EUROPEAN SPALLATION SOURCE

Beam instrumentation and limitations for Multi MW pulsed proton linacs

Andreas Jansson

ESS, Lund, Sweden

www.europeanspallationsource.se

11 November 2014

Talk Scope

EUROPEAN SPALLATION SOURCE

- Multi MW
  - Very high product of current and energy. Potential for beam induced damage in ~ us. (Use beam current to compare machines)
- Pulsed
  - Ability to calibrate, take baselines and process data between pulses. Possibility of missing triggers/beam when not expected. DC response not needed.
- Proton
  - Heavy particle (low beta). No electrons to strip.
- Linac
  - Very short bunches (~ps). Single pass. Abort vs interrupt for machine protection. Need to phase individual cavities.

Overview

EUROPEAN SPALLATION SOURCE

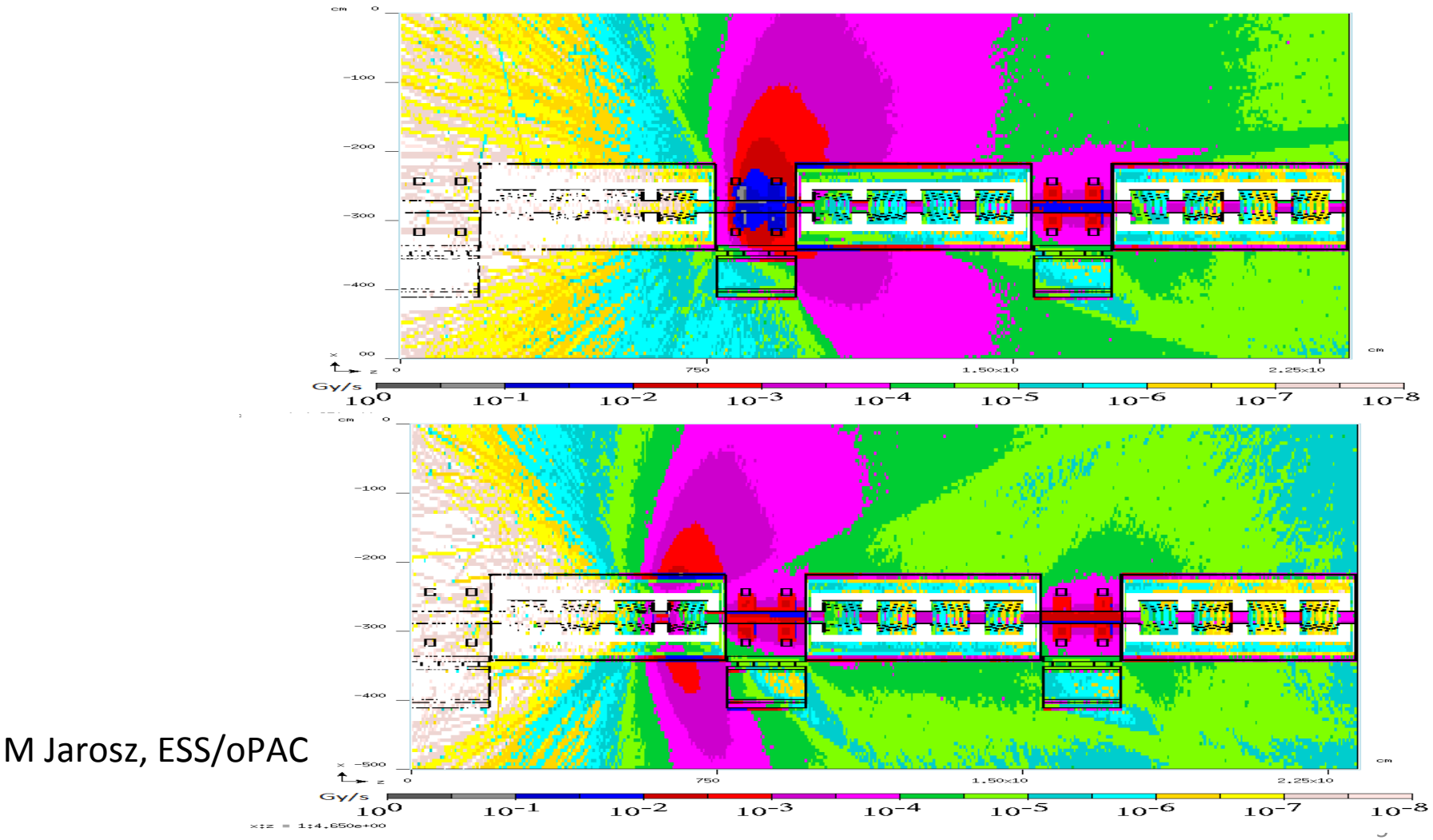
- Beam Loss
- Beam Current (and differential current)
- Beam Position, phase and bunch length (at low beta)
- Beam Profile (non-invasive and invasive)
- Beam Halo
- Target Beam Profile
- Errant Beam/Data on demand

Loss Monitors

EUROPEAN SPALLATION SOURCE

- Loss monitor system is the most important diagnostics system in a high power machine.
- Losses typically occur where beam size to aperture ratio is largest (ie in quadrupoles)
- BLM system should have coverage to detect losses anyware, and be able to pinpoint the loss location and magnitude with reasonable accuracy.
- If there a blind spots, operational tuning will move the losses there.
- Need to be fast (~5-10us) and very sensitive <1W/m (10^-6 of total beam), but not necessarily at the same time (use of multiple integration times).

