EUROPEAN SPALLATION SOURCE

The ESS Accelerator

LINAC 2012

Mats Lindroos
Head of ESS Accelerator Division and projects

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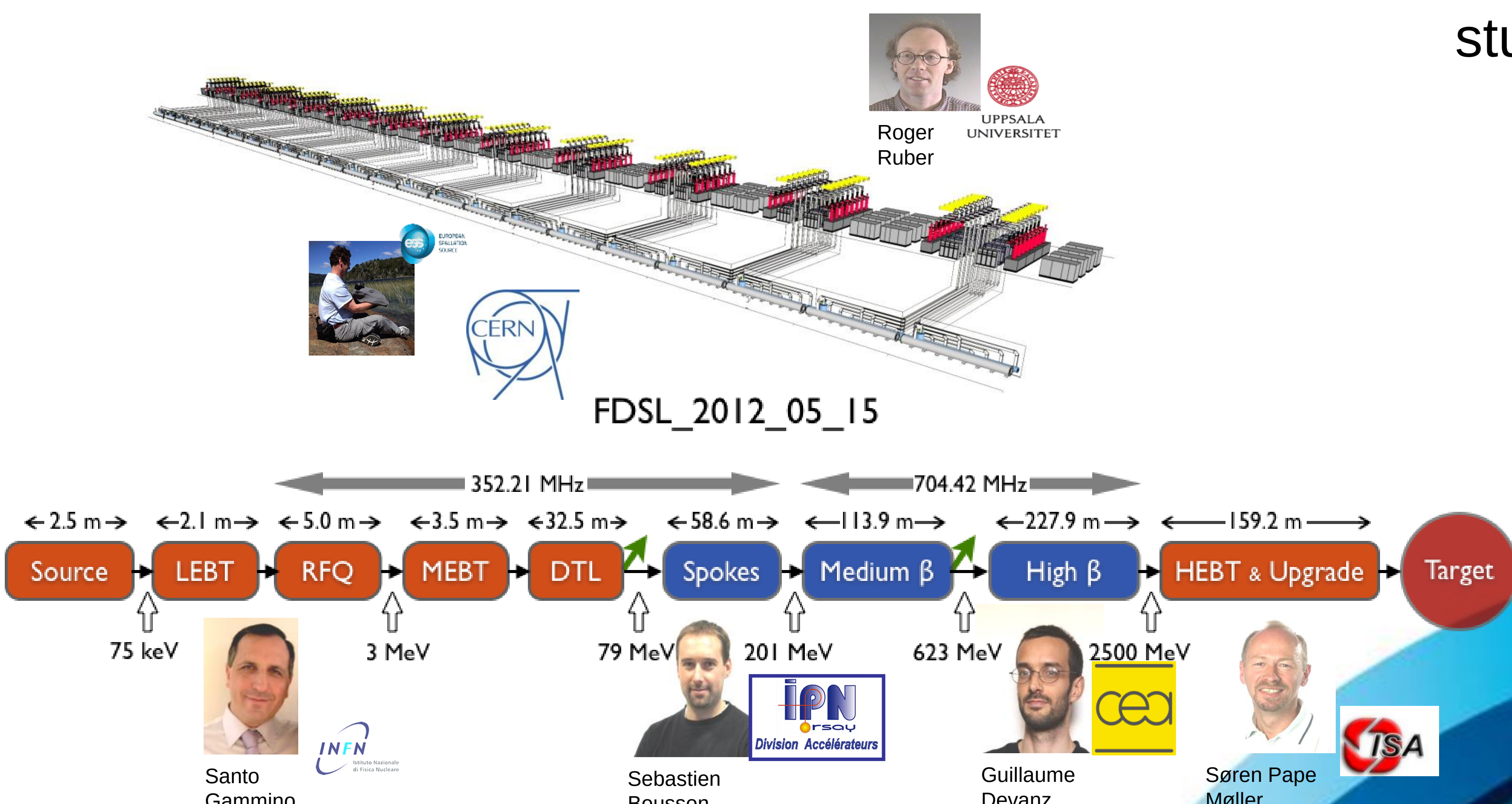
ESS

17 Partners today

Investment: 1478 M€ / ~10y
Operations: 106 M€ / y
Decomm. : 346 M€
(Prices per 2008-01-01)

Facility for the search of new states of matter (ie new materials)

Proposals for nEDM, muons, neutrino physics are being studied



5 MW long pulse source:
- -2.86 ms, 50 mA pulse current, 14 Hz
- -Protons (H+)
- -High availability, >95%
- -First neutrons 2019 with 7 instruments and completion 2025 with 22 instruments at 5 MW operation

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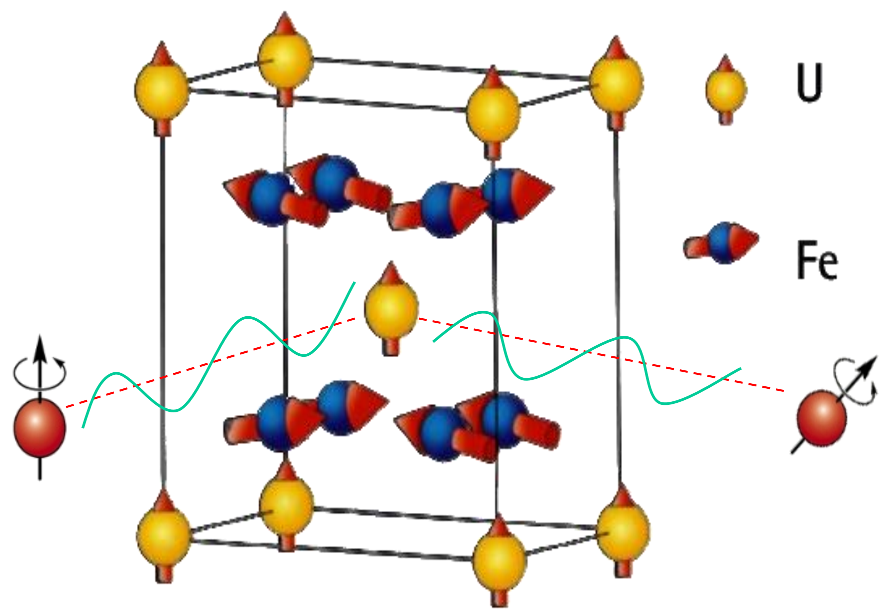
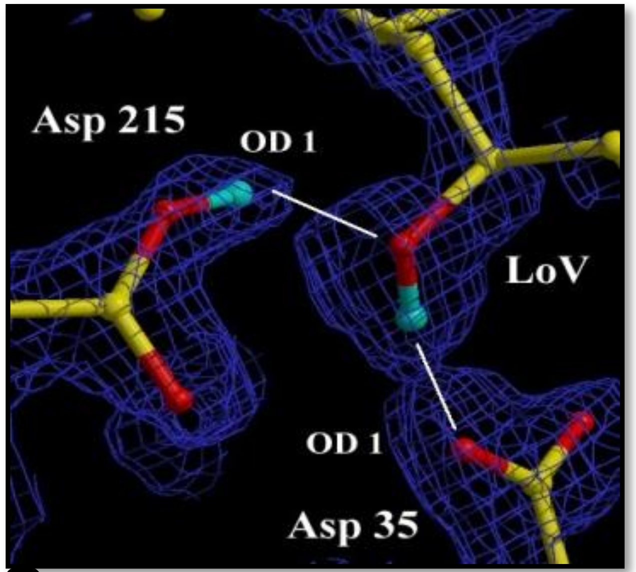
Neutrons are beautiful...

