EUROPEAN
SPALLATION
SOURCE

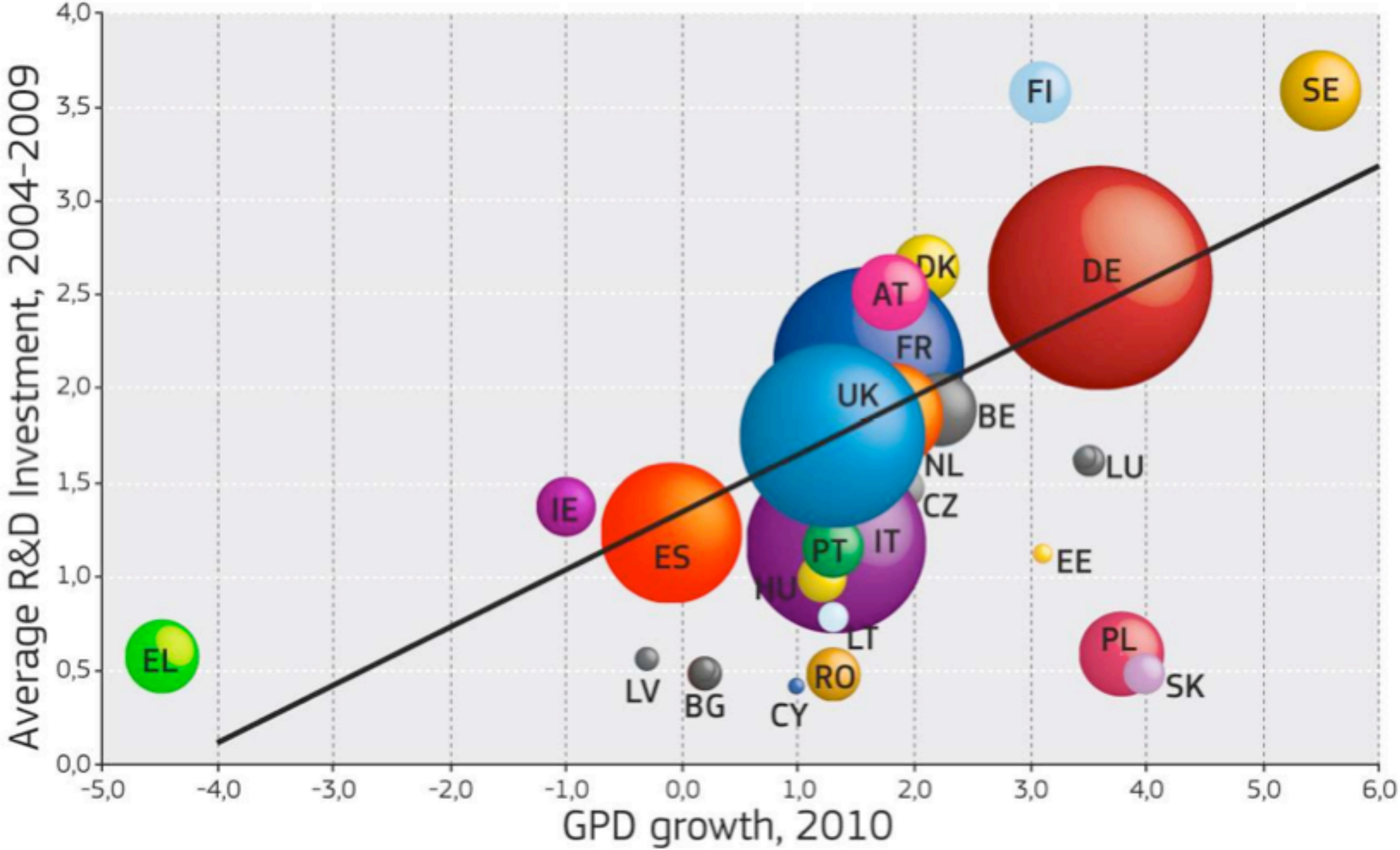
European Spallation Source

EPS Technology & Innovation Workshop

Steve Peggs
ESS Acc. Division

Introduction / context

"R&D as part of the solution to the economic crises"



Technology & Innovation in Acc. Sci.

Well-stated problems focus the mind, but ...

“Accelerator Science is moving from being facility oriented” (Discuss)

ESS is an instructive example

Green field site

A multi-lab collaboration of peers, following the SNS example

An accelerator build (now) becomes a user-facility (2019)

Accelerator Science mandates:

First, do no harm

Second, generate PhD's in the “post-HEP” world

Well-stated Techology & Innovation **problems:**

1) How should National Labs take technical risk for the taxpayer?
    - Eg Medical Accelerators (like iRCMS) as industry-builder
2) “What is the critical evaluation of the SBIR/STTR programme?”

What kind of spallation accelerator?

1) **Linacs** provide high energies & current, & appear to offer the greatest reliability and availability, with rapid fault recovery.

2) **Cyclotrons** are restricted to non-relativistic energies. Separated sector cyclotrons (PSI, TRIUMF) have MW-class beam powers.

3) **Rapid Cycling Synchrotrons** like ISIS operate at frequencies as fast as 50 Hz with beam powers well above 100 kW.

- Much faster repetition rates are attractive, but face the need to develop rapid frequency swing RF systems, et cetera.

4) **Fixed-Field Alternating Gradient** accelerators currently exist only as low power prototypes, both proton & electron.

- Non-isochronous designs face the same frequency swing challenges as RCS RF systems.

ESS on the ADS roadmap?

Finding #5: "The missions for Accelerator Driven Sub-critical (ADS) technology lend themselves to a technology development, demonstration & deployment strategy in which successively complex missions build upon technical developments of the preceding mission." U.S. Dept. of Energy White Paper (2010).

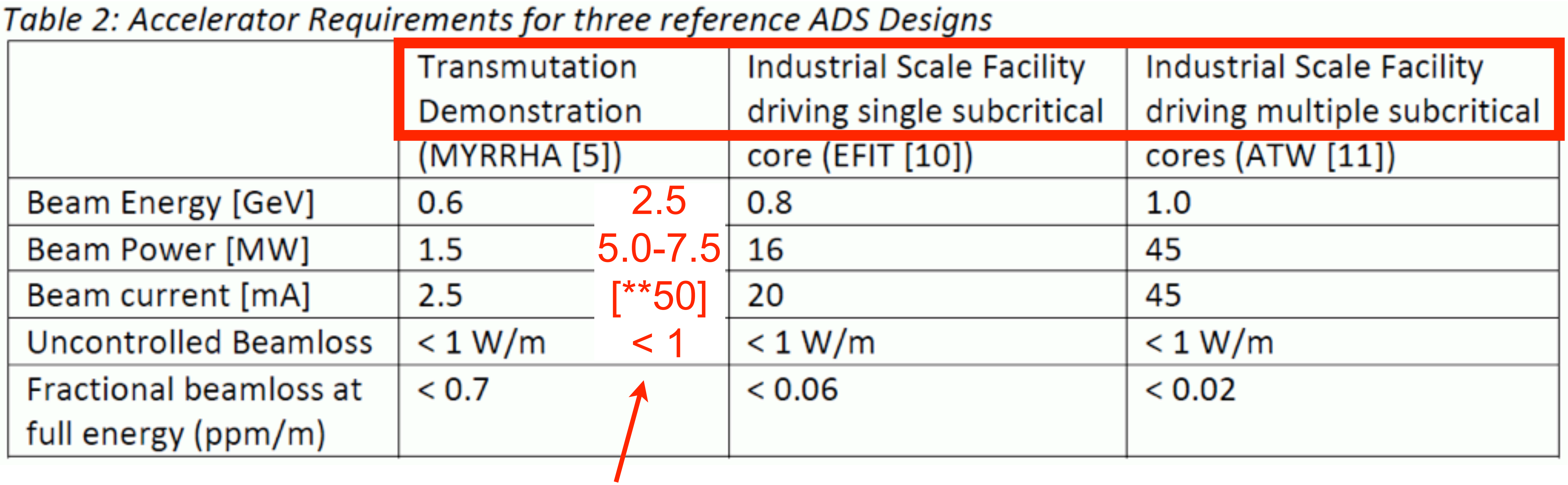


Table 2: Accelerator Requirements for three reference ADS Designs

	Transmutation Demonstration (MYRRHA [5])		Industrial Scale Facility driving single subcritical core (EFIT [10])	Industrial Scale Facility driving multiple subcritical cores (ATW [11])
Beam Energy [GeV]	0.6	2.5	0.8	1.0
Beam Power [MW]	1.5	5.0-7.5	16	45
Beam current [mA]	2.5	[**50]	20	45
Uncontrolled Beamloss	< 1 W/m	< 1	< 1 W/m	< 1 W/m
Fractional beamloss at full energy (ppm/m)	< 0.7		< 0.06	< 0.02

ESS [**50 mA in 2.9 ms pulses at 14 Hz]

