ESS Beam Diagnostics Overview

Andreas Jansson, ESS/BI Group

IBIC12, Tsukuba, Japan

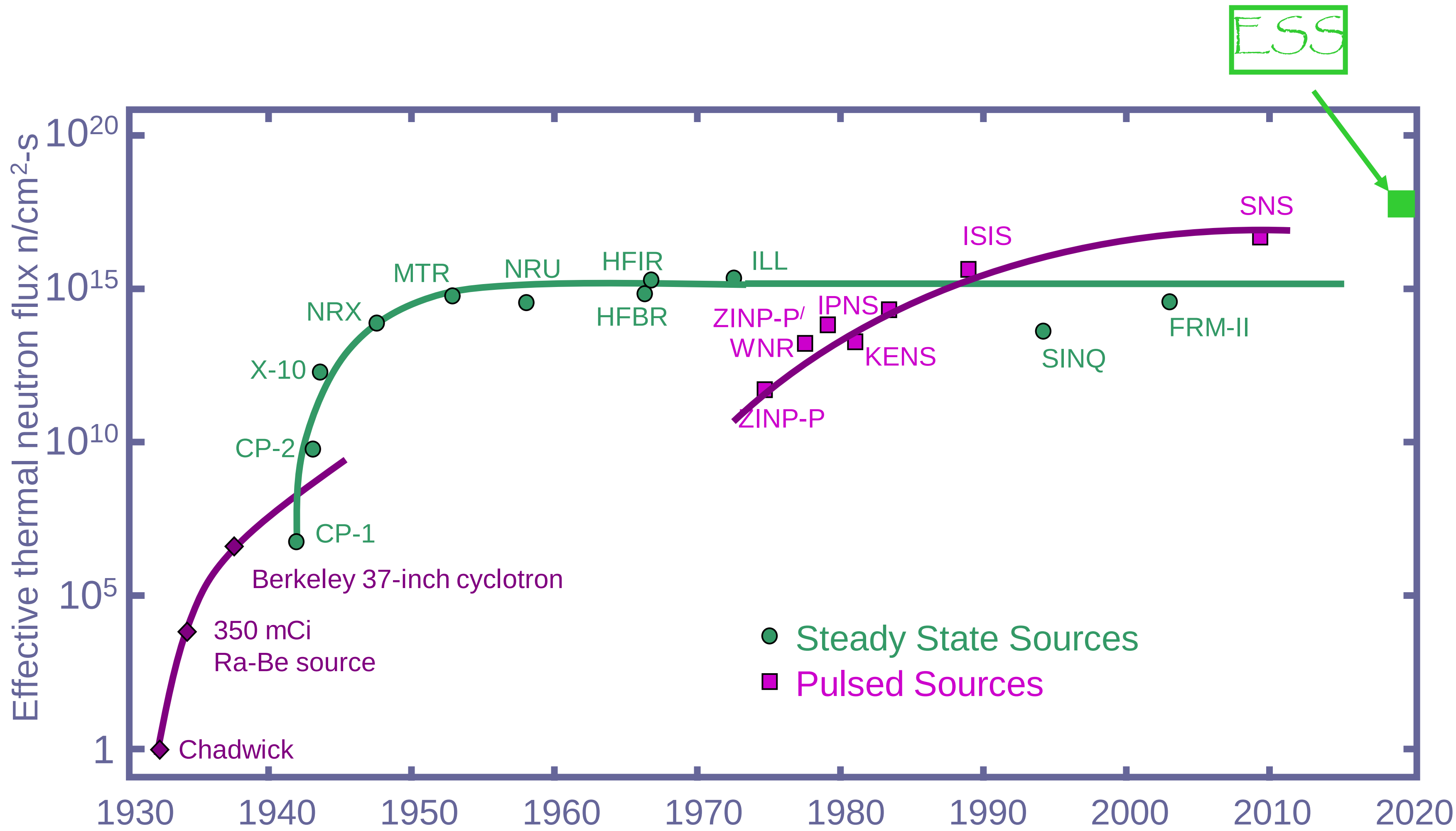
2012-10-3

Overview

- Overview of ESS Project
- Baseline diagnostics layout
- “Bread-and-butter” diagnostics systems
- Some particular challenges

ESS - the neutron source for tomorrow

Evolution of the performance of neutron sources



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

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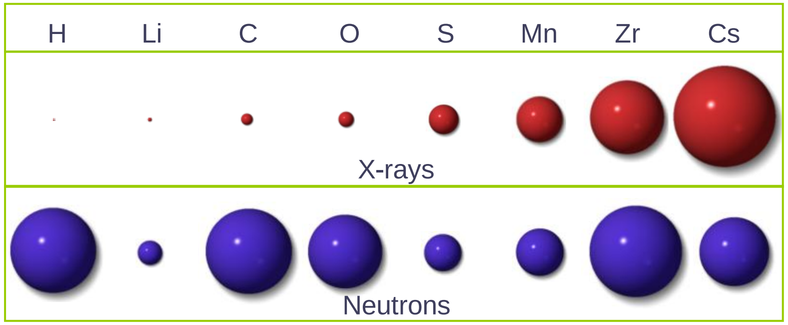
Why Neutrons?

- Thermal neutrons have a wavelength (2 Å) similar to inter-atomic distances, and an energy (20 meV) similar to elementary excitations in solids.
- Simultaneous information on the structure and dynamics of materials.

- Cross section varies between elements and even between different isotopes of the same element.
- In particular, hydrogen has a large neutron cross section, different from deuterium.

- Neutrons probe the bulk of the sample, and not only its surface.



- Since neutrons penetrate matter easily, neutron scattering can be performed with samples stored in all sorts of sample environment: Cryostats, magnets, furnaces, pressure cells, etc.

- The neutron magnetic moment makes neutrons scatter from magnetic structures or magnetic field gradients.

From K. Lefmann

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Intensity opens new possibilities

Complexity/
Count-rate

ESS intensity allows studies of

- complex materials
- weak signals
- important details
- time dependent phenomena

Details/Resolution

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International Collaboration

Sweden, Denmark and Norway cover 50% of construction cost

Remaining 50% from European partners

Letters of intent from 17 European states

Multilateral MoU for pre-construction signed in Paris 11 Feb 2012

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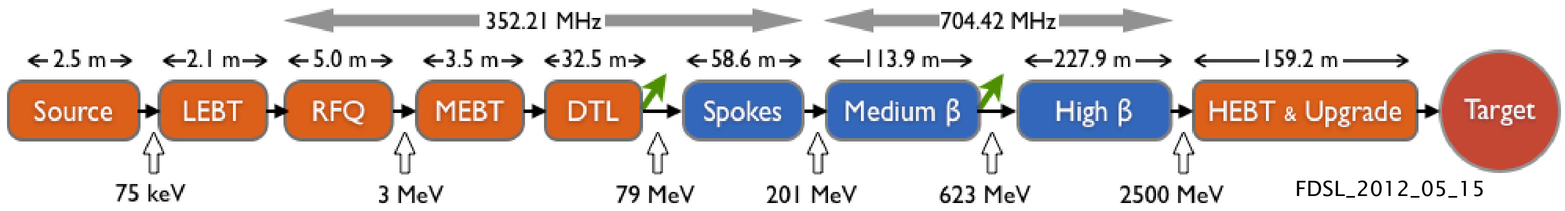
Where is ESS?

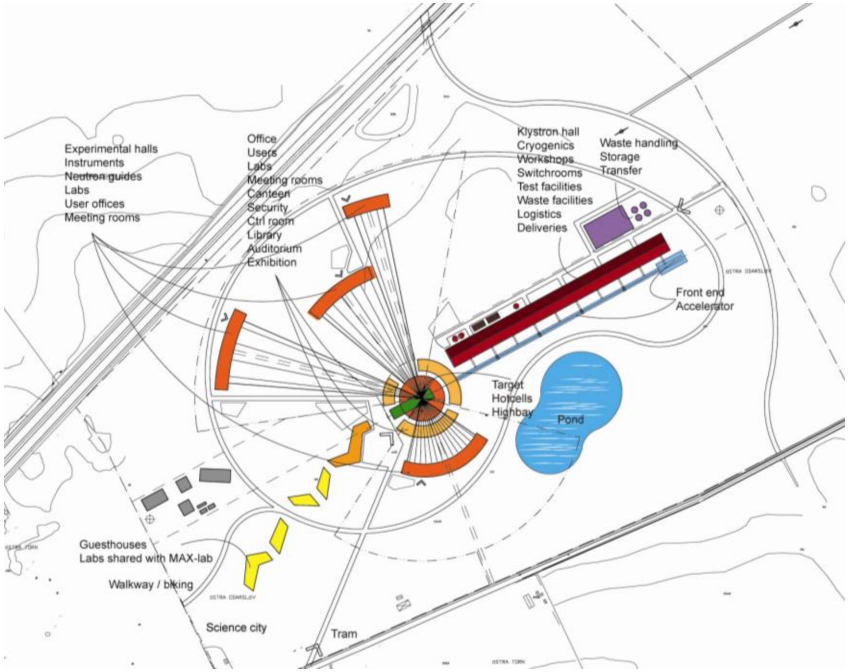
Where is ESS?


The ESS Scandinavia site
The Öresund
Lund
Copenhagen
Airport
Skåne
Malmö
The Öresund Bridge

ESS Linac Parameters

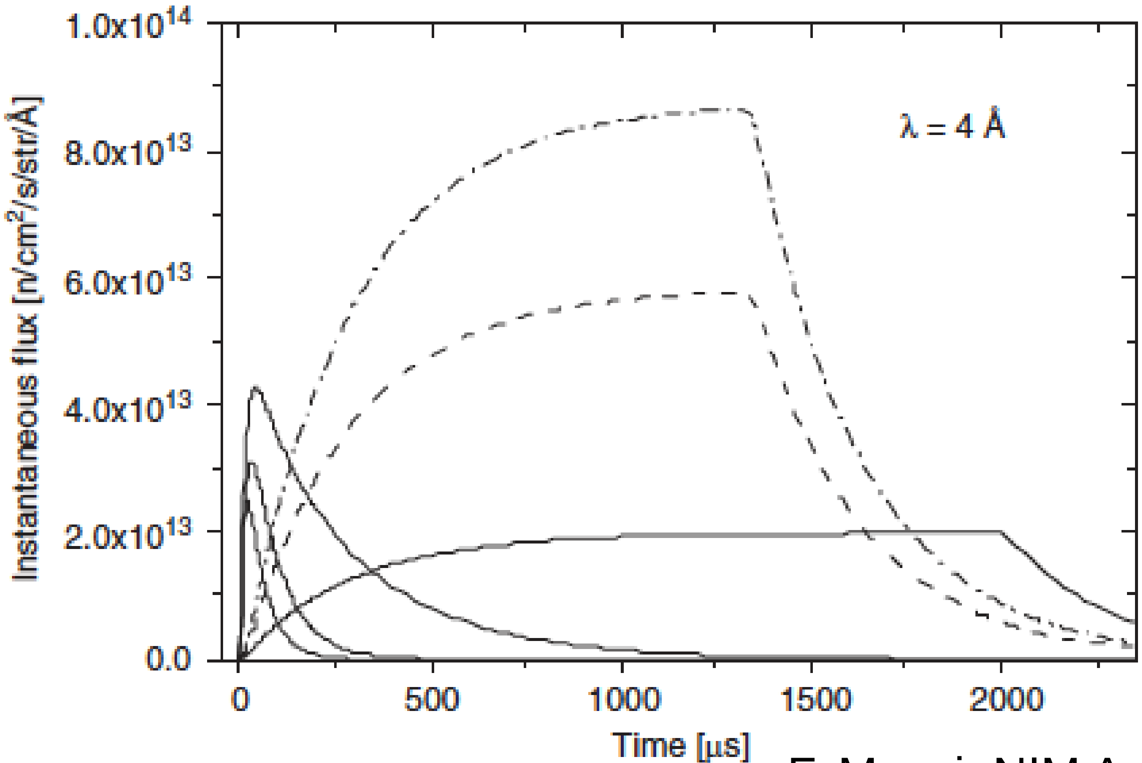


Particle species	p
Energy	2.5 GeV
Current	50 mA
Average power	5 MW
Peak power	125 MW
Pulse length	2.86 ms
Rep rate	14 Hz
Max cavity surface field	40 MV/m
Operating time	5200 h/year
Reliability (all facility)	95%