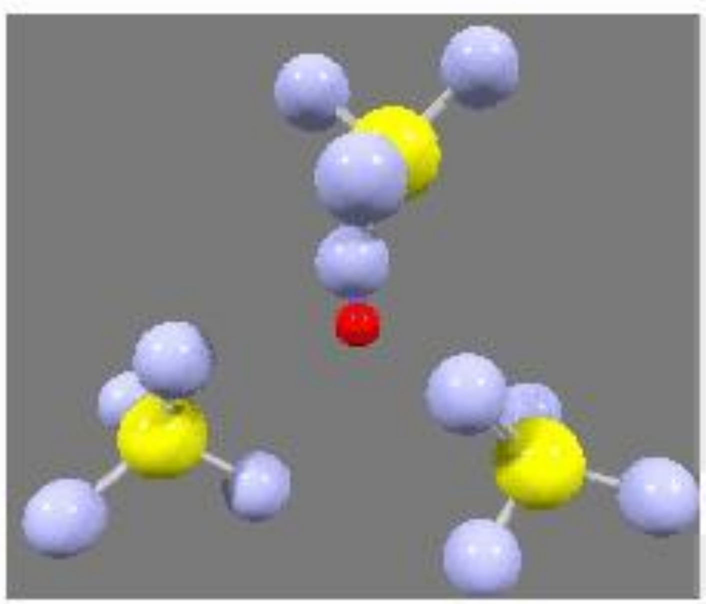


..see magnetic atoms

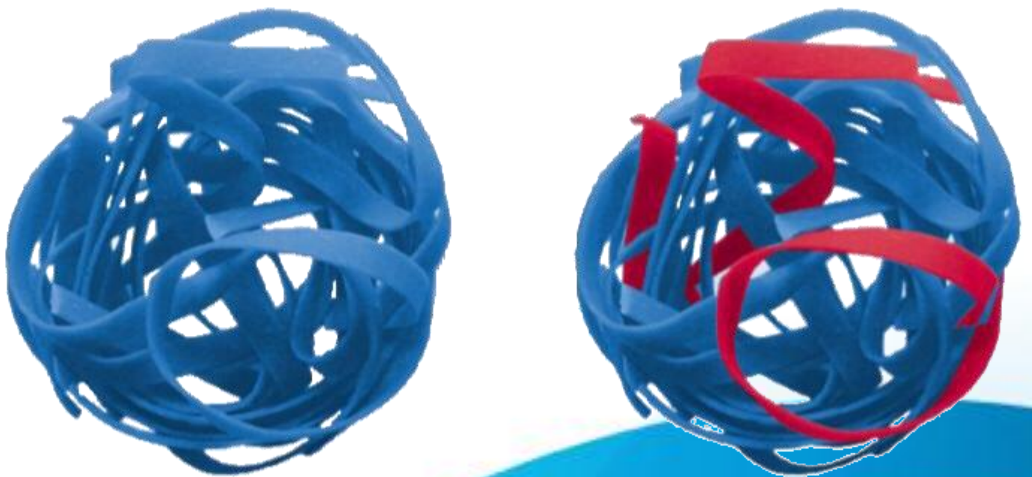
..see inside materials



..see light atoms



..see atoms move

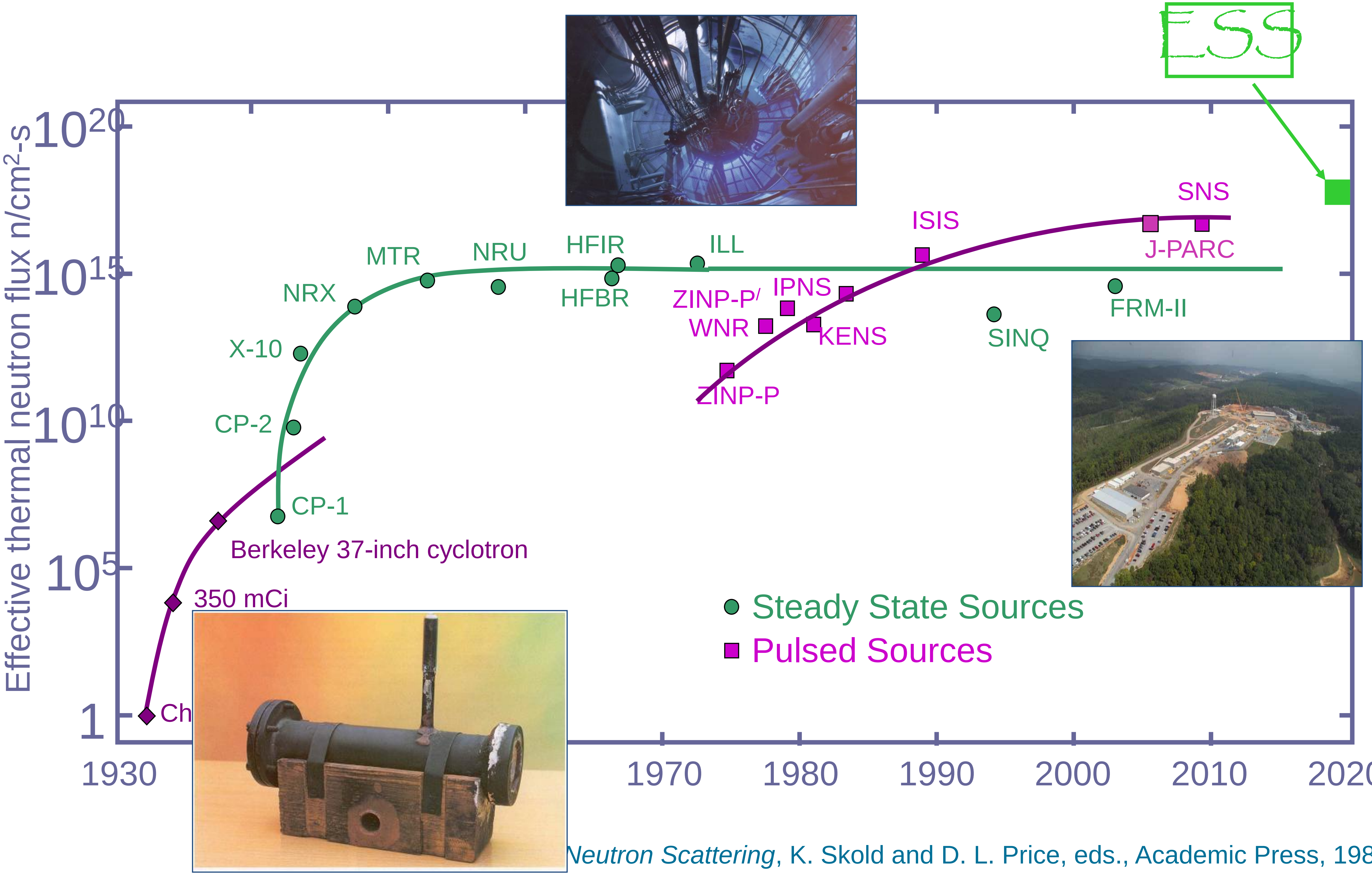


..see isotopes

Courtesy of Ian S. Anderson

Why ESS? - High time average and peak flux

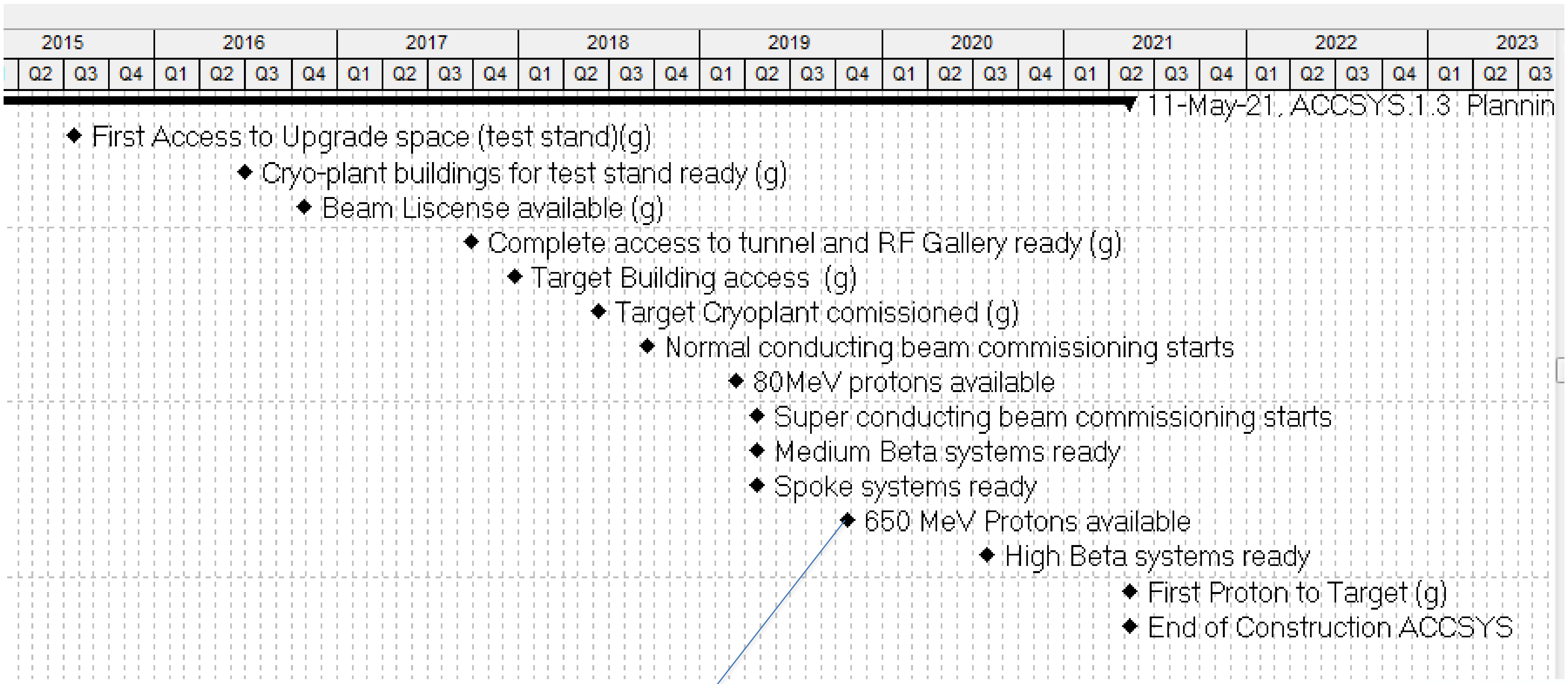
Evolution of the performance of neutron sources



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

ESS Programme Organisation

Accelerator milestones



First Neutrons at ESS!

Accelerator Design Update

Romuald Duperrier (30 years ago)

Steve Peggs

Cristina Oyon

David McGinnis

Work Package (work areas)

1. Management Coordination – ESS AB (Mats Lindroos)
2. Accelerator Science – ESS AB (Steve Peggs)
(3. Infrastructure Services – now ESS AB!)
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 – ESS AB (Dave McGinnis)
19. P2B: Test stands – Uppsala University (Roger Ruber)

Mats Lindroos

Guillaume Devanz

Roger Ruber

UPPSALA UNIVERSITET

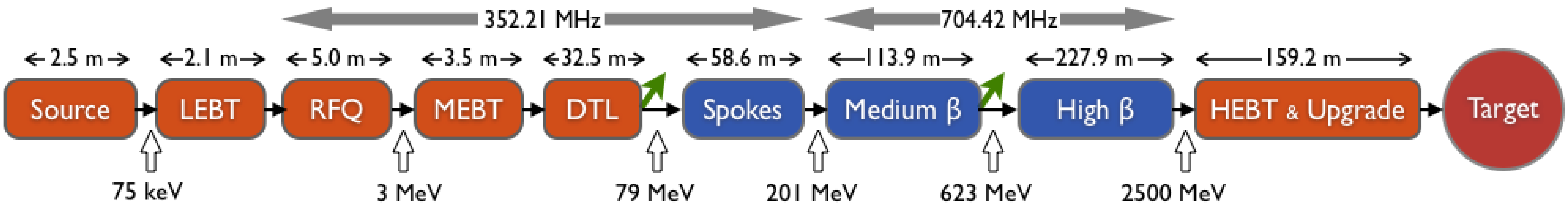
Søren Pape Møller

Santo Gammino

Sebastien Bousson

LINAC layout

FDSL_2012_05_15

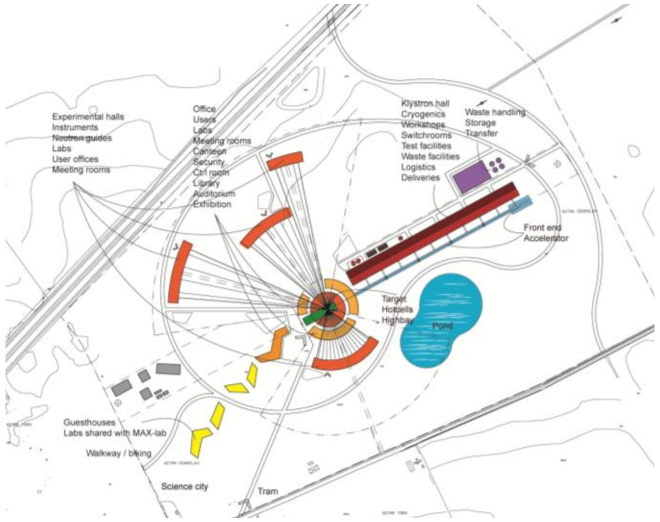


	Length (m)	Input Energy (MeV)	Frequency (MHz)	Geometric β	# of Sections	Temp (K)
LEBT	2.05	75×10^{-3}	--	--	--	≈ 300
RFQ	4.95	75×10^{-3}	352.21	--	1	≈ 300
MEBT	3.53	3	352.21	--	--	≈ 300
DTL	32.58	3	352.21	--	4	≈ 300
Spoke	58.46	79	352.21	0.50	14 (2C)	≈ 2
Medium Beta	113.84	201	704.42	0.67	15 (4C)	≈ 2
High Beta	227.86	623	704.42	0.92	15 × 2 (4C)	≈ 2
HEBT (Projection)	158.66	2500	--	--	--	--