ESS

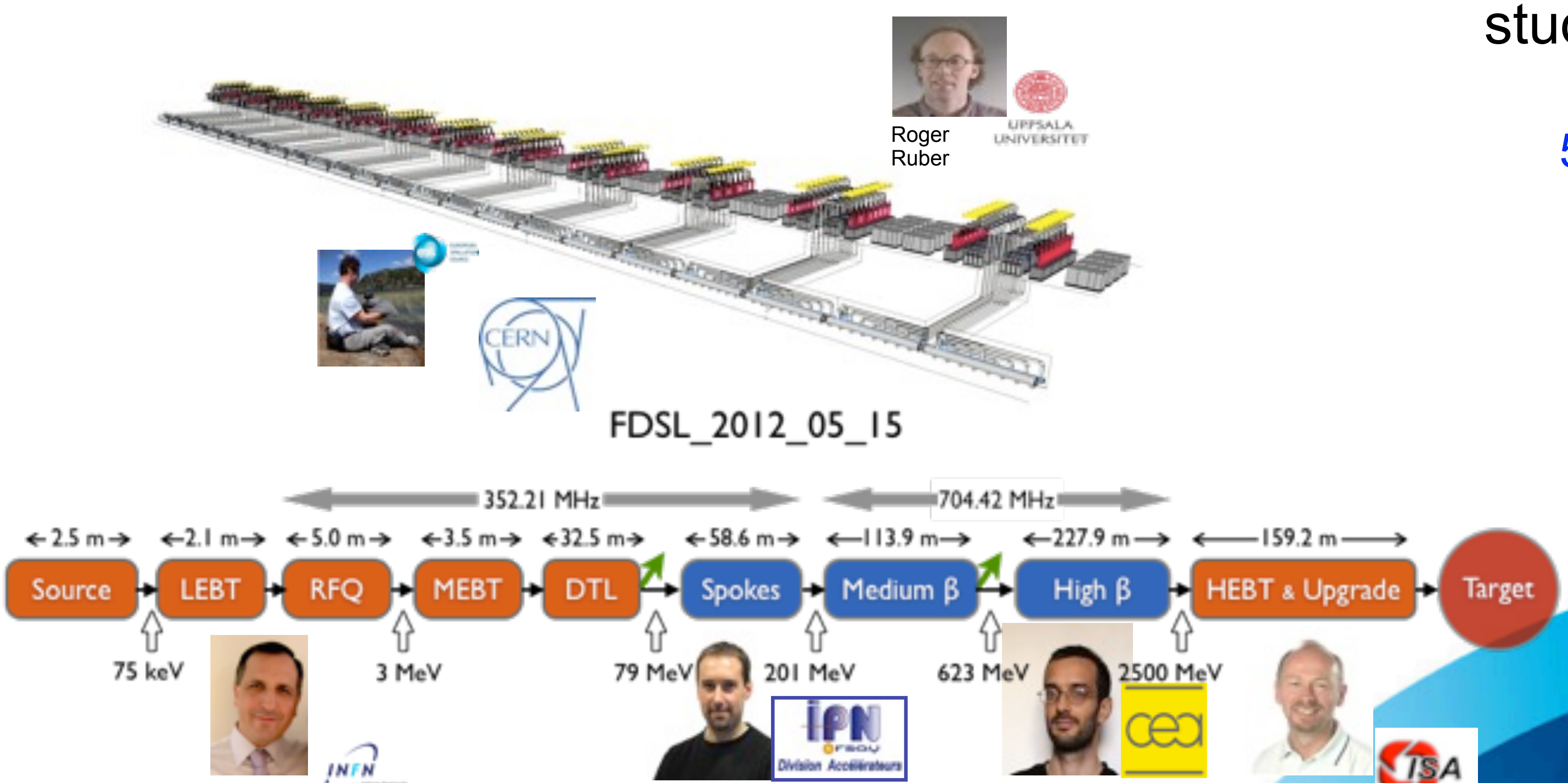
ESS

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



Roger Ruber

FDSL_2012_05_15

Santo Gammino

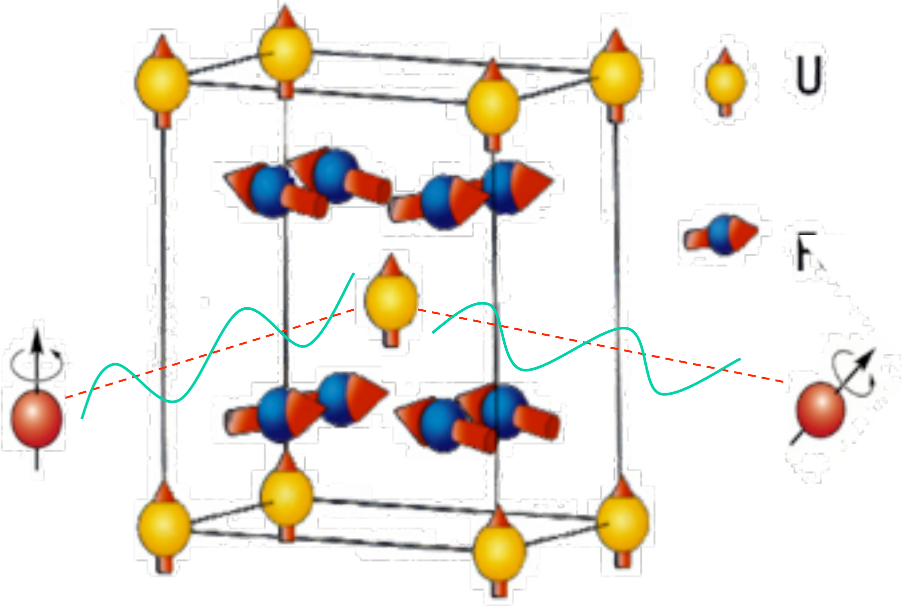
Sebastien Bousson

Guillaume Devanz

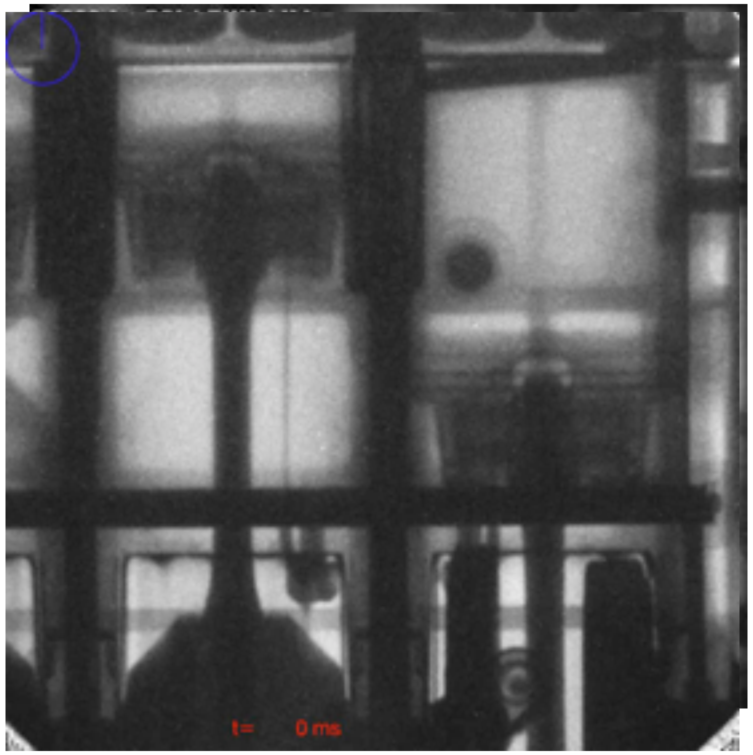
Søren Pape Møller

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

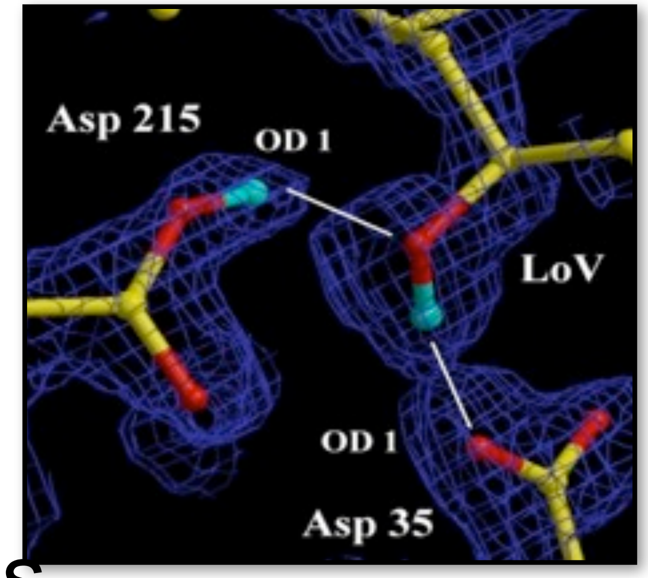
Neutrons are beautiful…



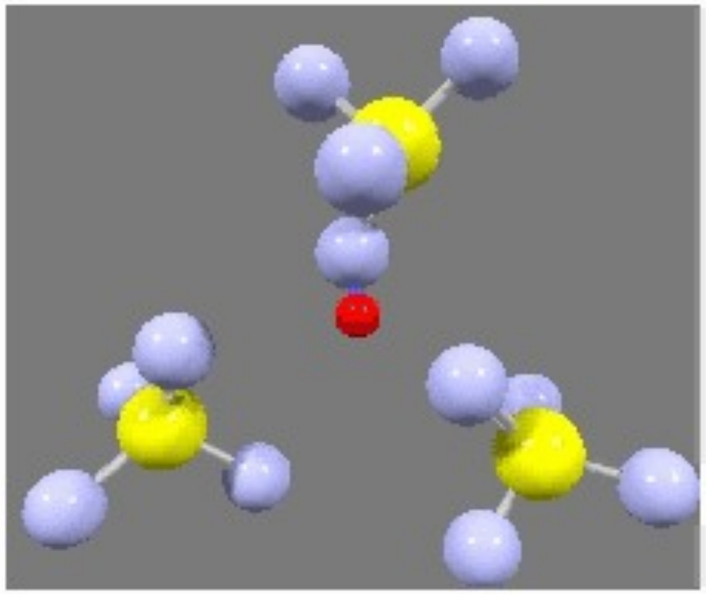
..see magnetic atoms



..see inside materials



..see light atoms



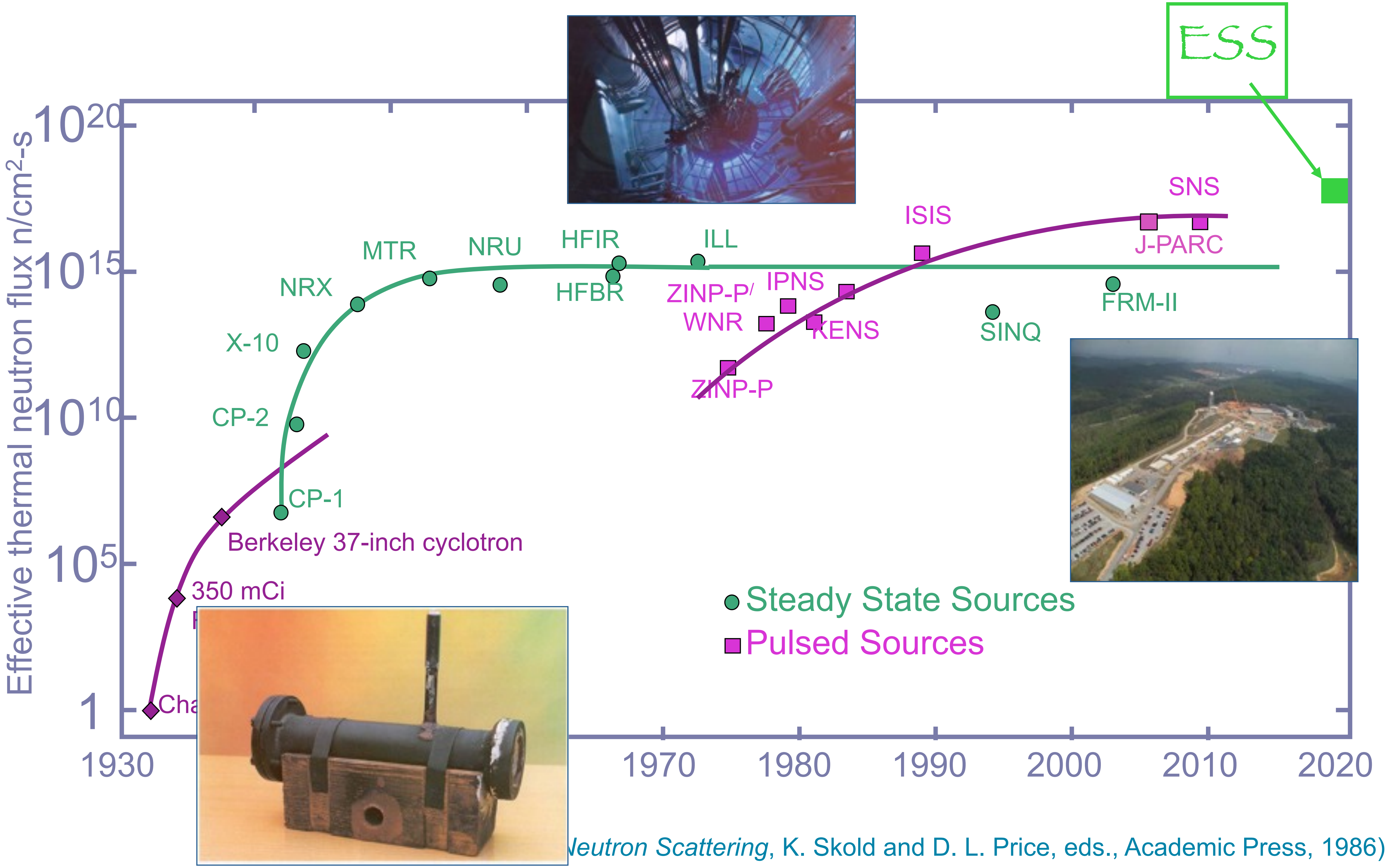
..see atoms move

..see isotopes

Courtesy of Ian S. Anderson

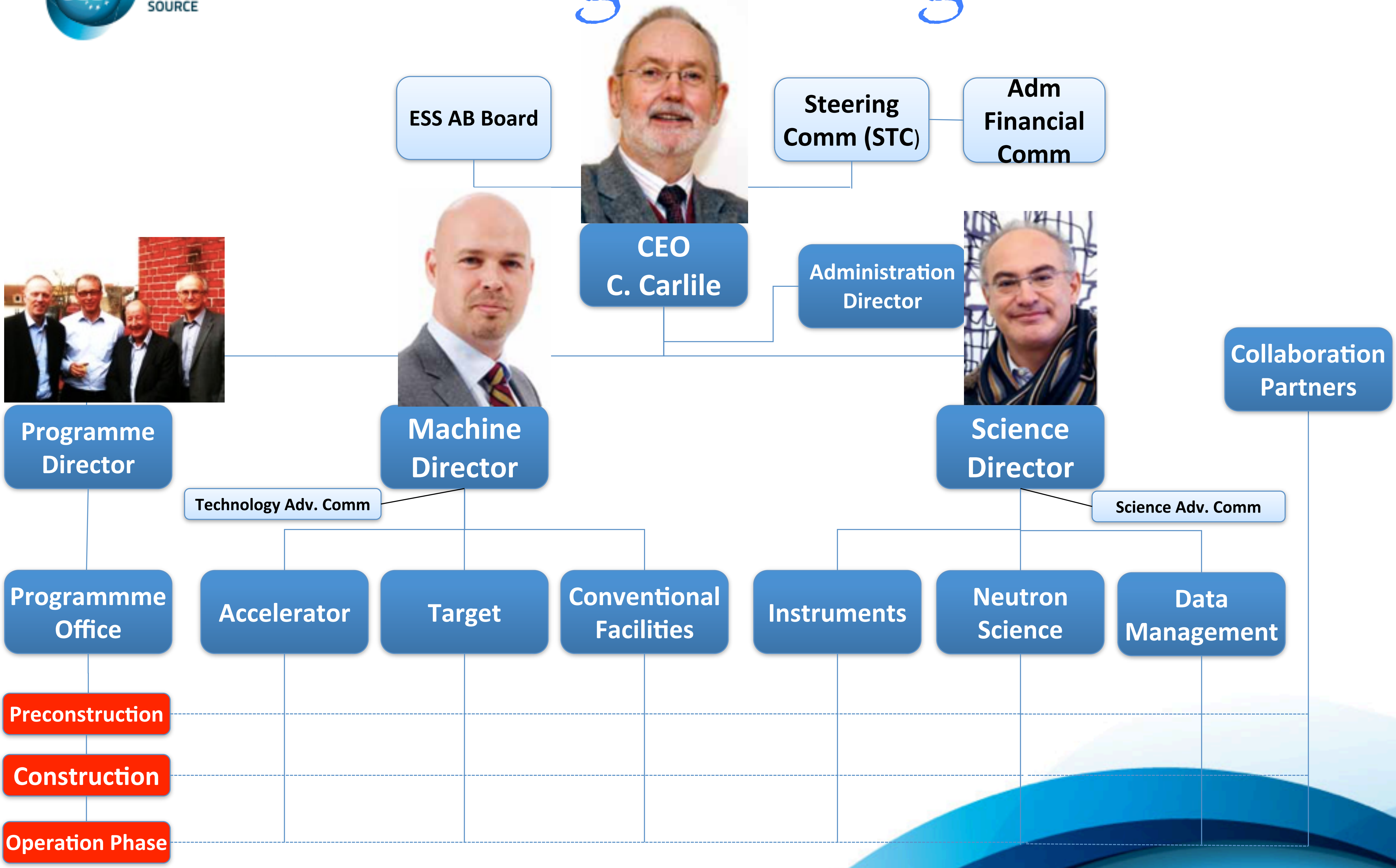
Why ESS? - High time average and peak flux