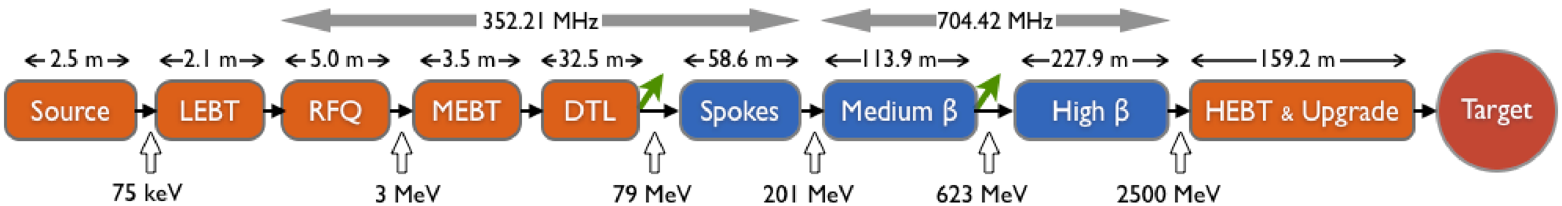
Cold neutrons – Long Pulse

- Up to 90% of neutron experiments use cold neutrons
- Pulsed cold neutrons always come as long pulses as a result of the moderation process
- No compressor ring required, major difference from earlier ESS proposal



F. Mezei, NIM A, 2006

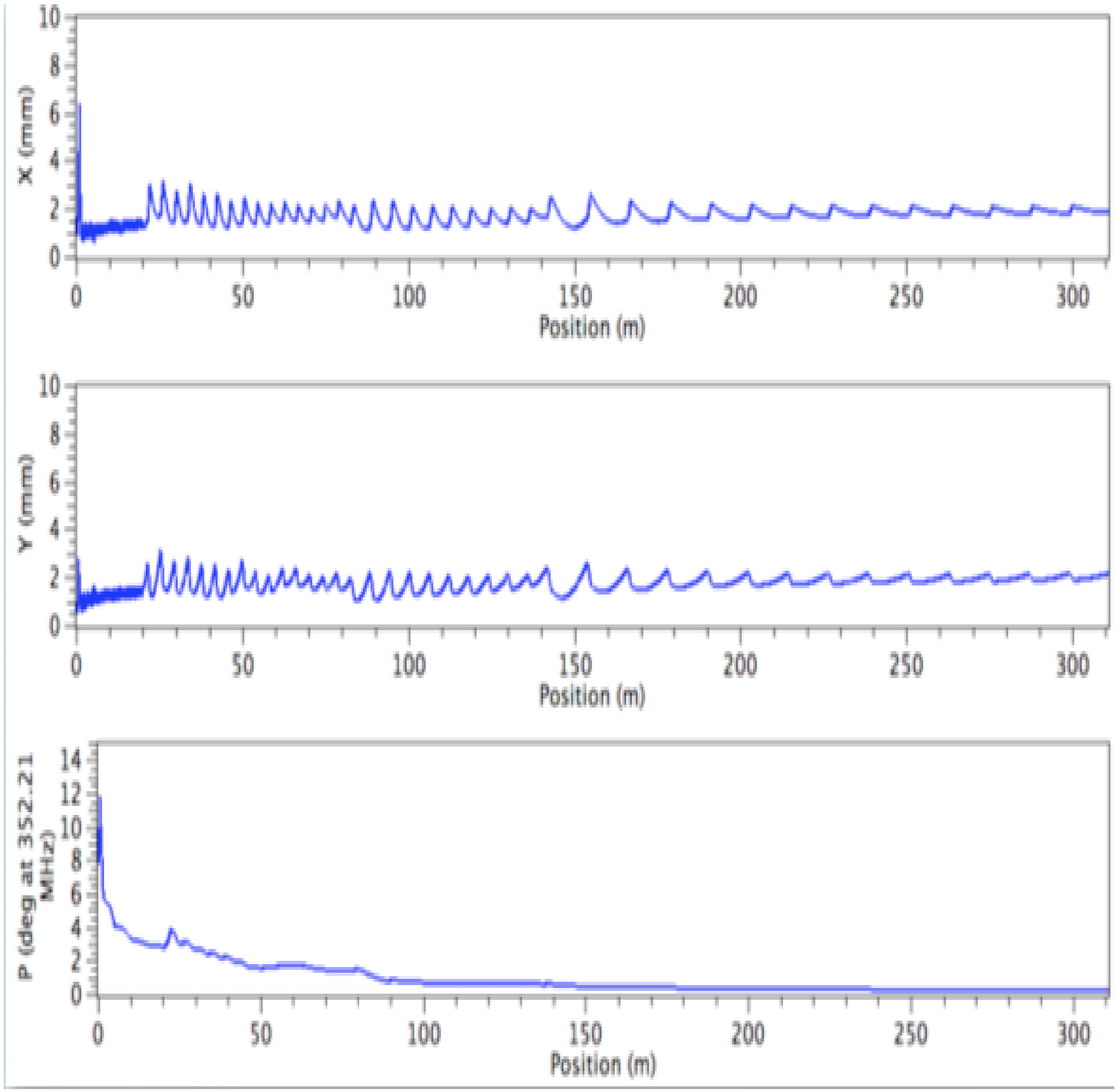
Linac Layout



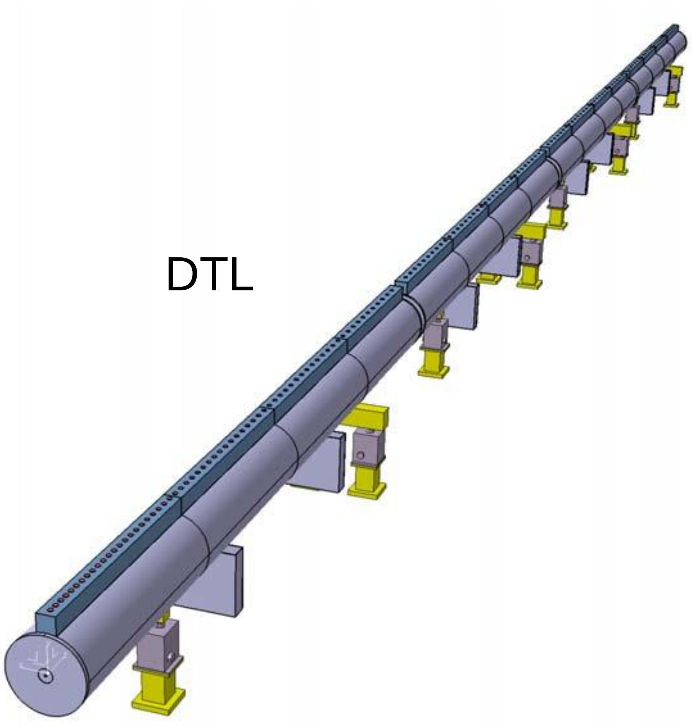
	Lab	E_{out} (MeV)	$Beta_{out}$	Length (m)	Temp (K)	Freq (MHz)
Ion source + LEBT	Catania	0.075	0.01	4.6	300	–
RFQ	Saclay	3	0.08	5.0	300	352.21
MEBT	Bilbao	3	0.08	3.5	300	352.21
DTL	Legnaro	79	0.39	32.5	300	352.21
Spoke cavities	Orsay	201	0.57	58.6	2	352.21
Medium-beta ellipticals	Saclay	623	0.80	113.9	2	704.42
High-beta ellipticals	Saclay	2500	0.96	227.9	2	704.42
HEBT	Aarhus	2500	0.96	159.2	300	–

	Spoke resonators	Medium-beta ellipticals	High-beta ellipticals
Cells per cavity	3	5	5
Cavities per cryomodule	2	4	4
Number of cryomodules	14	15	30

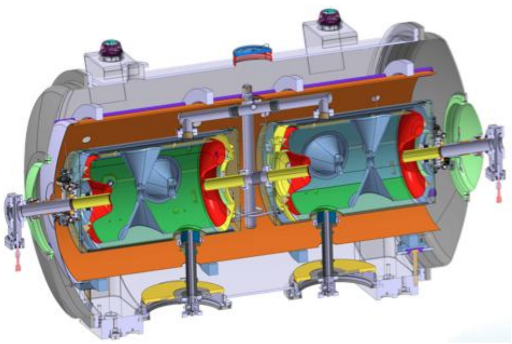
ESS Linac Optics



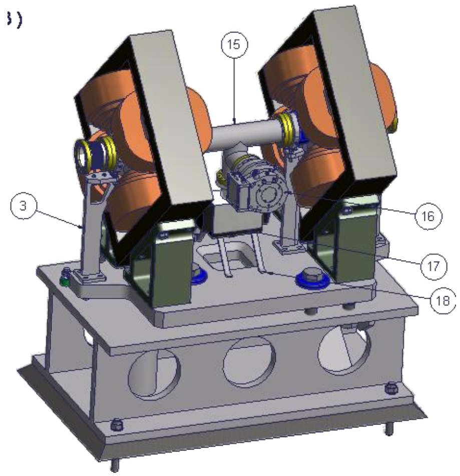
Linac Component Designs



DTL



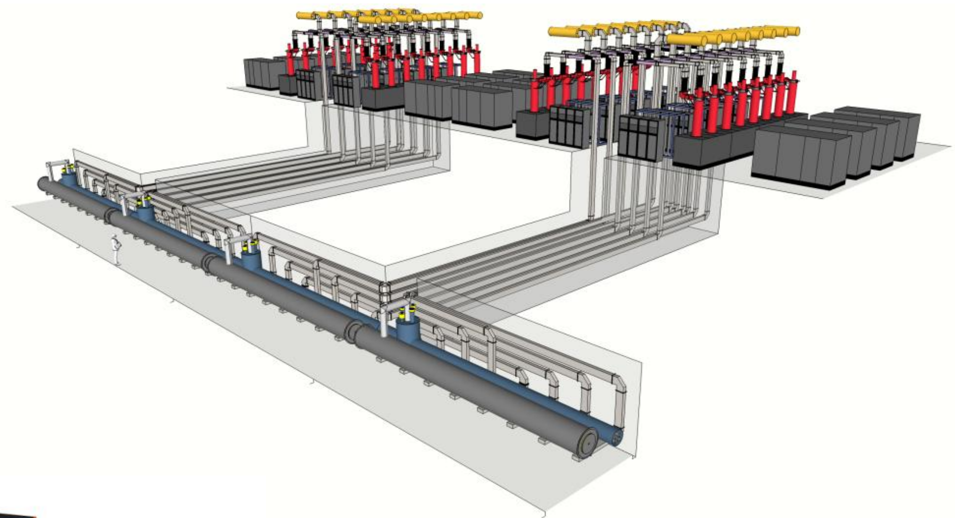
Spoke Cryomodule

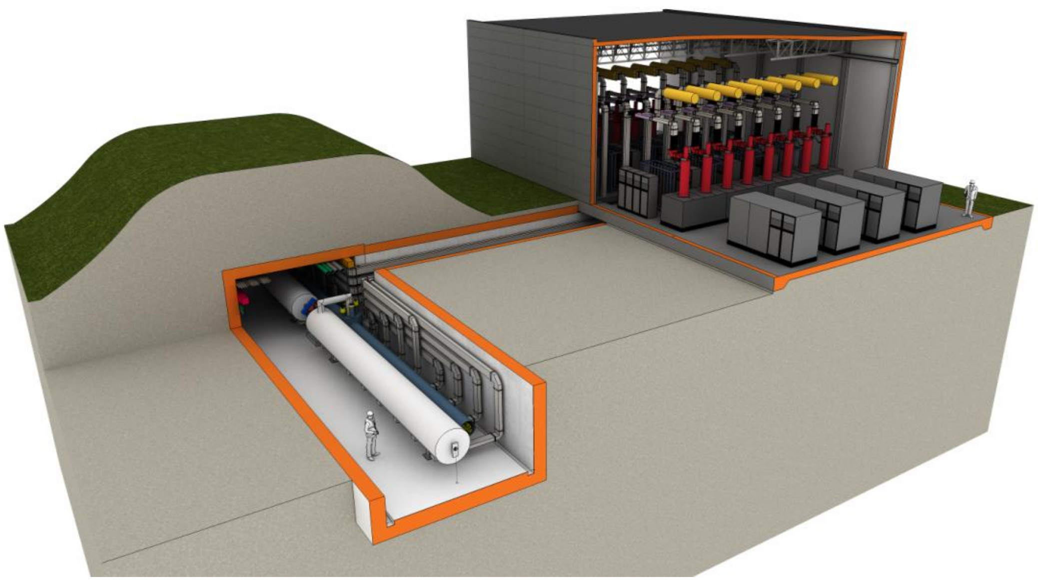


Warm Quad Doublet Unit

Elliptical Cavity Cryomodule

Tunnel & RF Gallery Layout

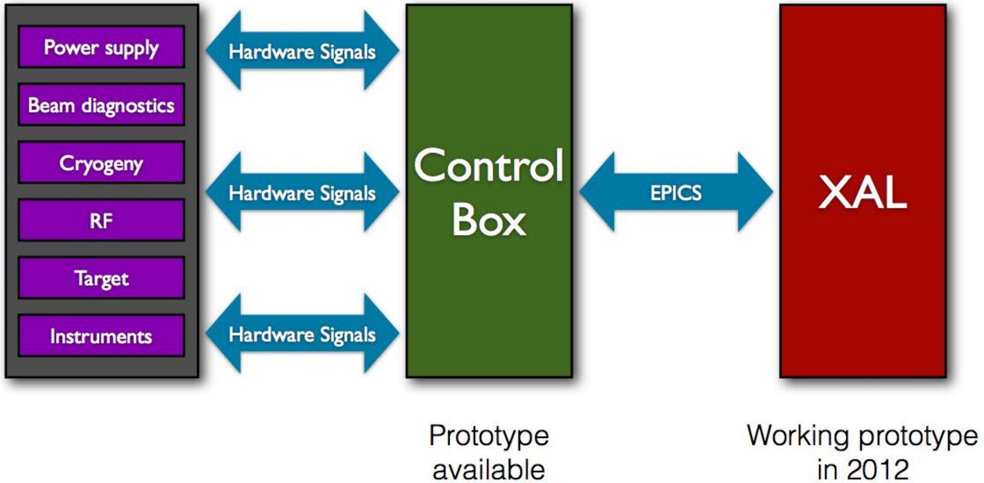




	Frequency (MHz)	No. of couplers	Max power (kW)
RFQ	352.21	1	900
DTL	352.21	4	2150
Spokes	352.21	28	280
Medium betas	704.42	60	560
High betas	704.42	129	850