Input to Linac Configuration

Top-level 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%



Mechanical and electromagnetic properties of building blocks

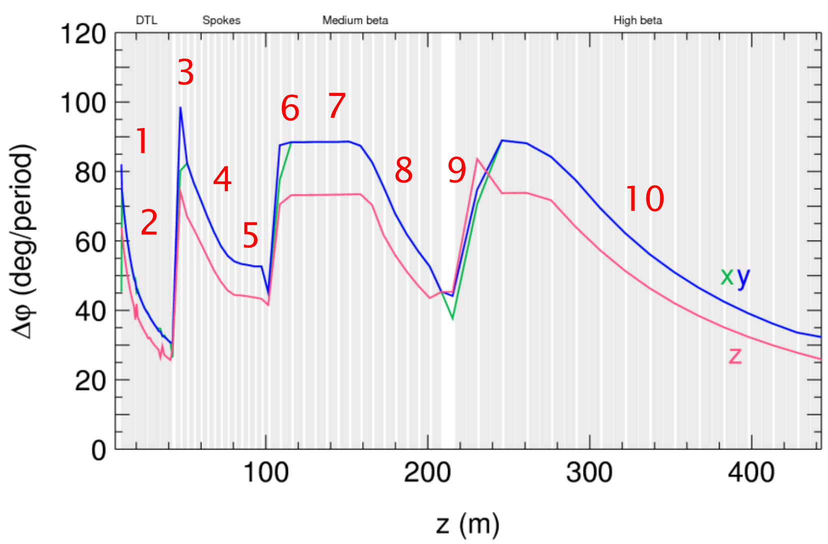
Beam-dynamics laws and rules-of-thumb

Transverse phase advance < 90 deg/cell
Longitudinal phase advance below transverse phase advance
Smooth change of phase advances per meter
Tune depression not too high
Watch out for unwanted cavity modes
Et cetera

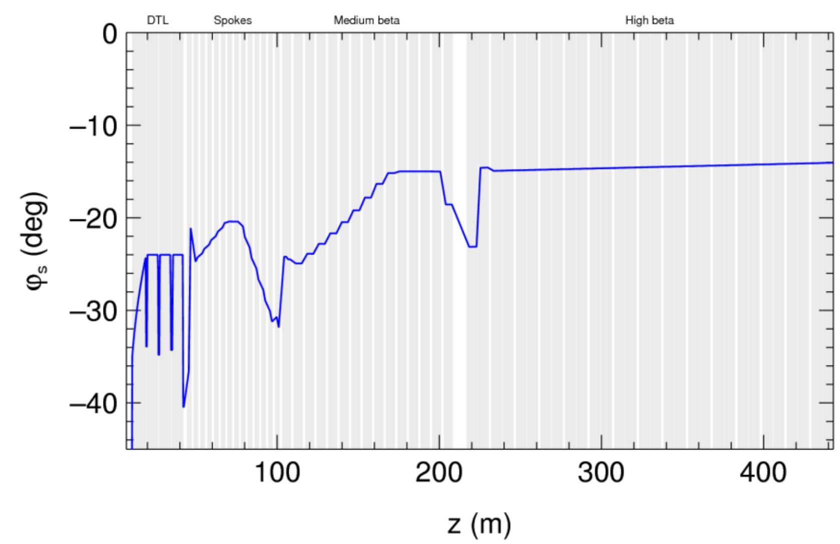
Optimization criteria

Beam quality
Short linac (correlates well with many desirable properties)
Small number of components (reliability)
Upgrade potential
Et cetera

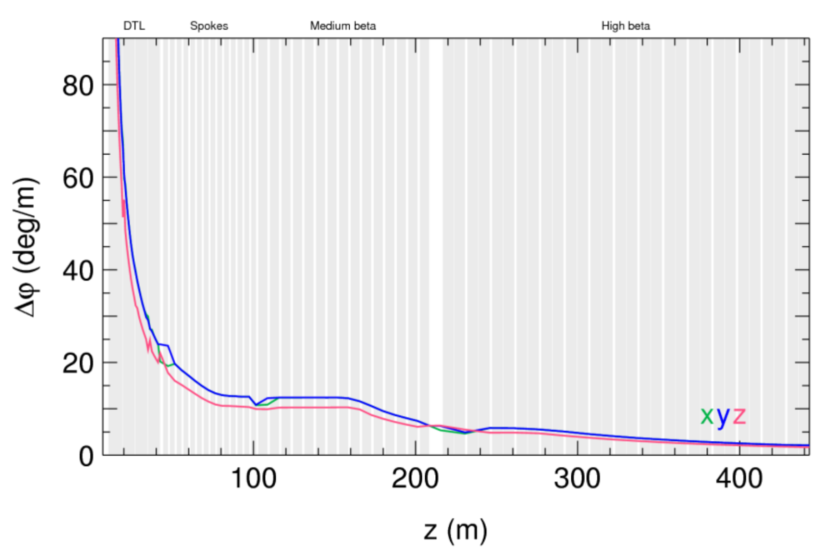
Linac Optics - Longitudinal



Phase advance per transverse period, without space charge. Longitudinal < transverse < 90 degrees to avoid emittance transfer between planes.



Synchronous phase. Maximum energy gain at zero but margin for Δp/p needed.

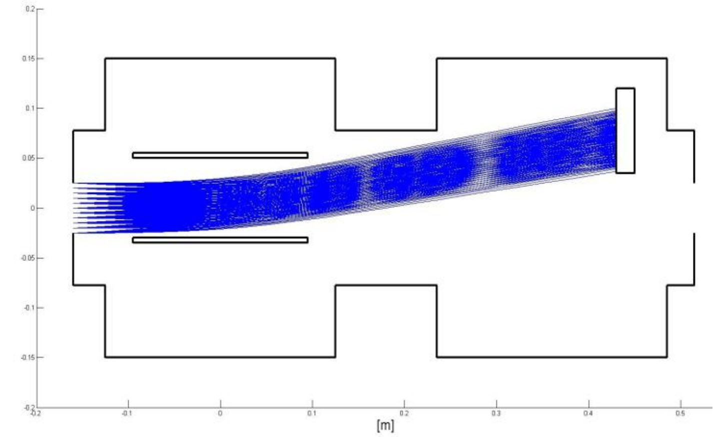


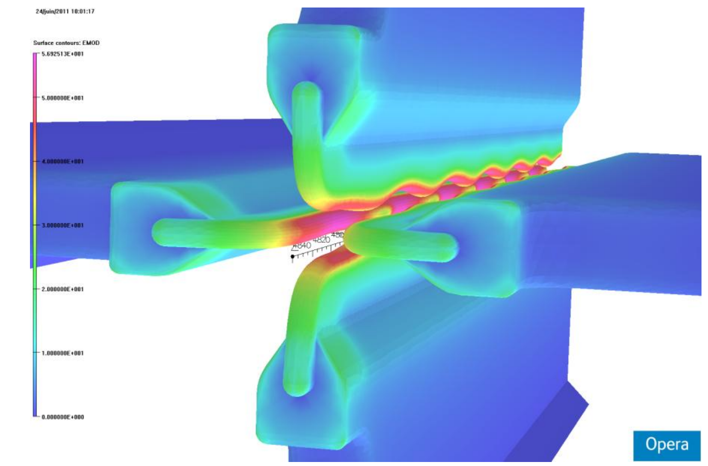
Phase advance per meter, without space charge. Are made smooth functions of z to avoid emittance and halo increase.

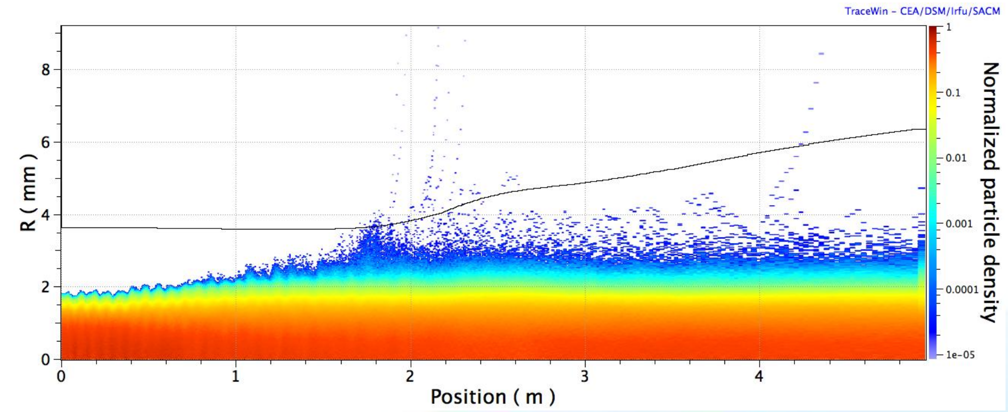
1. RFQ and DTL have strong longitudinal focusing.
2. Phase advance decreases with $(\beta\gamma)^{3/2}$.
3. Spokes have longer period, so same focusing due to mathced cavity voltages gives more phase advance per period.
4. Phase advance decreases with $(\beta\gamma)^{3/2}$, ϕ_s increases to increase energy gain.
5. Decrease ϕ_s to get stronger focusing and more phase advance per meter...
6. ...to match the focusing and phase advance of the medium betas after frequency jump and with higher cavity voltages.
7. Increasing ϕ_s and decreasing $(\beta\gamma)^{3/2}$ reduces focusing, but voltage increase compensates and keeps phase advance at 90° .
8. Again increase focusing, now to match high-beta voltages and to match empty period.
9. Increasing cavity voltage increases focusing and phase advance.
10. Energy gain limited by cavity voltage.

Ion source and NC linac

- Prototype proton ion source operational (and under further development) Catania
- RFQ tests for ESS conditions at CEA
- RFQ design ready for 5 m IPHI like RFQ
- MEBT design work at ESS Bilbao
- DTL design work at ESS and in Legnaro

