The European Spallation Source

Andreas Jansson

DITANET School, Haninge, 2011-03-10

Overview

- The ESS Project
  - History, Motivation, Status & Cost
- The ESS Linac
  - Current (baseline) design & plans
- ESS Beam Diagnostics
  - Overview and specific challenges

ESS in Lund


Finland
Norway
Sweden
Bergen
Oslo
Stockholm
Helsinki
Denmark
Copenhagen
Malmo
The Öresund
The ESS Scandinavia site
Lund
Copenhagen Airport
Skåne
Malmö
The Öresund Bridge

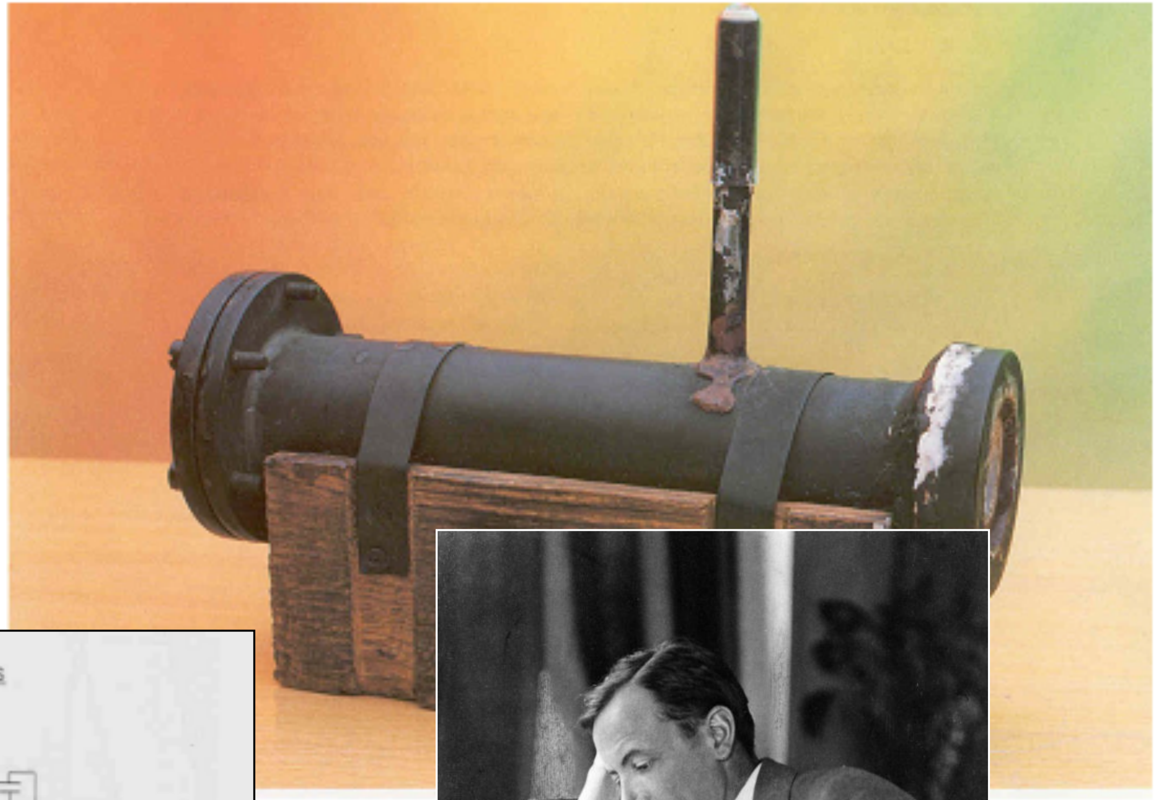
Something about Neutrons

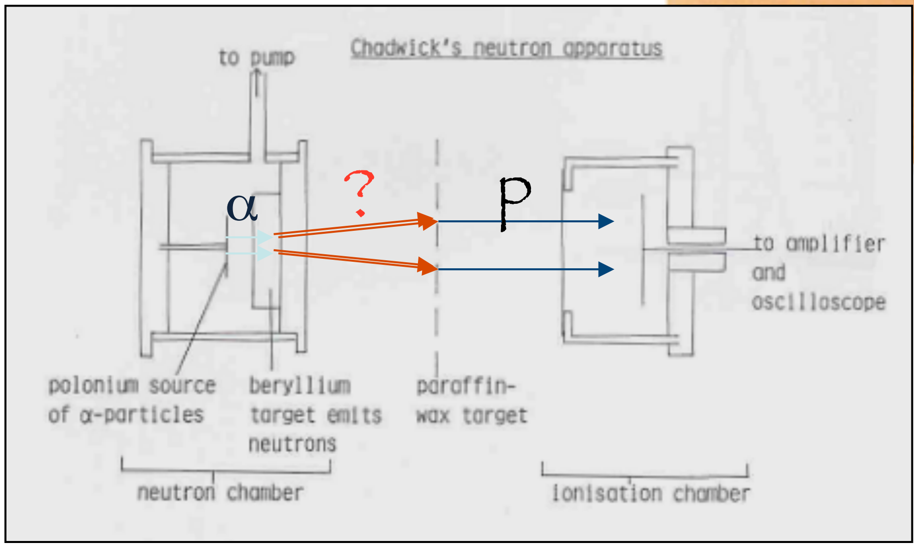
Its discovery

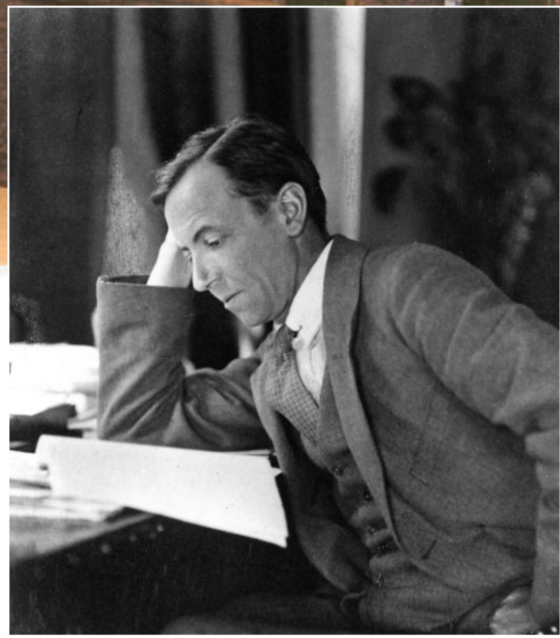
James Chadwick

1932

(α,n) reaction







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"…. it has most remarkable properties"

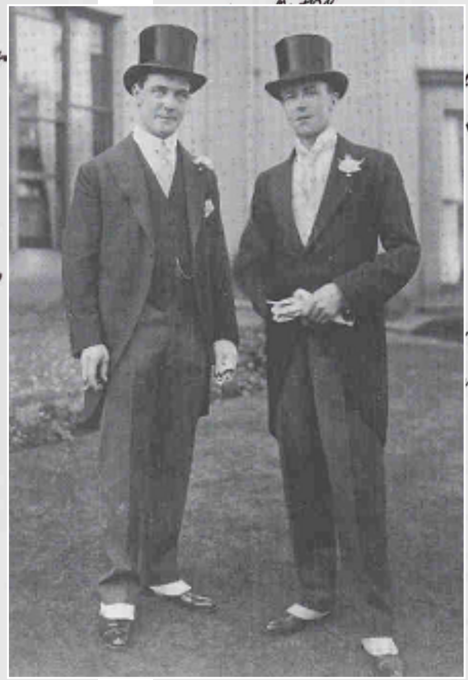
Cavendish Laboratory,
Cambridge.

24 February 1932.

Dear Bohr,

I enclose the proof of a letter I have written to "Nature" and which will appear either this week or next. I thought you might like to know about it beforehand.

The suggestion is that α particles eject from beryllium (and also from boron) particles which have no nett charge, and which probably have a mass about equal to that of the proton. As you will see, I put this forward rather cautiously, but I think the evidence is really rather strong. Whatever the radiation from Be may be, it has most remarkable properties. I have made many experiments which I do not mention in the

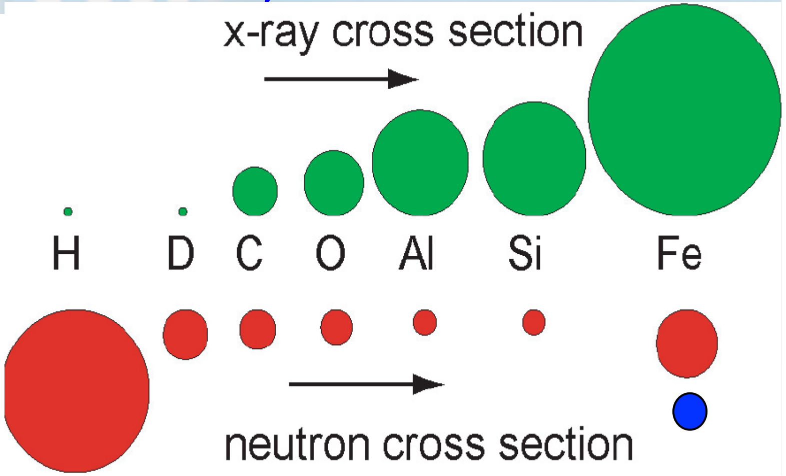


letter to "Nature" and they can all be interpreted readily on the assumption that the particles are neutrons. Feather has taken some pictures in the expansion chamber and we have already found about 20 cases of recoil atoms. About 4 of these show an abrupt fork
almost certain that one arm
sents a recoil atom and the other
, probably an α particle. They
due to the capture of the neutron
I enclose two photographs
the simple recoil atom, and the
ppose is a disintegration. The
t very good but they were printed

With best regards
Yours sincerely
J. Chadwick.

Neutrons & X-rays

The Neutron is a unique probe:



A neutral particle (with mass) which can penetrate materials without damaging them

While X-rays interact with the electron clouds of atoms, the neutron interact with the nucleus: gives exact position in e.g. crystal lattice

Scattering amplitude depends in the isotope (big difference in scattering ampltiude between isotopes)

Sensitivity to light elements (independent of Z)

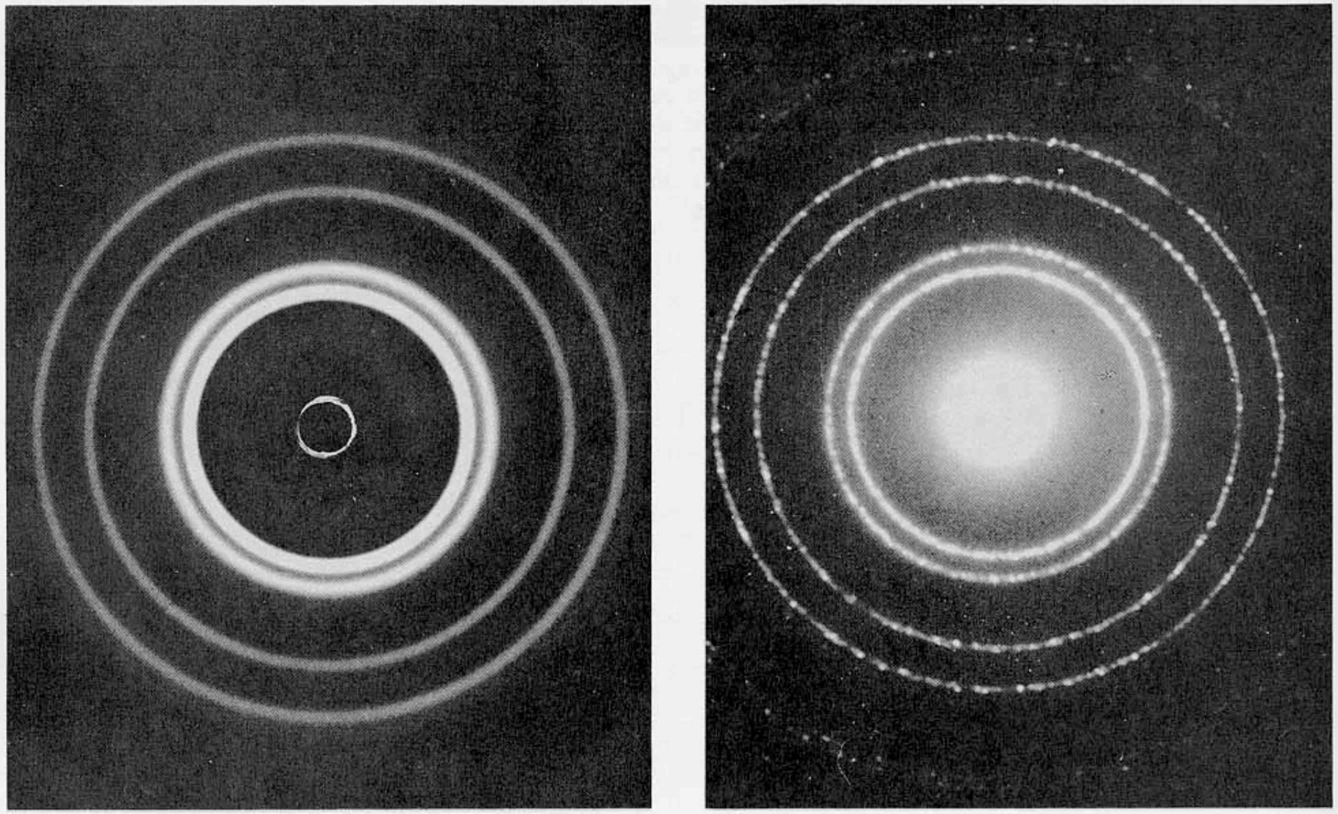
Neutron beams can be genereted at energies that correspond to atomic and molecular motion: measure dynamics