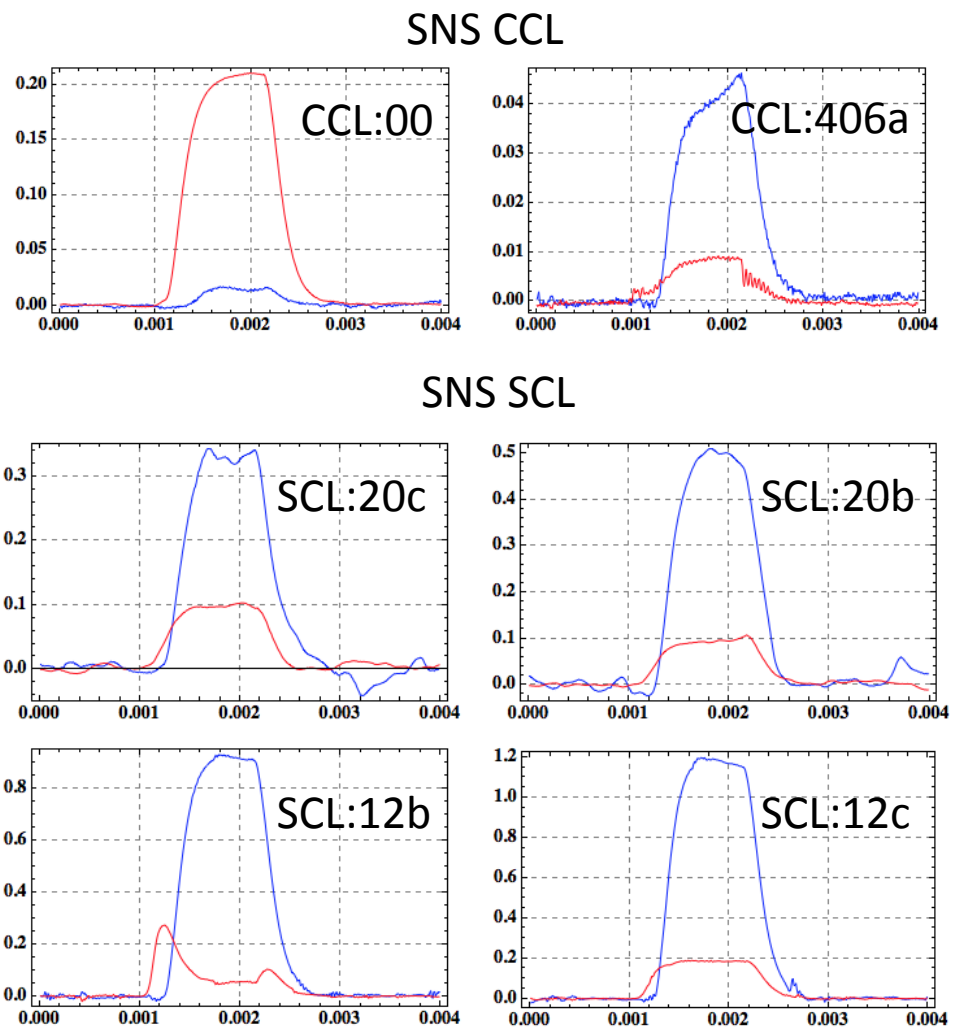
Location of beam loss monitors



M Jarosz, ESS/oPAC

X-ray background

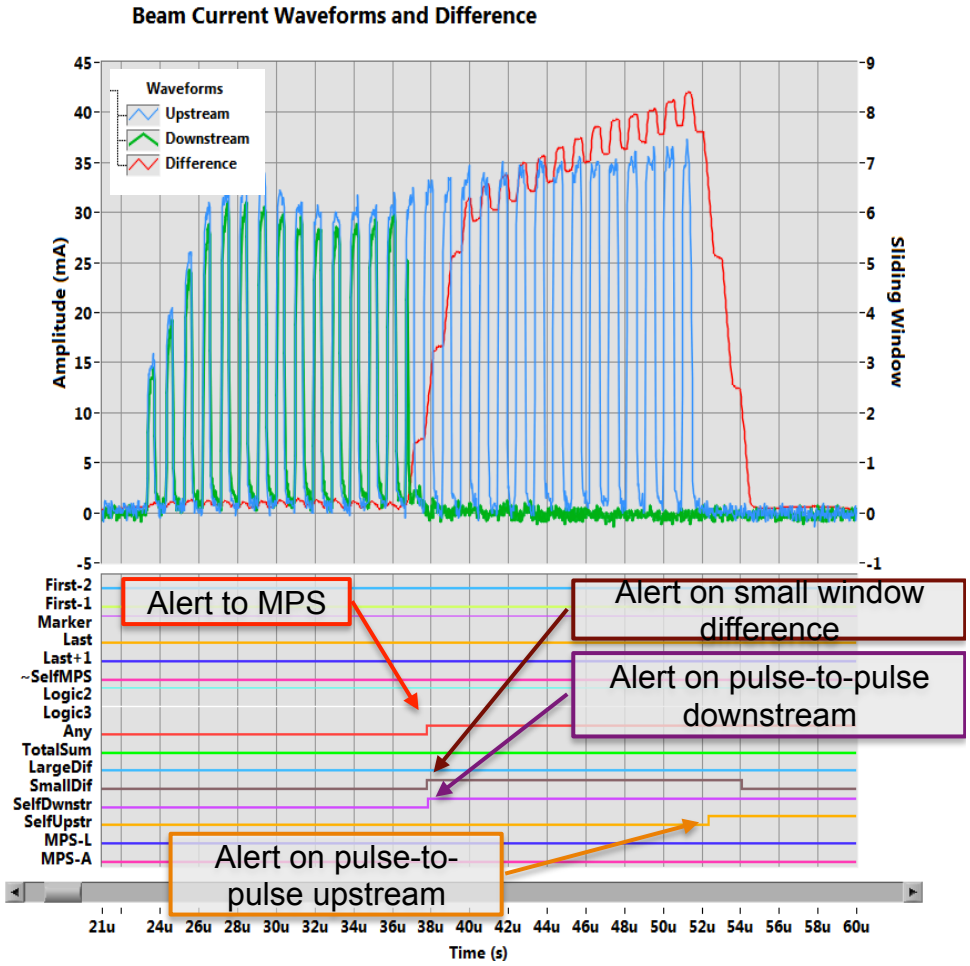
- Ionisation chambers are sensitive to x-rays from cavities.
- X-ray background varies from cavity to cavityEmpty pulse for background measurement
- Dual BPM for on-line subtraction (SNS)



A. Zhukov, SNS

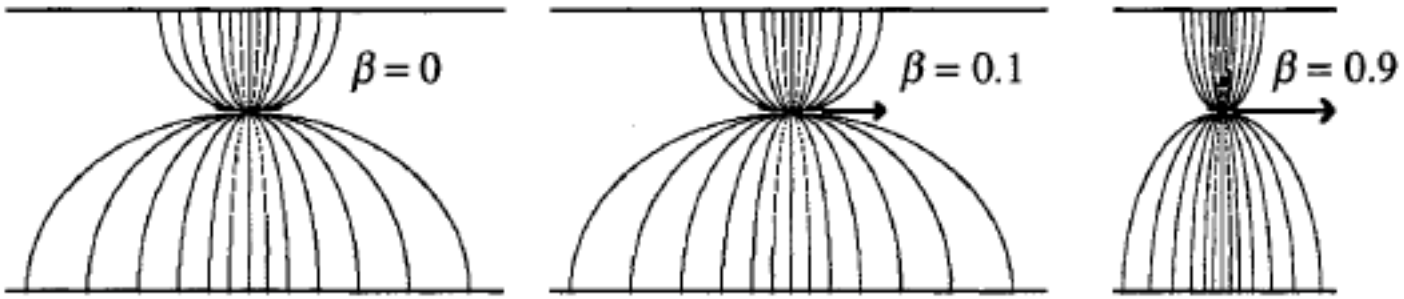
BCM & Differential Current

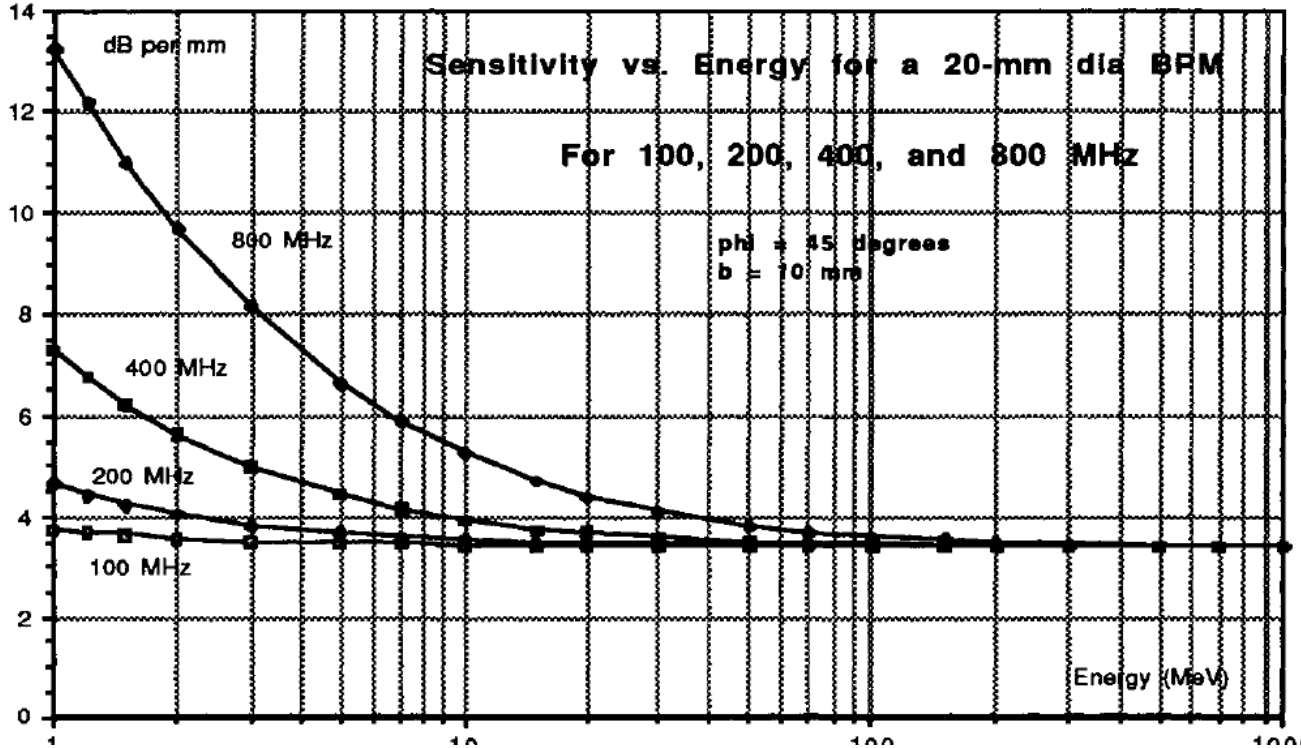
- At low energies, BLMs not sensitive enough.
- Differential current monitoring can be used instead.
- Can also compare to expected pulse shape, including unexpected beam pulse/missing trigger.
- BPM sum signal can also be used for differential current