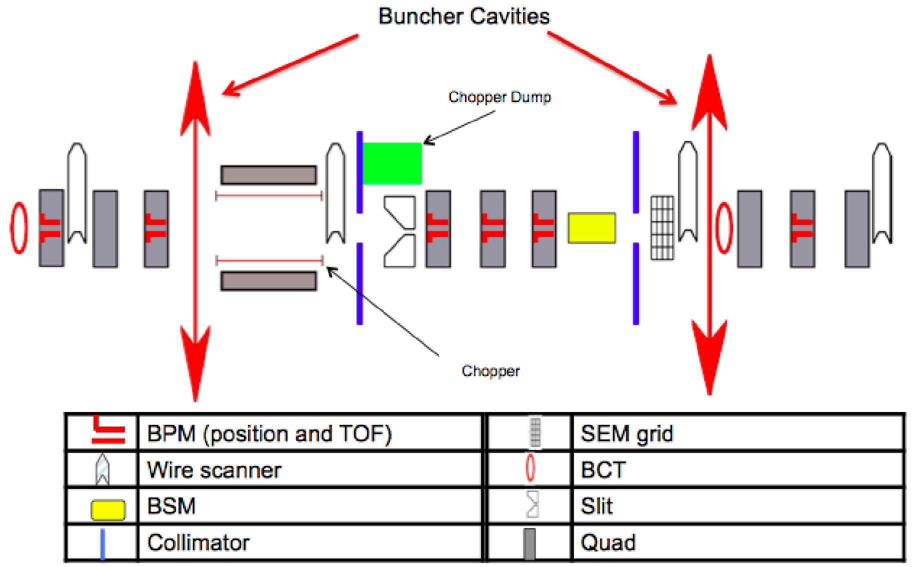




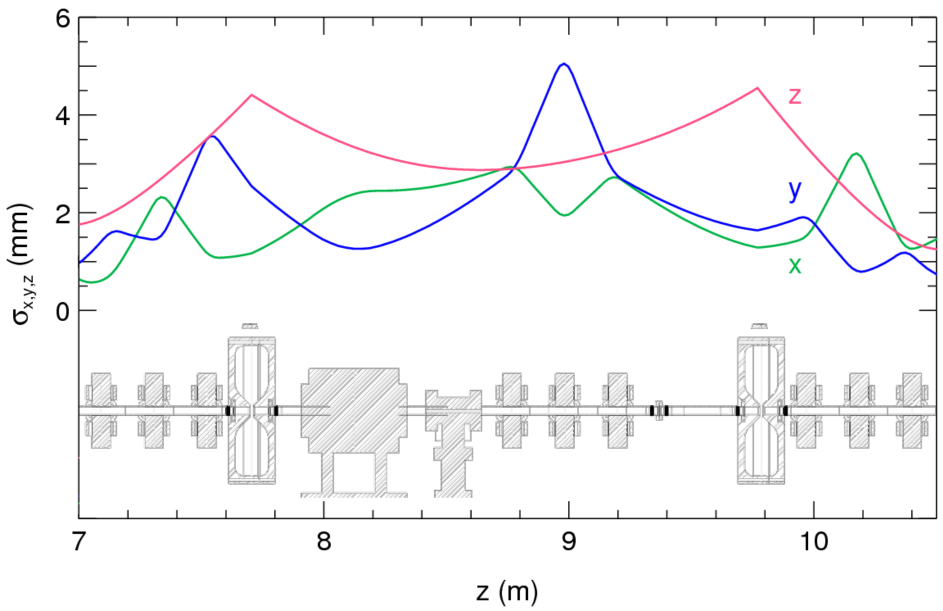


Beam density as a function of radius along the RFQ

Medium-Energy Beam Transport



Schematic design with instrumentation, chopping and collimation.



Mechanical layout and beam-physics design with 10 quadrupoles and 2 buncher cavities.

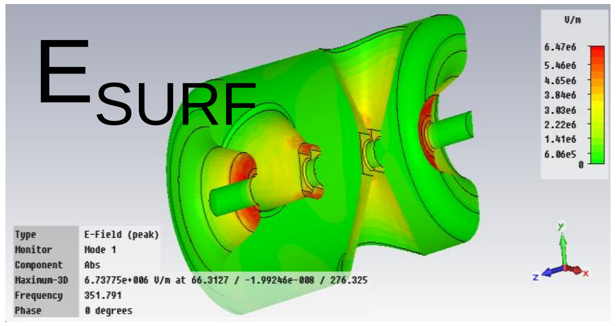
Spoke resonators/cavities

- Spoke cavity RF design:
  - Double spoke beta 0.5

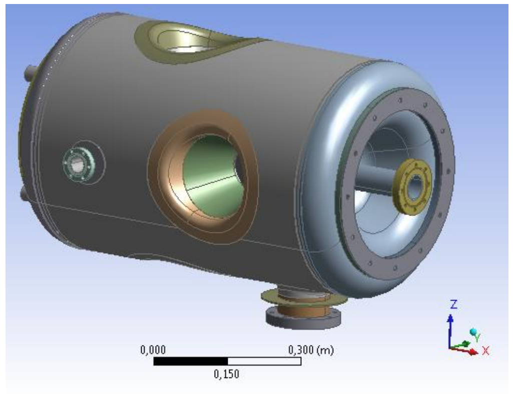
- Spoke cavity mechanical design

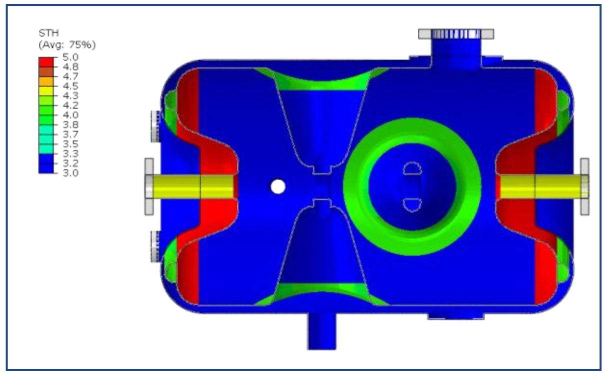
- Power coupler
  - EURISOL type design

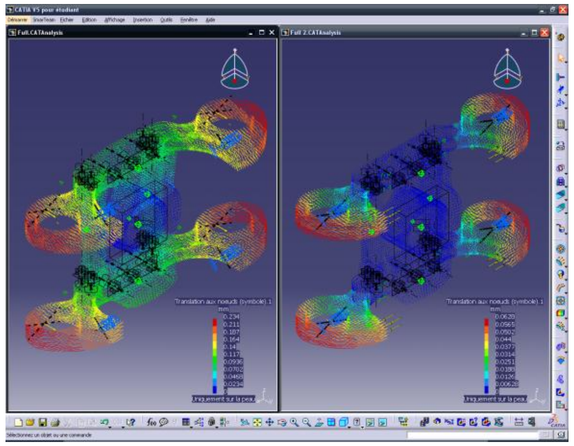
- Spoke cold tuning system

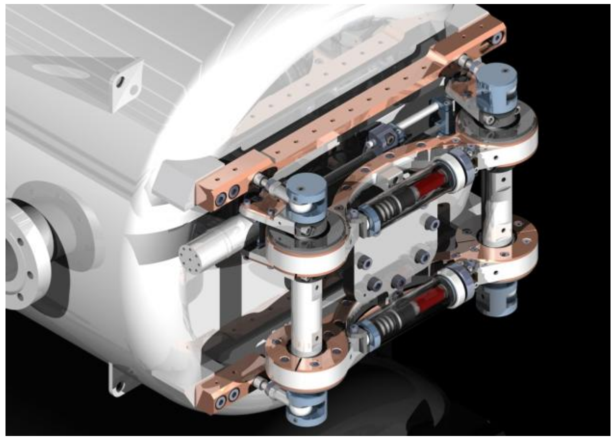


Cavity RF parameters	
R/Q	426 Ω
G	130 Ω
Q_o at 4K	2.6 10^9
Q_o at 2K	1.2 10^{10}
E_{pk} / E_{acc}	4.43
B_{pk} / E_{acc}	7.08





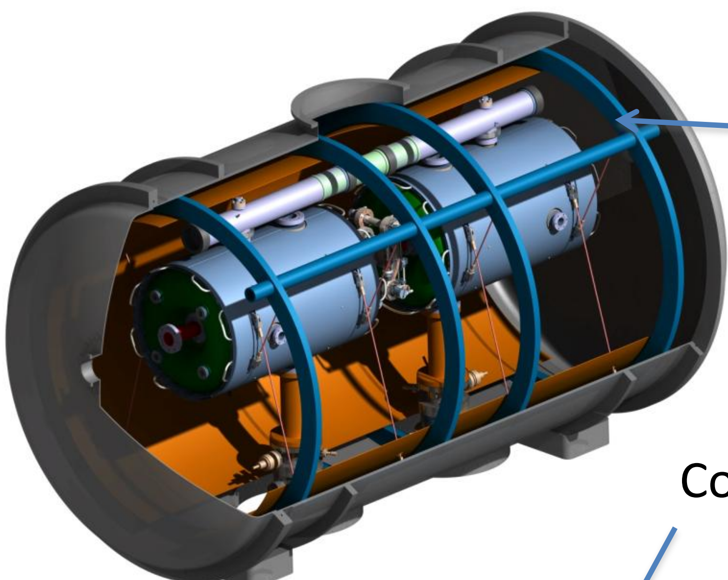


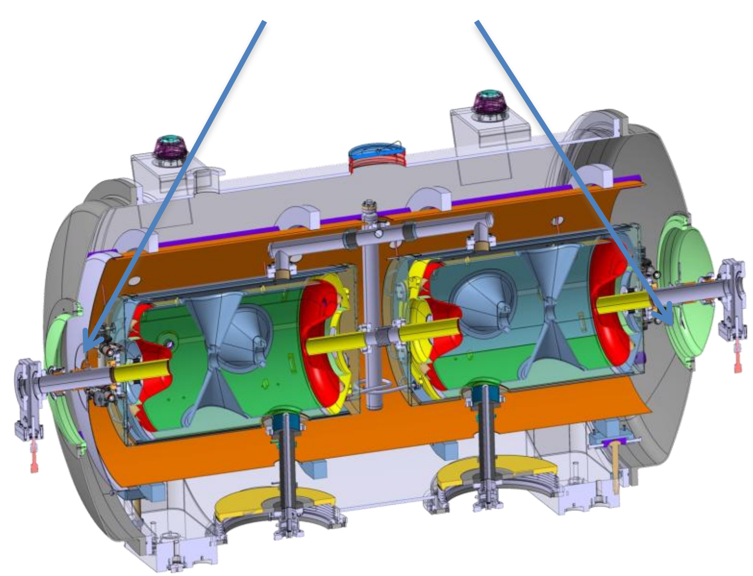


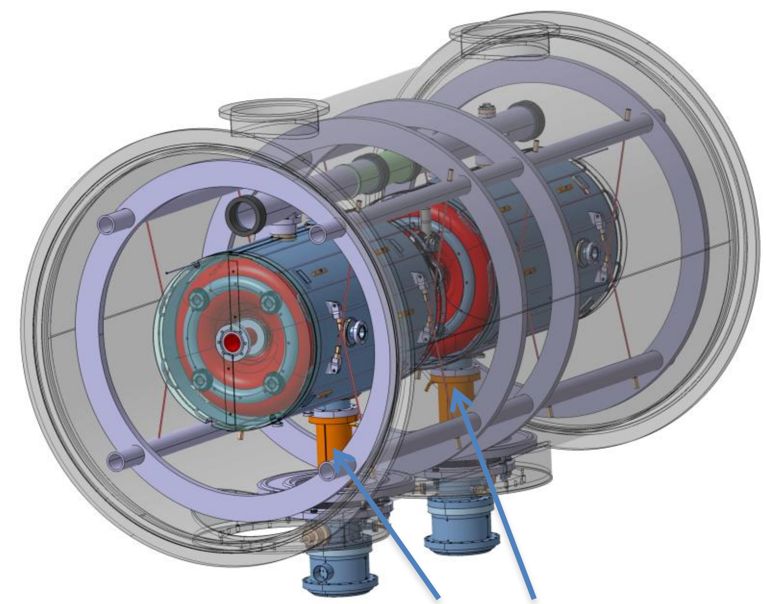
Spoke Cryomodules

The fully equipped spoke cryomodules provide operating conditions (vacuum, cryogenics) to the spoke resonators.