Neutrons have a magnetic moment, spin, and can interact with magnetic materials to reveal structure…

The wavelength of the neutrons correspond to the distance between atoms in materials, diffraction patterns are generated when neutrons pass through materials.

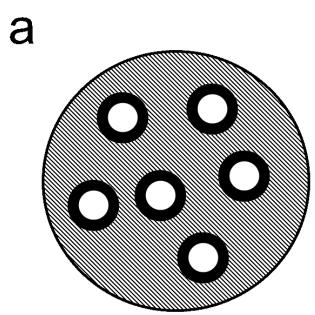
Diffraction pattern

The diffraction pattern on the left was made by a beam of x rays passing through thin aluminum foil. The diffraction pattern on the right was made by a beam of electrons passing through the same foil.



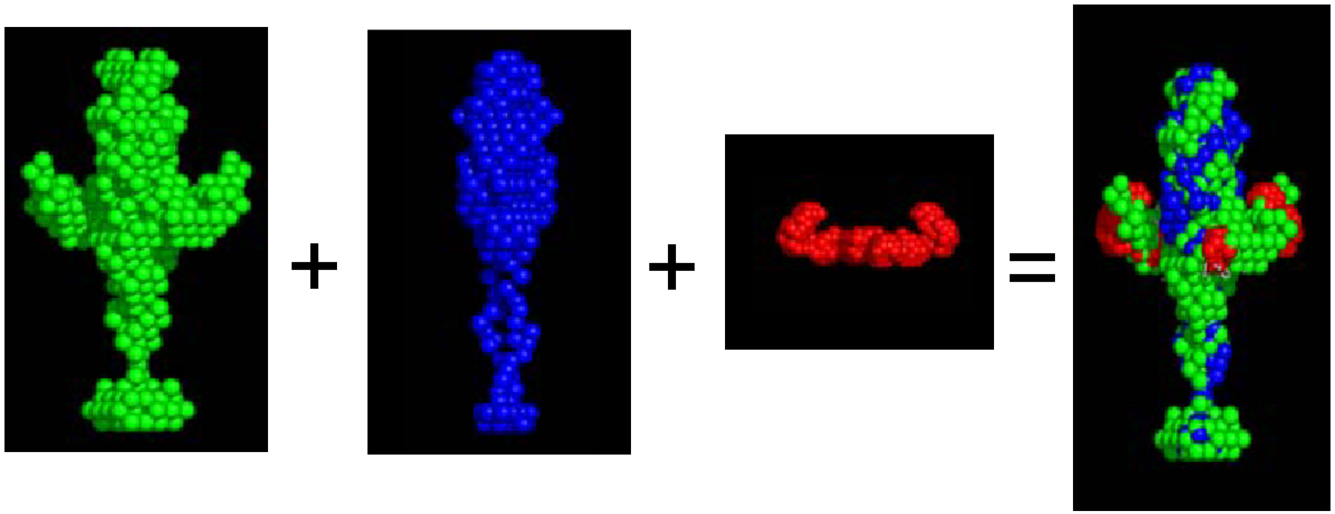
Contrast Matching: H vs D

•By varying the solvent composition (H_20 or D_20) one can distinguing between components in very complex systems.



- Molecules can also be Deuterated to create contrast

- E.g. protein:

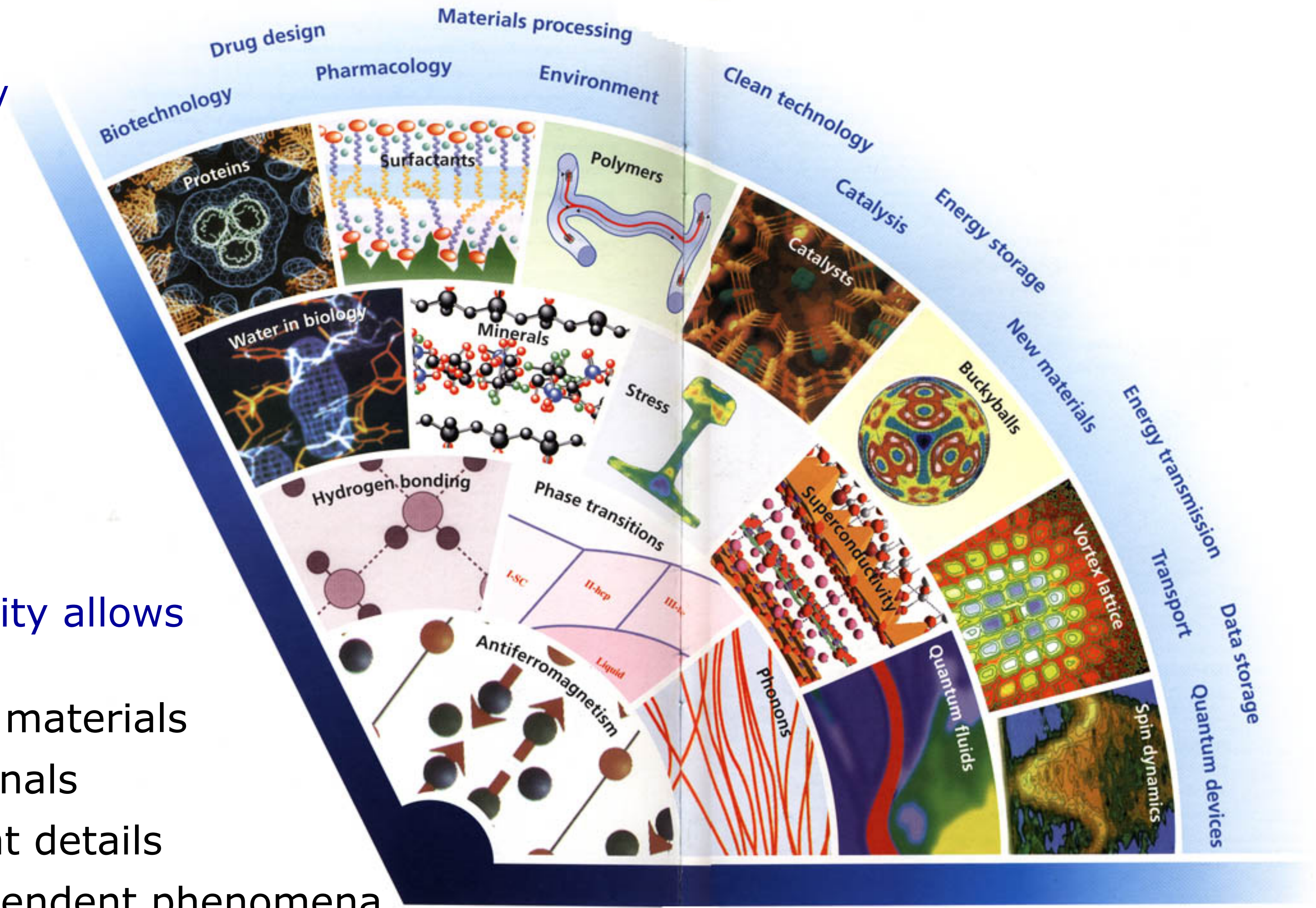


Material Science is important for our health, environment and welfare


Pace Maker
Li-Batteries
New Materials for Energy
Fuel cell &
Hydrogen storage
Functional Materials
Air Bag
Accelaration Sensors
MEMS
Cosmetics
TiO_2 Nanoparticle
Artificial Lens
Biocompatible polymers
Glasses &
Coatings
Optical Materials
UV Filter
Mobile Phone
SAW structures
Artificial Hips
Biocompatible
Materials
Digital Camera
CCD Chip
Bike Frame
Carbon Fibres
Composite Materials
GMR Read Head
Magnetic Multilayers
LED Display
Photonic Materials
Intelligent Credit Card
Integrated Circuits
Exact Time via satellite
Semiconducting devices
Micro-Batteries