Evolution of the performance of neutron sources



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

ESS Programme Organisation



ESS AB Board

Steering Comm (STC)

Adm Financial Comm

CEO
C. Carlile

Administration Director

Collaboration Partners

Programme Director

Machine Director

Science Director

Technology Adv. Comm

Science Adv. Comm

Programmme Office

Accelerator

Target

Conventional Facilities

Instruments

Neutron Science

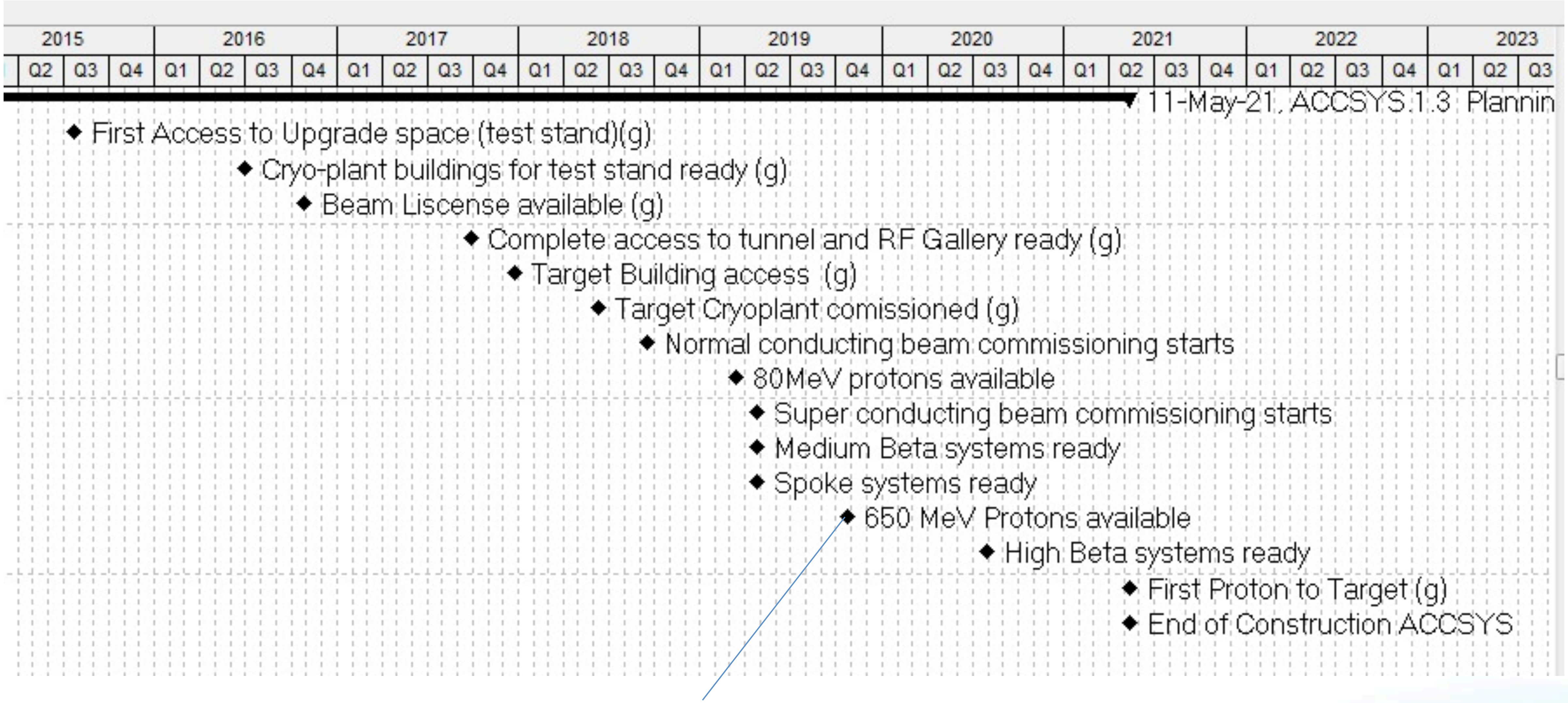
Data Management

Preconstruction

Construction

Operation Phase

Accelerator milestones



11-May-21, ACCSYS.1.3 Plannin

◆ First Access to Upgrade space (test stand)(g)
◆ Cryo-plant buildings for test stand ready (g)
◆ Beam Liscense available (g)
◆ Complete access to tunnel and RF Gallery ready (g)
◆ Target Building access (g)
◆ Target Cryoplant comissioned (g)
◆ Normal conducting beam commissioning starts
◆ 80MeV protons available
◆ Super conducting beam commissioning starts
◆ Medium Beta systems ready
◆ Spoke systems ready
◆ 650 MeV Protons available
◆ High Beta systems ready
◆ First Proton to Target (g)
◆ End of Construction ACCSYS

First
Neutrons
at ESS!

Accelerator Design Update


Romuald Duperrier (30 years ago)


Steve Peggs

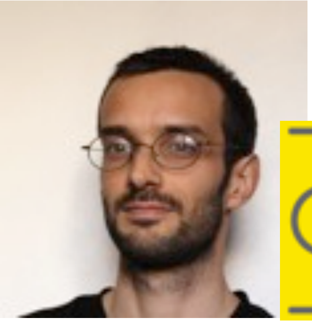

Cristina Oyon


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


Søren Pape Møller


Santo Gammino


Sebastien Bousson

LINAC layout

Note beam stubs !

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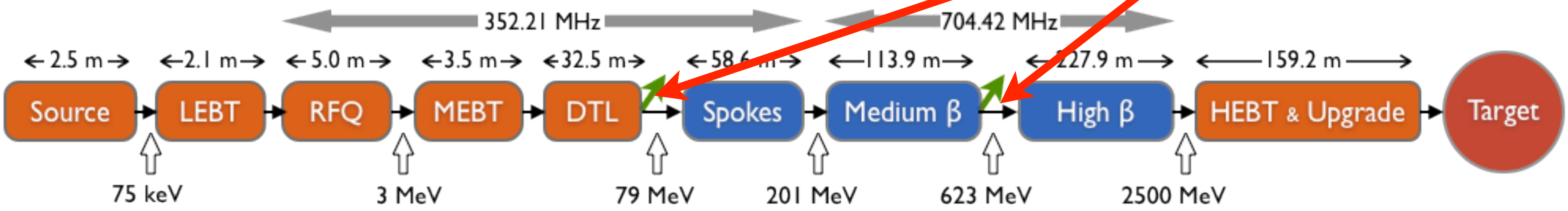


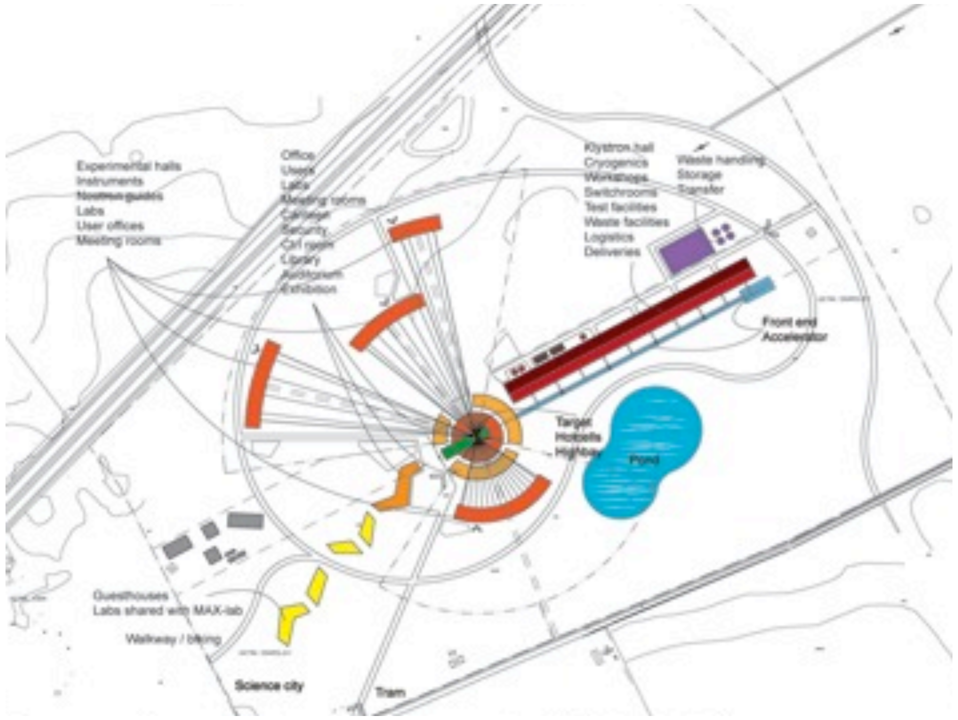
	Length (m)	**Input Energy (MeV)**	**Frequency (MHz)**	**Geometric β**	**# of Sections**	**Temp (K)**
LEBT	2.05	75×10^{-3}	--	--	--	≈ 300
RFQ	4.95	75×10^{-3}	352.21	--	1	≈ 300
MEBT	3.53	3	352.21	--	--	≈ 300
DTL	32.58	3	352.21	--	4	≈ 300
Spoke	58.46	79	352.21	0.50	14 (2C)	≈ 2
Medium Beta	113.84	201	704.42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

running every 10 or 20 minutes in working hours

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%



Beam-dynamics laws and rules-of-thumb

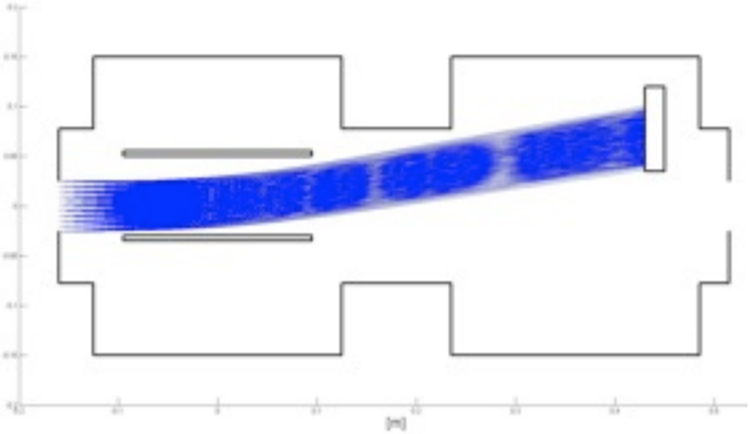
Transverse phase advance < 90 deg/cell
Longitudinal phase advance below transverse phase advance
Smooth change of phase advances per meter
Tune depression not too high
Watch out for unwanted cavity modes
Optimization criteria

