ESS PROGRESSING INTO CONSTRUCTION

Mats Lindroos
Head of accelerator at ESS
Adjungated Professor at Lund University, Physics
And the ESS accelerator collaboration

www.europeanspallationsource.se
13 May 2016
A European research center for the world
A European research center for the world
Progress on civil construction

27 April 2016
Progress on civil construction

27 April 2016
Progress on civil construction

27 April 2016

EV=20.1%
Neutrons & x-rays: similar methods, sensitive to different elements.
Neutrons

Its discovery
James Chadwick
1932
\((\alpha,n)\) reaction
Its discovery
James Chadwick
1932
($\alpha$,n) reaction

Neutrons
Its discovery
James Chadwick
1932
(α,n) reaction

“Whatever the radiation from Be may be, it has most remarkable properties”
Neutrons are beautiful!

<table>
<thead>
<tr>
<th>Wave</th>
<th>Magnetic moment</th>
<th>Particle</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Wave Image" /></td>
<td><img src="image2.png" alt="Magnetic moment Image" /></td>
<td><img src="image3.png" alt="Particle Image" /></td>
<td><img src="image4.png" alt="Neutral Image" /></td>
</tr>
</tbody>
</table>
Neutrons are beautiful!
Neutrons are beautiful!
Neutrons are beautiful!

Wave  Magnetic moment  Particle  Neutral
Neutrons are beautiful!

Diffractometers - Measure structures
  – Where atoms and molecules are

Spectrometers - Measure dynamics
  – What atoms and molecules do
Neutrons are beautiful!

Diffractometers - Measure structures
  — Where atoms and molecules are

Spectrometers - Measure dynamics
  — What atoms and molecules do
Some visions for neutron and light source science

- Higher (Room?) Temperature Super Conductors
- Hydrogen storage substrate
- Efficient membrane for fuel cells
- Flexible and highly efficient solar cells
- Understanding liquid membranes
- Nano scaled structures for controlled drug release
- Self healing materials – smart materials
- Spintronics - Spin-state as a storage of data ($10^{23}$ gain in capacity)
- CO$_2$ sequestration
- Neutron electric dipole moment
- Neutron oscillations
- And much more...
Journey to deliver the world’s leading facility for research using neutrons

- **2003**: First European design effort of ESS completed
- **2009**: Decision: ESS will be built in Lund
- **2012**: ESS Design Update phase complete
- **2014**: Construction work starts on the site
- **2019**: First beam on Target
- **2023**: ESS starts user program
- **2025**: ESS construction complete
ESS design

Total cost: 1843 MEuros 2013
ESS design

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High Power Linear Accelerator:
- Energy: 2 GeV
- Rep. Rate: 14 Hz
- Current: 62.5 mA

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Target Station:
- He-gas cooled rotating W-target (5MW average power)
- 42 beam ports

Total cost: 1843 MEuros 2013
High Power Linear Accelerator:
- Energy: 2 GeV
- Rep. Rate: 14 Hz
- Current: 62.5 mA

Target Station:
- He-gas cooled rotating W-target (5MW average power)
- 42 beam ports

16 Instruments in Construction budget
Committed to deliver 22 instruments by 2028
Peak flux ~30-100 brighter than the ILL

Total cost: 1843 MEuros 2013
Long-pulse performance

Brightness (n/cm²/s/sr/Å)

λ = 1.5 Å

ESS 5 MW
2015 design

Possibilities of pulse shaping

UK TS1 128 kW
UK TS2 32 kW
SNS 1-2 MW
JPARC 0.3-1 MW
ILL 57 MW

ESS 5 MW
2012 design (TDR)
Financing includes cash and deliverables

Host Countries of Sweden and Denmark

- Construction: 47.5%
- Operations: 15%

In-kind Deliverables: ~3%
Cash Investment: ~97%

Non Host Member Countries

- Construction: 52.5%
- Operations: 85%

In-kind Deliverables: ~70%
Cash Investment: ~30%
Financing includes cash and deliverables

Host Countries of Sweden

- Construction: 47.5%
- Operations: 15%

Non Host Member Countries

- Construction: 52.5%
- Operations: 85%

In-kind Deliverables: ~3%
Cash Investment: ~97%
Construction cost: €1.84 Billion
In-kind: €747.5 Million