Intensity opens new possibilities

Complexity/
Count-rate



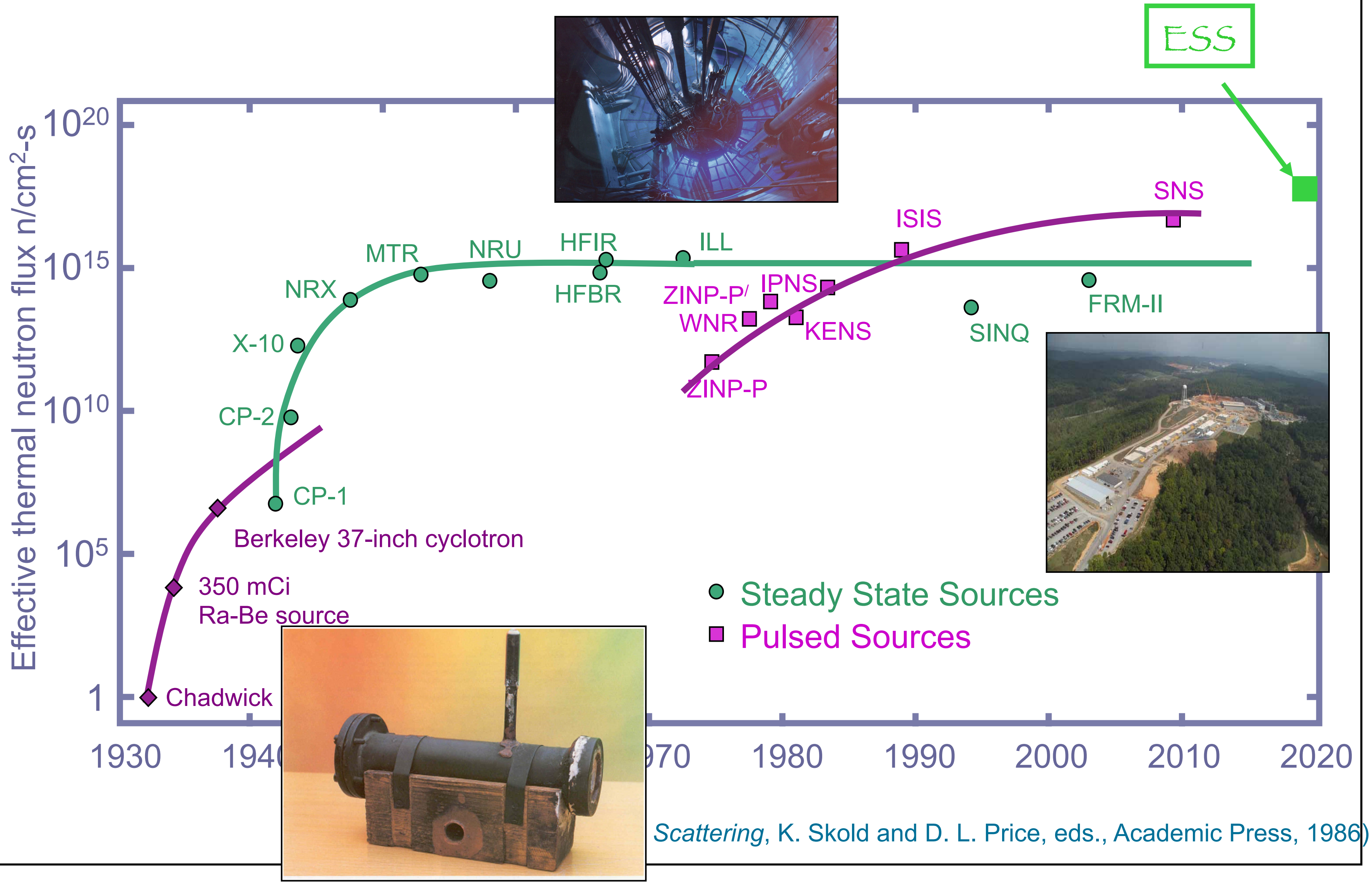
ESS intensity allows studies of

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

Details/Resolution

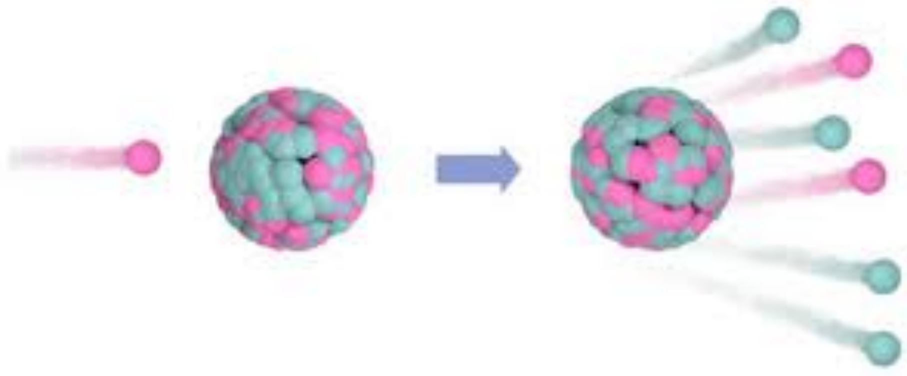
Why ESS? - High time average and peak flux

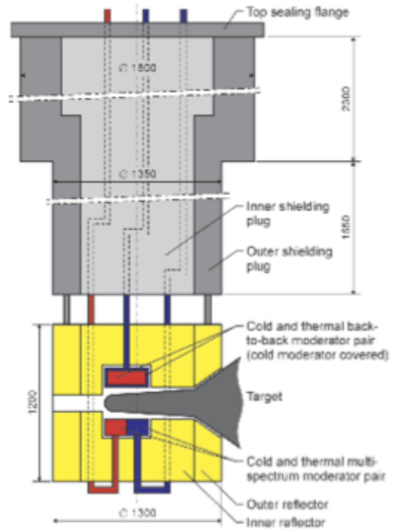
Evolution of the performance of neutron sources

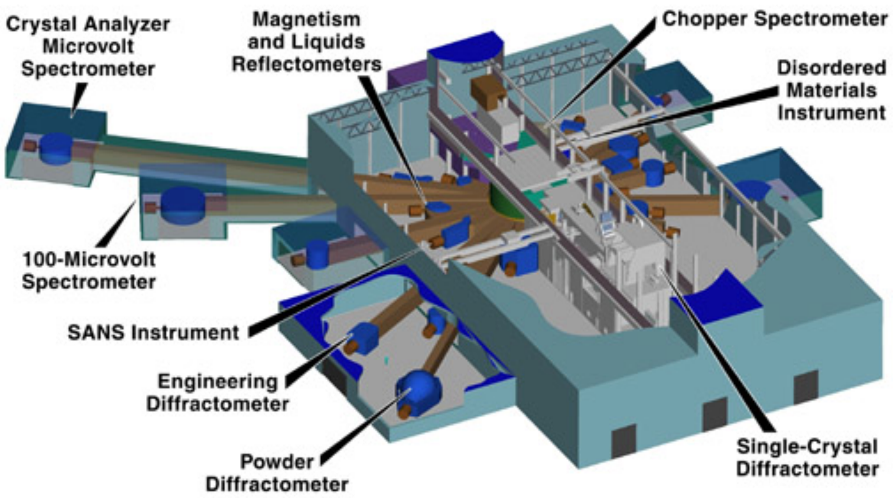


Scattering, K. Skold and D. L. Price, eds., Academic Press, 1986)

Neutrons by Spallation







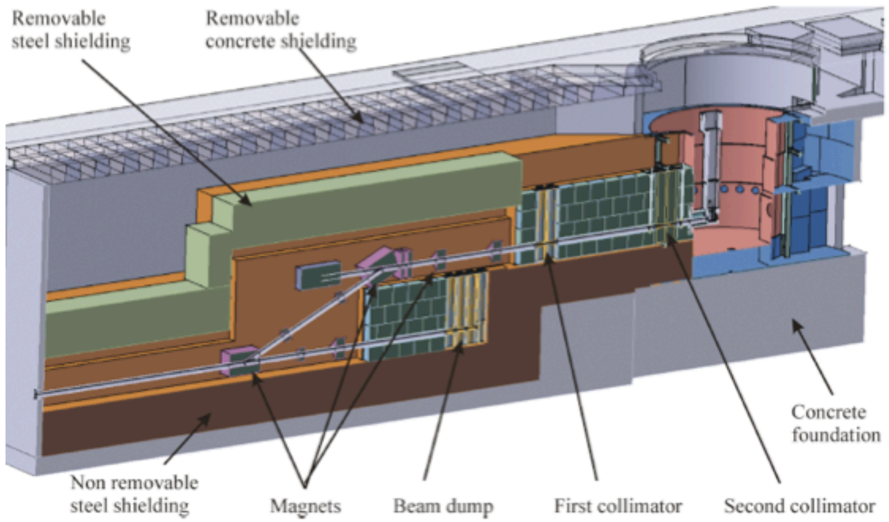
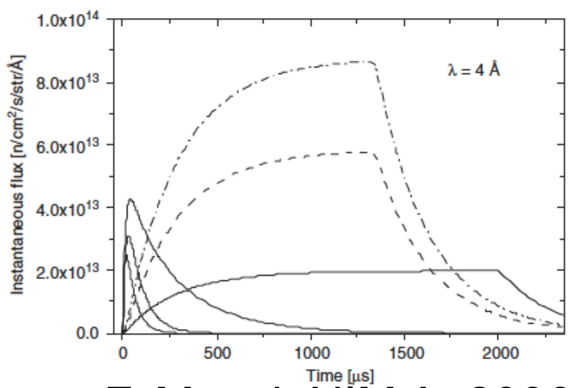


Figure 4.2.4.1: General view of the beam line shielding (longitudinal cut)

Why ESS? – Cold neutrons

- Many research reactors in Europe are aging and will be closed before 2020
  - Up to 90% of the use is with cold neutrons
- There is a urgent need for a new **high flux cold neutron** source in Europe
  - The vast majority will profit from a pulsed structure
  - A large fraction (70%) are fully satisfied by a long pulse source (approx 2 ms, 20 Hz)
  - Existing short pulse sources (ISIS, JPARC and SNS) can supply the present and imminent future need of short pulse users
  - Construction must start now for use in 2018-2019

"Pulsed cold neutrons will always be long pulsed as a result of the moderation process"



F. Mezei, NIM A, 2006

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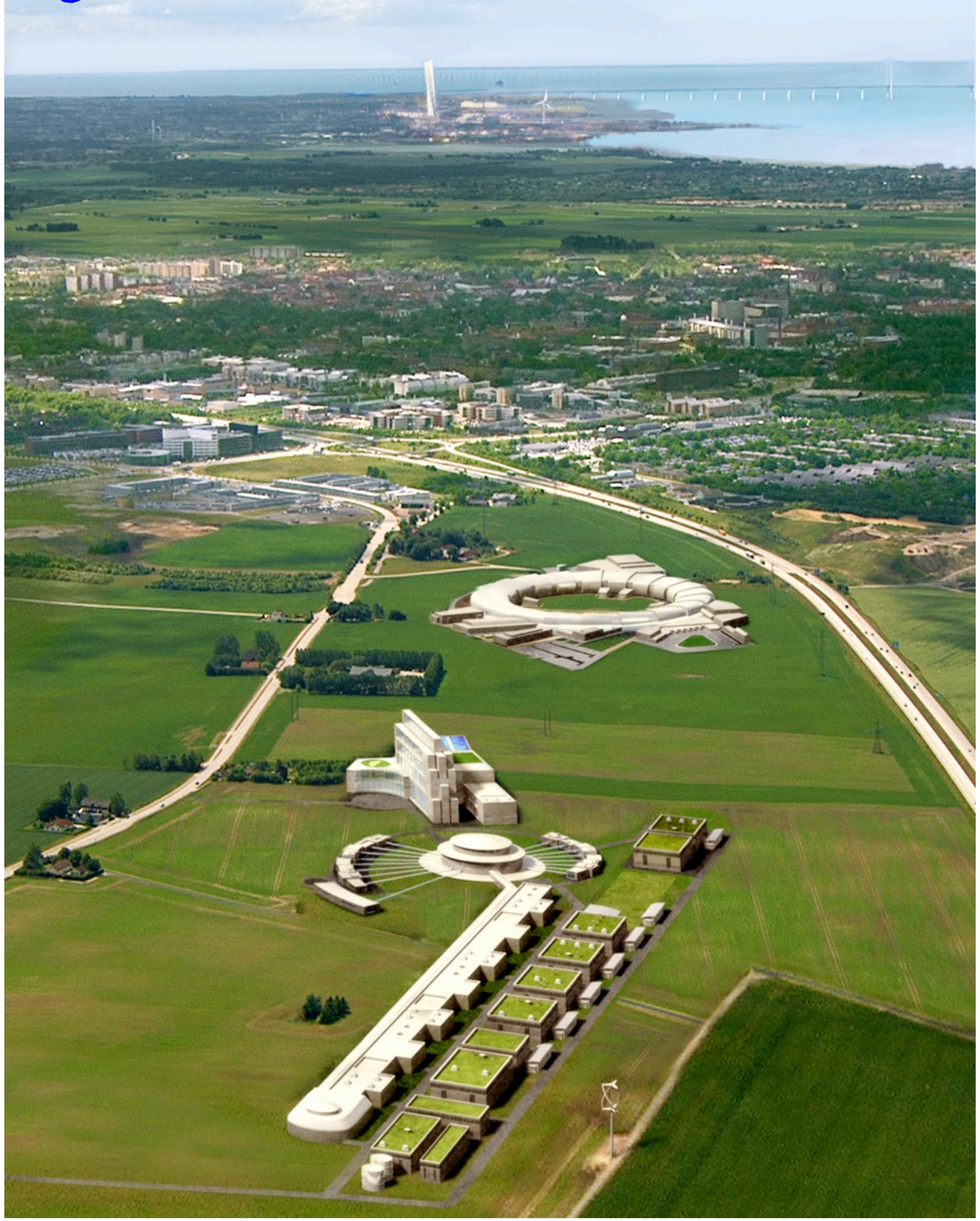
Why Lund?

- Neutrons and SR at the same site
  - MAX-IV and ESS
- A World-leading cluster of science facilities
  - XFEL, ESS, PETRA and MAX-IV
- Excellent Communications
  - 41 minutes to airport
  - 125 direct destinations
  - A cross-roads for 10 European countries
- Intellectual capital
  - 10,000 scientists - 140,000 students
  - 3rd biopole in Europe
  - Lund University 3rd largest attractor of EU R&D funds
  - IDEON



The LINAC comes back home

Gustav Ising
Swedish Physicist

Inventor of the
Linear accelerator
(1924)

ARKIV FÖR MATEMATIK, ASTRONOMI OCH FYSIK.
BAND 18. N:o 30.