- 2 double-spoke resonators per cryomodule
- 14 cryomodules in total to cover Energy range between 79 MeV to 201 MeV
- Operation at 2 K
- Dimension : 2.9 m long , 1.3 m diameter

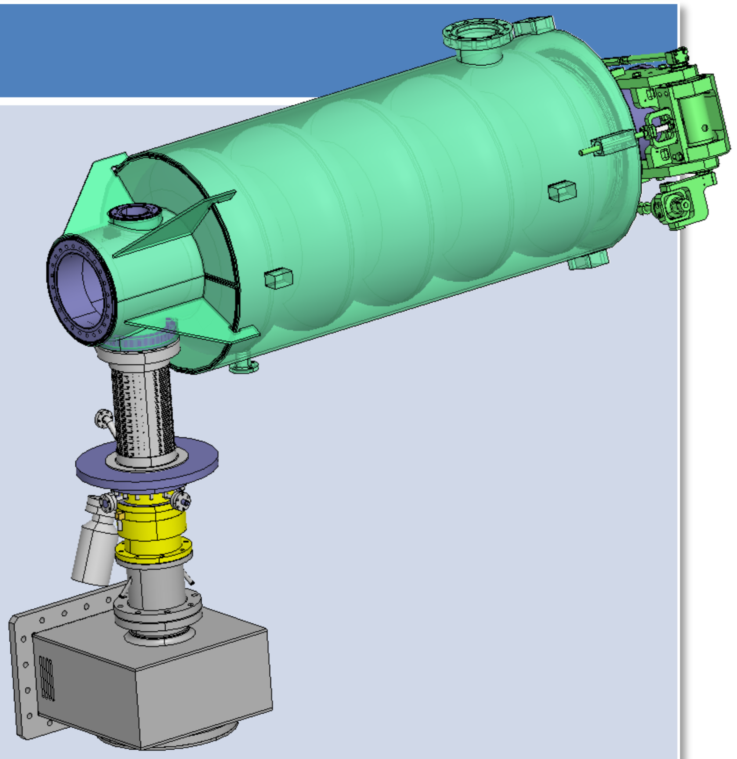






Elliptical cavities

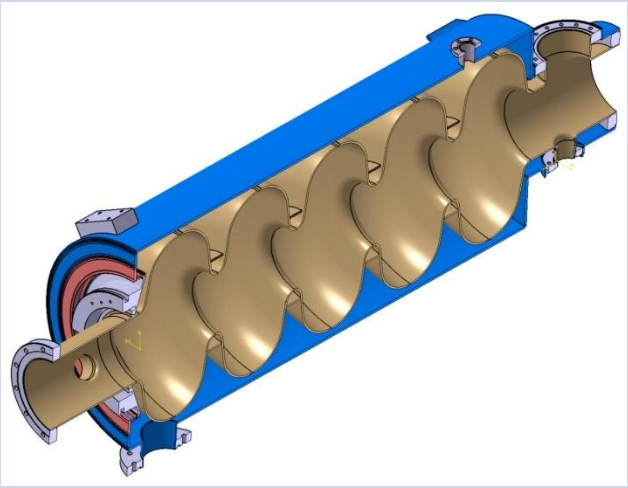
Latest key achievements



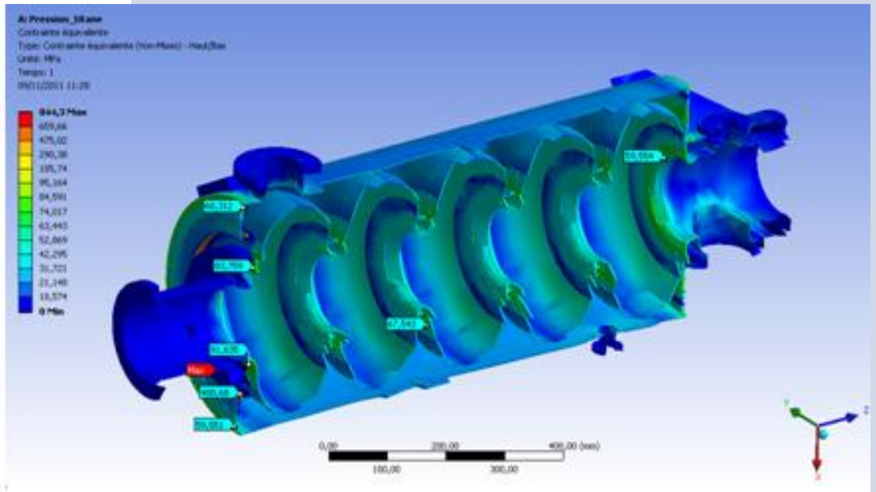
- Ordered two prototype cavities (Nb, fabrication)
- Clean room tooling design for prototypes 50 % completed
- Medium beta PhD started at Lund-U
- Study of HOM effects on the beam dynamics and RF dissipations completed

→ No need of HOM

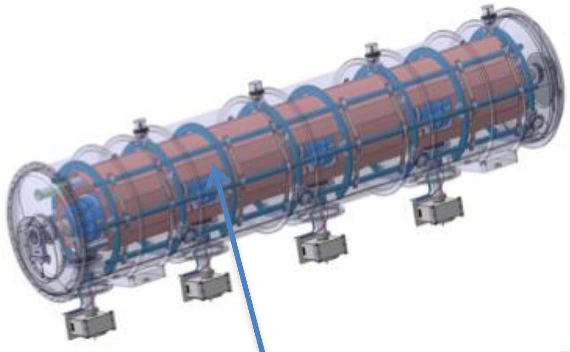
- Some CM activities:
  - Combined effort of Orsay/Saclay to design and build a 4-elliptical cavity cryomodule on-going
  - Cryoload evaluation



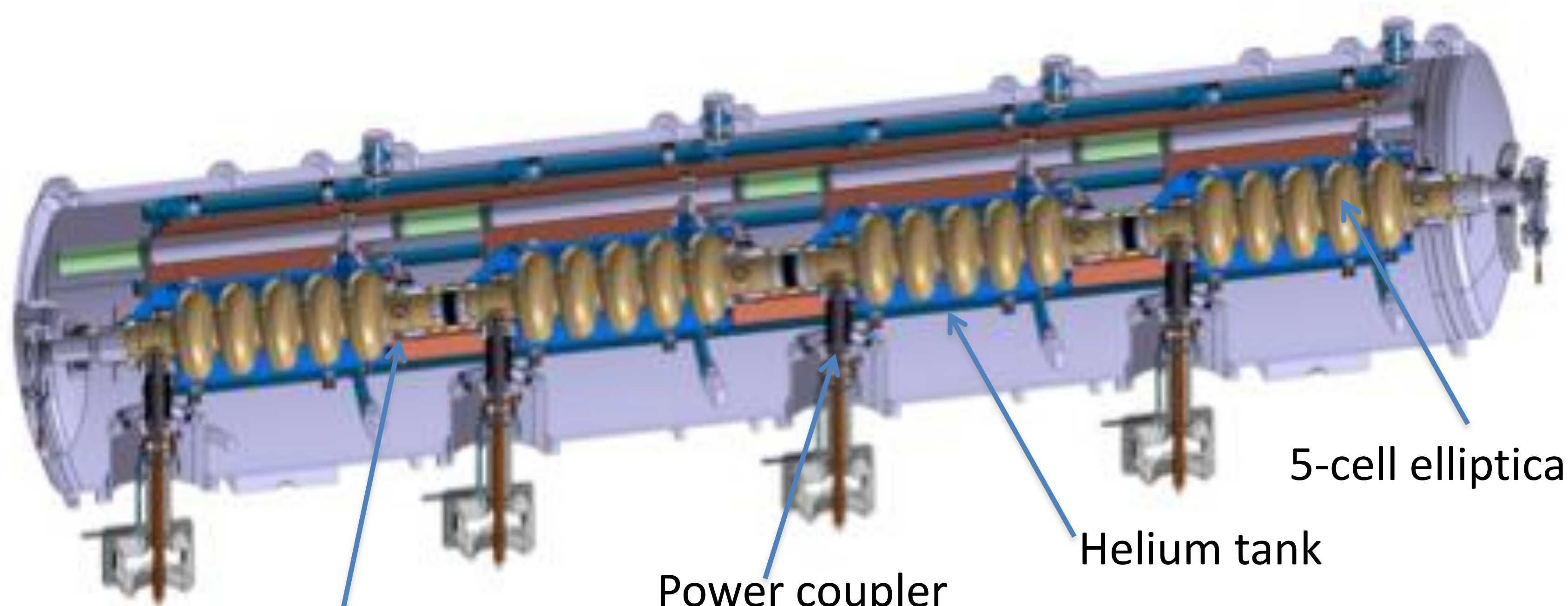
beta	Eacc VT (MV/m)	Eacc Linac (MV/m)z	Qo @ nominal Eacc
0.67	17	15	5e9
0.92	20	18	6e9

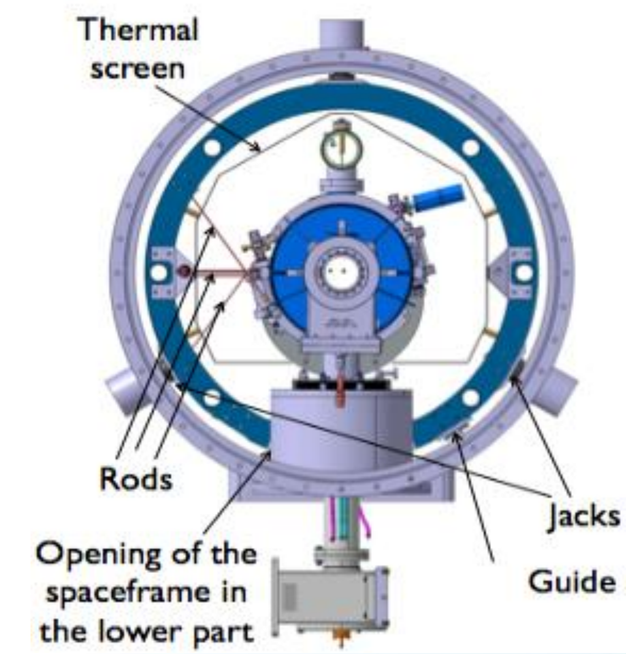


Elliptical Cryomodules



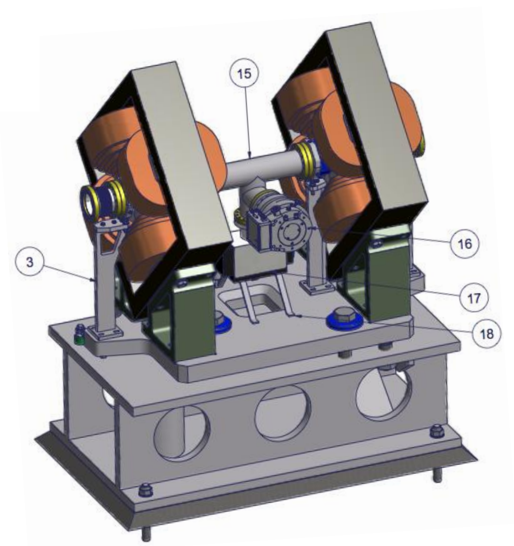
Section	Total number of Modules	Cavity package frequency [MHz]	Cavity count per module	Cavity count per sector	Cryo-module length [m]	Sector length [m]
Spoke	14	352	2	28	~ 2.9	58.46
Medium-beta	15	704	4	60	~ 6.7	113.84
High-beta	30	704	4	120	~ 6.7	227.86
Total	59			208		400.16



