Low energy front-end: RFQ

Aurélien Ponton

European Spallation Source ESS AB
Accelerator Division

CEA in-kind contribution to the ESS accelerator,
European Spallation Source head quarters,
Lund, Sweden 2012-10-10

Outline

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Introduction

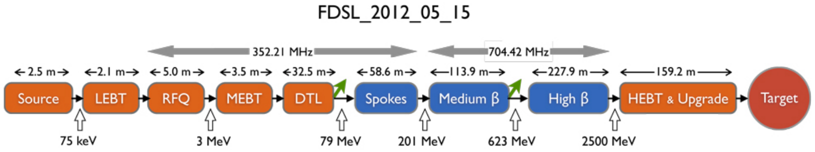

Figure: ESS linac baseline layout.

Work units	Leader	Institutes	Locations
Management	S. Gammino	INFN-LNS	Catania
Source and LEBT	L. Celona	INFN-LNS	Catania
RFQ	B. Pottin	CEA-Irfu	Saclay
MEBT	I. Bustinduy	ESS-Bilbao	Bilbao
DTL	A. Pisent	INFN-LNL	Legnaro

Table: From ADU to contruction phase.

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Outline

Meeting and presentations

- **May 2011**, *"RFQ input to MEBT"*, ESS-Bilbao meeting on MEBT and Spoke Resonators
  → Pole tip design of the 5 m RFQ completed
- **July 2011**, *"RFQ: basic considerations, achievements and criticalities"*, ESS warm linac meeting
  → RF 2D model, vacuum grids, tuners, 3D model of the end-cells
- **December 2011**, *"The ESS front end"*, ESS AD retreat
  → BD RFQs comparison: needs >5 m to meet the ESS requirements
- **February 2012**, *"Defining the RFQ requirements"*, ESS warm linac meeting
  → RFQ designers work with a list of requirements
- **June 2012**, *"Beam dynamics", "IPHI status", "RF design", "Stability of shorter RFQs"*, ESS warm linac internal review
  → RF design completed on the 5 m RFQ, stability of a shorter RFQ evaluated, preliminary BD design of a 4 m RFQ (green light from the reviewers)

Milestones

CEA contribution

- **July 2011**, *"The ESS RFQ pole tip geometry profile"*, ESS Technote
- **September 2011**, *"High Power Proton Linac Front-End: Beam Dynamics Investigation and Plans for the ESS"*, IPAC'11
- **May 2012**, *"RF design of the ESS RFQ"*, IPAC'12
- **October 2012**, *"TDR"*

The 5 m RFQ has been considered in the CEA studies

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Ressource criticality

Recent change in the RFQ design: from 5 to 4 m

- **September 2012**, *"the ESS RFQ beam dynamics design"*, LINAC'12
- **October 2012**, *"TDR"*

- Additional resources required from CEA to perform the RF design and the thermo-mechanical calculations on the 4 m RFQ (methodology already established)
- Availibility of CEA staff may be an issue
- Task to be achieved in parallel with the preparation of the industrial drawings

Early agreement between CEA and ESS is mandatory

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Previous requirements

Imposed/Limitations

- initial operation at peak current of 50 mA but upgradable to 75 mA
- beam loss above 2 MeV is limited to 1 W/m
- both transverse and longitudinal emittances are minimized to reduce the potential for subsequent halo development
- there should be no longitudinal tails as they are known to translate into transverse halo

Additional requirements

- Kilpatrick limit: $K_p \leq 1.8$
- constant vane radius of curvature
- 20 % margin: 90 mA design

2011 design:
4 vanes RFQ composed of 5 segments of 1 m each

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4 vanes RFQ composed of 5 segments of 1 m each

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New requirements

Imposed/Limitations

- peak operational beam current will not exceed 50 mA
- no limit to allowable beam loss below 3 MeV
- halo development and beam loss in the high energy linac section traceable to the RFQ are minimized
- no longitudinal tails as they are known to translate into transverse halo
- phase advances are matched to adjacent sections

2012 BD design:
4 vanes RFQ composed of 4 segments of 1 m each

To be completed in 2013:

- **RF design with new resource**
- **Thermo-mecanichal calculations with unused 2012 resource**

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Benefits of a shorter RFQ

1. A shorter RFQ has reduced the potential fabrication and operational risks since less tuners and vacuum and RF seals as well as vacuum pumps are required.
2. The construction cost will also be lower as machining and brazing are known to impact significantly the overall cost of the RFQ.
3. Less power dissipated in copper will as well reduce the cost in operation.
4. Removing one segment will finally ease the alignment procedure.