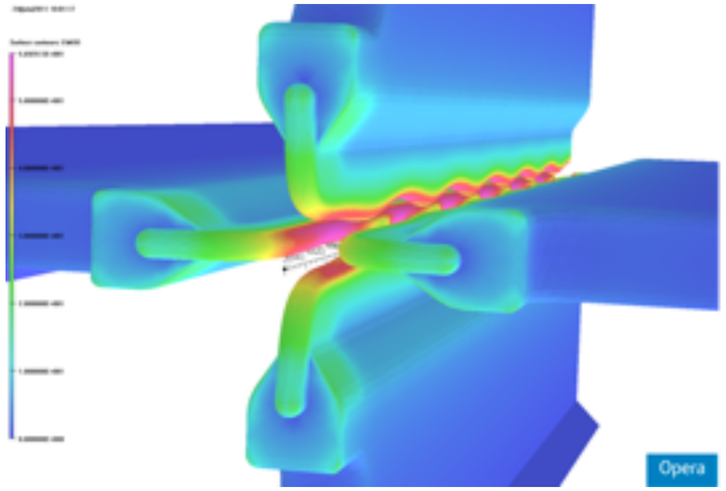
Beam quality

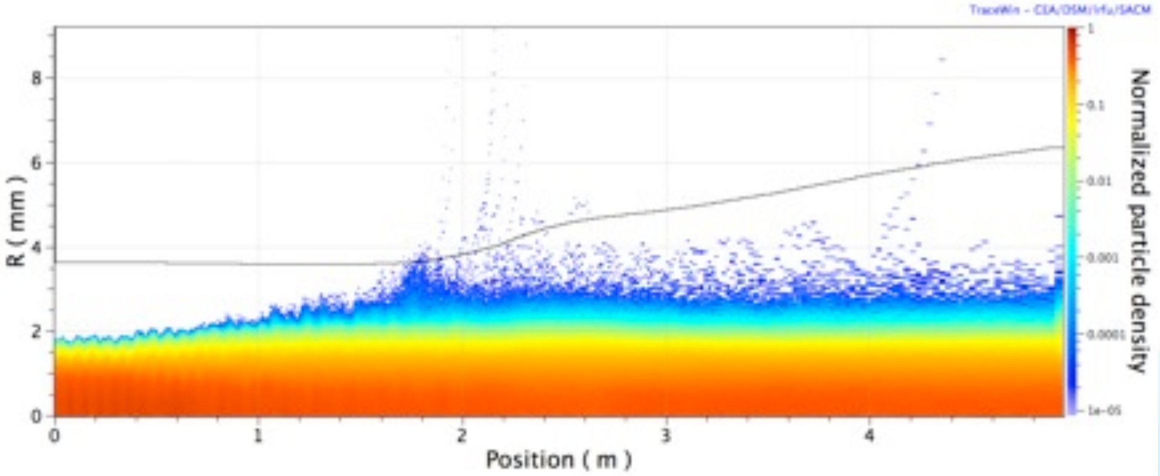
Short linac (correlates well with many desirable properties)
Small number of components (reliability)
Upgrade potential
Et cetera ....

Ion source & 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

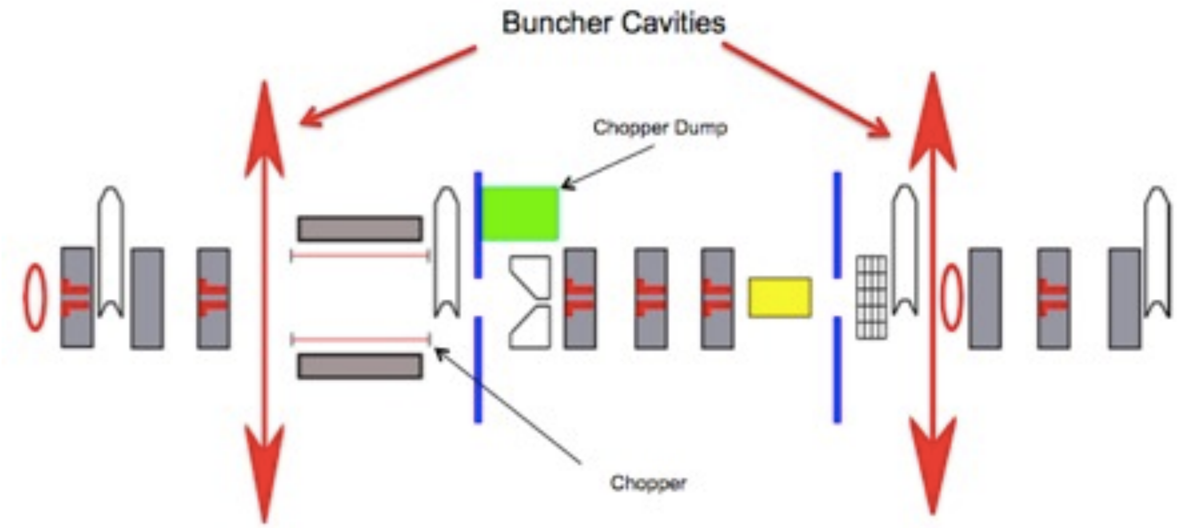






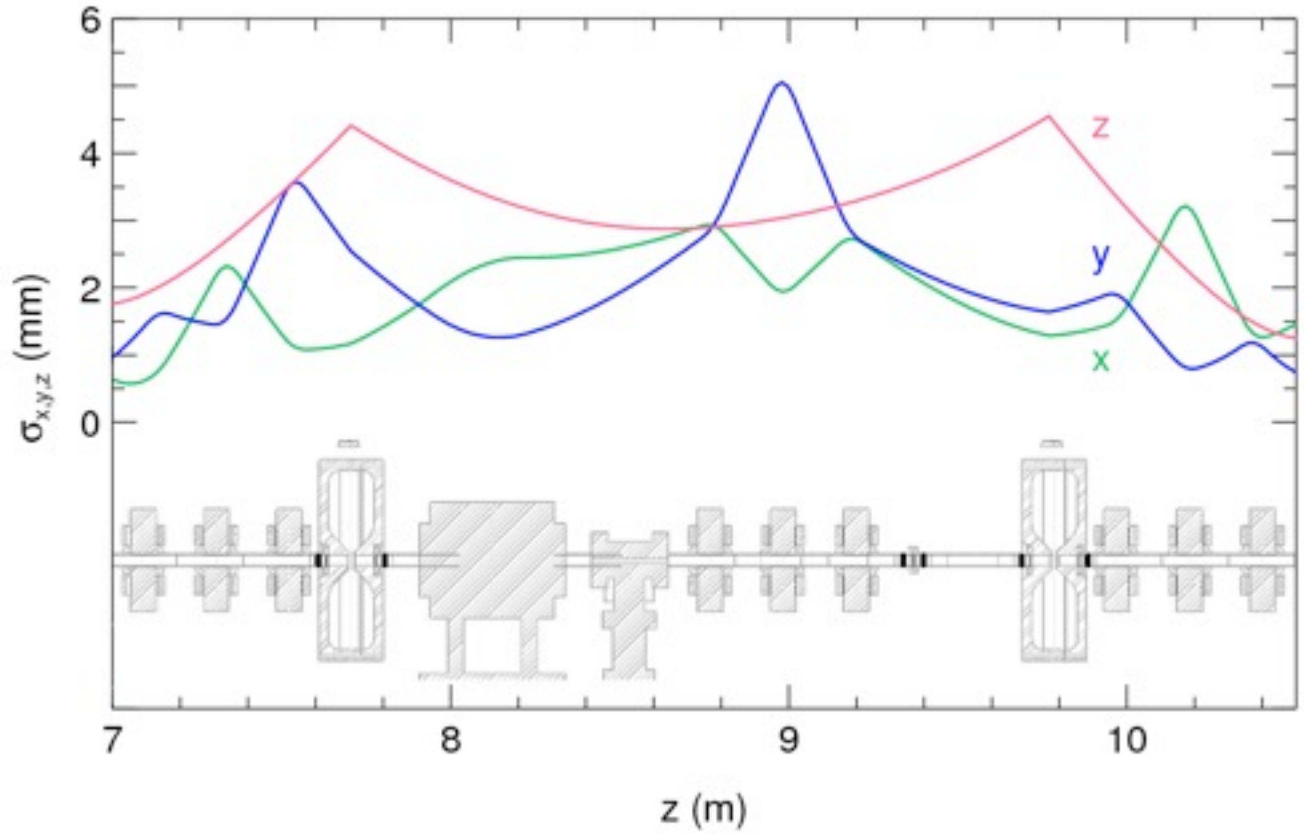
Beam density as a function of radius along the RFQ

Medium-Energy Beam Transport



⊑	BPM (position and TOF)	▦	SEM grid
⌂	Wire scanner	○	BCT
🟨	BSM	⧖	Slit
|	Collimator	▮	Quad

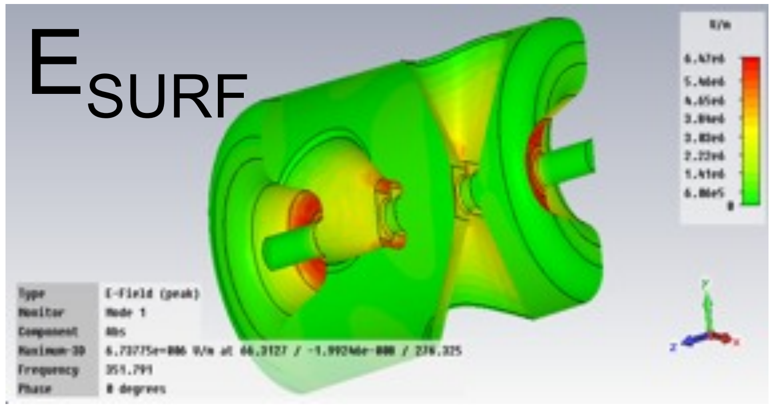
Schematic design with instrumentation, chopping and collimation.



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

Spoke resonators/cavities

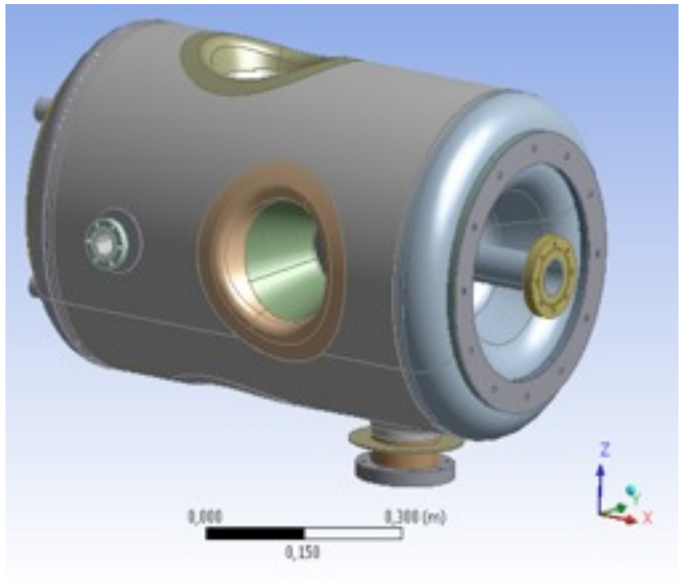
- Spoke cavity RF design:
  - Double spoke beta 0.5
- Spoke cavity mechanical design
- Power coupler
  - EURISOL type design
- Spoke cold tuning system

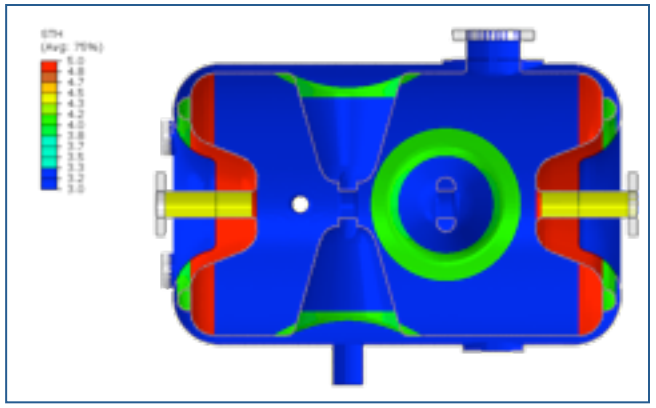


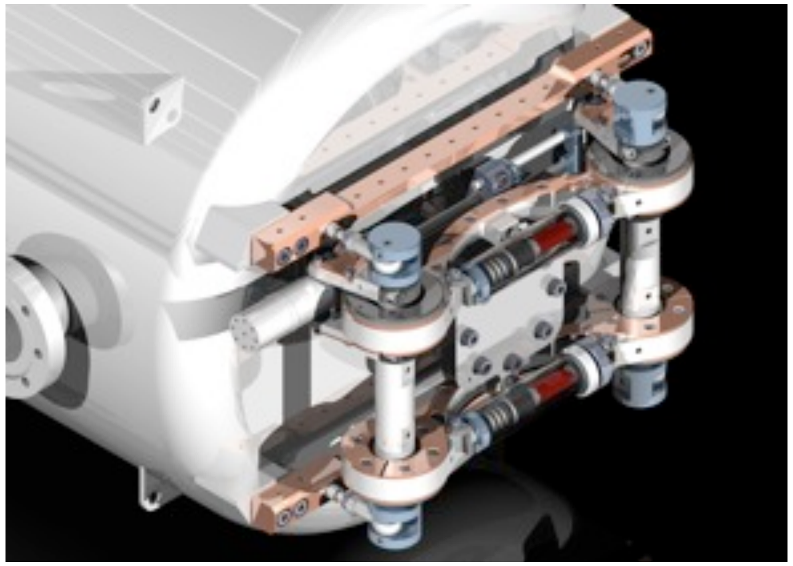
Type: E-Field (peak)
Monitor: Mode 1
Component: Abs
Maximum-3D: 6.73775e+006 V/m at 46.3127 / -1.99240e-008 / 276.325
Frequency: 351.791
Phase: 0 degrees