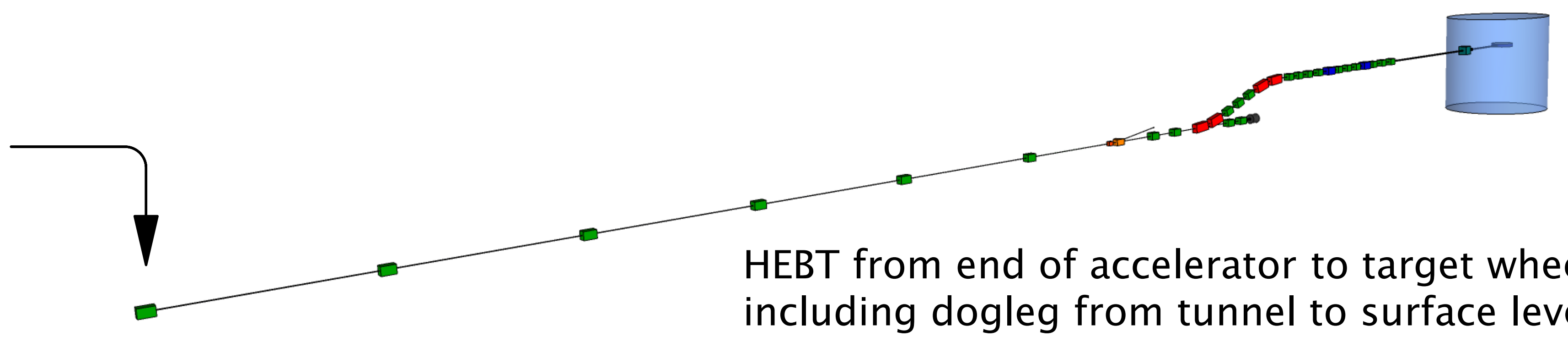


- Elliptical Cavities Cryomodule Technology Demonstrator results by the end of 2015 → start pre-series

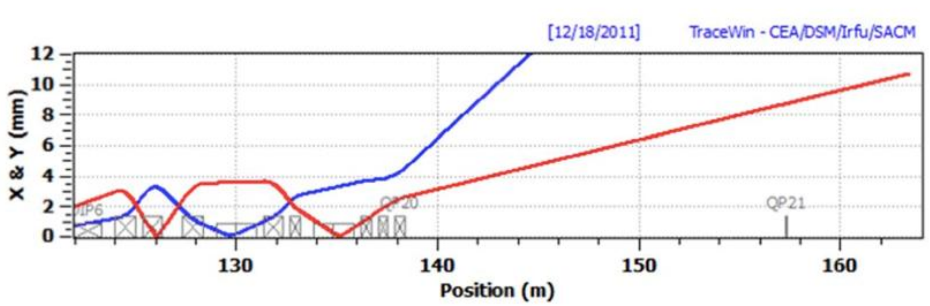
High-Energy Beam Transport



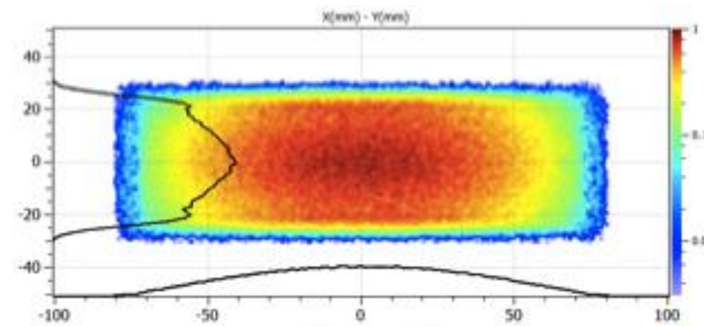
Quadrupole doublet for linac and HEBT.



HEBT from end of accelerator to target wheel, including dogleg from tunnel to surface level, expansion magnets and tuning beam dump.



Beam expansion on target with quadrupole magnets plus two octupoles.



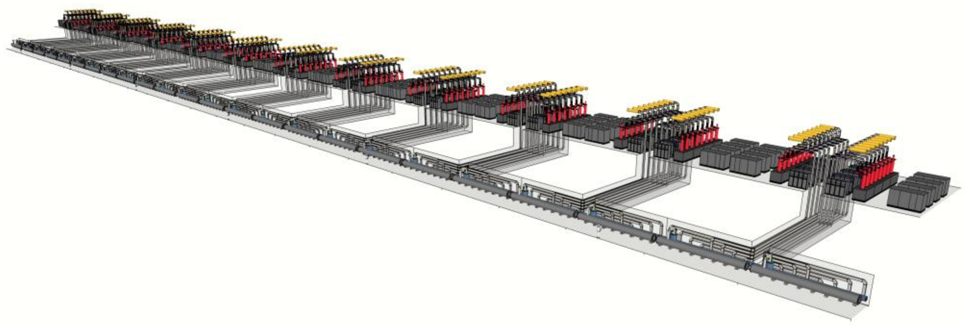
Example of beam profile on target (160 mm × 60 mm) with a peak current density of 49 μA/cm^2.

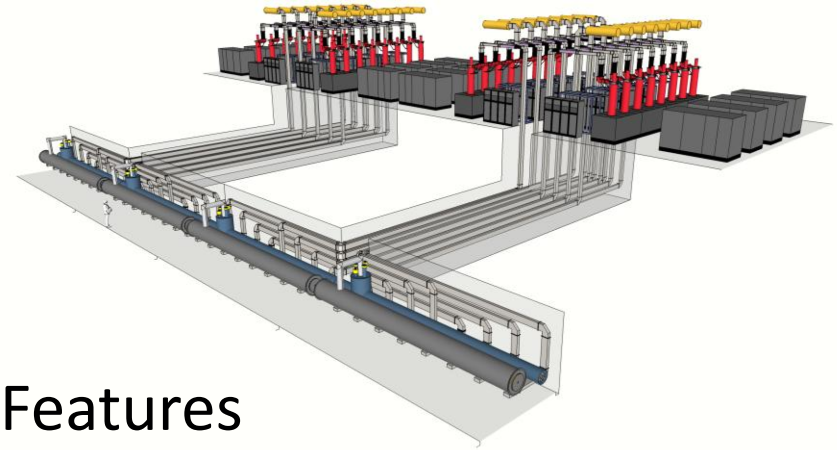
Fixed collimator outside proton-beam window with design depending on beam halo and acceptable peak current density.

Beam instrumentation

Sector	BLM	BCM	BPM	Slit	Grid	FC	WS	NPM	Img	Halo	BSM
LEBT	0	2	0	1	2	1	0	0	0	0	0
MEBT	0	2	6	1	1	1	4	0	0	2	1
DTL	3	5	8	0	0	3	3	0	0	0	0
SPK	42	1	28	0	0	2	5	5	0	4	3
MB	48	2	32	0	0	0	4	4	0	4	3
HB	60	1	30	0	0	0	4	4	0	4	3
UHB	22	2	14	0	0	0	4	4	0	2	2
A2T	19	2	15	0	2	0	3	4	2	4	0
DmpL	10	2	8	0	1	0	1	1	1	1	0
TOTAL	204	19	141	2	6	7	28	22	3	21	12

RF systems





- Main Challenges
  - Large number or resonators (>200)
  - Large beam loading ($Q_L < 7x10^5$)
  - Large Lorentz de-tuning (>50 degrees)
  - Long Pulse length (3 mS ~3 Lorentz detuning time constants)
  - Large dynamic range in power(elliptical cavities range from 50kW – to 900kW)
  - Large average power (15 MW of AC power)

- Main Features
  - One RF power source per resonator
  - RF Sources
    - Pulsed cathode klystrons for elliptical, DTL, and RFQ
    - Gridded tube for spokes (IOTs)
  - Two klystrons per modulator for high beta ellipticals and four klystrons per modulator for medium beta ellipticals
  - 30% overhead for RF regulation
    - Adaptive low level feed-forward algorithms and Low gain feedback
    - High bandwidth piezo tuners on superconducting cavities
  - Bundled waveguide stub layout

RF System Procurement Strategy

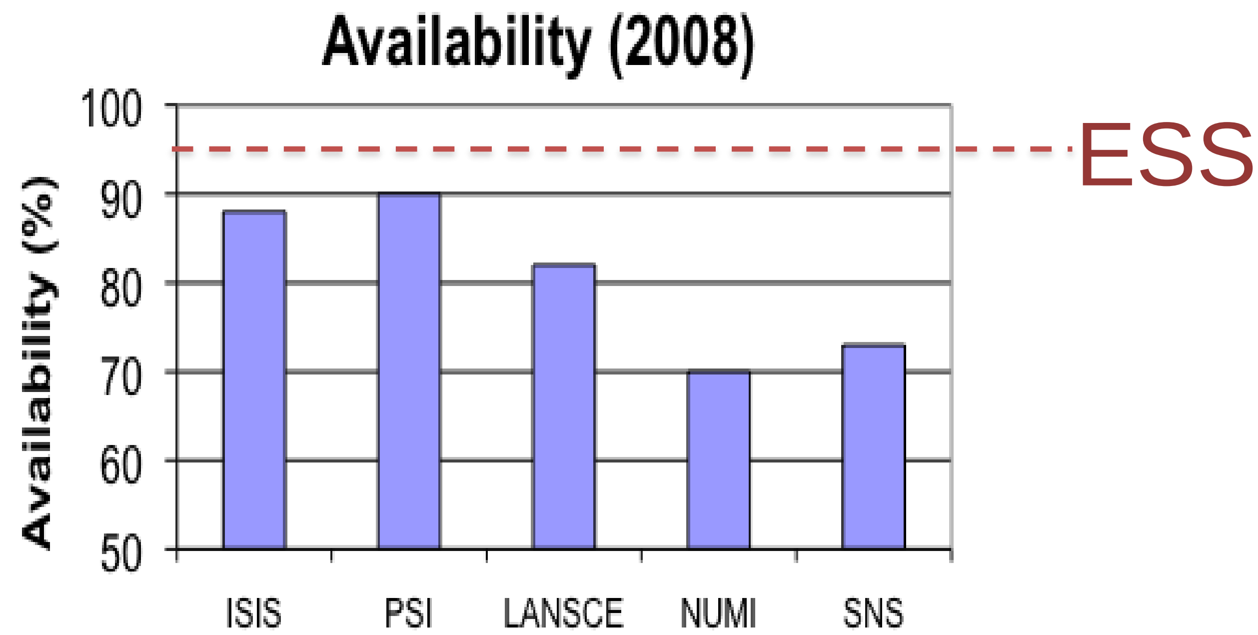
- <u>Schedule is strongly emphasized</u>
- Procurement Strategy
  - ESS will write functional technical specifications
    - **Does *not* impose a topology on the vendors**
  - Will have at least 2 vendors produce components (modulators, klystrons, circulators for series production)
  - Call for tender for production of multiple (3) prototypes
    - Possibility for multiple vendors to be successful
    - At least 1 year soak test on prototypes
  - Call for tender for series production based on vendors with successful prototypes