Prinzip einer Methode zur Herstellung von Kanalstrahlen hoher Voltzahl.

Von

GUSTAF ISING.

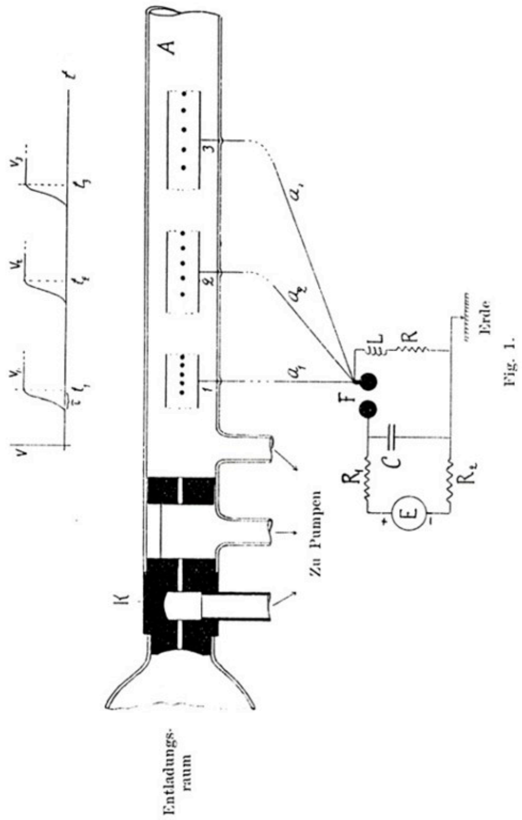
Mit 2 Figuren im Texte.

Mitgeteilt am 12. März 1924 durch C. W. OSEEN und M. SIEGBAHN.

Die folgenden Zeilen beabsichtigen eine Methode zu skizzieren, welche im Prinzip erlaubt, mit einer zu Verfügung stehenden mässigen Spannung Kanalstrahlen (ev. Kathodenstrahlen) beliebiger Voltzahl zu erzeugen. Dies soll dadurch erreicht werden, dass die Strahlenpartikel während ihrer Bahn die Spannung *mehrmals* durchlaufen müssen. Die Spannung wird als Ladungswellen längs Drähten an verschiedenen Stellen des Teilchenbahns mit passenden Zeitdifferenzen zugeführt.

Eine diesbezügliche Anordnung zeigt schematisch die Fig. 1: Von dem Entladungsraum links treten Kanalstrahlen durch die geerdete Kathode K nach rechts in das gut evakuierte *Accelerationsrohr* A ein. In diesem befinden sich eine Reihe zylindrischer Metallkäfige 1, 2, 3 . . ., deren Enden mit Drahtgitter verschlossen sind. Die Käfige sind durch die verschieden langen Drähte $a_1, a_2, a_3 \ldots$ über den grossen Widerstand R (ev. auch eine Selbstinduktionsspule L) geerdet und besitzen somit im allgemeinen die Spannung Null gegen Erde. In diesem Falle gehen die Partikel durch die Zylinderreihe hin mit der konstanten Geschwindigkeit, welche sie im Entladungsraum erhielten. Wenn aber eine Funke bei F überschlägt[1], wandern Ladungswellen längs der Drähte $a_1, a_2, a_3 \ldots$

[1] E ist eine Elektrizitätsquelle, R_1 und R_2 grosse Widerstände, C eine Kapazität.



nach den Zylindern; die Längen der Drähte (und der Zylinder) sind so bemessen, dass diejenigen Teilchen, welche bei Ankunft der Welle an den Zylinder 1 sich in diesem befinden, gerade Zeit genug haben in den Käfig 2 zu schlüpfen, bevor die Ladungswelle an diesen anlangt u. s. w.

Accelerator design task

ESS **accelerator** high-level technical objectives:

- 5 MW long pulse source
  - ≤2 ms pulses
  - ≤20 Hz
  - Protons (H+)
  - Low losses
  - Very high reliability
  - Flexible design for
  - Future upgrades

The Sustainable Research Centre

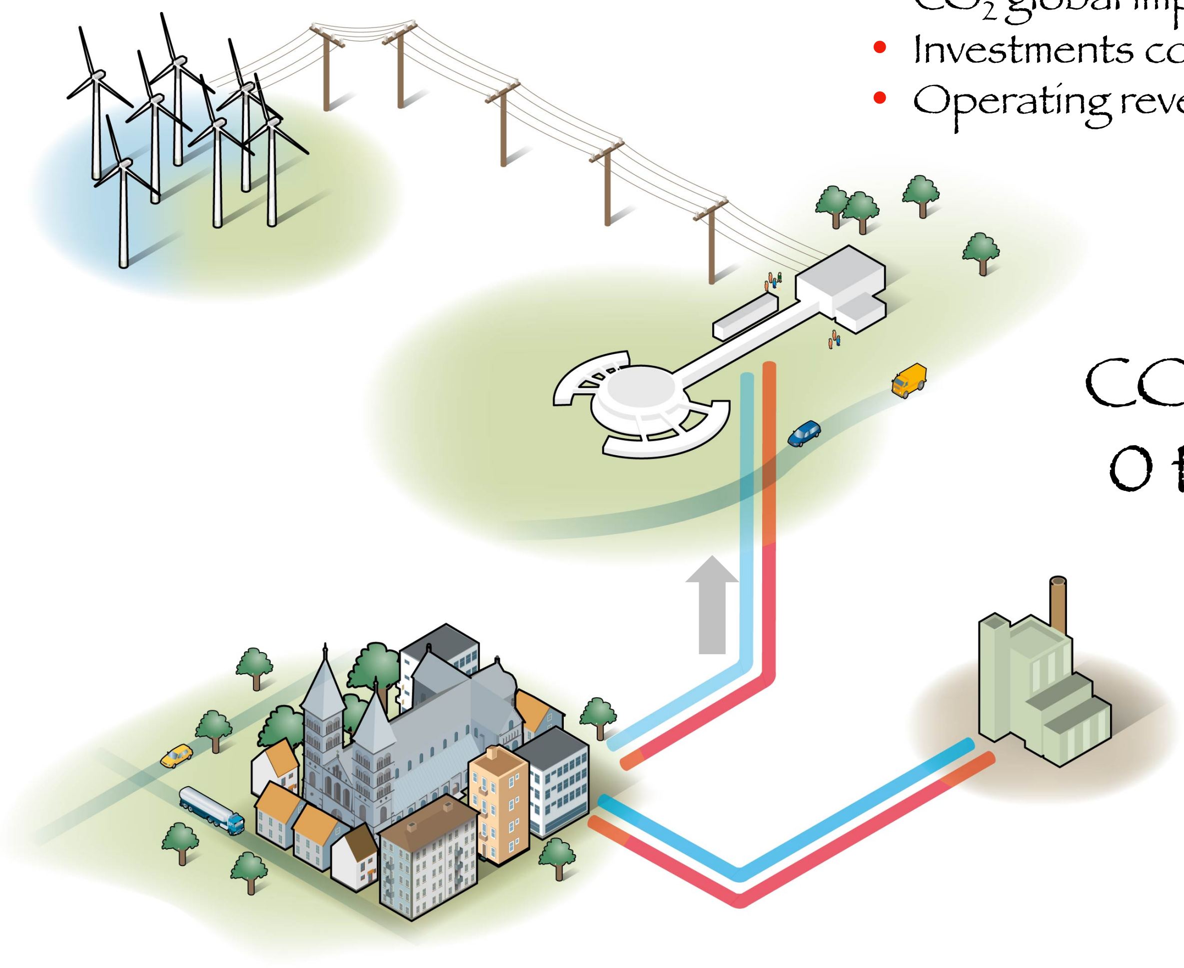
Responsible – Recyclable – Renewable

↓

To be carbon dioxide neutral over the lifetime of the facility, including transportation to and from the site.

ESS Energy Solution - Economy and Sustainablility Advantage

- Energy savings in improved efficiency equipment: 20 %
- CO_2 global impact: 0 ton/year
- Investments connection DH: 1 M€
- Operating revenue : ~ 1,5 M€



CO_2 production
0 tonnes/year

Income 1.5 M€

Recent ESS developments

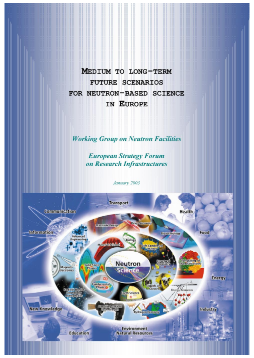
- Site decision in 2009
    - Strong support from 13 countries to engage in design update and preparations for construction
    - Number eventually grew to 16 (others may join)
- Independent legal entity (ESS AB) created in summer 2010
    - Swedish shareholding company, initially fully owned by the Swedish state.
- Danmark becomes shareholder - Dec 2010
    - Danmark will be co-host of the project, along with Sweden
- MoU signed in Paris (Feb 3), defining the roles of the member states in the preconstruction phase.

Time lines

first design

2002-2003

ESFRI Report
2003



site
decision
2009

ESS Pre-construction phase	2010-2012
ESS Construction phase	2013-2018
Completion phase	2018-2025
Operations phase	2026-2066
My retirement	~2037
Decommissioning phase !!!	2067-2071

ESS cost estimate

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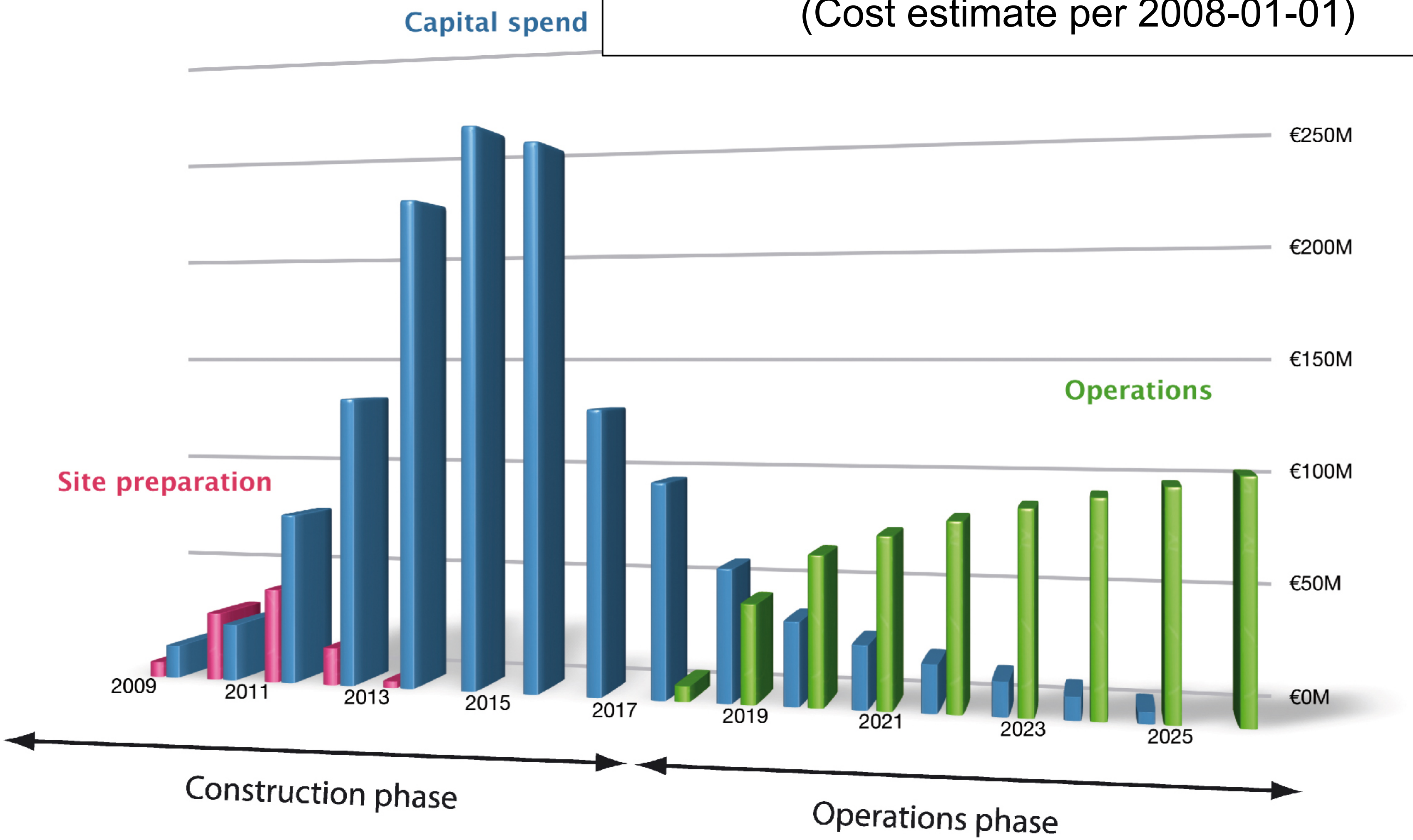
Investment: 1478 M€ / ~10y
Operations: 89 M€ / y
Decomm. : 346 M€
(Cost estimate per 2008-01-01)



What can you get for 1.5B€ today ?