W. Blokland, SNS

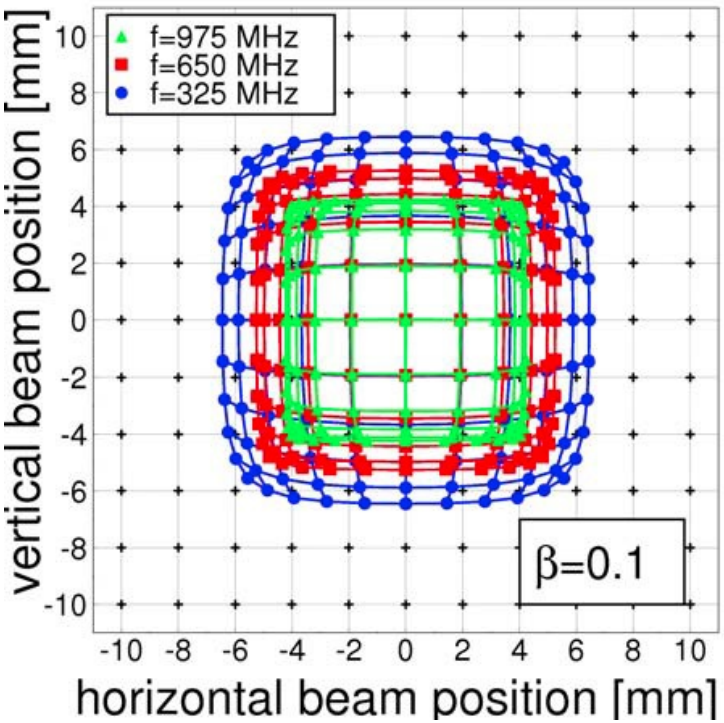
Low beta EM fields and BPM sensitivity

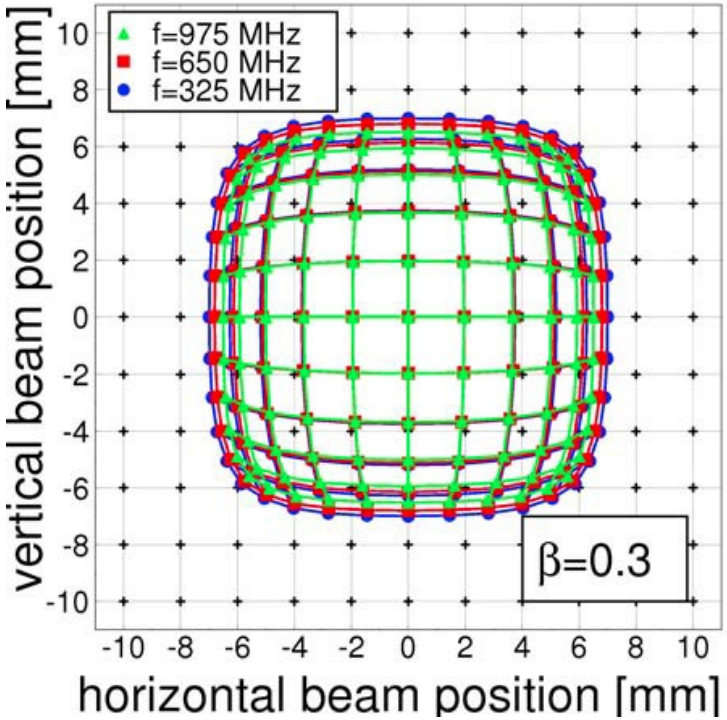




Shafer, LANL

Beta sensitivity of BPMs

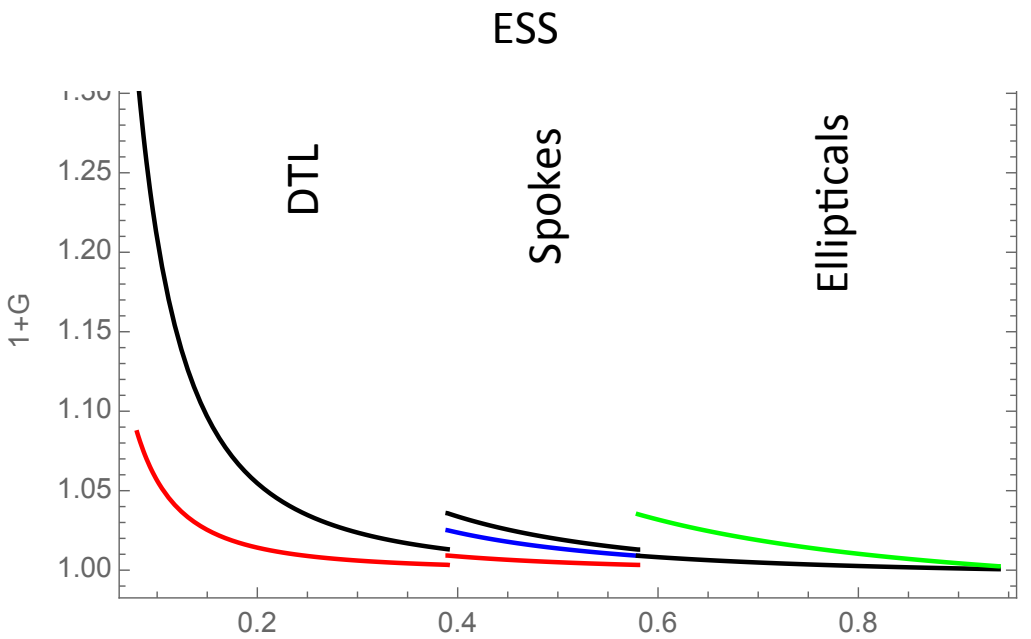




P. Kowina (GSI), DIPAC09

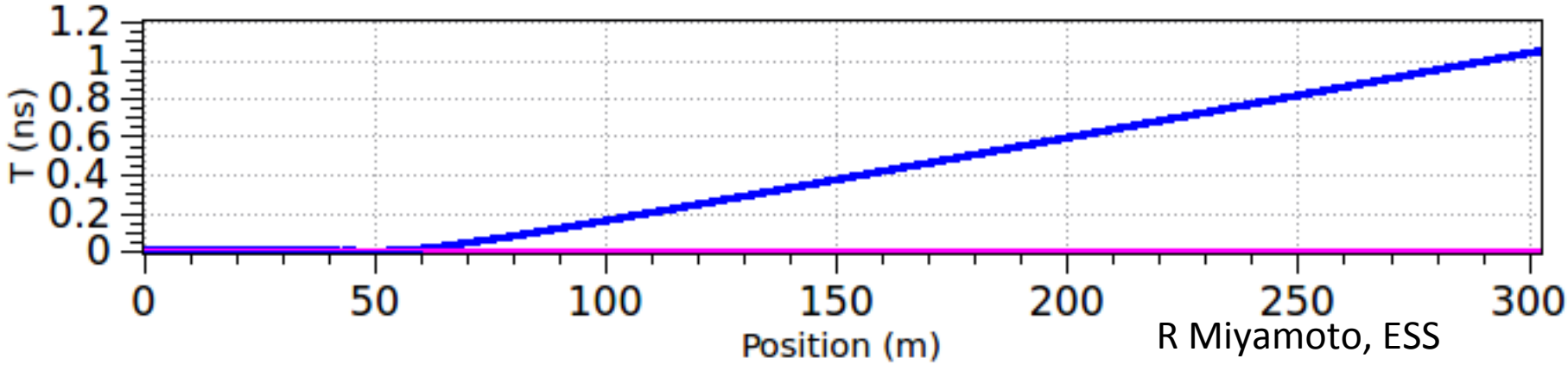
BPM position sensitivity vs beta

- BPM calibration changes with energy.
- Fixed calibration factors may be OK for trajectory correction
- Corrections may be necessary for e.g. differential orbit studies at varying energies.