Integrated Control System

Decision to have a single integrated control system for ESS:
- EPICS-based
- ITER control-box concept



Two hardware ***prototyping*** platforms selected:
- cPCIe
- uTCA.4

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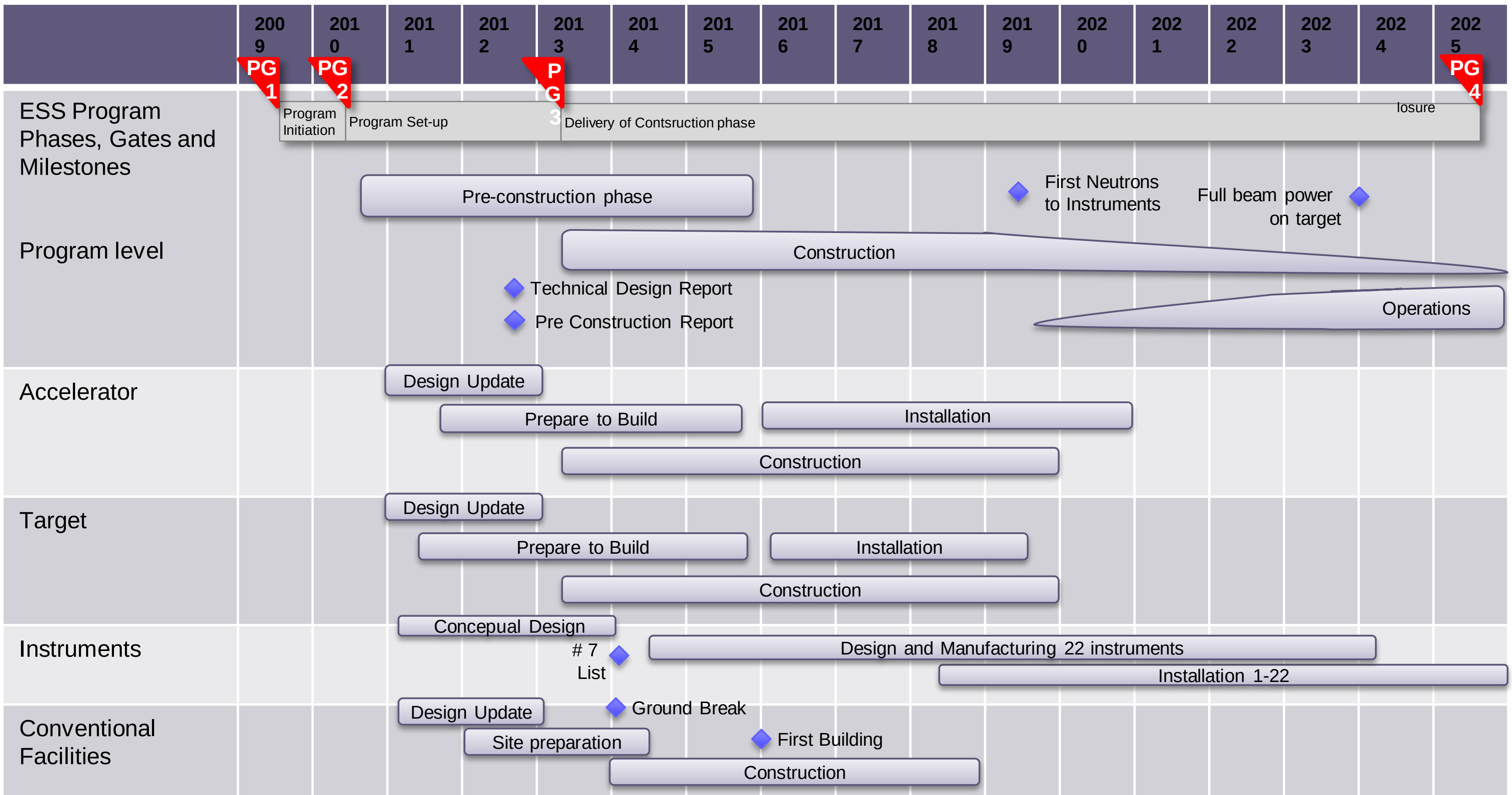
ESS Master Schedule



The ESS Site Today

The ESS Site Today

Photo: Roger Eriksson

The ESS Site Today

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The ESS Site Today

New CEO, announced today

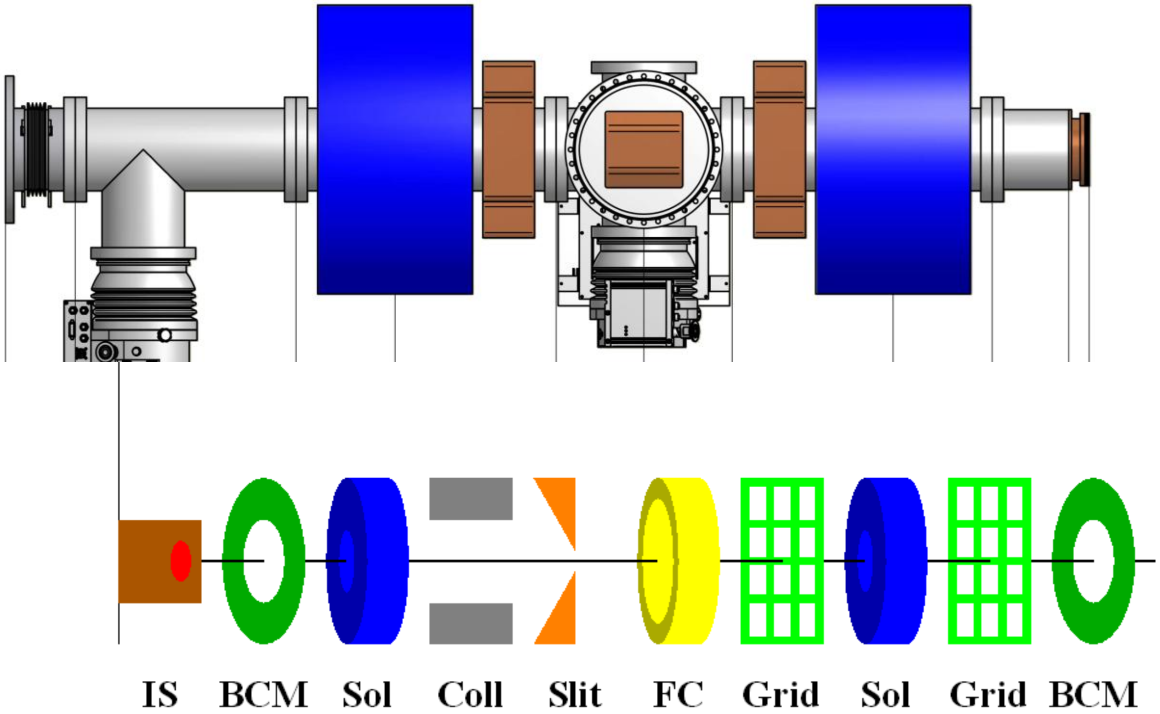
James Yeck

Starting at ESS January 1, taking over as CEO March 1

Most recently:
Assistant Project Director for Conventional Construction at NSLS-II
and Director of IceCube,
previously Project Director for US-LHC, and
DOE Project Manager for RHIC construction project

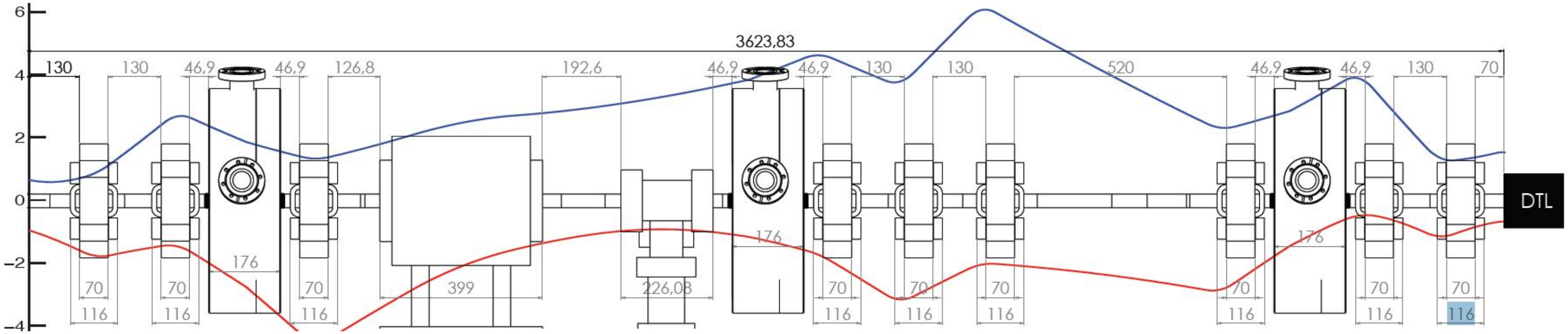
… and now, to the diagnostics part…

LEBT



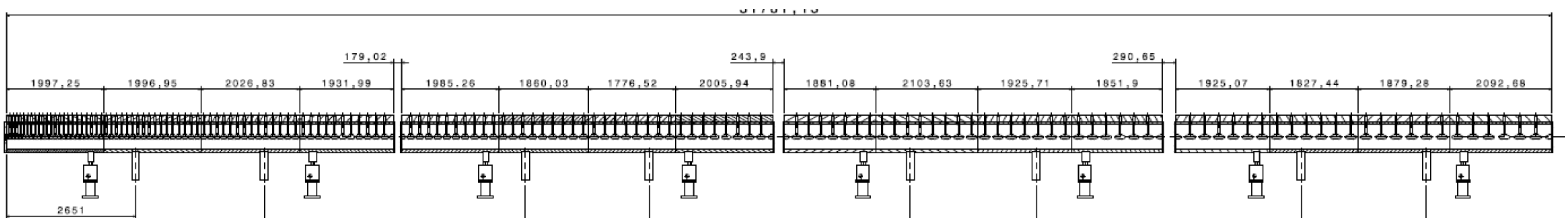
2 BCMs
1 Slit + 2 H/V Grids
1 Faraday Cup
Viewports (for profile)

MEBT



6 BPMs
4 BCMs (2 fast, 2 slow)
1 Slit + 1 H/V Grid
1 Faraday Cup
4 Wire Scanners
2 Non-invasive profile devices (viewports w camera)
2 Halo Monitors

DTL



12 BLMs (4 ICs, 4 Fast BLMs, 4 Neutron Detectors)
8 BPMs
6 BCMs (5 slow, 1 fast)
4 Faraday Cups
4 Wire Scanners
4 Non-invasive profile devices (viewports w camera)
1 BSM
1 Halo Monitor