Outline

Without the Saclay test stand for the ESS front-end

Name	Duration	Start	Finish
Warm Linac Construction	1,569 days	**1/1/13 8:00 AM**	**1/4/19 5:00 PM**
Management	1,569 days	1/1/13 8:00 AM	1/4/19 5:00 PM
Source and LEBT	1,049 days	**1/1/13 8:00 AM**	**1/6/17 5:00 PM**
LEBT procurement	149 days	1/1/13 8:00 AM	7/26/13 5:00 PM
LEBT prototype	175 days	7/29/13 8:00 AM	3/28/14 5:00 PM
Proton Source #1 prototype	260 days	4/1/13 7:00 AM	3/28/14 5:00 PM
Proton Source #2 procurement	150 days	11/3/14 8:00 AM	5/29/15 5:00 PM
Proton Source #1 and LEBT beam test	300 days	3/31/14 8:00 AM	5/22/15 5:00 PM
Proton Source #1 dismantle and transport to Lund	20 days	5/25/15 8:00 AM	6/19/15 5:00 PM
Proton Source #2 assembly	260 days	6/1/15 8:00 AM	5/27/16 5:00 PM
Proton Source #2 and LEBT beam test	120 days	5/30/16 8:00 AM	11/11/16 5:00 PM
Proton Source #2 and LEBT dismantle and transport to Lund	40 days	11/14/16 8:00 AM	1/6/17 5:00 PM
RFQ	1,149 days	**1/1/13 8:00 AM**	**5/26/17 5:00 PM**
Industrial drawings ready for procurement	174 days	1/1/13 8:00 AM	8/30/13 5:00 PM
Tests with IPHI (ESS configuration)	129 days	4/1/13 7:00 AM	9/26/13 5:00 PM
Procurement	255 days	9/2/13 8:00 AM	8/22/14 5:00 PM
Adjustments	105 days	3/31/14 7:00 AM	8/22/14 5:00 PM
Construction and assembly	680 days	8/25/14 8:00 AM	3/31/17 5:00 PM
Dismantle and transport to Lund	40 days	4/3/17 8:00 AM	5/26/17 5:00 PM
MEBT	810 days	**4/1/13 7:00 AM**	**5/6/16 5:00 PM**
Prototype	195 days	4/1/13 7:00 AM	12/27/13 5:00 PM
Procurement	150 days	12/30/13 8:00 AM	7/25/14 5:00 PM
Adjustments	75 days	7/28/14 8:00 AM	11/7/14 5:00 PM
Assembly and light tests	350 days	11/10/14 8:00 AM	3/11/16 5:00 PM
Dismantle and transport to Lund	40 days	3/14/16 8:00 AM	5/6/16 5:00 PM

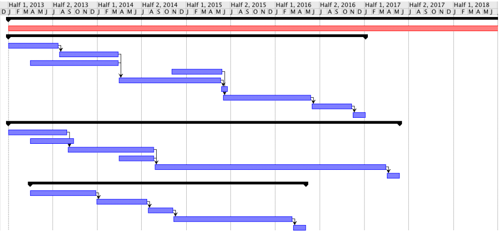

Figure: Front-end construction planning without the Saclay test stand.