You could buy four A380 airbuses…

or, 28% of the Fehmarn Bridge

or, you could pay the bonuses of US bankers for…

24 days

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Design Update Project

Goal: To provide updated design and cost by end 2012

Romuald Duperrier
(30 years ago)

Steve Peggs

Cristina Oyon

Josu Eguia

Work Package (work areas)

1. Management Coordination – ESS (Mats Lindroos)
2. Accelerator Science – ESS (Steve Peggs)
3. Infrastructure Services – Tekniker, Bilbao (Josu Eguia)
4. SCRF Spoke cavities – IPN, Orsay (Sebastien Bousson)
5. SCRF Elliptical cavities – CEA, Saclay (Guillaume Devanz)
6. Front End and NC linac – INFN, Catania (Santo Gammino)
7. Beam transport, NC magnets and Power Supplies – Århus University (Søren Pape-Møller)
8. RF Systems – Uppsala university (Roger Ruber)

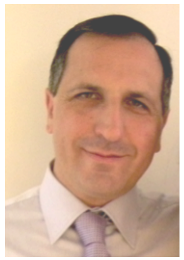
Guillaume Devanz

Mats Lindroos

Roger Ruber

UPPSALA UNIVERSITET

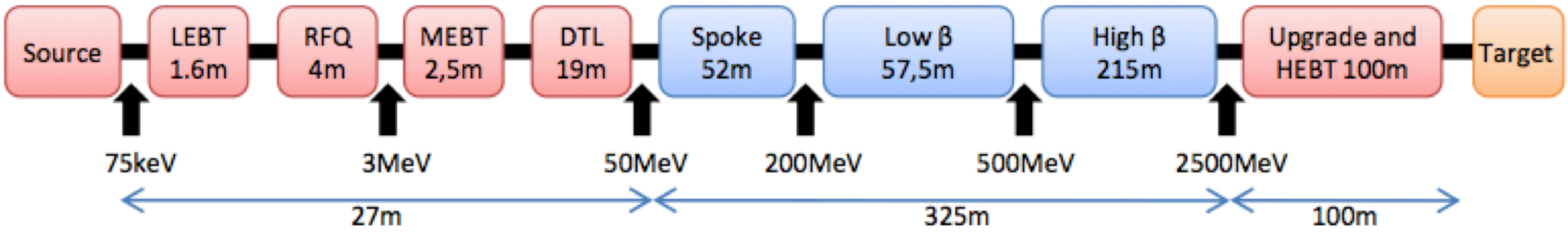
Søren Pape Møller



Santo Gammino

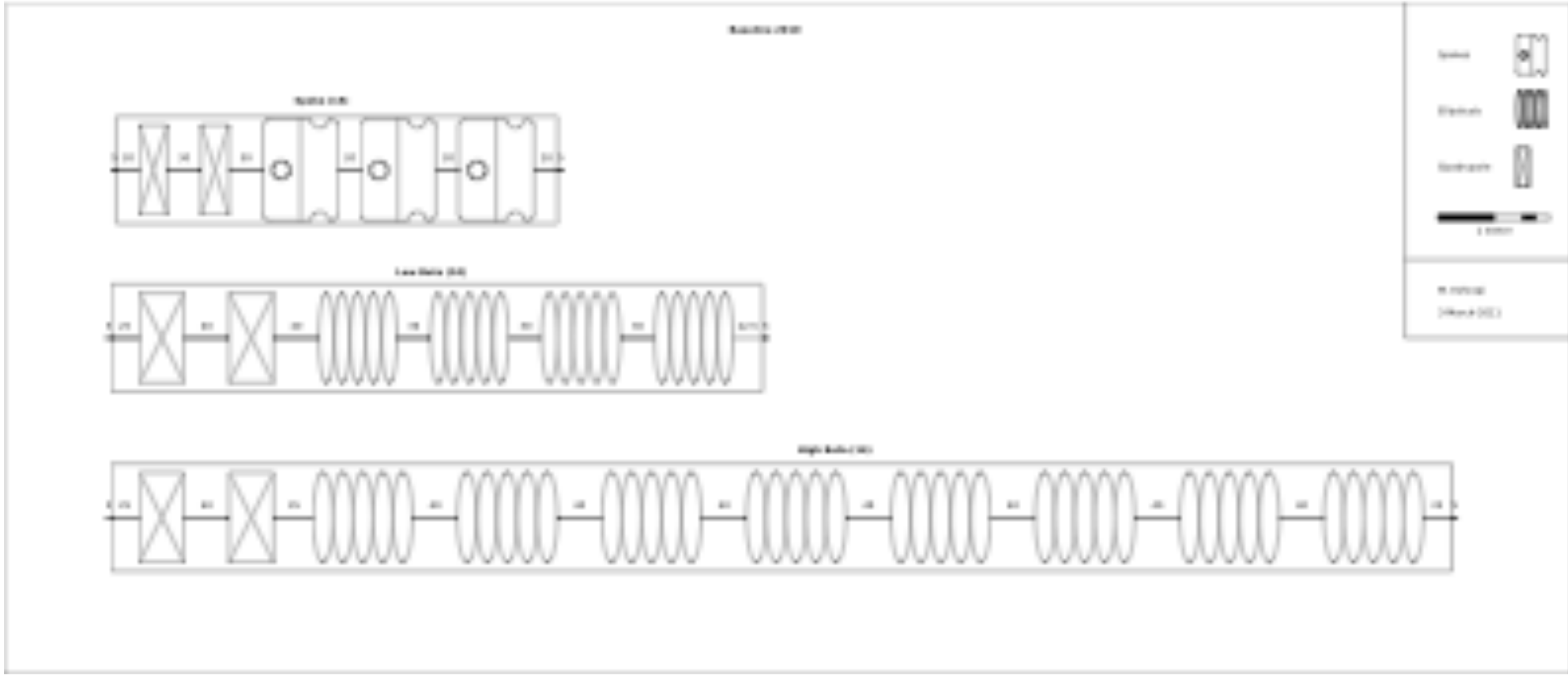
Sebastien Bousson

LINAC baseline layout

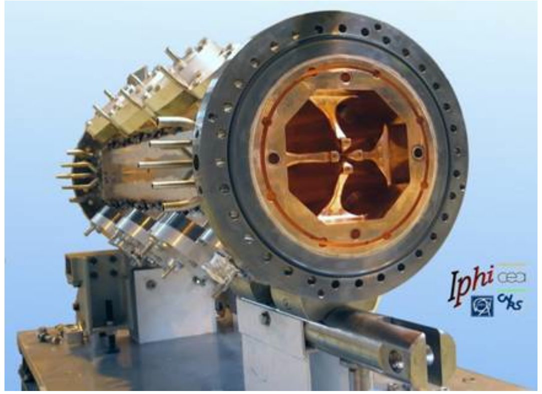


	Length (m)	Input Energy (MeV)	Frequency (MHz)	Geometric β	# of Sections	Temp (K)
RFQ	4	75×10^{-3}	352.2	--	1	≈ 300
DTL	19	3	352.2	--	3	≈ 300
Spoke	61	50	352.2	0.54	15	≈ 2
Low Beta	59	240	704.4	0.67	10	≈ 2
High Beta	169	590	704.4	0.84	14	≈ 2
HEBT	100	2500	--	--	--	--

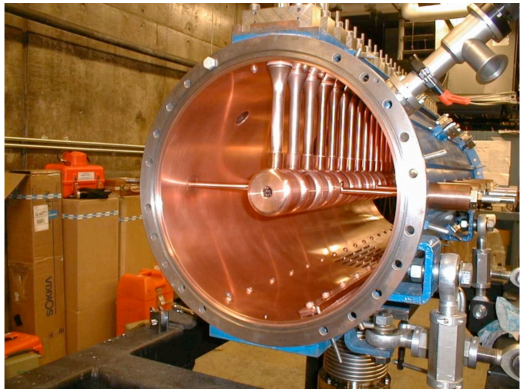
Baseline Cryomodule Layout



Linac R&D in progress

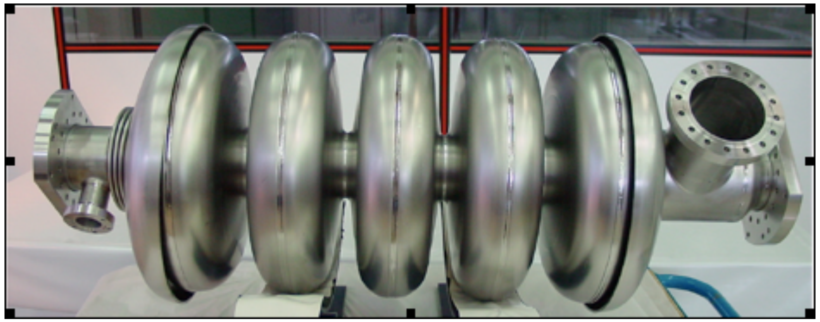


IPHI RFQ at CEA-Saclay



http://www.jpaw.com

SC triple spoke cavity, ANL

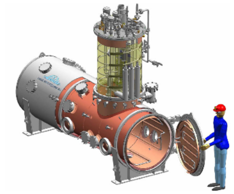


SC 5 cell cavity for 704 MHz, CEA and CNRS

RF Test stand strategy

- 704 MHz test stand for SC elliptical cavities and a cryomodule
  - Possible sites CERN, CEA, Uppsala and DESY (after XFEL)
  - Study and costing in progress for CERN, CEA and Uppsala
  - Focus in Uppsala on RF source, control and distribution

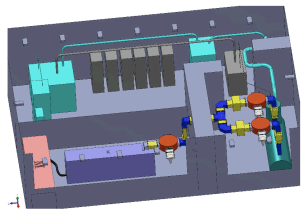
Test cryostat



- 352 MHz test stand for SC spoke cavities and cryomodules
  - One test stand at CEA
  - One test stand under construction at IPNO in Paris