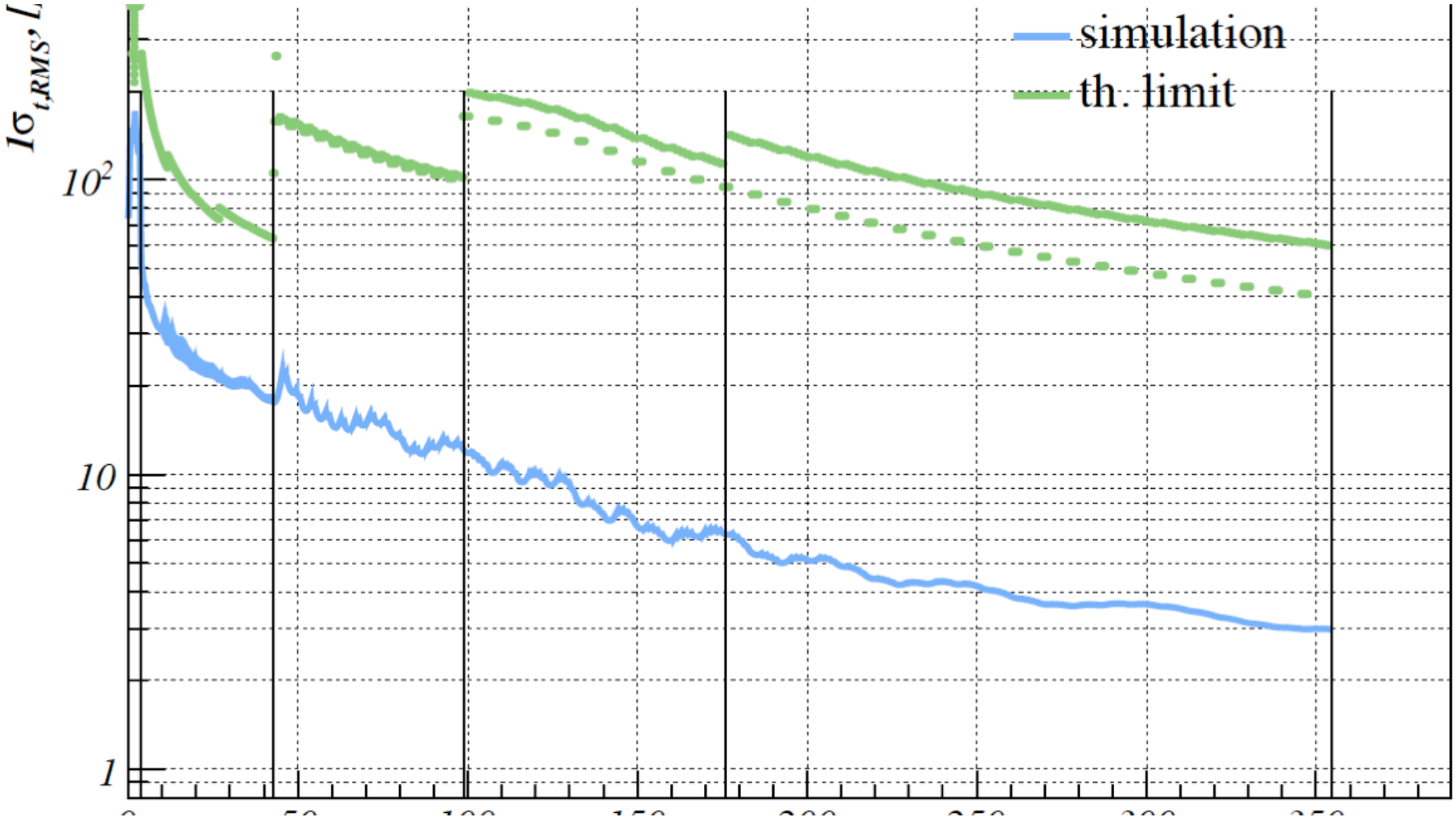
BPM during linac tune-up

- When starting up linac, the beam may need to be transported a long distance at very low energy to get to dump
- Debunching may lead to very low BPM signal, in particular for low current pilot beams
- May need gain switching and/or intermediate beam dumps for comissioning/tune up.



R Miyamoto, ESS

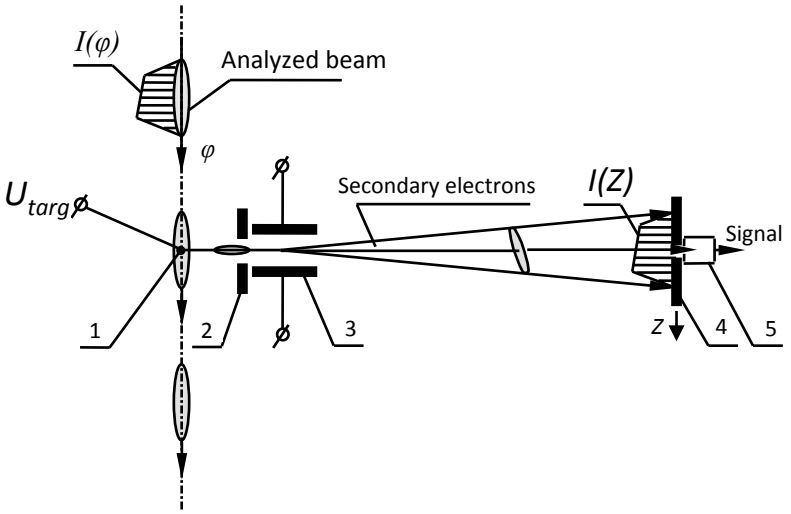
EM bunch length measurement limitations

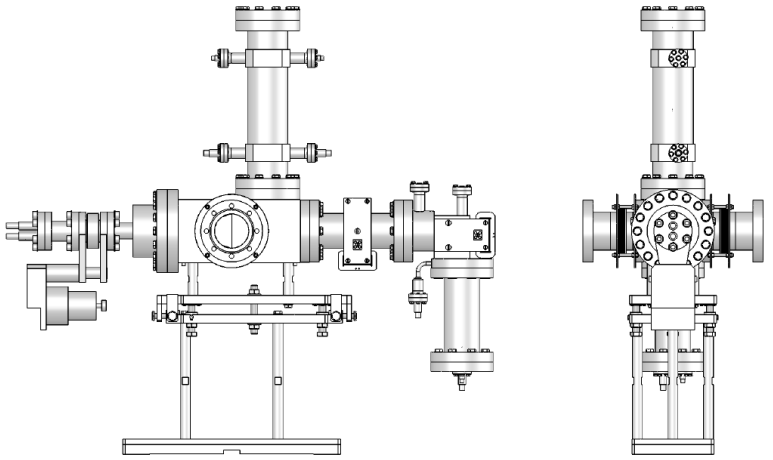


I.Dolenc Kittelmann, ESS

Bunch Length Measurement

- "Feschenko monitor" useful down to ~10ps, possibly lower
  - Space charge
  - Emission delays
- Development needed for ~ps measurement
  - OTR + streak camera?
  - Cherenkov + streak camera?



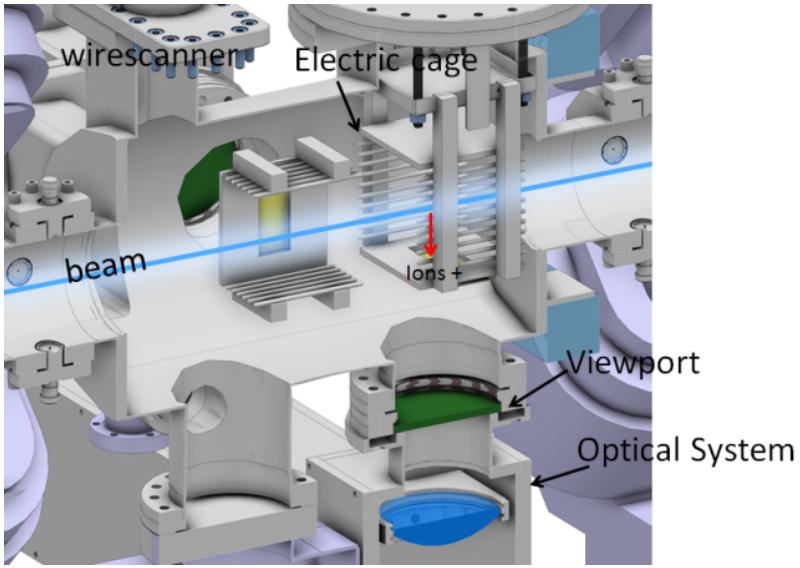


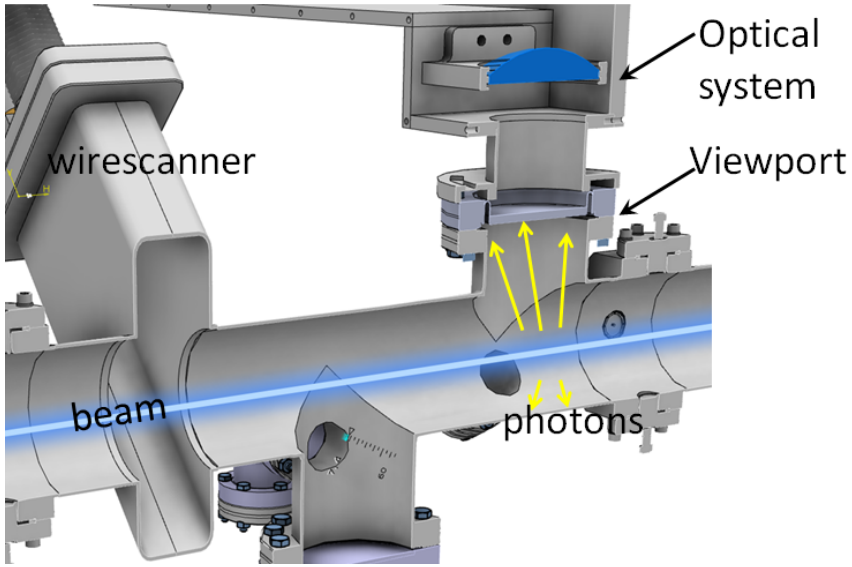
A Feschenko, INR

Transverse profile

- Non invasive profile needed for high power beams
- No electrons to strip restricts the available methods
  - Ionization Profile Monitor
  - Beam Induced Fluorescence Monitor
  - Electron Beam Scanner
  - Gas jet (w IPM or BIF)
  - …
- Non-invasive profile methods may not perform well with short pulse, low currents (pilot beams)
- Need cross calibration to gain acceptance.

