P. Forck et al, Measurement with a Novel Non-Intercepting Bunch Shape Monitor at the High Current GSI LINAC, DIPAC'05

ANL (Ostroumov) Variant

- The ANL variant uses x-rays, which are turned into electrons at a photocathode.
- Space charge not an issue
- Wire or gas target could be used.
- Needs further development





P. Ostroumov et al, Bunch Length Detector Based on X-Ray Produced Electrons, PAC'09

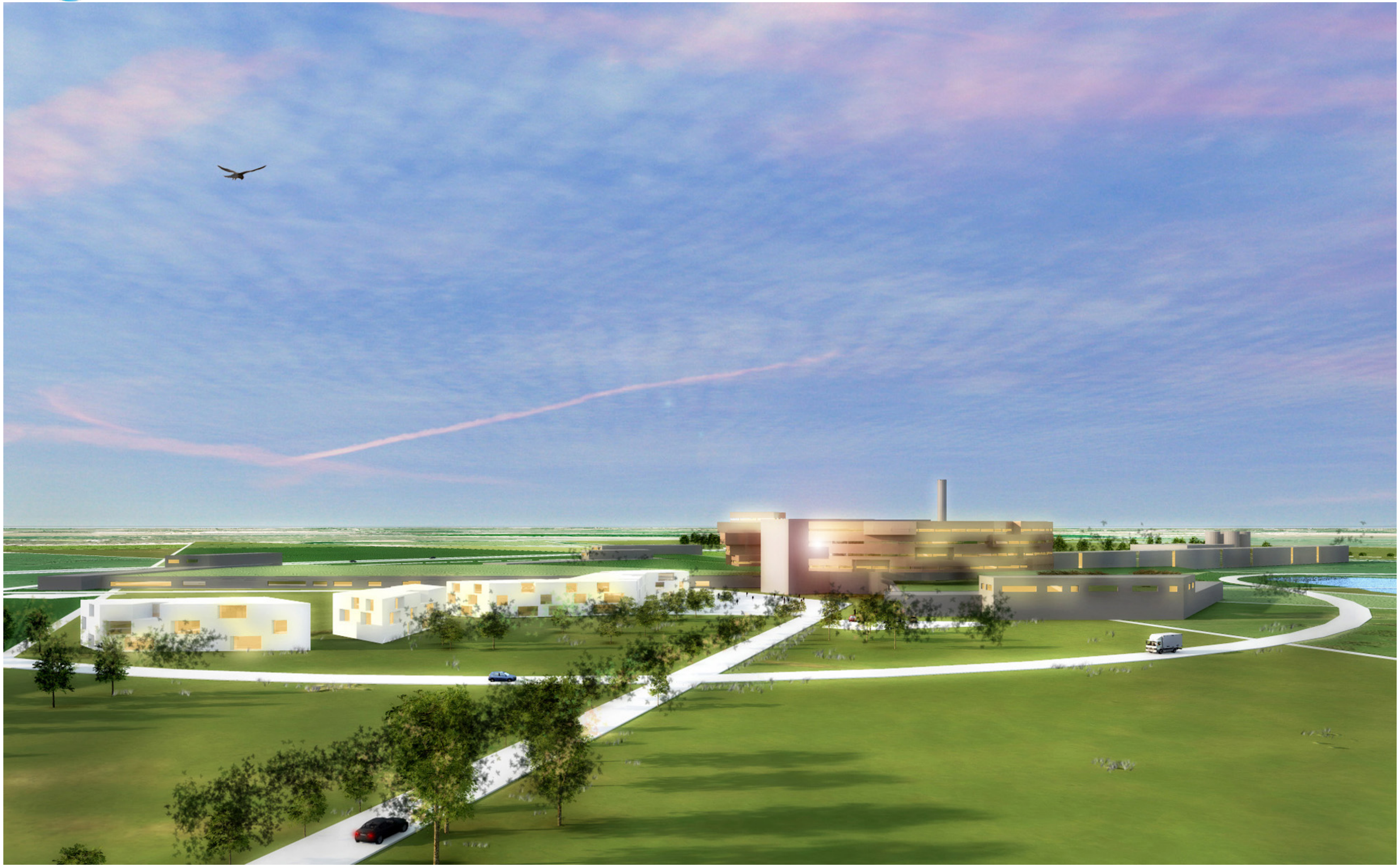
Issues not covered

- Synch light
- High-power faraday cups
- High power slit-grids
- Beam-in-gap diagnostics
- Electron cloud diagnostics
- …

Conclusions

- ESS is a high power proton machine, which involves some particular challenges
- Recent SNS loss experiment may mean that some planned H- machines (e.g. Project X) may run protons at least part of the time.
- Particular challenges are transverse beam size and longitudinal bunch shape diagnostics.
- One of the oPAC fellows will work on this at ESS.

Thanks for your attention!



PS. We are hiring. http://www.esss.se/jobs

The ESS Site Today

ESS Master Schedule