40.5%
ESS In-kind goals

Construction cost: €1.84 Billion
In-kind: €747.5 Million

40.5%

Controls: €37 M
Target: €54 M
Instruments (NSS): €228 M
Accelerator: €382 M

Cash: €350 M
IKC: €382 M

Agreed IKC, 0.4%
Planned IKC, 51.7%
Possible IKC, 12.7%
Not IKC, 32.1%
Partner institutions responsible for delivering the design & construction of ESS

Aarhus University
Atomki - Institute for Nuclear Research
Agder University
Bergen University
CEA Saclay, Paris
Centre for Energy Research, Budapest
Centre for Nuclear Research, Poland, (NCBJ)
CERN, Geneva
CNR, Rome
CNRS Orsay, Paris
Cockcroft Institute, Daresbury
DESY, Hamburg
Delft University of Technology
Edinburgh University
Elettra – Sincrotrone Trieste
ESS Bilbao
Forschungszentrum Jülich
Helmholtz-Zentrum Geesthacht
Huddersfield University
IFJ PAN, Krakow
INFN, Catania
INFN, Legnaro
INFN, Milan
Institute for Energy Research (IFE)
Institut Laue-Langevin (ILL)
Rutherford-Appleton Laboratory, Oxford (ISIS)
Kopenhagen University
Laboratoire Léon Brillouin (LLB)
Lodz University of Technology
Lund University
Nuclear Physics Institute of the ASCR
Oslo University
Paul Sherrer Institute
Roskilde University
Tallinn Technical University
Technical University of Chemnitz
Technical University of Denmark
Technical University Munich
Science and Technology Facilities Council (STFC)
University of Tartu
Uppsala University
WIGNER Research Centre for Physics
Wroclaw University of Technology
Warsaw University of Technology
Zurich University of Applied Sciences (ZHAW)
Accelerator Division – Scope
Accelerator Technical performances

Design Drivers:
High Average Beam Power
5 MW
High Peak Beam Power
125 MW
High Availability

Key parameters:
- 2.86 ms pulses
- 2 GeV
- 62.5 mA peak
- 14 Hz
- Protons (H+)
- Low losses
- Minimize energy use
- Flexible design for mitigation and future upgrades

• First beam at 572 MeV in June 2019
• 5 MW capacity for 2023

RF sources for HB part is the scope contingency for accelerator
Accelerator Collaboration - Accelerator
Accelerator Collaboration - Accelerator

Source | LEBT | RFQ | MEBT | DTL | Spokes | Medium β | High β | HEBT & Contingency | Target

- 2.4 m
- 4.6 m
- 8.8 m
- 39 m
- 56 m
- 77 m
- 179 m

- 75 keV
- 3.6 MeV
- 90 MeV
- 216 MeV
- 571 MeV
- 2000 MeV

- 352.21 MHz
- 704.42 MHz
Accelerator Collaboration – RF and STS

Concept, courtesy of GRE (UK)
Open in-kind contributions

<table>
<thead>
<tr>
<th>Topic</th>
<th>Value (k€)</th>
</tr>
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<tbody>
<tr>
<td>Cold linac wire scanners</td>
<td>274</td>
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<tr>
<td>Beam instrumentation for target and tuning beam dump</td>
<td>564</td>
</tr>
<tr>
<td>Medium-beta klystrons</td>
<td>10 965</td>
</tr>
<tr>
<td>High-beta klystrons or IOTs</td>
<td>26 135</td>
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<tr>
<td>Cables, power distribution cabinets</td>
<td>1 600</td>
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<tr>
<td>Design, construction, installation of water cooling skids and pipes</td>
<td>2 000</td>
</tr>
<tr>
<td>High-beta modulators</td>
<td>23 507</td>
</tr>
</tbody>
</table>

Although several of these are large commercial items with little or small potential for developments but with large commercial risk, potential interest has been expressed by a few partners.

Total remaining possible IK is 65 045 k€
High Level Master Schedule (Level 1)
# High Level Master Schedule (Level 1)

**Total:** 513 M€

### HIGH LEVEL SCHEDULE - ESS ACCELERATOR

<table>
<thead>
<tr>
<th>Year</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q1</th>
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</tbody>
</table>

**Activities:**
- Conceptual Design: ESS ADU starts
- SC RF: First cavity ordered, CMs prototype launched, Spoke cavities prototypes tested, Spoke & MB CM production launched, Spoke CM testing starts, MB CM testing starts, RFI 1st spoke CM, RFI DTL4 (1st DTL)
- NLINAC: ISc DT4 (1st DTL) assembly starts, ISc & LEBT & RFQ & MEBT commissioned
- Technical Stop: NLINC ready
- Technical Stop: SC LINAC 2 GeV ready
- Technical Stop: RF for high beta ready
- Technical Stop: 2 GeV protons available

**Budget Profile - Construction Phase**

- TOTAL: 513 M€

**Data Extracted by P6 Planning - April 2016**

**Prepared by WP Leaders & L. Karlsson, G. Gunnarsson**

**Checked by J. Weinend**

**Approved by M. Lindroos**
Integration Test Stand – Getting our hands dirty!
Integration Test Stand – Getting our hands dirty!