IPM and BIF





Signal depends on gas pressure in both cases (low in SC linacs)

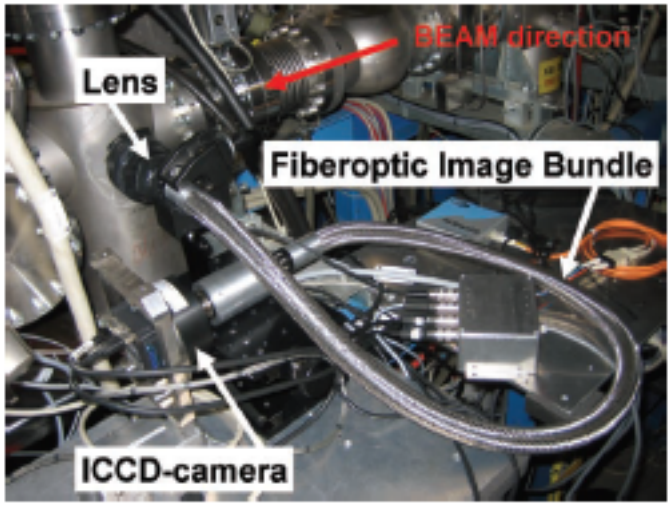
IPM more effective in collecting signal, fluorescence light emitted in 4π solid angle.

May need high voltage due to beam space charge

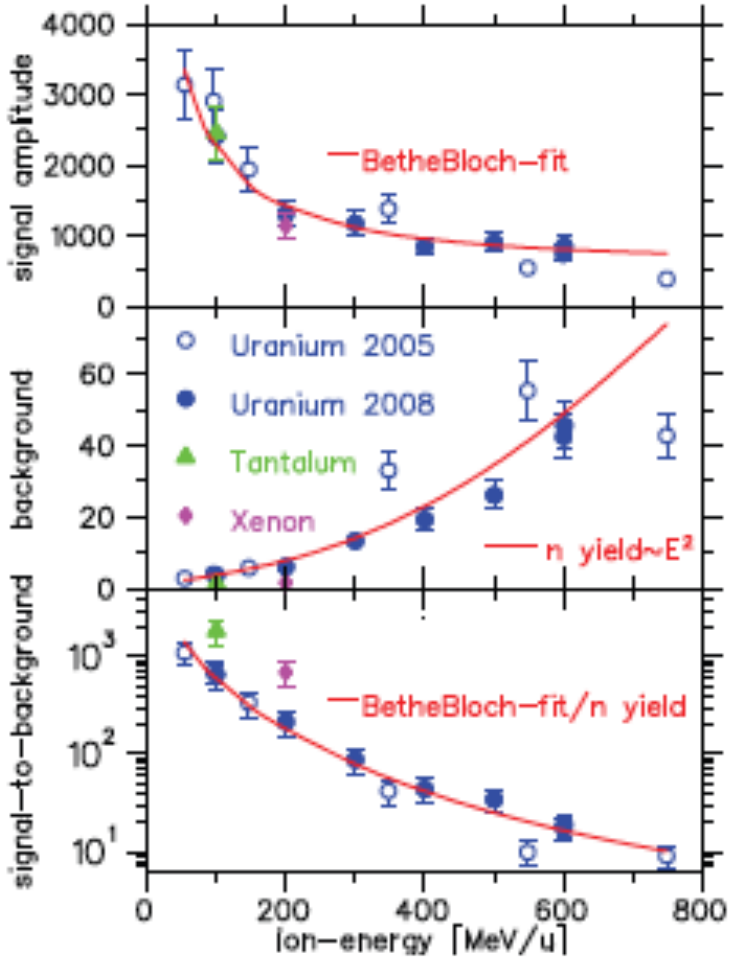
Ionization signal can be collected on anode strips, or converted to photons and measured with camera/multichannel PMT.

Background and shielding

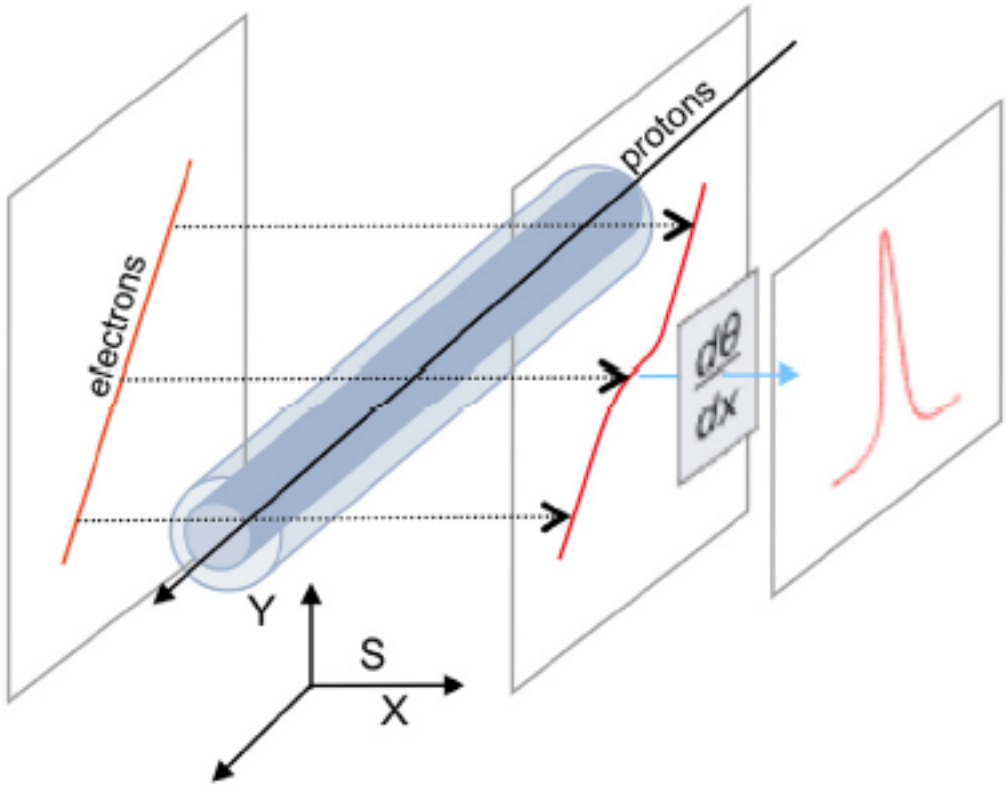
- Low signal level, may be affected by background from beam losses.
- May be alleviated by choice of photocathode and local shielding