With the Saclay test stand for the ESS front-end

Name	Duration	Start	Finish
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Proton Source #2 dismantle and transport to Lund	20 days	8/22/16 8:00 AM	9/16/16 5:00 PM
⊟RFQ	1,109 days	1/1/13 8:00 AM	3/31/17 5:00 PM
Industrial drawings ready for procurement	174 days	1/1/13 8:00 AM	8/30/13 5:00 PM
Tests with IPHI (ESS configuration)	129 days	4/1/13 7:00 AM	9/26/13 5:00 PM
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Construction and assembly	680 days	8/25/14 8:00 AM	3/31/17 5:00 PM
⊟Saclay test	711 days	9/4/15 8:00 AM	5/25/18 5:00 PM
Source and LEBT beam testing	260 days	9/4/15 8:00 AM	9/1/16 5:00 PM
Source, LEBT and RFQ beam test	120 days	4/3/17 8:00 AM	9/15/17 5:00 PM
MEBT installation and beam test	120 days	9/18/17 8:00 AM	3/2/18 5:00 PM
Source, LEBT, RFQ and MEBT dismantle and transport to Lund	60 days	3/5/18 8:00 AM	5/25/18 5:00 PM
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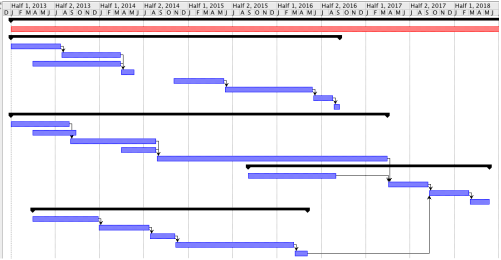

Figure: Front-end construction planning with the Saclay test stand.

The Saclay test:

- **711 working days**
- **180 days of high power test**

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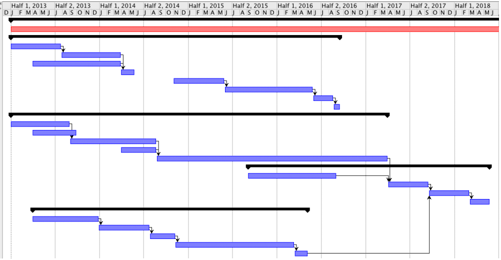

Figure: Front-end construction planning with the Saclay test stand.

The Saclay test:

- 711 **working days**
- 180 **days of high power test**

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Using the CERN test stands

We are investigating all possibilities for testing the ESS RFQ:

- RF conditioning
- test with beam

ESS and CERN are currently discussing potential availibilities of the CERN test stand (LINAC 4 RFQ) for the ESS RFQ and front-end.

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Tentative labor cost estimate in man.days for prototyping, assembly and test

	Without Saclay TS	With Saclay TS
Source and LEBT	3070	1510
RFQ	3236	3236
MEBT	1635	1635
Saclay test	0	3200
Total	7941	9581

Table: Man.days comparison.

- the Saclay front-end test requires 1640 man.days more (+20 %)
- it corresponds to $\sim$ 7 persons working during one year
- it is roughly the amount of external workers that ESS will need for the conditionning and the commissioning of the front-end

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Full front-end test

From source to MEBT

Pro

- Room and infrastructure available
- CEA expertise
- Pre-conditioning of the front-end
- Plug and run strategy
- Not a labor cost issue
- Lower potential risks during installation
- Participation of the CEA-Irfu/SIS to help us with controls

Contra

1. Schedule [a]:
   - RF ready for RFQ: December 2017
   - fron-end at Lund: May 2018 (+1 year)
2. Modulator and high power klystron:
   - Not available at Saclay
   - ESS needs only 9 months of high power test

[a] If the RFQ is not commissioned at high powe months of commissioning may be necessary

Front-end test without MEBT

	Without Saclay TS	With Saclay TS
Source and LEBT	3080	1510
RFQ	3236	3236
MEBT	1635	1635
Saclay test	0	2000
Total	7951	8381

Table: Man.days comparison (tentative estimate).

the Saclay front-end test without MEBT requires:

- 430 man.days more (+5 %): $<$ 2 persons working during one year
- 591 days with 120 days of high power tests
- The front-end will arrive at Lund in December 2017

Outline

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Conclusions

We have to discuss the following points:

1. Team availability for the RF design and thermo-mechanical calculations of the 4 m RFQ
2. Potential contribution for the RF source necessary for the the ESS front-end beam test at Saclay
3. The SIS participation in the ICS for the front-end