- Early in 2009 after the ESS site decision the accelerator division (AD) consisted of two person, today we are 86.
- Forming an ESS accelerator collaboration permitted us to early launch a design update and start IK prototyping based on mature designs from very experienced partners.
- The small ESS team initially focused on the Technical requirements, cost book, schedule, finding in-kind partners and recruitment.
- After a few internationally renowned experts joined AD, it permitted some Technical development work to start in Lund e.g. Modulator development, cryogenics work, beam instrumentation and more.
- Today AD focuses on Project management, some technical developments, integration work, technical coordination, installation and RATS planning, commissioning planning and operation planning.
**Microwave Discharge Ion Source (MDIS)**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal proton peak current</td>
<td>74 mA</td>
</tr>
<tr>
<td>Proton fraction</td>
<td>&gt; 80 %</td>
</tr>
<tr>
<td>Stable operation current range</td>
<td>60-74 mA</td>
</tr>
<tr>
<td>Current stability (over 50us period)</td>
<td>± 2 %</td>
</tr>
<tr>
<td>Pulse to pulse variation</td>
<td>± 3.5 %</td>
</tr>
<tr>
<td>Beam Energy</td>
<td>75 keV (200.03)</td>
</tr>
<tr>
<td>Distance between pulses</td>
<td>1 Hz, f &lt;14 Hz</td>
</tr>
<tr>
<td>Restart after vacuum break</td>
<td>&lt;32 h</td>
</tr>
<tr>
<td>Restart after cold start</td>
<td>&lt;16 h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam current change (2 mA step, 13 mA res)</td>
<td>2-74 mA</td>
</tr>
<tr>
<td>Nominal pulse length</td>
<td>2.86 ms</td>
</tr>
<tr>
<td>Pulse length range (±0.001 ms)</td>
<td>±0.005-2.88 ms</td>
</tr>
<tr>
<td>50 % rms norm. emit. at RFQ input</td>
<td>± 3.25 pl, mm, mrad</td>
</tr>
<tr>
<td>Twiss parameter: δ</td>
<td>1.02 ±10%</td>
</tr>
<tr>
<td>Twiss parameter: β</td>
<td>0.11 ±10%</td>
</tr>
<tr>
<td>Rise and fall time</td>
<td>&gt;20 ns</td>
</tr>
<tr>
<td>Maximum LEBT pressure</td>
<td>1×10⁻⁵ mbar</td>
</tr>
</tbody>
</table>
Modulator SML proto status March 2016

Electrical schematic

90 kV operation
Closed loop
Medium beta klystrons

- The Toshiba prototype passed FAT in February and has been delivered to ESS
- Thales and CPI klystrons due May and July respectively
- Operation at low voltage and use of iris on the output maintains high efficiency even at reduced power levels

![Graph showing output power vs drive power for different voltages and currents.](image-url)
Multi beam IOT

- L3 IOT FAT started last week (contractual date October 2016)
- 15 kW solid state driver delivered (to L3) for use with factory testing
- Driver, HV PSU, interlocks being testing on the single beam IOT, prior to MB-IOT tests
- L3 extended testing being discussed to follow up on the contractual factory testing

- Thales/CPI IOT is planned for delivery to CERN in July 2016
- Tube will be integrated at CERN by Thales
- CERN test stand (for Thales/CPI) under construction
- Formal Factory testing expected November 2016
Spoke Cavities design & prototype performances

Spoke cavity prototype test results (Jan15 – Feb16):

- Excellent performances, well within specifications (both on Eacc & Qo)

ESS Double-Spoke prototype cavities
ZA-01 Romea, ZA-02 Giulietta & SD-01 Germaine

- Chemical etching
- Ultra pure water high pressure rinsing
Selected technologies

- Medium beta cavity prototype
- High beta cavity prototype with its helium tank
- Blank assembly of the spaceframe inside the vacuum tank
- Q curve of the High beta prototype cavities
Summary

• ESS is well into construction and the accelerator project is progressing according to plan towards first beam at 572 MeV in June 2019

• The ESS facility is built by a collaboration of some 100 research institutes and universities
  – The Accelerator is built with a very high percentage of IK contributions (>50%) with most major accelerator systems being designed, prototypes and built outside ESS and we are still looking for partners!