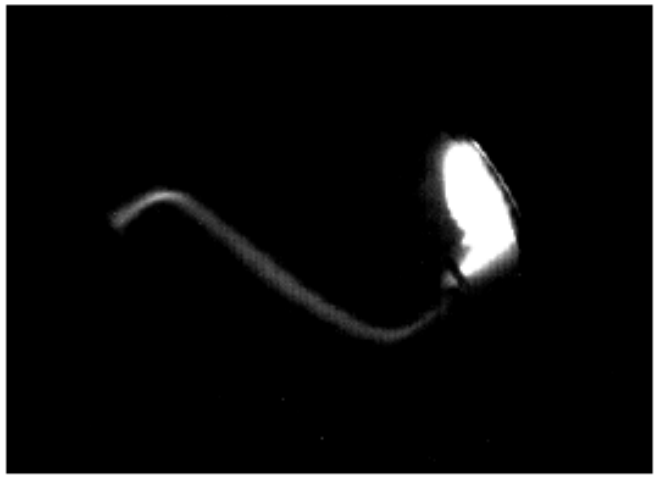


P. Forck, GSI



E-beam Scanner

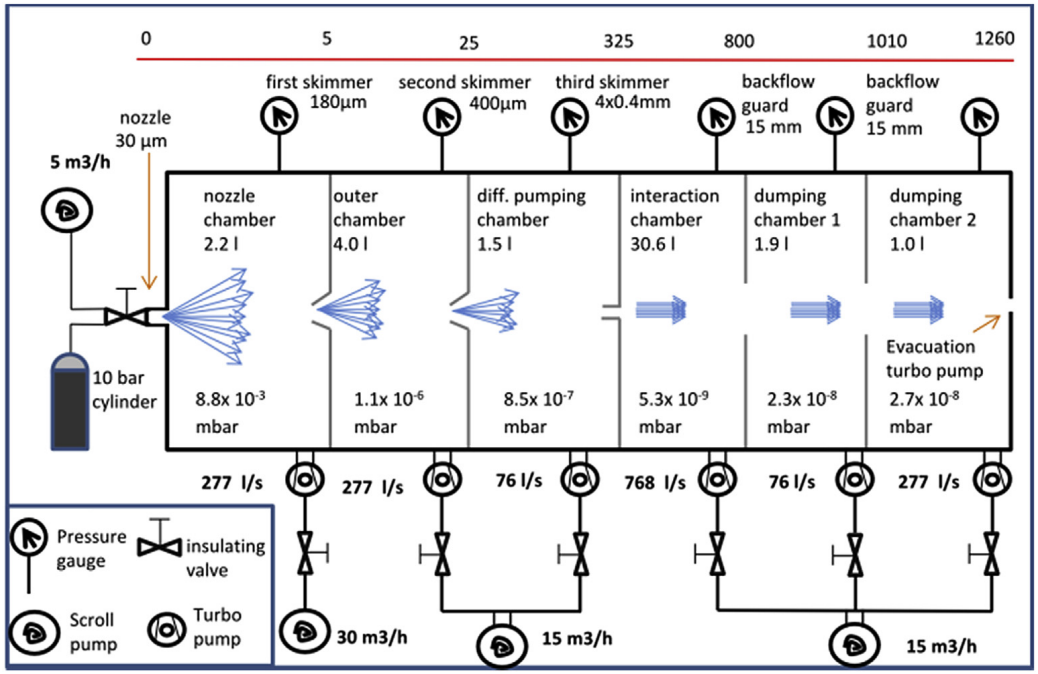


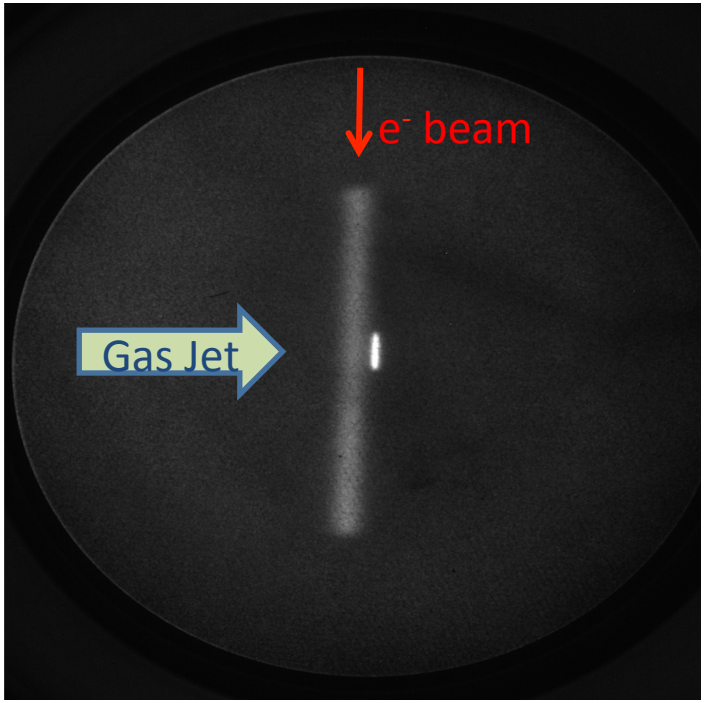


W. Blokland, DIPAC09

Can also use electron sheet
Ion probe beam has also been tested (CERN)

Gas Jet

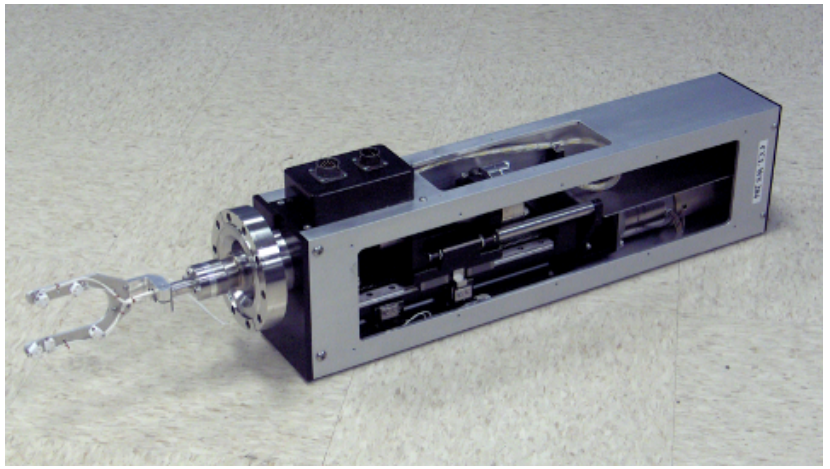




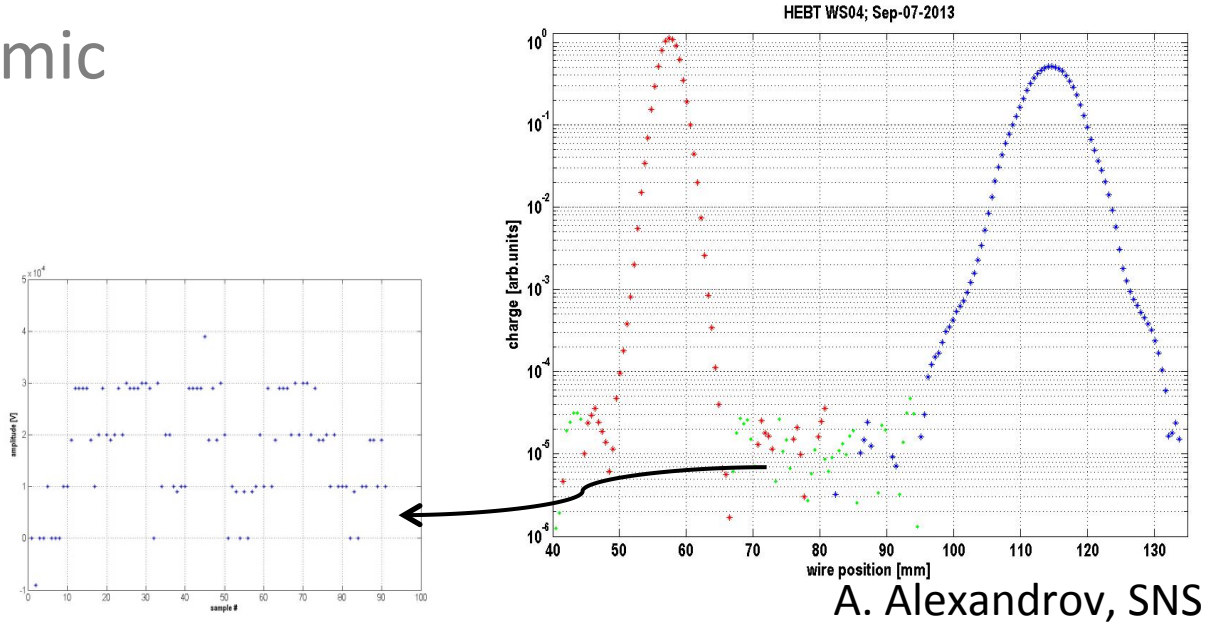
A Jeff. IPAC14

Wire scanner and Halo

- Slow wire scanners can generally be used for short pulses only.
  - ~50us at ESS
- Both SNS and PSI achieve ~1e5 dynamic range with wire scanners