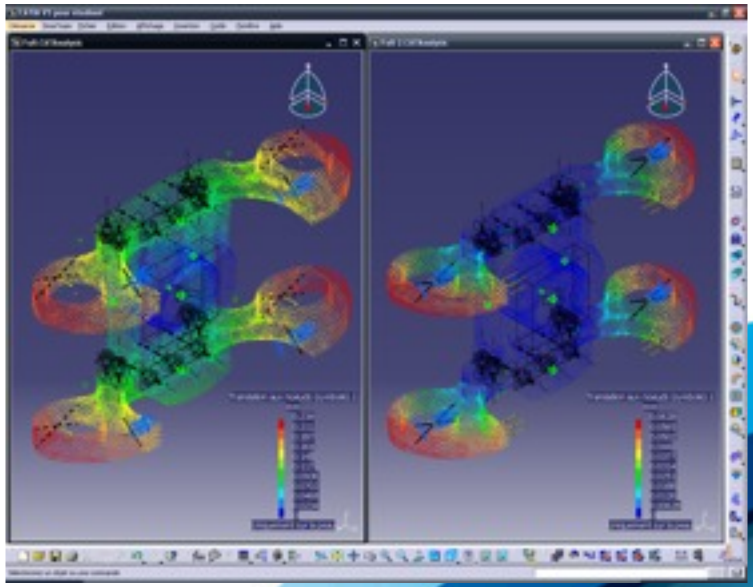
Cavity RF parameters

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





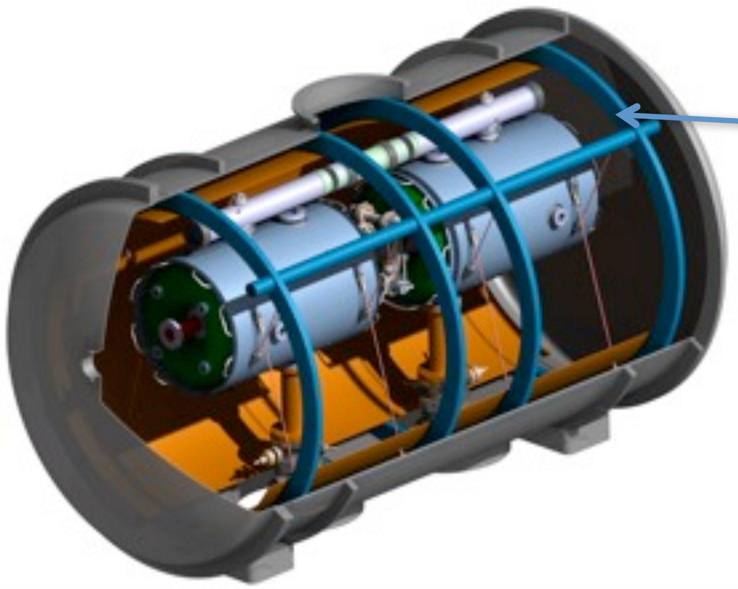


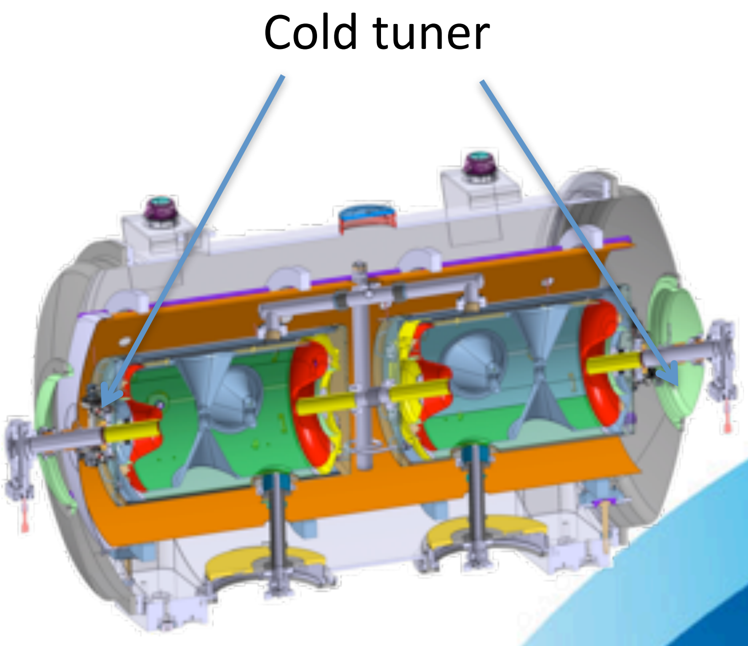


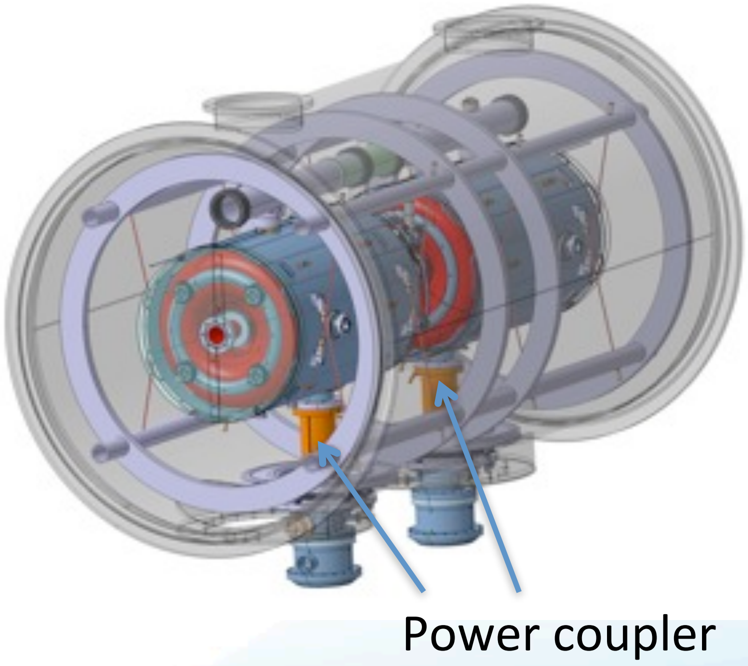
Spoke Cryomodules

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

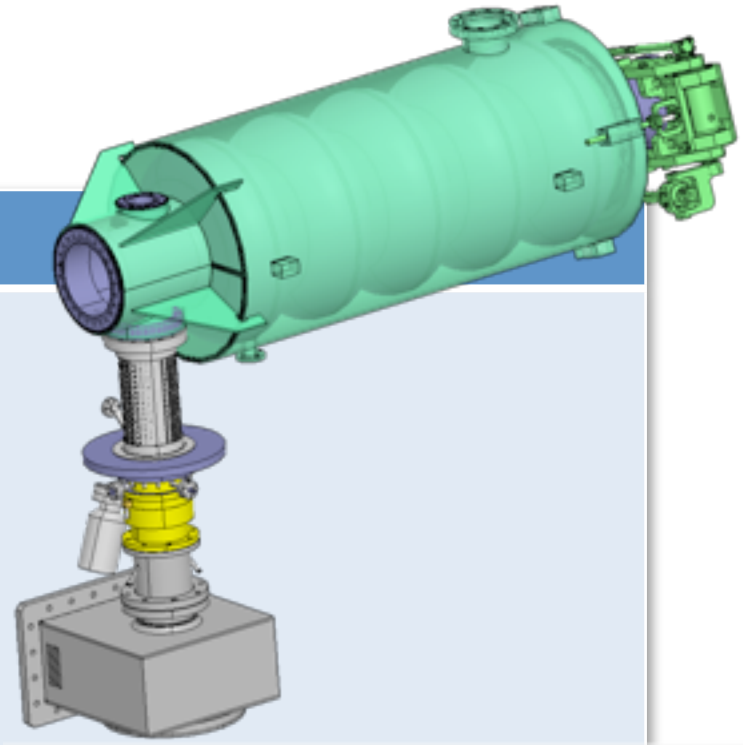
- ➢ 2 double-spoke resonators per cryomodule
- ➢ 14 cryomodules in total to cover Energy range between 79 MeV to 201 MeV
- ➢ Operation at 2 K
- ➢ Dimension : 2.9 m long , 1.3 m diameter





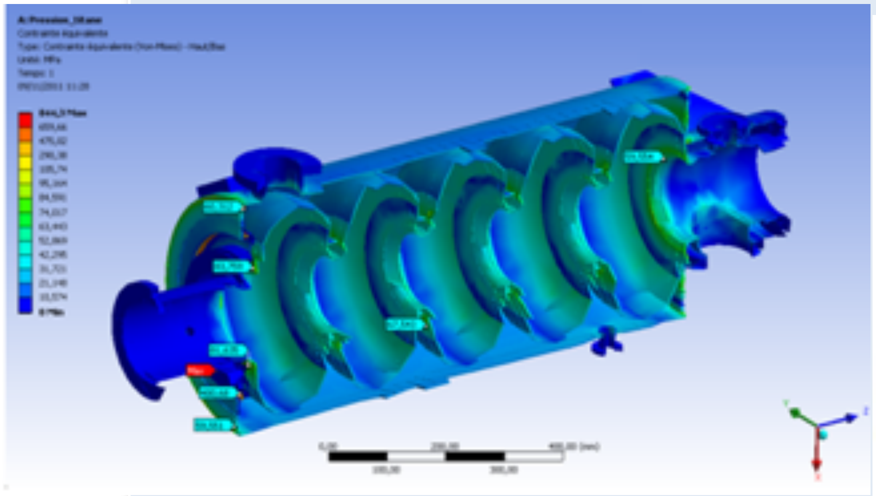


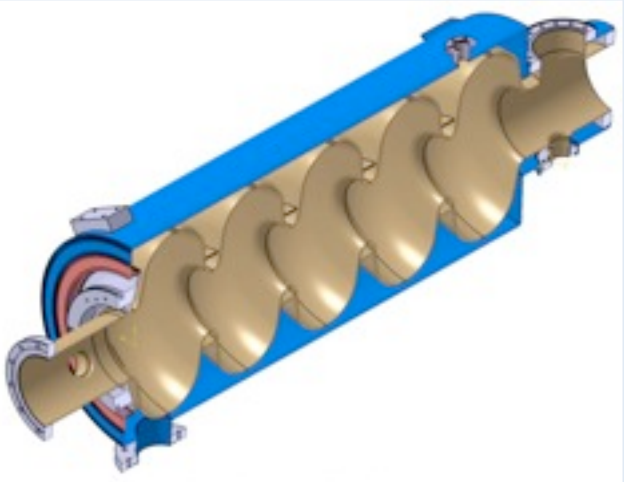
Elliptical cavities



Latest key achievements

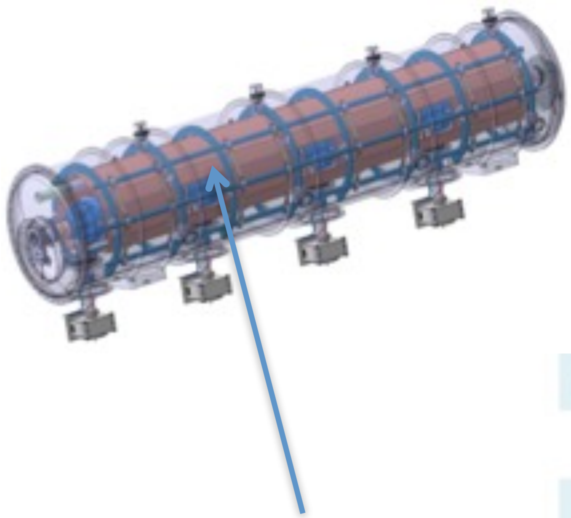
- Ordered two prototype cavities (Nb, fabrication)
- Clean room tooling design for prototypes 50 % completed
- Medium beta PhD started at Lund-U
- Study of HOM effects on the beam dynamics and RF dissipations completed
→ No need of HOM
- Some CM activities:
  - On-going effort of Orsay/Saclay to design and build a 4-elliptical cavity cryomodule
  - Cryoload evaluation