- 352 MHz test stand for NC structures

- Test area for Ion Source development in Catania



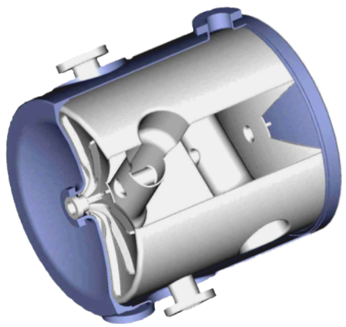
Proposed test stand in Uppsala

Prototype strategy

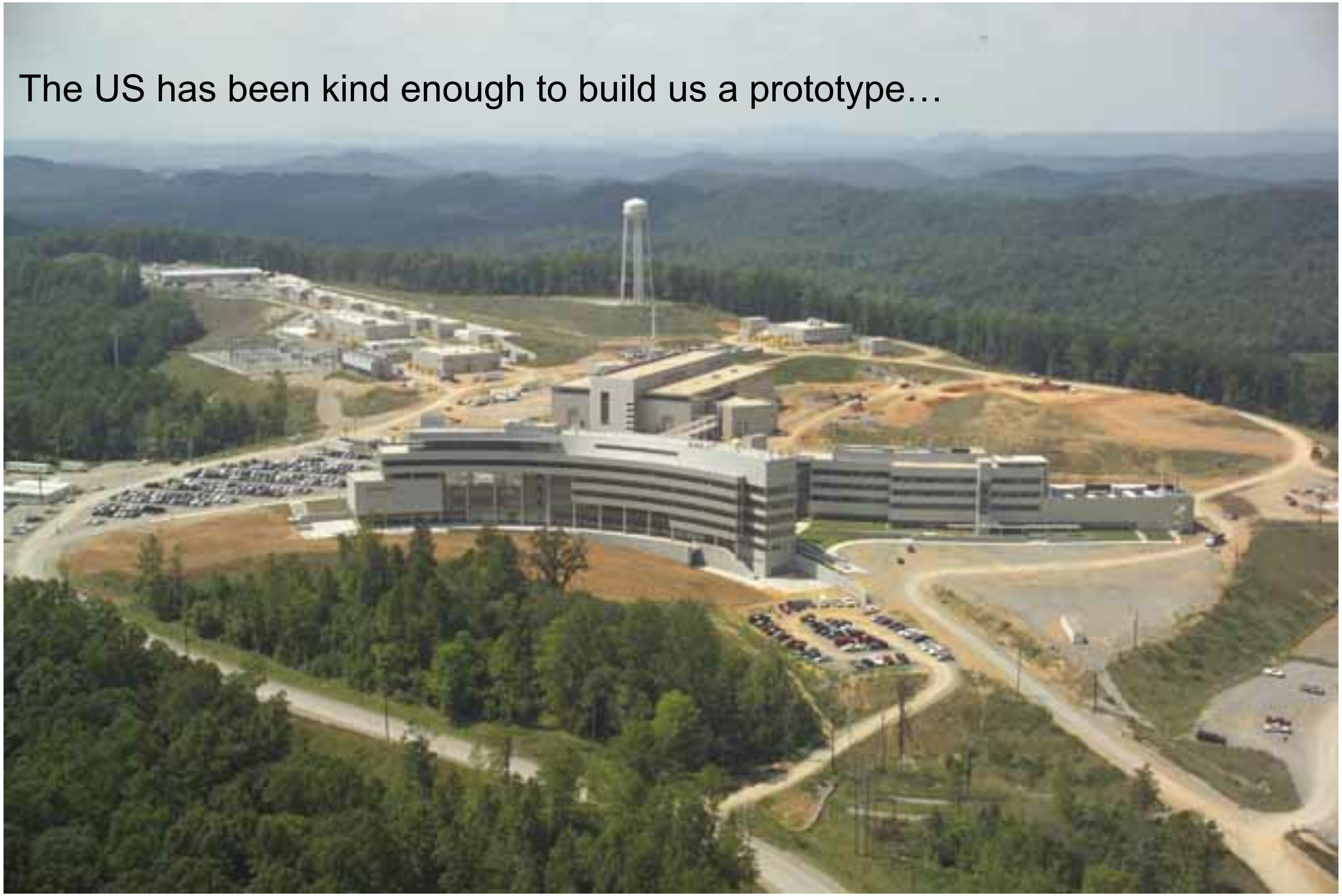
- Planned and proposed prototypes in DU phase (before 2013):
  - SC Cavities (All elliptical and spoke types) at CEA and IPNO
  - Half length cryomodule for 4 elliptical, with CERN (SPL)
  - Existing ion source and RFQ in Catania and at CEA
  - Control system HW unit with SW interface ("Control box")
  - Beam instrumentation

- Planned and proposed prototypes in construction phase based on preparatory work in DU phase (2013++)
  - RF source, control and distribution system in Uppsala
  - Full length cryomodules for all SC cavity types
  - Beam instrumentation
  - Final version of Ion source in Catania
  - DTL

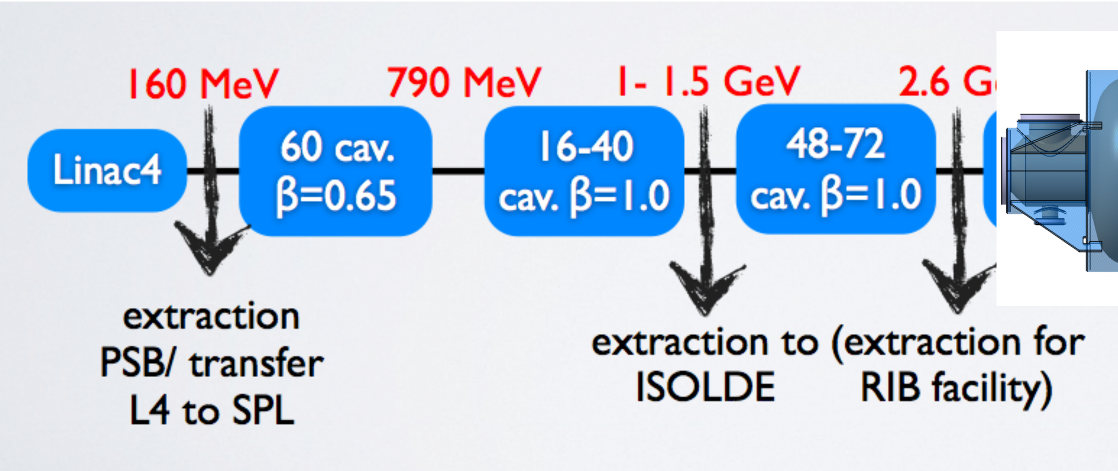

SC elliptical cavity

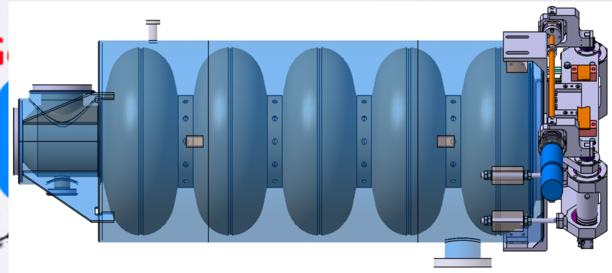

SC spoke cavity

Prototypes

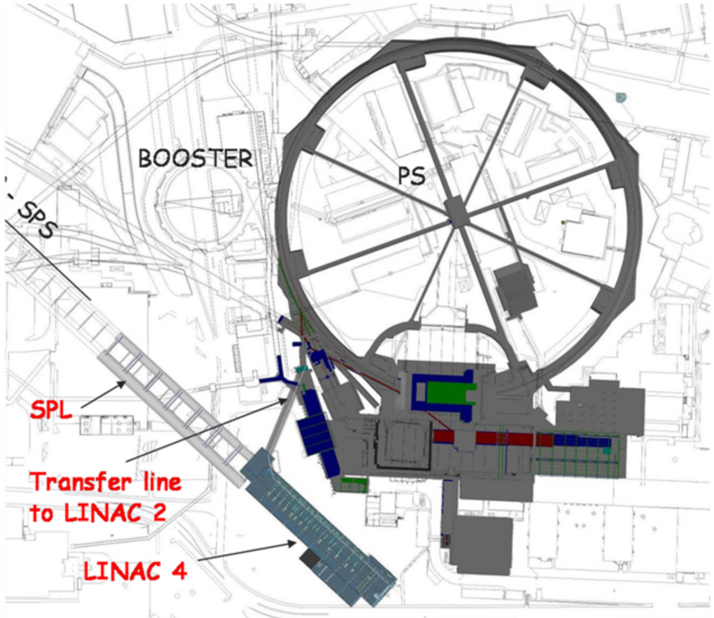


Synergies with High Power SPL study at CERN





SPL SC cavity built within Eucard at CEA-Saclay (beta=1)



Construction of joint prototype cryomodule for ESS and SPL under discussion

ESS Accelerator Division

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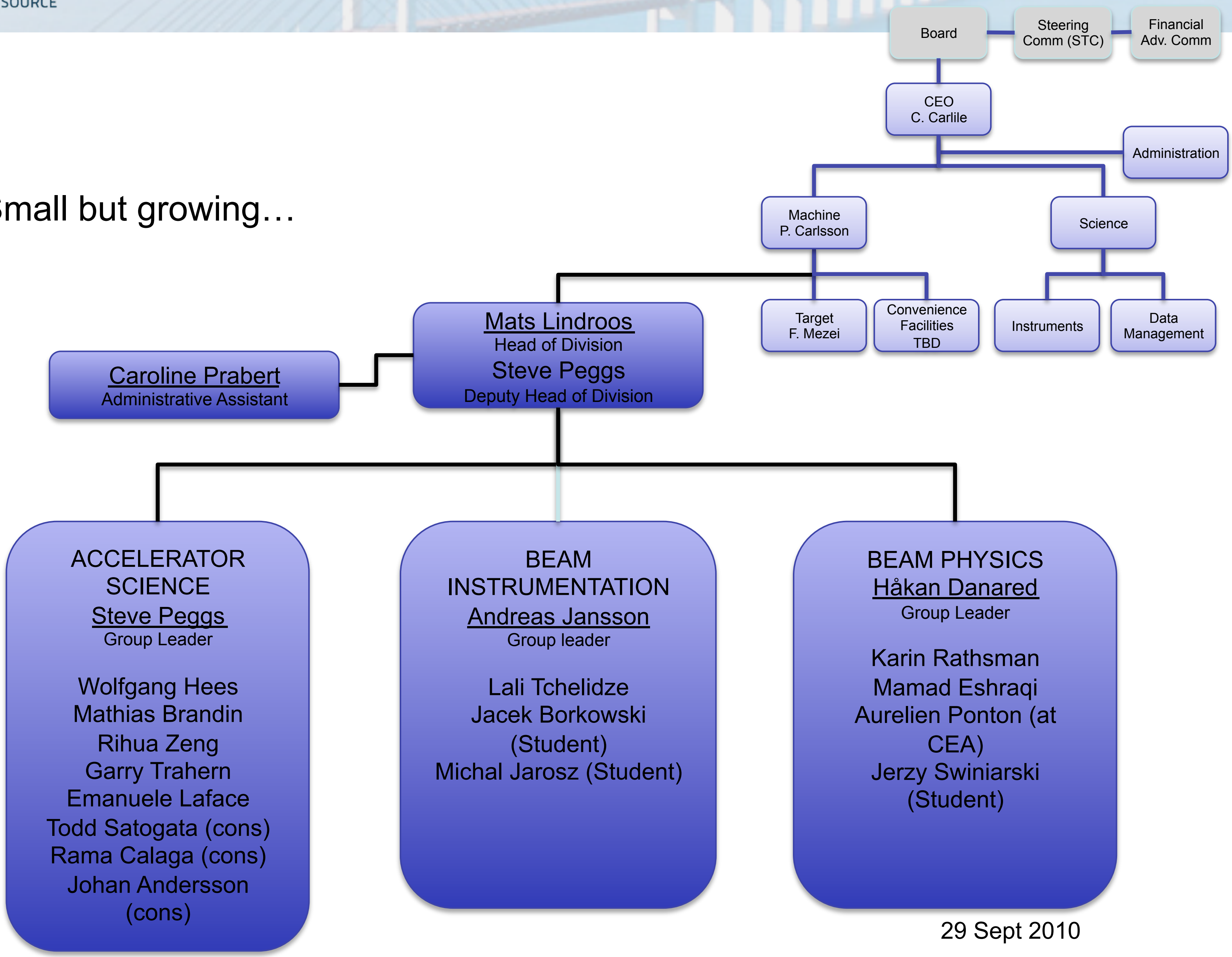
Small but growing…



29 Sept 2010

Beam Instrumentation Strategy

- Collaborate with labs that have similar machines (or similar machine parameters)
- ‘Borrow’ and adapt existing designs where possible, in particular for mission critical diagnostics
  - BPMs, BLMs, BCMs, …
  - Linac4 & SNS are some prime candidates for collaboration
- A particular area that needs R&D is beam size and halo measurements
  - 5MW, need non-invasive or minimally invasive
  - Wire scanners will not work for full pulse
  - Concern about contamination of SC by broken wires
  - ESS use protons, so laser wire is not an option.
  - Will investigate other options (e-beam scanner, IPMs, quadrupole pick-ups, fluorescence, compton scattering, …)

Physical Quantities of Interest

- Beam intensity
- Beam position
- Beam arrival time (phase)
- Beam loss
- Bunch length (longitudinal, also shape)
- Beam size (transverse, core and halo/tails)

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Instrumentation Specs?