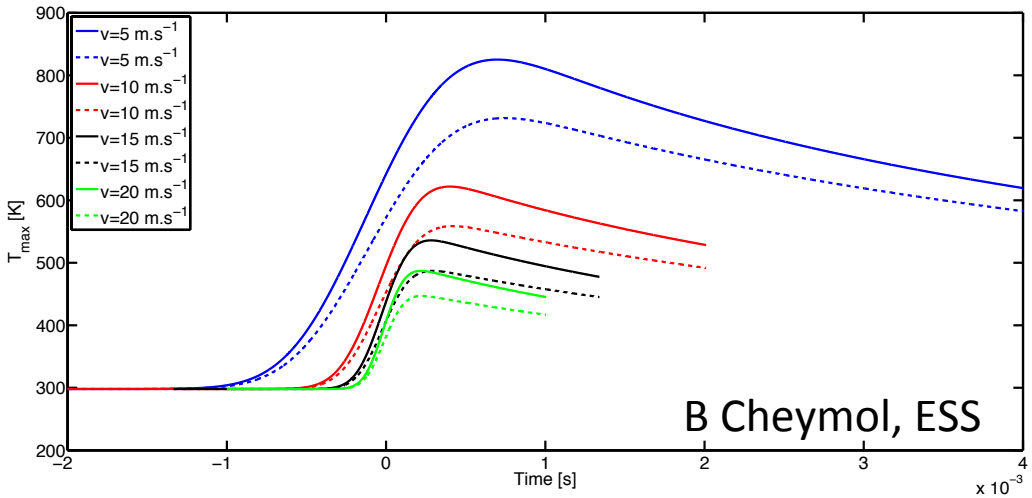


NB. Dedicated talk on Halo

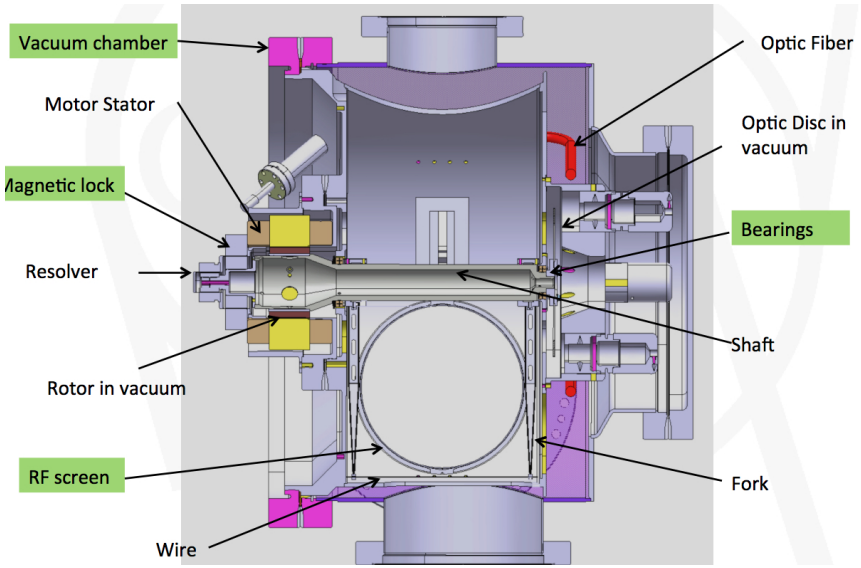


A. Alexandrov, SNS

Fast (flying) wire scanner



Evolution of wire peak temperature during a scan at 560 MeV (solid line) and 2000 MeV (dashed line) for different wire velocity. (ESS beam paramters)



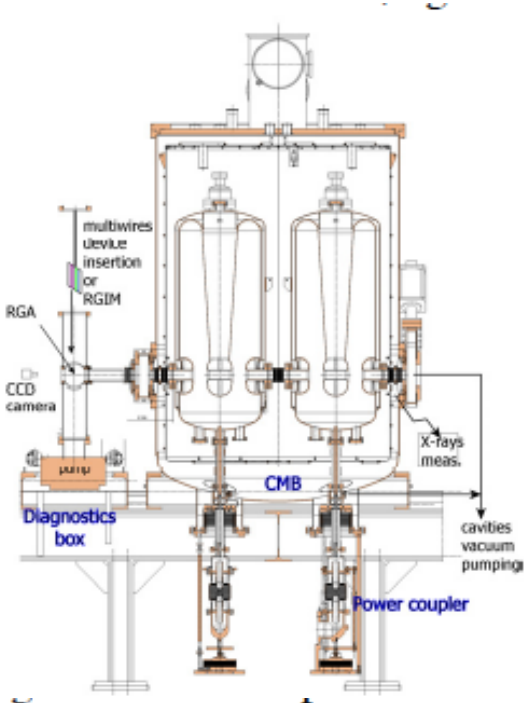
Design of the new CERN flying wire scanner (courtesy of CERN BI group)

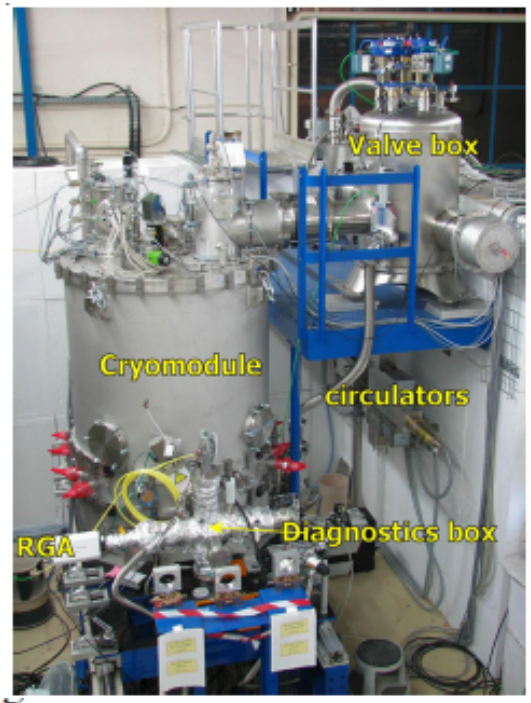
R. Veness, CERN

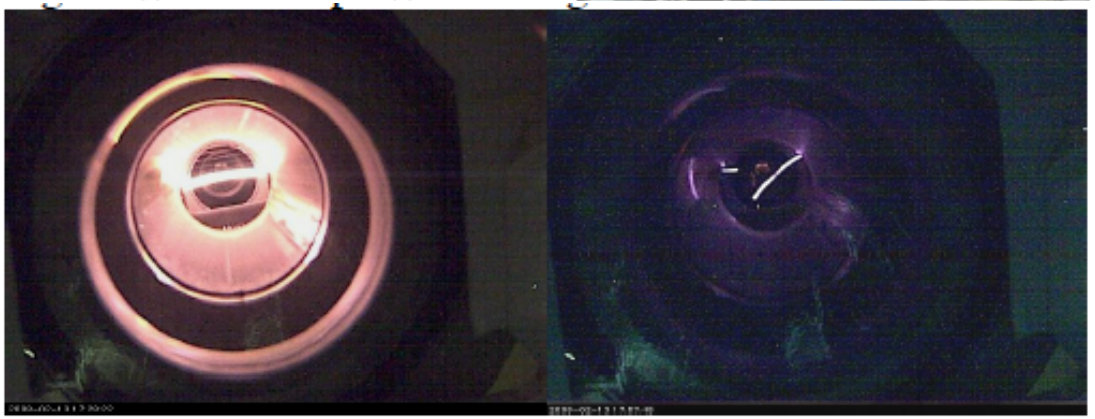
With wire speeds in the 10m/s range, could scan single pulse at full current (ESS).

Wire scanners and SC cavities

- Tests by Spiral2 project concluded that carbon wires are bad for SC cavities, Tungsten wires OK.