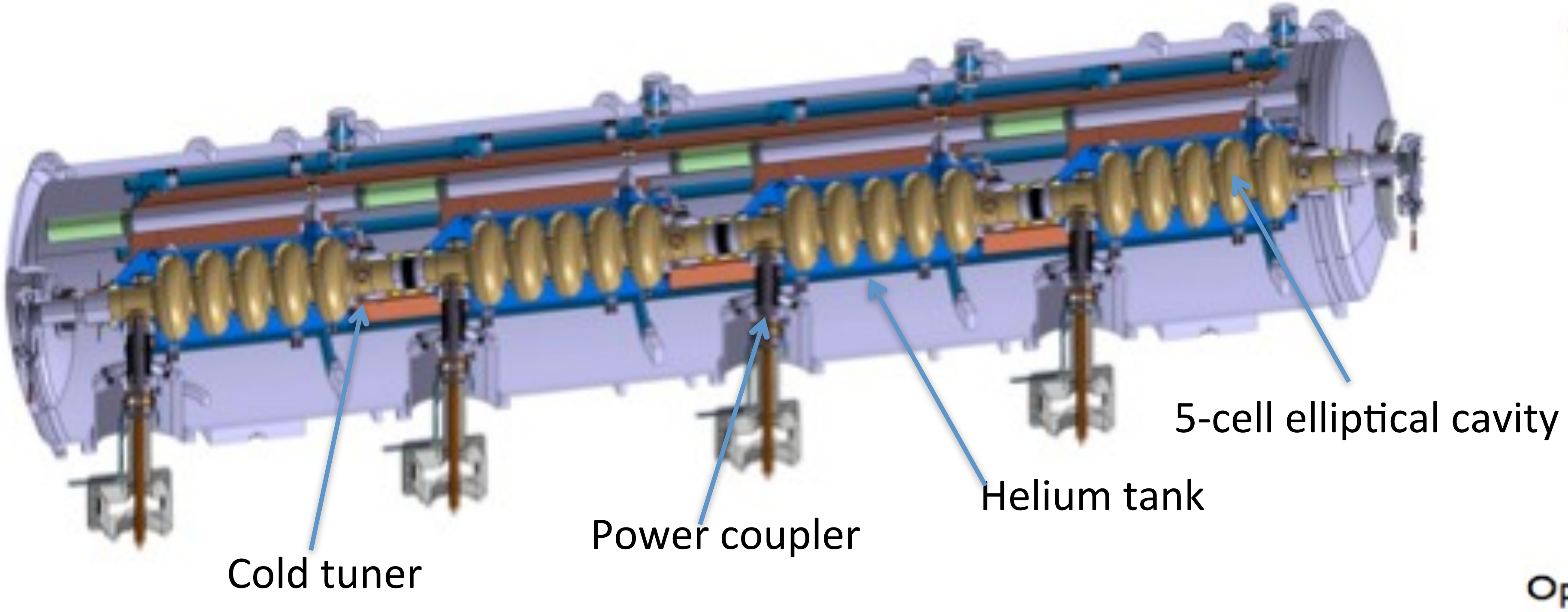


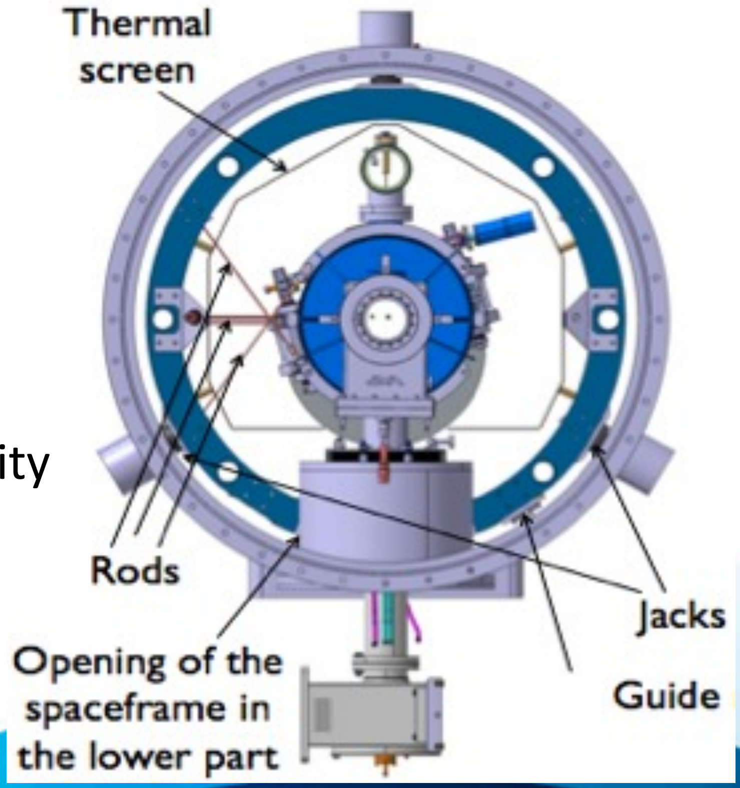
beta	Eacc VT (MV/m)	Eacc Linac (MV/m)z	Qo @ nominal Eacc
0.67	17	15	5e9
0.92	20	18	6e9

Elliptical Cryomodules



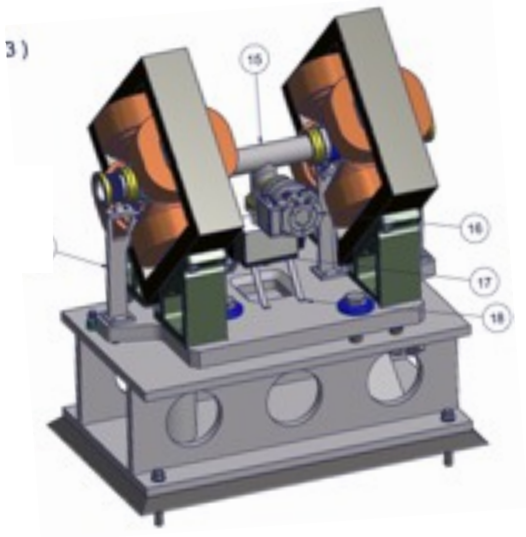
Section	Total number of Modules	Cavity package frequency [MHz]	Cavity count per module	Cavity count per sector	Cryo-module length [m]	Sector length [m]
Spoke	14	352	2	28	~ 2.9	58.46
Medium-beta	15	704	4	60	~ 6.7	113.84
High-beta	30	704	4	120	~ 6.7	227.86
Total	59			208		400.16



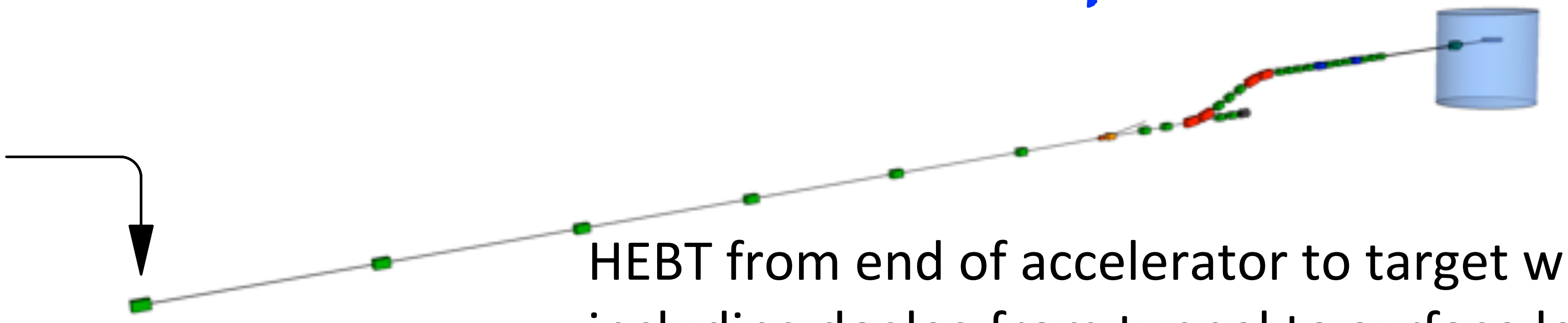


- Elliptical Cavities Cryomodule Technology Demonstrator results by the end of 2015 start pre-series

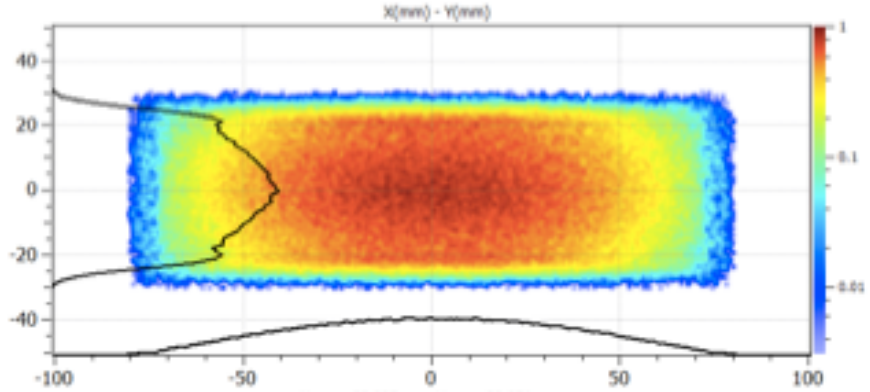
High-Energy Beam Transport



Quadrupole doublet
for linac and HEBT.

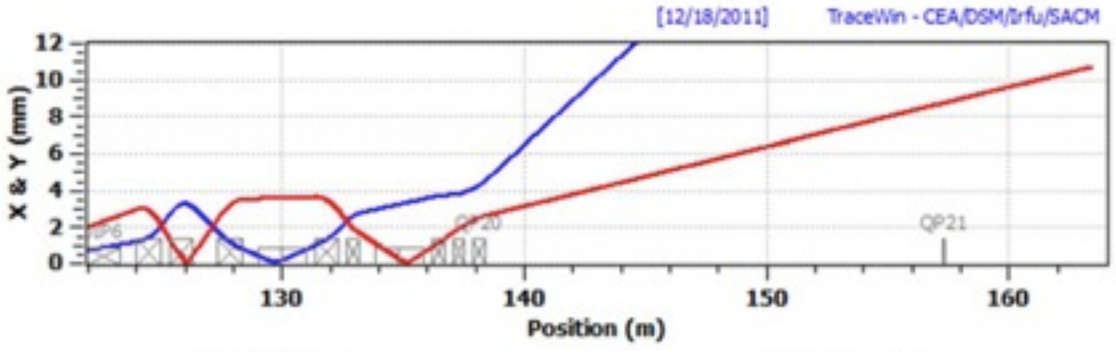


HEBT from end of accelerator to target wheel, including dogleg from tunnel to surface level, expansion magnets and tuning beam dump.



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

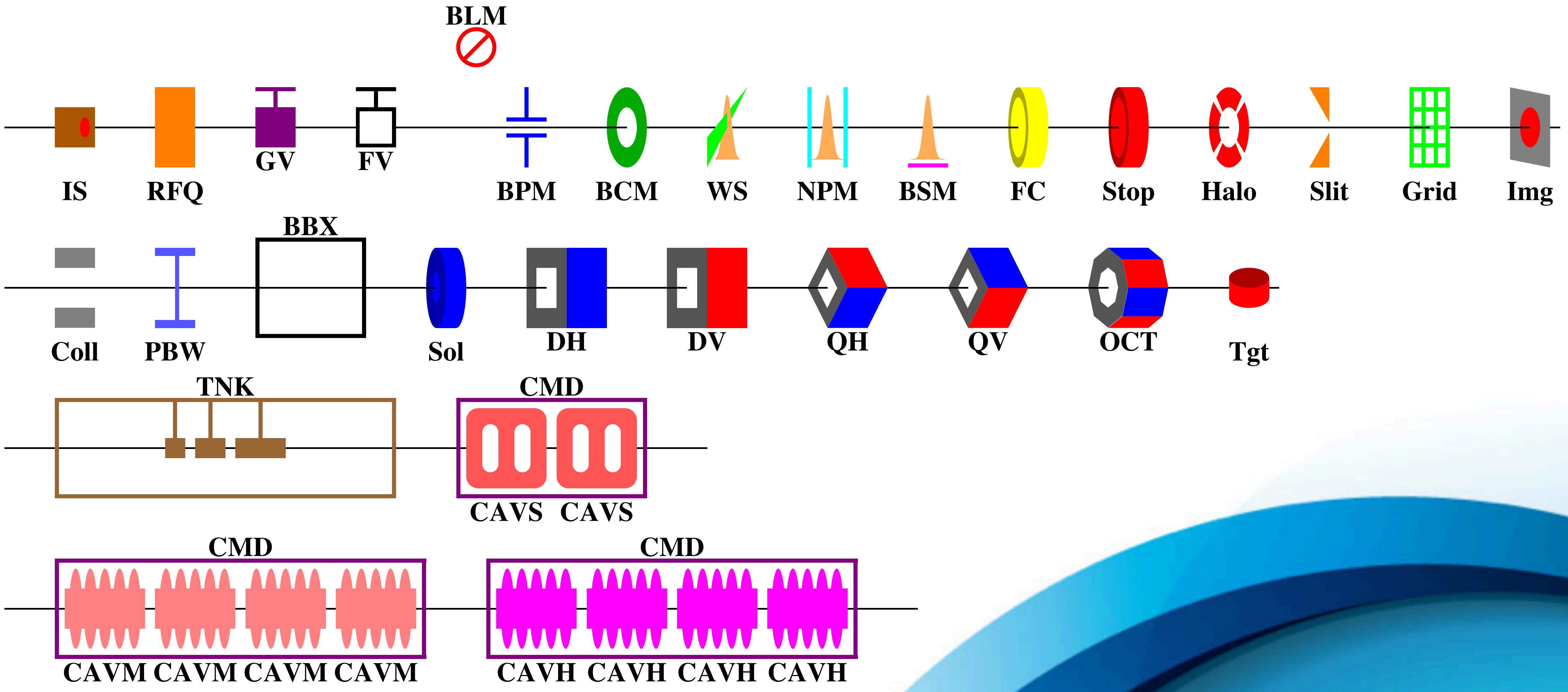
Fixed collimator outside proton-beam window with design depending on beam halo and acceptable peak current density.