• Prototypes for the all major accelerator elements are now being assembled and tested and the low energy part is under manufacturing

• The Accelerator Division is recruiting according to plan and will be ready to take ownership of the accelerator, install it, commission it and enter it into operation for the 2019 milestone

• Most future large scale project are likely to be IK projects and this is a very powerful model. Together we are strongest!
Many thanks to all my colleagues in the ESS accelerator collaboration

Thank you for listening!
Many thanks to all my colleagues in the ESS accelerator collaboration.

Thank you for listening!
A partnership of 17 European nations
Extracted teeth restored with glass ionomer cement (GIC)

TEAM
Supervisors and contacts: H.N. Bordallo (NBI-KU & ESS), A.R. Benetti (Department of Odontology, KU), M. Strobl (ESS)

Collaborators: Nikolay Kardjilov (HZB), Denis Okhimenko (KU, Chemistry)

Researcher: Marcella C. Berg (PhD Student), Casper Madsen (MSc Student)
Neutron Imaging - Examples

\[ I = I_0 e^{-\mu d} \]

neutron \( \mu \) different to x-ray

contrast hydrogen / deuterium.

not increasing with \( Z^2 \)
Neutron Imaging - Examples

\[ I = I_0 e^{-\mu d} \]

neutron $\mu$ different to x-ray

contrast hydrogen / deuterium.

not increasing with $Z^2$
## RF Technical performances

<table>
<thead>
<tr>
<th>Source</th>
<th>Energy (MeV)</th>
<th>Frequency /MHz</th>
<th>No. of Cavities</th>
<th>βg</th>
<th>Temp / K</th>
<th>RF power /kW</th>
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</thead>
<tbody>
<tr>
<td>Source</td>
<td>0.075</td>
<td>-</td>
<td>0</td>
<td>–</td>
<td>~300</td>
<td>–</td>
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<tr>
<td>LEBT</td>
<td>0.075</td>
<td>-</td>
<td>0</td>
<td>–</td>
<td>~300</td>
<td>–</td>
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<tr>
<td>RFQ</td>
<td>3.6</td>
<td>352.21</td>
<td>1</td>
<td>–</td>
<td>~300</td>
<td>1600</td>
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<tr>
<td>MEBT</td>
<td>3.6</td>
<td>352.21</td>
<td>3</td>
<td>–</td>
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<td>20</td>
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<td>DTL</td>
<td>90</td>
<td>352.21</td>
<td>5</td>
<td>–</td>
<td>~300</td>
<td>2200</td>
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<td>Spoke</td>
<td>220</td>
<td>352.21</td>
<td>26 (2/C)</td>
<td>0.5 β_{opt}</td>
<td>~2</td>
<td>330</td>
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<td>Medium β</td>
<td>571</td>
<td>704.42</td>
<td>36 (4/C)</td>
<td>0.67</td>
<td>~2</td>
<td>870</td>
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<td>High β</td>
<td>2000</td>
<td>704.42</td>
<td>84 (4/C)</td>
<td>0.86</td>
<td>~2</td>
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<td>HEBT</td>
<td>2000</td>
<td>–</td>
<td>0</td>
<td>–</td>
<td>~300</td>
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</table>
High level accomplishments last year

- A plan for all Preliminary and Critical Design Reviews have been established and is executed and a detailed plan for installation has been completed.
- Prototypes for e.g. Elliptical SC cavities, spoke cavities, modulator, spoke RF amplifiers, klystrons have been completed and are being tested.
- The ion source (IS2), the accelerator cryoplant and test stand and instruments cryoplant is under construction. The RFQ and MEBT manufacturing have been launched and the DTL manufacturing will be launched in April.
- A task force with contracted staff from industry has been set-up to complete all Technical annexes for IK contracts.
- A test stand proposed by last years annual review for integrations tests have been set-up with equipment on loan from CERN and a license to operate the klystron will soon be available.
- The ESS modulator prototype presently being tested at the test stand, the first ESS 704 MHz klystron has gone through Factory acceptance test and has been received in Lund for testing.
- The division has been re-organized to avoid split responsibility for WPs between groups and to strengthen work on interfaces. The first 3 technicians have been recruited.
- Topical regular collaboration workshops have been launched for SCRF and beam instrumentation to strengthen communication and know-how transfer between all involved partners.