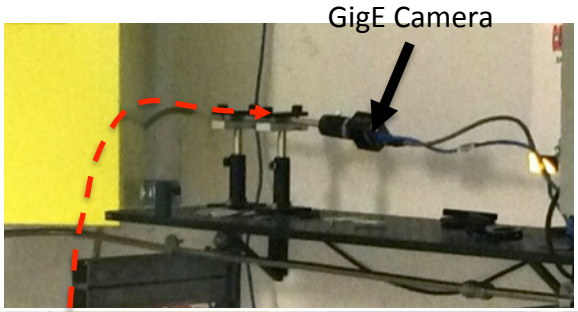




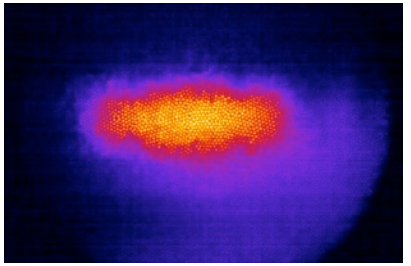


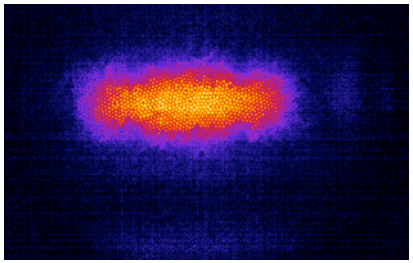
R. Ferdinand et al, LINAC08

Target imaging (SNS)

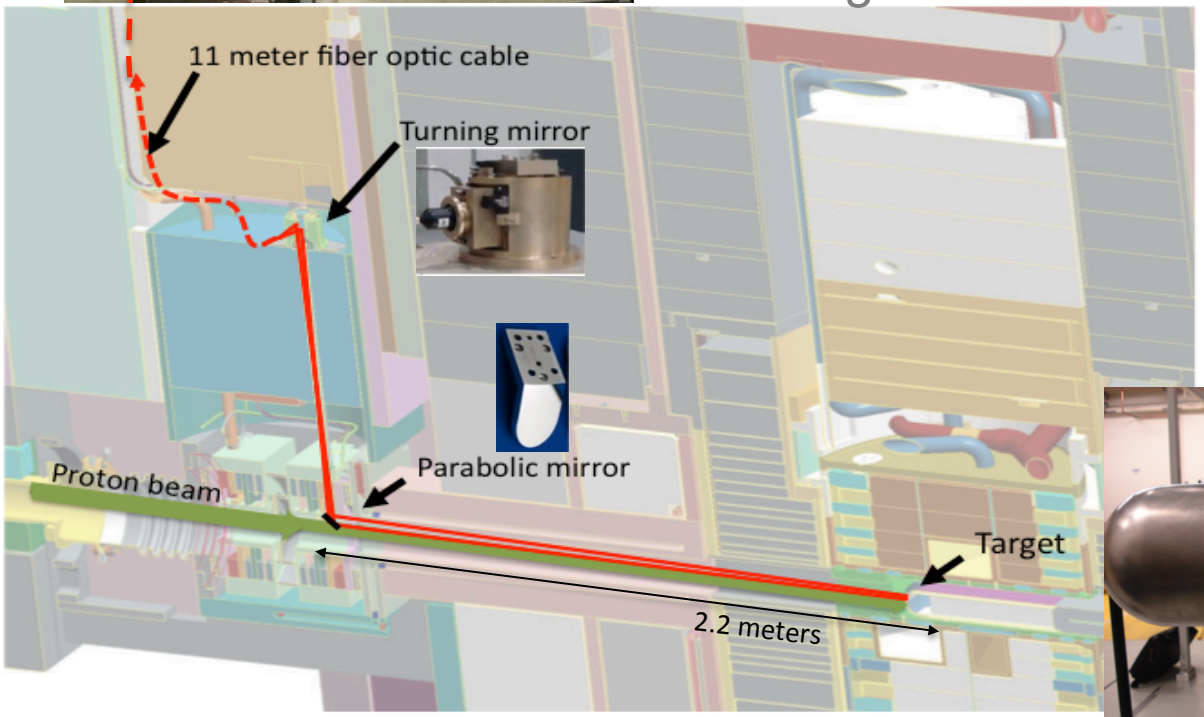


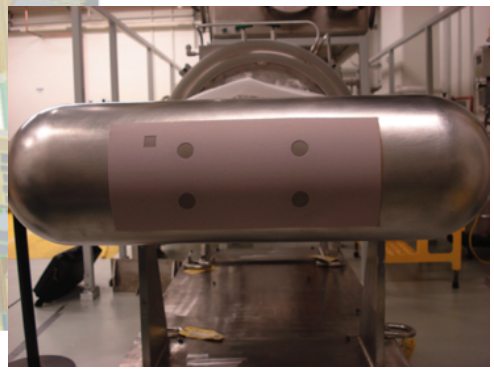
- Use fluorescent $Cr:Al_2O_3$ coating to make proton beam visible
- Also thermocouples and SEM grid





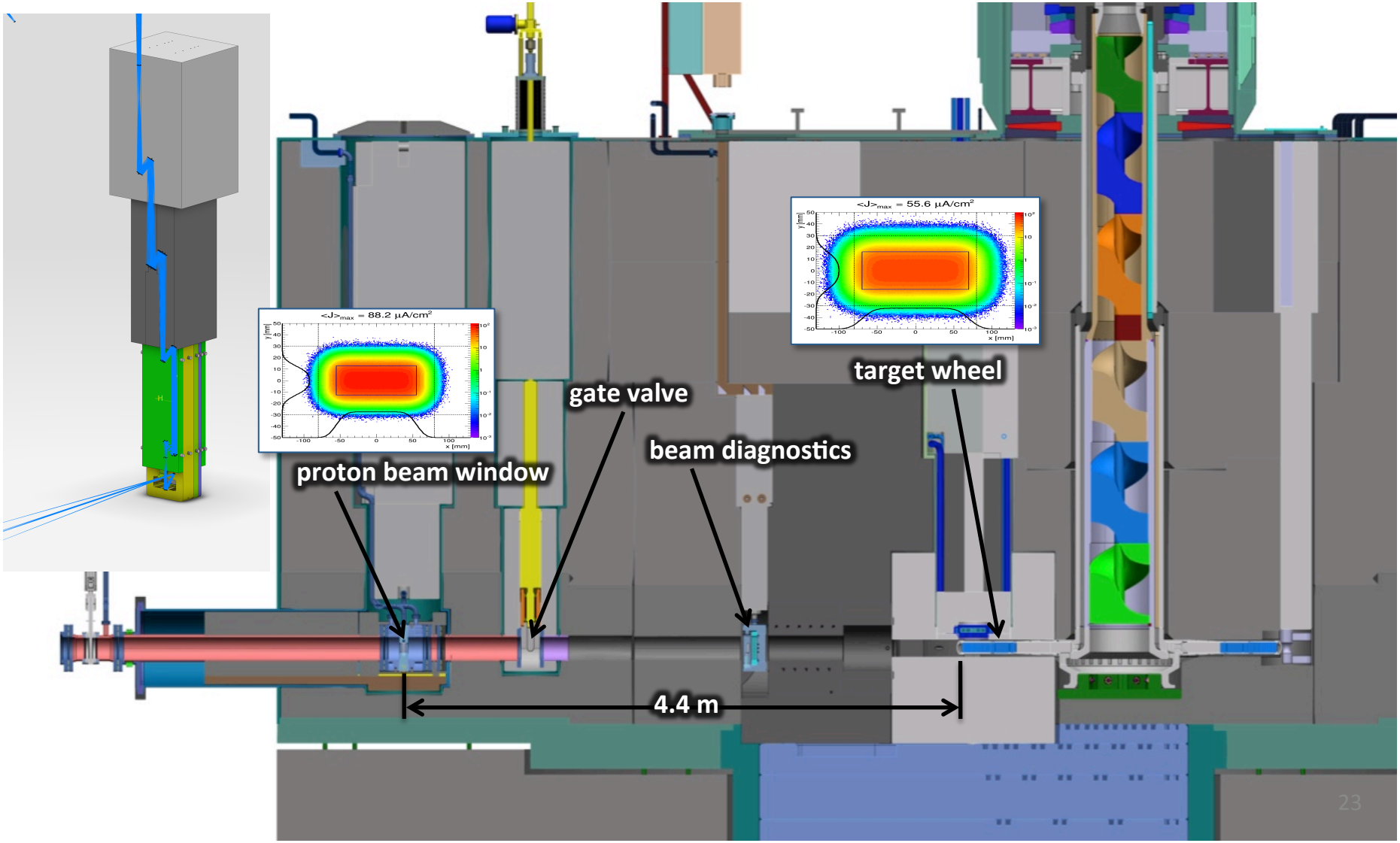
With and without gas scintillation





W. Blokland

ESS target imaging plans



Errant beam/Data-on-demand

- Experience from e.g. SNS shows that one can learn a lot by studying near misses, ie abnormal pulses that did not trigger machine protection.
- Fast data useful from “errant” pulses, but impractical to save for all pulses
- In SNS, solved with dedicated “errant beam” system.
- At ESS, implementing generic controls functionality to buffer fast data and save to logger on demand (post- trigger)

Summary

- Multi-MW hadron machines need fast loss detection (for damage protection) with high dynamic range (tp avoid activation).
- Non-invasive profile (transverse and longitudinal) measurement needed, and is more difficult with protons than H- (and partially stripped ions).
- Halo measurement important, but difficult to predict.
- Diagnostics with machine protection function need to protect even if timing fails.

Achnowledgement

Thanks to all those who supplied material