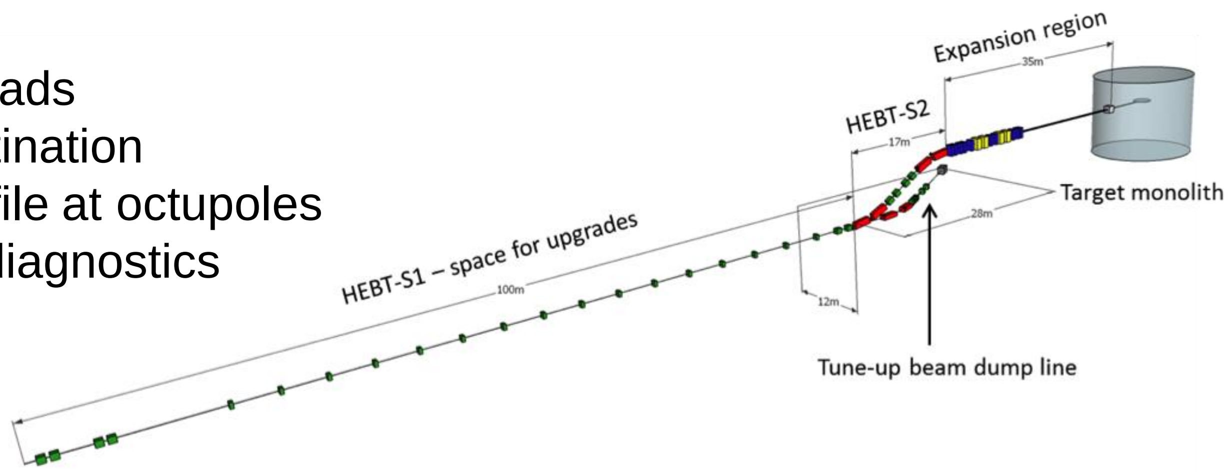
Cold Linac and upgrade space

Example:Spoke Section

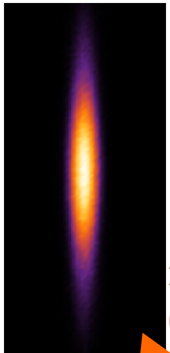
3 BLMs per cell
1 BPM per quadrupole
1 BCM per transition between main sections
4 Wire-scanners co-located with non-invasive profile monitors at each transition
4 BSMs at each transition

Target and Dump lines

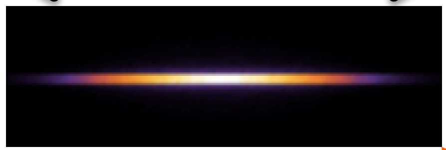
BLM and BPM at most quads
BCMs to verify beam destination
WS and non-invasive profile at octupoles
Redundant target profile diagnostics



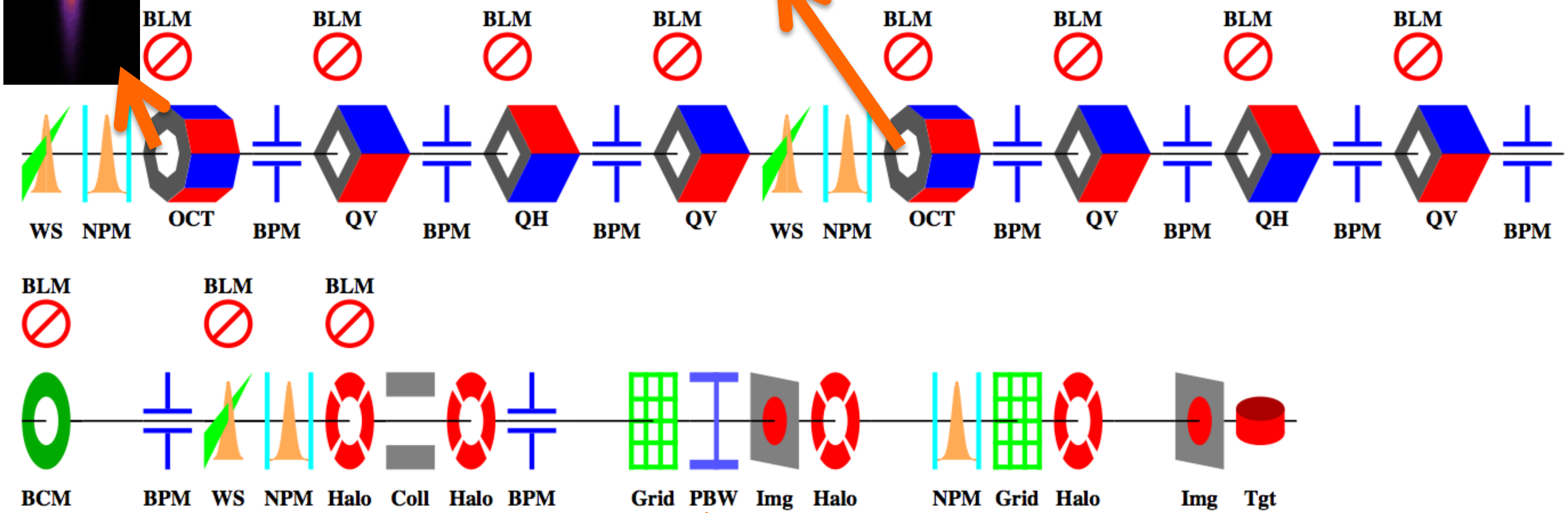
Accelerator to Target Line

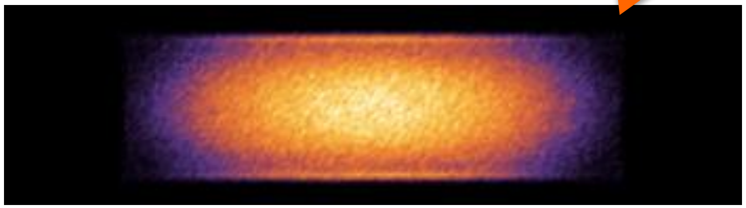


25 mm

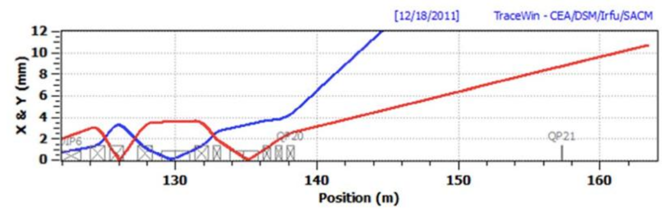


- Simulation with 500,000 particles



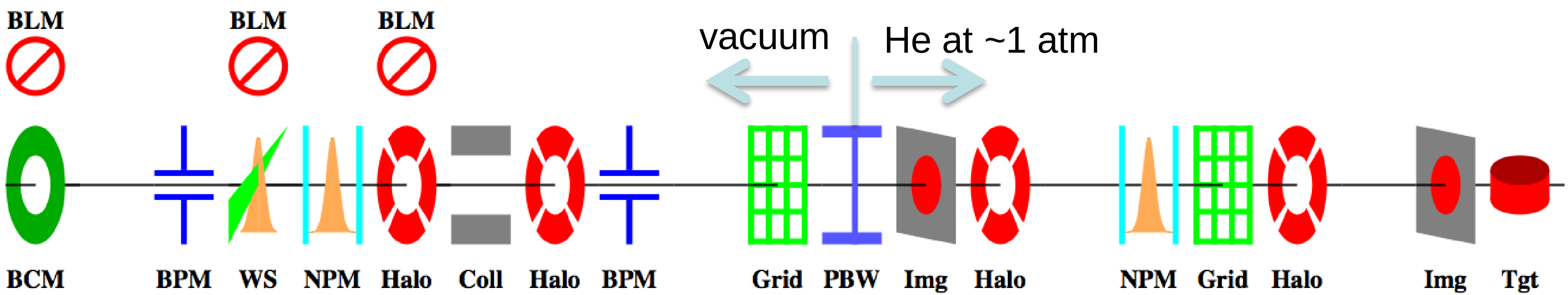


200 mm



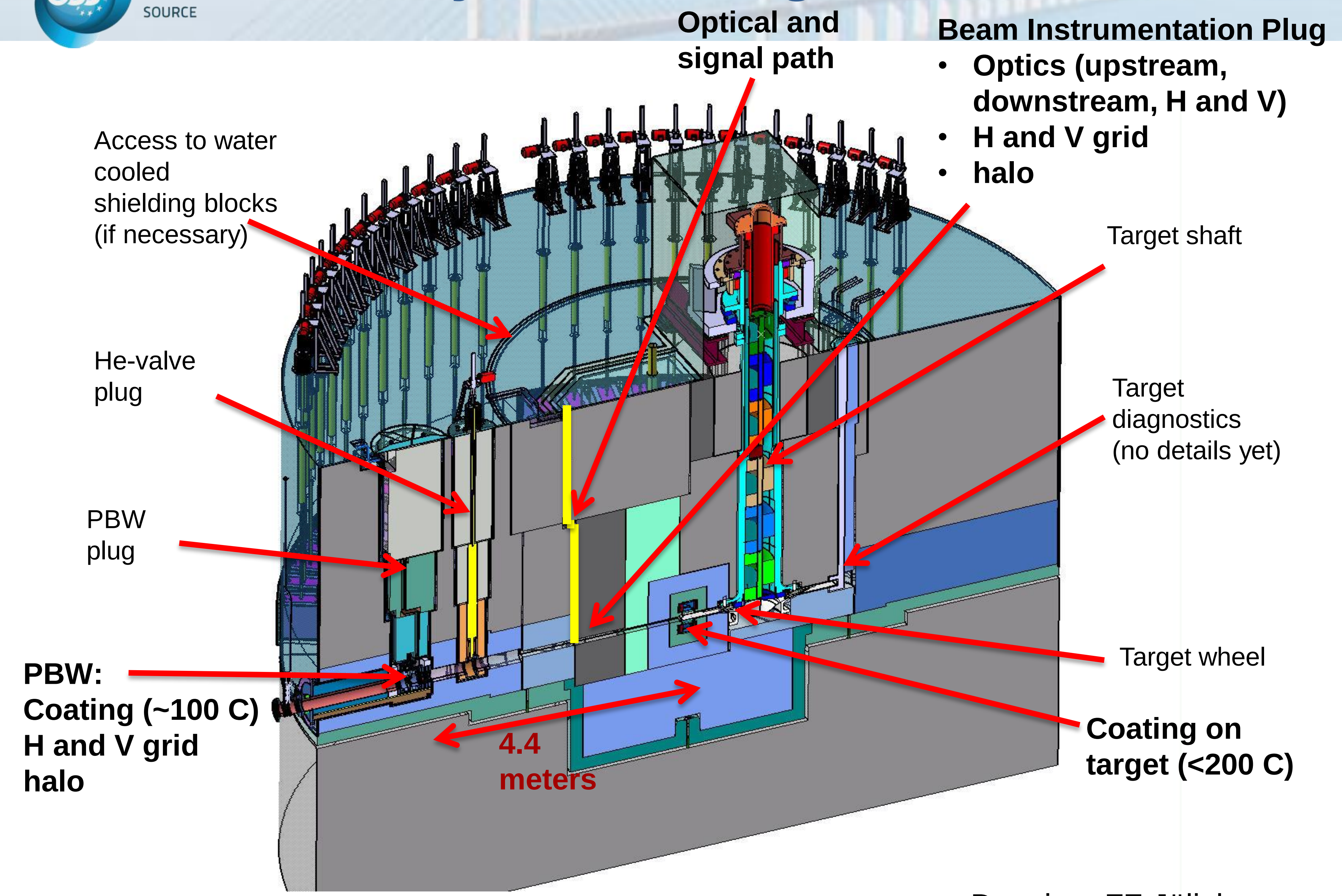
Simulation data: Aarhus

Target Diagnostics Layout



- Upstream wire scanners to measure emittance (not shown here)
- BCM above:
  - Used to normalize beam density measurements
  - Beam accounting (power on target, total energy delivered, etc)
- Redundant measurements at proton beam window and target:
  - Halo: Halo monitoring via thermocouple assemblies
  - Img: Imaging (luminescent coatings on Proton Beam Window and Target)
  - NPM: Non-Invasive Profile monitor (He gas luminescence)
  - Grid: SEM in vacuum and ionization in Helium

Layout of Target Monolith



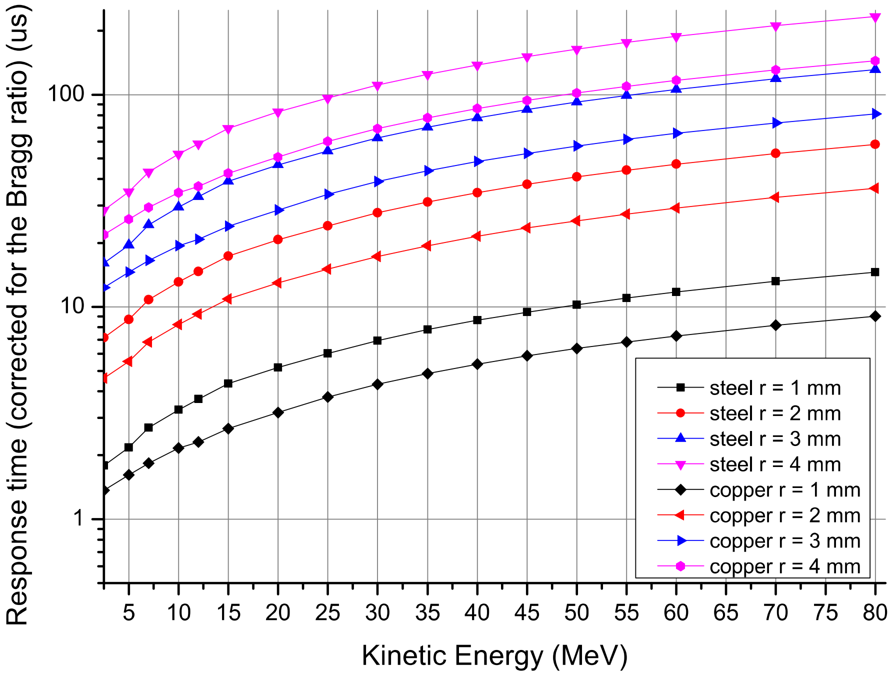
Drawing: FZ Jülich

Beam Loss

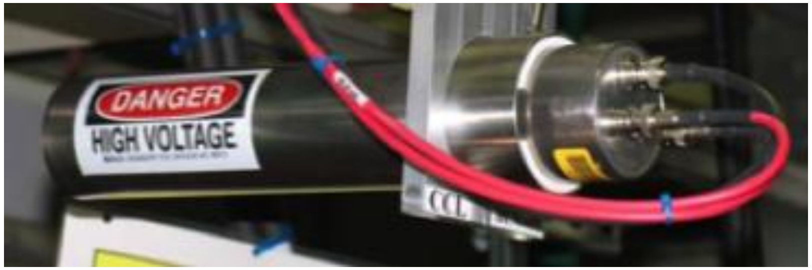
If lost in one spot, the beam can melt steel in a few microseconds