Integrated Control System for ESS

- Decision to have a single integrated control system for ESS
  - EPICS based
  - ITER control box concept
- Achievements:
  - Control Box prototype running at ESS
  - Naming Convention with tools implemented
  - Working Development Environment and prototype ESS CODAC
  - Well defined Safety / Protection system architecture
  - Parameter List tools developed
  - Interfaces with the Instrument Controls defined
  - BLED database for parameters
- Issues:
  - Target Safety System and Infrastructure Controls requirements immature
  - Fast data acquisition for Accelerator AND Instruments?
  - ICS scope not resourced

Reliability, Availability and the ESS

-ESS aim: 95% availability
- higher than any existing facility

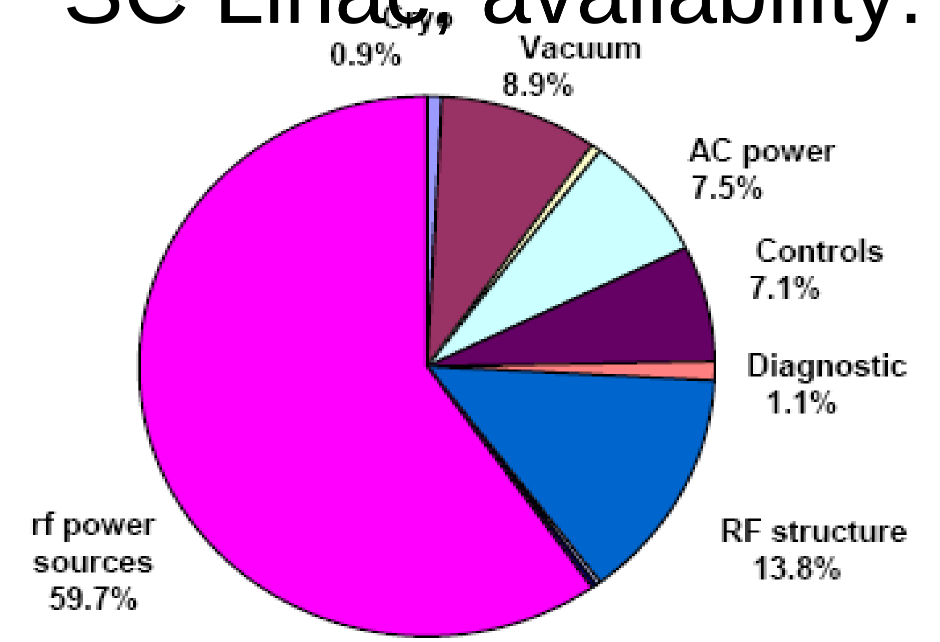


- User Centric Availability Definition

Based on discussions with users:
Using weighted % of scheduled beam power >70% averaged over 1 second.

For example :
Consider a day: one hour of 70% power, 4 Hrs with 90%, 18.9 Hrs with 100% power and 6 min accelerator trip gives an availability of: 96.66%

Analyses for RIA – 400 KW SC Linac, availability: 0.96



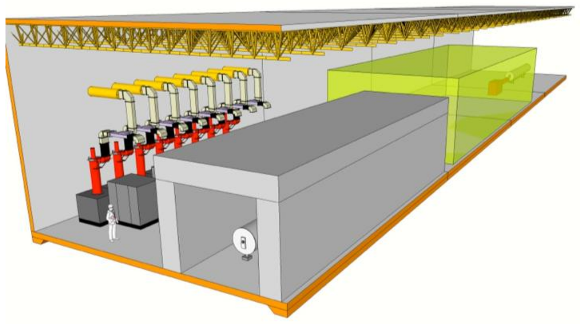
Contribution to down time (>0.4%)

E. S. Lessner and P. N. Ostroumov (2005)

Uppsala Test Stand

- FREIA hall
  - ground breaking 14 May 2012
  - hall ready by 1 July 2013
- 352 MHz source choice
  - report delivered 16 May 2012 (awaiting approval ESS)
  - preparing detailed specs for tendering
- cryogenics
  - liquefier deadline 20 June 2012
  - starting test cryostat design
- installation and commissioning
  - preparing detailed planning

Test Stand in Lund

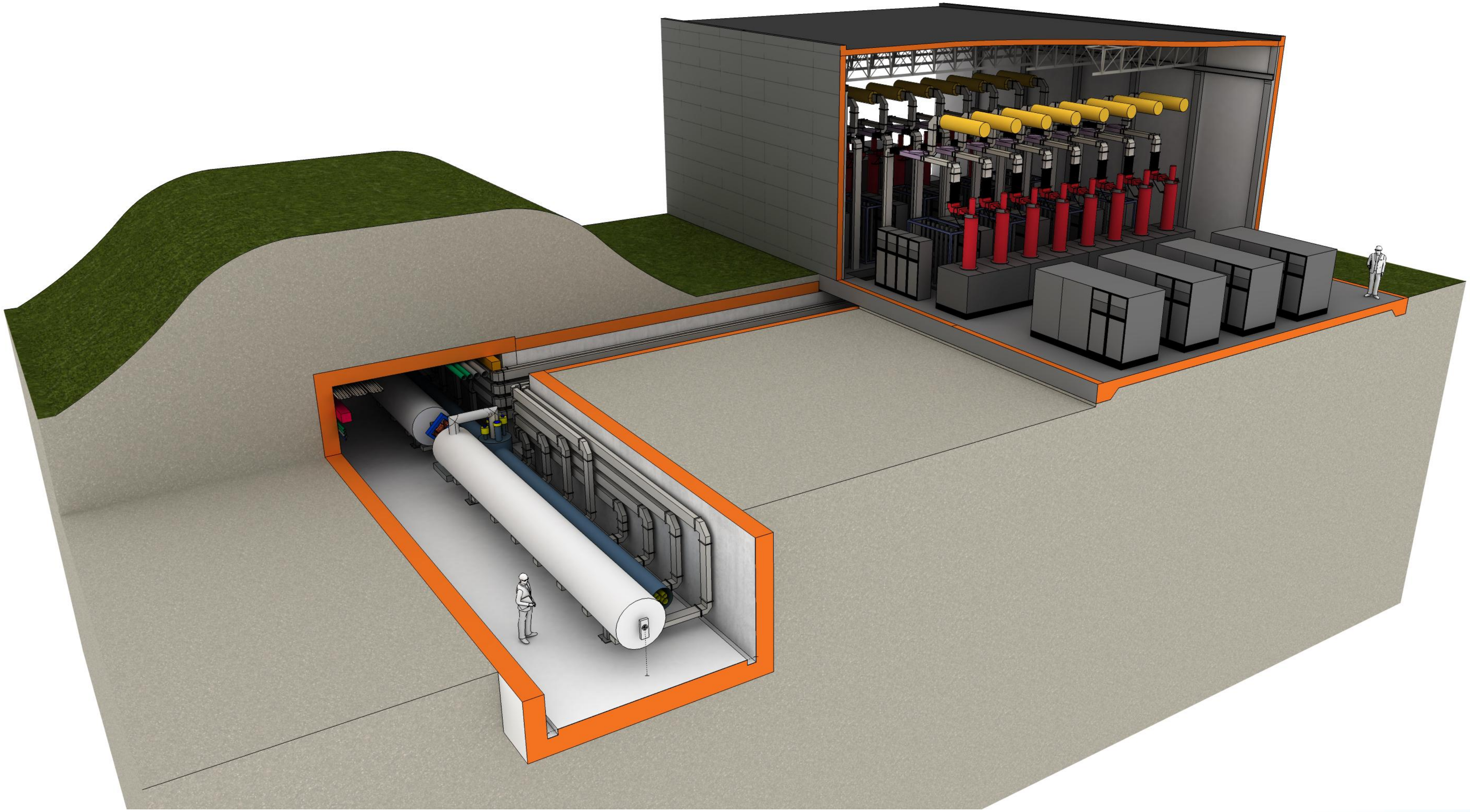


Scope:

1. soak tests (1 y) of 3 different prototypes of the 704 MHz **modulator**;
2. long term (appx 9 m) test of three identical prototypes of the 704 MHz **klystron**;
3. testing of 704 MHz RF components (circulators, dummy loads);

1. series testing in situ of all 704 MHz modulators
2. series testing in situ of all 704 MHz klystrons
3. series testing of all elliptical cavities **cryomodules** at full RF load and at final operating temperature
4. vertical test stand for future testing of cavities

- Decision to go ahead with detailed plans for the testing facilities in Lund in summer 2012 to stay on schedule
    - Uppsala crucial for 352 MHz development and spokes



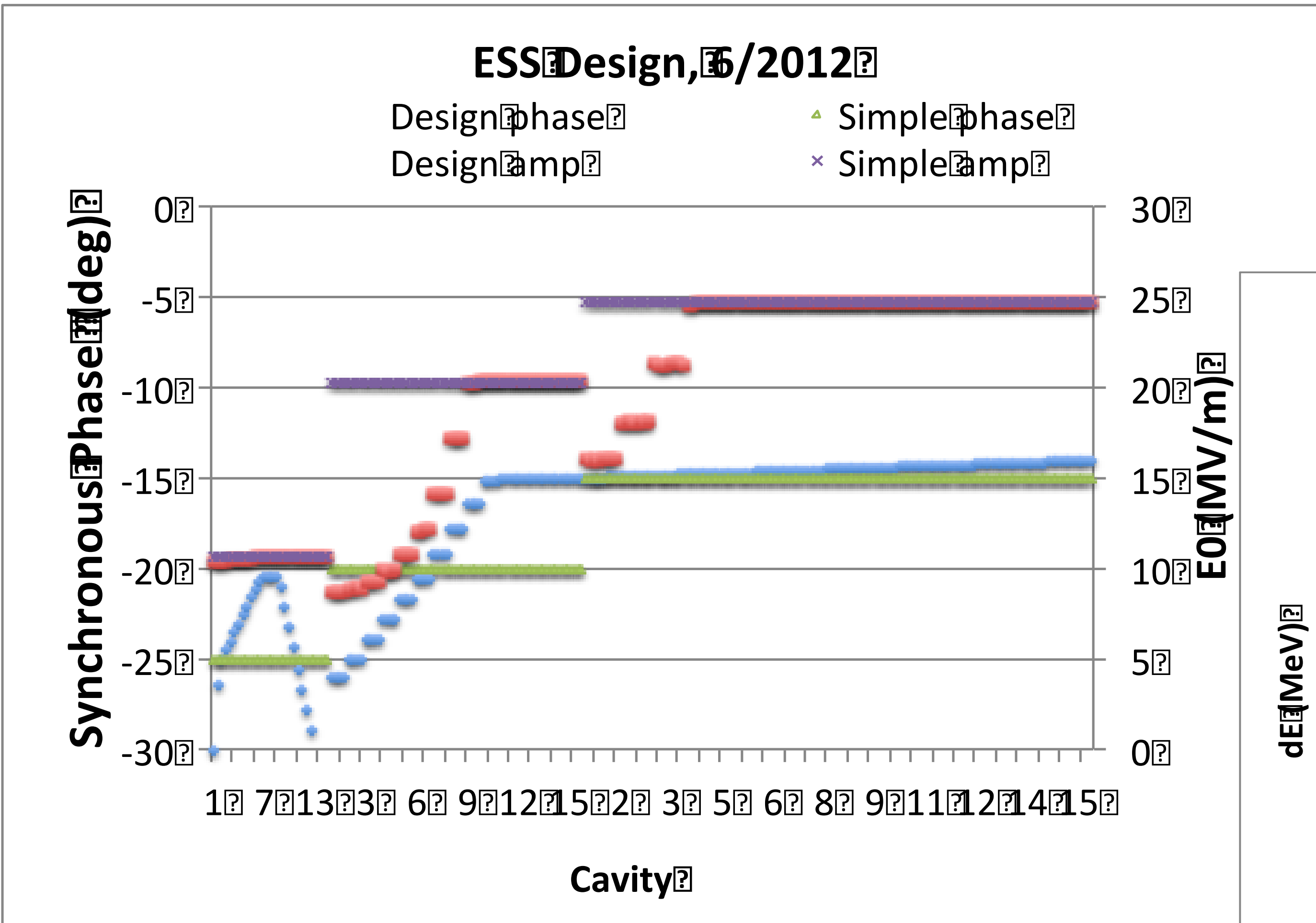
LINAC and klystron buildings, principal structure