Official specs for beam instrumentation will not be available for another year or so (need e.g. error sensitivity analysis).

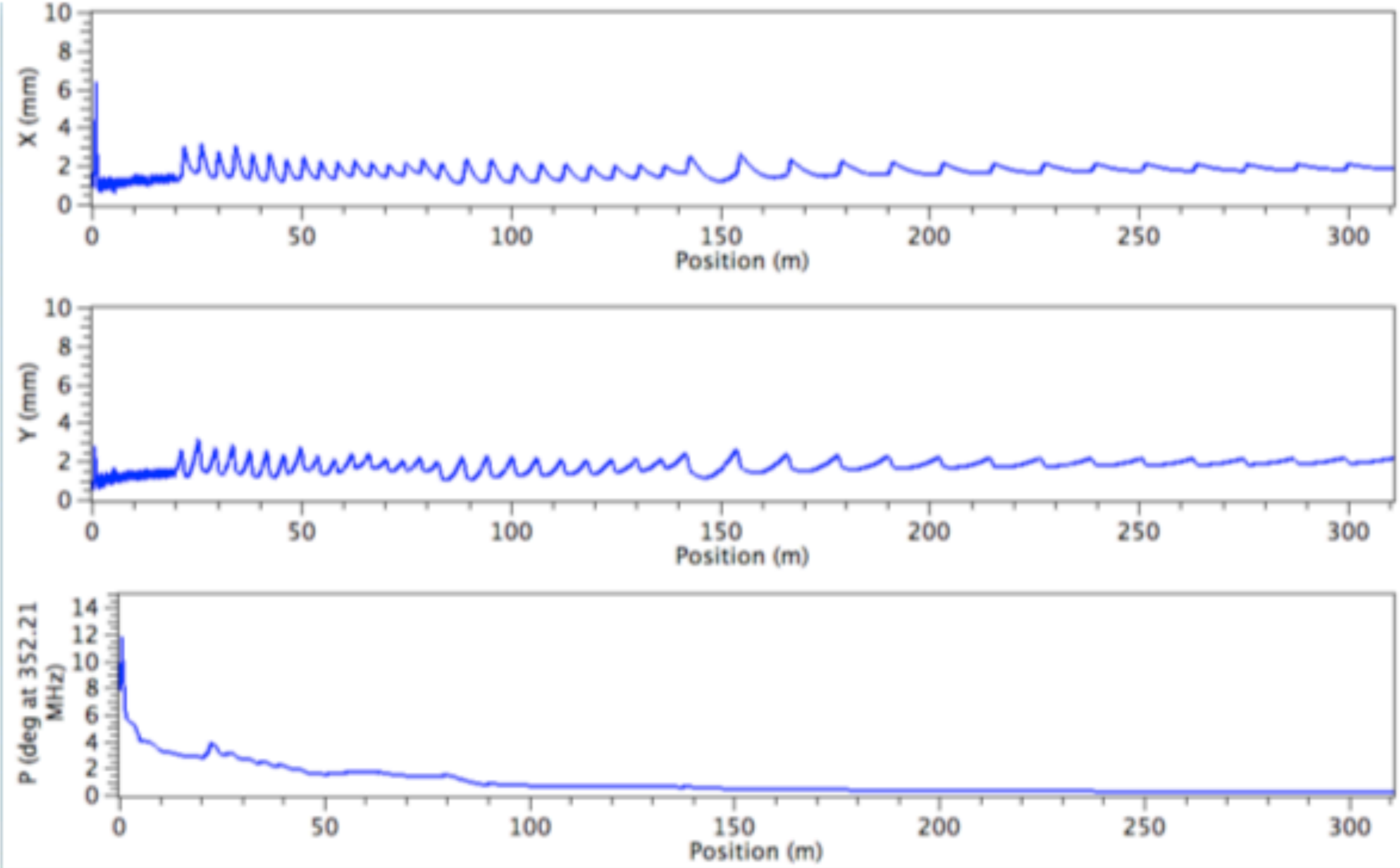
What to do in the meantime?

- Assume bunch timing accuracy of a fraction of a degree of RF phase (time response of order us).
- Assume beam position of a couple % of beam size (time response of order us).
- Assume beam size/bunch length accuracy of 10% (or less) of beam size/bunch length (pulse average).
- Assume we will need (transverse) halo diagnostics.
- Assume we need to measure spot size on target
- Determine the beam loss monitor accuracy and time response requirements based on simulations, taking into account the 1W/m rule of thumb.

Beam Parameters

- Beam Pulse Current: 50 mA (60mA from source)
- Pulse length: 2ms
- Pulse repetition rate: 20Hz
- Bunch repetition rate: 352 MHz (2.8ns)
- Bunch charge: 140 pC
- Bunch length (r.m.s.): 10-40 ps
- Beam size (r.m.s.): 1-3 mm

Beam Envelopes

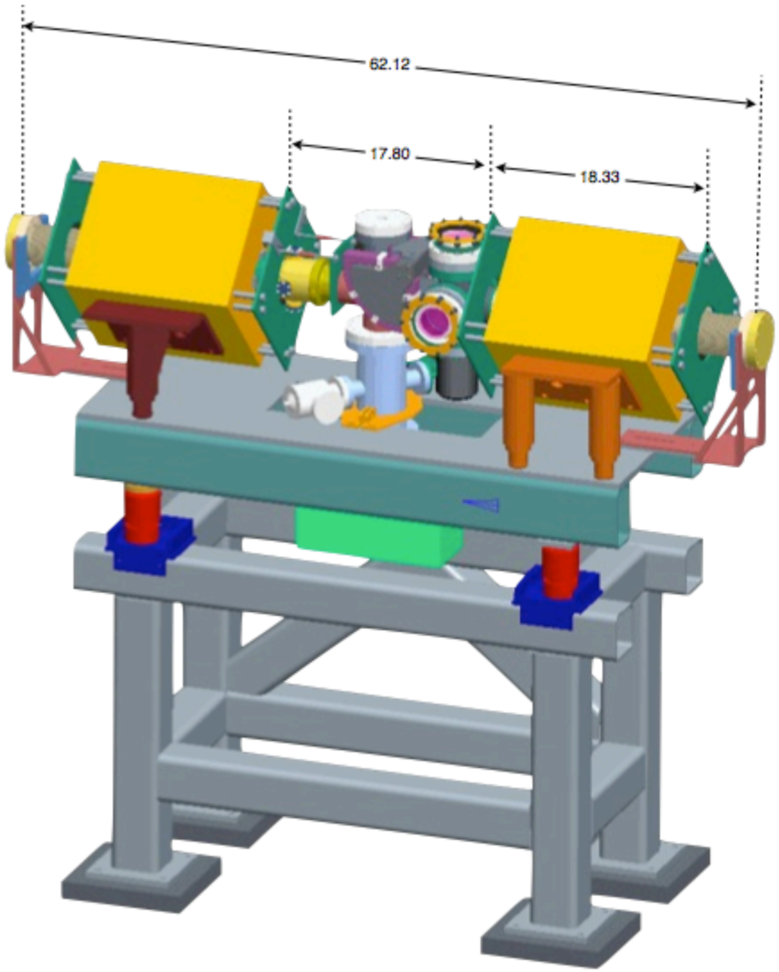


SC LINAC Diagnostic

- Baseline SC linac is currently a continuous cryostat (to be energy efficient)
  - OK (in principle) for BPMs
  - BLMs outside cryostat likely to be blind
  - Where to put profile and bunch length measurement?
- Proposing modular design with a “utility section” between cryomodules which can be operated warm or cold-ish (50-80K).
  - Would decouple diagnostics development from cryomodule design.
- Investigating cryogenic BLMs

Space restriction

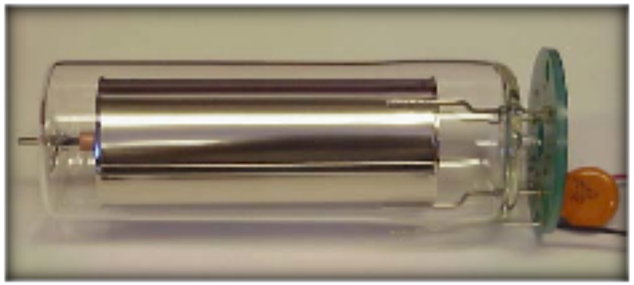
- Linac designers do not like drift spaces for beam dynamics reasons
- There is pressure to keep machine short to save tunnel construction cost
- Limited space for diagnostics (46cm/CM in SNS)



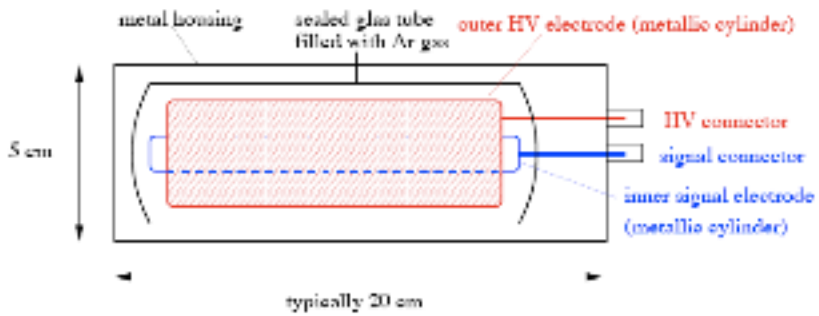
SNS warm doublet with instrumentation space

Beam Loss Monitors

- Arguably the most important diagnostic system at ESS.
- Important input to machine protection system. ESS will not run without them.
- Distributed all along linac, assume one or several per tank/cryomodule.
- Exact location, type and sensitivity of detectors should be studied carefully
  - LHC or SNS type ionization chambers could be used
  - May also need other detectors such as PIN diodes, scintillator/PM, neutron detectors,…
- BLMs system may also be used to measure machine activation and cavity performance (X-ray emission)

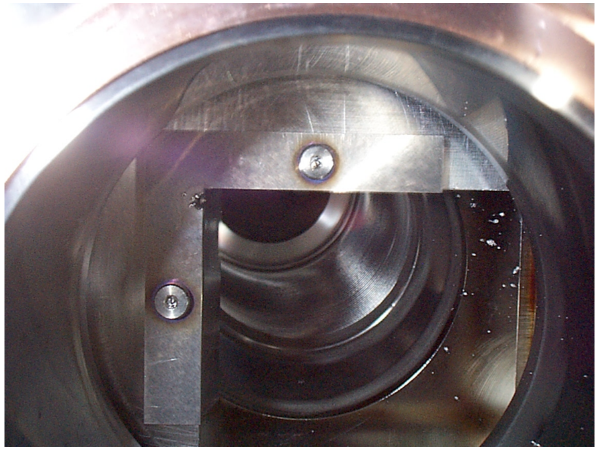


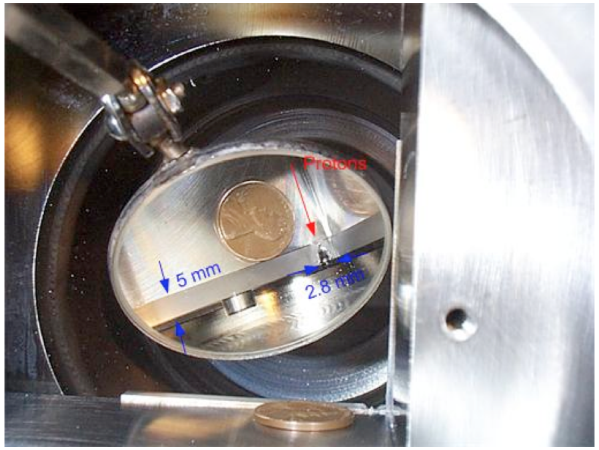
Measurement of charged particles *only.*