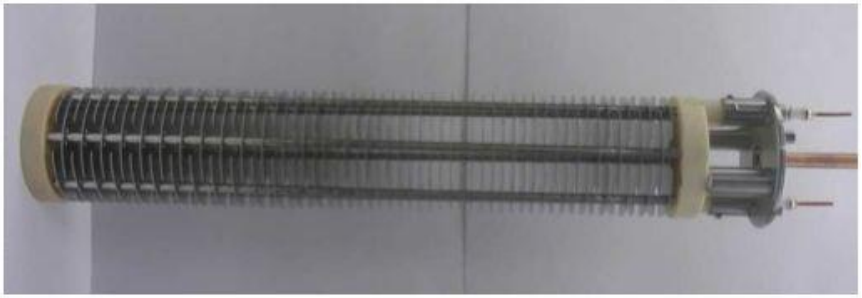
BLM system needs to detect large losses in 2us (10us in cold linac)

For small continuous losses, BLMs should have sensitivity to detect losses leading to activaton of 1% of the hand-on limit (~0.01W/m)



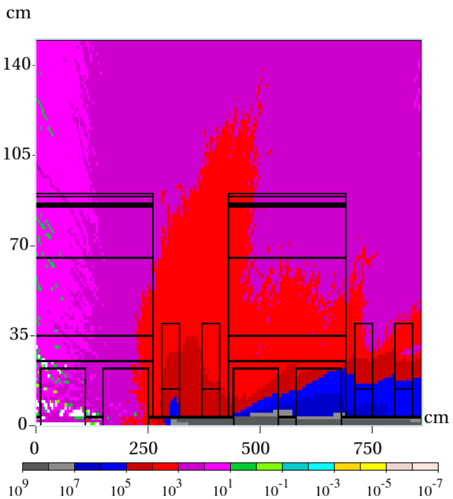
Ionization Chamber will be main detector type. (LHC or SNS type could be used)
Some fast monitors (scintillator, diamond) and neutron detectors will be used



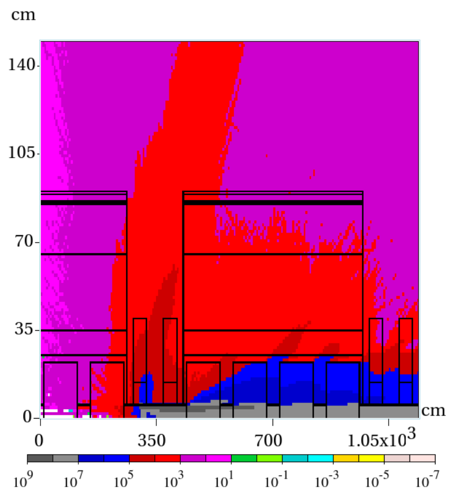


Beam Loss

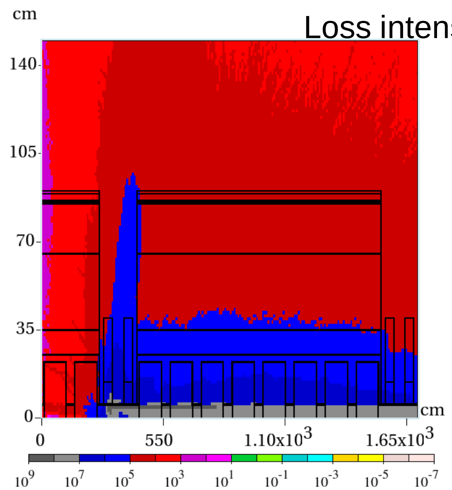
Loss location = middle of first quadrupole
Loss angle = 1.5 mrad
Loss intensity = 10^12 protons/sec



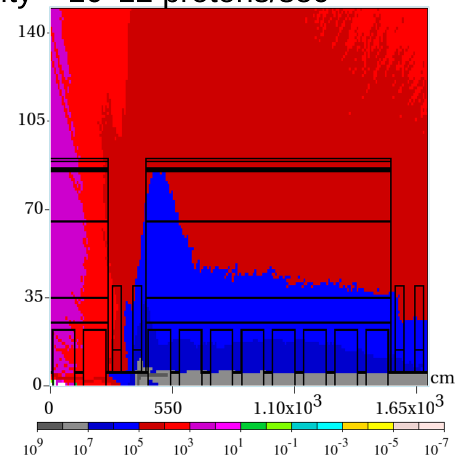
Loss in the middle of first quadrupole magnet, in xz plane, with 150 MeV energy.



Loss in the middle of first quadrupole magnet, in xz plane, with 200 MeV energy.



Loss in the middle of first quadrupole magnet, in xz plane, with 1 GeV energy.

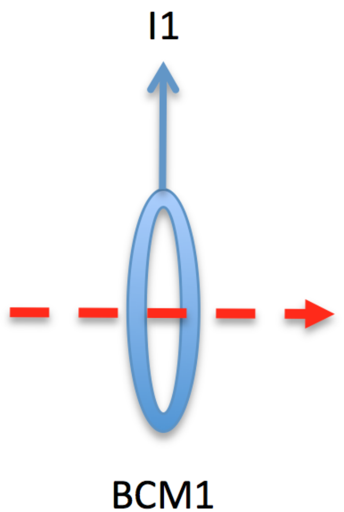


Loss in the middle of first quadrupole magnet, in yz plane, with 2 GeV energy.

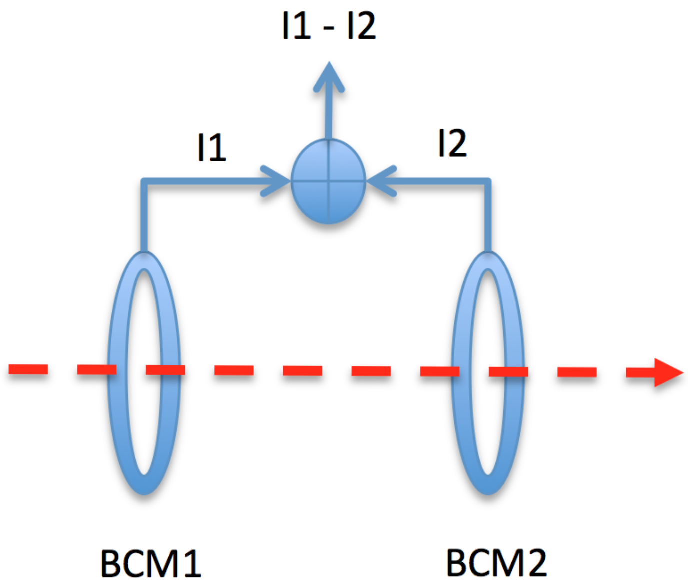
- Simulations ongoing to optimize exact detector location
- Have Marie Curie Fellow (through oPAC network) to work on this

Beam Current

Absolute measurement:



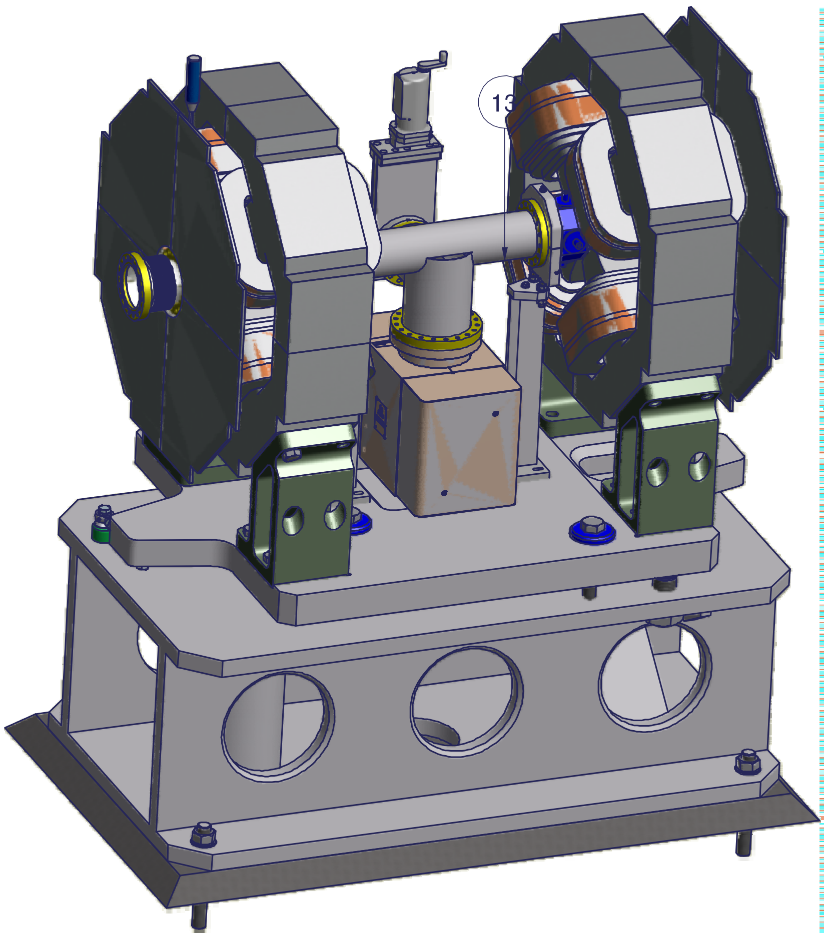
Differential measurement:



- Plan to use mainly ACCTs, with some FCTs for bunch studies
- Beam current should be measured to 1%.
- Differential BCM measurements will be used to complement BLMs for beam loss in the low energy section -> same response time requirements as BLMs

BPMs

- Need a sensitvity of <0.1mm for position and 1 degree for phase.
- Plan to use mostly buttons, similar to those in E-XFEL
- SNS-like stripline in DTL
- Prototyping electronics in uTCA.4 (one of two prototyping platforms agreed on with Controls Group).