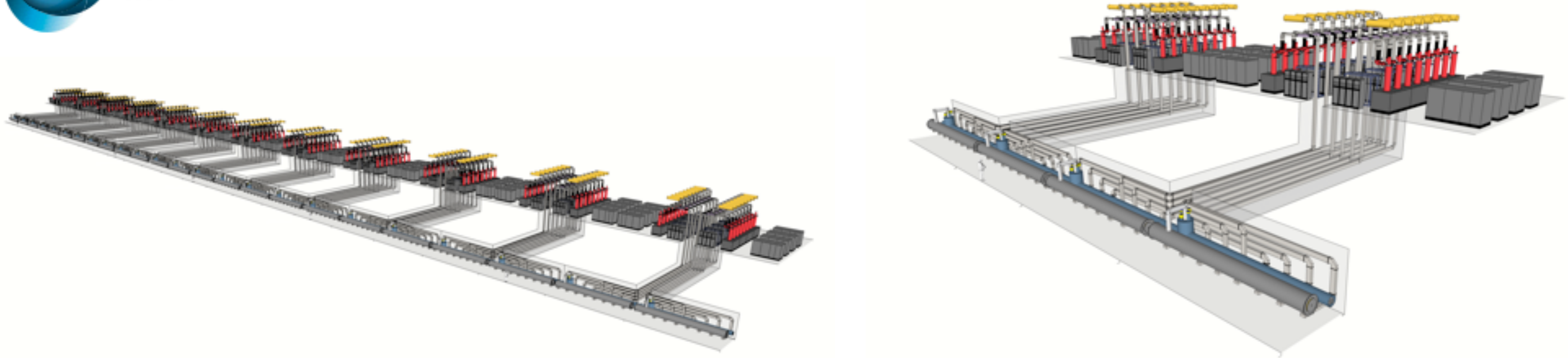
Beam expansion on target with quadrupole magnets plus two octupoles.

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

RF System Procurement Strategy

- Schedule is strongly emphasized
- 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 and Availability

ESS aim: 95% availability

- higher than any existing facility

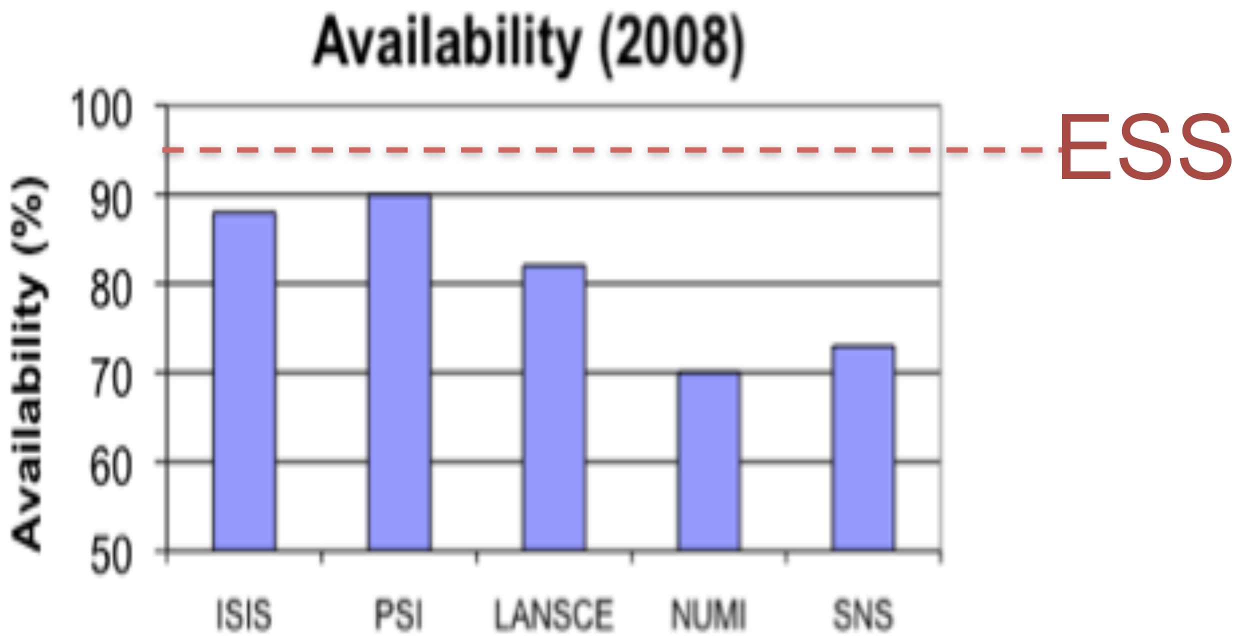
User Centric Availability Definition

Based on discussions with users:

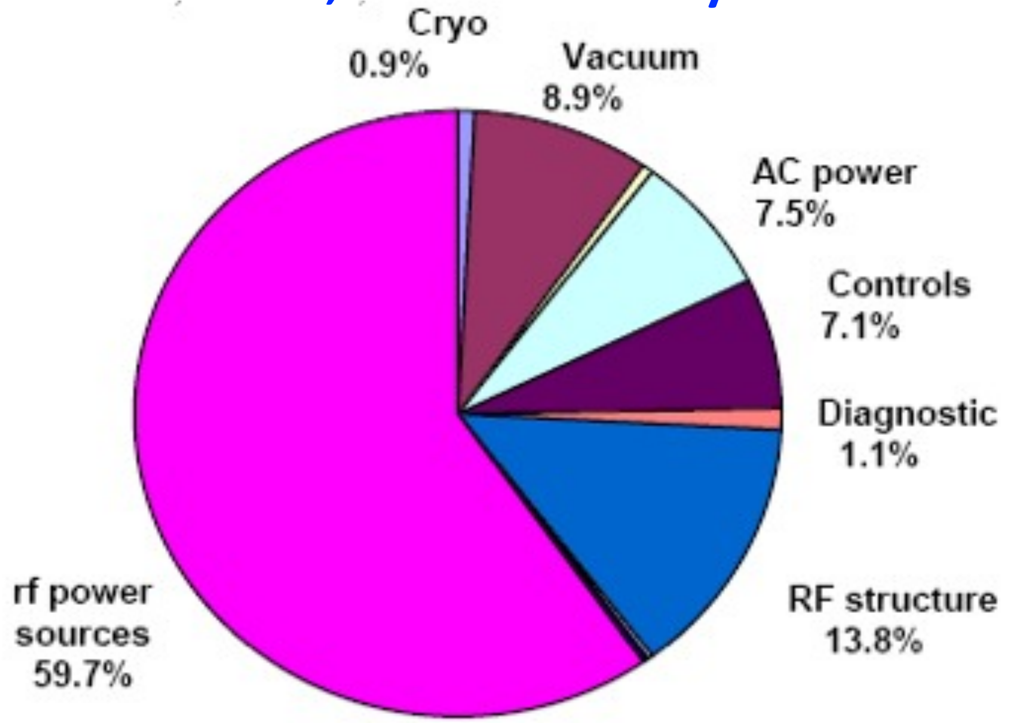
Using weighted % of scheduled beam power >70% averaged over 1 second.

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

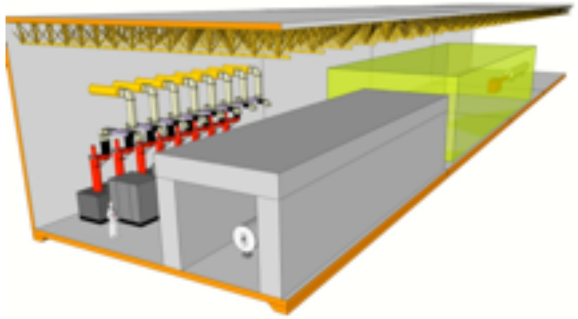
Installation & commissioning

- preparing detailed planning

14 May 2012

1 July 2013

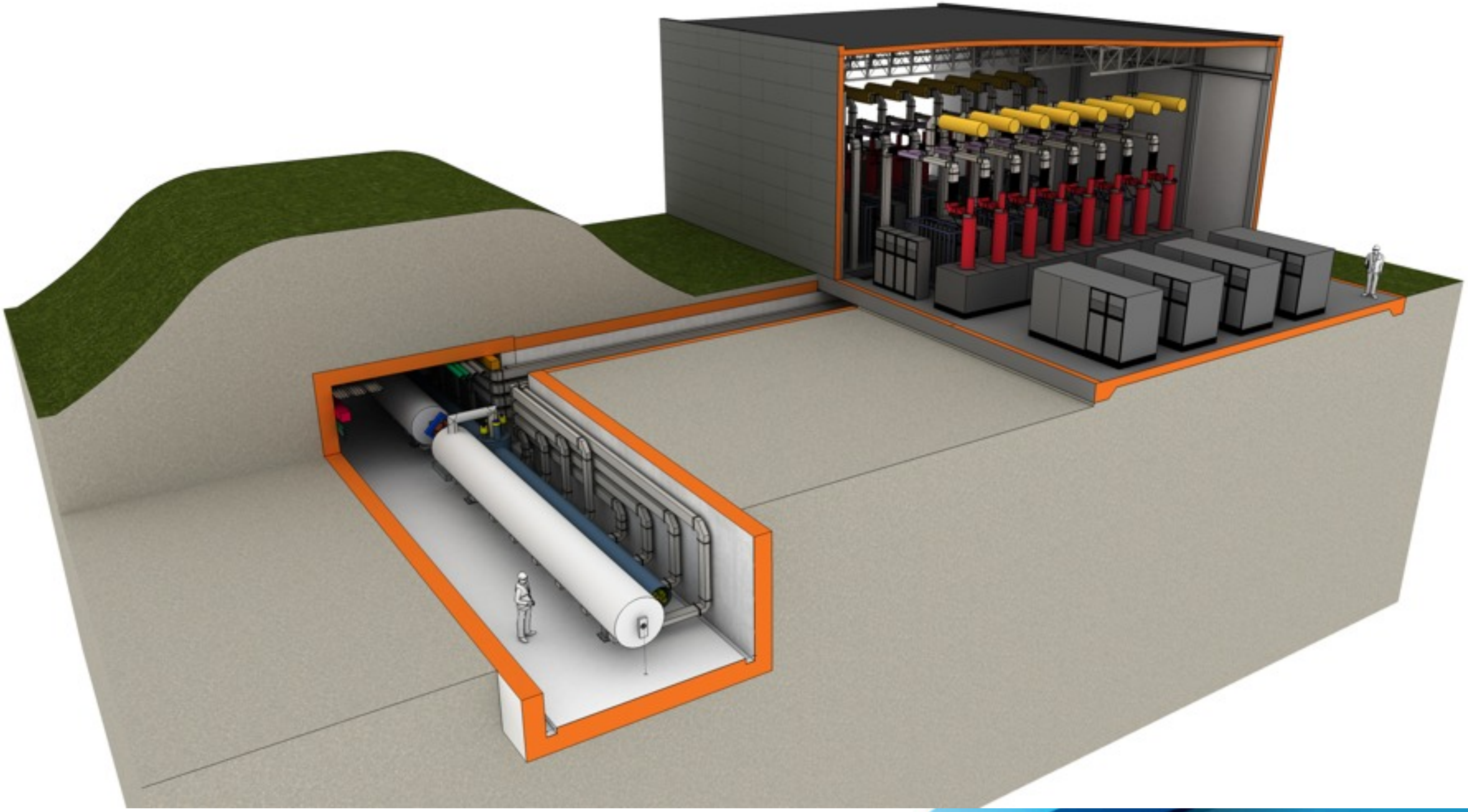
Test Stand in Lund



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);
4. series testing in situ of all 704 MHz modulators
5. series testing in situ of all 704 MHz klystrons
6. series testing of all elliptical cavities cryomodules at full RF load and at final operating temperature
7. vertical test stand for future testing of cavities

LINAC and klystron buildings, principal structure



Possible Design Changes

Flat power profile ("Galambos margin")