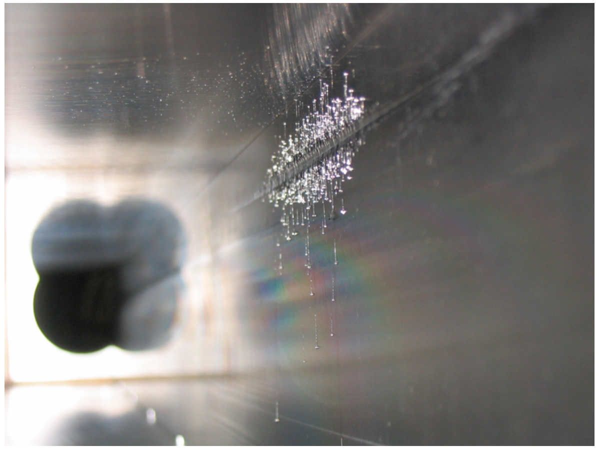


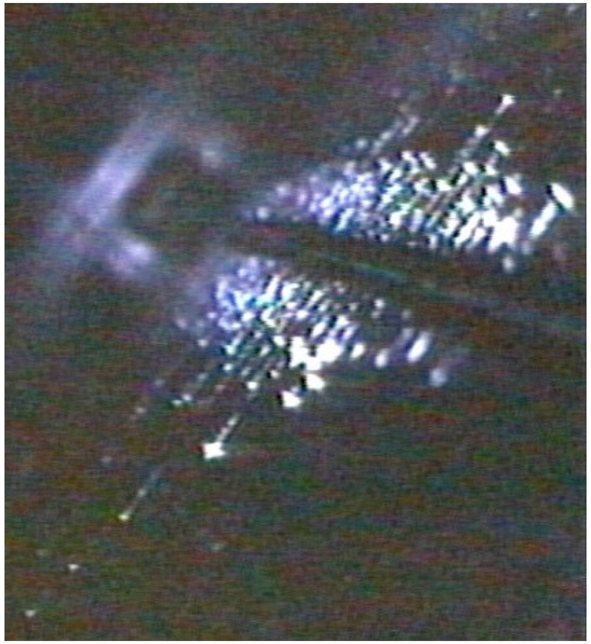
Creation of Ar^{-}-e^{-} pairs and measurement of this current.
Slow time response due to $\sim 100\ \mu s$ drift time of Ar^{-}.
Per definition: direct measurement of dose.

What 1MJ did to the Tevatron









Tevatron 16 House Quench on December 5, 2003 (BLM system too slow)

Beam Position Monitors

- As BLMs, BPMs need to work from day one.
- Assume one dual plane stripline or button BPM per lattice cell/cryomodule, with narrowband signal processing.
- Also to be used as phase/arrival time monitors
- Input to Machine Protection System?
- BPMs could potentially also be used to get information on beam size (quadrupole BPM)
- Will likely also instrument HOM dampers to use as position monitors.

Transverse Profile Diagnostics

- Baseline solution: Wire Scanner in special "short pulse" mode
  - How to guarantee short pulse?
- Also investigate non-invasive methods.
  - Electron beam scanner
  - Ionization profile monitor
  - Quadrupole pick-ups
  - Fluorescence
  - Compton scattering
  - …
- Cryogenic operation?

Wires originally planned for SNS, with reduced pulse length (100us). No show stoppers found, laser wire chosen for extra safety and versatility.
SNS studies indicated ideally one needed every tank/cryomodule for proper matching.

Bunch Length Diagnostics

- Possible options:
  - Feschenko style Bunch Shape Monitor
  - Electro-optical technique
  - …
- How does a birefringent crystal deal with radiation
- Can the BSM share a wire (or wire mount) with the wire scanners?
- Cryogenic operation?

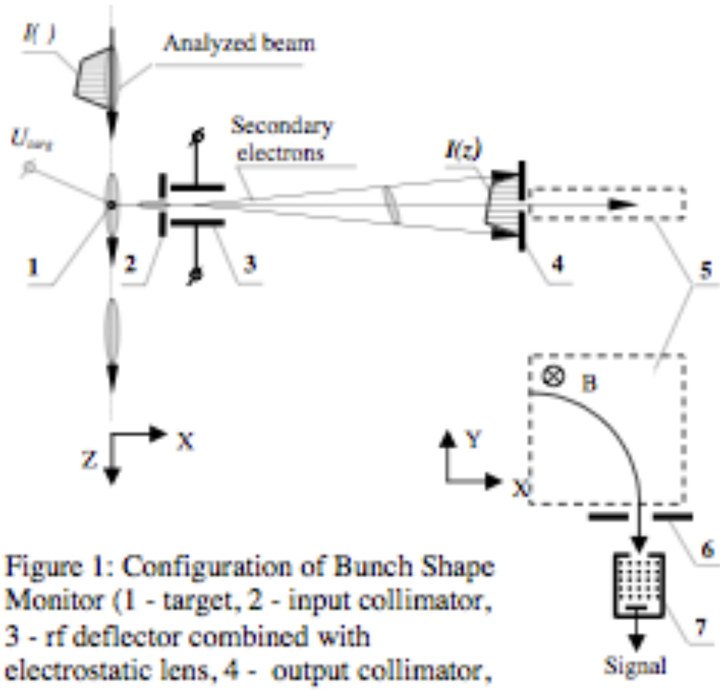


Figure 1: Configuration of Bunch Shape Monitor (1 - target, 2 - input collimator, 3 - rf deflector combined with electrostatic lens, 4 - output collimator, 5 – bending magnet, 6 – collimator, 7 – Secondary Electron Multiplier).

EUROPEAN SPALLATION SOURCE

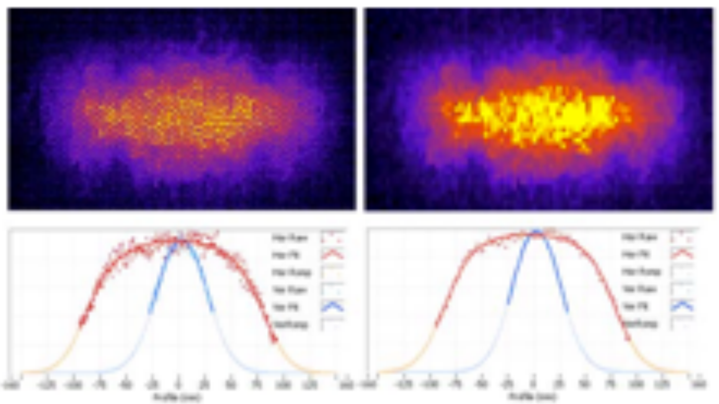
Halo Diagnostics

- Possible options for transverse halo
  - Wire scanners (high gain mode)
  - Instrumented (active) scrapers
  - Vibrating wire
  - …
- Cryogenic operation?

Vibrating wire measures frequency shift due to halo particles heating up the wire.

Target spot size

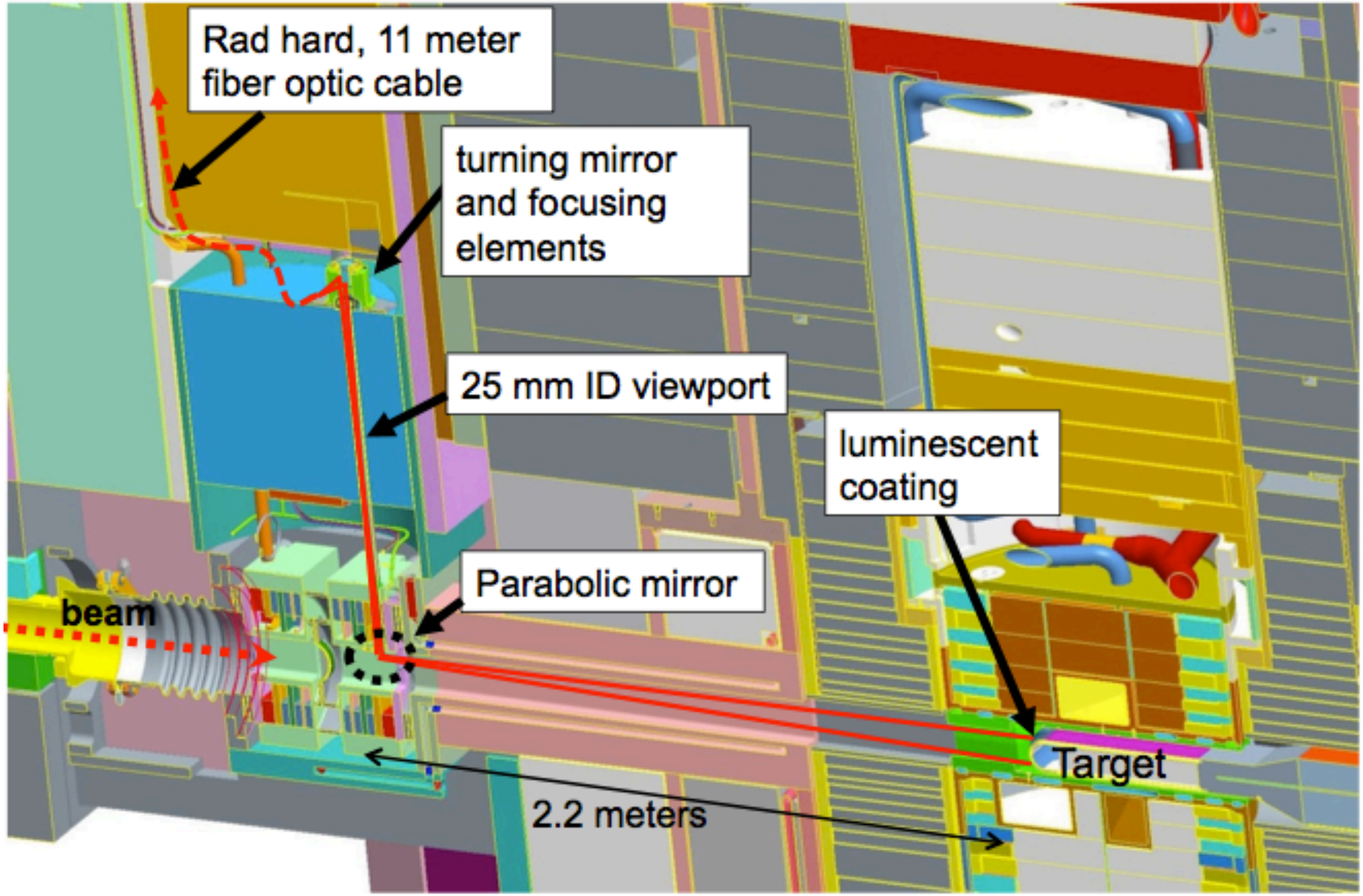
- SNS target coated with CrAl2O3, works fine
  - Radiation reduces the light yield, but the reduction is uniform and seems to have stabilized
- Could also look at OTR from proton beam window
- Challenge is to bring optical signal out through target shielding stack



Target with Cr:Al2O3 coating

W. Blokland et al, BIW10

SNS Target Diagnotics System



Summary

- ESS will be the worlds most powerful neutron source
- Based on a 5MW 2.5GeV proton linac
- The project is currently in a preparatory phase, construction expected to start in 2013
- There are interesting beam diagnostics challenges specific to high power proton (not H-) operation, limited space, and possibly cryogenic operation.
    - In particular, related to beam dimensions (length, size and halo)
  - Looking for collaborators!

Acknowledgement

Many thanks to all colleagues and collaborators from whom I have borrowed many slides and figures.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