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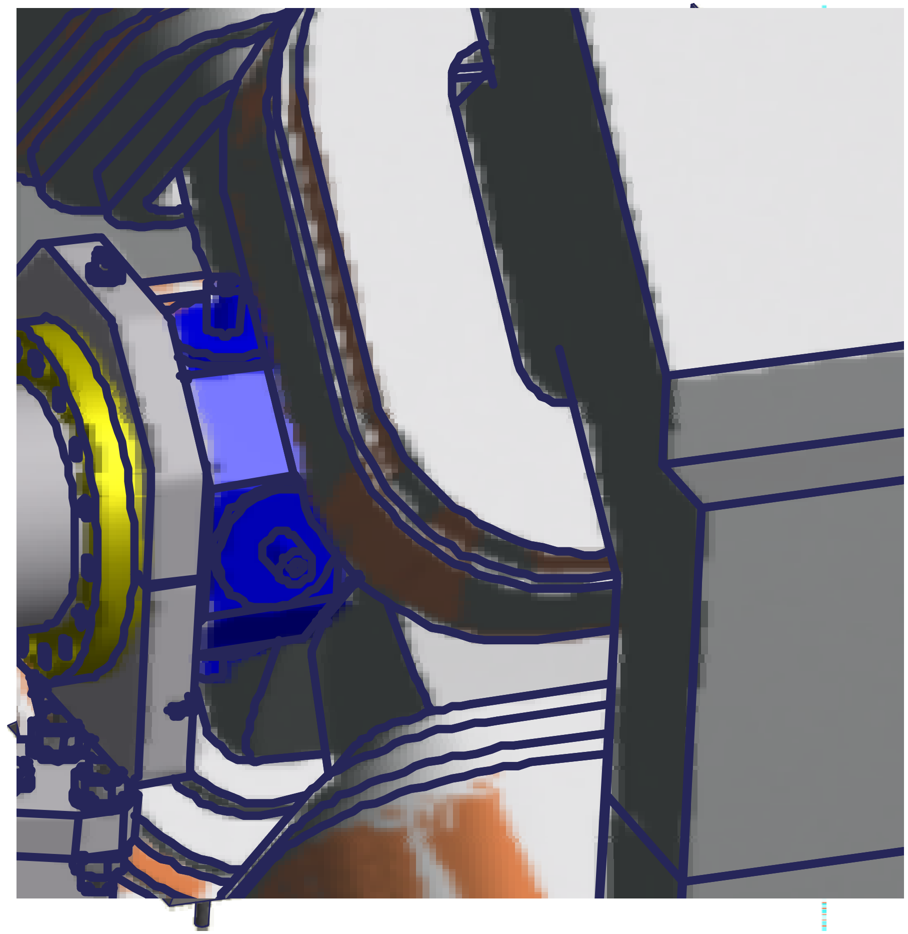
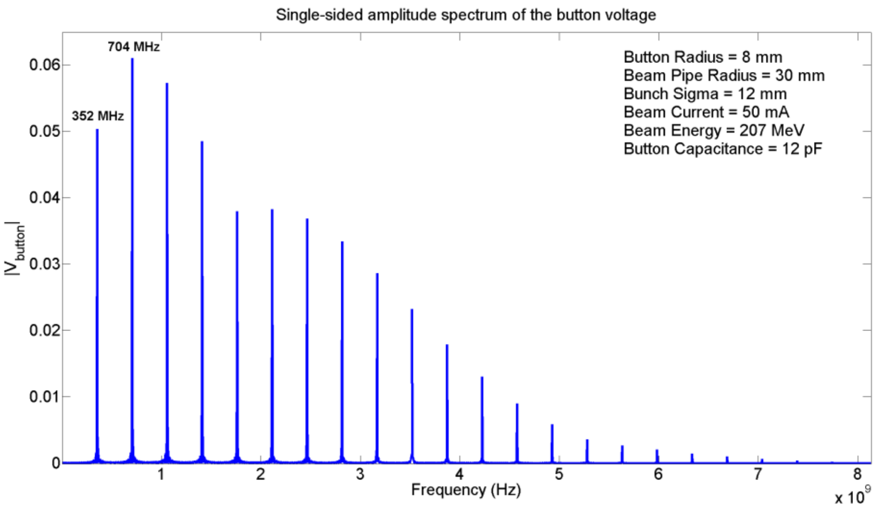
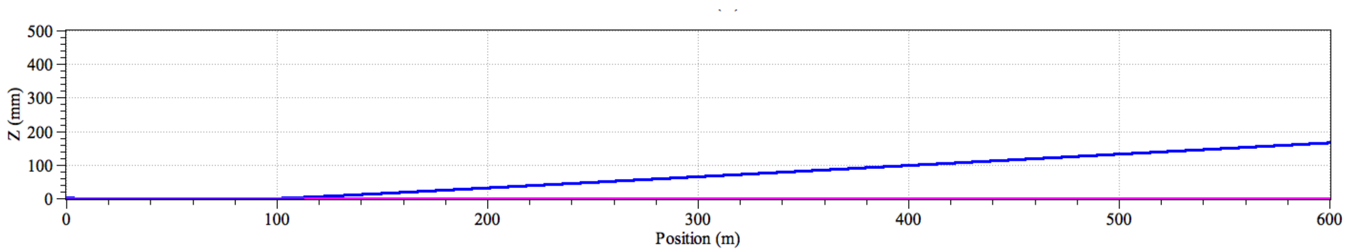


BPM Signals

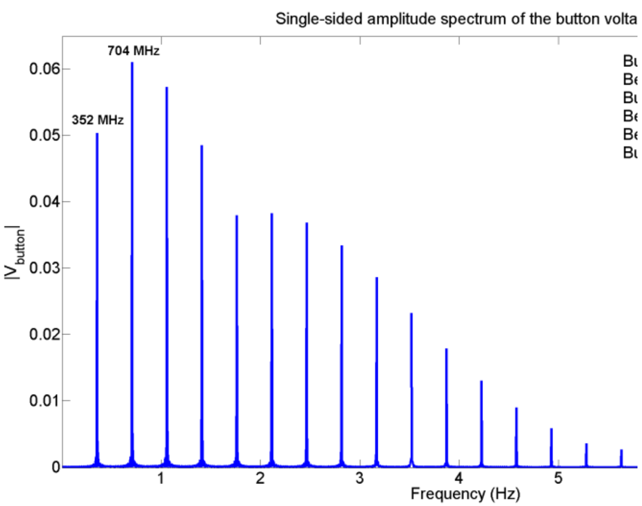


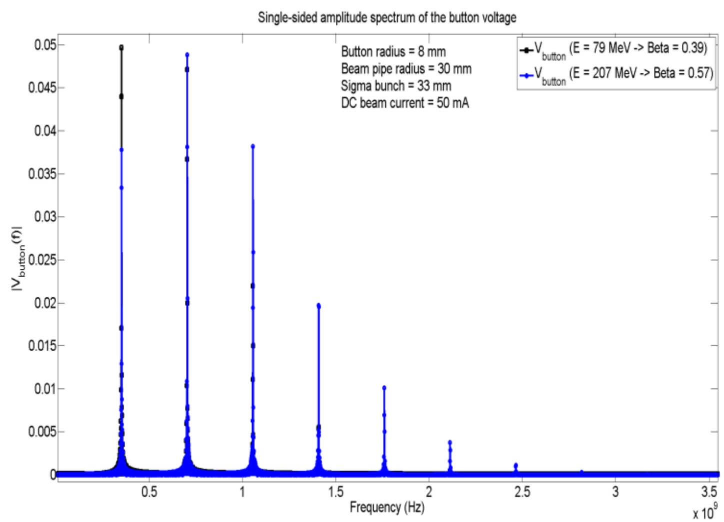


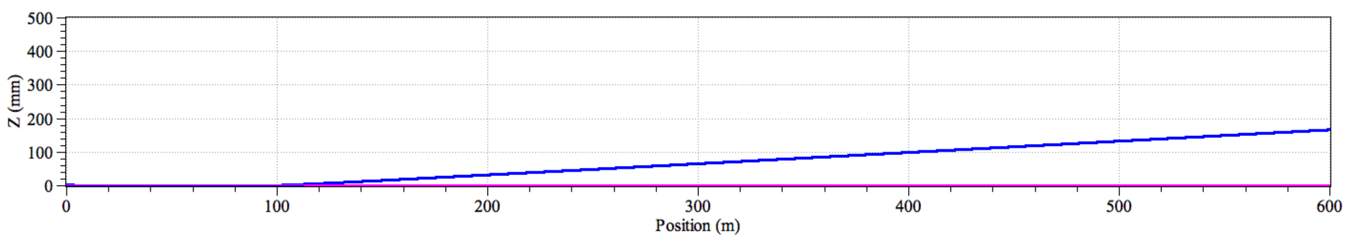
Preliminary studies (using E-XFEL button size) show that button signal gives adequate sensitivity for production and diagnostics beam for nominal bunch length.

During tune-up of the cold linac, beam will be transported long distances without longitudinal focussing. The BPM system should be able to provide some position information to allow to center debunched beam. May need larger buttons for this.

BPM Signals







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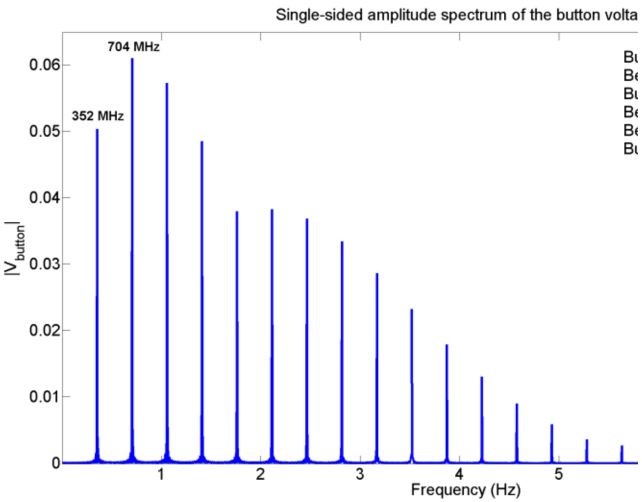

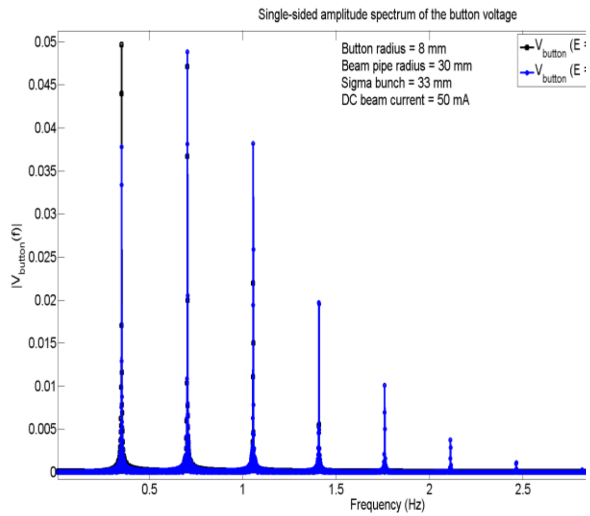

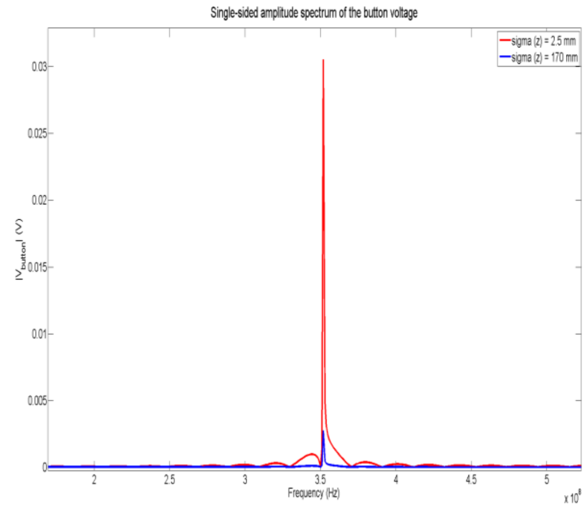

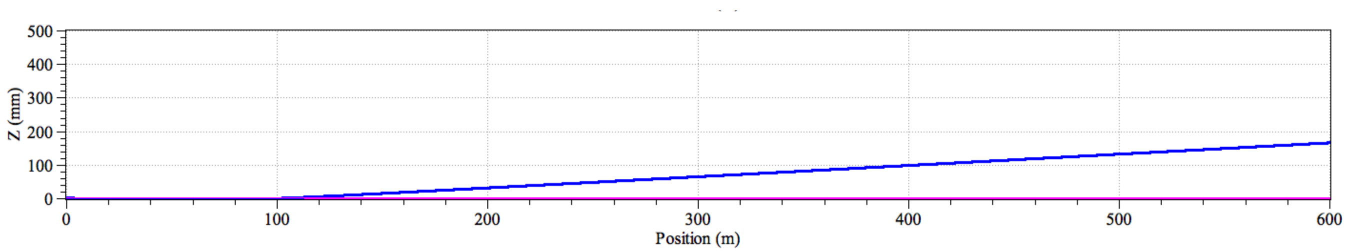

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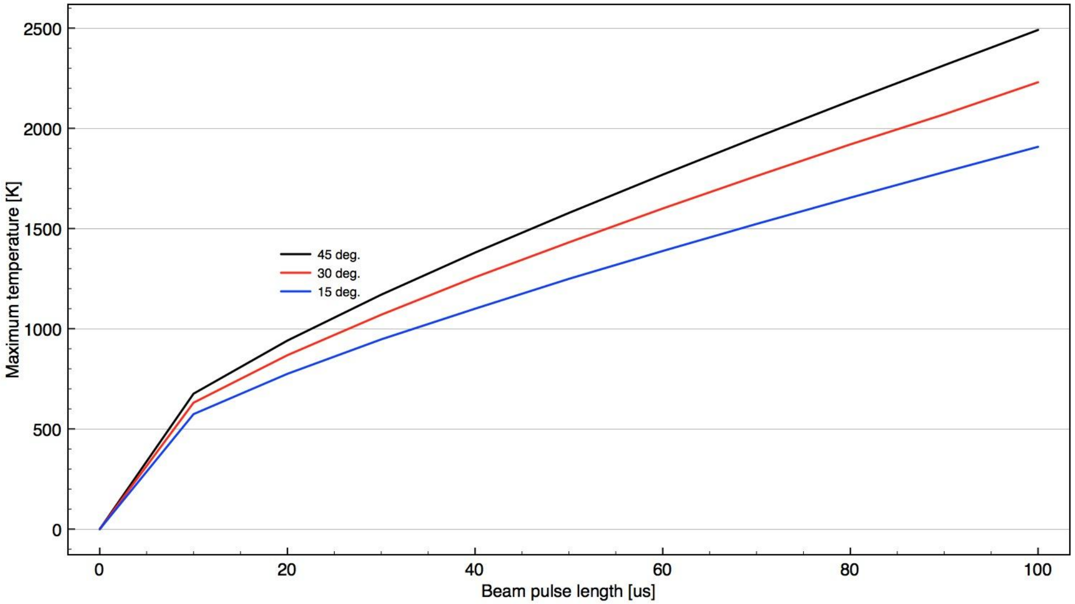
Emittance Measurement

- Preliminary ANSYS simulations studies show that the LEBT slits can be used with the full production beam.
- TZM, graphite, tungsten are possible materials.