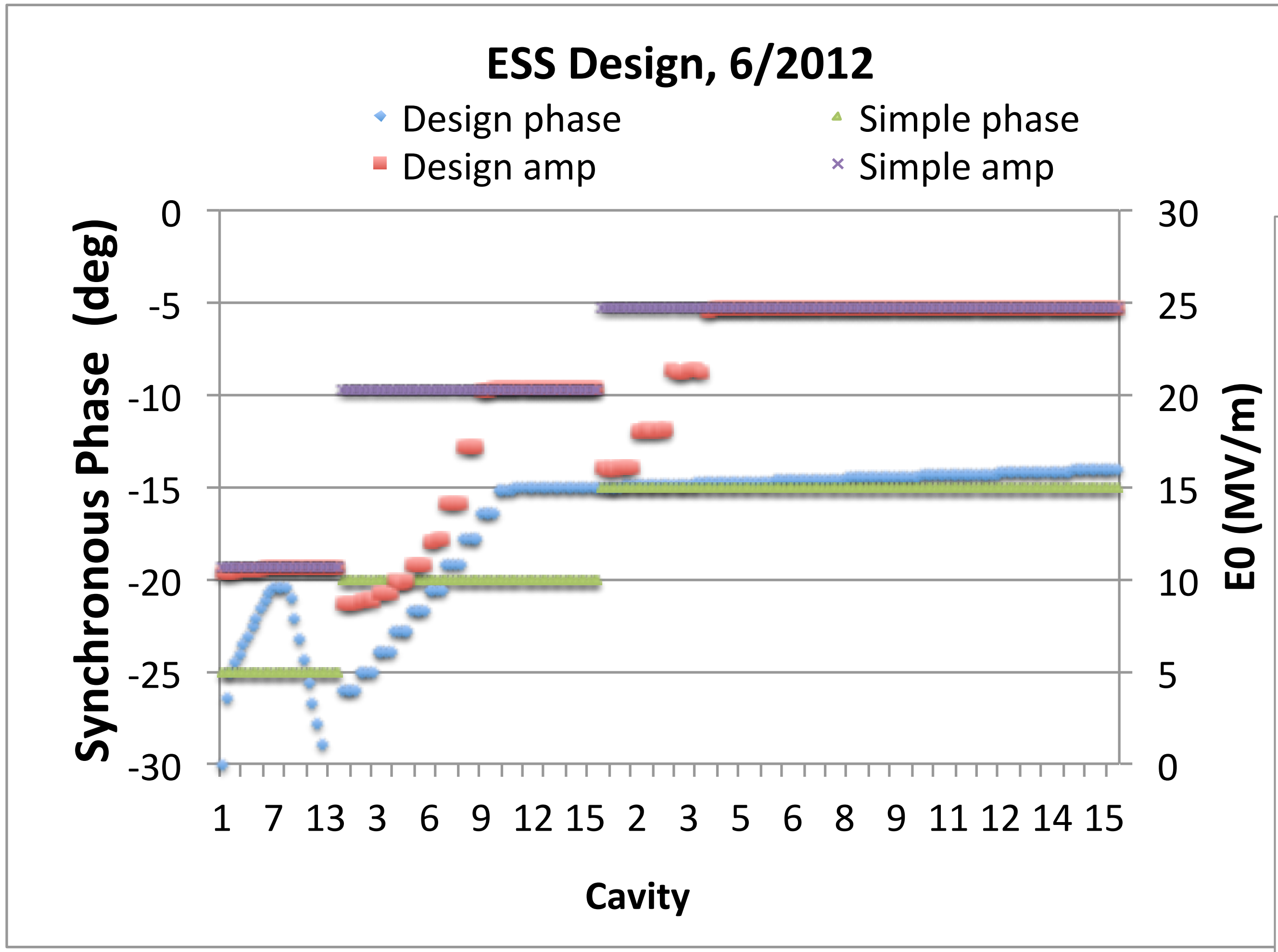
- Could reduce linac length by 400 MeV (6 cryomodules)
- Saves money in RF Stations and in cryomodules

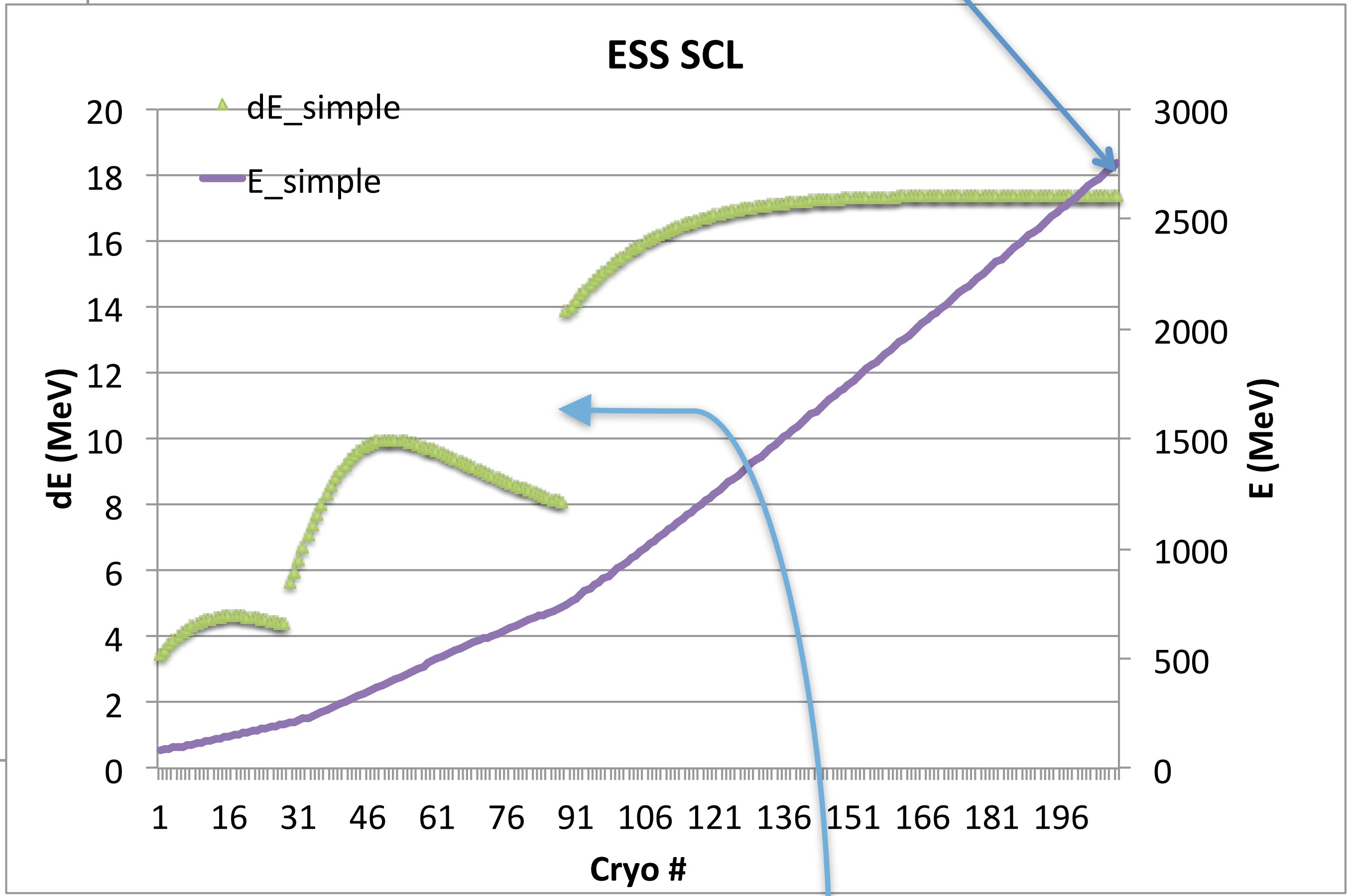
IOT's

- 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


ESS Design, 6/2012


ESS SCL

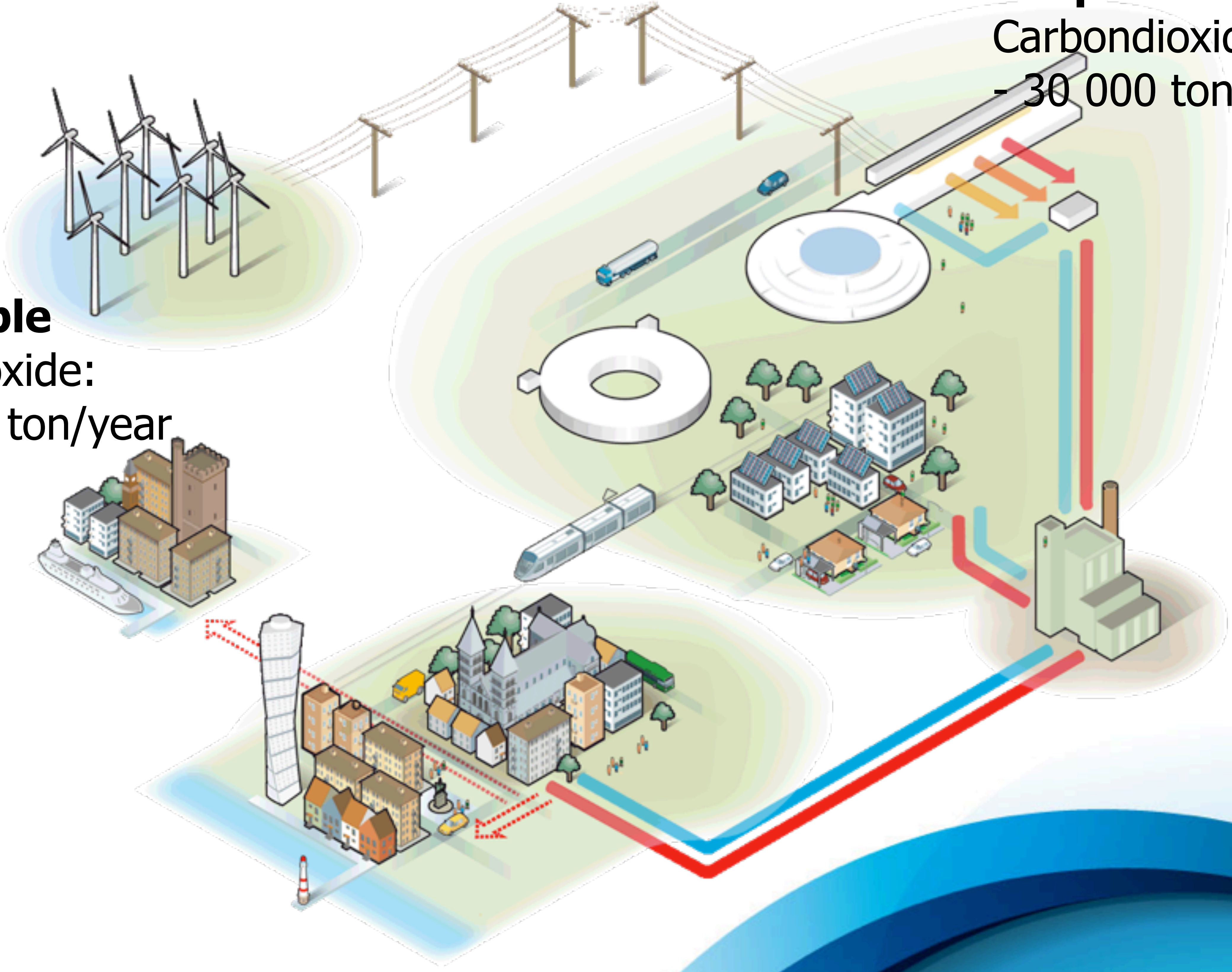
E_out = ~2750 MeV

- Gain ~10% energy margin, or gradient margin
  - Or save cryomodules

Discontinuity => need a phase/amplitude ramp
An odd way to design a machine?

J. Galambos, 2012

A sustainable research facility



Responsible
Carbondioxide:
- 30 000 ton/year

Renewable
Carbondioxide:
- 120 000 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 Cryomodules
  - Staged installation of ESS with 1.5 MW capability in 2019 and 5 MW capability in 2025

Conclusions

ESS as an example

ESS is an example of the coming post-HEP world

A different sociology from HEP and NP

- An accelerator build becomes a user-facility
- How to do accelerator Science R&D, after commissioning?

Green-field site

- Multi-lab collaboration of peers is essential
- Following the SNS example, but in European style
- All therapy centers are green-field

Accelerator Physics is an applied Science that is maturing to address "well-stated problems" that are not one-to-one with facilities

Eg 1: ESS & ADS technologies are closely tied

Eg 2: The RF frequency sweep problem is common to FFAGs, RCSs, Medical, ADS, spallation, but is orthogonal to facilities

Contributors

- Many thanks to the ESS Accelerator Division, the ADU collaboration and to 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

Accelerator design was “frozen” in Falsterbo 2011

ESS, A wonderfull challenge!