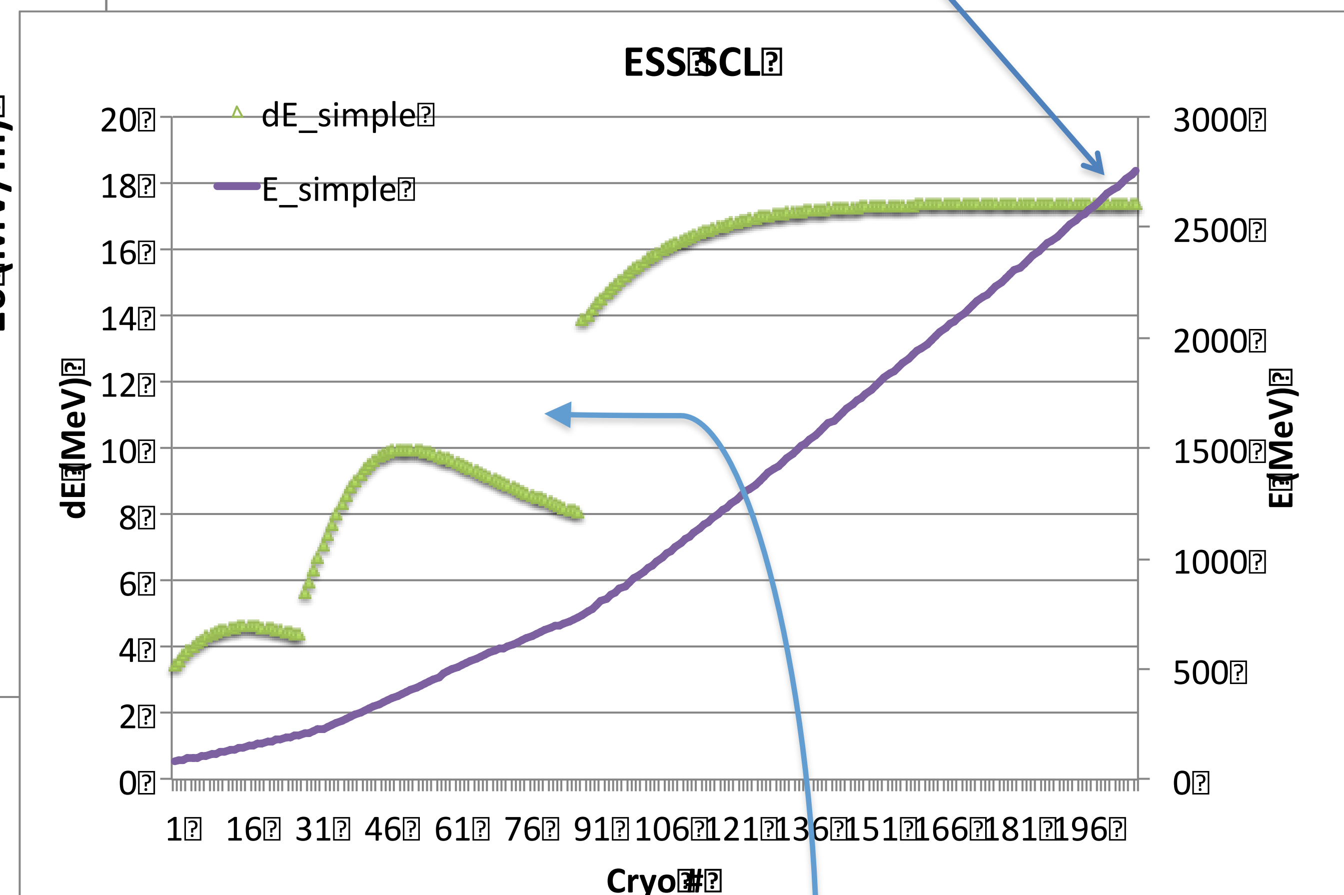
Possible Design Changes

- Flat power profile ("Galambos margin")
  - Could reduce linac length by 400 MeV (6 cryomodules)
  - Saves money in RF Stations and in cryomodules
- IOT's
  - Replace klystrons with IOT's
    - Modulators become much simpler with lower voltage and no switching
    - Higher efficiency requires fewer modulators
  - Saves:
    - Saves money as modulator are 30% cheaper
    - 3-4 MW in RF power (~2-3 Meuro/year)

What if ESS did have constant phase??

Get an extra 250 MeV





E_out = ~2750 MeV

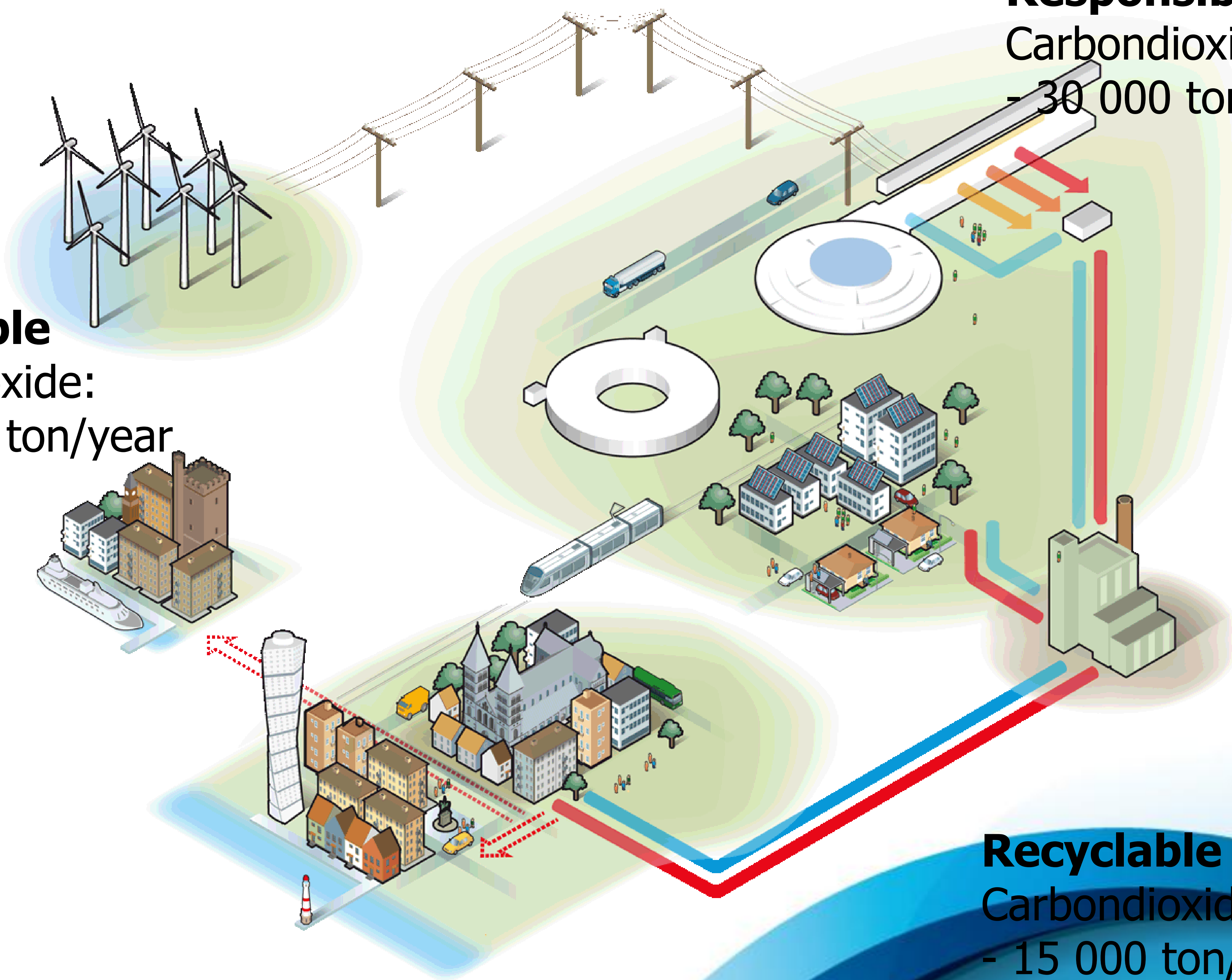
- Extra energy gain is ~ 10% energy margin, or gradient margin
  - Or save cryomodules

Discontinuity => need for phase/amplitude ramp
Seems odd way to design a machine

J. Galambos, 2012

A sustainable research facility

EUROPEAN
SPALLATION
SOURCE



Responsible
Carbondioxide:
- 30 000 ton/year

Renewable
Carbondioxide:
- 120 000 ton/year

Recyclable
Carbondioxide:
- 15 000 ton/year

Challenges

- Energy efficiency and recovery is a design goal for a multi MW facility
  - Heat recovery is good but even better are: efficient RF sources, high Q_0 cavities, …
- SNS experience indicates that multi MW SC linacs are very flexible and “permitting”
  - Can we do joint work on understanding this so that we can do better design work?
- Critical path is RF systems followed by CMs
  - Staged installation of ESS with 1.5 MW capability in 2019 and 5 MW capability in 2025

Contributors

- Many, many, many thanks to the ESS Accelerator Division, the ADU collaboration and ESS AB
- Slides contributed by:
  - Håkan Danared, John Galambos, Christine Darve, David McGinnis, Suzanne Gysin, Juliette Plouin, Guillaume Devanz, Sebastien Bousson, Santo Gammino, Roger Ruber, Søren Pappe-Møller, Andreas Jansson, Mohammad Eshraqi

EUROPEAN SPALLATION SOURCE

Frozen accelerator design in Falsterbo 2011

ESS, A wonderfull challenge!