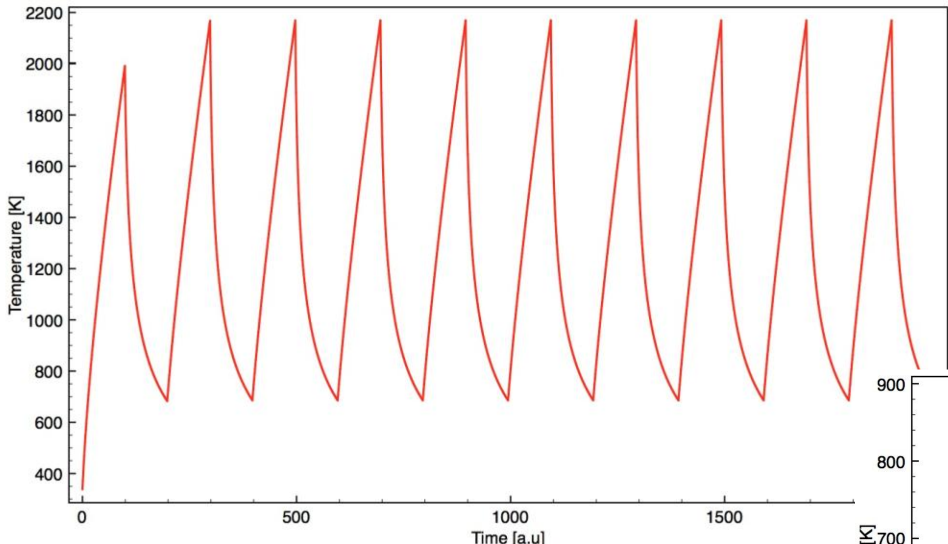
Maximum temperature on a graphite slit for different slit angle and pulse length, the mechanical limits of graphite is around 1600K

For MEBT slits, beam pulse must be reduced to 50 μs

Short available drift space leads to challenging SEM wire pitch (0.1mm).

Warm Linac Wire Scanners

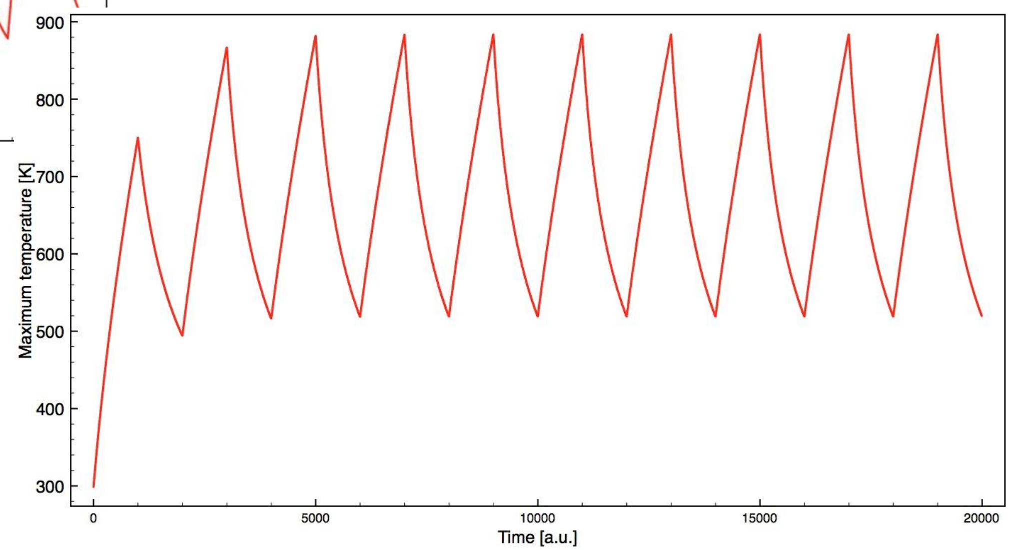
- Carbon (33 μm) is the primary choice for wire scanner in warm linac



Maximum temperature on a carbon wire installed in the MEBT (1Hz, 50 mA, 50 μs) .

In MEBT, beam pulse has to reduced to 50 μs in order to avoid thermionic emission and wire damages

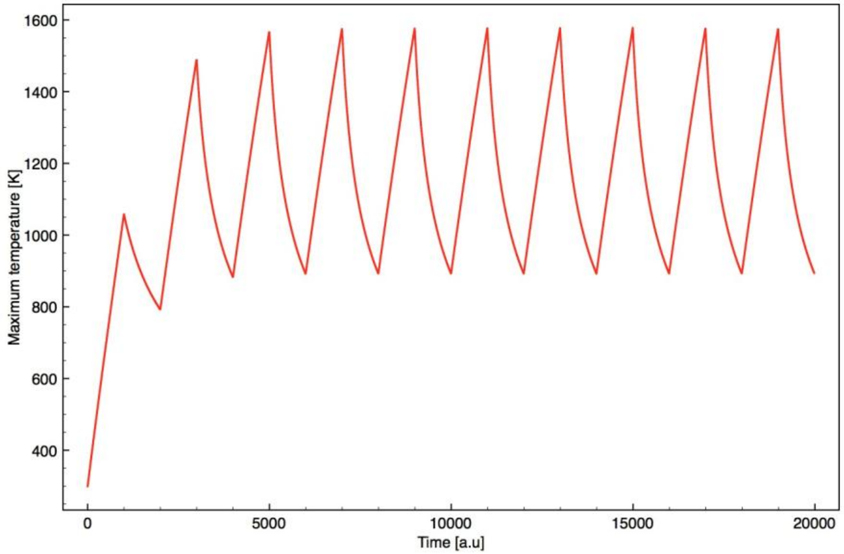
In the DTL the stopping power is lower and a pulse length of 100 μs can be used.



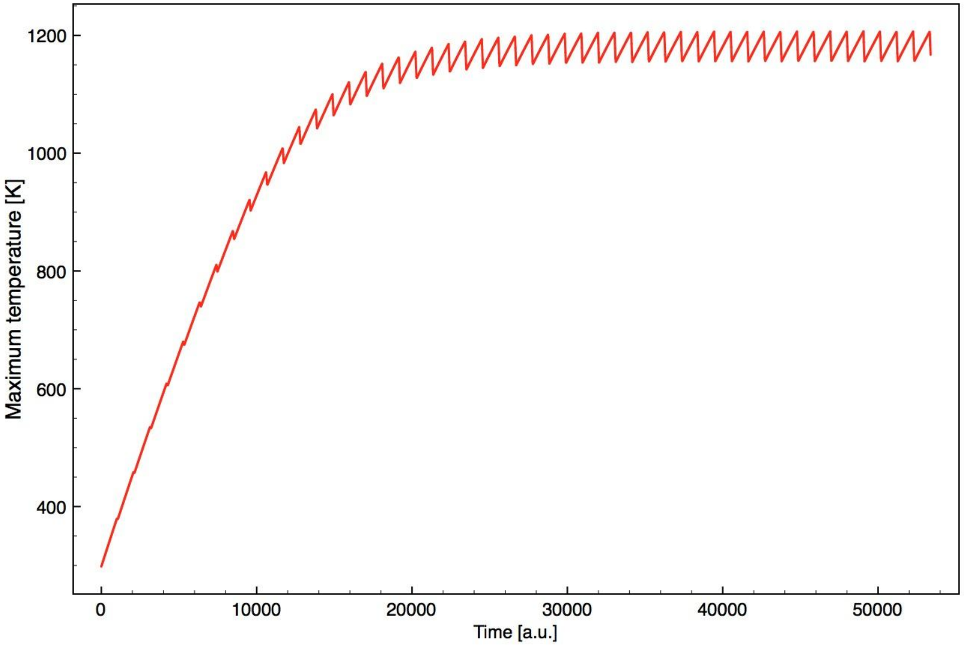
Maximum temperature on a carbon wire during the slow tuning mode (1Hz, 50 mA, 100 μs) at the exit of the first DTL tank (beam sizes are 2 mm in both planes).

Cold Linac Wire Scanners

- Carbon wires are not allowed in cold linac!
- 20 μm tungsten wires are considered.
- Expect no issue with temperature in the cold linac



Estimation of the temperature has been done assuming $\sigma_x = \sigma_y = 2$ mm, with a beam energy of 80 MeV (no acceleration from the superconducting cavity)

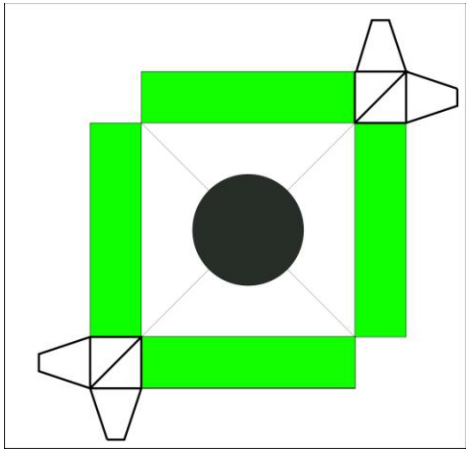


At around 2 GeV, the stopping power reaches its minimum, assuming the same beam sizes, the expected temperature are:

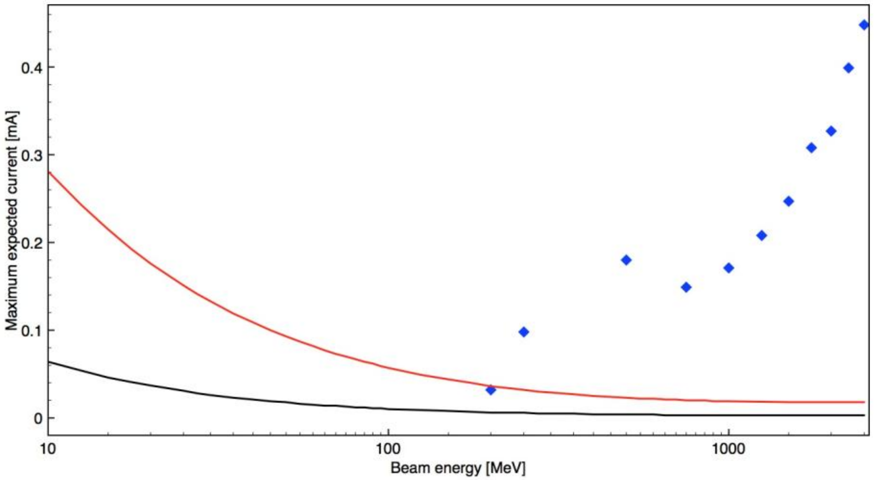
- 850 K during the fast tuning mode
- 950 K during the slow tuning mode

Wire Scanner signal

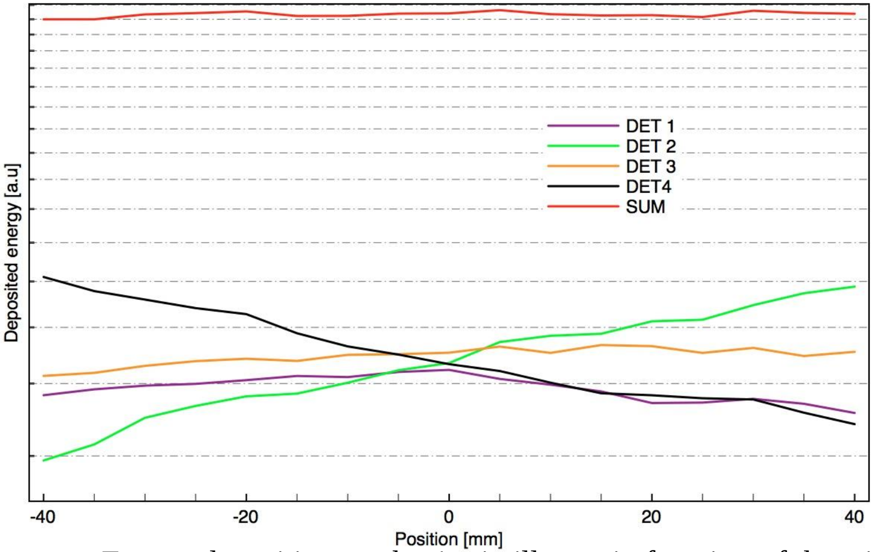
- Below the pion production threshold: measure secondary emission
  - low level of signal above 100 MeV
- Above threshold, detect shower with scintillator
  - the geometry of the detector can affect the beam profile reconstruction
- SCL Wire scanner will be used with care, for initial commissioning and for calibration of non-invasive method



Scintillator geometry, in green the scintillator with the light guide (black line) .and in grey the beam pipe



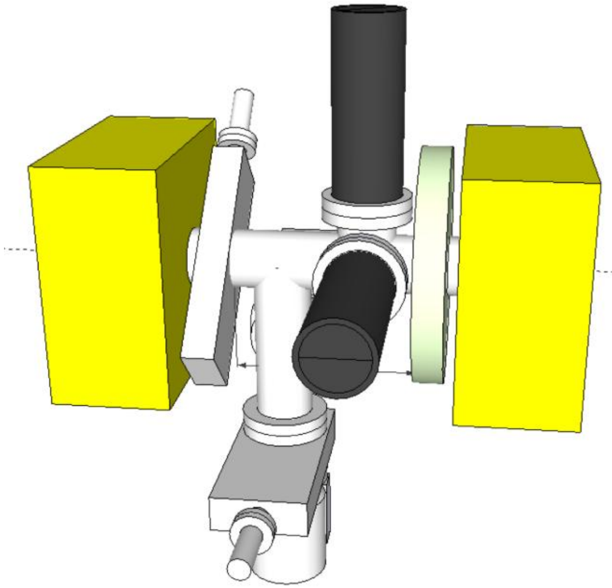
Maximum expected current on the wire in function of the beam energy in SEM mode for carbon wire (black line), tungsten wire (red line) and in shower mode (blue dots).

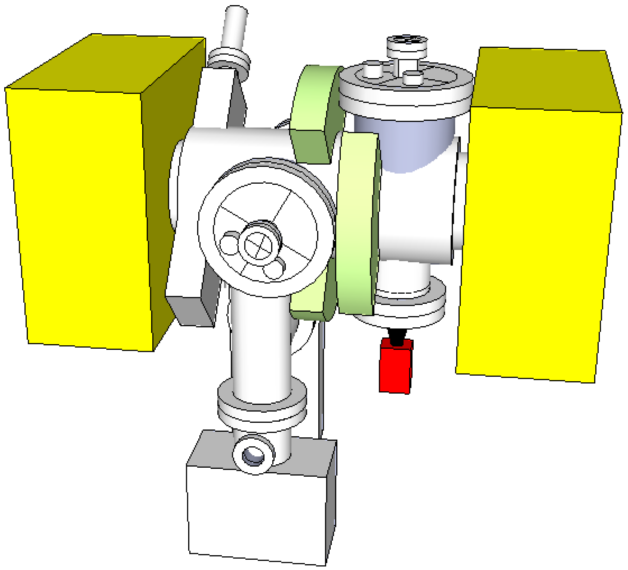


Energy deposition on the 4 scintillators in function of the wire position (E=1GeV)

Non-invasive profile

- Want non-invasive monitor of beam profile during neutron production
  - Co-located with WS for cross-calibration
- No sync light, and lasers don’t work on protons …
- Methods under consideration
  - Luminescence
  - Ionization profile
  - Electron/Ion beam scanner
- Recently started tests of luminesce yield in the SNS HEBT

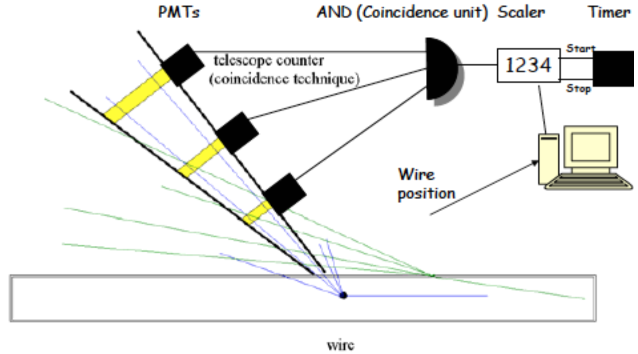




Halo Measurement

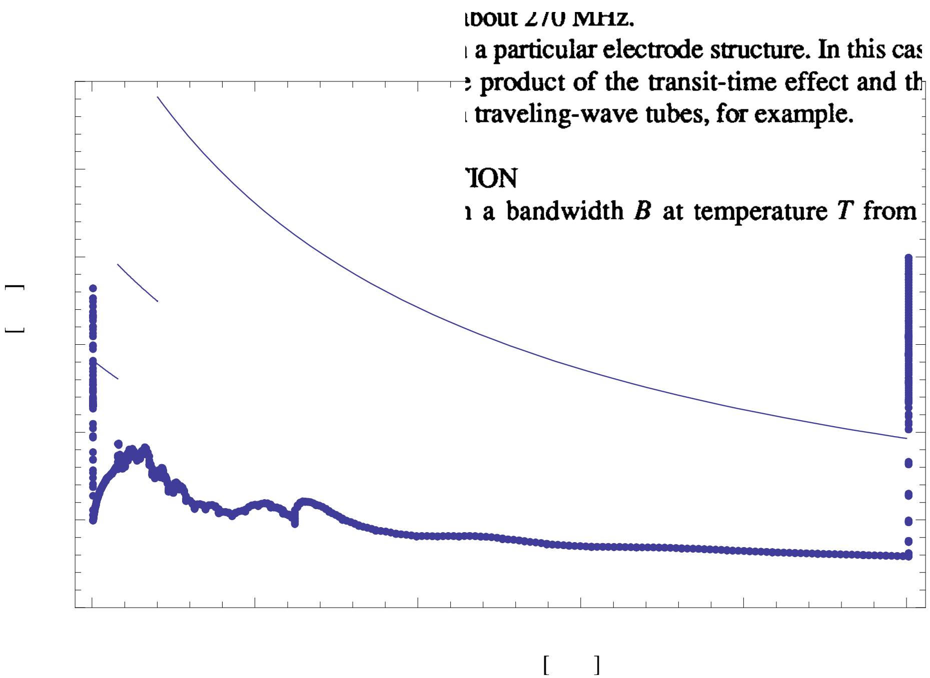
- Candidate Halo Methods:
  - Wire Scanner
    - can be used only at low energy where the secondary emission signal is high
  - Wire Scanner with telescope
    - can be used only in the HEBT due to the lake on space in the Linac
  - Diamond
    - The radiation could be an issue
  - Cherenkov fiber scanner
    - The radiation could be an issue
- MEBT Scrapers and collimators will also be instrumented
- Thermocouples at windows and target

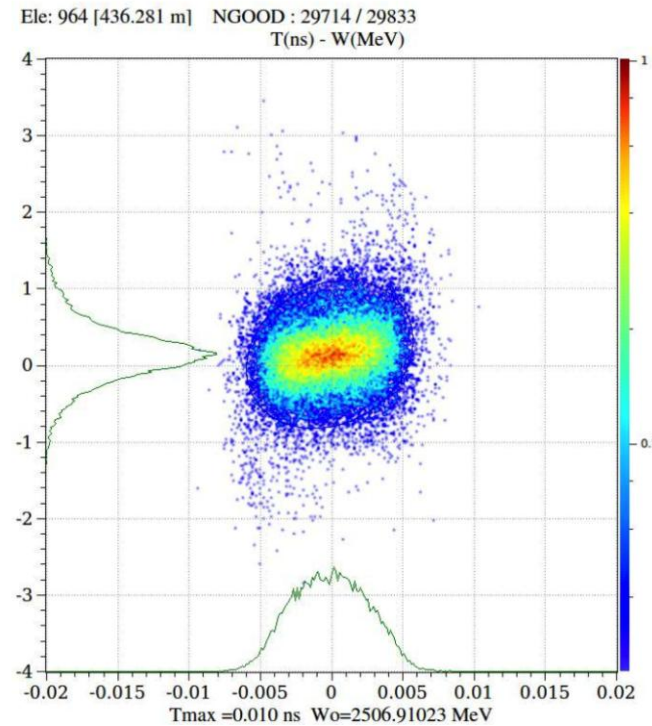
Diamond based detector used at spring8 for halo measurement (more detail in TUPB24, DIPAC09, Basel)



Principe of the telescope in counting mode

Bunch Length





- Bunch length measurement in proton linacs is challenging (short bunch, low beta).
- Feschenko style monitors will be used (several versions has been proposed and developed)
- Plan topical workshop at ESS in Lund (tentatively week of January 14th).

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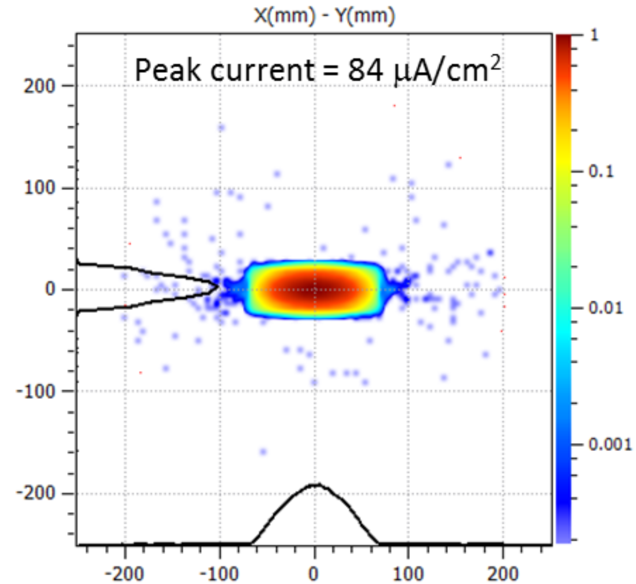
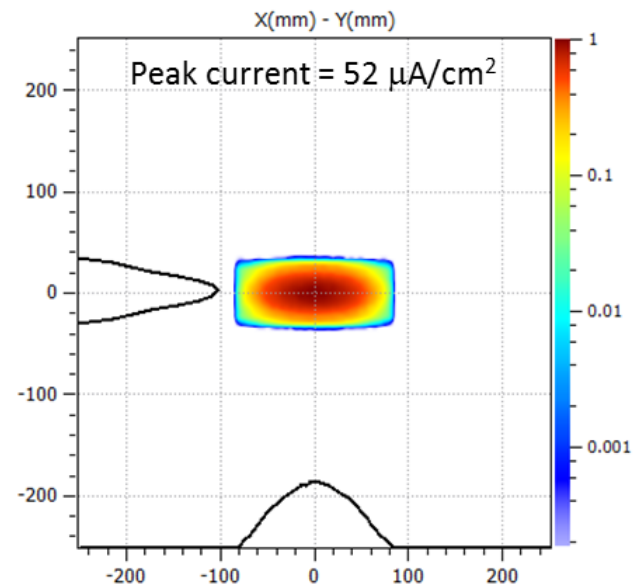
Target monitoring

- Plan to use coat target and window as at SNS
- Proton Beam Window is the most critical
  - Highest current density
- Also the most challenging
  - Very thin, SNS style luminescent coating would add significant mass
  - Need coating R&D





Summary

- ESS project is ramping up!
  - TDR being finalized
  - Local organization is growing (and will continue to grow)
  - Expect to formally enter construction phase next year.
- Baseline diagnostics suite defined. Many diagnostics systems planned
  - Some particular challenges include target monitoring, bunch length and noninvasive profile and halo
- Expect many more papers at coming IBICs…

ESS/AD

ESS Accelerator Divison (+guests), December 2011

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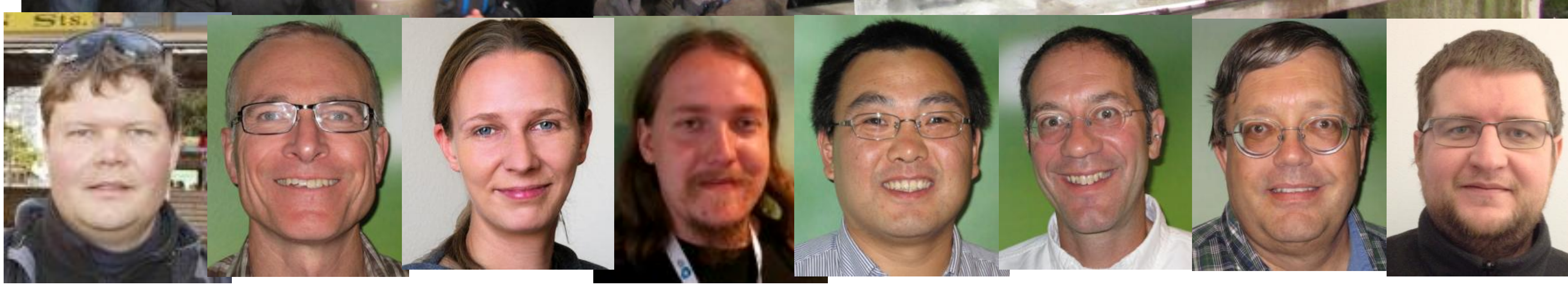

Recent newcomers!

We are hiring! Check out http://www.esss.se/jobs

Welcome to Lund, Sweden